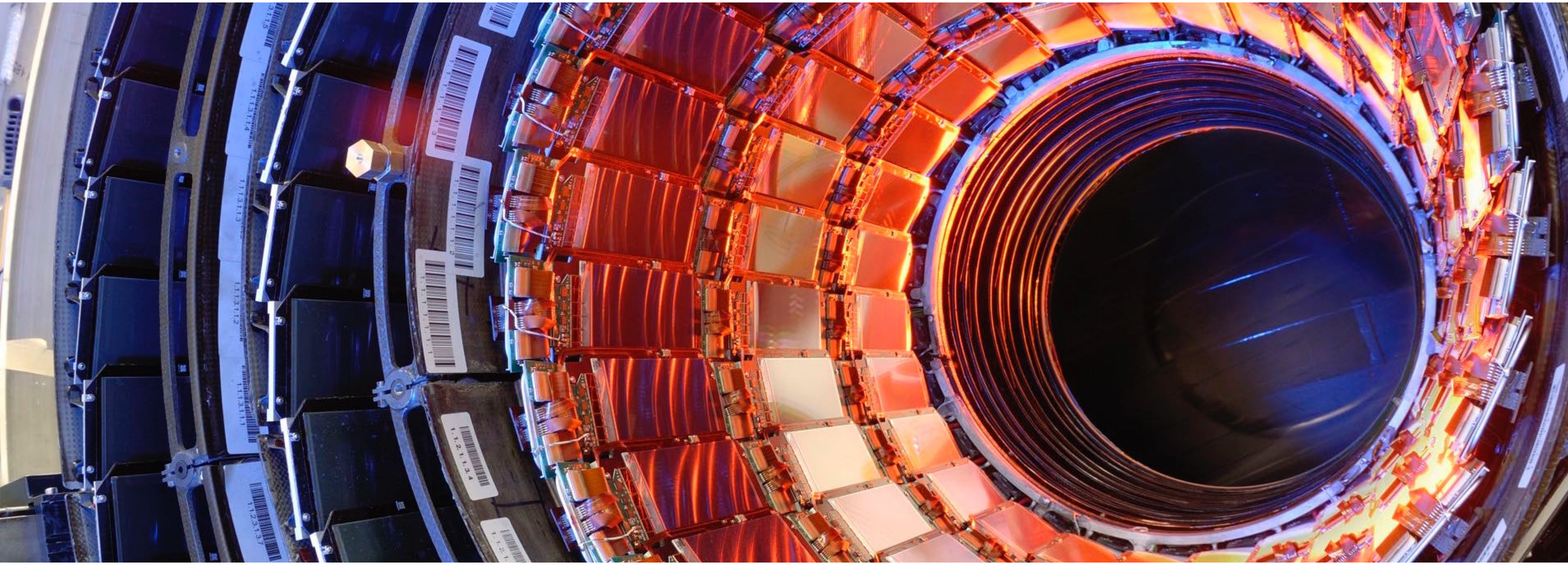
Search for a neutral MSSM Higgs boson decaying into two tau leptons

with 12.9 fb^{-1} of 2016 data at 13 TeV



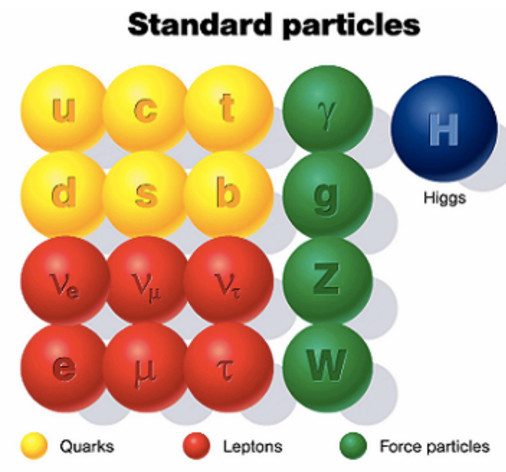
Yiwen Wen
DESY
on behalf of CMS collaboration

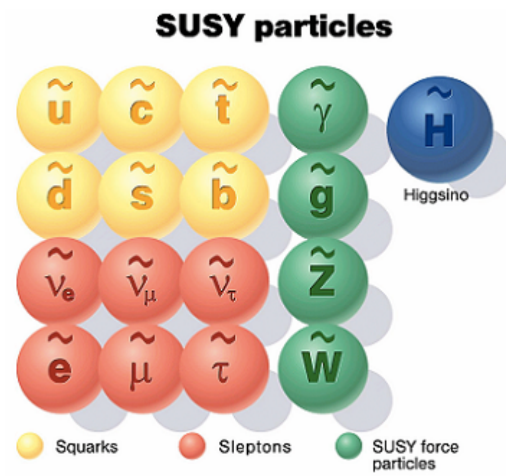
10th Annual Meeting of the Helmholtz Alliance
"Physics at the Terascale"
DESY, 22nd November 2016

HELMHOLTZ ASSOCIATION

introduction

- discovery of SM-compatible ~125 GeV Higgs boson in 2012
  - great success of SM
- shortcomings of SM: dark matter and hierarchy problem
- one of simplest extensions is **M**inimal **S**upersymmetric **S**tandard **M**odel(**MSSM**)
  - all SM particles have superpartner
  - two Higgs doublets
- R-parity conserved → lightest sparticle stable → dark matter candidate
- cancellation of quadratically divergent self energy corrections to Higgs mass → tiny Higgs mass protected → solve hierarchy problem





