Generator Dependence of Muon Isolation Efficiency

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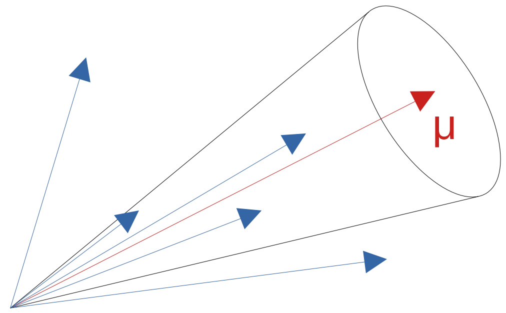
ATLAS EXPERIMENT

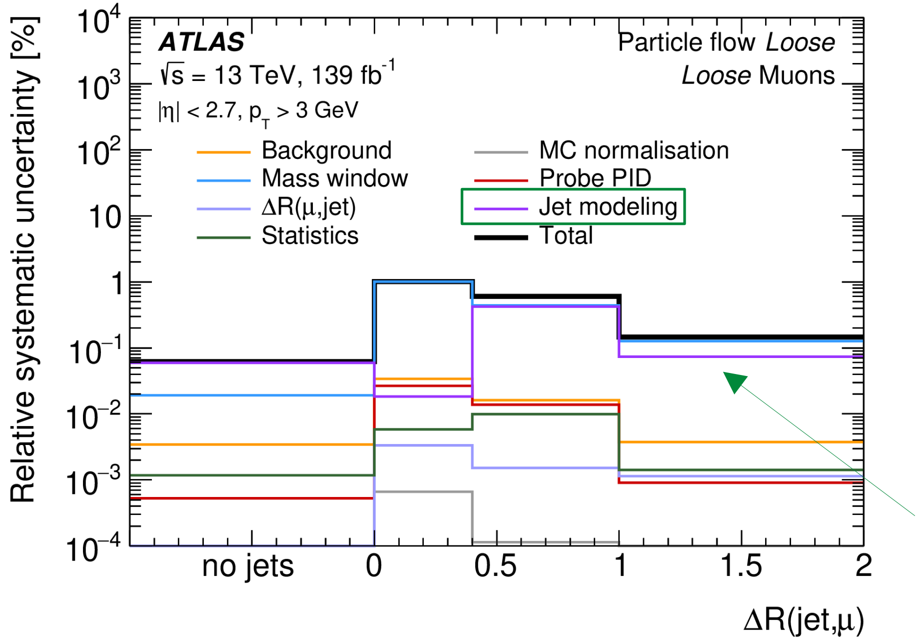
Introduction (Muon Isolation)

- Describes the amount of close range activity around muons
- Charged contributions are evaluated by summing p_T of tracks within a cone close to muons
- Neutral particles are accounted for by using particle flow and calorimeter energy deposits
- Use these variables together with muon p_T to create an isolation score



Motivation

- Isolation efficiency is generator dependent
- This creates an uncertainty for analyses
  - ➤ Largest contribution to uncertainty for efficiency measurements
- We want to better understand and reduce this uncertainty if possible



Methodology

- For these studies Z decays into a pair of muons are used
- Two datasets created with different shower generators: Powheg + Pythia 8 and Sherpa 2.2.11
- Compare shapes of distributions for various variables to look for inconsistencies
- Try to find the precise cause for the observed differences
- This study was done using Run 2 MC

