Physics object reconstruction in ATLAS: tau, b-jets, Etmiss, etc.

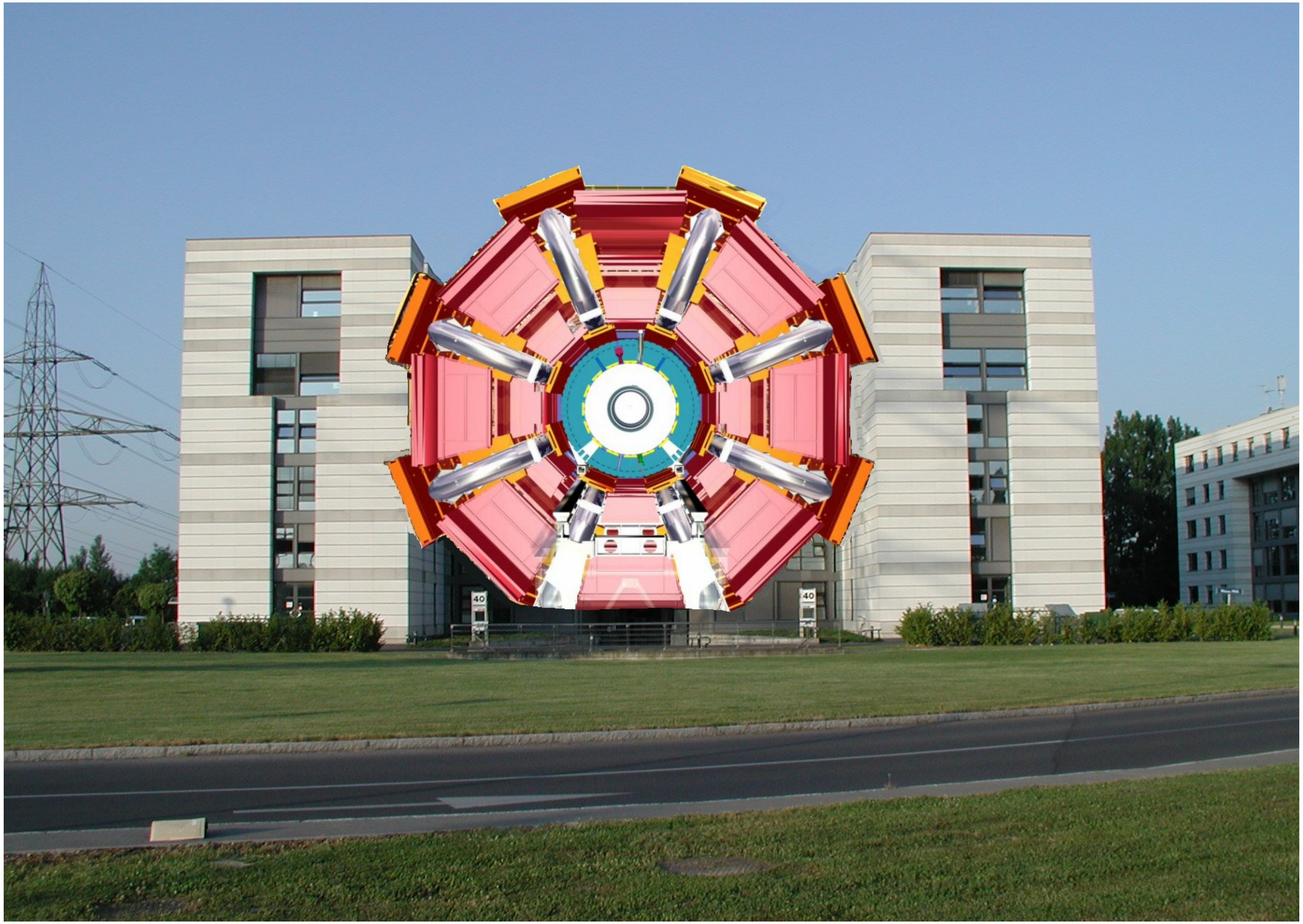
S. Xella (Niels Bohr Institute)

On behalf of the ATLAS collaboration

Outline

- ATLAS detector
- Reconstruction and performance of
  - Tau
  - Jet
  - B-jet
  - Electron/Muon
  - EtMiss
- Summary

ATLAS Detector

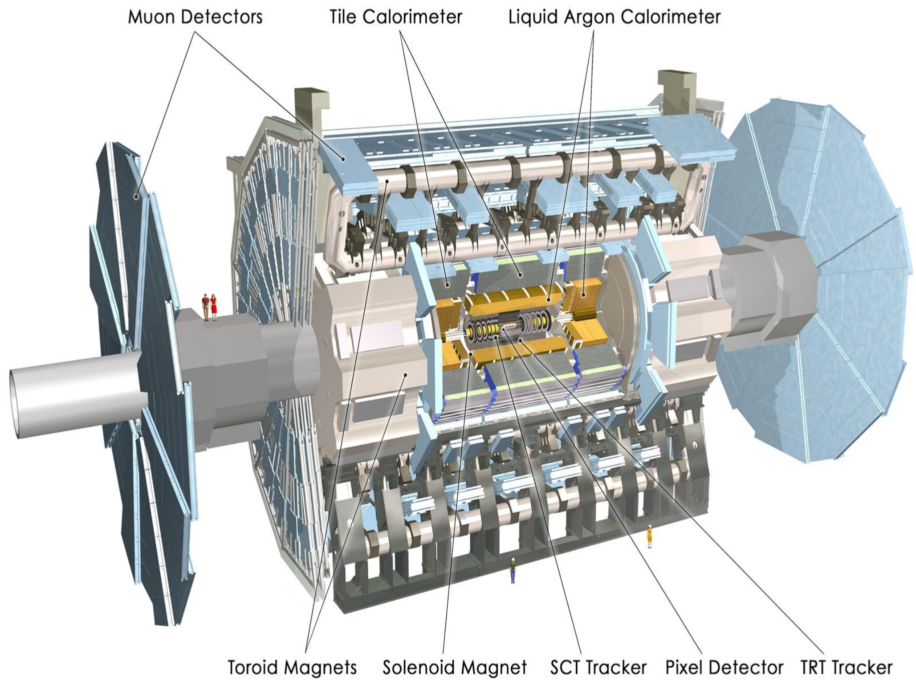


ATLAS Detector

44 m

7000 Tons

25 m

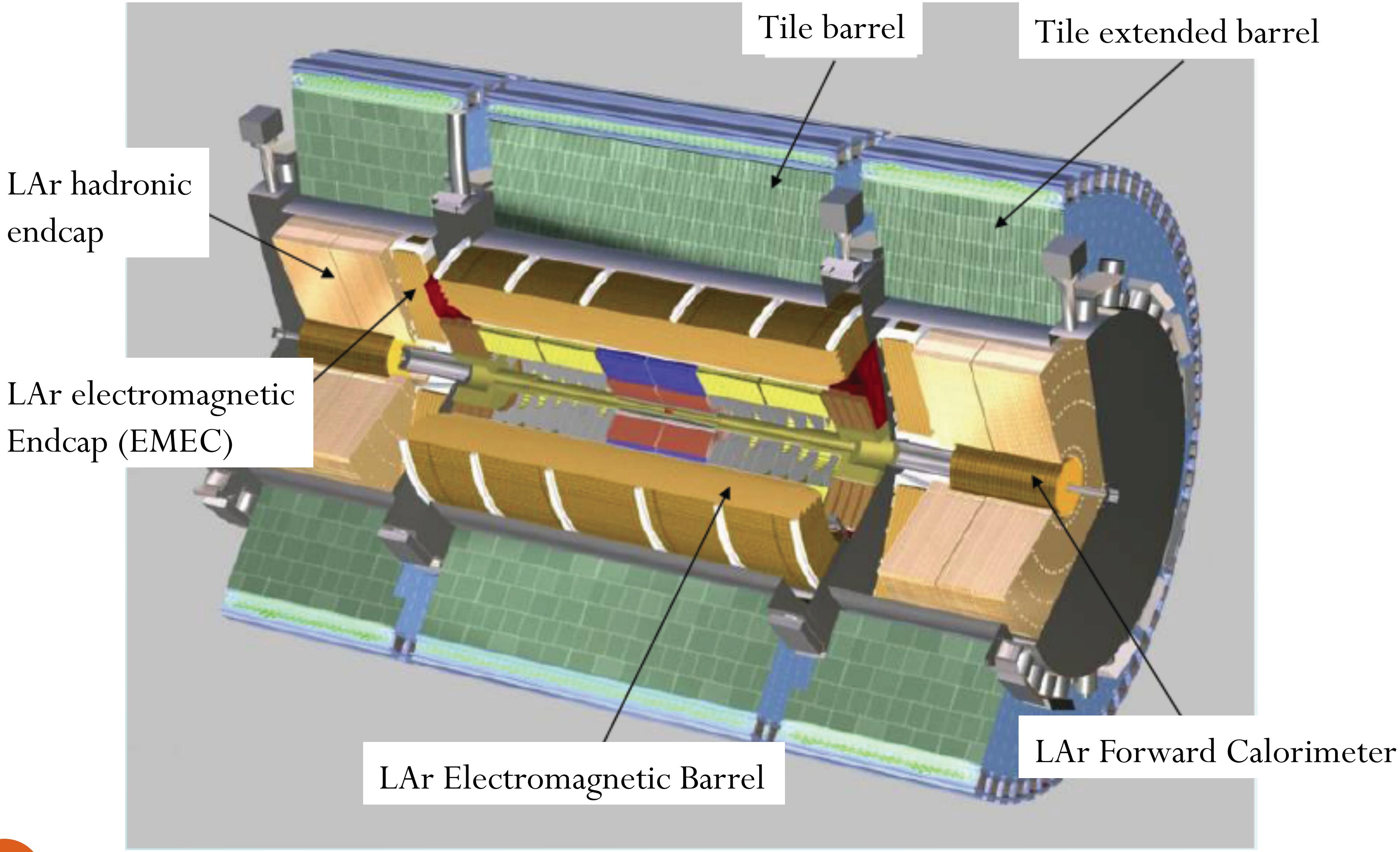


- A general purpose detector
- Inner detector (ID)
  - Pixel
  - Silicon microstrip tracker (SCT)
  - Transition radiation tracker (TRT)
- Solenoid
  - 2T magnetic field
- Calorimeter
  - Electromagnetic (EM)-Liquid Argon (LAr)
  - Hadronic (HAD)- LAr and scintillating tiles
- Muon Spectrometer (MS)
- Three large superconducting toroids
  - One barrel and two EC

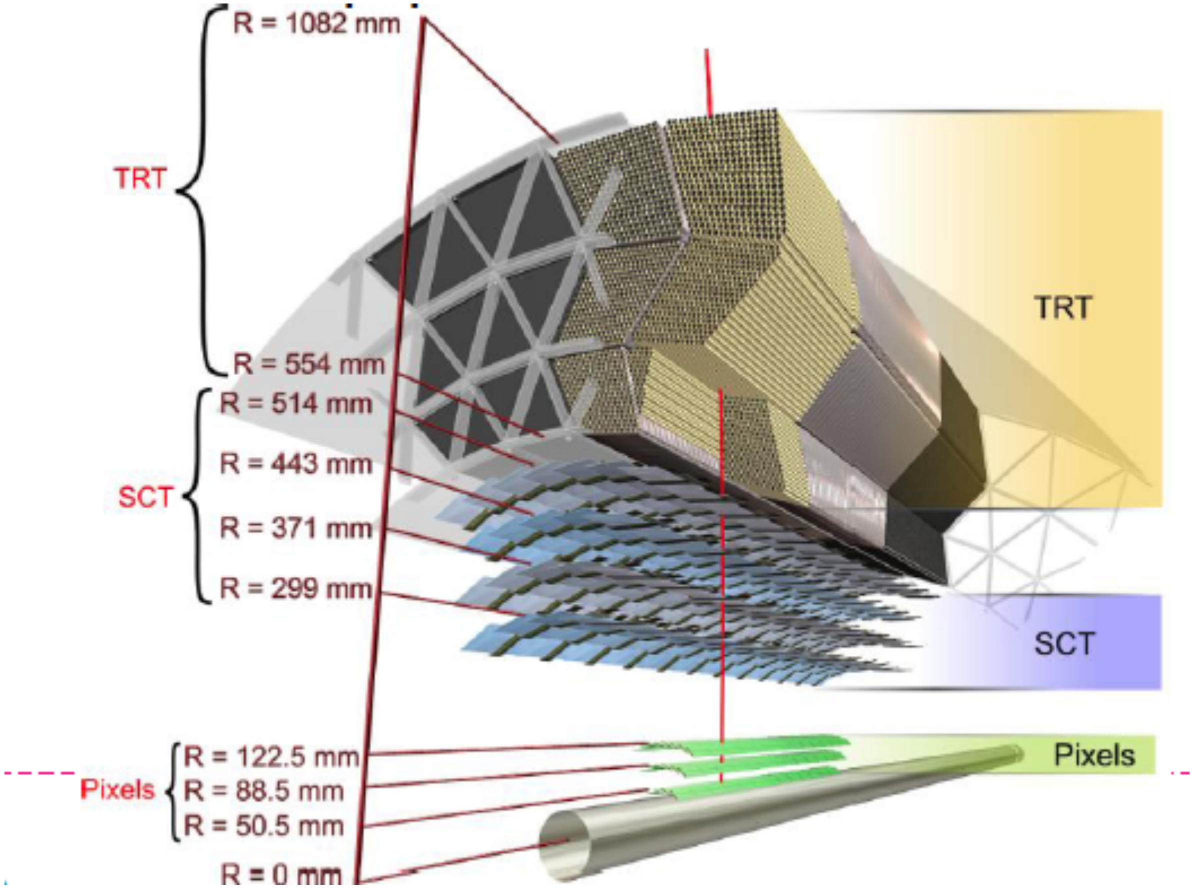
$\eta \equiv -\ln\tan(\theta/2)$; polar angle θ is the angle from the beam axis

