Tau ID in CMS and new developments

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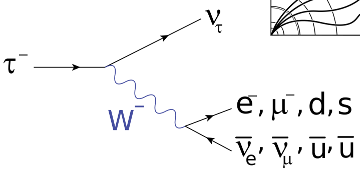
S3Be, IIHE Brussels

Tau Lepton

- Heaviest charged lepton (1.8 GeV)
- Decays to leptons and hadrons
- Charge conservation⇒ odd number of tracks
  - "1-prong" and "3-prong"



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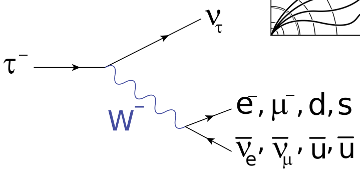

decays of τ^-

Decay Mode	Resonance	BR[%]
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$\mu^-\bar{\nu}_\mu\nu_\tau$		17.4
$h^-\nu_\tau$		11.6
$h^-\pi^0\nu_\tau$	$\rho(770)$	25.9
$h^-\pi^0\pi^0\nu_\tau$	$a_1(1260)$	9.5
$h^-h^-h^+\nu_\tau$	$a_1(1260)$	9.8
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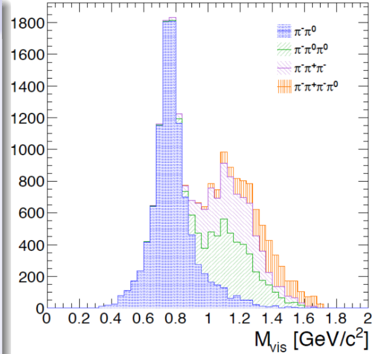
other hadronic		3.2



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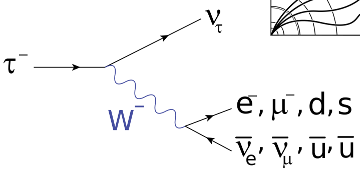

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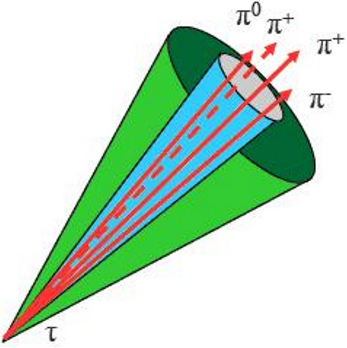
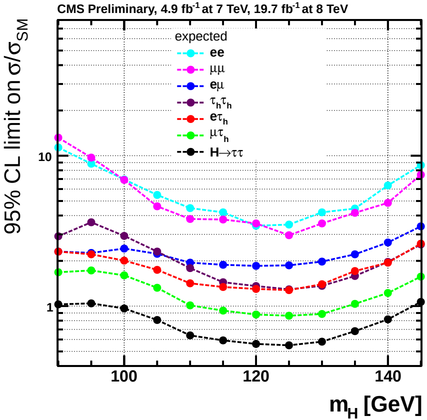
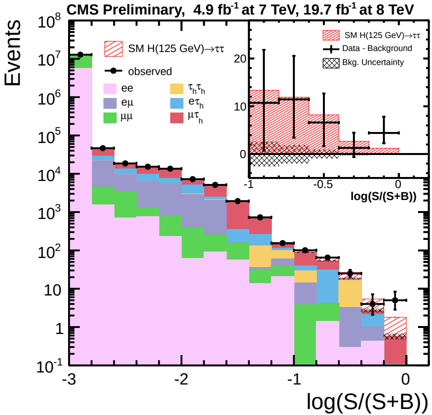


Tau ID crucial for the evidence of $H \to ff$

CMS-HIG-13-004-005, arXiv:1401.5041, submitted to JHEP





The 3 most sensitive channels contain at least one τ_h

CMS: Hadron+strip (HPS) algorithm

- **input:** Particle flow ⇒ list of particles ⇒ jets

Reconstruction and identification of hadronic taus

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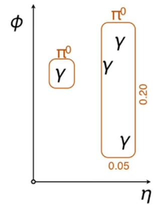

