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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

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Searching for the Higgs Boson with tau leptons at CMS

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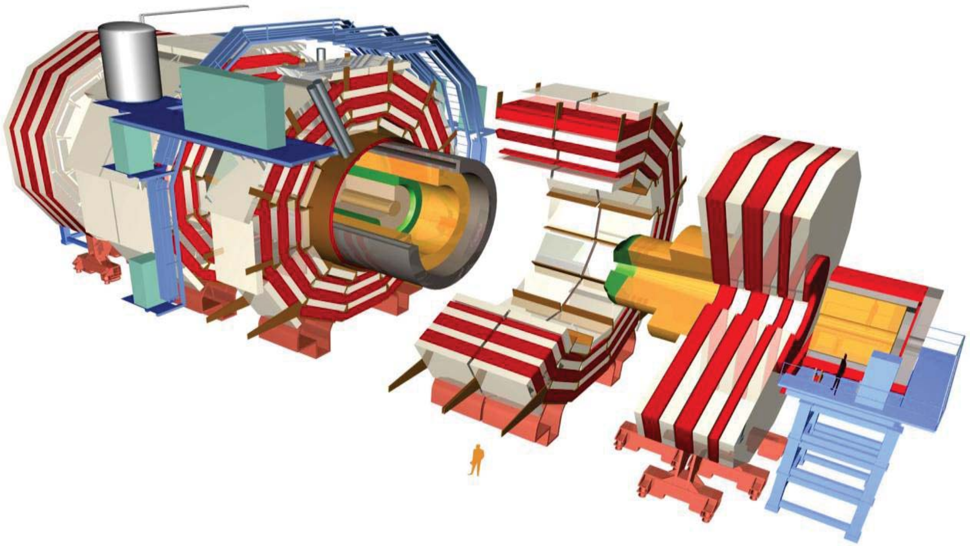
Searching for the Higgs Using τ Leptons in CMS

Joshua J Swanson on behalf of the CMS collaboration

Outline

- Tau Reconstruction in CMS
- $H \rightarrow ZZ \rightarrow 2l2\tau$ (l=eμ) analysis overview
- $H \rightarrow \tau\tau$ analysis overview

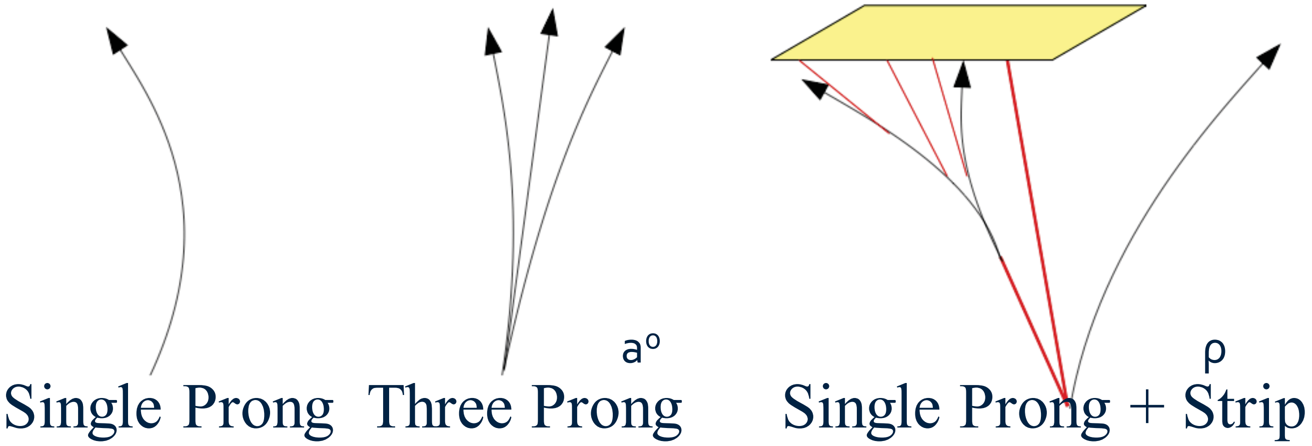


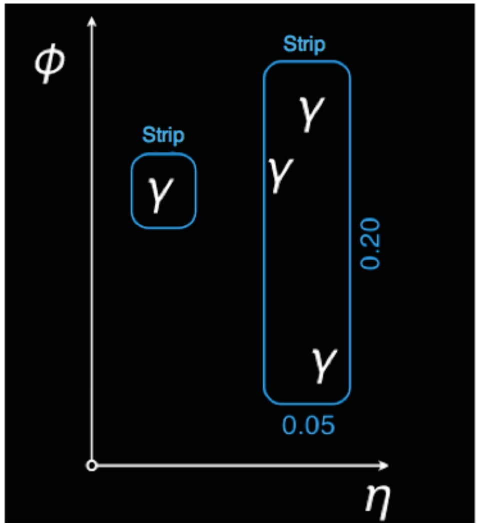
Hadronic Tau Reconstruction

http://cms-physics.web.cern.ch/cms-physics/public/TAU-11-001-pas.pdf

Tau ID – Hadron Plus Strips (HPS)

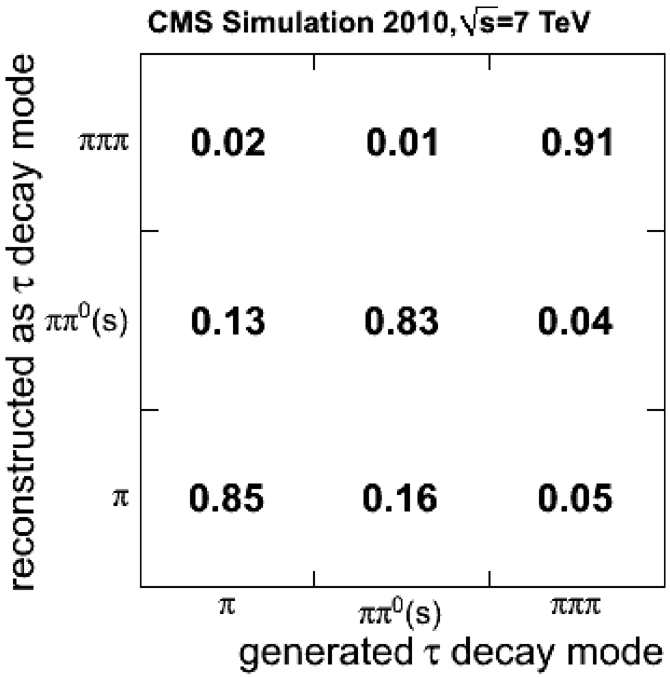
- τ leptons decay to one or more hadrons 64% of the time.
- Charged hadrons are combined electromagnetic objects, arranged in strips or single photons

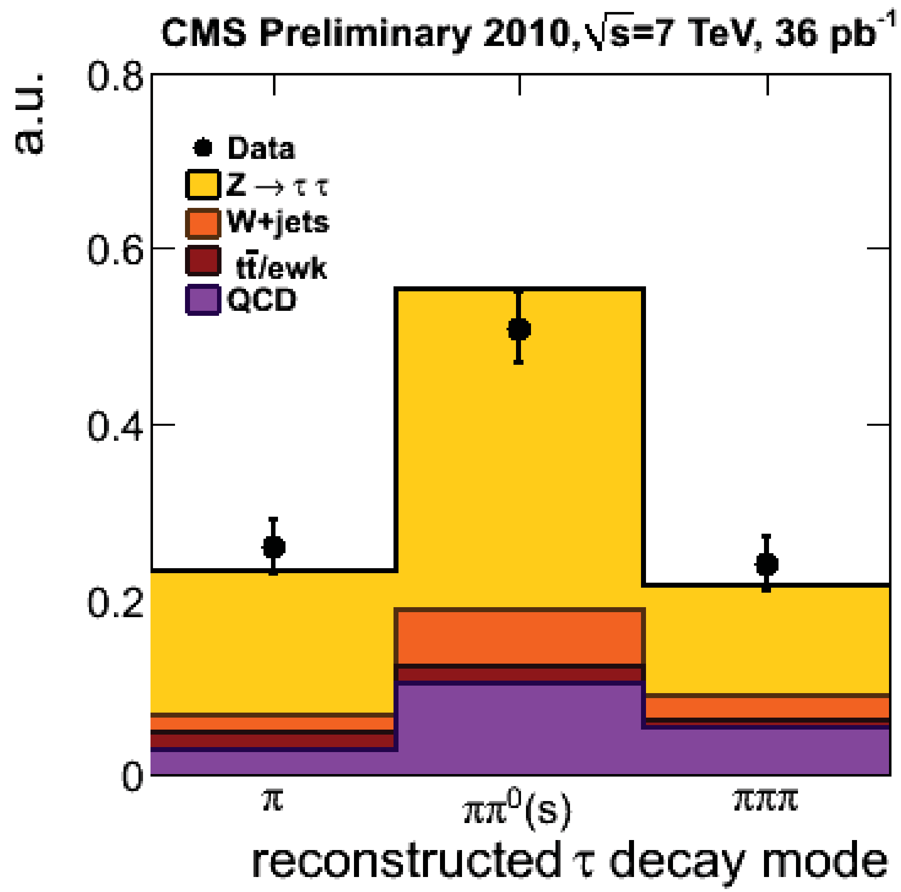




- Taus are isolated using a dR cone around the leading charged candidate after removing the reconstructed tau decay products.

