

Tight Muon Reconstruction Efficiency

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Overview

- Two methods can be used to compute reconstruction efficiency of muons of a specific quality (tight, medium, or loose, etc.).
 - Tag and probe method (see detail in slide 4-5) that approximates muon reconstruction efficiency $\varepsilon(\mu)$ using muon reconstruction efficiency with respect to inner detector $\varepsilon(\mu|ID)$, corrected by inner detector efficiency with respect to muon spectrometer $\varepsilon(ID|MS)$.
 - $\varepsilon(\mu) = \varepsilon(\mu|ID) \times \varepsilon(ID) \cong \varepsilon(\mu|ID) \times \varepsilon(ID|MS)$
 - Truth match method that finds how many out of all truth muons have a reconstructed muon (of a specific quality, for example, tight or medium) located close to it in the same event.
 - Distance between truth muon and reco muon (dR) smaller than 0.05
 - This method is only applicable to MC.
- The results from the two methods do not agree for tight muon in PbPb MC (pp overlay), with the efficiency by truth match method being ~30% lower than T&P.
 - The efficiency is dependent on centrality, pT and eta, but the difference cannot be accounted by these factors.
 - The efficiency for loose and medium muons using truth match method is also low in PbPb MC.
- The results from the two methods agree within ~2% for tight muon in pp MC.
- The results from the two methods agree within ~3% for medium muon in pp MC.
- Is there a problem with the tracks in overlay? Is there a work-around?

Plan and Progresses

- Verify that the methods work fine in pp MC
 - Tight muon efficiencies agree within $\sim 2\%$. (see slide 7)
 - Medium muon efficiencies agree within $\sim 3\%$. (see slide 14)
 - Will calculate for muon reco efficiency at data to use as a systematics.
 - There was a mistake in the code which filters out many data, this has been fixed.
 - With narrowing range of fitting/better tuning parameter now the fitting works better (visually good since we care more about peak matching, chi-square $0 \sim 5$), and scale factors are in better agreement. (see slide 13)
 - Medium are done, but not shown today as they're being tuned for best results.
 - Systematics by negative and positive charges are smoother now from point to point, and they're now smaller than systematics by using different fitting model.
- Currently the two methods for $\varepsilon(\mu)$ do not agree in overlay, what can we do?
 - Try figure out which method gives correct answer (Either? Neither?)
 - Separate the two parts in T&P method: $(\varepsilon(\text{ID}|\text{MS})_{\text{MC}}$ and $\varepsilon(\mu|\text{ID})$)
 - A suspicion: there is a problem with $(\varepsilon(\text{ID}|\text{MS})_{\text{MC}}$
 - Check whether the $\varepsilon(\text{ID}|\text{MS})_{\text{MC}}$ agrees with efficiency of ID by directly matching available ID track to truth muon. (slide 7)
 - Assuming $\varepsilon(\text{ID}|\text{MS})_{\text{MC}}$ is the problem, a potential workaround to get $\varepsilon(\mu)$ in data (given that data has low statistics in MS):
 - Get $\varepsilon(\mu|\text{ID})_{\text{data}}$ (assumed to be fine)
 - Get $\varepsilon(\mu|\text{ID})$ in data and $\varepsilon(\mu|\text{ID})$ in MC, these are the un-corrected muon efficiency, both assumed to be fine with respect to ID, and calculate scale factor (SF)

Tag & Probe Method

- Used Tag & Probe method to calculate the reconstruction efficiency of tight muon.

$$\varepsilon(\mu) = \varepsilon(\mu|\text{ID}) \times \varepsilon(\text{ID}) \cong \varepsilon(\mu|\text{ID}) \times \varepsilon(\text{ID}|\text{MS})$$

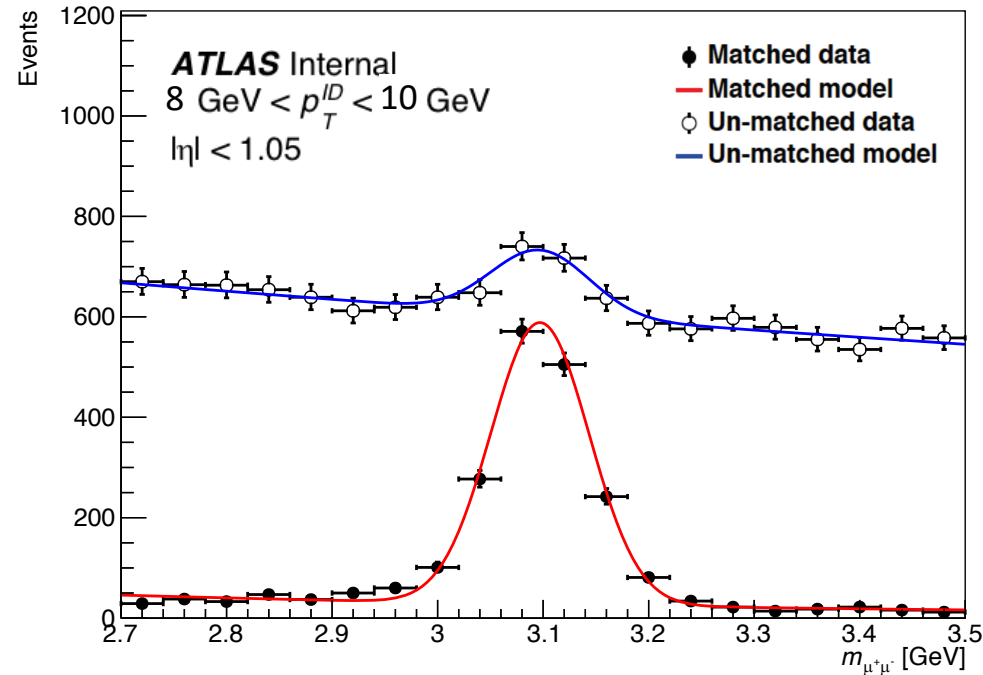
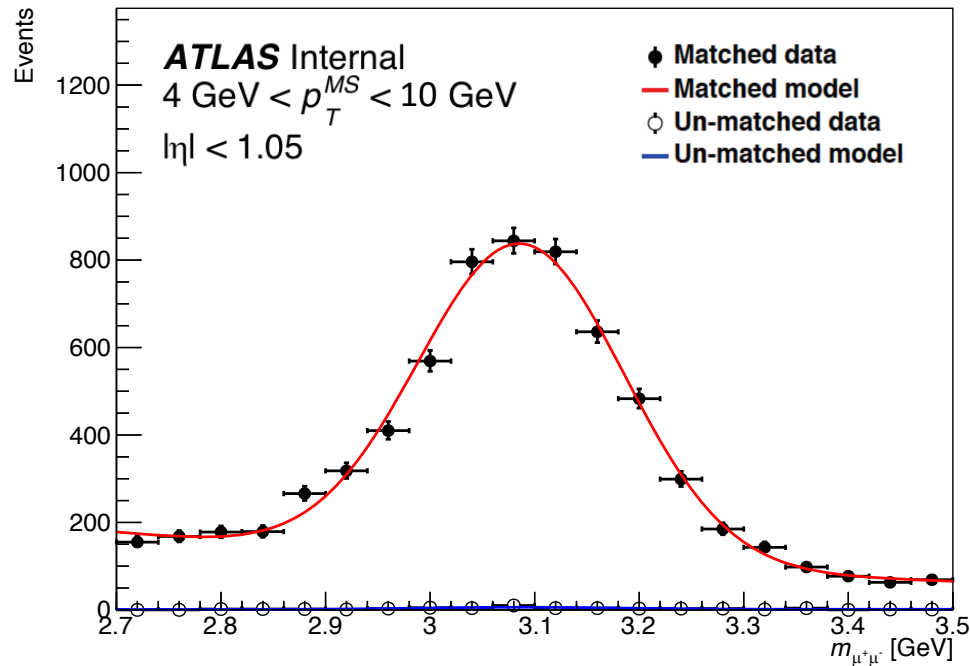
- $\varepsilon(\mu|\text{ID})$ Muon Reconstruction efficiency with respect to inner detector.
- $\varepsilon(\text{ID}|\text{MS})$ Inner Detector efficiency with respect to muon chamber.
- Event Selection:
 - Trigger mu3 || mu8 || mu10
 - GRL
 - At least 1 primary vertex
- $\varepsilon(\text{ID}|\text{MS})$ match: MS track with an ID track $dR < 0.2$
- $\varepsilon(\mu|\text{ID})$ match: ID track with a reconstructed muon $dR < 0.01$
- Probe tracks Selection:
 - Opposite charge with tag
 - ID tracks: Muon ID Selections (No TRT)
 - MS tracks: No Selections
- Invariant mass window
 - for data: J/ψ 2.6 -3.6 GeV
 - for mc: J/ψ 2.6 -3.6 GeV
- Data: 2018 Pb-Pb Hard Probe Stream Data at 5.02 TeV
- Monte Carlo: Pythia8B with Prompt J/ψ to Muons with Heavy Ion Overlay.
mc16_5TeV:mc16_5TeV.300000.Pythia8BPhotospp_A14_CTEQ6L1_pp_Jpsimu2p5mu2p5.merge.AOD.e4973_d1521_r11472_r11217

Tag & Probe Fitting

- Efficiency centroid values extraction
 - Invariant mass of matched and unmatched samples are fitted simultaneously (signal has same mean and sigma for matched and unmatched).
 - $N_{\text{match}} = N_{\text{tot}} * \varepsilon * \text{Sig}(\text{mass}) + N_{\text{bkg1}} * \text{Bkg1}(\text{mass})$
 - $N_{\text{unmatch}} = N_{\text{tot}} * (1-\varepsilon) * \text{Sig}(\text{mass}) + N_{\text{bkg2}} * \text{Bkg2}(\text{mass})$
 - The fitting outputs N_{tot} and ε .

