MUON RECONSTRUCTION PERFORMANCE WITH THE ATLAS EXPERIMENT AT THE LHC USING RUN-3 PP COLLISION DATA

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MAX-PLANCK-INSTITUT
FÜR PHYSIK

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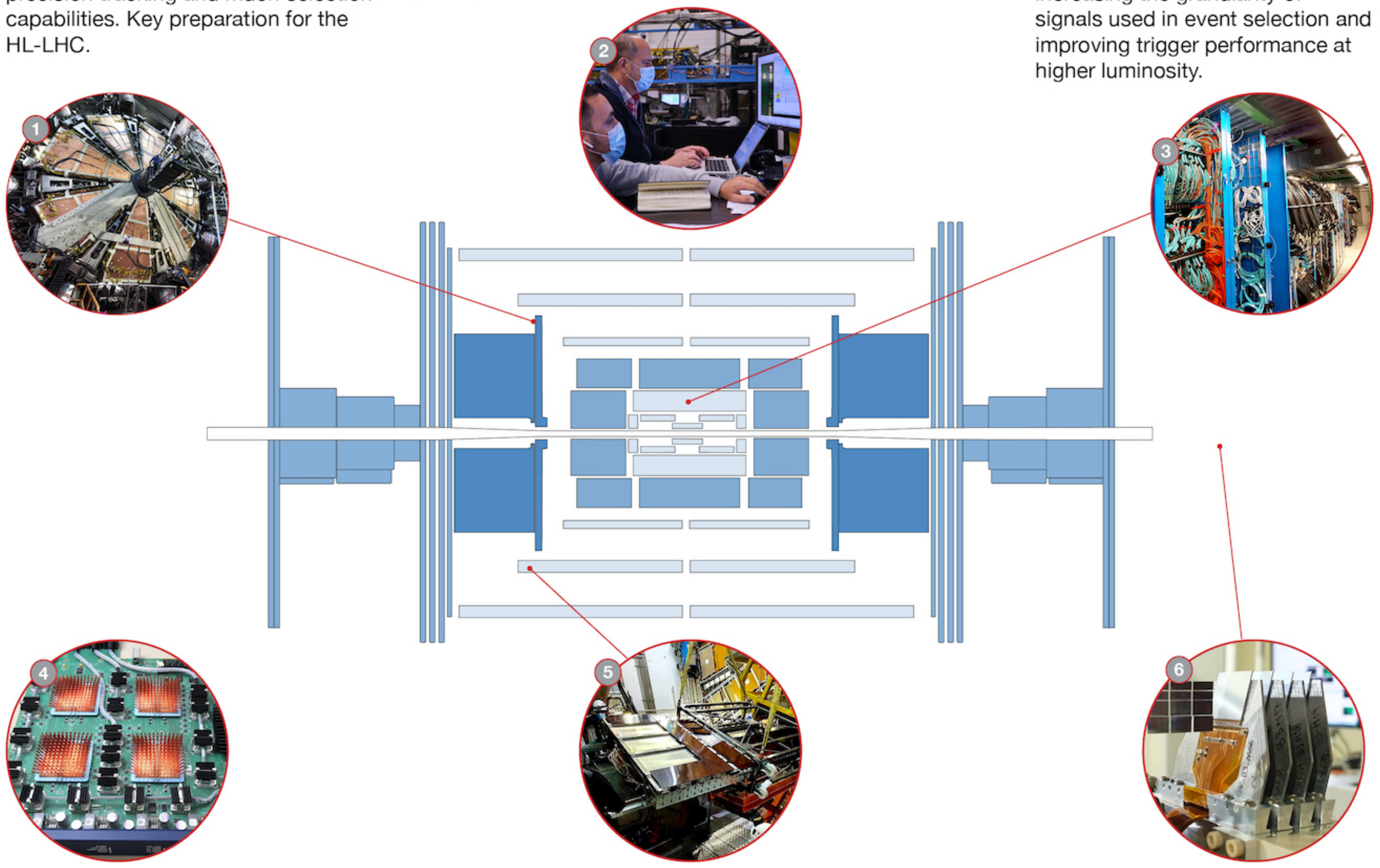
ATLAS IN RUN-3

ATLAS DETECTOR LS2 UPGRADES

MUON NEW SMALL WHEELS (NSW)
Installed new muon detectors with precision tracking and muon selection capabilities. Key preparation for the HL-LHC.

NEW READOUT SYSTEM FOR THE NSWs
The NSW system includes two million micromega readout channels and 350 000 small strip thin-gap chambers (sTGC) electronic readout channels.

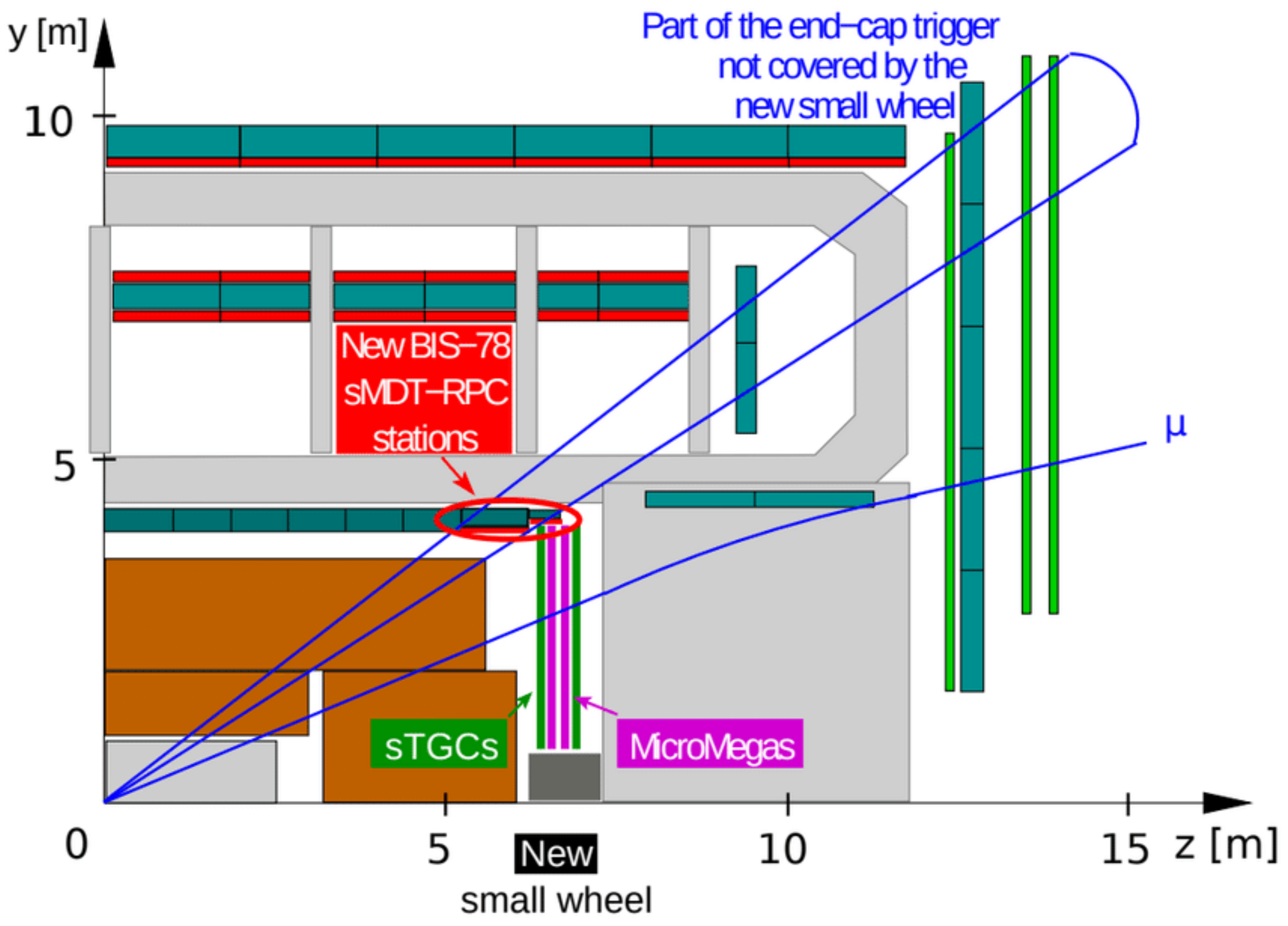
LIQUID ARGON CALORIMETER
New electronics boards installed, increasing the granularity of signals used in event selection and improving trigger performance at higher luminosity.



TRIGGER AND DATA ACQUISITION SYSTEM (TDAQ)
Upgraded hardware and software allowing the trigger to spot a wider range of collision events while maintaining the same acceptance rate.

NEW MUON CHAMBERS IN THE CENTRE OF ATLAS
Installed small monitored drift tube (sMDT) detectors alongside a new generation of resistive plate chamber (RPC) detectors, extending the trigger coverage in preparation for the HL-LHC.

ATLAS FORWARD PROTON (AFP)
Re-designed AFP time-of-flight detector, allowing insertion into the LHC beamline with a new "out-of-vacuum" solution.



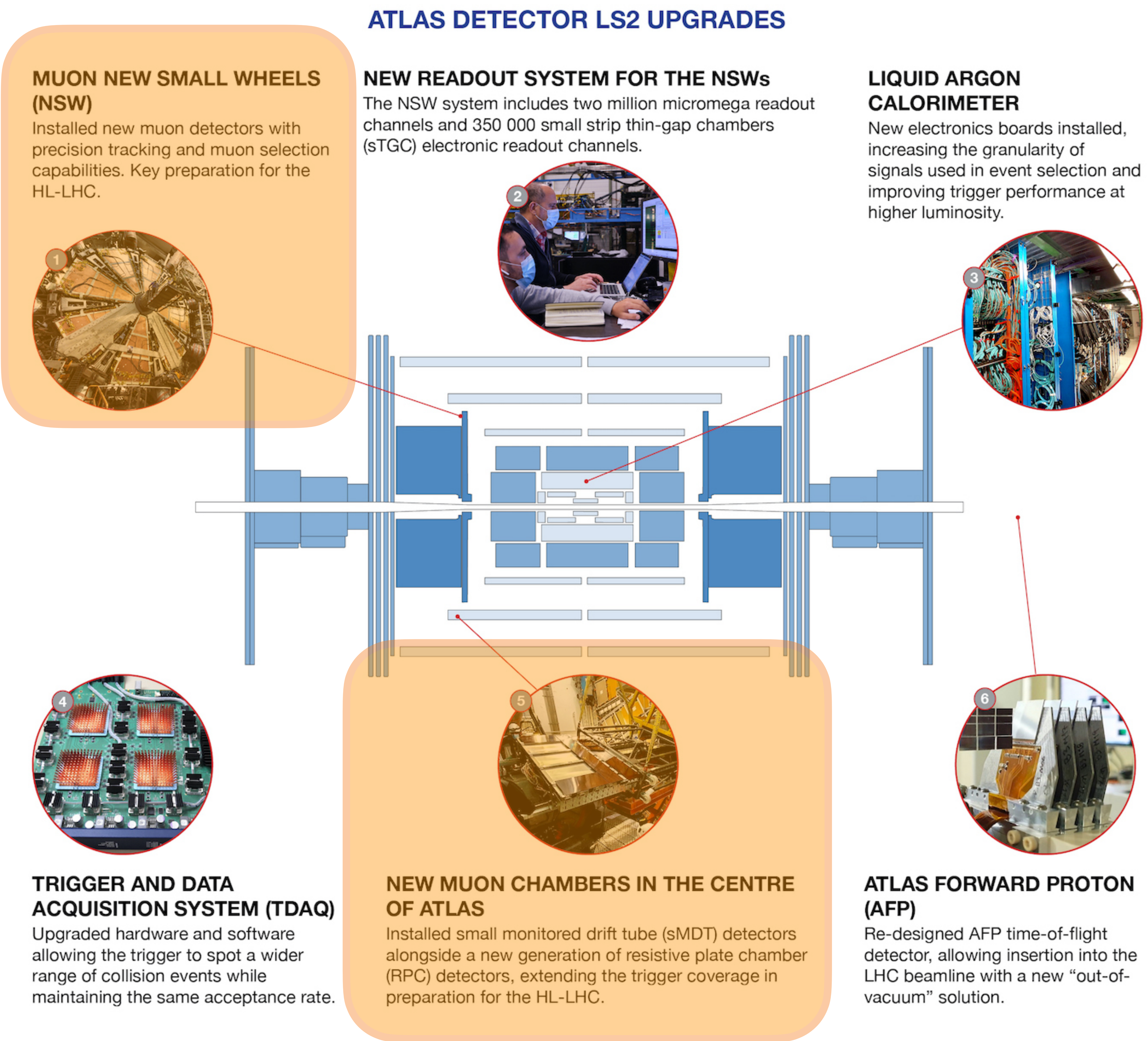
The New Small Wheel (NSW)

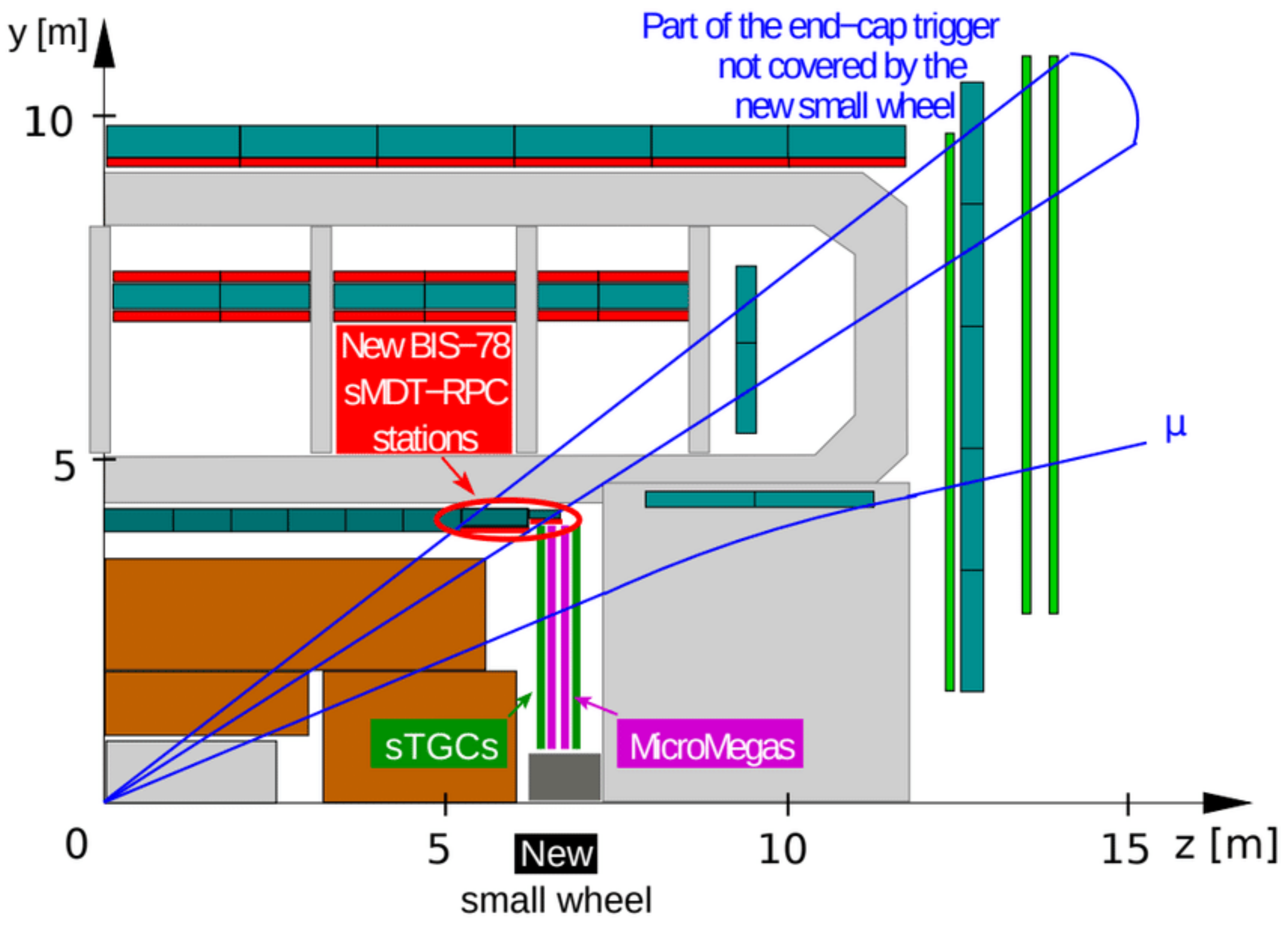
New sTGC (small-strip Thin Gap Chambers) and MicroMegas station, replacing the old Small Wheel with Cathode Strip Chambers.
NSW η range: [1.3, 2.7]

