Tau reconstruction with 7 TeV pp collisions in ATLAS

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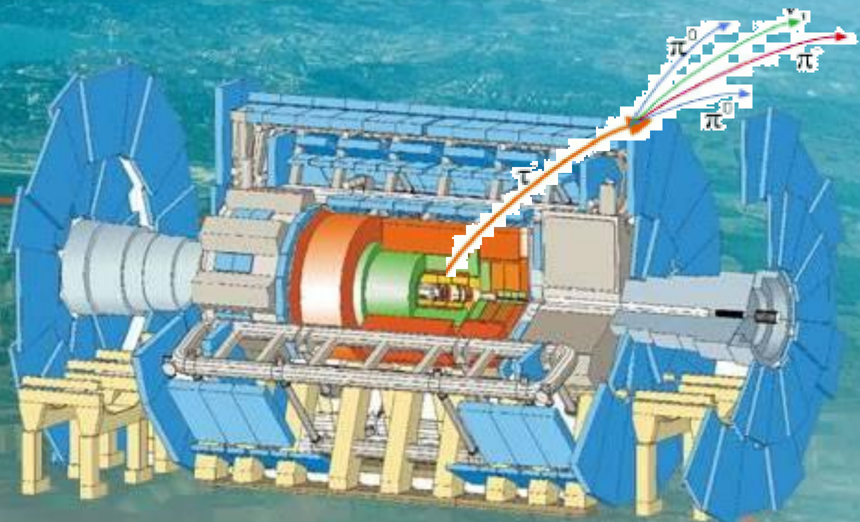


The 11th International
Workshop on Tau Lepton Physics
Manchester, UK, 13-17 Sep 2010

Why we are interested in taus?

Tau leptons play an important role in the physics program of the ATLAS experiment as they are „tools" in many areas

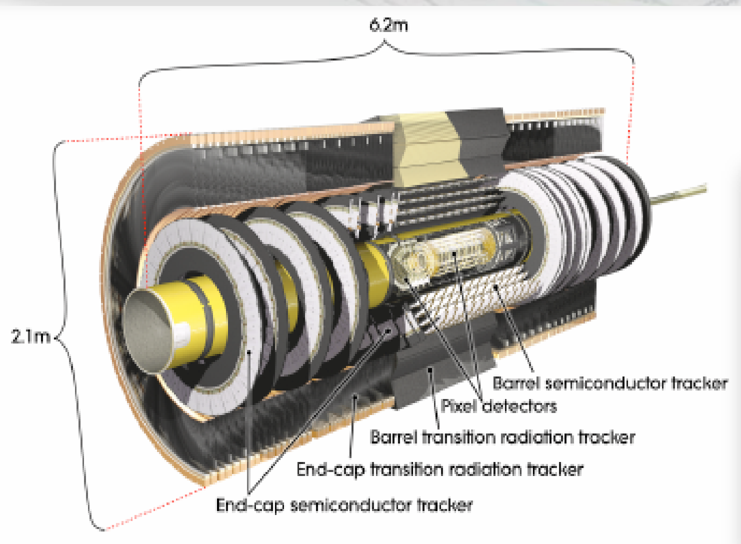
- Tau leptons provide useful signatures in searches for new phenomena like
  - Higgs bosons
  - Supersymmetry
  - Exotics scenarios

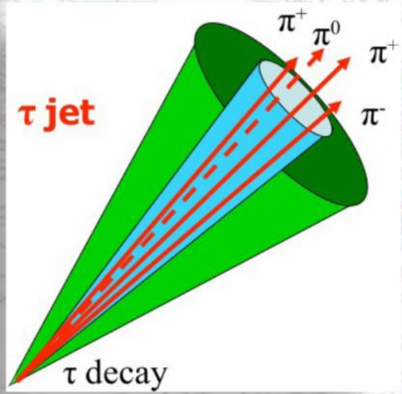
see talks by Dorthe Ludwig and Ricardo Goncalo

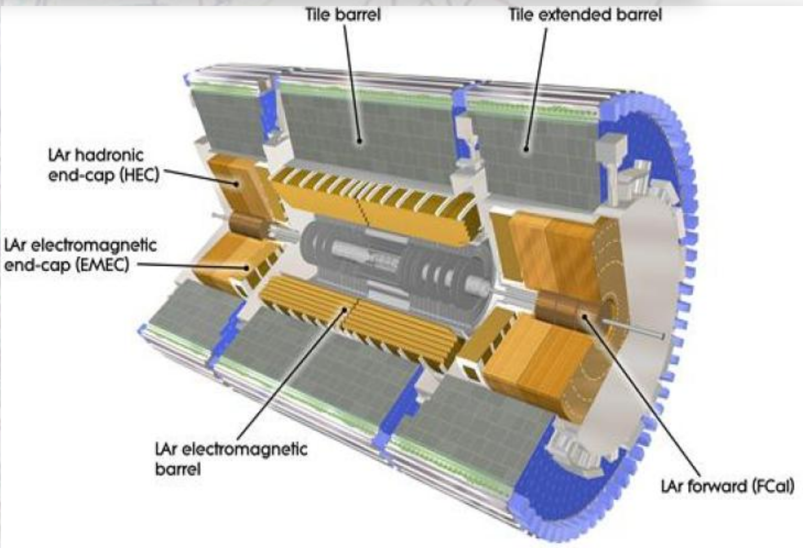
- Standard Model processes with taus in final states will be also the key
  - to understand the detector (for example $Z \rightarrow \tau\tau$ as golden channel)
  - Measurement of Z/W production with taus in final states
    - interesting itself as first time at so high energy
    - background to New Physics searches

Detector ingredients for tau identification

- Because of short lifetime, it is difficult to separate tau decaying to e/μ from prompt e/μ
  - we focus on reconstruction of hadronic decays of tau leptons
- Identifying hadronically decaying tau leptons requires good understanding of the detector performance, combining the calorimeter and tracking detectors.







Tracking System

- Low track multiplicity
  - 1 or 3 charged decay products ($\pi^{\pm}$)
- Collimated object and isolation from other tracks
- Modest but significant proper lifetime ($c\tau$ = 87.11 μm) -> displaced secondary vertex

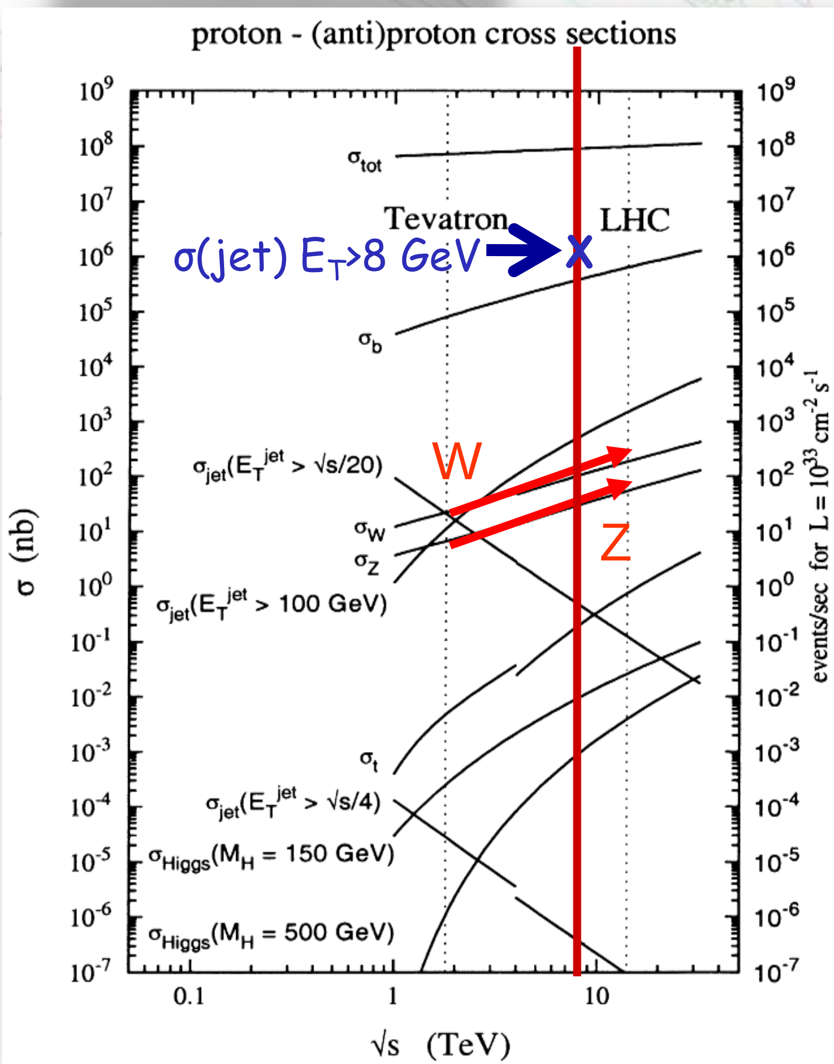
Calorimetry

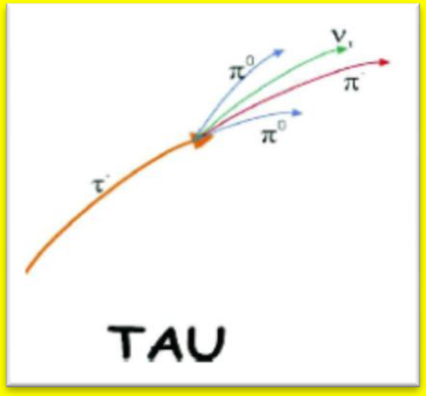
- Collimated and isolated energy deposit in both EM and HAD calorimeters
- Strong EM component
  - possibility to identify π^0 clusters

Main sources of fake taus

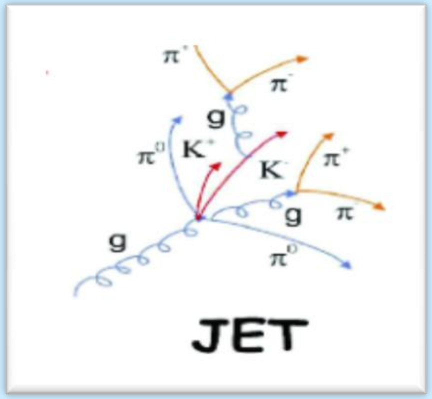
- QCD jets
- Electrons
- Muons

Main challenge: separate out a clean sample of taus from the overwhelming QCD jet rate!





