Results from muon reconstruction performance with ATLAS at Run-3

Damiano Vannicola
on behalf of the ATLAS Collaboration

TEL AVIV UNIVERSITY

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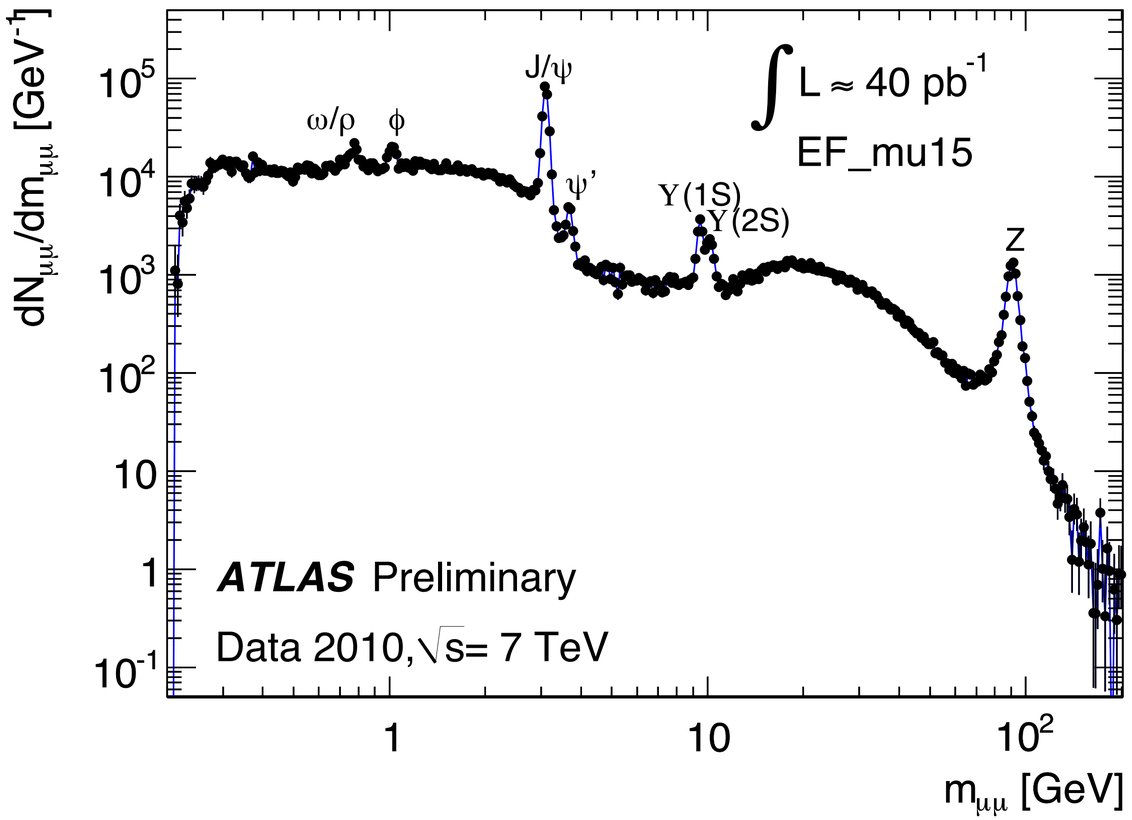
BoostDiscovery

ATLAS EXPERIMENT

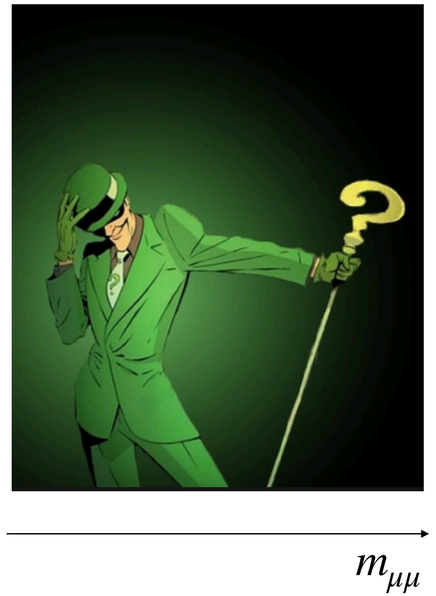
Why muons?

