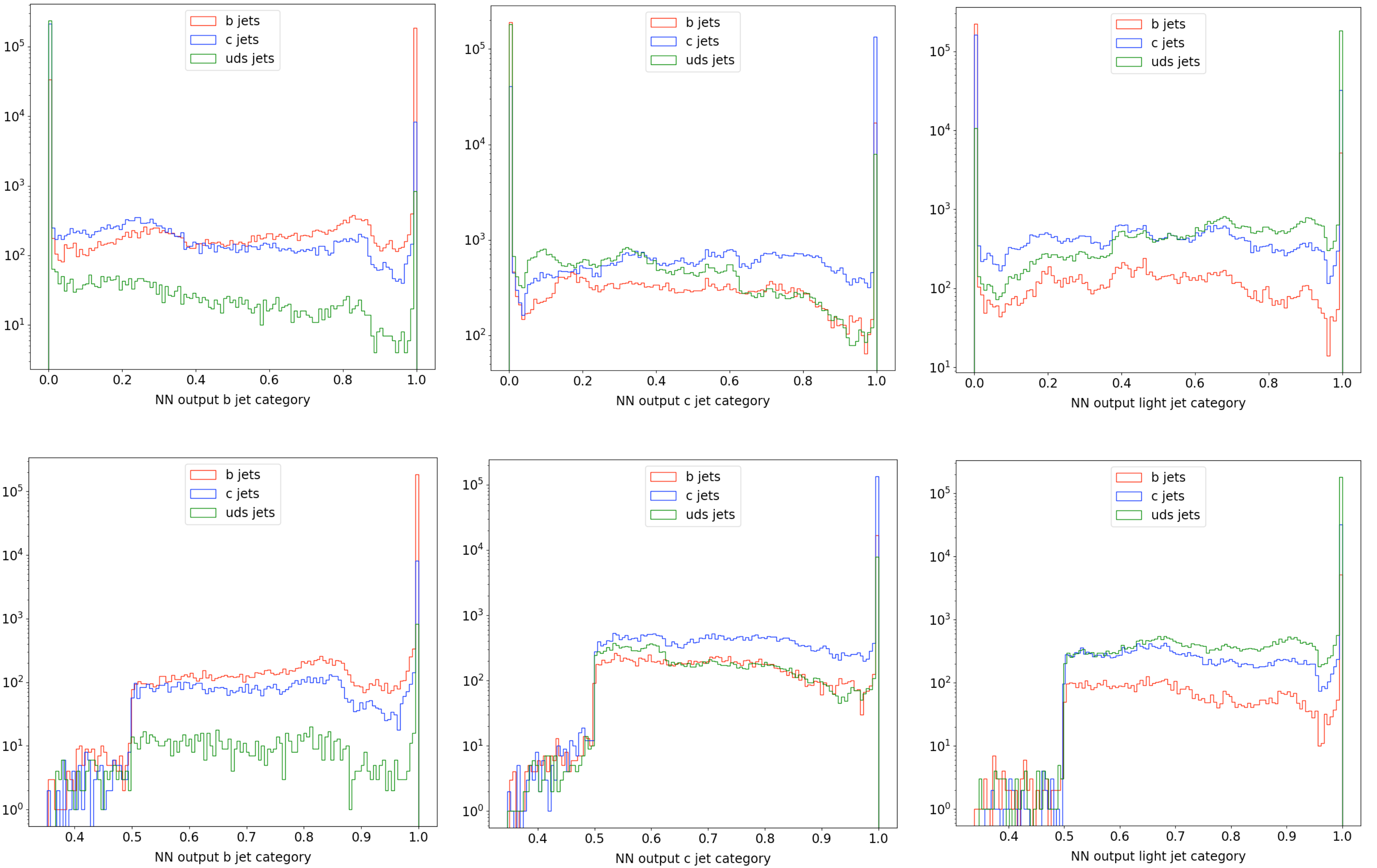
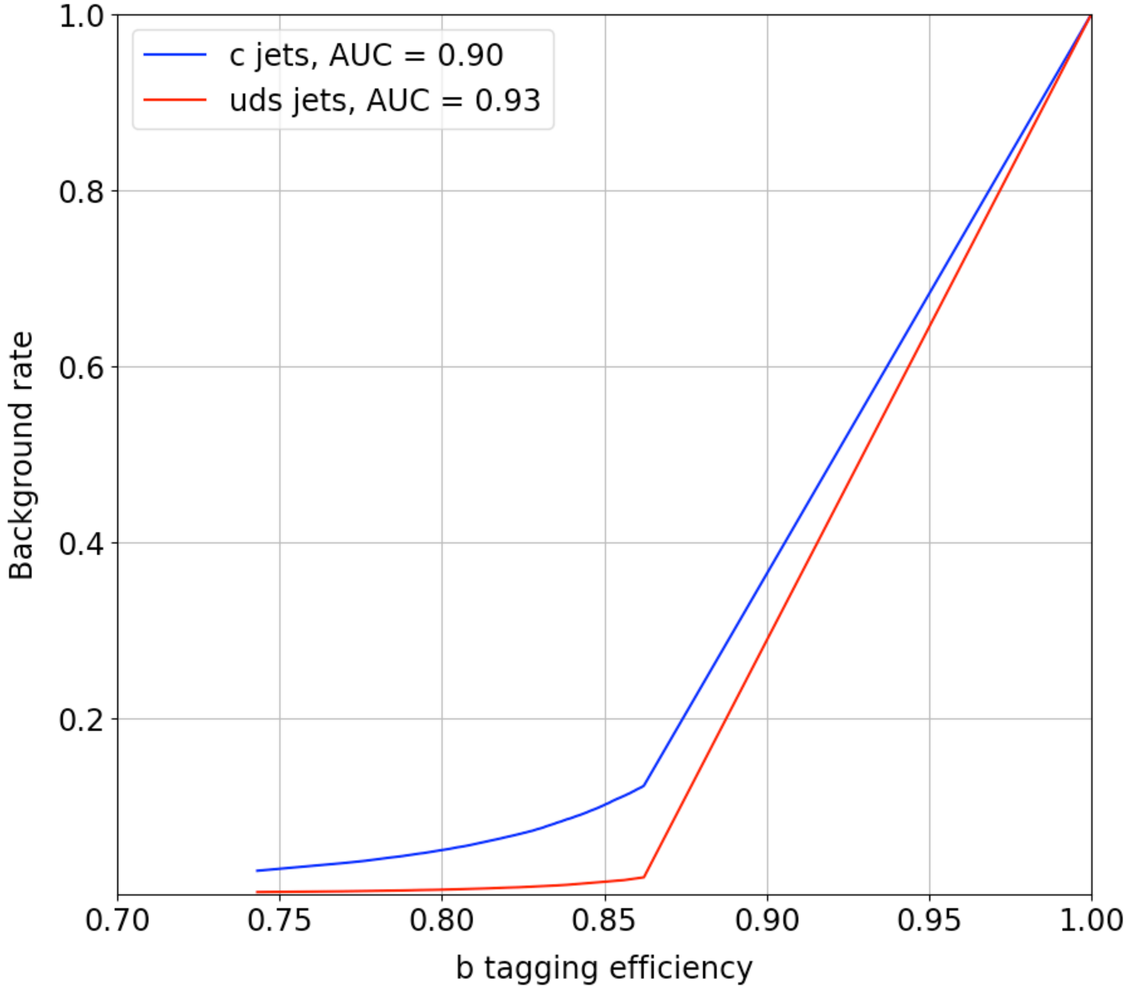
NN output

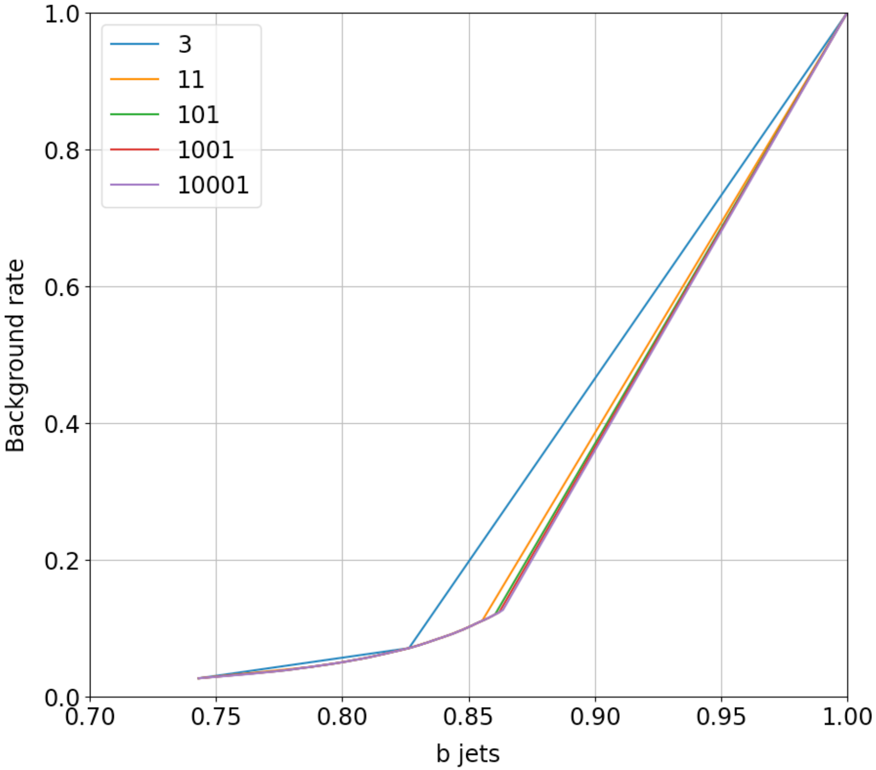

b jets
c jets
uds jets
NN output b jet category
NN output c jet category
NN output light jet category

