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 “$H_0^0$”, 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 $e^+e^- \to H_1^0Z^0$ in the channels used for the Standard Model Higgs searches and $e^+e^- \to H_1^0A^0$ in the final states $b\overline{b}b\overline{b}$ and $b\overline{b}\tau^+\tau^-$. 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 $p\overline{p}$ 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
Mass Limits for heavy neutral Higgs bosons ($H_0^+, A^0$) in the MSSM

The limits rely on $pp \rightarrow H_0^+/A^0 \rightarrow \tau^+\tau^-$ and assume that $H_0^+$ and $A^0$ are (sufficiently) mass degenerate. The limits depend on $\tan \beta$.

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

3 AAD 20 ATLS $H_0^0$ properties
4 AAD 20AA ATLS $H_0^+/A^0 \rightarrow \tau^+\tau^-$
5 AAD 20C ATLS $H_0^+/A^0 \rightarrow \tau^+\tau^-$
6 AAD 20L ATLS $H_0^+ \rightarrow b\bar{b}$
7 SIRUNYAN 20AC CMS $A^0 \rightarrow Z H^0$
8 SIRUNYAN 20AF CMS $H_0^+/A^0 \rightarrow \tau^+\tau^-$
9 SIRUNYAN 20Y CMS $H_0^+/A^0 \rightarrow \mu^+\mu^-$
10 SIRUNYAN 19CR CMS $H_0^+/A^0 \rightarrow \mu^+\mu^-$
11 SIRUNYAN 18A CMS $H_0^+/A^0 \rightarrow \mu^+\mu^-$
12 SIRUNYAN 18BP CMS $pp \rightarrow H_0^+/A^0 + b + X$

13 AABOUD 16AA ATLS $A^0 \rightarrow \tau^+\tau^-$
14 KHACHATRYAN 16A CMS $H_0^+/A^0 \rightarrow \mu^+\mu^-$
15 KHACHATRYAN 16P CMS $H_0^+/A^0 \rightarrow \mu^+\mu^-$
16 KHACHATRYAN 15AY CMS $pp \rightarrow H_0^+/A^0 + b + X$

17 AAD 14AW ATLS $pp \rightarrow H_0^+/A^0 + X$
18 KHACHATRYAN 14M CMS $pp \rightarrow H_0^+/A^0 + X$

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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 CHATRCHYAN 13AG 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 CHATRCHYAN 12K 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 $E_{\text{cm}} \leq 209 \text{ GeV}$

$> 93.4$

30 SCHAELE 06B LEP $E_{\text{cm}} \leq 209 \text{ GeV}$

31 ACOSTA 05Q CDF $p\bar{p} \rightarrow H_{1,2}^0/A^0 + X$

$> 85.0$

32,33 ABBEI0DI 04M OPAL $E_{\text{cm}} \leq 209 \text{ GeV}$

34 ABBEI0DI 03G OPAL $H_1^0 \rightarrow A^0 A^0$

$> 86.5$

32,35 ACHARD 02H L3 $E_{\text{cm}} \leq 209 \text{ GeV}, \tan\beta > 0.4$

36 AKEROYD 02 RVUE $E_{\text{cm}} \leq 209 \text{ GeV}$

$> 90.1$

32,37 HEISTER 02 ALEP $E_{\text{cm}} \leq 209 \text{ GeV}, \tan\beta > 0.5$

1 AABOUD 18G search for production of $H_{2}^0/A^0 \rightarrow \tau^+\tau^-$ by gluon fusion and $b$-associated production in 36.1 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.

2 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 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.

3 AAD 20 combine measurements on $H_{1}^0$ production and decay using data taken in years 2015–2017 (up to 79.8 fb$^{-1}$) of $pp$ collisions at $E_{\text{cm}} = 13 \text{ TeV}$. See their Fig. 19 for excluded region in the hMSSM parameter space.
4 AAD 20AA search for $H^0_0/A^0 \rightarrow \tau^+\tau^-$ produced by gluon fusion or $b$-associated production using 139 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Fig. 2(c) for excluded region in the $M_{125}^h$ scenario of MSSM. Values of $\tan\beta>8$ (21) are excluded for $m_{A^0}=1.0$ (1.5) TeV at 95%CL.

5 AAD 20c combine searches for a scalar resonance decaying to $H^0_0 H^0_0$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV from AABOUD 19A, AABOUD 19B, AABOUD 19C, AABOUD 19T, AABOUD 18CW, and AABOUD 18BU. See their Fig. 7(b) for the excluded region in the hMSSM parameter space.

6 AAD 20l search for $b$-associated production of $H^0_2$ decaying to $b\bar{b}$ in 27.8 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Fig. 9 for excluded regions in hMSSM, $m_{h_{mod+}}$ and $m_{h_{mod-}}$ scenarios of MSSM.

7 SIRUNYAN 20AC search for gluon-fusion and $b$-associated production of $A^0$ decaying to $ZH^0$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Fig. 6 for excluded regions in the $M_{125}^h$ and hMSSM scenarios of the MSSM.

8 SIRUNYAN 20AF search for $H^0_2/A^0 \rightarrow t\bar{t}$ with one or two charged leptons in the final state using kinematic variables in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ 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 $m_{A^0}=0.4$–0.75 TeV at 95%CL.

9 SIRUNYAN 20Y search for gluon-fusion and vector-boson-fusion production of $H^0_2$ decaying to $W^+W^-$ in the final states $\ell\nu\ell\nu$ and $\ell\nu q\bar{q}$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Figs. 8 and 9 for excluded regions in various MSSM scenarios.

10 SIRUNYAN 19CR search for production of $H^0_2/A^0$ in gluon fusion and in association with a $b\bar{b}$ pair, decaying to $\mu^+\mu^-$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Fig. 5 for the excluded region in the MSSM parameter space in the $m_{h_{mod+}}$ and hMSSM scenarios.

11 SIRUNYAN 18A search for production of a scalar resonance decaying to $H^0_0 H^0_0 \rightarrow b\bar{b} \tau^+\tau^-$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Fig. 5 (lower) for excluded regions in the $m_{A^0}-\tan\beta$ plane in the hMSSM scenario.

12 SIRUNYAN 18BP search for production of $H^0_2/A^0 \rightarrow b\bar{b}$ by $b$-associated production in 35.7 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Fig. 6 for the limits on cross section times branching ratio for $m_{H^0_2}/m_{A^0}=0.3$–1.3 TeV, and Fig. 7 for excluded regions in the $m_{A^0}-\tan(\beta)$ plane in several MSSM scenarios.

13 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 fb$^{-1}$ of $pp$ collisions at $E_{cm}=13$ TeV. See their Fig. 5(a, b) for limits on cross section times branching ratio for $m_{A^0}=200$–1200 GeV, and Fig. 5(c, d) for the excluded region in the MSSM parameter space in the $m_{h_{mod+}}$ and hMSSM scenarios.

14 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 $H^0_{1,2}/A^0 \rightarrow \mu^+\mu^-$ in 5.1 fb$^{-1}$ of $pp$ collisions at $E_{cm}=7$ TeV and 19.3 fb$^{-1}$ at $E_{cm}=8$ TeV. See their Fig. 7 for the excluded region in the MSSM parameter space in the $m_{h_{mod+}}$ benchmark scenario and Fig. 9 for limits on cross section times branching ratio.

15 KHACHATRYAN 16P search for gluon fusion production of an $H^0_2$ decaying to $H^0_0 H^0_0 \rightarrow b\bar{b} \tau^+\tau^-$ and an $A^0$ decaying to $ZH^0 \rightarrow \ell^+\ell^-\tau^+\tau^-$ in 19.7 fb$^{-1}$ of $pp$ collisions at $E_{cm}=8$ TeV. See their Fig. 12 for excluded region in the $\tan\beta - \cos(\beta-\alpha)$ plane for $m_{H^0_2}=m_{A^0}=300$ GeV.
16 KHACHATRYAN 15AY search for production of a Higgs boson in association with a $b$ quark in the decay $H_{1,2}^0/A^0 \to b\bar{b}$ in 19.7 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV and combine with CHATRCHYAN 13AG 7 TeV data. See their Fig. 6 for the limits on cross section times branching ratio for $m_{A^0} = 100$–900 GeV and Figs. 7–9 for the excluded region in the MSSM parameter space in various benchmark scenarios.

17 AAD 14A\textsc{W} search for production of a Higgs boson followed by the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$ in 19.5–20.3 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ 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 $m_{A^0} = 140$ GeV, the region $\tan\beta > 5.4$ is excluded at 95% CL in the $m^\text{max}_h$ 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 $H_{1,2}^0/A^0 \to \tau^+\tau^-$ in 4.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ TeV and 19.7 fb$^{-1}$ at $E_{cm} = 8$ 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 $m_{A^0} = 140$ GeV, the region $\tan\beta > 3.8$ is excluded at 95% CL in the $m^\text{max}_h$ scenario.

19 AAD 13O search for production of a Higgs boson in the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$ and $\mu^+\mu^-$ with 4.7–4.8 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ 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 $m_{A^0} = 110$–170 GeV, $\tan\beta \gtrsim 10$ is excluded, and for $\tan\beta = 50$, $m_{A^0}$ below 470 GeV is excluded at 95% CL in the $m^\text{max}_h$ scenario.

20 AALTONEN 13T search for production of a Higgs boson in the forward region in the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$ in 1.0 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ 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 $H_{1,2}^0/A^0 \to b\bar{b}$ in 2.7–4.8 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ 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 $m_{A^0} = 90$–350 GeV, upper bounds on $\tan\beta$ of 18–42 at 95% CL are obtained in the $m^\text{max}_h$ scenario with $\mu = +200$ 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 $H_{1,2}^0/A^0 \to b\bar{b}$, with 2.6 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{cm} = 1.96$ 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 $H_{1,2}^0/A^0 \to \tau^+\tau^-$ with 7.3 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{cm} = 1.96$ 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 $m_{A^0} = 90$–180 GeV, $\tan\beta \gtrsim 30$ is excluded at 95% CL in the $m^\text{max}_h$ scenario.

25 CHATRCHYAN 12K search for production of a Higgs boson in the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$ with 4.6 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ TeV. See their Fig. 3 and Table 4 for the excluded region in the MSSM parameter space. For $m_{A^0} = 160$ GeV, the region $\tan\beta > 7.1$ is excluded at 95% CL in the $m^\text{max}_h$ 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 $E_{cm} = 1.96 \text{ TeV}$. 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 $E_{cm} = 1.96 \text{ TeV}$. 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 09A search for Higgs bosons decaying to $\tau^+\tau^-$ in two doublet models in $1.8 \text{ fb}^{-1}$ of $p\bar{p}$ collisions at $E_{cm} = 1.96 \text{ TeV}$. See their Fig. 2 for the limit on $\sigma \cdot B(H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-)$ 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 SCHAEL 06B make a combined analysis of the LEP data. The quoted limit is for the $m_h^{max}$ scenario with $m_t = 174.3 \text{ GeV}$. 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 $\sigma(ZH^0) \cdot B(H^0 \rightarrow b\bar{b}, \tau^+\tau^-)$ and $\sigma(H_1^0H_2^0) \cdot B(H_1^0H_2^0 \rightarrow b\bar{b}, \tau^+\tau^-)$.