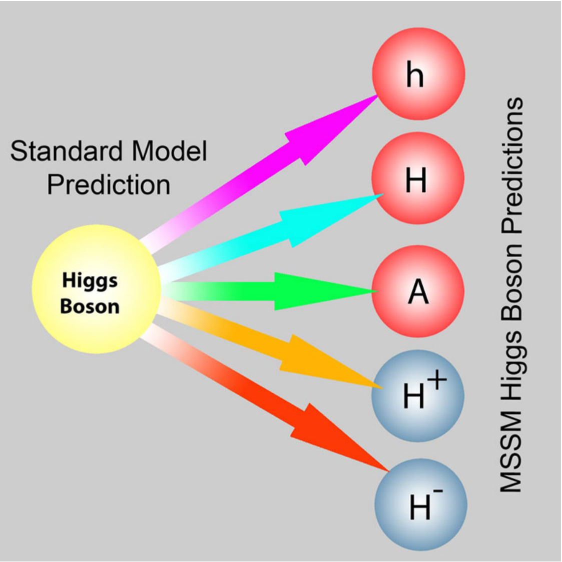
introduction: MSSM Higgs sector

> **two Higgs doublets**:

- one coupling to up-type and one to down-type fermions

> lead to **5 physical Higgs particles**:

- 2 charged H+, H-
- 2 neutral scalar H, h
- 1 neutral pseudoscalar A



> 2 parameters in tree level:

- **tanβ**, ratio of vacuum expectation value of 2 doublets
- **m_A**, mass of the pseudoscalar A

> take **Higgs(125) as lightest h**, searches for H/A

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introduction: why in 2 taus final states

- Higgs coupling is **proportional** to fermion mass:

  τ b t

- **large tanβ** leads to enhanced rate of decay width to **down-type** fermion:

  τ b

- **good discrimination** against SM background at LHC

  τ

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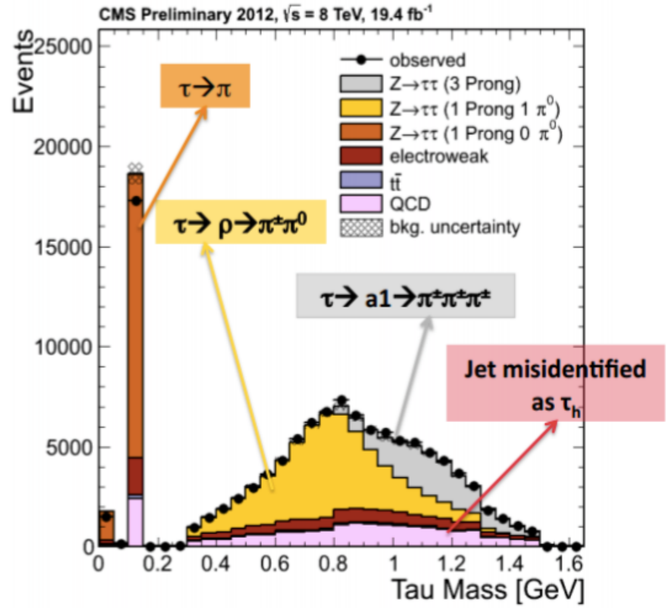
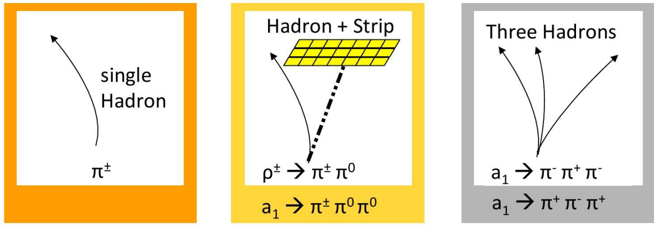
tau ID: tau reconstruction in CMS

- leptonic decay ->35%: standard electron ID or Muon ID
- hadronic decay ->65%: **hadron-plus-strip(HPS)** algorithm

	Decay Mode	Resonance	$\mathcal{B}$ [%]
leptonic decays	$\tau^- \to e^- \overline{\nu}_e \nu_\tau$		17.8
	$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$		17.4
1 - prong decays	$\tau^- \to \pi^- \nu_\tau$	$\pi(140)$	11.6
	$\tau^- \to \pi^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
	$\tau^- \to \pi^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	10.8
3 - prongs decays	$\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$	$a_1(1260)$	9.8
	$\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$		4.8
	Other hadronic modes		1.7
	All hadronic modes		64.8

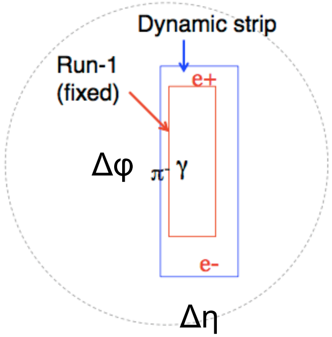


- hadronic taus reconstructed from a combination of tracks, and strips of energy deposits in the ECAL



1 track | 1 track+1 strip, 1 track+2 strips | 3 tracks

- tau mass calculated from tracks and strips should be compatible with tau decay
- in run-2, strip size adjusted dynamically!

