Neutral MSSM Higgs searches with CMS

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On behalf of the CMS Collaboration

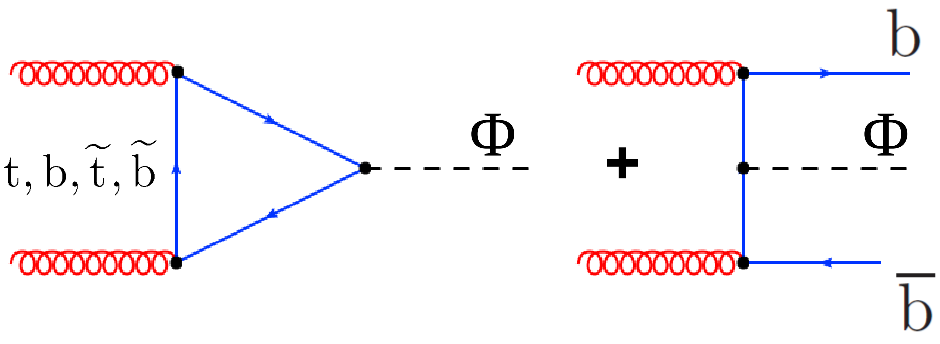
MSSM Higgs bosons

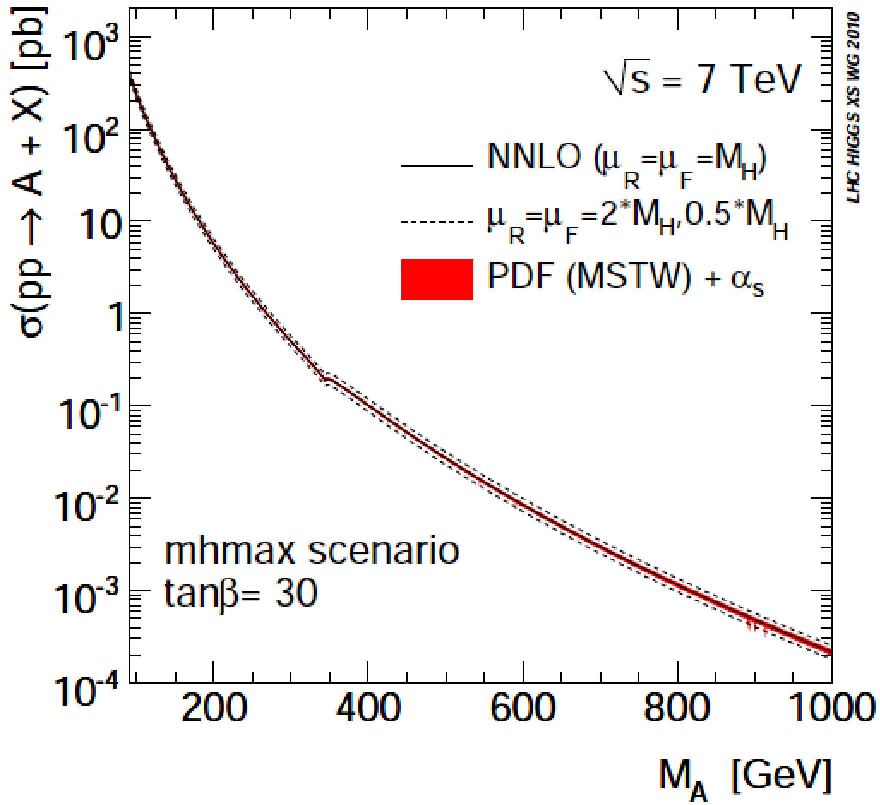
- 2 Higgs doublets
  - 5 Physical Higgs bosons
    - 2 CP even h, H, 1 CP odd A and 2 charged H^+, H^-
- At tree level
  - Higgs sector described by M_A, tan β
  - $M_h < M_Z$
- Large loop corrections from SUSY parameters
  - M_h<133 GeV (for M_t=175 GeV, M_{SUSY}= 1TeV)
- Corrections depend on SUSY parameters
  - Fixed in benchmark scenarios
    - mh^{max} scenario used

MSSM Higgs bosons

- Two main production mechanisms

arXiv:1101.0593v2 [hep-ph]





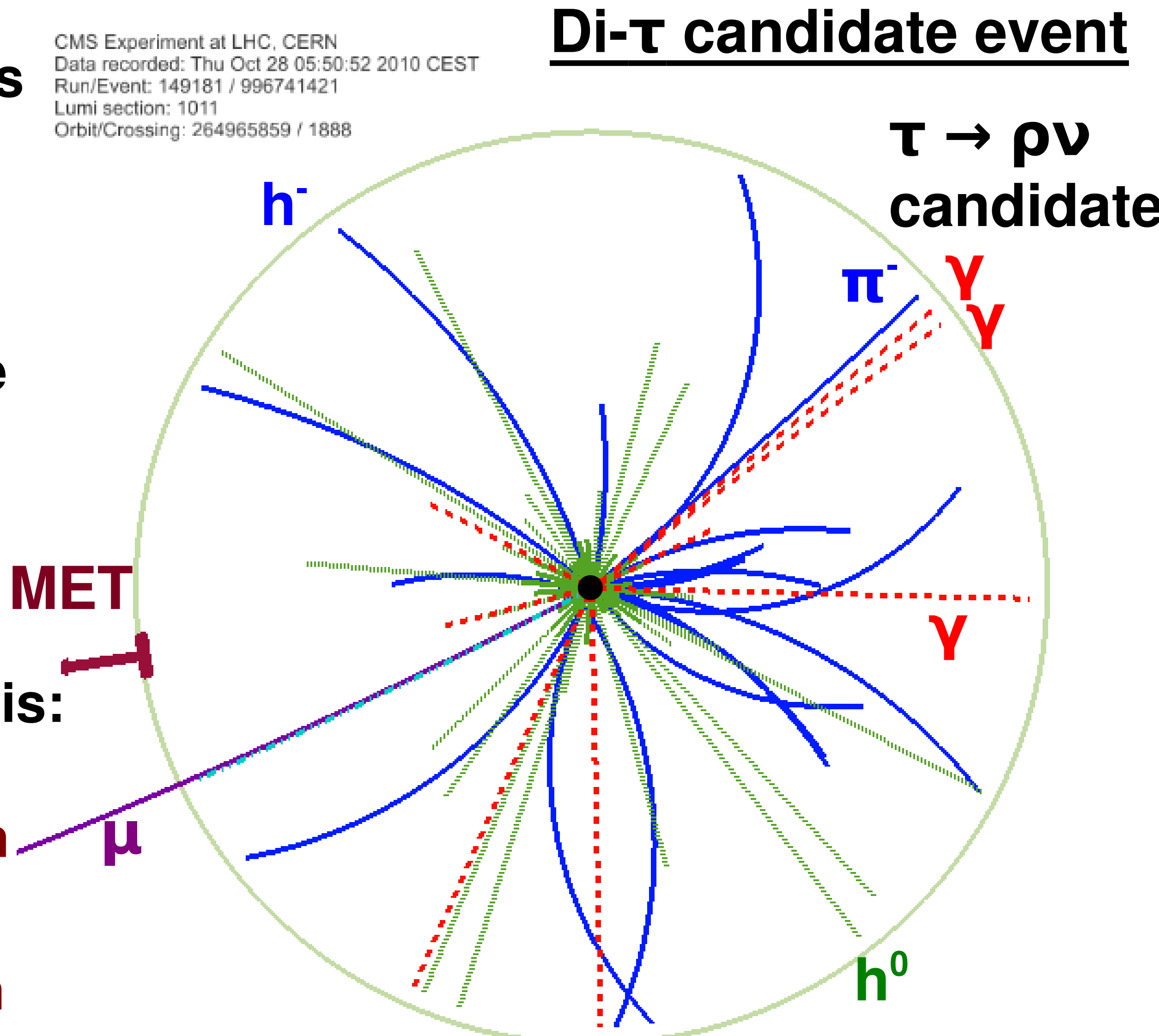
- At large tan β:
  - Cross section enhanced
  - BR(A → ττ) → 10-15%
  - h+A or H+A degenerate
- Φ → ττ is the ideal final state for the search!

Analysis Overview

- Tau decays
  - To light leptons (e,μ) and 2 neutrinos with BR ~35%
  - To hadrons(τ_h) and one neutrino with BR ~65 %
    - Dominated by π^+/K^+ ,$\rho^+ \rightarrow \pi^+\pi^0$ and $\alpha_1 \rightarrow \pi^+\pi^-\pi^+(\pi^+\pi^0\pi^0)$
- Final states with at least one light lepton preferred
  - Easier to trigger
  - Lower QCD background
- Events selected in the following final states
  - $\mu + \tau_h$: High signal yield, BR ~ 22.7%
  - $e + \tau_h$: High signal yield, BR ~ 23.1%
    - Larger background than $\mu+\tau_h$
  - e + μ : Very clean, but low branching ratio (~ 6%)
- $Z \rightarrow \tau\tau$ standard candle important for validation of the methods
  - Complete Analysis performed and submitted for publication

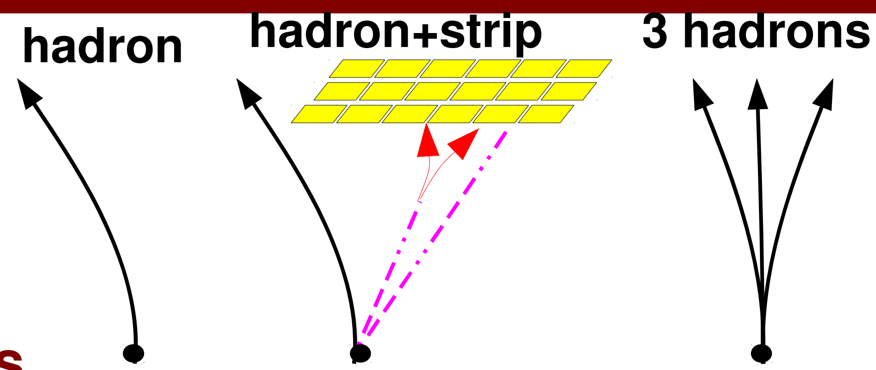
Particle Flow(PF) Reconstruction

- Combines information from all sub-detectors
- Provides unique event description
  - Particles!
- Particle candidates are combined to create composite objects
  - Taus, Jets and Missing ET
- PF used in this analysis:
  - Tau + Jet reconstruction
  - Missing ET
  - Lepton Isolation



