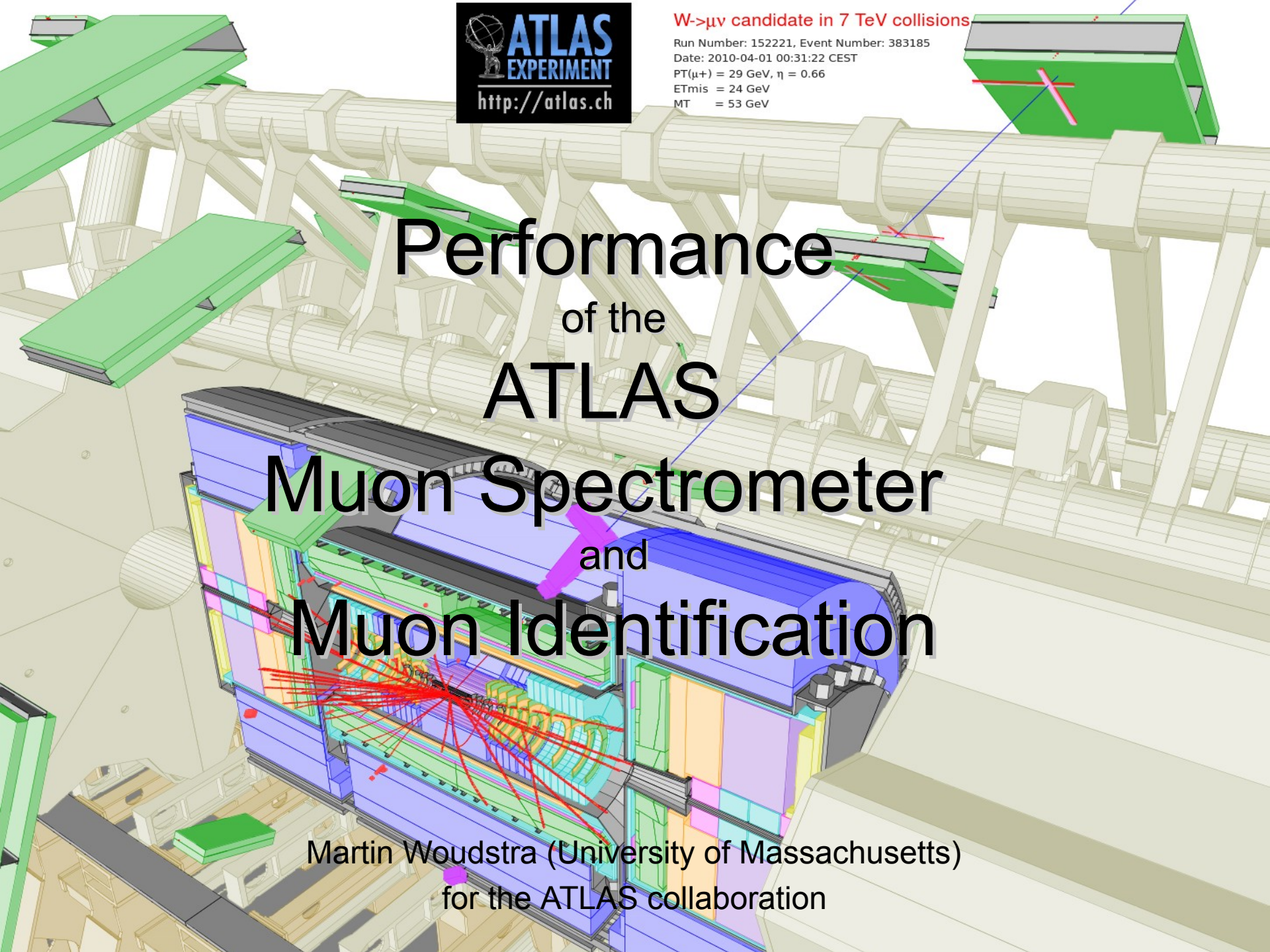
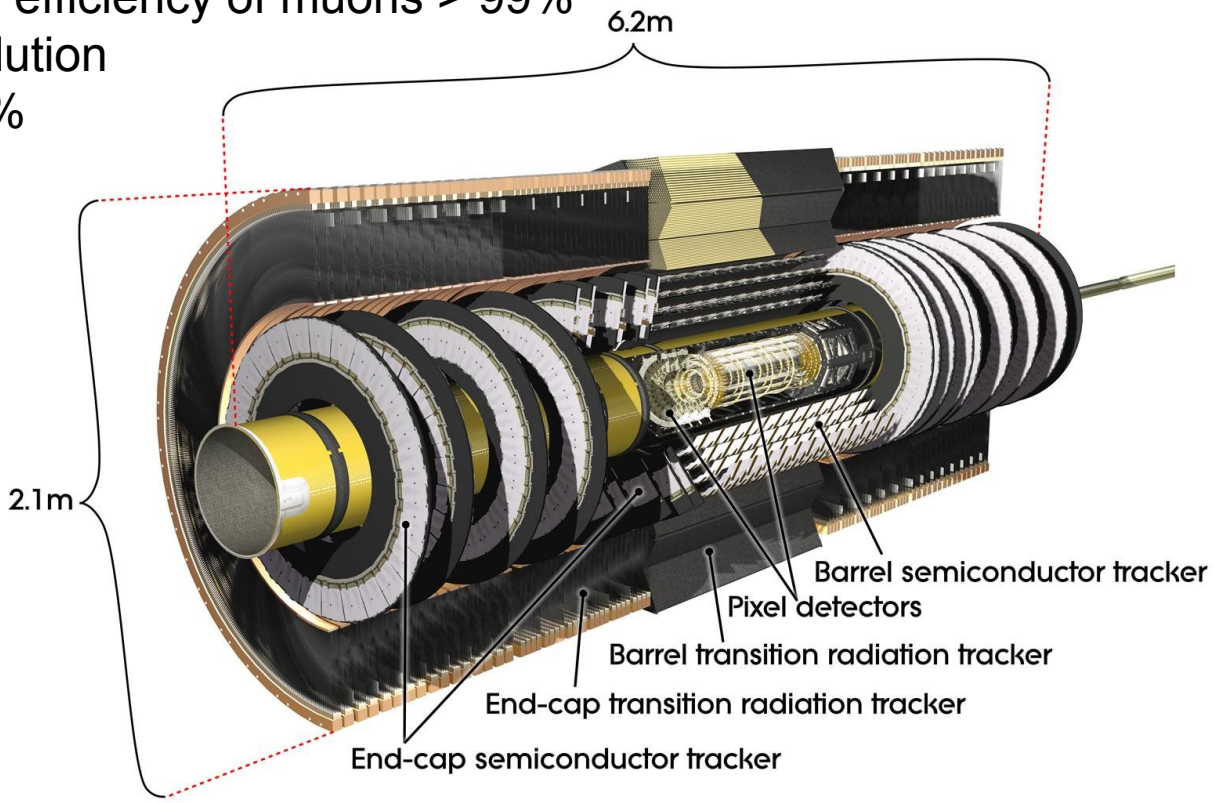