Muons ⟶ very clean signature

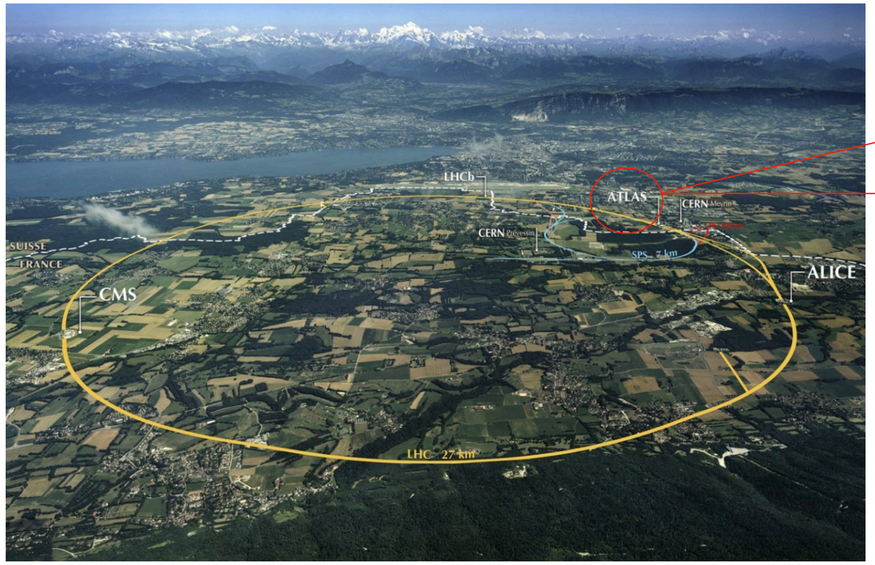
Public Plot Reference



precision measurements
new physics searches



ATLAS Experiment at LHC

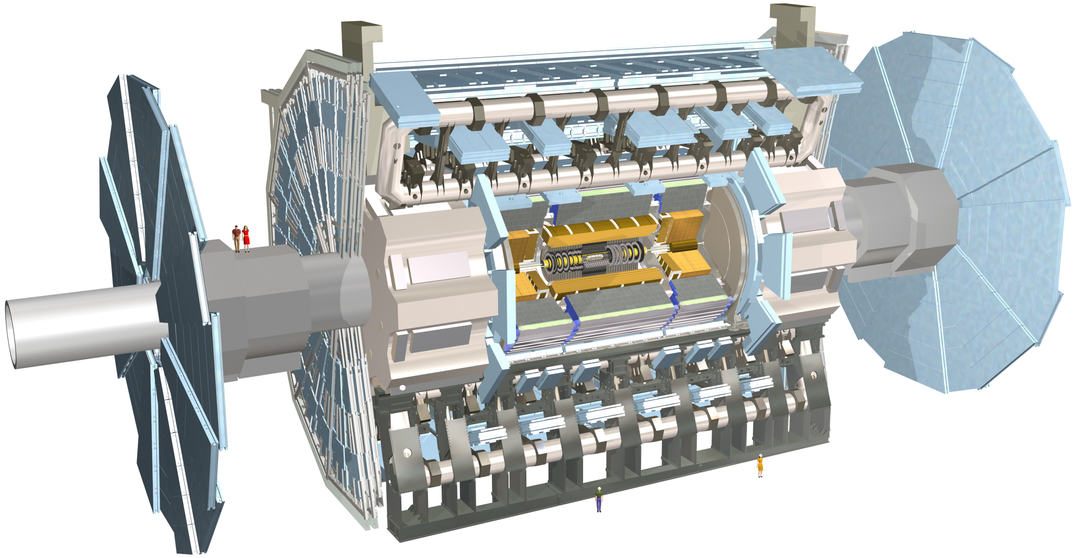


Proton-proton collisions at