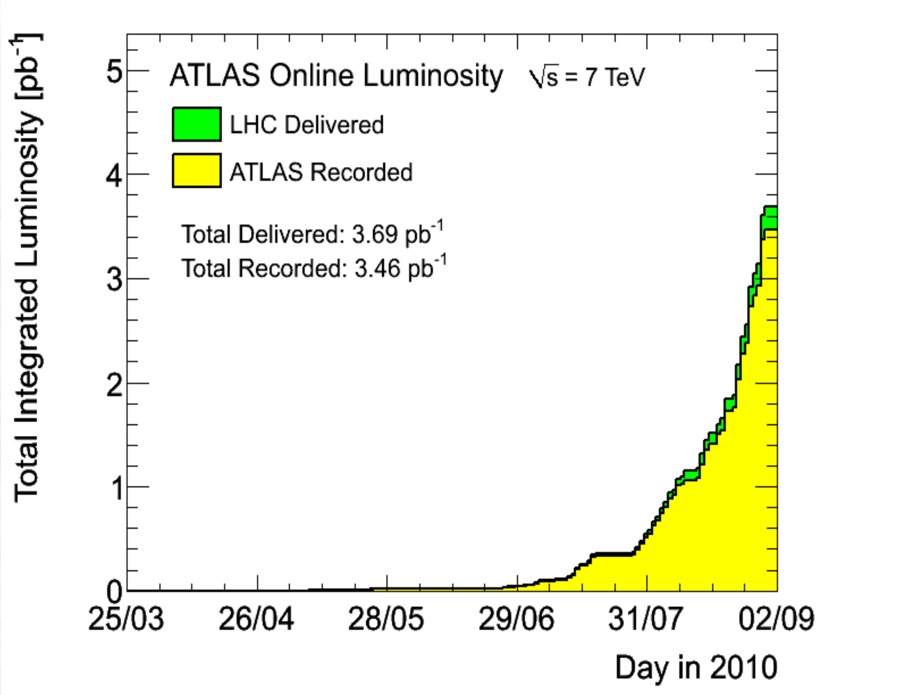
- narrow, collimated
- 1 or 3 tracks
- can define isolation regions with low activity
- leading track carries much of tau momentum



- wide
- can have many tracks
- isolation regions busy
- jet momenta spread over tracks

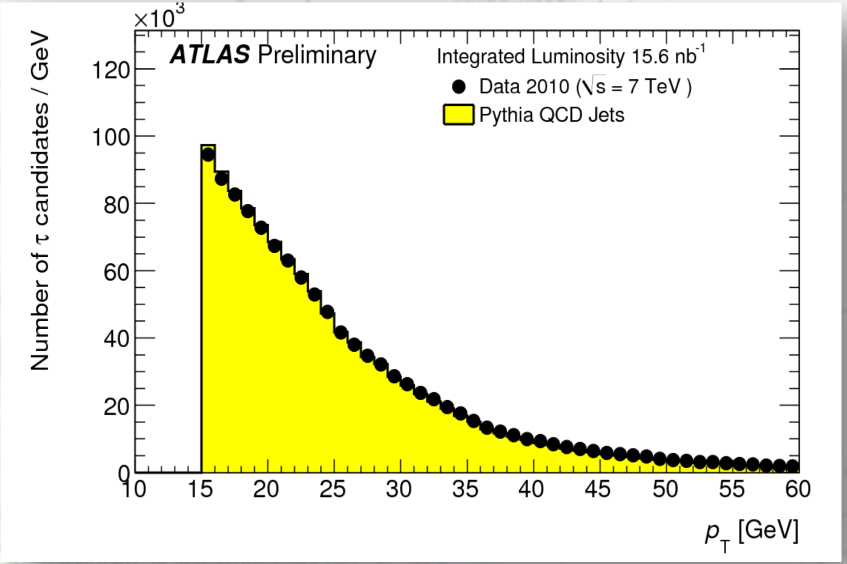
Disclaimer

- ATLAS detector has so far recorded several pb^{-1}'s of data
- But all plots I can show you today have been prepared with data taken up to mid-July 2010 ($L \approx 244\ nb^{-1}$ for majority of plots)
- This dataset has been used to study the reconstruction and identification algorithms for hadronic tau decays
  - No real tau leptons are expected to be observed in this dataset
  - But identification variables for QCD jets reconstructed as tau candidates can be compared to predictions from Monte Carlo simulations
- There are many studies ongoing to find real taus coming from W and Z decays in full statistics of data recorded by ATLAS
  - Stay tuned for new results!

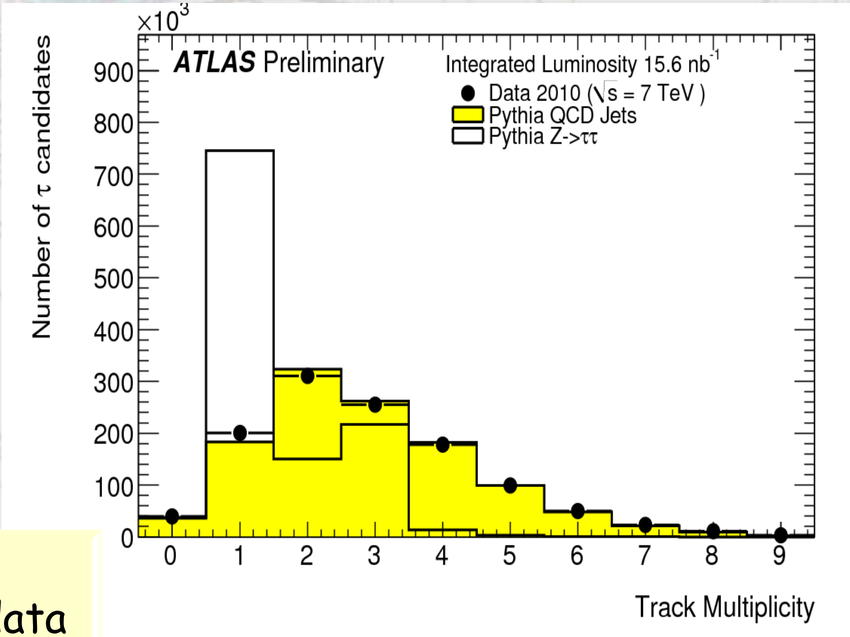


Tau Reconstruction Algorithm

Hadronically decaying taus are reconstructed from:
- Track seeds good quality track with p_T>6 GeV
- Calorimeter seeds: topologically clustered jets with p_T > 10 GeV
- Candidates can be double-seeded when ΔR(seeds) < 0.2



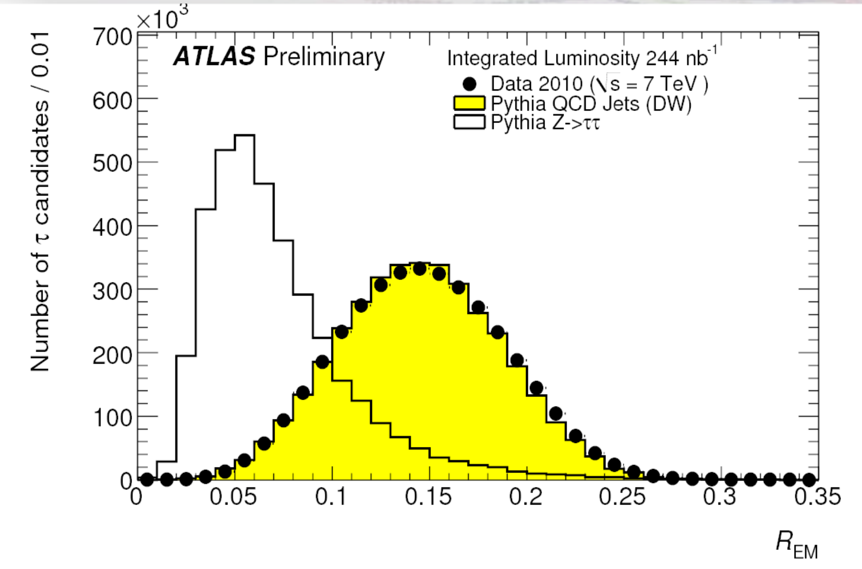
- **Energy** of tau candidates calculated using both
  - Calorimeter cell weighting dependent on energy density (calorimeter seeded)
  - Energy-flow method separating charged and neutral sources of energy (track seeded)
- **Direction** of tau candidates is derived from
  - p_T weighted track directions (track seed)
  - E_T barycentre of cells (calorimeter seed)
- **Track multiplicity** and **charge** from associated quality tracks within a cone of ΔR<0.2
- The π^0 decay products reconstructed using EM topological clusters



