Search for a neutral MSSM Higgs boson decaying into two tau leptons at 13 TeV

Teresa Lenz
(on behalf of the DESY CMS group)

LHC Physics Discussions (DESY)

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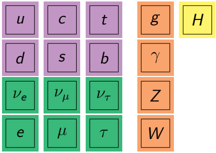
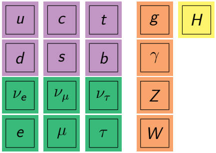
The Standard Model and beyond



- The Standard Model is a very successful theory, but suffers from shortcomings ...
  - Hierachy problem
  - Dark Matter
  - ...
- Many possible extensions ...

The Standard Model and beyond



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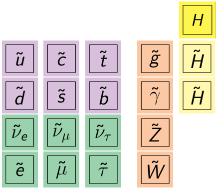
The Minimal Supersymmetric Standard Model



- Hierarchy problem: $m_H^2 \propto \ln(\Lambda_{UV})$
- R-parity conserved → Lightest sparticle stable → DM candidate

The Higgs sector of the MSSM

- Two higgs doublets needed because of
  - Supersymmetry condition (holomorphic superpotential)
  - Anomaly cancellation (fermion triangle anomalies)

After sponatenous symmetry breaking (8-3 degrees of freedom):

h_0 H_0 A_0 $H^{\pm}$

- Relevant parameters in the higgs sector: $\tan\beta$, M_A
- Lightest Higgs (h_0) usually associated with H(125 GeV) state

Search for H_0 and A_0

(would be an unambiguous proove of new physics)

Searching for a heavy Higgs with tau leptons

Why to search in the ditau final state?

- Higgs coupling proportional to mass

$$\rightarrow \boldsymbol{\tau}, \boldsymbol{b}, \boldsymbol{t}$$

- Large $\tan\beta \rightarrow$ couplings to down-type fermions are enhanced

$$\rightarrow \boldsymbol{\tau}, \boldsymbol{b}$$

- Good discrimination against SM processes: LHC = *pp* collider

$$\rightarrow \boldsymbol{\tau}$$

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Promising channel to search for new physics in the Higgs sector

The tau lepton and its detection

- Down-type lepton, charged, $m = 1.7\,\text{GeV}$
- Tau lifetime $= 3 \cdot 10^{-13} s$

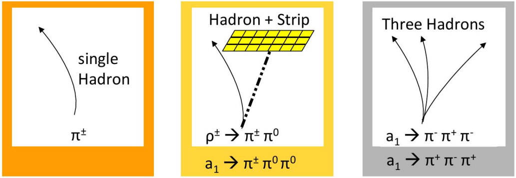
$\rightarrow$ only decay products are detectable

Tau decays

Decay mode	Meson resonance	$\mathcal{B}$ [%]
$\tau^- \to e^- \overline{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$		17.4
$\tau^- \to h^- \nu_\tau$		11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other modes with hadrons		3.2
All modes containing hadrons		64.8

Reconstruction of taus at the CMS detector

- **Leptonic decays:** standard muon/electron reconstruction
- **Hadronic decays:** "Hadrons-plus-strips algorithm" (particle flow)



Reconstruction of hadronically decaying taus (τ_h):

1. Seeded by a jet
2. Photon/electron constituents are collected in "strips" (ECAL)
3. τ_h candidates formed by combining "strips" and charged jet constituents
4. Identification of decay mode (based on #charged particles, #strips and mass hypothesis)
5. Discrimination against jets (MVA based) and e, μ (discriminators)

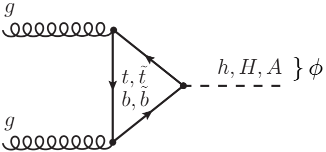
- New for 13 TeV: "dynamic" strip size, ...

