The ATLAS Detector Performance Results

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on behalf of the ATLAS collaboration

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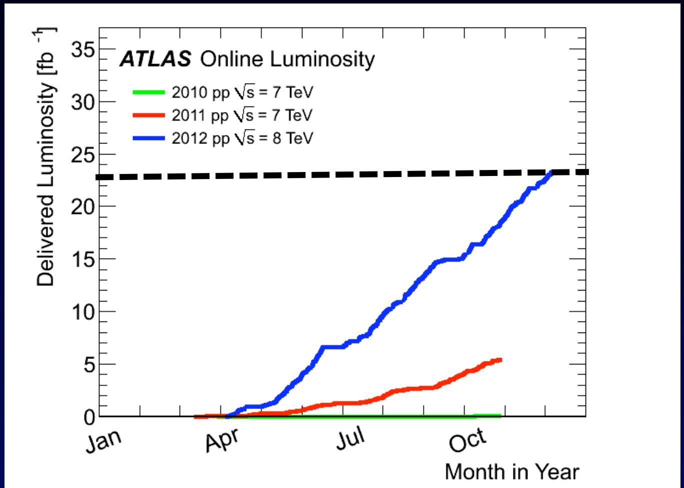
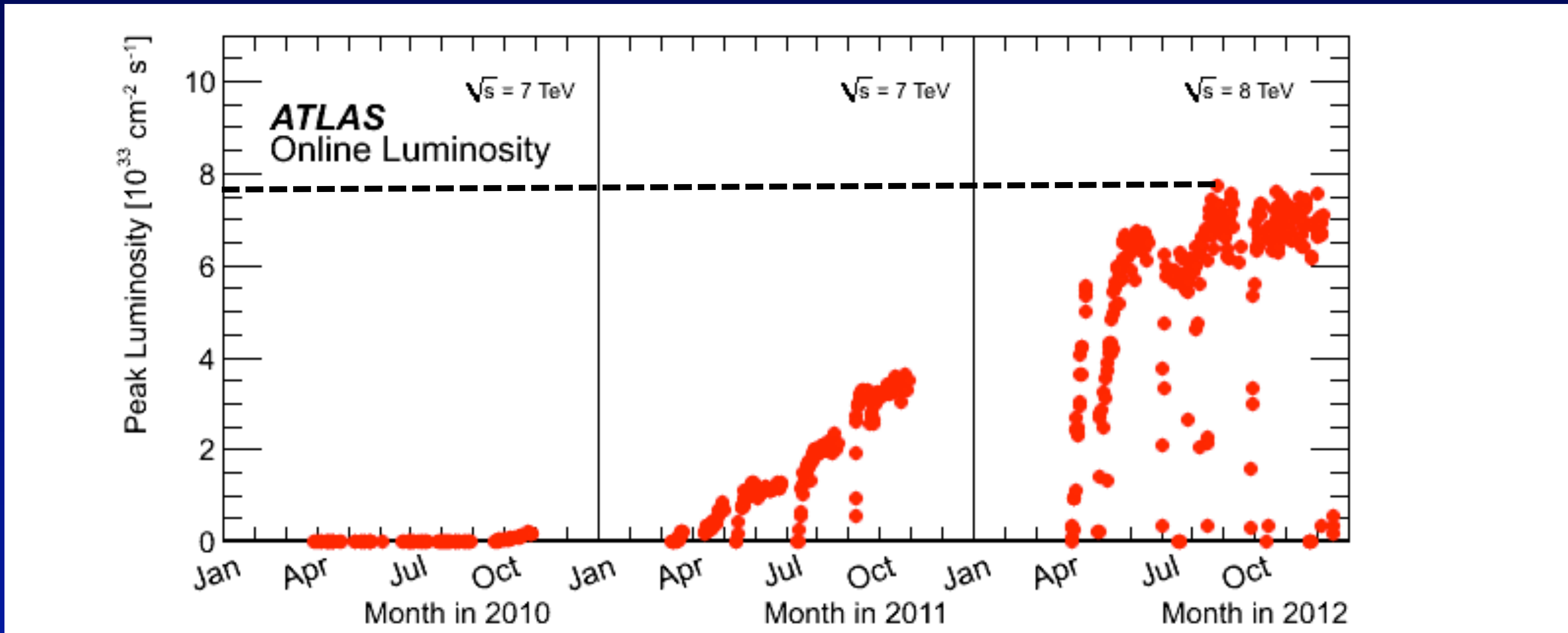
Outlook

- Introduction:
  - Overall LHC and ATLAS performance
  - The pile-up
- Inner Detector performance:
  - Vertexing and tracking
- Calorimeters performance:
  - Electron and photon performance
  - Jet and Missing E_T performance
  - b-tagging and tau performance
- Muon Spectrometer performance
- Conclusions and final outlook

LHC: luminosity achievement



- Great LHC performance!
  - Integrated luminosity delivered in 2012:
    - 23.3 fb^{-1}
  - Peak luminosity achieved:
    - 7.73×10^{33} cm^{-2} s^{-1}



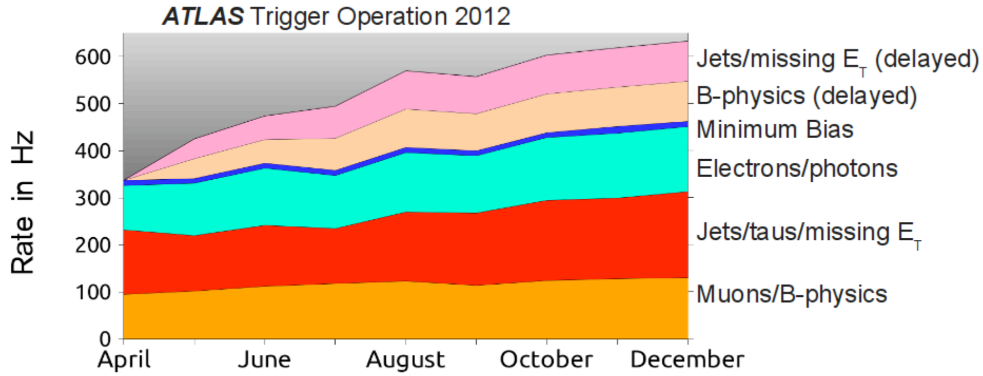
Overall ATLAS performance in 2012

Very small number of un-operational channels

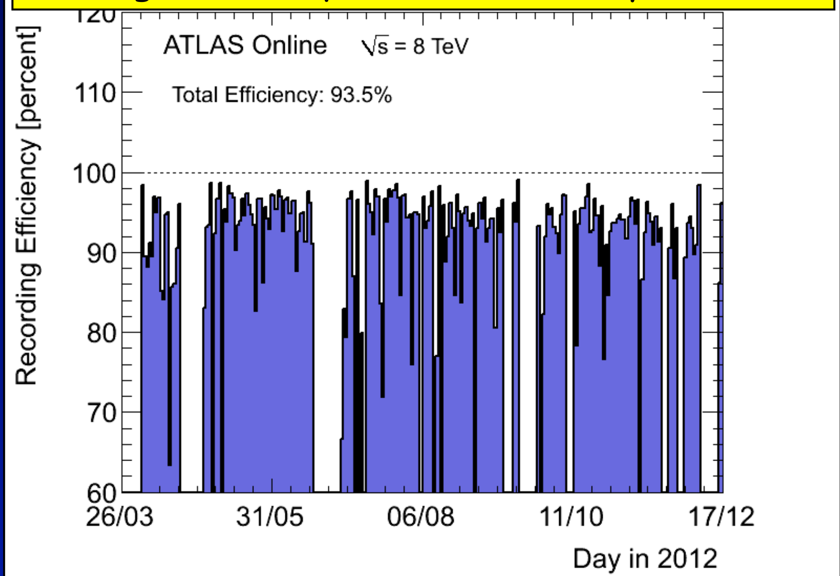
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

Detector uptime for all sub-detectors: > 99%

Excellent trigger operation and data streaming



Average data acquisition efficiency: ~93.5%



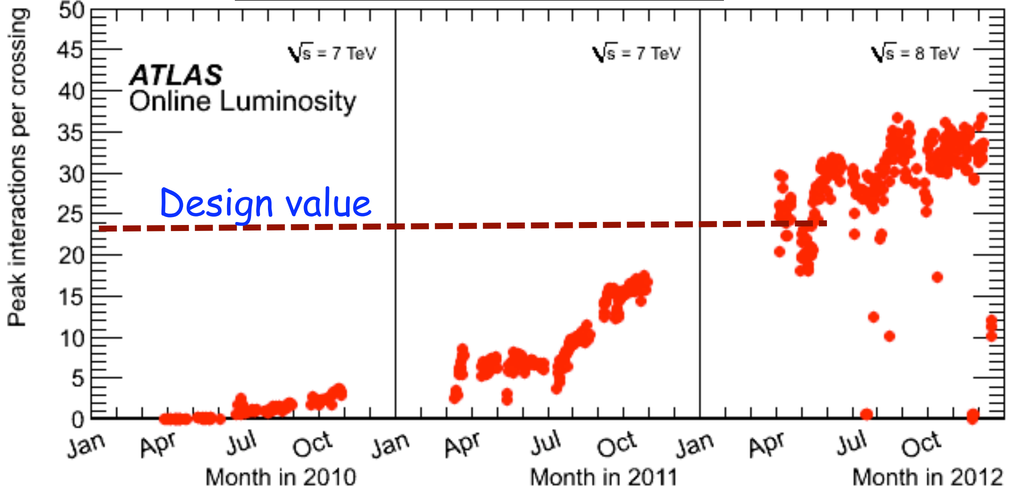
ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.1	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.5%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at $\sqrt{s}$=8 TeV between April 4th and December 6th (in %) – corresponding to 21.3 fb^{-1} of recorded data.

