Muon Performance Study

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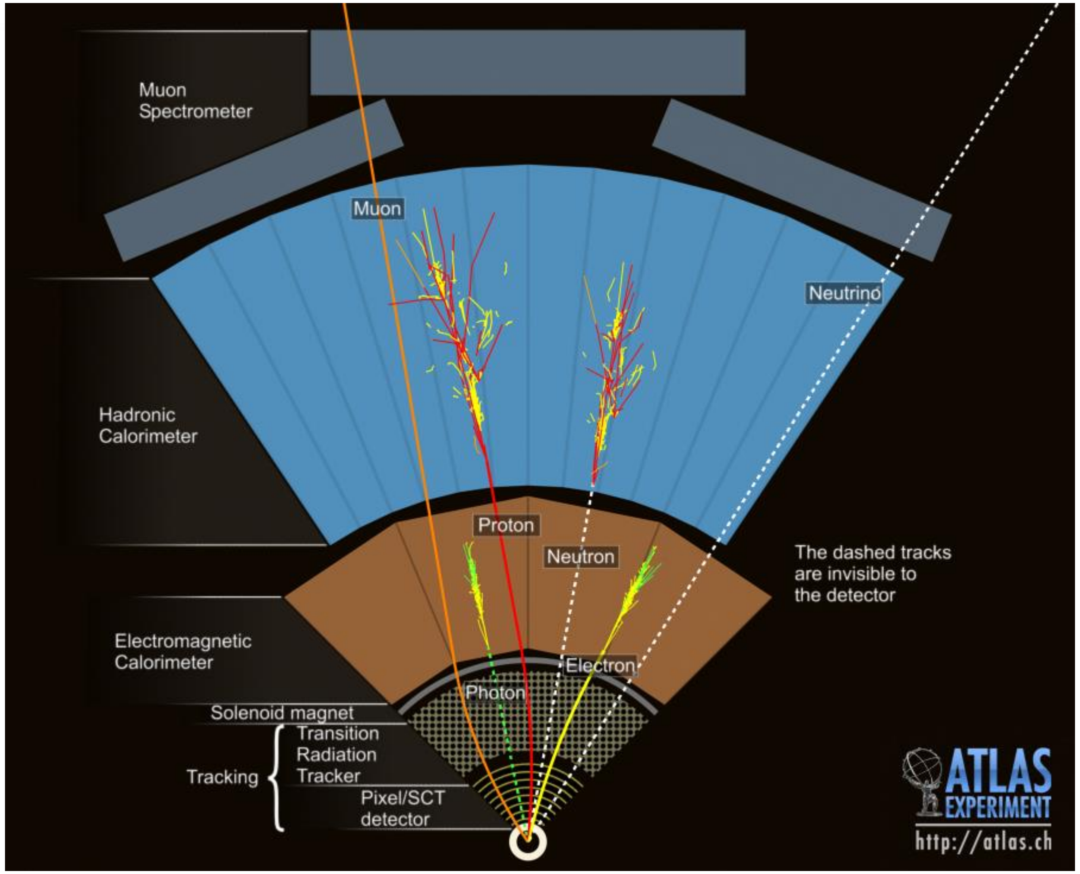
The Detector and Alignment

- Inner detector
- Muon spectrometer – muons travel much further than hadrons
- Misalignment in ID and MS causes issue, but it can be measured through ρ'
  - $\rho' = \frac{P_T^{ID} - P_T^{ME}}{P_T^{CB}}$ where ID is inner detector, ME is muon extrapolated to the inner detector, and CB is combined muons.
  - Better alignment -> less mismatch between ID and ME $\boldsymbol{P_T}$ -> smaller ρ.

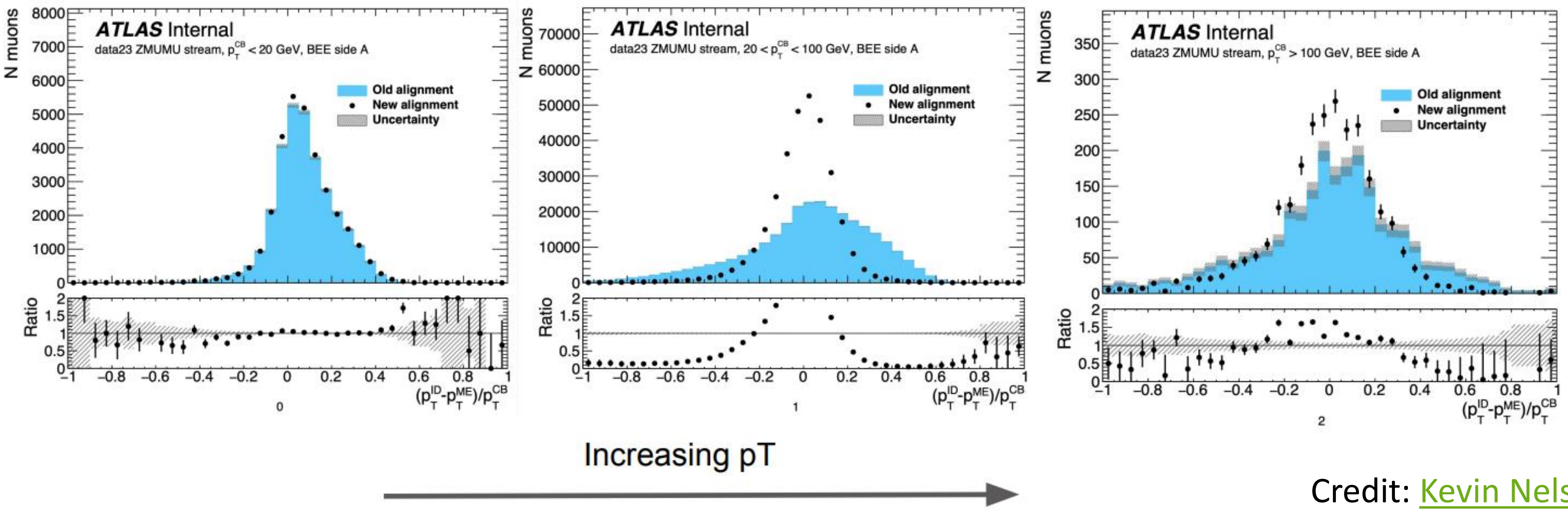


Part 1 – 2024 Alignment

BEE Side A

Data23 $Z\mu\mu$ Stream

Kevin showed this at muon week, studying $\boldsymbol{P_T}$ imbalance with latest updates to alignment conditions, which are now deployed at tier0



Credit: Kevin Nelson

Data 24 Study (Main Stream)

	Old Alignment	New Alignment
Tag	<= f1456	>= f1462
Run No.	<= 00474271	>= 00474441
Condition tag	CONDBR2-BLKPA-2024-02	CONDBR2_BLKPA_2024_03
Run Selected	data24_13p6TeV.00**473968**.physics_Main.deriv.DAOD_PHYS.**f1450**_m2248_p6142_tid38351515_00	data24_13p6TeV.00**474572**.physics_Main.deriv.DAOD_PHYS.**f1462**_m2248_p6142

Cuts Applied:

