Missing E_T Reconstruction in ATLAS

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ATLAS project

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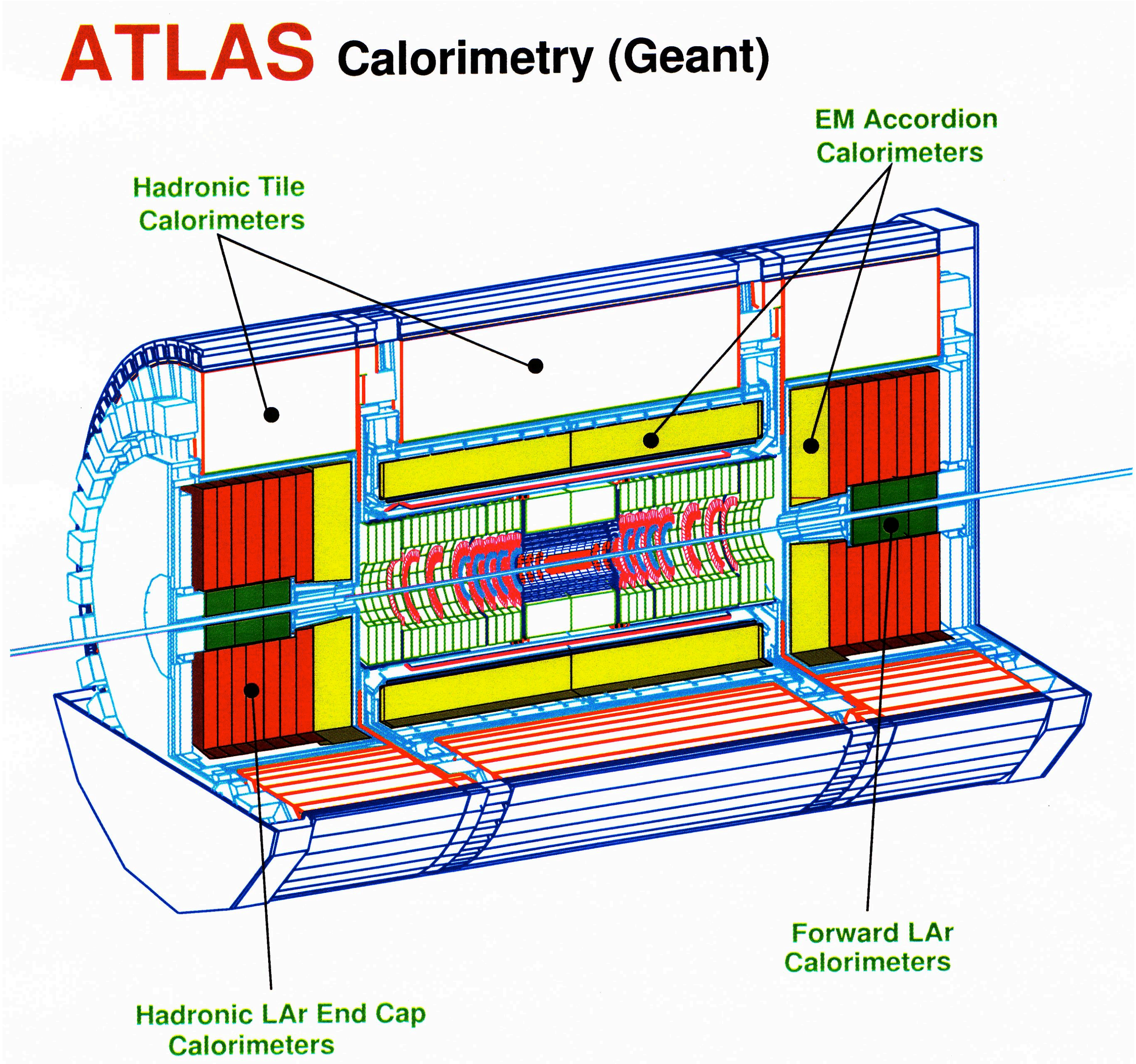
Special thanks to D.Cavalli & S. Resconi

ANL Analysis Jamboree, ANL, 20/05/09

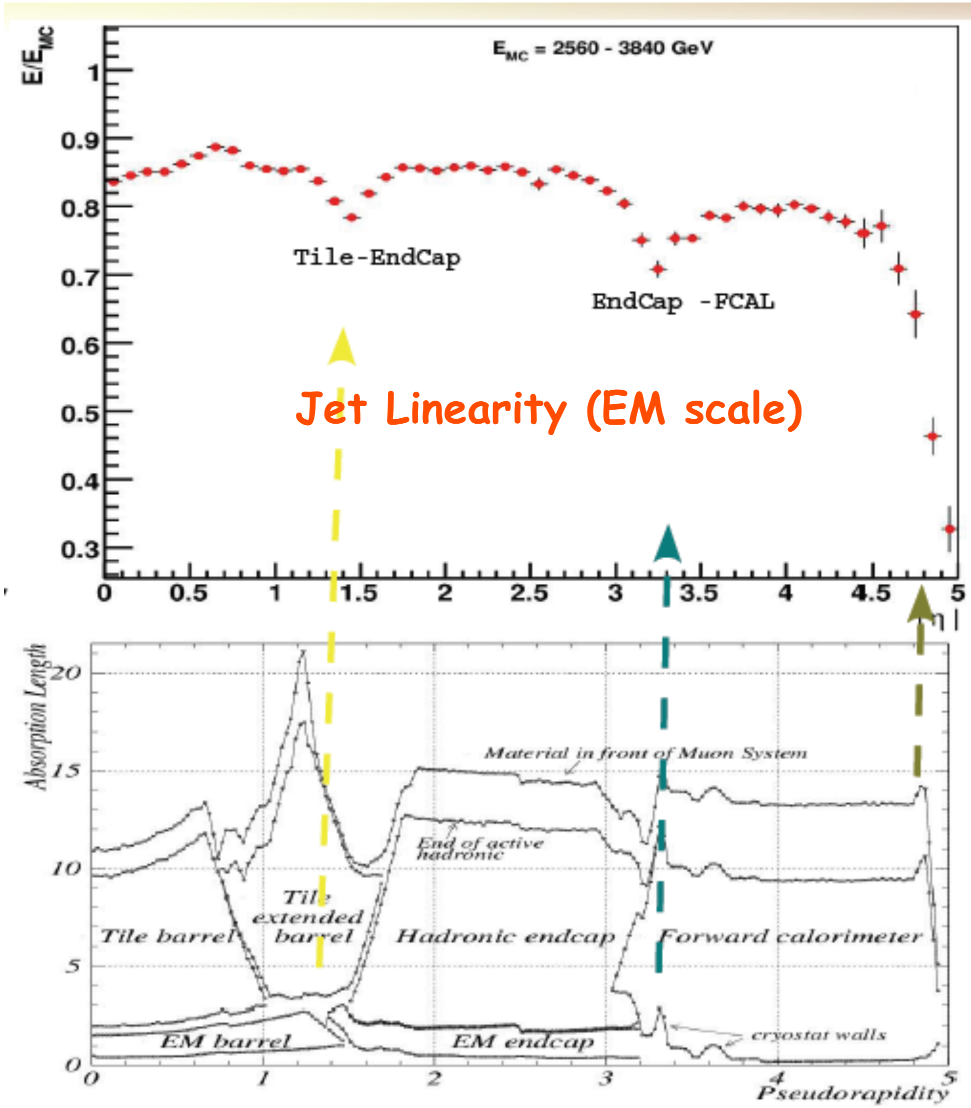
Outline

- Introduction
- MET in ATLAS
  - Overall performance
  - Studies of MET tails
  - Calo Noise
  - MET with First Data
- Software for Data Taking
  - Status of Release 14 and 15

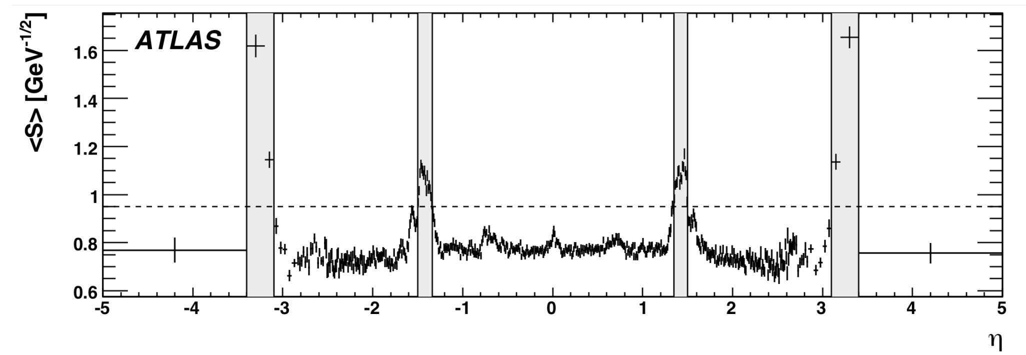
Making Emphasis on Readiness for Data Taking


ATLAS Calorimetry (Geant)
EM Accordion Calorimeters
Hadronic Tile Calorimeters
Forward LAr Calorimeters
Hadronic LAr End Cap Calorimeters

- ATLAS has cracks and significant amount of inactive material in front of the calorimeter



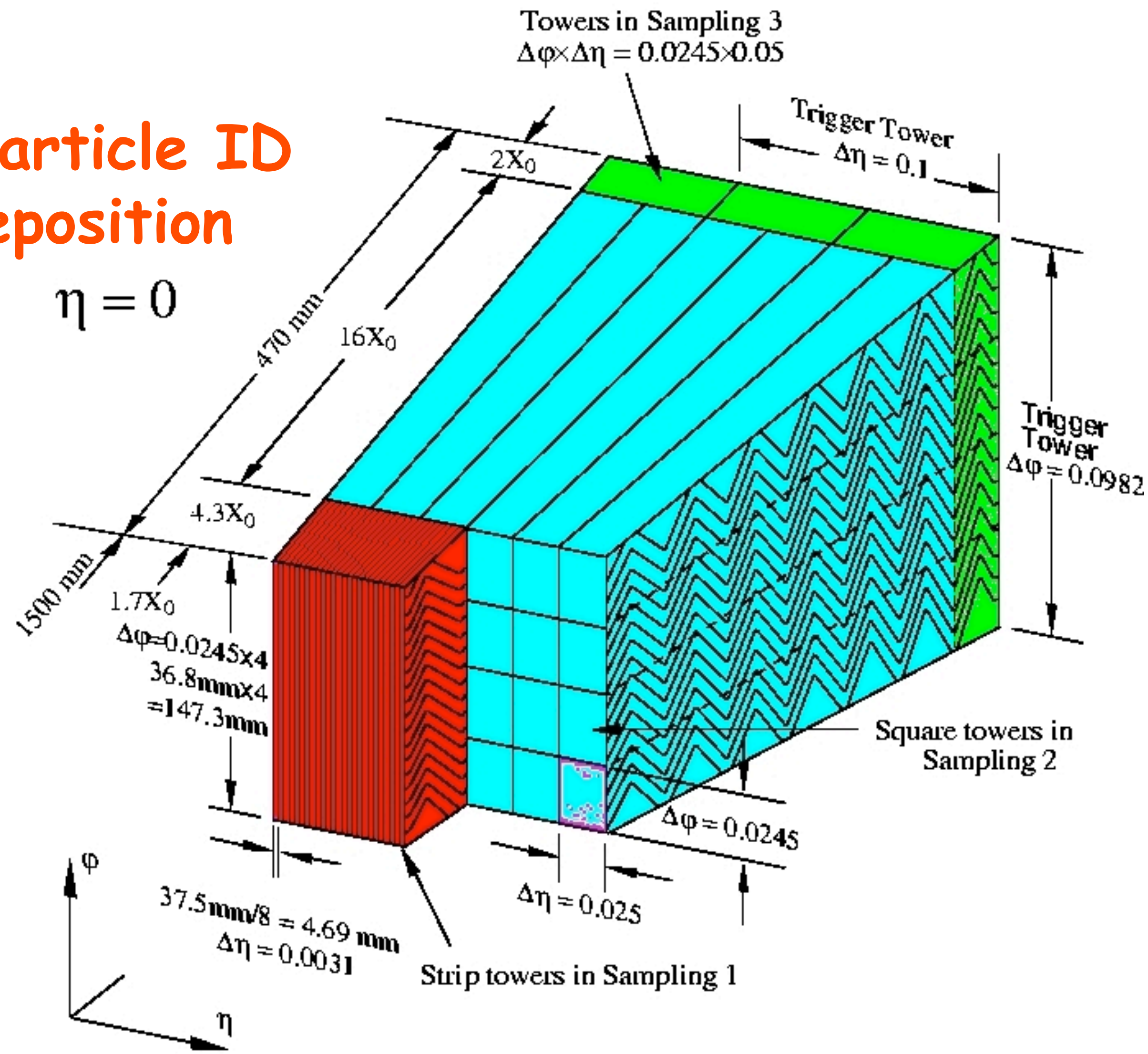
$$\frac{MET}{\sqrt{\sum E_T}}$$



η of leading or subleading jet

The LAr Calorimeter

Plays crucial role for particle ID and classification of deposition in final state



