ATLAS: Data and MC Comparisons for Muon Spectrometer, including Cavern Background

LPCC Simulation Workshop 6 October 2011

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On behalf of the ATLAS Collaboration

Overview

Data and Simulation Comparisons in the Muon Spectrometer

Important for agreement between simulation and data

- Alignment
- Material and energy loss
- Magnetic field

Current Results

- Muon reconstruction efficiency
- Muon momentum resolution
- High p_T muons

Cavern Background – hits from neutrons and photons

- Simulation work
- Data and simulation comparisons

The Muon Spectrometer

Designed to have around 3% momentum resolution over a range of muon p_T, and 10% resolution at 1 TeV
→Requires 50 μm sagitta resolution in a system with 4 technologies, 3 magnets, covering over 10,000 m^3!

Trigger chambers:

RPC Resistive Plate Chambers

TGC Thin Gap Chambers

Precision chambers:

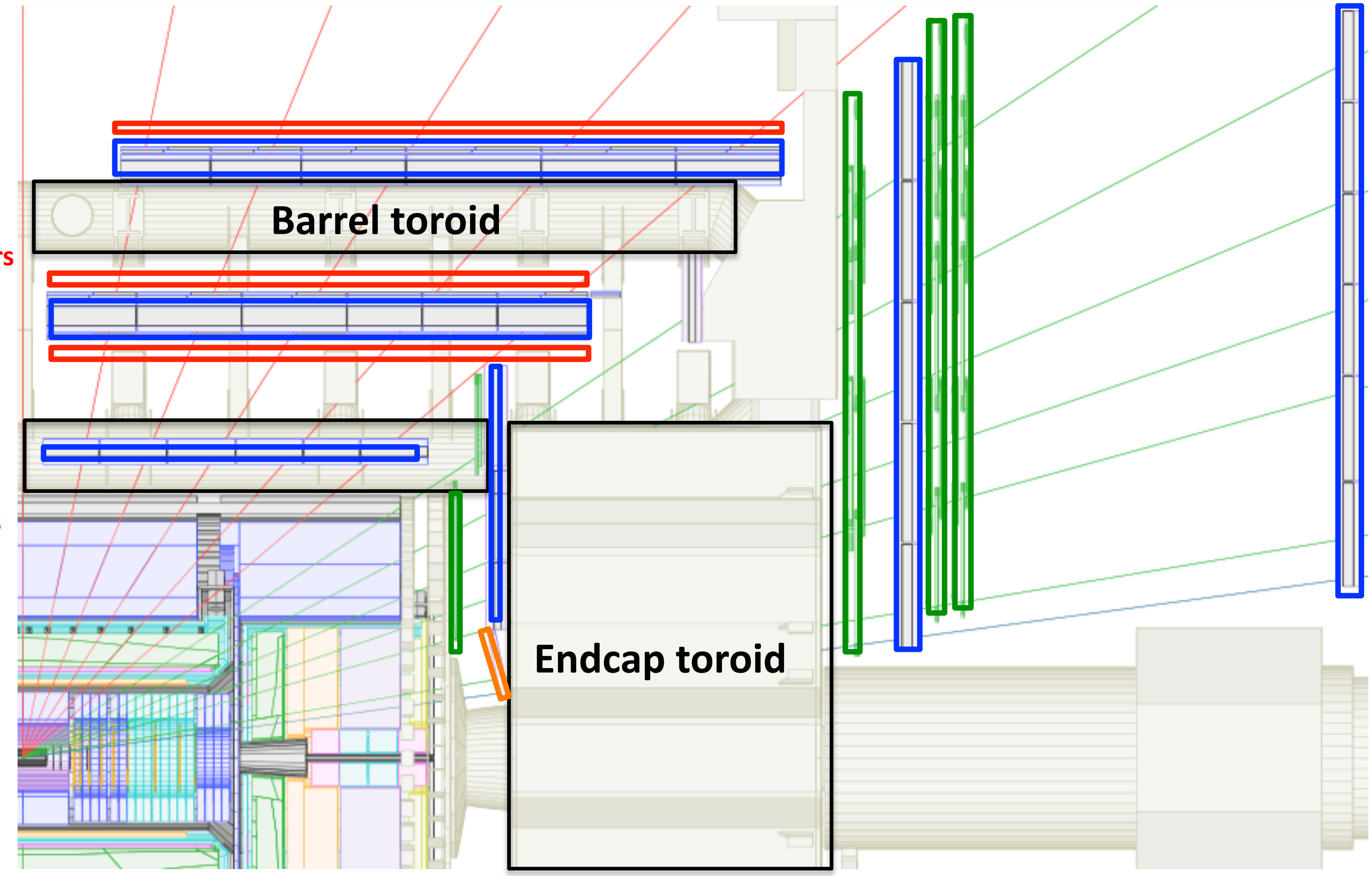
MDT Monitored Drift Tubes

CSC Cathode Strip Chambers

Magnets:

24 coils

Rapidly varying B field



R versus Z view of one quadrant of the Muon Spectrometer

Alignment

Overview

- Target: 10% resolution at 1 TeV

  → relative wire/strip alignment to ~ 40 µm

- Simulation assumes perfect alignment

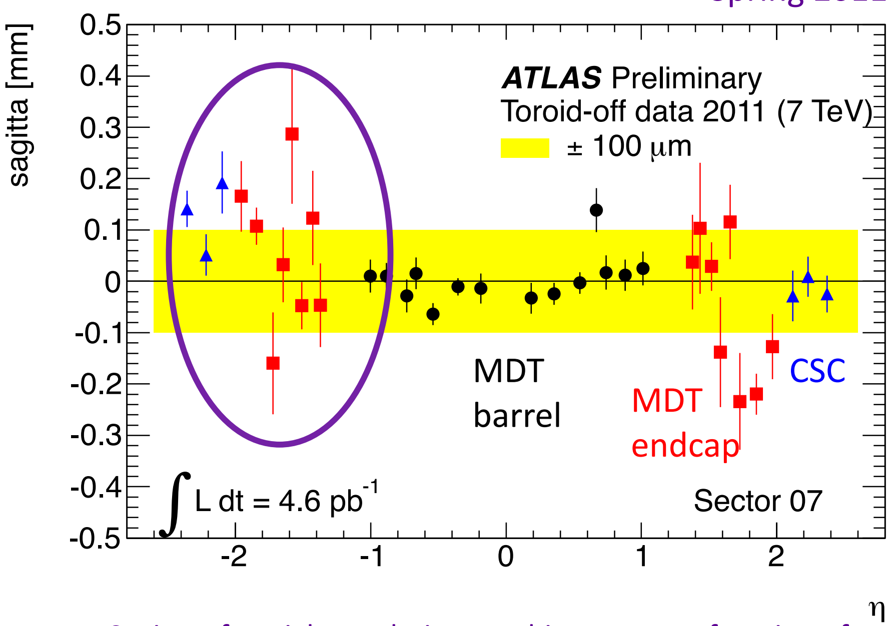
  → for data/MC agreement, need good alignment

- MDT and CSCs: Optically aligned and monitored
- MDT barrel aligned with cosmic rays

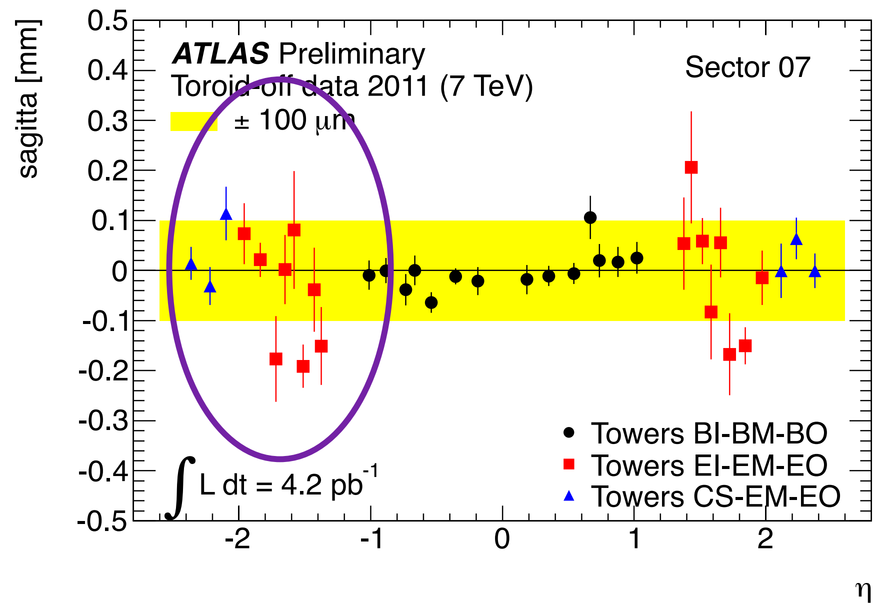
Recent Improvements

- CSC alignment refined with straight tracks
  - 2 runs of 4 pb^{-1} taken with toroid off
  - CSC: straight track sagitta 700 µm → 200 µm
- Refined alignment using optical info:
  - CSC internal alignments included: 200 → 60 µm
  - Inclusion of chamber deformations and thermal expansion in MDT endcaps: 200 →100 µm

