Results from muon reconstruction performance with ATLAS at Run-3

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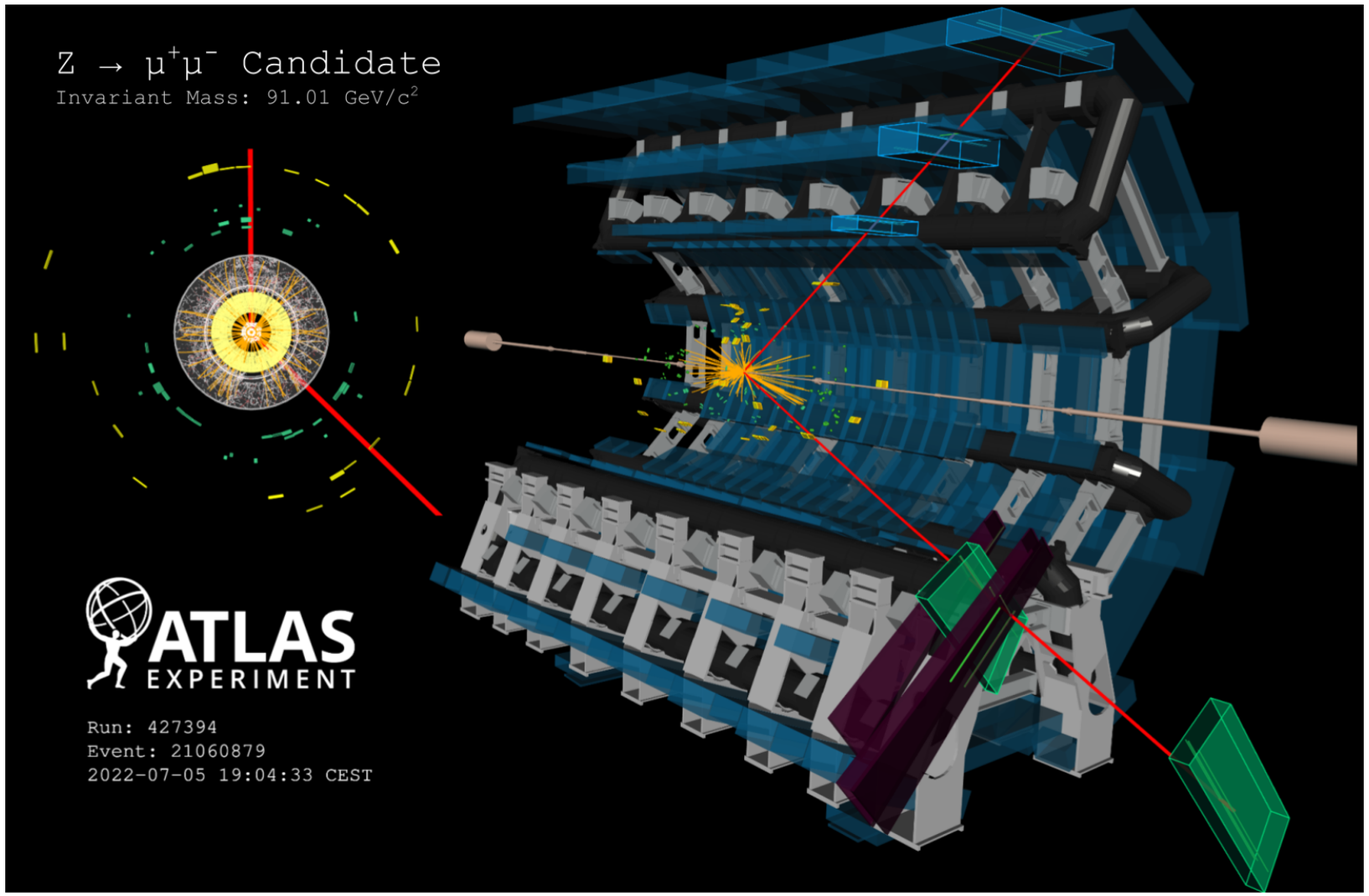
29th March, 2023

Challenges in Run 3

- Run 3: exciting time for detector performance, software and physics!
- Having a new detector (New Small Wheel muon chambers), centre of mass energy (13.6 TeV) — we will need to revamp muon performance!



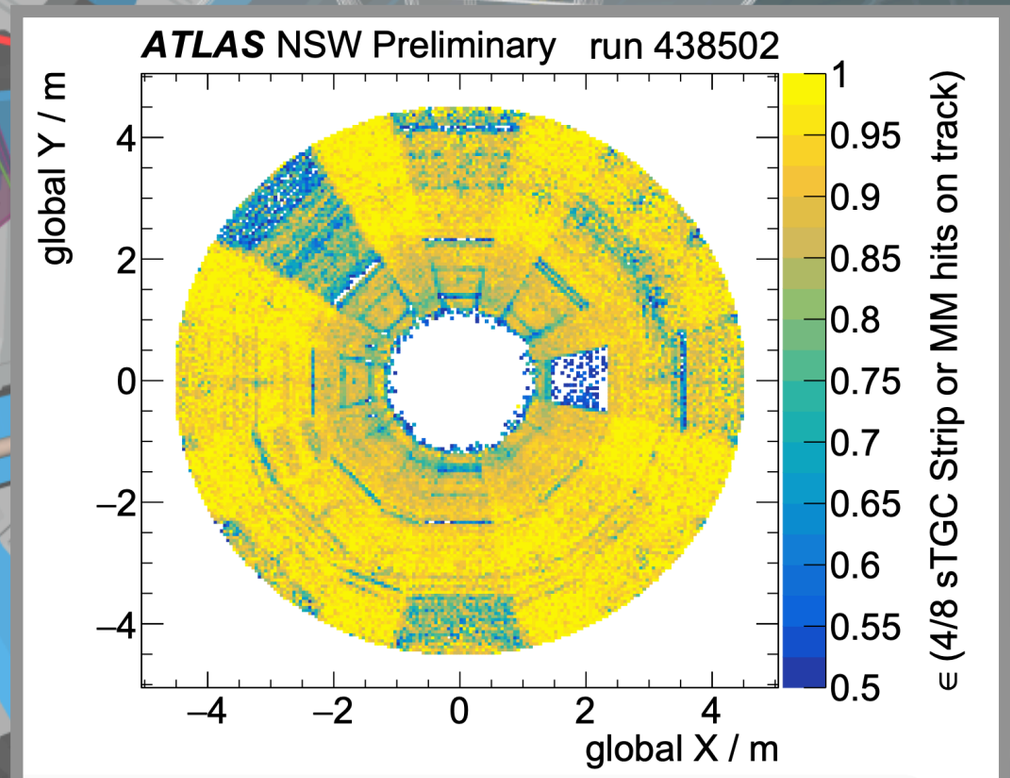
A glimpse of Run 3 data – exciting (and busy) time ahead for ATLAS physics!

Main Run 3 upgrades

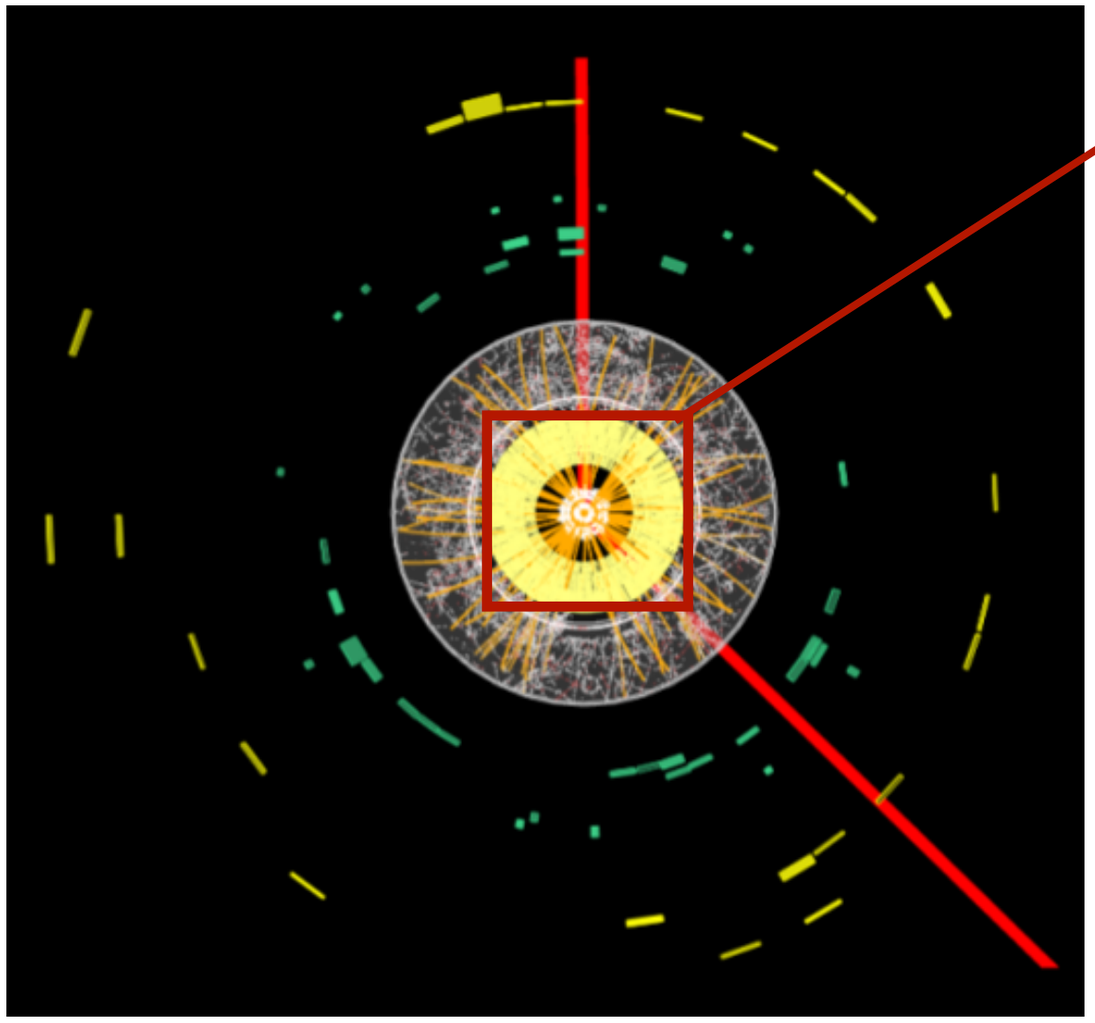
- L1Calo & L1 Trigger architecture: difference in trigger efficiency!
- L1Calo Trigger Readout: using commercial FELIX framework
- Trigger fast tracking: better handle on pileup
- For muon performance: **New Small Wheel** installation!

