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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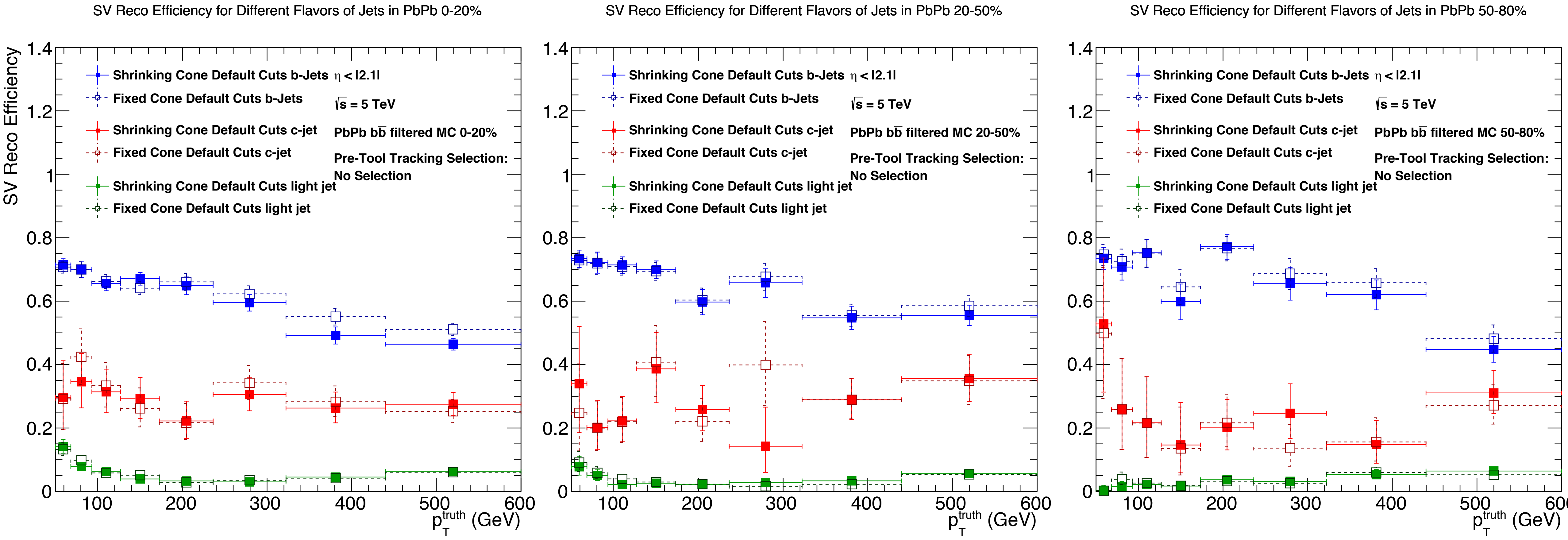
Homework List

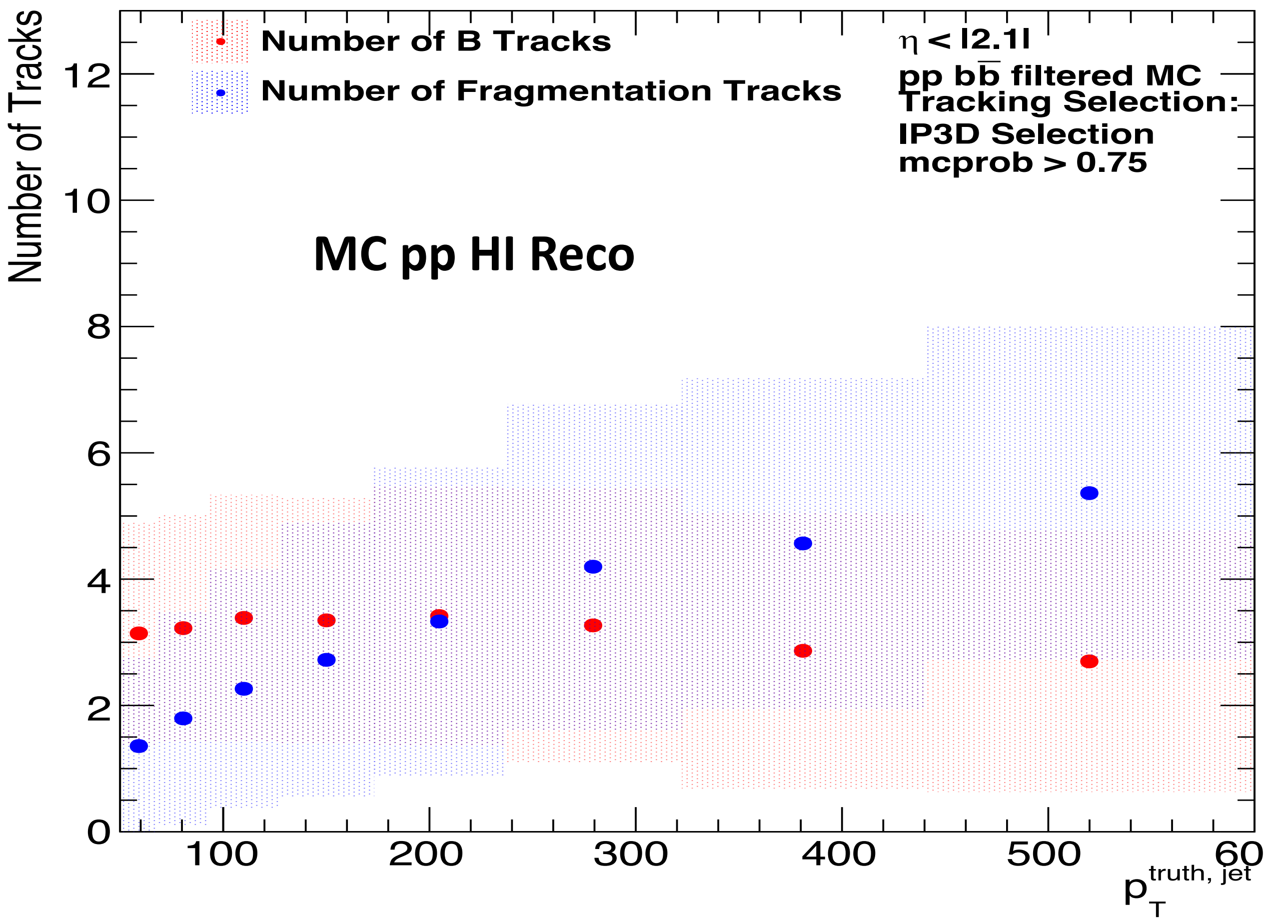
- Try fixed cone with environment of high track occupancy (MC overlay)
- Resolution vs L3d (whether this explains worse SV resolution at high pT)
- Factorize effect of selection and track association (plot B tracks vs fragmentation tracks before applying selections)
- Scope of study/region of effectiveness (what pT range to look at)
  - Still helpful to pinpoint why high pT region has lower efficiency
- Talk to Ogul about whether a low performance SV tagger still gives ok b-tagging performance
  - Learn about training with our samples.
  - Don’t have a lot of MC
- Pseudo Tracking? (new method, assume perfect track reconstruction?)
  - Not gonna consider for now

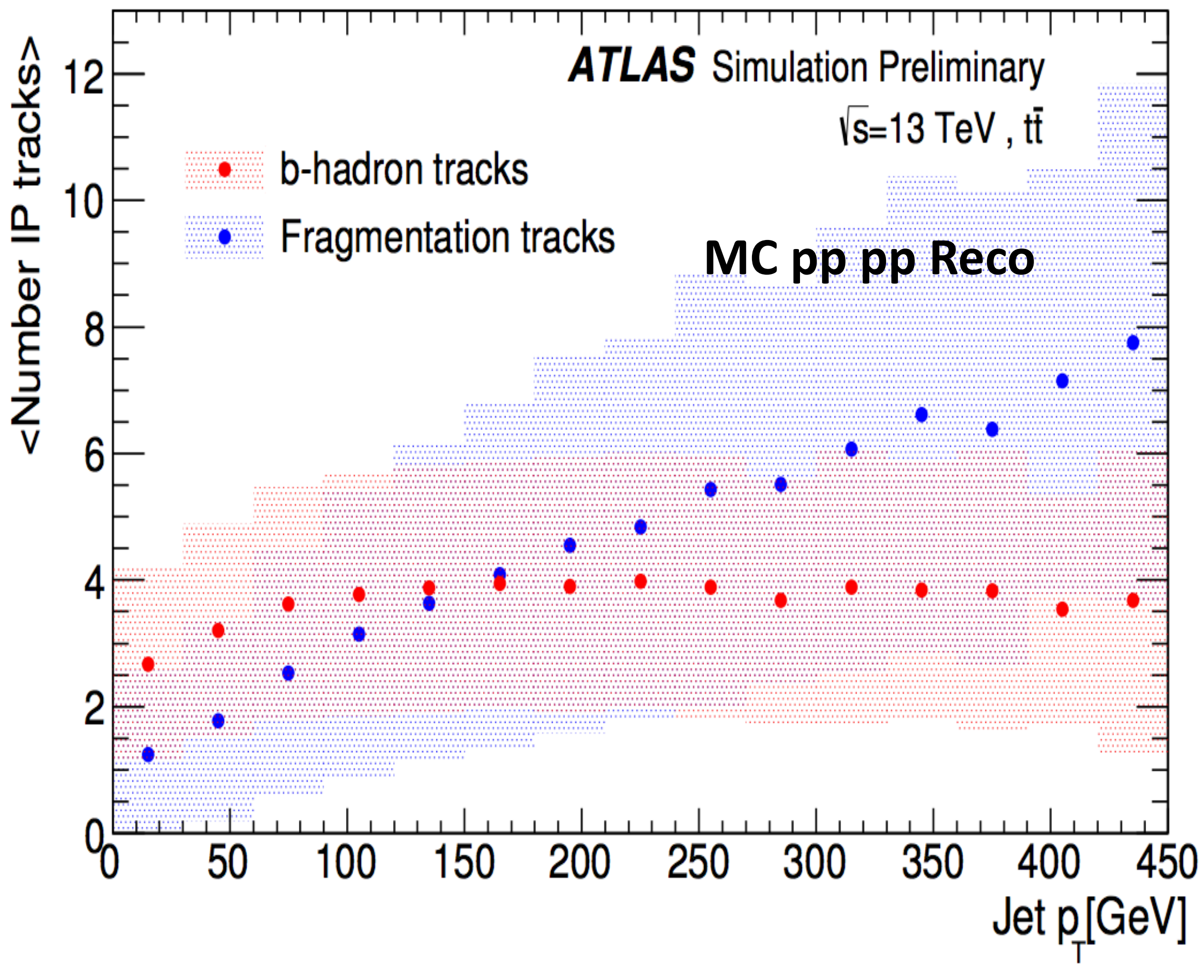
Response 1: Fixed Cone with Heavy Ion



- Secondary vertexing efficiency for b jet is increased at all centrality with the use of fixed cone at 0.4
- Secondary vertexing efficiency for c jet is slightly decreased at high pT region for peripheral and central but not in-between
  - Could be just statistical fluctuation due to small samples.
- Purity is not affected much.

Differences in Samples





- Similar overall trend.
- Fewer tracks.
- More obvious in high pT (might explain drop in SV efficiency)

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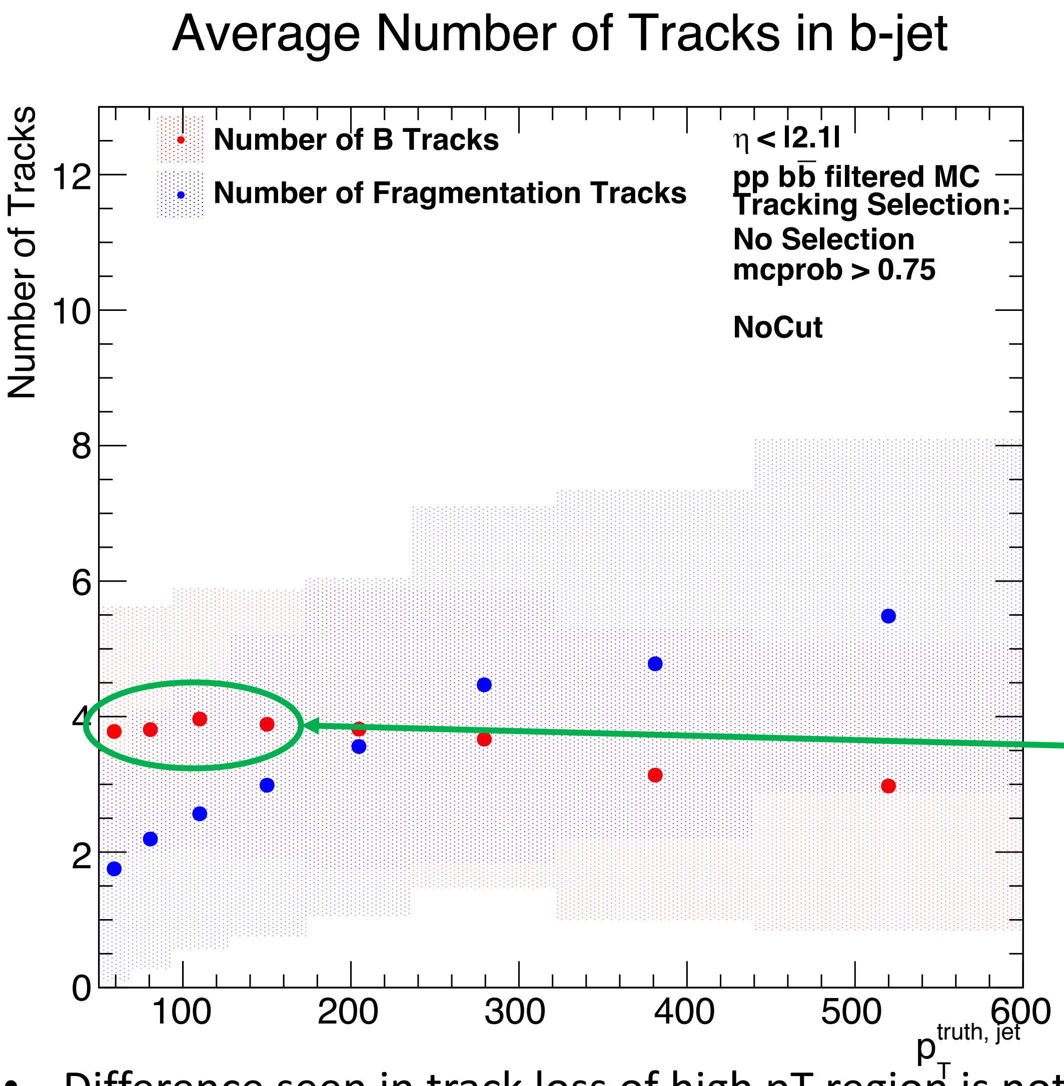
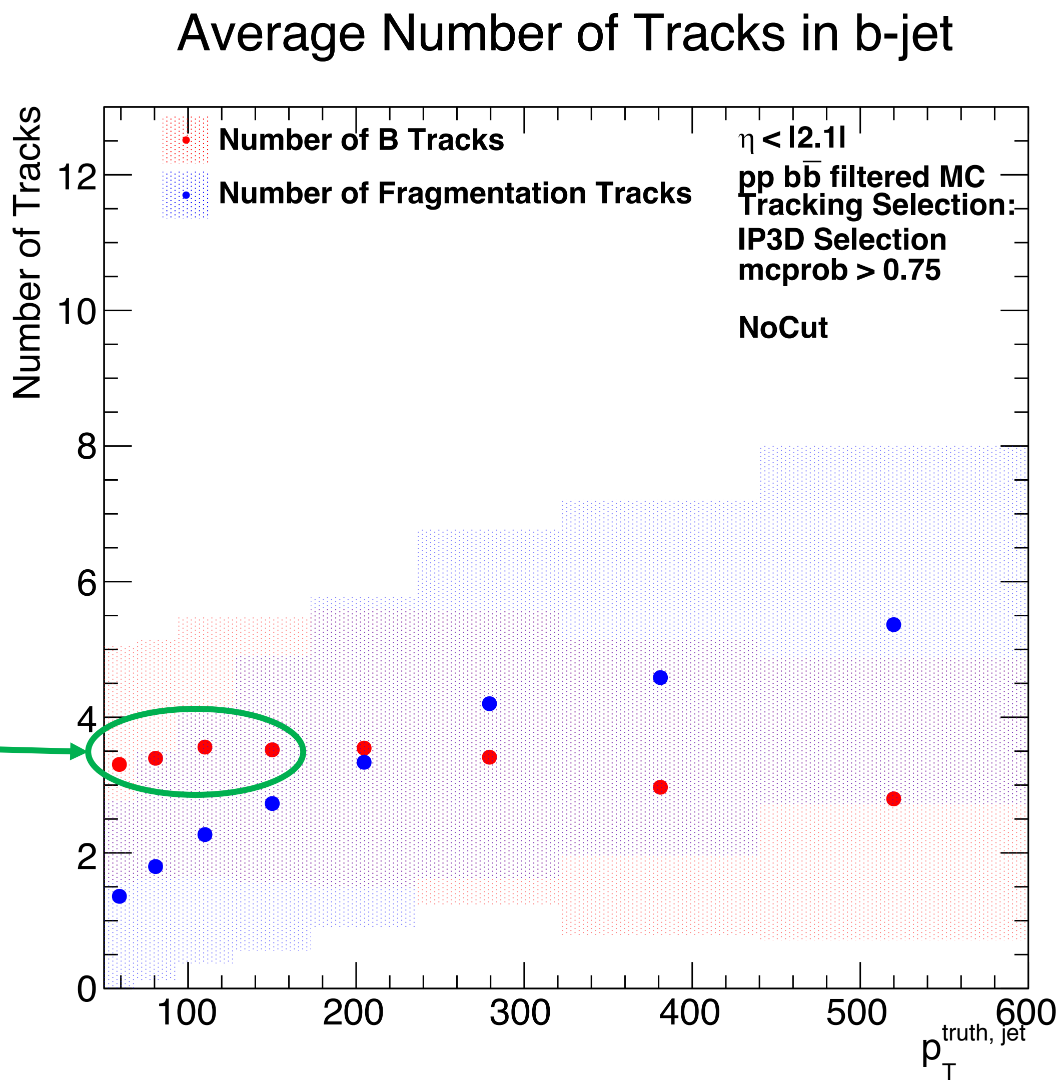
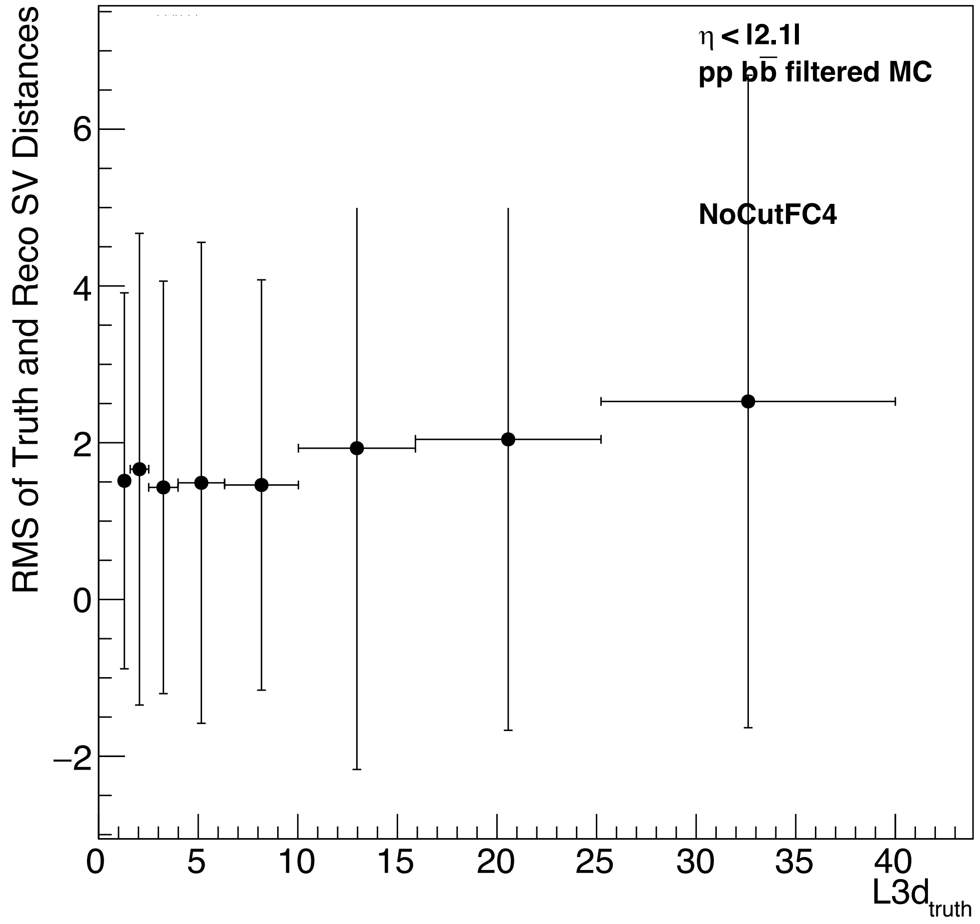
Response 2: whether the reduced number of tracks seen in bbar samples in comparison to ttar samples is from sample or tracking selection?