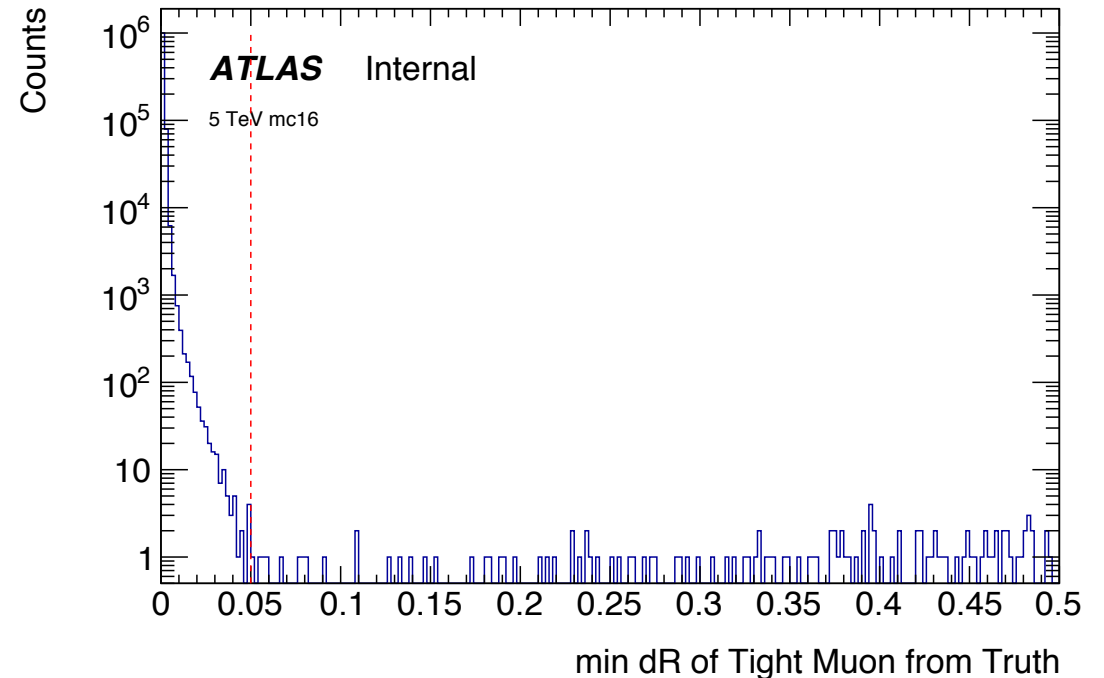
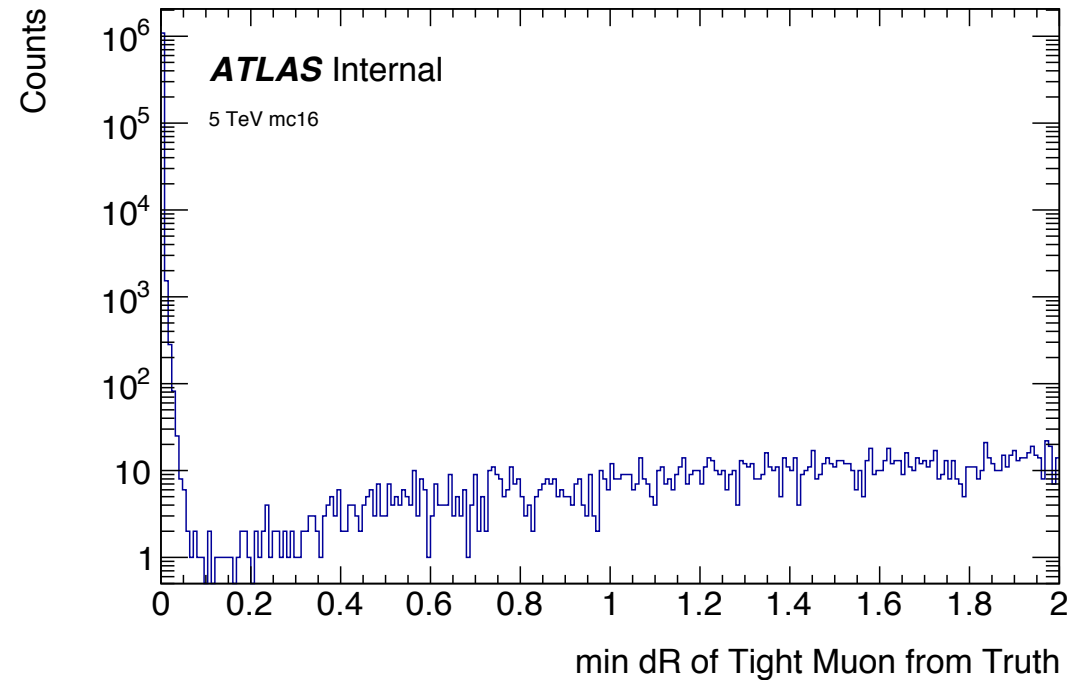
Sig(mass): Gaus

Bkg(mass): Exponential

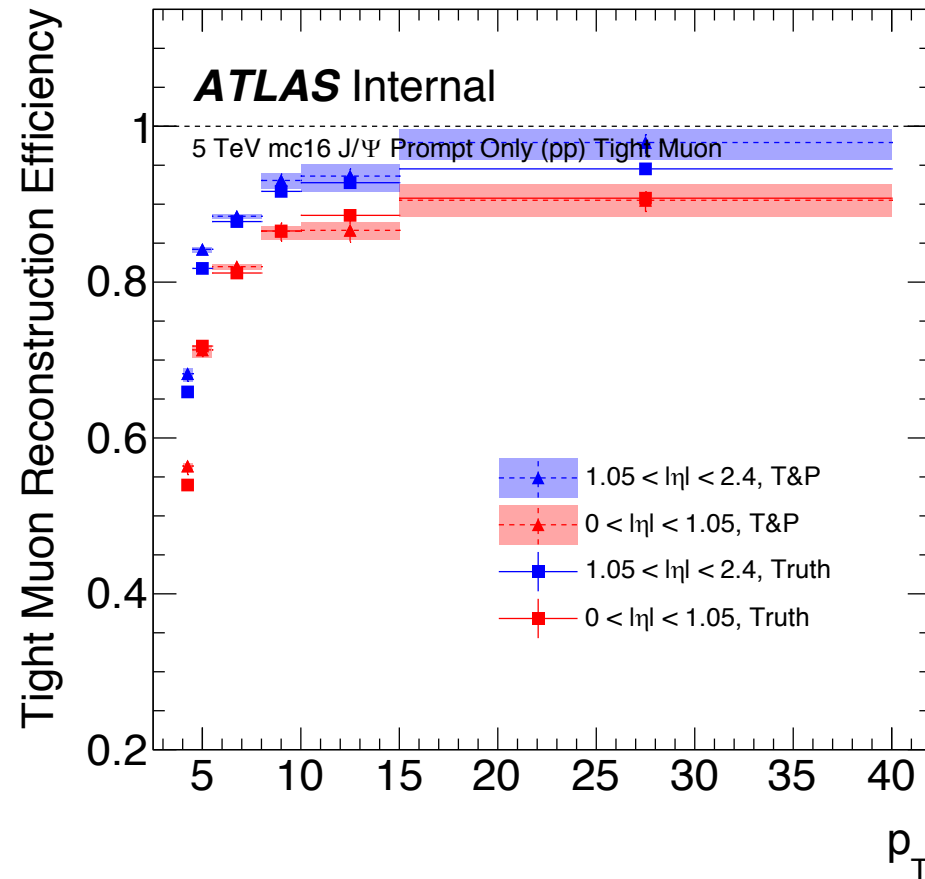
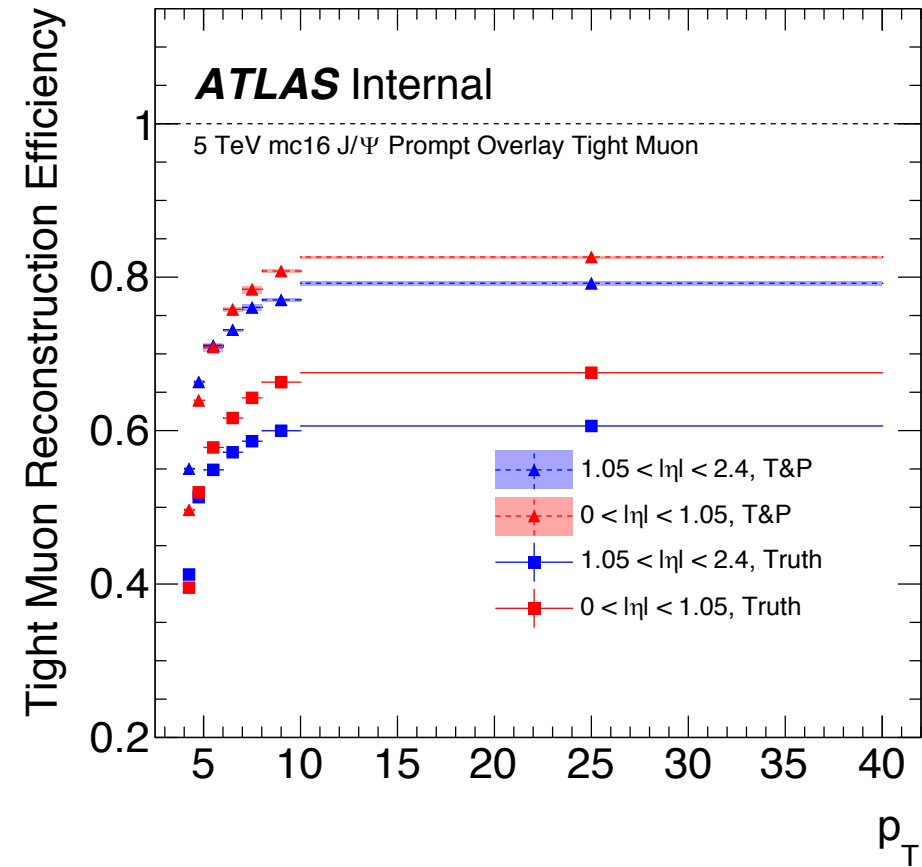


Truth Matching

- For each truth muon in an event, loop through each of all reconstructed muons of a certain quality (e.g., tight), find its distance to the truth muon, and record the closest distance for each truth muon. All overflow distances are set to 2.
- Define a cut based on the shape of curve.
- Shown on the right are the distribution of closest distances in 5 TeV mc16 J/Psi Prompt pp, and 0.05 is the threshold set for real matching from random matching.

