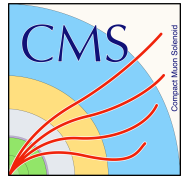

Study of Nuclear Interactions

IExp Meeting

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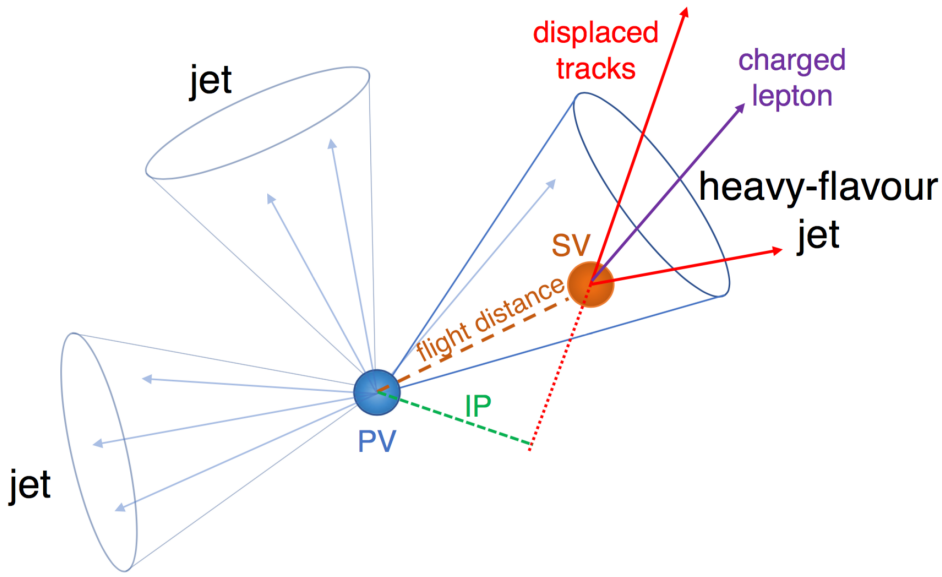
University of Hamburg

November 6, 2019

b-Jet Signature

- b-quarks forming B hadrons $\rightarrow$ jets
- Long lifetime of 1.5 ps $\rightarrow$ secondary vertex (SV) detected
- Large mass of 5 GeV
- Often leptons produced (20 %)
- Tracks with large impact parameter (IP)
  - Indicates displacement of tracks w.r.t. primary vertex (PV)
  - Closest approach used
  - Order: 100 μm
  - IP significance $S = \frac{IP}{\sigma}$



CMS-BTV-16-002

b-Tagging Algorithms arXiv:1712.07158

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Inclusive Vertex Finder (IVF) algorithm:

- SV reconstructed using suitable tracks
- IP and IP significance used to select specific events

Combined Secondary Vertex Finder (CSVv2) algorithm:

- Combines information of SV and displaced tracks
- Neural network (NN): feed-forward multilayer perceptron with one hidden layer to calculate probability for b like jet

deepCSV algorithm:

- Deep NN (DNN): more hidden layers, more nodes, simultaneous training for all jet flavours; same input as for CSVv2

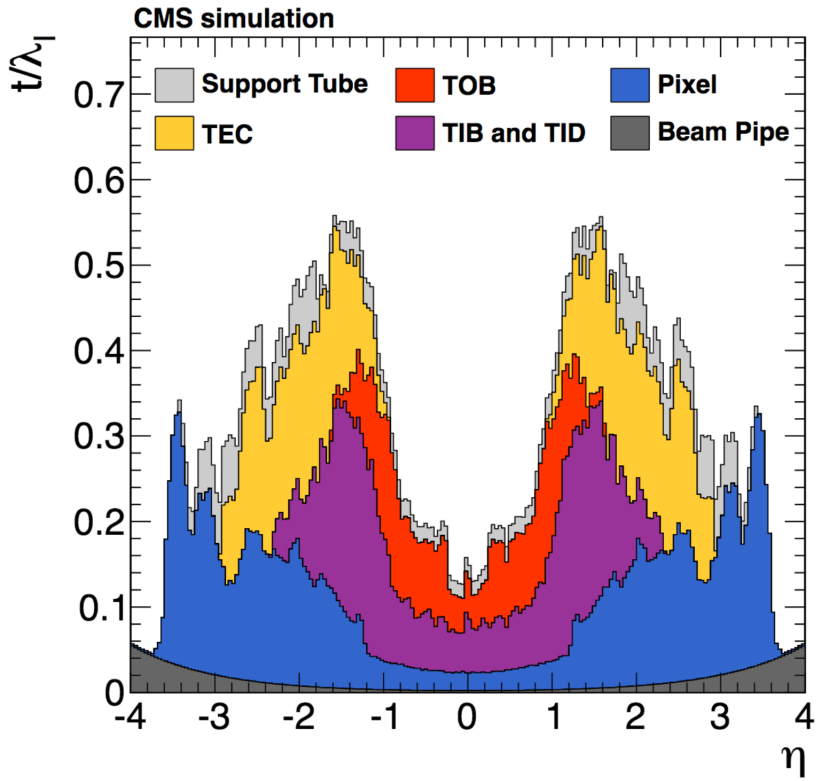
deepJet (= deepFlavour) algorithm: CMS AN-2017/188

- DNN with convolutional layers: more information per jet, vertex and particle candidate handed over

Nuclear Interactions

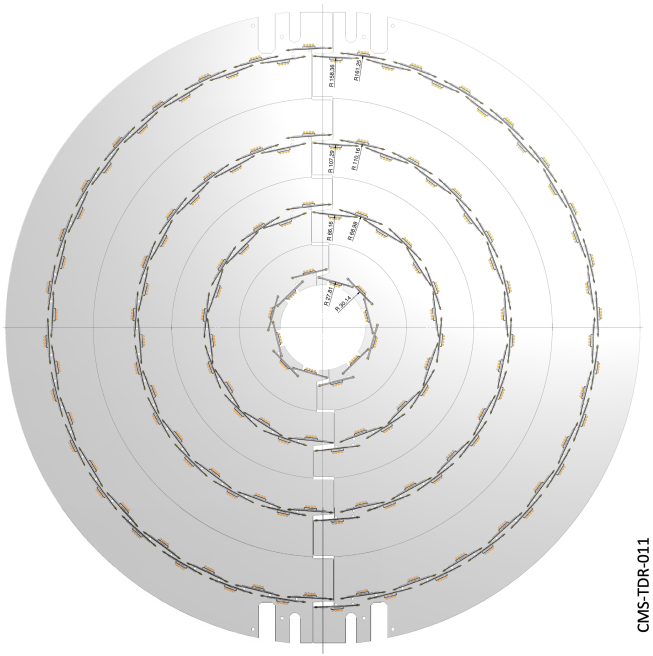
- Hadrons (mostly π) scatter with nucleons of the detector material $\rightarrow$ nuclear interactions (NI)
- SV from NI misidentified as b-jets
- Mimicking vertex displacement
- Such events tagged as b-jets
- Fraction of misidentified b-jets coming from NI

$\rightarrow$ Can we remove them?