Spring 2011



Summer 2011



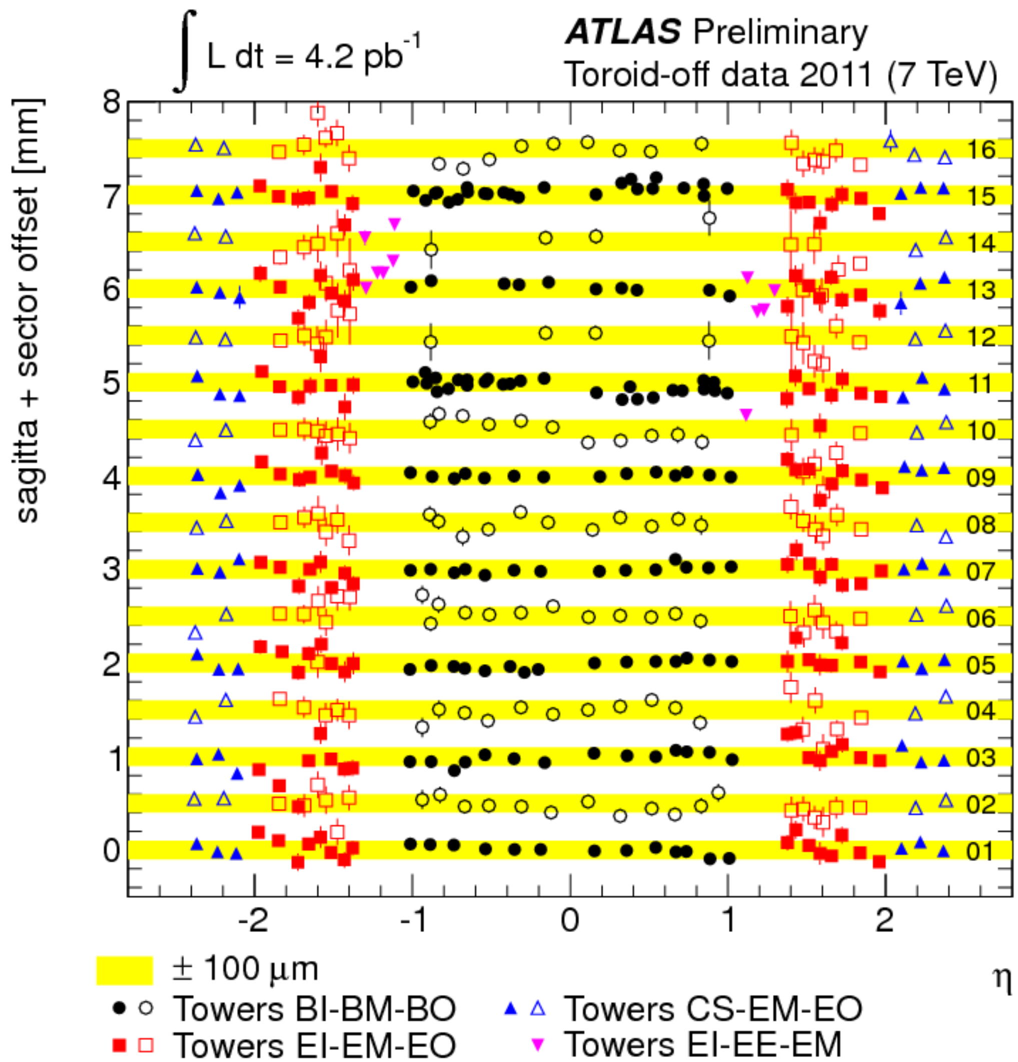
Sagitta of straight tracks in one phi sector, as a function of eta

2 different runs with toroid off show improvement in alignment, particularly in endcaps and CSC

Current Status: Alignment

Status – average bias on q/p_T:

Detector region	σ_{ali}
Barrel	$0.130 \pm 0.005 \pm 0.050\ \text{TeV}^{-1}$
MDT end-caps	$0.174 \pm 0.008 \pm 0.050\ \text{TeV}^{-1}$
CSC end-caps	$0.146 \pm 0.009 \pm 0.050\ \text{TeV}^{-1}$

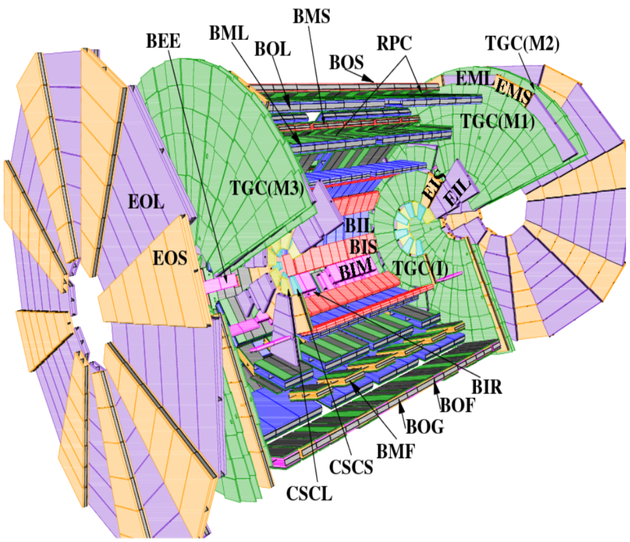


Challenges

- Improve relative alignment to 40 µm
  →more straight track data needed
- Alignment between endcap and barrel
  - No optical link, at 1-2 mm level
  → curved track alignment studies needed
- Alignment between MS and ID

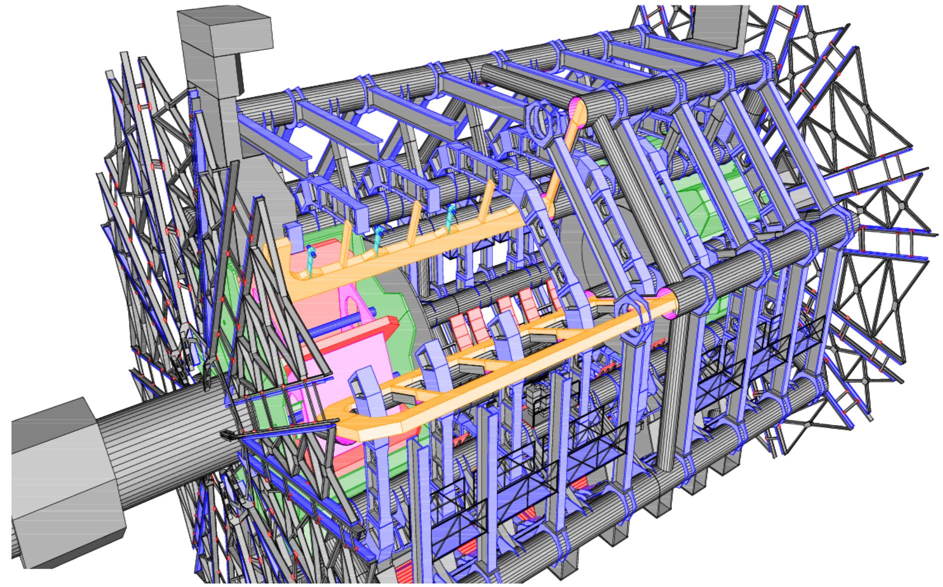
Material Description

Accurate description of material in spectrometer essential for reproducing multiple scattering and energy loss in simulation



active material in Muon Spectrometer

passive material in Muon Spectrometer



Average muon traveling through spectrometer:

- barrel: 3 X_0 total
- endcap: 15 X_0 total

Significant localized passive material:

- 10-20 X_0 for each barrel magnet coil, support
- 30 X_0 through an endcap coil

On-going effort:

- put all passive material into simulation: electronic boxes, support structures…
- recent refinement of rails, trigger boxes in barrel:

→ sagitta resolution in simulation moved from 30% to 20% lower than data

Magnetic Field Mapping

Overview

- highly non-uniform B field
- Target: describe field to ~ 0.003 Tesla
- Method:
  - 1800 B field sensors on toroids and chambers
  - With measurements and precise position of sensors, calculate full field
  - Need mm and mrad precision of sensor location

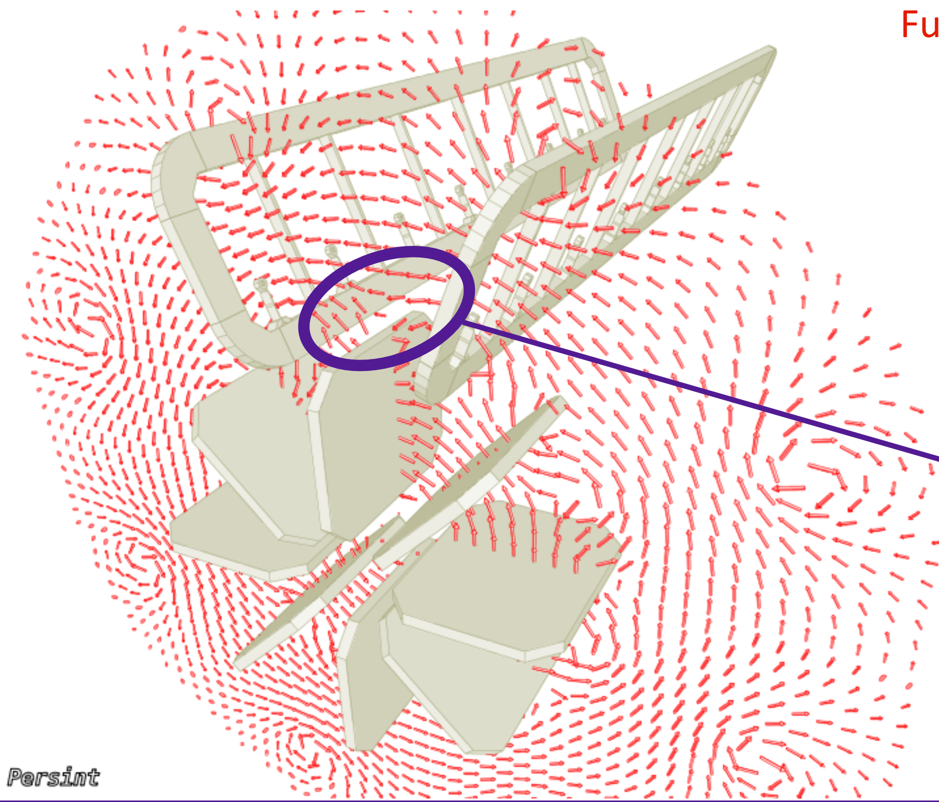
Recent Improvements

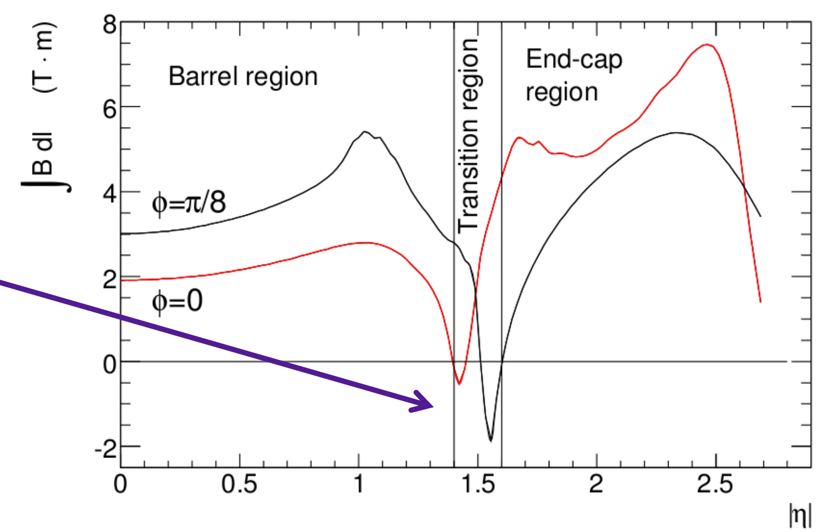
- Simulation map in 2010 assumed 8-fold symmetry in phi and 2-fold symmetry in Z
- New, asymmetric map used in 2011
  - Measurements, positions of 8 barrel toroid coils
  - Accurate global endcap toroid location

  → fixed 8% systematic deviation in p measurement between ID and MS in transition region

Future Improvements (by early 2012)

- Include precise position of endcap coils
- Include perturbations from calo support structure





Challenge for reconstruction: where endcap toroid meets barrel toroid, bending power drops to 0