Main Run 3 upgrades

- For muon performance: **New Small Wheel** installation!
  - Still in commissioning phase in 2022 (readout issues)
  - Used in muon reconstruction chain, with more stringent requirement on the rest of MS



Overview



1. Are these muons or light hadrons?
   - **Muon identification**
   - **Working point** (WP) definition and **efficiency measurement**

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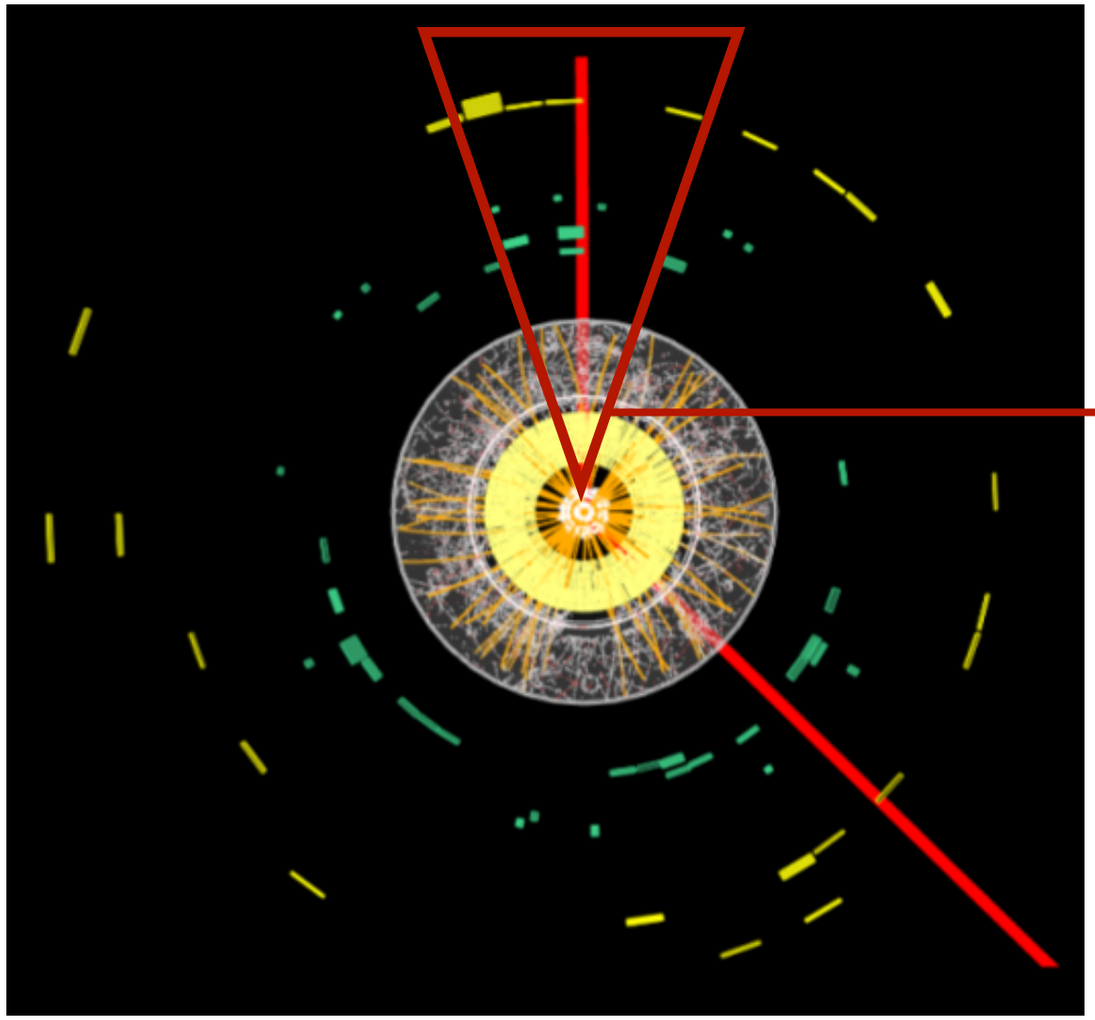

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2. Are these prompt muons or not?
   - **Muon isolation**
   - Important background rejection

Paper link for identification and isolation

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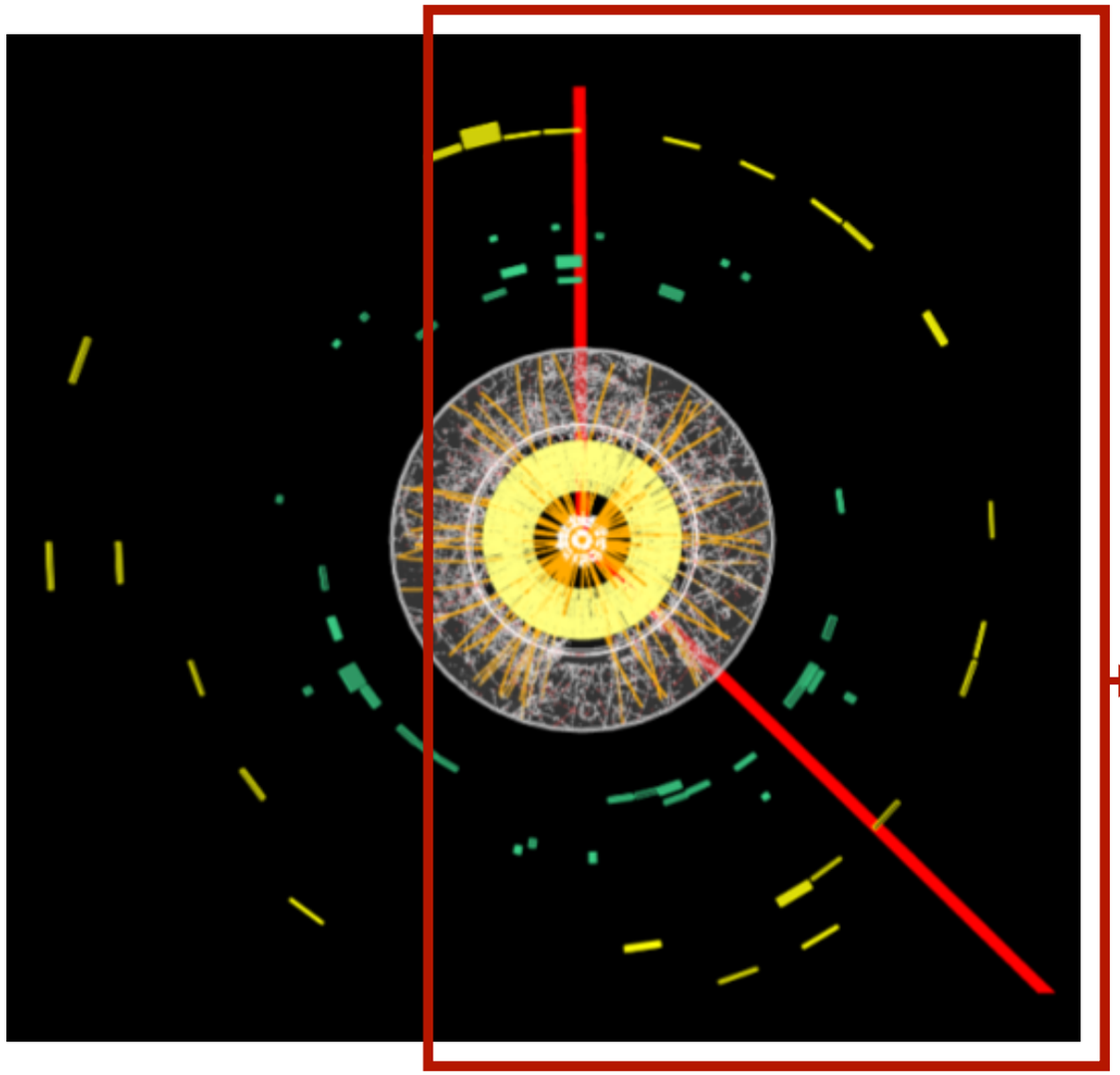

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2. Are these prompt muons or not?
   - **Muon isolation**
   - Important background rejection
3. Is the measured momentum biased?
   1. Data: **Sagitta bias** correction
   2. MC: **Scale and resolution** correction