Upgrade Goal

NSW designed for high background rate of HL-LHC.
Improved spatial resolution (100 μm)

ATLAS IN RUN-3





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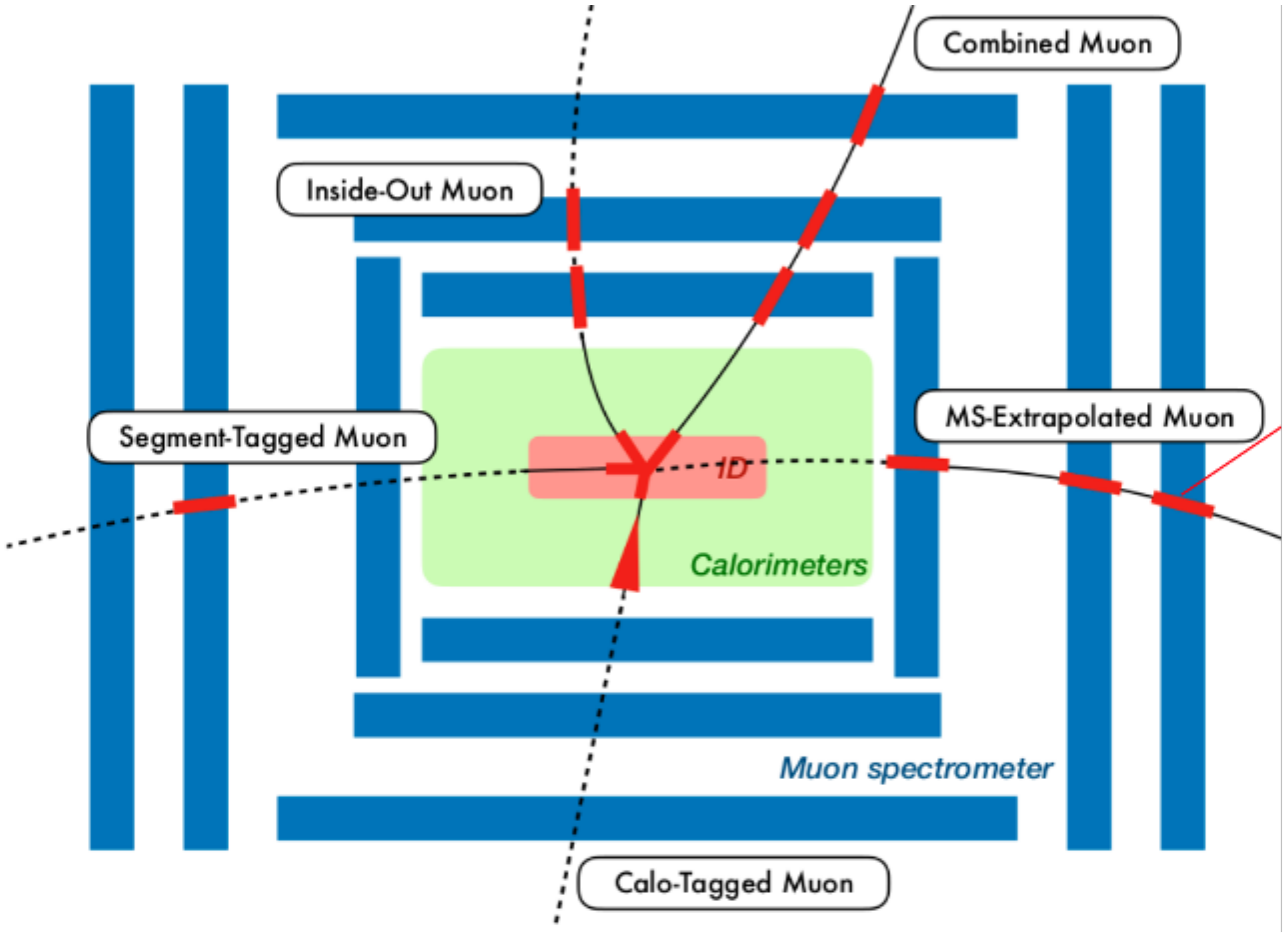
ATLAS MUON RECONSTRUCTION

Muons are reconstructed using information from the **Muon Spectrometer (MS)**, the **Inner Detector (ID)** and the **Calorimeter**.

Five categories of muons:



Standalone muons (MS-Extrapolated)

Identified using a track reconstructed only in the MS.

Combined Muons (CB)

Track reconstructed using information from both ID and MS

Segment-Tagged Muons (ST)

ID track matching in position and angle to a segment in the MS (useful for low-pT muon tracks and in region with reduced acceptance)

Calo-Tagged Muons (CT)

ID track matching an energy deposit in the calorimeter consistent with a minimum ionizing particle (improves purity in the region of limited MS coverage)

Inside-Out Muons

Track in the MS matched to segment in the silicon tracker

MUON IDENTIFICATION

Working Point	Description
Loose	Looser cuts to maximise the acceptance. High efficiency for analyses with multi-leptons.
Medium	Good acceptance, low fake rate, small systematic uncertainties. Best compromise eff/fake. Used by most analyses.
Tight	Harder cuts to maximise purity.
High pT	Good momentum resolution for very high pT muons (> 300 GeV).

In 2022, NSW hits were not used in all data-taking periods for the definition of working points, resulting in a lower efficiency in the end-cap regions with respect to simulated data.

MUON RECO & ID EFFICIENCY

Muon Reconstruction and Identification measured using **Tag & Probe** method, applied to Z→μ+ μ- or *J/Ψ*→μ+ μ- decays.

Events are selected by requiring:

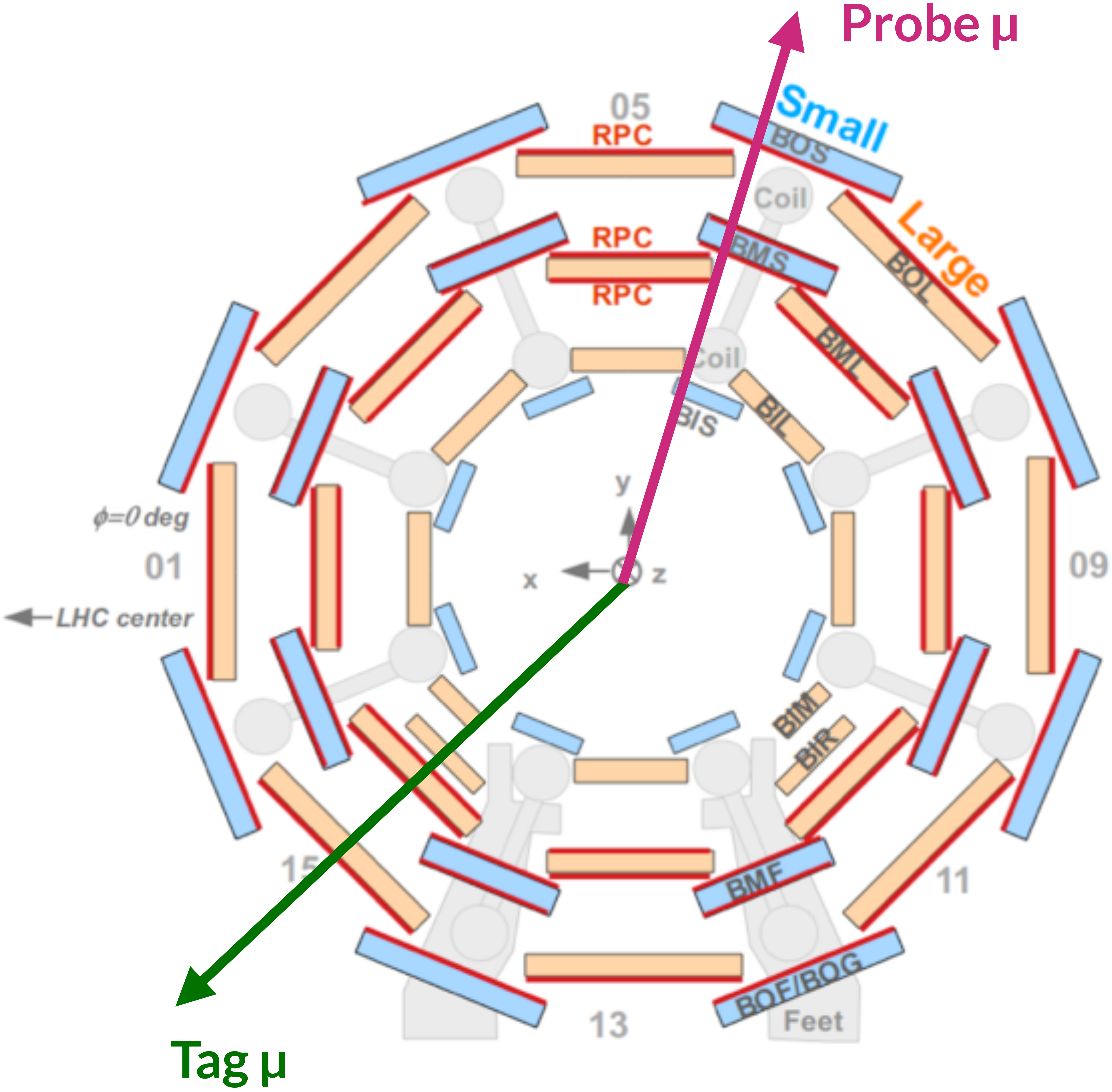
- A "**tag**" muon, satisfying **stringent** identification criteria and **triggering** the online event selection
- A "**probe** muon", used to test the efficiency of a certain reconstruction algorithm or identification working point
- Invariant mass $m_{\text{tag-probe}}$ compatible with *Z* or *J/Ψ* mass

The **efficiency** is then calculated by

$$\varepsilon(X) = \frac{N_{\text{matches}}(X)}{N_{\text{probes}}},$$

where $N_{\text{matches}}(X)$, is the number of probes "matched" to a muon candidate identified with the algorithm *X*.

Matched: $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.05$



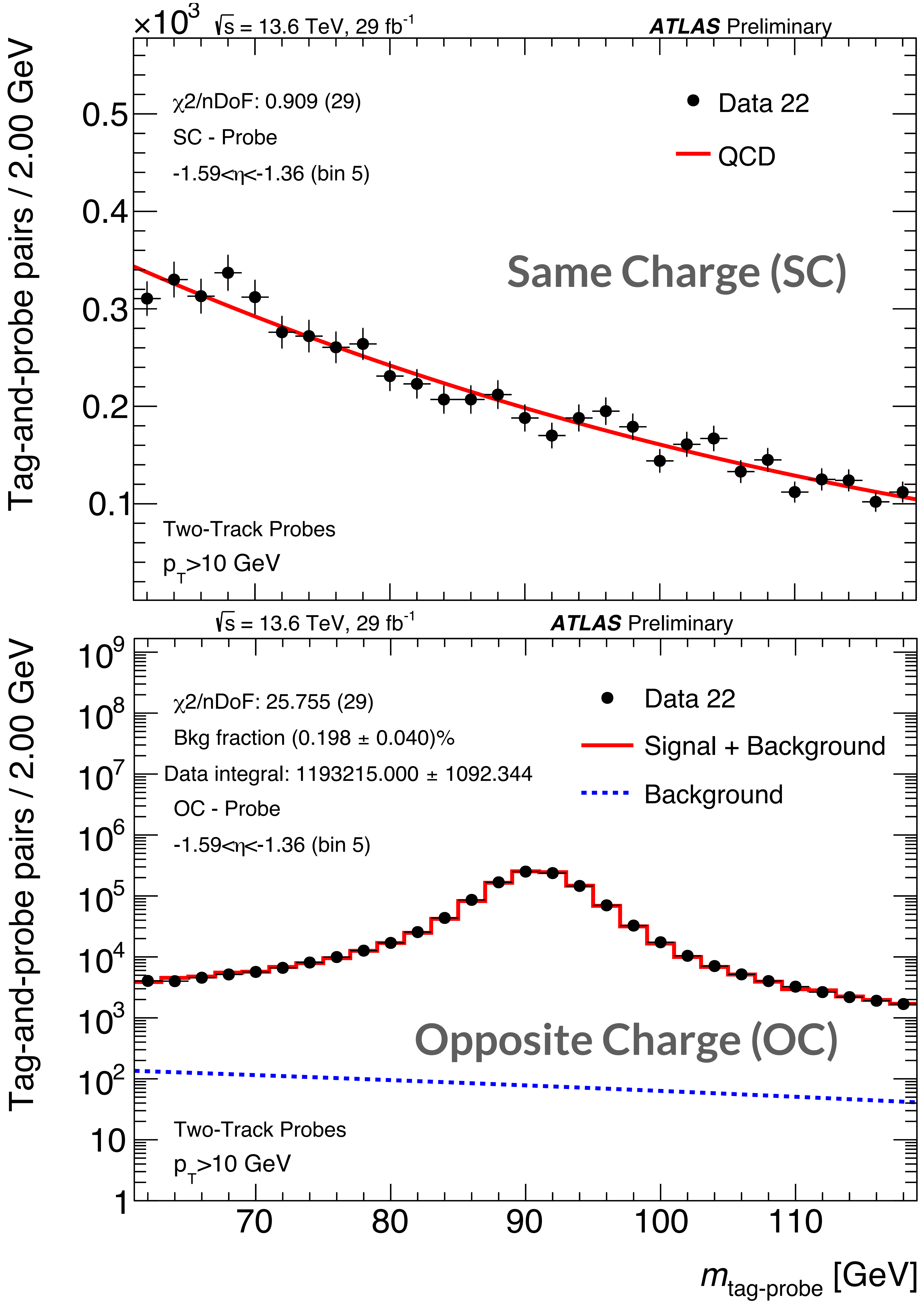
BACKGROUND SUBTRACTION

QCD background is estimated from the data using a **template fit** in the invariant mass spectrum, using **same charged muons (SC)**