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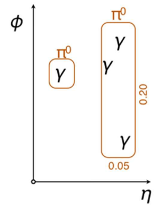

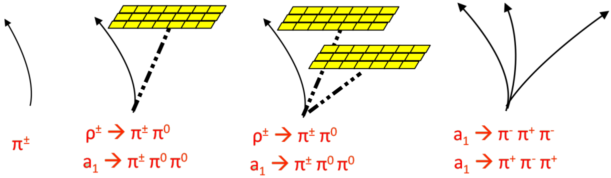

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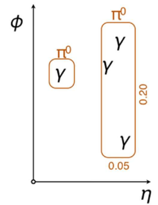

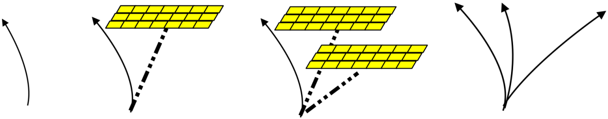

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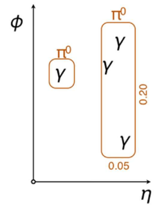

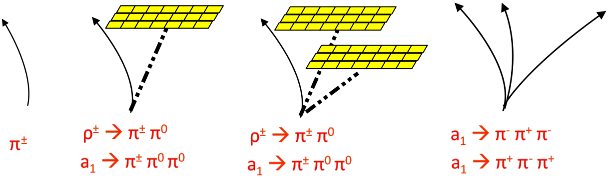

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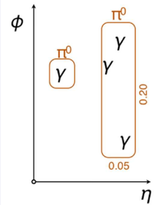

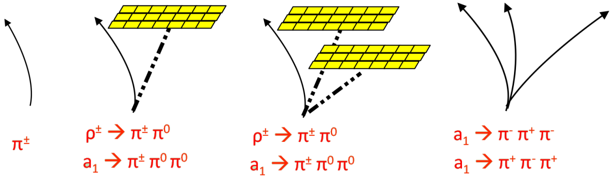

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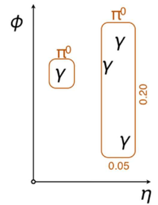
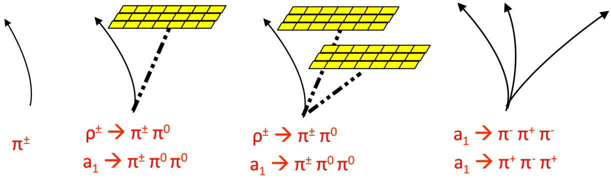
- **Jet rejection:** p_T of particles close to τ (cut on scalar sum or BDT)
- **Electron rejection**: Inverted electron ID + dedicated BDT
- **Muon rejection**: Inverted muon ID

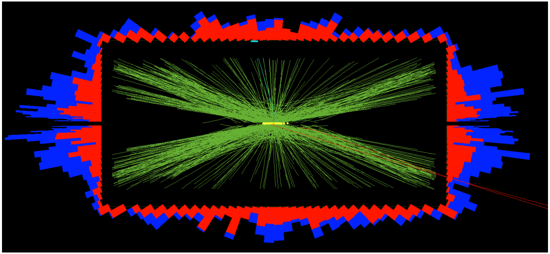




Pileup corrections

Pileup:

- $\sim$ 30 collisions at the same time $\Rightarrow$ additional particles not connected with primary interaction



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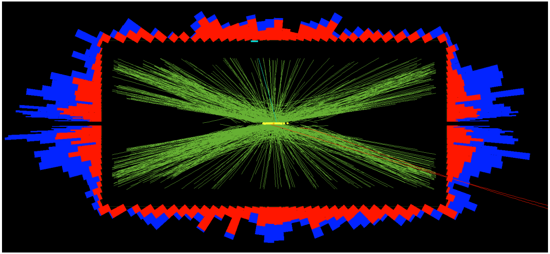


