# Jet and $E_T^{miss}$ Commissioning in ATLAS

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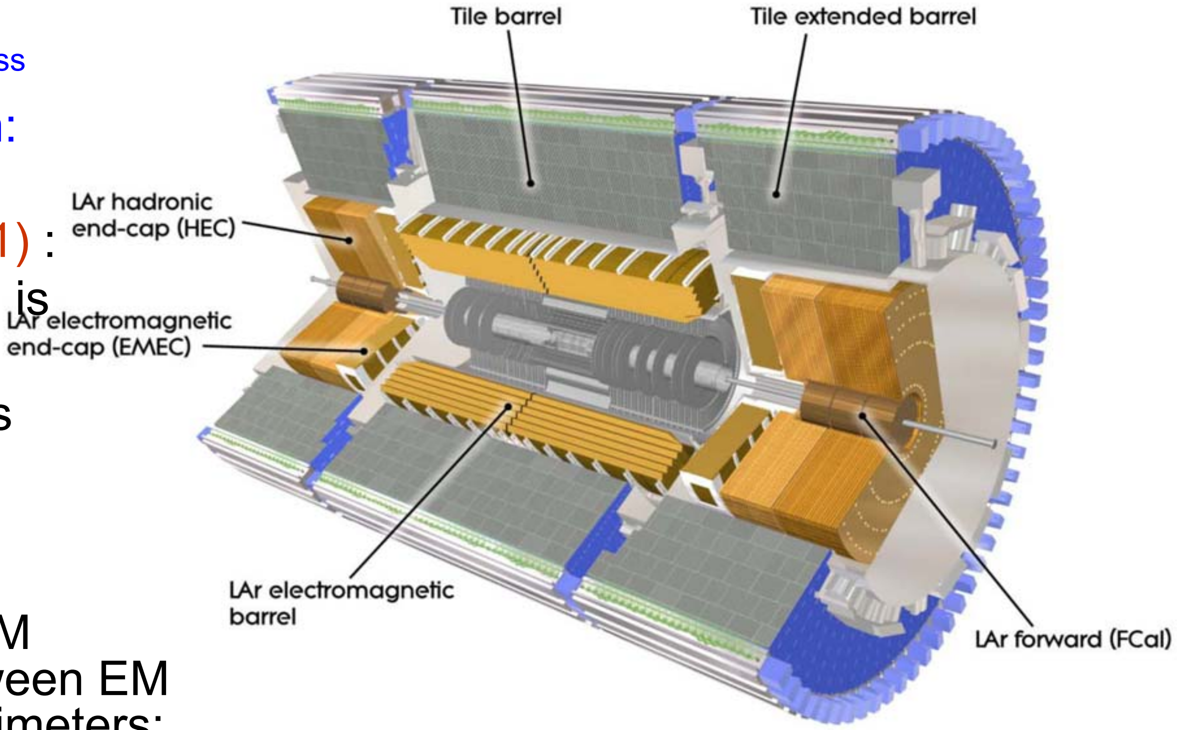
# Outline

- Atlas calorimeter:
  - main features for jets and $E_T^{miss}$
- Jet and EtMiss reconstruction:
  - input calorimeter signals
- Commissioning Jets and $E_T^{miss}$ :
  - with Cosmic Rays: noise studies, cleaning cuts
  - the challenge: understand the sources of “fake” $E_T^{miss}$
- Strategy for Jet calibration:
  - Global and Local calibration
  - “in-situ” Jet Energy Scale
- Strategy for $E_T^{miss}$ reconstruction and calibration:
  - from Basic to Refined $E_T^{miss}$
  - “in-situ” $E_T^{miss}$ commissioning: the road-map
- Summary

# ATLAS calorimeters

Main features for jet and $E_T^{Miss}$ reconstruction and calibration:

- Non compensating (e/h >1) :
  - Response to hadrons is lower than that to electrons and photons
  - Developed specific calibrations
- Dead material:
  - Energy loss before EM calorimeter and between EM and HAD barrel calorimeters:
    - dead material corrections
- Different technologies and many transition regions:
  - "Crack" regions: $\eta \approx 1.4, 3.2$
- Magnetic field bending



**ATLAS Fiducial Regions**

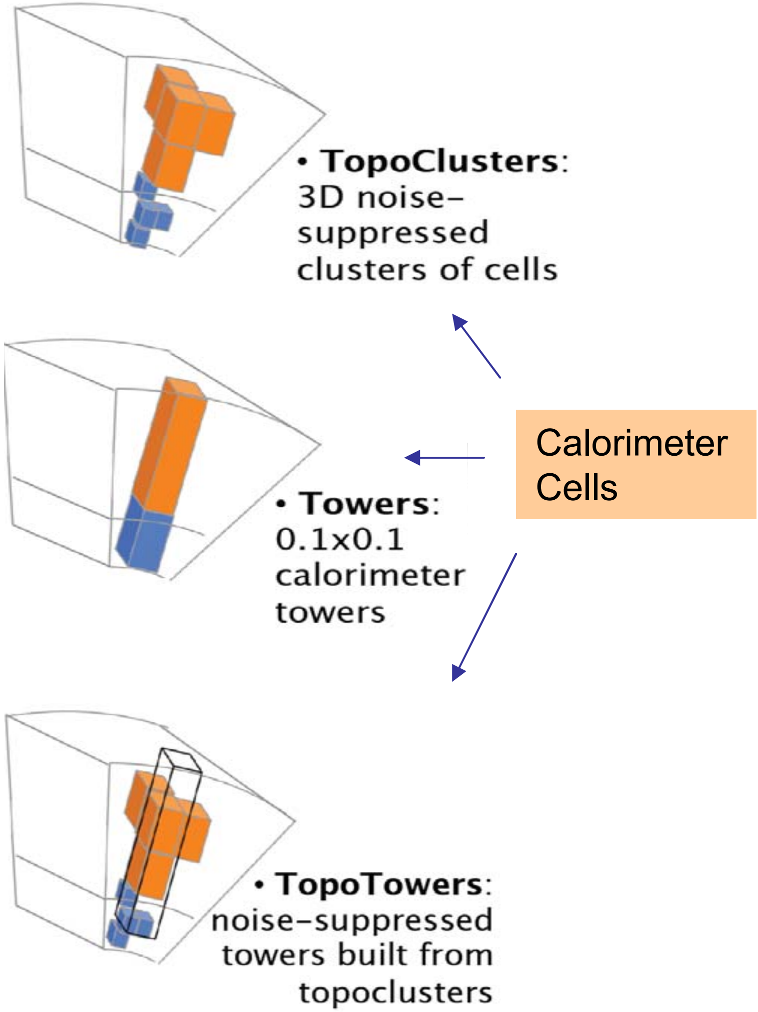
- Hadronic Calorimeter:
  - Barrel: $|\eta| < 1.7$
  - Endcap: $1.5 < |\eta| < 3.2$
- Electromagnetic Calorimeters
  - Barrel: $|\eta| < 1.4$
  - Endcap: $1.375 < |\eta| < 3.2$
- Forward: $3.2 < |\eta| < 4.9$

$\eta = -\log(\tan(\theta/2))$

# Input signals to Jets and ETmiss

- Topo-Clusters: group of calorimeter cells topologically connected
  - – Noise suppression via noise-driven clustering thresholds:
    - Seed, Neighbour, Perimeter cells ($S$,$N$,$P$) = (4,2,0)
      - – seed cells with $|E_{\text{cell}}| > S\sigma_{\text{noise}}$ ($S = 4$)
      - – expand in 3D; add neighbours with $|E_{\text{cell}}| > N\sigma_{\text{noise}}$ ($N = 2$)
        - » merge clusters with common neighbours (N < S)
      - – add perimeter cells with $|E_{\text{cell}}| > P\sigma_{\text{noise}}$ ($P = 0$)
  - – Attempt to reconstruct single particles in calorimeter
- Towers: thin radial slice of calorimeters of fixed size

