Muon identification and performance in the ATLAS experiment

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On behalf of the ATLAS Collaboration

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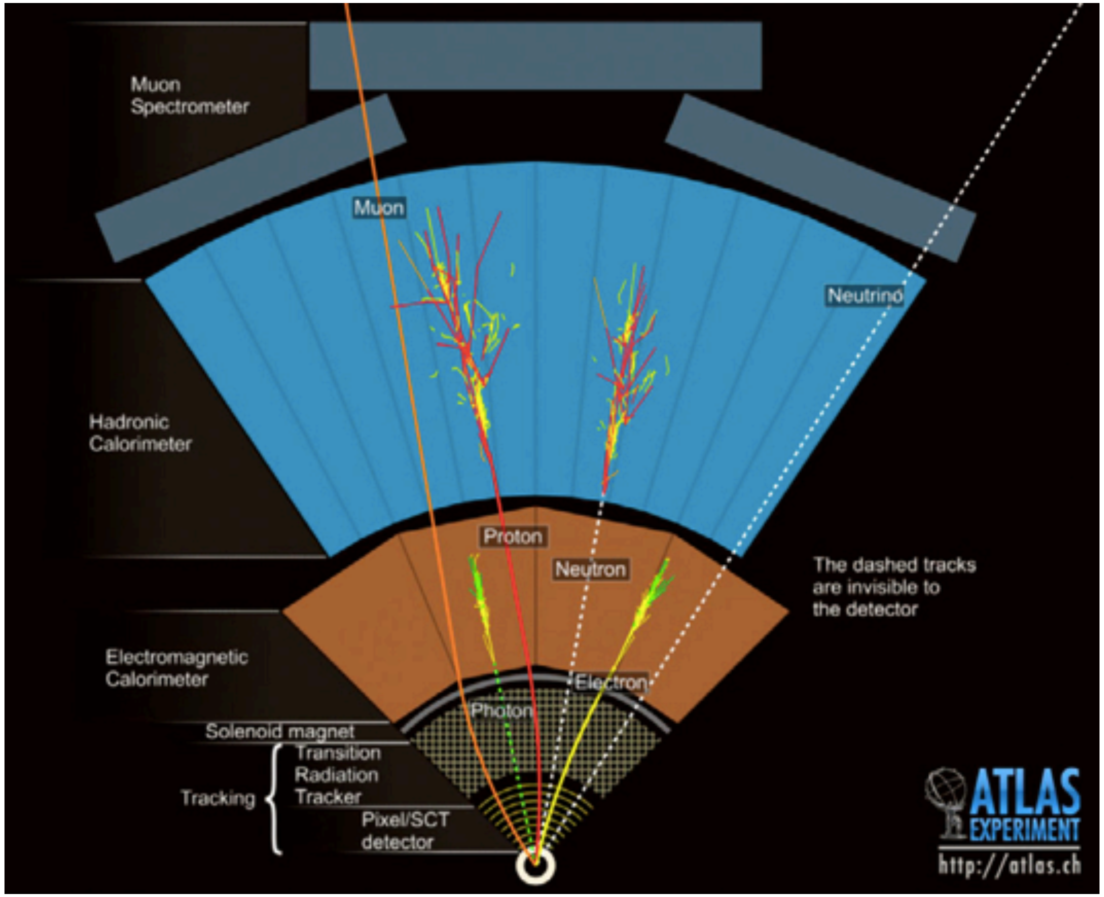
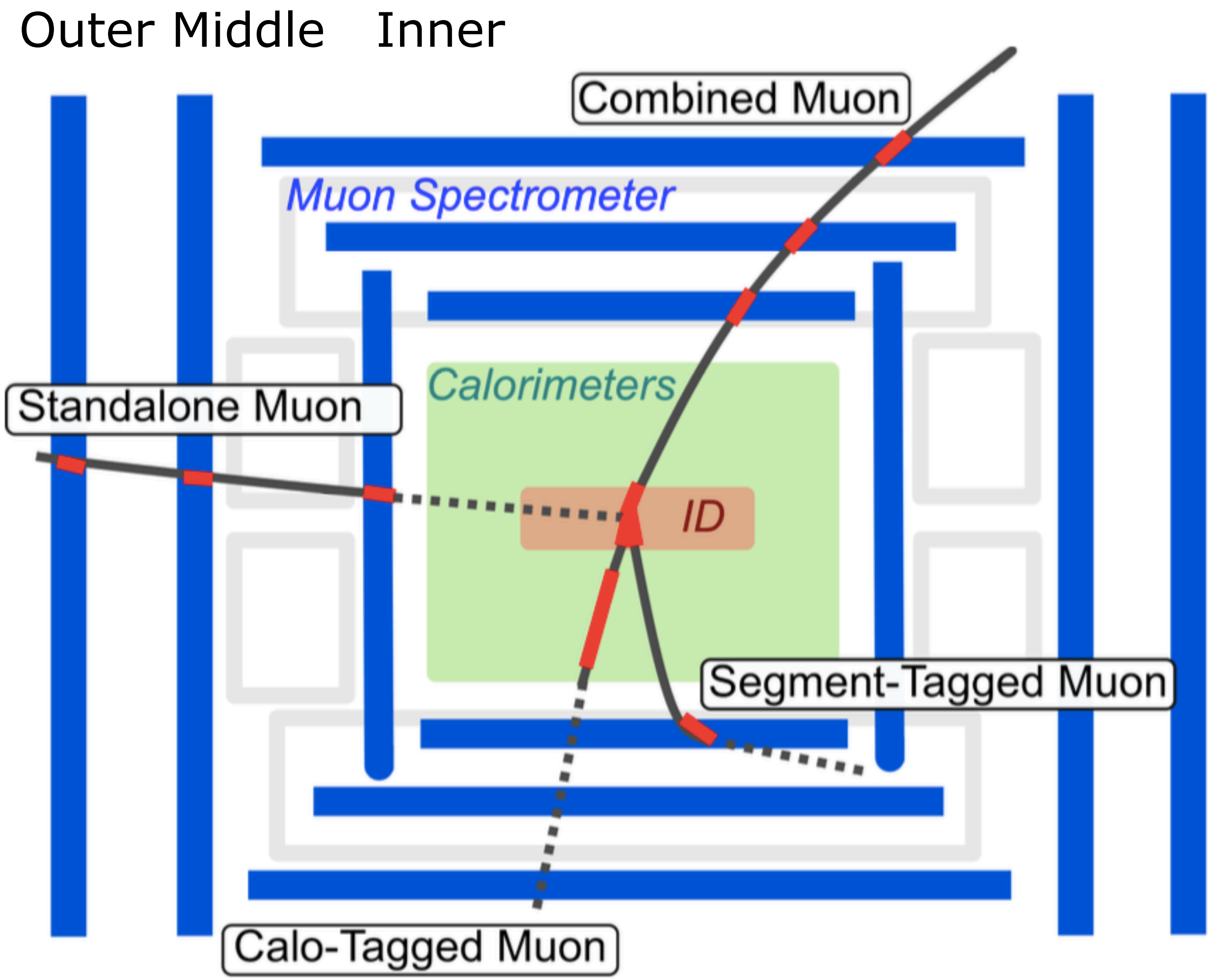
Muon Identification in ATLAS