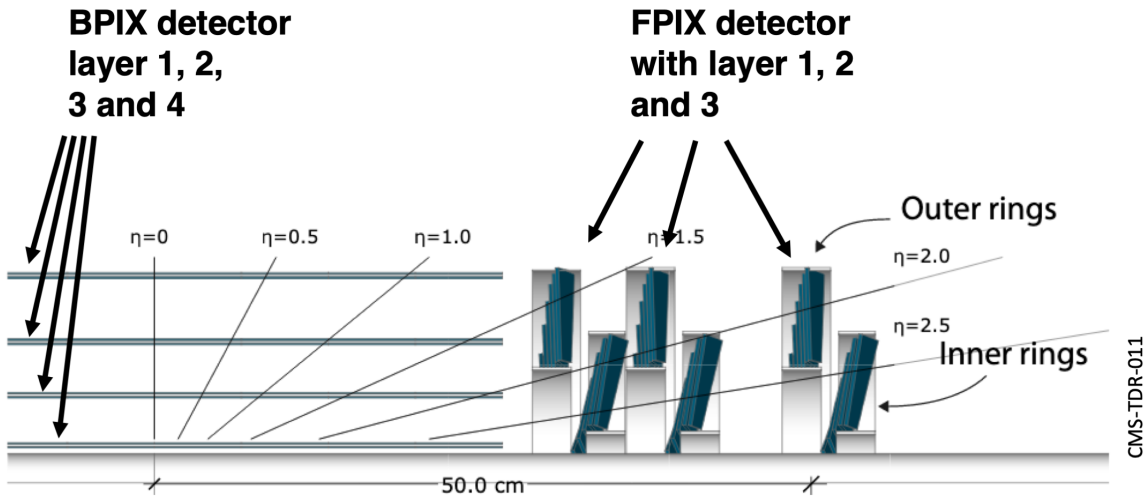


arxiv: 1405.6569

Pixel Detector



x-y view



z-r view

Profile Images

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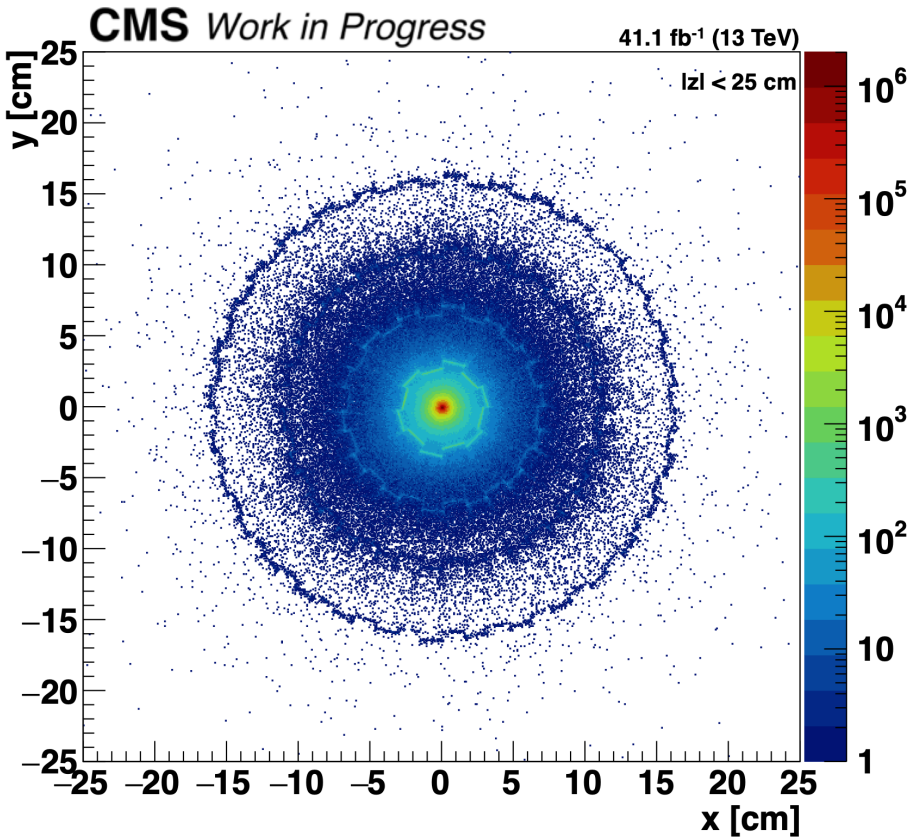
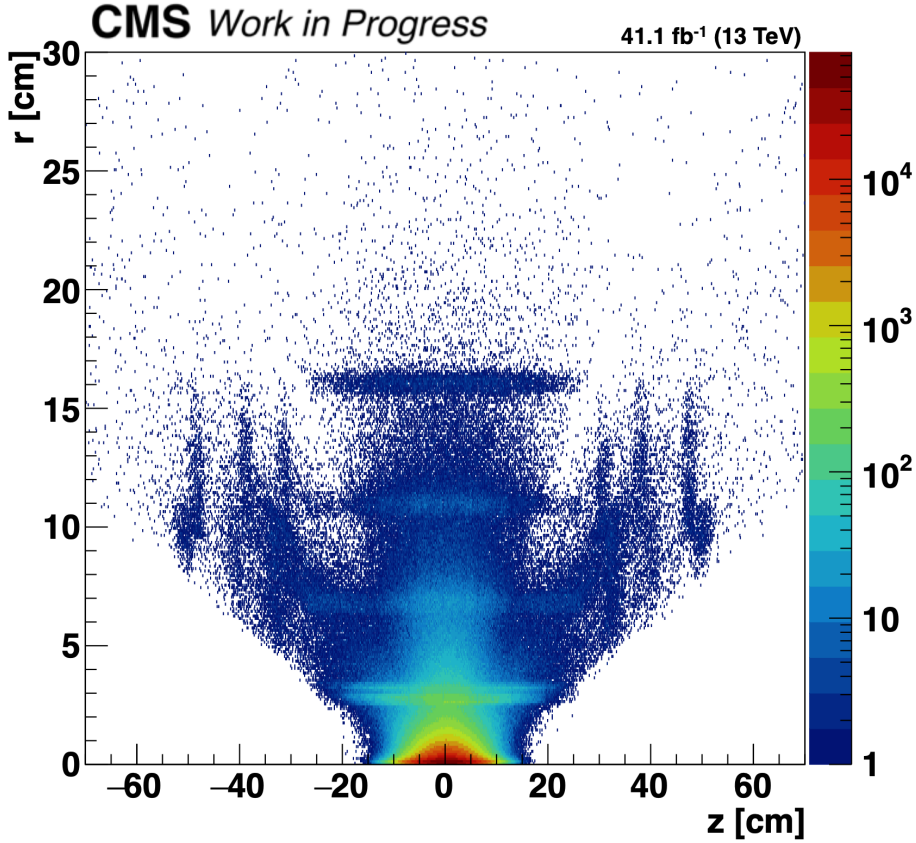
Events of 2017 ZeroBias Run B-F
SV candidates found by IVF