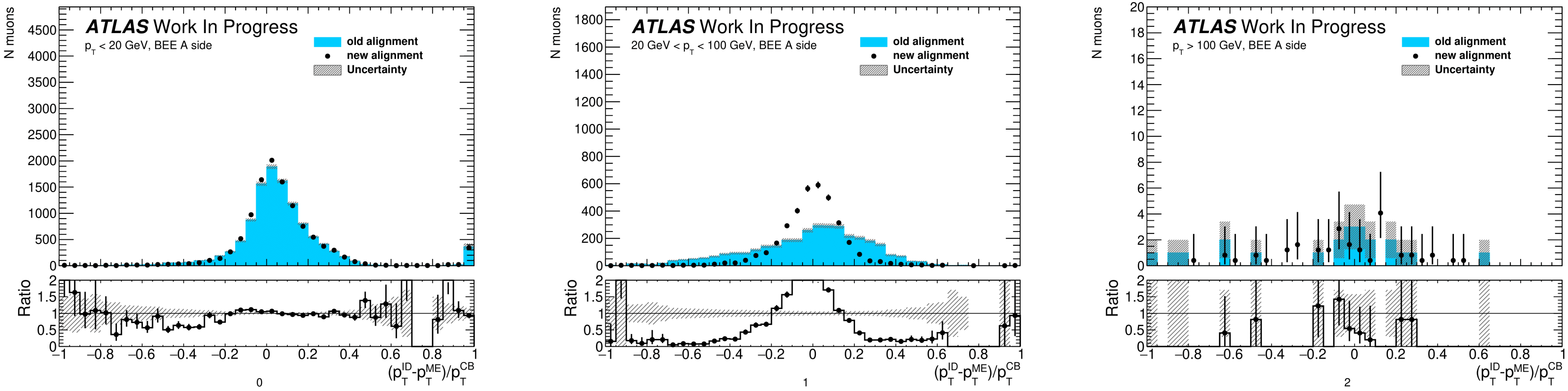
CB, Loose

BEE 1.44 < $|\eta|$ < 1.682 $|\varphi|$ in (0.301, 0.478), (1.086, 1.263), (1.872, 2.049), (2.657, 2.834)

BIS78 1.05 < $|\eta|$ < 1.3 $|\varphi|$ in (0.21, 0.57), (1, 1.33), (1.78, 2.14), (2.57, 2.93)

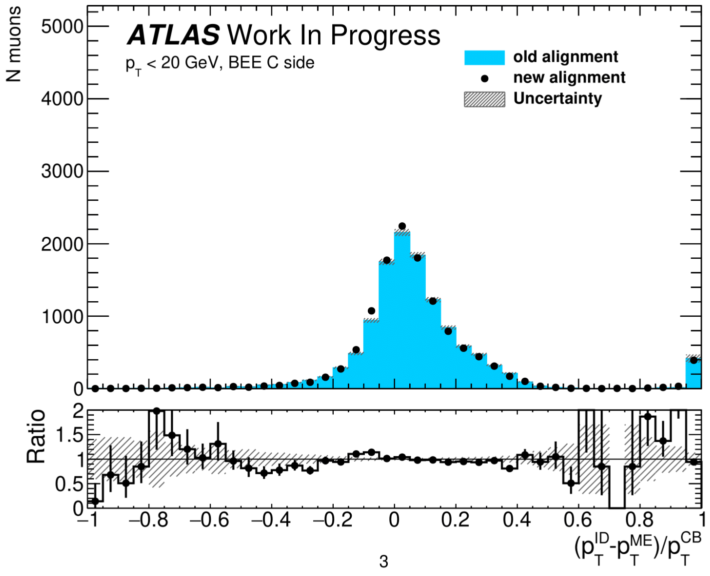
$\boldsymbol{P_T}$ < 20, (20, 100), and >100

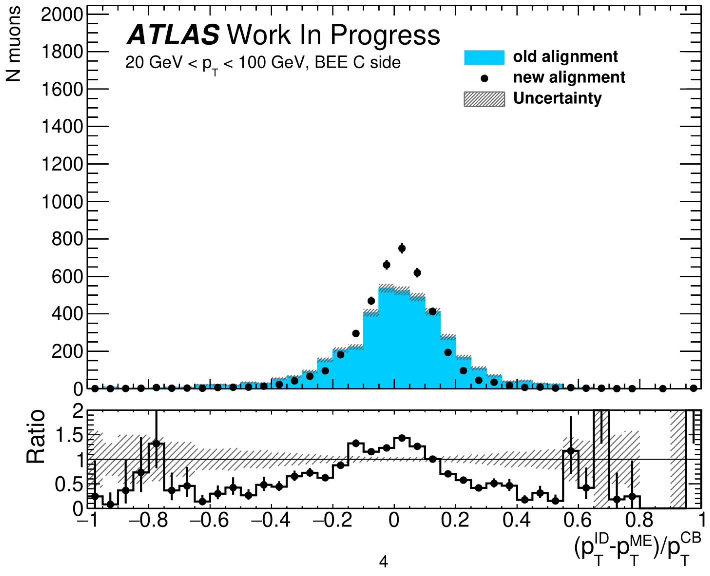
BEE Side A

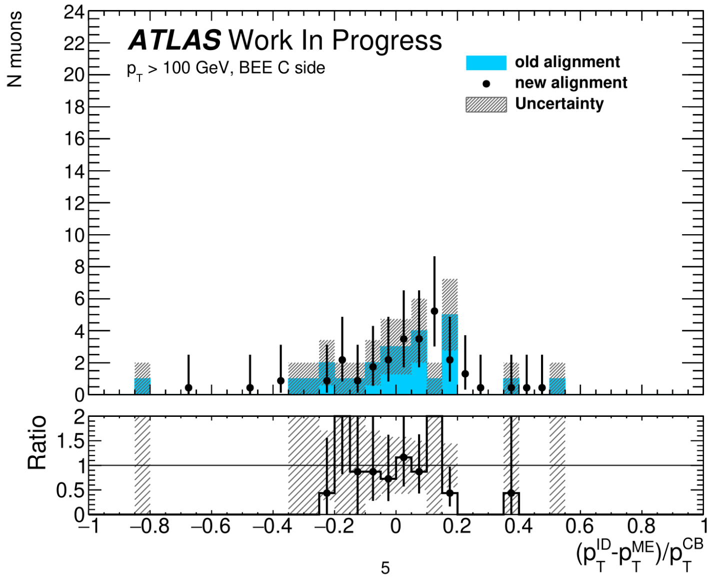


Improvement for 20 < P_T < 100 GeV. Not much improvement for P_T < 20 GeV due to lower $P_T{}^{ME}$ dependence. Not enough data for P_T > 100 GeV

BEE Side C

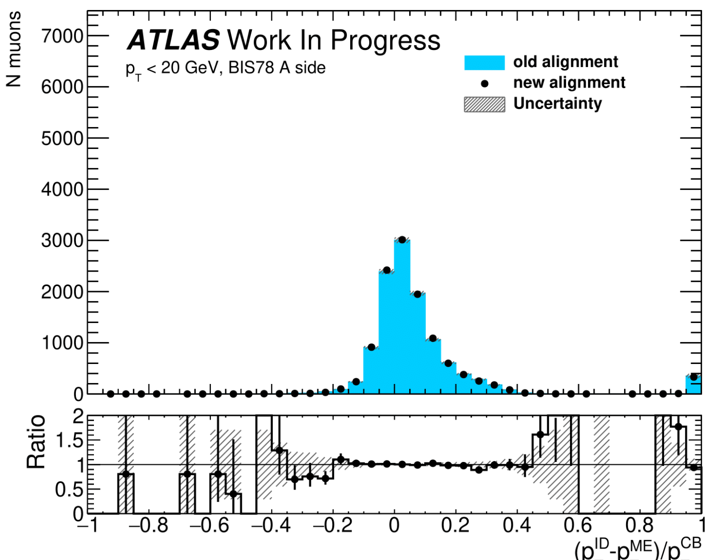






Similar changes as BEE side A

BIS78 Side A



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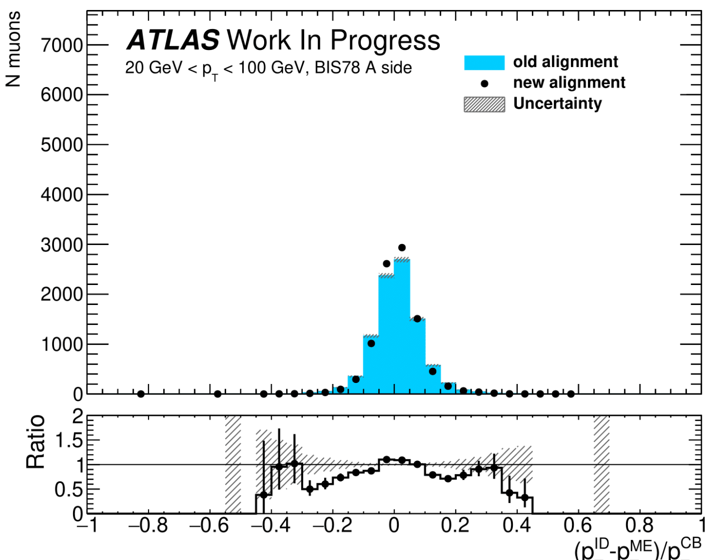