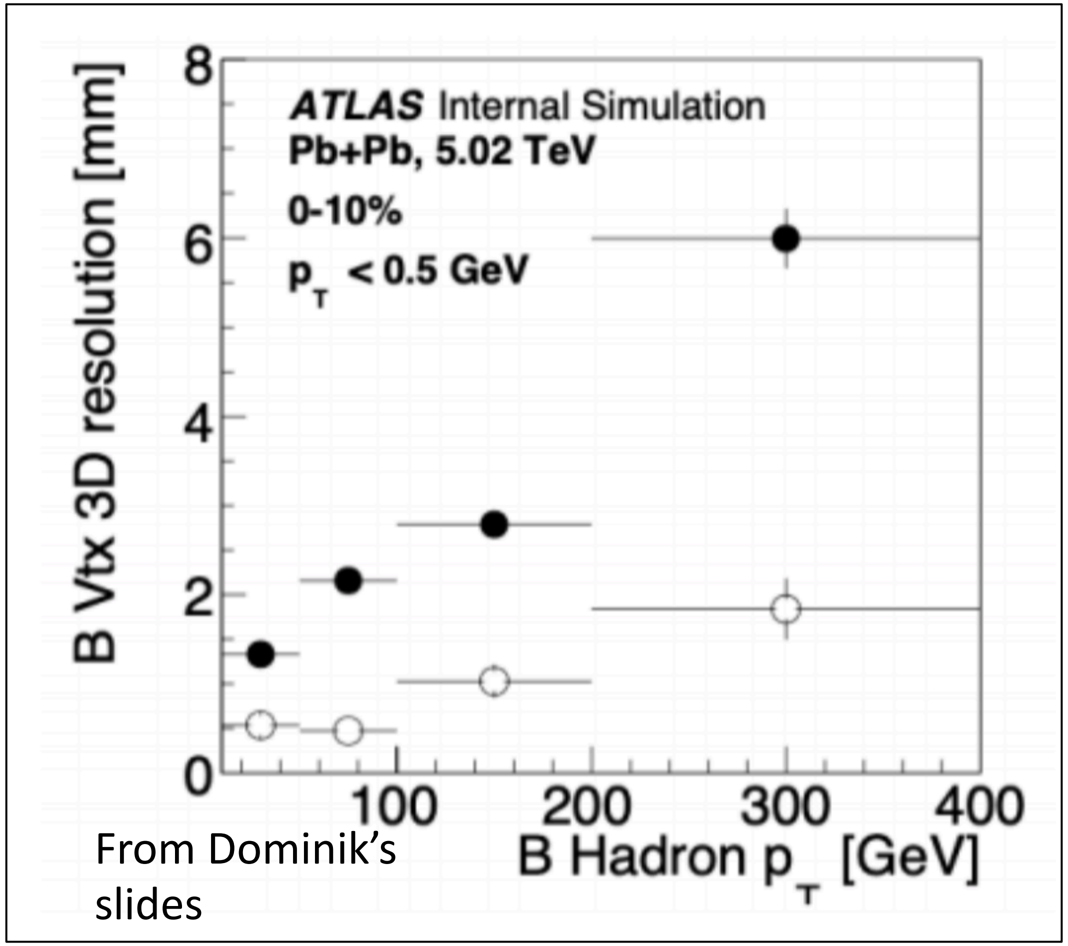




- Difference seen in track loss of high pT region is not from tracking selection, which affects mainly the low pT region.

Response 3: Resolution vs L3d



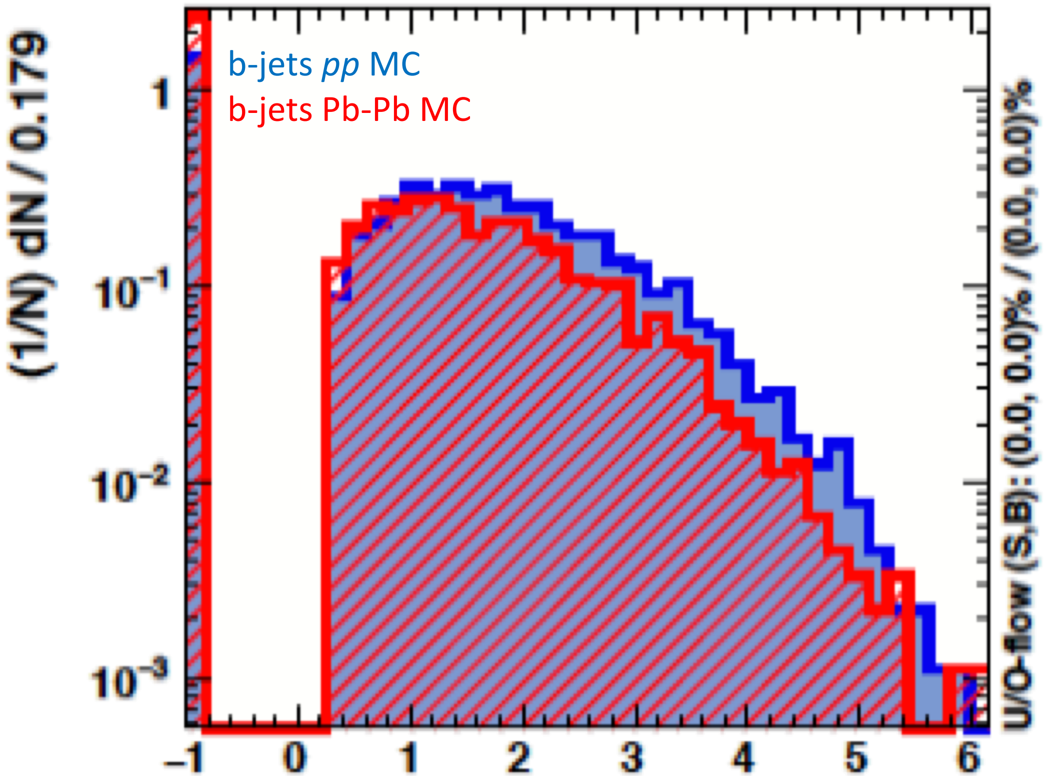


- Shown is the mean of distances between truth and reco SV.
- It can be seen that larger L3d region, i.e., high pT region has worse resolution.
- Qualitatively similar to Jetfitter results (from Performance paper and Dominik)

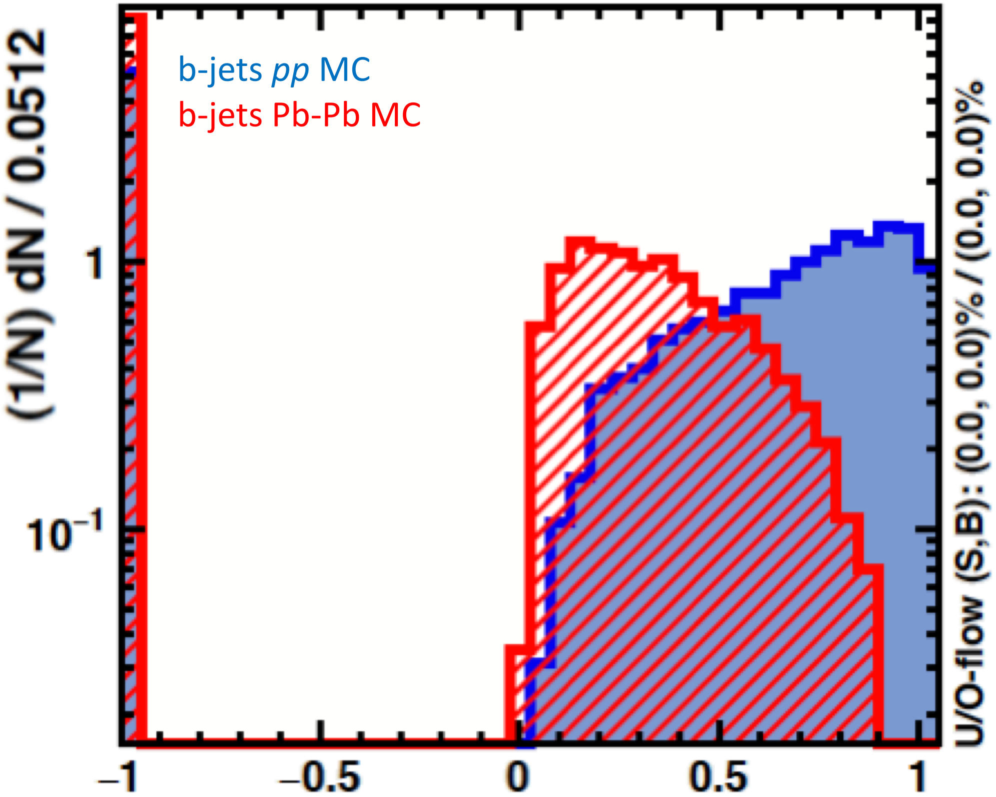
Description of Qualification Task (AFT-455)

- 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

  Last time

  - 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.
  - Investigated into observed difference.
  - Experimented with alternative track association and track cutting method.
  - Looked into difference between samples.

Track reconstruction in Heavy Ion Collisions

- Designed to work with high occupancy data (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

- Samples used:
  - 50k events (12.5k each for JZ1-JZ4) of pythia dijets events at 5.02 TeV, applied with bbar filter Selection on Jets.
  - Configuration file: https://gitlab.cern.ch/atlas-physics/pmg/infrastructure/mc15joboptions/blob/master/share/DSID420xxx/MC15.420271.Pythia8EvtGen_A14NNPDF23LO_jetjet_JZ1_bbfilter.py

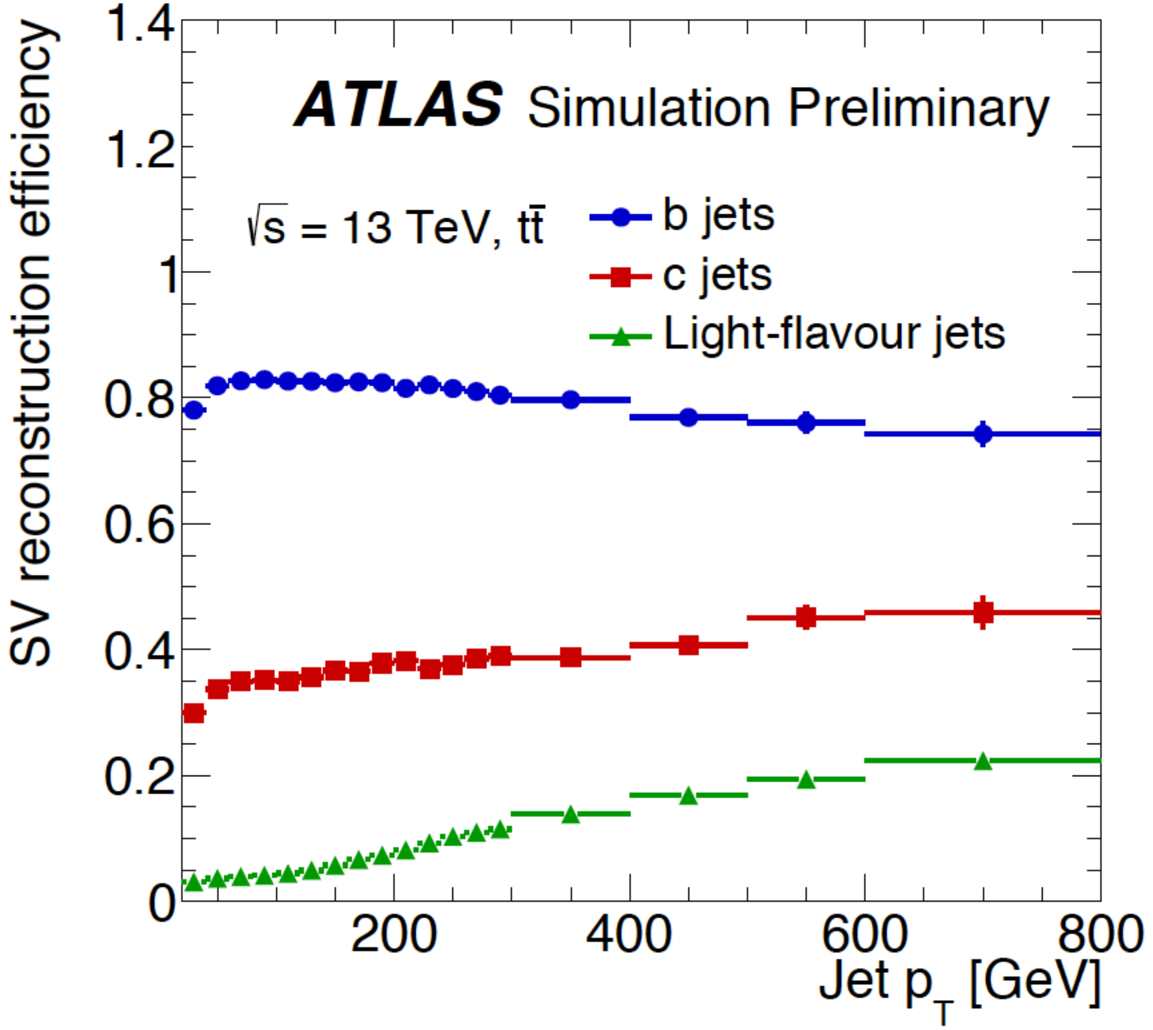
- Selection on Jets:
  - Reco jets with ΔR(truth-reco) < 0.3
  - $p_T^{truth\ jet} > 50$ GeV

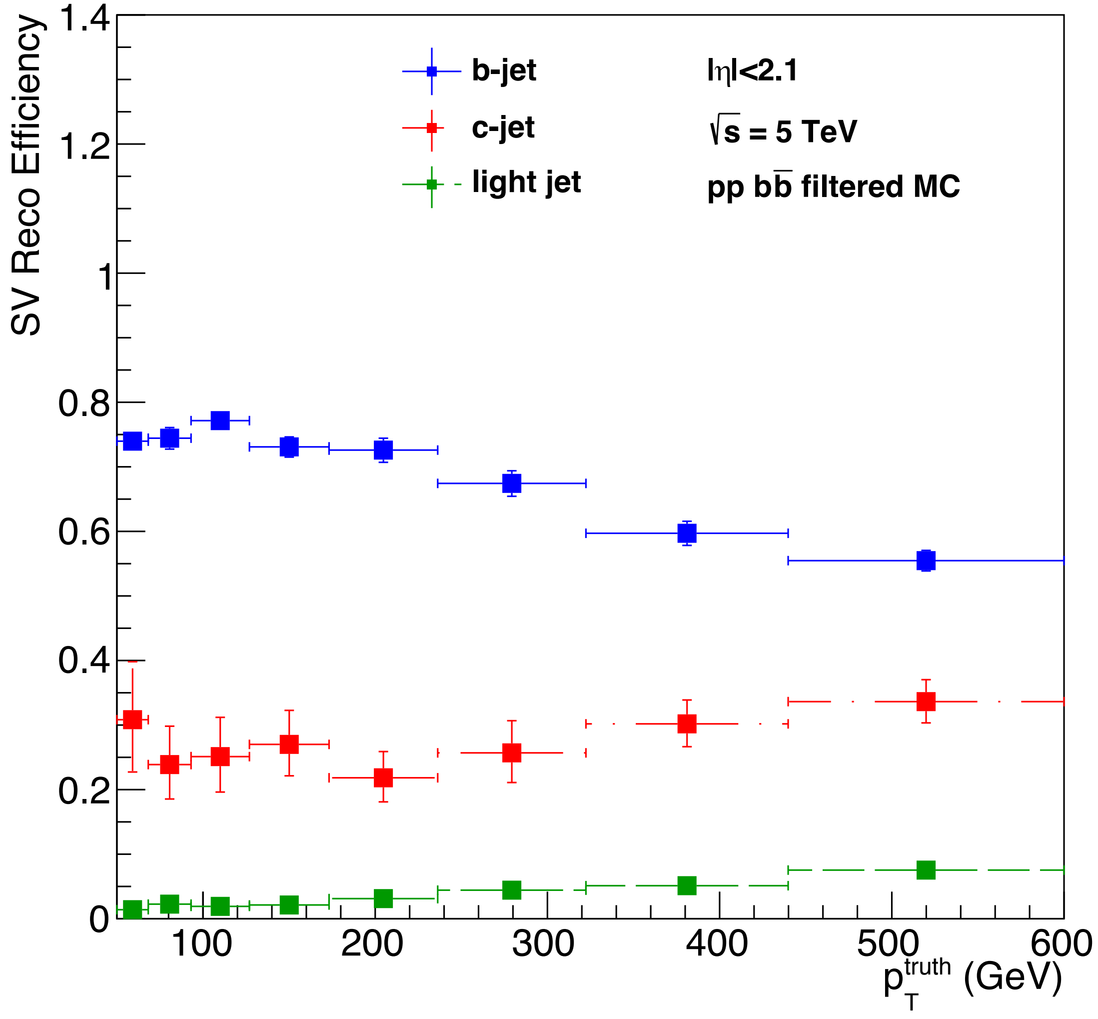
- B-Jets: jets with a truth B hadron associated with it.
  - $p_T^B > 5$ GeV
  - ΔR(truth-reco)(jet-B) < 0.3

- Selection on Tracks: No selections prior to SV reconstruction tool

- 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/xiaoning/hiretagging_framework allowing for selections of tracks before calling lower level taggers.

