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Identification of tau-Leptons

Measurement of Missing Transverse Energy

Michael Heldmann
University of Freiburg

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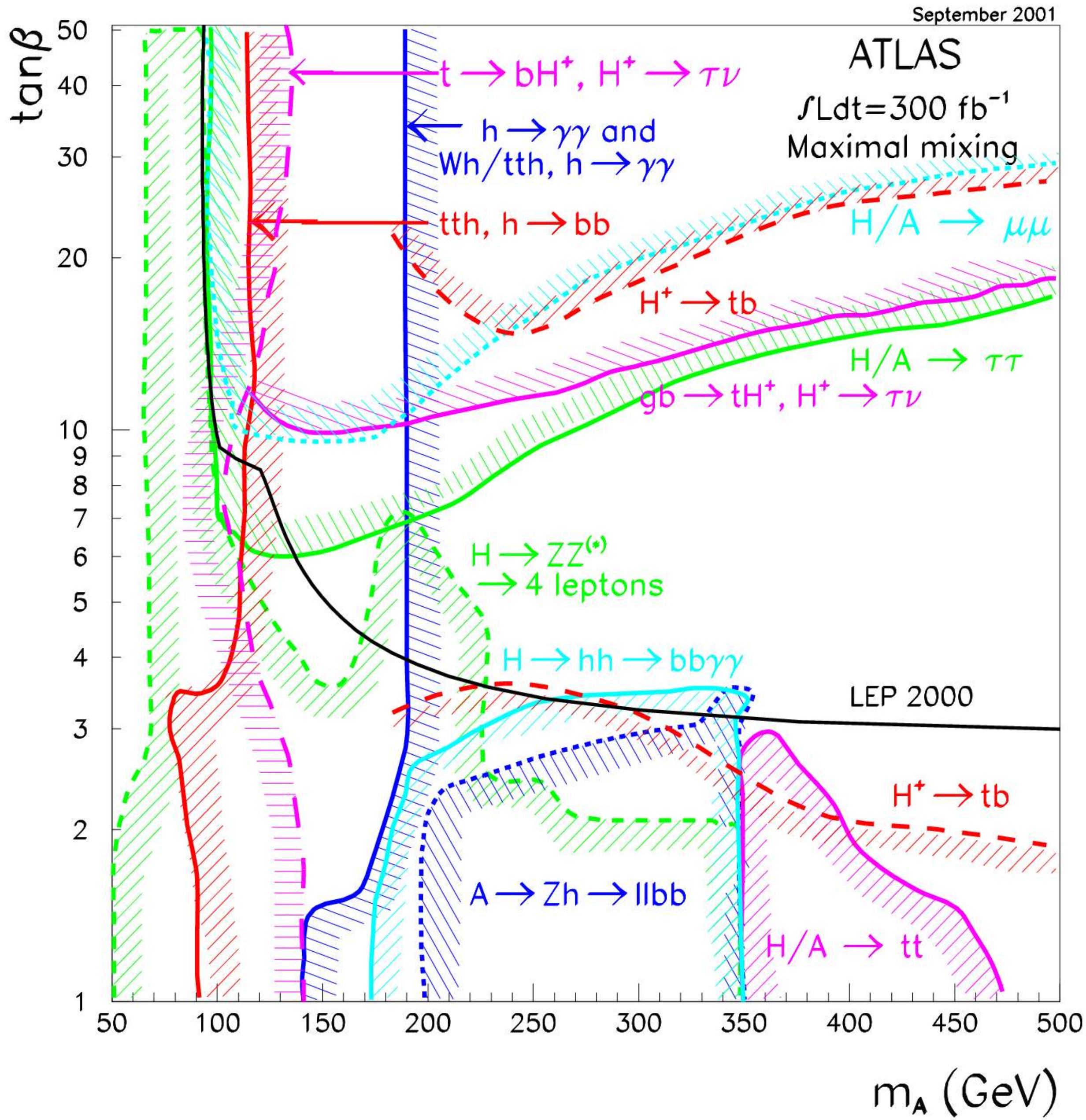
- **Performance**
- **Conclusions**

Remark: the content of this talk is the result of the work of many people in CMS and ATLAS, many thanks to all involved

Physics with Taus

- **Channels using taus**
- $A^0/H^0 \rightarrow \tau\ \tau$
- $H^+ \rightarrow \tau\ \nu$
- SUSY with prodcution of $\tilde{\tau} \rightarrow \tau + \tilde{\chi}^0_1$
- Standardmodell Higgs (VBF qq $H \rightarrow qq\ \tau\ \tau$)
- $Z \rightarrow \tau\ \tau$, $W \rightarrow \tau\ \nu$ (for comissioning)
- τ could perhaps provide a way to access the chiral structure of SUSY



Taus, a short reminder

- **Tau decay modes**
  - Leptonical decay modes
    - $\tau \rightarrow \nu_\tau + \nu_e + e$ (17.4%)
    - $\tau \rightarrow \nu_\tau + \nu_\mu + \mu$ (17.8%)

1 track
only thing different
from prompt leptons:
impact parameter

  - Hadronical decay modes
    - 1 prong
      - $\tau \rightarrow \nu_\tau + \pi^c$ (11.0%)
      - $\tau \rightarrow \nu_\tau + \pi^c + \pi^0$ (25.4%)
      - $\tau \rightarrow \nu_\tau + \pi^c + \pi^0 + \pi^0$ (10.8%)
      - $\tau \rightarrow \nu_\tau + \pi^c + \pi^0 + \pi^0 + \pi^0$ (1.4%)
      - $\tau \rightarrow \nu_\tau + K^c + x \cdot \pi^0$ (1.6%)

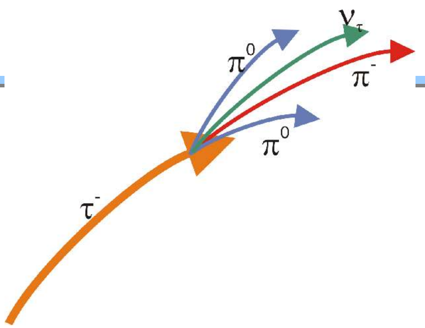
1 track, impact parameter

shower shape, energy sharing

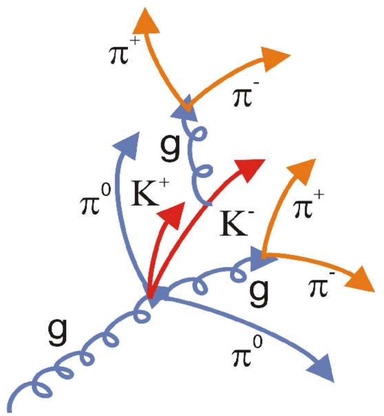
    - 3 prong
      - $\tau \rightarrow \nu_\tau + 3 \cdot \pi^c + x \cdot \pi^0$ (15.2%)

3 track, impact parameters,
secondary vertex
shower shape, energy sharing

Reconstruction of taus



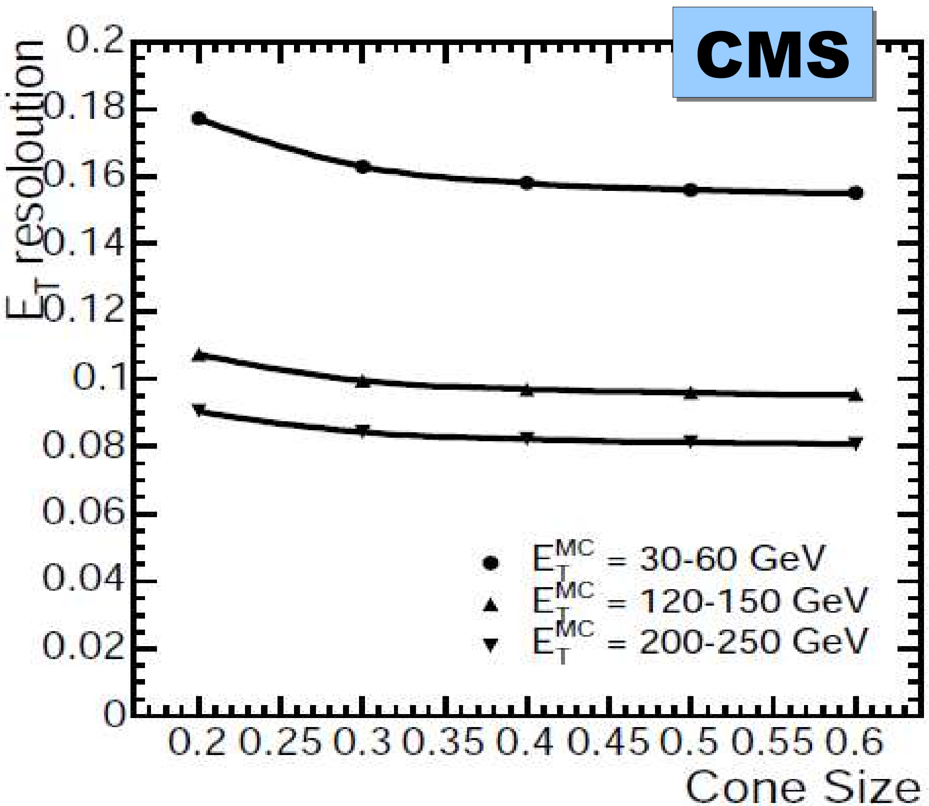
- **Reconstruction - How to find taus**
  - seeding from Calorimeter objects
    - Clusters from a sliding window algorithm
    - Jets from various jet algorithms
    - Topoclusters
  - seeding from Tracker objects
    - Isolated tracks above p_T threshold
  - Different seeds are optimal for different decay modes



- **ATLAS**
  - default is Cluster, with $p_T > 15$ GeV
  - seeding from isolated tracks with $p_T > 9$ GeV is also used a lot and well understood
- **CMS**
  - Cone jet algorithm, offline or from the trigger chain

