Searches for NON-Standard Model Higgs at CMS

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on behalf of the CMS Collaboration

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Why searching for BSM Higgs?

SM Higgs:

one doublet of complex scalar fields

\[ \mathcal{L} = -\frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu} + i\bar{\psi} \slashed{D}\psi + \psi^T \lambda \psi h + h.c. + |D_\mu h|^2 - V(h) \]

SM has some issues
• Quadratic divergences of Higgs mass
• Existence of Dark Matter
• Asymmetry between matter and antimatter
• Neutrino masses
• it does not include gravity
• it provides three different kind of interactions, each one with its coupling
• ..... 

we would like a theory which can explain the EWSB

many models have been developed that include the SM as its extrapolation at the energies explored so far, both within the SUSY scenario and in different frameworks

CMS has a wide research program

which covers many of such models in several signatures
### Outline

**Model:**

**Minimal Supersymmetric Standard Model** (2HDM type II)
- \((h^0, A^0, H^0)\)
- \((H^+, H^-)\)

**Next-to-Minimal Supersymmetric Standard Model**
- \((H^+, H^-)\)
- \((h_1, h_2, h_3)\)
- \((a_1, a_2)\)

**SM with 4th generation (SM4)**

**Minimal Seesaw Model of type II**
- triplet of Higgs fields
  - **doubly charged Higgs**
  - **Neutral Fermiophobic Higgs**

**2HDM type I**
- technicolor
- ......

**Signatures covered in this talk:**

- search for Neutral Higgs decaying to tau leptons
- search for Charged Higgs in top pairs production
- search for a *light boson* decaying in opposite sign di-muon pairs
- interpretation in SM4 of the same analyses used for SM Higgs searches
- search for double charged Higgs in 3 or more leptons final states

*it means: *non exclusively SUSY*
Higgs sector in SUSY (MSSM)

Minimal Supersymmetric extension to the SM
Higgs sector in SUSY theory needs 2 Higgs doublets each with 4 degrees of freedom

\[ H_u = (H_u^+, H_u^0) \text{ and } H_d = (H_d^0, H_d^-) \]

\[ v_u = \langle H_u^0 \rangle, \quad v_d = \langle H_d^0 \rangle \]

\[ \tan \beta \equiv \frac{v_u}{v_d} \]

8 real scalar degrees of freedom

after

EWSB => 3 d.o.f. go to “Goldstone”

5 scalar mass eigenstates:

1 Standard Model like Higgs: \( h \) with CP=+1
2 neutral Higgs: \( A \) with CP=-1 and \( H \) with CP=1
2 charged Higgs: \( H^+ \) and \( H^- \)

\[ m_h \text{ and } m_H \text{ bounds as a function of } m_A \]

\[ m_h < \min(m_A, M_Z)|\cos2\beta| < \min(m_A, M_Z) \]

\[ m_H > \max(m_A, M_Z) \]

with radiative corrections:

\[ m(\text{stop}) \sim 1 \text{ TeV} \]

Theory and Phenomenology of Sparticles
Drees, Godbole, Roy
The importance of final states with taus

Decays to $b$-quark ($\sim 90\%$) and $\tau$ ($\sim 10\%$) pairs enhanced at all masses

Production rate enhanced by $\times \tan^2 \beta$

CMS has performant and robust algorithms to reconstruct the tau decaying hadronically. In addition, the Particle Flow technique is particularly suitable to reconstruct the taus products.

see talk SM Higgs $\rightarrow$ taus by Michail Bachtis for details
MSSM \( H \rightarrow \tau \tau \)

**selection**

\( \tau \tau \) reconstructed in

leptons \((e, \mu)\) + hadrons \((1 \text{ prong} + n \pi^0, 3 \text{ prong})\)

the neutrinos produced in the decay tend to be produced nearly collinear with the visible products

this feature is exploited to construct a variable is with discriminant power between signal and background

Kinematic Fit to improve the mass resolution with missing neutrinos \(\delta m/m \approx 20\%\) (25\% without KF)

large probability for having a b-jet in the central region

two mutually exclusive categories:

**b-Tag category:** at most one jet with \(p_T > 30\) GeV and at least one b-tagged jet with \(p_T > 20\) GeV.

**Non b-Tag category:** at most one jet with \(p_T > 30\) GeV and no b-tagged jet with \(p_T > 20\) GeV.

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arXiv:1202.4083
MSSM $H \rightarrow \tau \tau$

for a fixed $\tan \beta$

CMS PAS HIG-11-029

CMS, $\sqrt{s} = 7$ TeV, $L = 4.6$ fb$^{-1}$

95% CL Excluded:
- Observed
- Expected
- $\pm 1\sigma$ Expected
- $\pm 2\sigma$ Expected
- LEP

CMS Preliminary $4.6$ fb$^{-1} \sqrt{s}=7$ TeV

95% CL Limits
- Observed
- Expected
- $\pm 1\sigma$ Expected
- $\pm 2\sigma$ Expected

$\tan \beta = 30$

MSSM $m_h^{\text{max}}$ scenario, $M_{\text{SUSY}} = 1$ TeV
\[ m_{H^+} < m_t - m_b \quad \rightarrow \quad t \rightarrow H^+b \]

For \( \tan\beta > 5 \)

\( H^+ \) preferentially decays as \( H^+ \rightarrow \tau^+\nu_\tau \)

**Selection:**
- One isolated hadronic tau,
- No isolated leptons
- Large missing ET
- At least 3 jets with at least a b-jet

**Leptonic I**
- One isolated hadronic tau
- One isolated opposite sign lepton
- Large missing ET
- At least 2 jets with at least a b-jet

**Leptonic II**
- One isolated muon and one isolated electron
- Large missing ET
- At least 2 jets with at least a b-jet
MSSM: charged Higgs in top pair

- Background estimated with simulation

- Data driven method used to estimate the fake taus background

- Other bkg contributions are estimated with simulation and correction factors from data

\[ m_{H^+} = 120 \text{ GeV} \]

\[ \text{BR}(t \rightarrow H^+ b) = 0.05 \]

\[ L = 2.2 \text{ fb}^{-1} \]

 CMS PAS HIG-11-019
number of expected events assuming
\[ BR(H^+ \rightarrow \tau^+ \nu) = 1 \]

\[ \Delta N = N_{\text{H}^+} - N_{\text{H}^+}^{\text{SM}} = N_{\text{WH}} (2(1-x) \cdot x + N_{\text{HH}} \cdot x^2 + N_{\text{H}^+}^{\text{SM}} \cdot ((1-x)^2 - 1) \]

and set upper limit to \( x \):

\[ x = BR(t \rightarrow bH^+) \]

determine \( x \) for each channel by using:

from simulation
**Next-to-Minimal Supersymmetric Standard Model (NMSSM):**

Adds singlet scalar field, thereby expanding the Higgs sector to three CP-even ($h_1$, $h_2$ and $h_3$), two CP-odd ($a_1$, $a_2$) and two charged scalars ($H^+$, $H^-$).

This model can survive also with a Higgs at 125 GeV!

A light (~10 GeV) boson produced

Search for $a_1$ in its decays to opposite sign di-muon pairs

![Diagram showing the process of NMSSM $a_1 \rightarrow \mu \mu$](image)

**Analysis strategy**

- Chose isolated opposite sign dimuons with $p_T \mu > 4$ GeV & $p_T(\mu\mu) > 6$ GeV
- Search above/below the upsilon peaks in dimuon invariant mass

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**Graphs showing CMS PAS HIG-12-004 results**

Barrel and Endcap plots showing the dimuon invariant mass distribution with various signal and background contributions.
**NMSSM $a_1 \rightarrow \mu \mu$**

**Upper limits to $\cos\theta_A$ as a function of $m(a_1)$ for several values of $\tan\beta$**

**Interpretation in NMSSM**

Three parameters:

- $m(a_1)$
- $\tan\beta$
- $\cos\theta_A$

$a_1 = \cos\theta_A a_{MSSM} + \sin\theta_A a_s$

- $\text{L}=1.3 \text{ fb}^{-1}$

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**Interpretation in NMSSM**

Three parameters:

- $m(a_1)$
- $\tan\beta$
- $\cos\theta_A$

$a_1 = \cos\theta_A a_{MSSM} + \sin\theta_A a_s$

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**Upper limits to $\cos\theta_A$ as a function of $m(a_1)$ for several values of $\tan\beta$**

---

**Interpretation in NMSSM**

Three parameters:

- $m(a_1)$
- $\tan\beta$
- $\cos\theta_A$

$a_1 = \cos\theta_A a_{MSSM} + \sin\theta_A a_s$
searches for Higgs in other models

Search for doubly charged Higgs
  • models with Higgs triplets (for example *Minimal Seesaw Model of type II*)

Search for SM Higgs with xsec and BR foreseen by the
  • Standard Model with a fourth generation of fermions

Four Statements about the Fourth Generation (B. Holdom, 2009)
  1) The 4th generation is not excluded by EW precision data;
  2) SM4 addresses some of the currently open questions;
  3) SM4 can accommodate emerging possible hints of new physics;
  4) LHC has the potential to discover or fully exclude it

Search for FermioPhobic(FP) Higgs:
EWSB mechanism responsible for generating the masses of gauge bosons is independent
from the mechanism that generate fermion masses

  ➔ H→ WW, ZZ : is SM-like
  ➔ H→ γγ : only W loop
  ➔ only VBF and VH production modes (assumed with the SM xsec) at least at tree level

this scenario is common in
  • Two Higgs Doublet Model (2HDM) type I
  • models with Higgs triplets (for example *Minimal Seesaw Model of type II*)
  • ...

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if there exist a **triplet of Higgs fields**? for example it is foreseen by the **Seesaw mechanism type II** (the most accredited model giving mass to neutrinos)

\[ \Phi^{++/-} \] would decay to same sign leptons, also flavor violation

**pair production**

\[ q \quad \Phi^{+}\quad \ell^+_j \quad \ell^+_k \quad \ell^-_l \]

**associated production**

\[ q \quad W^- \quad \Phi^{++} \quad \ell^+_j \quad \ell^+_k \quad \ell^-_l \]

the model with BR (\( \Phi \rightarrow \tau\tau \)) = 100% has a different selection (the kinematic of the final leptons is different)
doubly charged H

data driven methods used to estimate the background (sidebands and ABC method)

- \( e^\pm e^\pm = 100\% \)
- \( e^\pm \mu^\pm = 100\% \)
- \( \mu^\pm \mu^\pm = 100\% \)
- \( e^\pm \tau^\pm = 100\% \)
- \( \mu^\pm \tau^\pm = 100\% \)
- \( \tau^\pm \tau^\pm = 100\% \)

BP1: normal hierarchy
BP2: inverse hierarchy
BP3: degenerate masses
BP4: equal branchings

95% CL limit on mass of \( \Phi^{\pm\pm} \) [GeV]

<table>
<thead>
<tr>
<th>Benchmark point</th>
<th>ee</th>
<th>e(\mu)</th>
<th>e(\tau)</th>
<th>(\mu\mu)</th>
<th>(\mu\tau)</th>
<th>(\tau\tau)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP1</td>
<td>0</td>
<td>0.01</td>
<td>0.01</td>
<td>0.30</td>
<td>0.38</td>
<td>0.30</td>
</tr>
<tr>
<td>BP2</td>
<td>0.50</td>
<td>0</td>
<td>0</td>
<td>0.125</td>
<td>0.25</td>
<td>0.125</td>
</tr>
<tr>
<td>BP3</td>
<td>1/3</td>
<td>0</td>
<td>0</td>
<td>1/3</td>
<td>0</td>
<td>1/3</td>
</tr>
<tr>
<td>BP4</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
</tr>
</tbody>
</table>
the existence of a 4th generation of fermions is not forbidden by any physical principle of the SM

\[ m_{D4} \sim 600 \text{ GeV} \]

\[ m_{U4} - m_{D4} = (50 + 10 \ln(m_H/115)) \text{ GeV} \]

