PANIC11

Higgs boson searches with tau leptons in CMS

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On behalf of the CMS Collaboration

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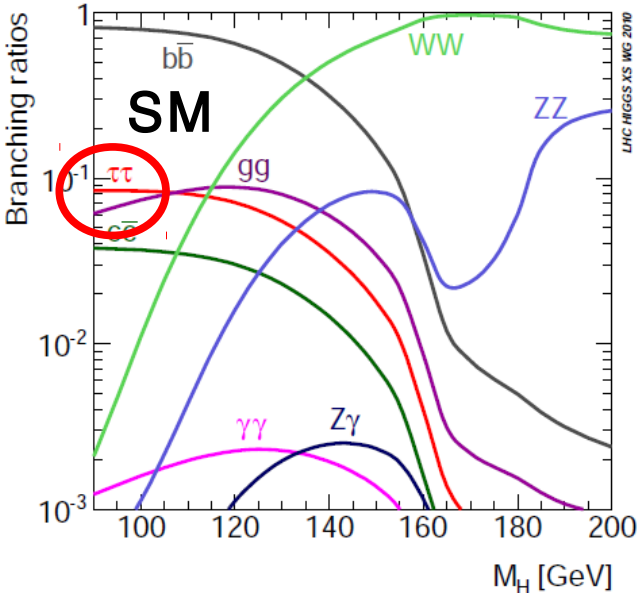
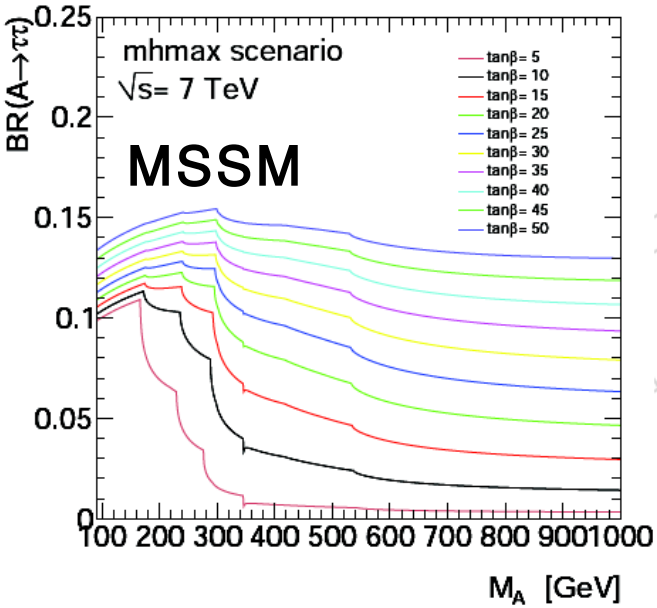
CMS PAS HIG-11-008,HIG-11-009

Introduction

- Tau is the heaviest lepton
  - Higgs couples to mass
  - Violation of lepton universality
    - direct evidence for tau decays of Higgs bosons
- Standard Model(SM)
  - Branching fraction ($H \rightarrow \tau\tau$) of ~10% for low Higgs mass
- Minimal Supersymmetric Standard Model(MSSM)
  - Branching fraction ($\Phi \rightarrow \tau\tau$) of 10-15% at low M_A
  - Enhanced at high tanβ
  - Charged Higgs possible
    - $H^+ \rightarrow \tau\,\nu$
- Results are presented for $H/\Phi \rightarrow \tau\tau$ and $H^+ \rightarrow \tau\nu$ with 1.1 fb^{-1} of data

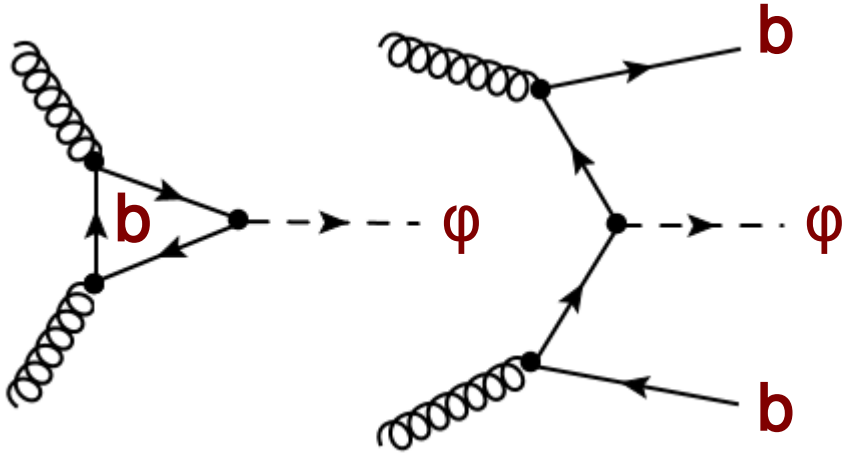




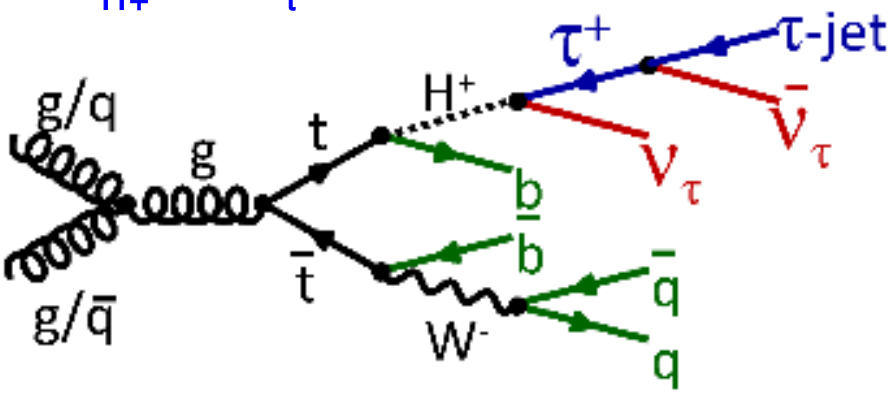
Production Mechanisms @ LHC

MSSM(2 doublets/5 Higgs bosons)

φ via gluon fusion or associated production with b quarks(σ ~ tanβ^2)

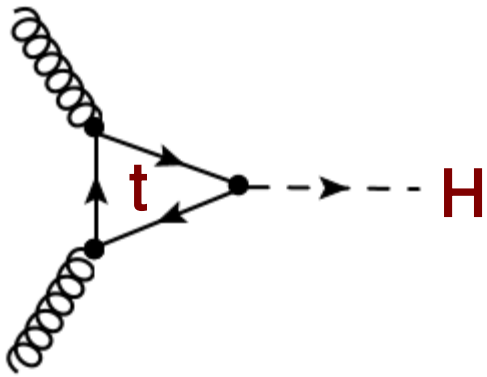


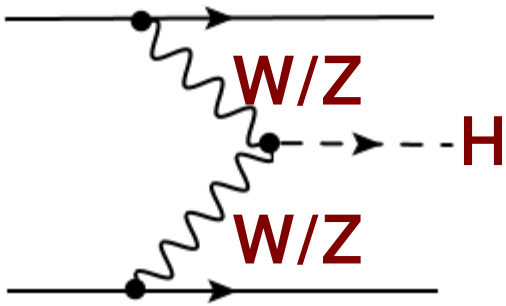
For $M_{H+} < M_t$, t → bH



SM

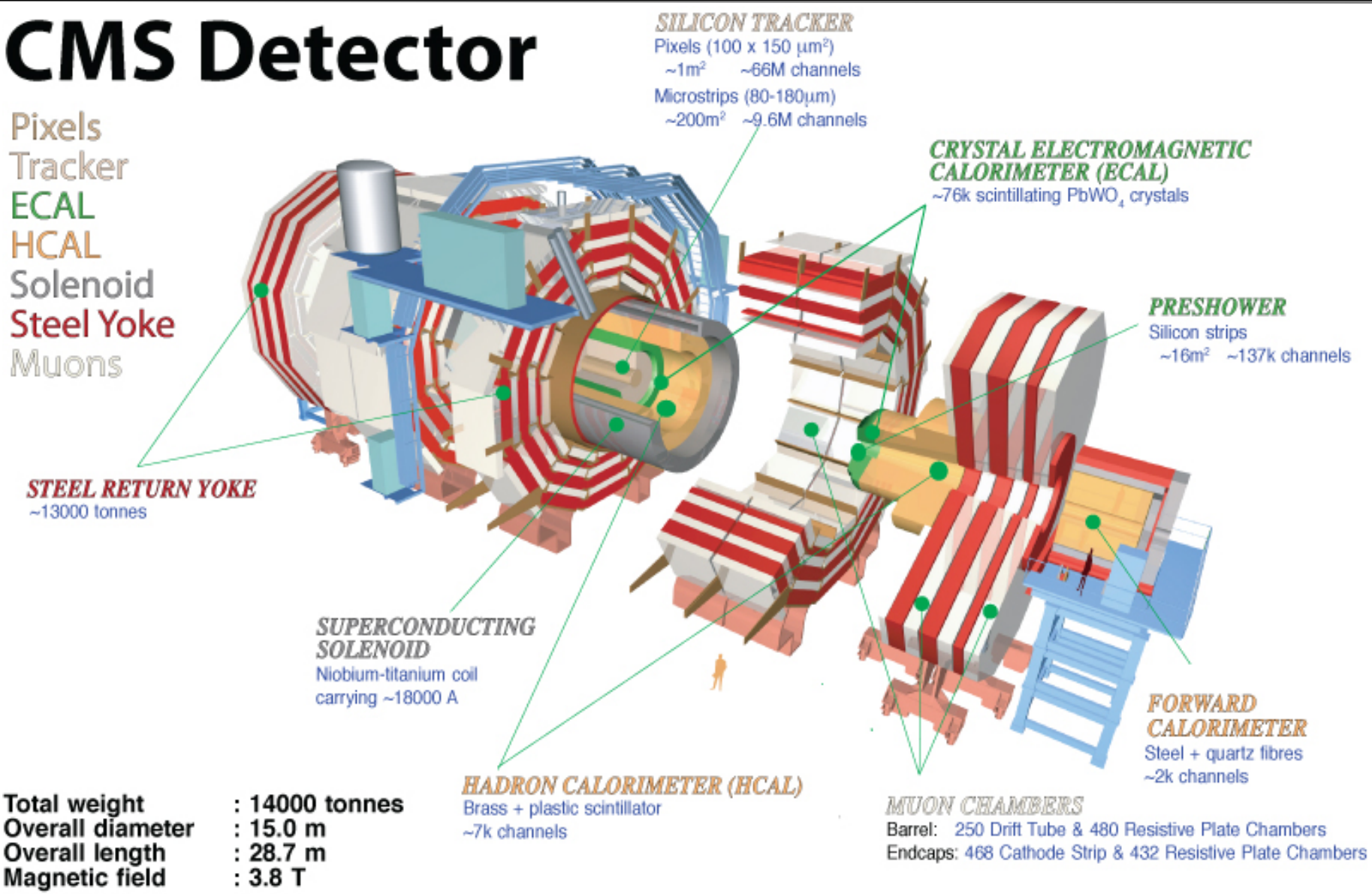
Gluon fusion dominates (irreducible Z → ττ)





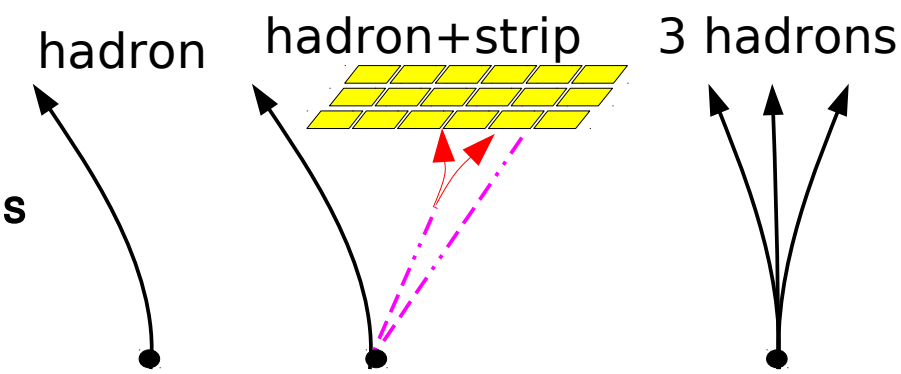
VBF: Low cross section
Z → ττ suppressed

