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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Task Description and Summary of Plan

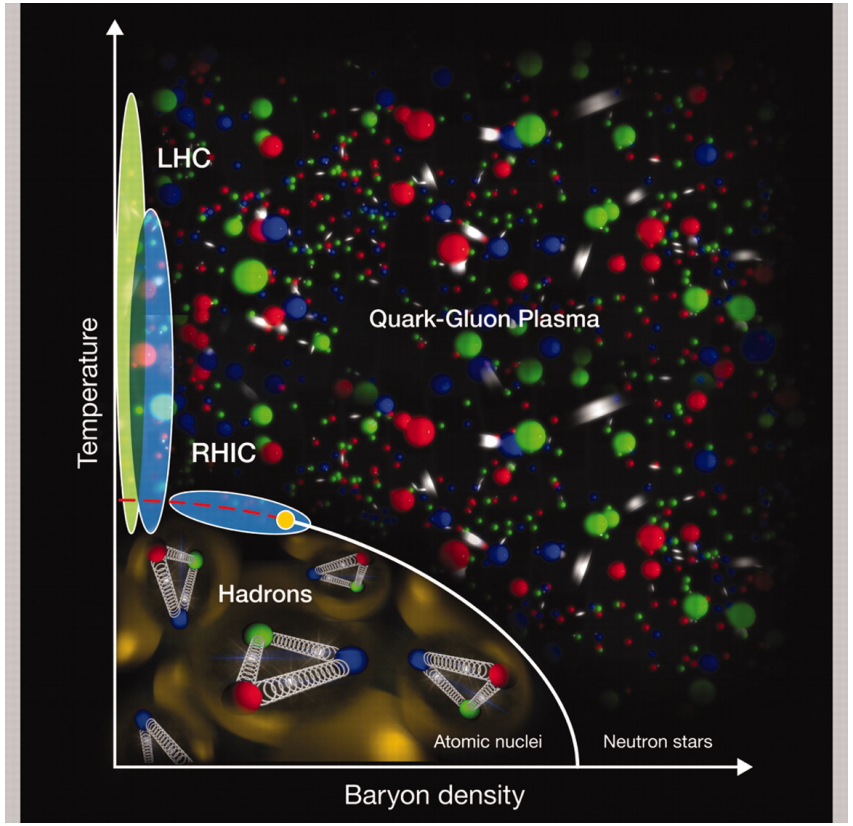
- Goal: optimize the inputs of high-level discriminates (DL1 & MV2) for b-tagging in HI collisions.
- Problem: HI collisions have large number of Underlying Event (UE) tracks that modify some inputs.

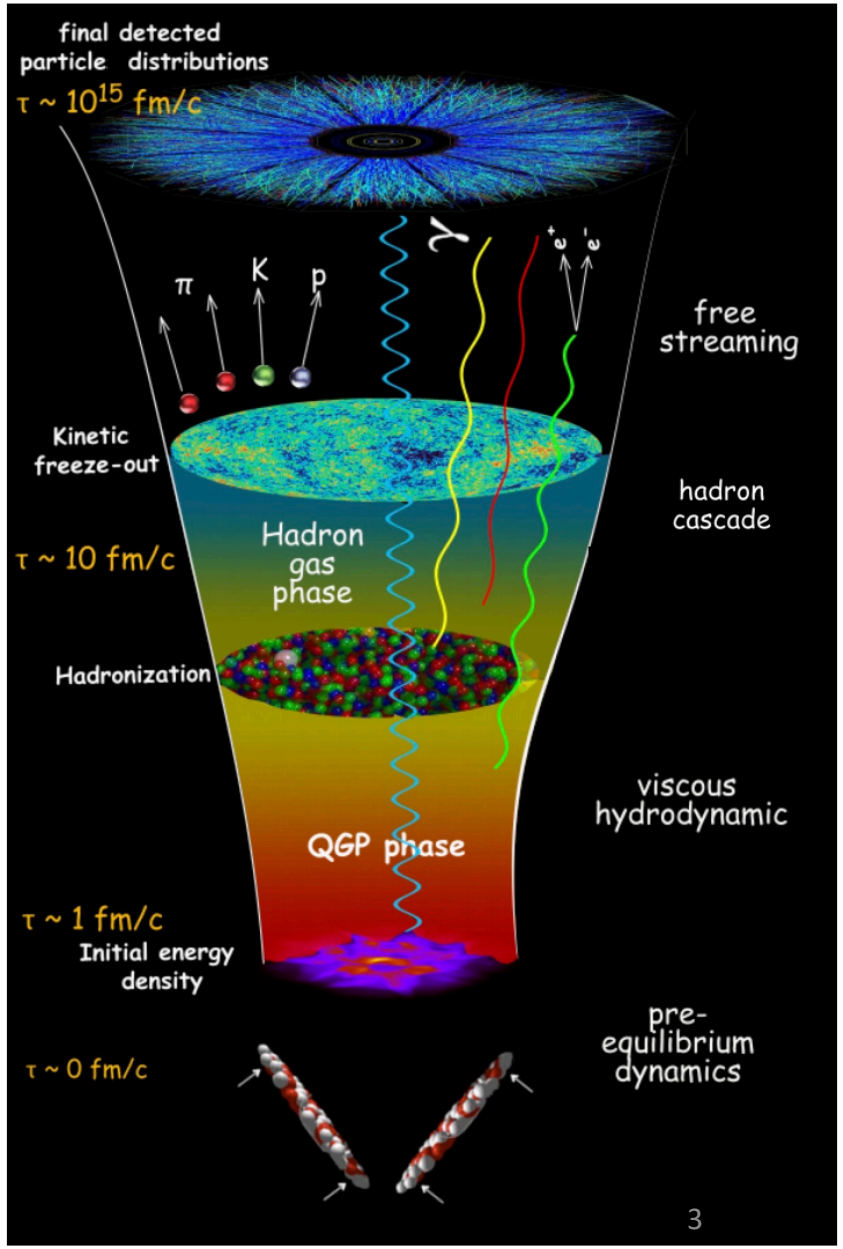
- First step plans: apply selections on tracks in HI MC to see whether performance improves
  - Impose cuts on p_T.
  - Apply “cone method” to subtract UE tracks effect.