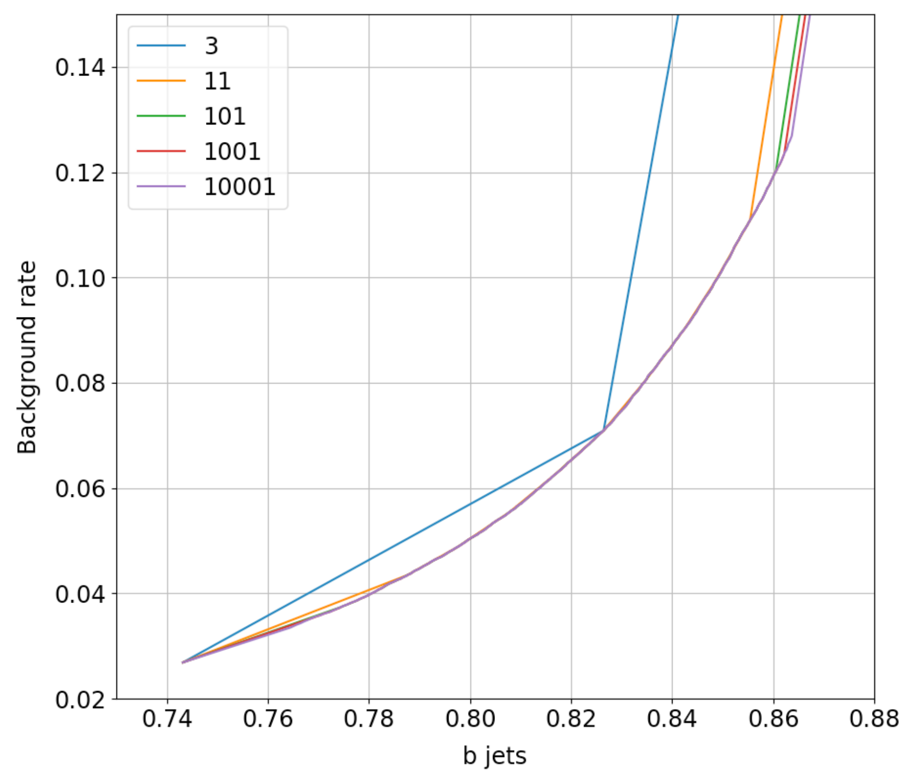
ROC curves



- ~74.3% of all b jets have NN output (b jet category) ==1

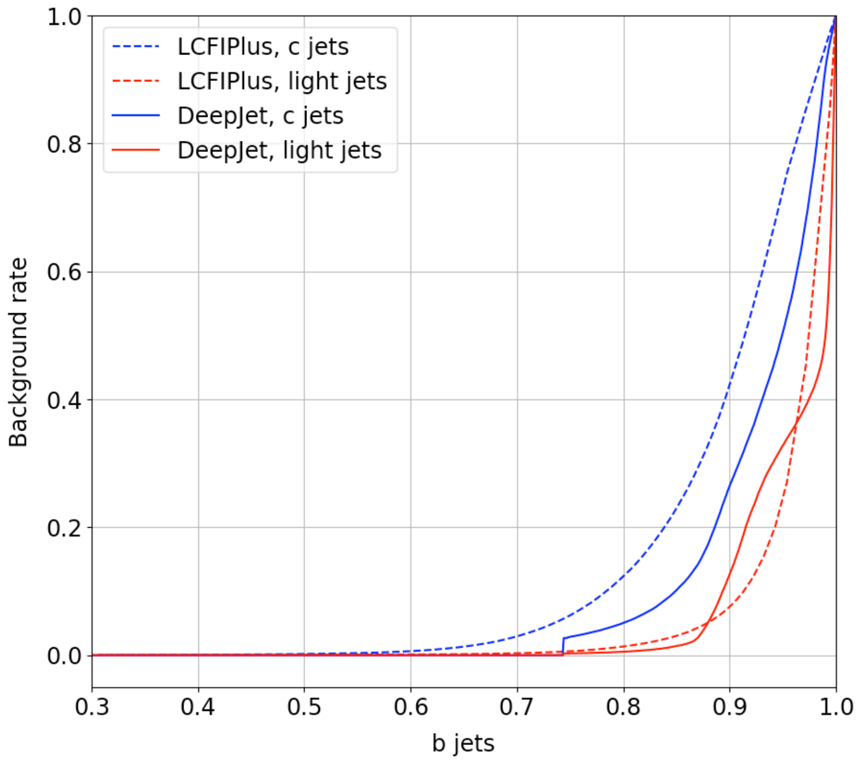
ROC curves



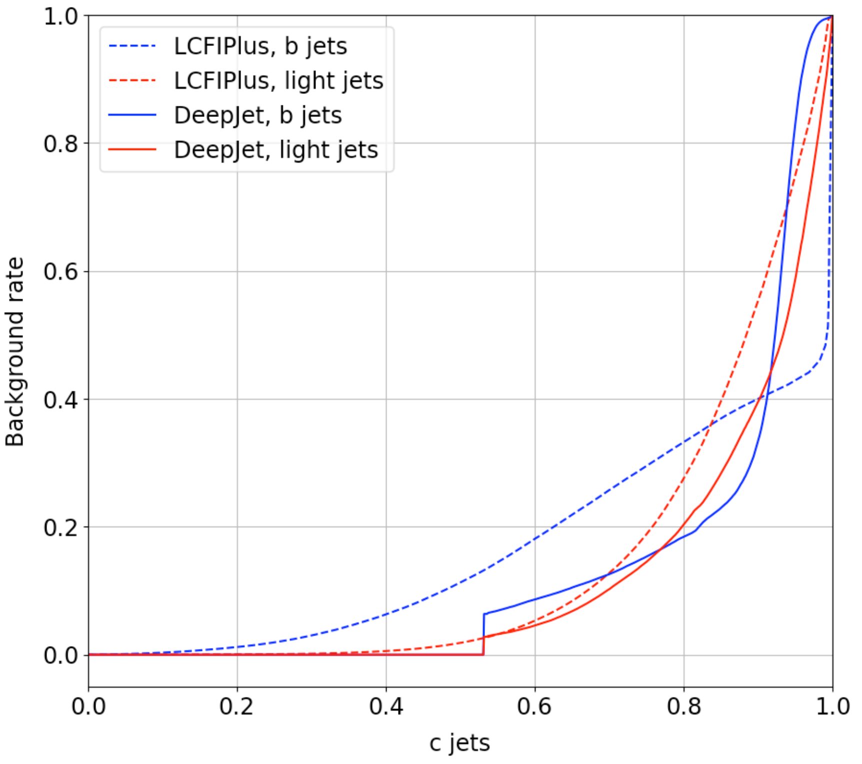


- ~91.5% of all b jets have NN output (b jet category) >= 10^(-9)
- ~89.3% of all b jets have NN output (b jet category) >= 10^(-7)
- ~86.6% of all b jets have NN output (b jet category) >= 10^(-5)
- ~86.2% of all b jets have NN output (b jet category) >= 10^(-3)

ROC curves



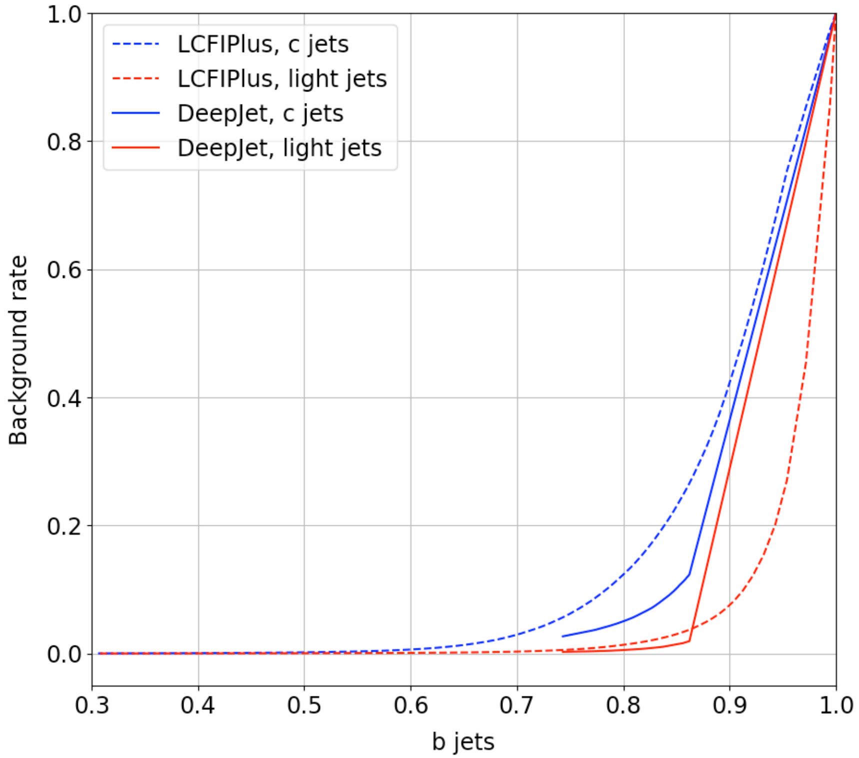
LCFIPlus, c jets
LCFIPlus, light jets
DeepJet, c jets
DeepJet, light jets
Background rate
b jets
1.0
0.8
0.6
0.4
0.2
0.0
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

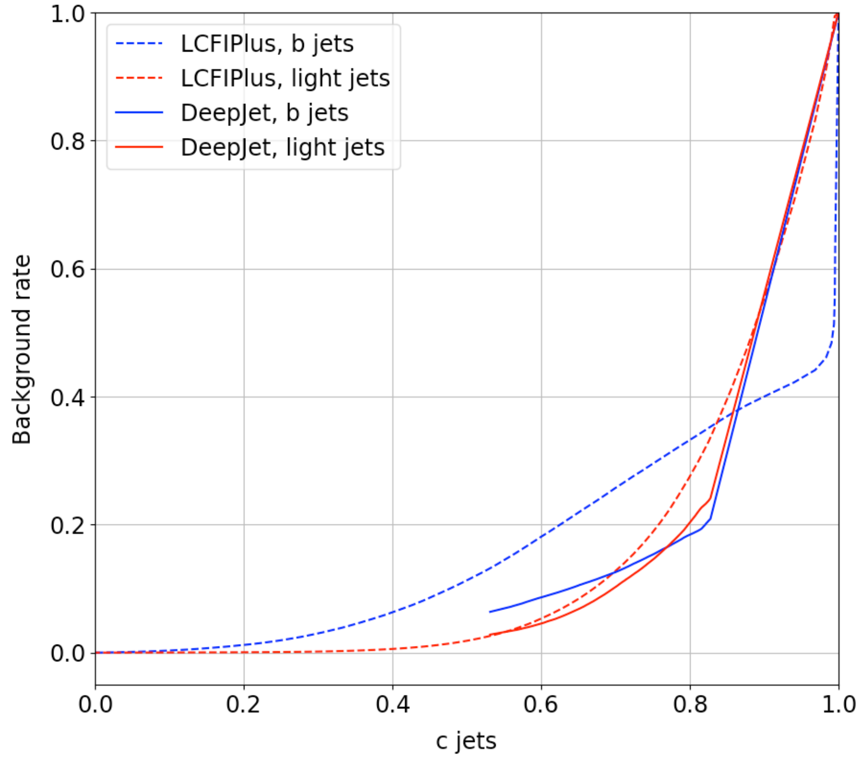


LCFIPlus, b jets
LCFIPlus, light jets
DeepJet, b jets
DeepJet, light jets
Background rate
c jets
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0