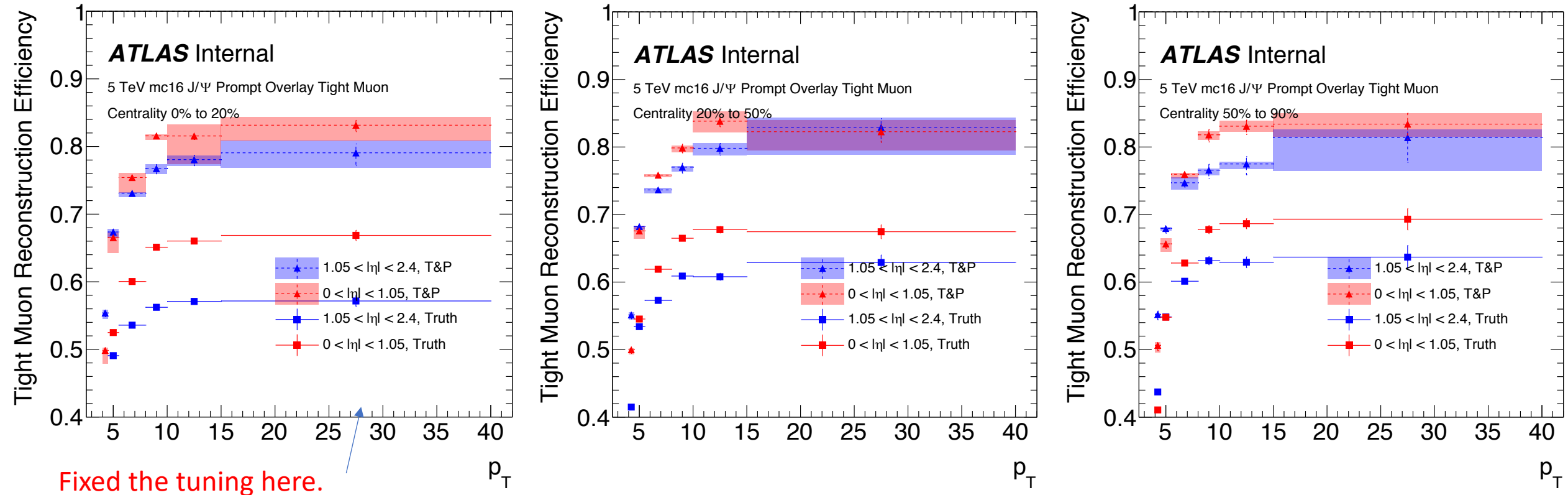


Results of Tight Muon in PbPb and pp MC



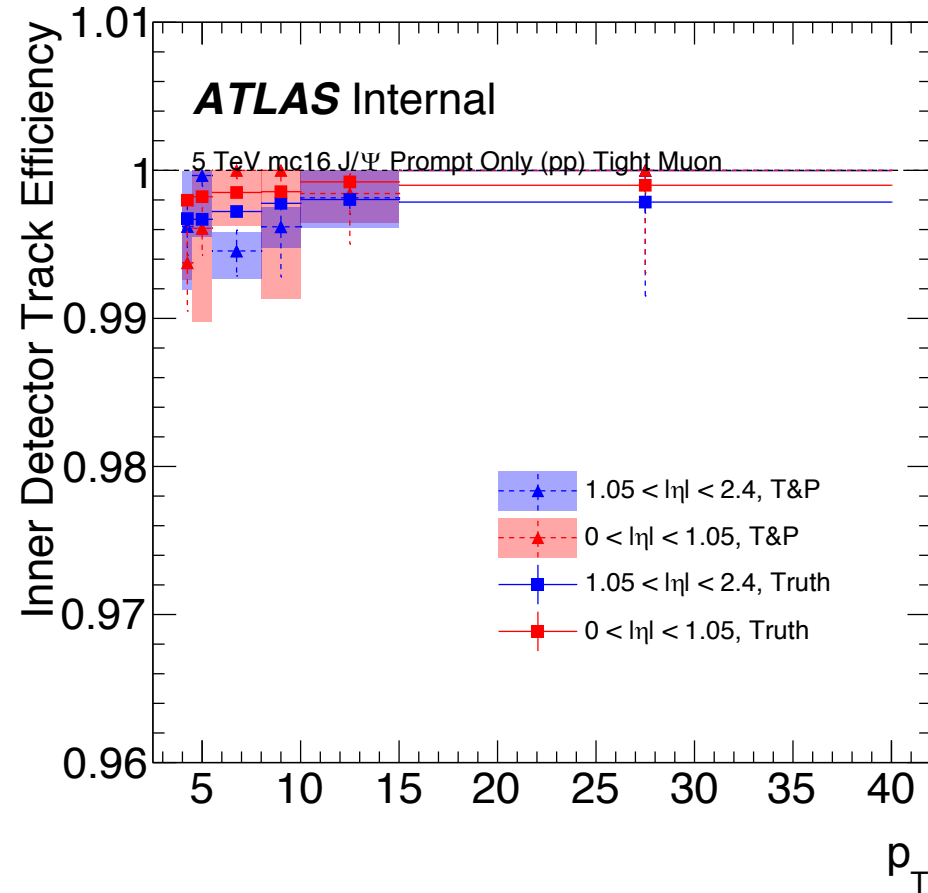
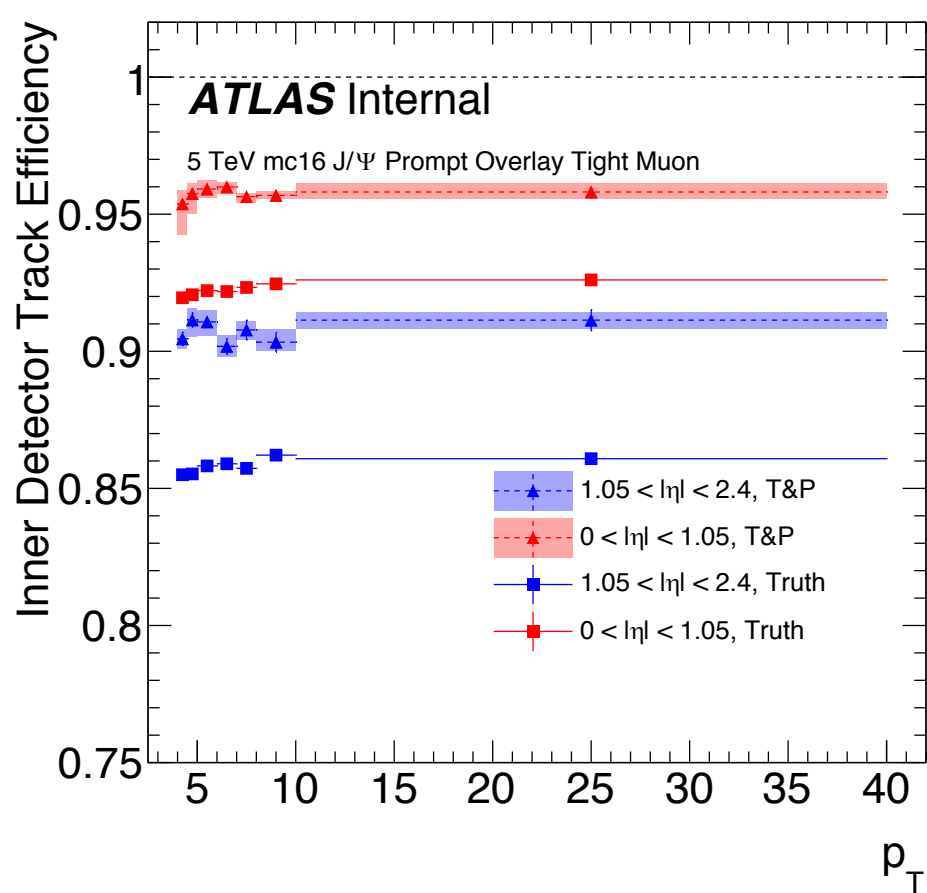
- There's about 15% difference in PbPb MC for tight muon recos using T&P method and using Truth Matching method ($dR < 0.05$).
 - PbPb results are all centrality, unweighted, see reweighted and centrality dependent in next slide.
 - The tight muon efficiencies in pp MC by using the two methods agree with each other within ~2%.

Reweighted PbPb (Credit of Debugging goes to Sebastian and Thank you!!)



