MissingET in the ATLAS detector

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Dr Giovanni Siragusa

The XIV LNF Spring School
"Bruno Touschek"
in Nuclear, Subnuclear and Astroparticle Physics

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

BMBF-Forschungsschwerpunkt
ATLAS Experiment
Physics on the TeV-scale at the Large Hadron Collider
FSP 101
ATLAS

ATLAS

Physics motivation

- A very good measurement of the Missing Transverse Energy (E_T^{miss}) is essential for many physics studies
  - Events with large E_T^{miss} are expected to be key signatures for new physics (SUSY, Extra Dimensions)
  - A good measurement in terms of linearity and resolution is also important for reconstruction of the top-quark mass from ttbar events with one of the top-quark decaying semi-leptonically
  - Crucial for the efficient and accurate reconstruction of the Higgs boson mass, when decaying to a pair of τ-leptons
  - SM studies also require a good knowledge of the E_T^{miss} (e.g. W boson cross section and mass measurement)

The Large Hadron Collider

Design parameters

$\sqrt{s}$=14 TeV

$\mathscr{L}=10^{34}\,cm^{-2}s^{-1}$

40 MHz bunch-crossing rate

Initial operation

$\sqrt{s}$=10 TeV

$\mathscr{L}=10^{31}$-$10^{32}\,cm^{-2}s^{-1}$

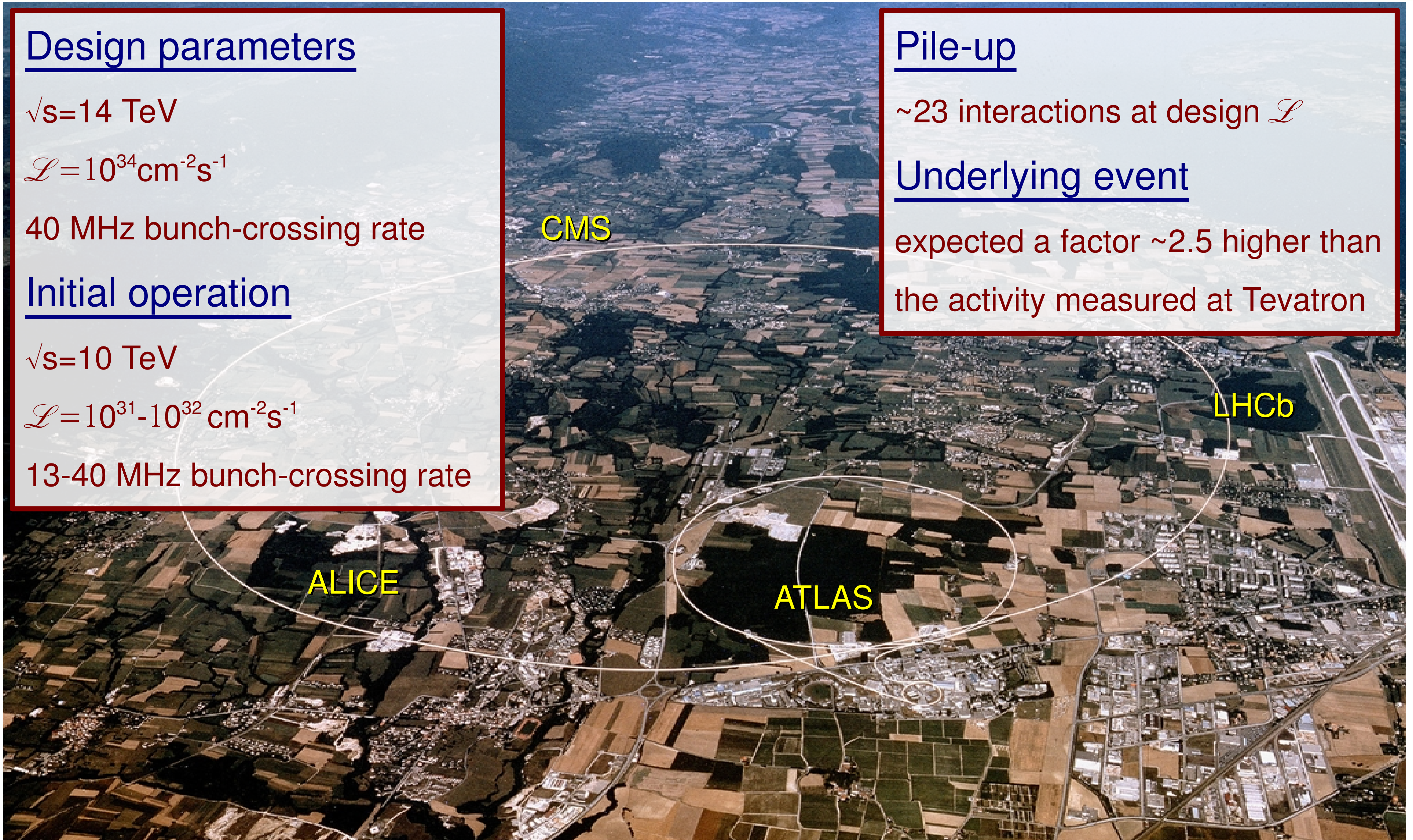
13-40 MHz bunch-crossing rate

Pile-up

~23 interactions at design $\mathscr{L}$

Underlying event

expected a factor ~2.5 higher than the activity measured at Tevatron



The ATLAS detector

General purpose detector

Inner Detector ($|\eta| < 2.5$)

