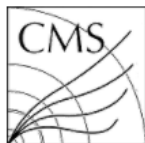
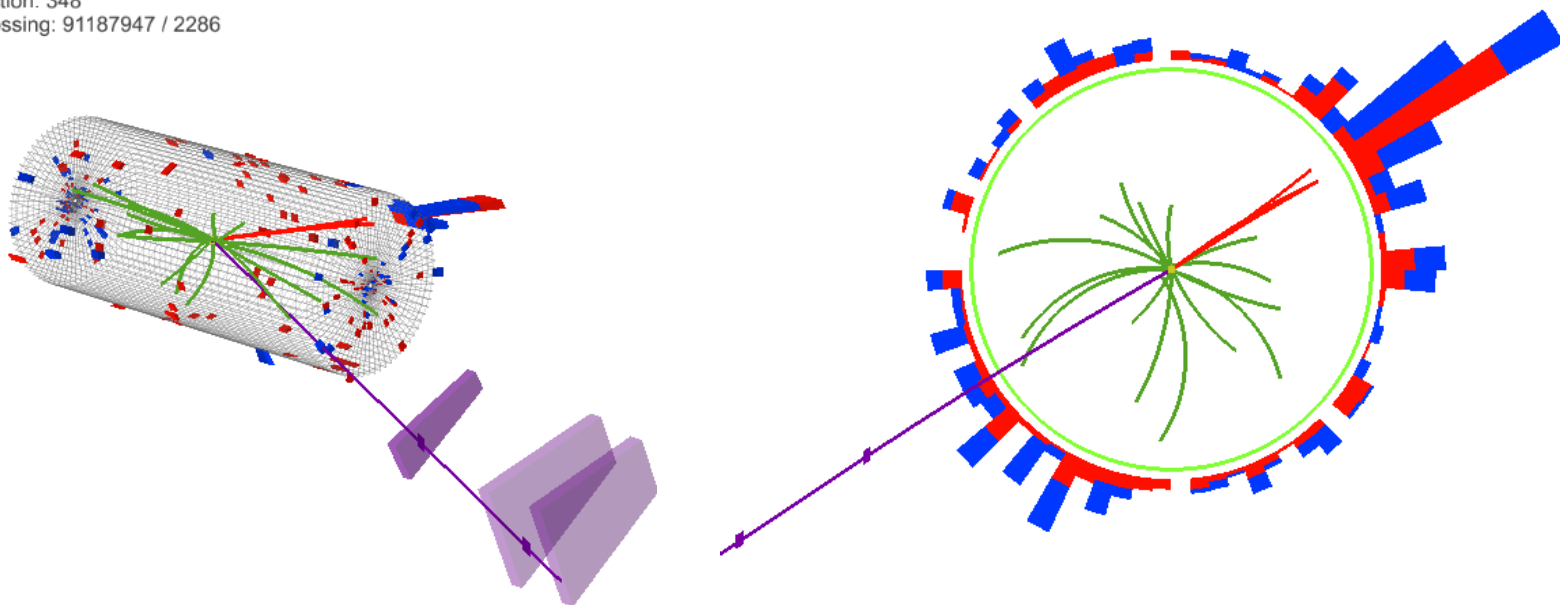


# $\tau$ reconstruction and identification in CMS

A. Nikitenko, Imperial College. LHC Days in Split

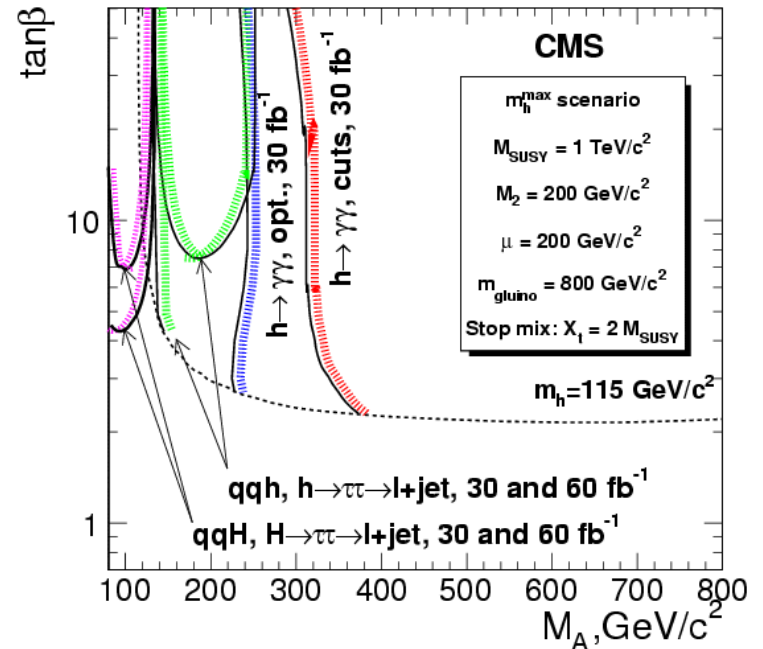
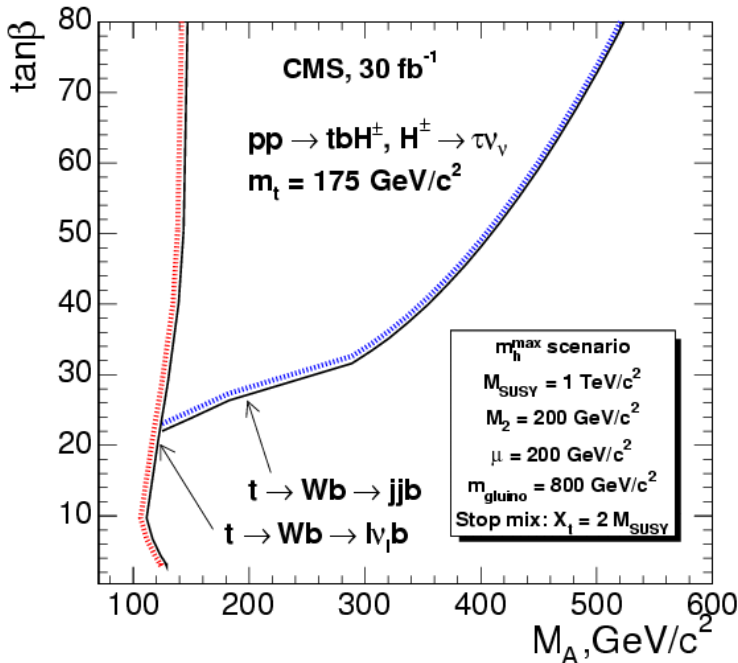
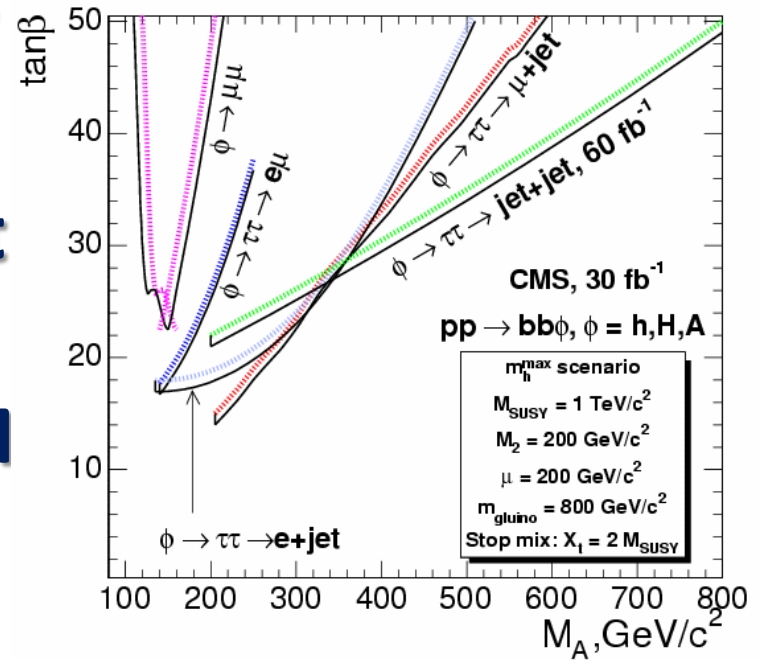


CMS Experiment at LHC, CERN  
Data recorded: Sun Aug 15 03:57:48 2010 CEST  
Run/Event: 142971 / 323188785  
Lumi section: 348  
Orbit/Crossing: 91187947 / 2286



# Why $\tau$ s are important ?

- Final states with  $\tau$ 's are most powerful for Higgs boson(s) discovery at LHC in (N)MSSM
- $-p_T^\tau \sim [20-300] \text{ GeV}$



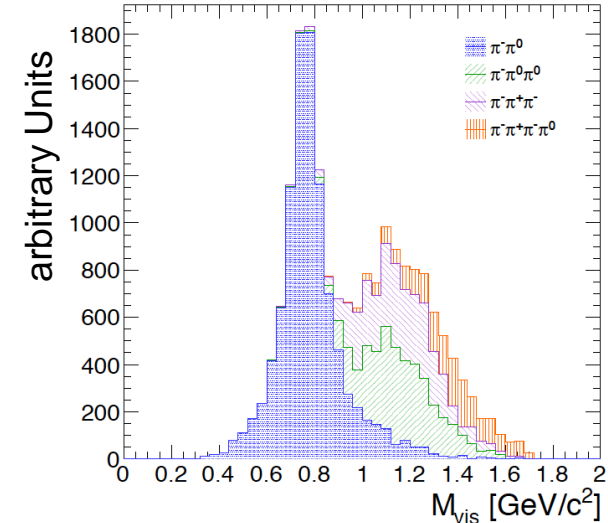
# $\tau$ -lepton properties

Mass  $m_\tau = 1.78 \text{ GeV}$

Lifetime  $c \tau = 87 \mu\text{m}$

*Decays predominantly into hadrons:*

(branching ratio into  $e/\mu$  about 17% each)



