Tau Lepton Reconstruction and Identification with the ATLAS detector at the LHC

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Outline:

- ATLAS features useful for hadronic tau reconstruction.
- Hadronic Tau Reconstruction.
- Identification and Jet Rejection
- Plans for first data.

Introduction:

The τ lepton is a useful probe for new physics due to its:

- Large mass (1.778GeV) expected to couple to new processes.
- Measurable lifetime - $c\tau = 87.11\mu m$
- Well understood decay modes from previous experiments.

- Different decay modes:
  - 35% leptonic: the tau decays into a single electron or muon plus a neutrino.
  - 50% 1prong: $\tau^+ \longrightarrow \bar{\nu_\tau} + \pi^+ + n\pi^0$
  - 15% 3prong: $\tau^+ \longrightarrow \bar{\nu_\tau} + \pi^+ + \pi^- + \pi^+ + n\pi^0$

The hadronic decays with their unique signatures will be the focus of this talk.

- The τ leptons to be reconstructed in ATLAS will have transverse momentum between 10GeV - 500GeV.

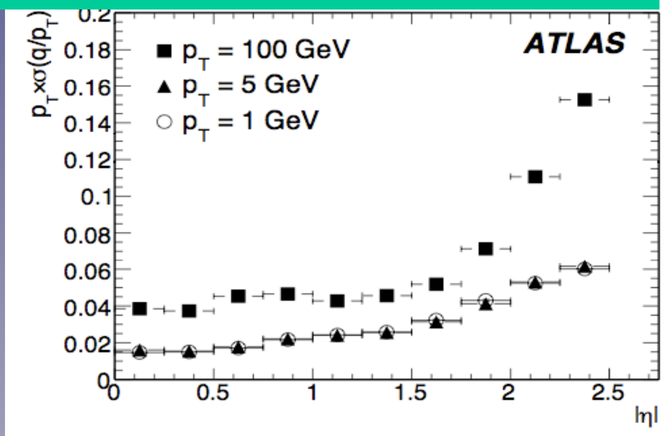
- The main source of fakes are expected from QCD Jets, electrons and muons.

ATLAS:

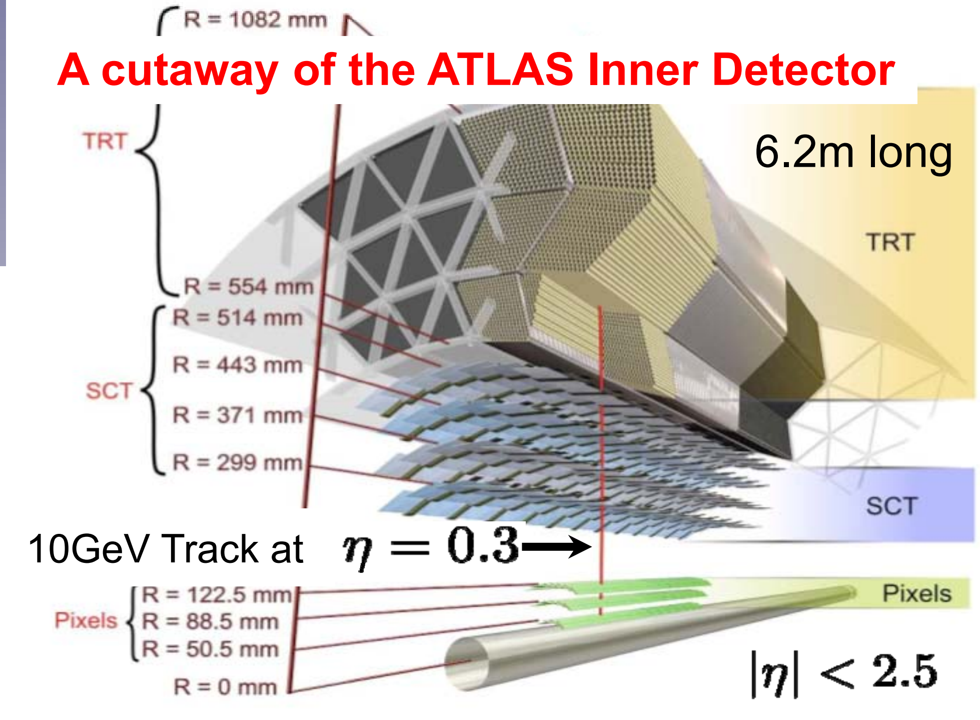
- Two sub-detectors in ATLAS play an important role in τ reconstruction.
  - **The Inner Detector: Tracking**.
  - **The Calorimeters: Charged+Neutral Energy**

The performance of the tracking for simulated single particles.