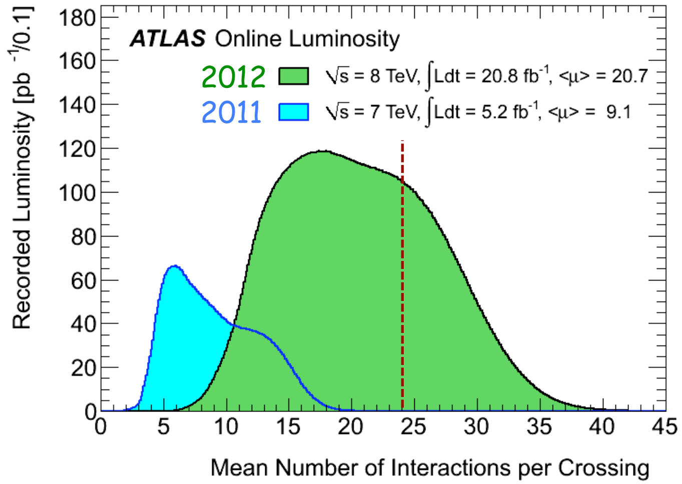
All good for physics data: 95.5% !

The challenge: the pile-up

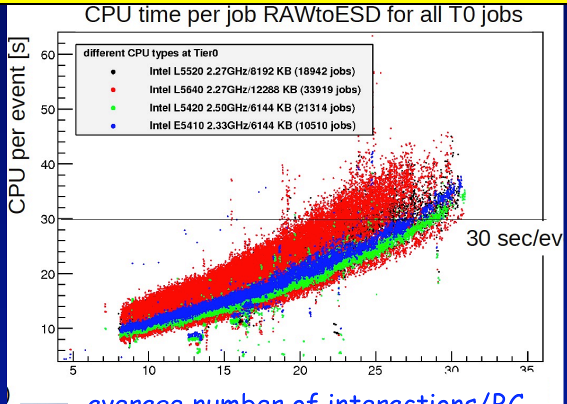
Pile-up increase over time



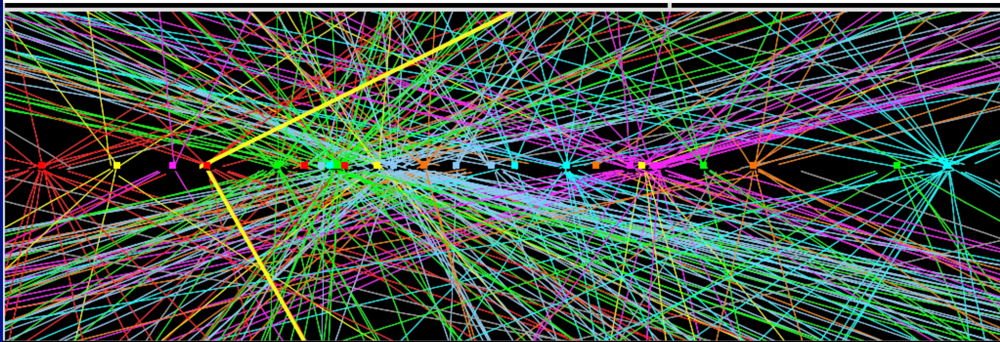
Luminosity vs mean pile-up



CPU reconstruction time vs pile-up



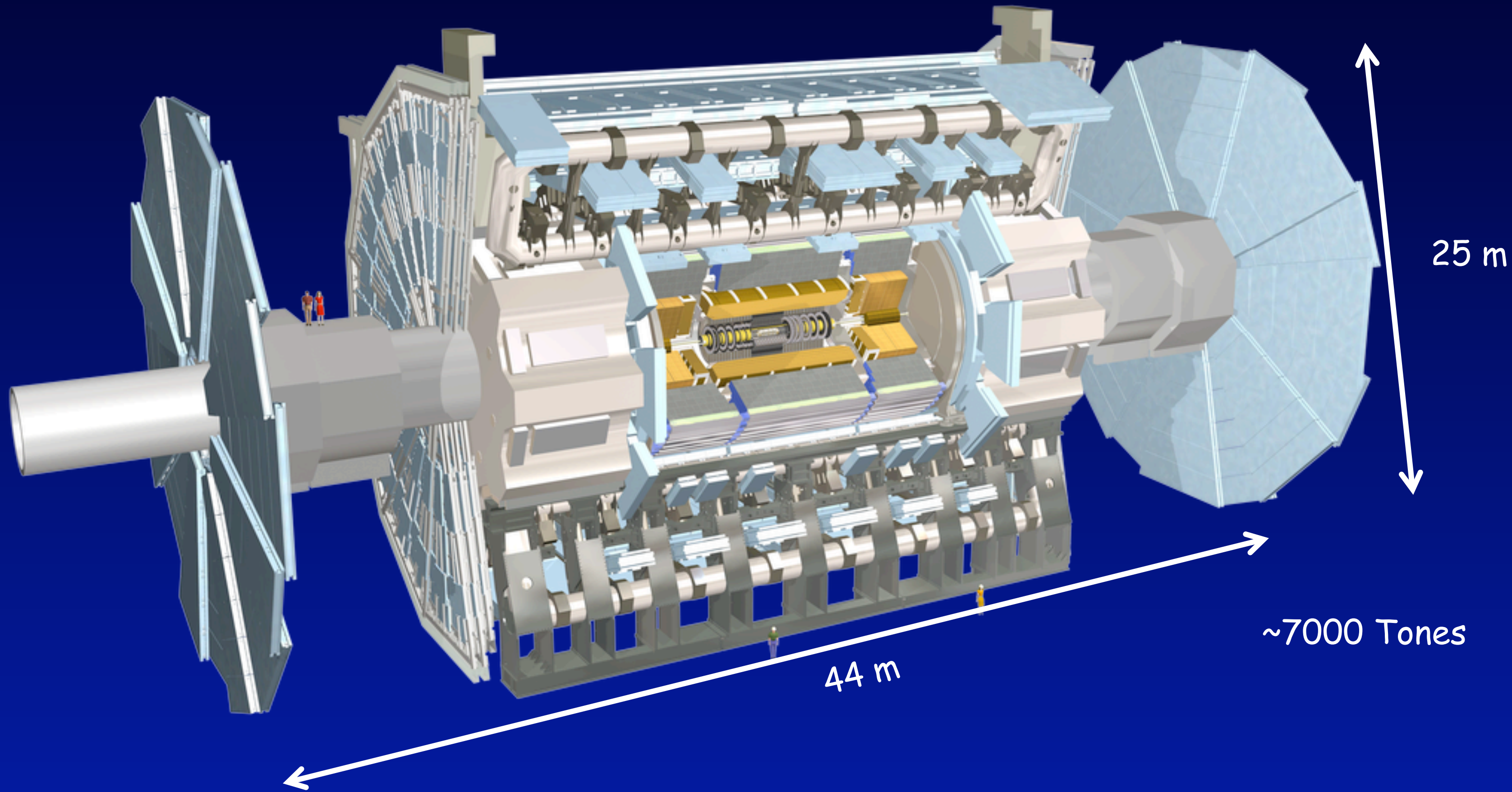
In 2012, LHC ran with 50 ns bunch spacing:
→ double pile-up w.r.t. 25 ns for the same luminosity