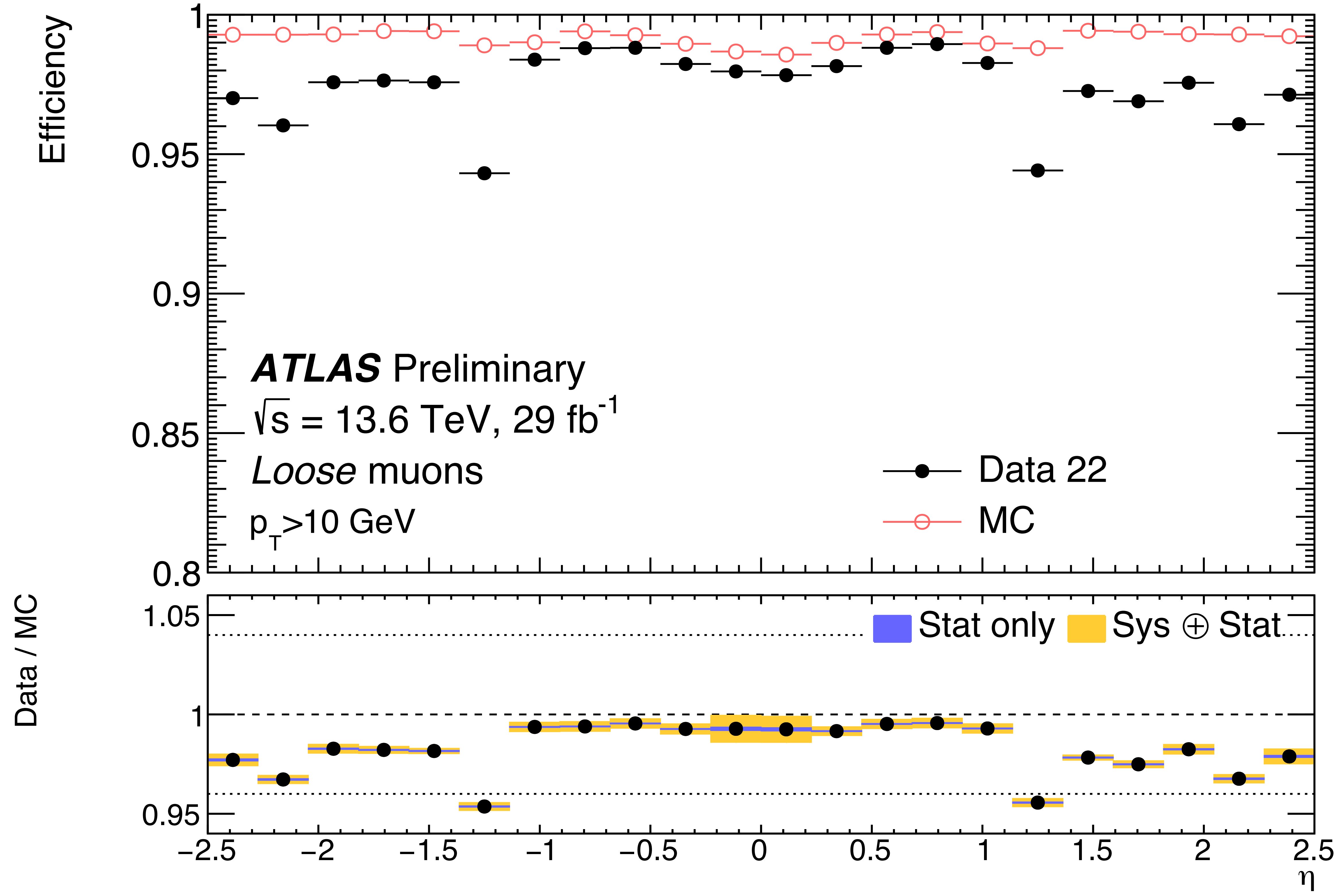
For the **signal**, a template is created using **all Standard Model processes** that can produce an **opposite-charged muon pair (OC)**, and it is then fit to the data, after having subtracted the QCD background.

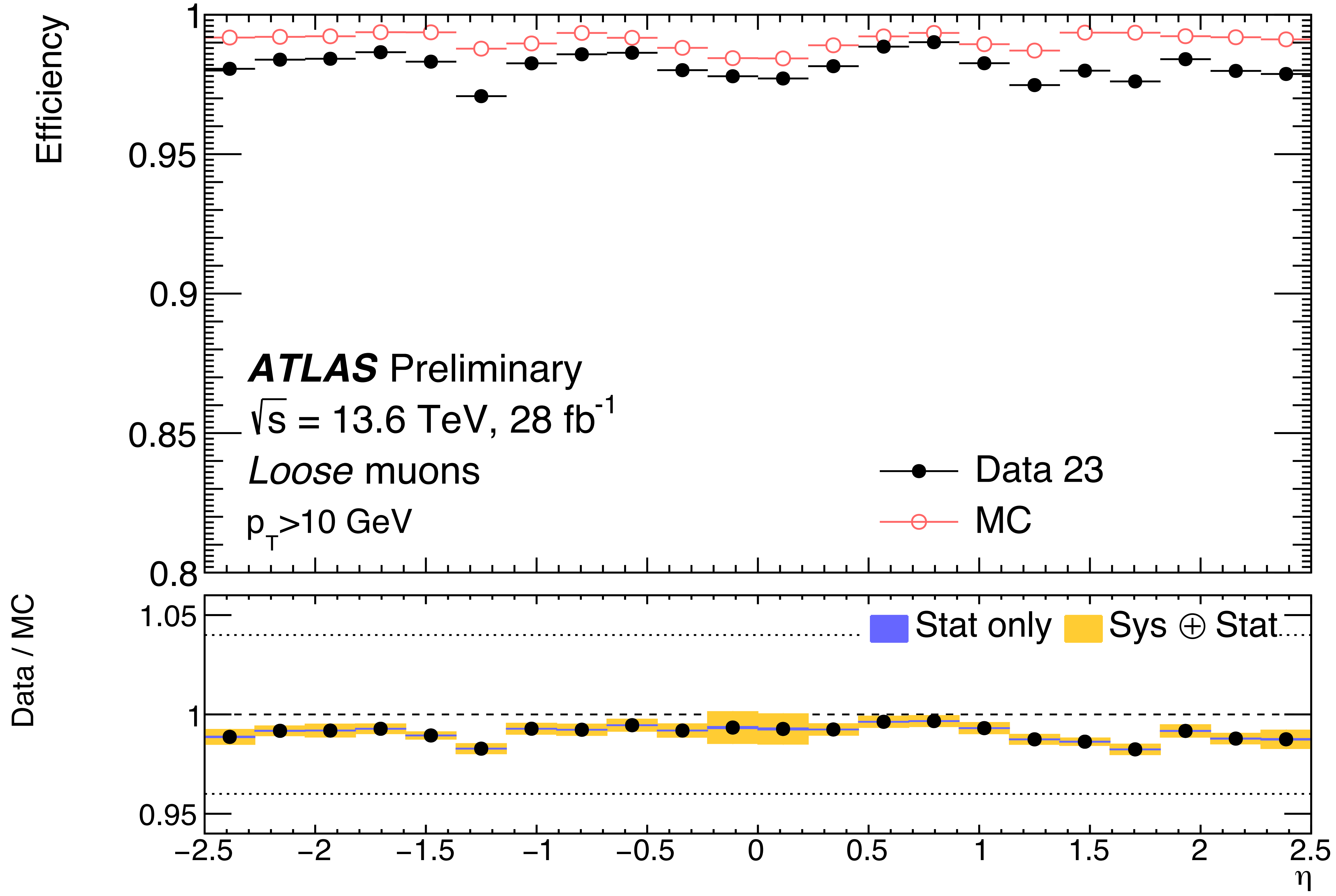
Number of **probes and matches** are then extracted from the fits in data.

In **simulation**, the probes and matches are directly **counted**, considering only reconstructed muons associated to a truth particle.



LOOSE SELECTION (Z)

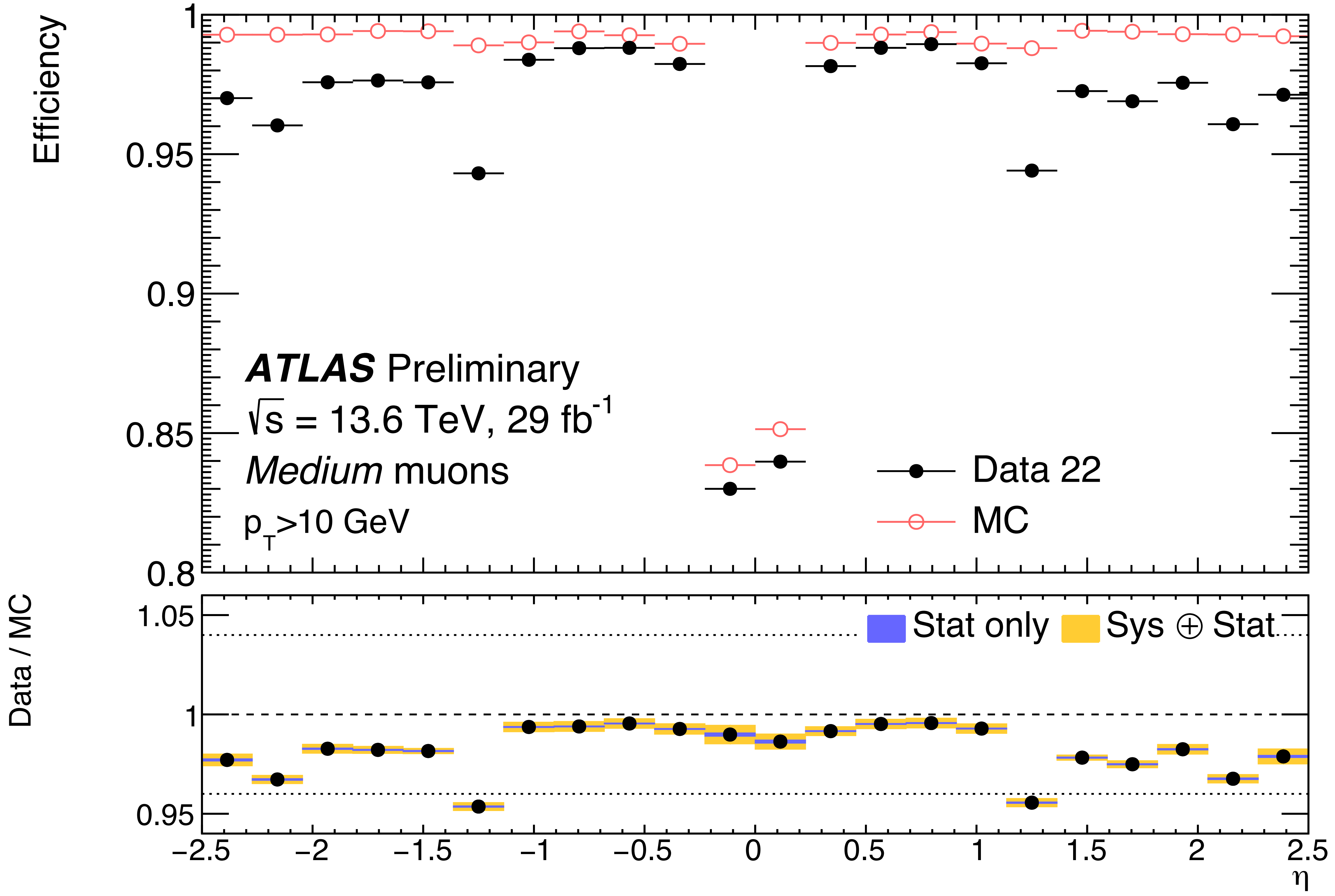


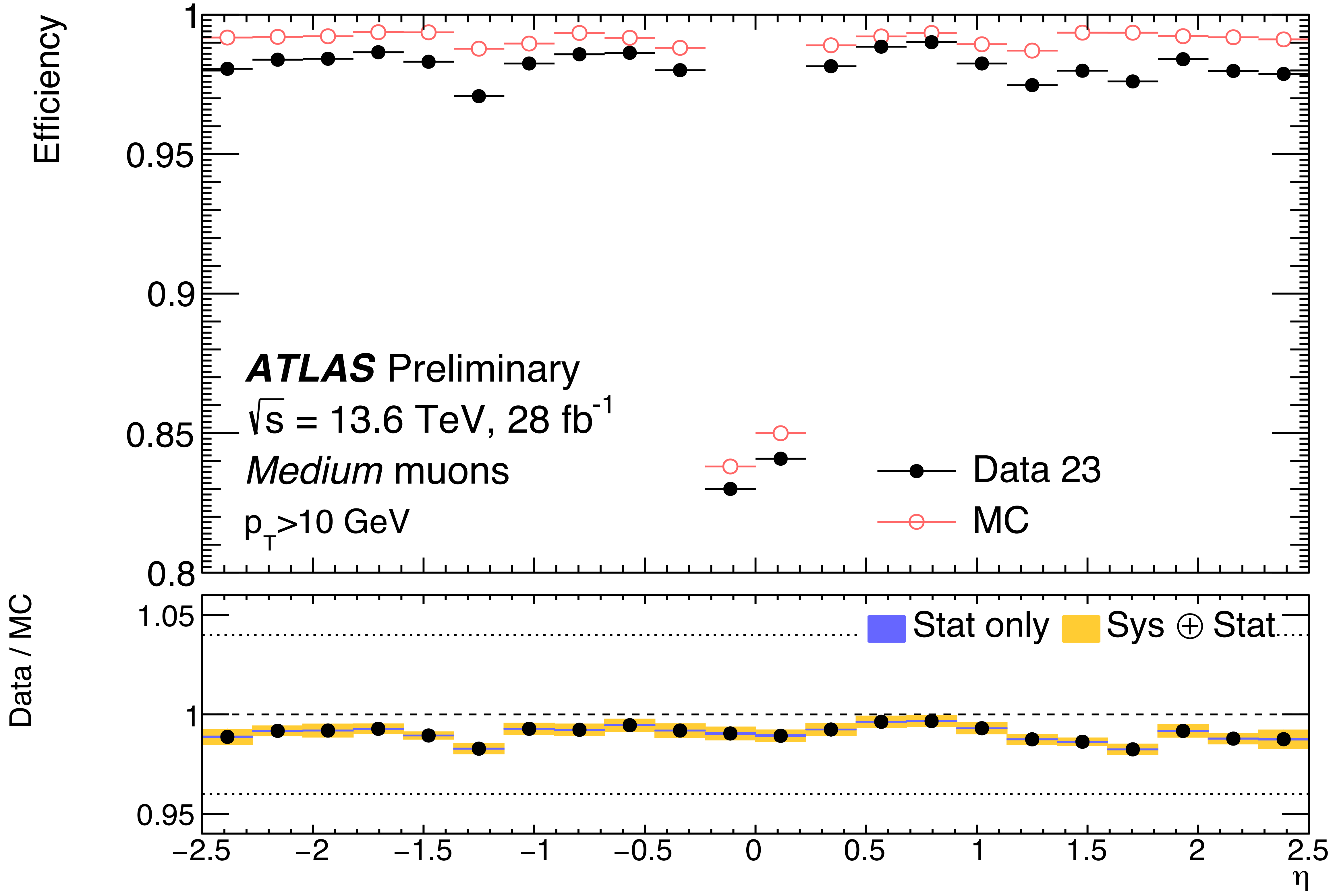


In data 2022, NSW was considered in selection cuts only for the latest data-taking periods.
This mirrors in a lower efficiency in the endcaps, w.r.t. to simulation.