- Topo-Tower: selecting only the cells in the tower with a significant signal



- **TopoClusters**: 3D noise-suppressed clusters of cells

- **Towers**: 0.1x0.1 calorimeter towers

- **TopoTowers**: noise-suppressed towers built from topoclusters

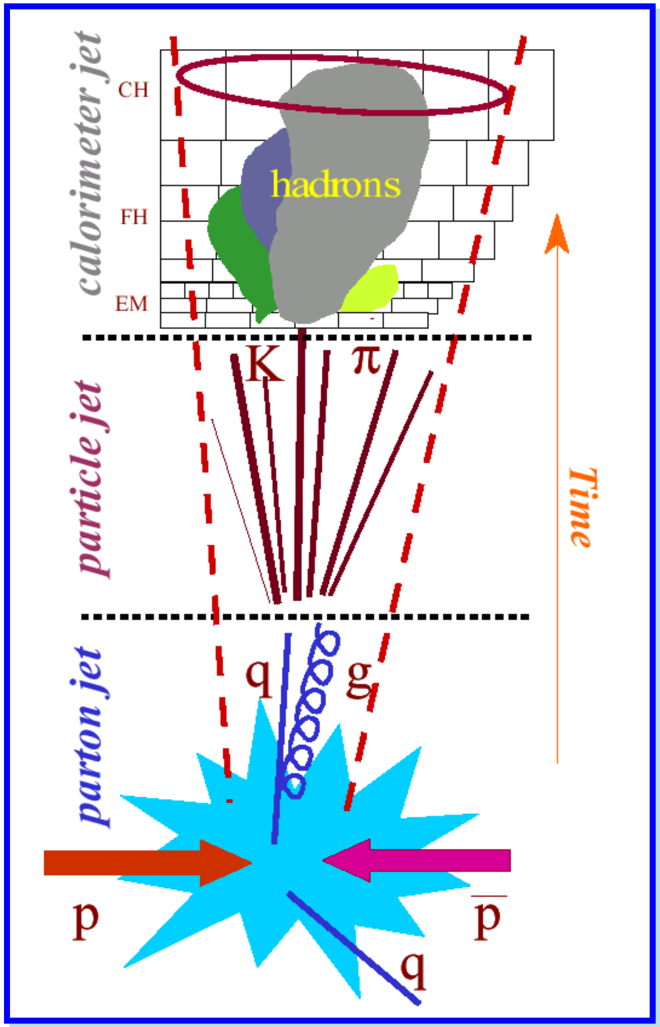
Calorimeter Cells

# Jet Reconstruction

Sequential process:

- Input signal selection:
  - TopoClusters, Towers, TopoTowers
- Jet finding:
  - The jet finding algorithm groups the collection of clusters(towers) according to geometrical and/or kinematic criteria.
  - Many algorithms studied in ATLAS: ⇒ recently concentrated on

    AntiKt algorithm
- Jet calibration:
  - depending on detector input signal definition, jet finder choices…
- Jet selection:
  - apply cuts on kinematics to select jets of interest



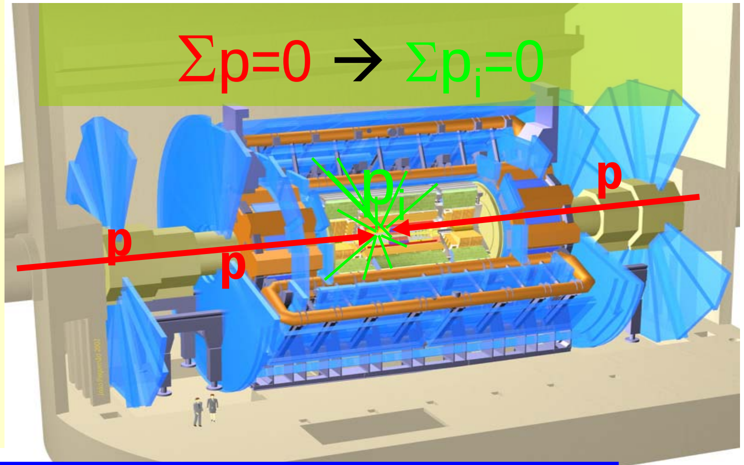
# $E_T^{miss}$ Reconstruction

Transverse Missing Energy:

$$E_T\text{miss} = \sqrt{E_X\text{miss}^2 + E_Y\text{miss}^2}$$

$$\left.\begin{array}{l} E_x\text{miss} = -\Sigma Ex \\ E_y\text{miss} = -\Sigma Ey \\ \text{Sum}E_T = \Sigma E_T \end{array}\right\}$$

Sum of energy of all particles seen in the detector

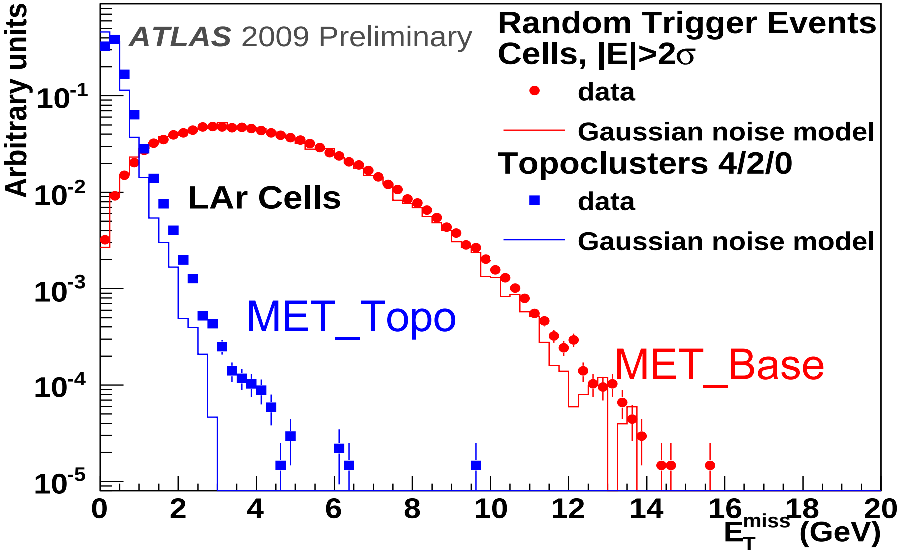


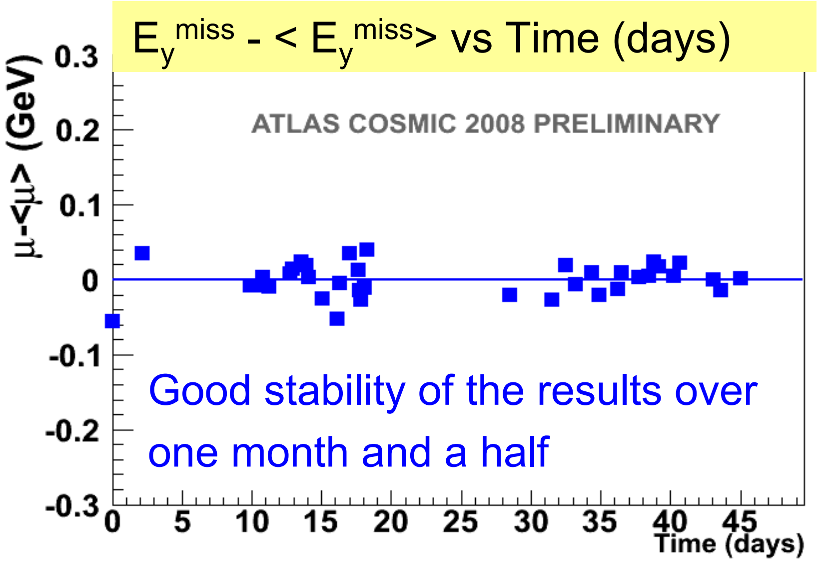
**$E_T^{miss}$ is a complex event quantity:**

- It is calculated adding all significant signals from all detectors:
  - Calorimeter input signals (Cells, TopoClusters):
    - in physics objects
    - not used in physics objects
  - Muons
  - Tracks in regions where Calorimeter/Muon Spectrometer are inefficient
  - Correction for energy lost in dead material

# Noise studies on $E_T^{miss}$

- Basic $E_T^{miss}$ studied in Random Trigger events from cosmics ray runs
- Resulting $E_T^{miss}$ is summed from all calorimeter cells applying two different methods for noise suppressions:
  - from all Cells with $|E|>2\sigma$ noise ⇒ MET_Base
  - from all Cells inside TopoClusters ⇒ MET_Topo, better noise suppression