$\sqrt{s} = 13.6\ TeV$

Collision rate 40 MHz

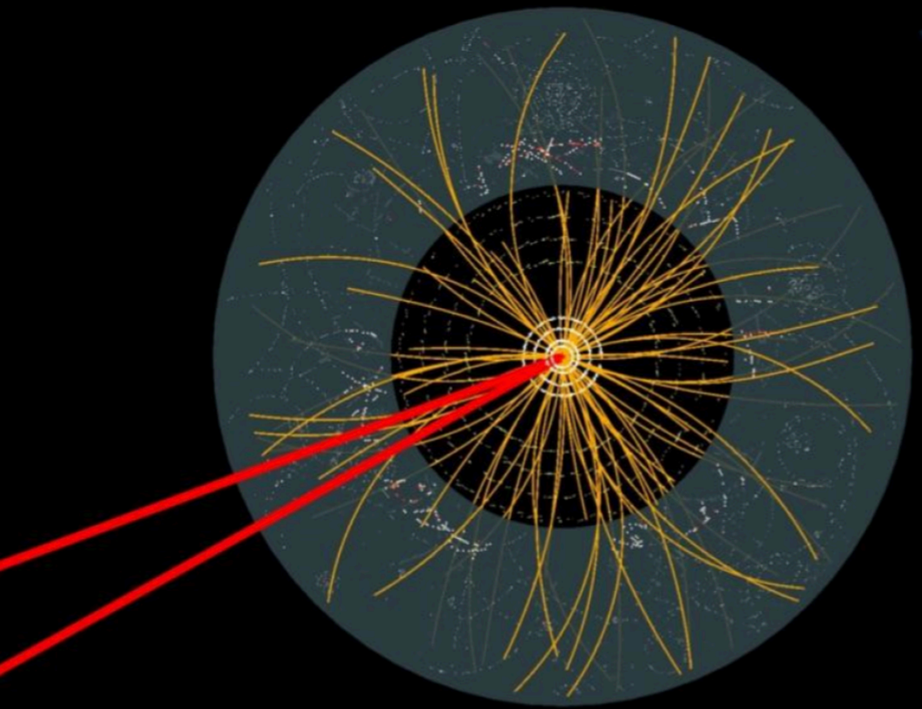
Number of collisions ~ 33.7

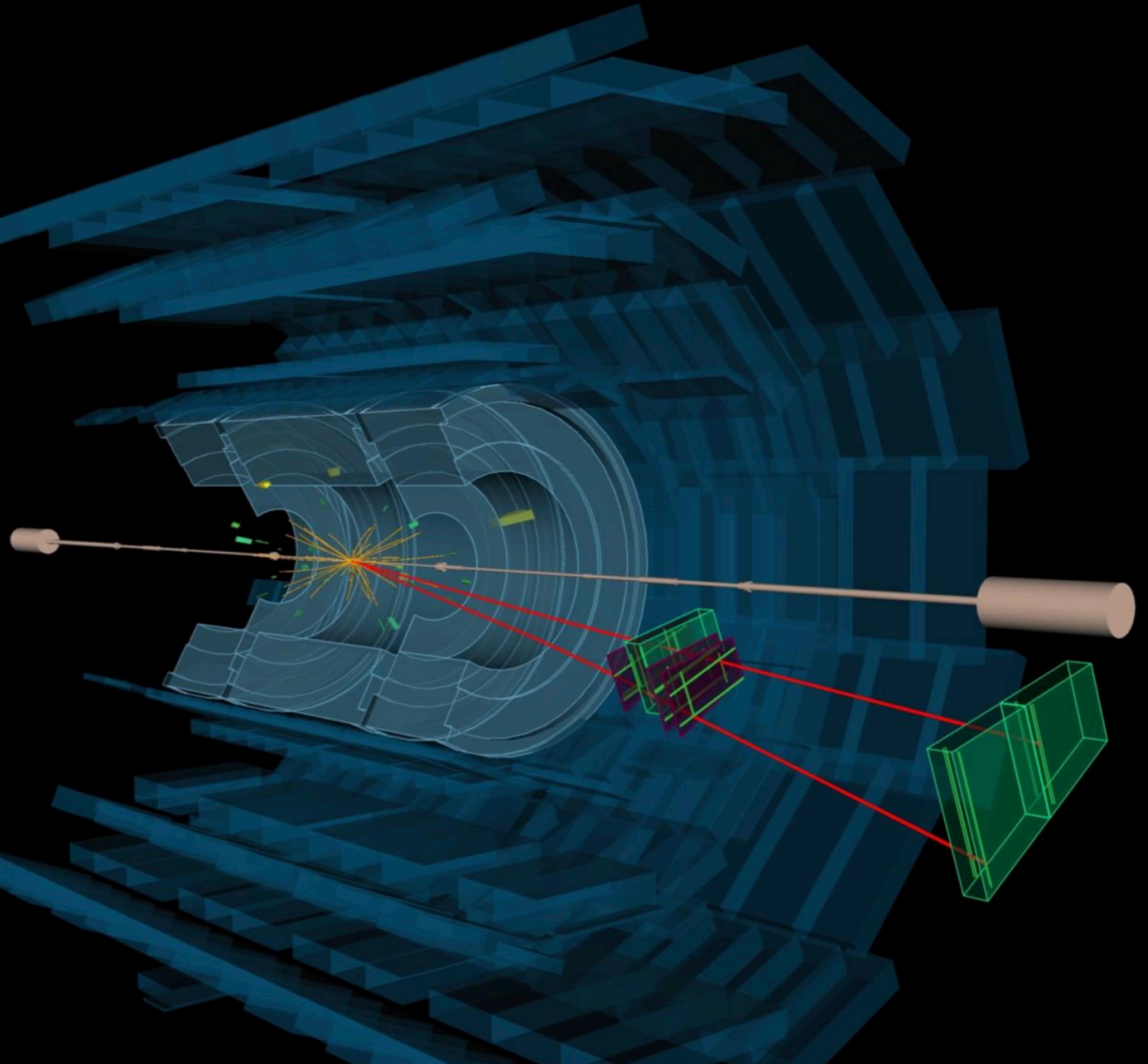


- Inner Detector (ID)
- Electromagnetic and hadronic Calorimeter
- Muon Spectrometer (MS)