Search for a neutral MSSM Higgs boson
at 13 TeV with 12.9 fb^{-1}

(CMS-PAS-HIG-16-037)

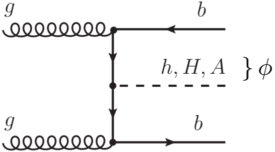
Production modes of the Higgs boson

- Small, medium $\tan\beta$



- no b-tags

- Large $\tan\beta$



- $\geq$ 1 b-tags

→ Search for events with two taus

→ For 2 taus → 4 of 6 possible "channels" used:

$\tau_h\tau_h$, $\tau_h e$, $\tau_h\mu$, $e\mu$

→ Generally differ in background composition → optimized seperately

Event selection (channel dependent)

Selected pair required to be

- of opposite charge
- spacially seperated $\Delta R > 0.5(0.3)$

$\tau_h\tau_h$, $\tau_h e$, $\tau_h\mu$, $e\mu$

	$\mu\tau_\mathrm{h}$	$\mathrm{e}\tau_\mathrm{h}$	$\tau_\mathrm{h}\tau_\mathrm{h}$	$\mathrm{e}\mu$
Trigger (threshold in GeV)	$\mu(22)$	$\mathrm{e}(25)$	$\tau_h(35)$ & $\tau_h(35)$	$\mu(8)$ & $\mathrm{e}(23)$ or $\mu(23)$ & $\mathrm{e}(12)$
Offline selection	$p_\mathrm{T}^{\mu} > 23$ GeV, $\|\eta^{\mu}\| < 2.1$ $p_\mathrm{T}^{\tau_h} > 30$ GeV, $\|\eta^{\tau_h}\| < 2.3$	$p_\mathrm{T}^{\mathrm{e}} > 26$ GeV, $\|\eta^{\mathrm{e}}\| < 2.1$ $p_\mathrm{T}^{\tau_h} > 30$ GeV, $\|\eta^{\tau_h}\| < 2.3$	$p_\mathrm{T}^{\tau_h} > 40$ GeV, $\|\eta^{\tau_h}\| < 2.1$ $p_\mathrm{T}^{\tau_h} > 40$ GeV, $\|\eta^{\tau_h}\| < 2.1$	$p_\mathrm{T}^{\mu} > 10(24)$ GeV, $\|\eta^{\mu}\| < 2.4$ $p_\mathrm{T}^{\mathrm{e}} > 13(24)$ GeV, $\|\eta^{\mathrm{e}}\| < 2.5$
Additional ID	Medium ID -	MVA ID 80% -	- -	Medium ID MVA ID 80%
Isolation	$I_{\mu}^{rel} < 0.15$ MVA Medium	$I_{\mathrm{e}}^{rel} < 0.1$ MVA Medium	MVA Tight MVA Tight	$I_{\mu}^{rel} < 0.2$ $I_{\mathrm{e}}^{rel} < 0.15$
Impact parameter (cm)	$d_{xy}^{\mu} < 0.045$ $d_z^{\mu} < 0.2$ $d_z^{\tau_h} < 0.2$	$d_{xy}^{\mathrm{e}} < 0.045$ $d_z^{\mathrm{e}} < 0.2$ $d_z^{\tau_h} < 0.2$	$d_z^{\tau_h} < 0.2$ $d_z^{\tau_h} < 0.2$	$d_{xy}^{\mu/\mathrm{e}} < 0.045$ $d_z^{\mu/\mathrm{e}} < 0.2$
Lepton vetoes	No loose $\mu^+\mu^-$ pair with $p_\mathrm{T}^{\mu} > 15$ GeV	No loose $\mathrm{e}^+\mathrm{e}^-$ pair with $p_\mathrm{T}^{\mathrm{e}} > 15$ GeV		-
	No additional loose e with $p_\mathrm{T} > 10$ GeV and $\|\eta\| < 2.5$ No additional loose μ with $p_\mathrm{T} > 10$ GeV and $\|\eta\| < 2.4$			

Background contributions

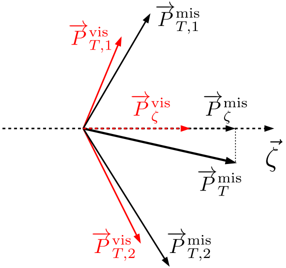
What processes can also lead to two taus (and b-jets) in the final state?