Performance of the ATLAS Muon Spectrometer and Muon Identification

Martin Woudstra (University of Massachusetts)
for the ATLAS collaboration

Inner Detector (ID)

- Solenoidal magnetic field of 2 T
- 3 sub-detectors:
  - Silicon Pixels, Silicon Strips (SCT), Transition Radiation Tracker (TRT)
- Covers $|\eta| < 2.5$ (2.0 for TRT)
- Designed for tracking efficiency of muons > 99% with momentum resolution
  $\sigma_{pT}/p_T = 0.05\%\ p_T \oplus 1\%$

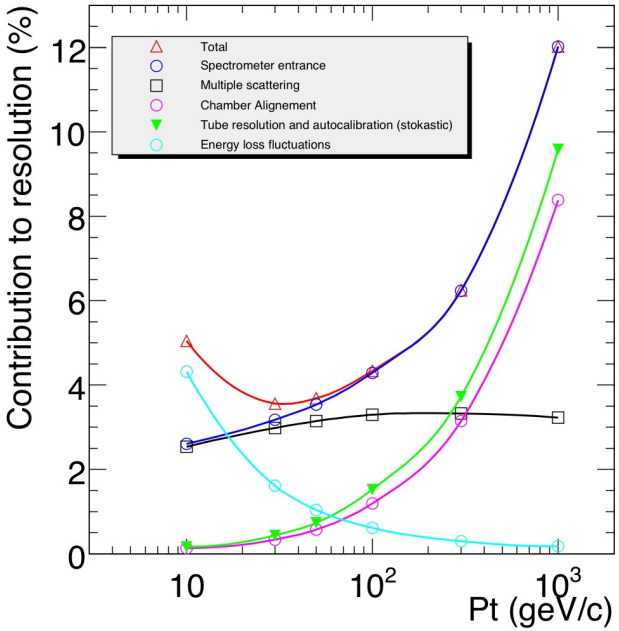


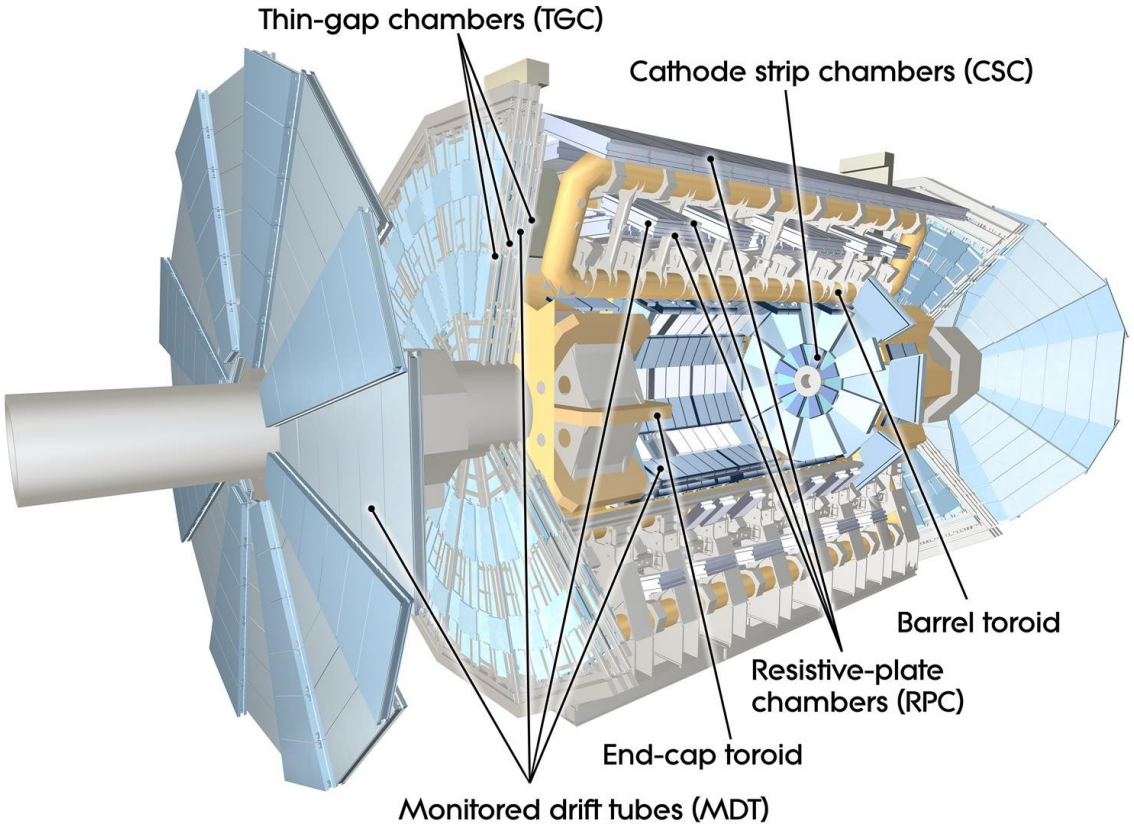
Muon Spectrometer (MS)

- Toroidal magnetic field of 0.5 T by 8 barrel coils + 2 x 8 end-cap coils
- 2 trigger chamber technologies: RPC (barrel), TGC (end-caps)
- 2 precision tracking technologies: MDT, CSC (high occupancy)

- coverage $|\eta| < 2.7$

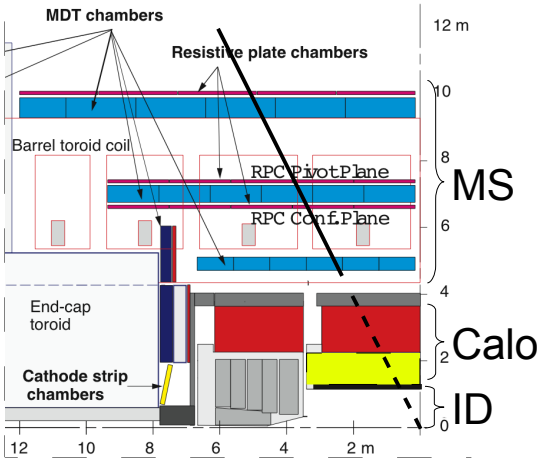
Transverse momentum resolution



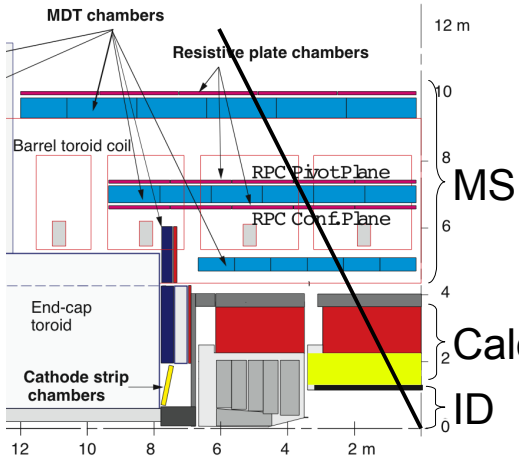


Muon Identification Algorithms

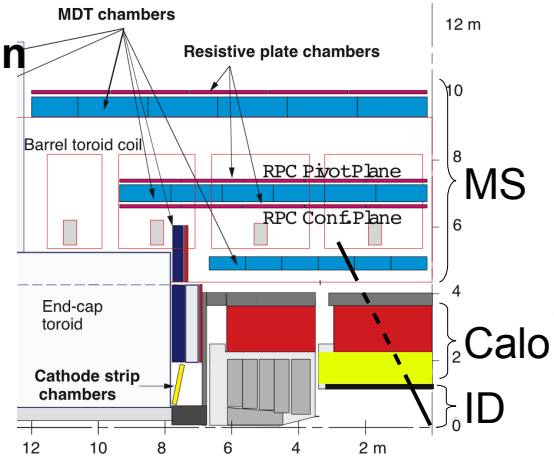
Standalone Muon
track in MS
extrapolated to IP
corrected for
Calo E-loss