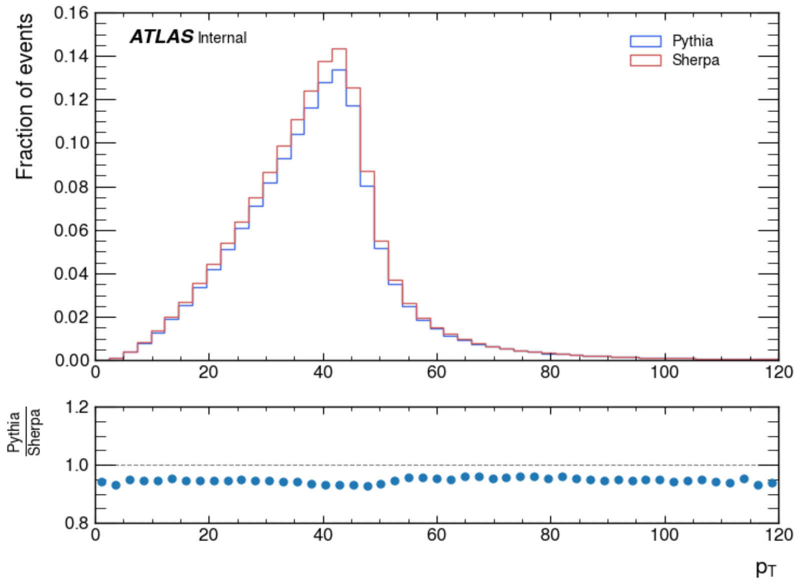
Event Selection

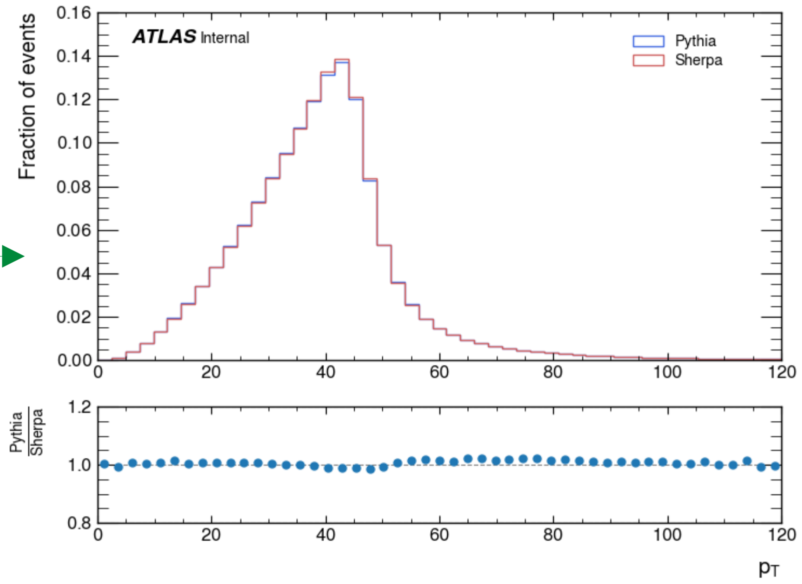
- Analysis is done on ntuples produced from these samples using MuonxAODAnalysis
- Event selection details:
  - Only look at events with exactly 2 muons, both originating from the Z boson
  - Cut on dimuon mass: 80 GeV < m_{ll} < 100 GeV
  - Data is normalized with respect to its respective dataset
- Shapes of distributions more important than absolute numbers

→ Scale one of the distributions so the total number of entries matches the other in order to make comparison of distribution shapes easier

Distribution Scaling

- Absolute numbers do not match after normalization
- Use average of ϕ ratio plot to determine scaling factor