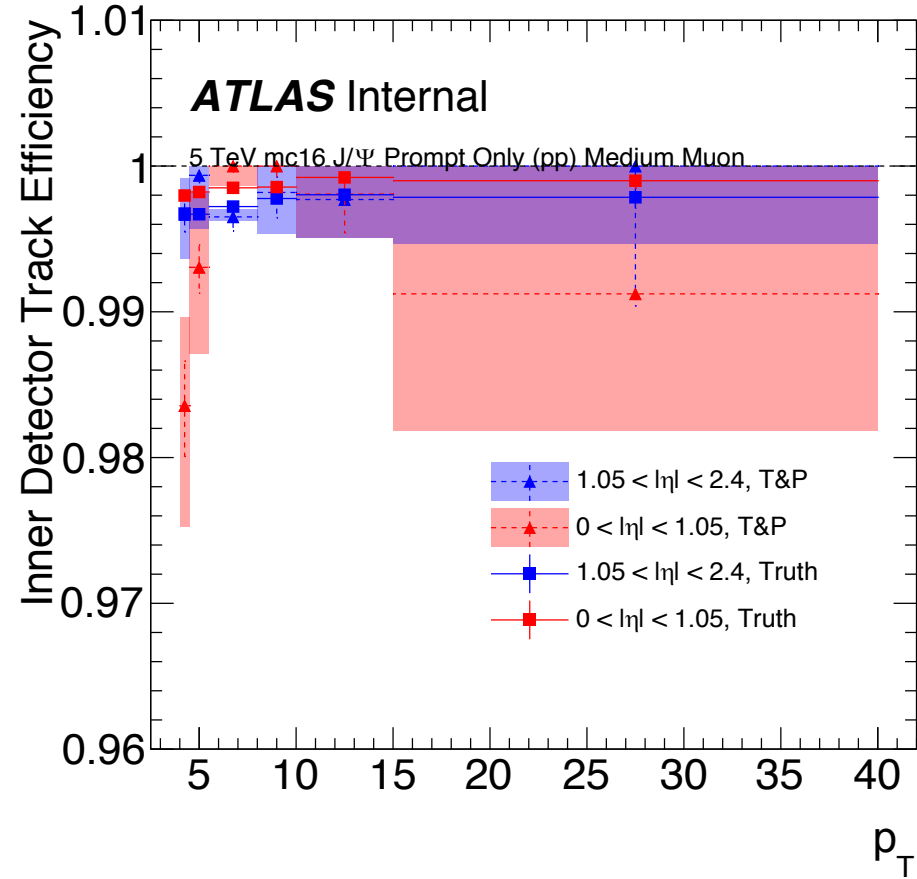
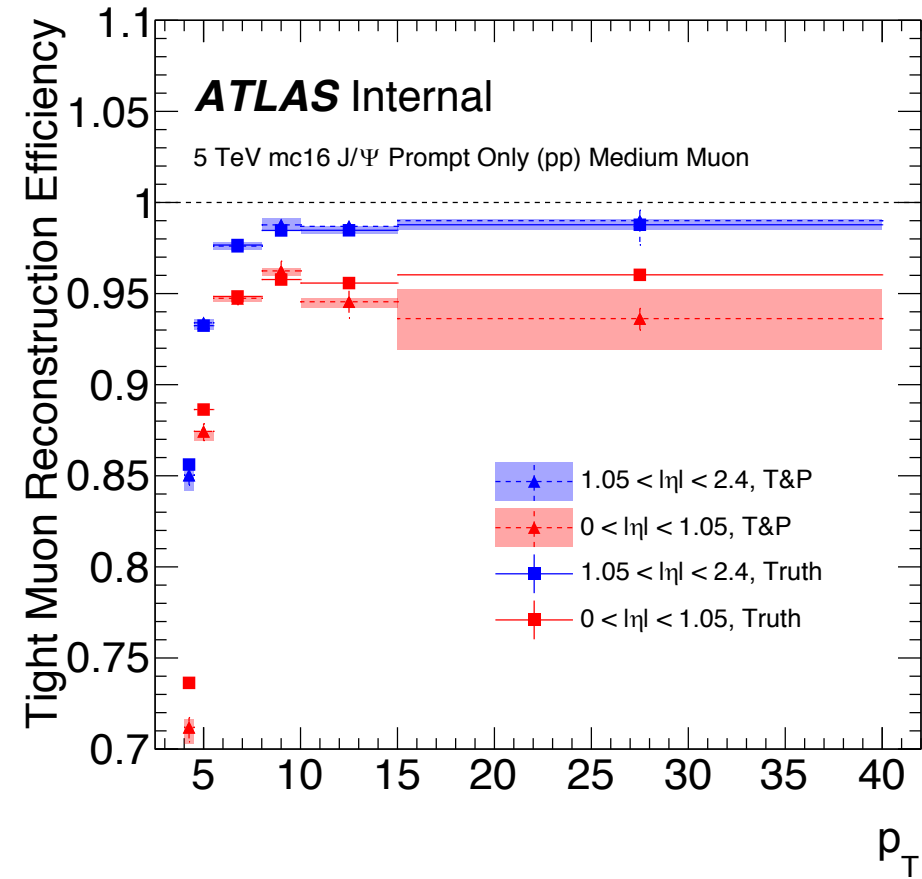
- PbPb results differ by $\sim 15\%$ for all centrality. (T&P method gives higher efficiency)
- End cap truth matching method efficiency has a centrality dependence, and the peripheral efficiency is higher.
- End cap T&P method efficiency has a similar centrality dependence at its centroid values.
- Barrel region efficiency shows no clear centrality dependence.

Results of ID Track in PbPb and pp MC



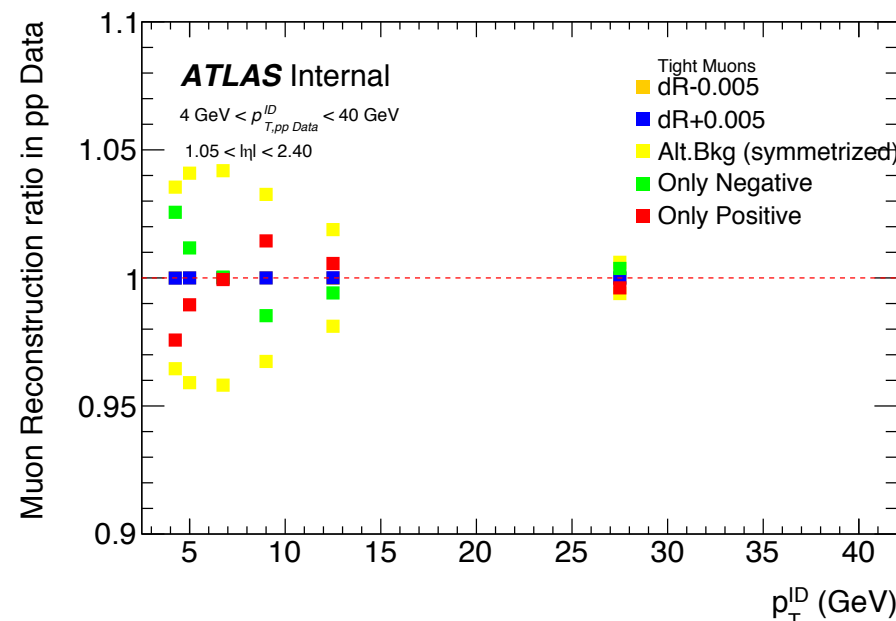
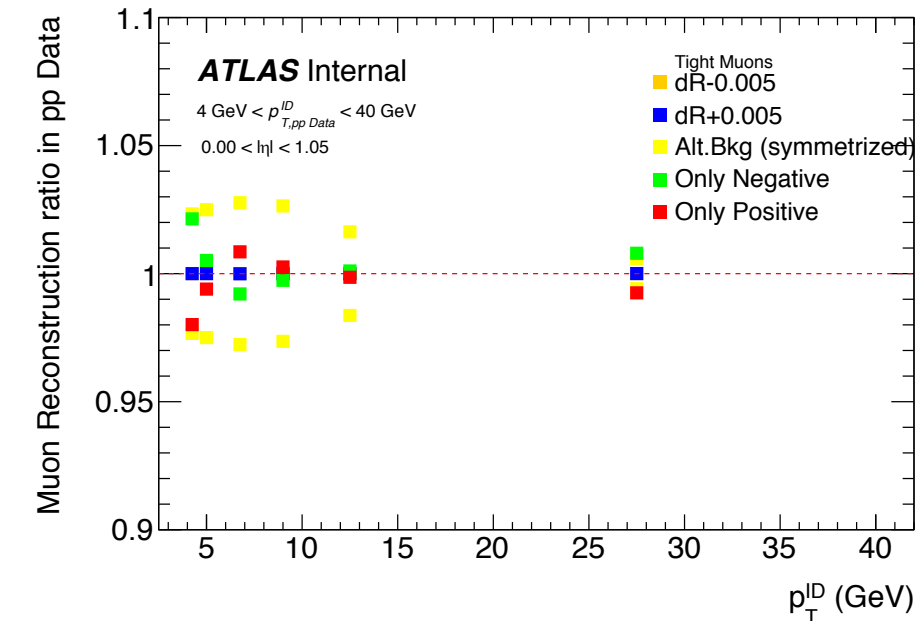
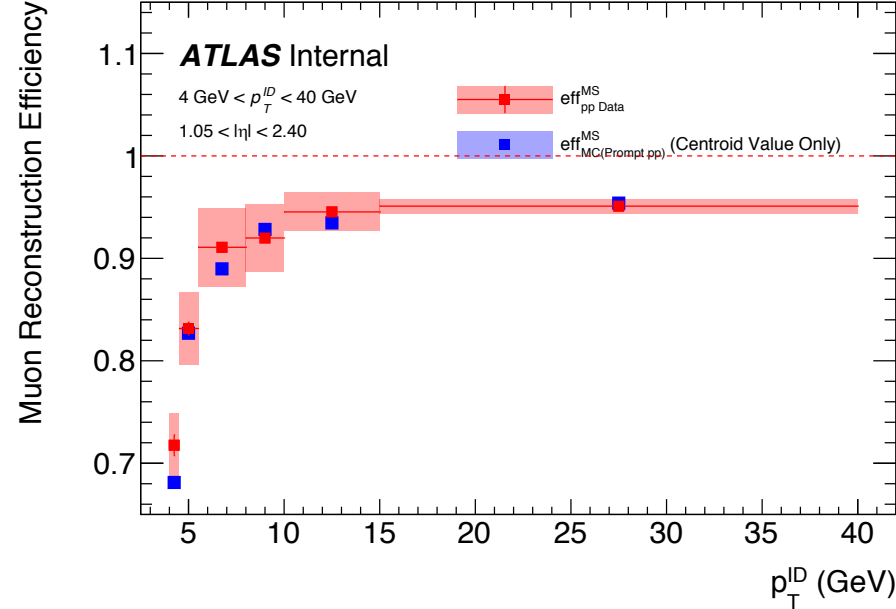
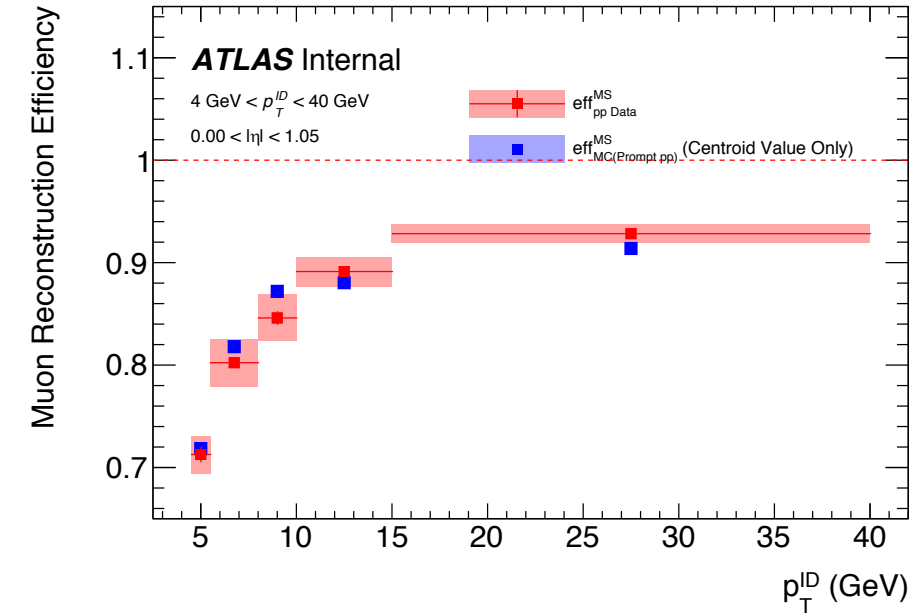
- There's about 5% difference in PbPb MC for tight muon recos using T&P method and using Truth Matching method ($dR < 0.05$).
 - PbPb results are all centrality, unweighted. Reweighting is being made.
- ID efficiencies using both methods are extremely high and close to each other in pp MC.

