Missing E_T Reconstruction in the ATLAS Calorimeter

Calor 2006, Chicago

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For the ATLAS Jet/E_TMiss Group

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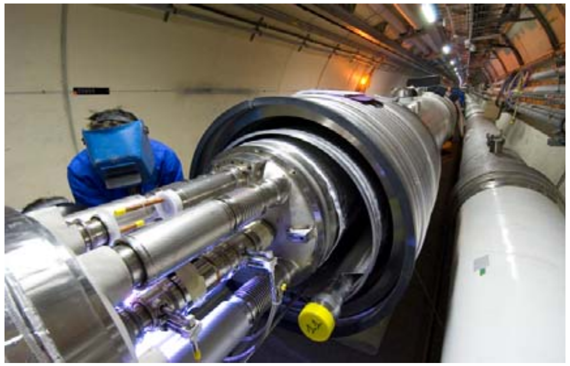
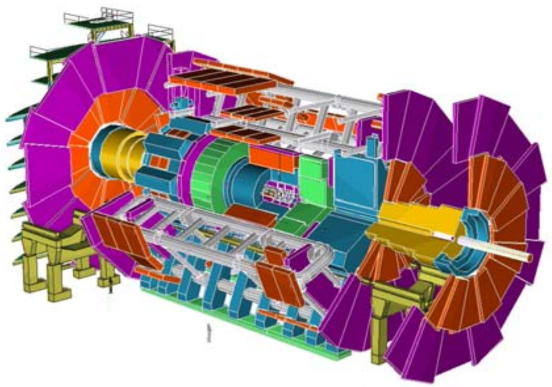
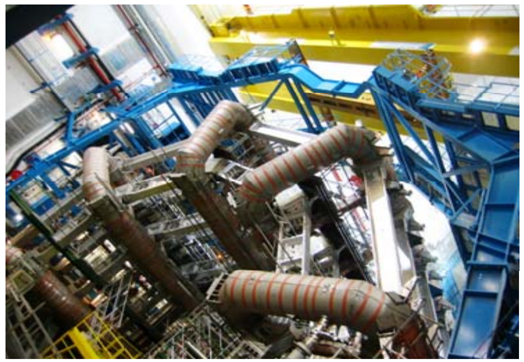
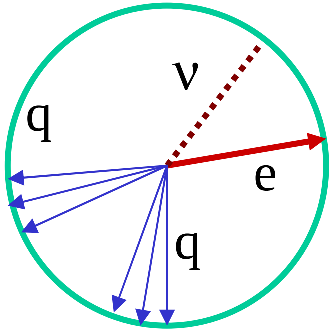






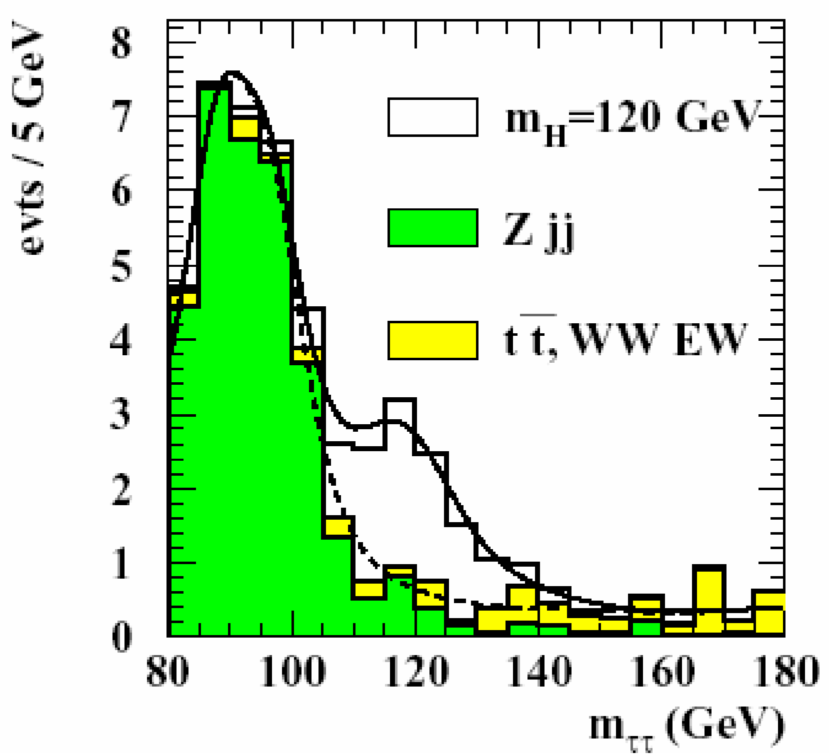
Introduction

- Non-interacting particles do not leave direct signature in the detector
  - ⇒ They are measured by measuring everything else and appealing to energy and moment conservation.
  - ⇒ In proton-proton collision measure transverse energy to reduce the effect of boost and activity in forward regions.



- Many physics process involve missing energy
  - ⇒ Standard Model process with neutrinos
    - W-boson, Z-boson, Higgs
  - ⇒ SUSY
    - In R-parity conserving scenario the lightest super-symmetric particle (LSP) is stable and weakly interacting. SUSY Higgs decaying to taus.
  - ⇒ Extra Dimensions
    - In large extra dimension models gravitons will interact gravitationally and escape direct detection leaving missing energy.

