Missing E_T Reconstruction in ATLAS

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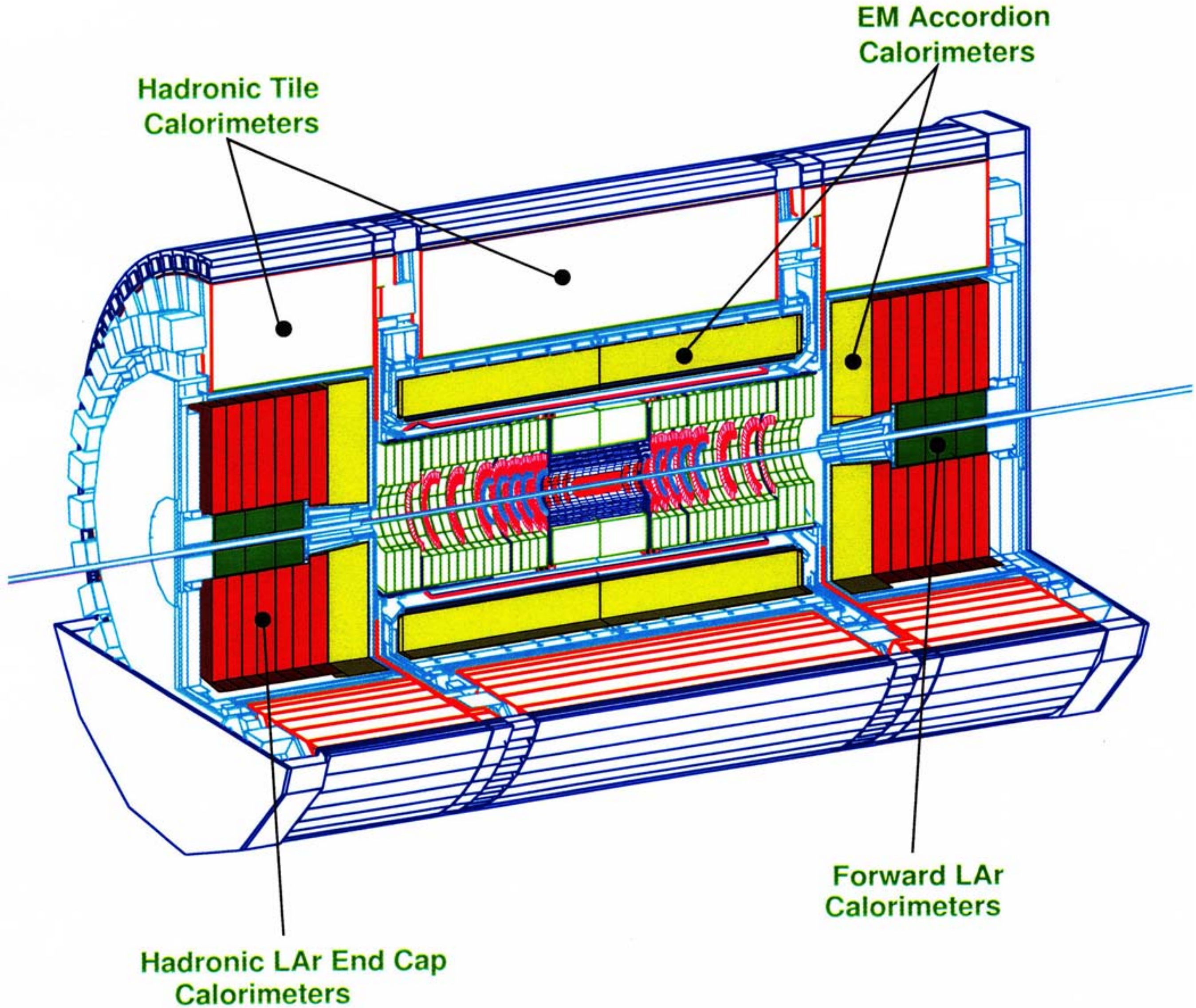
ATLAS Analysis Tutorial, TAU 11/02/07

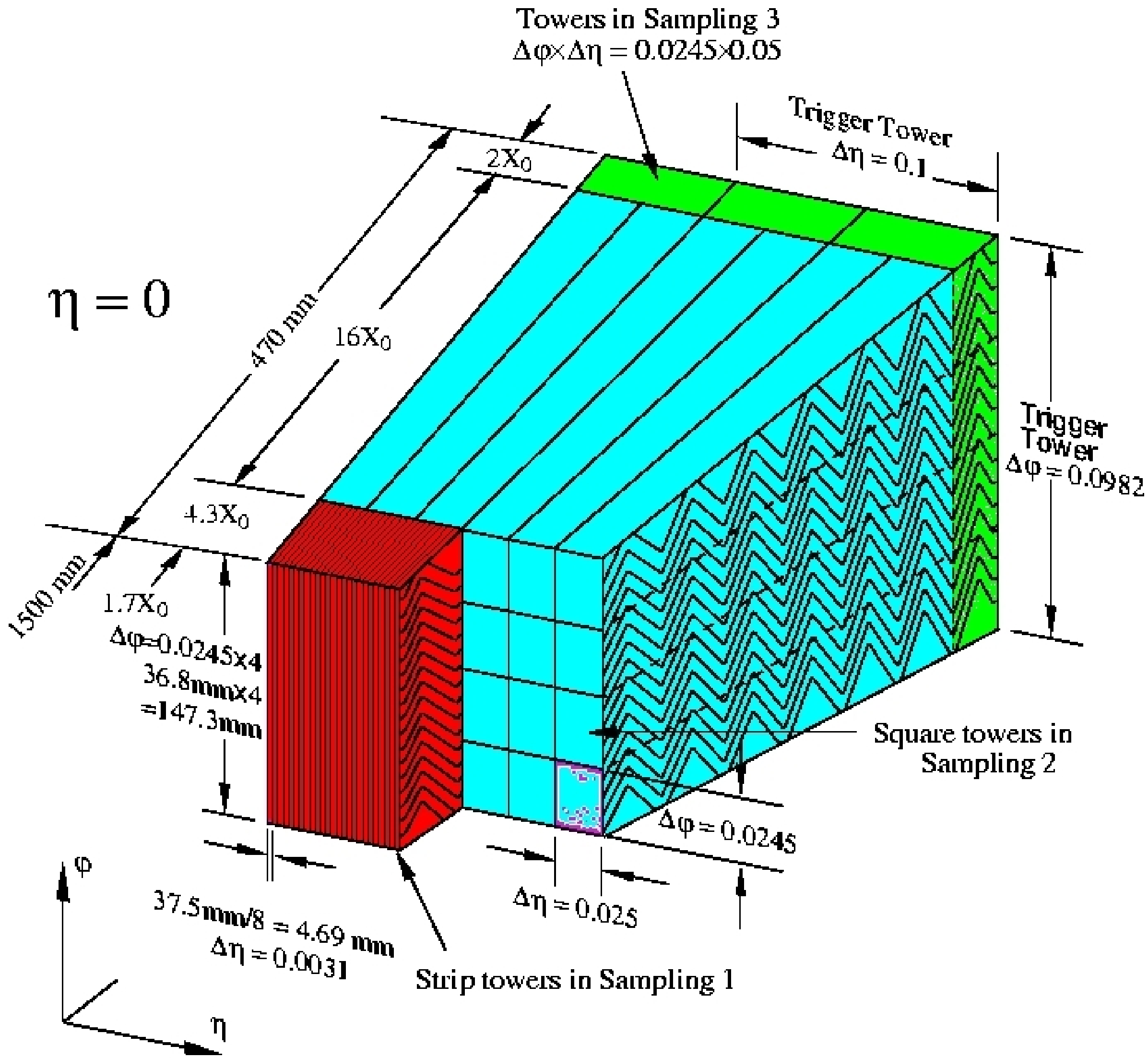
Outline

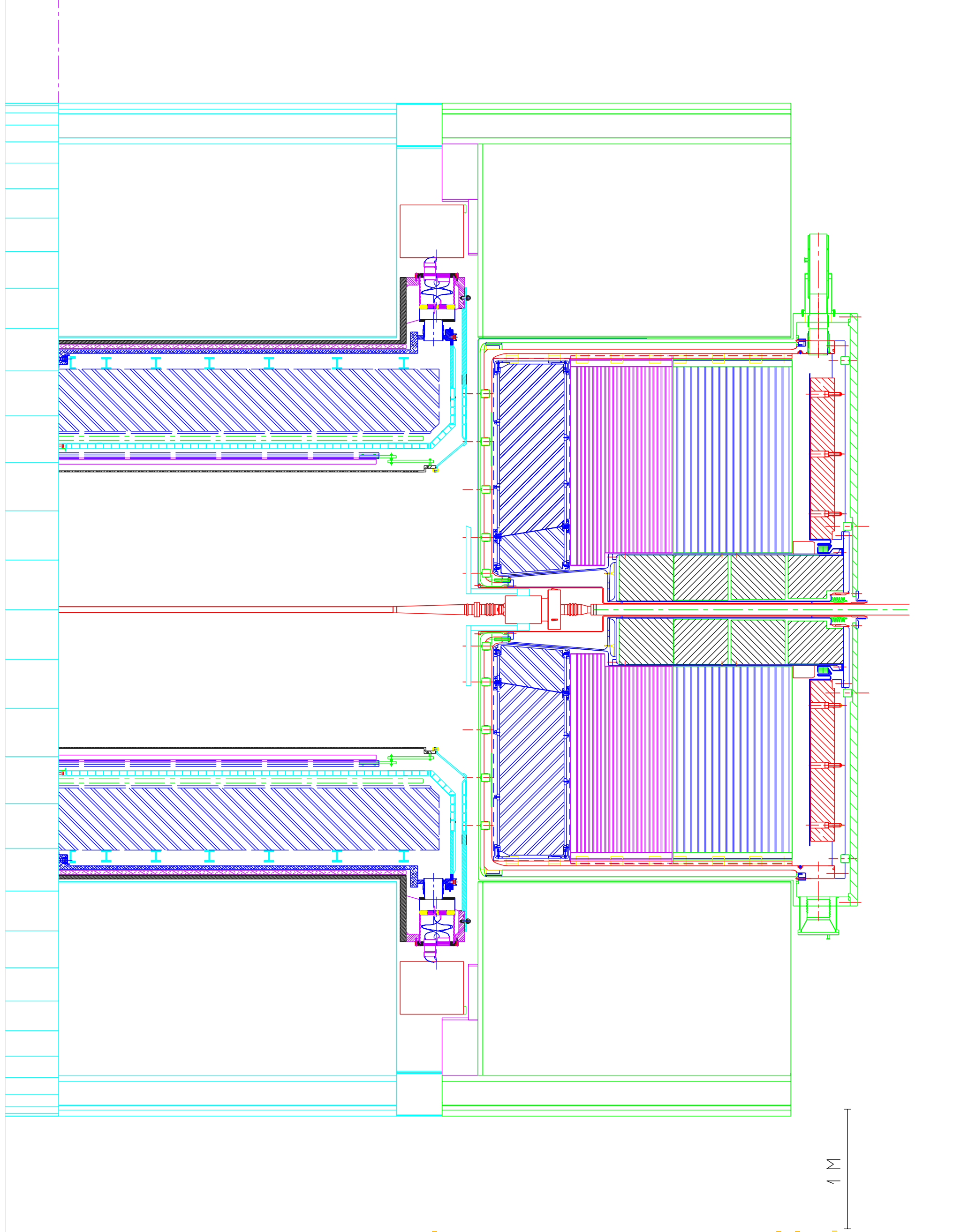
- Introduction
- Status of Cell-Based MET package in Athena
- Status of Object-Based MET package in Athena
- MET Tails and Fake MET studies
- MET checks with (first) data

ATLAS Calorimetry (Geant)

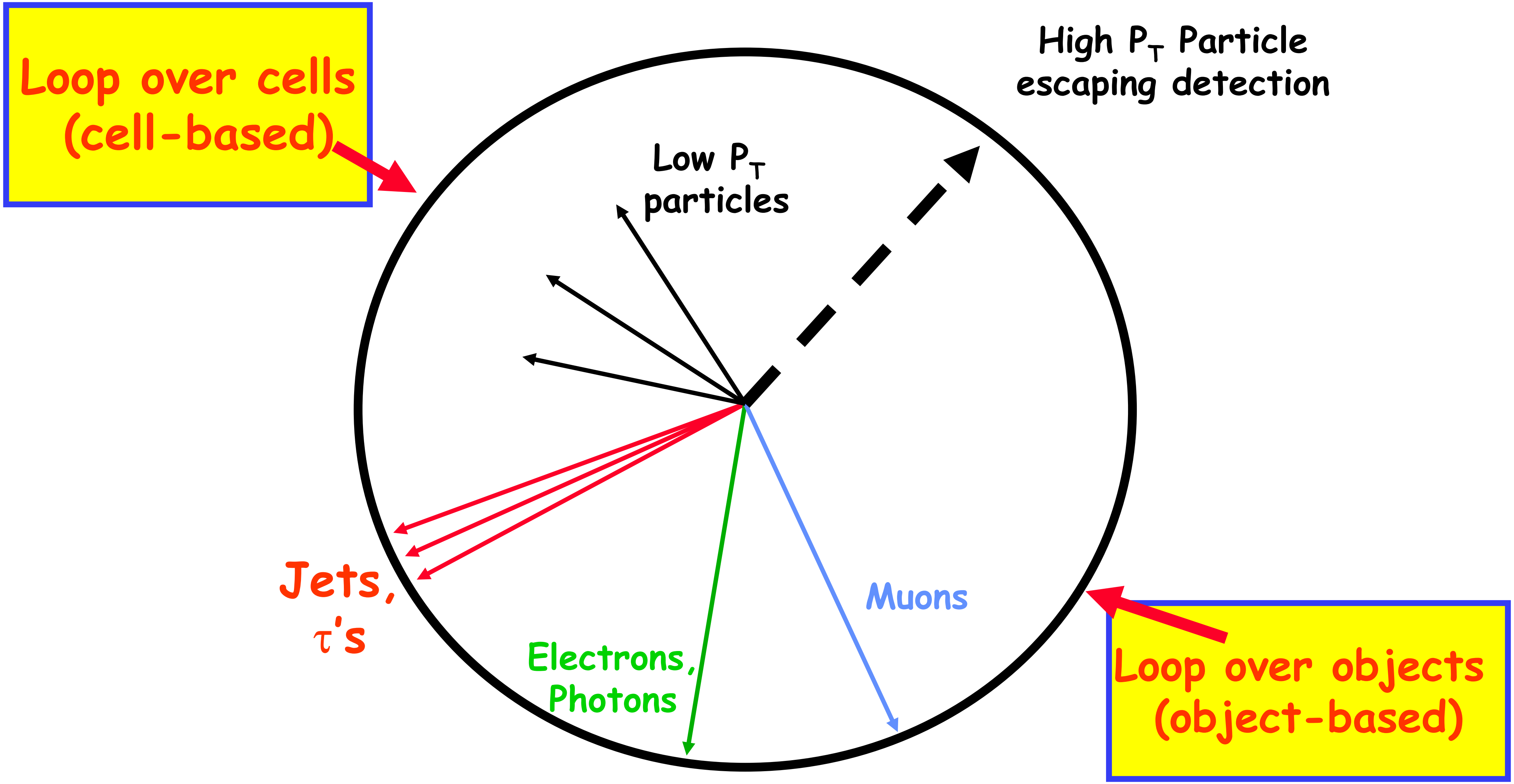


The LAr Calorimeter

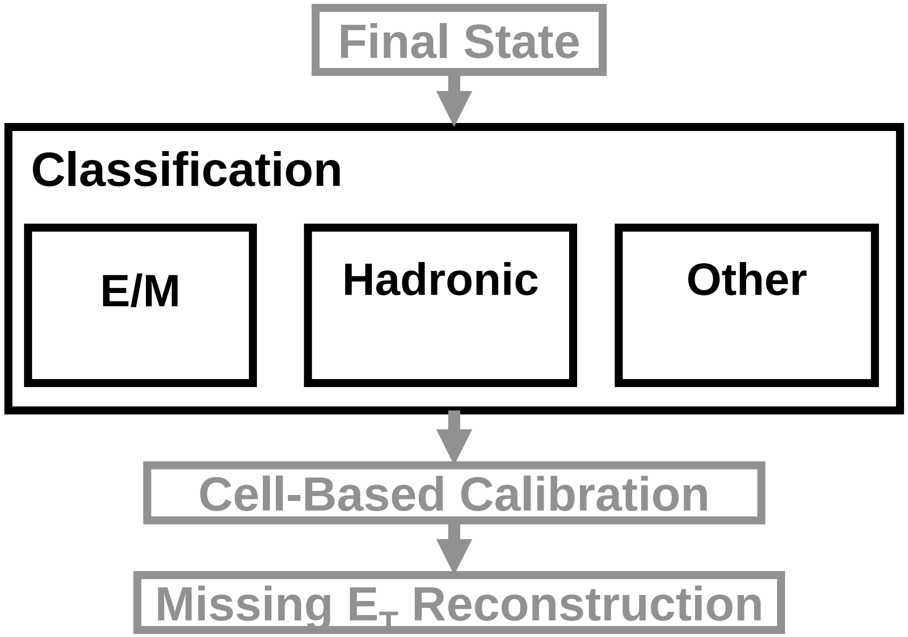



1 M

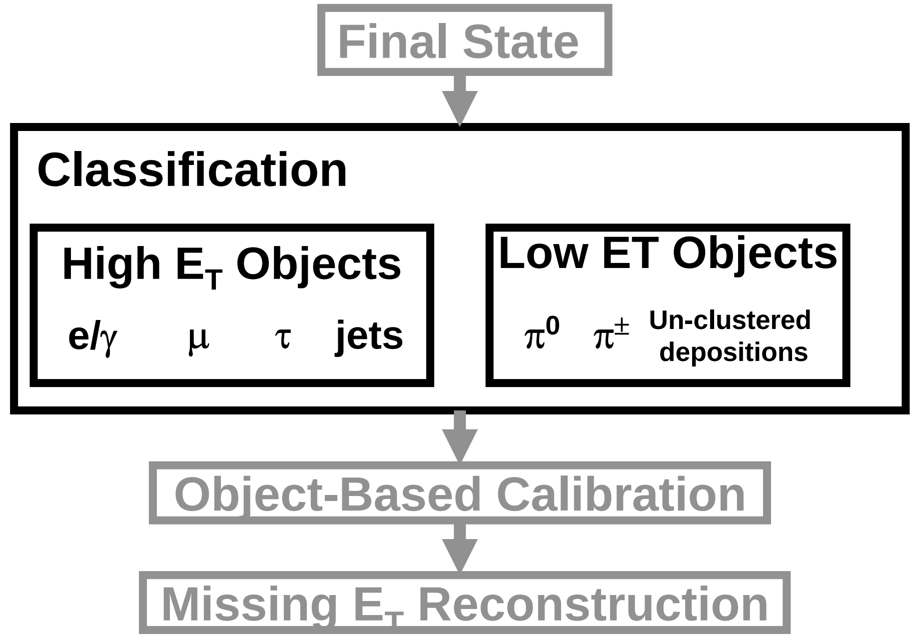
ATLAS is developing a robust effort to understand MET issues produced in physics events