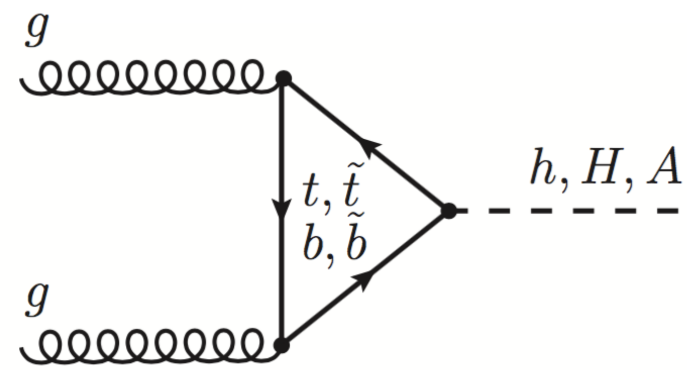


analysis: categorization

- searches for 2 taus
- 4 of 6 final states considered: $\mu\tau_h, e\tau_h, \tau_h\tau_h, e\mu$ (τ_h: hadronically decaying tau), accounts for ~ 80% of di-tau decay
- split events into 2 categories based on number of b-tagged jets

no b-tags

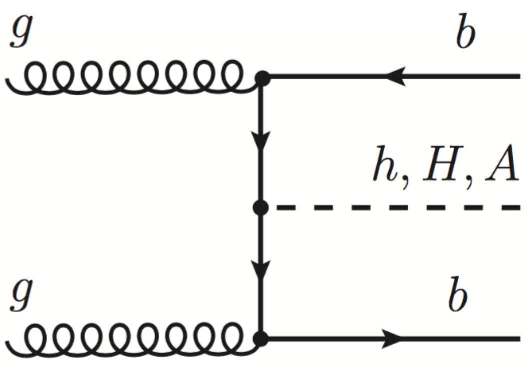
small, medium tan β



gluon fusion, ggφ, φ={h,H,A}

>=1 b-tags

large tan β



b-associated Higgs production, bbφ

analysis: baseline selections

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

trigger: single μ, single e

Selections:

good identified **μ:** pT>23 GeV, **e:** pT>26 GeV **τ_h:** pT > 20 GeV

eμ

trigger: eμ cross trigger

Selections:

good identified **μ**: pT>10 GeV **e**: pT >13 GeV

$\tau_h\tau_h$

trigger: di-tau trigger

Selections:

good identified **τ_h:** pT >40 GeV

all channels:

pair opposite-signed

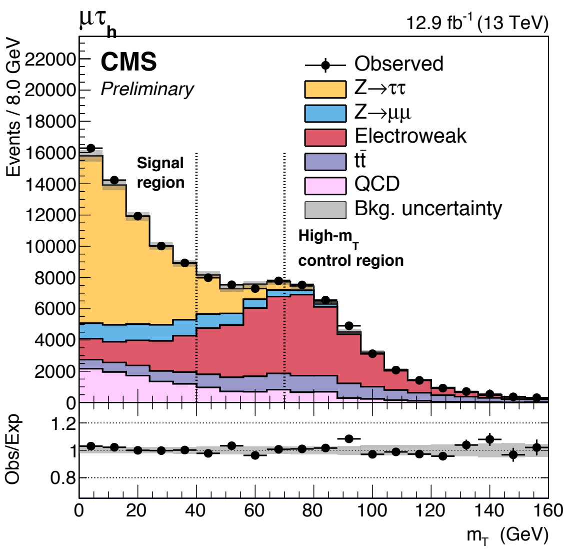
no additional loose e, μ

space separated ΔR > 0.5(0.3 in **eμ**)

analysis: additional selection

- to reduce W+Jets in **eτ$_h$**, **μτ$_h$** channel

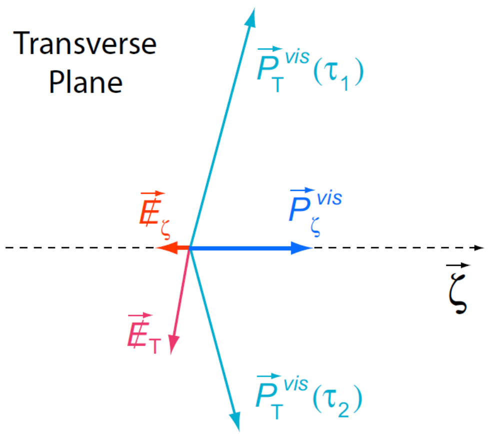
$$m_T = \sqrt{2 p_T^{e,\mu} E_T^{miss} (1 - \cos\Delta\phi)} < 50(40) GeV$$

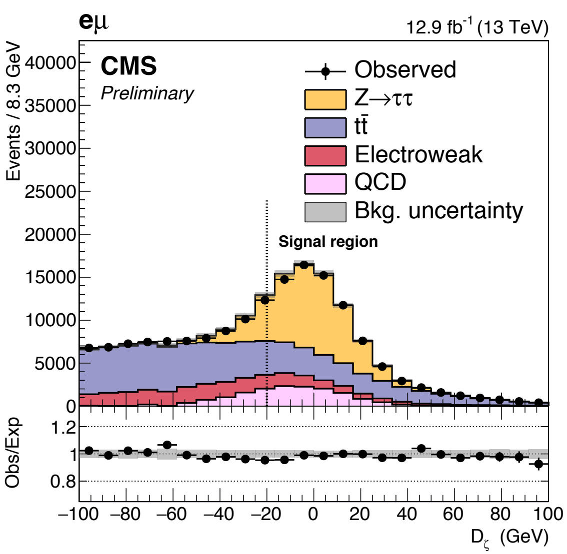


- to reduce Top pair production in **eμ** channel

$$D_\zeta = P_\zeta - 1.85 \cdot P_\zeta^{vis} > -20 GeV$$

  - $\vec{\zeta}$ is axis bisecting directions $\vec{p}_T^{\,e}$ and $\vec{p}_T^{\,\mu}$
  - with $P_\zeta = (\vec{p}_T^{\,e} + \vec{p}_T^{\,\mu} + \vec{p}_T^{\,miss}) \cdot \frac{\vec{\zeta}}{|\zeta|}$ and $P_\zeta^{vis} = (\vec{p}_T^{\,e} + \vec{p}_T^{\,\mu}) \cdot \frac{\vec{\zeta}}{|\zeta|}$





