Qualification Task AFT 455:

Optimization of Inputs for High Level Discriminants (DL1 and MV2) to Improve Performance of B-Tagging in Heavy Ion Collisions

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Homework List

- talk to Ogul & SV1 expert for how to implement track selections in SVF tool.
  - SV1 expert Vadim responded with new homework: reproduce this plot from the 2016 b-tagging performance paper: http://cdsweb.cern.ch/record/2160731/files/ATL-PHYS-PUB-2016-012.pdf
- Things to plot:
  - Reco SV dR from jet axis comparing to truth SV dR from jet axis. (maybe for different pT)

Other Things to Look at

- Reco track efficiency inside reco jets.

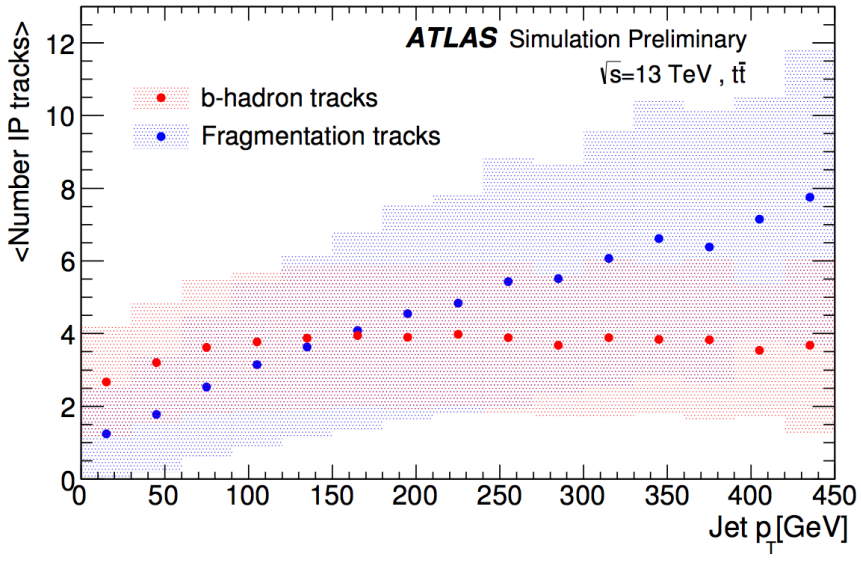
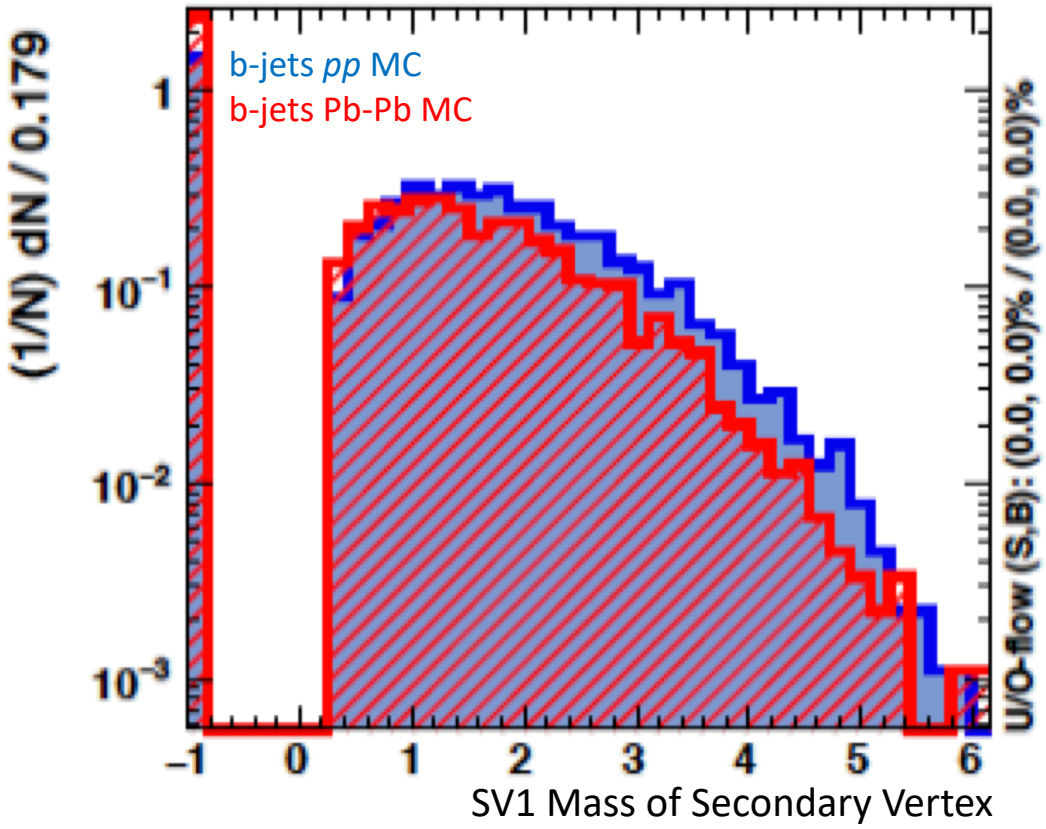


Figure 5: Average number of b-hadron and jet fragmentation tracks selected for the IP algorithm as a function of the jet p_T. The shaded band around the two contributions represents the RMS for each p_T bin.

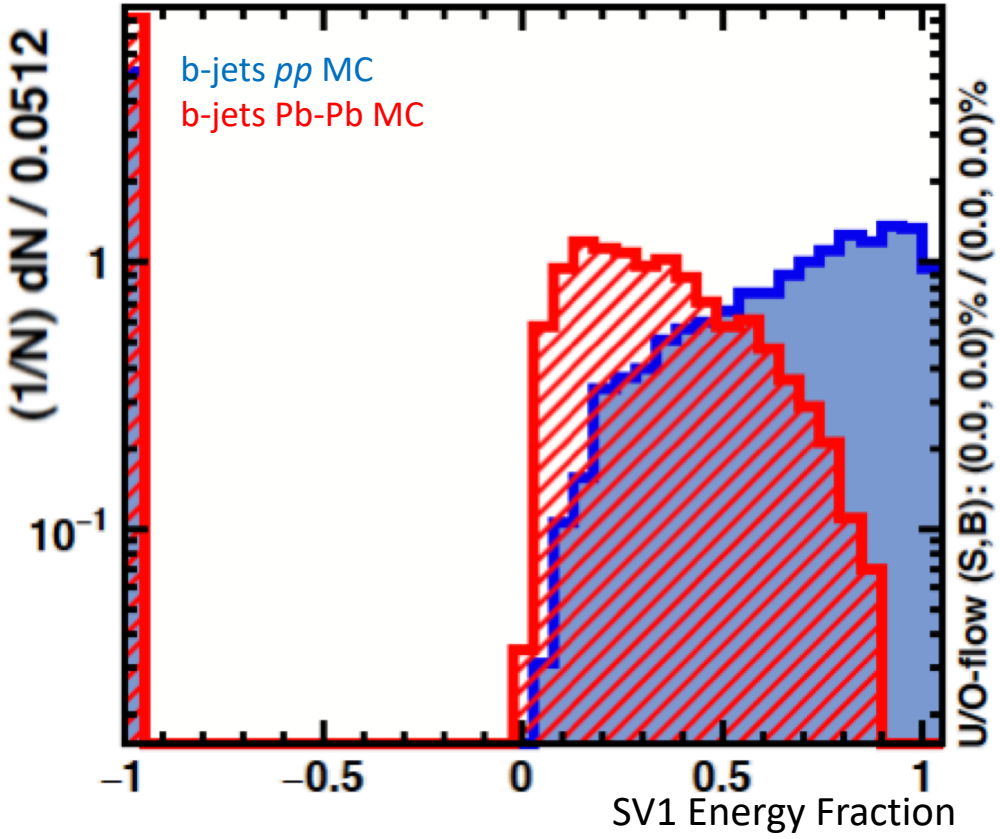
Description of Qualification Task (AFT-455)

- Optimization of inputs for high level discriminants (DL1 and MV2) to improve performance of B-tagging in heavy ion collisions.
- More underlying events (UE) in HI collisions, and some inputs are affected.

Mass of secondary vertex is similar in pp and Pb-Pb



Energy Fraction peaks differently in pp and Pb-Pb



Task Description and Summary of Plan

- Goal: optimize the inputs of high-level discriminates (DL1 & MV2) for b-tagging in HI collisions.
- Problem: HI collisions have large number of Underlying Event (UE) tracks that modify some inputs.
- First step plans: apply selections on tracks in HI MC to see whether performance improves
  - Impose cuts on p_T.
  - Apply "cone method" to subtract UE tracks effect.