Cell-based Refined Method (TP 1994 and TDR 1999)



Object-Based Method (inspired by D0)



ATLAS and CMS are moving towards the object-based method

Topological Clustering
(Sven Menke)

- **Cell clusterization is a crucial tool**
  - Define thresholds on the seed and the neighboring cells
    - Cuts on seed, neighbor and rest of clustered cells
      - Cut on rest of cells is as low as 0σ
      - We do not observe bias on physics

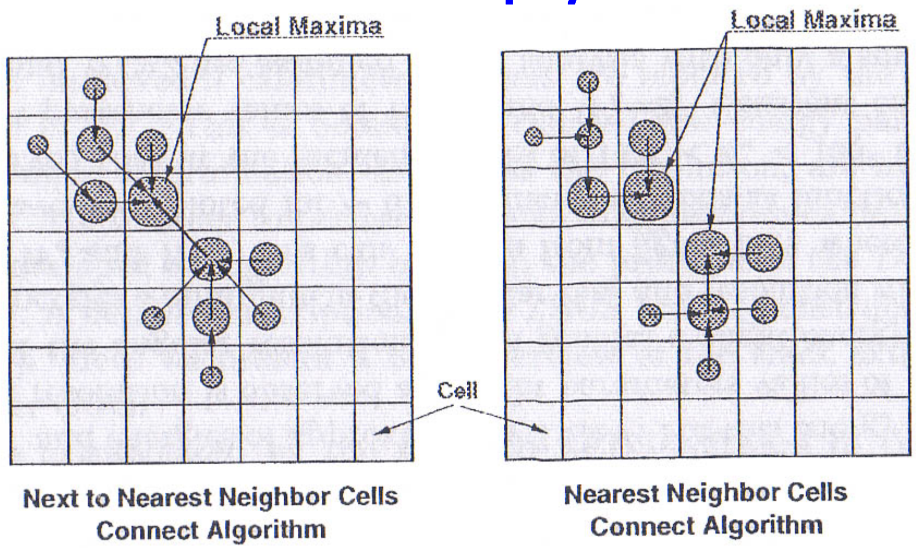


Figure 5.7: *Schematic representation of the cell island clustering.*

D. Cavalli, S.Resconi (INFN/Milan)

Cell-Based Approach

ATHENA MissingET : EtMiss Reconstruction and Calibration

MET_Final = MET_Calib + MET_Cryo + MET_ Muon

All Calorimeter cells in |η|<5

|Ecell | > 2σ(noise)

H1-like weights from jets

OR

Calorimeter cells in Topoclusters 4/2/0

H1-like weights from jets

Calorimeter cells in Topoclusters 4/2/0

LocalHadronCalibration (under test)

Estimated energy loss in cryostat between LAr and Tile

from reco jets (cone07) w*sqrt(EM3*TILE1)

OR

from reco jets (kT)

Topoclusters 4/2/0

LocalHadronCalibration (under test)

OR

from MOORE mu |η|<2.7

pT from external Spectrometer

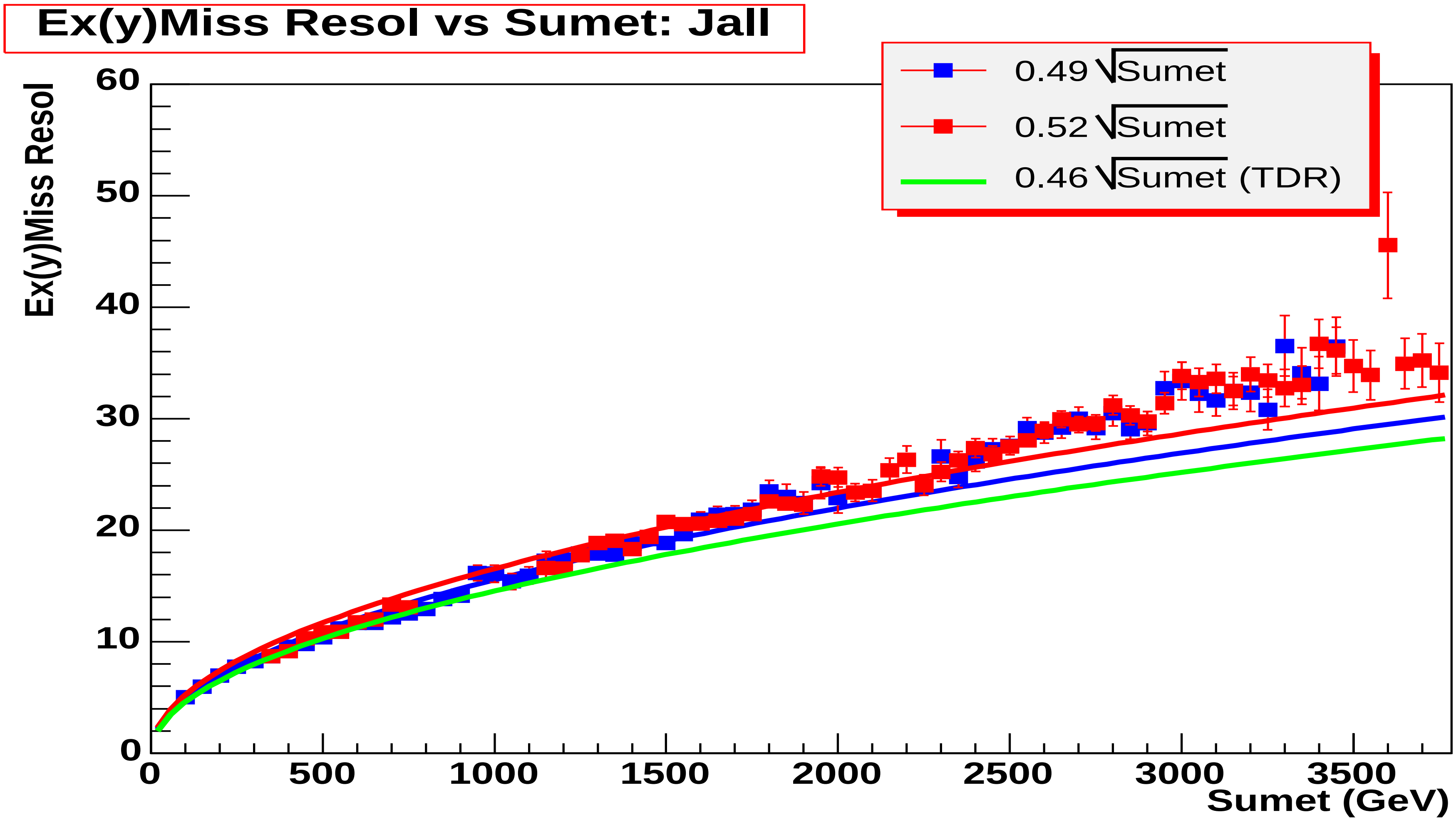
BestMatch /good quality

from MuonBoy muons in |η| < 2.7

Refinement of Calibration for cells in different objects (e/γ, τ, μ ,jets...) a la TDR

(implementation in 12.0.2)

Montecarlo comparison
σ(Ex(y)miss) vs SumET in CSC Jets data (Pythia and Herwig)



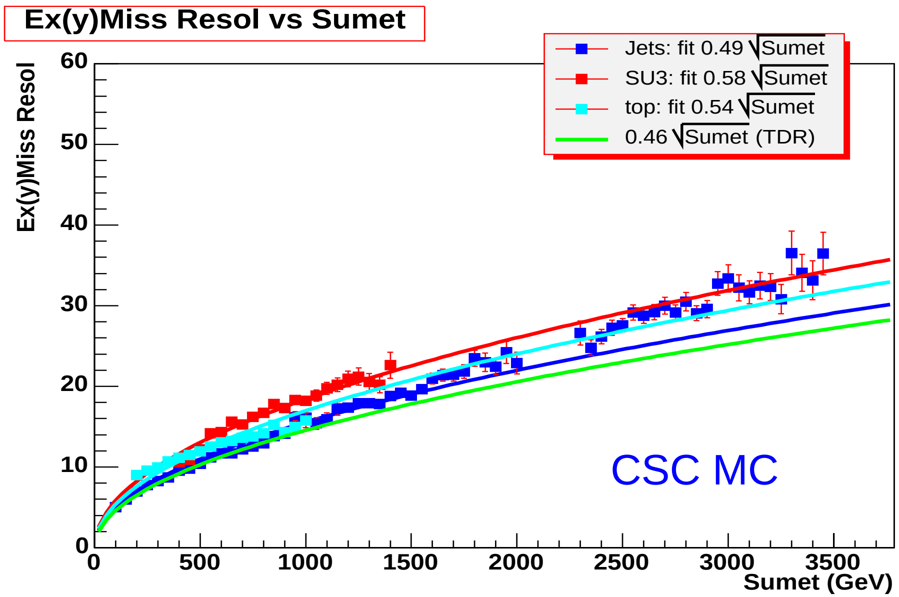
ATHENA MissingET: Performance

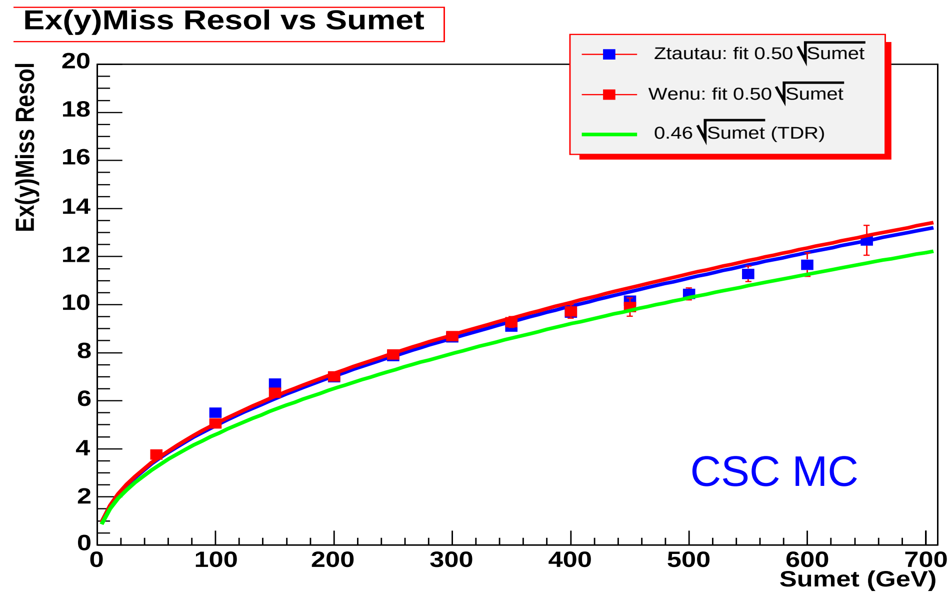
Good EtMiss measurement crucial for mass reco in $Z \rightarrow \tau\tau$ and $H \rightarrow \tau\tau$

Performance depends on:

- Noise suppression, Calibration, Dead material correction …
- Physics channel topology: presence of leptons, Eleptons, Njets, Ejets, energy outside phys objects, activity out of coverage…
- No dependence on Montecarlo observed (Pythia QCD jets very similar to Herwig jets)

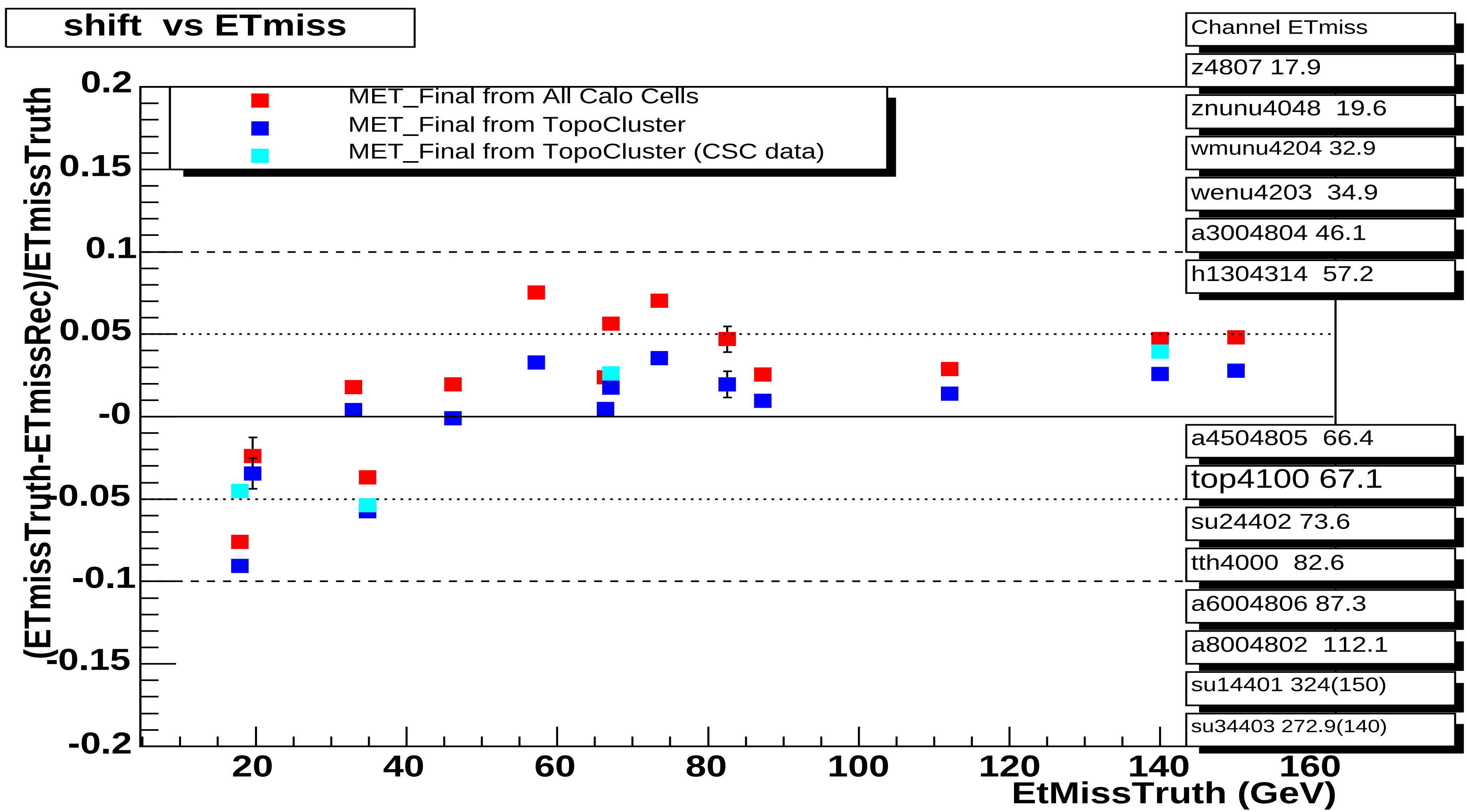
EtMiss resolution vs SumET





For CSC linearity within 5%, resolution slightly worse respect to TDR parametrisation (σ(EtMiss)=0.46*sqrt(SumET))

Linearity vs EtMiss_Truth

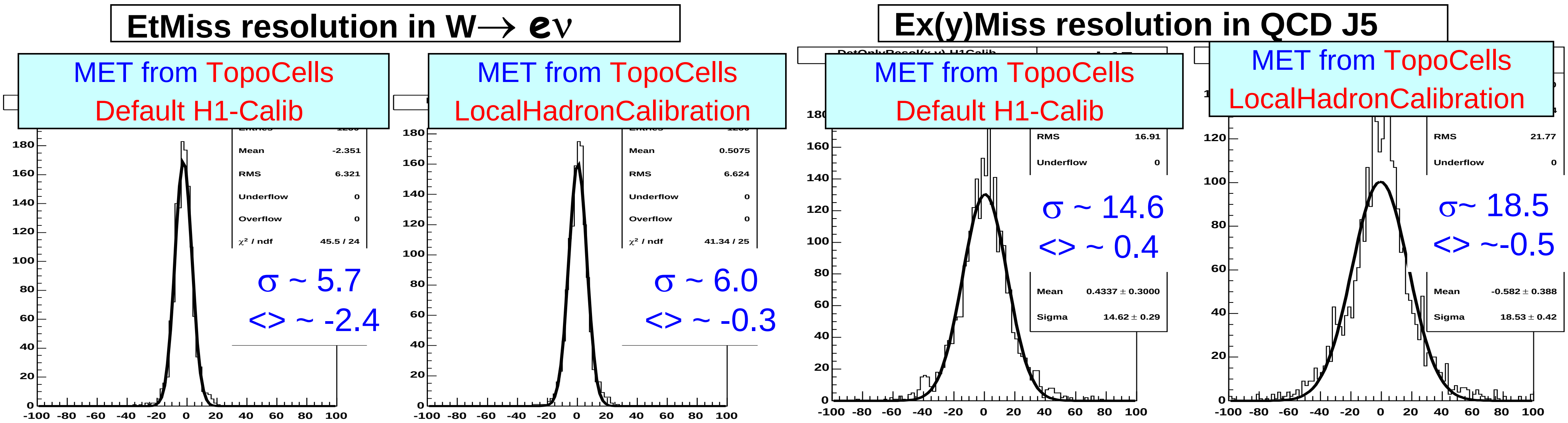


ATHENA MissingET: First look at LocalHadronCalibration

⇒ looked at some CSC samples (low statistics!) using cell weights from LocalHadronCalibration implemented in 12.0.1 (including Dead Material corrections up to $|\eta| < 3$)

⇒ $W \rightarrow e\nu$, $Z \rightarrow \tau\tau$ sample, minimum bias events: EtMiss resolution and linearity comparable to the ones from default H1-like calibration

⇒ in QDC J5 (280<pT<560GeV) sample, EtMiss resolution is worse respect to H1-like calib and there are larger tails to be understood