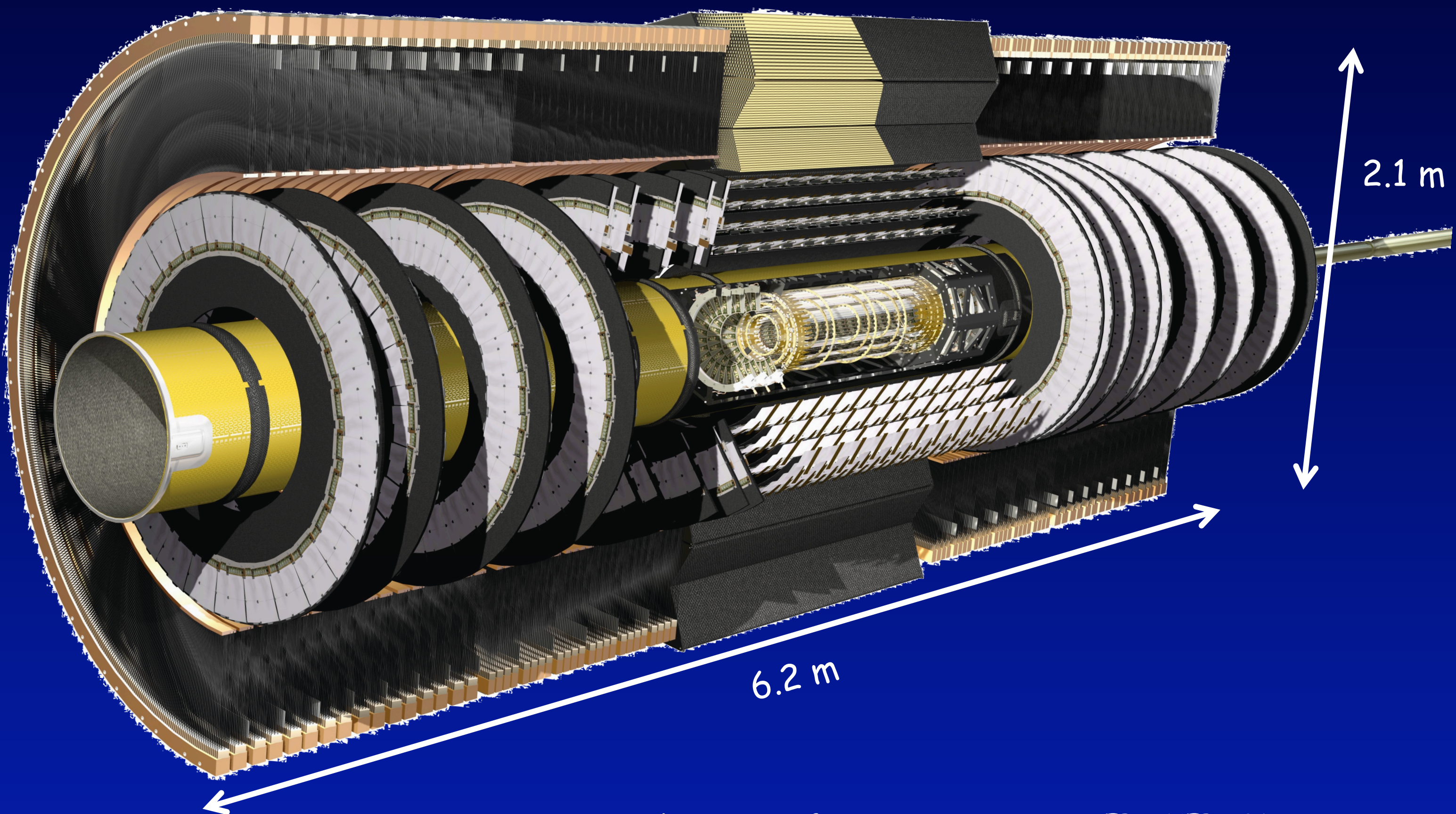
$Z \rightarrow \mu\mu$ event candidate with 25 reconstructed vertices

Pile-up affects all levels: trigger, data reconstruction, physics objects, isolation

- Inner Detector performance
- Calorimeters performance
- Muon performance



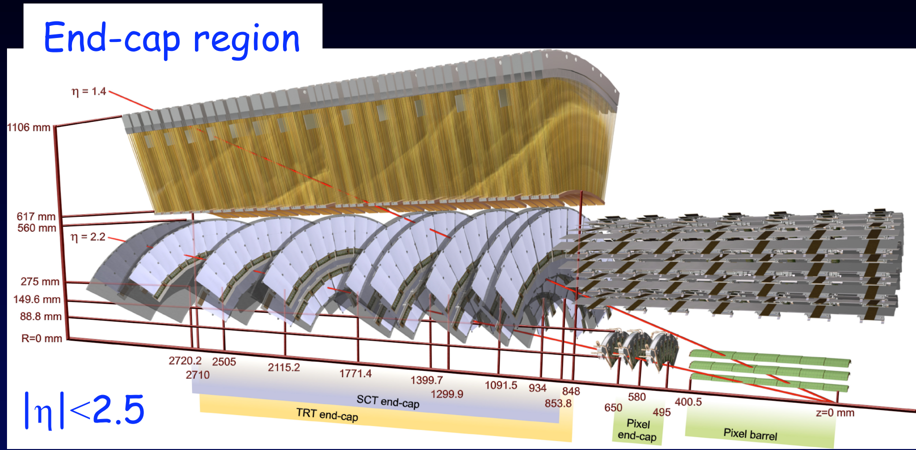
- Inner Detector performance
  - Inner detector geometry
  - Track and vertex performance
  - Performance with high pile-up

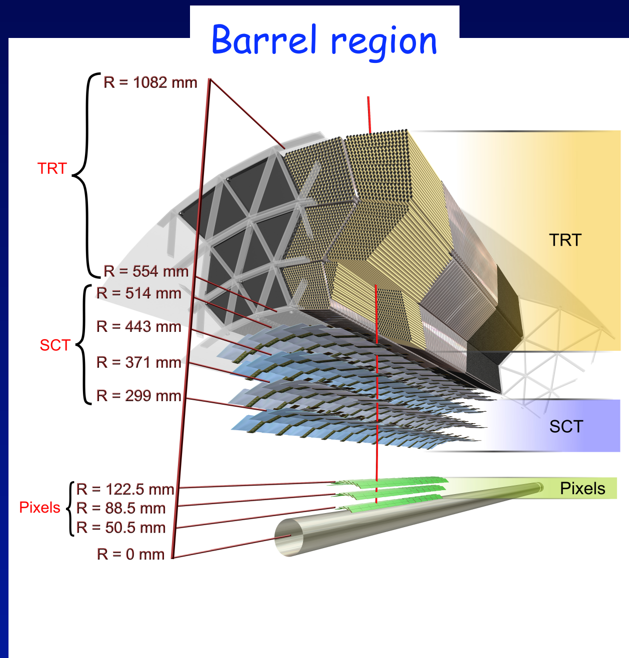


Inner Detector geometry

- Inner Detector provides:
  - Precision measurement of charged particle trajectories
  - particle identification
  - vertex reconstruction
  - b-tagging in jets

- Inside a 2T solenoid magnetic field are:
  - Pixel detector:
    - 80M pixels in 3 barrels (R=5,9,12 cm) and 3 disks in each end-cap
    - 10 μm x 115 μm ($R\Phi$ x Z resolution)
  - SemiConductor Tracker (SCT):
    - 6.3M strips in 4 barrel layers and 9 disks/end-cap
    - 17 μm x 580 μm ($R\Phi$ x Z resolution)
  - Transition Radiation Tracker (TRT):
    - 350k straws with 2 mm radius
    - 130 μm ($R\Phi$ resolution)





Track and vertex resolution

T R A C K I N G

Algorithms:

- Inside-out algorithm (p_T>400 MeV)
- Conversions or long-lived: backtracking

Performance:

- Track reconstruction eff. computed from MC and compared to low luminosity runs
- Good resolution and MC comparison

V E R T E X I N G

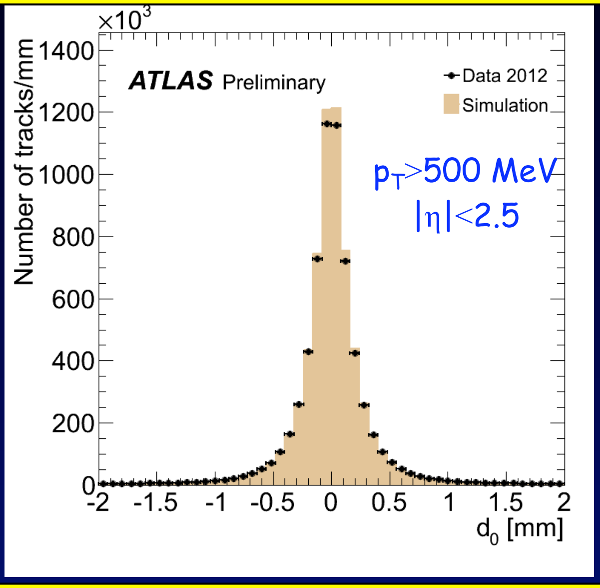
Reconstruction method:

- Seed: position of z_0 (2nd seed if >7σ)
- Iterative χ^2 fit of nearby tracks
- Primary vertex: with highest Σp_T^2

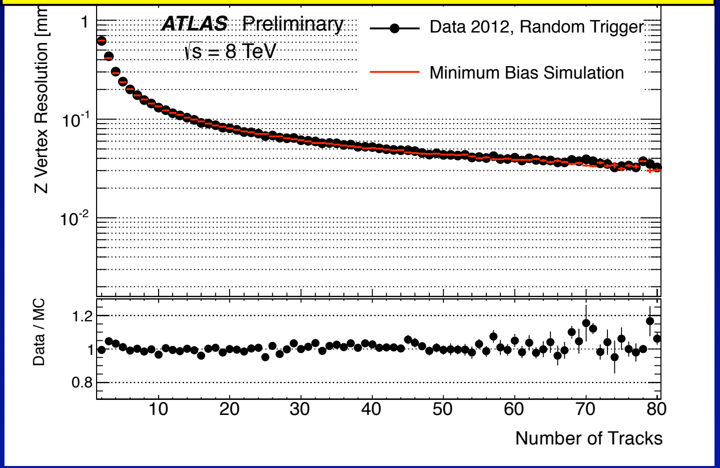
Resolution:

- Method:
  - Tracks from the same vertex are split into two sets; new vertices formed; resolution obtained from Δ
- Resolution decreases with #tracks
- Smallest resolution: ~20/30 μm in X/Z
- Agreement between MC and data

Transverse impact parameter resolution



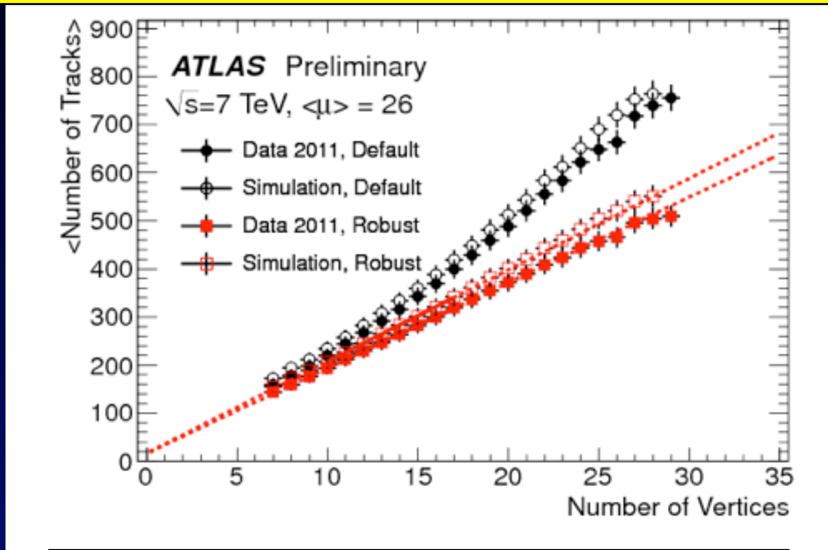
Longitudinal vertex position resolution



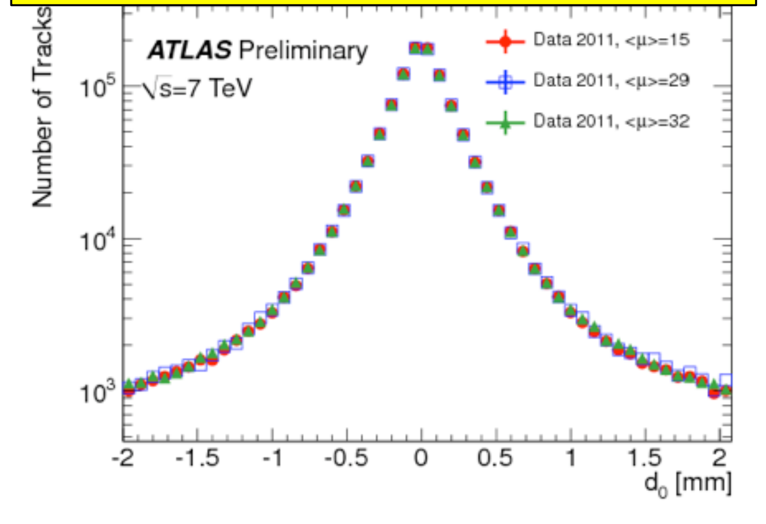
Pile-up effect on tracking

- Challenge:
  - The presence of multiple interactions and higher occupancy complicates the tracking reconstruction
  - Increase of fake rate (combinatorial)
- Dealing with it:
  - More robust reconstruction cuts:
    - ≥9 hits (vs 7) and 0 missing in pixel
- Result:
  - Decrease rate of fakes
  - Small effect on track efficiency

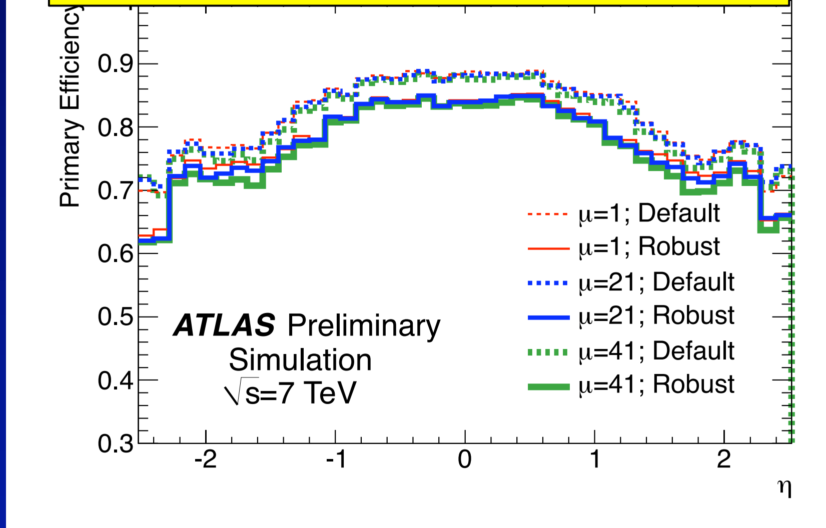
<Number of tracks> for default & robust cuts



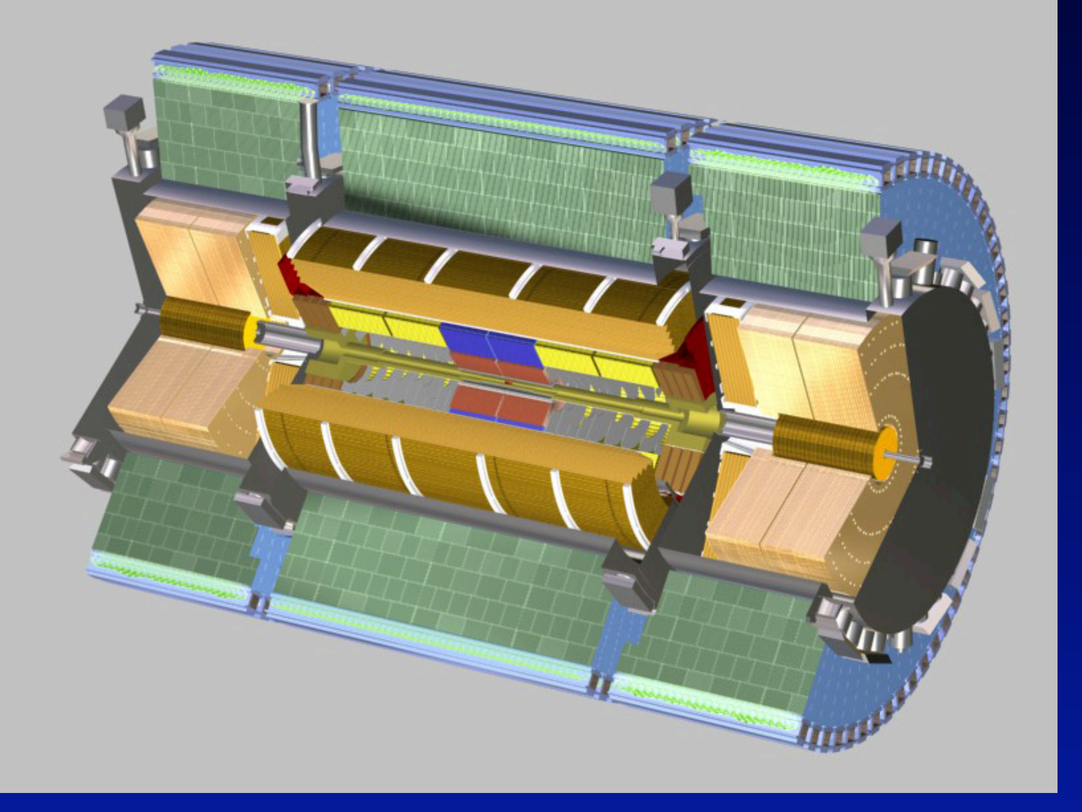
Transverse impact parameter resolution



Primary track reconstruction efficiency



- Inner Detector performance
- Calorimeters performance
  - Calorimeters geometry and overall performance
  - Electron, photon, jets and MET performance



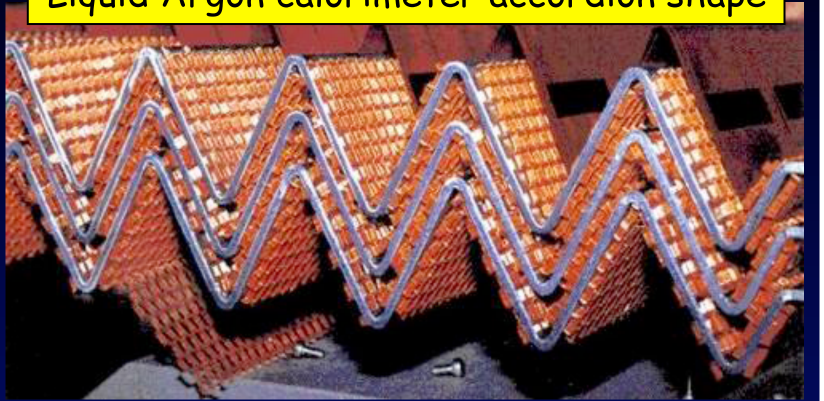
Calorimeters geometry

- Electromagnetic calorimeter ($|\eta|<3.2$)
  - Liquid Argon- Pb sampling calorimeter with accordion geometry
  - ~180k channels
  - 3 longitudinal layers + pre-sampler ($|\eta|<1.8$)
  - $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
  - Provides e/γ trigger, energy measurement and particle identification

