Tau identification and reconstruction at CMS

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On behalf of the CMS Collaboration

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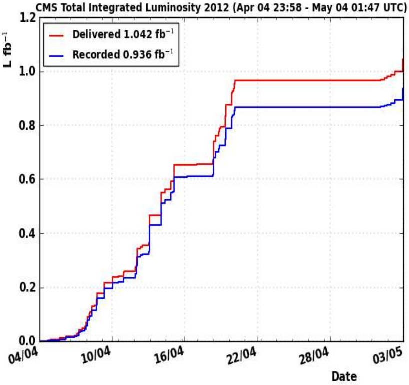
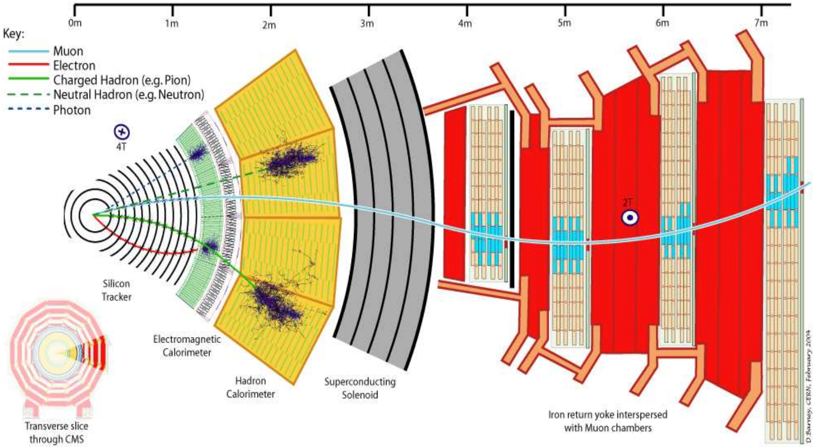
LHC

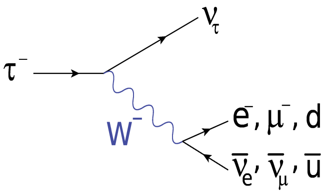


1. 5 fb^{-1} at 7 TeV
2. 1 fb^{-1} at 8 TeV
3. $\approx$ 20 fb^{-1} by end of the year

CMS


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
D Barney, CERN, February 2004

Tau lepton



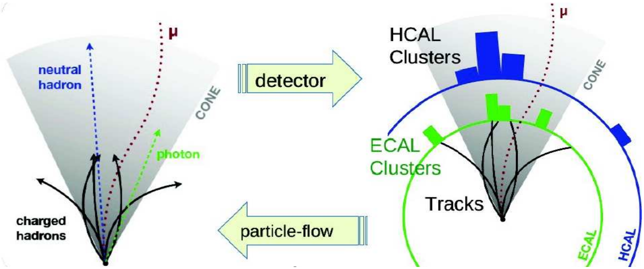
τ properties:

- $m_\tau = 1.776$ GeV
- $c\tau = 87.11\mu m$
- leptonic decay: 35.2%
- hadronic 1 and 3-prong: 63.1%
- significant part of τ momentum escapes with neutrino.

Tau lepton is a very suitable tool for studying many physical processes at LHC

Decay Mode	Resonance	Mass, MeV/c^2	Branching ratio, %
$\tau \rightarrow h^- \nu_\tau$			11.6%
$\tau \rightarrow h^- \pi^0 \nu_\tau$	ρ	770	26.0%
$\tau \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	a1	1200	10.8%
$\tau \rightarrow h^- h^+ h^- \nu_\tau$	a1	1200	9.8%
$\tau \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$			4.6%
Total			63.1%
Other hadronic decays			1.7%

