Calibration of the ATLAS Hadronic Calorimeter using E/p from Single Hadrons

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Introduction

absolute energy scale must be known at the level of 1%

$\Longrightarrow$ need to use physical processes

The E/p Method

Based on charged energetic isolated hadrons ($\pi^{\pm}$ or $K^{\pm}$).

- p precisely measured in the ID
  E measured in the calorimeters $\Longrightarrow$ $\boxed{E/p = 1}$
- results directly transportable from test-beam to the ATLAS detector
- η coverage limited by the Inner Detector: $|\eta| \leq 2.5$
- inter-calibration of the sub-detectors
- high rate signals

$W^{\pm}(+jet) \rightarrow \tau^{\pm}\nu_{\tau}$ with $\tau^{\pm} \rightarrow h^{\pm}\nu_{\tau}$

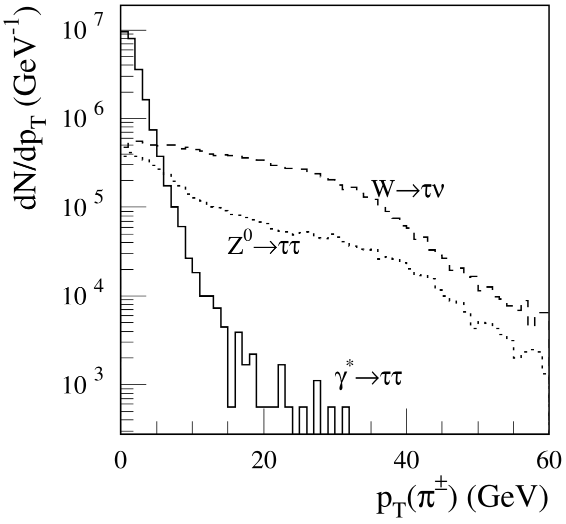
$Z^0/\gamma^{\star}(+jet) \rightarrow \tau^{+}\tau^{-}$ with at least one $\tau^{\pm} \rightarrow h^{\pm}\nu_{\tau}$

Signal Events Rate at Particle Level

Events generation: PYTHIA 6.122 (no pile-up events)
+ TAUOLA 2.6 + CTEQ4M (+ ATLFAST 2.20)
Integrated luminosity is 10 fb^{-1}.

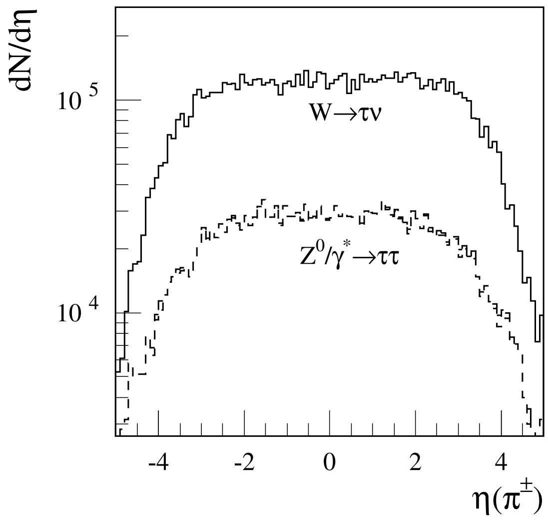
At least 1 $\pi^{\pm}/K^{\pm}$ with $p_T \geq$15 GeV in the tracker.

$W^{\pm}(+jet) \rightarrow \tau^{\pm}\nu_{\tau}$
$\sigma\times$ BR=2.16 nb
N^{ev}=6.58 M



$Z^0(+1jet) \rightarrow \tau\tau$
$\hat{m} > 15\ GeV$
$\sigma\times$ BR=0.88 nb
N^{ev}=1.51 M

$\gamma^{\star}(+1jet) \rightarrow \tau\tau$
$4 < \hat{m} < 15\ GeV$
$\sigma\times$ BR=4.76 nb
N^{ev} =0.02 M



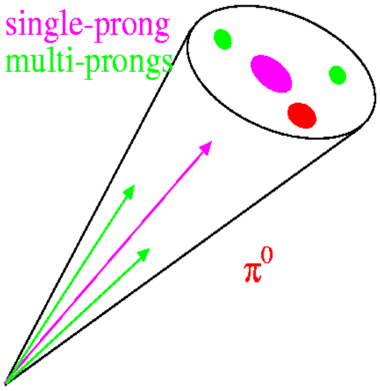
Backgrounds Events

QCD events $(2 \rightarrow 2)$

- $qq \rightarrow qq \; (q = u, d, c, s, g)$ $\sigma = 5.5 \times 10^7$ nb
- $b\bar{b}$ production $\sigma = 1.8 \times 10^5$ nb