In 2023, NSW has been fully included and the efficiency is similar to the rest of spectrometer.

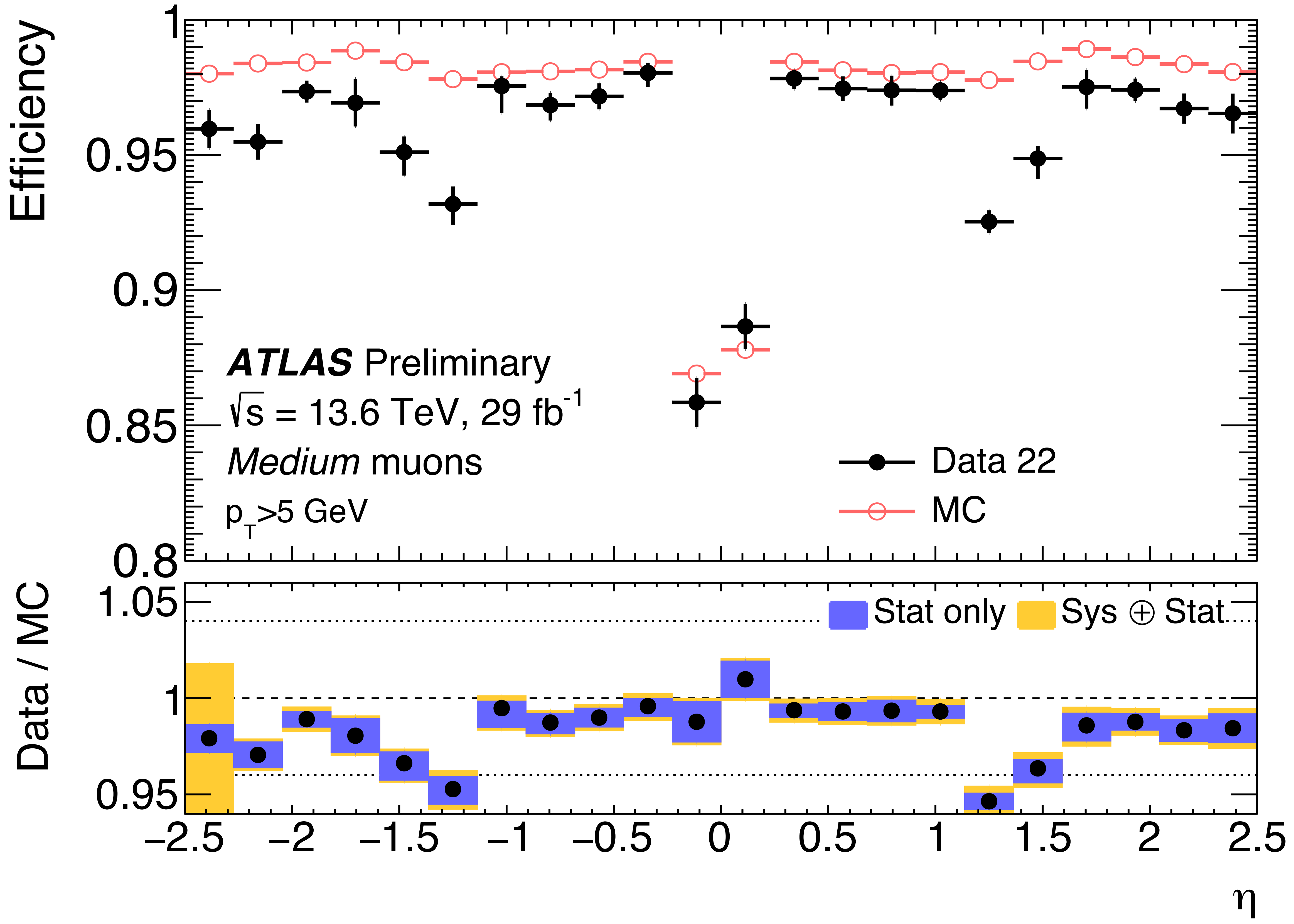
MEDIUM SELECTION (Z)

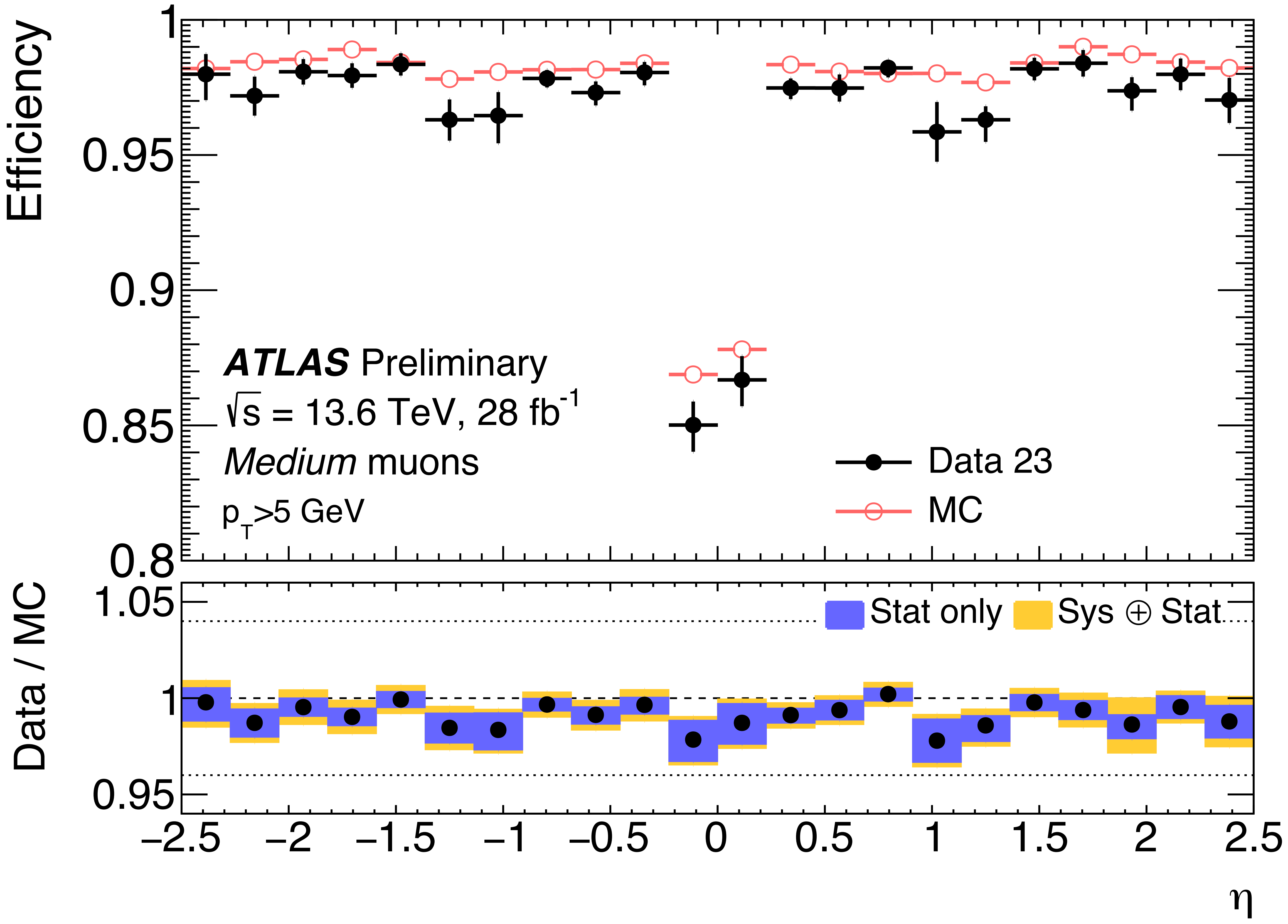




Looser cuts have effects only in the crack around η = 0, which is the location of the ATLAS services

MEDIUM SELECTION (J/Ψ)





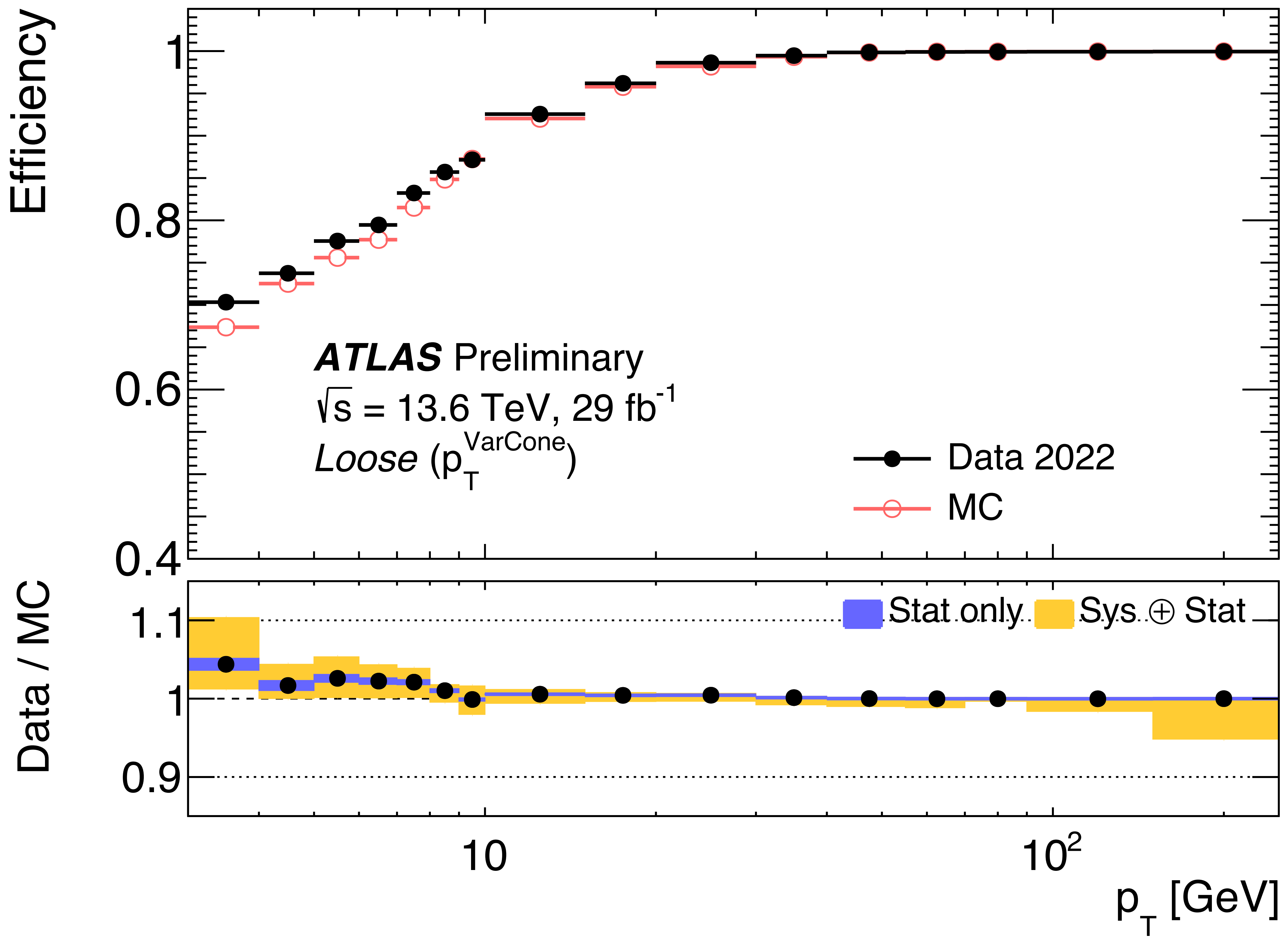
Same efficiency to reconstruct muons from the J/ψ decays with a p_T > 5 GeV.

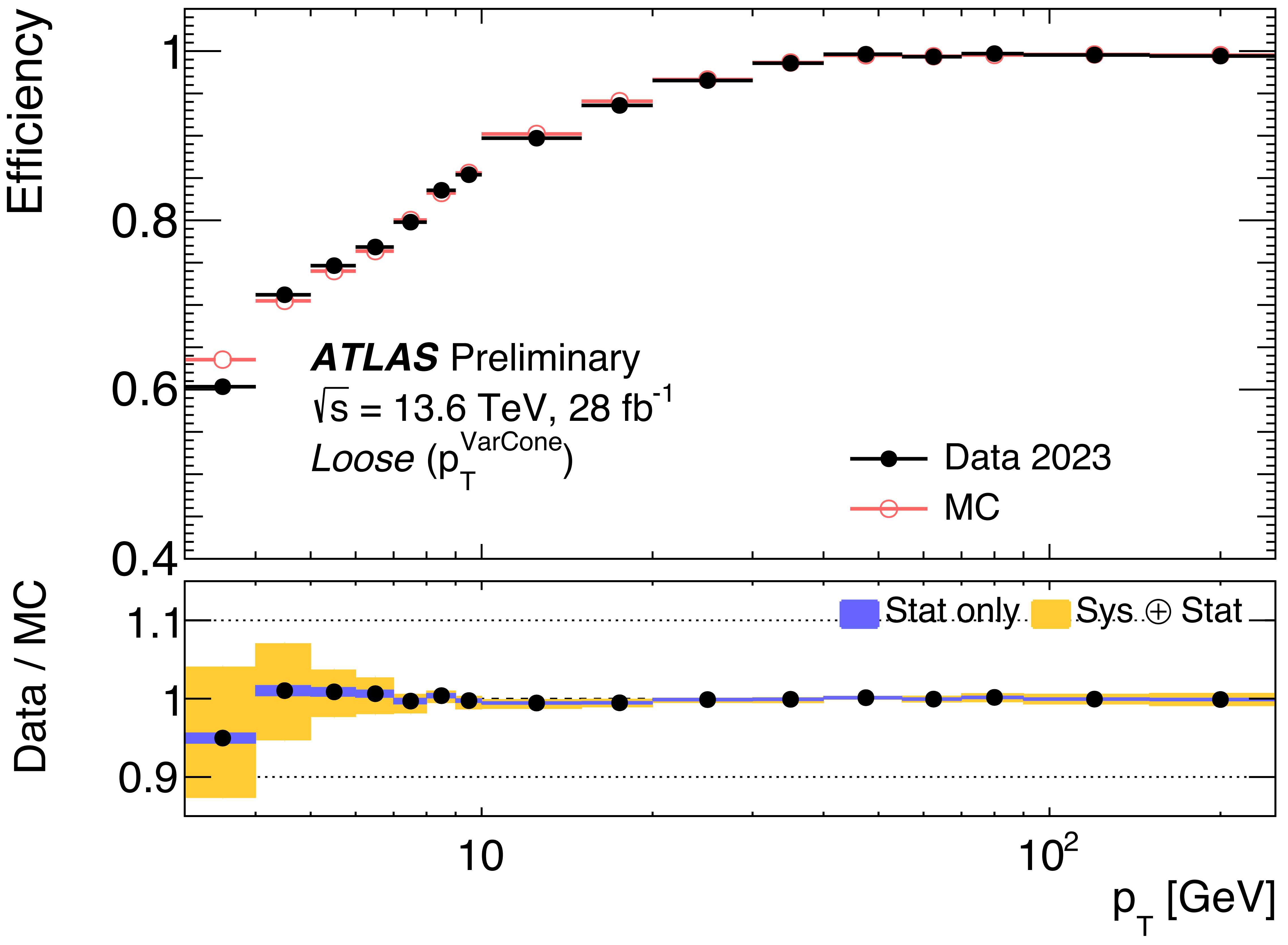
MUON ISOLATION

Working Point	Description
Loose	Looser cuts to maximise the acceptance.
Tight	Harder cuts to maximise purity.