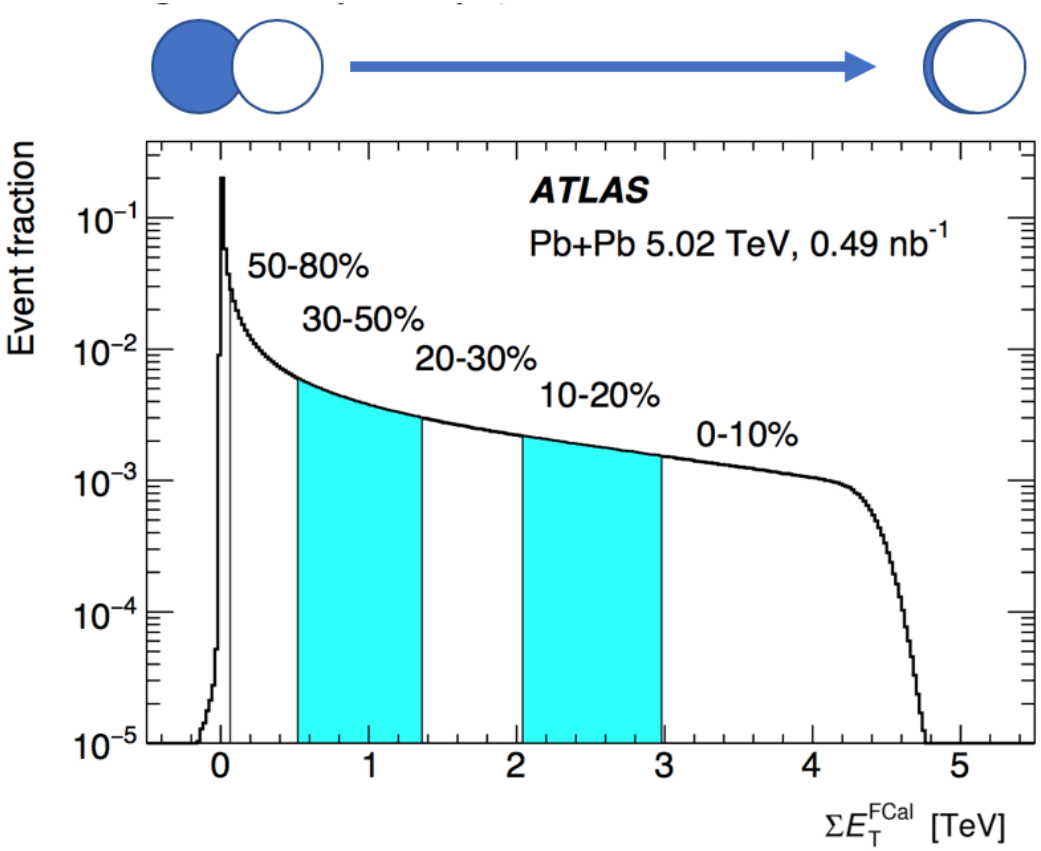
"The optimization of the inputs of high-level taggers(DL1 and MV2) for b-tagging in heavy ion collisions, following the work done in a previous QT described in AFT-233. It is known that some inputs for the taggers training are affected (like ipxd probabilities and jet fitter and sv1 energy fraction) by the large number of tracks coming from the HI collision underlying event (UE). This degrades the performance for central collisions and induces a strong centrality dependence. This effect can be reduced by implementing tighter tracking selections or an UE subtraction at the tracking level prior the calculation of the tagger inputs. If time permits, following the optimization, the calibration of the taggers will be done using HI data control samples that have a specific flavor composition e.g. jets with a muon from a heavy flavor semi-leptonic decay. This study will be documented in an internal note and the analysis recommendations will be described on a twiki."

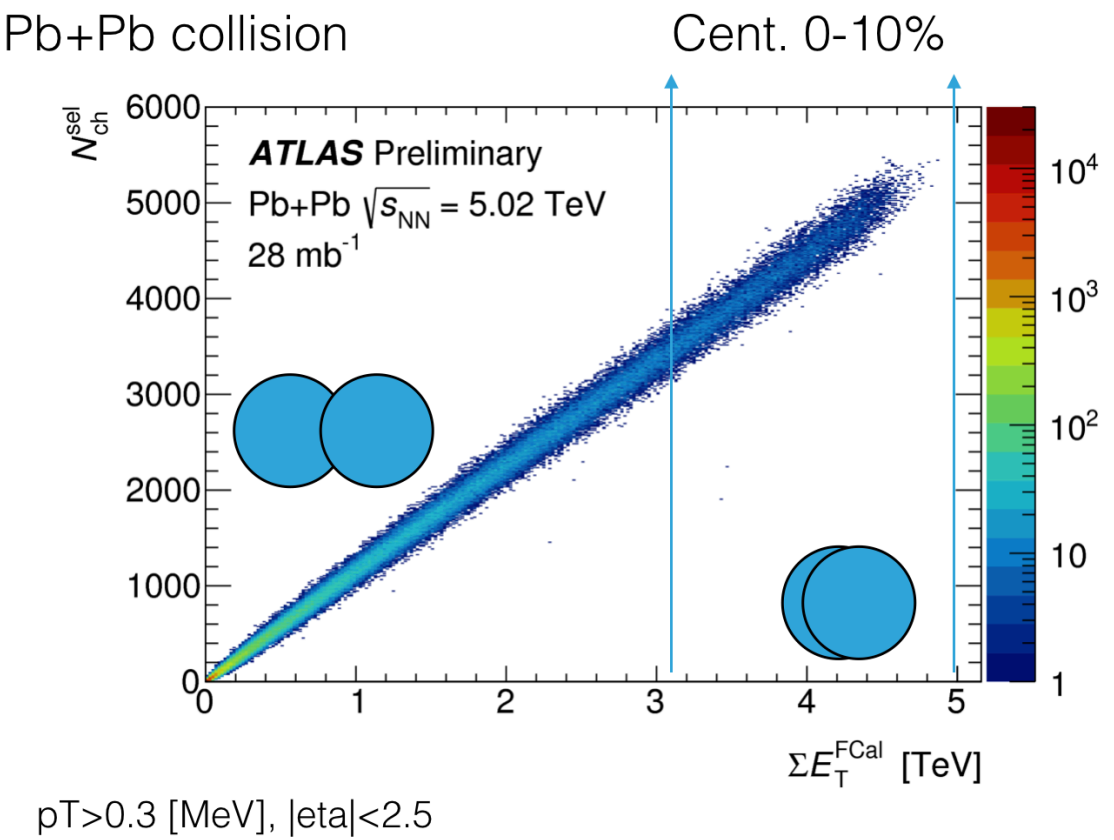
Plan from slides on Oct, 17, 2019 Flavour tagging meeting. https://indico.cern.ch/event/855757/

- Looked at performance of secondary vertex reconstruction in lower level tagger
- Implemented machinery to apply track cuts on inputs of lower level taggers
- Investigating candidate track cuts.

Centrality

- Centrality:
  - Whether the collision is central (“head-on”) or peripheral (“glancing”)
  - Estimated using the total transverse energy measured in the ATLAS Forward Calorimeter (ΣE_T)
- Central collisions have high occupancy (thousands of tracks per event)





Track reconstruction in Heavy Ion Collisions

- High occupancy (order of 1000 tracks)
  - Occupancy has a centrality dependence
- Only one primary vertex per event
- Many more underlying event tracks in comparison to pp collisions
- Different track recommendations for analysis from pp collisions
  - https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/TrackingCPMoriond2017

Heavy Ion Loose
- $|\eta| < 2.5$
- if an IBL hit is expected, then $N_{IBL} \geq 1$. if an IBL hit is not expected, then $N_{B\text{-}layer} \geq 1$ if a BLayer hit is expected.
- $N_{Pix} \geq 1$
- $N_{SCT} \geq 2,4,6$ for $p_T > 0,300,400$ MeV
- $d_0^{PV} < 1.5$ mm
- $z_0^{PV} \sin\theta < 1.5$ mm

Heavy Ion Tight
- $|\eta| < 2.5$
- if an IBL hit is expected, then $N_{IBL} \geq 1$. if an IBL hit is not expected, then $N_{B\text{-}layer} \geq 1$ if a BLayer hit is expected.
- $N_{Pix} \geq 2$
- $N_{SCT} \geq 4,6,8$ for $p_T > 0,300,400$ MeV
- $d_0^{PV} < 1.0$ mm
- $z_0^{PV} \sin\theta < 1.0$ mm
- $\chi^2 / NDF < 6$