Decay Mode	Resonance	Mass ( $\text{MeV}/c^2$ )	Branching ratio(%)
$\tau^- \rightarrow h^- \nu_\tau$			11.6 %
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	$\rho$	770	26.0 %
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a_1$	1200	10.8 %
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a_1$	1200	9.8 %
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$			4.8 %
Total			63.1%
Other hadronic modes			1.7%

**collimated jet of mainly one or three charged pions plus  $\pi^0$ s  $\rightarrow \gamma\gamma$   
expected in the detector**

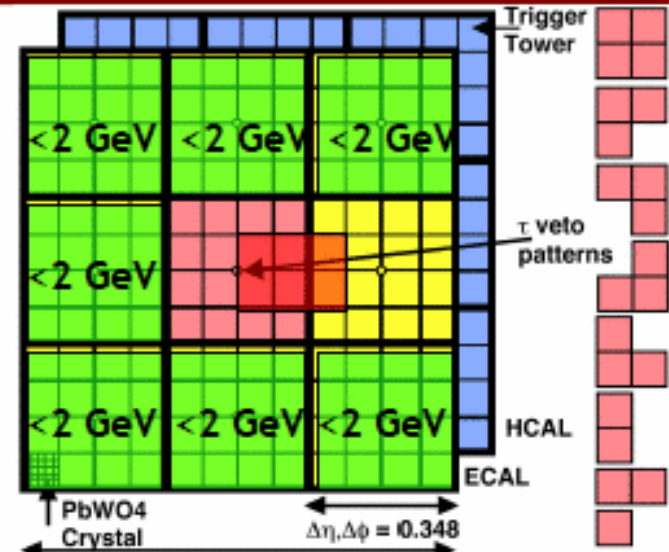
# reconstruction and identification of $\tau$ -jet in trigger and off-line

*$H \rightarrow \tau\tau$  and  $H^\pm \rightarrow \tau\nu$  were the main motivation for Tau trigger in CMS*

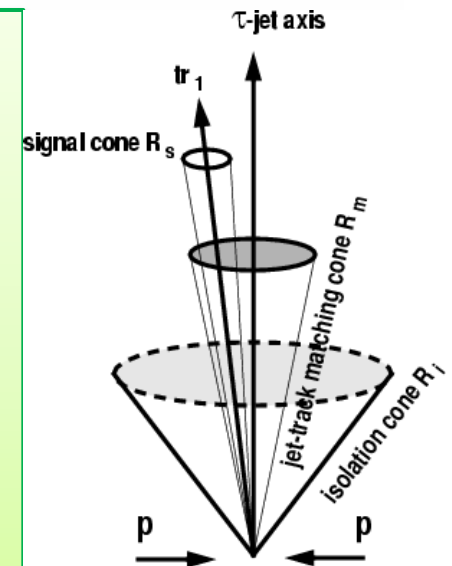
# $\tau$ trigger at Level-1

## New L1 Tau Algorithm

- Working on a L1 jet (3x3 regions)
- Requires specific patterns in the central region denoting a narrow jet
- Isolation applied in 7/8 neighbors
  - Latest addition to GCT firmware (Thanks!)
- Jet energy corrections is an issue

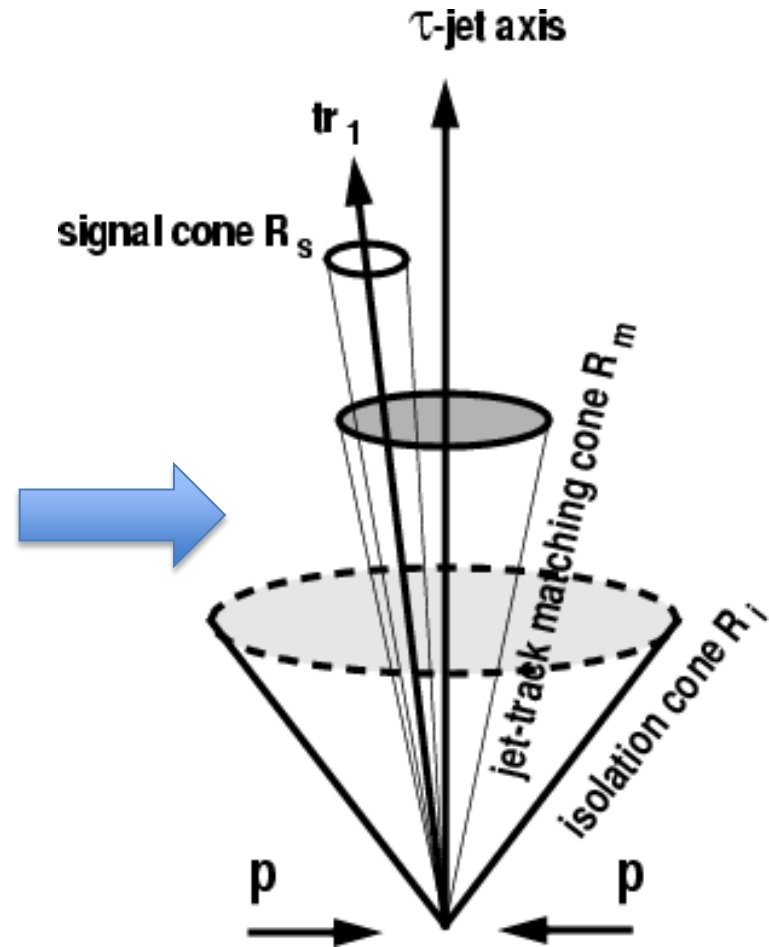


$\tau$  identification at HLT  
is very similar to  
basic off-line  $\tau$  ID



# Off-line $\tau$ -jet reco and ID

- **Reconstruction of  $\tau$ -jet using**
  - Particle Flow objects; PF Tau
  - track corrected calo jet; TC Tau
- **Identification**
  - basic selections based on isolation criteria for PF and TC Taus
  - advanced ID based on reconstruction of  $\tau$  decay modes using PF objects
    - Hadron Plus Strip (HPS)
    - Tau Neural Classifier (TaNC)