31 ACOSTA 05Q search for $H_{1,2}^0/A^0$ production in $p\bar{p}$ collisions at $E_{cm} = 1.8 \text{ TeV}$ 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 $e^+e^- \rightarrow H_1^0A^0$ in the final states $b\bar{b}b\bar{b}$ and $b\bar{b}\tau^+\tau^-$, and $e^+e^- \rightarrow H_1^0Z$. 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 $m_h^{max}$ scenario.

33 ABDIENDI 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 ABDIENDI 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 no-mixing scenario, the region $m_{H_1^0} = 45-85 \text{ GeV}$ and $m_{A^0} = 2.95 \text{ GeV}$ is excluded at 95% CL.

35 ACHAR 02H also search for the final state $H_1^0Z \rightarrow 2A^0q\bar{q}, A^0 \rightarrow q\bar{q}$. 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

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

7 AALTONEN 12AQ TEVA $p\bar{p} \rightarrow H_{1,2}^0/A^0 + b + X$, $H_{1,2}^0/A^0 \rightarrow b\bar{b}$

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

2 SCHAEL 06b make a combined analysis of the LEP data. The quoted limit is for the $m_{H_1}^{\text{max}}$ scenario with $m_t = 174.3$ GeV. In the CP-violating CPX scenario no lower bound on $m_{H_1}$ 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 $\sigma(Z H^0) \cdot B(H^0 \to b\bar{b}, \tau^+\tau^-)$ and $\sigma(H_1^0 H_2^0) \cdot B(H_1^0, H_2^0 \to b\bar{b}, \tau^+\tau^-)$.

3 Search for $e^+e^- \to H_1^0 A^0$ in the final states $b\bar{b}b\bar{b}$ and $b\bar{b}\tau^+\tau^-$. 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 $m_{H_1}^{\text{max}}$ scenario.

4 ABBIENDI 04b 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.

5 ACHARD 02H also search for the final state $H_1^0 Z \to 2A^0 q\bar{q}, A^0 \to q\bar{q}$. In addition, the MSSM parameter set in the “large-$\mu$” and “no-mixing” scenarios are examined.

6 HEISTER 02 excludes the range 0.7 < tan$\beta$ < 2.3. A wider range is excluded with different stop mixing assumptions. Updates BARATE 01C.

7 AALTONEN 12Q 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.

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**MSS 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$^0$”, can be interpreted as one of the neutral Higgs bosons of an extended Higgs sector.

<table>
<thead>
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<tr>
<td>6 SIRUNYAN 19AV CMS</td>
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<td>7 AABOUD 18AH ATLS</td>
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https://pdg.lbl.gov  Page 7  Created: 6/1/2021 08:33
1 AAD 20 combine measurements on $H^0$ production and decay using data taken in years 2015–2017 (up to 79.8 fb$^{-1}$) of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 18 for excluded regions in various 2HDMs.

2 AAD 20L search for $b$-associated production of $H^0_2$ decaying to $b\bar{b}$ in 27.8 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Figs. 10 and 11 for excluded regions in the flipped two Higgs doublet model.

3 SIRUNYAN 20A search for $H^0_2 \rightarrow Z A^0$, $A^0 \rightarrow b\bar{b}$ or $A^0 \rightarrow Z H^0_2$, $H^0_2 \rightarrow b\bar{b}$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Figs. 8 and 9 for excluded regions in the parameter space of Type-II two Higgs doublet model.

4 SIRUNYAN 20Y search for gluon-fusion and vector-boson-fusion production of $H^0_2$ decaying to $W^+ W^-$ in the final states $\ell\nu\ell\nu$ and $\ell\nu q\bar{q}$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 7 for excluded regions in Type I and II two Higgs doublet models.

5 SIRUNYAN 19A search for a pseudoscalar resonance produced in association with a $b\bar{b}$ pair, decaying to $\tau^+ \tau^-$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 4 for excluded regions in the parameter space of Type-II two Higgs doublet model.
for cross section limits for \( m_{A^0} = 25–70 \text{ GeV} \) and comparison with some representative 2HDMs.

6 SIRUNYAN 19AV search for a scalar resonance produced by gluon fusion or \( b \) associated production, decaying to \( Z H^0 \to \ell^+ \ell^- b\bar{b} \) (\( \ell = e, \mu \)) or \( \nu \tau b\bar{b} \) in 35.9 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.

7 AABOUD 18AH search for production of an \( A^0 \) in gluon-gluon fusion and in association with a \( b\bar{b} \), decaying to \( Z H^0 \to \ell^+ \ell^- b\bar{b} \) in 36.1 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.

8 AABOUD 18AI search for production of an \( A^0 \) in gluon-gluon fusion and in association with a \( b\bar{b} \), decaying to \( Z H^0 \) in the final states \( \nu \tau b\bar{b} \) and \( \ell^+ \ell^- b\bar{b} \) in 36.1 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 of various 2HDMs.

9 AABOUD 18BF search for production of a heavy \( H_2^0 \) state decaying to \( ZZ \) in the final states \( \ell^+ \ell^- \ell^+ \ell^- \) and \( \ell^+ \ell^- \nu \tau \) in 36.1 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.

10 AABOUD 18CE search for the process \( pp \to H_2^0/A^0 \to \tau \tau \) followed by the decay \( H_2^0/A^0 \to \ell^+ \ell^- \) in 36.1 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 \( m_{H_2^0}, m_{A^0} = 0.4–1.0 \text{ TeV} \) in the 2HDM type II.

11 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.

12 SIRUNYAN 18BP search for production of \( H_2^0/A^0 \to b\bar{b} \) by \( b \)-associated production in 35.7 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 \( m_{H_2^0}, m_{A^0} = 0.3–1.3 \text{ TeV} \), and Figs. 8 and 9 for excluded regions in the parameter space of type-II and flipped 2HDMs.

13 SIRUNYAN 18ED search for production of an \( A^0 \) in gluon-gluon fusion and in association with a \( b\bar{b} \), decaying to \( Z H^0 \) in the final states \( \nu \tau b\bar{b} \) or \( \ell^+ \ell^- b\bar{b} \) in 35.9 fb\(^{-1}\) of \( pp \) collisions at \( E_{\text{cm}} = 13 \text{ TeV} \). See their Fig. 9 for excluded regions in the parameter space in various 2HDMs.

14 AABOUD 17AN search for production of a heavy \( H_2^0 \) and/or \( A^0 \) decaying to \( \tau \tau \) in 20.3 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.

15 SIRUNYAN 17AX search for \( A^0 b\bar{b} \) production followed by the decay \( A^0 \to \mu^+ \mu^- \) in 19.7 fb\(^{-1}\) of \( pp \) collisions at \( E_{\text{cm}} = 8 \text{ TeV} \). Limits are set in the range \( m_{A^0} = 25–60 \text{ GeV} \). See their Fig. 5 for upper limits on \( \sigma(A^0 b\bar{b}) B(A^0 \to \mu^+ \mu^-) \).

16 AAD 16AX search for production of a heavy \( H^0 \) state decaying to \( ZZ \) in the final states \( \ell^+ \ell^- \ell^+ \ell^- \), \( \ell^+ \ell^- \nu \tau \), \( \ell^+ \ell^- q\bar{q} \), and \( \nu \tau q\bar{q} \) in 20.3 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.

17 KHACHATRYAN 16P search for gluon fusion production of an \( H_2^0 \) decaying to \( H_2^0 \to b\bar{b} \) and an \( A^0 \) decaying to \( Z H^0 \to \ell^+ \ell^- \tau^+ \tau^- \) in 19.7 fb\(^{-1}\) of \( pp \) collisions at \( E_{\text{cm}} = 8 \text{ TeV} \). See their Fig. 11 for limits on \( \tan \beta \) for \( m_{A^0} = 230–350 \text{ GeV} \).

18 KHACHATRYAN 16W search for \( A^0 b\bar{b} \) production followed by the decay \( A^0 \to \tau^+ \tau^- \) in 19.7 fb\(^{-1}\) of \( pp \) collisions at \( E_{\text{cm}} = 8 \text{ TeV} \). See their Fig. 3 for upper limits on \( \sigma(A^0 b\bar{b}) B(A^0 \to \tau^+ \tau^-) \).

19 KHACHATRYAN 16Z search for \( H_2^0 \to Z A^0 \) followed by \( A^0 \to b\bar{b} \) or \( \tau^+ \tau^- \), and \( A^0 \to Z H_2^0 \) followed by \( H_2^0 \to b\bar{b} \) or \( \tau^+ \tau^- \) in 19.8 fb\(^{-1}\) of \( pp \) collisions at \( E_{\text{cm}} \).
A 15B9K search for production of a heavy $H_2^0$ decaying to $H^0 H^0$ in the final state $b \overline{b} b \overline{b}$ in 19.5 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Figs. 15–18 for excluded regions in the parameter space.

A 15s search for production of $A^0$ decaying to $ZH^0 \rightarrow \ell^+ \ell^- b \overline{b}$, $\nu \tau b \overline{b}$ and $\ell^+ \ell^- \tau^+ \tau^-$ in 20.3 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Figs. 4 and 5 for excluded regions in the parameter space.

KHACHATRYAN 15BB search for $H_2^0$, $A^0 \rightarrow \gamma \gamma$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 10 for excluded regions in the two-Higgs-doublet model parameter space.

KHACHATRYAN 15N search for production of $A^0$ decaying to $ZH^0 \rightarrow \ell^+ \ell^- b \overline{b}$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 5 for excluded regions in the $\tan \beta - \cos(\beta - \alpha)$ plane for $m_{A^0} = 300$ GeV.

A 14M search for the decay cascade $H_2^0 \rightarrow H^0 W^+ \rightarrow H^0 W^+ W^+ W^-$, $H^0$ decaying to $b \overline{b}$ in 20.3 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Table IV for limits in a two-Higgs-doublet model for $m_{H_2^0} = 325–1025$ GeV and $m_{H^0} = 225–825$ GeV.

KHACHATRYAN 14Q search for $H_2^0 \rightarrow H^0 H^0$ and $A^0 \rightarrow Z H^0$ in 19.5 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Figs. 4 and 5 for limits on cross section times branching ratio for $m_{H_2^0 A^0} = 260–360$ GeV and their Figs. 7–9 for limits in two-Higgs-doublet models.

AALTONEN 09 search for Higgs bosons decaying to $\tau^+ \tau^-$ in two doublet models in 1.8 fb$^{-1}$ of $p \overline{p}$ collisions at $E_{cm} = 1.96$ TeV. See their Fig. 2 for the limit on $\sigma \cdot B(H^0_{1,2}/A_0 \rightarrow \tau^+ \tau^-)$ for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space.