Example Processes with Missing ET

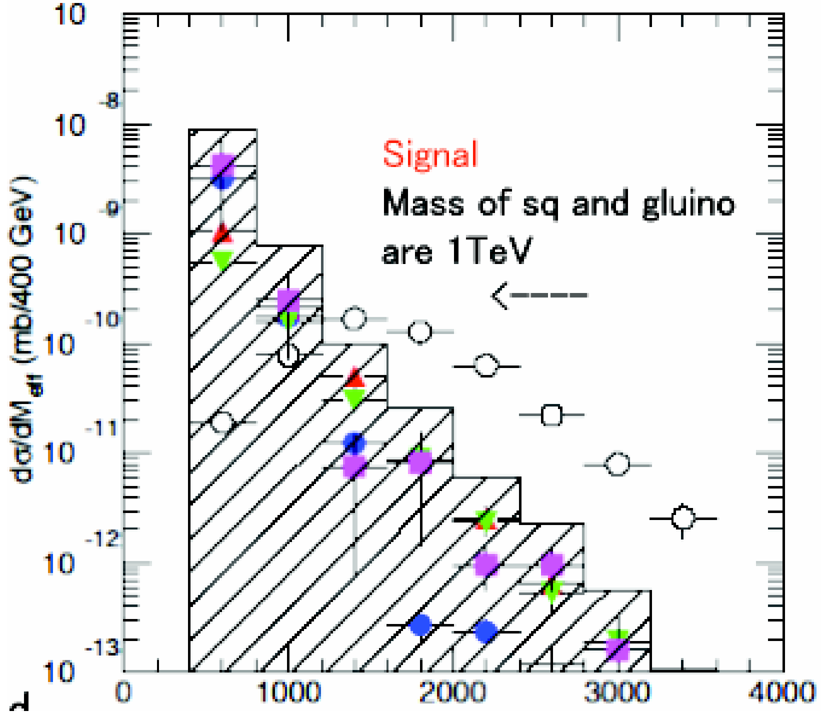


- Higgs production in vector boson fusion and decay to two taus.

  ⇒ typical selection cuts require at least 50 GeV missing ET

- SUSY signatures involve large missing ET

  ⇒ typical selection cuts require at least 100 GeV missing ET

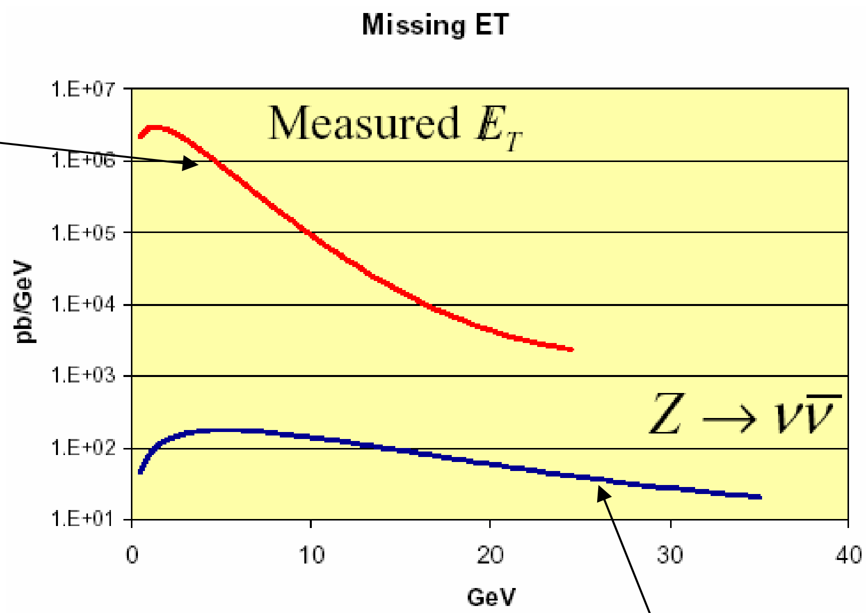


Meff = missing ET + 4jet Pt sum (GeV)

