

# Neutral Higgs Bosons, Searches for

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## MASS LIMITS FOR NEUTRAL HIGGS BOSONS IN SUPERSYMMETRIC MODELS

The minimal supersymmetric model has two complex doublets of Higgs bosons. The resulting physical states are two scalars [ $H_1^0$  and  $H_2^0$ , where we define  $m_{H_1^0} < m_{H_2^0}$ ], a pseudoscalar ( $A^0$ ), and a charged Higgs pair ( $H^\pm$ ).  $H_1^0$  and  $H_2^0$  are also called  $h$  and  $H$  in the literature. There are two free parameters in the Higgs sector which can be chosen to be  $m_{A^0}$  and  $\tan\beta = v_2/v_1$ , the ratio of vacuum expectation values of the two Higgs doublets. Tree-level Higgs masses are constrained by the model to be  $m_{H_1^0} \leq m_Z$ ,  $m_{H_2^0} \geq m_Z$ ,  $m_{A^0} \geq m_{H_1^0}$ , and  $m_{H^\pm} \geq m_W$ . However, as described in the review on “Status of Higgs Boson Physics” in this Volume these relations are violated by radiative corrections.

The observed signal at about 125 GeV, see section “H”, can be interpreted as one of the neutral Higgs bosons of supersymmetric models. Unless otherwise noted, we identify the lighter scalar  $H_1^0$  with the Higgs discovered at 125 GeV at the LHC (AAD 12AI, CHATRCHYAN 12N).

Unless otherwise noted, the experiments in  $e^+e^-$  collisions search for the processes  $e^+e^- \rightarrow H_1^0 Z^0$  in the channels used for the Standard Model Higgs searches and  $e^+e^- \rightarrow H_1^0 A^0$  in the final states  $b\bar{b}b\bar{b}$  and  $b\bar{b}\tau^+\tau^-$ . Unless otherwise stated, the following results assume no invisible  $H_1^0$  or  $A^0$  decays. Unless otherwise noted, the results are given in the  $m_h^{max}$  scenario, CARENA 13.

In  $p\bar{p}$  and  $pp$  collisions the experiments search for a variety of processes, as explicitly specified for each entry. Limits on the  $A^0$  mass arise from these direct searches, as well as from the relations valid in the minimal supersymmetric model between  $m_{A^0}$  and  $m_{H_1^0}$ . As discussed in the review on “Status of Higgs Boson Physics” in this Volume, these relations depend, via potentially large radiative corrections, on the mass of the  $t$  quark and on the supersymmetric parameters, in particular those of the  $\tilde{t}$  sector. These indirect limits are weaker for larger  $t$  and  $\tilde{t}$  masses.

To include the radiative corrections to the Higgs masses, unless otherwise stated, the listed papers use theoretical predictions incorporating two-loop corrections, and the results are given for the  $m_h^{mod+}$  benchmark scenario, see CARENA 13.

### Mass Limits for heavy neutral Higgs bosons ( $H_2^0, A^0$ ) in the MSSM

The limits rely on  $pp \rightarrow H_2^0/A^0 \rightarrow \tau^+\tau^-$  and assume that  $H_2^0$  and  $A^0$  are (sufficiently) mass degenerate. The limits depend on  $\tan\beta$ .

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
> 377	95	1 AABOUD	18G ATLS	$\tan\beta = 10$ GeV
> <b>863</b>	95	1 AABOUD	18G ATLS	$\tan\beta = 20$ GeV
> <b>1157</b>	95	1 AABOUD	18G ATLS	$\tan\beta = 30$ GeV
>1328	95	1 AABOUD	18G ATLS	$\tan\beta = 40$ GeV
>1483	95	1 AABOUD	18G ATLS	$\tan\beta = 50$ GeV
> <b>1613</b>	95	1 AABOUD	18G ATLS	$\tan\beta = 60$ GeV
> <b>389</b>	95	2 SIRUNYAN	18CX CMS	$\tan\beta = 10$ GeV
> 832	95	2 SIRUNYAN	18CX CMS	$\tan\beta = 20$ GeV
>1148	95	2 SIRUNYAN	18CX CMS	$\tan\beta = 30$ GeV
> <b>1341</b>	95	2 SIRUNYAN	18CX CMS	$\tan\beta = 40$ GeV
> <b>1496</b>	95	2 SIRUNYAN	18CX CMS	$\tan\beta = 50$ GeV
> <b>1613</b>	95	2 SIRUNYAN	18CX CMS	$\tan\beta = 60$ GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

3	AAD	20 ATLS	$H^0$ properties
4	AAD	20AA ATLS	$H_2^0/A^0 \rightarrow \tau^+\tau^-$
5	AAD	20C ATLS	$H_2^0 \rightarrow H^0 H^0$
6	AAD	20L ATLS	$H_2^0 \rightarrow b\bar{b}$
7	SIRUNYAN	20AC CMS	$A^0 \rightarrow ZH^0$
8	SIRUNYAN	20AF CMS	$H_2^0/A^0 \rightarrow t\bar{t}$
9	SIRUNYAN	20Y CMS	$H_2^0 \rightarrow W^+W^-$
10	SIRUNYAN	19CR CMS	$H_2^0/A^0 \rightarrow \mu^+\mu^-$
11	SIRUNYAN	18A CMS	$H_2^0 \rightarrow H^0 H^0$
12	SIRUNYAN	18BP CMS	$pp \rightarrow H_2^0/A^0 + b + X,$ $H_2^0/A^0 \rightarrow b\bar{b}$
13	AABOUD	16AA ATLS	$A^0 \rightarrow \tau^+\tau^-$
14	KHACHATRY...	16A CMS	$H_{1,2}^0/A^0 \rightarrow \mu^+\mu^-$
15	KHACHATRY...	16P CMS	$H_2^0 \rightarrow H^0 H^0, A^0 \rightarrow ZH^0$
16	KHACHATRY...	15AY CMS	$pp \rightarrow H_{1,2}^0/A^0 + b + X,$ $H_{1,2}^0/A^0 \rightarrow b\bar{b}$
17	AAD	14AW ATLS	$pp \rightarrow H_{1,2}^0/A^0 + X,$ $H_{1,2}^0/A^0 \rightarrow \tau\tau$
18	KHACHATRY...	14M CMS	$pp \rightarrow H_{1,2}^0/A^0 + X,$ $H_{1,2}^0/A^0 \rightarrow \tau\tau$
19	AAD	13O ATLS	$pp \rightarrow H_{1,2}^0/A^0 + X,$ $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-,$ $\mu^+\mu^-$

	20	AAIJ	13T	LHCB	$pp \rightarrow H_{1,2}^0/A^0 + X,$ $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$		
	21	CHATRCHYAN13AG	CMS		$pp \rightarrow H_{1,2}^0/A^0 + b + X,$ $H_{1,2}^0/A^0 \rightarrow b\bar{b}$		
	22	AALTONEN	12AQ	TEVA	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + b + X,$ $H_{1,2}^0/A^0 \rightarrow b\bar{b}$		
	23	AALTONEN	12X	CDF	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + b + X,$ $H_{1,2}^0/A^0 \rightarrow b\bar{b}$		
	24	ABAZOV	12G	D0	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + X,$ $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$		
	25	CHATRCHYAN12K	CMS		$pp \rightarrow H_{1,2}^0/A^0 + X,$ $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$		
	26	ABAZOV	11K	D0	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + b + X,$ $H_{1,2}^0/A^0 \rightarrow b\bar{b}$		
	27	ABAZOV	11W	D0	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + b + X,$ $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$		
	28	AALTONEN	09AR	CDF	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + X,$ $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$		
>	90.4	29	ABDALLAH	08B	DLPH	$E_{\text{cm}} \leq 209 \text{ GeV}$	
>	93.4	95	30	SCHAEL	06B	LEP	$E_{\text{cm}} \leq 209 \text{ GeV}$
			31	ACOSTA	05Q	CDF	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + X$
>	85.0	95	32,33	ABBIENDI	04M	OPAL	$E_{\text{cm}} \leq 209 \text{ GeV}$
			34	ABBIENDI	03G	OPAL	$H_1^0 \rightarrow A^0 A^0$
>	86.5	95	32,35	ACHARD	02H	L3	$E_{\text{cm}} \leq 209 \text{ GeV}, \tan\beta > 0.4$
			36	AKERROYD	02	RVUE	
>	90.1	95	32,37	HEISTER	02	ALEP	$E_{\text{cm}} \leq 209 \text{ GeV}, \tan\beta > 0.5$

<sup>1</sup> AABOUD 18G search for production of  $H_2^0/A^0 \rightarrow \tau^+\tau^-$  by gluon fusion and  $b$ -associated production in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 10 for excluded regions in the  $m_{A^0} - \tan\beta$  plane in several MSSM scenarios.

<sup>2</sup> SIRUNYAN 18CX search for production of  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$  by gluon fusion and  $b$ -associated production in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 9 for excluded regions in the  $m_{A^0} - \tan(\beta)$  plane in several MSSM scenarios.

<sup>3</sup> AAD 20 combine measurements on  $H^0$  production and decay using data taken in years 2015–2017 (up to  $79.8 \text{ fb}^{-1}$ ) of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 19 for excluded region in the hMSSM parameter space.

<sup>4</sup> AAD 20AA search for  $H_2^0/A^0 \rightarrow \tau^+\tau^-$  produced by gluon fusion or  $b$ -associated production using  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 2(c) for excluded region in the  $M_h^{125}$  scenario of MSSM. Values of  $\tan\beta > 8$  (21) are excluded for  $m_{A^0} = 1.0$  (1.5) TeV at 95%CL.

<sup>5</sup> AAD 20C combine searches for a scalar resonance decaying to  $H^0 H^0$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$  from AABOUD 19A, AABOUD 19O, AABOUD 18CQ,

- AABOUD 19T, AABOUD 18CW, and AABOUD 18BU. See their Fig. 7(b) for the excluded region in the hMSSM parameter space.
- <sup>6</sup> AAD 20L search for  $b$ -associated production of  $H_2^0$  decaying to  $b\bar{b}$  in  $27.8 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 9 for excluded regions in hMSSM,  $m_h^{\text{mod}+}$  and  $m_h^{\text{mod}-}$  scenarios of MSSM.
  - <sup>7</sup> SIRUNYAN 20AC search for gluon-fusion and  $b$ -associated production of  $A^0$  decaying to  $ZH^0$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for excluded regions in the  $M_{\text{hEFT}}^{125}$  and hMSSM scenarios of the MSSM.
  - <sup>8</sup> SIRUNYAN 20AF search for  $H_2^0/A^0 \rightarrow t\bar{t}$  with one or two charged leptons in the final state using kinematic variables in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 8 for excluded region in the hMSSM scenario of MSSM. Values of  $\tan\beta$  below 1.0–1.5 are excluded for  $m_{A^0} = 0.4\text{--}0.75 \text{ TeV}$  at 95%CL.
  - <sup>9</sup> SIRUNYAN 20Y search for gluon-fusion and vector-boson-fusion production of  $H_2^0$  decaying to  $W^+W^-$  in the final states  $\ell\nu\ell\nu$  and  $\ell\nu qq$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 8 and 9 for excluded regions in various MSSM scenarios.
  - <sup>10</sup> SIRUNYAN 19CR search for production of  $H_2^0/A^0$  in gluon fusion and in association with a  $b\bar{b}$  pair, decaying to  $\mu^+\mu^-$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for the excluded region in the MSSM parameter space in the  $m_h^{\text{mod}+}$  and hMSSM scenarios.
  - <sup>11</sup> SIRUNYAN 18A search for production of a scalar resonance decaying to  $H^0H^0 \rightarrow b\bar{b}\tau^+\tau^-$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 (lower) for excluded regions in the  $m_{A^0} - \tan\beta$  plane in the hMSSM scenario.
  - <sup>12</sup> SIRUNYAN 18BP search for production of  $H_2^0/A^0 \rightarrow b\bar{b}$  by  $b$ -associated production in  $35.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for the limits on cross section times branching ratio for  $m_{H_2^0}, m_{A^0} = 0.3\text{--}1.3 \text{ TeV}$ , and Fig. 7 for excluded regions in the  $m_{A^0} - \tan(\beta)$  plane in several MSSM scenarios.
  - <sup>13</sup> AABOUD 16AA search for production of a Higgs boson in gluon fusion and in association with a  $b\bar{b}$  pair followed by the decay  $A^0 \rightarrow \tau^+\tau^-$  in  $3.2 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5(a, b) for limits on cross section times branching ratio for  $m_{A^0} = 200\text{--}1200 \text{ GeV}$ , and Fig. 5(c, d) for the excluded region in the MSSM parameter space in the  $m_h^{\text{mod}+}$  and hMSSM scenarios.
  - <sup>14</sup> KHACHATRYAN 16A search for production of a Higgs boson in gluon fusion and in association with a  $b\bar{b}$  pair followed by the decay  $H_{1,2}^0/A^0 \rightarrow \mu^+\mu^-$  in  $5.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7 \text{ TeV}$  and  $19.3 \text{ fb}^{-1}$  at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 7 for the excluded region in the MSSM parameter space in the  $m_h^{\text{mod}+}$  benchmark scenario and Fig. 9 for limits on cross section times branching ratio.
  - <sup>15</sup> KHACHATRYAN 16P search for gluon fusion production of an  $H_2^0$  decaying to  $H^0H^0 \rightarrow b\bar{b}\tau^+\tau^-$  and an  $A^0$  decaying to  $ZH^0 \rightarrow \ell^+\ell^-\tau^+\tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 12 for excluded region in the  $\tan\beta - \cos(\beta - \alpha)$  plane for  $m_{H_2^0} = m_{A^0} = 300 \text{ GeV}$ .
  - <sup>16</sup> KHACHATRYAN 15AY search for production of a Higgs boson in association with a  $b$  quark in the decay  $H_{1,2}^0/A^0 \rightarrow b\bar{b}$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$  and combine with CHATRCHYAN 13AG 7 TeV data. See their Fig. 6 for the limits on cross section times branching ratio for  $m_{A^0} = 100\text{--}900 \text{ GeV}$  and Figs. 7–9 for the excluded region in the MSSM parameter space in various benchmark scenarios.

- 17 AAD 14AW search for production of a Higgs boson followed by the decay  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$  in  $19.5\text{--}20.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8\text{ TeV}$ . See their Fig. 11 for the limits on cross section times branching ratio and their Figs. 9 and 10 for the excluded region in the MSSM parameter space. For  $m_{A^0} = 140\text{ GeV}$ , the region  $\tan\beta > 5.4$  is excluded at 95% CL in the  $m_h^{\text{max}}$  scenario.
- 18 KHACHATRYAN 14M search for production of a Higgs boson in gluon fusion and in association with a  $b$  quark followed by the decay  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$  in  $4.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7\text{ TeV}$  and  $19.7\text{ fb}^{-1}$  at  $E_{\text{cm}} = 8\text{ TeV}$ . See their Figs. 7 and 8 for one- and two-dimensional limits on cross section times branching ratio and their Figs. 5 and 6 for the excluded region in the MSSM parameter space. For  $m_{A^0} = 140\text{ GeV}$ , the region  $\tan\beta > 3.8$  is excluded at 95% CL in the  $m_h^{\text{max}}$  scenario.
- 19 AAD 13O search for production of a Higgs boson in the decay  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$  and  $\mu^+\mu^-$  with  $4.7\text{--}4.8\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7\text{ TeV}$ . See their Fig. 6 for the excluded region in the MSSM parameter space and their Fig. 7 for the limits on cross section times branching ratio. For  $m_{A^0} = 110\text{--}170\text{ GeV}$ ,  $\tan\beta \gtrsim 10$  is excluded, and for  $\tan\beta = 50$ ,  $m_{A^0}$  below  $470\text{ GeV}$  is excluded at 95% CL in the  $m_h^{\text{max}}$  scenario.
- 20 AAIJ 13T search for production of a Higgs boson in the forward region in the decay  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$  in  $1.0\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7\text{ TeV}$ . See their Fig. 2 for the limits on cross section times branching ratio and the excluded region in the MSSM parameter space.
- 21 CHATRCHYAN 13AG search for production of a Higgs boson in association with a  $b$  quark in the decay  $H_{1,2}^0/A^0 \rightarrow b\bar{b}$  in  $2.7\text{--}4.8\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7\text{ TeV}$ . See their Fig. 6 for the excluded region in the MSSM parameter space and Fig. 5 for the limits on cross section times branching ratio. For  $m_{A^0} = 90\text{--}350\text{ GeV}$ , upper bounds on  $\tan\beta$  of  $18\text{--}42$  at 95% CL are obtained in the  $m_h^{\text{max}}$  scenario with  $\mu = +200\text{ GeV}$ .
- 22 AALTONEN 12AQ combine AALTONEN 12X and ABAZOV 11K. See their Table I and Fig. 1 for the limit on cross section times branching ratio and Fig. 2 for the excluded region in the MSSM parameter space.
- 23 AALTONEN 12X search for associated production of a Higgs boson and a  $b$  quark in the decay  $H_{1,2}^0/A^0 \rightarrow b\bar{b}$ , with  $2.6\text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96\text{ TeV}$ . See their Table III and Fig. 15 for the limit on cross section times branching ratio and Figs. 17, 18 for the excluded region in the MSSM parameter space.
- 24 ABAZOV 12G search for production of a Higgs boson in the decay  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$  with  $7.3\text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96\text{ TeV}$  and combine with ABAZOV 11W and ABAZOV 11K. See their Figs. 4, 5, and 6 for the excluded region in the MSSM parameter space. For  $m_{A^0} = 90\text{--}180\text{ GeV}$ ,  $\tan\beta \gtrsim 30$  is excluded at 95% CL. in the  $m_h^{\text{max}}$  scenario.
- 25 CHATRCHYAN 12K search for production of a Higgs boson in the decay  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$  with  $4.6\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7\text{ TeV}$ . See their Fig. 3 and Table 4 for the excluded region in the MSSM parameter space. For  $m_{A^0} = 160\text{ GeV}$ , the region  $\tan\beta > 7.1$  is excluded at 95% CL in the  $m_h^{\text{max}}$  scenario. Superseded by KHACHATRYAN 14M.
- 26 ABAZOV 11K search for associated production of a Higgs boson and a  $b$  quark, followed by the decay  $H_{1,2}^0/A^0 \rightarrow b\bar{b}$ , in  $5.2\text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96\text{ TeV}$ . See their Fig. 5/Table 2 for the limit on cross section times branching ratio and Fig. 6 for the excluded region in the MSSM parameter space for  $\mu = -200\text{ GeV}$ .