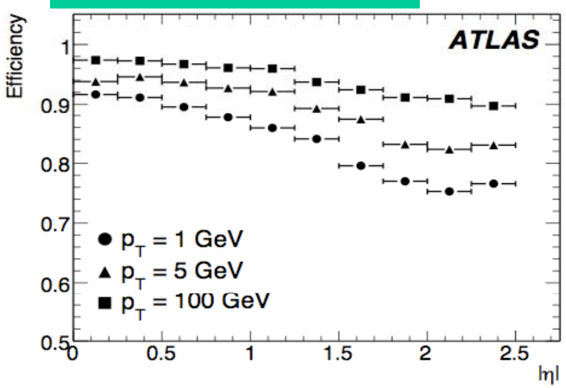
Transverse momentum Resolution



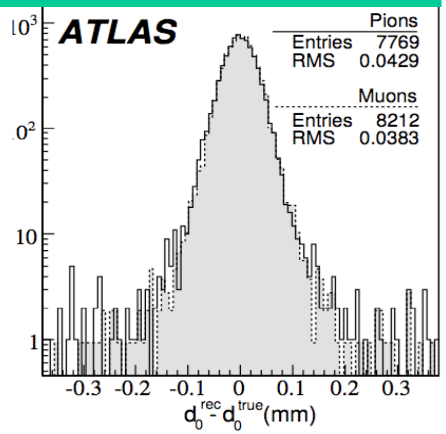
A cutaway of the ATLAS Inner Detector



Efficiency vs Eta

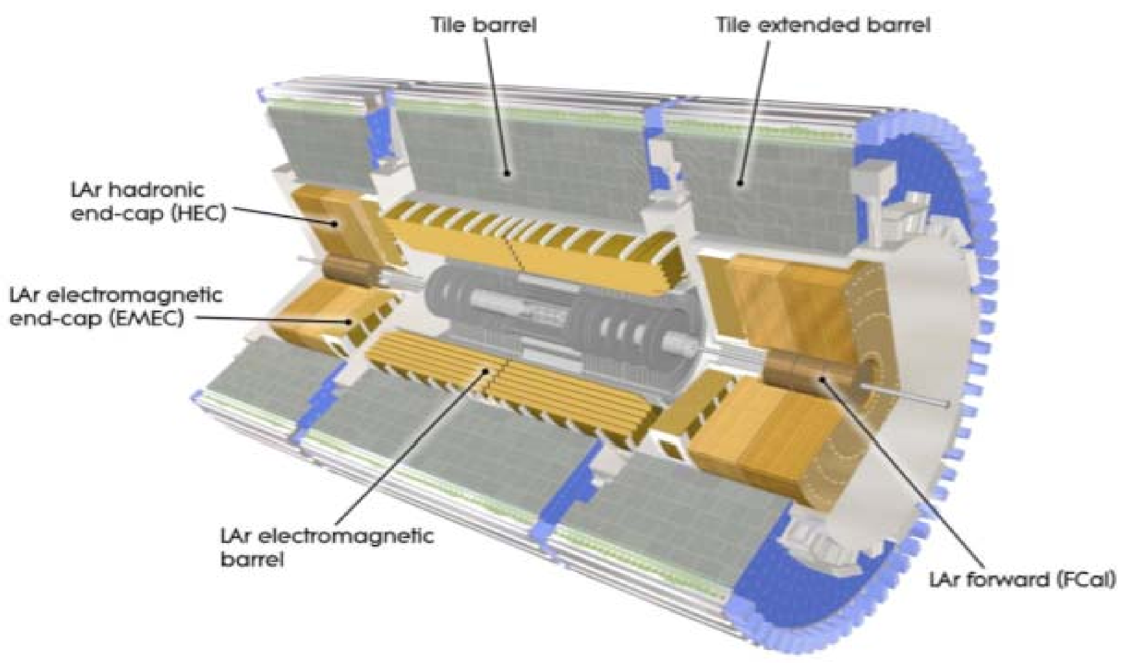


Impact parameter resolution



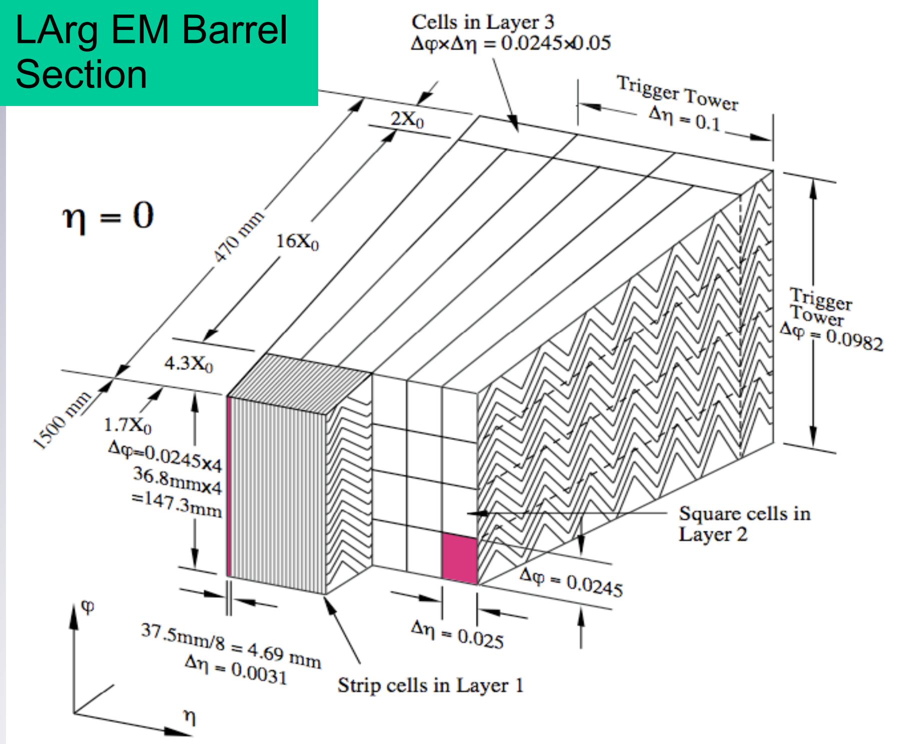
Item	Intrinsic accuracy (μm)	Alignment tolerances (μm)		
		Radial (R)	Axial (z)	Azimuth (R-ϕ)
Pixel				
Layer-0	10 (R-ϕ) 115 (z)	10	20	7
Layer-1 and -2	10 (R-ϕ) 115 (z)	20	20	7
Disks	10 (R-ϕ) 115 (R)	20	100	7
SCT				
Barrel	17 (R-ϕ) 580 (z)[1]	100	50	12
Disks	17 (R-ϕ) 580 (R)[1]	50	200	12
TRT	130			30[2]

The ATLAS Calorimeter System: The EM Calorimeter



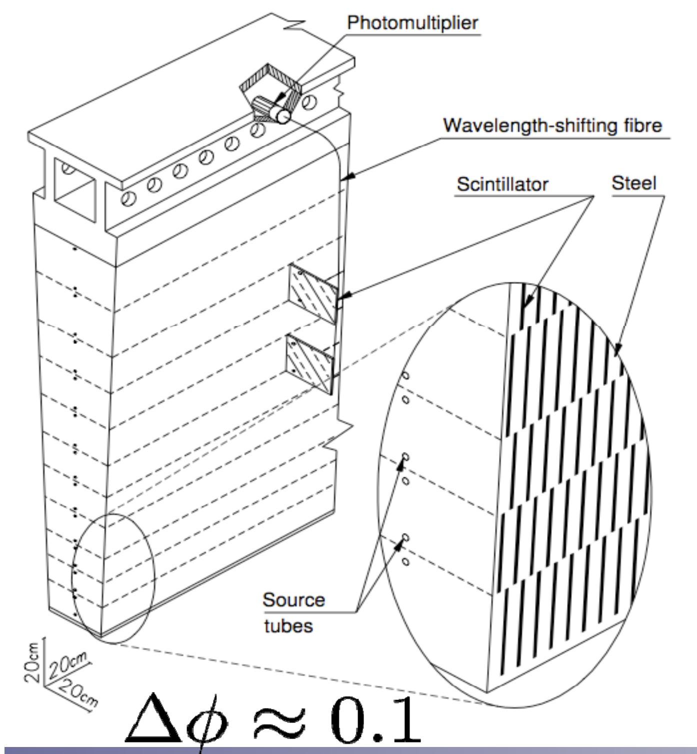
- A total coverage of $|\eta| < 3.2$
- Sampling material: Liquid Argon
- Absorber: Lead

LArg EM Barrel Section



Barrel Section

Measuring Unit (section)	$\Delta\eta \times \Delta\phi$ (Granularity)	
Pre Sampler	0.025 x 0.1	$\|\eta\| < 1.52$
Strips Cells (Layer1)	0.003 x 0.025	$\|\eta\| < 1.40$
Square Cells (Layer2)	0.025 x 0.025	$\|\eta\| < 1.40$
Square Cells (Layer3)	0.05 x 0.025	$\|\eta\| < 1.35$



$\Delta\phi \approx 0.1$

The hadronic Tile calorimeter for $|\eta| < 1.7$.

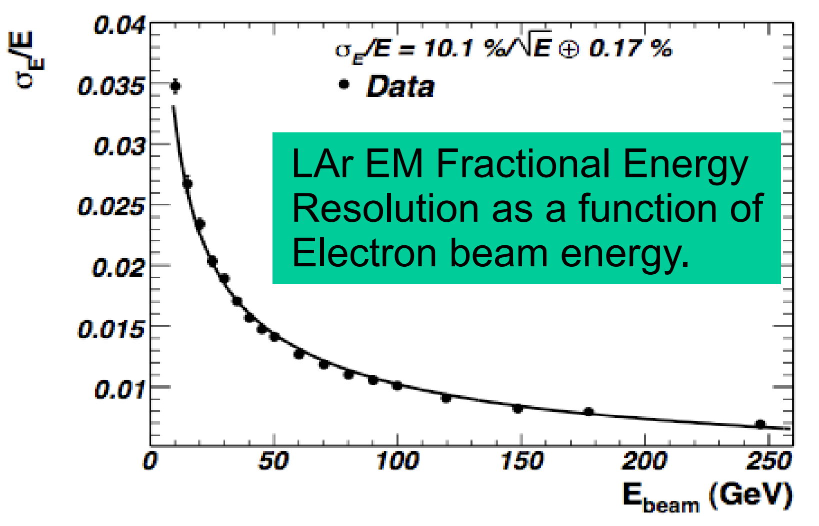
- Sampling material: scintillator tiles.
- Absorber: steel .

The Hadronic End Cap (HEC) $1.5 < |\eta| < 3.2$

- Sampling material: Liquid Argon
- Absorber: Copper

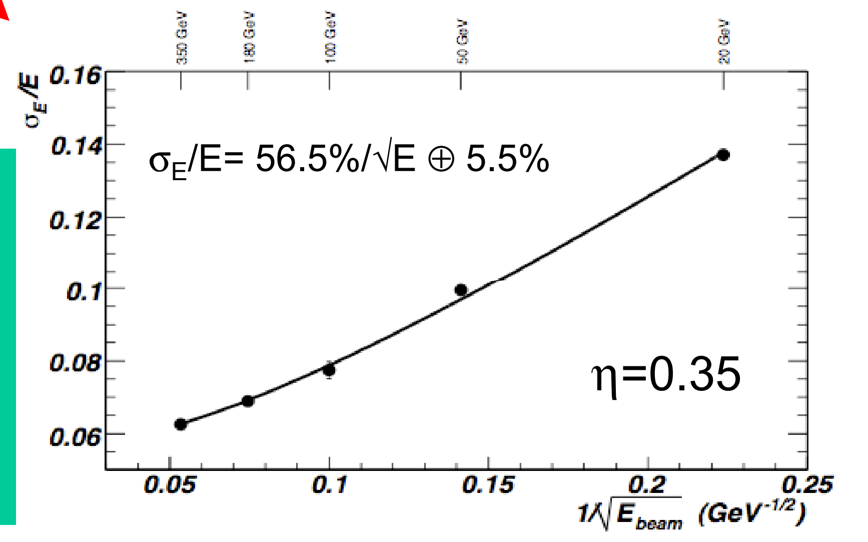
Hadronic Calorimeter	$\Delta\eta \times \Delta\phi$(Granularity)
Tile Cal 3 Layers	0.1 x 0.1 0.2 x 0.1 (last layer)
HEC 4 Layers	0.1 x 0.1 $1.5 < \|\eta\| < 2.5$ 0.2 x 0.2 $2.5 < \|\eta\| < 3.2$

Testbeam Performance



LAr EM Fractional Energy Resolution as a function of Electron beam energy.

TileCal Fractional Energy Resolution as a function of the inverse square root of the incident pion beam energy.



Tau Reconstruction:

The ATLAS τ working group has developed two reconstruction algorithms using the tracks and jets measured by the detectors previously presented.