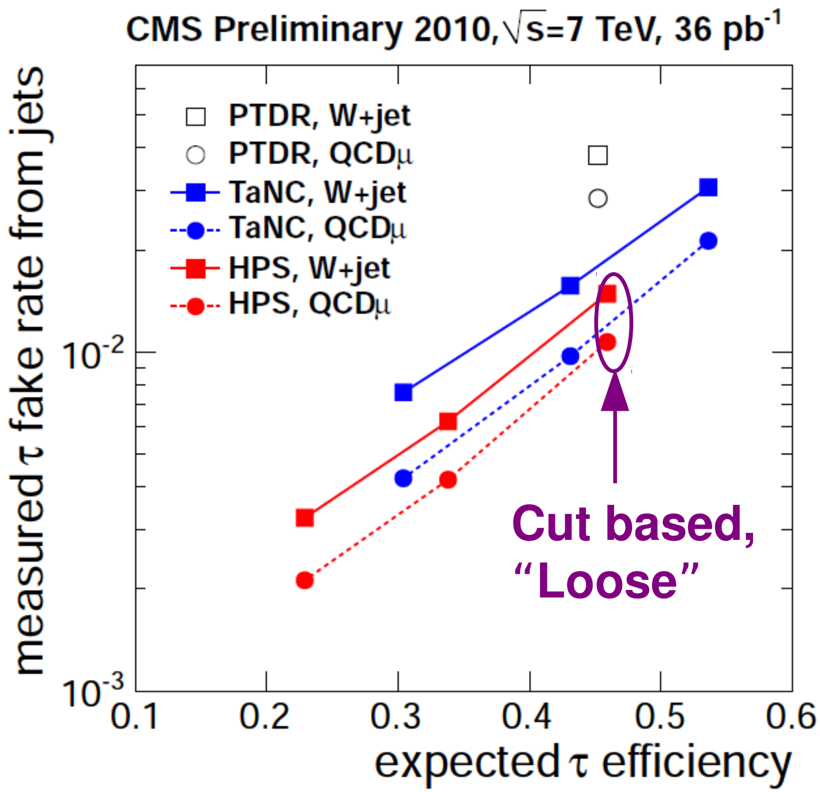
Tau Identification

- Decay mode based Tau ID used
  - Combines Particle Flow candidates
- Builds individual decay modes
  - Accounts for conversions
    - strip of EM objects
- Energy measured only by the tau constituents



Well commissioned in data

- Fake rates in di-jets
- Fake rates in W + jets and inclusive muon sample
- Data driven efficiency measurement on sample of real taus



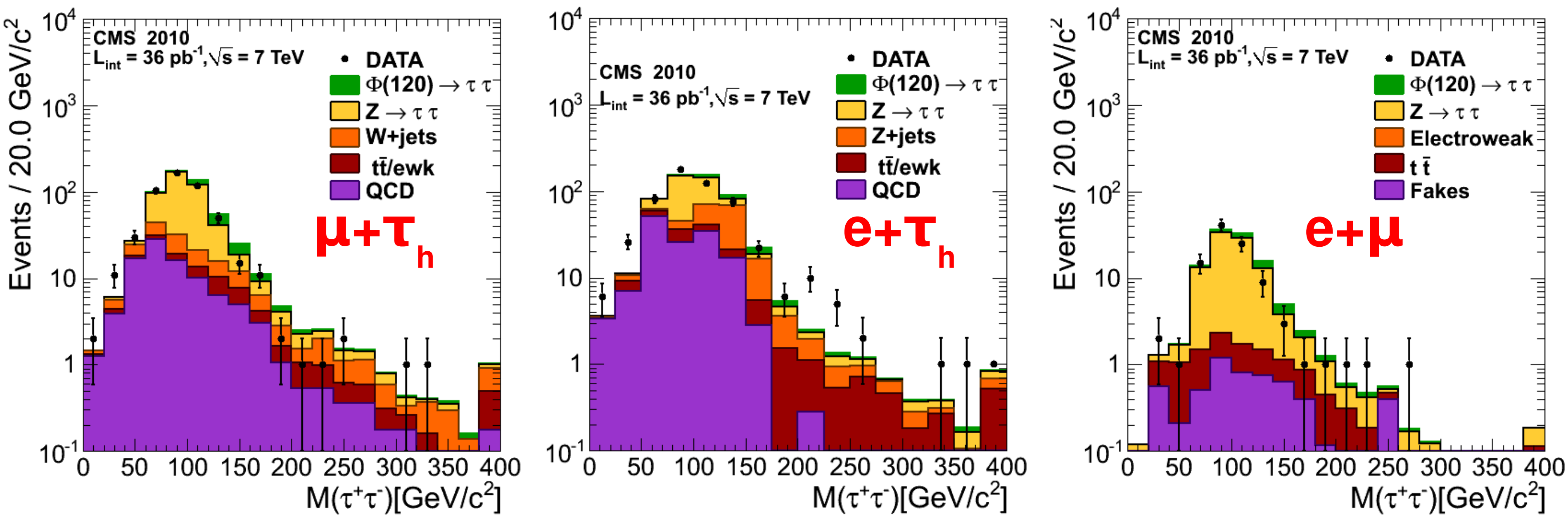
Event selection

- Trigger
  - $\mu+\tau_h$, μ+e triggered by a Single Muon Trigger
    - P_T >7 GeV @ L1 , 9- 15 GeV @ High Level Trigger(HLT)
  - $e+\tau_h$, triggered by a Single Isolated Electron trigger
    - E_T> 8 GeV @ L1, >12 GeV + isolation @ HLT
    - During last period of data taking tau leg of 15 GeV and loose isolation required @ HLT
- Offline selection
  - Muons and Electrons are required to be isolated and have P_T>15 GeV
  - Taus are required to be isolated and have P_T>20 GeV
  - W+jets/TTbar is suppressed by applying a transverse mass requirement
    - M_T< 40 GeV ($e/\mu + \tau_h$),M_T< 50 GeV ($e + \mu$)
  - Additional di-lepton veto for $e/\mu+\tau_h$ final states
    - Vetoing isolated high quality $\mu\mu$/ee pairs

Full $\tau^+\tau^-$ mass reconstruction

- Likelihood fit of visible tau momenta and neutrinos produced in tau decays
    - Using likelihood terms of tau decay kinematics and missing transverse energy
- Better discrimination compared to visible mass

Final Event selection (DATA with MC overlaid)



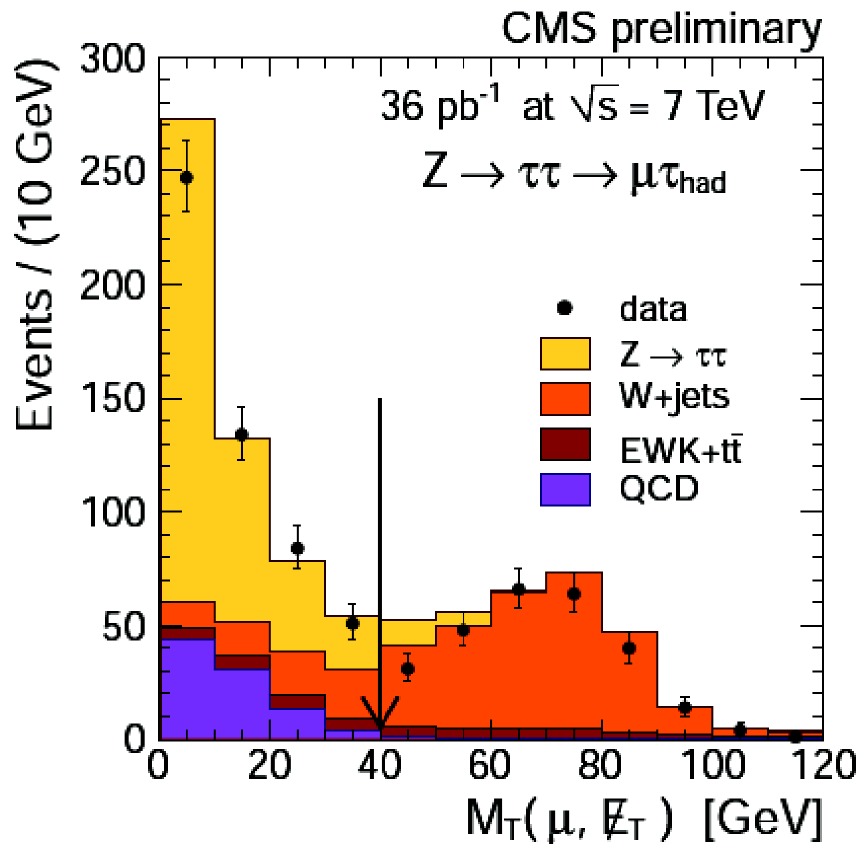
Expecting ~100 Φ events in M_A=120 , tan β = 30!