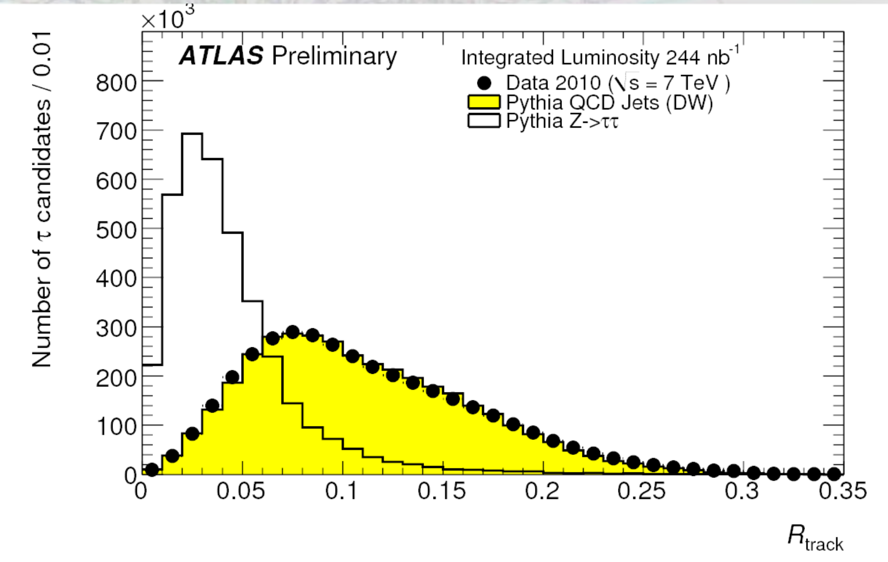
For all plots: the number of tau candidates in MC are normalized to the number of tau candidates selected in data

Tau Identification Methods

- Reconstruction of tau candidates provides very little rejection against QCD jets
  - Thus we apply separate identification step based on several discriminating variables
- Identification methods for tau candidates include selections based on simple cuts, boosted decision trees, and projective likelihood methods
  - Identification variables used for these methods have shown good tau/jet separation potential in MC studies
- Variables that are used in the identification of tau leptons with early data include:

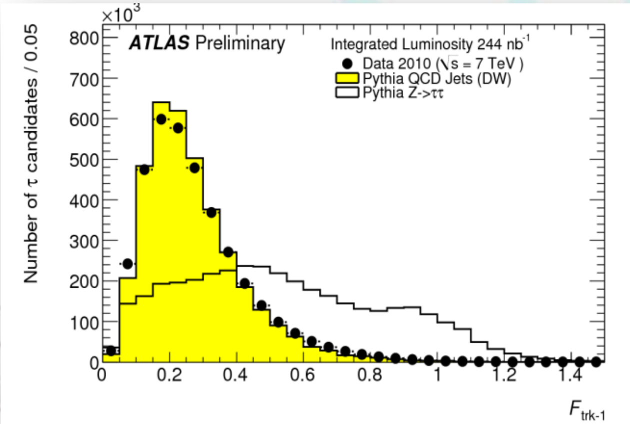


Electromagnetic radius: E_T weighted shower width in EM Calo

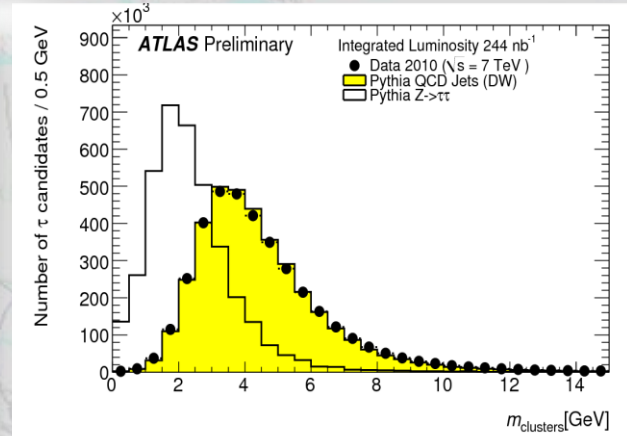


Track radius: p_T weighted track width

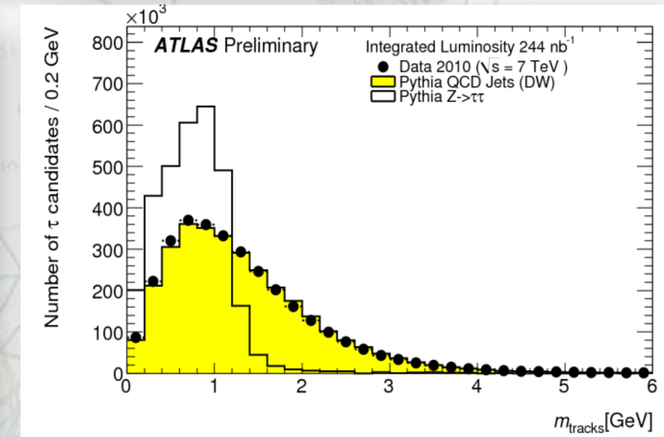
Tau/jet discriminating variables



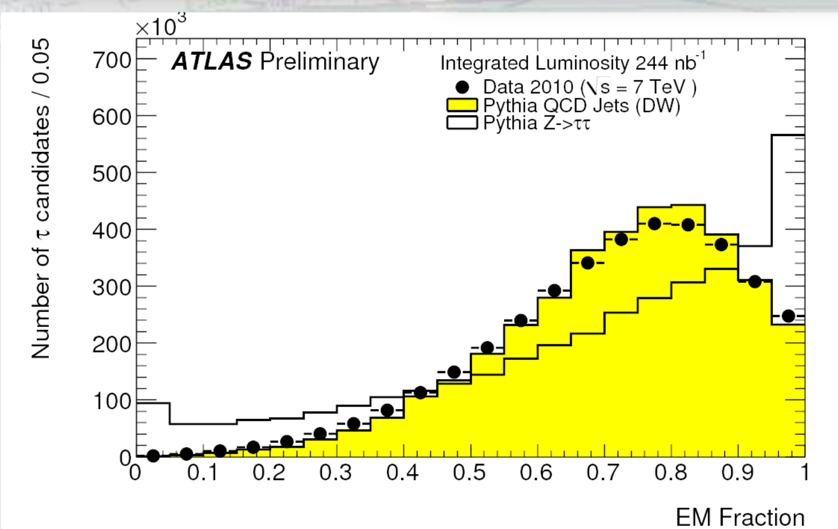
Leading track momentum fraction



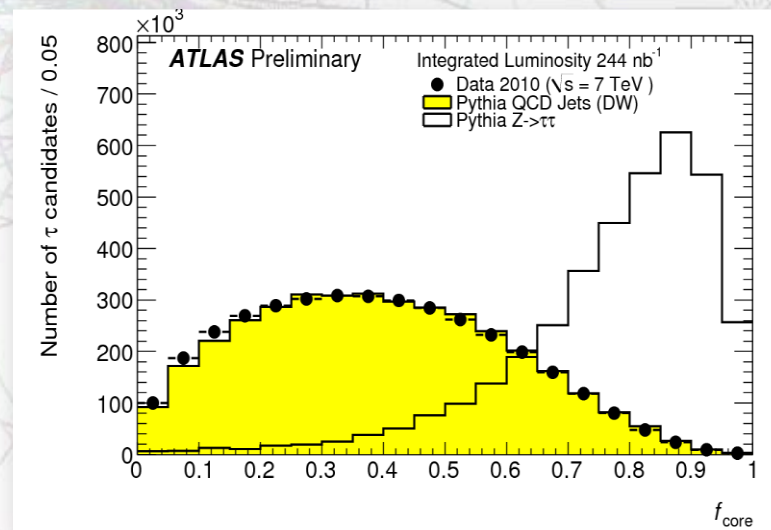
Cluster mass: Invariant mass computed from associated topological clusters



