Tight Muon Reconstruction Efficiency

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Dec 2, 2019

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 $\varepsilon(\mu|\mathrm{ID})$, corrected by inner detector efficiency with respect to muon spectrometer $\varepsilon(\mathrm{ID}|\mathrm{MS})$.
    - $\varepsilon(\mu) = \varepsilon(\mu|\mathrm{ID})\times\varepsilon(\mathrm{ID}) \cong \varepsilon(\mu|\mathrm{ID})\times\varepsilon(\mathrm{ID}|\mathrm{MS})$
  - 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 ~2%. (see slide 7)
  - Medium muon efficiencies agree within ~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 0~5), 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: ($\varepsilon(\mathrm{ID}|\mathrm{MS})_{\mathrm{MC}}$ and $\varepsilon(\mu|\mathrm{ID})$)
    - A suspicion: there is a problem with ($\varepsilon(\mathrm{ID}|\mathrm{MS})_{\mathrm{MC}}$)
      - Check whether the $\varepsilon(\mathrm{ID}|\mathrm{MS})_{\mathrm{MC}}$ agrees with efficiency of ID by directly matching available ID track to truth muon. (slide 7)
    - Assuming $\varepsilon(\mathrm{ID}|\mathrm{MS})_{\mathrm{MC}}$ is the problem, a potential workaround to get $\varepsilon(\mu)$ in data (given that data has low statistics in MS):
      - Get $\varepsilon(\mu|\mathrm{ID})_{\mathrm{data}}$ (assumed to be fine)
      - Get $\varepsilon(\mu|\mathrm{ID})$ in data and $\varepsilon(\mu|\mathrm{ID})$ 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.

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

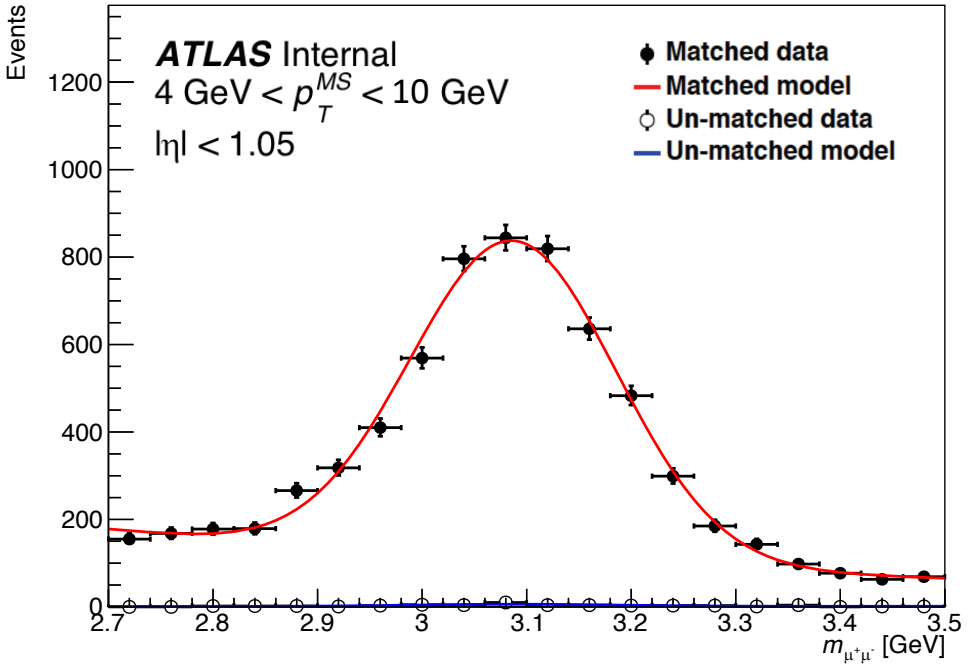
- $\varepsilon(\mu|\mathrm{ID})$ Muon Reconstruction efficiency with respect to inner detector.
- $\varepsilon(\mathrm{ID}|\mathrm{MS})$ Inner Detector efficiency with respect to muon chamber.
- Event Selection:
  - Trigger mu3 || mu8 || mu10
  - GRL
  - At least 1 primary vertex
- $\varepsilon(\mathrm{ID}|\mathrm{MS})$ match: MS track with an ID track dR < 0.2
- $\varepsilon(\mu|\mathrm{ID})$ 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

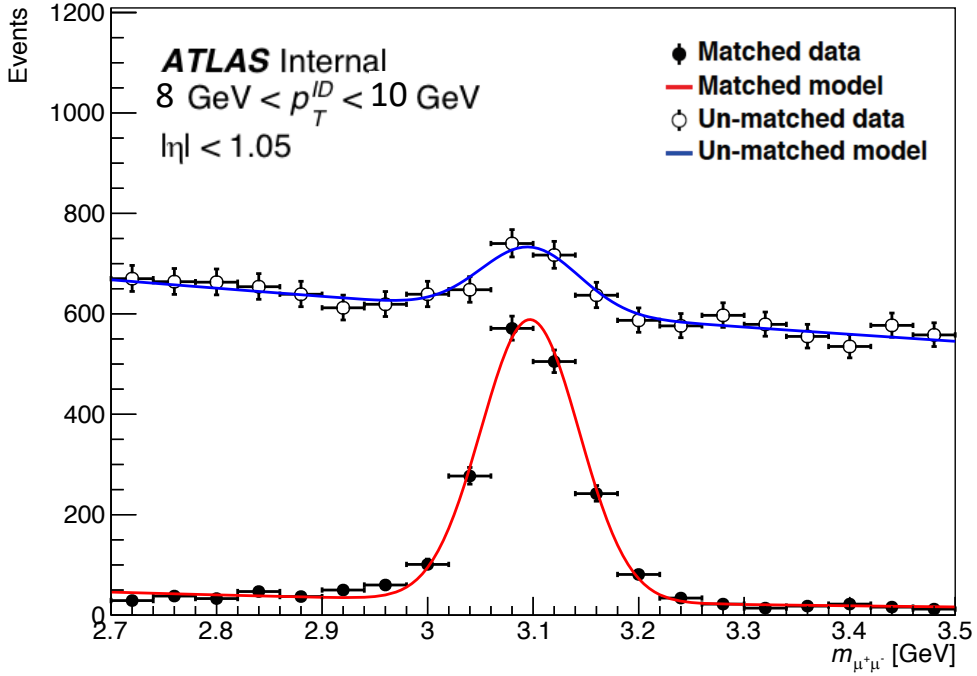
- Data: 2018 Pb-Pb Hard Probe Stream Data at 5.02 TeV
- Monte Carlo:Pythia8B with Prompt J/psi to Muons with Heavy Ion Overlay. mc16_5TeV:mc16_5TeV.300000.Pythia8BPhotospp_A14_CTEQ6L1_pp_Jpsimu2p5mu2p5.merge.AOD.e4973_d1521_r11472_r11217

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).
  - $N_{match} = N_{tot} * \varepsilon * Sig(mass) + N_{bkg1} * Bkg1(mass)$
  - $N_{unmatch} = N_{tot} * (1-\varepsilon) * Sig(mass) + N_{bkg2} * Bkg2(mass)$
  - The fitting outputs N_{tot} and ε.