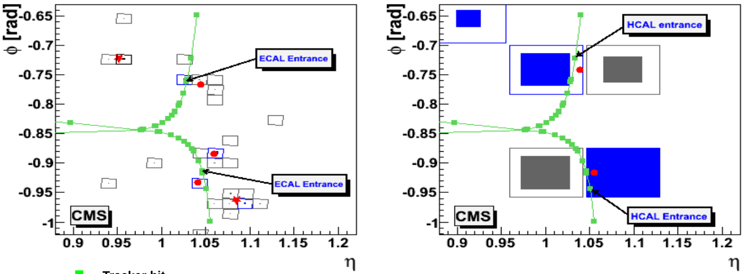
Particle Flow Algorithm



- Particle Flow (PFlow) combines and links signals coming from different CMS sub-detectors to provide a complete event description
- As an output PFlow gives a list of reconstructed particle candidates (e, μ, γ, $h^{\pm}$, h^{0})
- Tau lepton reconstruction algorithms start from PFlow candidates

Particle Flow Algorithm (CMS PAS PFT-10-001)

Example of links between tracks and ECAL/HCAL clusters



Tracker hit

Cluster linked to track

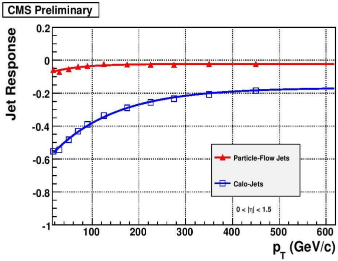
Unlinked Ecal cluster (photon)

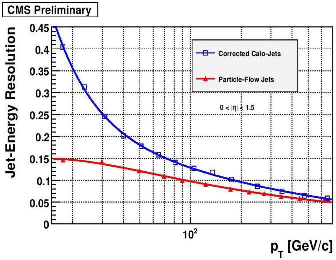
$$\eta = -ln(tg\frac{\theta}{2})$$

The link distance is defined as ΔR in the (η,ϕ) plane between objects positions. $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$

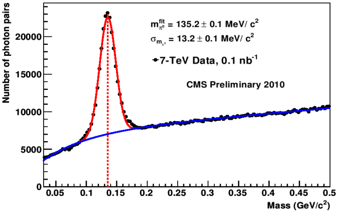
Particle Flow Performance

Simulated QCD-multijet events:
PFlow jet energy **response** $(p_T^{rec} - p_T^{gen})/p_T^{gen}$ and **resolution**





Mass of PF photon pair. **Agreement for mass within $\pm$ 2% of the PDG value**



see CMS PAS PFT-10-001

Tau Reconstruction and identification

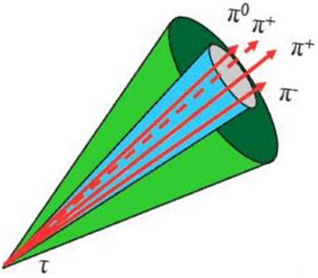
The main challenge in tau reconstruction is to discriminate between τ_{had} and QCD jets.

The experimental signatures of hadronically-decaying taus:

- collimated jet
- low multiplicity (up to three charged hadrons and up to two π^0's)
- decay products are isolated (require low detector activity around tau-jet direction)

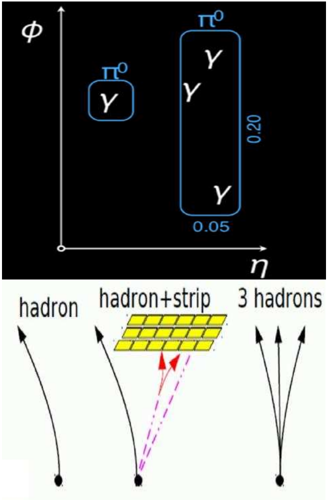
The best performance in terms of efficiency&fake-rate is achieved by analyzing PFlow jet constituents and building individual decay modes.

Two main alghorithms are developed. Presented today: Hadron Plus Strips Algorithm.