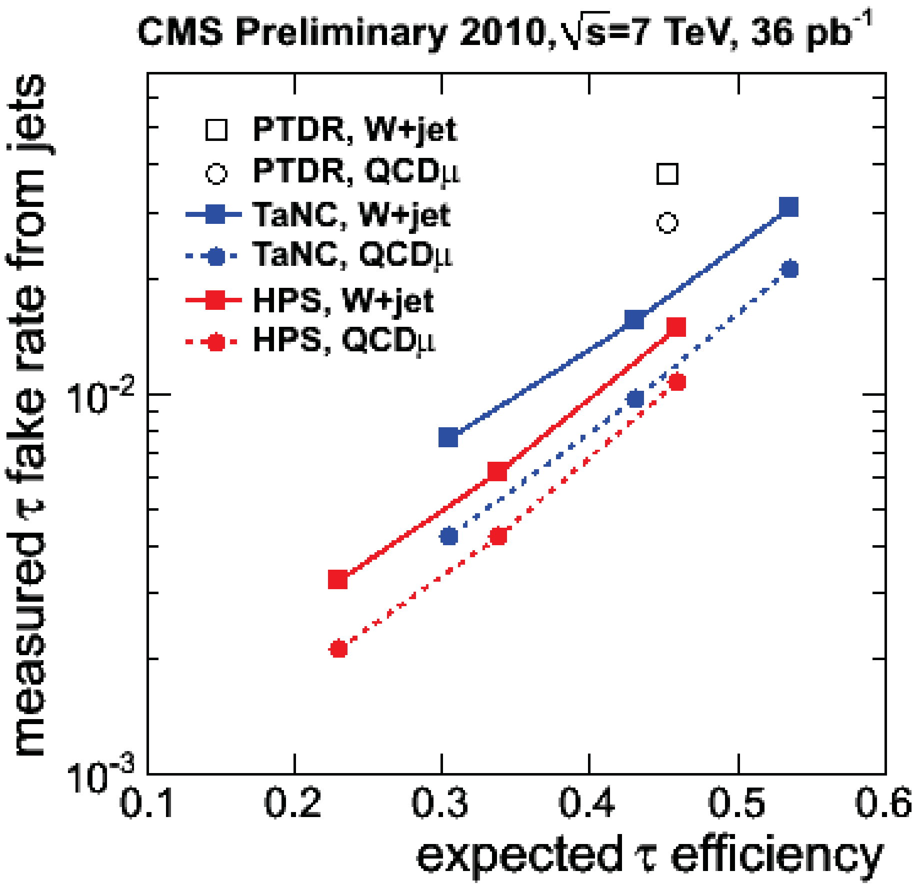
Decay Mode Reconstruction





- HPS does an good job reconstructing the correct decay mode.

Performance of τ reconstruction in CMS



- HPS provides very efficient hadronic tau identification with a very manageable fake rate.
- Efficiency is measured in data using Z→μ-τ events.
- Fake rate is measured in data using di-jet events.

H→ZZ→2l2τ analysis

http://cms-physics.web.cern.ch/cms-physics/public/HIG-11-013-pas.pdf

H→ZZ→2l2τ, Analysis Overview

- 8 Final States Considered
  - Leading Z→μμ or ee, on shell passing di-μ or di-e trigger
    - $p_T > 20(10)$ GeV for leading (sub-leading), $|\eta| < 2.4(2.5)$ for μ(e)
  - Subleading Z→ττ, decaying to (h,e,μ)
    - $p_T > 20$ (τ), 10 (e,μ) GeV; $|\eta| < 2.3$ (τ) 2.4 (μ) 2.5 (e)
  - μμeτ, μμμτ, μμττ, μμeμ, eeeτ, eeμτ, eeττ, eeeμ
- Dominant Backgrounds:
  - Irreducible ZZ
  - Reducible: Z+jets, WZ, Zbb/cc, TT, QCD
  - Crossover from 4 light lepton (4l) final states, with one of the leptons faking a τ

ZZ Background Estimation

- ZZ estimation based on comparison to inclusive Z production:

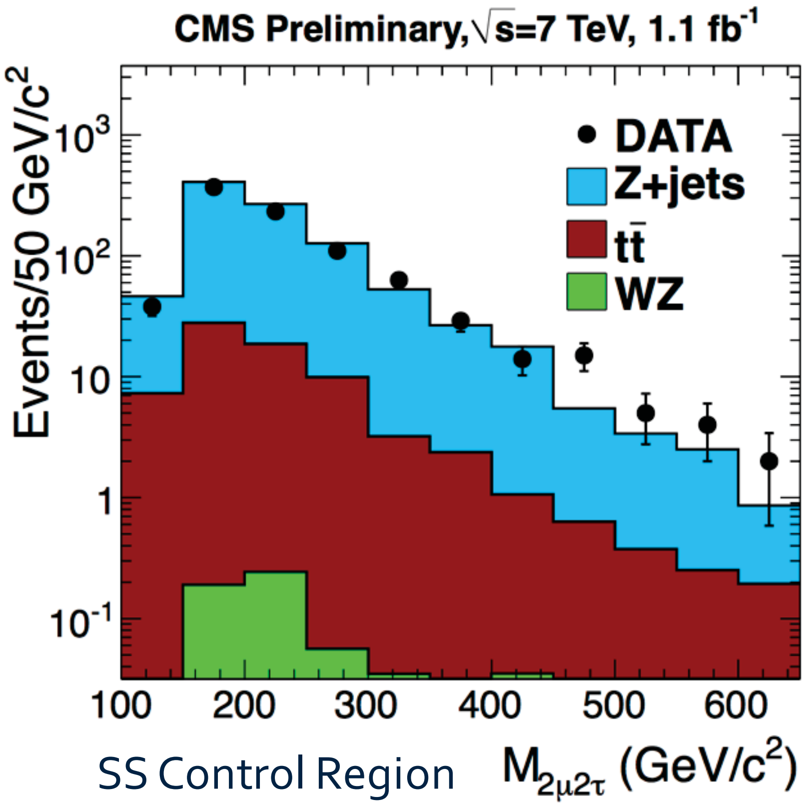
$$N_{ZZ}^{\text{estimated}} = N_Z^{\text{obs}} \cdot \frac{\sigma_{ZZ}^{\text{SM}} \cdot A_{ZZ}}{\sigma_Z^{\text{SM}} \cdot A_Z}$$

- 10% systematic due to theory error on σ_{ZZ} and statistical error for ZZ MC.

	N_{ZZ}^{exp}	N_{ZZ}^{est}
$\mu\mu\tau\tau$	0.142 ± 0.013	0.145 ± 0.013
$\mu\mu\mu\tau$	0.281 ± 0.017	0.287 ± 0.018
$\mu\mu e\tau$	0.316 ± 0.019	0.323 ± 0.019
$\mu\mu e\mu$	0.179 ± 0.014	0.183 ± 0.014
$ee\tau\tau$	0.120 ± 0.012	0.125 ± 0.012
$ee\mu\tau$	0.240 ± 0.016	0.250 ± 0.017
$eee\tau$	0.311 ± 0.018	0.323 ± 0.019
$eee\mu$	0.157 ± 0.013	0.163 ± 0.014

Expected and Estimated ZZ background in 1.1fb^{-1}

Reducible background estimation

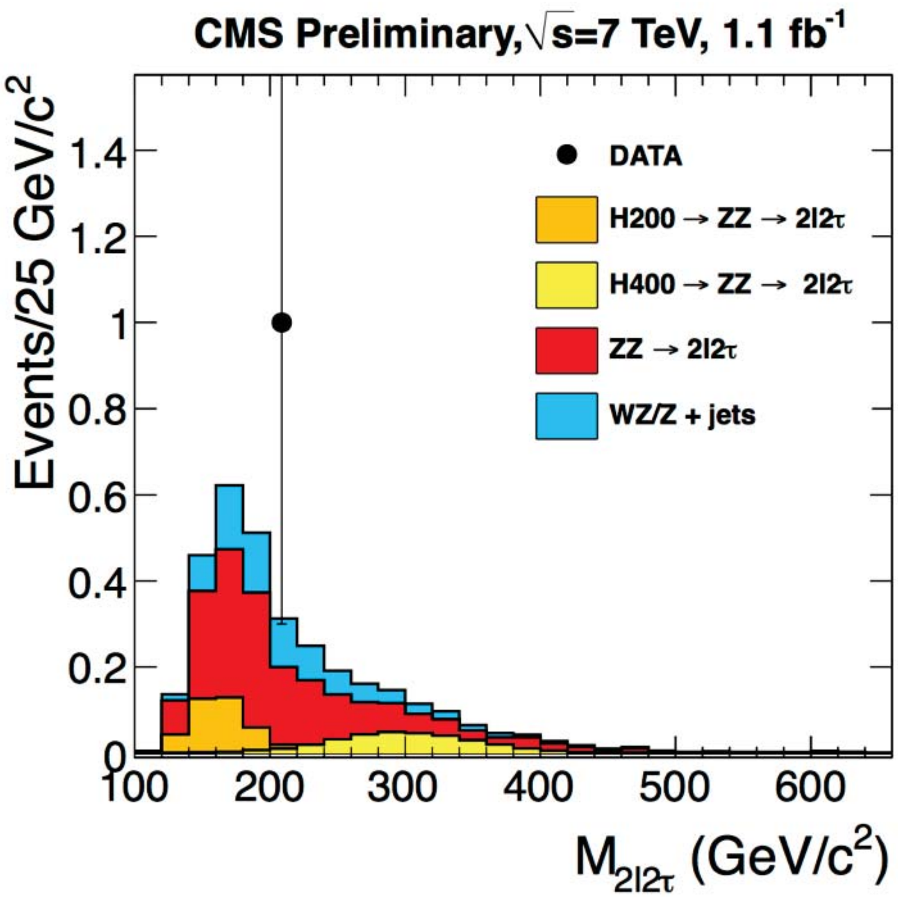


SS Control Region

- Select Z+Jet like events in $ll\tau\tau$ channels:
  - SS, No Tau Iso
- Functional form of the fake rate vs. p_T is found by preforming a fit.
- Fake rate applied to signal like region:
  - OS, Tau anti-isolated