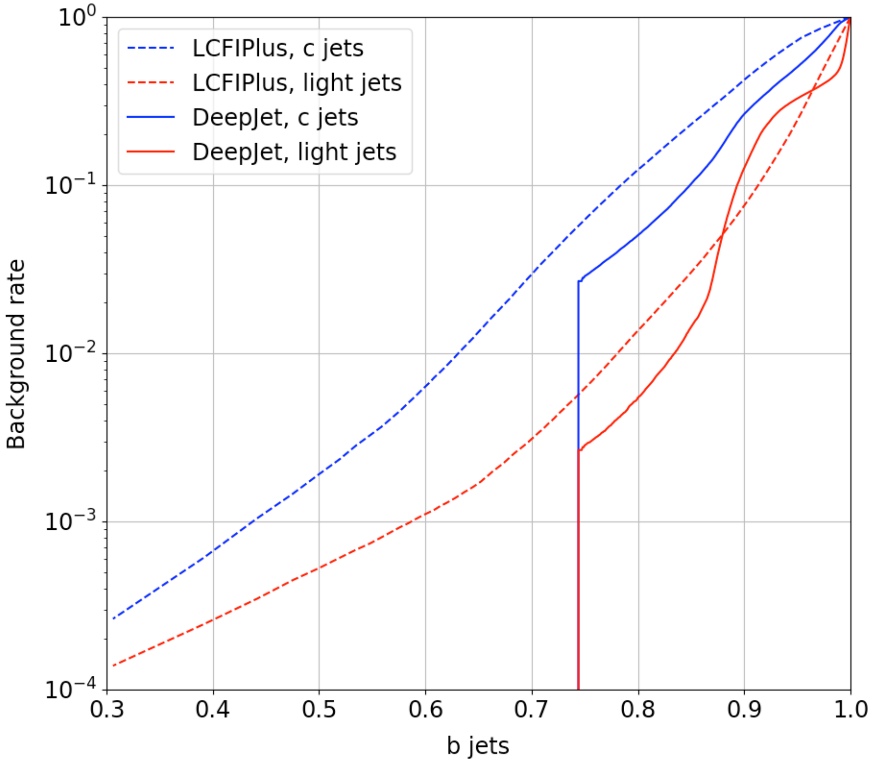
ROC curves

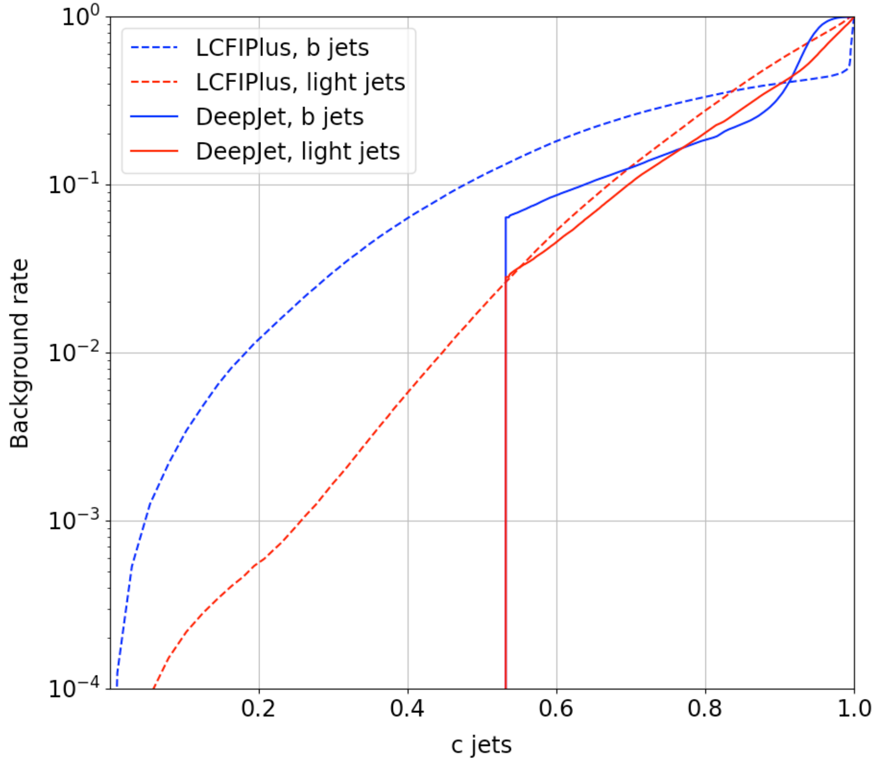
validation data





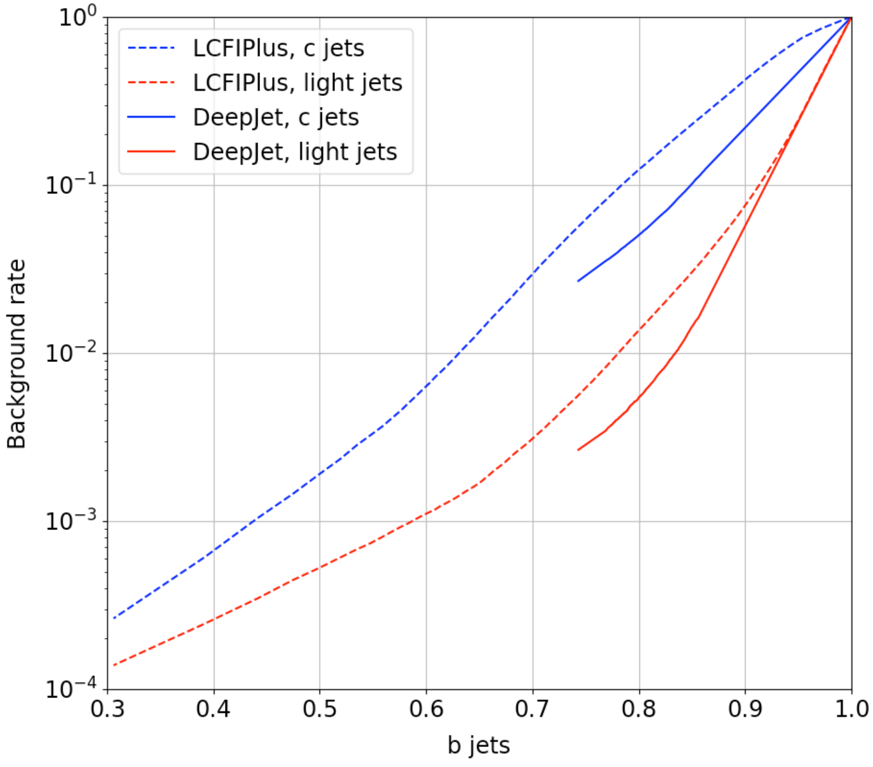
ROC curves

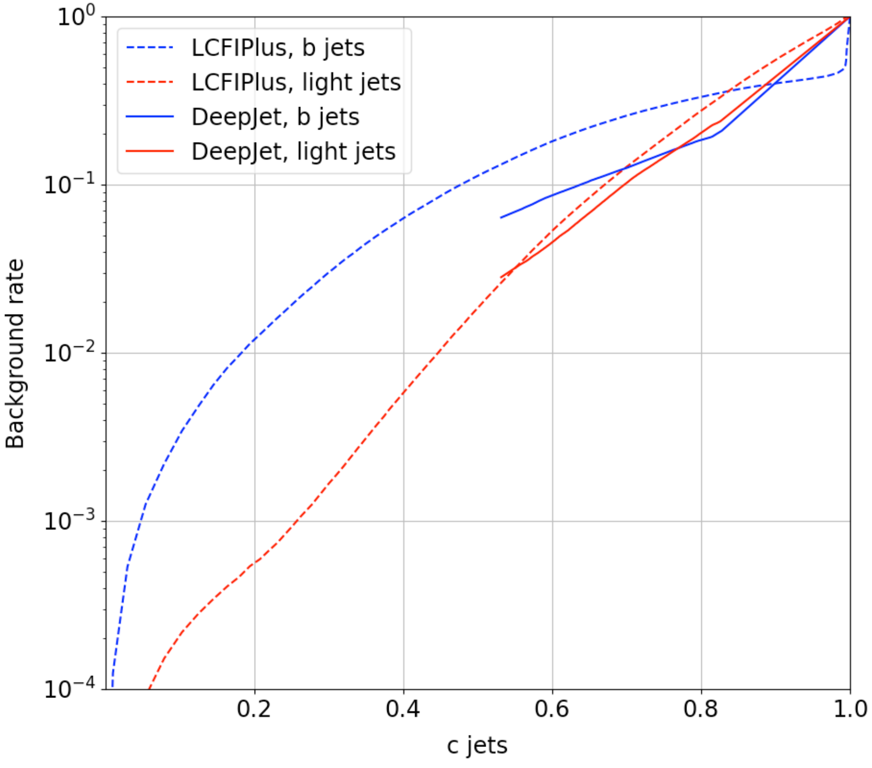

LCFIPlus, c jets
LCFIPlus, light jets
DeepJet, c jets
DeepJet, light jets
Background rate
b jets
10^0
10^−1
10^−2
10^−3
10^−4
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


LCFIPlus, b jets
LCFIPlus, light jets
DeepJet, b jets
DeepJet, light jets
Background rate
c jets
10^0
10^−1
10^−2
10^−3
10^−4
0.2
0.4
0.6
0.8
1.0

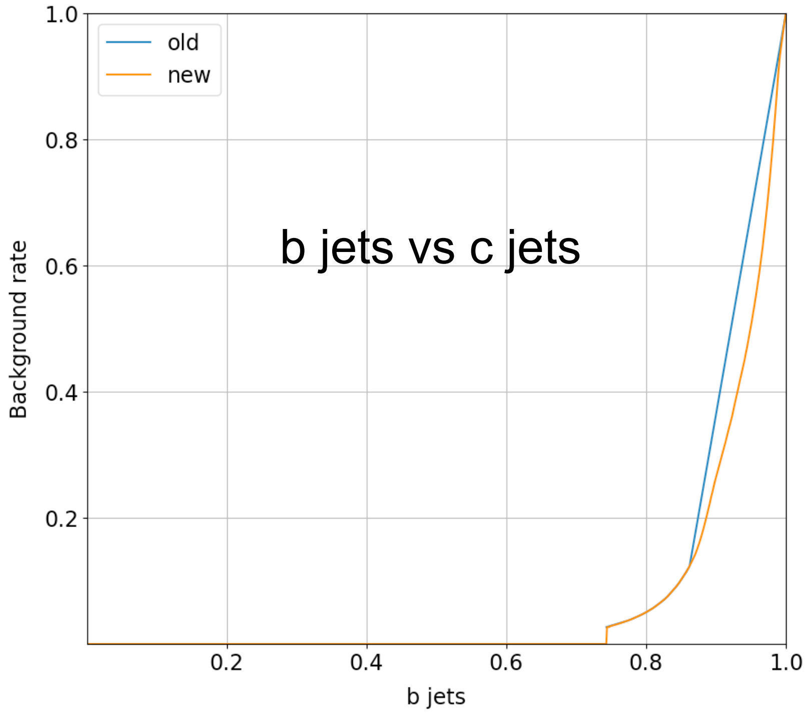
ROC curves

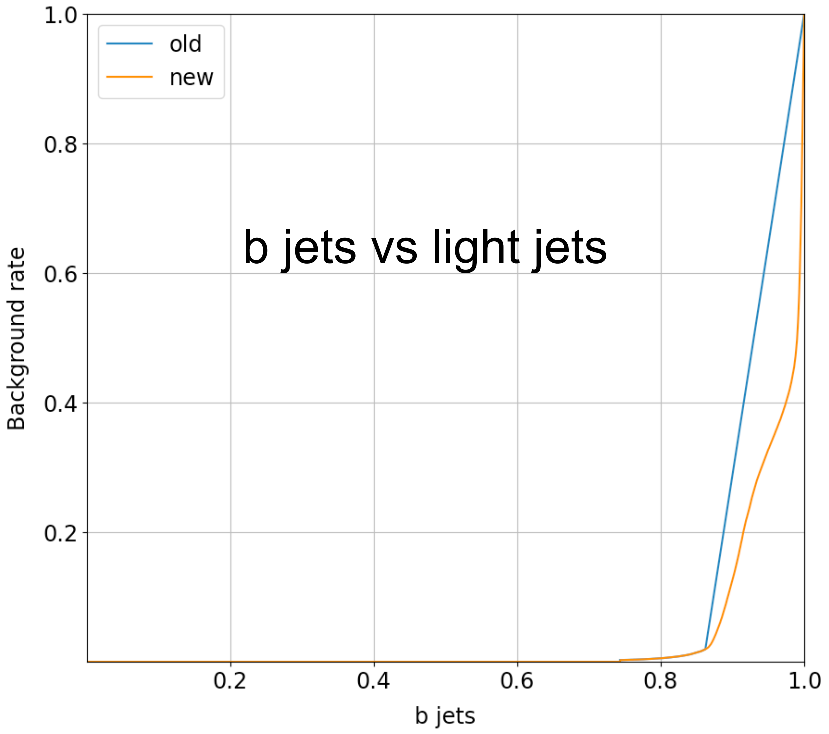
validation data



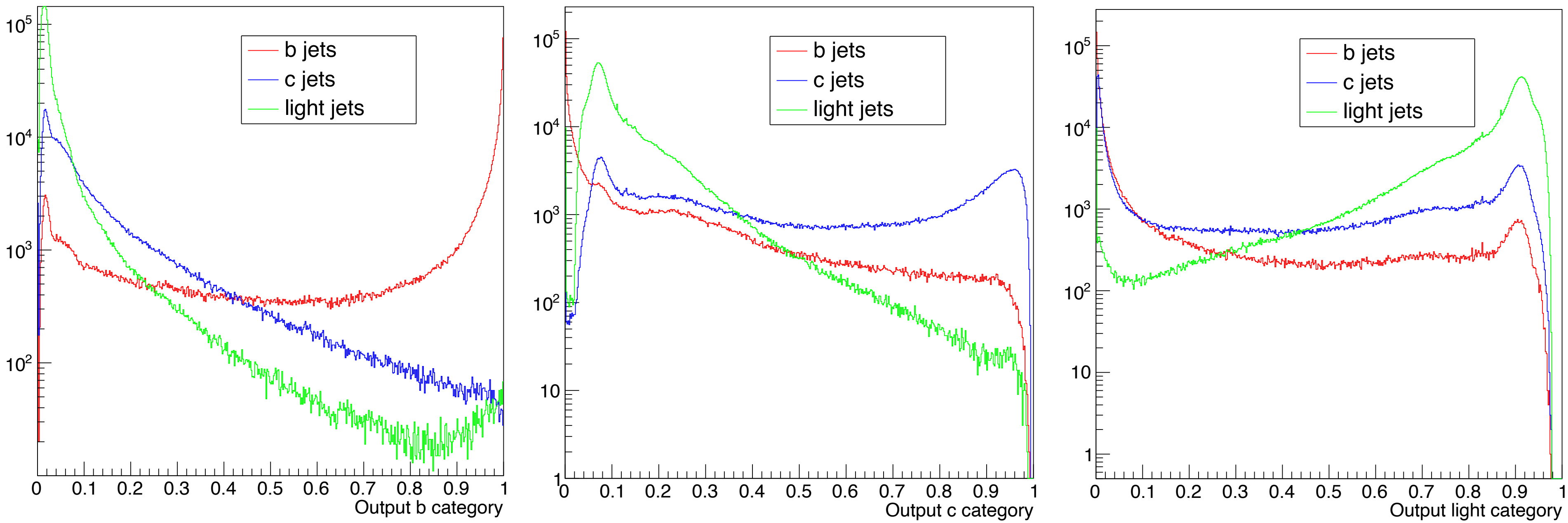


ROC curves


1.0
0.8
0.6
0.4
0.2
old
new
b jets vs c jets
Background rate
0.2
0.4
0.6
0.8
1.0
b jets