Data and Simulation: Muon Reconstruction Efficiency

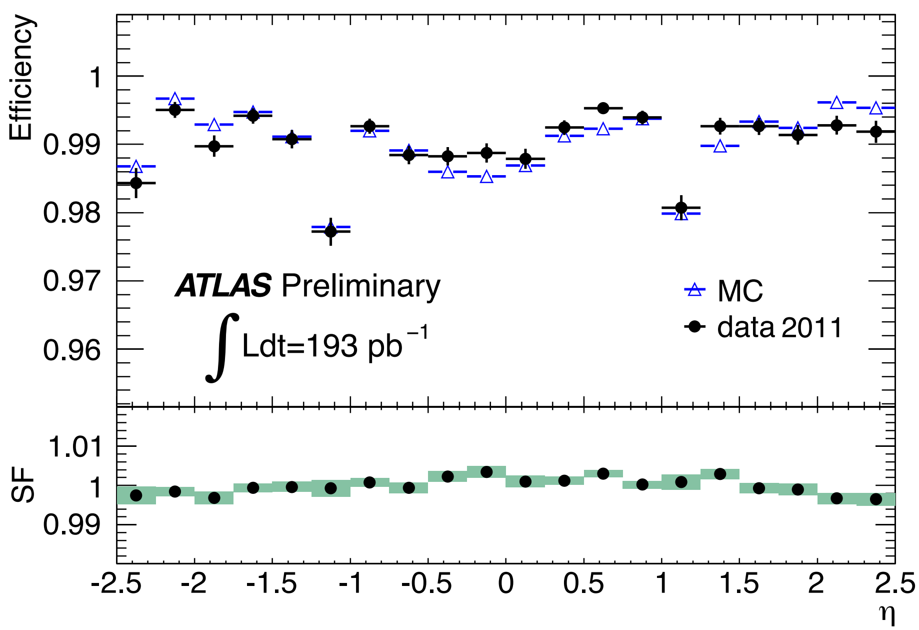
Method

- Efficiency measured with tag and probe method in $Z \rightarrow \mu\mu$ events
- Isolated muons with $p_T > 20$ GeV
- Combined muons = both an ID and MS track

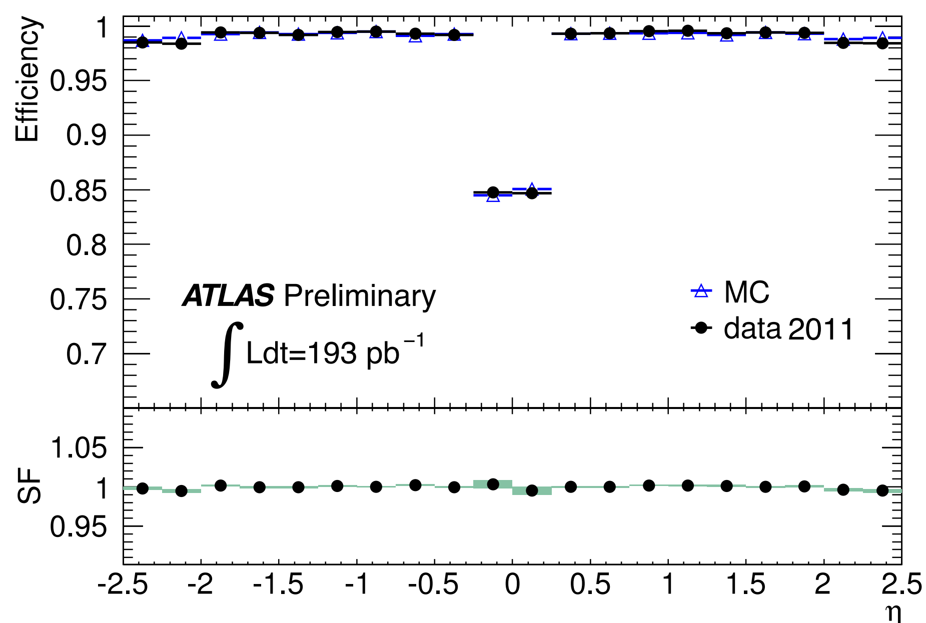
Results

- Muon reconstruction efficiency in ID close to 1 in all regions
- Reco. efficiency for combined muons above 97%
- Simulation models measured efficiency well, as a function of eta

Muon reconstruction efficiency in the Inner Detector measured in $Z \rightarrow \mu\mu$ events



SF = the ratio between data and simulation



Combined muon reconstruction efficiency, with respect to the ID tracking efficiency, measured in $Z \rightarrow \mu\mu$ events

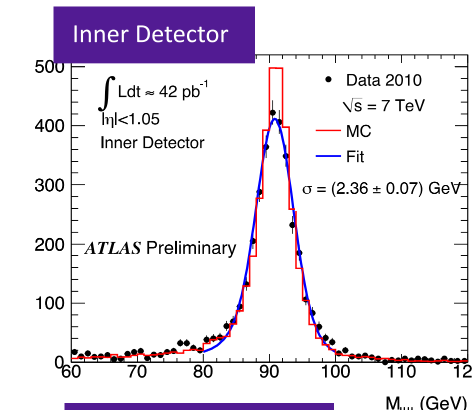
Data and Simulation Performance: Z Mass Resolution

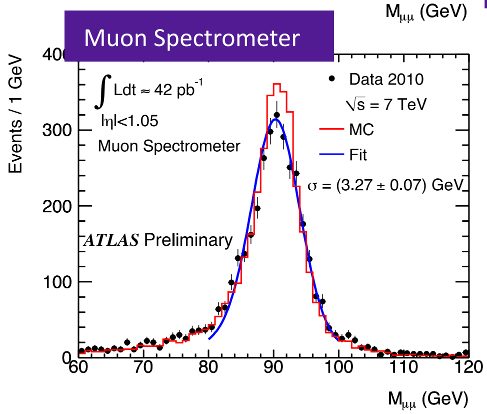
Method

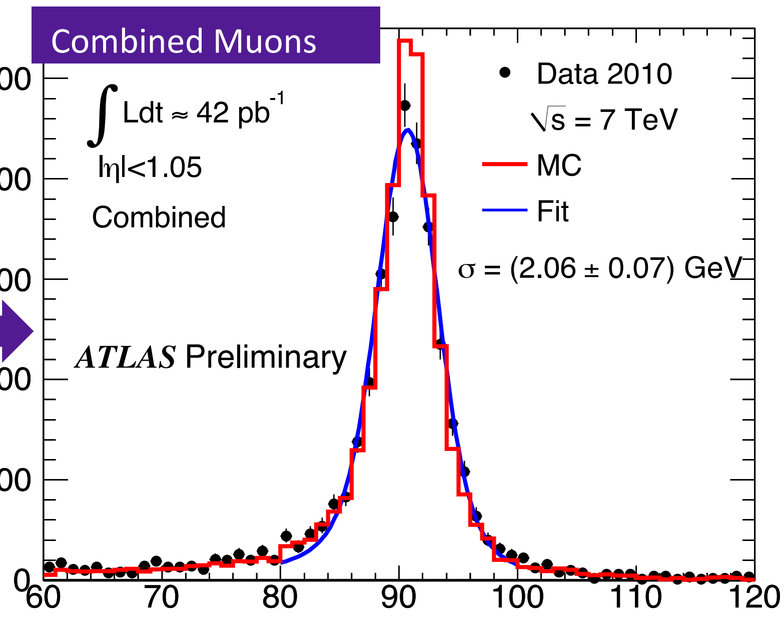
- Z mass resolution measured in isolated, $p_T > 20$, di-muon events
- Combined muons = both an inner detector and muon spectrometer track

Results

- Combined μ mass resolution better than ID or MS alone
- Simulation predicts narrower mass resolution than data. Contributions:
  - Material description (multiple scattering should dominate at these momenta for spectrometer)
  - Magnetic field description (has improved since this study)

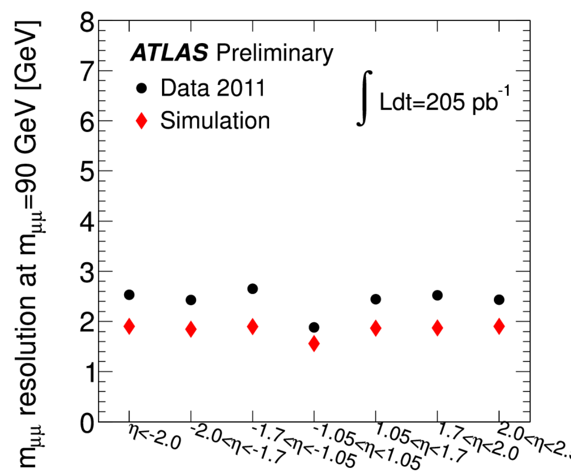






Mμμ (GeV)

Z mass resolution of combined muons in the barrel, which require both an inner detector and muon spectrometer track



Z mass resolution of combined muons as a function of eta regions. The barrel region has the best mass resolution.

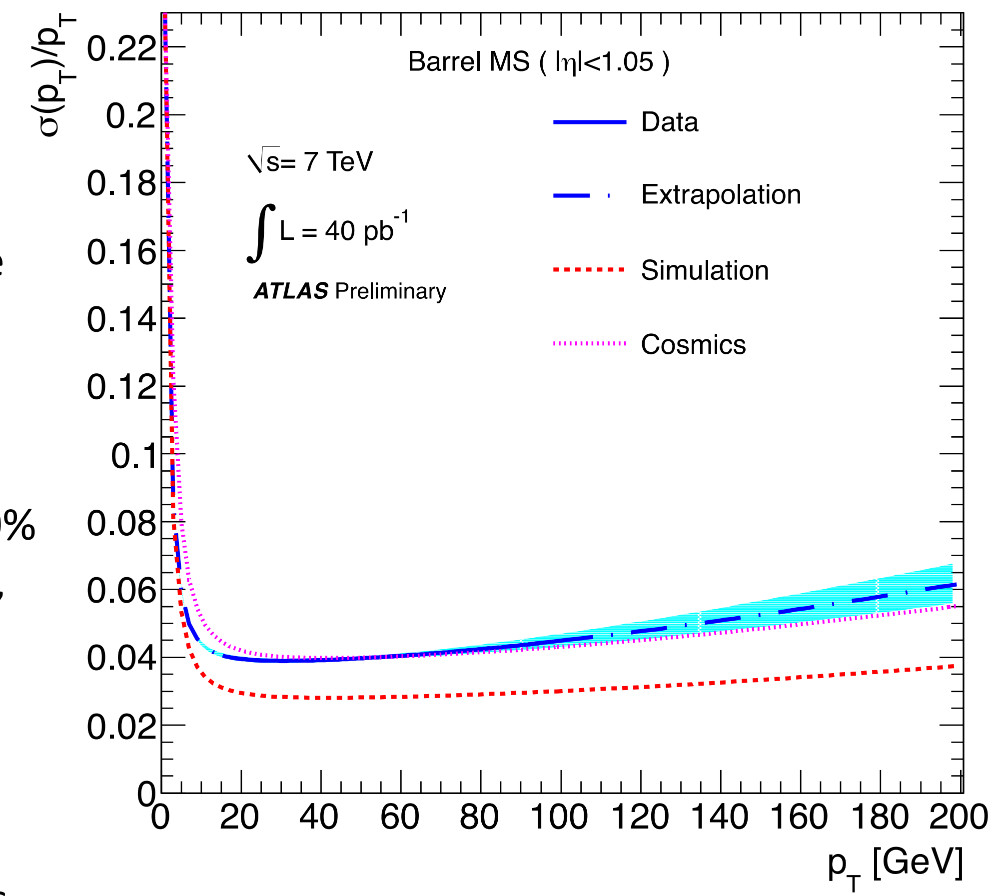
Data and Simulation Performance: High p_T Muons

