Results from muon reconstruction performance with ATLAS at Run-3

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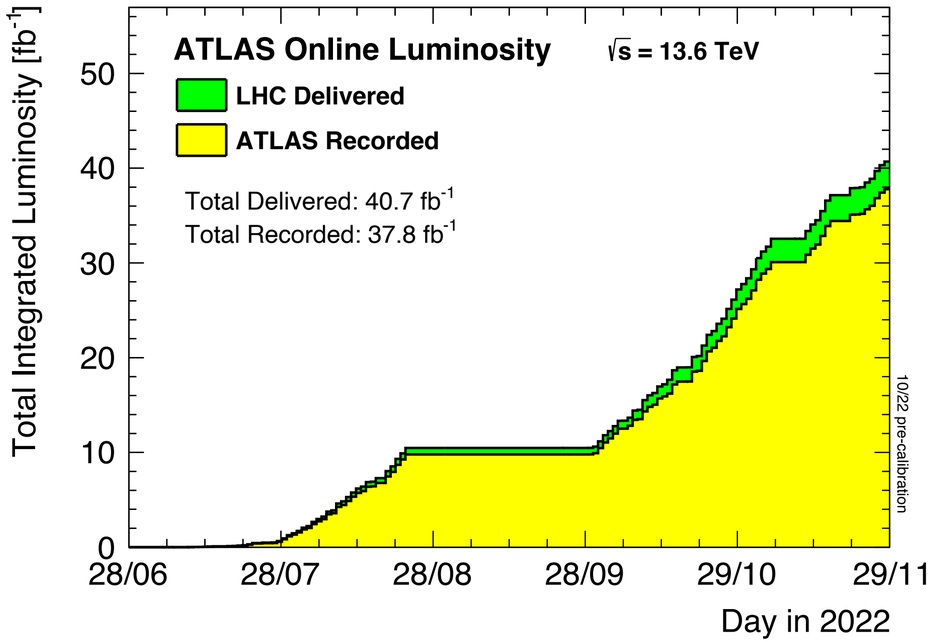
UMass Amherst

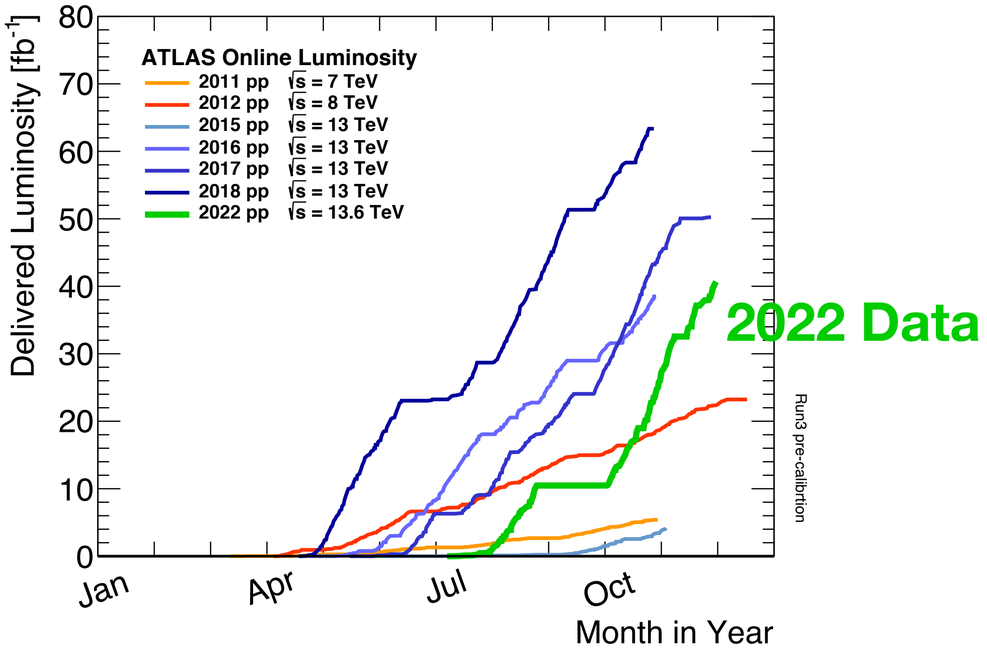
ATLAS EXPERIMENT

Outline

- ATLAS Muon Spectrometer in Run-3
- Muon Reconstruction in ATLAS
- Muon Calibration
- Measuring Muon Momentum Scale and Resolution in Run-3 Data

ATLAS in Run-3

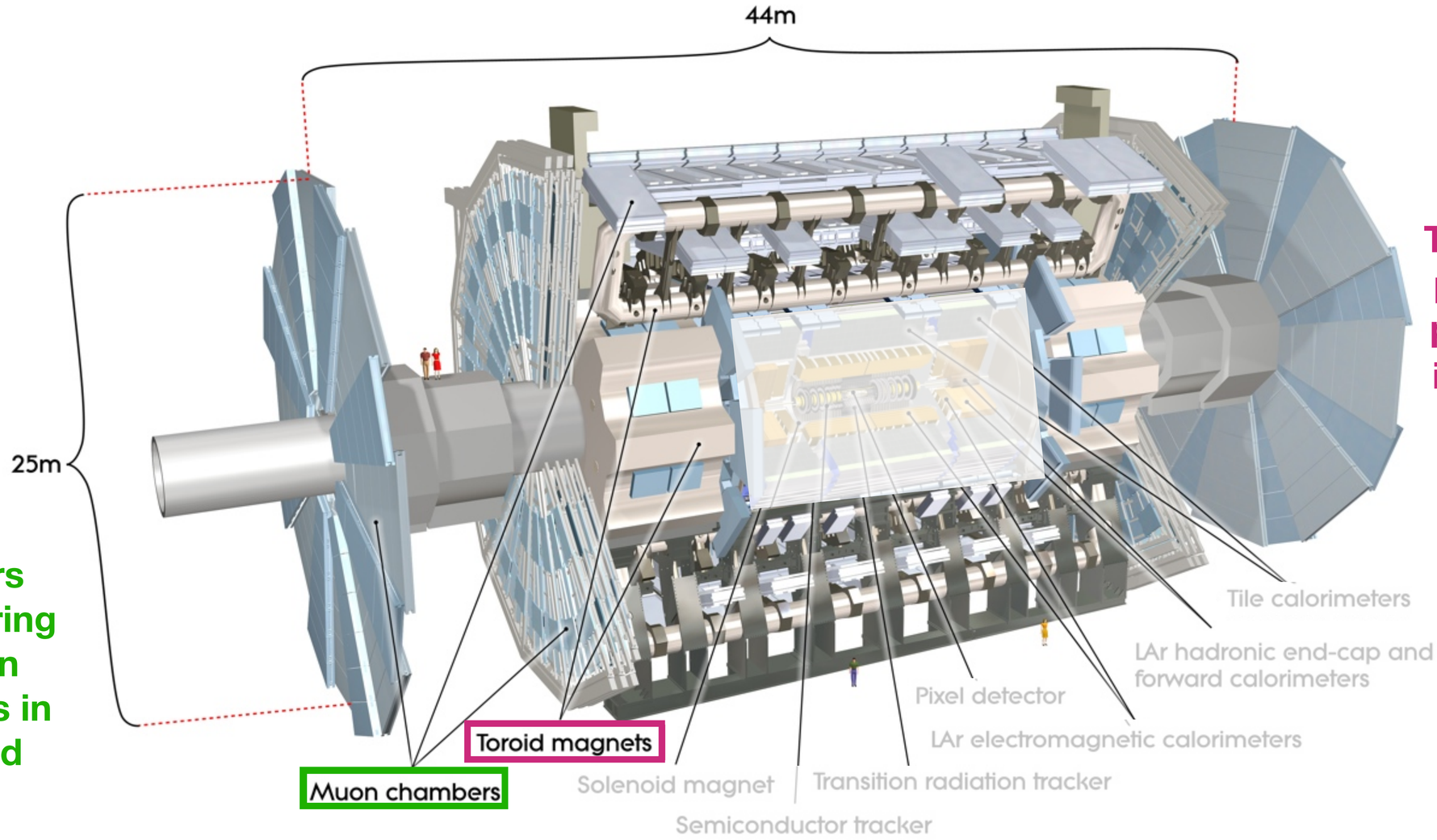




2022 Data

- Data-taking in Run-3 has been proceeding smoothly
- The 2022 dataset is important for adjusting our reconstruction and calibrations for Run-3 conditions