Events from $\tau^{\pm}$ decay itself

- into more than 1 track
  E(3 tracks)/p(1 track)>1
- with π^0 in the cascade decay
  E(1 track+π^0)/p(1 track)>1



$\tau^{\pm} \rightarrow \pi^{\pm}\nu_{\tau}$	11.1%
$\tau^{\pm} \rightarrow K^{\pm}\nu_{\tau}$	0.7%
$\tau^{\pm} \rightarrow e^{\pm}\nu_e\nu_{\tau}$	18.1%
$\tau^{\pm} \rightarrow \mu^{\pm}\nu_{\mu}\nu_{\tau}$	17.6%
$\tau^{\pm} \rightarrow \rho^{\pm}\nu_{\tau};\; \rho^{\pm} \rightarrow \pi^{\pm}\pi^0$	24.2%
$\tau^{\pm} \rightarrow a_1^{\pm}\nu_{\tau};\; a_1^{\pm} \rightarrow \pi^{\pm}\pi^{\pm/0}\pi^{\mp/0}$	13.0%
$\tau^{\pm} \rightarrow K^{\star\pm}\nu_{\tau}$	1.3%
$\tau^{\pm} \rightarrow n\pi^{\pm} + m\pi^0$	5.6%

$\tau^{\pm}$ BR estimated with TAUOLA 2.6

ON-LINE SELECTION - available menus

LHC (40 MHz) $\rightarrow$ LVL1 (100 kHz) $\rightarrow$ LVL2 (1 kHz) $\rightarrow$ EF (100 Hz)

$\tau^{\pm} \rightarrow h^{\pm}\nu_{\tau}$ leads to $\not{E}_T$ + 1 τ-jet

$\Longrightarrow$ $\not{E}_T$ trigger combined with τ/had trigger

$\Longrightarrow$ LVL1 trigger menu: T20+XE30 (fast simulation)

$\Longrightarrow$ LVL2 trigger menu: τ20+xE30 (not simulated here)

$Z^0/\gamma^{\star} \rightarrow \tau^{+}\tau^{-}$: event can contain 1 isolated lepton (BR($\tau \rightarrow l\nu\nu$)=35%)

$\Longrightarrow$ lepton triggers

$\Longrightarrow$ LVL1 trigger menus: EM20I or MU6

$\Longrightarrow$ LVL2 trigger menus: e20i or μ20 (fast simulation)

T20+XE30 or e20i or μ20

(not official simulation
$\rightarrow$ not official rates)

Nexp(Signal)	=	3.3 M
Nexp($\tau \rightarrow n\pi$)	=	13.3 M
Nexp(QCD 2$\rightarrow$2)	=	6.0 G

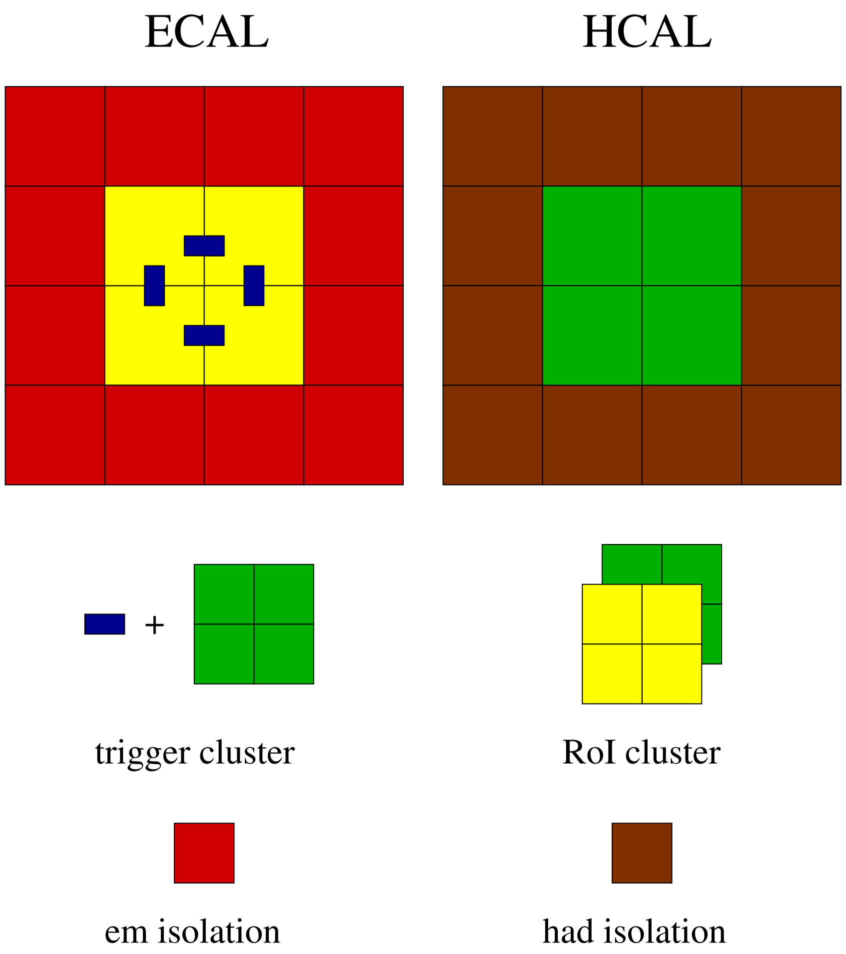
ON-LINE SELECTION - LVL1 tau/had trigger