- 27 ABAZOV 11W search for associated production of a Higgs boson and a  $b$  quark, followed by the decay  $H_{1,2}^0/A^0 \rightarrow \tau\tau$ , in  $7.3 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ . See their Fig. 2 for the limit on cross section times branching ratio and for the excluded region in the MSSM parameter space.
- 28 AALTONEN 09AR search for Higgs bosons decaying to  $\tau^+\tau^-$  in two doublet models in  $1.8 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ . See their Fig. 2 for the limit on  $\sigma \cdot \text{B}(H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-)$  for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space.
- 29 ABDALLAH 08B give limits in eight  $CP$ -conserving benchmark scenarios and some  $CP$ -violating scenarios. See paper for excluded regions for each scenario. Supersedes ABDALLAH 04.
- 30 SCHAEEL 06B make a combined analysis of the LEP data. The quoted limit is for the  $m_h^{\text{max}}$  scenario with  $m_t = 174.3 \text{ GeV}$ . In the  $CP$ -violating CPX scenario no lower bound on  $m_{H_1^0}$  can be set at 95% CL. See paper for excluded regions in various scenarios. See Figs. 2–6 and Tabs. 14–21 for limits on  $\sigma(ZH^0) \cdot \text{B}(H^0 \rightarrow b\bar{b}, \tau^+\tau^-)$  and  $\sigma(H_1^0 H_2^0) \cdot \text{B}(H_1^0, H_2^0 \rightarrow b\bar{b}, \tau^+\tau^-)$ .
- 31 ACOSTA 05Q search for  $H_{1,2}^0/A^0$  production in  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.8 \text{ TeV}$  with  $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$ . At  $m_{A^0} = 100 \text{ GeV}$ , the obtained cross section upper limit is above theoretical expectation.
- 32 Search for  $e^+e^- \rightarrow H_1^0 A^0$  in the final states  $b\bar{b}b\bar{b}$  and  $b\bar{b}\tau^+\tau^-$ , and  $e^+e^- \rightarrow H_1^0 Z$ . Universal scalar mass of 1 TeV, SU(2) gaugino mass of 200 GeV, and  $\mu = -200 \text{ GeV}$  are assumed, and two-loop radiative corrections incorporated. The limits hold for  $m_t = 175 \text{ GeV}$ , and for the  $m_h^{\text{max}}$  scenario.
- 33 ABBIENDI 04M exclude  $0.7 < \tan\beta < 1.9$ , assuming  $m_t = 174.3 \text{ GeV}$ . Limits for other MSSM benchmark scenarios, as well as for  $CP$  violating cases, are also given.
- 34 ABBIENDI 03G search for  $e^+e^- \rightarrow H_1^0 Z$  followed by  $H_1^0 \rightarrow A^0 A^0$ ,  $A^0 \rightarrow c\bar{c}$ ,  $g g$ , or  $\tau^+\tau^-$ . In the no-mixing scenario, the region  $m_{H_1^0} = 45\text{--}85 \text{ GeV}$  and  $m_{A^0} = 2\text{--}9.5 \text{ GeV}$  is excluded at 95% CL.
- 35 ACHARD 02H also search for the final state  $H_1^0 Z \rightarrow 2A^0 q\bar{q}$ ,  $A^0 \rightarrow q\bar{q}$ . In addition, the MSSM parameter set in the “large- $\mu$ ” and “no-mixing” scenarios are examined.
- 36 AKEROYD 02 examine the possibility of a light  $A^0$  with  $\tan\beta < 1$ . Electroweak measurements are found to be inconsistent with such a scenario.
- 37 HEISTER 02 excludes the range  $0.7 < \tan\beta < 2.3$ . A wider range is excluded with different stop mixing assumptions. Updates BARATE 01C.

### Mass Limits for $H_1^0$ (Higgs Boson) in Supersymmetric Models

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>89.7		<sup>1</sup> ABDALLAH 08B	DLPH	$E_{\text{cm}} \leq 209 \text{ GeV}$
>92.8	95	<sup>2</sup> SCHAEEL 06B	LEP	$E_{\text{cm}} \leq 209 \text{ GeV}$
>84.5	95	<sup>3,4</sup> ABBIENDI 04M	OPAL	$E_{\text{cm}} \leq 209 \text{ GeV}$
>86.0	95	<sup>3,5</sup> ACHARD 02H	L3	$E_{\text{cm}} \leq 209 \text{ GeV}, \tan\beta > 0.4$
>89.8	95	<sup>3,6</sup> HEISTER 02	ALEP	$E_{\text{cm}} \leq 209 \text{ GeV}, \tan\beta > 0.5$

• • • We do not use the following data for averages, fits, limits, etc. • • •

$$\begin{aligned} & \sup{7} \text{ AALTONEN 12AQ TEVA } p\bar{p} \rightarrow H_{1,2}^0/A^0 + b + X, \\ & H_{1,2}^0/A^0 \rightarrow b\bar{b} \end{aligned}$$

<sup>1</sup> ABDALLAH 08B give limits in eight  $CP$ -conserving benchmark scenarios and some  $CP$ -violating scenarios. See paper for excluded regions for each scenario. Supersedes ABDALLAH 04.

- <sup>2</sup> SCHAEL 06B make a combined analysis of the LEP data. The quoted limit is for the  $m_h^{\max}$  scenario with  $m_t = 174.3$  GeV. In the  $CP$ -violating CPX scenario no lower bound on  $m_{H_1^0}$  can be set at 95% CL. See paper for excluded regions in various scenarios. See Figs. 2–6 and Tabs. 14–21 for limits on  $\sigma(ZH^0)$ ,  $B(H^0 \rightarrow b\bar{b}, \tau^+\tau^-)$  and  $\sigma(H_1^0 H_2^0)$ ,  $B(H_1^0, H_2^0 \rightarrow b\bar{b}, \tau^+\tau^-)$ .
- <sup>3</sup> Search for  $e^+e^- \rightarrow H_1^0 A^0$  in the final states  $b\bar{b}b\bar{b}$  and  $b\bar{b}\tau^+\tau^-$ , and  $e^+e^- \rightarrow H_1^0 Z$ . Universal scalar mass of 1 TeV, SU(2) gaugino mass of 200 GeV, and  $\mu = -200$  GeV are assumed, and two-loop radiative corrections incorporated. The limits hold for  $m_t = 175$  GeV, and for the  $m_h^{\max}$  scenario.
- <sup>4</sup> ABBIENDI 04M exclude  $0.7 < \tan\beta < 1.9$ , assuming  $m_t = 174.3$  GeV. Limits for other MSSM benchmark scenarios, as well as for  $CP$  violating cases, are also given.
- <sup>5</sup> ACHARD 02H also search for the final state  $H_1^0 Z \rightarrow 2A^0 q\bar{q}$ ,  $A^0 \rightarrow q\bar{q}$ . In addition, the MSSM parameter set in the “large- $\mu$ ” and “no-mixing” scenarios are examined.
- <sup>6</sup> HEISTER 02 excludes the range  $0.7 < \tan\beta < 2.3$ . A wider range is excluded with different stop mixing assumptions. Updates BARATE 01C.
- <sup>7</sup> AALTONEN 12AQ combine AALTONEN 12X and ABAZOV 11K. See their Table I and Fig. 1 for the limit on cross section times branching ratio and Fig. 2 for the excluded region in the MSSM parameter space.

## MASS LIMITS FOR NEUTRAL HIGGS BOSONS IN EXTENDED HIGGS MODELS

This Section covers models which do not fit into either the Standard Model or its simplest minimal Supersymmetric extension (MSSM), leading to anomalous production rates, or nonstandard final states and branching ratios. In particular, this Section covers limits which may apply to generic two-Higgs-doublet models (2HDM), or to special regions of the MSSM parameter space where decays to invisible particles or to photon pairs are dominant (see the review on “Status of Higgs Boson Physics”). Concerning the mass limits for  $H^0$  and  $A^0$  listed below, see the footnotes or the comment lines for details on the nature of the models to which the limits apply.

The observed signal at about 125 GeV, see section “H”, can be interpreted as one of the neutral Higgs bosons of an extended Higgs sector.

### Mass Limits in General two-Higgs-doublet Models

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
1	AAD	21AF ATLS	$H_2^0 \rightarrow ZZ$	
2	AAD	21AI ATLS	$A^0 \rightarrow ZH_2^0$	
3	AAD	20 ATLS	$H^0$ properties	
4	AAD	20L ATLS	$H_2^0 \rightarrow b\bar{b}$	
5	SIRUNYAN	20AA CMS	$H_2^0 \rightarrow ZA^0$ or $A^0 \rightarrow ZH_2^0$	
6	SIRUNYAN	20Y CMS	$H_2^0 \rightarrow W^+W^-$	
7	SIRUNYAN	19AE CMS	$A^0 \rightarrow \tau^+\tau^-$	
8	SIRUNYAN	19AV CMS	$A^0 \rightarrow ZH^0$	
9	AABOUD	18AH ATLS	$A^0 \rightarrow ZH_2^0$	
10	AABOUD	18AI ATLS	$A^0 \rightarrow ZH^0$	

		11	AABOUD	18BF ATLS	$H_2^0 \rightarrow ZZ$
		12	AABOUD	18CE ATLS	$pp \rightarrow H_2^0/A^0 t\bar{t}$ , $H_2^0/A^0 \rightarrow t\bar{t}$
		13	HALLER	18 RVUE	global fits
		14	SIRUNYAN	18BP CMS	$pp \rightarrow H_2^0/A^0 + b + X$ , $H_2^0/A^0 \rightarrow b\bar{b}$
		15	SIRUNYAN	18ED CMS	$A^0 \rightarrow ZH^0$
		16	AABOUD	17AN ATLS	$H_2^0, A^0 \rightarrow t\bar{t}$
		17	SIRUNYAN	17AX CMS	$A^0 b\bar{b}, A^0 \rightarrow \mu^+ \mu^-$
		18	AAD	16AX ATLS	$H_2^0 \rightarrow ZZ$
		19	KHACHATRY...16P	CMS	$H_2^0 \rightarrow H^0 H^0, A^0 \rightarrow ZH^0$
		20	KHACHATRY...16W	CMS	$A^0 b\bar{b}, A^0 \rightarrow \tau^+ \tau^-$
		21	KHACHATRY...16Z	CMS	$H_2^0 \rightarrow ZA^0$ or $A^0 \rightarrow ZH_2^0$
		22	AAD	15BK ATLS	$H_2^0 \rightarrow H^0 H^0$
		23	AAD	15S ATLS	$A^0 \rightarrow ZH^0$
		24	KHACHATRY...15BB	CMS	$H_2^0, A^0 \rightarrow \gamma\gamma$
		25	KHACHATRY...15N	CMS	$A^0 \rightarrow ZH^0$
		26	AAD	14M ATLS	$H_2^0 \rightarrow H^\pm W^\mp \rightarrow$ $H^0 W^\pm W^\mp, H^0 \rightarrow b\bar{b}$
		27	KHACHATRY...14Q	CMS	$H_2^0 \rightarrow H^0 H^0, A^0 \rightarrow ZH^0$
		28	AALTONEN	09AR CDF	$p\bar{p} \rightarrow H_{1,2}^0/A^0 + X$ , $H_{1,2}^0/A^0 \rightarrow \tau^+ \tau^-$
none 1–55 >110.6	95	29	ABBIENDI	05A OPAL	$H_1^0$ , Type II model
	95	30	ABDALLAH	05D DLPH	$H^0 \rightarrow 2 \text{ jets}$
		31	ABDALLAH	04O DLPH	$Z \rightarrow f\bar{f}H$
		32	ABDALLAH	04O DLPH	$e^+ e^- \rightarrow H^0 Z, H^0 A^0$
		33	ABBIENDI	02D OPAL	$e^+ e^- \rightarrow b\bar{b}H$
none 1–44 > 68.0	95	34	ABBIENDI	01E OPAL	$H_1^0$ , Type-II model
	95	35	ABBIENDI	99E OPAL	$\tan\beta > 1$
		36	ABREU	95H DLPH	$Z \rightarrow H^0 Z^*, H^0 A^0$
		37	PICH	92 RVUE	Very light Higgs

<sup>1</sup> AAD 21AF search for production of a heavy  $H_2^0$  state decaying to  $ZZ$  in the final states  $\ell^+ \ell^- \ell'^+ \ell'^-$  and  $\ell^+ \ell^- \nu \bar{\nu}$  in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 6 and 7 for excluded parameter regions of the 2HDM Type I and II.

<sup>2</sup> AAD 21AI search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH_2^0 \rightarrow \ell^+ \ell^- b\bar{b}$  or  $\ell^+ \ell^- W^+ W^-$  in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 10 and 14 for excluded regions in the parameter space of various 2HDMs.

<sup>3</sup> AAD 20 combine measurements on  $H^0$  production and decay using data taken in years 2015–2017 (up to  $79.8 \text{ fb}^{-1}$ ) of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 18 for excluded regions in various 2HDMs.

<sup>4</sup> AAD 20L search for  $b$ -associated production of  $H_2^0$  decaying to  $b\bar{b}$  in  $27.8 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 10 and 11 for excluded regions in the flipped two Higgs doublet model.

<sup>5</sup> SIRUNYAN 20AA search for  $H_2^0 \rightarrow ZA^0, A^0 \rightarrow b\bar{b}$  or  $A^0 \rightarrow ZH_2^0, H_2^0 \rightarrow b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 8 and 9 for excluded regions in the parameter space of Type-II two Higgs doublet model.



- 6 SIRUNYAN 20Y search for gluon-fusion and vector-boson-fusion production of  $H_2^0$  decaying to  $W^+W^-$  in the final states  $\ell\nu\ell\nu$  and  $\ell\nu q\bar{q}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 7 for excluded regions in Type I and II two Higgs doublet models.
- 7 SIRUNYAN 19AE search for a pseudoscalar resonance produced in association with a  $b\bar{b}$  pair, decaying to  $\tau^+\tau^-$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 4 for cross section limits for  $m_{A^0} = 25\text{--}70 \text{ GeV}$  and comparison with some representative 2HDMs.
- 8 SIRUNYAN 19AV search for a scalar resonance produced by gluon fusion or  $b$  associated production, decaying to  $ZH^0 \rightarrow \ell^+\ell^-b\bar{b}$  ( $\ell = e, \mu$ ) or  $\nu\bar{\nu}b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 6 and 7 for excluded regions in the parameter space of various 2HDMs.
- 9 AABOUD 18AH search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH_2^0 \rightarrow \ell^+\ell^-b\bar{b}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for excluded regions in the parameter space of various 2HDMs.
- 10 AABOUD 18AI search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH^0$  in the final states  $\nu\bar{\nu}b\bar{b}$  and  $\ell^+\ell^-b\bar{b}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 7 and 8 for excluded regions in the parameter space in various 2HDMs.
- 11 AABOUD 18BF search for production of a heavy  $H_2^0$  state decaying to  $ZZ$  in the final states  $\ell^+\ell^-\ell^+\ell^-$  and  $\ell^+\ell^-\nu\bar{\nu}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 8 and 9 for excluded parameter regions in 2HDM Type I and II.
- 12 AABOUD 18CE search for the process  $pp \rightarrow H_2^0/A^0 t\bar{t}$  followed by the decay  $H_2^0/A^0 \rightarrow t\bar{t}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 12 for limits on cross section times branching ratio, and for lower limits on  $\tan\beta$  for  $m_{H_2^0}, m_{A^0} = 0.4\text{--}1.0 \text{ TeV}$  in the 2HDM type II.
- 13 HALLER 18 perform global fits in the framework of two-Higgs-doublet models (type I, II, lepton specific, flipped). See their Fig. 8 for allowed parameter regions from fits to LHC  $H^0$  measurements, Fig. 9 bottom and charm decays, Fig. 10 muon anomalous magnetic moment, Fig. 11 electroweak precision data, and Fig. 12 by combination of all data.
- 14 SIRUNYAN 18BP search for production of  $H_2^0/A^0 \rightarrow b\bar{b}$  by  $b$ -associated production in  $35.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for the limits on cross section times branching ratio for  $m_{H_2^0}, m_{A^0} = 0.3\text{--}1.3 \text{ TeV}$ , and Figs. 8 and 9 for excluded regions in the parameter space of type-II and flipped 2HDMs.
- 15 SIRUNYAN 18ED search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH^0$  in the final states  $\nu\bar{\nu}b\bar{b}$  or  $\ell^+\ell^-b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 9 for excluded regions in the parameter space in Type I and II 2HDMs.
- 16 AABOUD 17AN search for production of a heavy  $H_2^0$  and/or  $A^0$  decaying to  $t\bar{t}$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 3 and Table III for excluded parameter regions in Type II Two-Higgs-Doublet-Models.
- 17 SIRUNYAN 17AX search for  $A^0 b\bar{b}$  production followed by the decay  $A^0 \rightarrow \mu^+\mu^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . Limits are set in the range  $m_{A^0} = 25\text{--}60 \text{ GeV}$ . See their Fig. 5 for upper limits on  $\sigma(A^0 b\bar{b})\cdot\text{B}(A^0 \rightarrow \mu^+\mu^-)$ .
- 18 AAD 16AX search for production of a heavy  $H^0$  state decaying to  $ZZ$  in the final states  $\ell^+\ell^-\ell^+\ell^-$ ,  $\ell^+\ell^-\nu\bar{\nu}$ ,  $\ell^+\ell^-q\bar{q}$ , and  $\nu\bar{\nu}q\bar{q}$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Figs. 13 and 14 for excluded parameter regions in Type I and II models.
- 19 KHACHATRYAN 16P search for gluon fusion production of an  $H_2^0$  decaying to  $H^0 H^0 \rightarrow b\bar{b}\tau^+\tau^-$  and an  $A^0$  decaying to  $ZH^0 \rightarrow \ell^+\ell^-\tau^+\tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 11 for limits on  $\tan\beta$  for  $m_{A^0} = 230\text{--}350 \text{ GeV}$ .