Detector component	$\lvert\eta\rvert$ coverage measurement	$\lvert\eta\rvert$ coverage trigger
tracking	2.5	2.5
EM calorimeter	3.2	2.5
Hadron calorimeter: Barrel and endcap forward	 3.2 $3.1<\lvert\eta\rvert<4.9$	 3.2 $3.1<\lvert\eta\rvert<4.9$
muon	2.7	2.4

Calorimeter



Inner detector

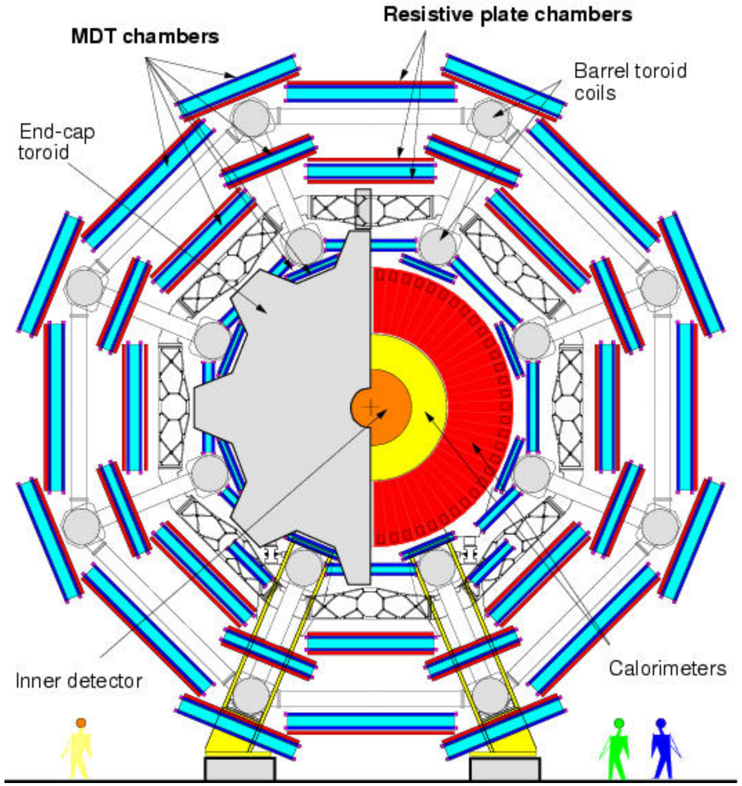


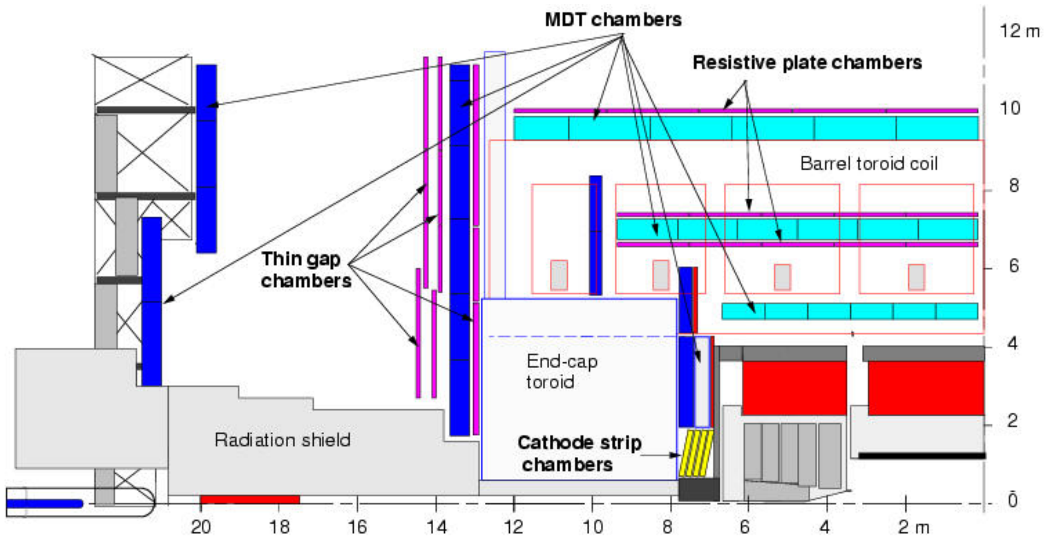
Transition Radiation Tracker: straw tubes

SemiConductor Tracker: silicon micro-strip detector

Pixel detector

Muon spectrometer





Three toroidal magnets create a magnetic field with:

Barrel: $\int Bdl = 2 - 6\,Tm$

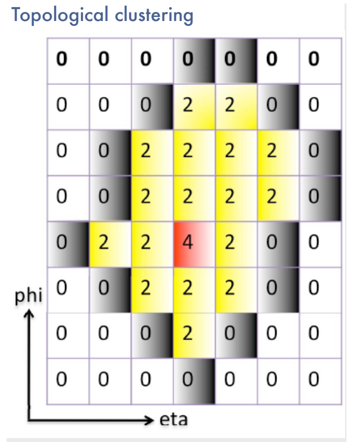
Endcaps: $\int Bdl = 4 - 8\,Tm$

RPC and TGC: Trigger purpose.
Measurement xy, Rz accuracy ~mm.

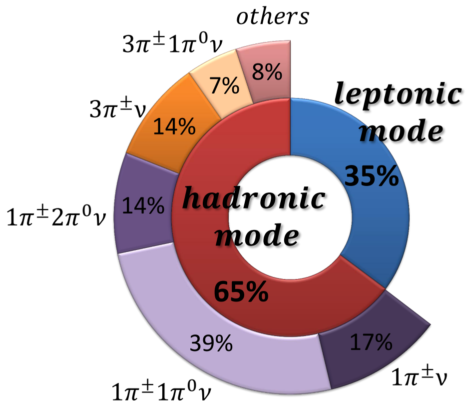
CSC: Measurement xy, Rz accuracy ~mm, ~80 μm.
Cover $2<|\eta|<2.7$

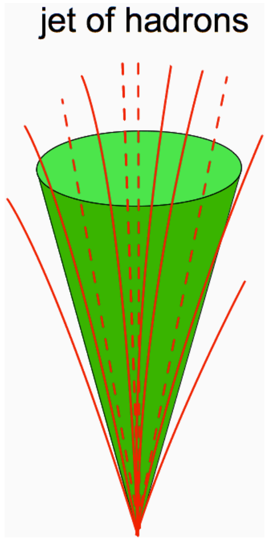
MDT: Measurement accuracy Rz ~80 μm . Cover $|\eta|<2$

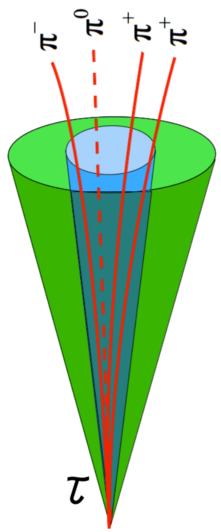
Tau hadronic decay reconstruction



- Hadronic decays of tau: 65%
- Reconstruction seeded by anti-kt jets(R=0.4)
  - $p_T > 10$ GeV, $|\eta| < 2.5$
  - calibrated 3D topological clusters
  - good quality tracks with $p_T > 1$ GeV
  - discriminating variables
    - combined information from calorimeter and tracking
    - input to multi-variate algorithms







core cone
$\Delta R < 0.2$

isolation cone
$0.2 < \Delta R < 0.4$

Tau identification

Decay properties of tau	Detector information used
Collimated decay products	Jet width in tracker and calorimeter
Leading charged hadron	Leading track
No gluon radiation	Isolation
Low invariant mass	Invariant mass of tracks and clusters
Lifetime	Impact parameter, secondary vertex
EM energy fraction different from electrons	Longitudinal position of energy deposits
EM component from π^0	LAr strip
Less transition radiation than electrons	TRT

Discrimination against Jets

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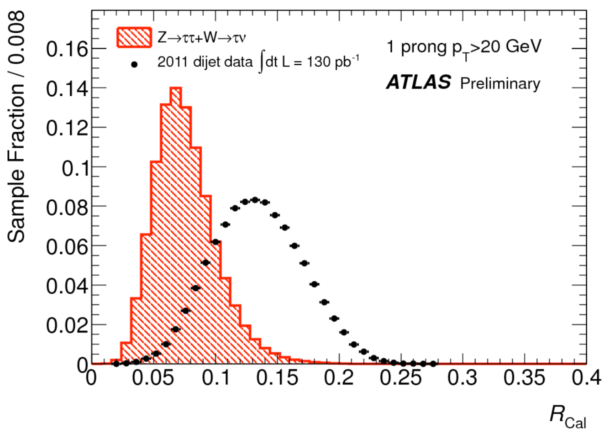
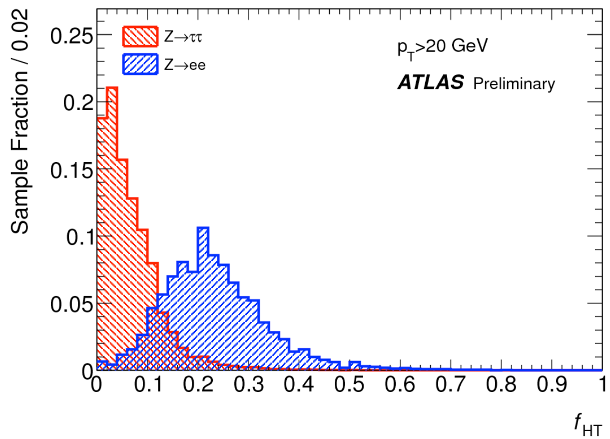
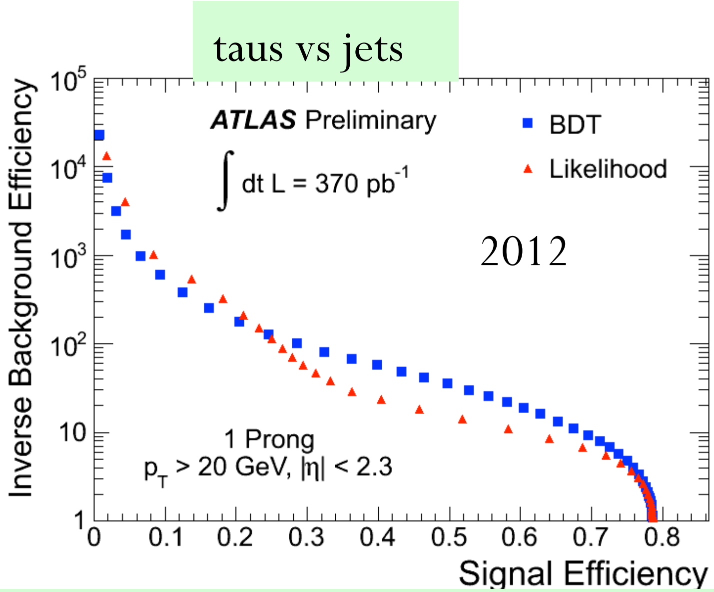
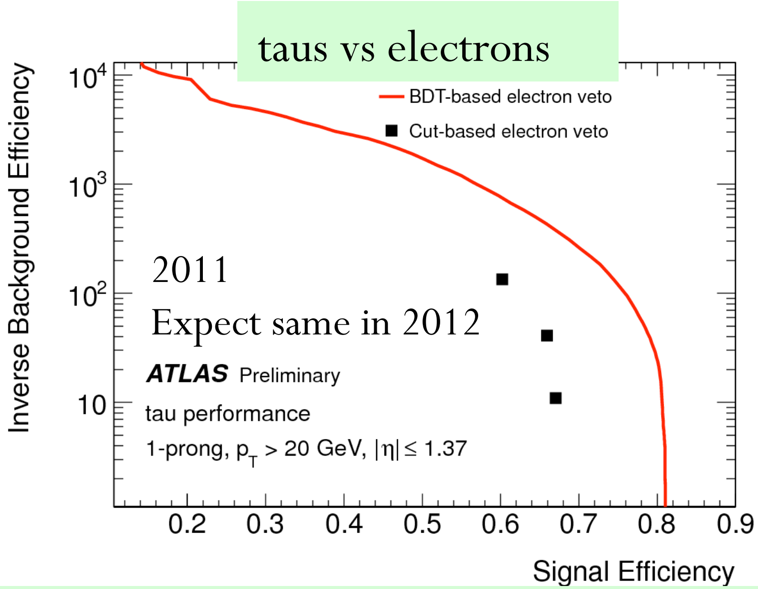