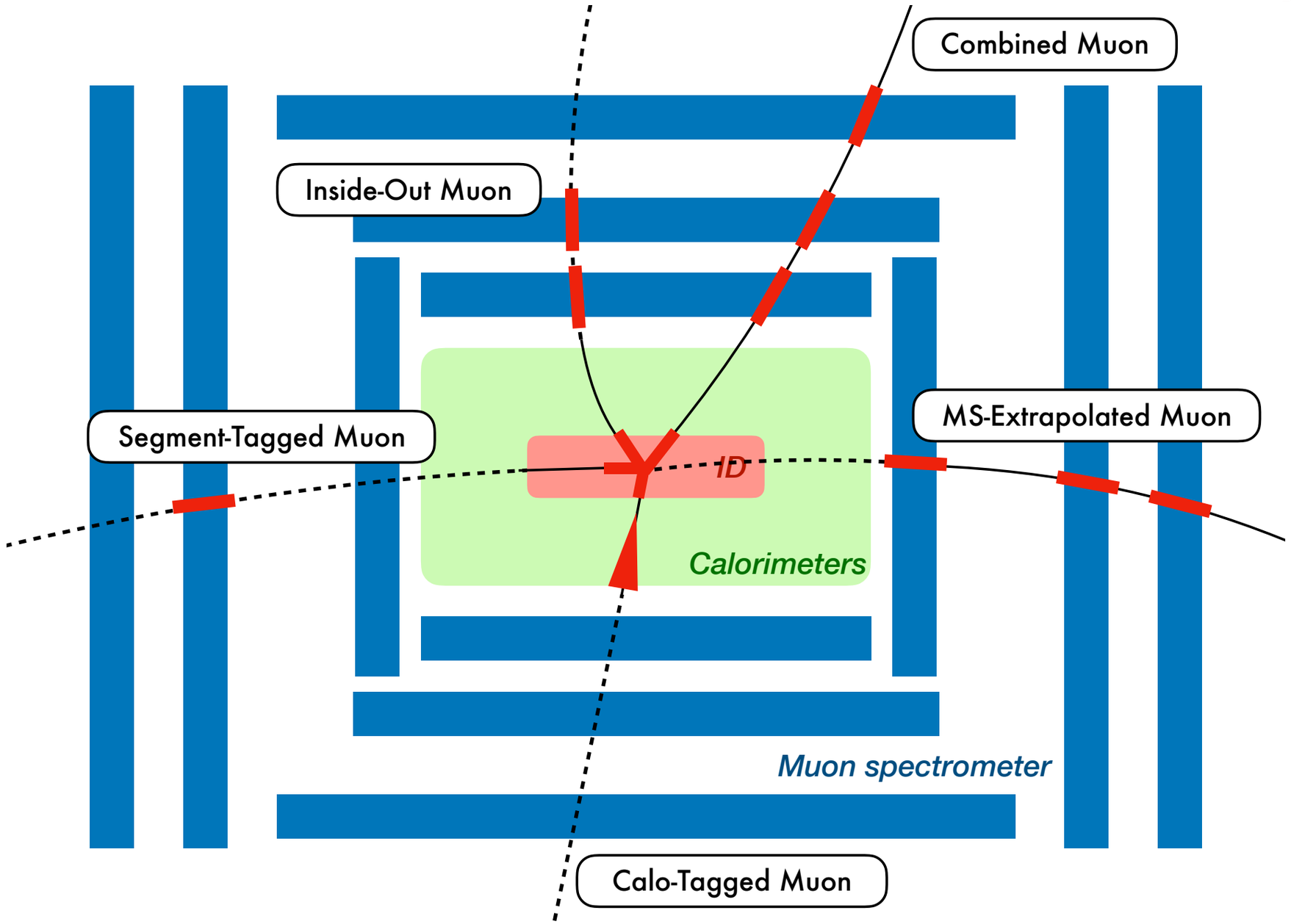
Paper link for identification and isolation

Paper link for momentum correction

Muon reconstruction

- Based on available detector coverage, we developed several chains for reconstruction:

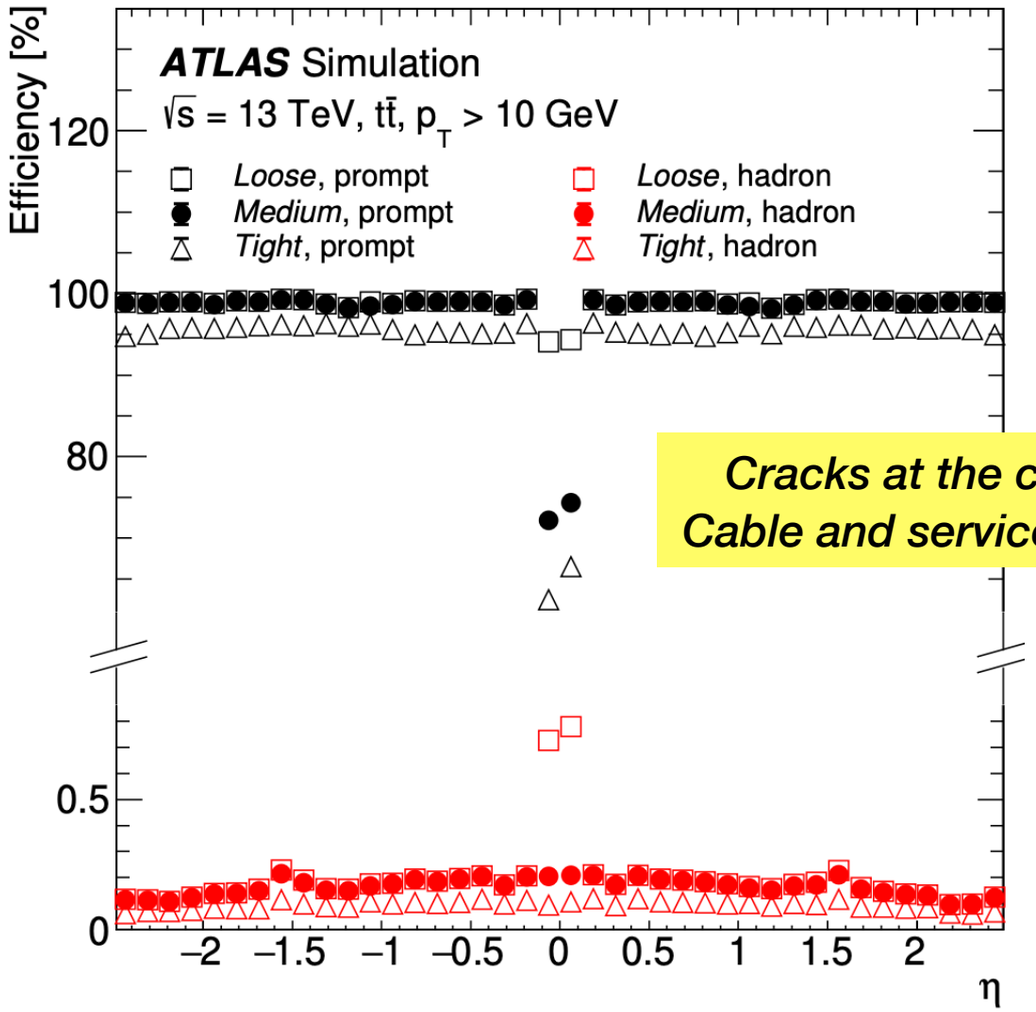
Most commonly used!



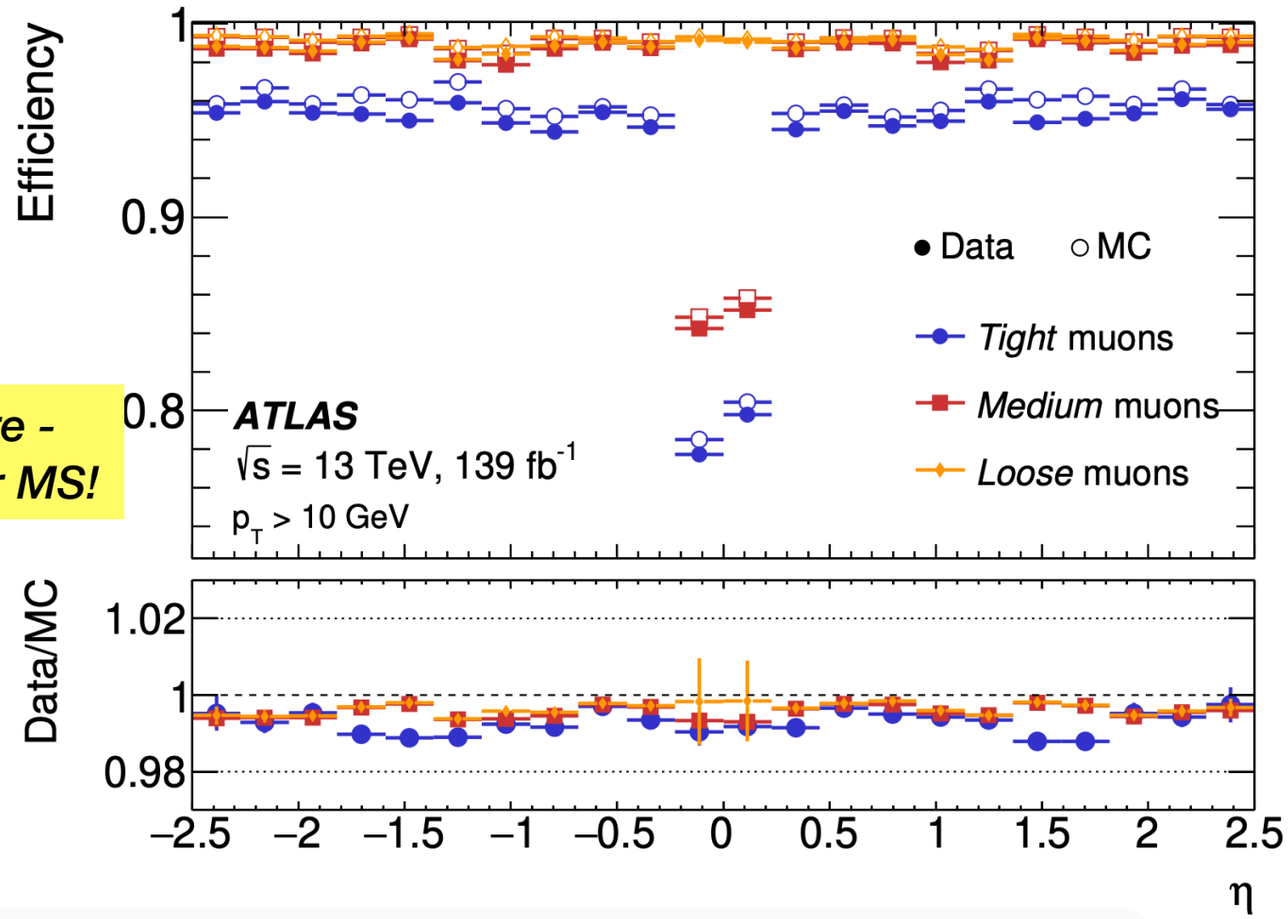
And based on these muon types, define Identification & Isolation working points (WPs)!