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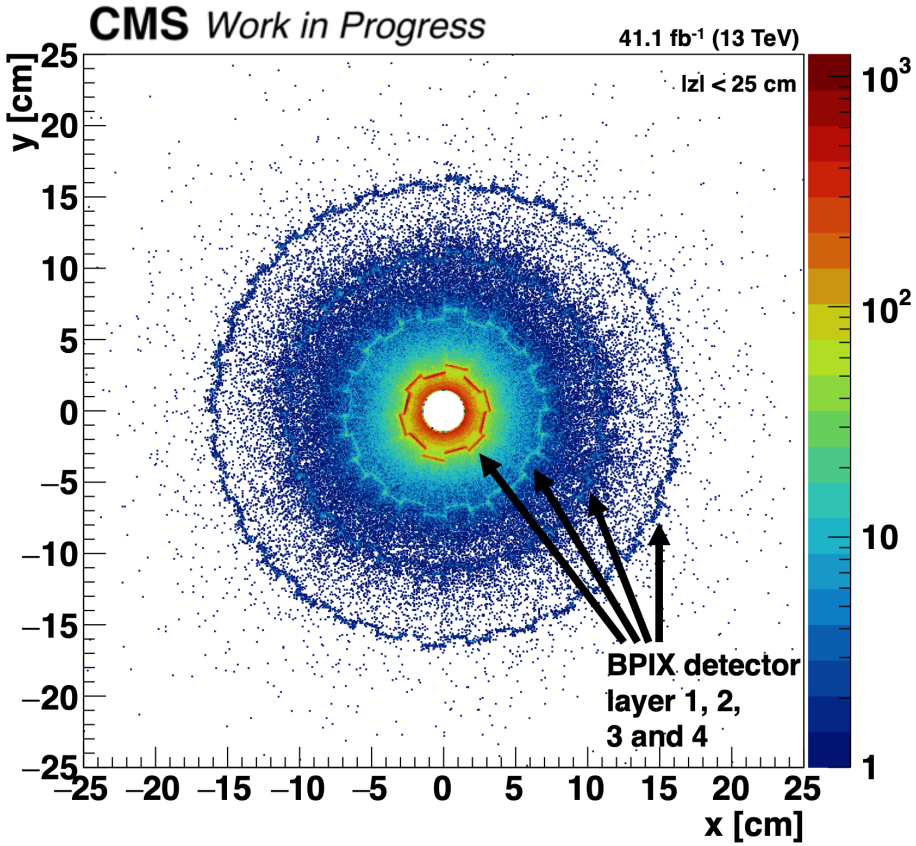
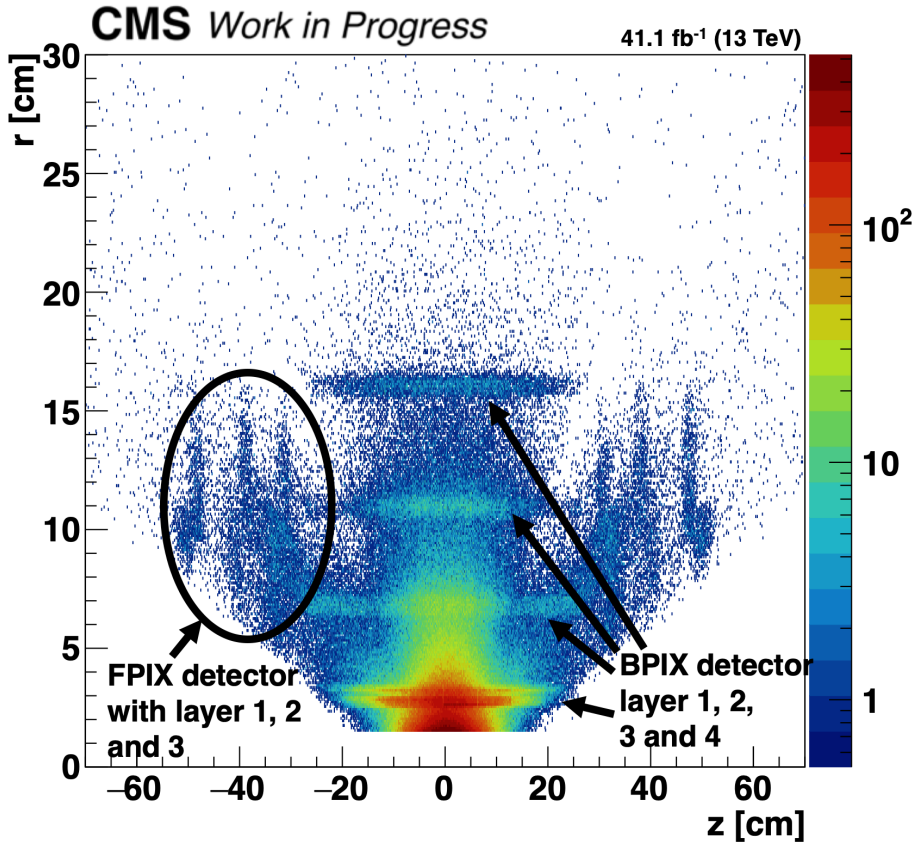
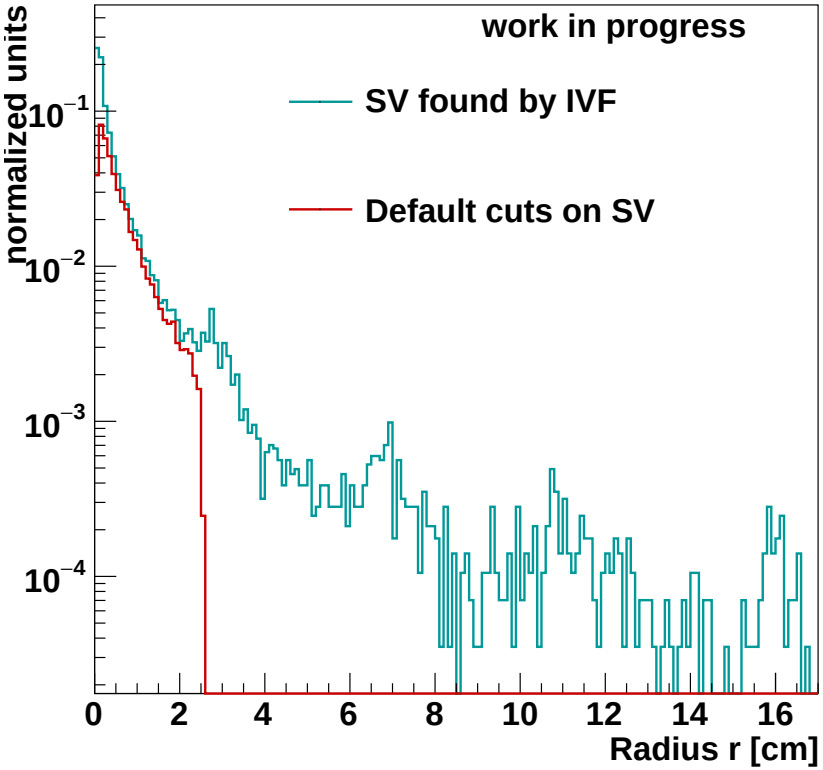
Events of 2017 ZeroBias Run B-F
SV candidates found by IVF (vertices within beam pipe cut away)





Motivation



- SV contain NI
- Hard cuts used
  - e.g. max flight distance limit in 2D = 2.5 cm
- Reduces as well signatures from b-quarks

→ Exchange hard cuts reducing mainly NI

Sample: /TTToHadronic_TuneCP5_13TeV-powheg-pythia8/RunIISpring18DRPremix-100X_upgrade2018_realistic_v10-v1/GEN-SIM-RECODEBUG