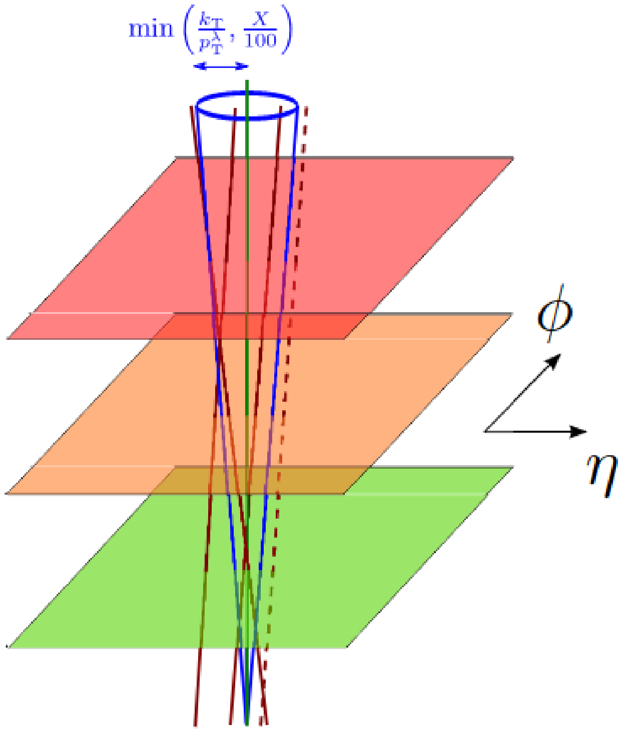


Isolation Efficiency

- Isolation WPs implemented as: track_iso + 0.4 * calo_iso < threshold * p_T
- Check the efficiency binned in the track and calo isolation variables for following isolation WPs
  - PFlow_Loose_VarRad
  - PFlow_Tight_VarRad
- Relevant isolation variables are $p_T^{varcone30}$ and $E_T^{neflow20}$
- Thresholds are 0.045 for tight and 0.16 for loose WP
- Isolation Efficiency of a WP given by $\frac{\text{number of muons passing isolation WP}}{\text{total number of selected muons}}$

Definition of ptvarcone30

- Look for tracks in isolation cone centered around muons
- Cone radius given by $\Delta R = min\left(\frac{10\,\mathrm{GeV}}{p_T}, 0.3\right)$
- Consider all tracks with p_T > 500 MeV
- Add p_T of all tracks together
- The p_T of the muon track is not added



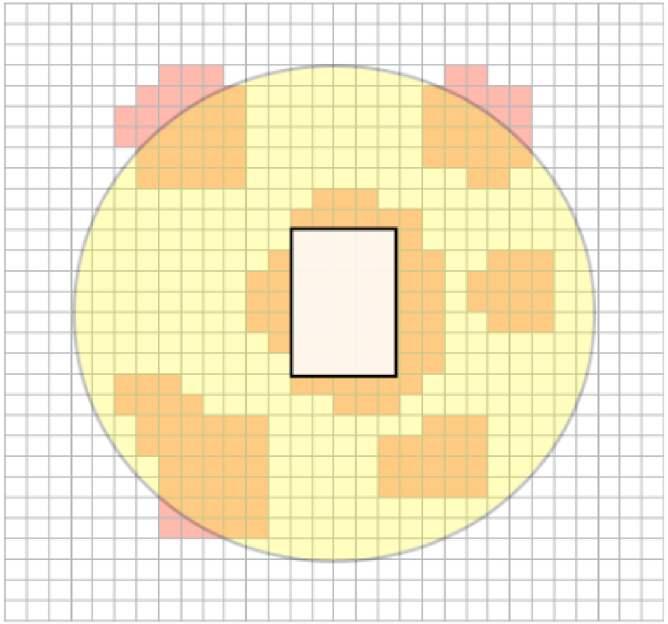
Definition of neflowiso20 (simplified)