ABBIENDI 05A search for $e^+ e^- \rightarrow H_1^0 A^0$ in general Type-II two-doublet models, with decays $H_1^0, A^0 \rightarrow q \overline{q}, g g, \tau^+ \tau^-$, and $H_1^0 \rightarrow A^0 A^0$.

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 $B(H^0 \rightarrow jj) = 1$.

ABDALLAH 04O search for $Z \rightarrow b \overline{b} H^0, b \overline{b} A^0, \tau^+ \tau^- H^0$ and $\tau^+ \tau^- A^0$ in the final states $4b$, $b \tau^+ \tau^-$, and $4r$. See paper for limits on Yukawa couplings.

ABDALLAH 04O search for $e^+ e^- \rightarrow H^0 Z$ and $H^0 A^0$, with $H^0, A^0$ decaying to $b \overline{b}$, $\tau^+ \tau^-$, or $H^0 \rightarrow A^0 A^0$ at $E_{cm} = 189–208$ GeV. See paper for limits on couplings.

ABBIENDI 02D search for $Z \rightarrow b \overline{b} H_1^0$ and $b \overline{b} A^0$ with $H_1^0 / A^0 \rightarrow \tau^+ \tau^-$, in the range $4 < m_H < 12$ GeV. See their Fig. 8 for limits on the Yukawa coupling.

ABBIENDI 01E search for neutral Higgs bosons in general Type-II two-doublet models, at $E_{cm} \leq 189$ GeV. In addition to usual final states, the decays $H_1^0, A^0 \rightarrow q \overline{q}, g g$ are searched for. See their Figs. 15, 16 for excluded regions.

ABBIENDI 99E search for $e^+ e^- \rightarrow H^0 A^0$ and $H^0 Z$ at $E_{cm} = 183$ 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.

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, $m_{H^0} < 74$ GeV is excluded at 95% CL.

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”).

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<td>1 AALTONEN 13K CDF</td>
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<td>none 100–113</td>
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1 AALTONEN 13K search for $H^0 \rightarrow WW^(*)$ in 9.7 fb$^{-1}$ 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.

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

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

4 ABAZOV 13G search for $H^0 \rightarrow WW^(*)$ in 9.7 fb$^{-1}$ 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 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{cm} = 1.96$ 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 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{cm} = 1.96$ 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 $m_{H^0} = 100–200$ GeV at 95% CL.

7 ABAZOV 13J search for $H^0$ production in the final states $e^+e^-$, $e\mu\mu$, $\mu\tau\tau$, and $e^\pm\mu^\pm$ in 8.6–9.7 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{\text{CM}} = 1.96$ TeV. The search is sensitive to $W H^0$, $Z H^0$ production with $H^0 \rightarrow W W^{(*)}$, $Z Z^{(*)}$, 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 $m_{H^0} = 100–200$ GeV at 95% CL.

8 ABAZOV 13L combine all D0 results with up to 9.7 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{\text{CM}} = 1.96$ TeV.

9 CHATRCHYAN 13A search for $H^0 \rightarrow \gamma\gamma$ in 5.1 fb$^{-1}$ and 5.3 fb$^{-1}$ of $pp$ collisions at $E_{\text{CM}} = 7$ and 8 TeV.

10 AAD 12N search for $H^0 \rightarrow \gamma\gamma$ with 4.9 fb$^{-1}$ of $pp$ collisions at $E_{\text{CM}} = 7$ TeV in the mass range $m_{H^0} = 110–150$ GeV.

11 AALTONEN 12AN search for $H^0 \rightarrow \gamma\gamma$ with 10 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{\text{CM}} = 1.96$ TeV in the mass range $m_{H^0} = 100–150$ GeV.

12 CHATRCHYAN 12AO use data from CHATRCHYAN 12C, CHATRCHYAN 12E, CHATRCHYAN 12H, CHATRCHYAN 12I, CHATRCHYAN 12D, and CHATRCHYAN 12C.

13 AALTONEN 09AB search for $H^0 \rightarrow \gamma\gamma$ in 3.0 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{\text{CM}} = 1.96$ TeV in the mass range $m_{H^0} = 70–150$ GeV. Associated $H^0 W$, $H^0 Z$ production and $WW$, $ZZ$ fusion are considered.

14 ABAZOV 08U search for $H^0 \rightarrow \gamma\gamma$ in $p\bar{p}$ collisions at $E_{\text{CM}} = 1.96$ TeV in the mass range $m_{H^0} = 70–150$ GeV. Associated $H^0 W$, $H^0 Z$ 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 $m_{H^0} \sim B(H^0 \rightarrow \gamma\gamma)$ plane.

15 SCHAEF 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 $Z \rightarrow q\bar{q}$, $e^+e^-$, or $\nu\bar{\nu}$, at $E_{\text{CM}} \leq 209$ GeV. The limit is for a $H^0$ with SM production cross section.

17 Updates ABREU 01F.

18 ACHARD 03C search for $e^+e^- \rightarrow Z H^0$ followed by $H^0 \rightarrow WW^*$ or $ZZ^*$ at $E_{\text{CM}} = 200–209$ GeV and combine with the ACHARD 02C result. The limit is for a $H^0$ with SM production cross section. For $B(H^0 \rightarrow WW^*) + B(H^0 \rightarrow ZZ^*) = 1$, $m_{H^0} > 108.1$ GeV is obtained. See fig. 6 for the limits under different BR assumptions.

19 For $B(H^0 \rightarrow \gamma\gamma) = 1$, $m_{H^0} > 117$ GeV is obtained.

20 ACHARD 02C search for associated production of a $\gamma\gamma$ resonance with a $Z$ boson, followed by $Z \rightarrow q\bar{q}$, $e^+e^-$, or $\nu\bar{\nu}$, at $E_{\text{CM}} \leq 209$ GeV. The limit is for a $H^0$ with SM production cross section. For $B(H^0 \rightarrow \gamma\gamma) = 1$, $m_{H^0} > 114$ 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 005 search for associated production of a $\gamma\gamma$ resonance with a $q\bar{q}$, $\nu\bar{\nu}$, or $e^+e^-$ pair in $e^+e^-$ collisions at $E_{\text{CM}} = 189$ 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 $B(H \rightarrow \gamma\gamma) / \sigma(e^+e^- \rightarrow H f \bar{T}) / \sigma(e^+e^- \rightarrow H f \bar{T})$ (SM).

23 BARATE 00L search for associated production of a $\gamma\gamma$ resonance with a $q\bar{q}$, $\nu\bar{\nu}$, or $e^+e^-$ pair in $e^+e^-$ collisions at $E_{\text{CM}} = 188–202$ 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 $B(H \rightarrow \gamma\gamma) / \sigma(e^+e^- \rightarrow H f \bar{T}) / \sigma(e^+e^- \rightarrow H f \bar{T})$ (SM).

24 ABBIENDI 99 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 $\sigma(e^+ e^- \to H^0 Z^0) \times \mathcal{B}(H^0 \to \gamma \gamma) \times \mathcal{B}(X^0 \to f \bar{f})$ for various masses. Updates the results of ACKERSTAFF 98y.

25 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 $\sigma(H^0 + Z/W \to H^0 \to \gamma \gamma) = 0.80–0.34$ pb are obtained in the mass range $m_{H^0} = 65–150$ GeV.

26 ABREU 99p search for $e^+ e^- \to H^0 \gamma$ with $H^0 \to b \bar{b}$ or $\gamma \gamma$, and $e^+ e^- \to H^0 q \bar{q}$ with $H^0 \to \gamma \gamma$. See their Fig. 4 for limits on $\sigma \times \mathcal{B}$. 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.

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1 AABOUD 19AI search for $H^0_{1.2}$ production by vector boson fusion and decay to invisible final states in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 6(b) for limits on cross section times branching ratios for $m_{H^0_{1.2}} = 0.1–3$ TeV.

2 AAD 15BD search for $pp \to H^0 W X$ and $pp \to H^0 Z X$ with $W$ or $Z$ decaying hadronically and $H^0$ decaying to invisible final states in 20.3 fb$^{-1}$ at $E_{cm} = 8$ TeV. See their Fig. 6 for a limit on the cross section times branching ratio for $m_{H^0} = 115–300$ GeV.

3 AAD 15BH search for events with a jet and missing $E_T$ in 20.3 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV. Limits on $\sigma(H^0) \times B(H^0 \to \text{invisible}) < (44–10)$ pb (95%CL) is given for $m_{H^0} = 115–300$ GeV.

4 AAD 14BA search for $H^0$ production in the decay mode $H^0 \to \chi^0 \chi^0$, where $\chi^0$ is a long-lived particle which decays to collimated pairs of $e^+ e^-, \mu^+ \mu^-$, or $\pi^+ \pi^-$ plus other final states. Standard Model values are assumed for the couplings of $H^0$ to ordinary particles unless otherwise stated.

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invisible particles, in 20.3 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.

5 AAD 140 search for \(pp \rightarrow H^0 \, Z \, X, \, Z \rightarrow \ell \ell\) with \(H^0\) decaying to invisible final states in 4.5 fb\(^{-1}\) at \(E_{\text{cm}} = 7\) TeV and 20.3 fb\(^{-1}\) at \(E_{\text{cm}} = 8\) TeV. See their Fig. 3 for a limit on the cross section times branching ratio for \(m_{H^0} = 110–400\) GeV.

6 CHATRCHYAN 14b search for \(pp \rightarrow H^0 \, Z \, X, \, Z \rightarrow \ell \ell\) and \(Z \rightarrow b\bar{b}\), and also \(pp \rightarrow q\bar{q}H^0 \, X\) 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 \(m_{H^0} = 100–400\) GeV.

7 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 fb\(^{-1}\) of \(pp\) collisions at \(E_{\text{cm}} = 7\) TeV. See their Fig. 7 for limits on cross section times branching ratio.

8 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 fb\(^{-1}\) of \(pp\) collisions at \(E_{\text{cm}} = 7\) TeV. See their Fig. 3 for limits on cross section times branching ratio.

9 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 fb\(^{-1}\) of \(pp\) collisions at \(E_{\text{cm}} = 7\) TeV. See their Fig. 2 for limits on cross section times branching ratio.

10 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 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.

11 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 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.

12 AALTONEN 12BH 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 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 \(m_{H^0} = (130–170)\) GeV, \(m_{X^0} = 20, 40\) GeV.

13 ABBIENDI 10 search for \(e^+ \, e^- \rightarrow H^0 \, Z\) with \(H^0\) decaying invisibly. The limit assumes SM production cross section and \(B(H^0 \rightarrow \text{invisible}) = 1\).

14 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 \(\sigma \cdot B(H^0 \rightarrow \text{invisible}) < (0.07–0.57)\) pb (95\%CL) is obtained at \(E_{\text{cm}} = 206\) GeV for \(m_{H^0} = 60–114\) GeV.

15 Search for \(e^+ \, e^- \rightarrow H^0 \, Z\) with \(H^0\) decaying invisibly. The limit assumes SM production cross section and \(B(H^0 \rightarrow \text{invisible}) = 1\).