- 20 KHACHATRYAN 16W search for  $A^0 b\bar{b}$  production followed by the decay  $A^0 \rightarrow \tau^+ \tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 3 for upper limits on  $\sigma(A^0 b\bar{b}) \cdot \text{B}(A^0 \rightarrow \tau^+ \tau^-)$ .
- 21 KHACHATRYAN 16Z search for  $H_2^0 \rightarrow ZA^0$  followed by  $A^0 \rightarrow b\bar{b}$  or  $\tau^+ \tau^-$ , and  $A^0 \rightarrow ZH_2^0$  followed by  $H_2^0 \rightarrow b\bar{b}$  or  $\tau^+ \tau^-$ , in  $19.8 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 4 for cross section limits and Fig. 5 for excluded region in the parameter space.
- 22 AAD 15BK search for production of a heavy  $H_2^0$  decaying to  $H^0 H^0$  in the final state  $b\bar{b}b\bar{b}$  in  $19.5 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Figs. 15–18 for excluded regions in the parameter space.
- 23 AAD 15S search for production of  $A^0$  decaying to  $ZH^0 \rightarrow \ell^+ \ell^- b\bar{b}$ ,  $\nu\bar{\nu}b\bar{b}$  and  $\ell^+ \ell^- \tau^+ \tau^-$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Figs. 4 and 5 for excluded regions in the parameter space.
- 24 KHACHATRYAN 15BB search for  $H_2^0$ ,  $A^0 \rightarrow \gamma\gamma$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 10 for excluded regions in the two-Higgs-doublet model parameter space.
- 25 KHACHATRYAN 15N search for production of  $A^0$  decaying to  $ZH^0 \rightarrow \ell^+ \ell^- b\bar{b}$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 5 for excluded regions in the  $\tan\beta - \cos(\beta - \alpha)$  plane for  $m_{A^0} = 300 \text{ GeV}$ .
- 26 AAD 14M search for the decay cascade  $H_2^0 \rightarrow H^\pm W^\mp \rightarrow H^0 W^\pm W^\mp$ ,  $H^0$  decaying to  $b\bar{b}$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Table IV for limits in a two-Higgs-doublet model for  $m_{H_2^0} = 325\text{--}1025 \text{ GeV}$  and  $m_{H^\pm} = 225\text{--}825 \text{ GeV}$ .
- 27 KHACHATRYAN 14Q search for  $H_2^0 \rightarrow H^0 H^0$  and  $A^0 \rightarrow ZH^0$  in  $19.5 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Figs. 4 and 5 for limits on cross section times branching ratio for  $m_{H_2^0, A^0} = 260\text{--}360 \text{ GeV}$  and their Figs. 7–9 for limits in two-Higgs-doublet models.
- 28 AALTONEN 09AR search for Higgs bosons decaying to  $\tau^+ \tau^-$  in two doublet models in  $1.8 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ . See their Fig. 2 for the limit on  $\sigma \cdot \text{B}(H_{1,2}^0/A^0 \rightarrow \tau^+ \tau^-)$  for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space.
- 29 ABBIENDI 05A search for  $e^+ e^- \rightarrow H_1^0 A^0$  in general Type-II two-doublet models, with decays  $H_1^0$ ,  $A^0 \rightarrow q\bar{q}$ ,  $g g$ ,  $\tau^+ \tau^-$ , and  $H_1^0 \rightarrow A^0 A^0$ .
- 30 ABDALLAH 05D search for  $e^+ e^- \rightarrow H^0 Z$  and  $H^0 A^0$  with  $H^0$ ,  $A^0$  decaying to two jets of any flavor including  $g g$ . The limit is for SM  $H^0 Z$  production cross section with  $\text{B}(H^0 \rightarrow jj) = 1$ .
- 31 ABDALLAH 04O search for  $Z \rightarrow b\bar{b}H^0$ ,  $b\bar{b}A^0$ ,  $\tau^+ \tau^- H^0$  and  $\tau^+ \tau^- A^0$  in the final states  $4b$ ,  $b\bar{b}\tau^+ \tau^-$ , and  $4\tau$ . See paper for limits on Yukawa couplings.
- 32 ABDALLAH 04O search for  $e^+ e^- \rightarrow H^0 Z$  and  $H^0 A^0$ , with  $H^0$ ,  $A^0$  decaying to  $b\bar{b}$ ,  $\tau^+ \tau^-$ , or  $H^0 \rightarrow A^0 A^0$  at  $E_{\text{cm}} = 189\text{--}208 \text{ GeV}$ . See paper for limits on couplings.
- 33 ABBIENDI 02D search for  $Z \rightarrow b\bar{b}H_1^0$  and  $b\bar{b}A^0$  with  $H_1^0/A^0 \rightarrow \tau^+ \tau^-$ , in the range  $4 < m_H < 12 \text{ GeV}$ . See their Fig. 8 for limits on the Yukawa coupling.
- 34 ABBIENDI 01E search for neutral Higgs bosons in general Type-II two-doublet models, at  $E_{\text{cm}} \leq 189 \text{ GeV}$ . In addition to usual final states, the decays  $H_1^0$ ,  $A^0 \rightarrow q\bar{q}$ ,  $g g$  are searched for. See their Figs. 15,16 for excluded regions.
- 35 ABBIENDI 99E search for  $e^+ e^- \rightarrow H^0 A^0$  and  $H^0 Z$  at  $E_{\text{cm}} = 183 \text{ GeV}$ . The limit is with  $m_H = m_A$  in general two Higgs-doublet models. See their Fig. 18 for the exclusion limit in the  $m_H - m_A$  plane. Updates the results of ACKERSTAFF 98S.

<sup>36</sup> See Fig. 4 of ABREU 95H for the excluded region in the  $m_{H^0} - m_{A^0}$  plane for general two-doublet models. For  $\tan\beta > 1$ , the region  $m_{H^0} + m_{A^0} \lesssim 87$  GeV,  $m_{H^0} < 47$  GeV is excluded at 95% CL.

<sup>37</sup> PICH 92 analyse  $H^0$  with  $m_{H^0} < 2m_\mu$  in general two-doublet models. Excluded regions in the space of mass-mixing angles from LEP, beam dump, and  $\pi^\pm$ ,  $\eta$  rare decays are shown in Figs. 3,4. The considered mass region is not totally excluded.

### Mass Limits for $H^0$ with Vanishing Yukawa Couplings

These limits assume that  $H^0$  couples to gauge bosons with the same strength as the Standard Model Higgs boson, but has no coupling to quarks and leptons (this is often referred to as “fermiophobic”).

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		1 AALTONEN 13K	CDF	$H^0 \rightarrow WW^{(*)}$
none 100–113	95	2 AALTONEN 13L	CDF	$H^0 \rightarrow \gamma\gamma, WW^*, ZZ^*$
none 100–116	95	3 AALTONEN 13M	TEVA	$H^0 \rightarrow \gamma\gamma, WW^*, ZZ^*$
		4 ABAZOV 13G	D0	$H^0 \rightarrow WW^{(*)}$
none 100–113	95	5 ABAZOV 13H	D0	$H^0 \rightarrow \gamma\gamma$
		6 ABAZOV 13I	D0	$H^0 \rightarrow WW^{(*)}$
		7 ABAZOV 13J	D0	$H^0 \rightarrow WW^{(*)}, ZZ^{(*)}$
none 100–114	95	8 ABAZOV 13L	D0	$H^0 \rightarrow \gamma\gamma, WW^*, ZZ^*$
none 110–147	95	9 CHATRCHYAN 13AL	CMS	$H^0 \rightarrow \gamma\gamma$
none 110–118, 119.5–121	95	10 AAD 12N	ATLS	$H^0 \rightarrow \gamma\gamma$
none 100–114	95	11 AALTONEN 12AN	CDF	$H^0 \rightarrow \gamma\gamma$
none 110–194	95	12 CHATRCHYAN 12AO	CMS	$H^0 \rightarrow \gamma\gamma, WW^{(*)}, ZZ^{(*)}$
none 70–106	95	13 AALTONEN 09AB	CDF	$H^0 \rightarrow \gamma\gamma$
none 70–100	95	14 ABAZOV 08U	D0	$H^0 \rightarrow \gamma\gamma$
>105.8	95	15 SCHAEAL 07	ALEP	$e^+e^- \rightarrow H^0 Z, H^0 \rightarrow WW^*$
>104.1	95	16,17 ABDALLAH 04L	DLPH	$e^+e^- \rightarrow H^0 Z, H^0 \rightarrow \gamma\gamma$
>107	95	18 ACHARD 03C	L3	$H^0 \rightarrow WW^*, ZZ^*, \gamma\gamma$
>105.5	95	16,19 ABBIENDI 02F	OPAL	$H^0 \rightarrow \gamma\gamma$
>105.4	95	20 ACHARD 02C	L3	$H^0 \rightarrow \gamma\gamma$
none 60–82	95	21 AFFOLDER 01H	CDF	$p\bar{p} \rightarrow H^0 W/Z, H^0 \rightarrow \gamma\gamma$
> 94.9	95	22 ACCIARRI 00S	L3	$e^+e^- \rightarrow H^0 Z, H^0 \rightarrow \gamma\gamma$
>100.7	95	23 BARATE 00L	ALEP	$e^+e^- \rightarrow H^0 Z, H^0 \rightarrow \gamma\gamma$
> 96.2	95	24 ABBIENDI 99O	OPAL	$e^+e^- \rightarrow H^0 Z, H^0 \rightarrow \gamma\gamma$
> 78.5	95	25 ABBOTT 99B	D0	$p\bar{p} \rightarrow H^0 W/Z, H^0 \rightarrow \gamma\gamma$
		26 ABREU 99P	DLPH	$e^+e^- \rightarrow H^0 \gamma$ and/or $H^0 \rightarrow \gamma\gamma$

<sup>1</sup> AALTONEN 13K search for  $H^0 \rightarrow WW^{(*)}$  in 9.7 fb<sup>-1</sup> of  $p\bar{p}$  collisions at  $E_{cm} = 1.96$  TeV. A limit on cross section times branching ratio which corresponds to (1.3–6.6) times the expected cross section is given in the range  $m_{H^0} = 110–200$  GeV at 95% CL.

<sup>2</sup> AALTONEN 13L combine all CDF searches with 9.45–10.0 fb<sup>-1</sup> of  $p\bar{p}$  collisions at  $E_{cm} = 1.96$  TeV.

<sup>3</sup> AALTONEN 13M combine all Tevatron data from the CDF and D0 Collaborations of  $p\bar{p}$  collisions at  $E_{cm} = 1.96$  TeV.

<sup>4</sup> ABAZOV 13G search for  $H^0 \rightarrow WW^{(*)}$  in 9.7 fb<sup>-1</sup> of  $p\bar{p}$  collisions at  $E_{cm} = 1.96$  TeV. A limit on cross section times branching ratio which corresponds to (2–9) times the expected cross section is given for  $m_{H^0} = 100–200$  GeV at 95% CL.

- 5 ABAZOV 13H search for  $H^0 \rightarrow \gamma\gamma$  in  $9.6 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ .
- 6 ABAZOV 13I search for  $H^0$  production in the final state with one lepton and two or more jets plus missing  $E_T$  in  $9.7 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ . The search is sensitive to  $WH^0$ ,  $ZH^0$  and vector-boson fusion Higgs production with  $H^0 \rightarrow WW^{(*)}$ . A limit on cross section times branching ratio which corresponds to (8–30) times the expected cross section is given in the range  $m_{H^0} = 100\text{--}200 \text{ GeV}$  at 95% CL.
- 7 ABAZOV 13J search for  $H^0$  production in the final states  $ee\mu$ ,  $e\mu\mu$ ,  $\mu\tau\tau$ , and  $e^\pm\mu^\pm$  in  $8.6\text{--}9.7 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ . The search is sensitive to  $WH^0$ ,  $ZH^0$  production with  $H^0 \rightarrow WW^{(*)}$ ,  $ZZ^{(*)}$ , decaying to leptonic final states. A limit on cross section times branching ratio which corresponds to (2.4–13.0) times the expected cross section is given in the range  $m_{H^0} = 100\text{--}200 \text{ GeV}$  at 95% CL.
- 8 ABAZOV 13L combine all D0 results with up to  $9.7 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ .
- 9 CHATRCHYAN 13AL search for  $H^0 \rightarrow \gamma\gamma$  in  $5.1 \text{ fb}^{-1}$  and  $5.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  and  $8 \text{ TeV}$ .
- 10 AAD 12N search for  $H^0 \rightarrow \gamma\gamma$  with  $4.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7 \text{ TeV}$  in the mass range  $m_{H^0} = 110\text{--}150 \text{ GeV}$ .
- 11 AALTONEN 12AN search for  $H^0 \rightarrow \gamma\gamma$  with  $10 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$  in the mass range  $m_{H^0} = 100\text{--}150 \text{ GeV}$ .
- 12 CHATRCHYAN 12AO use data from CHATRCHYAN 12G, CHATRCHYAN 12E, CHATRCHYAN 12H, CHATRCHYAN 12I, CHATRCHYAN 12D, and CHATRCHYAN 12C.
- 13 AALTONEN 09AB search for  $H^0 \rightarrow \gamma\gamma$  in  $3.0 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$  in the mass range  $m_{H^0} = 70\text{--}150 \text{ GeV}$ . Associated  $H^0W$ ,  $H^0Z$  production and  $WW$ ,  $ZZ$  fusion are considered.
- 14 ABAZOV 08U search for  $H^0 \rightarrow \gamma\gamma$  in  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$  in the mass range  $m_{H^0} = 70\text{--}150 \text{ GeV}$ . Associated  $H^0W$ ,  $H^0Z$  production and  $WW$ ,  $ZZ$  fusion are considered. See their Tab. 1 for the limit on  $\sigma \cdot B(H^0 \rightarrow \gamma\gamma)$ , and see their Fig. 3 for the excluded region in the  $m_{H^0} - B(H^0 \rightarrow \gamma\gamma)$  plane.
- 15 SCHAEEL 07 search for Higgs bosons in association with a fermion pair and decaying to  $WW^*$ . The limit is from this search and HEISTER 02L for a  $H^0$  with SM production cross section.
- 16 Search for associated production of a  $\gamma\gamma$  resonance with a  $Z$  boson, followed by  $Z \rightarrow q\bar{q}$ ,  $\ell^+\ell^-$ , or  $\nu\bar{\nu}$ , at  $E_{\text{cm}} \leq 209 \text{ GeV}$ . The limit is for a  $H^0$  with SM production cross section.
- 17 Updates ABREU 01F.
- 18 ACHARD 03C search for  $e^+e^- \rightarrow ZH^0$  followed by  $H^0 \rightarrow WW^*$  or  $ZZ^*$  at  $E_{\text{cm}} = 200\text{--}209 \text{ GeV}$  and combine with the ACHARD 02C result. The limit is for a  $H^0$  with SM production cross section. For  $B(H^0 \rightarrow WW^*) + B(H^0 \rightarrow ZZ^*) = 1$ ,  $m_{H^0} > 108.1 \text{ GeV}$  is obtained. See fig. 6 for the limits under different BR assumptions.
- 19 For  $B(H^0 \rightarrow \gamma\gamma)=1$ ,  $m_{H^0} > 117 \text{ GeV}$  is obtained.
- 20 ACHARD 02C search for associated production of a  $\gamma\gamma$  resonance with a  $Z$  boson, followed by  $Z \rightarrow q\bar{q}$ ,  $\ell^+\ell^-$ , or  $\nu\bar{\nu}$ , at  $E_{\text{cm}} \leq 209 \text{ GeV}$ . The limit is for a  $H^0$  with SM production cross section. For  $B(H^0 \rightarrow \gamma\gamma)=1$ ,  $m_{H^0} > 114 \text{ GeV}$  is obtained.
- 21 AFFOLDER 01H search for associated production of a  $\gamma\gamma$  resonance and a  $W$  or  $Z$  (tagged by two jets, an isolated lepton, or missing  $E_T$ ). The limit assumes Standard Model values for the production cross section and for the couplings of the  $H^0$  to  $W$  and  $Z$  bosons. See their Fig. 11 for limits with  $B(H^0 \rightarrow \gamma\gamma) < 1$ .
- 22 ACCIARRI 00S search for associated production of a  $\gamma\gamma$  resonance with a  $q\bar{q}$ ,  $\nu\bar{\nu}$ , or  $\ell^+\ell^-$  pair in  $e^+e^-$  collisions at  $E_{\text{cm}} = 189 \text{ GeV}$ . The limit is for a  $H^0$  with SM

- production cross section. For  $B(H^0 \rightarrow \gamma\gamma)=1$ ,  $m_{H^0} > 98$  GeV is obtained. See their Fig. 5 for limits on  $B(H \rightarrow \gamma\gamma) \cdot \sigma(e^+e^- \rightarrow Hf\bar{f})/\sigma(e^+e^- \rightarrow Hf\bar{f})$  (SM).
- <sup>23</sup> BARATE 00L search for associated production of a  $\gamma\gamma$  resonance with a  $q\bar{q}$ ,  $\nu\bar{\nu}$ , or  $\ell^+\ell^-$  pair in  $e^+e^-$  collisions at  $E_{\text{cm}} = 88\text{--}202$  GeV. The limit is for a  $H^0$  with SM production cross section. For  $B(H^0 \rightarrow \gamma\gamma)=1$ ,  $m_{H^0} > 109$  GeV is obtained. See their Fig. 3 for limits on  $B(H \rightarrow \gamma\gamma) \cdot \sigma(e^+e^- \rightarrow Hf\bar{f})/\sigma(e^+e^- \rightarrow Hf\bar{f})$  (SM).
- <sup>24</sup> ABBIENDI 99O search for associated production of a  $\gamma\gamma$  resonance with a  $q\bar{q}$ ,  $\nu\bar{\nu}$ , or  $\ell^+\ell^-$  pair in  $e^+e^-$  collisions at 189 GeV. The limit is for a  $H^0$  with SM production cross section. See their Fig. 4 for limits on  $\sigma(e^+e^- \rightarrow H^0 Z^0) \times B(H^0 \rightarrow \gamma\gamma) \times B(X^0 \rightarrow f\bar{f})$  for various masses. Updates the results of ACKERSTAFF 98Y.
- <sup>25</sup> ABBOTT 99B search for associated production of a  $\gamma\gamma$  resonance and a dijet pair. The limit assumes Standard Model values for the production cross section and for the couplings of the  $H^0$  to  $W$  and  $Z$  bosons. Limits in the range of  $\sigma(H^0 + Z/W) \cdot B(H^0 \rightarrow \gamma\gamma) = 0.80\text{--}0.34$  pb are obtained in the mass range  $m_{H^0} = 65\text{--}150$  GeV.
- <sup>26</sup> ABREU 99P search for  $e^+e^- \rightarrow H^0\gamma$  with  $H^0 \rightarrow b\bar{b}$  or  $\gamma\gamma$ , and  $e^+e^- \rightarrow H^0 q\bar{q}$  with  $H^0 \rightarrow \gamma\gamma$ . See their Fig. 4 for limits on  $\sigma \times B$ . Explicit limits within an effective interaction framework are also given.

### Mass Limits for $H^0$ Decaying to Invisible Final States

These limits are for a neutral scalar  $H^0$  which predominantly decays to invisible final states. Standard Model values are assumed for the couplings of  $H^0$  to ordinary particles unless otherwise stated.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

		<sup>1</sup> AABOUD	19AI ATLS	$W W/Z Z$ fusion
		<sup>2</sup> AAD	15BD ATLS	$pp \rightarrow H^0 W X, H^0 Z X$
		<sup>3</sup> AAD	15BH ATLS	jet + missing $E_T$
		<sup>4</sup> AAD	14BA ATLS	secondary vertex
		<sup>5</sup> AAD	14O ATLS	$pp \rightarrow H^0 Z X$
		<sup>6</sup> CHATRCHYAN	14B CMS	$pp \rightarrow H^0 Z X, qqH^0 X$
		<sup>7</sup> AAD	13AG ATLS	secondary vertex
		<sup>8</sup> AAD	13AT ATLS	electron jets
		<sup>9</sup> CHATRCHYAN	13BJ CMS	
		<sup>10</sup> AAD	12AQ ATLS	secondary vertex
		<sup>11</sup> AALTONEN	12AB CDF	secondary vertex
		<sup>12</sup> AALTONEN	12U CDF	secondary vertex
>108.2	95	<sup>13</sup> ABBIENDI	10 OPAL	
		<sup>14</sup> ABBIENDI	07 OPAL	large width
>112.3	95	<sup>15</sup> ACHARD	05 L3	
>112.1	95	<sup>15</sup> ABDALLAH	04B DLPH	
>114.1	95	<sup>15</sup> HEISTER	02 ALEP	$E_{\text{cm}} \leq 209$ GeV
>106.4	95	<sup>15</sup> BARATE	01C ALEP	$E_{\text{cm}} \leq 202$ GeV
> 89.2	95	<sup>16</sup> ACCIARRI	00M L3	

<sup>1</sup> AABOUD 19AI search for  $H_{1,2}^0$  production by vector boson fusion and decay to invisible final states in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Fig. 6(b) for limits on cross section times branching ratios for  $m_{H_{1,2}^0} = 0.1\text{--}3$  TeV.