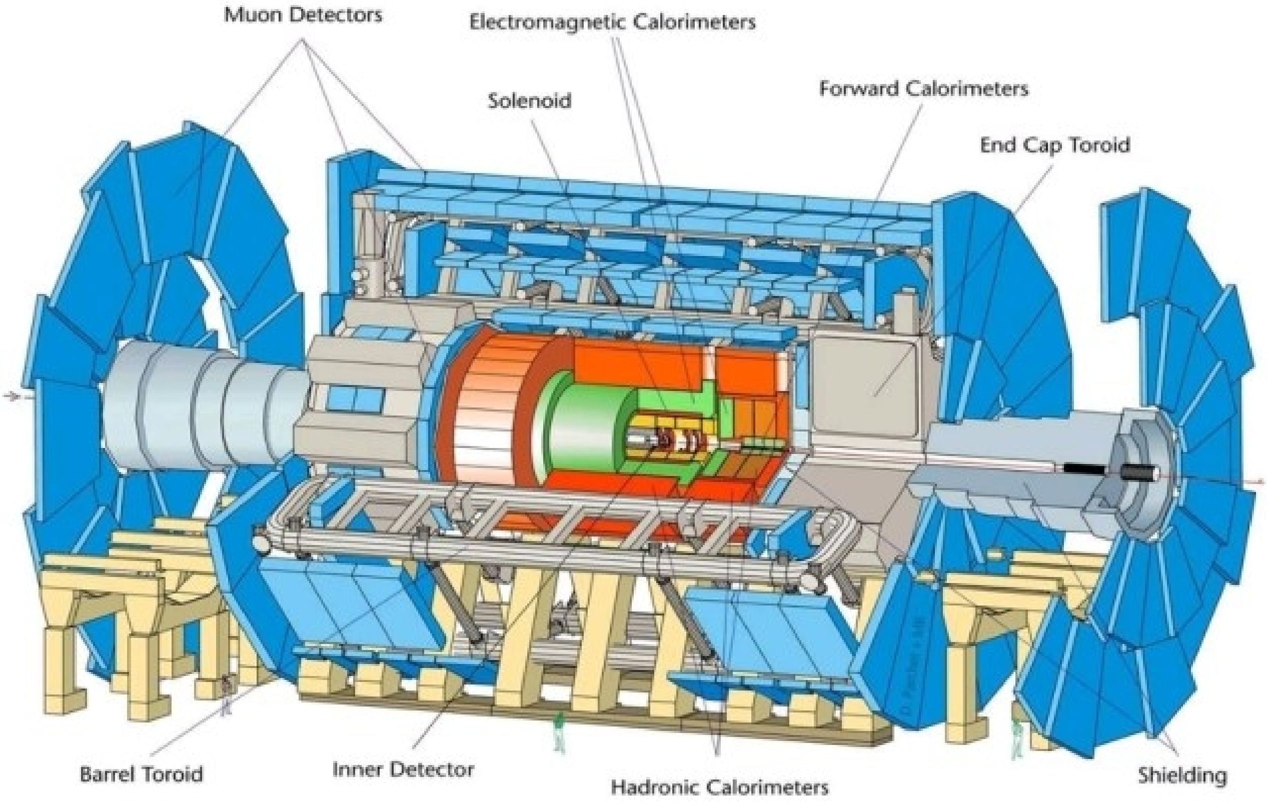
- Homogeneous solenoidal field (2T)
- High resolution/granularity, particle ID

Calorimeter ($|\eta| < 4.9$)

- Electron/photon
  - $\sigma(E)/E = 10\%/\sqrt{E(GeV)} + 0{,}7\%$
  - linearity better than 0.5%
- Jets
  - $\sigma(E)/E = 50\%/\sqrt{E} + 3\%$ ($|\eta|<3$)
  - $\sigma(E)/E = 100\%/\sqrt{E} + 10\%$ ($|\eta|>3$)

Muon Spectrometer ($|\eta| < 2.7$)

- Air core toroidal field
- 10% resolution for muons p_T of 1 TeV
  - Less than 5% up to 100 GeV



The Missing Transverse Energy

$E_{x,y}^{miss} = - \sum E_{x,y}$ (where the sum is done over all the energy deposits in the event)

- At hadronic colliders it is not possible to use the Centre of Mass Energy to constrain the kinematic of the event
  - The conservation of the transverse momentum (orthogonal to the beam direction) can be used to measure the transverse momentum of non interacting particles
- Such a measurement requires the knowledge of the entire event and of the calibrations
  - Need to understand the calibration with high accuracy for high p_T objects and for the "soft" part of the event (mainly pions)
  - Affected by underlying event/pile-up and limited detector coverage

The algorithm for E_T^{miss} reconstruction in ATLAS

- The reconstruction of the E_T^{miss} is mainly based on the Calorimeter measurement
- Corrections are applied for muons and energy lost in dead materials

Cell-based calculation

- Collect the energy deposits in cells that survive a noise cut
- Calibrate cells accordingly to their energy density or cluster shape
- Add the muon p_T (from MS)
- Correct for energy loss in dead regions of the detector
- Refine calibration according to reconstructed objects