$J/\Psi \rightarrow \mu^+\mu^-$ Candidate

Invariant Mass: 3.08 GeV/c^2





ATLAS EXPERIMENT

Run: 427394
Event: 3606971

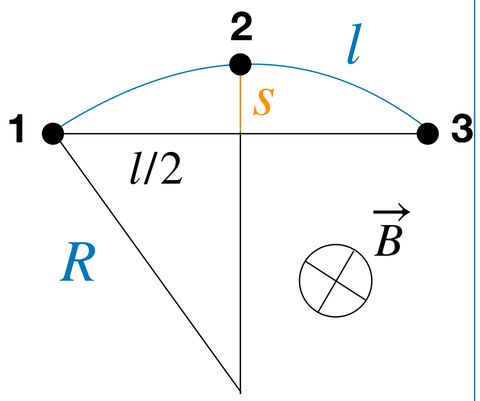
ATLAS muon reconstruction

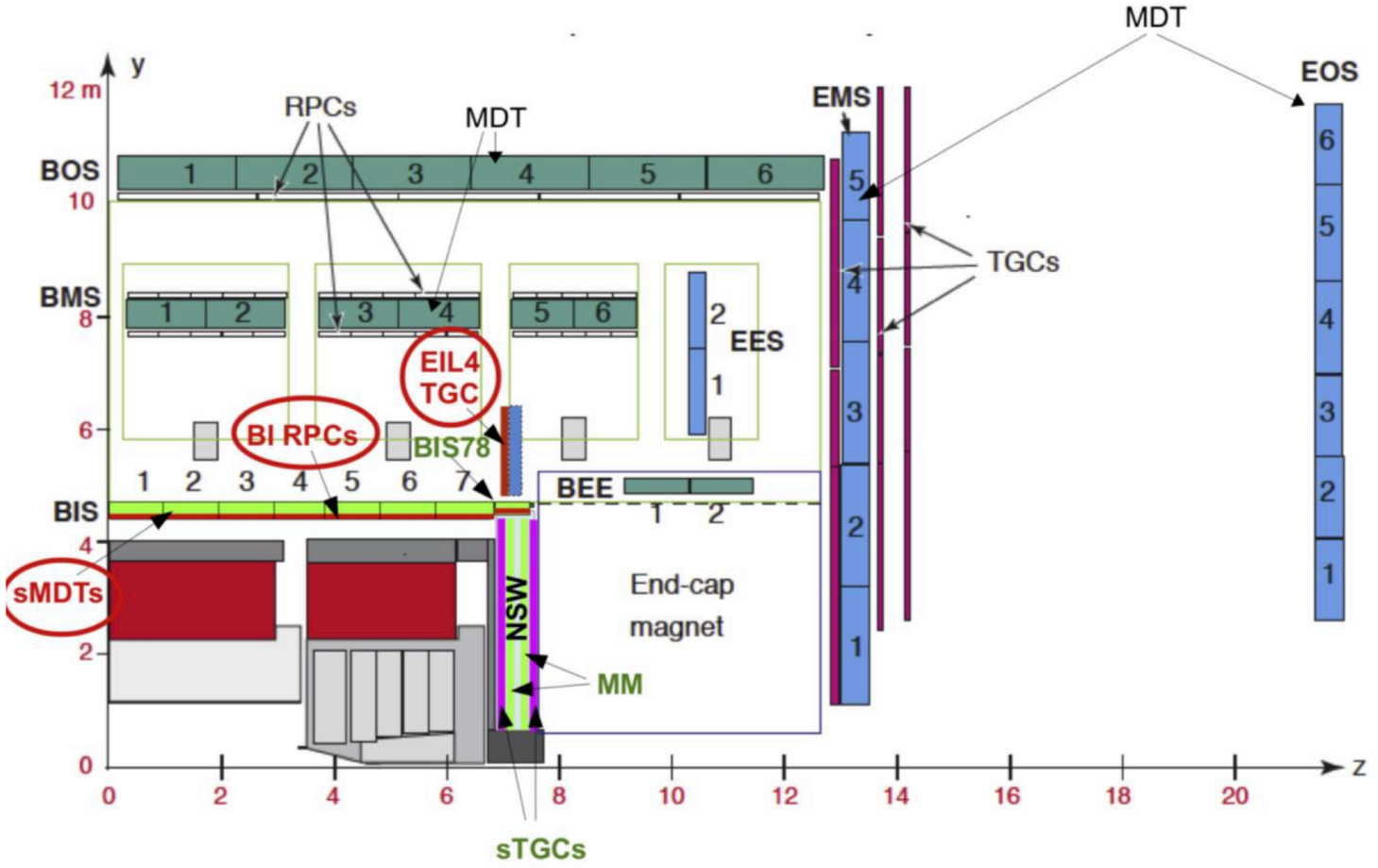
MS sub-detector

- Trigger chambers
  - RPC
  - TGC
  - sTGC
- Precision chambers
  - MDT
  - MicroMegas

Sagitta :

$$s \simeq \frac{l^2 B}{8 p_T}$$





ATLAS different muons

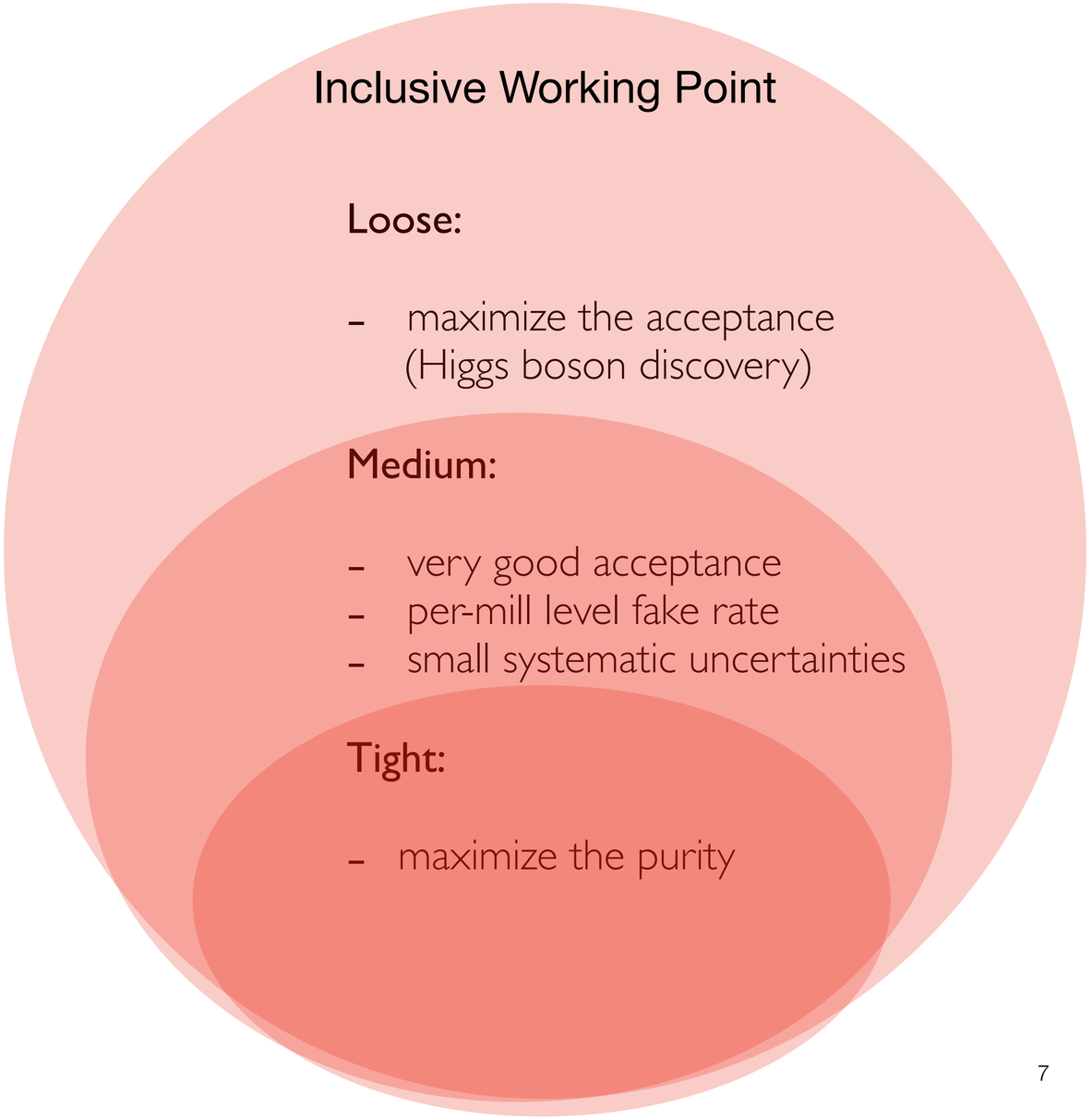
Muon Reconstruction { Inner Detector (ID)
Calorimeter (Calo)
Muon Spectrometer (MS)

Different algorithm to reconstruct a muon:

- Combined (CB)
- Extrapolated (ME)
- Calorimeter - Tagged (CT)
- Segment - Tagged (ST)