Results in:

- Track Seeded
- Calo Seeded

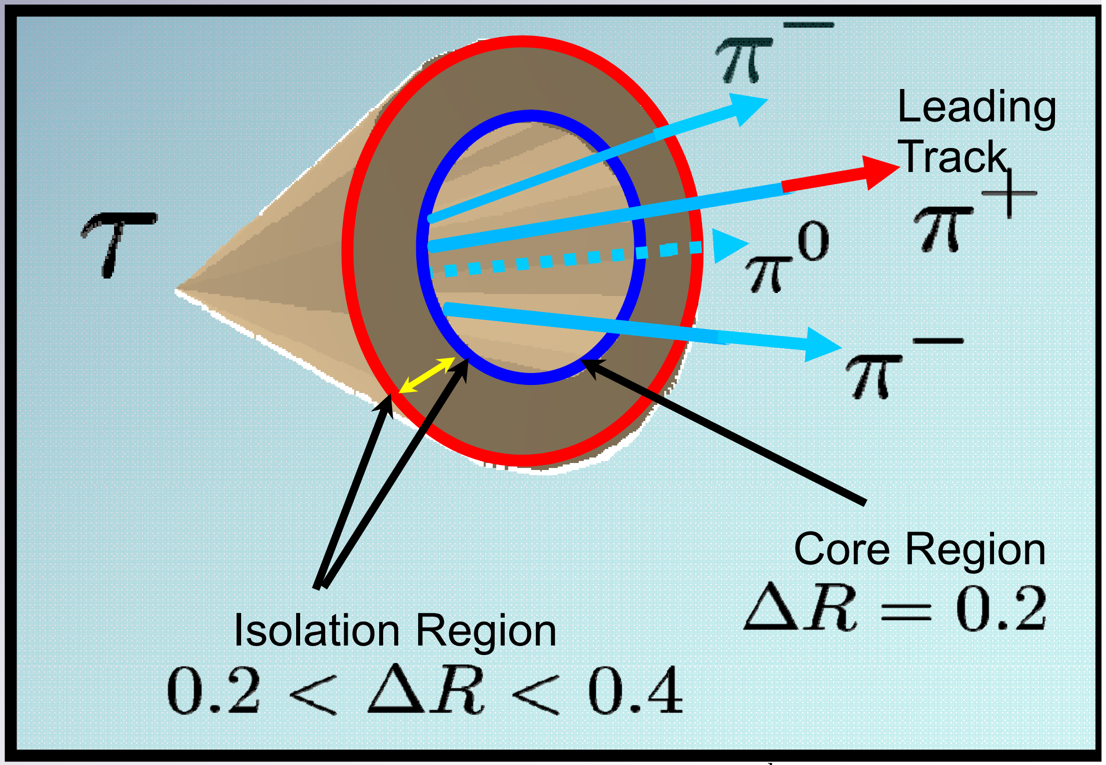
→ **Merged**
(A reconstructed object with both seeds)

$$\Delta R = \sqrt{(\eta_o - \eta_i)^2 + (\phi_o - \phi_i)^2}$$

Track Seeded Philosophy:

1. A low track multiplicity region centred about the leading track will contain most of the τ's transverse energy.
2. Only a minimum amount of energy is deposited in an annulus around the core region.

The hadronic τ decay results in visible components such as charged and neutral pions that are well collimated.



Track seeded reconstruction:

1. A track with $P_T > 6GeV$ plus other properties such as number of hits, impact parameter, etc is chosen as the seed.

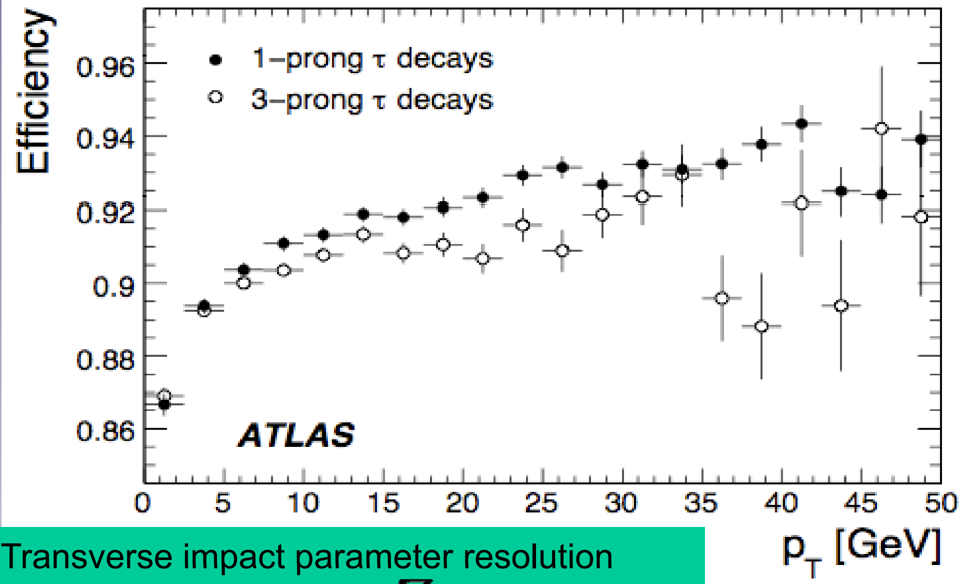
2. Tracks around this leading track are gathered within the core region $\Delta R = 0.2$.
   The track has similar properties as above except $P_T > 1GeV$

3. The energy of the reconstructed tau is determined using the Energy Flow algorithm.

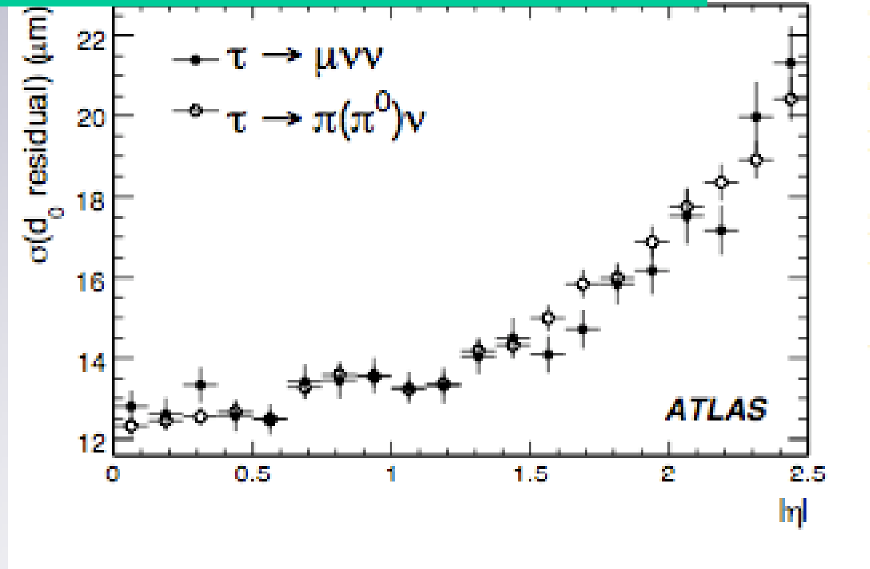
Energy Flow algorithm (in a nutshell):

The energy measured in the calo clusters due to the τ charged daughters is replaced by the tracks momenta + plus corrections due to the neutrals and charged pions being deposited in the same cluster.

Reconstruction Efficiency for Tracks from $Z \rightarrow \tau\tau$ $W \rightarrow \nu\tau$



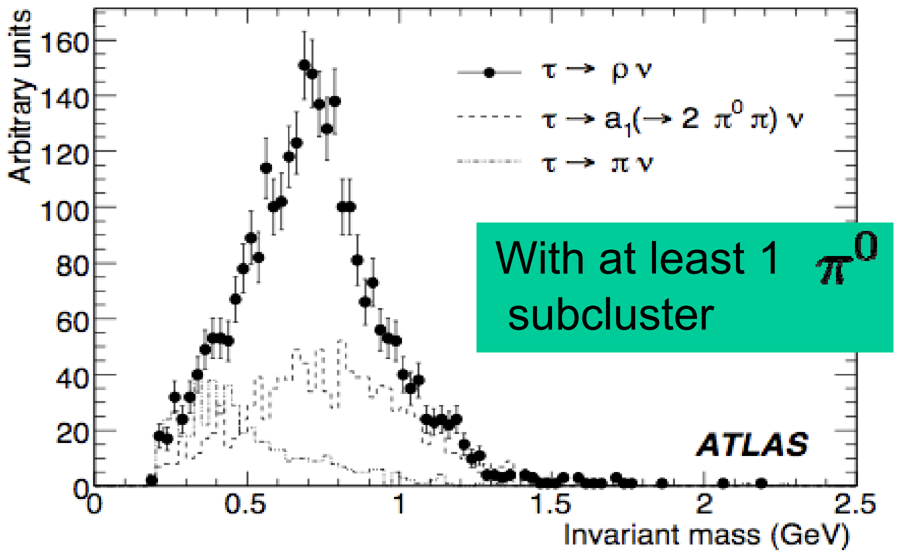
Transverse impact parameter resolution $Z \rightarrow \tau\tau$



Track seeded reconstruction:

- The reconstruction of the π^0 is possible because of the segmentation of the ATLAS EM Calorimeter.