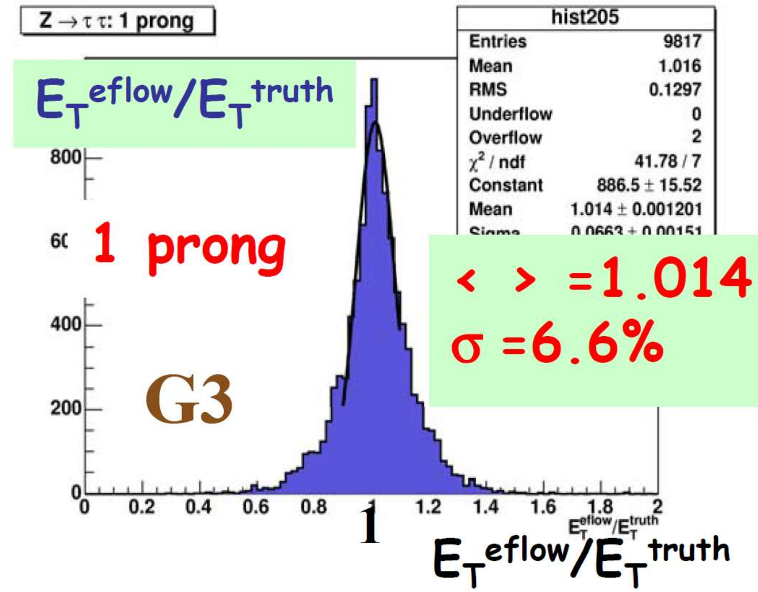
Calibration

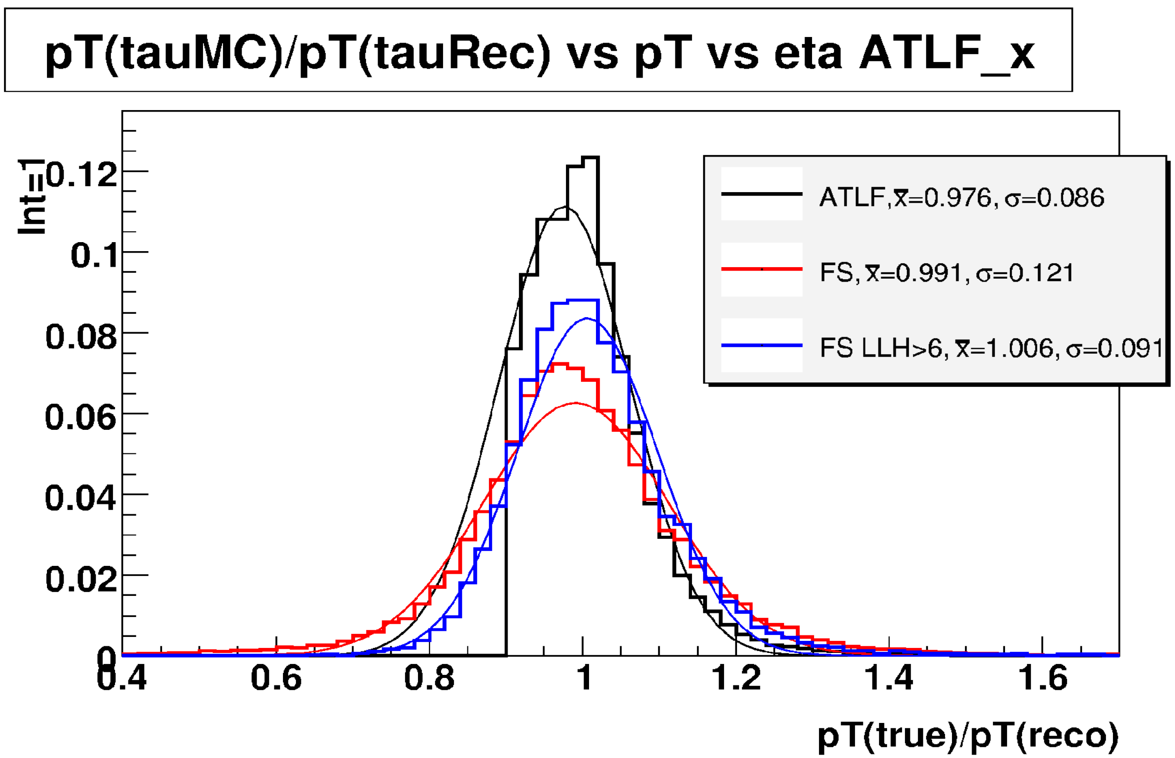
- Calibration of taus is based on the calibration of jets -> see also talk of I.Vivarelli
- **CMS**
  - E=(a*EC+b*HC)
  - EFlow methods developed for jets could also be easily used for taus and have there potentially an easier environment (not studied yet to my knowledge)
- **ATLAS**
  - "H1 style method" : cells are weighted and summed in a cone of $\Delta R < 0.4$
    - weights depend on the energy density in the cells
    - idea is that em energy has higher density, hadronic energy has lower density
  - EFlow method : energy with tracks nearby is (nearly) always hadronic energy, the rest is em energy (from $\pi^0 \rightarrow \gamma\gamma$)

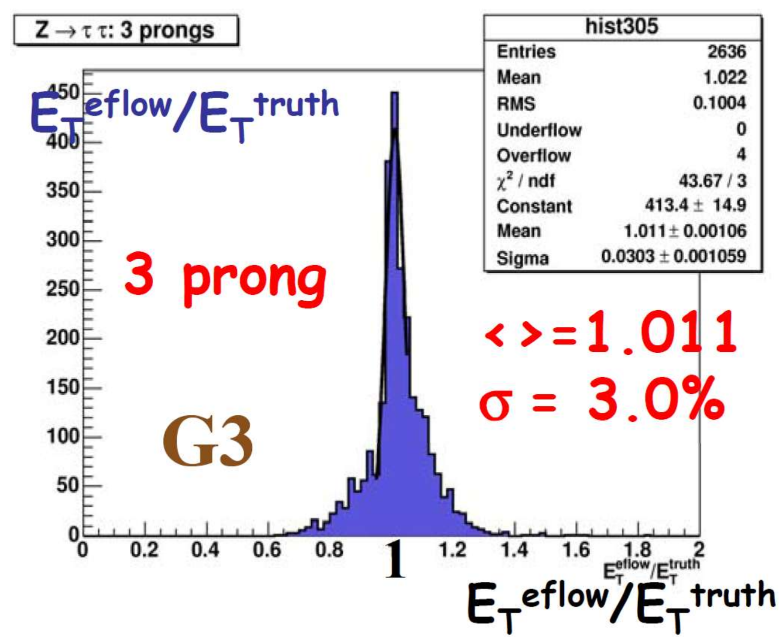


Energy flow

- **ATLAS**
  - EFlow method comparison to "H1 style method", for $Z \rightarrow \tau\ \tau$
  - EFlow improves significantly for low p_T < 50 GeV





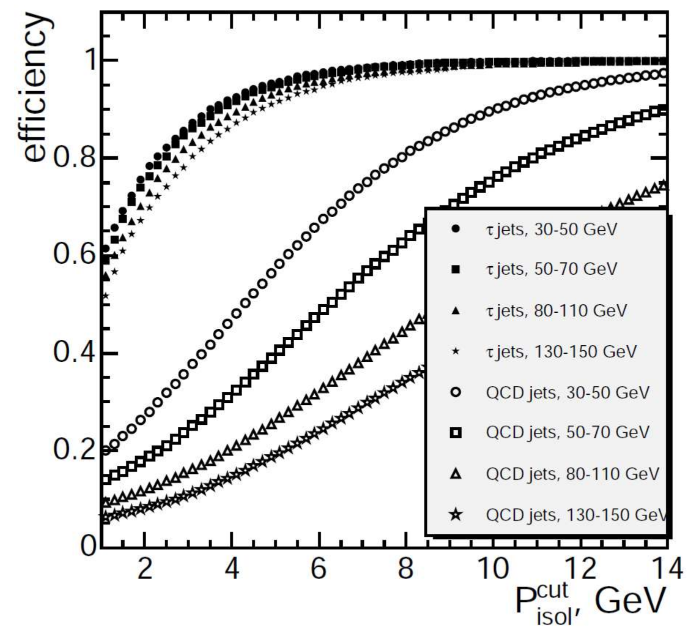


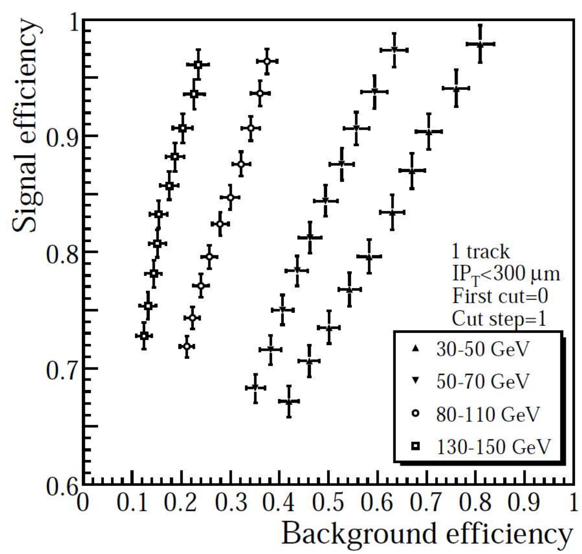
Identification

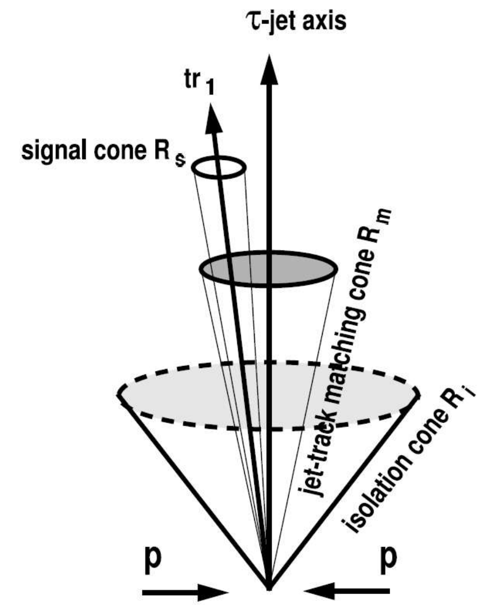
- **Identification – How to tell them apart from jets**
  - **calorimeter information**
    - narrow
    - isolated
    - mixture of em energy and hadronic energy
  - **tracker information**
    - one or three isolated tracks
    - good tracks
    - impact parameter
    - three prong: limited invariant mass
  - **vertexing**
    - for three prong decays reconstruction of secondary vertex may be possible
    - decay length (distance primary vertex → secondary vertex)
  - **combination with multivariate technics**