Muon isolation efficiency is also measured using the Tag&Probe method applied to $Z \to \mu^+ \mu^-$ decays, selecting probes with a p_T > 3 GeV

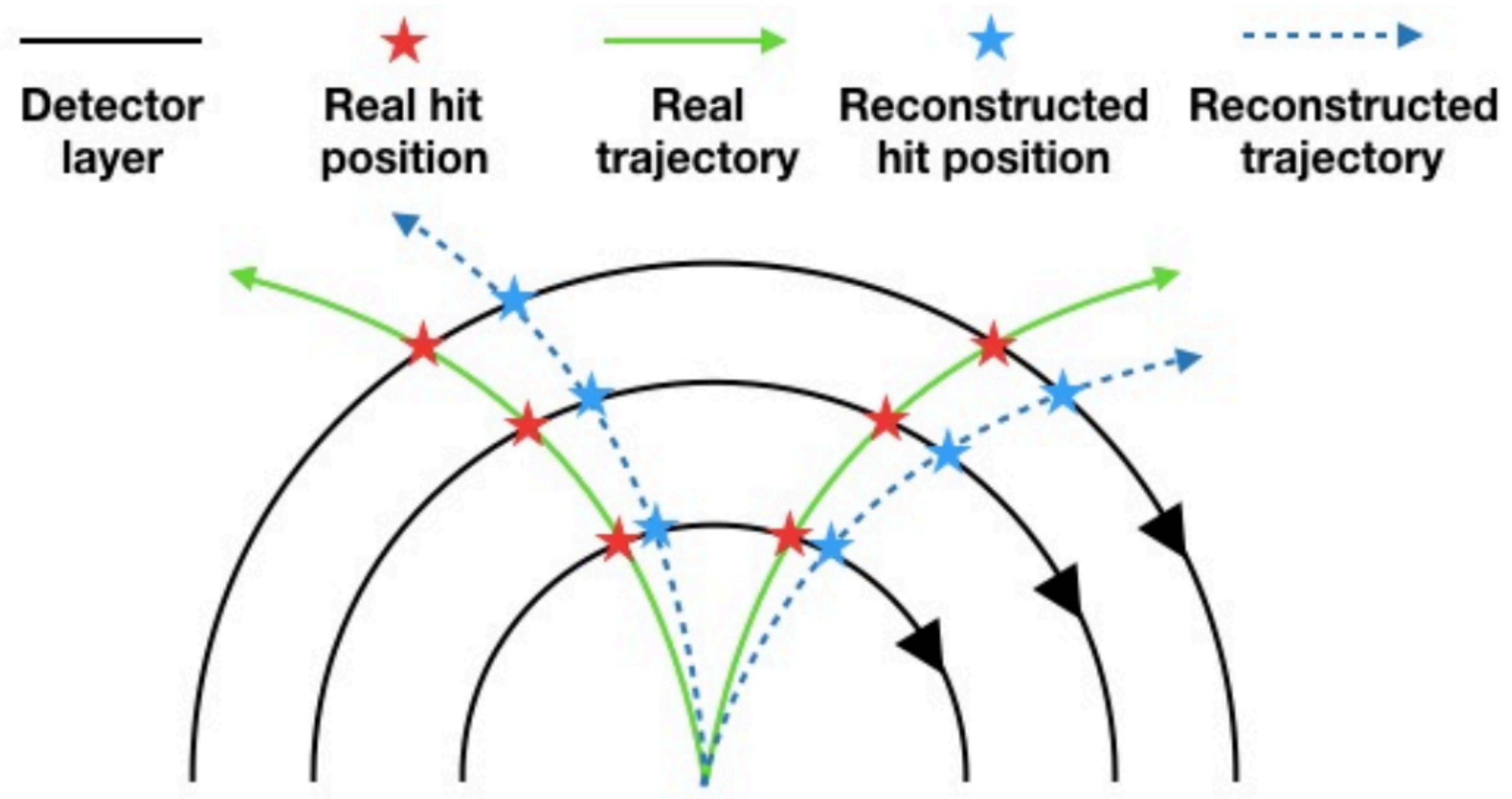
LOOSE ISOLATION SELECTION





Lower efficiency at low pT in 2023 due to increase of the number of pile-up collisions.

MUON MOMENTUM CALIBRATION



Opposite charge bias (applied to data)

Twist, Curls and Shift in the detector can create charge-dependent effects: opposite p_T bias on opposite charge muons.

Minimise resolution between pos/neg charges assuming $p_T^{\text{corr}} = \frac{p_T^{\text{reco}}}{1 - q \cdot \delta_s \cdot p_T^{\text{reco}}}$, where δ_s is estimated using Z→μ+ μ- simulation and applied to data

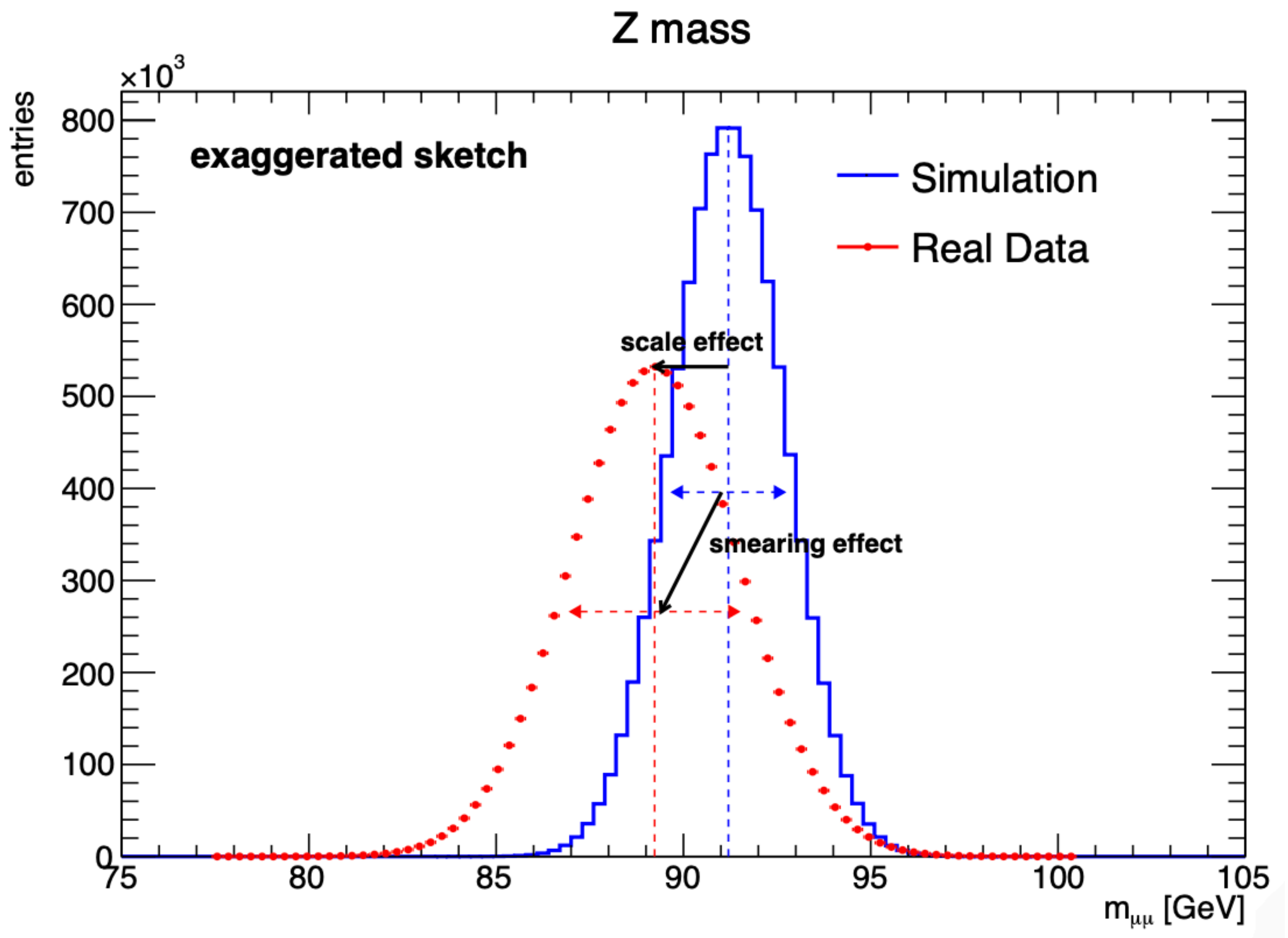
Scale and Smearing (applied to simulation)

Corrections of mismodelling effects in simulation

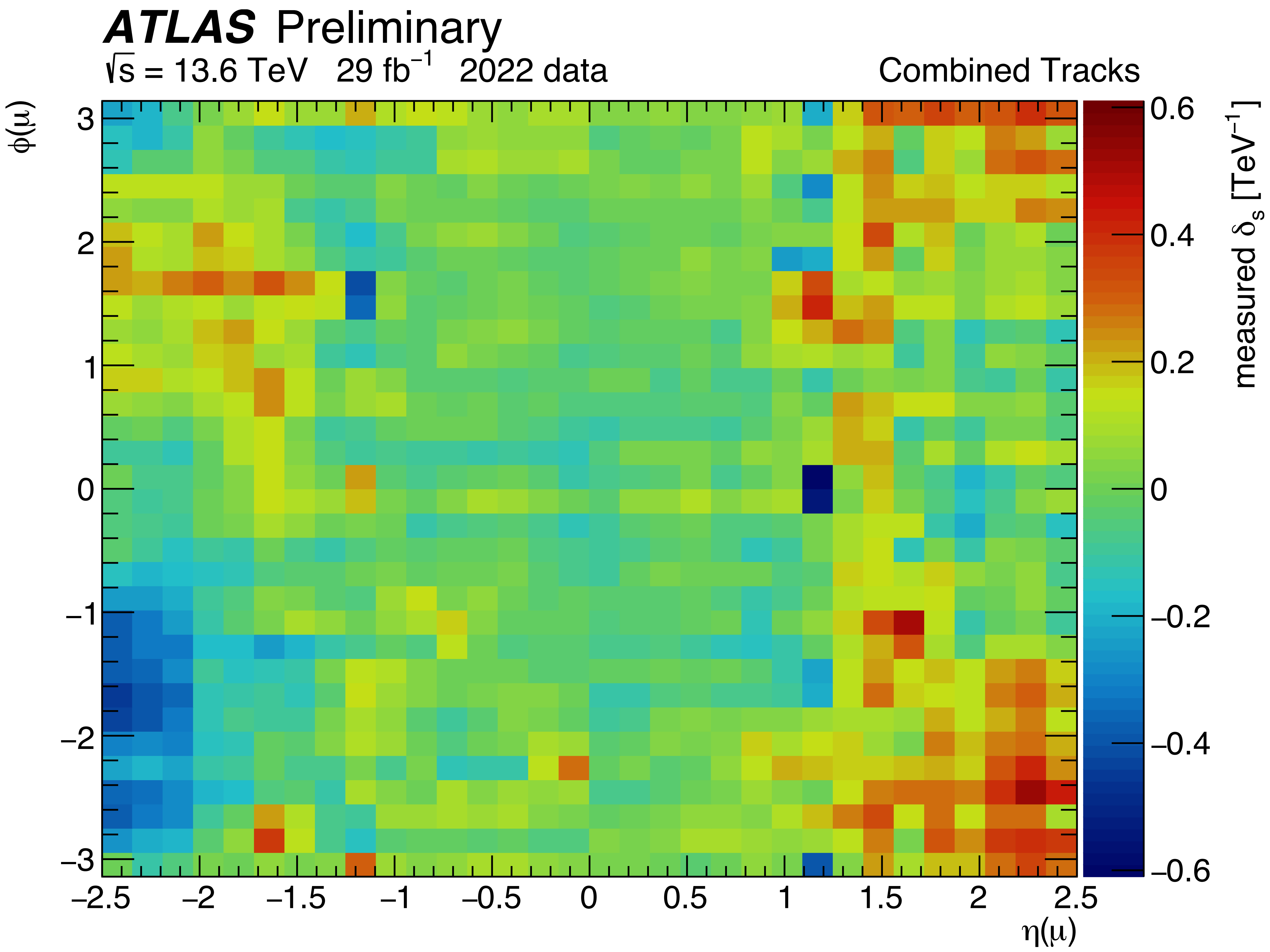
$$p_T^{corr} = \frac{p_T^{reco} + (s_0 + s_1 \cdot p_T^{reco})}{1 + g_0 \cdot \frac{r_0}{p_T^{reco}} + g_1 \cdot r_1 + g_2 \cdot r_2 \cdot p_T^{reco}}$$