1.0
0.8
0.6
0.4
0.2
old
new
b jets vs light jets
Background rate
0.2
0.4
0.6
0.8
1.0
b jets

BDT output LCFIPlus



Backup

LCFIPlus variables

Name	Description	Normalization factor	Used by category
trk1d0sig	d0 significance of track with highest d0 significance	1	A, B, C, D
trk2d0sig	d0 significance of track with second highest d0 significance	1	A, B, C, D
trk1z0sig	z0 significance of track with highest d0 significance	1	A, B, C, D
trk2z0sig	z0 significance of track with second highest d0 significance	1	A, B, C, D
trk1pt	transverse momentum of track with highest d0 significance	$1/E_{\text{jet}}$	A, B, C, D
trk2pt	transverse momentum of track with second highest d0 significance	$1/E_{\text{jet}}$	A, B, C, D
jprobr	joint probability in the r-phi plane using all tracks	1	A, B, C, D
jprobr5sigma	joint probability in the r-phi plane using all tracks having impact parameter significance exceeding 5 sigma	1	A, B, C, D
jprobz	joint probability in the z projection using all tracks	1	A, B, C, D
jprobz5sigma	joint probability in the z projection using all tracks having impact parameter significance exceeding 5 sigma	1	A, B, C, D
d0bprob	product of b-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions	1	A, B, C, D
d0cprob	product of c-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions	1	A, B, C, D
d0qprob	product of q-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions	1	A, B, C, D
z0bprob	product of b-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions	1	A, B, C, D
z0cprob	product of c-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions	1	A, B, C, D
z0qprob	product of q-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions	1	A, B, C, D
nmuon	number of identified muons	1	A, B, C, D
nelectron	number of identified electrons	1	A, B, C, D
trkmass	mass of all tracks exceeding 5 sigma significance in d0/z0 values	1	A, B, C, D

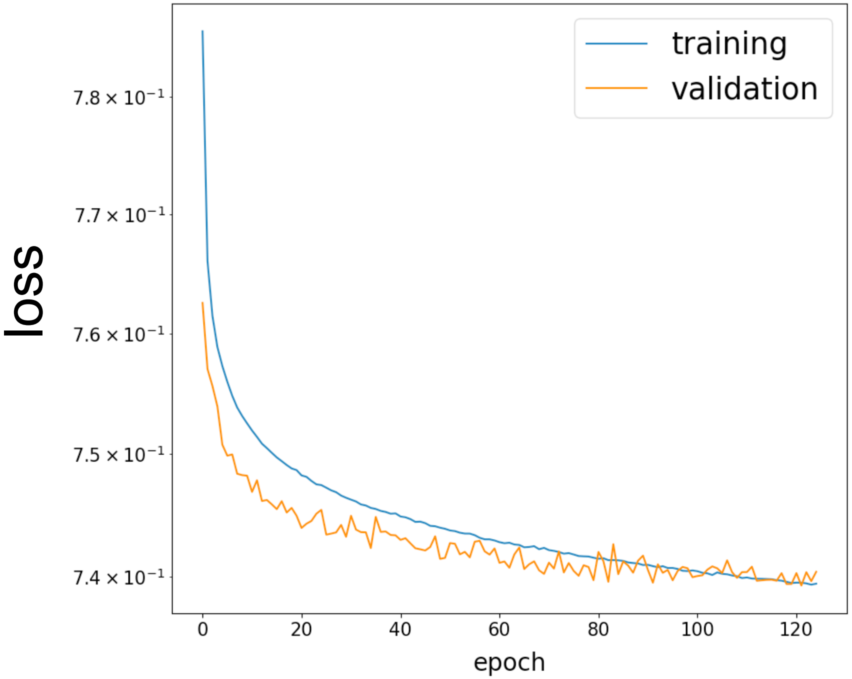
used as global variables

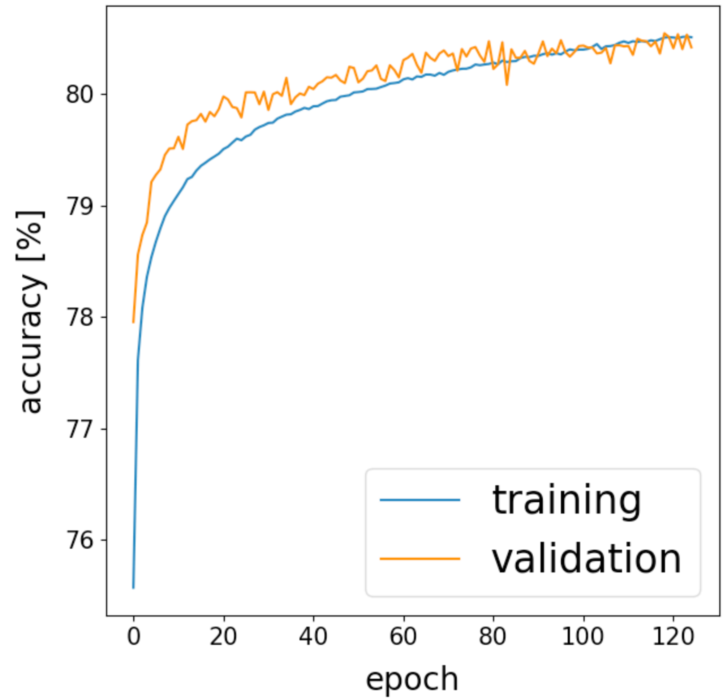
LCFIPlus variables

Name	Description	Normalization factor	Used by category
1vtxprob	vertex probability with all tracks associated in vertices combined	1	B, C, D
vtxlen1	decay length of the first vertex in the jet (zero if no vertex is found)	$1/E_{\text{jet}}$	B, C, D
vtxlen2	decay length of the second vertex in the jet (zero if number of vertex is less than two)	$1/E_{\text{jet}}$	D
vtxlen12	distance between the first and second vertex (zero if number of vertex is less than two)	$1/E_{\text{jet}}$	D
vtxsig1	decay length significance of the first vertex in the jet (zero if no vertex is found)	$1/E_{\text{jet}}$	B, C, D
vtxsig2	decay length significance of the second vertex in the jet (zero if number of vertex is less than two)	$1/E_{\text{jet}}$	D
vtxsig12	vtxlen12 divided by its error as computed from the sum of the covariance matrix of the first and second vertices, projected along the line connecting the two vertices	$1/E_{\text{jet}}$	D
vtxdirang1	the angle between the momentum (computed as a vector sum of track momenta) and the displacement of the first vertex	E_{jet}	B, C, D
vtxdirang2	the angle between the momentum (computed as a vector sum of track momenta) and the displacement of the second vertex	E_{jet}	D
vtxmult1	number of tracks included in the first vertex (zero if no vertex is found)	1	B, C, D
vtxmult2	number of tracks included in the second vertex (zero if number of vertex is less than two)	1	D
vtxmult	number of tracks which are used to form secondary vertices (summed for all vertices)	1	D
vtxmom1	magnitude of the vector sum of the momenta of all tracks combined into the first vertex	$1/E_{\text{jet}}$	B, C, D
vtxmom2	magnitude of the vector sum of the momenta of all tracks combined into the second vertex	$1/E_{\text{jet}}$	D
vtxmass1	mass of the first vertex computed from the sum of track four-momenta	1	B, C, D
vtxmass2	mass of the second vertex computed from the sum of track four-momenta	1	D
vtxmass	vertex mass as computed from the sum of four momenta of all tracks forming secondary vertices	1	B, C, D
vtxmasspc	mass of the vertex with minimum pt correction allowed by the error matrices of the primary and secondary vertices	1	B, C, D
vtxprob	vertex probability; for multiple vertices, the probability P is computed as 1-P = (1-P1)(1-P2)...(1-PN)	1	B, C, D