NI Identification

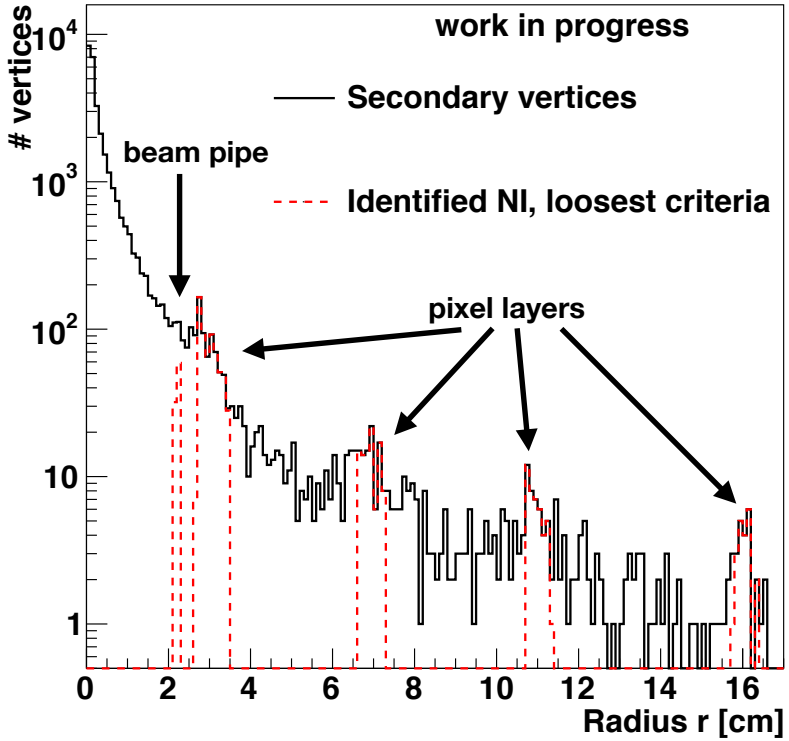
- Use SV found with IVF algorithm
- Use different configuration to identify NI

→ Loosest criteria: position of beam pipe and pixel layers (b pix only)

→ Plus tunable parameters:

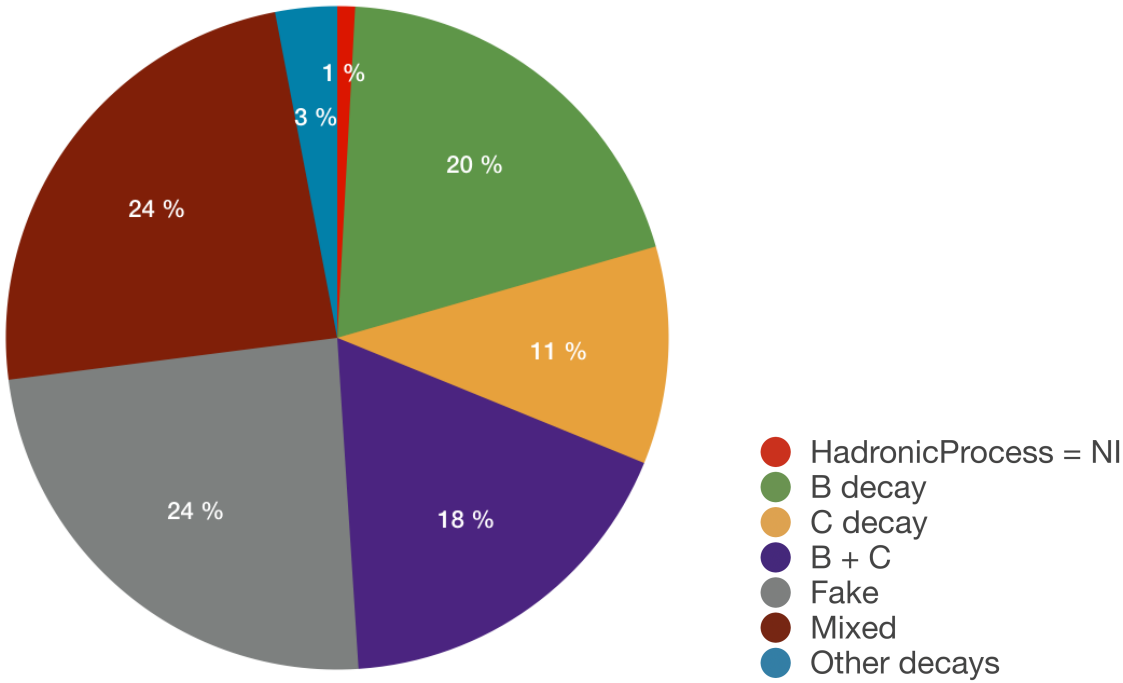
  - Vertex mass
  - Number of particles produced per vertex
  - Distance between NI and next SV
  - Minimum of Nc_τ to check for flight length

$$Nc_\tau = \frac{\text{flightDistance2D} \times \text{mass}}{p_T \times 0.05\text{cm}}$$



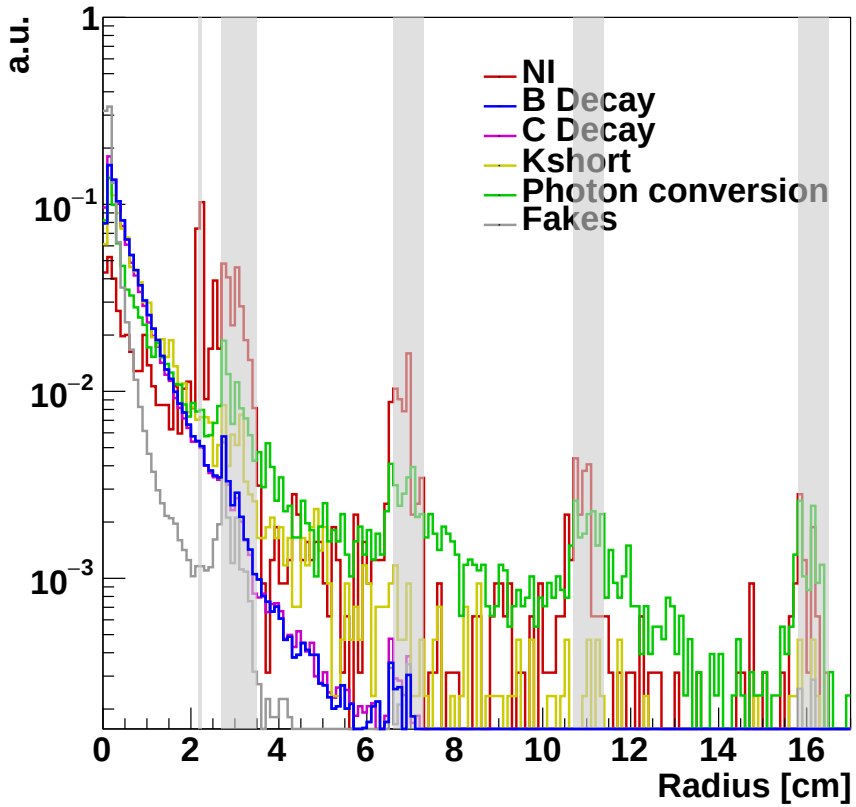
Sample: /TTToHadronic_TuneCP5_13TeV-powheg-pythia8/RunIISpring18DRPremix-100X_upgrade2018_realistic_v10-v1/GEN-SIM-RECODEBUG

Flags of Different Categories



- Fake: Pile-up, nothing detected in that region
- Mixed: Long-lived decay, unknown process, undefined process
- Other decays: Of τ, Λ, J/Ψ, X_i $\Sigma^{\pm}$, Ω, K_s , conversion, compton