based uppon a 4×4 array of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ "trigger-tower" in the em and had calorimeters (within $|\eta| \leq 2.5$)

- at least 1 trigger cluster with $E_T >$ cluster threshold
- E_T sum in em isolation region $<$ isolation threshold
- E_T sum in had isolation region $<$ isolation threshold
- the central 2×2 RoI cluster is a local E_T maximum

  (i.e. $E_T >$ than the 8 clusters of the same type in the same 4×4 window)

TDR tau/hadron trigger algorithm



OFF-LINE SELECTION - preselection

$W^\pm \to \tau^\pm \nu_\tau$	$\longrightarrow$	1 jet (+recoiling jet)
$Z^0/\gamma^\star \to \tau^+\tau^-$	$\longrightarrow$	1 jet + 1 lepton or 2 jets (+recoiling jet)
QCD	$\longrightarrow$	high jet multiplicity events

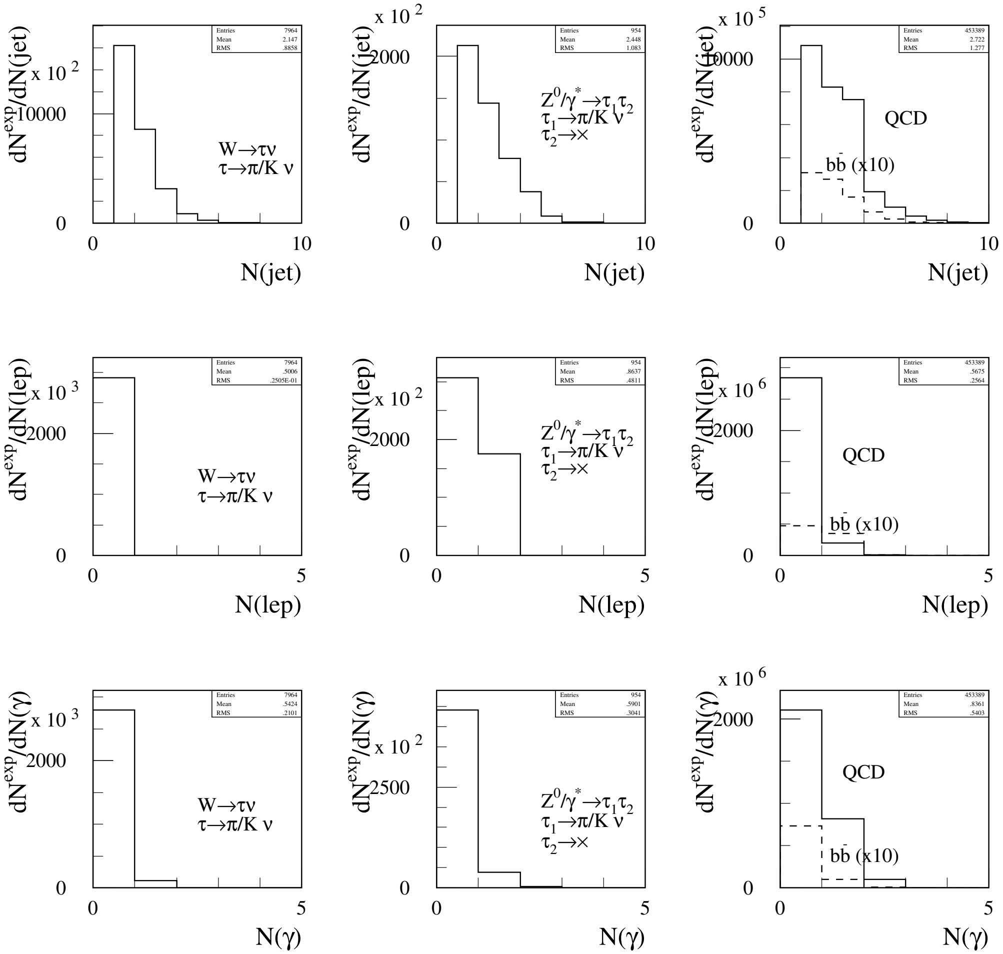
- $N(jet) \geq 1$ — $E_T(jet)$ threshold=15 GeV
- $N(jet + isolated\, lepton) \leq 2$ — $E_T(lep)$ threshold=10 GeV