ATLAS Muon Spectrometer

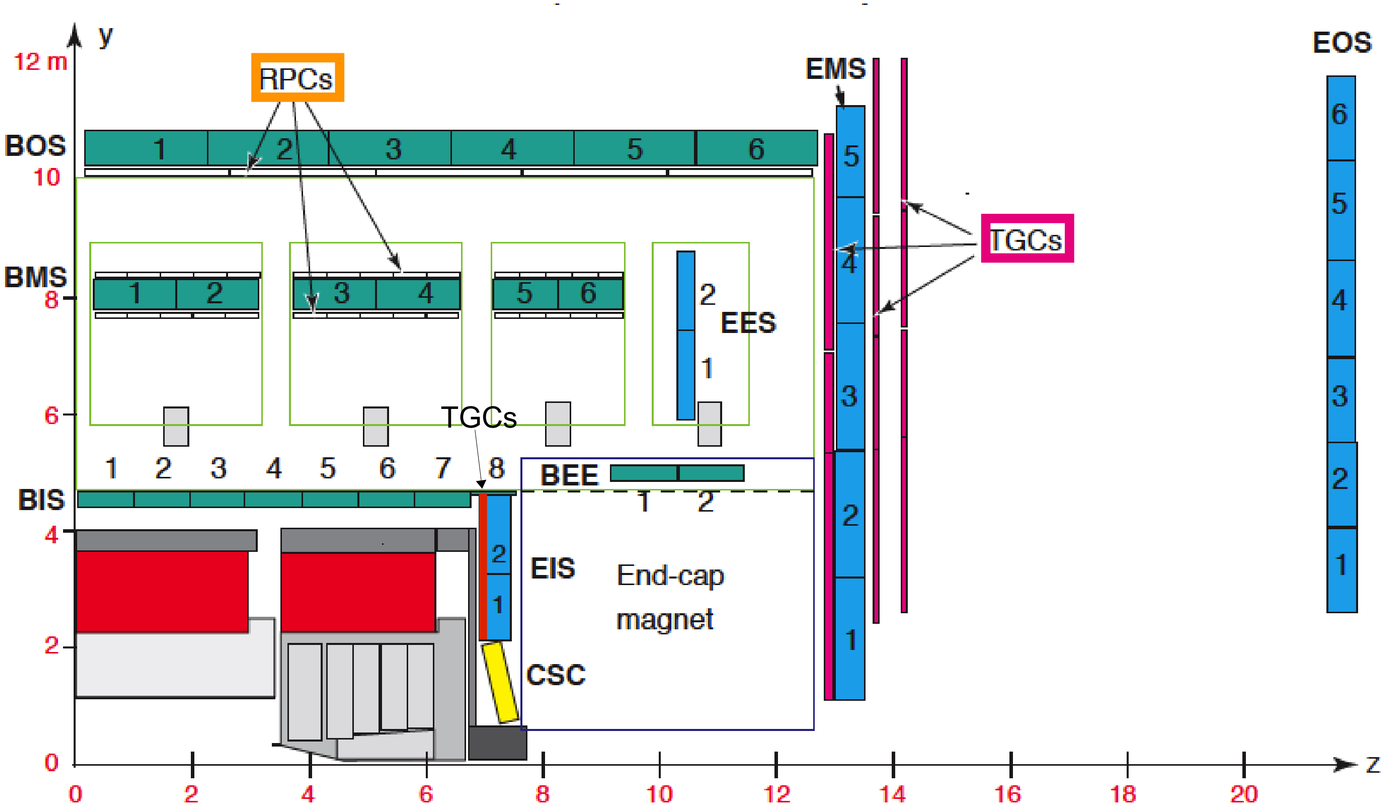


Gas detectors provide triggering and precision measurements in the barrel and endcap

Toroidal magnets provide bending power of ~3 T·m in the barrel and ~6 T·m in the endcap

ATLAS Muon Spectrometer

- Drift tube chambers (MDT) provide precision measurements in the barrel and the endcap
- Resistive plate chambers (RPC) provide triggering in the barrel

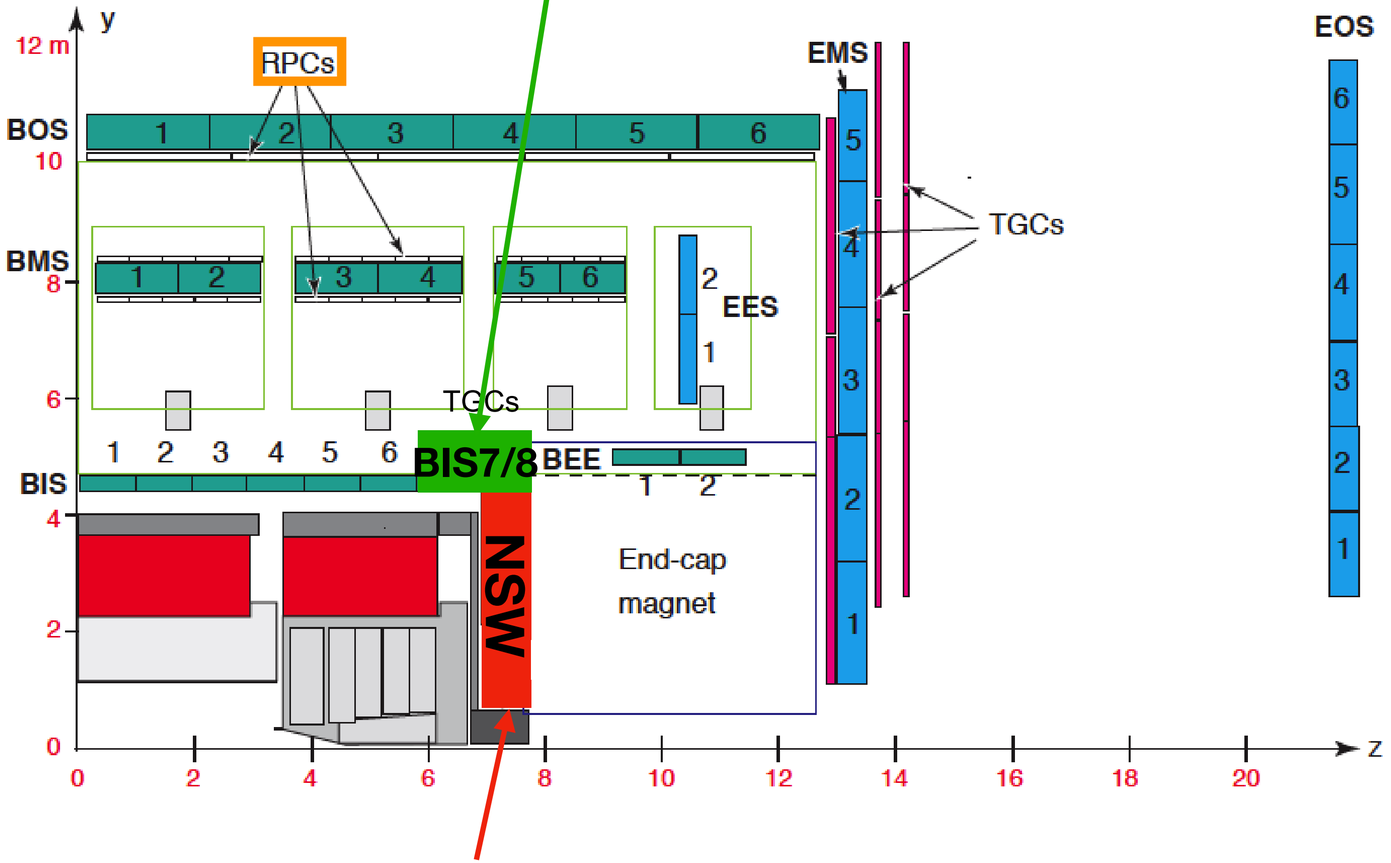


Thin-gap chambers (TGC) provide triggering in the endcap

MS Upgrades

New for Run-3: upgrade of the BIS 7 and 8 chambers to include RPCs for triggering and small-tube MDTs for better high-rate performance