“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.”

Background: Heavy Ion (PbPb) Collisions

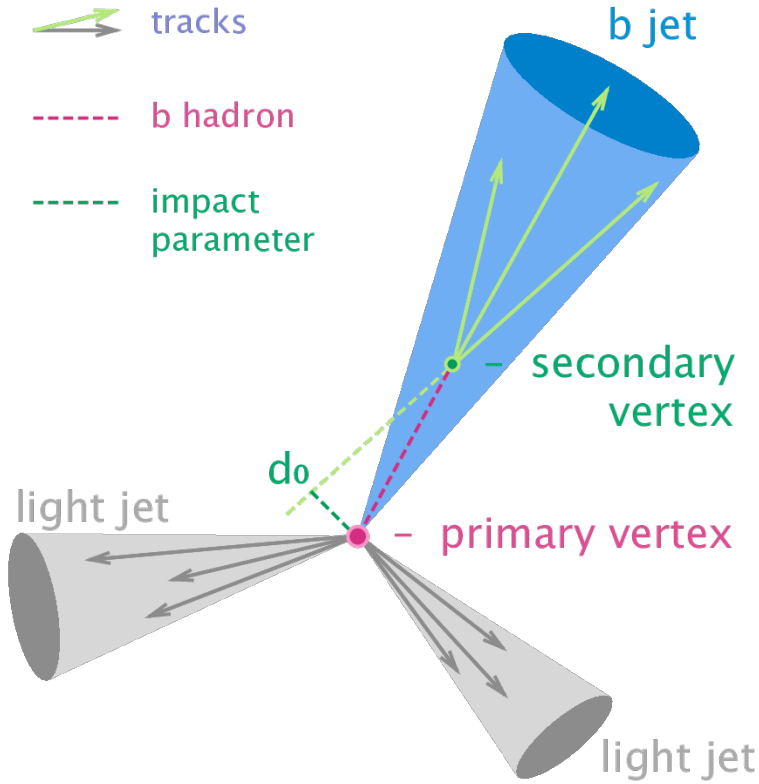
- Quark Gluon Plasma (QGP) are formed in heavy ion collisions.
- Partons are confined in normal matter, free in QGP.
- Jets are used as probes to study QGP.
- For central collision, about 1600 interactions from a single vertex.





Description of Task Background (AFT-455)

- B-tagging: the identification of jets containing b-hadrons
  - Several dedicated algorithms exploiting specific proprieties like long lifetime, high mass and decay multiplicity of b-hadrons and the hard b-quark fragmentation.
  - Low Level Discriminants:
    - IP3: Impact Parameter (d0, z0) based
    - SV1: Secondary Vertex based
    - JetFitter: Secondary Vertex based
  - As input of High Level Discriminants:
    - MV2 and DL1



- Algorithms are trained on *pp* simulations.
- B-tagging algorithms can now run heavy ion data from AFT-233.