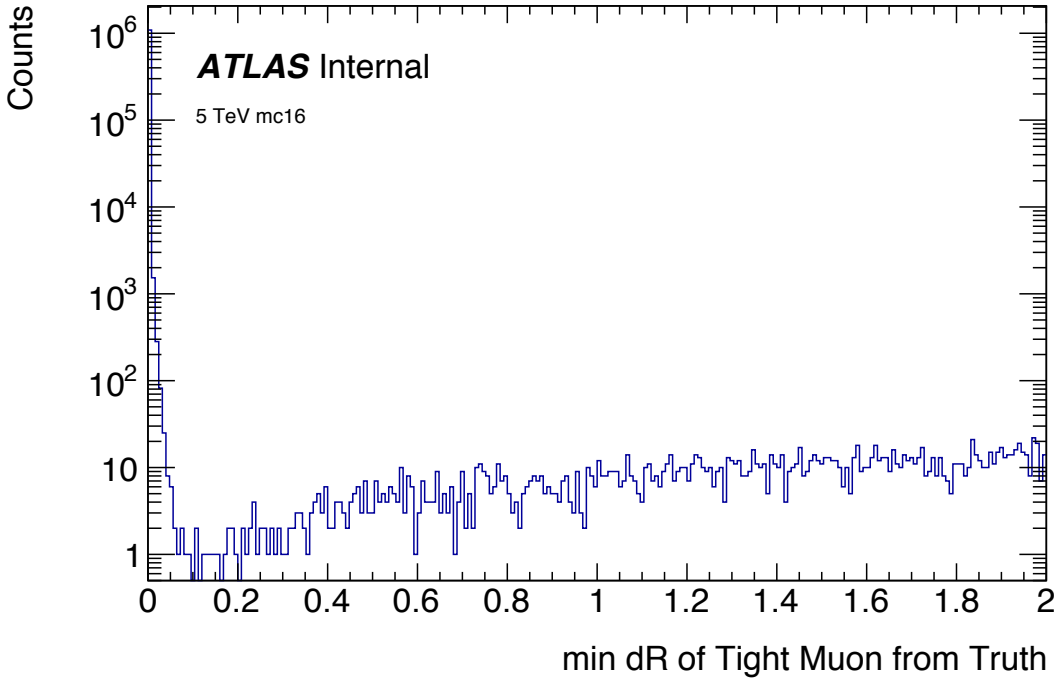
Sig(mass): Gaus
Bkg(mass): Exponential

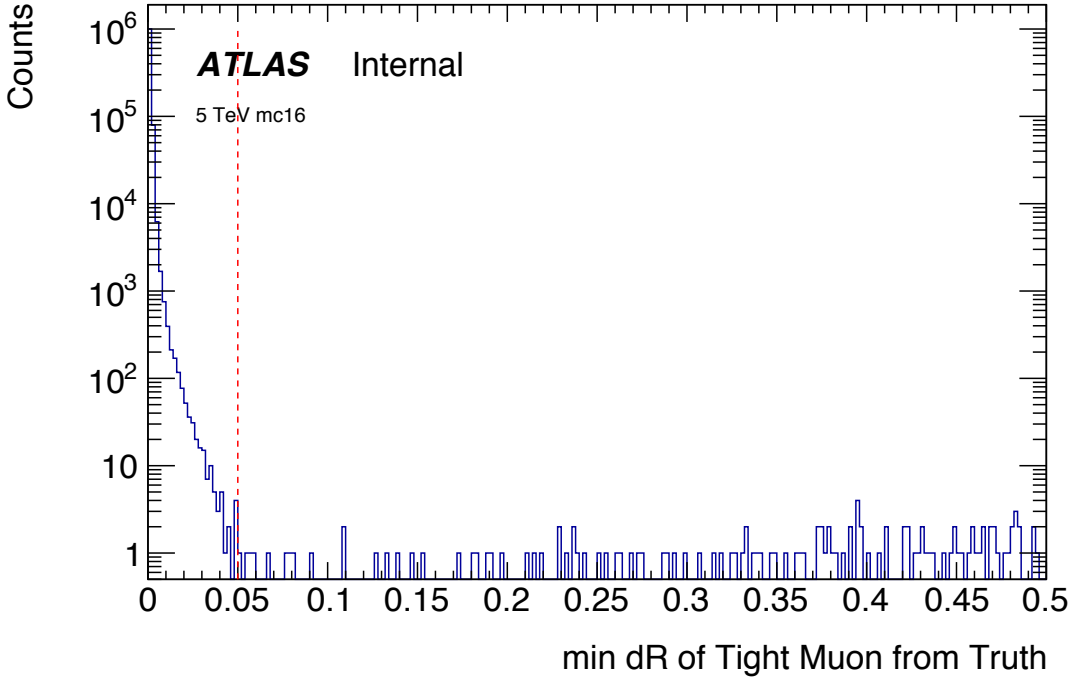




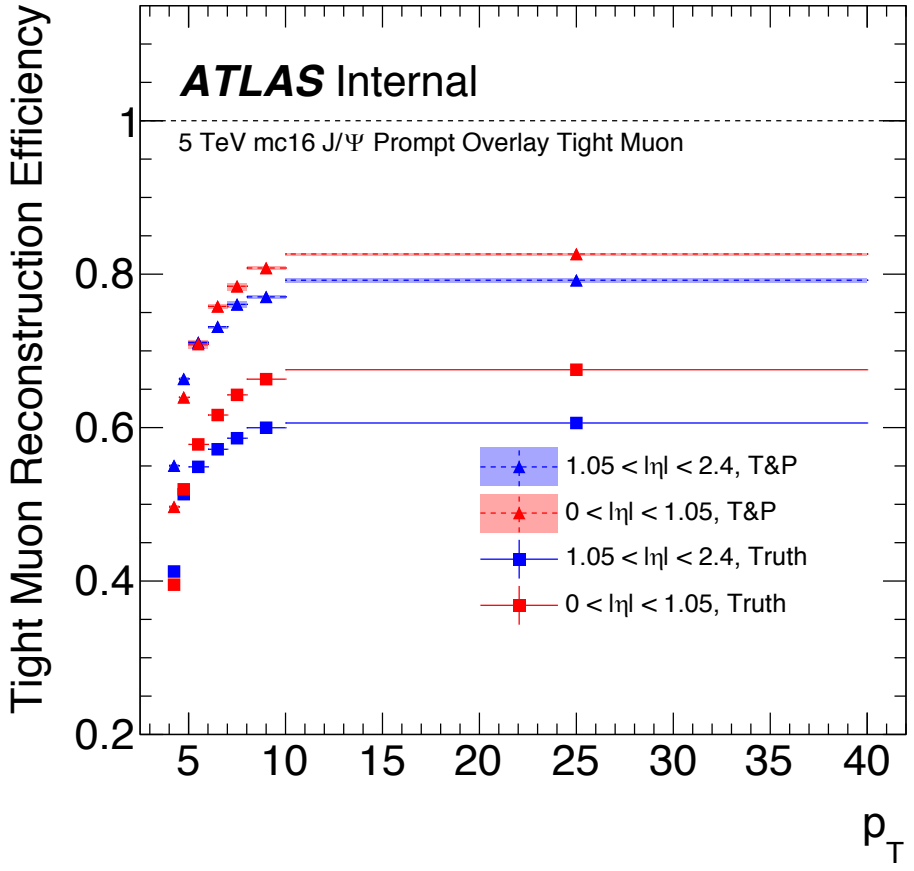
Truth Matching

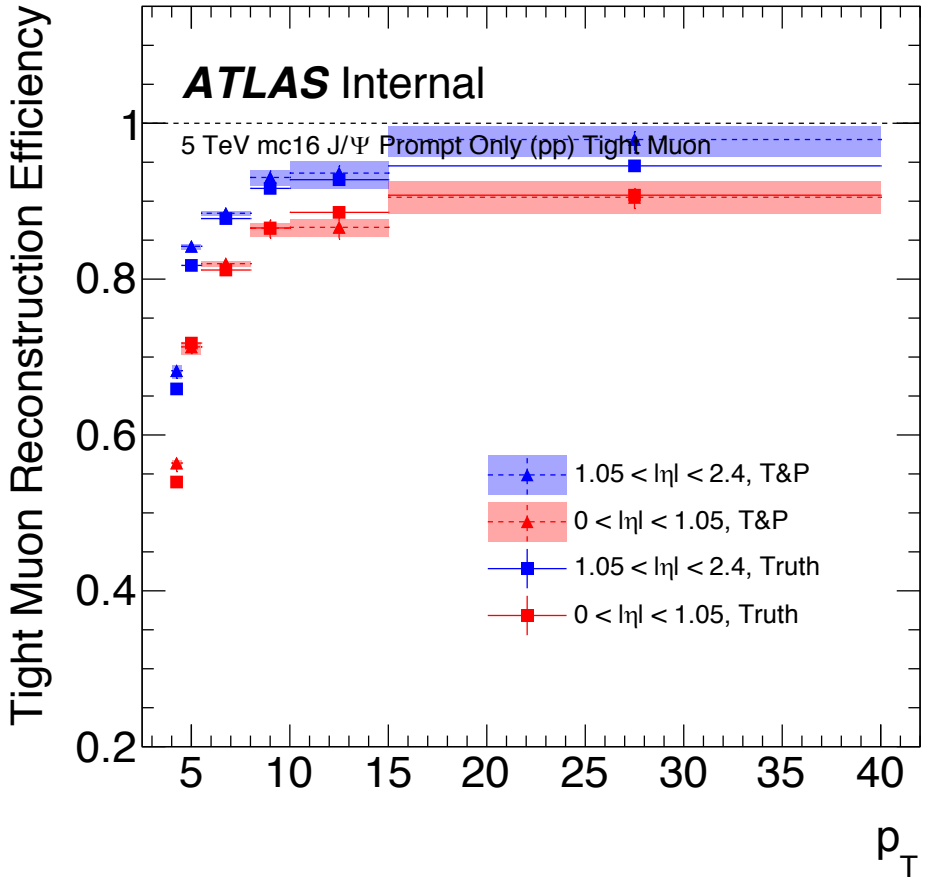
- For each truth muon in an event, loop through each of all reconstructed muons of a certain quality (e.g., tight), find its distance to the truth muon, and record the closest distance for each truth muon. All overflow distances are set to 2.
- Define a cut based on the shape of curve.
- Shown on the 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.