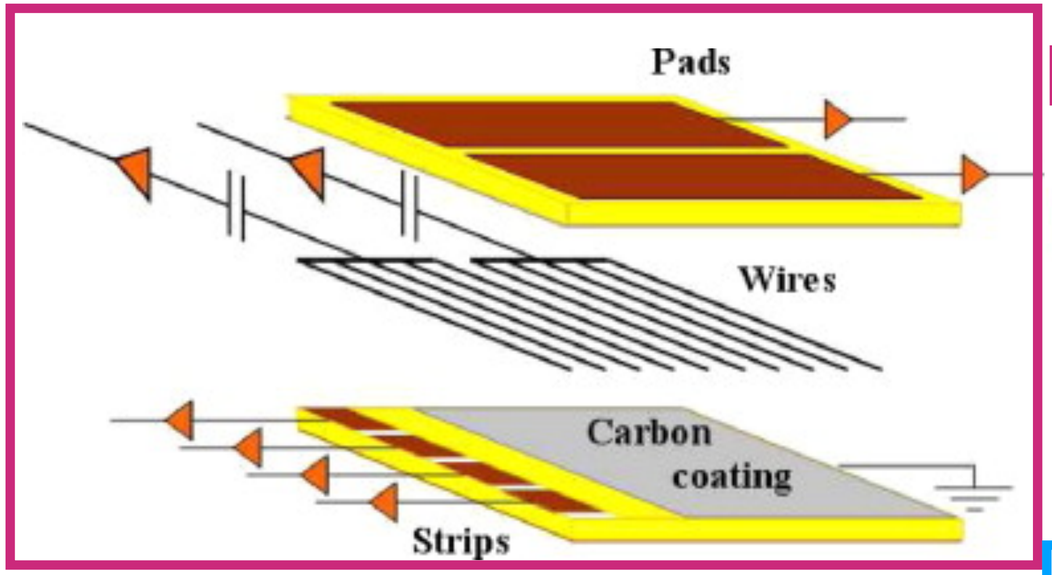
- Drift tube chambers (MDT) provide precision measurements in the barrel and the endcap
- Resistive plate chambers (RPC) provide triggering in the barrel

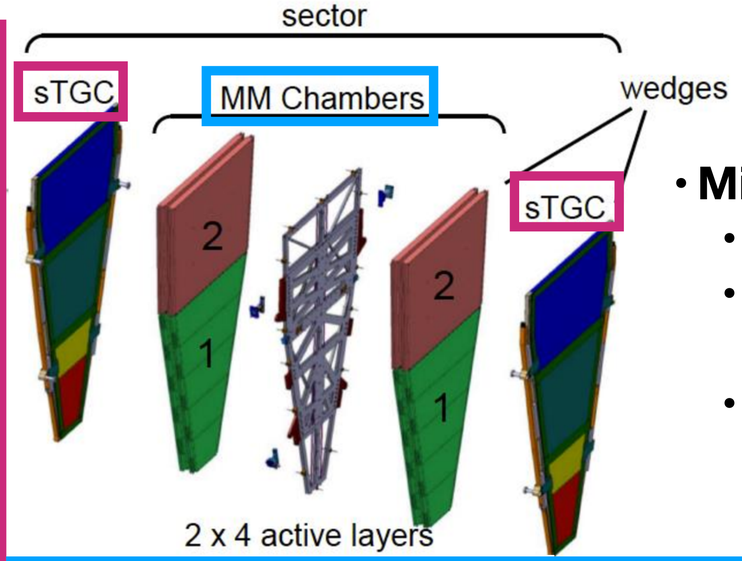


- Thin-gap chambers (TGC) provide triggering in the endcap

New for Run-3: upgrade of the Small Wheels to handle higher luminosities with better spatial resolution and improved triggering

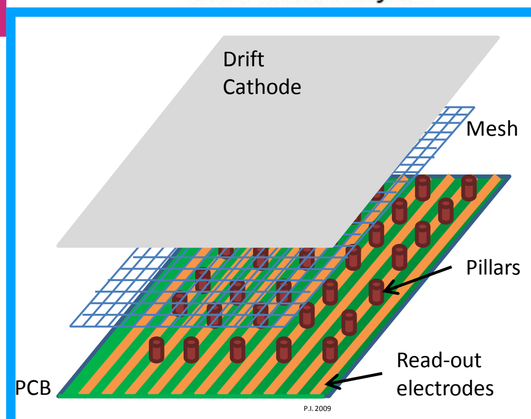
New Small Wheel

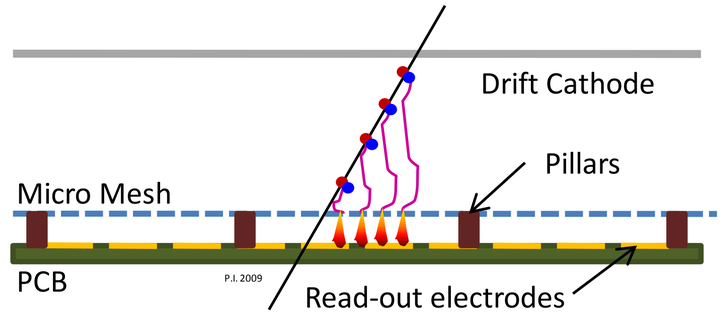




- MicroMega detectors
  - Eight total planes in each sector
  - High-precision detectors that can handle higher rates than MDTs
  - Expect <100 μm precision per plane

- sTGC detectors provide triggering
  - 4 planes on each side of a sector
  - Similar to old TGCs but smaller strips can handle higher rates
  - 1 mrad resolution for the reconstructed segment angle in the trigger



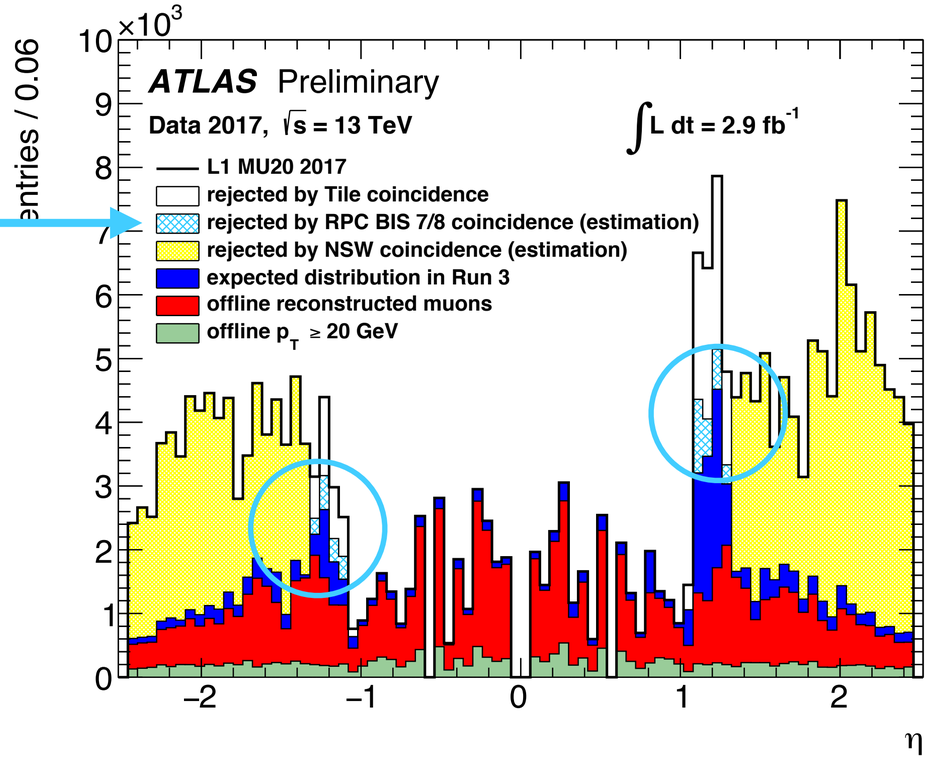


New for Run-3: upgrade of the Small Wheels to handle higher luminosities with better spatial resolution and improved triggering