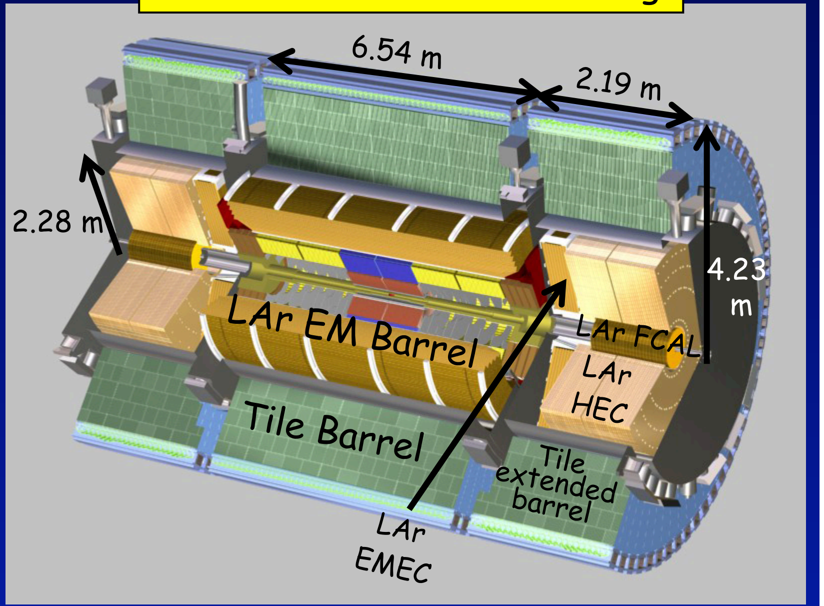
Julien Maurer's poster: Liquid Argon EM calorimeter performance

- Hadron Calorimeter:
  - Used in trigger; provides jet energy, position & E_T^{miss} measurements, helps identify muons
  - Sub-divided in three regions:
    - $|\eta| < 1.7$: Fe/scintillating tiles
      - 3 or 4 longitudinal layers
      - ~20k channels
    - $3.2 < |\eta| < 1.5$: Cu –LAr (HEC)
    - $3.1 < |\eta| < 4.9$: FCAL Cu/W- LAr

Liquid Argon calorimeter accordion shape



ATLAS calorimeters drawing



Electron and Photon performance

LAr calorimeter overall performance:

- Frequent calibrations with constant updates → excellent stability of the energy scale both over time and with pile-up

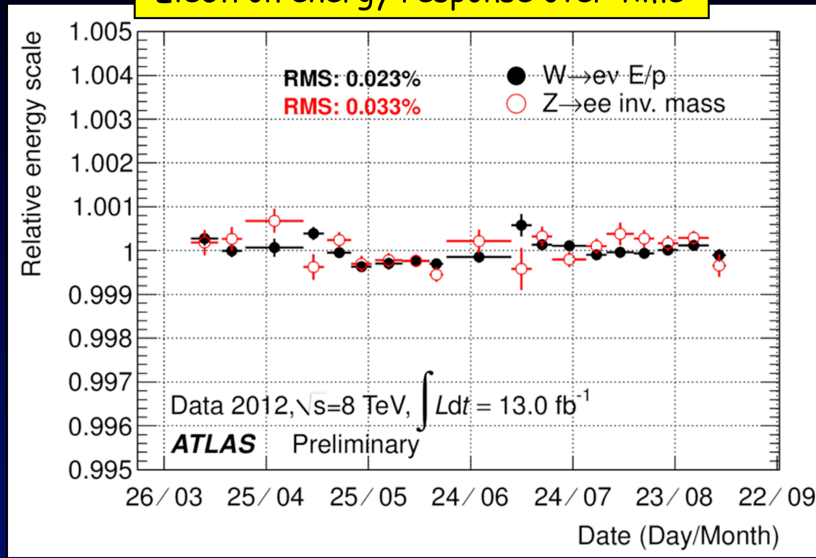
Electron identification:

- Use of shower shape characteristics combined with tracker information
- Optimization of cuts for loose, medium and tight definitions: 95/88/79% efficiencies obtained from $Z \to ee$ tag-and-probe method in 2012

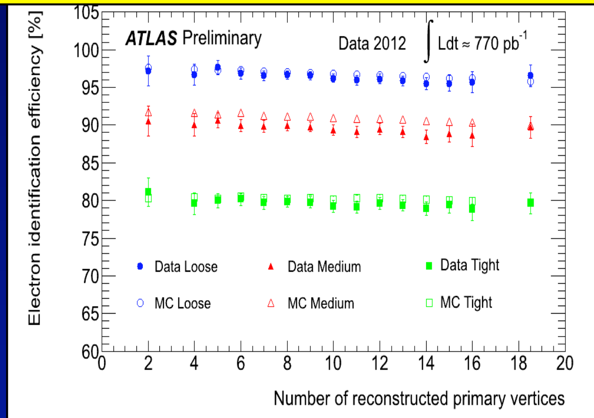
Photon identification:

- Make use of fine segmentation to reject background (jets with leading π^0 decaying primarily to two photons)
  - Unconverted: no trk to EM cluster
  - Converted: associated with ≥ 1 trk
- Use radiative $Z \to ll\gamma$ to study efficiency

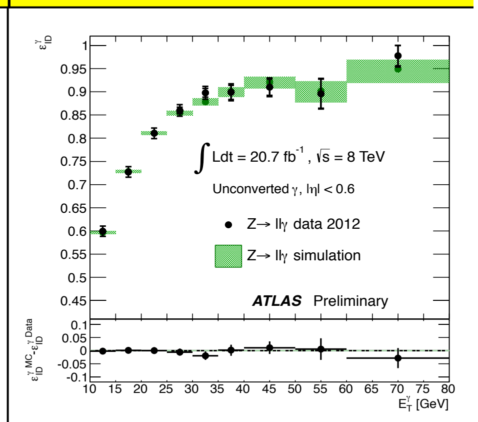
Electron energy response over time



Electron eff dependence with pile-up



Unconverted photon efficiency



Jets and E_T^{miss} performance

Tile calorimeter performance:

- Periodic monitoring of cells response: <1% precision on the EM scale

Jet performance:

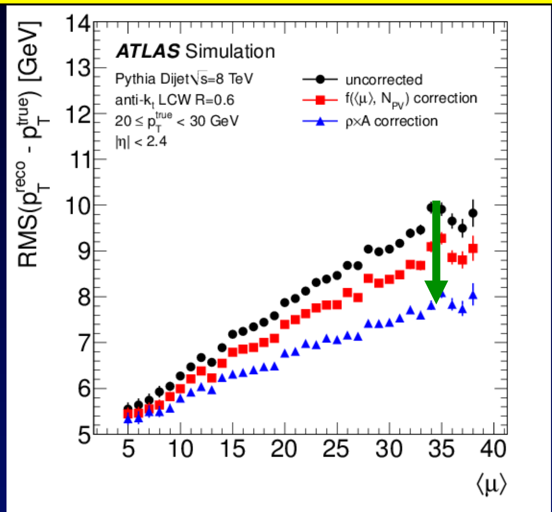
- Jet energy resolution and pile-up dependence improved with a correction: $\rho \times A^{jet}$
- The total Jet energy scale uncertainty is <2% for central jets p_T>100 GeV (used γ/Z+jet & di/multi-jet events)
- Work on jet sub-structure techniques ongoing

Peter Loch's talk: jet shapes and substructure QCD session yesterday

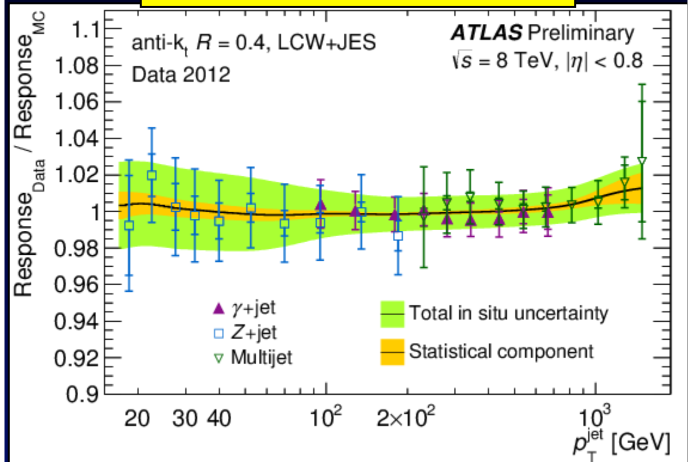
E_T^{miss} performance:

- Pile-up dependence improved with a pile-up suppression method based on the ratio:
  - $\sum p_T^{trk(PV)} / \sum p_T^{trk(all)}$