Localized ($\Delta\beta$) pileup corrections

- Using only charged particles compatible with jet/tau vertex $\Rightarrow$ charged pileup robust
- Estimate the neutral pileup contribution (sum of charged pileup around τ $\times$ correction factor $\Delta\beta$) and subtract

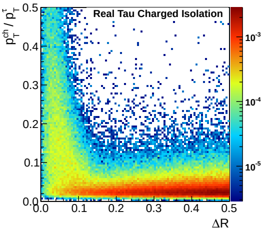
Discrimination by isolation

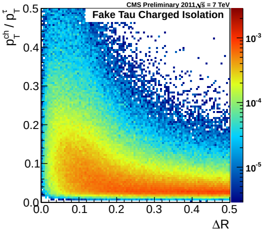
Combined isolation with pile-up correction

- Absolute sum of charged and neutral PF isolation in $\Delta R < 0.5$
- Correction for charged pile-up is "automatic" from construction
- Contributions from neutral pile-up are subtracted using scalar p_T sum of charged pile-up (all PF particles within $\Delta R < 0.8$ of τ **not** coming from τ vertex) and a correction factor

MVA isolation

- Spatial p_T distribution (τ shape) is used to select real τ's
- MultiVariate Analysis (Boosted Decision Trees) variables:
  - scalar p_T sum of charged and neutral PF candidates in 4 annuli and 1 cone around τ
  - p_T weighted mean and variance of $\Delta\eta$ and $\Delta\phi$ between isolation particle and τ





Electron and Muon rejection

Cut based electron rejection

- PF electron ID uses MVA discriminator
- Loose electron rejection inverts the MVA electron ID
- Tighter working points use additional cuts to reject single charged hadrons and high bremstrahnulg electrons

MVA based electron rejection

- Specific MVA dicriminator to distinguish τ's from electrons
- tau candidates are categorized using
  - number of neutral PF among τ constituents
  - pseudorapidity
  - presence of e reconstructed in the tracker and associated to leading τ track
- Dedicated BDT training in each category

Muon rejection

- **Loose:** leading τ track cannot be matched with a track segment in the muon chambers
- **Medium:** The leading τ track not reconstructed as loose muon
- **Tight:** Same as medium + cut on minimum relative p_T deposit for single prong and 0 strips candidates

Current recommendations of the Tau POG

"Legacy" recommendations

- The recipe used for HIG-13-004 paper and shown few moments ago
- Contained in CMSSW_5_3_12 and newer
  - **But:** it is necessary to **re-run PFTau sequence** on 8 TeV AODs
  - **Nevertheless:** contained in AODs from 7 TeV legacy reprocessing
- If you really need to use older recipes, contact Tau POG

"Tau ID 2014" recommendations

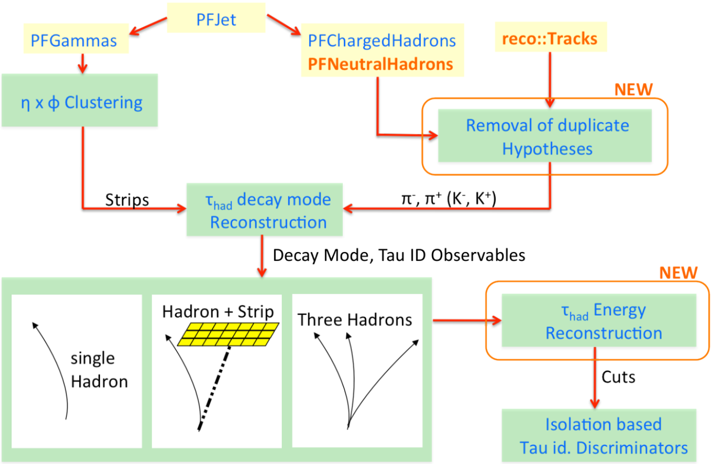
- The code is stabilized and running in 53x and 62x and 70x
- Contains
  - Fix for high p_T behaviour
  - Code for boosted tau reconstruction in subjects
  - Tau lifetime information
  - **Better performing discriminators**
- Dedicated branches in github obtained via `cms-merge-topic`
- Will be included in 7_0_0_pre13