- Particle flow based track and calorimeter measurements

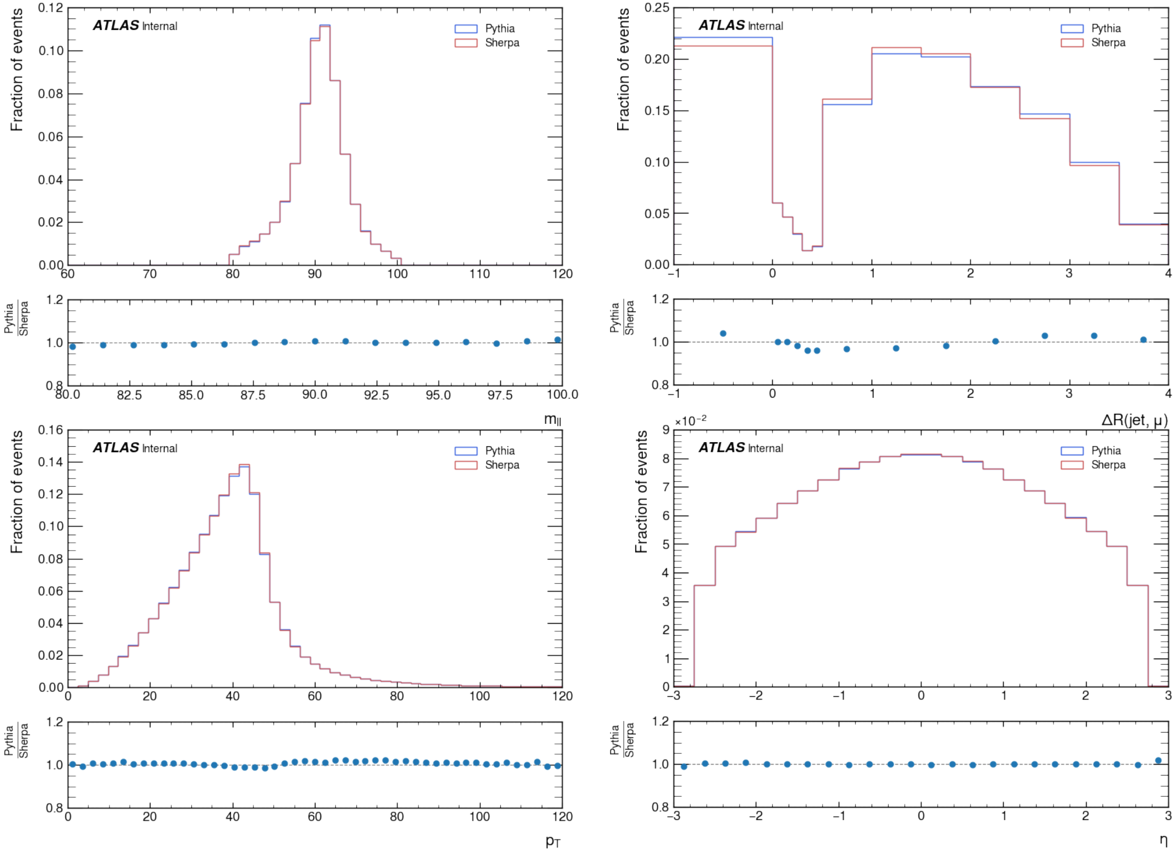
  → Allows determining neutral particle calorimeter contribution

- Select good tracks and remove muons
- Match to calorimeter clusters within 0.2 ΔR radius
- Substract clusters matched to tracks
- Add up contributions of remaining cells

  → Get value of isolation variable

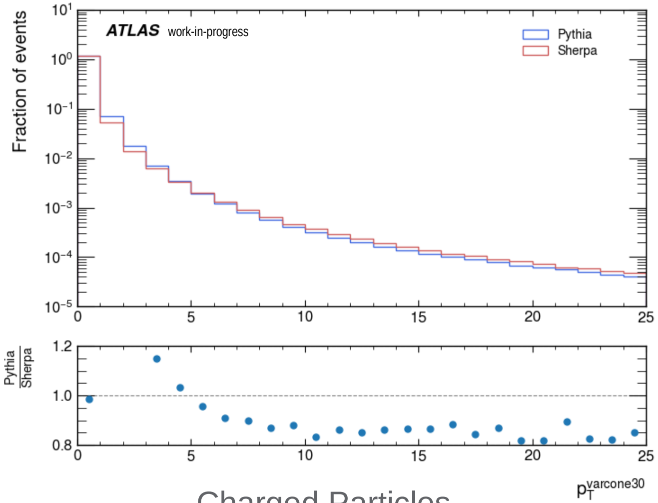


Generator Differences for Muon Variables

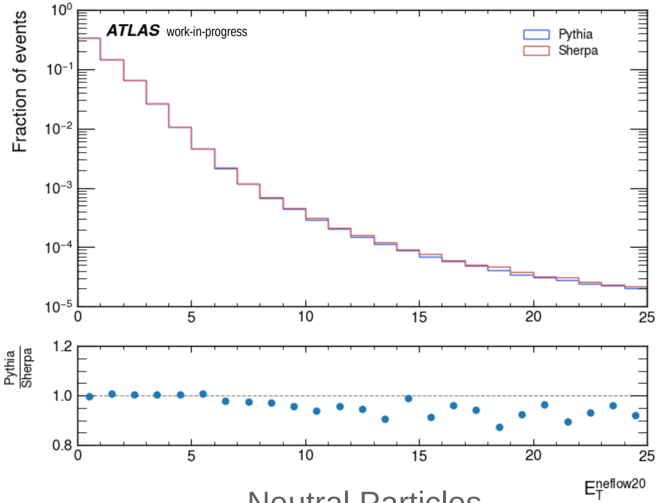


- Sanity check to see if distributions of basic muon properties are affected
- Distributions match almost perfectly, as expected
- ΔR(jet,μ) shows slight differences due to different shower behavior