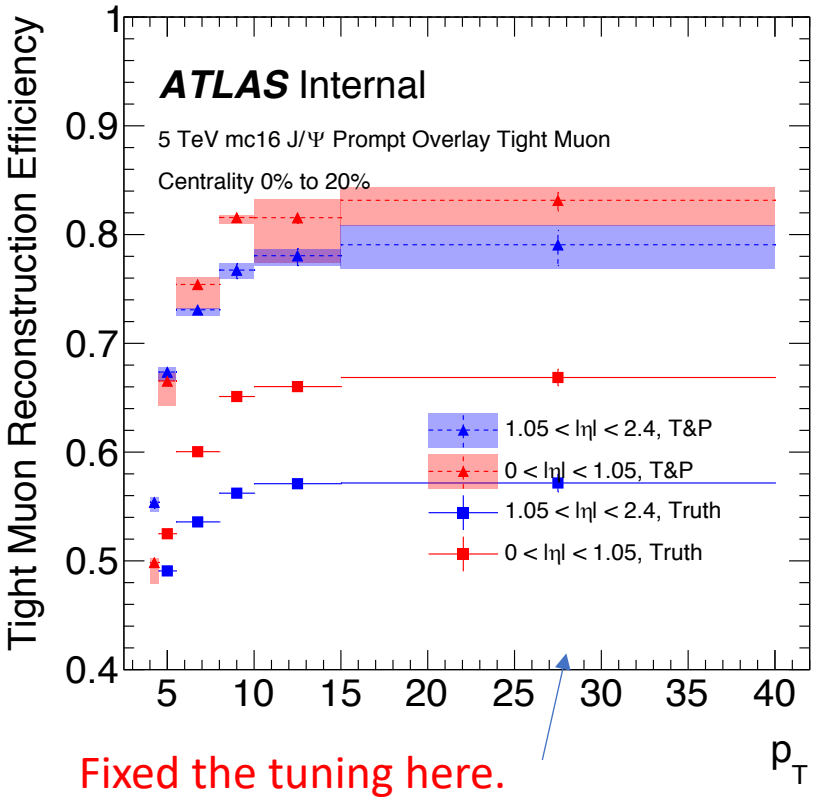
Results of Tight Muon in PbPb and pp MC



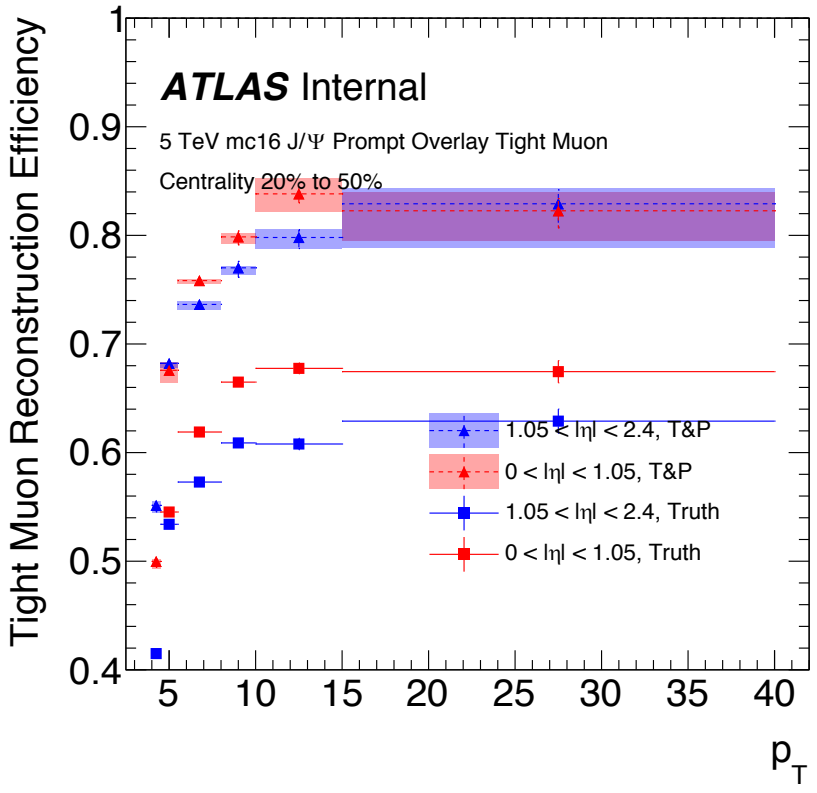


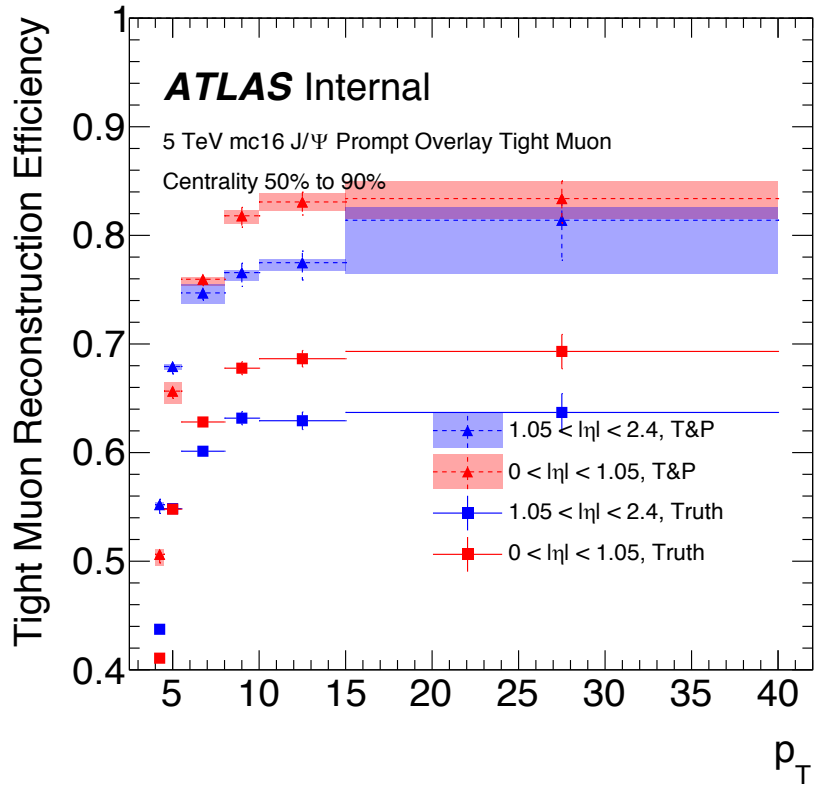
- There's about 15% difference in PbPb MC for tight muon recos using T&P method and using Truth Matching method (dR < 0.05).
  - PbPb results are all centrality, unreweighted, see reweighted and centrality dependent in next slide.
  - The tight muon efficiencies in pp MC by using the two methods agree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

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



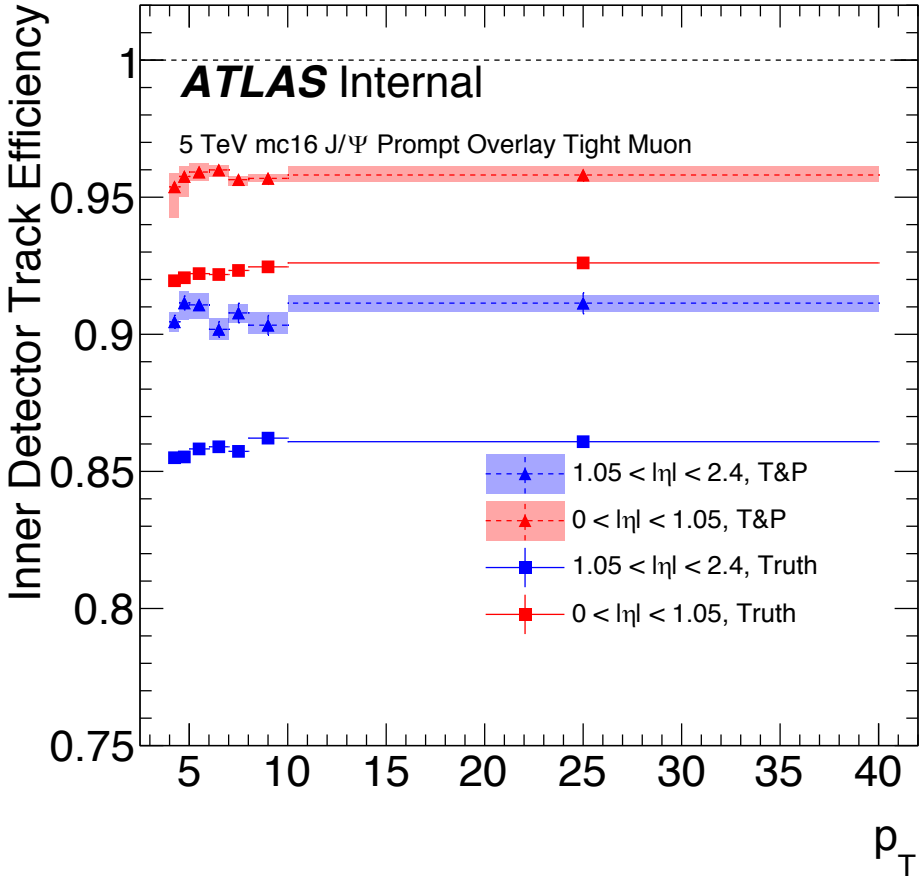
Fixed the tuning here.

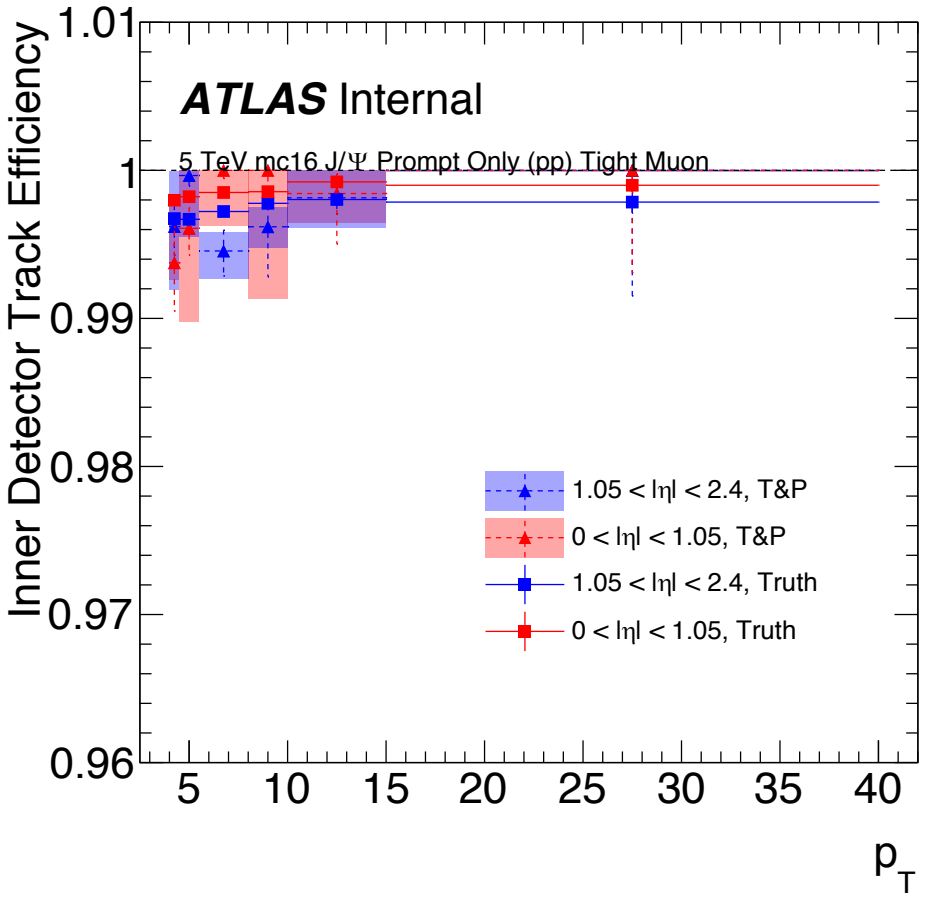




- PbPb results differ by ~15% for all centrality. (T&P method gives higher efficiency)
- End cap truth matching method efficiency has a centrality dependence, and the peripheral efficiency is higher.
- End cap T&P method efficiency has a similar centrality dependence at its centroid values.
- Barrel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