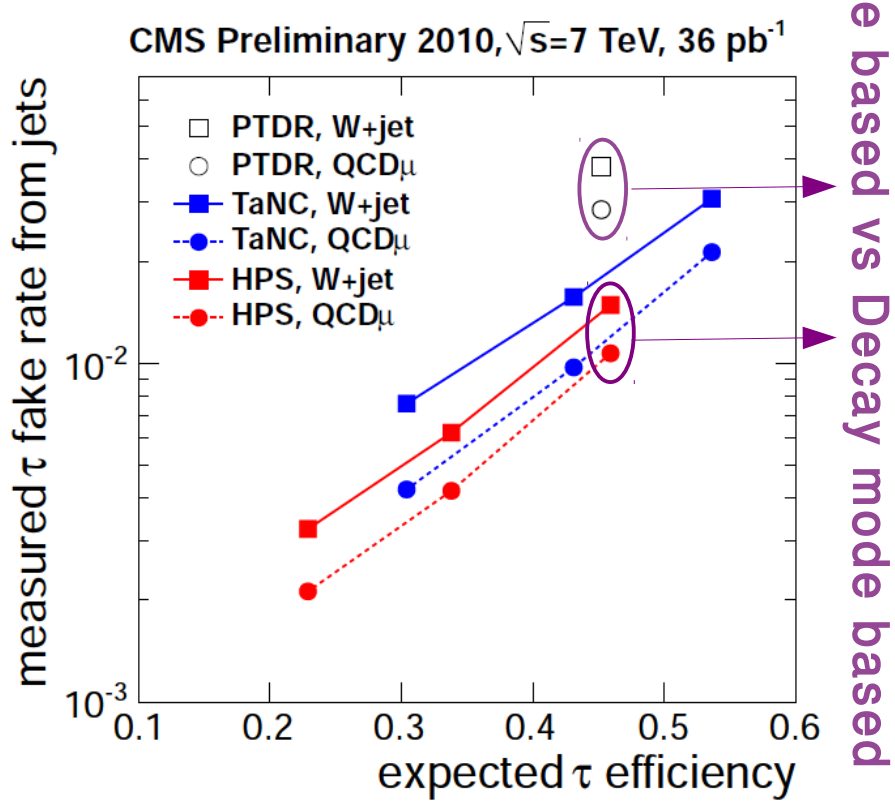
The CMS Detector



Hadronic Tau Identification

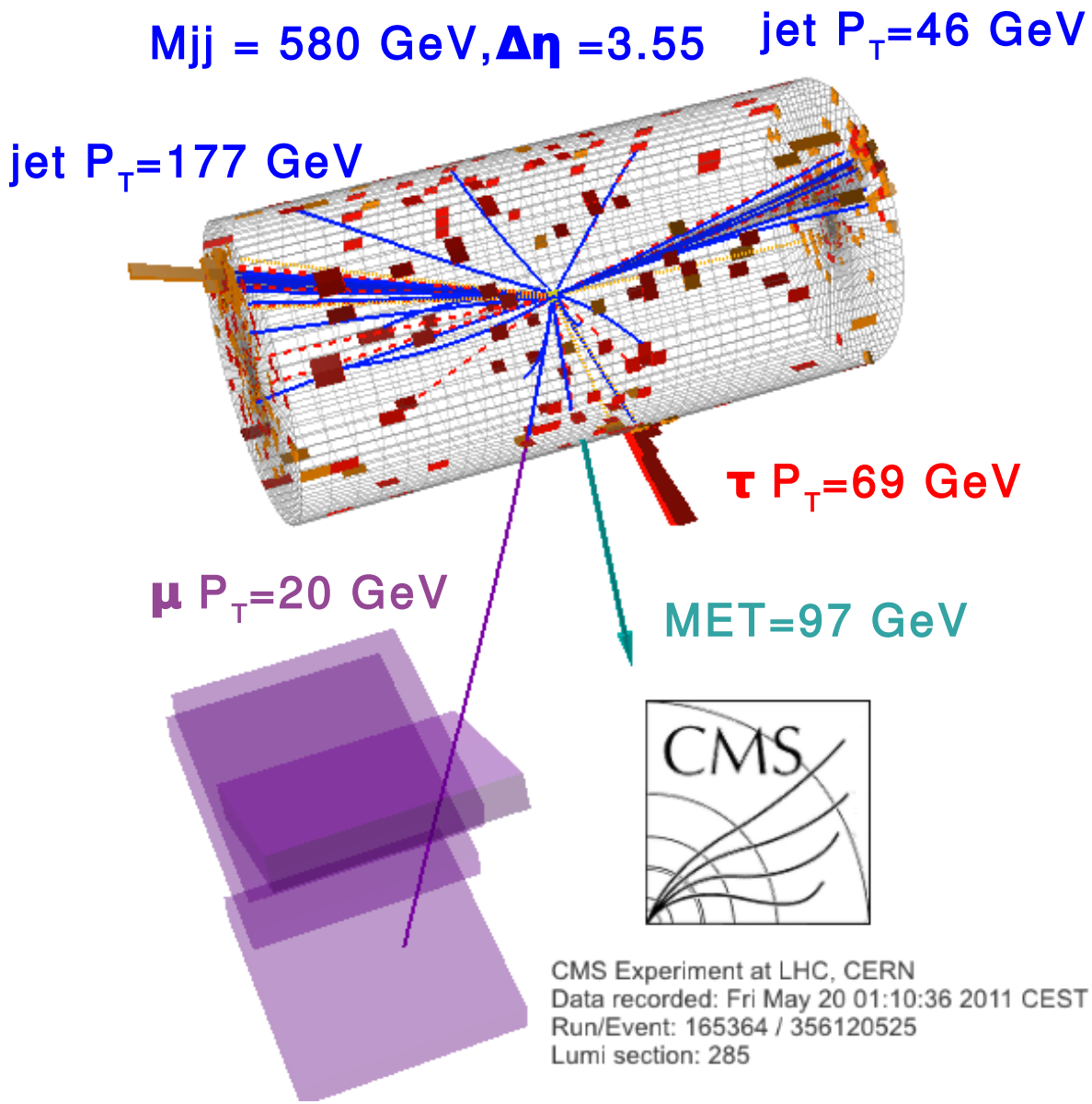
- Cut based/ using Particle Flow(PF)
- Starts from Jets made of PF candidates
- Creates tau decay mode combinations
  - Reconstructs individual **ρ/α**[1] resonances
    - Introducing strip of EM objects
      - For **γ** conversions
    - Tau energy measured only by the constituents!
- Applies criteria on narrowness,mass and isolation
- Efficiency of ~50% for 20 GeV taus , fakes < 1%
- Efficiency scale factor from data (~1 fb^{-1}) = 1.00 ± 0.06
- Simple version of the algorithm (using PF) runs on the high level trigger





VBF H → ττ candidate event display

SM/MSSM
H → ττ
search



Event Preselection

Analysis is performed using four final states

μ+τ

- Trigger
  - μ(15)+τ(15/20)
- Offline
  - μ P_T>15 GeV, η<2.1
  - τ P_T>20 GeV, η<2.3
  - Opposite charge

e+τ

- Trigger
  - e(18)+τ(20)
- Offline
  - e P_T>20 GeV,η<2.1
  - τ P_T>20 GeV, η<2.3
  - Opposite charge

e+μ

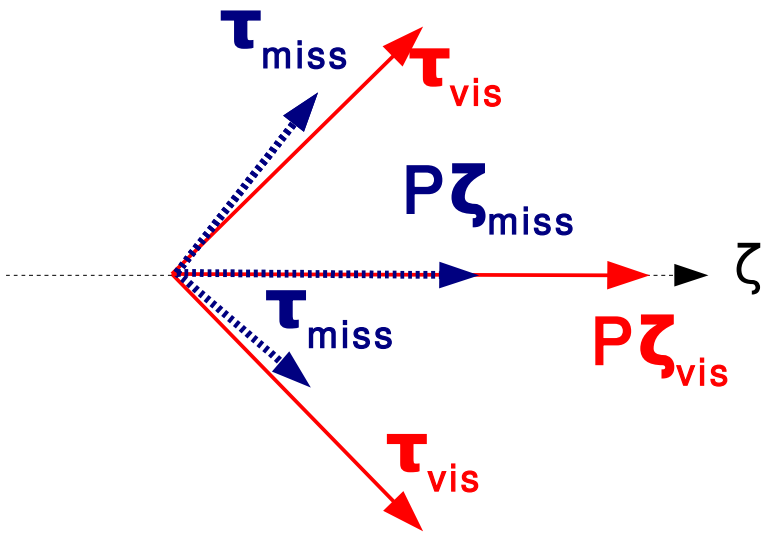
- Trigger
  - μ(17/8)+ e(8/17)
- Offline
  - μ P_T> 20/10 GeV,η<2.1
  - e P_T>10/20 GeV, η<2.5
  - Opposite charge

μ+μ

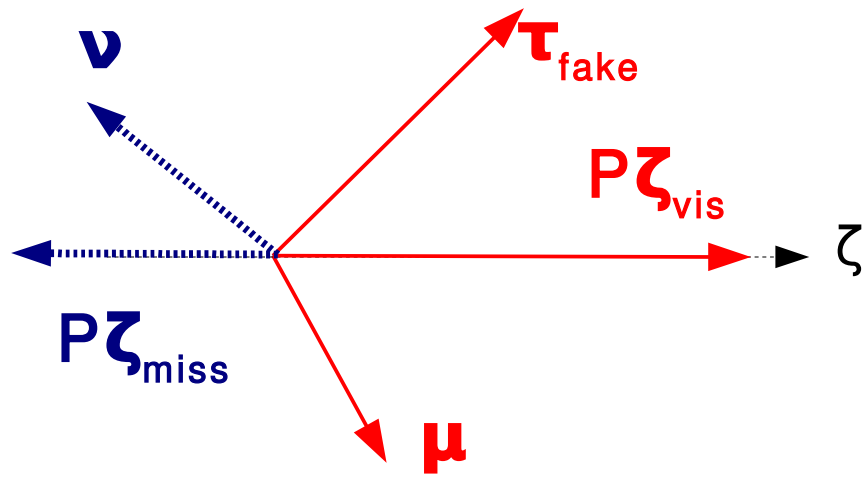
- Trigger
  - μ(17)
- Offline
  - 1st μ P_T>20 GeV,η<2.1
  - 2nd μ P_T>10 GeV,η<2.4
  - Opposite charge

Topological requirements

Real ττ event



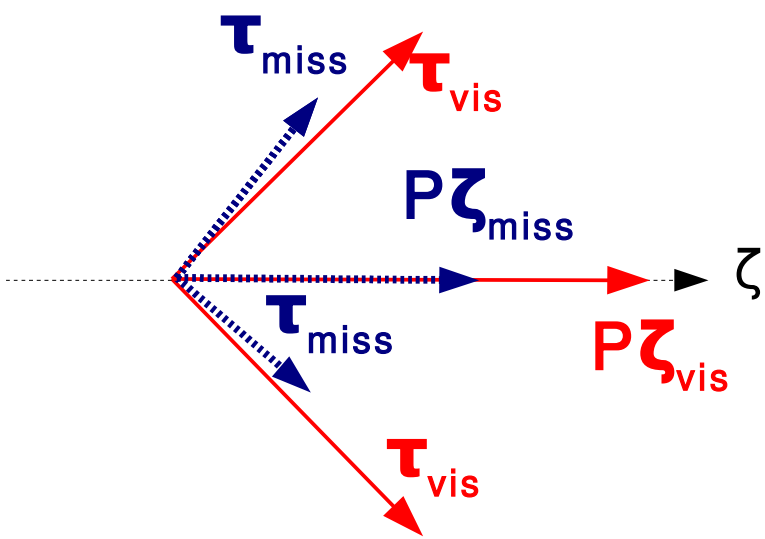
W+jets event

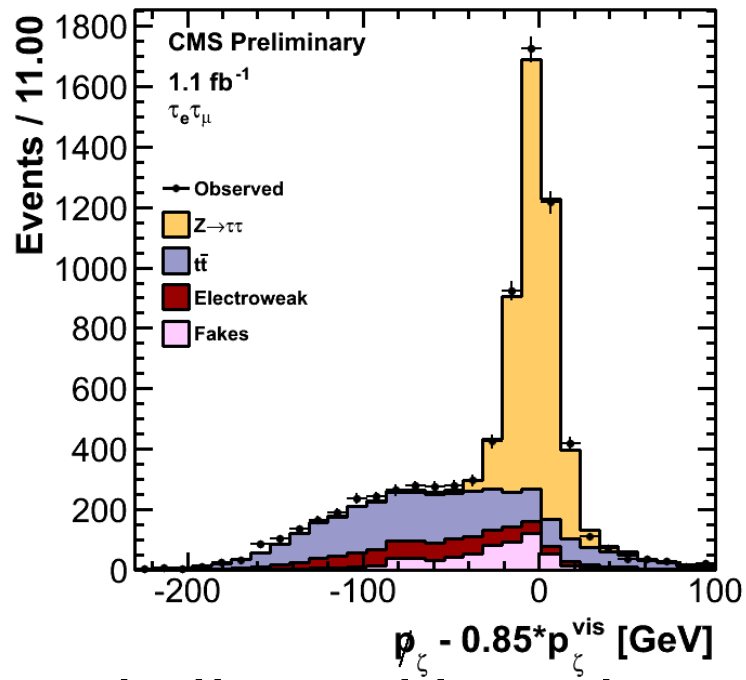


- Neutrinos from taus tend to be collinear to the visible part
  - Not the case for W+jets and TTBar
- Define P_ζ variables(introduced in CDF)
  - Project visible di-tau transverse momentum vector and MET in the bisector axis of the visible products
  - Request collinearity between visible and missing E_T part

Topological requirements

Real ττ event





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  - Request collinearity between visible and missing E_T part

Event Categorization

Analysis is performed using four categories

MSSM(b-tag)

- Require less than 2 jets with P_T>30 GeV
- Require at least one b-tagged jet with P_T>20 GeV

SM(VBF)

- Require exactly two jets with P_T>30 GeV,opposite **η**
- Require $\Delta\eta(jj)$ >3.5 , M(jj)>350 GeV

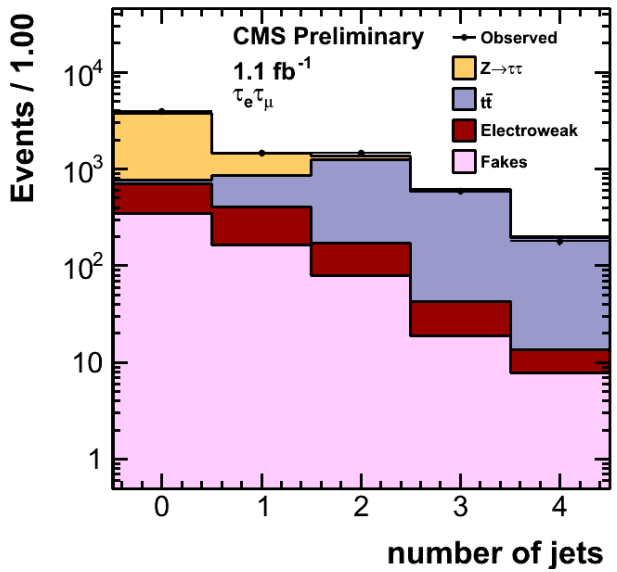
MSSM(No b-tag)