	ID	Calo	MS
CB	✓		✓
ME			✓
CT	✓	✓	
ST	✓		✓

ATLAS muon Working Point



Special Working Point

Low-p_T :

- good muon reconstruction efficiency down to p_T of 3 GeV
- keeping the fake rate under control

High-p_T :

- optimized to provide good momentum resolution for very high-p_T muons, of O(1) TeV

Muon Momentum Calibration

Procedure used to identify the corrections to the reconstructed muon p_T in simulation

↓

to match the measurement of the same quantities in data

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

Corrections are defined in $\eta - \phi$ regions

s_n scale corrections

s_0 ⟶ the effect on the CB and MS momentum from the inaccuracy in the simulation of the energy loss in the calorimeter

s_1 ⟶ for inaccuracy in the description of the magnetic field integral

Muon Momentum Resolution

Δr_m ⟶ momentum resolution smearing

The expected resolution of the momentum measurement is: $\sigma_{rel}^{exp} = \sqrt{(r_0/p_{\mathrm{T}})^2 + r_1^2 + (r_2 \cdot p_{\mathrm{T}})^2}$

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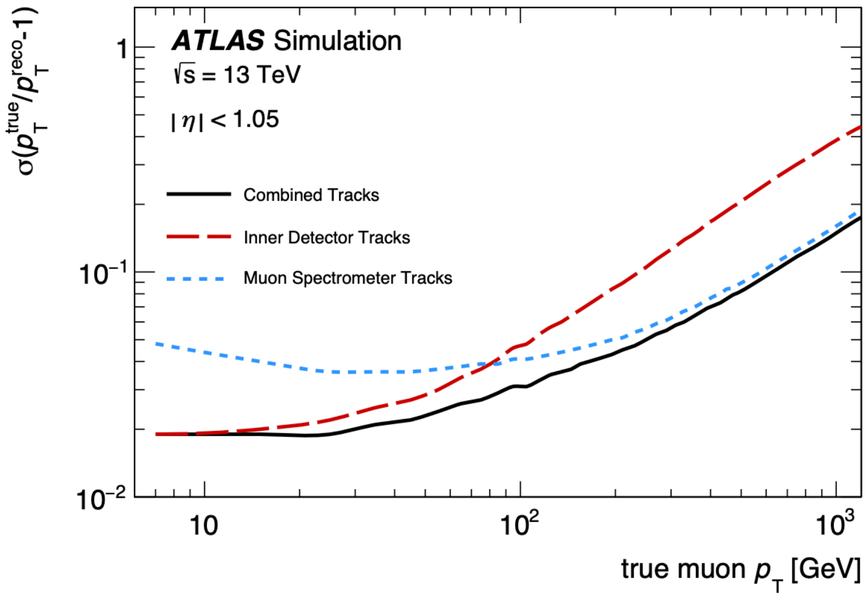
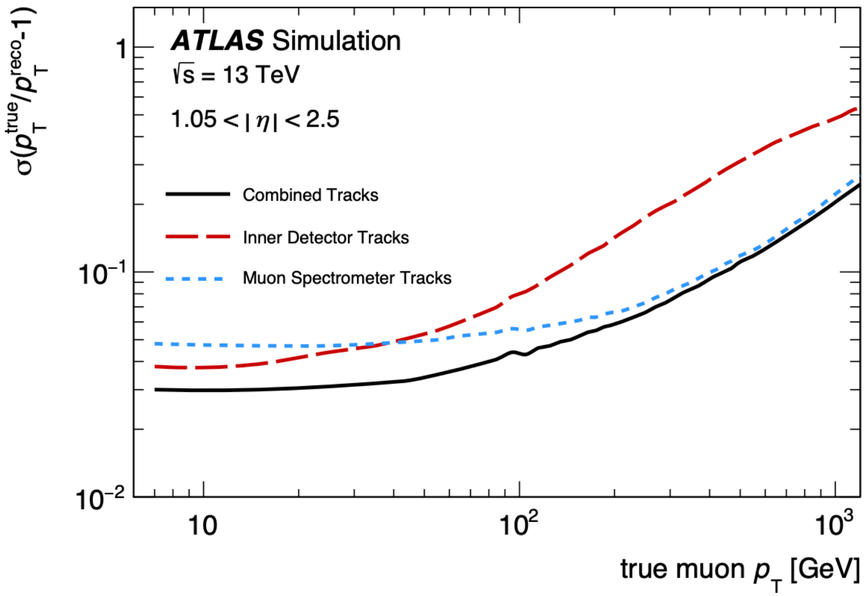
energy loss in the calorimeter | multiple scattering | sagitta

Barrel



End - Cap



Determination of p_T calibration parameters

The CB, ID, and MS correction parameters are extracted from data using a fitting procedure that compares the invariant mass distributions for $J/\Psi \to \mu\mu$, $Z \to \mu\mu$ candidates in data and simulation

Δr_2 initial value set from muon alignment studies!

All sources of uncertainties are evaluated by varying the parameters of the template fit