Channel	Estimated Events
$ee\tau\tau$	0.084 ± 0.004
$\mu\mu\tau\tau$	0.066 ± 0.004
$eee\tau$	0.24 ± 0.07
$\mu\mu e\tau$	0.12 ± 0.05
$ee\mu\tau$	0.07 ± 0.04
$\mu\mu\mu\tau$	0.05 ± 0.03
$\mu\mu e\mu$	0.12 ± 0.09
$eee\mu$	0.06 ± 0.05

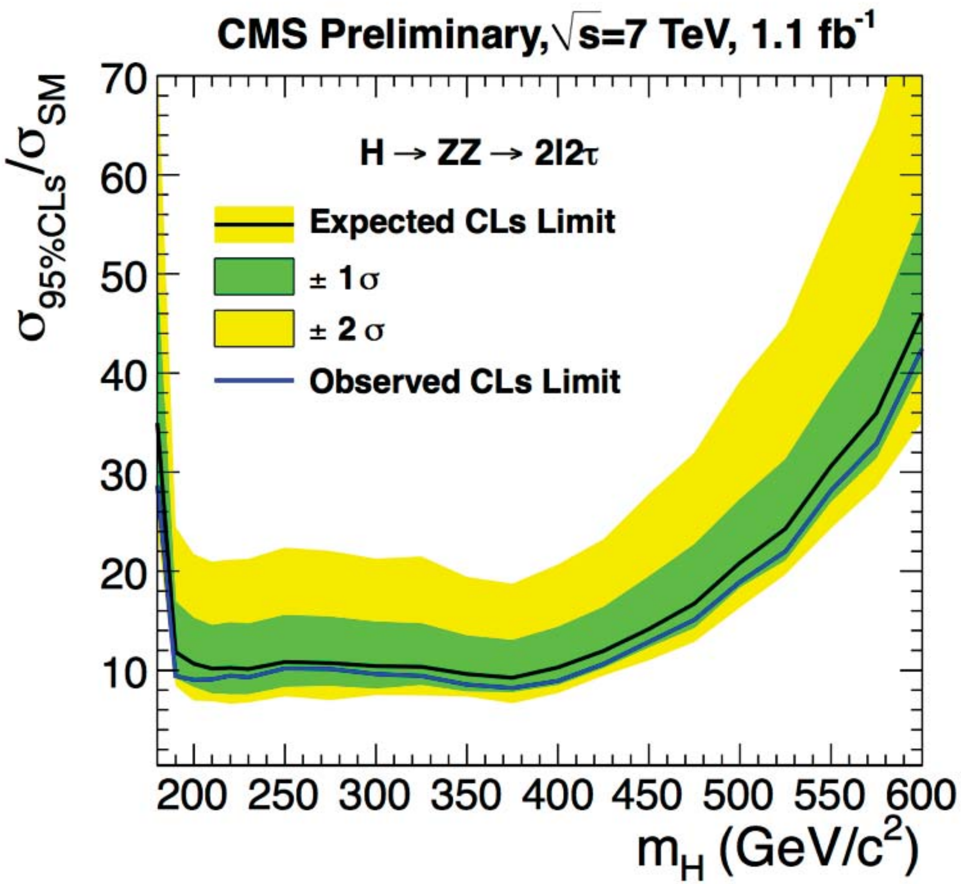
4 Lepton Mass Spectrum



- Combined 4l visible mass plot for all 8 channels.
- ZZ, WZ/Z+Jets stacked with Higgs overlaid.
- Backgrounds normalized to value from data driven estimate.

Limit, CLs using Shapes

- Limits are done using visible 4l mass shape.
  - Shapes are allowed to morph with respect to τ energy scale uncertainty.
- Expected and Observed 95% CLs limits are ~10 times the SM between 200-400 GeV/c^2 with 1.1 fb^{-1}



H→ττ Analysis

http://cms-physics.web.cern.ch/cms-physics/public/HIG-11-020-pas.pdf

Event Pre-selection

Analysis is performed using three 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

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

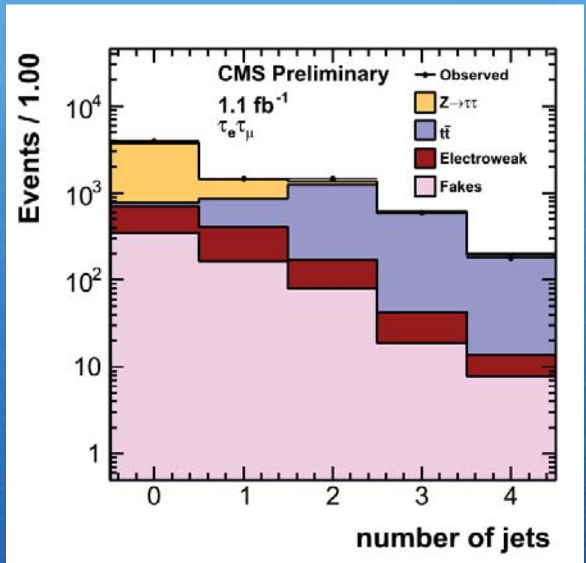
MSSM(No b-tag)

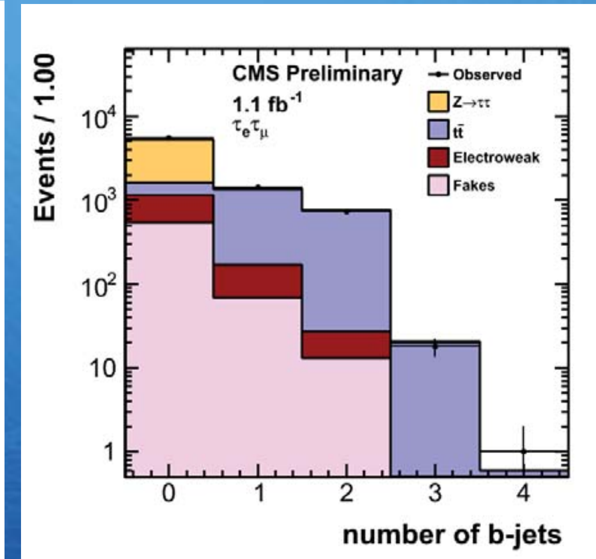
- Require less than two jets with P_T>30 GeV
- Require no b-tagged jets with P_T> 20 GeV

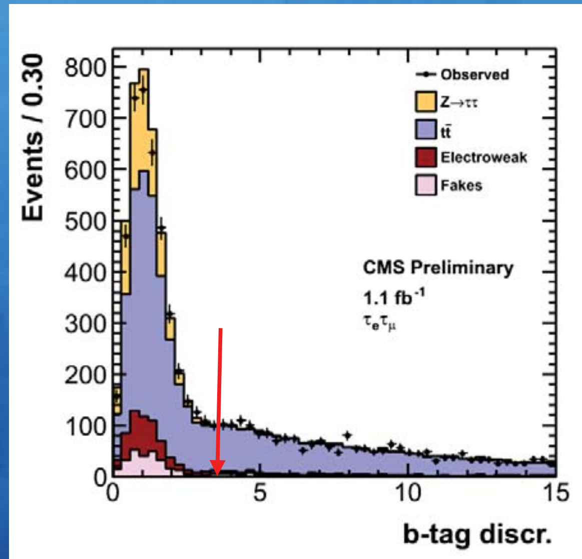
SM(No VBF)

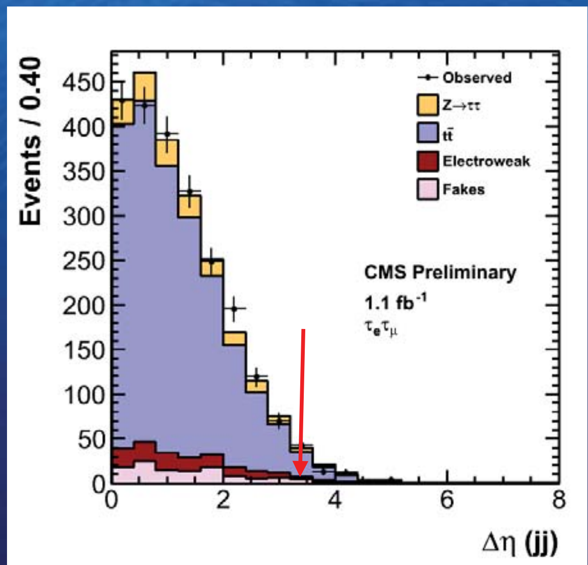
- Require less than two jets with P_T>30 GeV
- OR two jets failing VBF criteria