Scope of This Study

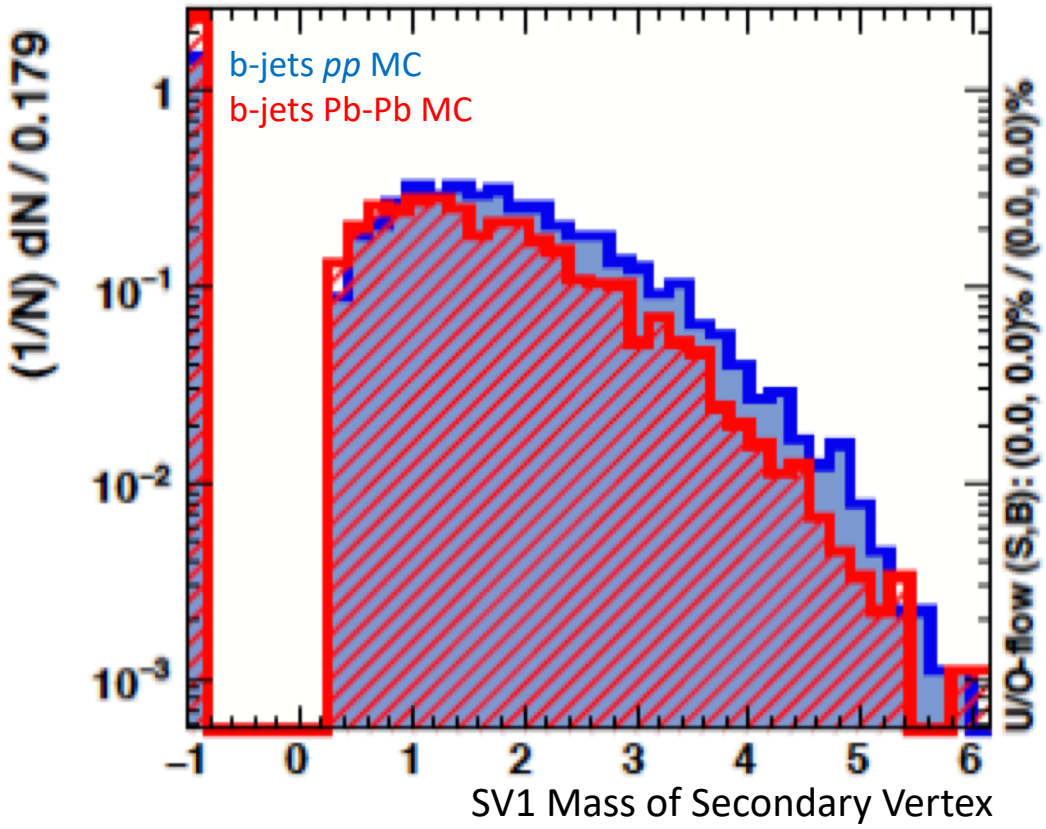
- PbPb 2018 5.02 TeV data with integrated luminosity 1.76 nb^{-1}.
- We estimate to have order of 100 b-jets at p_T 200-300 GeV, and order of 10 b-jets at p_T 300-400 GeV, and the latter will be the upper limit of this optimization.
  - The estimation was made for all centrality using the $L_{int} \times \sigma^{pp}_{b-jets} \times \langle N_{coll} \rangle \times \frac{\sigma^{tot}_{AA}}{\sigma^{pp}_{tot}}$, where $\langle N_{coll} \rangle \times \frac{\sigma^{tot}_{AA}}{\sigma^{pp}_{tot}}$ was estimated as 40,000. (N_{coll} is the expected number of binary nucleon-nucleon collisions)
  - The theoretical calculation for b-jets cross section is from this paper by Hai Tao Li and Ivan Vitev: https://arxiv.org/abs/1811.07905

- There are ongoing measurements within the HI group of b-jet cross-sections in PbPb and *pp* at 5.02 TeV using muon based tagging, which can provide cross checking reference.
  - The link to this internal note is here: https://cds.cern.ch/record/2683608?#

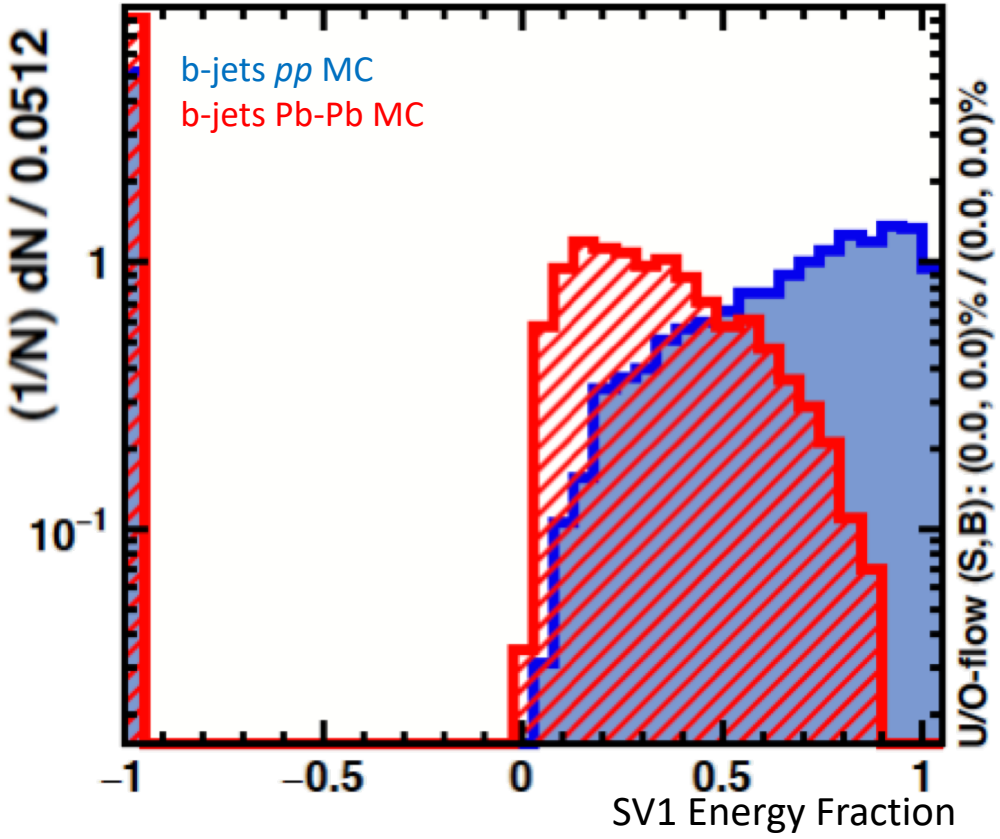
Description of Qualification Task (AFT-455)