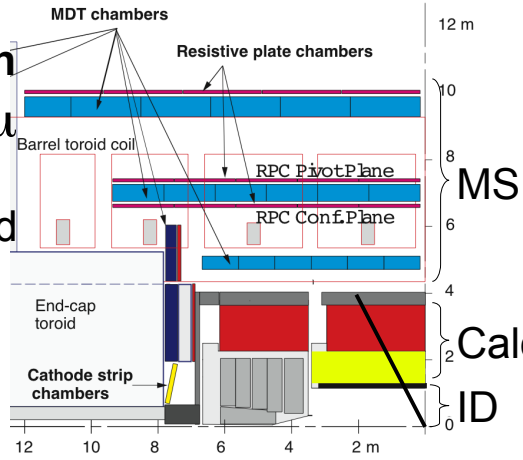
Combined Muon
track in MS
combined with
track in ID
Calo E-loss taken
into account



Segment Tagged Muon
track in ID tagged μ
if matched to
segment in MS

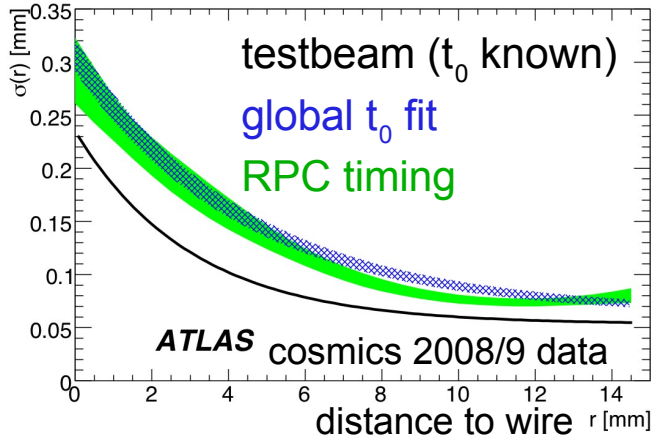


Calo Tagged Muon
track in ID tagged μ
if signals in Calo
around extrapolated
track consistent
with a M.I.P.

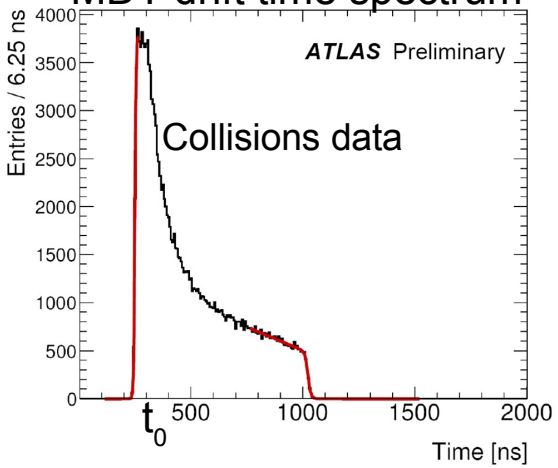


Drift chamber calibration

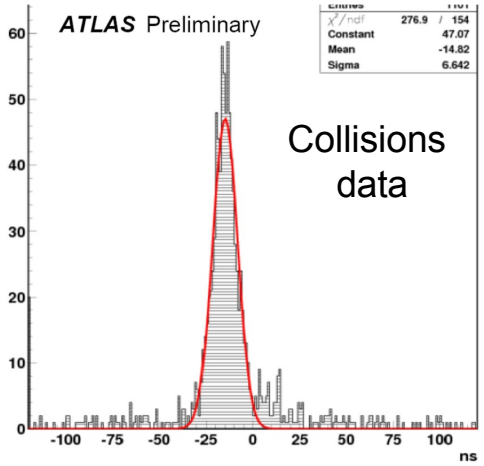
- MDT chambers calibration
  - Constant time offset t_0 (cable lengths etc.) for each channel
    - Determined from leading edge of drift-time spectrum
  - space - drift-time relation from auto-calibration method
- Not optimal resolution yet
  - Not enough statistics to determine t_0 per channel
  - Dedicated track segment fitter with time-offset as extra parameter ('global t_0 fit')
    - Compensates for unknown channel t_0
    - Compensates for randomness of cosmic trigger time
    - Resolution 20-50% worse than optimal



MDT drift time spectrum



Segment fit t_0 tuning parameter

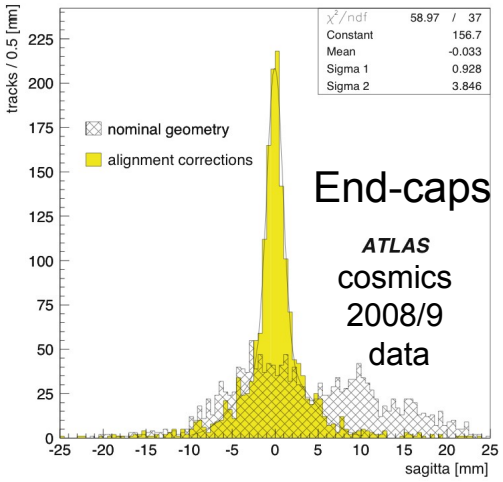


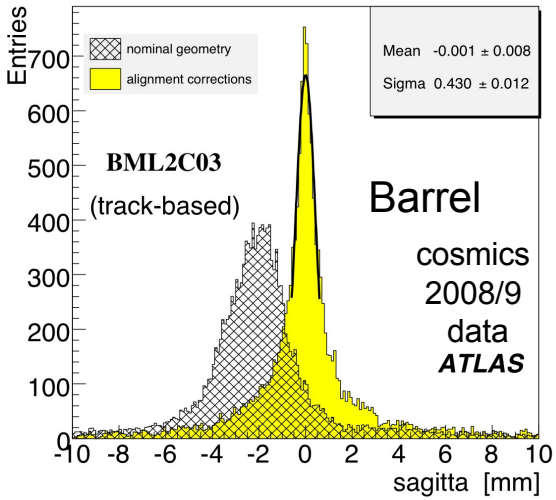
Muon Spectrometer Alignment

Alignment systems:
Endcap:
optical system
gives absolute positions

Barrel:
optical system
gives displacements,
using tracks to get
absolute reference

Assess alignment precision with
sagitta distribution of straight tracks (toroid off)