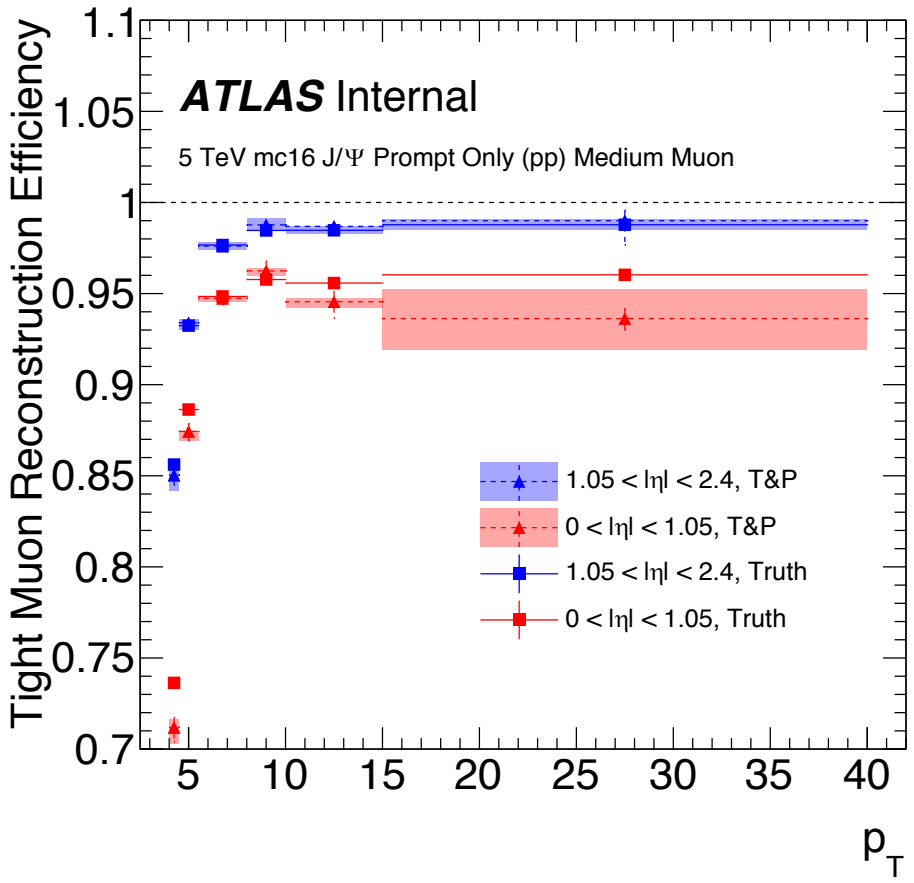
Results of ID Track in PbPb and pp MC

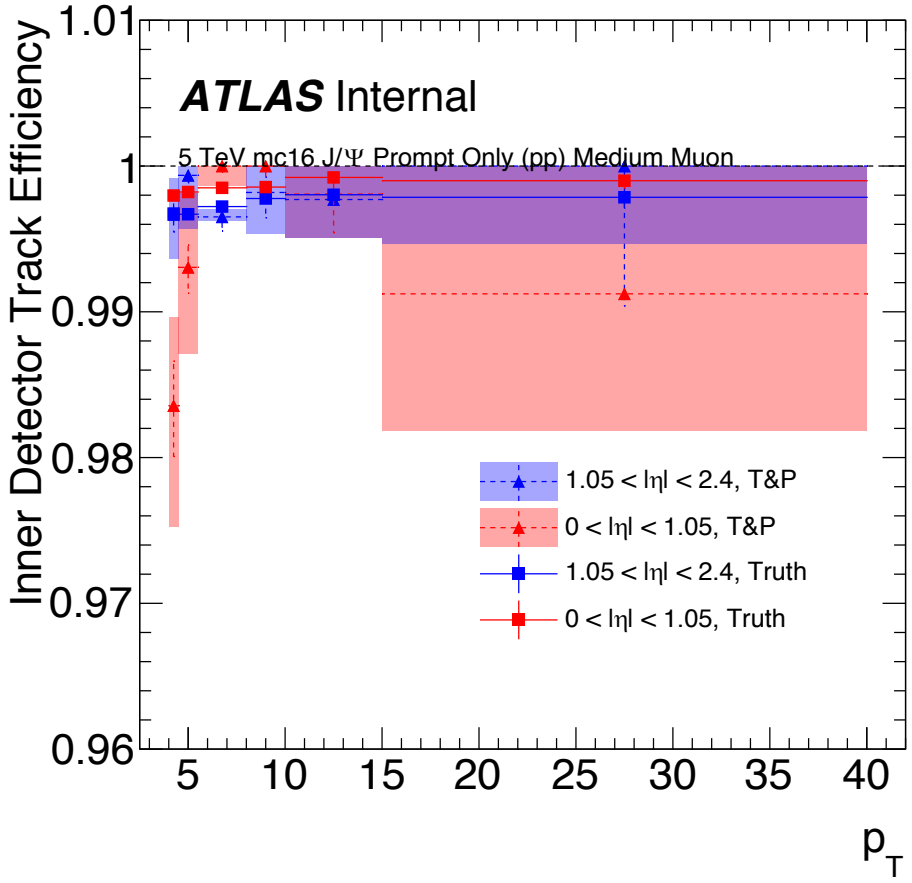




- There's about 5% difference in PbPb MC for tight muon recos using T&P method and using Truth Matching method (dR < 0.05).
  - PbPb results are all centrality, unreweighted. Reweighting is being made.
- ID efficiencies using both methods are extremely high and close to each other in pp MC.

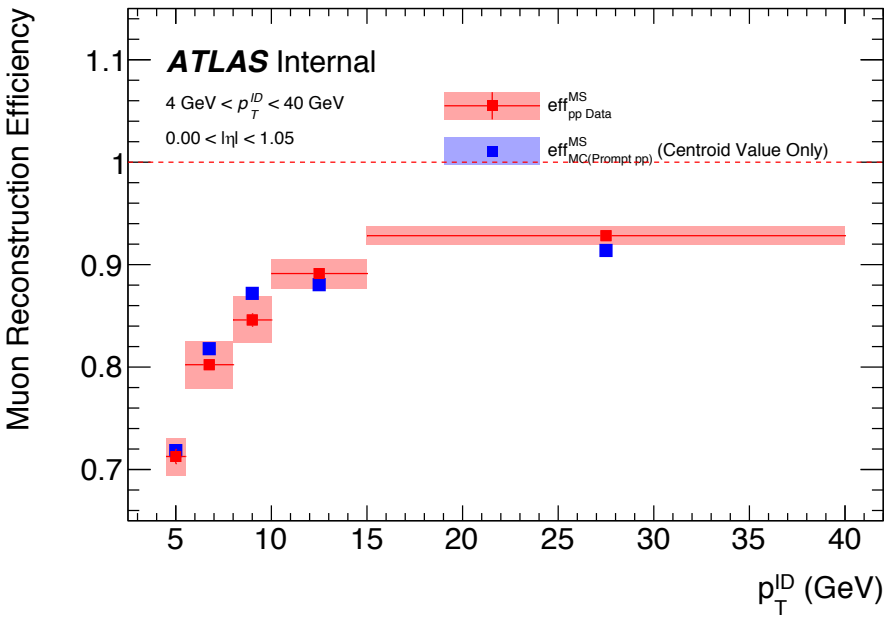
pp MC for Medium Muon

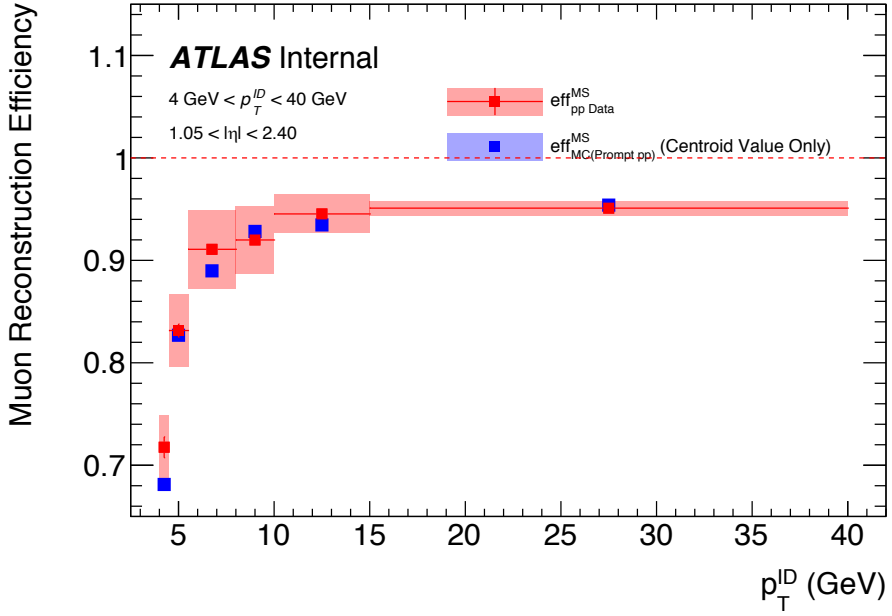


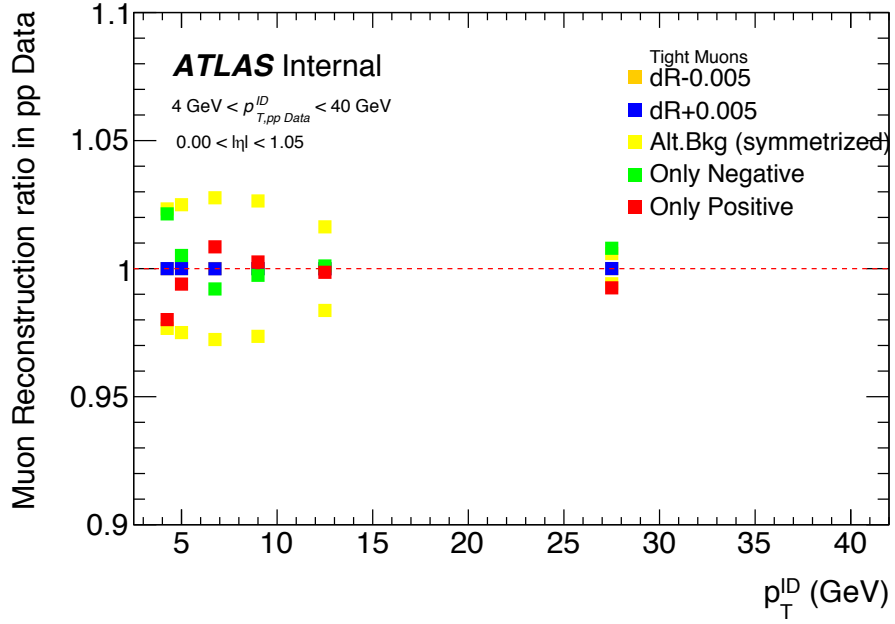


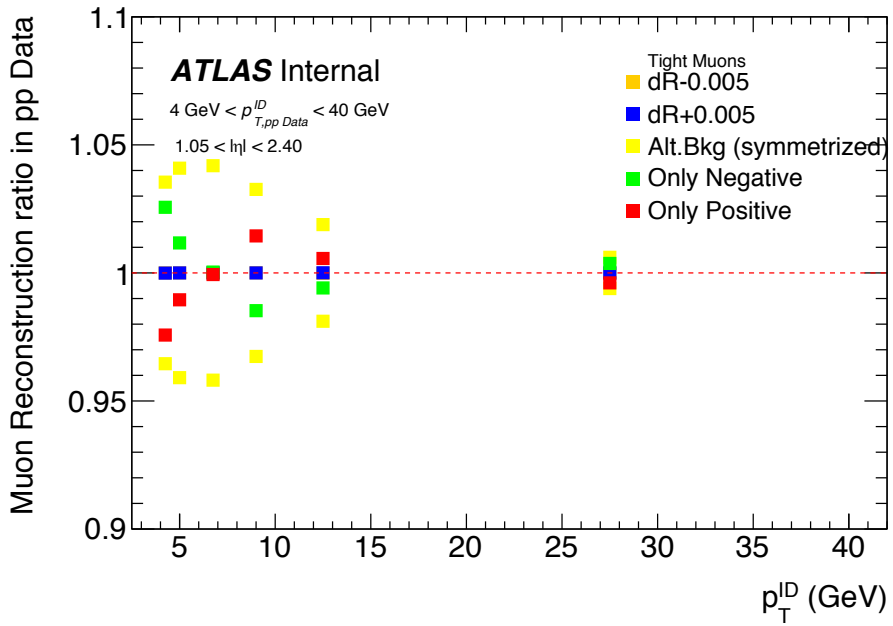
- Medium muon reconstruction efficiency agrees with each other within ~3%
- ID efficiency agrees with each other