Track mass: Invariant mass of the track system



Electromagnetic fraction: fraction of calibrated E_T deposited in EM Calo



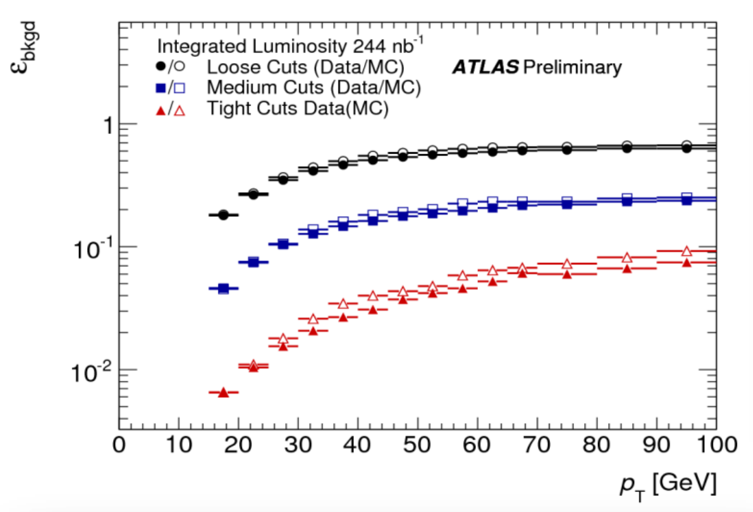
Core energy fraction: fraction of transverse energy in the core ($\Delta R<0.1$)

Background rejection in QCD events

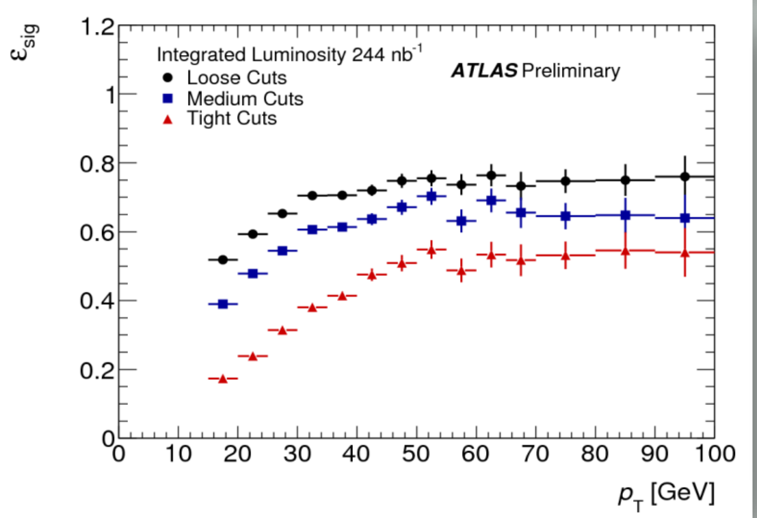
- The cut-based ID uses three variables: electromagnetic and track radius and leading track momentum fraction
- Three selections according to signal efficiencies of 30% (tight), 50% (medium) and 60% (loose) are optimized.
- Different cuts applied for tau candidates with $N_{track} = 1$ and $N_{track} \geq 2$.

signal efficiency $\varepsilon_{sig} = \frac{N^{\tau}_{pass,match}}{N^{\tau}_{match}}$,

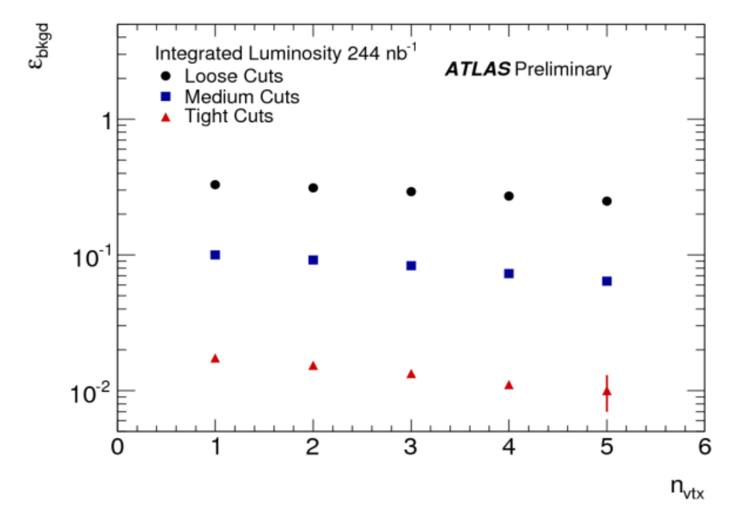
background efficiency $\varepsilon_{bkgd} = \frac{N^{bkgd}_{pass}}{N^{bkgd}_{total}}$,



Background efficiencies for data and MC samples as a function of reconstructed $p_T(\tau)$

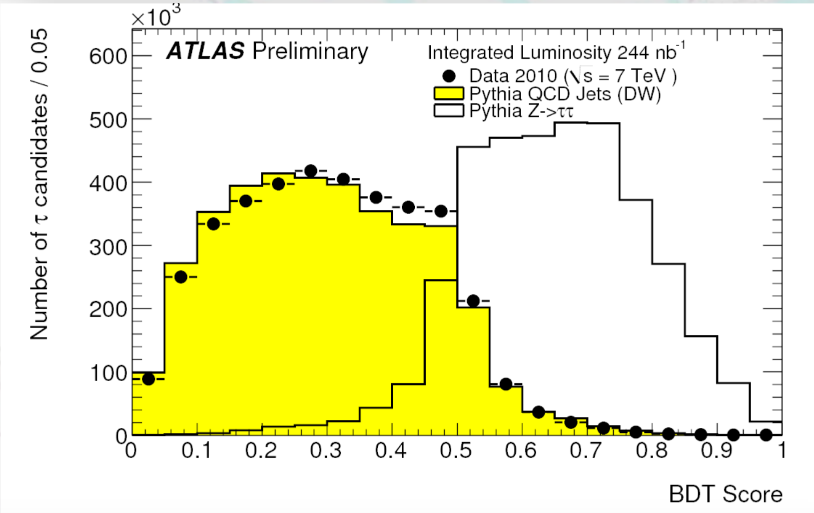


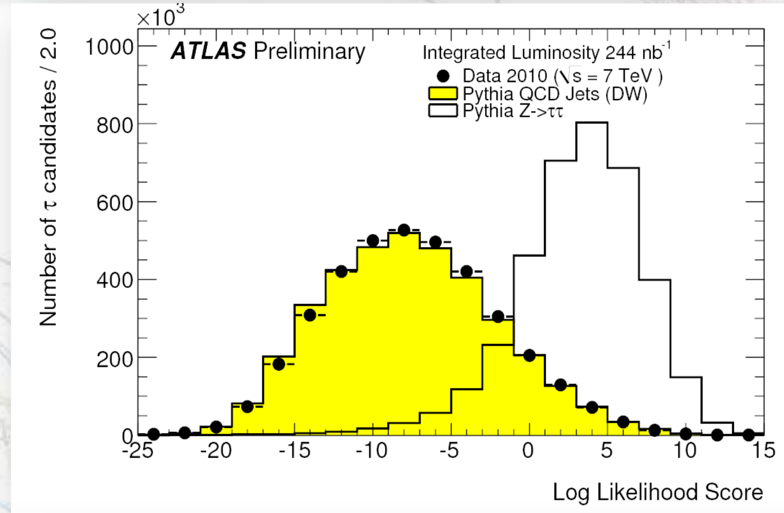
Signal efficiencies predicted by $Z \rightarrow \tau\tau$ MC sample as a function of reconstructed $p_T(\tau)$

