Tau trigger and tau reconstruction, efficiency and fake rates in ATLAS

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Prospects for Charged Higgs Discovery at Colliders
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cnrs dépasser les frontières
IN2P3
Les deux infinis

Taus in new phenomena

- Heavy lepton $\Rightarrow$ present in many final states of physics beyond the Standard Model (SM)
- Higgs bosons: $H/A/h \rightarrow \tau\tau$, $H^{\pm} \rightarrow \tau\nu$
- supersymmetry (multilepton decays)
- exotic scenarios

Taus in Standard Model processes

- But before we claim new physics...
- ... Need to understand detector
- And re-observe SM processes ($Z \rightarrow \tau\tau$, $W \rightarrow \tau\nu$, $t\bar{t} \rightarrow \tau + X$):
  - to demonstrate feasibility
  - to calibrate tau performance
  - to understand backgrounds to new physics

Hadronic tau lepton decays

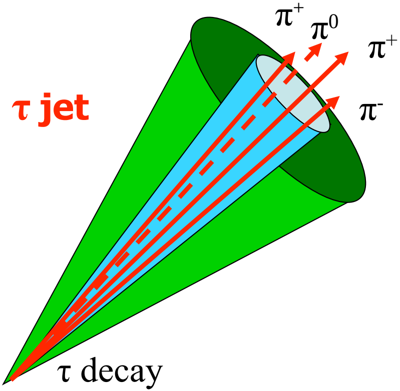
(Leptonic decays: hard to distinguish from prompt e/μ)

Tracking

- Low track multiplicity (1 or 3 $\pi^{\pm}$)
- Collimated tracks
- Track isolation cone
- Sizable decay length $\Rightarrow$ impact parameter, transverse flight path

Calorimetry

- Collimated energy deposition (use shower shape)
- Often strong EM component (π^0 in τ decays)
- Can reconstruct π^0 subclusters
- Isolation cone

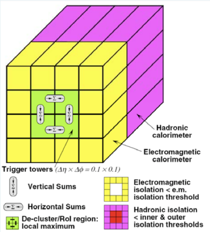


	tau	b quark
Mass	1.78 GeV	4.7 GeV
Lifetime	0.29 ps	1.5 ps
Decay length	87 μm	500 μm

Tau trigger

Level 1 (L1)

- 0.1×0.1 $(\eta \times \phi)$ towers (coarser than full granularity, summed in depth)
- Local maximum in 0.2×0.2 region above E_T threshold
- Outer cells for optional isolation
- Determines region of interest (RoI)



Level 2 (L2)

- Tracking and jets from cells (no noise subtraction) in RoI from L1
- Combined to build tau ID variables

Event filter (EF)

- Algorithm similar to offline
- Calorimeter clusters with proper calibration and noise suppression
- Cut-based selection

Tau trigger menu

Primary triggers

Single tau triggers with increasing energy thresholds and ID tightness.
Used for heavy $H \to \tau\tau$, Z', $H^{\pm} \to \tau\nu$

Ditau triggers for heavy resonances

Combined triggers often required to reduce rates and to minimise trigger bias on tau object

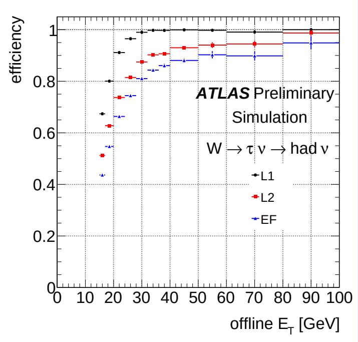
- tau+e/μ: $Z \to \tau\tau$, $t\bar{t}$, $H \to \tau\tau$, SUSY
- tau+$\not{E}_T$: $W \to \tau\nu$, $H^{\pm} \to \tau\nu$, SUSY
- tau+(b)jets: $t\bar{t}$, SUSY