- Two systems
- Inner Detector ID Tracker
  - Solenoidal B field (bends in phi, xy)
- Muon System MS
  - Toroidal B field (bends in theta, rz)

- Muons can be identified combining detectors
  - ID track – Calorimeter deposits
  - MS track
  - These two are fully independent
- ATLAS exploits different strategies – detector combinations - for muon identification.

Muon Identification

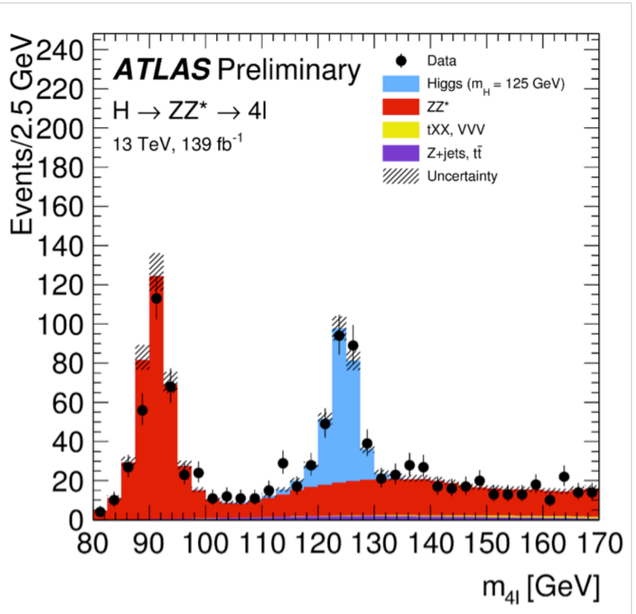


- Muon Spectrometer reconstruction
  - Segments (straight line track in MS station)
  - Standalone MS track (fitting segments)

- Standalone muons based on MS
- Tagged muons based on ID track "inside-out"
  - Matched with MS segment
  - Matched with Calorimeter deposits
- Combined Muons i.e. MS & ID
  - Fit ID track with MS track
  - Inside-out ID track – MS hits – MS segments – fit ID & MS hits