Invariant Mass of Visible Decay Products



Decay Modes	Number of π^0 subclusters reconstructed		
	0	1	≥ 2
All $\tau \rightarrow had\nu$	32%	35%	33%
$\tau \longrightarrow \pi\nu$	**65%**	20%	15%
$\tau \longrightarrow \rho\nu$	15%	**50%**	35%
$\tau \rightarrow a_1(\rightarrow 2\pi^0\pi)\nu$	9%	34%	**57%**

- The area from each contribution is proportional to the branching ratio + the efficiencies of the algorithm.

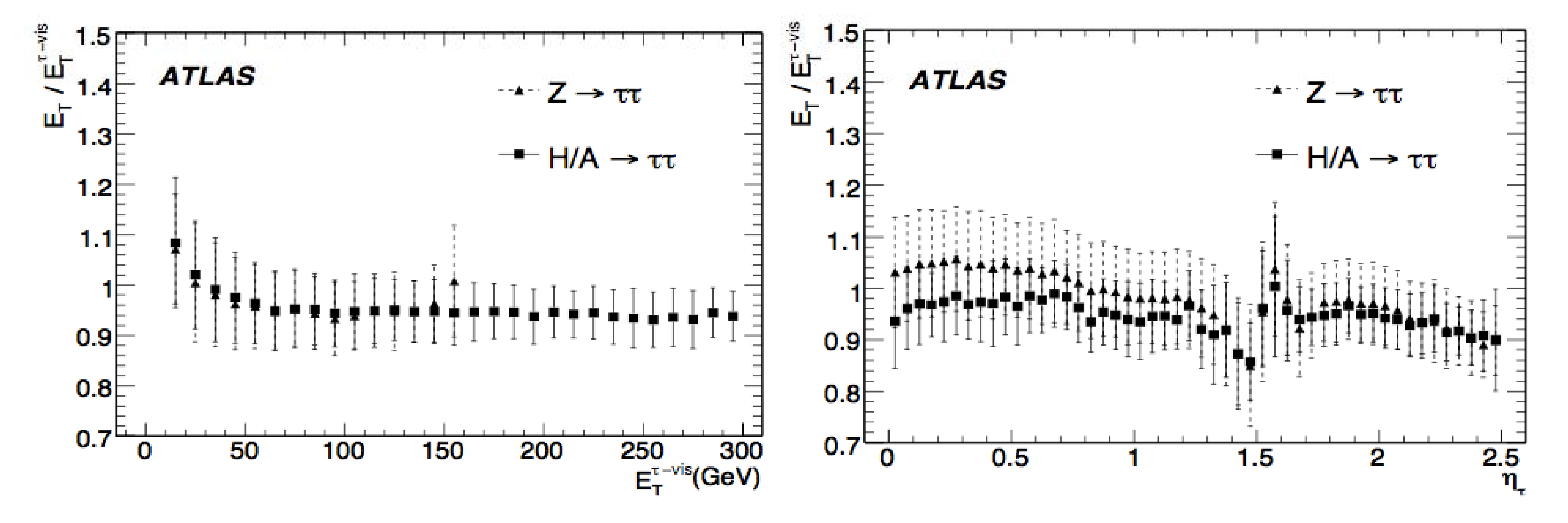
Calo Seeded Reconstruction:

A hadronically decaying τ will always leave its signature on the calorimeter.

1. A jet with transverse energy, $E_T > 10GeV$ is the seed for the tau reconstruction.
2. An energy estimate is obtained from for all the cells within $\Delta R < 0.4$ of the barycenter.

   The cells are calibrated using H1 calibration method. The energy of the cells is calibrated to the jet energy scale..
3. From the calorimeter tracks are matched that are located within $\Delta R < 0.3$ and their is $P_T > 1GeV$. These tracks will be included in the reconstructed tau object.

The ratio between the reconstructed E_T and the true visible E_T from its charged daughters.



Reconstruction Performance:

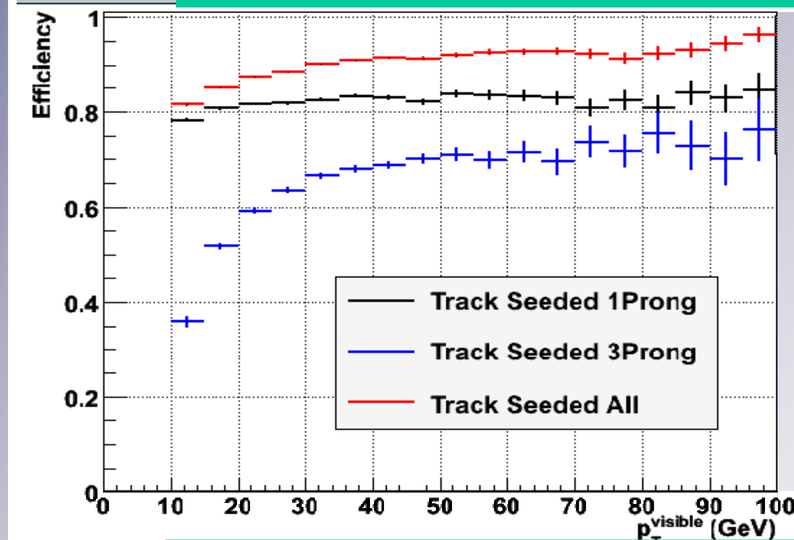
Resolution obtained from the reconstructed candidates from a $Z \rightarrow \tau\tau$ sample.

Variable	Track Seeded Mean(RMS)	Calo Seeded Mean(RMS)
1Prong		
$\frac{(P_T - P_T^{visible})}{P_T^{visible}}$	1.1e-02 (1.4e-01)	9.1e-03 (1.3e-01)
$\phi - \phi_{visible}$	3.0e-05 (1.8e-02)	5.7e-05 (2.3e-02)
$\eta - \eta_{visible}$	5.1e-05 (1.9e-02)	2.5e-05 (1.6e-02)
3Prong		
$\frac{(P_T - P_T^{visible})}{P_T^{visible}}$	-7.9e-04 (1.1e-01)	4.5e-02 (1.3e-01)
$\phi - \phi_{visible}$	5.9e-05 (6.6e-03)	-6.5e-05 (2.6e-02)
$\eta - \eta_{visible}$	-7.6e-05 (6.8e-03)	7.1e-05 (1.8e-02)

RMS is preferred because of non-gaussian tails

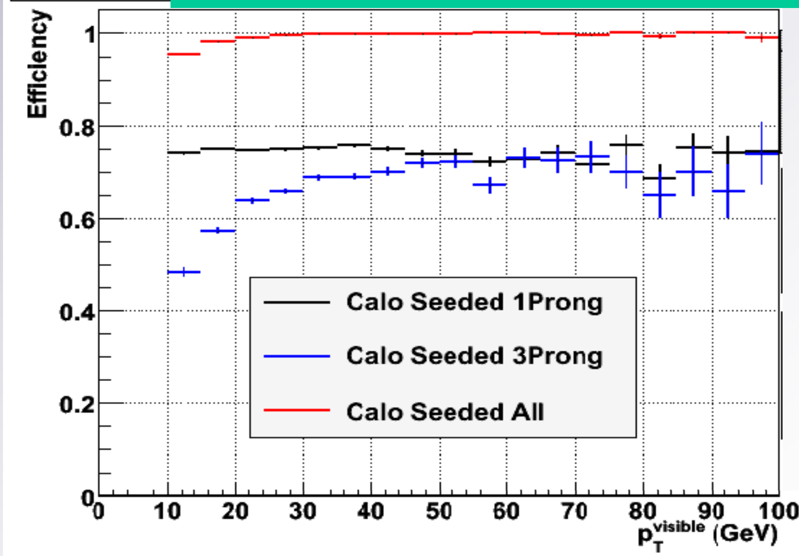
Efficiency with respect to Monte Carlo Truth, 1Prong and 3Prong require #tracks to match.