Isolation Variables



Charged Particles



Neutral Particles

- Generator differences are visible in the isolation variables
- Inconsistencies seem to be larger for the component of the isolation variable based on charged tracks

Investigate Impact on Isolation Efficiency

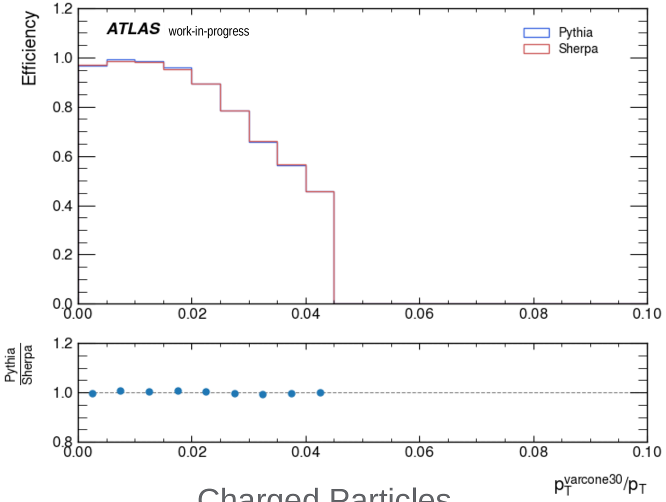
- How do these observed differences affect the isolation efficiency?
- Idea: look at the efficiency of the isolation variables themselves
- The efficiency in each of the bins then depends only on the other variable
- Example for plotting track_iso/p_T efficiency:
- track_iso/p_T + 0.4 * calo_iso/p_T < threshold

→ The number of isolated muons in each bin of track_iso/p_T depends on the 2^{nd} term

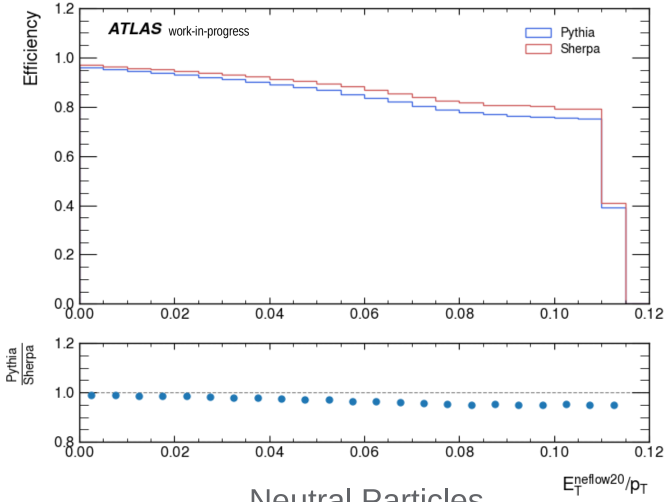
→ If there are differences in efficiency it is because of the calo_iso/p_T variable

Efficiency of Isolation Variables

- Allows to investigate effect of differences in isolation variables on isolation results



Charged Particles



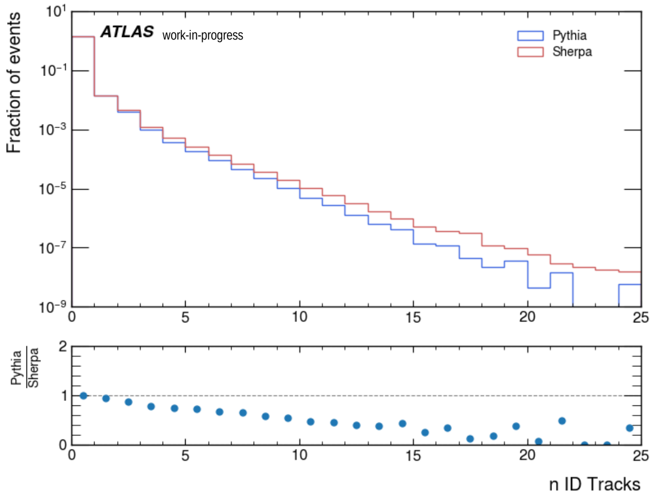
Neutral Particles

→ Efficiency unaffected by neutral particle differences

→ Efficiency significantly affected by charged track differences

Inner Detector Track Analysis

- Check activity around muons in inner detector
- Use only tracks with p_T > 500 MeV
- Count number of tracks within a cone with $\Delta R < 0.3$
- Sherpa dataset shows more tracks on average
  - → Extra shower particles affect isolation efficiency
  - → Investigate the nature of these particles