Other triggers

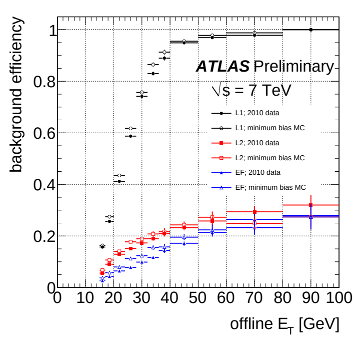
Monitoring Few events with no selection applied, to verify in each run that all detector components perform optimally

Calibration Using single track triggers for single hadron calibration

$W \to \tau\nu$ Monte Carlo signal



Minimum bias background



- Fraction of reconstructed tau candidates (no ID applied) passing L1 (5 GeV), L2 (7 GeV) and EF (12 GeV) loose trigger conditions as a function of E_T of offline candidate
- Tau candidate matched to true tau for signal
- Good data-MC agreement

(ATLAS-CONF-2010-090)

Measuring trigger efficiency in data

Tau-like QCD jets

- Select tau-like jets in QCD
- Good statistics but not real taus

Bootstrap

- Assume one can measure efficiency ε_A of trigger A
- Then compute trigger B efficiency as $\varepsilon_B = \varepsilon_{B|A} \times \varepsilon_A$ (if all events that trigger B also trigger A)
- Useful for higher p_T items

Tag and probe

- From $Z \to \tau\tau$: tag with e/μ (used both by online trigger and in offline selection), measure efficiency on opposite side to get single tau trigger efficiency
- From $t\bar{t}$: trigger with four jets, measure efficiency for tau+$\not{E}_\mathrm{T}$ trigger

Track-seeded and calo-seeded (double-seeded) candidates

- Tracks ($p_T > 6$ GeV) used as seed
- Collect tracks ($p_T > 1$ GeV) around seed in cone $\Delta R < 0.2$, use them to define η, ϕ
- Look for jet (anti-k_t algorithm with $R = 0.4$ on topological clusters) around track system (> 10 GeV, $\Delta R < 0.2$)
- Reconstruct π^0 subclusters
- Calibrated calorimetric E_T, E_T^{flow} from tracks and calo

Calo-seeded only candidates

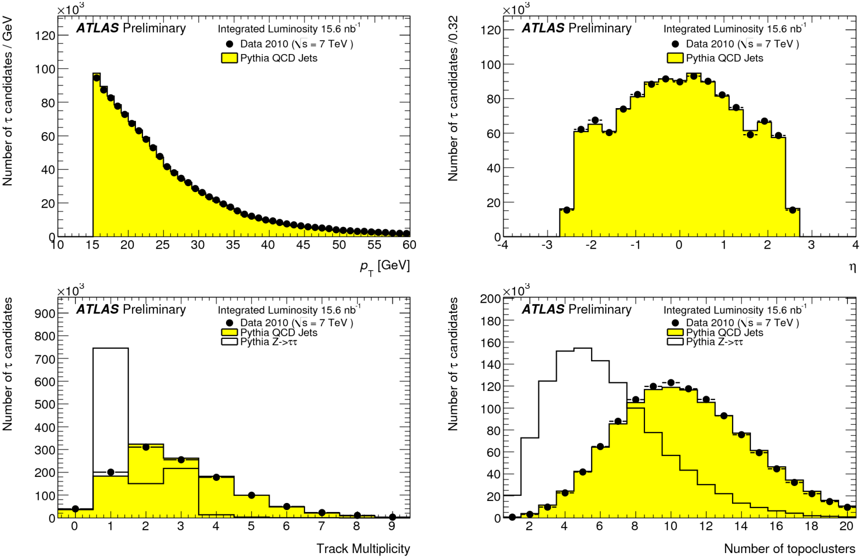
- Jet seed (not used as seed above)
- η, ϕ from calorimeter (corrected for vertex z position)
- Looser-quality track selection
- Calibrated calorimetric E_T

Track-seeded only candidates

- Only a few percent of all tau candidates

Tau reconstruction performance

(ATLAS-CONF-2010-059)



Good data-MC agreement on background jets

Other aspects of reconstruction

Photon conversions

- Identify tracks from conversions in tau cone and remove them
- $\Rightarrow$ minimise electron contamination, improve charge and track multiplicity determination