Loose SV Criteria, Radius



Gray shaded: Position of beam pipe and Bpix layers

$\rightarrow$ Accumulation of NI's mainly in that regions

Loose SV Criteria, Variables

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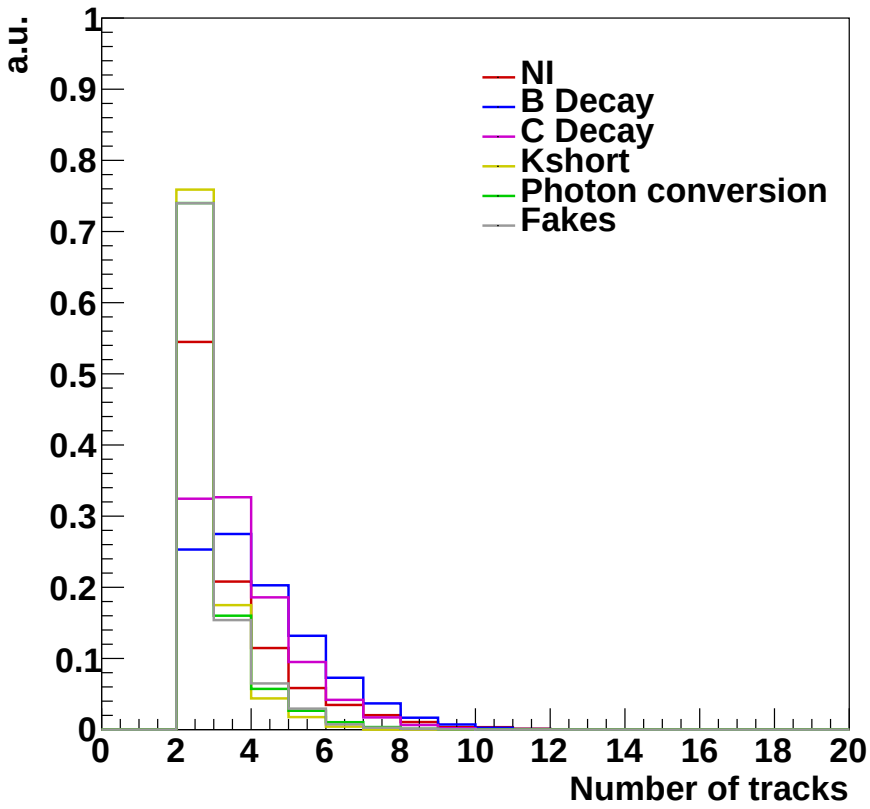
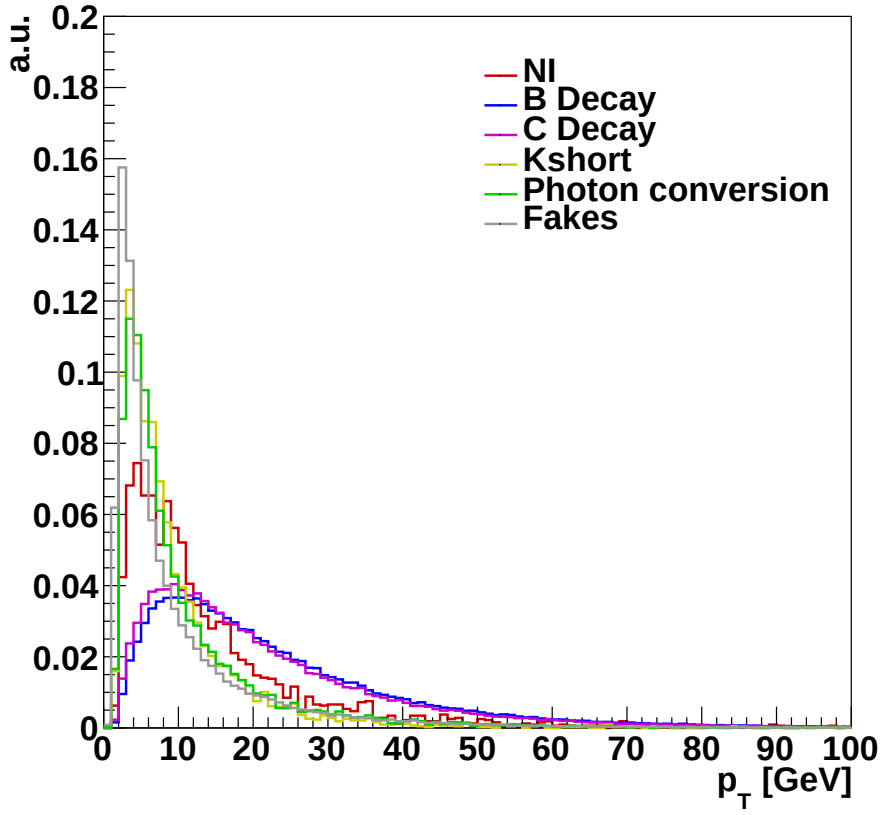
Number of tracks