Robust already at initial data taking

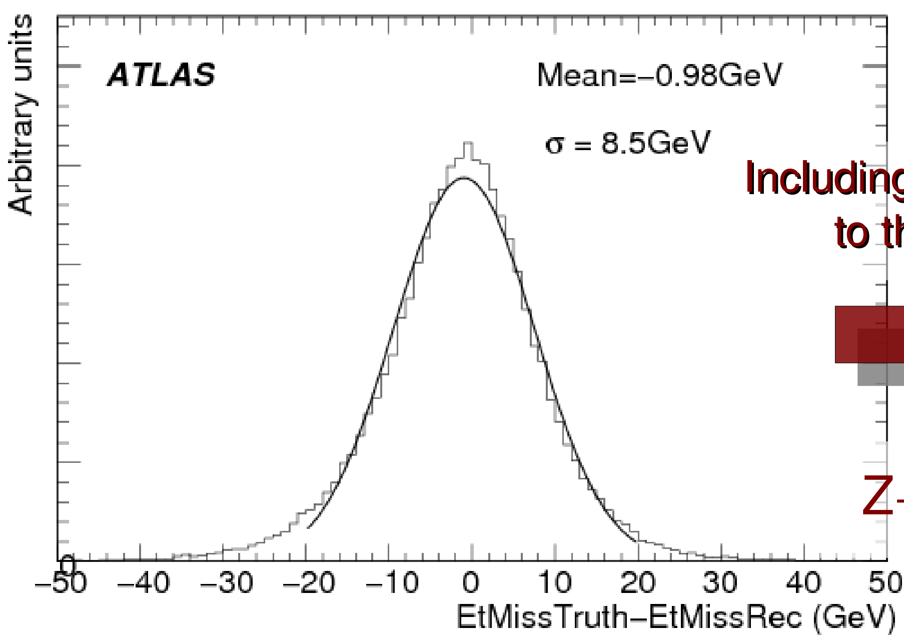
Object based calculation

- Classification of high- and low-p_T
- Identify e, γ, μ, τ (high-p_T)
- Identify jets (without the clusters previously assigned to high-p_T)
- Remaining cluster classified as low-p_T deposits
  - $\pi^{\pm}$, π^0, soft jets
- High- and low-p_T objects are calibrated

Better against low energy deposits

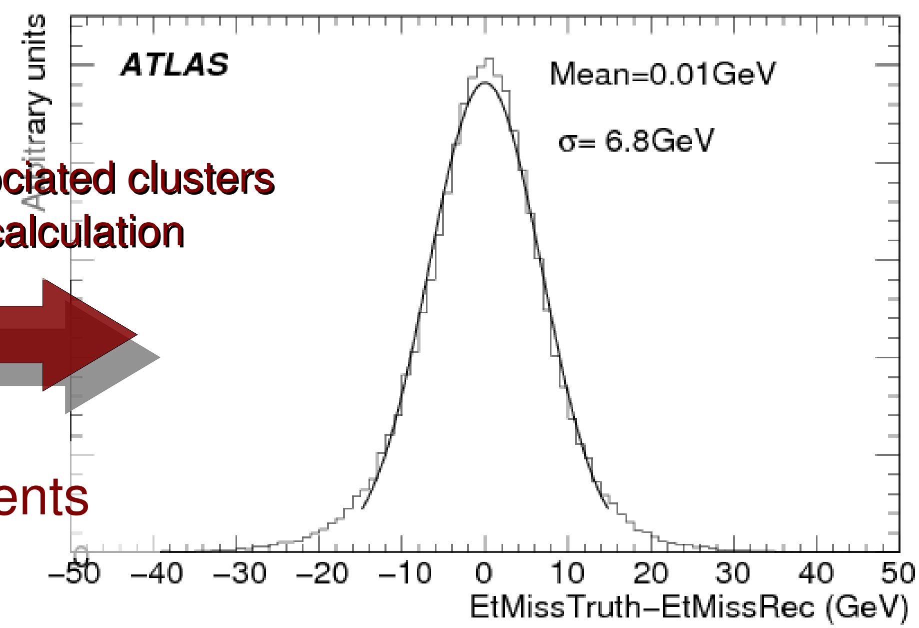
Effect of the "soft" part of the event

- All Cells surviving the noise cuts, even if not associated with any high-p_T reconstructed object, are used in the E_T^{miss} calculation (calibrated using the global calibration schema)
  - Recover bias of ~1 GeV
  - Resolution improved by a factor ~1.25