Motivation for new ID

- In December 2012 a problem discovered with performance at very high p_T (1 TeV)
  - significant efficiency decrease
  - underestimation of tau momentum
- A taskforce was set-up and identified causes:
  1. Underestimation of track p_T (small curvature) $\Rightarrow$ fake neutral PF particles $\Rightarrow$ Decay mode finding fails
  2. Kinematical cuts too tight
  3. (Decreased track reconstruction efficiency at high p_T)[3]

Solution to Decay mode finding fails

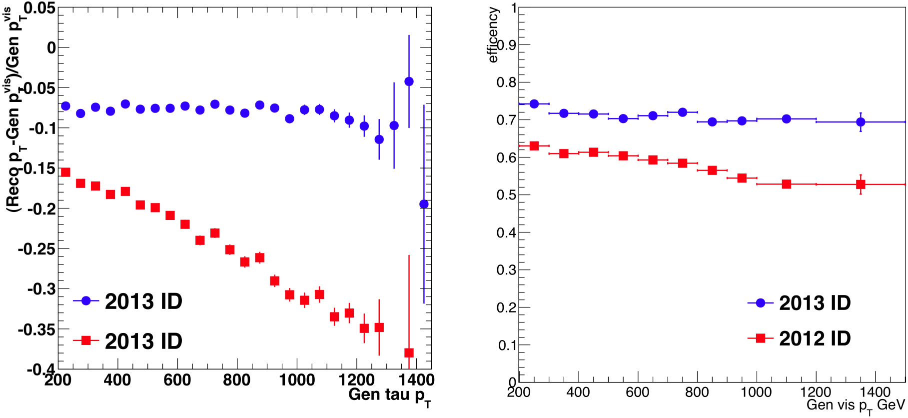
Adding an "afterburner" that reconstructs high p_T π's and K's from PFlow output + tracks



Solution to other issues: change of kinematical cuts

- Mass window cut was changed (Sliding mass window)
- New decay modes were defined
  - Recovering 3-prong decays by looking at **2 tracks + neutral particle**
  - About 10% efficiency gain at very high p_T
  - p_T dependent increase in jet$\rightarrow \tau_h$ fakes
  - Analyst can choose whether to use 2-prong decay modes or not

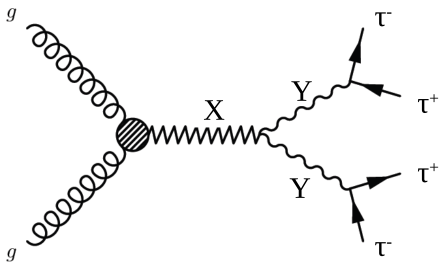
Results



- Stable tau energy response
- Efficiency increased due to new algorithm, new decay modes and relaxed decay mode cuts

Boosted tau reconstruction

Motivation



- Taus difficult to reconstruct when $\Delta R < 0.5$
- $\Delta R = \frac{2M_Y}{p_T^Y}$, $p_T^Y \approx \frac{M_X}{2}$
- If $p_T^Y > 5M_Y$ or $M_X > 10M_Y$ $\Rightarrow$ difficult kinematic regimes with standard tau reco

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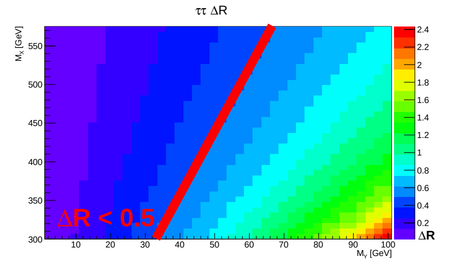