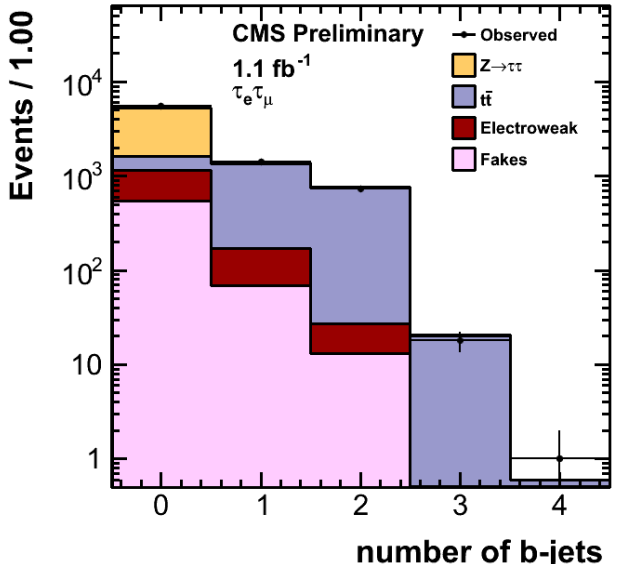
- Require less than two jets with P_T>30 GeV
- Require no b-tagged jets with P_T> 20 GeV

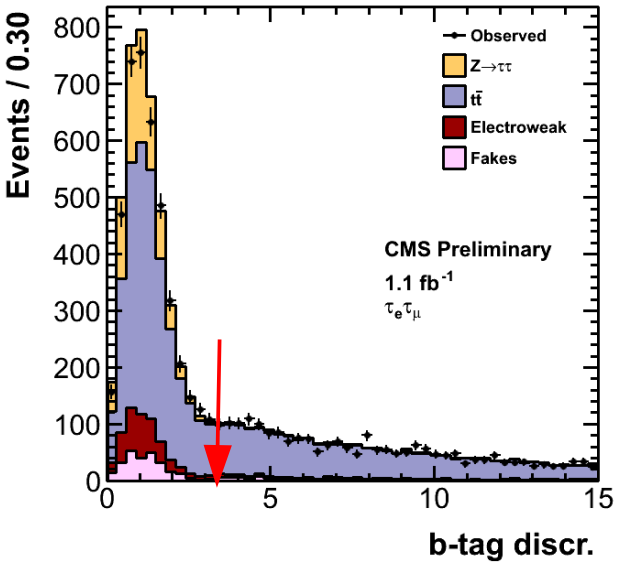
SM(No VBF)

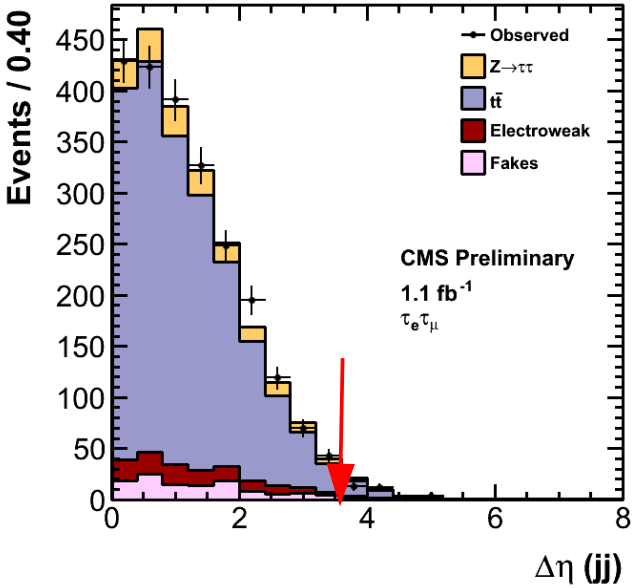
- Require less than two jets with P_T>30 GeV
- OR two jets failing VBF criteria

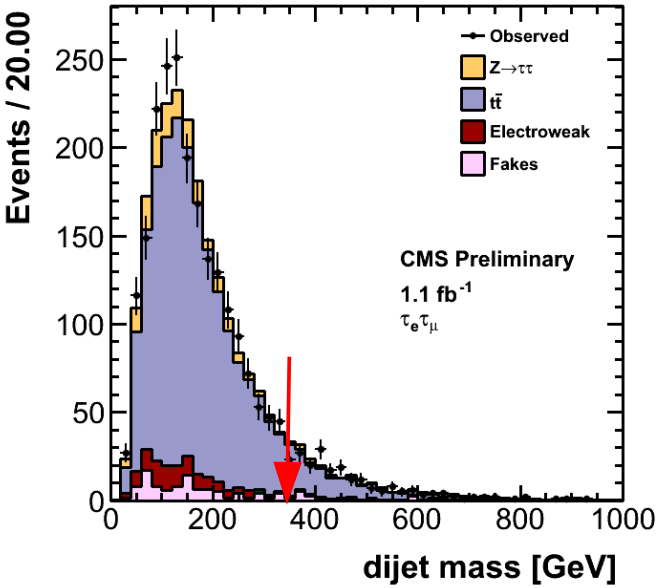
Categorization related variables







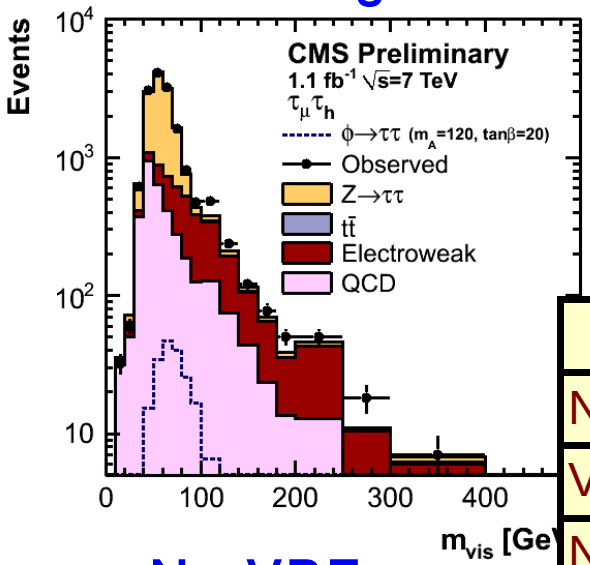




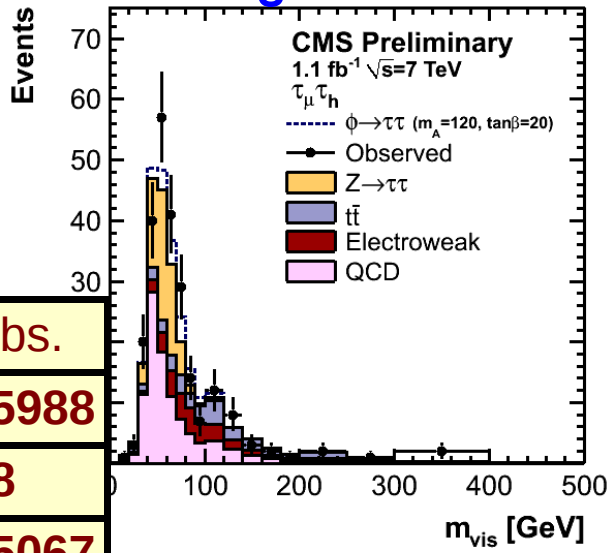
Visible Mass after all requirements(μ+τ)

MSSM

No b-tag



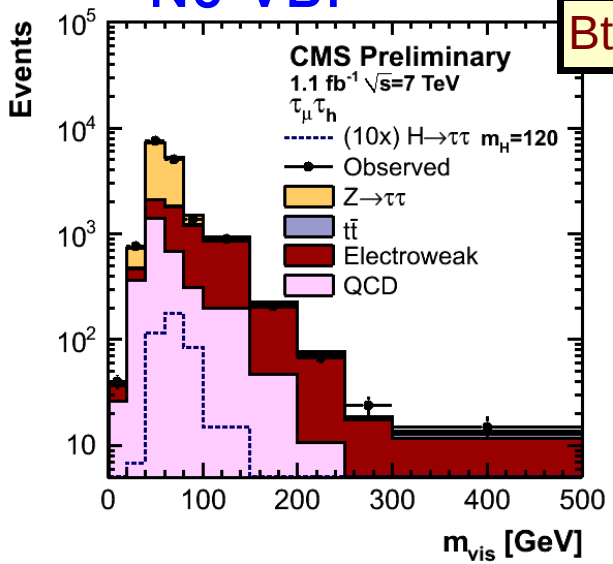
b-tag



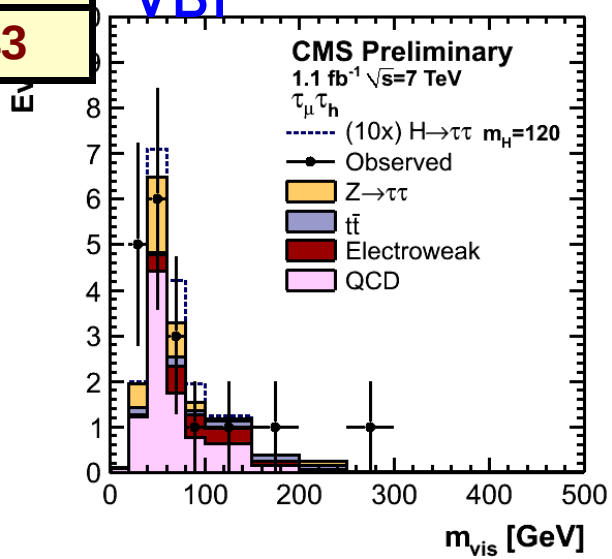
	Background	Obs.
No-VBF	**15544 ± 685**	**15988**
VBF	**14.2 ± 4.0**	**18**
No btag	**14514 ± 640**	**15067**
Btag	**193 ± 13**	**243**

SM

No VBF



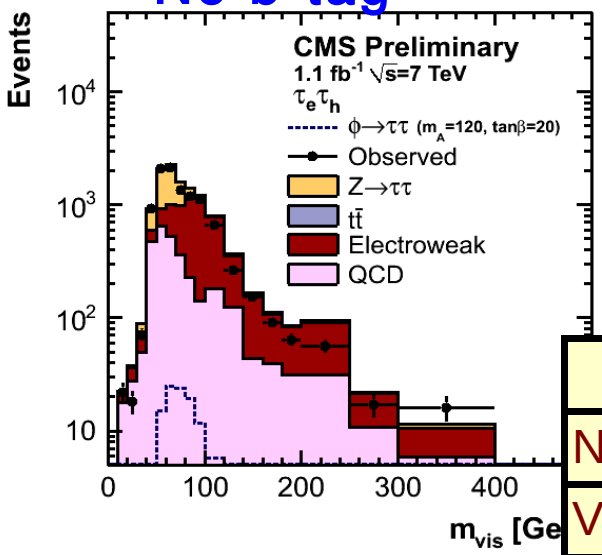
VBF



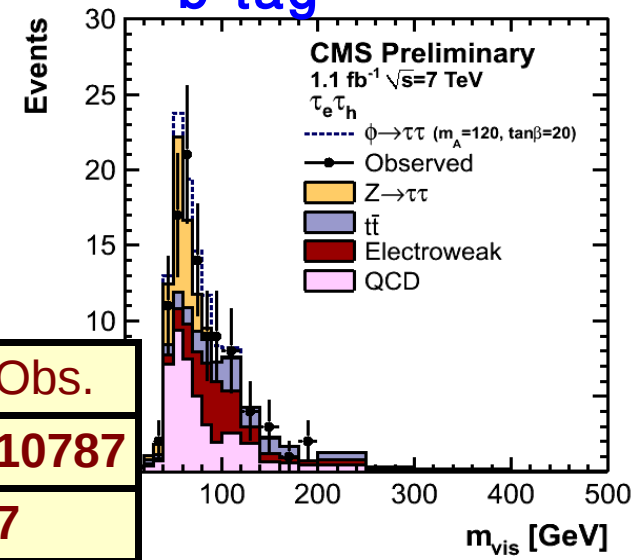
Visible Mass after all requirements(e+τ)

MSSM

No b-tag



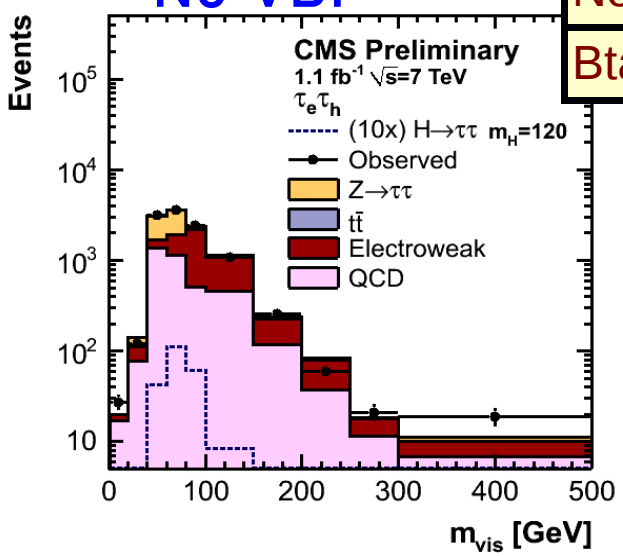
b-tag



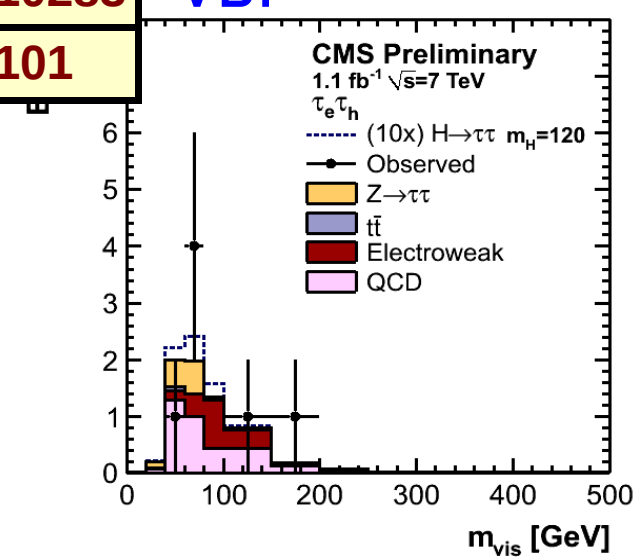
	Background	Obs.
No-VBF	**9980 ± 302**	**10787**
VBF	**5.9 ± 2.5**	**7**
No btag	**9398 ± 320**	**10283**
Btag	**105 ± 9**	**101**