Performance of Secondary Vertex Reconstruction in SVF

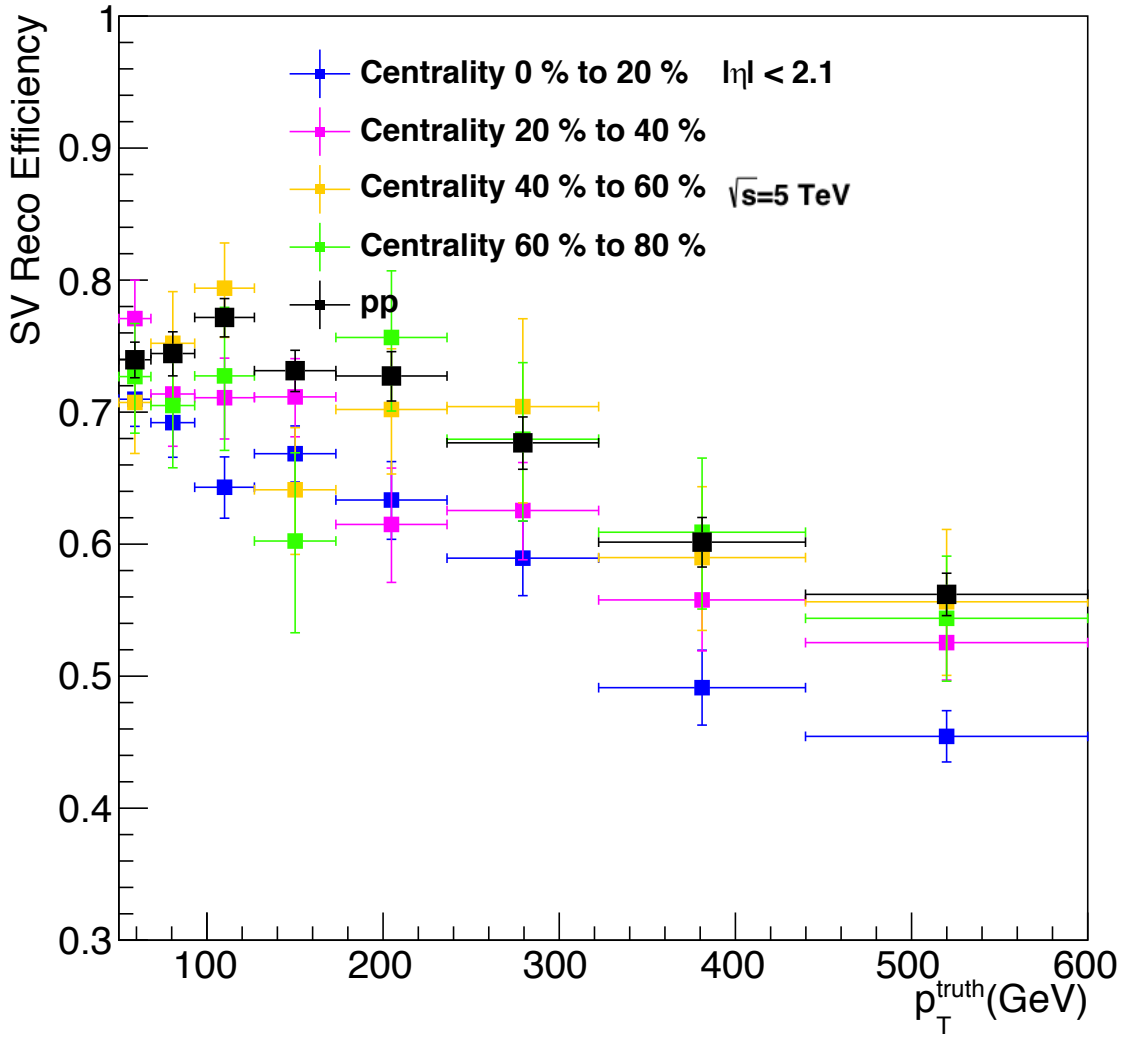
- Selection on Jets:
  - Reco jets with ΔR(truth-reco) < 0.3
  - $p_T^{truth\ jet} > 50$ GeV
  - B-Jets: jets with a truth B hadron associated with it.
    - $p_T^B > 5$ GeV
    - ΔR(truth-reco)(jet-B) < 0.3

- Selection on Tracks:
  - No selections before SV reconstruction tool
  - Default tool selection from https://acode-browser.usatlas.bnl.gov/lxr/source/athena/InnerDetector/InDetRecTools/InDetVKalVxInJetTool/src/InDetVKalVxInJetTool.cxx?v=21.2

- Tool: bTagFramework with retag flag set to on
  - https://gitlab.cern.ch/stapiaar/tagging_framework_hi/tree/master/
  - This is a modified version of https://gitlab.cern.ch/atlas-flavor-tagging-tools/FlavourTagPerformanceFramework/tree/freshstart/, allowing for selections of tracks before calling lower level taggers.

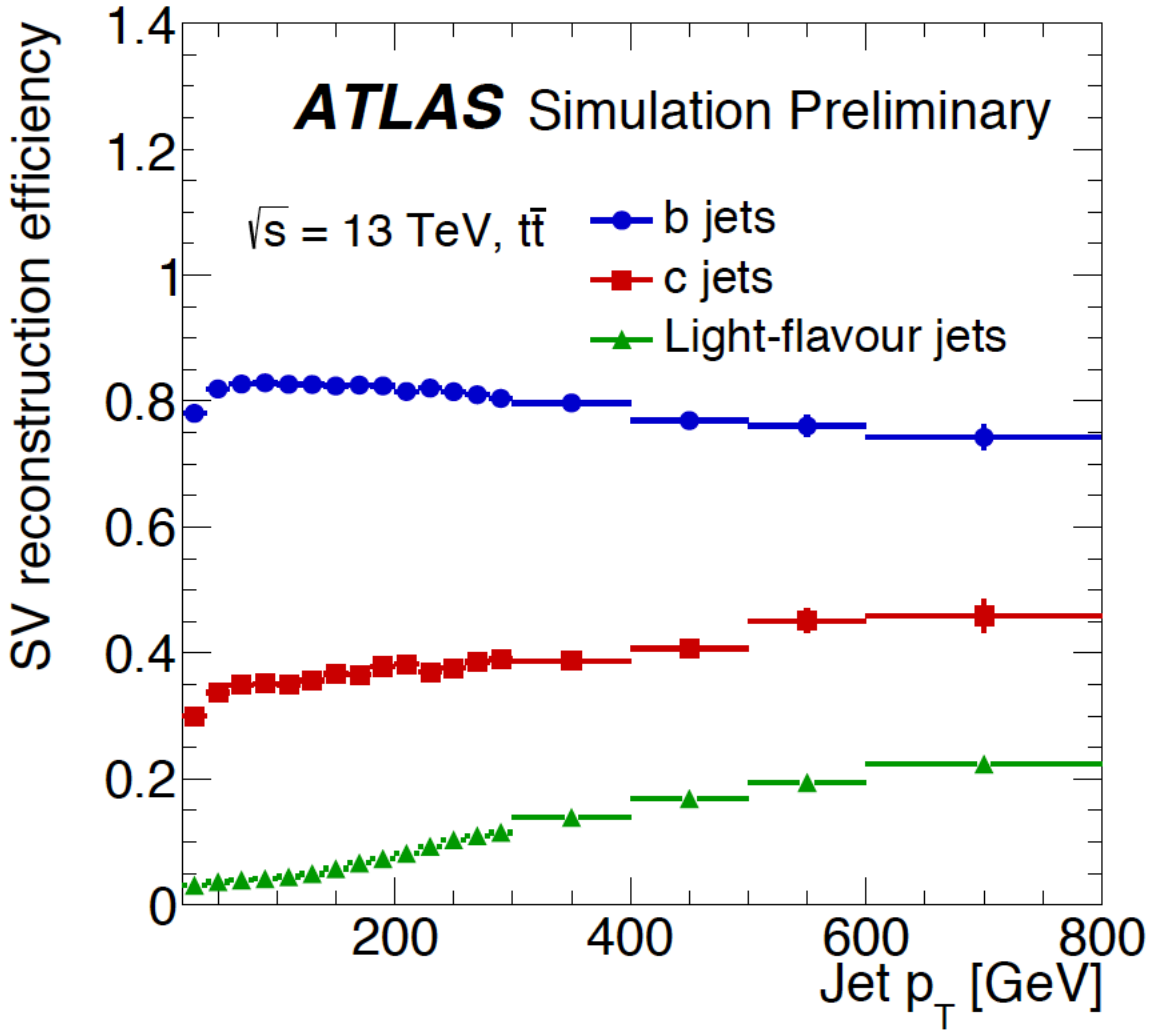
Performance of Secondary Vertex Reconstruction in SVF

