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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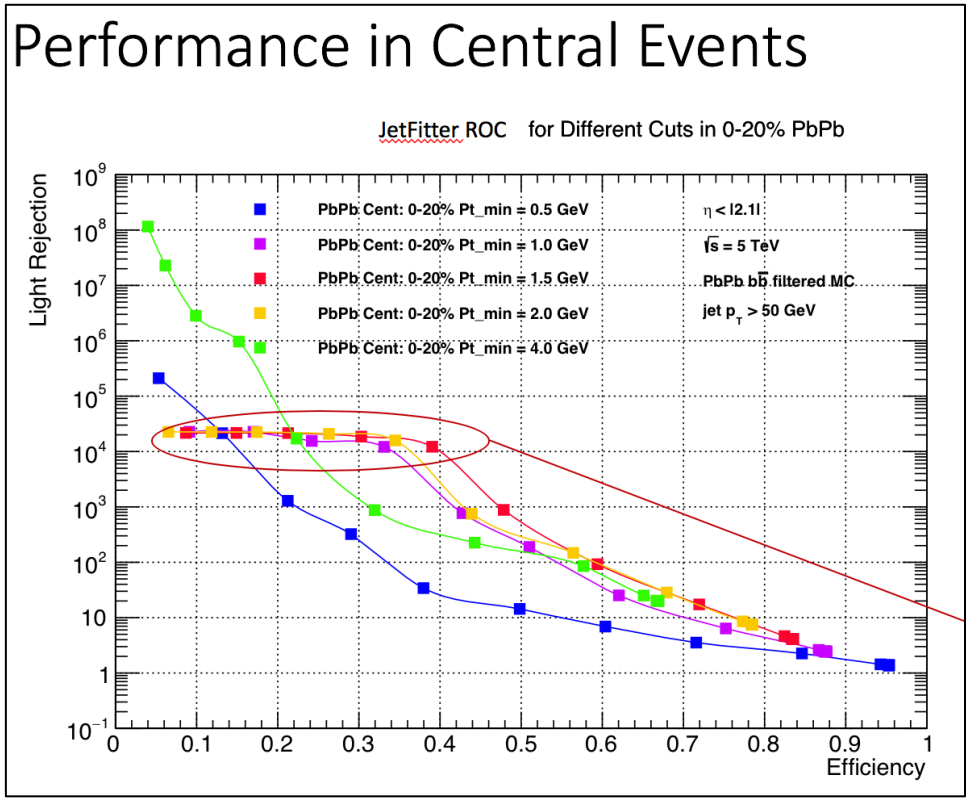
Homework/Discussion

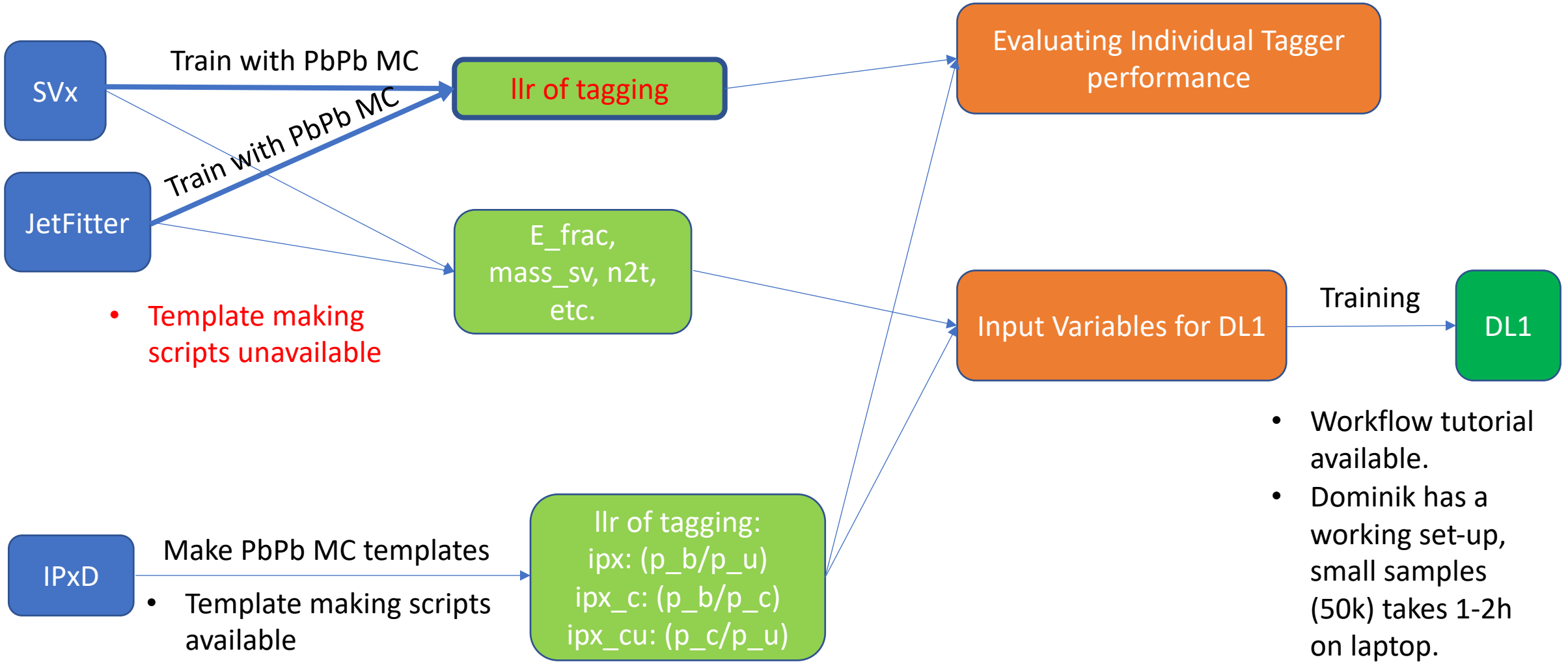
- Individual tagger results (llr directly from JF or SV1) are not recommended for using. Taggers haven't been retrained for a while.
- Recommendation: look into inputs from individual taggers.
- Retraining:
  - For IPxD taggers, flavor tagging people will provide retraining scripts.
  - JF, SV1 retraining scripts haven't been used for a while. What are the possibilities?

Performance in Central Events



Individual tagger performance from pp sampled trained (long time ago) consistent with vertexing performance, but retraining is recommended.

“Workflow” of btagging



- Template making scripts unavailable

- Template making scripts available
- Needs to run retagging framework on grid.

- Workflow tutorial available.
- Dominik has a working set-up, small samples (50k) takes 1-2h on laptop.
- Not looked at grid resources yet.

Possible workaround

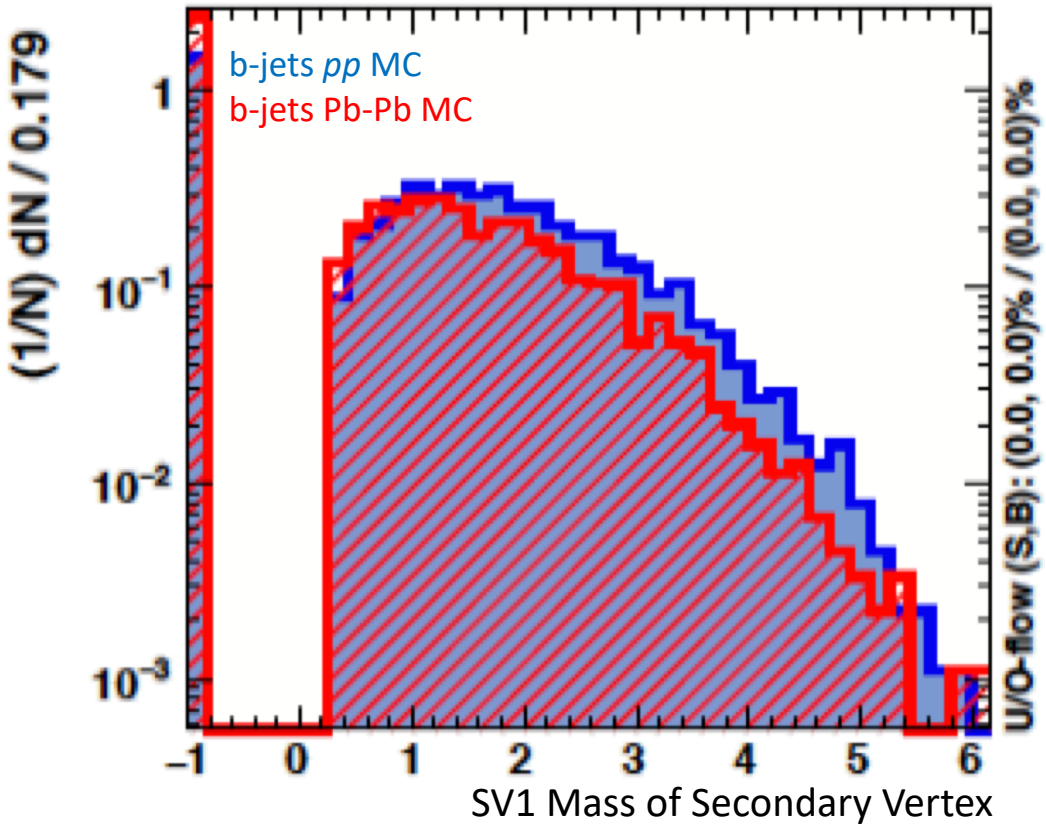
- To evaluate JF and SVx performance:
  - Write our own training scripts for each of them and see performance
    - Simple, easy to change, probably quicker for testing.
    - Doesn’t give final performance of DL
  - Evaluate JF and SVx using vertexing performance, and retrain DL once in a while
    - Retrained DL gives final performance. No need to code custom training scripts.
    - Vertexing performance also doesn’t reflect tagging performance exactly, and training DL on large samples could take long.

- Next Steps:
  - Look at distributions of JF/SVx input variables and compare with pp.
  - Tune IPxD and check improvements.
  - Question: how to coordinate with Dominik?

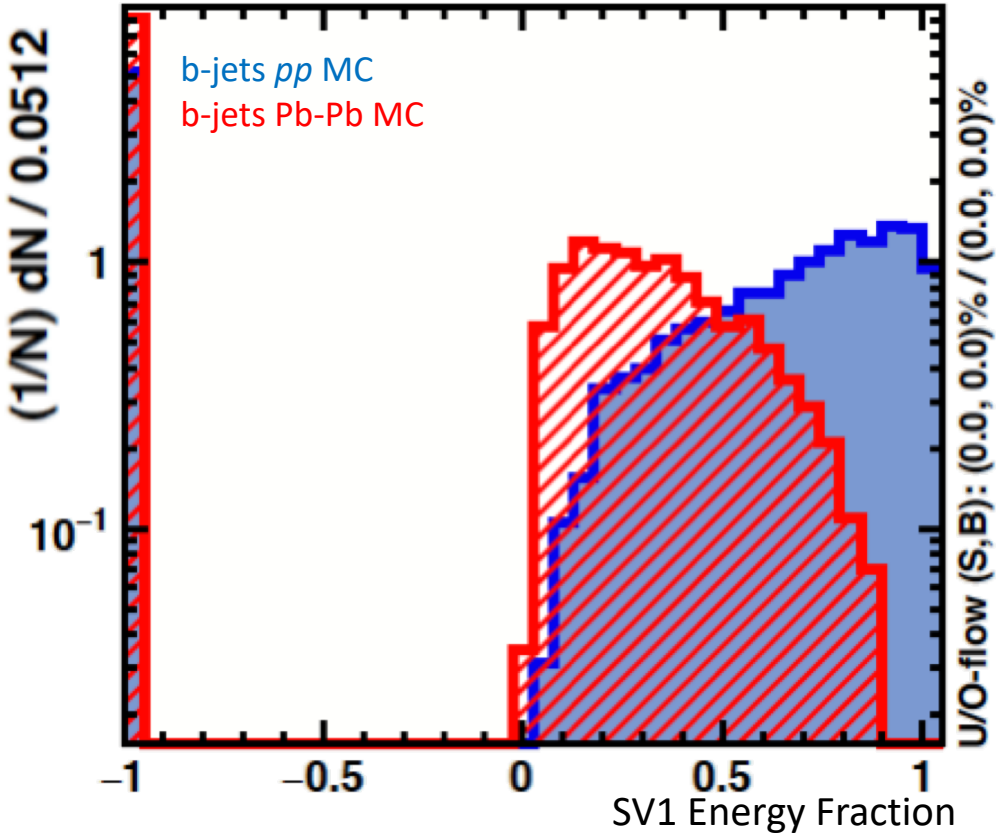
Description of Qualification Task (AFT-455)

- 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

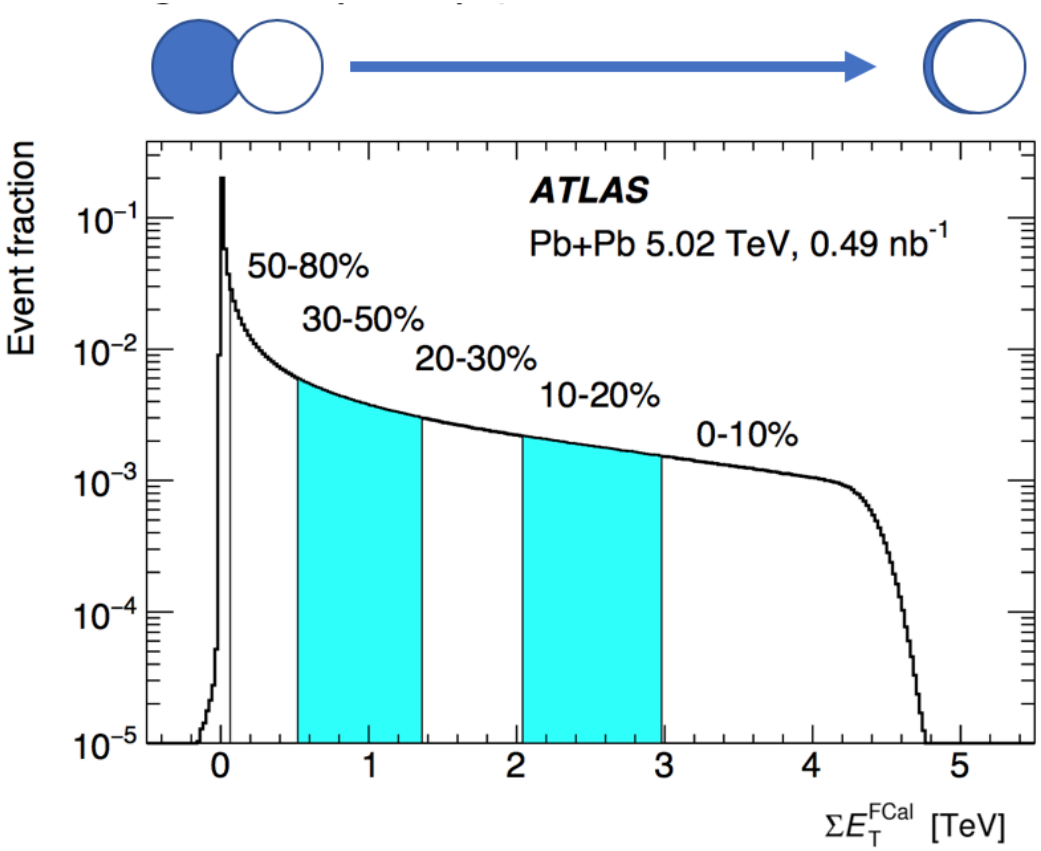


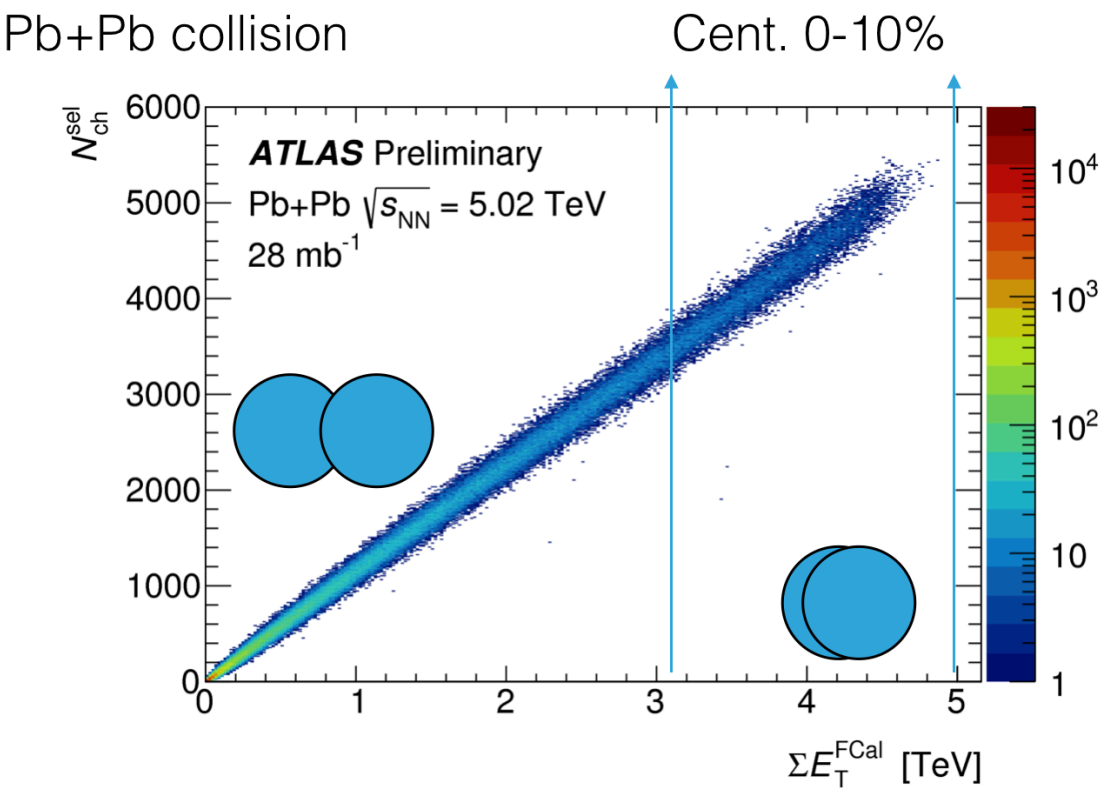
Energy Fraction peaks differently in pp and Pb-Pb



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)

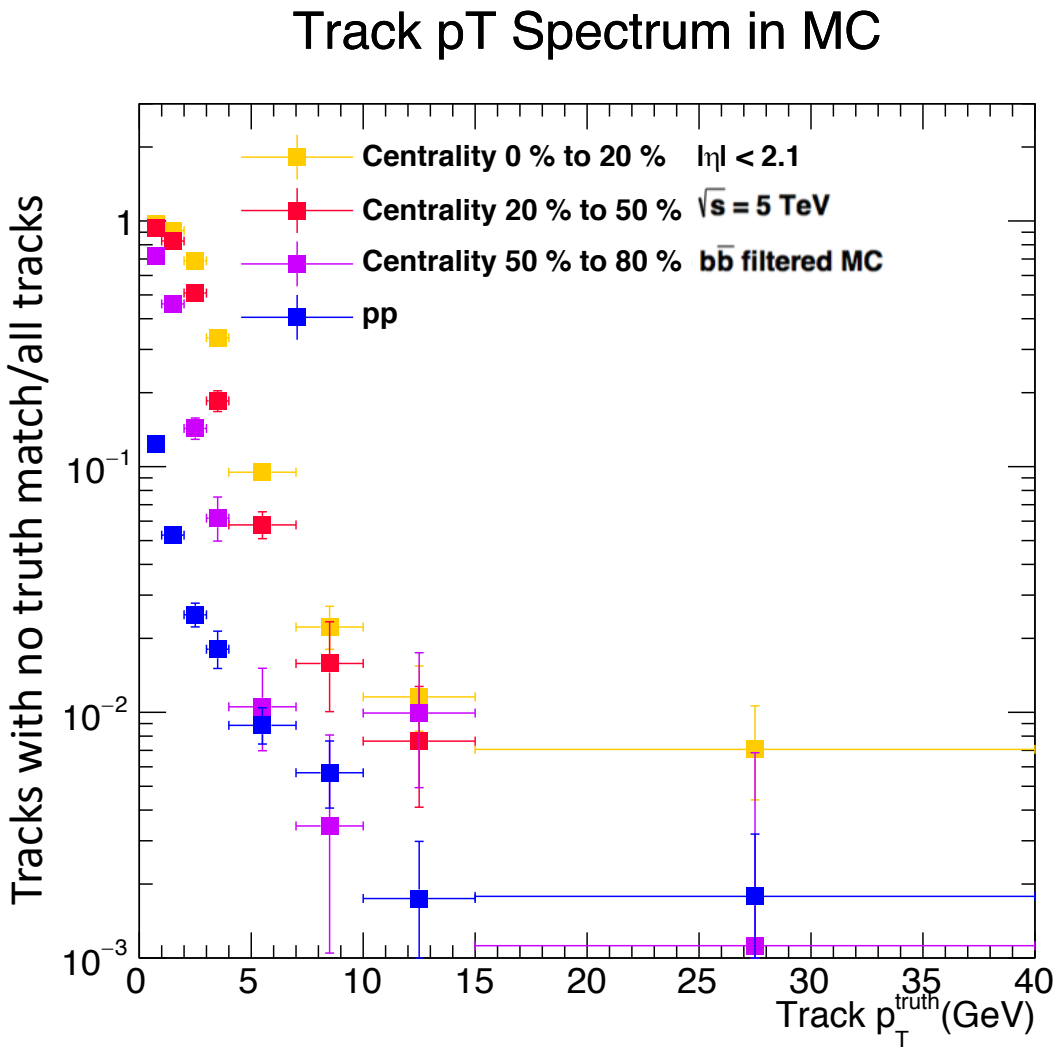




pT>0.3 [MeV], |eta|<2.5

Tracks reconstruction in Heavy Ion Collisions

- Reconstruction is different, designed to work with high occupancy data (order of 1000 tracks)
  - Occupancy has a centrality dependence
- Only one primary vertex per event. No pile-up effect.
- Many more underlying event tracks in comparison to pp collisions.
  - Especially at central events, and are mostly low energy.
- Different track recommendations for analysis from pp collisions
  - https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/TrackingCPMoriond2017