EtMiss CSC Note

Authors
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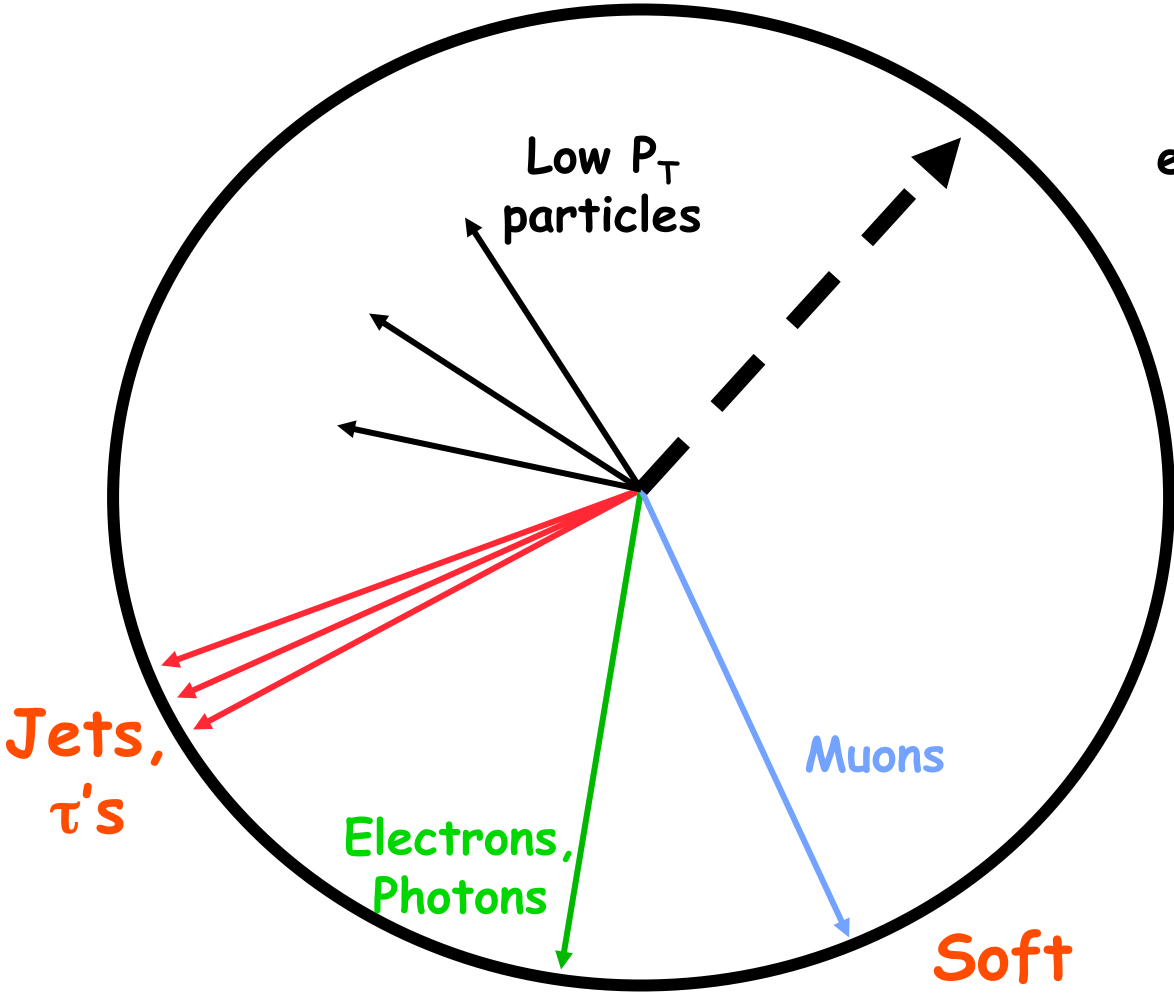
https://twiki.cern.ch/twiki/bin/view/Atlas/EtMissCSCNote



- ATLAS is developing a robust effort to understand MET reconstruction

Jet resolution

Lepton resolution

Soft depositions

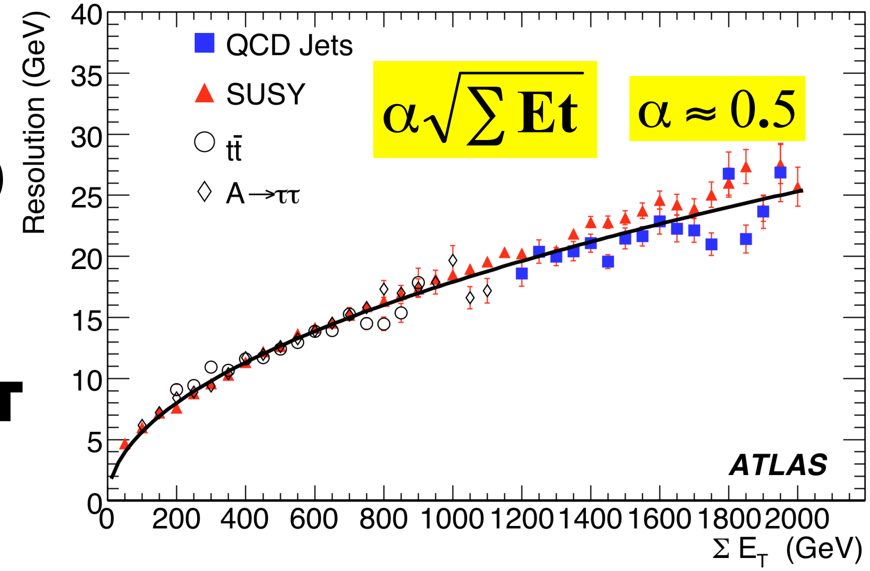
Forward physics

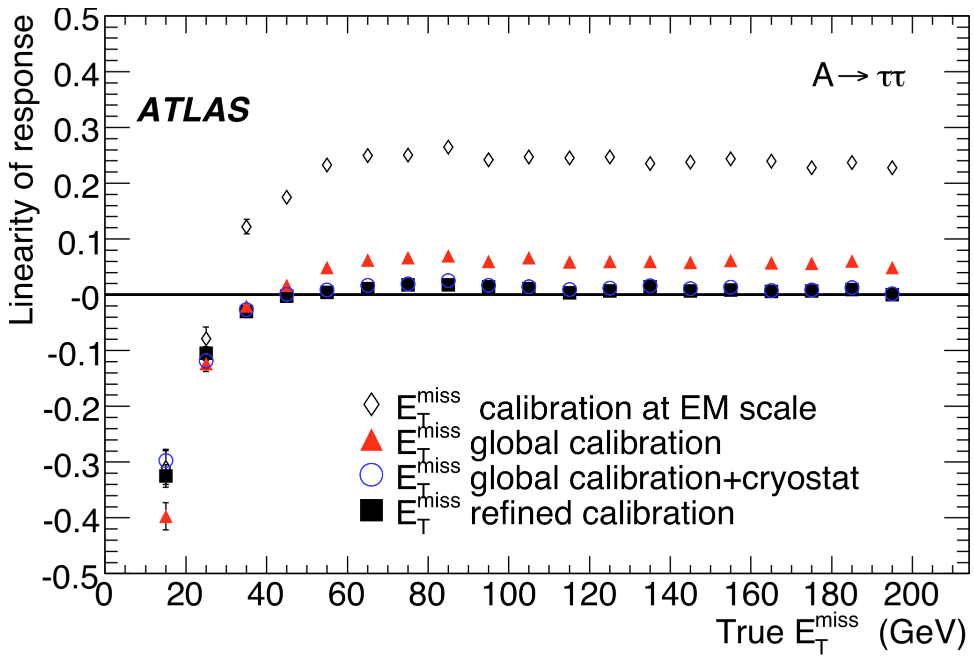
Intrumentals
Calo noise
Beam related
etc…

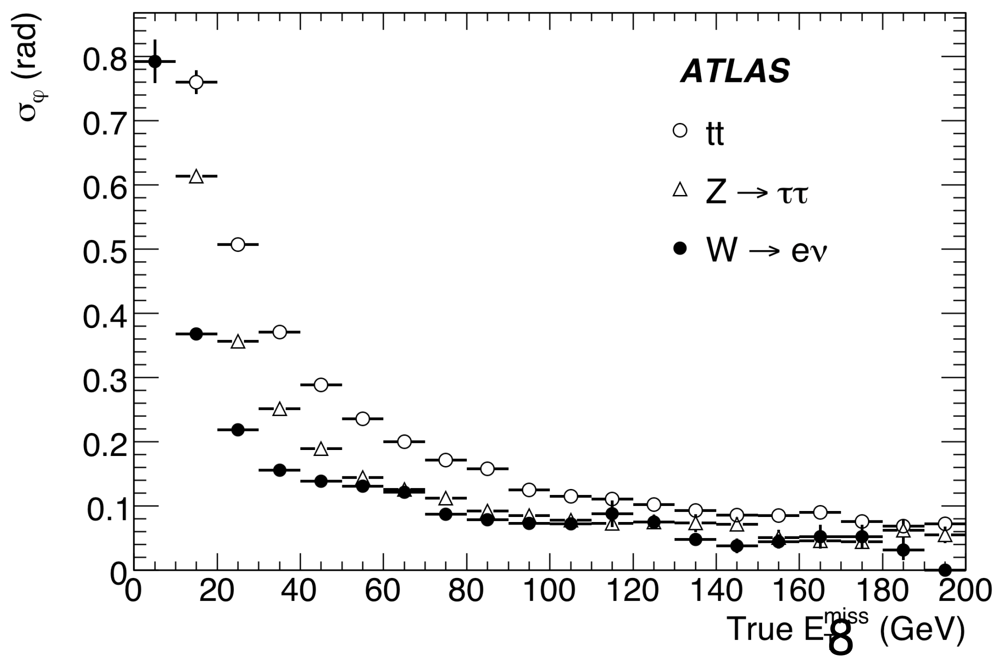
$$\sigma(MET) \approx \sigma^{Jet} \oplus \sigma^{Lep} \oplus \sigma^{Soft} \oplus \sigma^{Forw} \oplus \sigma^{Other}$$

MET Performance

- ❑ **Resolution = σ(MET (Rec)-MET(truth))**
  - ❑ **Degradation for large (high pt jets) and very low SumET regions (noise suppression method)**
- ❑ **Linearity =(MET (truth)-MET(Rec))/MET (truth) within 5%**
- ❑ **Angular resolution**
  - ❑ **100 mrad for EtMiss> ~ 80 GeV**
- ❑ **Obserseve Dependence on event topology**

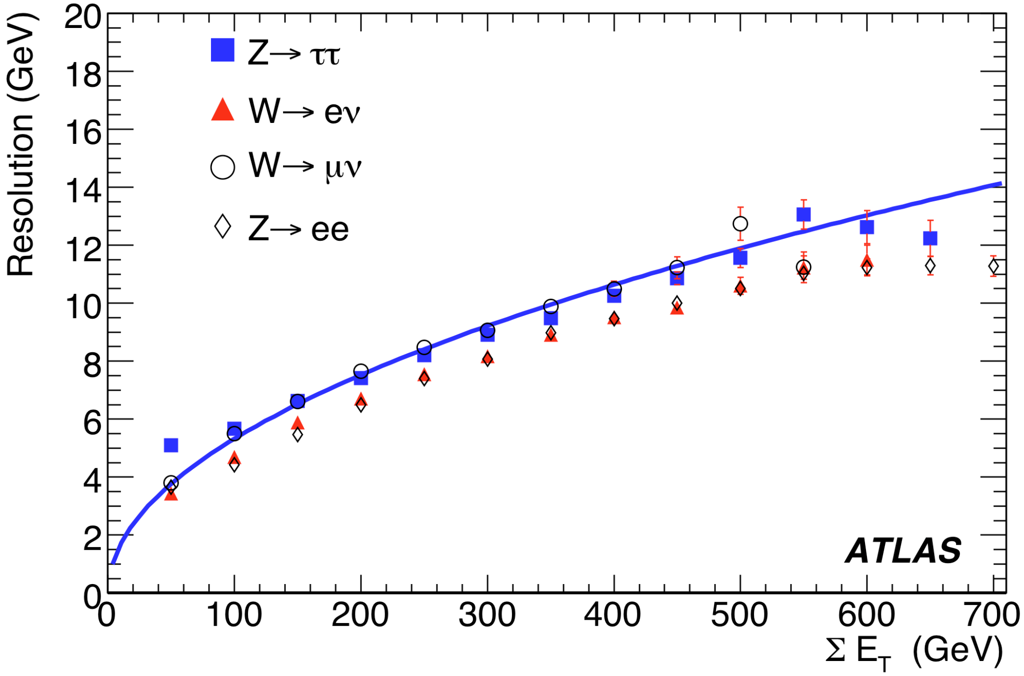


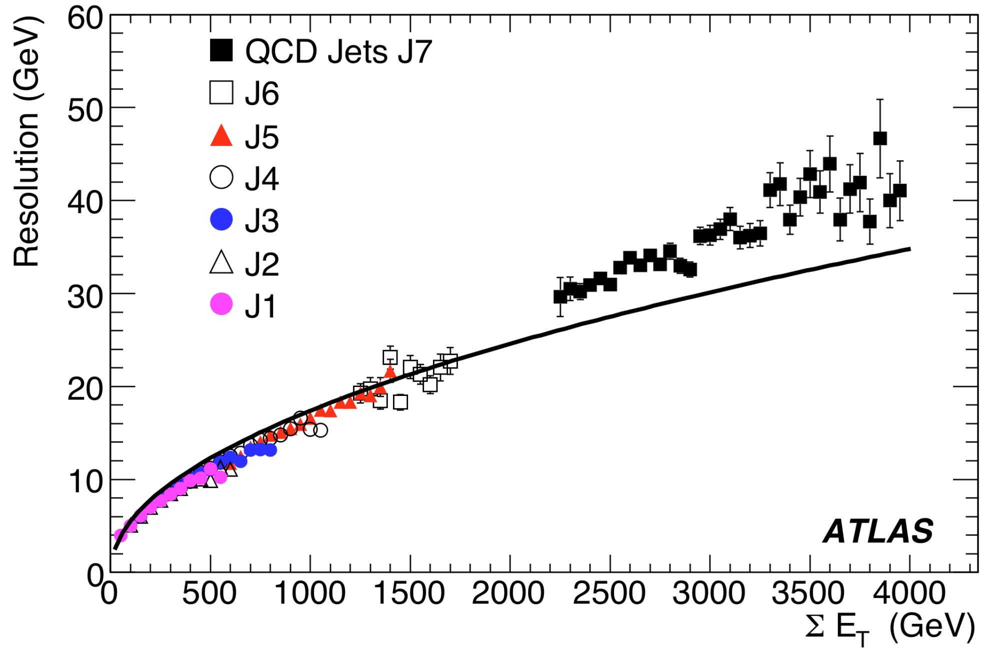




MET Resolution

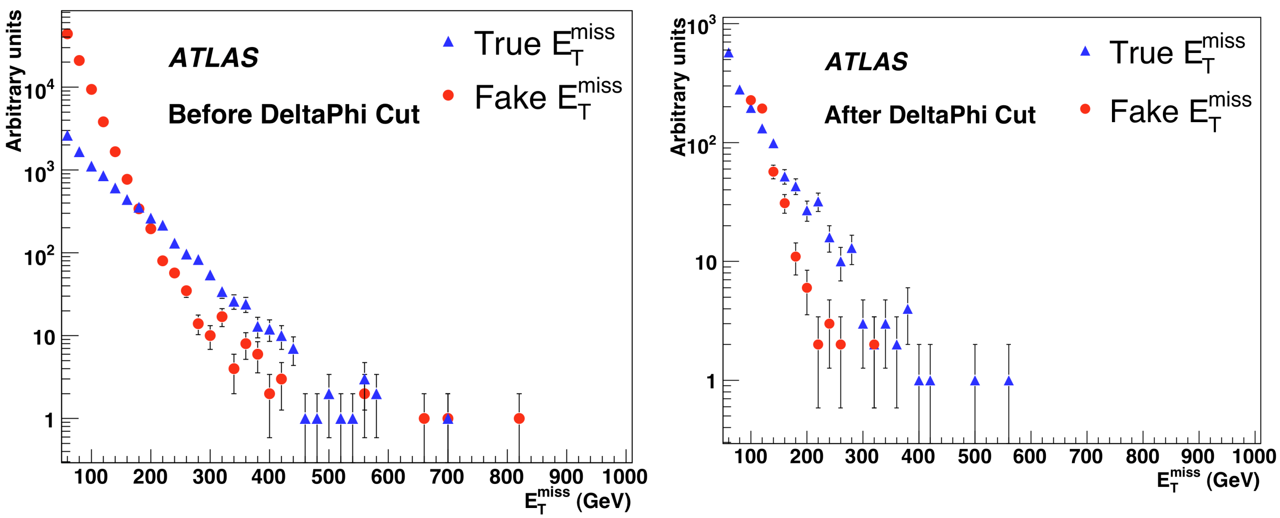
- ❑ **MET resolution is not a universal function and depends on the composition of the final state**
  - ❑ **Leptons, soft physics, angular correlations, etc...**