Physics with muons: working points

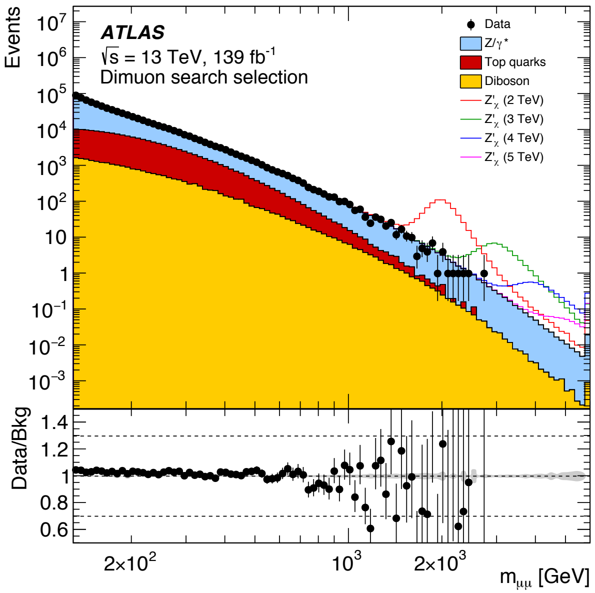
- Loose: Maximize reconstruction efficiency; uses all muon types
- Medium: Default selection for ATLAS; uses CB & MS muons
- Tight: Maximize purity; uses only CB & MS muons
- Low-pT: Maximize efficiency and fake-rejection for pT < 5 GeV
- High-pT: Maximize momentum resolution for pT > 100 GeV



Loose

Higgs →4l

ATLAS-CONF 2019-045

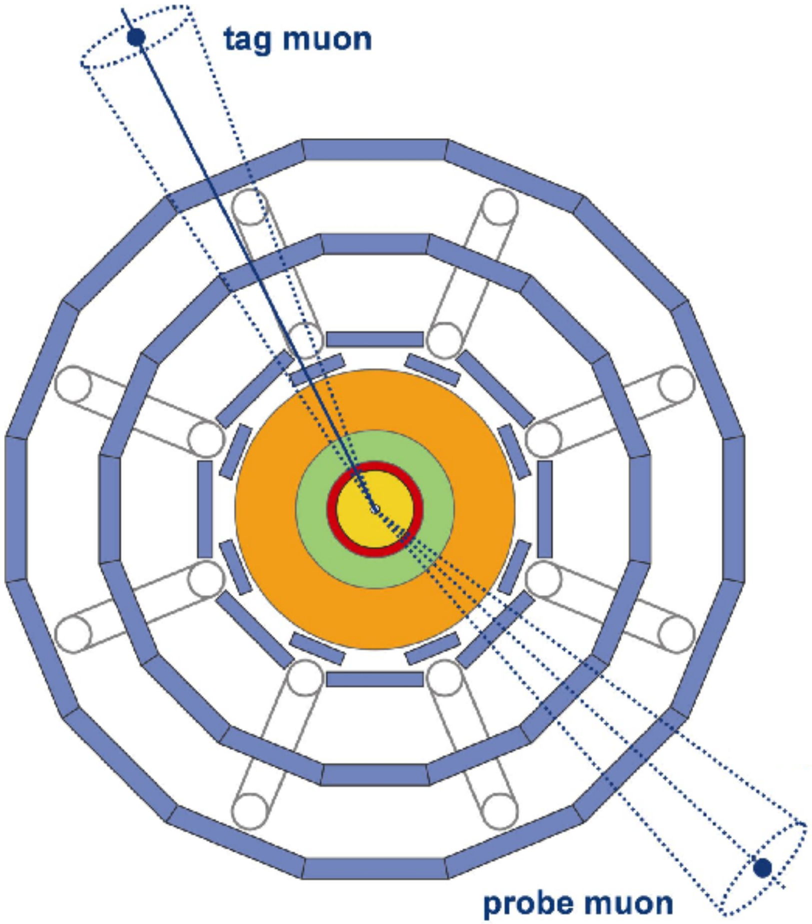


High-pT

Z′ →μμ search

arXiv 1903.06248v2

Efficiencies for muons: Z tag and probe



Use high-statistics samples of $Z \rightarrow \mu\mu$

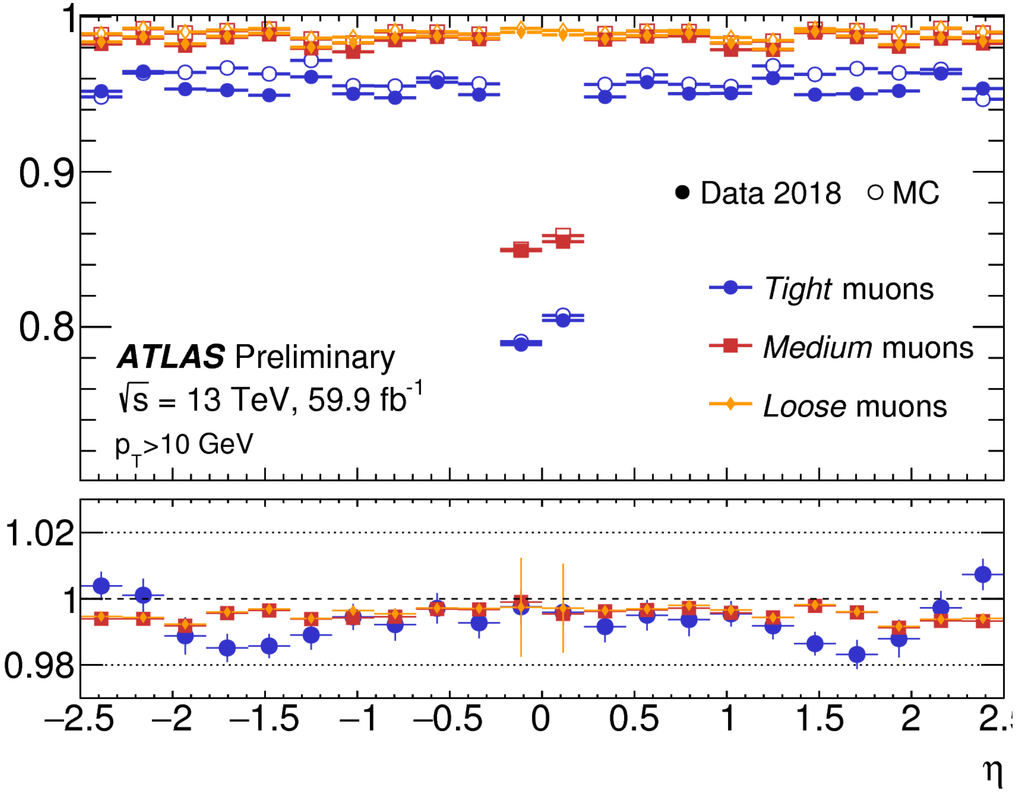
- Tag: Medium muon that fires the trigger
- Probe: e.g Calo-Tagged muon; mass Z
- Check Probe side if Loose, Medium, Tight, low-pT, high-pT muon (not Calo-Tagged) is found
- This gives efficiency ε(muon|ID)