Identification CMS 1

- **Calorimeter Isolation:** $P_{isol} = \Sigma_{\Delta R<0.4} E_T - \Sigma_{\Delta R<0.15} E_T$
- **Tracker Isolation:**
  - search leading track in a cone of $\Delta R < R_m$, around the calorimeter jet axis
  - "signal tracks" around leading track, $\Delta R < R_{s,}$ "isolation tracks", around jet axis $\Delta R < R_i$
  - R_s and R_i depend on the energy of the τ-jet
  - no isolation tracks are allowed
- **Impact parameter:**
  - IPsignificance = IP/σ_{IP}
  - sign tried but found to be not useful
  - only useful for 1 prong decays





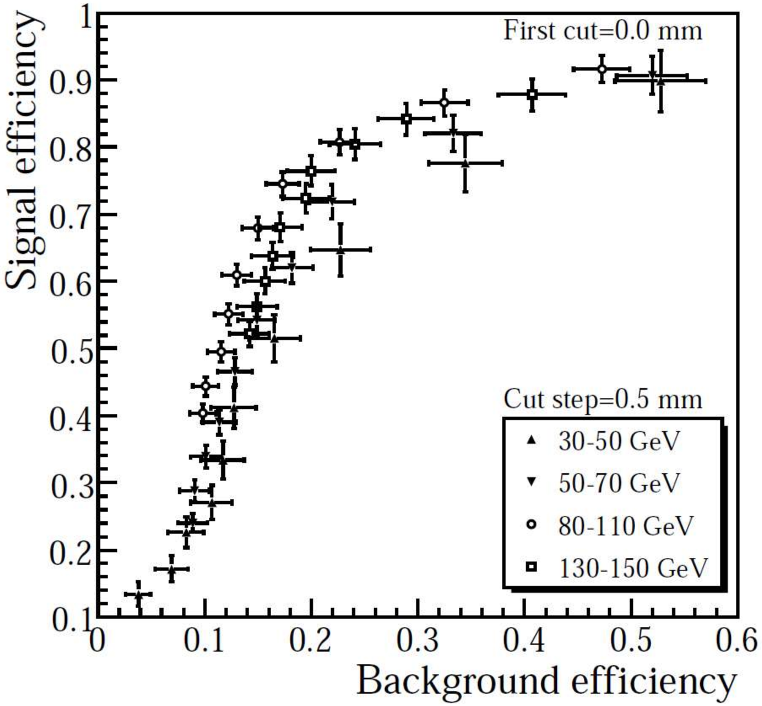


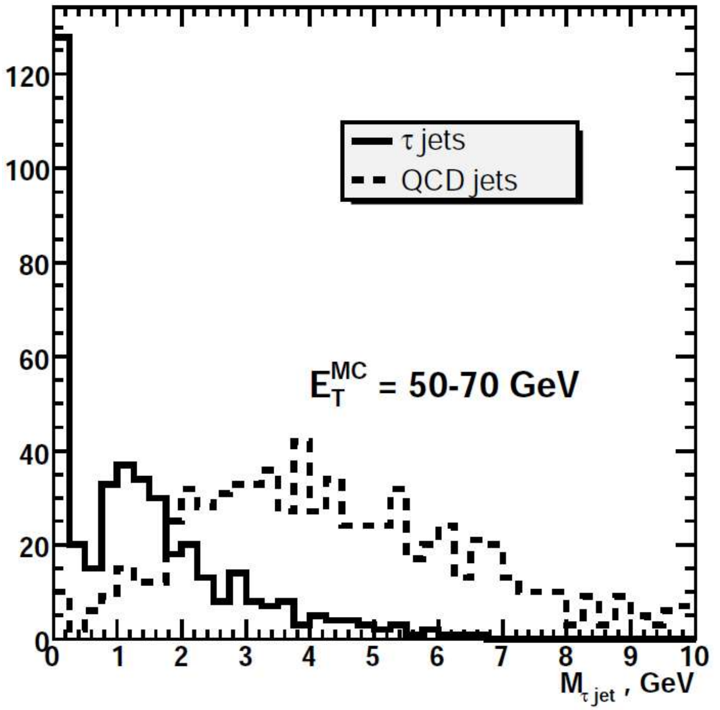
Identification CMS 2

- **flight-path**
  - IP not useful for 3 prong → use flight-path
  - propability for finding 3 signal tracks for a 3 prong decay is ~ 63%
  - reconstruction of secondary vertex for taus challenging
- **tau-mass**
  - calculate invariant mass from signal tracks and EM-Calo only clusters

recommended strategy

- use calo and tracker isolation
- 1 prong: use IP, 3 prong use flight path
- mass cut may be used for both
- cut on pT of the leading track may be useful
- optimal strategy depends on the channel

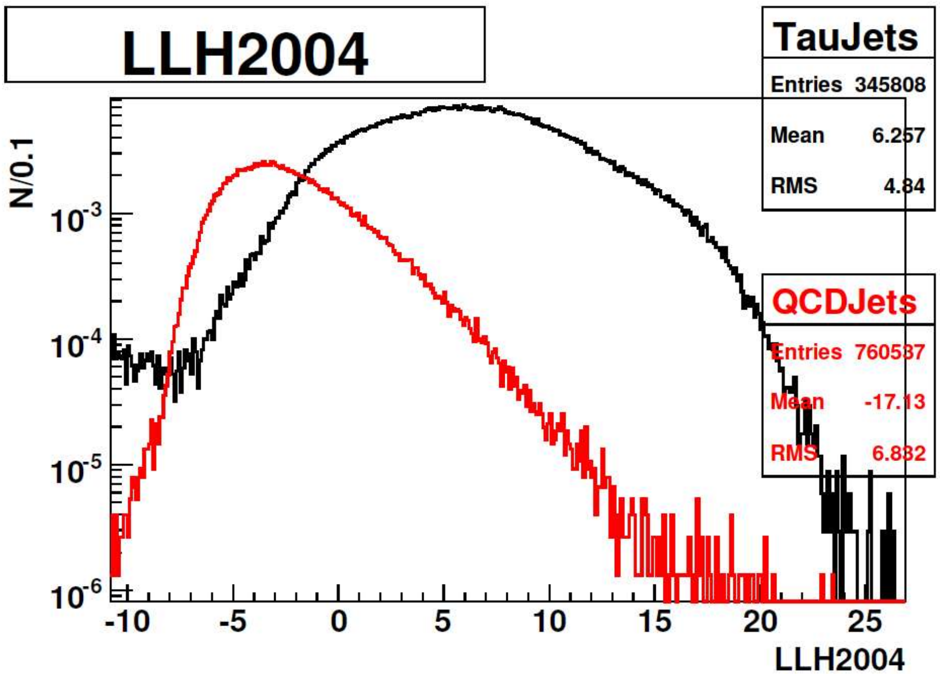


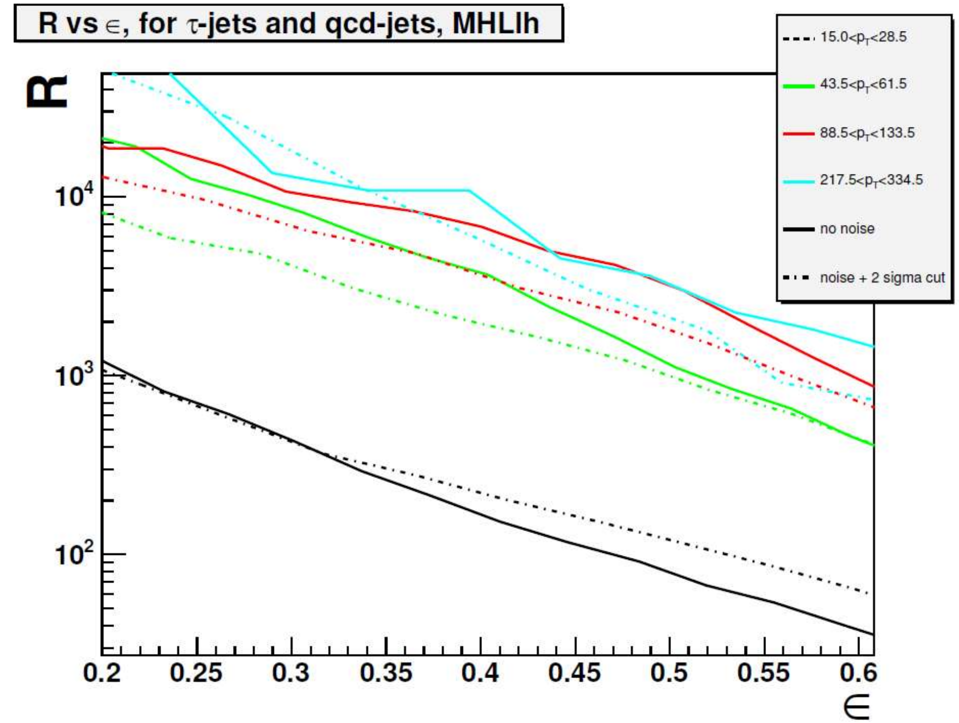


Identification ATLAS 1

- **calorimeter variables**
  - R_{em} : transverse energy weighted radius in the EM calorimter
  - ΔE_T^{12} : transverse energy between $\Delta R < 0.2$ and $\Delta R < 0.1$
  - N_{strip} : Number of cells with E > 200 MeV in the η-strip layer
  - $E_{T,width, strip}$: transverse energy weighted width calculated only in the η-strip layer
- **tracker variables**
  - N_{tr} : number of tracks, p_T > 2 GeV, ΔR (jet axis) < 0.2
  - Charge : sum of charge of tracks (like for N_{tr})
  - E_T / p_{T1} : Ratio between calorimeter and tracker energy
  - signed Impactparameter (for 1 prong)
  - secondary vertex (3 prongs)
- combine them all with a likelihood method
- Variables depend heavily on $p_T \rightarrow p_T$ dependant likelihood

