In Situ jet energy calibration in the ATLAS experiment

- Goal : jet energy scale known at 1% level
  - From test-beam ≈ 5 -10%
    - Transfer of calibration data to ATLAS environment
    - Monte-Carlo simulation of fragmentation
  - Need *In Situ* calibration
- Comparison with test-beam results
  - Single track *E/p* calibration
- Jet energy scale and resolution
  - $p + p \rightarrow t\bar{t} + X$
    - Semi-leptonic decays
    - $M_{jj} = M_W$
  - $p + p \rightarrow Z^0 + jet$
    - Z^0 in electron or muon pair
    - $p_T(jet) = p_T(Z^0)$

E/p calibration

- Based on charged energetic isolated hadrons ($\pi^{\pm}$ or $K^{\pm}$)
- *p* precisely measured in tracker, *E* measured in calorimeters
  - $E/p = 1$
- Comparison with test-beam results
- Inter-calibration of sub-detectors
- η coverage limited by the Inner Detector : $|\eta| \leq 2.5$
- High rate signals
  - $W^{\pm}\,(+jets) \rightarrow \tau^{\pm}\upsilon_{\tau}\,(+jets)$ *with* $\tau^{\pm} \rightarrow h^{\pm}\upsilon_{\tau}$
  - $Z^0/\gamma^*\,(+jets) \rightarrow \tau^{+}\tau^{-}\,(+jets)$ *with at least one* $\tau^{\pm} \rightarrow h^{\pm}\upsilon_{\tau}$
- Backgrounds
  - QCD events
  - Events from $\tau^{\pm}$ decays itself : multi-prongs, π^0 in the decay

E/p calibration : events selection

- Trigger menus
  - One τ jet (≥ 20 *GeV/c*) + missing E_T (≥ 30 *GeV*)
    or one isolated electron (≥ 20 *GeV/c*) or one isolated muon (≥ 20 *GeV/c*)
- Pre-selection
  - N (jet) ≥ 1
  - N (jet + isolated lepton) ≤ 2
  - N (isolated photon) $= 0$
- Selection
  - Jet candidate
    - $|\eta \text{ (jet)}| \leq 2.5$, $p_T \geq 20$ *GeV/c*
  - Matching cut : $\Delta R = 0.15$ cone centred on jet direction
    - N (matching tracks) ≥ 1 , p_T (hardest matching track) ≥ 25 *GeV/c*
  - Tracker isolation : $\Delta R = 0.4$ cone centred on the hardest matching track direction
    - N (extra-tracks) ≤ 1 , p_T (extra-track) ≤ 1 *GeV/c*

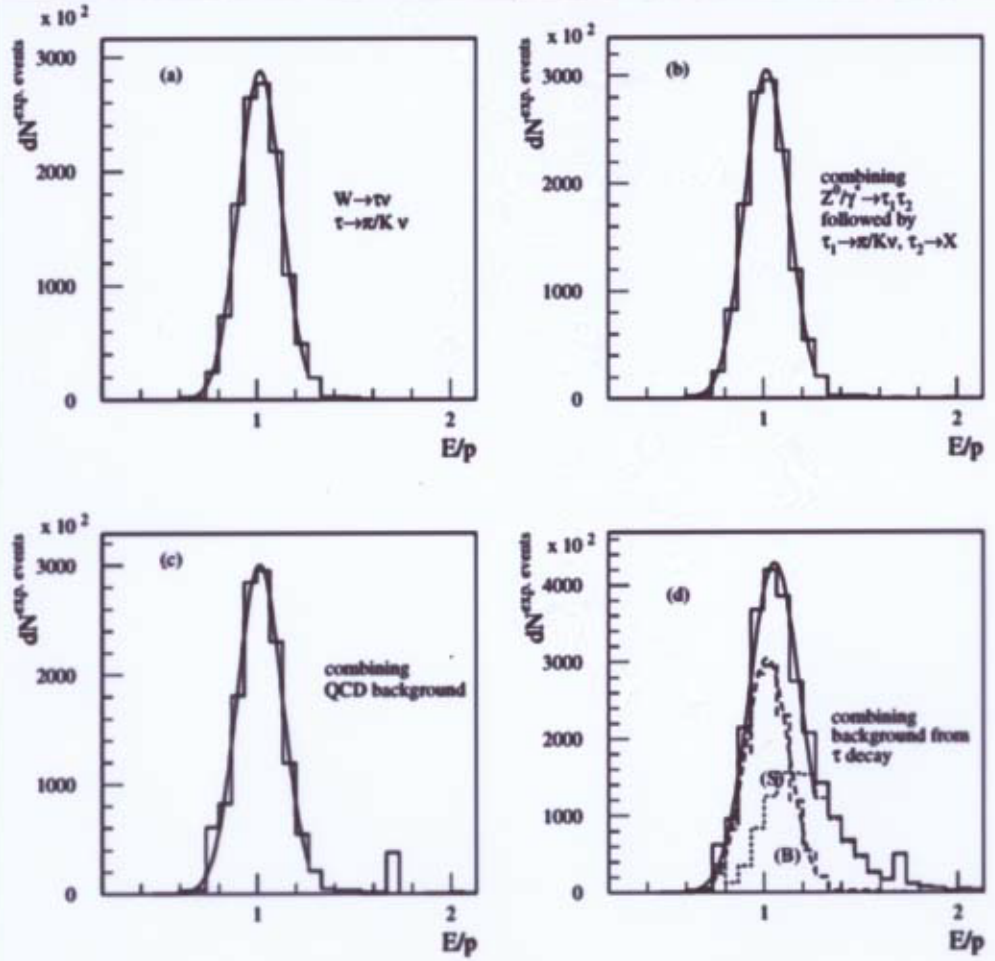
E/p calibration : results (preliminary)