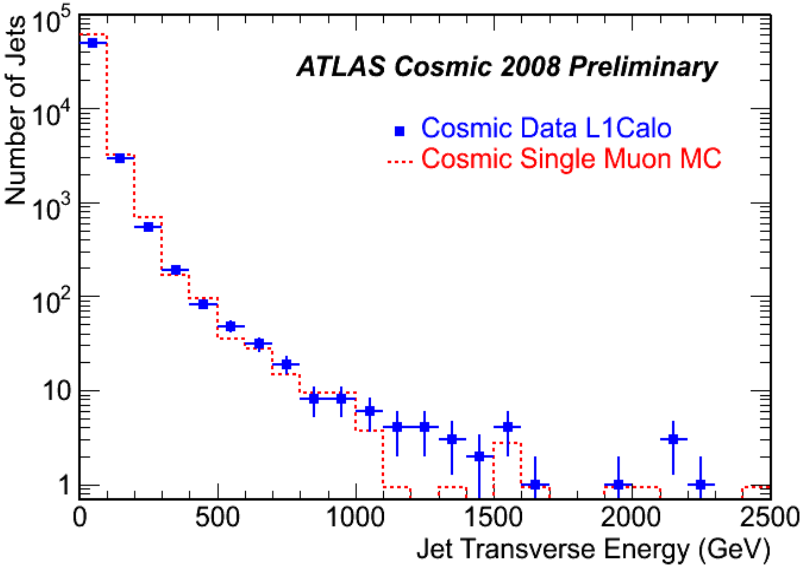




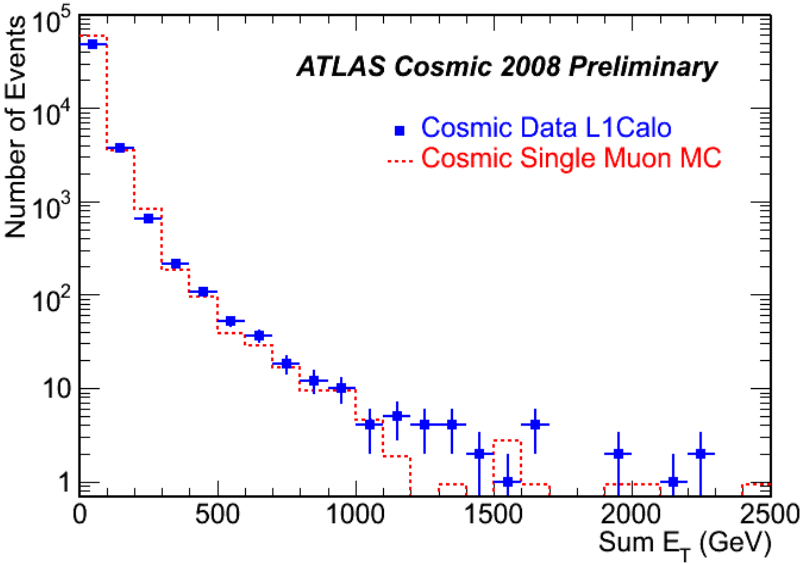
Good stability of the results over one month and a half

- Distributions are consistent with Gaussian noise
- High noisy channels masked at calorimeter cell level but possibility to mask also at $E_T^{miss}$ reconstruction level

# Commissioning Jet and $E_T^{miss}$ with Cosmic Rays



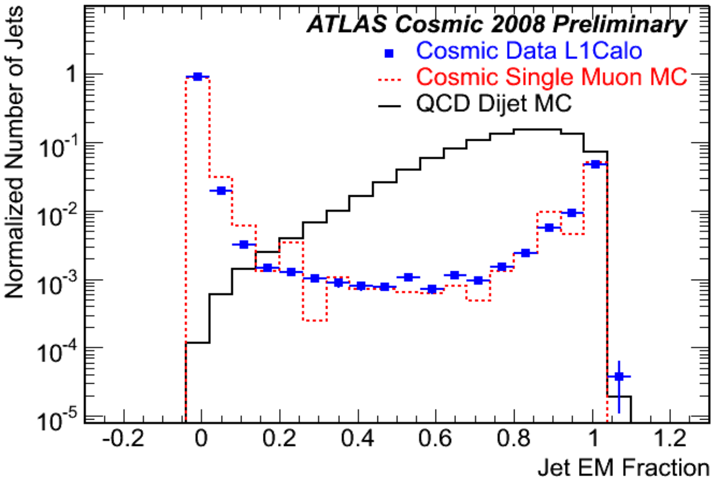
Jets at the EM scale

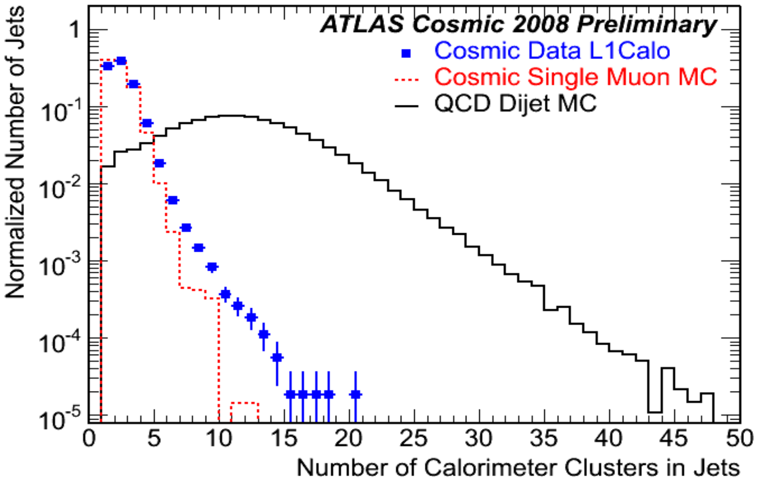


Sum $E_T$ at EM scale:
scalar sum of Cell $E_T$ with $|E|>2\sigma$ noise

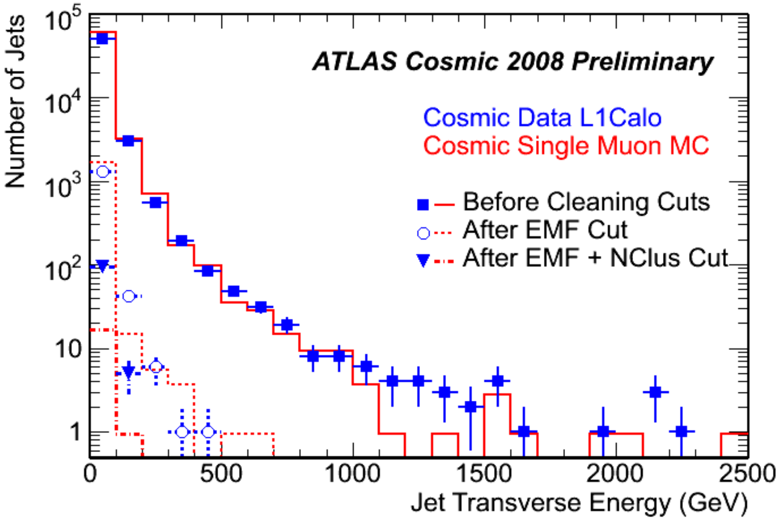
- Jets and large $E_T^{miss}$ can originate from high energy cosmic muons passing through the ATLAS calorimeter and undergoing hard bremsstrahlung
- Good agreement with MonteCarlo aside from a slight discrepancy in tails due to MC statistics and from cosmic ray air showers (not modelled in MC)

# Cleaning Cuts against cosmics





- Jets from cosmics can be a background for many physics channels
- set of cleaning cuts that can almost completely eliminate it:
  - Jet EM fraction
    - typically 0 or 1 for muons undergoing bremstrahlung in (TileCal or LAr)
  - Number of clusters:
    - fewer clusters in cosmics
  - Also tracking (not shown)



# $E_T^{miss}$ challenge with first data

$E_T^{miss}$ is due to non interacting particles in detector (neutrinos, LSP) ⇒ **True $E_T^{miss}$**

But it is also due to:

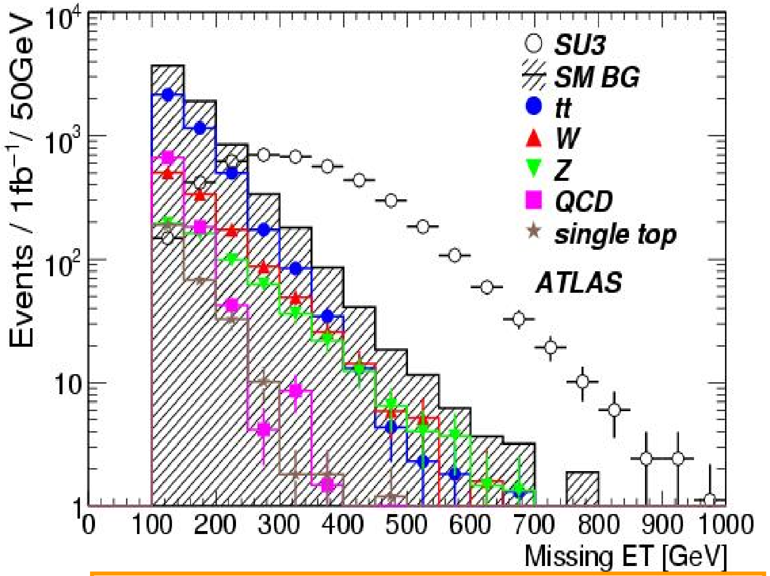
- Problems in detector:
  - dead, hot, noisy channels, problems in HV sectors…
- Noise, pile-up noise
- Energy lost in dead materials (cracks, cryostats..)
- Backgrounds:
  - cosmic rays, beam halo, beam gas
- Mismeasurements of muons, jets