Muon Spectrometer Efficiency for pp data/pp MC Tight Muon



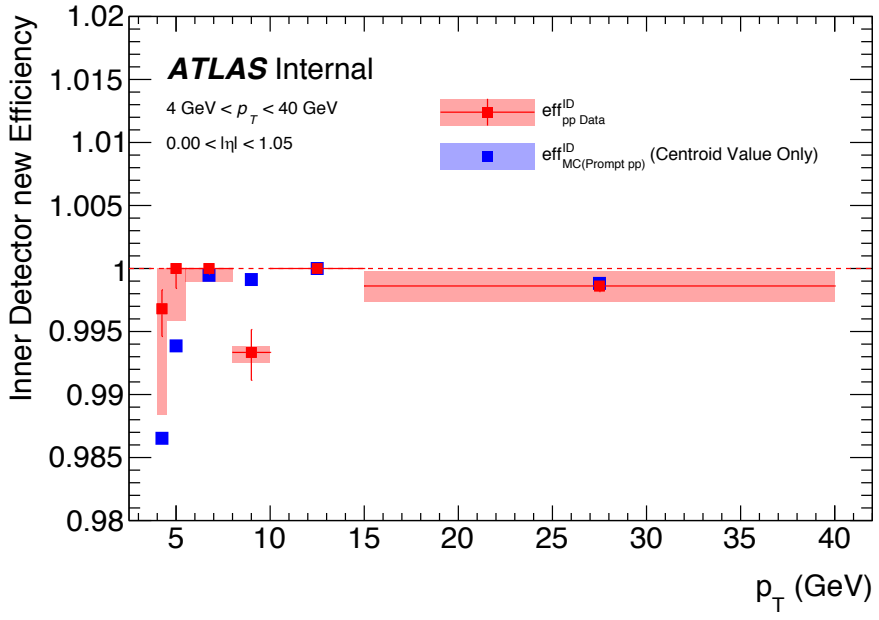


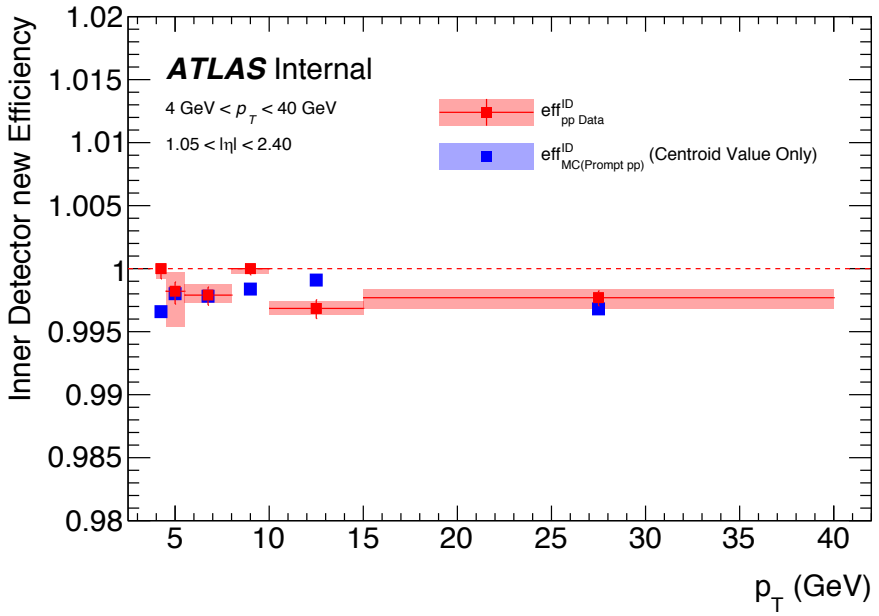


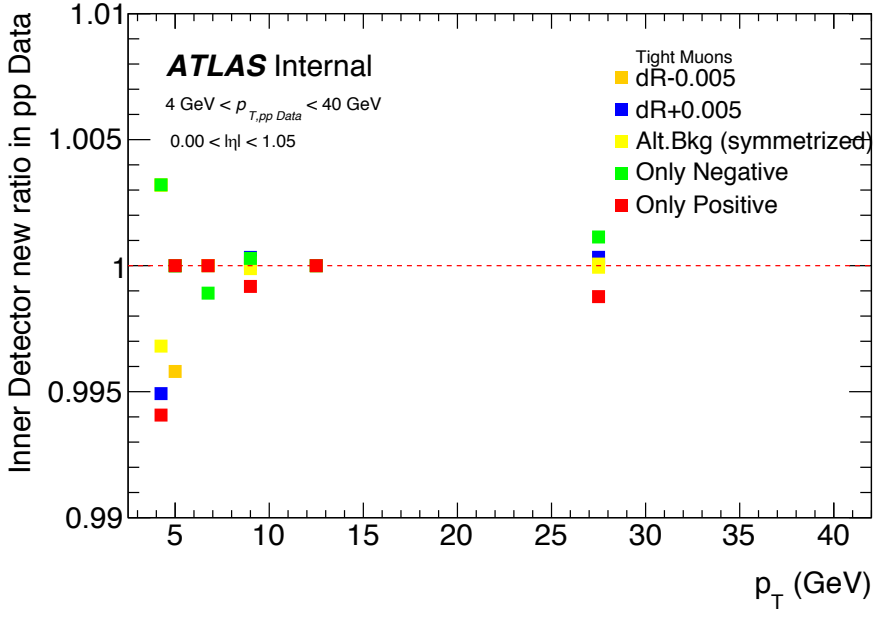


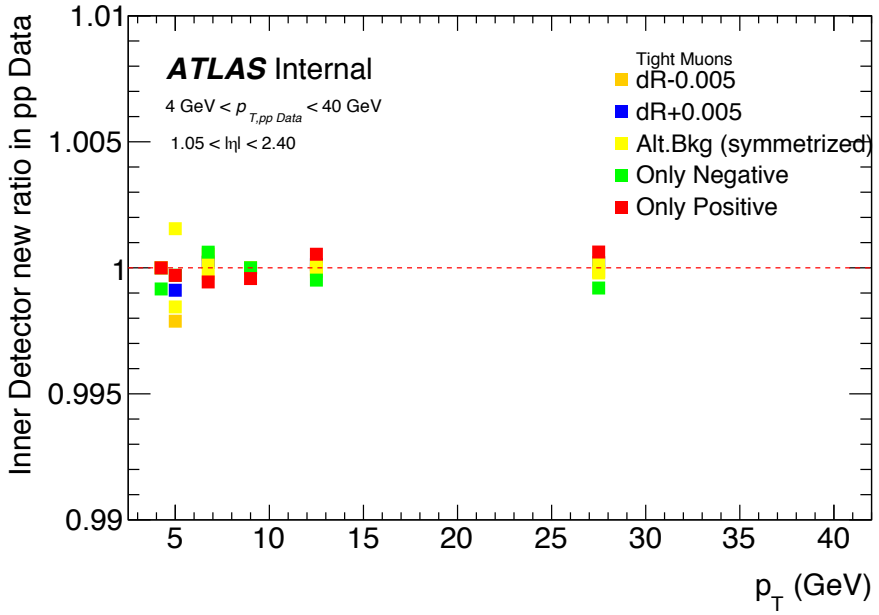
- Major source of uncertainty comes from separating charges.
- Barrel region has slightly lower efficiency (same as PbPb)
- See scale factor in slide 13 for comparison of data and MC.
- Negative charges and positive charges