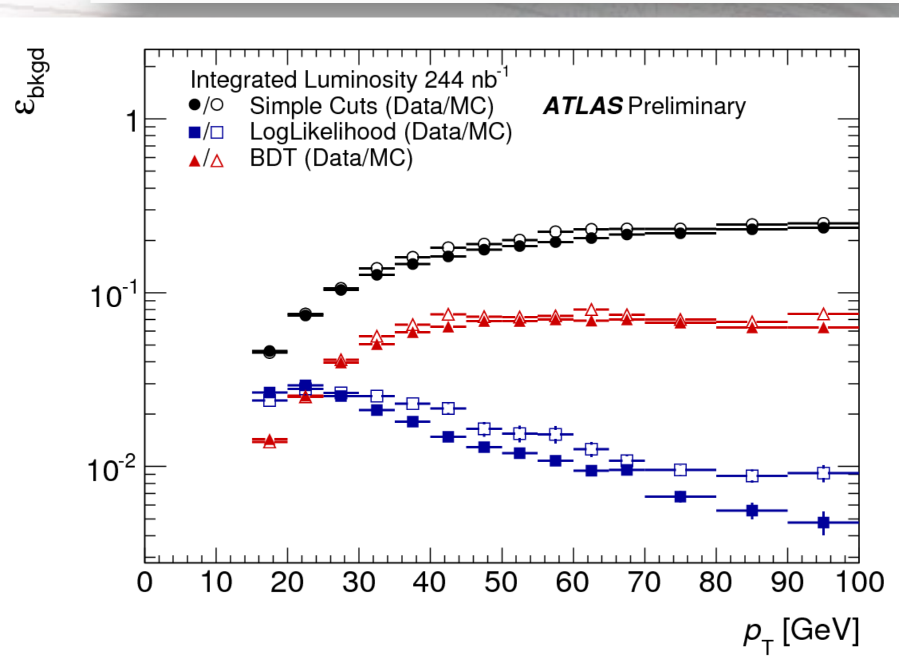


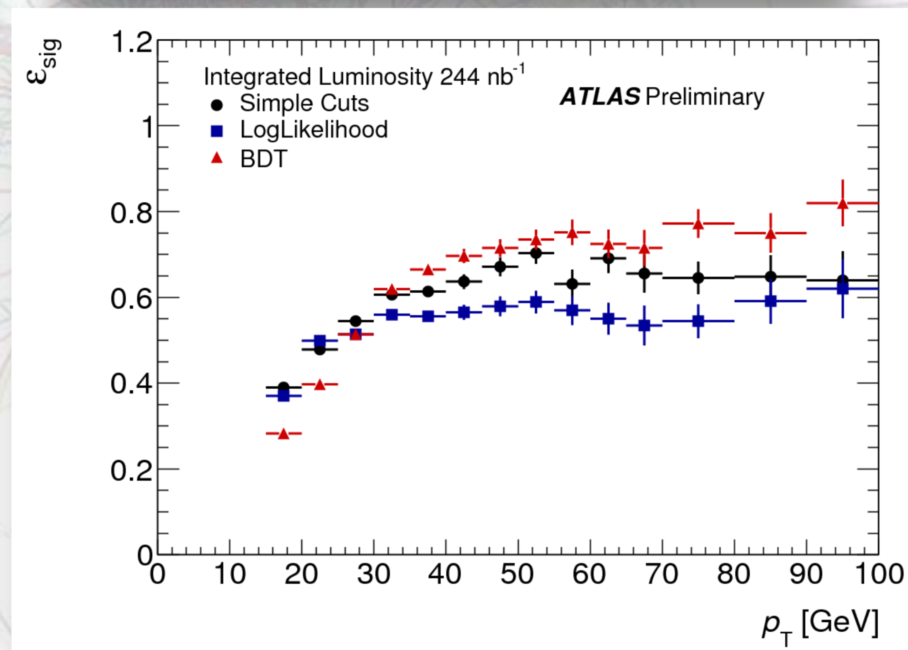
Background efficiencies as a function of the number of vertices => robustness of the simple cut ID against the presence of pile up

BDT and LL methods





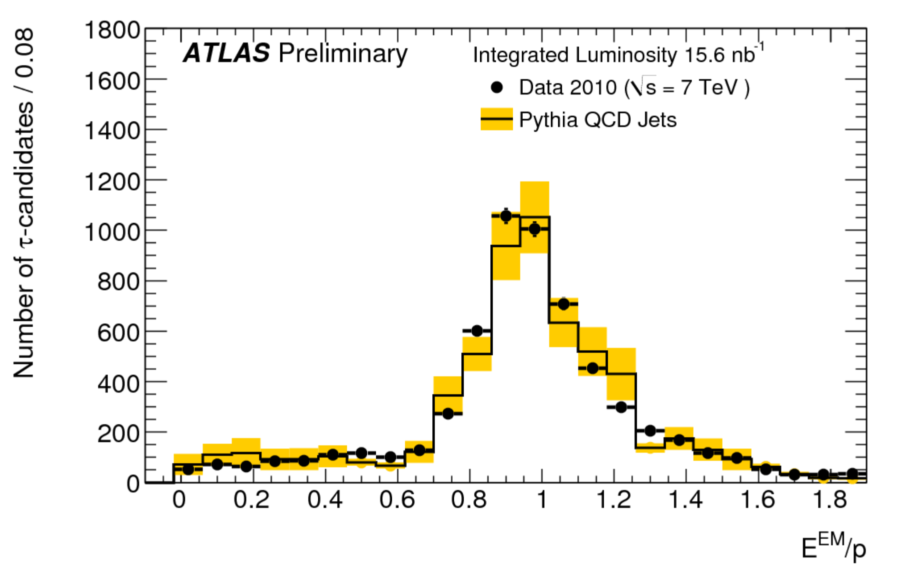




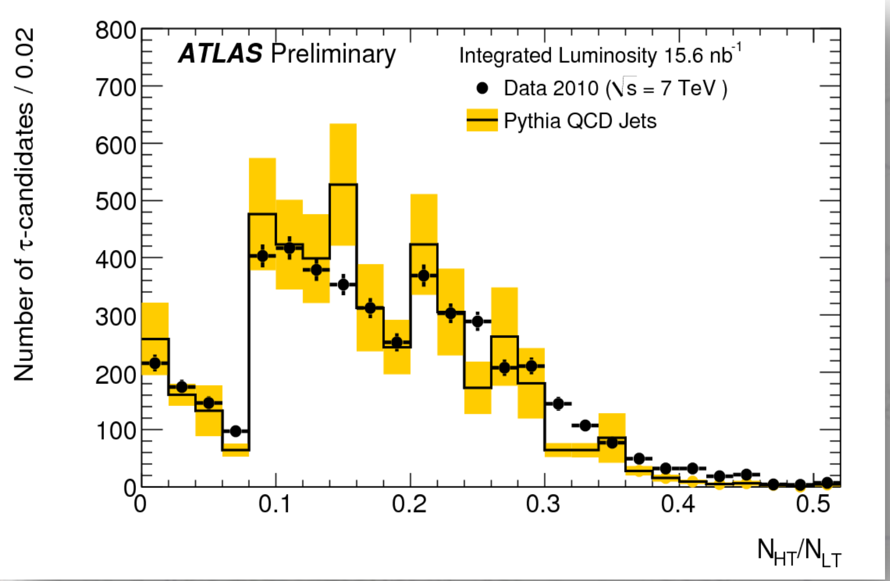
- Background eff. from Data/MC as function of reconstructed p_T for medium selection
- Signal efficiency from $Z \rightarrow \tau\tau$ MC as function of reconstructed p_T for medium selection

Electron Veto Algorithm

- Rejection of isolated electrons from W->eν and Z->ee etc processes
- Suppress electrons with a dedicated algorithm
- Several variables are used to distinguish tau leptons from electrons
- The following are the two most important:



Ratio of EM energy in a narrow window around the impact cell to the leading track momentum for tau candidates identified as electrons by standard ele ID

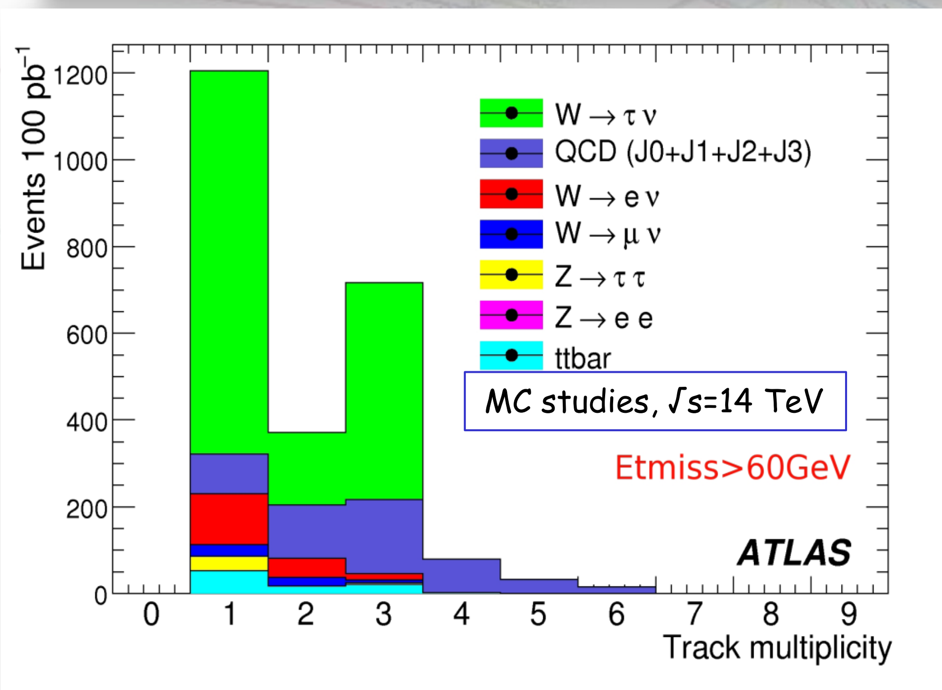


Ratio of high threshold to low threshold hits in the Transition Radiation Tracker for tau candidates identified as electrons by standard ele ID