- 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



Pb-Pb MC Samples

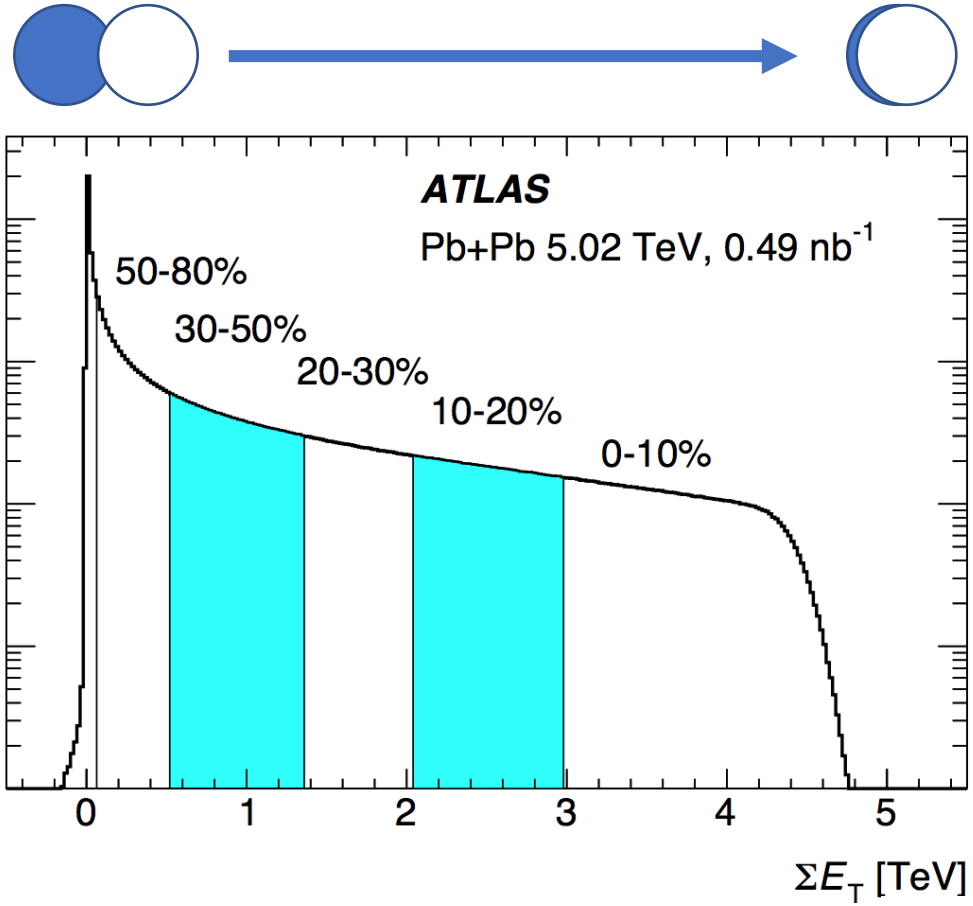
- Pythia MC Overlay as Heavy Ion simulation.
  - Pythia MC events embedded into minimum-bias data from Heavy Ion collisions .

- 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.