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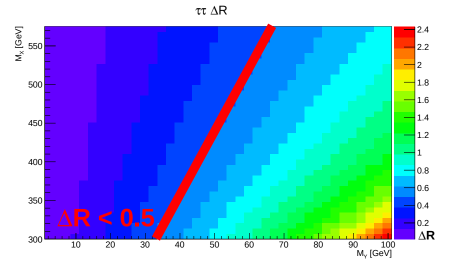

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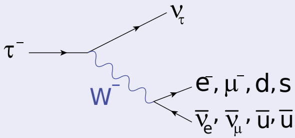
Solution

- Subjet techniques are used to get input for tau reconstruction
- Algorithm functional and running
- Everybody is welcome to use it

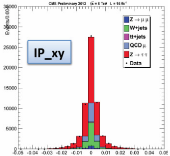
Tau lifetime information

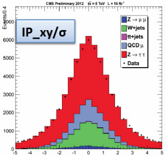
Motivation



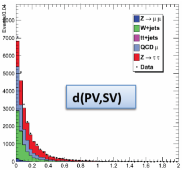
- Tau decays via weak interaction⇒ measurable length-of-flight
- 1 mm (20 GeV)/ 4.9 cm (1 TeV)
- additional handle to identify τ_h

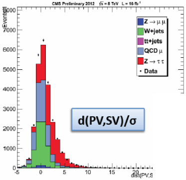
1-prong: impact parameter





3-prong: |PV-SV|

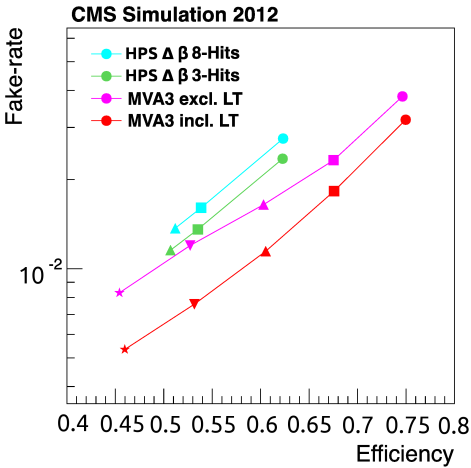




- Good Data/MC aggreement
- Improves tau ID performance

Evolution of the tau ID performance

Performance is improving every year!



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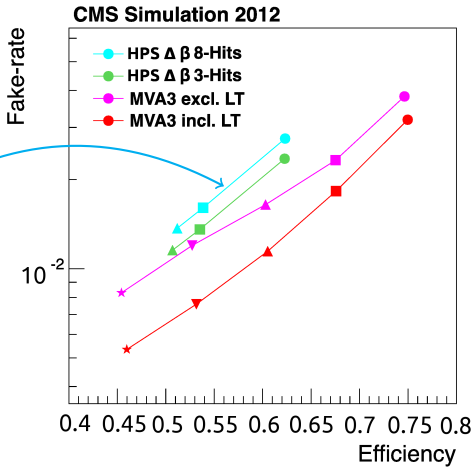

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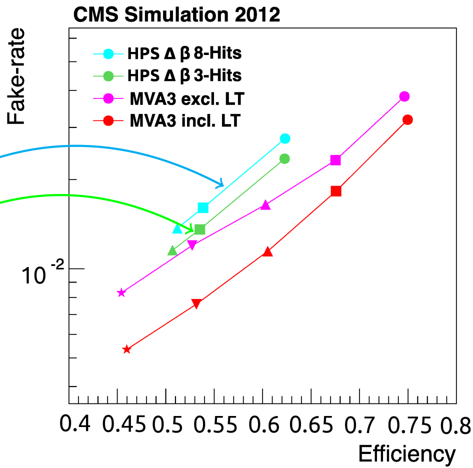