Identification ATLAS 2

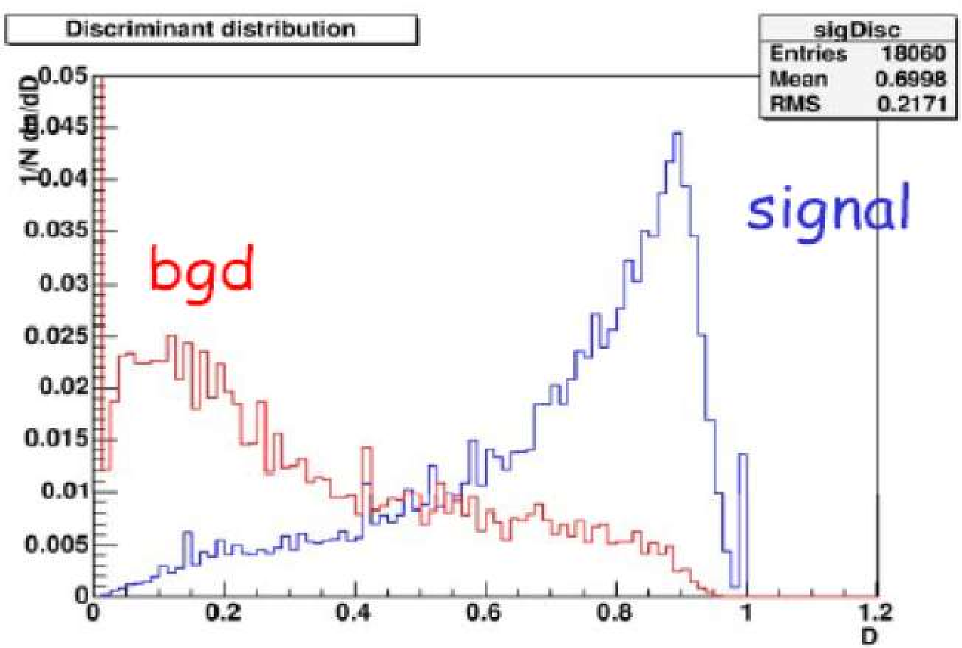


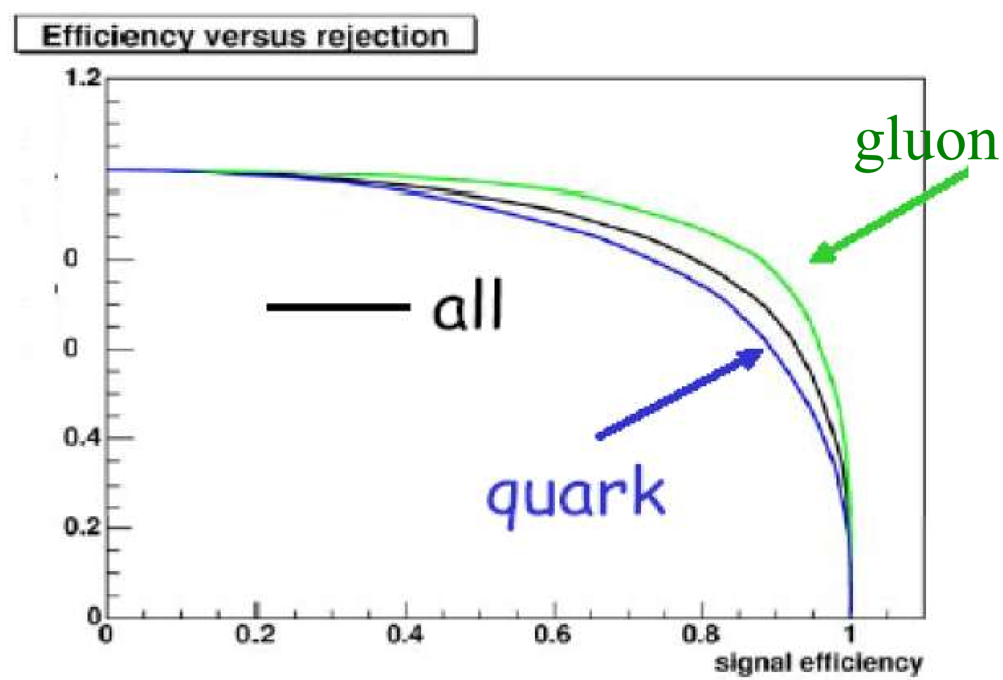


- **alternative approach:**
  - seed from good quality, isolated tracks p_T > 9 GeV
  - accept only exactly two nearby tracks with p_T > 2 GeV
  - build EFlow (as shown before)
  - combine Id variables as before (with narrower cone) and from EFlow using a multivariate technic (here PDRS)

Identification ATLAS 3

- more exclusive reconstruction
- PDRS powerful multivariate technic
- energy scale from EFlow
- good to have two independent methods to cross check





Conclusions (taus)

- Final states including tau-leptons are interesting for standard model and beyond the standard model physics
- hadronically decayed taus can be separated against jets, using tracker and calorimeter information
- reconstruction of candidates is done starting with calorimeter objects or tracks
- energy can be obtained calibrating calorimeter information or with EFlow technics
- with an efficiency of 50% for taus, rejections from ~100-3000 are possible against QCD-jets, for 20 - 200 GeV tau-jets
- CMS provides a series of well studied variables to the user (analysis)
- ATLAS provides multivariate discriminants to the user

ETMiss 1

- ETMiss is an important ingredient for many channels, for standard model studies like top quark production, W but especially for beyond the standard model studies like search for Supersymmetry, invisible Higgs, certain types of extra dimensions and so on
- Missing transverse energy is based on the 2D (in the transverse plane) vector sum of certain objects
- two extreme approaches
  - transverse vector sum of all calorimeter cells + detected muons
    - sums up all electronic and pileup noise too
  - transverse vector sum of all objects
      - muons, electrons, jets, b-jets, taus
    - a lot of energy comes from low E_T objects that may not end up in reconstructed objects
- question of calibration is very important

ETMiss 2

- many different contributions to ETMiss resolution
  - calorimeter resolution
  - limited calorimeter coverage: $|\eta| < 5$
  - electronic noise
  - pile up energy (in-time and out-of-time)
  - non compensating calorimeter → e/h
  - magnetic field (curling particles, particles bend out of coverage)

- many of these are of the same order of magnitude → difficult to improve ETMiss resolution

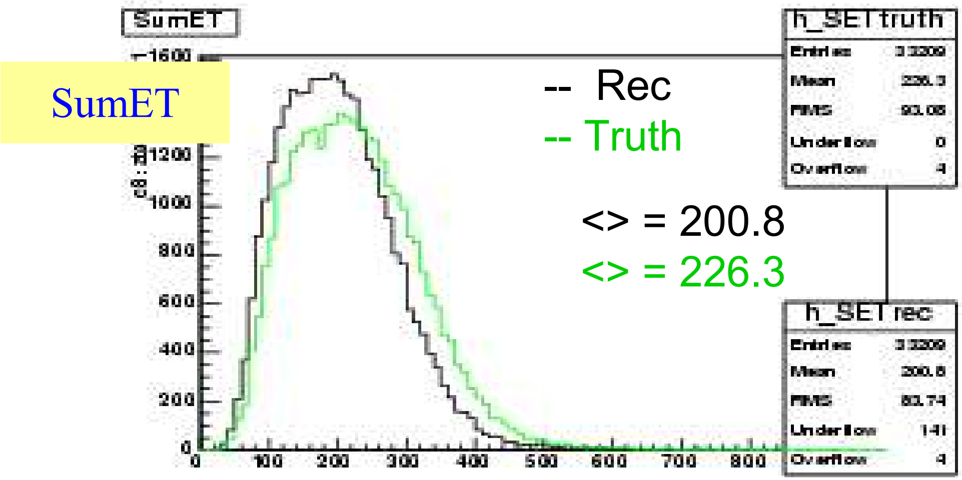
ETMiss ATLAS 1

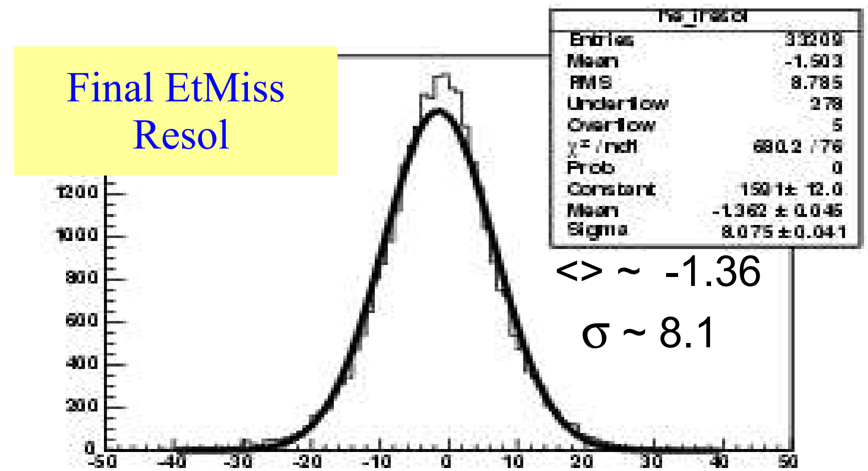
- ATLAS persues mainly two strategies
- both are based on calo cells + detected muons + cryo correction
- method 1 : take all calorimeter cells with |E| > 2 •σ(noise of the cell)
- method 2 : take only calorimeter cells which belong to a TopoCluster
  - a TopoCluster is a collection of cells that fullfill certain neighbour criteria and tries to grab the full 3D shower of single particles
- for both methods cells are then calibrated using the same H1 style calibration as jets and taus (mentioned before)
- same weights as for jets (and taus)
- the energy lost in the cryostat (between EM and HAD calorimeter) is estimated for all reconstructed jets and added to ETMiss
  - cryo correction = c•sqrt(E(last EM layer) • E(first HAD layer))
- also an object based calibration is currently under investigation

ETMiss ATLAS 2

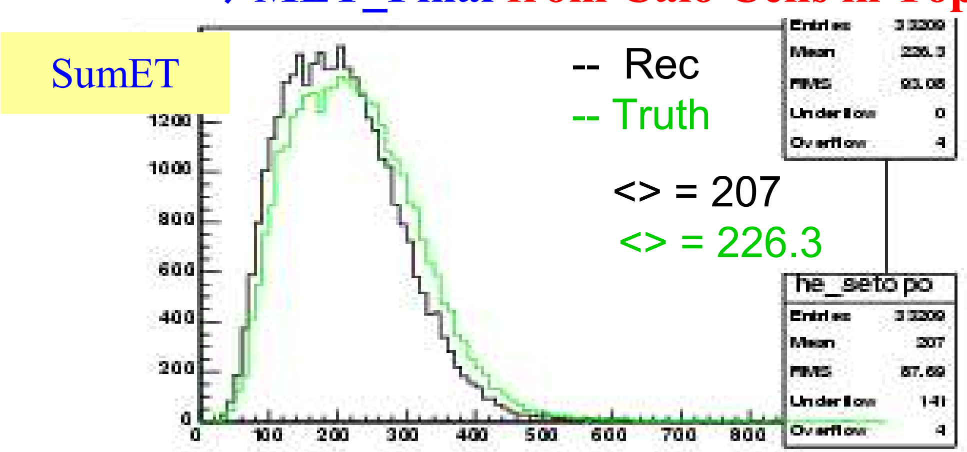
- Resolution: METTruth - METReco, SumET = scalar sum(particles/cells)
- Event sample: $Z \rightarrow \tau\tau$