$Z \rightarrow \tau\tau$ **Track Seeded Reconstruction Efficiency**



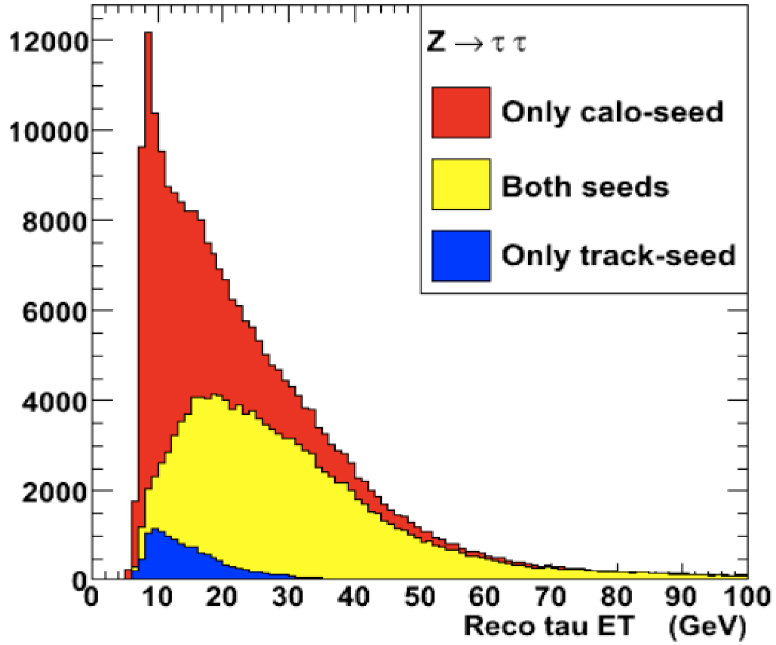
AvEff
82%
62%
89%

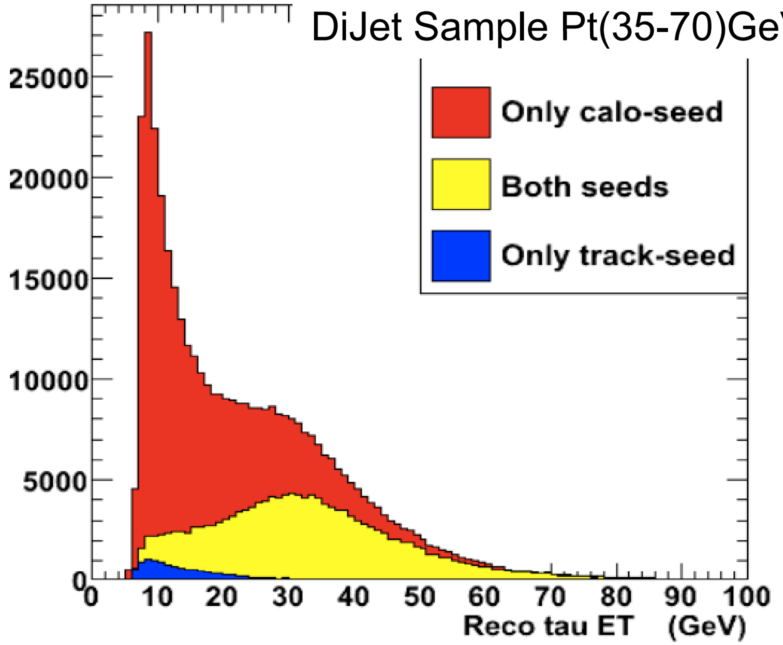
$Z \rightarrow \tau\tau$ **Calo Seeded Reconstruction Efficiency**



AvEff
75%
65%
99%

Composition of the reconstruction:





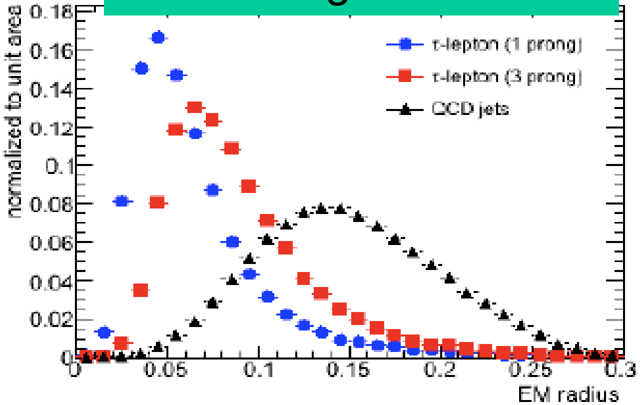
The *both seeds* category has the higher efficiency and suppression.

	Sample - % of total candidates reconstructed (% of true τs reconstructed)			
Reconstructed Type	$Z \to \tau\tau$	QCD DiJet Pt Range (8-17)GeV	QCD DiJet Pt Range (35-70)GeV	QCD DiJet Pt Range (70-140)GeV
Both Seeds	49.0 (70)	10	31	45
Only Calo Seed	45.5 (25)	88	66	50
Only Track Seed	5.0 (5)	2	2	5

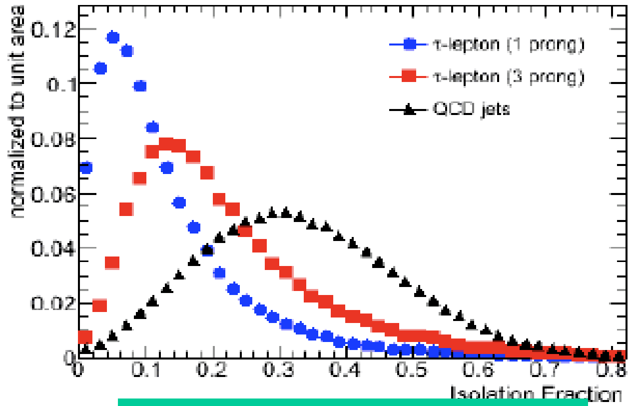
Tau Identification:

- An important component of the overall tau reconstruction strategy is its identification.
- The identification will need select true taus while providing a strong rejection against jets reconstructed as taus.

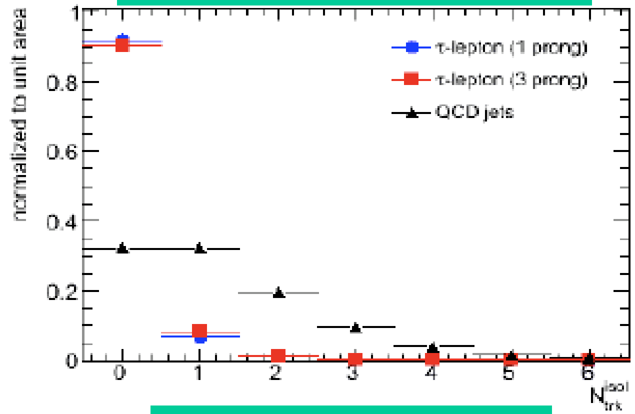
Electromagnetic Radius



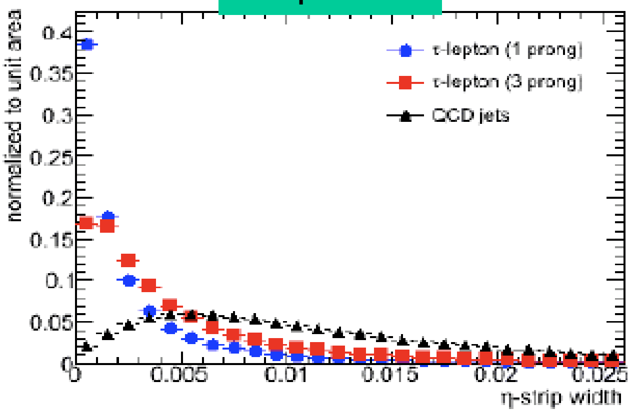
Energy fraction in the isolation region



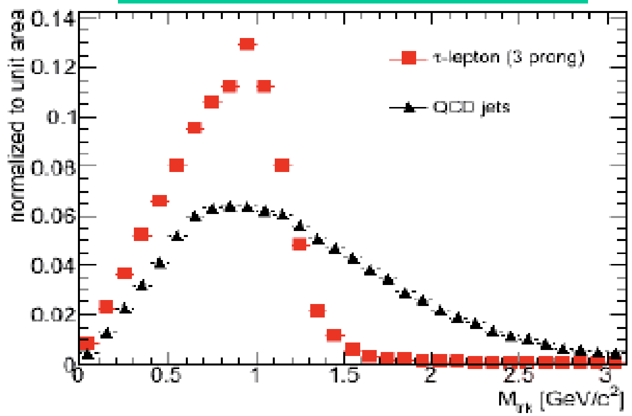
Number of Tracks in the isolation region



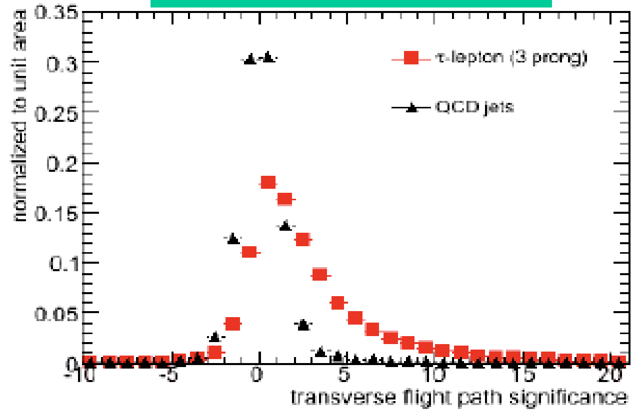
Strip width



Visible Mass from tracks



Tranverse flight path



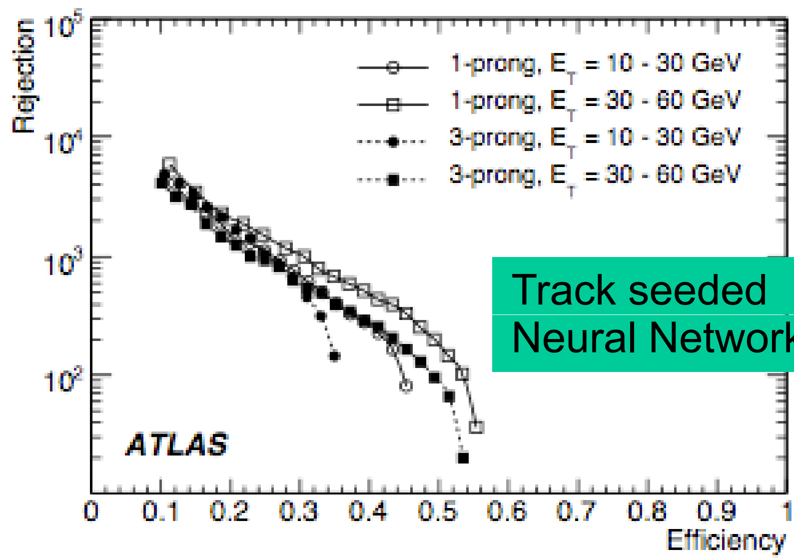
Variable and their distribution for hadronic decaying taus and Jets