for some decay modes and Higgs mass ranges, xsec x BR in SM4 can be appreciably larger than in SM

same analyses developed for SM interpreted assuming SM4 cross sections and BRs

see dedicated talks for details
non SUSY

H → ττ search is the most sensitive channel

excluded in the mass range 120-600 GeV at 95% CL and in 125-600 at 99% CL

H→2 photons contributes little, so, despite the excess observed in that channel, the combined one is not consistent with SM4
at low masses the FP rate can be much larger than in SM for some processes

m~120-125 GeV
rate(SM)~rate(FP)
for $\gamma\gamma$

m~115 GeV
rate(SM)~rate(FP) for ZZ WW

**FermioPhobic (FP)- Introduction**

“definition”:

$gg\rightarrow H$

$tt\bar{t} + H$

$VH$

$VBF$

$\sqrt{s} = 7\text{TeV}$

Fermiophobic

$\gamma\gamma$ dominates when $W$ and $Z$ leptonic BRs included
Selection:
- 3 high energy isolated leptons (e,\(\mu\))
- Large Missing transverse energy
- Z removal by cutting on the invariant mass of two leptons
- Top pair veto by vetoing on btagged jets
- Smallest \(\Delta R(l^{+}l^{-})<2\)
- 12 GeV<smallest \(\Delta m(l^{+}l^{-})<100\) GeV

Background estimation:
ZZ, Z\(\gamma\) and WZ estimated with simulations and correction from data

Background with at least a fake lepton:
Top pairs, tW, DY, + jets
Completely data-driven background:
The “Tight to Loose” method

syst: 30%
diphoton selection as in baseline analysis (NON-MVA)

- HLT
- vertex finding
- 4 di-photon categories to optimize the photon selection:
  1. both photons in EB and not converted
  2. both photons in EB and at least one converted
  3. at least a photon in EE and both not converted
  4. at least a photon in EE and at least one converted

\[ p_T(\gamma) \text{ cuts slightly different} \]

\[ \text{isololation} \]
\[ \text{shower shape} \]
\[ \text{conversion rejection} \]
\[ \text{electron veto} \]

Details on the di-photon selection have been explained by Olivier Bondu last Monday

different sub-channels in order to improve the S/B in specific production mechanisms

- **VH**
  - 1 or 2 charged leptons
  - require at least 1 lepton (μ or e)

- **VBF**
  - require two energetic forward jets

and, for the non tagged events, exploitation of the main kinematic feature of the FP Higgs production:

the Higgs is always produced with other objects, so it is more boosted w.r.t. the SM one (where the gg->H is the main production mode)

\[ p_T(\gamma\gamma) \text{ has a good discriminant power against the background} \]
\[ \text{it’s used in addition to } m(\gamma\gamma) \]
\[ \text{to model the background} \]
FP 2 photons \textbf{VH lep, VBF sel} 

exclusive channels with tagged objects: start looking for muon (1), then for electron (2), then for two jets (3)

3) Dijet tag

2 energetic forward jets, Zeppenfeld variable

\( \Delta R(\gamma e) > 1 \)
\( |Z| = |\eta - \frac{1}{2}(\eta_1 + \eta_2)| < 2.5 \)
\( m_{jj} > 350 \text{GeV} \)

\( m_{\gamma\gamma} \) fit with data BG (2nd order polyn.)

1) Muon tag

\( \Delta R(\gamma\mu) > 1 \)

- MC for the shape
- selected data for normalization

1 energetic forward jet, Zeppenfeld variable

\( p_{T1}/m_{\gamma}\gamma > 55/120 > 25 \text{ GeV} \)
\( p_{T2} > 30, 20 \text{ GeV} \)
\( \Delta\eta_{jj} > 3.5 \)
\( \Delta\phi(jj, \gamma\gamma) > 2.6 \)

irreducible bkg: 50%

2) Electron tag

\( \Delta R(\gamma e) > 1 \)
\( |M(\gamma e) - M_Z| \) Z-veto

- shape obtained from MC and control sample dominated by the largest reducible background: \( Z(\rightarrow ee) \gamma \)
- normalization from selected data

irreducible bkg: 30%

\( m_{\gamma\gamma} \) (GeV)