Isolated photons from jet fragmentation can be reconstructed.
(QCD: mainly from FSR)

- $N(isolated\, photon) = 0$
  $E_T(photon)$ threshold=10 GeV

Nexp(Signal)	=	2.7 M
Nexp($\tau \to n\pi$)	=	11.9 M
Nexp(QCD 2→2)	=	1.3 G

OFF-LINE SELECTION - *preselection*



Events selected by the on-line selection.

$N(jet) \geq 1$
$N(jet{+}is.lep.) \leq 2$
$N(is.pho.) = 0$

OFF-LINE SELECTION

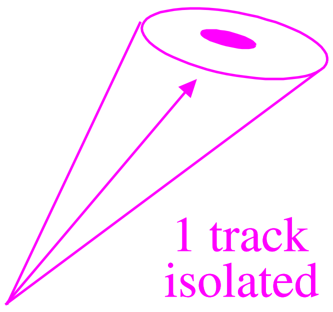
$\tau^{\pm} \rightarrow h^{\pm}\nu_{\tau}$: 1 charged isolated energetic hadron.

$\Longrightarrow$
- 1 isolated track in tracker
- 1 narrow jet in calorimetres

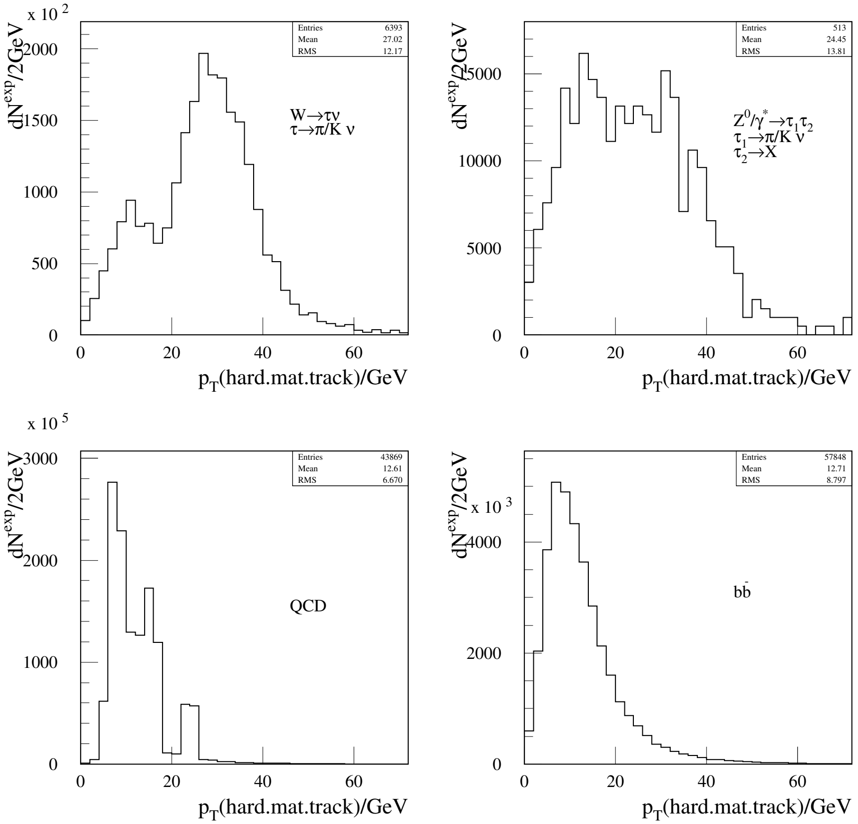
- jet candidate selection

1 jet /
- $p_T(jet) \geq 20\,GeV$
- $|eta(jet)| \leq 2.5$ (tracker acceptance)

- Matching cut: tracks in a $\Delta R = 0.15$ cone centered on the jet direction are under consideration.
- Tracker isolation: extra-tracks in a ΔR=0.4 cone centered on the hardest matching track direction are under consideration.