- Results for 10 fb^{-1} based on a fast simulation study
- Expected events (millions)

Selection	Signal	$\tau^{\pm}$ BKG ($n\,\pi^{\circ}$ %)		QCD
Trigger	3.30	13.3		6000
Pre-selection	2.66	11.3	(> 40)	1300
τ-jet	1.53	2.00	(> 60)	29
Single track	1.31	1.14	(> 80)	0.13

- E/p bias
  - QCD background : no shift
  - All background : shift = +3.9%
- Conclusion
  - Only basic cuts used (robust)
  - Multi-tracks backgrounds well rejected
  - $\tau^{\pm} \rightarrow \pi^{\pm} \upsilon_{\tau} + n\,\pi^{0}$ is the main remaining background
    - Need full simulation to study π^0 rejection

E/p calibration : bias (preliminary)



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

QCD
no shift

ALL BKG
shift = +3.9%

Calibration of jet energy using Z^0 + jet events

- Improve resolution and linearity using events
  - $q + g\,(\bar{q}) \rightarrow Z^0 + q\,(g)$
    with $Z^0 \rightarrow e^+e^-$ *or* $\mu^+\mu^-$
    - Easy trigger and event selection
    - p_T (Z^0) very well measured
  - Calibration constraint : $p_T(jet) = p_T(Z^0)$
- High statistic : $\sigma \approx 100$ pb
- Large η coverage : $|\eta| \leq 4.9$
- Large energy coverage
- b-jet energy scale
- This study is based on :
  - Full simulated events in the low luminosity case
  - Fast simulated events for systematic errors

Z^0 + jet events : calibration procedure

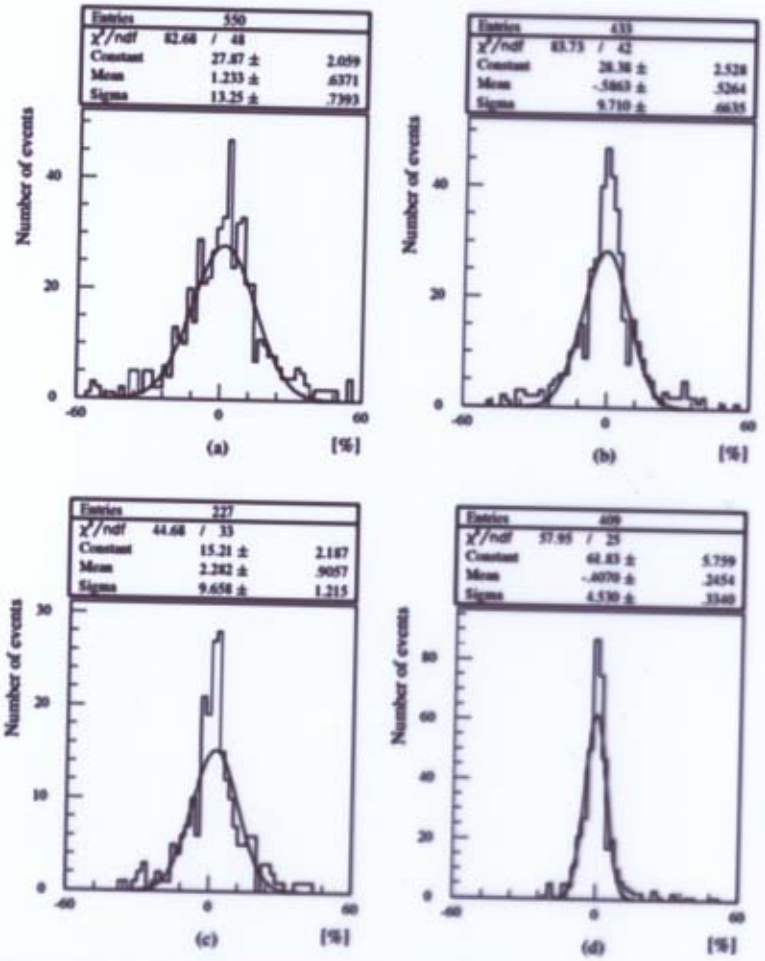
- **STEP 1 :**
  - Reconstructed transverse energy : $E_{T\,rec} = \dfrac{f(a_l, E_{cell})}{\cosh(\eta_{jet})}$
    - E_{cell} coming from electromagnetic scale calibration
    - Calibration constants, a_l's, obtained for each interval in $\left(p_T(Z^0), |\eta_{jet}|\right)$ plane by minimising : $\sum_k \left(E^k_{T\,rec} - p^k_T(Z^0)\right)^2 + \alpha \sum_k \left(E^k_{T\,rec} - p^k_T(Z^0)\right)$
- **STEP 2 :**
  - Reconstruction of transverse energy without any *a priori* knowledge : $E^i_{T\,rec}$
    - Linear interpolation of a_l's as functions of jet transverse energy from electromagnetic scale calibration $E_T(jet)$
- **STEP 3 :**
  - Corrections to take into account residual unbalance (Initial State Radiation)
    - Based on Monte-Carlo Simulation