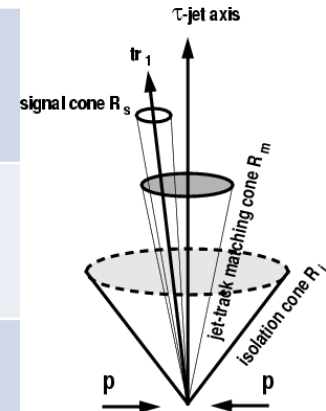


# Basic $\tau$ selections

## Basic Tau ID with PF and tcTau $\tau$ s

**PF Tau**

**TCTau**



**1. Jet-track matching,  $\Delta R(\text{jet-track}) < 0.1$**

*jet build from PF objects*

*calo jet corrected with tracks*

**2. Cut on  $p_T$  of leading track in signal cone ( $R_s=0.07$  or  $R_s=5/E_T$  \*)**

**3. No tracks in annulus between signal and isolation cones**

**4. Electromagnetic isolation**

*no  $\gamma$ s in isolation annulus*

*$E_T$  in ECAL isolation annulus < cut*

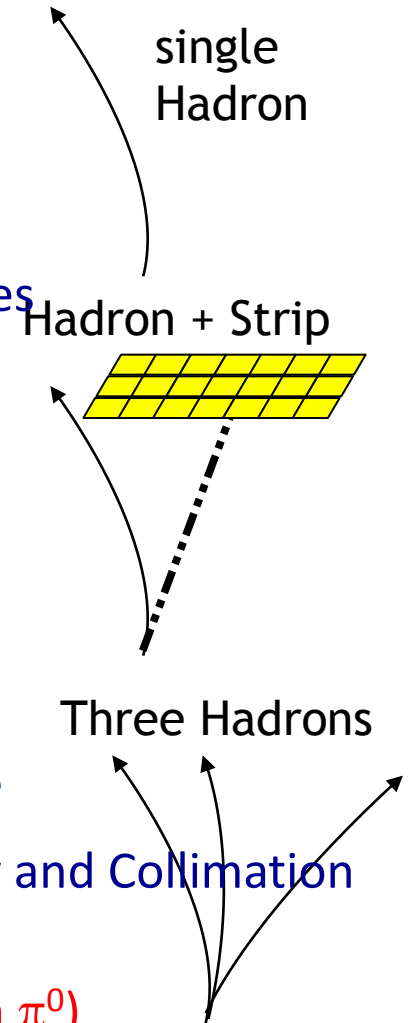
**5. electron and muon vetoes**

\* shrinking signal cone

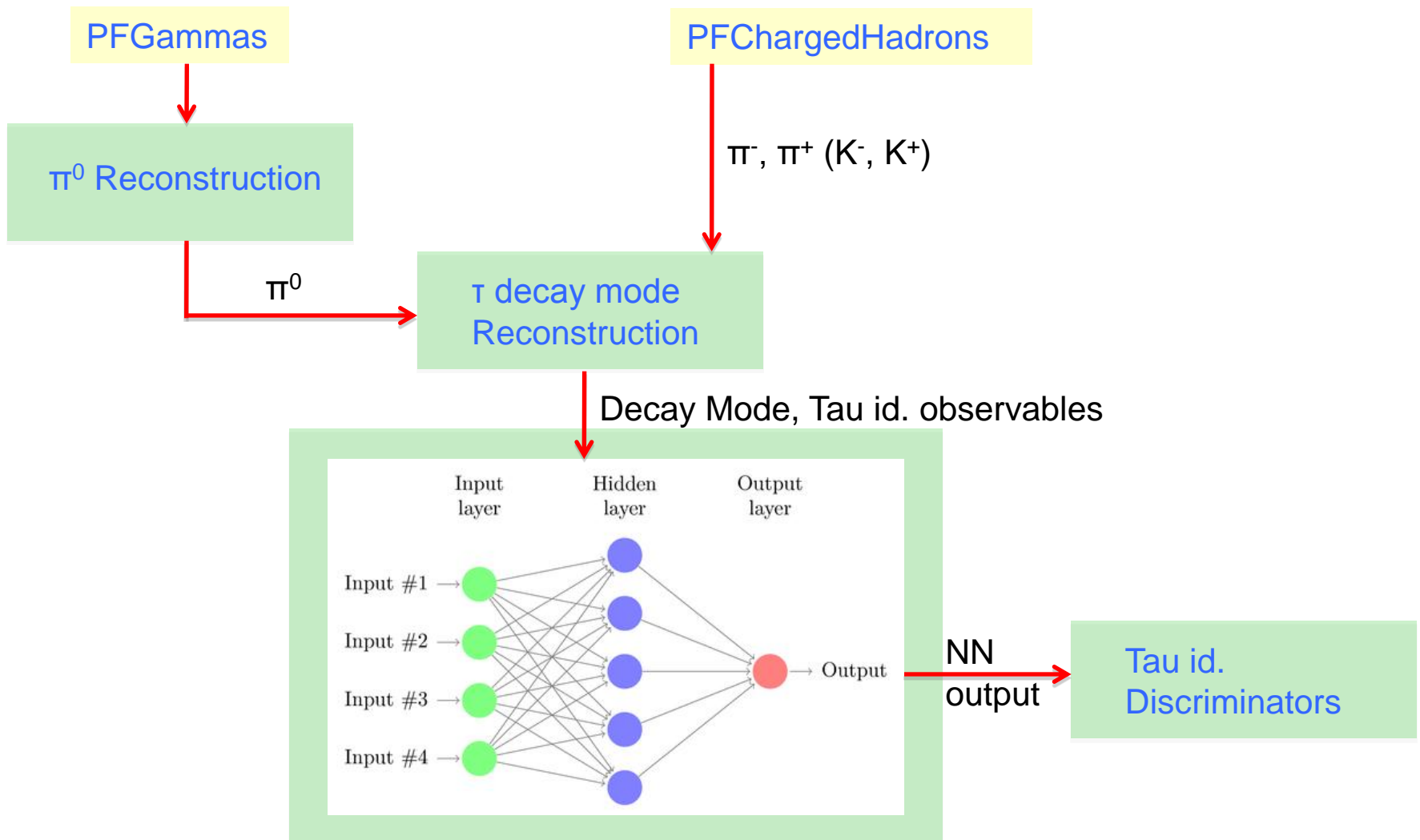
**PF and TC Taus give similar ID performance  
for the similar set of parameters**

# Hadron + Strips (HPS) algorithm

- HPS algorithm starts by clusterizing EM PF candidates to Strips starting from highest EM PF candidate inside jet
  - association distance  $\Delta\eta < 0.05$ ,  $\Delta\phi < 0.2$
  - threshold is applied in the Strips (1 GeV)
- Strips and PFChargedHadrons are combined to  $\tau$  Candidates
  - single Hadron
    - aiming for one prong taus ( $\pi^+$ ,  $\pi^-$ ,  $K^+$ ,  $K^-$ )
  - Hadron + Strip
    - aiming for tau decays via  $\rho(770)$  resonance
  - Three Hadrons
    - aiming for three prong decays via  $a_1$  resonance
- After the decay mode is reconstructed, mass compatibility and Collimation of Jet are required
  - mass compatible with  $\rho/a_1$  (strips compatible with  $\pi^0$ )
  - all decay Products within Cone of size  $\Delta R = 2.8/P_T^{\tau\text{-jet}}$



# Tau Neural Classifier (TaNC)



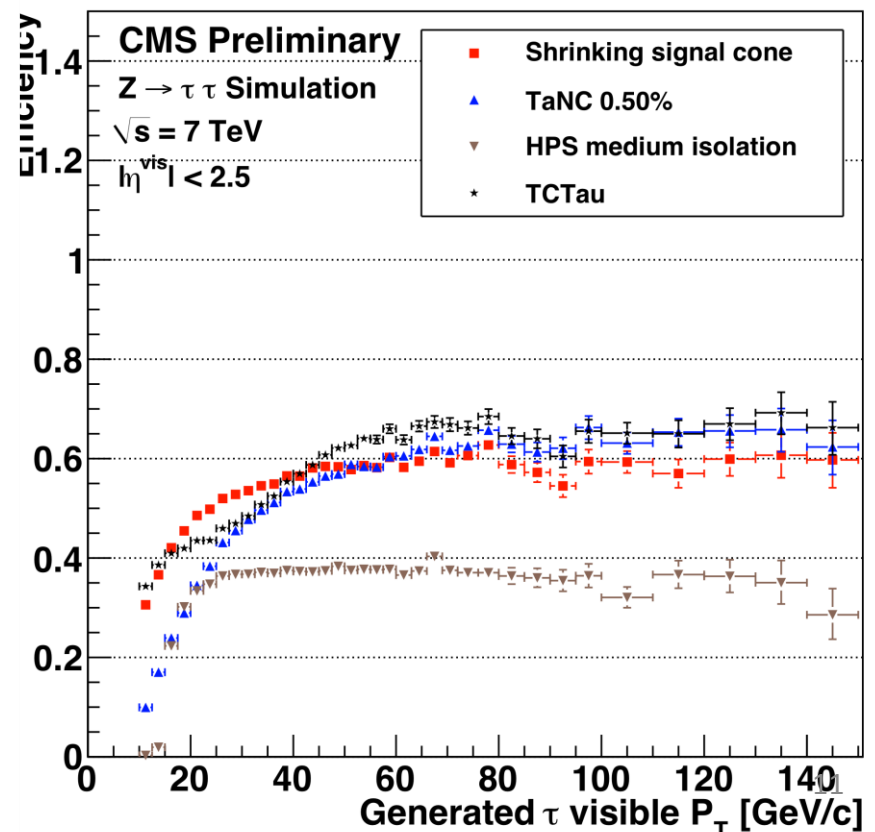
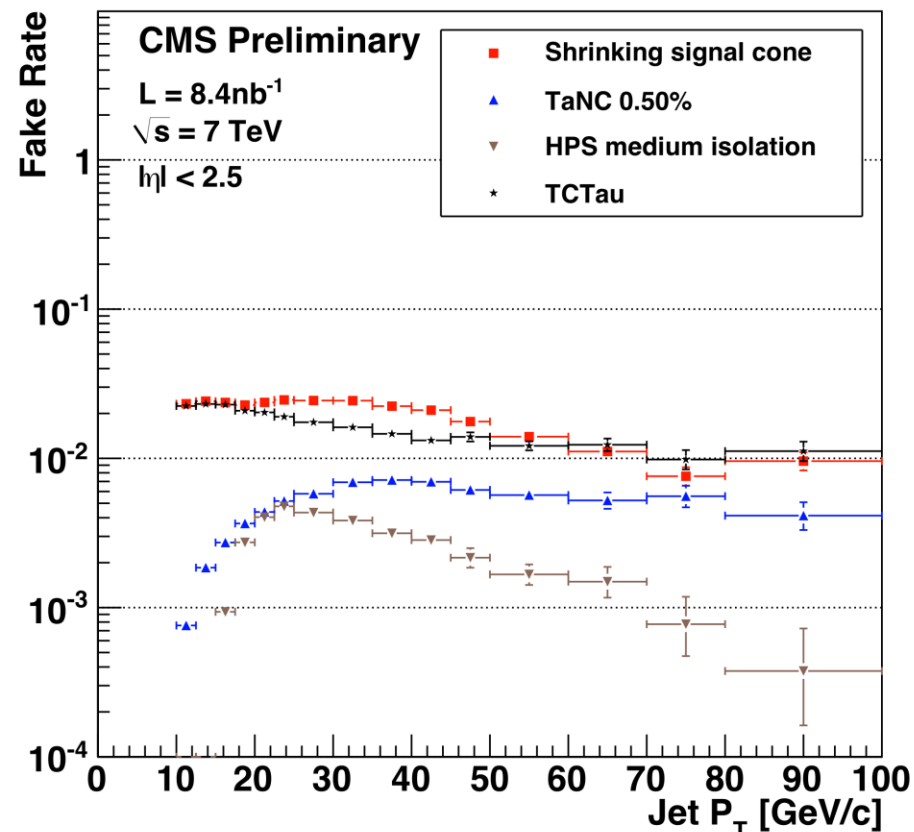
(5 different Neural Networks using Tau id. observables as input trained to identify individual  $\tau$ -Lepton decay modes)

# Jet- $\rightarrow\tau_{\text{had}}$ fake rate from data vs efficiency for $\tau$ s from Z- $\rightarrow\tau\tau$ MC

- will be shown basic selections with
  - fixed signal cone (TCTau)
  - shrinking signal cone
- “advanced” algorithms
  - HPS with “medium” isolation
  - TaNC with 0.5% fake rate operation point