OFF-LINE SELECTION - τ-jet selection



p_T of the hardest track matching the jet candidate for events accepted by the jet selection.

- $N(match.track) \geq 1$
- $p_T^{max}(match.tr.) \geq 25\,GeV$

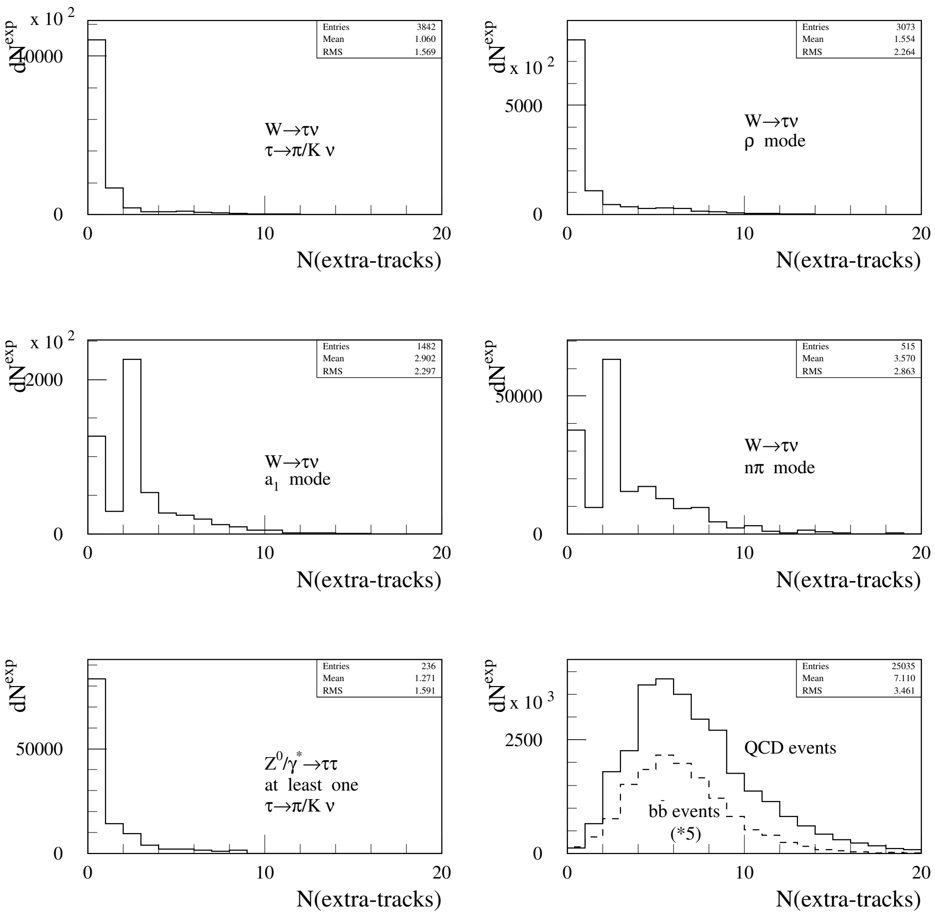
$\Downarrow$

rejection of fake τ-jet:

recoiling jet (W/Z events)
& multi-prongs τ-jet (Z events)
& QCD.

Nexp(Signal)	$=$	1.5 M
Nexp($\tau \to n\pi$)	$=$	2.0 M
Nexp(QCD 2$\to$2)	$=$	29.0 M

OFF-LINE SELECTION - single track selection



Number of extra-tracks after the τ-jet selection.