Post selection analysis

- Data driven background estimation
  - $Z \rightarrow \tau\tau$ irreducible :
    - Estimated from $Z \rightarrow \mu\mu$/ee measurement + NLO acceptance modeling + DATA/MC correction factors
  - Other backgrounds reducible
    - Remaining events estimated by data driven methods
- Simultaneous fit performed an all channels for the Higgs cross section
  - Data driven estimated yields and systematic uncertainties introduced as nuisance parameters
- All nuisance parameter values and uncertainties estimated from data

Background Estimation (e/μ + τ_h)

- $Z \to \tau\tau$ irreducible
- Dominant reducible backgrounds : QCD, W+jets
- QCD expected to have OS/SS ratio ~ unity
  - Measured by anti-isolating the muon/electron)
    - 1.06 +- 0.03 ($\mu+\tau_h$)
    - 1.06 +- 0.09 ($e+\tau_h$)
- W transverse mass shape is used to extrapolate the W events in the signal region
  - Separately in OS , SS
- Small backgrounds estimated by MC (TTBar/Dibosons) or using $\tau \to$ lepton fake rates ($Z \to ee/ \mu\mu$)



Results cross-checked with independent method

Background Estimation Input to the fit

Process	$\mu+\tau_h$	$e+\tau_h$	$e+\mu$
$Z \to \tau\tau$	329 ± 77	190 ± 44	88 ± 5
TTBar	6 ± 3	2.6 ± 1.3	7.1 ± 1.3
$Z \to ee/\mu\mu$ +jets , jet fakes tau	6.4 ± 2.4	15 ± 6.2	-
$Z \to ee/\mu\mu$	12.9 ± 3.5	109 ± 28	2.4 ± 0.3
$W \to e/\mu\ \nu$ + jets	54.9 ± 4.8	30.6 ± 3.1	1.5 ± 0.5
$W \to \tau\ \nu$	14.7 ± 1.3	7.0 ± 0.7	
QCD	132 ± 14	181 ± 23	
Di bosons	1.6 ± 0.8	0.8 ± 0.4	3.0 ± 0.4
Total	**557 ± 79**	**536 ± 57**	**102 ± 5**
Observed	**517**	**540**	**101**

- $Z \to \tau\tau$ from $\sigma(Z \to ee/\mu\mu)$, others with data driven extraction

Systematic uncertainties

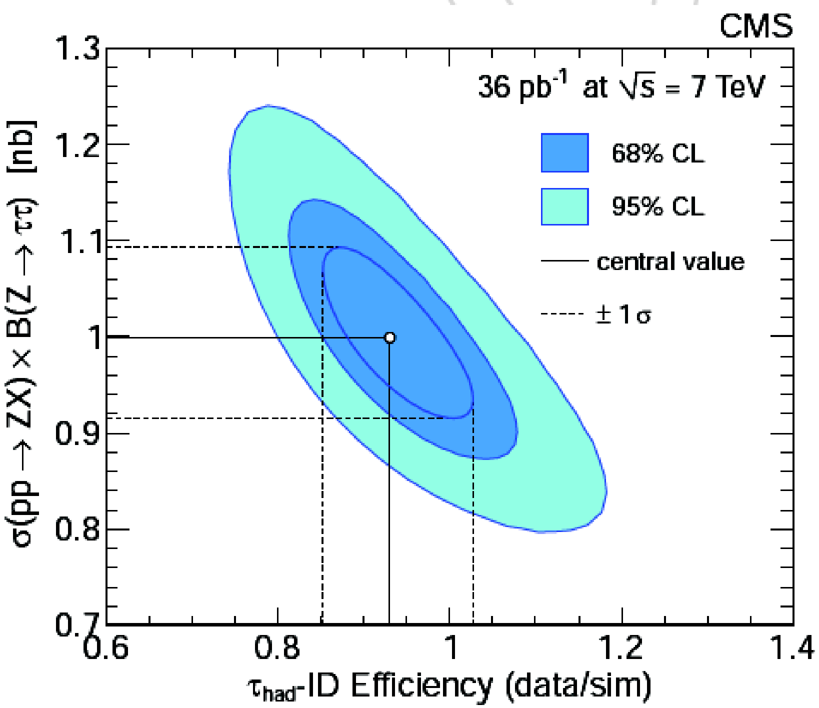
Source	Uncertainty	Usage
Lepton ID /trigger	0.2-2%	Efficiency correction factors
Tau ID efficiency	24%	Efficiency correction factor
Lepton Pt scale	1-2%	Shape uncertainties
Tau energy scale	3%	Shape uncertainties
Jet energy scale	3%	Shape uncertainties from MET
Unclustered ET scale	10%	Shape uncertainties from MET
$\sigma(Z \rightarrow \mu\mu/ee)$	4%	$Z \rightarrow \tau\tau$ yield normalization
Luminosity	11%	

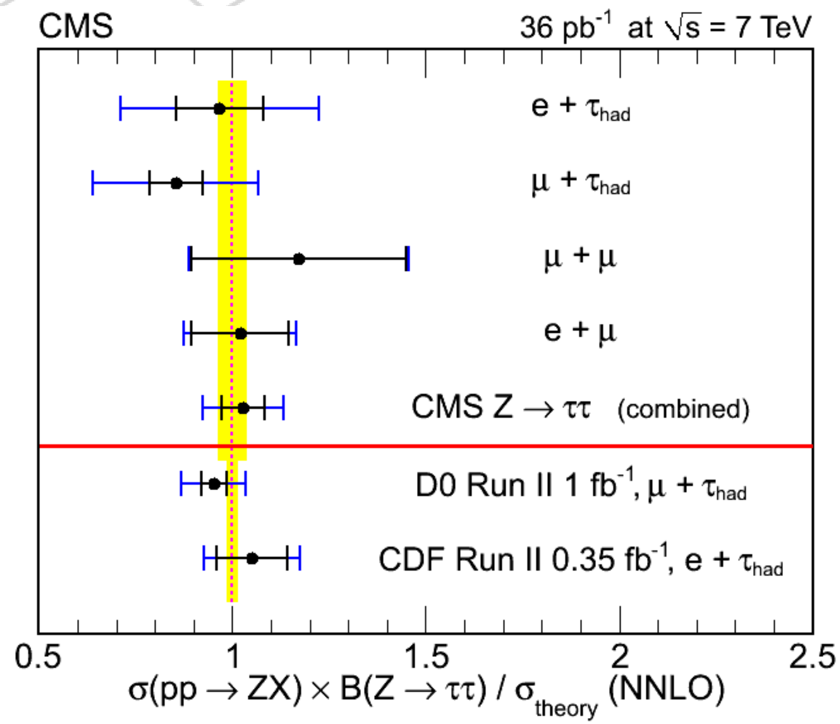
Tau ID efficiency dominates the systematics
(measured in data sample of real taus → low statistics)

Constrained Fit for the Higgs cross section

- Constrained fit applied on the $M_{\tau\tau}$ spectrum for each Higgs mass hypothesis
  - QCD and $Z \rightarrow ee/\mu\mu$ shapes taken from data
    - All other shapes from simulation
      - Agreement with data verified in sideband regions
    - Shapes from simulation allowed to vary within the scale uncertainties
  - Background estimated yields constrained by Gamma distributions and scale factors by Lognormal distributions
- $gg\Phi$ and $bb\Phi$ relative cross section ratio constrained to the expected value at $\tan\beta = 30$ (different for each mass point)
- Higgs width assumed for $\tan\beta = 30$
  - Negligible wrt experimental mass resolution
- For $M_\Phi > M_Z$ Z peak self calibrates tau ID to higher precision (~7%)
- For $M_\Phi \sim M_Z$, e+mu channel dominates (lower systematics)