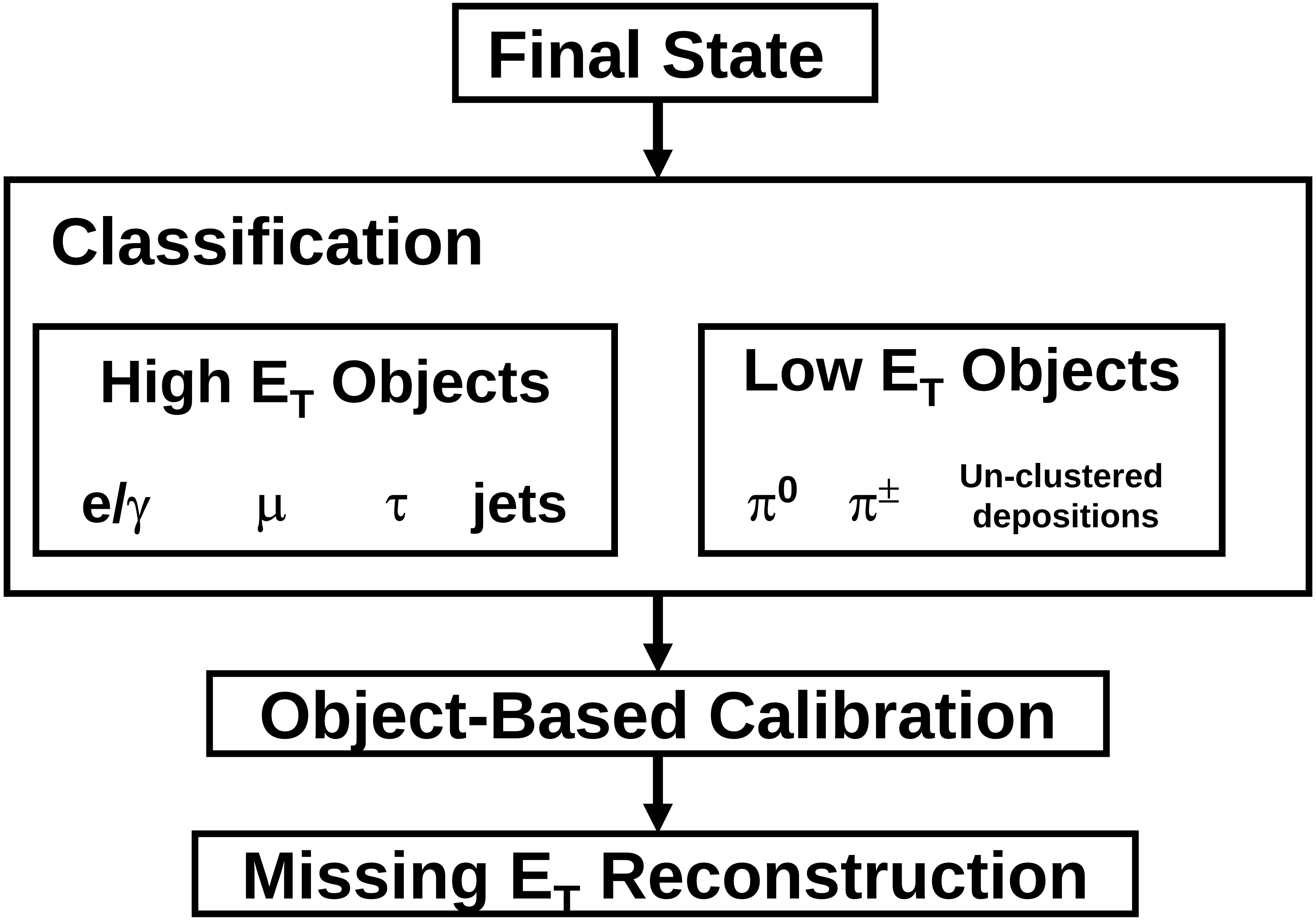
⇒ New simulation/weights determination with 12.0.1 → hopefully more significant results for Barcelona Calorimeter Calibration workshop

X.Cueh, L.Flores, B.Mellado, S.Padhi,
Sau Lan Wu (Wisconsin)

Object-Based Approach

(In Athena since 12.1.0/12.0.2)

Object-Based Missing E_T



Object Based Calibration

- The Object-Based approach is <u>very FLEXIBLE</u>. It accommodates any calibration strategy

Local Hadronic calibration

↓

Use local hadronic calibration or in-situ calibration or a combination of both

↑

In-situ calibration

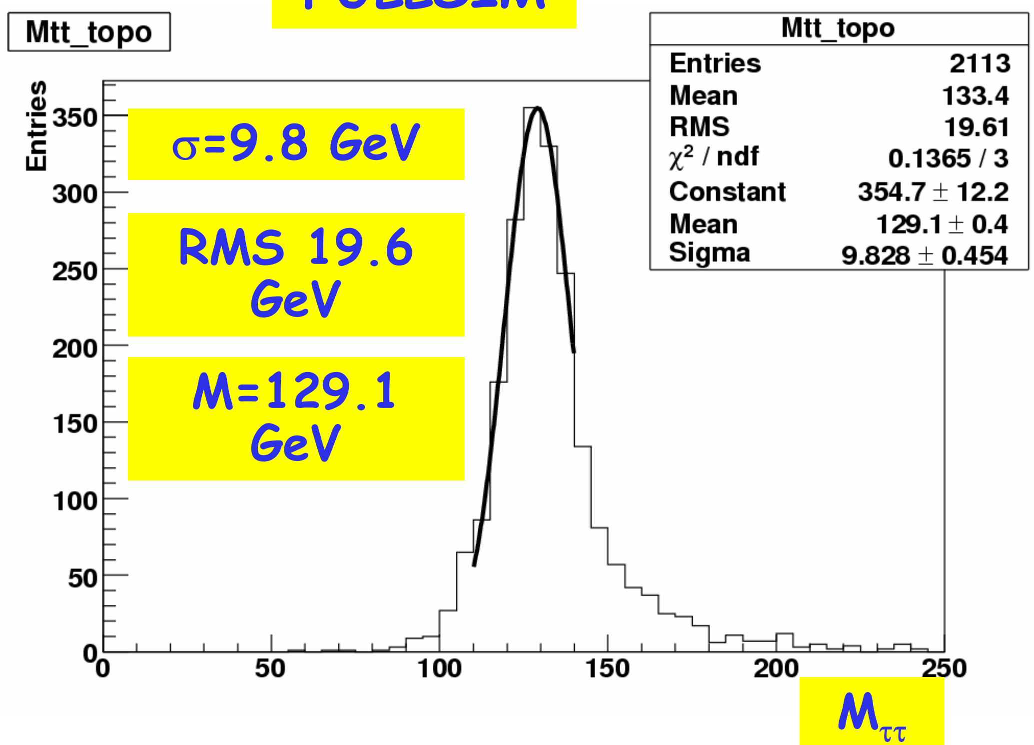
Object	Calibration Sample	Calibration Method
Electrons	$Z \rightarrow ee$	Mass constraint
Photons	$Z \rightarrow ee\gamma, \mu\mu\gamma$	Mass constraint
Jets	Z+jets, γ+jets, di-jets, $W \rightarrow jj$ (in tt)	P_T balance, W mass constraint
Single $\pi^{\pm}$	min-bias, $W \rightarrow \tau\nu$	E/P
Single π^0	$Z \rightarrow ee\gamma, \mu\mu\gamma$	Mass constraint, $E_{\pi 0}/E_{\gamma}$ from MC

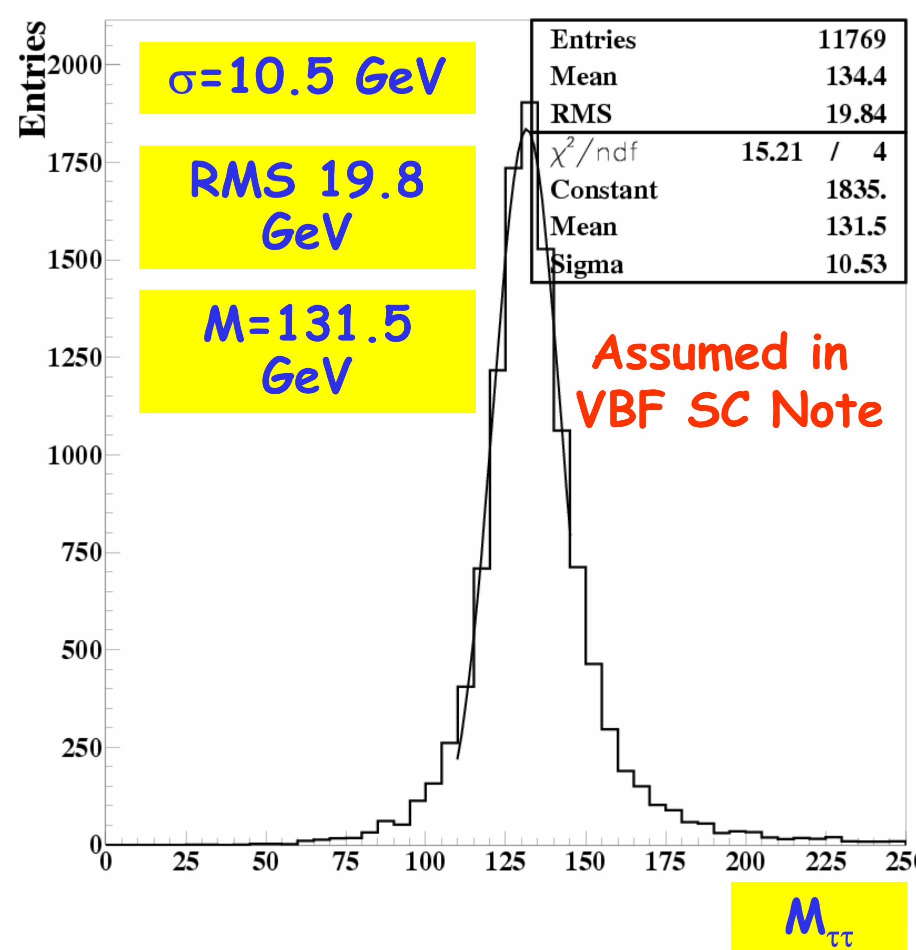
- OBMET solved long standing shifts and degraded resolution in $H \to \tau\tau$, so important for low mass Higgs searches
- Higgs mass reconstruction after the application of all cuts in page 9 (except for mass window) with $H \to \tau\tau \to ll$

ATLFAST

Summer 2005

FULLSIM

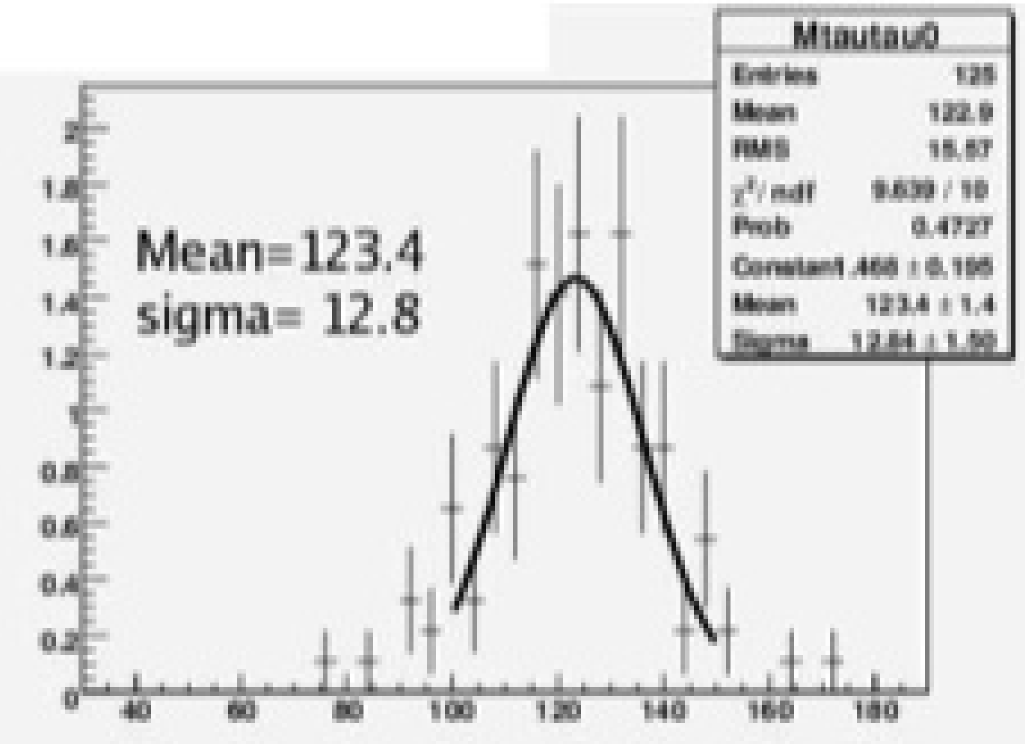


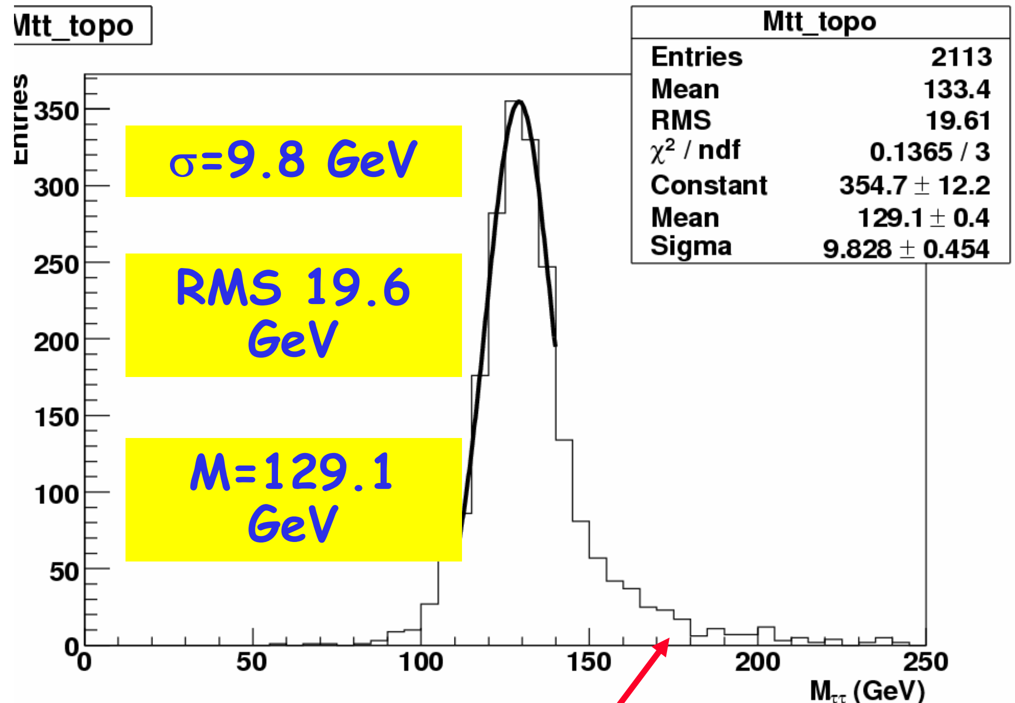


Performance comparison with default method at the time (first half of 2005)

- That method is no more default in ATLAS

Summer 2005





Tails were significantly improved later on

$M_{\tau\tau}$

Missing E_T resolution after the VBF analysis cuts

- Table with Gaussian mean, width and RMS before and after the implementation of low E_T objects (in GeV)

$$\vec{P}_{Tmiss} = -\vec{P}_{Tjets} - \vec{P}_{Leptons} - \vec{P}_{Tmini-jets} - \vec{P}_{Tunclustered}$$

	Gaussian Mean	Gaussian Width (σ)	RMS
Include Low E_T objects	0.54	8.4	10.2
Un-clustered Depositions not included	0.51	9.4	11.6
Low E_T objects not included	0.53	10.7	12.9

OBMET in Athena

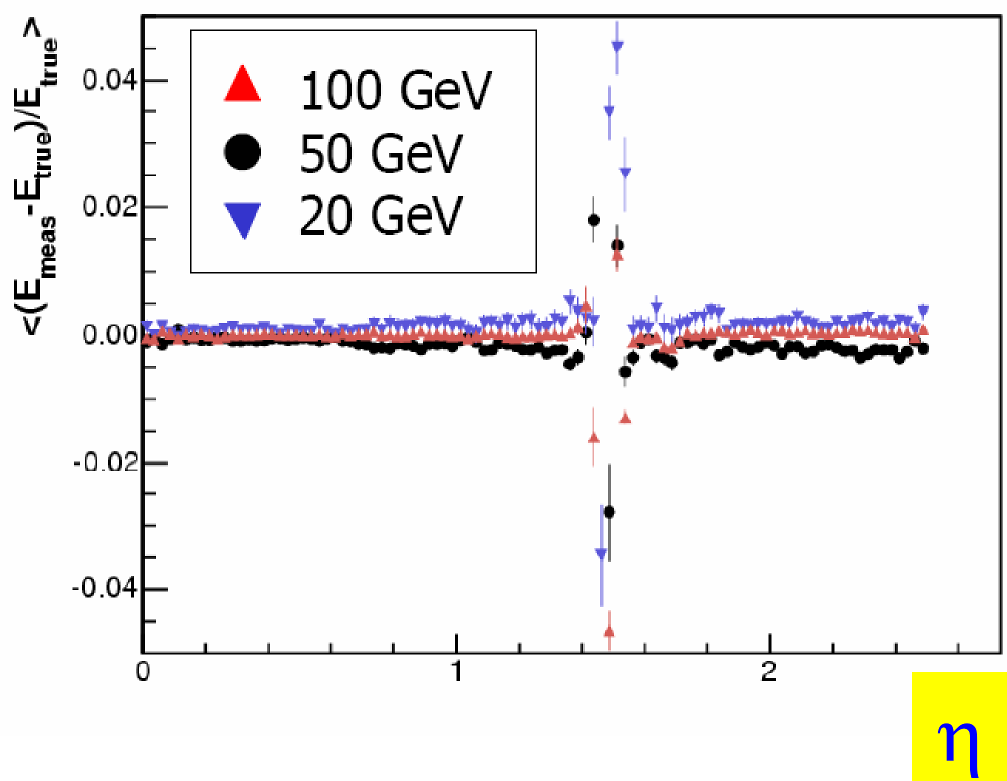
Sample	Range	Application in package
Single electrons	10<E<1000 GeV $\|\eta\|<2.5$	Electron reconstruction
Single π^0's	1<E<500 GeV $\|\eta\|<2.5$	Low E_T π^0's, poorly reconstructed electrons, γ's
Single $\pi^\pm$	3<E<500 GeV $\|\eta\|<5$	Low E_T $\pi^\pm$ (τ's?)
J1-J8	$20<E_T<3000$ GeV $\|\eta\|<5$	High P_T hadronic depositions, τ's
Single muons	$6<P_T<1000$ GeV	Addition of Calo-based muon ID