used as global variables

Results: loss & accuracy

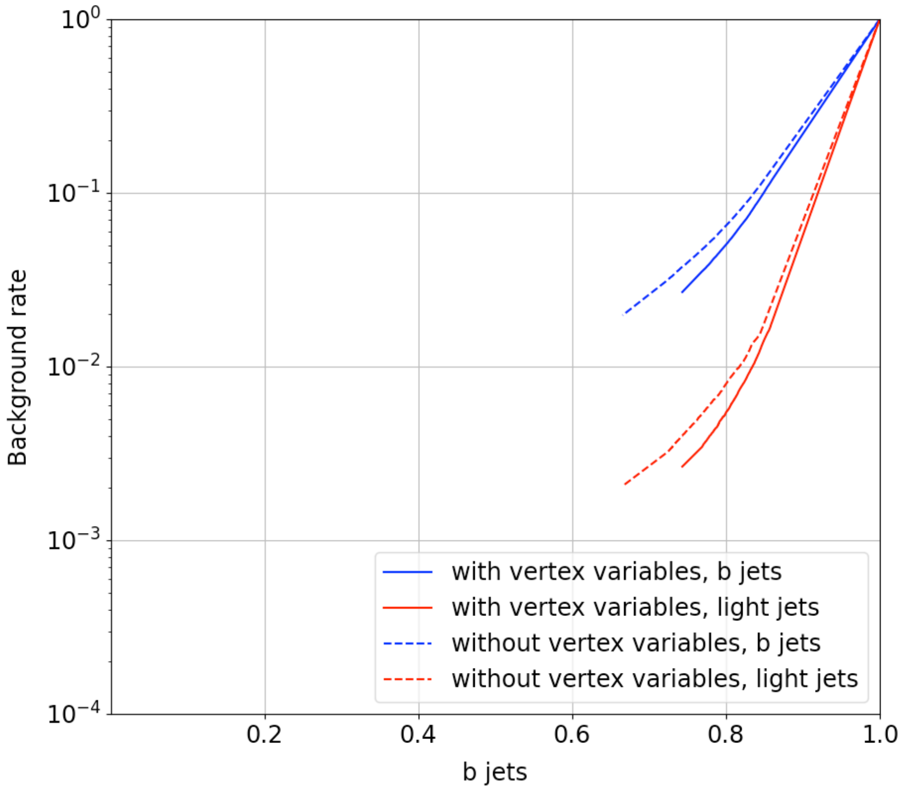


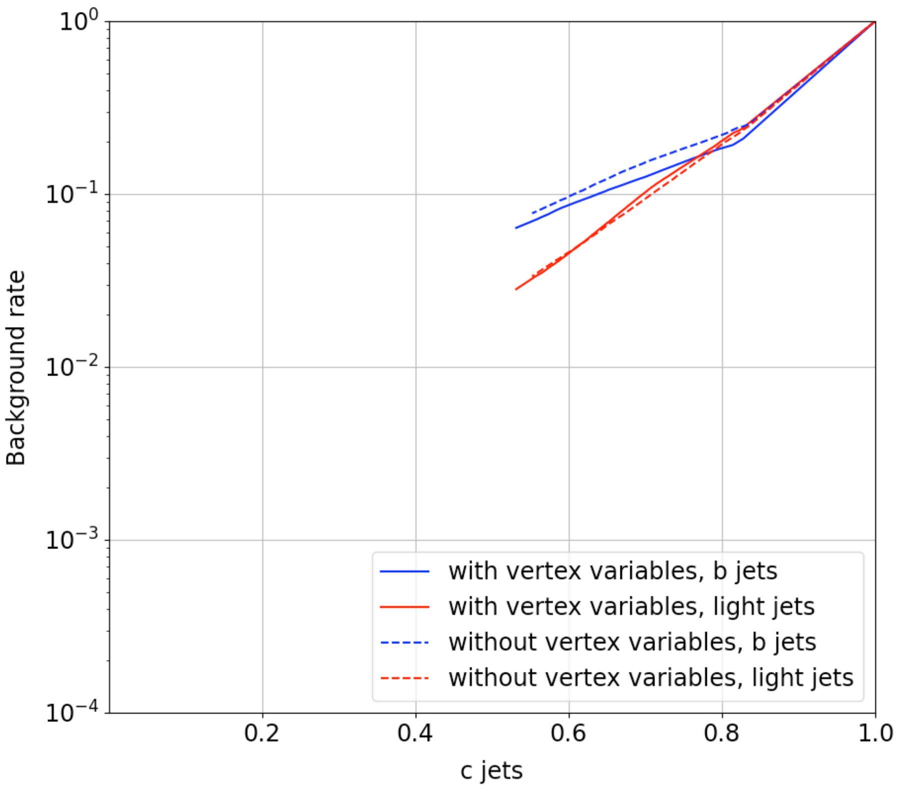


- no overtraining
- accuracy ~80.5% in validation data

ROC curves

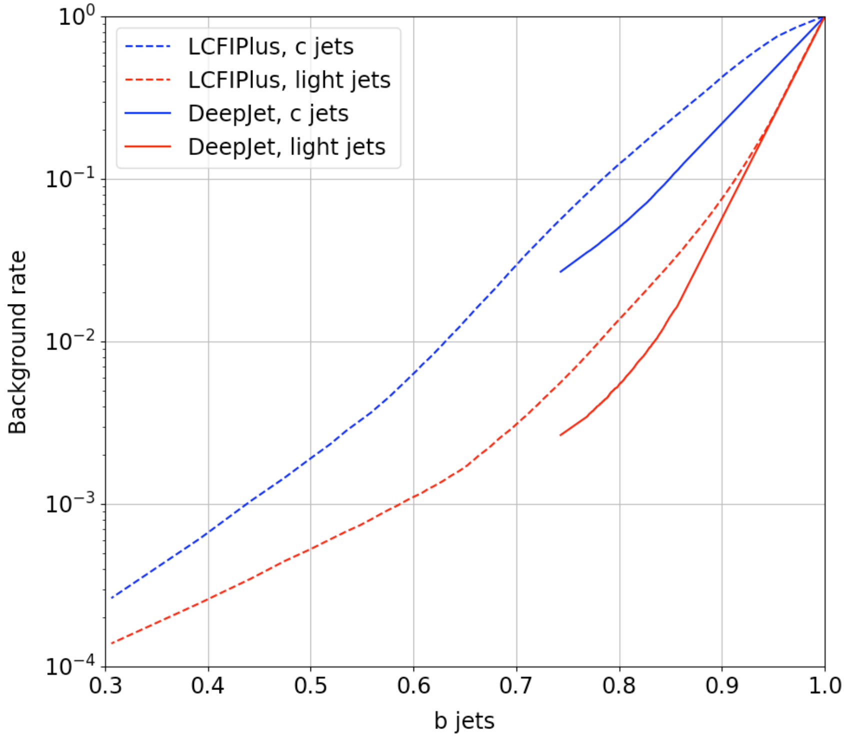
validation data

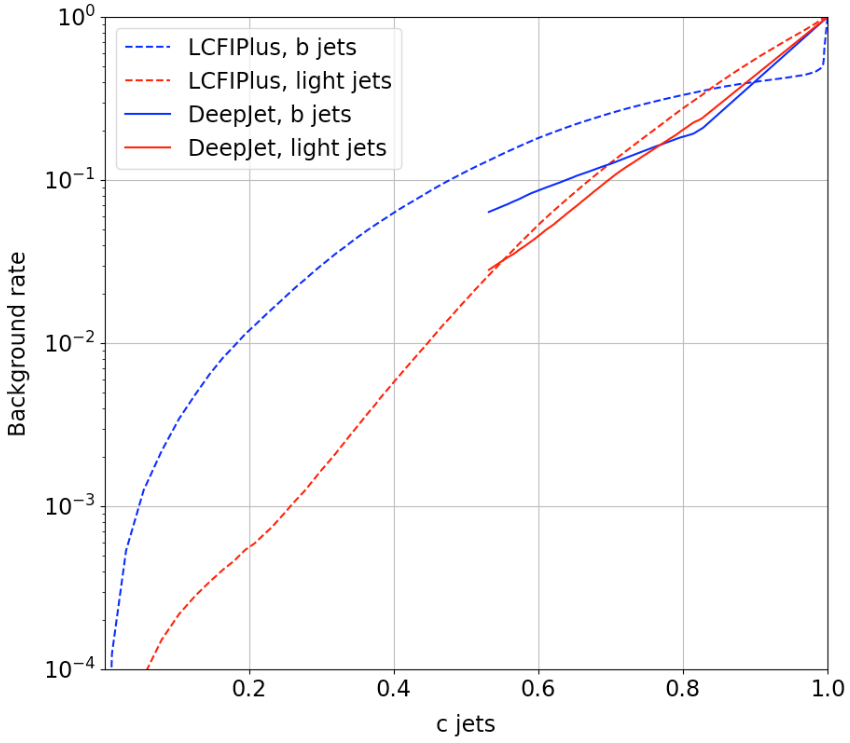




ROC curves

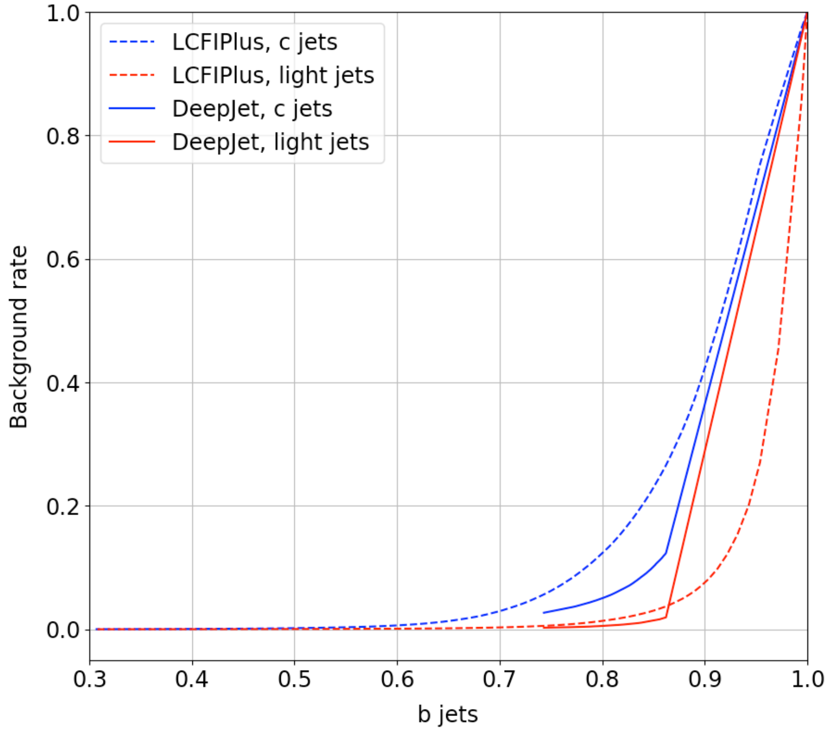
validation data

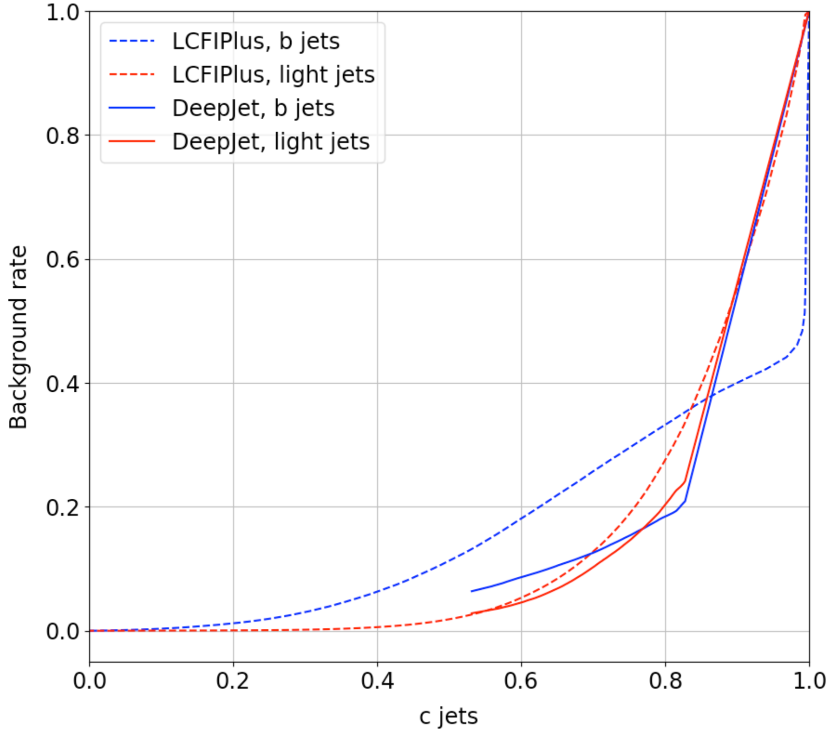




ROC curves

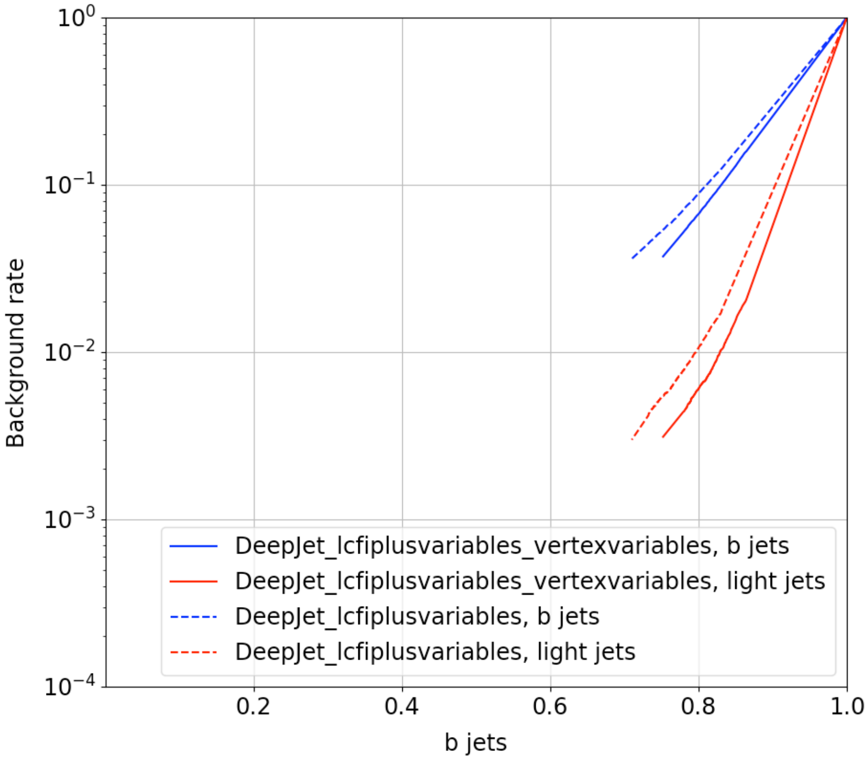
validation data

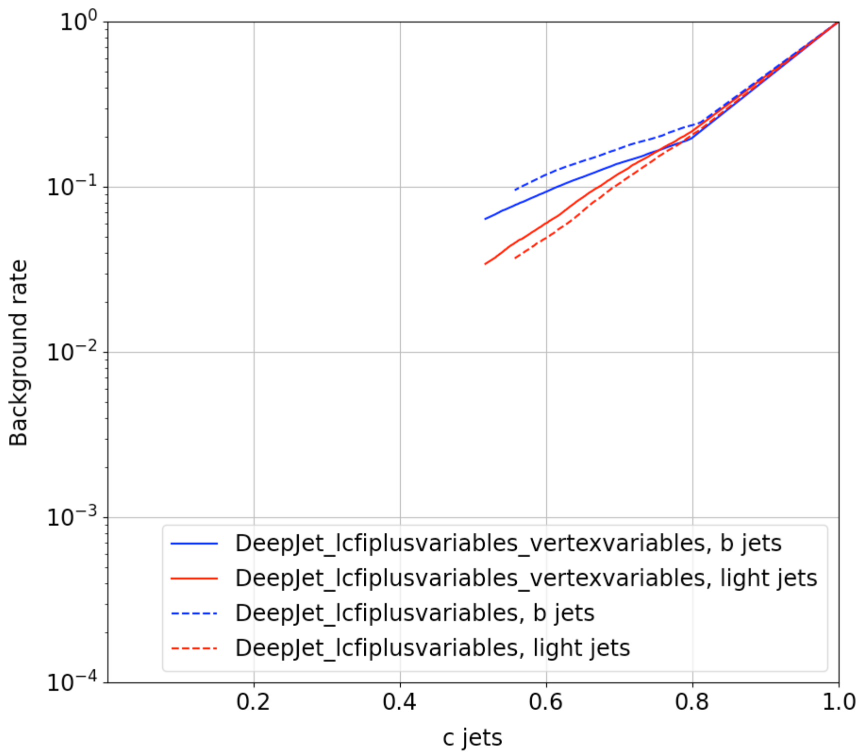




ROC curves

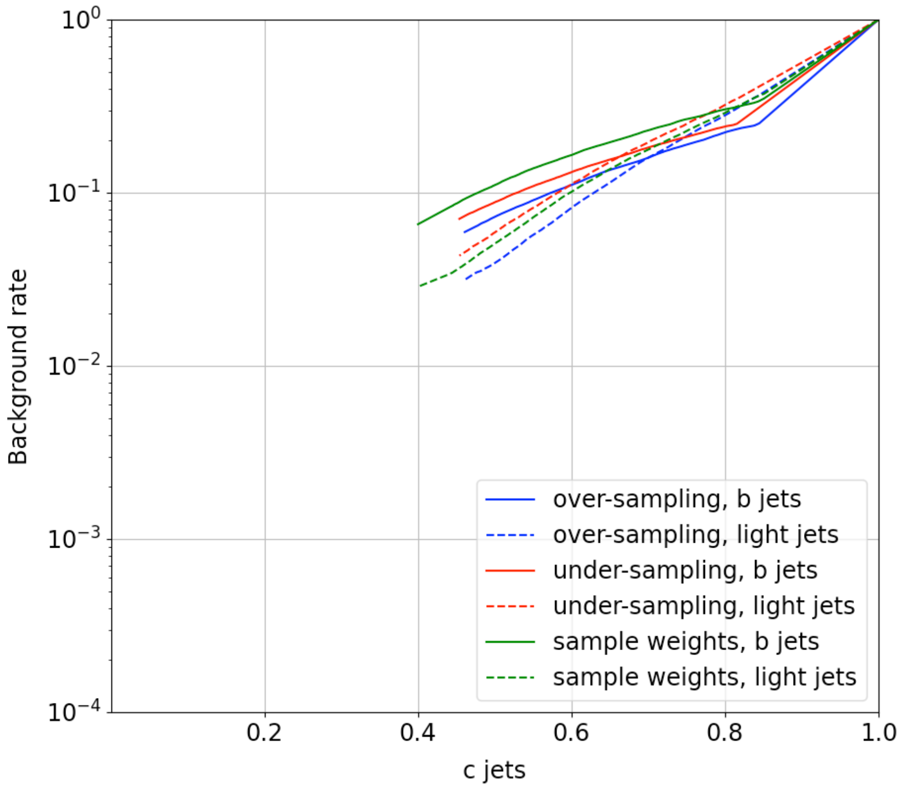
validation data

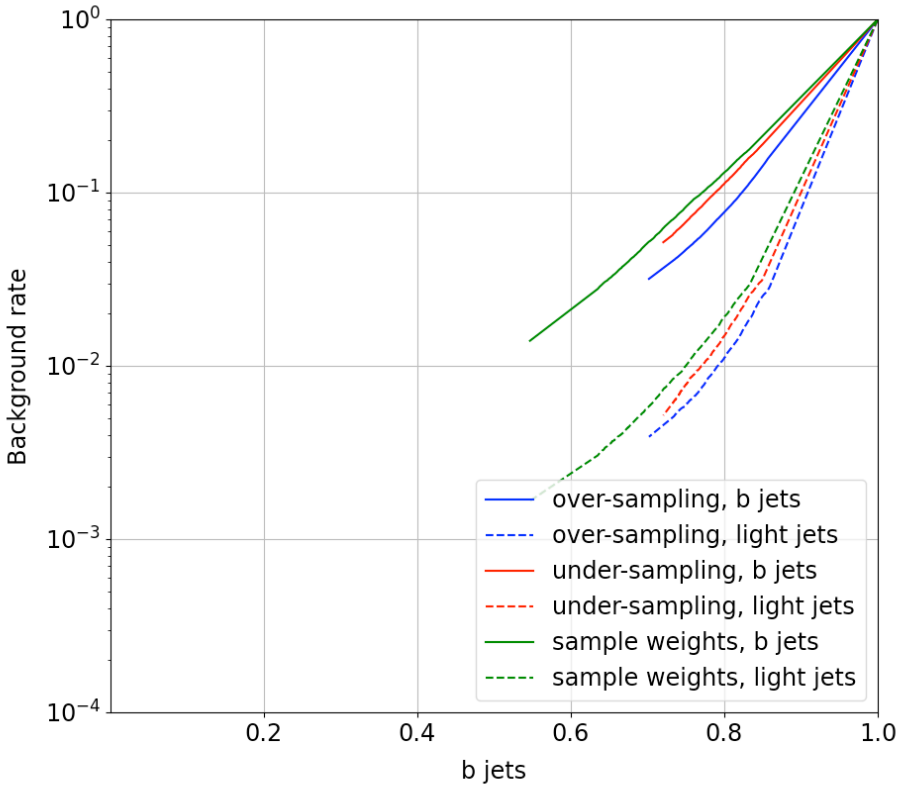