MC Samples

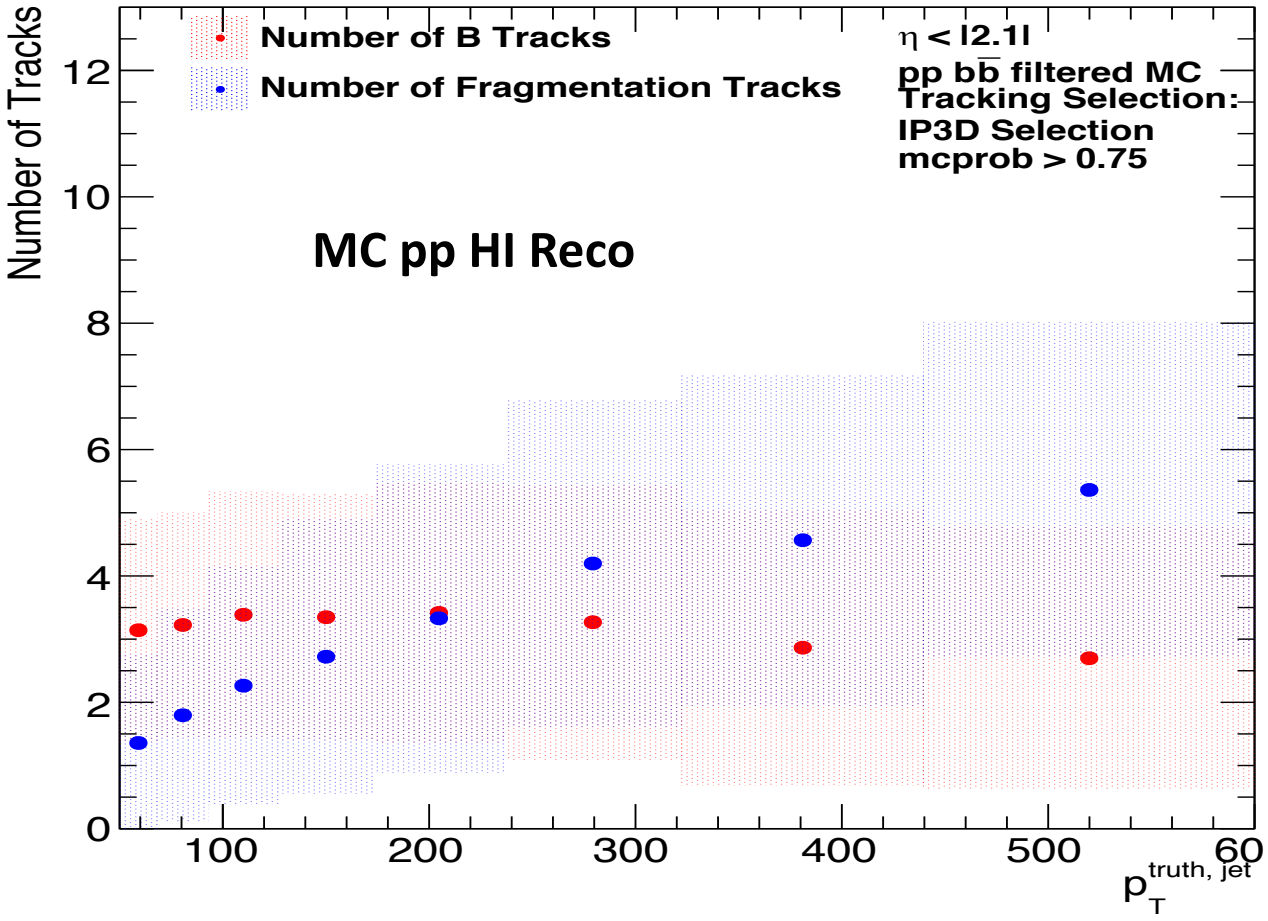
- pp MC and MC overlay:
  - pp MC: 50k events (12.5k each for JZ1-JZ4) of pythia dijets events at 5.02 TeV, applied with bbar filter Selection on Jets.
  - Configuration file: https://gitlab.cern.ch/atlas-physics/pmg/infrastructure/mc15joboptions/blob/master/share/DSID420xxx/MC15.420271.Pythia8EvtGen_A14NNPDF23LO_jetjet_JZ1_bbfilter.py
  - Overlay: pp MC + 2018 minBias data to simulate underlying events.

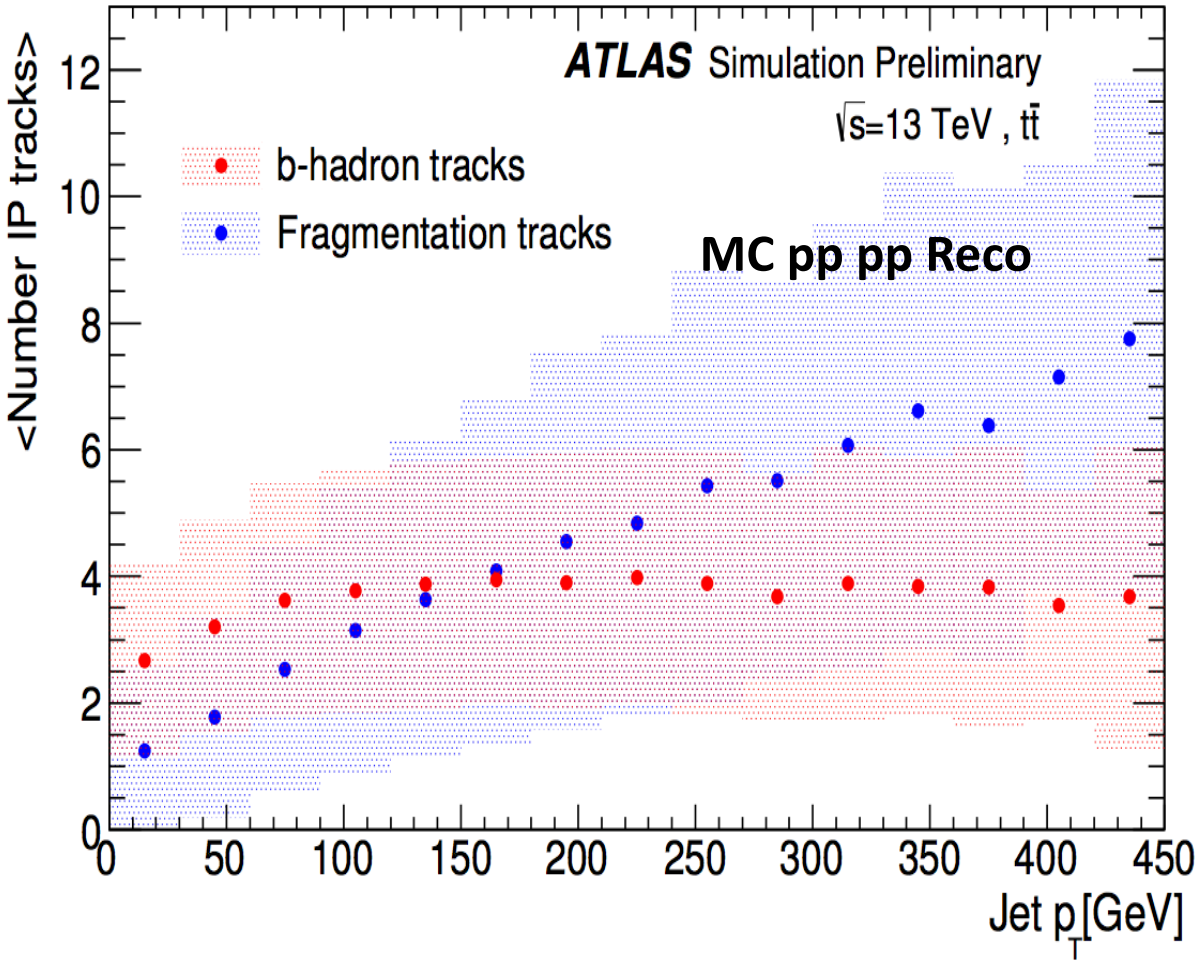
- Selection on Jets:
  - Reco jets with ΔR(truth-reco) < 0.3
  - $p_T^{truth\ jet} > 50$ GeV

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

- Tool: https://gitlab.cern.ch/stapiaar/tagging_framework_hi/tree/master/
  - The most updated modified version is at https://gitlab.cern.ch/xiaoning/hiretagging_framework

Differences in pp MC Samples





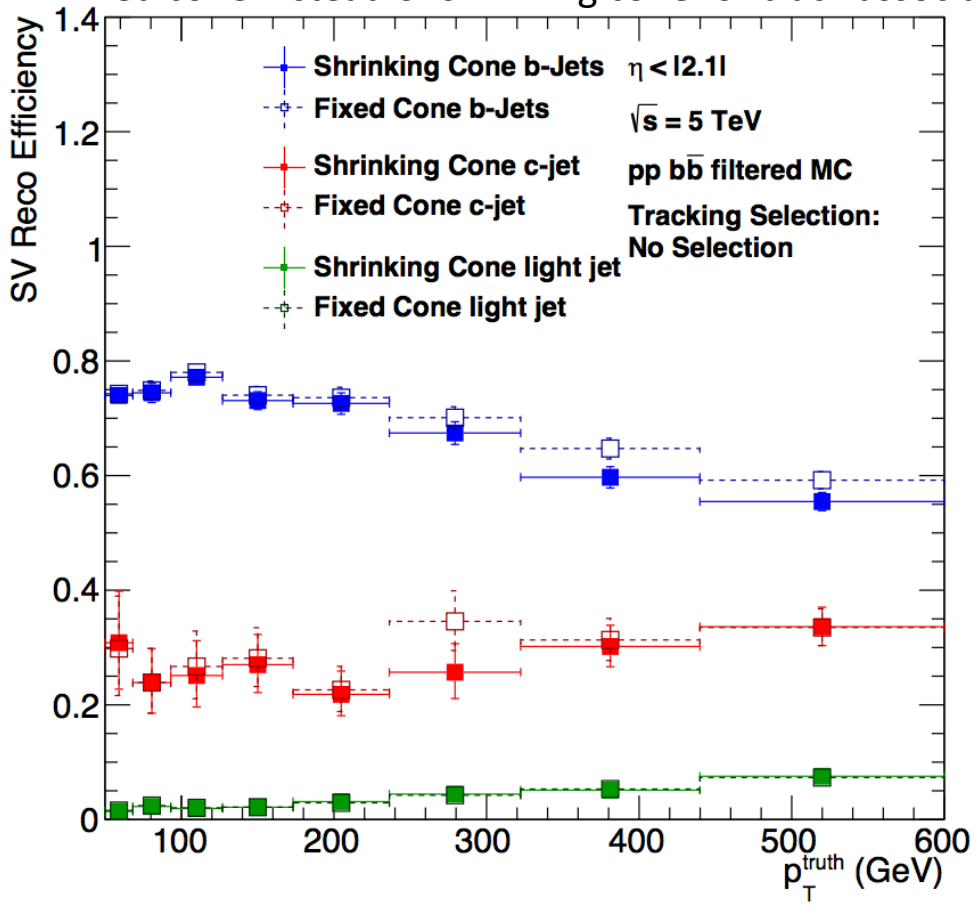
In comparison to standard pp MC sample:

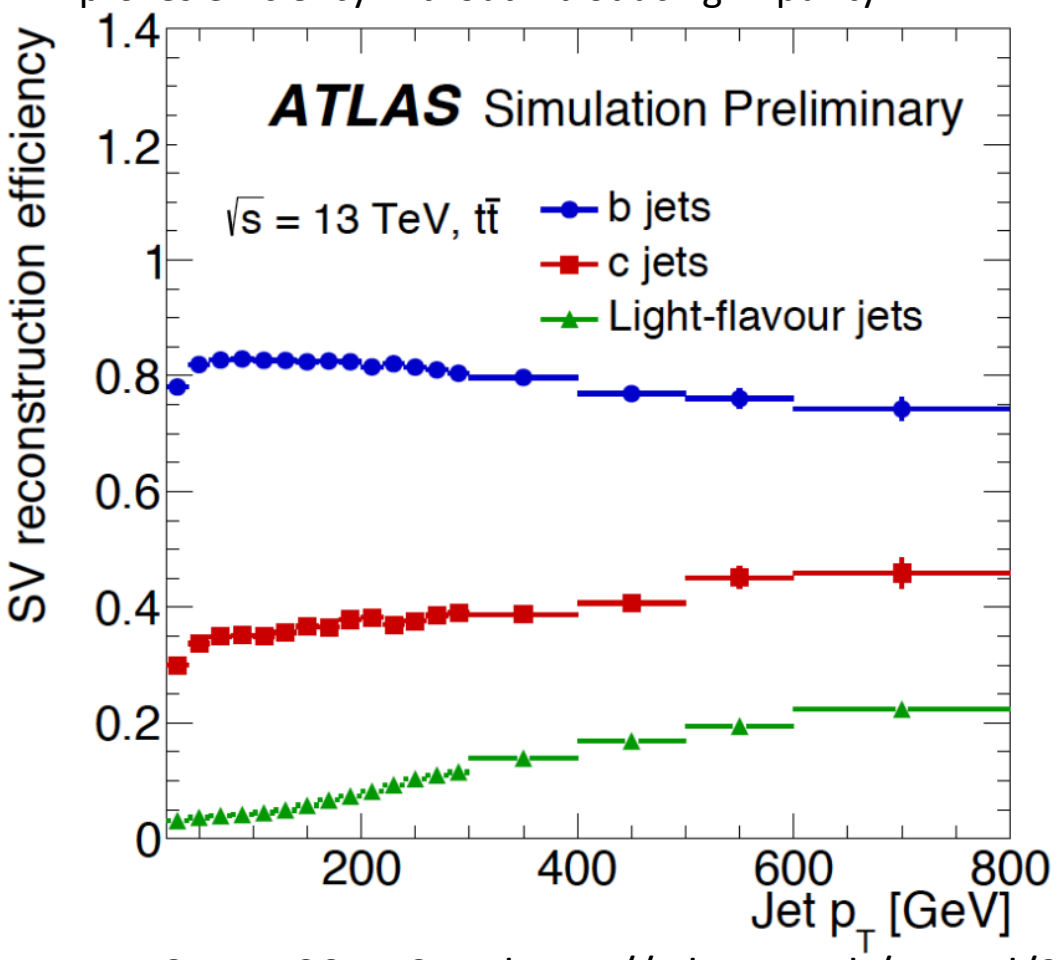
- Similar overall trend.
- Fewer tracks.
- More obvious in high pT.

ATL-PHYS-PUB-2016-012

Last Time

- SVF shows a pT dependent efficiency, with high jet pT region lower efficiency.
  - https://indico.cern.ch/event/896413/contributions/3785014/attachments/2002609/3343462/QT11-20200312.pdf
- Tried with different cuts in SVF and effects in secondary vertexing efficiency.
  - Fixed cone instead of shrinking cone for track association improves efficiency without introducing impurity.





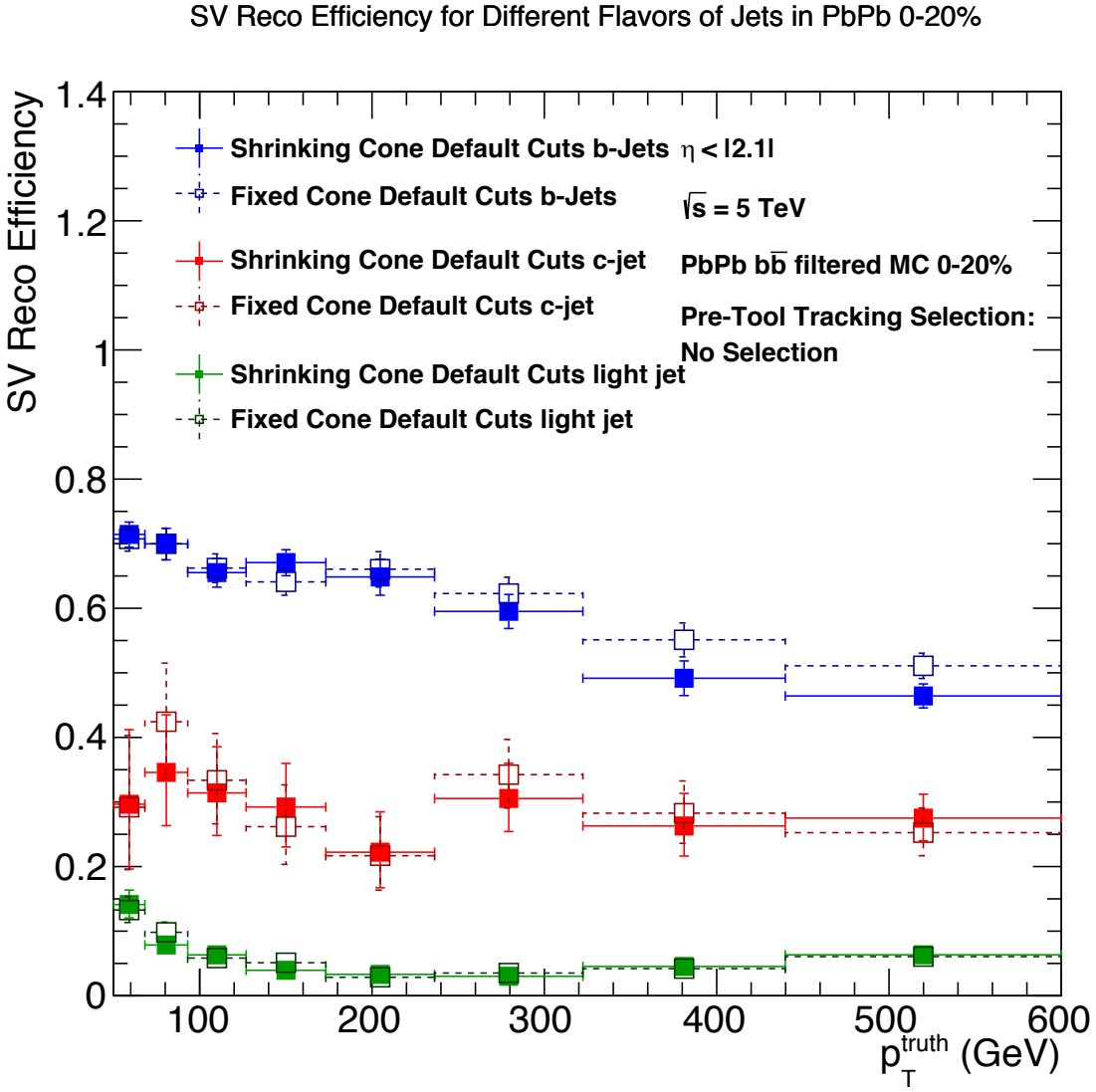
ATL-PHYS-PUB-2017-011: https://cds.cern.ch/record/2270366