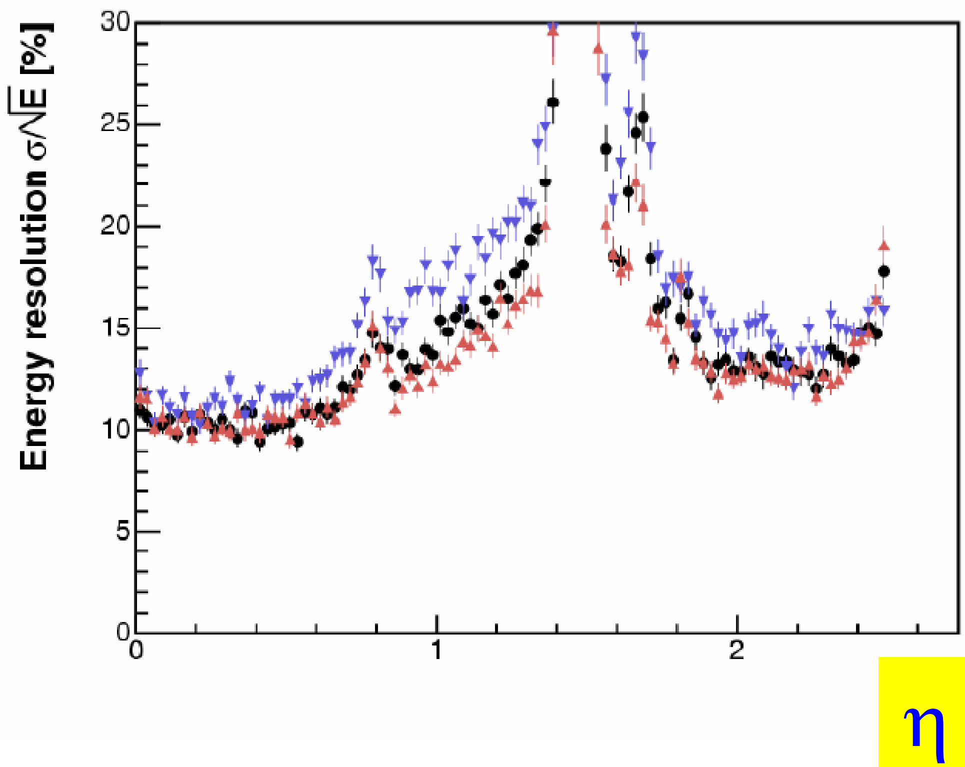
Current Classification

- In 12.0.1 we read out to AAN the following objects
  1. Leptons (electrons and muons)
     - Muons reconstructed with Likelihood are separated from muons reconstructed with other packages
  2. Jets (E_T>20 GeV):
     - Taus are still treated as jets. Will separate taus and jets in subsequent versions
  3. Mini-Jets:
     - Depositions with 1<E_T<20 GeV in Barrel and Endcap
       - Charges and neutral pions are treated separately, but the AAN does not have that information yet. Will do that soon
  - Rest (or "unclustered" energy)
     - Depositions with E_T<1 GeV in Barrel and Endcap and E_T<20 GeV in FCAL
     - Three components (Barrel/HEC/FCAL) are separated

Calibration of High E_T objects in ATHENA: Electrons

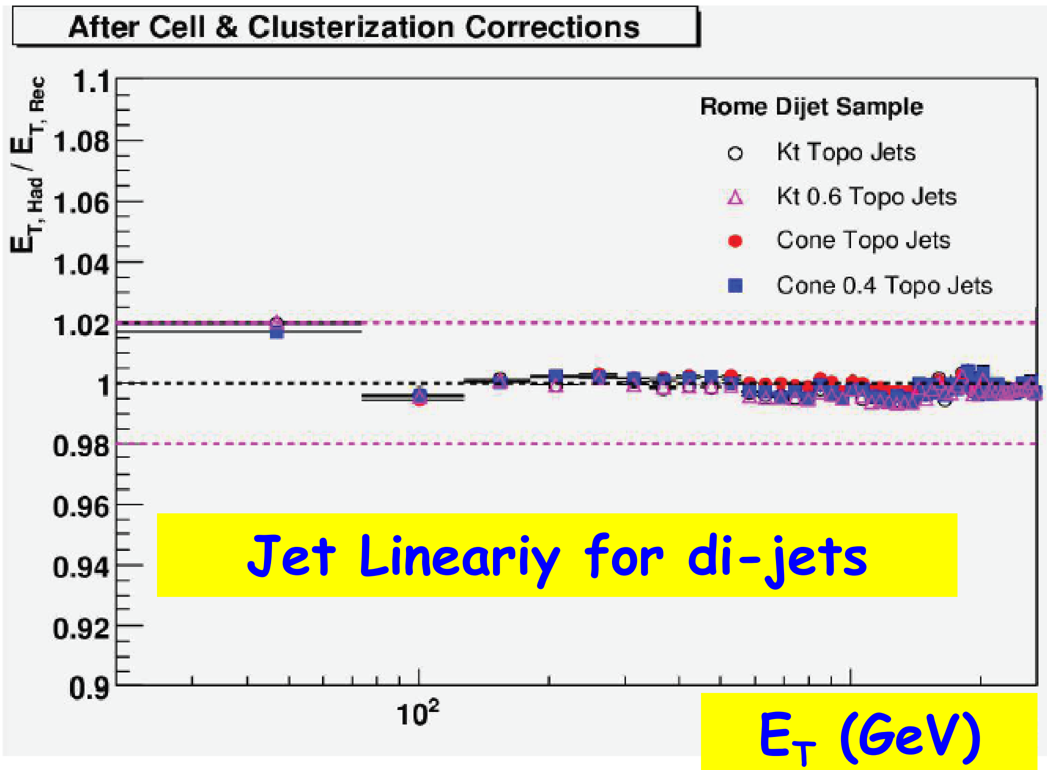
- Electron calibration performed with 6,3,0 topo-clusters using single electrons (see L.Flores talks)

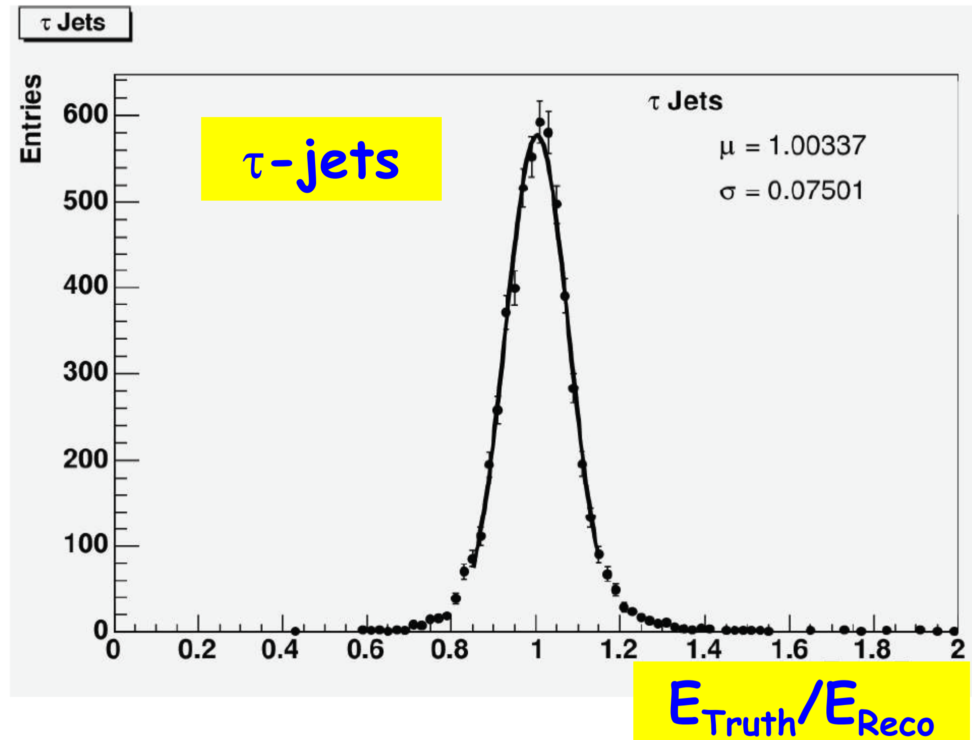




Calibration of High E_T objects in ATHENA: Jets

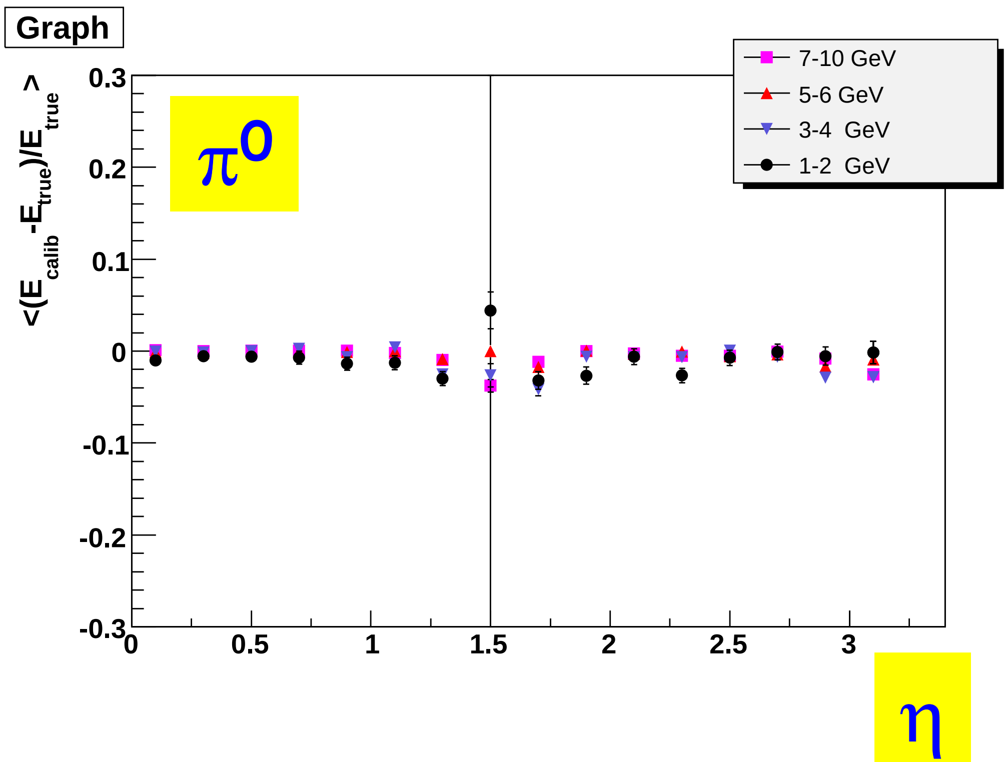
- Jet calibration using Pseudo-H1 weights obtained with di-jets (see S.Padhi's talks). Work very well for τ-jets too

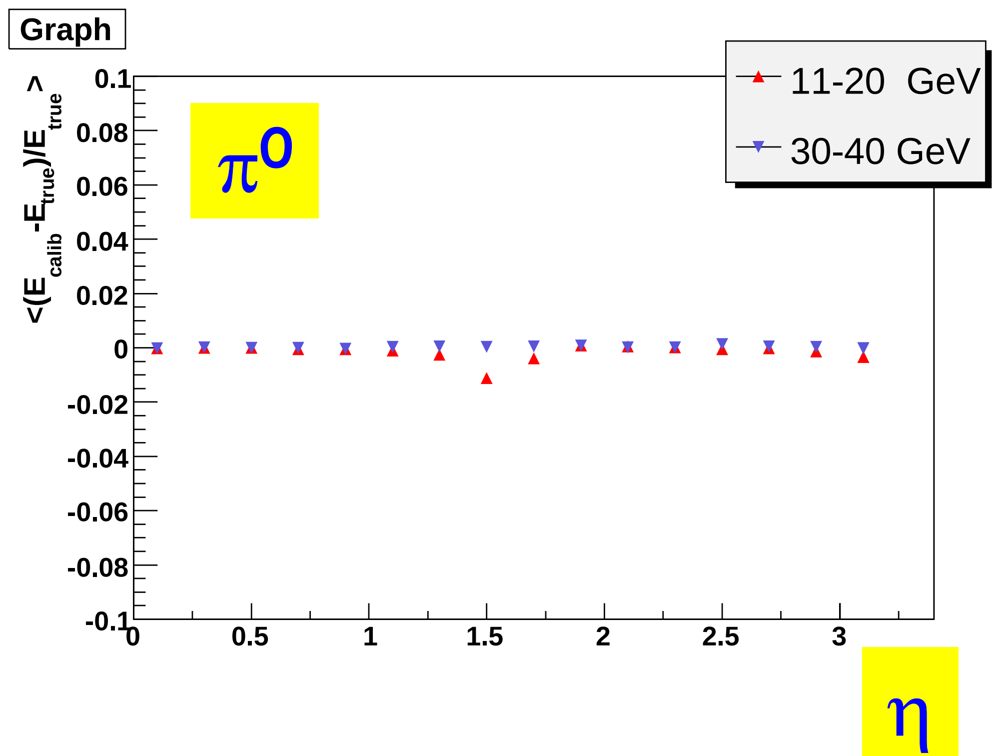




Calibration of Low E_T Objects: Single π^0

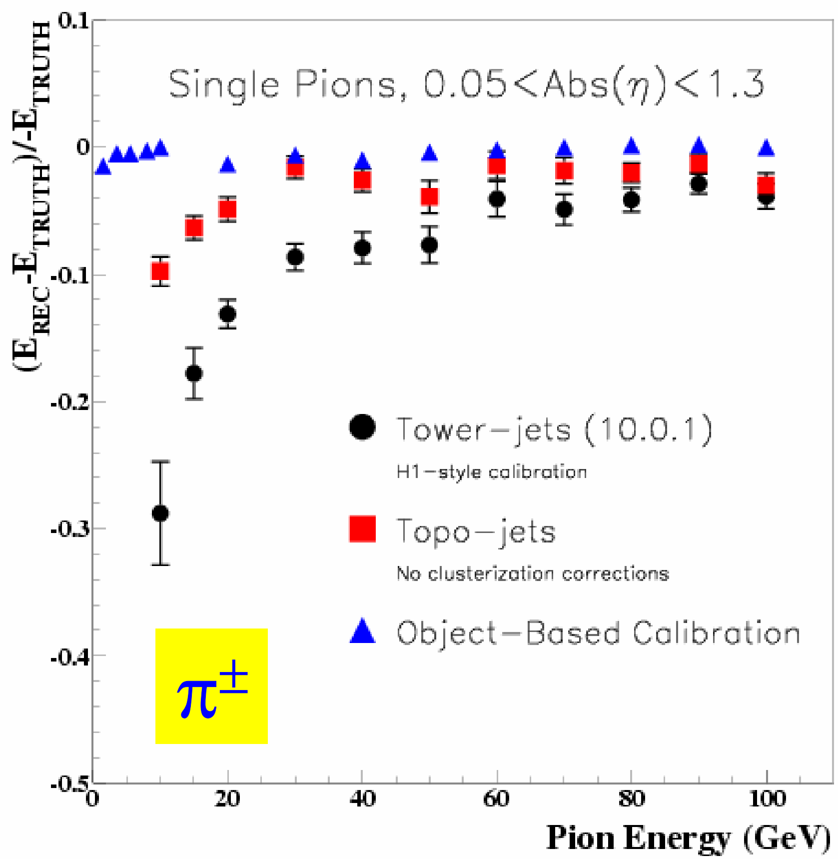
- Calibration of single pions using sampling method with TDR functional form (see B.M. talks)

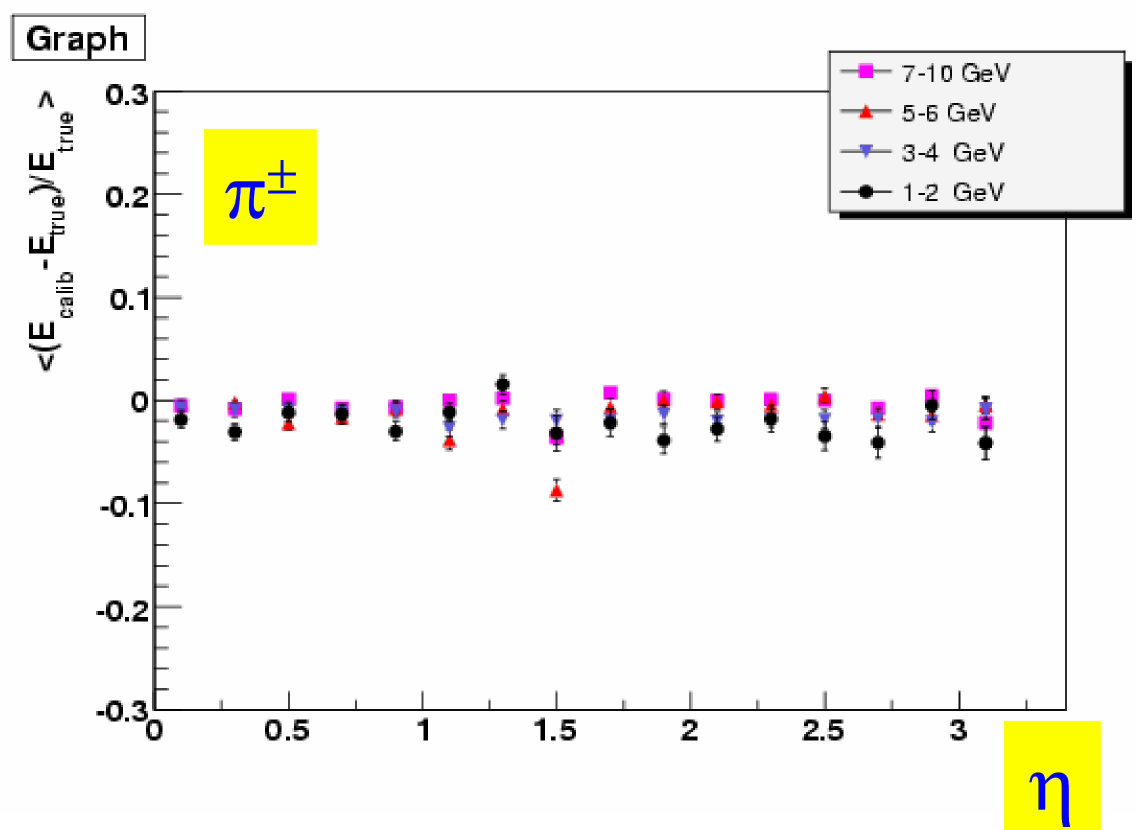




Calibration of Low E_T Objects: Single $\pi^{\pm}$

- Calibration of single pions using different functional forms for different $|\eta|$ (see B.M. talks)





SumET (Truth vs. Rec.)