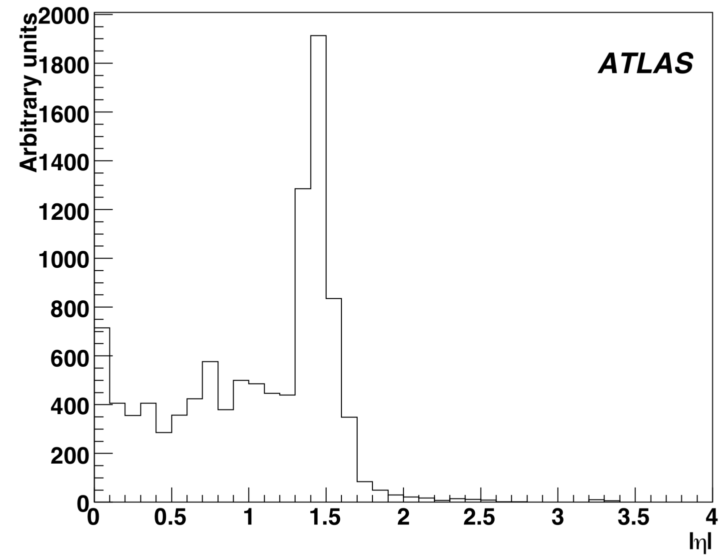




Fake MET from Jets

- Calorimeter mismeasurement
- Jets in cracks, gaps, dead material, large fluctuations





Expected rates of true and fake *MET (75pb-1)* (left) after $\Delta\phi$(jet,EtMiss) cut (>17°) (right) – J6 events

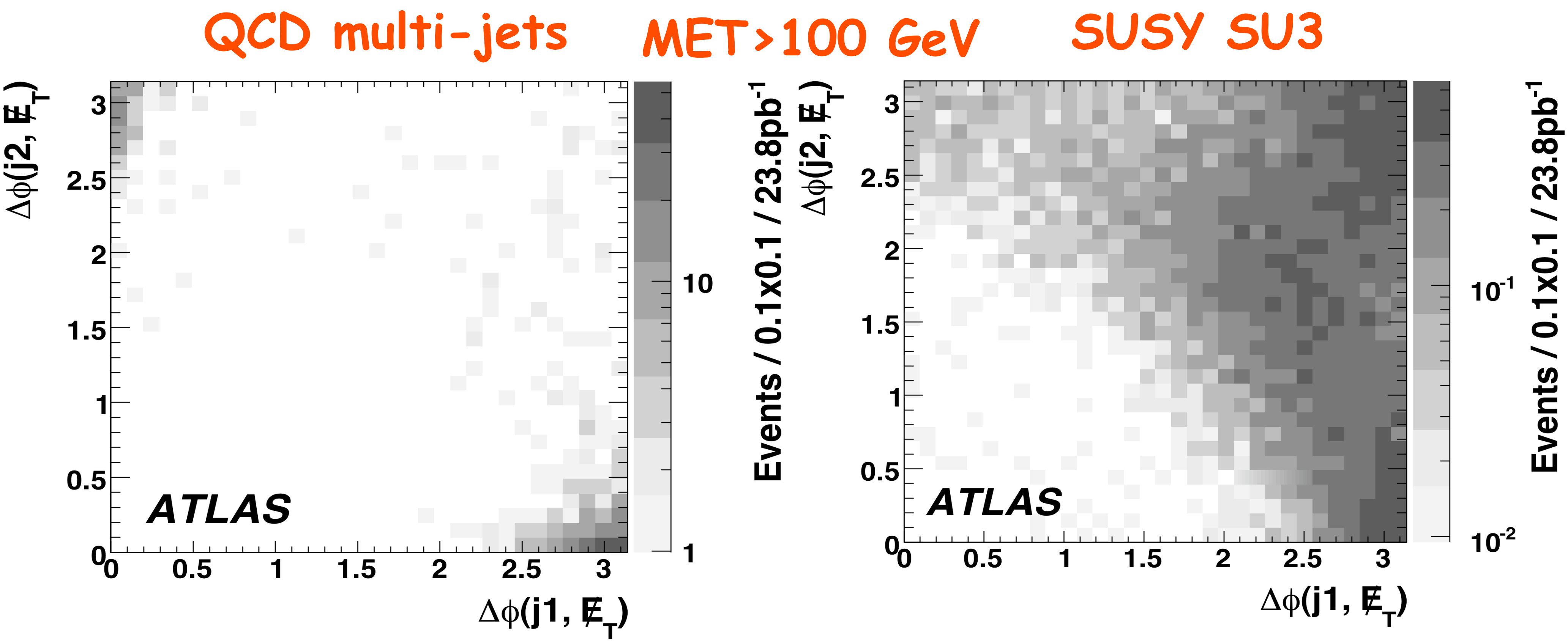
EtMiss is in the direction of the mismeasured jet

|η| of the worst reconstructed jet for J6 events with a EtMissFake>100GeV.

This cut needs to be understood well with data

Fake MET from Jets (cont)

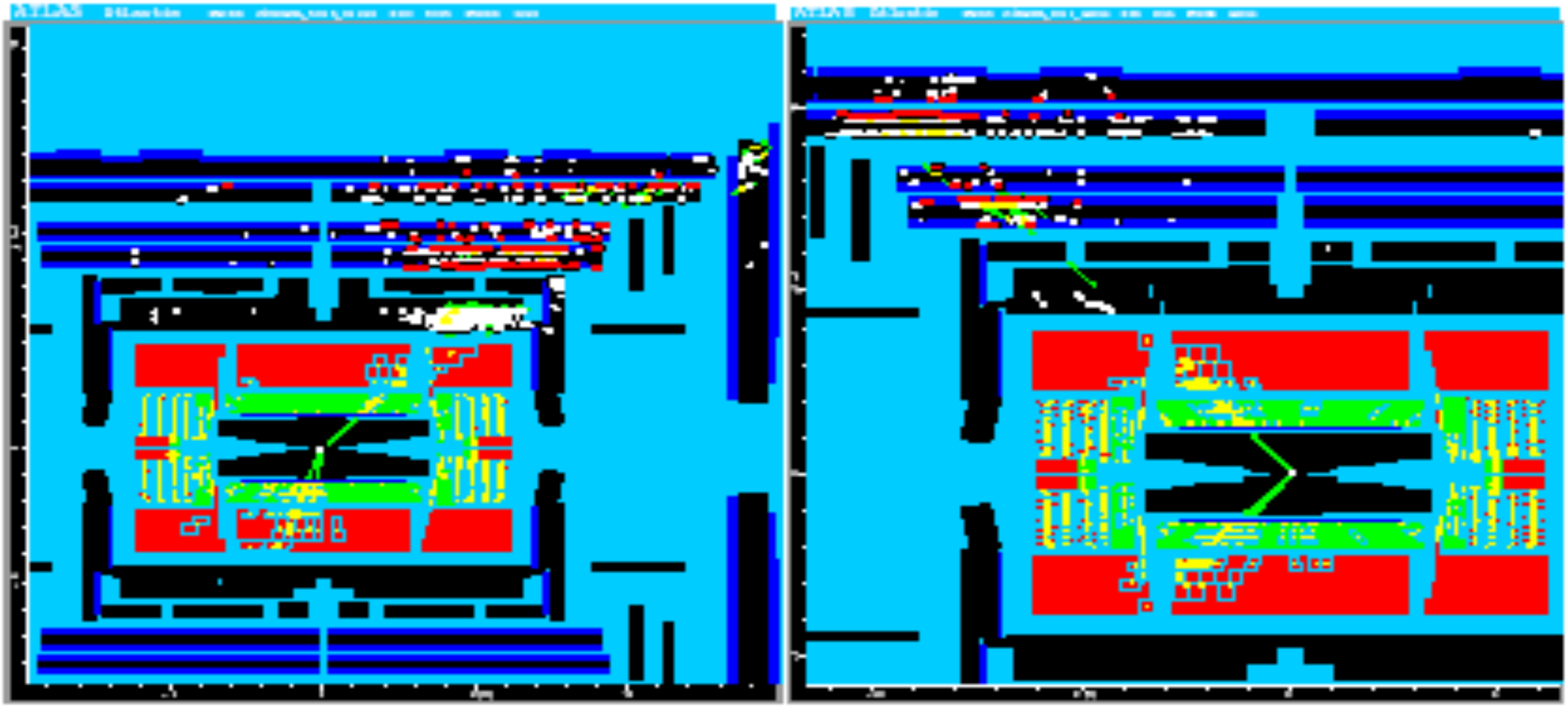
- Fake MET due to Jet resolution effects tends to point along the direction of the jet. Cuts on the opening angle between the jets and the MET are very effective in fake MET in multi-jet topologies, corresponding to SUSY searches



Jet leakage from Tile/ExtTile crack, shower in muon system

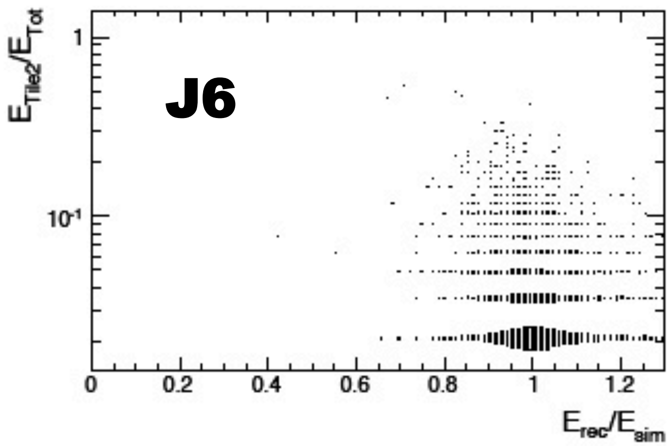
Three events with jet leakage from TileBar/TileExt crack, shower in muon system (1321, 44816, 45309):

F.Paige (06)

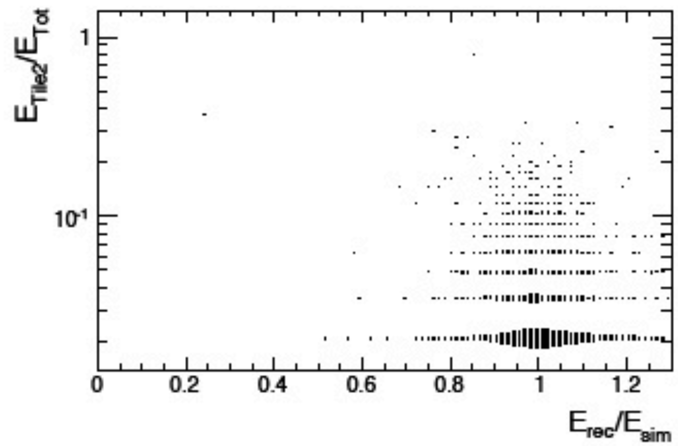


Fake MET from Jets (cont)

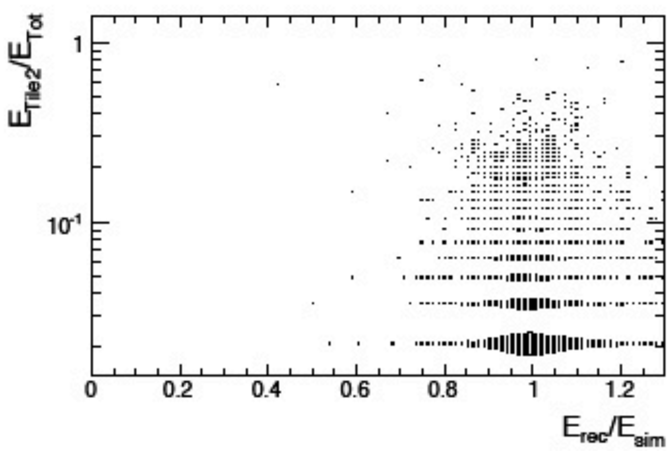
- Even after cleaning cuts we may have longitudinal leackage. This is correlated with the energy on the outer layer of the TileCal