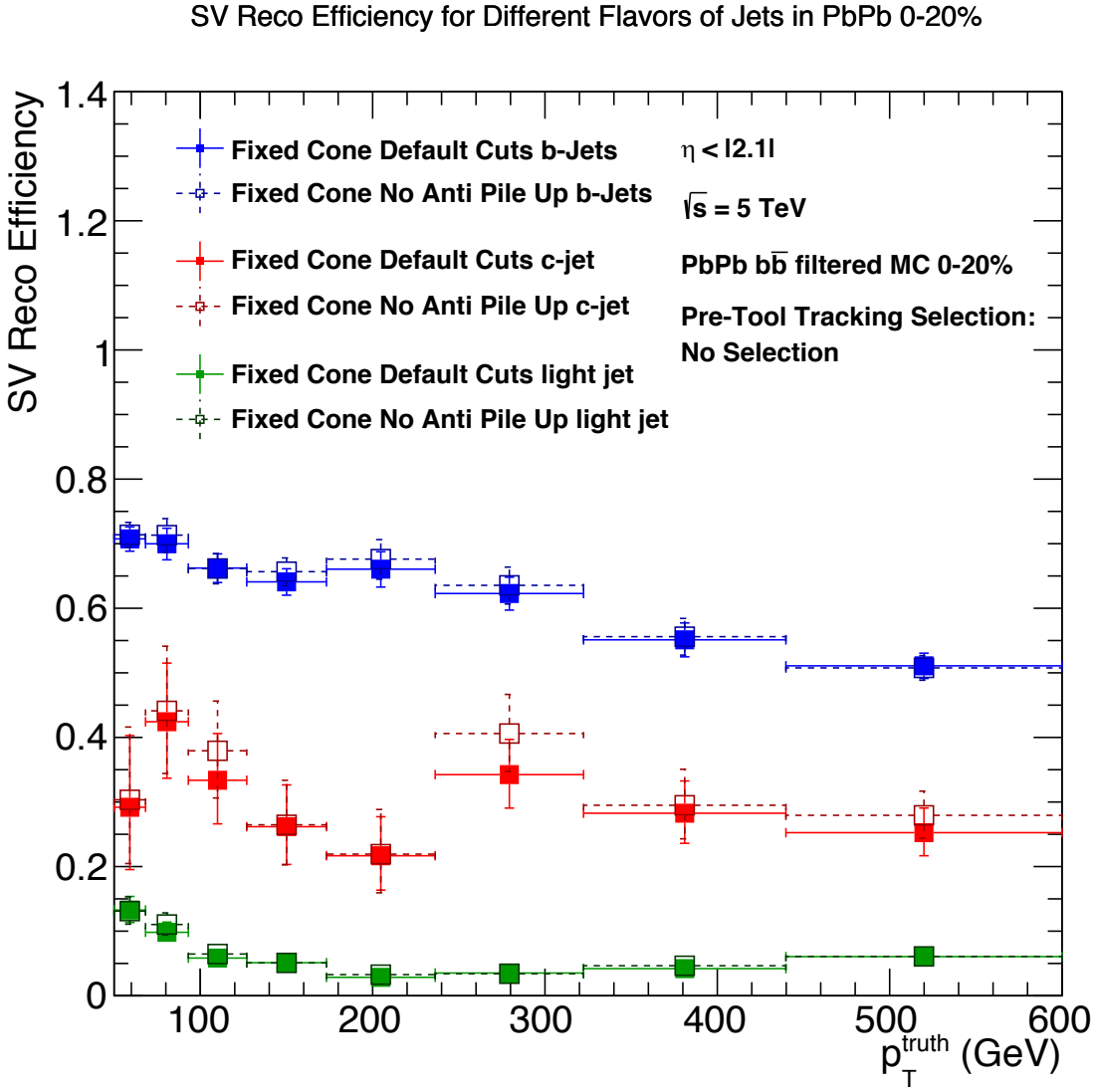
This Time

- SVF: Effects of the cuts with overlay sample on vertexing efficiency with SVF.
- JetFitter:
  - Effects of setting different minimum pT in vertexing efficiency and tagging efficiency.

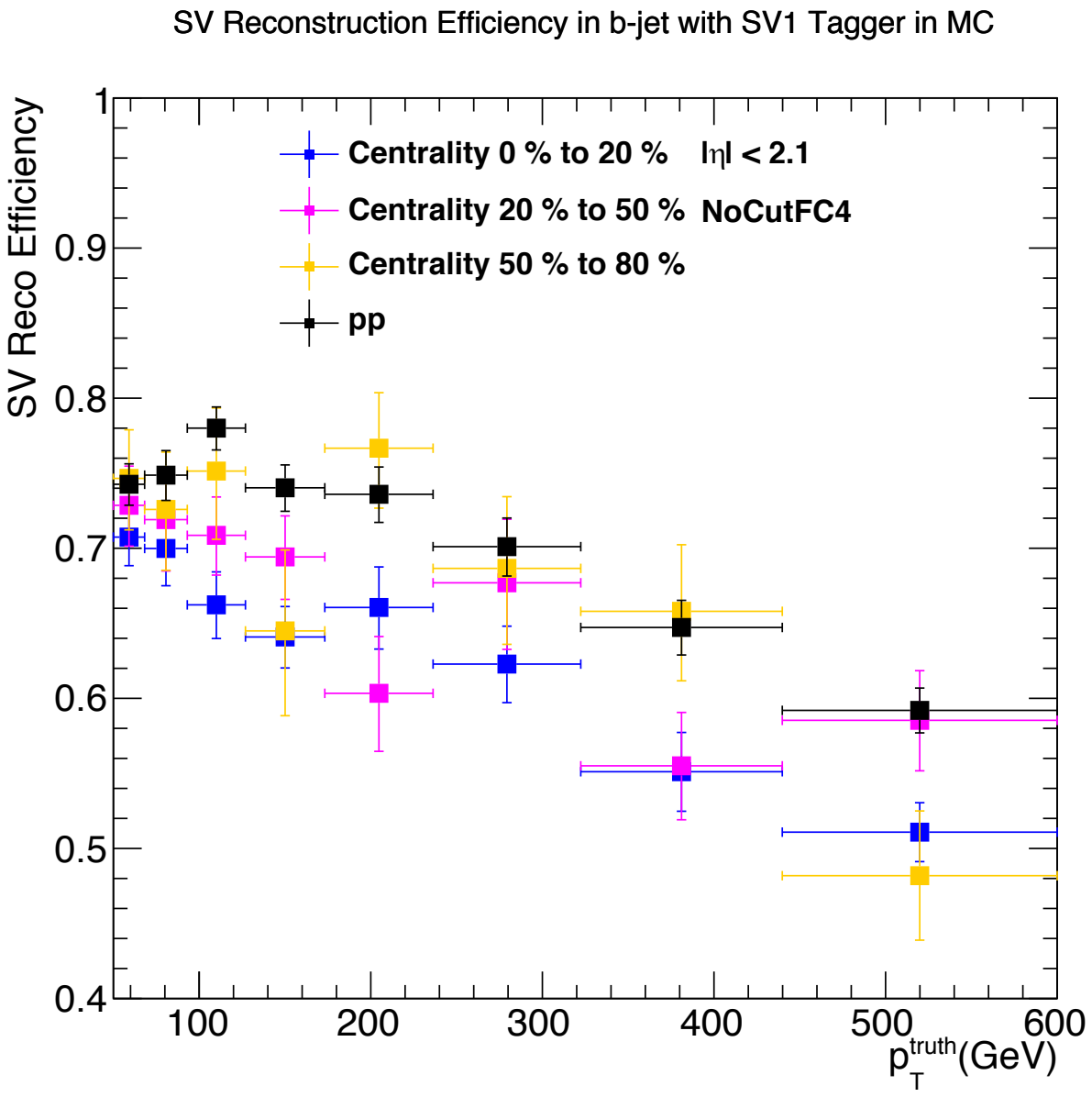
Summary of Effects of Cuts on Overlay (0-20%) in SVF

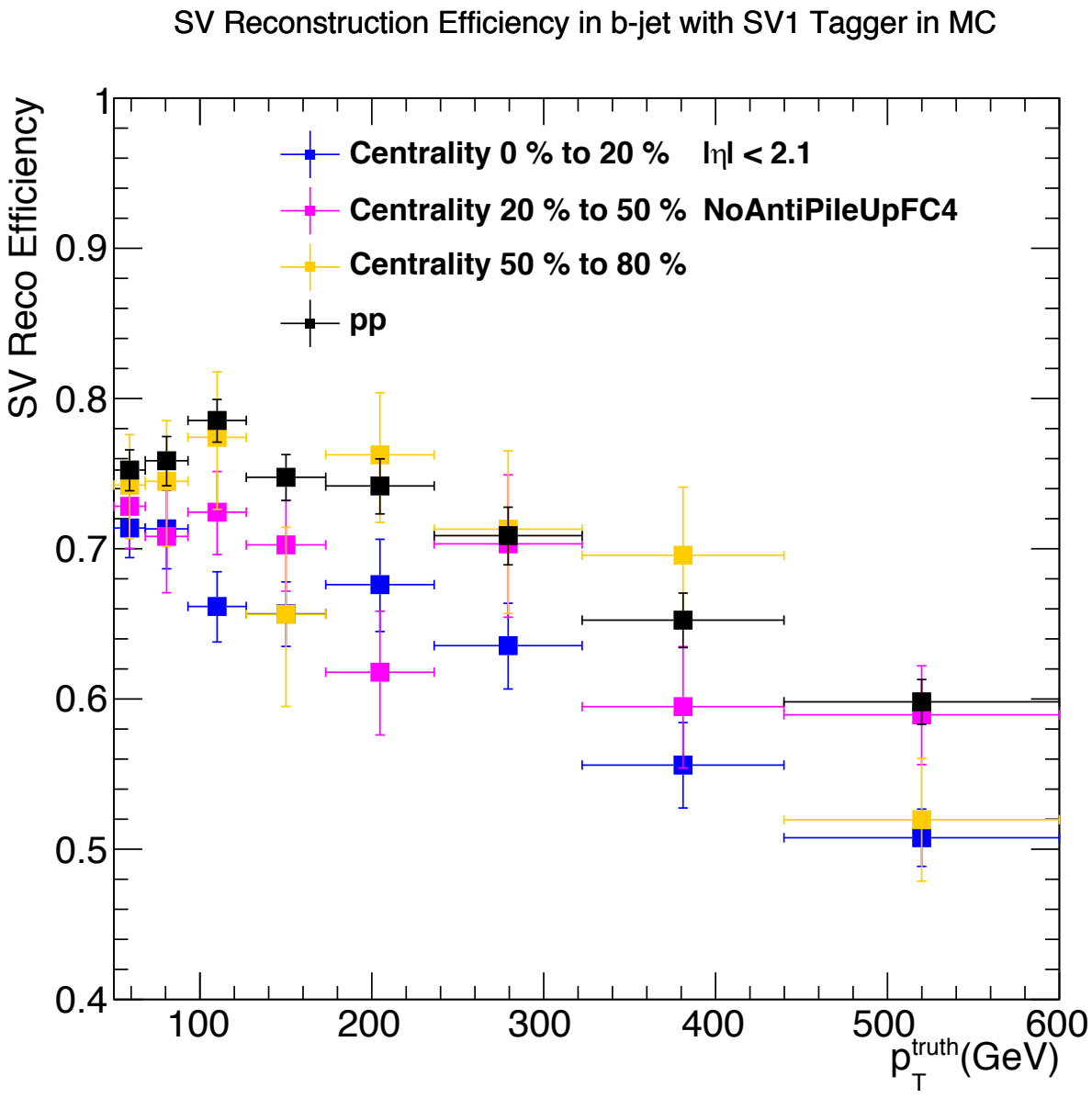
Cuts (original) (New)	Efficiency	Purity	Comment	Action
Fixed Cone (0.4)	+(~5%) at high pT	No change	Safer to use for HI jets	Use the cut
Min pT Fraction(0.01) (0.00)	+(~2%) at high pT b +(~3%) at high pT c	+(~3%) fake ☹	Although HI jets have less tracks, high pT jets should still be limited in track pT.	Do not change
Anti Pile Up tool (On) (Off)	+(~2%) at high pT c	No change	Irrelevant in HI track reconstruction (single PV)	Use the cut
IP Selection(On) (Off)	No significant Effect	No change	Original boundary is already very big.	Do not change





Cuts with improvements in efficiency in most central events (0-20%) in MC overlay.





- Overall follow the trend (most central -> worse performance)
- Limited by statistics.

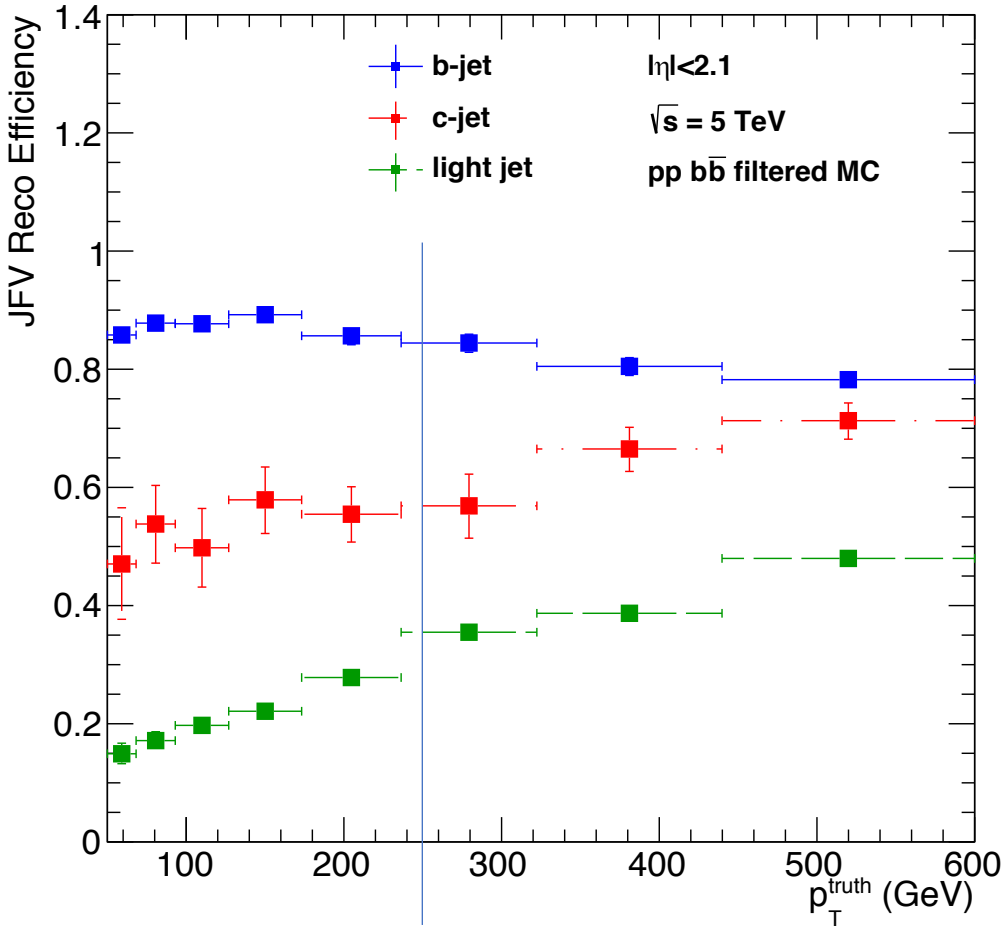
Cuts on JetFitter Track Selection

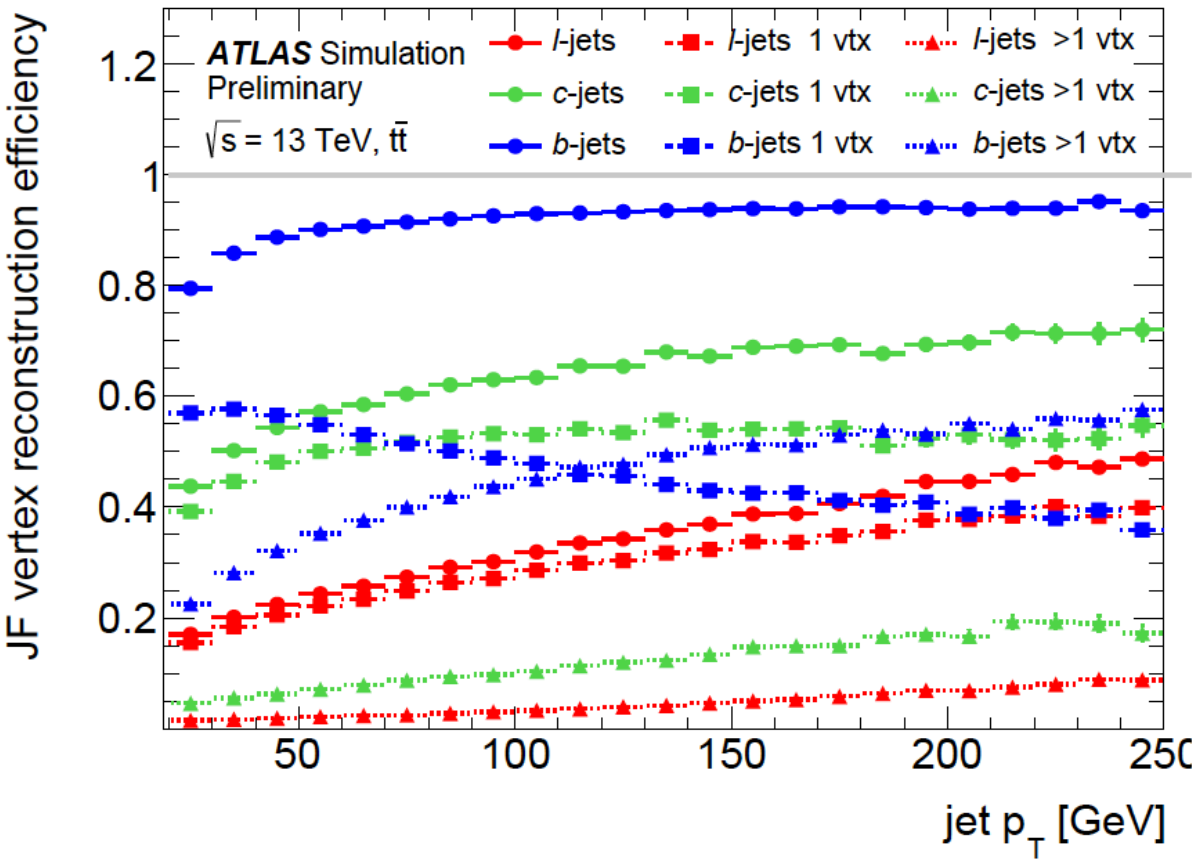
- Fixed Cone track association.
- Disabled anti-pile up track selections. (small Rϕ and large Z)
- Minimum pT requirements for tracks. (0.5, 1.0, 1.5, 2.0, 4.0 GeV)

- Performance measurements shown here are for most central events (0-20%),
  - Efficiency vs Pt plots
  - Integrated efficiency vs fake rate
  - Integrated efficiency vs purity (tracks used in SV)
  - JetFitter individual tagging efficiency.

Efficiency: b-jets tagged as b/total b-jets
Fake rate: light jets tagged as b/total light-jets
Purity: tracks from B or D decay/tracks associated with JF vertices
Light rejection: total light-jets/light jets tagged as b

Efficiency Comparison to pp at 13 TeV from default JF





- Observed a minor decrease in efficiency at higher pT
- Higher than 250 GeV results are not shown in the performance paper
- 50-250 range is relatively flat.