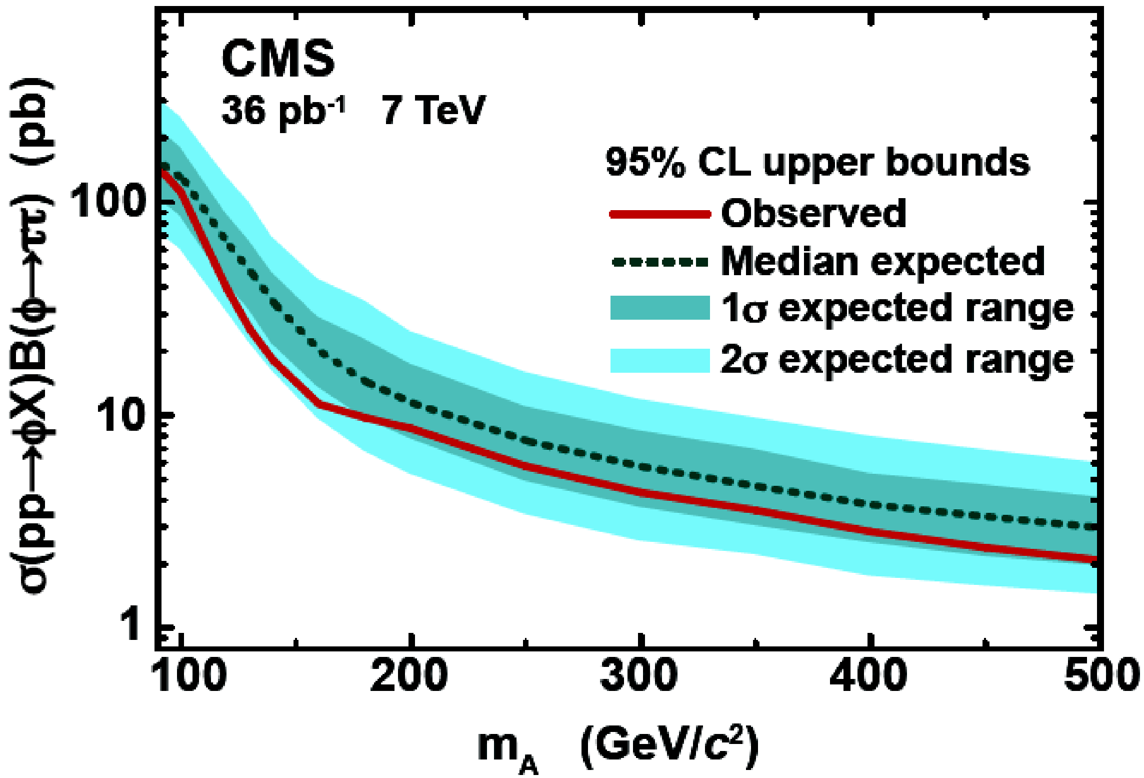
Establishing the Z → ττ standard candle





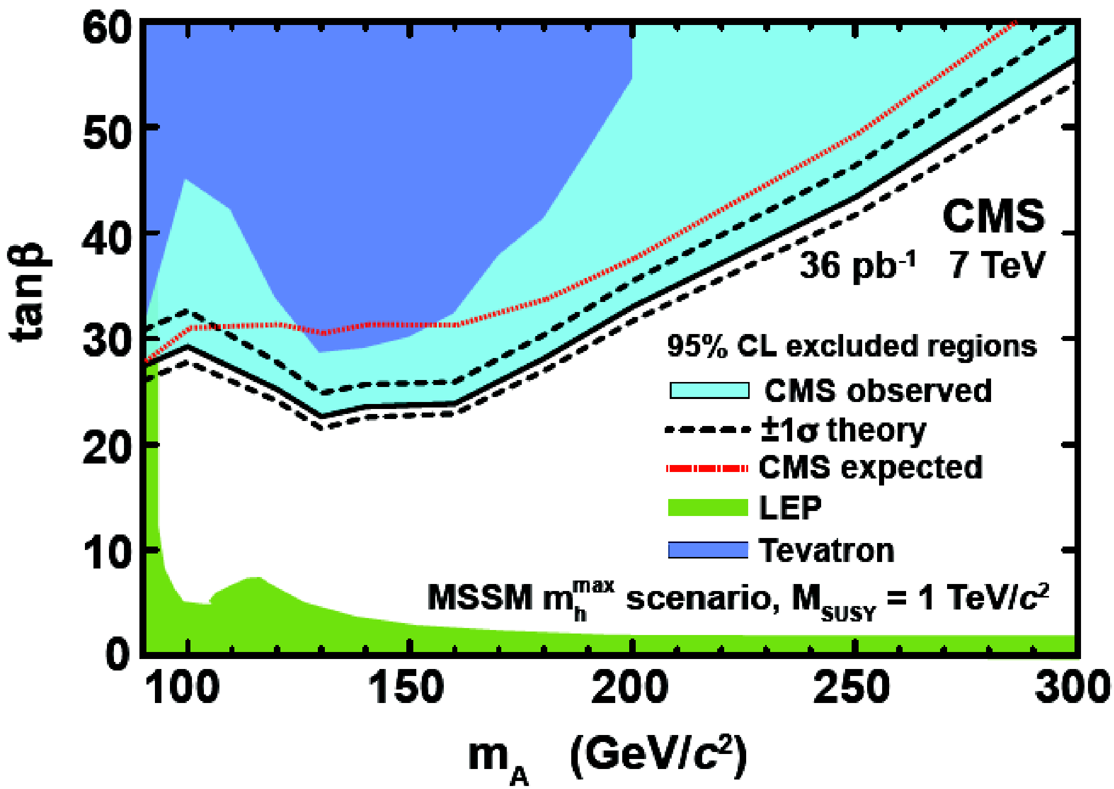
- **Performing similar fit without Higgs signal for the Z → tau tau cross section & Tau ID correction factor**
  - **Includes also Z → ττ → μμ final state**
- **σ = 1.00 ± 0.05 (stat) ± 0.08 (syst) ± 0.04 (lumi) nb**
- **Cross section in agreement with NNLO prediction(0.972 nb)**
- **ArXiv:1104.1617(hep-ex) -Submitted to JHEP**

Results of the Higgs search



- No excess is observed in the di-tau mass spectrum
- 95% CL upper limits are set to the Higgs production cross section
  - Using suggested methods in PDG
- Limits reported with Bayesian integration method with flat prior in cross section ($\sigma > 0$)
  - Cross checked with profile likelihood (Bayesian more conservative)

Interpretation in the MSSM parameter space



- With 36 pb-1 CMS sets better limits than published Tevatron results
  - Improved sensitivity at low mass – New unexplored region at high mass
- Theoretical cross sections and uncertainties taken from LHC Higgs Cross section working group
  - 5 Flavor Scheme has been used
  - Tanβ > 60 not considered (theoretically unstable)

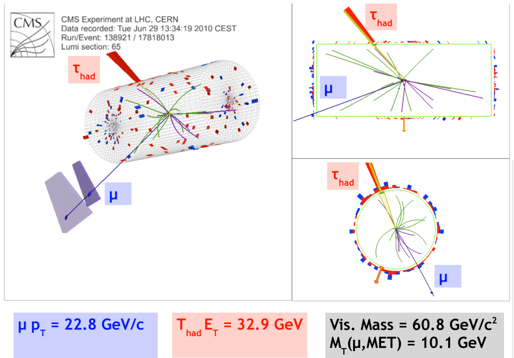
Conclusions

- A search for MSSM Neutral Higgs has been performed in CMS with 36 pb^{-1} of data
- Experimental methods have been validated in $Z \rightarrow \tau\tau$ cross section measurement
- No evidence of signal observed
- Upper limits have been set in Higgs production cross section and translated to M_A – tan β plane
- CMS results exclude previously unexplored region in MSSM parameter space

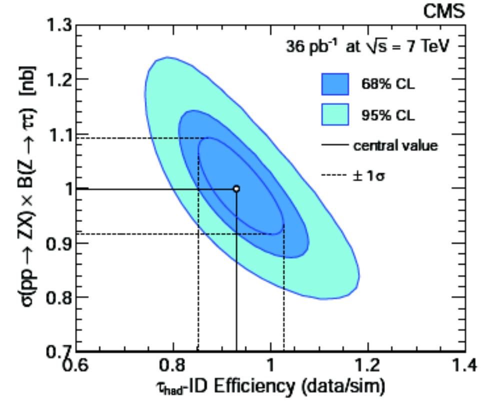
- ArXiv:1104.1619(hep-ex) - Submitted to Physical Review Letters

CMS Di-Tau Evolution...

First Di-Tau candidate



Z → ττ cross section



ICHEP 2010(Jul)

Tau 2010 (Sep)

Moriond 2011 (Mar)

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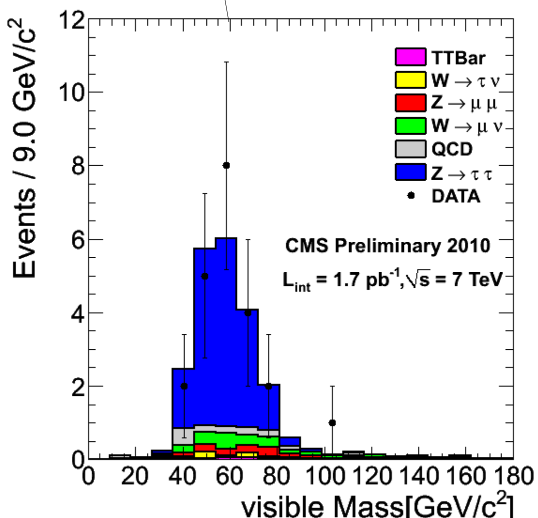
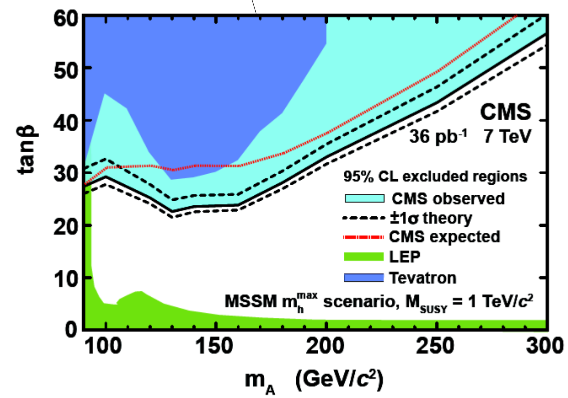