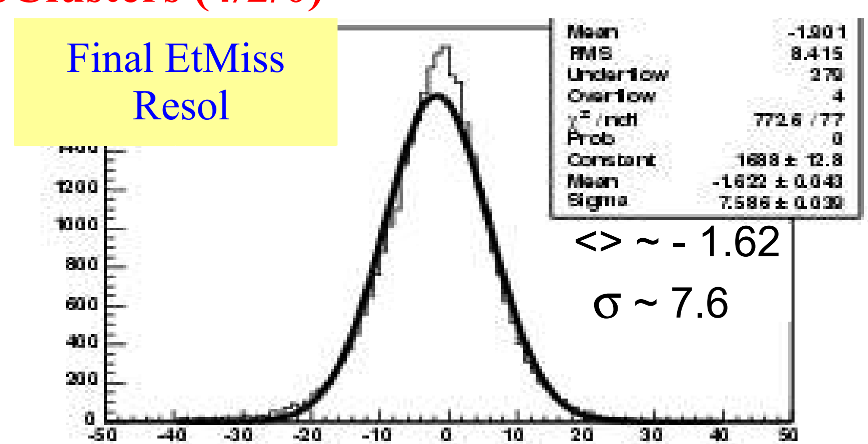
⇒ **MET_Final from All Calo Cells with $|E_{cell}| > 2\sigma$ (noise)**





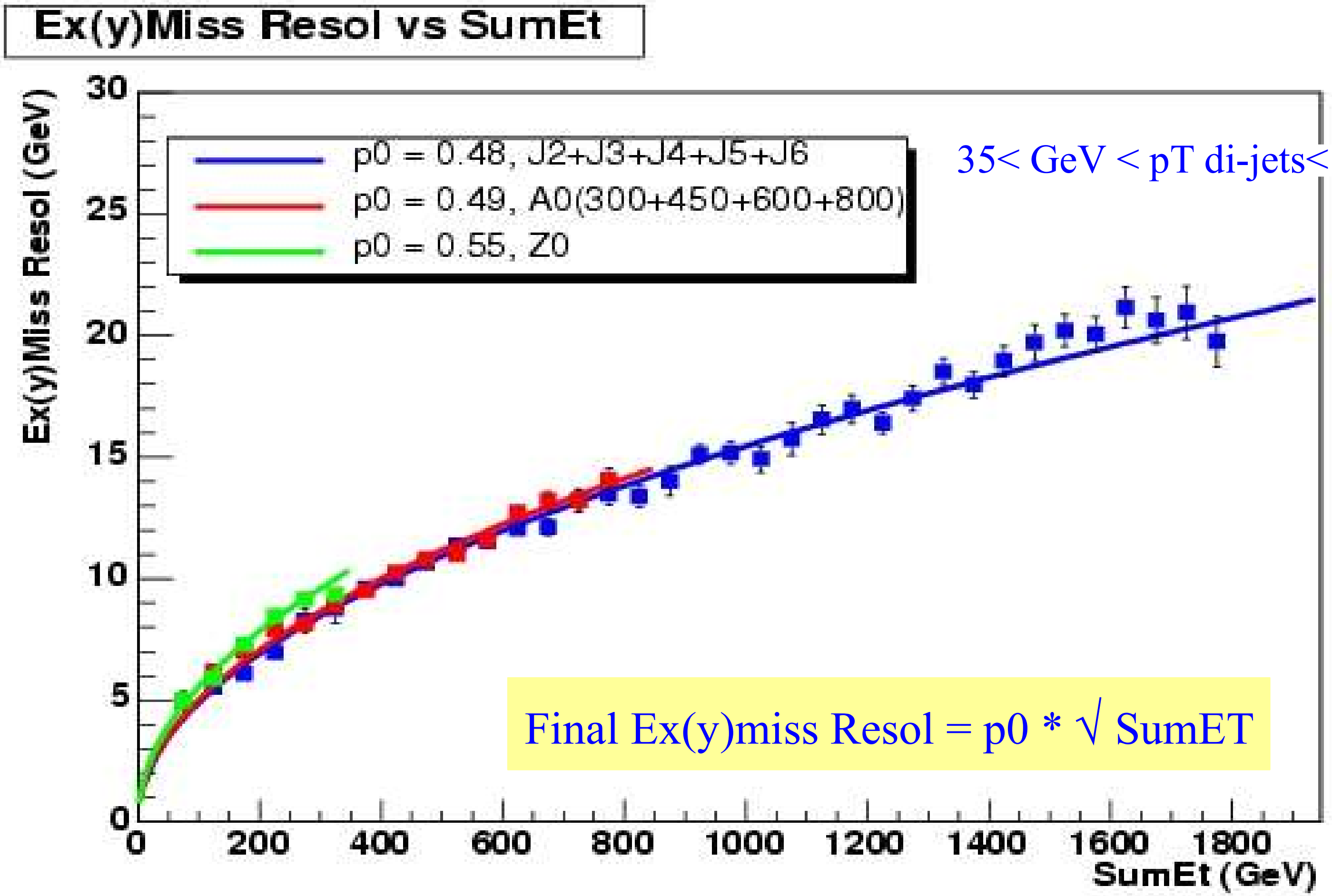
⇒ **MET_Final from Calo Cells in TopoClusters (4/2/0)**





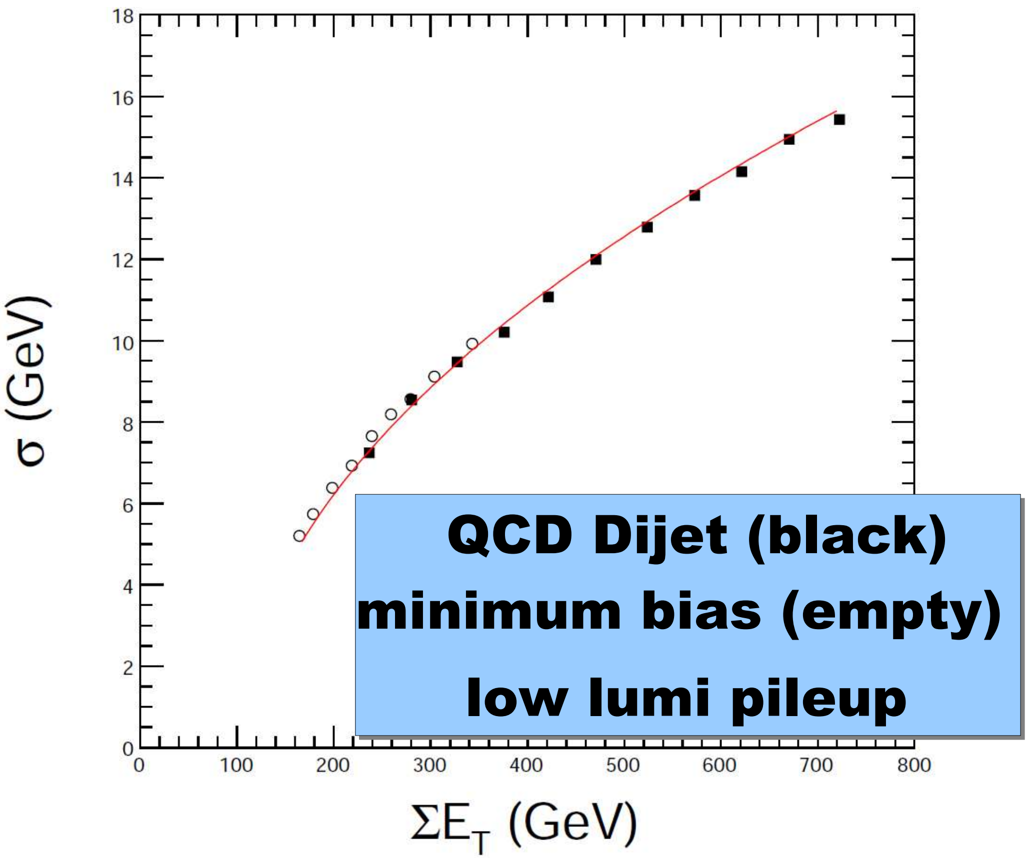
ETMiss ATLAS 3

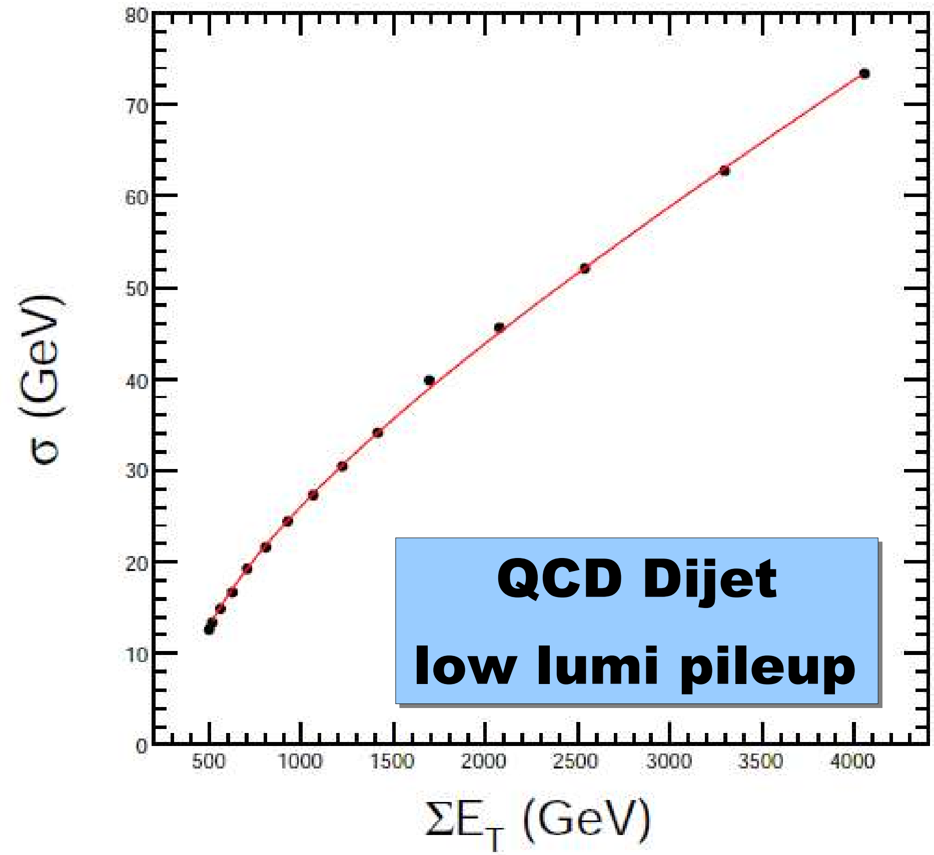
- ETMiss is calculated from the energy one sees in the calorimeter
- → the resolution depends on how much energy is in the calorimeter
- → parametrisation as : ex/ymiss resolution = p0•√(SumET)