# Fake rate and efficiency vs $p_T^{\tau\text{-jet}}$

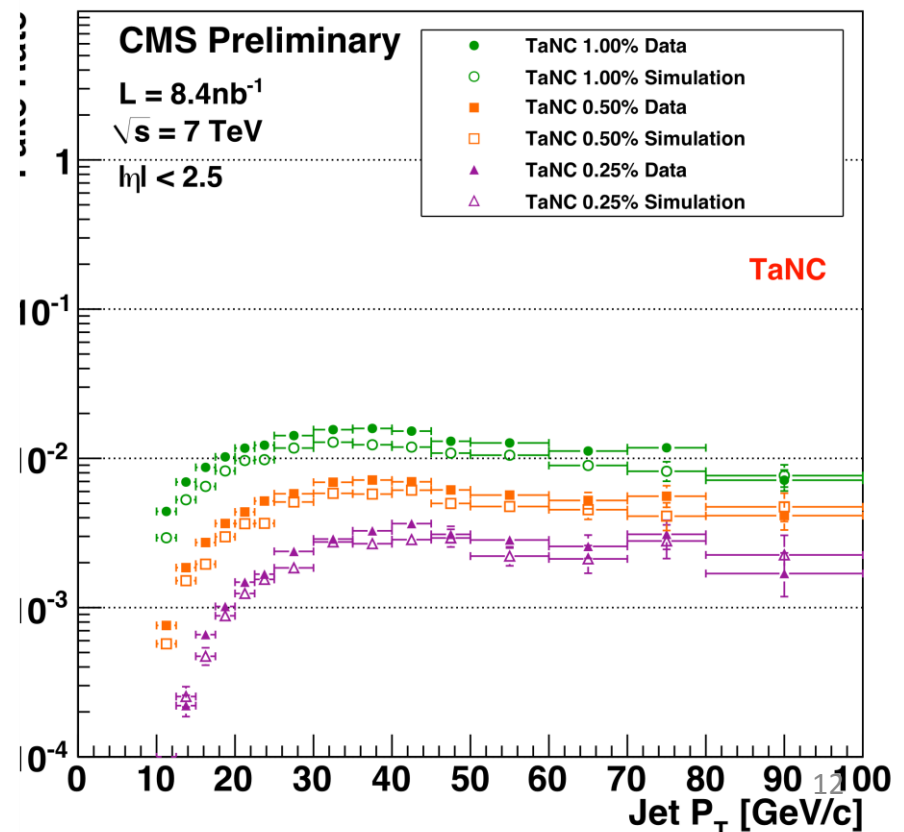
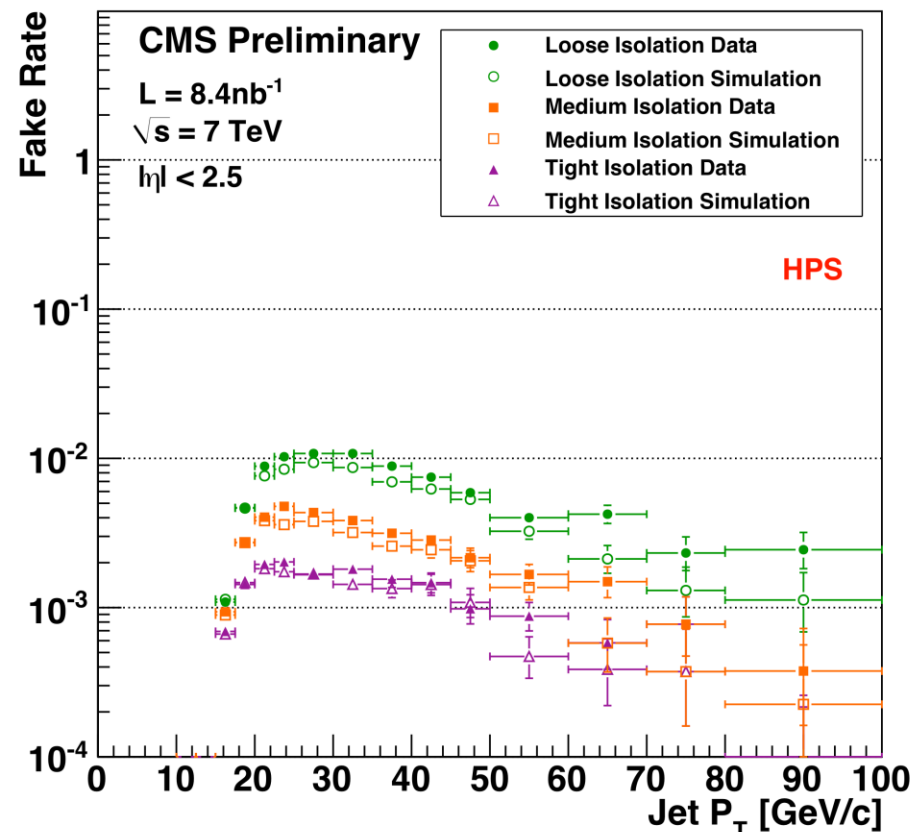
- Shrinking cone recovers 3-prong  $\tau$ s at  $p_T^{\tau\text{-jet}} < 30$  GeV by price of increased bkg. rate
- “advanced”  $\tau$  ID provides better S/B ratio



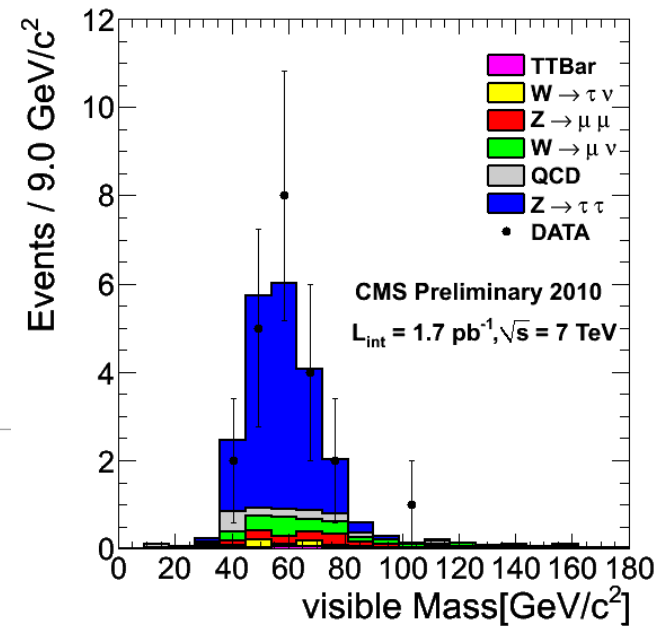
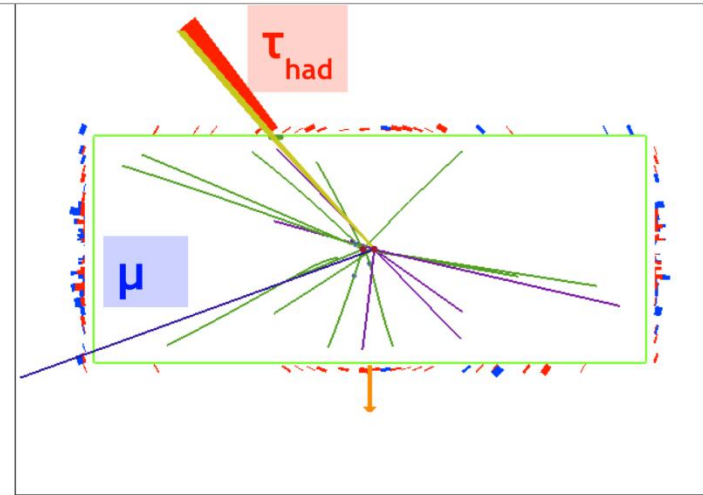
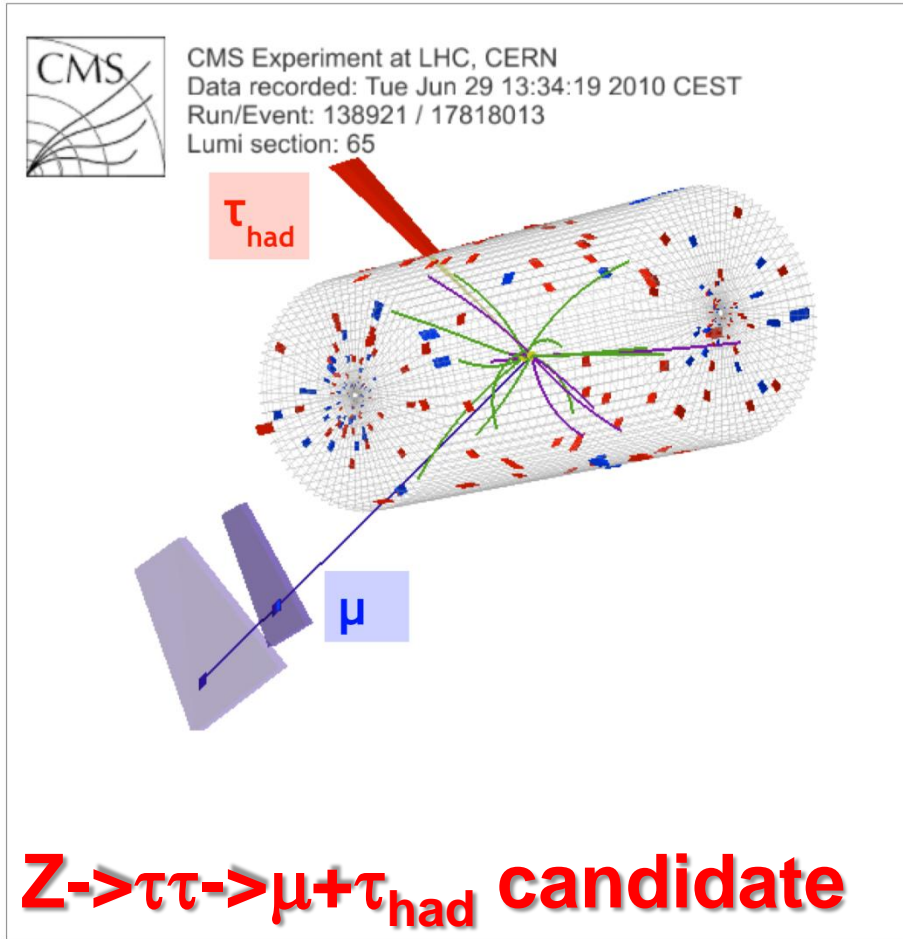
# Data and MC for fake rate vs $p_T^{\tau\text{-jet}}$