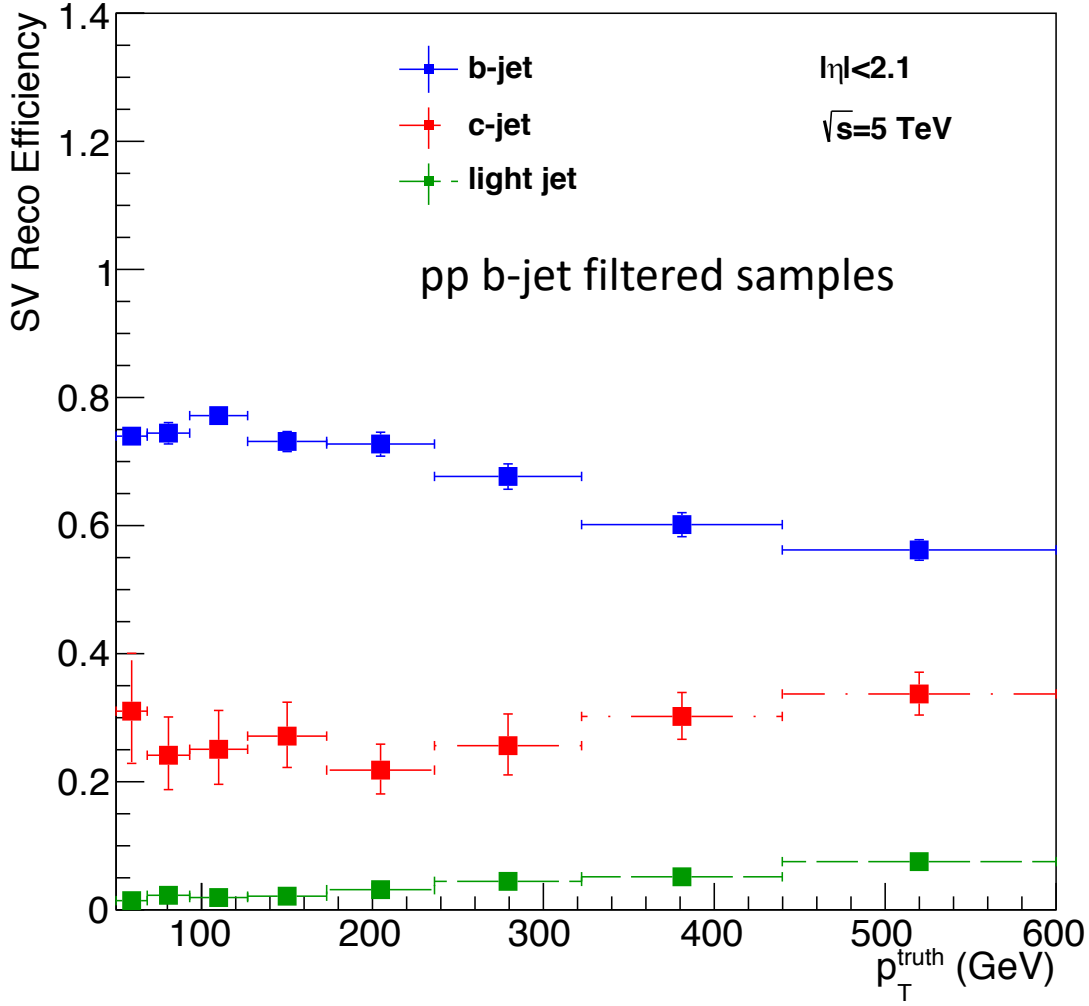
SV Reconstruction Efficiency vs Jet Truth Pt in pp MC and MC Overlay



- SV reco efficiency is dependent on $p_T^{jet\ truth}$
- Overall central events perform worse than peripheral events as expected.
- MC pp: 50k bbar filtered pp events at 5.02 GeV
- MC overlay: 50k bbar filtered pp events at 5.02 GeV overlay with 2018 MinBias data
- https://its.cern.ch/jira/browse/ATLHI-240

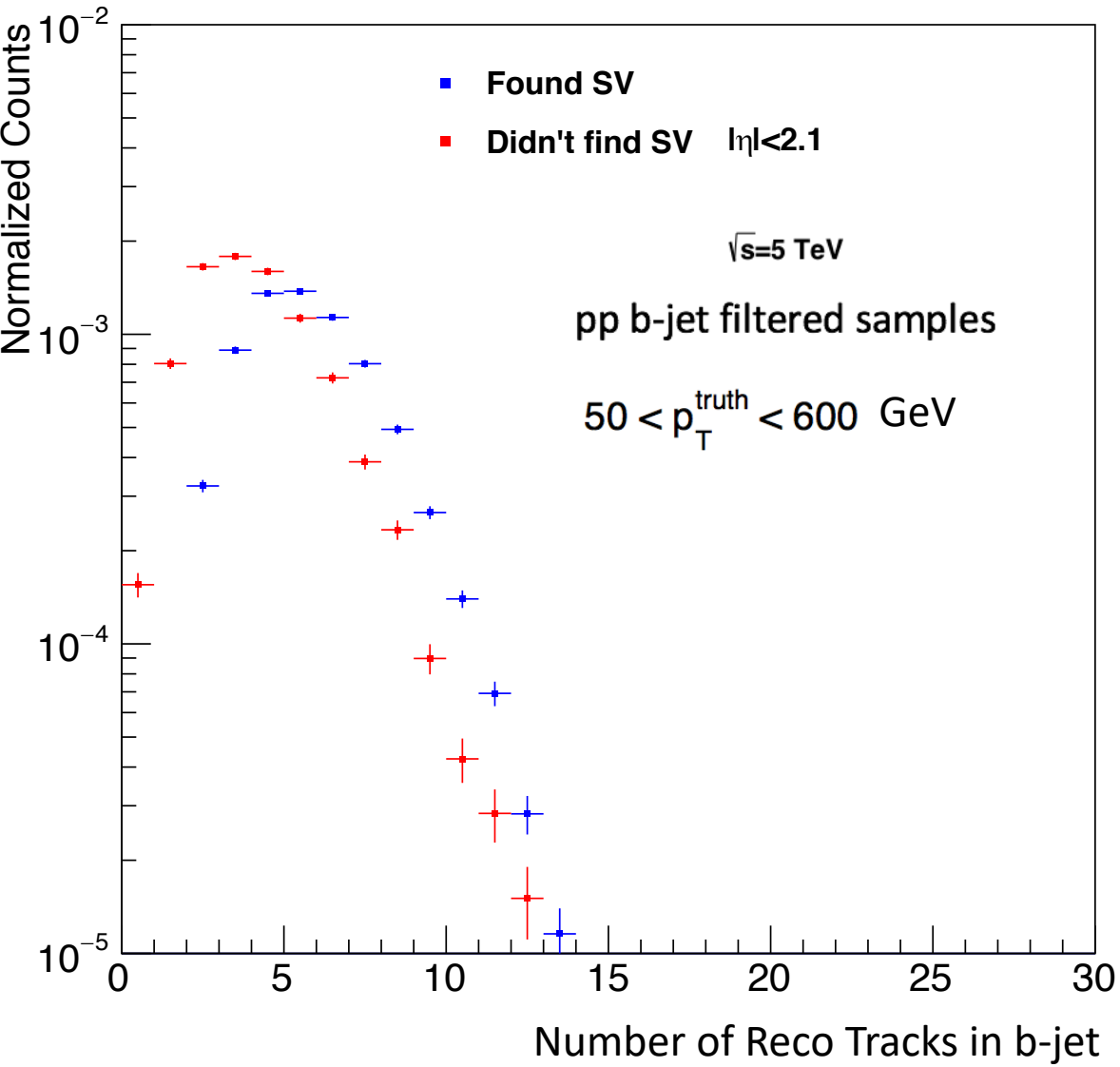
SV Reco Efficiency from SVF performance paper





- ATL-PHYS-PUB-2017-011: https://cds.cern.ch/record/2270366

Distribution of Number of Tracks Reconstructed in b-jet

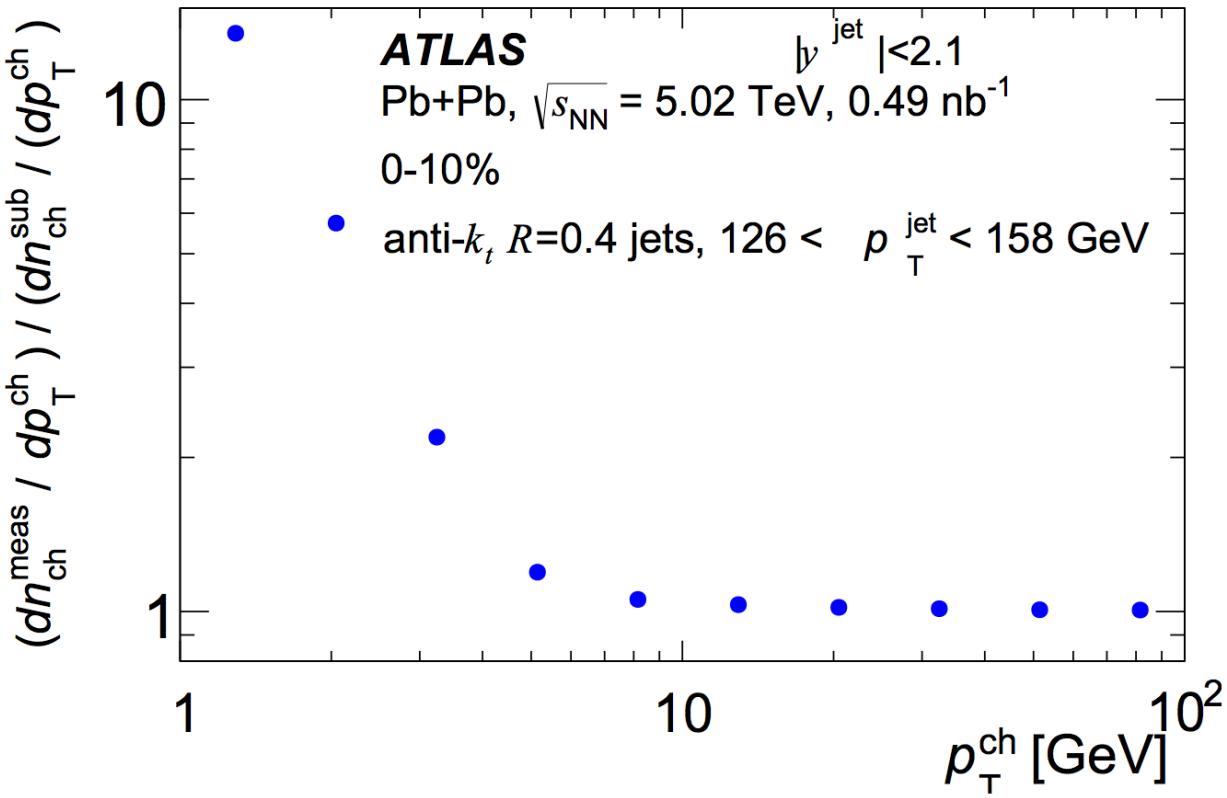


- Less number of tracks are reconstructed in b-jets without SV reconstructed.
- Possible reason for loss of efficiency