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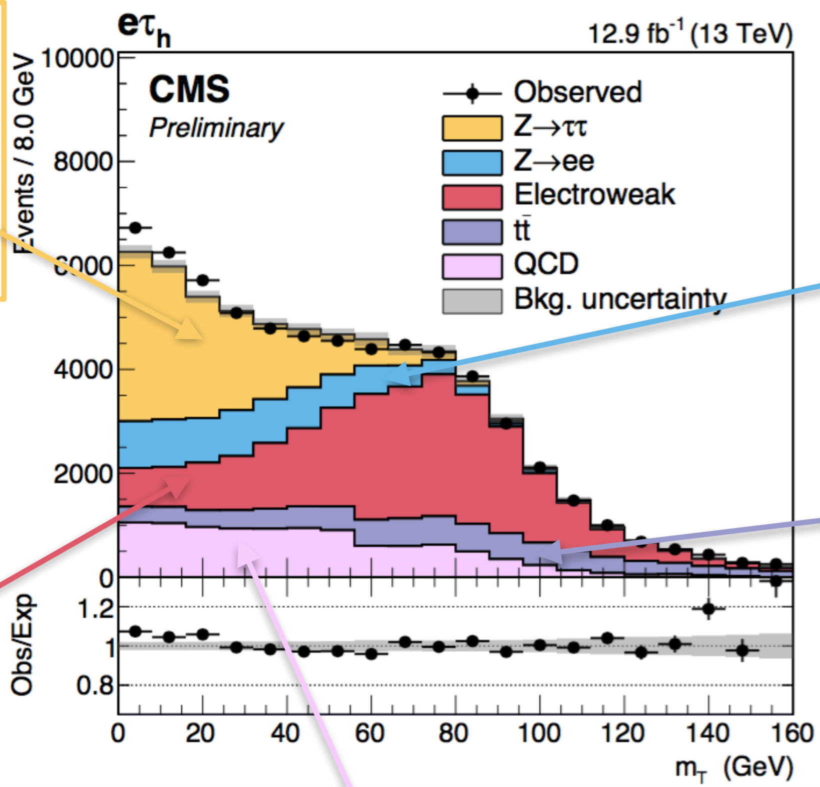
analysis: background estimation overview

Z—>ττ: Norm and shape from Monte Carlo(MC), with data-driven correction applied

W+Jets: $\mu\tau_h, e\tau_h$: Norm from high m_T control region **shape** from MC
$\tau_h\tau_h$, eμ: Norm and shape from MC



Z—>ll: Norm and shape from MC

ttbar: Norm and shape from MC, with data-driven corrections

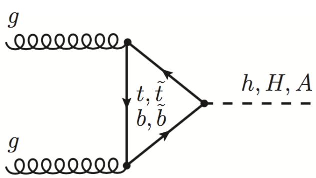
QCD: Fully data-driven $\mu\tau_h, e\tau_h$, eμ: Norm from SS with other backgrounds subtracted, and OS/SS ratio applied, **shape** from SS
$\tau_h\tau_h$: Norm from OS region with loose isolation, with scale factor loose—>tight isolation applied.
Shape from OS region with loose isolation

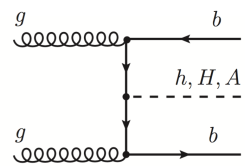
results: observable

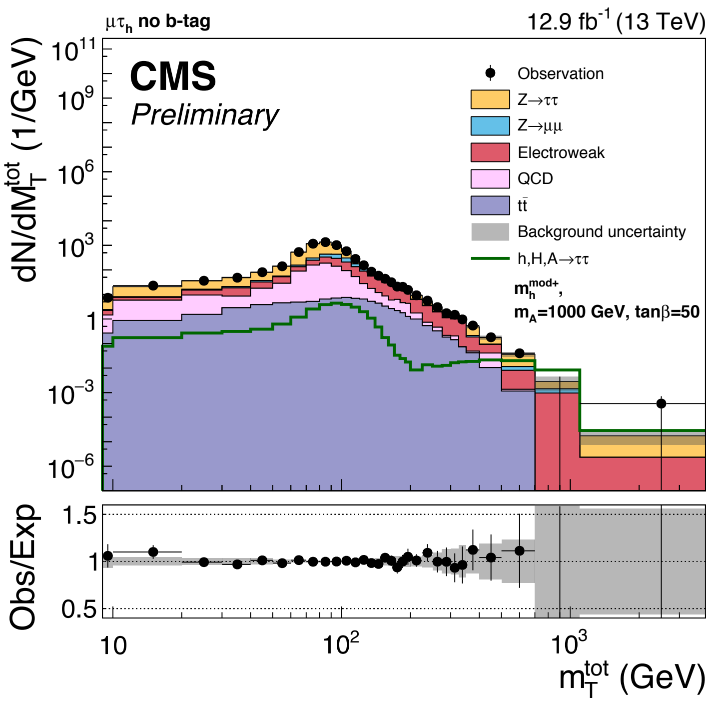
- observable to extract signal: **total transverse mass**