End-caps

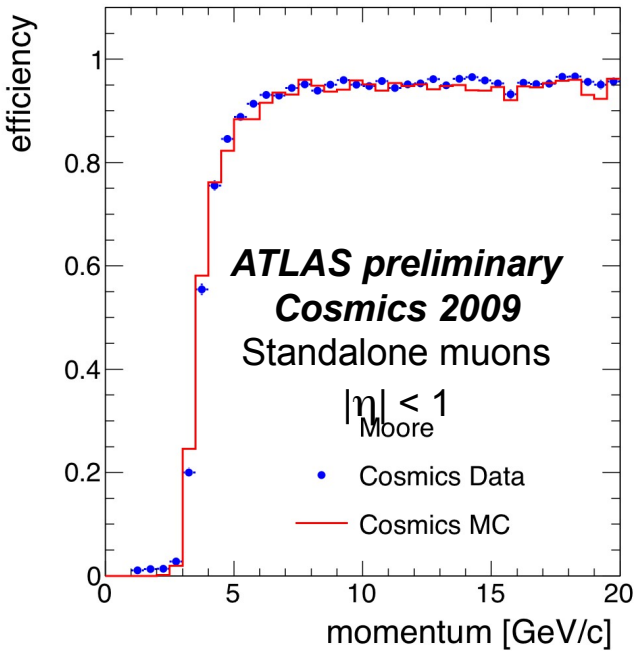
Optical systems only
overall mean value
within 40 μm

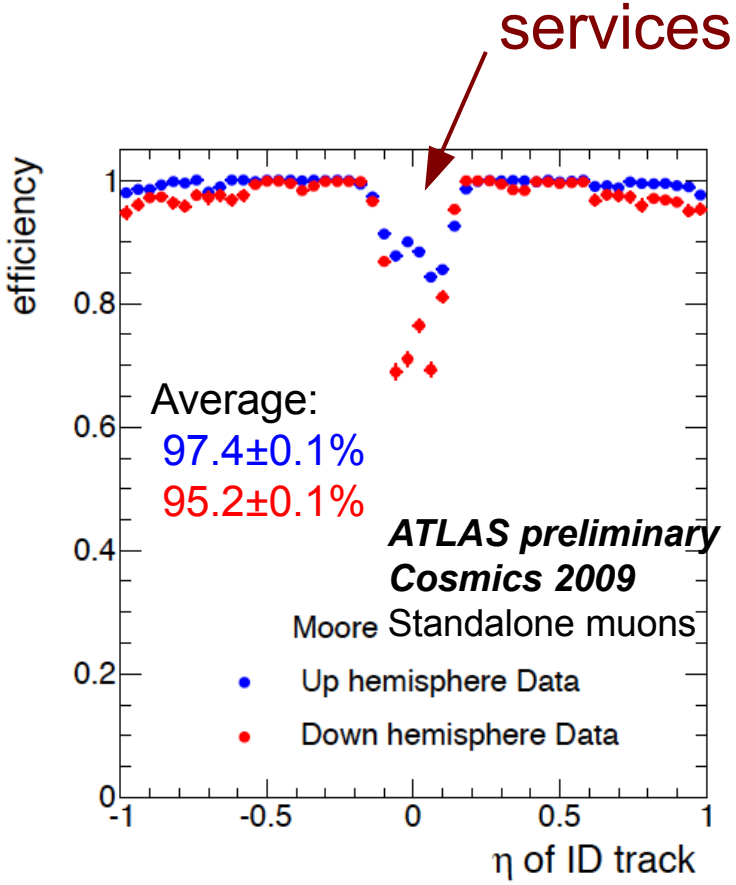
Barrel

typical mean values of sectors:
30 μm (large sectors),
70 μm (small sectors)

Efficiency from Cosmics

- Select events with high quality 'collision-like' ID tracks going through MS barrel
  - Check if a MS track is reconstructed in
    - top hemisphere (if p_{ID} > 5 GeV)
    - bottom hemisphere (if p_{ID} > 9 GeV)



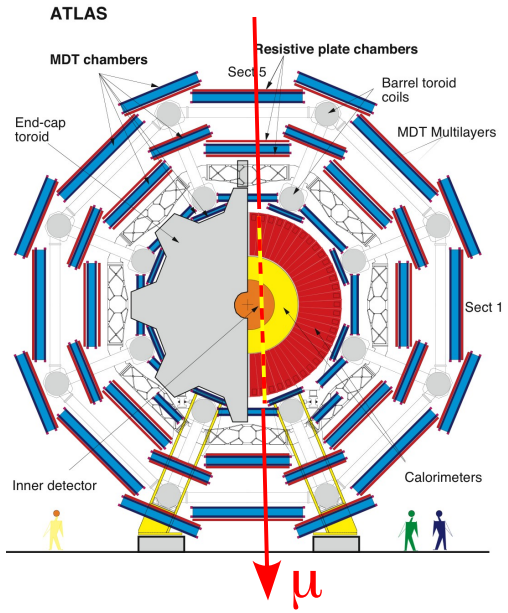


- Efficiency turn-on curve:

  Good agreement between data and MC

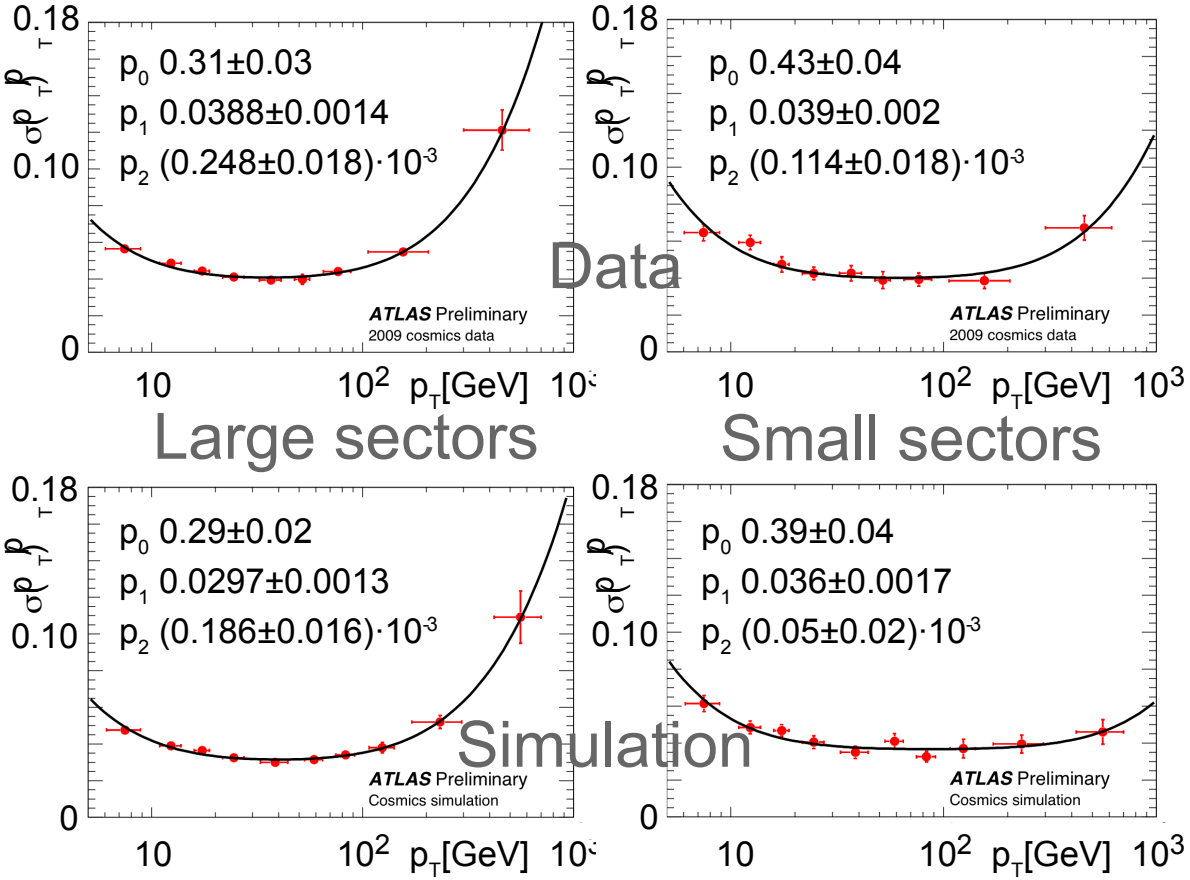
Resolution from Cosmics

Compare 2 halves of same track:



Fitting function:

$$\frac{\sigma_{p_T}}{p_T} = \frac{p_0}{p_T} \oplus p_1 \oplus p_2 p_T$$



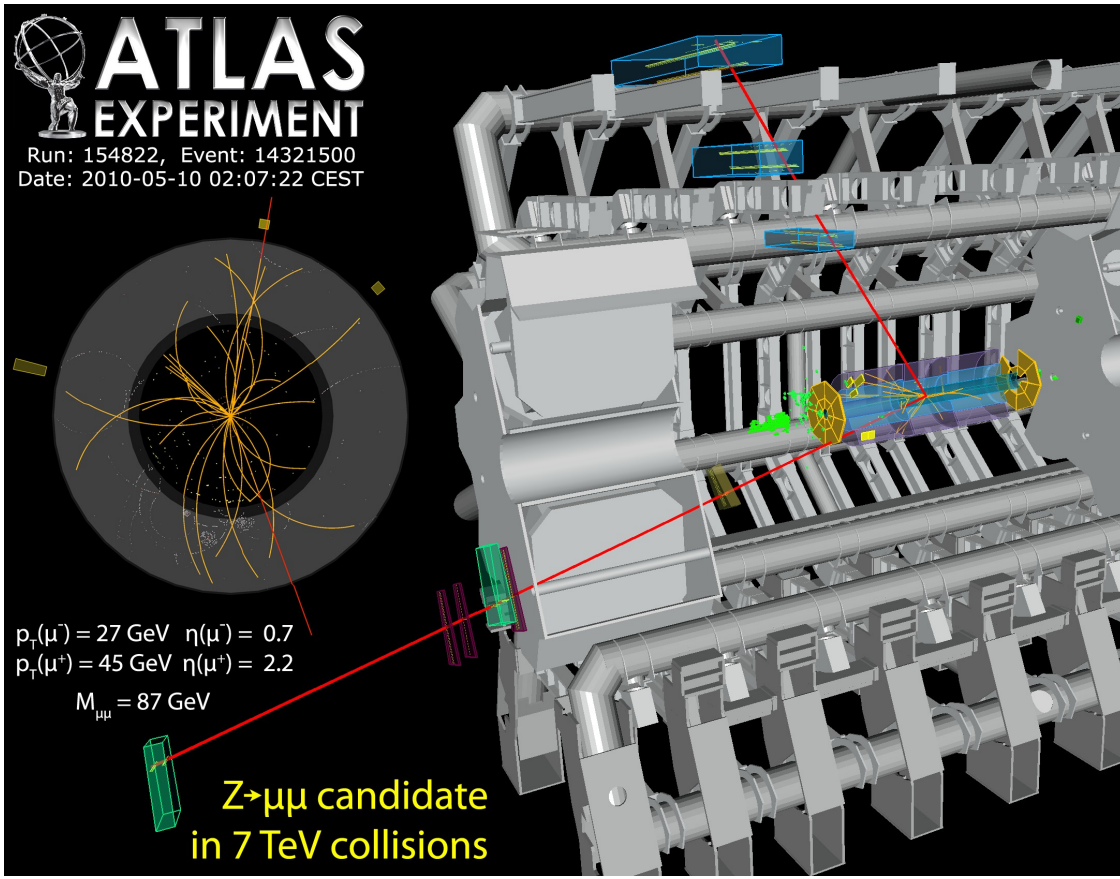
Energy loss fluctuations (p_0) : data and MC compatible → Calo material OK in MC

Multiple scattering (p_1) : data worse than MC → missing MS material in MC

Intrinsic resolution (p_2) : data worse than MC → alignment & calibration not yet optimal

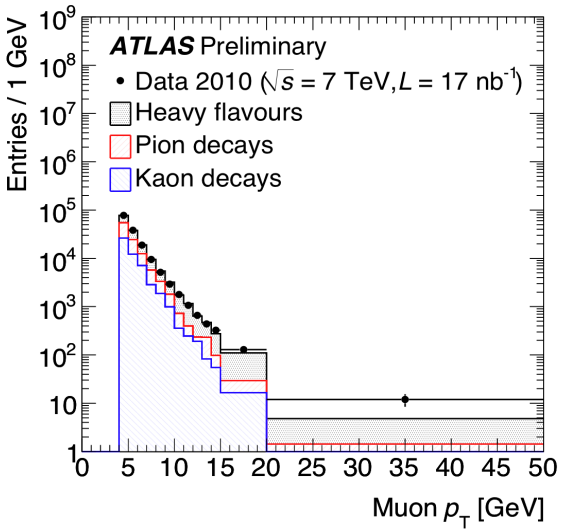
Collisions at 7 TeV

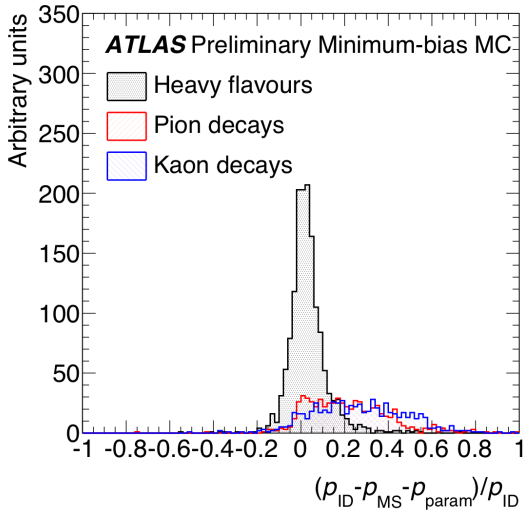
- Results correspond to a detailed study on the first 17 nb^{-1} of integrated luminosity
- Focused mainly on single muon triggered events
- Used calorimeter trigger for some studies to avoid bias
- Focus on combined and segment tagged muons