ROC curves

validation data





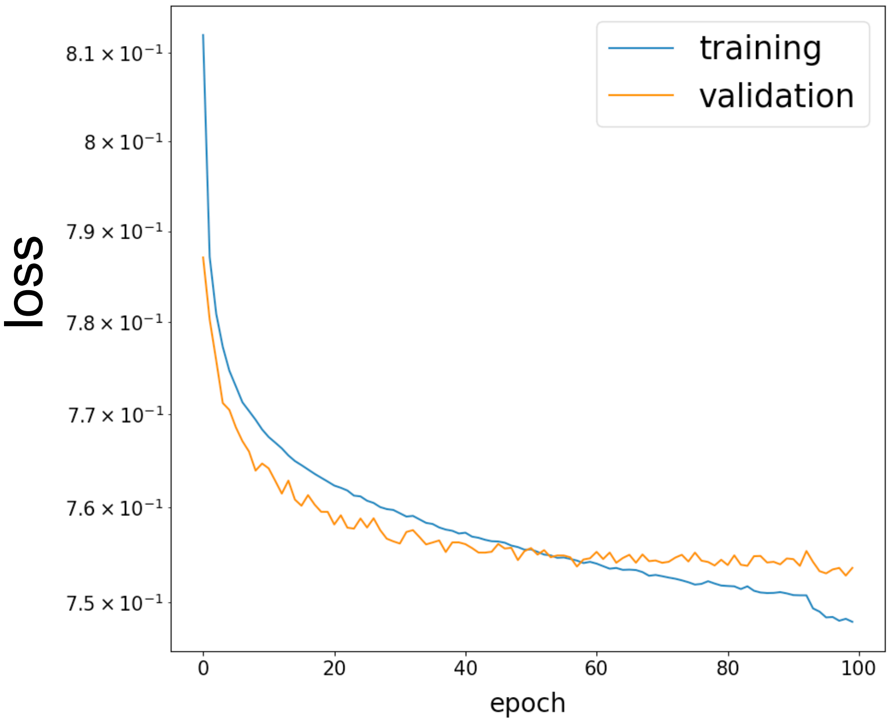
Next steps

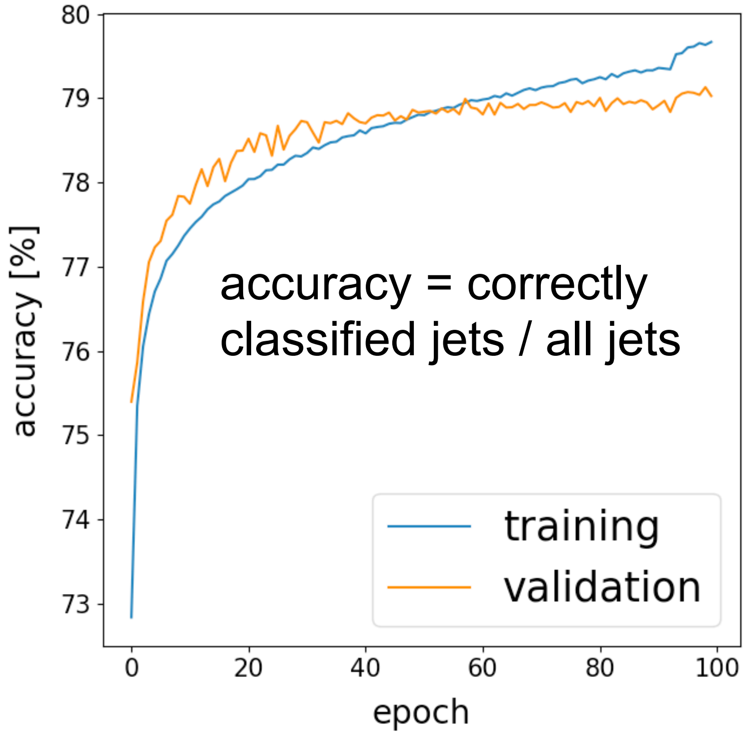
- implement the new variables into my Marlin processor
- use new variables as features of charged jet constituents (per track and not combined for all tracks)?
- add more variables of LCFIPlus?

- start to integrate into iLCSoft, make it usable for others
    - meeting with Frank, Thomas & Uli

- testing over-sampling, other activation functions, …

Results: loss & accuracy



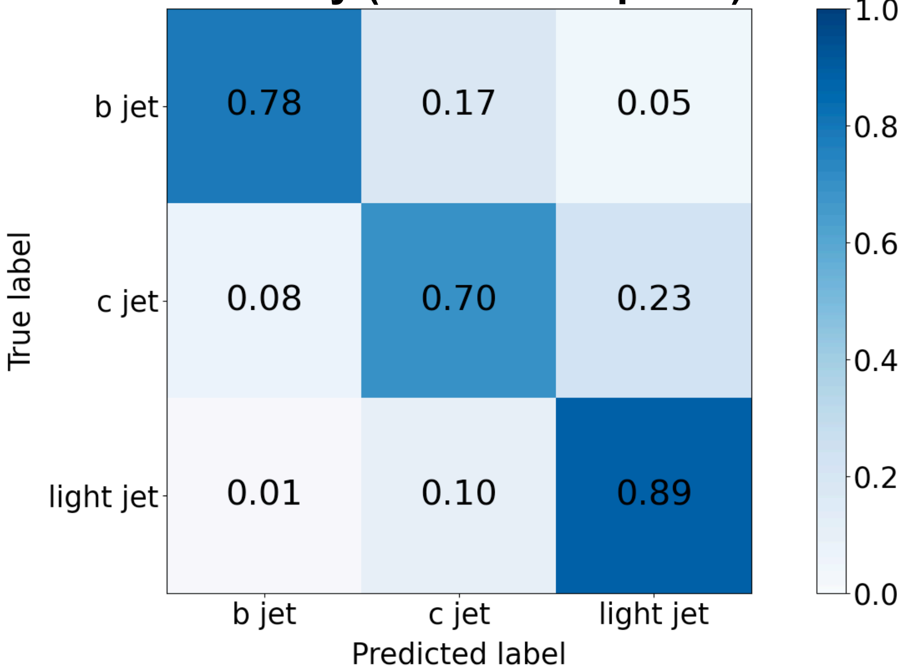


- overtraining
- accuracy ~79% in validation data (before ~76%)