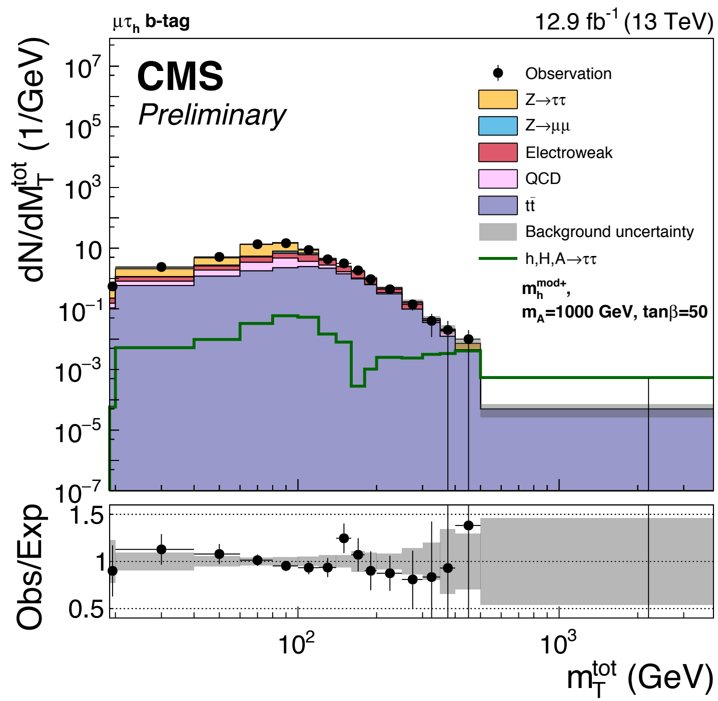
$$m_T^{tot} = \sqrt{m_T(E_T^{miss},\tau_1^{vis})^2 + m_T(E_T^{miss},\tau_2^{vis})^2 + m_T(\tau_1^{vis},\tau_2^{vis})^2}$$