CMS PAS HIG-12-002

L = 4.8 \text{ fb}^{-1}

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MCTP 2012, Ann Arbor, April 16-20
FP 2 photons: 2D analysis

after removal of dijet and lepton tagged events, the remaining signal is ~74% the remaining data are ~99%

4 $\gamma\gamma$ categories
(Like in $\gamma\gamma$ non-MVA)

$E_{T1} > 40 \times M_{\gamma\gamma}/120$ GeV, $E_{T2} > 30 \times M_{\gamma\gamma}/120$ GeV

aim: use information from both $m(\gamma\gamma)$ and $p_T(\gamma\gamma)$
main issue: possible correlation between the 2 variables

$p_T(\gamma\gamma)$ and $m(\gamma\gamma)$ are correlated.

$\pi_T(\gamma\gamma) = p_T(\gamma\gamma)/m(\gamma\gamma)$ (def.)

$\pi_T(\gamma\gamma)$ and $m(\gamma\gamma)$ ~uncorrelated
for $\pi_T(\gamma\gamma) > 0.1$ --> cut

2D fit to ($m(\gamma\gamma)$, $\pi_T(\gamma\gamma)$) projected on single dimensions

signal: gauss+ bifurcated gauss
bkg: exponential+gauss (centr. at 0)

signal: no correlations
bkg: assume linear correlation

L=4.8 fb$^{-1}$
FP 2 photons: combination

combination of the exclusive statistically uncorrelated classes:

- muon tag, electron tag
- di-jet VBF tag
- 4 diphoton classes of the rest of the events with $p_T(\gamma\gamma)/\text{mass}(\gamma\gamma)>0.1$

$L=4.8$ fb$^{-1}$
FP: combination

### Table

<table>
<thead>
<tr>
<th>Channel</th>
<th>$m_H$ range (GeV)</th>
<th>Luminosity (fb$^{-1}$)</th>
<th>Sub-channels</th>
<th>$m_H$ resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \rightarrow \gamma\gamma$ (fermiophobic)</td>
<td>110-150</td>
<td>4.8</td>
<td>4</td>
<td>1-3%</td>
</tr>
<tr>
<td>$H \rightarrow WW^* \rightarrow 2\ell 2\nu$</td>
<td>110-600</td>
<td>4.6</td>
<td>5</td>
<td>20%</td>
</tr>
<tr>
<td>WH $\rightarrow W(W^*) \rightarrow 3\ell 3\nu$</td>
<td>110-200</td>
<td>4.6</td>
<td>1</td>
<td>20%</td>
</tr>
<tr>
<td>$H \rightarrow ZZ^{(*)} \rightarrow 4\ell$</td>
<td>110-600</td>
<td>4.7</td>
<td>3</td>
<td>1-2%</td>
</tr>
<tr>
<td>$H \rightarrow ZZ^* \rightarrow 2\ell 2\nu$</td>
<td>250-600</td>
<td>4.6</td>
<td>2</td>
<td>7%</td>
</tr>
<tr>
<td>$H \rightarrow ZZ^{(*)} \rightarrow 2\ell 2q$</td>
<td>130-164</td>
<td>4.6</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>200-600</td>
<td>4.6</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td>$H \rightarrow ZZ \rightarrow 2\ell 2\tau$</td>
<td>190-600</td>
<td>4.7</td>
<td>8</td>
<td>10-15%</td>
</tr>
</tbody>
</table>

The exclusion at 99% CL is in the range 110-188 GeV except for the ranges 124.5 - 128 GeV and 148 - 154 GeV.

Excess at ~125 GeV is too weak to be consistent with a FP Higgs signal (partial fermiophobia?)