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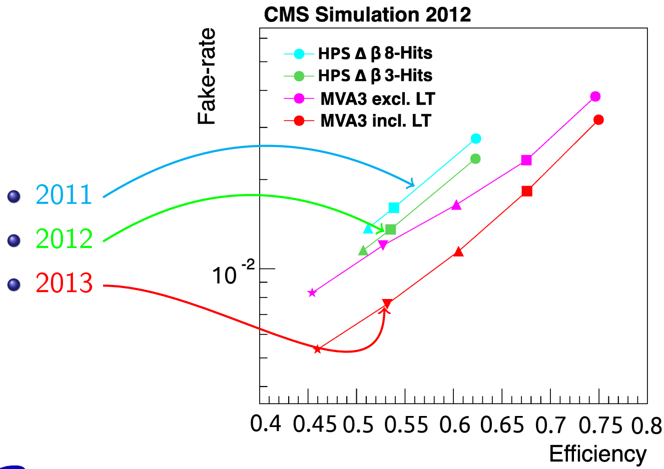

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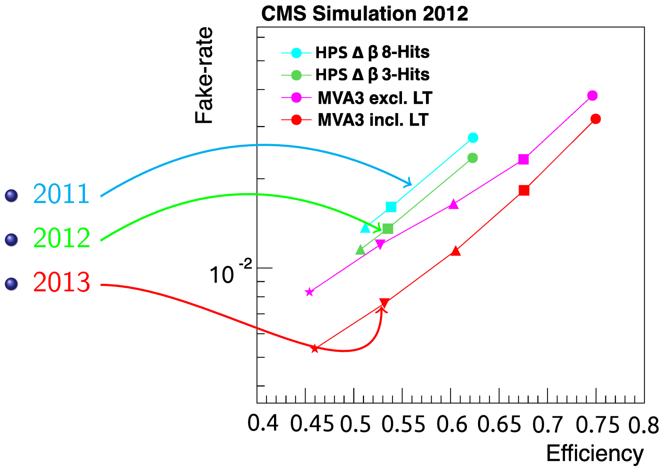


Addition of the lifetime information seems to lead to a large performance improvement

Plan for 2014

1. Move to the new tau ID
   - Everything seems to indicate that the new tau ID is vastly superior to the current one in all categories
   - The algorithm will be made part of official CMSSW releases and extensively validated in various analyses
2. Prepare for Run 2 (continuation of present studies)
   - Different running conditions $\Rightarrow$ re-tune $\Delta\beta$ corrections
   - Retuning of cuts and retraining MVA's
   - Trying to maintain our Run 1 performance or better

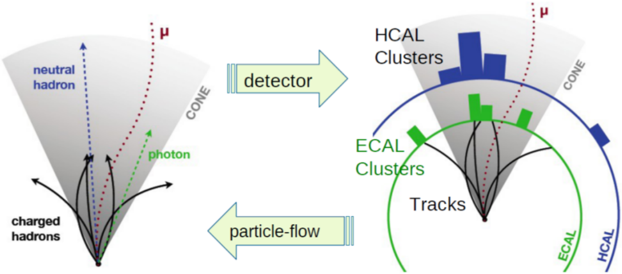
Summary

- Tau POG offers 2 flavours of tau ID
  1. "Legacy" recommendation
     - ★ standard, well tested, well performing
     - ★ in CMSSW > 5_3_12
  2. "2014 Tau ID" recommendation
     - ★ state-of-the-art, not that much tested yet, everybody is invited to try
     - ★ `git cms-merge-topic -u cms-tau-pog:CMSSW_5_3_X_boostedTaus`
- The recipes for installation are kept at Twiki
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuidePFTauID
- The recommendation for analyses are also in Twiki
  - https://twiki.cern.ch/twiki/bin/view/CMS/TauIDRecommendation
- Questions? Comments? Suggestions?
  - Write to hypernews hn-cms-tauid@cern.ch
  - Come to meet us: Mondays @ 16:00