SV Reco Efficiency from SVF performance paper



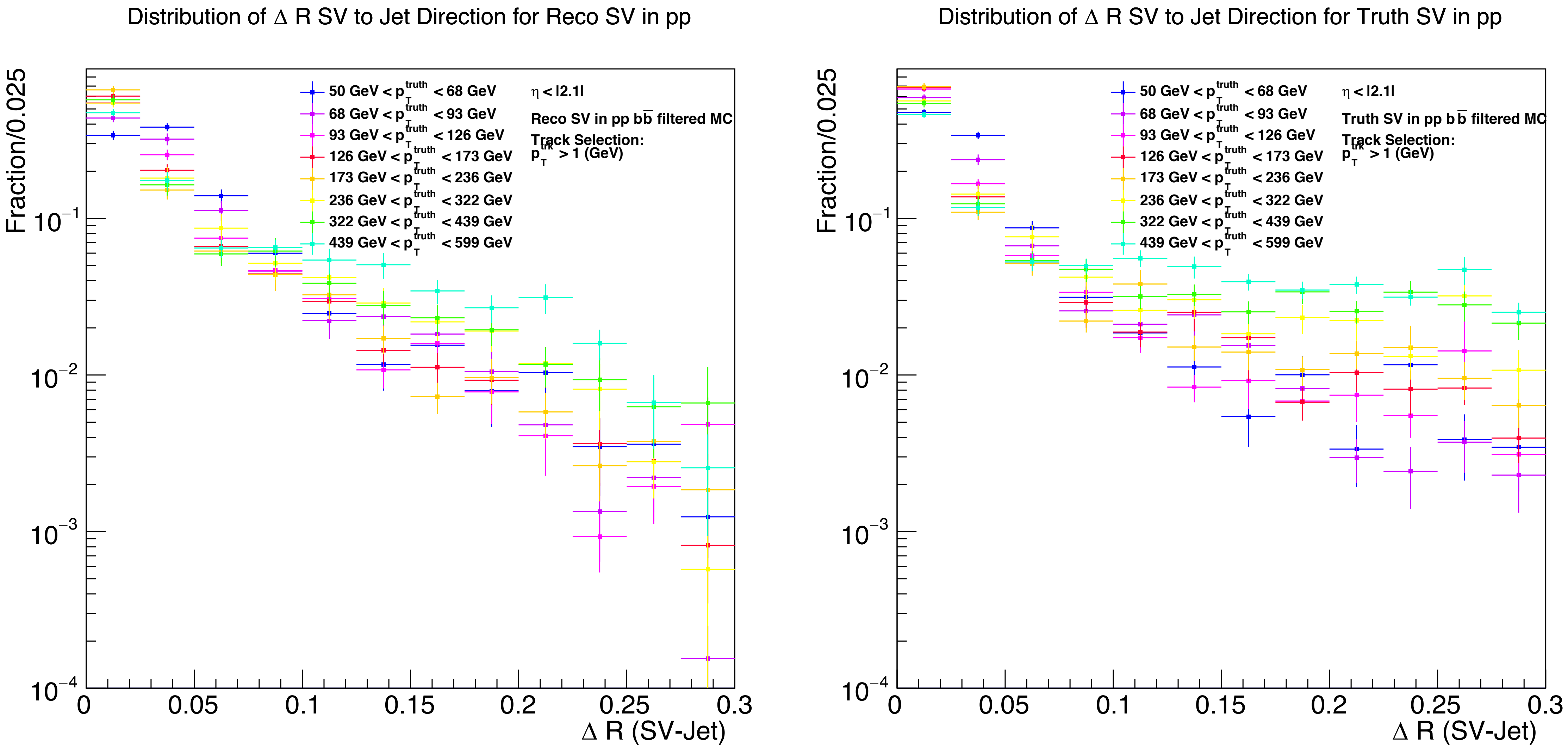


- ATL-PHYS-PUB-2017-011: https://cds.cern.ch/record/2270366

Discussions following Last Meetings

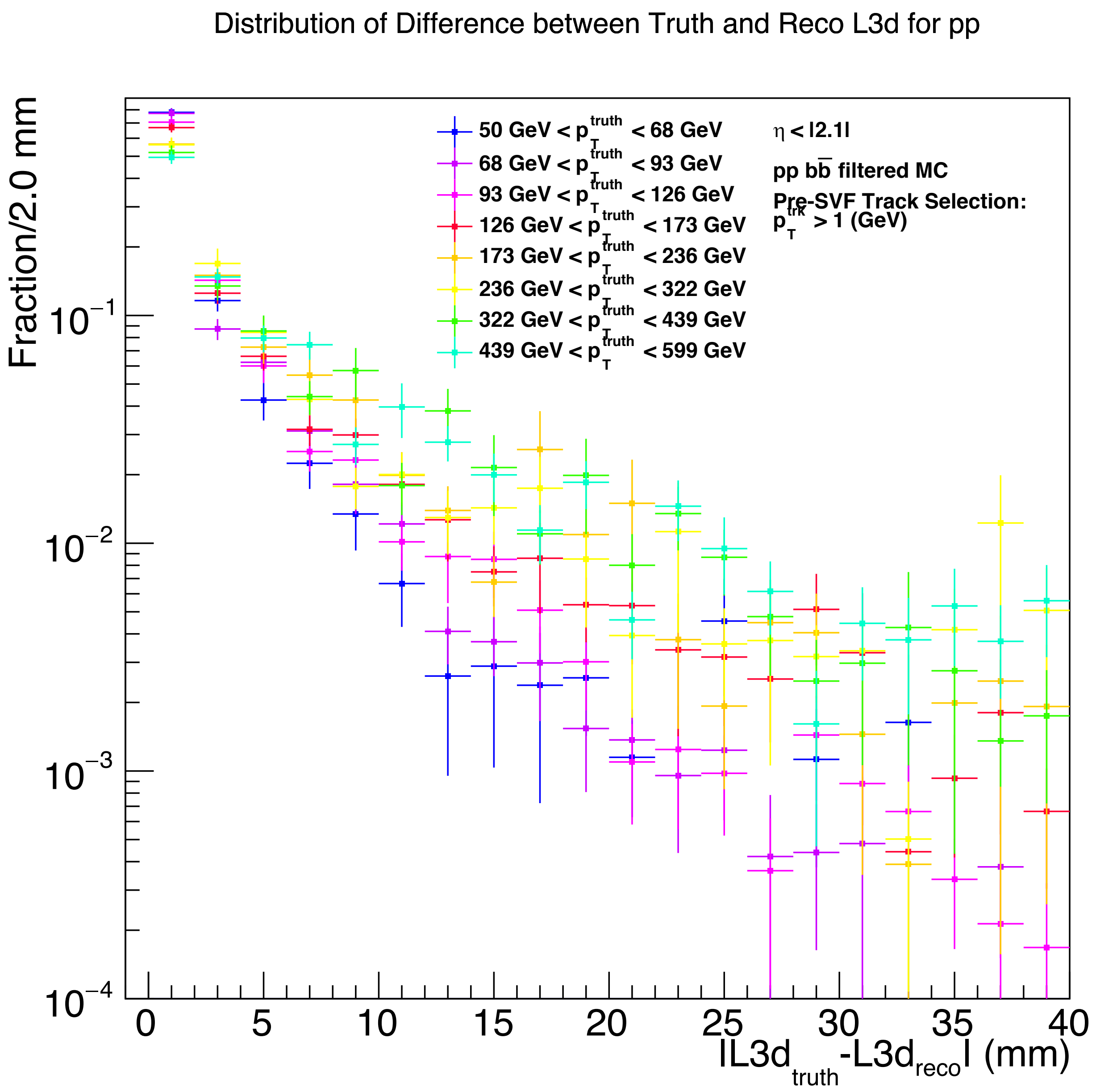
- Do resolution of secondary vertex differ a lot/is there systematic bias in secondary vertex between truth and reco?
- What is different between the two samples?
  - E.g., There might be more multi-B jets in high pt.
- Suggestions:
  - Look into whether multi-b jets are lowering high pt efficiency
  - Look into available B-track vs fragmentation track in b jets.

pT Dependence of SV-Jet Distance



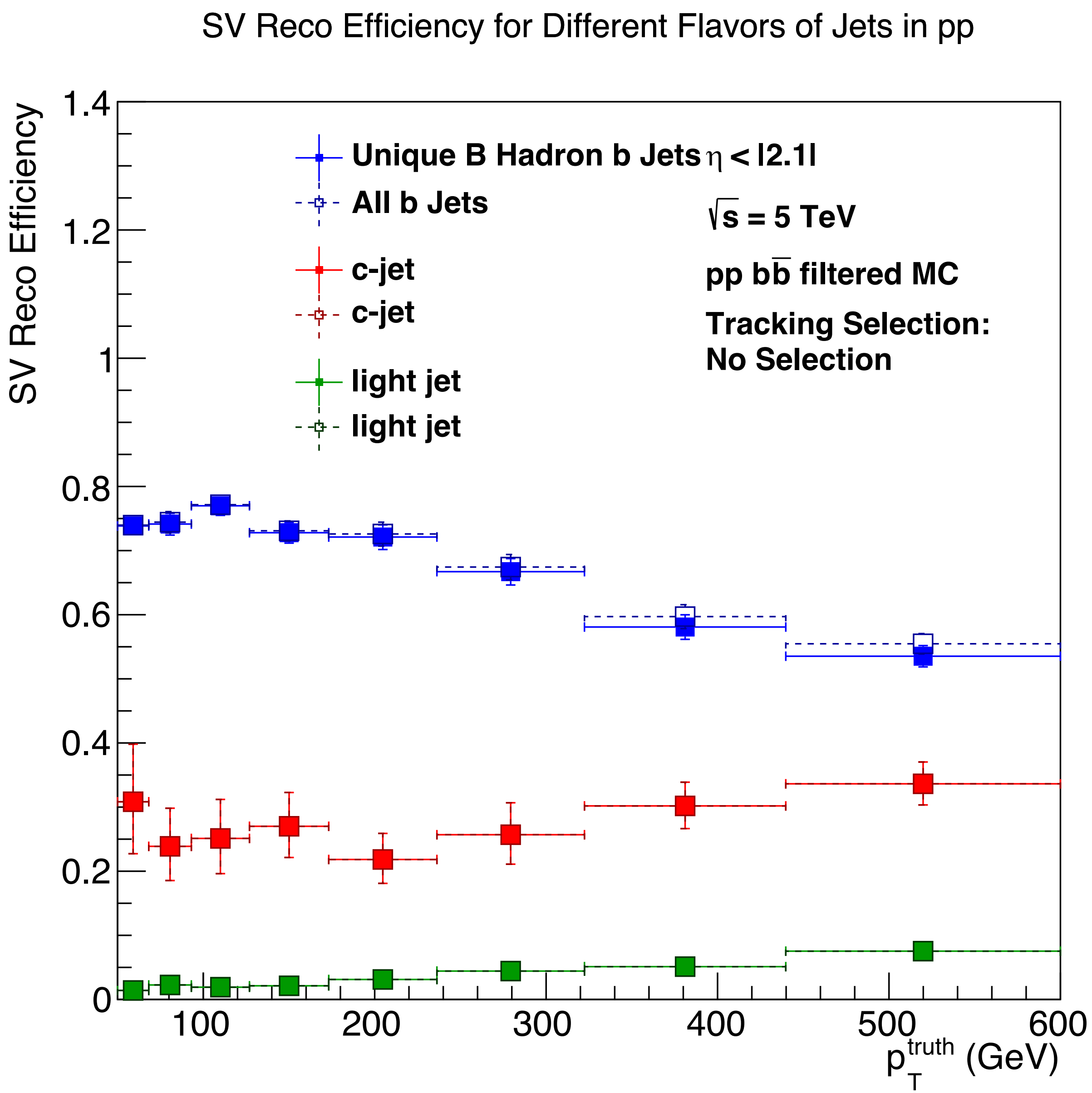
- Narrower distribution at high pt.
- Truth and reco show no systematic bias in resolution.

Distribution of Distance between Truth and Reco L3d as a function of pT



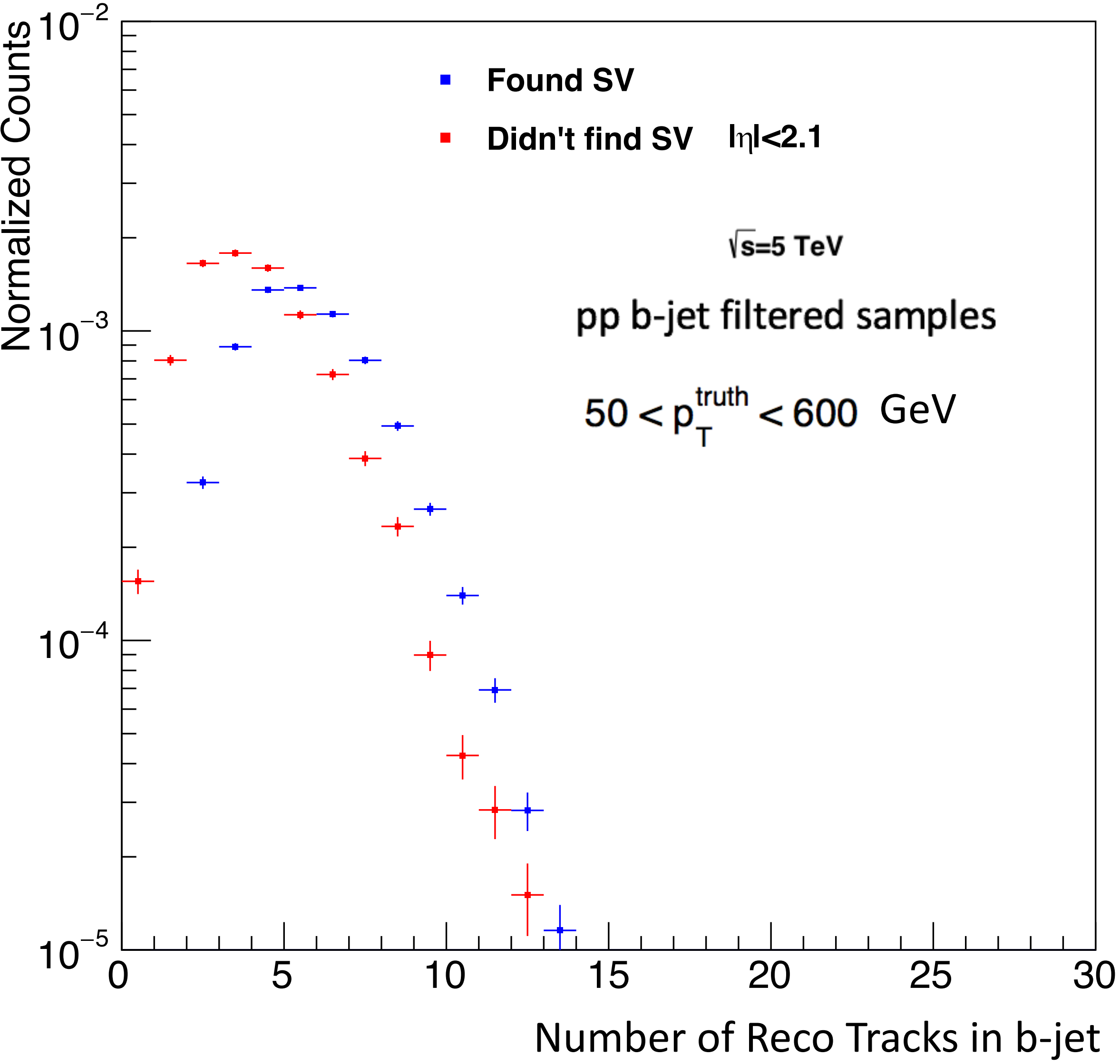
- Wider separation at higher pT.