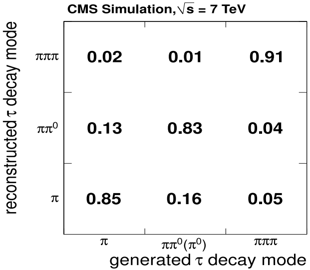
Hadron Plus Strips Algorithm (HPS)

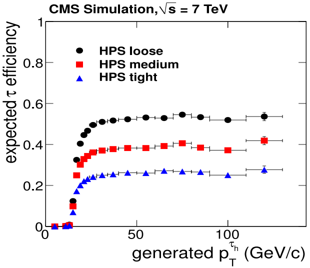
1. Cluster photons within the PFJet into strips accounting for possible broadening due to photon conversions
2. Combine charged particles in the jet with strips and reconstruct individual τ_h decay mode: $\pi^{\pm}\nu_{\tau}$,$\pi^{\pm}\pi^{0}\nu_{\tau}$, $(\pi\pi\pi)^{\pm}\nu_{\tau}$
3. Require charged and strips to be contained within a cone $\Delta R = 2.8/P_T^{\tau}$
4. Most isolated decay “hypothesis” with compatible visible mass is given preference



Hadron Plus Strips Algorithm (HPS) (J. Instrum. 7 (2012) P01001)

Matching efficiency between generated taus and reconstructed by HPS loose working point (>80% for all three channels)



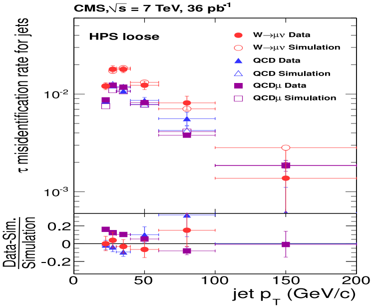


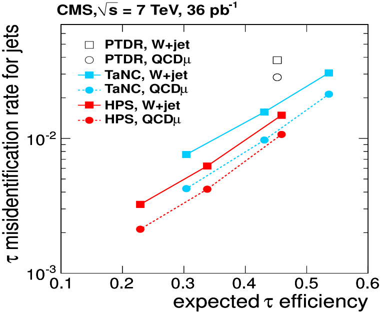
Expected reconstruction efficiency for three "working-points" defined by isolation tresholds

- loose
- medium
- tight

Hadron Plus Strips Algorithm (HPS) (J. Instrum. 7 (2012) P01001)

The tau fake-rate from jets in three different samples.

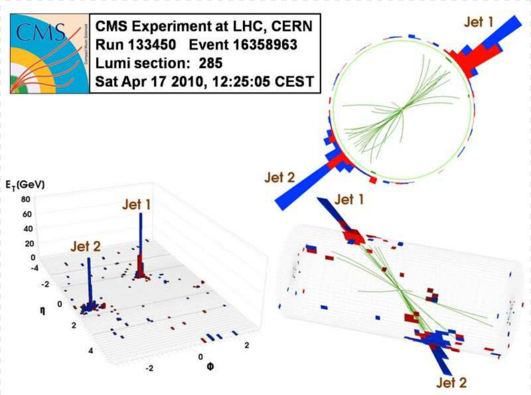




- QCDj: jet $p_T > 15$GeV, $|\eta| < 2.5$
- QCDμ: non-iso μ, MET < 40 GeV
- Wj: iso μ, MET > 50 GeV

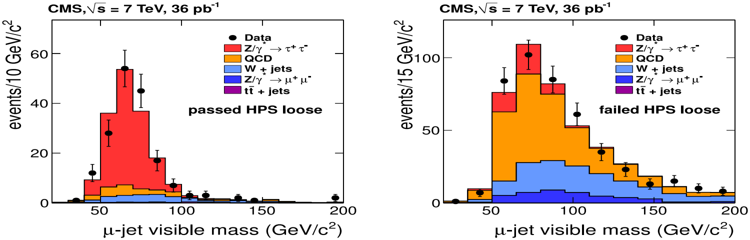
HPS "loose" efficiency ≈ 50% at 1% fake-rate