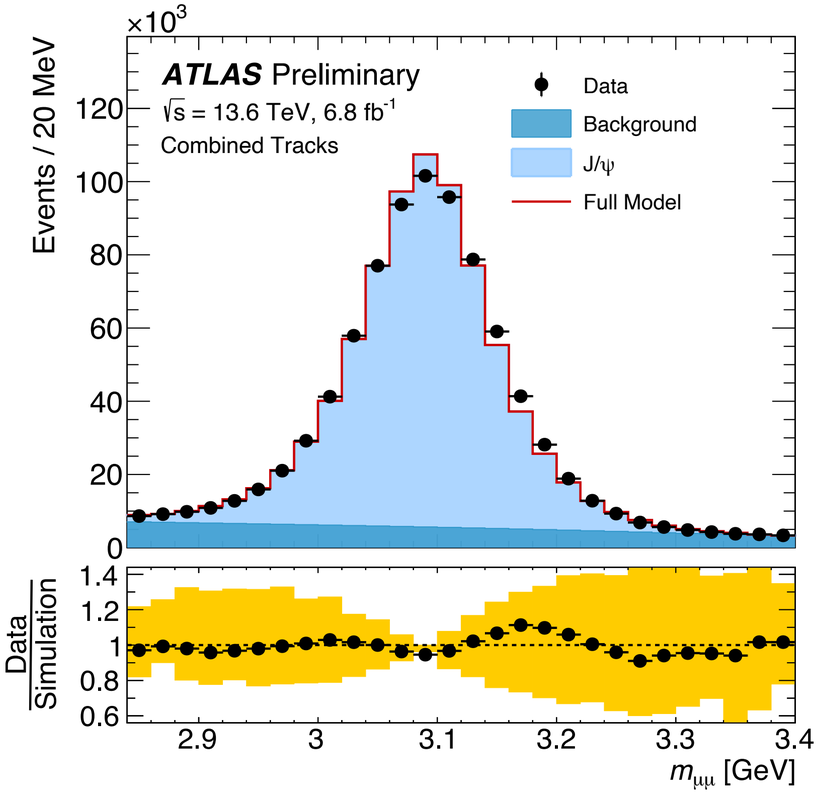
CB corrections

Region	$\Delta r_1^{\mathrm{CB}}(\times 10^{-3})$	Δr_2^{CB} [TeV^{-1}]	s_0^{CB} [MeV]	$s_1^{\mathrm{CB}}(\times 10^{-3})$
$\lvert\eta\rvert < 1.05$ (large)	$6.7^{+1.4}_{-0.9}$	$0.08^{+0.04}_{-0.05}$	$-5.0^{+2.9}_{-4.0}$	$0.35^{+0.24}_{-0.22}$
$\lvert\eta\rvert < 1.05$ (small)	$6.5^{+1.3}_{-1.0}$	$0.11^{+0.05}_{-0.05}$	$-0.9^{+2.5}_{-3.6}$	$-0.83^{+0.25}_{-0.14}$
$1.05 \leq \lvert\eta\rvert < 2.0$ (large)	$10.3^{+2.6}_{-2.7}$	$0.24^{+0.10}_{-0.07}$	$-2.0^{+5.7}_{-6.7}$	$-0.83^{+0.39}_{-0.30}$
$1.05 \leq \lvert\eta\rvert < 2.0$ (small)	$8.9^{+1.7}_{-2.7}$	$0.29^{+0.08}_{-0.03}$	$-3.0^{+3.3}_{-4.0}$	$-0.80^{+0.26}_{-0.21}$
$\lvert\eta\rvert \geq 2.0$ (large)	$10.6^{+2.2}_{-2.7}$	$0.21^{+0.10}_{-0.07}$	$2.3^{+13}_{-9.3}$	$0.80^{+1.09}_{-0.42}$
$\lvert\eta\rvert \geq 2.0$ (small)	$11.5^{+2.2}_{-2.1}$	$0.26^{+0.08}_{-0.06}$	$-12.6^{+8.2}_{-9.7}$	$1.59^{+0.47}_{-0.43}$

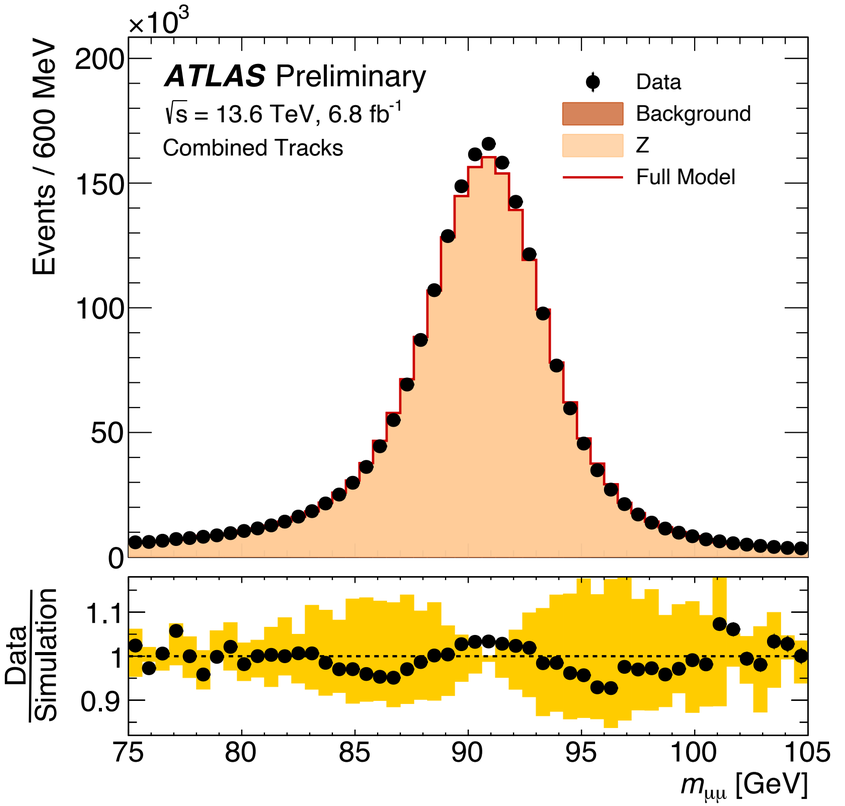
Muon Momentum Reconstruction

[Public Plots Reference]