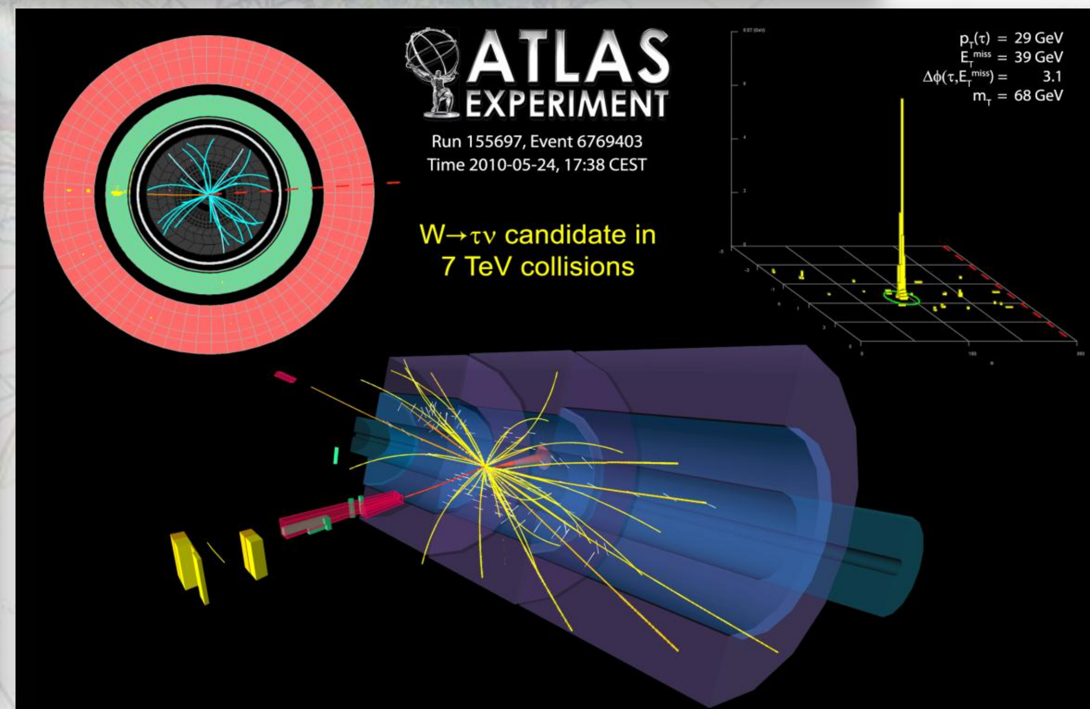
- From MC studies: the algorithm yields rejection factor of ~100 against electrons from W at the expense of losing few % of the signal W->τν events.

W→τ ν channel

- First source of observed tau leptons in ATLAS !
  - cross-section: σ x BR = 10.46 x 10^3 pb, 10x larger than Z→ττ
- But very challenging channel due to lack of additional lepton like in Z channel and tau produced with low momenta
- Trigger: tau-lepton and the missing energy trigger
- Main Backgrounds: W→eυ, W→μυ, Z→ττ, Z→ee, top pairs, multi-jets



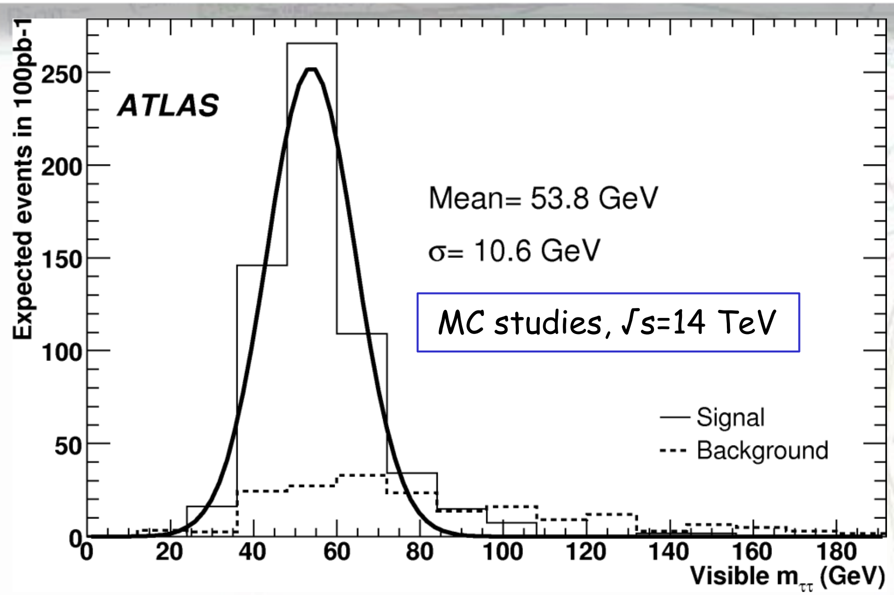
The track multiplicity spectrum of tau candidates after analysis selection with E_T^{miss} > 60 GeV. Numbers given for 100 pb^{-1}.



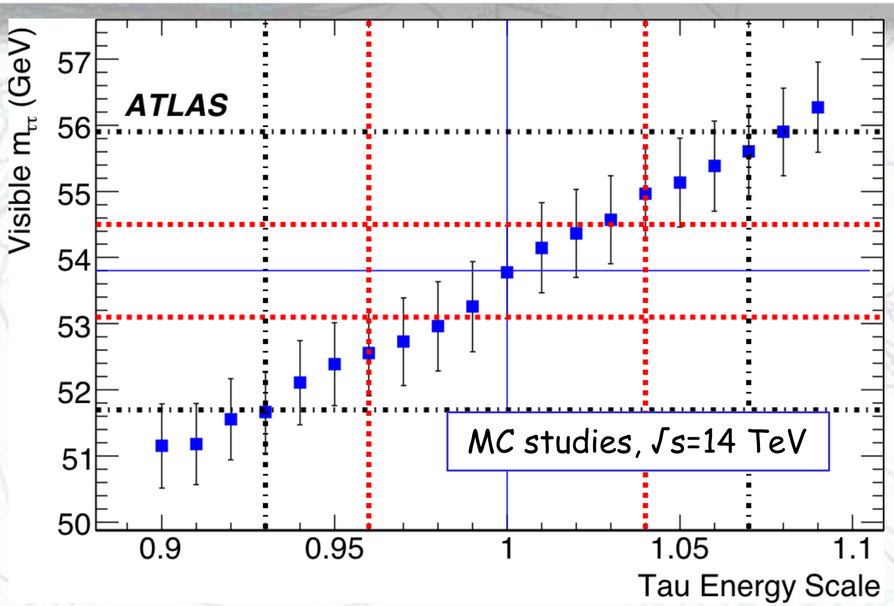
Event display of a W → τnu candidate collected on 24 May 2010
-> first observed tau candidate in ATLAS

$Z \rightarrow \tau(lep)\tau(had)$ channel

- Our golden channel for taus
  - Triggered on one tau decaying leptonically gives us unbiased sample of tau leptons
  - Control sample for understanding tau ID and tau trigger efficiency with data
- The visible mass distribution of the $Z\rightarrow\tau\tau$ products can be used to evaluate the energy scale for the tau leptons
- The invariant mass of $Z\rightarrow\tau\tau$ products can be reconstructed using the missing energy information and should peak at well measured Z mass
  - peak of distribution gives us a handle on the missing energy scale
- Main Backgrounds: W+jets, Z+jets, multi-jet production, top pair production



Reconstructed visible mass of the (l tau) pair for Z->ττ decays and QCD, W->lν, Z->ll backgrounds



Reconstructed visible mass of the (l tau) pair from Z->ττ decays as a function of the tau energy scale

Conclusions

- The ATLAS collaboration has developed robust tau reconstruction and identification algorithms

- Although the dataset used for presented plots corresponds only to an integrated luminosity of 244 nb^{-1}, and contains a small number of real tau leptons, the QCD jets reconstructed as tau candidates could be used to study performance of these algorithms
  - Identification variables are compared in data and Monte Carlo samples, and the background efficiency of cut-based and multi-variate identification is measured in data sample of QCD jets.
  - Good agreement is observed between data and the fake tau candidates from simulated QCD jet events
    - this gives us confidence in the performance of the algorithms on real tau leptons, to be observed soon.

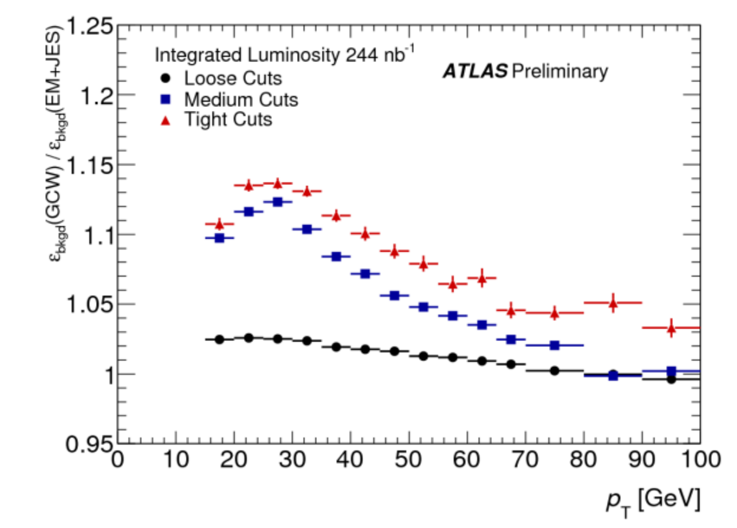
- The ATLAS physics program with taus is very extensive
  - At first SM channels (W, Z, top pairs) will provide invaluable feedback for the existing tau reconstruction algorithms - results to come very soon
  - Then many exciting physics possibilities beyond the Standard Model that involve tau lepton final states
    - see talks by Dorthe Ludwig and Ricardo Goncalo