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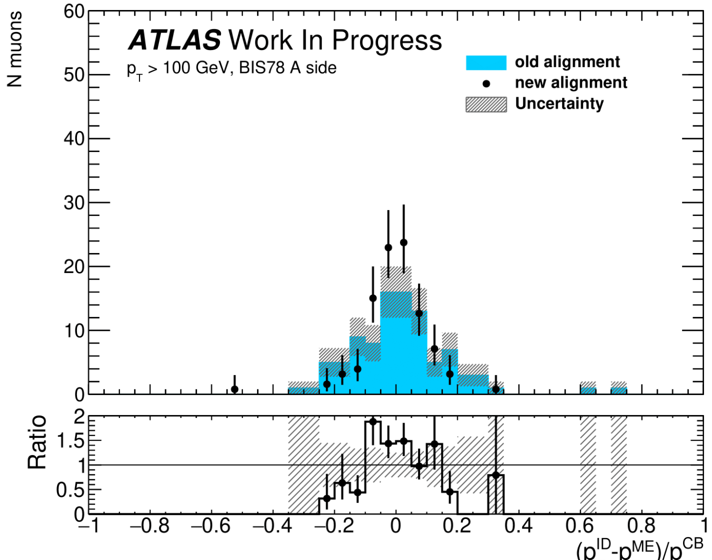

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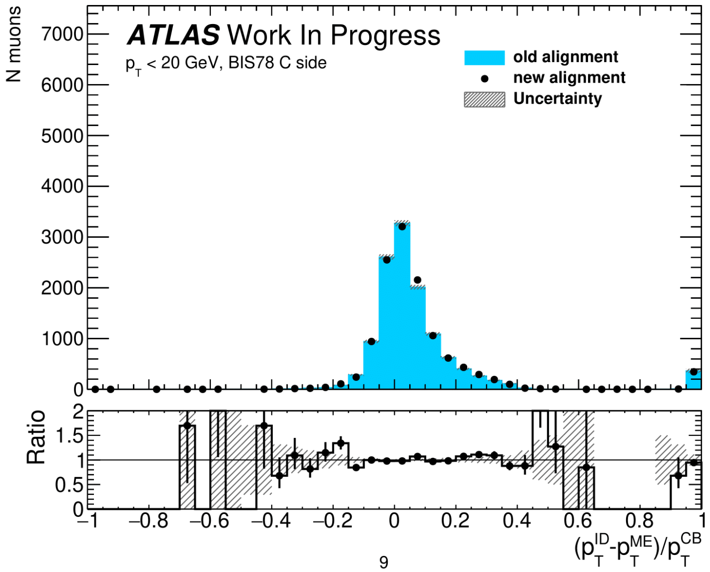
Small improvement in 20 < P_T < 100 GeV. Not enough data for P_T > 100 GeV still but seems to have improvement.

BIS78 Side C



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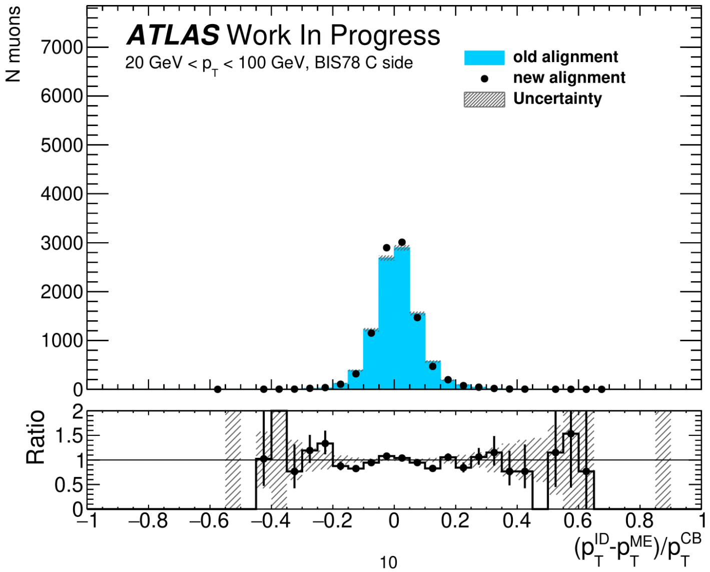

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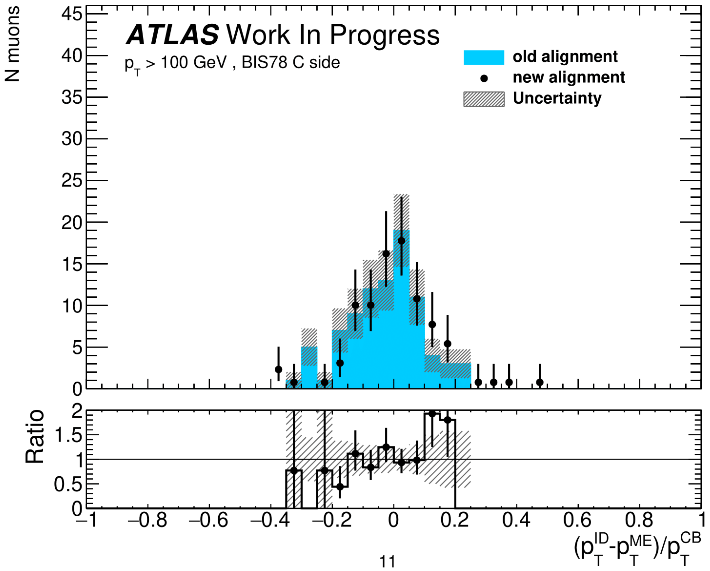