Default JetFitter Results and Fixed Cone Results

Default Cuts

Integrated Efficiency (pT >20 GeV)	0-20%	20-50%	50-80%	pp
B-jet	0.939	0.901	0.844	0.865
C-jet	0.708	0.553	0.519	0.496
Light-jet (fake)	0.645	0.409	0.152	0.165

Performance Paper results:

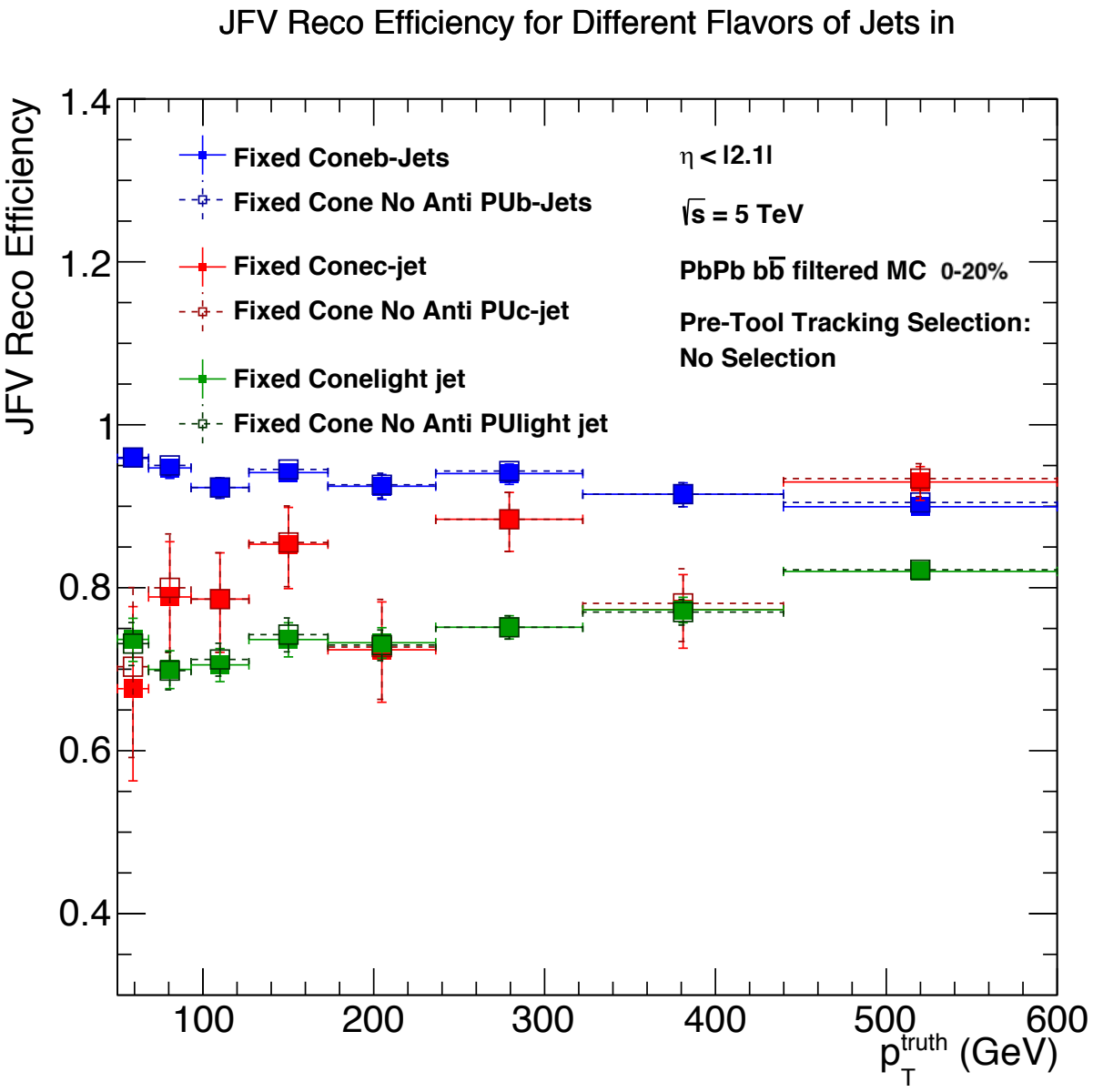
	JF Vertices All
b-jets	0.893
c-jets	0.556
light jets	0.234

Fixed Cone at 0.4

Integrated Efficiency (pT >20 GeV)	0-20%	20-50%	50-80%	pp
B-jet	0.954	0.907	0.860	0.872
C-jet	0.716	0.579	0.507	0.507
Light-jet (fake)	0.723	0.468	0.160	0.174

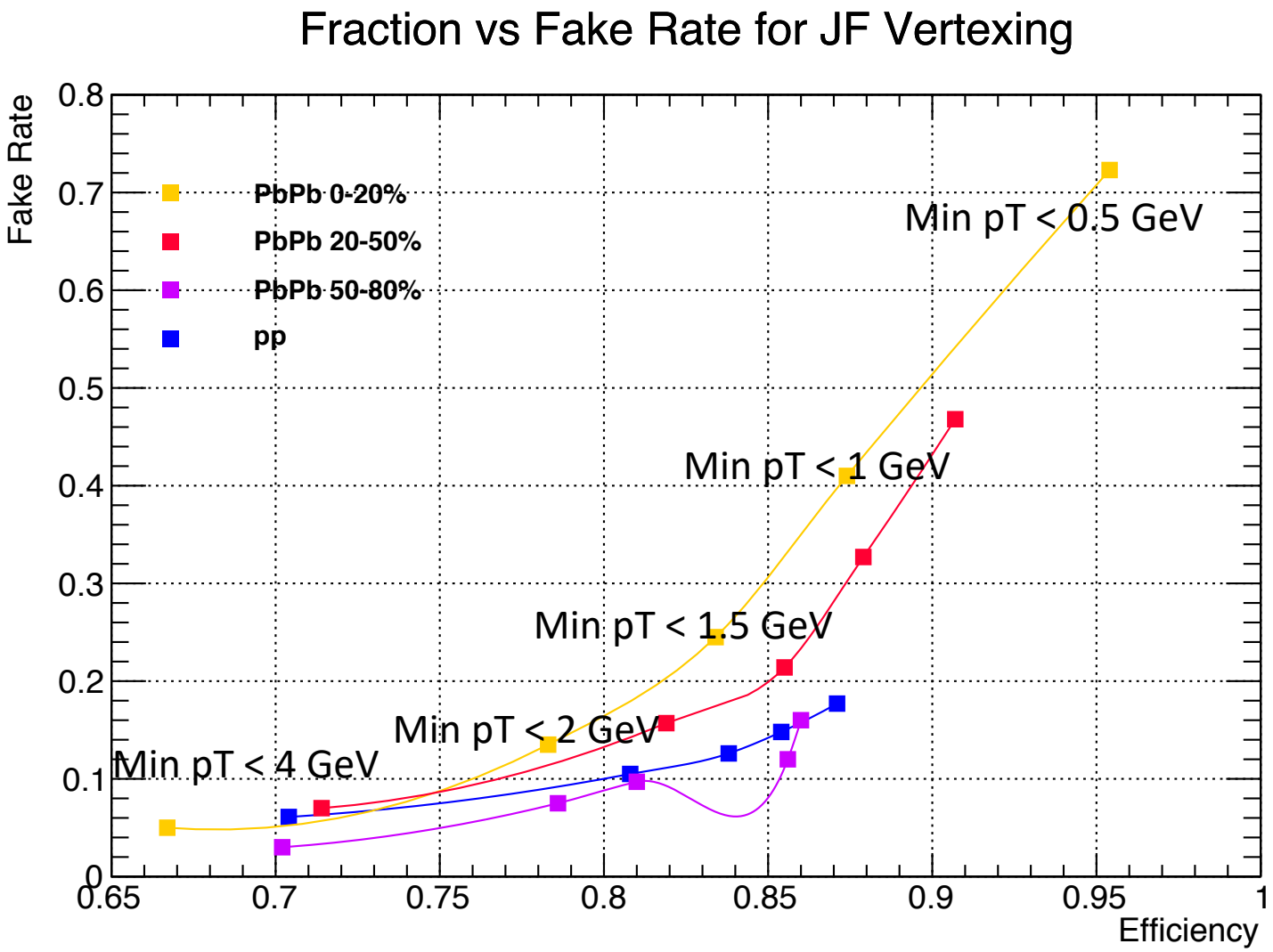
Fixed cone introduced ~10% fake rate in central events.

Disabling anti pile-up cuts



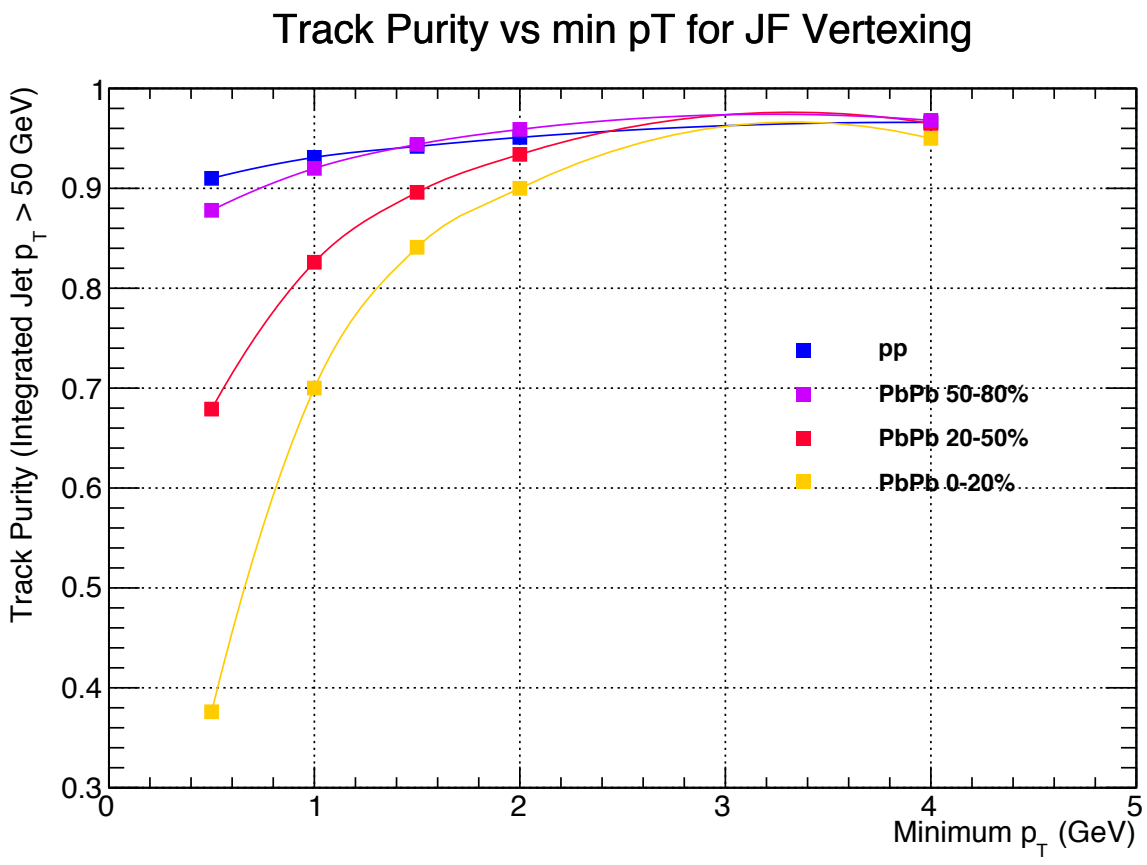
- Turning off anti pile-up cuts have no visible effects.

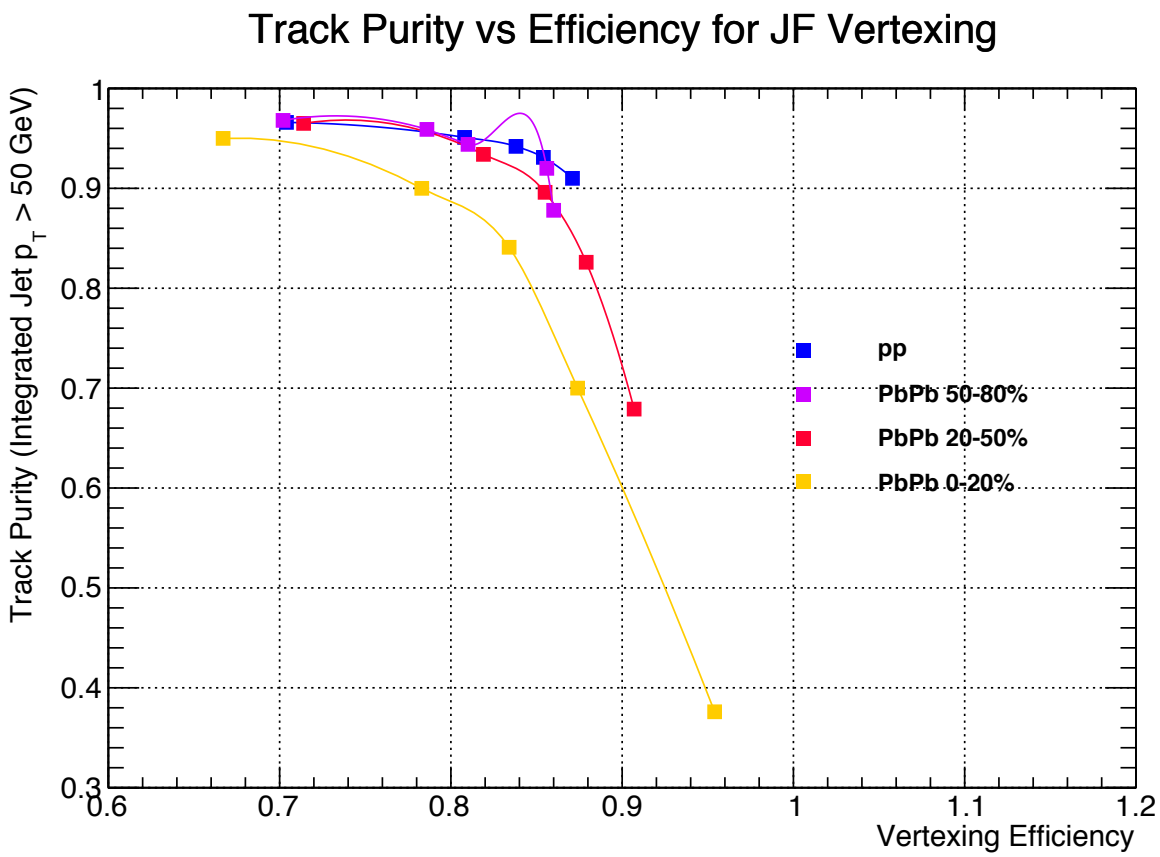
Effects of Min pT Cuts



- From right to left, points are made with increasing min pT cut.
- Central events' fake rate is greatly affected.
- Centrality dependence decreases at ~ 1.5 GeV.
- Shape of efficiency vs pT is not heavily modified by changing min pT cut (see back up 24)
- Shown curve is not fitted
  - Fluctuation in 50~80% is probably due to statistics. (see back up 30)

Track Purity as a function of min pT



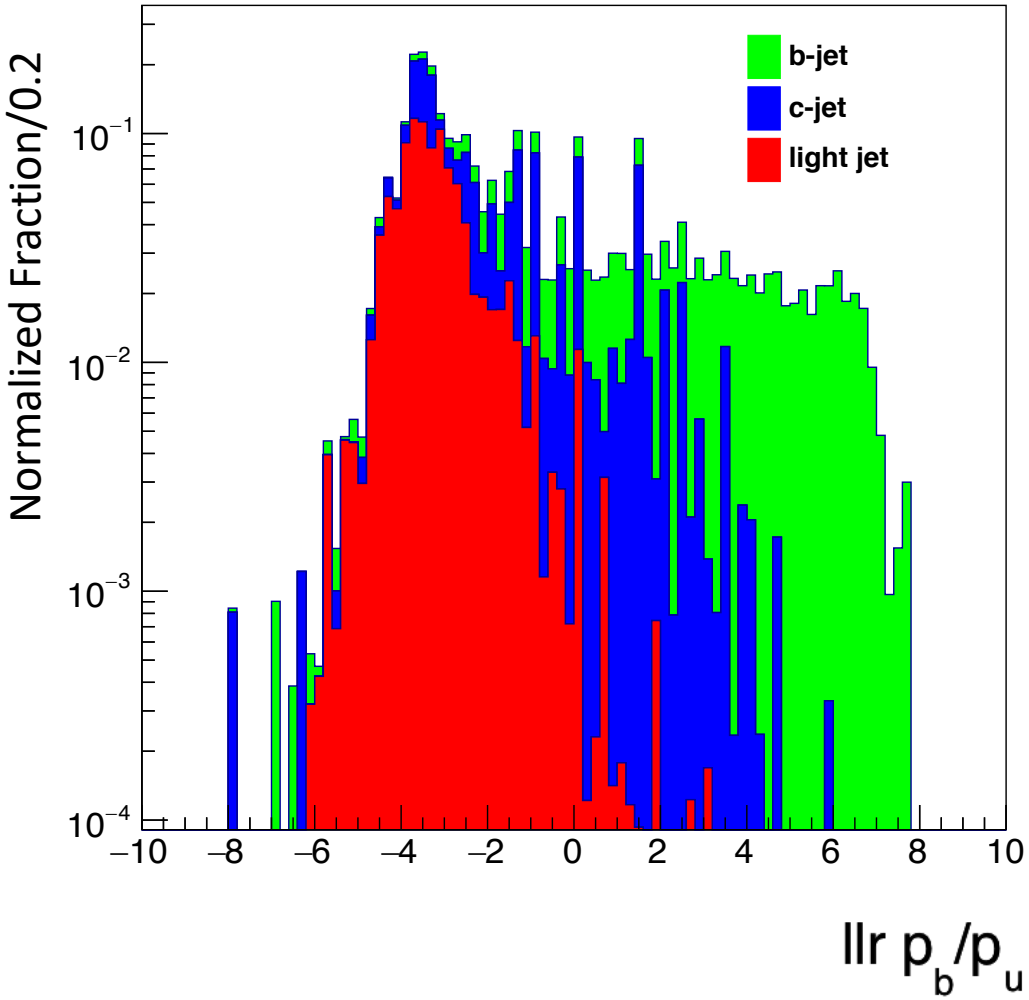


Centrality dependence decreases as min pT is increased, as expected.

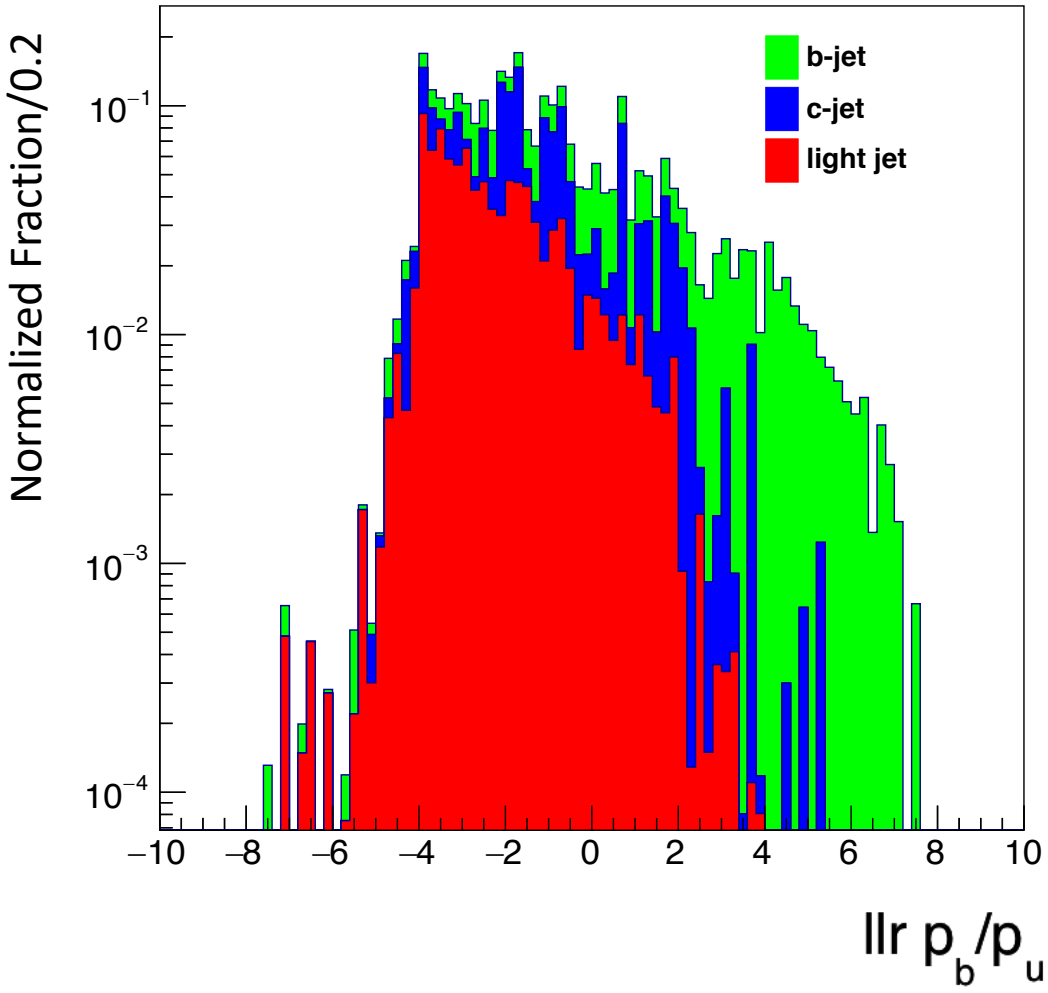
Points from right to left corresponds to small min pT requirement to larger min pT requirement.