❖ $N(extra\text{−}track) \leq 1$

$\Downarrow$

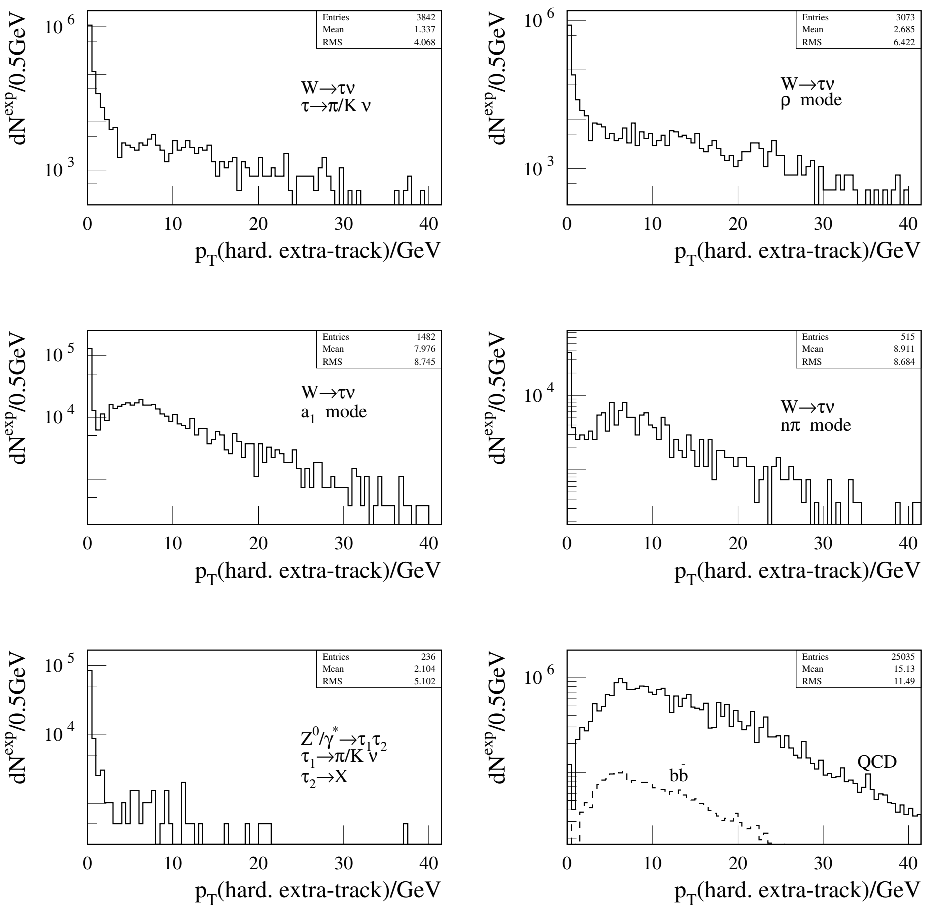
multi-prongs $\tau^{\pm}$ decay modes and QCD strongly rejected

&

$\tau^{\pm} \rightarrow \rho^{\pm}\nu_{\tau}$ decay mode NOT rejected

$$\text{Nexp(Signal)} = 1.4 \text{ M}$$
$$\text{Nexp}(\tau \rightarrow n\pi) = 1.2 \text{ M}$$
$$\text{Nexp(QCD } 2\rightarrow2) = 0.8 \text{ M}$$

OFF-LINE SELECTION - single track selection



p_T of hardest extra-track after the τ-jet selection.

✦ $p_T^{max}(extra{-}tr.) \leq 1GeV$

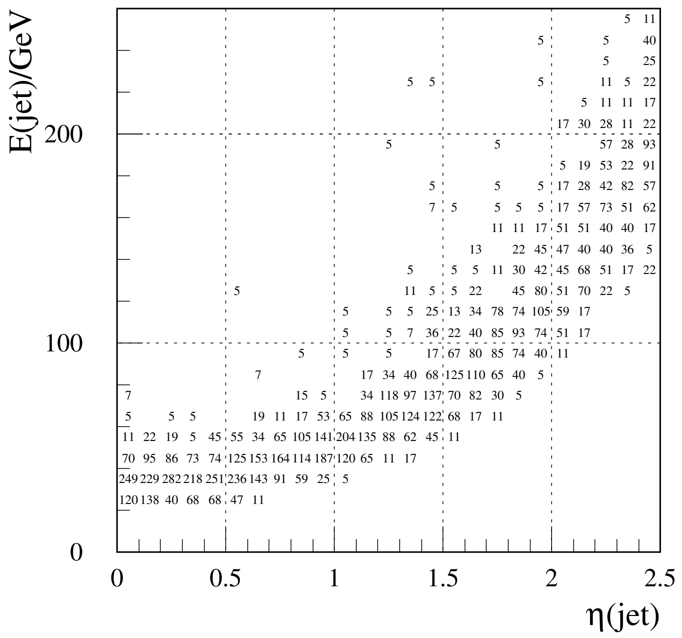
$\Downarrow$

rejection of QCD and multi-prongs τ-jet candidates.