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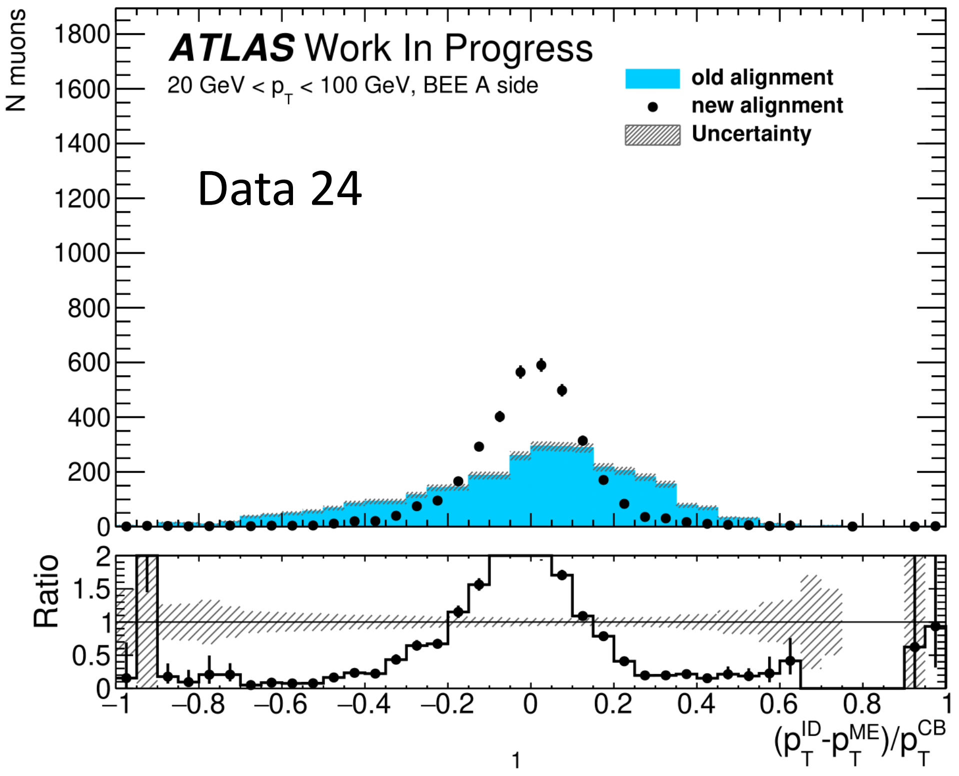
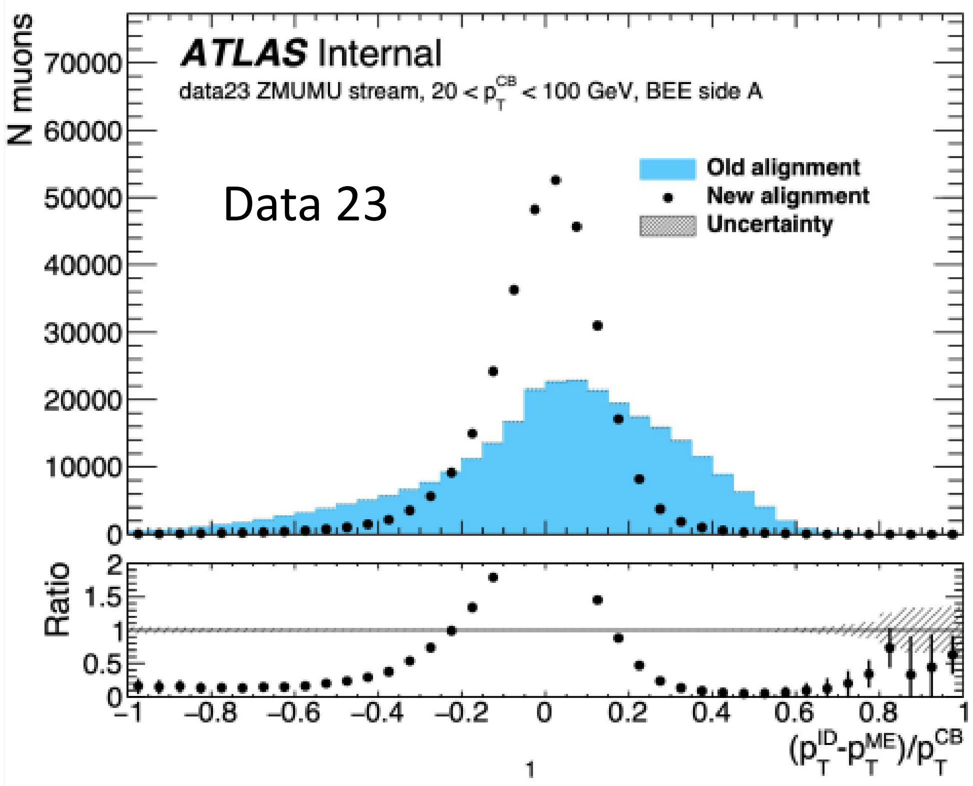
Little change

Comparison



ATLAS Work In Progress
20 GeV < p_T < 100 GeV, BEE A side
old alignment
new alignment
Uncertainty
Data 24
N muons
Ratio
$(p_T^{ID}-p_T^{ME})/p_T^{CB}$
1

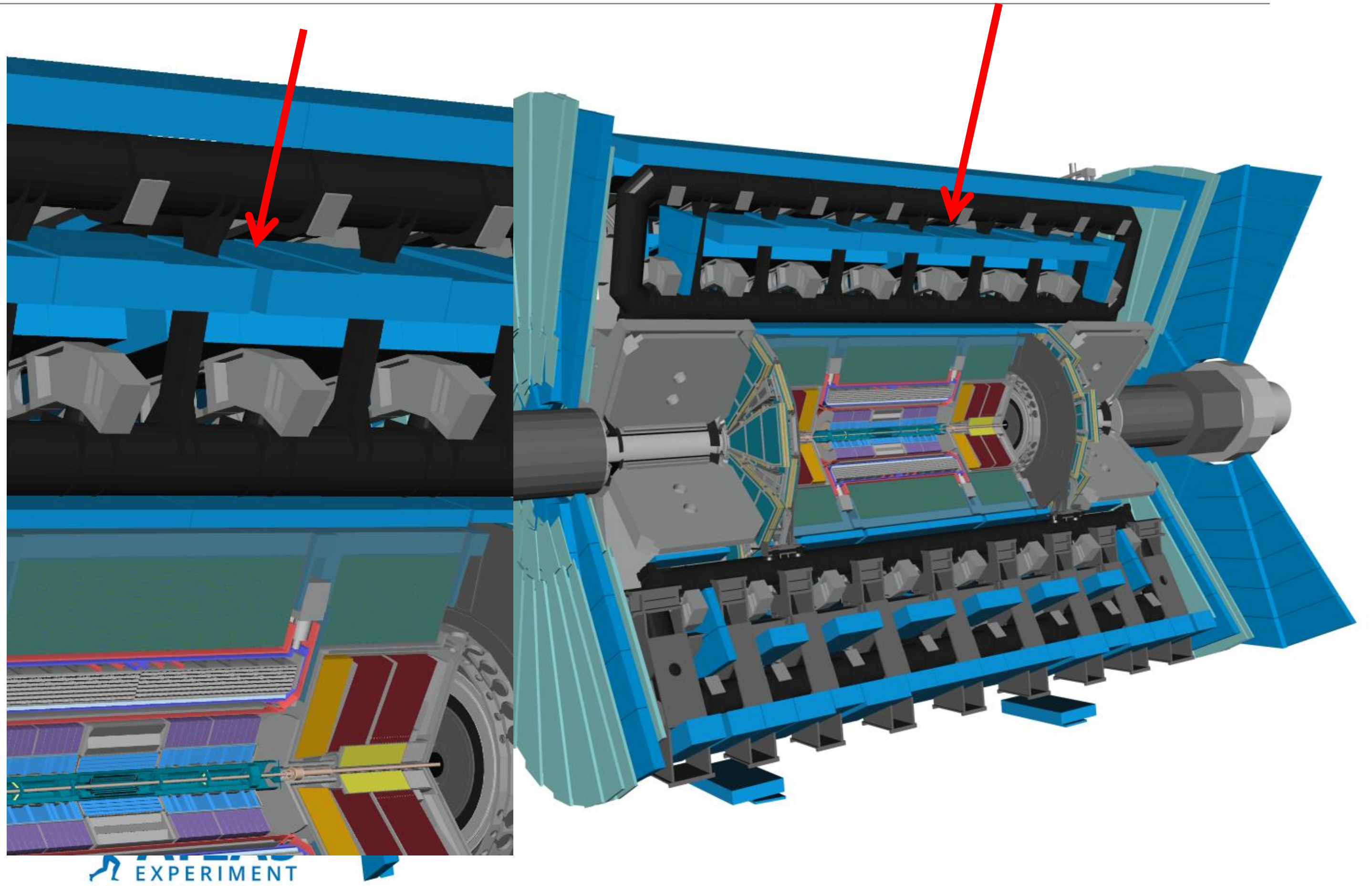


ATLAS Internal
data23 ZMUMU stream, 20 < p_T^{CB} < 100 GeV, BEE side A
Old alignment
New alignment
Uncertainty
Data 23
N muons
Ratio
$(p_T^{ID}-p_T^{ME})/p_T^{CB}$
1