SM

No VBF



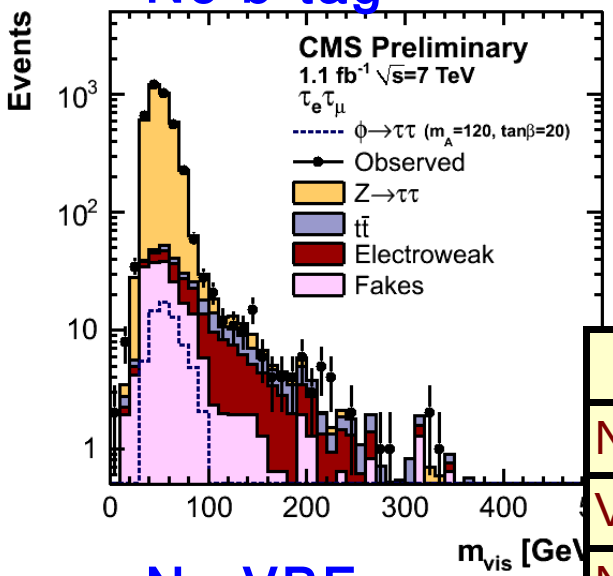
VBF



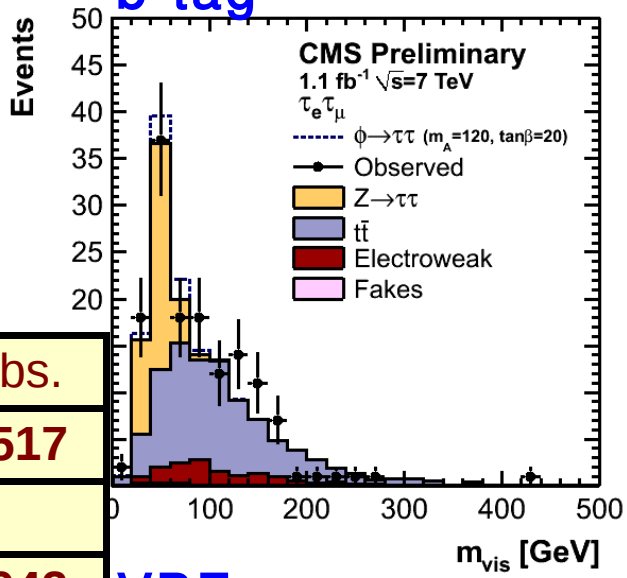
Visible Mass after all requirements(e+μ)

MSSM

No b-tag



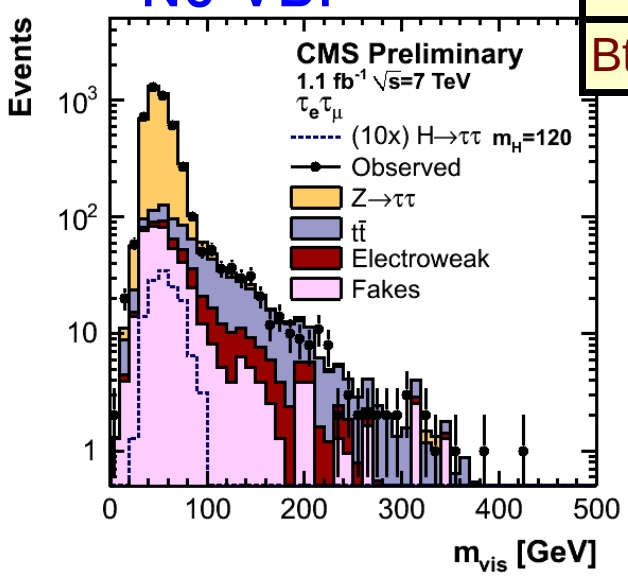
b-tag



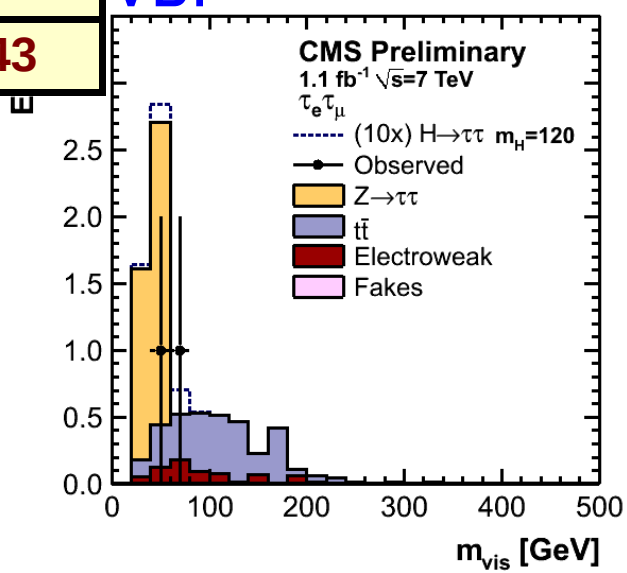
	Background	Obs.
No-VBF	**4251 ± 151**	**4517**
VBF	**6.7 ± 0.9**	**2**
No btag	**3643 ± 131**	**3942**
Btag	**150 ± 12**	**143**

SM

No VBF



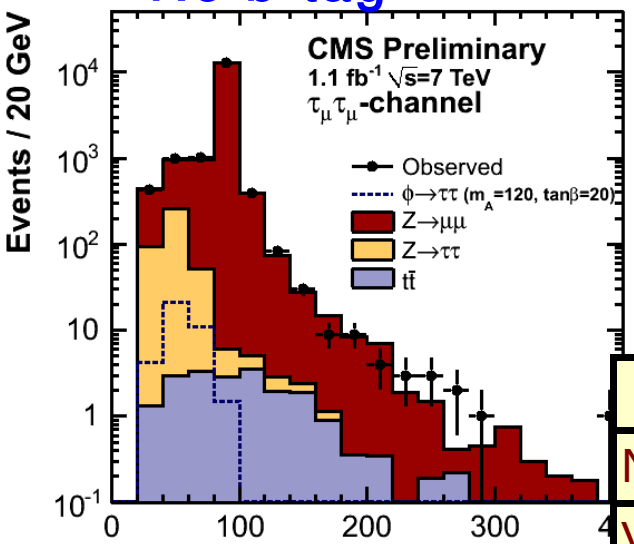
VBF



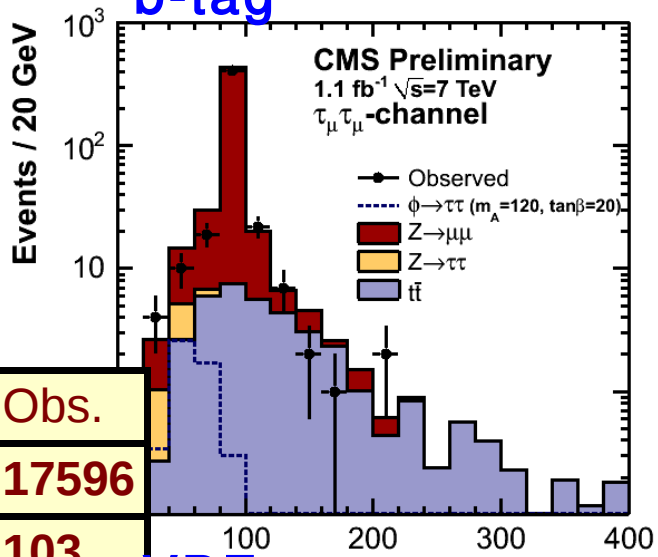
Visible Mass after all requirements(μ+μ)

MSSM

No b-tag



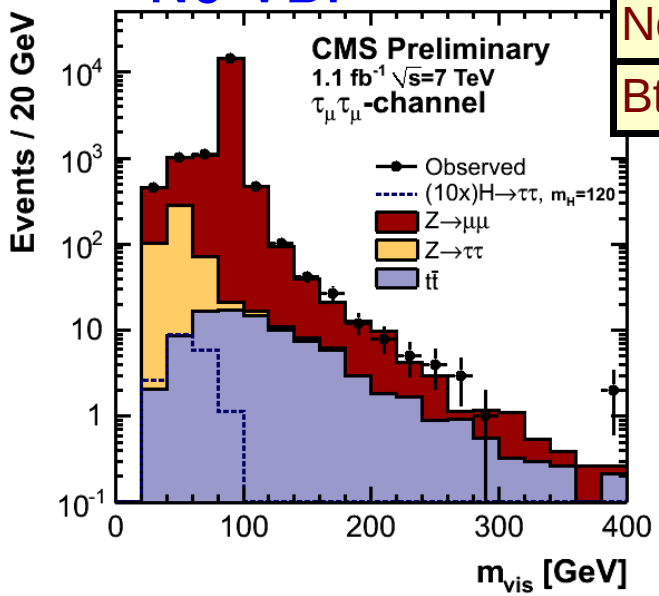
b-tag



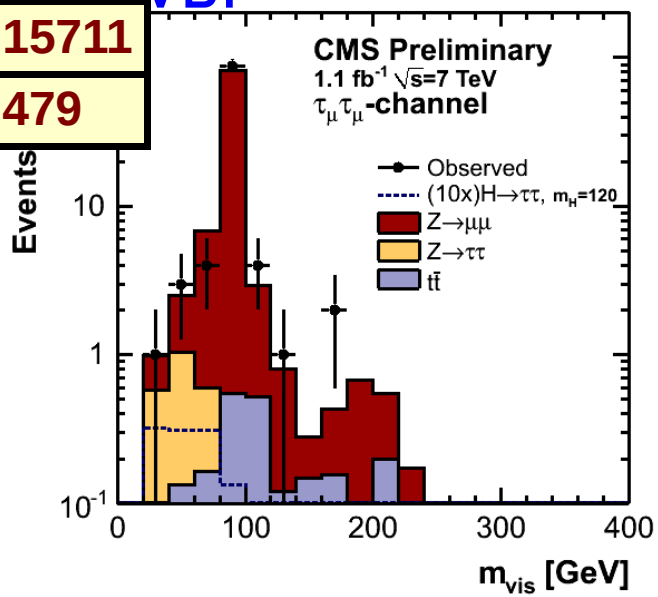
	Background	Obs.
No-VBF	17392 ± 117	17596
VBF	91.6 ± 7.0	103
No btag	15645 ± 105	15711
Btag	460 ± 12	479

SM

No VBF



VBF



Background estimation and systematics

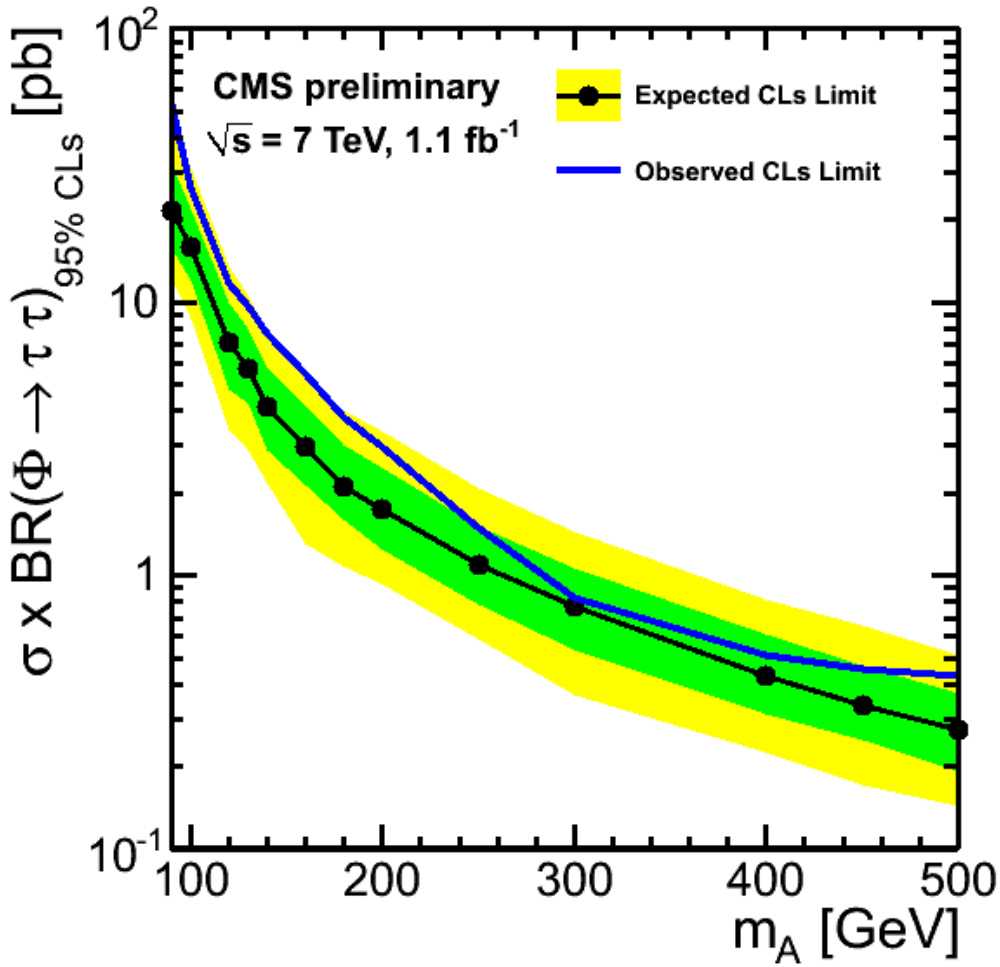
- **Z → ττ** and TTbar : irreducible
  - Estimated from CMS **σ**(Z) /**σ**(ttbar)
- Data driven estimation for QCD/W+jets
  - OS/SS+W sideband for l+**τ**
  - Fake rate for e+**μ**
- Constrained fit performed to extract signal cross section or set limit
  - Background and systematic uncertainties as nuisance parameters
  - Shapes from data(QCD) or MC
    - Shape agreement checked in sideband regions
    - MC shapes allowed to vary in the fit