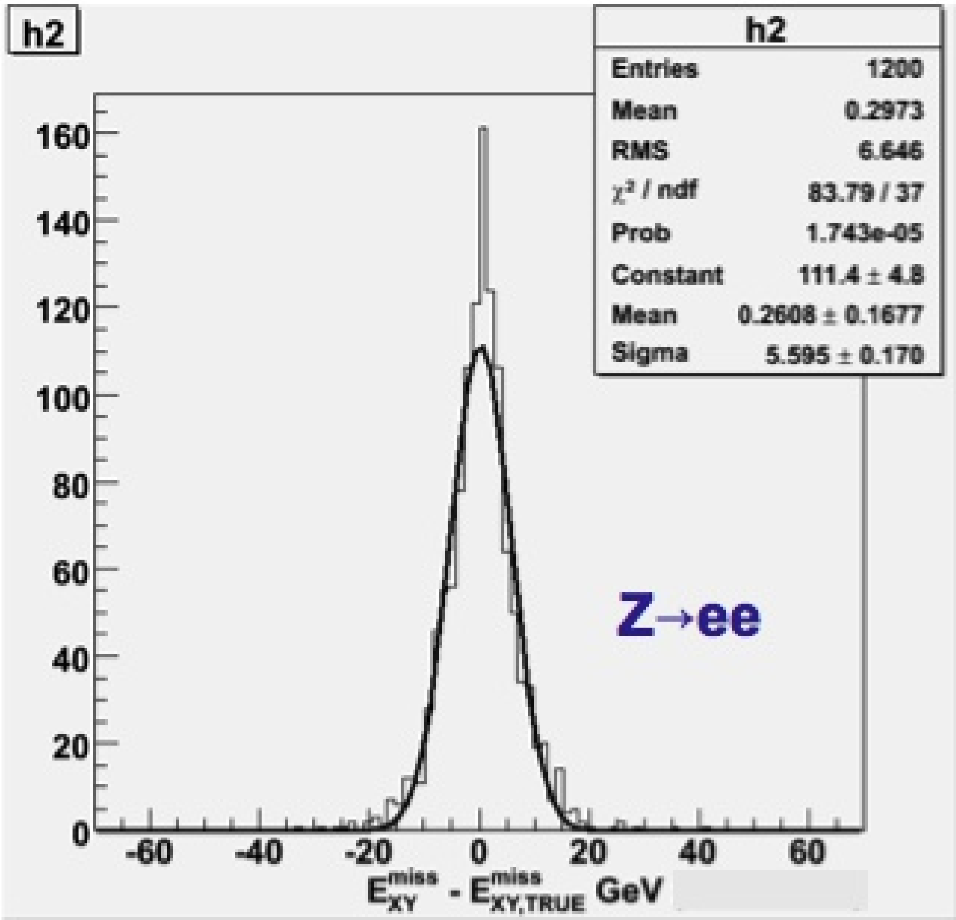
- Truth and reconstructed SumET in GeV
  - Need to study in truth fraction of SumET from very low E_T particles (with 11.0.42)

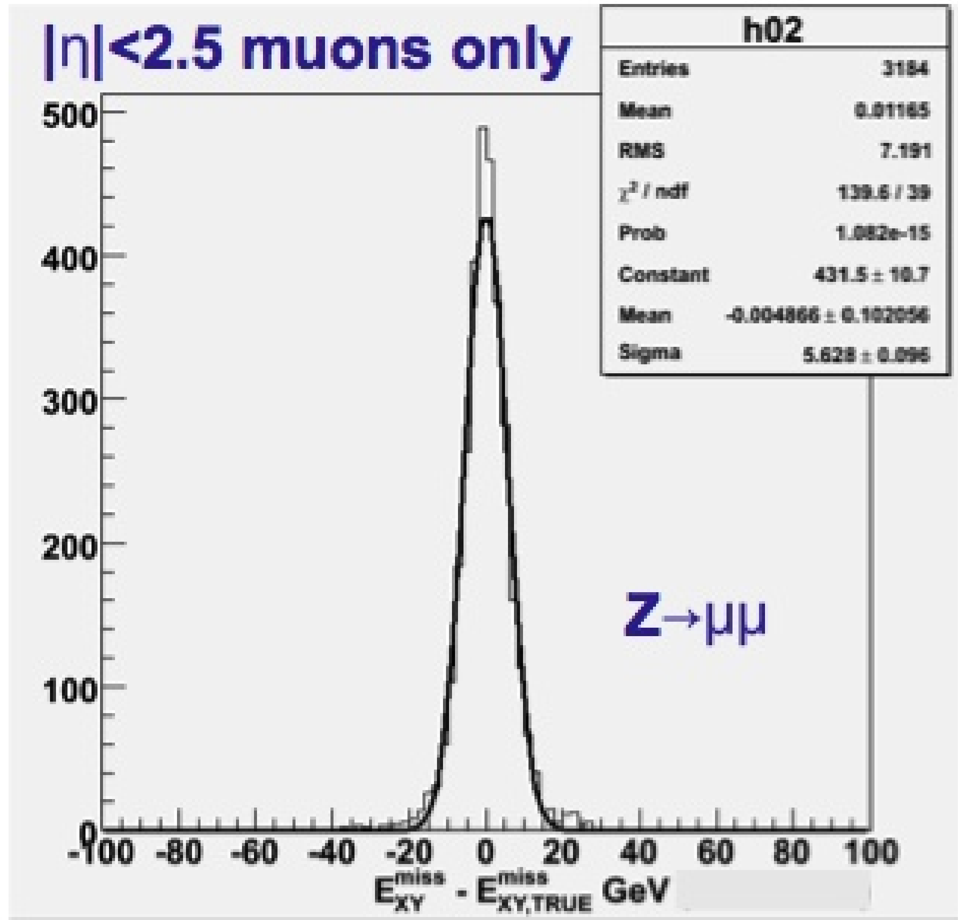
Sample	Truth SumET	Rec. SumET	ΔSumET
$Z\rightarrow\mu\mu$ ($\|\eta_l\|<2.5$)	226	210	16
$Z\rightarrow ee$ ($\|\eta_l\|<2.5$)	217	201	16
$W\rightarrow\mu\nu$ ($\|\eta_l\|<2.5$)	207	188	19
$W\rightarrow e\nu$ ($\|\eta_l\|<2.5$)	206	188	18
VBF $H\rightarrow\tau\tau\rightarrow ll$ ($\|\eta_l\|<2.5$)	403	386	17
$W' \rightarrow l\nu$ (M_W=1 TeV)	544	527	17
SUSY (SU3)	889	870	19

Ratio of SumEt of various components to the Total truth SumEt for different samples

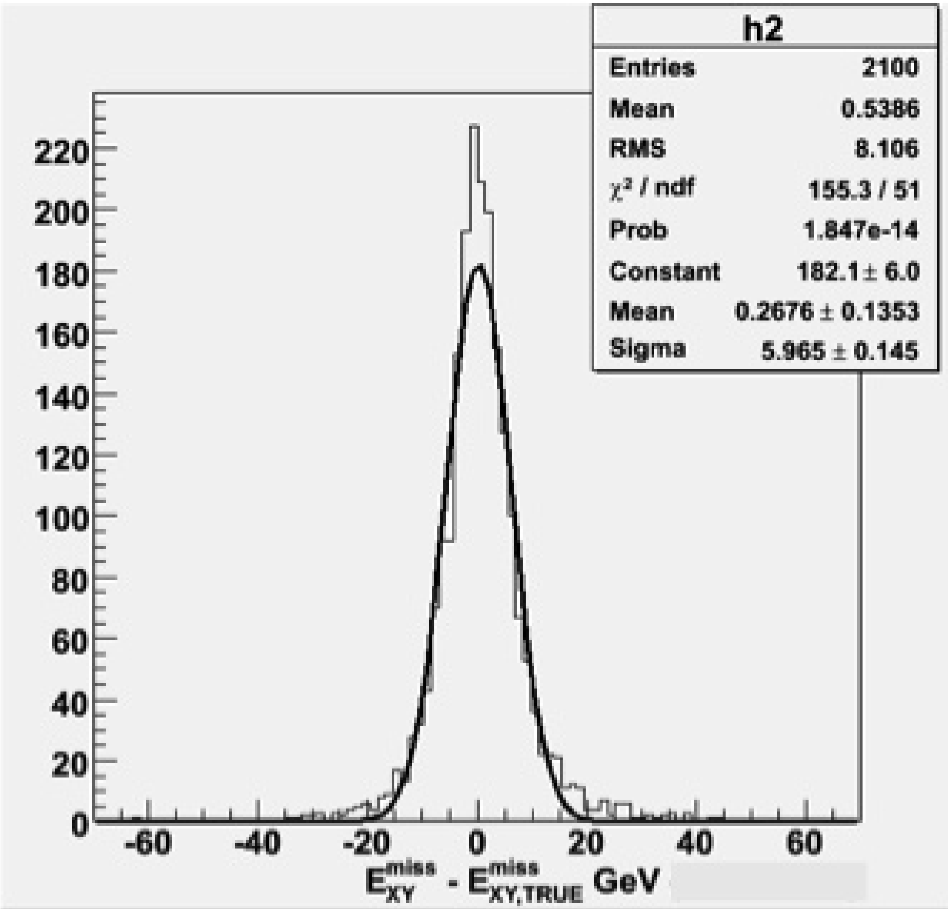
Sample	$\Sigma E_T(Lep)/\Sigma E_T$	$\Sigma E_T(Jet)/\Sigma E_T$	$\Sigma E_T(MJet)/\Sigma E_T$	$\Sigma E_T(Rest)/\Sigma E_T$
$Z\to\mu\mu$ ($\lvert\eta_l\rvert<2.5$)	0.43	0.08	0.19	0.23
$Z\to ee$ ($\lvert\eta_l\rvert<2.5$)	0.36	0.16	0.19	0.23
$W\to\mu\nu$ ($\lvert\eta_l\rvert<2.5$)	0.23	0.10	0.29	0.30
$W\to e\nu$ ($\lvert\eta_l\rvert<2.5$)	0.19	0.14	0.29	0.30
$W'\to l\nu$ (M_W=1 TeV)	0.68	0.13	0.08	0.08
$W'\to l\nu$ (M_W=2 TeV)	0.74	0.12	0.05	0.05
SUSY (SU3)	0.04	0.77	0.09	0.08