JetFitter Tagger Performance using JF_loglikelihoodratio

pp Default Cuts

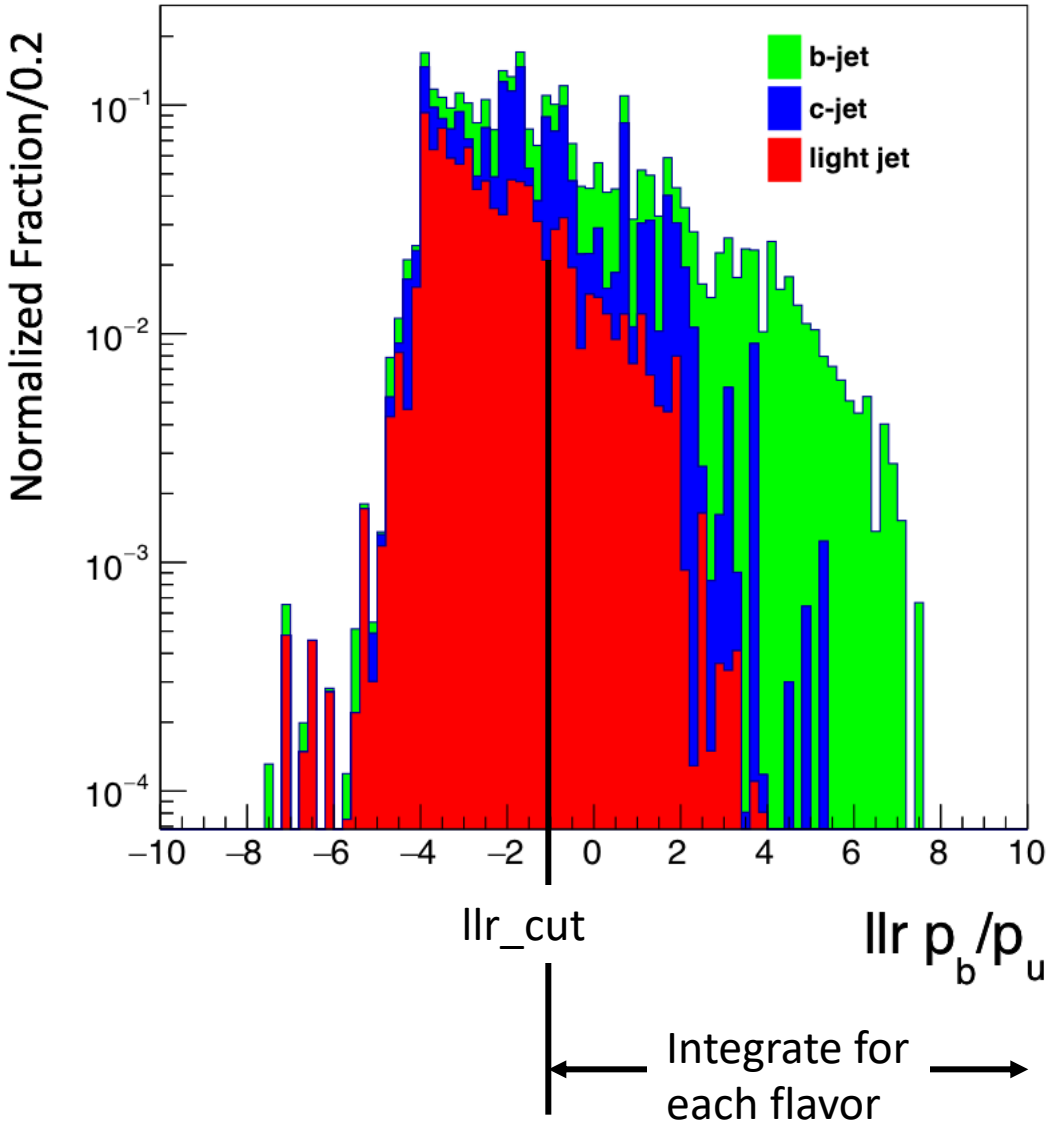


PbPb 0-20% Default Cuts



- Both B-jet and light jet distribution are more toward right in central events in comparison to pp. Central events have better efficiency but worse light rejection as expected.

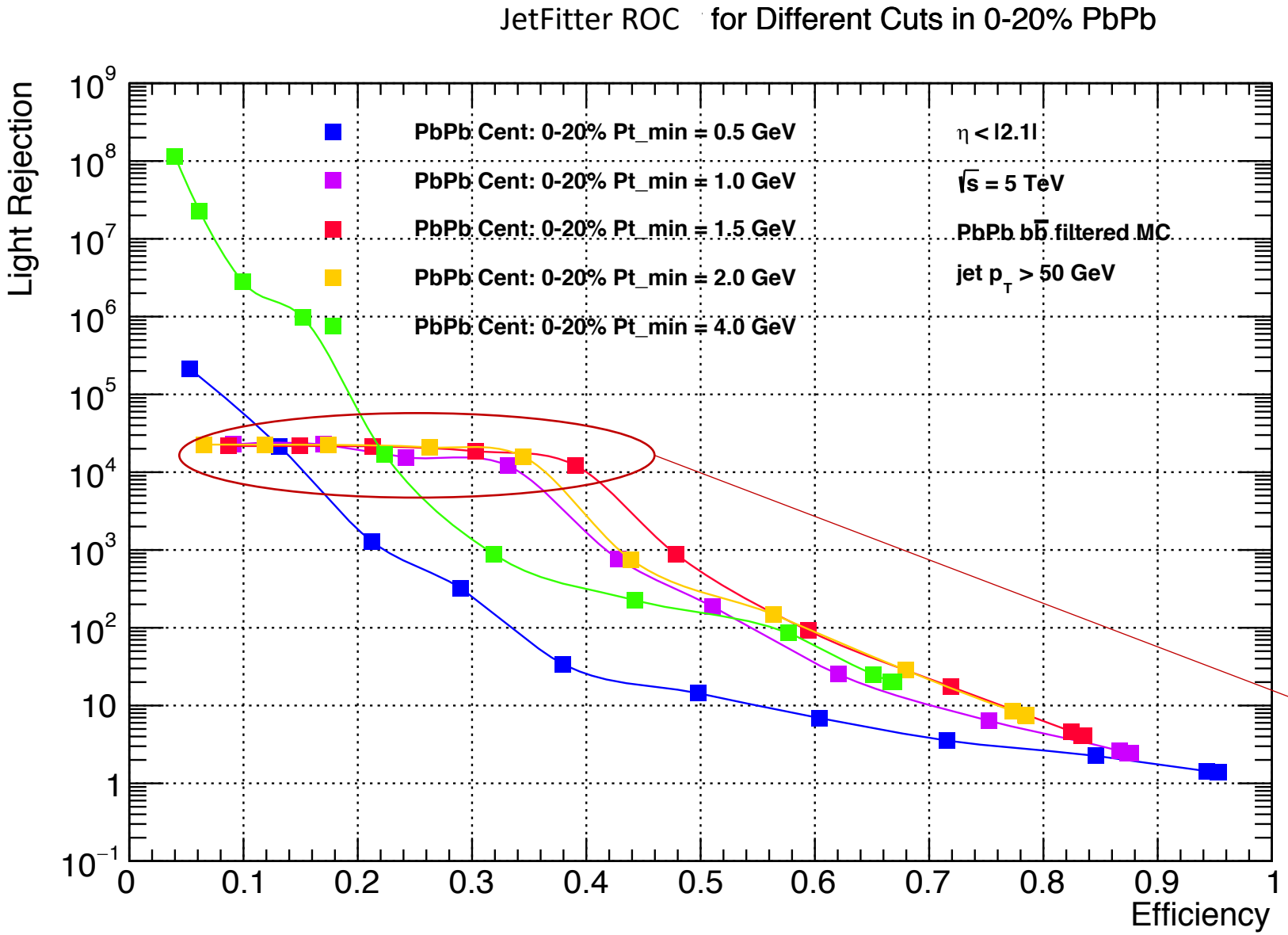
Efficiency vs Light Efficiency (ROC Curve)



- Efficiency:
- $\epsilon = \frac{\int_{llr\_cut}^{\infty} b-jet}{\int_{-\infty}^{\infty} b-jet}$
- Light Rejection:
- $r = \frac{\int_{-\infty}^{\infty} light\ jet}{\int_{llr\_cut}^{\infty} light\ jet}$

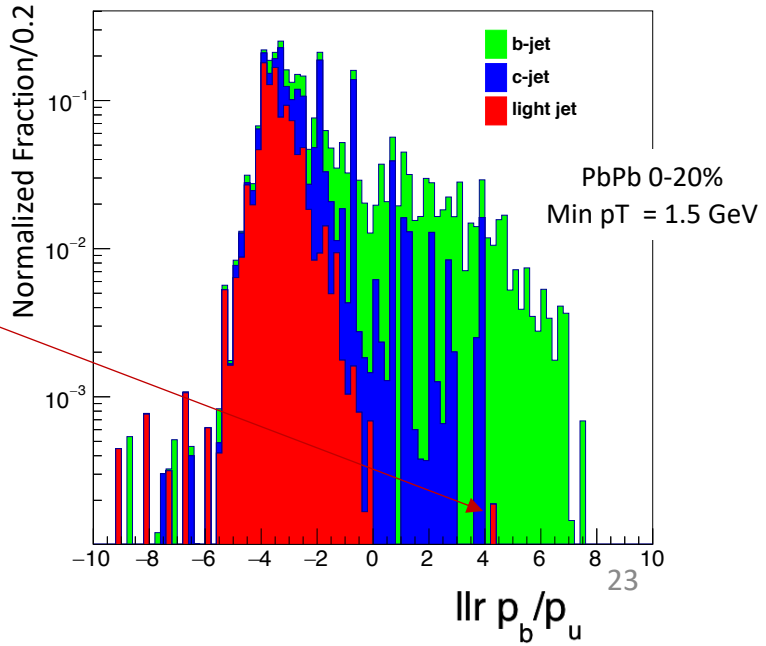
- Graph in next slide used 20 cuts evenly from -10 to 10.

Performance in Central Events



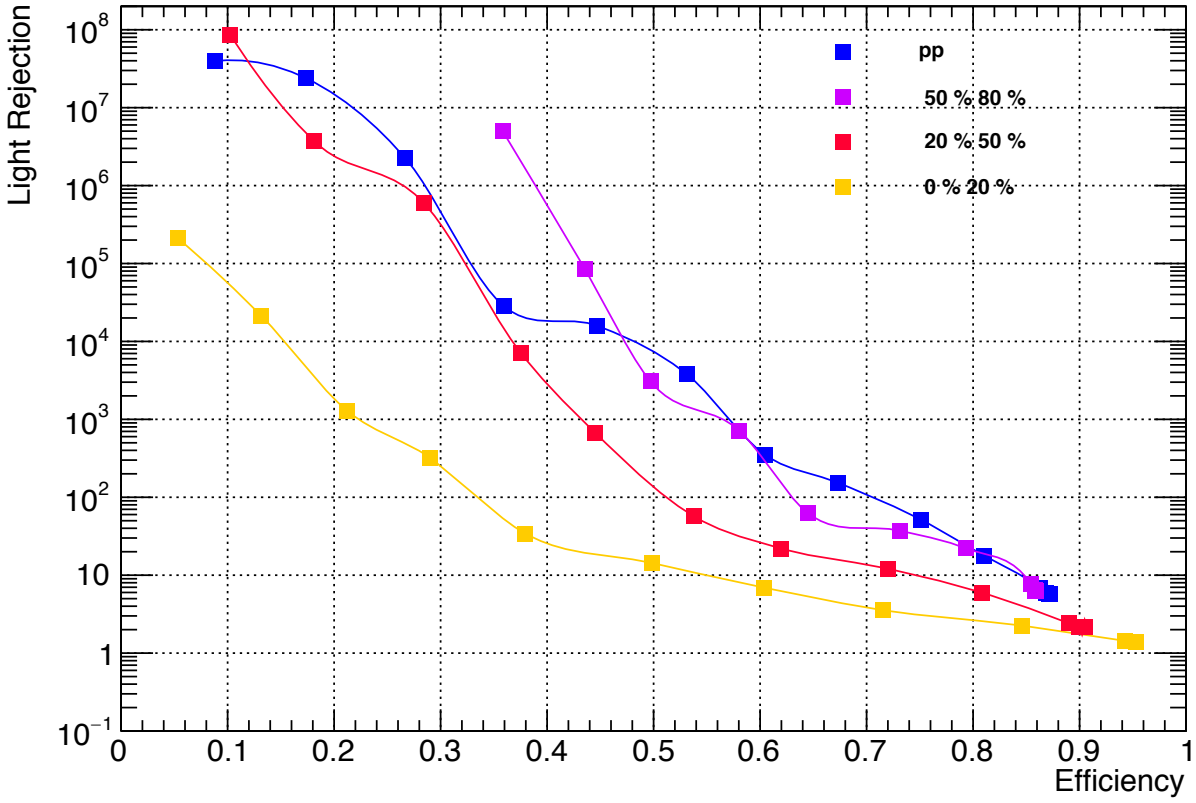
- **Min_pT = 1.5 GeV best balances out Efficiency vs light rejection.**
- llr_cut increases from right points to left ones.
- Curves are not smooth due to limited statistics.

Flatness caused by bin at ~4

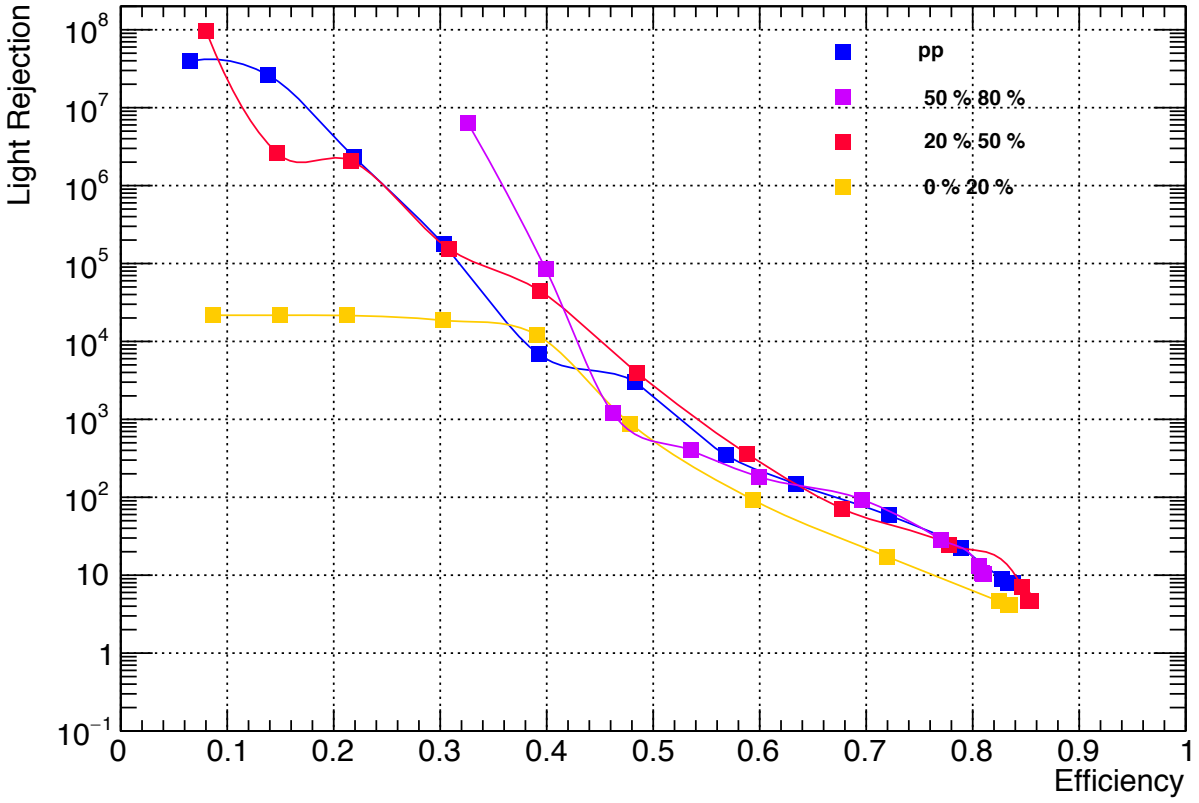


Centrality Dependence of Tagger Performance

JetFitter ROC Min pT = 0.5 GeV



JetFitter ROC Min pT = 1.5 GeV



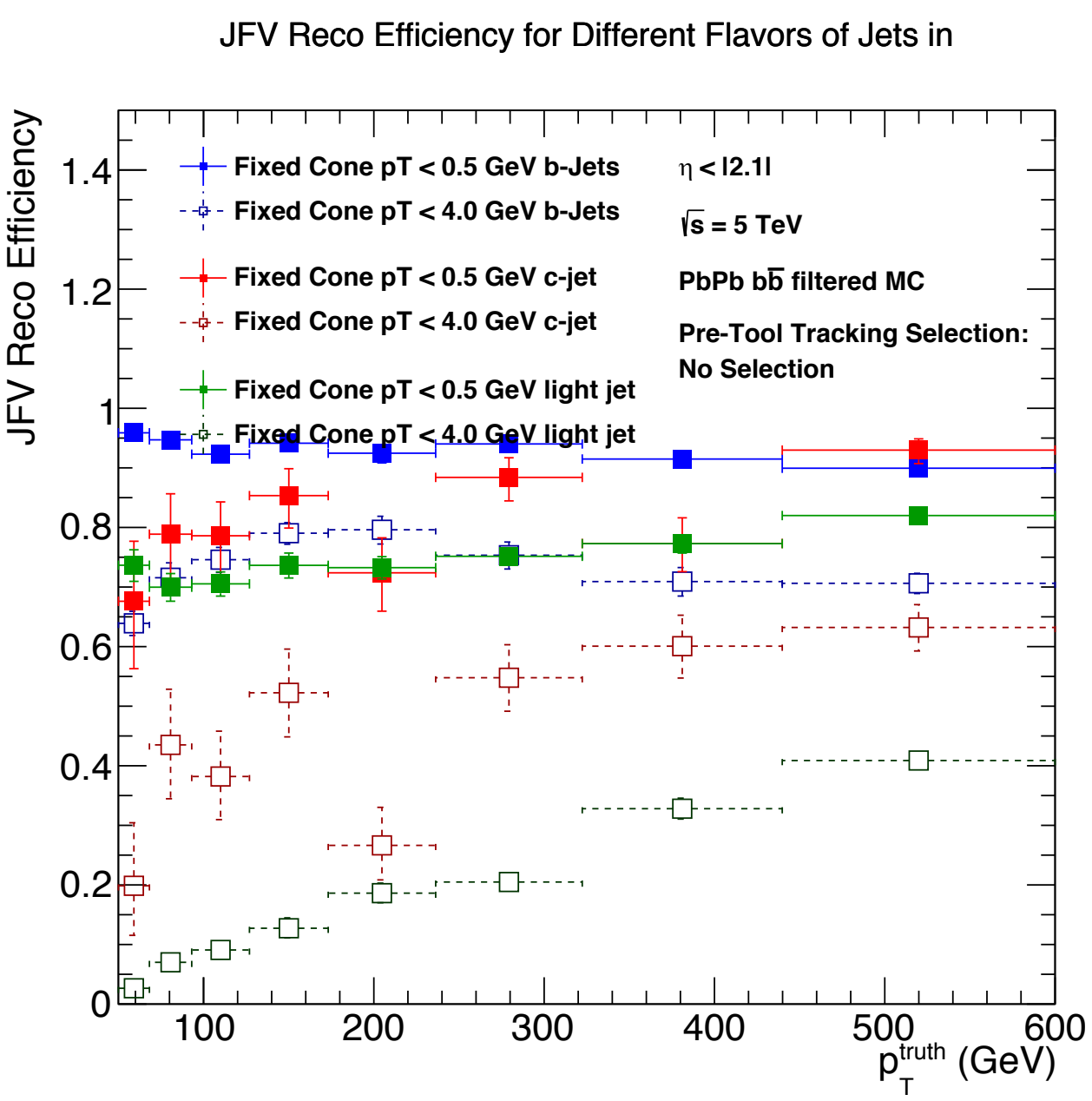
- With the new cut, the centrality dependence of tagger performance decreases significantly.

Summary

- Selected cuts for improving vertexing and individual tagger's b-tagging performance for SVF and JetFitter algorithms
  - Use fixed cone at 0.4 instead of shrinking cone and disable anti pile-up cuts.
  - Use min pT at 1.5 GeV for JetFitter algorithms.

- Plan:
  - Migrate to use inclusive dijet samples for better statistics.
  - Look into other taggers and combined performance.