Non SUSY

L=4.6-4.8 fb$^{-1}$

CMS PAS HIG-12-008
Summary

✓ excluded considerable region in the parameters space of MSSM thanks to the H-\(\to\tau\tau\) analysis and to the search for t-\(\to bH^+\)

✓ limit to parameters in the NMSSM with a_1\(\to \mu\mu\)

✓ the search for doubly charged H in multilepton final state allowed for the exclusion of several benchmark points of models with Higgs triplet

✓ SM4 has been excluded in a wide mass range: 120-600 GeV

✓ Analyses developed specifically to search for FP Higgs allowed for exclusion at 95\%CL of FP models in the mass range 110-192 GeV. The famous excess at \(~125\) GeV doesn’t look like a FP Higgs signal

waiting for 2012 LHC data in order to use these and new ideas to kill many other Higgs masses, benchmark points, and possibly whole scenarios ... or (better) decide which is the real one
**mhmax**

\[ M_{\text{SUSY}}^* = 1 \text{ TeV}/c^2, \quad \mu = +200 \text{ GeV}/c^2, \quad M_2 = 200 \text{ GeV}/c^2 \]

\[ m_\tilde{g} = 0.8M_{\text{SUSY}}, \quad \tilde{X}_t = 2M_{\text{SUSY}} \text{ (FD calculation)}, \quad X_t^{\text{MS}} = \sqrt{6}M_{\text{SUSY}} \text{ (RG calculation)}, \quad A_b = A_t \]
selection of doubly charged H

<table>
<thead>
<tr>
<th>Variable</th>
<th>$ee, e\mu, \mu\mu$</th>
<th>$e\tau, \mu\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum p_T$</td>
<td>$&gt; 0.6 \cdot m_{H^{++}} + 130\text{ GeV}$</td>
<td>$&gt; m_{H^{++}} + 100\text{ GeV}$ or $&gt; 400\text{ GeV}$</td>
</tr>
<tr>
<td>$</td>
<td>m(\ell^+\ell^-) - m_{Z^0}</td>
<td>$</td>
</tr>
<tr>
<td>Mass window</td>
<td>$[0.9 \cdot m_{H^{++}}; 1.1 \cdot m_{H^{++}}]$</td>
<td>$[m_{H^{++}}/2; 1.1 \cdot m_{H^{++}}]$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>$ee, e\mu, \mu\mu$</th>
<th>$e\tau, \mu\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum p_T$</td>
<td>$&gt; 1.1 \cdot m_{H^{++}} + 60\text{ GeV}$</td>
<td>$&gt; 0.85 \cdot m_{H^{++}} + 125\text{ GeV}$</td>
</tr>
<tr>
<td>$</td>
<td>m(\ell^+\ell^-) - m_{Z^0}</td>
<td>$</td>
</tr>
<tr>
<td>$\Delta \phi$</td>
<td>$&lt; m_{H^{++}}/600\text{ GeV} + 1.95$</td>
<td>$&lt; m_{H^{++}}/200\text{ GeV} + 1.15$</td>
</tr>
<tr>
<td>$E_T^{miss}$</td>
<td>none</td>
<td>$&gt; 20\text{ GeV}$</td>
</tr>
<tr>
<td>Mass window</td>
<td>$[0.9 \cdot m_{H^{++}}; 1.1 \cdot m_{H^{++}}]$</td>
<td>$[m_{H^{++}}/2; 1.1 \cdot m_{H^{++}}]$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>$3\tau$</th>
<th>$4\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum p_T$</td>
<td>$&gt; m_{H^{++}} - 10\text{ GeV}$ or $&gt; 200\text{ GeV}$</td>
<td>$\sum p_T &gt; 120\text{ GeV}$</td>
</tr>
<tr>
<td>$</td>
<td>m(\ell^+\ell^-) - m_{Z^0}</td>
<td>$</td>
</tr>
<tr>
<td>$\Delta \phi$</td>
<td>$&lt; 2.1$</td>
<td>$&lt; 2.5$</td>
</tr>
<tr>
<td>$E_T^{miss}$</td>
<td>$&gt; 40\text{ GeV}$</td>
<td>none</td>
</tr>
<tr>
<td>Mass window</td>
<td>$[m_{H^{++}}/2 - 20; 1.1 \cdot m_{H^{++}}]$</td>
<td>none</td>
</tr>
</tbody>
</table>
### H -> tau tau