pp MC for Medium Muon



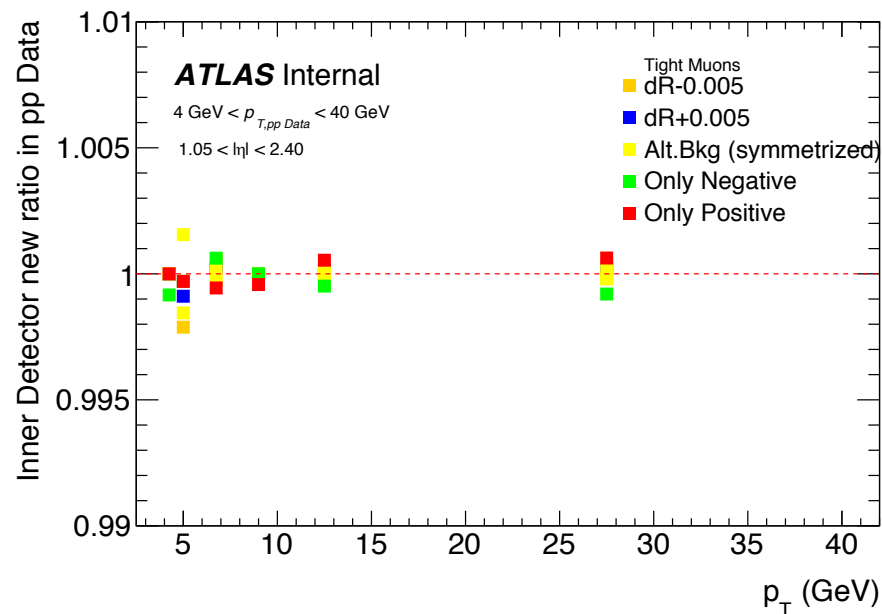
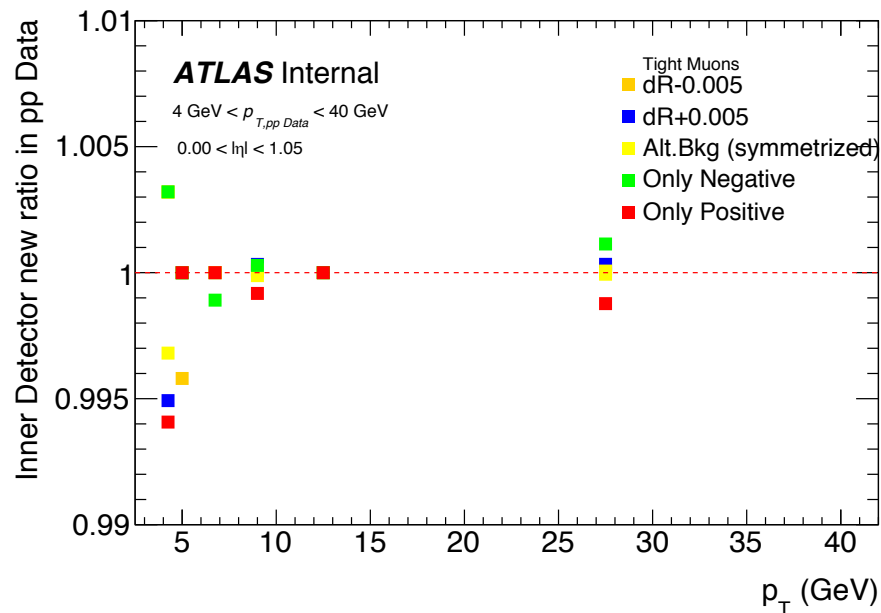
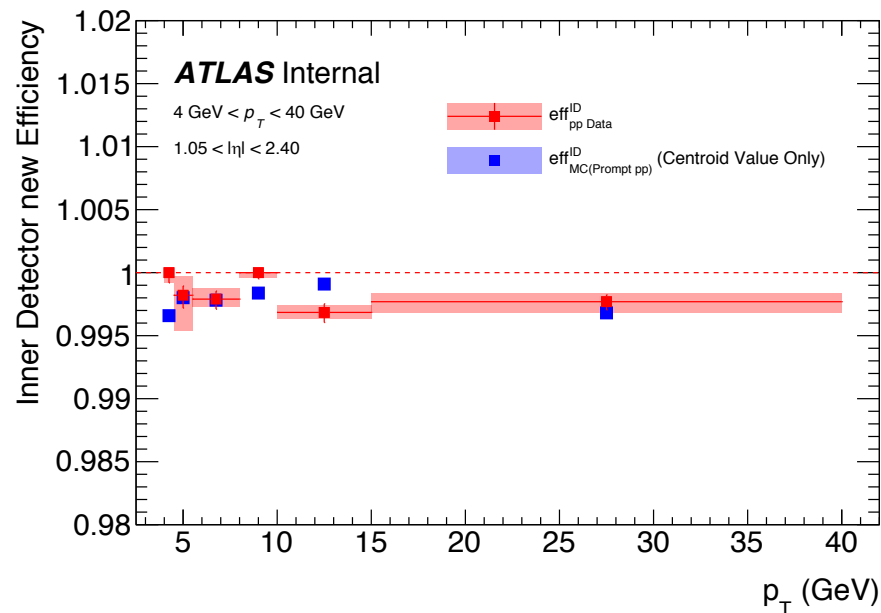
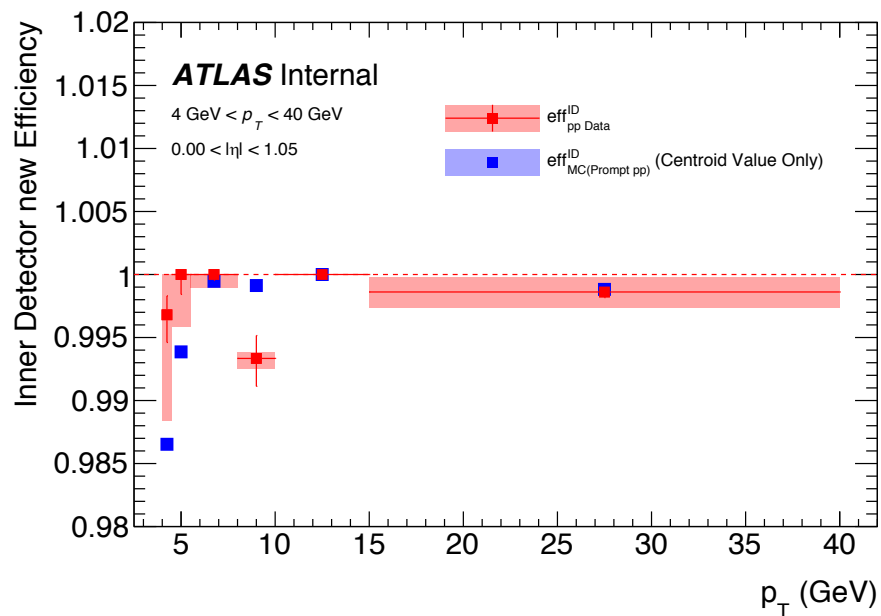
- Medium muon reconstruction efficiency agrees with each other within $\sim 3\%$
- ID efficiency agrees with each other

Muon Spectrometer Efficiency for pp data/pp MC Tight Muon



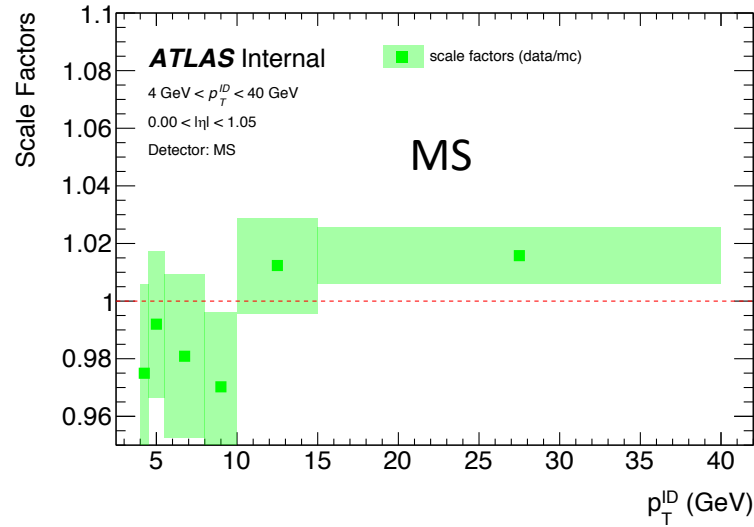
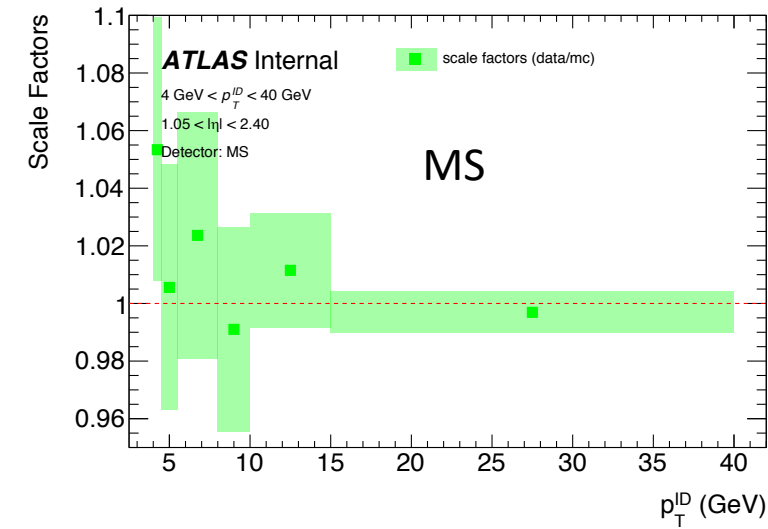
- Major source of uncertainty comes from separating charges.
- Barrel region has slightly lower efficiency (same as PbPb)
- See scale factor in slide 13 for comparison of data and MC.
- Negative charges and positive charges