16 ACCIARRI 00M search for \(e^+ \, e^- \rightarrow Z \, H^0\) with \(H^0\) decaying invisibly at \(E_{\text{cm}} = 183–189\) GeV. The limit assumes SM production cross section and \(B(H^0 \rightarrow \text{invisible}) = 1\). 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 \(O(10)\) GeV.

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<td>4 ABLIKIM 16e BES3</td>
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<td>6 LEES 15H BABR</td>
<td>(T(1S) \rightarrow A^0 \gamma)</td>
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https://pdg.lbl.gov
7 LEES 13c BABR \( \Upsilon(1S) \rightarrow A^0 \gamma \)
8 LEES 13l BABR \( \Upsilon(1S) \rightarrow A^0 \gamma \)
9 LEES 13r BABR \( \Upsilon(1S) \rightarrow A^0 \gamma \)
10 ABLIKIM 12 BES3 \( J/\psi \rightarrow A^0 \gamma \)
11 CHATRCHYAN 12v CMS \( A^0 \rightarrow \mu^+\mu^- \)
12 AALTONEN 11p CDF \( t \rightarrow bH^+, H^+ \rightarrow W^+ A^0 \)
13 DEL-AMO-SA... 11j BABR \( \Upsilon(1S) \rightarrow A^0 \gamma \)
14 ABOUZAID 11 f KTEV \( K_L \rightarrow \pi^0 \pi^0 A^0, A^0 \rightarrow \mu^+\mu^- \)
15 LEES 11h BABR \( \Upsilon(2S, 3S) \rightarrow A^0 \gamma \)
16 ANDREAS 10 RVUE \( b \rightarrow K^0 A^0, A^0 \rightarrow \mu^+\mu^- \)
17 HYUN 10 BELLE \( b \rightarrow K^+ A^0, A^0 \rightarrow \mu^+\mu^- \)
20 AUBERT 09p BABR \( \Upsilon(3S) \rightarrow A^0 \gamma \)
21 AUBERT 09z BABR \( \Upsilon(2S) \rightarrow A^0 \gamma \)
22 AUBERT 09z BABR \( \Upsilon(3S) \rightarrow A^0 \gamma \)
23 TUNG 09 K391 \( K_L \rightarrow \pi^0 \pi^0 A^0, A^0 \rightarrow \gamma\gamma \)
24 LOVE 08 CLEO \( \Upsilon(1S) \rightarrow A^0 \gamma \)
25 BESSON 07 CLEO \( \Upsilon(1S) \rightarrow \eta b \gamma \)
26 PARK 05 HYCP \( \Sigma^+ \rightarrow p A^0, A^0 \rightarrow \mu^+\mu^- \)
27 BALEST 95 CLEO \( \Upsilon(1S) \rightarrow A^0 \gamma \)
28 ANTreASYAN 90c CBAL \( \Upsilon(1S) \rightarrow A^0 \gamma \)

1 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 fb\(^{-1} \) of \( pp \) collisions at \( E_{cm} = 13 \) 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 \( m_{A^0} = 0.5–4.0 \) GeV, see their Table I.

2 AABoud 18AP search for the decay \( H^0 \rightarrow A^0 A^0 \rightarrow \mu^+\mu^- \mu^+\mu^- \) in 36.1 fb\(^{-1} \) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 10(b) for limits on B(\( H^0 \rightarrow A^0 A^0 \)) in the range \( m_{A^0} = 1–2.5, 4.5–8 \) GeV, assuming a type-II two-doublet plus singlet model with \( \tan(\beta) = 5 \).

3 KHACHATRYAN 17AZ search for the decay \( H^0 \rightarrow A^0 A^0 \rightarrow \pi^+\pi^-\pi^+\pi^- \), \( \mu^+\mu^- \mu^+\mu^- \) and \( \mu^+\mu^- \pi^+\pi^- \) in 19.7 fb\(^{-1} \) of \( pp \) collisions at \( E_{cm} = 8 \) TeV. See their Figs. 4, 5, and 6 for cross section limits in the range \( m_{A^0} = 5–62.5 \) 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.

4 ABLIKIM 16E search for the process \( J/\psi \rightarrow A^0 \gamma \) with \( A^0 \) decaying to \( \mu^+\mu^- \) and give limits on B(\( J/\psi \rightarrow A^0 \gamma \))B(\( A^0 \rightarrow \mu^+\mu^- \)) in the range 2.8 \times 10^{-8}–5.0 \times 10^{-6} (90% CL) for 0.212 \( \leq m_{A^0} \leq 3.0 \) GeV. See their Fig. 5.

5 KHACHATRYAN 16F search for the decay \( H^0 \rightarrow A^0 A^0 \rightarrow \pi^+\pi^-\pi^+\pi^- \) in 19.7 fb\(^{-1} \) of \( pp \) collisions at \( E_{cm} = 8 \) TeV. See their Fig. 8 for cross section limits for \( m_{A^0} = 4–8 \) GeV.

6 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(\( \Upsilon (1S) \rightarrow A^0 \gamma \))B(\( A^0 \rightarrow c\bar{c} \)) in the range 7.4 \times 10^{-5}–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.

7 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(\( \Upsilon (1S) \rightarrow A^0 \gamma \))B(\( A^0 \rightarrow \mu^+\mu^- \)) in the range (0.3–9.7) \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 \( b \rightarrow A^0 \) Yukawa coupling derived by combining this result with AUBERT 09Z.
lees 13l search for the process \( \Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^- \rightarrow A^0 \gamma \pi^+ \pi^- \) with \( A^0 \) decaying to \( gg \) or \( s \bar{s} \) and give limits on \( B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow gg) \) 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.

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 \( 0.9-13 \times 10^{-5} \) (90% CL) for \( 3.6 \leq m_{A^0} \leq 9.2 \) GeV. See their Fig. 4 for limits on the \( b-A^0 \) Yukawa coupling derived by combining this result with AUBERT 09p.

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 \( 4 \times 10^{-7} - 2.1 \times 10^{-5} \) (90% C.L.) for \( 0.212 \leq m_{A^0} \leq 3.0 \) GeV. See their Fig. 2.

chatrchyan 12v search for \( A^0 \) production in the decay \( A^0 \rightarrow \mu^+ \mu^- \) with 1.3 fb\(^{-1} \) of \( pp \) collisions at \( E_{cm} = 7 \) TeV. A limit on \( \sigma(A^0) \cdot B(A^0 \rightarrow \mu^+ \mu^-) \) in the range \( (1.5-7.5) \) pb is given for \( m_{A^0} = (5.5-8.7) \) and \( (11.5-14) \) GeV at 95% CL.

aaltonen 11p search in 2.7 fb\(^{-1} \) of \( p \bar{p} \) collisions at \( E_{cm} = 1.96 \) 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.

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.

The search was motivated by PARK 05.

del-amoresanchez 11g 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 \( B(\Upsilon(1S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow invisible) \) in the range \( (1.9-4.5) \times 10^{-6} \) (90% CL) for \( 0 \leq m_{A^0} \leq 8.0 \) GeV, and \( (2.7-37) \times 10^{-6} \) for \( 8.0 \leq m_{A^0} \leq 9.2 \) GeV.

lees 11h search for the process \( \Upsilon(2S,3S) \rightarrow A^0 \gamma \) with \( A^0 \) decaying hadronically and give limits on \( B(\Upsilon(2S,3S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow hadrons) \) 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.

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.

hyun 10 search for the decay chain \( B^0 \rightarrow K^+ A^0, A^0 \rightarrow \mu^+ \mu^- \) and give a limit on \( B(B^0 \rightarrow K^+ A^0) \cdot B(A^0 \rightarrow \mu^+ \mu^-) \) 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}.

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 \( (1.76-4.51) \times 10^{-8} \) 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}.

aubert 09p search for the process \( \Upsilon(3S) \rightarrow A^0 \gamma \) with \( A^0 \rightarrow \gamma \tau^+ \tau^- \) for \( 4.03 < m_{A^0} < 9.52 \) and \( 9.61 < m_{A^0} < 10.10 \) GeV, and give limits on \( B(\Upsilon(3S) \rightarrow A^0 \gamma) \cdot B(A^0 \rightarrow \gamma \tau^+ \tau^-) \) in the range \( (1.5-16) \times 10^{-5} \) (90% CL).

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).

https://pdg.lbl.gov
22 AUBERT 09 search for the process \( \Upsilon(3S) \to A^0 \gamma \) with \( A^0 \to \mu^+ \mu^- \) for \( 0.212 < m_{A^0} < 9.3 \) GeV and give limits on \( B(\Upsilon(3S) \to A^0 \gamma) \cdot B(A^0 \to \mu^+ \mu^-) \) in the range \((0.3-5) \times 10^{-6} \) at 90% CL.

23 TUNG 09 search for the decay chain \( K_L \to \pi^0 \pi^0 A^0, A^0 \to \gamma \) and give a limit on \( B(K_L \to \pi^0 \pi^0 A^0) \cdot B(A^0 \to \gamma) \) 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 \( 2.4 \times 10^{-7} \).

24 LOVE 08 search for the process \( \Upsilon(1S) \to A^0 \gamma \) with \( A^0 \to \mu^+ \mu^- \) (for \( m_{A^0} < 2m_\tau \)) and \( A^0 \to \tau^+ \tau^- \). Limits on \( B(\Upsilon(1S) \to A^0 \gamma) \cdot B(A^0 \to \ell^+ \ell^-) \) in the range \( 10^{-6}-10^{-4} \) (90% CL) are given.

25 BESSON 07 give a limit \( B(\Upsilon(1S) \to \eta B) \cdot B(\eta B \to \tau^+ \tau^-) < 0.27% \) (95% CL), which constrains a possible \( A^0 \) exchange contribution to the \( \eta B \) decay.

26 PARK 05 found three candidate events for \( \Sigma^+ \to \rho \mu^+ \mu^- \) 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 \( B(\Sigma^+ \to \rho A^0) \cdot B(A^0 \to \mu^+ \mu^-) = (3.1^{+2.4}_{-1.9} \pm 1.5) \times 10^{-8} \).

27 BALEST 95 give limits \( B(\Upsilon(1S) \to A^0 \gamma) \) \( i \cdot 1.5 \times 10^{-5} \) at 90% CL for \( m_{A^0} < 5 \) GeV. The limit becomes \( < 10^{-4} \) for \( m_{A^0} < 7.7 \) GeV.

28 ANTREASYAN 90 give limits \( B(\Upsilon(1S) \to A^0 \gamma) \) \( i \cdot 5.6 \times 10^{-5} \) 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 \( H^0 \) if mass < 125 GeV or \( H^0_2 \) if mass > 125 GeV. The notation \( H^0 \) is reserved for the \( 125 \) GeV particle.