Different selection algorithms for tau identification have been developed and studied:

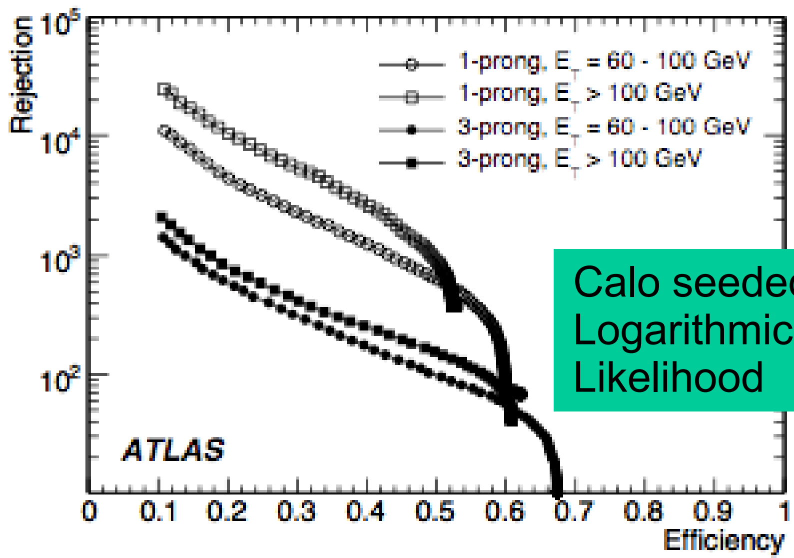
- Cut based.
- Neural networks.
- Probablility Density Range Searches. (PDRS)
- Boosted Decision trees.
- Logarithmic Likelihood

Algorithm	E_T = 10-30 GeV	E_T = 30-60 GeV	E_T = 60-100 GeV	E_T > 100 GeV
Track-based (neural network)	1p: 740 ± 70 3p: 590 ± 50	1p: 1030 ± 160 3p: 590 ± 70		
Calo-based (likelihood)		1p: 1130 ± 50 3p: 187 ± 3	1p: 2240 ± 140 3p: 310 ± 7	1p: 4370 ± 280 3p: 423 ± 8

Rejection of Jets From True taus 30% Efficiency Divided into 1prong and 3prong.



Track seeded Neural Network



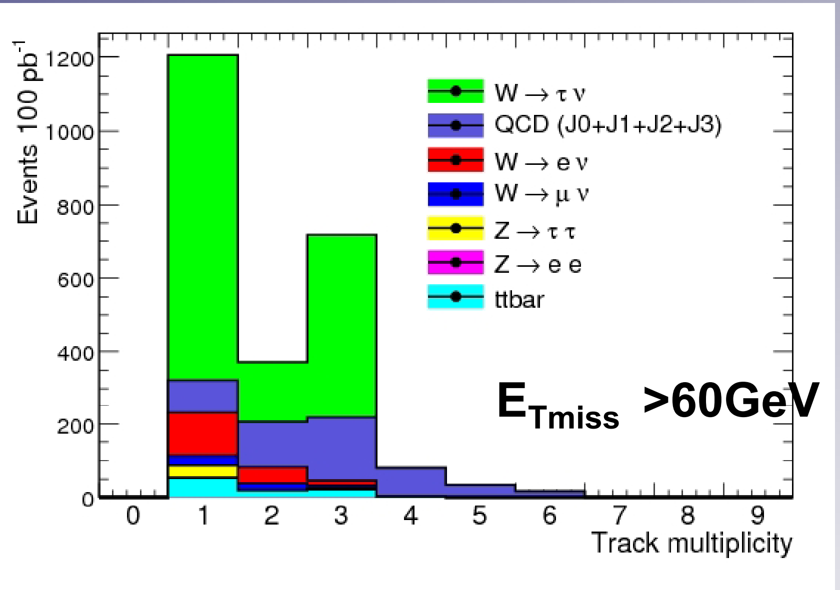
Calo seeded Logarithmic Likelihood

First Physics Data:

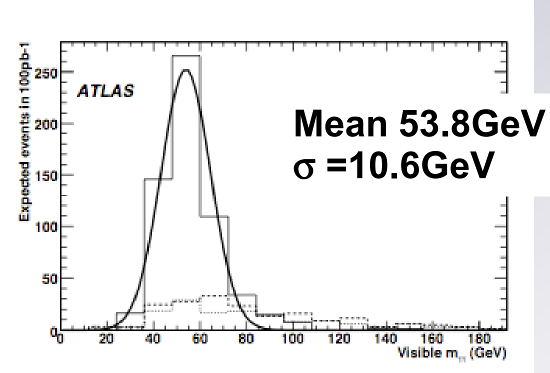
The aim for the first 100pb^{-1} is to:

- Optimise the QCD Jet rejection using a real QCD sample.
- Measure identification and reconstruction efficiency using a real tau sample.
- Determine the tau energy scale from data.

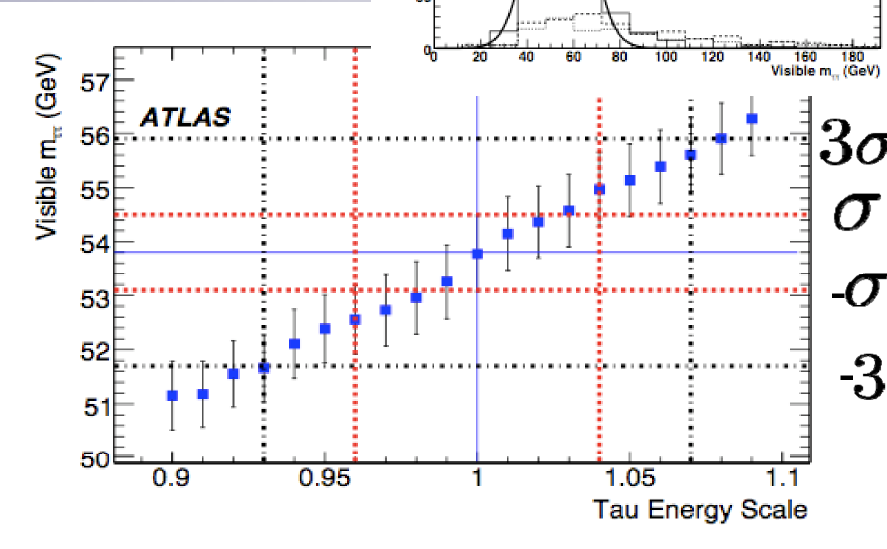
$W \rightarrow \tau_{had} \upsilon$



$Z \rightarrow \tau_{had} \tau_{lep}$



Mean 53.8GeV
σ =10.6GeV



3σ
σ
$-\sigma$
-3σ

Reconstructed Visible Mass $l\tau_{had}$;
energy scale τ_{had}

Conclusion: □

The hadronic tau reconstruction in the ATLAS experiment has matured and is stable.

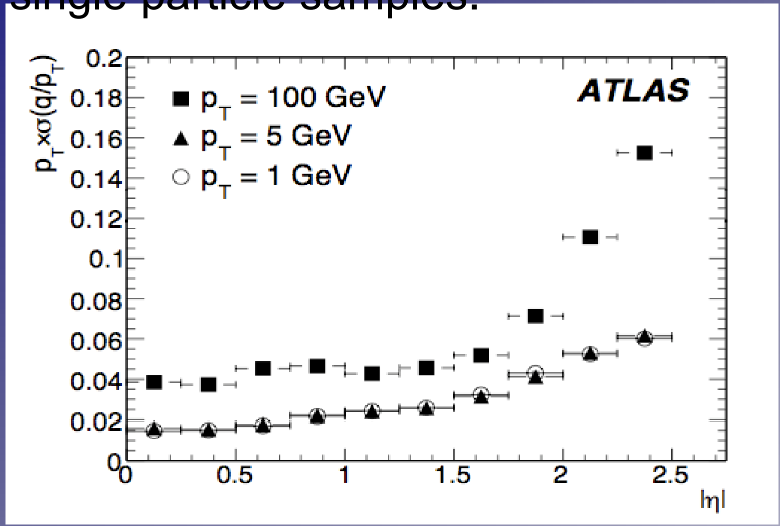
- Two algorithms that take advantage of different properties of the tau and the detector have been developed and their properties merged.