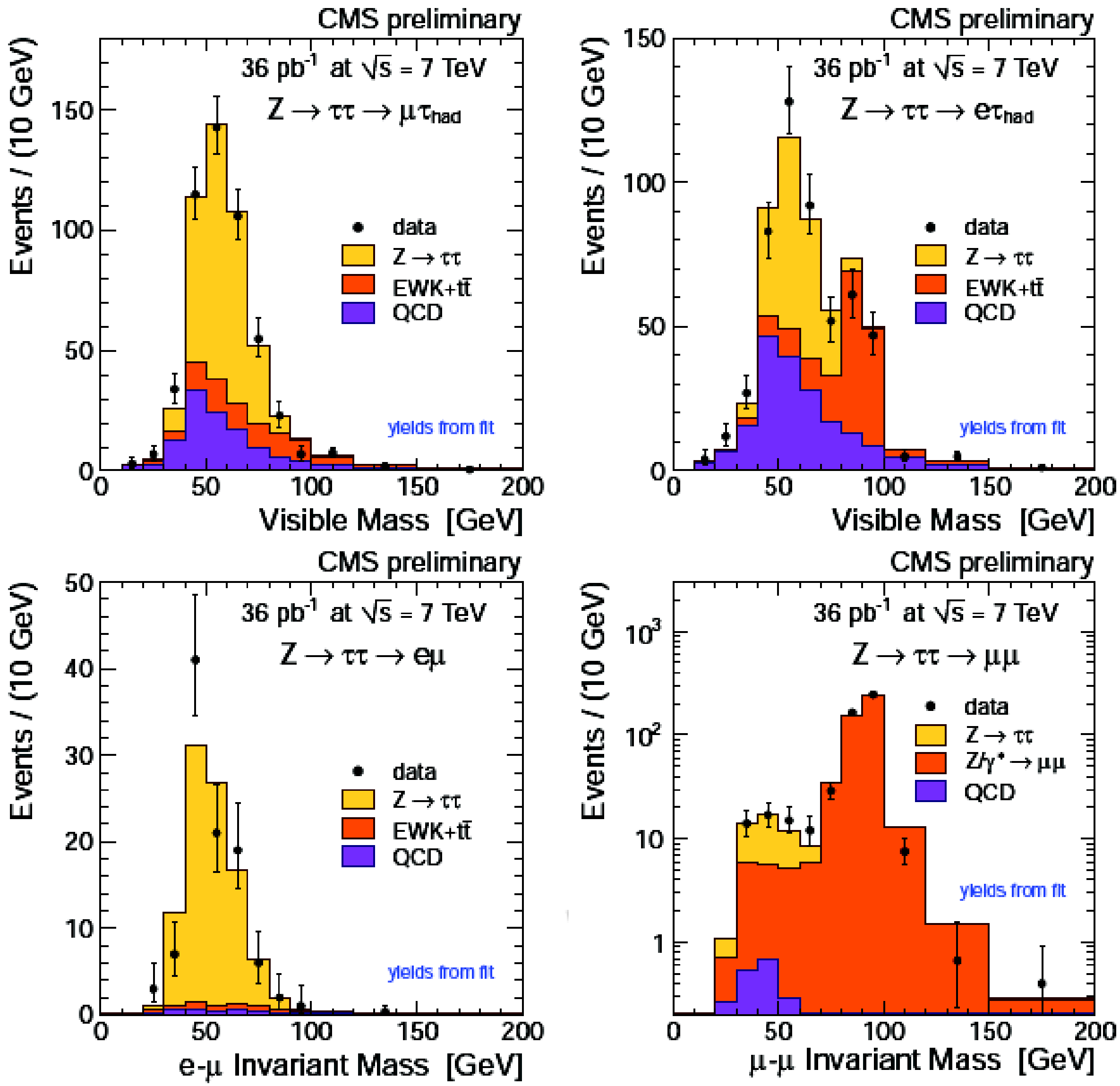
First Z → ττ signal



MSSM Higgs limits

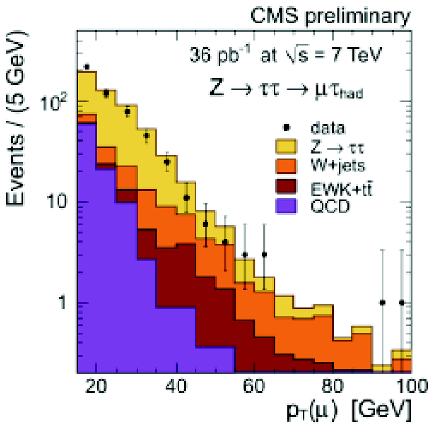
BACKUP SLIDES

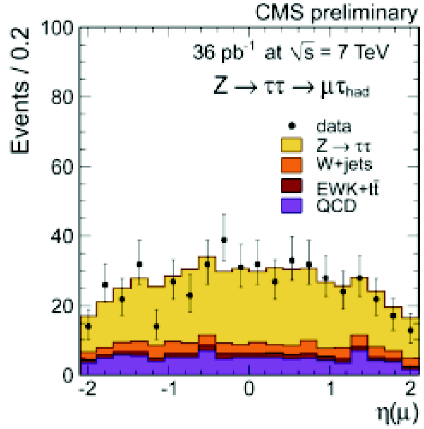
Visible Mass shapes after fit (Z → ττ)

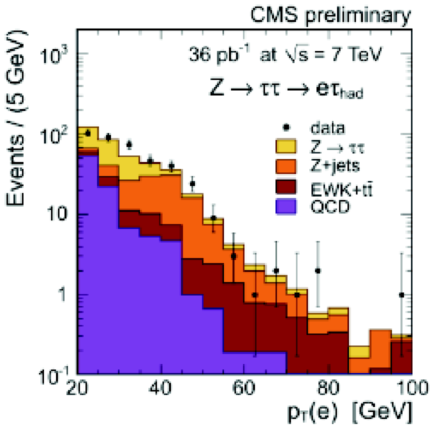


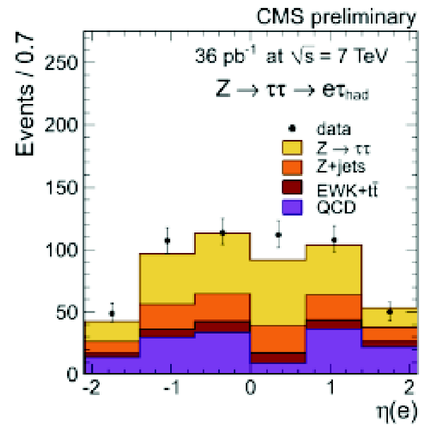
Control Plots ($e/\mu + \tau_h$)