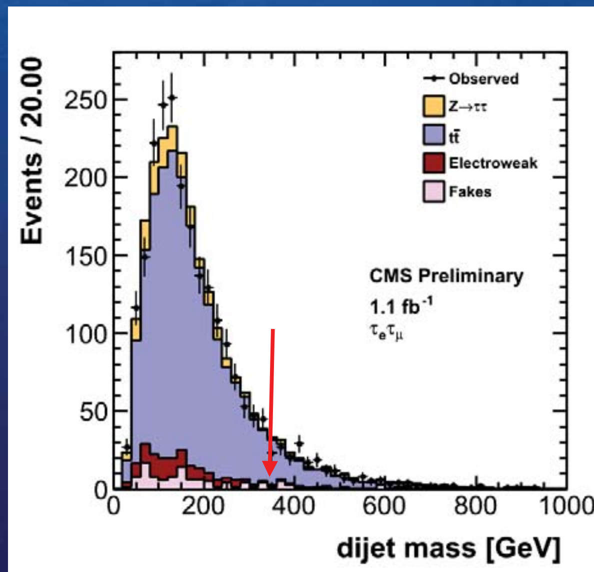
Categorization related variables







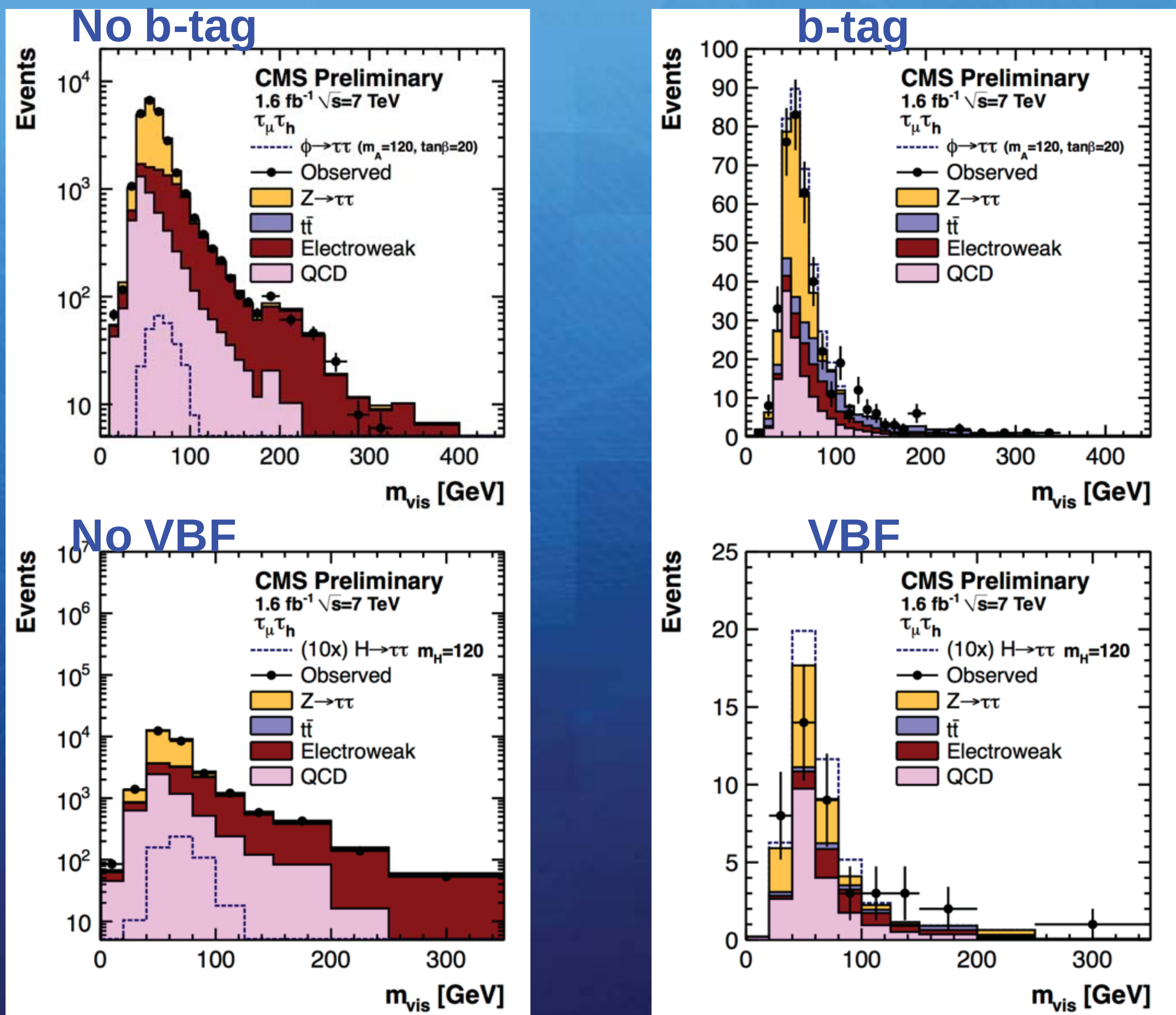




Visible Mass after all requirements(μ+τ)

MSSM

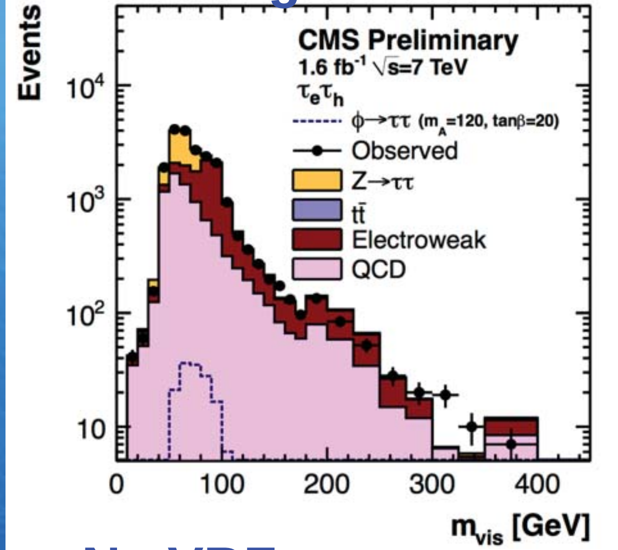
SM



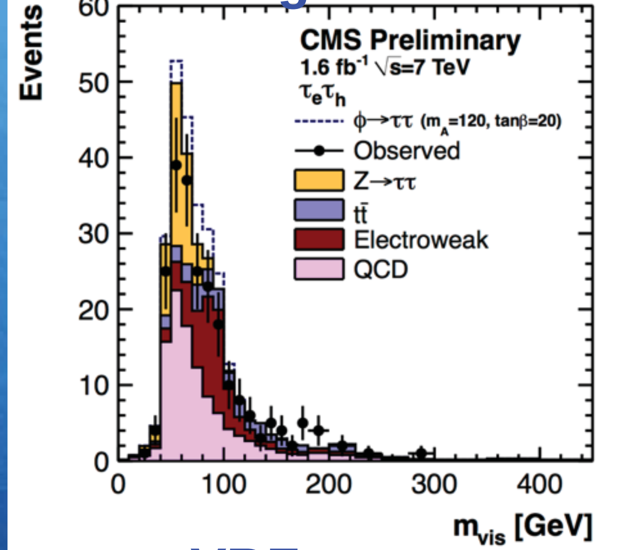
Visible Mass after all requirements(e+τ)