- where $$m_T = \sqrt{2 p_T^1 p_T^2 (1-\cos\Delta\phi)}$$



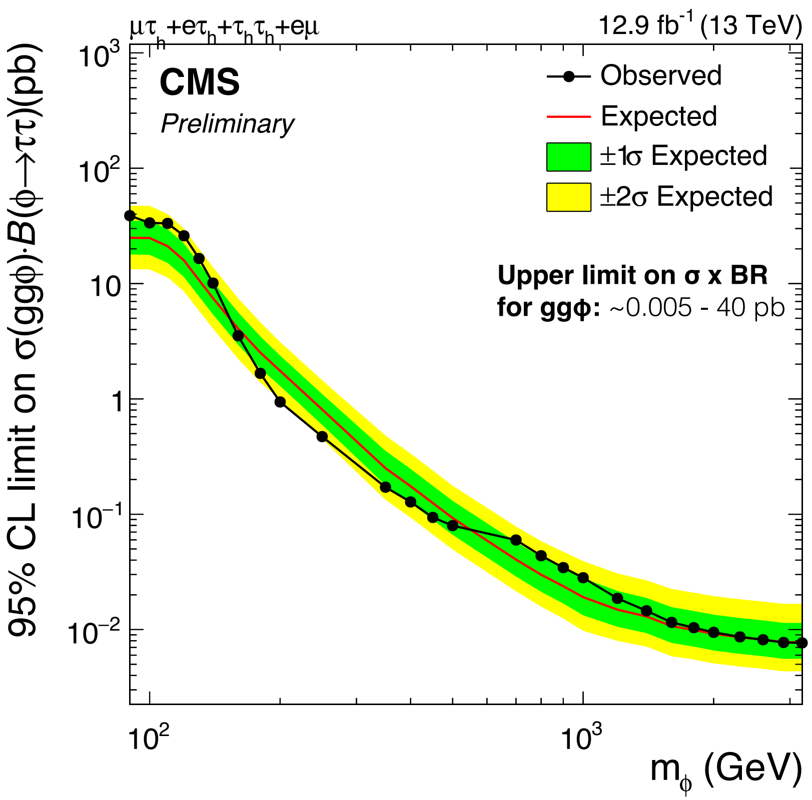


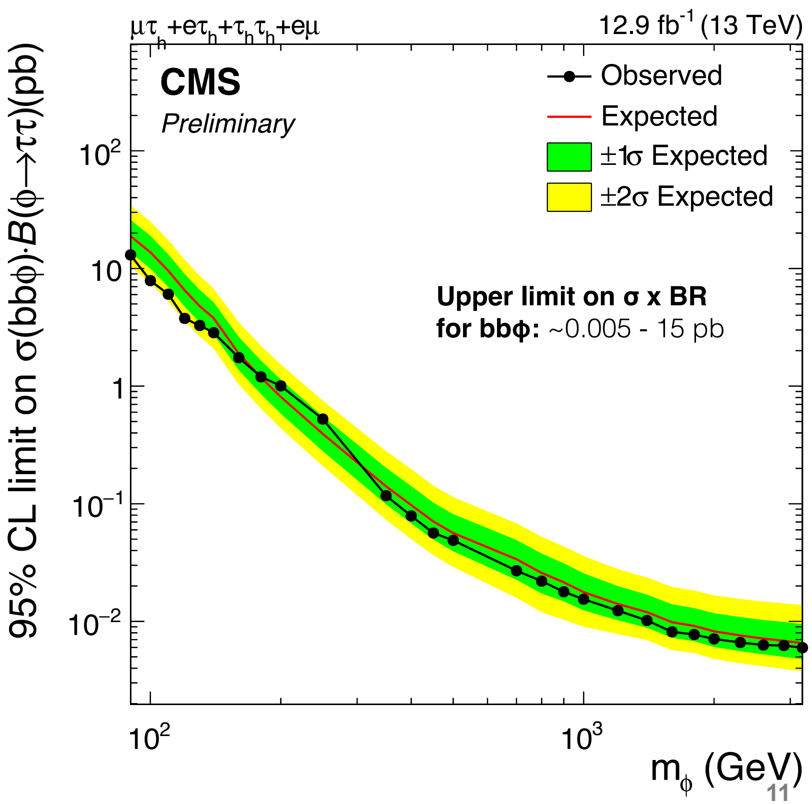




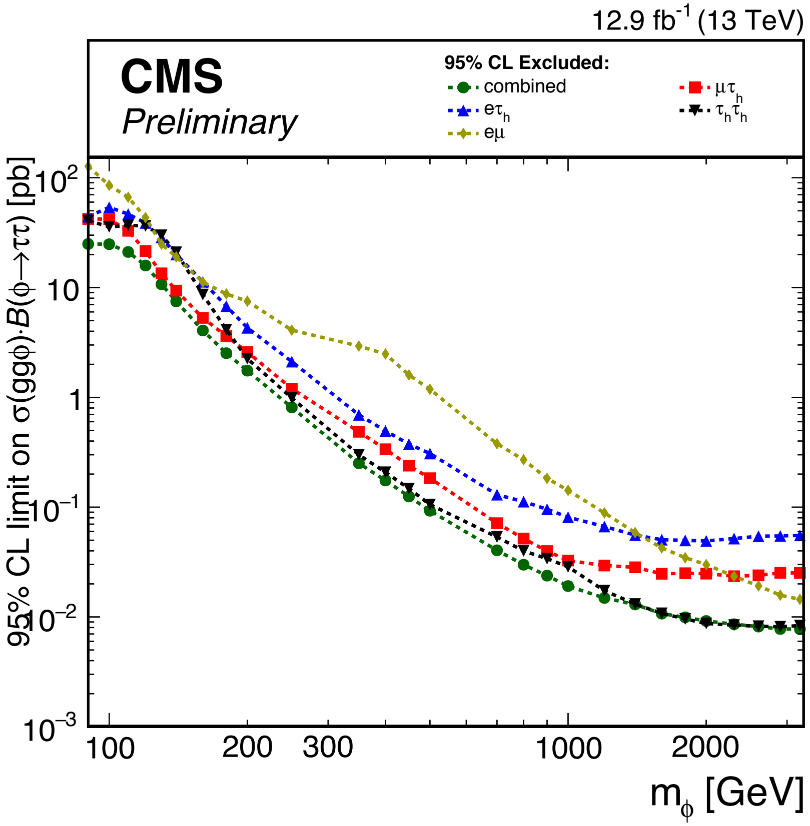
results: limit plots

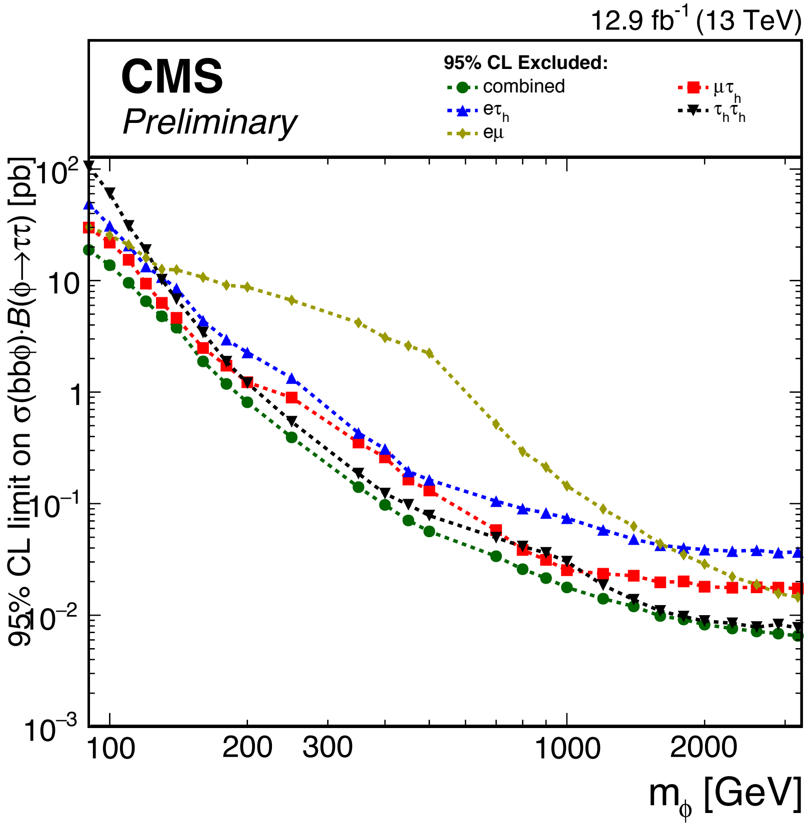
- all four channels are combined
- fit total transverse mass to set model independent upper limits on σ x BR
- background only hypothesis: SM without Higgs(125)