- Fake rate is higher in data than in MC for all algorithms

– need more understanding



# Z- $\rightarrow$ $\tau\tau$ is benchmark for $\phi$ - $\rightarrow$ $\tau\tau$



$$\mu p_T = 22.8 \text{ GeV}/c$$

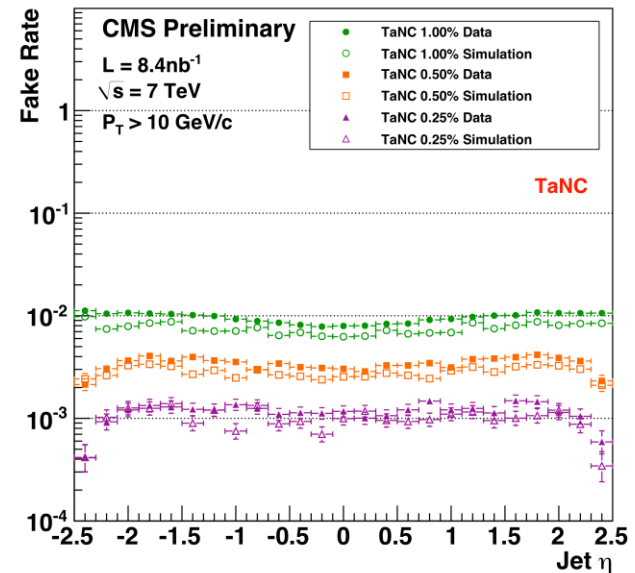
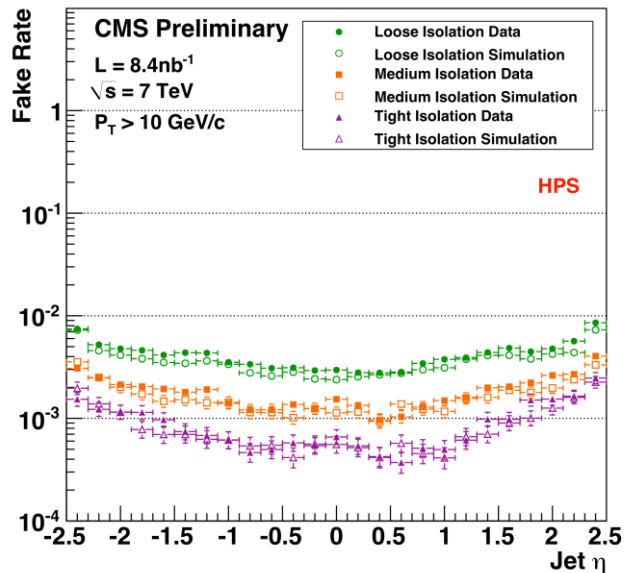
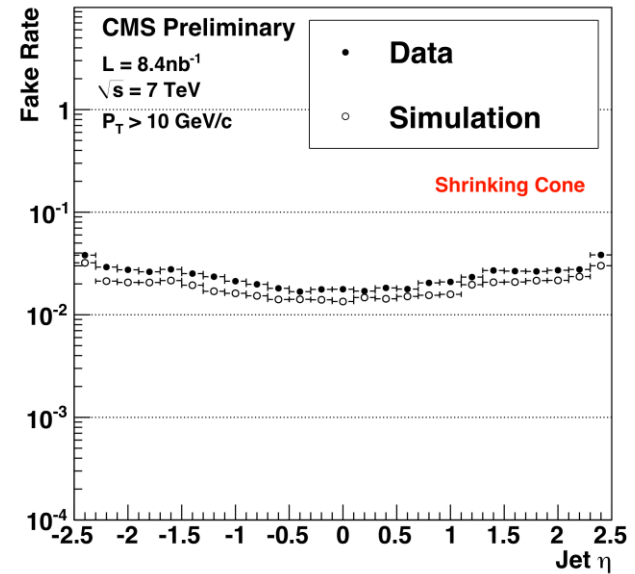
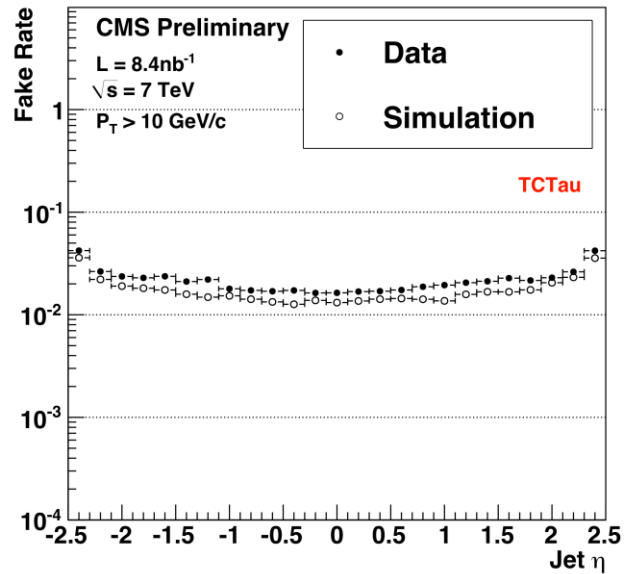
$$\tau_{had} E_T = 32.9 \text{ GeV}$$

# Conclusions

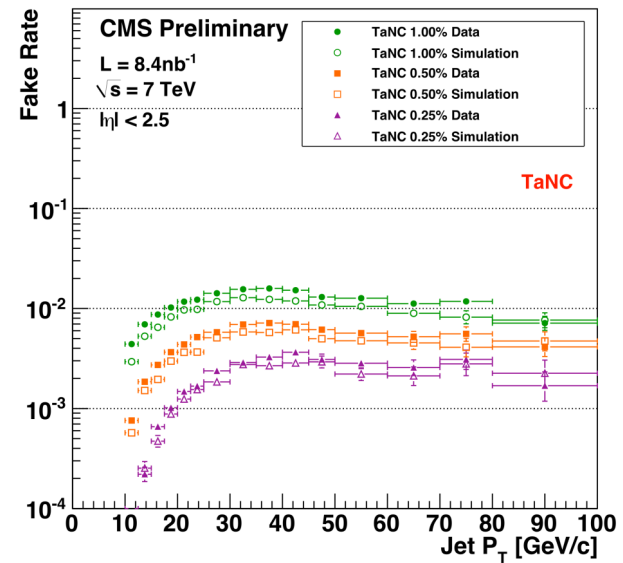
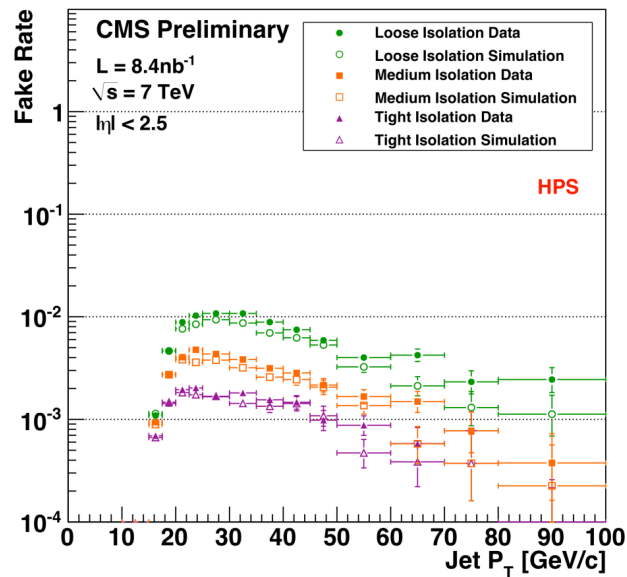
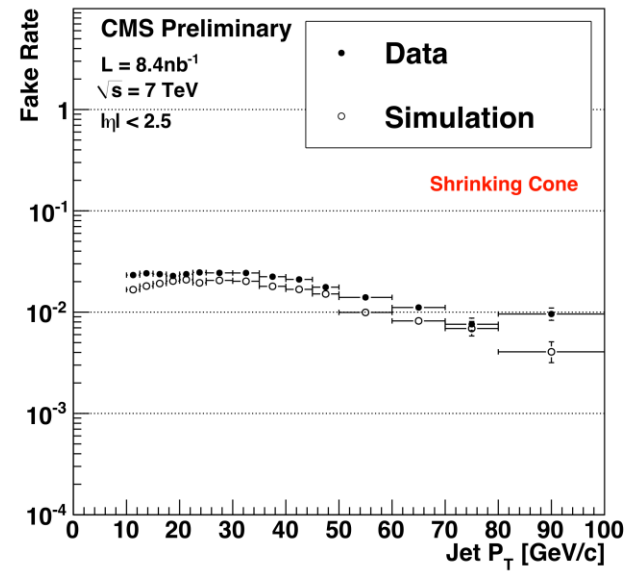
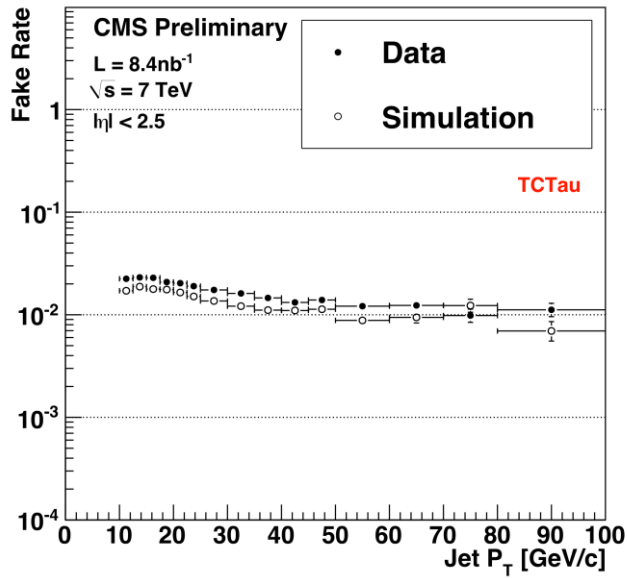
- $\tau$  ID commissioning has started from measurement of jet- $\tau_{\text{had}}$  fake rate
  - fake rate in data is higher than in Monte-Carlo
- Not plenty of real taus yet from  $Z \rightarrow \tau\tau$  /  $W \rightarrow \tau\nu$  to compare in details performance of different algorithms