Additional Material

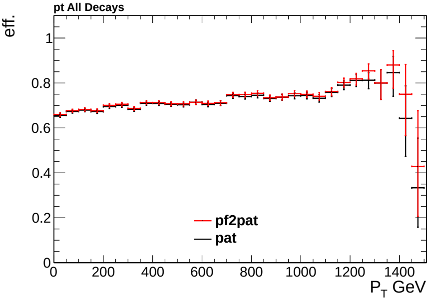
Particle Flow

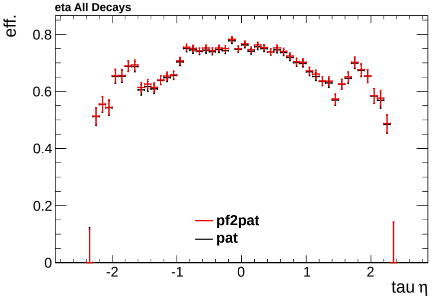
- Algorithm to reconstruct all stable particles in the event
  - e, μ, γ, charged and neutral hadrons
- allows parton-level-like analysis
- individual particles are used e.g. to
  - reconstruct jets and τ's
  - determine E_T^{miss}
  - quantify particle isolation
  - tag b-jets
- possible due to high precision tracker and EM calorimeter (allows to separate γ's and charged particles deposits in the calorimeter)



Status of PFTau→GED integration

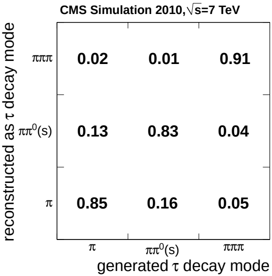
- The plan of the RECO/AT group is to eventually move to PFBRECO and GED
- In every official release, tau sequence is working in PFBRECO
- The PFBRECO is also working on the *_highPt/boostedTaus branches of cms-tau-pog
- PFBRECO was **successfully validated** against simple PFTau sequence in 53x
- Validation and clean-up in 62x/70x is ongoing

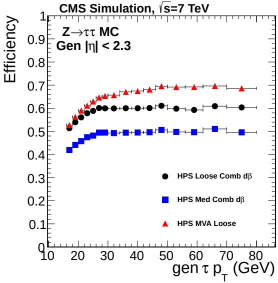


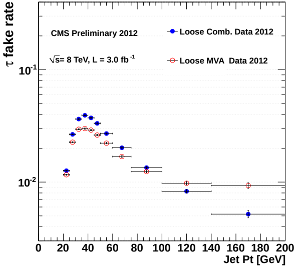


Performance of CMS Tau ID

Decay mode finding and isolation







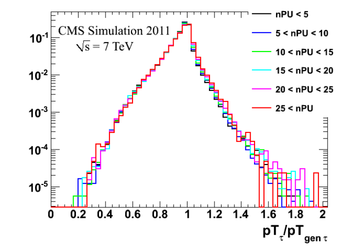
Efficiency and Fake rate definitions

- Tau selection: $p_T > 20$ GeV, $|\eta| < 2.3$
- In efficiency and FR plots, τ's are passing Decay mode selection, loose e and μ rejection
- For efficiency - reconstructed τ matched to generated τ ($\Delta R < 0.5$)
- Fake rate measured in jet data

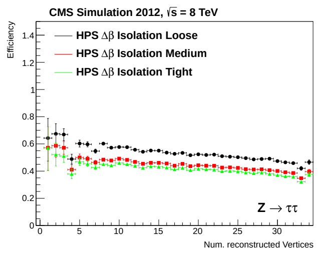
Performance of Tau ID

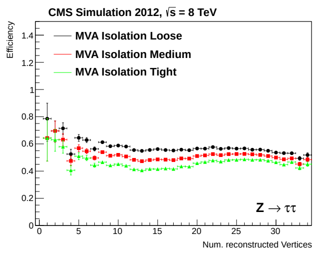
Stability with pile-up

p_T resulution for 1 prong + π^0 events



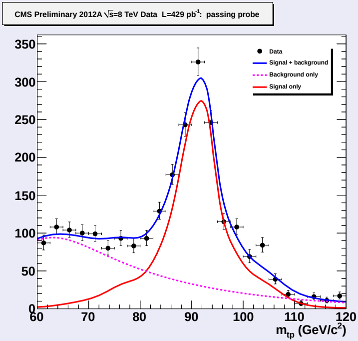
Isolation efficiency as a function of reconstructed vertices