Systematic uncertainties

Source	Uncertainty
Lepton ID /trigger	**1%**
Tau ID efficiency	6%
Tau energy scale	**3%**
σ(Z → μμ/ee)	**3%**
σ(ttbar)	12%
B-Tag Efficiency	10%
B-Tag Mistag rate	14%
Jet energy scale	2-5%
PDFs	3%
UE/Parton Shower	4%
QCD Scale	4-12%
Luminosity	6%

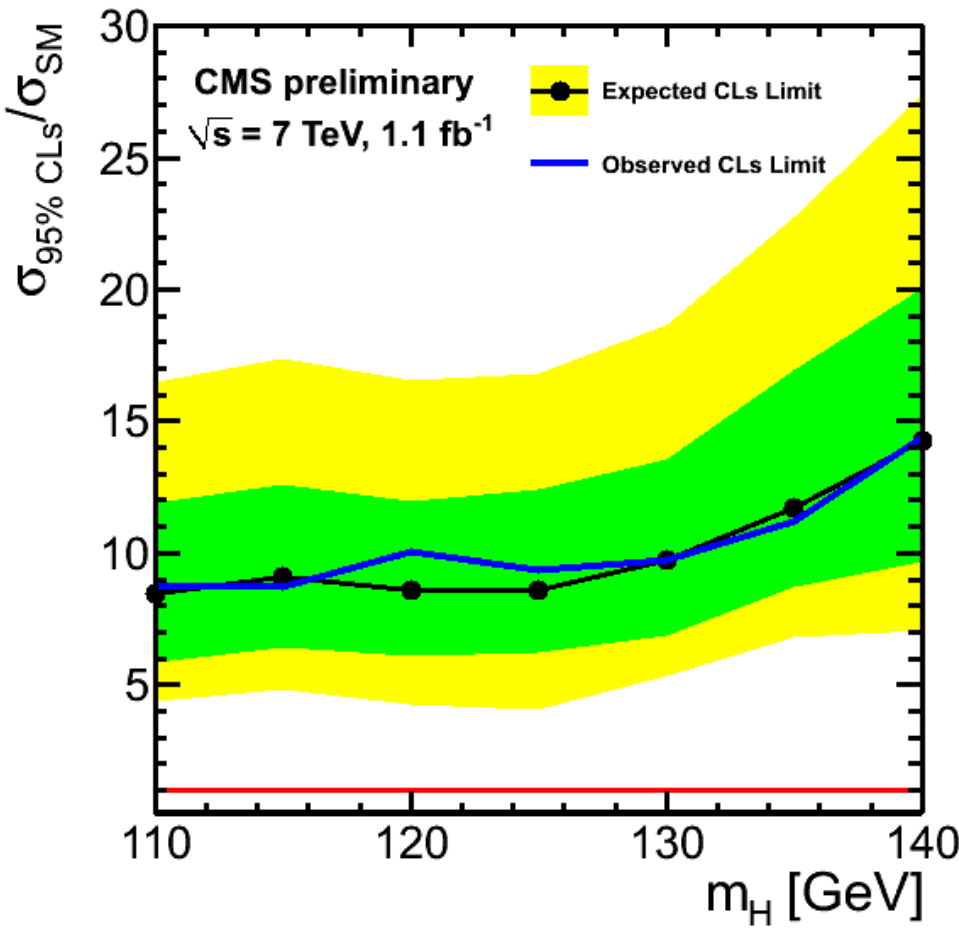
MSSM Higgs search results

- No significant excess observed in MSSM search
- Limits set on cross section xBR($\Phi \rightarrow \tau\tau$)
- Using CLs method
- σ x BR Limit not model independent
  - MSSM specific
  - bbH/ggH cross section ratio constrained to the ratio in MSSM
    - tanβ =30
    - Changes with M_A

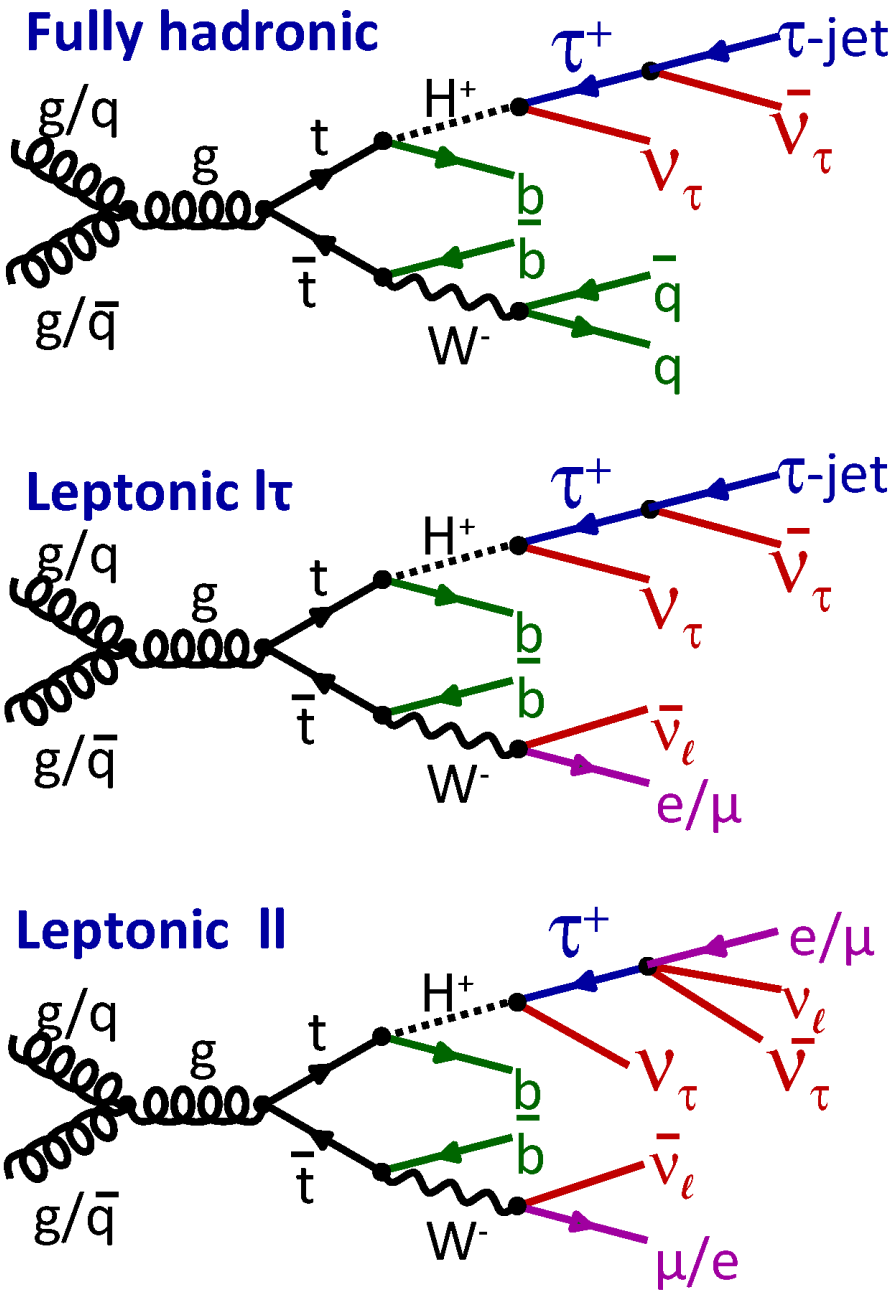


SM Higgs search results

- Expect to exclude <10x SM at low mass region
- Observed compatible with expectation
- Included in the CMS grand combination
- Achieved much better sensitivity compared to projections
  - Tau ID / Trigger improvements
- Full analysis potential not exploited yet



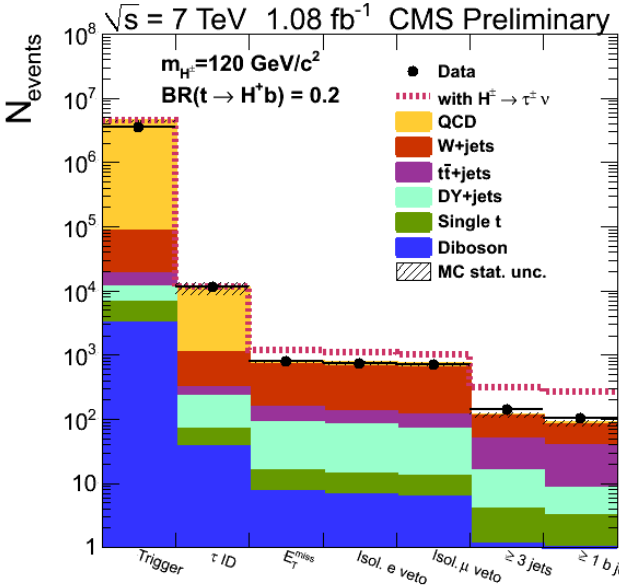
Light Charged Higgs search



Final states

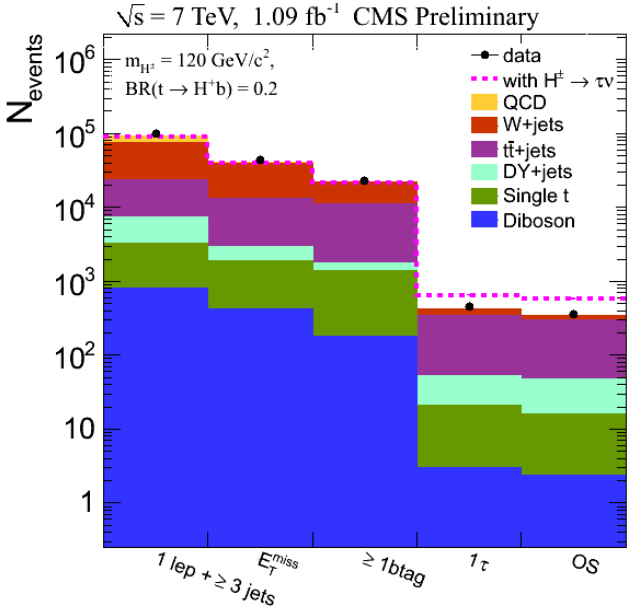
Fully Hadronic

- Trigger
  - Tau(35)+MET(60)
- Offline
  - τ P_T>40 GeV, η<2.3(1 prong)
  - At least 3 jets P_T>30 GeV
  - MET>70 GeV
  - One b-tag



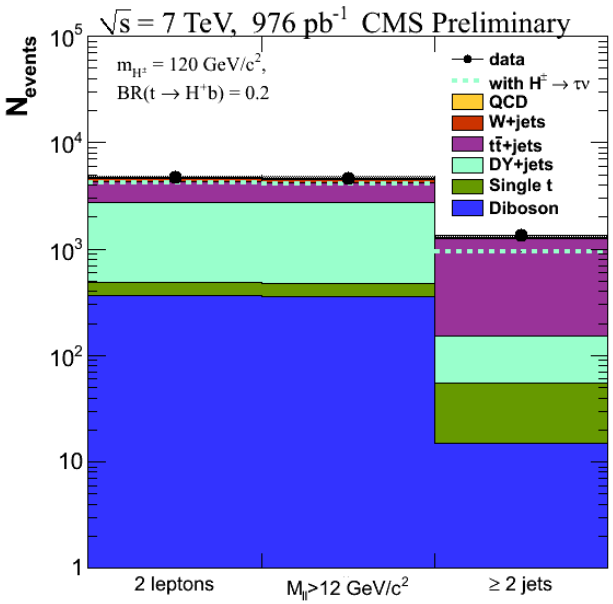
μ+τ

- Trigger
  - μ(17)
- Offline
  - μ P_T>20 GeV, η<2.1
  - τ P_T>20 GeV, η<2.4
  - At least 2 jets P_T>30 GeV
  - MET> 40 GeV
  - One b-tag



μ+e

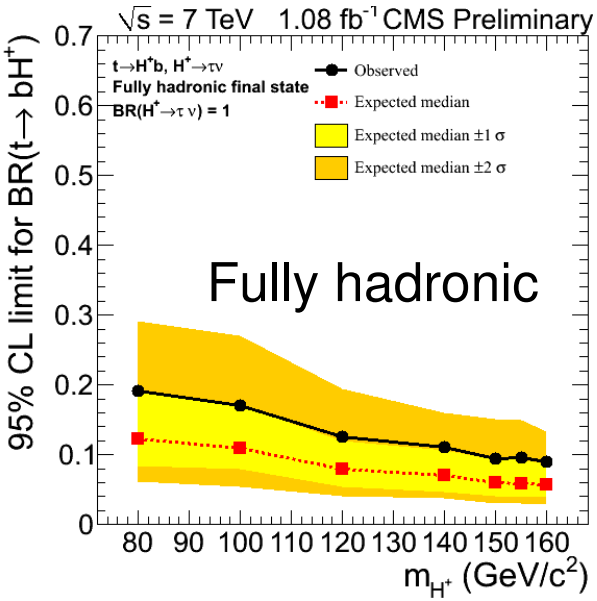
- Trigger
  - e(8)+μ(17)
  - e(17) +μ(8)
- Offline
  - Lepton P_T>20, η<2.4
  - At least 2 jets P_T>30 GeV