SV Reconstruction Efficiency for Unique and Multiple B Hadron Jets



- Almost no difference in low pt region.
- Slight decrease of SV for unique b hadron jets in high pt.

Distribution of Number of Tracks Reconstructed in b-jet

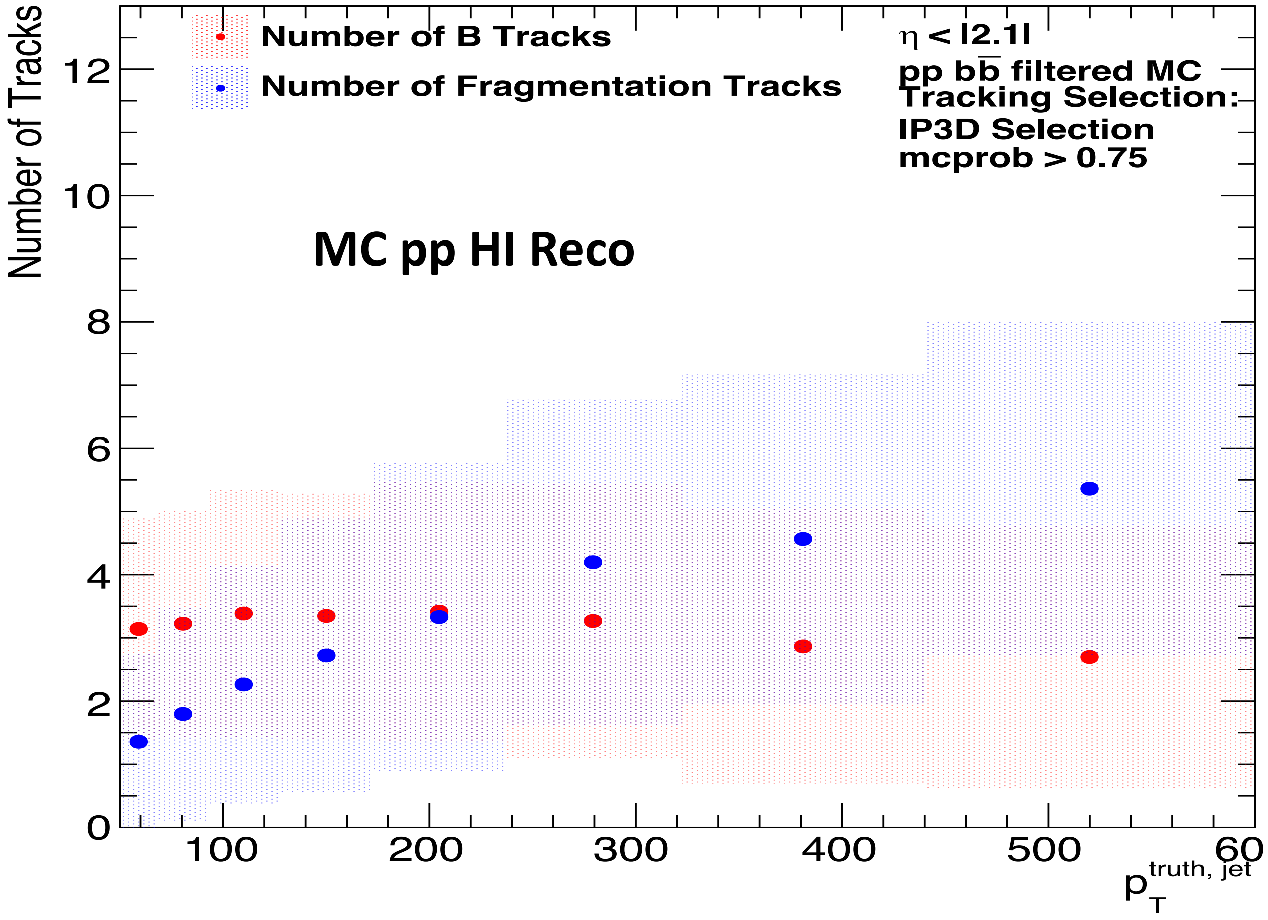


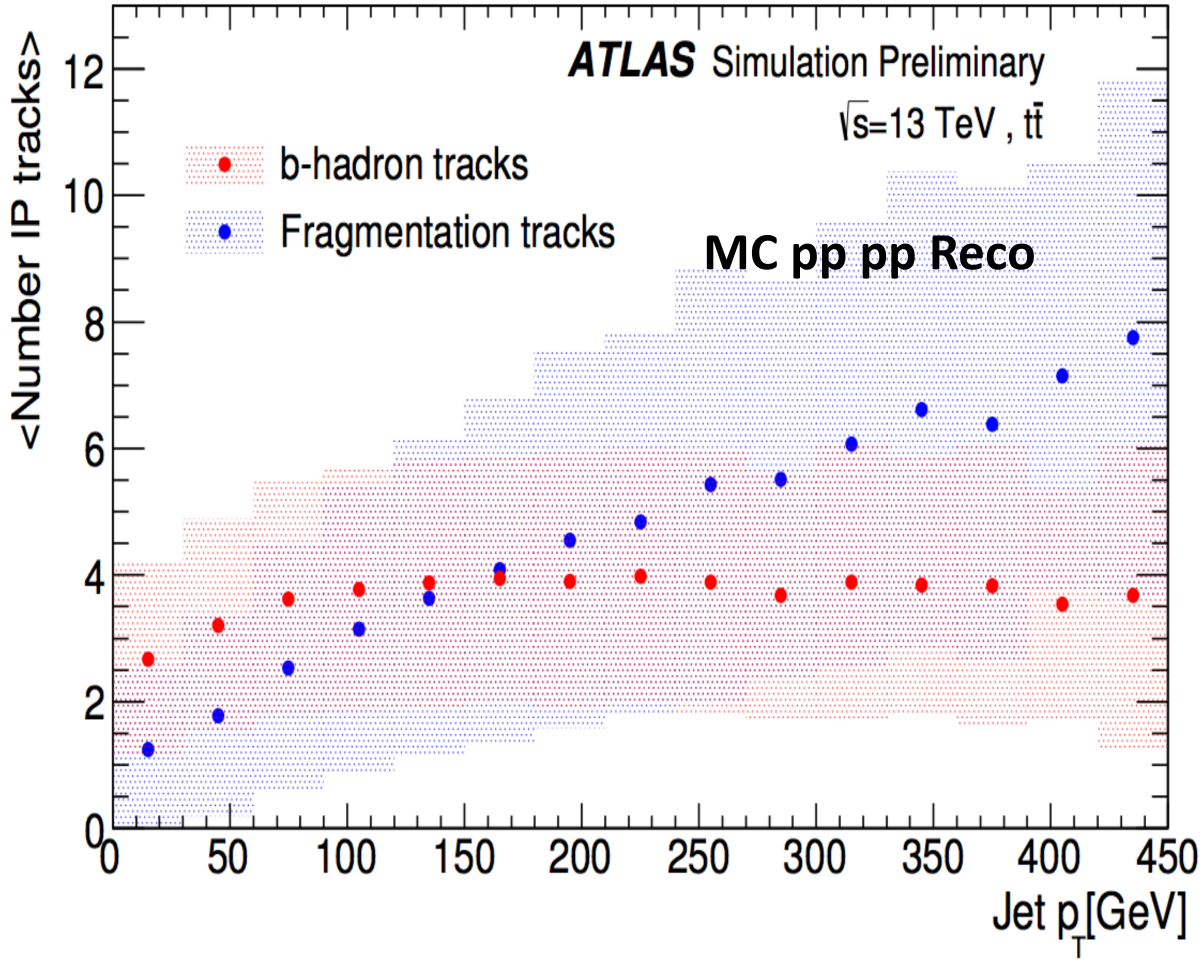
- Less number of tracks are available in b-jets without SV reconstructed.
- Possible reason for loss of efficiency.

Comparison of Tracks between two Samples

- Loop over tracks associated with a jet using shrinking cone.
- Select tracks that pass IP3D selections:
  - p_T^{trk} > 1 GeV;
  - |d0| < 1 mm;
  - |z0*sin(θ)| < 1.5 mm;
  - Pixel Hits + SCT Hits >=7;
  - Pixel Holes <=1;
  - Pixel Holes + SCT Holes <=2;
- Select tracks with mcprob > 0.75.
- Look at matched truth track's production vertex (trk_orig)
- B tracks:
  - trk_orig == truth B decay vertex
  - or trk_orig == (truth C decay vertex) and (this C decays from B)
- Fragmentation tracks: other truth tracks in jet

Differences in Samples





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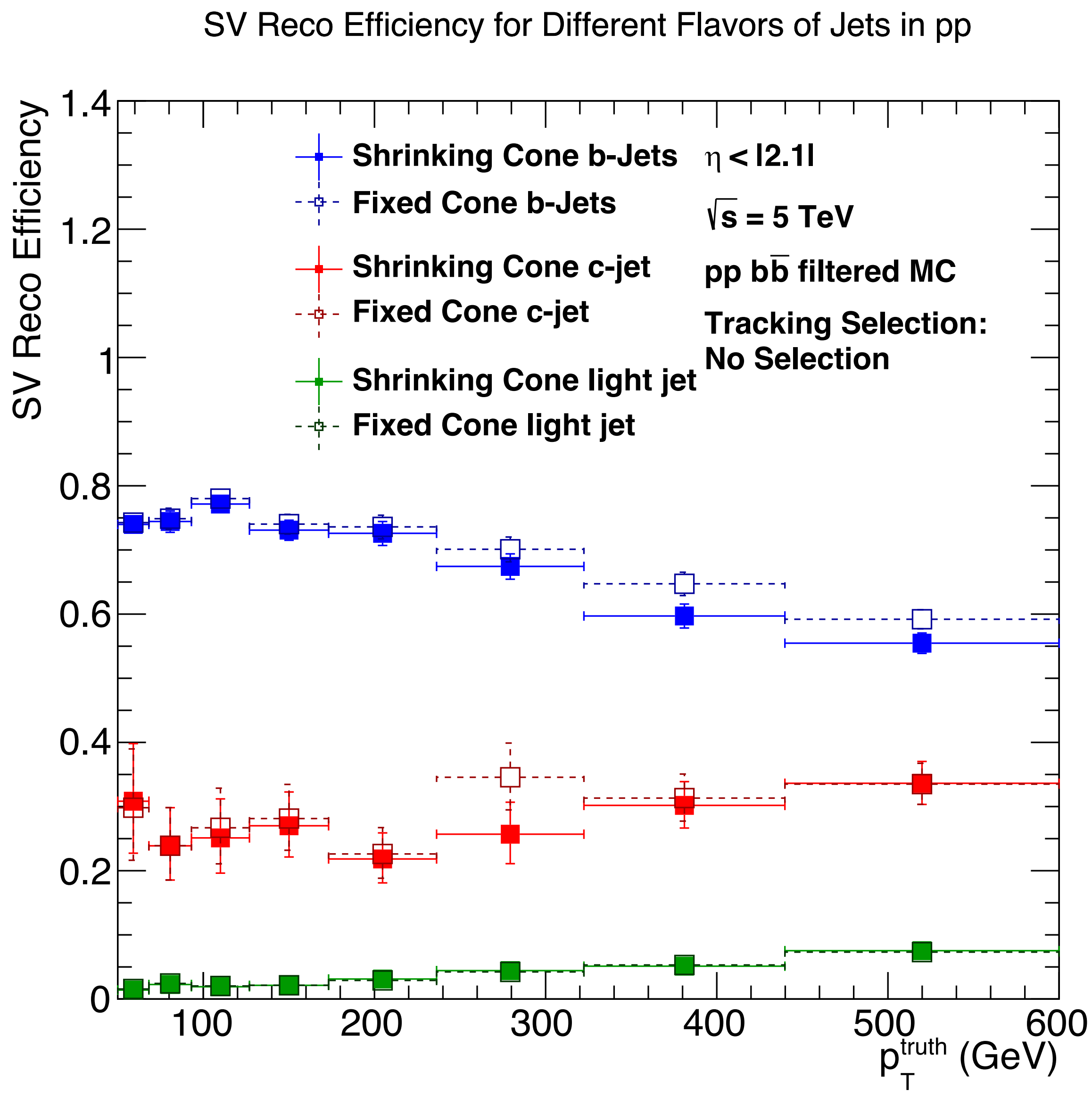
- Similar overall trend.
- Fewer tracks.
- More obvious in high pT (might explain drop in SV efficiency)

Track Selections

- Track-jet Association in HI reconstruction
  - Tried fixed cone=0.4 instead of shrinking cone for track to jet association
- Different track selections in secondary vertexing
  - Disabled z0 and d0 cuts
  - Disabled anti pile-up cuts
  - Disabled jet pT fraction cut

Alternative Track Association

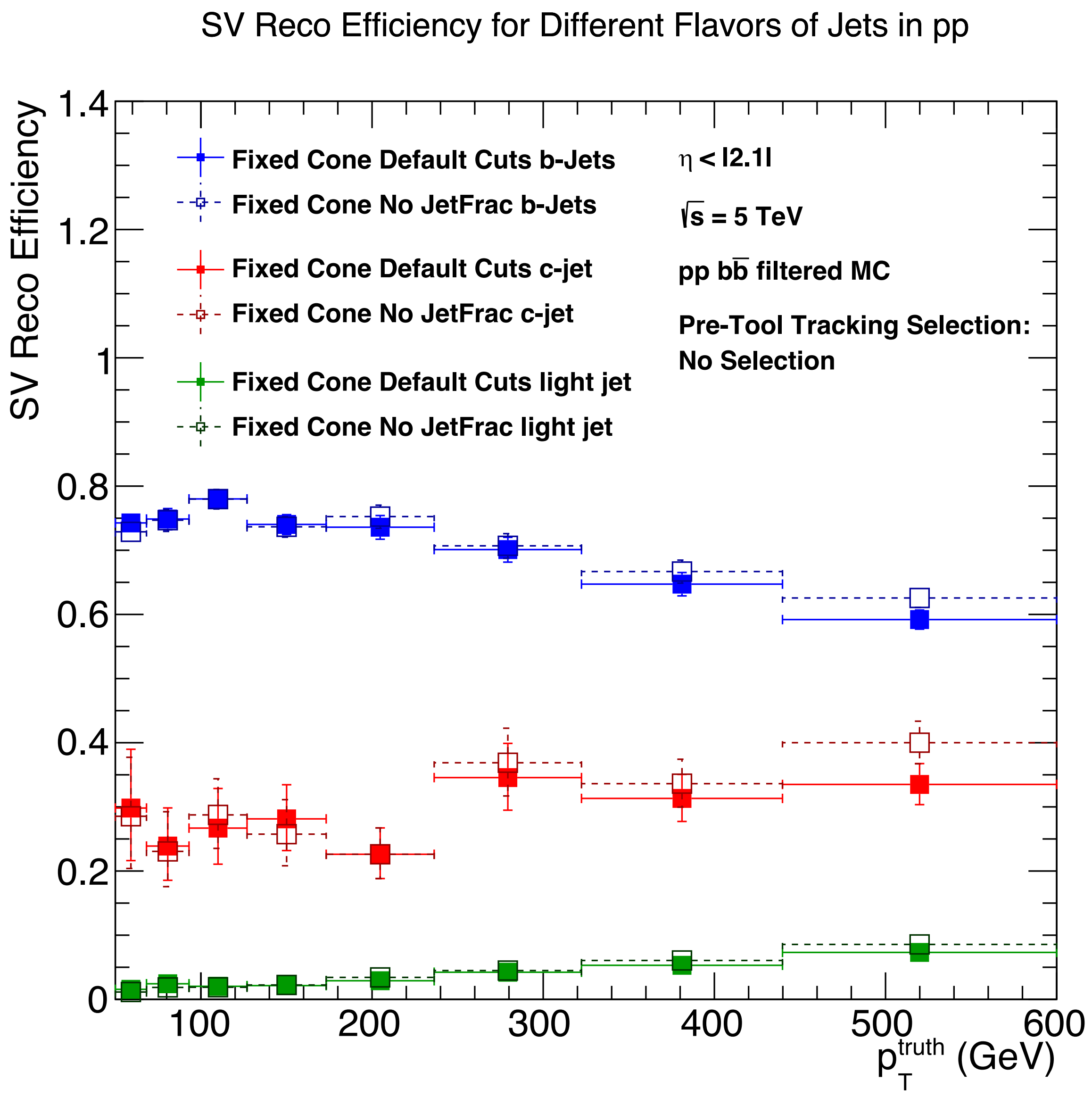


- Switched from shrinking cone to fixed cone = 0.4

- ~5% improvement in high pT efficiency
- Almost no effect to purity.