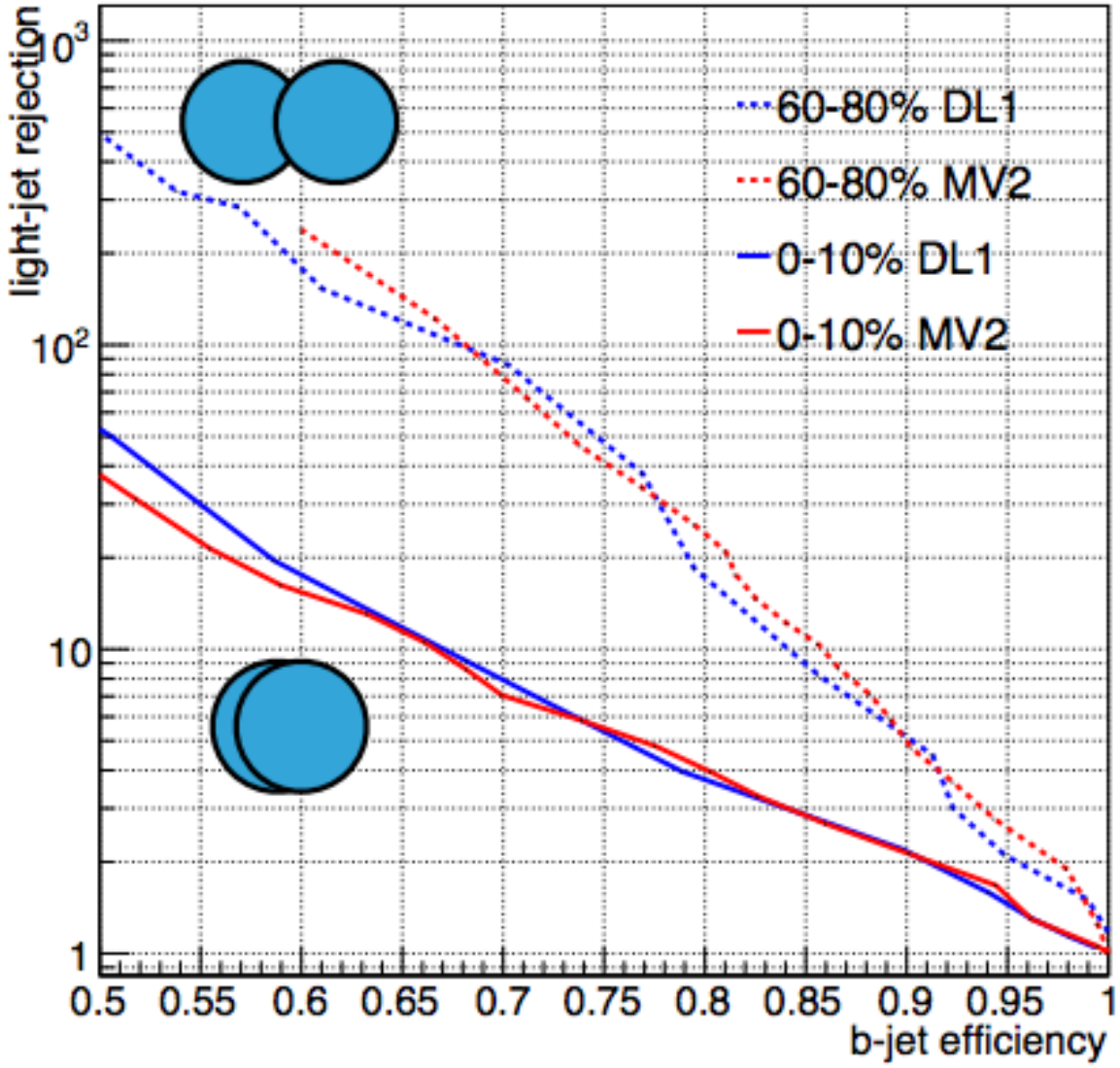
Challenge in Heavy Ion Collisions

- Centrality Dependence
  - 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 (~1600 nucleon-nucleon interactions / collision)