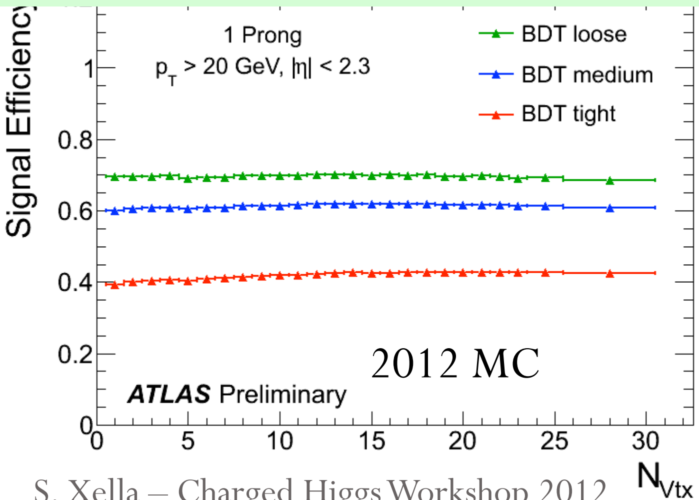


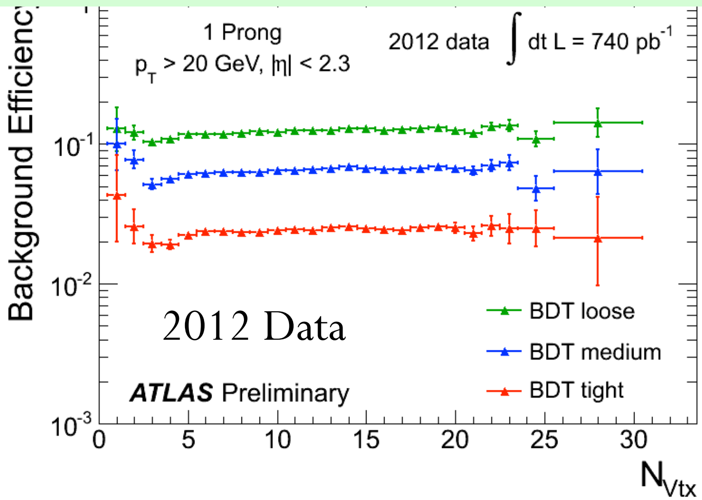
Performance of tau identification





Same procedure applied to identify three prong taus using additional information on lifetime



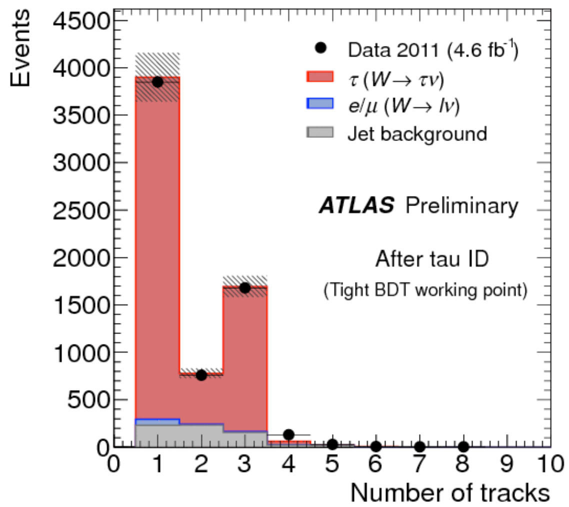


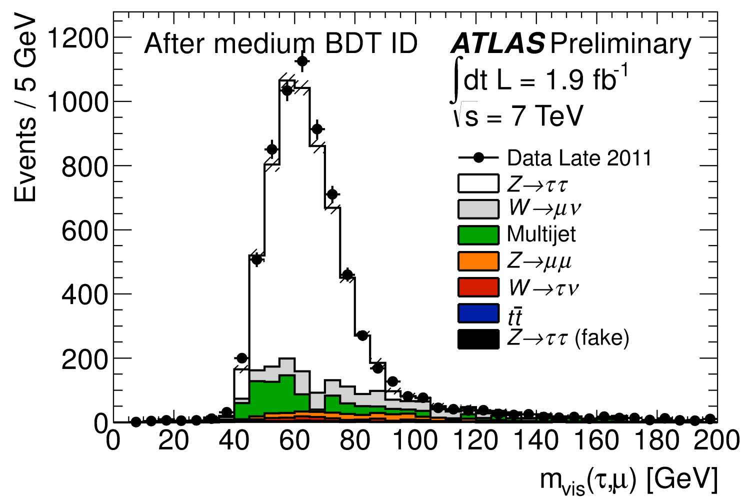
Tau identification efficiency measurement

- Efficiency measured in data using
  - Z -> $\tau_\mu \tau_h$ and W-> $\tau \nu$ events with tag and probe selection
    - require events to pass muon/MET trigger to tag a tau
    - probe hadronically decaying tau
  - Data/MC scale factors (SF) consistent with 1

% uncertainty on data/MC SF

Tau ID	$p_T > 22$ GeV Inclusive	1-prong	3-prong
LLH Loose	5	4	10
LLH Medium	4	5	10
LLH Tight	5	5	11
BDT Loose	4	4	8
BDT Medium	4	5	8
BDT Tight	4	4	7





Tau energy scale

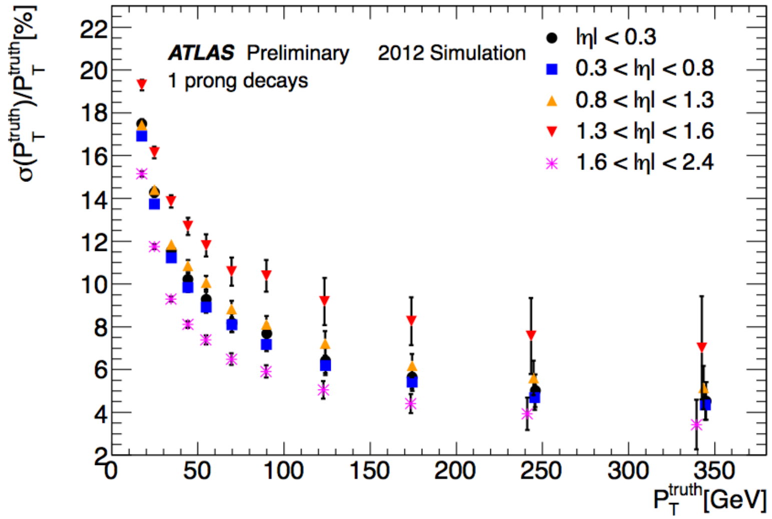
Determined from MC :

Topological clusters calibrated using local hadron calibration (LC) LC accounts for

- Non-compensation of calorimeters
- Energy deposited outside the reconstructed cluster
- Dead material

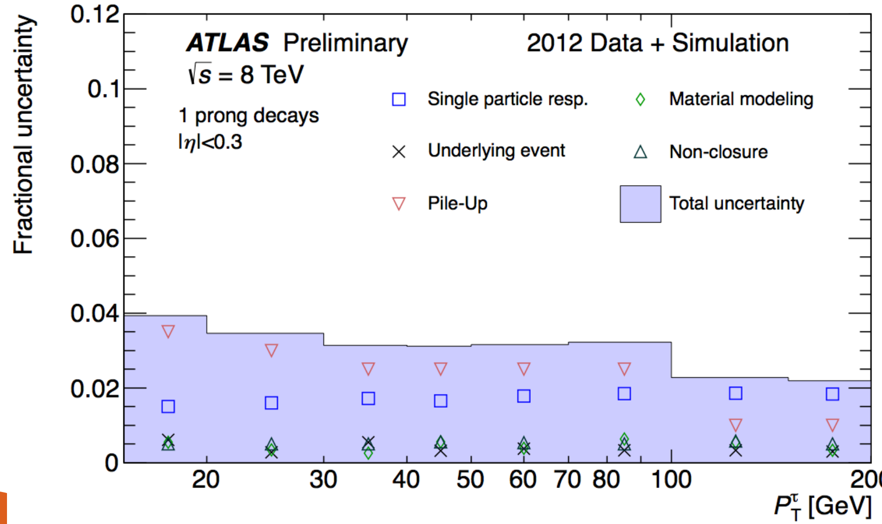
LC weights derived from MC

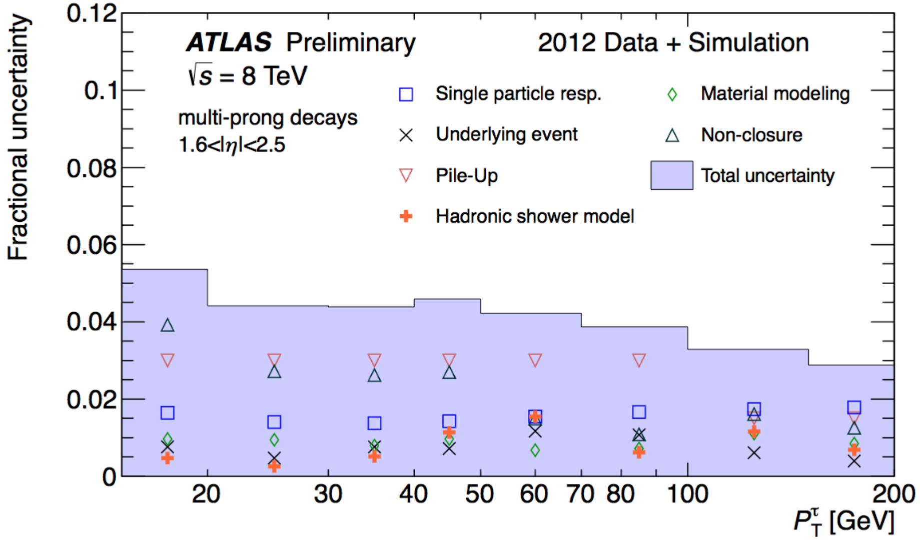
Additional corrections applied to restore true energy value (TES)