Muon identification WPs - Run 2 strategy

- Aim: to reject backgrounds from light hadrons
  - Using track qualities and detector variables (details in backup)
- Estimate muon efficiency in data using tag-and-probe method



Signal efficiency vs
background rejection
as estimated in simulation



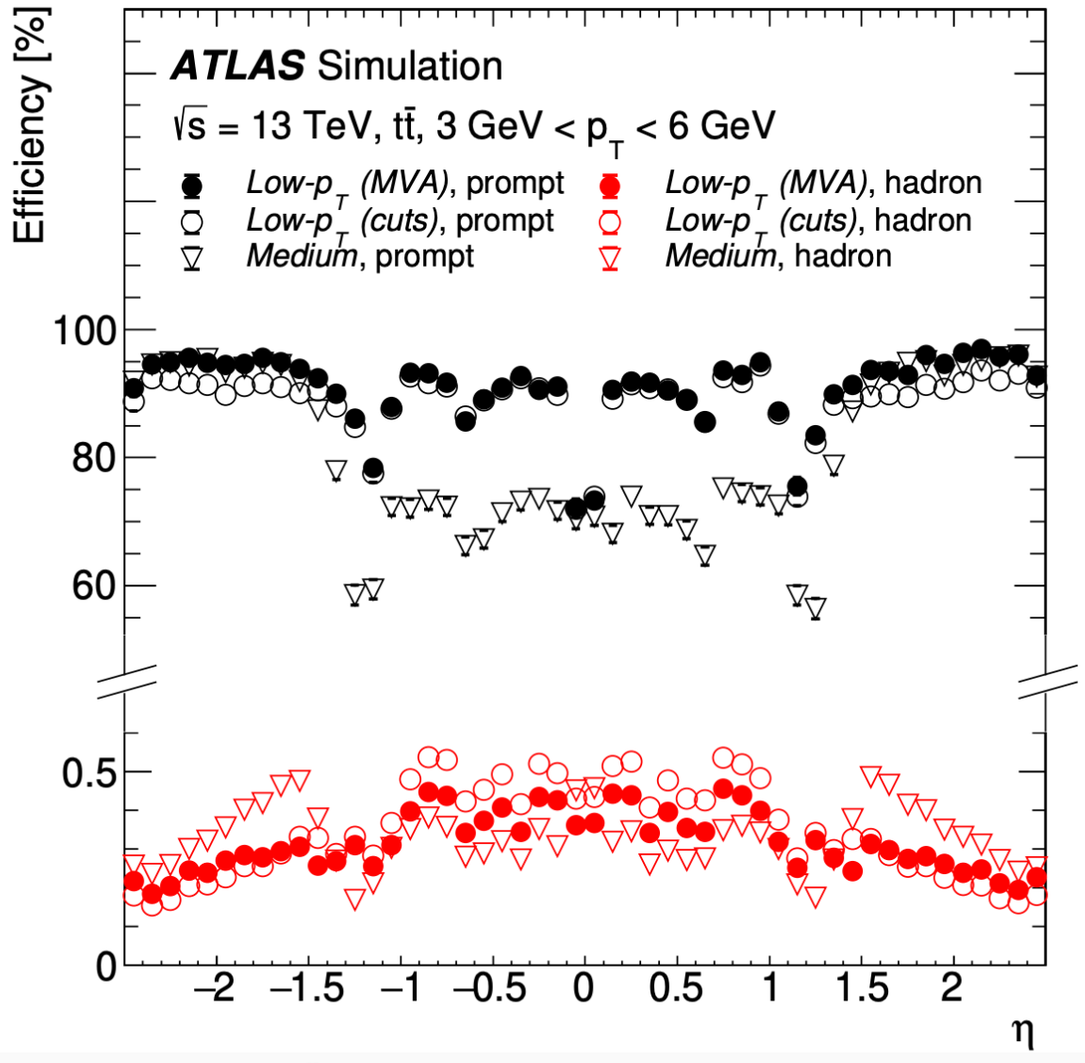
Muon efficiency in data vs **simulation**
for different WPs

Muon reconstruction WPs - Run 2 strategy

- Additionally, two WPs for extreme regions of phase space — low and high p_T
- High p_T: optimised for muons with p_T > 100 GeV for resolution and fake rejection
- Low p_T: optimised for muons with p_T down to 3 GeV

For low p_T muons, two WPs are developed:

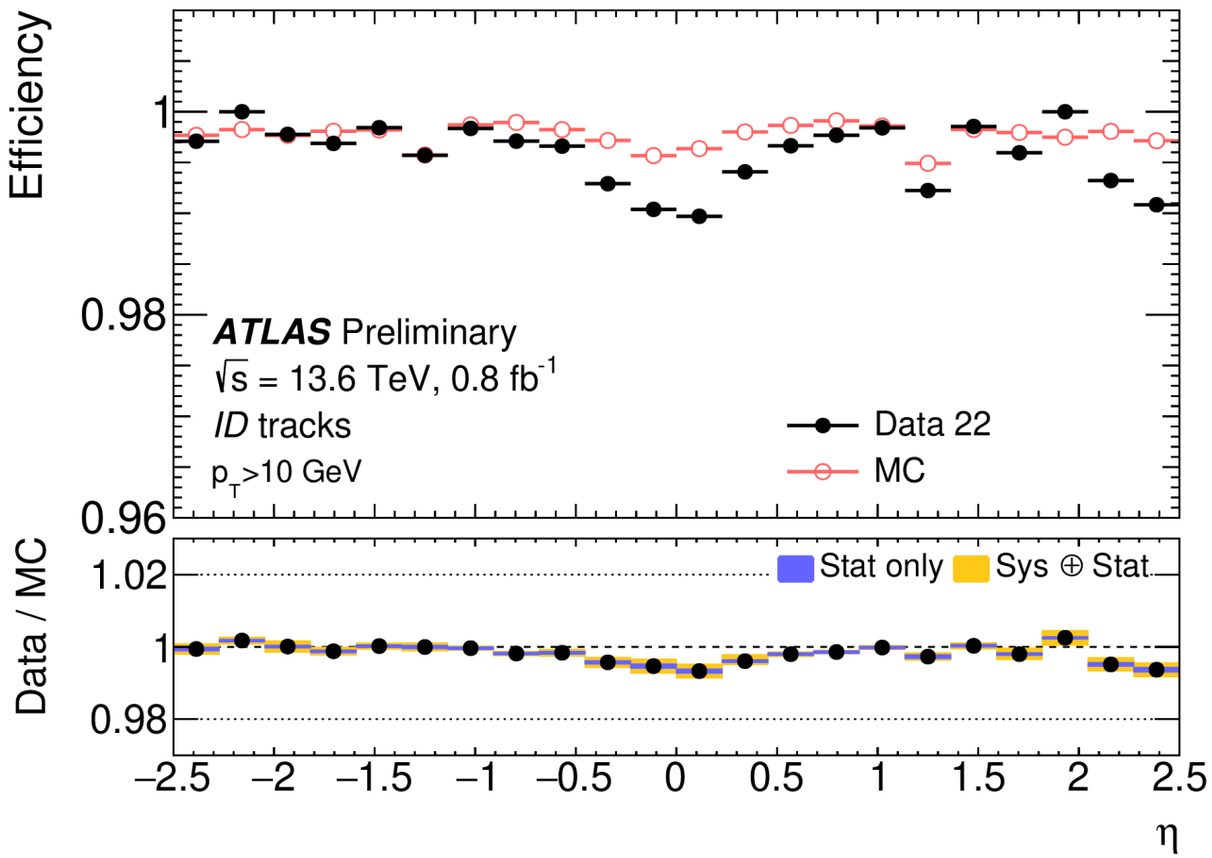
- Cut-based method: better background rejection at high η
- Multivariate-based method: better signal efficiency at high η