Including un-associated clusters to the E_T^{miss} calculation

$Z \rightarrow \tau\tau$ events

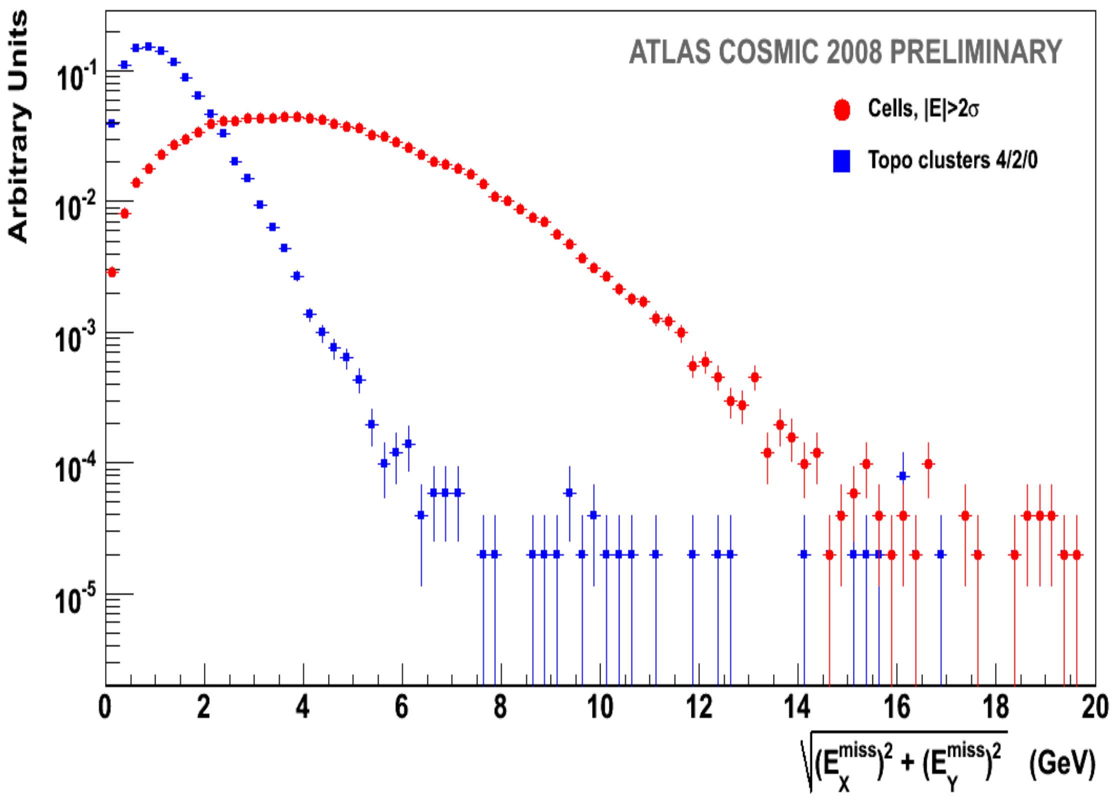


Calorimeter noise suppression

The electronic noise alone in ~200k readout channels of the calorimeter contributes about 13GeV to the width of the E_T^{miss}

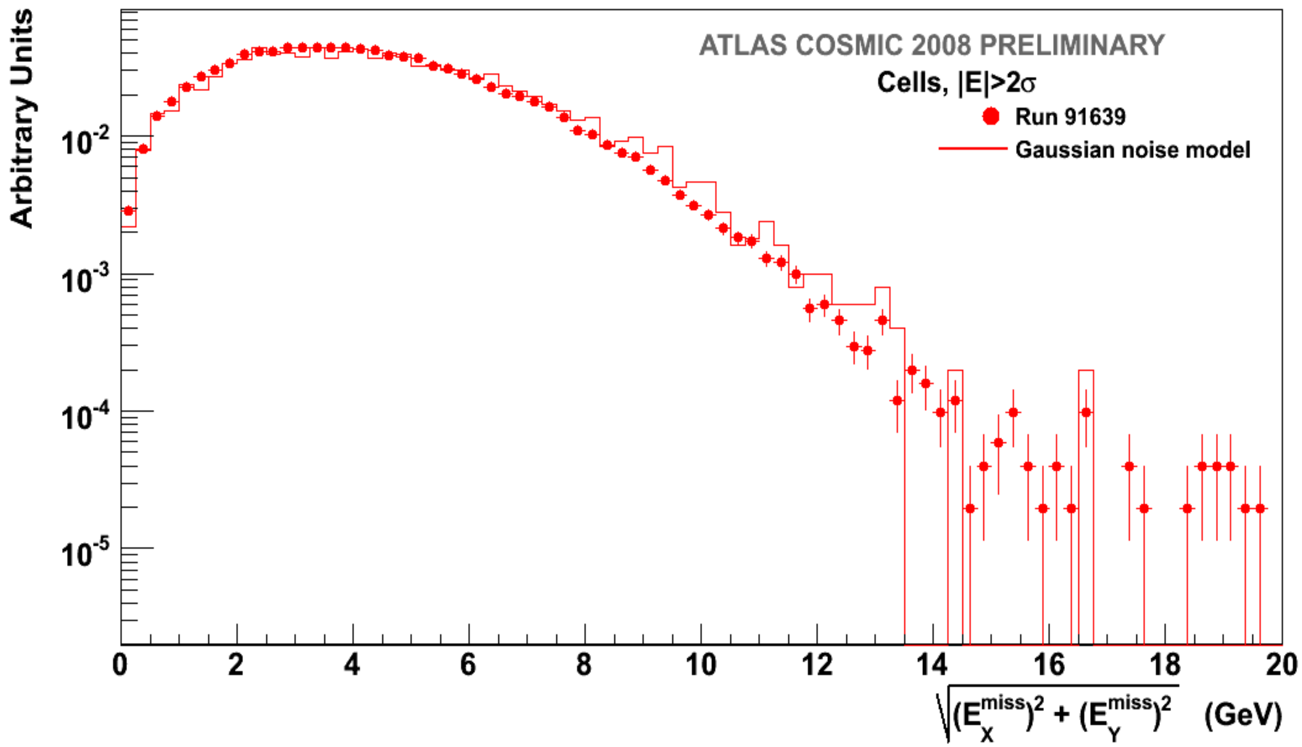
- Standard noise suppression
  - $E_{cell} > n \cdot \sigma_{noise}$
- Topological clustering: collect neighbouring cells until the cell energy falls below a threshold (4/2/0)
  - Cells with very low signal can survive based on the signal in neighbouring cells

Random trigger events: no real E_T^{miss} sources expected



Data-Simulation comparison

- The expected E_T^{miss} distribution obtained by a randomisation of the cell energy with a Gaussian noise of width σ_{noise}, superimposed on the measured cell-based ETmiss distribution
  - A good description of the observed distribution is seen