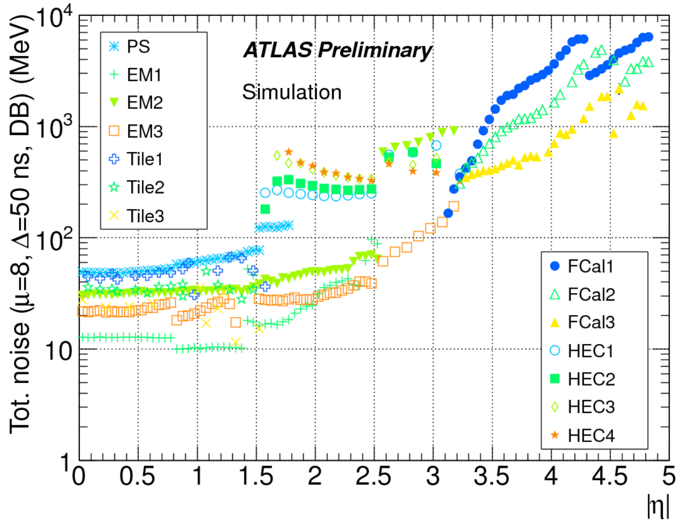
$$P^{\tau}_{pileup\,corr} = P^{\tau}_{LC} - P_{pileup}$$

$$P^{\tau} = \frac{1}{R(P^{\tau}_{LC}, \eta, n_p)} P^{\tau}_{pileup\,corr}$$





Jet Reconstruction

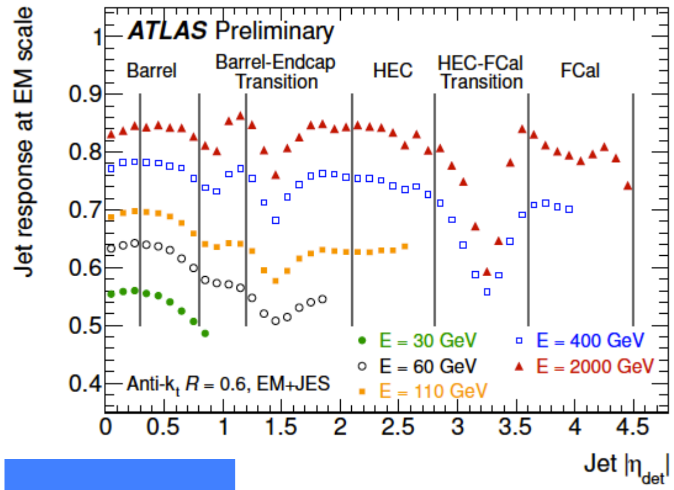


Inputs to jet reconstruction:
3-dimensional calorimeter topological clusters:

- Follow shower development
- Pile-up + electronic noise suppression
- Local hadron calibration (EM/HAD weights) derived from single pion simulations

Tracks

- Independent from calorimeter
- Additional z-vertex information



Jet algorithms: anti-kt R=0.4, 0.6, 1.0, C/A R=1.2

- **Factorized jet energy calibration**
  - Pile-up, non-compensation, inactive material, shower leakage
  - Residual insitu calibration

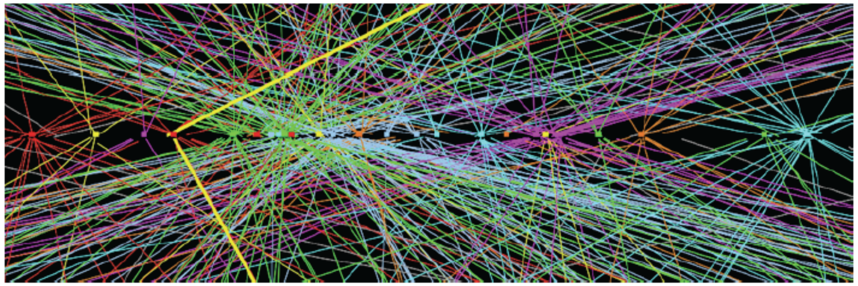
Pileup subtraction → MonteCarlo JES calibration → Jet-by-jet post-calibration corrections → In-situ residual calibration

Jet pileup offset correction

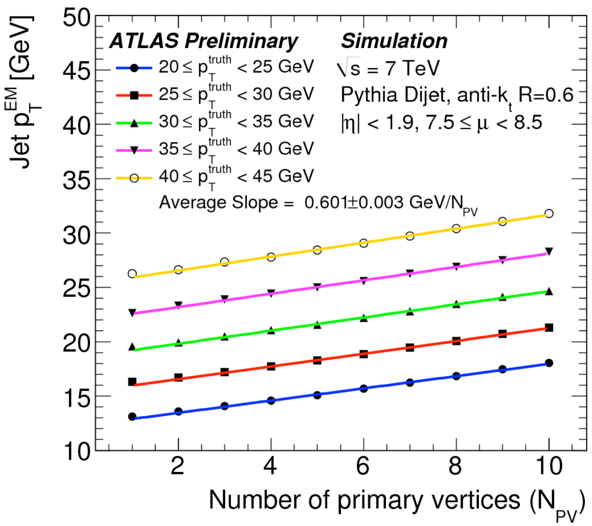
Offset correction to account for
in-time (N_{PV}) and out-of-time (μ) pile-up

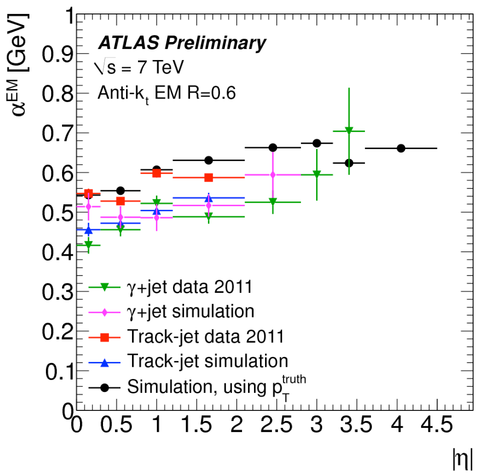
- Determined from Monte Carlo
- Uncertainty from data/MC differences in dijet and γ +jet insitu offset measurements.

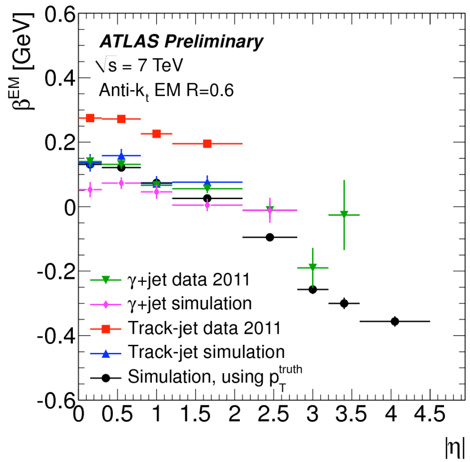
Total pile-up uncertainty <1%/vertex



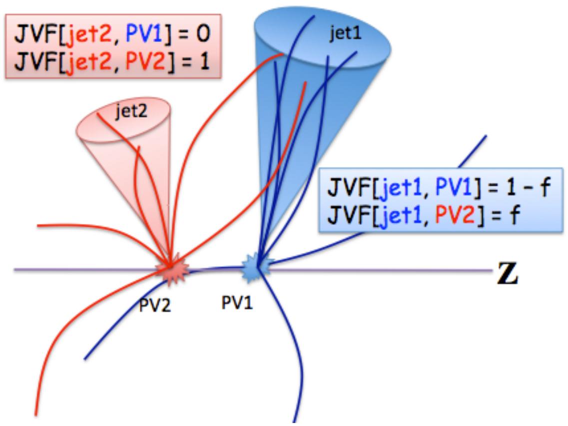
$$\mathcal{O}(N_{\rm PV},\mu,\eta_{\rm det}) = \frac{\partial p_{\rm T}}{\partial N_{\rm PV}}(\eta_{\rm det})\left(N_{\rm PV}-N_{\rm PV}^{\rm ref}\right)+\frac{\partial p_{\rm T}}{\partial \mu}(\eta_{\rm det})\left(\mu-\mu^{\rm ref}\right)$$





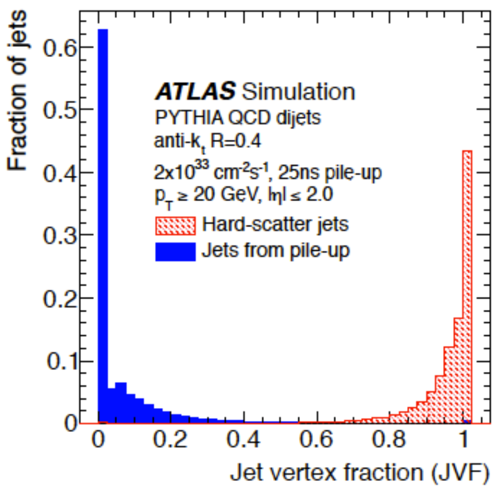


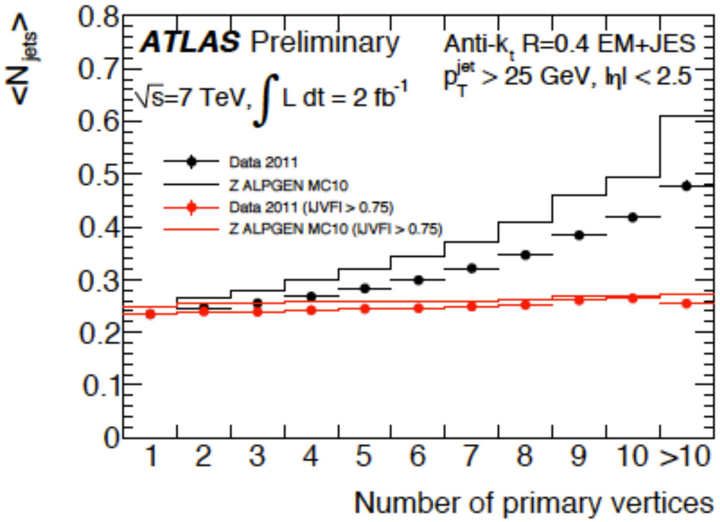
Pileup jets suppression



$$JVF(\text{jet}_i, \text{vtx}_j) = \frac{\sum_k p_T(\text{trk}_k^{\text{jet}_i}, \text{vtx}_j)}{\sum_n \sum_l p_T(\text{trk}_l^{\text{jet}_i}, \text{vtx}_n)},$$

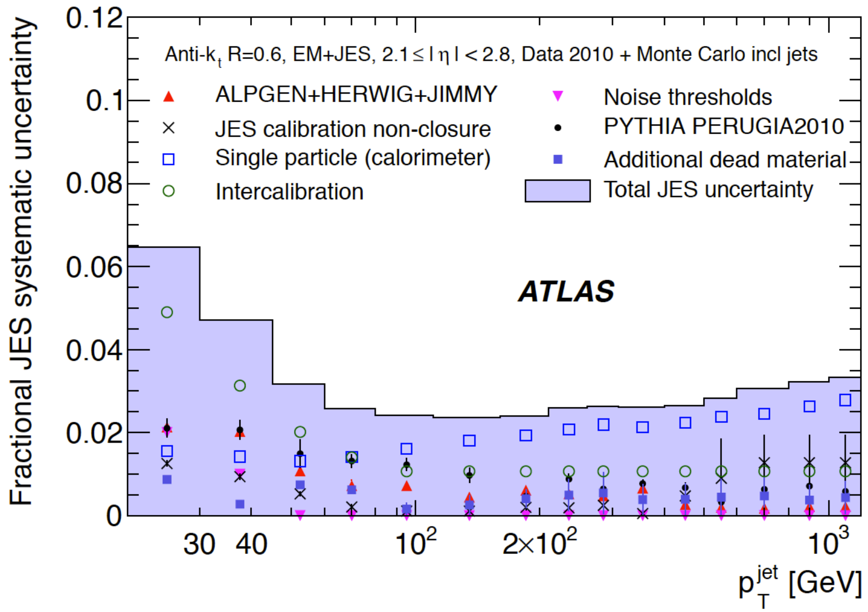
Reject fake jets from pile-up fluctuations by selecting jets with JVF (jet_i, primary vertex) > cut.
Primary vertex selected as one with highest ΣpT.
Similar technique used to suppress pile-up on missing ET.