Method

- In Z→μμ events, measure resolution by changing simulation resolution until Z mass resolution matches data
- In W→μν events, measure resolution in MS relative to ID
- Combine measurements and extrapolate to higher p_T

Results

- MS momentum resolution in data 30-50% worse than simulation where measured, ×2 worse extrapolated to 1 TeV
- Contributing factors:
  - Alignment (has improved since this study)
  - Magnetic field description (also has improved)



Muon Spectrometer momentum resolution curve from a fit to W and Z events, as a function of p_T, in data and simulation

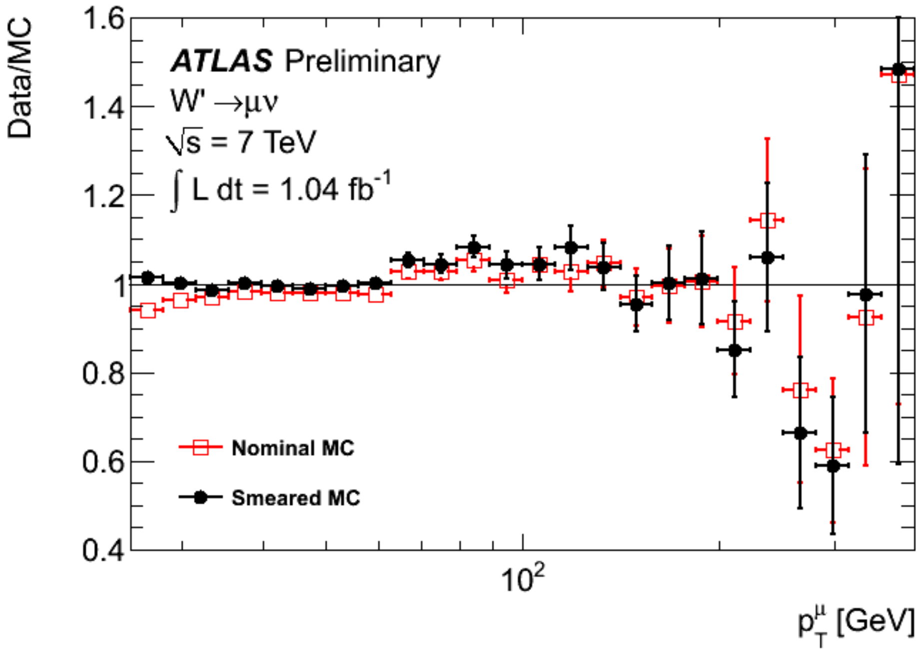
Data and Simulation Performance: High p_T Muons

Method

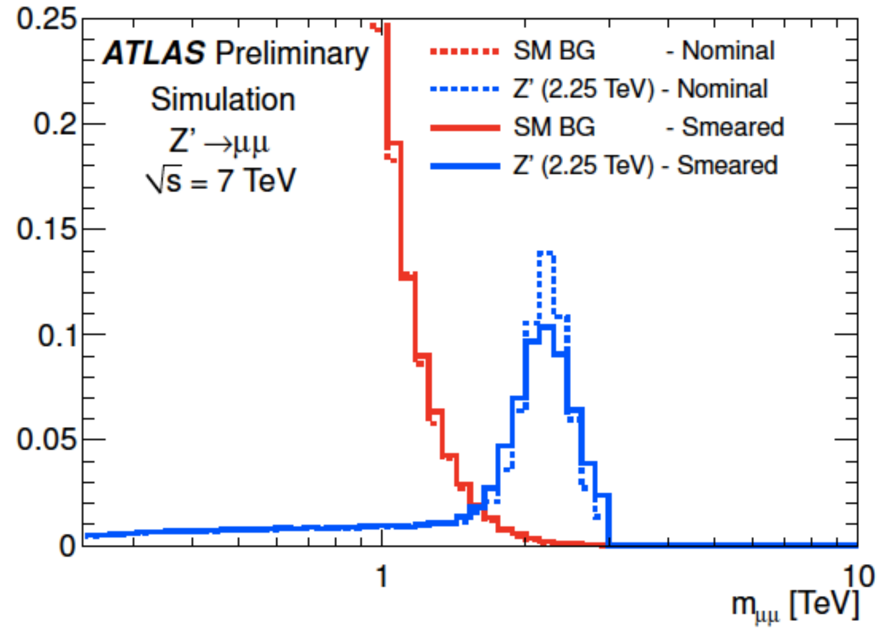
- Smear momentum resolution in simulation to match resolution measured in data

Results

- Smearing improves data/simulation agreement in W' search at low p_T
- Smearing has only minor impact on sensitivity of high p_T searches



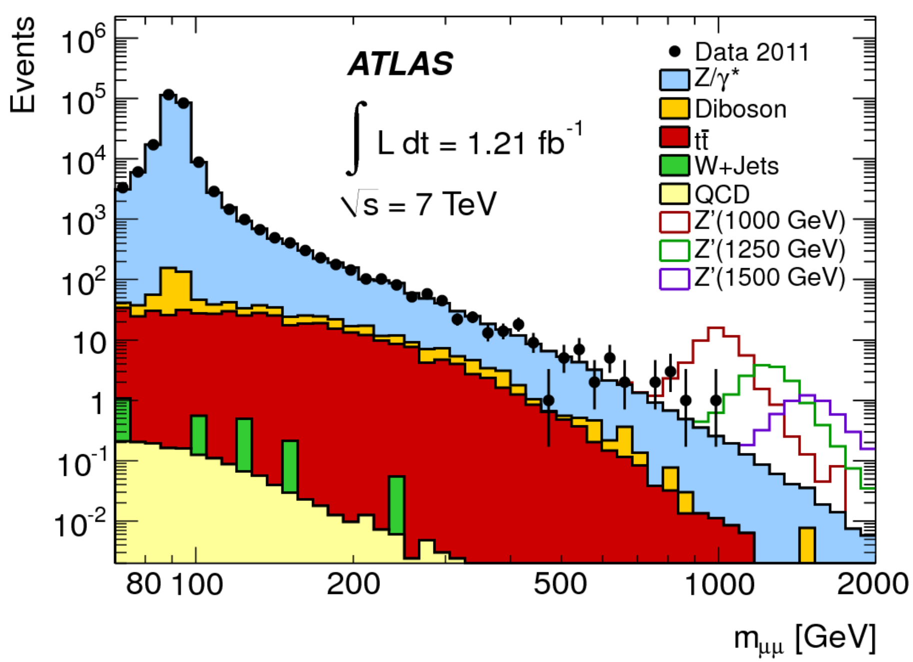
Ratio between data and MC for W' search before and after momentum smearing of simulation

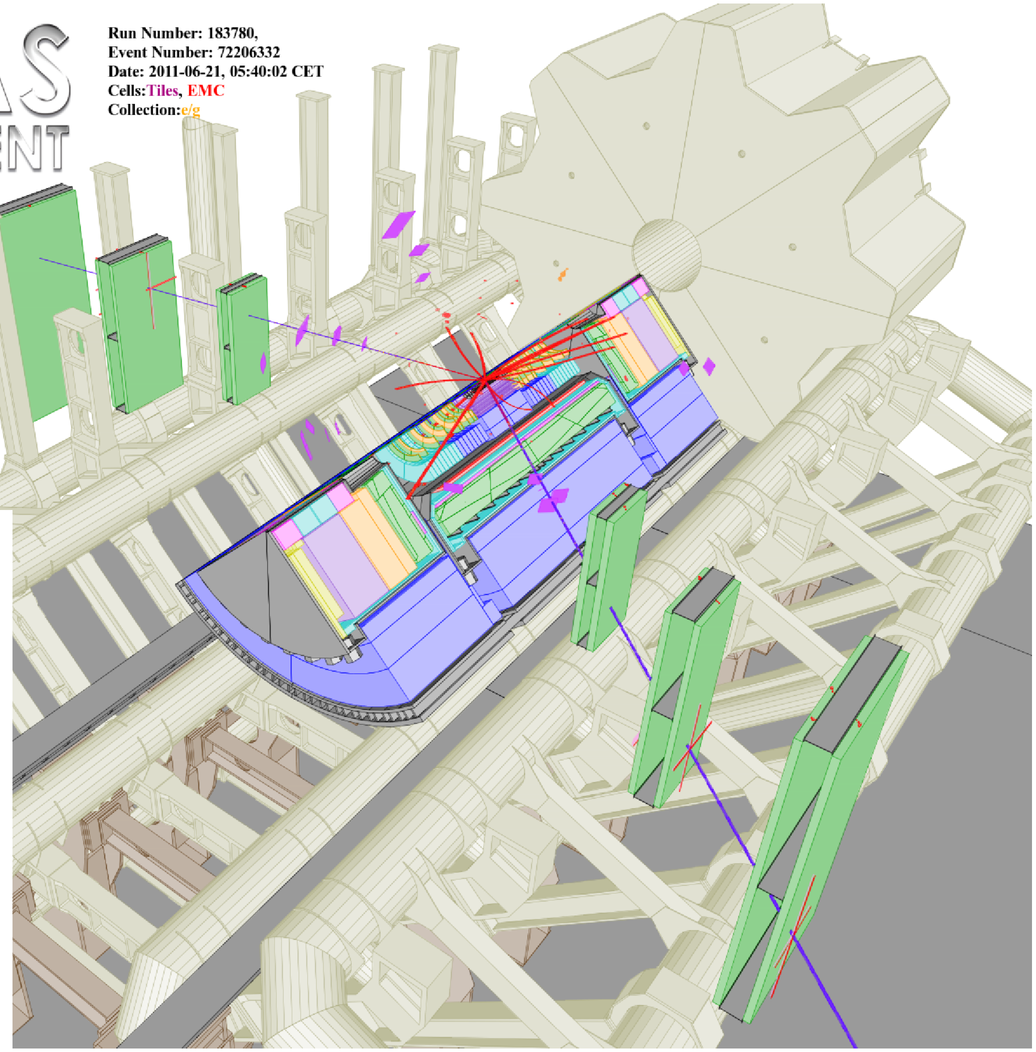


Z' signal and background shapes before and after smearing

Data and Simulation Performance: High p_T Muons

After full corrections to simulation, good agreement between di-muon data and Pythia Z/γ* simulation