# Backup

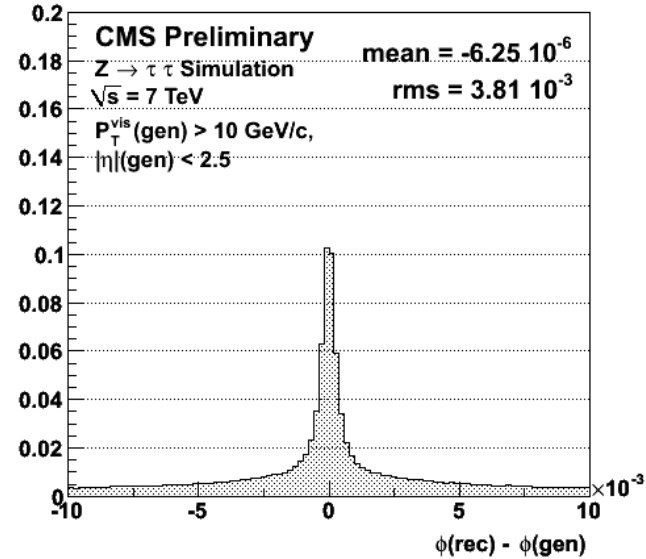
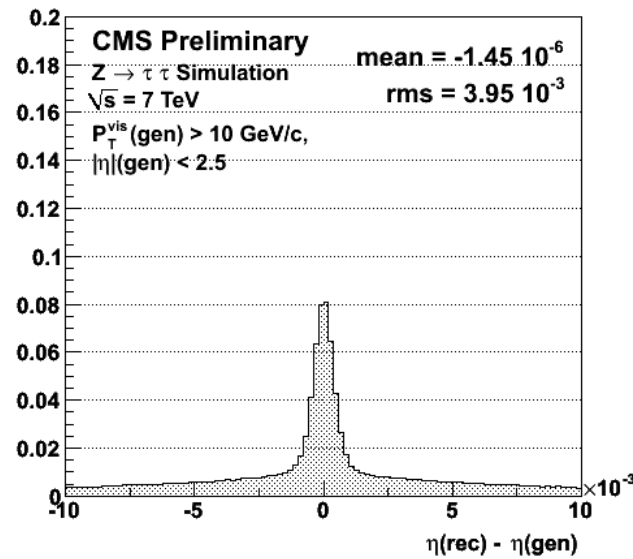
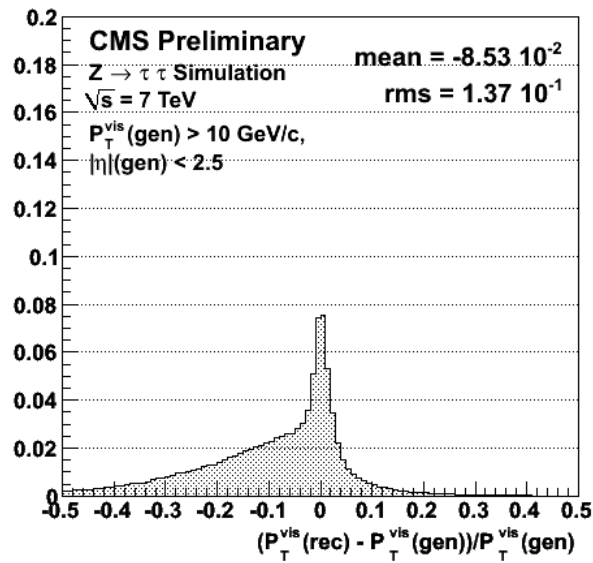
# Agreement with MC Simulation - $\eta$



# Agreement with MC Simulation - $P_T$

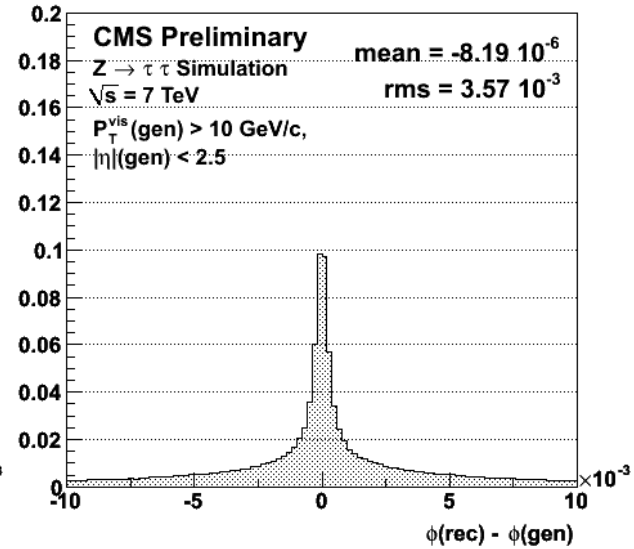
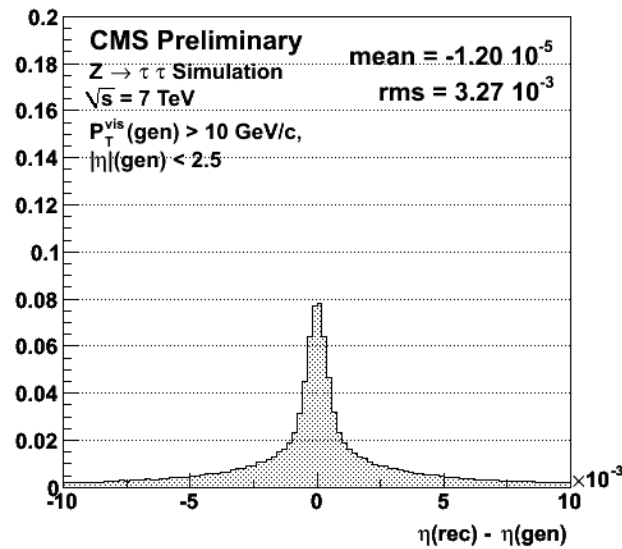
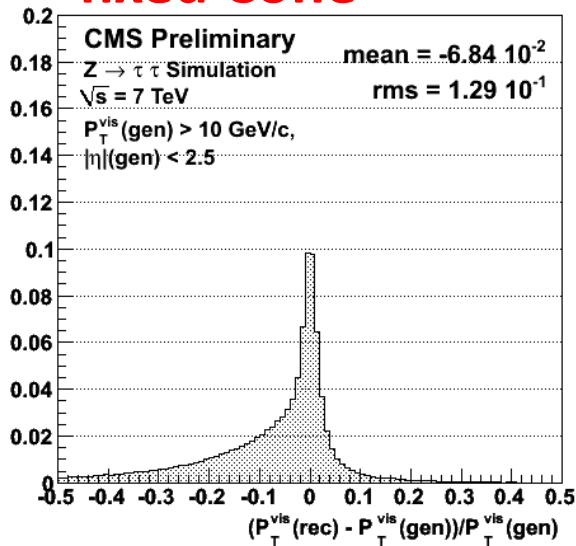


# TCTau fixed cone algorithm

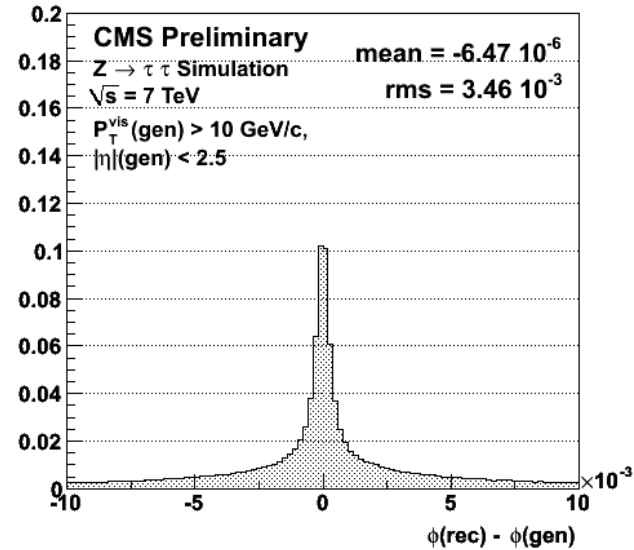
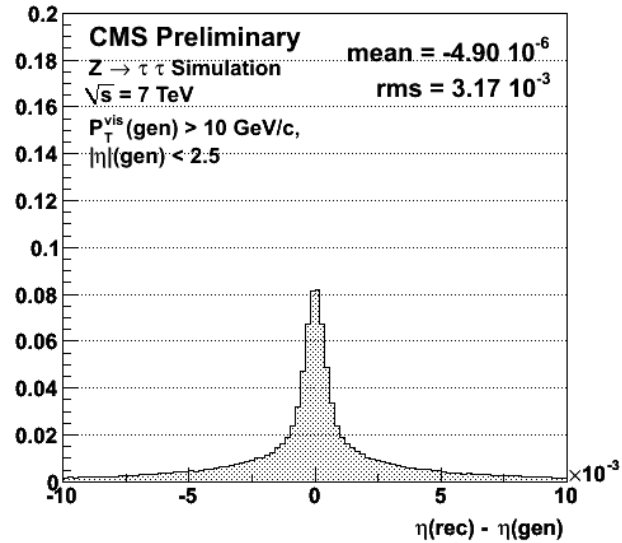
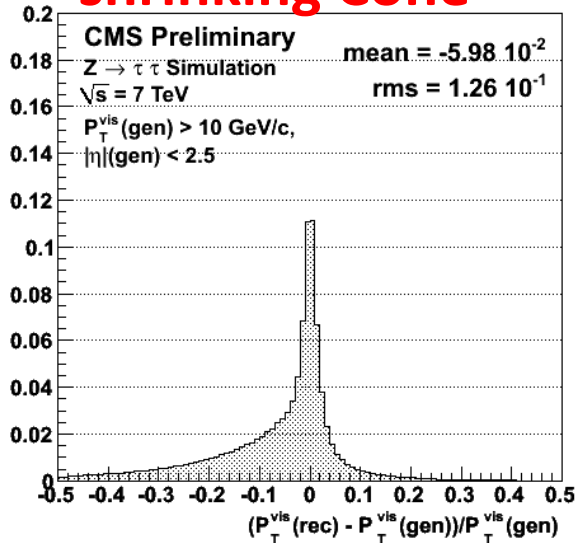