BIS7/8

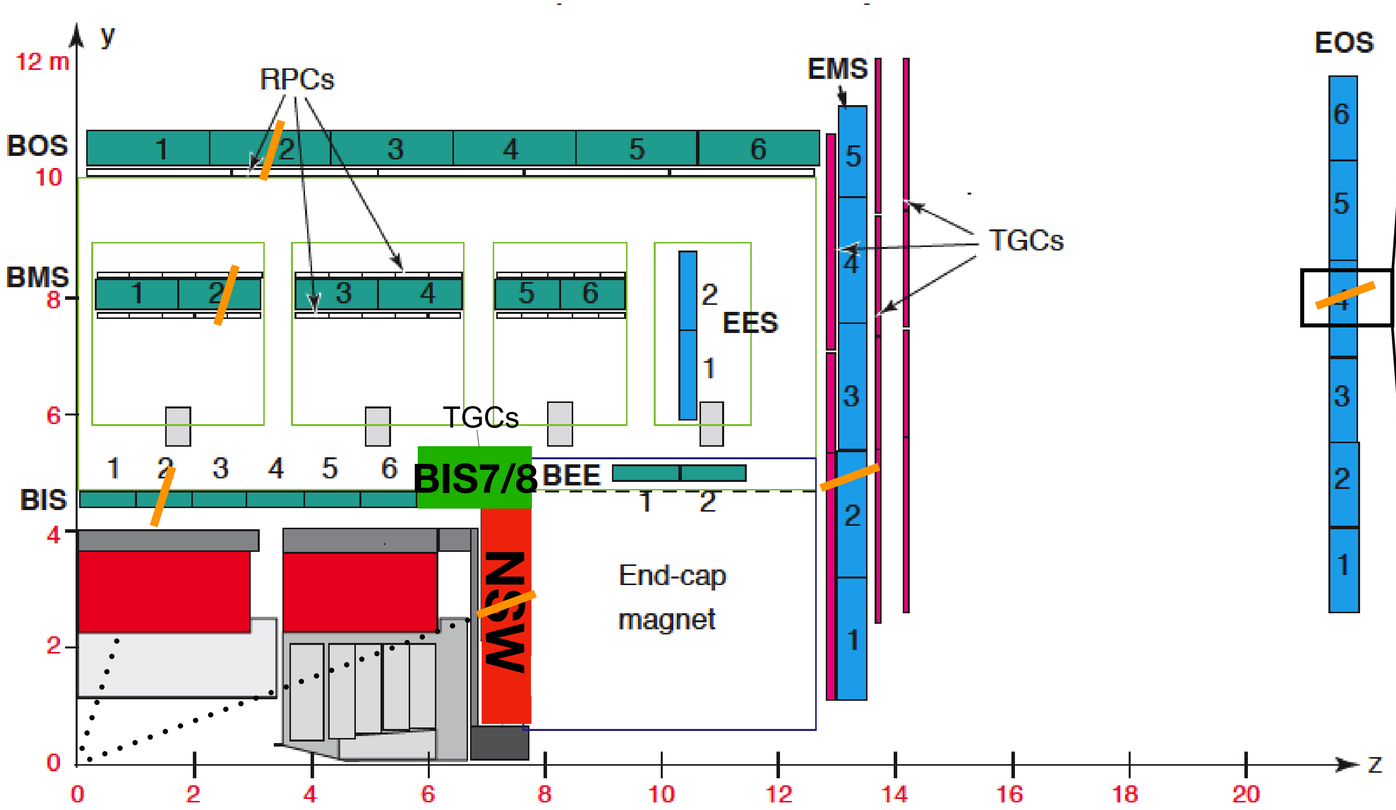
New for Run-3: upgrade of the BIS 7 and 8 chambers to include RPCs for triggering and small-tube MDTs for better high-rate performance

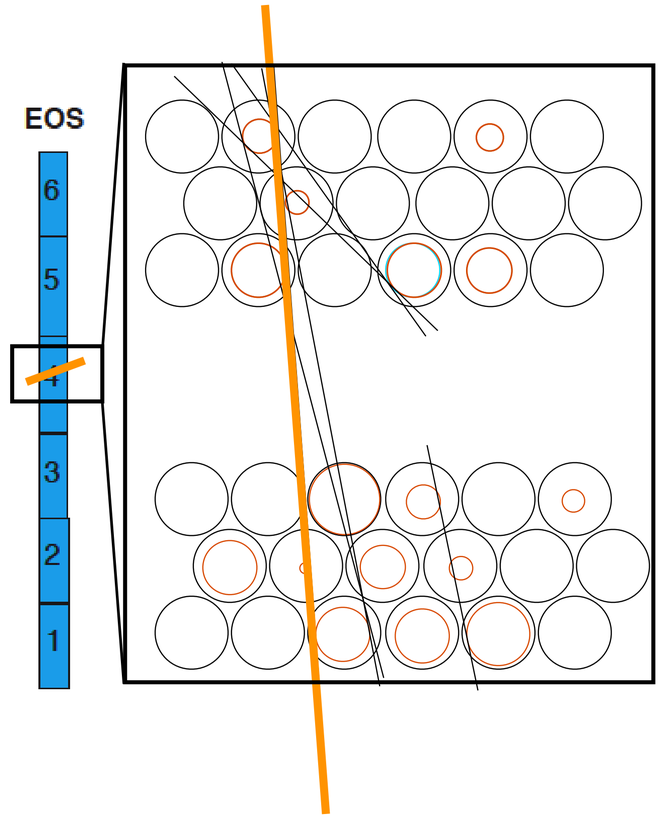
- Covers half of the 1.0<|η|<1.3 region (the small sectors only)
  - This region has similar particle fluxes to that covered by the NSW
- Provides trigger coverage with RPC triplets
  - New RPC version reduces time resolution from 1 ns to 0.4 ns
  - Also improved spatial resolution
- To make space for RPCs, switch to smaller MDTs
  - Half the radius of currently used MDTs, will improve performance at higher luminosity
- Also serves as a pilot project for the Phase II upgrade of the MS barrel
  - The first barrel layer will be replaced by a similar sMDT+RPC layout



Muon Reconstruction

— **MS Segments**
···· **ID tracks**

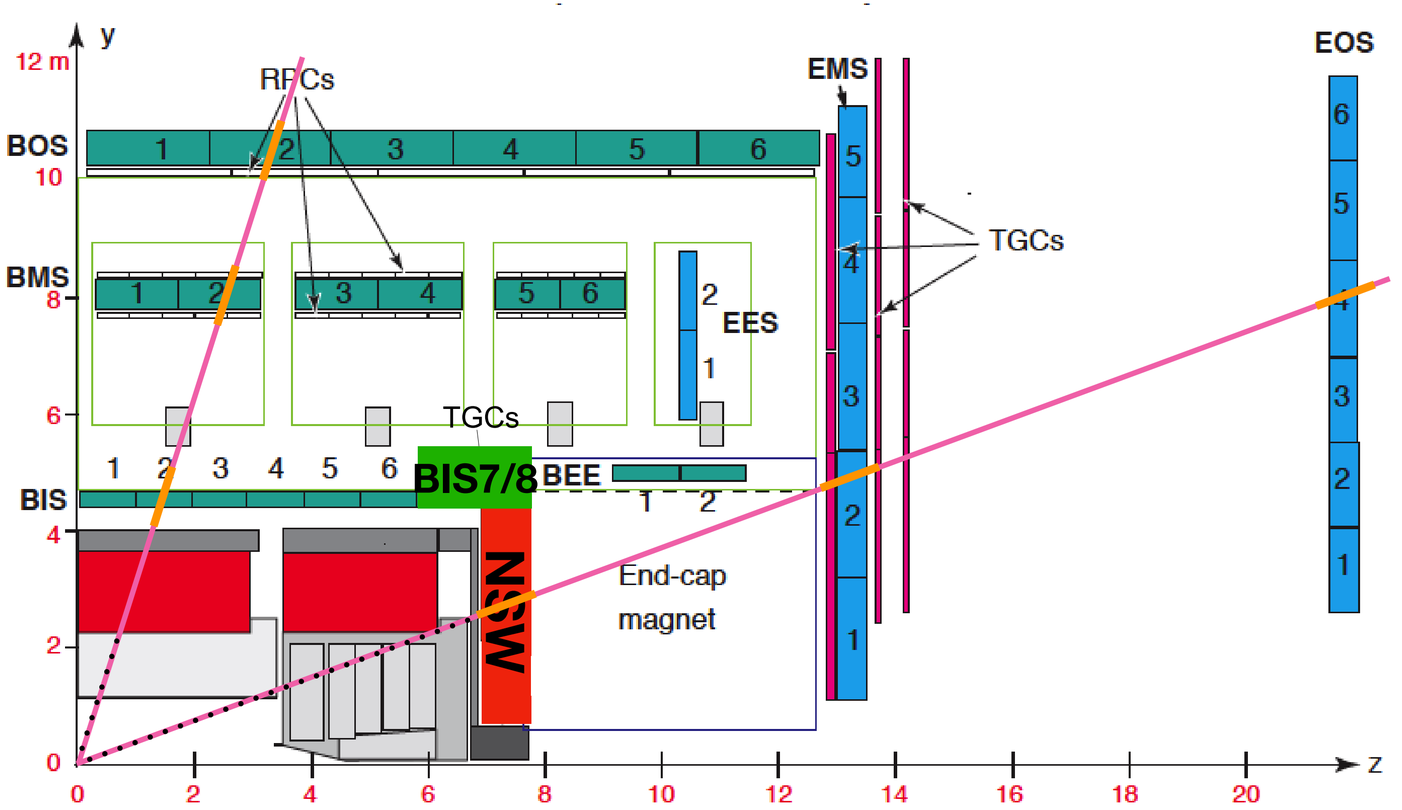




- Segments are reconstructed in each layer of the MS
  - Including trigger hits for information about the phi plane