$Z \to \tau\tau$ and tau-ID estimation



- two nearly back-to-back taus
- tag&probe with 4 combinations:
  - $\tau_\mu \tau_{had}$
  - $\tau_e \tau_{had}$
  - $\tau_e \tau_\mu$
  - $\tau_\mu \tau_\mu$
- $\tau_{had}\tau_{had}$ difficult but doable

Z→ ττ and tau-ID estimation (J. Instrum. 7 (2012) P01001)



The reco and ID efficiency of tau algorithm is obtained from data using a tag&probe approach.

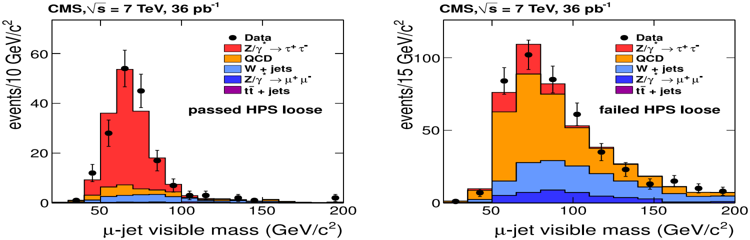
Preselection

- only one iso μ with $p_T > 15$ GeV, $|\eta| < 2.1$
- iso tau-jet candidate with $p_T > 20$ GeV, $|\eta| < 2.3$
- leading track within tau-jet with $p_T > 5$ GeV
- $M_T < 40$ GeV
  $M_T(\mu, E_T^{miss}) = \sqrt{2 p_T^{\mu} E_T^{miss} (1 - cos\Delta\phi)}$

Efficiency

- apply TauID
- fit visible $\mu\tau_{jet}$ invariant mass using signal and background templates
- $\epsilon = \frac{N_{pass}^{Z\to\tau\tau}}{N_{pass}^{Z\to\tau\tau} + N_{fail}^{Z\to\tau\tau}}$

Z→ ττ and tau-ID estimation



The reco and ID efficiency of tau algorithm is obtained from data using a tag&probe approach.

Algorithm	Fit data	Expected MC	DATA/MC
TaNC "loose"	0.76 ± 0.20	0.72	1.06 ± 0.30
TaNC "medium"	0.63 ± 0.17	0.66	0.96 ± 0.27
TaNC "tight"	0.55 ± 0.15	0.55	1.00 ± 0.28
HPS "loose"	0.70 ± 0.15	0.70	1.00 ± 0.24
HPS "medium"	0.53 ± 0.13	0.53	1.01 ± 0.26
HPS "tight"	0.33 ± 0.08	0.36	0.93 ± 0.25
HPS "loose"	combined fit [4]		0.94 ± 0.09
HPS "loose"	$\tau\tau$ to $\mu\mu, ee$ fit [4]		0.96 ± 0.07

Z→ $\tau\tau$ cross section measurement (J. High Energy Phys. 08 (2011) 117)

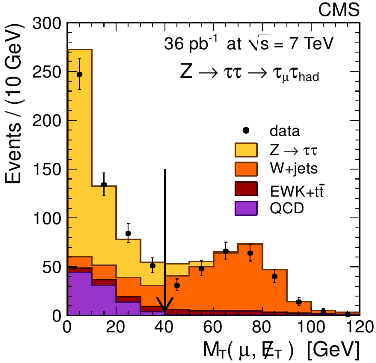
Measurement of Z→ $\tau\tau$ cross section wtih $36pb^{-1}$ combining 4 channels: $\tau_\mu\tau_{had}$ channel, $\tau_e\tau_{had}$ channel, $\tau_e\tau_\mu$ channel and $\tau_\mu\tau_\mu$ channel.