Inner Detector Efficiency for pp data/pp MC Tight Muon



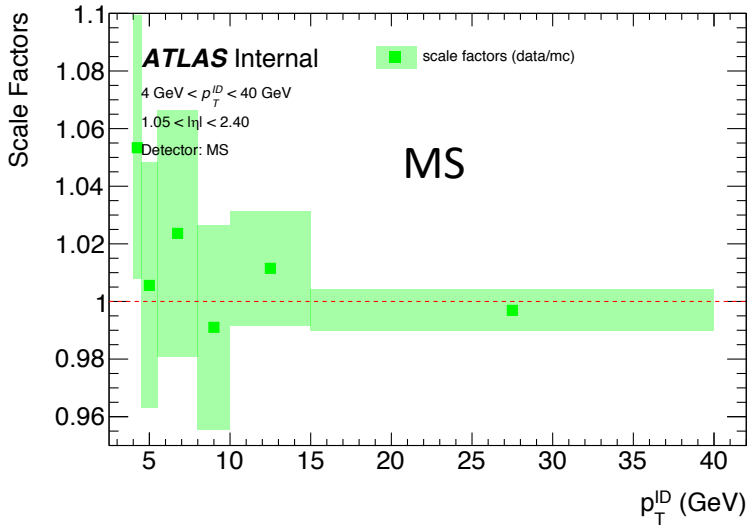


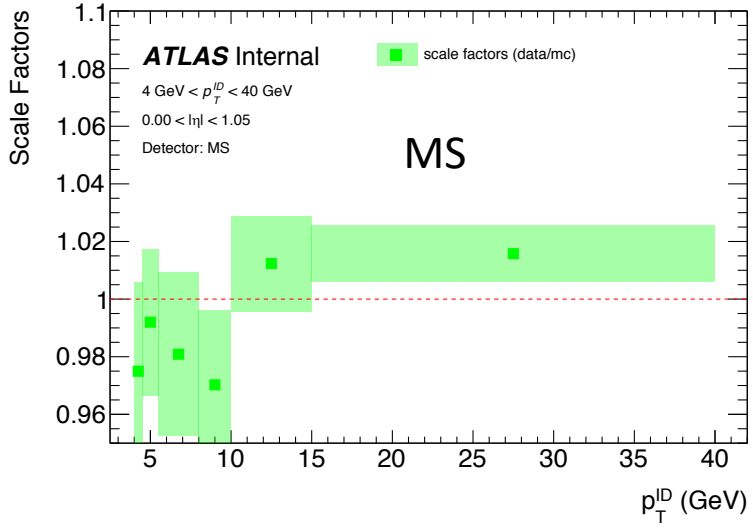


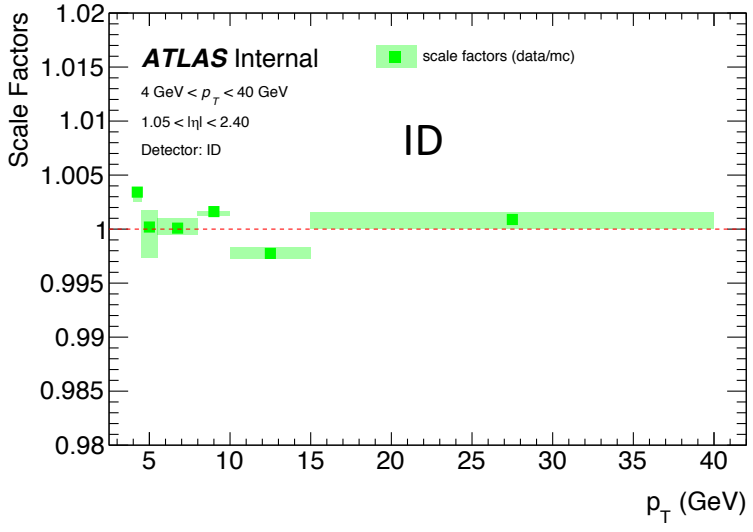


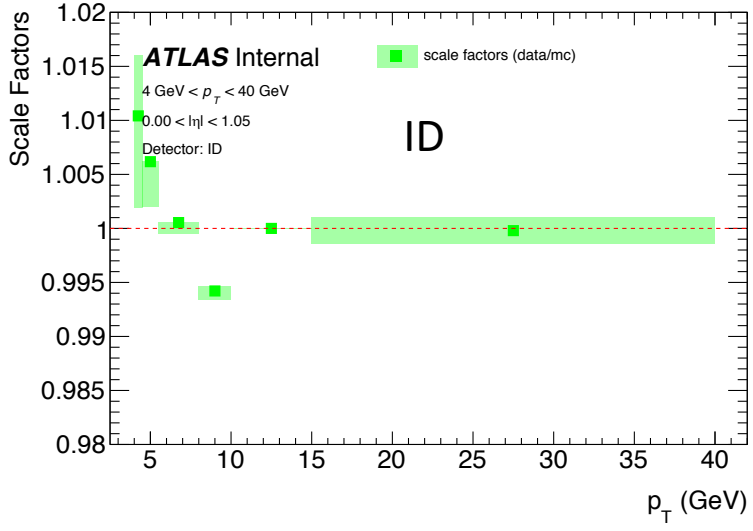
- Major source of uncertainty comes from separating charges.
- Barrel region has slightly lower efficiency (same as PbPb)
- See scale factor in slide 13 for comparison of data and MC.
- Systematics for separating the charges are smaller now and is smoother from point to point.

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 pT < 10 GeV agree with each other around 0.98
  - for pT > 10 GeV agree with each other around 1.02

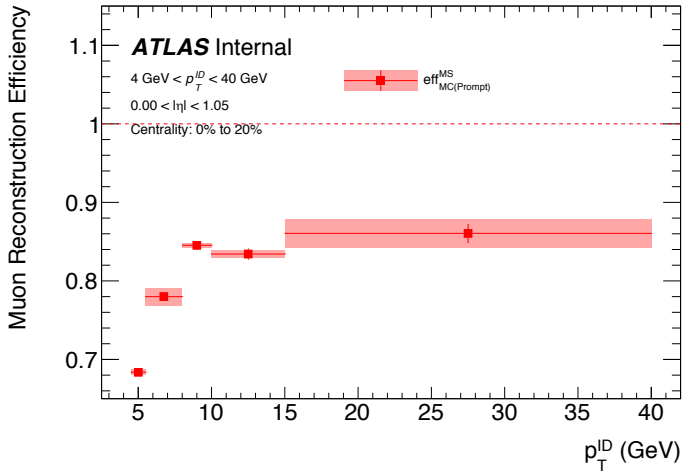
Summary

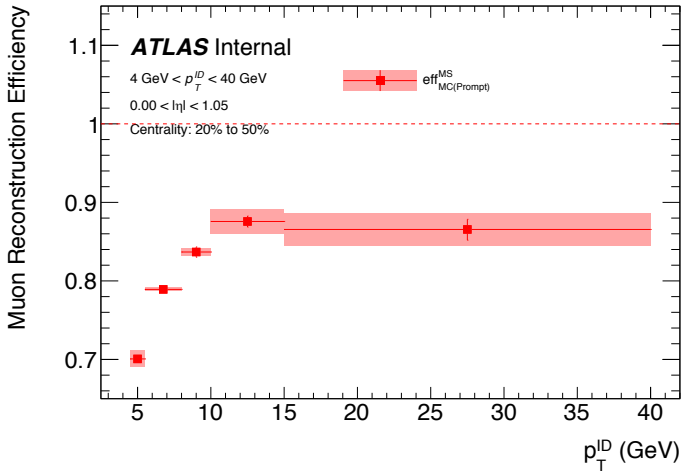
- There two methods for calculating the reconstruction efficiencies of muons (or tracks) with a certain quality:
  - The tag and probe (T&P) uses $\varepsilon(\mu) = \varepsilon(\mu|\mathrm{ID})\times\varepsilon(\mathrm{ID}) \cong \varepsilon(\mu|\mathrm{ID})\times\varepsilon(\mathrm{ID}|\mathrm{MS})$. (MC and data)
  - The truth match method find whether there's a reconstructed muon close to each truth muon.
- In pp MC, the two methods agree within ~2% and ~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 ~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 ~15% higher efficiency than truth for tight muons, and ~5% higher efficiency for ID tracks.
    - What else contribute to the difference?
  - *In progress: Compare the two methods for medium muons in PbPb MC. Will look into whether we see a similar difference.*

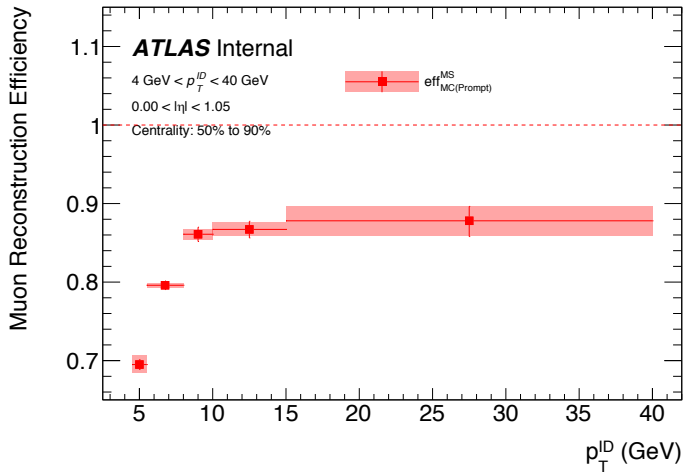
Back-up

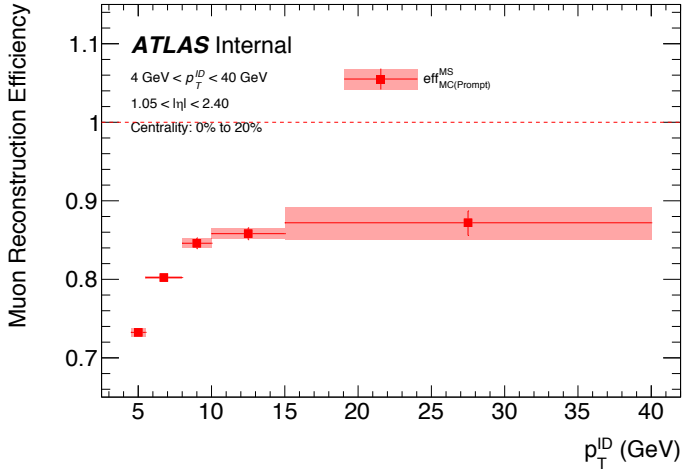
- Truth is reweighted by id tracks, which saves most of the events.