MSSM

No b-tag

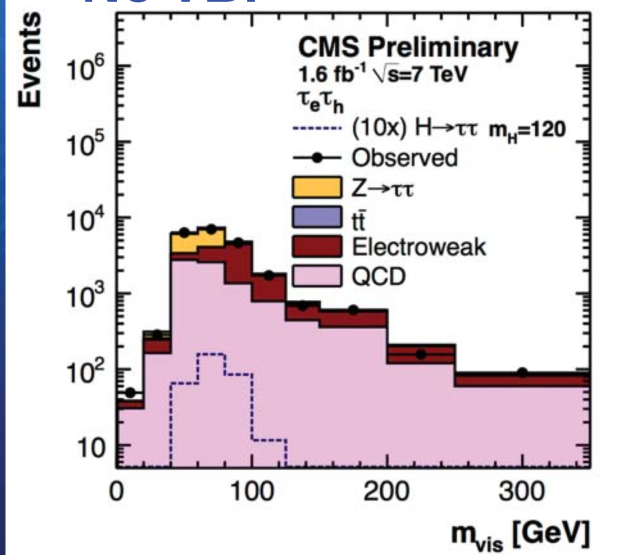


b-tag

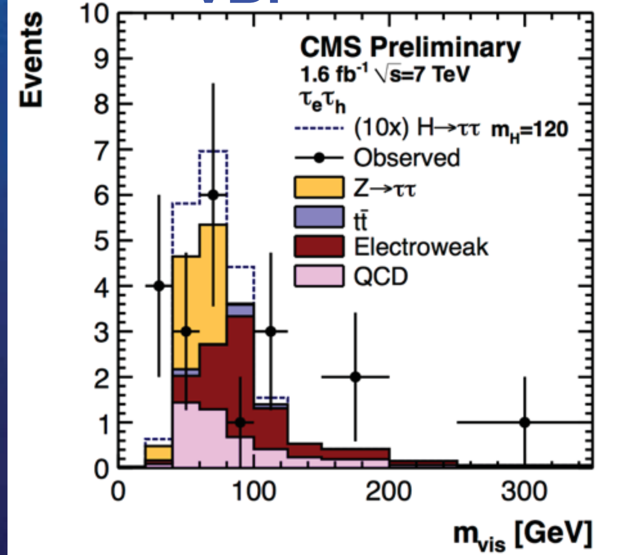


SM

No VBF



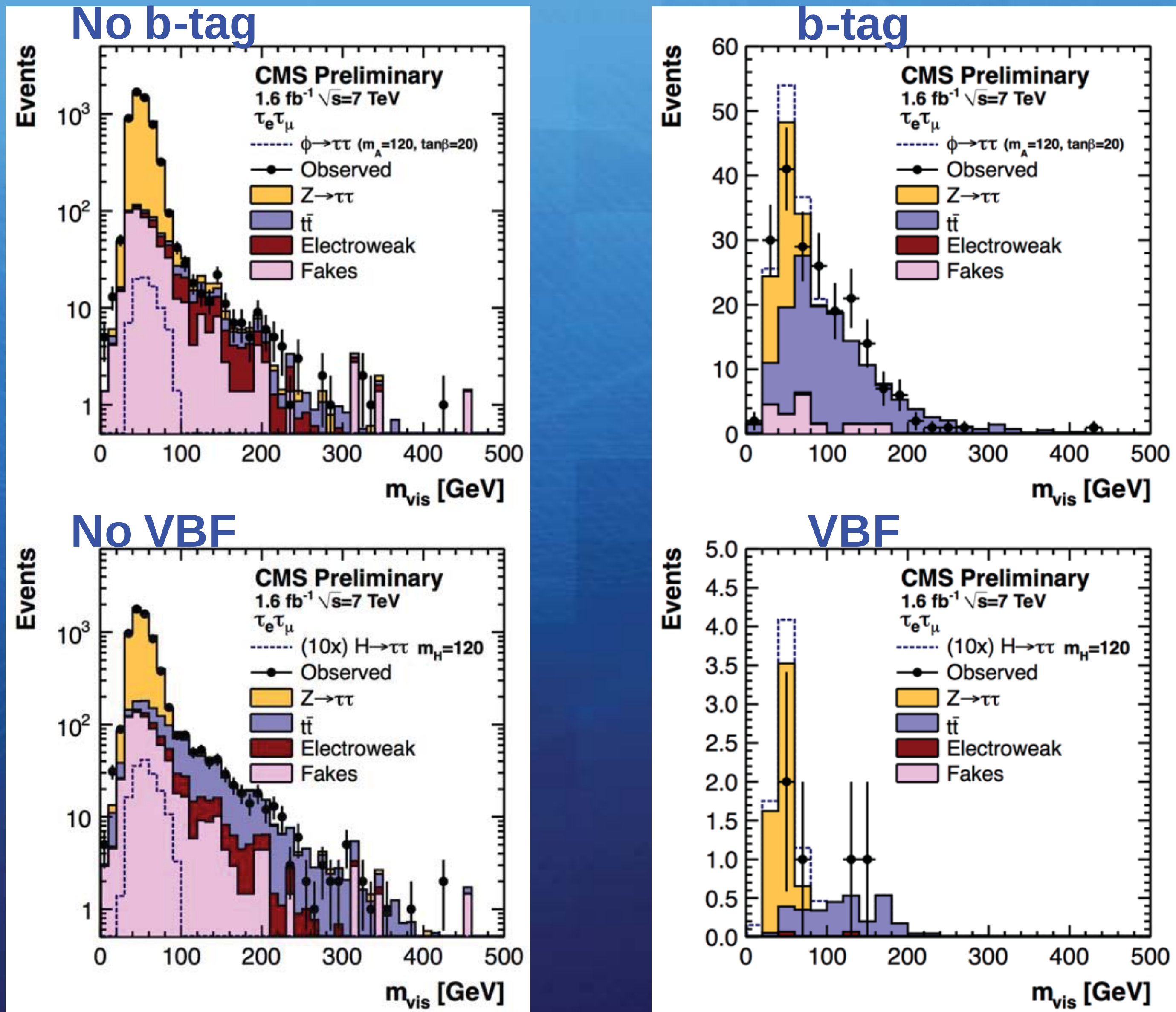
VBF



Visible Mass after all requirements(e+μ)

MSSM

SM



Background estimation and systematics

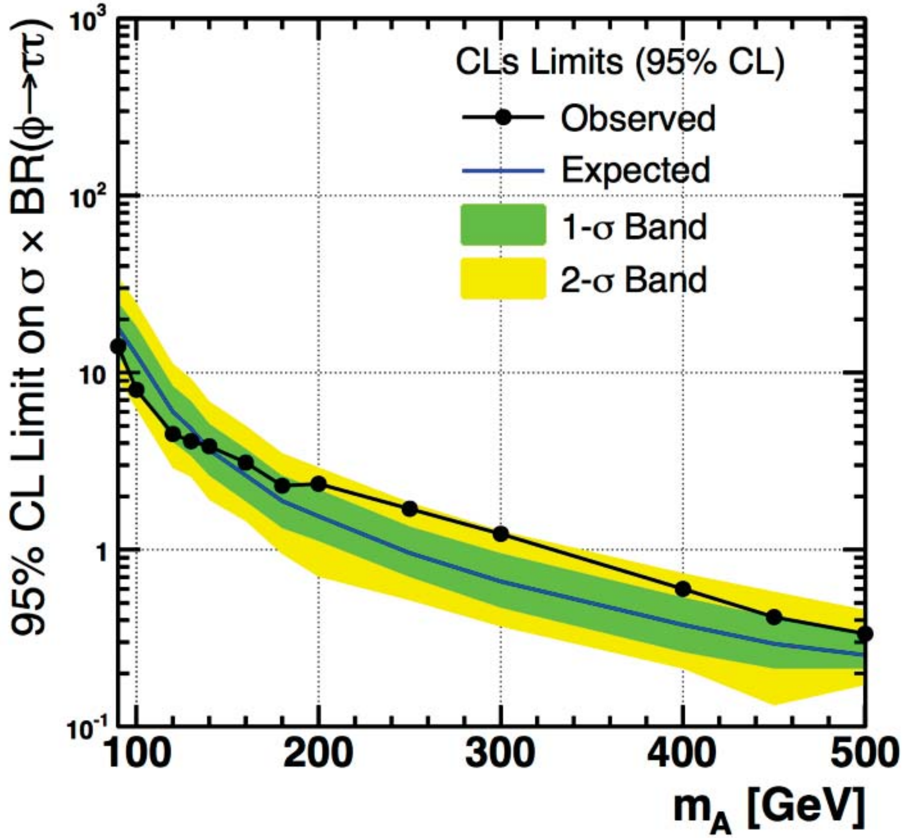
- $Z \to \tau\tau$ and TTbar : irreducible
  - Estimated from CMS $\sigma(Z)$ / $\sigma(\text{ttbar})$
- Data driven estimation for QCD/W+jets
  - OS/SS+W sideband for $l+\tau$
  - Fake rate for $e+\mu$
- Constrained fit performed to extract signal cross section or set limit
  - Background and systematic 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%
$\sigma(Z \to \mu\mu/ee)$	3%
$\sigma(\text{ttbar})$	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%

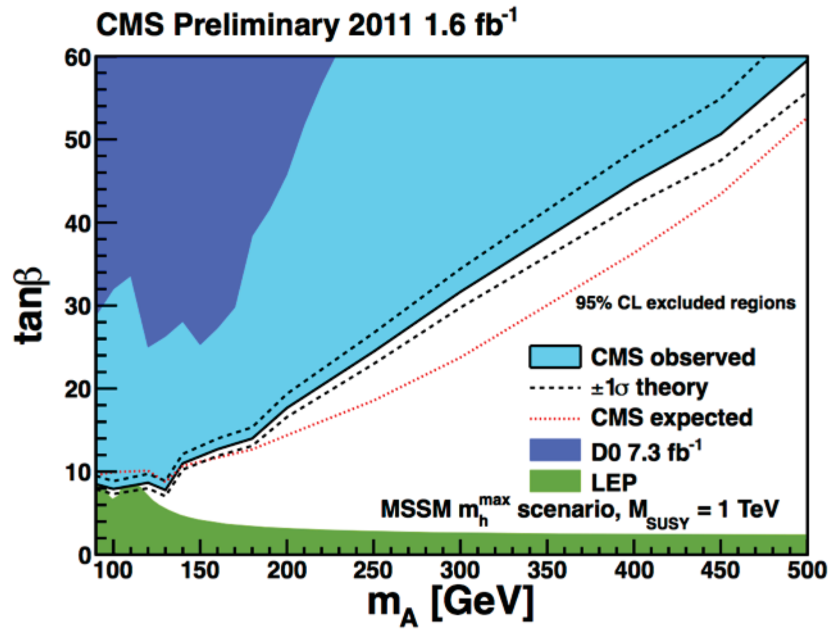
MSSM Higgs search results

- 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



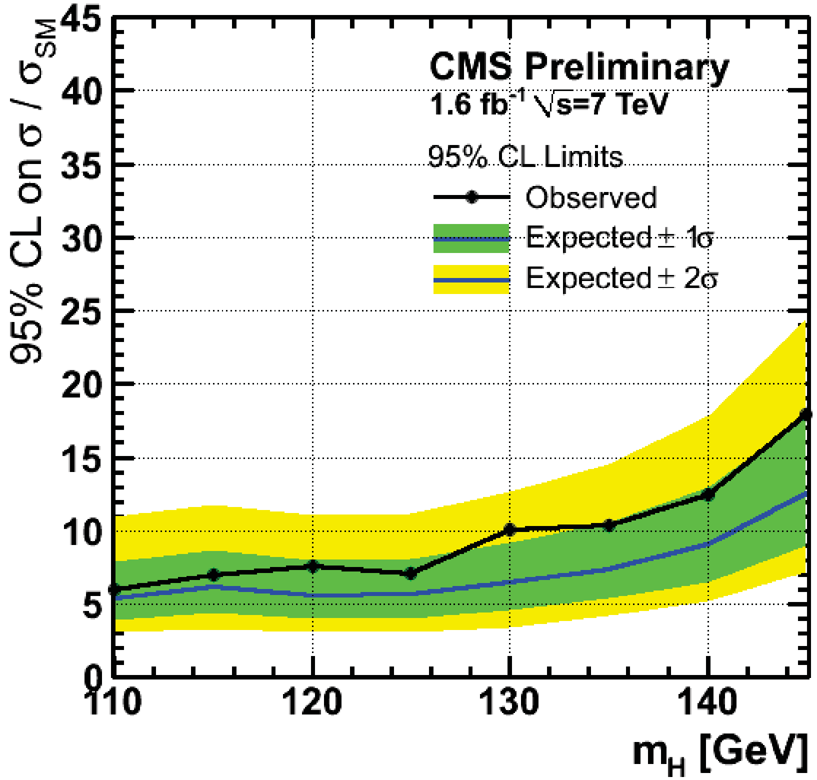
CMS statement on the MSSM with 1.6 fb^{-1}

- MSSM mostly excluded at M_A< 120 (CMS-LEP)
- Opening new regime at high M_A
- Huge improvement wrt 2010 result
    - B-tagging/tau ID efficiency and more data!