results: sensitivity of different channels



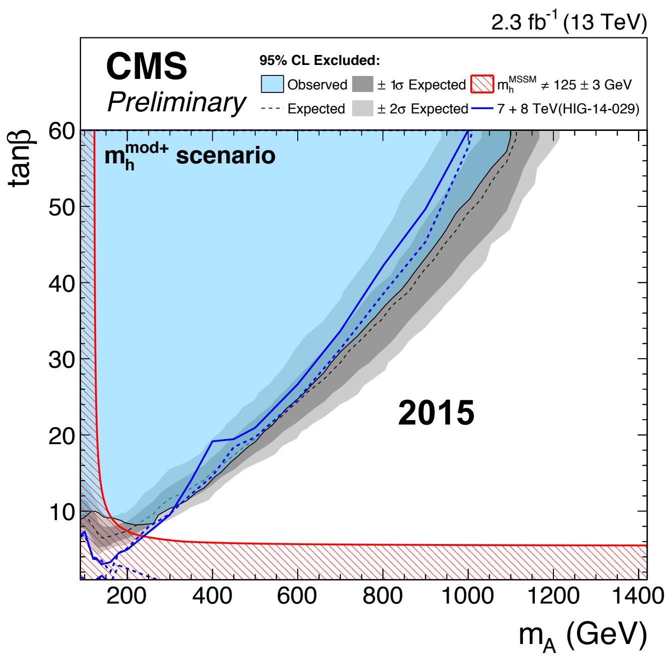


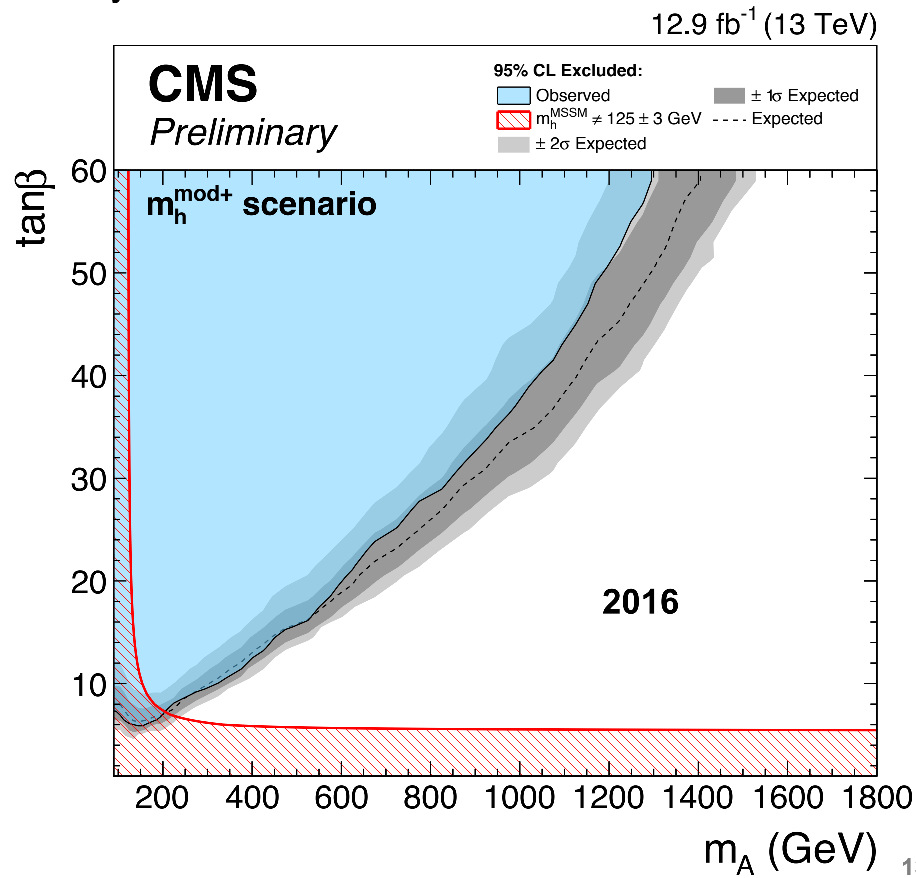
$\tau_h\tau_h$: best sensitivity in high mass region, because of falling QCD background

eμ: good sensitivity in very high mass region due to vanishing ttbar background

results: H/A→ττ model interpretation

- scan $\mathbf{m_A}$**-tanβ** plane in $m_h^{\text{mod+}}$ scenario
- light blue shaded region: observed exclusion
- grey bands: ±1, ±2 σ expected exclusion
- red shaded region: excluded due to lack of scalar h compatible with m_h=125±3 GeV
- already surpassed **run 1 limit** in 2015 analysis for mass > 300 GeV





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conclusions

- **new results** of MSSM Higgs -> tau tau at 13 TeV (HIG-16-037)

  http://cds.cern.ch/record/2231507

- **no evidence** for a signal has been found and **exclusion limits** are presented
- **improved sensitivity** and **extended the mass scale** with respect to previous 2015 analysis and run 1 analysis
- result has been interpreted in MSSM benchmark scenarios
- 37.8/fb data has been collected in 2016 by CMS
- stay tuned, **more results** will arrive soon!

Backups

analysis: baseline selections

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

trigger: μ (22), e(25)

Selections:

μ: pT>23GeV, |η|<2.1, Iso<0.15 **e:** pT>26GeV, |η|<2.1, Iso<0.1 **τ:** p > 20GeV, |η|<2.3, Medium Tau Iso ID

eμ

trigger: μ(8), e (23) or μ(23), e (12)

Selections:

μ: pT>10(24)GeV, |η|<2.4, Iso<0.2 **e**: p >13(24)GeV, |η|<2.5, Iso<0.15

$\tau_h\tau_h$

trigger: τ_h(35) & τ_h(35)

Selections:

τ: p >40GeV, |η|<2.1, Tight Tau Iso ID

all channels:

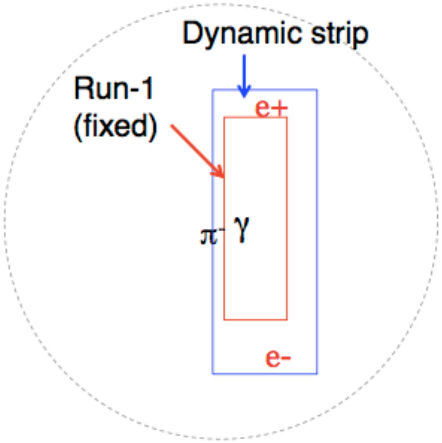
pair opposite-sign

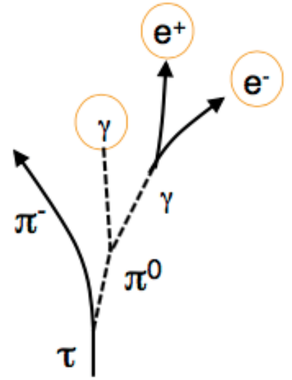
No additional loose e, μ

space separated $\Delta R > 0.5$

tau ID: dynamics strip reconstruction

- strip size in Run-1: $\Delta\eta \times \Delta\varphi = 0.05 \times 0.20$
- in Run-2, strip size adjusted dynamically as a function of the pT of e/γ to account for:
  - nuclear interactions of charged pions with the tracker material, which create low pT e/γ that may go outside the fixed strip
  - conversions of photons from neutral pion decays to electron/positron pairs, and bremsstrahlung
  - boosted tau decay products in the case of high-pT taus