π^0 reconstruction

- Remove energy from charged pions
- Find π^0 candidates in remaining EM energy
- Allows identification of specific tau decays ($\pi^\pm, \rho^\pm, a_1$)

Lepton rejection

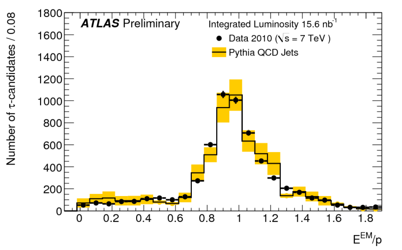
- Identify tau candidates that come from electrons or muons

Electron veto

Dedicated algorithm

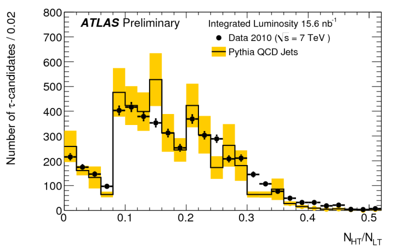
- Narrow jet with few tracks ⇒ electrons are good tau candidates
- Use specific variables to reject electrons
- From MC studies: rejection around 100 for a few percent loss in signal efficiency

E^{EM}/p



Ratio of EM energy in narrow window around impact cell and momentum of leading track for tau candidates identified as electron candidates

N_{HT}/N_{LT}



Ratio of high threshold to low threshold hits in the transition radiation tracker for tau candidates identified as electron candidates

Multivariate approaches to tau identification

Taus are difficult objects

- Will need full power of input variables
- Multivariate approaches successfully used in previous experiments
- Not the highest priority with first data: need to understand input variables first
- Therefore focus first on well understood variables...
- ... while preparing the tools for better tau identification, to be used for discovery physics

Various approaches

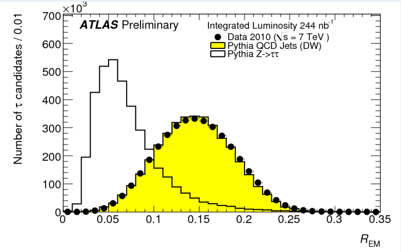
- Already being commissioned on data, in parallel with cut-based ID
- Likelihood ratio
- Boosted decision trees

Discriminating variables for cut-based ID

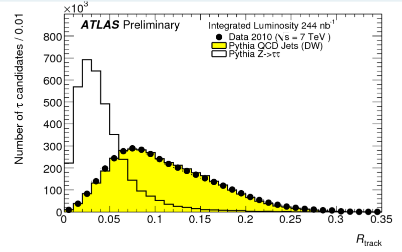
Keep it simple

- Focus on only three well modelled relatively uncorrelated variables
- Optimise for 30% (tight), 50% (medium) and 60% (loose) signal efficiency, separately for candidates with 1 track and at least two tracks (ATLAS-CONF-2010-086)

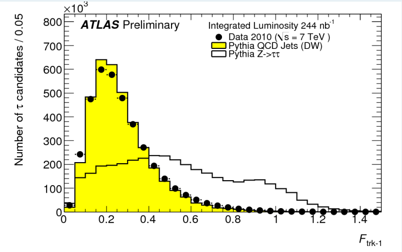
EM radius (E_T weighted shower width in EM calo)



Track radius (p_T weighted track width)

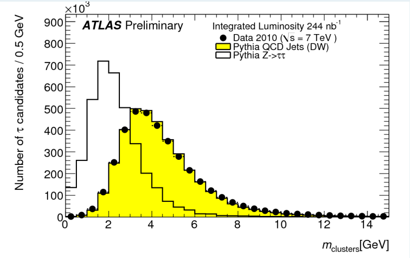


Leading track p_T fraction

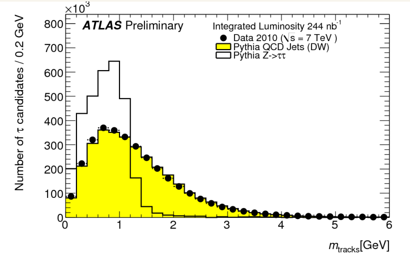


More variables for multivariate techniques

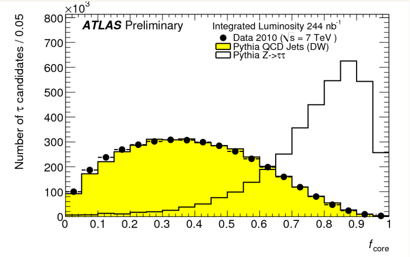
Cluster mass (inv. mass of clusters)