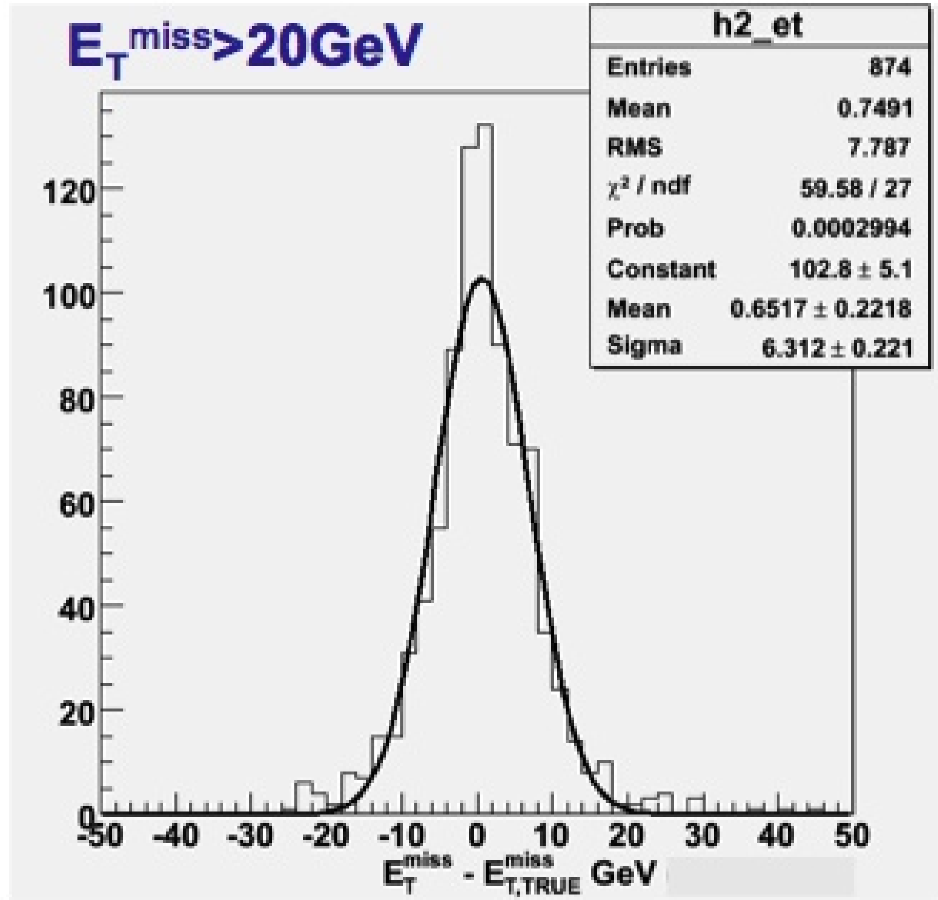
Misssing E_T in $Z \rightarrow ll$

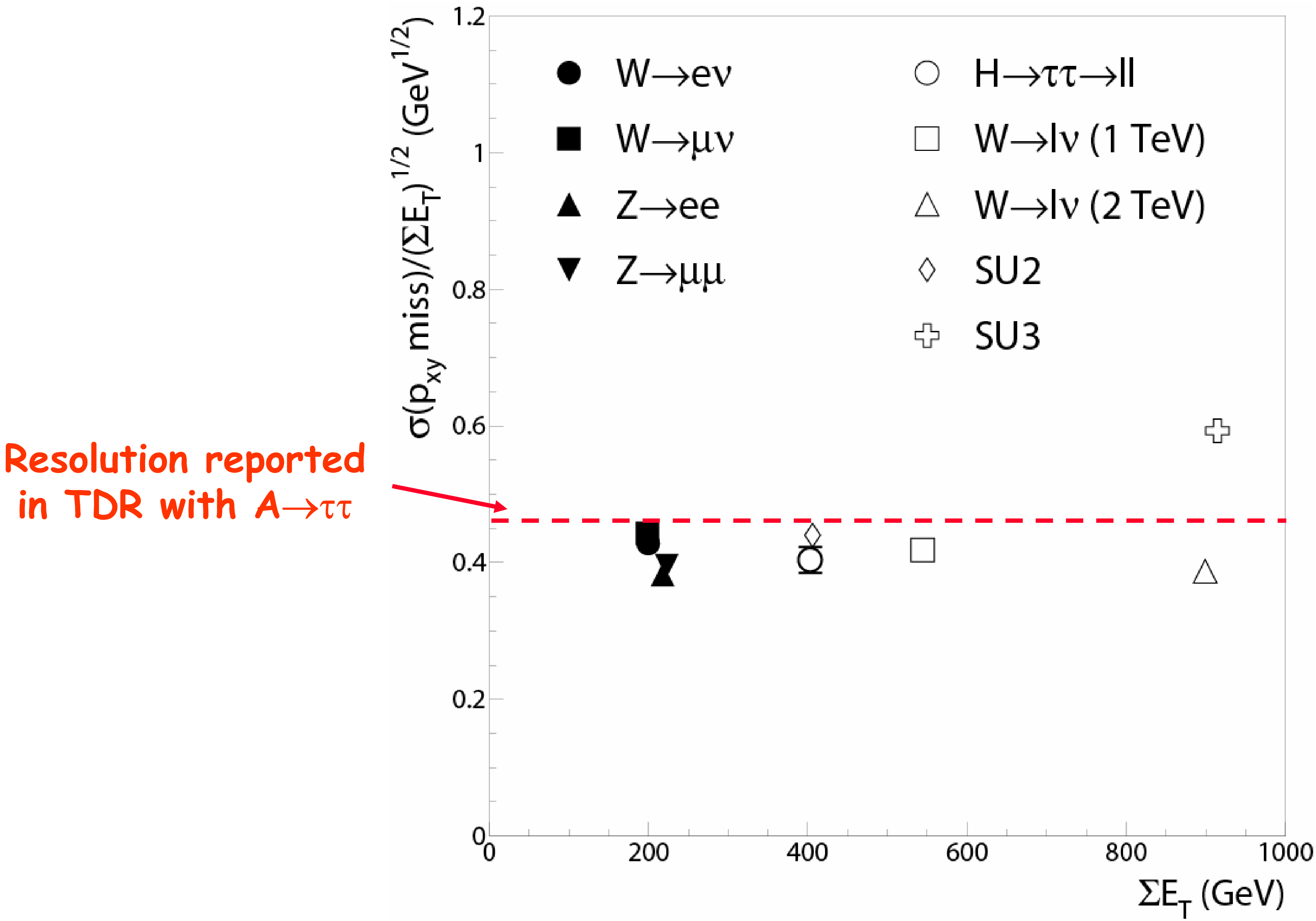




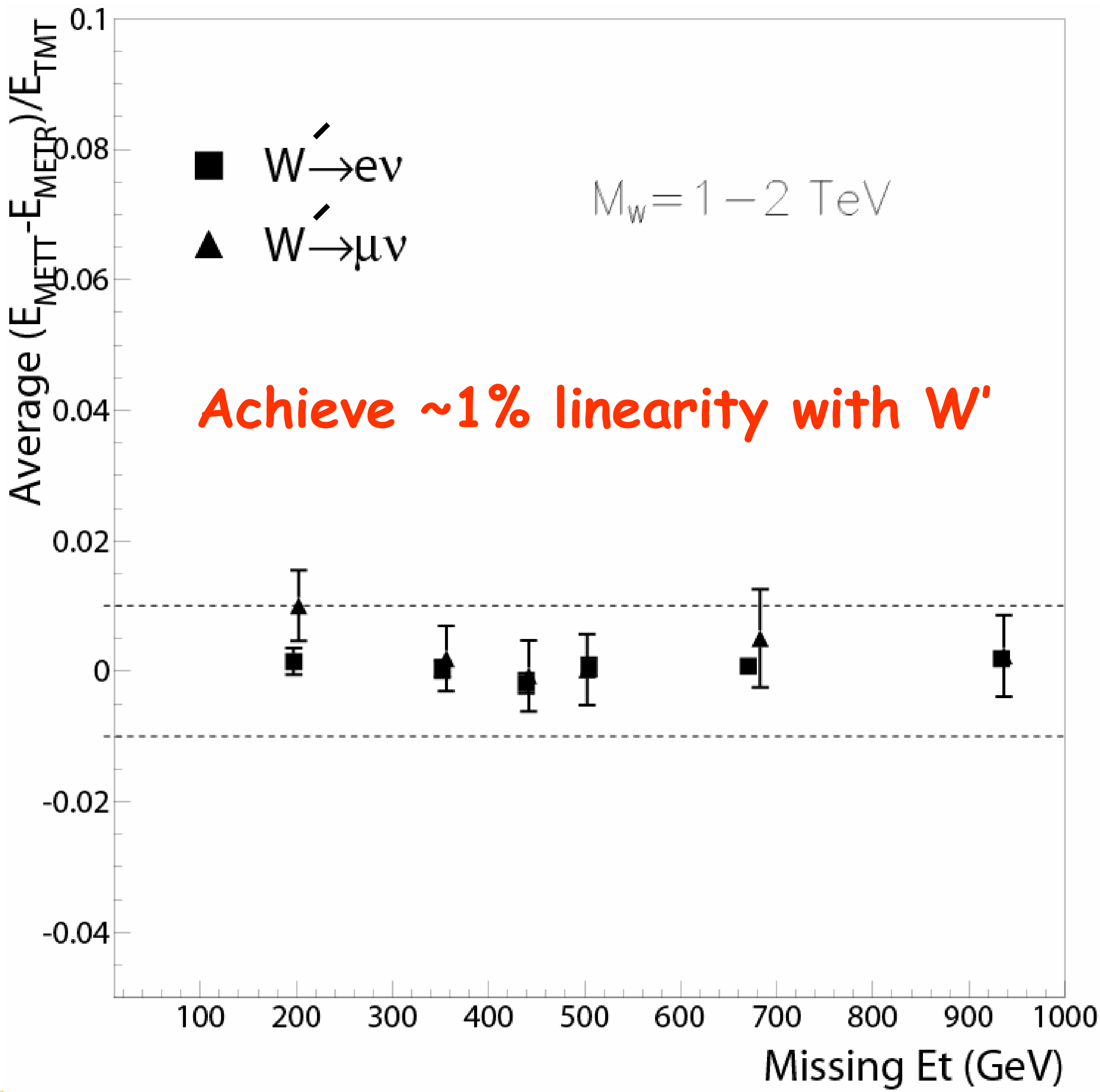
Misssing E_T in $W \to e\nu$



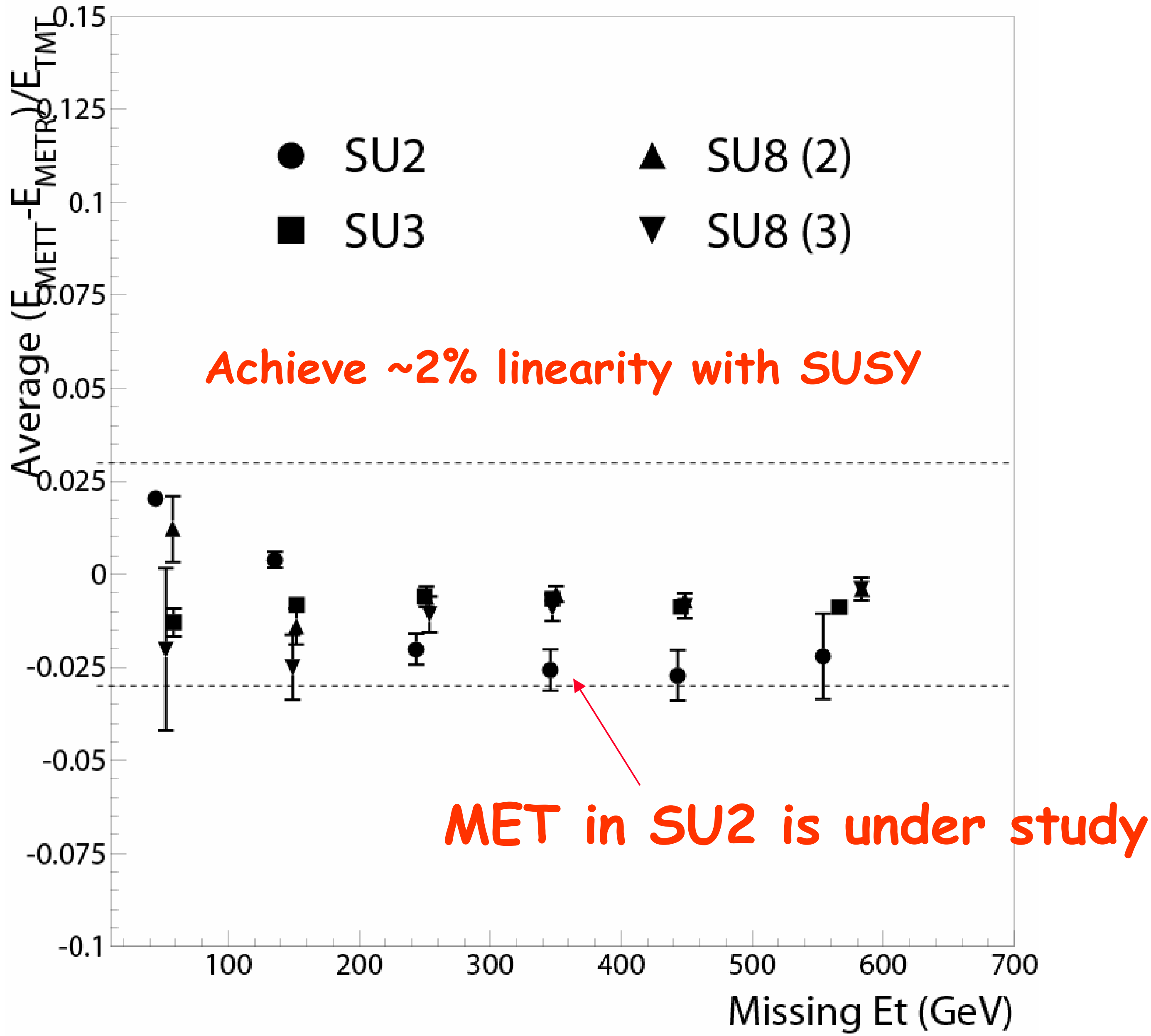




Resolution reported in TDR with A→ττ
σ(p_xy miss)/(ΣE_T)^1/2 (GeV^1/2)
W→eν
W→μν
Z→ee
Z→μμ
H→ττ→ll
W→lν (1 TeV)
W→lν (2 TeV)
SU2
SU3
ΣE_T (GeV)
0
0.2
0.4
0.6
0.8
1
1.2
200
400
600
800
1000

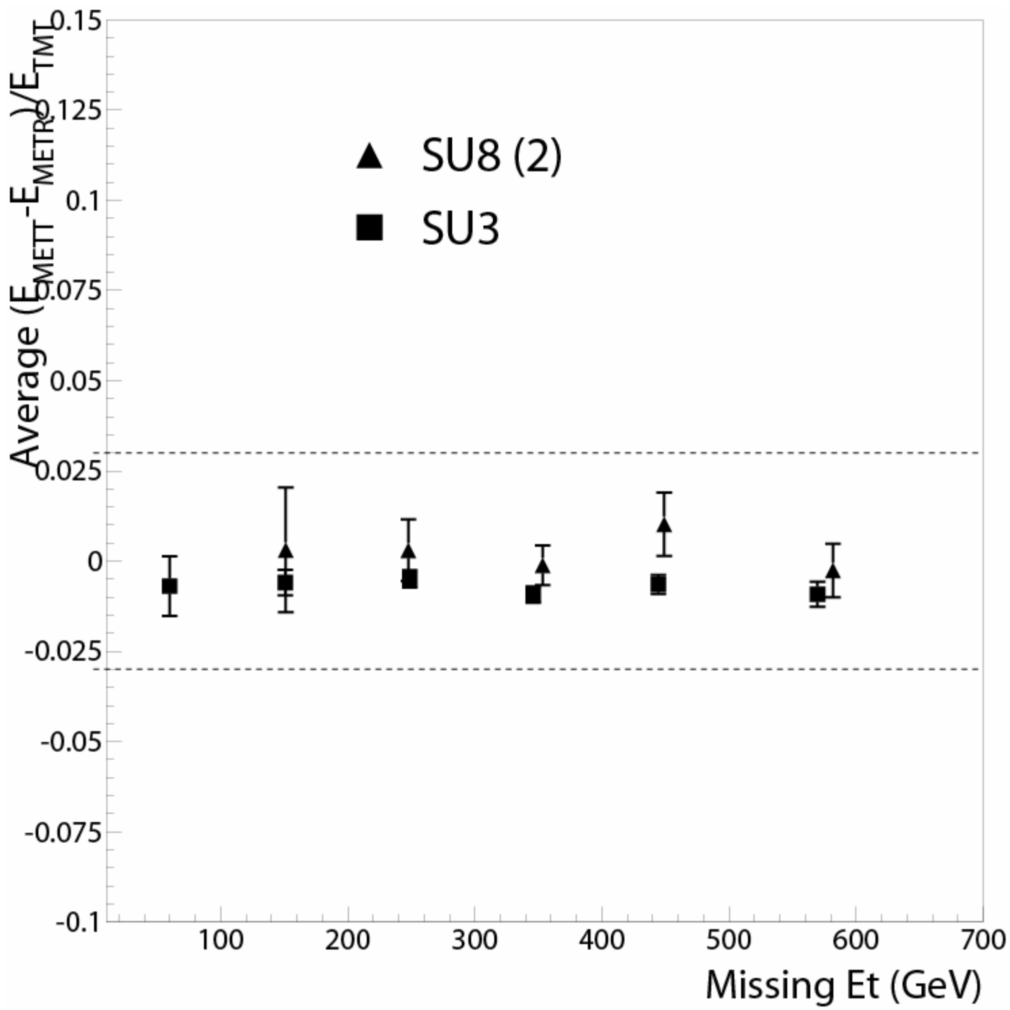


Average $(E_{METT}-E_{METR})/E_{TMT}$
W′→eν
W′→μν
M_W=1−2 TeV
Achieve ~1% linearity with W'
Missing Et (GeV)

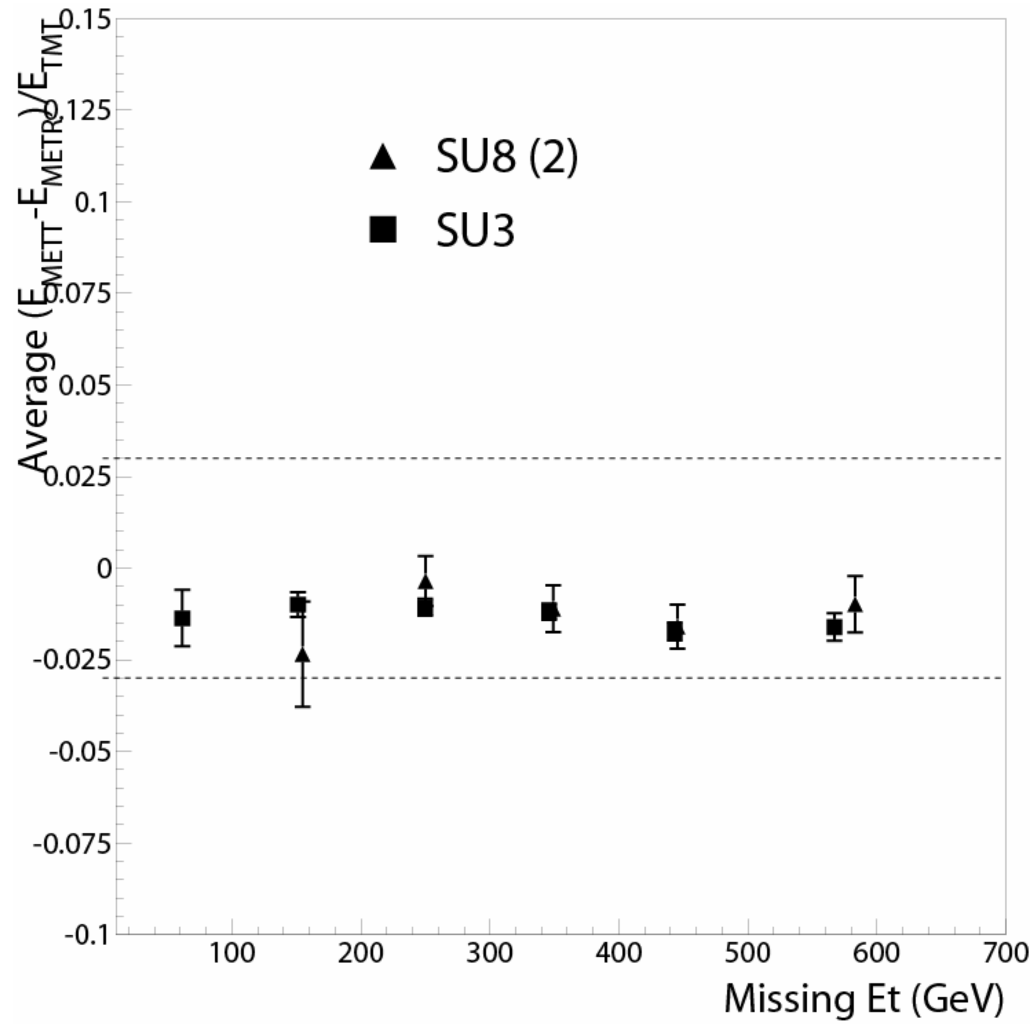

Average $(E_{METT}-E_{METRC})/E_{TMT}$
0.15
0.125
0.1
0.075
0.05
0.025
0
-0.025
-0.05
-0.075
-0.1
SU2
SU3
SU8 (2)
SU8 (3)
Achieve ~2% linearity with SUSY
MET in SU2 is under study
100
200
300
400
500
600
700
Missing Et (GeV)

SUSY events with high P_T leptons (e,μ) (OBMET)

P_{Te}>20 GeV



$P_{T\mu}$>20 GeV



MET Tails and Fake MET studies

ATHENA MissingET: detailed study of events in EtMiss tails

CSC QCD J6 (560<pT<1120GeV), 50Kevts (129pb-1) reconstructed with 11.041

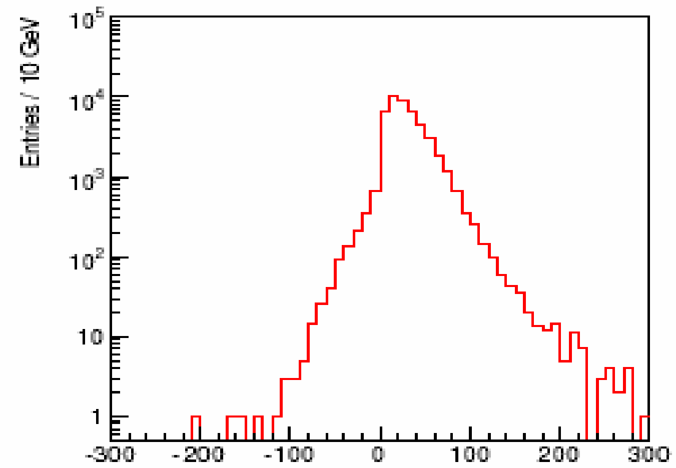
EtMiss_rec-EtMiss_true tipically < 100GeV, look at events with ΔEtMiss>250GeV

F. Paige, Spephane Willoq

Have rerun reconstruction on 16/26 events with RDO files available at BNL and examined them with Atlantis. Classify as follows:

Class	Number
Jet leakage from TileBar/TileExt crack	4
Fake muons from TileBar/TileExt crack	1
Jet Leakage from TileBar/HEC crack	1
Fake muons from TileBar/HEC crack	4
Jet punchthrough	5
Other	1

Limited statistics, but no single class dominates.



EtMiss_rec-EtMiss_true (GeV)

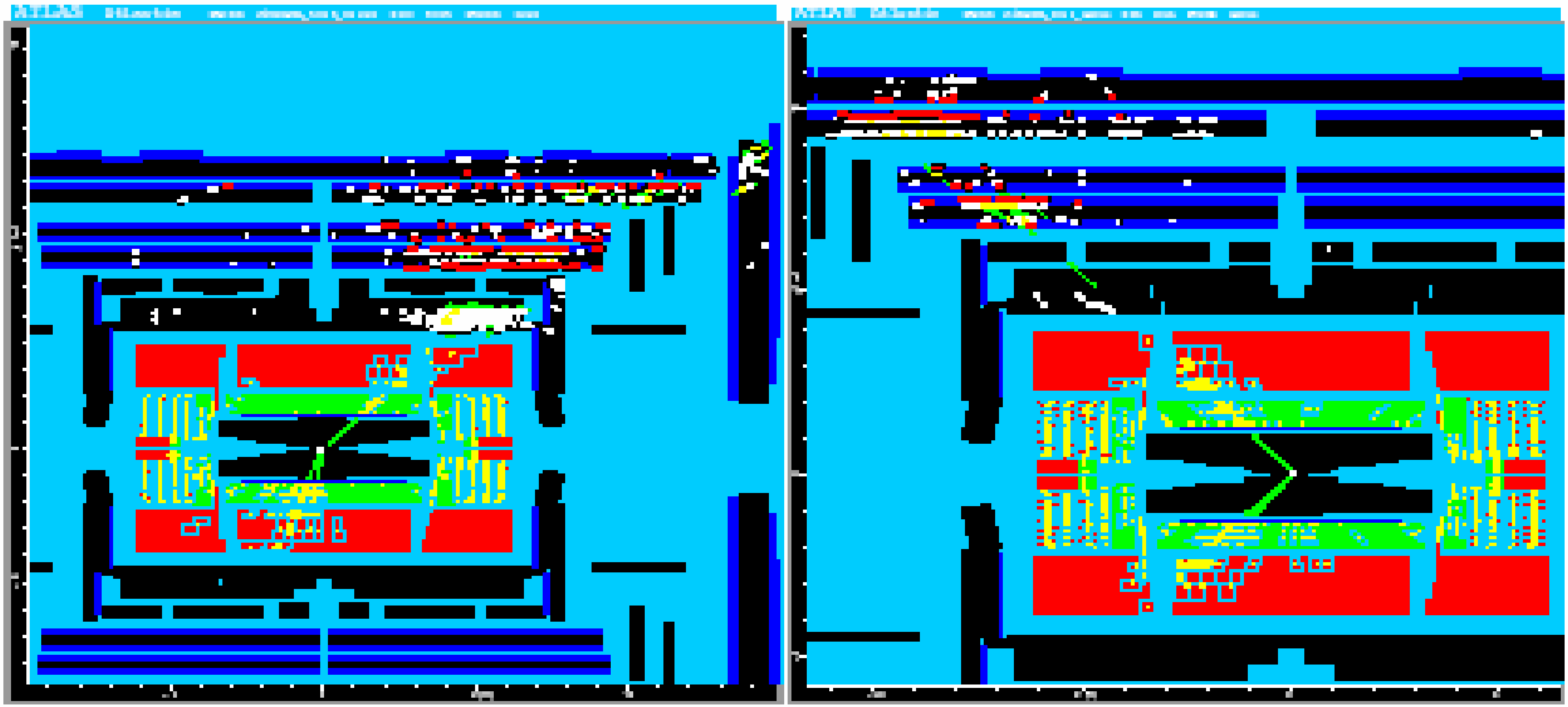
Shower leakage both from punchtrough and cracks important. Veto on muons chamber activity seems effective

Fake muons also important: can reduce with more severe muon quality cuts

For ΔEtMiss>100GeV less muon activity, cracks do not seem dominant

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):