Inner Detector Efficiency for pp data/pp MC Tight Muon

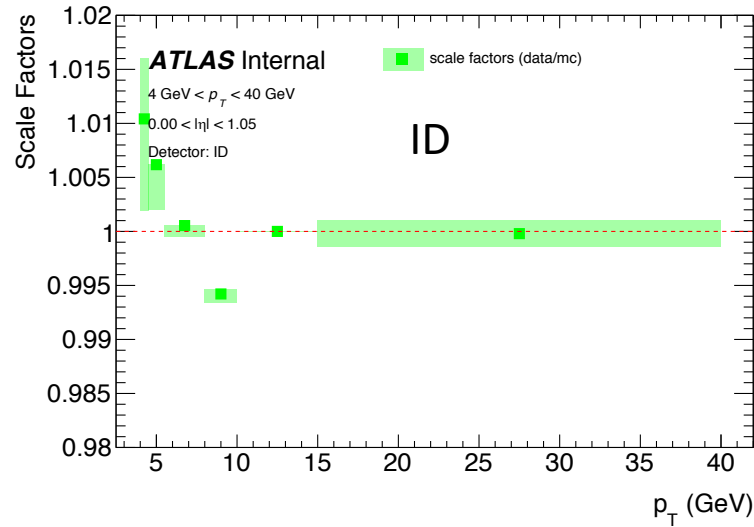
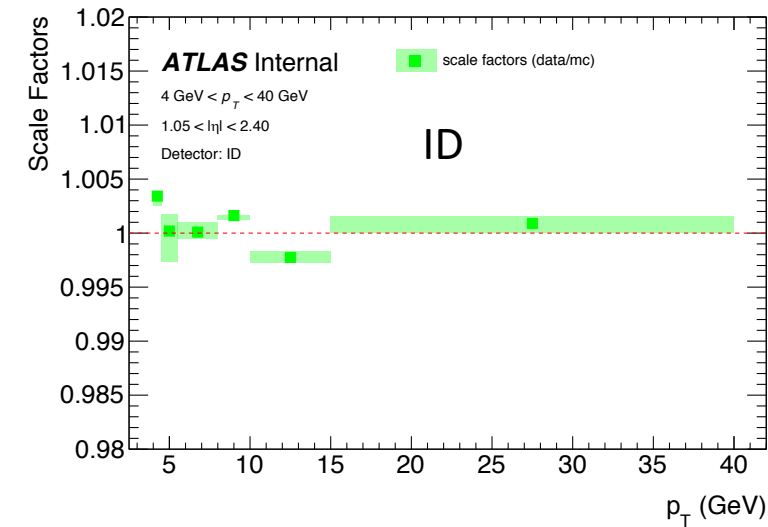


- Major source of uncertainty comes from separating charges.
- Barrel region has slightly lower efficiency (same as PbPb)
- See scale factor in slide 13 for comparison of data and MC.
- Systematics for separating the charges are smaller now and is smoother from point to point.

Scale Factors for pp tight muons in MS and ID



- For MS efficiency, the scale factors agree with each other around 1 except for the first data point.
- For ID efficiency,
 - for the $p_T < 10 \text{ GeV}$ agree with each other around 0.98
 - for $p_T > 10 \text{ GeV}$ agree with each other around 1.02



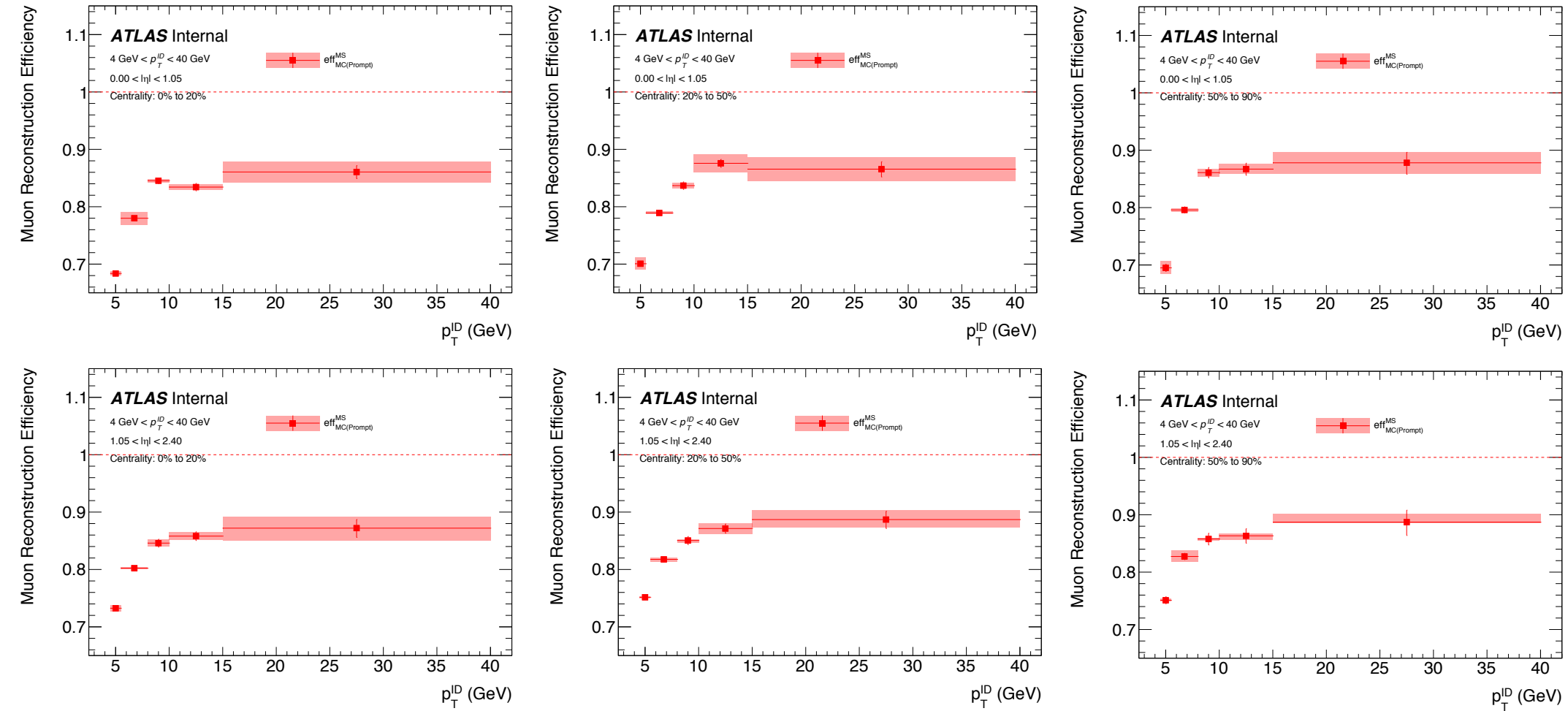
Summary

- There are two methods for calculating the reconstruction efficiencies of muons (or tracks) with a certain quality:
 - The tag and probe (T&P) uses $\varepsilon(\mu) = \varepsilon(\mu|\text{ID}) \times \varepsilon(\text{ID}) \cong \varepsilon(\mu|\text{ID}) \times \varepsilon(\text{ID}|\text{MS})$. (MC and data)
 - The truth match method finds whether there's a reconstructed muon close to each truth muon.
- In pp MC, the two methods agree within $\sim 2\%$ and $\sim 3\%$ respectively for tight muon and medium muon. It makes sense to use T&P with pp data.
 - **Scale factors are calculated for tight muons**
 - For the end cap region of MS 5 out of 6 points agree around 1.
 - For the barrel region of MS 4 out of 6 points agree around 0.98, and the other 2 agree around 1.02.
 - Scale factors for ID are distributed around 1 within $\sim 1\%$.
 - *In progress: Tuning scale factors for medium muon in pp to further compare.*
- In PbPb MC, the two methods do not yield the same results for tight muons and for ID tracks
 - T&P gives $\sim 15\%$ higher efficiency than truth for tight muons, and $\sim 5\%$ higher efficiency for ID tracks.
 - What else contributes to the difference?
 - *In progress: Compare the two methods for medium muons in PbPb MC. Will look into whether we see a similar difference.*

