Reconstruction and Identification of hadronic τ -decays in ATLAS

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Outlook

- Motivation
- Characteristic of τ leptons
- The ATLAS detector
- τ -jets identification
- Algorithms
 - TauRec
 - Tau1P3P
- Summary

Physics processes with τ 's

Higgs Processes :

- **Standard Model Higgs (VBF, ttH)**
 $qqH \rightarrow qq\tau\tau$, $ttH \rightarrow tt\tau\tau$
- **MSSM Higgs (A/H, H[±])**
 $A/H \rightarrow \tau\tau$, $H^+ \rightarrow \tau\nu$

Exotic Processes :

- **SUSY** signature with τ 's in final state
- **Extra dimensions** ... new theories (?)

Standard Model :

- $Z \rightarrow \tau\tau$
 - $W \rightarrow \tau\nu_\tau$
- } important for the commissioning

τ decays

τ decay modes :

- Leptonic decay modes**

$$\left. \begin{array}{ll} \tau \rightarrow \nu_\tau + \nu_e + e & (17.4\%) \\ \tau \rightarrow \nu_\tau + \nu_\mu + \mu & (17.8\%) \end{array} \right\} \sim 35 \%$$

How to identify them ?

- Hadronic decay mode**

$$\begin{array}{l} \sim 77 \% \left\{ \begin{array}{ll} \text{1 prong} & \\ \tau \rightarrow \nu_\tau + \pi^\pm & (11.0\%) \\ \tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 & (25.4\%) \\ \tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0 & (10.8\%) \\ \tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0 + \pi^0 & (1.4\%) \\ \tau \rightarrow \nu_\tau + K^\pm + n\pi^0 & (1.6\%) \end{array} \right. \\ \\ \sim 23 \% \left\{ \begin{array}{ll} \text{3 prong} & \\ \tau \rightarrow \nu_\tau + 3 \pi^\pm + n\pi^0 & (15.2\%) \end{array} \right. \end{array} \quad \left. \vphantom{\begin{array}{l} \sim 77 \% \\ \sim 23 \% \end{array}} \right\} \tau \text{ jets}$$

1 track,
impact parameter
shower shape,
energy sharing

3 tracks, impact parameter
secondary vertex
shower shape, energy
sharing

ATLAS layout

ATLAS tracking

Inner Detector

Inner Detectors (ID) :

- **Precision Tracking :**
Pixel detector, Semiconductor Tracker (SCT)
- **Continuous Tracking for pattern recognition and e id**
Transition Radiation Tracker (TRT)
- **Resolution :**
 $\sigma(P_T)/P_T = 0.05\% P_T (\text{GeV}) \oplus 1\%$
- **Tracking** in range $|\eta| < 2.5$

Magnetic Field :

- ID inside **2 Tesla** solenoid field

ATLAS calorimetry

Calorimeter :

- Electromagnetic : (in $|\eta| < 3.2$)

$$\sigma_E/E = 10\%/\sqrt{E(\text{GeV})} \oplus 0.245/E(\text{GeV}) \oplus 0.7\%$$

(low luminosity)

Layer	Granularity ($\Delta\eta \times \Delta\phi$)
Pre-sampler	0.025 x 0.1
Strips	0.003 x 0.1
Middle	0.025 x 0.025
Back	0.05 x 0.025

- Hadronic : (in $|\eta| < 3$)

$$\sigma_E/E = 50\%/\sqrt{E(\text{GeV})} \oplus 3.0 \%$$

Layer	Granularity ($\Delta\eta \times \Delta\phi$)
Tile0	0.1 x 0.1
Tile1	0.1 x 0.1
Tile2	0.2 x 0.1

τ -jets reconstruction

τ Jets Candidate Reconstruction :

- **characteristics**
well-collimated calorimeter **cluster** with a **small number** of associated **charged tracks**
- **acceptance**
 $|\eta| < 2.5$ acceptance of the **inner detector**

Backgrounds misidentified as τ jets:

- **QCD** jets
- **electrons** that shower **late** or with **strong Bremsstrahlung**
- **muons** interacting in the calorimeter

τ jet reconstruction algorithms in ATLAS :

- **TauRec** and **Tau1P3P**

Reconstruction

TauRec (default algorithm) :