→ NI's mainly less tracks per vertex

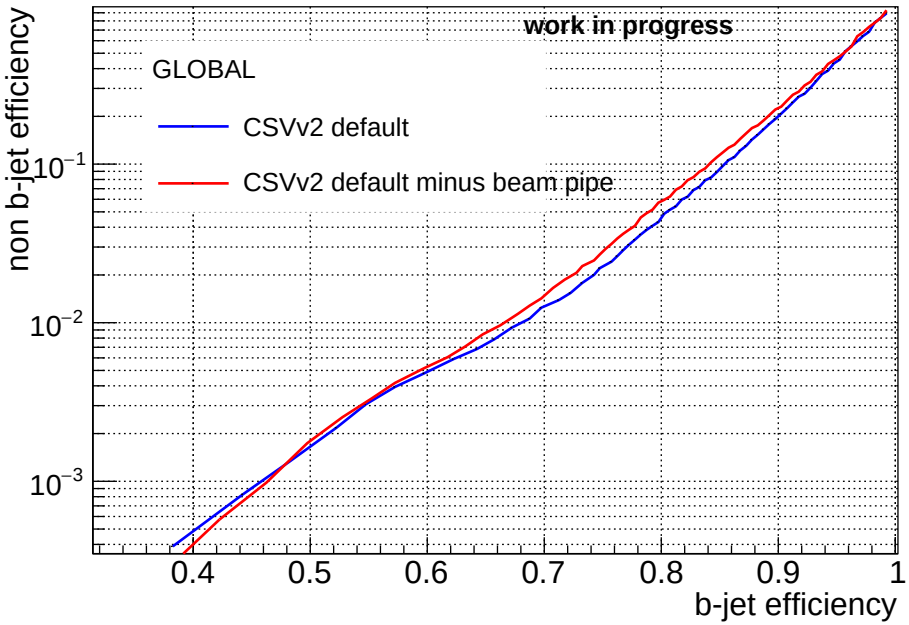
p_T

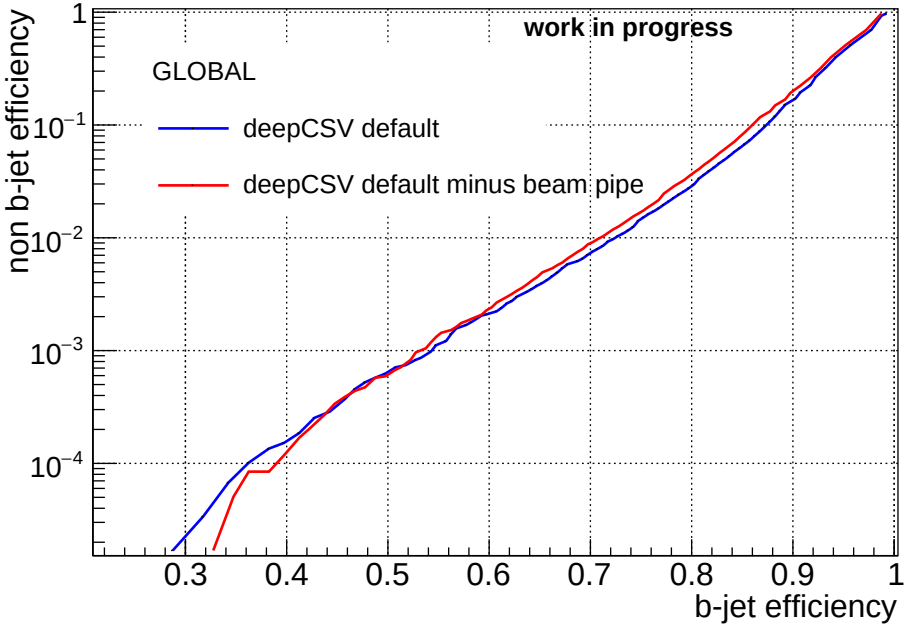


→ NI's mainly lower p_T

Results with Default Cuts

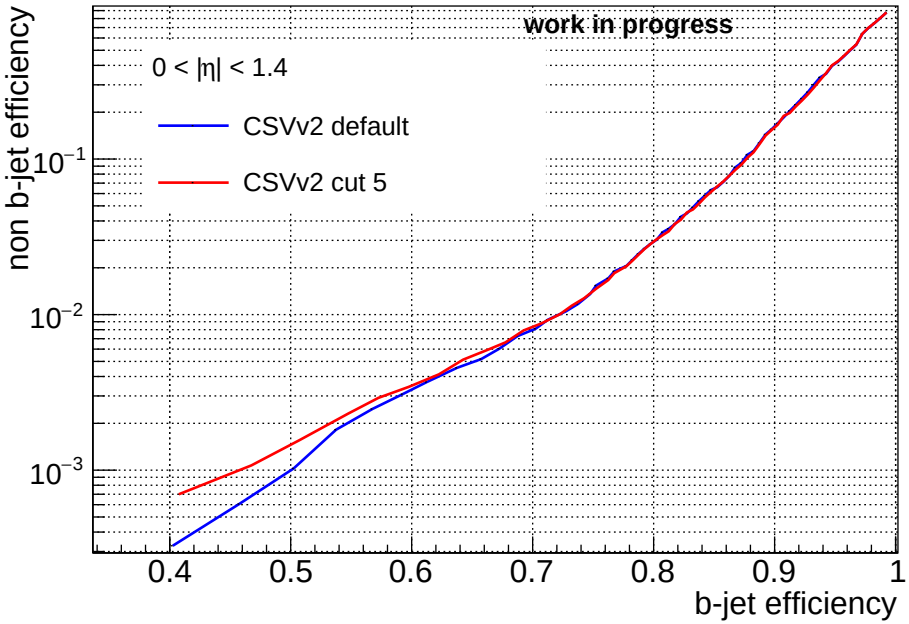
- b vs. udsg
- Default: Radius cut at 2.5 cm
- Default minus beam pipe: Radius cut + all SV inside beam pipe positions cut away

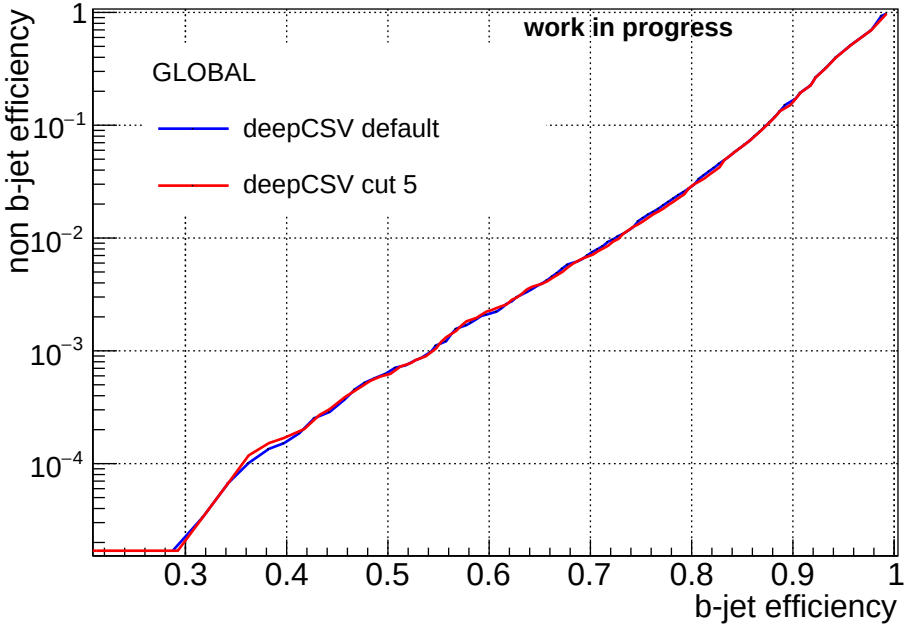




Results with Modified Cuts

- b vs. udsg
- Default: Radius cut at 2.5 cm
- Modified cut: Remove SV's within beam pipe and pixel positions "recover" SV's with: Number tracks > 2, vertex mass $> 1.5\,\text{GeV}$, $\text{Nc}_\tau < 3.5$



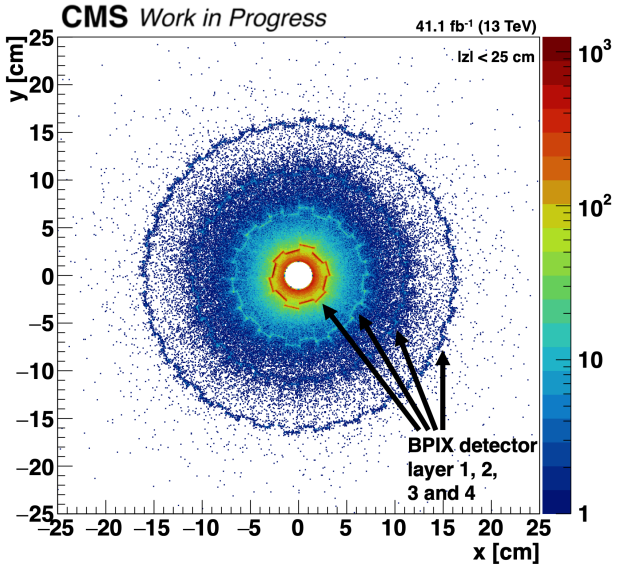


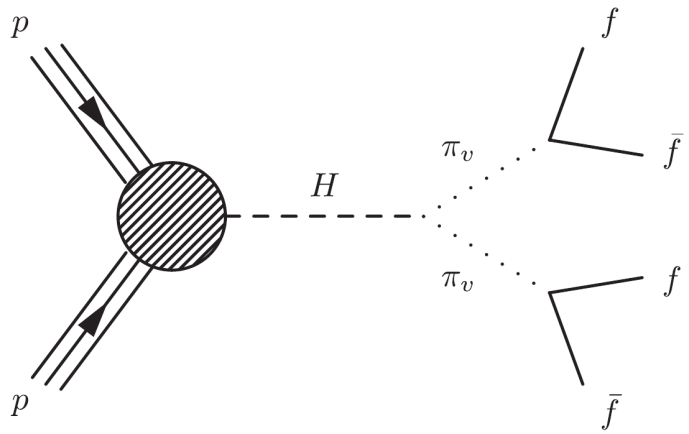
Summary

- Idea: Hard cuts for b-tagging input replace with looser cuts

→ Remove mainly NI and recover b's

- No improvement for b-tagging visible for CSVv2 and deepCSV
- No studies for deepJet, since no cuts applied as for the previous tagger





Outlook - Analysis with long-lived particles

- Is it possible to distinguish NI and displaced vertices from signal?