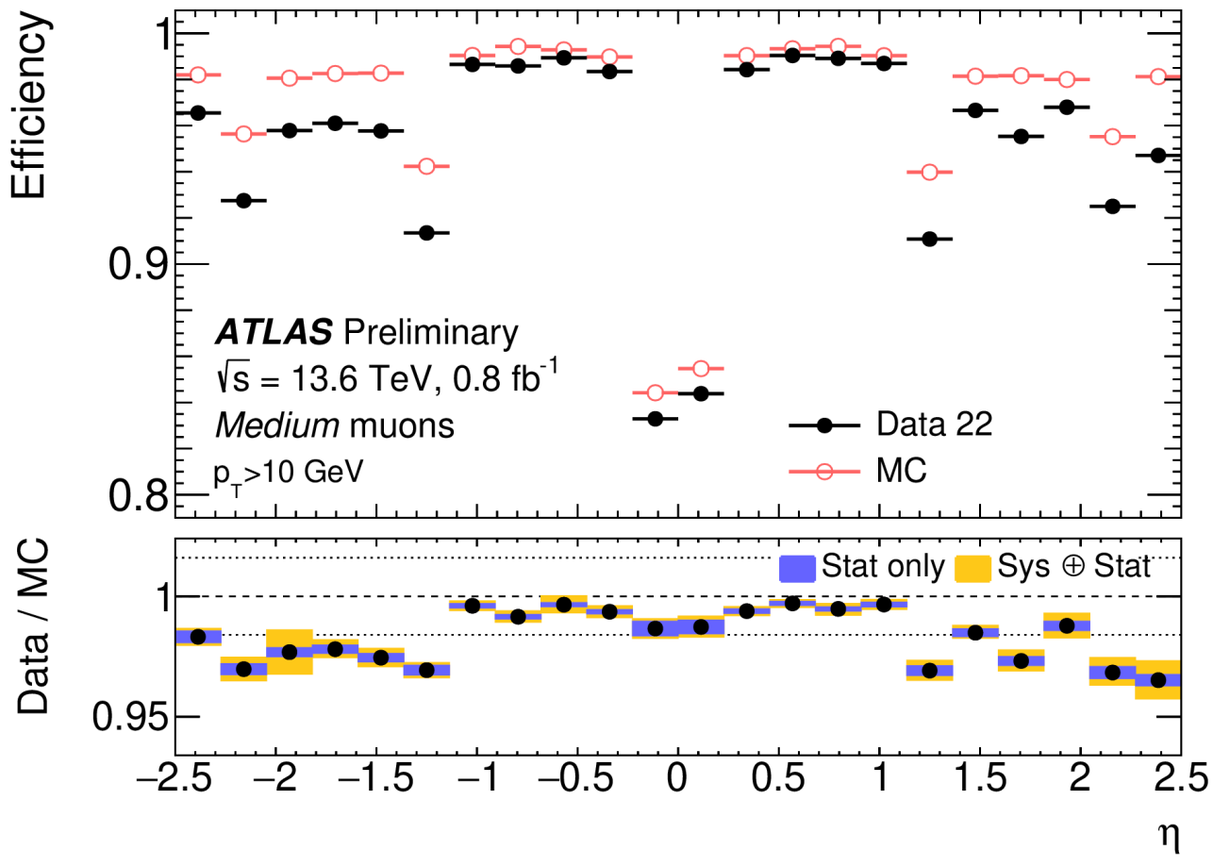
Signal efficiency vs **background rejection** for low pT WP

Muon reconstruction - Run 3 strategy

- As NSW is still in commissioning phase, stricter requirements on the rest of the detector hits for combined muons
  - ID tracks largely unaffected
  - Reduced efficiency in $|\eta| > 1.5$ for muons in medium WP
- Similarly, more stringent cut criteria on other WPs



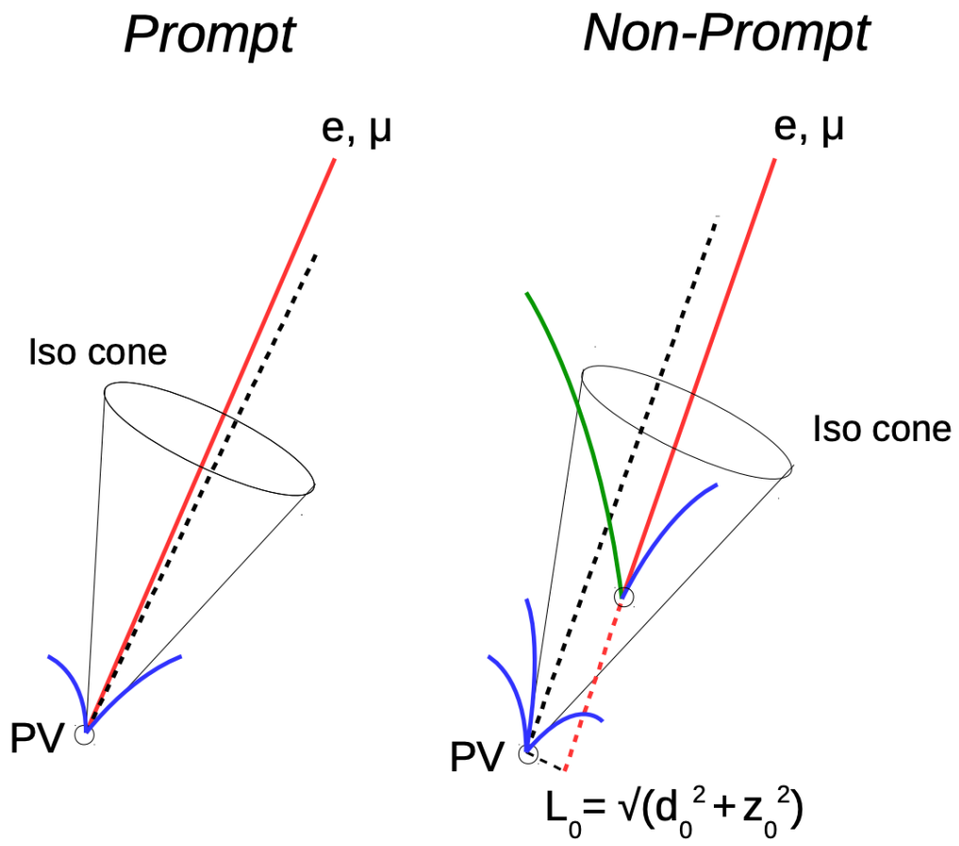
Data and MC efficiency for ID tracks



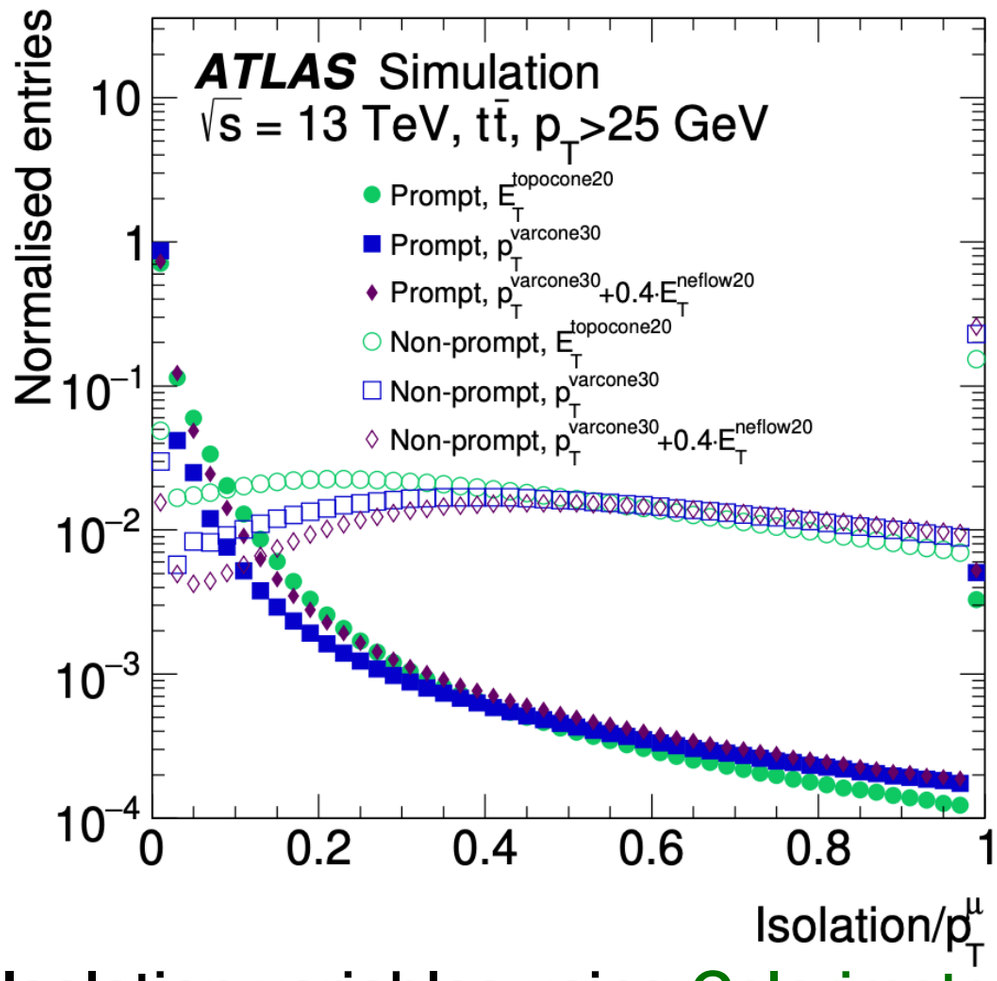
Data and MC efficiency for medium WP

Muon isolation - Run 2 Strategy

- Isolation WPs targets the separation between prompt and non-prompt muons from heavy hadrons, taus or heavy quark decays
- Can be probed by additional hadronic activities!