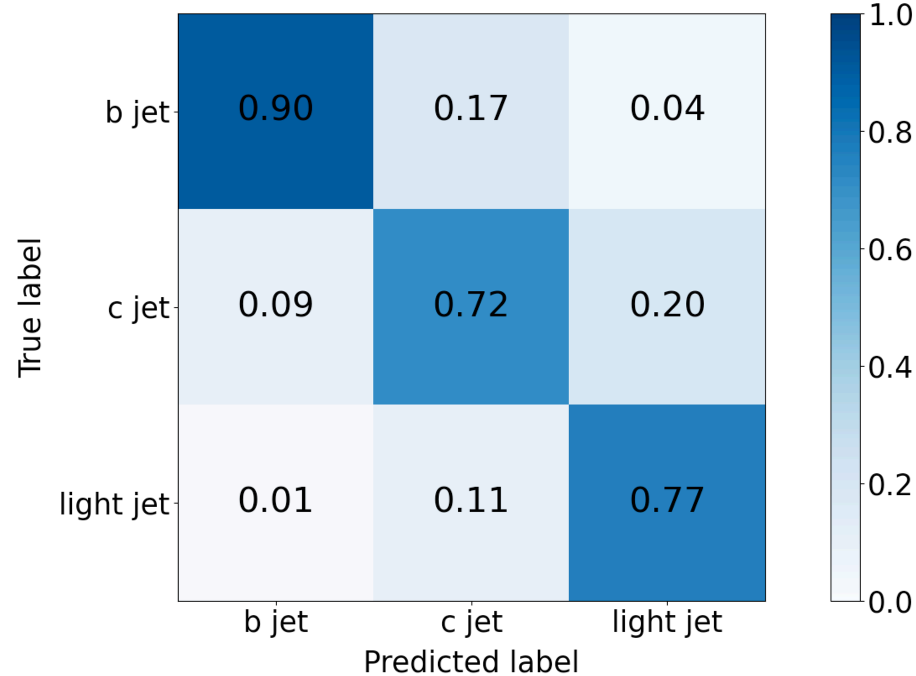
Results: confusion matrices

validation data

efficiency (rows sum up to 1)



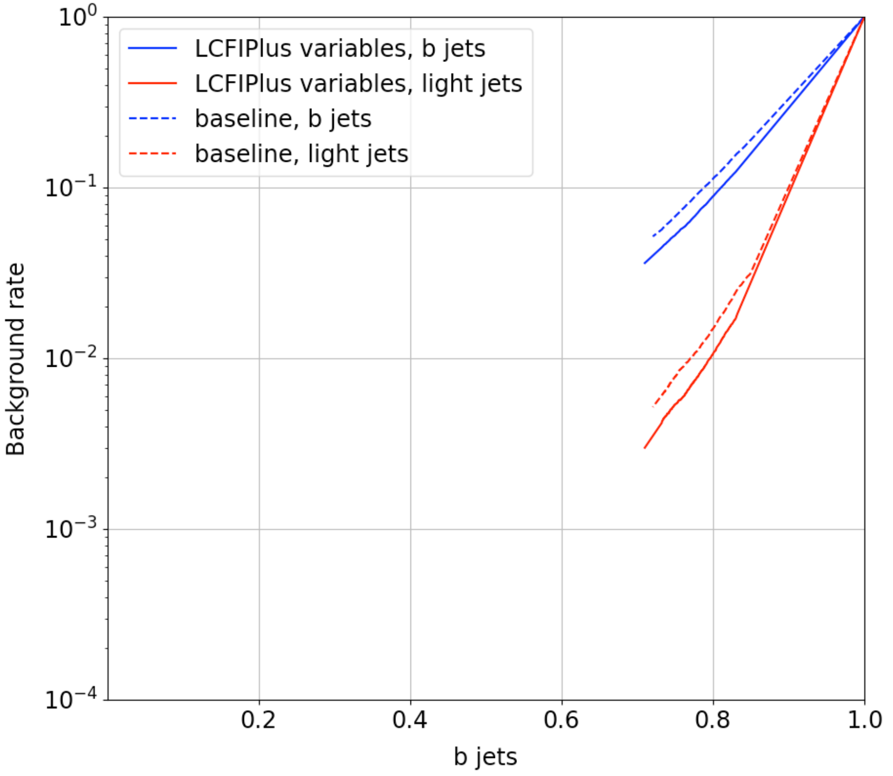
purity (columns sum up to 1)

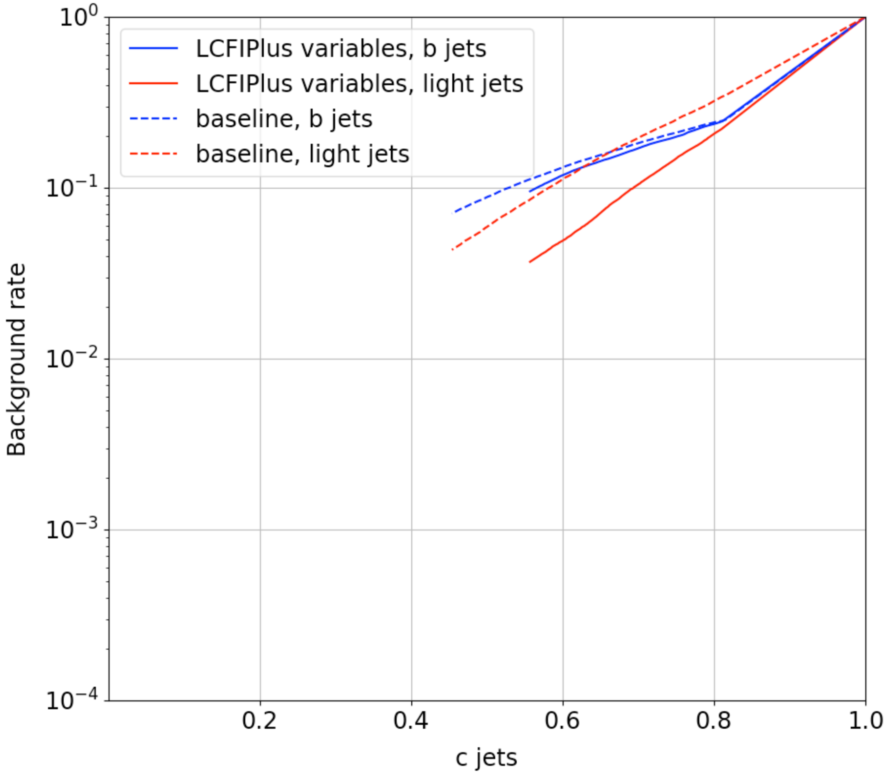


- better identification efficiencies for c jets and light jets (66% & 85% before)
- improved purity in all classes (before 88% for b jets, 68% for c jets, 74% for light jets)
- especially separation between c jets and light jets improved