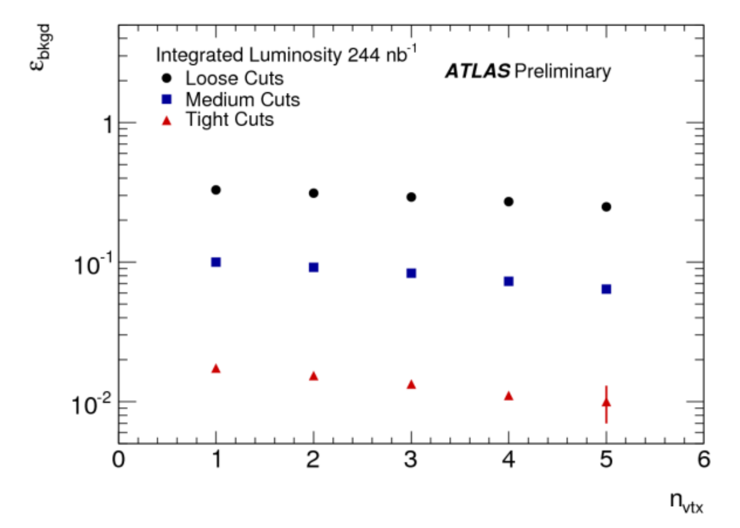
Additional slides for curious kids

Tau ID results and systematics

Two effects contribute to systematic uncertainties:

- The transverse momentum calibration: two calibration schemes compared:
  - Global cell energy-density weighting (GCW), ATLAS default
  - Simple *pT and η dependent calibration (EM+JES)*
- Pile-up effects since beam intensity has increased by a factor of 3 during the data taking period





Selection	ε_{bkgd} (data)	ε_{bkgd} (MC)	ε'_{bkgd} (data)	ε'_{bkgd} (MC)
loose	$(3.2 \pm 0.2) \times 10^{-1}$	3.4×10^{-1}	$(9.4 \pm 0.6) \times 10^{-2}$	10×10^{-2}
medium	$(9.5 \pm 1.0) \times 10^{-2}$	9.9×10^{-2}	$(3.1 \pm 0.4) \times 10^{-2}$	3.3×10^{-2}
tight	$(1.6 \pm 0.3) \times 10^{-2}$	1.9×10^{-2}	$(5.6 \pm 0.9) \times 10^{-3}$	6.8×10^{-3}

An alternative background efficiency, that requires in addition that candidates must have *ntrack = 1 or ntrack = 3,*

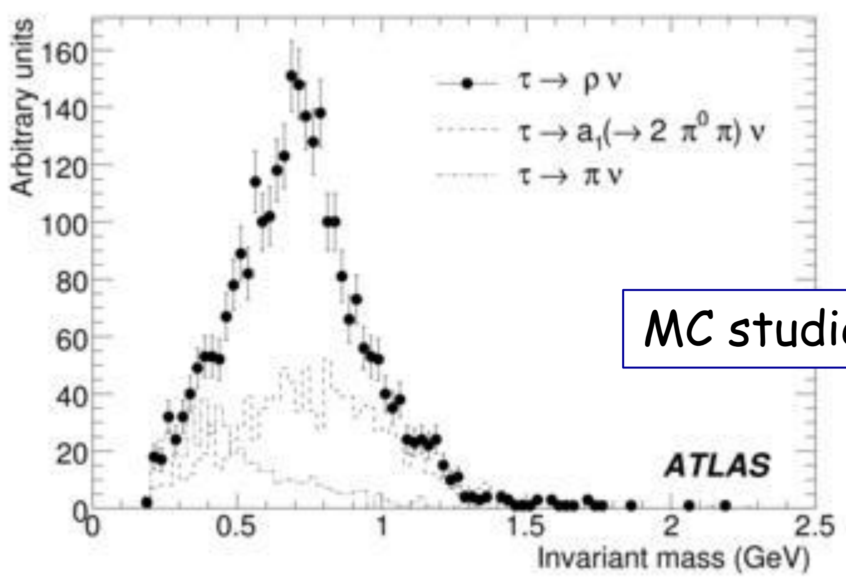
Reconstruction of π^0 subclusters

- High granularity of ATLAS electromagnetic calorimeter allows reconstruction of isolated subclusters from pi0s
- This allow to distinguish between different decay modes of tau leptons

Single prong candidates: fractions with zero, one and two or more reconstructed π^0 subclusters.

decay mode	no π^0 subclusters	1 π^0 subcluster	$\geq 2\ \pi^0$ subclusters
all $\tau \to$ hadν	32%	35%	33%
$\tau \to \pi\nu$	65%	20%	15%
$\tau \to \rho\nu$	15%	50%	35%
$\tau \to a_1(\to 2\pi^0\pi)\nu$	9%	34%	57%

MC studies



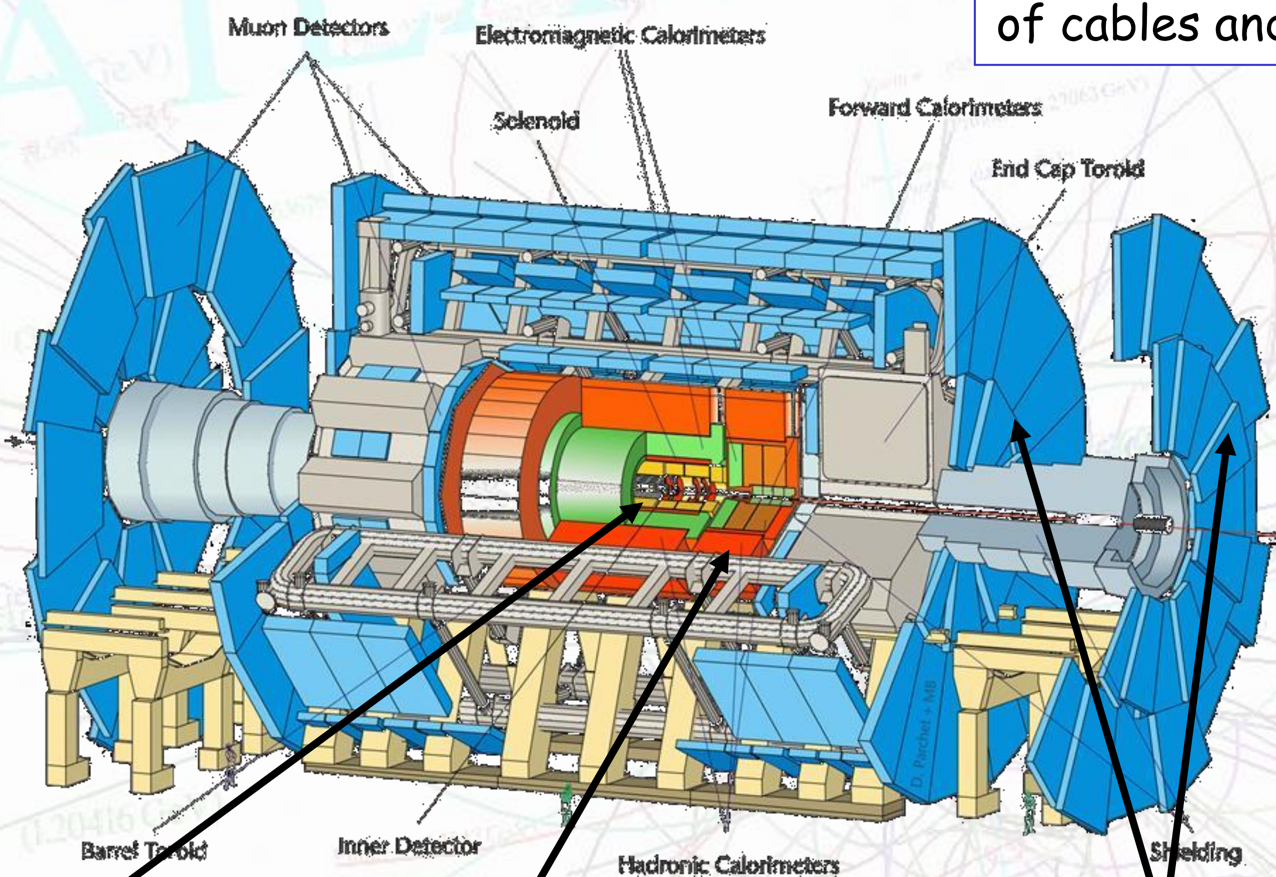
MC studies

The invariant mass of the visible decay products for hadronic single-prong $\tau \to \rho\nu$, $\tau \to a_1$ ($\to 2\ \pi^0\ \pi$) ν, and $\tau \to \pi\nu$ decays using candidates from $W \to \tau\nu$ events with at least one π^0 subcluster reconstructed

ATLAS – A Toroidal LHC ApparatuS

25m diameter, 46m long, weighing 7000T, with 3000km of cables and 10^8 channels

p 7TeV



p 7TeV

Tracking ($|\eta|<2.5$, B=2T):
- Silicon pixels and strips
- Transition Radiation Tracker

σ/PT=0.05% PT + 1%
(2%@20GeV)
σ(d0)=15 um@20 GeV

Calorimetry ($|\eta|<5$)
EM : Pb-LAr
HAD: Fe/scintillator (central), Cu/W-LAr (fwd)

EM : $\sigma(E)/E = 10\%/\sqrt{E} + 0.7\%$

Hadron : $\sigma(E)/E = 50\%/\sqrt{E} + 3\%\ (\eta < 3)$

$\sigma(E)/E = 100\%/\sqrt{E} + 10\%\ (\eta > 3)$

Muon spectrometer ($|\eta|<2.7$, B=4T max)
Toroid magnet system with precision and trigger chambers

σ/PT=2-7%

Tau/jet discriminating variables

Cluster mass: Invariant mass computed from associated topoclusters: m_{clusters}.