Muon Reconstruction

MS Segments
ID tracks
MS Tracks

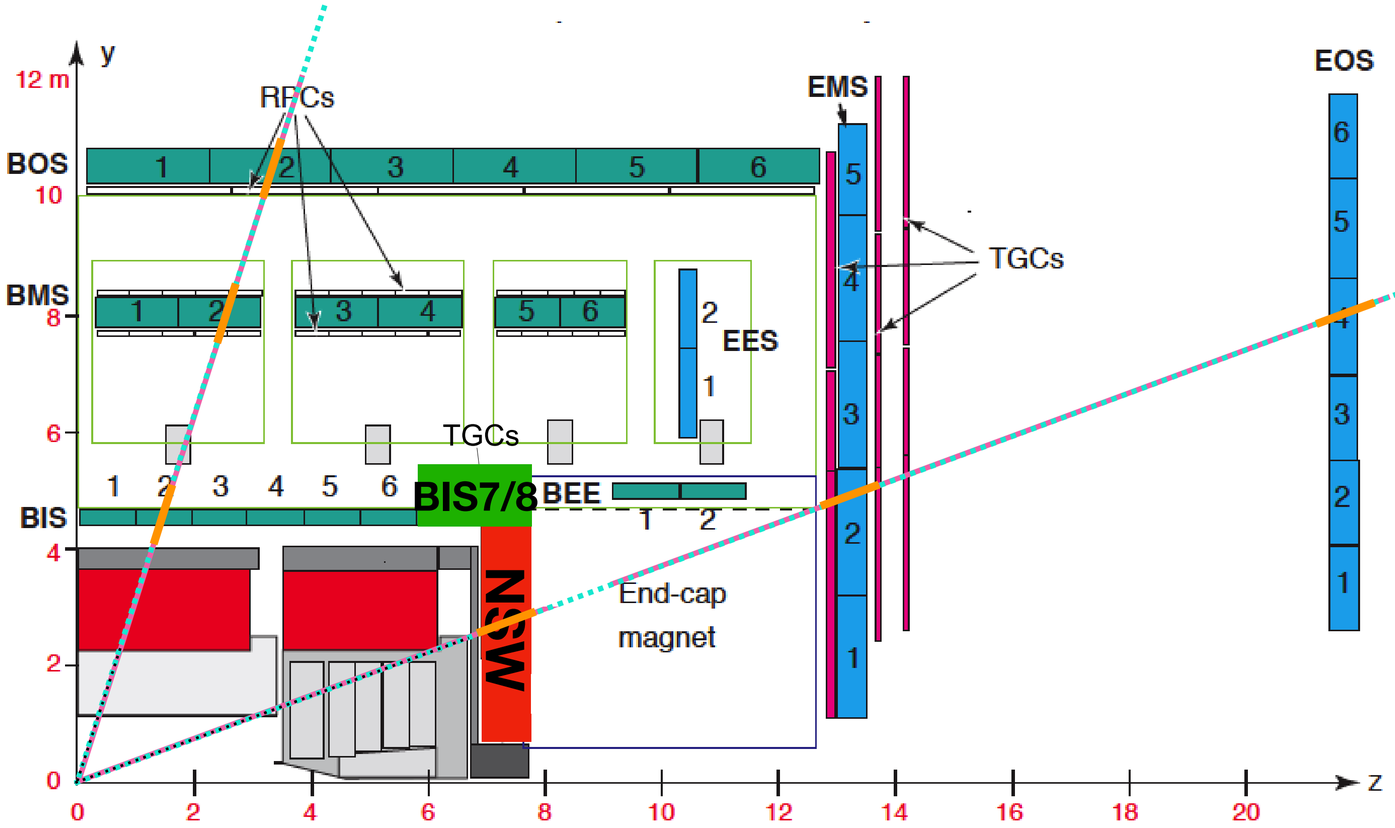


- Minimum of two segments required
- Additional hits can be added during the fit

- MS Tracks are reconstructed from the segments
  - Including a beam-spot constraint and energy loss from the calorimeters

Muon Reconstruction

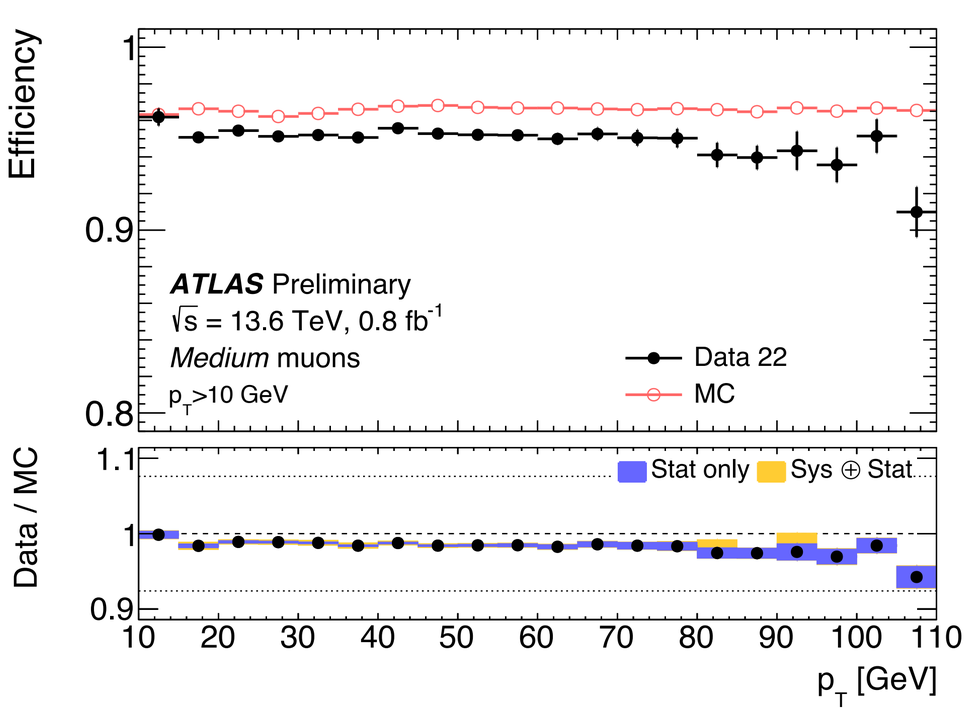
- **MS Segments**
- **ID tracks**
- **MS Tracks**
- **Combined Tracks**