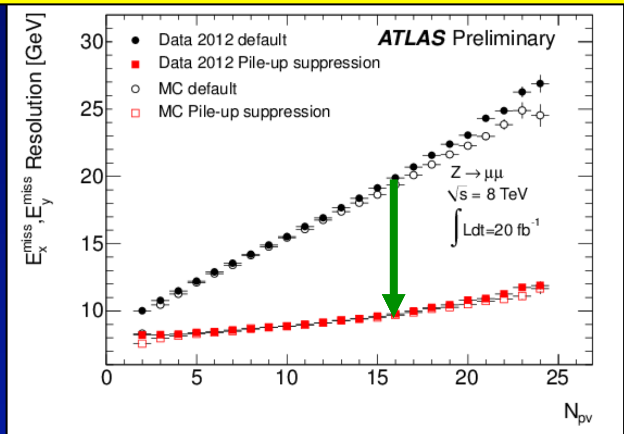
p_T^{jet} resolution improvement vs <μ>



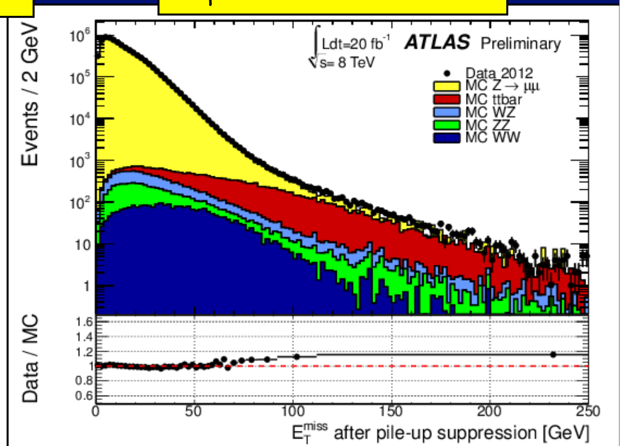
Jet response data/MC



E_T^{miss} resolution improvement vs <μ>



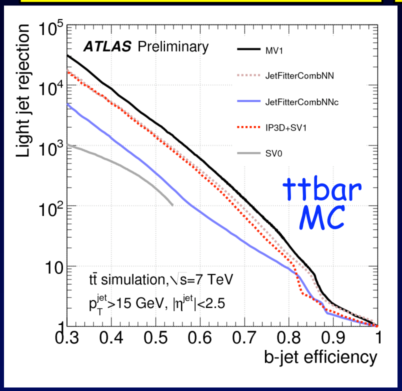
E_T^{miss} distribution



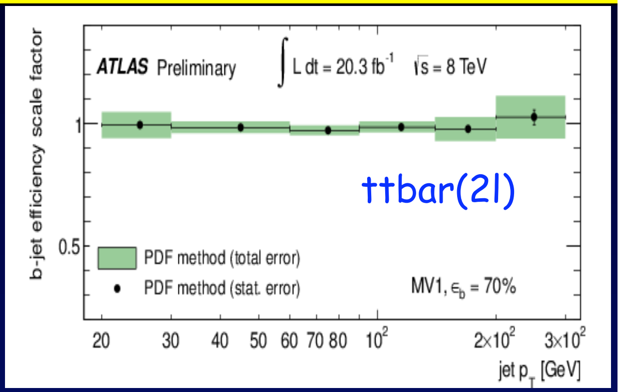
b-tagging and taus performance

- b-tagging performance:
  - Different algorithms exist based on impact parameter tracks, secondary vertex, its invariant mass, etc.
  - Neural network using output weights of all algorithms is used in analyses (MV1)
  - Implemented methods to measure mis-tag rates as well as charm jet and light jet efficiencies

light jet rejection

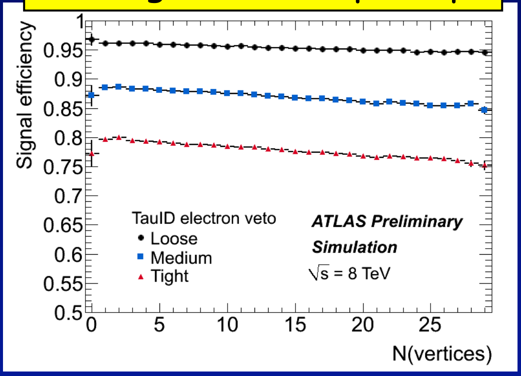


b-jet eff. data to MC scale factor

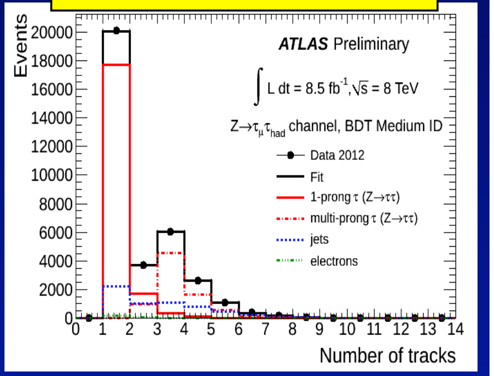


- Tau performance:
  - Implemented dedicated jets and electron discriminants based on multiple variables (BDT or LLH) based on:
    - narrow calorimeter deposits
    - few tightly spaced tracks
  - Tau identification efficiency is measured using the tag-and-probe method in $Z \rightarrow \tau\tau$ or $W \rightarrow \tau\nu$ data

Tau signal eff. vs pile-up

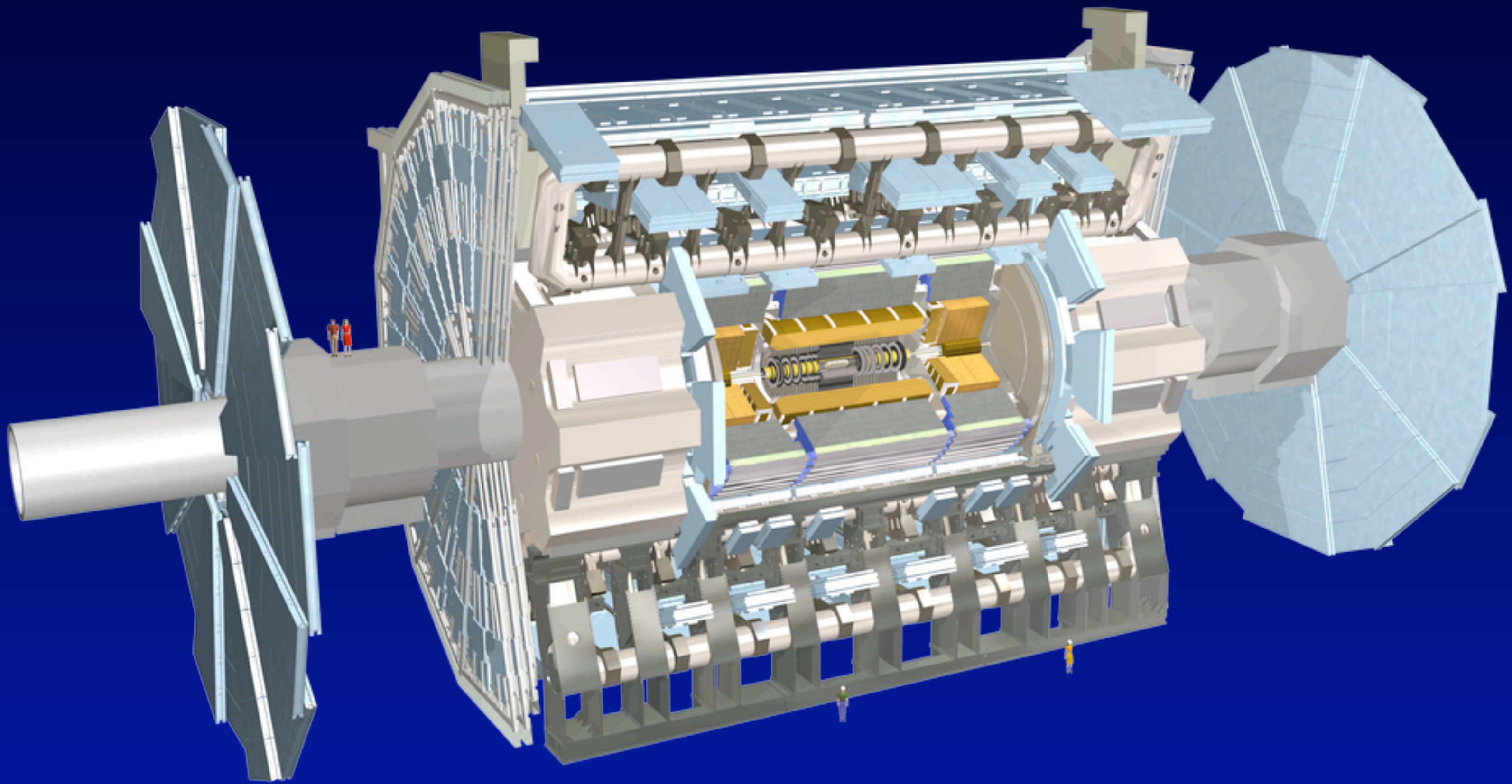


Ntks of τ candidate



Andrew Leister's poster: Tau reco and id
Amelia Brennan's poster: Tau energy scale