- Start from different objects : **clusters** or isolated track
- Associate **tracks** to the τ jet candidate
- **Calibrate** τ jet candidate energy (**calorimeters**)

Tau1P3P (new algorithm):

- Start from a good leading hadronic **track**
- Create **single-prong** or **three-prong** τ jet candidate
- **Calibrate** candidate energy (**tracker+calorimeters**)

For TauRec and Tau1P3P :

- Determination of the **discriminant variables** (calculate **likelihood**, **discriminant multi-variate**)
- Apply set of basic **cuts** for **τ -Identification**

TauRec : preselection

Default τ jets reconstruction and identification in ATLAS :

- Cluster ($E_T > 15$ GeV), or track ($p_T > 2$ GeV)
- Associate tracks pointing to the object if $\Delta R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)} < 0.3$
- Select candidate with 1, 2 or 3 tracks

TauRec τ jet candidate

TauRec : variables

- Build a set of **discriminant variables** for τ jets reconstruction and identification and for the rejection of QCD jets

R_{EM}

ΔE_T^{12}

N_{strip}

Strip Width

Charge

$E_T/p_T(1^{st} \text{ track})$

Signal
 $Z \rightarrow \tau\tau$

Bkg
QCD jets

TauRec : identification

- calculate **likelihood** using :
 R_{EM} , ΔE_T^{12} , N_{track} , Strip Width, N_{strip} , Charge,
 Impact parameter, $E_T/p_T(1^{st}track)$
- calibrate τ jets candidates energy **weights** (Monte Carlo) applied directly to cell energies depending on their **E/V content** (cell energy density), η and **layer** (à la H1)
- Apply set of basic **cuts** for **τ -Identification**

τ jet identified with TauRec

Possibility to start with different objects

Good reconstruction efficiency

Good energy resolution

Tau1P3P : preselection

new algorithm for τ jets reconstruction and identification in ATLAS :

dedicated Tau1P3P in searches for the light Higgs or soft SUSY: τ 's with $E_T^{\text{vis}} = 20\text{-}70$ GeV

Explores **exclusive feature** of the τ lepton hadronic does not correspond to a typical jet but :

1 track + $n \pi^0$ (Tau1P)

3 tracks + $n \pi^0$ (Tau3P)

Good quality hadronic track ($p_T > 9$ GeV), find nearby good quality track ($p_T > 1$ GeV, $\Delta R < 0.2$)

1 track of good quality

+ no nearby track + 2 nearby tracks

τ jet candidate of Tau1P **τ jet candidate of Tau3P**

Tau1P3P : variables

- Build a set of **discriminant variables** for τ jets reconstruction and identification and for the rejection of QCD jets
- Energy scale for τ jet candidates using **energy flow** based on **tracks** instead of pure calorimeter jet techniques

$W \rightarrow \tau \nu$ and $Z \rightarrow \tau \tau$ events

Tau1P

$W \rightarrow \tau \nu$ and $Z \rightarrow \tau \tau$ events

Tau3P

Tau1P3P : identification

- Based on sampling the **signal** and **background** densities in a **multi-dimensional phase-space** using range-searching and probability density estimation. Combine all observables in one **discriminant** variable
- Apply set of basic **cuts** for **τ -Identification**

**τ jet identified
with Tau1P**

**τ jet identified
with Tau3P**

Start by a good quality track

τ jets separation with 1 or 3 tracks

Good energy resolution

For $\epsilon(\tau)=30\%$, $15 < p_T < 60$
 $\text{Rej}(\text{QCD jets}) = 600 - 1\,000$

Summary

- Efficient τ identification is crucial for several physics studies
- Good sensitivity for identifying τ 's in many physics channels, from light Higgs to Heavy SUSY

τ jets reconstruction algorithms in ATLAS :

- **TauRec** gives good results, possibility to use different seeds : cluster, track ...
- Track based **Tau1P3P** gives good results, separation of τ jet with 1 or 3 tracks is most powerful for low P_T
- The tau-identification achieved will allow the study of physics channels where the jets background is very large

Perspectives :

- two complementary τ algorithms have been developped in ATLAS, so a robust τ reconstruction and identification should be available to be checked with early data