⇒ **"Fake" $E_T^{miss}$**

⇒ First require detailed understanding of instrumental $E_T^{miss}$ sources →Event Cleaning

⇒ Then understand other source of "fake" $E_T^{miss}$ (missing/fake muons, jets in cracks…)

Susy no-leptons (SU3) and backgrounds

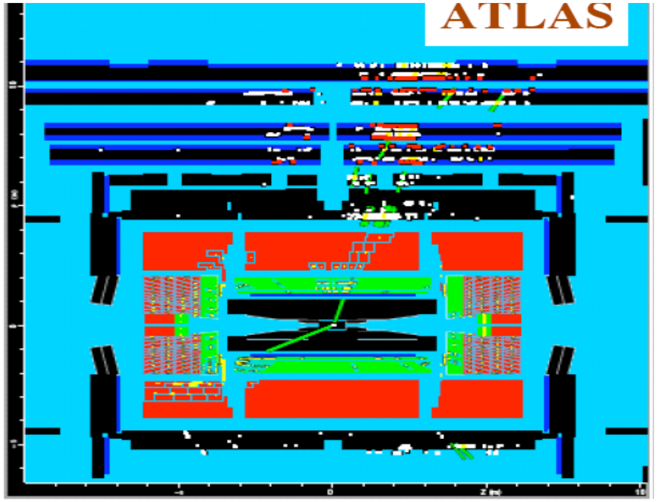


- QCD with "fake" $E_T^{miss}$ are background for inclusive no-lepton SUSY events

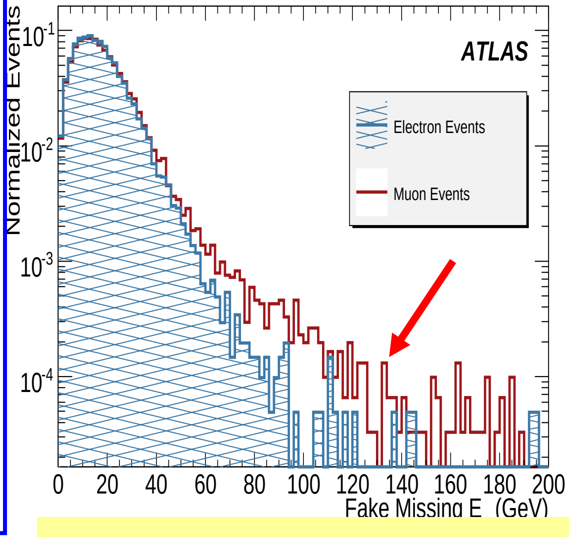
- understanding this background is crucial before beginning a SUSY search in early data !

# Fake $E_T^{miss}$ from fake or missing Muons

- Fake muons can be caused by jet punch-through detected as excess activity in Muon Chambers.
- Cleaning criteria: count of muon hits and of muon segments within a cone around jet axes.



- Missing muons due to detector features:
  - η=0: holes in Muon Spectrometer for cables, services to Inner Detector & Calorimeter.
  - |η| ~1.2: middle muon station missing for initial data taking
  - |η|>2.7: no muon coverage
- use calorimeter and track information to recover missing muons used in $E_T^{miss}$ calculation



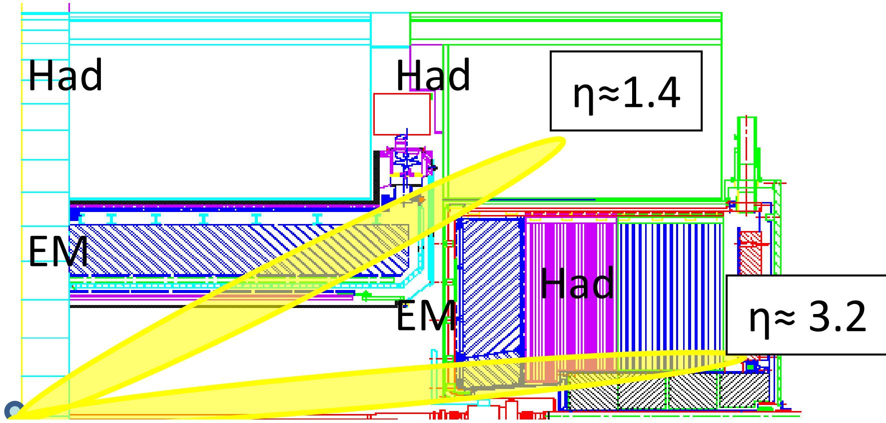
$E_T^{miss}$ Fake in ttbar events in the electron and muon channel: ⇒large tails due to missed or fake muons

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

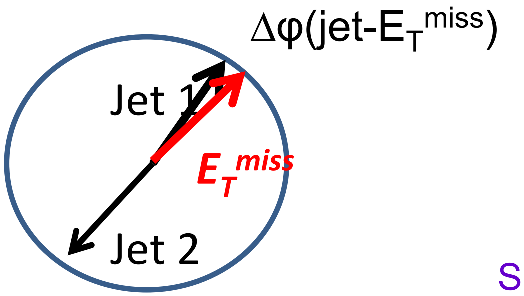
# Fake $E_T^{miss}$ from Jet Leakage

Fake $E_T^{miss}$ in calorimeter can also be produced by mis-measurements of jets due to cracks, gaps, transition regions used for services.

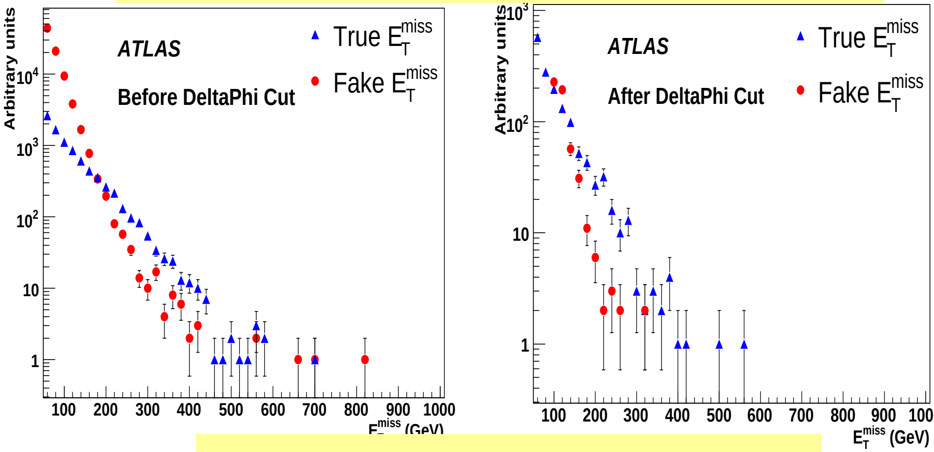
Crack" regions: η ≈1.4, 3.2



- Leakage of jets entering 'crack' region 1.3<|η|<1.6 can be detected:
  - looking for large deposits in the outermost layers of the calorimeter
  - checking the $E_T^{miss}$ calculated from tracks found in the Inner Detector that can provide a complementary information
  - checking if $E_T^{miss}$ is closely associated with one of the leading jets in the transverse (φ) plane
- Cleaning cuts based on those criteria could be applied⇒ analysis dependent



Di-jet QCD sample 560 GeV<$p_T$<1120 GeV



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

# Strategy for Jet Calibration

- **Factorized multi-step approach**
  - Flexibility to understand corrections individually and use different techniques as they become validated with data within a same framework
  - Combination of "in-situ" and Monte Carlo (MC) methods

**Hadronic Calibration:**

- correct for calorimeter effects: non-compensation, dead material
- ATLAS developped two different strategies: **Global and Local calibration**