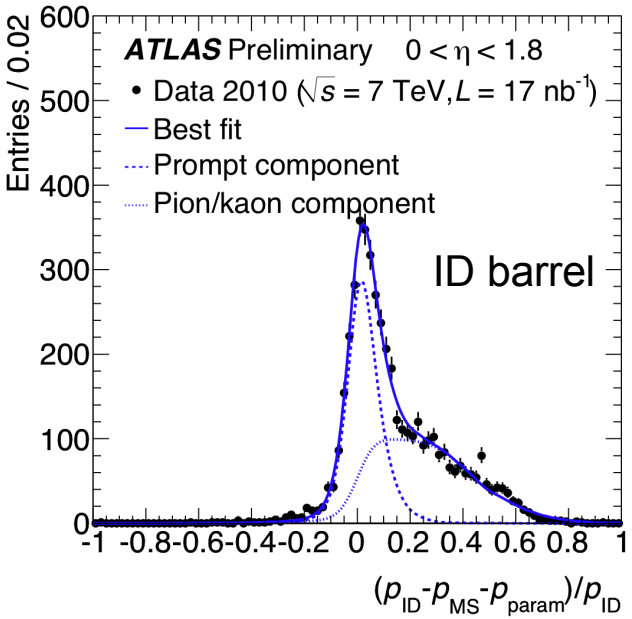
Prompt muon component

- 'Prompt' μ (mainly from b, c) contaminated with (late) decays of π and K





- Fit fractions using templates derived from MC



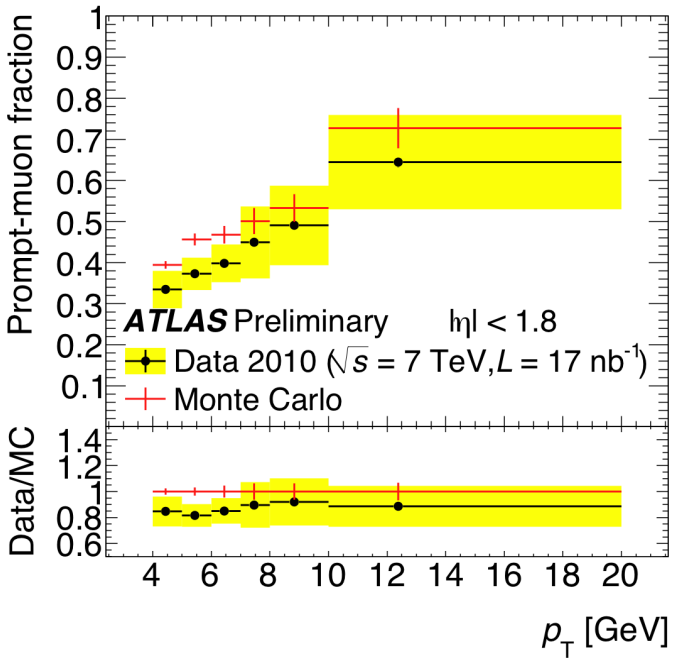
- Determine 'prompt' fraction by exploiting the double momentum measurement of combined muons
- Discriminating variable: relative ID-MS momentum imbalance : $\dfrac{(p_{ID}-p_{MS}-p_{param})}{p_{ID}}$

p_{param} = average energy loss in the Calorimeter

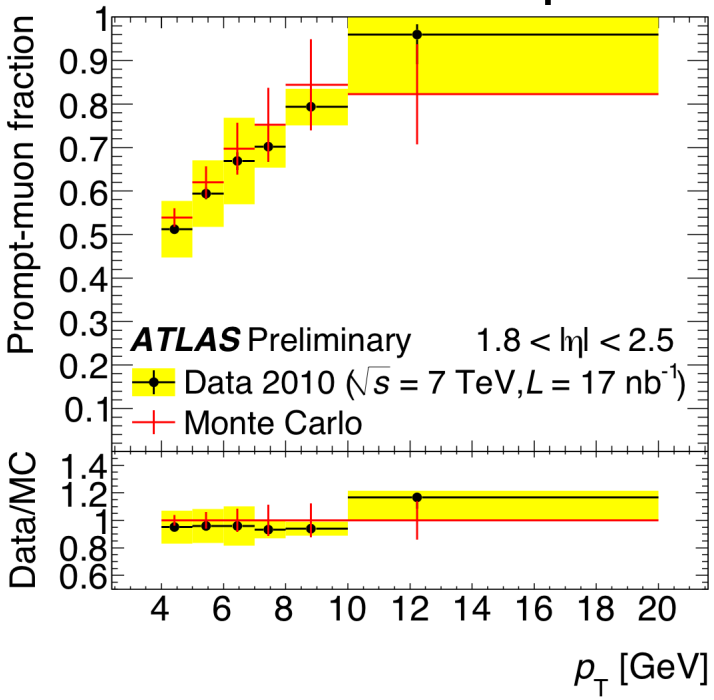
Prompt muon component

Measured fraction vs. p_T

ID barrel



ID endcap



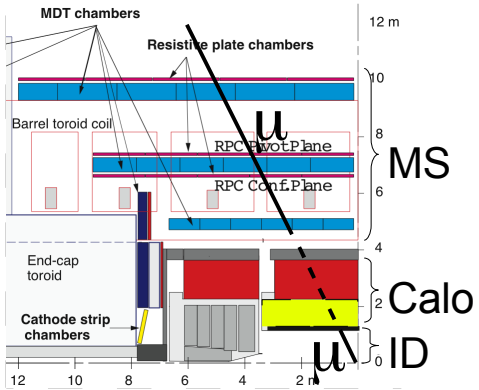
Data generally agrees with MC within errors

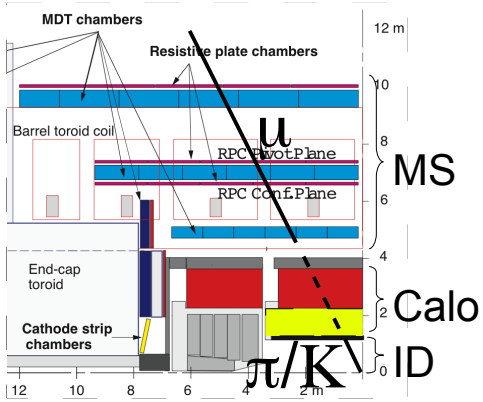
Momentum scale & resolution

- Relative MS-ID comparison : $\Delta p/p = (p_{ID} - p_{MS}) / p_{ID}$

  p_{MS} : muon standalone track (at IP, corrected for Calo E-loss)