Possible flags to change in SVF tool

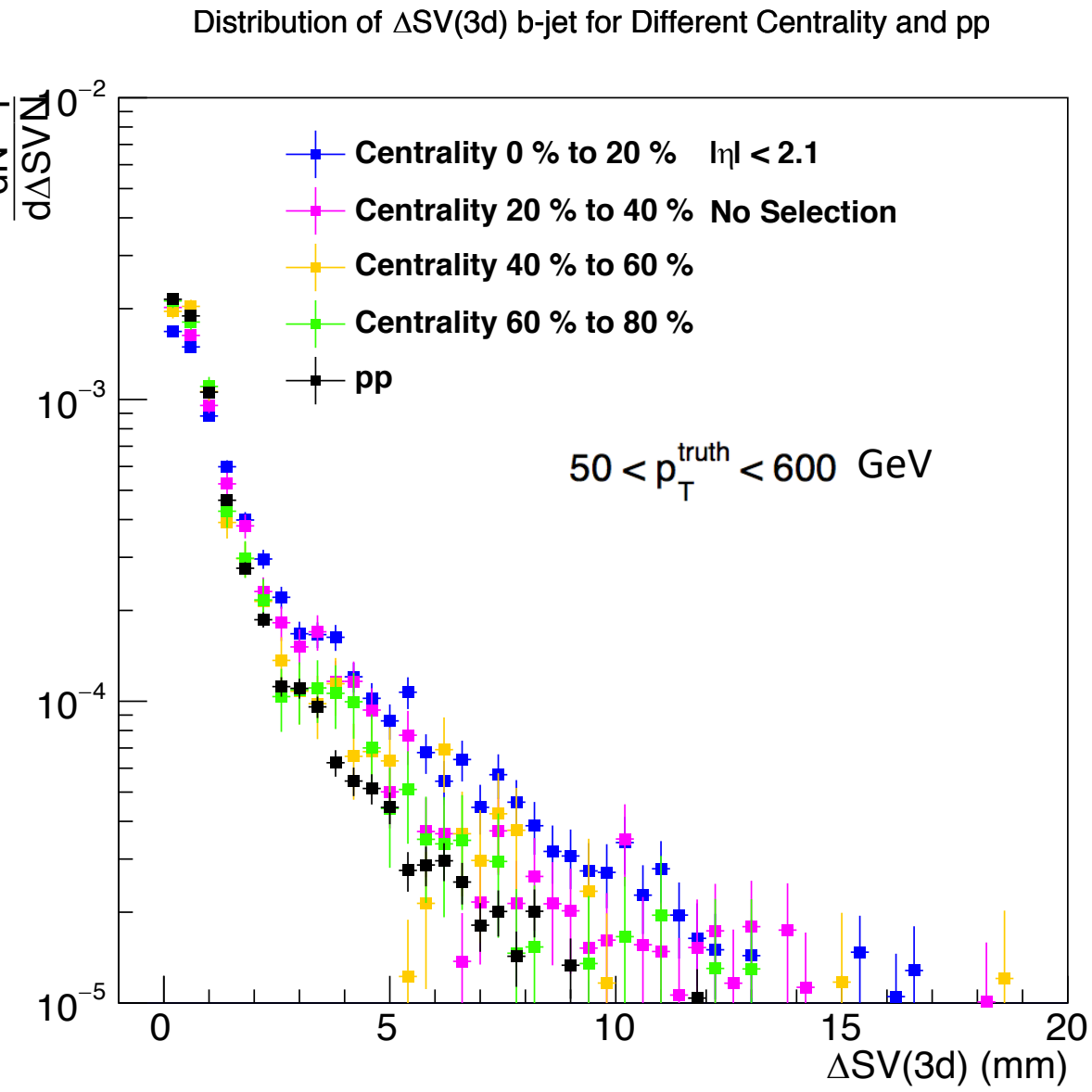
- Drop in SV reco efficiency of b-jets at high pT region.
- b-jets with SV missing have less number of tracks.

- Possible reason: track selections in SVF tool?
- For example:
  - $p_T^{track} < 700$ MeV: will include many UE tracks
  - Max shared hits for 2 track vertices 1: exclude too many tracks for high occupancy event



https://arxiv.org/pdf/1805.05424.pdf

Performance of Secondary Vertex Reconstruction in SVF



- SV reconstruction resolution here is defined as distances between truth SV and reco SV.
- More central events have worse resolution, and peripheral events have similar to pp resolution, as expected.
- Hope to reduced centrality dependence of SV reconstruction resolution.

Summary

- Looked at SVF reconstruction resolution in pp MC and MC overlay with HI track reconstruction.
  - Reconstruction efficiency has a pT dependence with lower efficiency at high pT region.
  - Less tracks are reconstructed in tracks missing reco SV.
  - Will investigate whether track selections in tagger affect SV reconstruction.

- Will continue experimenting with how track cuts affect secondary vertex reconstruction.

Backups

- # of reco tracks vs Fcal (1) + centrality vs fcal plot
- Different reconstruction algo, requires single PV.
- Ran things out of the box. Sample name.
- Some flags in SV may not apply well in HI, possible sources for
  - Are the flags motivated by how well the algorithm work or how well track reconstructions are?
  - Track momentum (UE tracks)
  - Chi^2 on tracks
  - Shared hits
- Ask about the motivations for selecting the specific flags.
- For links/some one to follow up/notes

Summary

- This task will optimize the inputs for the high level discriminants (MV2 and DL1) in order to improve the B-tagging performance in heavy ion collisions.
  - Performance of high level discriminants on HI collisions have a strong centrality dependence.
  - More underlying events are present in central collision, lowering the performance.
  - It is found that some inputs are significantly modified in heavy ion collisions.

- First steps planned are to develop selections to reduce effects of underlying event (UE) tracks using Pythia dijets overlay.
  - Looked into current performance of secondary vertex reconstruction in PbPb and pp MC by lower level taggers.
  - Implemented machinery for applying selections on tracks going into lower level taggers

- The p_T range of this study will overlap with the ongoing measurements for b-jets using muon-based tagging within the HI group, which can provide reference for result comparison.

Pb-Pb MC Samples

- Pythia MC Overlay as Heavy Ion simulation.
  - Pythia MC events embedded into minimum-bias data from Heavy Ion collisions .

- As of now, we have 50k events of bbar pythia dijets embedded in PbPb 2018 MinBias data as a start.
  - https://its.cern.ch/jira/browse/ATLHI-240
  - Release 21

- We will validate these MC and request more.

Plans and Progresses (Dec 9, 2019)

- Complied the btagging tool out-of-box and tried on one MC sample from https://its.cern.ch/jira/browse/ATLHI-240
  - Program ran, is looking at debugging for calibration tool.
    - Meanwhile understanding the details of b-tagging algorithms.
  - Add FCal information into the algorithm.
  - MC needs validation (waiting for people's work on inner detector track issues)
    - Need to request more MC samples
  - Explanation of the algorithm flow.