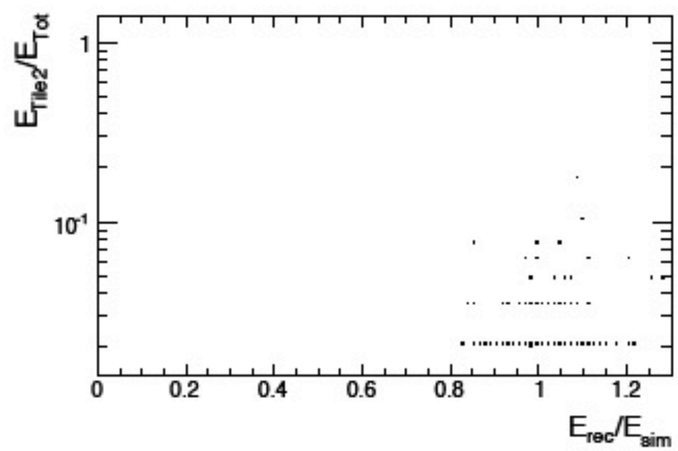
(a) $|\eta| < 0.3$



(b) $0.3 < |\eta| < 0.6$



(c) $0.6 < |\eta| < 1.3$

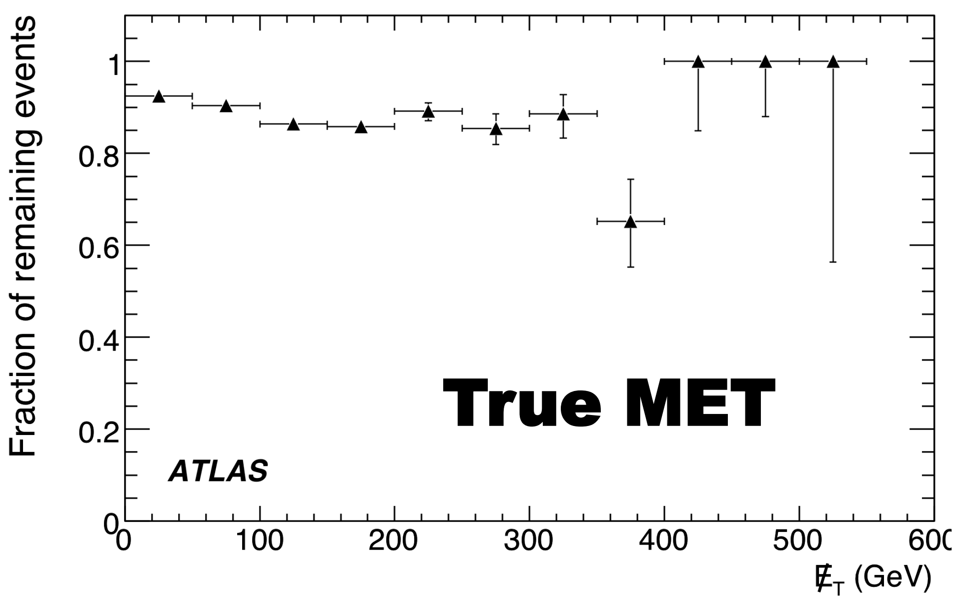


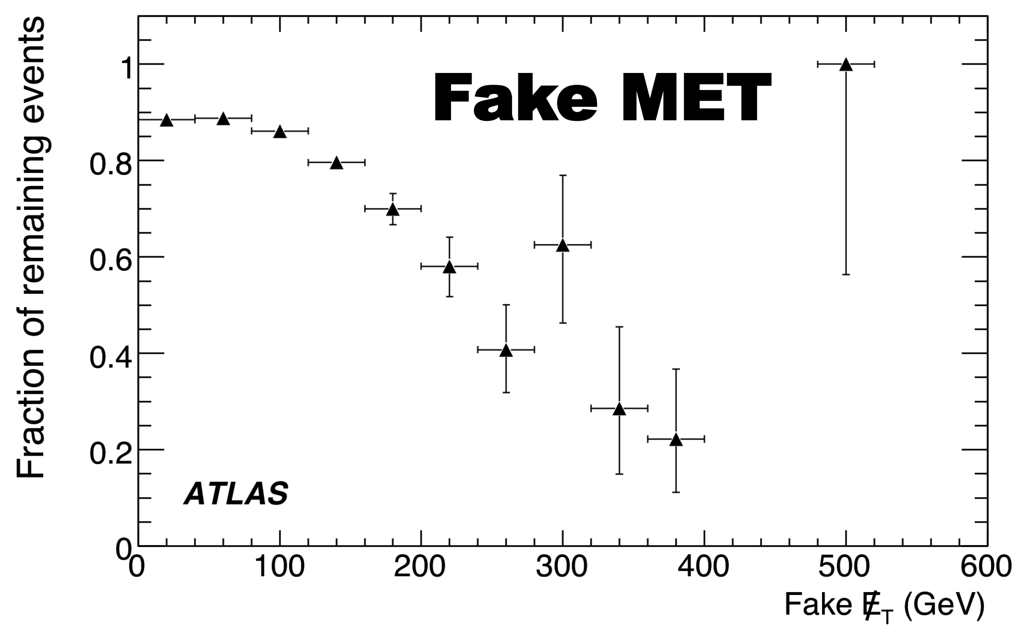
(d) $1.3 < |\eta| < 2$

Fake MET from Jets (cont)

- After jet cleaning cuts most of the fake MET is suppressed while true MET remains
  - Tested in Di-jets (plots obtained with J6)

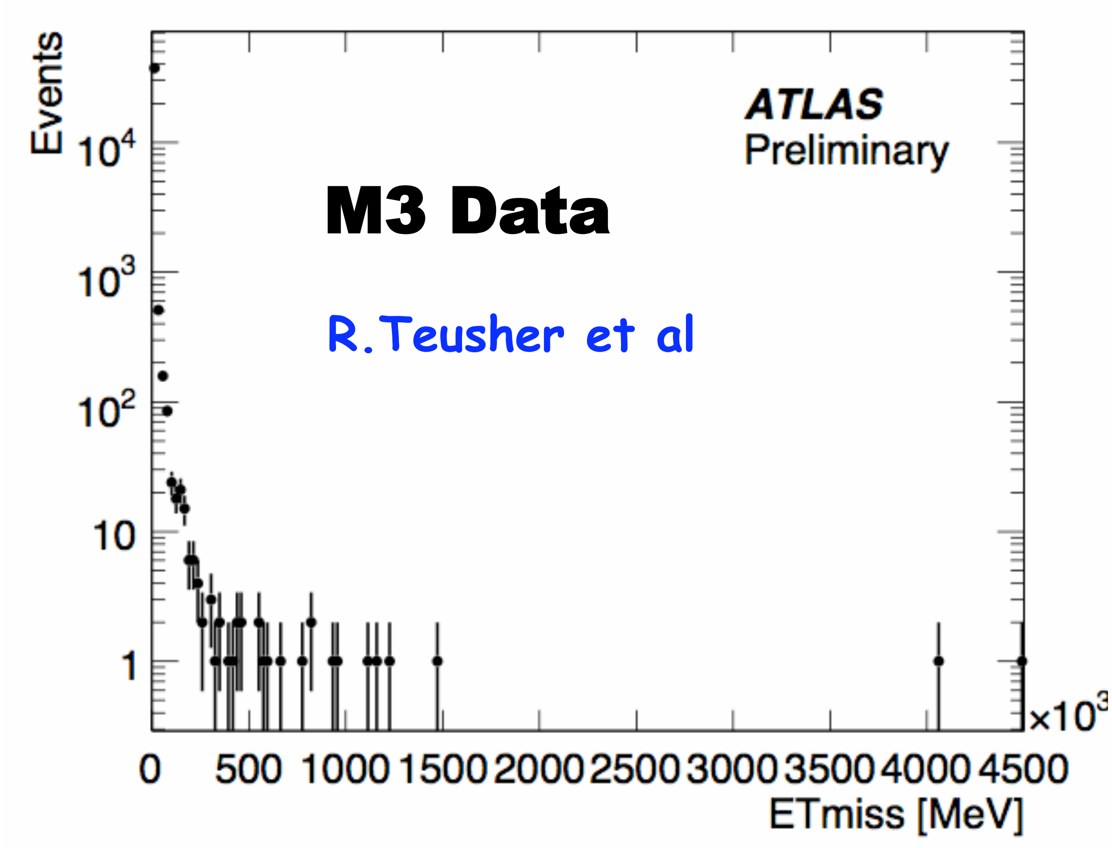
	$\|\eta\| < 0.3$	$0.3 < \|\eta\| < 0.6$	$0.6 < \|\eta\| < 1.3$	$1.3 < \|\eta\| < 2.0$	$2.0 < \|\eta\| < 3.0$
$E_{\mathrm{Tile2}}/E_{\mathrm{Tot}}$	0.05	0.05	0.1	0.02	-
$E_{\mathrm{Tile10}}/E_{\mathrm{Tot}}$	0.8	0.8	0.7	0.2	-
$E_{\mathrm{Cryo}}/E_{\mathrm{Tot}}$	0.2	0.2	0.2	-	-
$E_{\mathrm{Gap}}/E_{\mathrm{Tot}}$	-	-	0.2	0.3	-
$E_{\mathrm{HEC3}}/E_{\mathrm{Tot}}$	-	-	-	0.05	0.05

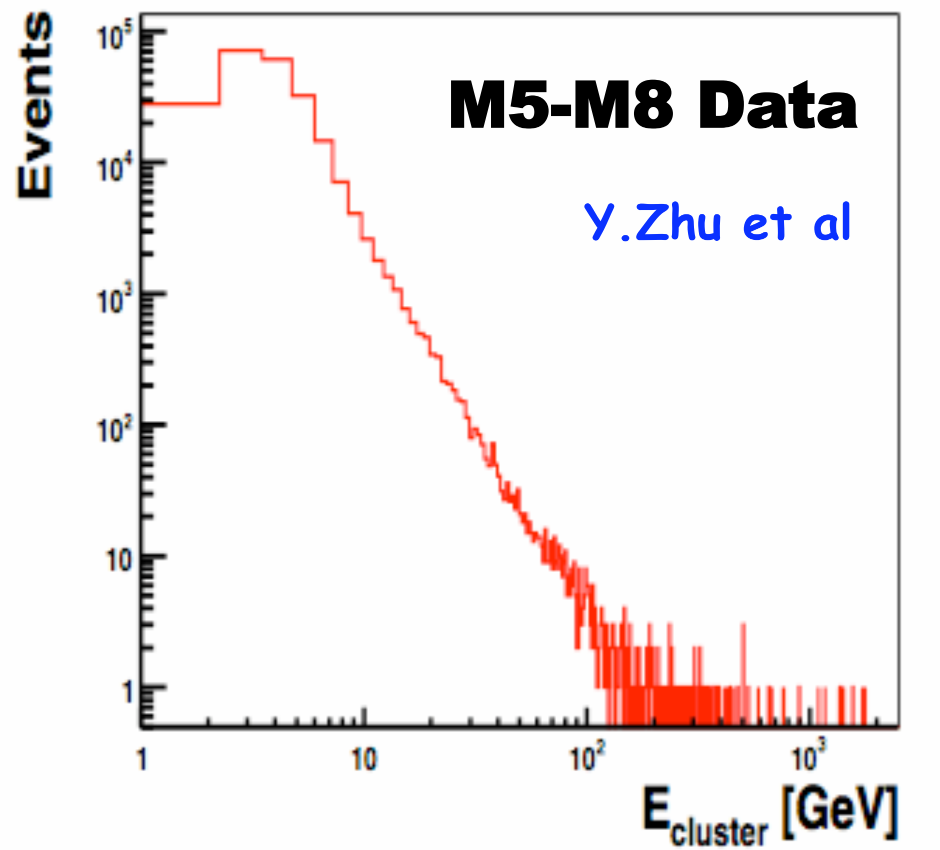




MET From Cosmics

- Milestone exercise have been very useful to understand the energy depositions from cosmic muons

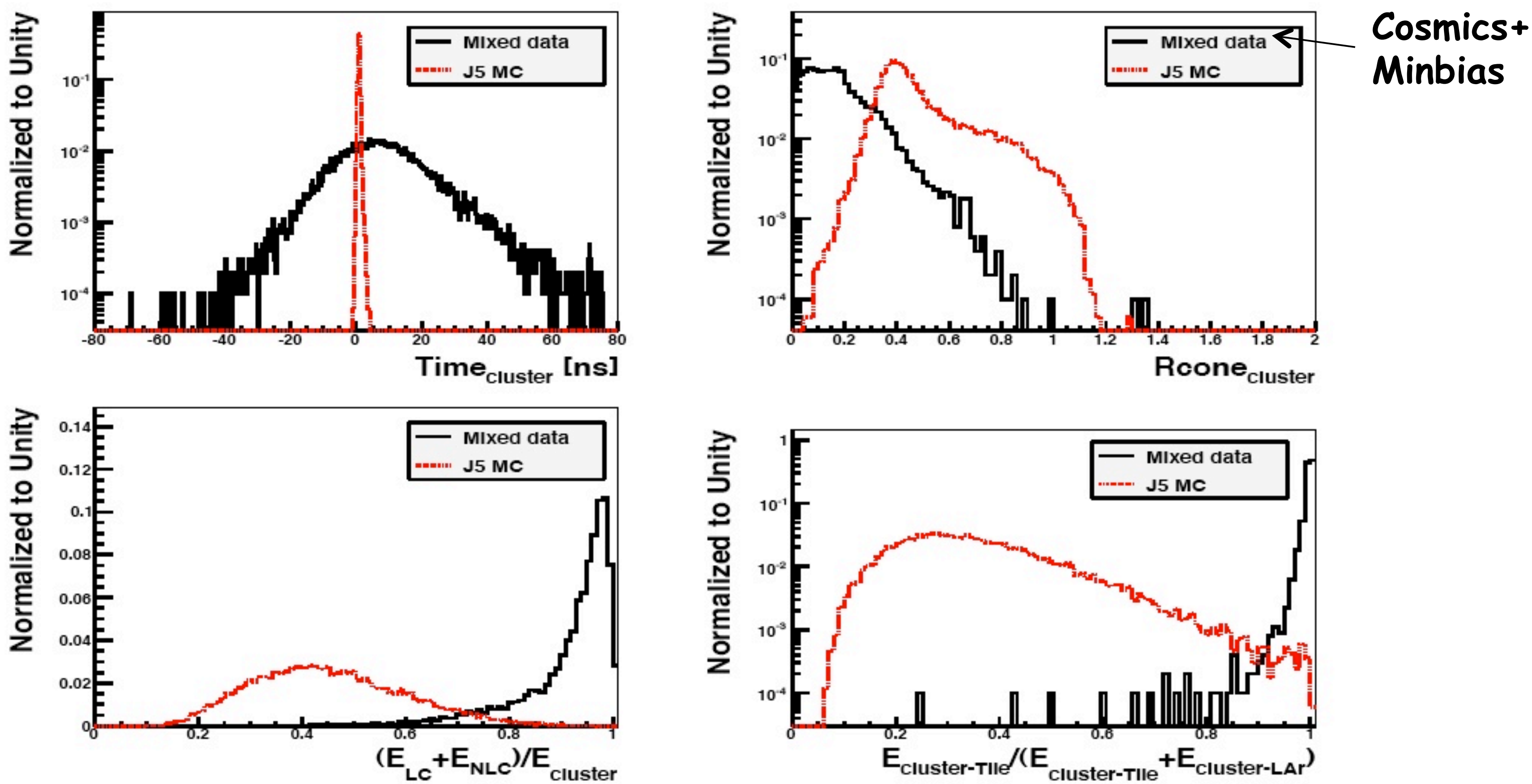




MET From Cosmics (2)

- Combined use of timing, EM fraction, shower shapes and analysis cuts should get rid of these events

Y.Zhu et al



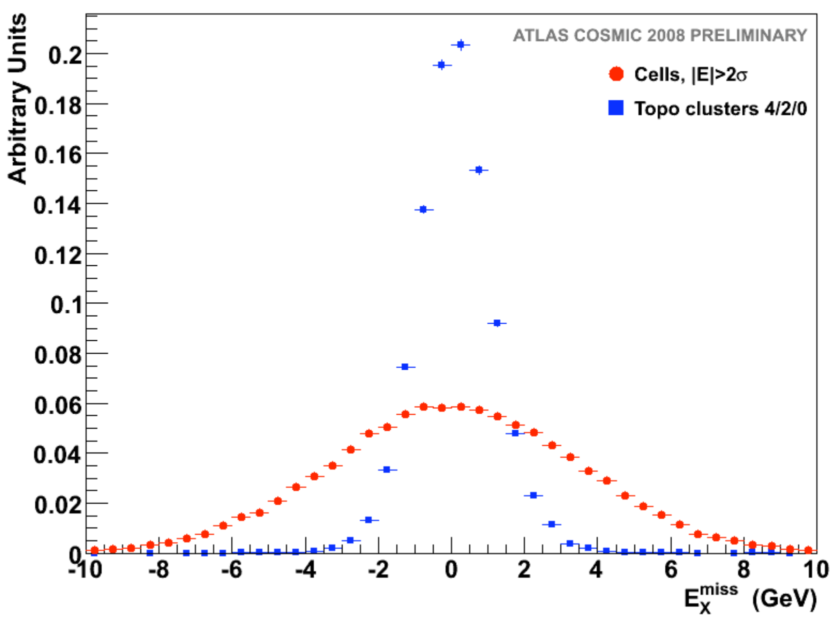
After timing and shower shape cuts, impact on physics with leptons and multi-jets should be negligible. <u>Mono-jet search may be affected</u>