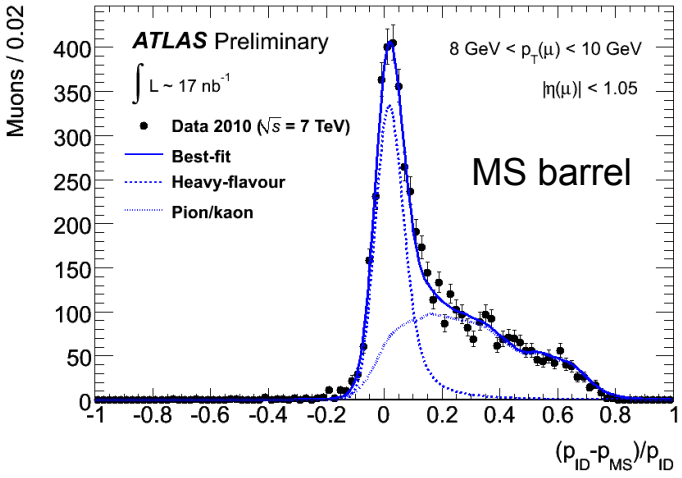
'Prompt' muons (b,c,... decays) usable for this measurement ('signal')





Background muons from (late) π/K decays bias the measurement

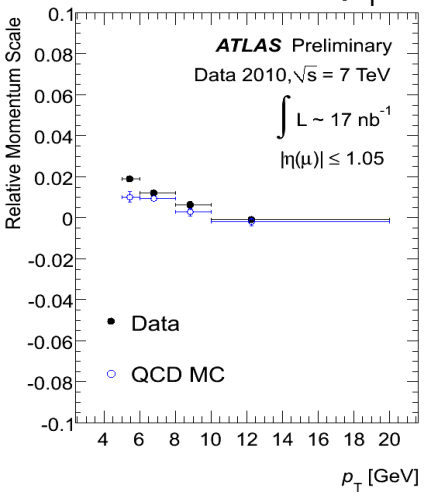
- Disentangle 'signal' and background as for prompt muon fraction
  - Background template: from QCD MC
  - 'Signal' template function : Gauss ⊗ Landau
    - ➔ gives Scale & Resolution



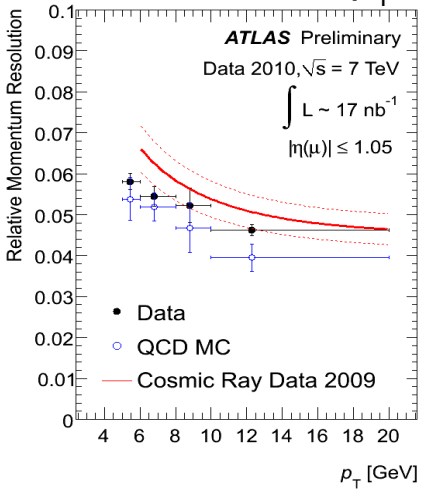
Momentum scale & resolution

- **Barrel**
  - ID resolution much better than MS for shown p_T range
    - Sum resolution ≈ MS resolution
  - Good overall agreement between data and MC

Scale vs. p_T

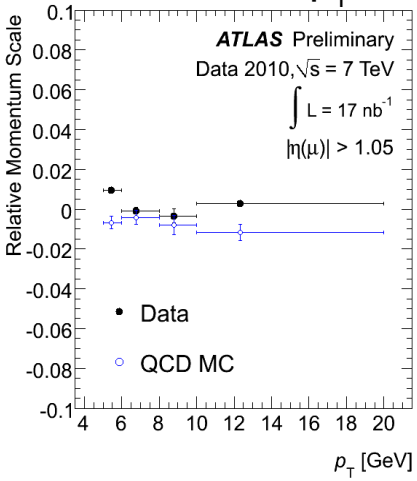


Resolution vs. p_T

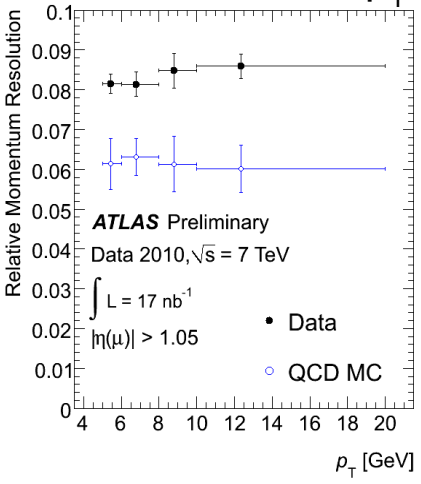


- **End-cap**
  - ID resolution ≈ MS resolution
  - Worse resolution in data due to imperfect alignment

Scale vs. p_T

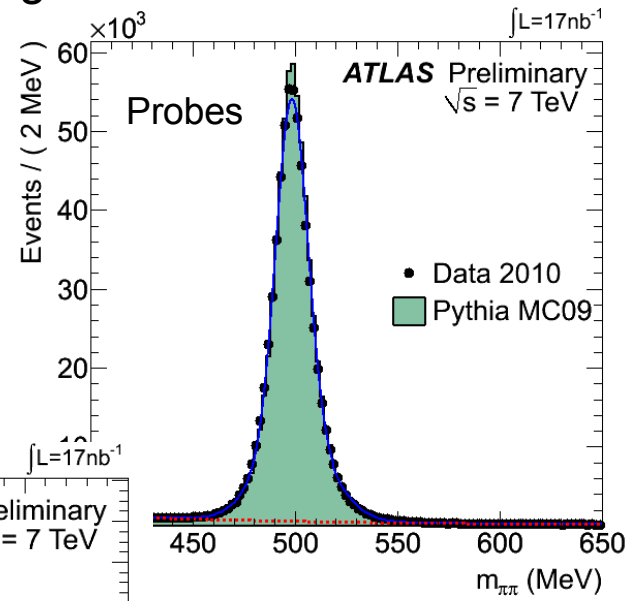


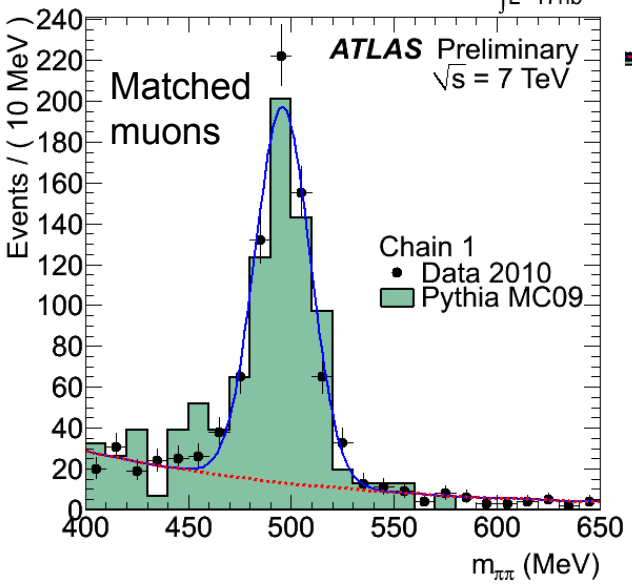
Resolution vs. p_T



Low momentum background

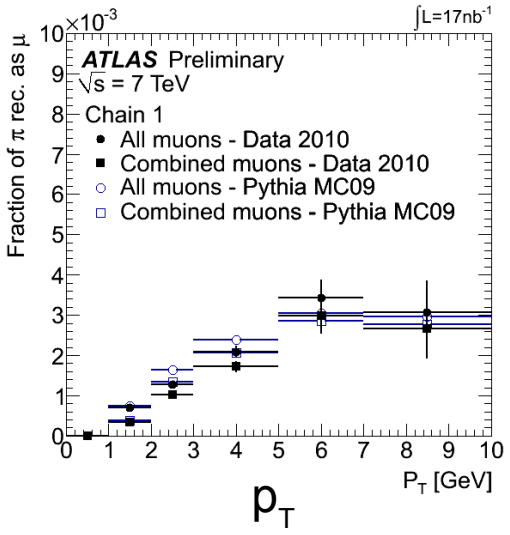
- π/K decays-in-flight to μ are the main sources of background at low momentum
- Test background rejection of muon identification with pure sample of $K^0 \rightarrow \pi^+\pi^-$ candidates
- Probe track: highest p_T ID track (of K^0 track pair)
- Matched muon:
  - reconstructed muon with an ID track = probe track
- Number of candidates: entries in K^0 mass peak
  - 636940 probes (95% purity)
  - 644 muons (461 combined)