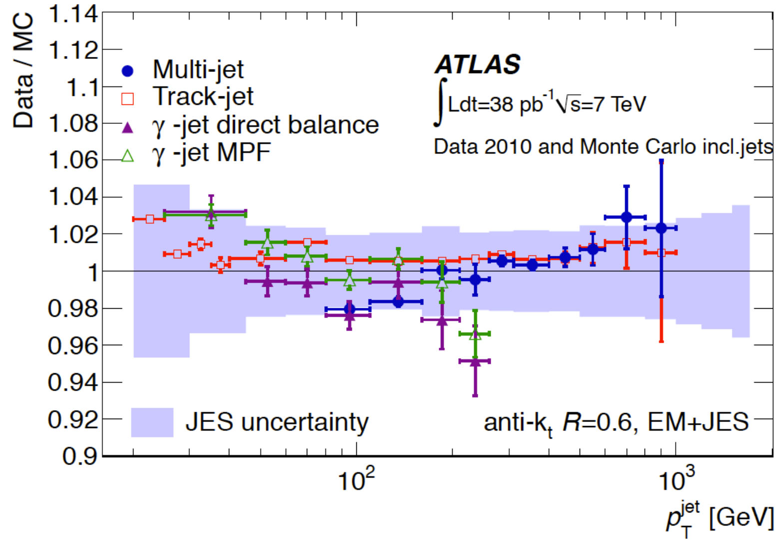
Jet energy scale uncertainty

- Single particle response (test beam / insitu)
- Monte Carlo samples with different physics modeling and detector configurations
- Relative pT balance in dijet events



< 2.5% for central jets, pT>100 GeV

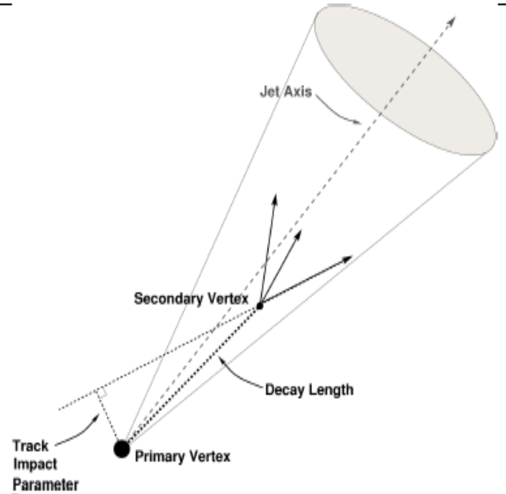
< 7 (14)% for endcap (forward) jets

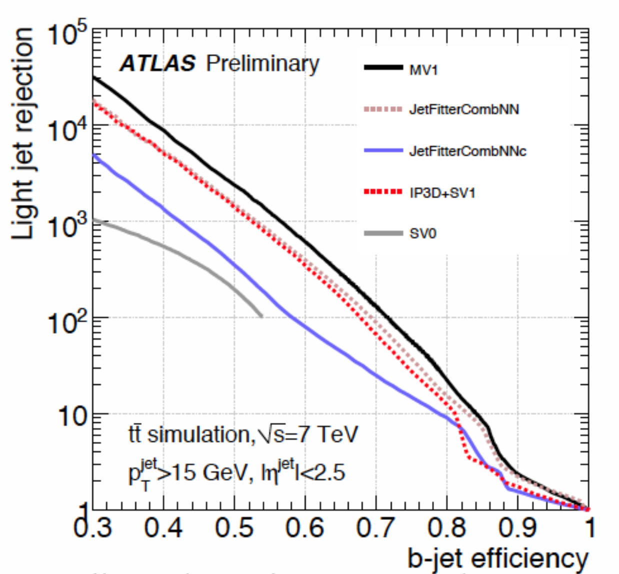


Insitu tests of the jet energy scale:

- γ +jets (MPF and direct balance)
- track/calorimeter jet ratio
- Multi-jet balance

B-jet tagging





Algorithms to identify heavy flavour content in reconstructed jets using properties of high mass and long lifetime of b quark wrt lighter quarks:

Impact parameter of tracks in jet:
IP3D uses track weights based on longitudinal and transverse IP significance

Displaced secondary vertex:
SV1 reconstructs inclusive displaced vertex
JetFitter reconstructs multiple vertices along implied b-hadron line of flight

- Cascade decay topologies

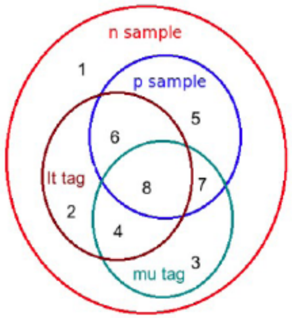
Advanced NN based algorithms
JetFitterCombNN: IP3D+JetFitter
MV1: IP3D+JetFitter+SV1

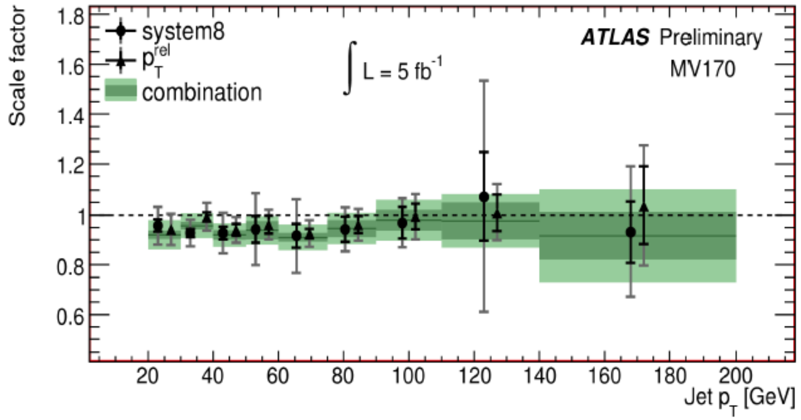
B-jet efficiency measurement

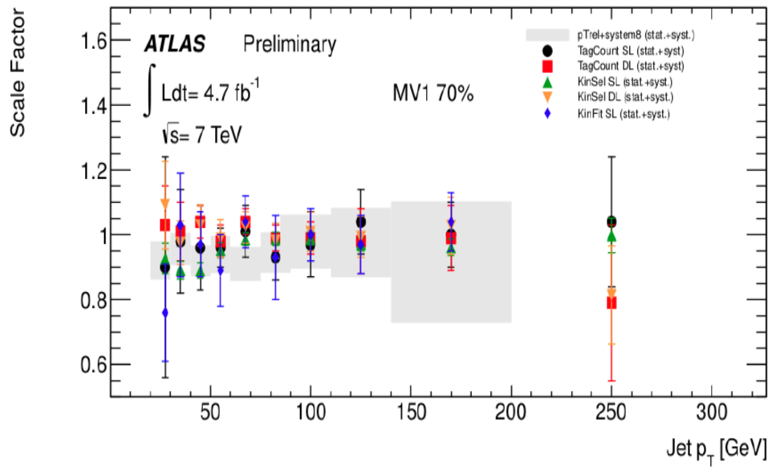
b-jet tag efficiencies measured in data from jets containing muons. Two complementary methods:

pTrel: Likelihood fits of muon pT relative to jet axis pre & post tag

System8:







Results combined for increased precision, excellent agreement!

In addition 3 methods in ttbar events using t->Wb control sample, Single and Di Lepton channels. Methods agree very well & compatible.

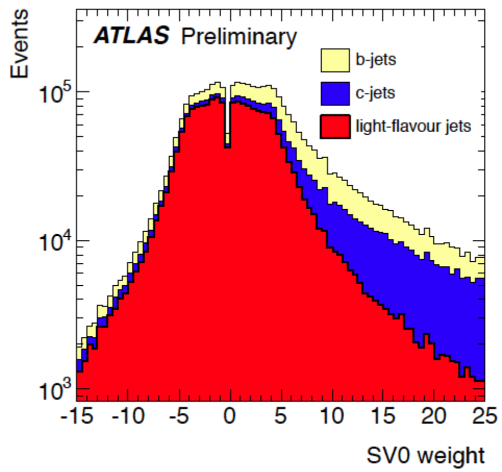
B mistagging efficiency

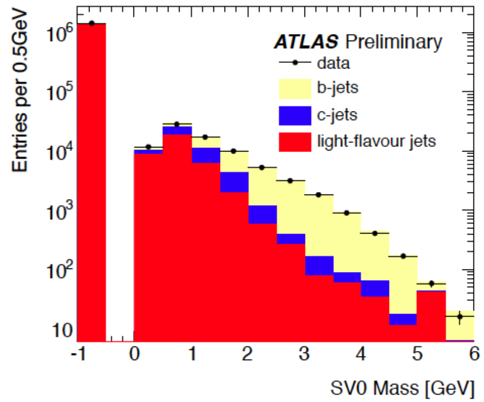
Rate of non-heavy flavour jets passing tag criteria measured in dijet data

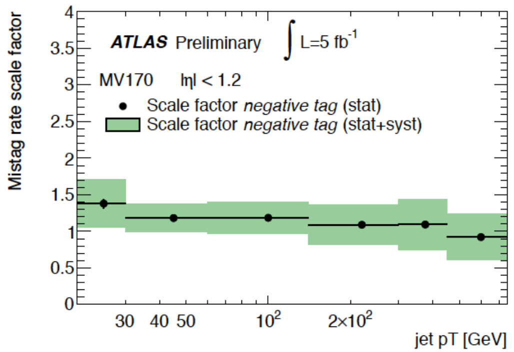
Two complementary methods

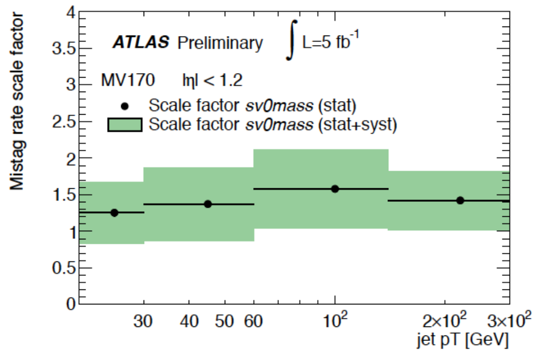
– **Negative tag:** Uses the negative side of the decay length or impact parameter significance distribution (or more complex distribution for advanced taggers); correct for long lived hadrons & material interactions

– **secondary vertex mass:** Uses the invariant mass distribution from tracks associated to the secondary vertex









Electron & Photon reconstruction

Use sliding window algorithm

- Find seed with energy >2.5 GeV

Form clusters $\Delta\eta \times \Delta\phi$

- For electrons and converted photons:
  0.075x0.175 (barrel), 0.125x0.125 (end-cap)
- For unconverted photons: 0.125x0.125

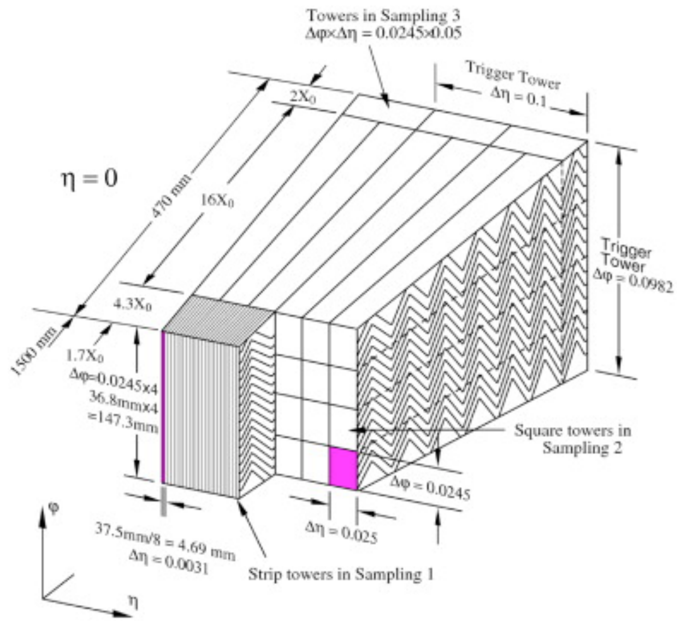
Measure cluster energy → Calibrate energy