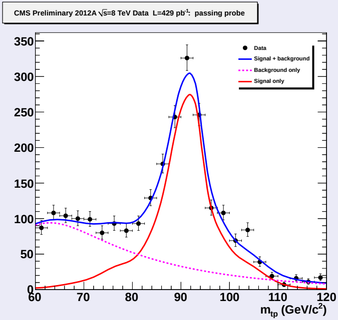
Light lepton rejection

Electron fake rate



- Electron fake rate measured in sample of isolated electrons from $Z \to ee$ using tag and probe
- Measured fake rate in barrel 0.5%/13% (MVA/loose) in barrel and 0.9%/29% in endcap
- Efficiency is 85%/100% (65%/100%) in barrel (endcap)

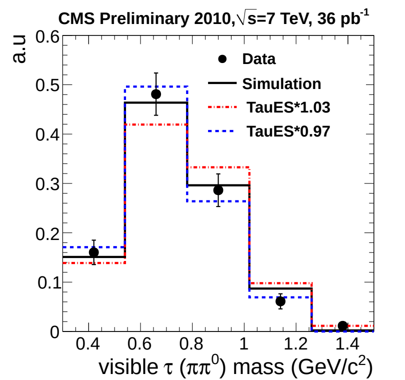
Muon fake rate



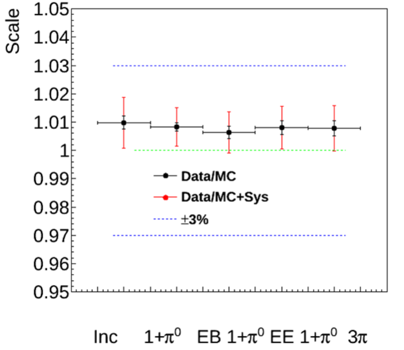
- Muon fake rate measured in sample of isolated electrons from $Z \to \mu\mu$ using tag and probe
- Upper limit 0.24% on $\mu \to \tau$ fake rate

Tau energy scale

2010



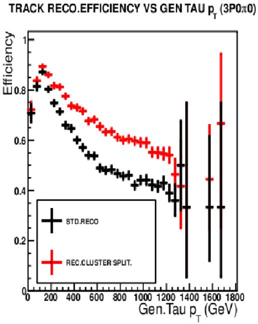
2011

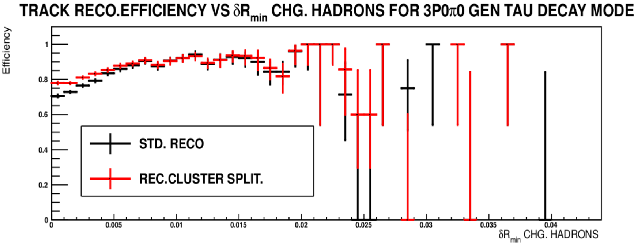


- Hadronic taus composed of charged hadrons and γ's that are reconstructed with high precision in PF
- Tau energy scaled is well described in data and our understanding is steadily improving

Study of high p_T tracking

- Tracks lying close to each other can have their cluster merged
- Affects tracking efficiency quality
- Tried to apply cluster splitting algorithm and check its effect on the tau performance
- 15% efficiency gain for 3-prong taus ¿ 800 GeV, 5% gain overall for $p_T > 800$ GeV





Study of the post-LS1 performance

- Already started to look on the tau performance after the LS1
- No proper MC samples available, so only very preliminary studies:
  - Study 1
  - Study 2
- Not much conclusions but it will be probably necessary to re-tune $\Delta\beta$ corrections
  - Present value is slightly overcorrecting $\Rightarrow$ safe for 25 ns
  - The tau performance is not affected much by changing the $\Delta\beta$