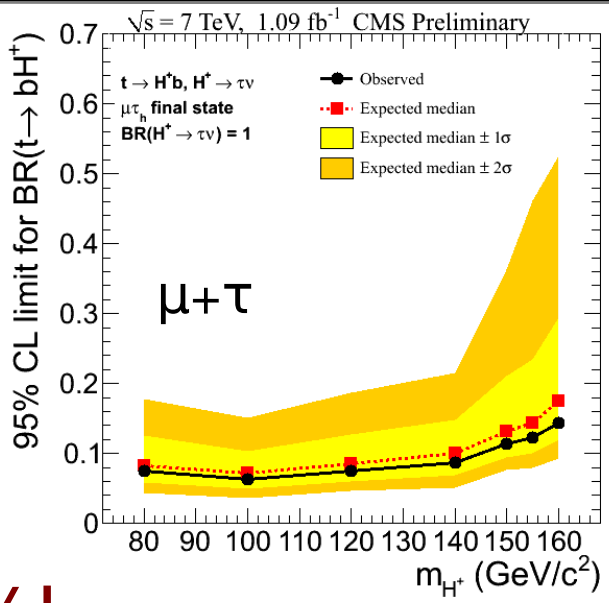


Background estimation

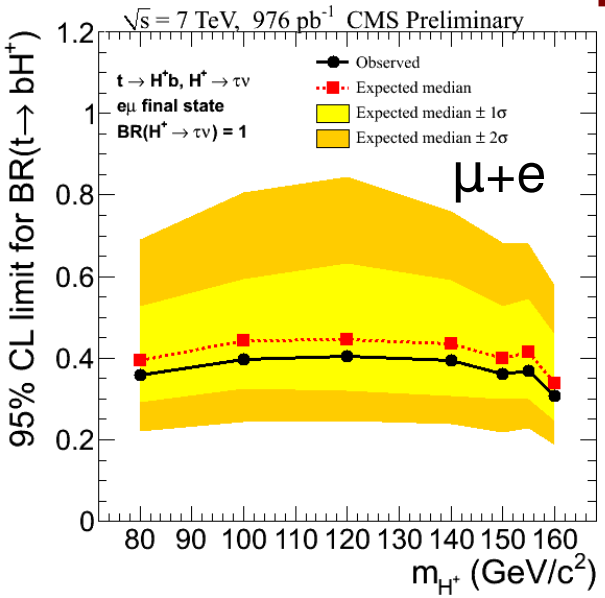
- Fully hadronic
  - QCD multijet background from data
  - EWK +tt with real taus estimated with embedding on muon events
  - EWK+ tt with fake taus by simulation
- $\mu+\tau$
  - QCD estimated by tau fake rate method
  - Other backgrounds from simulation
- $e+\mu$
  - Ttbar background dominant
  - Estimated from simulation

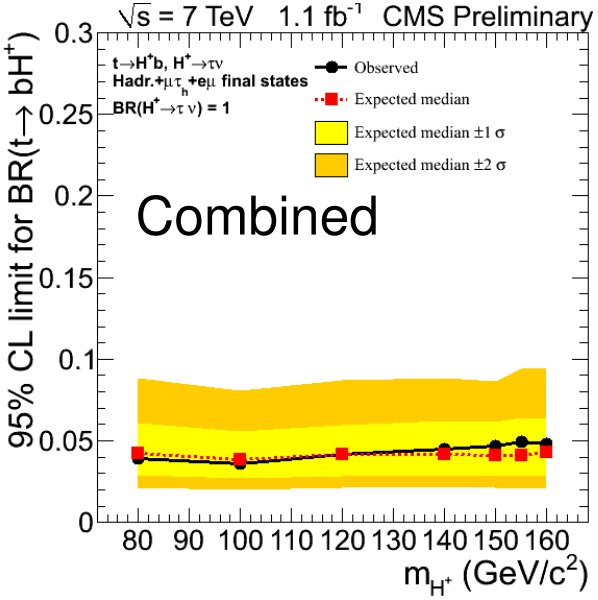
Branching fraction limits



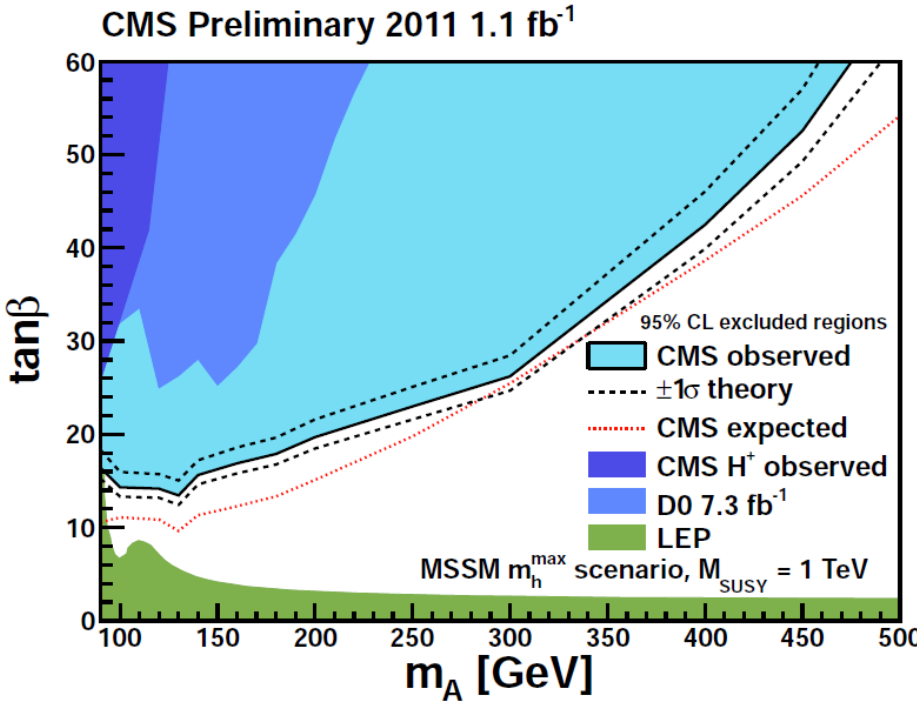


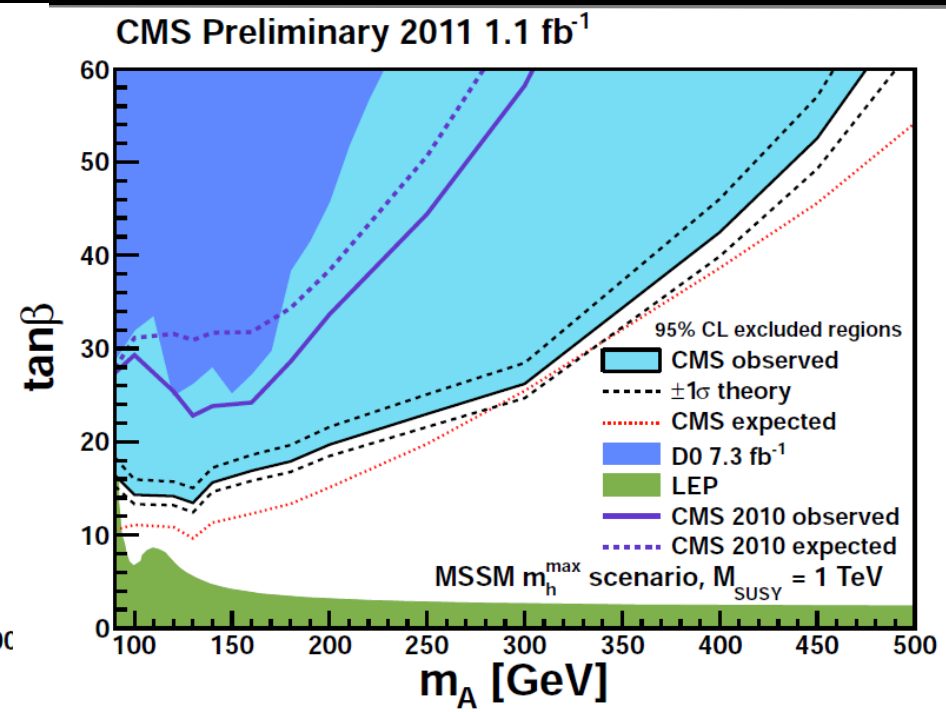
Excluding BR(t → bH) ~5%!





CMS statement on the MSSM with 1.1 fb^{-1}





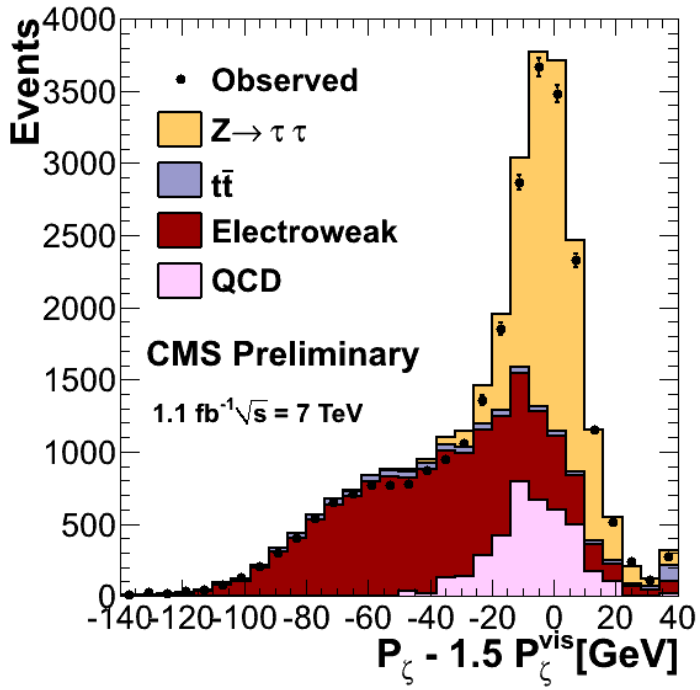
- H^+ contributes at low M_A, $H \rightarrow \tau\tau$ drives the sensitivity
- Excluding MSSM at tanβ ~ 15 for low MA
- Opening new regime at high M_A
- Huge improvement wrt the Moriond result
  - B-tagging/tau ID efficiency and more data!

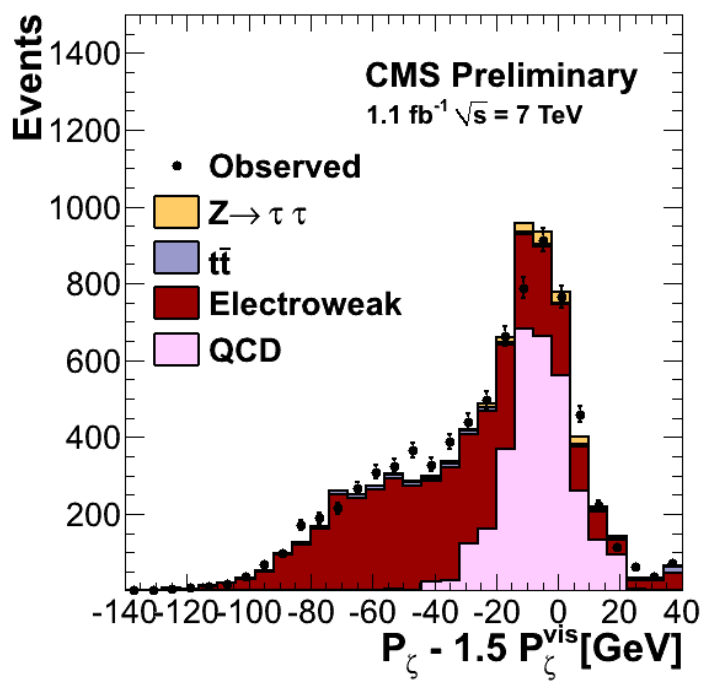
Conclusions

- Results have been presented on SM/MSSM Higgs searches with taus using 1.1 fb^{-1} of CMS data
  - Thanks to the excellent performance of LHC and CMS
- Results set new stringent limits in MSSM parameter space
- First results on SM Higgs in di-tau final state are very promising

BACKUP SLIDES

Background estimation(l+τ)