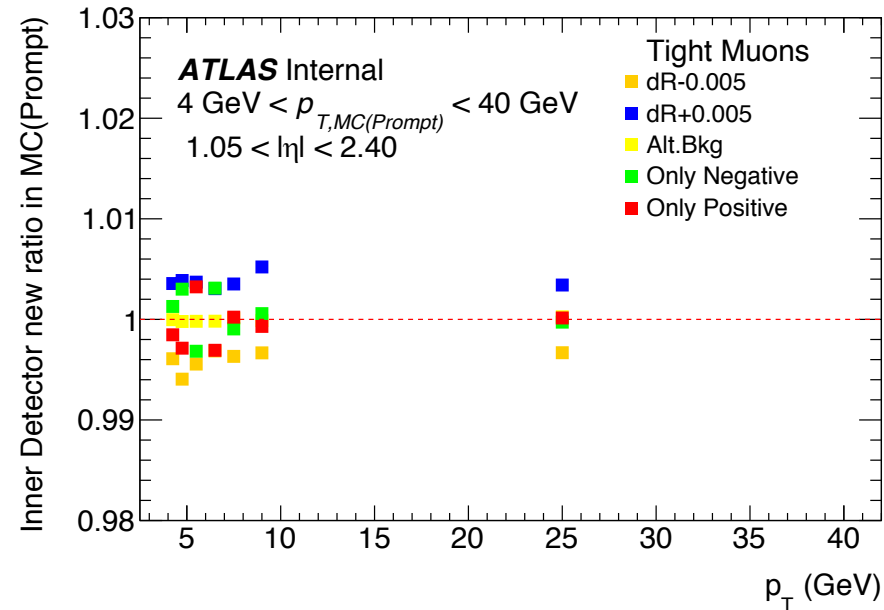
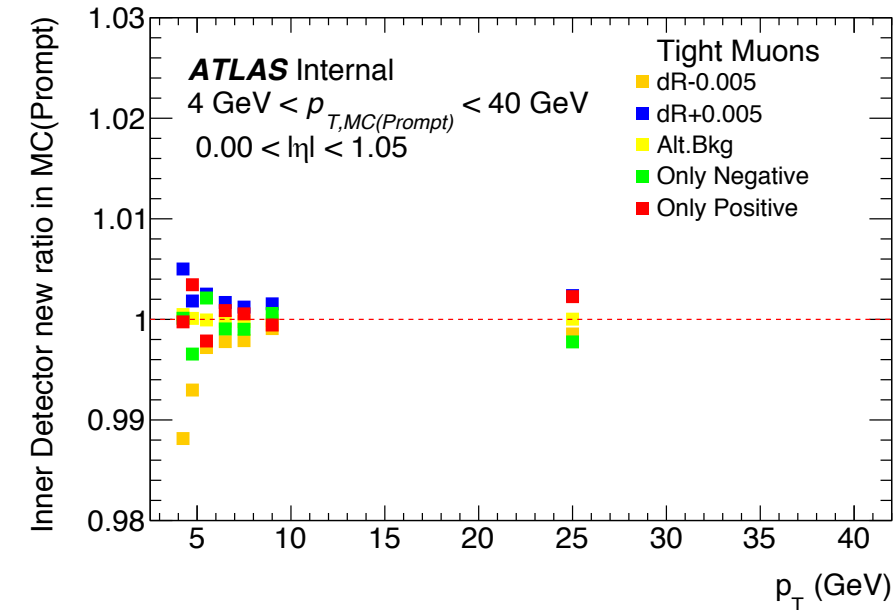
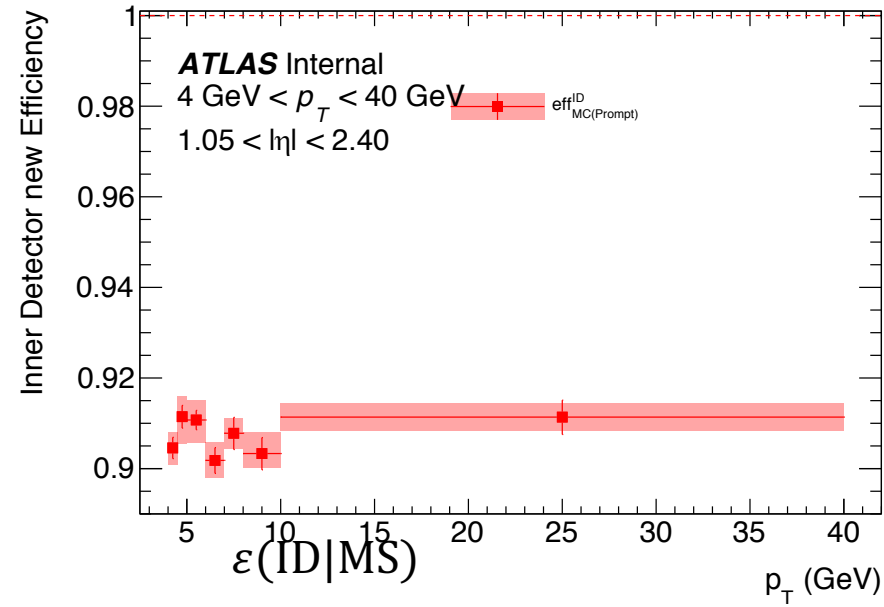
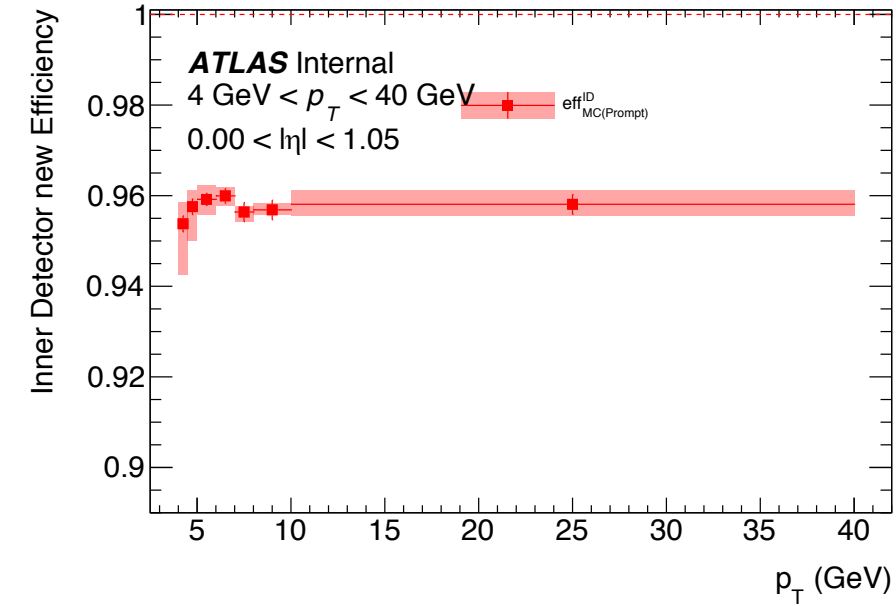
Back-up

- Truth is reweighted by id tracks, which saves most of the events.

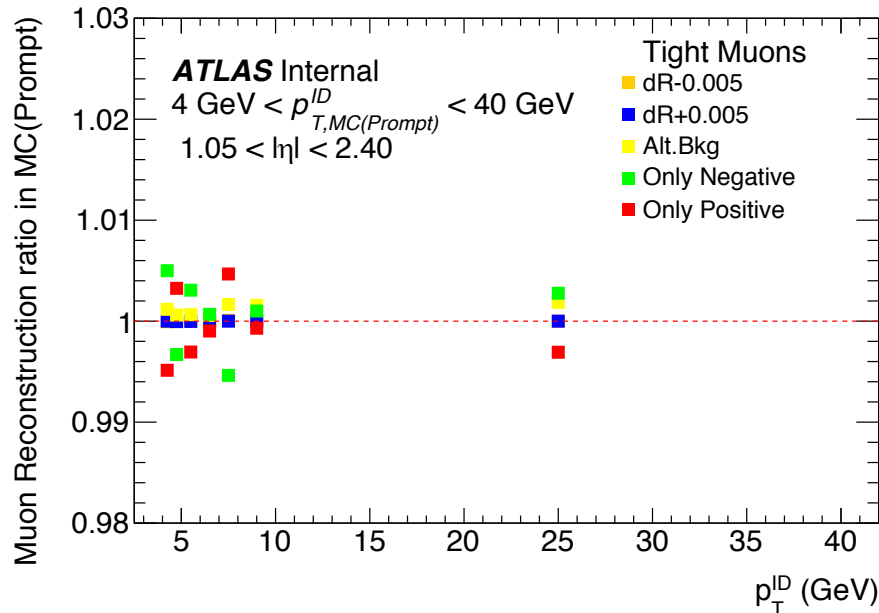
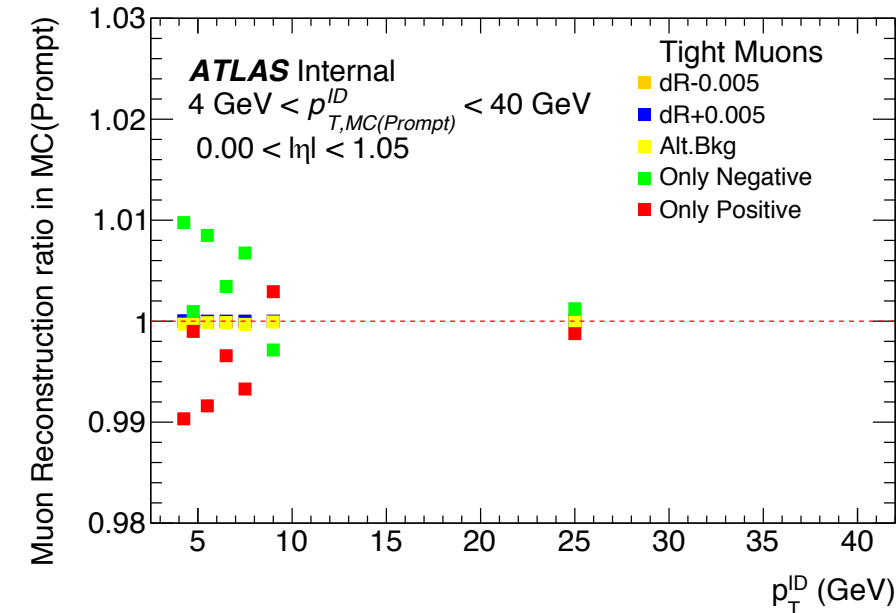
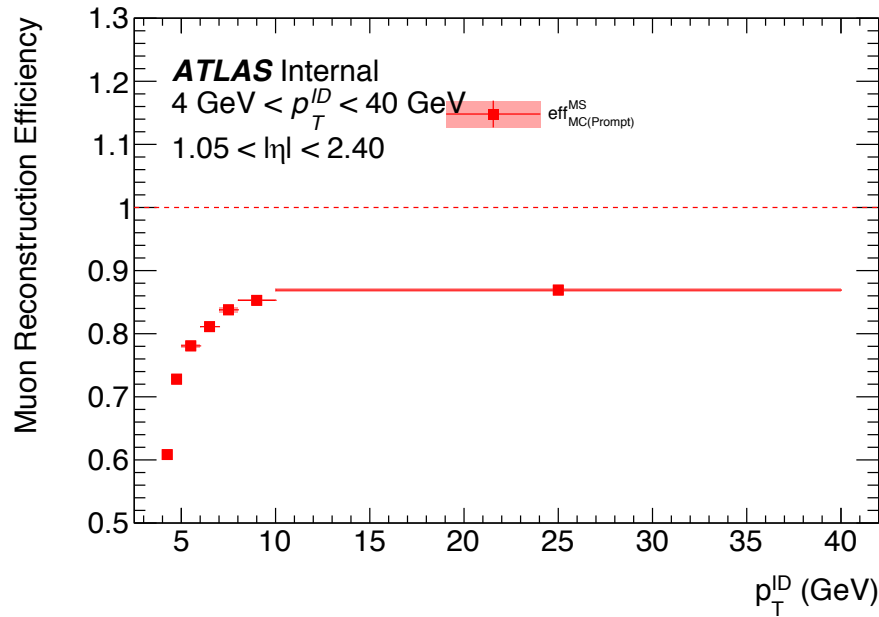
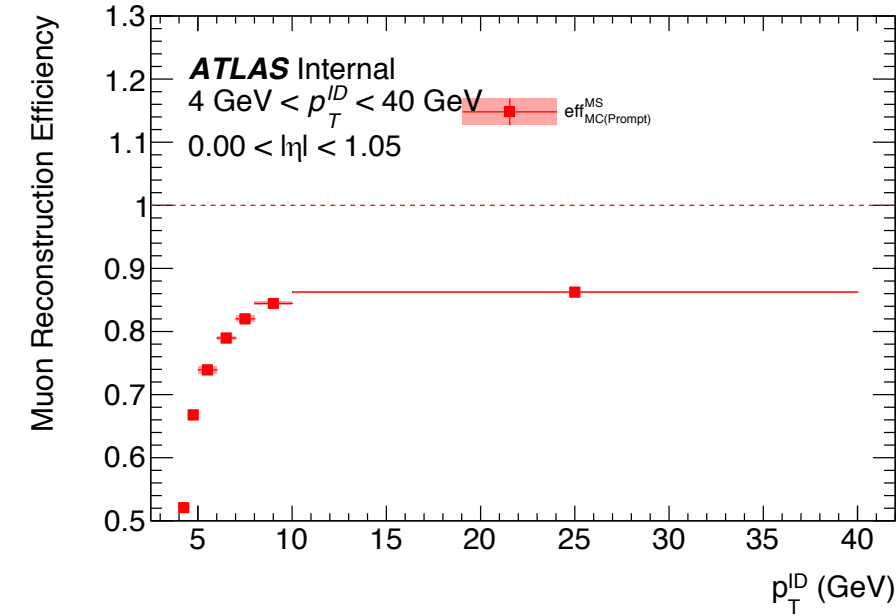
Reweighted PbPb MC T&P Results