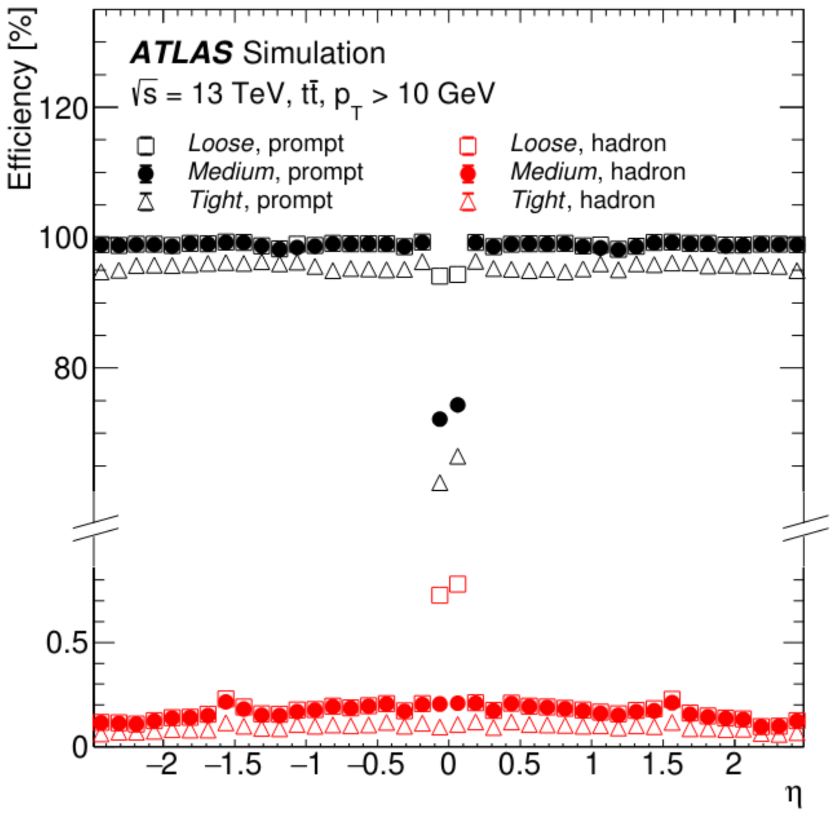
Part 2 – Tight WP Optimization

Muon Efficiency

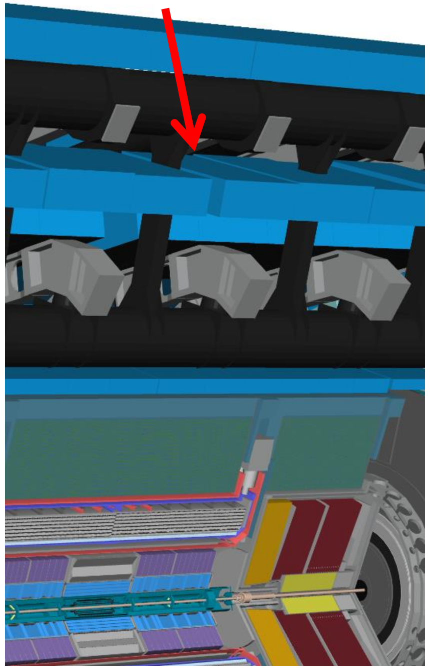
- There is a gap at $|\eta| < 0.1$ in the muon spectrometer for the wires
- In this region, we can only reconstruct muons using the inner detector, which greatly reduces muon efficiency



Muon Working Point



- Efficiency for prompt muons drop (especially tight WP), and even worse, fake muons (light flavor) increase
- It has been the goal for the past 16 years to increase the efficiency of this region.
- We want better signal efficiency or lower background.



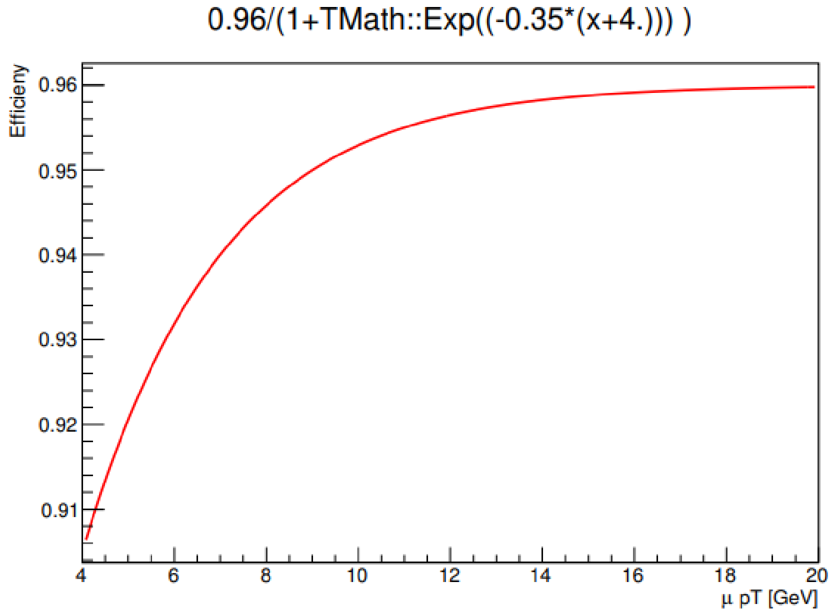
Optimizing Tight WP - ρ and $\mathrm{q/p}$ signif

Tight WP definitions:

- CB, precision layers > 1, medium WP, reduced $\boldsymbol{\chi}^2$ < 8,
- 2D cut on ρ and $\mathrm{q/p}$ signif with discrete $\boldsymbol{P_T}$ bins such that prompt muon efficiency is above $0.96/(1 + e^{-0.35*(\boldsymbol{P_T}+4)})$ while maximizing background rejection
  - The study uses discrete $\boldsymbol{P_T}$ intervals so the optimized ρ and $\mathrm{q/p}$ signif cuts are applicable to other processes with different $\boldsymbol{P_T}$ distribution
  - We focus on light flavor decay rejection because these are not muons from heavy particles or high energy process of interest. Therefore, light flavor ρ distribution is a lot different from prompt (t) and nonprompt (τ and b, c jets).

Motivation:

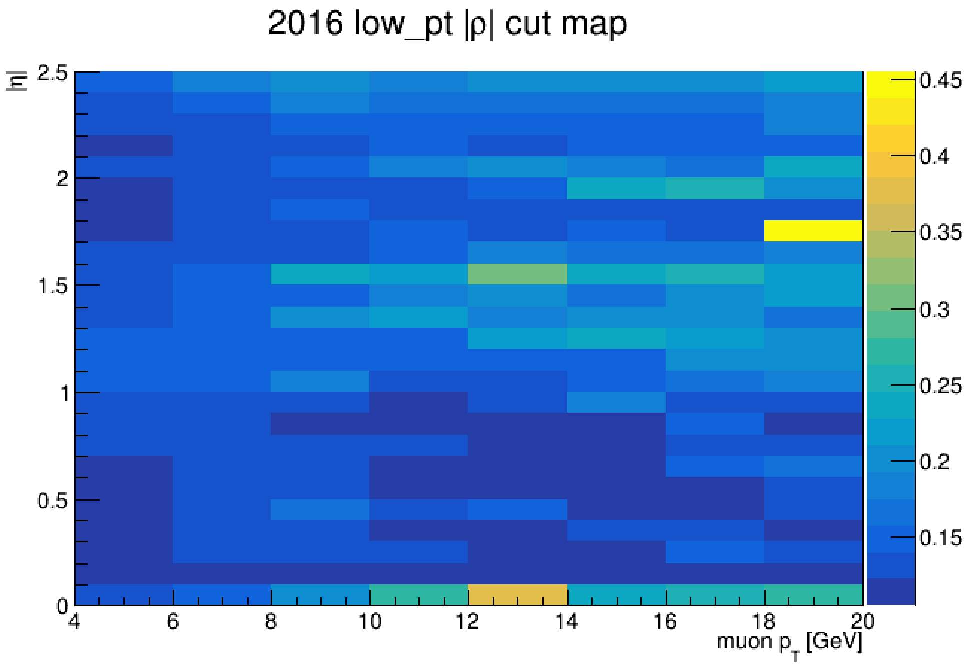
- Working on ρ and $\mathrm{q/p}$ signif cuts because this study was last done with 2016 data. Pileup and the detector has changed significant since then.