Measuring Missing ET

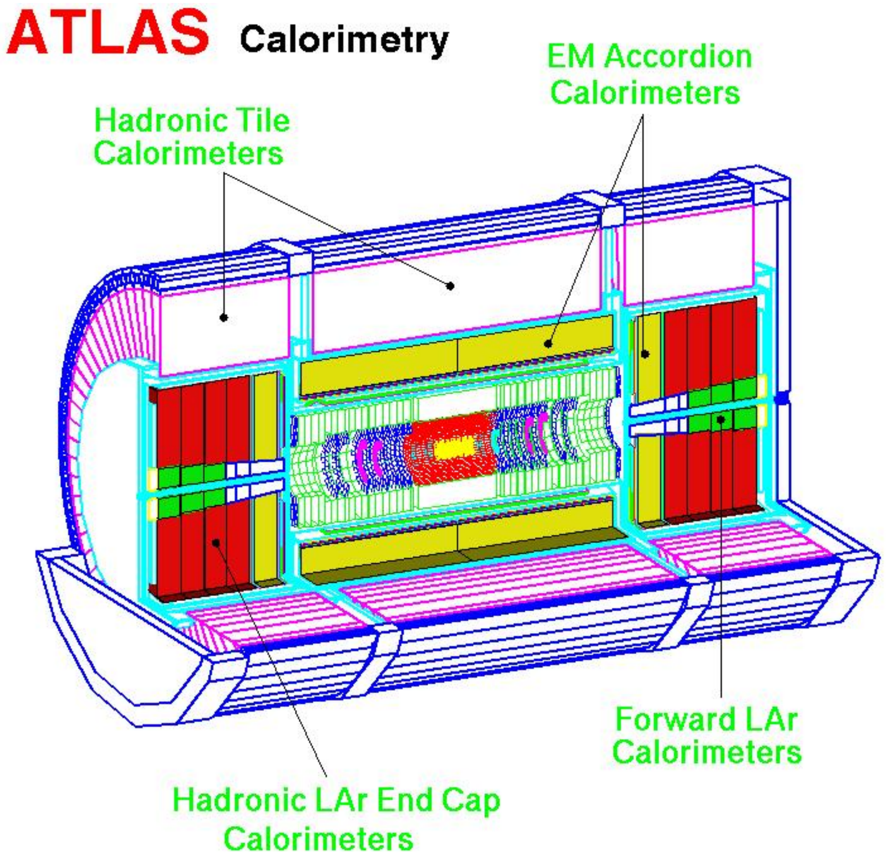
- Why is measuring Missing ET challenging?
  - ⇒ Because apart from the source of real missing ET (ν,LSP,G), any mis-measurement in the detector will also produce missing ET (fake missing ET)
    - particles lost in the gap and dead material, dead/noisy/hot calorimeter cell, noise/pile-up suppression, energy scale error, resolution etc.

Illustration of fake missing ET from minimum bias events at level1 trigger

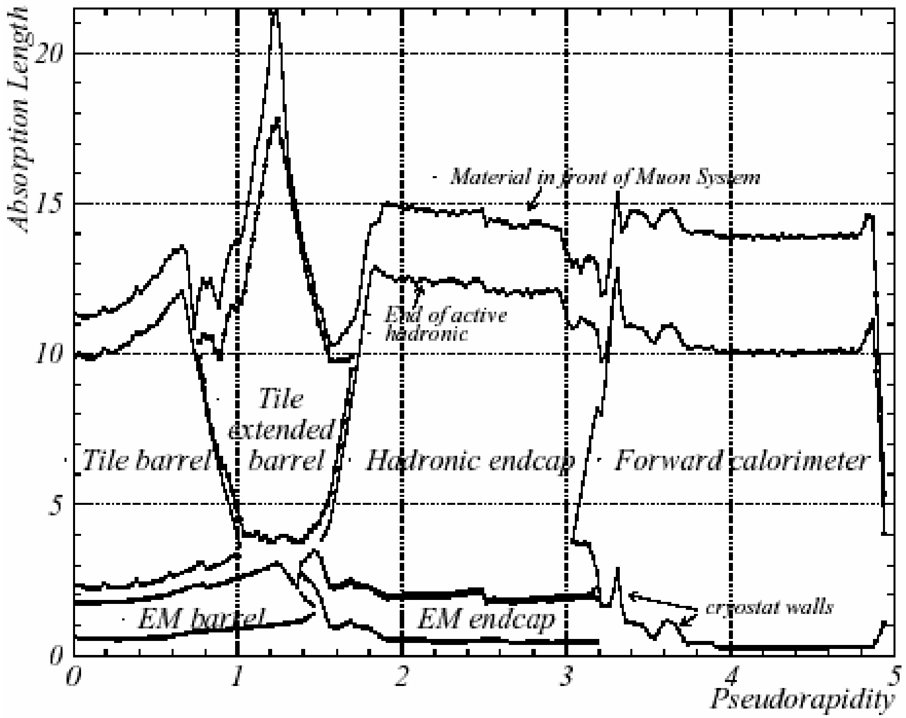


True missing ET from neutrino

- Measuring Missing ET will involve
  - ⇒ Vetoing events with un-interesting missing energy
  - ⇒ Understanding EM scale (expected to be known to 1-3% from testbeam) and hadronic scale of the calorimeter.



- Full coverage |eta| < 5
- Pb/LAr EM calorimeter
  - ⇒ 22-26 X, 1.2 λ
- Fe/Scintilator HAD Cal. |eta| < 1.7
  - ⇒ 7.2 λ
- Cu/LAr End Cap Cal. 1.7 < |eta|< 3.2
- Cu/LAr, W/LAr Forward Cal. 3<|eta|<5



- Non compensating
  - ⇒ e/h ~ 1.4
- Dead materials
  - ⇒ Gaps for services outlet
  - ⇒ LAr Calorimeter Cryostat

ATLAS Calorimeter

- Collision rate 40 MHz,
- 23 interaction/crossing, 1725 particles
- 200 K readout channel

  ⇒ Expected noise/cell low

  - 30-50MeV Central

  - Larger in forward calorimeters

  ⇒ Stringent requirement on coherent noise for Missing Et measurements
- Effects of Pile-up due to energy deposit other than the primary hard process

  ⇒ in time pileup - interactions from same crossing

  ⇒ out-of-time pileup - effect from interactions from previous crossing due to electronics shaping time larger than 25 ns bunch crossing.