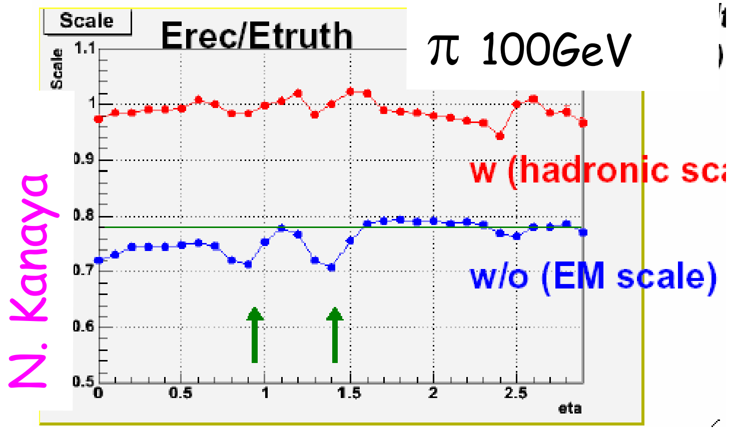
Fake EtMiss study

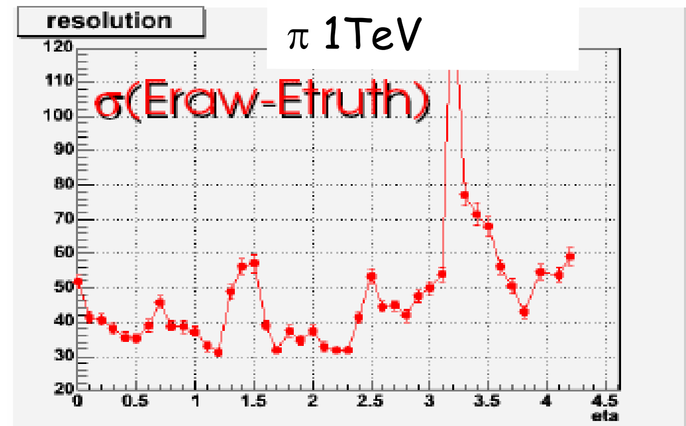
A bad EtMiss mesurement could fake a non-zero reconstructed EtMiss in events with no true EtMiss

⇒ dedicated meetings each 1-2 months

- Event production (S.Asai, A. Gupta)
  - QCD jets (background for SUSY) - and
  - Z(→ll)+jets events (background for H→llνν)
- Filters
  - Events with true EtMiss>threshold (study true EtMiss distribution)
  - Events with a jet pointing to a crack (study fake EtMiss)

  (R. Pradhu)
- Definition of crack regions





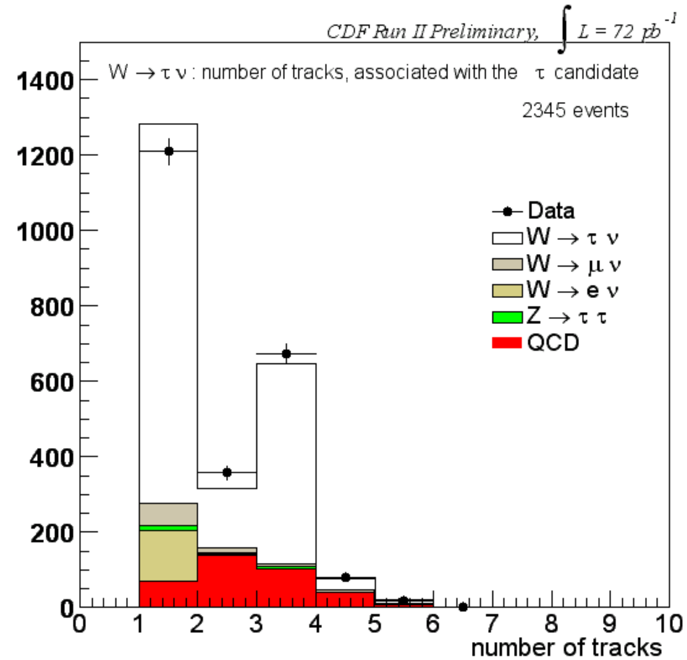
- Dead material hits information
  - Contribution to EtMiss from DM regions will be calculated in MissingET
- Study Instrumental effects: problems in electronic channels, crates, HV sectors… give fake EtMiss. Can correct and recover EtMiss? (R. McPherson et al)
- Define Event quality variables: out-of-time cells, hot cells, number of muon segments… (D. Tovey et al)

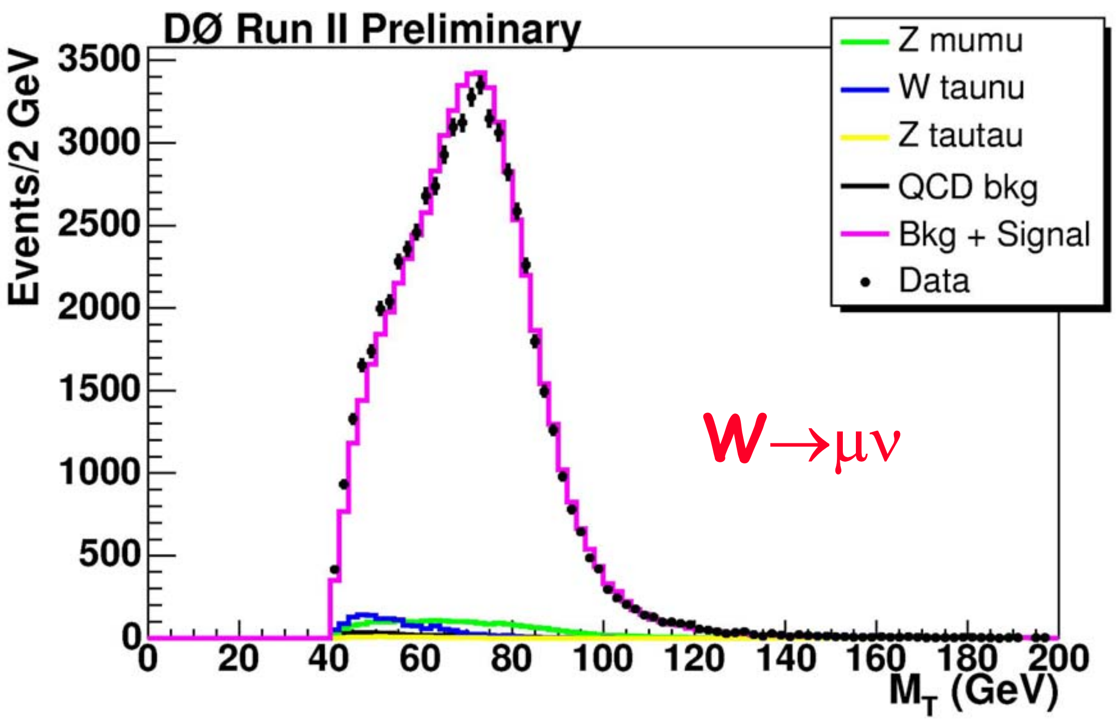
MET with Data

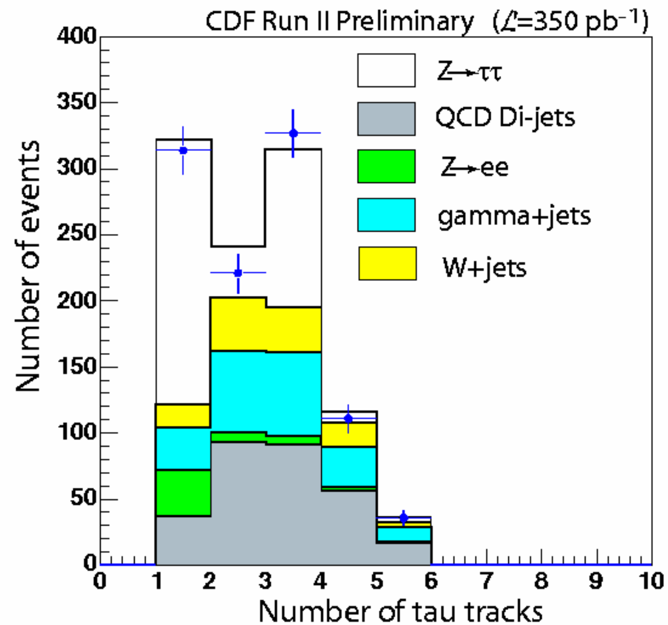
W and Z decays are a copious source of τ's and Missing E_T

- Expect S/B worse at LHC w.r.t. Tevatron. Especially important for $W\to\tau\nu$

$$\left.\frac{\sigma(W,Z)}{\sigma(QCD)}\right|_{LHC} = \frac{1}{10}\cdot\left.\frac{\sigma(W,Z)}{\sigma(QCD)}\right|_{Tev}$$







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

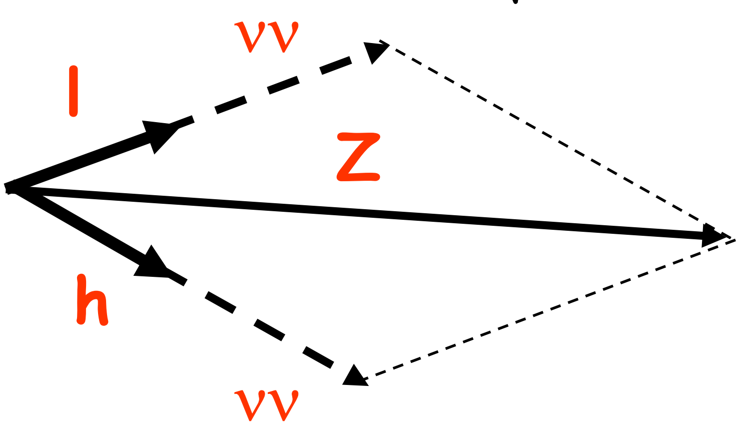
- In order to reconstruct the Z mass need to use the collinear approximation

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

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



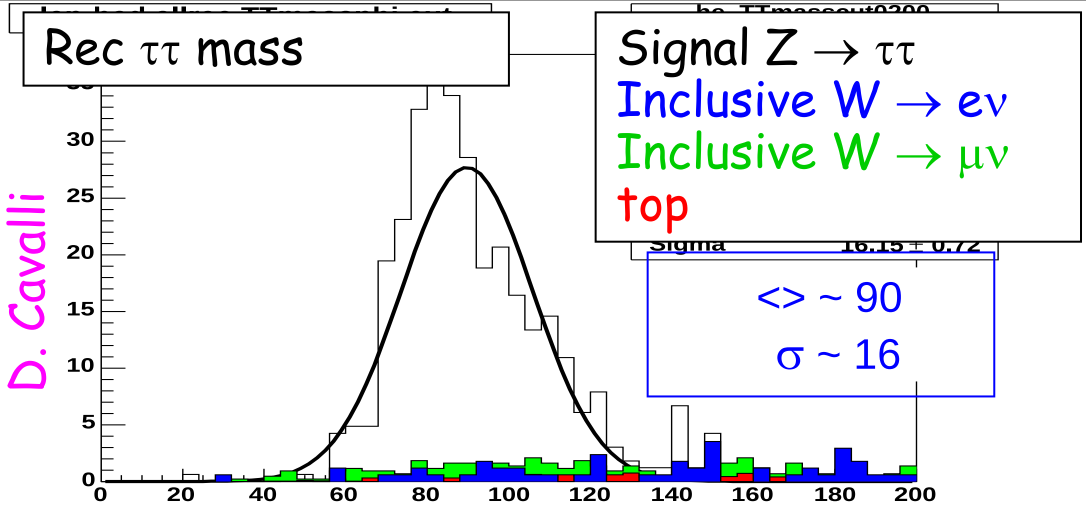
$$\vec{P}_{T\tau 1} + \vec{P}_{T\tau 2} = \vec{P}_{Tl1} + \vec{P}_{Tl2} + \vec{P}_{Tmiss}$$

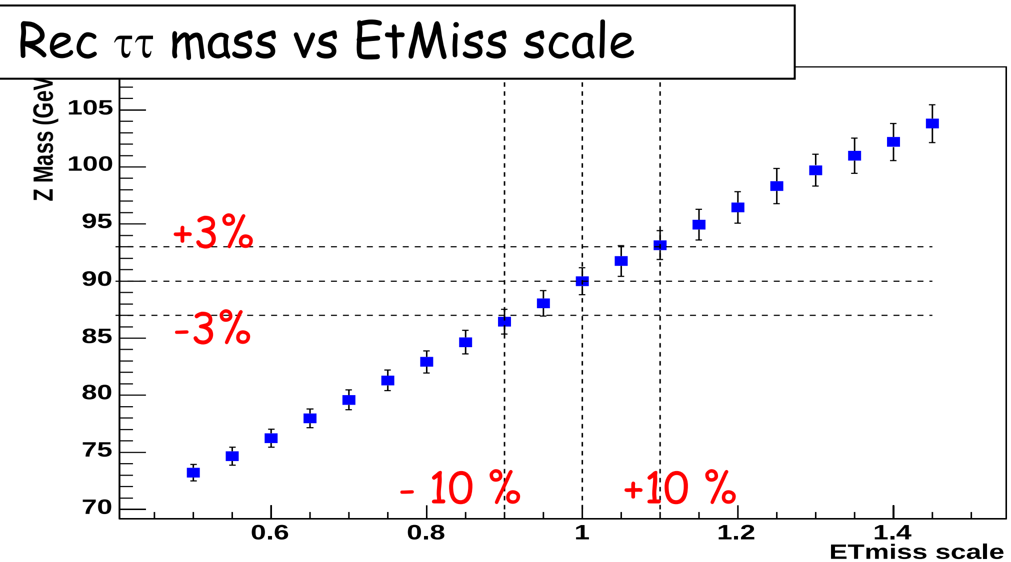
$$x_{\tau_1} = \frac{p_{T_{lep1},x} \cdot p_{T_{lep2},y} - p_{T_{lep1},y} \cdot p_{T_{lep2},x}}{p_{T_{Higgs},x} \cdot p_{T_{lep2},y} - p_{T_{Higgs},y} \cdot p_{T_{lep2},x}}$$

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

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

EtMiss with early data: in situ scale determination with $Z \rightarrow \tau\tau$





Rome data. Applied cuts :

pt(lep) > 15 GeV, $|\eta|$<2.5

pt(jet) > 15 GeV, $|\eta|$<2.5

isEM & 0x7FF) ==0 ,

lep isolation: Etcone30<5GeV

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

m_T(lept-EtMiss)<50GeV

τ-likelihood > 8 (τ-eff ~ 30%)

66<rec $m_{\tau\tau}$<116 GeV

Expected in 100pb-1

~ 300 evts with ~ 20% backgd

Possible to loosen cuts to increase statistics? Or more severe cuts necessary to reduce bb backgd?

In TDR :EtMiss>20 GeV

m_T(lept-EtMiss)<25GeV

Results still preliminary due to low statistics

Need to have also a bb sample

Trigger-aware analysis and Cuts tuning

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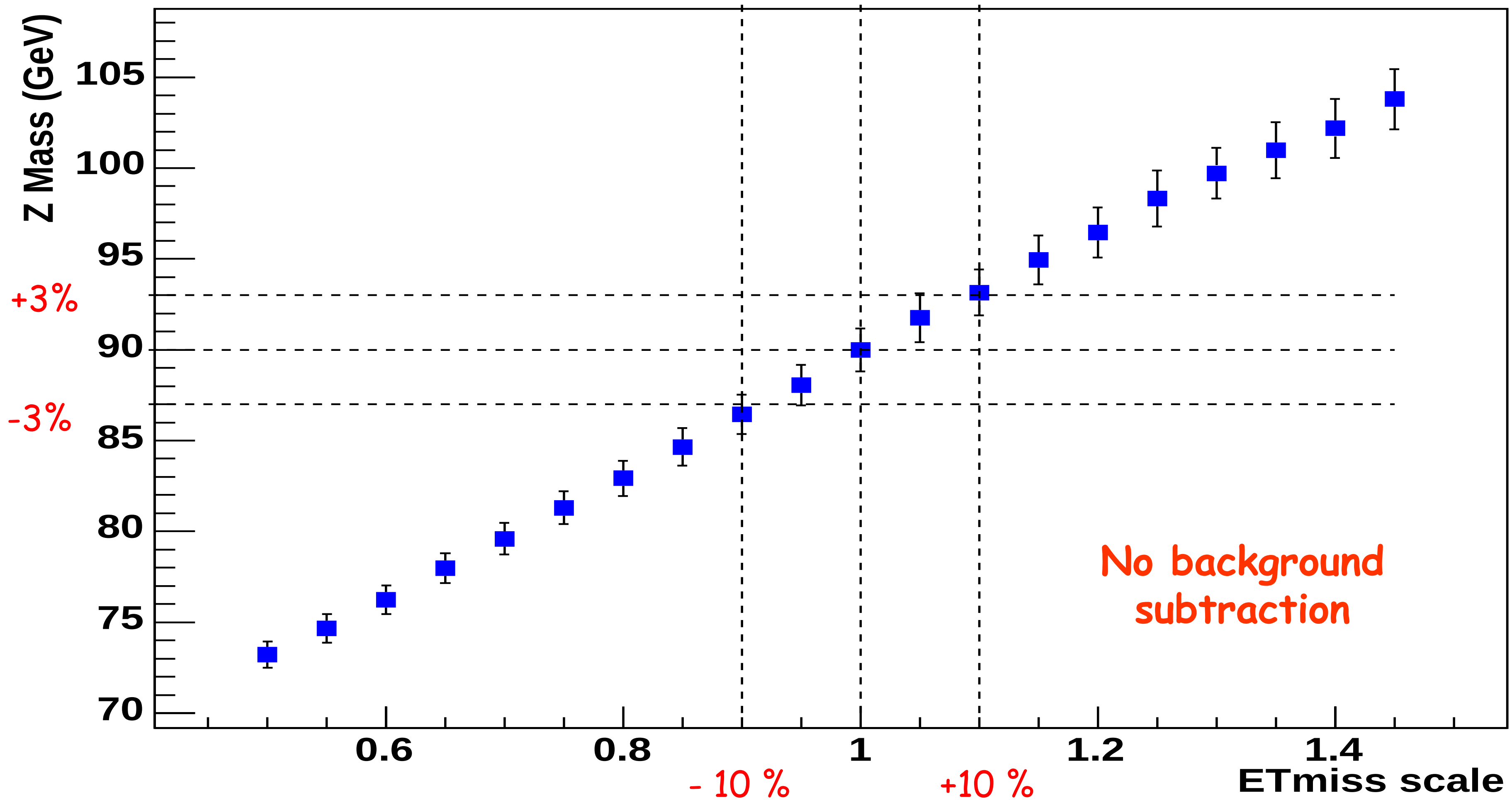
Rec ττ mass vs EtMiss scale