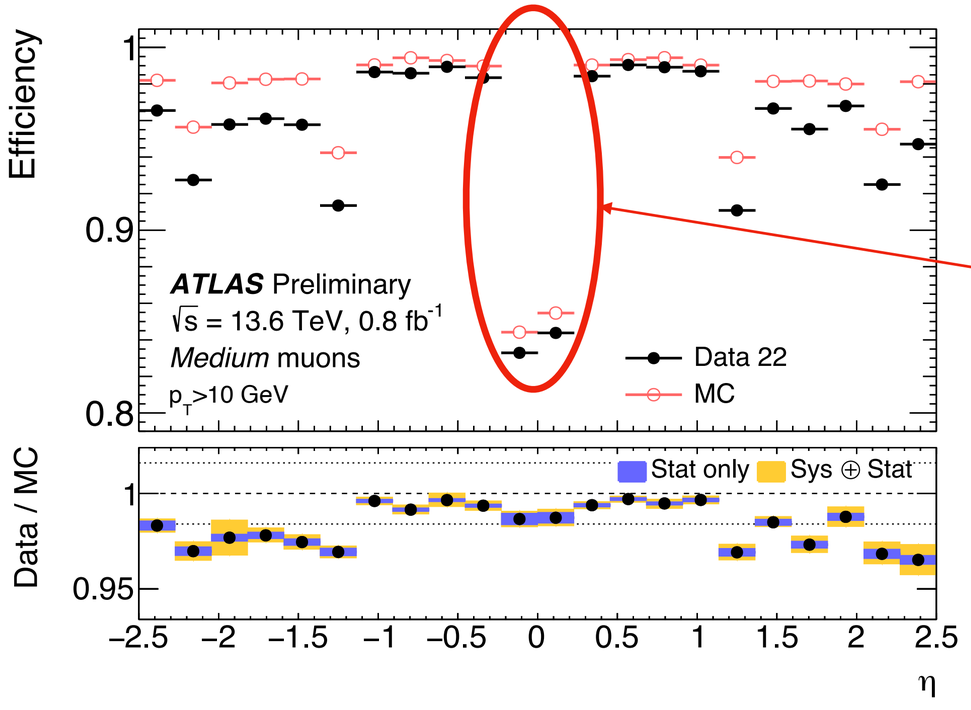


- Muons can be reconstructed without a combined track
- Trades efficiency for purity, not considered in this talk

- Combined tracks are built from MS tracks and ID tracks
  - A complementary inside-out algorithm matches ID tracks and segments

Run-3 Muon Reconstruction Efficiency





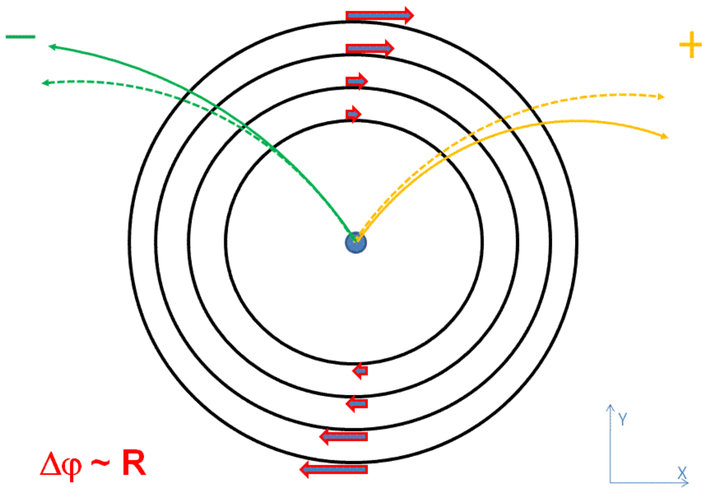
Acceptance hole at η~0 due to space for services

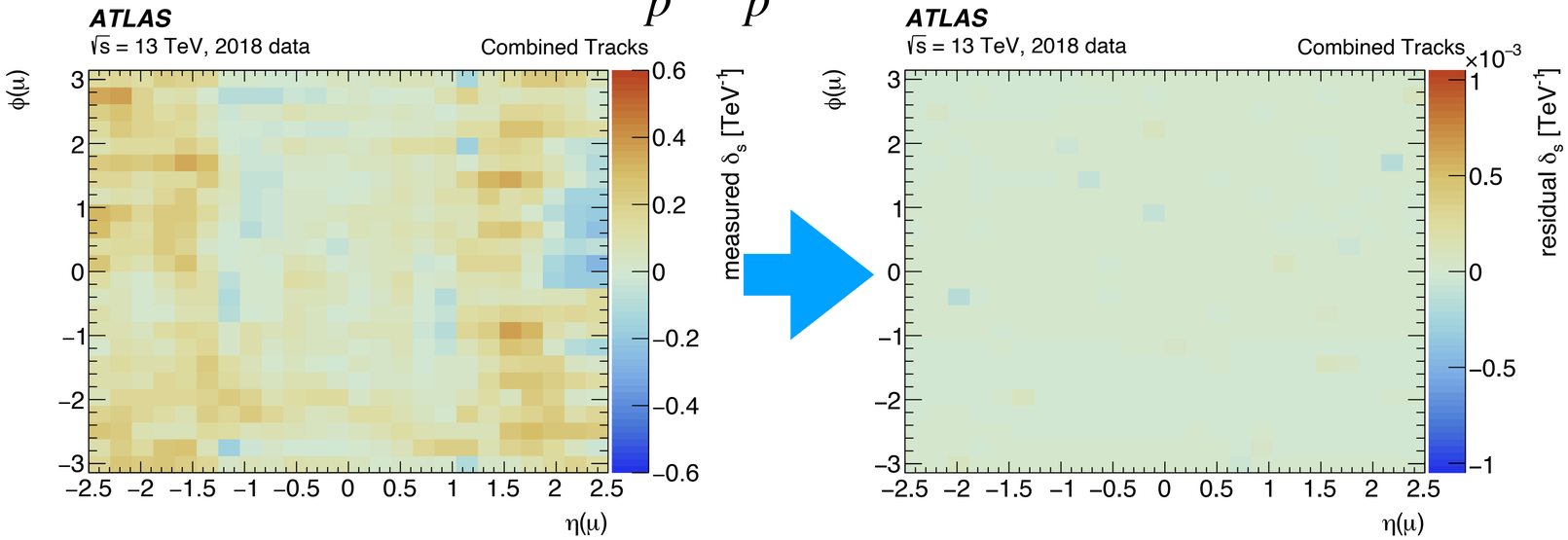
- Efficiency is for reconstructing muons that pass the Medium quality criteria
  - Mainly having to do with the number of hits in precise detectors
  - At least two layers with precision hits required
    - For now, the NSW is not counted as such in data, leading to loss of efficiency wrt MC

arXiv:2212.07338

Correcting for Charge-Dependent Effects

$$\frac{q}{\hat{p}} = \frac{q}{p} + q \cdot \delta_s$$





- Residual misalignment can induce charge-dependent effects on momentum measurement
  - So-called weak modes in the ID may not be corrected by global minimization of χ^2 residuals
  - Residual uncertainty in the MS alignment can be up to 120-130 μm
- Correction is obtained by minimizing the variance of $m_{\mu\mu}$ for Z bosons