Nexp(Signal)	$=$	1.3 M
Nexp($\tau \rightarrow n\pi$)	$=$	1.1 M
Nexp(QCD 2→2)	$=$	0.1 M

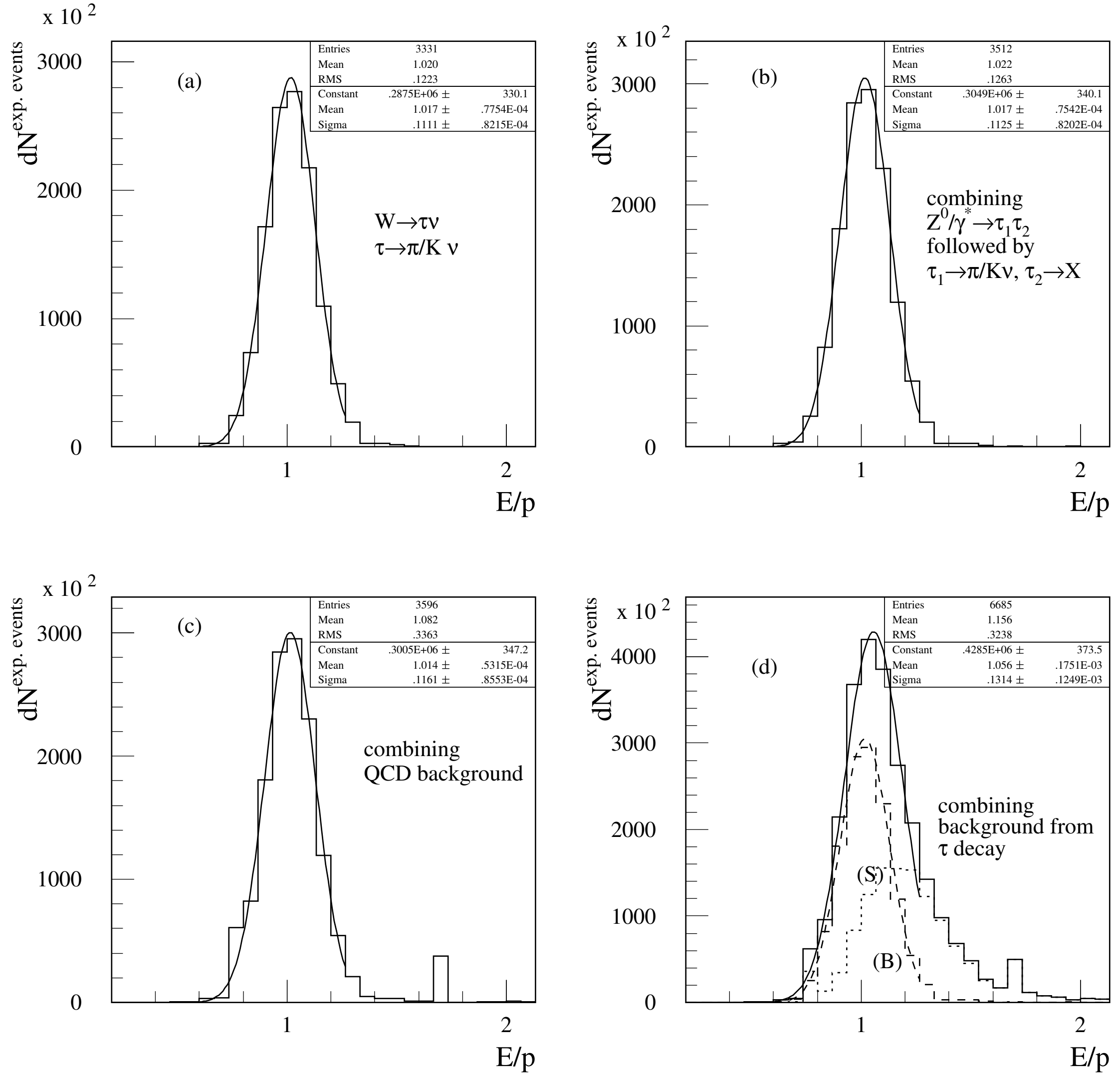
OFF-LINE SELECTION - *summary*

Selection Step	Signal Nexp	$\tau^{\pm}$ BKG Nexp	$\tau^{\pm}$ BKG W/ρ	QCD Nexp	QCD $b\bar{b}$
trigger	3.30 M	13.3 M		6.0 G	
preselection	2.66 M	11.9 M	$> 40\%$	1.3 G	$> 3\%$
τ-jet	1.53 M	2.00 M	$> 60\%$	29 M	$> 10\%$
single track	1.31 M	1.14 M	$> 80\%$	0.13 M	$> 29\%$