Z^0 + jet events : events selection

- Select topologies
  - Only one jet $\left(E_{T\,th} = 15\,GeV\right)$
  - $E_T(jet) \geq 20\,GeV$
  - $\left|\phi(jet) - \phi(Z^0) - \pi\right| \leq 0.15$
  - $\left|M_Z - 91.187\right| \leq 10\,GeV/c^2$
- Residual unbalance

$$\frac{p_T(Z^0) - p_T(parton)}{p_T(parton)}$$

- Results presented here correspond to $\left|\eta_{jet}\right| \leq 1.2$



Z^0 + jet events : STEP 1 results (preliminary)

- Parameterisation of the reconstructed energy

$$E^k_{rec} = \sum_{cells \in EM} \left(a_{EM} + \frac{b_{EM}}{|E^k_{cell}|} \right) E^k_{cell} + \sum_{cells \in HAD} \left(a_{HAD} + \frac{b_{HAD}}{|E^k_{cell}|} \right) E^k_{cell}$$
$$+ c\sqrt{E^k_{ACCB3} E^k_{TILE1}} + E^k_P + E^k_{TS}$$

- Resolution and linearity with respect to the Z^0 : $\dfrac{E_{T\,rec} - p_T(Z^0)}{p_T(Z^0)}$

$p_T(Z^0)$ [GeV/c]	μ_Z [%]	σ_Z [%]
40-60	-1.9±0.8	17.2±0.7
60-100	-0.4±0.8	16.3±0.8
100-200	1.3±0.8	9.3±0.7
200-300	0.4±0.4	7.5±0.4