Track mass: Invariant mass of the track system: m_{tracks}.

Track radius: p_{T} weighted track width:

$$R_{\text{track}} = \frac{\sum_i^{\Delta R_i<0.2} p_{\text{T},i}\Delta R_i}{\sum_i^{\Delta R_i<0.2} p_{\text{T},i}},$$

where i runs over all tracks associated to the τ candidate, ΔR_i is defined relative to the τ jet seed axis and $p_{\text{T},i}$ is the track transverse momentum.

Leading track momentum fraction:

$$f_{\text{trk},1} = \frac{p_{\text{T},1}^{\text{track}}}{p_{\text{T}}^{\tau}},$$

where $p_{\text{T},1}^{\text{track}}$ is the transverse momentum of the leading track of the τ candidate and p_{T}^{τ} is the transverse momentum of the τ candidate.

Tau/jet discriminating variables

Electromagnetic radius: Transverse energy weighted shower width in the electromagnetic (EM) calorimeter:

$$R_{\mathrm{EM}} = \frac{\sum_i^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}} \Delta R_i}{\sum_i^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}}},$$

where i runs over cells in the first three layers of the EM calorimeter associated to the τ candidate, ΔR_i is defined relative to the τ jet seed axis and $E_{\mathrm{T},i}^{\mathrm{EM}}$ is the cell transverse energy.

Core energy fraction: Fraction of transverse energy in the core ($\Delta R < 0.1$) of the τ candidate:

$$f_{\mathrm{core}} = \frac{\sum_i^{\Delta R<0.1} E_{\mathrm{T},i}}{\sum_i^{\Delta R<0.4} E_{\mathrm{T},i}},$$

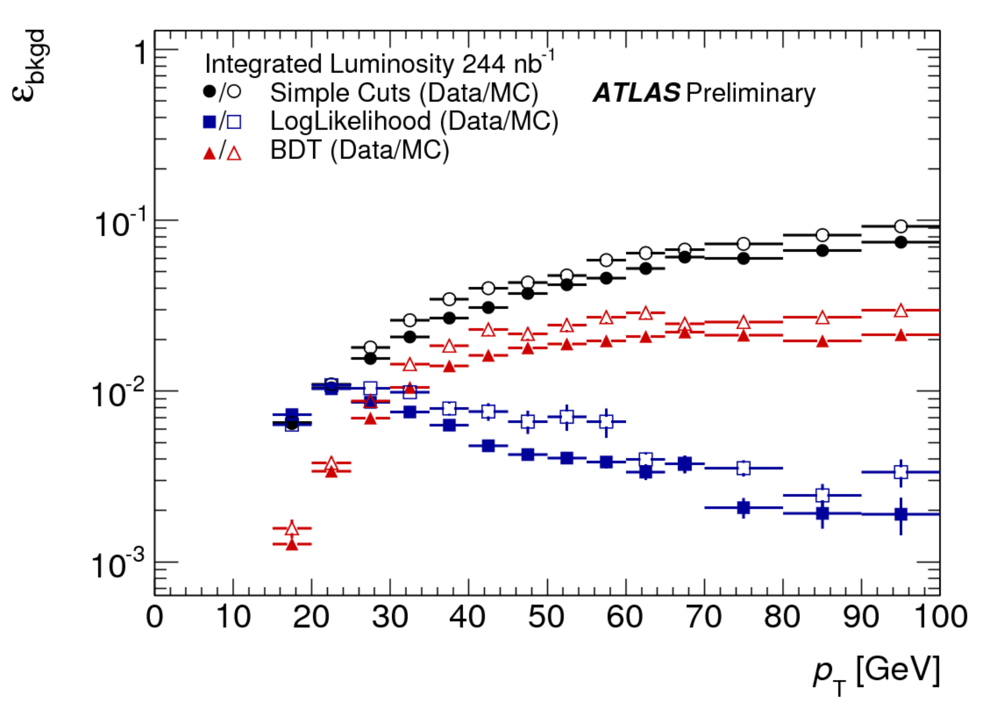
where i runs over all cells associated to the τ candidate within ΔR_i of the τ jet seed axis.

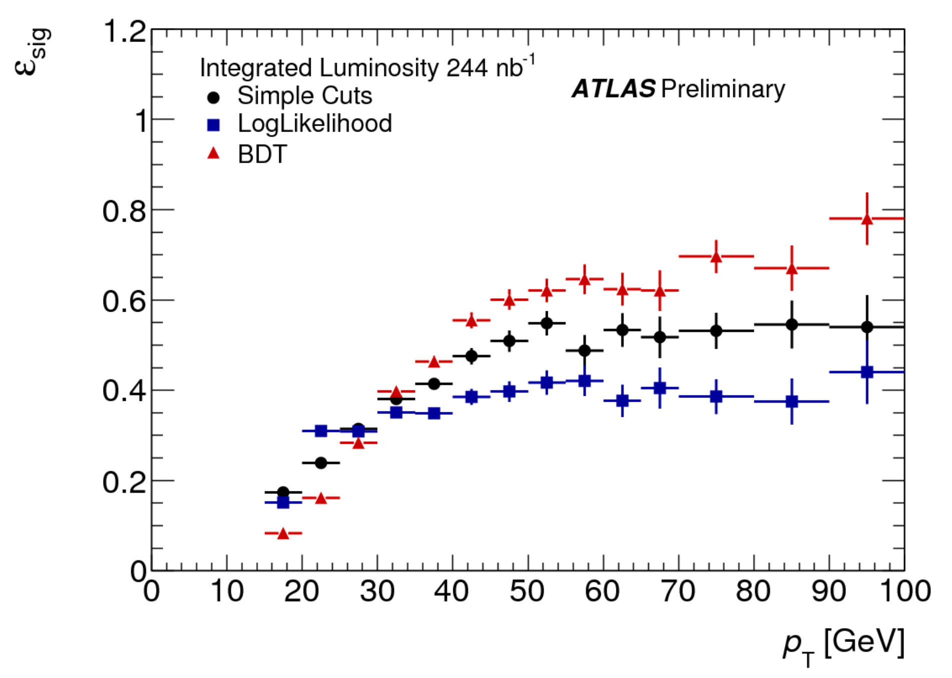
Electromagnetic fraction: Fraction of GCW calibrated transverse energy of the τ candidate deposited in the EM calorimeter:

$$f_{\mathrm{EM}} = \frac{\sum_i^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{GCW}}}{\sum_j^{\Delta R_i<0.4} E_{\mathrm{T},j}^{\mathrm{GCW}}},$$

where $E_{\mathrm{T},i}$ ($E_{\mathrm{T},j}$) is the GCW calibrated transverse energy deposited in cell i (j), and i runs over the cells in the first three layers of the EM calorimeter, while j runs over the cells in all layers of the calorimeter.

BDT and LL methods - tight



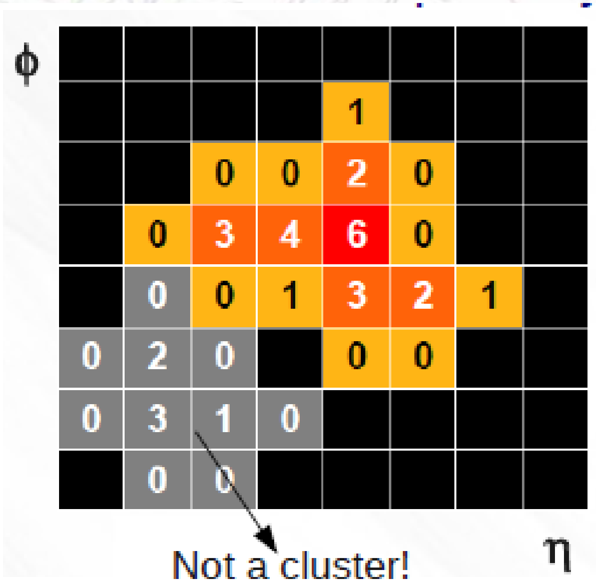


- Background eff. from Data/MC as function of reconstructed p_T for tight selection

- Signal efficiency from $Z \rightarrow \tau\tau$ MC as function of reconstructed p_T for tight selection

Topoclustering

- Topological Jet - cone algorithm run over TopoClusters
- Topological Cluster
  - group of calorimeter cells topologically
  - interconnected and selected by energy significance:
    - seed cell: |Ecell|> 4 sigma noise
    - neighbor cells: |Ecell|> 2 sigma
    - cells surrounding the cluster added
  - Tries somehow to match the shape of the shower.



- Details:
  - ATLAS Collaboration, *Calorimeter clustering algorithms: Description and performance,*

  ATL-LARG-PUB-2008-002 (2008).