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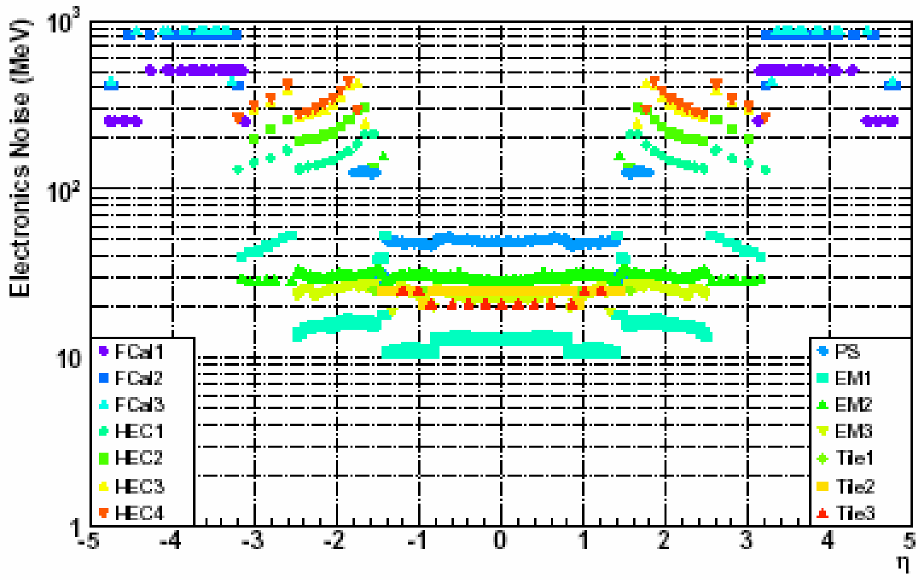
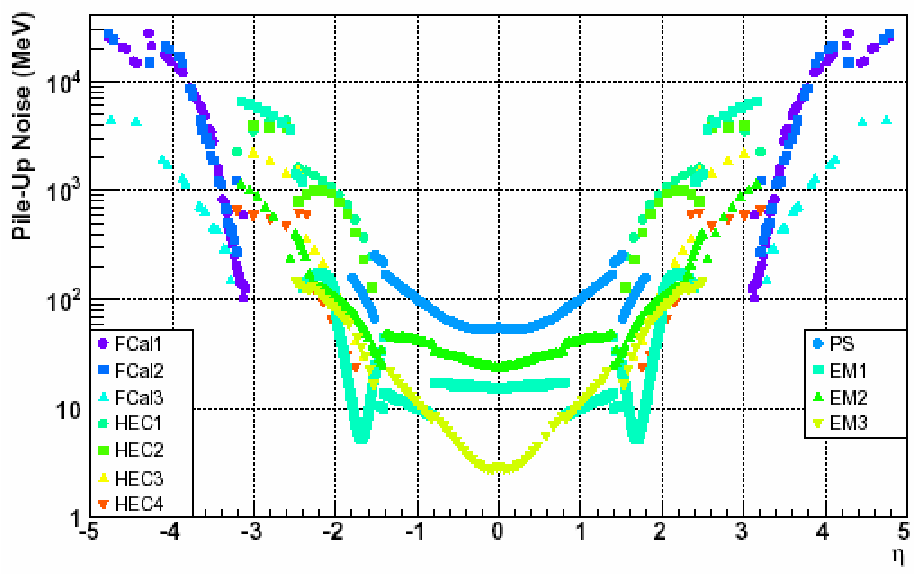