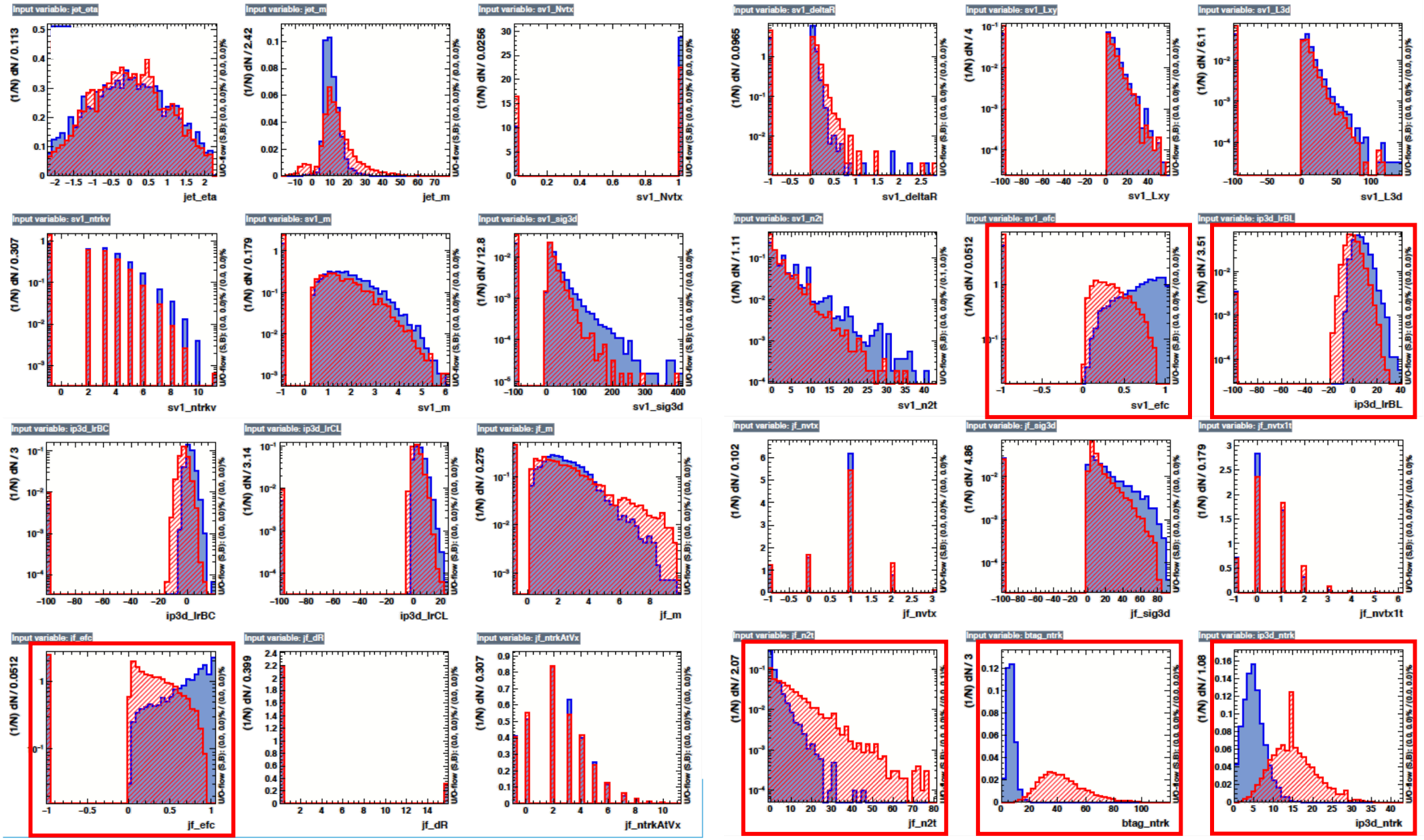
- Experiments with cutting on small samples locally (without re-training the network)
  - Applying pt cut in tracks used for tagging.
  - Get more ideas from comparing the distributions between pp and PbPb.

Back-up Slides

Questions

- What templates are used in the retagging algorithm?
- How is RNNIP/whether RNNIP information is used in high level discriminants?

Inputs of b-jets in pp and Pb-Pb simulations



b-jets Pythia MC

b-jets Pythia Overlay

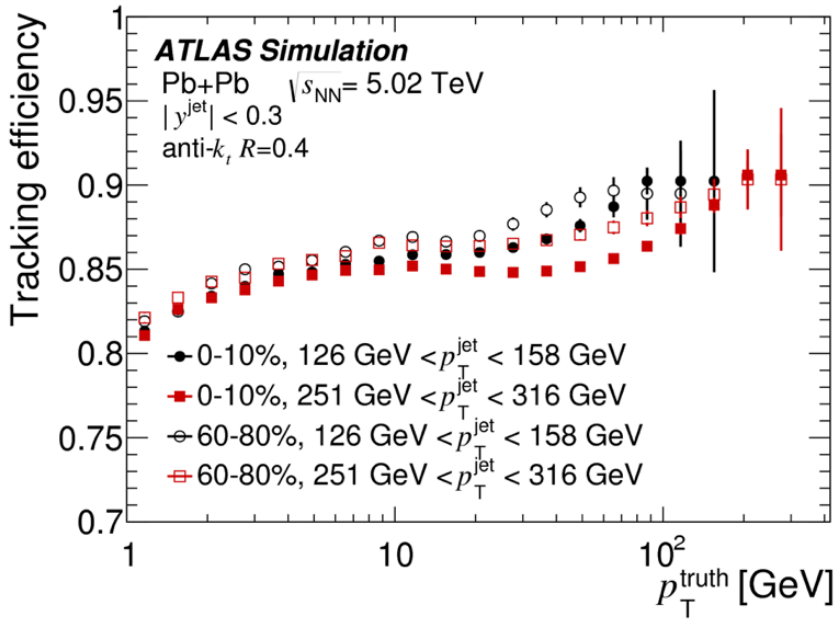
Significantly modified inputs.

List of Inputs for Low Level Discriminants

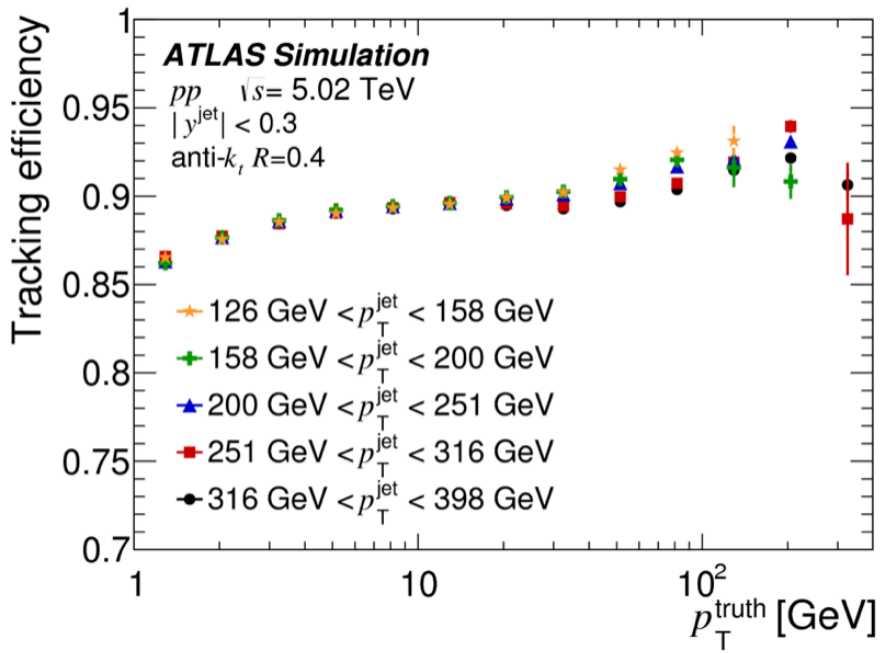
Input	Variable	Description
Kinematics	p_T (jet)	Jet transverse momentum
	$\eta(jet)$	Jet pseudorapidity
IP2D, IP3D	$\log(P_b/P_{light})$	Likelihood ratio between the b- and light-jet hypotheses
	$\log(P_b/P_c)$	Likelihood ratio between the b- and c-jet hypotheses
	$\log(P_c/P_{light})$	Likelihood ratio between the c- and light-jet hypotheses
SV	$m(SV)$	Invariant mass of tracks at the SV assuming π masses
	$f_E(SV)$	Fraction of the charged jet energy in the SV
	$N_{TrkAtVtx}(SV)$	Number of tracks used in the SV
	$N_{2TrkVtx}(SV)$	Number of two track vertex candidates
	$L_{xy}(SV)$	Transverse distance between the PV and the SVs
	$L_{xyz}(SV)$	Distance between the PV and the SVs
	$S_{xyz}(SV)$	Distance between the PV and SVs divided by its uncertainty
	$\Delta R(jet, SV)$	ΔR between the jet axis and the direction of the SV relative to the PV

Jet Fitter	$N_{2TrkVtx}(JF)$	Number of 2-track vertex candidates
	$m(JF)$	Invariant mass of tracks from displaced vertices assuming π masses
	$S_{xyz}(JF)$	Significance of the average distance between the PV and displaced vertices
	$f_E(JF)$	Fraction of the charged jet energy in the SVs
	$N_{1-trkvertices}(JF)$	Number of displaced vertices with one track
	$N_{\geq 2-trkvertices}(JF)$	Number of displaced vertices with more than one track
	$N_{TrkAtVtx}(JF)$	Number of tracks from displaced vertices with at least two tracks
	$\Delta R(\vec{p}_{jet}, \vec{p}_{vtx})$	ΔR between the jet axis and the vectorial sum of the momenta of all tracks attached to displaced vertices

Pb+Pb collision



pp collision



In jet tracking efficiency a bit worst in PbPb collisions

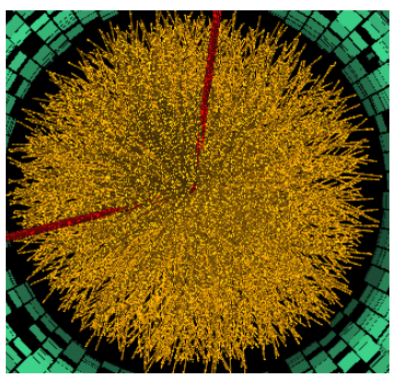
SIMULATION

HI simulation: Hard scattering + Underlying Events (UE) Overlay

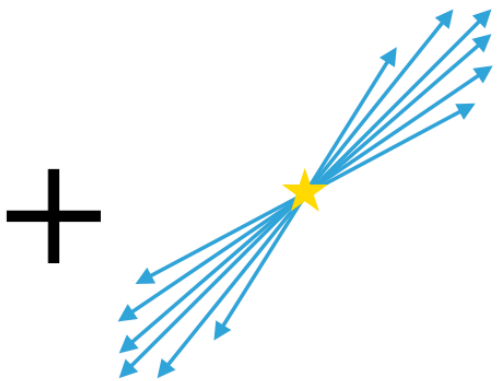
Hard scattering: Pythia, Powheg, Herwig …