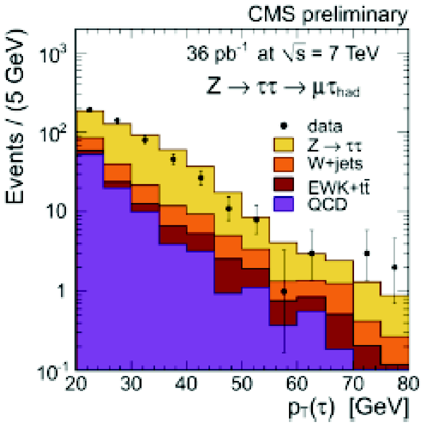
$\mu+\tau$ **$e+\tau$**

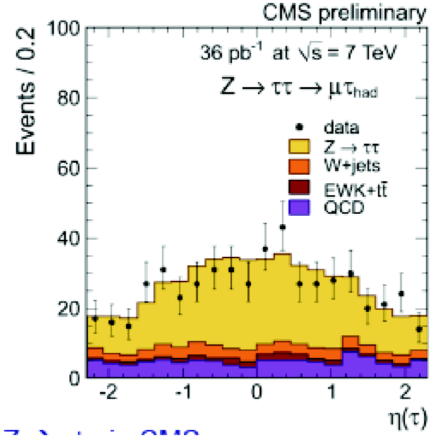


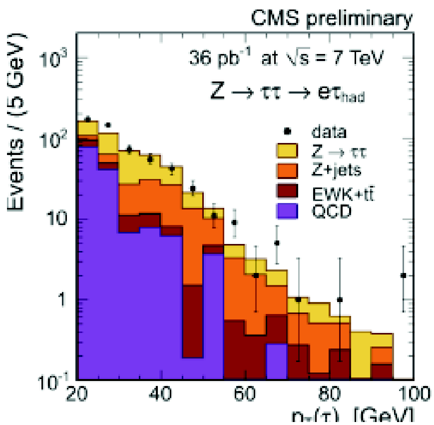


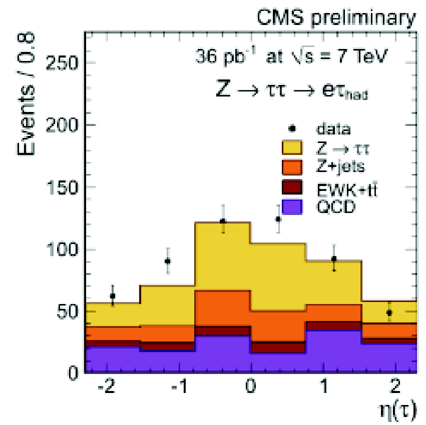




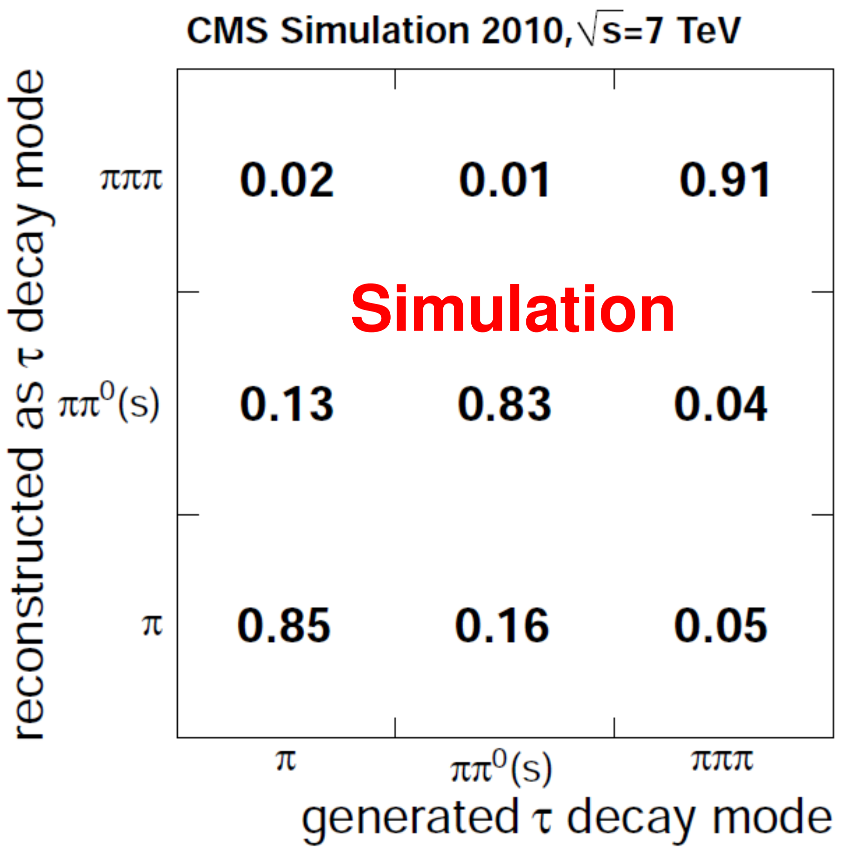


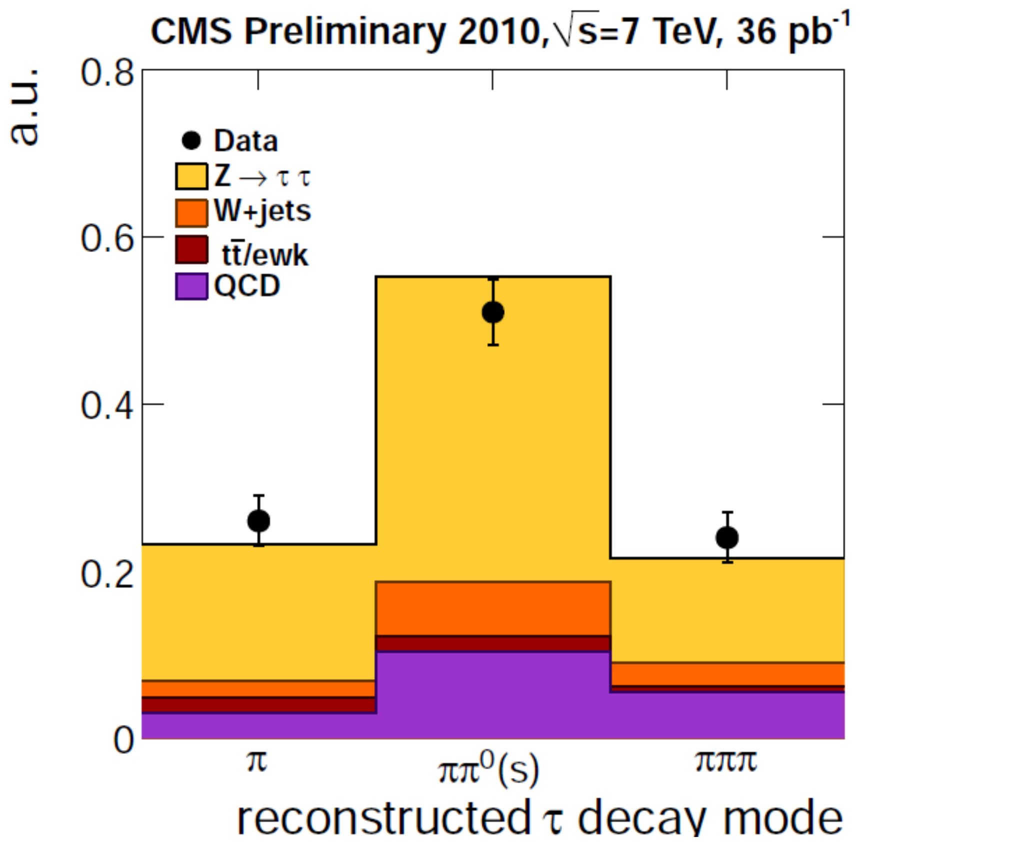






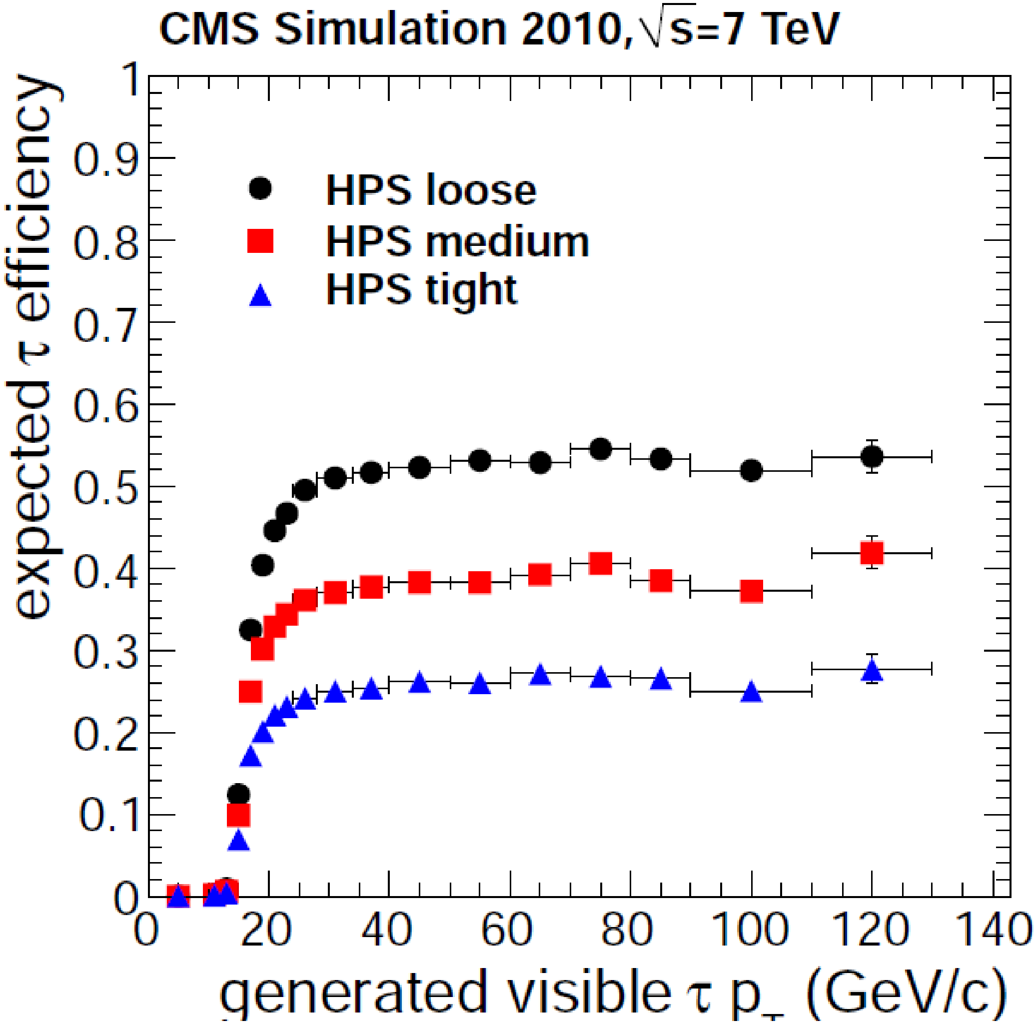
Tau ID performance (I)