Trigger

• Trigger in ATLAS

LVL1

Calorimeter+Muon Trigger,
coarse granularity

LVL2

Region of Interest, All detectors,
full granularity

Event Filter refines the selection,
can perform **event reconstruction**
using latest alignment and calibration
data (full offline reconstruction)

τ triggers

Possible way of selecting taus with the ATLAS trigger

- **Lepton Trigger**

trigger with the electron or the muon

- **Hadronic Tau Trigger**

PRELIMINARY

- LVL1 Tau Trigger (Calo)

use EM (0.2×0.2) and hadronic (0.2×0.2) towers to define a Region of Interest and also for the isolation in the EM (1.2×1.2) and hadronic (1.2×1.2) calorimeter

- LVL2 Tau Trigger (Calo+Tracking)

evaluating offline variables : em radius of the cluster, width in energy deposition, isolation fraction, track ...

- Event Filter

based on the default τ -jet reconstruction code

τ trigger efficiency : still under evaluation

LVL1 Tau-Trigger

- A 2x2 tower EM cluster + 2 x 2 hadronic cluster used to ID cand. ROIs
- A 2x1/1x2 tower EM clusters added to the energy in the hadronic inner region (shown in red) is compared to a threshold. There are 4 in the ROI the highest ET is taken.
- A ring of 12 EM towers surrounding the clusters, which is used for isolation in the EM calorimeters
- 12 hadronic towers (behind the EM isolation ring) for isolation in the hadronic calo.

Definition : efficiencie and rejection

- Efficiencie and Rejection

$$\text{eff}_{\text{RECONSTRUCTION}} = \frac{N_{\tau(\text{Reco \& labeled } \tau)}}{N_{\tau(\text{in acceptance})}}$$

$$\text{eff}_{\text{IDENTIFICATION}} = \frac{N_{\tau(\text{Reco \& labeled } \tau \& \tau \text{ Id})}}{N_{\tau(\text{Reco \& labeled } \tau)}}$$

$$\text{Rejection} = \frac{N(\text{Reco \& non labeled } \tau)}{N(\text{Reco \& non labeled } \tau \& \tau \text{ Id})}$$

Variables for TauID

tau_EMRadius :

$$R_{EM} = \Sigma (E_T^{EM} \times \Delta R) / \Sigma E_T^{EM}$$

tau_IsoFrac :

$$\Delta E_T^{12} = \Sigma (E_T^{EM} + E_T^{Had})_{0.1 < \Delta R < 0.2} / \Sigma (E_T^{EM} + E_T^{Had})$$

tau_stripWith2 :

$$\Delta \eta^2 = \Sigma (\eta^2 \times E_T) / \Sigma E_T - (\Sigma (\eta \times E_T) / \Sigma E_T)^2$$

Cluster and Energy scale

- Cone Algorithm

- Highest E_T tower for jet seed + cone
- Iteration of cone direction, jet overlap, energy sharing, merging

- H1 Method

$$E_{jet} = E_{PS} + \sum_j \alpha_{EM}(\varepsilon_{EM,j}) \times \varepsilon_{EM,j} + \sum_j \alpha_{HAD}(\varepsilon_{HAD,j}) \times \varepsilon_{HAD,j} + \alpha_C E_C$$

- Weights applied directly to cell energies
- Better resolution and residual non linearities

Parameter	Sampling Method		H1 Method	
	$\Delta R=0.4$	$\Delta R=0.7$	$\Delta R=0.4$	$\Delta R=0.7$
a (%GeV^{1/2})	66.0 $\pm$ 1.5	61.2 $\pm$ 1.3	53.9 $\pm$ 1.3	51.5 $\pm$ 1.1
b (%)	1.2 $\pm$ 0.3	1.4 $\pm$ 0.2	1.3 $\pm$ 0.2	2.5 $\pm$ 0.2
χ^2 prob. (%)	1.6	0.8	27.3	66.7

Energy Flow

$$E_{T\text{eflow}} = E_{T\text{emcl}} + E_{T\text{neuEM}} + \sum p_{T\text{track}} + \sum \text{res} E_{T\text{chrgEM}} + \text{res} E_{T\text{neuEM}}$$

used only EM cells within $\Delta R < 0.2$ around tau1P direction

$Z \rightarrow \tau\tau$