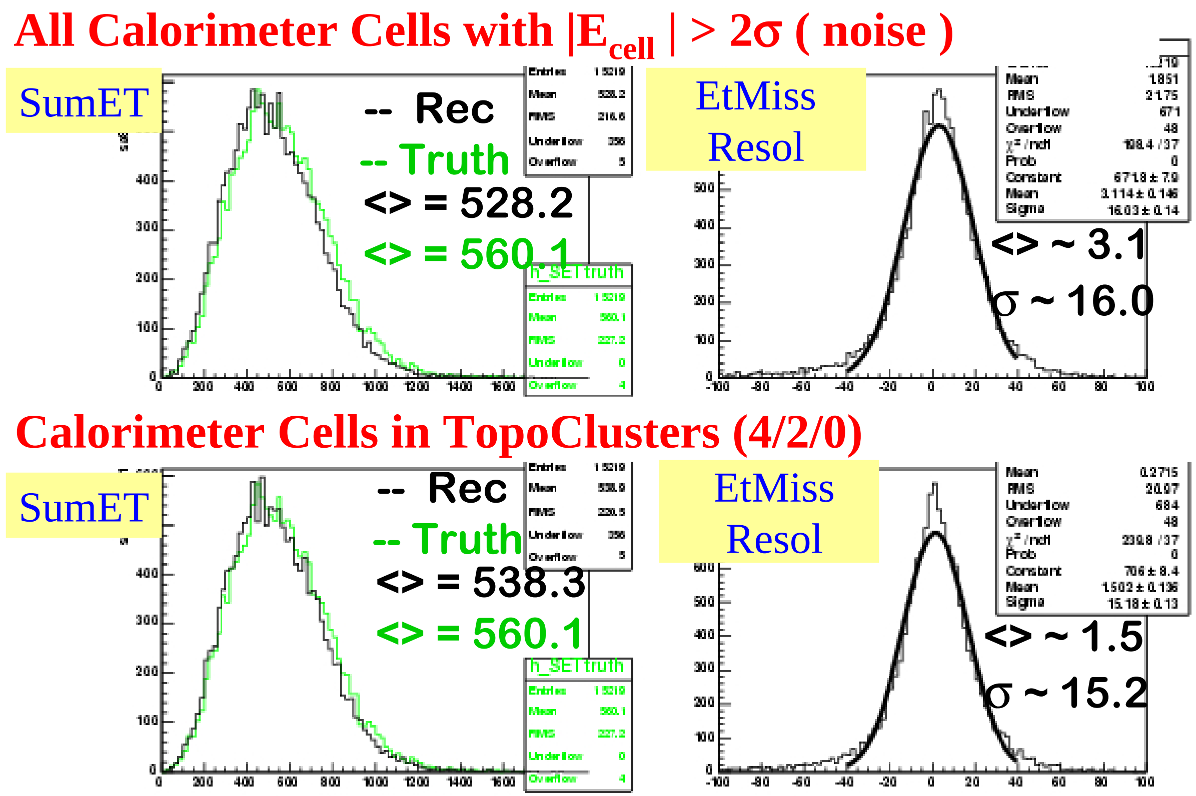


Reconstructing Missing ET in ATLAS

- Missing Et is reconstructed using the energy deposits in the Calorimeter cells.
  - ⇒ Calorimeter cells in the| eta| < 5 range used
  - ⇒ Calorimeter cells are calibrated depending on calorimeter region, eta position and energy density in the cell
    - - low energy density deposits considered hadronic.
    - - high energy density deposits considered electromagnetic.
- Rejection of noise based on either
  - ⇒ Applying 2 sigma symmetric cut on expected noise level
  - ⇒ Using three dimensional clusters made from calorimeter cell(CaloTopoCluster). The presence of cluster with positive energy represent a signal deposit rather random noise fluctuation. Building of cluster requires knowledge of expected noise.
- Energy lost in the cryostat is estimated using energy deposits in the last layer of LAr calorimeter and first layer of Tile calorimeter.
- Reconstructed muons in the event are taken into account.

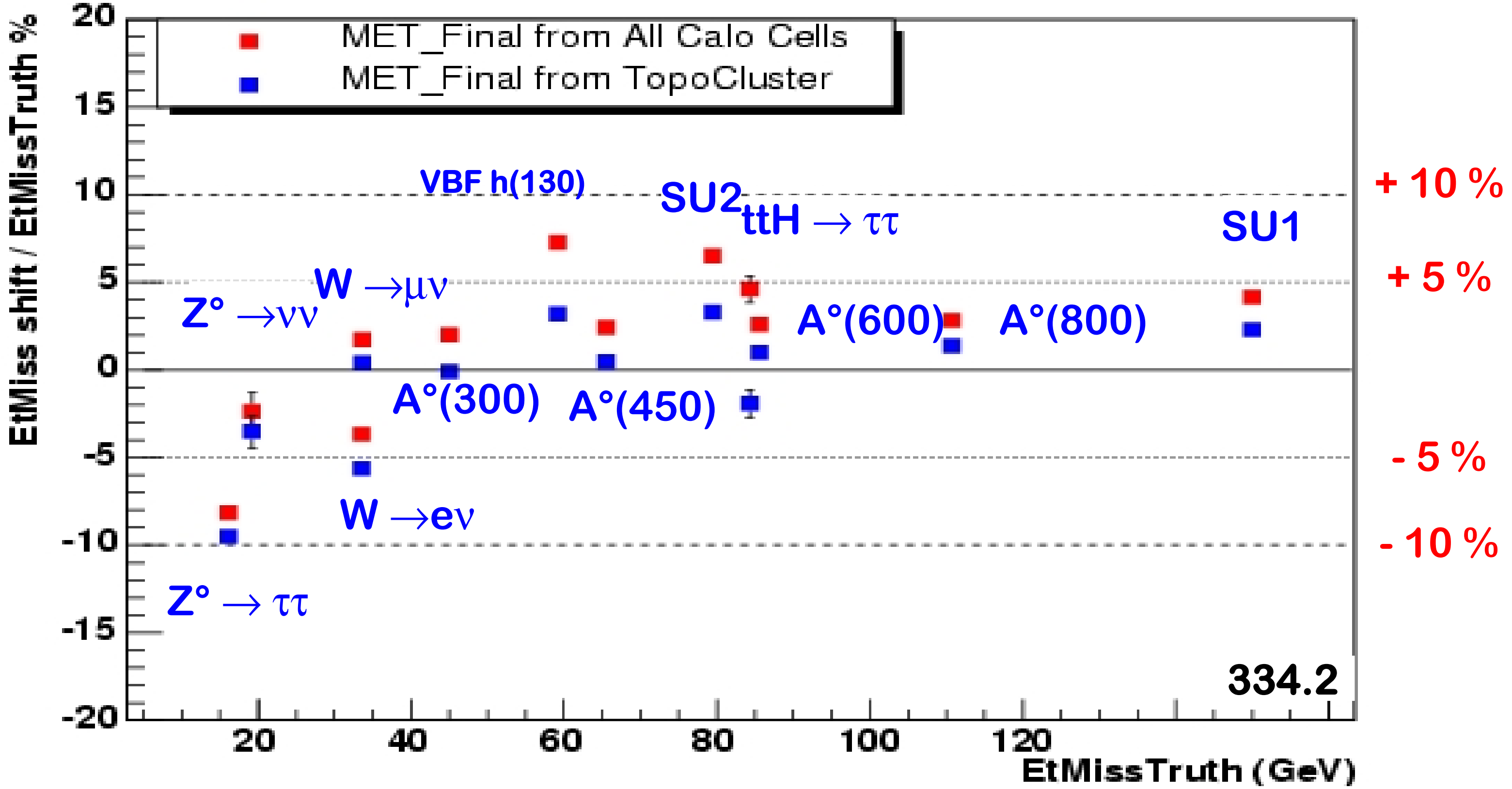
Reconstructing Missing ET in ATLAS

- Figure shows A $\rightarrow \tau\tau$ sample with mass of A = 800 GeV
- Resolution and scale improves with the use of noise suppression using CaloTopoCluster