Global and refined calibration

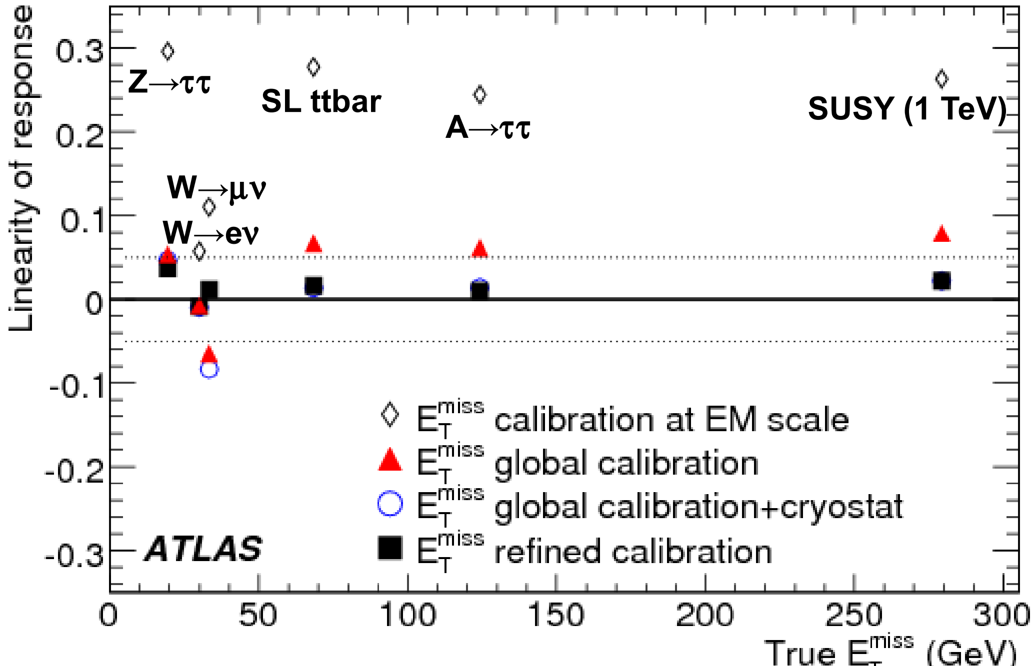
The Cell-based calculation applies calibration in two steps

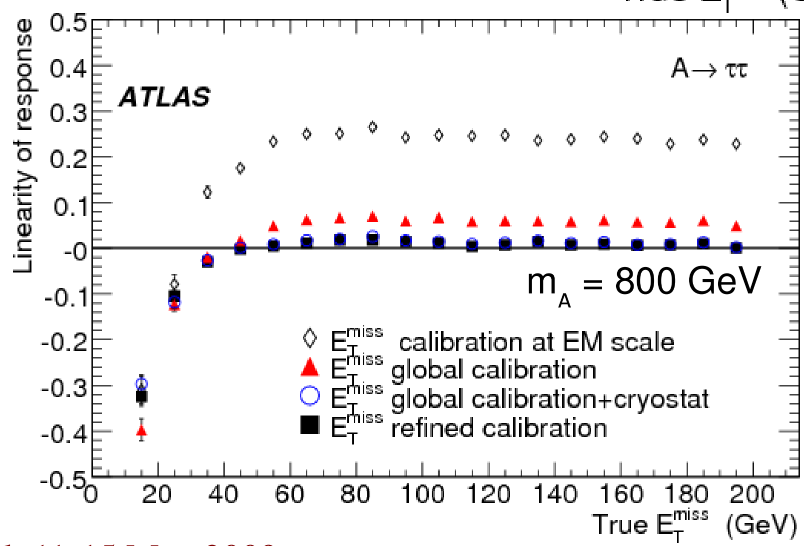
- Global calibration
  - Based on the energy density
  - Based on the signal shape
- Refined calibration
  - For each physics object

At the EM scale the E_T^{miss} linearity has a 30% bias, which is reduced to 5% using the global calibration

The level of hadronic activity in the event is crucial

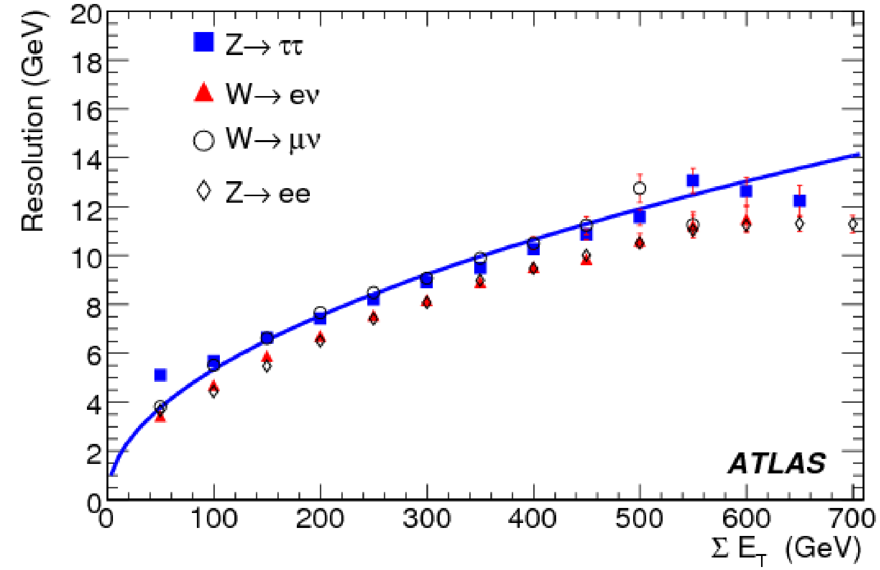
Linearity = $(E_t^{miss, True} - E_T^{miss}) / E_t^{miss, True}$