Overlay:

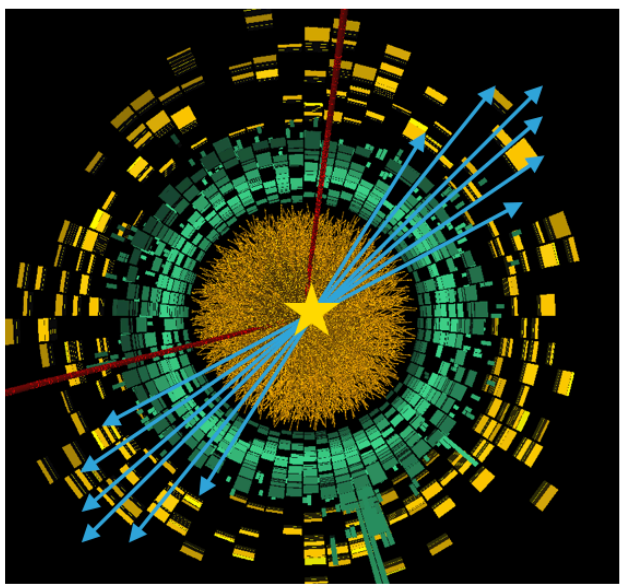
- HIJING: Simulated Underlying events.
- Data Overlay: Underlying events from real Pb+Pb collision data.



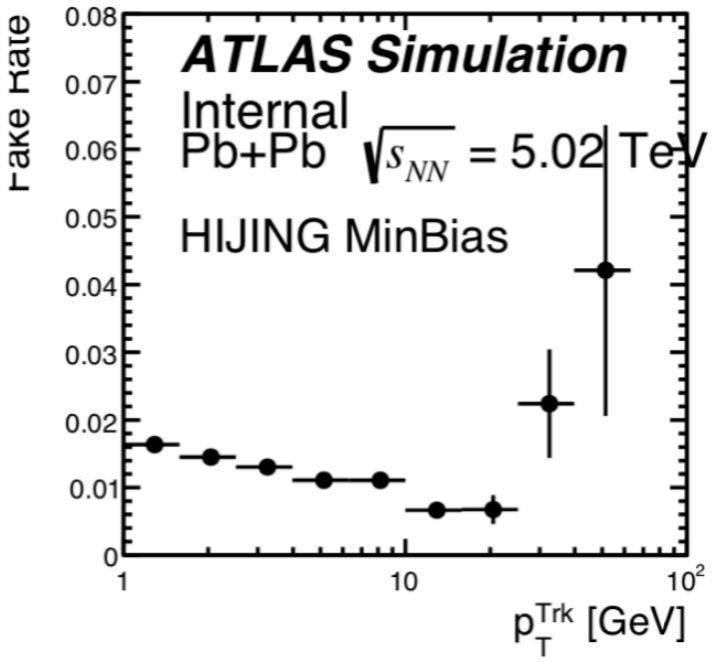
Underlaying Events



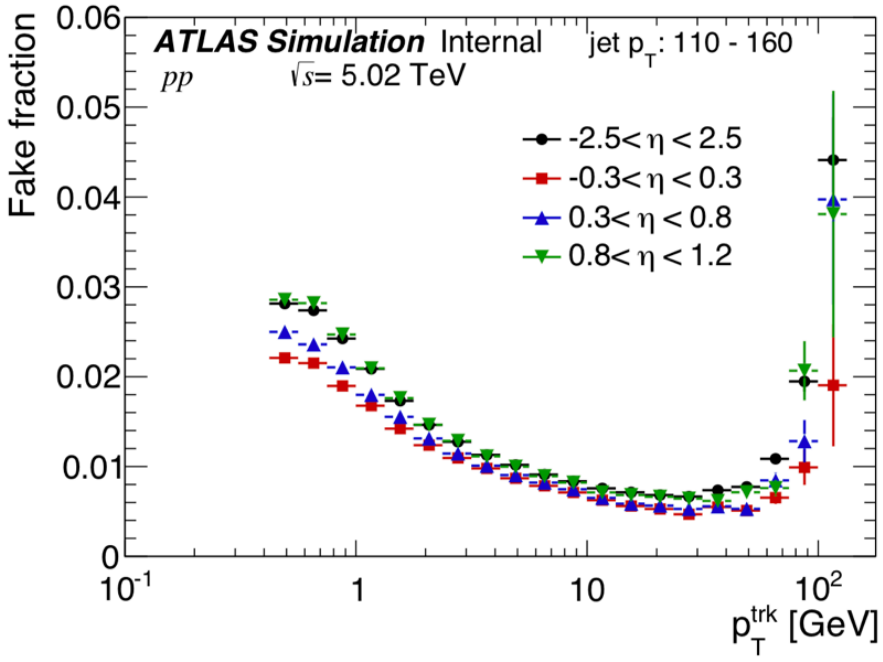
Phythia Di-jets



Pb+Pb central collision



pp collision



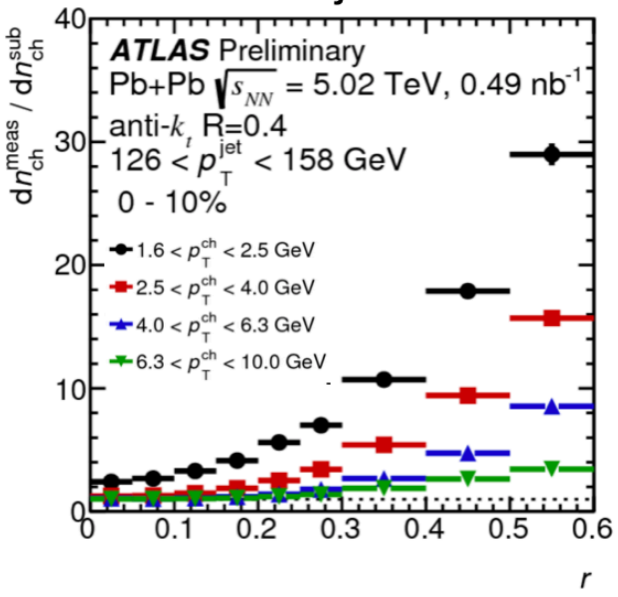
Similar fake rate for both type of collision