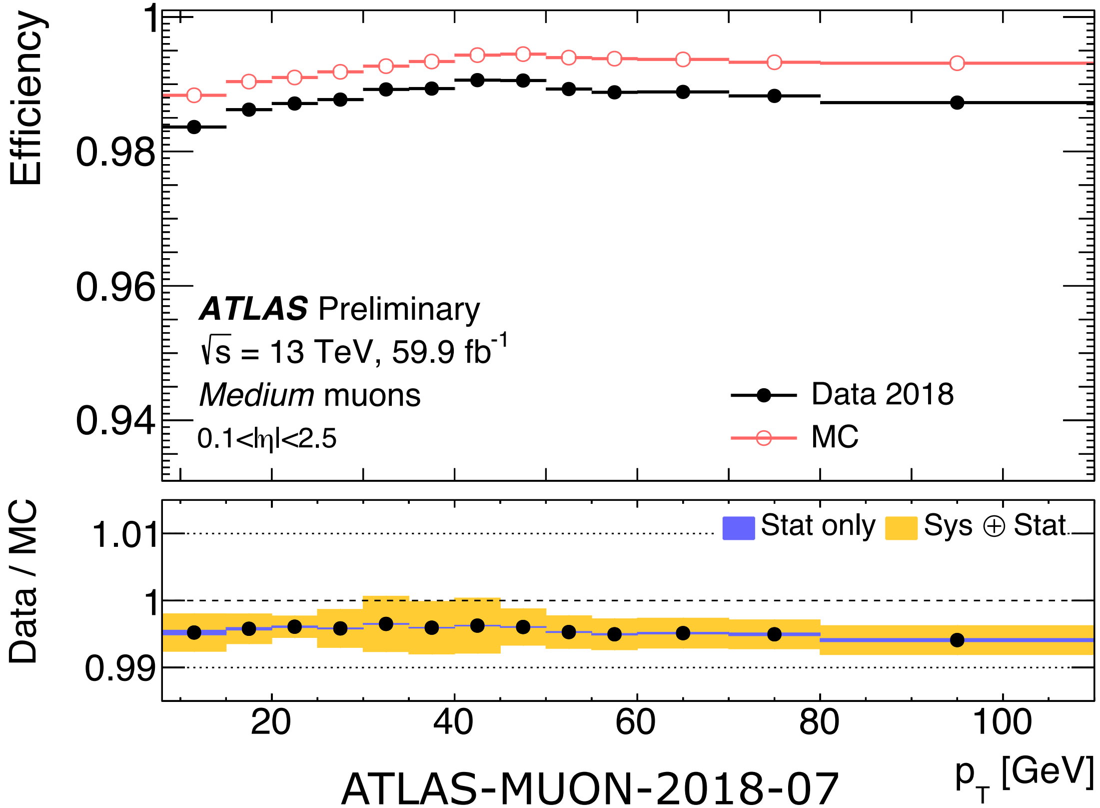
- The ID tracking efficiency ε(ID) can also be measured using MS probes

- The full ε(muon) equals ε(ID) ε(muon|ID)

Muon efficiencies: Z tag and probe

- Efficiency > 98% for medium |η|>0.1 data/MC within 1-2%
- Calorimeter muons recover |η|<0.1 systematics < 0.5%