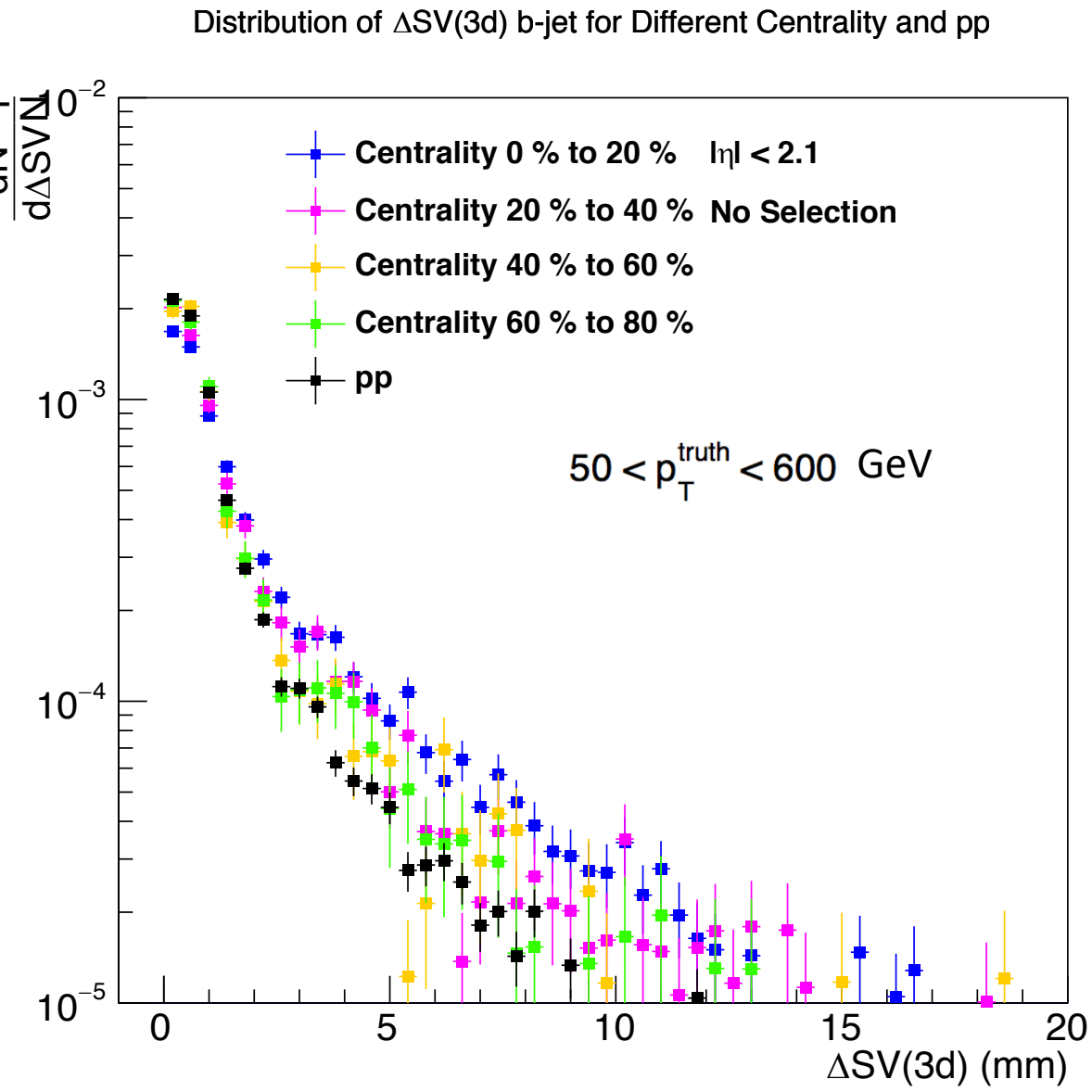
Back-Up


JFV Reco Efficiency for Different Flavors of Jets in
JFV Reco Efficiency
Fixed Cone pT < 0.5 GeV b-Jets
Fixed Cone pT < 4.0 GeV b-Jets
Fixed Cone pT < 0.5 GeV c-jet
Fixed Cone pT < 4.0 GeV c-jet
Fixed Cone pT < 0.5 GeV light jet
Fixed Cone pT < 4.0 GeV light jet
η < |2.1|
√s = 5 TeV
PbPb bb̄ filtered MC
Pre-Tool Tracking Selection:
No Selection
0
0.2
0.4
0.6
0.8
1
1.2
1.4
100
200
300
400
500
600
p_T^truth (GeV)

Jet Fitter Performances and Cuts

- Tested cuts:
  - Min pT on track selection (0.5 GeV, 1.0 GeV, 1.5 GeV, 2.0 GeV, 4.0 GeV)
  - Fixed cone track association
  - Removal of cuts associated with pile up tracks (graphs not shown here)
- Performance measurements
  - Efficiency vs Pt plots
  - Integrated efficiency vs fake rate
  - Integrated efficiency vs purity
    - Purity: fraction of tracks associated with JetFitter vertices that originate from B or D decay.
  - Source of tracks plots
    - Found differences between what Dominik saw in his study.. looking for the cause.
- Missing: cuts applied to jets used and track used
  - There's a difference between what I used and Domink had, looking at why.

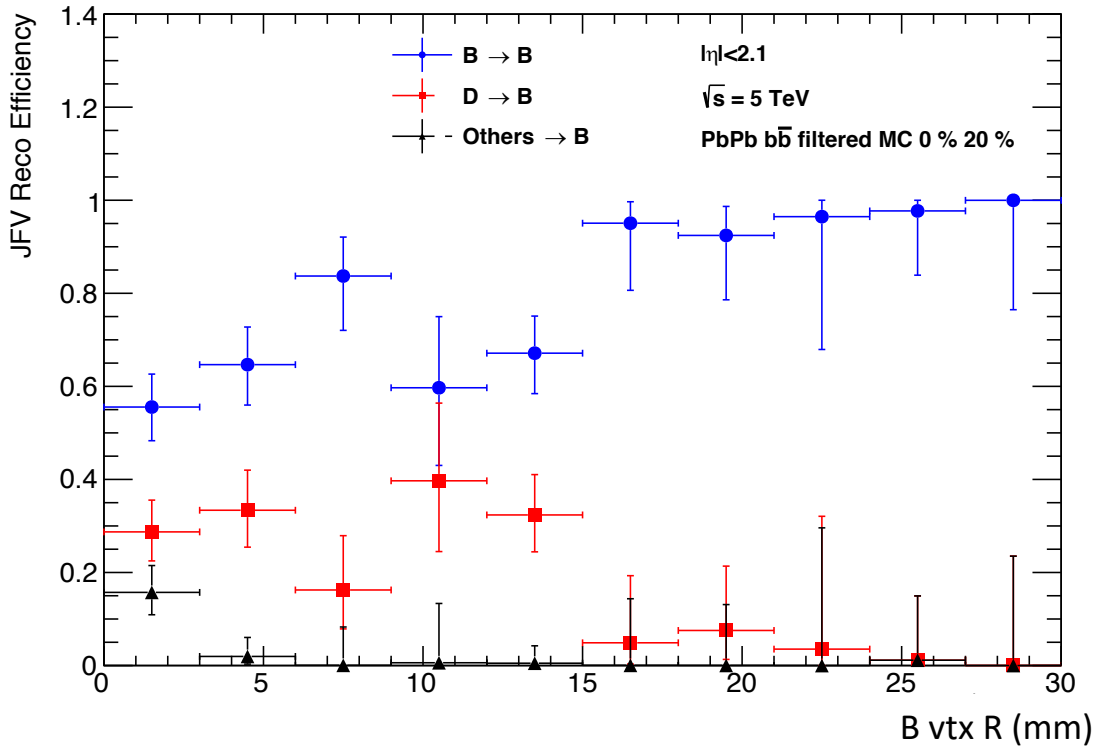
Performance of Secondary Vertex Reconstruction in SVF

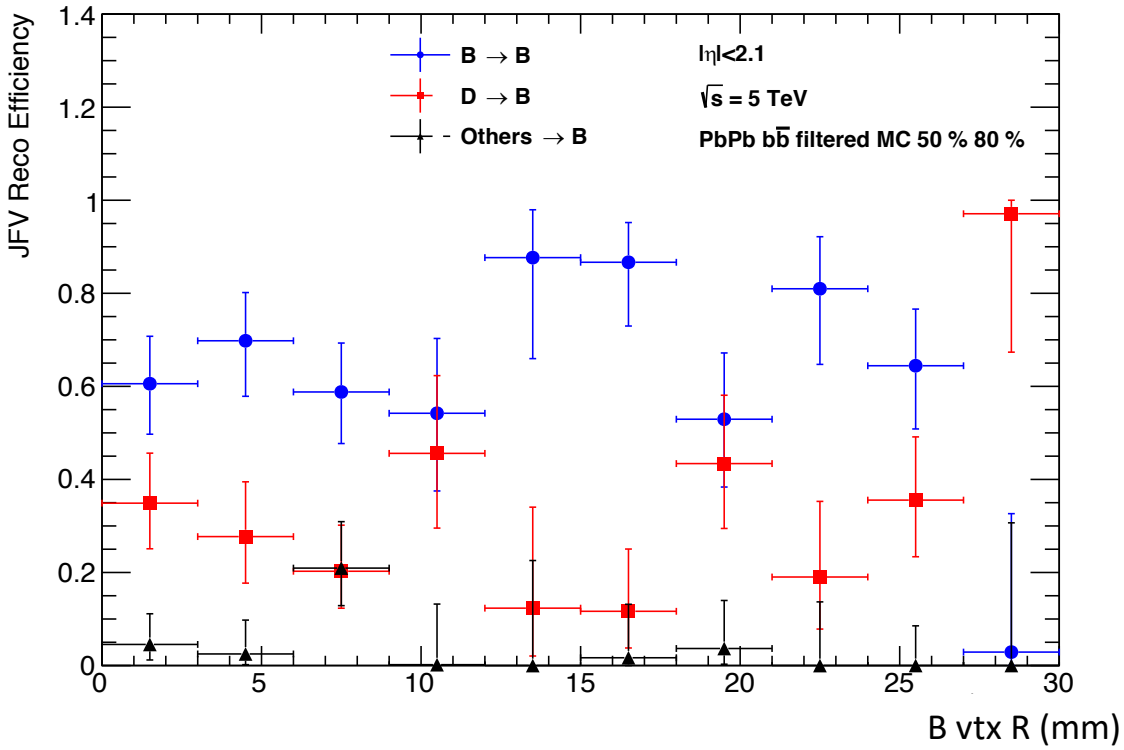


- SV reconstruction resolution here is defined as distances between truth SV and reco SV.
- More central events have worse resolution, and peripheral events have similar to pp resolution, as expected.
- Hope to reduced centrality dependence of SV reconstruction resolution.

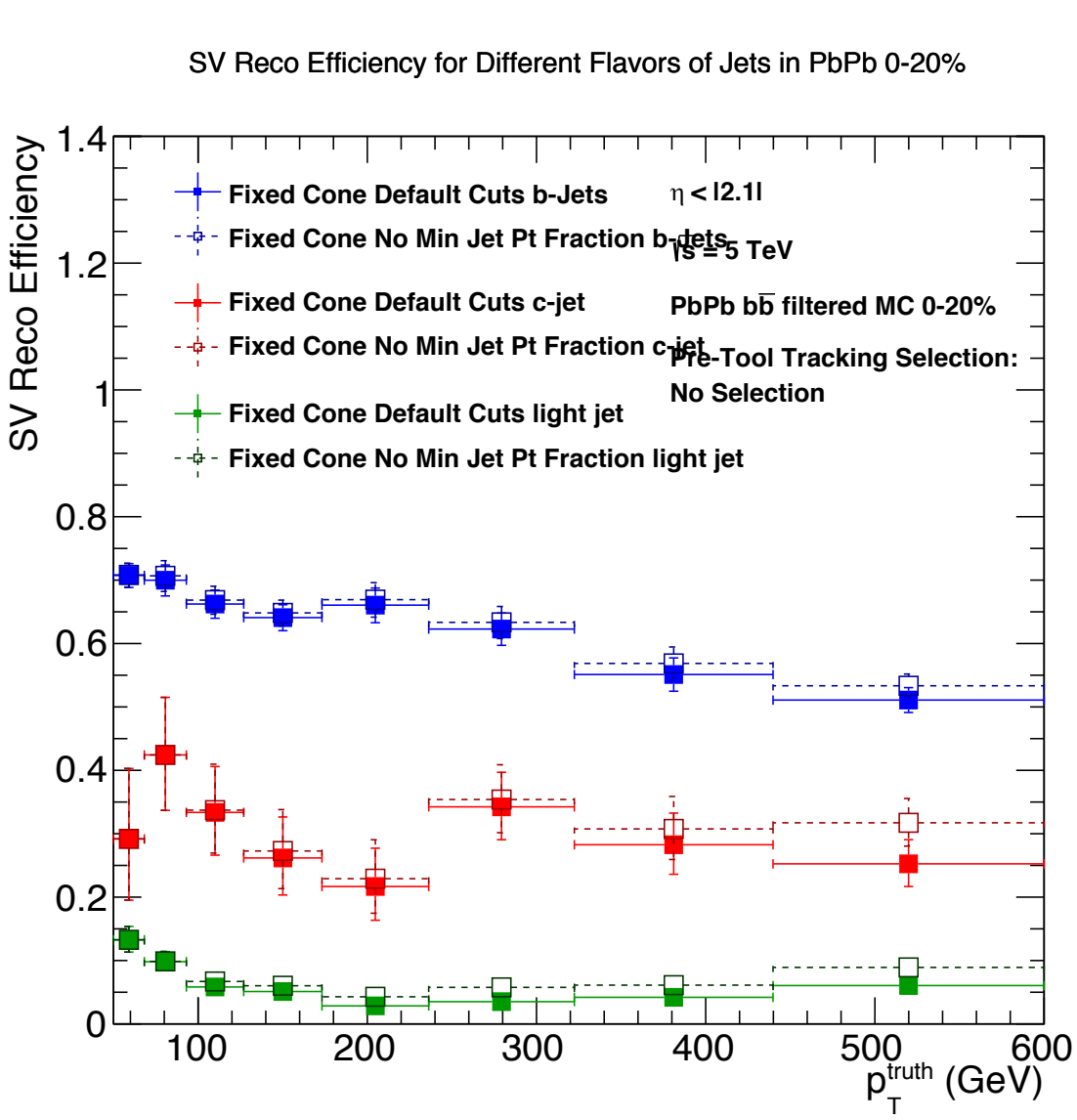
Track Purity Plot

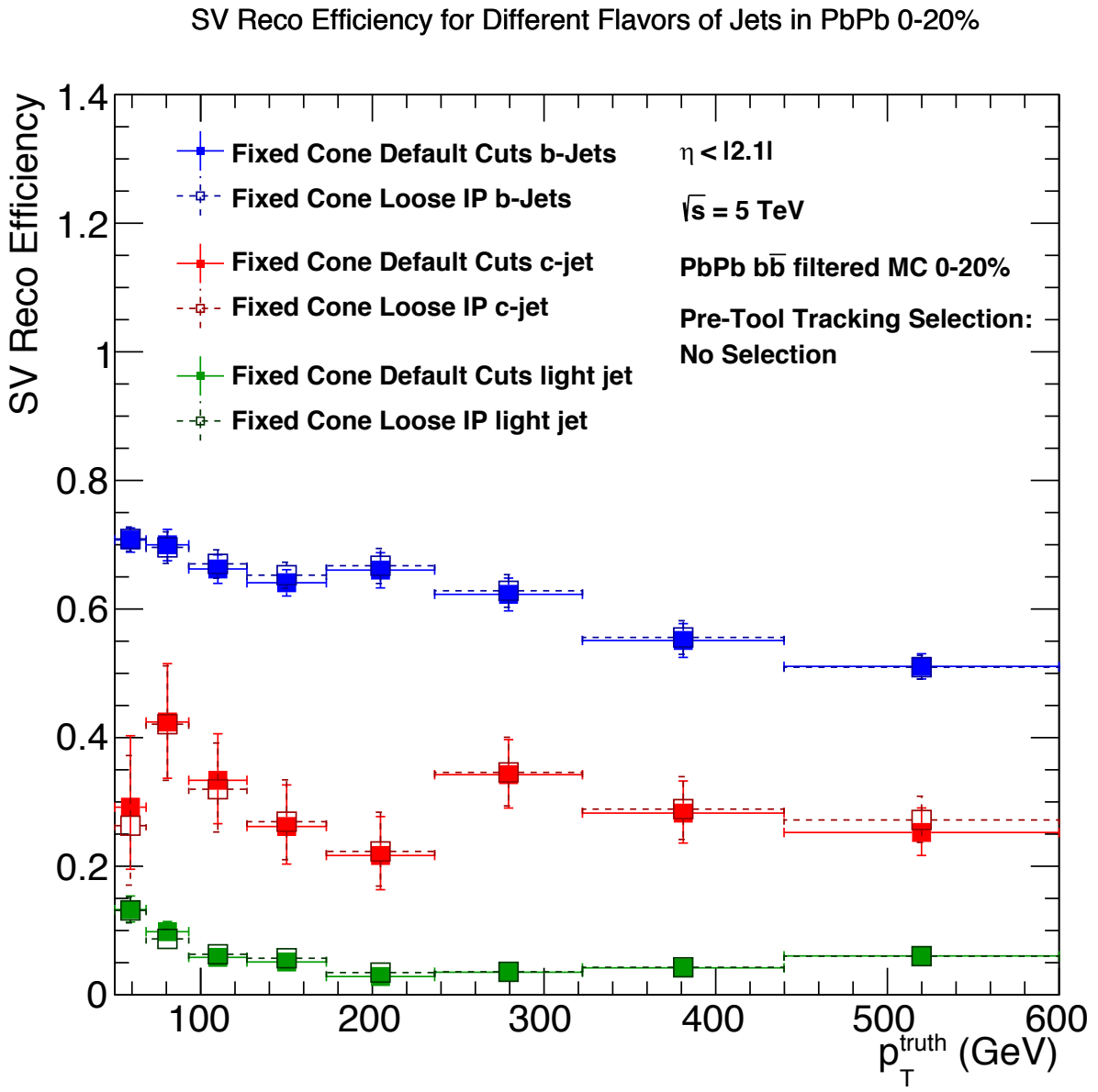
Track purity Plots





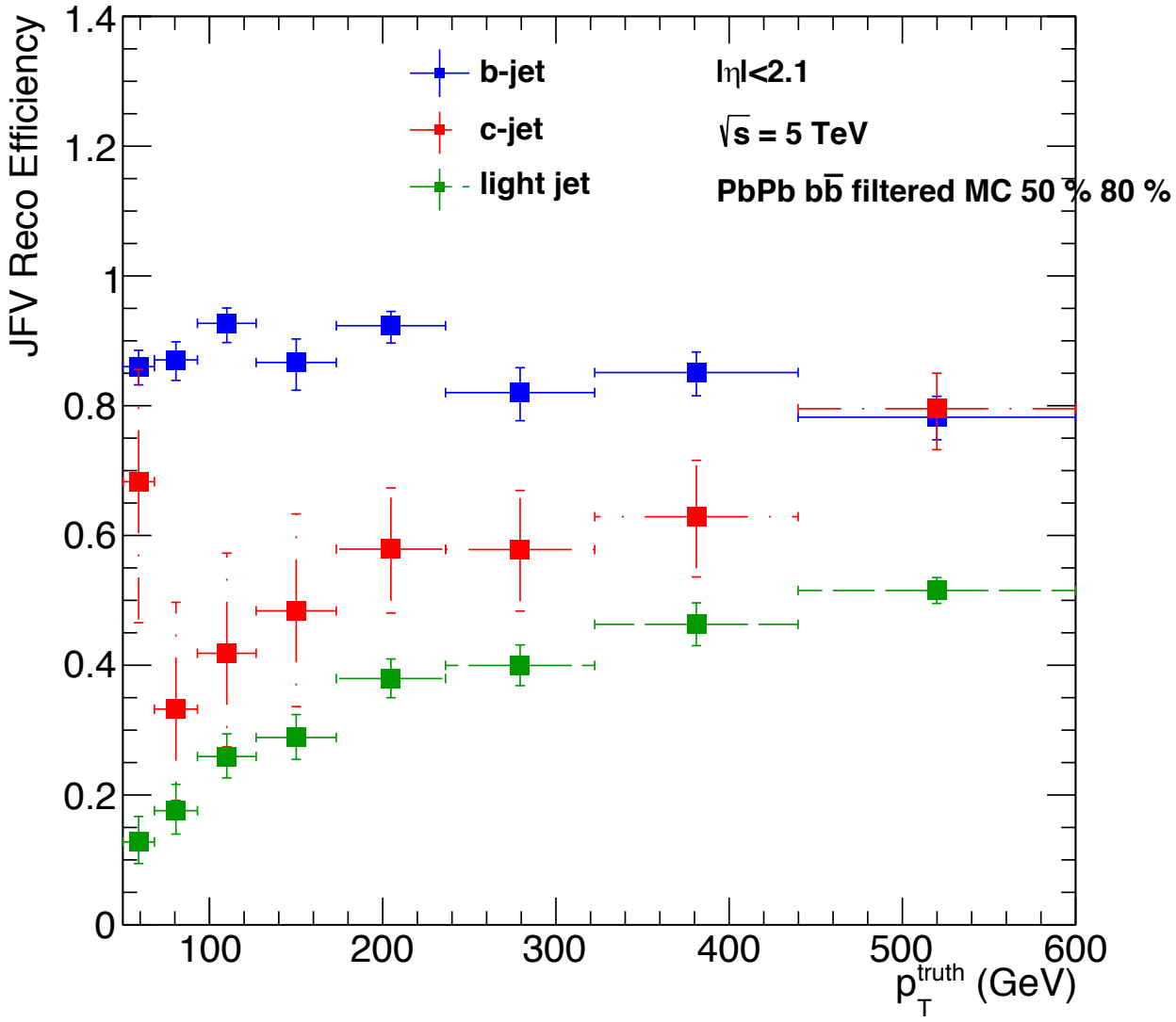
Pp integrated purity: 0.903
PbPb 0-20%: ~0.371 (seems really wrong…)





Cuts with no effect/impurity.