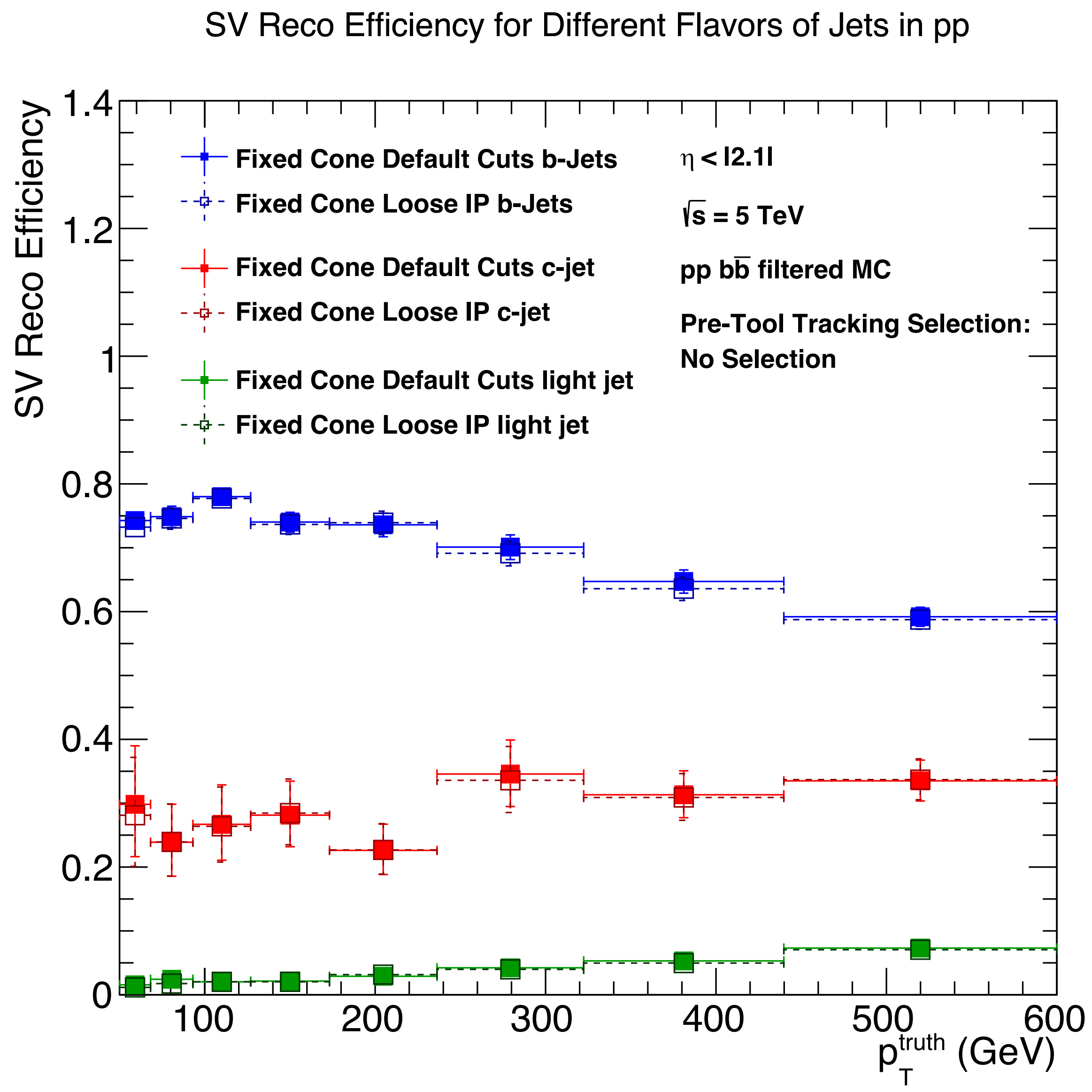
- Might be helpful for PbPb samples where the angular distribution of tracks in jet is different than those in pp.
- Shrinking cone parameters optimized for pp might bias PbPb jets.

Different SVF Track Cuts: Disabled Jet Pt Fraction Cut



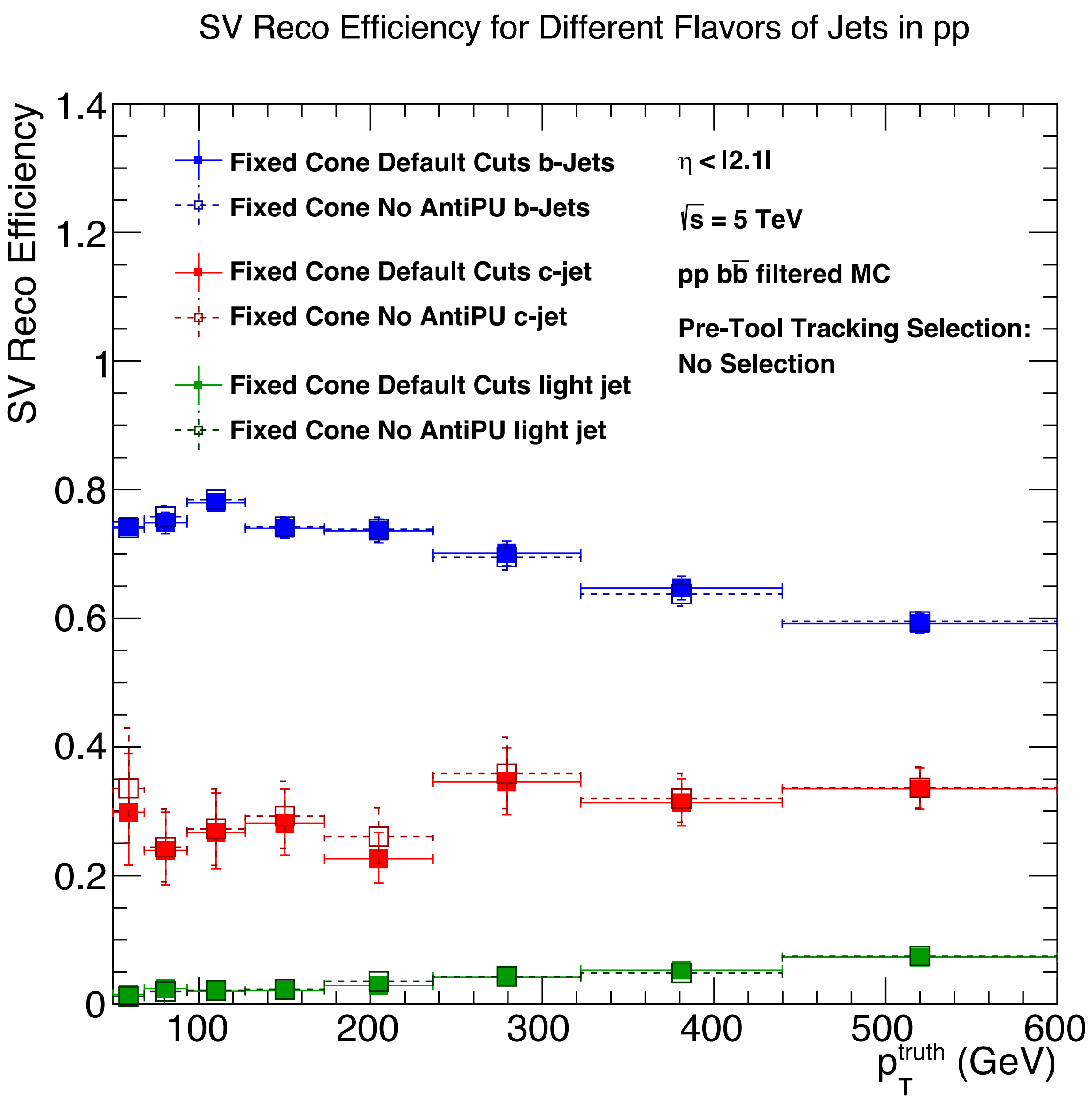
- Disabled jet pt fraction cut
  - Previous: 0.01
- Improved efficiency for additional ~4%, and introduced ~1% fake rate.

Different SVF Track Cuts: Loosened selection on z0 & A0



- Loosened selection on z0 & A0
  - Previous: z0: < 25 mm A0: < 5 mm
- No significant changes in efficiency.
- Maybe should combine with loosening cuts on z0 and A0 error?

Different SVF Track Cuts: Disabled Anti pileup



- Disabled selections for anti pile-up

AntiPileupSigRCut	Remove tracks with low Rφ and big Z impacts presumably coming from pileup
AntiPileupSigZCut	Remove tracks with low Rφ and big Z impacts presumably coming from pileup

- No significant changes in efficiency.

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.
  - Using fixed cone restore ~5% efficiency in high pT region without affecting purity much.
  - Disabling jet pt fraction cut further restores ~4% efficiency in high pT region while increasing ~1% fake rate.
  - Loosening impact parameter selections and anti pile-up selections do not have significant effects.

- Will continue experimenting with track cuts for PbPb samples.

Backups

Homework List

- Try fixed cone with environment of high track occupancy (MC overlay)
- Resolution vs L3d (whether this explains worse SV resolution at high pT)
- Factorize effect of selection and track association (plot B tracks vs fragmentation tracks before applying selections)
- Scope of study/region of effectiveness (what pT range to look at)
- Talk to Ogul about whether a low performance SV tagger still gives ok b-tagging performance
  - Learn about training with our samples.
  - Don’t have a lot of MC
- Pseudo Tracking? (new method, assume perfect track reconstruction?)

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.

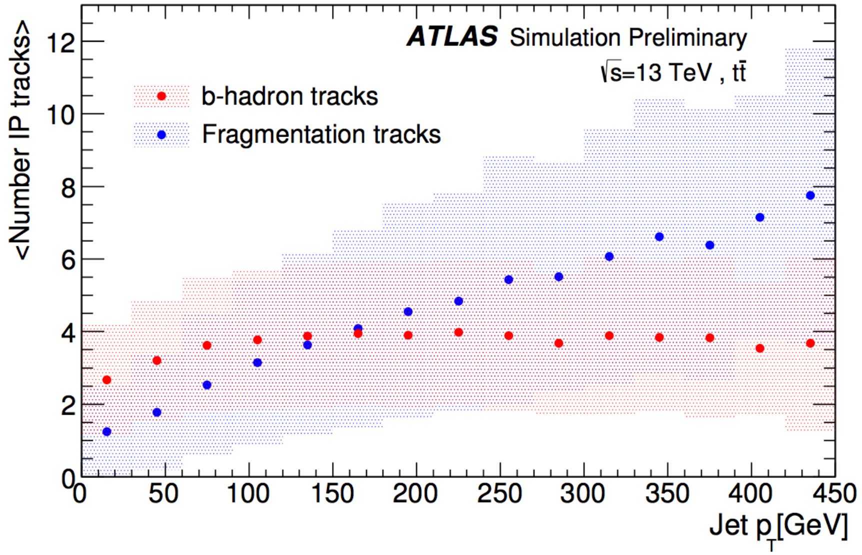
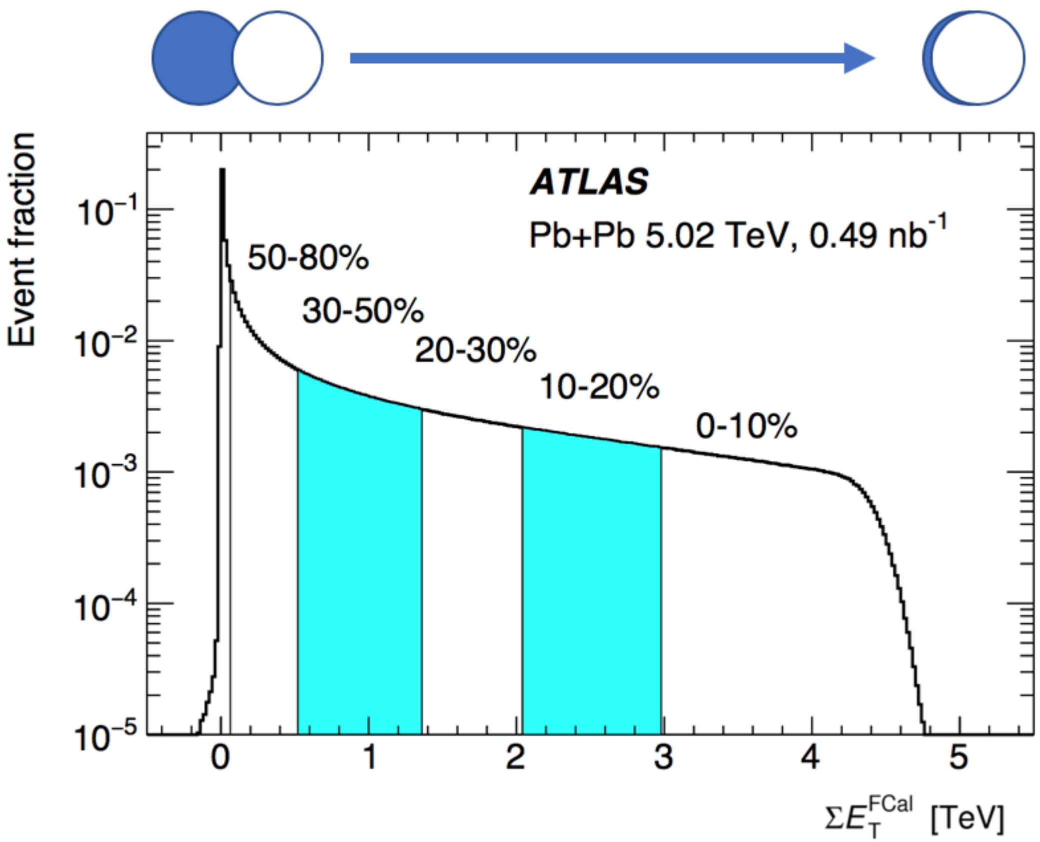


Figure 5: Average number of b-hadron and jet fragmentation tracks selected for the IP algorithm as a function of the jet p_T. The shaded band around the two contributions represents the RMS for each p_T bin.

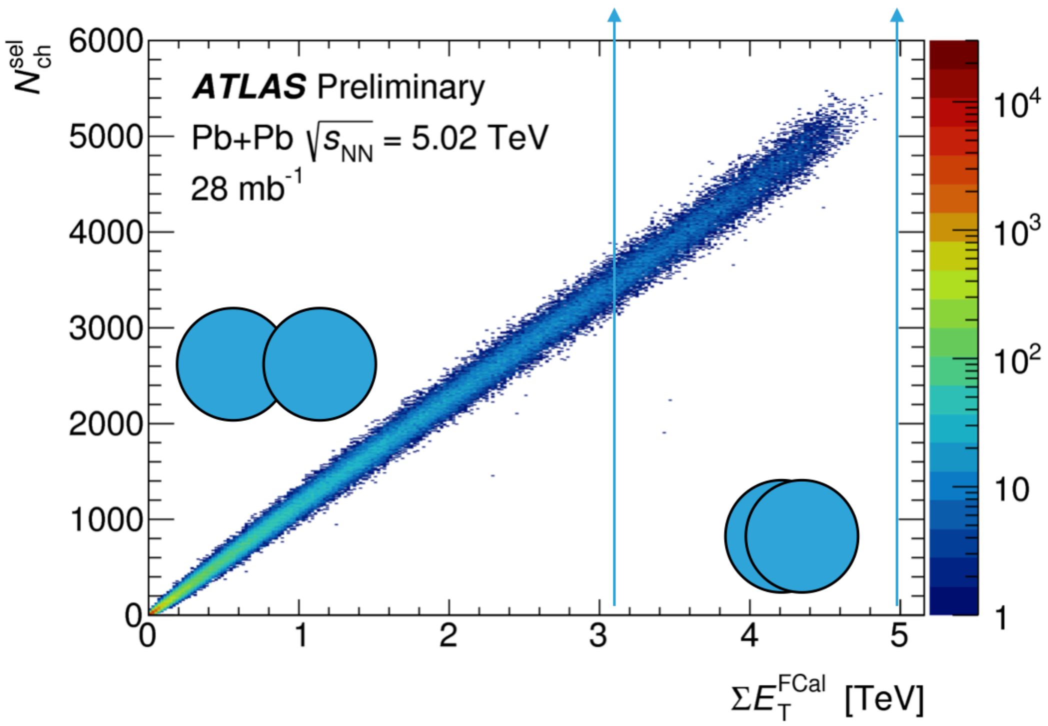
Centrality

- 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)