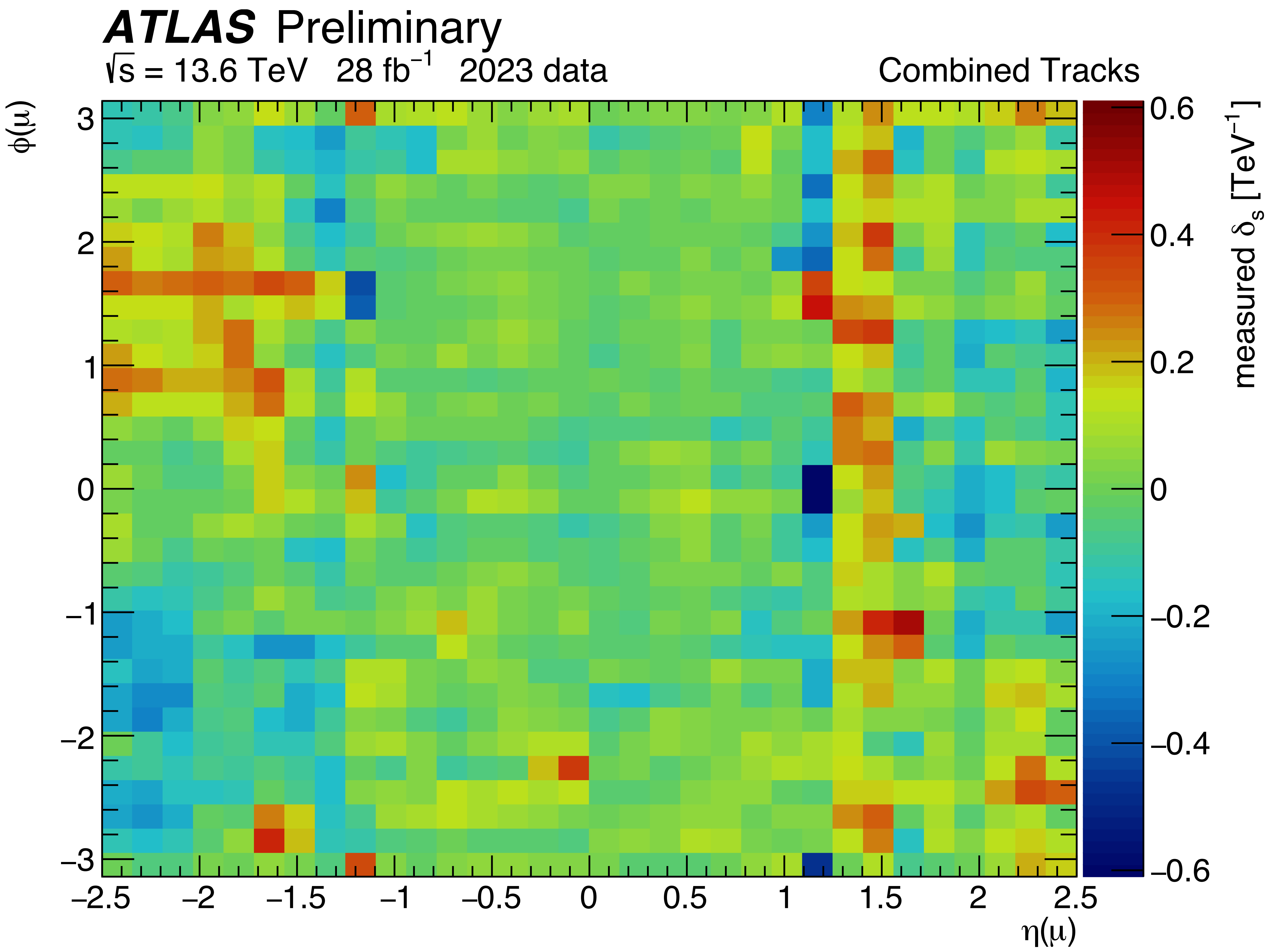
s_n describe momentum scale corrections (energy-loss, B-field mismodelling)

r_n describe momentum smearing that broadens the p_T resolution (energy-loss fluctuation, multiple scattering, spatial resolution and misalignment)



SAGITTA BIAS MAPS

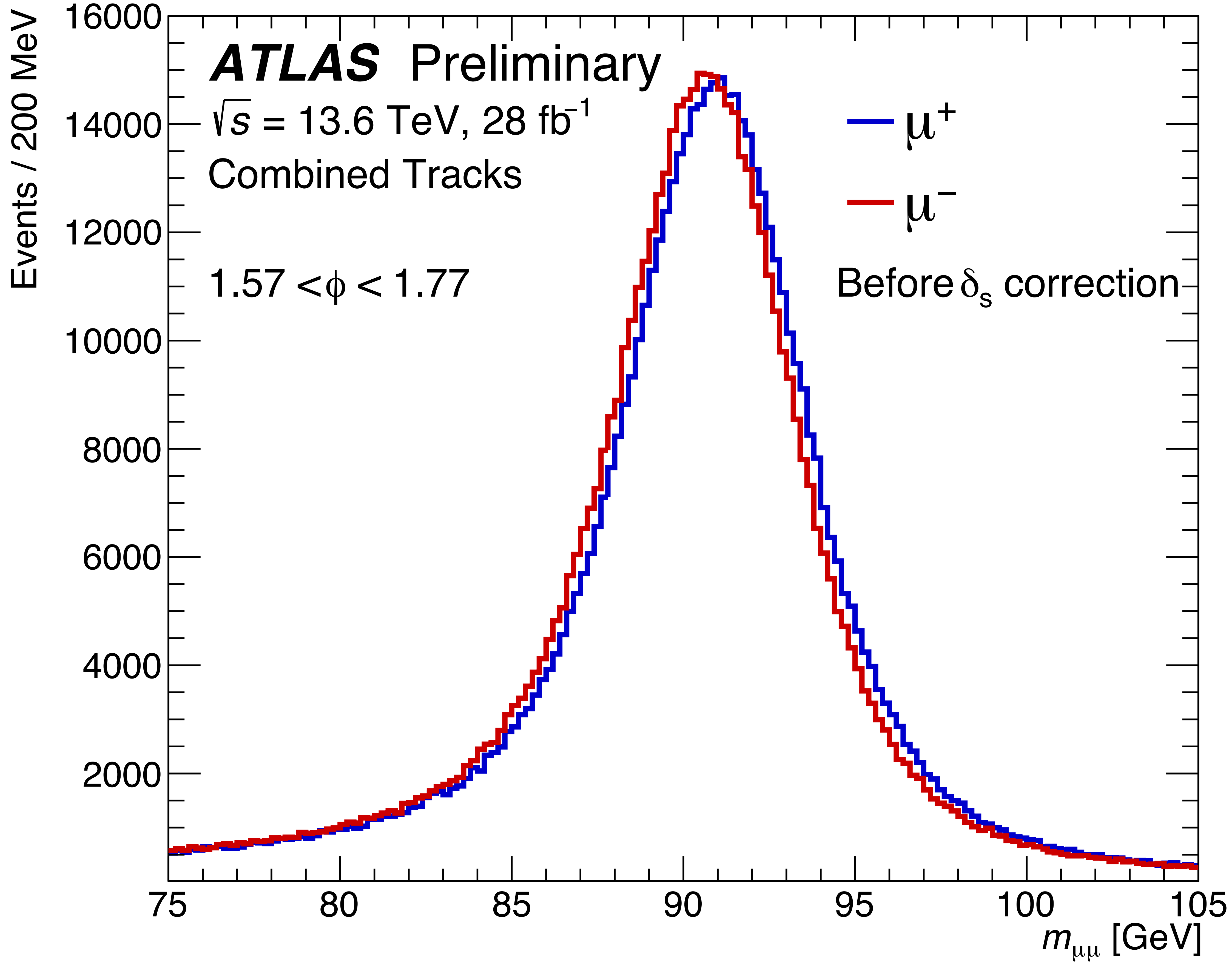




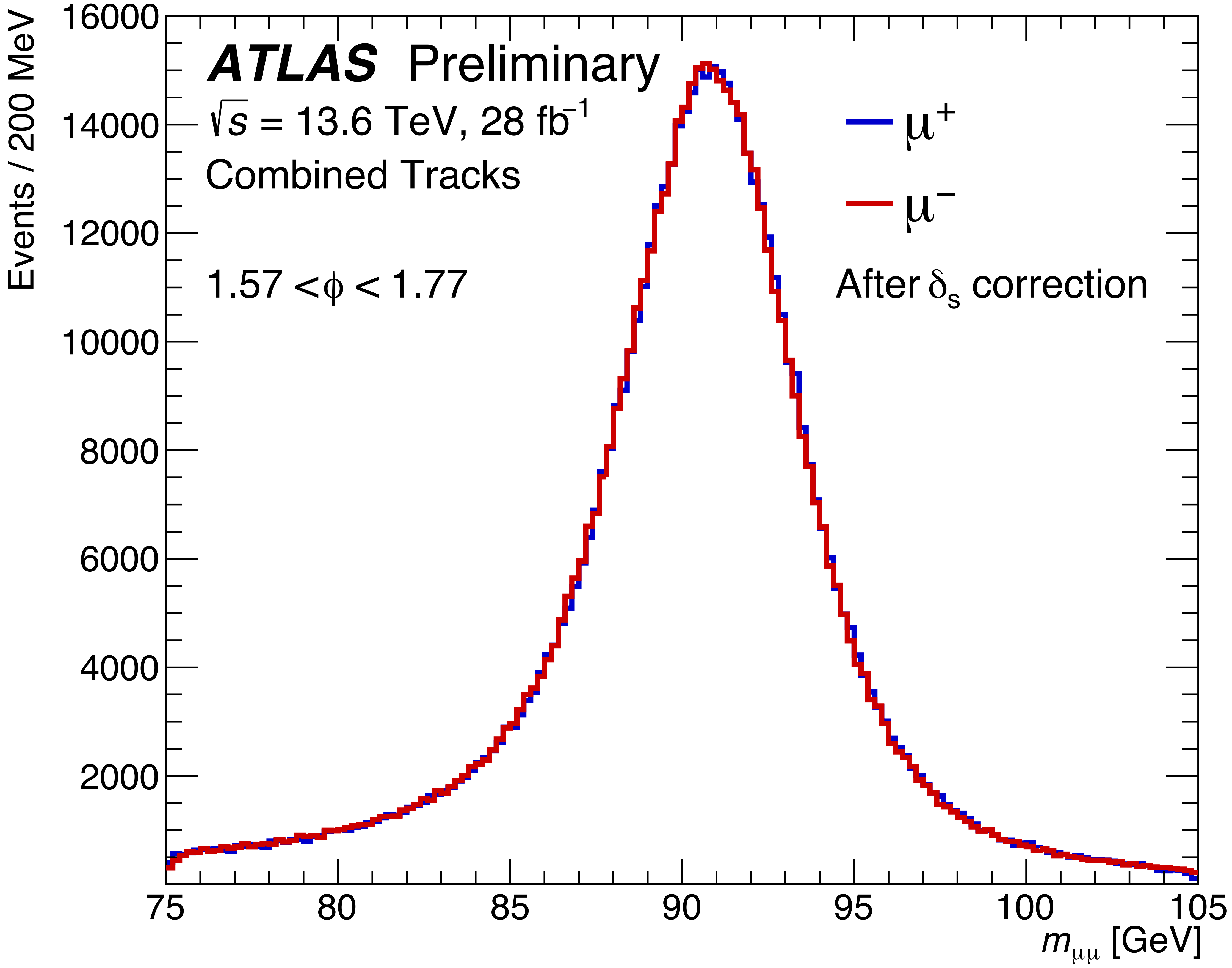
In 2023 NSW data have a major role in the muon reconstruction, resulting in minor opposite charge-based effect in the endcap regions

SAGITTA BIAS MAPS

Before Sagitta Correction

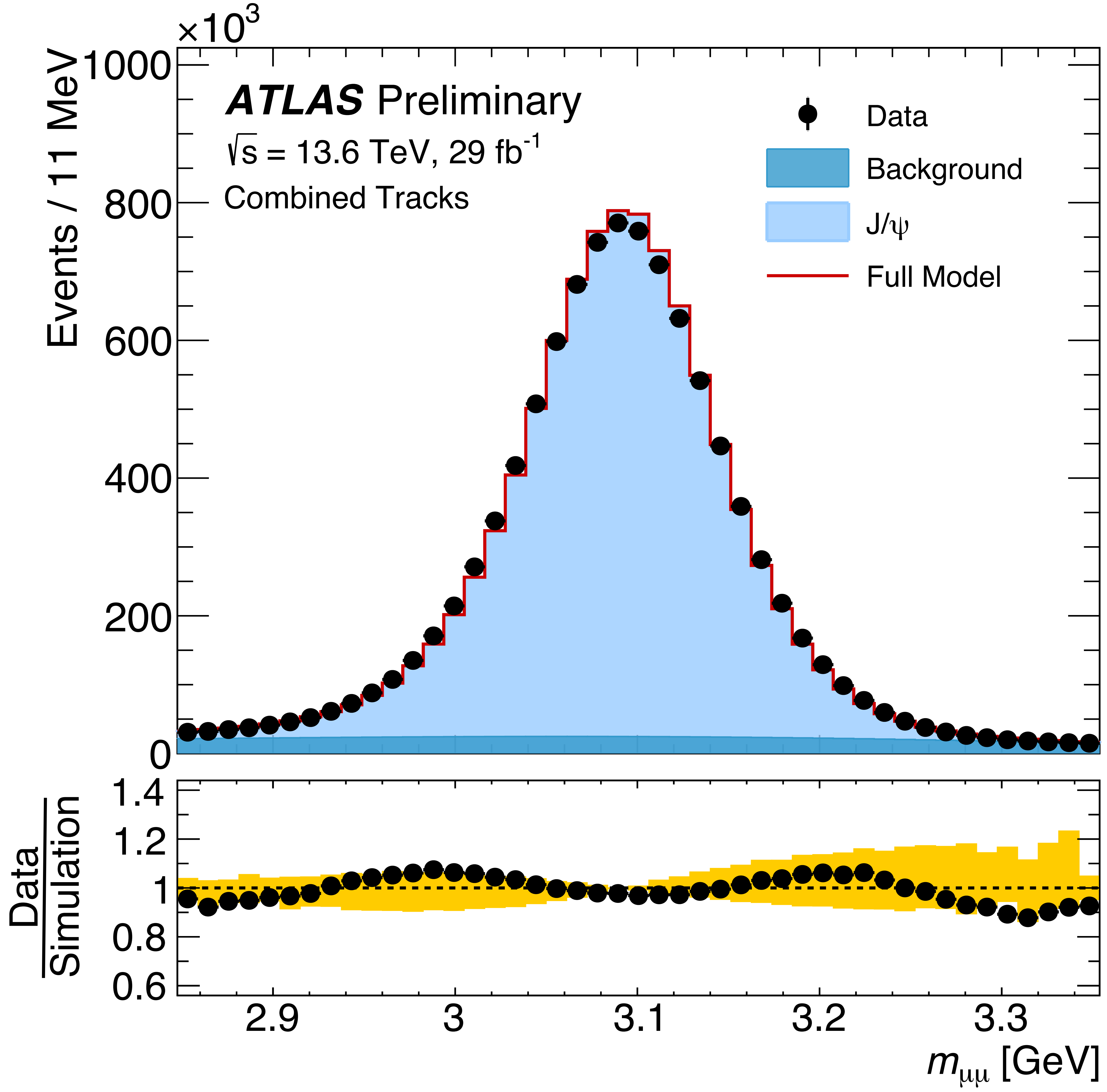


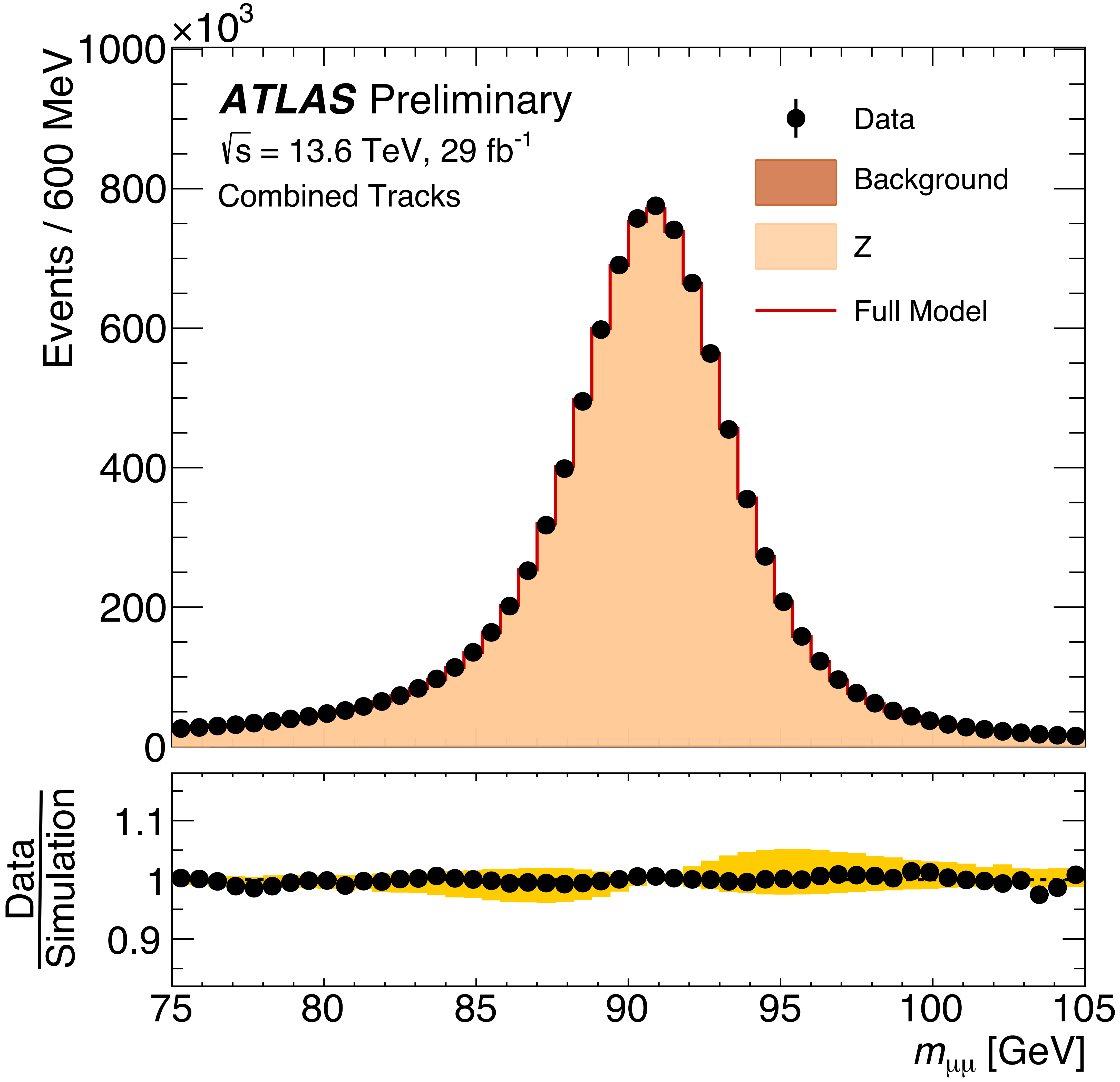
After Sagitta Correction



Calculated sagitta bias maps calibrate correctly the muon momentum in the simulation