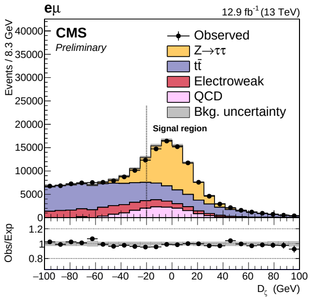
- $\boldsymbol{Z \to \tau\tau}$:
  Two taus in final state (contributing to all four channels)
- $\boldsymbol{W}$**+jets**:
  Fake tau from jet + lepton from W-decay (largest in $e\tau_h$, $\mu\tau_h$)
- **QCD multijet**:
  Two fake taus from jet (largest in $\tau_h\tau_h$)
- $\boldsymbol{t\bar{t}}$**+jets**:
  Lepton pair from two W-decays (largest in $e\mu$)

Final selection

- Reduction of W+jets in $e\tau_h$, $\mu\tau_h$:
  - $m_\mathrm{T} = \sqrt{2 p_\mathrm{T}^{e,\mu} \not{E}_\mathrm{T} \left(1 - cos\Delta\phi\right)} < 50\,\mathrm{GeV} (40\,\mathrm{GeV})$

- Reduction of $t\bar{t}$ in $e\mu$:
  - $D_\zeta = P_\zeta - 1.85 \cdot P_\zeta^\mathrm{vis} > -20\,\mathrm{GeV}$
    with $P_\zeta = \left(\vec{p}_\mathrm{T}^{e} + \vec{p}_\mathrm{T}^{\mu} + \vec{p}_\mathrm{T}^\mathrm{miss}\right) \cdot \frac{\vec{\zeta}}{|\vec{\zeta}|}$ and $P_\zeta^\mathrm{vis} = \left(\vec{p}_\mathrm{T}^{e} + \vec{p}_\mathrm{T}^{\mu}\right) \cdot \frac{\vec{\zeta}}{|\vec{\zeta}|}$





Estimation of background contributions

$Z/\gamma \rightarrow \tau\tau$

- Prediction taken from Monte Carlo (MC) simulation
- Shape correction in p_{T}^{Z} with data events
- Normalization: $Z \rightarrow \mu\mu$ control region included in final fit

$t\bar{t}$+jets

- Prediction taken from MC simulation
- Shape correction in top p_{T}
- Validation: control region with high $t\bar{t}$ purity in the $e\mu$ channel

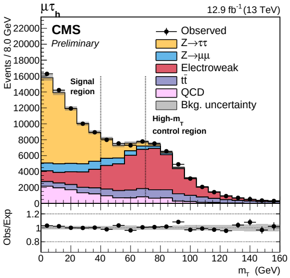
Estimation of background contributions

QCD multijet for $\mu\tau_h$, $e\tau_h$, $e\mu$

- Fully data-based estimation ("ABCD-like")
  - Estimated in control region with same-sign (SS) charges of leptons
  - SS→OS extrapolation factor determined in sideband with looser lepton isolation

W+jets for $\mu\tau_h$ and $e\tau_h$; others: fully simulation based

- Taken from MC simulation
- Corrected for data/MC differences in high m_T control region



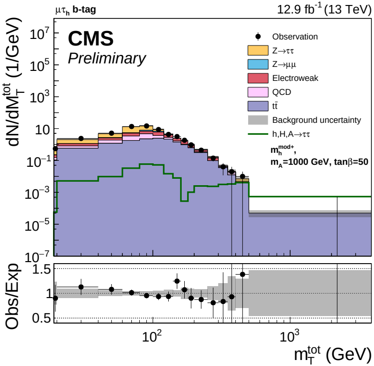
Mutual dependency: QCD and W+jets estimated simultaneously in final fit

Results

Final observable: The total transverse mass

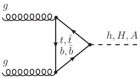
$$m_T^{tot} = \sqrt{m_T\left(\not{E}_T, \tau_1^{vis}\right)^2 + m_T\left(\not{E}_T, \tau_2^{vis}\right)^2 + m_T\left(\tau_1^{vis}, \tau_2^{vis}\right)^2}$$

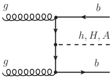
with $m_T\left(1,2\right) = \sqrt{2 \cdot p_T^1 \cdot p_T^2 \left(1 - \cos\left(\Delta\phi_{1,2}\right)\right)}$

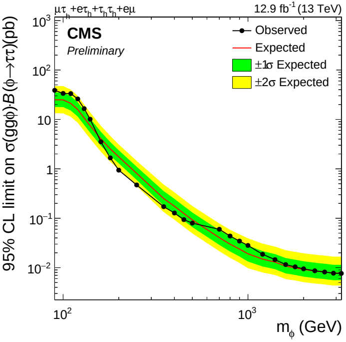


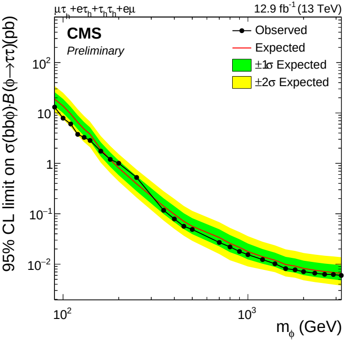
Model independent interpretation

- Background-only hypothesis: SM without Higgs
- Limits seperately set for $gg\phi$ or $bb\phi$