From WP internal note

Previous ρ and $\mathbf{q/p}$ Cut Study

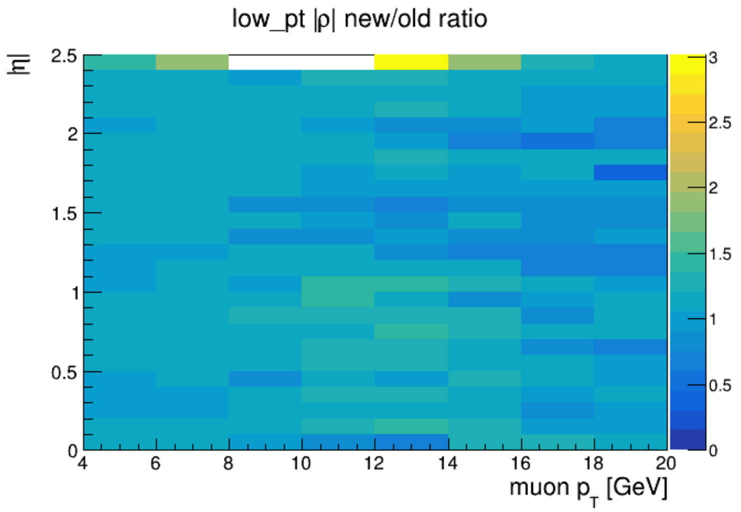
- Previous study performed the 2D cut on ρ and q/p signif in the low $\boldsymbol{P_T}$ region, and ρ cut only in medium and high $\boldsymbol{P_T}$.
- After the 2D cut in the low $\boldsymbol{P_T}$ region, the ρ and q/p signif cut were plotted individually, though dependent of each other. On the right is the low $\boldsymbol{P_T}$ ρ cut map.
- The x axis is $\boldsymbol{P_T}$, and the y axis is η . The shades identify the ρ cut resulting in ~96% of prompt muon signals in each $\boldsymbol{P_T}$, η region.

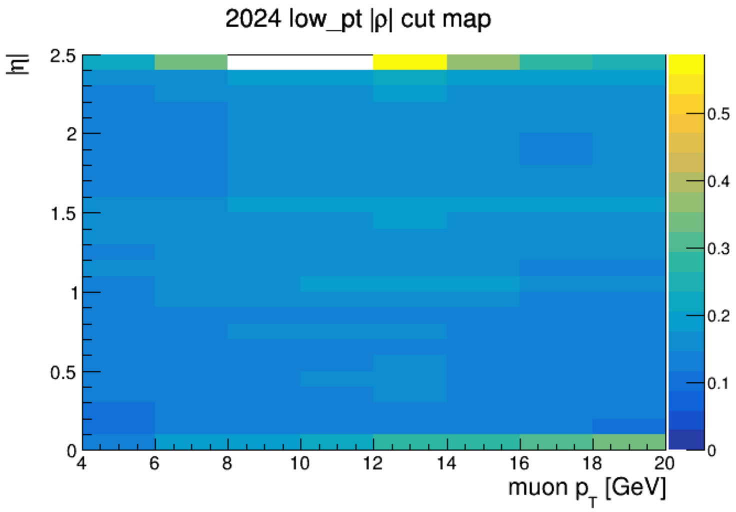


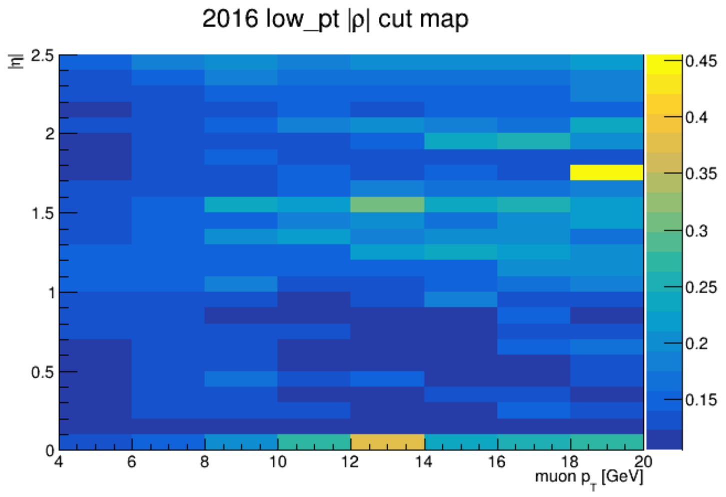
Method

- Dataset used: MC23d ttbar dilepton
  - mc23_13p6TeV.601230.PhPy8EG_A14_ttbar_hdamp258p75_dil.recon.AOD.e8514_s4159_r15224
- We are starting on 1D ρ and $\mathrm{q/p}$ signif cuts resulting in 96% signal efficiency without considering background rejection.
- Prompt muons identified through the muonTruthIFFType variable
- Nonprompt is from τ and b, c jets. Fakes are from light flavor (e.g. pion).
- We generated a 3D histogram of $\boldsymbol{P_T}$, η, ρ
  - For each $\boldsymbol{P_T}$, η bin, I integrated ρ and stored the ρ position resulted in 96% prompt muons in the bin