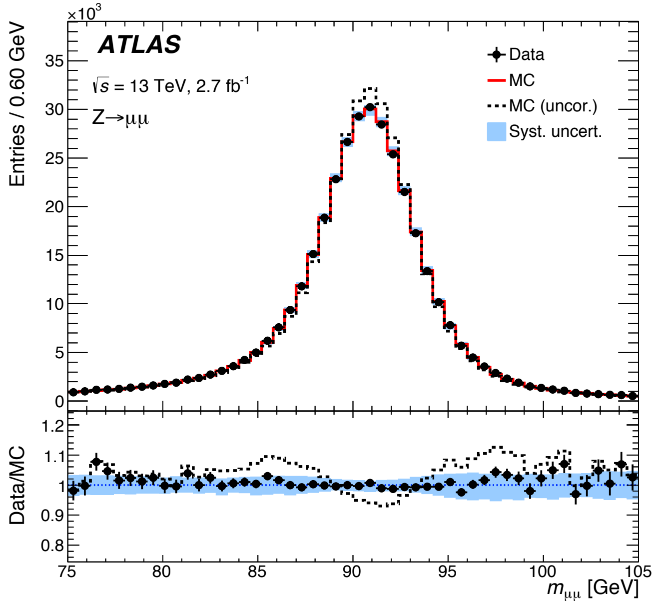
ATLAS-MUON-2018-07

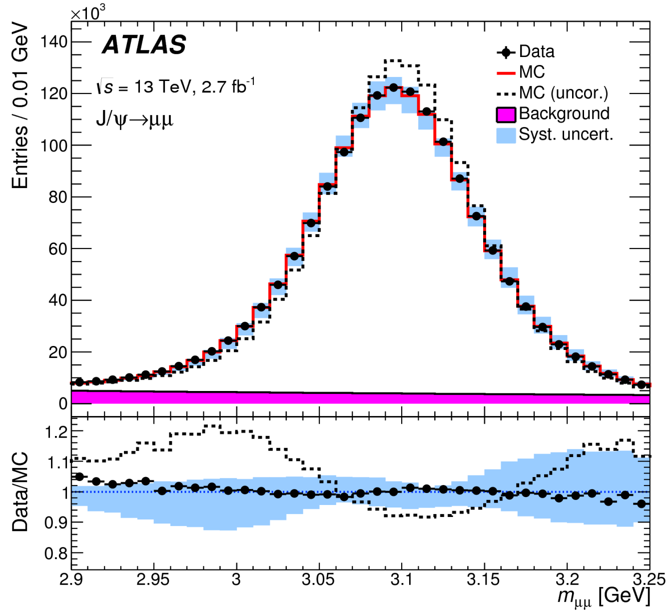
Muon momentum scale and resolution

- scale: $p_T' - p_T = \Delta_{s0} + \Delta_{s1}\, p_T$
  - Δ_{s0}: Energy loss in Calorimeter and Muon system
  - Δ_{s1}: B field and radial distortions
- resolution $\sigma'^2 - \sigma^2 = (\Delta_{p0}/p_T)^2 + \Delta_{p1}^2 + (\Delta_{p2}\, p_T)^2$
  - Δ_{p0}: Energy loss fluctuations
  - Δ_{p1}: multiple scattering (B field and radial distortions)
  - Δ_{p2}: detector resolution and misalignments

Use Z and J/ψ samples to measure scale and resolution in the Inner detector and Muon system