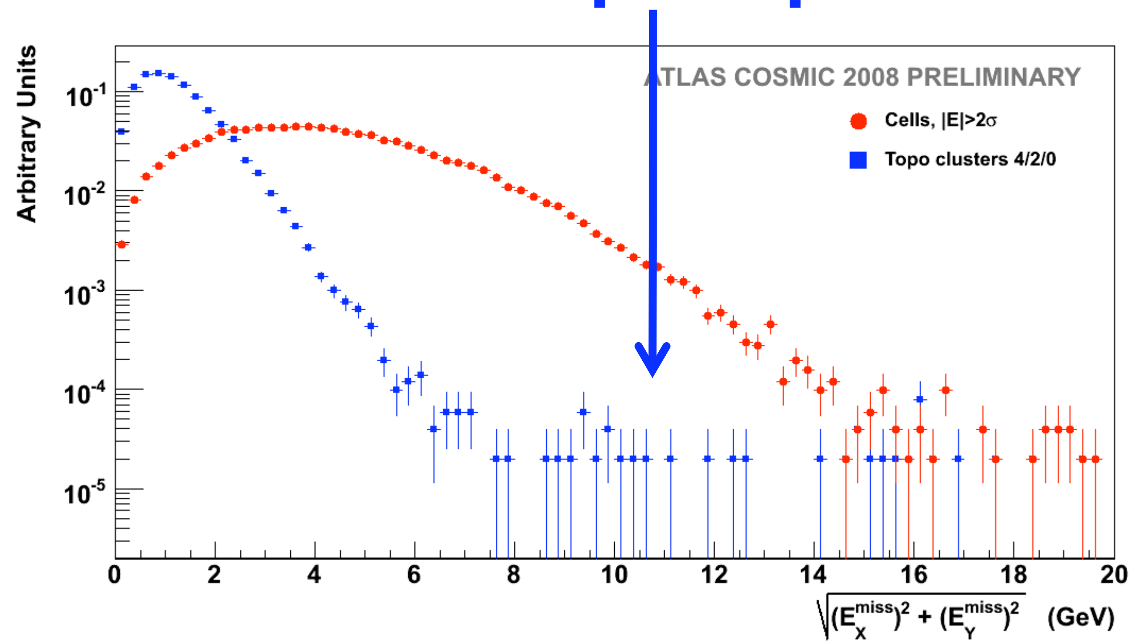
MET from Calo Noise

- Impact on MET from Calo noise is being studied with random triggers
  - Strong suppressing power of topo-clusters
  - Still need to evaluate potential impact on physics

run 91639

Coherent noise in presampler





MET with First Data

- Instrumental effects have be understood first!!

  EtMiss is sensible to each instrumental effect

  (cosmics, beam gas, beam halo, dead/hot/noisy cells/ regions….)

  Work in close contact with Detectors, Data Preparation, Data Quality groups

- Use SM events to understand MET reconstruction

  * minimum bias

  * $W \rightarrow l\ \nu$

  * $Z \rightarrow \tau\tau$

  * $Z \rightarrow ll$

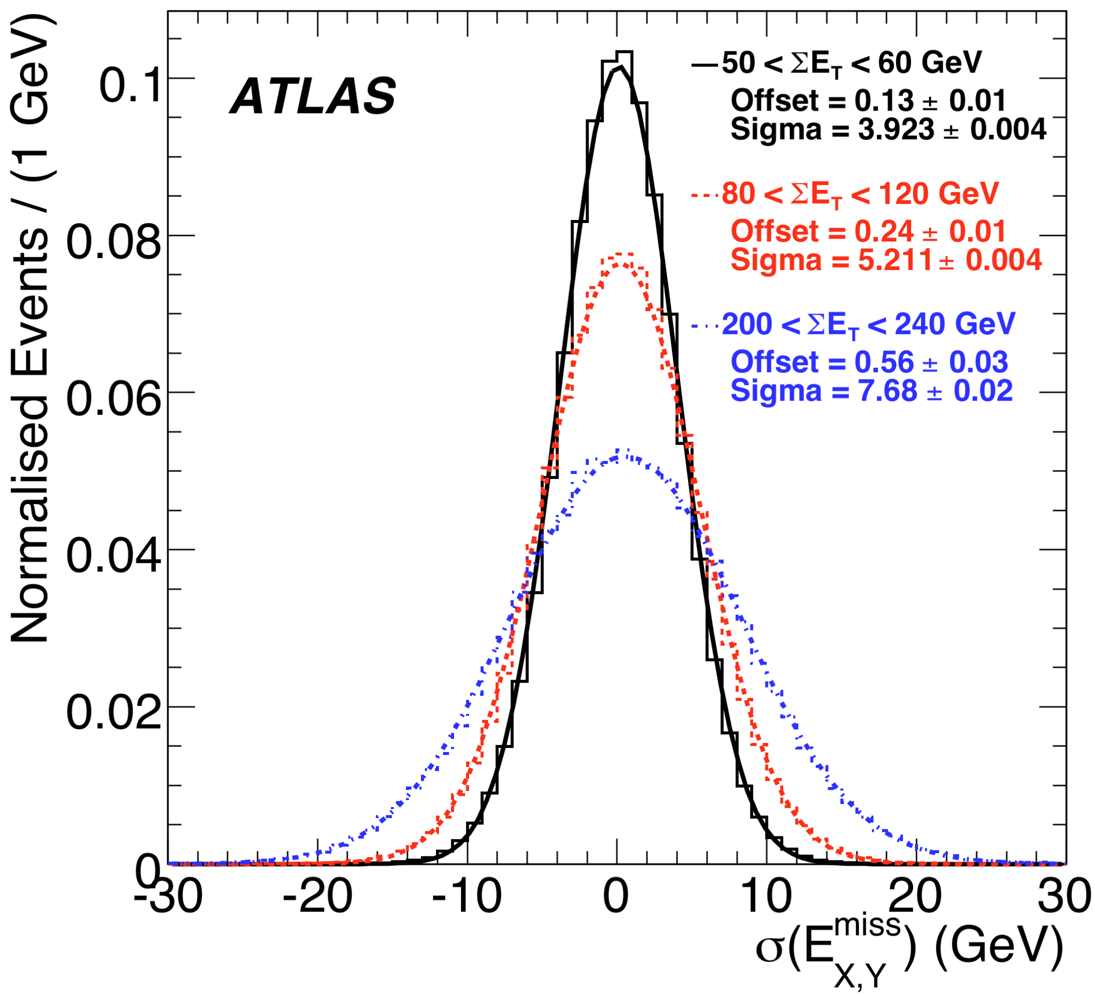
  * tt

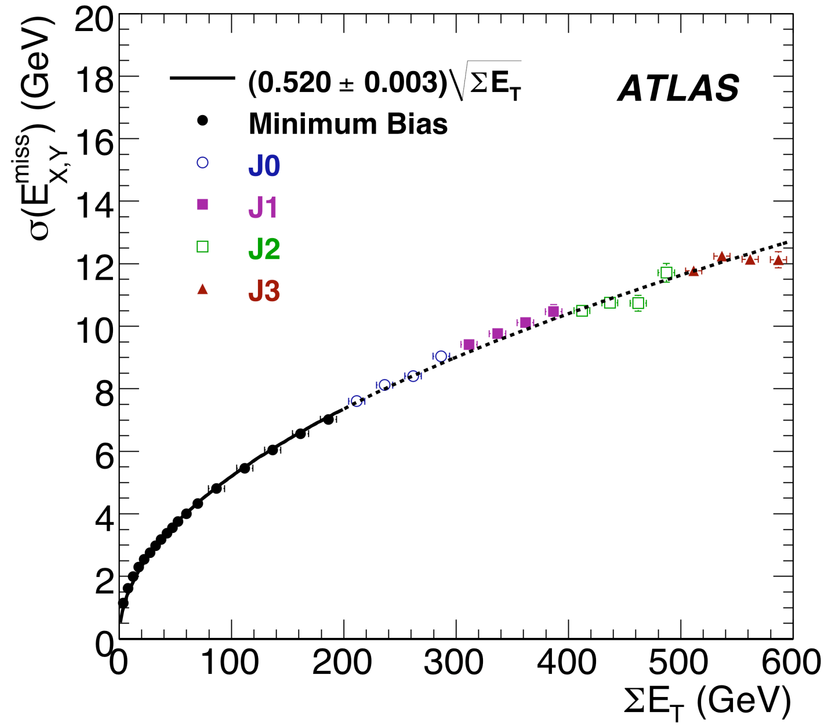
- Determine the absolute scale in-situ and Check the resolution

Minimum Bias

- control sample to test EtMiss resolution up to SumET~300 GeV (< $1 pb^{-1}$)
- Use QCD jets for higher SumET

- <SumETtrue>=64 GeV (non diffractive)
- Background: empty evts, beam gas, beam halo





Check of impact of "soft" physics on EtMiss reconstruction

1→9 jets with pT>7 GeV for SumET 50→250GeV

A. Phan, N. Kanaya

W,Z→leptons Rates at LHC

- Effective cross-sections and rates with basic cuts

	$W\to\tau\nu$ $\tau\to$had	$Z\to\tau\tau$ $\tau\tau\to l$ had	$W\to l\nu$ $l=e,\mu$	$Z\to ll$ $l=e,\mu$
σ*B*eff (pb)	3300	140	18000	1100
Rate for 10^{33} inst. Lumi. (Hz)	3.3	0.14	18	1.1
Events with 100 pb^{-1}	$3.3*10^5$	$1.4*10^4$	$1.8*10^6$	$1.1*10^5$

$Z\rightarrow\tau\tau$ Mass Reconstruction

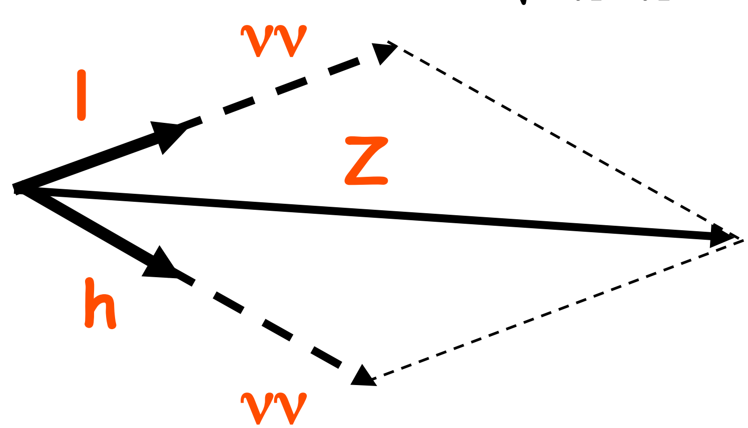
- In order to reconstruct the Z mass need to use the collinear approximation

Tau decay products are collinear to tau direction

$$\vec{P}_\tau = \frac{\vec{P}_l}{x_\tau}$$

Fraction of τ momentum carried by visible τ decay

$$M_{\tau\tau} \approx \frac{M_{ll}}{\sqrt{x_{\tau 1} x_{\tau 2}}}$$



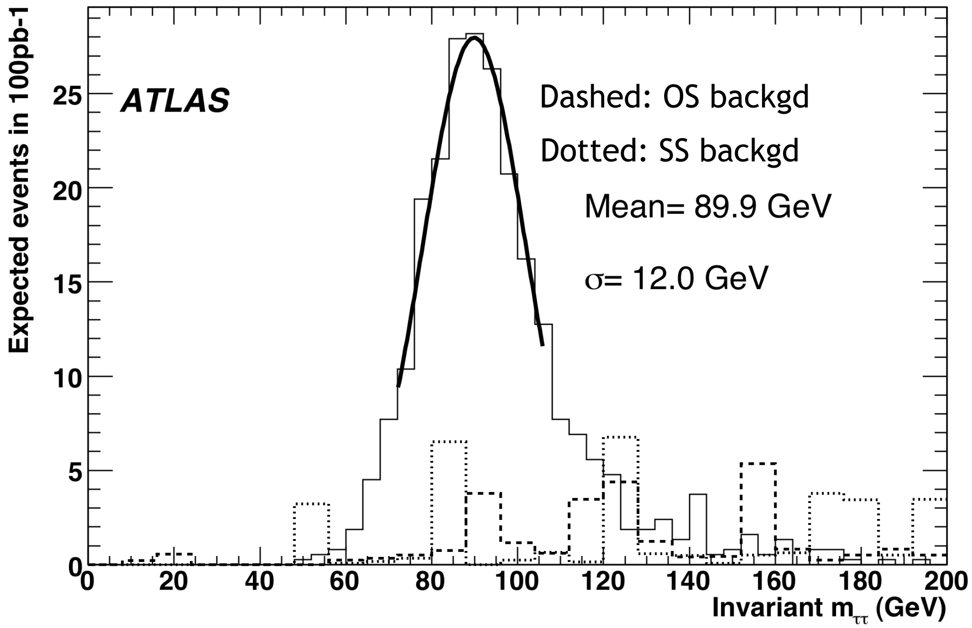
$$\vec{P}_{T\tau 1} + \vec{P}_{T\tau 2} = \vec{P}_{Tl1} + \vec{P}_{Tl2} + \vec{P}_{Tmiss}$$

$$x_{\tau_1} = \frac{p_{T_{lep1},x}\cdot p_{T_{lep2},y} - p_{T_{lep1},y}\cdot p_{T_{lep2},x}}{p_{T_{Higgs},x}\cdot p_{T_{lep2},y} - p_{T_{Higgs},y}\cdot p_{T_{lep2},x}}$$

$$x_{\tau_2} = \frac{p_{T_{lep1},x}\cdot p_{T_{lep2},y} - p_{T_{lep1},y}\cdot p_{T_{lep2},x}}{p_{T_{Higgs},y}\cdot p_{T_{lep1},x} - p_{T_{Higgs},x}\cdot p_{T_{lep1},y}}$$

- $x_{\tau 1}$ and $x_{\tau 2}$ can be calculated if the missing E_T is known
- Good missing E_T reconstruction is essential

$Z \rightarrow \tau\tau \rightarrow$ lepton-hadron



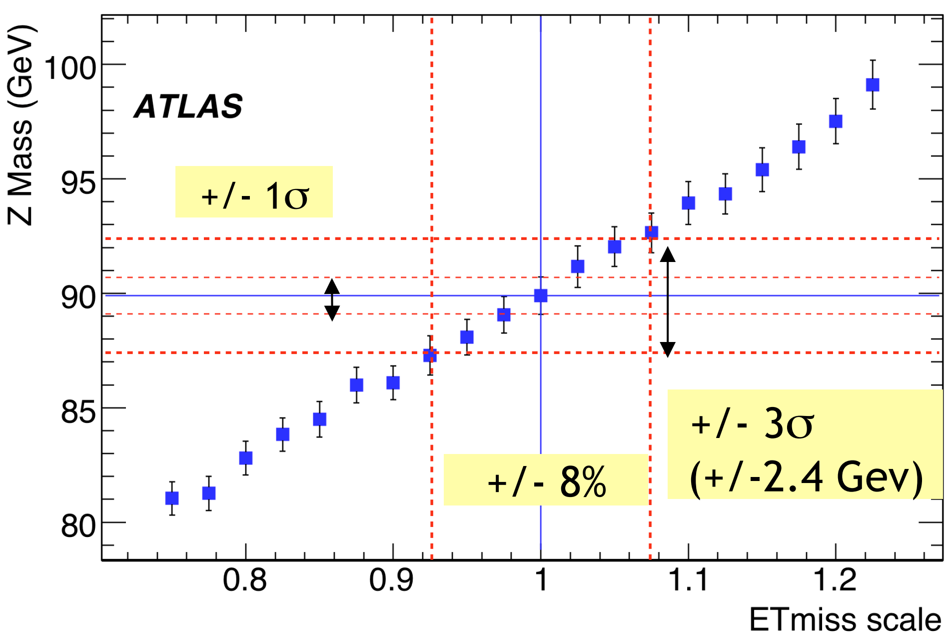
In 100 pb $^{-1}$

in the mass bin (66-116 GeV)

209 signal evts

16 backgds evts OS (B ≈ 8% S)

$S/\sqrt{B}$=50

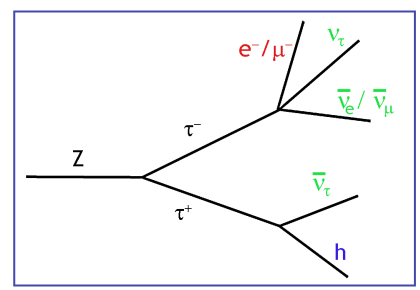


ETMiss scale precision:

3% with only stat errors

8% taking into account systematics, fit stability, ...