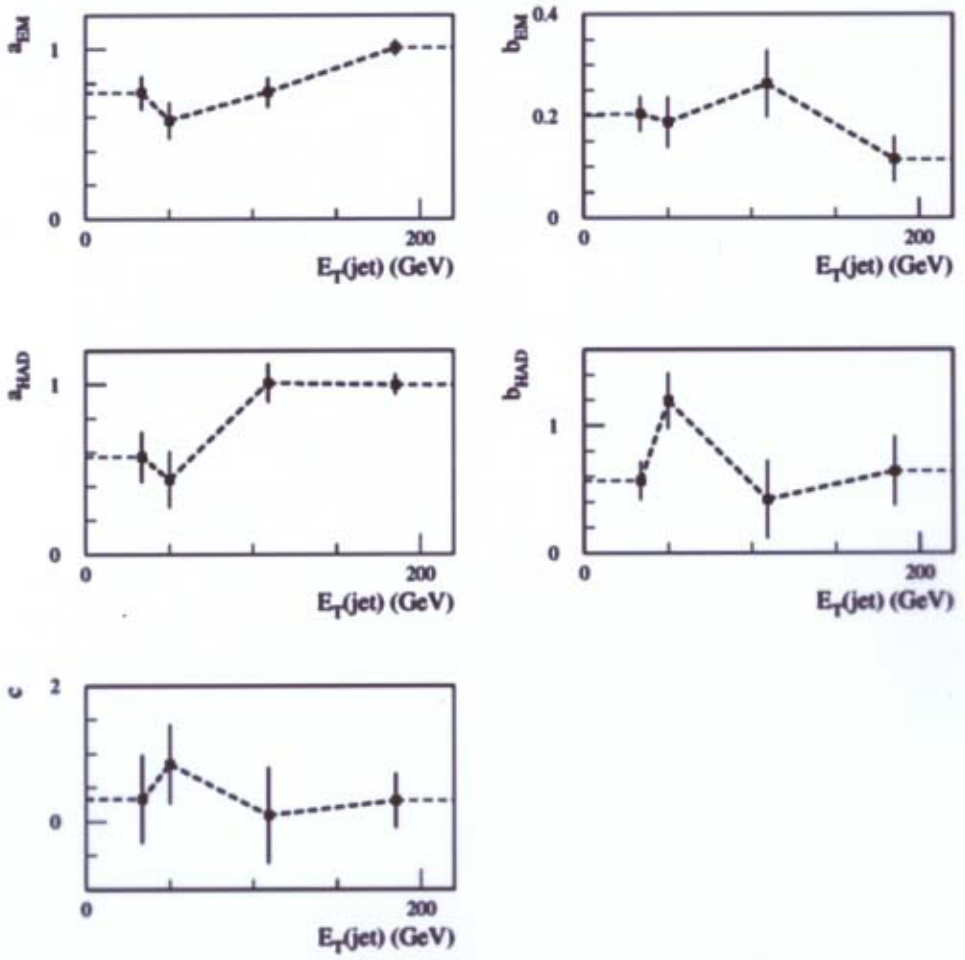
Z^0 + jet events : STEP 2 results (preliminary)

- Interpolation of calibration constants versus $E_T(jet)$
- Resolution and linearity with respect to the parton : $\dfrac{E^i_{T\,rec} - p_T(parton)}{p_T(parton)}$

$p_T(parton)$ [GeV/c]	μ^i_p [%]	σ^i_p [%]	μ_p [%]	σ_p [%]	$\mu^i_{p\ opt}$ [%]	$\sigma^i_{p\ opt}$ [%]
40-60	0.0±0.7	15.3±0.6	0.6±0.8	15.4±0.7	-1.0±0.7	14.4±0.5
60-100	2.2±0.6	12.5±0.6	1.8±0.7	12.6±0.7	-0.5±0.6	11.5±0.5
100-200	0.8±0.5	7.2±0.5	1.3±0.6	7.7±0.5	-0.4±0.4	6.1±0.4
200-300	0.8±0.3	5.3±0.2	0.9±0.3	5.7±0.3	-0.2±0.3	5.2±0.3

- Almost no differences between before and after interpolation
- Deterioration of about 10% with respect to the optimal resolution

Z^0 + jet events : STEP 2 interpolation (preliminary)



Z^0 + jet events : STEP 3 results (preliminary)

- To reduce systematic errors, use : $\mu_p^i = \mu_Z + \left(\mu_p^i - \mu_Z\right)_{MC}$

$$\sigma_p^i = \sigma_Z \times \left(\sigma_p^i / \sigma_Z\right)_{MC}$$

- Correction terms

$p_T(parton)$ [GeV/c]	$\left(\mu_p^i - \mu_Z\right)_{MC}$ [%]	$\left(\sigma_p^i / \sigma_Z\right)_{MC}$ [%]
40-60	1.9±1.1	89±6
60-100	2.6±1.0	77±5
100-200	-0.5±0.9	77±9
200-300	0.4±0.5	70±5

  - Results limited by statistics
  - Linearity results comparable with fast simulation ones
    - 4.9%, 1.5% and 0.4% for low, mid and high p_T range respectively

Z^0 + jet events : systematic study and conclusion

- Two sources of systematic errors have been considered
  - a) Imperfect modelling of back to back topologies of Z^0 + jet events
  - b) Modelling of Initial State Radiation
- Errors on resolution (full simulation)
  - Smaller than the present statistical ones
- Errors on linearity (fast simulation)
  - a) 0.7% for low p_T range and 0.1% for p_T greater than 60 *GeV/c*
  - b) 1.1% for 40 *GeV/c* $\leq p_T \leq$ 120 *GeV/c* and 0.3% for higher p_T
- Conclusion
  - High statistics : around 300 000 selected events for 10 fb^{-1}
    - Full simulation results clearly limited by present statistics
      - possible improvements
  - Calibration up to few hundred *GeV* and linearity response check up to 1 *TeV*
  - Seems possible to control the jet energy scale at the desired 1% level for transverse energy greater than 40 *GeV*