<sup>2</sup> AAD 15BD search for  $pp \rightarrow H^0 W X$  and  $pp \rightarrow H^0 Z X$  with  $W$  or  $Z$  decaying hadronically and  $H^0$  decaying to invisible final states in  $20.3 \text{ fb}^{-1}$  at  $E_{\text{cm}} = 8$  TeV. See

- their Fig. 6 for a limit on the cross section times branching ratio for  $m_{H^0} = 115\text{--}300$  GeV.
- <sup>3</sup> AAD 15BH search for events with a jet and missing  $E_T$  in  $20.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. Limits on  $\sigma(H'^0) \text{B}(H'^0 \rightarrow \text{invisible}) < (44\text{--}10)$  pb (95%CL) is given for  $m_{H'^0} = 115\text{--}300$  GeV.
  - <sup>4</sup> AAD 14BA search for  $H^0$  production in the decay mode  $H^0 \rightarrow X^0 X^0$ , where  $X^0$  is a long-lived particle which decays to collimated pairs of  $e^+ e^-$ ,  $\mu^+ \mu^-$ , or  $\pi^+ \pi^-$  plus invisible particles, in  $20.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Figs. 15 and 16 for limits on cross section times branching ratio.
  - <sup>5</sup> AAD 14O search for  $pp \rightarrow H^0 ZX$ ,  $Z \rightarrow \ell\ell$ , with  $H^0$  decaying to invisible final states in  $4.5\text{ fb}^{-1}$  at  $E_{\text{cm}} = 7$  TeV and  $20.3\text{ fb}^{-1}$  at  $E_{\text{cm}} = 8$  TeV. See their Fig. 3 for a limit on the cross section times branching ratio for  $m_{H^0} = 110\text{--}400$  GeV.
  - <sup>6</sup> CHATRCHYAN 14B search for  $pp \rightarrow H^0 ZX$ ,  $Z \rightarrow \ell\ell$  and  $Z \rightarrow b\bar{b}$ , and also  $pp \rightarrow qqH^0 X$  with  $H^0$  decaying to invisible final states using data at  $E_{\text{cm}} = 7$  and 8 TeV. See their Figs. 10, 11 for limits on the cross section times branching ratio for  $m_{H^0} = 100\text{--}400$  GeV.
  - <sup>7</sup> AAD 13AG search for  $H^0$  production in the decay mode  $H^0 \rightarrow X^0 X^0$ , where  $X^0$  is a long-lived particle which decays to  $\mu^+ \mu^- X'^0$ , in  $1.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV. See their Fig. 7 for limits on cross section times branching ratio.
  - <sup>8</sup> AAD 13AT search for  $H^0$  production in the decay  $H^0 \rightarrow X^0 X^0$ , where  $X^0$  eventually decays to clusters of collimated  $e^+ e^-$  pairs, in  $2.04\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV. See their Fig. 3 for limits on cross section times branching ratio.
  - <sup>9</sup> CHATRCHYAN 13BJ search for  $H^0$  production in the decay chain  $H^0 \rightarrow X^0 X^0$ ,  $X^0 \rightarrow \mu^+ \mu^- X'^0$  in  $5.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV. See their Fig. 2 for limits on cross section times branching ratio.
  - <sup>10</sup> AAD 12AQ search for  $H^0$  production in the decay mode  $H^0 \rightarrow X^0 X^0$ , where  $X^0$  is a long-lived particle which decays mainly to  $b\bar{b}$  in the muon detector, in  $1.94\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV. See their Fig. 3 for limits on cross section times branching ratio for  $m_{H^0} = 120, 140$  GeV,  $m_{X^0} = 20, 40$  GeV in the  $c\tau$  range of 0.5–35 m.
  - <sup>11</sup> AALTONEN 12AB search for  $H^0$  production in the decay  $H^0 \rightarrow X^0 X^0$ , where  $X^0$  eventually decays to clusters of collimated  $\ell^+ \ell^-$  pairs, in  $5.1\text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96$  TeV. Cross section limits are provided for a benchmark MSSM model incorporating the parameters given in Table VI.
  - <sup>12</sup> AALTONEN 12U search for  $H^0$  production in the decay mode  $H^0 \rightarrow X^0 X^0$ , where  $X^0$  is a long-lived particle with  $c\tau \approx 1$  cm which decays mainly to  $b\bar{b}$ , in  $3.2\text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96$  TeV. See their Figs. 9 and 10 for limits on cross section times branching ratio for  $m_{H^0} = (130\text{--}170)$  GeV,  $m_{X^0} = 20, 40$  GeV.
  - <sup>13</sup> ABBIENDI 10 search for  $e^+ e^- \rightarrow H^0 Z$  with  $H^0$  decaying invisibly. The limit assumes SM production cross section and  $\text{B}(H^0 \rightarrow \text{invisible}) = 1$ .
  - <sup>14</sup> ABBIENDI 07 search for  $e^+ e^- \rightarrow H^0 Z$  with  $Z \rightarrow q\bar{q}$  and  $H^0$  decaying to invisible final states. The  $H^0$  width is varied between 1 GeV and 3 TeV. A limit  $\sigma \cdot \text{B}(H^0 \rightarrow \text{invisible}) < (0.07\text{--}0.57)$  pb (95%CL) is obtained at  $E_{\text{cm}} = 206$  GeV for  $m_{H^0} = 60\text{--}114$  GeV.
  - <sup>15</sup> Search for  $e^+ e^- \rightarrow H^0 Z$  with  $H^0$  decaying invisibly. The limit assumes SM production cross section and  $\text{B}(H^0 \rightarrow \text{invisible}) = 1$ .
  - <sup>16</sup> ACCIARRI 00M search for  $e^+ e^- \rightarrow ZH^0$  with  $H^0$  decaying invisibly at  $E_{\text{cm}} = 183\text{--}189$  GeV. The limit assumes SM production cross section and  $\text{B}(H^0 \rightarrow \text{invisible}) = 1$ . See their Fig. 6 for limits for smaller branching ratios.

## Mass Limits for Light $A^0$

These limits are for a pseudoscalar  $A^0$  in the mass range below  $\mathcal{O}(10)$  GeV.

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

1	ABLIKIM	22H	BES3	$J/\psi \rightarrow A^0 \gamma$
2	JIA	22	BELL	$\Upsilon(1S) \rightarrow A^0 \gamma$
3	AAD	20AE	ATLS	$H^0 \rightarrow Z A^0$
4	AABOUD	18AP	ATLS	$H^0 \rightarrow A^0 A^0$
5	KHACHATRY...17AZ		CMS	$H^0 \rightarrow A^0 A^0$
6	ABLIKIM	16E	BES3	$J/\psi \rightarrow A^0 \gamma$
7	KHACHATRY...16F		CMS	$H^0 \rightarrow A^0 A^0$
8	LEES	15H	BABR	$\Upsilon(1S) \rightarrow A^0 \gamma$
9	LEES	13C	BABR	$\Upsilon(1S) \rightarrow A^0 \gamma$
10	LEES	13L	BABR	$\Upsilon(1S) \rightarrow A^0 \gamma$
11	LEES	13R	BABR	$\Upsilon(1S) \rightarrow A^0 \gamma$
12	ABLIKIM	12	BES3	$J/\psi \rightarrow A^0 \gamma$
13	CHATRCHYAN	12V	CMS	$A^0 \rightarrow \mu^+ \mu^-$
14	AALTONEN	11P	CDF	$t \rightarrow b H^+, H^+ \rightarrow W^+ A^0$
15,16	ABOUZAID	11A	KTEV	$K_L \rightarrow \pi^0 \pi^0 A^0, A^0 \rightarrow \mu^+ \mu^-$
17	DEL-AMO-SA..11J		BABR	$\Upsilon(1S) \rightarrow A^0 \gamma$
18	LEES	11H	BABR	$\Upsilon(2S, 3S) \rightarrow A^0 \gamma$
19	ANDREAS	10	RVUE	
16,20	HYUN	10	BELL	$B^0 \rightarrow K^{*0} A^0, A^0 \rightarrow \mu^+ \mu^-$
16,21	HYUN	10	BELL	$B^0 \rightarrow \rho^0 A^0, A^0 \rightarrow \mu^+ \mu^-$
22	AUBERT	09P	BABR	$\Upsilon(3S) \rightarrow A^0 \gamma$
23	AUBERT	09Z	BABR	$\Upsilon(2S) \rightarrow A^0 \gamma$
24	AUBERT	09Z	BABR	$\Upsilon(3S) \rightarrow A^0 \gamma$
16,25	TUNG	09	K391	$K_L \rightarrow \pi^0 \pi^0 A^0, A^0 \rightarrow \gamma \gamma$
26	LOVE	08	CLEO	$\Upsilon(1S) \rightarrow A^0 \gamma$
27	BESSON	07	CLEO	$\Upsilon(1S) \rightarrow \eta_b \gamma$
28	PARK	05	HYCP	$\Sigma^+ \rightarrow p A^0, A^0 \rightarrow \mu^+ \mu^-$
29	BALEST	95	CLE2	$\Upsilon(1S) \rightarrow A^0 \gamma$
30	ANTREASYAN	90c	CBAL	$\Upsilon(1S) \rightarrow A^0 \gamma$

<sup>1</sup> ABLIKIM 22H search for the process  $J/\psi \rightarrow A^0 \gamma$  with  $A^0$  decaying to  $\mu^+ \mu^-$  in  $9 \times 10^9$   $J/\psi$  events and give limits on  $B(J/\psi \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $1.2 \times 10^{-9} - 7.78 \times 10^{-7}$  (90% CL) for  $0.212 \text{ GeV} \leq m_{A^0} \leq 3.0 \text{ GeV}$ . See their Fig. 4.

<sup>2</sup> JIA 22 search for the process  $\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^- \rightarrow A^0 \gamma \pi^+ \pi^-$  with  $A^0$  decaying to  $\tau^+ \tau^-$  or  $\mu^+ \mu^-$  in  $158 \times 10^6$   $\Upsilon(2S)$  events and give limits on  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \tau^+ \tau^-)$  in the range  $3.8 \times 10^{-6} - 1.5 \times 10^{-4}$  (90% CL) for  $m_{A^0} = 3.6 - 9.2 \text{ GeV}$ , and  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $3.1 \times 10^{-7} - 1.6 \times 10^{-5}$  (90% CL) for  $m_{A^0} = 0.21 - 9.2 \text{ GeV}$ . See their Fig. 4.

<sup>3</sup> AAD 20AE search for the decay  $H^0 \rightarrow Z A^0, Z \rightarrow \ell^+ \ell^-, A^0$  decaying hadronically ( $A^0 \rightarrow g g$  or  $s \bar{s}$ ), in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . Limit on the product of production cross section and the  $H^0 \rightarrow Z A^0$  branching ratio in the range 17–340 pb (95% CL) is given for  $m_{A^0} = 0.5 - 4.0 \text{ GeV}$ , see their Table I.

<sup>4</sup> AABOUD 18AP search for the decay  $H^0 \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 10(b) for limits on  $B(H^0 \rightarrow A^0 A^0)$  in

- the range  $m_{A^0} = 1\text{--}2.5, 4.5\text{--}8$  GeV, assuming a type-II two-doublet plus singlet model with  $\tan(\beta) = 5$ .
- <sup>5</sup> KHACHATRYAN 17AZ search for the decay  $H^0 \rightarrow A^0 A^0 \rightarrow \tau^+ \tau^- \tau^+ \tau^-, \mu^+ \mu^- b \bar{b}$ , and  $\mu^+ \mu^- \tau^+ \tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Figs. 4, 5, and 6 for cross section limits in the range  $m_{A^0} = 5\text{--}62.5$  GeV. See also their Figs. 7, 8, and 9 for interpretation of the data in terms of models with two Higgs doublets and a singlet.
  - <sup>6</sup> ABLIKIM 16E search for the process  $J/\psi \rightarrow A^0 \gamma$  with  $A^0$  decaying to  $\mu^+ \mu^-$  and give limits on  $B(J/\psi \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $2.8 \times 10^{-8}\text{--}5.0 \times 10^{-6}$  (90% CL) for  $0.212 \leq m_{A^0} \leq 3.0$  GeV. See their Fig. 5.
  - <sup>7</sup> KHACHATRYAN 16F search for the decay  $H^0 \rightarrow A^0 A^0 \rightarrow \tau^+ \tau^- \tau^+ \tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Fig. 8 for cross section limits for  $m_{A^0} = 4\text{--}8$  GeV.
  - <sup>8</sup> LEES 15H search for the process  $\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^- \rightarrow A^0 \gamma \pi^+ \pi^-$  with  $A^0$  decaying to  $c \bar{c}$  and give limits on  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow c \bar{c})$  in the range  $7.4 \times 10^{-5}\text{--}2.4 \times 10^{-3}$  (90% CL) for  $4.00 \leq m_{A^0} \leq 8.95$  and  $9.10 \leq m_{A^0} \leq 9.25$  GeV. See their Fig. 6.
  - <sup>9</sup> LEES 13C search for the process  $\Upsilon(2S, 3S) \rightarrow \Upsilon(1S) \pi^+ \pi^- \rightarrow A^0 \gamma \pi^+ \pi^-$  with  $A^0$  decaying to  $\mu^+ \mu^-$  and give limits on  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $(0.3\text{--}9.7) \times 10^{-6}$  (90% CL) for  $0.212 \leq m_{A^0} \leq 9.20$  GeV. See their Fig. 5(e) for limits on the  $b\text{--}A^0$  Yukawa coupling derived by combining this result with AUBERT 09Z.
  - <sup>10</sup> LEES 13L search for the process  $\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^- \rightarrow A^0 \gamma \pi^+ \pi^-$  with  $A^0$  decaying to  $g g$  or  $s \bar{s}$  and give limits on  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow g g)$  between  $1 \times 10^{-6}$  and  $2 \times 10^{-2}$  (90% CL) for  $0.5 \leq m_{A^0} \leq 9.0$  GeV, and  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow s \bar{s})$  between  $4 \times 10^{-6}$  and  $1 \times 10^{-3}$  (90%CL) for  $1.5 \leq m_{A^0} \leq 9.0$  GeV. See their Fig. 4.
  - <sup>11</sup> LEES 13R search for the process  $\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^- \rightarrow A^0 \gamma \pi^+ \pi^-$  with  $A^0$  decaying to  $\tau^+ \tau^-$  and give limits on  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \tau^+ \tau^-)$  in the range  $0.9\text{--}13 \times 10^{-5}$  (90% CL) for  $3.6 \leq m_{A^0} \leq 9.2$  GeV. See their Fig. 4 for limits on the  $b\text{--}A^0$  Yukawa coupling derived by combining this result with AUBERT 09P.
  - <sup>12</sup> ABLIKIM 12 searches for the process  $\psi(3686) \rightarrow \pi \pi J/\psi, J/\psi \rightarrow A^0 \gamma$  with  $A^0$  decaying to  $\mu^+ \mu^-$ . It gives mass dependent limits on  $B(J/\psi \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $4 \times 10^{-7}\text{--}2.1 \times 10^{-5}$  (90% C.L.) for  $0.212 \leq m_{A^0} \leq 3.0$  GeV. See their Fig. 2.
  - <sup>13</sup> CHATRCHYAN 12V search for  $A^0$  production in the decay  $A^0 \rightarrow \mu^+ \mu^-$  with  $1.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV. A limit on  $\sigma(A^0) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $(1.5\text{--}7.5)$  pb is given for  $m_{A^0} = (5.5\text{--}8.7)$  and  $(11.5\text{--}14)$  GeV at 95% CL.
  - <sup>14</sup> AALTONEN 11P search in  $2.7 \text{ fb}^{-1}$  of  $p \bar{p}$  collisions at  $E_{\text{cm}} = 1.96$  TeV for the decay chain  $t \rightarrow b H^+, H^+ \rightarrow W^+ A^0, A^0 \rightarrow \tau^+ \tau^-$  with  $m_{A^0}$  between 4 and 9 GeV. See their Fig. 4 for limits on  $B(t \rightarrow b H^+)$  for  $90 < m_{H^+} < 160$  GeV.
  - <sup>15</sup> ABOUZAID 11A search for the decay chain  $K_L \rightarrow \pi^0 \pi^0 A^0, A^0 \rightarrow \mu^+ \mu^-$  and give a limit  $B(K_L \rightarrow \pi^0 \pi^0 A^0) \cdot B(A^0 \rightarrow \mu^+ \mu^-) < 1.0 \times 10^{-10}$  at 90% CL for  $m_{A^0} = 214.3$  MeV.
  - <sup>16</sup> The search was motivated by PARK 05.
  - <sup>17</sup> DEL-AMO-SANCHEZ 11J search for the process  $\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^- \rightarrow A^0 \gamma \pi^+ \pi^-$  with  $A^0$  decaying to invisible final states. They give limits on  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \text{invisible})$  in the range  $(1.9\text{--}4.5) \times 10^{-6}$  (90% CL) for  $0 \leq m_{A^0} \leq 8.0$  GeV, and  $(2.7\text{--}37) \times 10^{-6}$  for  $8.0 \leq m_{A^0} \leq 9.2$  GeV.