ETMiss CMS 1

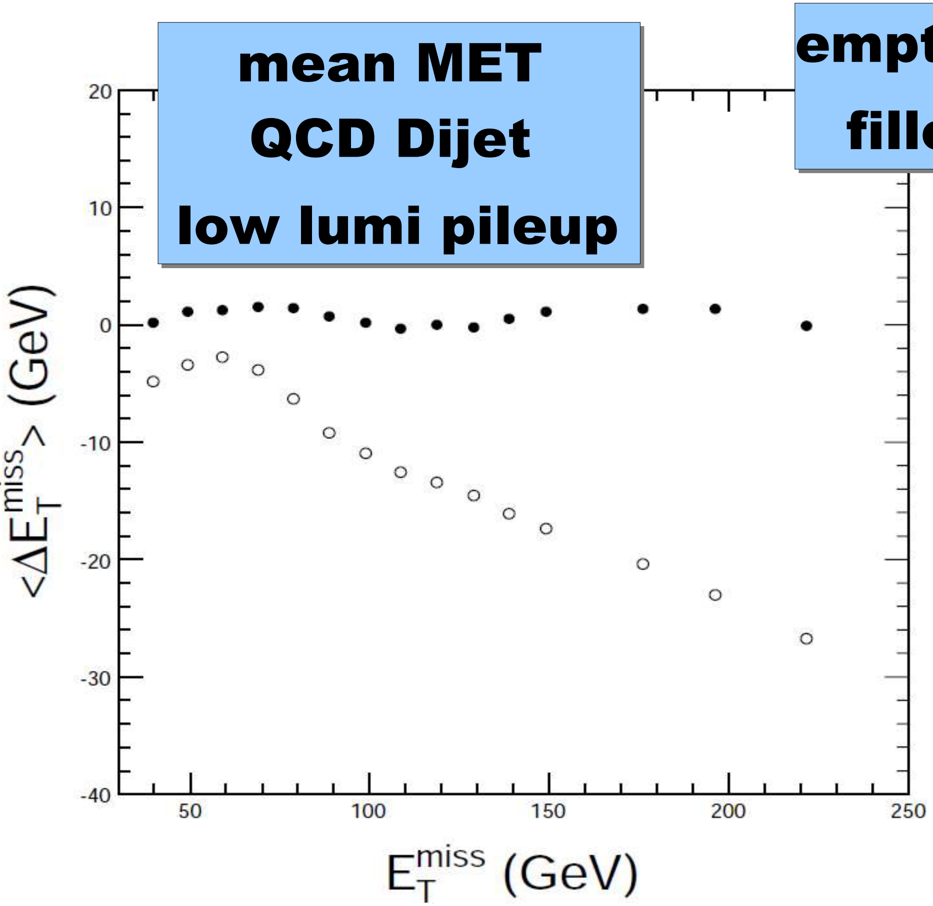
- ETMiss is calculated from the transverse energy sum of calorimeter cells
- cells with a muon track going through have the expected deposit substracted and the muon energy is added
- EM calo cells are used with a photon calibration and HAD calo cells are used with the hadron calibration

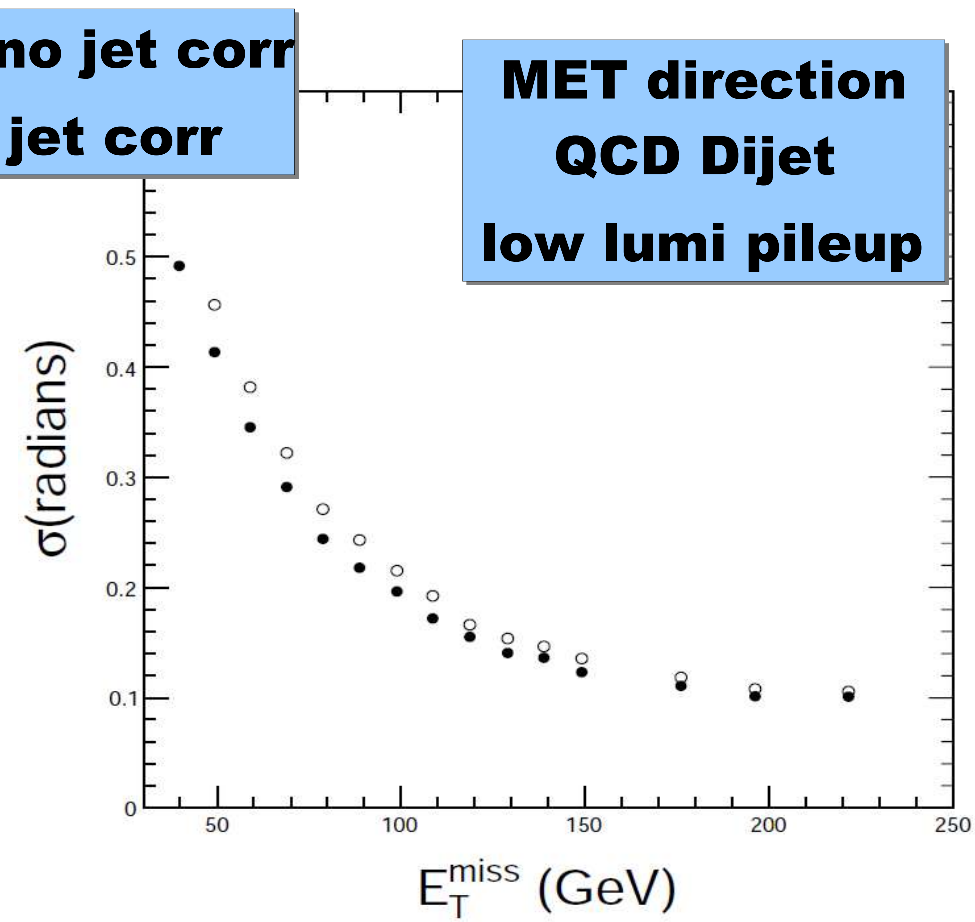




ETMiss CMS 2

- Jet corrected MET is calculated as
- $MET=\Sigma^{i}_{recojets}\ E_T(\text{jet } j) \bullet C_{jet} + \Sigma^{i}_{towers}\ E_T(\text{tower } i) \bullet C_{tower}$