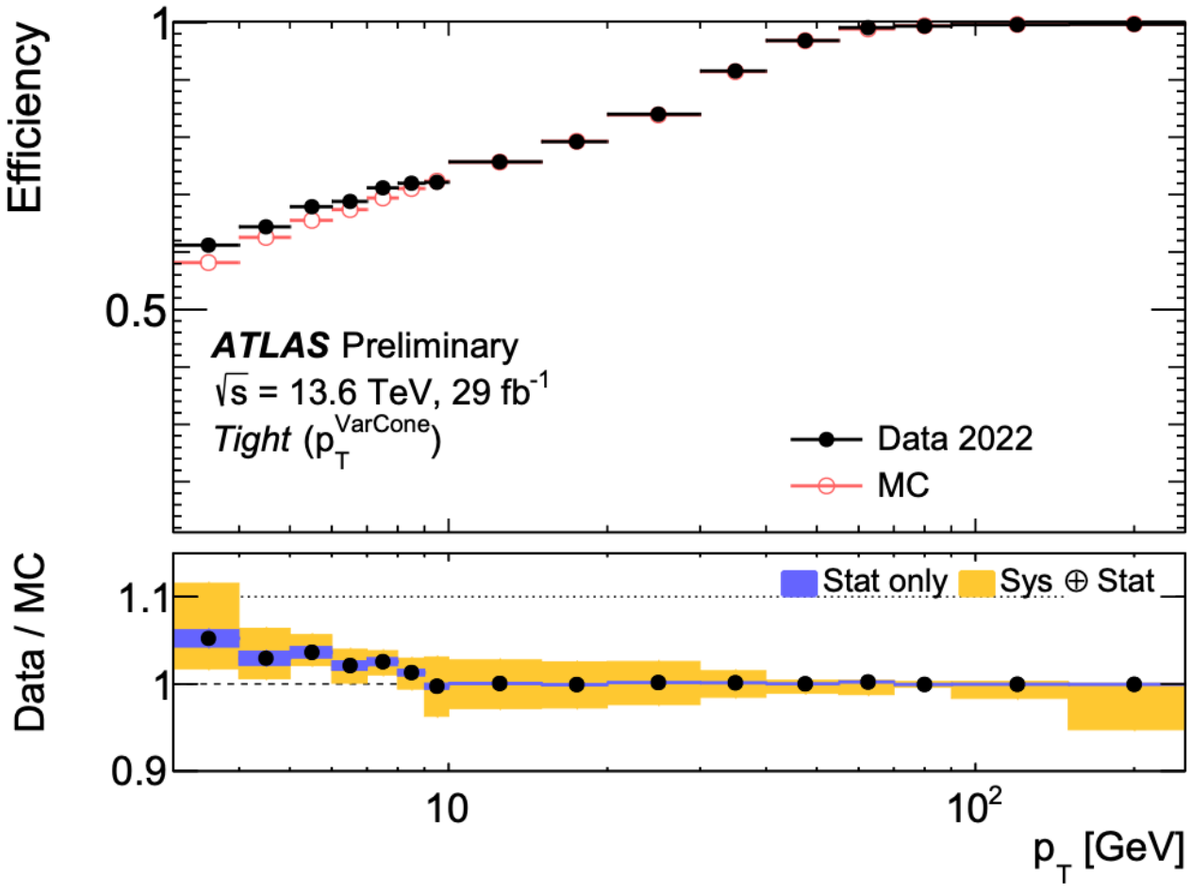
We use scalar sum of p_T (or E_T) within a cone around the muon track!



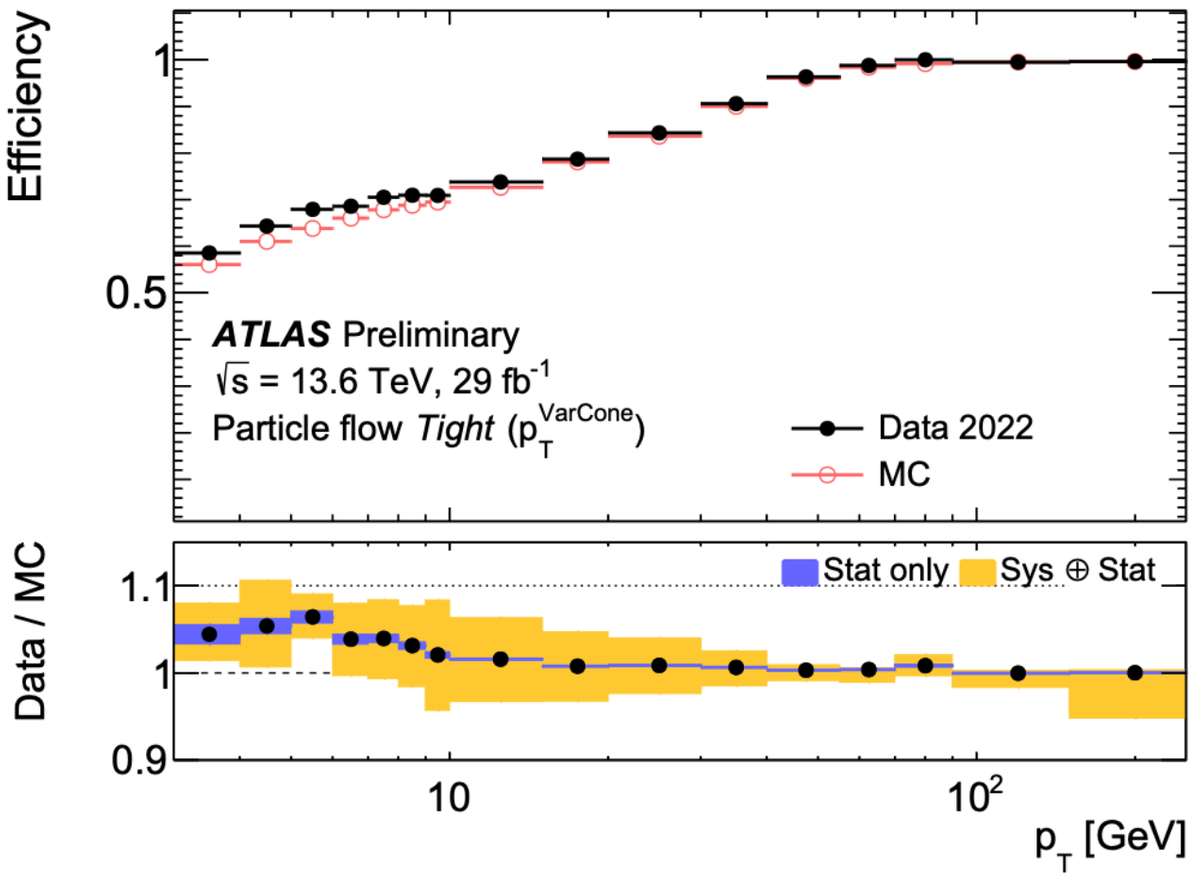
Isolation variables using Calorimeter, ID and combined information for prompt **and non-prompt muons**

Muon efficiencies - Run 3 Result

- Followed the same strategy as Run 2
- Measured using Zμμ event with tag-and-probe method
- Overall observed good agreement between data and MC in Run 3



Data and MC isolation efficiency
Using track-based isolation variable
(*Tight WP*)



Data and MC isolation efficiency using
particle flow—based isolation variable
(*PFlowTight WP*)

Muon calibration - Run 2 Strategy

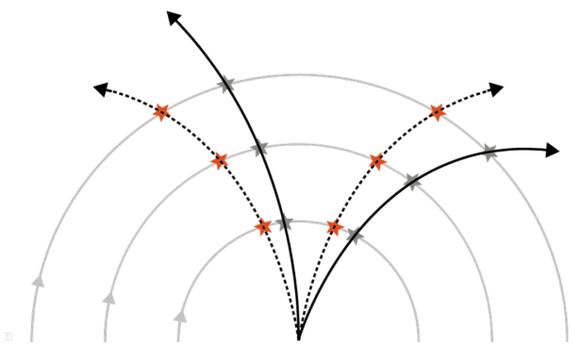
- We correct for the following effects:

Sagitta bias

Twist & curls of the detector

(Local) charge dependent effects

(Global) charge dependent effect



Scale & resolution mismodelling

Magnetic field mismodelling

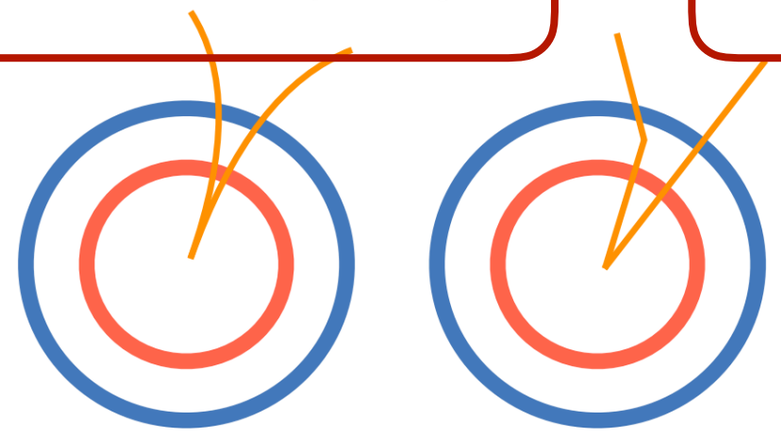
Spatial resolution mismodelling

Energy loss mismodelling

Multiple scattering mismodelling

(Local) momentum scale discrepancy

(Local) momentum resolution discrepancy



$B = \frac{1}{4}B_0$ $B = B(x, y, z)$

Present in data

Present in MC

Resultant discrepancy

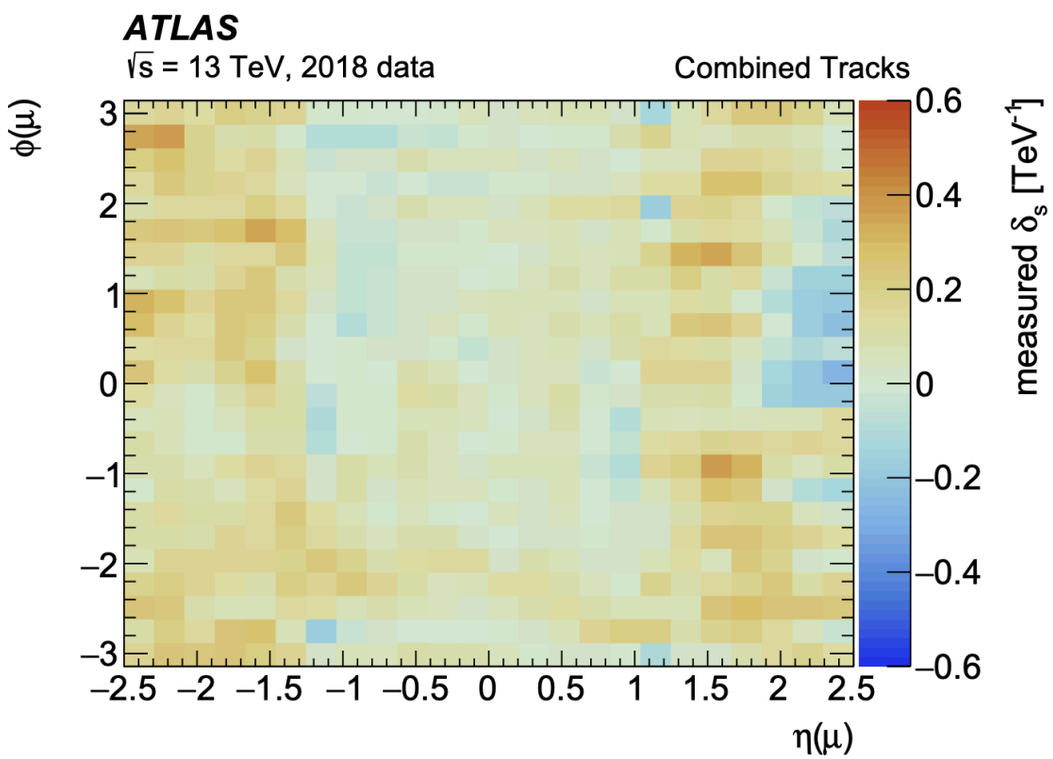
Muon calibration - Run 2 Strategy

- And these effects are parametrised as follows:

Sagitta bias (on data)

$$p_T' = \frac{p_T}{1 + q p_T \delta_s(\eta, \phi)}$$

- Iterative fit on Z peak — minimising the variance on the dimuon mass peak
- Measured in bins of η and ϕ



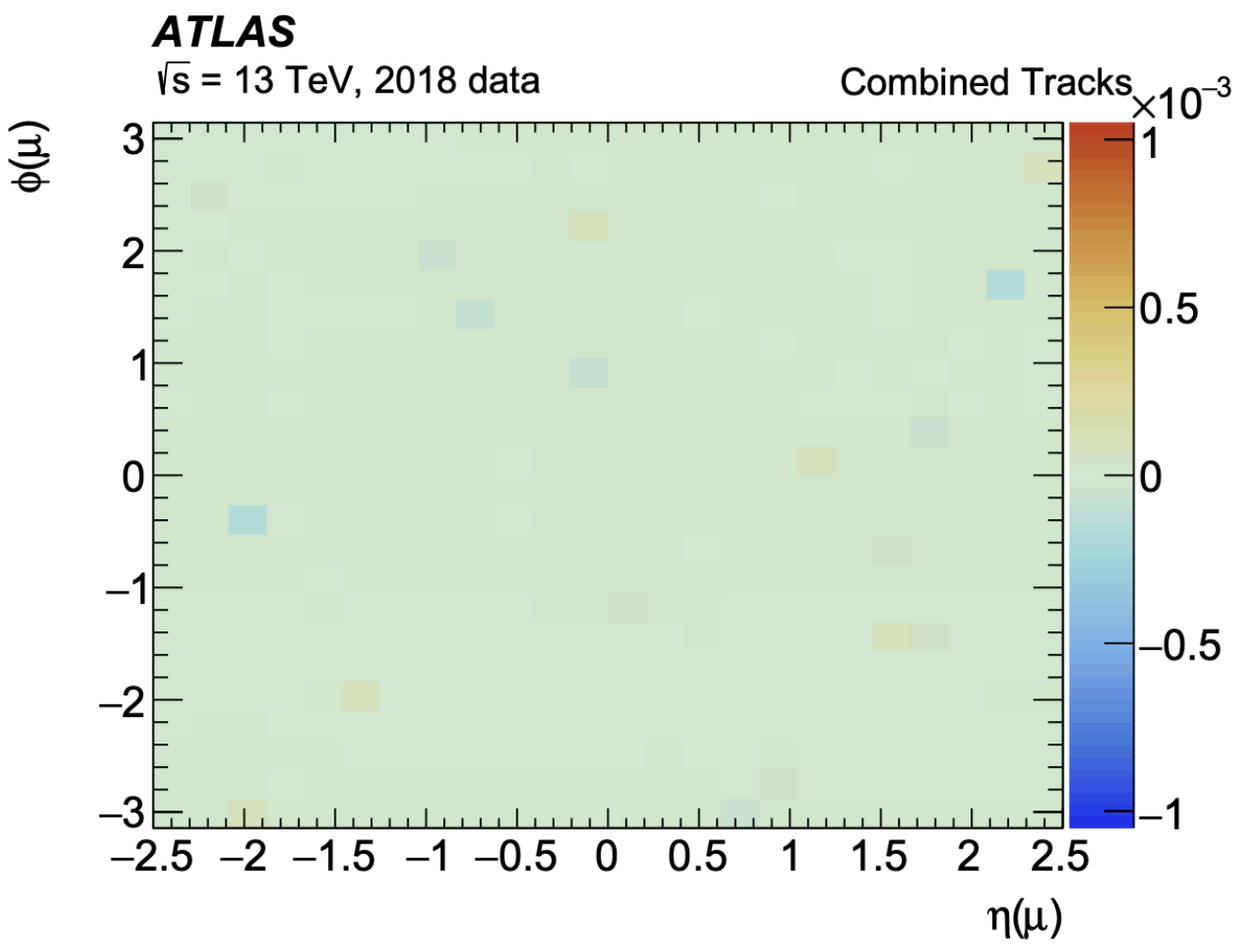
Scale & resolution mismodelling (on MC)

$$p_T' = \frac{p_T + \sum_{n=0}^{1} \Delta s_n(\eta, \phi)(p_T)^n}{1 + \sum_{m=1}^{2} \Delta r_m(\eta, \phi)(p_T)^{m-1} g_m}$$

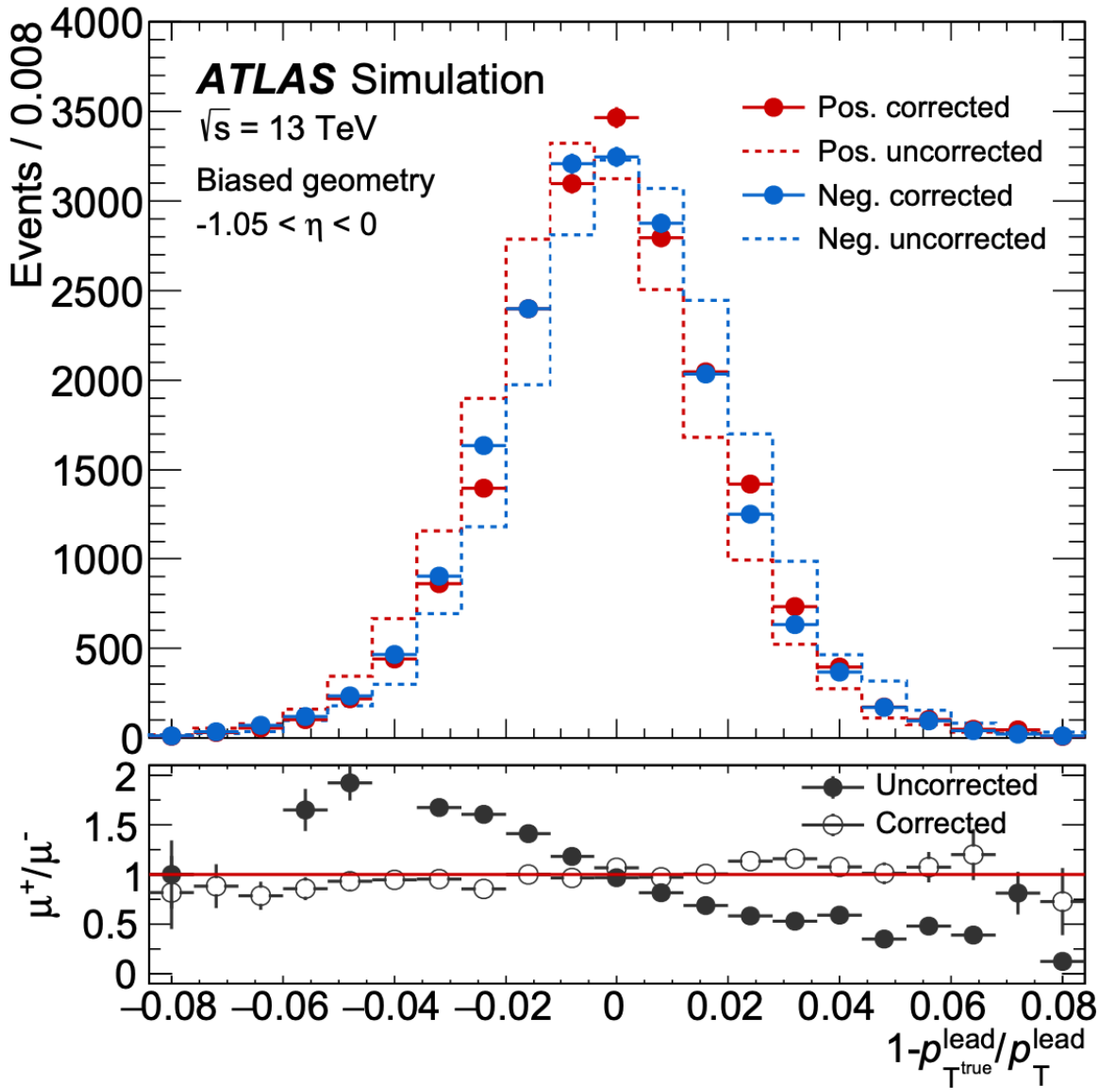
- Using Z and J/ψ mass spectrum to simultaneously capture low and high-p_T mismodelling
- Iteratively fitted by χ^2 minimisation
- Measured in regions of eta and phi

Sagitta bias correction - Run 2 Results

- Residual bias are reduced to less than $2*10^{-4}$ TeV in all regions of detector!
- Cross validated using simulated sample with misaligned MS geometry — good closure observed!
- Will be applied on Run 3 soon!