Missing ET Scale

- Missing ET shift = True Missing ET - Reconstructed Missing ET
  - ⇒ Shift within 5% except at low Sum ET.
  - ⇒ Shift can come due to noise cut, non-optimal calibration, activity out of coverage etc.

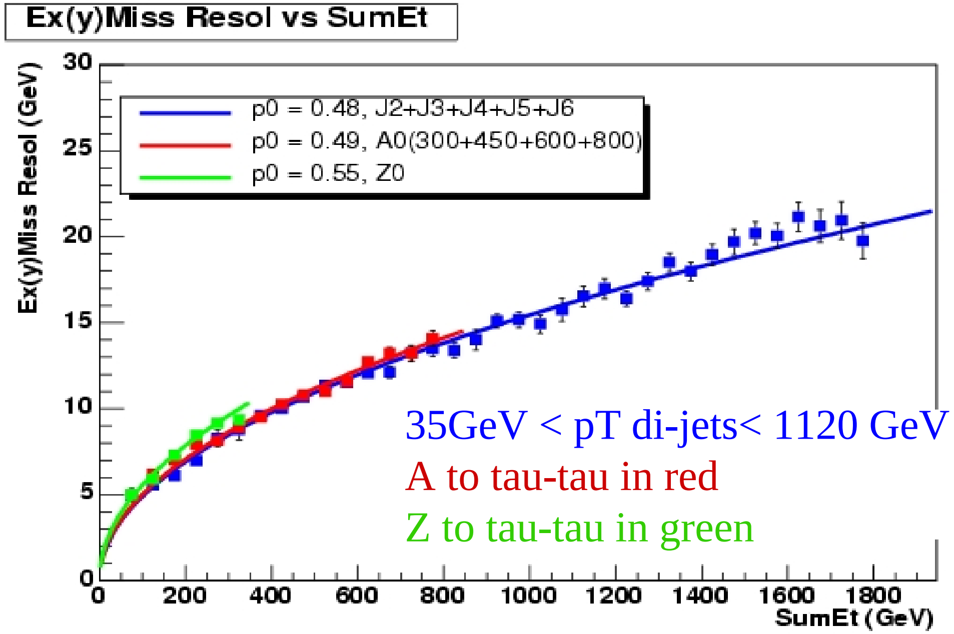


Missing ET Resolution

- EtMiss resolution well modeled with the functional form -

  Ex(y)miss Resol = p0 * $\sqrt{}$ SumET

  where, p0=0.46 from TDR studies.
- New studies with full simulation show similar behavior (fig).
- The present calibration based only on energy density only is not optimal for low energies.

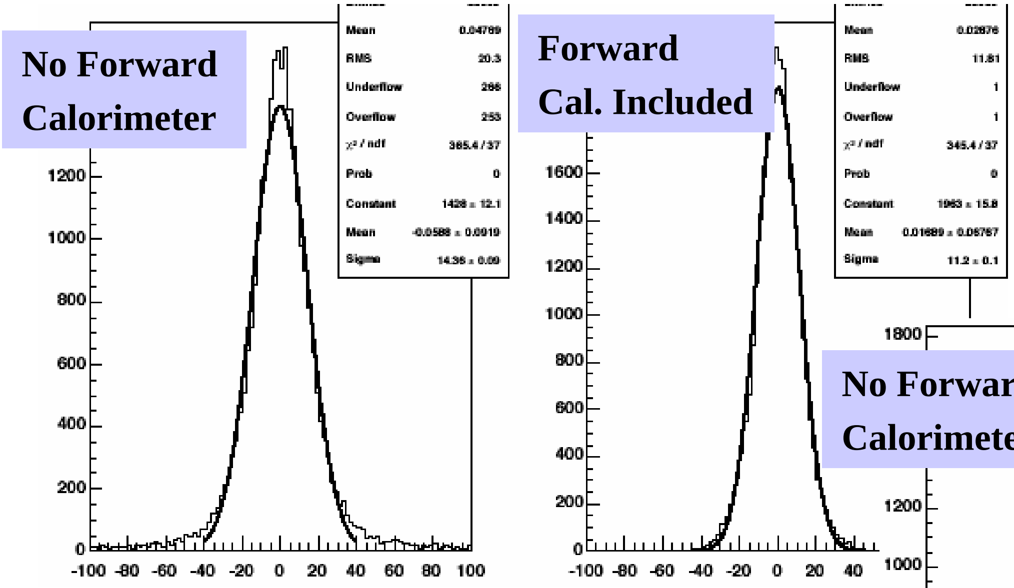


- Monitoring tails in Missing transverse energy distributions in simulation has helped debug simulation and reconstruction software.