<table>
<thead>
<tr>
<th>Process</th>
<th>Non B-Tag</th>
<th>B-Tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z \rightarrow \tau \tau$</td>
<td>13115 ± 908</td>
<td>126 ± 8</td>
</tr>
<tr>
<td>Fakes</td>
<td>6482 ± 305</td>
<td>101 ± 9</td>
</tr>
<tr>
<td>W+jets</td>
<td>5441 ± 377</td>
<td>32 ± 2</td>
</tr>
<tr>
<td>$Z \rightarrow ll$</td>
<td>6029 ± 646</td>
<td>26 ± 3</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>44 ± 7</td>
<td>69 ± 10</td>
</tr>
<tr>
<td>Di-Boson</td>
<td>98 ± 21</td>
<td>1 ± 1</td>
</tr>
</tbody>
</table>

| Total Background | 31208 ± 2264 | 355 ± 35 |
| $H \rightarrow \tau \tau$ | 44 ± 4     | 4 ± 1  |
| Data           | 32062      | 391     |

<table>
<thead>
<tr>
<th>Signal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>$gg \rightarrow \phi$</td>
</tr>
<tr>
<td>$gg \rightarrow bb\phi$</td>
</tr>
</tbody>
</table>

### MSSM Higgs

<table>
<thead>
<tr>
<th>$m_A$ [GeV]</th>
<th>−2σ</th>
<th>−1σ</th>
<th>Median</th>
<th>+1σ</th>
<th>+2σ</th>
<th>Obs. tan β limit</th>
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## FP 2 photons

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<tr>
<th></th>
<th>Dijet + lepton tag</th>
<th>Both photons in barrel</th>
<th>One or both in endcap</th>
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<tr>
<td></td>
<td>( R_{9}^{\text{min}} &gt; 0.94 )</td>
<td>( R_{9}^{\text{min}} &lt; 0.94 )</td>
<td>( R_{9}^{\text{min}} &gt; 0.94 )</td>
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<tr>
<td>FP signal expected</td>
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<tr>
<td>Data (events)</td>
<td>24.7 (27.4%)</td>
<td>22.3 (24.7%)</td>
<td>23.0 (25.5%)</td>
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<tr>
<td></td>
<td>129 (0.8%)</td>
<td>3740 (22.9%)</td>
<td>5363 (32.9%)</td>
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<tr>
<td>( \sigma_{\text{off}} ) (GeV)</td>
<td>1.72</td>
<td>1.39</td>
<td>1.84</td>
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<tr>
<td>FWHM/2.35 (GeV)</td>
<td>1.37</td>
<td>1.19</td>
<td>1.53</td>
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<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>EB high ( R_{9} ) (0)</th>
<th>EB low ( R_{9} ) (1)</th>
<th>non EB high ( R_{9} ) (2)</th>
<th>non EB low ( R_{9} ) (3)</th>
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<tbody>
<tr>
<td>MC Signal</td>
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<td>Dijet tag</td>
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<td>Dijet or lepton tag</td>
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<td>0.70</td>
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<td>0.993</td>
<td>0.997</td>
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<td>WH (120) H → WW</td>
<td>data</td>
<td>all bkg.</td>
<td>WZ → 3ℓν</td>
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<td>3-lepton preselection</td>
<td>2.1 ± 0.0</td>
<td>3.5 ± 0.1</td>
<td>950</td>
<td>968.3 ± 11.9</td>
<td>482.9 ± 1.8</td>
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<td>min-MET &gt; 40 GeV</td>
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<td>1.8 ± 0.1</td>
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<td>270.5 ± 4.4</td>
<td>208.2 ± 1.1</td>
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<td>Z removal</td>
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<td>1.0 ± 0.1</td>
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<td>47.9 ± 3.1</td>
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<td>top veto</td>
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<td>0.6 ± 0.1</td>
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<td>14.2 ± 1.3</td>
<td>8.8 ± 0.4</td>
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<tr>
<td>ΔR_{ℓ+ℓ−} &amp; m_{ℓℓ}</td>
<td>0.1 ± 0.0</td>
<td>0.5 ± 0.1</td>
<td>7</td>
<td>8.4 ± 0.9</td>
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