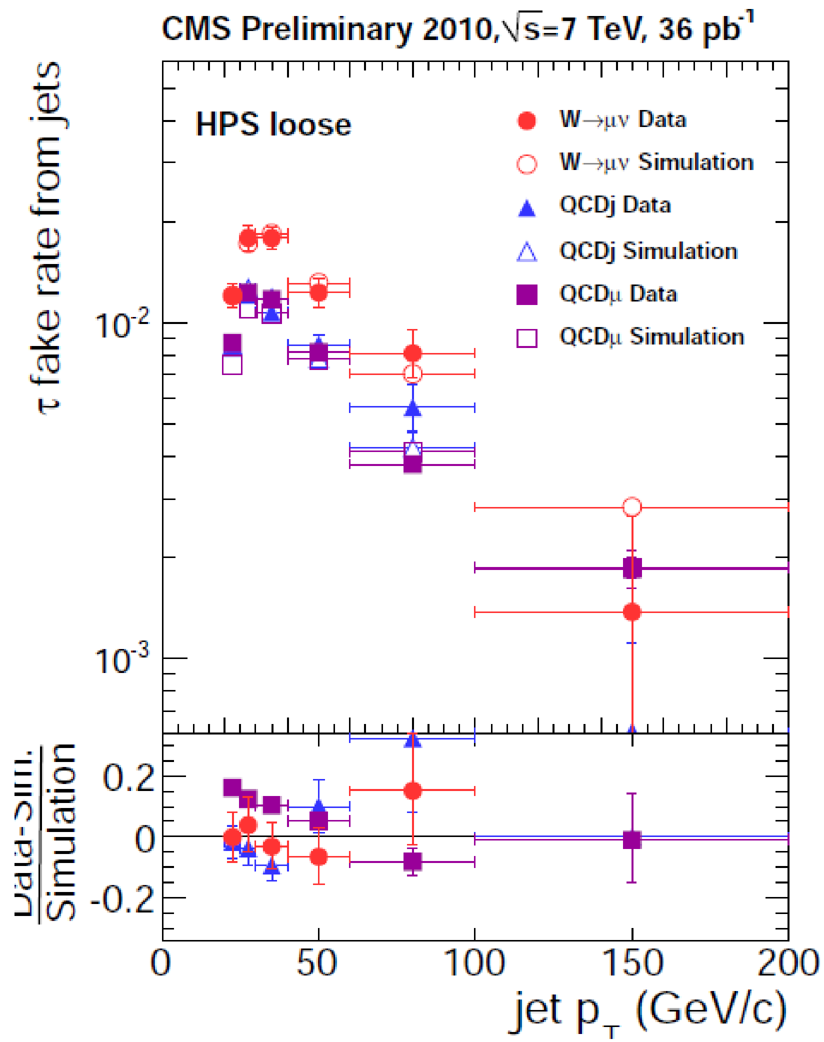




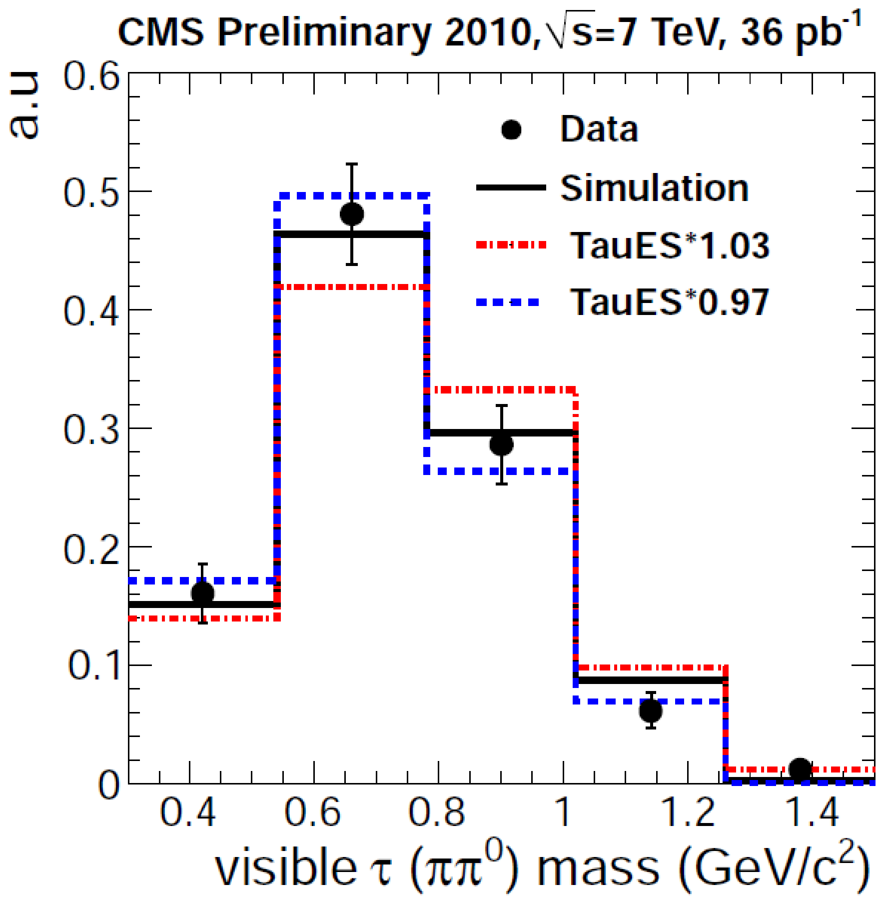
- **Tau ID algorithm reconstructs the proper decay modes**

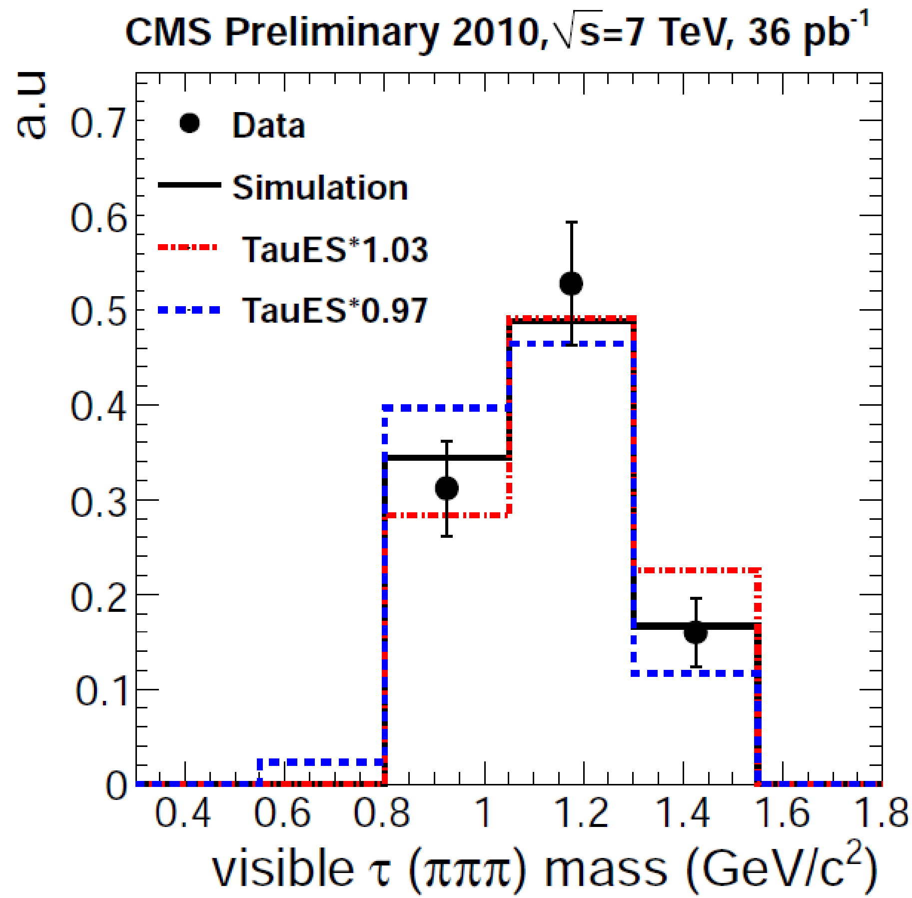
Tau ID performance(II)





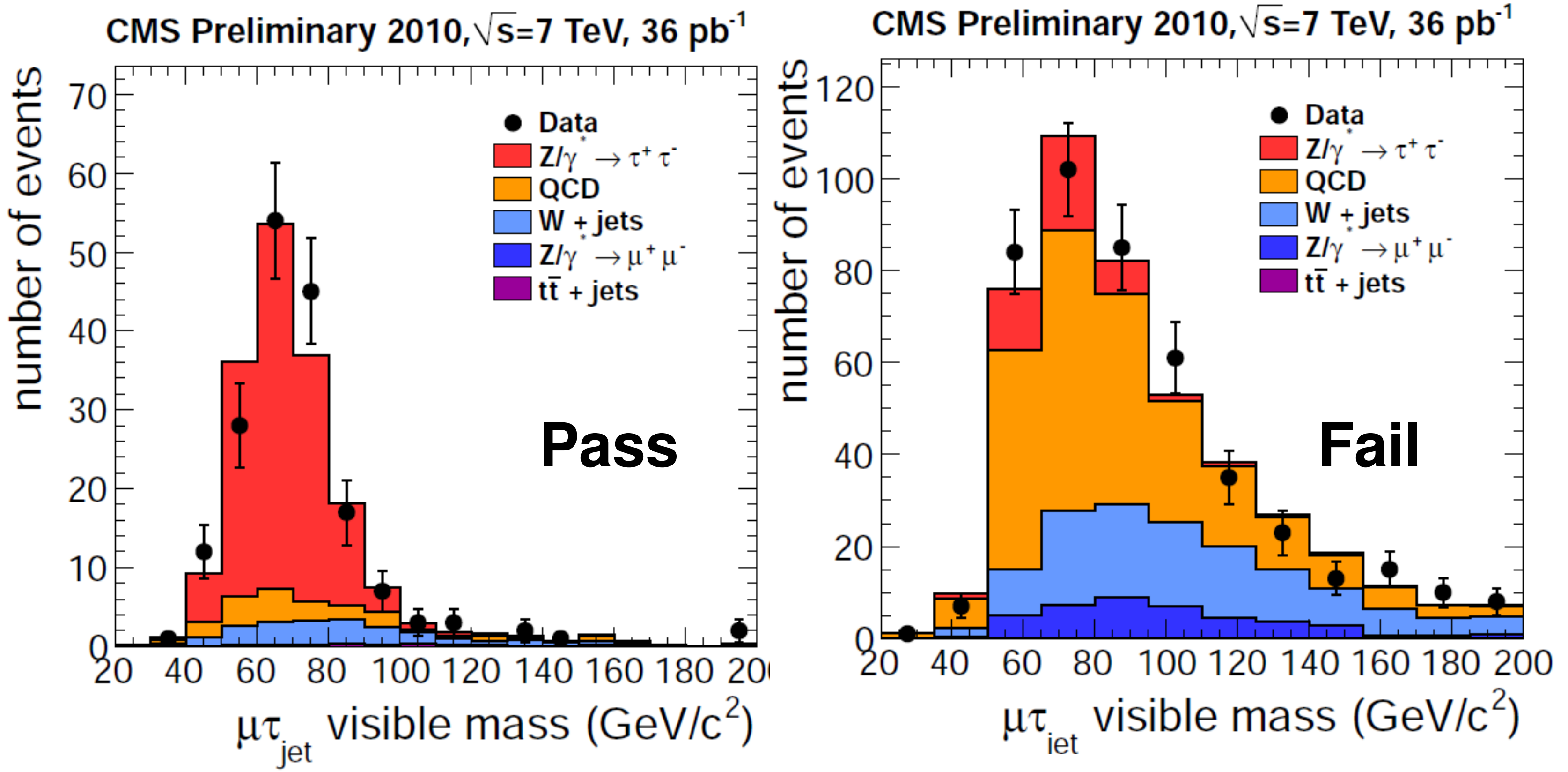
Reconstructed Tau Mass





- Good agreement with simulation
- Precise reconstruction of the resonances

Tau ID efficiency measurement



- **Using Tag and probe on a sample of μ+ PF Jet**
- **Spit Pass and Fail samples and perform simulated fit for the efficiency (Pass/ (Pass + Fail))**
- **Efficiency uncertainty ~ 23 % (Dominated by Fail sample statistics)**