Backup

Input Variables CSVv2 and deepCSV

Input variable
SV 2D flight distance significance
Number of SV
Track η_{rel}
Corrected SV mass
Number of tracks from SV
SV energy ratio
$\Delta R(\mathrm{SV}, \mathrm{jet})$
3D IP significance of the first four tracks
Track $p_{\mathrm{T,rel}}$
$\Delta R(\mathrm{track}, \mathrm{jet})$
Track $p_{\mathrm{T,rel}}$ ratio
Track distance
Track decay length
Summed tracks E_{T} ratio
$\Delta R(\mathrm{summed\ tracks}, \mathrm{jet})$
First track 2D IP significance above c threshold
Number of selected tracks
Jet p_{T}
Jet η

Input Variables deepJet

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Global input features

feature
$p_T(j)$
$\eta(j)$
N_{cPF}
N_{nPF}
N_{SV}
N_{PV}
trackSumJetEtRatio
trackSumJetDeltaR
vertexCategory
trackSip2dValAboveCharm
trackSip2dSigAboveCharm
trackSip3dValAboveCharm
trackSip3dSigAboveCharm
jetNSelectedTracks
jetNTracksEtaRel

Charged PF candidates input features

feature
trackEtaRel
trackPtRel
trackPPar
trackDeltaR
trackPParRatio
trackSip2dVal
trackSip2dSig
trackSip3dVal
trackSip3dSig
trackJetDistVal
trackJetDistSig
$p_T(cPF)/p_T(j)$
$\Delta R_m(cPF, SV)$
fromPV
VTXass
$w_p(cPF)$
χ^2
quality

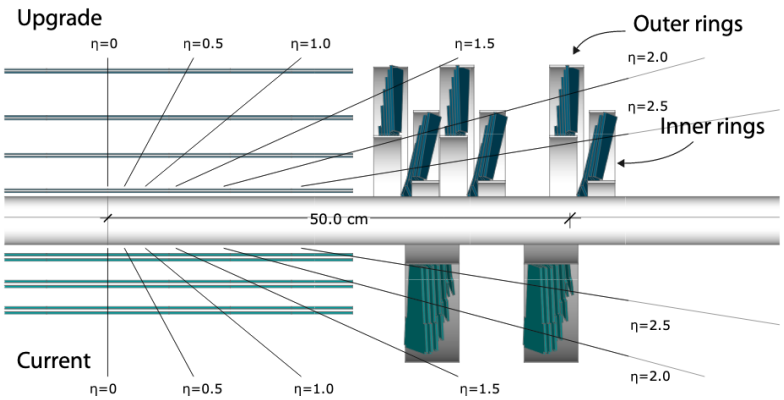
Neutral PF candidates input features

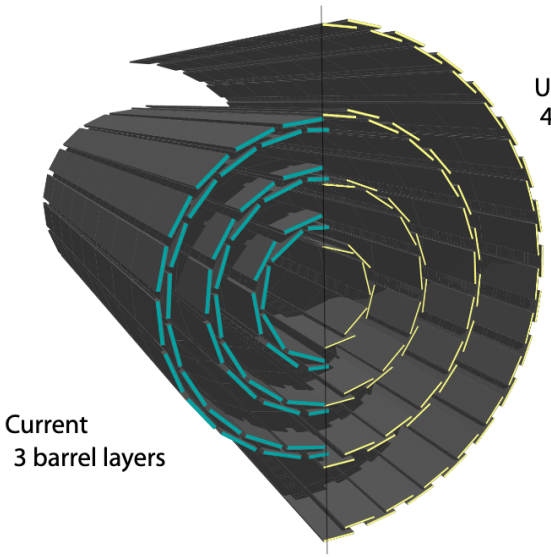
feature
$p_T(nPF)/p_T(j)$
$\Delta R_m(nPF, SV)$
isGamma
hadFrac
$\Delta R(nPF)$
$w_p(cPF)$

SV input features

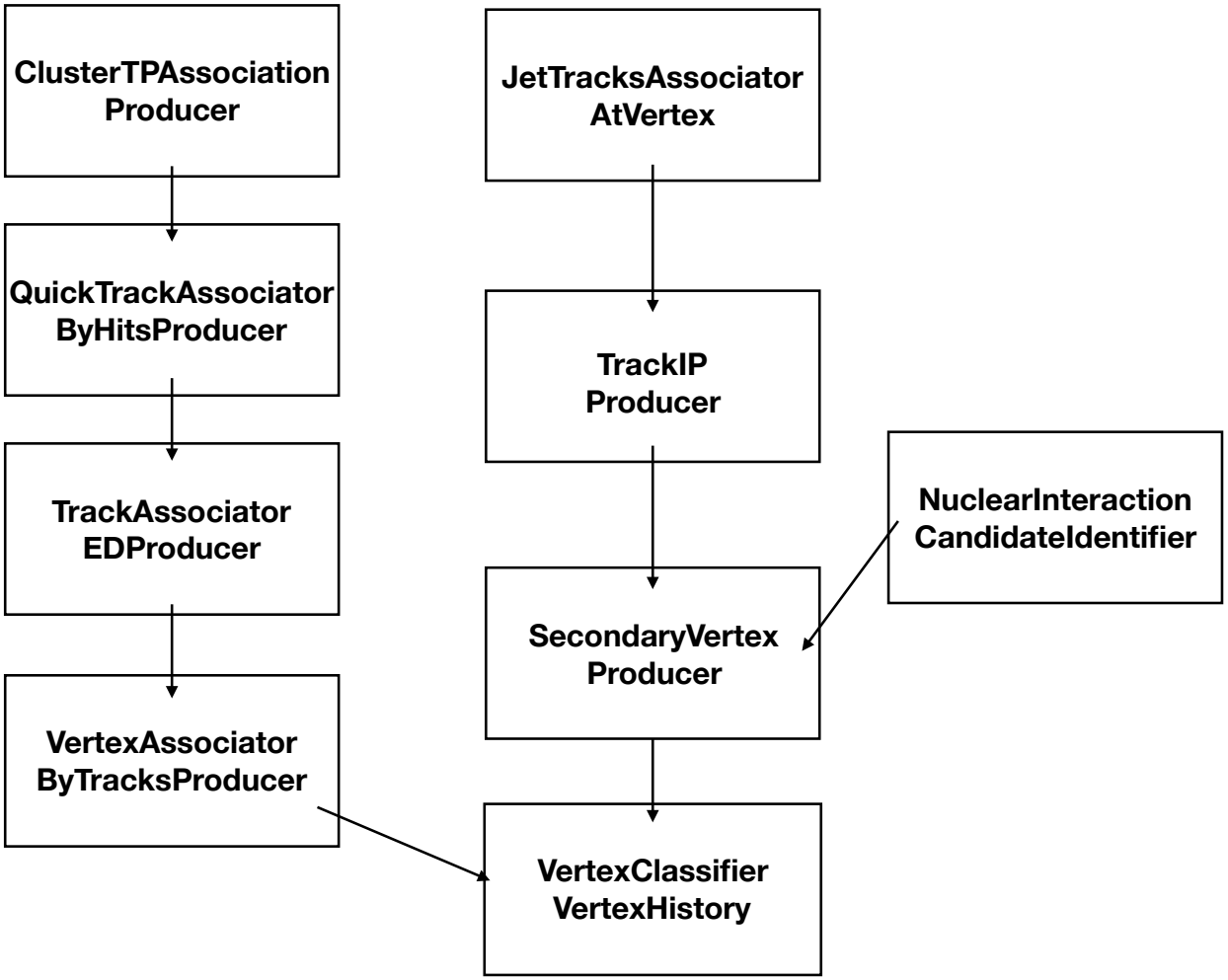
feature
$p_T(SV)$
$\Delta R(SV)$
$m_{SV})$
$N_{\text{tracks}}(SV)$
$\chi^2(SV)$
$\chi^2_n(SV)$
$d_{xy}(SV)$
$S_{xy}(SV)$
$d_{3D}(SV)$
$S_{3D}(SV)$
$\cos\theta(SV)$
$E_{rel}(SV)$