D. Cavalli, C. Pizio



MET with W→lν (1)

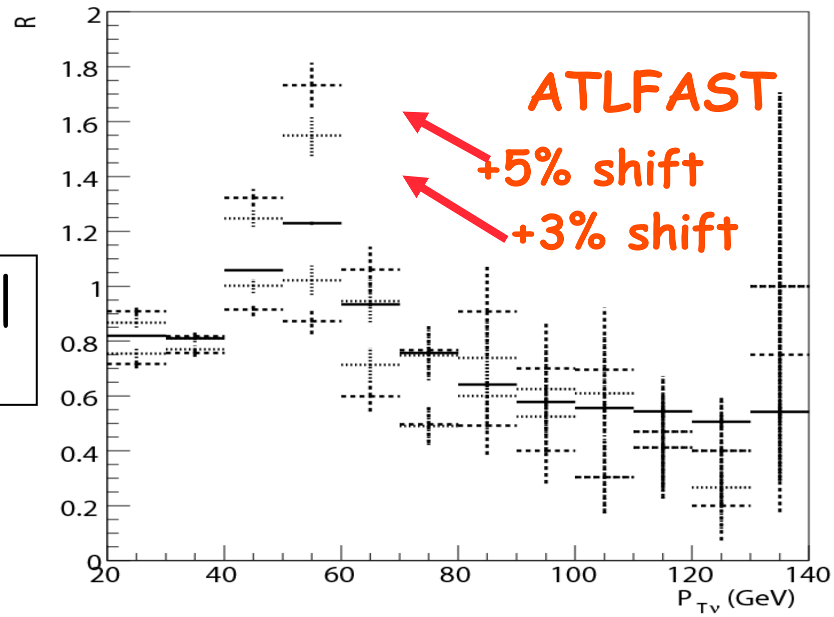
X.Chen, B.Mellado, S.Padhi and Sau Lan Wu

- **Use the ratio of average pT of the neutrino and of the charged lepton in W decay.**

$$\frac{d\sigma}{dP_{T\nu}} \Big/ \frac{d\sigma}{dP_{TL}} = f(P_{TL})$$

P_{TL}>20 GeV, $|\eta_l|$ <2.5

This ratio should be =1, but its distribution is distorted by the experimental cuts



- Method is sensible to EtMiss scale up to EtMiss values of 60 GeV already with 1 pb-1.
- Not particularly sensible to resolution

W →τν, τ →lνν background is small

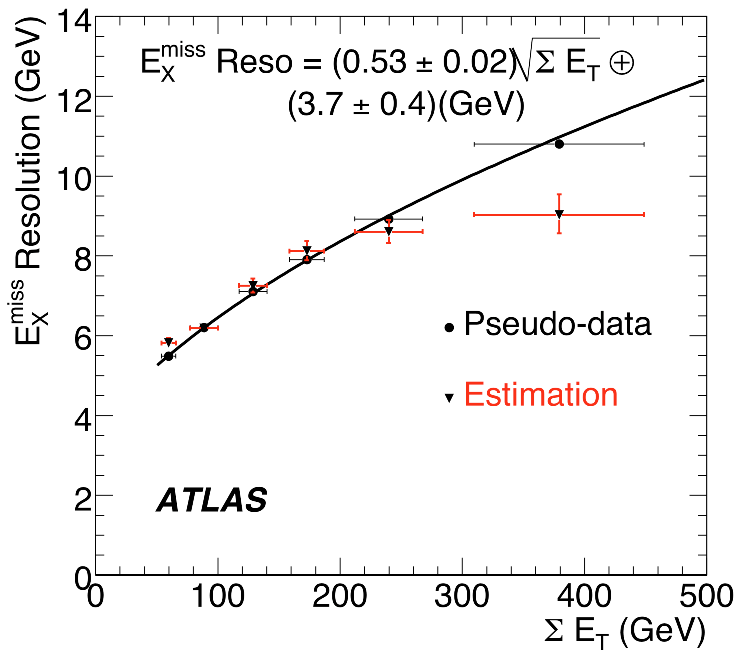
Z → ll, QCD and tt backgrounds to be studied in full simulation

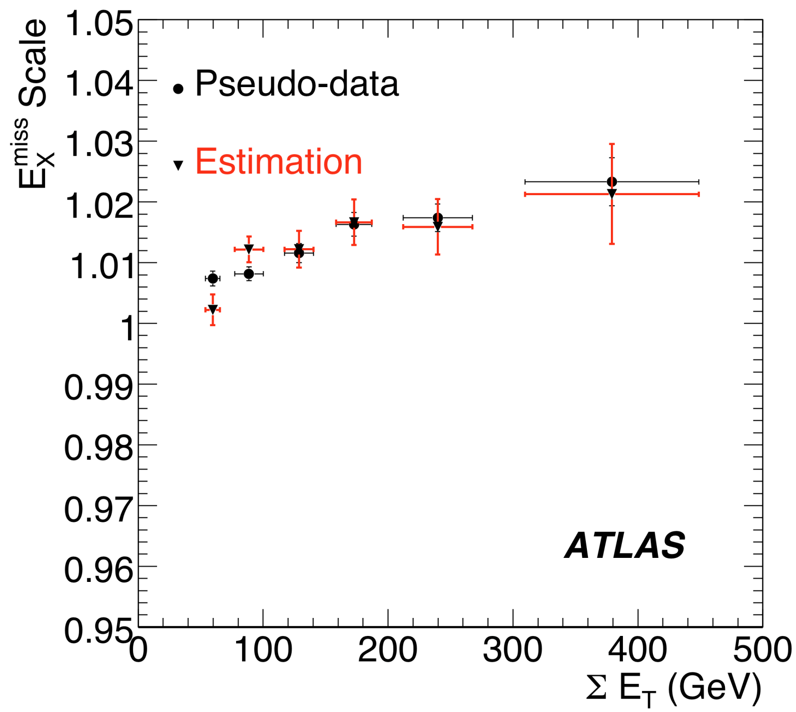
MET with W→lν (2)

N. Kanaya, H. Okawa

Template method: convolute true transverse W mass distribution with EtMiss response to create a set of template histograms with which to fit the transverse mass distribution.

W→μν



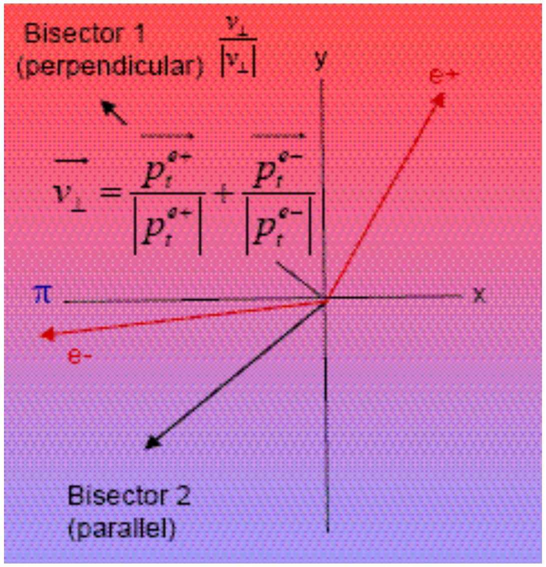


Results of the fit agree well with the expectations using truth information (pseudo-data). The scale can be measured at 1% level, no systematics.

W→τν and Z→μμ can be included in the Template, tt suppressed by requiring low jet multiplicity

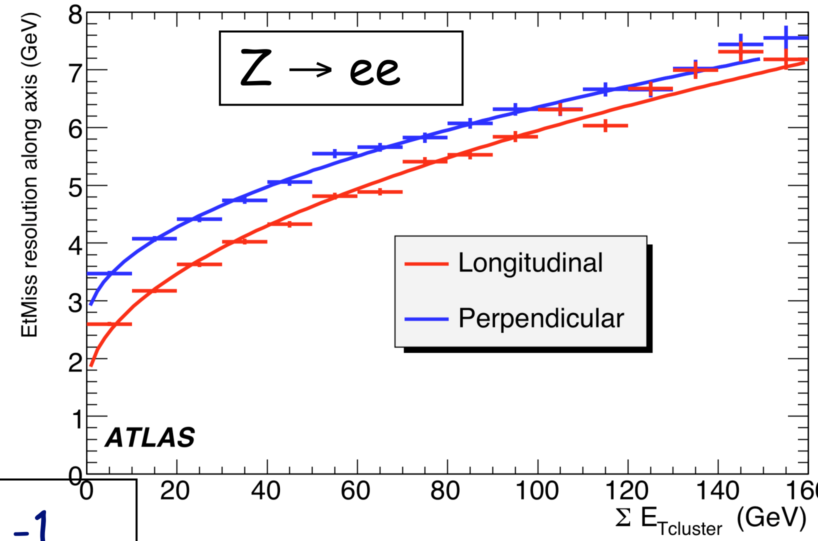
MET with Z → ll

E. Dobson



Choose axis minimising the errors on the pT measurement of electron/ positron.

- The perpendicular axes points in the direction of flight of the Z and away from the hadronic recoil

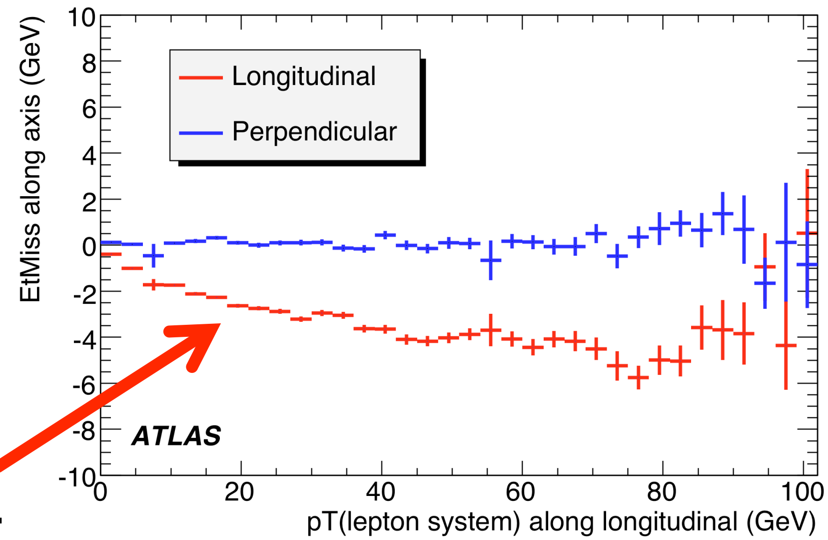


250 pb -1

- <SumETtrue> few 100GeV
- Background: Ztt and Wln negligible, QCD jets is small

Diagnostic plot

EtMiss along perpendicular has offset of about 4 GeV at high pT values of lepton system



This seems to be understood as effect of particles going down the beam pipe and particles with low P_T

MET with tt

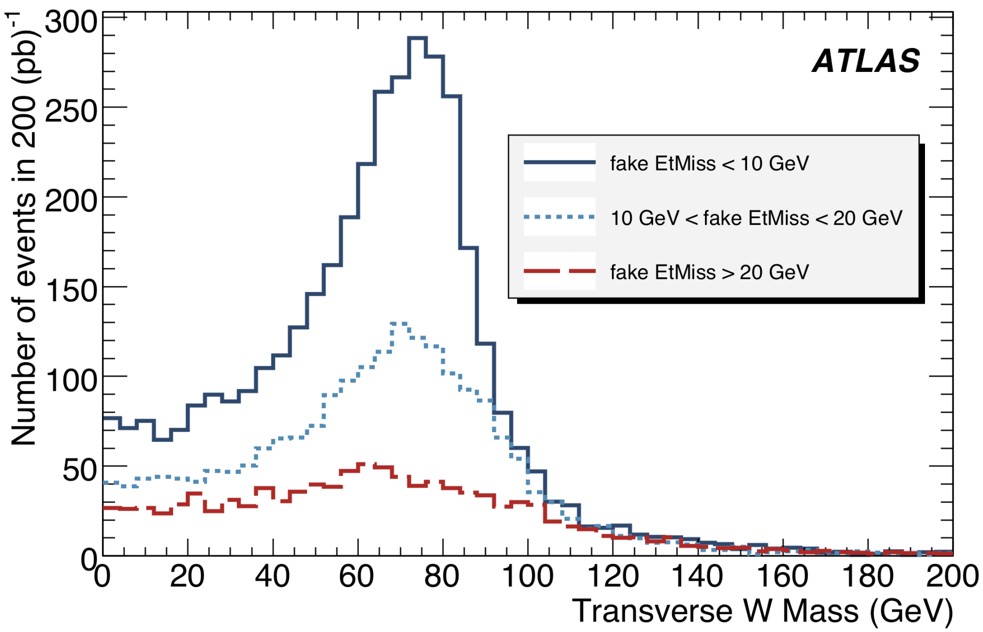
M. Rijpstra, M. Vreeswijk

Semileptonic tt events

⇒**Investigate possible problems of EtMiss measurement in early data**

⇒**Sensitivity to EtMiss scale (200 pb $^{-1}$)**

Reconstruct transverse W mass



- **<EtMiss true>=20-100GeV <SumETtrue>=500 GeV**
- **Background: W+jets (20%), Susy can have severe impact on the distribution**

Peak position shifts by -7 (7) GeV when EtMiss scaled by 0.8 (1.2)

Software for Data Taking (Release 14->15)