Limits calculation

- 95 % CL Limits calculated by Bayesian integration

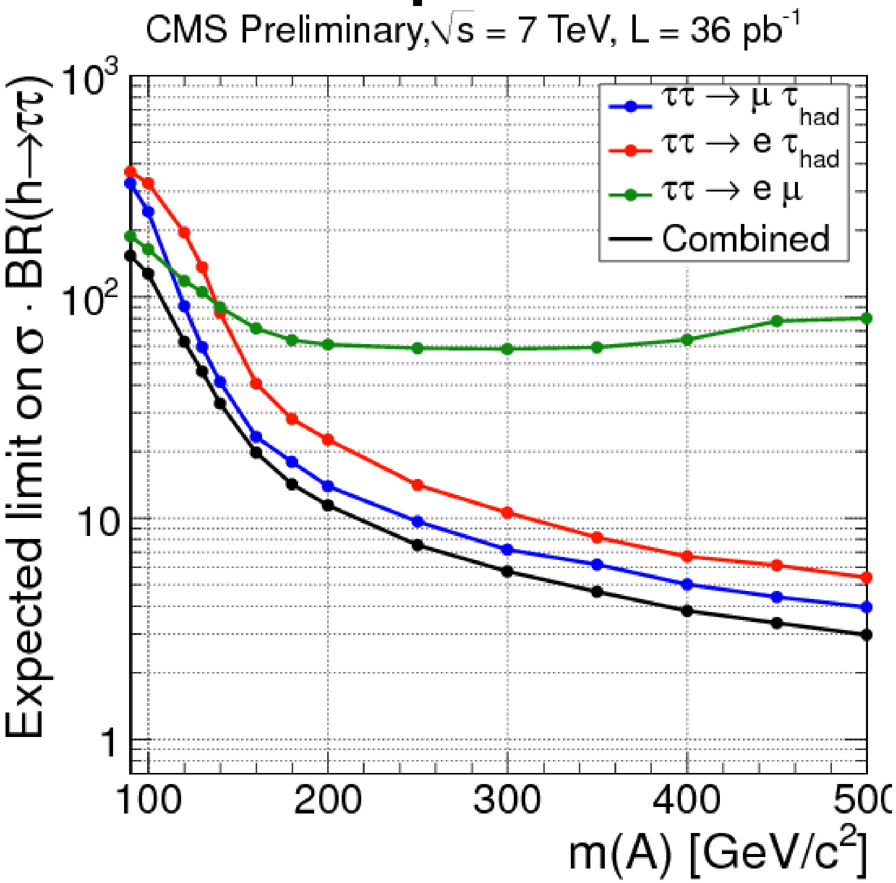
$$\int_{\sigma=0}^{\sigma_{95\%}} \frac{\int \mathcal{L}(\text{data},\sigma,\nu)\,\pi(\sigma)\mathrm{d}\nu}{\int \mathcal{L}(\text{data},\sigma',\nu')\,\pi(\sigma')\mathrm{d}\sigma'\mathrm{d}\nu'}\mathrm{d}\sigma = 0.95$$

assuming flat prior for the cross section(σ>0)

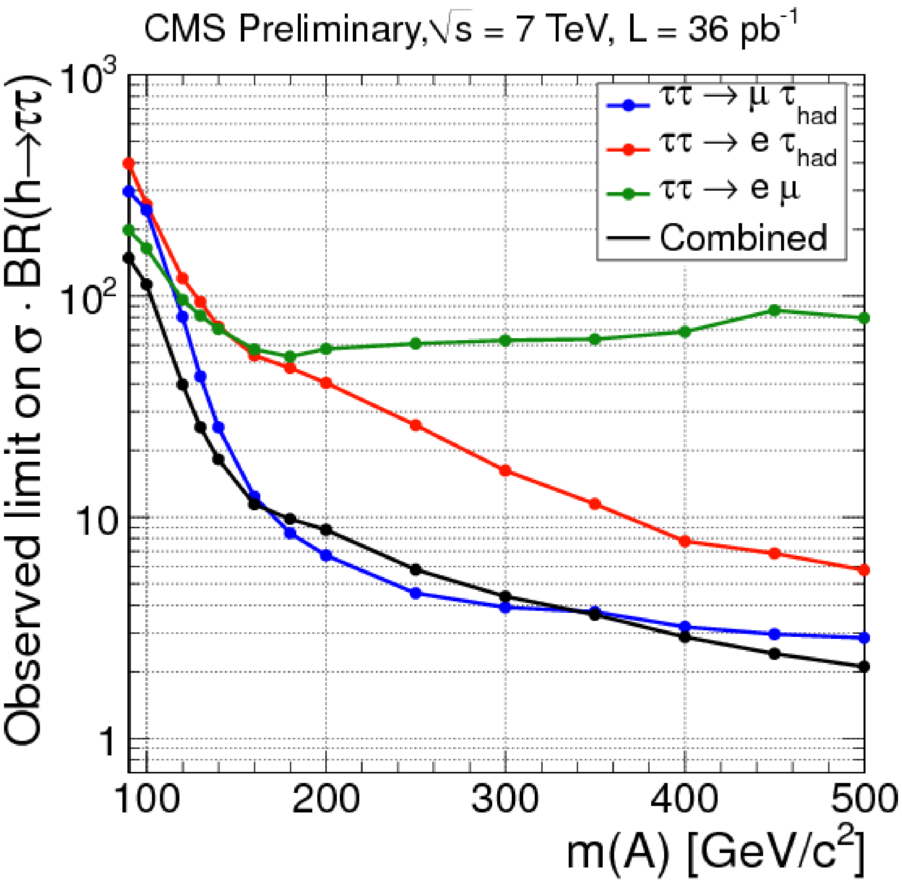
- Integration performed with Markov Chain MC over all nuisance parameters
- Expected limits obtained by Toy MC (Median)
    - For each toy systematics produced based on the nuisance pdf
    - Shapes are generated with these systematics values

Limits : Channel by Channel

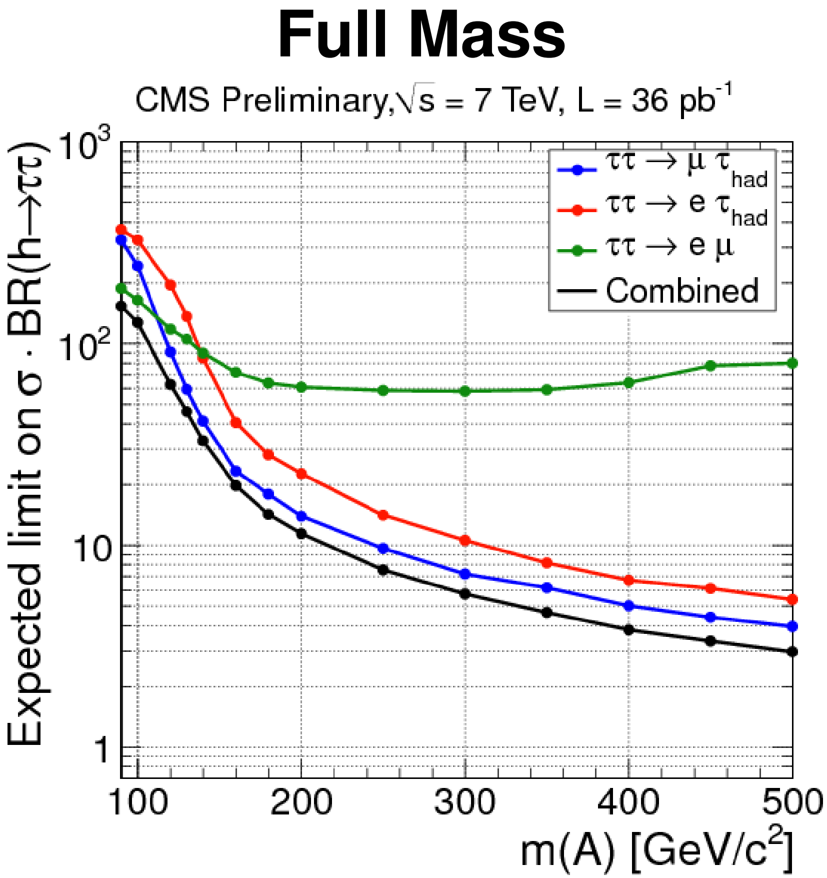
Expected

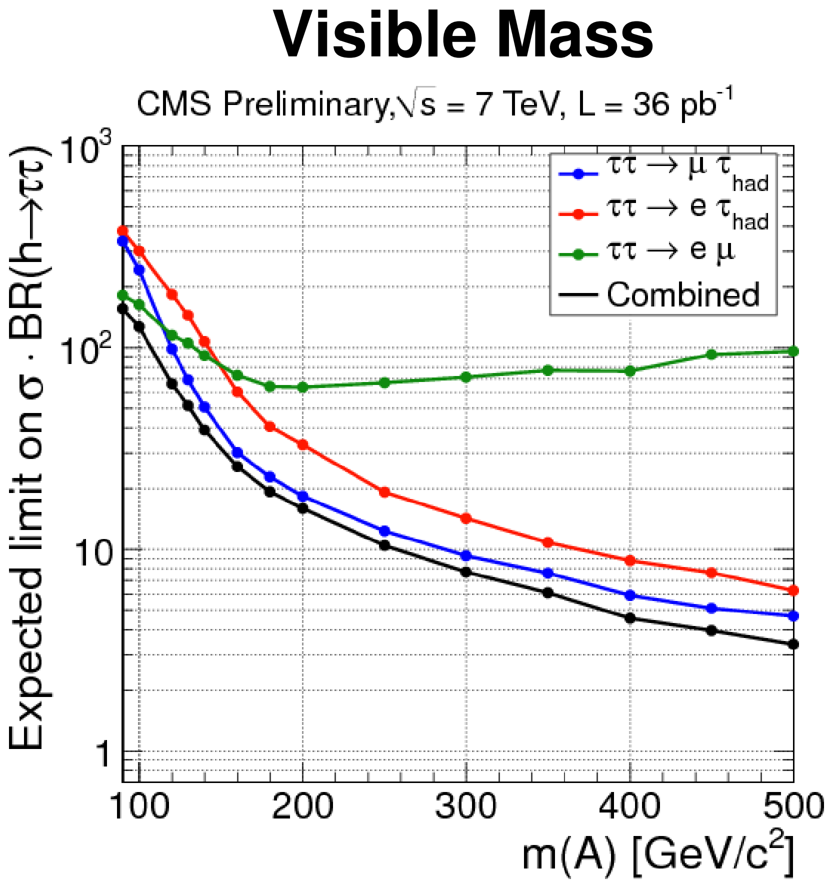


Observed



Expected Limits : Vis Mass vs SV fit Mass





- **Full reconstructed mass gives better expected limit**

4FS vs 5FS

- At low MA 4FS cross section higher
- At large MA 5FS higher
- Red band has only scale uncertainties for 4FS