Pb+Pb collision

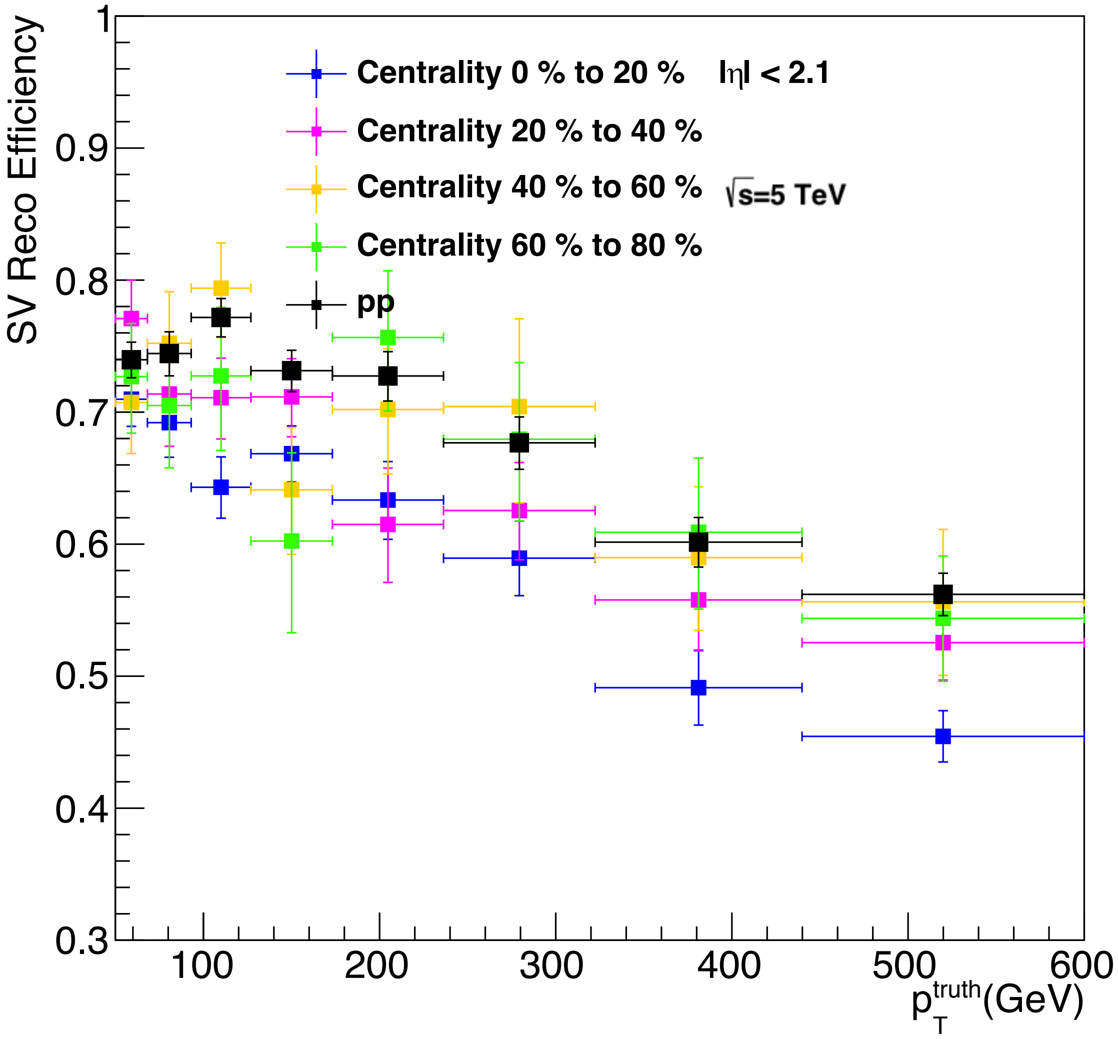
Cent. 0-10%



pT>0.3 [MeV], |eta|<2.5

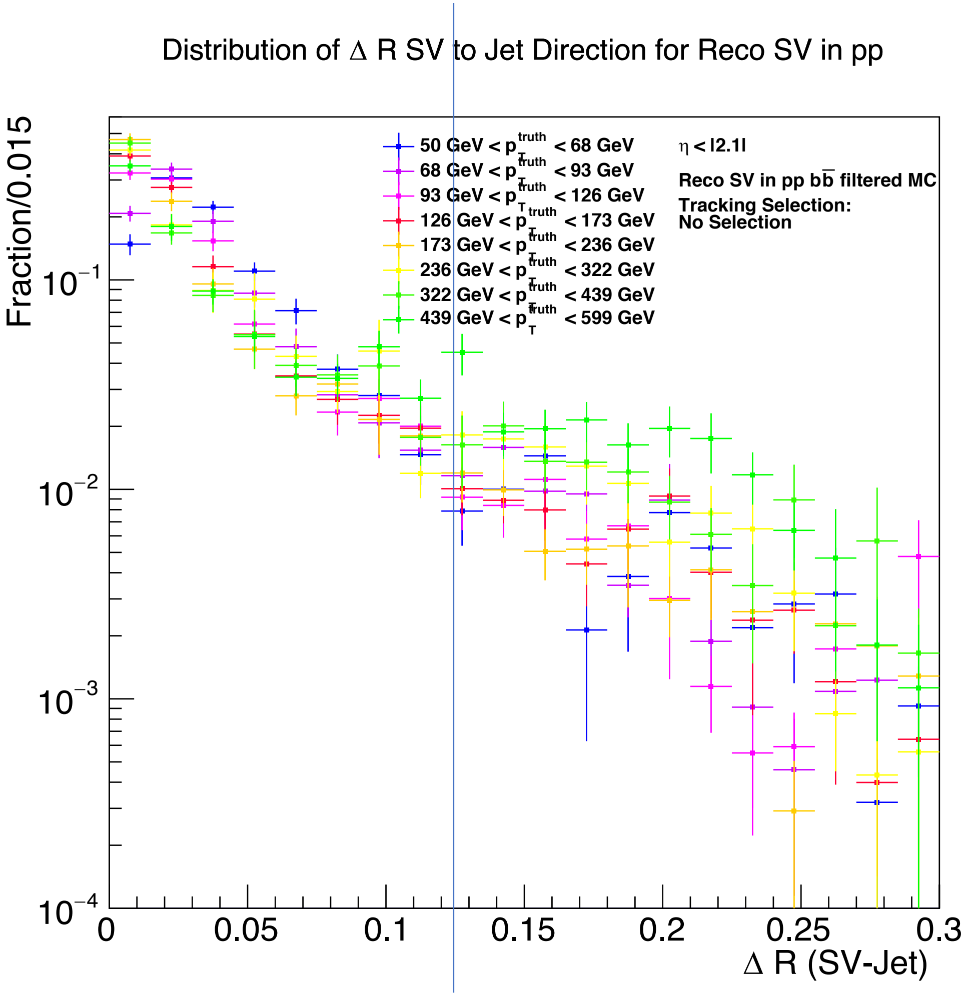
Performance of Secondary Vertex Reconstruction in SVF

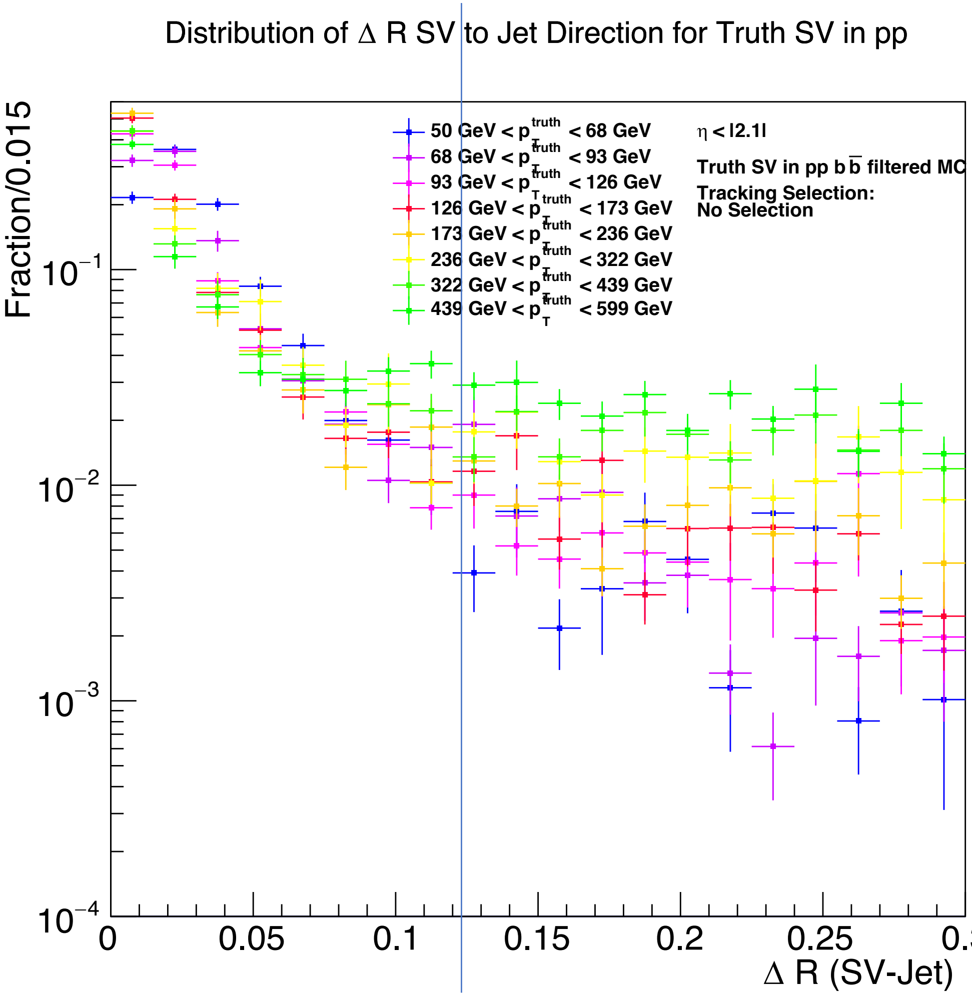
SV Reconstruction Efficiency vs Jet Truth Pt in pp MC and MC Overlay



- 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

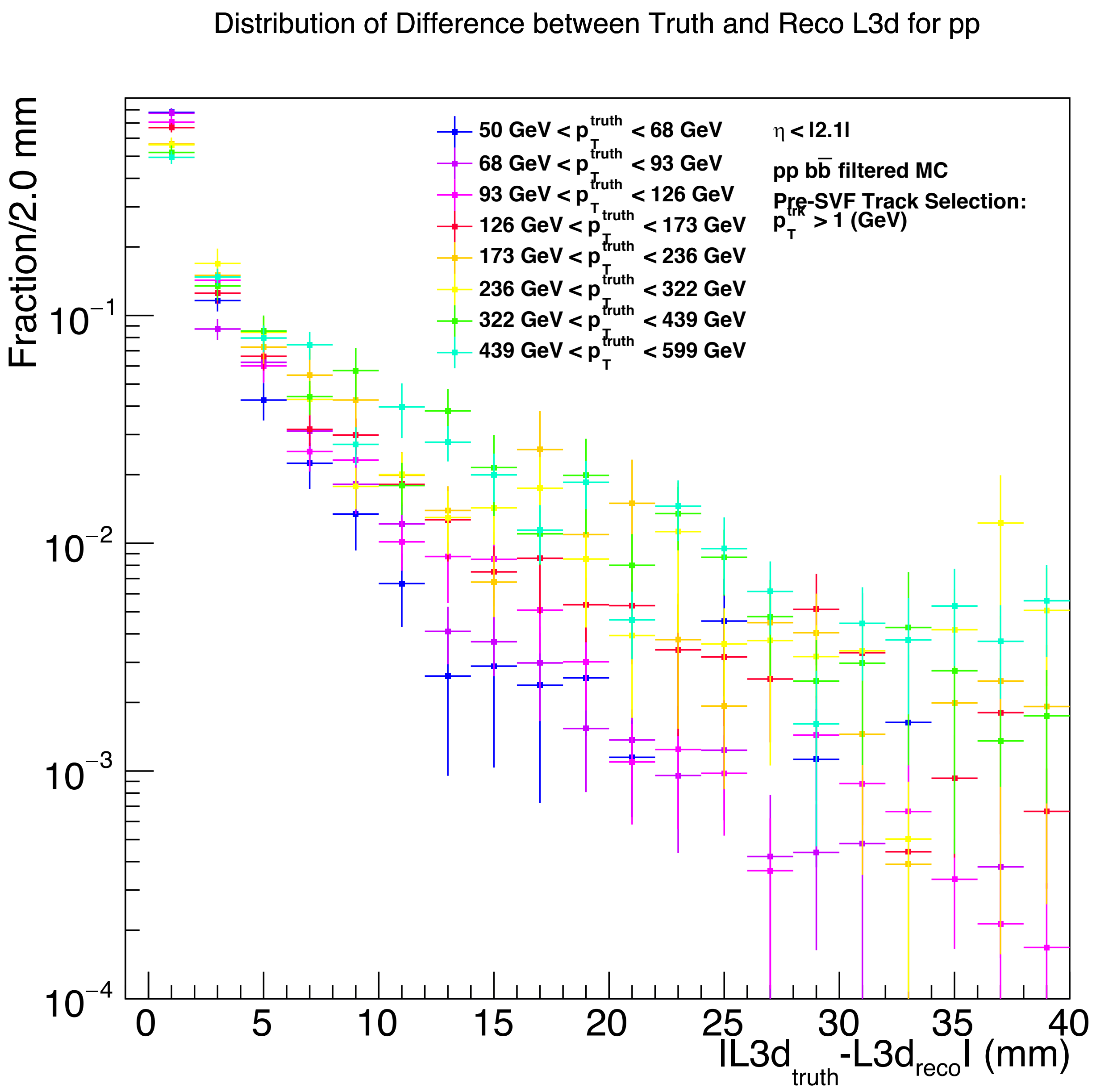
pT Dependence of SV-Jet Distance





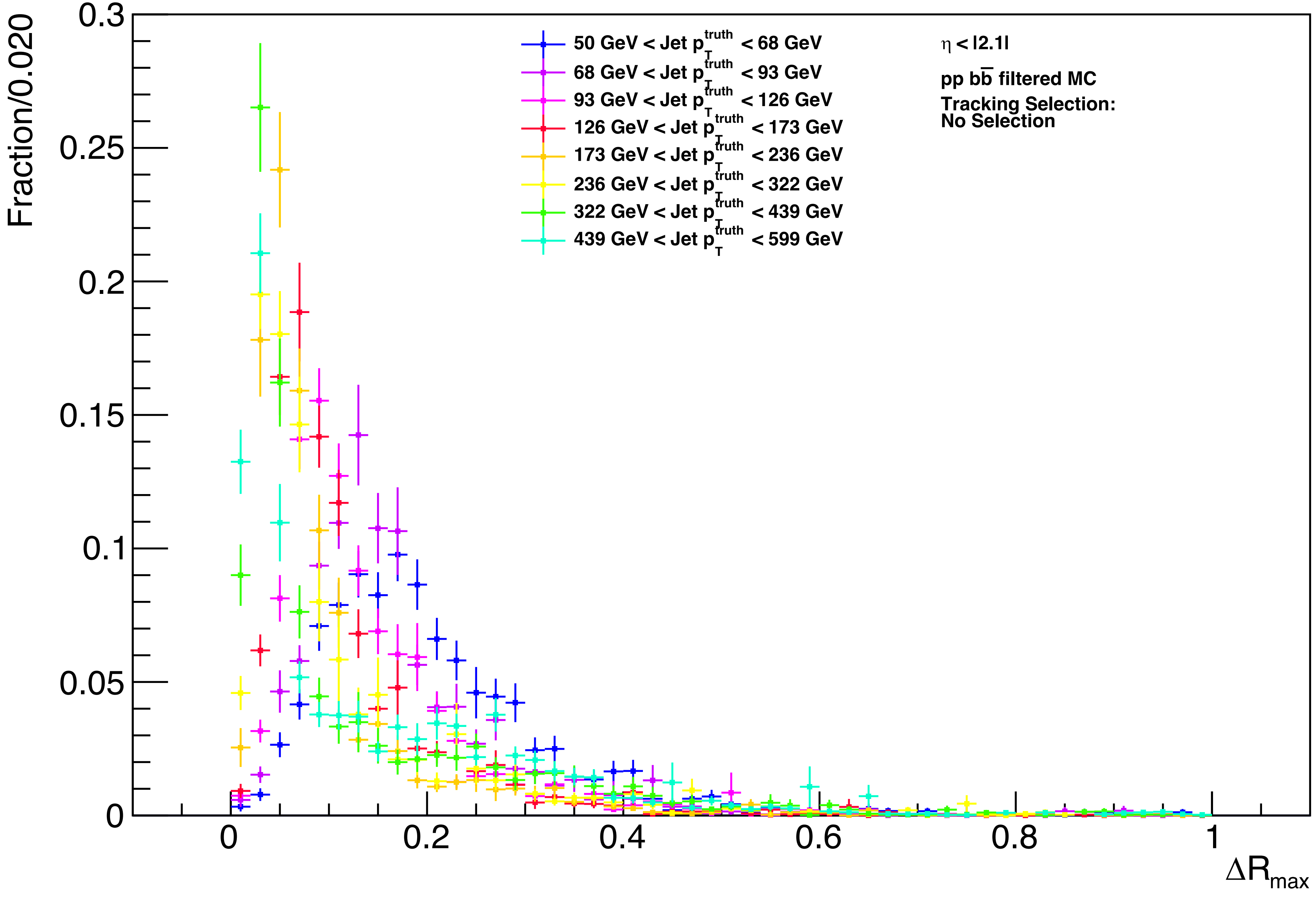
- Narrower distribution at high pt.

Distribution of Distance between Truth and Reco L3d as a function of pT



- Wider separation at higher pT.

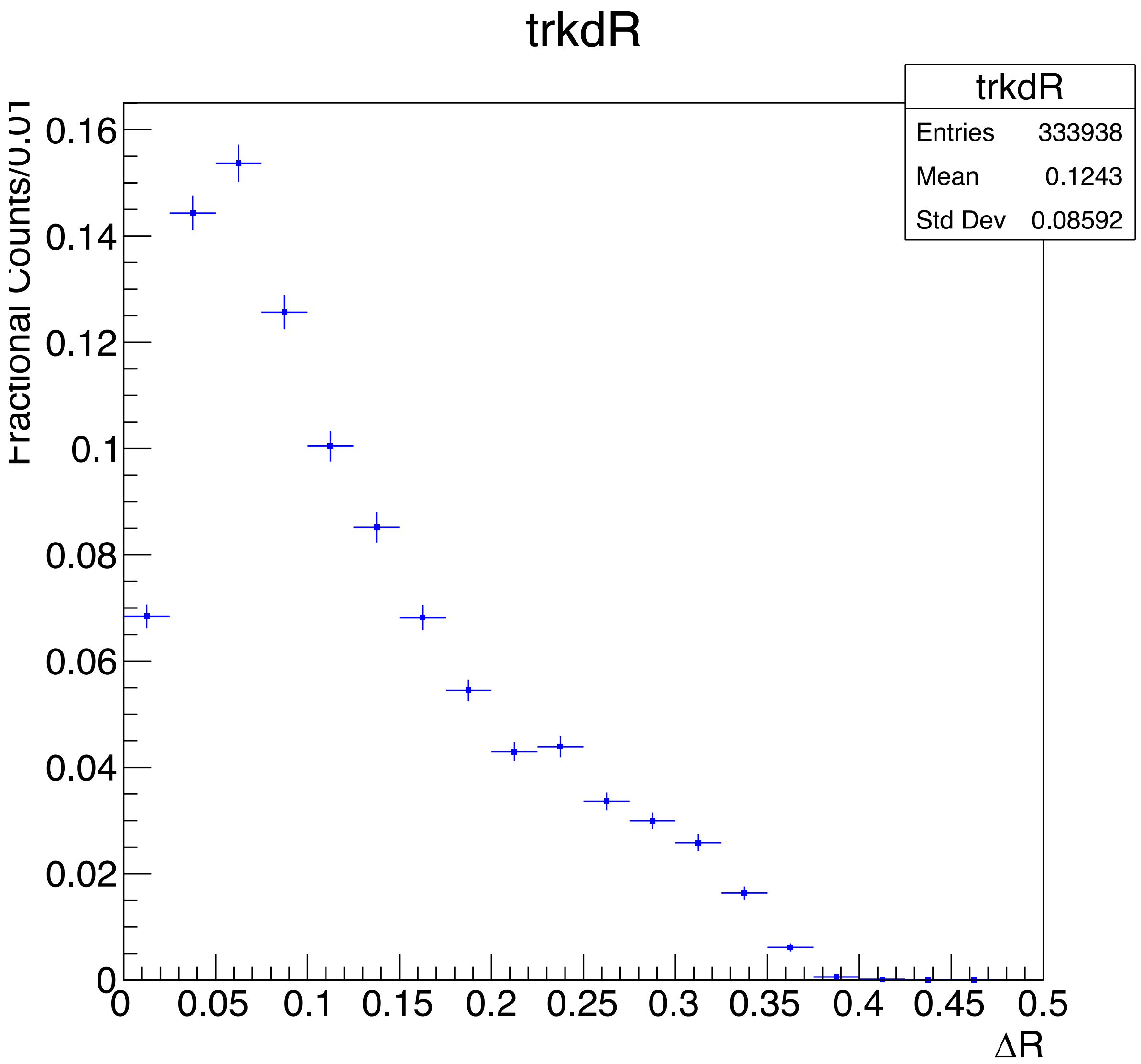
Distribution of Maximum ΔR between B tracks and jet in B jet