Low P_T - ρ Map

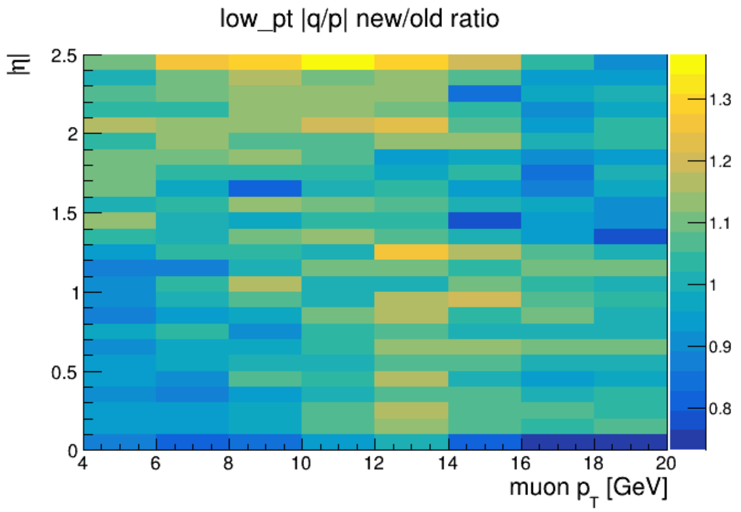


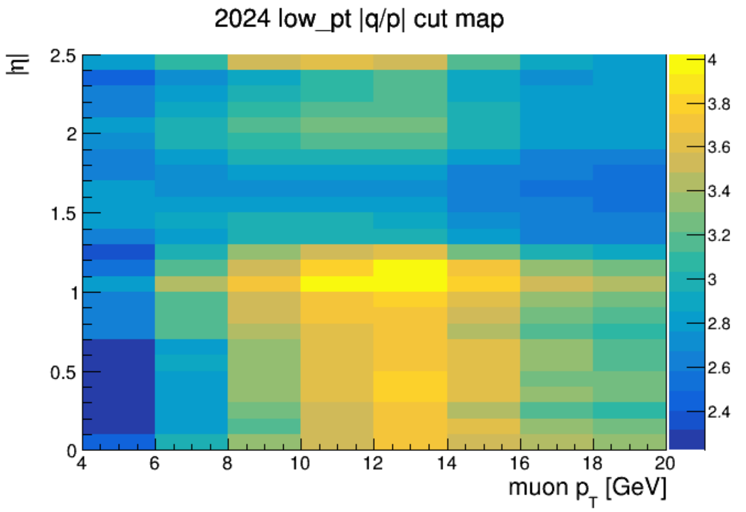


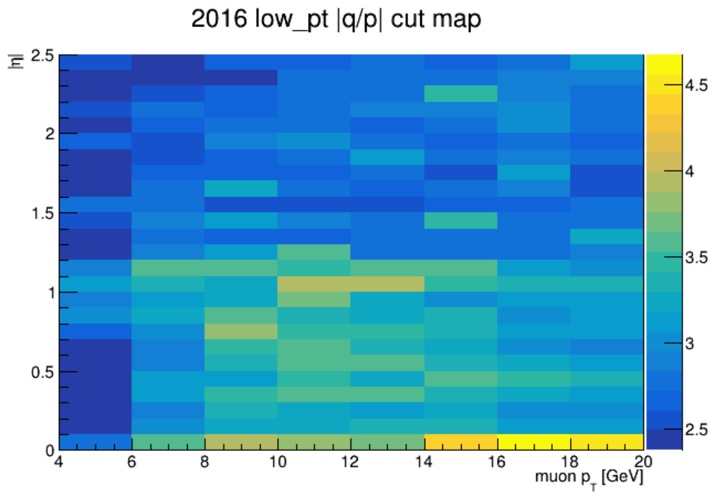


- Got similar results as the 2016 study

Low P_T - q/p significance Map

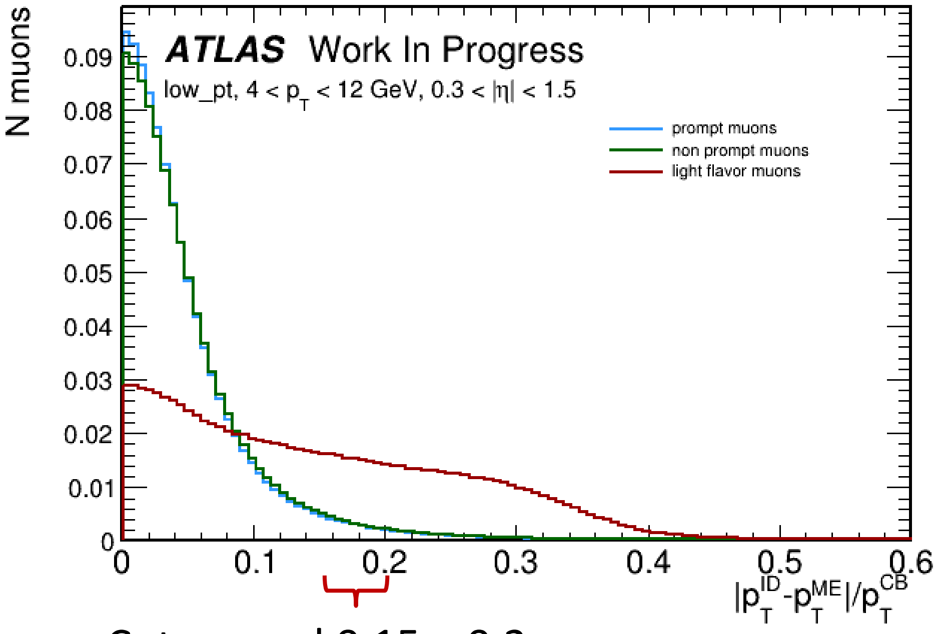




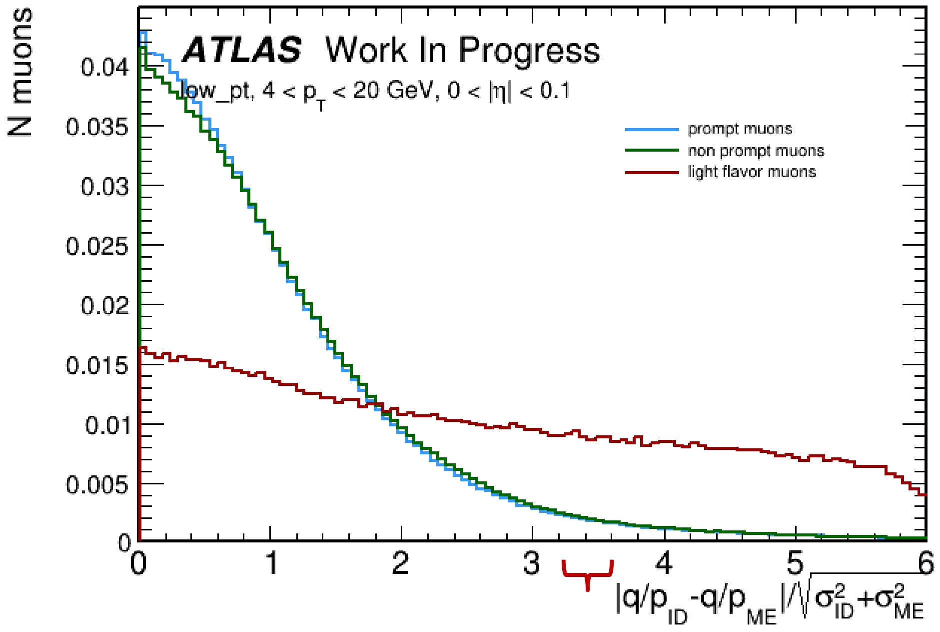


- There isn't a difference in $|\eta| < 0.1$ compared with $|\eta| > 0.1$ in the 2024 study, in contrast with the 2016 study.
- We observe pattern across P_T regions. Highest q/p signif cut in the 10 – 16 GeV region.
- We also observe difference between $|\eta| < 1.3$ and $|\eta| > 1.3$.