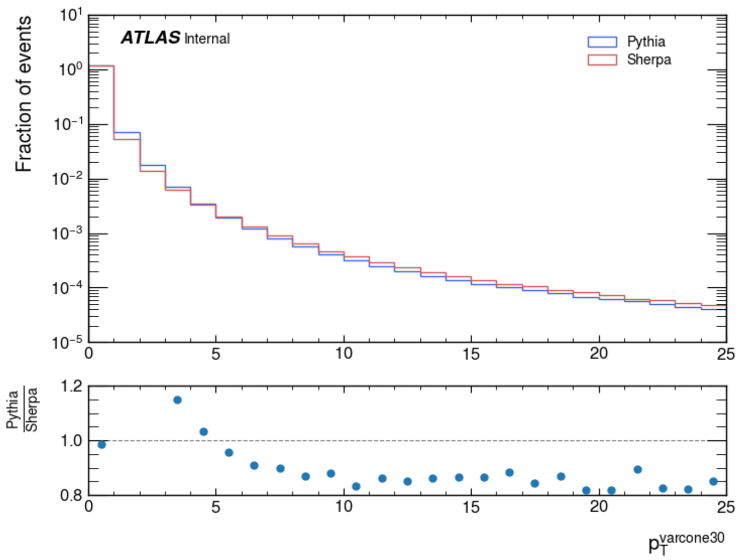


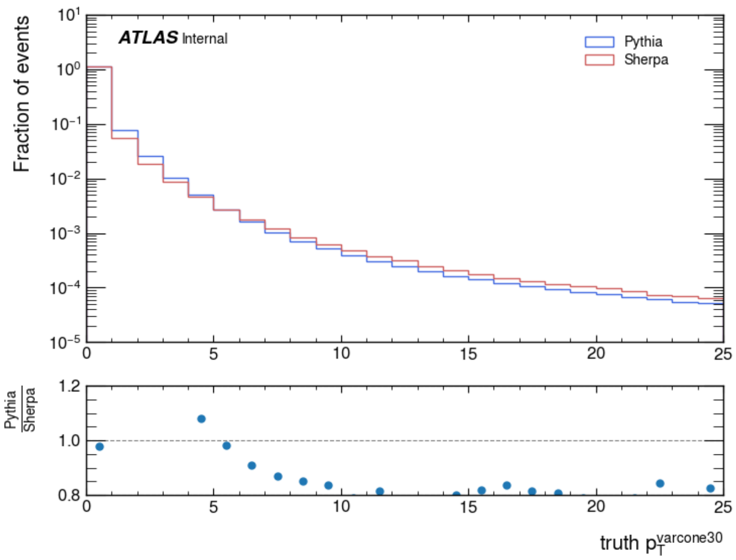
Implementing Truth ptvarcone30

- Find truth particles corresponding to muon and other id tracks
- For each inner detector track truth particle:
  - Calculate ΔR between truth muon and truth particle
  - Check if ΔR is smaller than the radius min(0.3, 10GeV/p_T) using truth muon p_T
  - If yes, add truth particle p_T to truth ptvarcone30 of muon

    → Also retrieve truth particle pdg id in this case (slide 17)
- Missing or invalid truth particles are interpreted as nonexistent