- 18 LEES 11H search for the process  $\Upsilon(2S, 3S) \rightarrow A^0 \gamma$  with  $A^0$  decaying hadronically and give limits on  $B(\Upsilon(2S, 3S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \text{hadrons})$  in the range  $1 \times 10^{-6} - 8 \times 10^{-5}$  (90% CL) for  $0.3 < m_{A^0} < 7$  GeV. The decay rates for  $\Upsilon(2S)$  and  $\Upsilon(3S)$  are assumed to be equal up to the phase space factor. See their Fig. 5.
- 19 ANDREAS 10 analyze constraints from rare decays and other processes on a light  $A^0$  with  $m_{A^0} < 2m_\mu$  and give limits on its coupling to fermions at the level of  $10^{-4}$  times the Standard Model value.
- 20 HYUN 10 search for the decay chain  $B^0 \rightarrow K^{*0} A^0, A^0 \rightarrow \mu^+ \mu^-$  and give a limit on  $B(B^0 \rightarrow K^{*0} A^0) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $(2.26-5.53) \times 10^{-8}$  at 90%CL for  $m_{A^0} = 212-300$  MeV. The limit for  $m_{A^0} = 214.3$  MeV is  $2.26 \times 10^{-8}$ .
- 21 HYUN 10 search for the decay chain  $B^0 \rightarrow \rho^0 A^0, A^0 \rightarrow \mu^+ \mu^-$  and give a limit on  $B(B^0 \rightarrow \rho^0 A^0) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $(1.73-4.51) \times 10^{-8}$  at 90%CL for  $m_{A^0} = 212-300$  MeV. The limit for  $m_{A^0} = 214.3$  MeV is  $1.73 \times 10^{-8}$ .
- 22 AUBERT 09P search for the process  $\Upsilon(3S) \rightarrow A^0 \gamma$  with  $A^0 \rightarrow \tau^+ \tau^-$  for  $4.03 < m_{A^0} < 9.52$  and  $9.61 < m_{A^0} < 10.10$  GeV, and give limits on  $B(\Upsilon(3S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \tau^+ \tau^-)$  in the range  $(1.5-16) \times 10^{-5}$  (90% CL).
- 23 AUBERT 09Z search for the process  $\Upsilon(2S) \rightarrow A^0 \gamma$  with  $A^0 \rightarrow \mu^+ \mu^-$  for  $0.212 < m_{A^0} < 9.3$  GeV and give limits on  $B(\Upsilon(2S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $(0.3-8) \times 10^{-6}$  (90% CL).
- 24 AUBERT 09Z search for the process  $\Upsilon(3S) \rightarrow A^0 \gamma$  with  $A^0 \rightarrow \mu^+ \mu^-$  for  $0.212 < m_{A^0} < 9.3$  GeV and give limits on  $B(\Upsilon(3S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \mu^+ \mu^-)$  in the range  $(0.3-5) \times 10^{-6}$  (90% CL).
- 25 TUNG 09 search for the decay chain  $K_L \rightarrow \pi^0 \pi^0 A^0, A^0 \rightarrow \gamma \gamma$  and give a limit on  $B(K_L \rightarrow \pi^0 \pi^0 A^0) \cdot B(A^0 \rightarrow \gamma \gamma)$  in the range  $(2.4-10.7) \times 10^{-7}$  at 90%CL for  $m_{A^0} = 194.3-219.3$  MeV. The limit for  $m_{A^0} = 214.3$  MeV is  $2.4 \times 10^{-7}$ .
- 26 LOVE 08 search for the process  $\Upsilon(1S) \rightarrow A^0 \gamma$  with  $A^0 \rightarrow \mu^+ \mu^-$  (for  $m_{A^0} < 2m_\tau$ ) and  $A^0 \rightarrow \tau^+ \tau^-$ . Limits on  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \ell^+ \ell^-)$  in the range  $10^{-6}-10^{-4}$  (90% CL) are given.
- 27 BESSON 07 give a limit  $B(\Upsilon(1S) \rightarrow \eta_b \gamma) \cdot B(\eta_b \rightarrow \tau^+ \tau^-) < 0.27\%$  (95% CL), which constrains a possible  $A^0$  exchange contribution to the  $\eta_b$  decay.
- 28 PARK 05 found three candidate events for  $\Sigma^+ \rightarrow p \mu^+ \mu^-$  in the HyperCP experiment. Due to a narrow spread in dimuon mass, they hypothesize the events as a possible signal of a new boson. It can be interpreted as a neutral particle with  $m_{A^0} = 214.3 \pm 0.5$  MeV and the branching fraction  $B(\Sigma^+ \rightarrow p A^0) \cdot B(A^0 \rightarrow \mu^+ \mu^-) = (3.1^{+2.4}_{-1.9} \pm 1.5) \times 10^{-8}$ .
- 29 BALEST 95 give limits  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \leq 1.5 \times 10^{-5}$  at 90% CL for  $m_{A^0} < 5$  GeV. The limit becomes  $< 10^{-4}$  for  $m_{A^0} < 7.7$  GeV.
- 30 ANTREASYAN 90C give limits  $B(\Upsilon(1S) \rightarrow A^0 \gamma) \leq 5.6 \times 10^{-5}$  at 90% CL for  $m_{A^0} < 7.2$  GeV.  $A^0$  is assumed not to decay in the detector.

### Other Mass Limits

We use a symbol  $H_1^0$  if mass  $< 125$  GeV or  $H_2^0$  if mass  $> 125$  GeV. The notation  $H$  is reserved for the 125 GeV particle.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

1	AAD	22A	ATLS	$H \rightarrow A^0 A^0$
2	AAD	22D	ATLS	$Z A^0, A^0 \rightarrow \text{invisible}$

3	AAD	22F	ATLS	$H_2^0 \rightarrow HH$
4	AAD	22I	ATLS	$H \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0, \tilde{\chi}_2^0 \rightarrow A^0 \tilde{\chi}_1^0,$ $A^0 \rightarrow b\bar{b}$
5	AAD	22J	ATLS	$H \rightarrow ZA^0$
6	AAD	22J	ATLS	$H \rightarrow A^0 A^0, H_1^0 H_1^0$
7	AAD	22P	ATLS	$H_1^0, H_2^0 \rightarrow \text{invisible}$
8	AAD	22Y	ATLS	$H_2^0 \rightarrow HH$
9	ABRATENKO	22A	MCBN	$K^+ \rightarrow H_1^0 \pi^+$
10	TUMASYAN	22AK	CMS	$H_3^0 \rightarrow H_1^0 H_1^0$
11	AAD	21AF	ATLS	$H_2^0 \rightarrow ZZ$
12	AAD	21AI	ATLS	$A^0 \rightarrow ZH_2^0$
13	AAD	21AY	ATLS	$H_2^0 \rightarrow \gamma\gamma$
14	AAD	21AZ	ATLS	$A_2^0 \rightarrow HA_1^0$
15	AAD	21BB	ATLS	$A_2^0 \rightarrow HA_1^0$
16	AAD	21BE	ATLS	$A_1^0 \rightarrow \text{invisible}$
17	ABRATENKO	21	MCBN	$K^+ \rightarrow H_1^0 \pi^+$
18	SIRUNYAN	21A	CMS	$H_2^0 \rightarrow ZA^0, A^0 \rightarrow \text{invisible}$
19	TUMASYAN	21F	CMS	$H_3^0 \rightarrow HH_{1,2}^0$
20	AAD	20AA	ATLS	$H_2^0/A^0 \rightarrow \tau^+ \tau^-$
21	AAD	20AI	ATLS	$H \rightarrow A^0 A^0$
22	AAD	20AO	ATLS	$H_2^0 \rightarrow HH$
23	AAD	20C	ATLS	$H_2^0 \rightarrow HH$
24	AAD	20L	ATLS	$H_2^0 \rightarrow b\bar{b}$
25	AAD	20X	ATLS	$H_2^0 \rightarrow HH$
26	AAIJ	20AL	LHCB	$A^0 \rightarrow \mu^+ \mu^-$
27	SIRUNYAN	20	CMS	$H \rightarrow A^0 A^0$
28	SIRUNYAN	20AA	CMS	$H_2^0 \rightarrow ZA^0$ or $A^0 \rightarrow ZH_2^0$
29	SIRUNYAN	20AC	CMS	$A^0 \rightarrow ZH$
30	SIRUNYAN	20AD	CMS	$H_2^0 \rightarrow \mu\tau, e\tau$
31	SIRUNYAN	20AF	CMS	$H_2^0/A^0 \rightarrow t\bar{t}$
32	SIRUNYAN	20AP	CMS	$H, H_2^0 \rightarrow A^0 A^0$
33	SIRUNYAN	20Y	CMS	$H_2^0 \rightarrow W^+ W^-$
34	SIRUNYAN	20Z	CMS	$t\bar{t}H_{1,2}^0$ or $t\bar{t}A^0, H_{1,2}^0/$ $A^0 \rightarrow e^+ e^-, \mu^+ \mu^-$
35	AABOUD	19A	ATLS	$H_2^0 \rightarrow HH$
36	AABOUD	19AG	ATLS	$H \rightarrow A^0 A^0$
37	AABOUD	19O	ATLS	$H_2^0 \rightarrow HH$
38	AABOUD	19T	ATLS	$H_2^0 \rightarrow HH$
39	AABOUD	19V	ATLS	two doublet + pseudoscalar model
40	AABOUD	19Y	ATLS	$H_2^0 \rightarrow \mu^+ \mu^-$
41	AALTONEN	19	CDF	$H_{1,2}^0 \rightarrow b\bar{b}$
42	SIRUNYAN	19	CMS	$H_2^0 \rightarrow HH$
43	SIRUNYAN	19AE	CMS	$A^0 \rightarrow \tau^+ \tau^-$

44	SIRUNYAN	19AN CMS	$A_2^0 \rightarrow HA_1^0$
45	SIRUNYAN	19AV CMS	$A_0^0 \rightarrow ZH$
46	SIRUNYAN	19B CMS	$H_{1,2}^0/A^0 \rightarrow b\bar{b}$
47	SIRUNYAN	19BB CMS	$H_1^0 \rightarrow \gamma\gamma$
48	SIRUNYAN	19BD CMS	$H \rightarrow A^0 A^0$
49	SIRUNYAN	19BE CMS	$H_2^0 \rightarrow HH$
50	SIRUNYAN	19BQ CMS	$H_{1,2}^0 \rightarrow A^0 A^0$
51	SIRUNYAN	19CR CMS	$H_2^0/A^0 \rightarrow \mu^+ \mu^-$
52	SIRUNYAN	19H CMS	$H_2^0 \rightarrow HH$
53	AABOUD	18AA ATLS	$H_2^0 \rightarrow Z\gamma$
54	AABOUD	18AG ATLS	$H \rightarrow A^0 A^0$
55	AABOUD	18AH ATLS	$A^0 \rightarrow ZH_2^0$
56	AABOUD	18AI ATLS	$A^0 \rightarrow ZH$
57	AABOUD	18BF ATLS	$H_2^0 \rightarrow ZZ$
58	AABOUD	18BU ATLS	$H_2^0 \rightarrow HH$
59	AABOUD	18BX ATLS	$H \rightarrow A^0 A^0$
60	AABOUD	18CQ ATLS	$H_2^0 \rightarrow HH$
61	AABOUD	18F ATLS	$H_2^0 \rightarrow W^+ W^-, ZZ$
62	AAIJ	18AMLHCB	$H_{1,2}^0 \rightarrow \mu\tau$
63	AAIJ	18AQ LHCB	$A^0 \rightarrow \mu^+ \mu^-$
64	AAIJ	18AQ LHCB	$H \rightarrow A^0 A^0, A^0 \rightarrow \mu^+ \mu^-$
65	SIRUNYAN	18AF CMS	$H_2^0 \rightarrow HH$
66	SIRUNYAN	18BA CMS	$H_2^0 \rightarrow ZZ$
67	SIRUNYAN	18CWCMS	$H_2^0 \rightarrow HH$
68	SIRUNYAN	18DK CMS	$H_2^0 \rightarrow Z\gamma$
69	SIRUNYAN	18DT CMS	$H \rightarrow A^0 A^0$
70	SIRUNYAN	18DU CMS	$H_2^0 \rightarrow \gamma\gamma$
71	SIRUNYAN	18ED CMS	$A_0^0 \rightarrow ZH$
72	SIRUNYAN	18EE CMS	$H \rightarrow A^0 A^0$
73	SIRUNYAN	18F CMS	$pp, 13 \text{ TeV}, H_2^0 \rightarrow HH$
74	AABOUD	17 ATLS	$H_2^0 \rightarrow Z\gamma$
75	AABOUD	17AP ATLS	$H_2^0 \rightarrow \gamma\gamma$
76	AABOUD	17AW ATLS	$H_2^0 \rightarrow Z\gamma$
77	KHACHATRY...	17AZ CMS	$H \rightarrow A^0 A^0$
78	KHACHATRY...	17D CMS	$pp, 8, 13 \text{ TeV}, H_2^0 \rightarrow Z\gamma$
79	KHACHATRY...	17R CMS	$H_2^0 \rightarrow \gamma\gamma$
80	SIRUNYAN	17CN CMS	$pp, 8 \text{ TeV}, H_2^0 \rightarrow HH$
81	SIRUNYAN	17Y CMS	$pp, 8, 13 \text{ TeV}, H_2^0 \rightarrow Z\gamma$
82	AABOUD	16AB ATLS	$H \rightarrow A^0 A^0$
83	AABOUD	16AE ATLS	$H_2^0 \rightarrow W^+ W^-, ZZ$
84	AABOUD	16H ATLS	$H_2^0 \rightarrow \gamma\gamma$
85	AABOUD	16I ATLS	$H_2^0 \rightarrow HH$
86	AAD	16AX ATLS	$H \rightarrow ZZ$
87	AAD	16C ATLS	$H \rightarrow W^+ W^-$

		88	AAD	16L	ATLS	$H \rightarrow A^0 A^0$
		89	AAD	16L	ATLS	$H_2^0 \rightarrow A^0 A^0$
		90	AALTONEN	16C	CDF	$H_1^0 H^\pm \rightarrow H_1^0 H_1^0 W^*$ , $H_1^0 \rightarrow \gamma\gamma$
		91	KHACHATRY...	16BG	CMS	$H_2^0 \rightarrow HH$
		92	KHACHATRY...	16BQ	CMS	$pp, 8 \text{ TeV}, H_2^0 \rightarrow HH$
		93	KHACHATRY...	16F	CMS	$H \rightarrow H_1 H_1$
		94	KHACHATRY...	16M	CMS	$H_2^0 \rightarrow \gamma\gamma$
		95	KHACHATRY...	16P	CMS	$H_2^0 \rightarrow HH$
		96	KHACHATRY...	16P	CMS	$A^0 \rightarrow ZH$
		97	AAD	15BK	ATLS	$H_2^0 \rightarrow HH$
		98	AAD	15BZ	ATLS	$H \rightarrow A^0 A^0$
		99	AAD	15BZ	ATLS	$H_2^0 \rightarrow A^0 A^0$
		100	AAD	15CE	ATLS	$H_2^0 \rightarrow HH$
		101	AAD	15H	ATLS	$H_2^0 \rightarrow HH$
		102	AAD	15S	ATLS	$A^0 \rightarrow ZH$
		103	KHACHATRY...	15AW	CMS	$H_2^0 \rightarrow W^+ W^-, ZZ$
		104	KHACHATRY...	15BB	CMS	$H \rightarrow \gamma\gamma$
		105	KHACHATRY...	15N	CMS	$A^0 \rightarrow ZH$
		106	KHACHATRY...	15O	CMS	$A^0 \rightarrow ZH$
		107	KHACHATRY...	15R	CMS	$H_2^0 \rightarrow HH$
		108	AAD	14AP	ATLS	$H \rightarrow \gamma\gamma$
		109	AAD	14M	ATLS	$H_2^0 \rightarrow H^\pm W^\mp \rightarrow$ $HW^\pm W^\mp, H \rightarrow b\bar{b}$
		110	CHATRCHYAN	14G	CMS	$H \rightarrow WW(*)$
		111	KHACHATRY...	14P	CMS	$H \rightarrow \gamma\gamma$
		112	AALTONEN	13P	CDF	$H^{i0} \rightarrow H^\pm W^\mp \rightarrow$ $HW^+ W^-$
		113	CHATRCHYAN	13BJ	CMS	$H \rightarrow A^0 A^0$
		114	AALTONEN	11P	CDF	$t \rightarrow bH^+, H^+ \rightarrow W^+ A^0$
		115	ABBIENDI	10	OPAL	$H \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$
		116	SCHAEL	10	ALEP	$H \rightarrow A^0 A^0$
		117	ABAZOV	09V	D0	$H \rightarrow A^0 A^0$
none 3–63	95	118	ABBIENDI	05A	OPAL	$A^0$ , Type II model
>104	95	119	ABBIENDI	04K	OPAL	$H \rightarrow 2 \text{ jets}$
		120	ABDALLAH	04	DLPH	$HVV$ couplings
>110.3	95	121	ACHARD	04B	L3	$H \rightarrow 2 \text{ jets}$
		122	ACHARD	04F	L3	Anomalous coupling
		123	ABBIENDI	03F	OPAL	$e^+ e^- \rightarrow HZ, H \rightarrow \text{any}$
		124	ABBIENDI	03G	OPAL	$H_1^0 \rightarrow A^0 A^0$
>105.4	95	125,126	HEISTER	02L	ALEP	$H_1^0 \rightarrow \gamma\gamma$
>109.1	95	127	HEISTER	02M	ALEP	$H \rightarrow 2 \text{ jets or } \tau^+ \tau^-$
none 12–56	95	128	ABBIENDI	01E	OPAL	$A^0$ , Type-II model
		129	ACCIARRI	00R	L3	$e^+ e^- \rightarrow H\gamma$ and/or $H \rightarrow$ $\gamma\gamma$
		130	ACCIARRI	00R	L3	$e^+ e^- \rightarrow e^+ e^- H$
		131	GONZALEZ...	98B	RVUE	Anomalous coupling

132 KRAWCZYK 97 RVUE  $(g-2)_\mu$ 133 ALEXANDER 96H OPAL  $Z \rightarrow H\gamma$ 

- <sup>1</sup> AAD 22A search for the decay chain  $H \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- b\bar{b}$  in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 9 for limits on the overall branching fraction in the range  $m_{A^0} = 16\text{--}62 \text{ GeV}$ . See also Fig. 11 for limits without assuming  $A^0$  is pseudoscalar.
- <sup>2</sup> AAD 22D search for  $ZA^0$  associate production with  $Z \rightarrow \ell^+ \ell^-$ ,  $A^0$  decaying invisibly, in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for excluded regions in the mass parameter space of two Higgs doublet plus singlet (2HDM+ $A^0$ ) model with a certain choice of the model parameters.
- <sup>3</sup> AAD 22F search for gluon fusion production of  $H_2^0$  decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  using  $126\text{--}139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ .  $B(H \rightarrow b\bar{b}) = 0.582$  is assumed. See their Fig. 14 for limit on the product of production cross section times branching ratios for  $m_{H_2^0} = 0.251\text{--}5.0 \text{ TeV}$ .
- <sup>4</sup> AAD 22I search for  $ZH$  associate production with the decay chain  $H \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0, \tilde{\chi}_2^0 \rightarrow A^0 \tilde{\chi}_1^0, A^0 \rightarrow b\bar{b}$ , and  $Z \rightarrow \ell^+ \ell^-$ , in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 3 and 4 for limits on the product of cross section times the branching ratios for  $m_{A^0} = 20\text{--}65 \text{ GeV}$  with various choices of NMSSM model parameters.
- <sup>5</sup> AAD 22J search for the decay  $H \rightarrow ZA^0$  with  $A^0 \rightarrow \mu^+ \mu^-$  and  $Z \rightarrow e^+ e^-$ ,  $\mu^+ \mu^-$  in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$  assuming SM gluon-gluon fusion production of the  $H$ . See their Fig. 17(b) for limits on the product of cross section times the branching ratios for  $m_{A^0} = 15\text{--}30 \text{ GeV}$ .
- <sup>6</sup> AAD 22J search for the decay  $H \rightarrow A^0 A^0$  with  $A^0 \rightarrow \mu^+ \mu^-$  in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$  assuming SM gluon-gluon fusion production of the  $H$  in the range of  $m_{A^0} = 1\text{--}60 \text{ GeV}$ . See their Fig. 14(b) for limits on the product of cross section times the branching ratios for  $m_{A^0} = 1.5\text{--}60 \text{ GeV}$  (excluding  $\psi$  and  $\Upsilon$  regions). The limit also applies to the decay  $H \rightarrow H_1^0 H_1^0$ .
- <sup>7</sup> AAD 22P search for invisibly decaying  $H_1^0, H_2^0$  produced by vector boson fusion in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . Limit on the product of cross section times branching ratio in the range  $0.1\text{--}1 \text{ pb}$  (95% CL) is given for the mass range  $0.05\text{--}2 \text{ TeV}$ . See their Fig. 14.
- <sup>8</sup> AAD 22Y search for gluon fusion production of  $H_2^0$  decaying to  $HH \rightarrow b\bar{b}\gamma\gamma$  in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 15 for limit on the product of production cross section times branching ratios to  $HH$  for  $m_{H_2^0} = 0.251\text{--}1.0 \text{ TeV}$ .
- <sup>9</sup> ABRATENKO 22A search for a singlet scalar boson  $H_1^0$  having a small mixing with the SM Higgs boson in the decay chain  $K^+ \rightarrow H_1^0 \pi^+, H_1^0 \rightarrow \mu^+ \mu^-$  from data corresponding to  $7.01 \times 10^{20}$  protons on NuMI target. See their Fig. 13 (right) and Table V for limits on the SM Higgs component of  $H_1^0$  for  $m_{H_1^0} = 212\text{--}279 \text{ MeV}$ .
- <sup>10</sup> TUMASYAN 22AK search for gluon-fusion production of  $H_3^0$  decaying to  $H_1^0 H_1^0 \rightarrow b\bar{b}b\bar{b}$  in  $138 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for limits on cross section times branching ratio for  $m_{H_3^0} = 1\text{--}3 \text{ TeV}$ ,  $m_{H_1^0} = 25\text{--}100 \text{ GeV}$ .
- <sup>11</sup> AAD 21AF search for production of a heavy  $H_2^0$  state decaying to  $ZZ$  in the final states  $\ell^+ \ell^- \ell'^+ \ell'^-$  and  $\ell^+ \ell^- \nu \bar{\nu}$  in  $139 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 4 for upper limits on cross section times branching ratio for  $m_{H_2^0} = 0.2\text{--}2.0 \text{ TeV}$  assuming ggF or VBF with narrow width approximation, and Fig. 5 for upper limits on