SCALE AND SMEARING





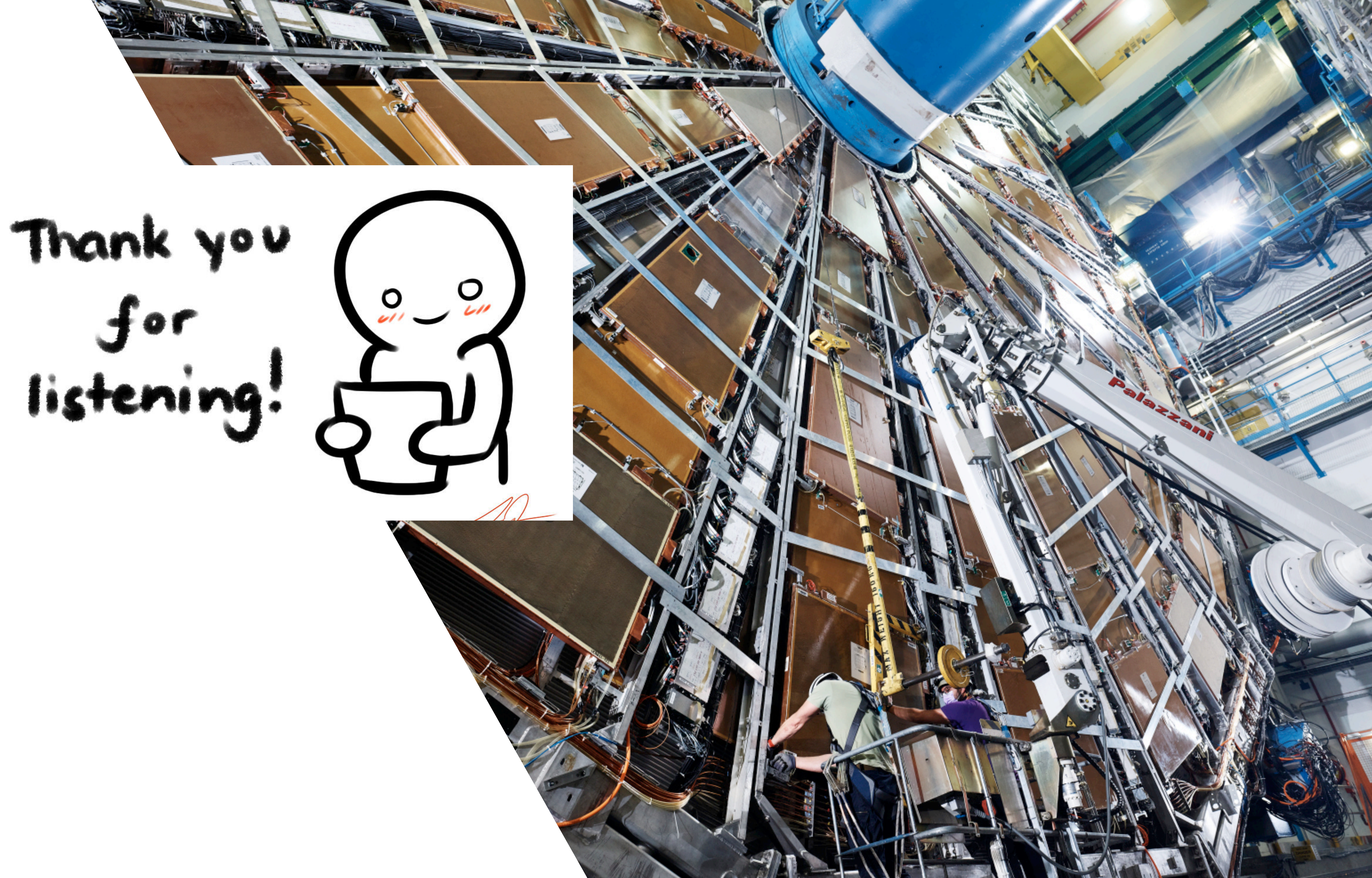
Data/Simulation agreement close to unity after scale and smearing calibration.
Not perfect agreement, due to missing alignment in the endcap regions and lower statistics

CONCLUSIONS

Satisfying muon reconstruction performance of the ATLAS experiment with run-3 data.

Identification and reconstruction efficiency almost at the level of run-2, after the addition of NSW data to the working point definition.

Calibration work ongoing to achieve similar performance in momentum resolution, considering the commissioning status of NSW and limited statistics.


Thank you
for
listening!
Palazzani

MUON COMBINED PERFORMANCE

ATLAS Muon Combined Performance (MCP) group is responsible for muon physics performance measurement and provides recommendation for usage of muons in physics analyses

Identification

Define selection for good quality muons

Efficiency

Measures the reconstruction, identification, isolation and vertex-association efficiency, and delivers efficiency scale factors

Momentum Calibration

Performs muon momentum calibration and provides corrections

Isolation and Fakes

Addresses common matters on lepton/photon isolation and prompt misidentification

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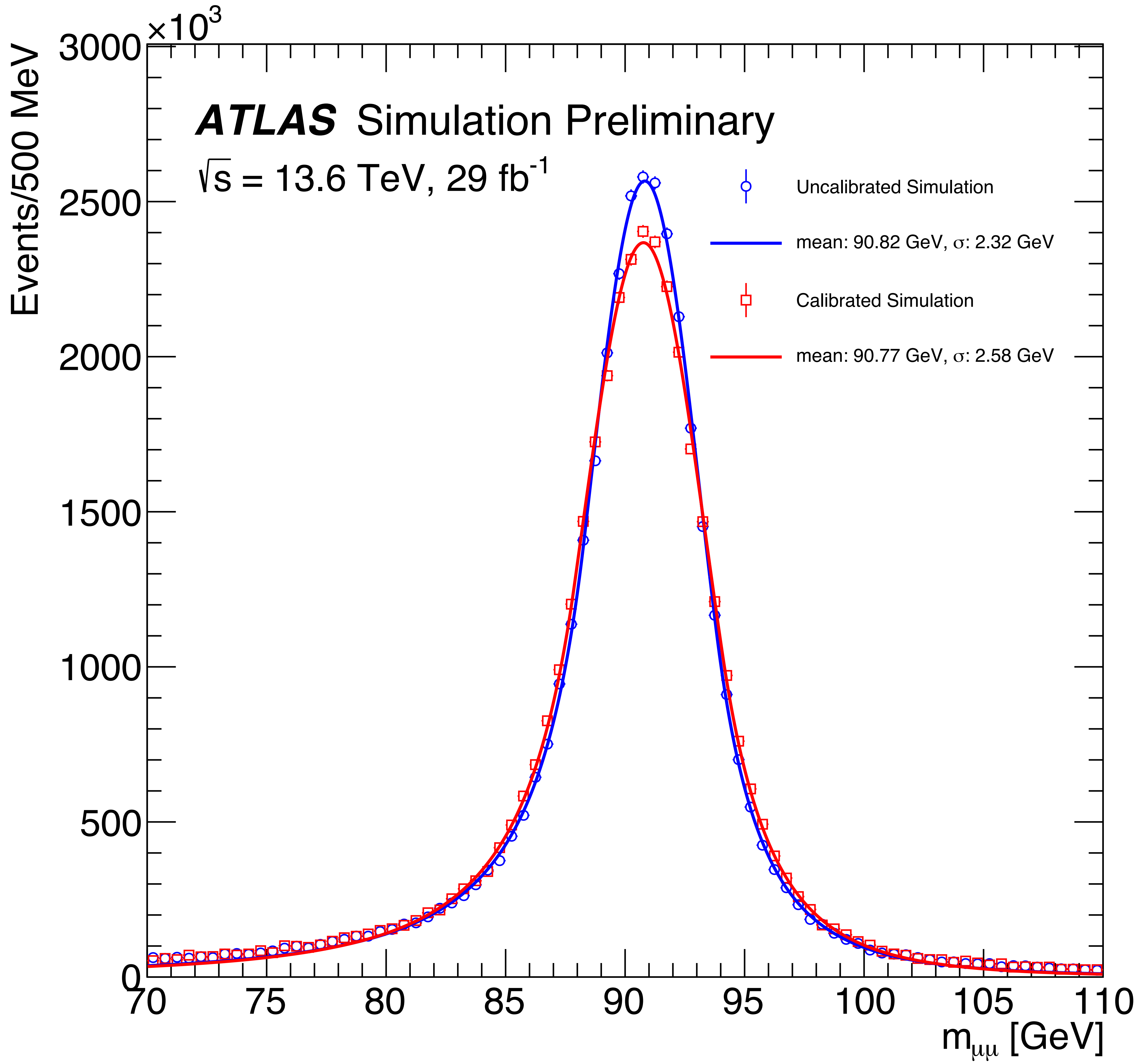
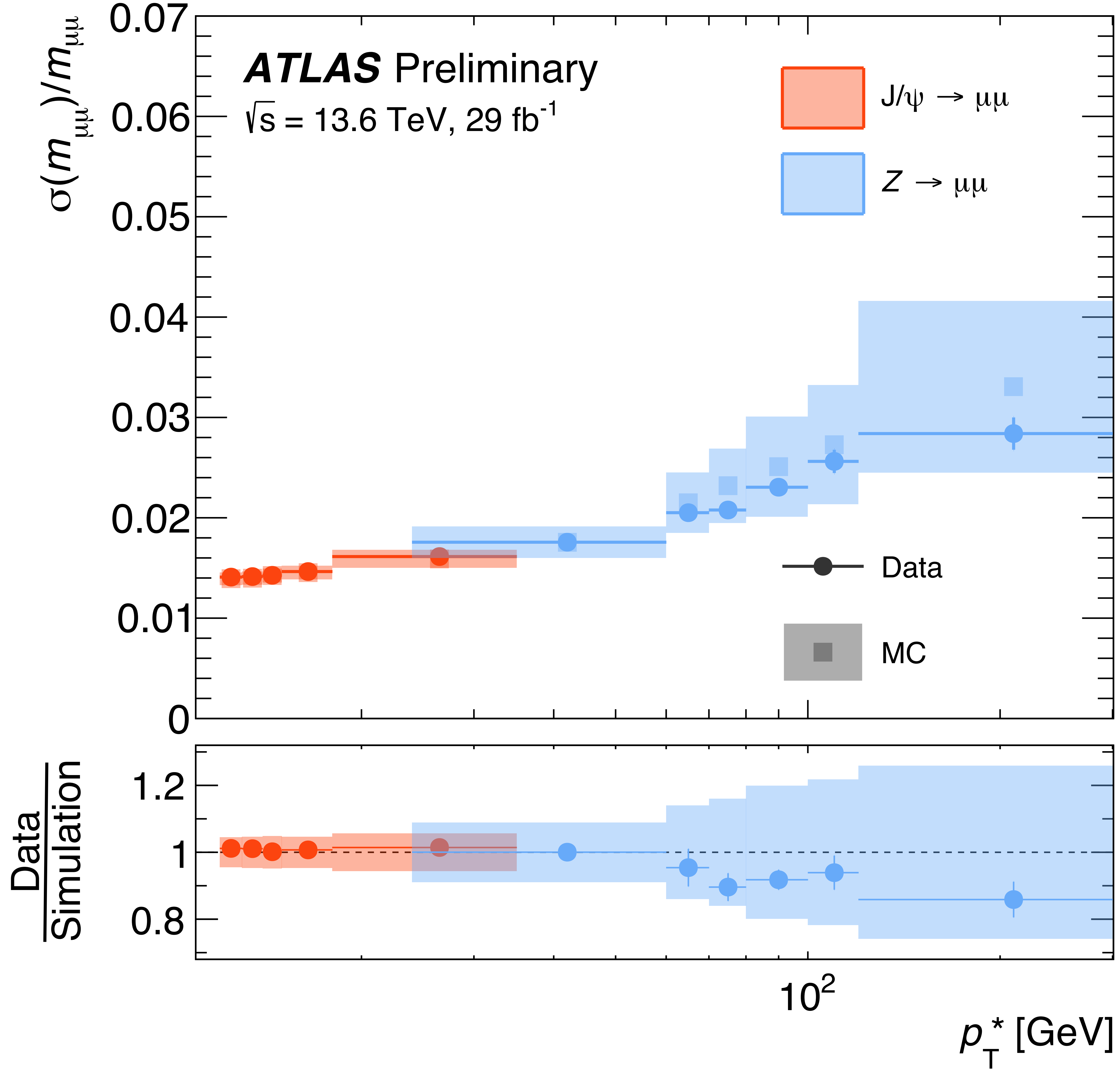
2. ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider: A Description of the Detector Configuration for Run 3, (2023), arXiv: 2305.16623 [physics.ins-det]
3. ATLAS Collaboration, Studies of the muon momentum calibration and performance of the ATLAS detector with pp collisions at $\sqrt{s}$ = 13 TeV, Eur. Phys. J. C 83 (2023) 686, arXiv: 2212.07338 [hep-ex]
4. https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/MUON-2023-02/index.html