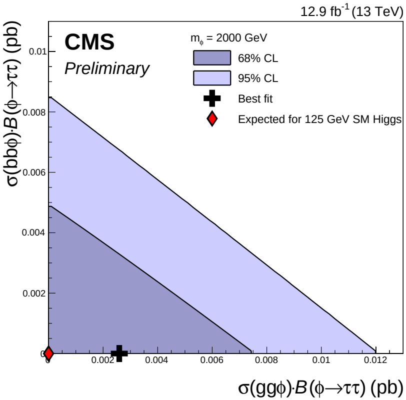




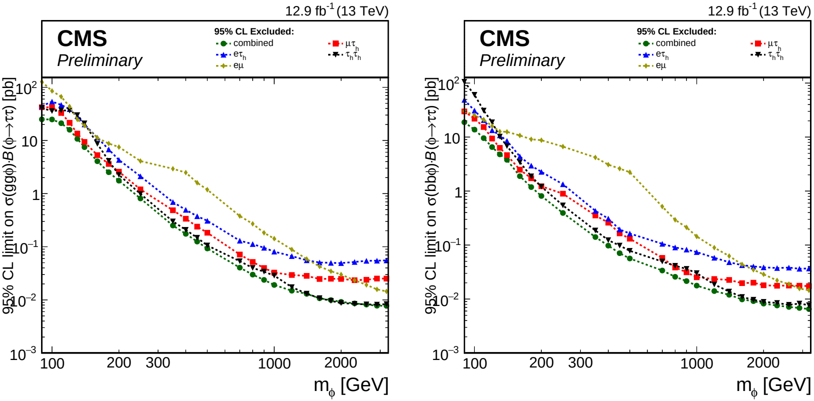


Model independent interpretation

- 2d limit plots in $gg\phi$ and $bb\phi$
- Red point: Best fit value for a 125 GeV SM Higgs only



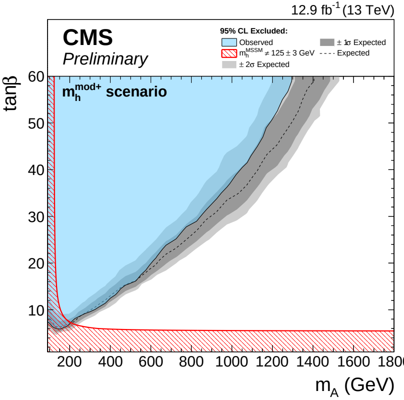
Sensitivity of different channels

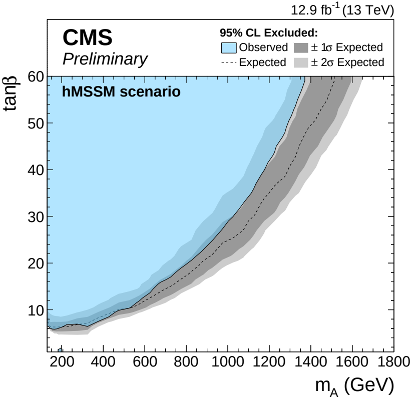


- $\tau_h\tau_h$: best sensitivity in high mass region due to rapid falling QCD bkg
- $e\mu$: good sensitivity in very high mass region due to vanishing $t\bar{t}$ events

Model dependent interpretation

- MSSM benchmark scenarios: $m_h^{\text{mod}+}$ and hMSSM
- $m_h = 125 \pm 3\,\text{GeV}$ over large part of parameter space





Conclusion

- Brand new result from CMS $H \to \tau\tau$ search at 13 TeV!
  - http://cds.cern.ch/record/2231507
- Builds upon earlier analyses with improvements
  - Use of $m_{\mathrm{T}}^{\mathrm{tot}}$ as discriminating variable
  - Adding $Z \to \mu\mu$ control region to the final fit
- First time limits extend to M_A beyond 1TeV
- Most sensitive analysis in the large $\tan\beta$ and high mass phase space

Thank you