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20 AABOUD 19T ATLS \( H^0_2 \rightarrow H^0 H^0 \)
21 AABOUD 19V ATLS two doublet + pseudoscalar model
22 AABOUD 19Y ATLS \( H^0_2 \rightarrow \mu^+ \mu^- \)
23 AALTONEN 19 CDF \( H^0_{1,2} \rightarrow b\bar{b} \)
24 SIRUNYAN 19 CMS \( H^0_2 \rightarrow H^0 H^0 \)
25 SIRUNYAN 19AE CMS \( A^0 \rightarrow \tau^+ \tau^- \)
26 SIRUNYAN 19AN CMS \( A^0_2 \rightarrow H^0 A^0_1 \)
27 SIRUNYAN 19AV CMS \( A^0 \rightarrow Z H^0 \)
28 SIRUNYAN 19B CMS \( H^0_{1,2} / A^0 \rightarrow b\bar{b} \)
29 SIRUNYAN 19BB CMS \( H^0_1 \rightarrow \gamma \gamma \)
30 SIRUNYAN 19BD CMS \( H^0_2 \rightarrow A^0 A^0 \)
31 SIRUNYAN 19BE CMS \( H^0_2 \rightarrow H^0 H^0 \)
32 SIRUNYAN 19BQ CMS \( H^0_{1,2} \rightarrow A^0 A^0 \)
33 SIRUNYAN 19CR CMS \( H^0_2 / A^0 \rightarrow \mu^+ \mu^- \)
34 SIRUNYAN 19H CMS \( H^0_2 \rightarrow H^0 H^0 \)
35 AABOUD 18AA ATLS \( H^0_2 \rightarrow Z \gamma \)
36 AABOUD 18AG ATLS \( H^0_2 \rightarrow A^0 A^0 \)
37 AABOUD 18AH ATLS \( A^0 \rightarrow Z H^0 \)
38 AABOUD 18AI ATLS \( A^0 \rightarrow Z H^0 \)
39 AABOUD 18BF ATLS \( H^0_2 \rightarrow ZZ \)
40 AABOUD 18BU ATLS \( H^0_2 \rightarrow H^0 H^0 \)
41 AABOUD 18BX ATLS \( H^0_2 \rightarrow A^0 A^0 \)
42 AABOUD 18CQ ATLS \( H^0_2 \rightarrow H^0 H^0 \)
43 AABOUD 18F ATLS \( H^0_2 \rightarrow W^+ W^-, ZZ \)
44 AAIJ 18AM LHCb \( H^0_{1,2} \rightarrow \mu \tau \)
45 AAIJ 18AQ LHCb \( A^0 \rightarrow \mu^+ \mu^- \)
46 AAIJ 18AQ LHCb \( H^0_0 \rightarrow A^0 A^0, A^0 \rightarrow \mu^+ \mu^- \)
47 SIRUNYAN 18AF CMS \( H^0_2 \rightarrow H^0 H^0 \)
48 SIRUNYAN 18BA CMS \( H^0_2 \rightarrow ZZ \)
49 SIRUNYAN 18CW CMS \( H^0_2 \rightarrow H^0 H^0 \)
50 SIRUNYAN 18DK CMS \( H^0_2 \rightarrow Z \gamma \)
51 SIRUNYAN 18DT CMS \( H^0_2 \rightarrow A^0 A^0 \)
52 SIRUNYAN 18DU CMS \( H^0_2 \rightarrow \gamma \gamma \)
53 SIRUNYAN 18ED CMS \( A^0 \rightarrow Z H^0 \)
54 SIRUNYAN 18EE CMS \( H^0 \rightarrow A^0 A^0 \)
55 SIRUNYAN 18F CMS \( pp, 13 \text{ TeV}, H^0_2 \rightarrow H^0 H^0 \)
56 AABOUD 17 ATLS \( H^0_2 \rightarrow Z \gamma \)
57 AABOUD 17AW ATLS \( H^0_2 \rightarrow Z \gamma \)
58 KHACHATRY...17AZ CMS \( H^0 \rightarrow A^0 A^0 \)
59 KHACHATRY...17D CMS \( pp, 8, 13 \text{ TeV}, H^0_2 \rightarrow Z \gamma \)
60 KHACHATRY...17R CMS \( H^0_2 \rightarrow \gamma \gamma \)
61 SIRUNYAN 17CN CMS \( pp, 8 \text{ TeV}, H^0_2 \rightarrow H^0 H^0 \)
62 SIRUNYAN 17Y CMS \( pp, 8, 13 \text{ TeV}, H^0_2 \rightarrow Z \gamma \)
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1 SIRUNYAN 21A search for $H_2^0 \to Z A^0$ with $Z \to \ell^+ \ell^-$, $A^0$ decaying invisibly, in 137 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.

2 AAD 20AA search for $H_0^0 / A^0 \to \tau^+ \tau^-$ produced by gluon fusion or $b$-associated production using 139 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 $m_{H_0^0}, m_{A^0} = 0.2–2.5$ TeV.

3 AAD 20AI search for $ZH^0$ production followed by the decay $H^0 \to A^0 A^0 \to b \bar{b} b \bar{b}$ in 36 fb$^{-1}$ of $pp$ collisions at $E_{\text{cm}} = 13$ TeV. The search looks for collimated $A^0 \to b \bar{b}$ decays and is complementary to AABOUD 18B. See their Fig. 10 for limits on the product of production cross section and branching ratios in the range $m_{A^0} = 15–30$ GeV.

4 AAD 20AO search for gluon fusion production of $H_2^0$ decaying to $H^0 H^0 \to \tau^+ \tau^- b \bar{b}$ (with hadronically decaying $\tau^+ \tau^-$) using 139 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 28–817 fb (95% CL) is given for $m_{A^0} = 1.0–3.0$ TeV, see their Fig. 13.

5 AAD 20C combine searches for a scalar resonance decaying to $H^0 H^0$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{\text{cm}} = 13$ 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 $m_{H_2^0} = 0.26–3$ TeV.

6 AAD 20L search for $b$-associated production of $H_2^0$ decaying to $b \bar{b}$ in 27.8 fb$^{-1}$ of $pp$ collisions at $E_{\text{cm}} = 13$ TeV. See their Fig. 8 for limits on the product of cross section and branching ratio for $m_{H_2^0} = 0.45–1.4$ TeV.

7 AAD 20X search for vector-boson-fusion production of $H_2^0$ decaying to $H^0 H^0$ using 126 fb$^{-1}$ of $pp$ collisions at $E_{\text{cm}} = 13$ 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.

8 AAIJ 20A search for dimuon resonance in the mass range 0.2–60 GeV in 5.1 fb$^{-1}$ of $pp$ collisions at $E_{\text{cm}} = 13$ TeV, in inclusive and $b$ quark associated production. Displaced decays are searched for for masses below 3 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).

9 SIRUNYAN 20 search for the decay $H^0 \to A^0 A^0 \to \tau^+ \tau^- \tau^+ \tau^-$ or $\tau^+ \tau^- \mu^+ \mu^-$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{\text{cm}} = 13$ TeV. See their Fig. 10 for limits on the product of production cross section (normalized to the SM) and branching ratios in the range $m_{A^0} = 4–15$ GeV.

10 SIRUNYAN 20AA search for $H_2^0 \to Z A^0$, $A^0 \to b \bar{b}$ or $A^0 \to Z H_0^0$, $H_0^0 \to b \bar{b}$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{\text{cm}} = 13$ TeV. See their Fig. 7 for limits on the product of cross section and branching ratio for $m_{H_2^0} = 0.12–1$ TeV and $m_{A^0} = 0.03–1$ TeV.
11 SIRUNYAN 20AC search for gluon-fusion production of $A^0$ decaying to $ZH^0$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 5 for limits on the product of cross section and branching ratios for $m_{A^0} = 220$–400 GeV.

12 SIRUNYAN 20AD search for lepton-flavor violating decays $H^0_2 \rightarrow \mu \tau$, $e \tau$ of gluon-fusion-produced $H^0_2$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 5 (9) and Table 5 (6) for limits on production cross section times branching ratio for $m_{H^0_2} = 0.2$–0.9 TeV for the $\mu \tau$ ($e \tau$) final state.

13 SIRUNYAN 20AF search for $H^0_2/A^0 \rightarrow t\bar{t}$ with one or two charged leptons in the final state using kinematic variables in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Figs. 5 and 6 for limits on top Yukawa coupling of $H^0_2$ and $A^0$ for $m_{H^0_2}$, $m_{A^0} = 0.4$–0.75 TeV for various width assumptions.

14 SIRUNYAN 20AP search for the decay $H^0$ or $H^0_2 \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- \tau^+ \tau^-$ (for $m_{H^0}$ = 300 GeV) with boosted final-state topology in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 7 for limits on the product of production cross section (normalized to the SM) and branching ratios in the range $m_{A^0} = 3.6$–21 GeV, and Figs. 8 and 9 for its interpretation in terms of models with two Higgs doublets plus a singlet.

15 SIRUNYAN 20Y search for gluon-fusion and vector-boson-fusion production of $H^0_2$ decaying to $W^+W^-$ in the final states $\ell\nu\ell\nu$ and $\ell\nu q\bar{q}$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 6 for limits on the product of cross section and branching ratio for $m_{H^0_2} = 0.2$–3 TeV.

16 SIRUNYAN 20z search for $H^0_{1,2}$ or $A^0$ production in association with a $t\bar{t}$ pair, decaying to $e^+e^-$ or $\mu^+\mu^-$, in 137 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 12 for limits on production cross section times branching ratio for $m_{H^0_{1,2}}$, $m_{A^0} = 15$–75 GeV and 108–340 GeV.

17 AABOUD 19A search for a narrow scalar resonance decaying to $H^0 H^0 \rightarrow b\bar{b}b\bar{b}$ in 27.5–36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 9(a) for limits on cross section times branching ratios for $m_{H^0} = 0.26$–3 TeV.

18 AABOUD 19AG search for the decay $H^0 \rightarrow A^0 A^0 \rightarrow \mu^+\mu^- b\bar{b}$ in 36.7 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ 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 $m_{A^0} = 20$–60 GeV.

19 AABOUD 19o search for a scalar resonance decaying to $H^0 H^0 \rightarrow b\bar{b}WW$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 12 (left) for limits on cross section times branching ratio for $m_{H^0} = 0.5$–3 TeV.

20 AABOUD 19t search for a scalar resonance decaying to $H^0 H^0 \rightarrow WW^* WW^*$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 3 for limits on cross section times branching ratio for $m_{H^0} = 260$–500 GeV, assuming SM decay rates for the $H^0$.

21 AABOUD 19v combine published ATLAS data to constrain two-Higgs-doublet plus singlet pseudoscalar model with $A^0_1$ decaying to invisible final states. See their Fig. 19 for excluded parameter regions.