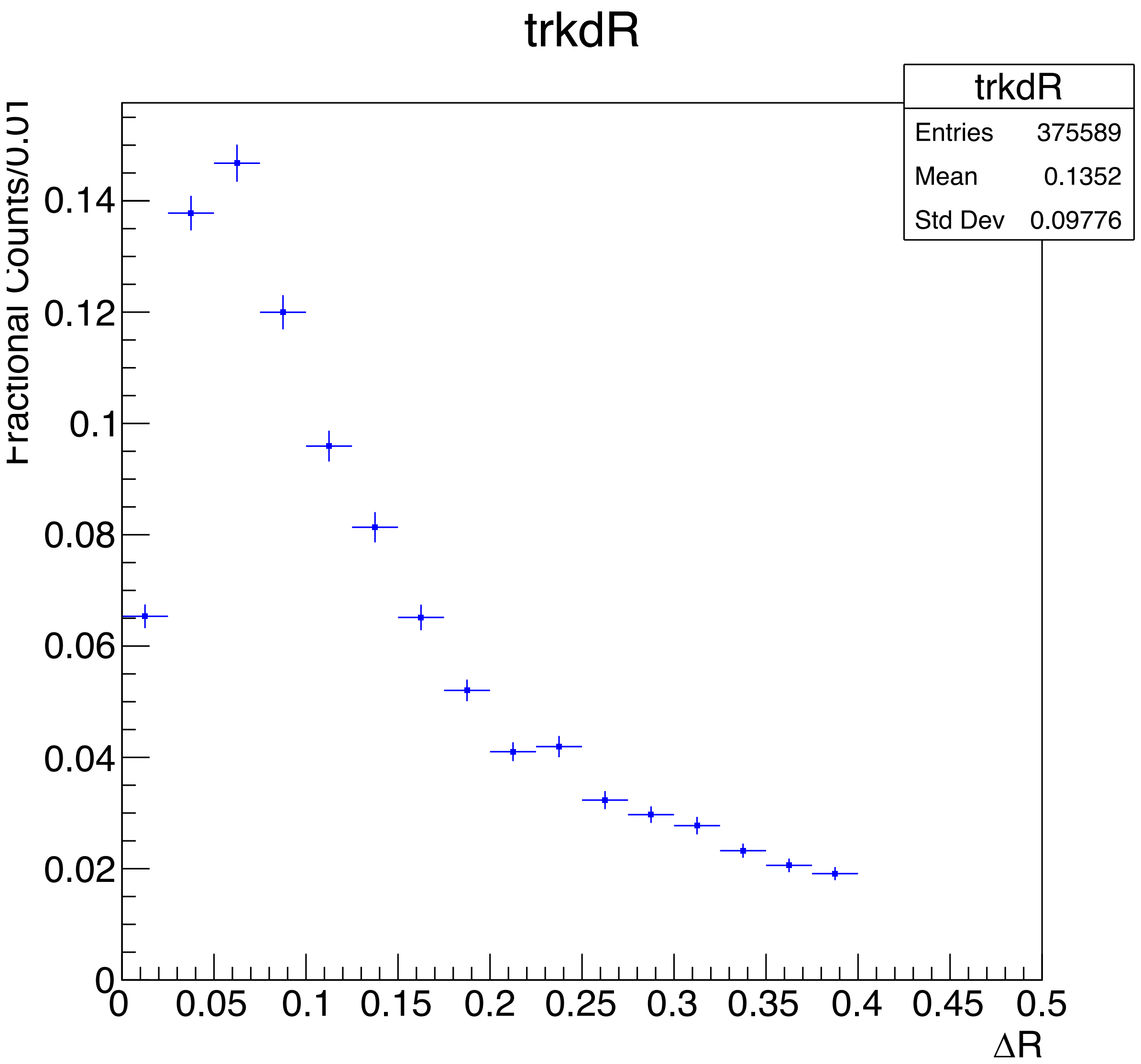


Questions

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

- How are x-y positions defined truth particles?

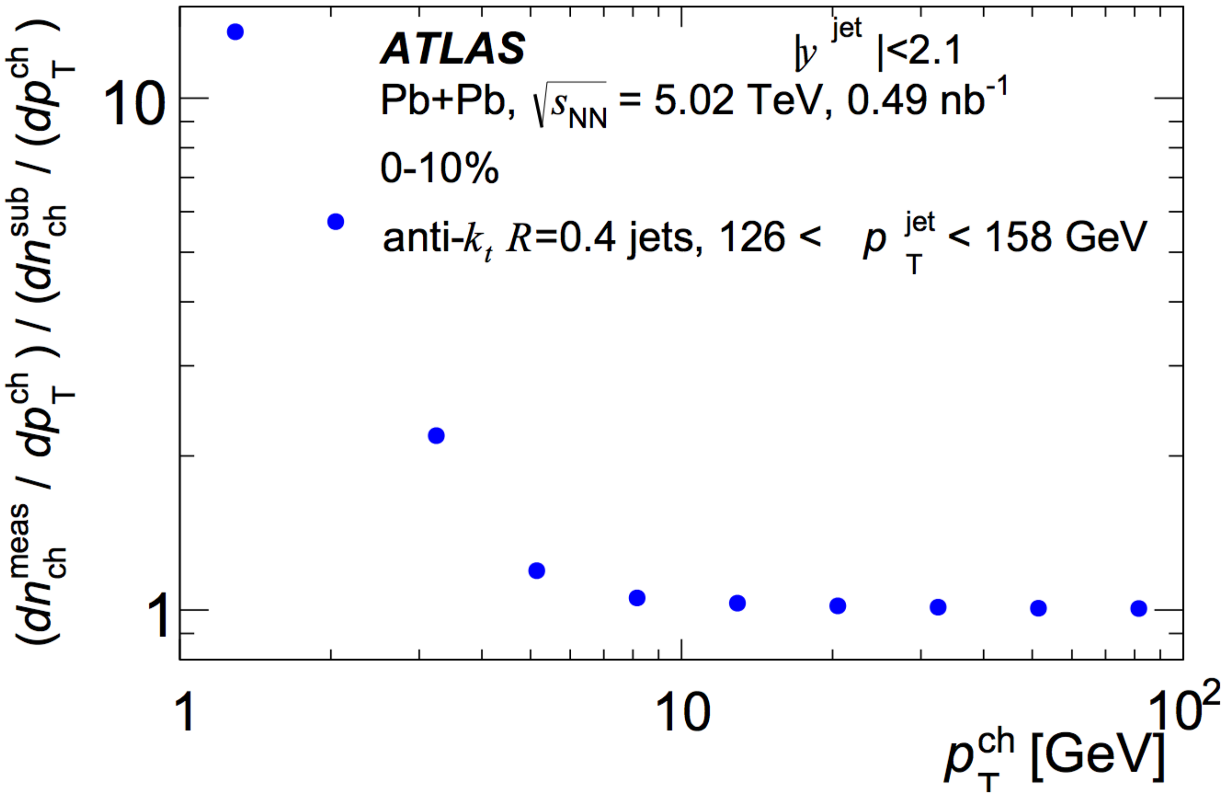

trkdR
trkdR
Entries 333938
Mean 0.1243
Std Dev 0.08592
Fractional Counts/0.01
ΔR


trkdR
trkdR
Entries 375589
Mean 0.1352
Std Dev 0.09776
Fractional Counts/0.01
ΔR

Possible flags to change in SVF tool

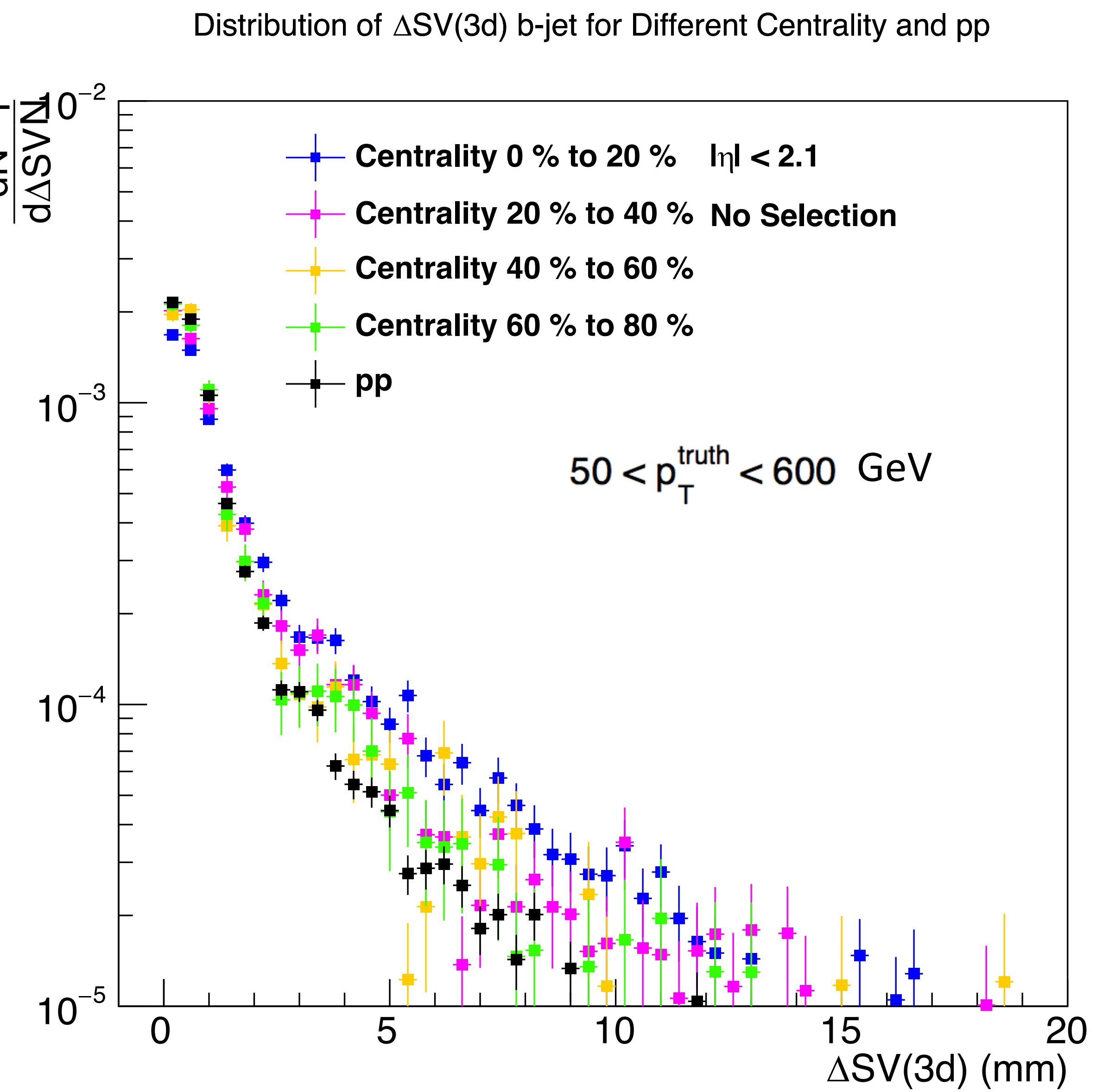
- Drop in SV reco efficiency of b-jets at high pT region.
- b-jets with SV missing have less number of tracks.

- 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.

- # 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

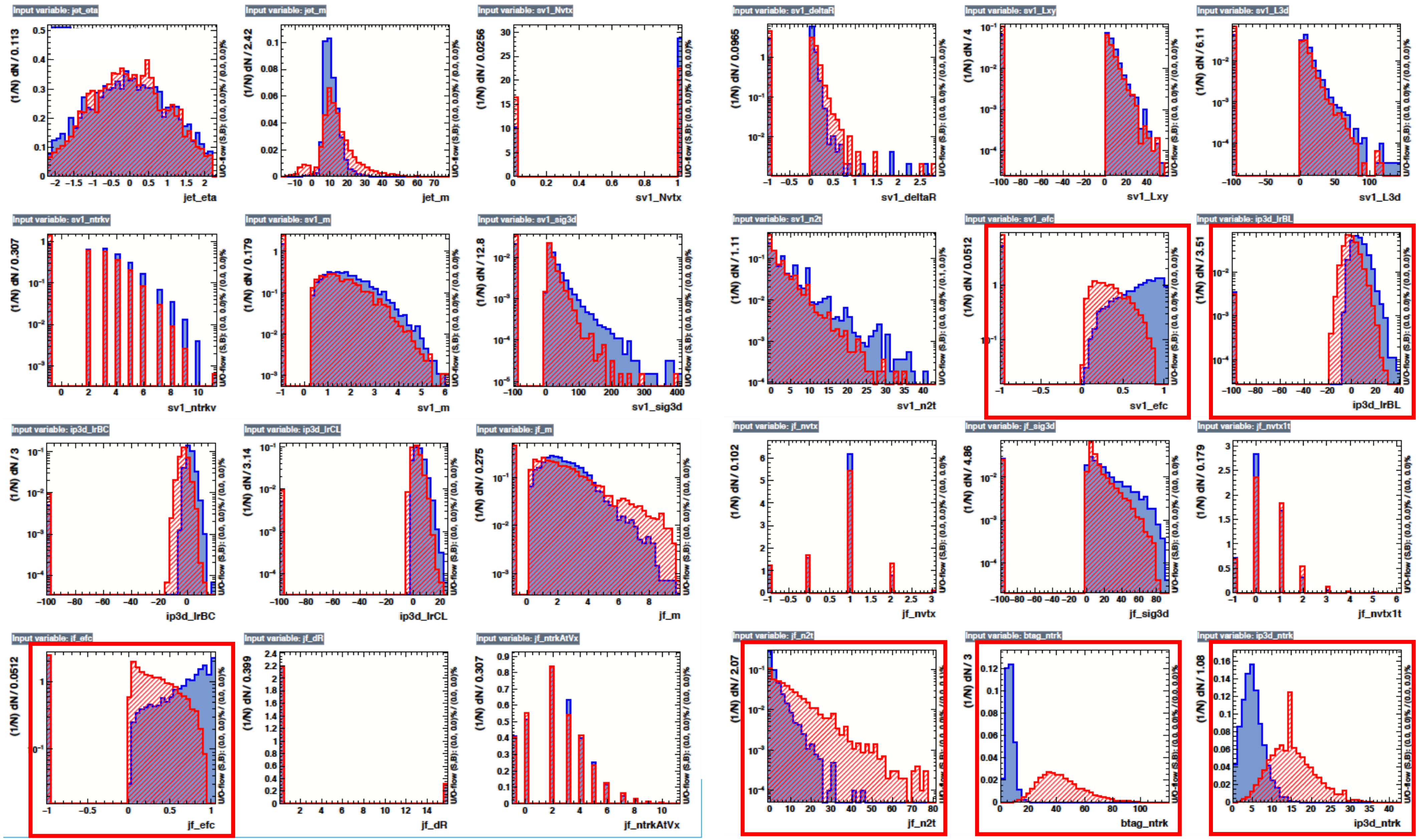
- We will validate these MC and request more.

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.

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

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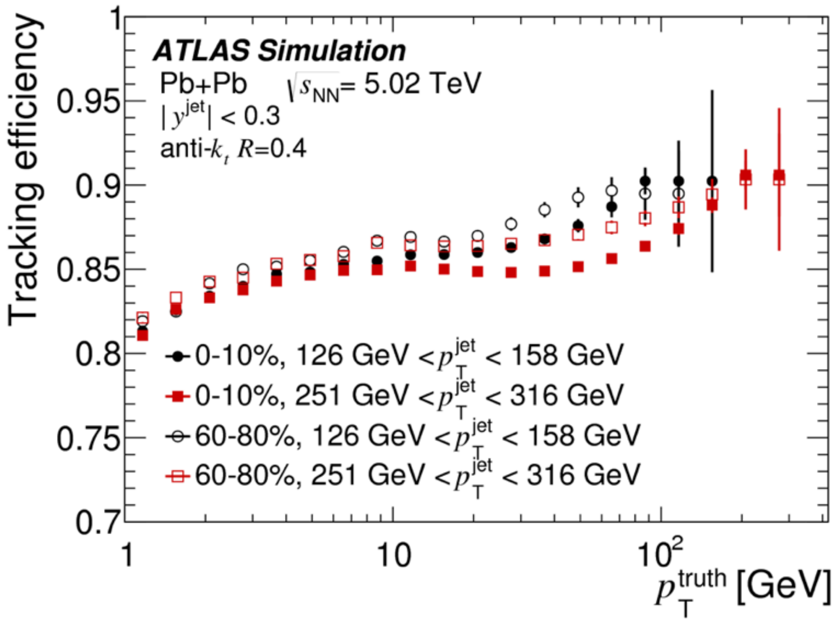
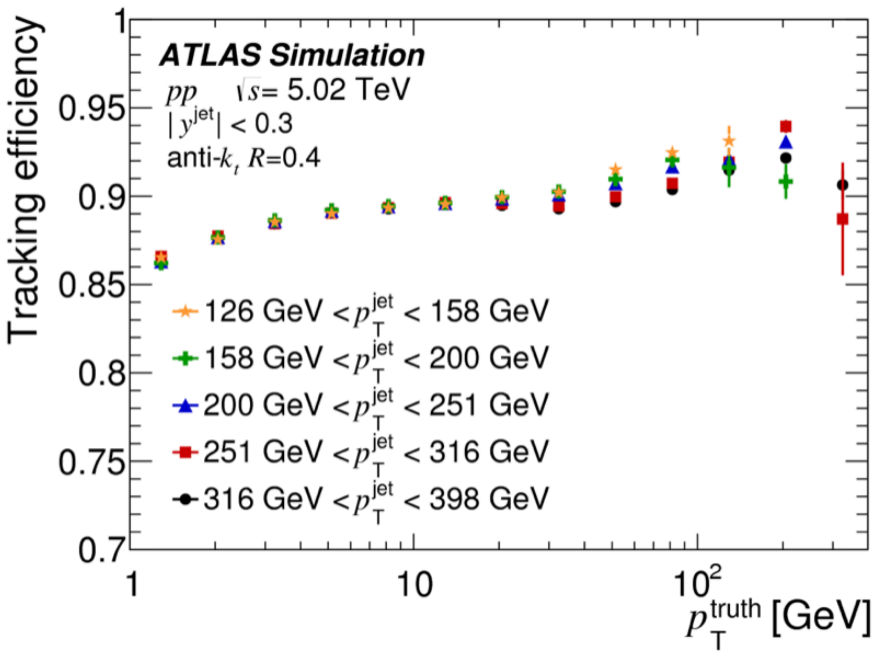
Pb+Pb collision



pp collision



In jet tracking efficiency a bit worst in PbPb collisions

ATLAS EXPERIMENT

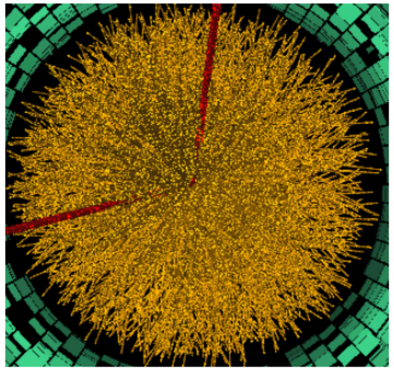
SIMULATION

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

Hard scattering: Pythia, Powheg, Herwig …

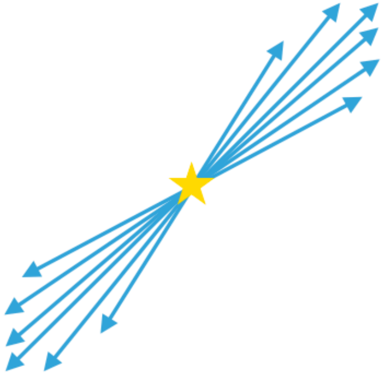
Overlay:

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



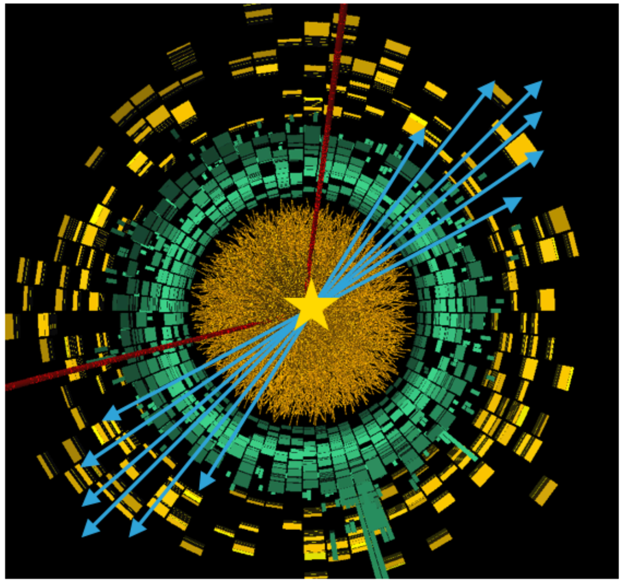
Underlaying Events

+

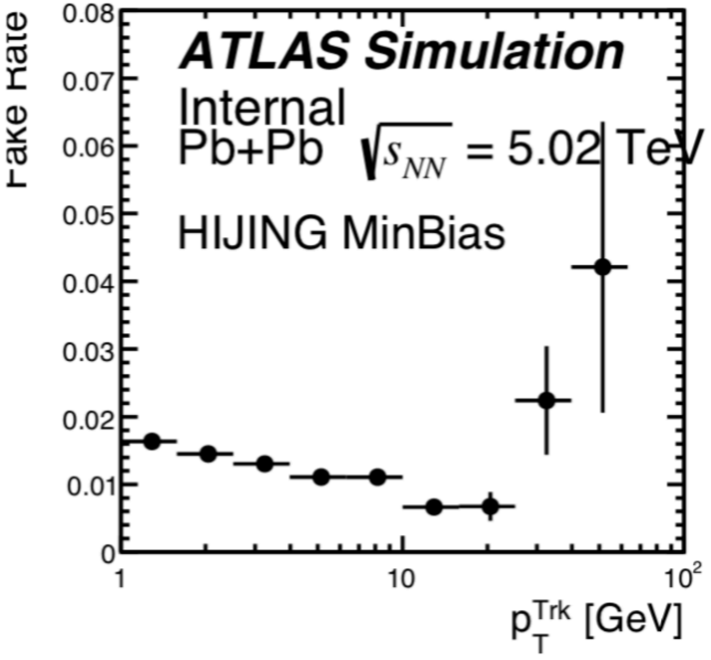


Phythia Di-jets

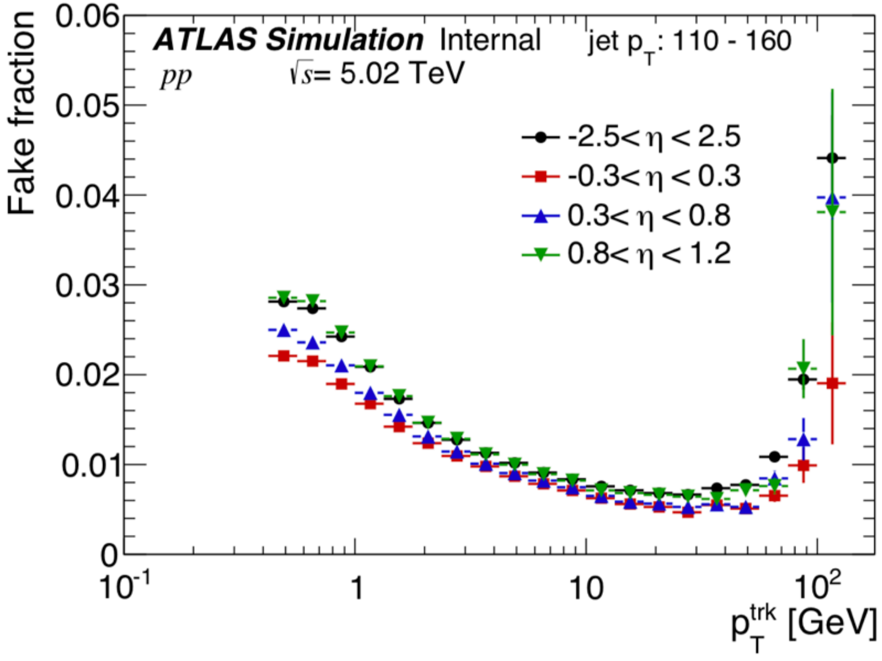
=



Pb+Pb central collision



pp collision



Similar fake rate for both type of collision

Tracking performance: Background

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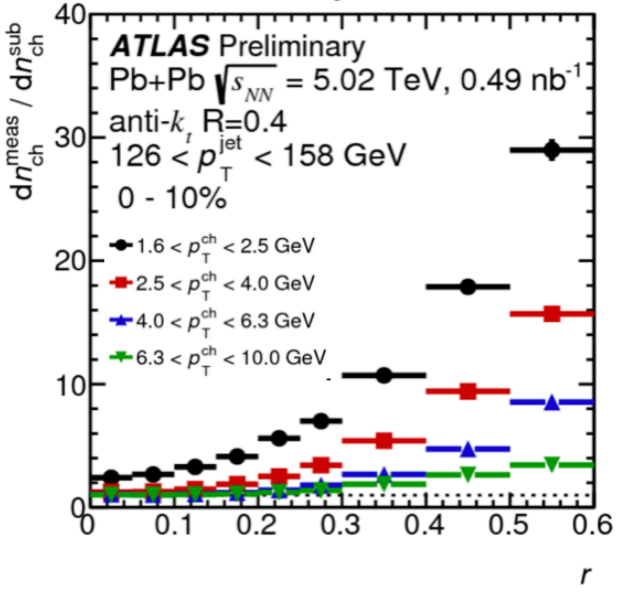
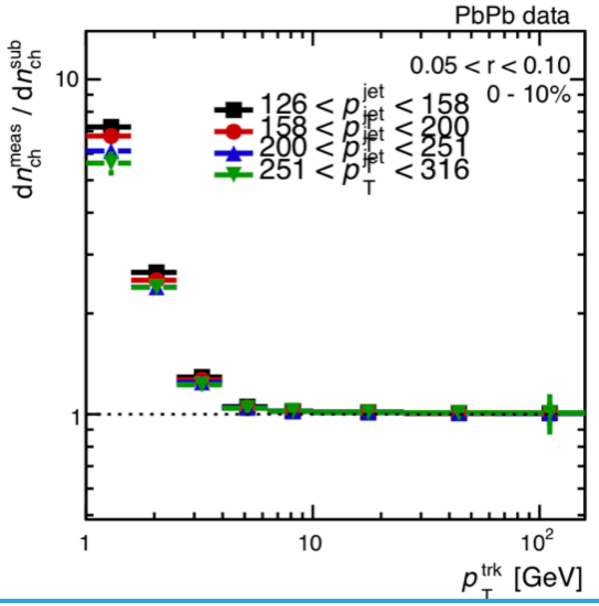
Function of jet R

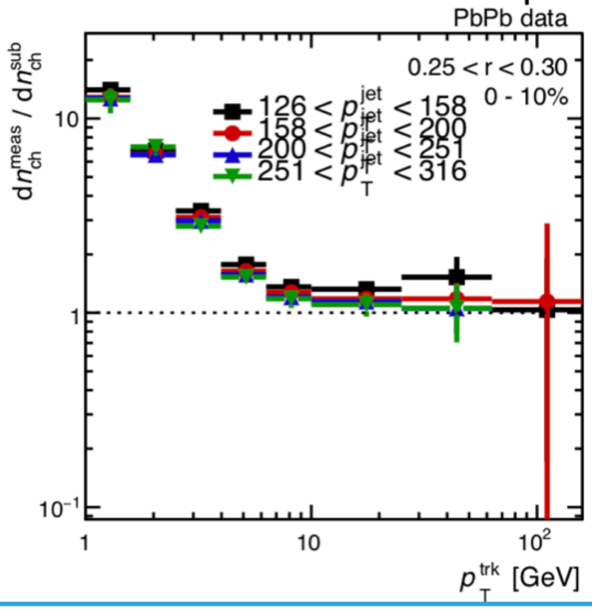


Measured Tracks/ Jet tracks = (signal + bkg.)/signal

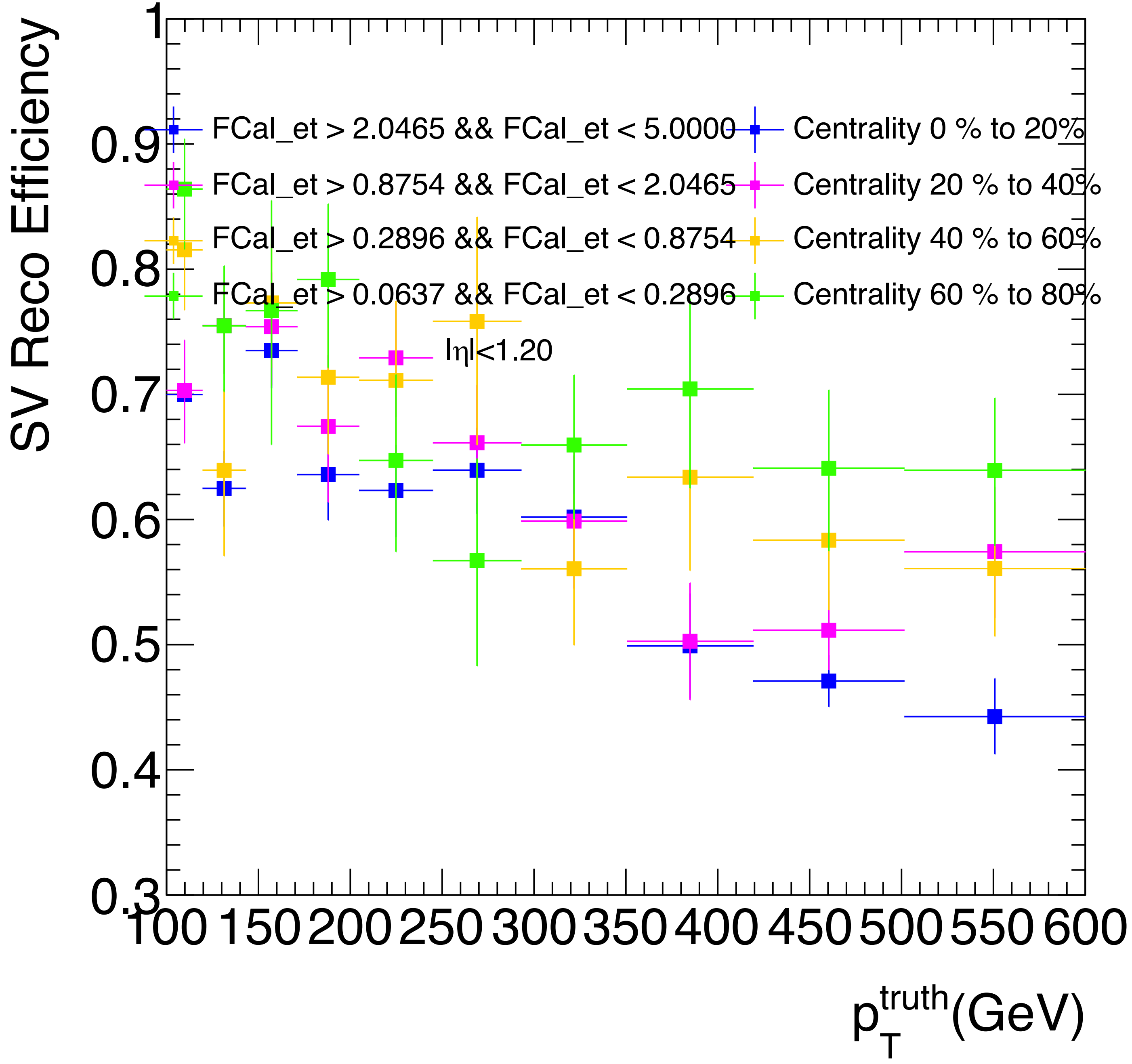
Most tracks not coming from jets (background), are below 4 GeV

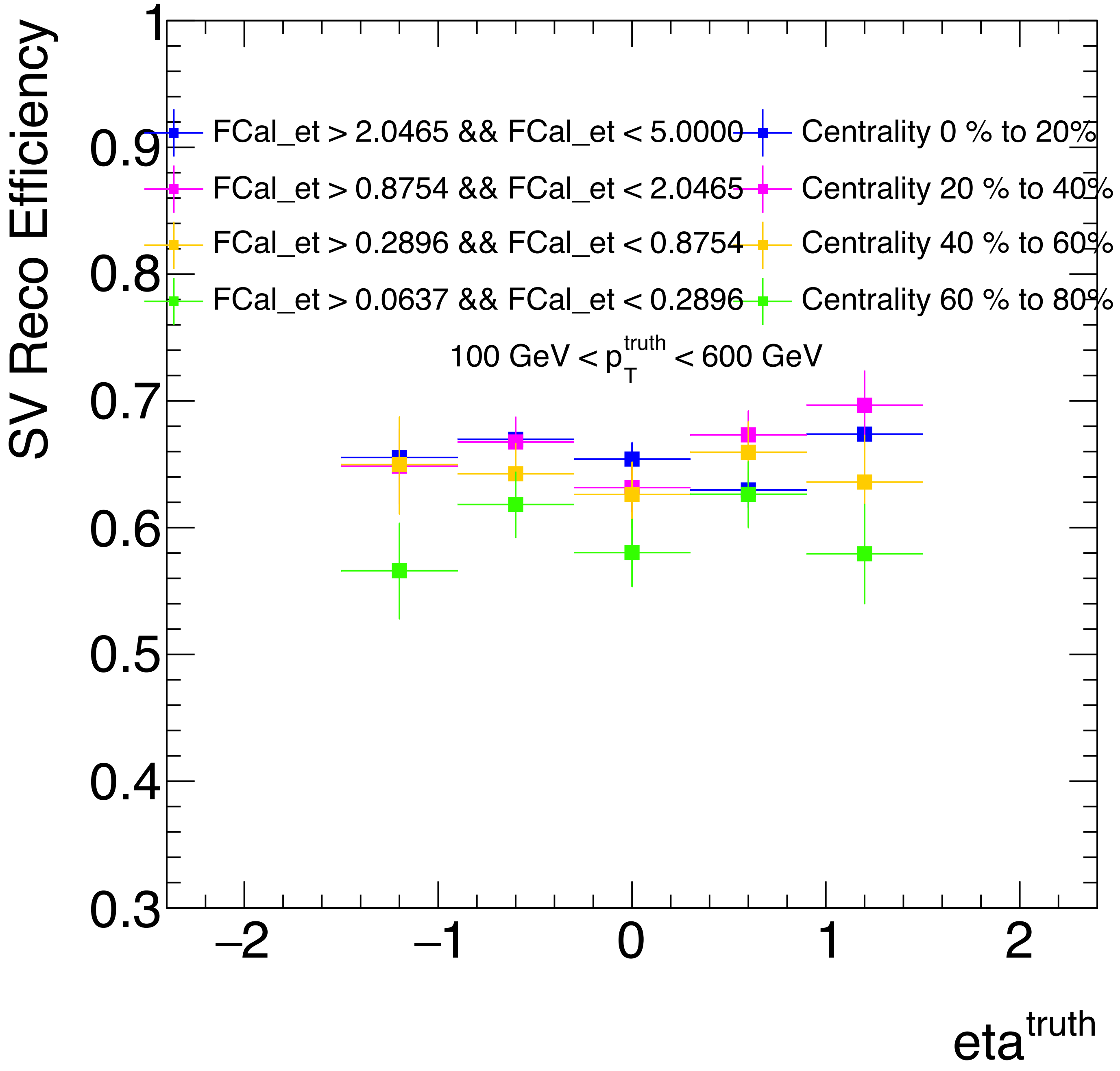
Function of track pT





S


SV Reco Efficiency
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%
|η|<1.20
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
100 150 200 250 300 350 400 450 500 550 600
p_T^{truth}(GeV)



SV Reco Efficiency
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
eta^{truth}