arXiv:2212.07338

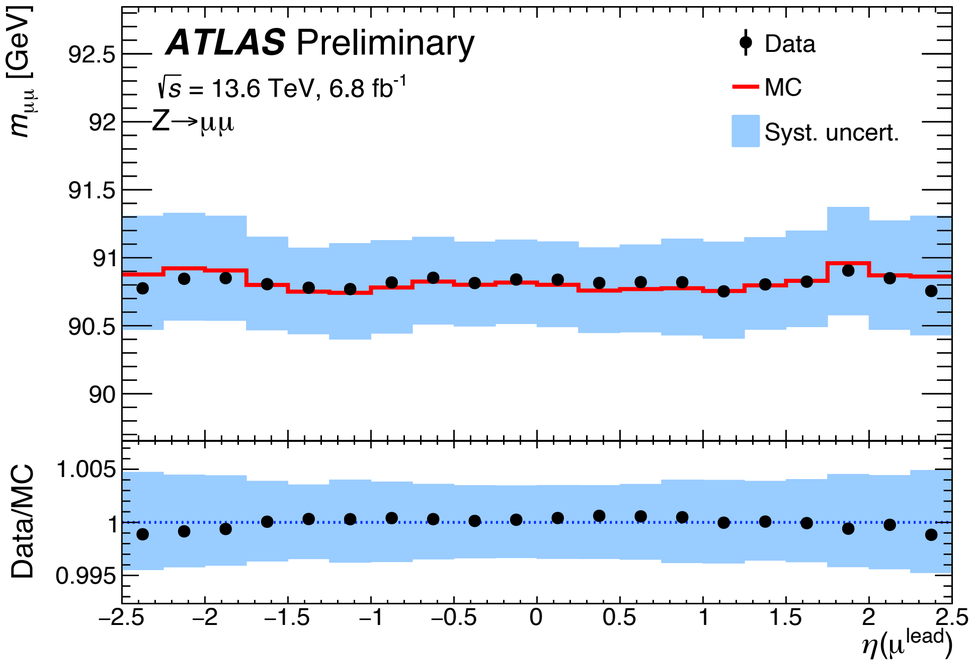
Momentum Calibration

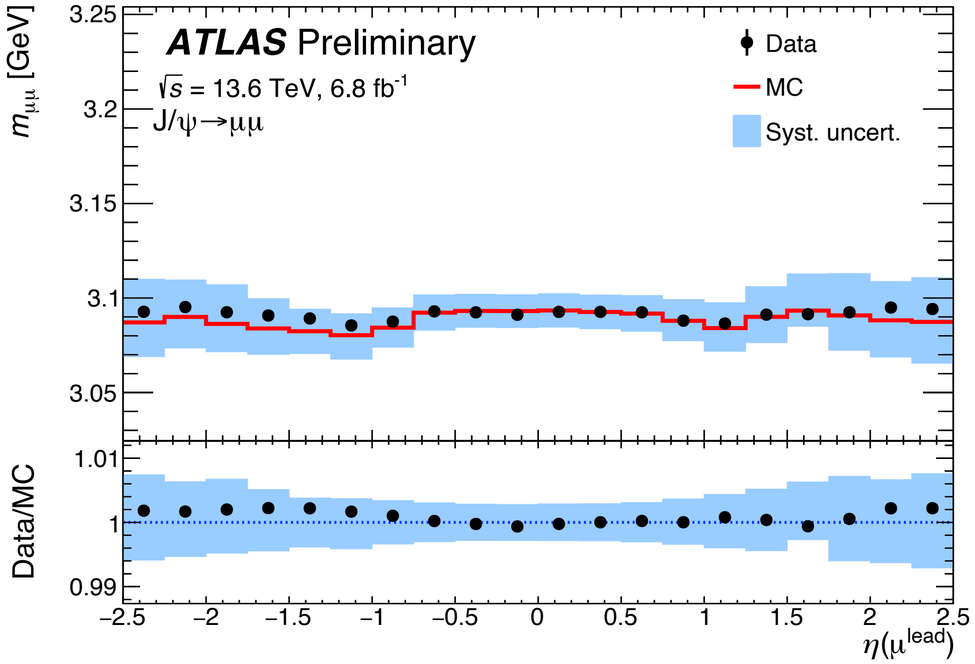
$$p_{\mathrm{T}}^{\mathrm{Cor,Det}} = \frac{p_{\mathrm{T}}^{\mathrm{MC,Det}} + \sum_{n=0}^{1} s_n^{\mathrm{Det}}(\eta,\phi)\left(p_{\mathrm{T}}^{\mathrm{MC,Det}}\right)^n}{1 + \sum_{m=0}^{2} \Delta r_m^{\mathrm{Det}}(\eta,\phi)\left(p_{\mathrm{T}}^{\mathrm{MC,Det}}\right)^{m-1} g_m}$$

- Simulated muon momentum resolution is smeared (Δr terms) to match data
  - Accounts for energy loss fluctuations, multiple scattering, intrinsic detector resolution, etc.
- Simulated muon momentum scale is corrected (s terms) to match data
  - Accounts for potential errors in simulation of energy loss, magnetic field, etc.
- Δr and s values are obtained from fits to $m_{\mu\mu}$ distribution of Z and J/Ψ events
  - Separately for large and small sectors, and in η bins
  - Z backgrounds are simulated, J/Ψ are taken from data

MUON-2022-02

Muon Momentum Scale in Run-3

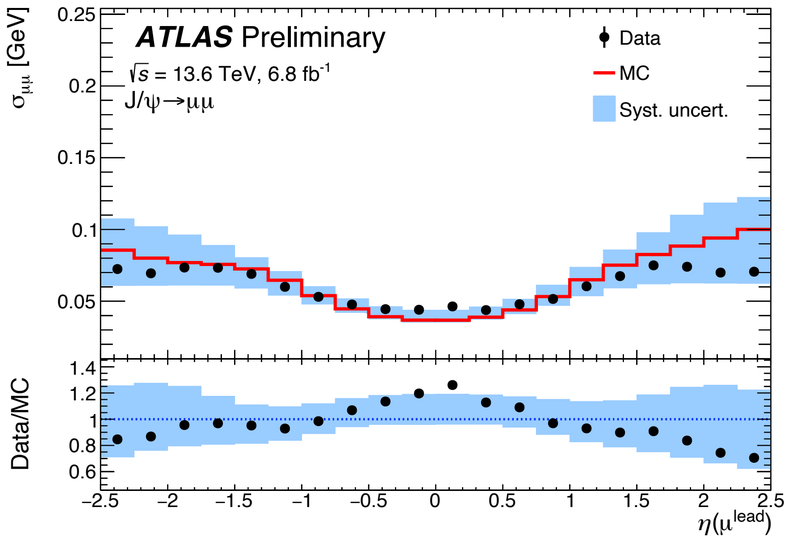


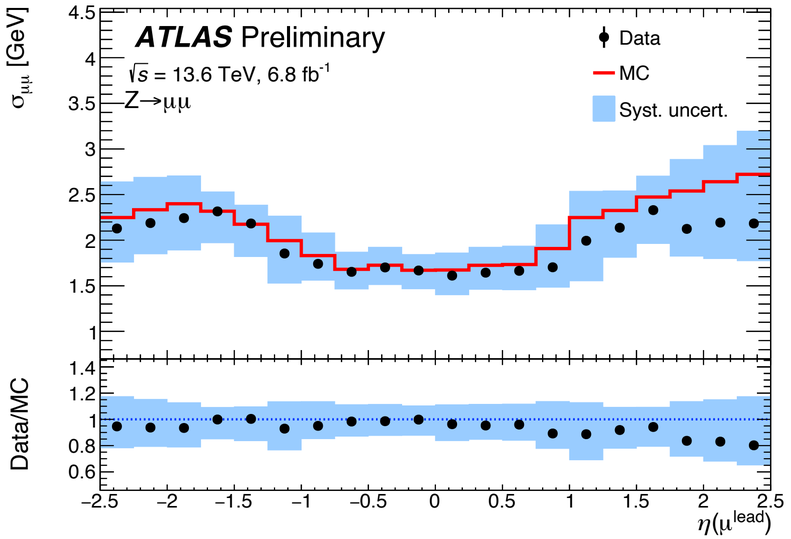


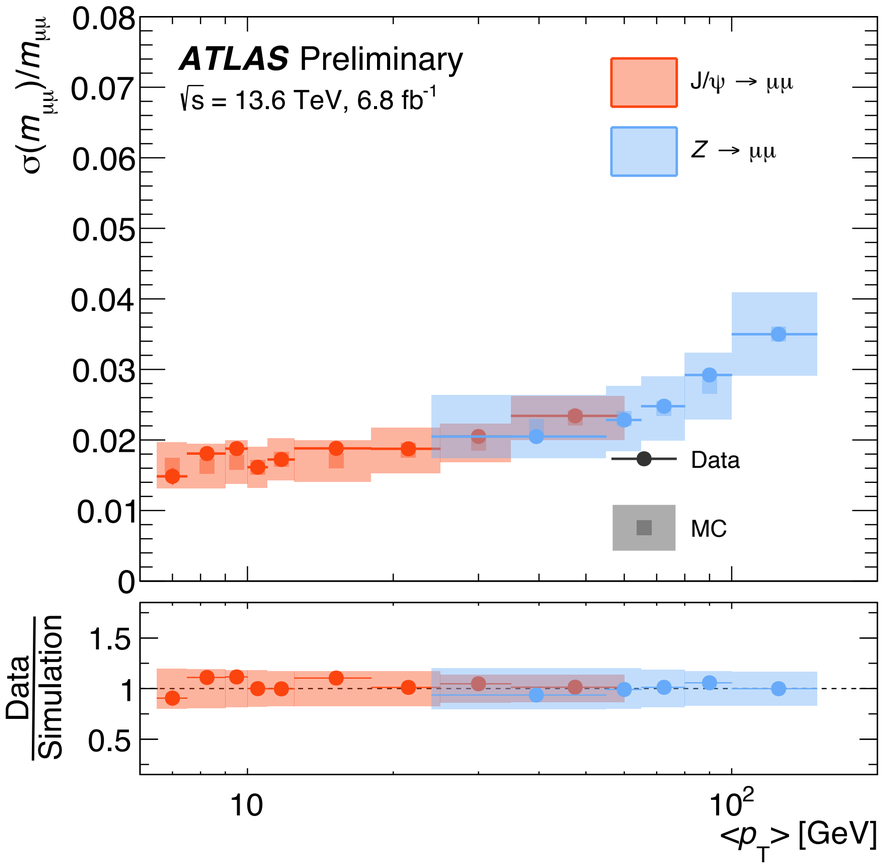
- Again, only Medium quality muons are considered
  - The NSW is again not considered as a precision station while it is being commissioned
- Calibration constants are derived from Run-3 data
  - Sagitta bias correction is not applied to data, not enough events to derive it yet
- Good data-MC agreement is observed