22 AABOUD 19y search for a narrow scalar resonance produced by gluon fusion or $b$ associated production, decaying to $\mu^+\mu^-$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Figs. 4 and 5(a) for cross section limits for $m_{H^0} = 0.2$–1.0 TeV.
23 AALTONEN 19 search for b associated production of a scalar particle decaying to b¯¯b in 5.4 fb$^{-1}$ of pp collisions at $E_{cm} = 1.96$ TeV. See their Fig. 3 for limits on cross section times branching ratio for $m_{H_{1,2}}^{0} =$ 100–300 GeV.

24 SIRUNYAN 19 search for a narrow scalar resonance decaying to $H^{0}H^{0} \rightarrow \gamma\gamma b\overline{b}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 9 (left) for limits on cross section times branching ratios for $m_{H_{0}}^{0} =$ 260–900 GeV.

25 SIRUNYAN 19AE search for a scalar resonance produced in association with a b¯¯b pair, decaying to $\tau^{+}\tau^{-}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 4 for cross section limits for $m_{A_{0}}^{0} =$ 25–70 GeV.

26 SIRUNYAN 19AN search for production of $A_{0}^{0}$ decaying to $H^{0}A_{1}^{0}$ followed by $H^{0} \rightarrow b\overline{b}$, $A_{1}^{0} \rightarrow$ invisible in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV, in the mass range $m_{A_{0}^{0}} = 0.2–1.6$ TeV, $m_{A_{1}^{0}} = 0.15–0.5$ TeV. See their Fig. 6 for limits in terms of two-Higgs-doublet plus singlet pseudoscalar model.

27 SIRUNYAN 19AV search for a scalar resonance produced by gluon fusion or b-associated production, decaying to $ZH^{0} \rightarrow \ell^{+}\ell^{-}b\overline{b}$ ($\ell = e, \mu$) or $\nu\overline{\nu}b\overline{b}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 5 for cross section limits for $m_{A_{0}^{0}} =$ 0.22–1.0 TeV.

28 SIRUNYAN 19B search for gluon fusion production of narrow scalar resonance with large transverse momentum, decaying to b¯¯b, in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Figs. 7 and 8 for limits on cross section times branching ratio for the resonance mass of 50–350 GeV.

29 SIRUNYAN 19BB search for the decay $H_{1}^{0} \rightarrow \gamma\gamma$ in 19.7 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV and 35.9 fb$^{-1}$ at $E_{cm} = 13$ TeV. See their Figs. 4–6 for limits on cross section times branching ratio for $m_{H_{1}^{0}} =$ 80–110 GeV (some results in Fig. 5 for $m_{H_{1}^{0}} =$ 70–110 GeV).

30 SIRUNYAN 19BD search for the decay $H^{0} \rightarrow A_{0}^{0}A_{0}^{0} \rightarrow \mu^{+}\mu^{-}b\overline{b}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 5 for limits on the product of cross section times branching ratios in the range $m_{A_{0}^{0}} =$ 20–62.5 GeV. See also their Figs. 6 and 7 for interpretation of the data in terms of models with two Higgs doublets and a singlet.

31 SIRUNYAN 19BE combine searches for $H_{2}^{0} \rightarrow H^{0}H^{0}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV in various $H^{0}$ 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 $m_{H_{2}^{0}} =$ 0.25–3 TeV.

32 SIRUNYAN 19BQ search for production of $H_{1,2}^{0}$ decaying to $A_{0}^{0}A_{0}^{0} \rightarrow \mu^{+}\mu^{-}\mu^{+}\mu^{-}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 2 for limits on cross section times branching ratio for $m_{H_{1,2}^{0}} =$ 90–150 GeV, $m_{A_{0}^{0}} =$ 0.25–3.55 GeV.

33 SIRUNYAN 19CR search for production of $H_{2}^{0}/A_{0}^{0}$ in gluon fusion and in association with a b¯¯b pair, decaying to $\mu^{+}\mu^{-}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 6 for limits on cross section times branching ratio.

34 SIRUNYAN 19H search for a narrow scalar resonance decaying to $H^{0}H^{0} \rightarrow b\overline{b}b\overline{b}$ in 35.9 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV, where one b¯¯b pair is resolved and the other not. Limits on cross section times branching ratios for $m_{H_{2}^{0}} =$ 0.75–1.6 TeV are obtained and combined with data from SIRUNYAN 18AF. See their Fig. 5 (right).

35 AABOUD 18AA search for production of a scalar resonance decaying to $Z\gamma$, with $Z$ decaying hadronically, in 36.1 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 8(a) for limits on cross section times branching ratio for $m_{H_{2}^{0}} =$ 1.0–6.8 TeV.
36 AABOUD 18AG search for the decay $H^0 \rightarrow A^0 A^0 \rightarrow \gamma \gamma g g$ in 36.7 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 2 and Table 6 for cross section limits in the range $m_{A^0} = 20$–60 GeV.

37 AABOUD 18AH search for production of an $A^0$ in gluon-gluon fusion and in association with a $b\bar{b}$, decaying to $Z H_2^0 \rightarrow \ell^+ \ell^- b\bar{b}$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 5 for cross section limits for $m_{A^0} = 230$–800 GeV and $m_{H_2^0} = 130$–700 GeV.

38 AABOUD 18AI search for production of an $A^0$ in gluon-gluon fusion and in association with a $b\bar{b}$, decaying to $Z H_2^0$ in the final states $\nu \pi b\bar{b}$ and $\ell^+ \ell^- b\bar{b}$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 6 for cross section limits for $m_{A^0} = 0.2$–2 TeV. See also AABOUD 18CC.

39 AABOUD 18BF search for production of a heavy $H_2^0$ state decaying to $Z Z$ in the final states $\ell^+ \ell^- \ell^+ \ell^-$ and $\ell^+ \ell^- \nu \tau$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 6 for upper limits on cross section times branching ratio for $m_{H_2^0} = 0.2$–1.2 TeV assuming ggF or VBF with the NWA. See their Fig. 7 for upper limits on cross section times branching ratio for $m_{H_2^0} = 0.4$–1.0 TeV assuming ggF, and with several assumptions on its width.

40 AABOUD 18BU search for a narrow scalar resonance decaying to $H^0 H^0 \rightarrow \gamma \gamma W^+ W^*$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 4 for limits on cross section times branching ratios for $m_{H_2^0} = 260$–500 GeV.

41 AABOUD 18BX search for associated production of $W H^0$ or $Z H^0$ followed by the decay $H^0 \rightarrow A^0 A^0 \rightarrow b\bar{b} b\bar{b}$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 9 for limits on cross section times branching ratios for $m_{A^0} = 20$–60 GeV. See also their Fig. 10 for the dependence of the limit on $A^0$ lifetime.

42 AABOUD 18CG search for a narrow scalar resonance decaying to $H^0 H^0 \rightarrow b\bar{b} \tau^+ \tau^-$ in 36.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 2 (above) for limits on cross section times branching ratios for $m_{H_2^0} = 260$–1000 GeV.

43 AABOUD 18F search for production of a narrow scalar resonance decaying to $W^+ W^-$ and $Z Z$, followed by hadronic decays of $W$ and $Z$, in 36.7 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 5(c) for limits on cross section times branching ratio for $m_{H_2^0} = 1.2$–3.0 TeV.

44 AAIJ 18AM search for gluon-fusion production of $H_{1,2}^0$ decaying to $\mu \tau$ in 2 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV. See their Fig. 2 for limits on cross section times branching ratio for $m_{H_{1,2}^0} = 45$–195 GeV.

45 AAIJ 18AQ search for gluon-fusion production of a scalar particle $A^0$ decaying to $\mu^+ \mu^-$ in 1.99 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV and 0.98 fb$^{-1}$ at $E_{cm} = 7$ TeV. See their Fig. 4 for limits on cross section times branching ratio for $m_{A^0} = 5.5$–15 GeV (using the $E_{cm} = 8$ TeV data set).

46 AAIJ 18AQ search for the decay $H^0 \rightarrow A^0 A^0$, with one of the $A^0$ decaying to $\mu^+ \mu^-$. in 1.99 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV and 0.98 fb$^{-1}$ at $E_{cm} = 7$ TeV. See their Fig. 5 (right) for limits on the product of branching ratios for $m_{A^0} = 5.5$–15 GeV (using the $E_{cm} = 8$ TeV data set).

47 SIRUNYAN 18AF search for a narrow scalar resonance decaying to $H^0 H^0 \rightarrow b\bar{b} b\bar{b}$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV, where both $b\bar{b}$ pairs are not resolved. See their Fig. 9 for limits on cross section times branching ratios for $m_{H_2^0} = 0.75$–3 TeV.

48 SIRUNYAN 18BA search for production of a heavy $H_2^0$ state decaying to $Z Z$ in the final states $\ell^+ \ell^- \ell^+ \ell^-, \ell^+ \ell^- q\bar{q}$, and $\ell^+ \ell^- \nu \tau$ in 35.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 13$ TeV. See their Fig. 7 for upper limits on cross section times branching ratio for $m_{H_2^0} = 0.4$–1.0 TeV assuming ggF, and with several assumptions on its width.
13 TeV. See their Figs. 10 and 11 for upper limits on cross section times branching ratio for \( m_{H^0} = 0.13–3 \) TeV with several assumptions on its width and on the fraction of Vector-Boson-Fusion of the total production cross section.

49 SIRUNYAN 18CW search for a narrow scalar resonance decaying to \( H^0 H^0 \to b\bar{b}b\bar{b} \) in 35.9 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV, where both \( b\bar{b} \) pairs are resolved. See their Fig. 9 for limits on cross section times branching ratios for \( m_{H^0} = 260–1200 \) GeV.

50 SIRUNYAN 18DK search for production of a scalar resonance decaying to \( Z\gamma \), with \( Z \) decaying to \( e^+e^- \) or hadronically, in 35.9 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 7 for limits on cross section times branching ratio for \( m_{H^0} = 0.35–4 \) TeV for different assumptions on the width of the resonance.

51 SIRUNYAN 18DT search for the decay \( H^0 \to A^0 A^0 \to \tau^+\tau^- b\bar{b} \) in 35.9 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 7 for limits on the product of branching ratios in the range \( m_{A^0} = 15–60 \) GeV. See also their Fig. 7 for interpretation of the data in terms of models with two Higgs doublets and a singlet.

52 SIRUNYAN 18DU search for production of a narrow scalar resonance decaying to \( \gamma\gamma \) in 35.9 fb\(^{-1}\) (taken in 2016) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 3 (right) for limits on cross section times branching ratio for \( m_{H^0} = 0.5–5 \) TeV for several values of its width-to-mass ratio.

53 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 \( e^+e^- b\bar{b} \) in 35.9 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 8 for cross section limits for \( m_{A^0} = 0.8–2 \) TeV.

54 SIRUNYAN 18EE search for the decay \( H^0 \to A^0 A^0 \to \mu^+\mu^- \tau^+\tau^- \) in 35.9 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 4 for limits on the product of branching ratios in the range \( m_{A^0} = 15–62.5 \) 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.