**Jet Energy Scale**

**Offset correction for pile-up:**

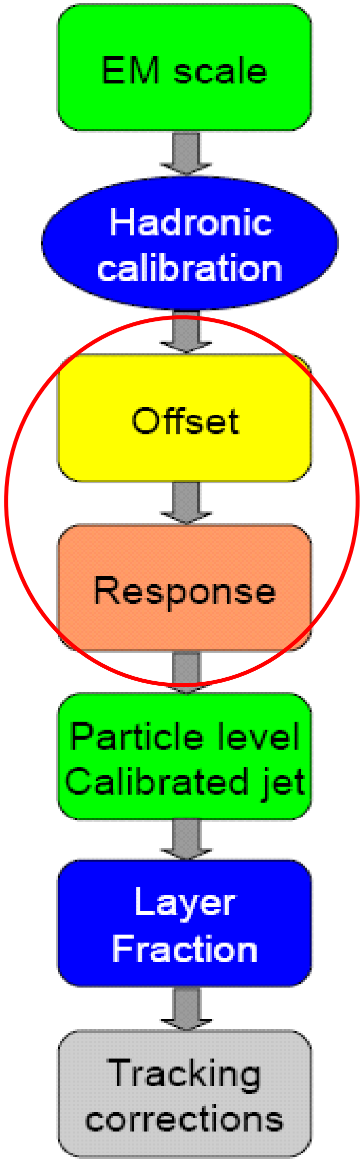
- subtract the average contribution to the jet energy not originating from the primary interaction

**Response correction:**

- **Eta intercalibration**: equalization of the jet response as a function of $\eta$
- **Absolute energy scale:** in-situ correction from gamma/Z-jet balance

**Other optional corrections** to improve resolution (scale unchanged):

- **Layer Fraction**: EM-scale jets + layer fraction, exploit longitudinal shower development
- **Tracking corrections**: fraction of jet momentum carried by charged tracks associated with the jet



EM scale

Hadronic calibration

Offset

Response

Particle level Calibrated jet

Layer Fraction

Tracking corrections

# Hadronic Calibration

## Global approach (jet level):

Calorimeter cell energy density method:

- Use cell energy density as an estimator of the electromagnetic and hadronic component of jet showers:
  - EM showers are characterized by high energy density depositions
  - HAD showers are broader and less dense
- Cells weights depending on the cell energy density are calculated optimizing the difference between reconstructed and truth jets found using the same algorithm:
  - The weights have been determined considering QCD di-jets events

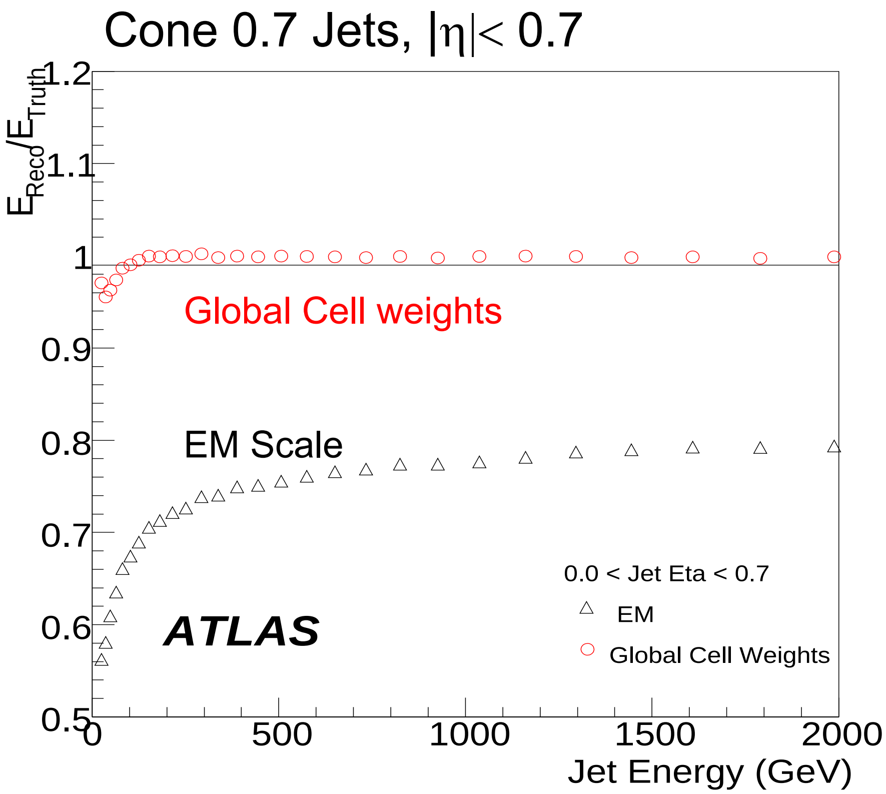
## Local approach (calorimeter level):

Based on Topo-Clusters as jet constituents:

- TopoCluster classification as EM/HAD based on cluster shape variables: energy density and depth
- Hadronic weighting of calorimeter cells derived from detailed GEANT4 simulations of charged pions
- Dead material (DM) and out of cluster corrections (OOC) applied

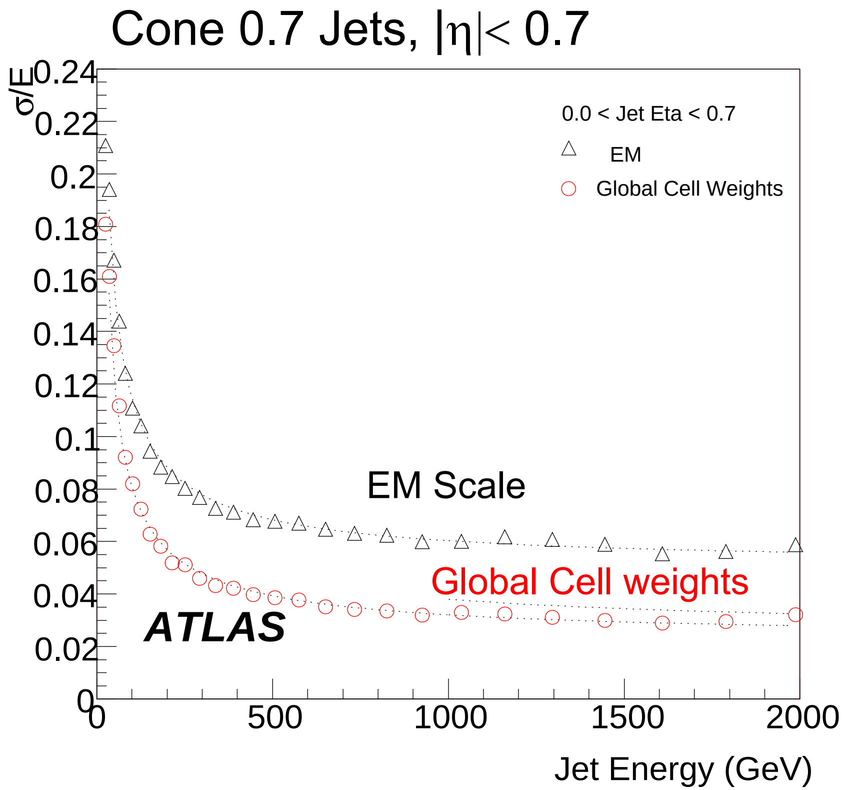
Both methods present comparable performances in the simulation

# Global Jet Calibration Performance



## Jet energy response linearity

- Global Cell weights within 2%
- largest non linearity coming from low energies

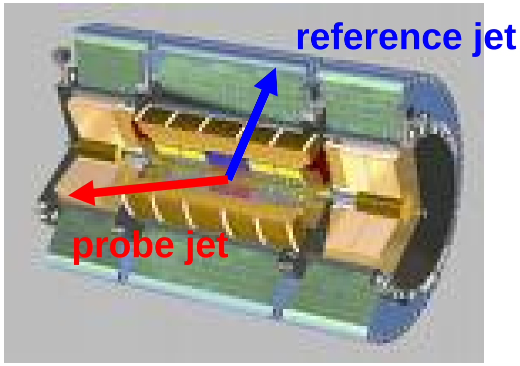


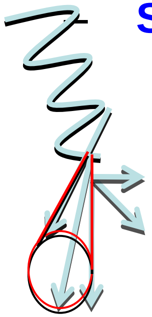
## Jet energy resolution

- Global Cell weights ~ 4% at high energy

# “In-situ” Jet Energy Scale

- **Correct and validate the energy scale of the calorimeter jet to the particle level energy scale.**
- **In-situ processes to define the entire jet energy scale:**
  - **Equalization of the jet response in η with QCD Di-jet events**
    - Di-jet $p_T$ balance uses reference jet in well calibrated (central) region to correct probe jet further away
    - Control uniformity of response on the percent level with ~ 10 pb $^{-1}$