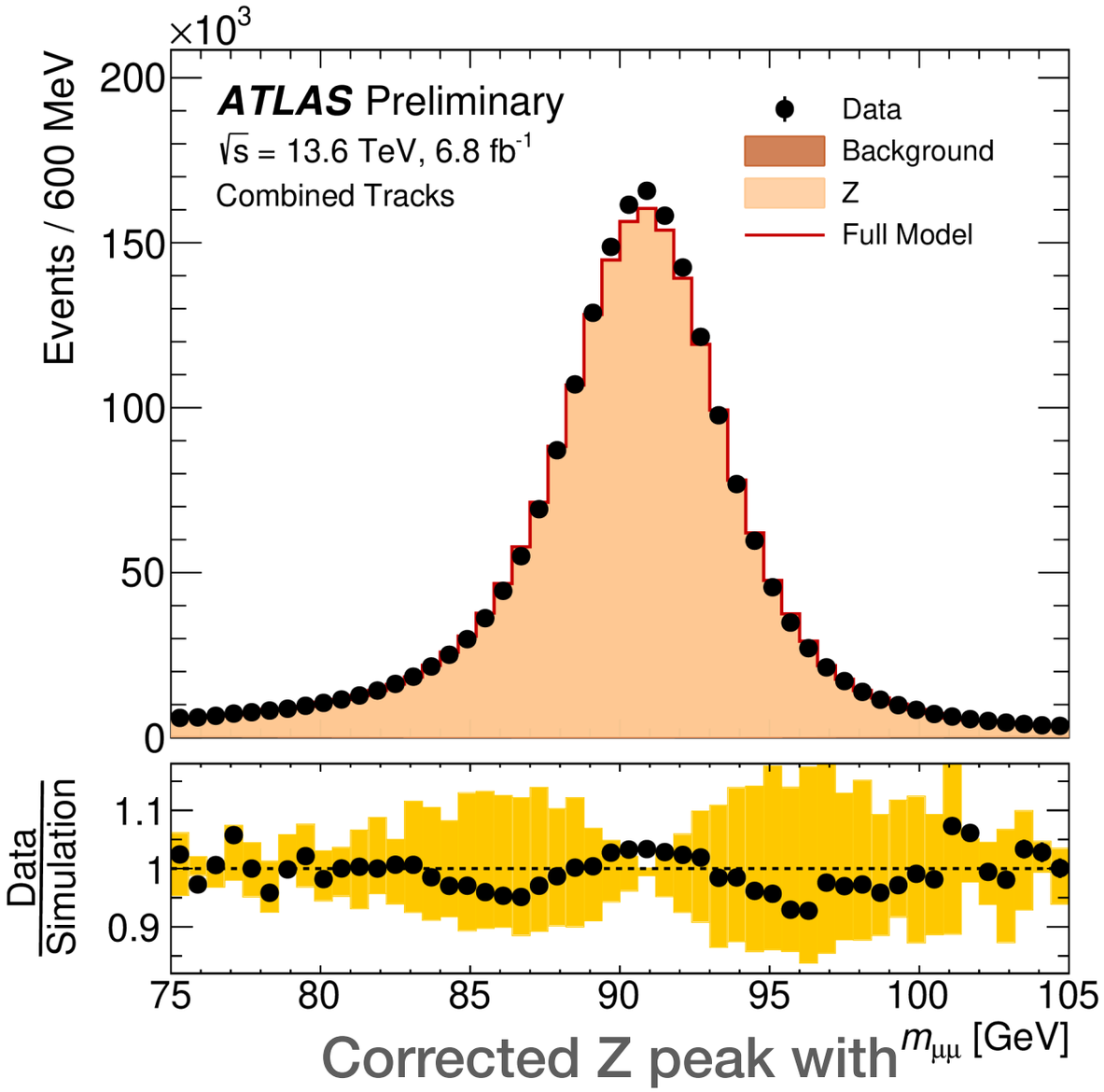
Residual bias on data after applying Sagitta bias correction



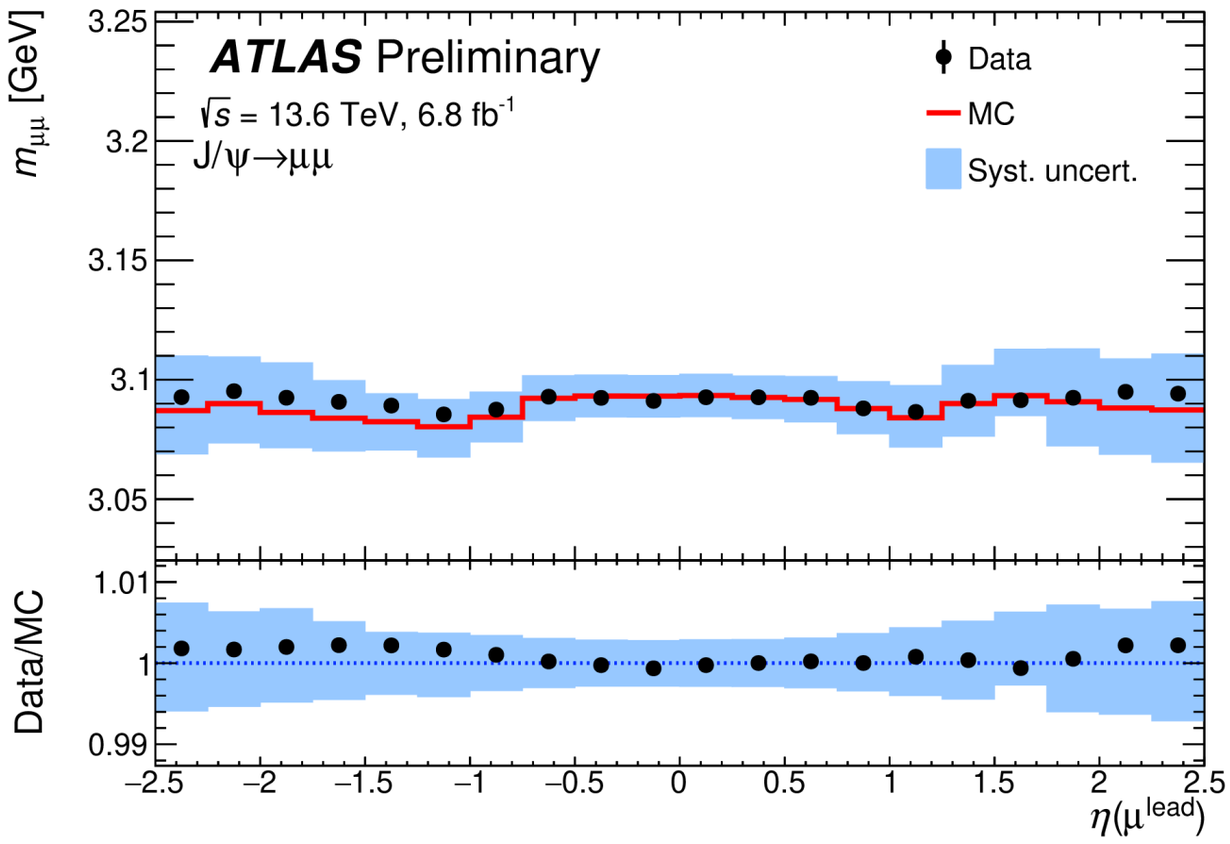
Fractional difference between truth pT and measured pT **before** and after Sagitta bias correction

Scale and resolution correction

- Cross validated on Z and J/ψ with binning in slices of η and p_T!
- Important systematic for early Run 3 analyses (top, Higgs…)



Corrected Z peak with systematic variation



Muon scale in slices of eta for **data** and **MC**

Conclusion & Outlook

- Presented the strategy and results of muon performance in Run 2 & 3
  - Similar strategy to Run 2
  - NSW still in commissioning phase
- Muon performance has been critical towards the understanding of the upgraded ATLAS
- A steady stream of Run 3 results are released/on the way - stay tuned for upcoming Run 3 physics results!

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Backup

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Muon reconstruction WPs (Run 2)

Quality	Muon type	Definition
Tight	Combined	nprecisionLayers > 1 **AND** combined fit chi2/Ndof < 8 **AND** η/pT dependent cuts on qOverP significance and ID/ME/CB momentum imbalance
Medium	Combined	qOverP significance < 7 **AND** (nprecisionLayers > 1 **OR** (nprecisionLayers == 1 **AND** nprecisionHoleLayers < 2 **AND** abs(η)<0.1))
	Silicon Forward & Standalone	abs(η) > 2.5 **AND** nprecisionLayers > 2
Loose	Combined	As for Medium **OR** (pT < 7 GeV **AND** abs(η) < 1.3 **AND** nprecisionLayers > 0 **AND** isAuthor(MuGirl) **AND** isAuthor(MuTagIMO))
	Silicon Forward & Standalone	As for Medium
	CaloTagged	abs(η) < 0.1 **AND** (passes CaloScore WP4)
	SegmentTagged	abs(η) < 0.1
High pT	Combined	nprecisionLayers > 2 (> 3 for BEE region and > 1 for particular "missing-inner" tracks) with non-overlapping small/large MS sectors **AND** veto on specific MS regions **AND** qOverP significance < 7
Low pT	Combined	(isAuthor(MuidCo) **OR** (isAuthor(MuGirl) **AND** isAuthor(MuTagIMO)) **AND** (nprecisionLayers > 1 for abs(η) in 1.3 - 1.55, otherwise nprecisionLayers > 0) **AND** (MBS < 3 **AND** SCS < 3 **AND** SNS < 3)

Muon reconstruction WPs (Run 2)

Quality	Muon type	Definition
Tight	Combined	**Not yet supported**
Medium	Combined	Same as Run 2 (NSW not counted in nprecisionlayers)
	MS-Extrapolated	**Not yet supported**
Loose	Combined	Same as Run 2
	MS-Extrapolated	**Not yet supported**
	CaloTagged	Same as Run 2
	SegmentTagged	Same as Run 2
High pT	Combined	Same as Run 2 **AND** abs(η) < 1.05
Low pT	Combined	**Not yet supported**