50-80%


b-jet
c-jet
light jet
|η|<2.1
√s = 5 TeV
PbPb bb̄ filtered MC 50 % 80 %
JFV Reco Efficiency
1.4
1.2
1
0.8
0.6
0.4
0.2
0
100
200
300
400
500
600
p_T^truth (GeV)

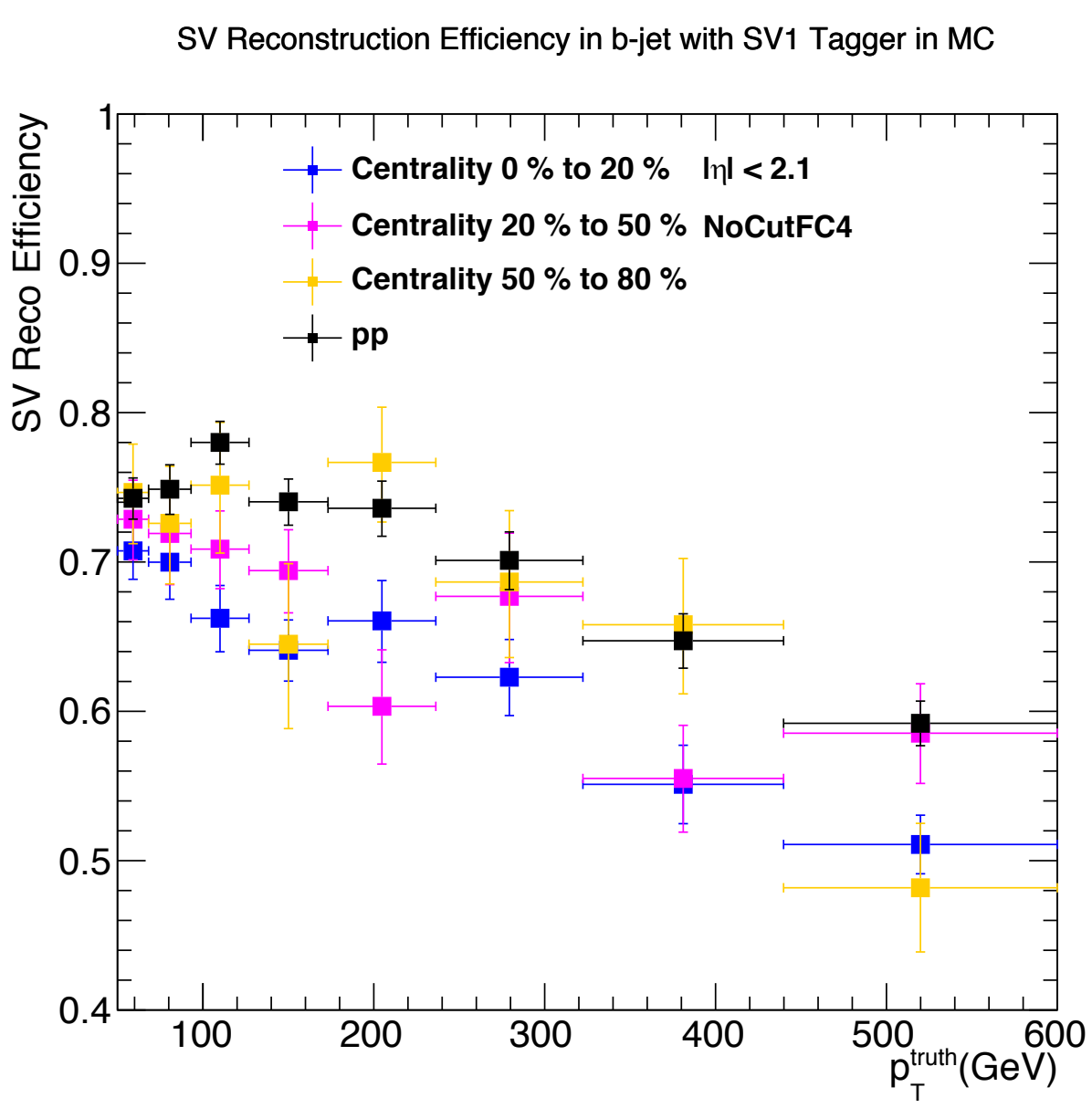
Effects of Cuts on Overlay

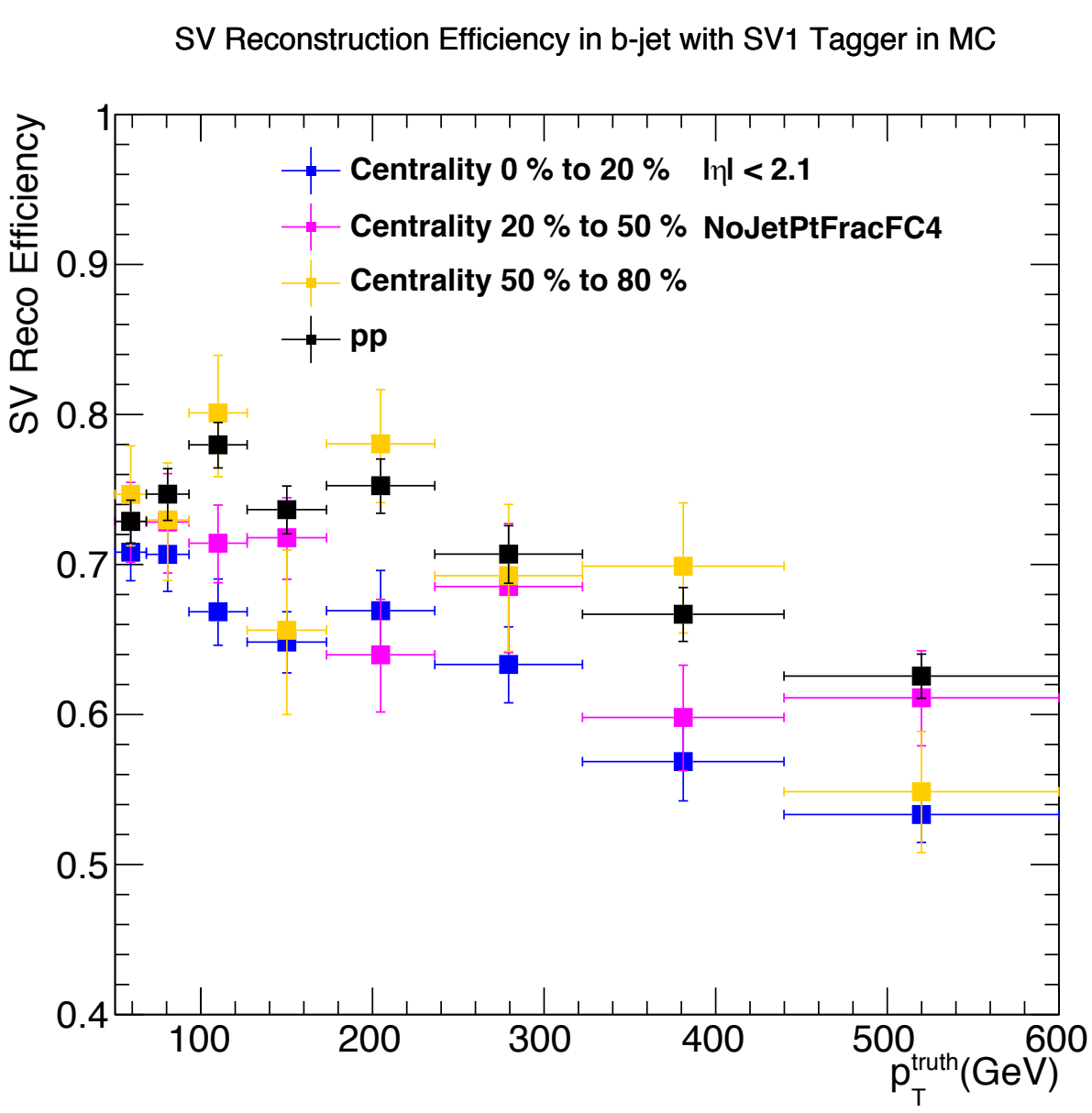
- Cuts those are effective in improving efficiency at pp MC were used in overlay.
- Fixed Cone: Using Fixed cone at 0.4 for tracks to jet association in contrast to shrinking cone algorithm optimized for pp.
- Minimum pT fraction: (wrong understanding previously)
  - 2-trk vertices candidates are created.
  - For tracks those are not in the candidates' tracks, if they pass minfraction*jet_Pt, then the common fitting algorithm will also use them.
  - Correction: minimum fraction of Pt used to select tracks used to form 2-trk vertices; misunderstood one of the selections last time (see back-up).
- Anti Pile Up tool:
  - Remove tracks with small xy impact parameter and big z impact parameter those are presumably from pileup.
- IP Selection:
  - Maximum xy-plane and z-plane impact parameter selections.

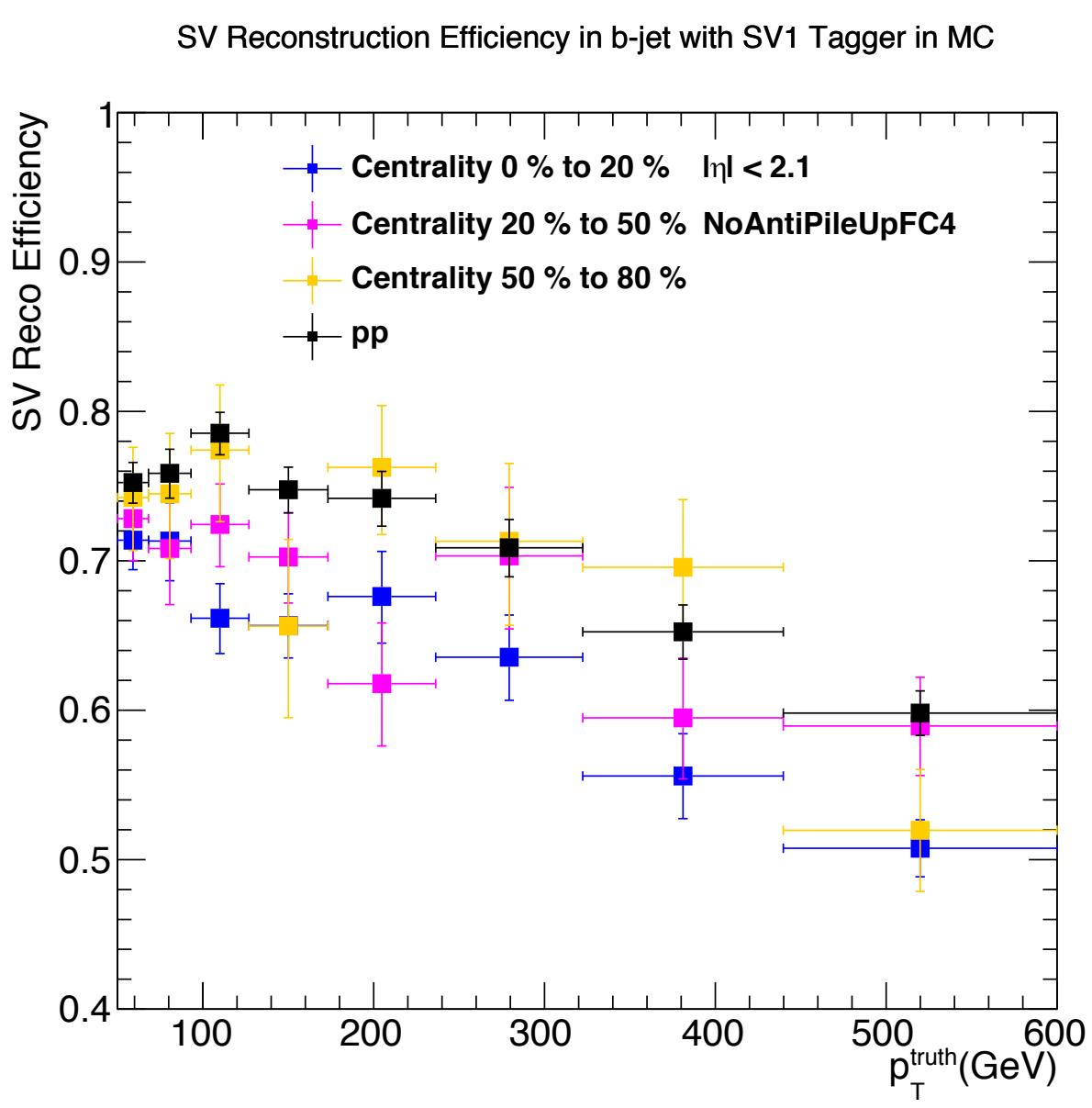
- This week:
  - looked at comparison with pp with SVF
  - A first look at JetFitter efficiency
- Things to look at :
  - Min number of shared hits. (the algorithm seems to not be using it? But there is an effect…)

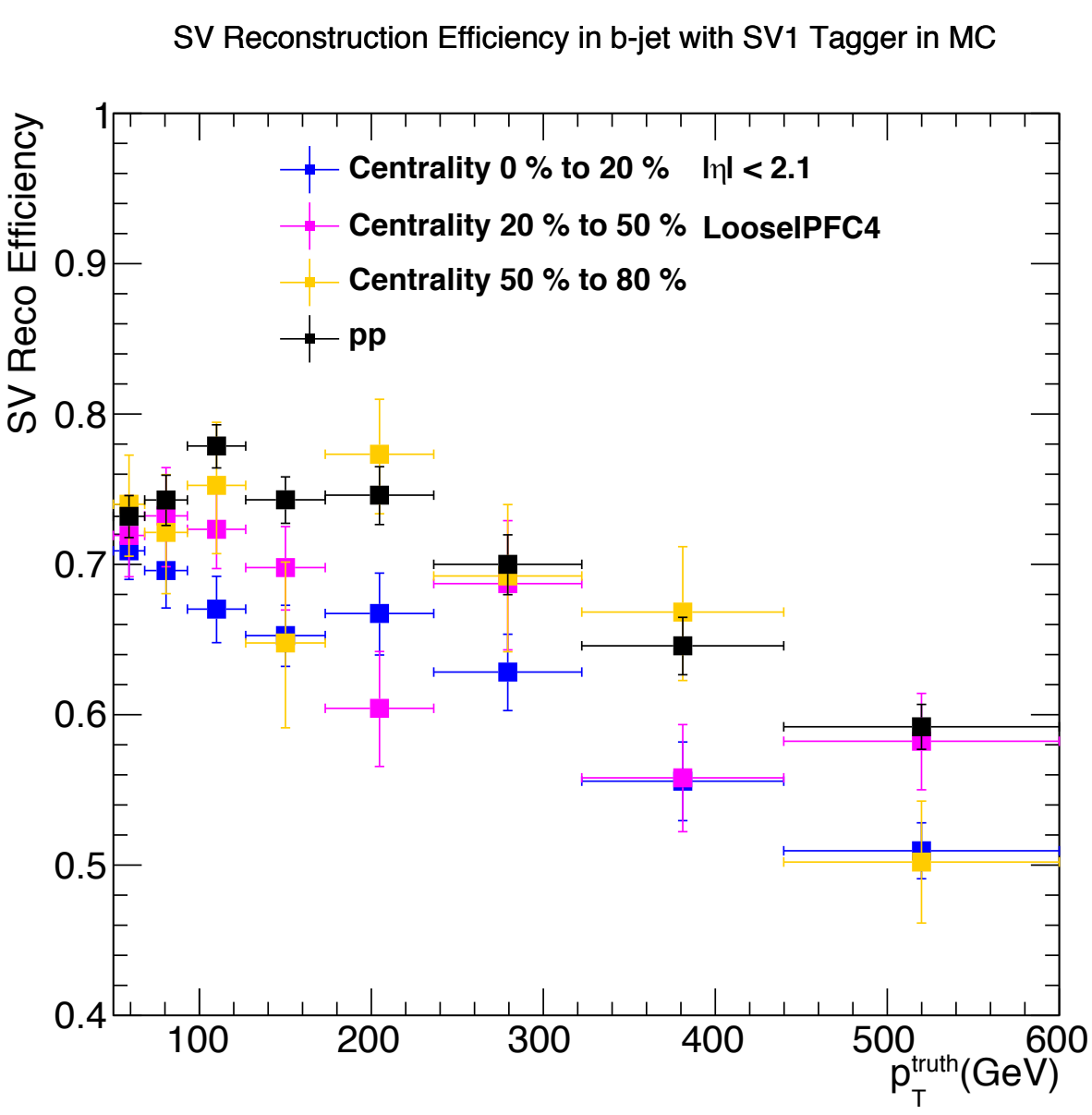
Summary of Effects of Cuts on Overlay (0-20%)

Cuts (original) (New)	Efficiency	Purity	Comment	Action
Fixed Cone (0.4)	+(~5%) at high pT	No change	Safer to use for HI jets	Keep using
Min pT Fraction(0.01) (0.00)	+(~2%) at high pT b +(~3%) at high pT c	+(~3%) fake ☹		Do not change
Anti Pile Up tool (On) (Off)	+(~2%) at high pT c	No change	Does it make sense to use in HI?	Keep using
IP Selection(On) (Off)	No significant Effect	No change		Do not change


SV Reconstruction Efficiency in b-jet with SV1 Tagger in MC
SV Reco Efficiency
Centrality 0 % to 20 %
Centrality 20 % to 50 %
Centrality 50 % to 80 %
pp
|η| < 2.1
NoCutFC4
1
0.9
0.8
0.7
0.6
0.5
0.4
100
200
300
400
500
600
p_T^truth(GeV)


SV Reconstruction Efficiency in b-jet with SV1 Tagger in MC
SV Reco Efficiency
Centrality 0 % to 20 %
Centrality 20 % to 50 %
Centrality 50 % to 80 %
pp
|η| < 2.1
NoJetPtFracFC4
1
0.9
0.8
0.7
0.6
0.5
0.4
100
200
300
400
500
600
p_T^truth(GeV)

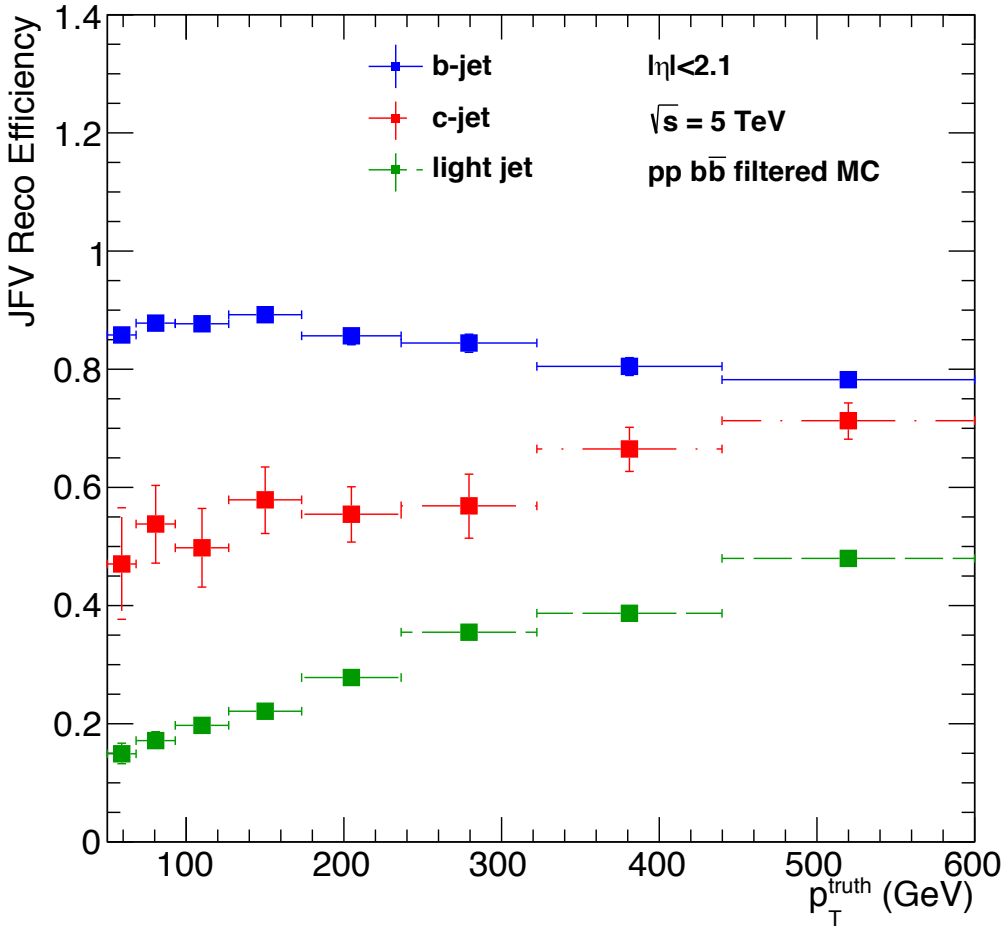

SV Reconstruction Efficiency in b-jet with SV1 Tagger in MC
SV Reco Efficiency
Centrality 0 % to 20 %
Centrality 20 % to 50 %
Centrality 50 % to 80 %
pp
|η| < 2.1
NoAntiPileUpFC4
1
0.9
0.8
0.7
0.6
0.5
0.4
100
200
300
400
500
600
p_T^truth(GeV)