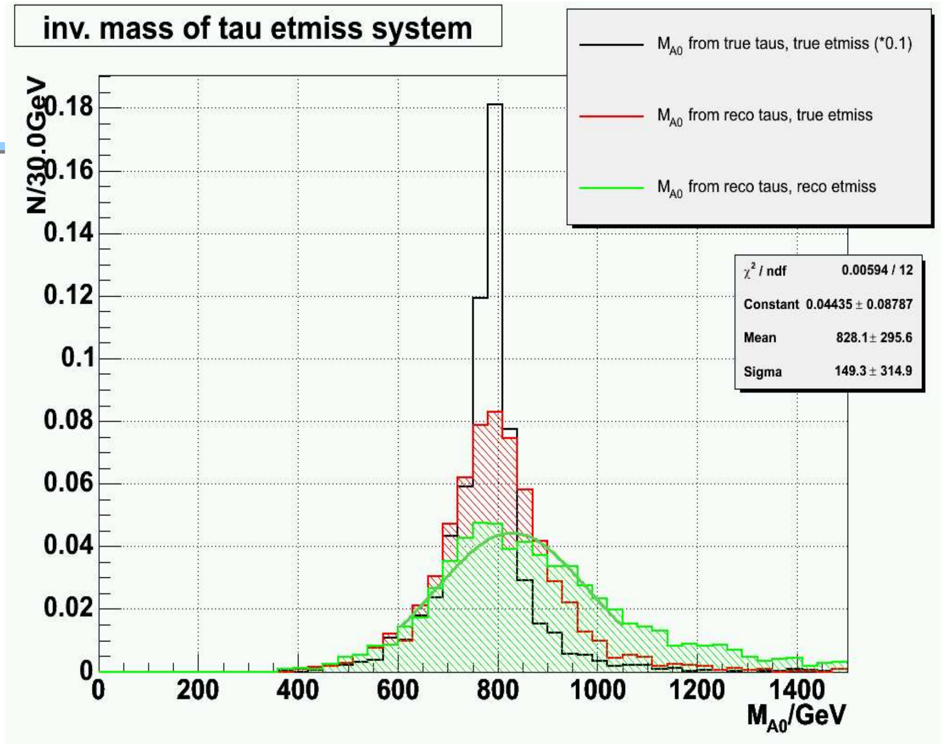


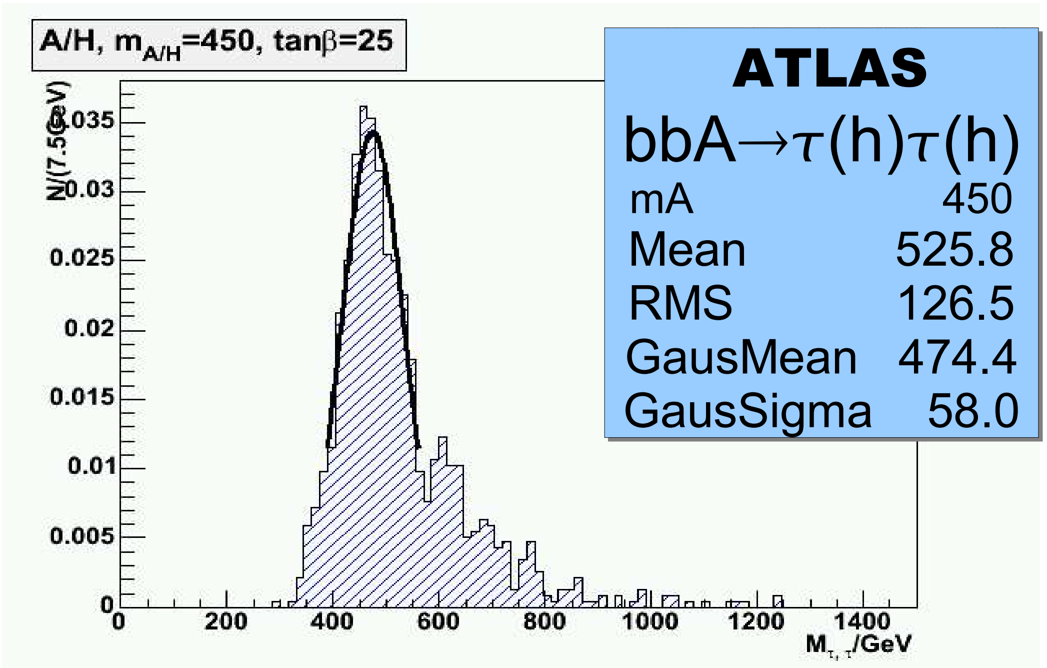


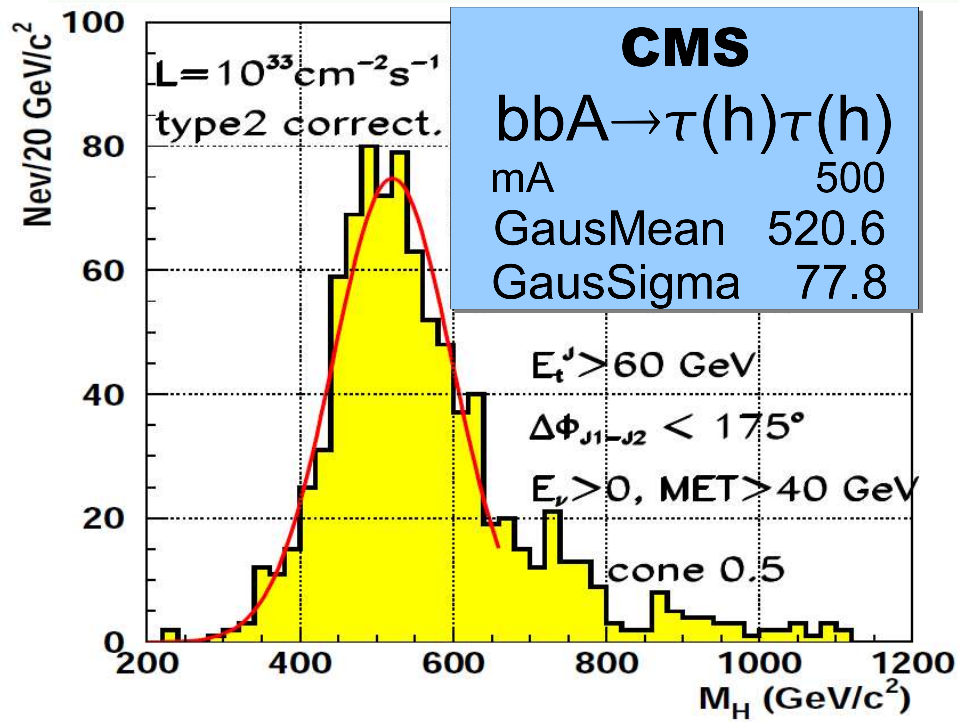
- EFlow strategies are expected to improve the MET resolution and are under investigation

ETMiss + Tau

- Many analysis use the collinear approximation (assumption: direction of tau = direction of tau jet)
- → reconstructed mass (e.g. Higgs mass) is composed of tau-jets and ETMiss
- ETMiss resolution usually dominates

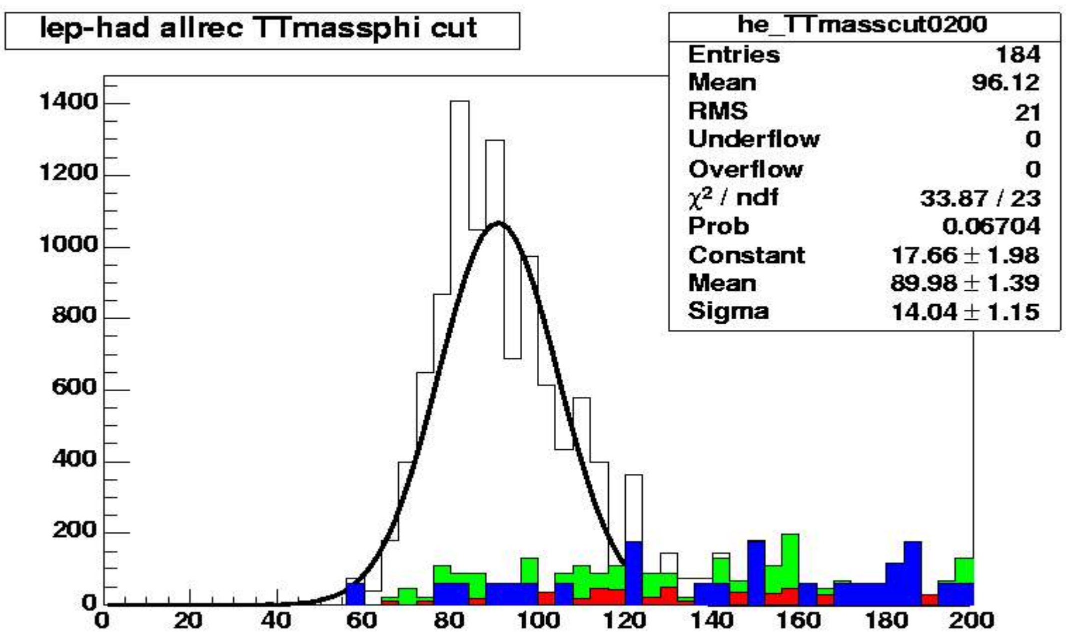


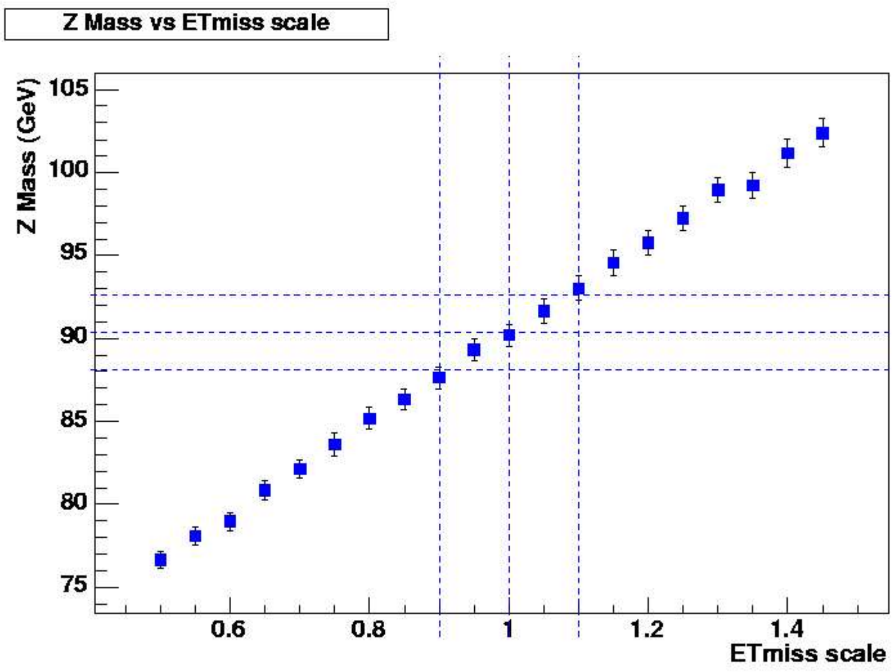




ETMiss Calibration

- $Z \rightarrow \tau(h)\tau(l)$ is one of the potential ETMiss calibration channels
- very preliminary ATLAS analysis
  - low background statistics
  - no bb background
  - cuts not tuned
- study made for $10 fb^{-1}$ → not for the first months of running
- 10% shift in the ETMiss scale gives 3% shift in the Z mass



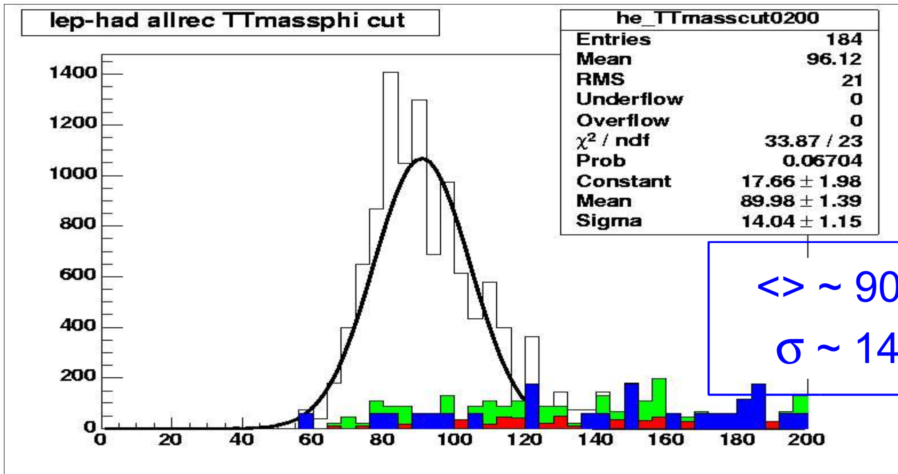


Conclusion (ETMiss)

- ETMiss can be a key incridient to many beyond the standard model searches (e.g. SUSY)
- most direct approach is to calculate tranverse vector sum of all calorimeter cells
- these can be calibrated following several strategies
- various corrections have to be applied
  - muons
  - jet corrections
  - cryostat corrections
  - electronic noise and pile-up has to be treated
- EFlow technics can be useful and are under investigation
- both experiments show comparable ETMiss resolutions
- both experiments show comparable inv. mass (with ETMiss) resolutions

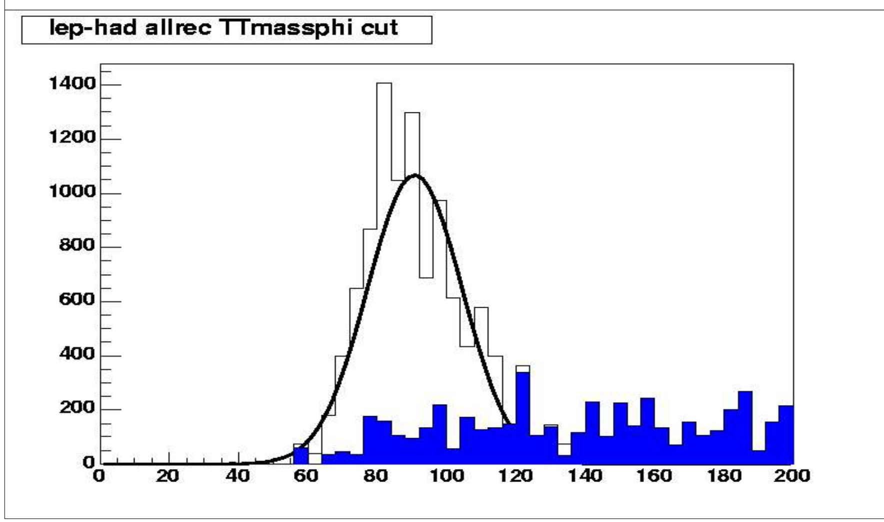
BACKUP SLIDES

Z°→ττ→ lept-had channel : ττ mass for Signal and Backgrounds with 10fb-1



<> ~ 90

σ ~ 14



Results still preliminar due to low bacgd statistics

Need to have also a bb sample!