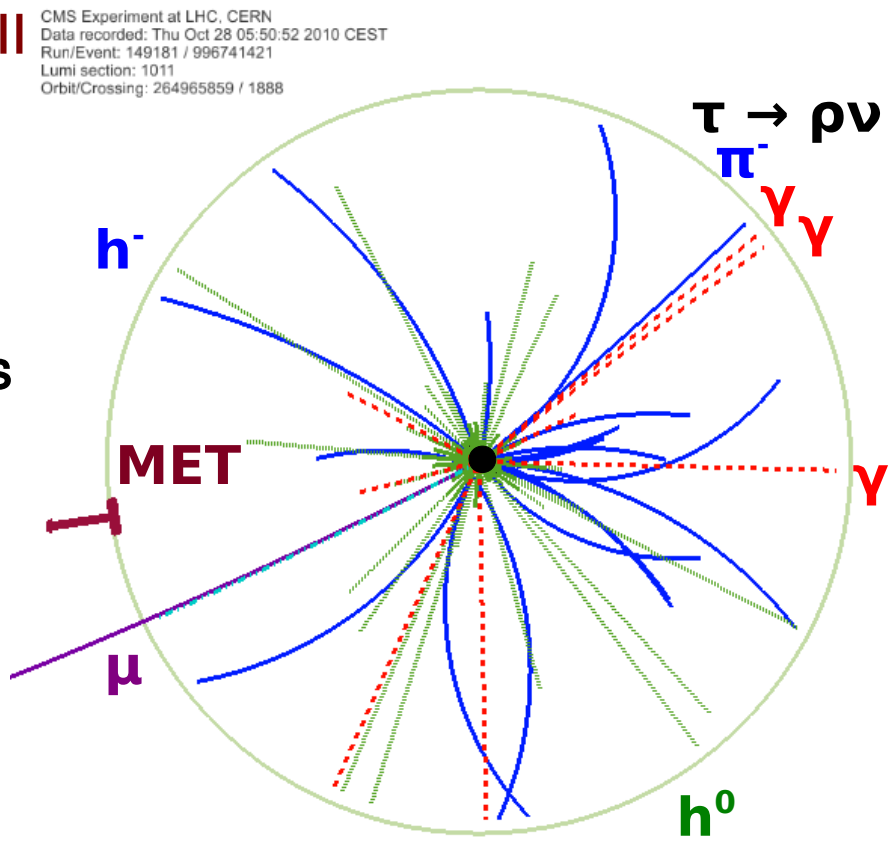




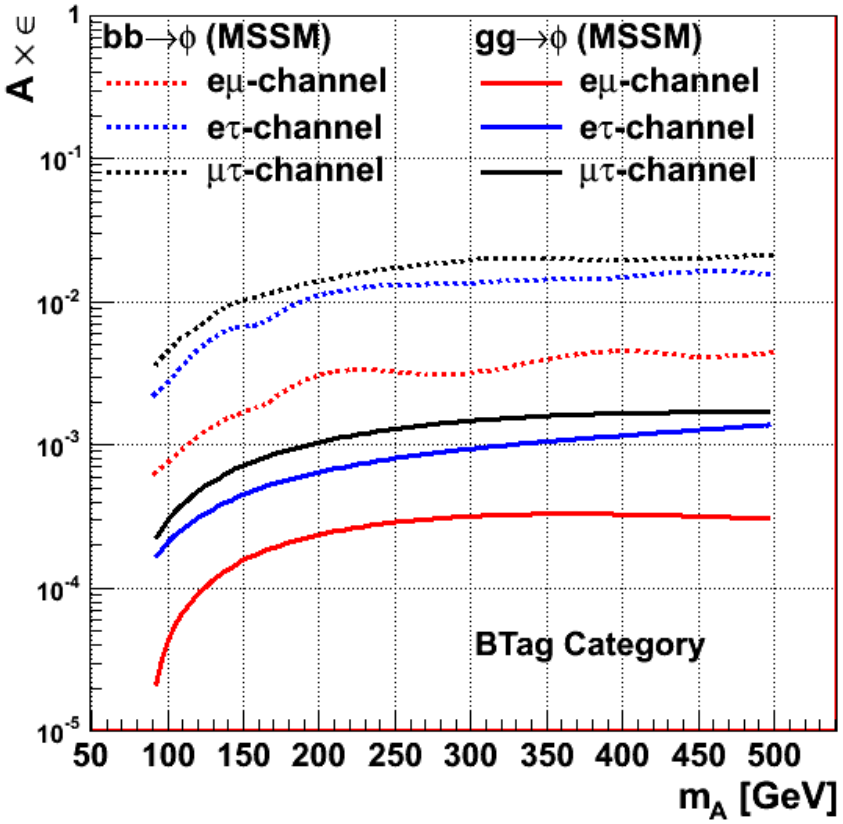
- Dominant backgrounds: QCD/W+jets
- W extrapolated from low P^{ζ} region (P^{ζ}<-40)
  - Separately for OS/SS (6% systematic for extrapolation factor)
- Z +jets backgrounds estimated from CMS measurement corrected for l → τ and j → τ fake rates
- TTBar from CMS measurement , Diboson from MC (30% uncertainty)
- In SS region W and other backgrounds are subtracted (QCD remaining)
- QCD extrapolated to OS region by a factor from data (~1.06 +- 5%)

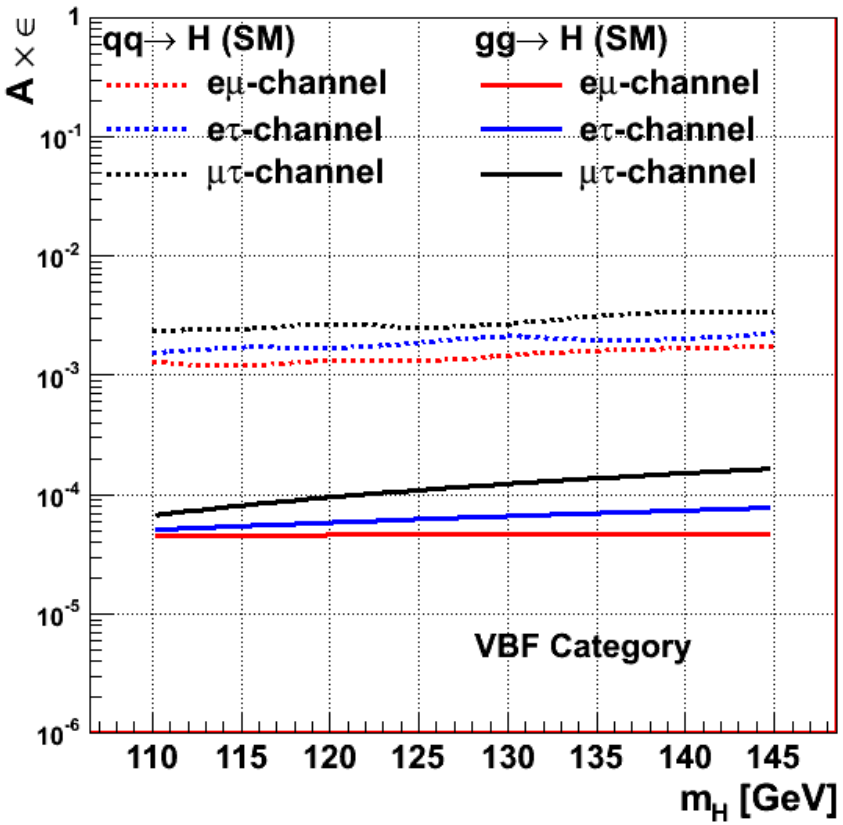
Particle Flow Reconstruction

- Particle Flow(PF) algorithm
  - Combines information from all sub-detectors
  - Provides unique event description
    - Particles
- PF candidates used in this analysis
  - Tau Identification
  - Jet Reconstruction
  - Missing E_T reconstruction
  - Lepton Isolation
- Light version of PF algorithm also running in the High Level Trigger
  - Crucial for tau triggers
    - Tau energy measured online with PF
    - Small turn on effects



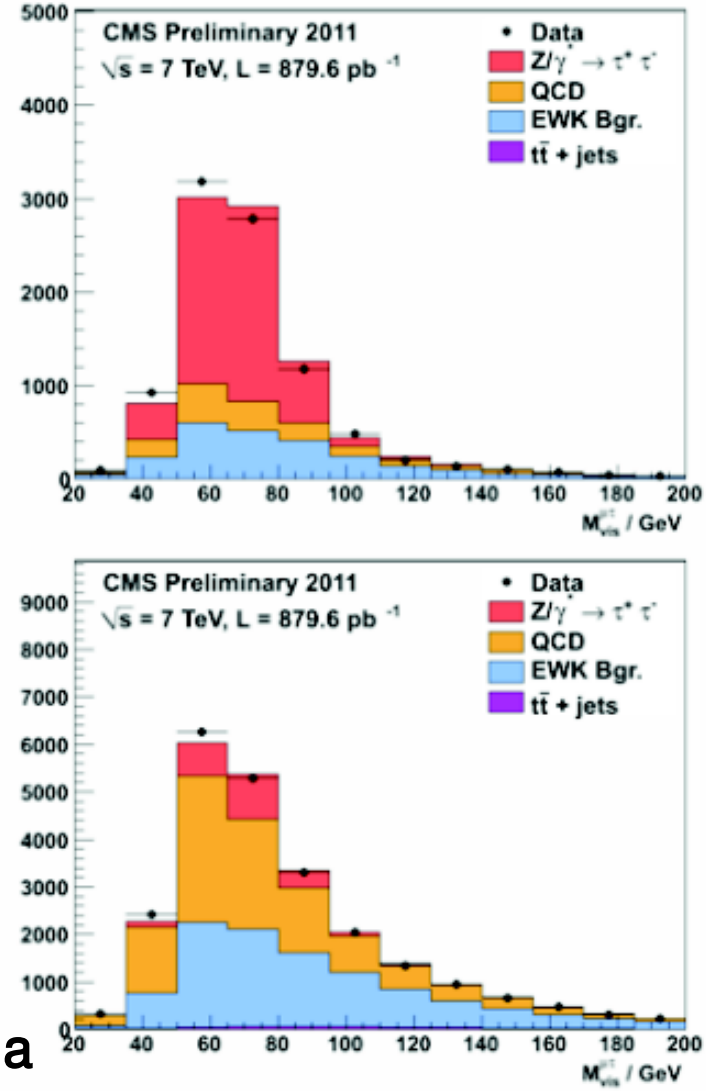
Acceptance x Efficiency vs mass





Tau ID efficiency

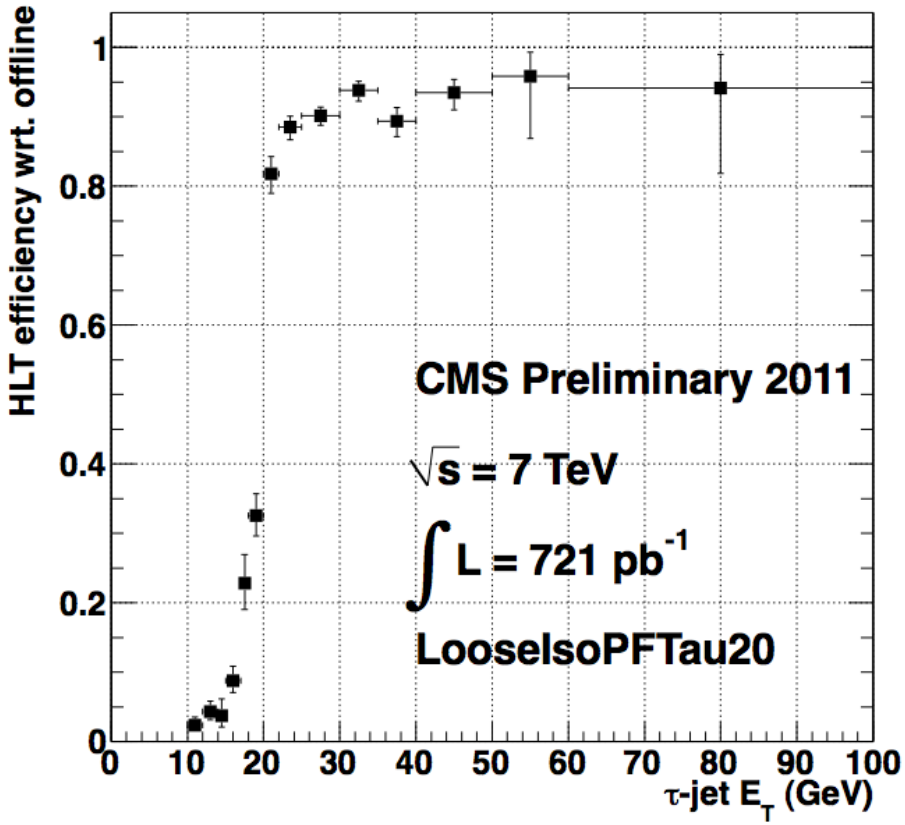
Uncertainty's source	HPS combined loose Δβ
Muon Momentum Scale	<< 1%
τ-Jet Energy Scale	< 1%
Track Reconstruction	3.9%
Track Momentum Scale	< 1%
Lead. Track P_T Cut	1%
Loose Isolation	2.5%
Jet → τ_{had} Fakes	1.2%
Lead. Track Corr. Factor	1.7%
Loose Iso. Corr. Factor	2.1%
Fit (Statistical Uncertainty)	2.6%
Sum	6.0%



Tag and probe applied in 1fb^{-1} of data
New uncertainty is 6%!

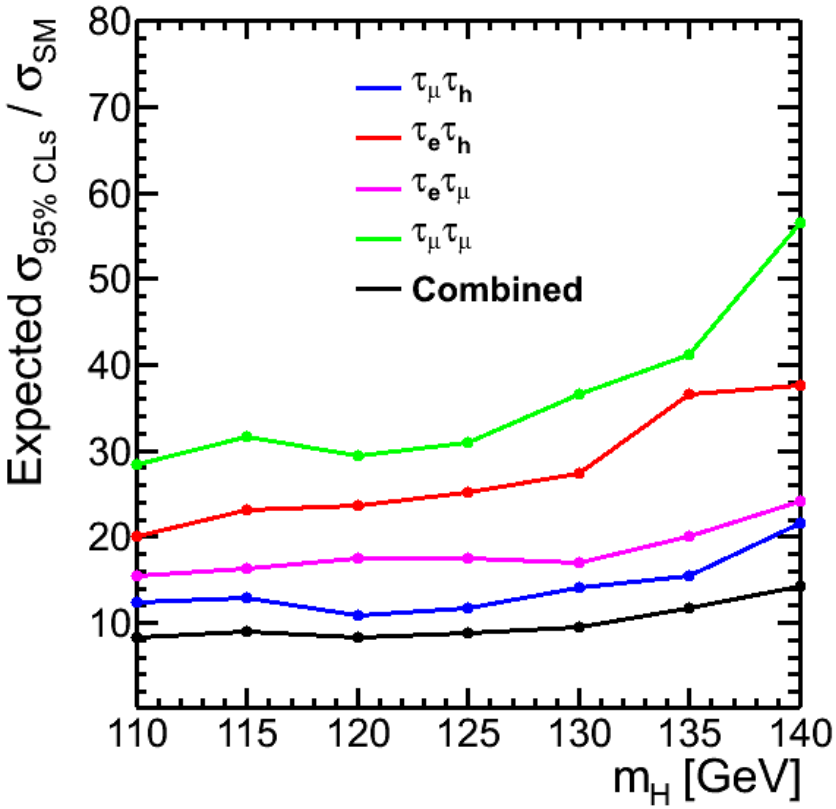
Tau Trigger Performance (l+τ)

- Triggers are using Particle Flow
- Energy of Tau in high level trigger is created only by the PF constitiuents
  - Consistent with offline tau
  - Small turn on effects