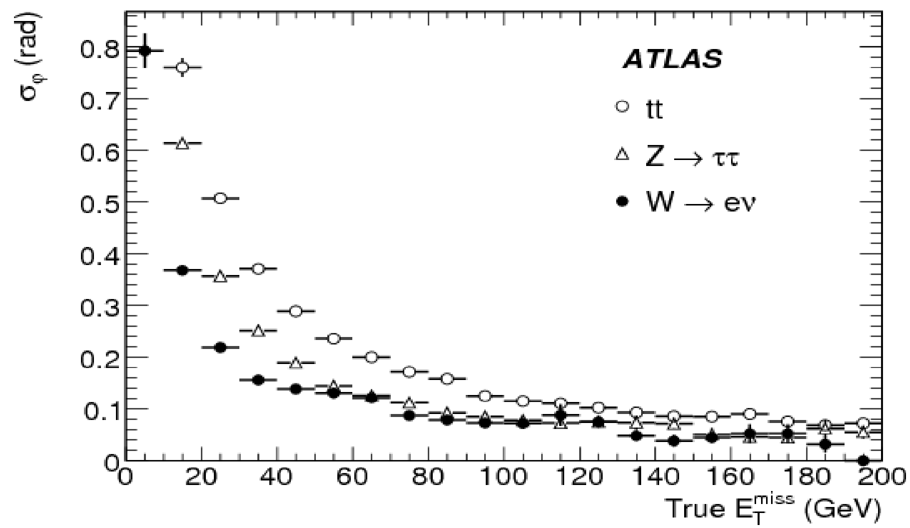




E_T^{miss} resolution

- The E_T^{miss} resolution follows approximately a stochastic behaviour as a function of ΣE_T
  - Deviation expected at low ΣE_T because of the noise and at high ΣE_T, where the constant term of the calorimeter resolution dominates
- The angular resolution in events with true E_t^{miss} is mainly guided by the presence of fake E_t^{miss}
  - Good for high values of $E_T^{miss,\ True}$
  - Detector inefficiencies may perturb the radial symmetry of the physics event

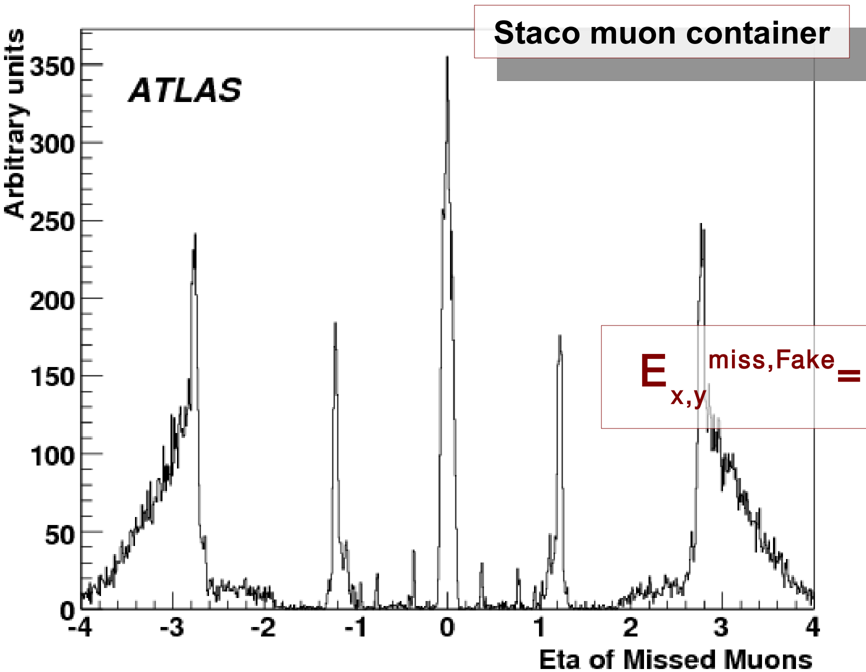




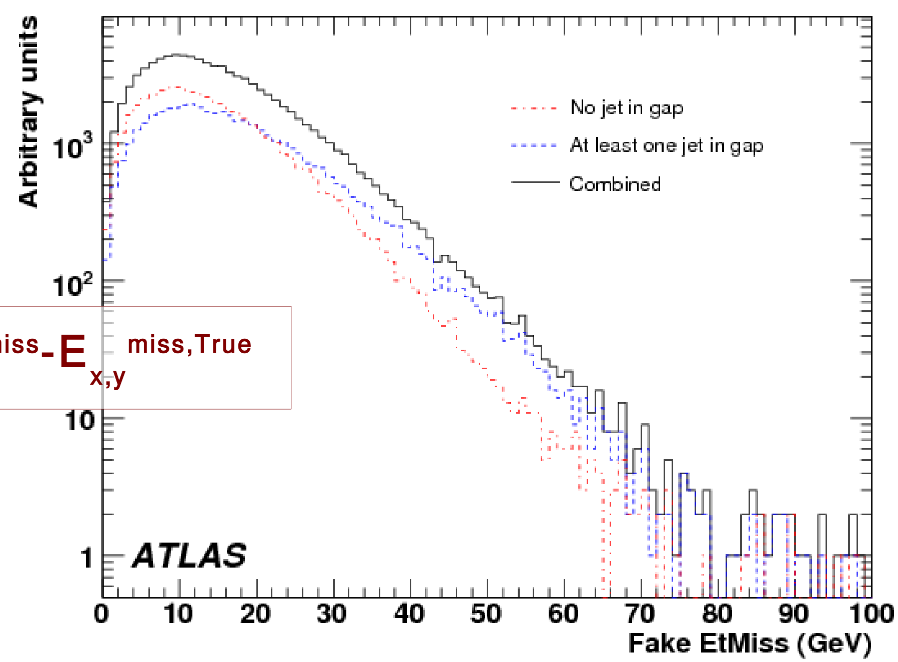
Fake E_T^{miss}

The main sources of Fake E_T^{miss}

- Muons which fly outside the detector acceptance or fake high-p_T muons
- Jet mis-measurement in poorly instrumented regions of the calorimeters
  - For high values (fake E_T^{miss} > 50 GeV) smearing of the effect of many jets
- Calorimeter leakage can be improved using tracking information
- Mis-modeling of material distribution or instrumental failures