Pixel Detector - CMS-TDR-011





Classes truth matching



- vertexClassifier uses generator and simulation information for flagging

→ Flags e.g. decays from b, c, K_s, NI and so on

SecondaryVertexProducer

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Default parameters:

- useSVClustering = false: No clustering of SVs and no assignment to different subjets

→ if true: jetAlgorithm and rParam needs to be set

- useExternalSV = false: Only information from IPTagInfos are used

→ if true: additionally e.g. "inclusiveCandidateSecondaryVertices" can be used

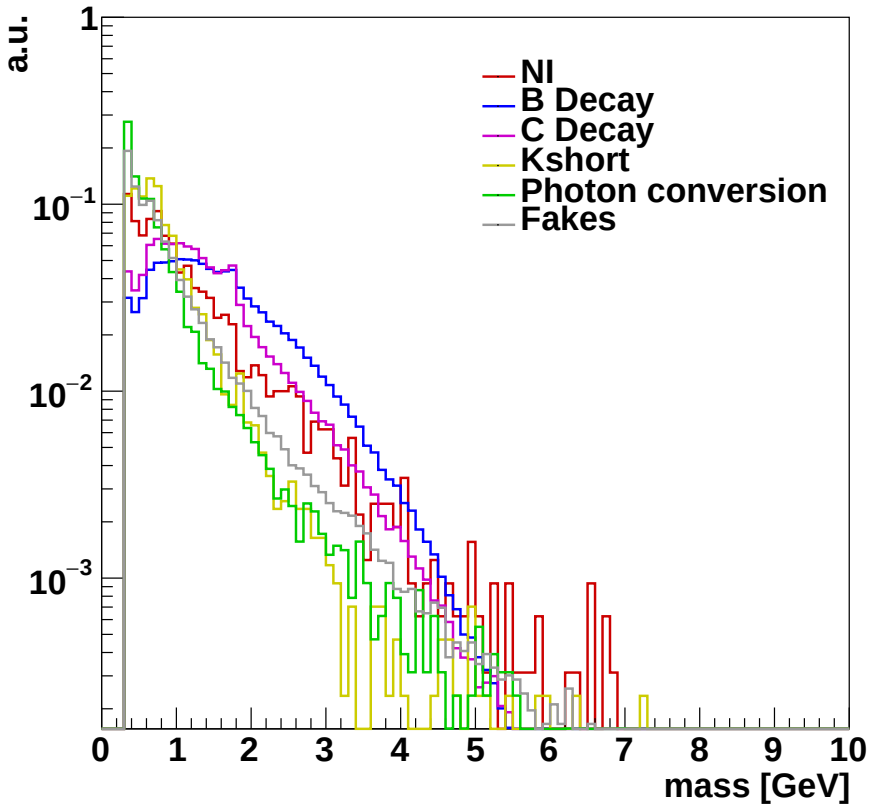
- fracPV = 0.45: value of shared tracks between PV and SV
- distVal2dMin = 0.01
- distVal2dMax = 2.5
- distSig2dMin = 3.0
- distSig2dMax = 99999.9

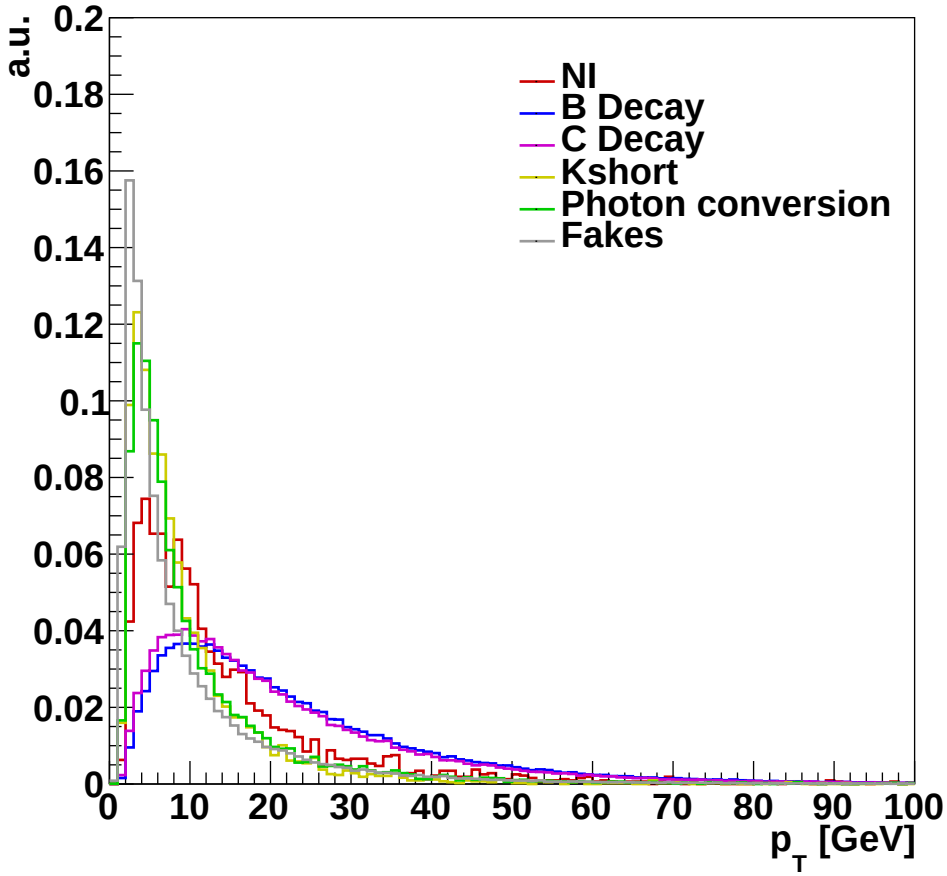
→ flight distance limits

Categories

- Generator information:
  - Depending on particle ID, can be:
    b, c, τ, J/ψ, K_s, X_i, Λ, Ω, $\Sigma^{\pm}$
- G4 information:
  - decay, primary, hadronic, conversion, compton, annihilation, bremsstrahlung
- Clustering:
  - primary, secondary or tertiary vertex

Loose SV Criteria, Mass





$\rightarrow$ NI's mainly low mass