Reco vs Truth ptvarcone30



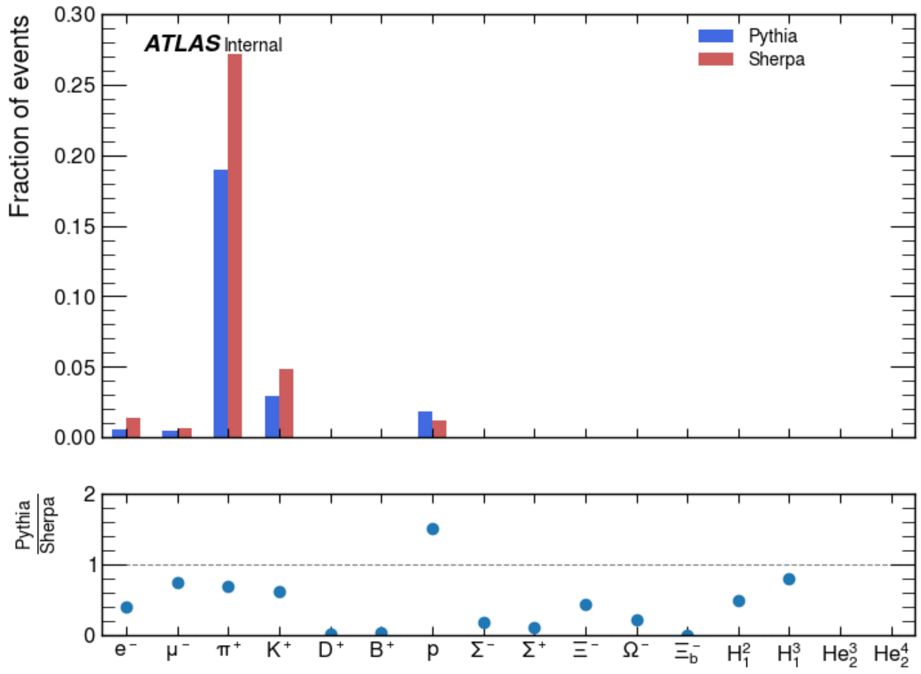


- Plots at truth or reconstruction level look very similar

→ Differences from the two generators Pythia and Sherpa present in both truth and reconstruction level

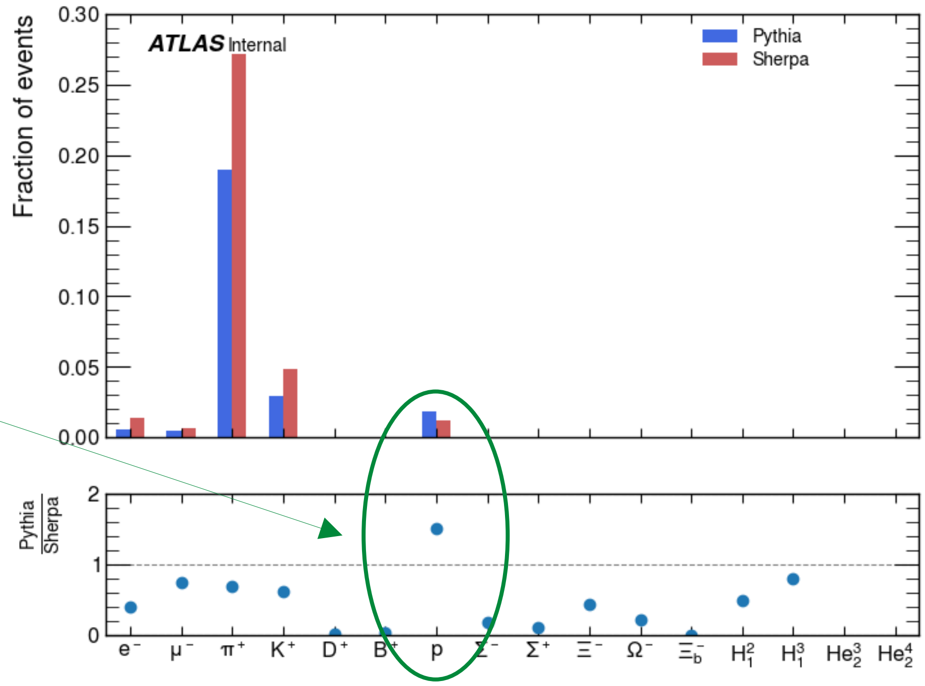
Types of Particles Close to Muons

- Collect pdg ids from truth track particles inside of the isolation cone
- Sherpa has more ID tracks so more entries
- Most rare particles seem to be even rarer in Pythia