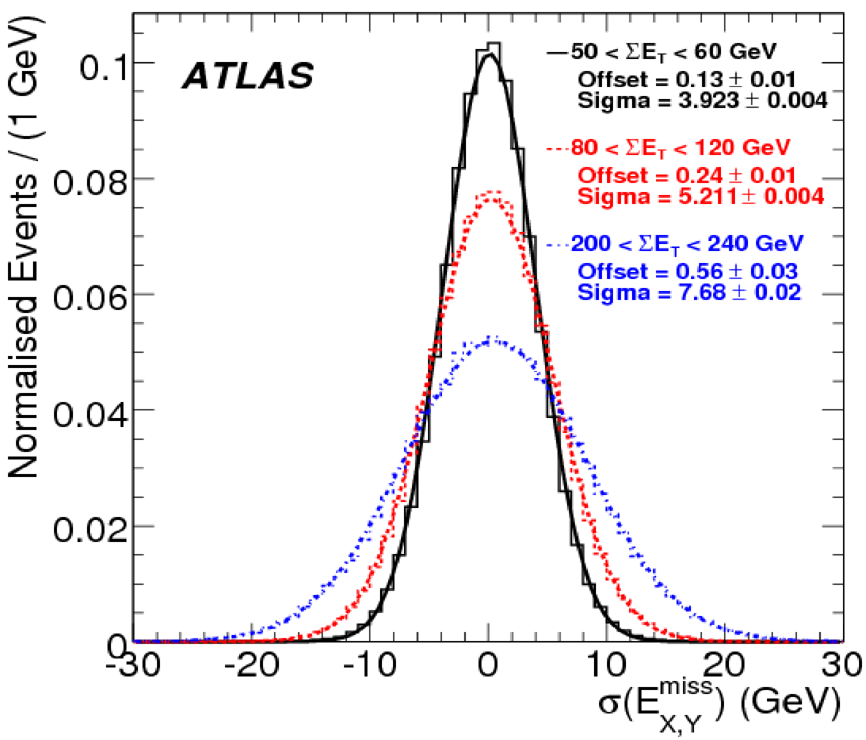


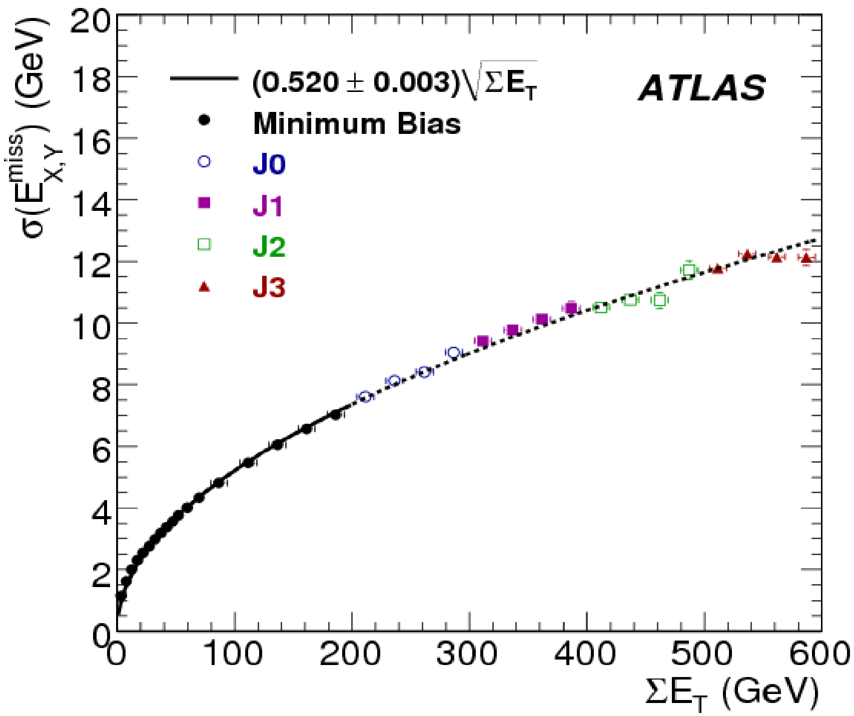
$$E_{x,y}^{miss,Fake} = E_{x,y}^{miss} - E_{x,y}^{miss,True}$$



E_T^{miss} in early data: Minimum Bias

- Many processes can be used to validate and optimize the E_T^{miss} reconstruction on first data
  - Minimum Bias events, mainly dominated by soft *pp* collisions have a large statistics (~100 mb) and a relatively simple selection