- A number of different discriminating algorithms have been developed that aim to increase the efficiency of selection and rejection power against QCD Jets.

- A program has been developed to take advantage of the first $100pb^{-1}$ of data to determine and improve the performance of the reconstruction and identification.

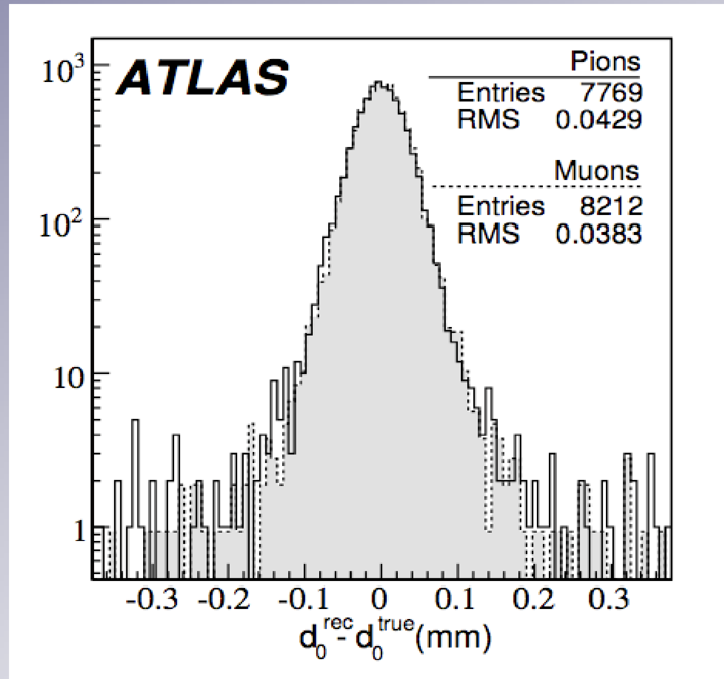
Back Up Slides

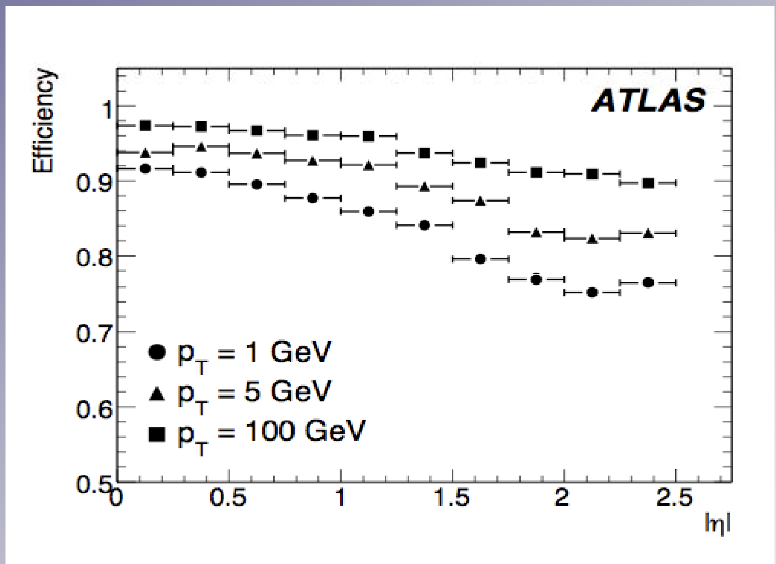
Some results to illustrate the expected tracking performance using simulated single particle samples.



The relative transverse momentum resolution for muons. (Only inner tracking) The graph for pions is identical.

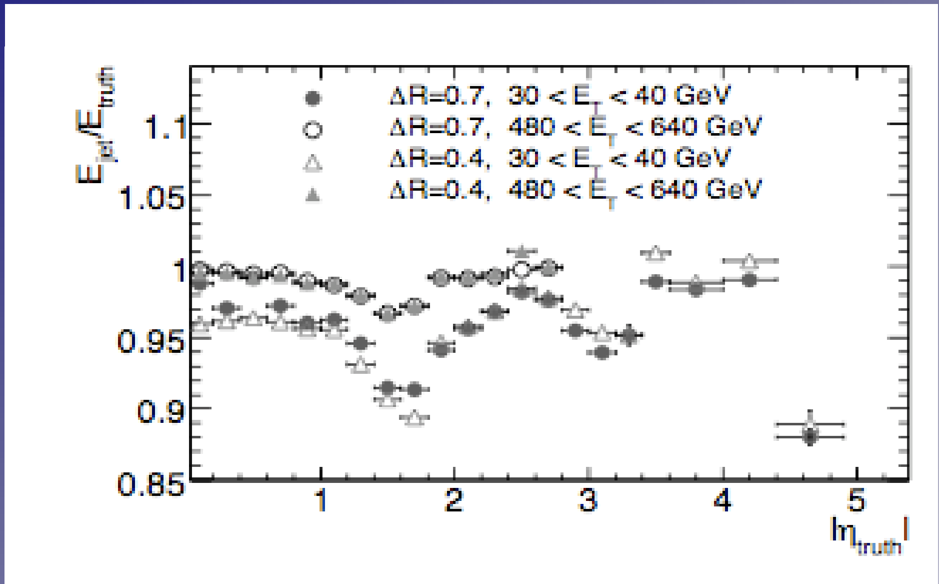
Transverse impact parameter resolution for primary single pions and muons.



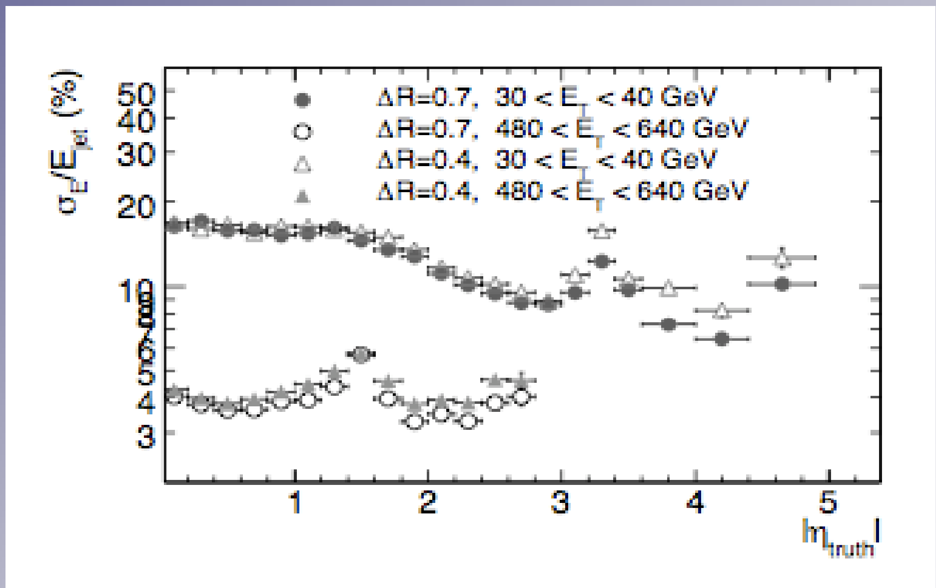


The efficiency of the track for pions of different Transverse momentum.

The simulated response of the calorimeter system for QCD jets:



The uniformity response of the calorimeter for two different cones and two transverse energy ranges.



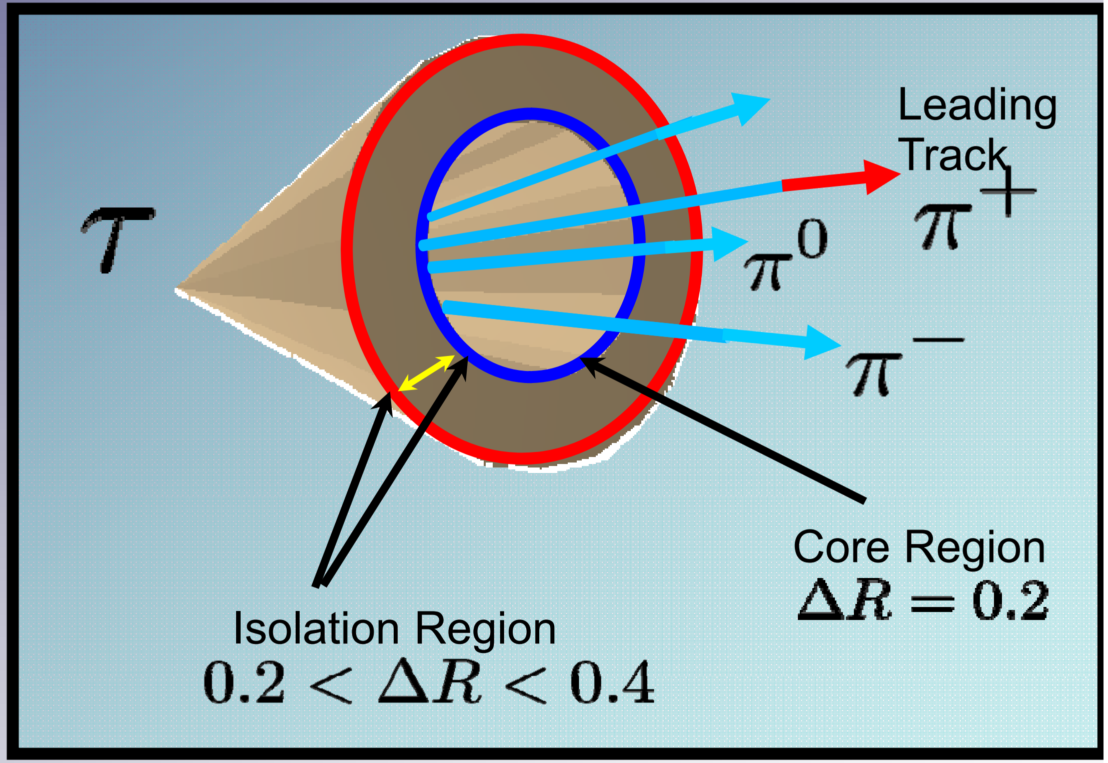
The resolution of the Jet energy for the same cone size and transverse energy range.