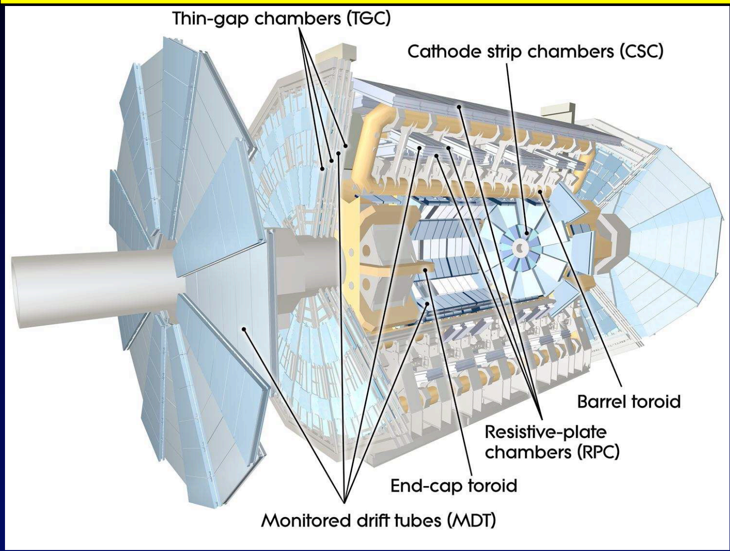
- Inner Detector performance
- Calorimeters performance
- Muon performance:
  - Muon geometry and performance



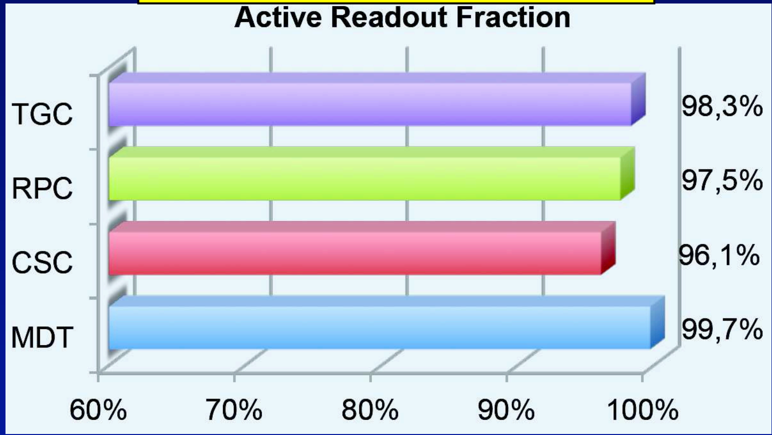
Muon spectrometer geometry

- One barrel and two end-cap sections within a field of ~0.5 T provided by an air-core toroid
- Muon spectrometer sub-divided into different sub-detectors for precision measurement and trigger
- Monitored Drift Tubes (MDT)
  - 3 layers for $|\eta|<2$ and 2 layers for $2<|\eta|<2.5$
  - hit resolution ~80μm per tube
- Cathode Strip Chambers (CSC)
  - 1 layer for $2<|\eta|<2.7$
  - 60μm X 5 mm resolution in ($\eta \times \phi$ planes)
- Resistive Plate Chambers (RPC)
  - Trigger chambers: 3 layers for $|\eta|<1.05$
  - η, ϕ measurements with 1 cm resolution
- Thin Gap Chambers (TGC):
  - Trigger chambers: 3 layers for $2.0<|\eta|<2.5$
  - η, ϕ measurements with 1 cm resolution

Muon spectrometer geometry ($|\eta|<2.7$)



Detector operation in 2012



Muon performance

Reconstruction methods:

- Stand-alone (muon spectrometer (MS) only)
- CaloTag (using only Inner detector & calo)
- Segment-tagged (ST) (IDtrk+MS segment)
- Combined reconstruction (CB) (use MS and ID): best purity and resolution

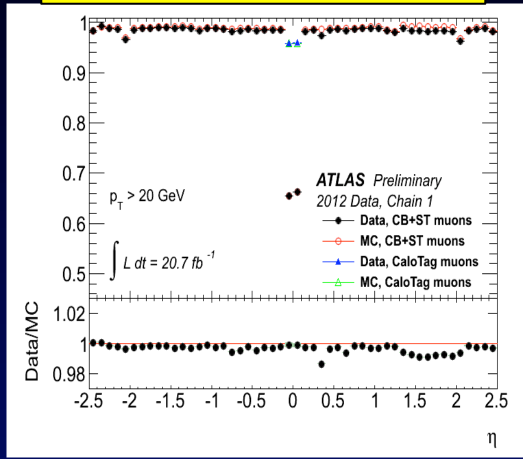
Reconstruction efficiency:

- Used tag-and-probe method with Z and J/ψ decays selected with one CB muon as tag
- Scale factor eff. corrections 0.1-1%

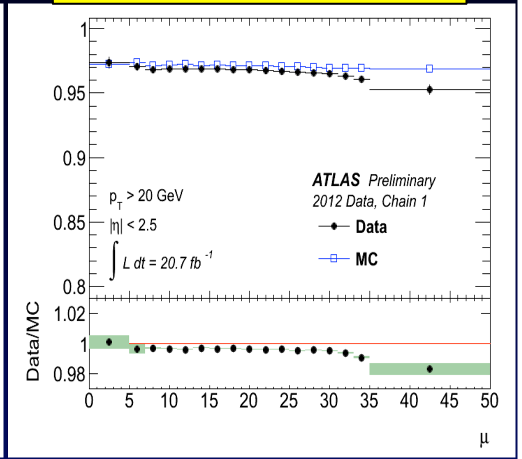
Momentum resolution and scale:

- Muon momentum simulation very good
- Corrections to the ID and MS measurements are derived from a fit of the di-μ invariant mass at the Z region in data
- Scale + smearing corrections applied to MC:
    - Final scale corrections ~0.1%