Selection of $\tau_l\tau_{had}$

- single lepton trigger
- iso μ or e with $p_T > 15$ GeV and $|\eta| < 2.1$
- associated τ oppositely charged
- $p_T^\tau > 20$ GeV and $|\eta| < 2.3$
- E_T^{miss} and $M_T(l, E_T^{miss}) < 40$ GeV

lepton isolation:

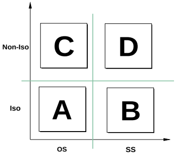
sum of transverse momentum of tracks, photons and neutrals within a cone of $\Delta R = 0.4/0.3$ divided by lepton p_T is required to be less that 0.1/0.08.



Z→ $\tau\tau$ cross section measurement

QCD background estimation from data

ABCD method OS/SS and lepton isolation



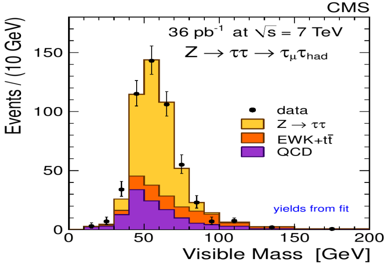
$$N_A = N_B \frac{N_C}{N_D}$$

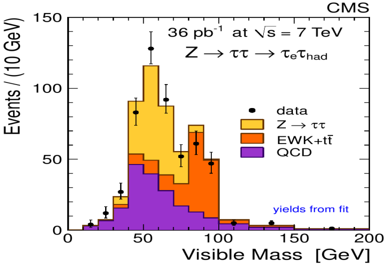
EWK and $t\bar{t}$ from MC

W + jets contribution:

- extrapolated from W dominated region ($M_T > 60$ GeV)
- shape from MC

Results for Z→ $\tau_l\tau_{had}$: visible invariant mass for $\tau_\mu\tau_{had}$ and $\tau_e\tau_{had}$ channels.





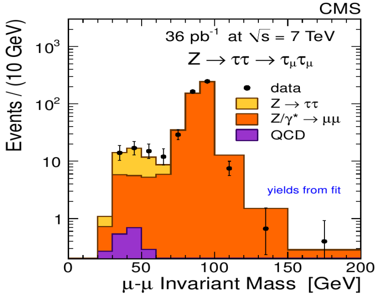
Z→ $\tau\tau$ cross section measurement

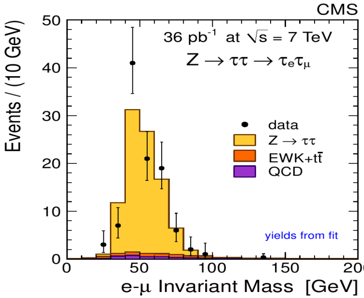
Selection for $\tau_\mu\tau_\mu$:

- two oppositely charged muons with $p_T > 19$ GeV and $p_T >10$ GeV within $|\eta| < 2.1$
- $E_T^{miss} < 50$ GeV
- $\Delta\phi_{\mu\mu} > 2$
- multivariate likelihood to suppress DY.

Selection for $\tau_e\tau_\mu$:

- $p_T^{e,\mu} > 15$ GeV with $|\eta| < 2.1$
- opposite charge
- $M_T(e, E_T^{miss}) < 50$ GeV
- $M_T(\mu, E_T^{miss}) < 50$ GeV





Z→ $\tau\tau$ cross section measurement

Total cross section:

$$\sigma(pp \rightarrow ZX) \times \mathcal{B}(Z \rightarrow \tau^+\tau^-) = \frac{N}{\mathcal{A}\epsilon\mathcal{B}'\mathcal{L}}$$

– $\mathcal{A}$ geometrical acceptance
– $N = N_{fit}(1 - f_{out})$ corrected fraction of signal events outside the generator-level mass window

Measured values:

Final state	$\sigma\,(\mathrm{pp} \rightarrow \mathrm{ZX}) \times \mathcal{B}\,(\mathrm{Z} \rightarrow \tau^+\tau^-)$ nb	stat.	syst.	lumi.	τ ID
$\tau_\mu \tau_{\mathrm{had}}$	0.83	0.07	0.04	0.03	0.19
$\tau_e \tau_{\mathrm{had}}$	0.94	0.11	0.03	0.04	0.22
$\tau_e \tau_\mu$	0.99	0.12	0.06	0.04	
$\tau_\mu \tau_\mu$	1.14	0.27	0.04	0.05	

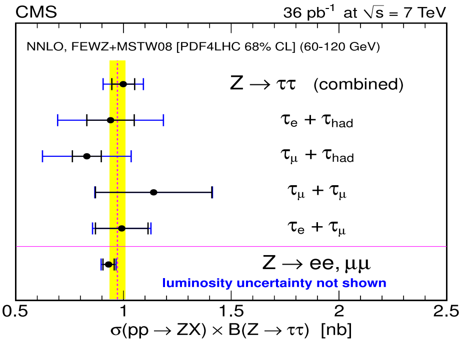
Main systematic uncertainties

– Tau ID 24%
– $\mathcal{A}$ 3.5%

Z$\rightarrow\tau\tau$ cross section measurement

combined result:

$$\sigma^{CMS}_{comb}(pp \rightarrow ZX) \times \mathcal{B}(Z \rightarrow \tau\tau) = 1.00 \pm 0.05(\text{stat}) \pm 0.08(\text{syst}) \pm 0.04(\text{lumi})\ \text{nb}$$
$$\sigma_{theor} = 0.972 \pm 0.042\ \text{nb}$$



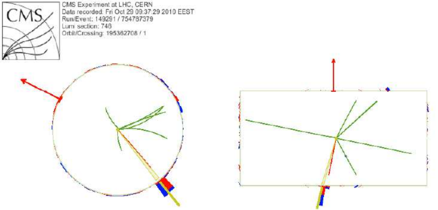
Total cross section of Z$\rightarrow\tau\tau$ in consistent with theoretical expectation and with result recently published by the ATLAS Collaboration:
$\sigma^{ATLAS}_{comb}(pp \rightarrow ZX) \times \mathcal{B}(Z \rightarrow \tau\tau) = 0.97 \pm 0.07(\text{stat}) \pm 0.06(\text{syst}) \pm 0.03(\text{lumi})$ nb
(arxiv: 1108.2016v1)

W→ $\tau\nu$ observation

W→ $\tau\nu$ candidate:

– isolated jet

– large E_T^{miss}



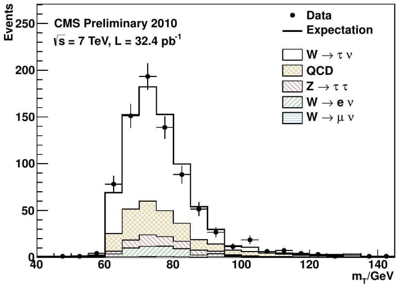
m_{vis} = 0.87 GeV

τ_{had} (1 prong, 1 π^0):
p_T = 33 GeV
η = -0.25
p_T(lead. track)= 21 GeV
E_T miss= 57 GeV
EM-fraction = 0.38
$m_T(\tau,\nu)$ = 88 GeV

W→ $\tau\nu$ cross section (CMS PAS EWK-11-019)

Selection for analysis with 32.4 pb^{-1}

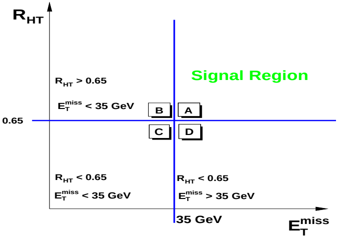
- τ_h + E_{miss} trigger
- τ_h with $p_T^{\tau} > 30$ GeV + $p_T^{lead.track} > 15$ GeV
- e/μ veto
- $E_T^{miss} > 35$ GeV
- $R_{HT} = p_T^{\tau}/\Sigma jetp_T > 0.65$