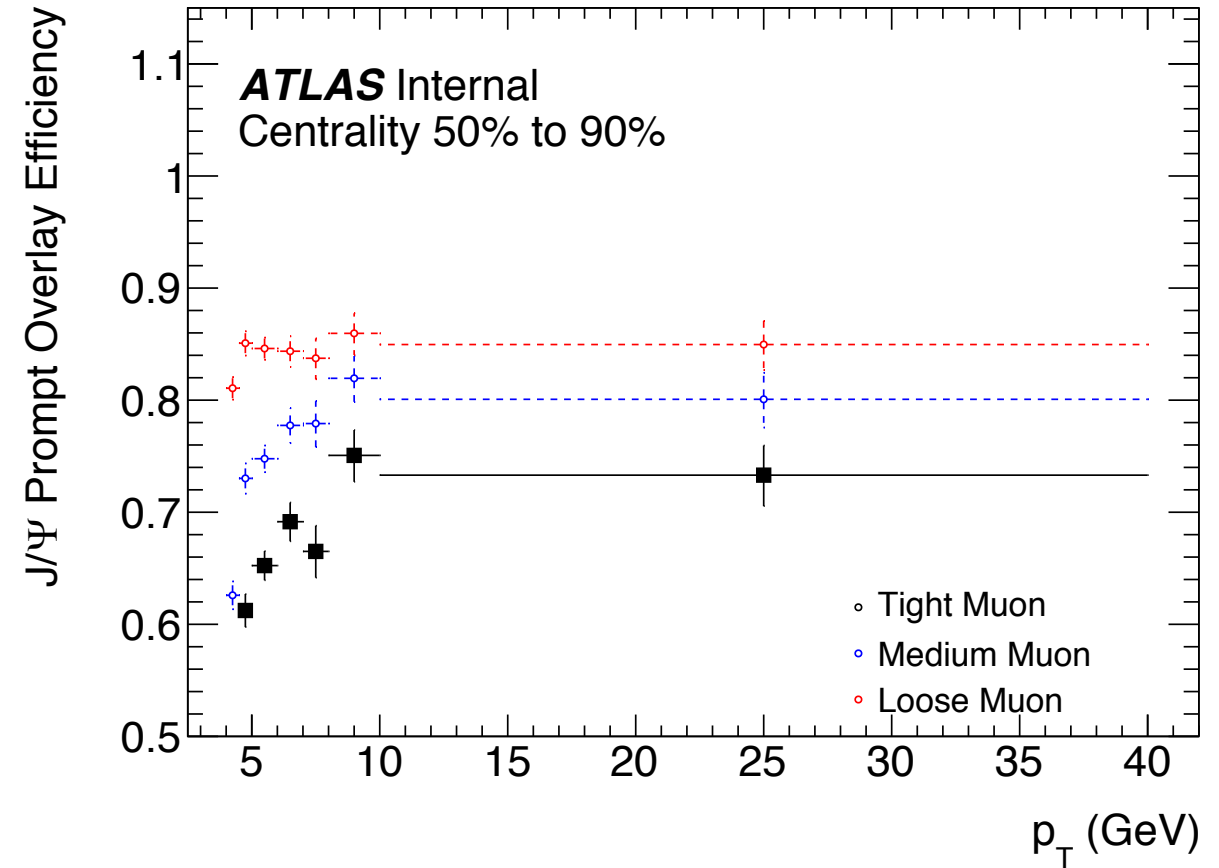
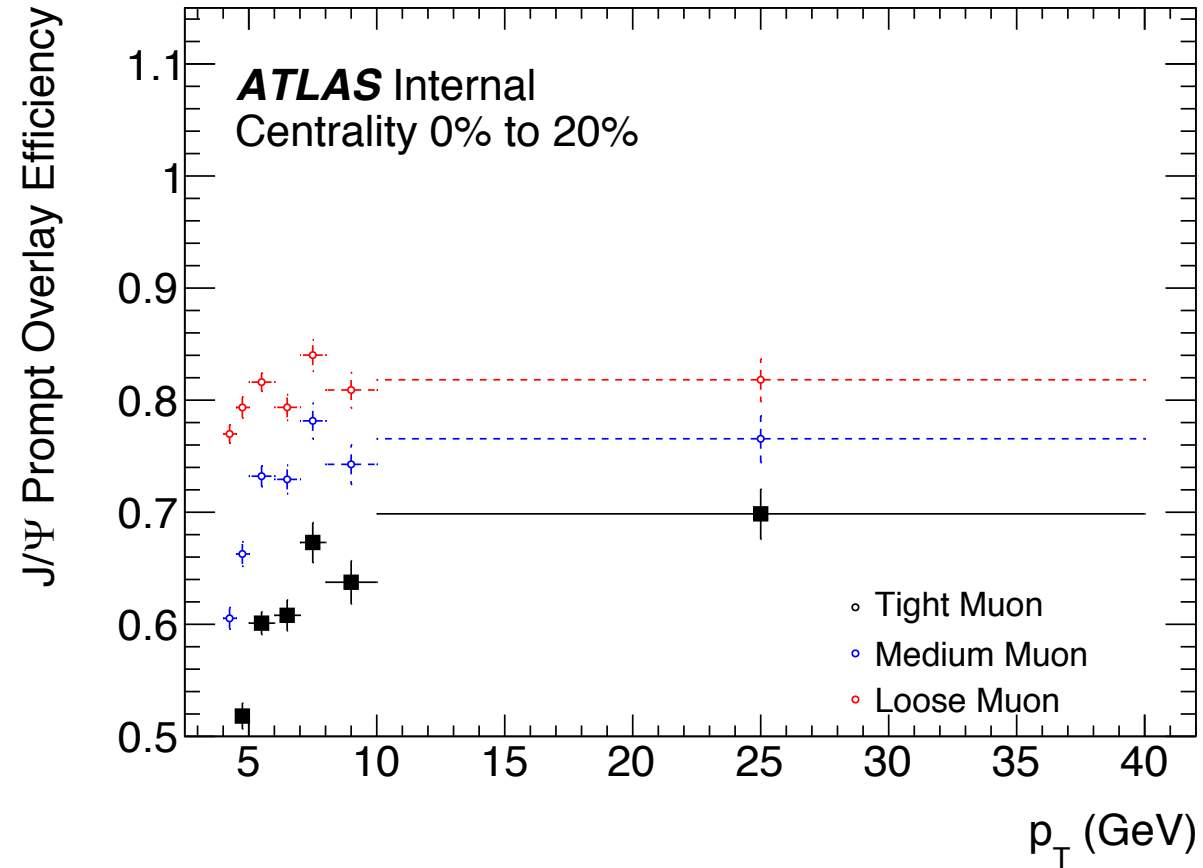
$\varepsilon(\text{ID}|\text{MS})$ in PbPb MC Tight Muon Using T&P (unweighted)



$\varepsilon(\mu|ID)$ in PbPb MC Tight Muon Using T&P (unweighted)



PbPb MC Tight Muon using Truth match



- Peripheral efficiency slightly better than central.
- All much lower than T&P.