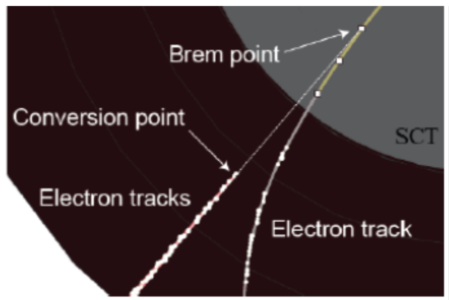
Match cluster to an ID track

- Electron – photon separation

Match track to a secondary vertex

- Converted – unconverted photons



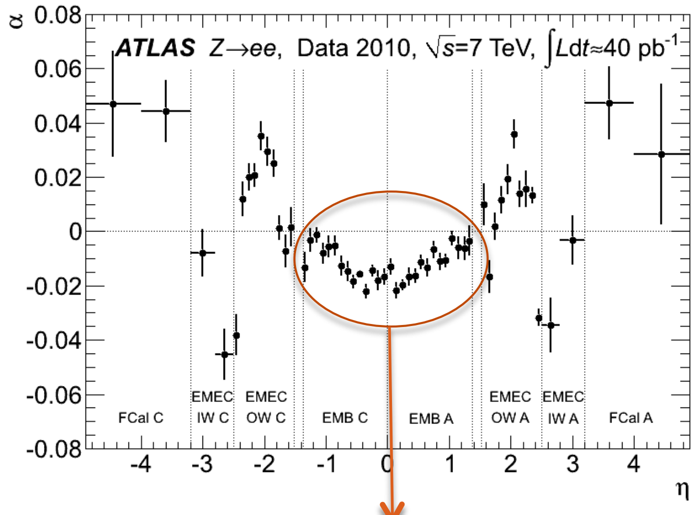


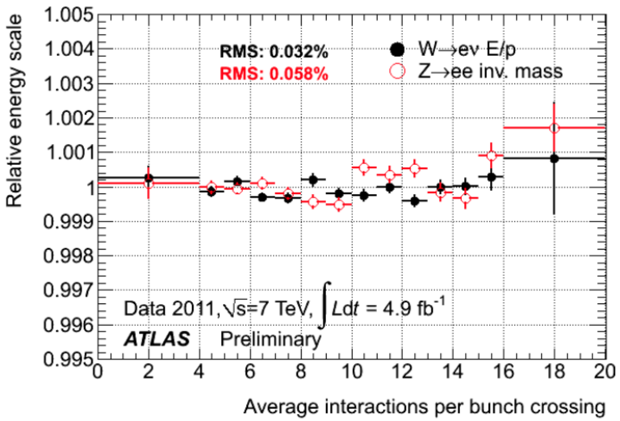
Electron reconstruction takes into account bremsstrahlung losses at pattern recognition level, using Gaussian Sum Filter method

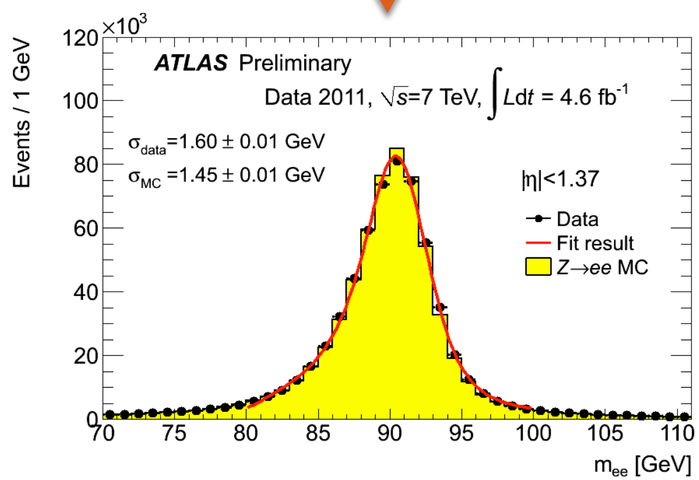
Electromagnetic energy calibration

The energy measured in the cluster cells is calibrated using simulation based methods and tuned with test beam results.
Z to ee in-situ calibration is used to correct the EM scale on data

Used for the full pseudorapidity region | η |<4.9
Cross-checked for linearity, uniformity and stability with J/ ψ and W events .



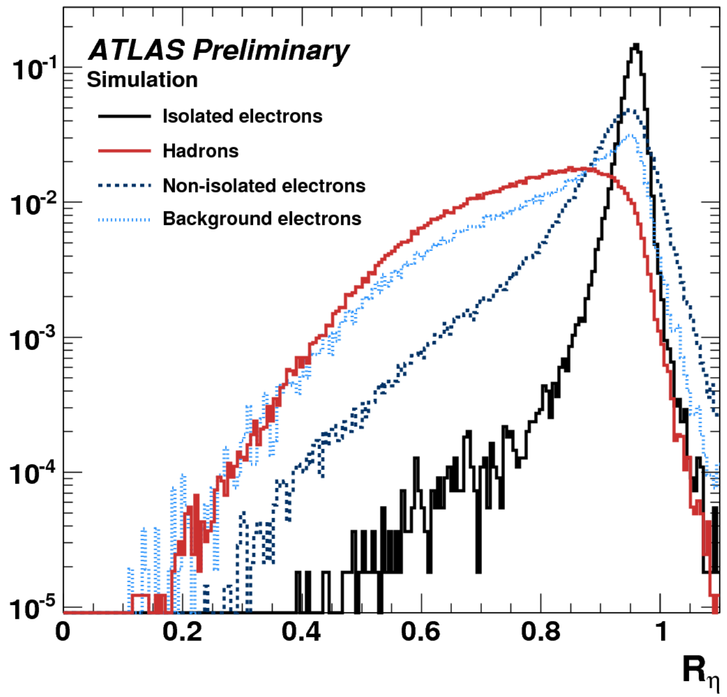




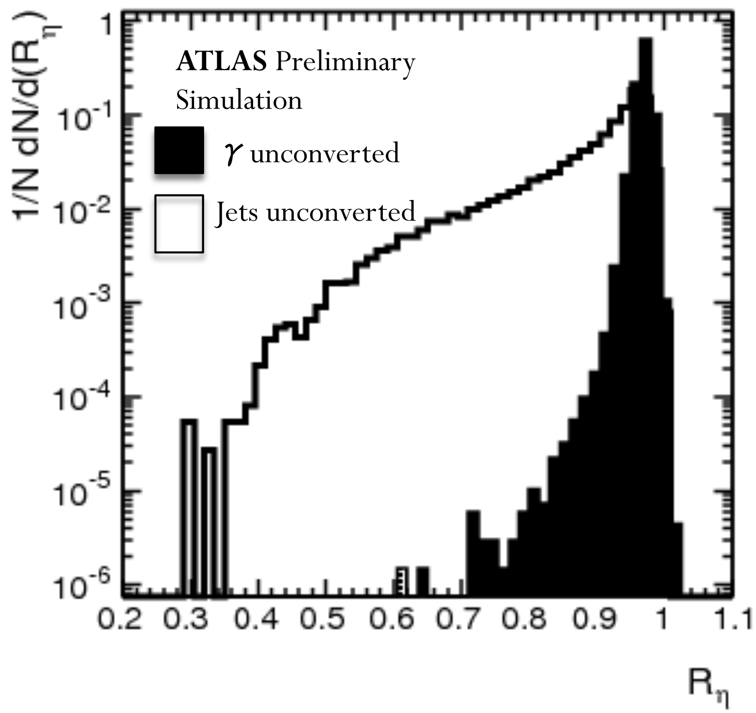
Electron/photon Identification variables

Identification criteria include calorimetric cuts using the information from the different layers of the EM calorimeter, leakage in the hadronic calorimeter, track quality variables and cluster-track matching.
R_η variable: ratio of energies of middle cells in $\Delta\eta \times \Delta\phi$=3x7 over 7x7. For electrons and photons it peaks close to 1

electrons

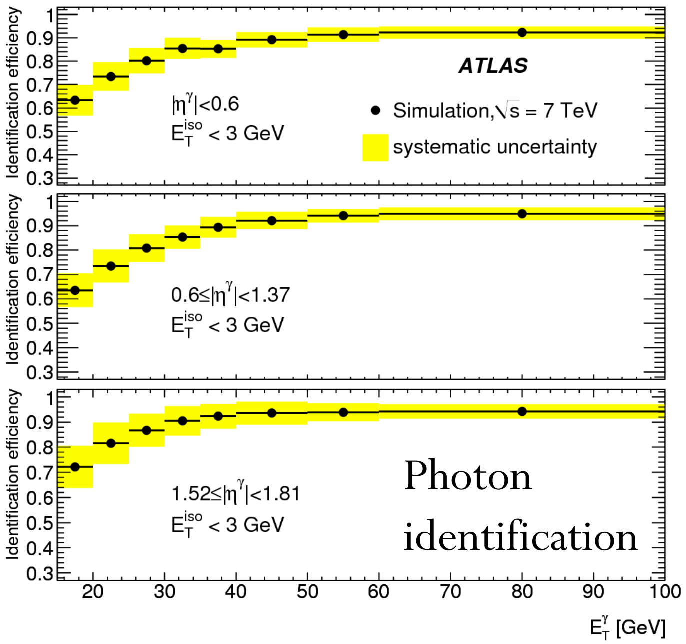


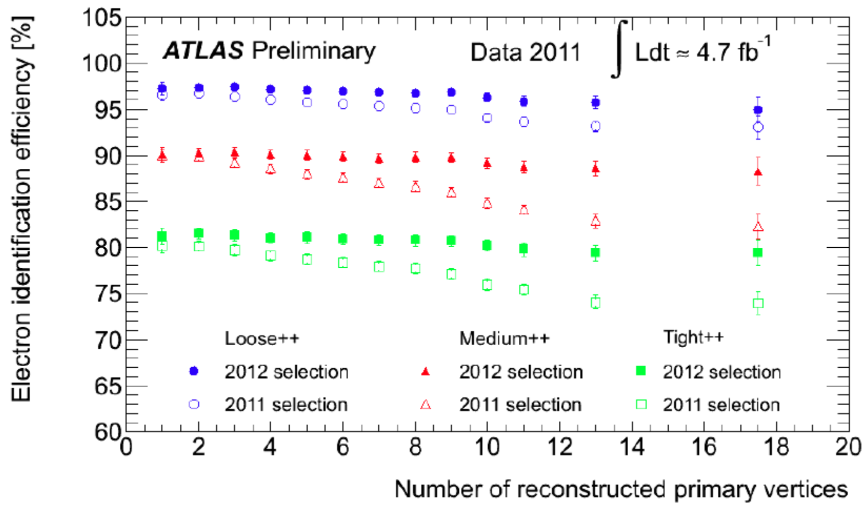
photons



Electron/Photon identification efficiency

Photon identification efficiency measured using Z->llgamma events or MC/data mixed procedures. Electron identification efficiency measured with tag&probe method on Z, W and J/psi (low pT)



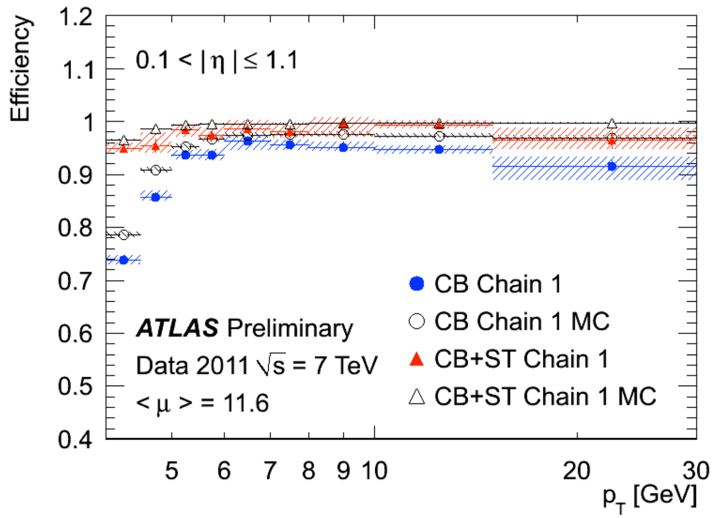


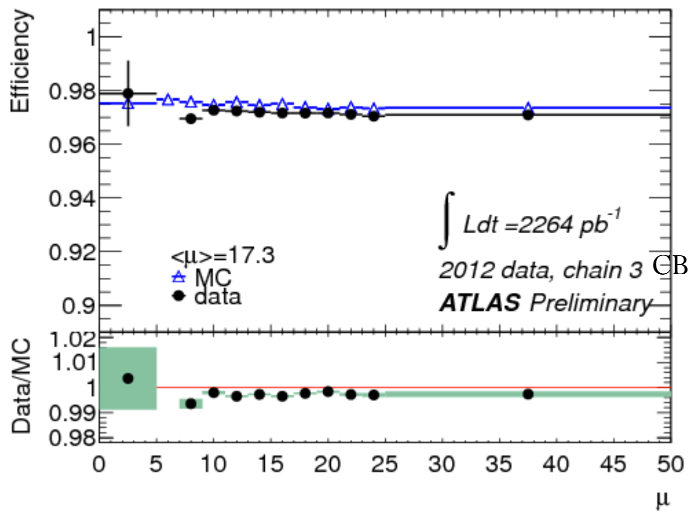
Various levels of identification:

- e : loose (eff=90%, Rej=500), medium, tight (eff=60%,R=10^5)
- γ : loose, tight (eff=85%, Rej=5 10^3)

Muon reconstruction efficiency

- Several reconstruction procedures: ComBination (CB) of inner detector and muon spectrometer MS (good for low pT), StandAlone (SA) MS (good for high pT), and calorimeter or inner detector alone (ST,CT) when in lack of acceptance from MS ($\eta \approx 1.2, 0$)
- Efficiency measured with tag and probe selection, probe muon chosen if invariant mass of two muons is close to
  - J/ψ mass for low p_T range
  - Z boson mass for high p_T range

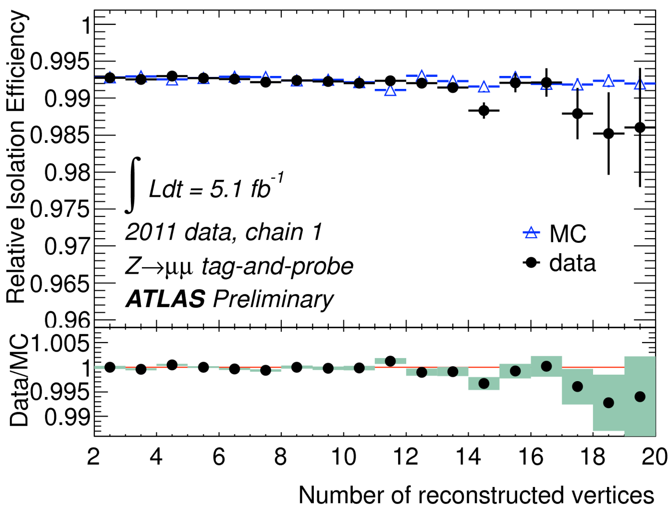




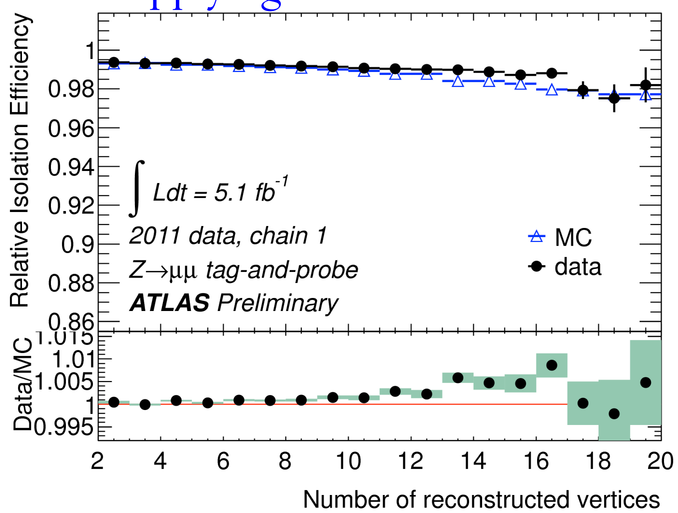
Muon isolation

- Muons required to be isolated to suppress background in many analyses
  - Calorimeter based isolation ΣEt(ΔR<0.3)/pt < X
    - Corrections applied to remove pile-up dependence
  - Track based isolation Σpt(ΔR<0.3)/pt < Y
    - Pile-up robust

Track based isolation

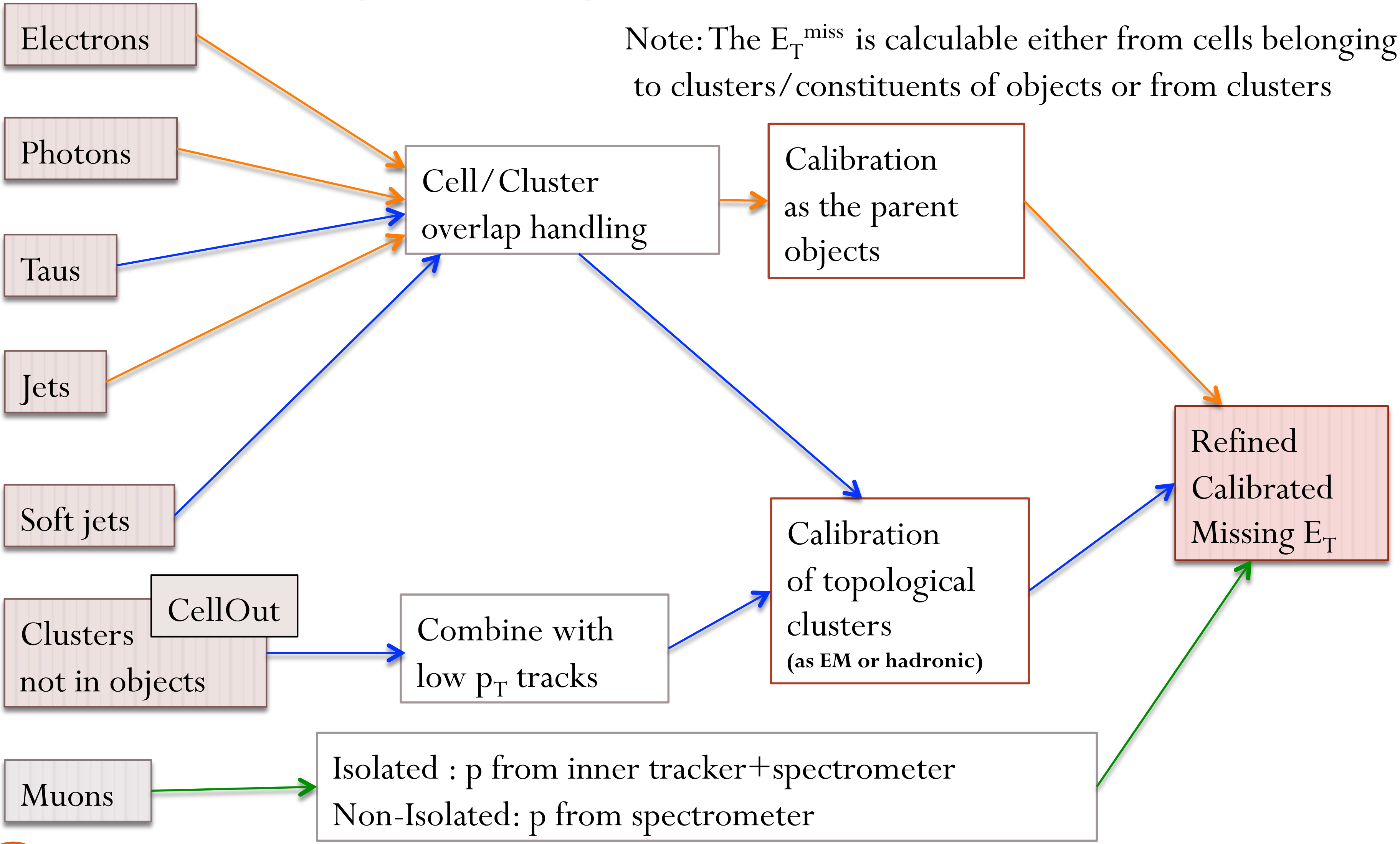


calorimeter based isolation after applying correction



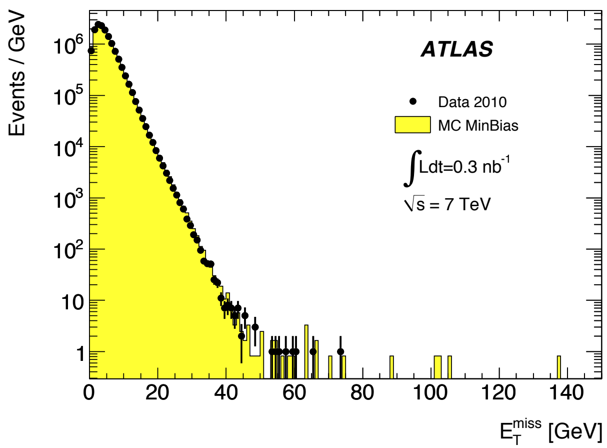
Missing energy

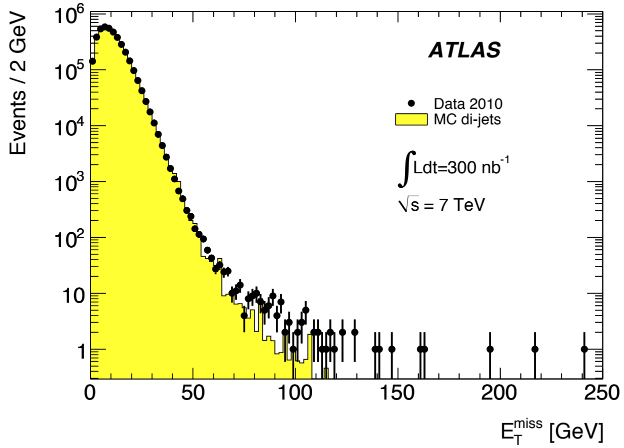
Note: The E_T^{miss} is calculable either from cells belonging to clusters/constituents of objects or from clusters