- cross section times branching ratio for  $m_{H_2^0} = 0.4\text{--}2.0$  TeV assuming ggF, and with several assumptions on its width.
- 12 AAD 21AI search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH_2^0 \rightarrow \ell^+\ell^-b\bar{b}$  or  $\ell^+\ell^-W^+W^-$  in  $139\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Figs. 9 and 13 for cross section limits for  $m_{A^0} = 230\text{--}800$  GeV and  $m_{H_2^0} = 130\text{--}700$  GeV.
  - 13 AAD 21AY search for production of a scalar resonance decaying to  $\gamma\gamma$  in  $139\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Fig. 5(a) for limits on fiducial cross section times branching ratio for  $m_{H_2^0} = 0.16\text{--}3$  TeV with narrow width approximation, and Table 2 with several assumptions on the width.
  - 14 AAD 21AZ search for production of  $A_2^0$  decaying to  $HA_1^0$  followed by  $H \rightarrow \gamma\gamma$ ,  $A_1^0 \rightarrow$  invisible in  $139\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Figs. 10–12 for limits in terms of two-Higgs-doublet model plus singlet pseudoscalar and a fermionic Dark Matter particle.
  - 15 AAD 21BB search for production of  $A_2^0$  by gluon fusion or associated  $A_2^0 b\bar{b}$  production, decaying to  $HA_1^0$  followed by  $H \rightarrow b\bar{b}$ ,  $A_1^0 \rightarrow$  invisible in  $139\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Fig. 8 for limits in terms of two-Higgs-doublet plus singlet pseudoscalar model.
  - 16 AAD 21BE search for production of  $A_1^0$  associated with a single top quark and either a light quark or a  $W$  boson, decaying to invisible final states, in  $139\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Figs. 13–15 for limits in terms of two-Higgs-doublet model plus singlet pseudoscalar, which is assumed to decay to a pair of Dark Matter particles.
  - 17 ABRATENKO 21 search for a singlet scalar boson  $H_1^0$  having a small mixing with the SM Higgs boson in the decay chain  $K^+ \rightarrow H_1^0 \pi^+$ ,  $H_1^0 \rightarrow e^+ e^-$  from data corresponding to  $1.93 \times 10^{20}$  protons on NuMI target. See their Fig. 2 for limits on the SM Higgs component of  $H_1^0$  for  $m_{H_1^0} = 3\text{--}210$  MeV.
  - 18 SIRUNYAN 21A search for  $H_2^0 \rightarrow ZA^0$  with  $Z \rightarrow \ell^+\ell^-$ ,  $A^0$  decaying invisibly, in  $137\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Fig. 8 for excluded regions in the mass parameter space of two Higgs doublet plus singlet model with a certain choice of the model parameters.
  - 19 TUMASYAN 21F search for gluon fusion production of  $H_3^0$  decaying to  $HH_{1,2}^0 \rightarrow \tau^+\tau^-b\bar{b}$  in  $137\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Figs. 5 and 6 for limits on cross section times branching ratios for  $m_{H_{1,2}^0} = 0.06\text{--}2.8$  TeV and  $m_{H_3^0} = 0.24\text{--}3.0$  TeV.
  - 20 AAD 20AA search for  $H_2^0/A^0 \rightarrow \tau^+\tau^-$  produced by gluon fusion or  $b$ -associated production using  $139\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. See their Fig. 2(a), 2(b) for limits on the product of cross section and branching ratio for  $m_{H_2^0}$ ,  $m_{A^0} = 0.2\text{--}2.5$  TeV.
  - 21 AAD 20AI search for  $ZH$  production followed by the decay  $H \rightarrow A^0 A^0 \rightarrow b\bar{b}b\bar{b}$  in  $36\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. The search looks for collimated  $A^0 \rightarrow b\bar{b}$  decays and is complementary to AABOUD 18BX. See their Fig. 10 for limits on the product of production cross section and branching ratios in the range  $m_{A^0} = 15\text{--}30$  GeV.
  - 22 AAD 20A0 search for gluon fusion production of  $H_2^0$  decaying to  $HH \rightarrow \tau^+\tau^-b\bar{b}$  (with hadronically decaying  $\tau^+\tau^-$ ) using  $139\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13$  TeV. Limit on the product of production cross section times branching ratios in the range  $28\text{--}817$  fb (95% CL) is given for  $m_{A^0} = 1.0\text{--}3.0$  TeV, see their Fig. 13.

- 23 AAD 20C combine searches for a scalar resonance decaying to  $HH$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$  from AABOUD 19A, AABOUD 19O, AABOUD 18CQ, AABOUD 19T, AABOUD 18CW, and AABOUD 18BU. See their Fig. 5(a) for limits on cross section times branching ratio for  $m_{H_2^0} = 0.26\text{--}3 \text{ TeV}$ .
- 24 AAD 20L search for  $b$ -associated production of  $H_2^0$  decaying to  $b\bar{b}$  in  $27.8 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 8 for limits on the product of cross section and branching ratio for  $m_{H_2^0} = 0.45\text{--}1.4 \text{ TeV}$ .
- 25 AAD 20X search for vector-boson-fusion production of  $H_2^0$  decaying to  $HH$  using  $126 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for limits on the product of cross section and branching ratio for the assumptions of a narrow- and broad-width resonance.
- 26 AAIJ 20AL search for dimuon resonance in the mass range  $0.2\text{--}60 \text{ GeV}$  in  $5.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ , in inclusive and  $b$  quark associated production. Displaced decays are searched for for masses below  $3 \text{ GeV}$ . See their Figs. 7–9 for cross section limits and Fig. 10 for limits for mixing angle in two Higgs doublet plus singlet model (at 90% CL).
- 27 SIRUNYAN 20 search for the decay  $H \rightarrow A^0 A^0 \rightarrow \tau^+ \tau^- \tau^+ \tau^-$  or  $\tau^+ \tau^- \mu^+ \mu^-$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 10 for limits on the product of production cross section (normalized to the SM) and branching ratios in the range  $m_{A^0} = 4\text{--}15 \text{ GeV}$ .
- 28 SIRUNYAN 20AA search for  $H_2^0 \rightarrow ZA^0$ ,  $A^0 \rightarrow b\bar{b}$  or  $A^0 \rightarrow ZH_2^0$ ,  $H_2^0 \rightarrow b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 7 for limits on the product of cross section and branching ratio for  $m_{H_2^0} = 0.12\text{--}1 \text{ TeV}$  and  $m_{A^0} = 0.03\text{--}1 \text{ TeV}$ .
- 29 SIRUNYAN 20AC search for gluon-fusion production of  $A^0$  decaying to  $ZH$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for limits on the product of cross section and branching ratios for  $m_{A^0} = 220\text{--}400 \text{ GeV}$ .
- 30 SIRUNYAN 20AD search for lepton-flavor violating decays  $H_2^0 \rightarrow \mu\tau$ ,  $e\tau$  of gluon-fusion-produced  $H_2^0$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 (9) and Table 5 (6) for limits on production cross section times branching ratio for  $m_{H_2^0} = 0.2\text{--}0.9 \text{ TeV}$  for the  $\mu\tau$  ( $e\tau$ ) final state.
- 31 SIRUNYAN 20AF search for  $H_2^0/A^0 \rightarrow t\bar{t}$  with one or two charged leptons in the final state using kinematic variables in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 5 and 6 for limits on top Yukawa coupling of  $H_2^0$  and  $A^0$  for  $m_{H_2^0}$ ,  $m_{A^0} = 0.4\text{--}0.75 \text{ TeV}$  for various width assumptions.
- 32 SIRUNYAN 20AP search for the decay  $H$  or  $H_2^0 \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- \tau^+ \tau^-$  (for  $m_{H_2^0} = 300 \text{ GeV}$ ) with boosted final-state topology in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 7 for limits on the product of production cross section (normalized to the SM) and branching ratios in the range  $m_{A^0} = 3.6\text{--}21 \text{ GeV}$ , and Figs. 8 and 9 for its interpretation in terms of models with two Higgs doublets plus a singlet.
- 33 SIRUNYAN 20Y search for gluon-fusion and vector-boson-fusion production of  $H_2^0$  decaying to  $W^+ W^-$  in the final states  $\ell\nu\ell\nu$  and  $\ell\nu qq$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for limits on the product of cross section and branching ratio for  $m_{H_2^0} = 0.2\text{--}3 \text{ TeV}$ .
- 34 SIRUNYAN 20Z search for  $H_{1,2}^0$  or  $A^0$  production in association with a  $t\bar{t}$  pair, decaying to  $e^+ e^-$  or  $\mu^+ \mu^-$ , in  $137 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 12 for limits on production cross section times branching ratio for  $m_{H_{1,2}^0}$ ,  $m_{A^0} = 15\text{--}75 \text{ GeV}$  and  $108\text{--}340 \text{ GeV}$ .

- 35 AABOUD 19A search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  in  $27.5\text{--}36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 9(a) for limits on cross section times branching ratios for  $m_{H_2^0} = 0.26\text{--}3 \text{ TeV}$ .
- 36 AABOUD 19AG search for the decay  $H \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- b\bar{b}$  in  $36.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 (a) for limits on the product of production cross section (normalized to the SM) and branching ratios in the range  $m_{A^0} = 20\text{--}60 \text{ GeV}$ .
- 37 AABOUD 19O search for a scalar resonance decaying to  $HH \rightarrow b\bar{b}WW^*$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 12 (left) for limits on cross section times branching ratio for  $m_{H_2^0} = 0.5\text{--}3 \text{ TeV}$ .
- 38 AABOUD 19T search for a scalar resonance decaying to  $HH \rightarrow WW^*WW^*$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 3 for limits on cross section times branching ratio for  $m_{H_2^0} = 260\text{--}500 \text{ GeV}$ , assuming SM decay rates for the  $H$ .
- 39 AABOUD 19V combine published ATLAS data to constrain two-Higgs-doublet plus singlet pseudoscalar model with  $A_1^0$  decaying to invisible final states. See their Fig. 19 for excluded parameter regions.
- 40 AABOUD 19Y search for a narrow scalar resonance produced by gluon fusion or  $b$  associated production, decaying to  $\mu^+ \mu^-$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 4 and 5(a) for cross section limits for  $m_{H_2^0} = 0.2\text{--}1.0 \text{ TeV}$ .
- 41 AALTONEN 19 search for  $b$  associated production of a scalar particle decaying to  $b\bar{b}$  in  $5.4 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ . See their Fig. 3 for limits on cross section times branching ratio for  $m_{H_{1,2}^0} = 100\text{--}300 \text{ GeV}$ .
- 42 SIRUNYAN 19 search for a narrow scalar resonance decaying to  $HH \rightarrow \gamma\gamma b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 9 (left) for limits on cross section times branching ratios for  $m_{H_2^0} = 260\text{--}900 \text{ GeV}$ .
- 43 SIRUNYAN 19AE search for a scalar resonance produced in association with a  $b\bar{b}$  pair, decaying to  $\tau^+ \tau^-$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 4 for cross section limits for  $m_{A^0} = 25\text{--}70 \text{ GeV}$ .
- 44 SIRUNYAN 19AN search for production of  $A_2^0$  decaying to  $HA_1^0$  followed by  $H \rightarrow b\bar{b}$ ,  $A_1^0 \rightarrow$  invisible in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ , in the mass range  $m_{A_2^0} = 0.2\text{--}1.6 \text{ TeV}$ ,  $m_{A_1^0} = 0.15\text{--}0.5 \text{ TeV}$ . See their Fig. 6 for limits in terms of two-Higgs-doublet plus singlet pseudoscalar model.
- 45 SIRUNYAN 19AV search for a scalar resonance produced by gluon fusion or  $b$ -associated production, decaying to  $ZH \rightarrow \ell^+ \ell^- b\bar{b}$  ( $\ell = e, \mu$ ) or  $\nu\bar{\nu} b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for cross section limits for  $m_{A^0} = 0.22\text{--}1.0 \text{ TeV}$ .
- 46 SIRUNYAN 19B search for gluon fusion production of narrow scalar resonance with large transverse momentum, decaying to  $b\bar{b}$ , in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 7 and 8 for limits on cross section times branching ratio for the resonance mass of  $50\text{--}350 \text{ GeV}$ .
- 47 SIRUNYAN 19BB search for the decay  $H_1^0 \rightarrow \gamma\gamma$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$  and  $35.9 \text{ fb}^{-1}$  at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 4–6 for limits on cross section times branching ratio for  $m_{H_1^0} = 80\text{--}110 \text{ GeV}$  (some results in Fig. 5 for  $m_{H_1^0} = 70\text{--}110 \text{ GeV}$ ).
- 48 SIRUNYAN 19BD search for the decay  $H \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for limits on the product of cross section times branching ratios in the range  $m_{A^0} = 20\text{--}62.5 \text{ GeV}$ . See also their Figs. 6 and 7 for interpretation of the data in terms of models with two Higgs doublets and a singlet.



- 49 SIRUNYAN 19BE combine searches for  $H_2^0 \rightarrow HH$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$  in various  $H$  decay modes, from SIRUNYAN 18A, SIRUNYAN 18AF, SIRUNYAN 18CW, SIRUNYAN 19, and SIRUNYAN 19H. See their Fig. 3 for limits on cross section times branching ratios for  $m_{H_2^0} = 0.25\text{--}3 \text{ TeV}$ .
- 50 SIRUNYAN 19BQ search for production of  $H_{1,2}^0$  decaying to  $A^0 A^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 2 for limits on cross section times branching ratio for  $m_{H_{1,2}^0} = 90\text{--}150 \text{ GeV}$ ,  $m_{A^0} = 0.25\text{--}3.55 \text{ GeV}$ .
- 51 SIRUNYAN 19CR search for production of  $H_2^0/A^0$  in gluon fusion and in association with a  $b\bar{b}$  pair, decaying to  $\mu^+ \mu^-$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for limits on cross section times branching ratio.
- 52 SIRUNYAN 19H search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  in  $35.9 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ , where one  $b\bar{b}$  pair is resolved and the other not. Limits on cross section times branching ratios for  $m_{H_2^0} = 0.75\text{--}1.6 \text{ TeV}$  are obtained and combined with data from SIRUNYAN 18AF. See their Fig. 5 (right).
- 53 AABOUD 18AA search for production of a scalar resonance decaying to  $Z\gamma$ , with  $Z$  decaying hadronically, in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 8(a) for limits on cross section times branching ratio for  $m_{H_2^0} = 1.0\text{--}6.8 \text{ TeV}$ .
- 54 AABOUD 18AG search for the decay  $H \rightarrow A^0 A^0 \rightarrow \gamma\gamma gg$  in  $36.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 2 and Table 6 for cross section limits in the range  $m_{A^0} = 20\text{--}60 \text{ GeV}$ .
- 55 AABOUD 18AH search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH_2^0 \rightarrow \ell^+ \ell^- b\bar{b}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 5 for cross section limits for  $m_{A^0} = 230\text{--}800 \text{ GeV}$  and  $m_{H_2^0} = 130\text{--}700 \text{ GeV}$ .
- 56 AABOUD 18AI search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH$  in the final states  $\nu\bar{\nu}b\bar{b}$  and  $\ell^+ \ell^- b\bar{b}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for cross section limits for  $m_{A^0} = 0.2\text{--}2 \text{ TeV}$ . See also AABOUD 18CC.
- 57 AABOUD 18BF search for production of a heavy  $H_2^0$  state decaying to  $ZZ$  in the final states  $\ell^+ \ell^- \ell^+ \ell^-$  and  $\ell^+ \ell^- \nu\bar{\nu}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 6 for upper limits on cross section times branching ratio for  $m_{H_2^0} = 0.2\text{--}1.2 \text{ TeV}$  assuming ggF or VBF with the NWA. See their Fig. 7 for upper limits on cross section times branching ratio for  $m_{H_2^0} = 0.4\text{--}1.0 \text{ TeV}$  assuming ggF, and with several assumptions on its width.
- 58 AABOUD 18BU search for a narrow scalar resonance decaying to  $HH \rightarrow \gamma\gamma WW^*$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 4 for limits on cross section times branching ratios for  $m_{H_2^0} = 260\text{--}500 \text{ GeV}$ .
- 59 AABOUD 18BX search for associated production of  $WH$  or  $ZH$  followed by the decay  $H \rightarrow A^0 A^0 \rightarrow b\bar{b}b\bar{b}$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 9 for limits on cross section times branching ratios for  $m_{A^0} = 20\text{--}60 \text{ GeV}$ . See also their Fig. 10 for the dependence of the limit on  $A^0$  lifetime.
- 60 AABOUD 18CQ search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}\tau^+\tau^-$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 2 (above) for limits on cross section times branching ratios for  $m_{H_2^0} = 260\text{--}1000 \text{ GeV}$ .
- 61 AABOUD 18F search for production of a narrow scalar resonance decaying to  $W^+W^-$  and  $ZZ$ , followed by hadronic decays of  $W$  and  $Z$ , in  $36.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}}$