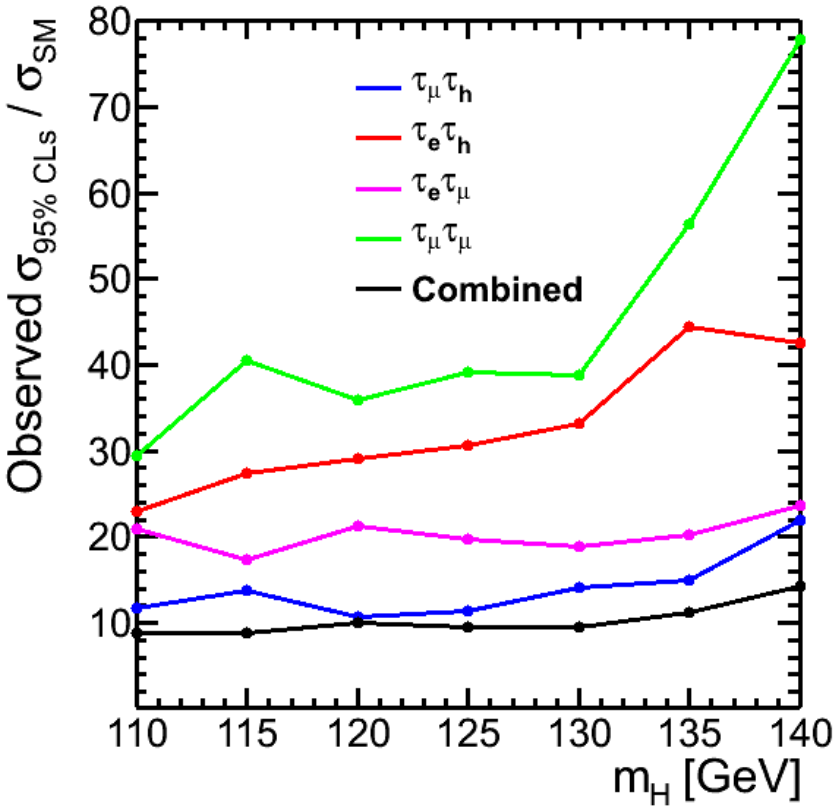


SM H Limits:Channel by channel

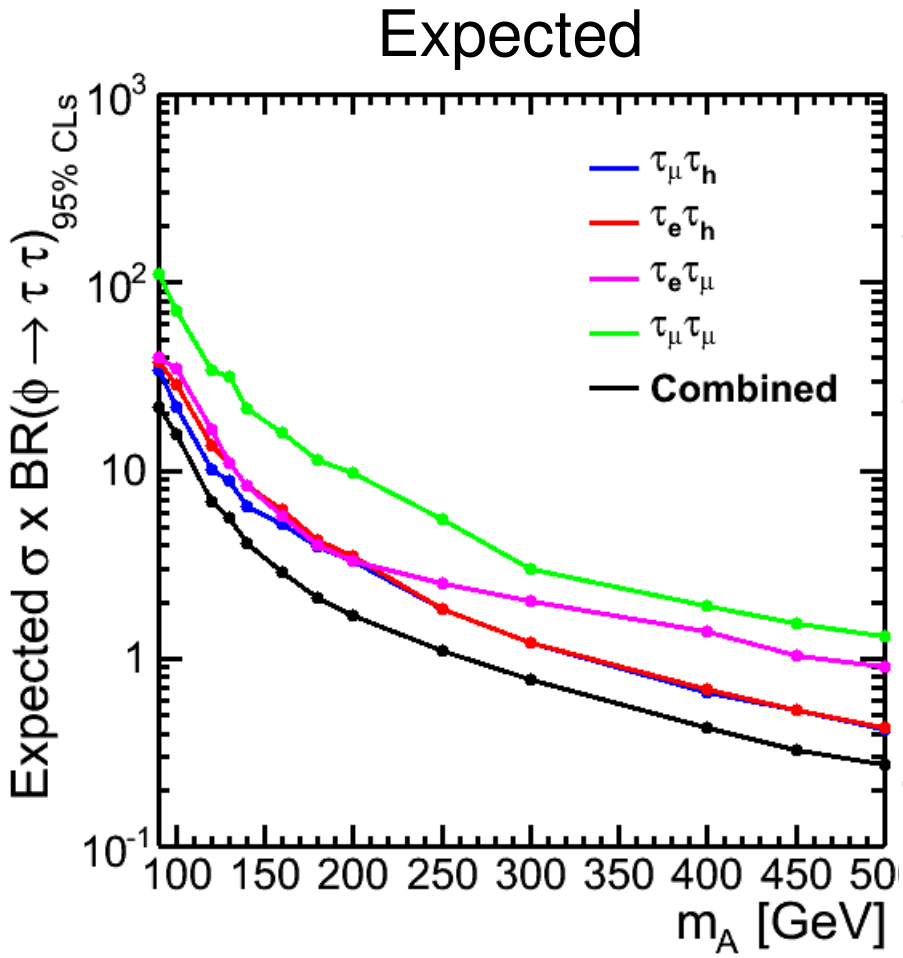
Expected

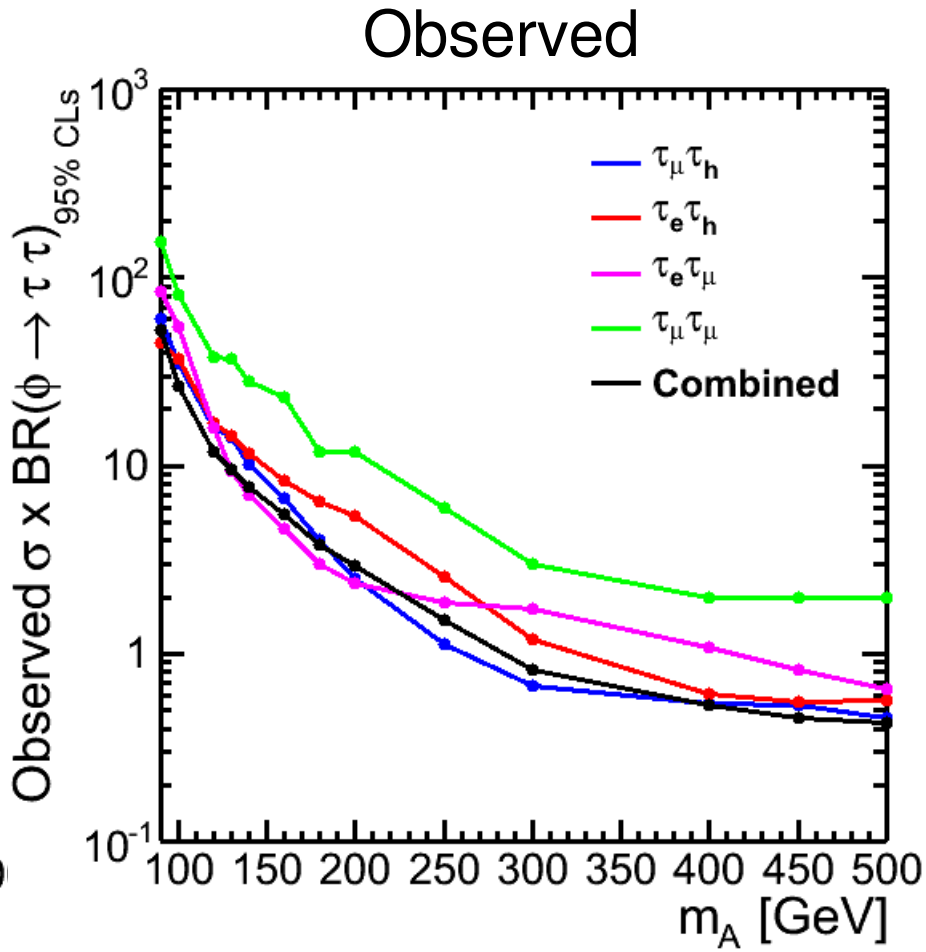


Observed



MSSM Limits : Channel by channel





Systematics(H^+/fully hadronic)

Table 1: The systematic uncertainties (in %) for the backgrounds and the signal from $t\bar{t} \to H^{\pm}bH^{\mp}\bar{b}$ (HH) and $t\bar{t} \to W^{\pm}bH^{\mp}\bar{b}$ (WH) processes at $m_{H^{\pm}}$=80-160 GeV/c^2.

	HH	WH	QCD	non QCD Type 1	non QCD Type 2				
					$t\bar{t}$	tW	W+jets	Z+jets	VV
$\tau - p_T^{miss}$ trigger	24–26	24–25		9.6	22	22	22	24	23
τ-jet id	7.0	7.0		7.0					
jet, $\ell \to \tau$ mis-id					15	15	15	15	15
JES+JER+MET	13–17	14–19		18	17	25	14	19	22
lepton veto	0.2–0.3	0.3–0.4			1.5	0.6	0.6	0.6	0.7
b-jet tagging	12–15	14-16			16	17			
jet→b mis-id							13	10	11
QCD stat.+syst.			7.1						
Non QCD Type 1 stat.				6.8					
$f_{W\to\tau\to\mu}$				0.7					
muon selections				0.6					
MC stat	4.1–7.0	4.8–7.2			16.3	56	100	100	90
cross-section	20	20			20	8	5	4	4
luminosity	6.0				6.0				

Systematics H^+ (μ+e/τ)

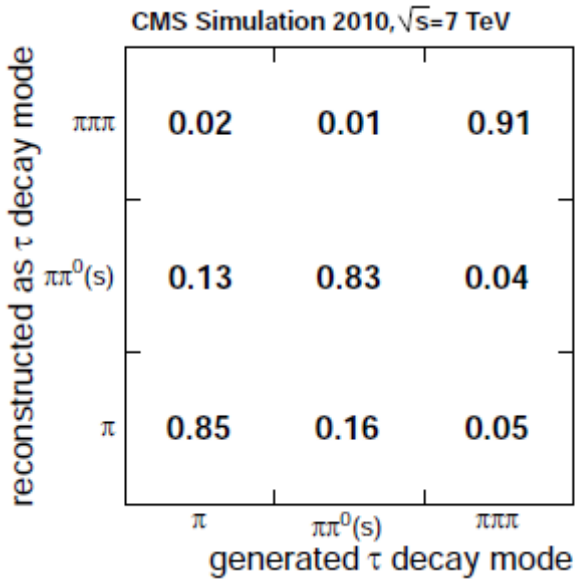
mu+tau channel

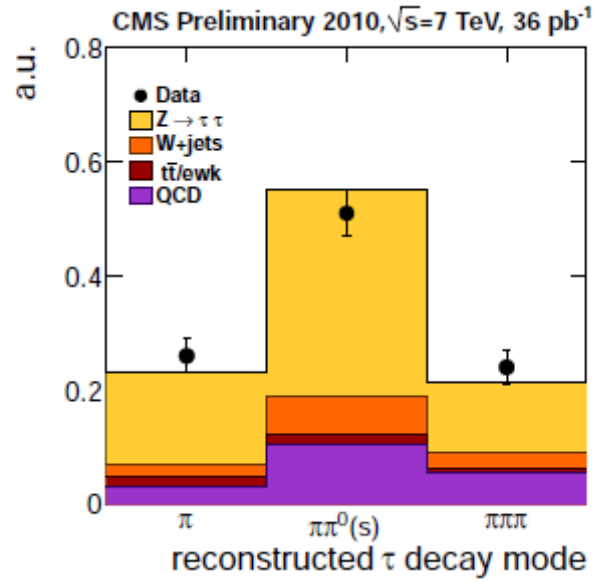
	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	τ fakes	Single top	VV	DY($\mu\mu$)	DY($\tau\tau$)
τ-jet id	7.0	7.0	7.0			7.0	7.0		7.0
jet, $\ell \to \tau$ mis-id				15.0				15.0	
JES+JER+MET	6.0	4.0	3.0	3.0		8.0	8.0	71.0	14.0
b-jet tagging	6.0	6.0	5.0	5.0		8.0			
jet→b mis-id							8.0	9.0	9.0
lepton selections	2.0	2.0	2.0	2.0		2.0	2.0	2.0	2.0
τ fakes (stat)					6.0				
τ fakes (syst)					11.0				
cross-section	20.0					8.0	4.0	4.0	
MC stats	3.0	3.0	2.0	6.0		5.0	8.0	71.0	12.0
luminosity	6					6			

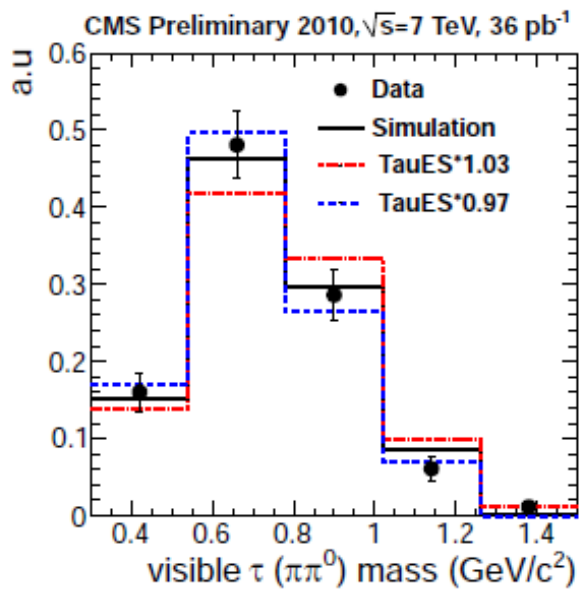
e-mu channel

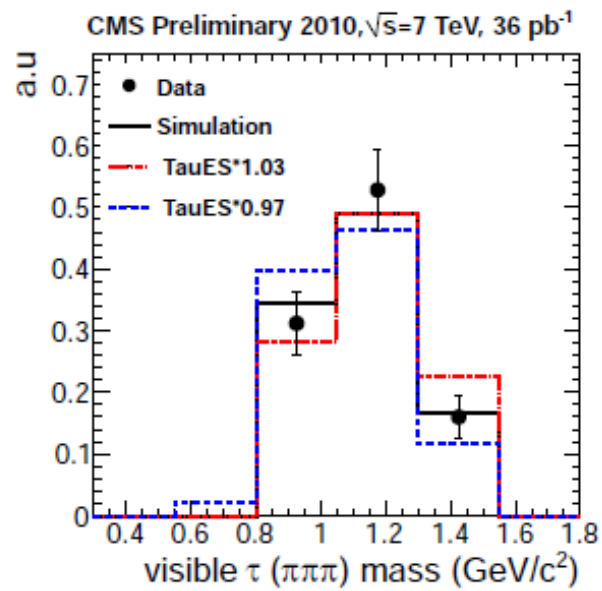
	HH	WH	$t\bar{t}$	DY(ll)	W+jets	Single top	VV
JES+JER+MET	2.8	2.8	2.8	7.0	6.0	4.9	4.8
dilepton selection	2.5	2.5	2.5	2.5	2.5	2.5	2.5
cross section	20.0	20.0	20.0	4.0	5.0	8.0	4.0
MC stats	7.5	3.4	0.5	3.2	16.0	2.5	2.7
luminosity	6						

Tau ID control variables









Establishing the standard candles