Tracking performance: Background

ATL-COM-PHYS-2018-130

ATLAS-CONF-2018-010

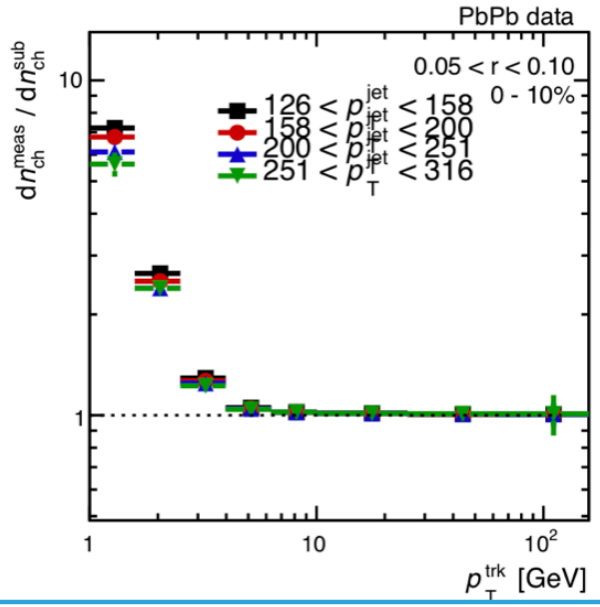
Function of jet R

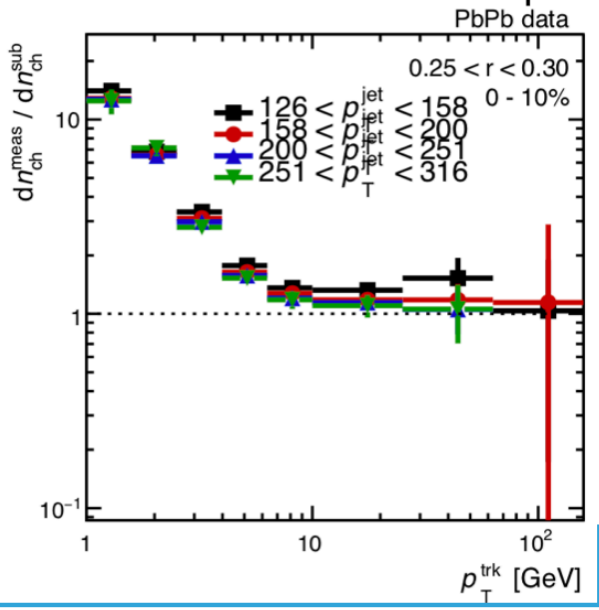


Measured Tracks/ Jet tracks = (signal + bkg.)/signal

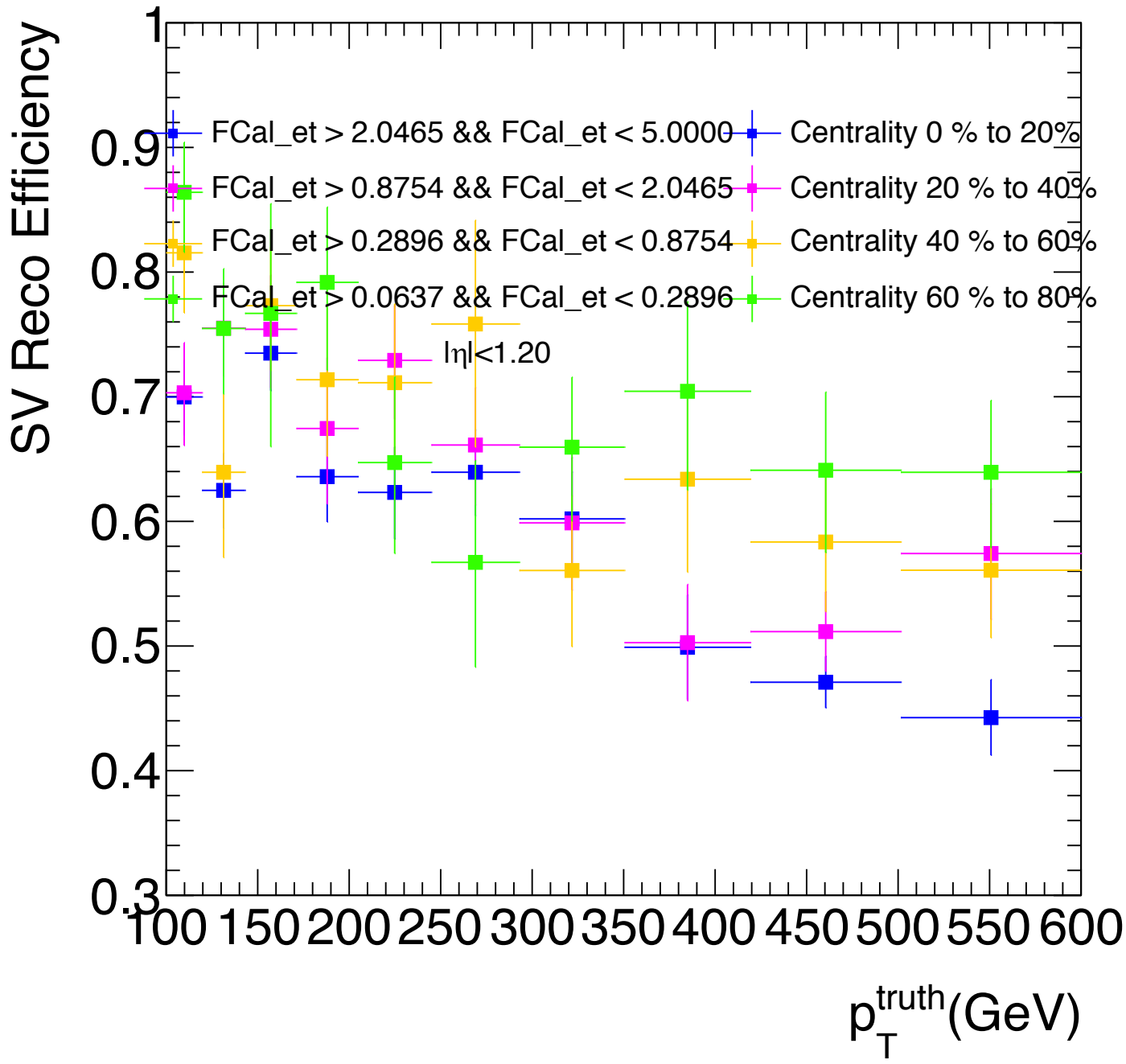
Most tracks not coming from jets (background), are below 4 GeV

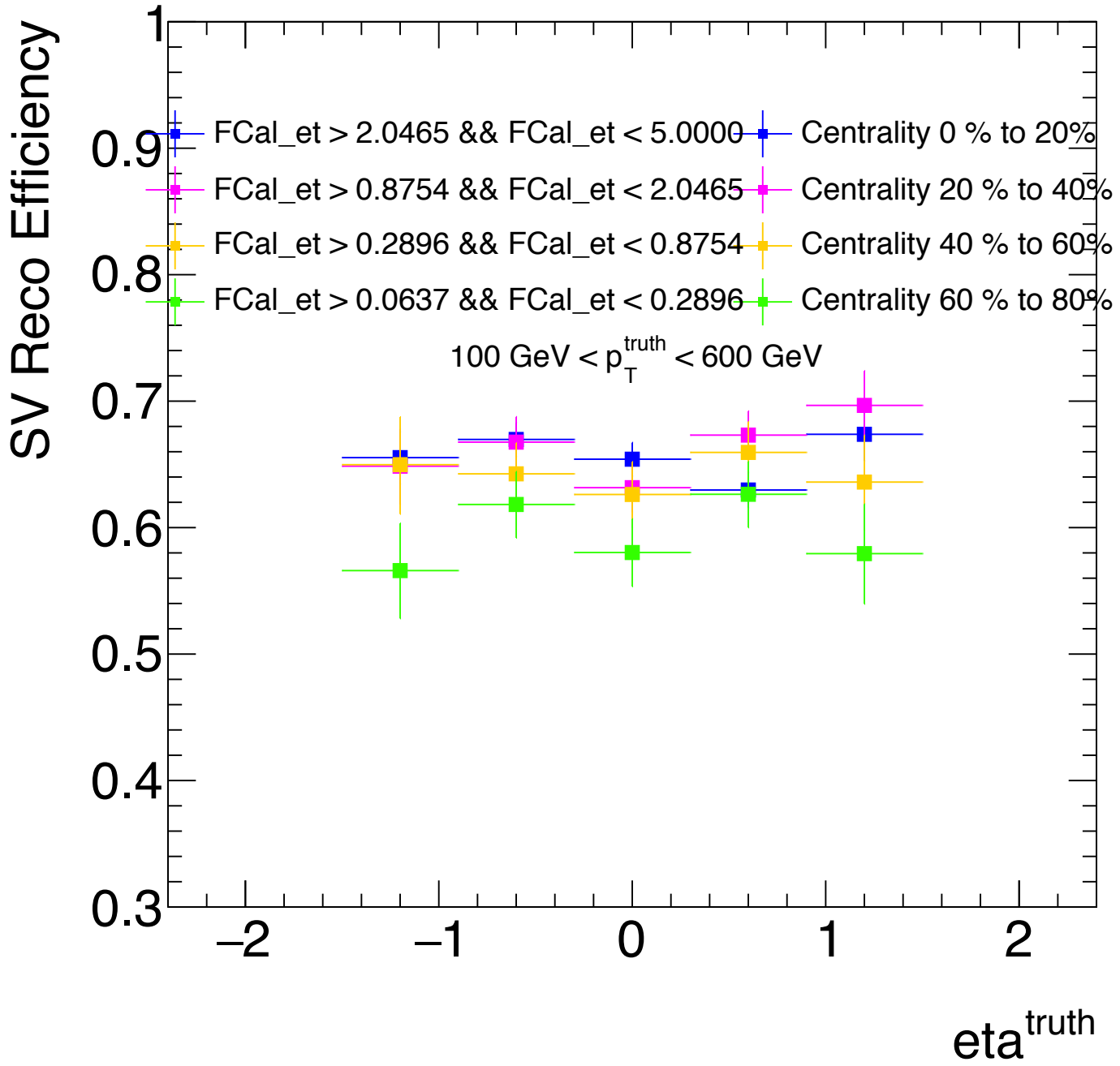
Function of track pT





ATLAS EXPERIMENT


SV Reco Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
100 150 200 250 300 350 400 450 500 550 600
p_T^{truth}(GeV)
FCal_et > 2.0465 && FCal_et < 5.0000
FCal_et > 0.8754 && FCal_et < 2.0465
FCal_et > 0.2896 && FCal_et < 0.8754
FCal_et > 0.0637 && FCal_et < 0.2896
|η|<1.20
Centrality 0 % to 20%
Centrality 20 % to 40%
Centrality 40 % to 60%
Centrality 60 % to 80%


SV Reco Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
−2
−1
0
1
2
eta^truth
FCal_et > 2.0465 && FCal_et < 5.0000
FCal_et > 0.8754 && FCal_et < 2.0465
FCal_et > 0.2896 && FCal_et < 0.8754
FCal_et > 0.0637 && FCal_et < 0.2896
Centrality 0 % to 20%
Centrality 20 % to 40%
Centrality 40 % to 60%
Centrality 60 % to 80%
100 GeV < p_T^truth < 600 GeV