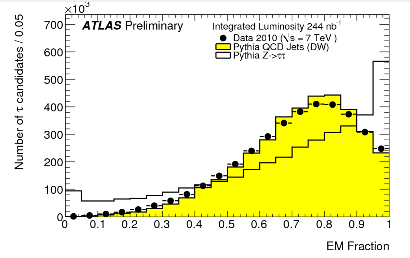
Track mass (inv. mass of tracks)



Core energy fraction (E_T fraction in $\Delta R<0.1$)



EM fraction (E_T fraction in EM calo)

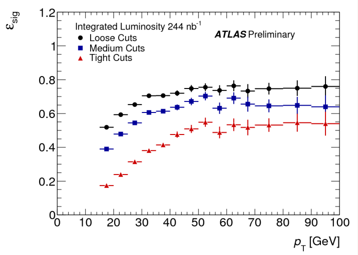


Cut-based efficiency and rejection

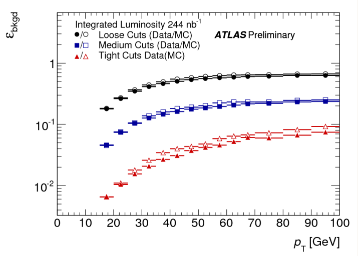
Efficiency definitions

- Signal: $\varepsilon_{\text{sig}} = \frac{N^{\tau}_{\text{pass,truth matched}}}{N^{\tau}_{\text{truth matched}}}$
- Background: $\varepsilon_{\text{bkgd}} = \frac{N^{\text{bkgd}}_{\text{pass}}}{N^{\text{bkgd}}_{\text{total}}}$
- $\varepsilon'_{\text{bkgd}}$: require candidates to have exactly 1 or 3 tracks

Signal efficiency ($Z \to \tau\tau$ MC)



Background efficiency



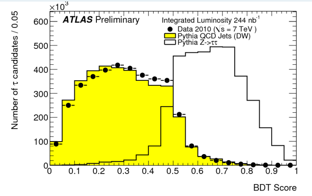
Selection	$\varepsilon_{\text{bkgd}}$ (data)	$\varepsilon_{\text{bkgd}}$ (MC)	$\varepsilon'_{\text{bkgd}}$ (data)	$\varepsilon'_{\text{bkgd}}$ (MC)
loose	$(3.2 \pm 0.2) \times 10^{-1}$	3.4×10^{-1}	$(9.4 \pm 0.6) \times 10^{-2}$	10×10^{-2}
medium	$(9.5 \pm 1.0) \times 10^{-2}$	9.9×10^{-2}	$(3.1 \pm 0.4) \times 10^{-2}$	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}

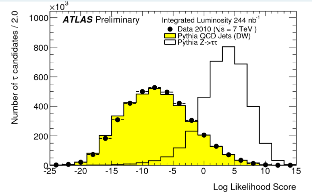
- Systematic uncertainties from transverse momentum calibration (2.1–9.6%) and pile-up effects (5.7–14.5%)

Multivariate techniques performance

Discriminant output

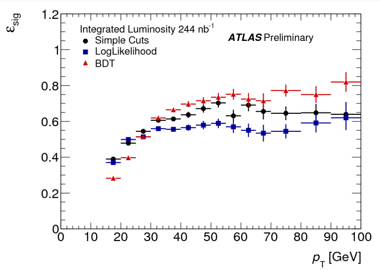
- Boosted decision trees (BDT) use all seven variables
- Log likelihood (LL) excludes core energy fraction (correlations)