SM Higgs search results

- Expect to exclude < 5x SM in 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



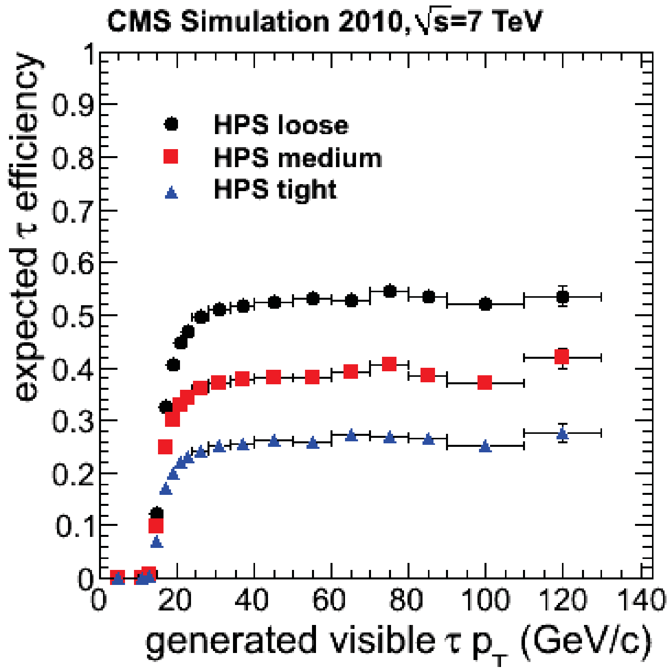
Conclusions

- CMS tau ID is performing very well, this allows us to extend analyses in ways that were previously not possible
- No excess above the standard model is observed in any of the search channels
- $ZZ \rightarrow 2l2\tau$ analysis improves standard model Higgs search power and exclusion limits for $M_H > 200$ GeV
  - Limits are ~10 times the standard model 200-400 GeV with 1.1 fb^{-1} of CMS data.
- $H \rightarrow \tau\tau$ analysis is benefiting from many factors allowing significant Higgs search power and exclusion limits for low M_H
  - Limits for MSSM $H \rightarrow \tau\tau$ is nearly excluded completely at low M_H with 1.6 fb^{-1} of CMS data.
  - Limits are ~5 times the standard model 120-130 GeV with 1.6 fb^{-1} of CMS data.

Backup

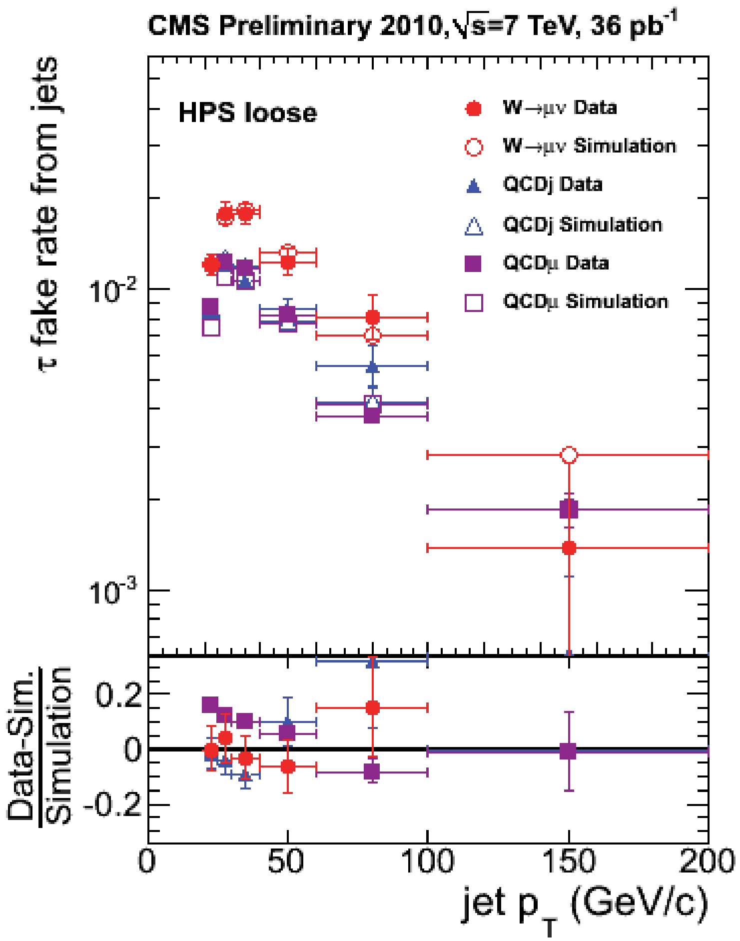
τ ID efficiency

- Efficiencies and fake rates measured using 2010, 2011 data
  - Tag and probe and combined fit methods
- τ reconstruction and ID are well understood in both 2010 and 2011 data, with Data/MC = 0.99±0.07
- 6% (6.8% Medium) uncertainty in Data/MC with tag and probe method

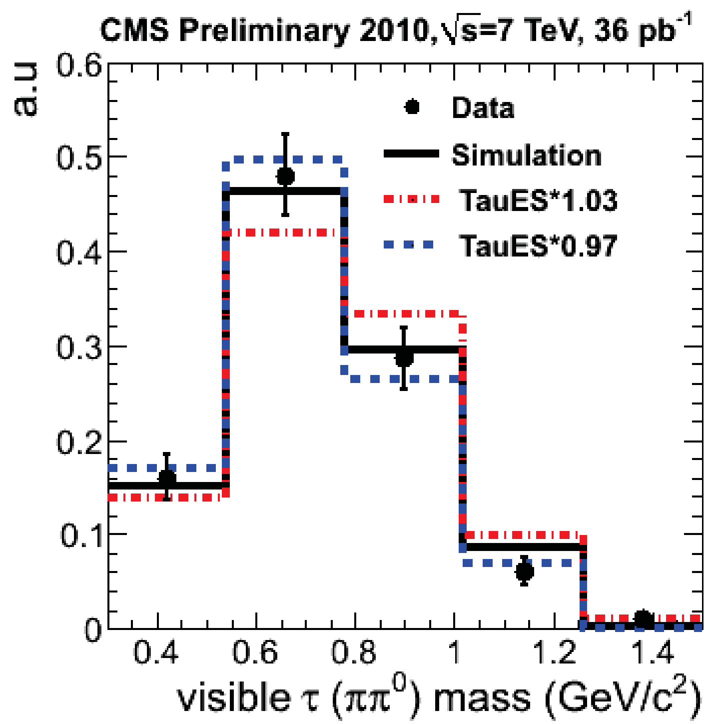


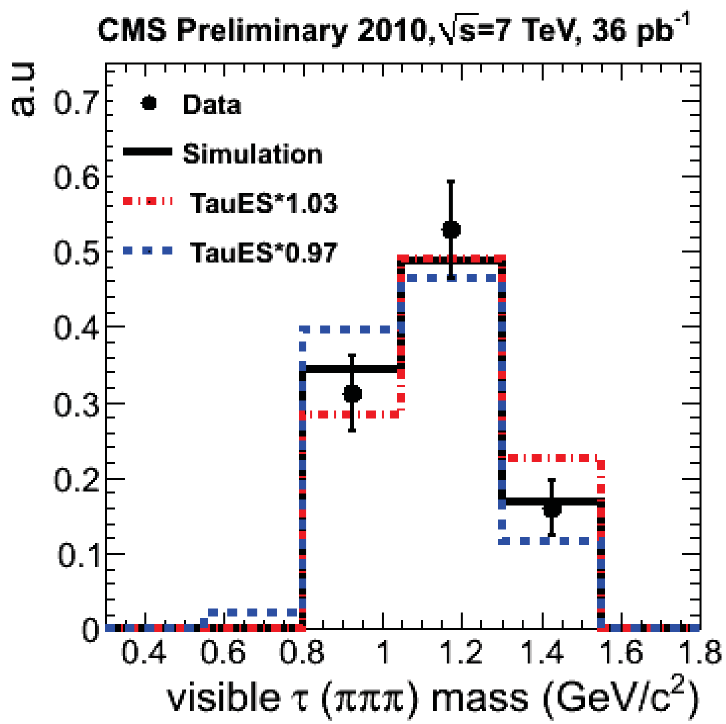
Tau Fake Rates

- Tau fake rates measured with data using a tag and probe method in di-jet events.
- HPS Loose has fake rates as low as 1% from QCD jets.



Tau Energy Scale





- Tau energy scale measured with 3% uncertainty.