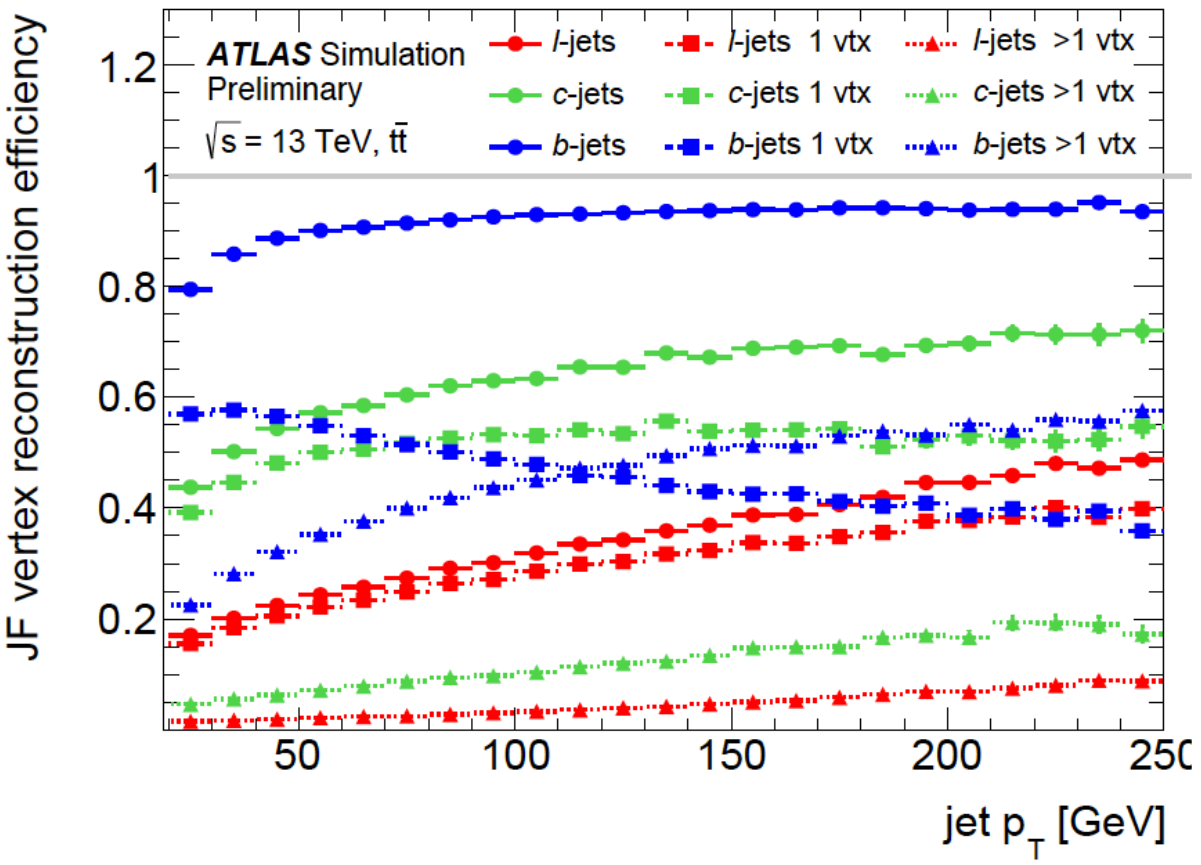

SV Reconstruction Efficiency in b-jet with SV1 Tagger in MC
SV Reco Efficiency
Centrality 0 % to 20 %
Centrality 20 % to 50 %
Centrality 50 % to 80 %
pp
|η| < 2.1
LooseIPFC4
1
0.9
0.8
0.7
0.6
0.5
0.4
100
200
300
400
500
600
p_T^truth(GeV)

JetFitter Algorithm—i.e., not only one vertex but also decay chain

- 1. Select Tracks
  - Form all possible 2-track vertices, and exclude tracks compatible with primary vertex, and hadronic material interactions.
- 2. Fitting and Merging
  - Initialize B-hadron flight direction as jet direction.
  - Initialize vertices candidates as closest approach position of each of the selected tracks to this direction.
  - Iteratively merge vertices and reject tracks with χ^2 cut.
  - Meanwhile iteratively align vertices with a common B-hadron flight direction and reject vertices with χ^2 cut.
  - Output a list of vertices aligned at common B-hadron flight axis
- Performance Paper: https://cds.cern.ch/record/2645405/files/ATL-PHYS-PUB-2018-025.pdf

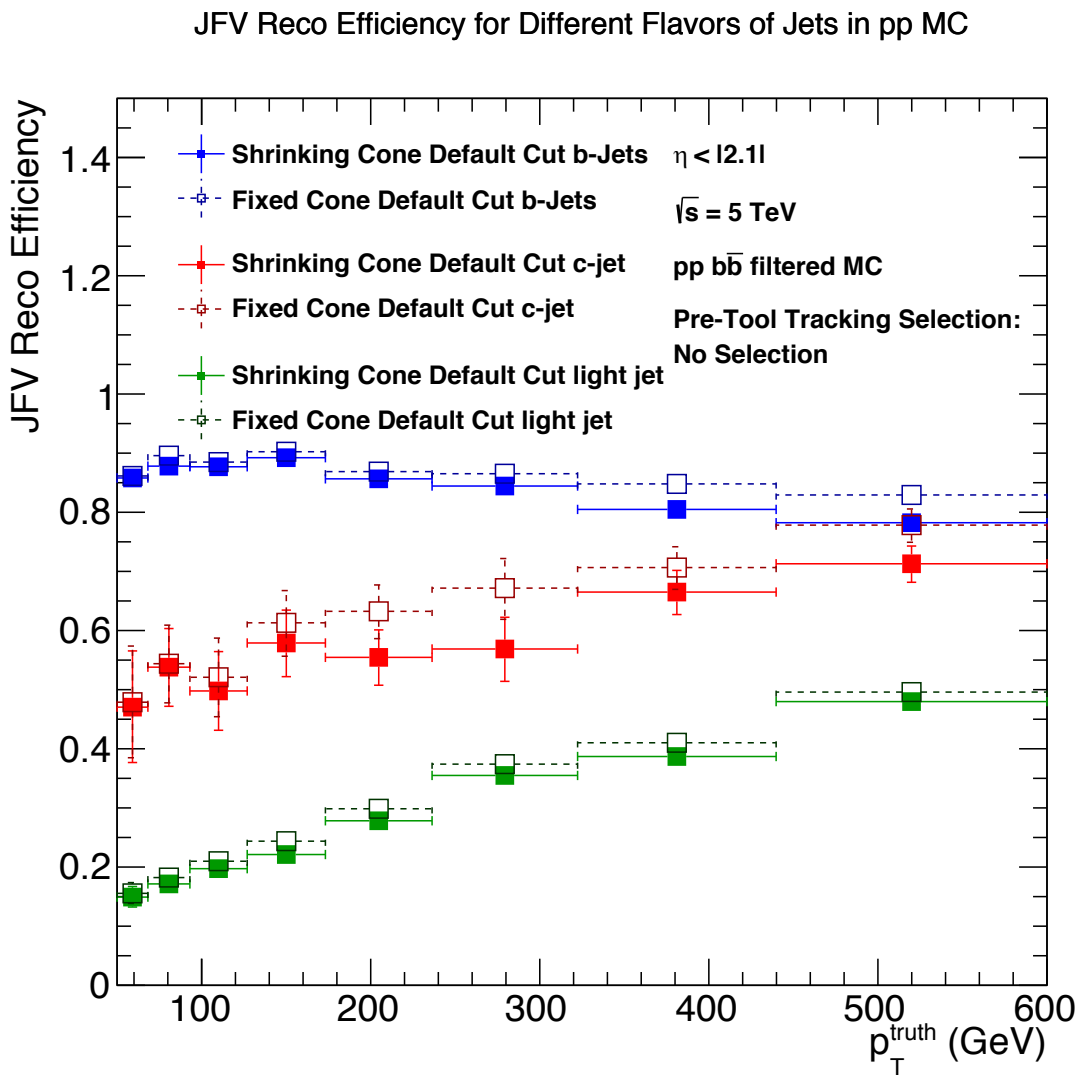
Efficiency Comparison to pp at 13 TeV

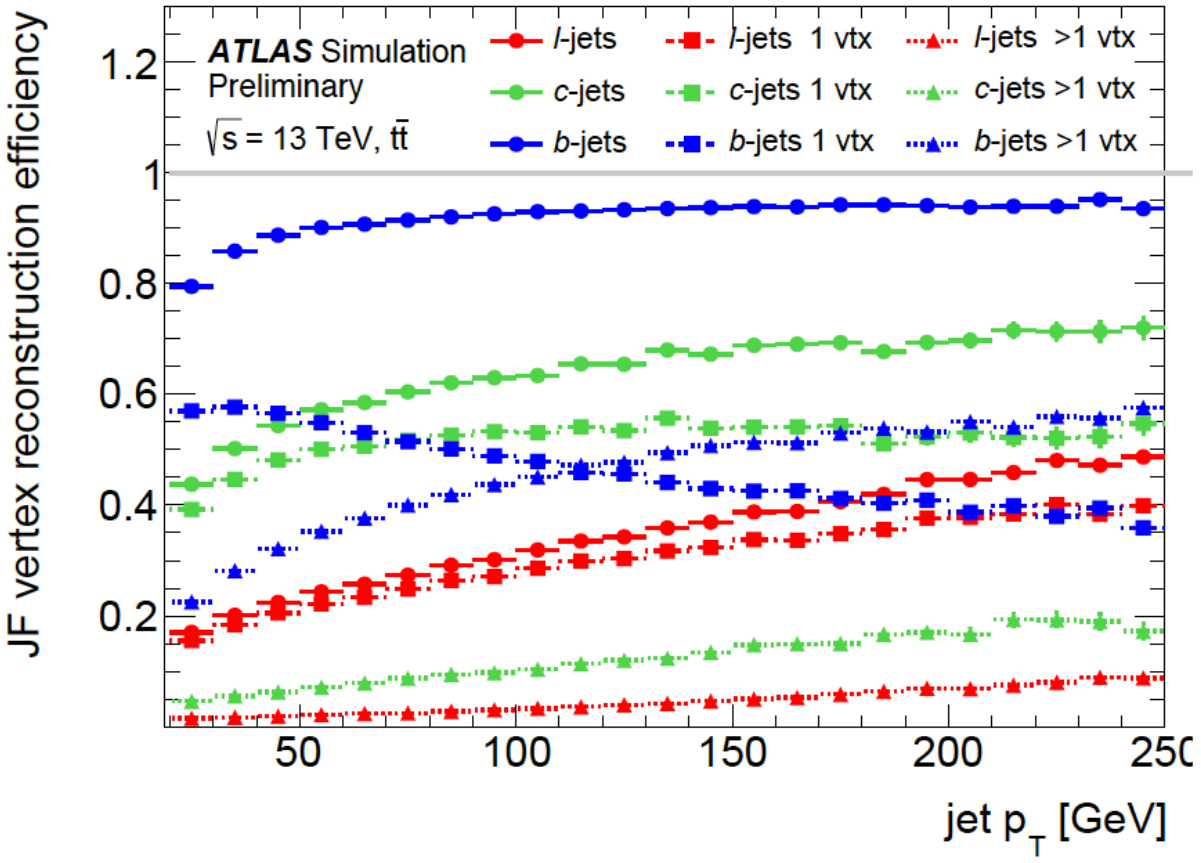




- Observed a minor decrease in efficiency at higher pT
- Higher than 250 GeV results are not shown in the performance paper
- 50-250 range is relatively flat.

Does Fixed Cone still work wit JetFitter?





Default JetFitter Results and Fixed Cone Results

Default Cuts

Integrated Efficiency (pT >20 GeV)	0-20%	20-50%	50-80%	pp
B-jet	0.939	0.901	0.844	0.865
C-jet	0.708	0.553	0.519	0.496
Light-jet (fake)	0.645	0.409	0.152	0.165

Fixed Cone at 0.4

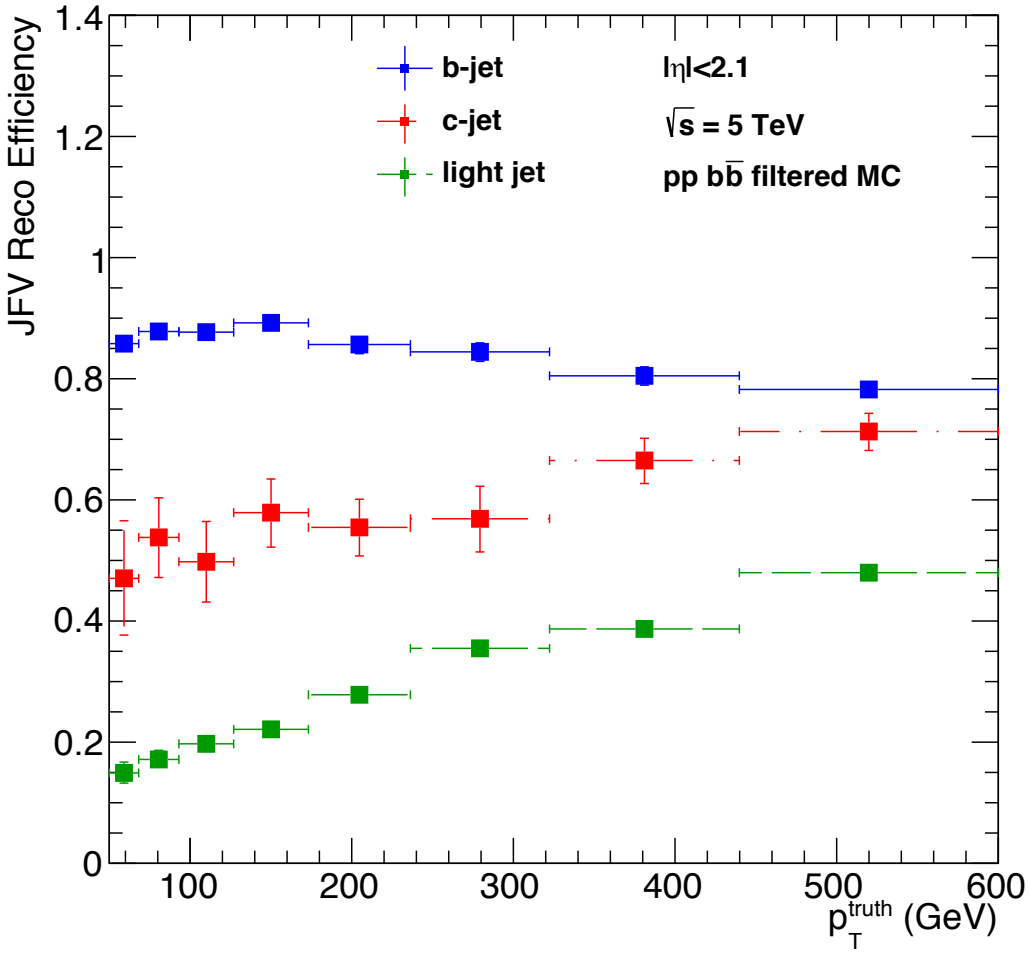
Integrated Efficiency (pT >20 GeV)	0-20%	20-50%	50-80%	pp
B-jet	0.954	0.907	0.860	0.872
C-jet	0.716	0.579	0.507	0.507
Light-jet (fake)	0.723	0.468	0.160	0.174

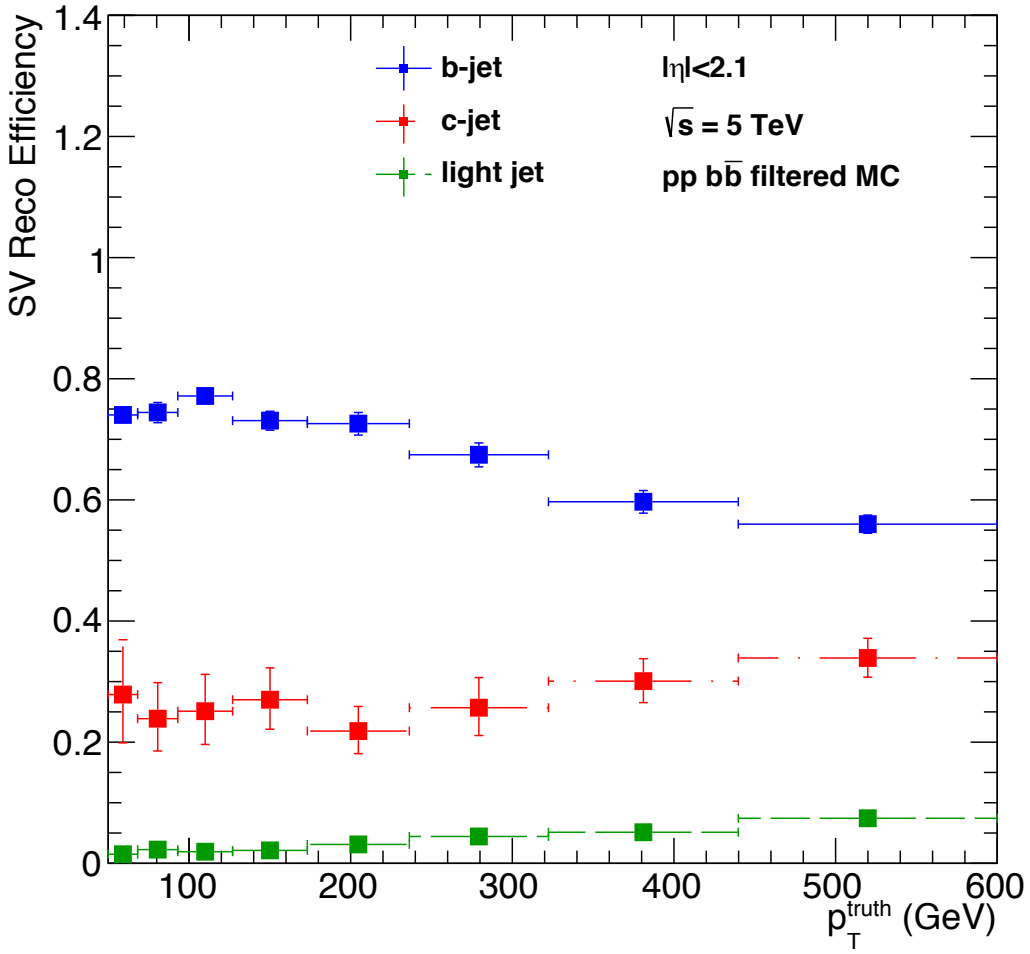
Performance Paper results:

	JF Vertices All
b-jets	0.893
c-jets	0.556
light jets	0.234

Back-up

Back-up: compare to SV





Minimum Jet Pt Fraction

- Algorithm overview:
  - 1. Select list of good particles
    - A0 Z0 track error cuts (Perigee quality)
    - For tracks with p > 10 GeV, stdev < 50%
    - Min Pixel hits, SCT hits and IBL hits requirement should be met
    - within 0.4 of JetDir
  - 2. Select list of two track vertices using selected good particles
    - Vertices are not in material layer and invariant mass is not a V^0 decay
    - Both track passes Jet Pt Fraction and vertex fitting quality

Other to-do

- Reproduce plots from JetFitter performance with our MC.
- Plan on summary of progress for flavour tagging group.