Types of Particles Close to Muons

- Collect pdg ids from truth track particles inside of the isolation cone
- Sherpa has more id tracks so more entries
- Most rare particles seem to be even rarer in pythia
- Protons are significantly more common in pythia despite the lower number of tracks



Conclusions

- Muon isolation efficiency depends on the choice of shower generator
- Searched for origin of this effect by comparing MC distributions
- Found ID tracks most affected by these differences

  → Related to a significant difference in number of id tracks close to muons
- Checked truth level information and found the same differences in distributions
- Aim is to better understand the differences in order to reduce systematic uncertainties on efficiency measurements

  → Currently discussing these findings together with ATLAS physics modeling group

Backup

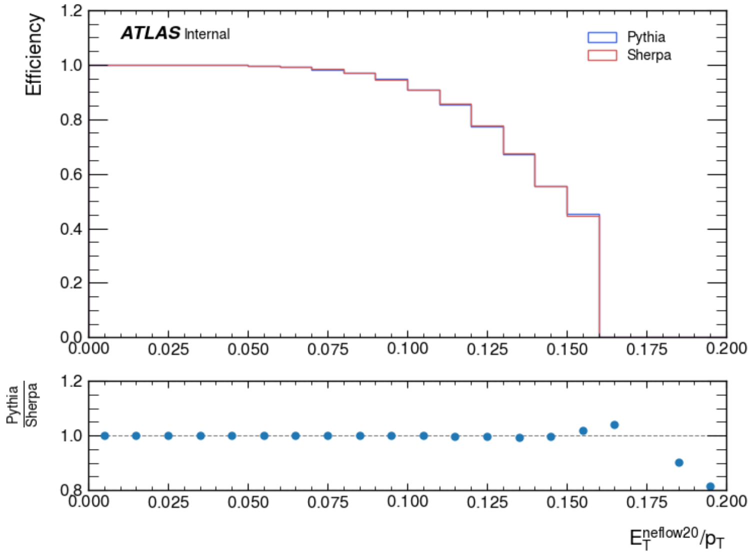
Isolation Track Selection Differences

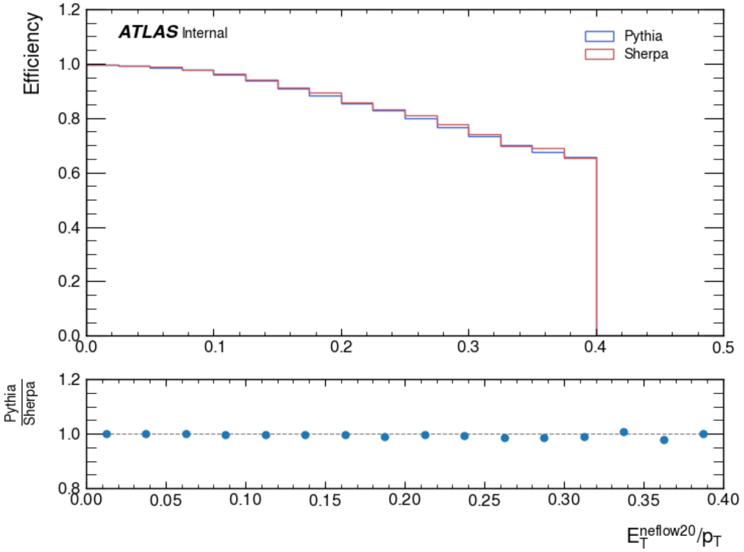
- Run 2 : ptvarconeXX_TightTTVA_ptXX
  - Track was used in vertex fit, or
  - Track was not used in any vertex fit and $|\Delta z \sin\theta| < 3$ mm
- Run 3 : ptvarconeXX_Nonprompt_All_MaxWeightTTVA_ptXX
  - Track was used in vertex fit and has maximum weight, or
  - Track was not used in a vertex fit and $|\Delta z \sin\theta| < 5$ mm and $|d_0| < 5$ mm
  - Further $|z_0 \sin\theta| < 3$mm

$|\Delta z \sin\theta|$: distance between z_0 of track and primary vertex

$|d_0|$: transverse impact parameter wrt beam line

Loose Isolation Variable Efficiencies





Particle Types With Normalized Distributions