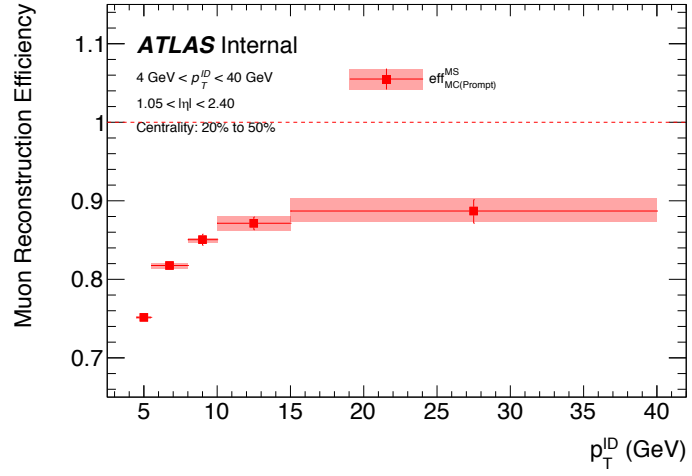
Reweighted PbPb MC T&P Results

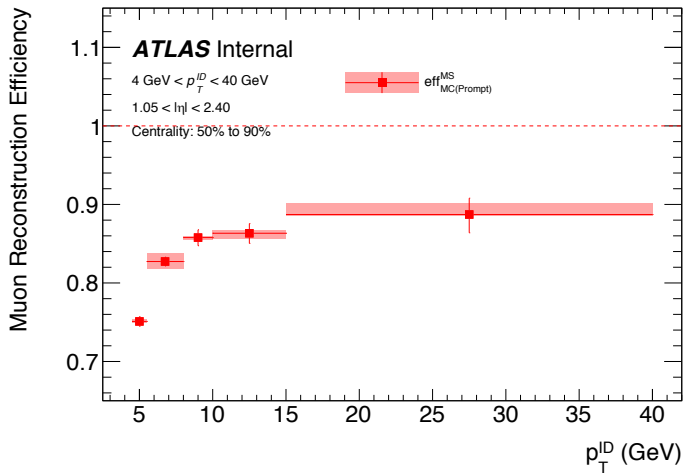




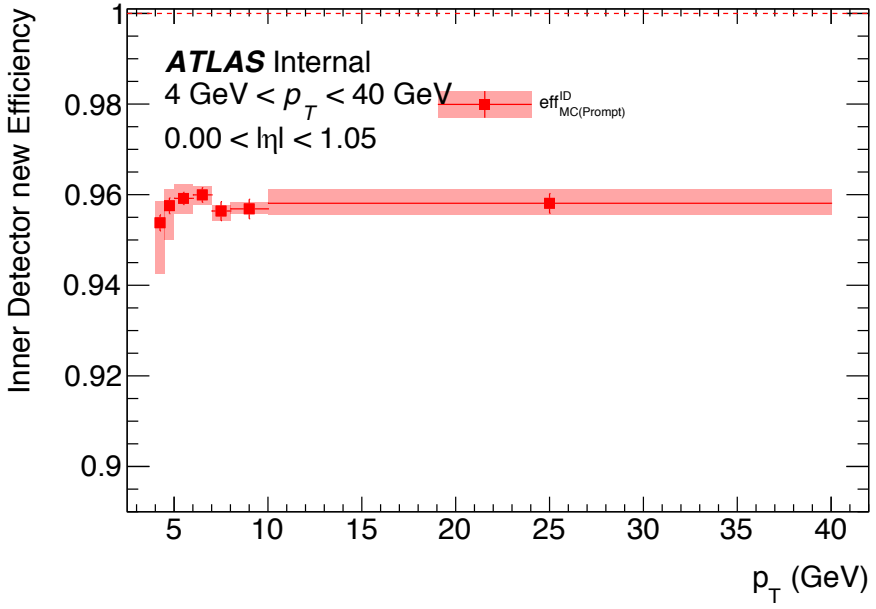


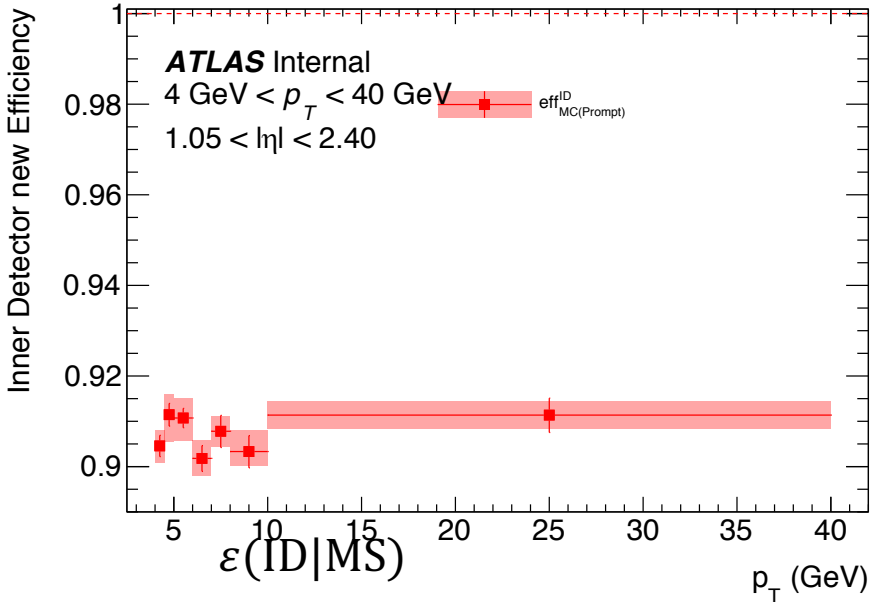




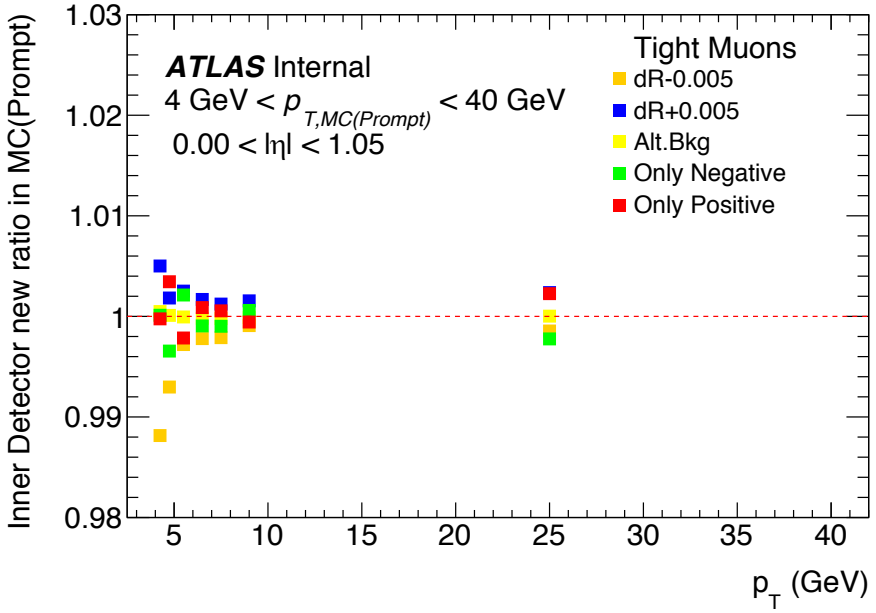


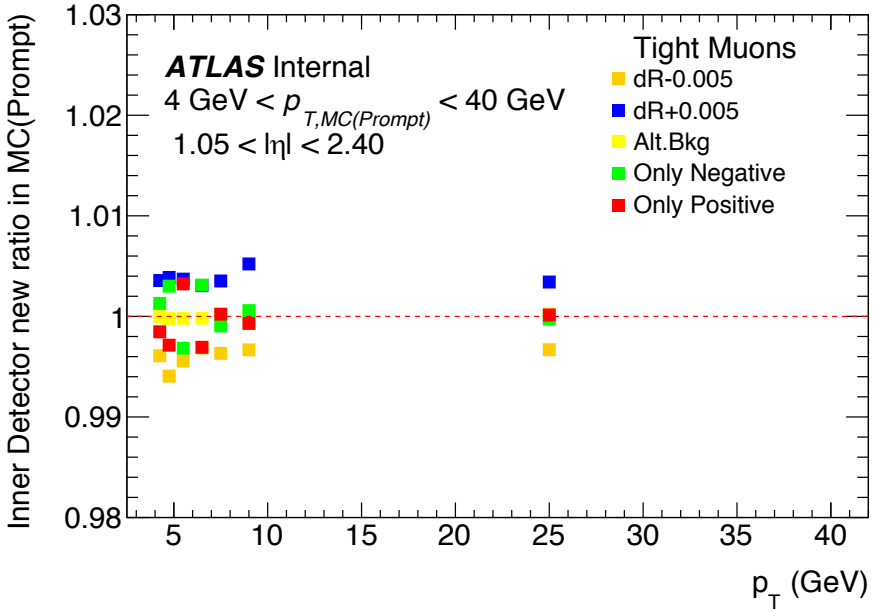
$\varepsilon(\mathrm{ID}|\mathrm{MS})$ in PbPb MC Tight Muon Using T&P (unreweighted)