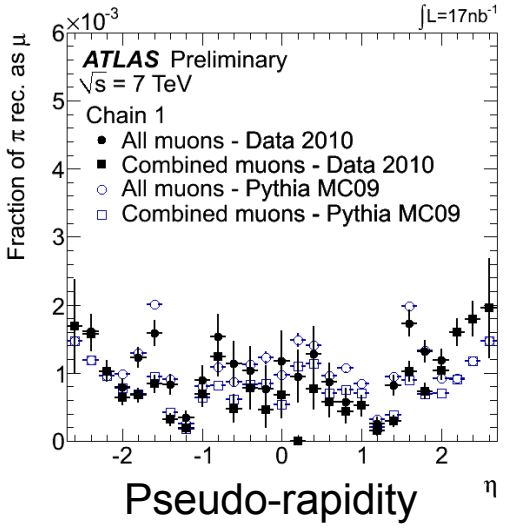


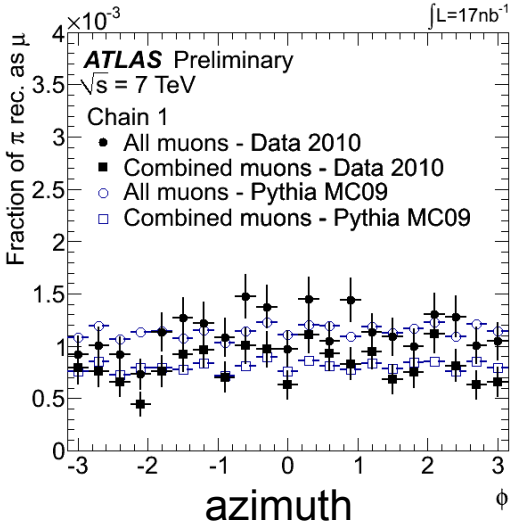


Low momentum background

- Fraction: $f = N_{muon}/N_{probe}$
  - All muons: 0.101±0.014 %
  - Combined muons: 0.070±0.012 %
    - ➔ Combined muons lower because of better rejection than segment tagged muons







- Good overall agreement between MC and data

Conclusions

- ATLAS Muon Spectrometer performance has been studied with cosmic muons
  - The track reconstruction efficiency (barrel): 96.3%
  - Momentum resolution (barrel): $\frac{\sigma_{p_T}}{p_T} = \frac{0.31}{p_T} \oplus 0.039 \oplus 0.00025\ p_T$ (large sectors)

    $\frac{\sigma_{p_T}}{p_T} = \frac{0.43}{p_T} \oplus 0.039 \oplus 0.00011\ p_T$ (small sectors)

- ATLAS Muon Identification Performance presented with 17 nb^{-1} collisions at 7 TeV
  - The muon contamination from π/K decays determined from data
  - Low momentum background from pion decays determined from data
    Fraction of pions reconstructed as muons:
    - 0.101±0.014% (combined + segment tagged)
    - 0.070±0.012 % (combined only)

- Good overall agreement between data and MC both for cosmics and collisions
  - The resolution somewhat worse than expected
    - non-optimal alignment and calibration in data : affects high p_T muons
    - too little material in MC : affects medium p_T muons (MC too optimistic)

Backup Slides

Cosmics track cuts

- Efficiency from Cosmics Inner Detector track selection
  - Select events with $\geq$ 1 ID track passing cuts:
    - $\geq$ 20 TRT hits, total $\geq$ 5 hits in SCT+pixel
    - $|d_0| < 1$ m, $|z_0| < 1$ m
    - Track $\chi^2/ndf < 3$
    - $|\eta| < 1$, $p > 5$ GeV
- Resolution from Cosmics Muon Spectrometer track selection:
  - ≥7/8+5/6+5/6 MDT hits, ≥2/3 RPC φ layers hit
  - $65^\circ < \Theta < 115^\circ$
  - $|d_0| < 1$ m, $|z_0| < 2$ m
  - $|\Delta\Theta| < 10^\circ$, $|\Delta\varphi| < 10^\circ$ of the pair
  - NB: no ID track required

Resolution from Cosmics

- Resolution from fit to distribution of $\frac{\Delta p_T}{p_T} = 2\frac{p_{Ttop} - p_{Tbottom}}{p_{Ttop} + p_{Tbottom}}$ in p_T bins
  - Tracks extrapolated to IP and corrected for average energy loss in calorimeter
  - Fit function: narrow Gauss convoluted with Landau plus a broad Gauss
    - Landau to take into account E-loss in the calorimeters (relevant for low p)
    - Resolution σ_{pT}/p_T = (narrow Gauss width + Landau width) / $\sqrt{2}$

Collisions track cuts

- Collision event selection
  - 3 ID tracks associated with a reconstructed primary vertex, each having
    - ≥1 pixel hit, ≥6 SCT hits
- Good muon selection
  - ID part of track: ≥1 pixel hit, ≥6 SCT hits
- Low momentum background $K^0 \rightarrow \pi^+\pi^-$ candidates:
  - ID tracks with ≥1 Pixel hit, ≥6 SCT hits, $p_T > 500$ MeV
  - Vertex fit to pairs of opposite charged tracks
    - $\forall$ $\chi^2/DoF < 15$
    - transverse decay length between 5 and 120 mm
  - angle Θ between the K^0 candidate flight direction and its p vector smaller than 14 mrad ($\cos\Theta_{pointing} > 0.9999$)
  - $\cos\Theta^* > -0.75$, to reject $\Lambda \rightarrow p^+\pi^-$ (Θ^* =angle between the p of the K^0 and the p of its lowest p_T track, in the K^0 rest frame)
  - Probe track: highest p_T ID track
    - $p > 3$ GeV (to reach MS)
    - $p_T > 1$ GeV (kinematics of reco)

Momentum Scale & Resolution

- Template fit to $(p_{MS}-p_{ID})/p_{ID}$ spectrum:
  - Resolution template:
    - Gaussian convoluted with a Landau
    - Landau to take into account energy loss fluctuations
  - Decays background template:
    - derived from QCD Monte Carlo
  - Resolution = Gaussian width + Landau width
  - Scale = Gaussian mean