  ⇒ Also, plans to study in detail the effect of gaps and dead material in the calorimeter with dedicated samples.
- Refined approaches - The final missing ET is to be reconstructed by refining calorimeter cell calibration by taking account of their position with respect to reconstructed electrons, photon, taus, muons and jets.

Missing ET Sensitivity and Forward Calorimeter

- FCAL 3.2 < |eta| < 5.0
- With no forward calorimeters the Missing ET resolution degrades,

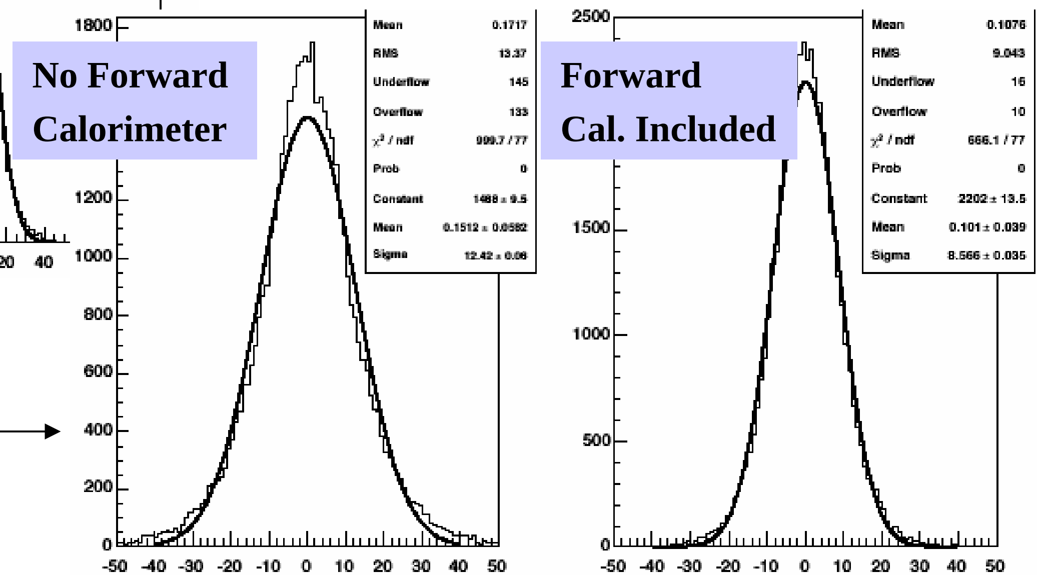


$\Rightarrow$ For dijet sample pT(140-280)

σ(Missing ET) 11 $\rightarrow$ 14 (GeV)

$\Rightarrow$ For Z to tau-tau sample

σ(Missing ET) 9 $\rightarrow$ 12 (GeV)



In-Situ Calibration: $Z \to \tau\tau \to$ *lept-had*

$\tau\tau$ invariant mass reconstruction

$Z^\circ \to \tau_1\, \tau_2 \to \text{prod}_1\, \nu_1\, \text{prod}_2\, \nu_2$ $\quad$ $\text{prod}_{1(2)}$ = jet , lept

- **Assumptions :**
  - $m_\tau = 0$
  - the two neutrino system directions are coincident with the ones of the measured τ-decay products (u_1, u_2)
  - τ-decay products are not back to back

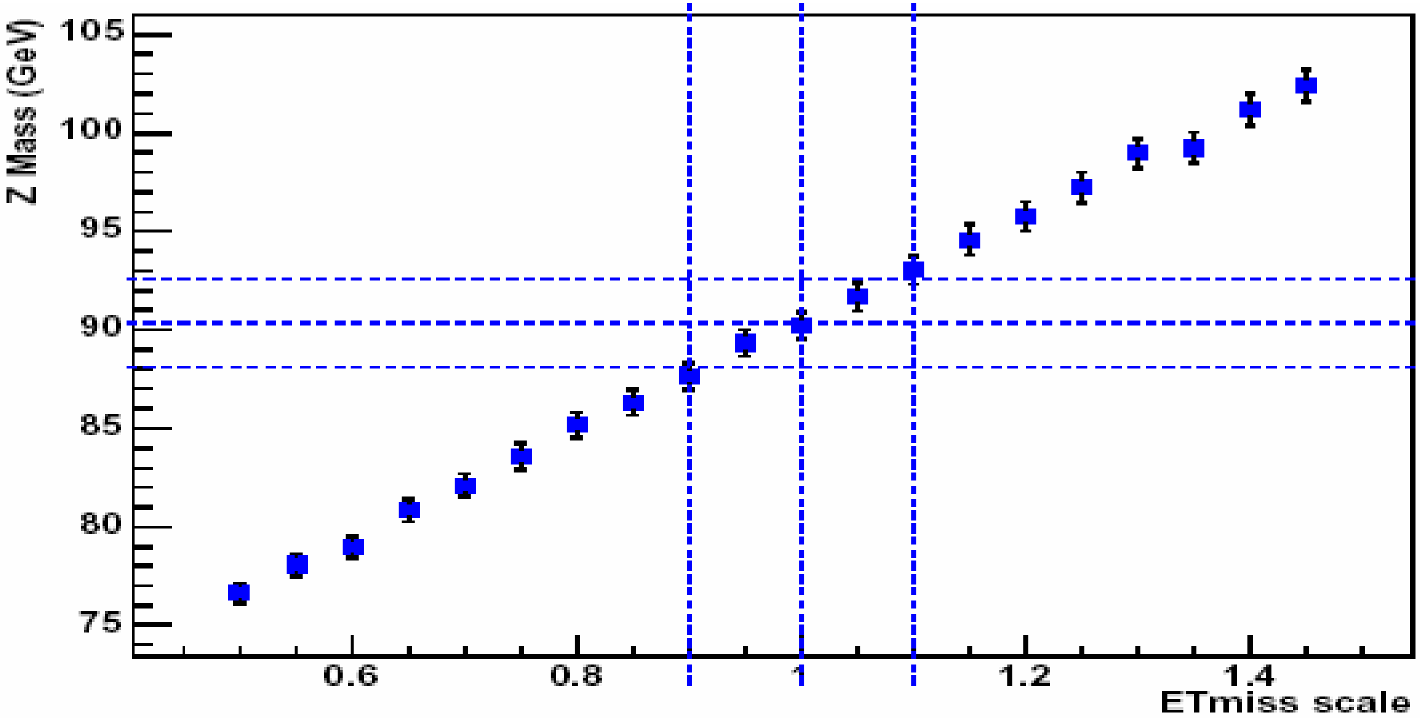
$$m_{\tau\tau} = \sqrt{2(E_1 + E_{\nu 1})(E_2 + E_{\nu 2})(1 - \cos\theta)}$$