The information from both of these detectors Will provide the ingredients for the tau reconstruction.

Tau Reconstruction:

The reconstructed τs in ATLAS are classified into three categories according to their seed.

- Track Seeded.
- Calo Cluster Seeded.
- Track + Calo Cluster Seeded.



Track Seeded Philosophy:

The hadronic τ decay results in visible components such as charged and neutral pions that are well collimated.

1. A low track multiplicity region centered about the leading track that contains most of the tau's transverse energy.

- **This is referred to as the *core* region.**

2. An only a minimum amount of energy is deposited in an annulus around the core region.

- **This is referred to as the *isolation* region.**

Track Seeded Reconstruction Steps:

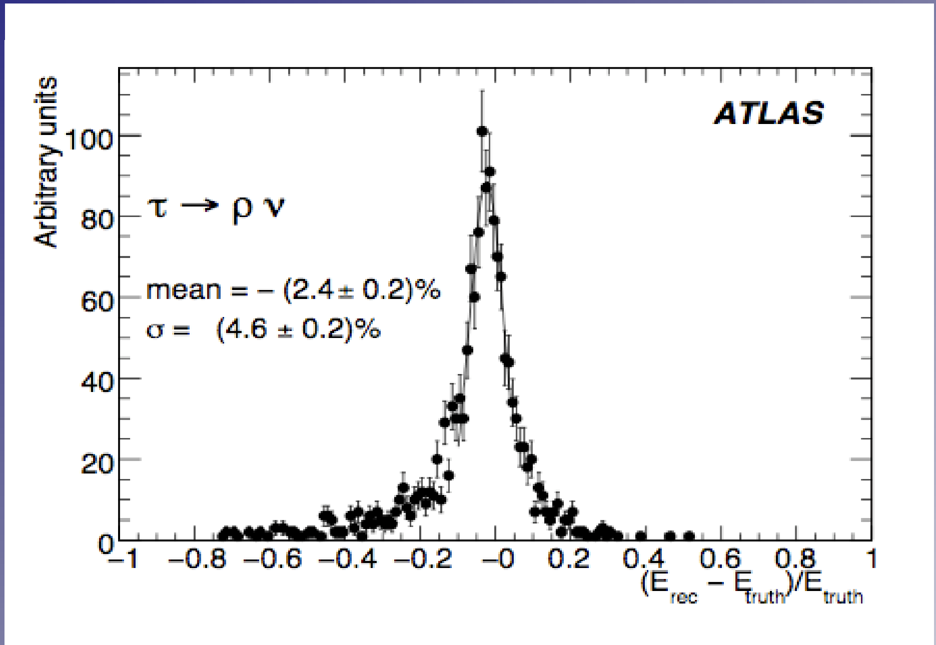
1. The seed is a track with a transverse momentum $P_T > 6GeV$
2. Selects 1 to 8 tracks within a $\Delta R = 0.2$ cone centred around the leading track.
3. Tracks need to posses (This also includes the leading track except for pt):
   - A $P_T > 1GeV$.
   - At least 18 Inner detector hits (At least 8 Silicon Hits and at least 10 TRT Hits)
   - An impact parameter $d_0 < 1mm$.
   - A χ^2/NDF less than 1.7 .
4. The energy scaled of the tau is defined by the energy flow algorithm.

$$E_T^{eflow} = E_T^{emcl} + E_T^{neuEM} + \sum p_T^{track} + \sum resE_T^{chrgEMtrk} + resE_T^{neuEM}$$

The contribution of the π^0 Is measured by the pure electromagnetic(EM) energy and the neutral electromagnetic energy.

The charged energy deposited on the EM and Hadronic Calorimeter is replaced by the momenta of the tracks.

These are correction terms. The first is for neutral leakage into the cells of the charged hadrons. Second is double counting of EM leakage of the charged hadron.



The visual energy resolution of the τ that includes one π^0 subcluster.

This was obtained using candidates Reconstructed with the track seeded Algorithm.

The reconstructed tau with both seeds has the best of worlds:

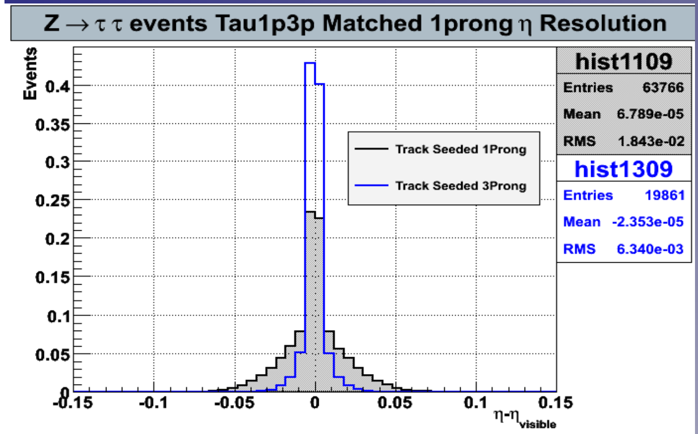
- The initial seed is a good quality tracks, $P_T > 6GeV$.
- The candidate needs 1-8 tracks within the ΔR < 0.2 cone and have a $P_T > 1GeV$.
- Eta and Phi are calculated using the tracks weighted by the Pt.
- The charge is checked to be |q|<= 2.
- Find the matching topojet (Cone 4) which is > 10GeV and ΔR < 0.2 .
- Transverse energy is calculated using Calorimeter information (H1 Calibration).
- Transverse energy is calculated using the Energy Flow algorithm.
- Pi0 clusters are constructed.

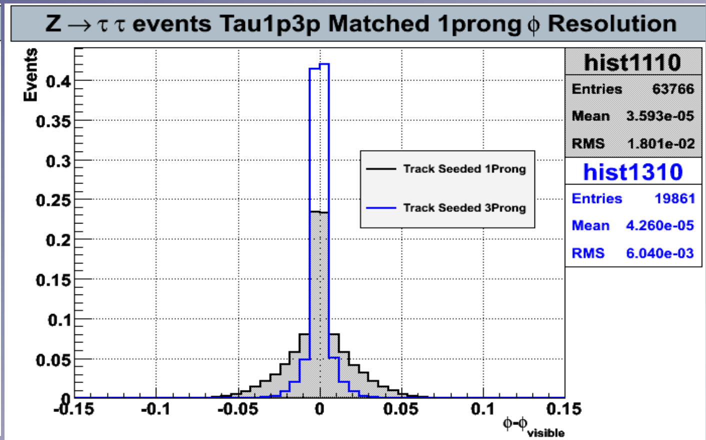
The electromagnetic Radius:

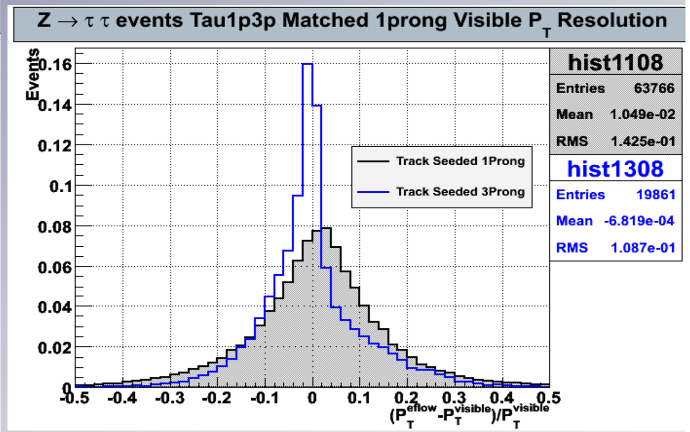
$$R_{\mathrm{em}} = \frac{\sum_{i=1}^{n} E_{T,i}\sqrt{(\eta_i - \eta_{\mathrm{cluster}})^2 + (\phi_i - \phi_{\mathrm{cluster}})^2}}{\sum_{i=1}^{n} E_{T,i}},$$

Resolution for Track and Calo Seeded:

Track Seeded Resolution







Calo Seeded Resolution