- = 13 TeV. See their Fig. 5(c) for limits on cross section times branching ratio for  $m_{H_2^0}$   
 = 1.2–3.0 TeV.
- 62 AAIJ 18AM search for gluon-fusion production of  $H_{1,2}^0$  decaying to  $\mu\tau$  in  $2\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8\text{ TeV}$ . See their Fig. 2 for limits on cross section times branching ratio for  $m_{H_{1,2}^0} = 45\text{--}195\text{ GeV}$ .
- 63 AAIJ 18AQ search for gluon-fusion production of a scalar particle  $A^0$  decaying to  $\mu^+\mu^-$  in  $1.99\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8\text{ TeV}$  and  $0.98\text{ fb}^{-1}$  at  $E_{\text{cm}} = 7\text{ TeV}$ . See their Fig. 4 for limits on cross section times branching ratio for  $m_{A^0} = 5.5\text{--}15\text{ GeV}$  (using the  $E_{\text{cm}} = 8\text{ TeV}$  data set).
- 64 AAIJ 18AQ search for the decay  $H \rightarrow A^0 A^0$ , with one of the  $A^0$  decaying to  $\mu^+\mu^-$ , in  $1.99\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8\text{ TeV}$  and  $0.98\text{ fb}^{-1}$  at  $E_{\text{cm}} = 7\text{ TeV}$ . See their Fig. 5 (right) for limits on the product of branching ratios for  $m_{A^0} = 5.5\text{--}15\text{ GeV}$  (using the  $E_{\text{cm}} = 8\text{ TeV}$  data set).
- 65 SIRUNYAN 18AF search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ , where both  $b\bar{b}$  pairs are not resolved. See their Fig. 9 for limits on cross section times branching ratios for  $m_{H_2^0} = 0.75\text{--}3\text{ TeV}$ .
- 66 SIRUNYAN 18BA search for production of a heavy  $H_2^0$  state decaying to  $ZZ$  in the final states  $\ell^+\ell^-\ell^+\ell^-$ ,  $\ell^+\ell^-q\bar{q}$ , and  $\ell^+\ell^-\nu\bar{\nu}$  in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ . See their Figs. 10 and 11 for upper limits on cross section times branching ratio for  $m_{H_2^0} = 0.13\text{--}3\text{ TeV}$  with several assumptions on its width and on the fraction of Vector-Boson-Fusion of the total production cross section.
- 67 SIRUNYAN 18CW search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ , where both  $b\bar{b}$  pairs are resolved. See their Fig. 9 for limits on cross section times branching ratios for  $m_{H_2^0} = 260\text{--}1200\text{ GeV}$ .
- 68 SIRUNYAN 18DK search for production of a scalar resonance decaying to  $Z\gamma$ , with  $Z$  decaying to  $\ell^+\ell^-$  or hadronically, in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ . See their Fig. 7 for limits on cross section times branching ratio for  $m_{H_2^0} = 0.35\text{--}4\text{ TeV}$  for different assumptions on the width of the resonance.
- 69 SIRUNYAN 18DT search for the decay  $H \rightarrow A^0 A^0 \rightarrow \tau^+\tau^-b\bar{b}$  in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ . See their Fig. 7 for limits on the product of branching ratios in the range  $m_{A^0} = 15\text{--}60\text{ GeV}$ . See also their Fig. 8 for interpretation of the data in terms of models with two Higgs doublets and a singlet.
- 70 SIRUNYAN 18DU search for production of a narrow scalar resonance decaying to  $\gamma\gamma$  in  $35.9\text{ fb}^{-1}$  (taken in 2016) of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ . See their Fig. 3 (right) for limits on cross section times branching ratio for  $m_{H_2^0} = 0.5\text{--}5\text{ TeV}$  for several values of its width-to-mass ratio.
- 71 SIRUNYAN 18ED search for production of an  $A^0$  in gluon-gluon fusion and in association with a  $b\bar{b}$ , decaying to  $ZH$  in the final states  $\nu\bar{\nu}b\bar{b}$  or  $\ell^+\ell^-b\bar{b}$  in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ . See their Fig. 8 for cross section limits for  $m_{A^0} = 0.8\text{--}2\text{ TeV}$ .
- 72 SIRUNYAN 18EE search for the decay  $H \rightarrow A^0 A^0 \rightarrow \mu^+\mu^-\tau^+\tau^-$  in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ . See their Fig. 4 for limits on the product of branching ratios in the range  $m_{A^0} = 15\text{--}62.5\text{ GeV}$ , normalized to the SM production cross section. See also their Fig. 5 for interpretation of the data in terms of models with two Higgs doublets and a singlet.
- 73 SIRUNYAN 18F search for a narrow scalar resonance decaying to  $HH \rightarrow WWb\bar{b}$  or  $ZZb\bar{b}$  in the final state  $\ell\ell\nu\nu b\bar{b}$  in  $35.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13\text{ TeV}$ . See their Fig. 7 for limits on cross section times branching ratios for  $m_{H_2^0} = 250\text{--}900\text{ GeV}$ .

- 74 AABOUD 17 search for production of a scalar resonance decaying to  $Z\gamma$  in  $3.2 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 4 for the limits on cross section times branching ratio for  $m_{H_2^0} = 0.25\text{--}3.0 \text{ TeV}$ .
- 75 AABOUD 17AP search for production of a scalar resonance decaying to  $\gamma\gamma$  in  $36.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 4(a) for limits on fiducial cross section times branching ratio for  $m_{H_2^0} = 0.2\text{--}2.7 \text{ TeV}$  with narrow width approximation.
- 76 AABOUD 17AW search for production of a scalar resonance decaying to  $Z\gamma$  in  $36.1 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 7 for limits on cross section times branching ratio for  $m_{H_2^0} = 0.25\text{--}2.4 \text{ TeV}$ .
- 77 KHACHATRYAN 17AZ search for the decay  $H \rightarrow A^0 A^0 \rightarrow \tau^+ \tau^- \tau^+ \tau^-, \mu^+ \mu^- b\bar{b}$ , and  $\mu^+ \mu^- \tau^+ \tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Figs. 4, 5, and 6 for cross section limits in the range  $m_{A^0} = 5\text{--}62.5 \text{ GeV}$ . See also their Figs. 7, 8, and 9 for interpretation of the data in terms of models with two Higgs doublets and a singlet.
- 78 KHACHATRYAN 17D search for production of a scalar resonance decaying to  $Z\gamma$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$  and  $2.7 \text{ fb}^{-1}$  at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 3 and 4 for the limits on cross section times branching ratio for  $m_{H_2^0} = 0.2\text{--}2.0 \text{ TeV}$ .
- 79 KHACHATRYAN 17R search for production of a narrow scalar resonance decaying to  $\gamma\gamma$  in  $12.9 \text{ fb}^{-1}$  (taken in 2016) of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 2 for limits on cross section times branching ratio for  $m_{H_2^0} = 0.5\text{--}4.5 \text{ TeV}$  for several values of its width-to-mass ratio. Limits from combination with KHACHATRYAN 16M are shown in their Figs. 4 and 6.
- 80 SIRUNYAN 17CN search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}\tau^+\tau^-$  in  $18.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 5 (above) and Table II for limits on the cross section times branching ratios for  $m_{H_2^0} = 0.3\text{--}1 \text{ TeV}$ , and Fig. 6 (above) and Table III for the corresponding limits by combining with data from KHACHATRYAN 16BQ and KHACHATRYAN 15R.
- 81 SIRUNYAN 17Y search for production of a scalar resonance decaying to  $Z\gamma$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$  and  $2.7 \text{ fb}^{-1}$  at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Figs. 3, 4 and Table 3 for limits on cross section times branching ratio for  $m_{H_2^0} = 0.7\text{--}3.0 \text{ TeV}$ , and Fig. 5 for the corresponding limits for  $m_{H_2^0} = 0.2\text{--}3.0 \text{ TeV}$  from combination with KHACHATRYAN 17D data.
- 82 AABOUD 16AB search for associated production of  $WH$  with the decay  $H \rightarrow A^0 A^0 \rightarrow b\bar{b}b\bar{b}$  in  $3.2 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 8 for limits on cross section times branching ratios for  $m_{A^0} = 20\text{--}60 \text{ GeV}$ .
- 83 AABOUD 16AE search for production of a narrow scalar resonance decaying to  $W^+W^-$  and  $ZZ$  in  $3.2 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 4 for limits on cross section times branching ratio for  $m_{H_2^0} = 0.5\text{--}3 \text{ TeV}$ .
- 84 AABOUD 16H search for production of a scalar resonance decaying to  $\gamma\gamma$  in  $3.2 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 12 for limits on cross section times branching ratio for  $m_{H_2^0} = 0.2\text{--}2 \text{ TeV}$  with different assumptions on the width.
- 85 AABOUD 16I search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  in  $3.2 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 10(c) for limits on cross section times branching ratios for  $m_{H_2^0} = 0.5\text{--}3 \text{ TeV}$ .
- 86 AAD 16AX search for production of a heavy  $H$  state decaying to  $ZZ$  in the final states  $\ell^+\ell^-\ell^+\ell^-$ ,  $\ell^+\ell^-\nu\bar{\nu}$ ,  $\ell^+\ell^-q\bar{q}$ , and  $\nu\bar{\nu}q\bar{q}$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig.12 for upper limits on  $\sigma(H) \text{B}(H \rightarrow ZZ)$  for  $m_H$  ranging from 140 GeV to 1000 GeV.

- 87 AAD 16C search for production of a heavy  $H$  state decaying to  $W^+W^-$  in the final states  $\ell\nu\ell\nu$  and  $\ell\nu qq$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Figs. 12, 13, and 16 for upper limits on  $\sigma(H) \text{B}(H \rightarrow W^+W^-)$  for  $m_H$  ranging from 300 GeV to 1000 or 1500 GeV with various assumptions on the total width of  $H$ .
- 88 AAD 16L search for the decay  $H \rightarrow A^0 A^0 \rightarrow \gamma\gamma\gamma\gamma$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 4 (upper right) for limits on cross section times branching ratios (normalized to the SM  $H$  cross section) for  $m_{A^0} = 10\text{--}60 \text{ GeV}$ .
- 89 AAD 16L search for the decay  $H_2^0 \rightarrow A^0 A^0 \rightarrow \gamma\gamma\gamma\gamma$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 4 (lower right) for limits on cross section times branching ratios for  $m_{H_2^0} = 600 \text{ GeV}$  and  $m_{A^0} = 10\text{--}245 \text{ GeV}$ , and Table 5 for limits for  $m_{H_2^0} = 300$  and  $900 \text{ GeV}$ .
- 90 AALTONEN 16C search for electroweak associated production of  $H_1^0 H^\pm$  followed by the decays  $H^\pm \rightarrow H_1^0 W^*$ ,  $H_1^0 \rightarrow \gamma\gamma$  for  $m_{H_1^0} = 10\text{--}105 \text{ GeV}$  and  $m_{H^\pm} = 30\text{--}300 \text{ GeV}$ .  
See their Fig. 3 for excluded parameter region in a two-doublet model in which  $H_1^0$  has no direct decay to fermions.
- 91 KHACHATRYAN 16BG search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 6 for limits on the cross section times branching ratios for  $m_{H_2^0} = 1.15\text{--}3 \text{ TeV}$ .
- 92 KHACHATRYAN 16BQ search for a resonance decaying to  $HH \rightarrow \gamma\gamma b\bar{b}$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 9 for limits on the cross section times branching ratios for  $m_{H_2^0} = 0.26\text{--}1.1 \text{ TeV}$ .
- 93 KHACHATRYAN 16F search for the decay  $H \rightarrow H_1^0 H_1^0 \rightarrow \tau^+\tau^-\tau^+\tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 8 for cross section limits for  $m_{H_1^0} = 4\text{--}8 \text{ GeV}$ .
- 94 KHACHATRYAN 16M search for production of a narrow resonance decaying to  $\gamma\gamma$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$  and  $3.3 \text{ fb}^{-1}$  at  $E_{\text{cm}} = 13 \text{ TeV}$ . See their Fig. 3 (top) for limits on cross section times branching ratio for  $m_{H_2^0} = 0.5\text{--}4 \text{ TeV}$ .
- 95 KHACHATRYAN 16P search for gluon fusion production of an  $H_2^0$  decaying to  $HH \rightarrow b\bar{b}\tau^+\tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 8 (lower right) for cross section limits for  $m_{H_2^0} = 260\text{--}350 \text{ GeV}$ .
- 96 KHACHATRYAN 16P search for gluon fusion production of an  $A^0$  decaying to  $ZH \rightarrow \ell^+\ell^-\tau^+\tau^-$  in  $19.7 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 10 for cross section limits for  $m_{H_2^0} = 220\text{--}350 \text{ GeV}$ .
- 97 AAD 15BK search for production of a heavy  $H_2^0$  decaying to  $HH$  in the final state  $b\bar{b}b\bar{b}$  in  $19.5 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 14(c) for  $\sigma(H_2^0) \text{B}(H_2^0 \rightarrow HH)$  for  $m_{H_2^0} = 500\text{--}1500 \text{ GeV}$  with  $\Gamma_{H_2^0} = 1 \text{ GeV}$ .
- 98 AAD 15BZ search for the decay  $H \rightarrow A^0 A^0 \rightarrow \mu^+\mu^-\tau^+\tau^-$  ( $m_H = 125 \text{ GeV}$ ) in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 6 for limits on cross section times branching ratio for  $m_{A^0} = 3.7\text{--}50 \text{ GeV}$ .
- 99 AAD 15BZ search for a state  $H_2^0$  via the decay  $H_2^0 \rightarrow A^0 A^0 \rightarrow \mu^+\mu^-\tau^+\tau^-$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$ . See their Fig. 6 for limits on cross section times branching ratio for  $m_{H_2^0} = 100\text{--}500 \text{ GeV}$  and  $m_{A^0} = 5 \text{ GeV}$ .
- 100 AAD 15CE search for production of a heavy  $H_2^0$  decaying to  $HH$  in the final states  $b\bar{b}\tau^+\tau^-$  and  $\gamma\gamma WW^*$  in  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8 \text{ TeV}$  and combine

- with data from AAD 15H and AAD 15BK. A limit  $\sigma(H_2^0) B(H_2^0 \rightarrow HH) < 2.1\text{--}0.011$  pb (95% CL) is given for  $m_{H_2^0} = 260\text{--}1000$  GeV. See their Fig. 6.
- 101 AAD 15H search for production of a heavy  $H_2^0$  decaying to  $HH$  in the final state  $\gamma\gamma b\bar{b}$  in  $20.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. A limit of  $\sigma(H_2^0) B(H_2^0 \rightarrow HH) < 3.5\text{--}0.7$  pb is given for  $m_{H_2^0} = 260\text{--}500$  GeV at 95% CL. See their Fig. 3.
- 102 AAD 15S search for production of  $A^0$  decaying to  $ZH \rightarrow \ell^+\ell^- b\bar{b}, \nu\bar{\nu} b\bar{b}$  and  $\ell^+\ell^-\tau^+\tau^-$  in  $20.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Fig. 3 for cross section limits for  $m_{A^0} = 200\text{--}1000$  GeV.
- 103 KHACHATRYAN 15AW search for production of a heavy state  $H_2^0$  of an electroweak singlet extension of the Standard Model via the decays of  $H_2^0$  to  $W^+W^-$  and  $ZZ$  in up to  $5.1\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV and up to  $19.7\text{ fb}^{-1}$  at  $E_{\text{cm}} = 8$  TeV in the range  $m_{H_2^0} = 145\text{--}1000$  GeV. See their Figs. 8 and 9 for limits in the parameter space of the model.
- 104 KHACHATRYAN 15BB search for production of a resonance  $H$  decaying to  $\gamma\gamma$  in  $19.7\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Fig. 7 for limits on cross section times branching ratio for  $m_H = 150\text{--}850$  GeV.
- 105 KHACHATRYAN 15N search for production of  $A^0$  decaying to  $ZH \rightarrow \ell^+\ell^- b\bar{b}$  in  $19.7\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Fig. 3 for limits on cross section times branching ratios for  $m_{A^0} = 225\text{--}600$  GeV.
- 106 KHACHATRYAN 15O search for production of a high-mass narrow resonance  $A^0$  decaying to  $ZH \rightarrow q\bar{q}\tau^+\tau^-$  in  $19.7\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Fig. 6 for limits on cross section times branching ratios for  $m_{A^0} = 800\text{--}2500$  GeV.
- 107 KHACHATRYAN 15R search for a narrow scalar resonance decaying to  $HH \rightarrow b\bar{b}b\bar{b}$  in  $17.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Fig. 5 (top) for limits on cross section times branching ratios for  $m_{H_2^0} = 0.27\text{--}1.1$  TeV.
- 108 AAD 14AP search for a second  $H$  state decaying to  $\gamma\gamma$  in addition to the state at about 125 GeV in  $20.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Fig. 4 for limits on cross section times branching ratio for  $m_H = 65\text{--}600$  GeV.
- 109 AAD 14M search for the decay cascade  $H_2^0 \rightarrow H^\pm W^\mp \rightarrow HW^\pm W^\mp, H$  decaying to  $b\bar{b}$  in  $20.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See their Table III for limits on cross section times branching ratio for  $m_{H_2^0} = 325\text{--}1025$  GeV and  $m_{H^\pm} = 225\text{--}925$  GeV.
- 110 CHATRCHYAN 14G search for a second  $H$  state decaying to  $WW^{(*)}$  in addition to the observed signal at about 125 GeV using  $4.9\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV and  $19.4\text{ fb}^{-1}$  at  $E_{\text{cm}} = 8$  TeV. See their Fig. 21 (right) for cross section limits in the mass range 110–600 GeV.
- 111 KHACHATRYAN 14P search for a second  $H$  state decaying to  $\gamma\gamma$  in addition to the observed signal at about 125 GeV using  $5.1\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV and  $19.7\text{ fb}^{-1}$  at  $E_{\text{cm}} = 8$  TeV. See their Figs. 27 and 28 for cross section limits in the mass range 110–150 GeV.
- 112 AALTONEN 13P search for production of a heavy Higgs boson  $H'^0$  that decays into a charged Higgs boson  $H^\pm$  and a lighter Higgs boson  $H$  via the decay chain  $H'^0 \rightarrow H^\pm W^\mp, H^\pm \rightarrow W^\pm H, H \rightarrow b\bar{b}$  in the final state  $\ell\nu$  plus 4 jets in  $8.7\text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96$  TeV. See their Fig. 4 for limits on cross section times branching ratio in the  $m_{H^\pm}\text{--}m_{H'^0}$  plane for  $m_H = 126$  GeV.
- 113 CHATRCHYAN 13BJ search for  $H$  production in the decay chain  $H \rightarrow A^0 A^0, A^0 \rightarrow \mu^+\mu^-$  in  $5.3\text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV. See their Fig. 2 for limits on cross section times branching ratio.