55 SIRUNYAN 18F search for a narrow scalar resonance decaying to \( H^0 \mu^0 \to WW b\bar{b} \) or \( ZZ b\bar{b} \) in the final state \( \ell\ell\nu\nu b\bar{b} \) in 35.9 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 7 for limits on cross section times branching ratios for \( m_{H^0} = 250–900 \) GeV.

56 AABOUD 17 search for production of a scalar resonance decaying to \( Z\gamma \) in 3.2 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 4 for the limits on cross section times branching ratio for \( m_{H^0} = 0.25–3.0 \) TeV.

57 AABOUD 17AW search for production of a scalar resonance decaying to \( Z\gamma \) in 36.1 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 7 for limits on cross section times branching ratio for \( m_{H^0} = 0.25–2.4 \) TeV.

58 KHACHATRYAN 17AZ search for the decay \( H^0 \to A^0 A^0 \to \tau^+\tau^- \), \( \mu^+\mu^- \) or \( b\bar{b} \), and \( \mu^+\mu^- \) or \( b\bar{b} \) in 19.7 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 8 \) TeV. See their Figs. 4, 5, and 6 for cross section limits in the range \( m_{A^0} = 5–62.5 \) GeV. See also their Figs. 7, 8, 9 and 10 for interpretation of the data in terms of models with two Higgs doublets.

59 KHACHATRYAN 17D search for production of a scalar resonance decaying to \( Z\gamma \) in 19.7 fb\(^{-1}\) of \( pp \) collisions at \( E_{cm} = 8 \) TeV and 2.7 fb\(^{-1}\) at \( E_{cm} = 13 \) TeV. See their Figs. 3 and 4 for the limits on cross section times branching ratio for \( m_{H^0} = 0.2–2.0 \) TeV.

60 KHACHATRYAN 17R search for production of a narrow scalar resonance decaying to \( \gamma\gamma \) in 12.9 fb\(^{-1}\) (taken in 2016) of \( pp \) collisions at \( E_{cm} = 13 \) TeV. See their Fig. 2 for limits on cross section times branching ratio for \( m_{H^0} = 0.5–4.5 \) TeV for several values of its width-to-mass ratio. Limits from combination with KHACHATRYAN 16M are shown in their Figs. 4 and 6.
61 SIRUNYAN 17CN search for a narrow scalar resonance decaying to $H^0 H^0 \rightarrow b \bar{b} \tau^+ \tau^-$ in 18.3 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV. See their Fig. 5 (above) and Table II for limits on the cross section times branching ratios for $m_{H^0_2} = 0.3$–1 TeV, and Fig. 6 (above) and Table III for the corresponding limits by combining with data from KHACHATRYAN 16BG and KHACHATRYAN 15R.

62 SIRUNYAN 17Y search for production of a scalar resonance decaying to $Z \gamma$ in 19.7 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV and 2.7 fb$^{-1}$ at $E_{cm} = 13$ TeV. See their Figs. 3, 4 and Table 3 for limits on cross section times branching ratio for $m_{H^0_2} = 0.7$–3.0 TeV, and Fig. 5 for the corresponding limits for $m_{H^0_2} = 0.2$–3.0 TeV from combination with KHACHATRYAN 17D data.

63 AABOUD 16AB search for associated production of $WH^0$ with the decay $H^0 \rightarrow A^0 A^0 \rightarrow b \bar{b} b \bar{b}$ in 3.2 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 8 for limits on cross section times branching ratios for $m_{A^0} = 20$–60 GeV.

64 AABOUD 16AE search for production of a narrow scalar resonance decaying to $W^+ W^-$ and $Z Z$ in 3.2 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 4 for limits on cross section times branching ratio for $m_{H^0_2} = 0.5$–3 TeV.

65 AABOUD 16H search for production of a scalar resonance decaying to $\gamma\gamma$ in 3.2 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 12 for limits on cross section times branching ratio for $m_{H^0_2} = 0.2$–2 TeV with different assumptions on the width.

66 AABOUD 16I search for a narrow scalar resonance decaying to $H^0 H^0 \rightarrow b \bar{b} b \bar{b}$ in 3.2 fb$^{-1}$ of pp collisions at $E_{cm} = 13$ TeV. See their Fig. 10(c) for limits on cross section times branching ratios for $m_{H^0_2} = 0.5$–3 TeV.

67 AAD 16AX search for production of a heavy $H^0$ state decaying to $Z Z$ 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 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV. See their Fig. 12 for upper limits on $\sigma(H^0) B(H^0 \rightarrow Z Z)$ for $m_{H^0}$ ranging from 140 GeV to 1000 GeV.

68 AAD 16c search for production of a heavy $H^0$ state decaying to $W^+ W^-$ in the final states $\ell \nu \ell \nu$ and $\ell \nu q q$ in 20.3 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV. See their Figs. 12, 13, and 16 for upper limits on $\sigma(H^0) B(H^0 \rightarrow W^+ W^-)$ for $m_{H^0}$ ranging from 300 GeV to 1000 or 1500 GeV with various assumptions on the total width of $H^0$.

69 AAD 16d search for the decay $H^0 \rightarrow A^0 A^0 \rightarrow \gamma \gamma \gamma \gamma$ in 20.3 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV. See their Fig. 4 (upper right) for limits on cross section times branching ratios (normalized to the SM $H^0$ cross section) for $m_{A^0} = 10$–60 GeV.

70 AAD 16e search for the decay $H^0_2 \rightarrow A^0 A^0 \rightarrow \gamma \gamma \gamma \gamma$ in 20.3 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV. See their Fig. 4 (lower right) for limits on cross section times branching ratios for $m_{H^0_2} = 600$ GeV and $m_{A^0} = 10$–245 GeV, and Table 5 for limits for $m_{H^0_2} = 300$ and 900 GeV.

71 AALTONEN 16c search for electroweak associated production of $H^0_1 H^\pm$ followed by the decays $H^\pm \rightarrow H^0_1 W^\mp$, $H^0_1 \rightarrow \gamma \gamma$ for $m_{H^0_1} = 10$–105 GeV and $m_{H^\pm} = 30$–300 GeV. See their Fig. 3 for excluded parameter region in a two-doublet model in which $H^0_1$ has no direct decay to fermions.

72 KHACHATRYAN 16BG search for a narrow scalar resonance decaying to $H^0_1 H^0_2 \rightarrow b \bar{b} b \bar{b}$ in 19.7 fb$^{-1}$ of pp collisions at $E_{cm} = 8$ TeV. See their Fig. 6 for limits on the cross section times branching ratios for $m_{H^0_2} = 1.15$–3 TeV.
73 KHACHATRYAN 16BQ search for a resonance decaying to $H^0 H^0 \rightarrow \gamma \gamma b \bar{b}$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 9 for limits on the cross section times branching ratios for $m_{H^0} = 0.26$–1.1 TeV.

74 KHACHATRYAN 16F search for the decay $H^0 \rightarrow H_1^0 H_1^0 \rightarrow \tau^+ \tau^- \tau^+ \tau^-$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 8 for cross section limits for $m_{H_1^0}$ in 4–8 GeV.

75 KHACHATRYAN 16M search for production of a narrow resonance decaying to $\gamma \gamma$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV and 3.3 fb$^{-1}$ at $E_{cm} = 13$ TeV. See their Fig. 3 (top) for limits on cross section times branching ratio for $m_{H_2^0}$ = 0.5–4 TeV.

76 KHACHATRYAN 16P search for gluon fusion production of an $H_2^0$ decaying to $H^0 H^0 \rightarrow b \bar{b} \tau^+ \tau^-$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 8 (lower right) for cross section limits for $m_{H_2^0} = 260$–350 GeV.

83 AAD 15BK search for production of a heavy $H_2^0$ decaying to $H^0 H^0$ in the final state $b \bar{b} \tau^+ \tau^-$ in 19.5 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 14(c) for $\sigma(H_2^0) B(H_2^0 \rightarrow H^0 H^0)$ for $m_{H_2^0} = 500$–1500 GeV with $\Gamma_{H_2^0} = 1$ GeV.

77 KHACHATRYAN 16P search for gluon fusion production of an $A^0$ decaying to $Z H^0 \rightarrow \ell^+ \ell^- \tau^+ \tau^-$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 10 for cross section limits for $m_{H_2^0} = 220$–350 GeV.

78 AAD 15BK search for production of a heavy $H_2^0$ decaying to $H^0 H^0$ in the final state $b \bar{b} \tau^+ \tau^-$ in 19.5 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 14(c) for $\sigma(H_2^0)$ $B(H_2^0 \rightarrow H^0 H^0)$ for $m_{H_2^0} = 500$–1500 GeV with $\Gamma_{H_2^0} = 1$ GeV.

79 AAD 15BZ search for the decay $H^0 \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- \tau^+ \tau^-$ ($m_{H^0} = 125$ GeV) in 20.3 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 6 for limits on cross section times branching ratio for $m_{A^0} = 3.7$–50 GeV.

80 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 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 6 for limits on cross section times branching ratio for $m_{H_2^0} = 100$–500 GeV and $m_{A^0} = 5$ GeV.

81 AAD 15CE search for production of a heavy $H_2^0$ decaying to $H^0 H^0$ in the final states $b \bar{b} \tau^+ \tau^-$ and $\gamma \gamma W^+ W^-$ in 20.3 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV and combine with data from AAD 15H and AAD 15BK. A limit $\sigma(H_2^0) B(H_2^0 \rightarrow H^0 H^0) < 2.1$–0.011 pb (95% CL) is given for $m_{H_2^0} = 260$–1000 GeV. See their Fig. 6.

82 AAD 15H search for production of a heavy $H_2^0$ decaying to $H^0 H^0$ in the finalstate $\gamma \gamma b \bar{b}$ in 20.3 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. A limit $\sigma(H_2^0) B(H_2^0 \rightarrow H^0 H^0) < 3.5$–0.7 pb is given for $m_{H_2^0} = 260$–500 GeV at 95% CL. See their Fig. 3.

83 AAD 15s search for production of $A^0$ decaying to $Z H^0 \rightarrow \ell^+ \ell^- b \bar{b}$, $\nu \bar{\nu} b \bar{b}$ and $\ell^+ \ell^- \tau^+ \tau^-$ in 20.3 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 3 for cross section limits for $m_{A^0} = 200$–1000 GeV.

84 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 $Z Z$ in up to 5.1 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 7$ TeV and up to 19.7 fb$^{-1}$ at $E_{cm} = 8$ TeV in the range $m_{H_2^0} = 145$–1000 GeV. See their Figs. 8 and 9 for limits in the parameter space of the model.

85 KHACHATRYAN 15BB search for production of a resonance $H^0$ decaying to $\gamma \gamma$ in 19.7 fb$^{-1}$ of $p p$ collisions at $E_{cm} = 8$ TeV. See their Fig. 7 for limits on cross section times branching ratio for $m_{H^0} = 150$–850 GeV.
86 KHACHATRYAN 15N search for production of $A^0$ decaying to $ZH^0 \rightarrow \ell^+ \ell^- b\bar{b}$ in 19.7 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV. See their Fig. 3 for limits on cross section times branching ratios for $m_{A^0} = 225–600$ GeV.