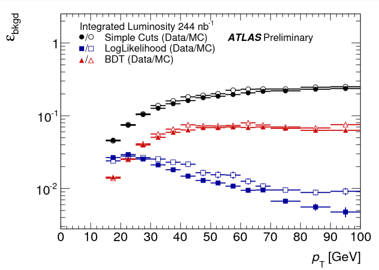


- Output well described by MC, quite discriminating

Signal efficiency ($Z \to \tau\tau$ MC)

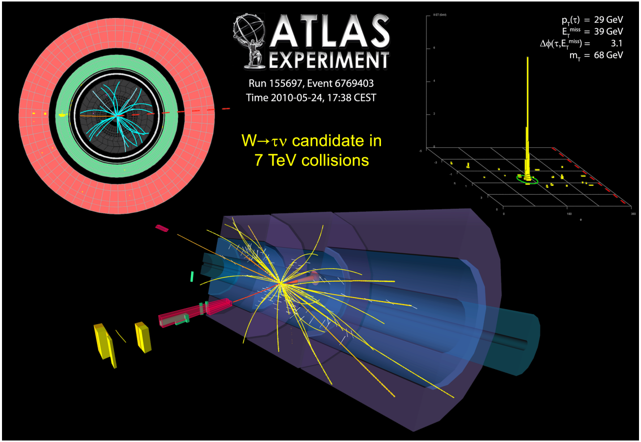


Background efficiency (medium)



First $W \to \tau\nu$ candidate observed in ATLAS

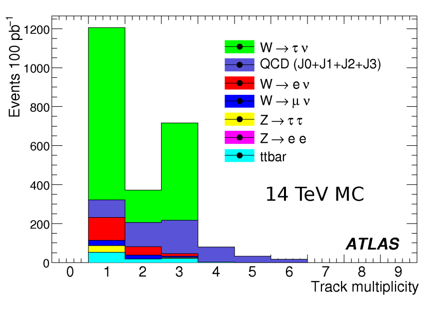
- Hadronically decaying tau (1-prong), $p_T = 29$ GeV, $\not{E}_T = 39$ GeV, $\Delta\phi(\tau, \not{E}_T) = 3.1$, transverse mass $m_T = 68$ GeV



Why and how?

- Cross section at 7 TeV: 10.46×10^3 pb, 10 times larger than $Z \to \tau\tau$
- But not as easy to access: only tau lepton and $\not\!\!E_T$

- Trigger on $\not\!\!E_T$ and tau candidate or single track
- Select events with large $\not\!\!E_T$ to reject QCD, veto e/μ
- May be used for tau ID efficiency measurement



7 TeV data analysis ongoing

First results soon!

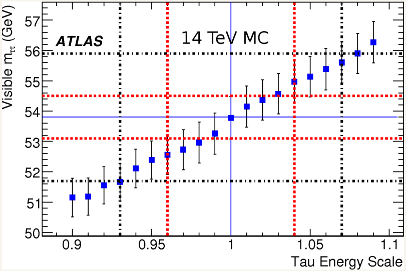
Towards SM rediscovery: $Z \to \tau\tau$

Golden channel: $Z \to \tau\tau \to \ell\text{had}$

- One tau decays leptonically: use for trigger, QCD rejection
- Second tau decays hadronically, kept as unbiased as possible
- Allows to derive tau trigger efficiency, tau reconstruction and identification efficiency

Further use

- Visible mass (from visible decay products) gives handle on tau energy scale
- Invariant mass (using also $\not{E}_T$, in the collinear approximation) should correspond to the Z mass $\Rightarrow$ control of the $\not{E}_T$ scale



7 TeV data analysis ongoing

First results soon!

Conclusion

- ATLAS has developed a full suite of tau reconstruction and identification algorithms
- Focused right now on robust performance rather than optimal rejection
- Good agreement between data and Monte Carlo predictions in all identification variables for background jets, as well as in fake rejection rates
- On top of basic cut-based selection, started to commission advanced multivariate techniques which confirm the good prospects expected from past MC studies
- Soon to be validated on real tau signal from $W \to \tau\nu$ and $Z \to \tau\tau$
- Good perspectives in introducing more complex variables into ID algorithms to increase performance
- Then tau ID will be ready to tackle the full ATLAS physics program and make possible the charged Higgs discovery!