# PF fixed & shrinking Cone algorithms

## fixed Cone

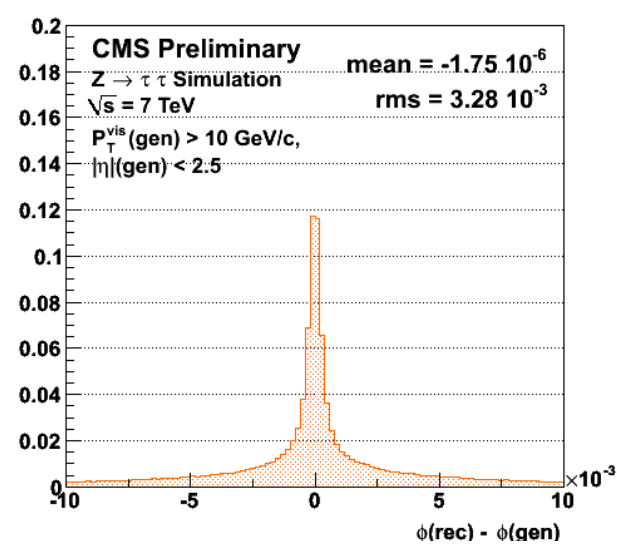
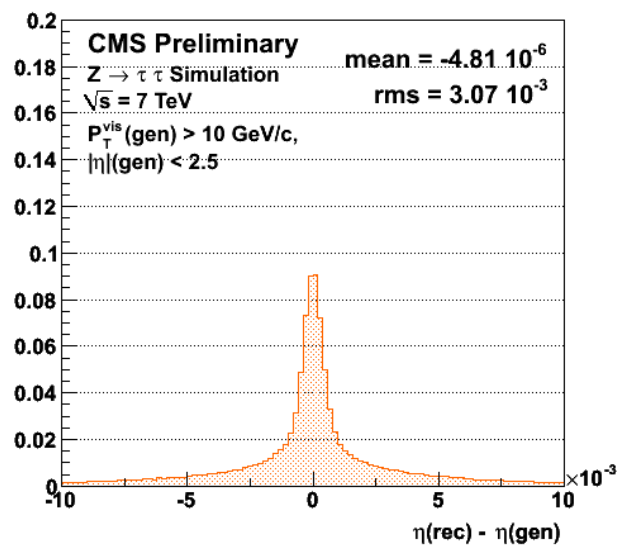
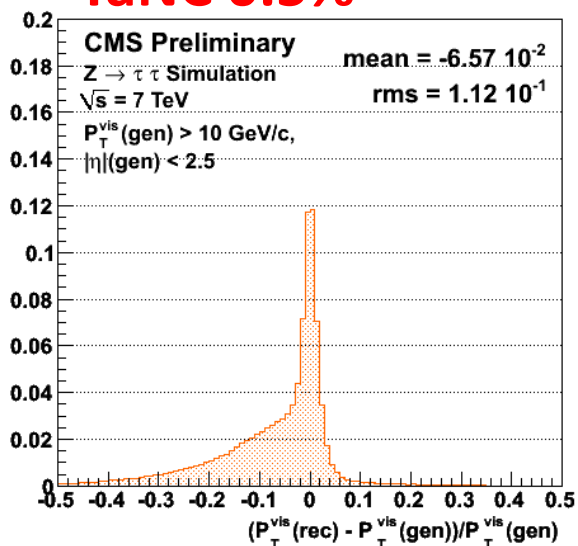


## shrinking Cone

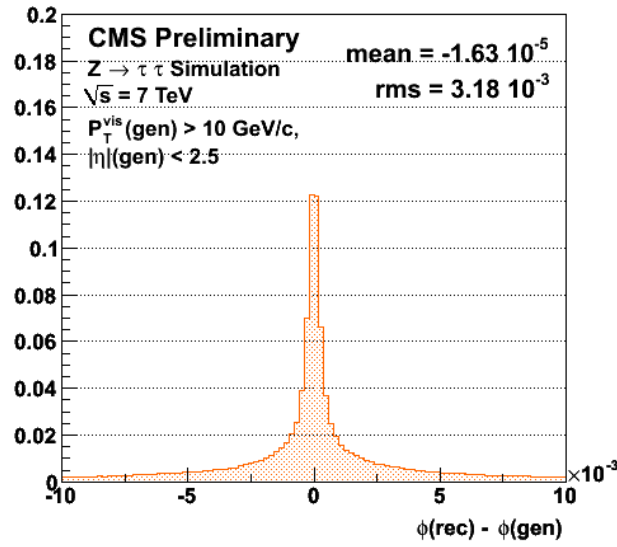
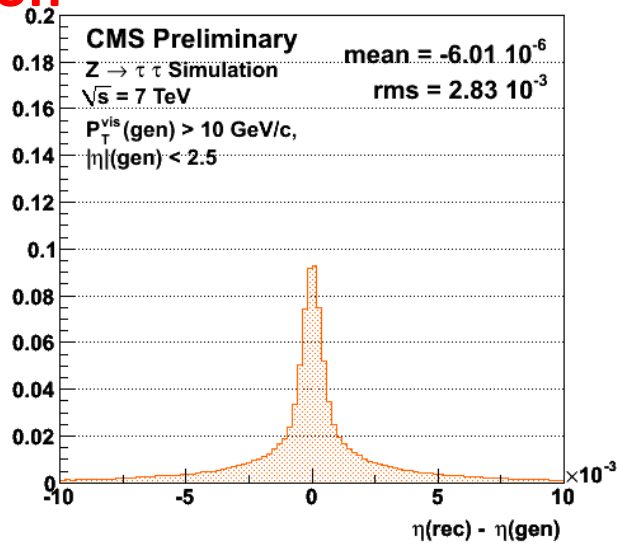
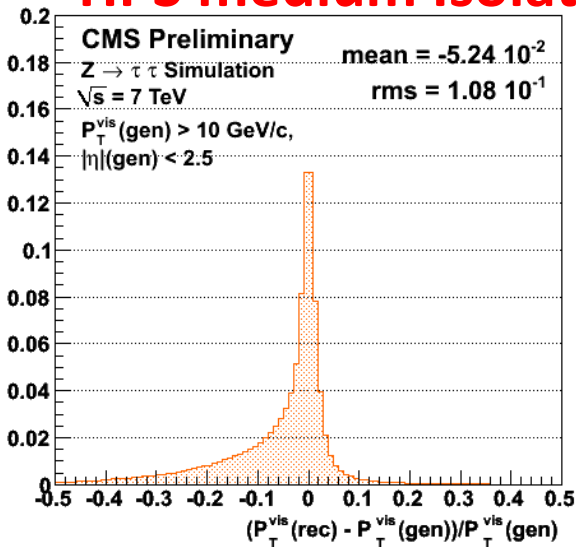


# HPS and TaNC algorithms

## TaNC 0.5%



## HPS medium Isolation



# Cone Isolation algorithms

Common Concept for TCTau, fixed Cone and shrinking Cone algorithms:

## Leading Track

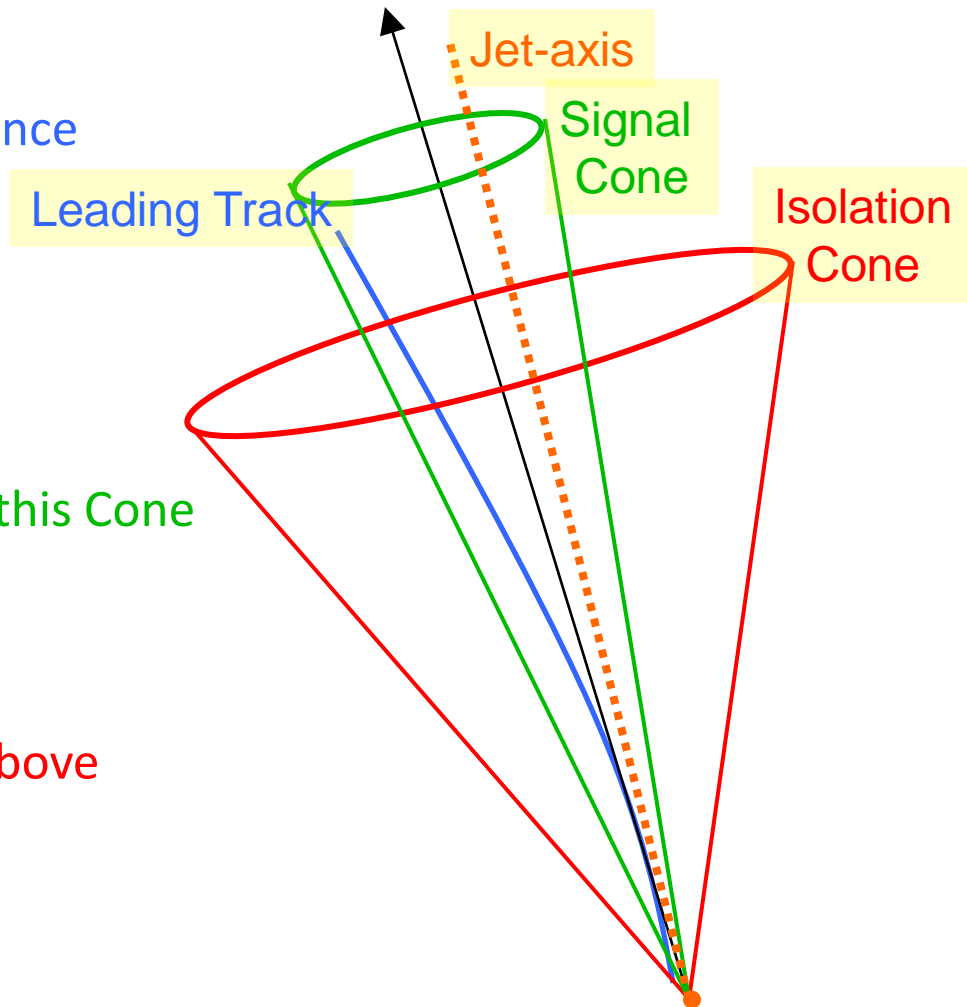
highest  $P_T$  Track within max. Distance  
 $dR = 0.1$  to Jet-axis