87 KHACHATRYAN 15O search for production of a high-mass narrow resonance $A^0$ decaying to $ZH^0 \rightarrow q\bar{q} \tau^+ \tau^-$ in 19.7 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV. See their Fig. 6 for limits on cross section times branching ratios for $m_{A^0} = 800–2500$ GeV.

88 KHACHATRYAN 15R search for a narrow scalar resonance decaying to $H^0 H^0 \rightarrow b\bar{b} b\bar{b}$ in 17.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV. See their Fig. 5 (top) for limits on cross section times branching ratios for $m_{H^0} = 0.27–1.1$ TeV.

89 AAD 14AP search for a second $H^0$ state decaying to $\gamma\gamma$ in addition to the state at about 125 GeV in 20.3 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV. See their Fig. 4 for limits on cross section times branching ratio for $m_{H^0} = 65–600$ GeV.

90 AAD 14M search for the decay cascade $H^0_2 \rightarrow H^\pm W^\mp \rightarrow H^0 W^\pm W^\mp$, $H^0$ decaying to $b\bar{b}$ in 20.3 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 8$ TeV. See their Table III for limits on cross section times branching ratio for $m_{H^0_2} = 325–1025$ GeV and $m_{H^0} = 225–925$ GeV.

91 CHATRCHYAN 14G search for a second $H^0$ state decaying to $WW(\ast)$ in addition to the observed signal at about 125 GeV using 4.9 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ TeV and 19.4 fb$^{-1}$ at $E_{cm} = 8$ TeV. See their Fig. 21 (right) for cross section limits in the mass range 110–600 GeV.

92 KHACHATRYAN 14P search for a second $H^0$ state decaying to $\gamma\gamma$ in addition to the observed signal at about 125 GeV using 5.1 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ TeV and 19.7 fb$^{-1}$ at $E_{cm} = 8$ TeV. See their Figs. 27 and 28 for cross section limits in the mass range 110–150 GeV.

93 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 $H^0$ via the decay chain $H^\ast/0 \rightarrow H^\pm W^\mp$, $H^\pm \rightarrow W^\pm H_0$, $H_0 \rightarrow b\bar{b}$ in the final state $\ell\nu$ plus 4 jets in 8.7 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 1.96$ TeV. See their Fig. 4 for limits on cross section times branching ratio in the $m_{H^\pm} - m_{H^0}$ plane for $m_{H^0} = 126$ GeV.

94 CHATRCHYAN 13Bj search for $H^0$ production in the decay chain $H_0 \rightarrow A^0 A^0$, $A^0 \rightarrow \mu^+ \mu^-$ in 5.3 fb$^{-1}$ of $pp$ collisions at $E_{cm} = 7$ TeV. See their Fig. 2 for limits on cross section times branching ratio.

95 AALTONEN 11P search in 2.7 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{cm} = 1.96$ 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.

96 ABBIENDI 10 search for $e^+ e^- \rightarrow ZH^0$ with the decay chain $H^0 \rightarrow \chi^0_1 \chi^0_2$, $\chi^0_1 \rightarrow \chi^{\ast}_1 + (\gamma$ or $Z^\ast)$, when $\chi^0_1$ and $\chi^0_2$ are nearly degenerate. For a mass difference of 2 (4) GeV, a lower limit on $m_{H^0}$ of 108.4 (107.0) GeV (95% CL) is obtained for SM $Z H^0$ cross section and $B(H^0 \rightarrow \chi^0_1 \chi^0_2) = 1$.

97 SCHAEF 10 search for the process $e^+ e^- \rightarrow H^0 Z$ followed by the decay chain $H^0 \rightarrow A^0 A^0 \rightarrow \tau^+ \tau^-$ with $Z \rightarrow \ell^+ \ell^-$, $\nu\bar{\nu}$ at $E_{cm} = 183–209$ GeV. For a $H^0 Z Z$ coupling equal to the SM value, $B(H^0 \rightarrow A^0 A^0) = B(A^0 \rightarrow \tau^+ \tau^-) = 1$, and $m_{A^0}$ = 4–10 GeV, $m_{H^0}$ up to 107 GeV is excluded at 95% CL.

98 ABZOV 09V search for $H^0$ production followed by the decay chain $H^0 \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ or $\mu^+ \mu^- \tau^+ \tau^-$ in 4.2 fb$^{-1}$ of $p\bar{p}$ collisions at $E_{cm} = 1.96$ TeV. See their Fig. 3 for limits on $\sigma(H^0) B(H^0 \rightarrow A^0 A^0)$ for $m_{A^0} = 3.6–19$ GeV.
99 ABBIENDI 05A search for $e^+ e^- \to H_1^0 A_1^0$ in general Type-II two-doublet models, with decays $H_1^0, A_1^0 \to q\overline{q}, g g, \tau^+ \tau^-$, and $H_1^0 \to A_0^0 A_0^0$.

100 ABBIENDI 04K search for $e^+ e^- \to H_0^0 Z$ with $H_0^0$ decaying to two jets of any flavor including $g g$. The limit is for SM production cross section with $B(H_0^0 \to jj) = 1$.

101 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.

102 ACHARD 04B search for $e^+ e^- \to H_0^0 Z$ with $H_0^0$ decaying to $b\overline{b}, c\overline{c}, g g$. The limit is for SM production cross section with $B(H_0^0 \to jj) = 1$.

103 ACHARD 04F search for $H_0^0$ with anomalous coupling to gauge boson pairs in the processes $e^+ e^- \to H_0^0 \gamma, e^+ e^- H_0^0, H_0^0 Z$ with decays $H_0^0 \to fT, \gamma\gamma, Z\gamma$, and $W^+ W^-$ at $E_{cm} = 189-209$ GeV. See paper for limits.

104 ABBIENDI 03F search for $H_0^0$ anywhere in $e^+ e^- \to H_0^0 Z$, using the recoil mass spectrum of $Z \to e^+ e^-$ or $\mu^+ \mu^-$. In addition, it searched for $Z \to \nu\overline{\nu}$ and $H_0^0 \to e^+ e^-$ or photons. Scenarios with large width or continuum $H_0^0$ mass distribution are considered. See their Figs. 11–14 for the results.

105 ABBIENDI 03C search for $e^+ e^- \to H_1^0 Z$ followed by $H_1^0 \to A_0^0 A_0^0, A_0^0 \to c\overline{c}, g g, \text{ or } \tau^+ \tau^-$ in the region $m_{H_1^0} = 45-86$ GeV and $m_{A_1^0} = 2-11$ GeV. See their Fig. 7 for the limits.

106 Search for associated production of a $\gamma\gamma$ resonance with a $Z$ boson, followed by $Z \to q\overline{q}, \ell^+ \ell^-$, or $\nu\overline{\nu}$, at $E_{cm} \leq 209$ GeV. The limit is for a $H_0^0$ with SM production cross section and $B(H_0^0 \to fT) = 0$ for all fermions $f$.

107 For $B(H_0^0 \to \gamma\gamma) = 1$, $m_{H_0^0} > 113.1$ GeV is obtained.

108 HEISTER 02M search for $e^+ e^- \to H_0^0 Z$, assuming that $H_0^0$ decays to $q\overline{q}, g g$, or $\tau^+ \tau^-$ only. The limit assumes SM production cross section.

109 ABBIENDI 01E search for neutral Higgs bosons in general Type-II two-doublet models, at $E_{cm} \leq 189$ GeV. In addition to usual final states, the decays $H_1^0, A_0^0 \to q\overline{q}, g g$ are searched for. See their Figs. 15,16 for excluded regions.

110 ACCIARRI 00R search for $e^+ e^- \to H_0^0 \gamma$ with $H_0^0 \to b\overline{b}, Z\gamma$, 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.

111 ACCIARRI 00R search for the two-photon type processes $e^+ e^- \to e^+ e^- H_0^0$ with $H_0^0 \to b\overline{b}$ or $\gamma\gamma$. See their Fig. 4 for limits on $\Gamma(H_0^0 \to \gamma\gamma) \cdot B(H_0^0 \to \gamma\gamma$ or $b\overline{b})$ for $m_{H_0^0} = 70-170$ GeV.

112 GONZALEZ-GARCIA 98b use DØ limit for $\gamma\gamma$ events with missing $E_T$ in $p\overline{p} \to ZH$ collisions (ABBOTT 98) to constrain possible $ZH$ or $WH$ production followed by unconventional $H \to \gamma\gamma$ decay which is induced by higher-dimensional operators. See their Figs. 1 and 2 for limits on the anomalous couplings.

113 KRAWCZYK 97 analyse the muon anomalous magnetic moment in a two-doublet Higgs model (with type II Yukawa couplings) assuming no $H_1^0 ZZ$ coupling and obtain $m_{H_1^0} \sim m_{A_0^0} \sim 5$ GeV or $m_{A_0^0} \sim 5$ GeV for $\tan\beta > 50$. Other Higgs bosons are assumed to be much heavier.

114 ALEXANDER 96H give $B(Z \to H_0^0 \gamma) \cdot B(H_0^0 \to q\overline{q}) < 1-4 \cdot 10^{-5}$ (95%CL) and $B(Z \to H_0^0 \gamma) \cdot B(H_0^0 \to b\overline{b}) < 0.7-2 \cdot 10^{-5}$ (95%CL) in the range $20 < m_{H_0^0} < 80$ GeV.
SEARCHES FOR A HIGGS BOSON WITH STANDARD MODEL COUPLINGS

These listings are based on experimental searches for a scalar boson whose couplings to $W$, $Z$ and fermions are precisely those of the Higgs boson predicted by the three-generation Standard Model with the minimal Higgs sector.

For a review and a bibliography, see the review on “Status of Higgs Boson Physics.”

Indirect Mass Limits for $H^0$ from Electroweak Analysis

The mass limits shown below apply to a Higgs boson $H^0$ with Standard Model couplings whose mass is a priori unknown.

For limits obtained before the direct measurement of the top quark mass, see the 1996 (Physical Review D54 1 (1996)) Edition of this Review. Other studies based on data available prior to 1996 can be found in the 1998 Edition (The European Physical Journal C3 1 (1998)) of this Review.

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<td>129 $^{+74}_{-49}$</td>
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1 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.

2 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.

3 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.

4 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.

5 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 $\Delta a^{(5)}_{\text{had}}(m_Z) = 0.02758 \pm 0.00035$. The 95% CL limit is 285 GeV.
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<td>(OPAL Collab.)</td>
<td>G. Alexander et al.</td>
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<td>R. M. Barnett et al.</td>
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<td>P. Abreu et al.</td>
<td>ZPHY C67</td>
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<td>R. Balest et al.</td>
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<td>A. Pich, J. Prades, P. Yepes</td>
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<td>(CERN, CPPM)</td>
<td>A. Pich, J. Prades, P. Yepes</td>
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<td>D. Antreasyan et al.</td>
<td>PL B251</td>
<td>204</td>
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