MUON-2022-02

Muon Momentum Resolution in Run-3







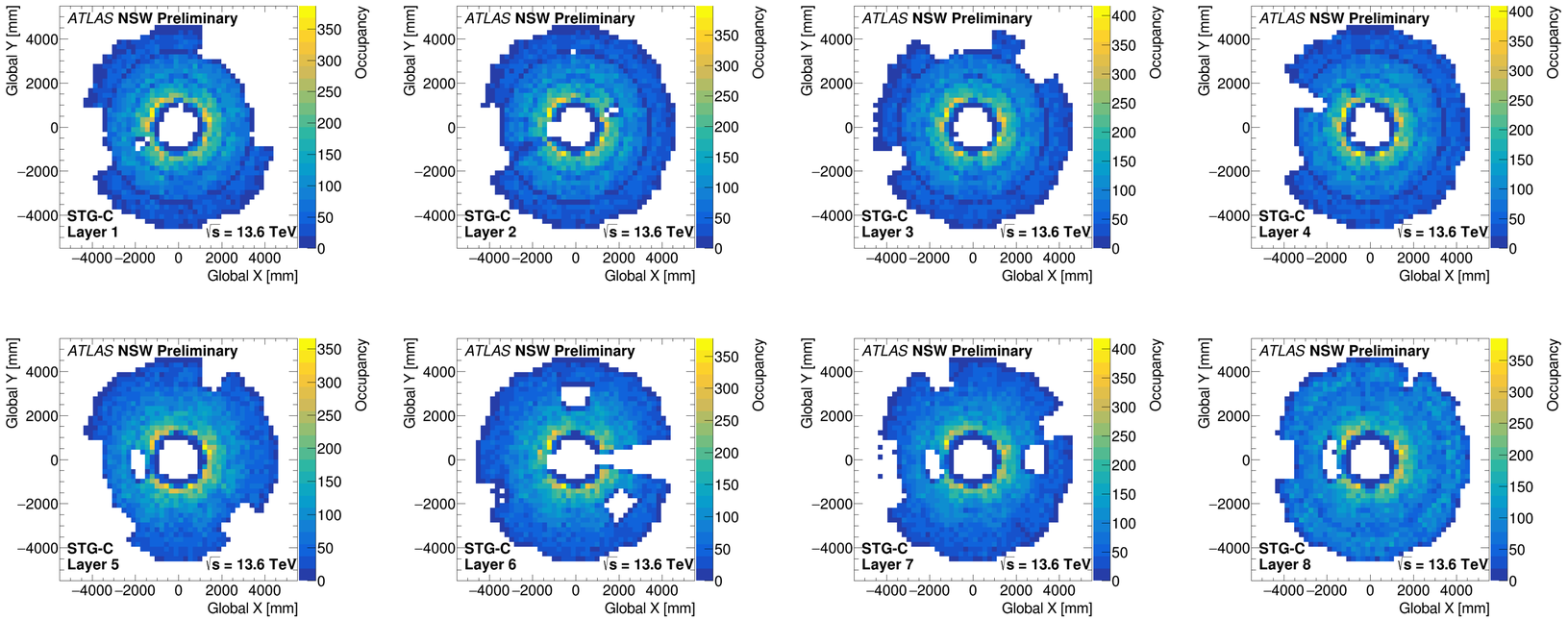
- Good data-MC agreement observed for resolution
- As well as in the overlap region between J/Ψ and Z
- Large uncertainty due to low stats

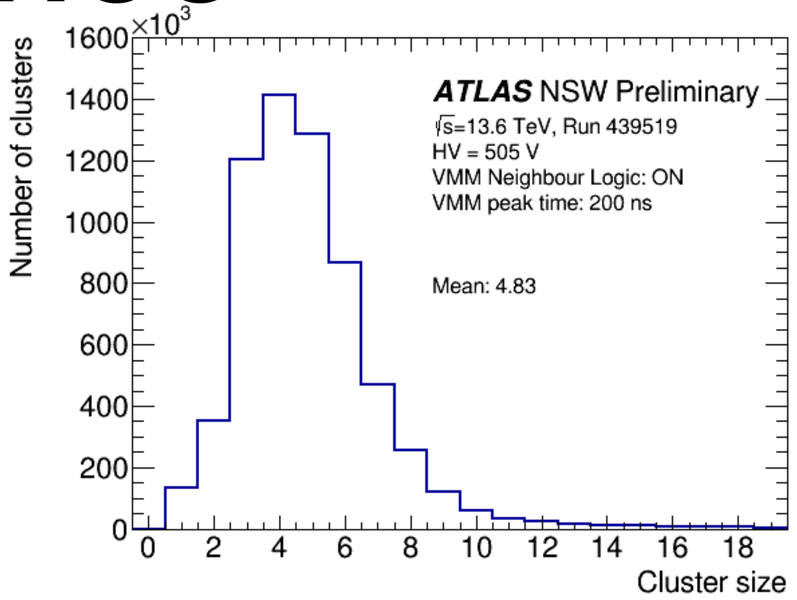
Summary

- ATLAS muon reconstruction is working well in Run-3
- Commissioning of the NSW is ongoing
- Preliminary momentum calibration derived
- Expect to reach Run-2 levels of performance with sufficient events
  - Scale uncertainty less than .05% (.1%) for Z (J/Ψ)
  - Resolution uncertainty less than 1.5% (2%) for Z (J/Ψ)

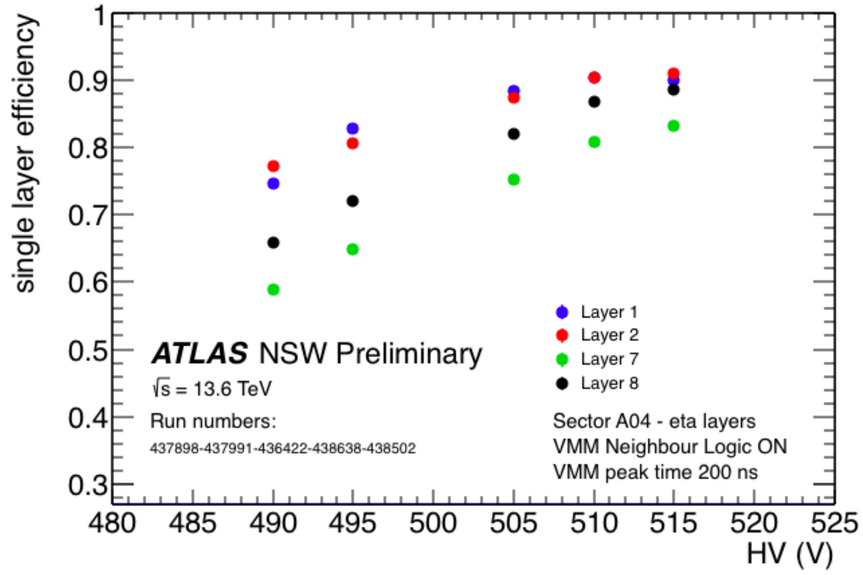
Backup

NSW Performance





- NSW detectors are taking data, commissioning is ongoing
  - Time alignment
  - Detector alignment
  - DAQ and software issues



Muon Calibration Uncertainties

- Systematic uncertainties include possible biases on the method and uncertainties in the background estimation
- The main uncertainty on the scale arises from performing the calibration using only Z or J/Ψ decays, instead of combining both
  - This accounts for extrapolation to p_T values away from the peak
- The main uncertainty on the resolution arises from varying the p_T ranges used in the fit
- Other sources of uncertainty include the choice of $m_{\mu\mu}$ range and binning, the kinematic reweighting applies to the simulated Z boson events, and the parameterization of the J/Ψ background