Event display for di-muon event with highest invariant mass (960 GeV)

Cavern Background

Overview

- Low energy neutrons and photons interact in muon system
  → majority of occupancy in spectrometer
- Understanding rate and distribution essential
  - Predict spectrometer and trigger performance at higher luminosities
  - Prepare for potential upgrades in high rate regions

Present Efforts

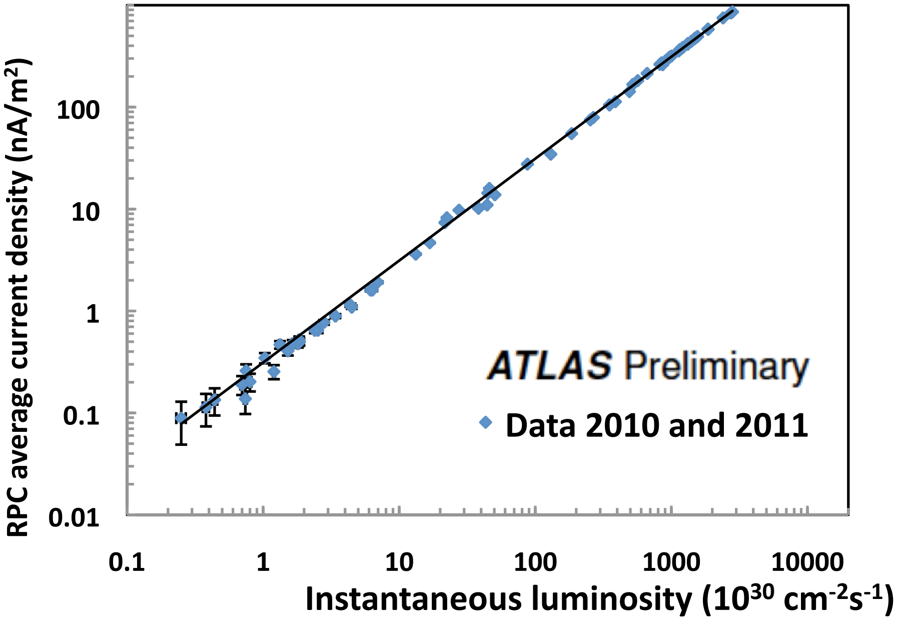
Data:

- monitor overall hit rate in MDT and CSCs
- monitor the HV current on RPC, MDT, and TGC chambers

Simulation:

- FLUGG-based approach
- Geant-4 based approach

Change in RPC current density between presence of beam and no beam as a function of luminosity shows a linear relation between total particle flux and luminosity



Simulation of Cavern Background

Full production of FLUGG and Geant4 samples and comparisons to data underway

Method for validating FLUGG flux predictions:

Generator
Pythia8 (tune4c)

→ **FLUGG**
Geometry: Geant4
Physics: FLUKA

→ **Flux Spectrometer entrance**
Particle type, energy, position, direction

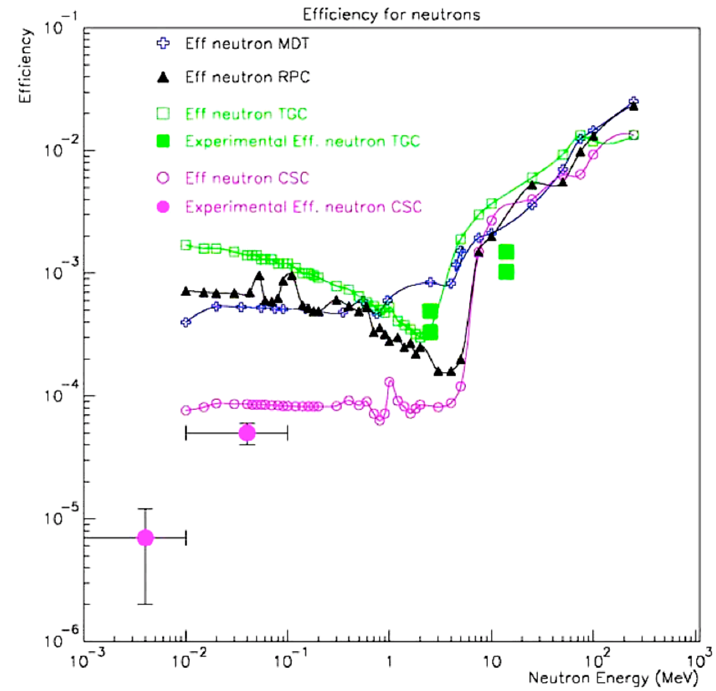
→ **Predicted Hit Rate**
Flux convoluted with detector sensitivity

Flux production same as for full simulation processing

Instead of Geant4 digitization of hits in spectrometer, convolute flux with detector sensitivity

Method

- Overlap events to get correct time structure
- Convolute flux at spectrometer entrance with detector sensitivity
  - Need reasonable estimates of detection efficiency for neutrons and photons across many decades of particle energy
  - Detector sensitivity taken from smooth fit to measurements and predictions from Geant3, GCALOR, and FLUKA



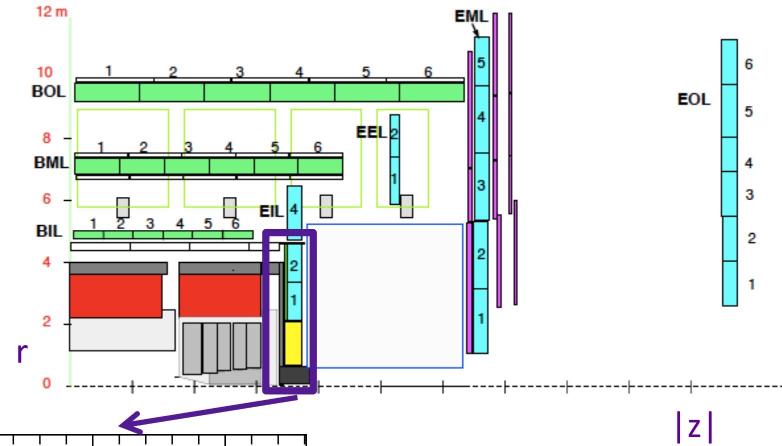
Data and Simulation: Cavern Background

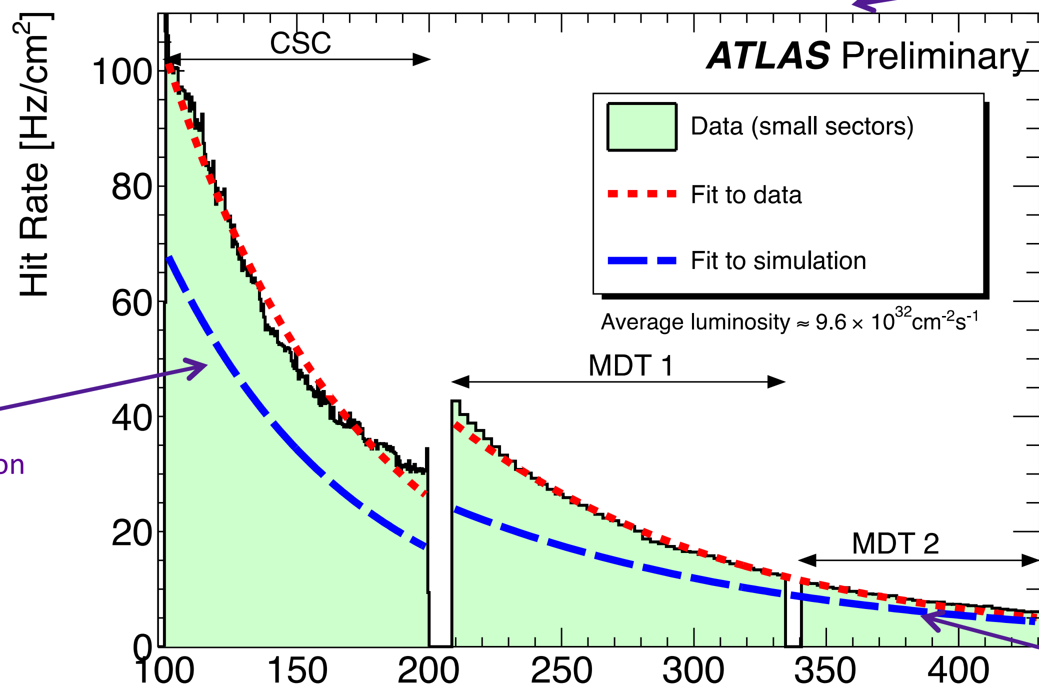
Data

- in MDT and CSC detectors, measure hit rate as a function of position
- monitor as luminosity increases and beam structure changes

Simulation

- Use FLUGG flux prediction convoluted with detector sensitivity





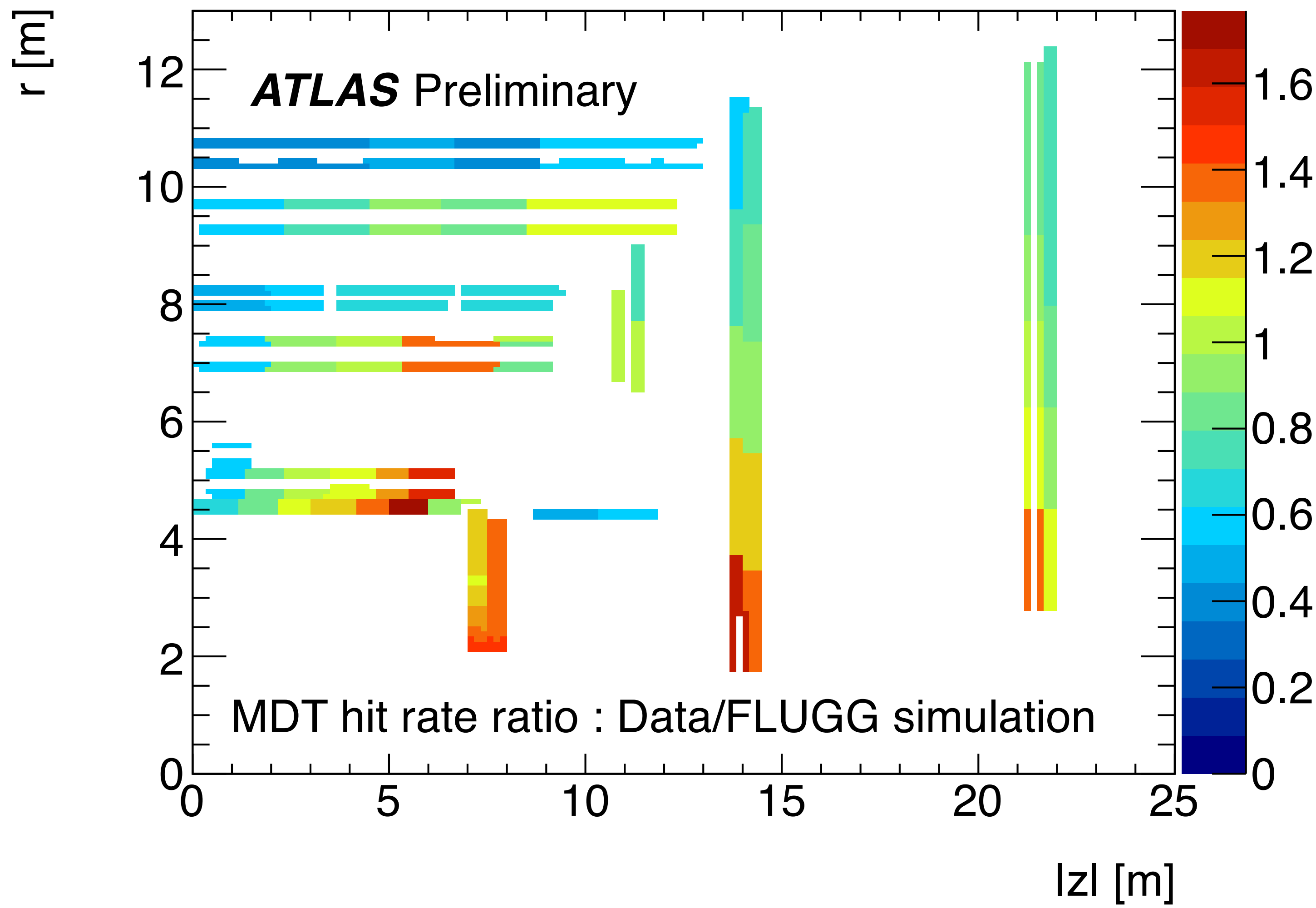
Simulation normalization may differ for CSCs