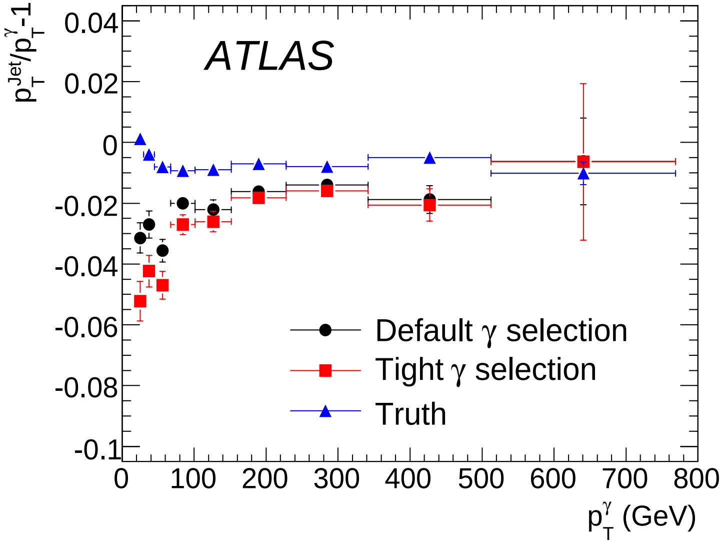




  - **Set the absolute energy scale with γ/Z-jet events:**
    - Well measured electromagnetic system balances jet res
      $p_T$ balance used to connect the two scales:

$$B = \frac{\vec{p}_T^{\,jet}}{\vec{p}_T^{\,\gamma}} - 1$$

    - Negative bias mainly due “out-of cone” losses related to the jet algorithm
    - The imbalance becomes ~ 1% at 100-200 GeV
    - Statistical precision of ~ 1-2% with ~ 100 pb $^{-1}$
    - Same method using Z-jets events but less statistics
    - **Precision dominated by the systematic uncertainty**



# Strategy for $E_T^{miss}$ reconstruction and calibration

**Step by step procedure of increasing complexity:**

- From Basic $E_T^{miss}$ ⇒ Final $E_T^{miss}$ ⇒ to Refined $E_T^{miss}$
  ⇒ To guarantee robustness with first data
- Several calculation/calibration schemes available to allow maximum degree of flexibility with first data and different sensitivity to systematic effects
- Calibrations adopted for $E_T^{miss}$ from reconstructed objects (no specific "ad hoc" corrections for $E_T^{miss}$ applied) to guarantee a coherent event reconstruction

# From Basic to Refined Calibrated $E_T^{miss}$

**Basic $E_T^{miss}$** from all calorimeter cells applying two possible noise suppression approaches:

- from all Cells with |E|>2σ noise
- from all Cells inside TopoClusters

⇒ NO calibration, usable since day 1

**Final $E_T^{miss}$** obtained adding:

- Calibration step: two different calibrations approaches (coherent with jets):
  - Global cell energy density calibration and local hadron calibration applied
- Contribution from muons: $E_{x,y}^{Muon} = -\sum_{RecMuons} E_{x,y}.$
- Correction for energy lost in cryostat between EM and Had calorimeters from jets:

$$E_{jet}^{cryo} = w^{cryo}\sqrt{E_{EM3}\times E_{HAD}}$$

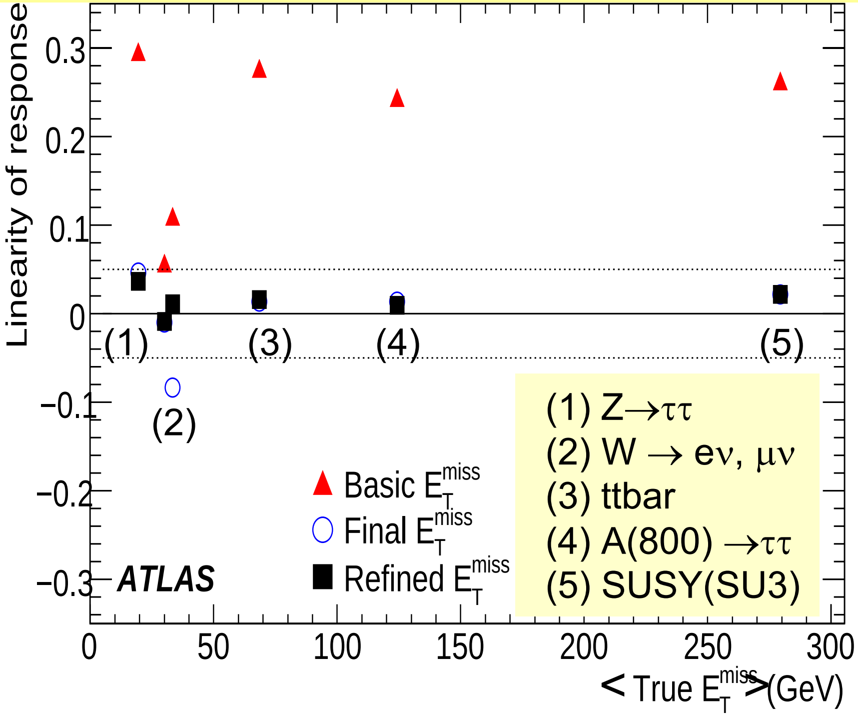
**Refined $E_T^{miss}$** original approach by ATLAS based on event signal ambiguity resolution:

- sequential decomposition of reconstructed objects: *electrons, photons, taus, jet, muons* into basic constituents (calorimeter cells or TopoClusters) and veto of multiple contribution to guarantee no double counting in $E_T^{miss}$ calculation
- Calibration weights applied to basic constituents depend on the type of reconstructed object
- Also TopoClusters not associated with any reconstructed objects taken into account

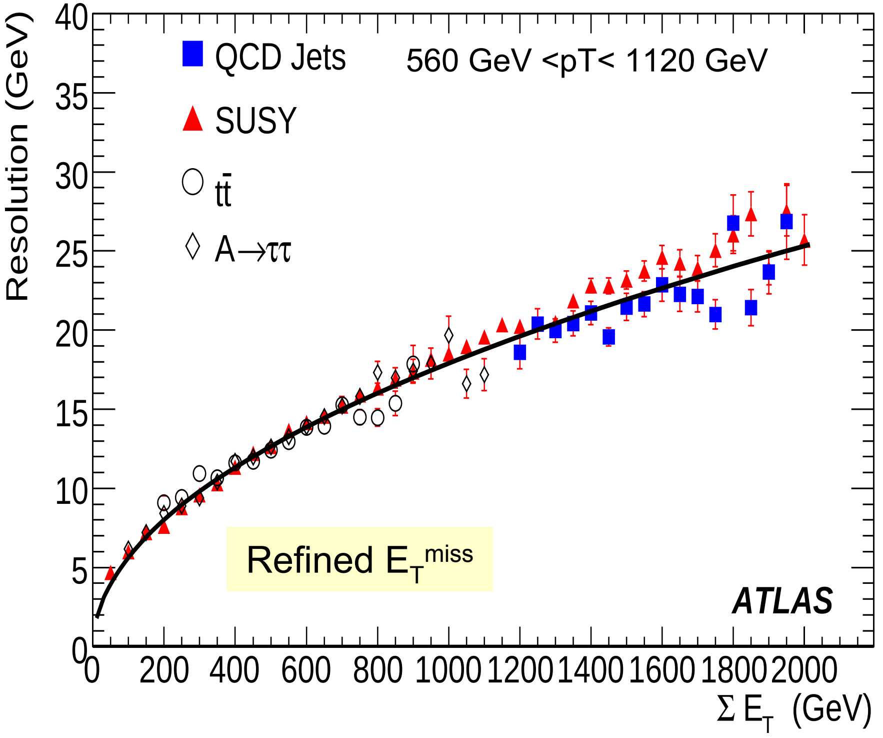
⇒ Most complex schema, usable after validation of reconstructed objects

# Refined $E_T^{miss}$ Performance

**Linearity** = (Truth $E_T^{miss}$ – Reco $E_T^{miss}$ )/Truth $E_T^{miss}$



**Resolution** = σ(Truth $E_{x,y}^{miss}$ – Reco $E_{x,y}^{miss}$ )



$E_T^{miss}$ Refined Calibration provides best performances in terms of Linearity and Resolution (resolution less sensitive to calibration):

- $E_T^{miss}$ Linearity within ~ 3% over wide $E_T^{miss}$ range for different processes
- $E_T^{miss}$ Resolution: mainly depend on ΣET in calorimeters, well described by: Resolution = k * $\sqrt{\Sigma E_T}$ (k ~ 0.5)

# "In-situ" $E_T^{miss}$ validation with Minimum Bias and QCD di-jets events

Road-map for $E_T^{miss}$ commissioning:

⇒ Minimum bias:

- the first control sample to test $E_T^{miss}$ resolution "in-situ" up to Sum$E_T$~ 200 GeV in very early data:

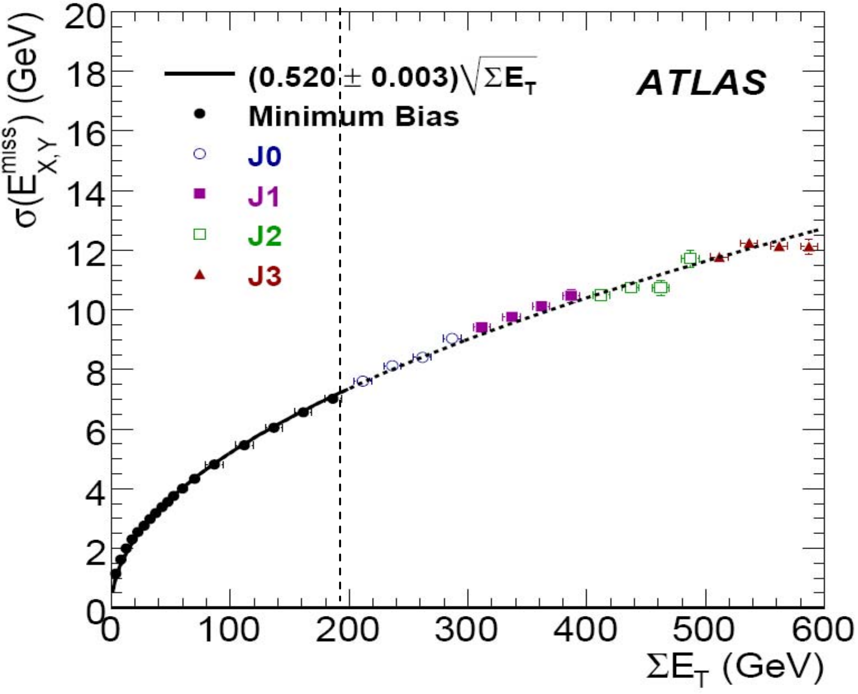
$$E_T^{miss}\ \text{Resolution} = k * \sqrt{\text{SumET}}$$

- Basic $E_T^{miss}$ calculation

⇒ QCD di-jets events:

- useful to test $E_T^{miss}$ resolution "in-situ" for higher $\Sigma E_T$ range (> 200 GeV)

- Final $E_T^{miss}$ calculation, start to check calibrations



$E_T^{miss}$ Resolution vs $\Sigma E_T$ from minimum bias and QCD di-jets evts

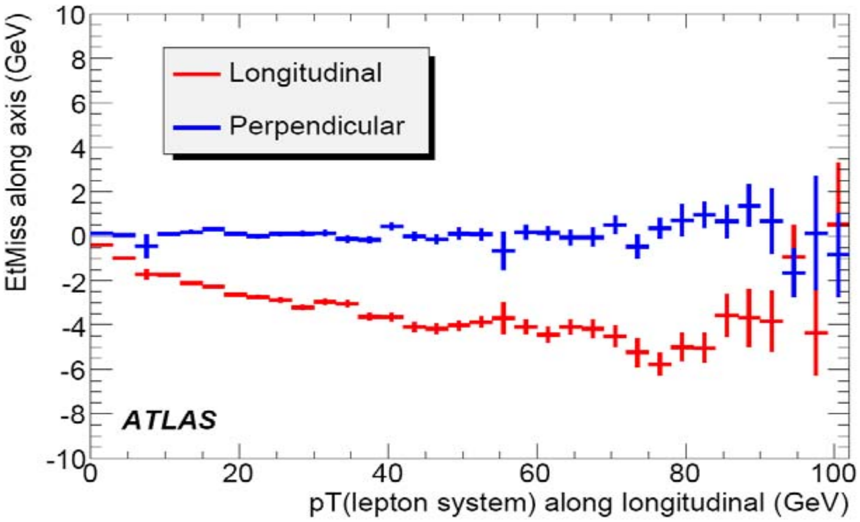
J0-J3: 8 GeV <$p_T$< 140 GeV

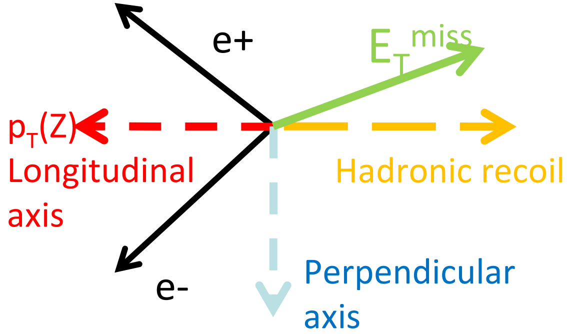
# “In-situ” $E_T^{miss}$ validation with Z→ll

- Test calibration and scale of $E_T^{miss}$ “in-situ”: expected ~ 350 evts/ $pb^{-1}$ Z→ee
- Transverse momentum of the two leptons from Z balanced by hadronic recoil:

  ⇒ diagnostic plot of $E_T^{miss}$ vs dilepton $p_T$ projected along longitudinal axis is powerful to discover potential $E_T^{miss}$ problems: negative offset due to miscalibration of low energy deposits in calorimeter:

  - ⇒ partially improved thanks to new calibration weights
  - ⇒ work in progress for a specific calibration for low energy deposits





The longitudinal axis defined by the vectorial sum of the 2 leptons momenta.

The perpendicular axis is placed at π/2 to the longitudinal axis.

⇒ With integrated luminosity 10-100$pb^{-1}$ possibility to determine the “in-situ” $E_T^{miss}$ scale with: W→eν transverse mass
Z→ττ →lepton-hadron invariant $m_{\tau\tau}$

# Summary

A reliable reconstruction and calibration of jets and $E_T^{miss}$ in ATLAS is crucial to understand Standard Model physics measurements and to discover new phenomena

The most challenging task with first data are:

- for jets ⇒ the establishment of the energy scale “in-situ”
- for $E_T^{miss}$ ⇒ the understanding of the main sources of fake $E_T^{miss}$ and the “in-situ” validation.

Both jets and $E_T^{miss}$ foresee to apply a step by step approach for calibration to guarantee flexibility and robustness:

- for jets ⇒ a factorized set of corrections has been prepared
- for $E_T^{miss}$ ⇒ an approach of increasing complexity is ready: from Basic $E_T^{miss}$ to Refined $E_T^{miss}$

Measuring jets and $E_T^{miss}$ is challenging but ATLAS has developed techniques and strategies to be ready for commissioning with real collisions

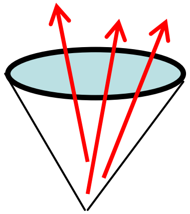
# Back up

# Jet Algorithms

“Cone” algorithms:

Geometrically motivated jet finders:

- Seeded fixed cones (R=0.4,0.7)
  - Collect particles or detector signals into fixed sized cone of chosen radius R



$$R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

  - Basic parameters are seed $p_T$ threshold and cone size
- Seedless fixed cones (R=0.4,0.7)
  - No seeds
  - Collect particles around any other particle into a fixed cone of chosen radius

All Cone algorithms require a split-merge procedure to define non overlapping exclusive jets.

“Cluster” algorithms:

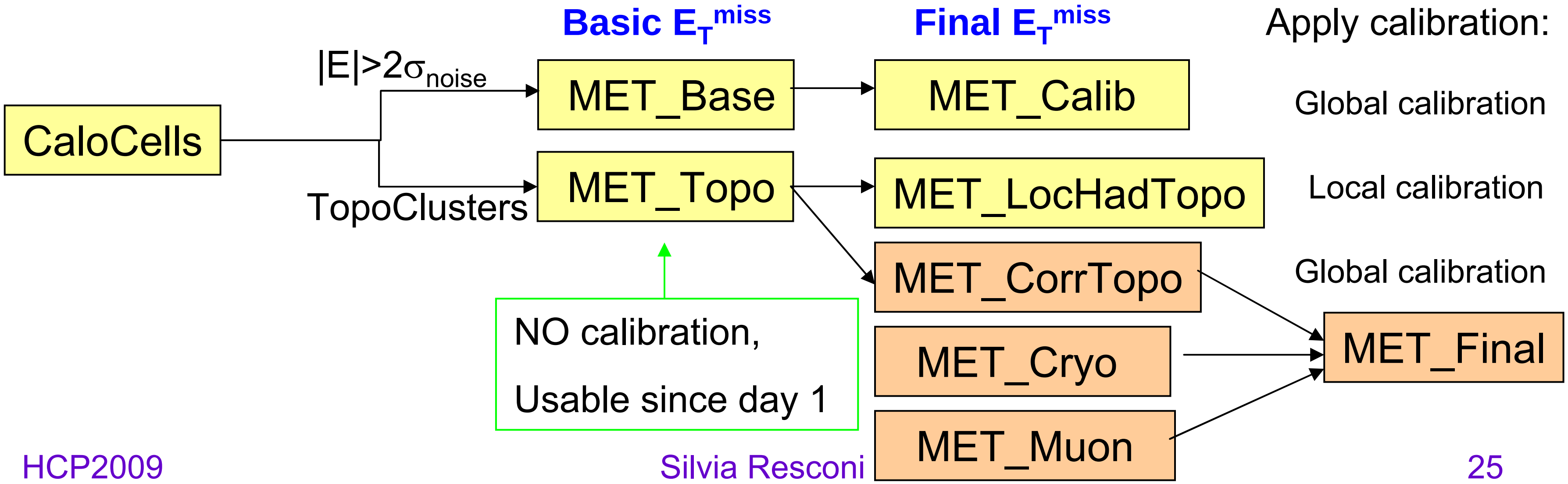
Start from particles or detector signals and perform an iterative pair-wise clustering to build larger objects.