Missing E_T with $W \rightarrow l\nu$

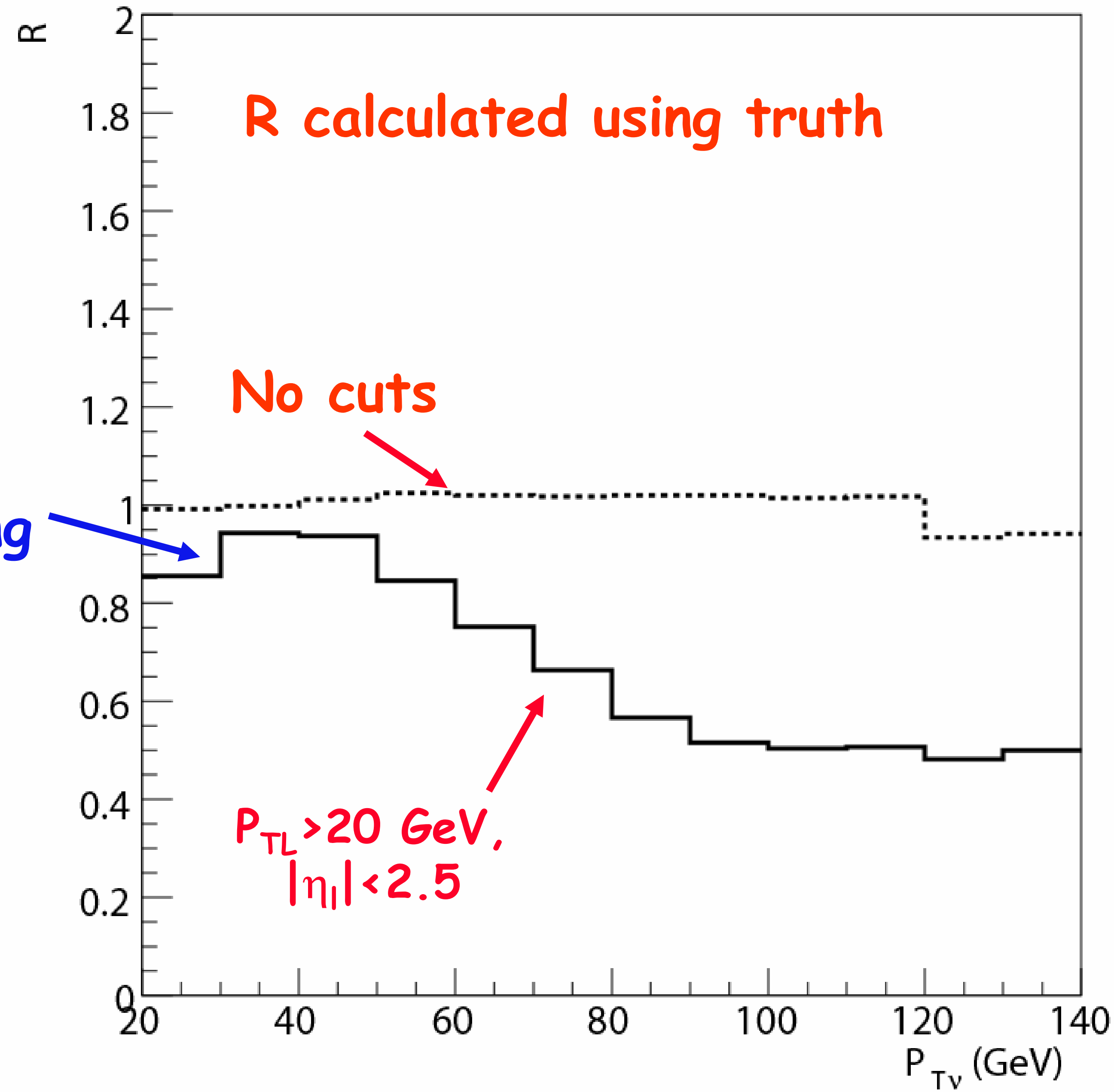
- One can use the sharp end of the transverse mass in different missing E_T bins
  - Shape of transverse mass changes with Missing E_T, due to acceptance
- One can also use the fact that in the average the pt of the charged lepton and the pt of the neutrino are of the W decay are known function, which can be calculated with MC

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

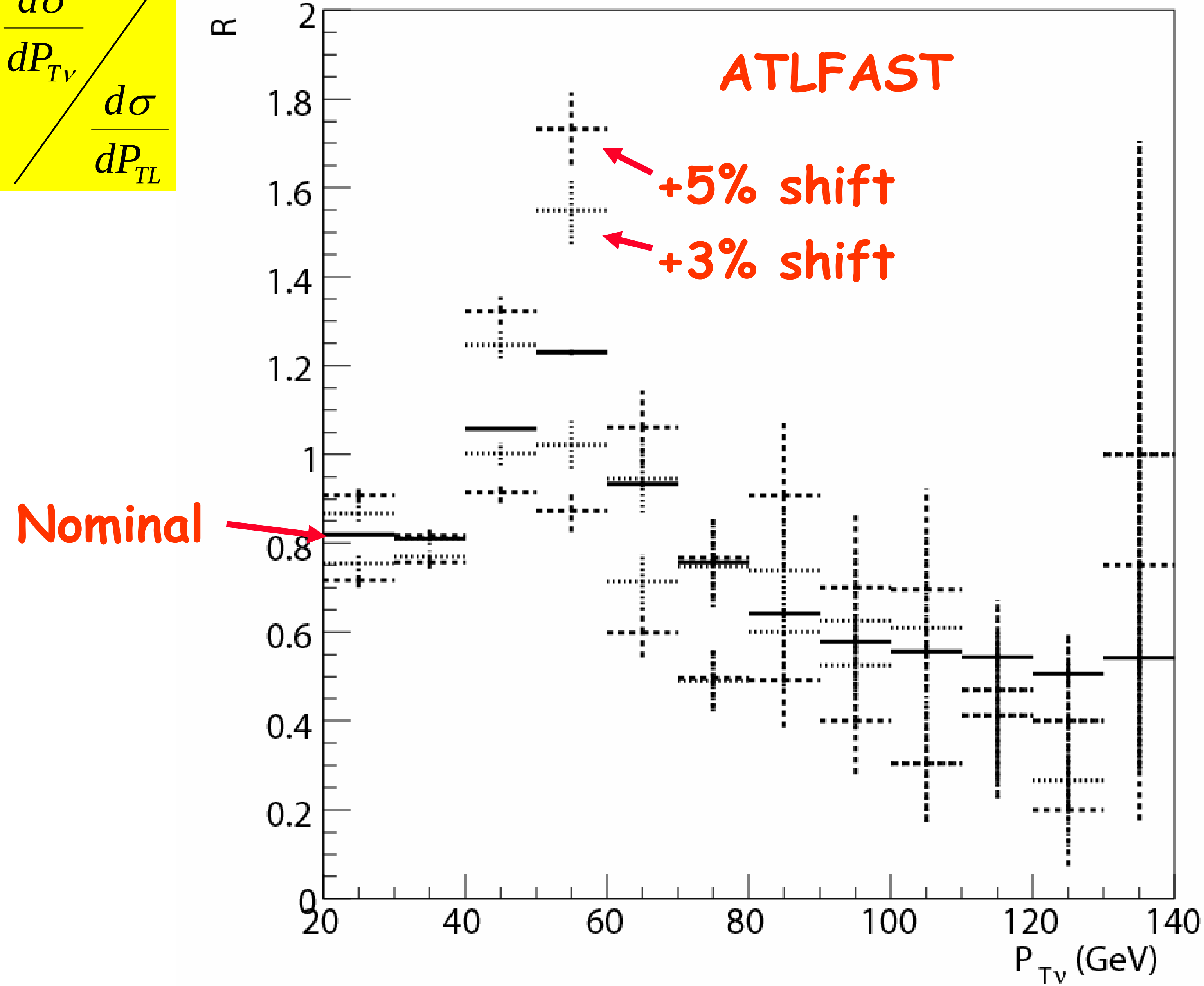
Function can be calculated with MC and depends on experimental cuts

$$R = \frac{d\sigma}{dP_{T\nu}} \Bigg/ \frac{d\sigma}{dP_{TL}}$$

Systematic errors are being addressed



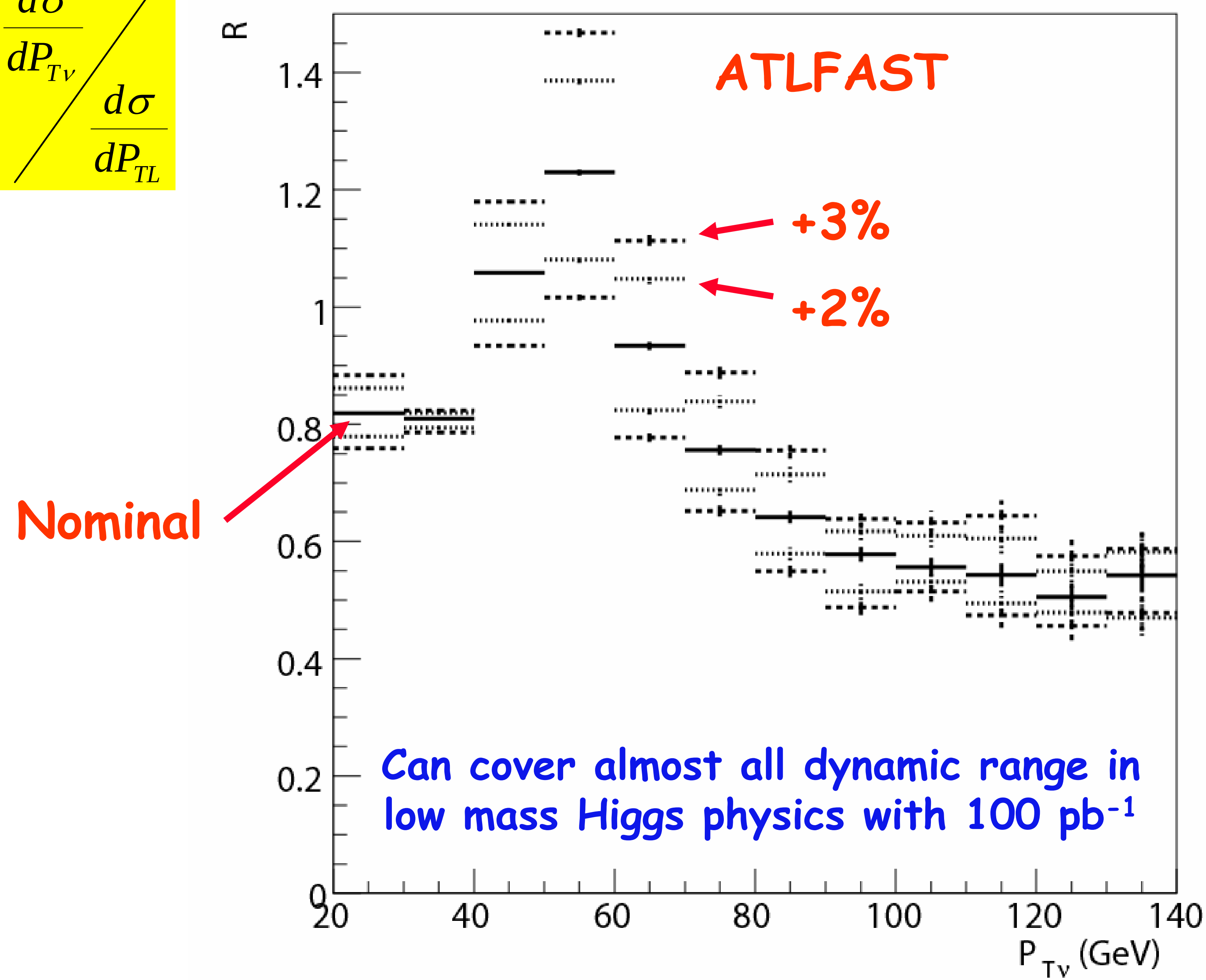
$$R = \frac{d\sigma}{dP_{T\nu}} \Big/ \frac{d\sigma}{dP_{TL}}$$



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

$1pb^{-1}$

$$R = \frac{d\sigma}{dP_{T\nu}} \Big/ \frac{d\sigma}{dP_{TL}}$$



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

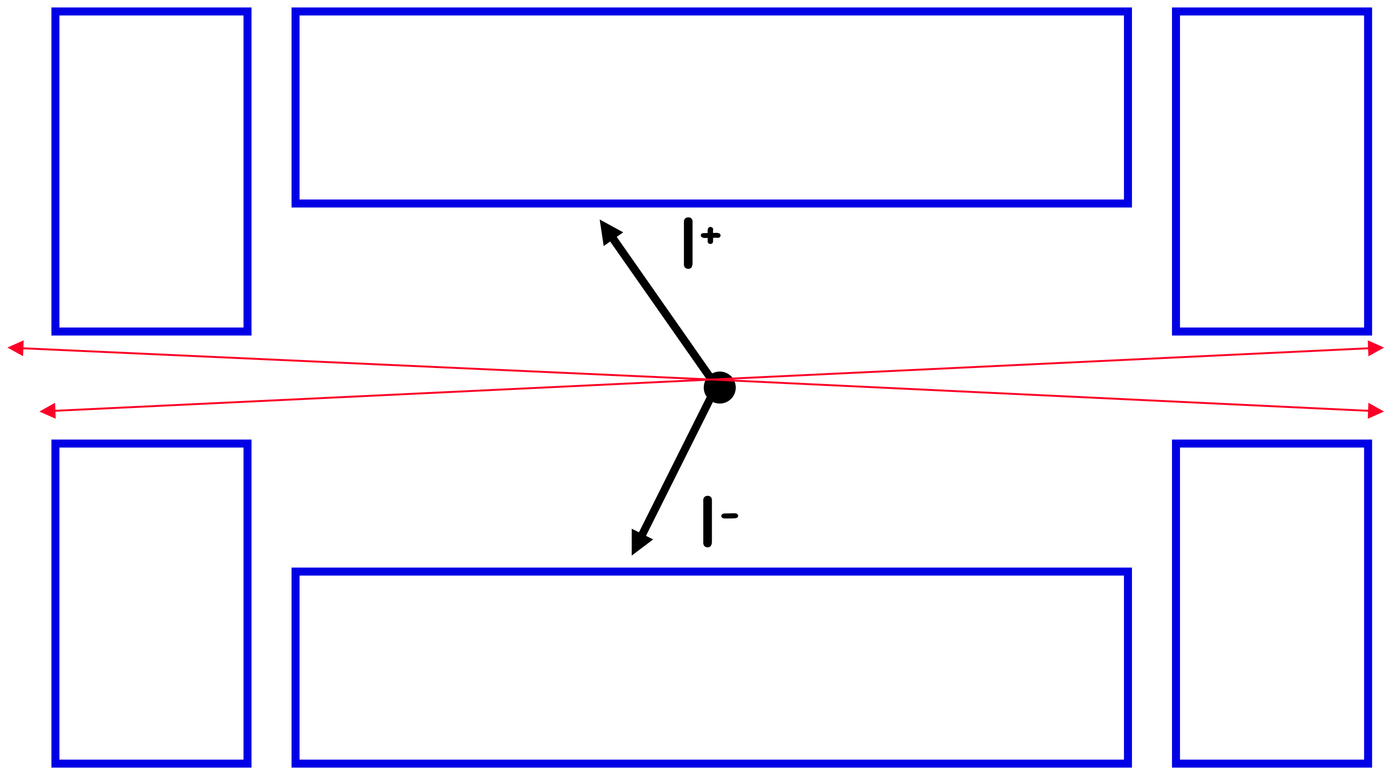
100pb^{-1}

Is the transverse momentum escaping calorimeter coverage due to particles escaping though the beam-pipe or partially depositing energy in the back of the FCAL?

- Use $Z \rightarrow ll$ as a sensitive tool

$$\sum \vec{P}_{Tl} + \vec{P}_{THad} + \vec{P}_{TEscape} = \vec{0}$$

Especial thanks to M.Krasny

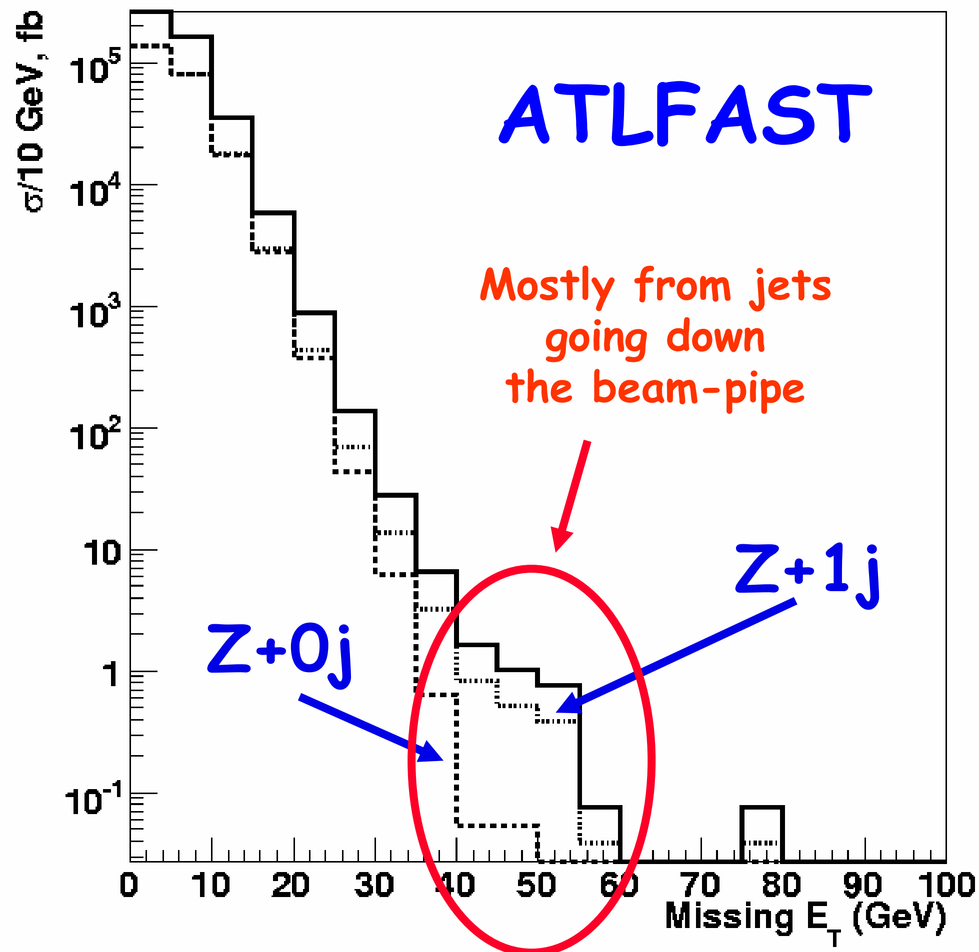


- Re-do older earlier studies with present-day MC
- Use ALPGEN to generate Z+njets (Matrix Element and Parton Shower matching) with $|\eta|<100$ (light flavor only)
  - Impact of ZQQbar will be addressed in the future

- Apply a veto on events with at least one jet with $P_T>10$ GeV in $|\eta|<5$: Events with Z+nj n>0 have a jet(s) going down the beam-pipe

- Effect of particles going down the beam-pipe is expected to be small

- Work needs to be done to understand instrumental effects of jets with partial depositions in FCAL



Outlook and Conclusions

- ATLAS has embarked in a vigorous collective effort to develop robust algorithms for Missing E_T reconstruction
  - Cell-Based and Object-Based algorithms available in ATHENA releases
  - MET performance is being evaluated and studies in a large variety of final states
  - Shifts in the module of MET are now significantly reduced. Efforts made to improve resolution
  - Study of various sources of tails and fake MET underway
    - Regular meetings set up and new tools are being developed
- Devising various methods for checking MET reconstruction with (early) data