## Signal Cone

centered on Leading Track  
all  $\tau$  Decay Products should be in this Cone

## Isolation Cone

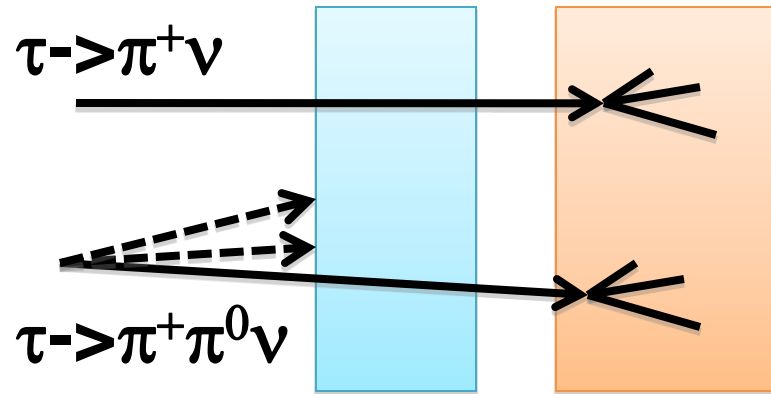
required to contain no Particles above  
some (low)  $P_T$  Threshold



# TCTau $\tau$ -Jet Reconstruction

1. charged hadron(s) start shower in HCAL :  $0.7 < E_{\text{HCAL}}/p^{\Sigma\text{trk}} < 2.0$

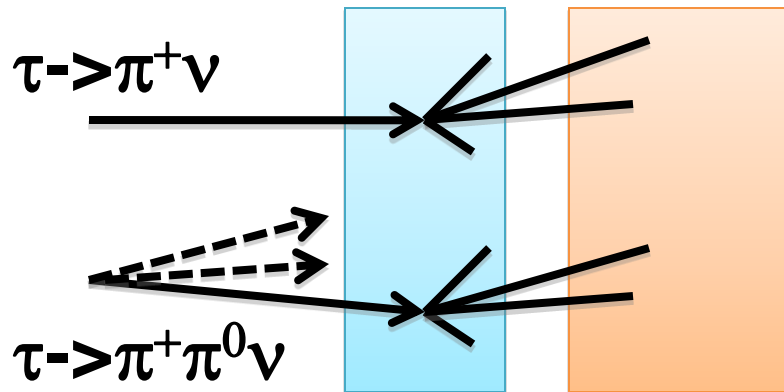
$$E_{\tau\text{-jet}} = p^{\Sigma\text{trk}} + E_{\text{ECAL}}^{0.5}$$



2. charged hadron(s) start shower in ECAL

- 2.1. *no  $\pi^0$ s in  $\tau$  decay*:  $0.1 < (E_{\text{ECAL}} + E_{\text{HCAL}})/p^{\Sigma\text{trk}} < 1.0$

$$E_{\tau\text{-jet}} = p^{\Sigma\text{trk}}$$



- 2.2.  *$\pi^0$ s in  $\tau$  decay*

$$E_{\tau\text{-jet}} = E^{\text{JPT}}$$

$E_{\text{ECAL(HCAL)}}$ ,  $p^{\Sigma\text{trk}}$  – calo energy, track momentum sum in cone 0.2 around impact point of leading  $p_T$  track to ECAL surface.  $\Delta R$  (leading track-JPT jet axis)  $< 0.1$ .

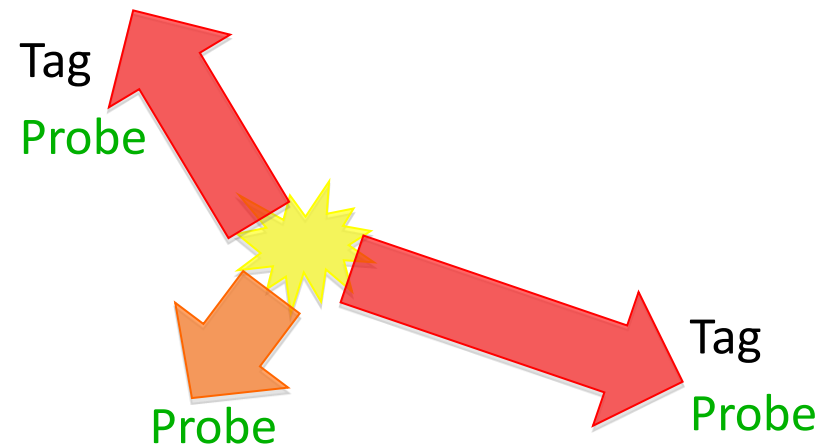
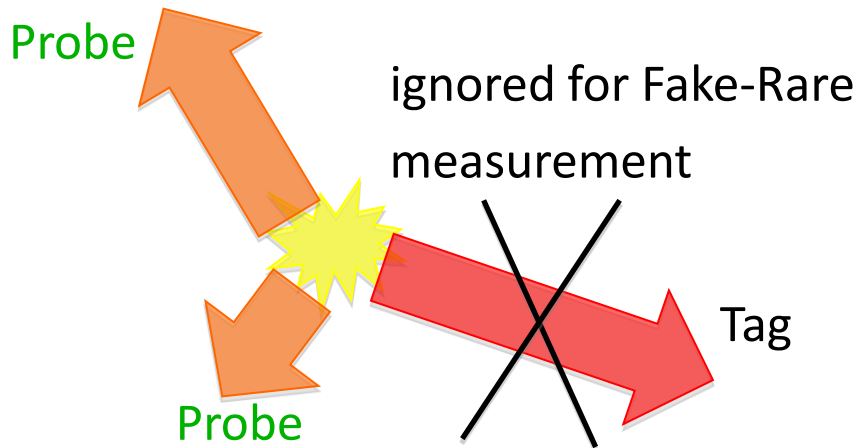
# “Tag” and “Probe” Jets

**Aim: to avoid Bias of Jet Shape due to HLT\_Jet15U Trigger requirement**

→ Distinguish two cases:

**1 Jet passes HLT\_Jet15U requirement**

**≥2 Jets pass HLT\_Jet15U requirement**



**N.B.:**

- all Jets passing HLT\_Jet15U are flagged as “Tag”
- Jets failing HLT\_Jet15U are flagged as “Probe”
- Jets passing HLT\_Jet15U are flagged as “Probe” (in addition to being flagged as “Tag”) if there is another Jet passing HLT\_Jet15U in the Event

# TaNC input variables

Input observable	Neural network				
	$\pi^- \nu_\tau$	$\pi^- \pi^0 \nu_\tau$	$\pi^- \pi^0 \pi^0 \nu_\tau$	$\pi^- \pi^+ \pi^- \nu_\tau$	$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$
ChargedOutlierAngle1	•	•	•	•	•
ChargedOutlierAngle2	•	•	•	•	•
ChargedOutlierPt1	•	•	•	•	•
ChargedOutlierPt2	•	•	•	•	•
ChargedOutlierPt3	•	•	•	•	•
ChargedOutlierPt4	•	•	•	•	•
Dalitz1			•	•	•
Dalitz2			•	•	•
Eta	•	•	•	•	•
InvariantMassOfSignal		•	•	•	•
MainTrackAngle		•	•	•	•
MainTrackPt	•	•	•	•	•
OutlierNCharged	•	•	•	•	•
OutlierSumPt	•	•	•	•	•
PiZeroAngle1		•	•		•
PiZeroAngle2			•		
PiZeroPt1		•	•		•
PiZeroPt2			•		
TrackAngle1				•	•
TrackAngle2				•	•
TrackPt1				•	•
TrackPt2				•	•

# TaNC decay mode Reconstruction

True decay mode	Reconstructed Decay Mode					Other
	$\pi^- \nu_\tau$	$\pi^- \pi^0 \nu_\tau$	$\pi^- \pi^0 \pi^0 \nu_\tau$	$\pi^- \pi^+ \pi^- \nu_\tau$	$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	
$\pi^- \nu_\tau$	16.2%	1.0%	0.1%	0.1%	0.0%	0.3%
$\pi^- \pi^0 \nu_\tau$	10.7%	21.4%	3.6%	0.2%	0.1%	1.9%
$\pi^- \pi^0 \pi^0 \nu_\tau$	1.8%	7.1%	4.4%	0.1%	0.0%	1.5%
$\pi^- \pi^+ \pi^- \nu_\tau$	0.9%	0.2%	0.0%	11.5%	0.6%	5.4%
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	0.1%	0.3%	0.0%	3.2%	2.9%	2.7%