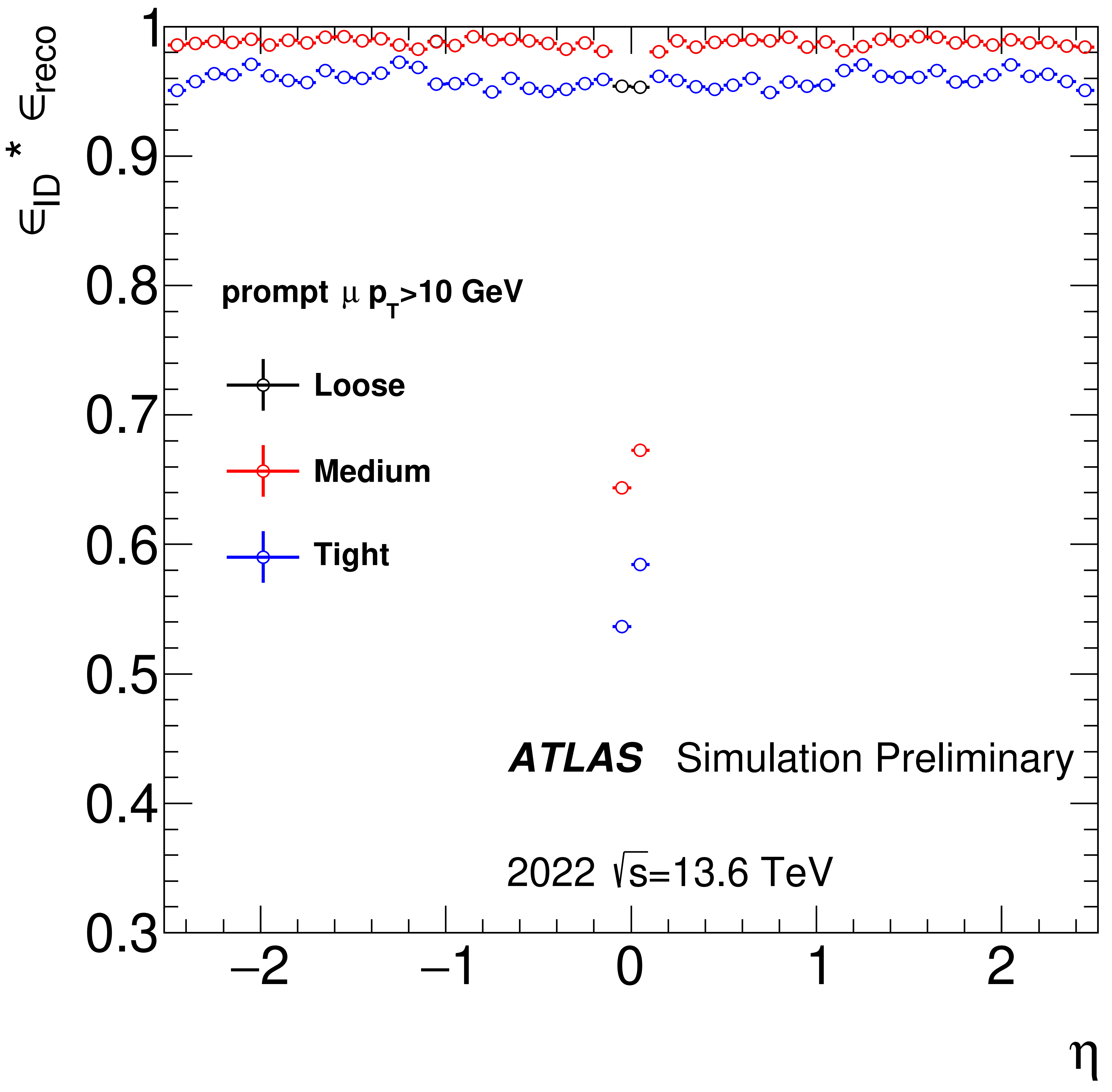
BACKUP

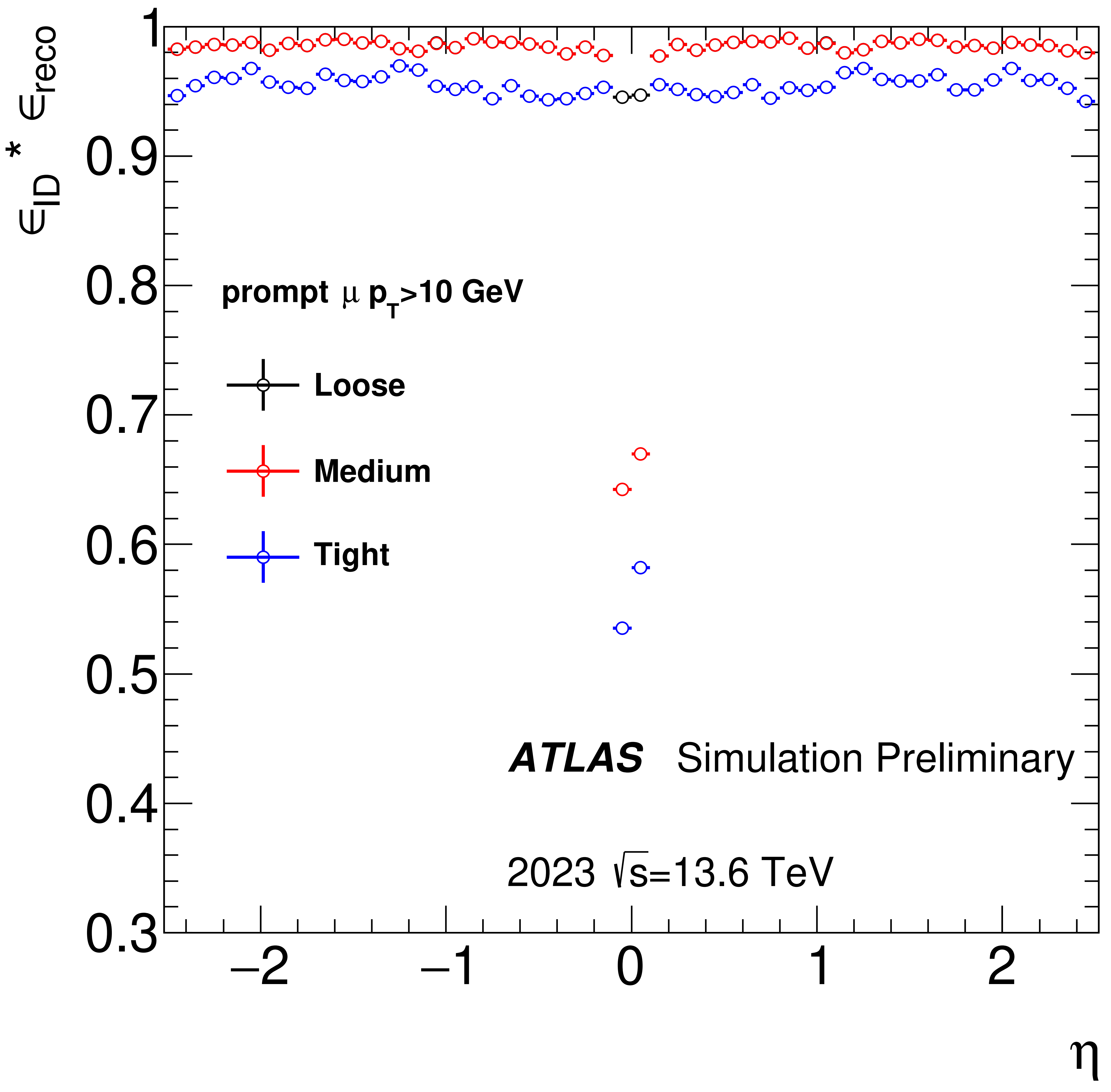
MOMENTUM RESOLUTION



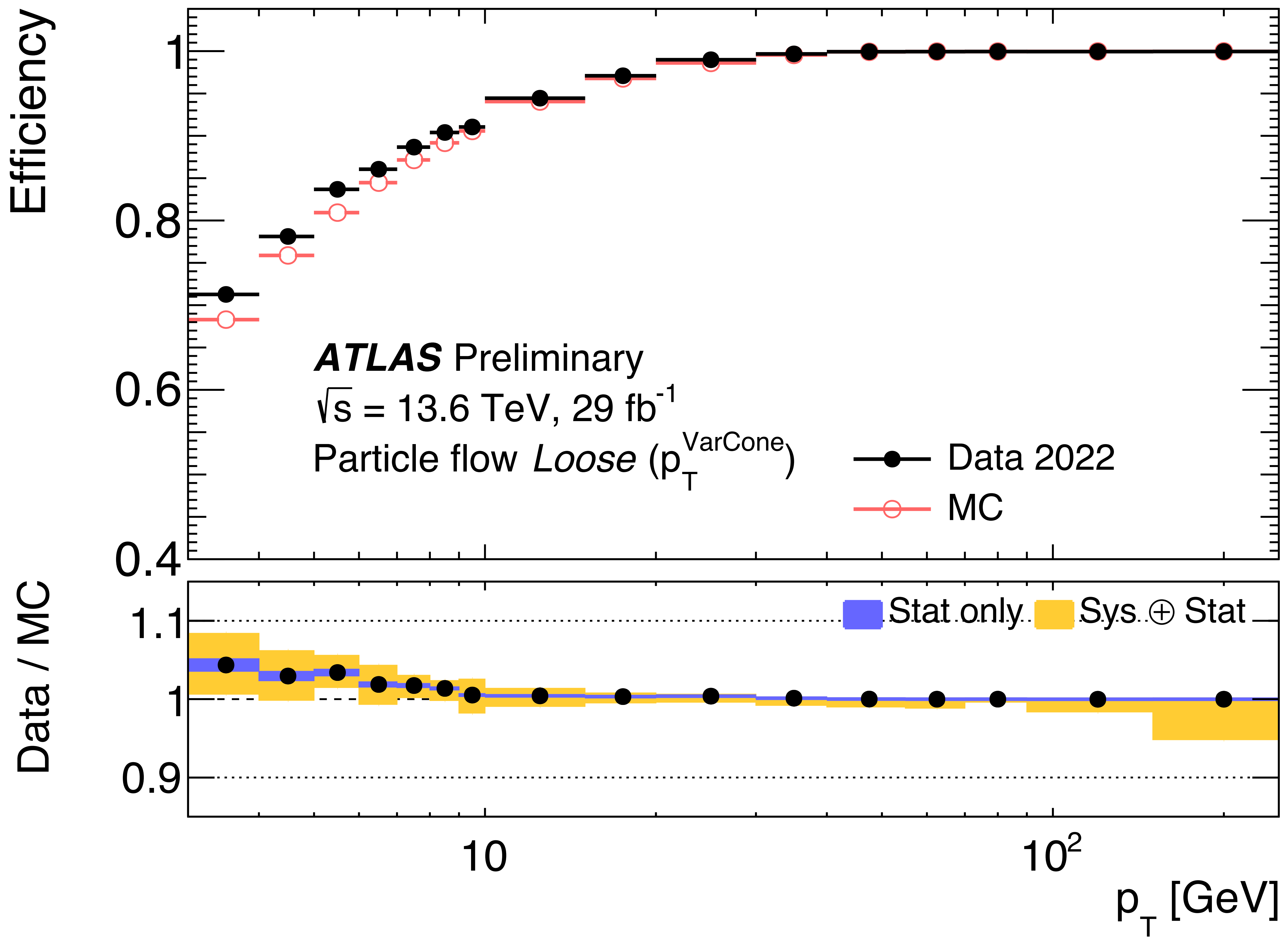


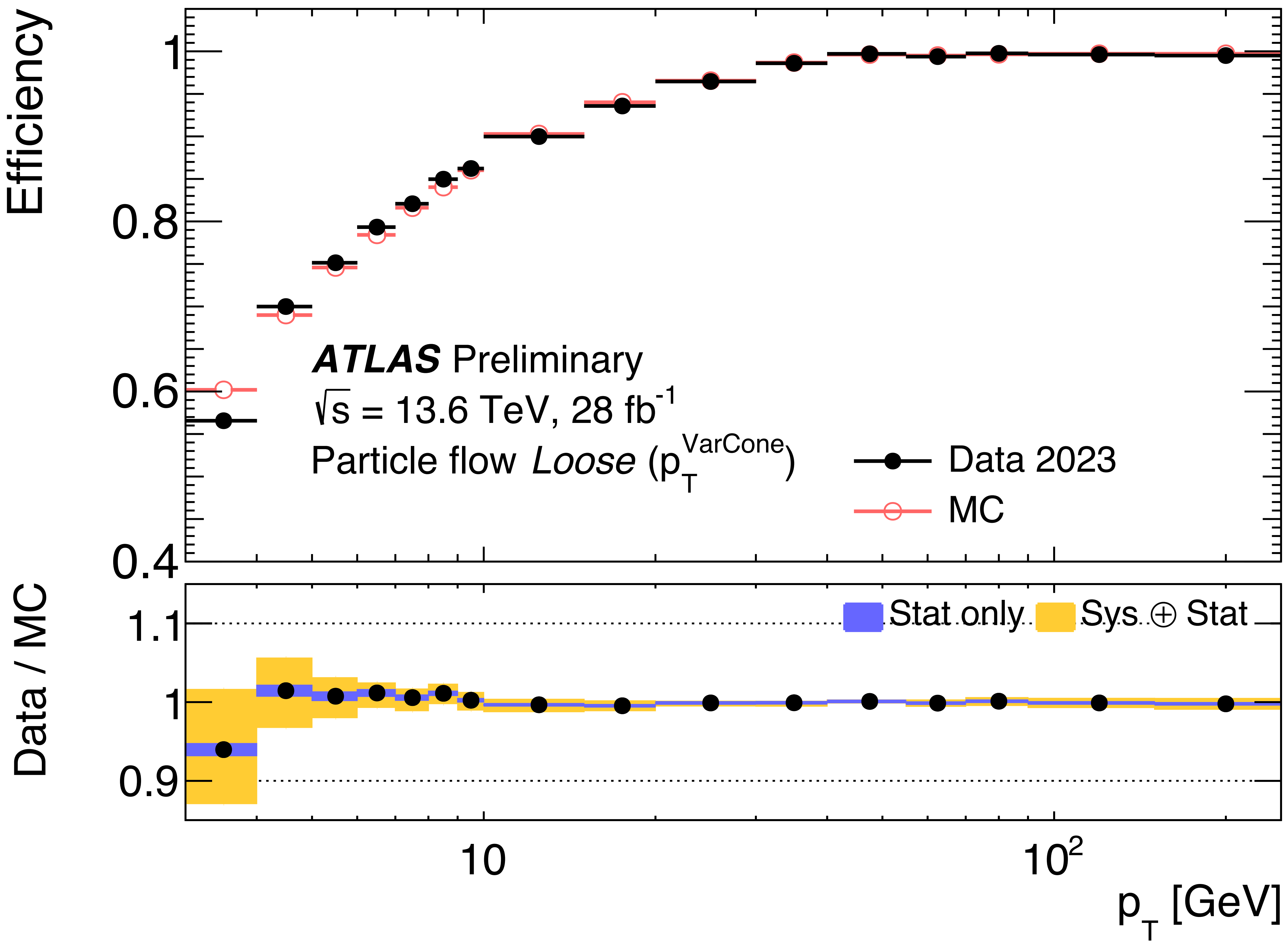
IDENTIFICATION EFFICIENCY





PFLOW LOOSE ISOLATION SELECTION





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