EtMiss Reconstruction and Calibration in MissingET Package

MET_Final =

MET _CaloCalib + MET _Cryo + MET _Muon

MET_CaloCalib options:

Calorimeter Cells
$|E_{cell}| > 2\sigma_{noise}$
calibrated with weights from jet calibration
"H1" style calibration

Calorimeter Cells
in TopoClusters (4σ/2σ/0σ)
calibrated with weights from jet calibration
"H1" style calibration

Calorimeter Cells
in TopoClusters (4σ/2σ/0σ)
cluster based calibration /dead material correction
local hadronic calibration

Calorimeter Cells
in e, photons, τ, jets, unused Topoclusters
with weights from physics object calibration
refined calibration

Calorimeter Cell Clusters
TopoClusters (4σ/2σ/0σ)
cluster based calibration /dead material correction
local hadronic calibration

MET_Cryo options:

Cryostat Losses EMB /Tile
correction factors from reconstructed seeded cone tower jets with ΔR<0. 7
based on cone Topocluster jets

Cryostat Losses EMB /Tile
correction factors from reconstructed seeded cone topocluster jets with ΔR<0. 7
based on cone Tower jets

MET_Muon options:

Staco
$|\eta| < 2.7$
best match /good quality required
p_t from ext spectrometer/from comb-calo

Muld
$|\eta| < 2.7$
best match /good quality required
p_t from external spectrometer

- **highlighted combination is the default in MissingET package**
- **each contribution is individually available in ESD/AOD (also not calibrated)**
  ⇒ **some degree of freedom in physics analysis**
- **very good MissingET flexibility: robustness with first data**
- **uses only official calibrations from reconstruction objects (no specific corrections for EtMiss applied)**

- Local Hadronic Calibration already includes Cryo correction

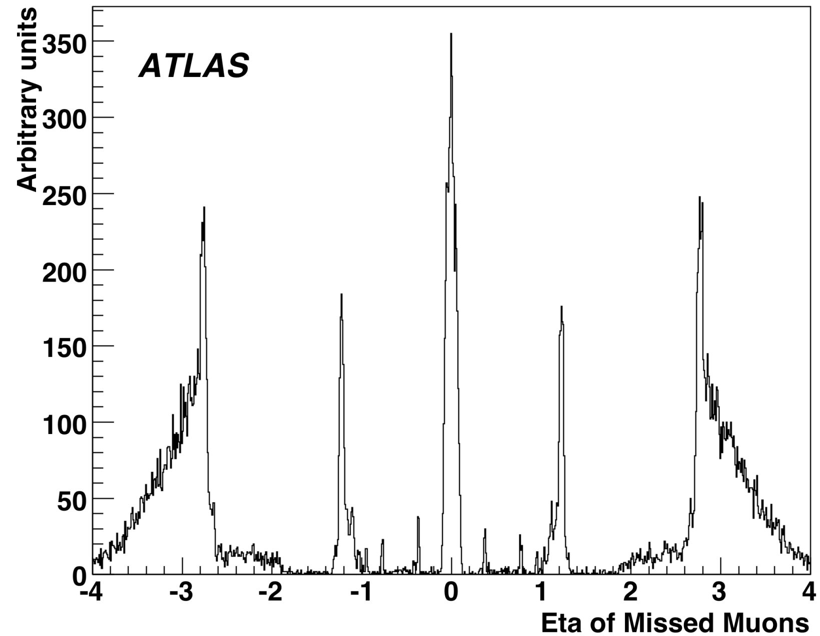
Improve the Muon term

- Muon mismeasurement ➡ Fake EtMiss

- not reconstructed muons (main contribution)
  - use Calobased algorithms to:
    - recover muons around $|\eta|=0$ (services gap)
    - recover muons around $|\eta|=1.2$ (middle Muon station missing for initial data taking)
- badly reconstructed muons
- fake muons (mainly due to jet punch-through)
- Improve cleaning cut (J. Goodson, A. Yurkevic)

- Different treatment for isolated and non-isolated muons

Merge the Muon term calculation from MissingET and ObjMET.
Use Calobased algorithms included now in rel 14



Eta of missed muons in $Z \rightarrow \mu\mu$
Events in release 12

Performance of improved muon treatment is being tested

MissingET reconstruction on AOD

⇒ **New code is finally ready in the nightlies for rel 15.1.0:**

⇒ Provides the possibility to rerun refined calibration on AOD

⇒ New design by P. Loch permits to use same METRefTools for ESD and AOD, configuring themselves with processors according to cell or cluster use ⇒ all METRefTools rewritten

⇒ All details in the talk by Peter at the last jet/EtMiss performance meeting:

http://indico.cern.ch/conferenceDisplay.py?confId=48775

⇒ **Which constituents are used at AOD level ?**

⇒ constituent TopoClusters of taus and jets (no more cell connection on AOD)

⇒ constituent CaloCells of electons/photons/muons (available on AOD)

⇒ **How to apply overlap removal at AOD level ?**

⇒ unfortunately cannot use only TopoClusters because electons/photons/muons are not built on TopoClusters

⇒ new method to associate CaloCells to TopoClusters:

- calculate the likelihood that a cell is within a TopoCluster envelop around its barycenter.
- For example: if the TopoCluster associated to the cells of an electron is found, that TopoCluster is included in the cluster map and not added anymore more in the MET calculation to avoid energy double counting.

Robustness of Algorithm with First Data

⇒ **The complete Refined Calibration, where the cell calibration depends on its parent object, has dependencies from all reconstructed objects**

⇒ **it could be not robust enough with first data**

Simpler EtMiss calculations can be used at the beginning of data-taking:

(1) Use CaloCells (unweighted-em scale or with H1-weights) + muons

⇒ **dependencies only from CaloCells and muons**

(2) Use CaloCells inside TopoClusters + muons

⇒ **dependencies from TopoClusters and muons**

(3) Add cryostat correction ⇒ dependency from TopoClusters, muons,jets

(4) Apply the Refined Calibration

⇒ **dependency from TopoClusters, ele/γ, τ, jets, and muons**

- all these scenarios are already implemented in MissingET package
- tools to recalculate EtMiss from AOD almost ready

Outlook and Conclusions

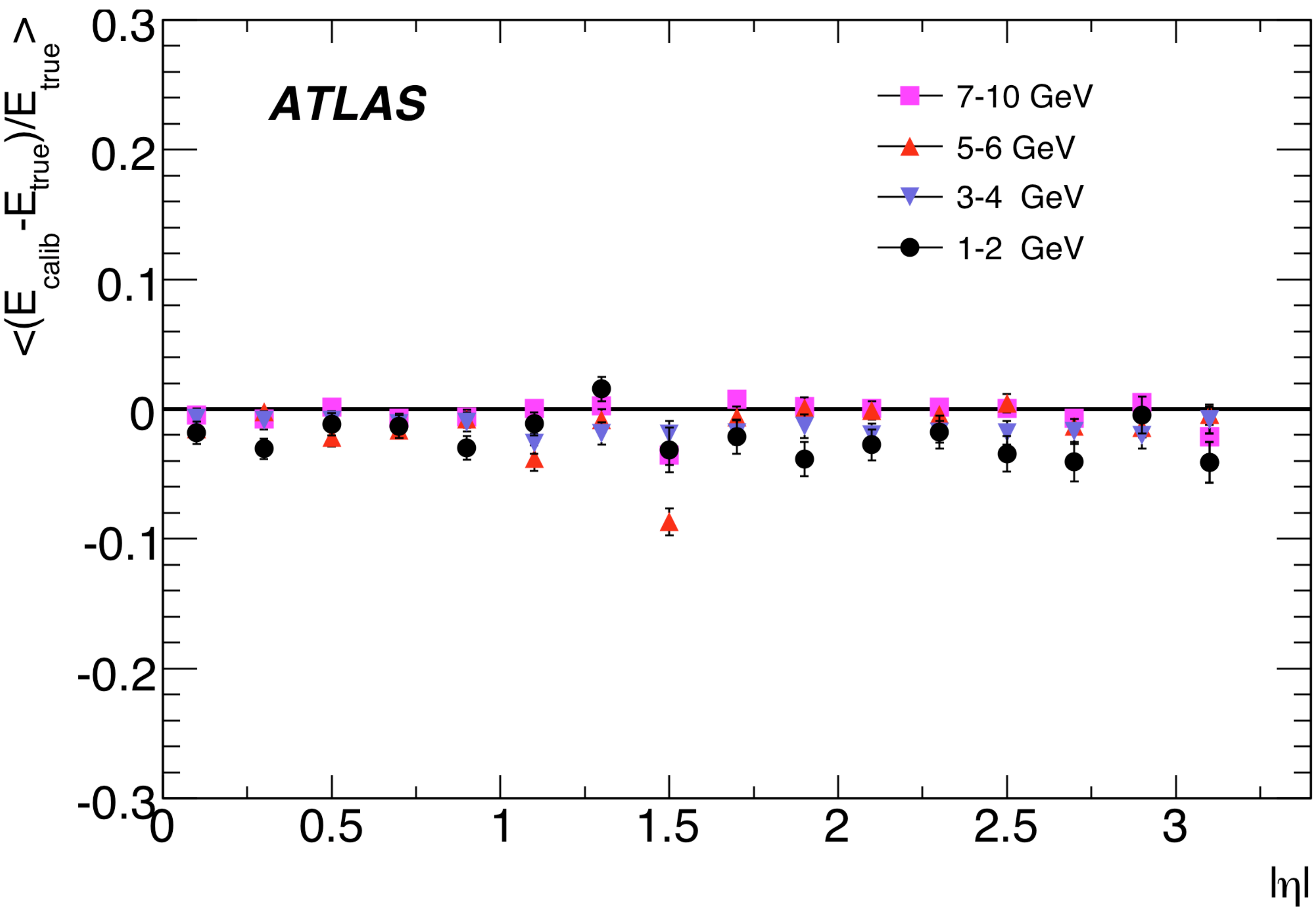
- **ATLAS is developing a robust effort to understand MET reconstruction**
  - **Addressing issues of performance (resolution, linearity, angular determination, topology dependence**
  - **Identify sources of fake MET with MC studies**
    - **Cosmic ray data proved very useful exercise**
  - **Detailed studies of prospects of MET reconstruction with various data samples**

  https://twiki.cern.ch/twiki/bin/view/Atlas/EtMissCSCNote
- **Development of software in release 14-15 to address needs of data taking**
  - **While providing tool to achieve best MET performance, allow for simpler procedures for first data**
  - **Reconstruction of MET at AOD level**

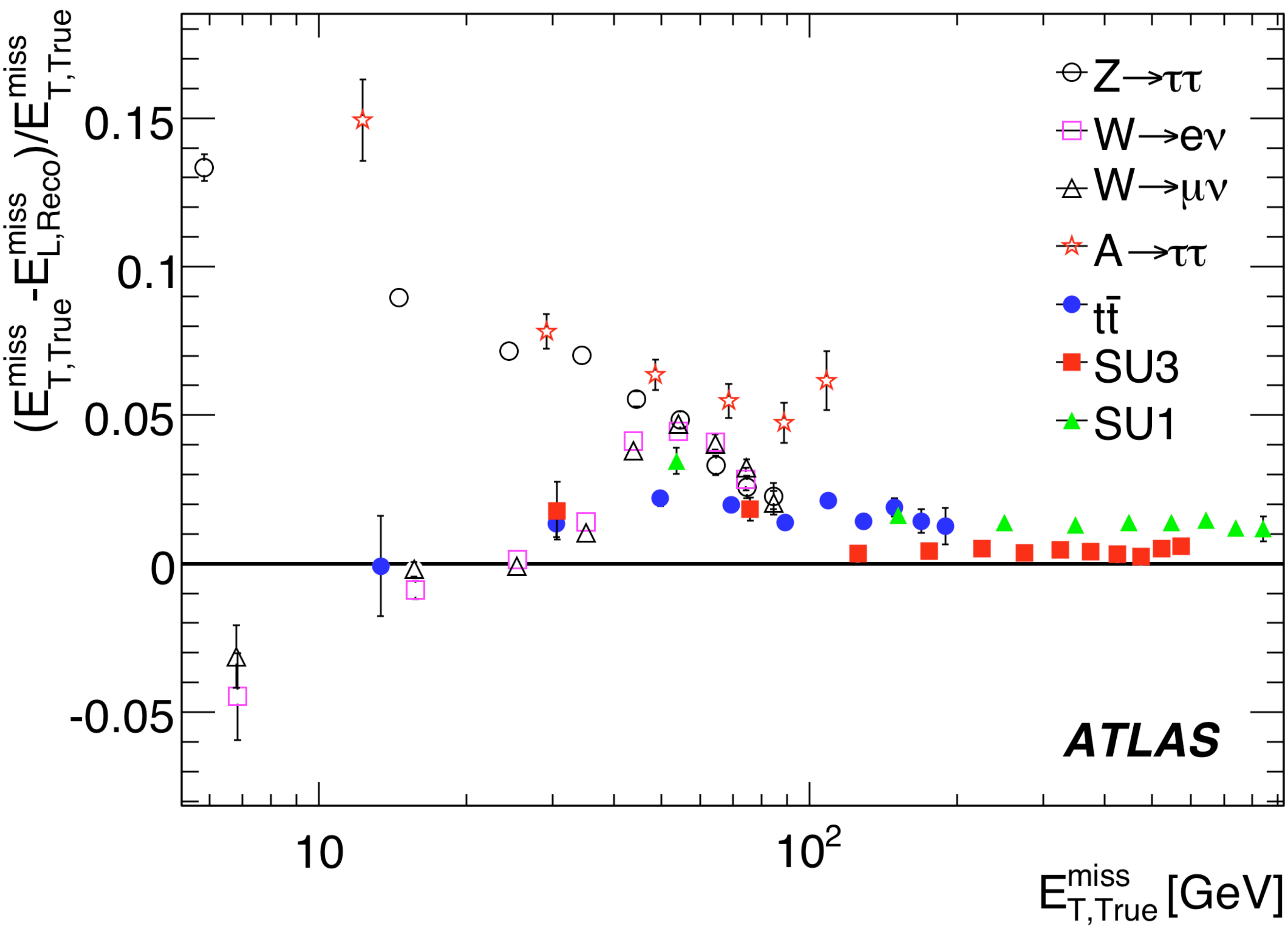
Back-up Slides

Linearity of Low P_T pions

- Calibration constants of low PT depositions obtained from single pions



MET Resolution



M3, Data, R. Teuscher et al.