Z: p_T 10-200 GeV
J/ψ: p_T 3-25 GeV
Υ: p_T 5-50 GeV





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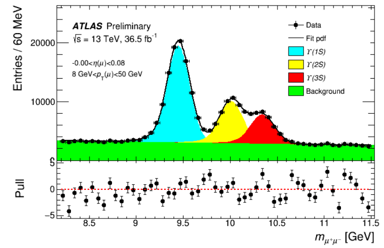
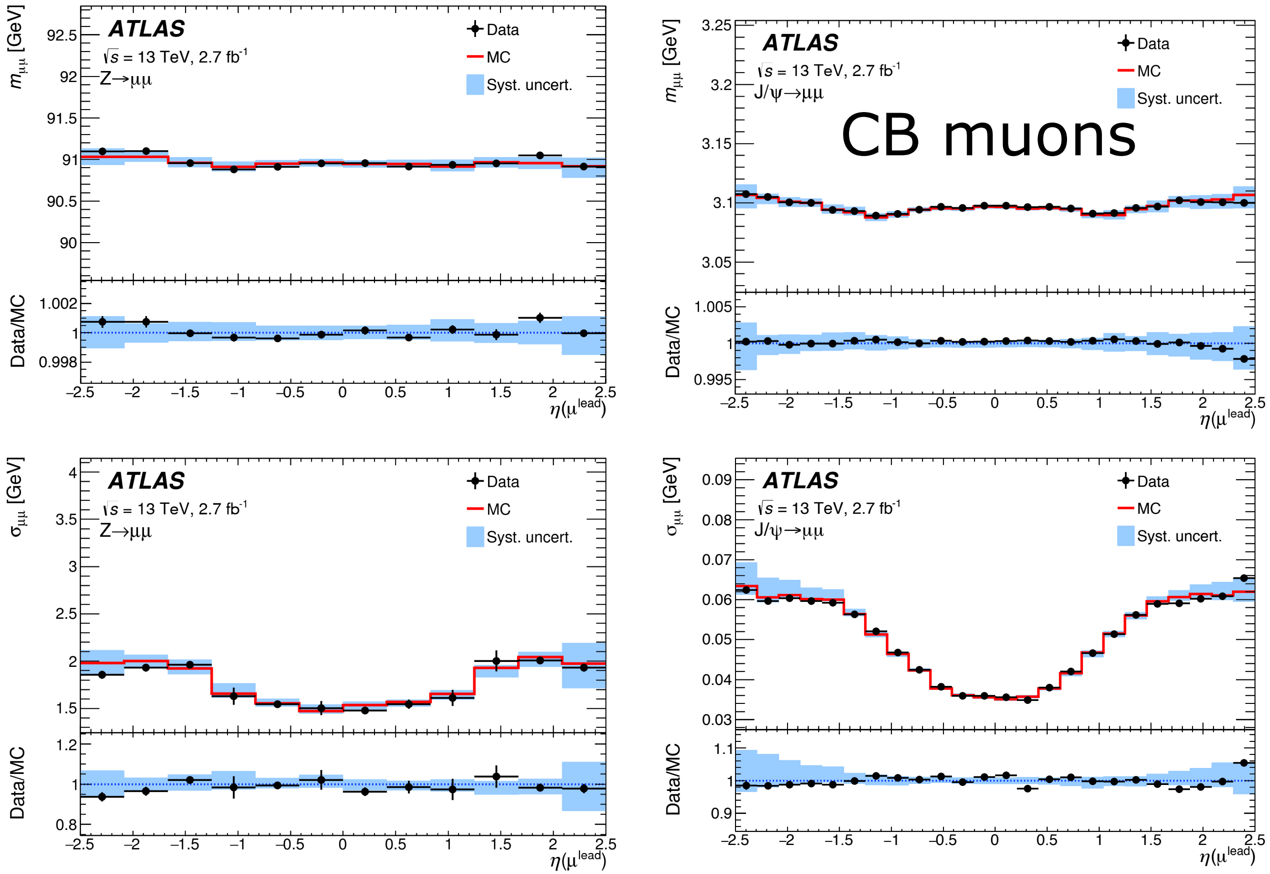
Muon momentum scale and efficiencies

- scale systematics: 0.1-0.2%
- resolution data/MC 5-10%
- Validation of the results on the Upsilon (2019)





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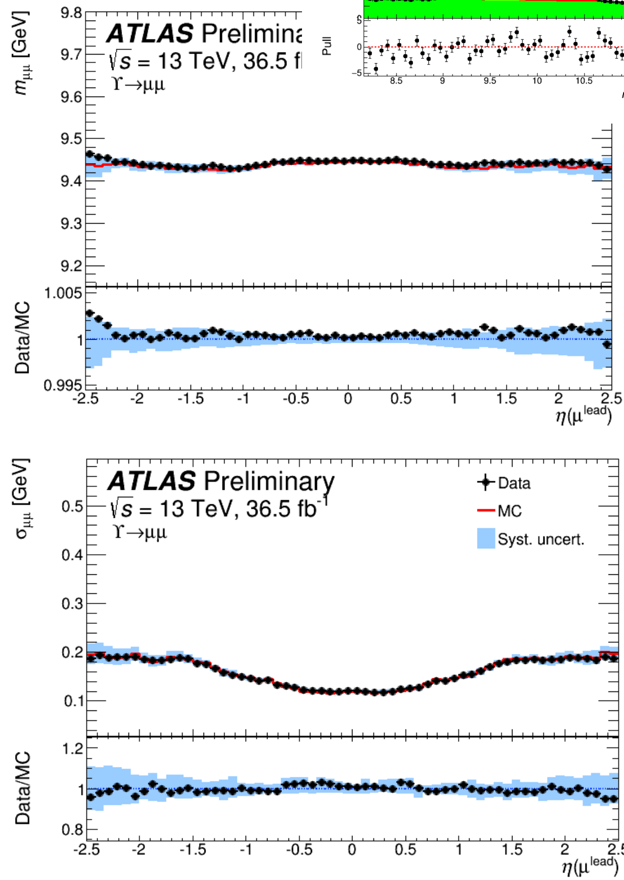
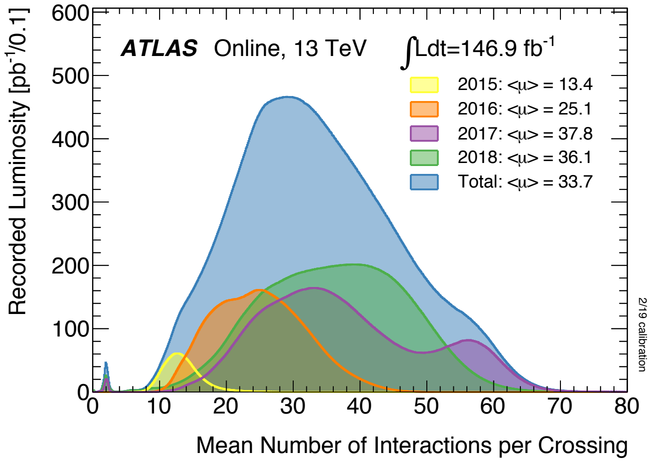