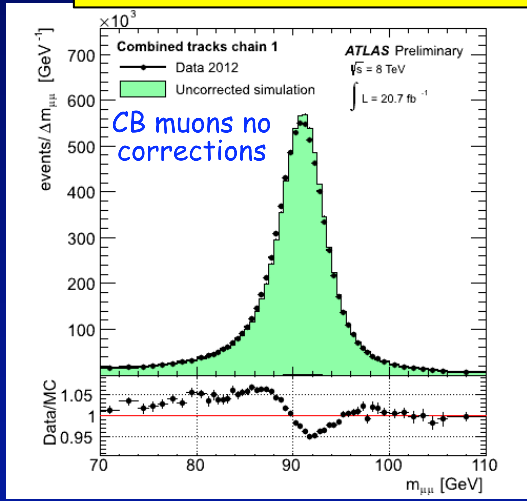
μ reco. efficiency vs η

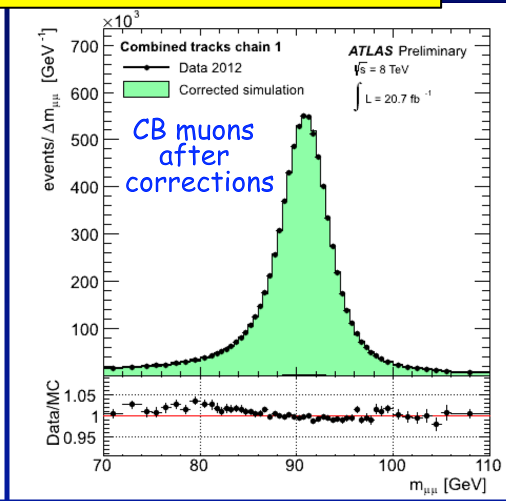


μ reco. eff. vs pile-up



Di-μ invariant mass without and with corrections



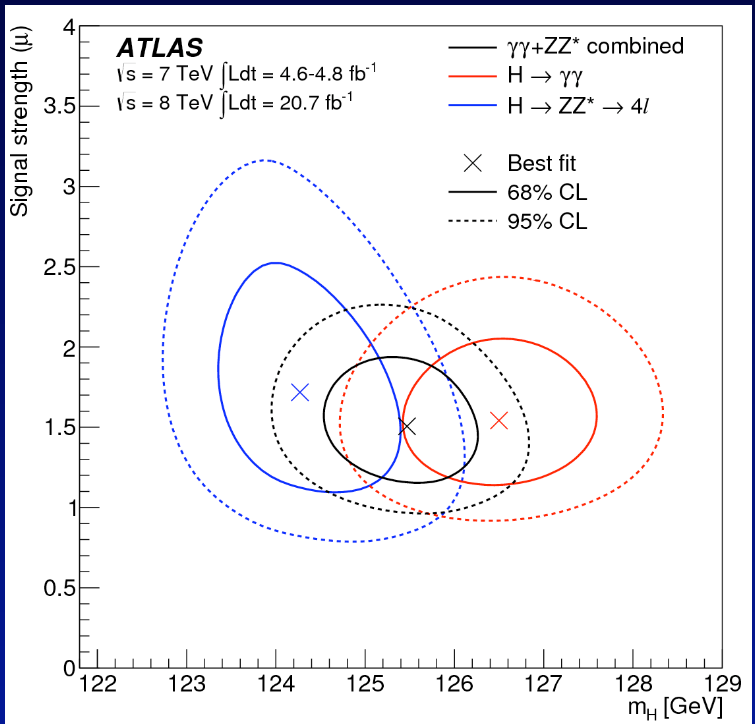


Summary and outlook

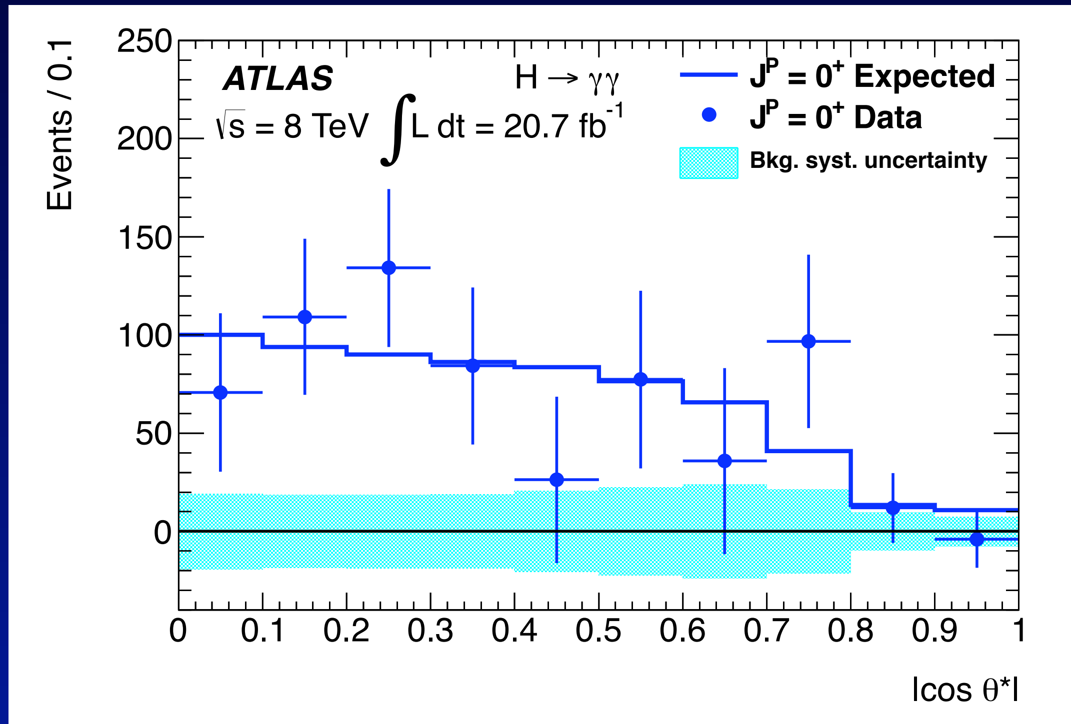
- LHC did excellent and delivered a large sample of data in 2012
  - Running at 50 ns bunch spacing, the pileup was higher than at the original design
- ATLAS acquired the data with very high efficiency
  - ~95% of the acquired data was good for physics analysis
  - Large number of studies were performed in order to improve the performance of physics objects reconstruction and identification against pileup
  - Very good performance as well as compatible with the MC predictions has been achieved
- ATLAS is currently proceeding through the plans during this shutdown:
  - Installation of a new beam pipe together with the new Insertable B-Layer
  - Installation of the extended end-cap muon chambers completing the original design
  - Refurbishments as well as many infrastructure improvements

Thanks to the good ATLAS overall performance

Measurements of Higgs boson production and couplings in diboson final states
arXiv:1307.1427 submitted to PLB
4 July 2013



Evidence for the spin-0 nature of the Higgs boson
arXiv:1307.1432 submitted to PLB
4 July 2013



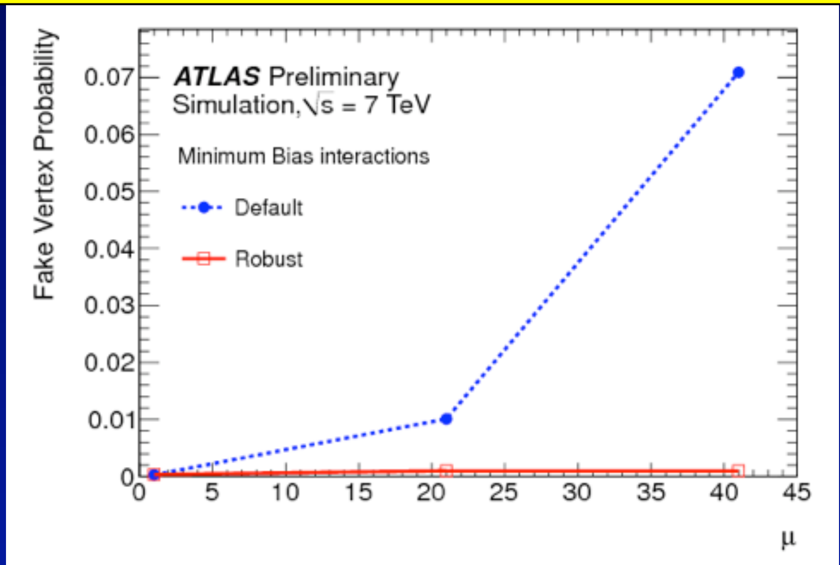
Thank You

Backup

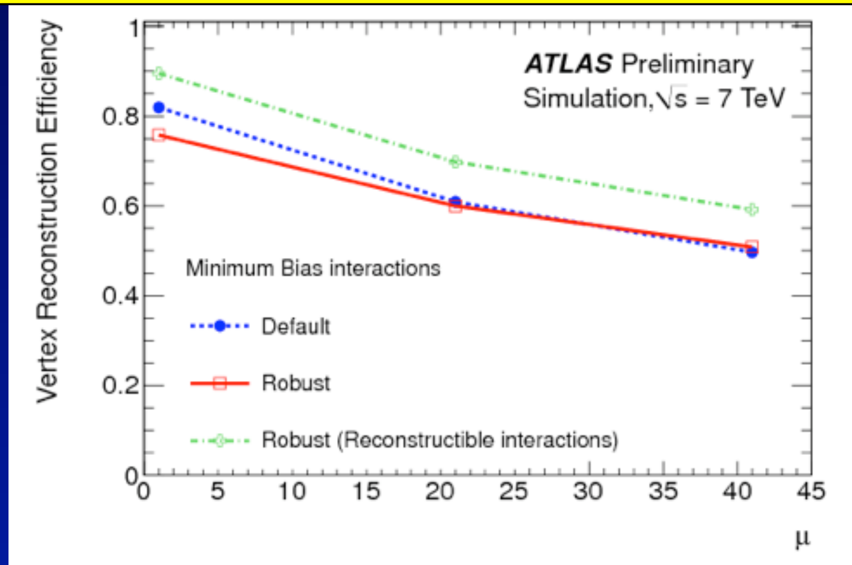
Pile-up effect on vertex reconstruction

- Effect:
  - With the increase of fake tracks, there is a higher chance to reconstruct a fake vertex (~7% at μ=40)
  - The vertex reconstruction efficiency decreases with μ:
    - A vertex of a too close nearby interaction cannot be resolved
- Result:
  - With the robust reconstruction, the fake vertices are reduced and the vertex reconstruction efficiency increased

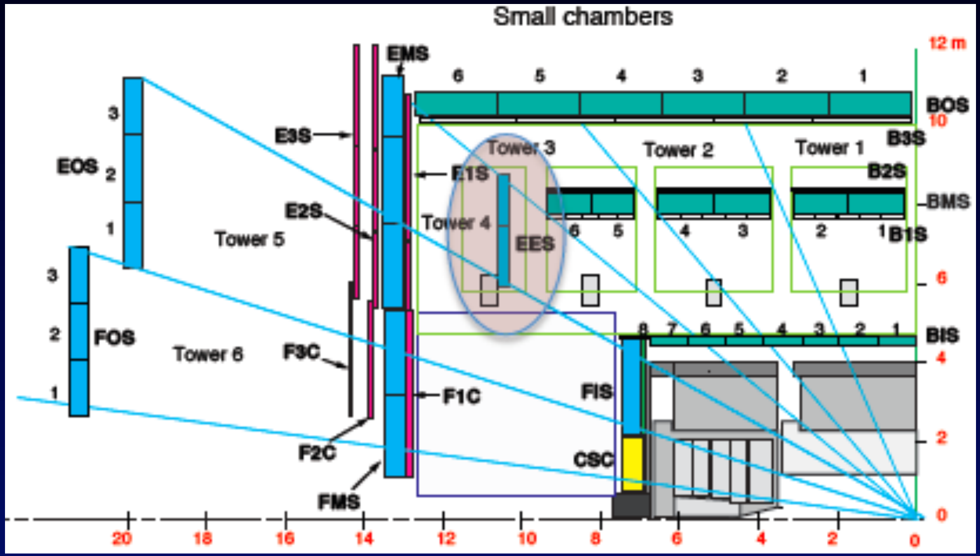
Fake vertex reco. probability for different cuts



Vertex reconstruction efficiency for different cuts



LS1: Muon Spectrometer



- Improvement of momentum resolution in the region $1 < |\eta| < 1.3$
- Improvement of acceptance for high p_T analyses