Event Selection, Leading Z

- Double Electron (17-8) and Double Muon (13-8, 7-7) Triggers
- Leading Z always decays to on shell ee/μμ pair
  - $p_T > 20$ (10) GeV for Leading (Sub-Leading) legs
  - $60 < M_{ll} < 120$ GeV
- Lepton ID
  - e: CiC Tight (ID Only), < 2 missing tracker hits
  - μ: Global, nHits > 10
- Relative PF Isolation
  - e: $I_{rel} < 0.2$
  - μ: $I_{rel} < 0.25$

Event Selection, Sub-leading Z

- Exclusively ττ decay
  - Cuts are final state dependent
- τ:
  - HPS Loose (eτ,μτ), HPS Medium (ττ)
  - Loose electron discrimination
  - Loose Muon discrimination (eτ, ττ), Tight μ discrimination (μτ)
- e:
  - CiC Tight (ID Only)
  - PF Iso < 0.05 (eτ), 0.2 (eμ)
  - Missing Inner Tracker Hits: <2 (eμ), <1 (eτ)
- μ:
  - PF Iso: < 0.15 (μτ), < 0.25 (eτ)
  - VBTF μ (μτ); Global, nHits>10 (eμ)
- $30 < M_{Z2} < 80$ (eτ, μτ, ττ) to reduce ee/μμ overlap.

Systematics (H→ZZ)

- Systematic uncertainties impacting expected yields:
  - Impacting signal:
    - Luminosity (4.5%)
    - H cross section (17-20%)
    - Electron reconstruction+ID+isolation efficiency (1-6%)
    - μ reconstruction+ID+isolation efficiency (1-3%)
    - τ ID efficiency (6-6.8%)
    - τ energy scale (3%)
    - Trigger Efficiency (1%)
  - 10% uncertainty in ZZ background estimate (dominated by cross-section uncertainty)
  - 30% uncertainty in WZ/Z+jets background estimate

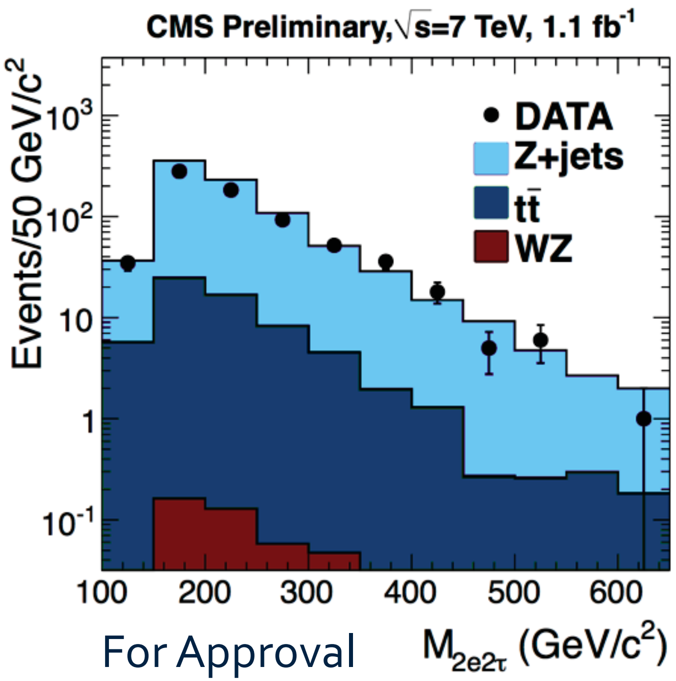
Systematics (H→ZZ)

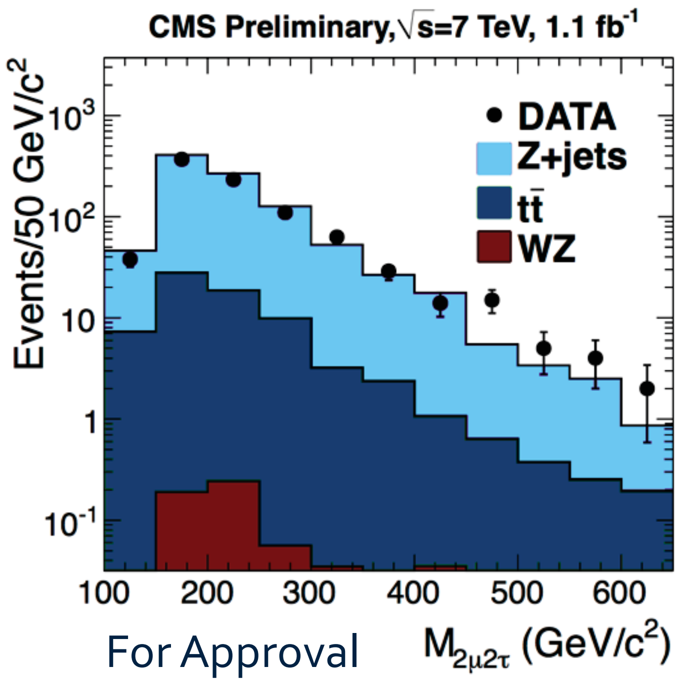
Channel	e Reco / ID/ Iso	μ Reco / ID / Iso	τ ID/ Iso	τ Energy Scale	Trigger
$\mu\mu\tau\tau$	-	1 %	10 %	4 %	1 %
$\mu\mu\mu\tau$	-	2 %	6 %	3 %	1 %
$\mu\mu e\tau$	6 %	1 %	6 %	3 %	1 %
$\mu\mu e\mu$	3 %	2 %	-	-	1 %
$ee\tau\tau$	2 %	-	10 %	4 %	1 %
$ee\mu\tau$	2 %	1 %	6 %	3 %	1 %
$eee\tau$	6 %	-	6 %	3 %	1 %
$eee\mu$	4 %	2 %	-	-	1 %

Table 4: Channel specific systematic uncertainties.

- Summary of channel specific systematics.
- Largest come from:
  - 6-10% for Tau ID Efficiency
  - 6% on 3rd tight electrons

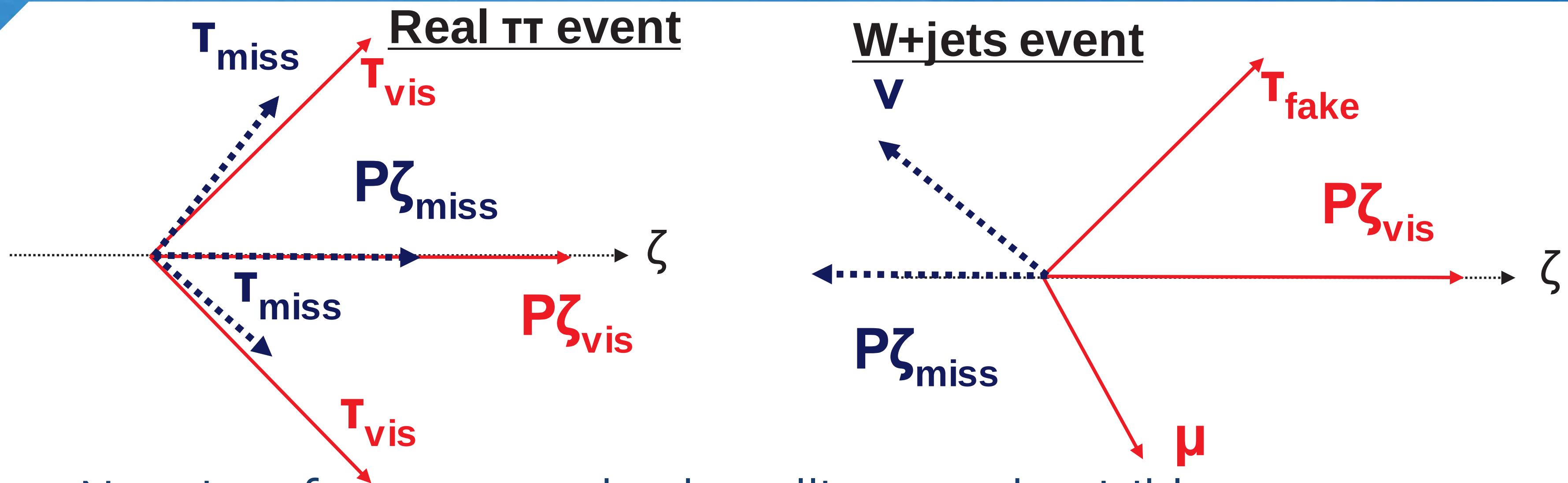
Z+Jets enriched region





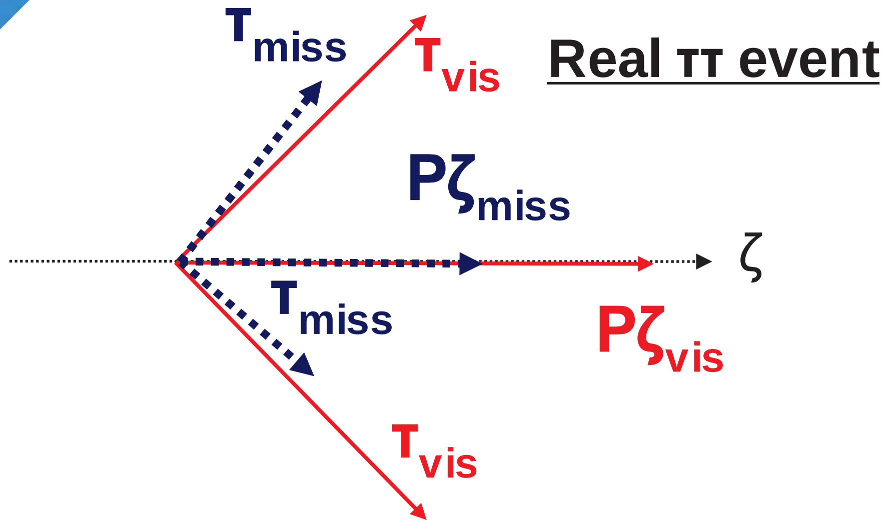
- Data/MC comparison for SS region where fake rates are measured.
- Dominated by Z+Jets background, negligible signal contribution.