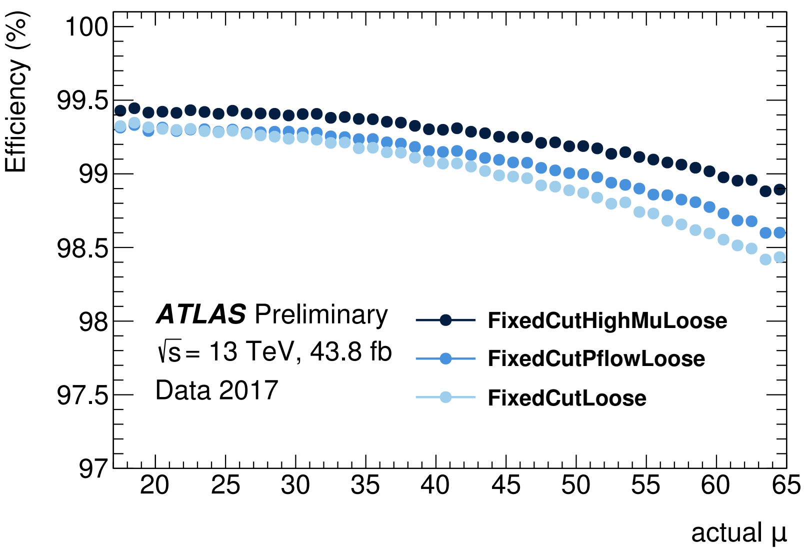
ATL-PHYS-PUB-2019-018

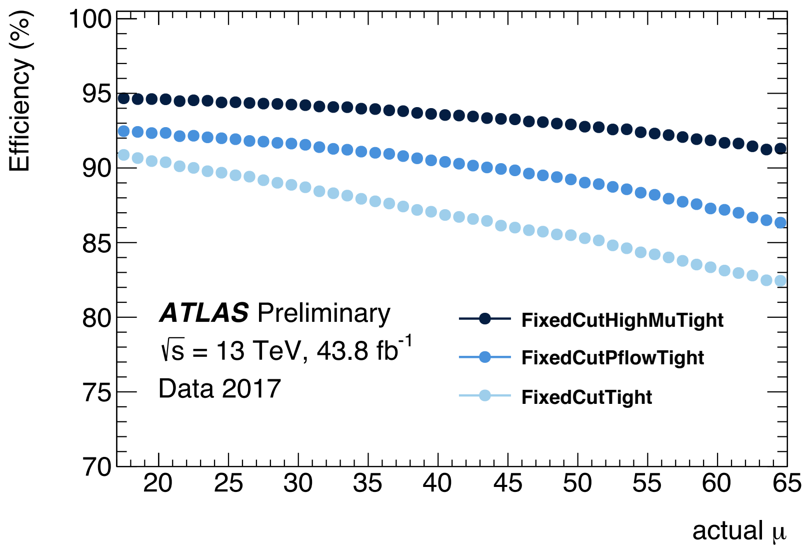
Muon isolation efficiencies and pile up



- The efficiency of different muon isolation algorithms can be measured by Z tag and probe
  - FixedCut: ΣE calorimeter or Σp track in a cone
  - FixedCutPflow: ΣE particle flow in a cone
  - FixedCutHighMu: combines all

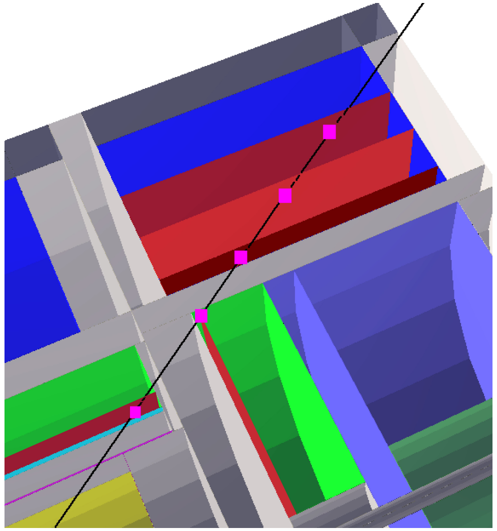
- The efficiency can be kept reasonably constant at high μ
  - Loose isolation 0.5-1% and Tight 2-10%