Better cuts tuning No pileup yet!

Applied cuts :

pt(jet) > 25 GeV, |η|<2.5

pt(lep) > 25/20 GeV, |η|<2.5

isEM & 0x7FF) ==0 ,

lep isolation: Etcone30<5geV

1.<Δϕ < 2.7 or 3.6<Δϕ <5.3

m_T(lept-pTmiss)<50GeV

τ-likelihood > 8 (τ-eff ~ 30%)

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

Expected in 10fb-1

~ 9000 evts with ~ 20% backgd

Lowering pt thresholds:

pt(jet) > 20 GeV, |η|<2.5

pt(lep) > 15 GeV, |η|<2.5

~ 25000 evts with 30% backg

But more severe cuts necessary to reduce bb backgd?

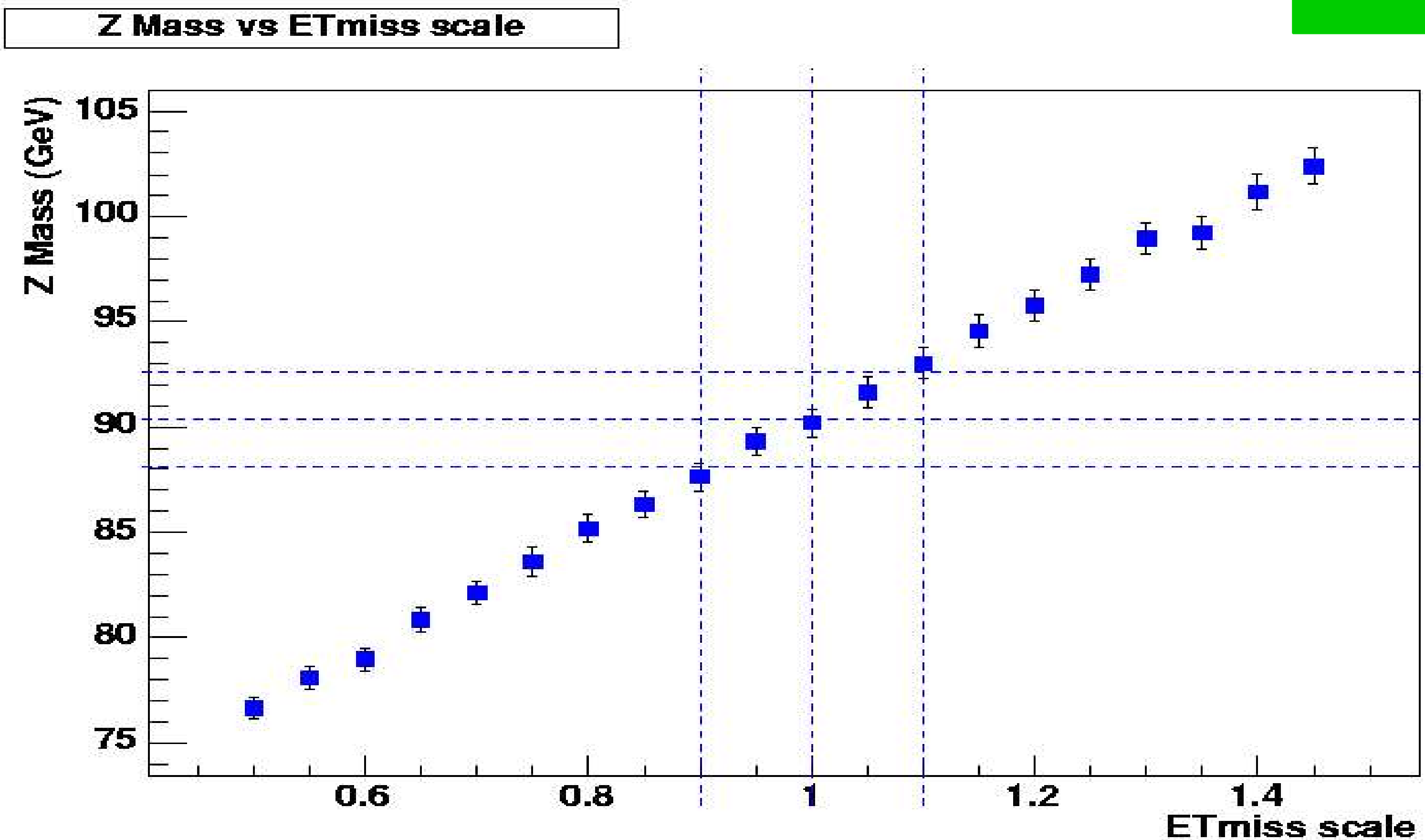
pTmiss>20 GeV

m_T(lept-pTmiss)<25GeV

$Z° \rightarrow \tau\tau \rightarrow$ lept-had channel : EtMiss Scale

sensitivity of the measured Z° mass to the absolute EtMiss scale

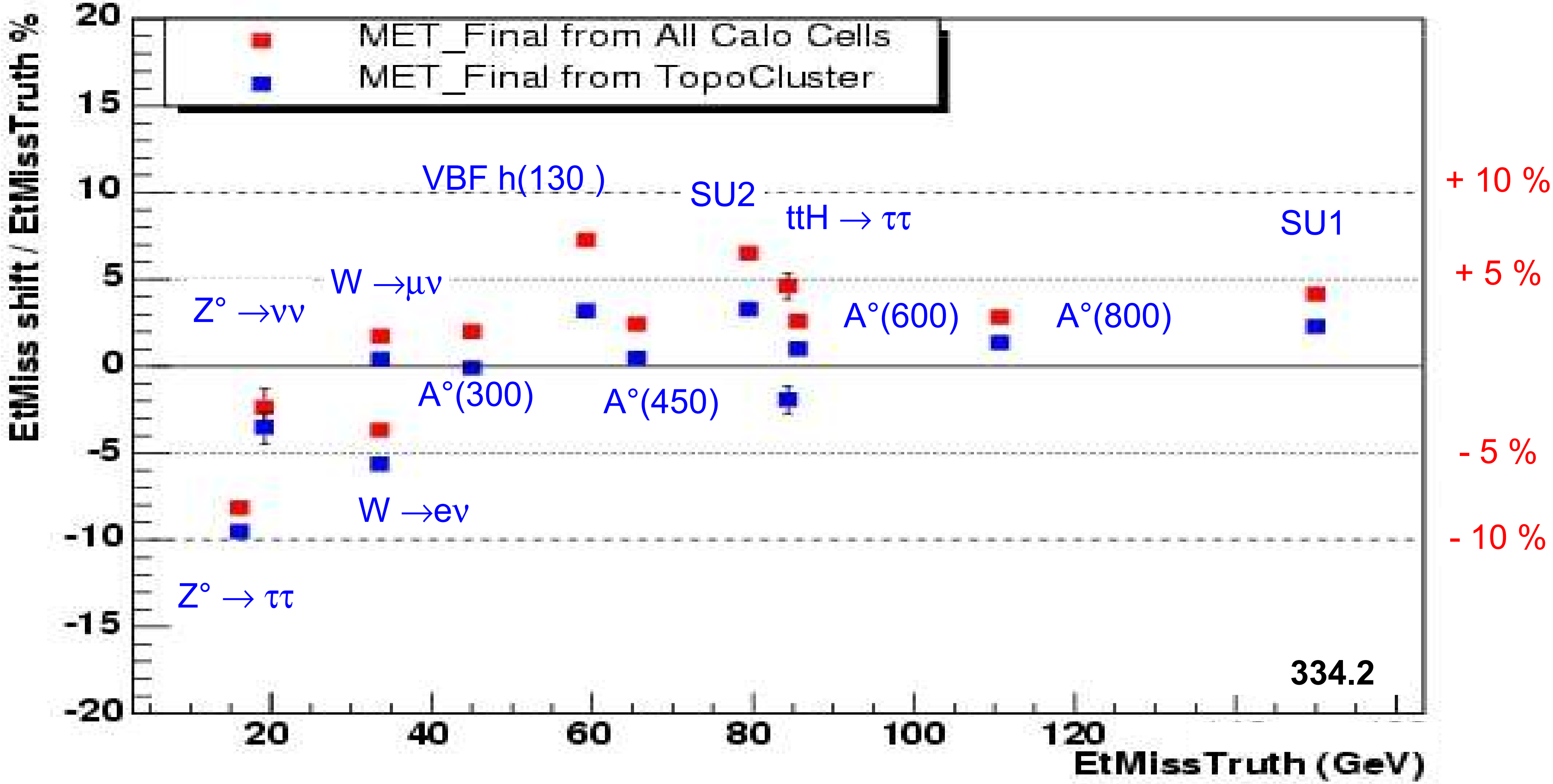
preliminar



plotted errors correspond to ~ 1000 evts

A variation of +/- 10 % of the EtMiss scale results in a shift of about 3% of the measured Z° mass

EtMiss Performance in 10.0.1 Rome data : Linearity
EtMiss shift / EtMiss Truth % vs EtMiss Truth



EtMiss shift = < **MET_Truth(NonInt) – MET_Final >**

Linearity from TopoCluster within 5 %, except for low energy region