B-Tagging Performance in Overlay MC

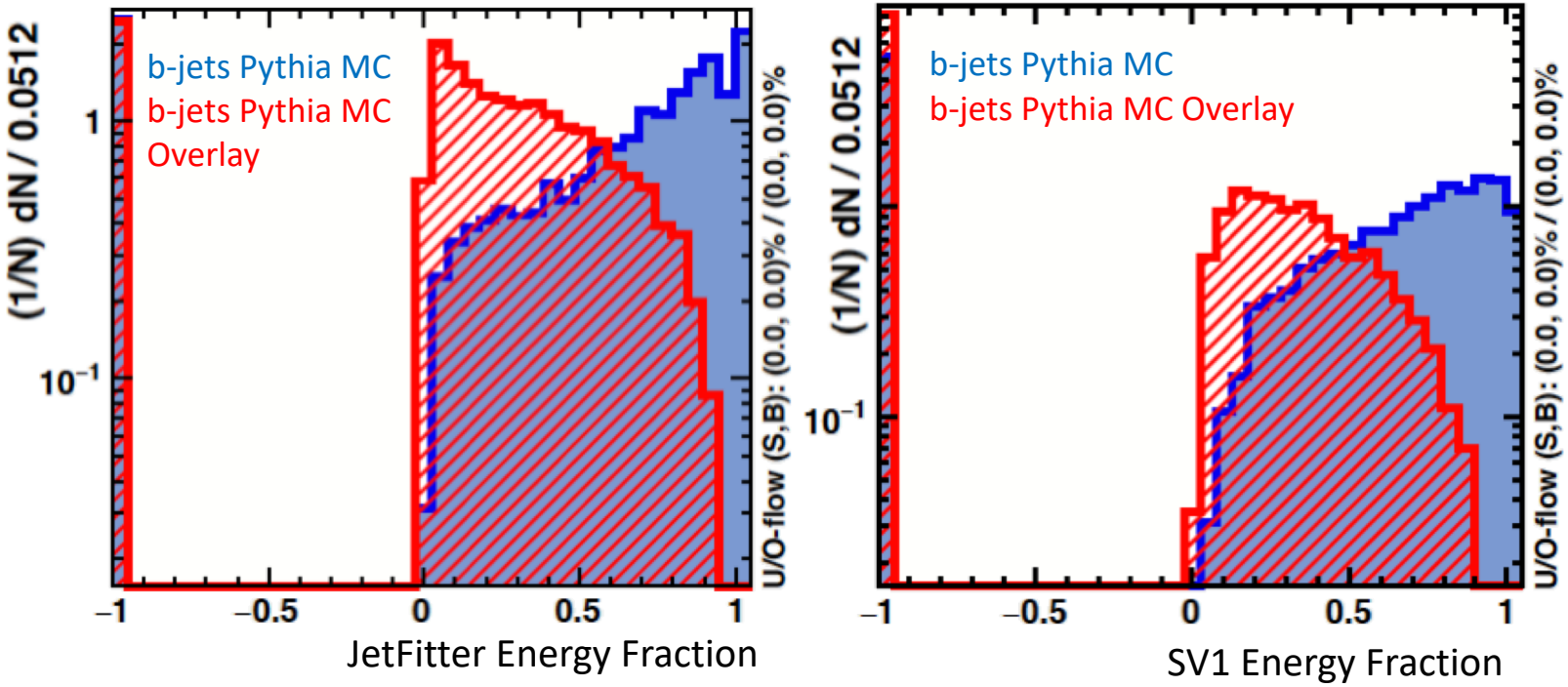
Inclusive Jet-MC

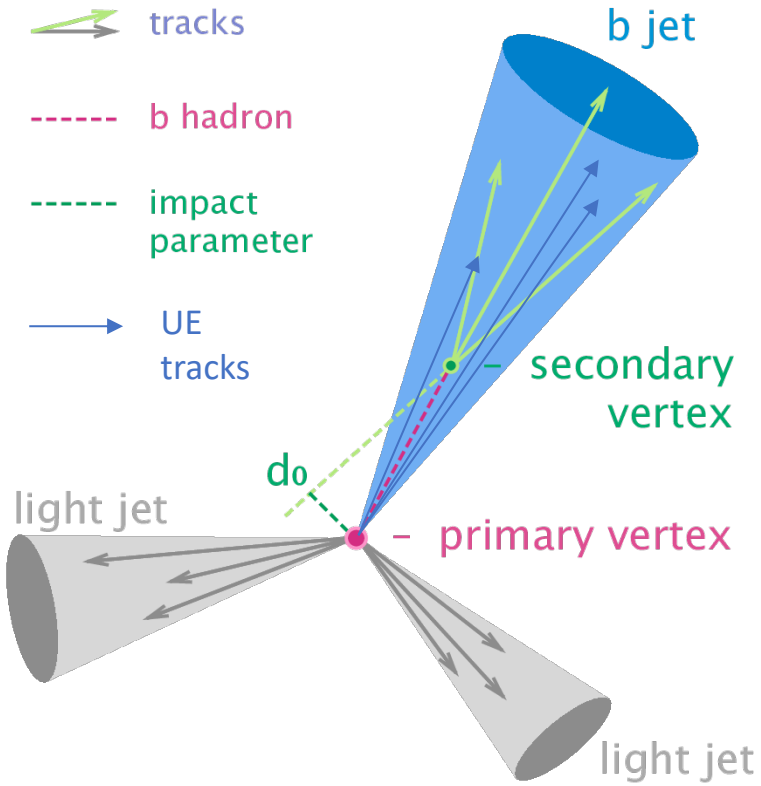


For the same efficiency in b-jet efficiency, central collisions have an order of magnitude lower of light-jet rejection than peripheral collisions.

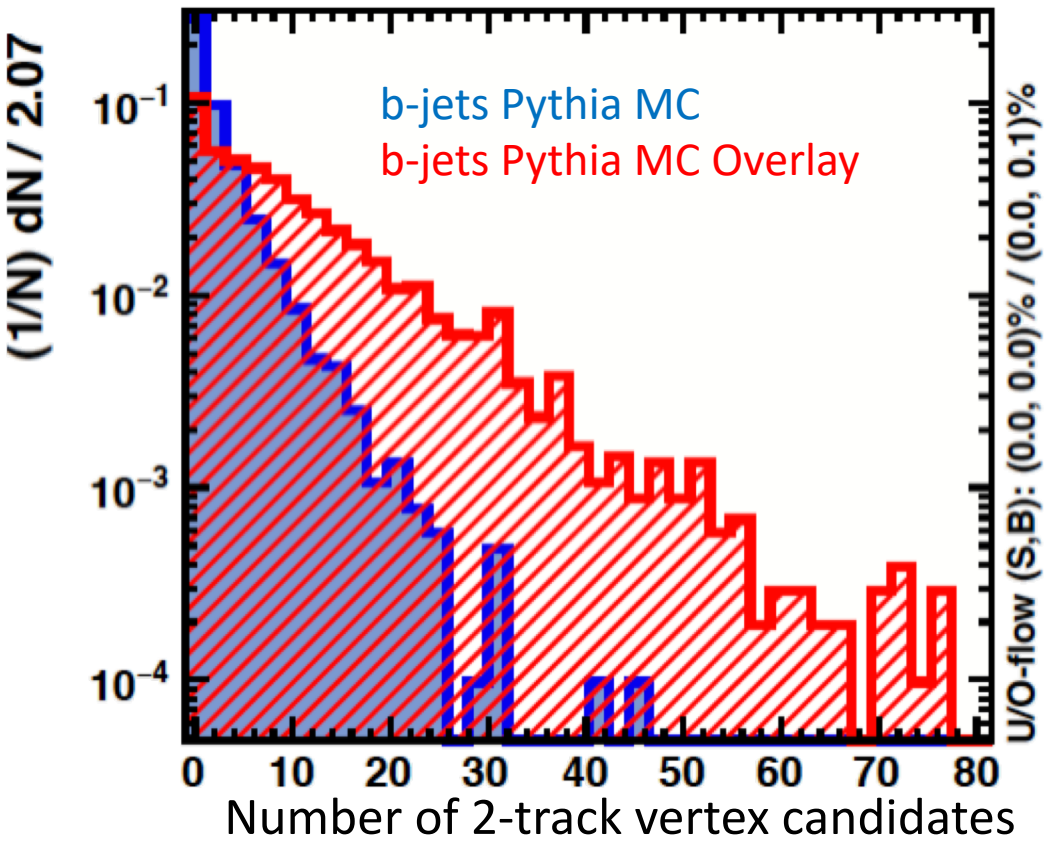
Inputs Significantly Modified by Underlying Events (UE)