Absolute simulation normalization for MDTs

Data Hit Rate and Simulation Prediction for CSC and MDT chambers closest to the interaction point at L ≈ 10^{33}

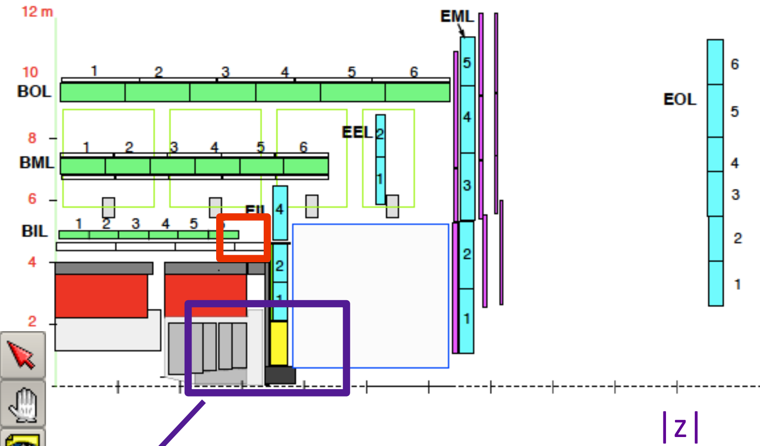
Data and Simulation: Cavern Background

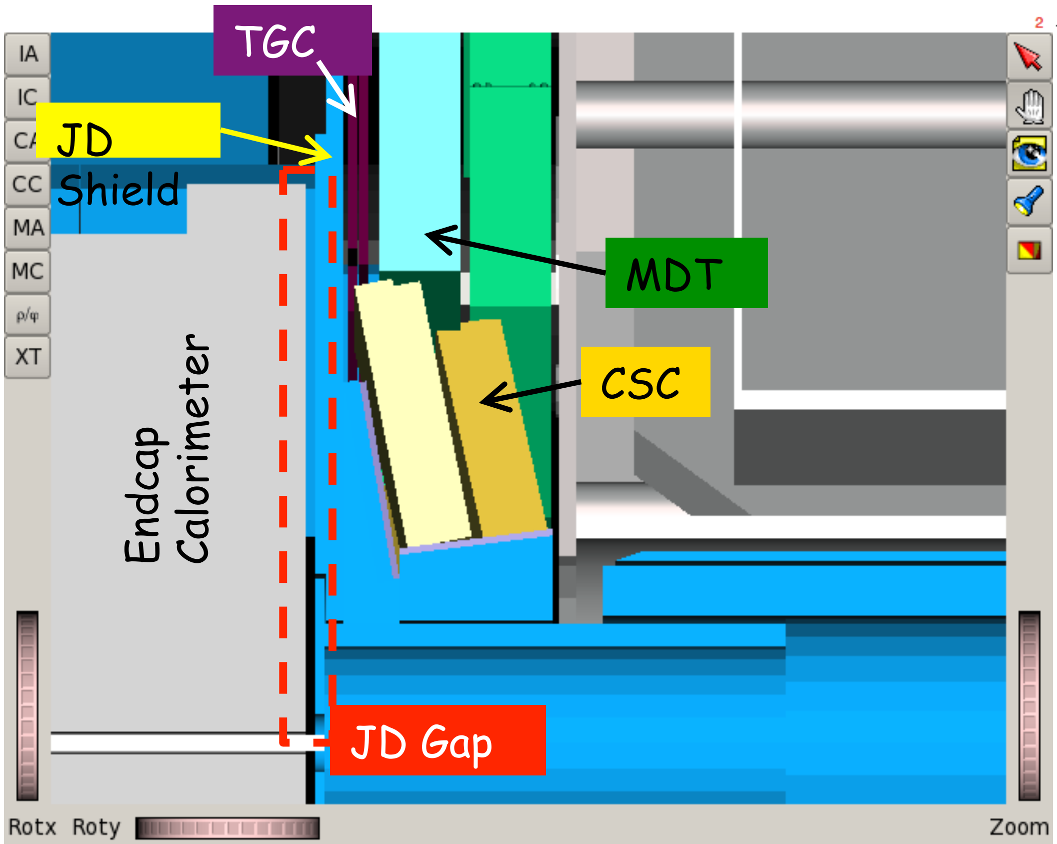
- FLUGG hite rate (= flux × sensitivity) and data agree within a factor of 2 everywhere in MDTs
- In early studies, safety factor of 5 was used



Simulation Geometry

Flux prediction is sensitive to small geometry changes in shielding





- Comparisons to data revealed initial discrepancy at z ≈ 6.5 m where hit rate was very high in data
  - discovered shielding not installed as planned
  - Particles stream from gap in shielding
- After adjusting simulation geometry, agreement improved significantly

→Improvement in shielding planned for winter 2011-2012 shutdown

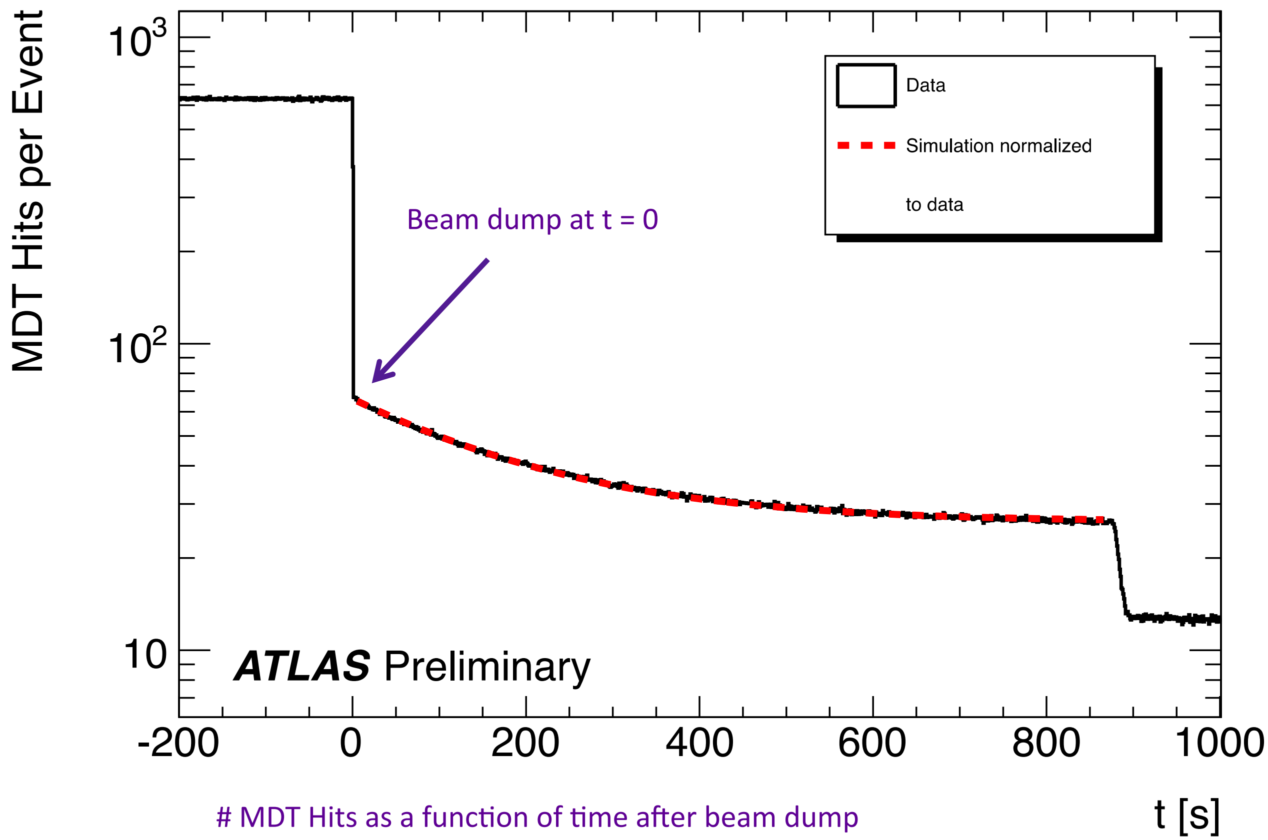
Data and Simulation: Detector Activation

Method

- In special runs, keep MDT HV on after planned beam dump
- Monitor hit rate after loss of beam (immediately lose 96% of hit rate)

Results

- Hit rate displays a ~ 200 s lifetime
- well reproduced by FLUGG flux prediction × detector sensitivity