- 114 AALTONEN 11P search in  $2.7 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$  for the decay chain  $t \rightarrow bH^+$ ,  $H^+ \rightarrow W^+A^0$ ,  $A^0 \rightarrow \tau^+\tau^-$  with  $m_{A^0}$  between 4 and 9 GeV. See their Fig. 4 for limits on  $B(t \rightarrow bH^+)$  for  $90 < m_{H^+} < 160 \text{ GeV}$ .
- 115 ABBIENDI 10 search for  $e^+e^- \rightarrow ZH$  with the decay chain  $H \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0$ ,  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + (\gamma \text{ or } Z^*)$ , when  $\tilde{\chi}_1^0$  and  $\tilde{\chi}_2^0$  are nearly degenerate. For a mass difference of 2 (4) GeV, a lower limit on  $m_H$  of 108.4 (107.0) GeV (95% CL) is obtained for SM  $ZH$  cross section and  $B(H \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0) = 1$ .
- 116 SCHAEEL 10 search for the process  $e^+e^- \rightarrow HZ$  followed by the decay chain  $H \rightarrow A^0A^0 \rightarrow \tau^+\tau^-\tau^+\tau^-$  with  $Z \rightarrow \ell^+\ell^-$ ,  $\nu\bar{\nu}$  at  $E_{\text{cm}} = 183\text{--}209 \text{ GeV}$ . For a  $HZZ$  coupling equal to the SM value,  $B(H \rightarrow A^0A^0) = B(A^0 \rightarrow \tau^+\tau^-) = 1$ , and  $m_{A^0} = 4\text{--}10 \text{ GeV}$ ,  $m_H$  up to 107 GeV is excluded at 95% CL.
- 117 ABAZOV 09V search for  $H$  production followed by the decay chain  $H \rightarrow A^0A^0 \rightarrow \mu^+\mu^-\mu^+\mu^-$  or  $\mu^+\mu^-\tau^+\tau^-$  in  $4.2 \text{ fb}^{-1}$  of  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96 \text{ TeV}$ . See their Fig. 3 for limits on  $\sigma(H) \cdot B(H \rightarrow A^0A^0)$  for  $m_{A^0} = 3.6\text{--}19 \text{ GeV}$ .
- 118 ABBIENDI 05A search for  $e^+e^- \rightarrow H_1^0A^0$  in general Type-II two-doublet models, with decays  $H_1^0, A^0 \rightarrow q\bar{q}, gg, \tau^+\tau^-$ , and  $H_1^0 \rightarrow A^0A^0$ .
- 119 ABBIENDI 04K search for  $e^+e^- \rightarrow HZ$  with  $H$  decaying to two jets of any flavor including  $gg$ . The limit is for SM production cross section with  $B(H \rightarrow jj) = 1$ .
- 120 ABDALLAH 04 consider the full combined LEP and LEP2 datasets to set limits on the Higgs coupling to  $W$  or  $Z$  bosons, assuming SM decays of the Higgs. Results in Fig. 26.
- 121 ACHARD 04B search for  $e^+e^- \rightarrow HZ$  with  $H$  decaying to  $b\bar{b}$ ,  $c\bar{c}$ , or  $gg$ . The limit is for SM production cross section with  $B(H \rightarrow jj) = 1$ .
- 122 ACHARD 04F search for  $H$  with anomalous coupling to gauge boson pairs in the processes  $e^+e^- \rightarrow H\gamma$ ,  $e^+e^-H$ ,  $HZ$  with decays  $H \rightarrow f\bar{f}, \gamma\gamma, Z\gamma$ , and  $W^*W$  at  $E_{\text{cm}} = 189\text{--}209 \text{ GeV}$ . See paper for limits.
- 123 ABBIENDI 03F search for  $H \rightarrow$  anything in  $e^+e^- \rightarrow HZ$ , using the recoil mass spectrum of  $Z \rightarrow e^+e^-$  or  $\mu^+\mu^-$ . In addition, it searched for  $Z \rightarrow \nu\bar{\nu}$  and  $H \rightarrow e^+e^-$  or photons. Scenarios with large width or continuum  $H$  mass distribution are considered. See their Figs. 11–14 for the results.
- 124 ABBIENDI 03G search for  $e^+e^- \rightarrow H_1^0Z$  followed by  $H_1^0 \rightarrow A^0A^0$ ,  $A^0 \rightarrow c\bar{c}, gg$ , or  $\tau^+\tau^-$  in the region  $m_{H_1^0} = 45\text{--}86 \text{ GeV}$  and  $m_{A^0} = 2\text{--}11 \text{ GeV}$ . See their Fig. 7 for the limits.
- 125 Search for associated production of a  $\gamma\gamma$  resonance with a  $Z$  boson, followed by  $Z \rightarrow q\bar{q}, \ell^+\ell^-$ , or  $\nu\bar{\nu}$ , at  $E_{\text{cm}} \leq 209 \text{ GeV}$ . The limit is for a  $H$  with SM production cross section and  $B(H \rightarrow f\bar{f})=0$  for all fermions  $f$ .
- 126 For  $B(H \rightarrow \gamma\gamma)=1$ ,  $m_H > 113.1 \text{ GeV}$  is obtained.
- 127 HEISTER 02M search for  $e^+e^- \rightarrow HZ$ , assuming that  $H$  decays to  $q\bar{q}, gg$ , or  $\tau^+\tau^-$  only. The limit assumes SM production cross section.
- 128 ABBIENDI 01E search for neutral Higgs bosons in general Type-II two-doublet models, at  $E_{\text{cm}} \leq 189 \text{ GeV}$ . In addition to usual final states, the decays  $H_1^0, A^0 \rightarrow q\bar{q}, gg$  are searched for. See their Figs. 15,16 for excluded regions.
- 129 ACCIARRI 00R search for  $e^+e^- \rightarrow H\gamma$  with  $H \rightarrow b\bar{b}, Z\gamma$ , or  $\gamma\gamma$ . See their Fig. 3 for limits on  $\sigma \cdot B$ . Explicit limits within an effective interaction framework are also given, for which the Standard Model Higgs search results are used in addition.
- 130 ACCIARRI 00R search for the two-photon type processes  $e^+e^- \rightarrow e^+e^-H$  with  $H \rightarrow b\bar{b}$  or  $\gamma\gamma$ . See their Fig. 4 for limits on  $\Gamma(H \rightarrow \gamma\gamma) \cdot B(H \rightarrow \gamma\gamma \text{ or } b\bar{b})$  for  $m_H=70\text{--}170 \text{ GeV}$ .
- 131 GONZALEZ-GARCIA 98B use  $D\bar{D}$  limit for  $\gamma\gamma$  events with missing  $E_T$  in  $p\bar{p}$  collisions (ABBOTT 98) to constrain possible  $ZH$  or  $WH$  production followed by unconventional

- $H \rightarrow \gamma\gamma$  decay which is induced by higher-dimensional operators. See their Figs. 1 and 2 for limits on the anomalous couplings.
- 132 KRAWCZYK 97 analyse the muon anomalous magnetic moment in a two-doublet Higgs model (with type II Yukawa couplings) assuming no  $H_1^0 Z Z$  coupling and obtain  $m_{H_1^0} \gtrsim 5$  GeV or  $m_{A^0} \gtrsim 5$  GeV for  $\tan\beta > 50$ . Other Higgs bosons are assumed to be much heavier.
- 133 ALEXANDER 96H give  $B(Z \rightarrow H\gamma) \times B(H \rightarrow q\bar{q}) < 1-4 \times 10^{-5}$  (95%CL) and  $B(Z \rightarrow H\gamma) \times B(H \rightarrow b\bar{b}) < 0.7-2 \times 10^{-5}$  (95%CL) in the range  $20 < m_H < 80$  GeV.
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## Electroweak Constraints on the Standard Model Higgs Boson Mass

Here we list constraints on the mass of the Higgs boson derived from fits to precision electroweak observables, assuming the minimal Standard Model with a doublet Higgs field and three generations of fermions.

<u>VALUE (GeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<b>90<sup>+21</sup><sub>-18</sub></b>	<sup>1</sup> HALLER	18 RVUE
• • • We do not use the following data for averages, fits, limits, etc. • • •		
91 <sup>+30</sup> <sub>-23</sub>	<sup>2</sup> BAAK	12 RVUE
94 <sup>+25</sup> <sub>-22</sub>	<sup>3</sup> BAAK	12A RVUE
91 <sup>+31</sup> <sub>-24</sub>	<sup>4</sup> ERLER	10A RVUE
129 <sup>+74</sup> <sub>-49</sub>	<sup>5</sup> LEP-SLC	06 RVUE

- <sup>1</sup> HALLER 18 make Standard Model fits to  $Z$  and neutral current parameters,  $m_t$ ,  $m_W$ , and  $\Gamma_W$  measurements available in 2018. The direct mass measurement at the LHC is not used in the fit.
- <sup>2</sup> BAAK 12 make Standard Model fits to  $Z$  and neutral current parameters,  $m_t$ ,  $m_W$ , and  $\Gamma_W$  measurements available in 2010 (using also preliminary data). The quoted result is obtained from a fit that does not include the limit from the direct Higgs searches. The result including direct search data from LEP2, the Tevatron and the LHC is  $120^{+12}_{-5}$  GeV.
- <sup>3</sup> BAAK 12A make Standard Model fits to  $Z$  and neutral current parameters,  $m_t$ ,  $m_W$ , and  $\Gamma_W$  measurements available in 2012 (using also preliminary data). The quoted result is obtained from a fit that does not include the measured mass value of the signal observed at the LHC and also no limits from direct Higgs searches.
- <sup>4</sup> ERLER 10A makes Standard Model fits to  $Z$  and neutral current parameters,  $m_t$ ,  $m_W$  measurements available in 2009 (using also preliminary data). The quoted result is obtained from a fit that does not include the limits from the direct Higgs searches. With direct search data from LEP2 and Tevatron added to the fit, the 90% CL (99% CL) interval is 115–148 (114–197) GeV.
- <sup>5</sup> LEP-SLC 06 make Standard Model fits to  $Z$  parameters from LEP/SLC and  $m_t$ ,  $m_W$ , and  $\Gamma_W$  measurements available in 2005 with  $\Delta\alpha_{\text{had}}^{(5)}(m_Z) = 0.02758 \pm 0.00035$ . The 95% CL limit is 285 GeV.
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AAD	22D	PL B829 137066	G. Aad <i>et al.</i>	(ATLAS Collab.)
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AAD	22I	JHEP 2201 063	G. Aad <i>et al.</i>	(ATLAS Collab.)
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AAD	22P	JHEP 2208 104	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	22Y	PR D106 052001	G. Aad <i>et al.</i>	(ATLAS Collab.)
ABLIKIM	22H	PR D105 012008	M. Ablikim <i>et al.</i>	(BESIII Collab.)
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JIA	22	PRL 128 081804	S. Jia <i>et al.</i>	(BELLE Collab.)
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AAD	20X	JHEP 2007 108	G. Aad <i>et al.</i>	(ATLAS Collab.)
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AAD	13AG	PL B721 32	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	13AT	NJP 15 043009	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	13O	JHEP 1302 095	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAIJ	13T	JHEP 1305 132	R. Aaij <i>et al.</i>	(LHCb Collab.)
AALTONEN	13K	PR D88 052012	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13L	PR D88 052013	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	13M	PR D88 052014	T. Aaltonen <i>et al.</i>	(CDF and D0 Collabs.)
AALTONEN	13P	PRL 110 121801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	13G	PR D88 052006	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	13H	PR D88 052007	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	13I	PR D88 052008	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	13J	PR D88 052009	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	13L	PR D88 052011	V.M. Abazov <i>et al.</i>	(D0 Collab.)
CARENA	13	EPJ C73 2552	M. Carena <i>et al.</i>	
CHATRCHYAN	13AG	PL B722 207	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	13AL	PL B725 36	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	13BJ	PL B726 564	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
LEES	13C	PR D87 031102	J.P. Lees <i>et al.</i>	(BABAR Collab.)
LEES	13L	PR D88 031701	J.P. Lees <i>et al.</i>	(BABAR Collab.)
LEES	13R	PR D88 071102	J.P. Lees <i>et al.</i>	(BABAR Collab.)
AAD	12AI	PL B716 1	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12AQ	PRL 108 251801	G. Aad <i>et al.</i>	(ATLAS Collab.)
AAD	12N	EPJ C72 2157	G. Aad <i>et al.</i>	(ATLAS Collab.)
AALTONEN	12AB	PR D85 092001	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	12AN	PL B717 173	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	12AQ	PR D86 091101	T. Aaltonen <i>et al.</i>	(CDF and D0 Collabs.)
AALTONEN	12U	PR D85 012007	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	12X	PR D85 032005	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	12G	PL B710 569	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABLIKIM	12	PR D85 092012	M. Ablikim <i>et al.</i>	(BESIII Collab.)
BAAK	12	EPJ C72 2003	M. Baak <i>et al.</i>	(Gfitter Group)
BAAK	12A	EPJ C72 2205	M. Baak <i>et al.</i>	(Gfitter Group)
CHATRCHYAN	12AO	JHEP 1209 111	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12C	JHEP 1203 081	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12D	JHEP 1204 036	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12E	PL B710 91	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12G	PL B710 403	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12H	PRL 108 111804	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12I	JHEP 1203 040	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12K	PL B713 68	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12N	PL B716 30	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
CHATRCHYAN	12V	PRL 109 121801	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
AALTONEN	11P	PRL 107 031801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	11K	PL B698 97	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	11W	PRL 107 121801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABOUZAID	11A	PRL 107 201803	E. Abouzaid <i>et al.</i>	(KTeV Collab.)
DEL-AMO-SA...	11J	PRL 107 021804	P. del Amo Sanchez <i>et al.</i>	(BABAR Collab.)
LEES	11H	PRL 107 221803	J.P. Lees <i>et al.</i>	(BABAR Collab.)
ABBIENDI	10	PL B682 381	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ANDREAS	10	JHEP 1008 003	S. Andreas <i>et al.</i>	(DESY)
ERLER	10A	PR D81 051301	J. Erler	(UNAM)
HYUN	10	PRL 105 091801	H.J. Hyun <i>et al.</i>	(BELLE Collab.)
SCHAEI	10	JHEP 1005 049	S. Schael <i>et al.</i>	(ALEPH Collab.)
AALTONEN	09AB	PRL 103 061803	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09AR	PRL 103 201801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	09V	PRL 103 061801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
AUBERT	09P	PRL 103 181801	B. Aubert <i>et al.</i>	(BABAR Collab.)
AUBERT	09Z	PRL 103 081803	B. Aubert <i>et al.</i>	(BABAR Collab.)
TUNG	09	PRL 102 051802	Y.C. Tung <i>et al.</i>	(KEK E391a Collab.)
ABAZOV	08U	PRL 101 051801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABDALLAH	08B	EPJ C54 1	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
Also		EPJ C56 165 (errat.)	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
LOVE	08	PRL 101 151802	W. Love <i>et al.</i>	(CLEO Collab.)
ABBIENDI	07	EPJ C49 457	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
BESSON	07	PRL 98 052002	D. Besson <i>et al.</i>	(CLEO Collab.)
SCHAEI	07	EPJ C49 439	S. Schael <i>et al.</i>	(ALEPH Collab.)
LEP-SLC	06	PRPL 427 257	ALEPH, DELPHI, L3, OPAL, SLD and working groups	
SCHAEI	06B	EPJ C47 547	S. Schael <i>et al.</i>	(LEP Collabs.)

ABBIENDI	05A	EPJ C40 317	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABDALLAH	05D	EPJ C44 147	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ACHARD	05	PL B609 35	P. Achard <i>et al.</i>	(L3 Collab.)
ACOSTA	05Q	PR D72 072004	D. Acosta <i>et al.</i>	(CDF Collab.)
PARK	05	PRL 94 021801	H.K. Park <i>et al.</i>	(FNAL HyperCP Collab.)
ABBIENDI	04K	PL B597 11	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	04M	EPJ C37 49	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABDALLAH	04	EPJ C32 145	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ABDALLAH	04B	EPJ C32 475	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ABDALLAH	04L	EPJ C35 313	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ABDALLAH	04O	EPJ C38 1	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ACHARD	04B	PL B583 14	P. Achard <i>et al.</i>	(L3 Collab.)
ACHARD	04F	PL B589 89	P. Achard <i>et al.</i>	(L3 Collab.)
ABBIENDI	03F	EPJ C27 311	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	03G	EPJ C27 483	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ACHARD	03C	PL B568 191	P. Achard <i>et al.</i>	(L3 Collab.)
ABBIENDI	02D	EPJ C23 397	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	02F	PL B544 44	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ACHARD	02C	PL B534 28	P. Achard <i>et al.</i>	(L3 Collab.)
ACHARD	02H	PL B545 30	P. Achard <i>et al.</i>	(L3 Collab.)
AKERROYD	02	PR D66 037702	A.G. Akeroyd <i>et al.</i>	
HEISTER	02	PL B526 191	A. Heister <i>et al.</i>	(ALEPH Collab.)
HEISTER	02L	PL B544 16	A. Heister <i>et al.</i>	(ALEPH Collab.)
HEISTER	02M	PL B544 25	A. Heister <i>et al.</i>	(ALEPH Collab.)
ABBIENDI	01E	EPJ C18 425	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABREU	01F	PL B507 89	P. Abreu <i>et al.</i>	(DELPHI Collab.)
AFFOLDER	01H	PR D64 092002	T. Affolder <i>et al.</i>	(CDF Collab.)
BARATE	01C	PL B499 53	R. Barate <i>et al.</i>	(ALEPH Collab.)
ACCIARRI	00M	PL B485 85	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00R	PL B489 102	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00S	PL B489 115	M. Acciarri <i>et al.</i>	(L3 Collab.)
BARATE	00L	PL B487 241	R. Barate <i>et al.</i>	(ALEPH Collab.)
ABBIENDI	99E	EPJ C7 407	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	99O	PL B464 311	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBOTT	99B	PRL 82 2244	B. Abbott <i>et al.</i>	(D0 Collab.)
ABREU	99P	PL B458 431	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABBOTT	98	PRL 80 442	B. Abbott <i>et al.</i>	(D0 Collab.)
ACKERSTAFF	98S	EPJ C5 19	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	98Y	PL B437 218	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
GONZALEZ...	98B	PR D57 7045	M.C. Gonzalez-Garcia, S.M. Lietti, S.F. Novaes	
KRAWCZYK	97	PR D55 6968	M. Krawczyk, J. Zochowski	(WARS)
ALEXANDER	96H	ZPHY C71 1	G. Alexander <i>et al.</i>	(OPAL Collab.)
ABREU	95H	ZPHY C67 69	P. Abreu <i>et al.</i>	(DELPHI Collab.)
BALEST	95	PR D51 2053	R. Balest <i>et al.</i>	(CLEO Collab.)
PICH	92	NP B388 31	A. Pich, J. Prades, P. Yepes	(CERN, CPPM)
ANTREASYAN	90C	PL B251 204	D. Antreasyan <i>et al.</i>	(Crystal Ball Collab.)