$J/\Psi \rightarrow \mu\mu$



$Z \rightarrow \mu\mu$



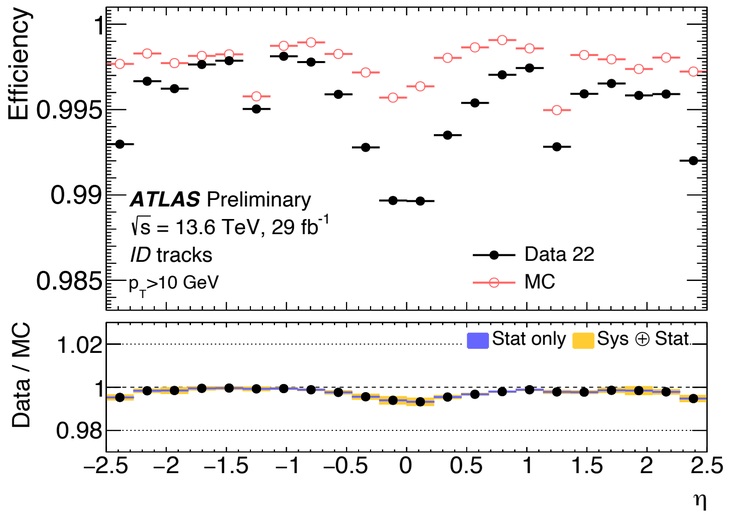
Very nice agreement → effectiveness of the p_T calibration

Muon Reconstruction and Identification Efficiency

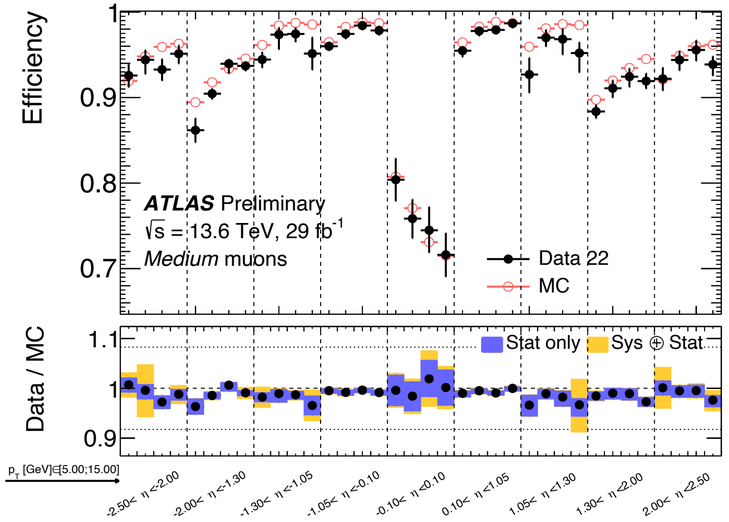
Reconstruction and identification efficiency measured from pp collision at $\sqrt{s} = 13.6\ TeV$ using 29 fb^{-1} of data collected in 2022, relying on muon triggers

[public plots reference]