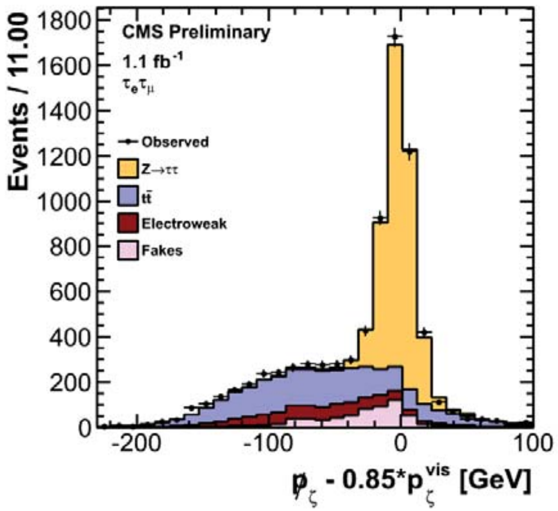
Topological requirements



- 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





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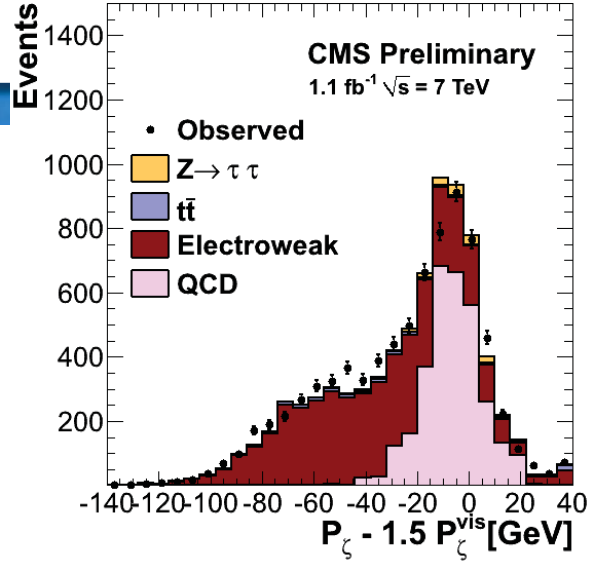
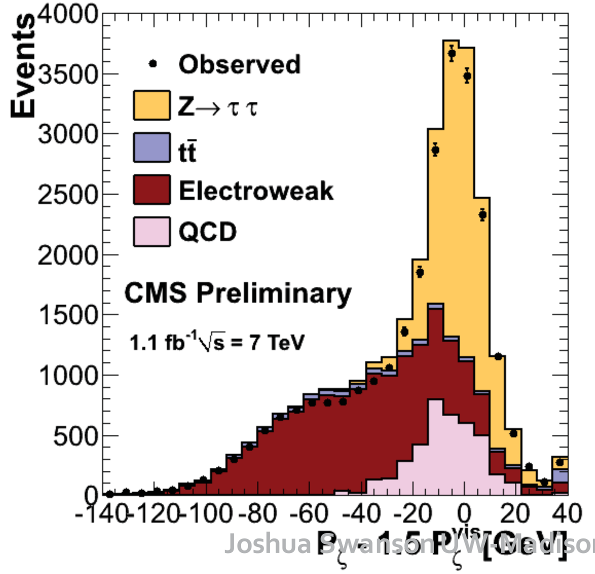
  - Request collinearity between visible and missing E_T part

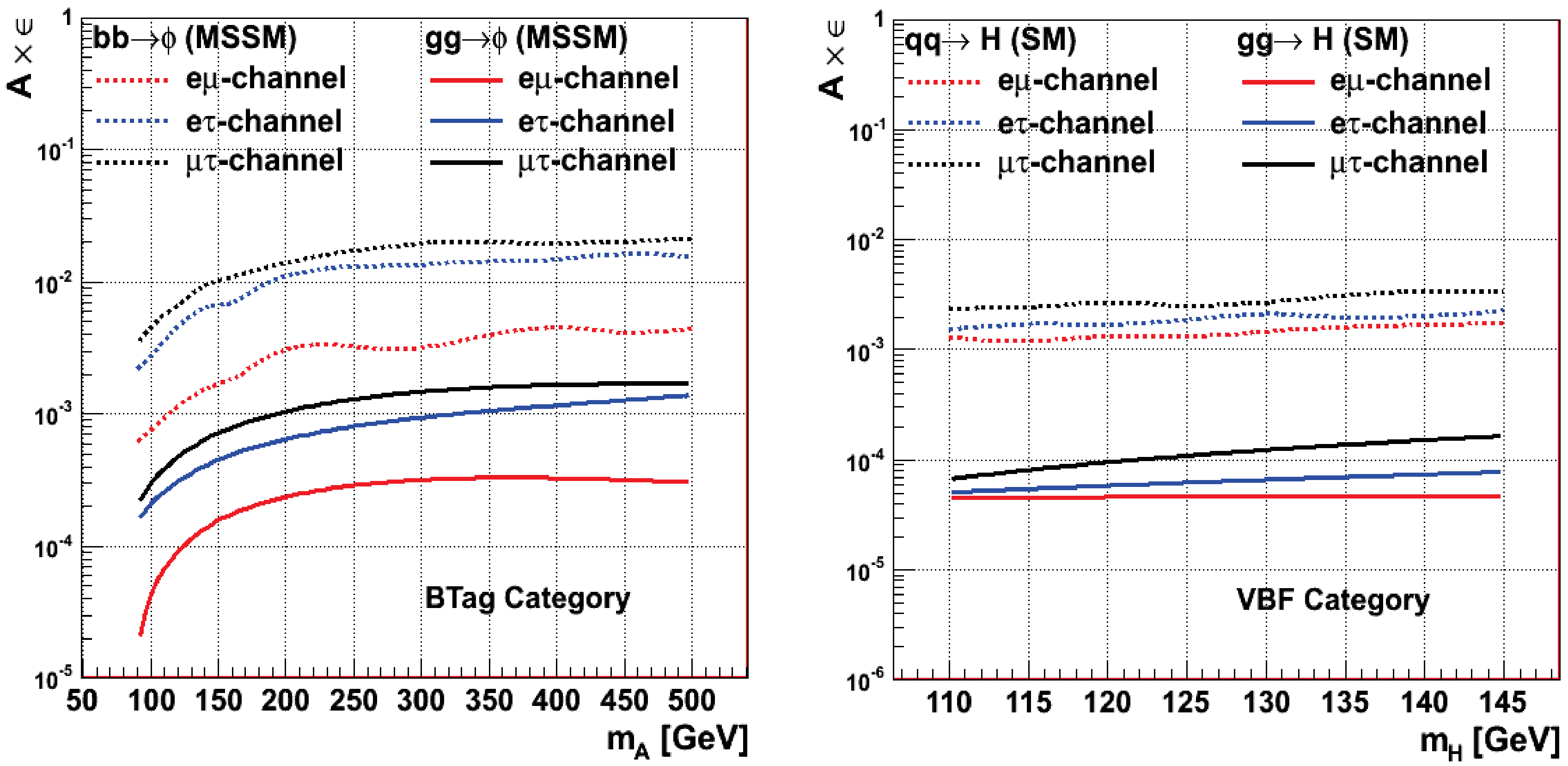
Background estimation(l+τ)

- 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 $l \rightarrow \tau$ and $j \rightarrow \tau$ 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%)



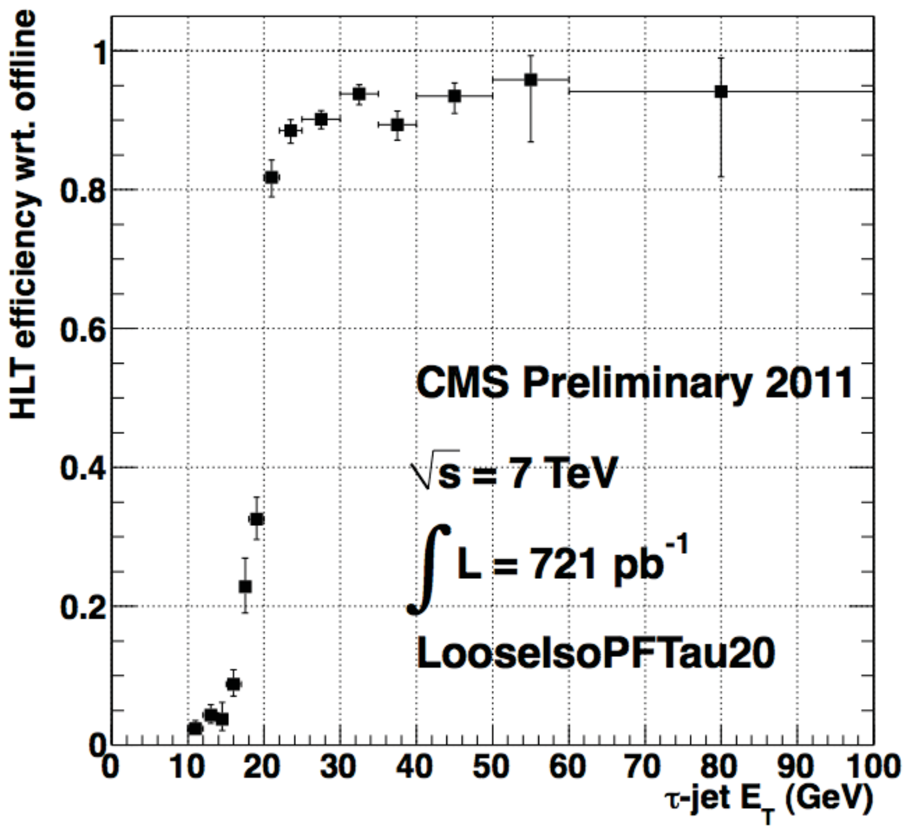


Acceptance x Efficiency vs mass



Tau Trigger Performance (l+τ)

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



Establishing the standard candles