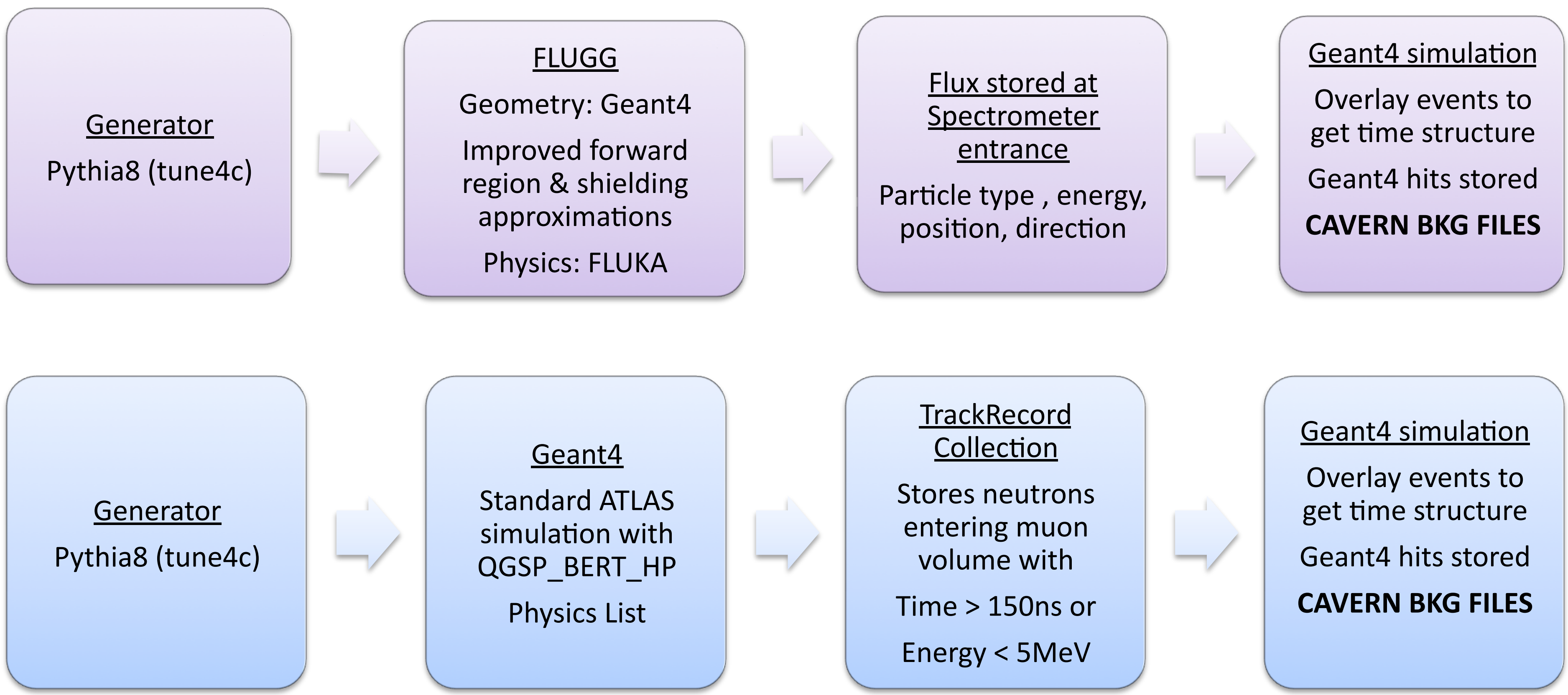
MDT Hits as a function of time after beam dump

Simulation of Cavern Background

Full production of FLUGG and Geant4 samples and comparisons to data underway

First test of digitization in ATLAS muon system of low energy neutrals

(See J. Chapman's talk for details)



Summary

Important for agreement between simulation and data

- Alignment — relative alignment to 50-100 µm, further improvement with more straight tracks
- Material and energy loss — sagitta resolution improving as description is refined
- Magnetic field — large array of B field sensors, refinement of sensor location improve field description

Current Results

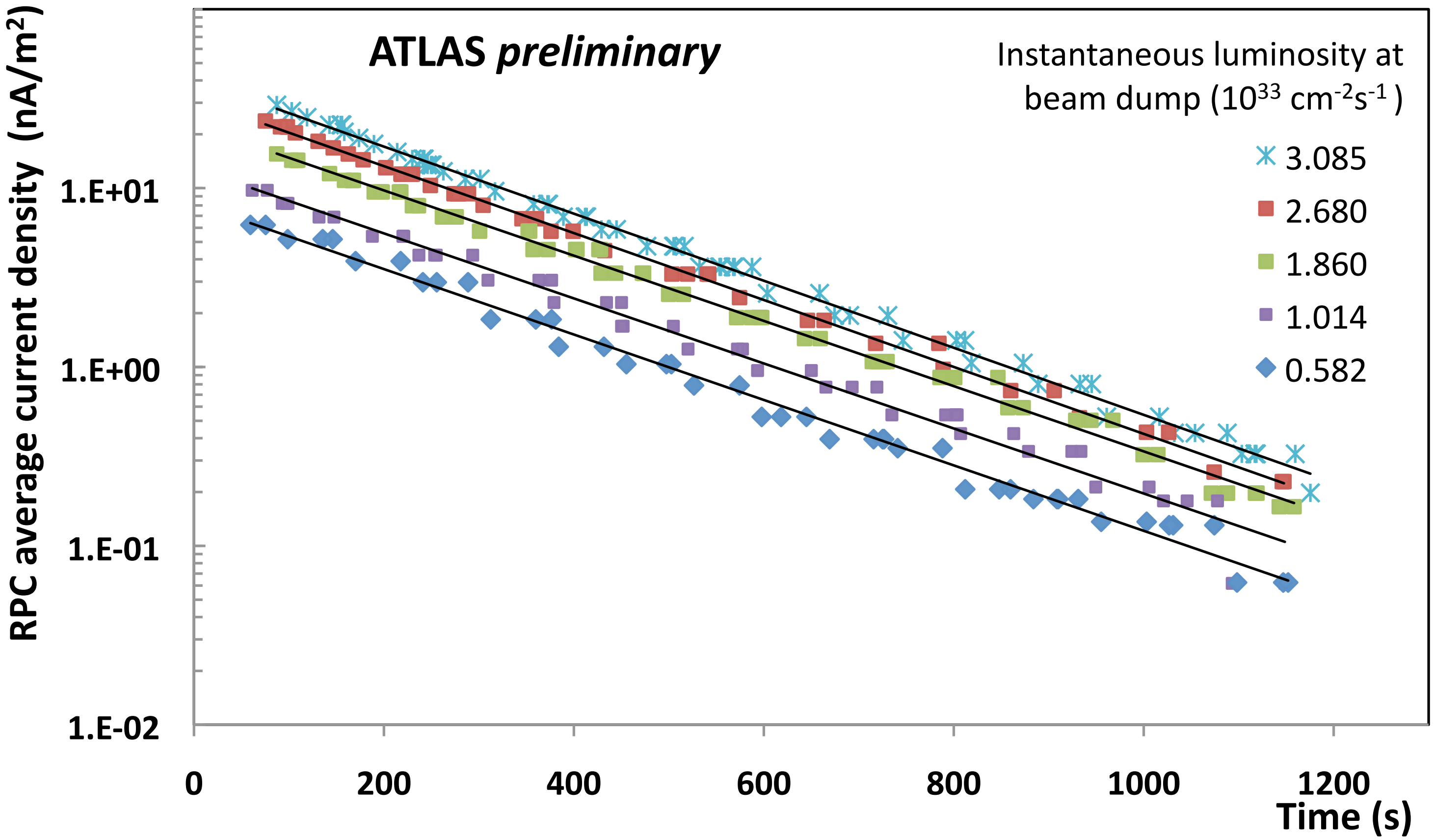
- Muon reconstruction efficiency — described to > 1% by simulation
- Muon momentum resolution — 4% at Z peak, improvements from material description in near future
- High p_T muons — 15-20% at 1 TeV, expected improvement from magnetic field and alignment work

Cavern Background – hits from neutrons and photons

- Simulation work — Geant4 and FLUGG, intermediate study using FLUGG flux and detector sensitivity
- Data and simulation comparisons — hit rate agreement to within a factor of 2 everywhere
  study of luminosity dependence of hit rate and reconstruction performance ongoing for upgrade planning