- large energy range
- $\pi^{\pm}$ test-beam energy range
- energy range of tracks within jets
- distribution uniform in η and ϕ
- 3 sub-systems of HCAL

E/p BIAS - final selection



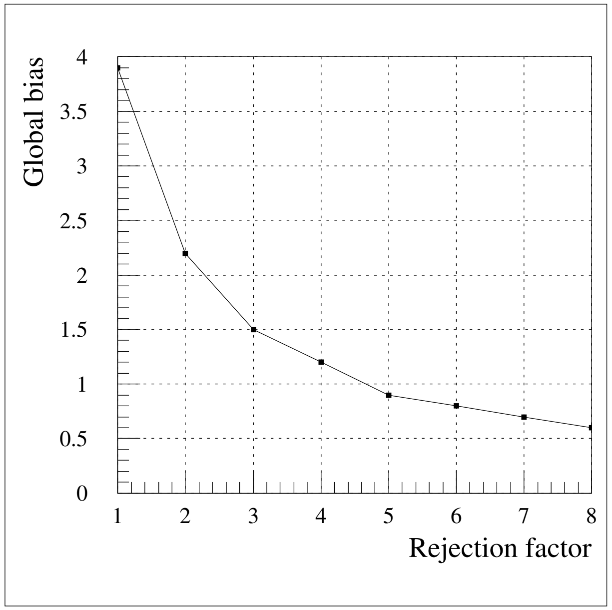
estimation of the E/p shift: gaussian fit [0.6:1.2]

QCD
shift=-0.3%

all BKG
shift=+3.9%

E/p BIAS - further rejection

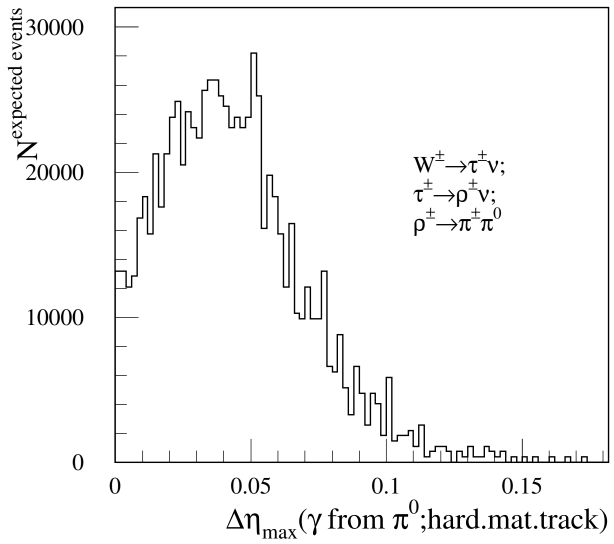
Selection Step	Bias(QCD)	Bias(all B)
τ-jet selection	+5.5%	8.5%
+ N(extra-track)$\leq$1	+0.1%	4.2%
+p_T(hard.extra-track)$\leq$1GeV	-0.3%	3.9%



The 1% expected calibration level can be reached applying a rejection factor of 5 against background events assuming no lost on signal efficiency.

Background Events from $\tau^{\pm}$ Decay

- >80% of remaining backgrounds events from $\tau^{\pm}$ decay are coming from $W^{\pm} \to \tau^{\pm}\nu_{\tau}$ followed by $\tau^{\pm} \to \rho^{\pm}\nu_{\tau}$ and $\rho^{\pm} \to \pi^{\pm}\pi^{0}$.
- Further rejection of background events with π^{0} might be obtained using the fine eta-strips of the first sampling of the EM calorimeter.
- PYTHIA: 90% of $\rho^{\pm} \to \pi^{\pm}\pi^{0}$ events from $W^{\pm} \to \tau^{\pm}\nu_{\tau}$ production are $\Delta|\eta|^{max}(hard.mat.tr.;\gamma) \geq 0.006$



$\Longrightarrow$ **Need to use full simulation (including the shower spreading) to study the electromagnetic component of the τ-jet**

Conclusions and Perspectives

- Analysis made with fast simulation.
- Only basic cuts were used (robust).
- The results obtained:

  QCD shift=-0.3%

  all BKG shift=3.9%

- Multi-tracks background is under control.
  $\tau^{\pm} \rightarrow \rho^{\pm}\nu_{\tau}$ with $\rho^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ chanel is the main problem.
- Further background rejection factor of 5 is needed to reach the desired 1% calibration level.
- Need full simulation to study the $h^{\pm}/\rho^{\pm}$ separation precisely.