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analysis: background modeling

eτ, μτ channel

> $Z/\gamma \rightarrow \tau$

- prediction taken from Monte Carlo (MC) simulation
- shape correction in p_T^Z with data events

> Top pair production

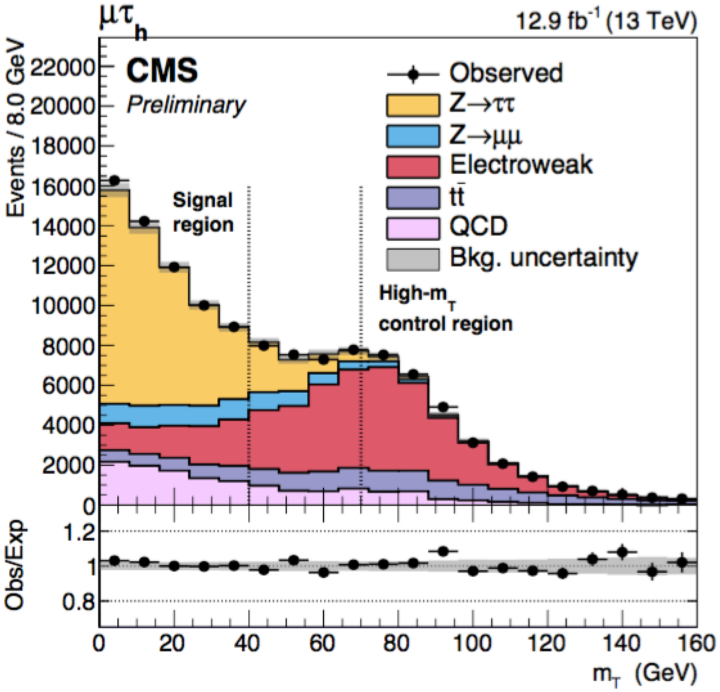
- prediction from MC simulation

> **W+Jets**

- shapes from MC simulation
- normalization from high mt sideband

> **QCD multijet**

- fully data-driven
- **shape** from same sign region
- **normalized** with OS/SS extrapolation factor derive from sideband region



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analysis: background modeling

eμ channel

> $Z/\gamma \rightarrow \tau$

- prediction taken from Monte Carlo (MC) simulation
- shape correction in p_T^Z with data events

> **Top pair production**

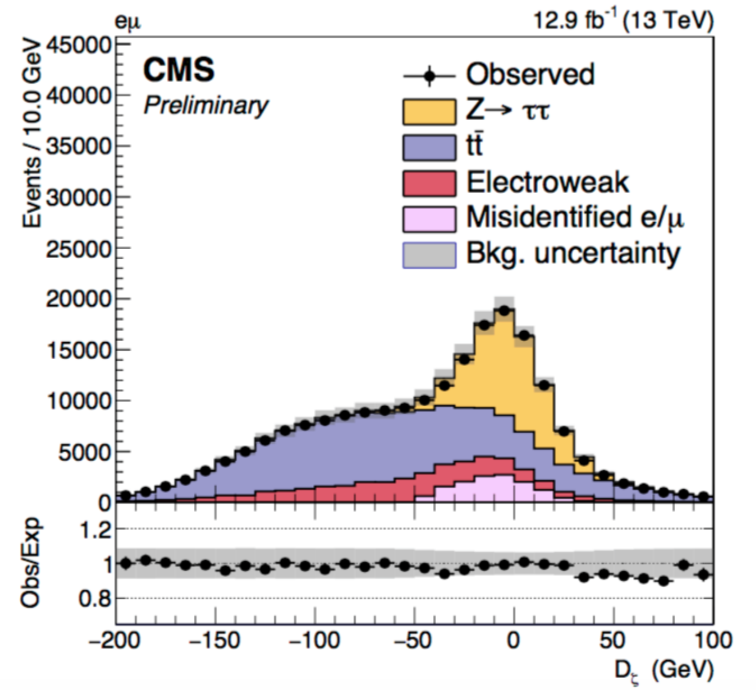
- prediction taken from MC simulation
- **shape** correction in top p_T

> W+Jets

- prediction from MC simulation

> **QCD multijet**

- fully data-driven
- **shape** from same sign region
- **normalized** with OS/SS extrapolation factor in function of leading lepton p_T, trailing lepton p_Td and and ΔR(e,μ), derive from sideband region



analysis: background modeling

ττ channel

> $Z \rightarrow \tau\,\tau$

- prediction taken from Monte Carlo (MC) simulation
- shape correction in p_T^Z with data events

> Top pair production and W+Jets

- prediction taken from MC simulation

> **QCD multijet**

- fully data-driven
- **shape** from OS region with loosened isolation
- **normalization** from OS region with loosened isolation (SR excluded), extrapolation factor loose—>tight isolation (measured in equivalent SS regions) applied.

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results: H/A→ττ model interpretation

- in hMSSM scenario
- light blue shaded region: observed exclusion
- Dashed line: expected exclusion
- Grey bands ± 1,2 σ expected
- no red shaded area in this figure, as m_h = 125 GeV enforced in the hMSSM