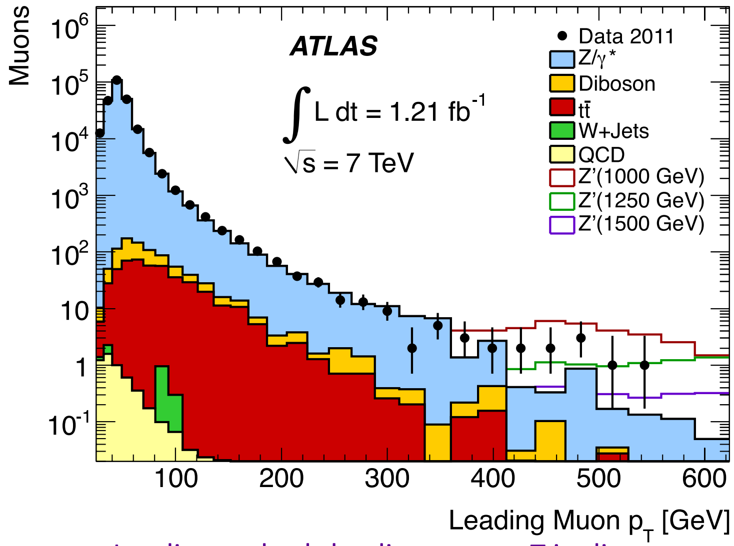
BACKUP

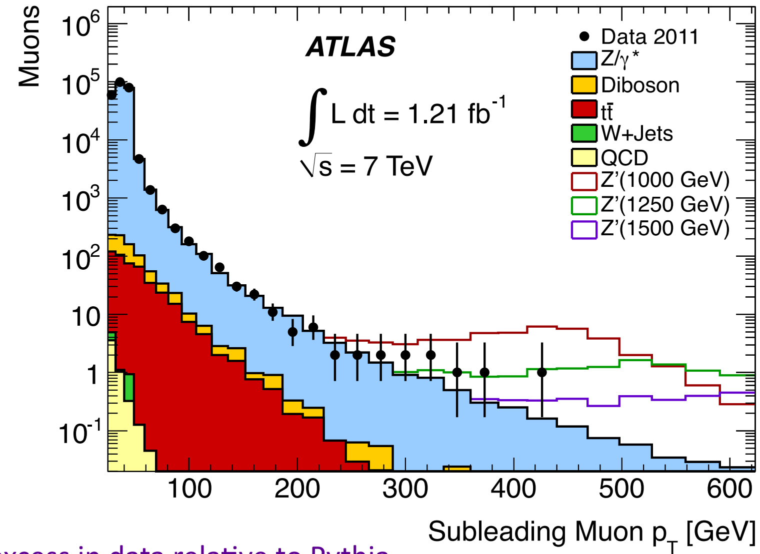
Cavern activation measurement in RPCs



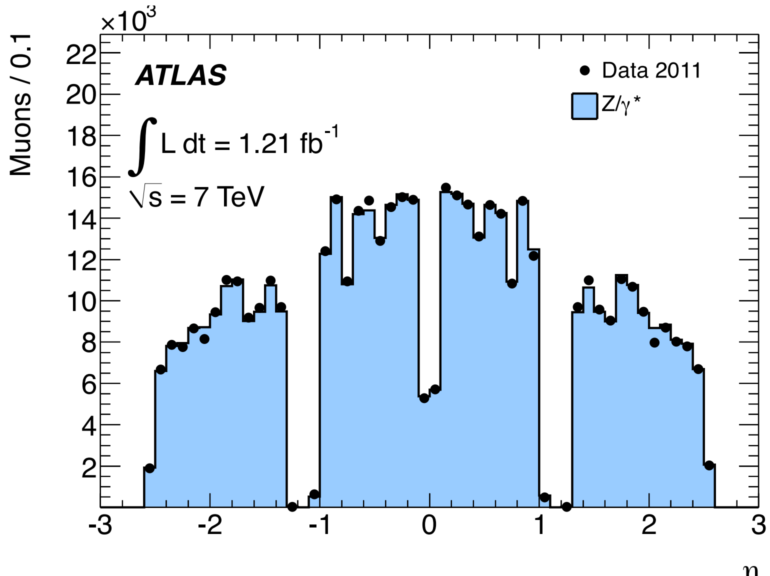
RPC average current density trend after the beam dump for different instantaneous luminosities.
The time is measured in seconds after the beam dump. The trends are fitted with an exponential decay function $y = A_0 * \exp(-t/\tau)$.
The decay rate is almost independent from the instantaneous luminosity and has an average estimated value of $\langle \tau \rangle = (234 \pm 1)$ s. The amplitude A_0 is directly proportional to the luminosity.

Data and Simulation performance: high pT muons

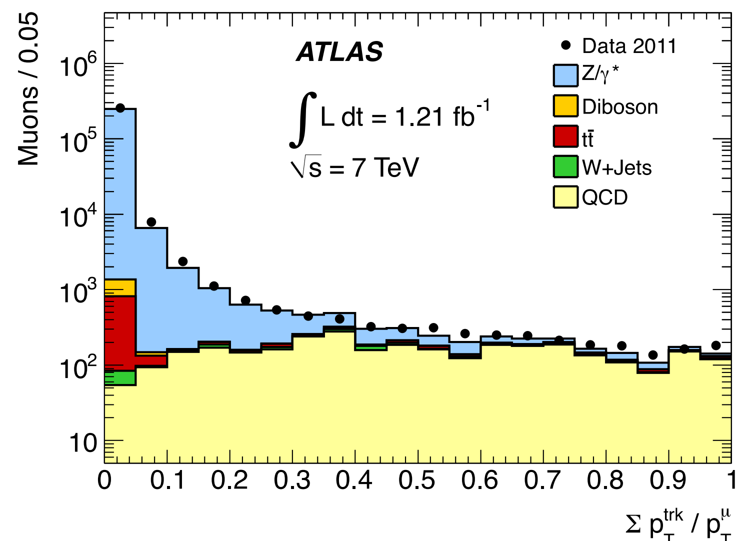




Leading and sub-leading muon pT in di-muon events have a small excess in data relative to Pythia simulation (shown), but agreement with ALPGEN simulation is much better (not shown)



The eta distribution of muons in di-muon events is well modeled



The track-based isolation of muons
QCD from Pythia, scaled by 0.5

Simulation in the Muon Spectrometer

Generator produces muons
Pythia, MC@NLO…

→

Simulation of muons through ATLAS
Geant4 steps muons through detector

→

Hits
Particle type , energy, position, direction stored by Geant4

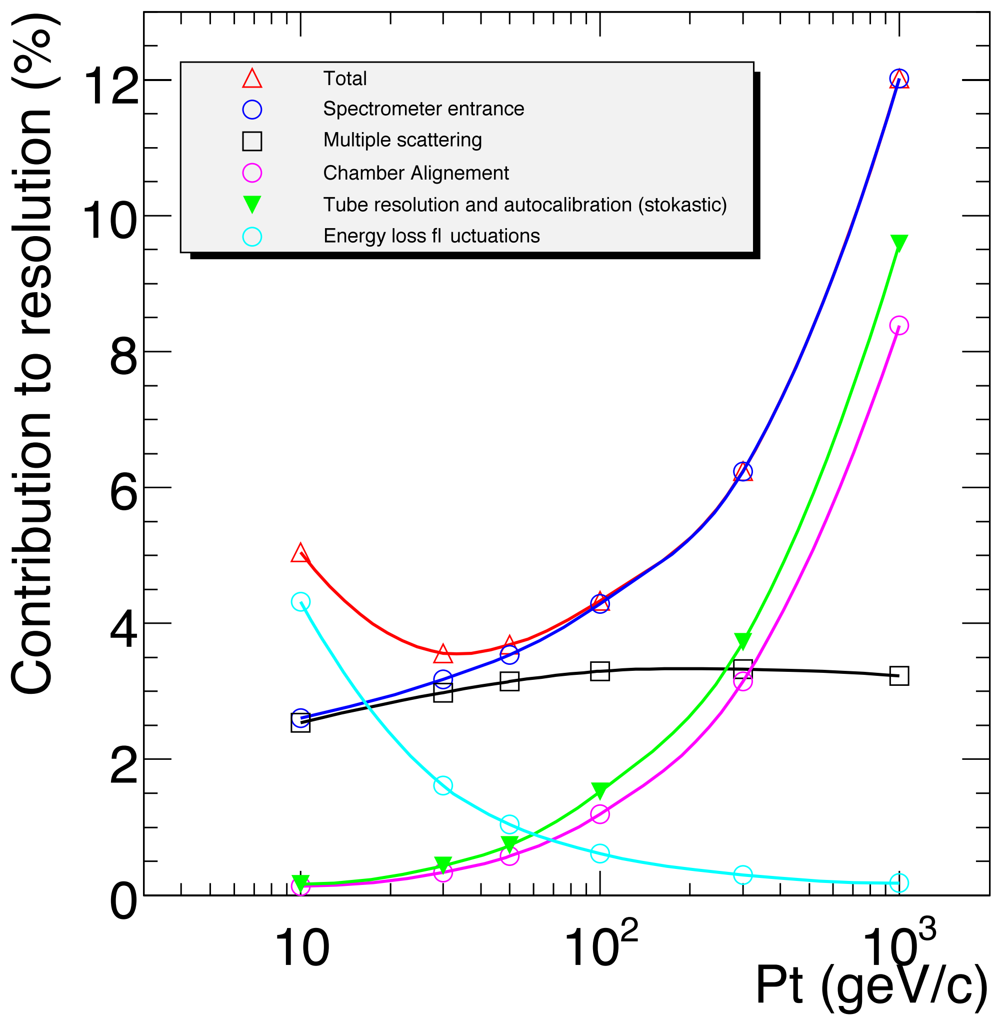
→

Digitization
Detector response simulated
Sub-detector specific

Challenges in Digitization:

- MDT
  - Reproduce the single hit resolution
    - Currently, simulate from cluster formation, diffusion, and electronic response time
    - Alternative: use resolution function measured on data
- RPC
  - Reproduce single hit efficiency and cluster size
- CSC
  - Simulate cross-talk between layers

Muon Spectrometer Momentum Resolution (TDR)



Historical Overview

Past

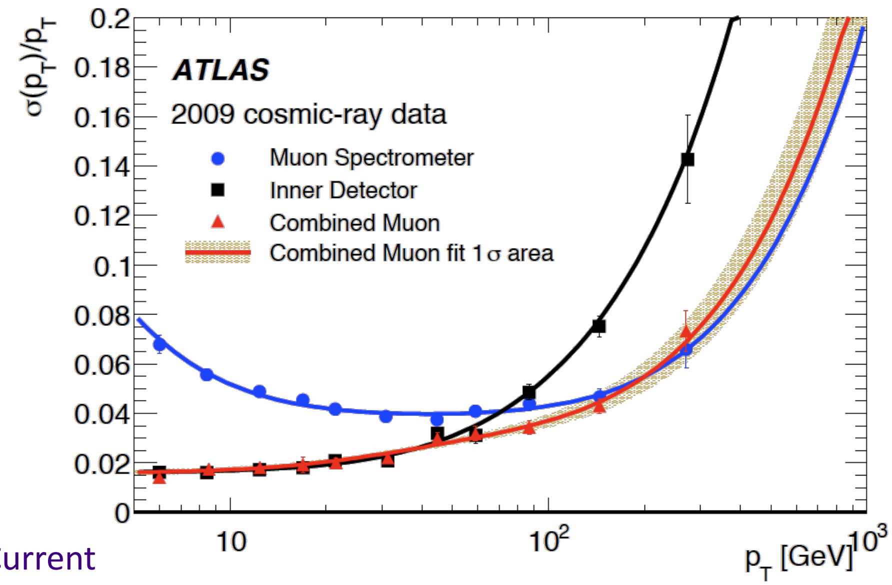
Cosmic ray data: first data-driven alignment, timing, energy loss, and momentum resolution measurements

Beam Splash events: used for tuning timing calibrations

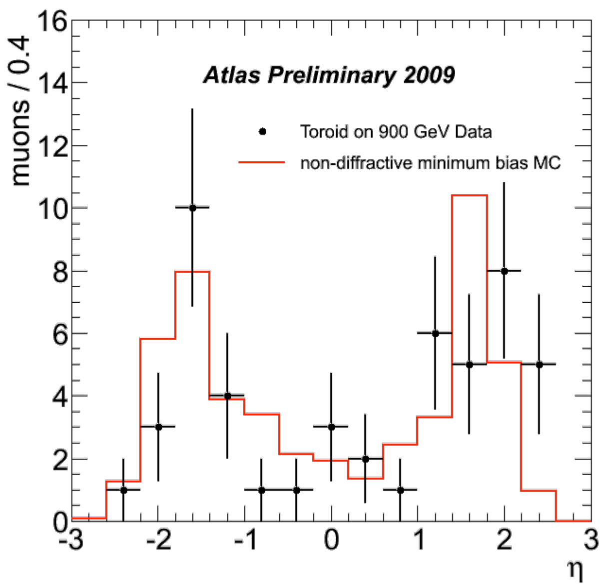
2009 data: first collision-based data and simulation comparisons

2010 data: great progress in alignment, magnetic field mapping, timing calibrations, material description, and first collision-based data and simulation comparisons at 7 TeV

First measured muon resolution in ATLAS from cosmic data



First collisions at 900 GeV allowed early MC to data comparisons



Current

2011 data:

continued improvement in alignment with dedicated runs taken with solenoid on and toroid off

improvements to material description and magnetic field description

Future

Continue improvements to simulation and reconstruction

As luminosity increases, presence of cavern background becomes important for muon reconstruction and trigger

Ongoing efforts in data measurement and simulation of cavern background