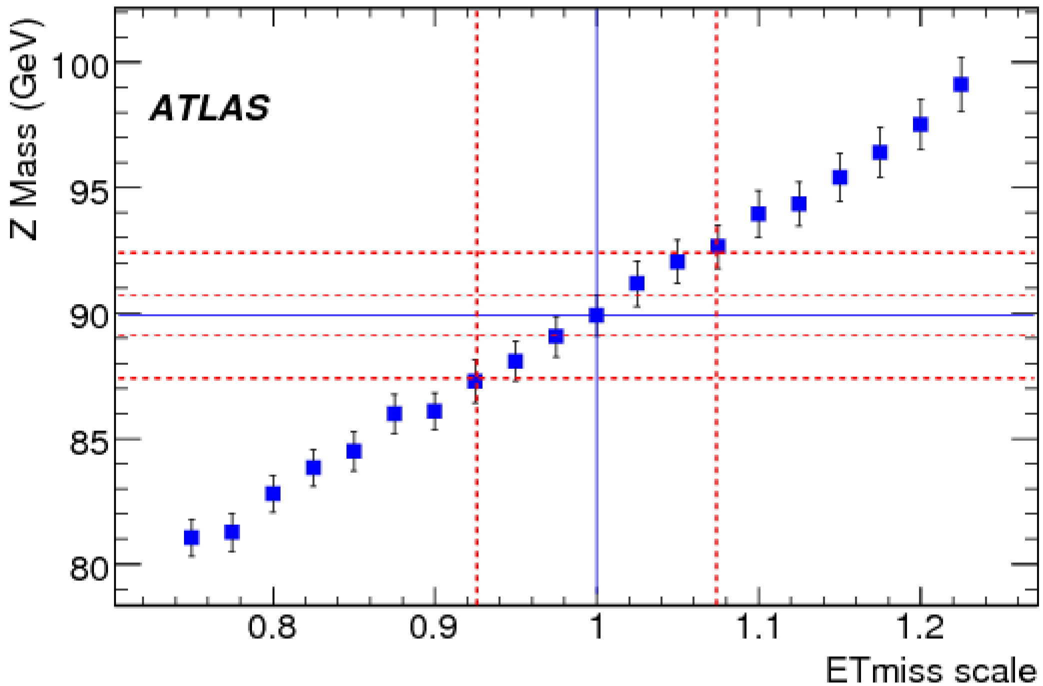




E_T^{miss} in early data: energy scale

$Z \rightarrow \tau\tau$ events are a powerful handle to estimate the E_T^{miss} scale, while affected by poor statistics (~200 events in 100 pb^{-1})

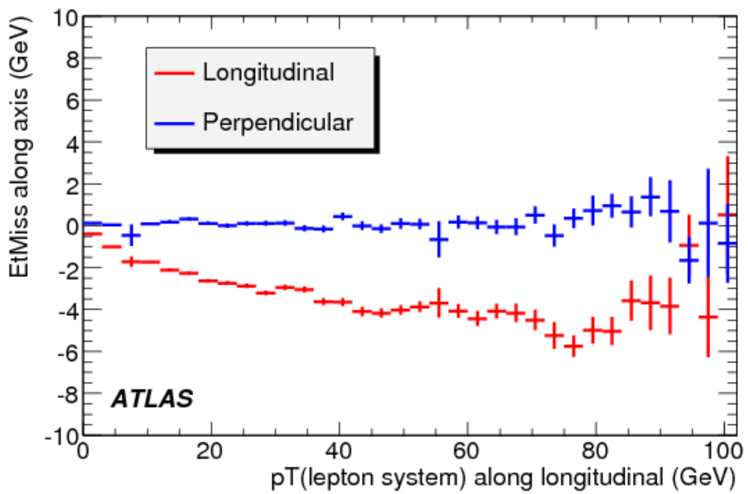
- Expected error on the scale: 3% (stat) + 5% (syst)



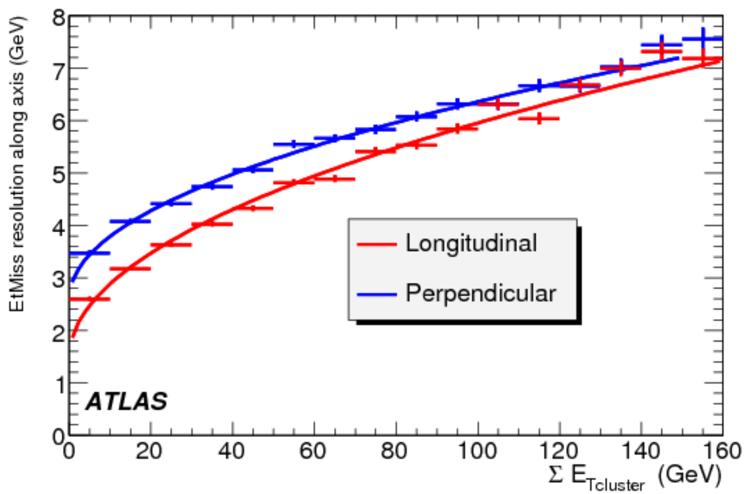
E_T^{miss} in early data: Z→ee

Z boson decay in the electron and muon channel are clear signatures

- Possibility to understand the E_T^{miss} resolution and bias
- Preferential axes maximize the sensitivity to E_T^{miss} measurement (under study)
  - Longitudinal (bisector of the angle formed by the electron
  - Perpendicular (orthogonal to the Longitudinal)
- A bias in the Longitudinal axe is due to the hadronic recoil underestimation



Simulated Z→ee events (250 pb^{-1})



Data driven measurement of E_T^{miss} resolution in W events

- At first stage of the analysis we need to know the acceptance (e.g. to measure cross section)
  - Correct MC using measured quantities and a smearing function: $W_{data}=W_{MC\_truth}+Gauss_{smear}(\langle hadronic\ recoil\rangle, \sigma)$
  - The smearing parameters can be obtained from data using Z events
    - Hadronic recoil (“true”)= reconstructed p_T^Z
    - Hadronic recoil (reconstructed) = reconstructed E_T^{miss} – electron's p_T
- The direct comparison of the Hadronic Recoil in W and Z events
  - Relies on the possibility to properly recalculate the E_T^{miss}
  - Remove the electrons from the decay: work on going, promising results

Conclusion

- A proper measurement of the Missing Transverse Energy is so crucial as challenging in the LHC environment
- An overview of the current status of the E_T^{miss} reconstruction has been presented, describing algorithms, performance and strategies
- Detailed MC studies demonstrate that the expected performance can be achieved, while runs with random triggers have demonstrated that the description and suppression of the instrumental noise work well
- On going analysis of cosmic and single beam data will provide further understanding in view of collisions

Outlook

- With 100 pb^{-1} of data (at E_{CM}=10 TeV) ATLAS can improve Tevatron measurements (e.g. limits on W', Z' masses)
- The way from data to physics will be hard, but exciting
- In view of first collision data physics and performance groups are refining the strategy for a proper E_T^{miss} measurement
- Priority is to understand SM physics from data (as is background to interesting new physics processes)