Background estimate:

EWK from simulation

QCD estimated from data. ABCD method with R_{HT} and E_T^{miss}



$W \to \tau\nu$ cross section (CMS PAS EWK-11-019)

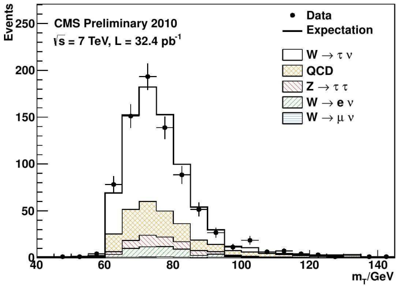
Selection for analysis with 32.4 pb^{-1}

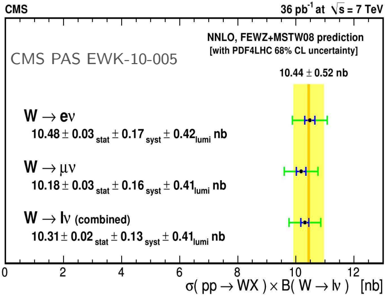
- $\tau_h + E_{miss}$ trigger
- τ_h with $p_T^\tau > 30$ GeV + $p_T^{lead.track} > 15$ GeV
- e/μ veto
- $E_T^{miss} > 35$ GeV
- $R_{HT} = p_T^\tau / \Sigma jet p_T > 0.65$

Observation

$\sigma(pp \to WX) \times \mathcal{B} = 8.96 \pm 0.51(\text{stat.})^{+2.32}_{-2.26} \pm 0.36(\text{lumi.})$ nb

$\frac{\sigma \times \mathcal{B}(W^+ \to \tau^+\nu)}{\sigma \times \mathcal{B}(W^- \to \tau^-\nu)} = 1.55 \pm 0.19(\text{stat.})^{+0.11}_{-0.13}(\text{syst.})$



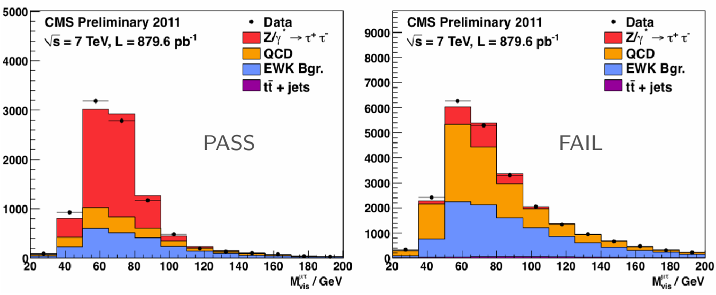


Summary

- Advanced tau reconstruction algorithm has been developed and succesfully commisioned with data collected
- HPS shows a good performance in terms of efficiency vs. fake-rate. With an efficiency of $\approx$ 50% only a few percent fake-rate from QCD jets
- Tau ID efficiency is measured with a precision of 24% (in 2011 data 6%)
- The Z$\rightarrow \tau\tau$ cross section is measured in four channels
  $\sigma_{comb}(pp \rightarrow ZX) \times \mathcal{B}(Z \rightarrow \tau^+\tau^-) = 1.00 \pm 0.05\text{(stat)} \pm 0.08$ (syst) $\pm$ 0.04(lumi) nb
  in good agreement with SM expectation as well as with Z$\rightarrow$ *ll* cross section
- Measured W$\rightarrow \tau\nu$ cross section $8.96 \pm 0.51(\text{stat.})^{+2.32}_{-2.26} \pm 0.36(\text{lumi.})$ nb agrees with expectation and μ/e channels

BACKUP

Z→ $\tau\tau$ and tau-ID estimation



In 2011 Data the identification efficiency is known with a precision of 6%.