Attempt to undo QCD parton fragmentation:

  - kT: with clustering sequence using $p_T$ and distance parameter (start from the softer components)
  - Anti-kT using $p_T$ and distance parameter with inverted sequence (start from the harder components)
- ATLAS recently has decided to adopt the AntiKt algorithm as default (D=0.4)

# From Basic to Final Calibrated $E_T^{miss}$

- ⇒ **Basic $E_T^{miss}$** from all Calorimeter cells with two possible noise suppression approaches (MET_Base, MET_Topo)
- ⇒ **Final $E_T^{miss}$** adding calibration step plus contribution from muons and for dead material (MET_Final):
  - Different calibrations approaches (coherent with jets):
    - Global cell energy density calibration and local hadron calibration applied
  - Correction for energy lost in cryostat between EM and Had calorimeters (MET_Cryo) from jets: $E_{jet}^{cryo} = w^{cryo}\sqrt{E_{EM3} \times E_{HAD}}$
  - Contribution from muons (MET_Muon)

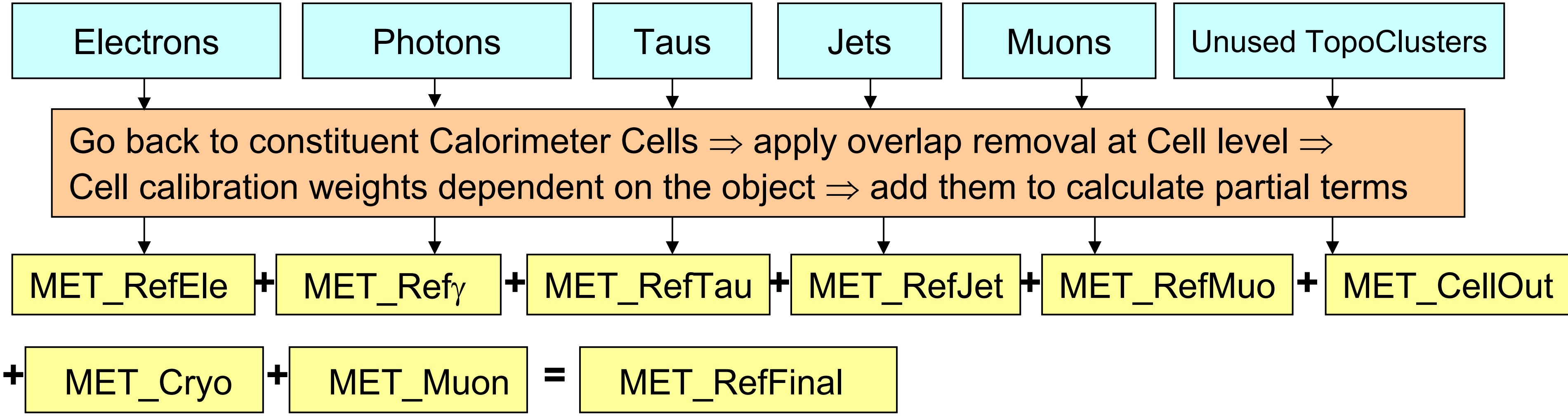


NO calibration,

Usable since day 1

# Refined Calibrated $E_T^{miss}$

- Based on all reconstructed physics objects (e/γ, τ, b-jet, jet, μ, ...)
- Most complex schema to apply after validation of reconstructed objects:
  - After particle identification, decomposition of each object into constituent Calorimeter Cells
  - Overlap removal done at cell level
  - Cell calibration weights depend on the type of the reconstructed object (e/γ, τ, b-jet, jet, μ …) they belong to
  - Also TopoClusters not in reconstructed objects are taken into account



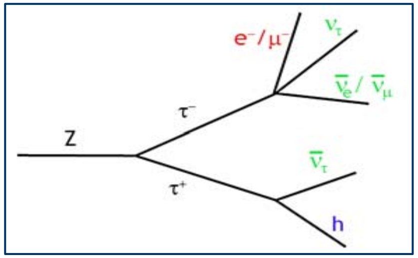
Electrons | Photons | Taus | Jets | Muons | Unused TopoClusters

Go back to constituent Calorimeter Cells ⇒ apply overlap removal at Cell level ⇒
Cell calibration weights dependent on the object ⇒ add them to calculate partial terms

MET_RefEle + MET_Refγ + MET_RefTau + MET_RefJet + MET_RefMuo + MET_CellOut

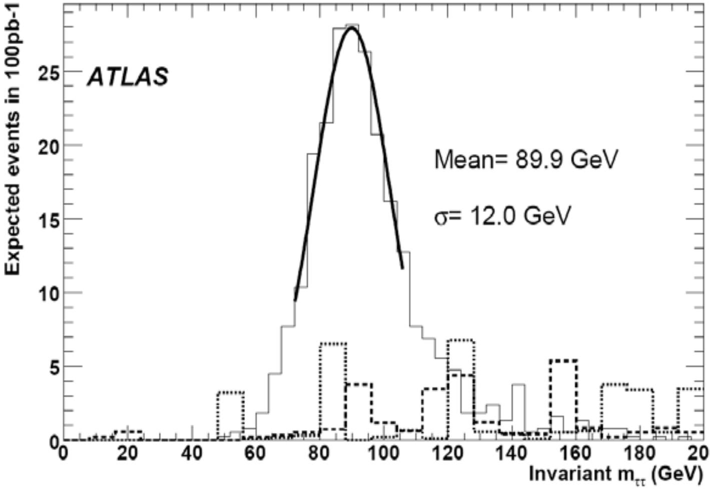
\+ MET_Cryo + MET_Muon = MET_RefFinal

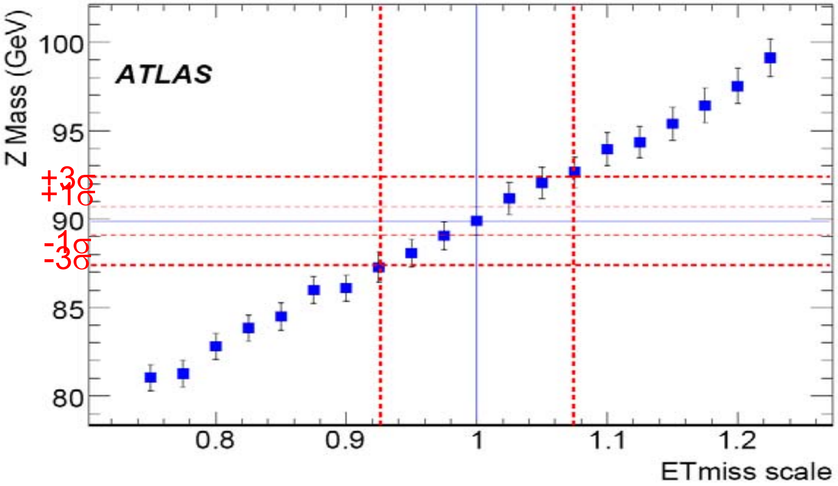
# "In-situ" $E_T^{miss}$ scale with $Z\to\tau\tau\to$lep-had



⇒ Determination of the $E_T^{miss}$ scale with invariant $m_{\tau\tau}$ :

- Estimate background "in-situ" using same sign (SS) events:
  - signal events have opposite sign (OS) lepton and τ-jet
- in 100 $pb^{-1}$ invariant $m_{\tau\tau}$ mass reconstructed with an error of less then 1 GeV
- taking into account only statistical error ⇒ $E_T^{miss}$ scale with a precision of ~3 %
- taking into account systematic effects ⇒ due to subtraction of the same sign (SS) events and the stability of the fit, $E_T^{miss}$ scale with a precision of ~ 8 %





- An other possibility to determine the EtMiss scale from W→eν transverse mass