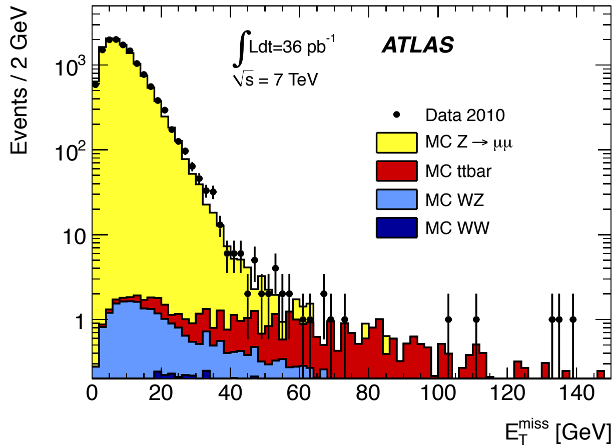


Missing energy at low pileup

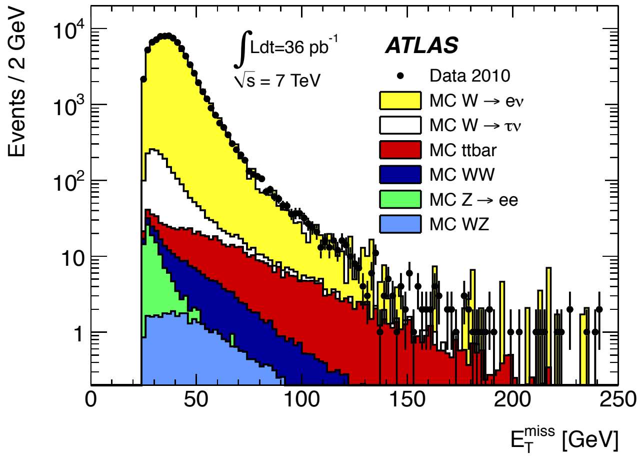
Events with no real missing energy ……





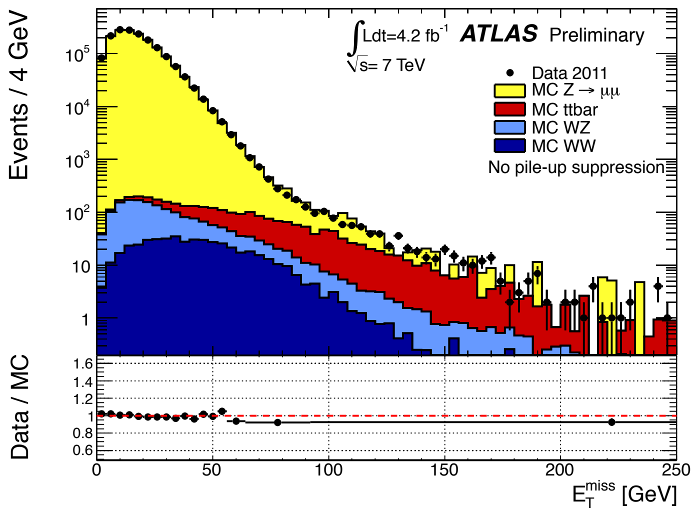


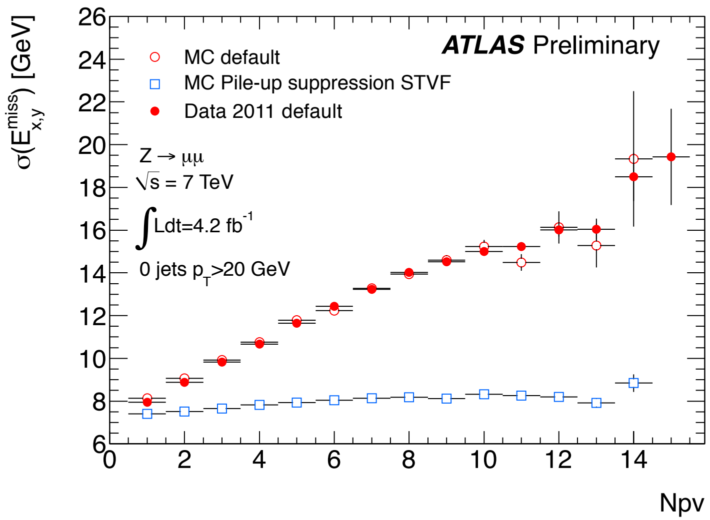
…And events with real missing energy



Very well understood

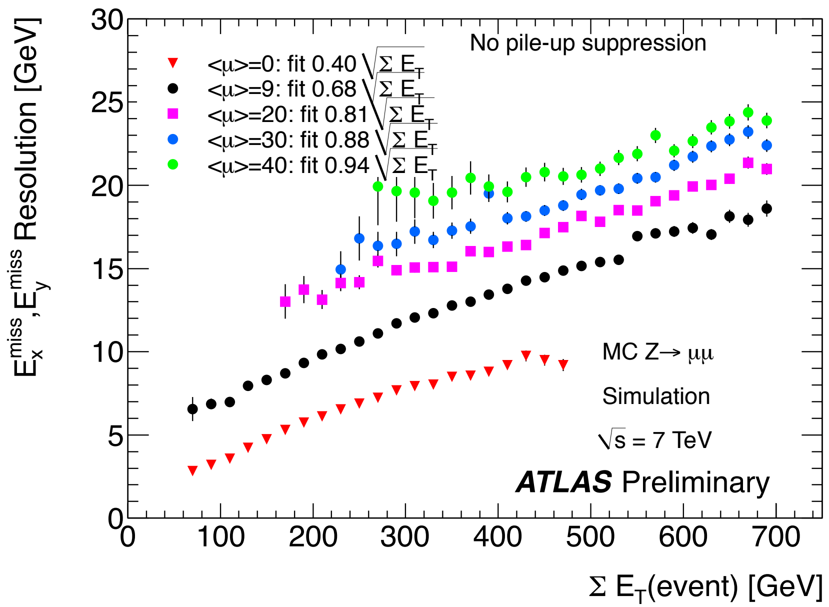
Pileup suppression (I)

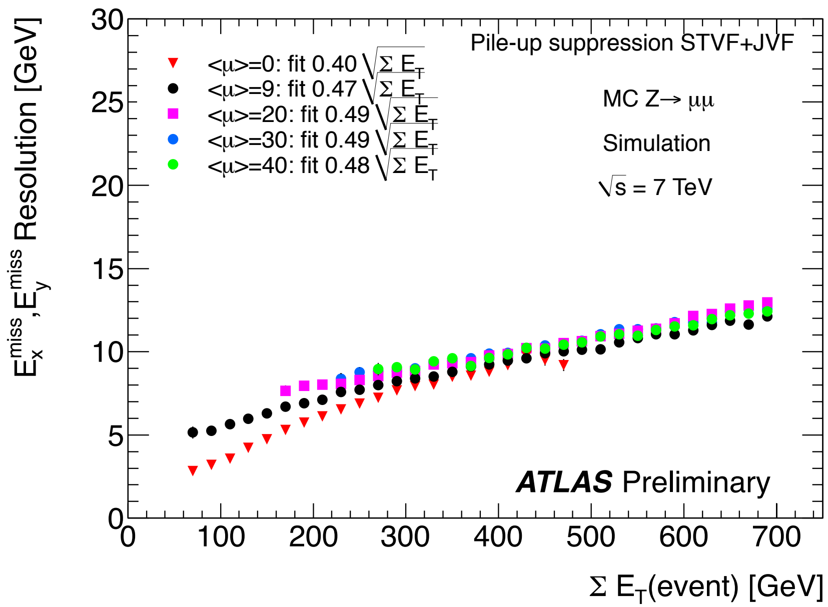




- Very good agreement with simulation in 2011 data.
- The resolution of E_T^{miss} worsens significantly with the increase of pile-up in pp collisions. Ways to suppress its effect have been evaluated.
- The CellOut and SoftJets terms are scaled by the ratio of:
  - the tracks' sum p_T associated to the main primary vertex over all tracks.
- The resulting dependence in the number of primary vertices becomes almost flat as shown for simulated data (representing the soft terms, no jets)

Pileup suppression (II)

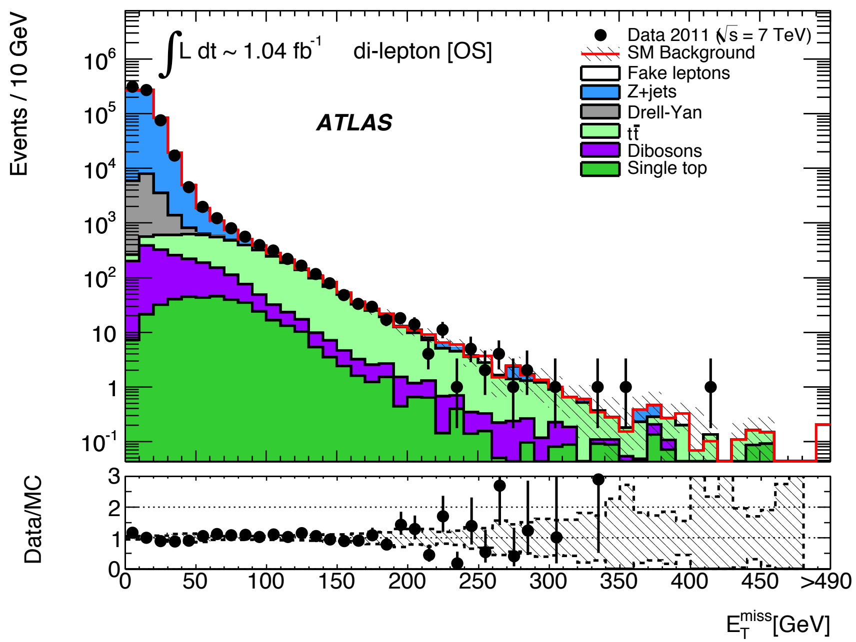


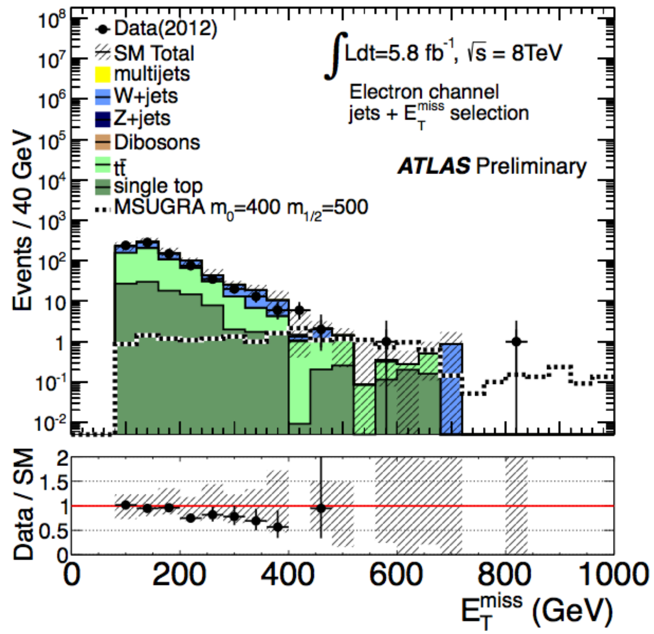


The pile-up suppression method as in the previous page is able to restore the resolution to values very close to the ones experienced with very low pile-up.

Example: In events with Z bosons with 30 additional pile-up interactions per event the "stochastic" term of the parameterized resolution is reduced to ~50% from ~90%.

Missing Et importance for searches



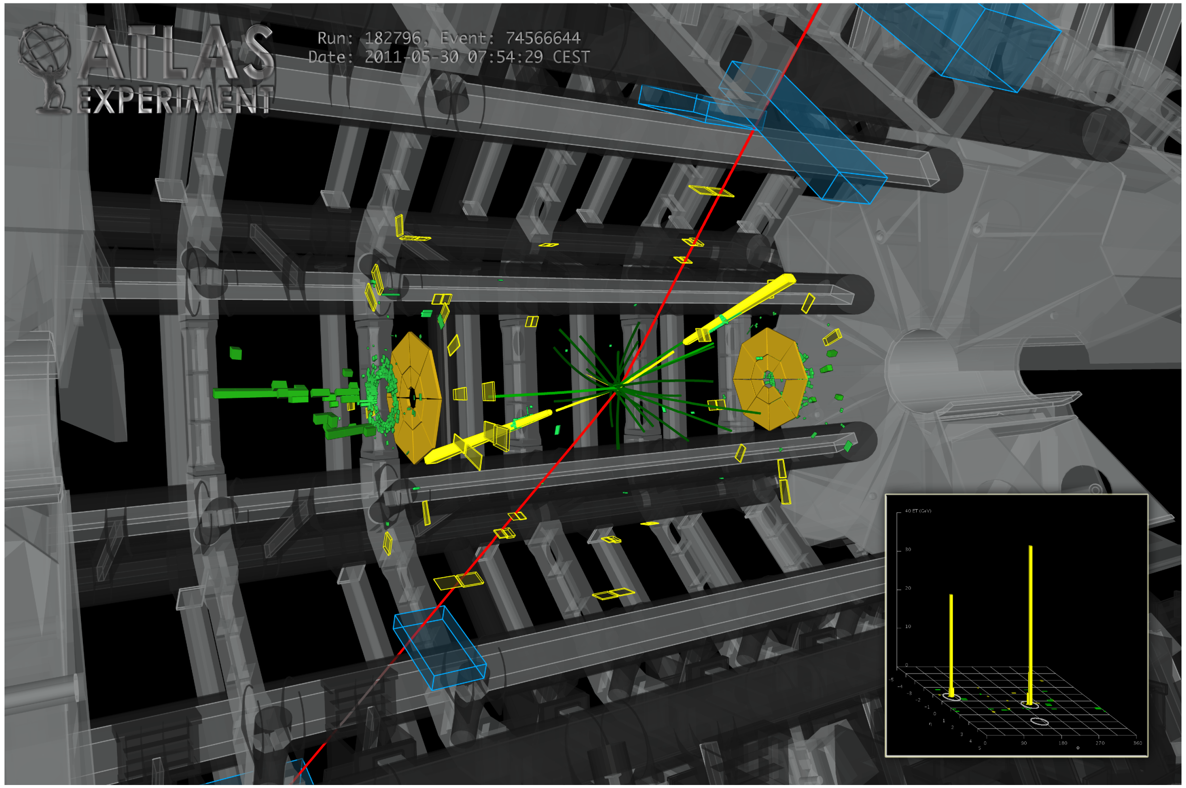


The missing E_T is of paramount importance for all SUSY analyses.
Here the distribution from the search in two leptons+E_t^{miss} final states 2011(left) and 1 lepton +jet +E_t^{miss} final states 2012(right).

The agreement and the control of tails is very good.

Outlook

These are exciting times. Lots of great physics can be discovered with the ATLAS detector, which has a very well understood performance, in high pileup conditions. A recent example ….. ☺



Higgs to ZZ to 2 e and 2 mu , candidate event seen from the ATLAS detector