- E_1, E_2 = τ-decay products energies
- θ = angle etween τ-decay products directions
- $E_{\nu 1}$, $E_{\nu 2}$ = energies of the two neutrino systems :

$$\sigma\,(m\tau\tau) = \sigma\,(\text{ETmiss}) \,/\, |\sin(\Delta\phi)_{\text{prod}_1\,\text{prod}_2}|$$

Sensitivity of in-situ calibration

- Z mass from $Z \to \tau\tau \to lept\text{-}had$ events

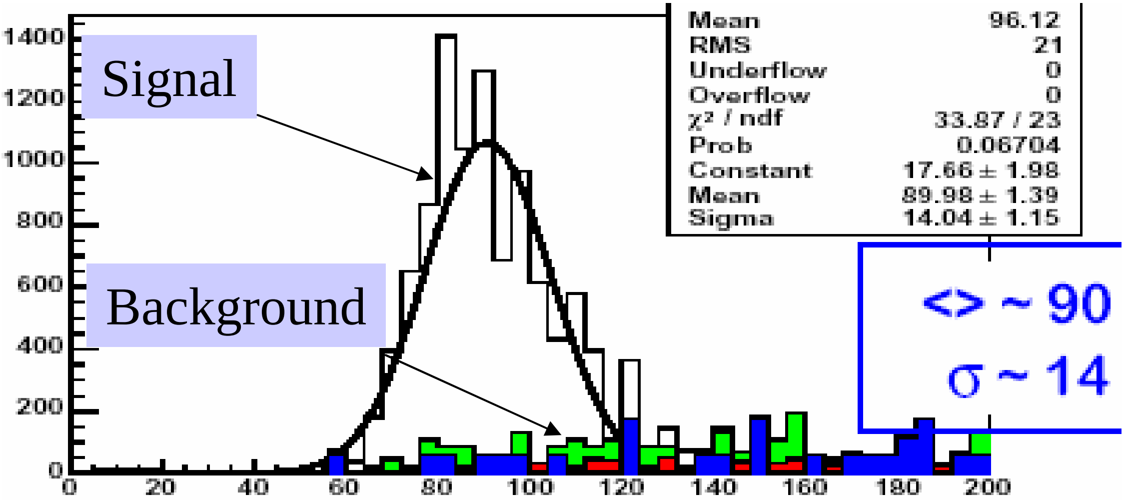


⇒ Plotted errors correspond to ~ 1000 evts

⇒ Signal only, background not added

- Z mass measured to 3% will result an error of 10% on Missing ET

In-Situ Analysis



Applied cuts :

pt(jet) > 25 GeV, $|\eta|<2.5$

pt(lep) > 25/20 GeV, $|\eta|<2.5$

$1.<\Delta\phi < 2.7$ or $3.6<\Delta\phi <5.3$

m_T(lept-pTmiss)<50GeV

τ-likelihood > 8

(τ-eff ~ 30%)

No lept isolation

- Expected number of events Z events for 1 fb-1 = 900.
- Backgrounds
  - ⇒ W+jets, $W \to e\nu$ (red), $W \to \mu\nu$(green)
  - ⇒ t,tbar, semi-leptonic decay of top with an electron or muon (blue)
  - ⇒ b bbar, with leptonic b decay → not considered yet.
- Expected backgrounds level 20-30%.
- Some typical cuts used in the analysis are shown.
- Full simulation studies ongoing with larger statistics background samples.

Summary

- Good missing ET measurement will be crucial for physics studies on ATLAS
  - ⇒ Both for Standard Model and beyond the Standard Model physics.
- Missing ET reconstruction algorithms show good linearity and resolution in Geant4 fully simulated MC samples for different physics channel
  - ⇒ Further refined approaches for better linearity and resolution are being studied.
- Events with Z decaying to tau pairs is a promising way to establish the missing ET scale
  - ⇒ Studies with larger background samples are under-way.