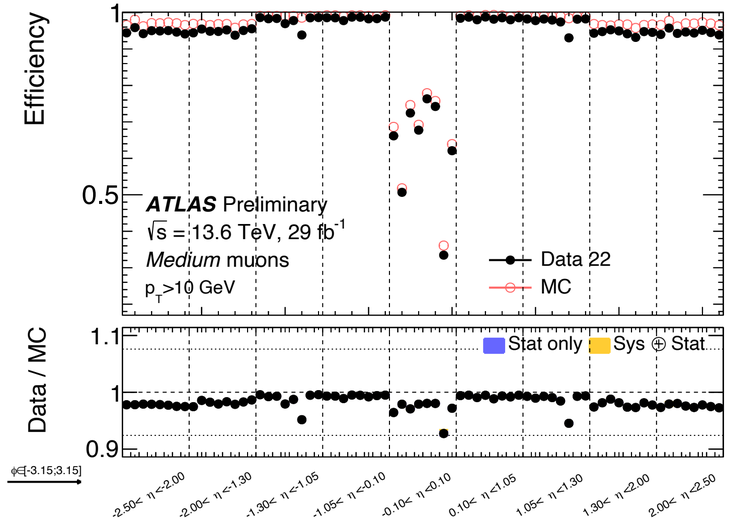
$Z \to \mu\mu$



$J/\Psi \to \mu\mu$



$J/\Psi \to \mu\mu$



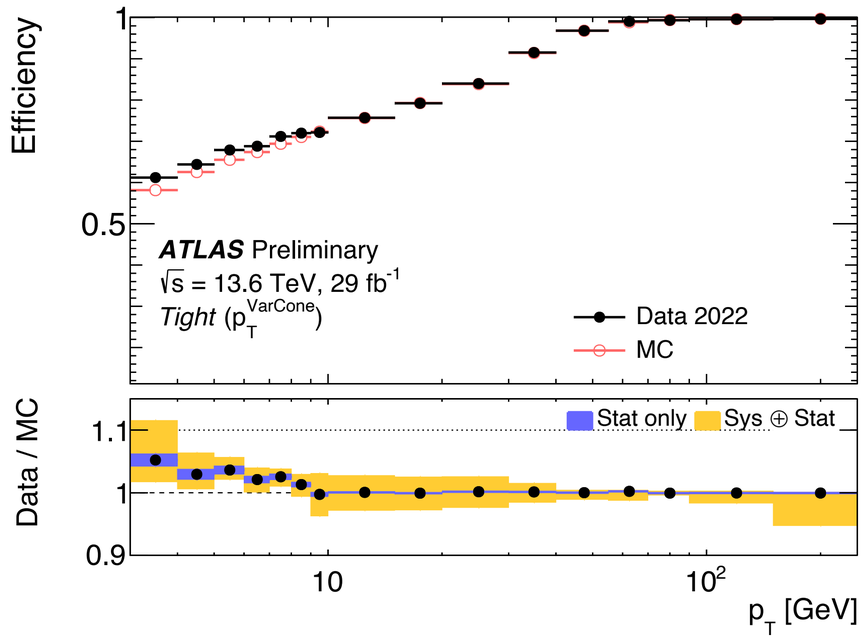
Very nice agreement between Data/MC

Muon Isolation Efficiency

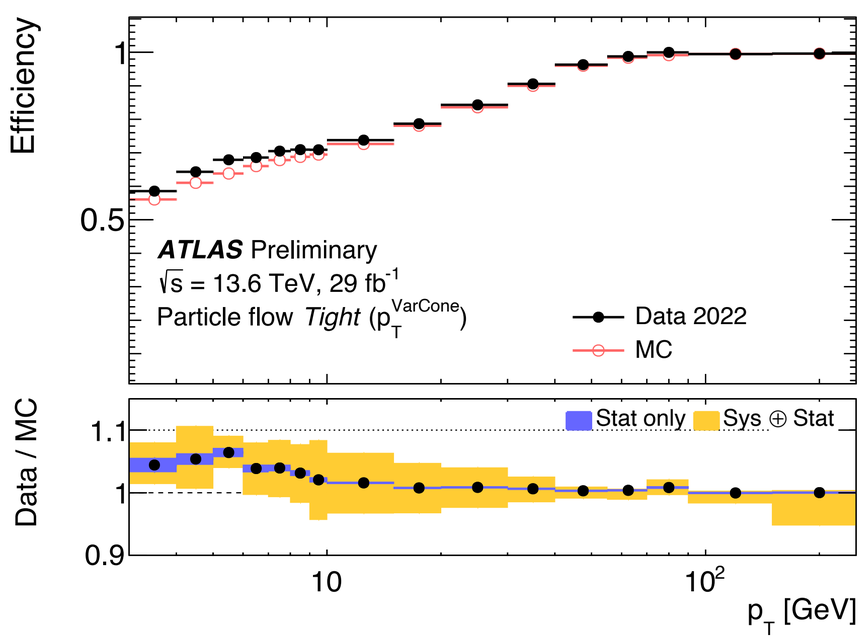
Isolation efficiency measured from pp collision at $\sqrt{s} = 13.6\ TeV$ using 29 fb^{-1} of data collected in 2022, relying on muon triggers

[public plots reference]

$Z \to \mu\mu$



$Z \to \mu\mu$



Very nice agreement between Data/MC

Summary

Run3 ⟶ new data (29 fb^{-1})

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new muon transverse momentum calibration needed!

New muon spectrometer alignment studies needed! (sample of cosmic ray tracks with toroid magnets turned off)

After correcting for the relative misalignment, new calibration studies for ID, MS and CB have been done!

New estimation for parameters correction have been obtained and validated via cross-check

Finally a data/MC comparison after applying all the corrections have been studied for the J/Ψ and Z events showing a very nice agreement and proving the effectiveness of the corrections!

Reconstruction, identification and isolation efficiency for different p_T range and Working Point have been presented using 29 fb^{-1}

ATLAS Combined Performance group provided the whole set of recommendations with the whole 2022 dataset and these are used in the analyses

Backup

Muon Momentum Calibration Cross-Check

The corrected combined momenta from ID and MS measurements $p_T^{Corr,ID-MS}$ is also obtained as:

$$p_T^{Corr,ID+MS} = f \cdot p_T^{Corr,ID} + (1-f) \cdot p_T^{Corr,MS}$$

The weight is calculated by solving the following equation:

$$p_T^{MC,CB} = f \cdot p_T^{MC,ID} + (1-f) \cdot p_T^{MC,MS}$$

ID corrections

Region	$\Delta r_1^{\mathrm{ID}}(\times 10^{-3})$	Δr_2^{ID} [TeV^{-1}]	$s_1^{\mathrm{ID}}(\times 10^{-3})$
$\lvert\eta\rvert < 1.05$	$4.4^{+3.0}_{-2.7}$	$0.12^{+0.03}_{-0.03}$	$-0.82^{+0.19}_{-0.06}$
$1.05 \leq \lvert\eta\rvert < 2.0$	$6.7^{+19.5}_{-3.1}$	$0.31^{+0.03}_{-0.03}$	$-0.86^{+0.36}_{-0.21}$
$\lvert\eta\rvert \geq 2.0$	$9.4^{+3.6}_{-5.3}$	$0.08^{+0.02}_{-0.02}$	$-0.45^{+1.19}_{-0.55}$

MS corrections

Region	Δr_0^{MS} [MeV]	$\Delta r_1^{\mathrm{MS}}(\times 10^{-3})$	Δr_2^{MS} [TeV^{-1}]	s_0^{MS} [MeV]	$s_1^{\mathrm{MS}}(\times 10^{-3})$
$\lvert\eta\rvert < 1.05$ (large)	71^{+41}_{-10}	$13.5^{+3.1}_{-2.6}$	$0.11^{+0.02}_{-0.02}$	-27^{+18}_{-14}	$2.33^{+0.61}_{-0.61}$
$\lvert\eta\rvert < 1.05$ (small)	63^{+35}_{-23}	$17.2^{+2.3}_{-3.6}$	$0.12^{+0.02}_{-0.02}$	-18^{+14}_{-24}	$-1.51^{+1.15}_{-0.45}$
$1.05 \leq \lvert\eta\rvert < 2.0$ (large)	42^{+401}_{-53}	$26.7^{+19.5}_{-2.8}$	$0.14^{+0.02}_{-0.02}$	-29^{+43}_{-57}	$-0.9^{+2.8}_{-1.9}$
$1.05 \leq \lvert\eta\rvert < 2.0$ (small)	44^{+437}_{-59}	$29.2^{+8.2}_{-1.5}$	$0.18^{+0.02}_{-0.02}$	-28^{+39}_{-43}	$-1.3^{+2.0}_{-1.6}$
$\lvert\eta\rvert \geq 2.0$ (large)	61^{+48}_{-27}	$16.8^{+3.2}_{-4.3}$	$0.11^{+0.02}_{-0.02}$	-1^{+43}_{-29}	$1.7^{+1.3}_{-1.4}$
$\lvert\eta\rvert \geq 2.0$ (small)	47^{+32}_{-40}	$17.8^{+1}_{-1.9}$	$0.16^{+0.02}_{-0.02}$	-8^{+14}_{-12}	$1.94^{+0.76}_{-0.54}$