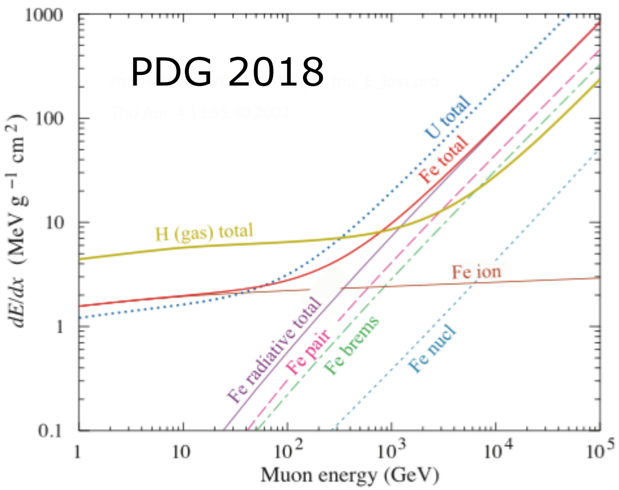




ATLAS-MUON-2018-02

Energy loss modeling in the track fit

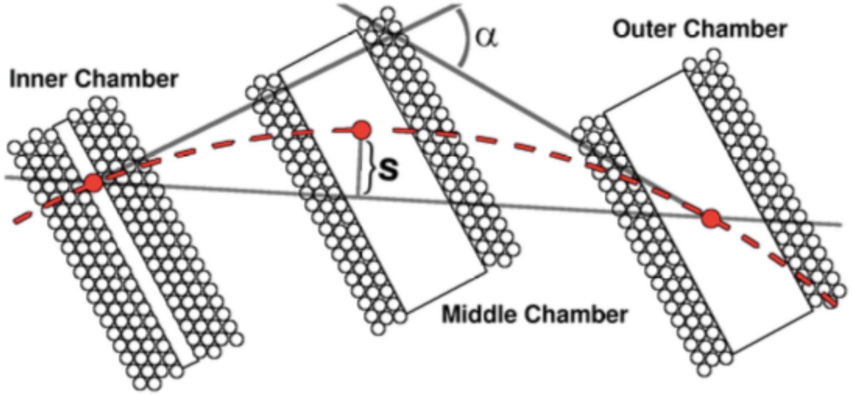


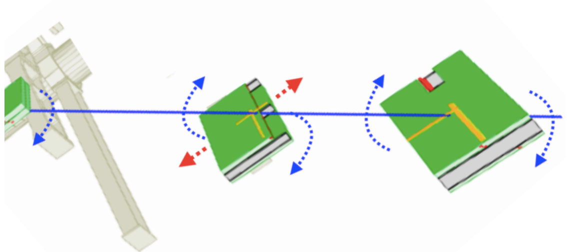


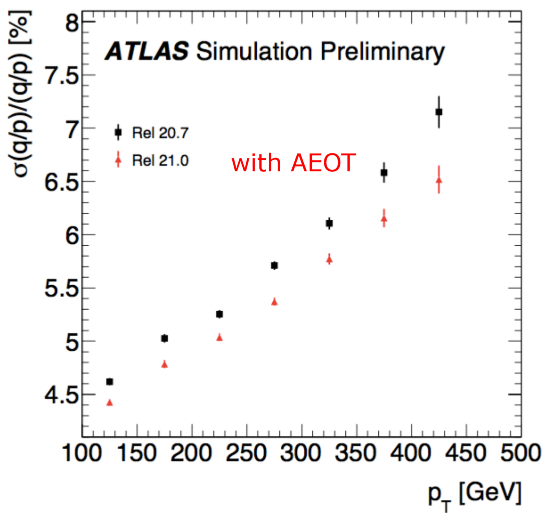
- The expected energy loss is modeled using a tracking geometry description of the material X_0 in the tracker, calorimeters and muon system based on PDG formula’s.
  - Ionization: Landau distribution with a E_{MOP} and σ_L
  - Radiation: Exponential with E_{rad}
- The energy loss is also measured E_{meas} in the calorimeters with σ_{meas}
- Two regimes are defined $E_{cut} = 2.5\ \sigma_{meas}$ IEEE (2007) 54 5
  - $E_{meas} - E_{MOP} - E_{rad} < E_{cut}$ use expected $E_{MOP}+E_{rad}$
  - $E_{meas} - E_{MOP} - E_{rad} > E_{cut}$ use measured E_{meas}

- Finally, from the E_{meas} σ_{meas} and E_{MOP} σ_L an Energy constraint was calculated with asymmetric errors. The constraint is used in the track fit.
- The technique was implemented in 2017 and the tracking geometry description of the simulated muon energy loss was scrutinized. This resulted in an improved momentum resolution and a smaller E loss momentum correction term Δs_0.

Alignment uncertainties in the track fit







ATL-SOFT-PROC-2018-052

- AlignmentEffectOnTrack AEOT has position and angle uncertainties on a group of hits (e.g. chamber)
- Typical sagitta (sys) uncertainty is 30-80 μm (RUN2) put in Middle Chamber
- Can also treat Barrel-Endcap alignment systematics (1 mm)
- Track fit performed using gaussian constraint on groups of hits with alignment uncertainties
- Implemented for the global χ^2 fitter

- Improves the track parameters e.g. momentum resolution by about 10 %; uncertainties are more realistic

Conclusions

- Muon Identification in ATLAS
  - complementary ways to identify a muon
- Physics with muons
  - working points for a wide physics range
- Efficiencies for muons: Z tag and probe
  - data/MC within 1-2% and systematics < 0.5%
- Muon momentum scale and resolution
  - scale systematics: 0.1-0.2%
  - resolution data/MC 5-10%
- Muon isolation efficiencies and pile up
  - Efficiencies stable: Loose at 0.5-1% and Tight 2-10%
- Energy loss modeling in the track fit
- Alignment uncertainties in the track fit