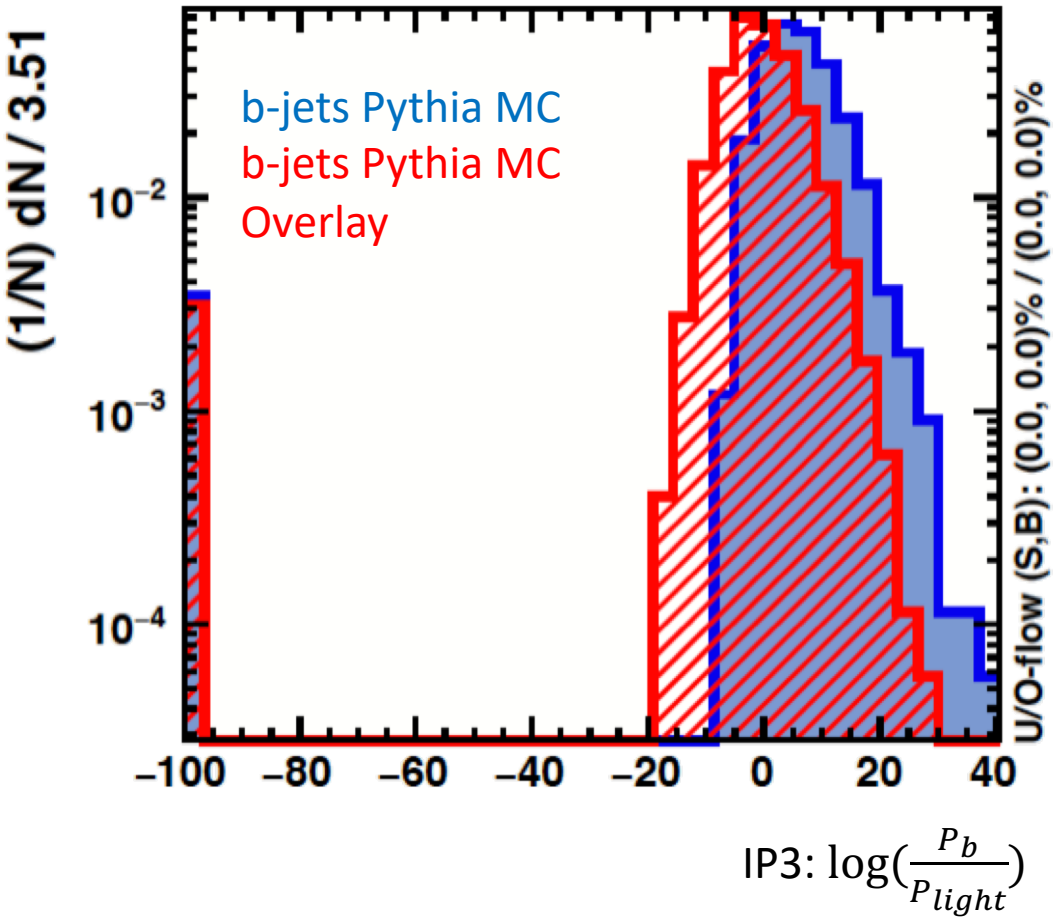
- Tracks from Underlying Events (UE) are mistaken as part of jet tracks.
  - Wrong energy fraction (efc=$E_{SV.trks}/E_{All\ trks}$), UE are included in denominator.





Inputs modified Heavily by Underlying Events (UE) (Continued)





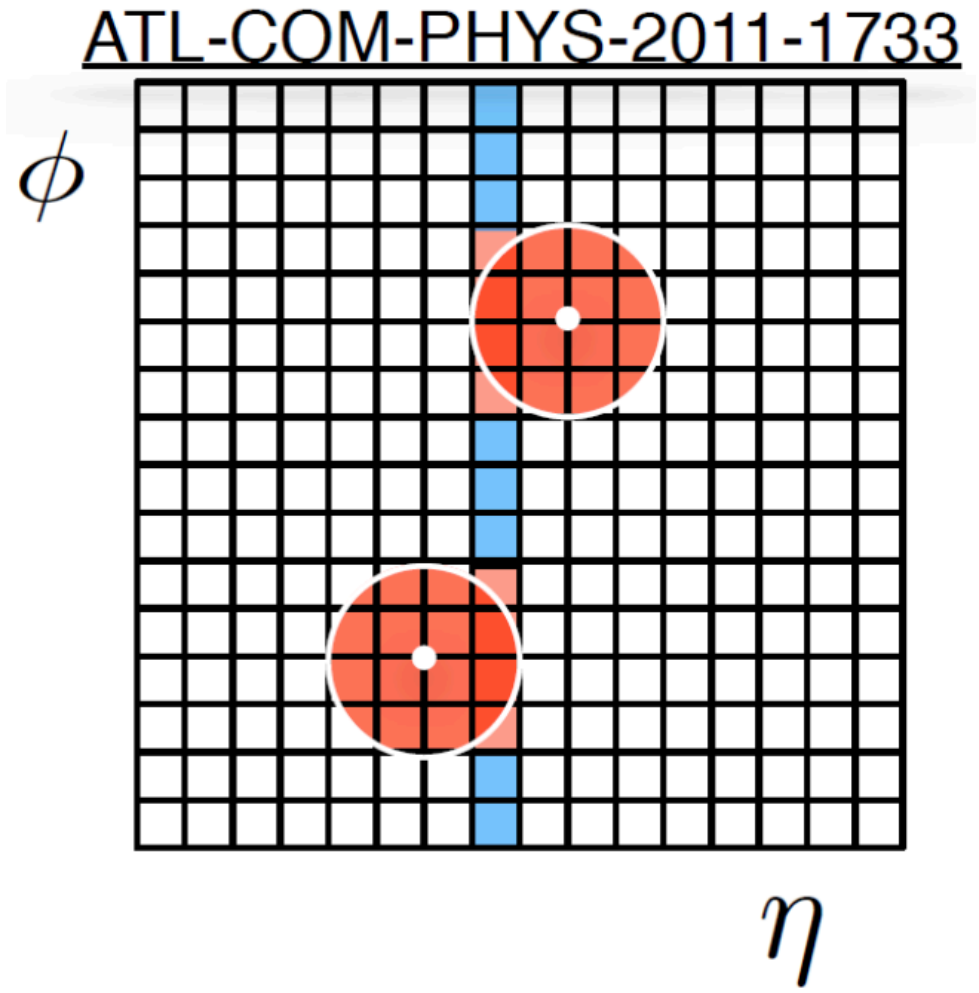
Question: What selections are applied?