ρ and q/p significance with η, P_T cut

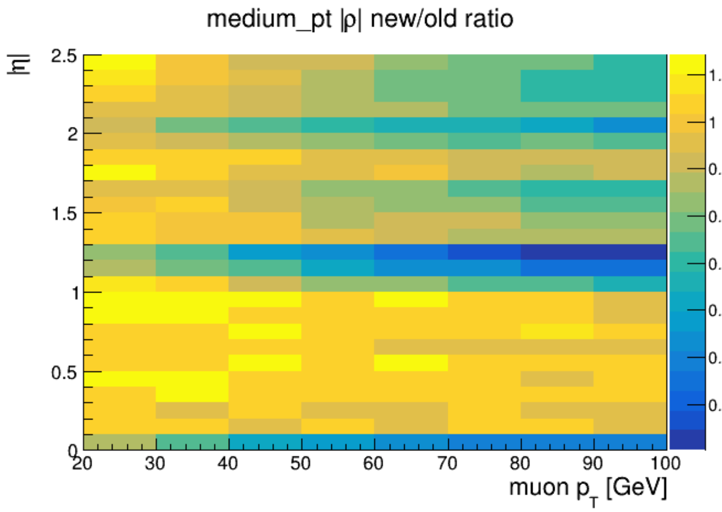


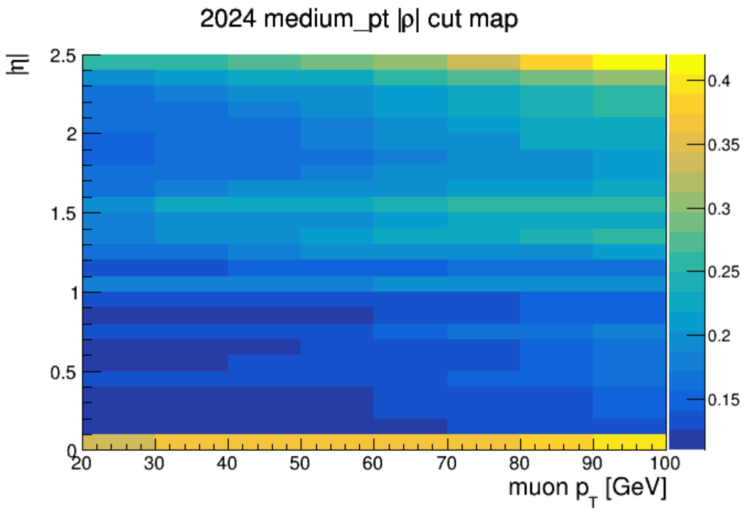
Cut around 0.15 – 0.2

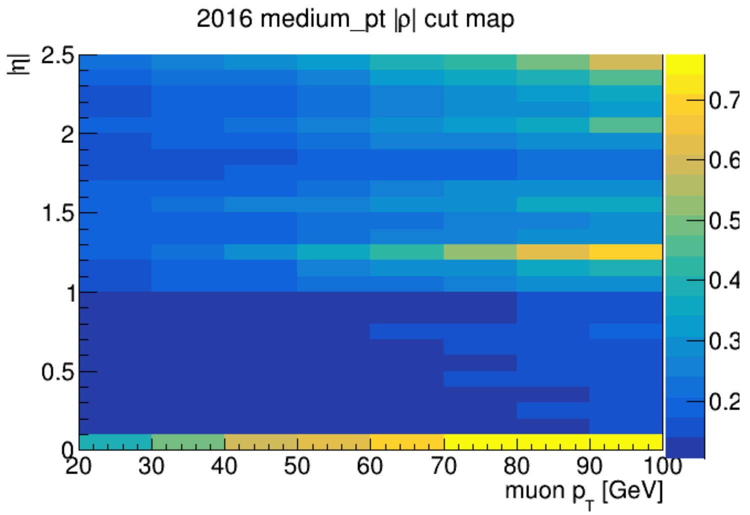


Cut around 3.2 – 3.6

Medium $\boldsymbol{P_T}$ - ρ Map

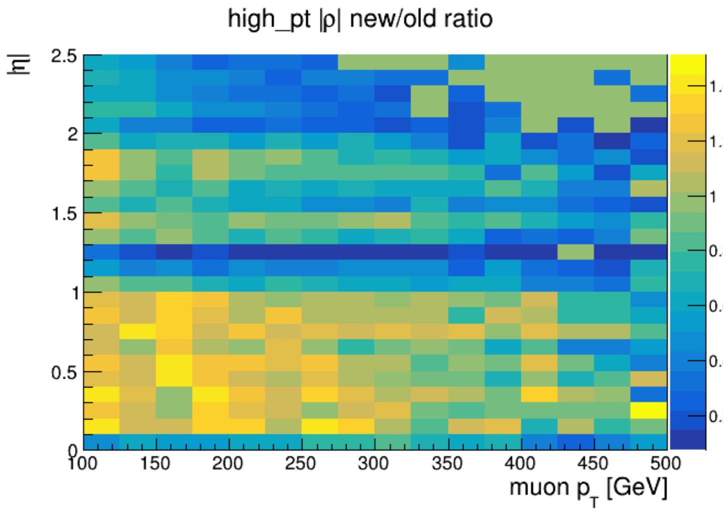


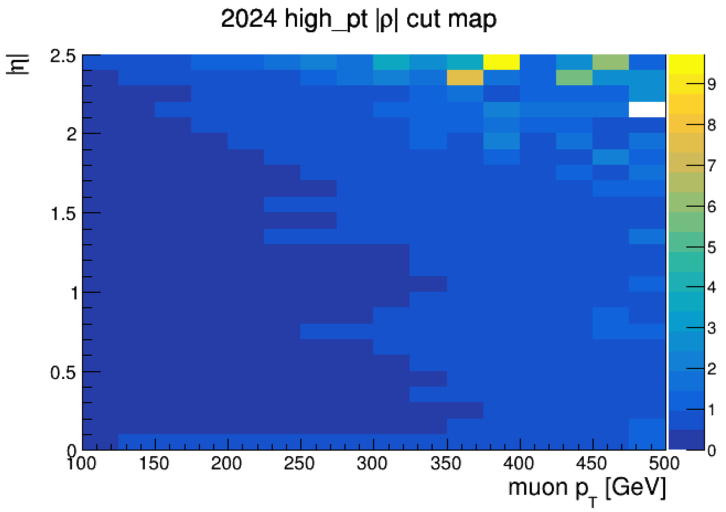


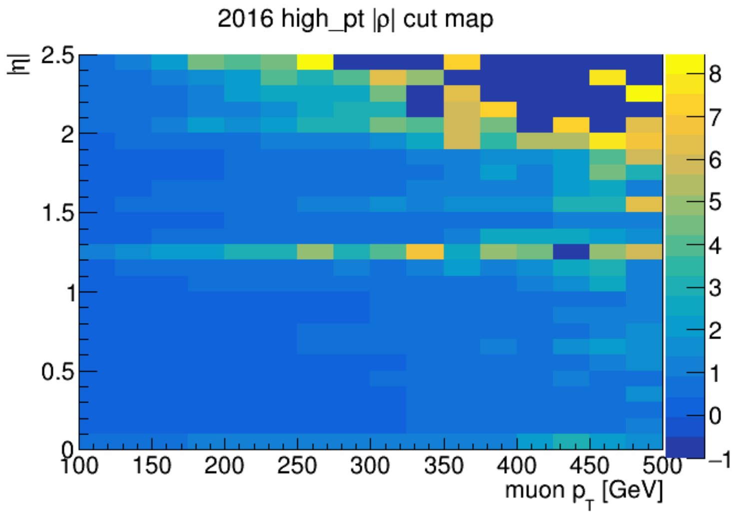


- The ρ cuts in the $1.1 < |\eta| < 1.3$ region are lower compared with the 2016 study due to a new chamber.
- The cuts at region $|\eta| < 0.1$ is also lower compared with the 2016 study. However, compared with $|\eta| > 0.1$ region, the ρ cut is significantly higher in both studies.

High $\boldsymbol{P_T}$ - ρ Map





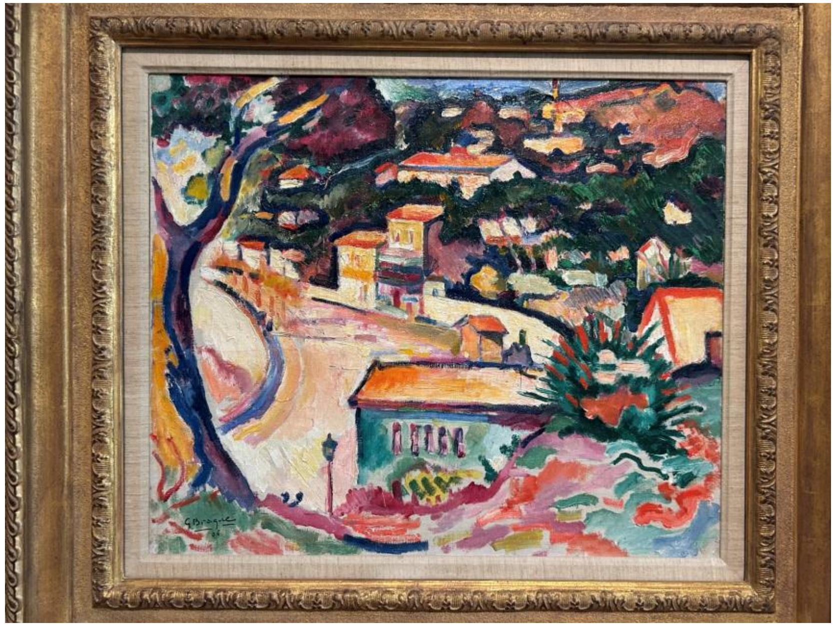


- Smaller $\boldsymbol{P_T}$ binning is used for high $\boldsymbol{P_T}$.
- The old plots used -1 for underflowing bins. For these values in the ratio plot, $|\eta|$ is set to 1.
- In the region 1.1 < $|\eta|$ < 1.3, the ρ cuts are also lower compared with the 2016 plot.

Next Steps

- Compare the efficiency of the 2024 1D ρ and $\mathrm{q/p}$ signif cut with the 2016 cuts.
- If necessary, complete 2D optimization for low pt regime.
- Validate and release WP recommendations using mcp-pipeline code (Developed by Kevin).

ETH main building



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