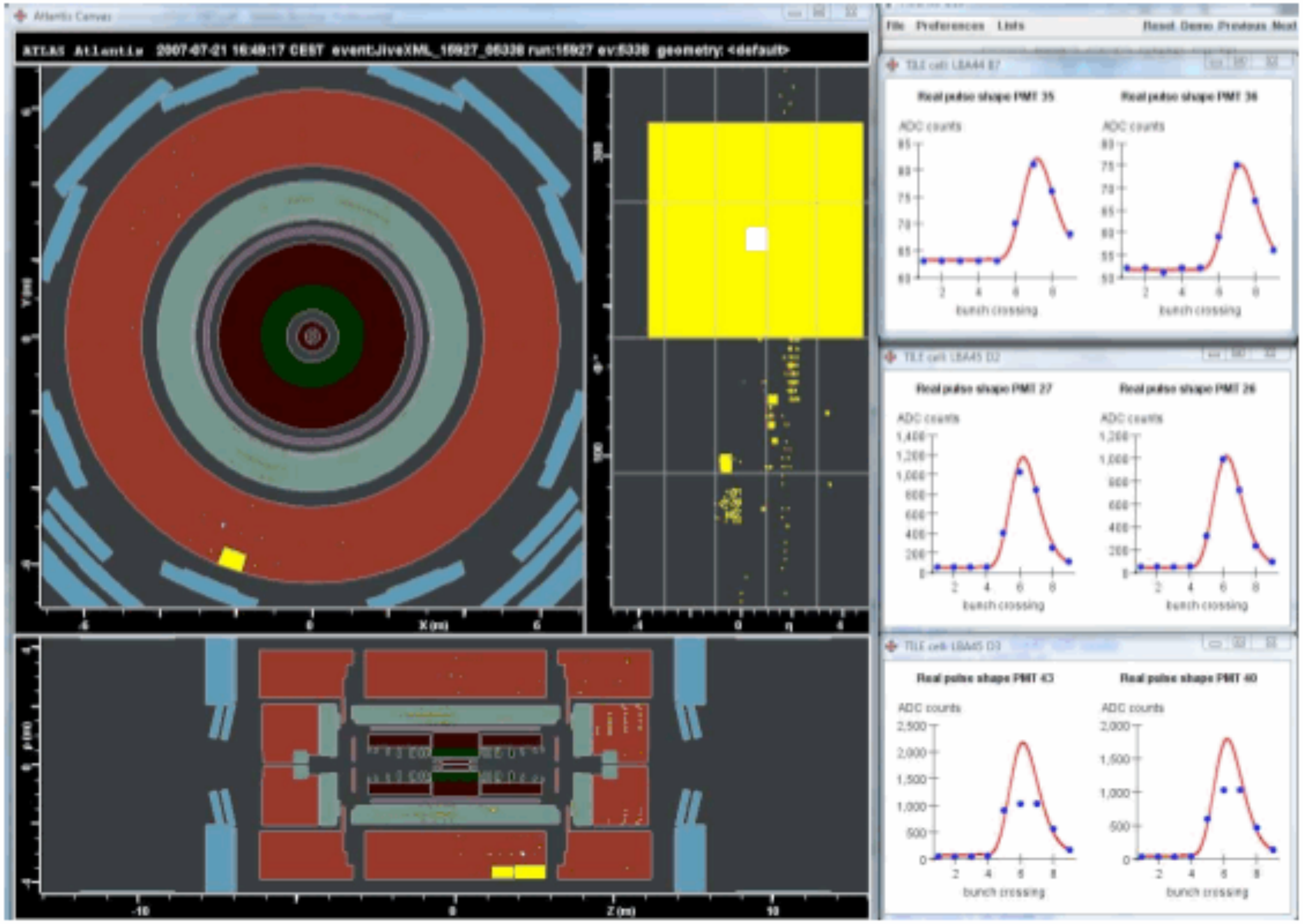
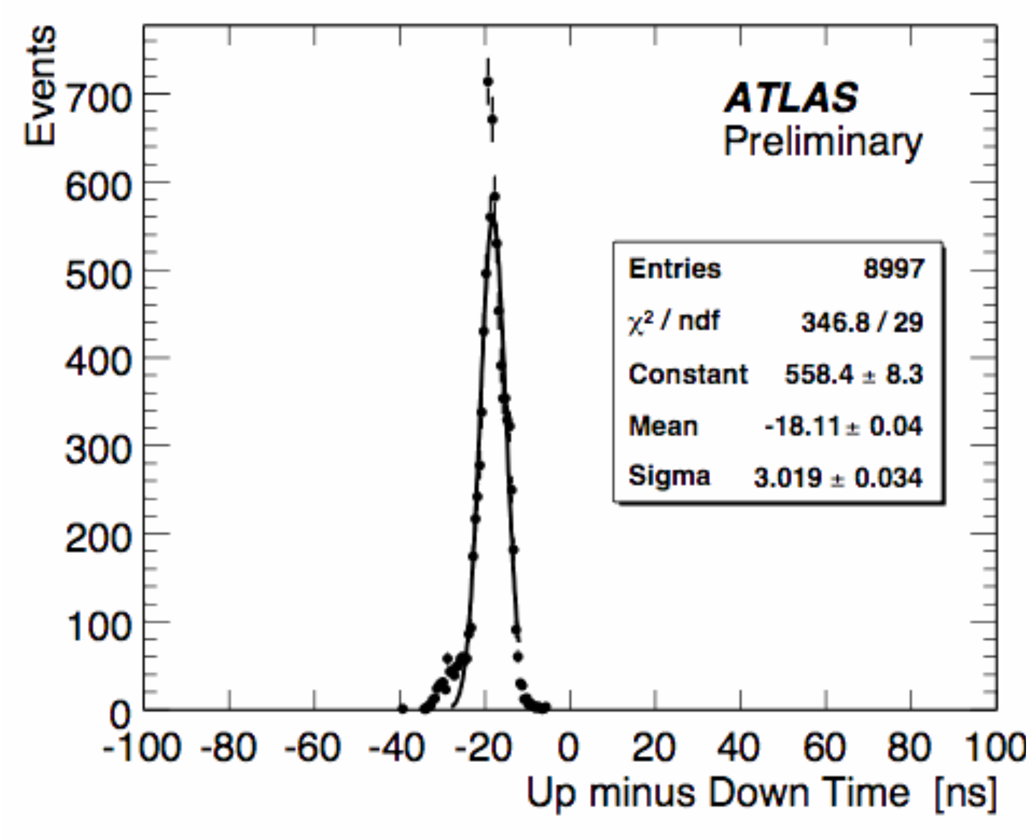


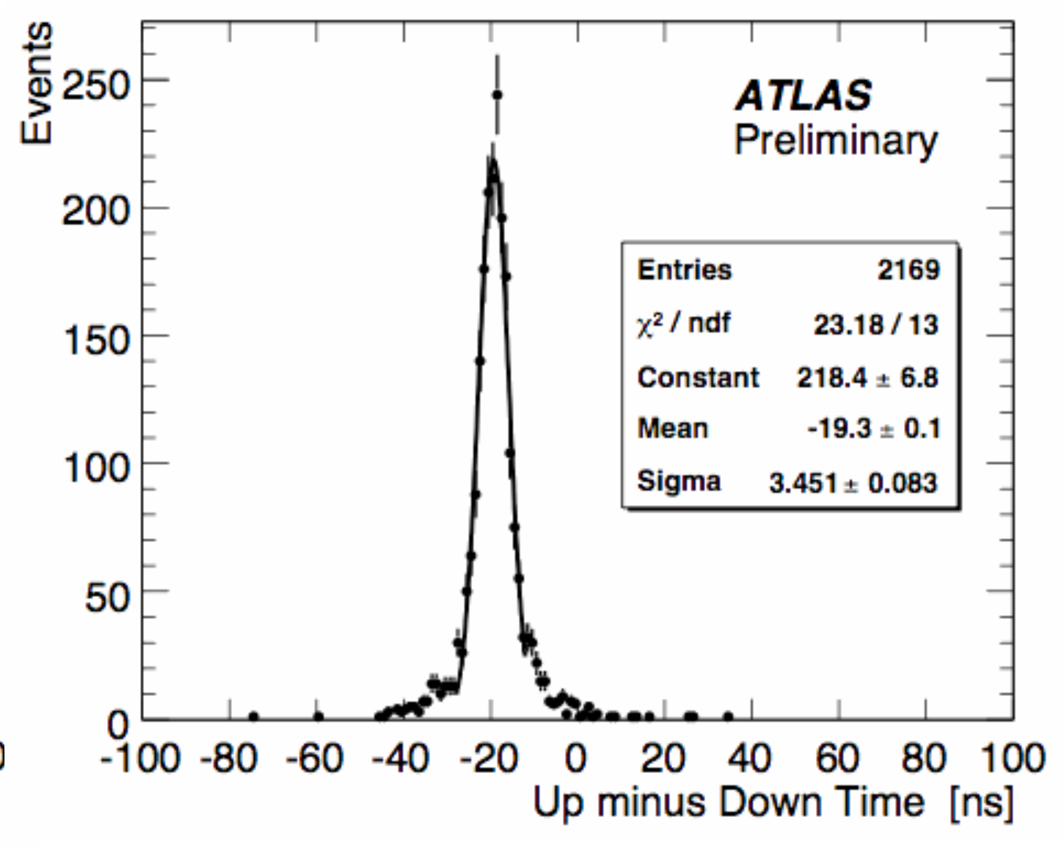
Figure 7: Cosmic ray muon which saturates a TileCal cell, generating 4 TeV of $\not\!\!E_T$. Note the saturated cell on the bottom, compared to the nominal pulse shape. The "up-minus-down" time of the highest energy cells is -30 ns.

MC



Events
ATLAS
Preliminary
Entries 8997
χ² / ndf 346.8 / 29
Constant 558.4 ± 8.3
Mean -18.11 ± 0.04
Sigma 3.019 ± 0.034
0
100
200
300
400
500
600
700
-100 -80 -60 -40 -20 0 20 40 60 80 100
Up minus Down Time [ns]

M3 Data



Events
ATLAS
Preliminary
Entries 2169
χ² / ndf 23.18 / 13
Constant 218.4 ± 6.8
Mean -19.3 ± 0.1
Sigma 3.451 ± 0.083
0
50
100
150
200
250
-100 -80 -60 -40 -20 0 20 40 60 80 100
Up minus Down Time [ns]

Cosmics Rejection
(calo only, no timing)

Jet efficiency (J5)

	Tile-cells method		Topo-cluster method	
	LLR_2	LLR_{final}	LLR_2	LLR_{final}
eff. %	rej.	rej.	rej.	rej.
97.493	855.3	10263.5	469.0	2286.4
98.997	570.2	3421.2	318.1	1261.5
99.598	230.6	1368.5	191.5	813.0
99.749	120.7	892.5	143.5	571.6
99.893	27.6	373.2	67.7	239.1
99.957	4.4	195.5	26.9	112.9
99.969	3.2	137.8	17.5	72.2
99.975	2.7	112.8	13.2	47.5
99.986	1.9	54.6	6.2	29.3

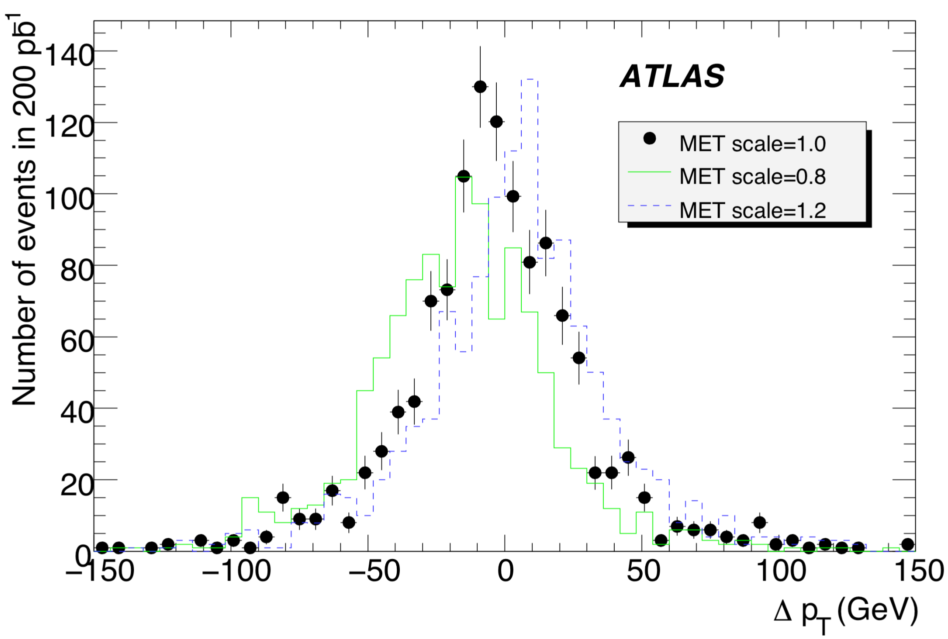
MET with tt

⇒Kinematic fit of events after selection using all mass constraints in tt events (MW_{lep},MW_{had},$Mtop_{lep}$,$Mtop_{had}$)

No b-tagging used

⇒The χ^2 of the kinematic fit can be used to suppress event with large Fake EtMiss. It is possible to classify events with a good EtMiss measurement useful to locate detector problems in first data

⇒Background suppressed by χ^2 cut



Δp_T of the two reconstructed top very sensitive to EtMiss scale (2% no systematics)

Towards the "best" MET Refined Calibration

⇒ **Refined Calibration:**

CaloCell weights depend on the type of the reconstructed object (e/γ, μ, τ, b-jet,jet…), cells in Topoclusters outside reco objects

Calibration in rel. 12/13 : e/γ: em scale, τ, jets, cells outside: H1-style

⇒ **further step needed: for each reconstructed object use the best calibration weights of constituent CaloCells**

- Electrons/photons:

  In CalibHits based e/γ calibration the different effects (sampling, material in front, longitudinal leakage, out of cone) are now separately corrected

  ⇒ include corrections for sampling, material in front, longitudinal leakage, BUT NOT the out of cone to avoid double counting (in rel.14)

- Jets:

  Separate corrections due to different effects (work in progress)

  Do NOT use the out of cone to avoid double counting

- Taus:

  Use the best Tau calibration to improve mass reconstruction of $\tau\tau$ final states

Calibration of Cells Outside Reconstructed Objects

- Cells in Topoclusters outside reconstructed objets:
  special calibration for low pT depositions from ObjMET (Wisconsin)
  - Build Minijets
    - calibrate charged pions
    - calibrate neutral pions
  - Calibrate the rest (cells outside Minijets)

  ⇒Now integrated in MissingET package (rel.14)

  - Checks in progress
  - Have to tune the best threshold:
    above: reconstruct jets
    below: reconstruct minijets

MET Calculation from AOD

⇒from AOD: NOT possible to re-calculate EtMiss at Cell level. Overlap removal between reco objects cannot be done at cell level.

All Topoclusters but only some sets of CaloCells will be available on AOD : e/γ, μ…

- Ambiguity resolution based on Topoclusters
  - electrons/photons and muons are NOT built from Topoclusters
    - electrons/photons from Sliding window clusters (fixed size)
    - No direct association between muons and Topoclusters

- measure common cell content between different clusters

- Re-use the same MET Tools written for ESD, same map as ESD Cell map can be used for clusters, use same MET EDM

⟶ Can change calibration and/or particle-Identification/thresholds and rerun MET algorithm from AOD