$\log(\frac{P_b}{P_{light}})$: Likelihood ratio between the b-jet and light-jet hypotheses

First Step: Apply Selections to Reduce UE Effects

- Develop selections for heavy ion collisions on HI MC (Pythia MC Overlay) to reject UE tracks before calculating inputs.

- Possible methods:
  - Tighter track selections
    - For example, most UE tracks have lower p_T.
  - Cone method
    - Exclude regions of jets and use remaining tracks to model UE tracks distribution to energy. Will help shift Energy Fraction to the right.
    - A method used by current HI groups to model and subtract UE tracks effect from jets.
    - https://arxiv.org/pdf/1805.05424.pdf



Summary

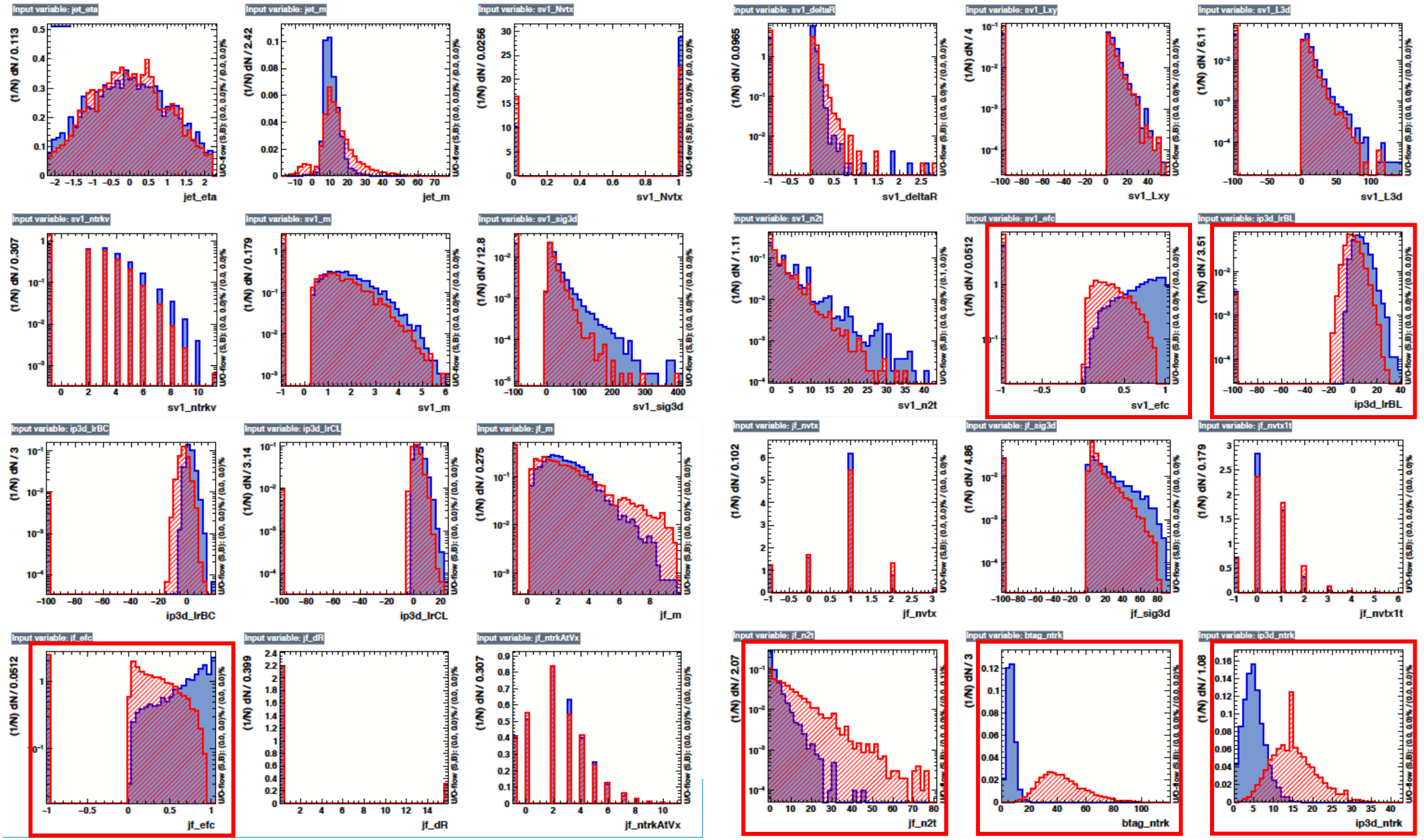
- This task will optimize the inputs for the high level discriminants (MV2 and DL1) in order to improve the B-tagging performance in heavy ion collisions.
  - Performance of high level discriminants on HI collisions have a strong centrality dependence.
  - More underlying events are present in central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

- 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.

Back-up Slides

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



b-jets Pythia MC

b-jets Pythia Overlay

Significantly modified inputs.

Notes for myself (question slide)

- Is there a difference between the 2 algorithms DL1 and MV2? (Should we optimize for each or the optimization should yield same improvements in both)
- Where can we access current algorithms of IP3, SV1, JF. to check what selections have been applied?
- Can the selections/method of calculating inputs be changed in these algorithms?
- Selections on calculating n2t

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