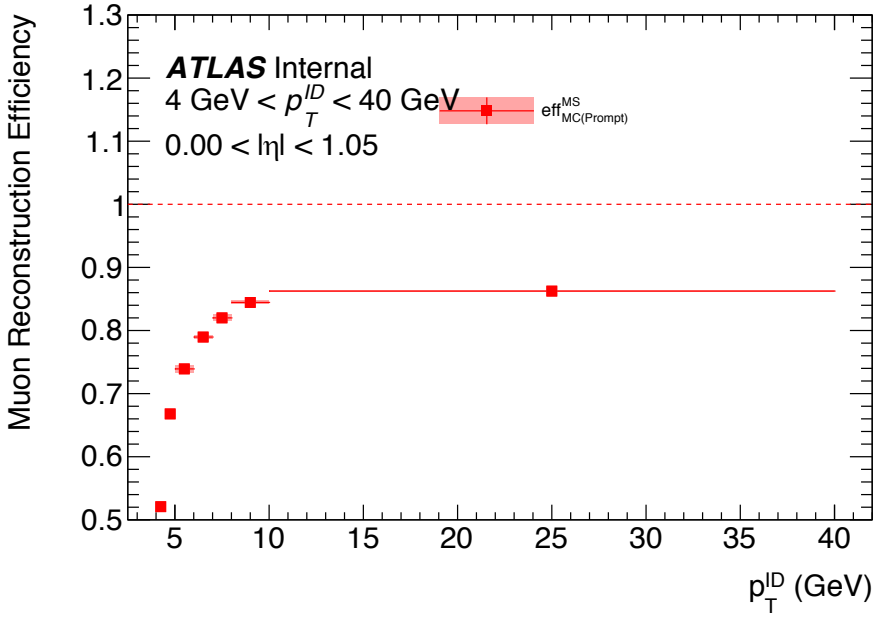


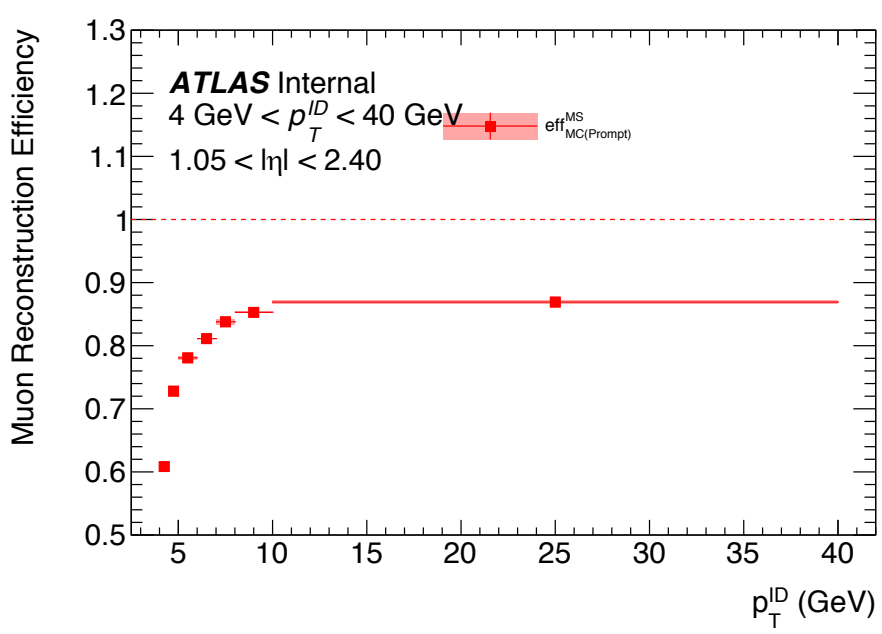
$\varepsilon(\mathrm{ID}|\mathrm{MS})$

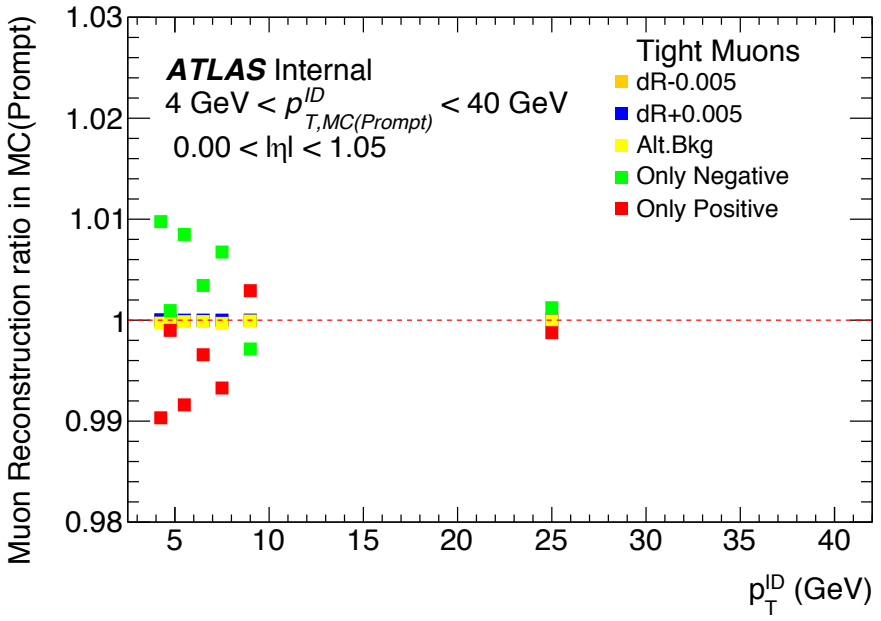


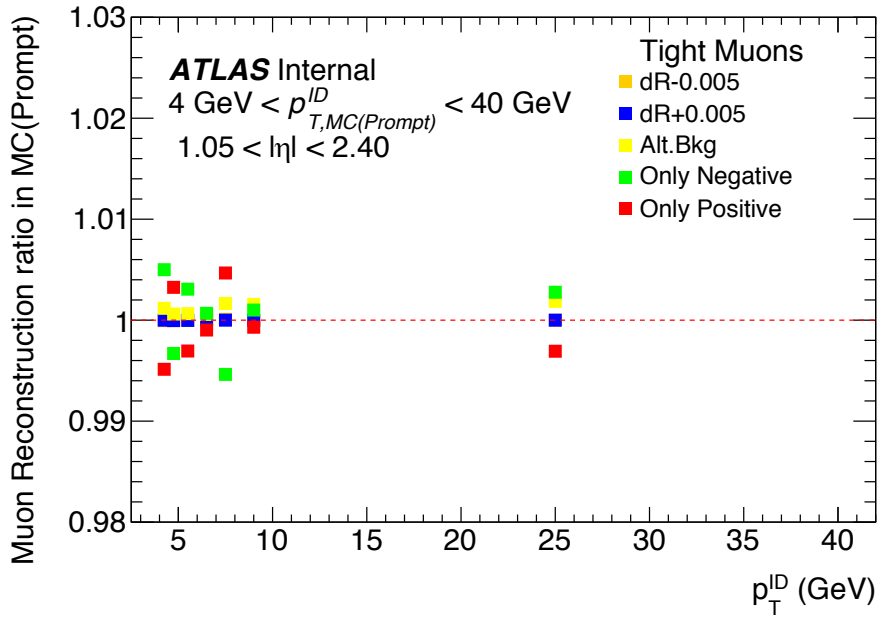


$\varepsilon(\mu|\mathrm{ID})$ in PbPb MC Tight Muon Using T&P (unreweighted)

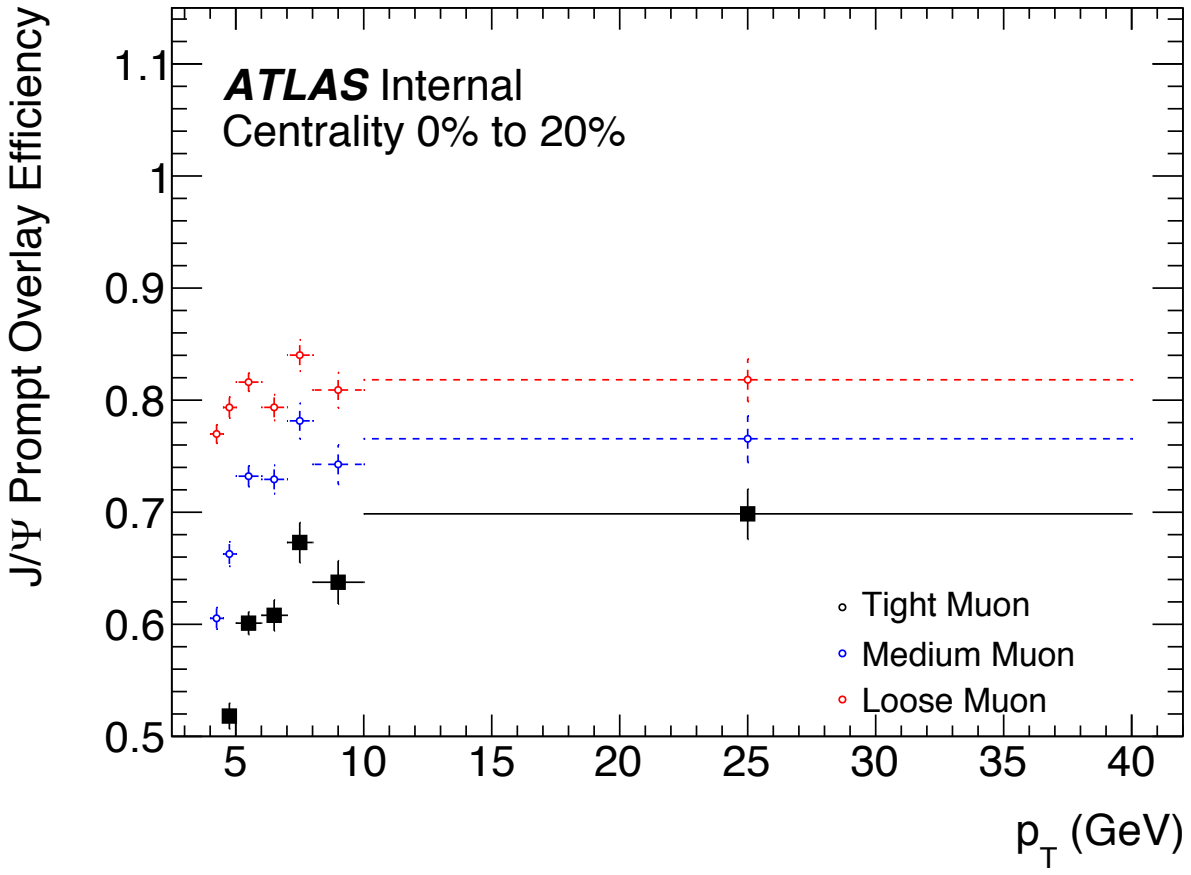


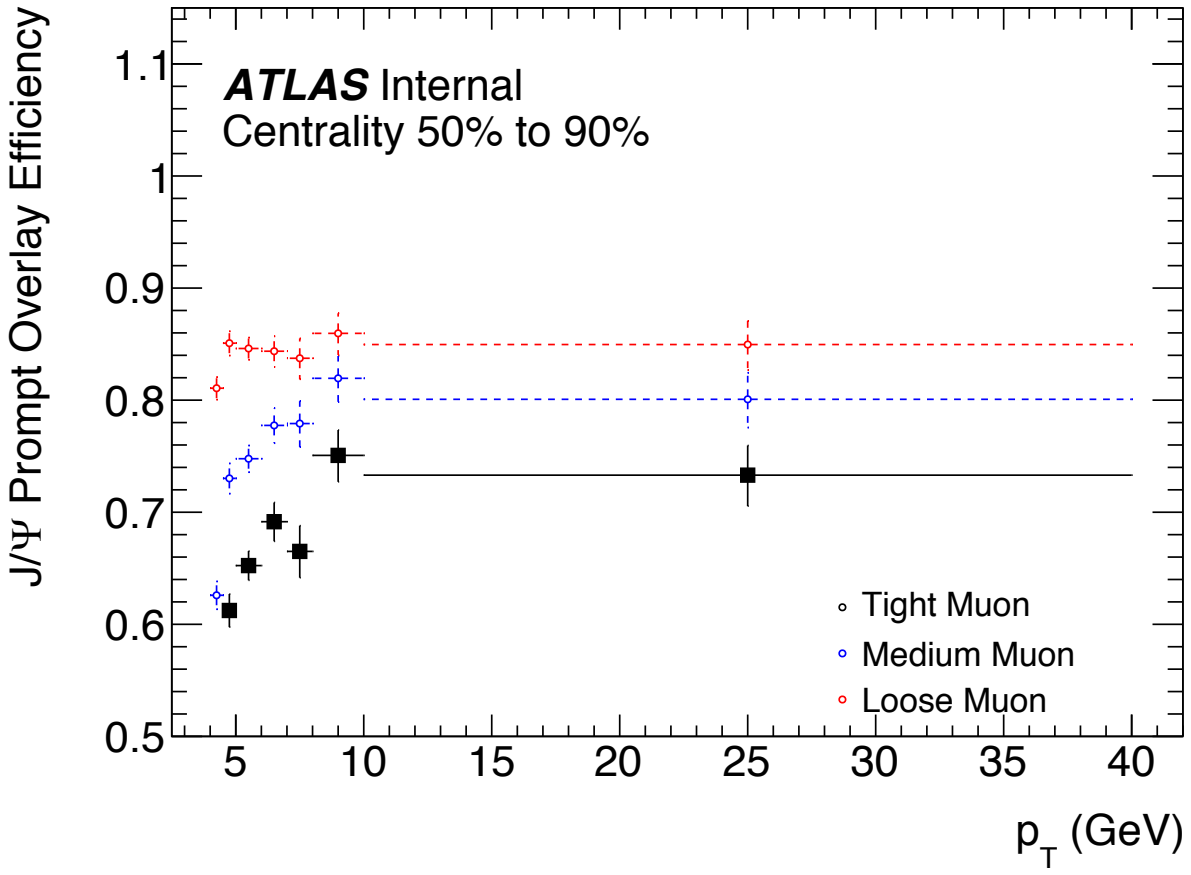






PbPb MC Tight Muon using Truth match





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