ROC curves

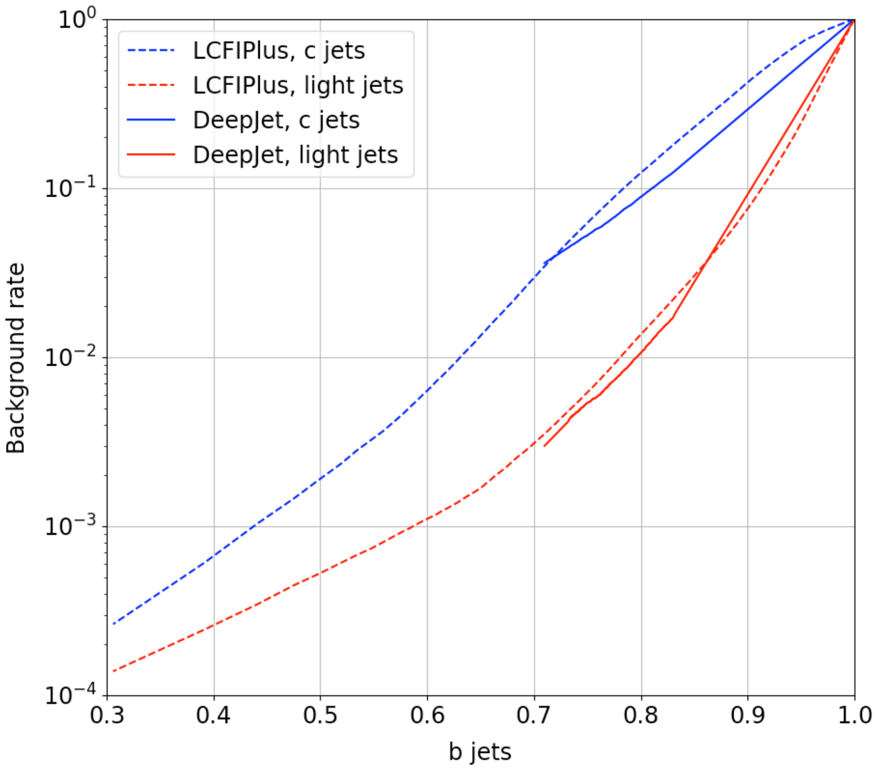
validation data

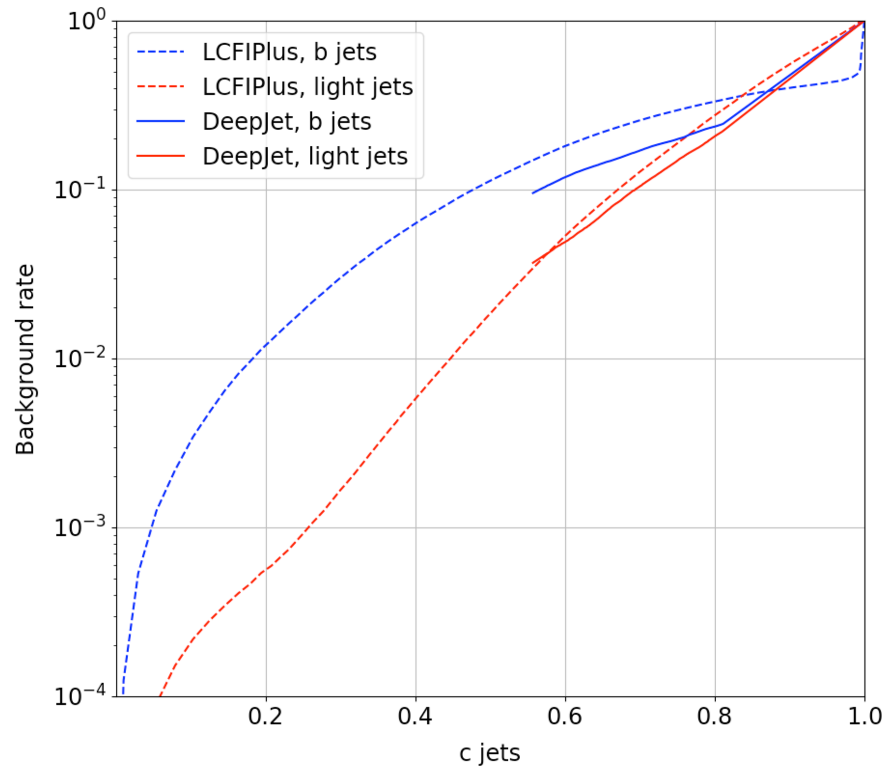




ROC curves - comparison to LCFIPlus

validation data

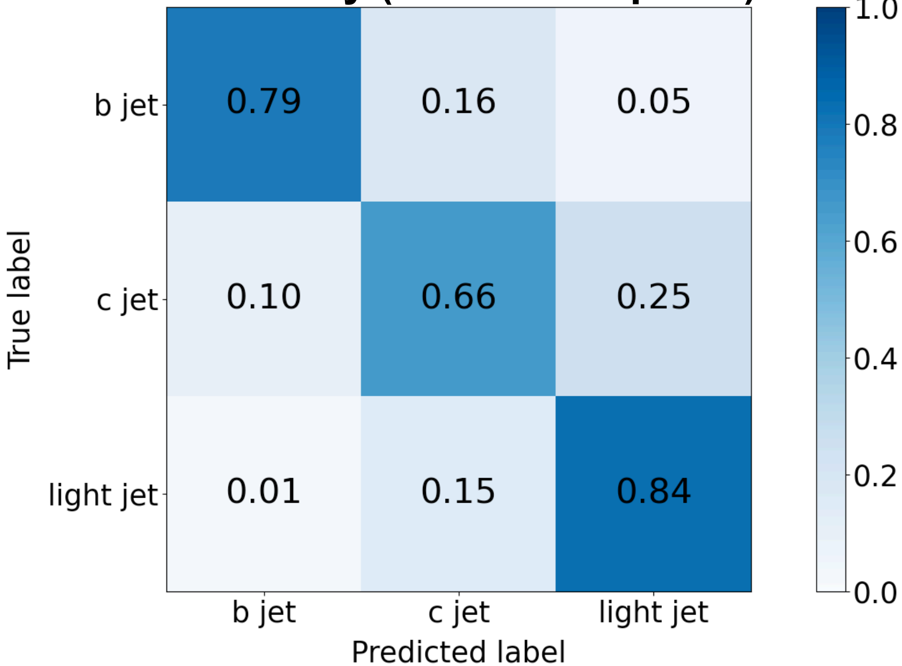




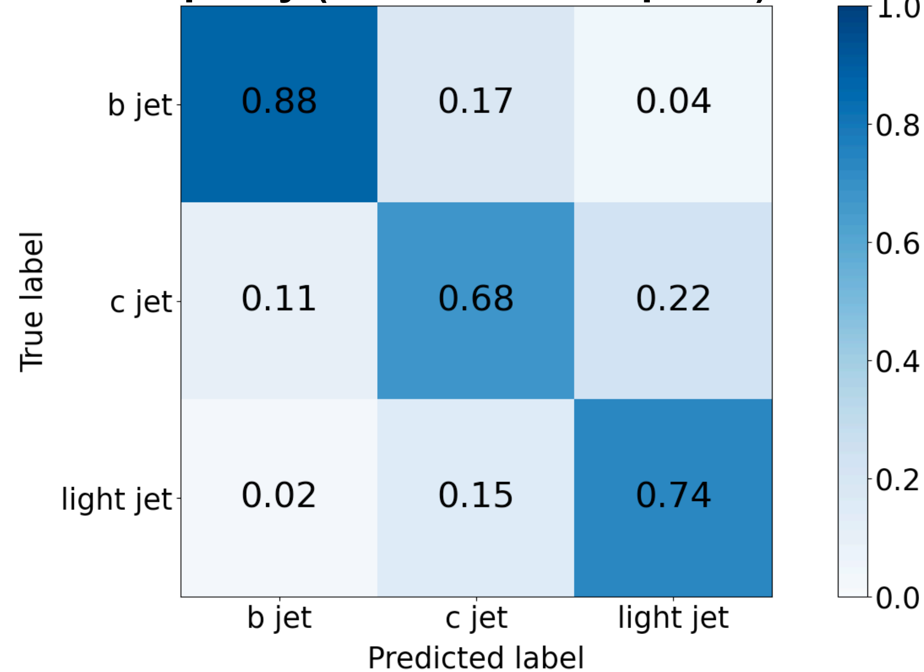
Results: confusion matrices

validation data

efficiency (rows sum up to 1)



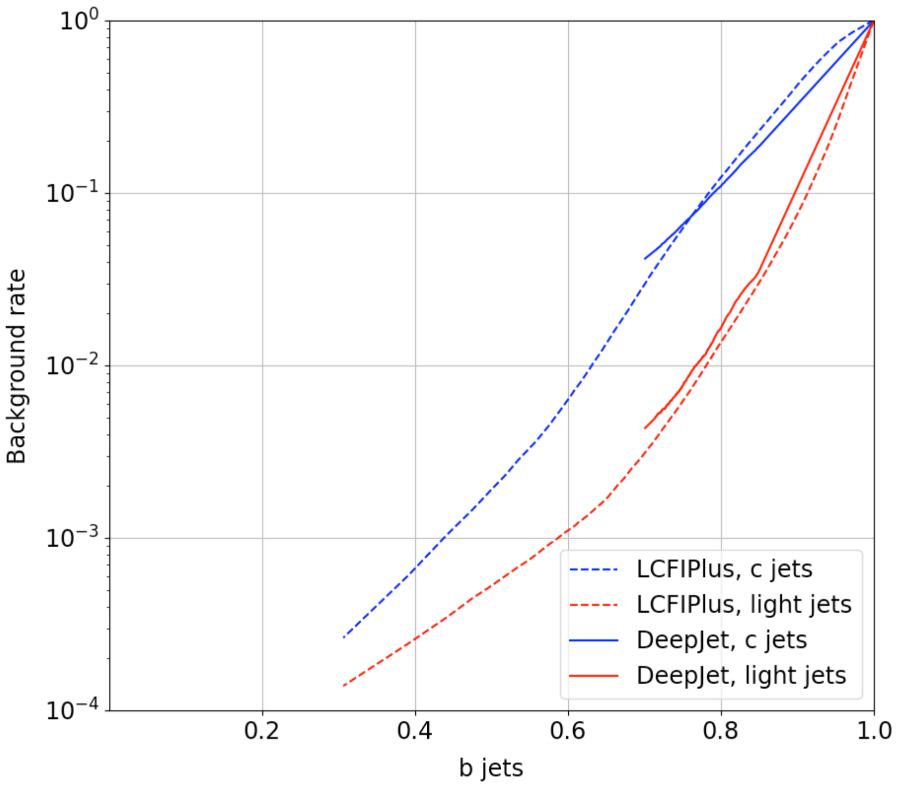
purity (columns sum up to 1)

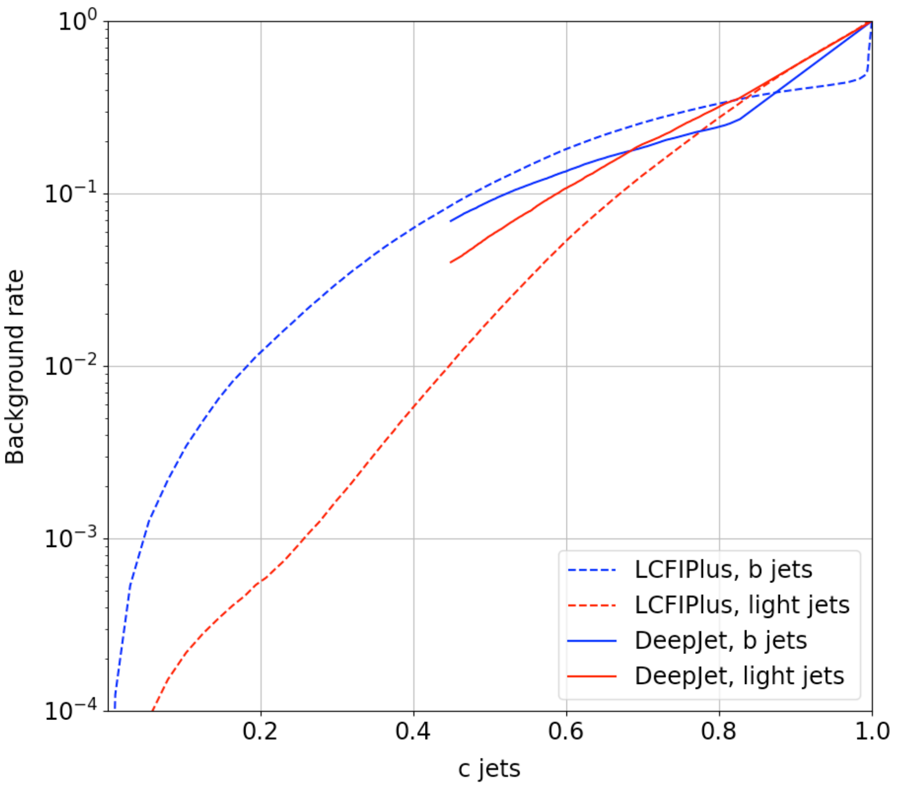


- identification efficiencies ~80% for b jets & light jets
- c jet identification quite low (66%)
- especially separation between c jets and light jets should be improved

ROC curves - comparison to LCFIPlus

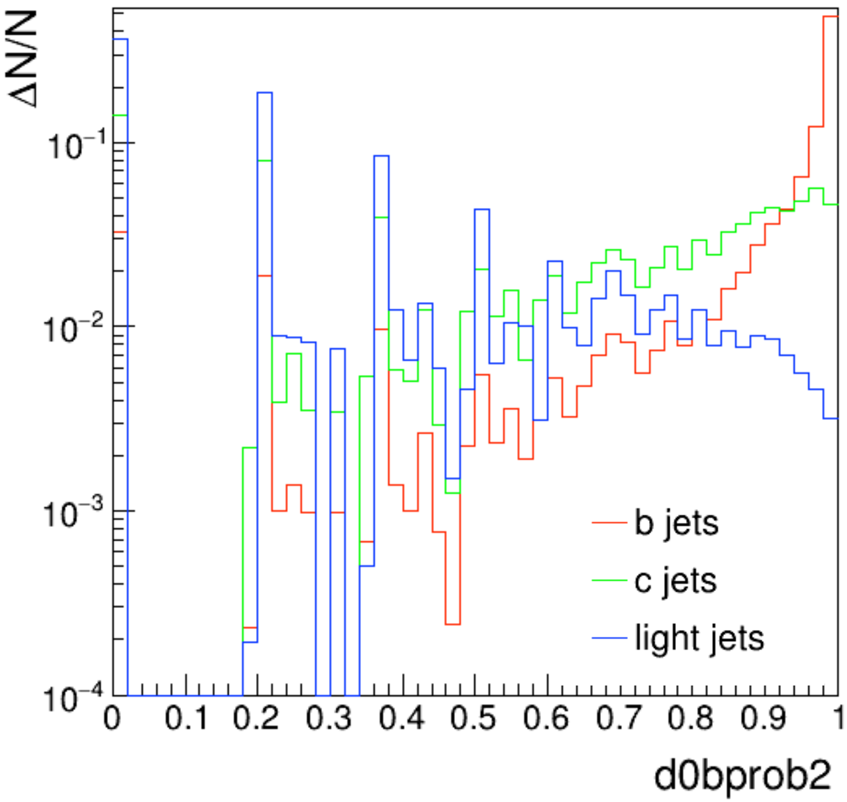
validation data

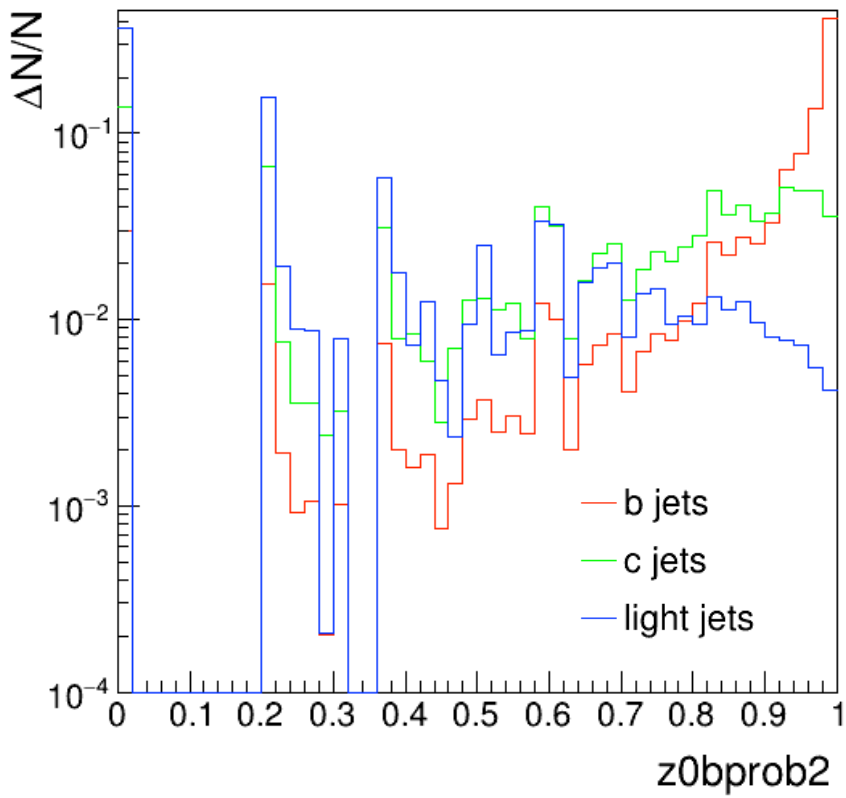




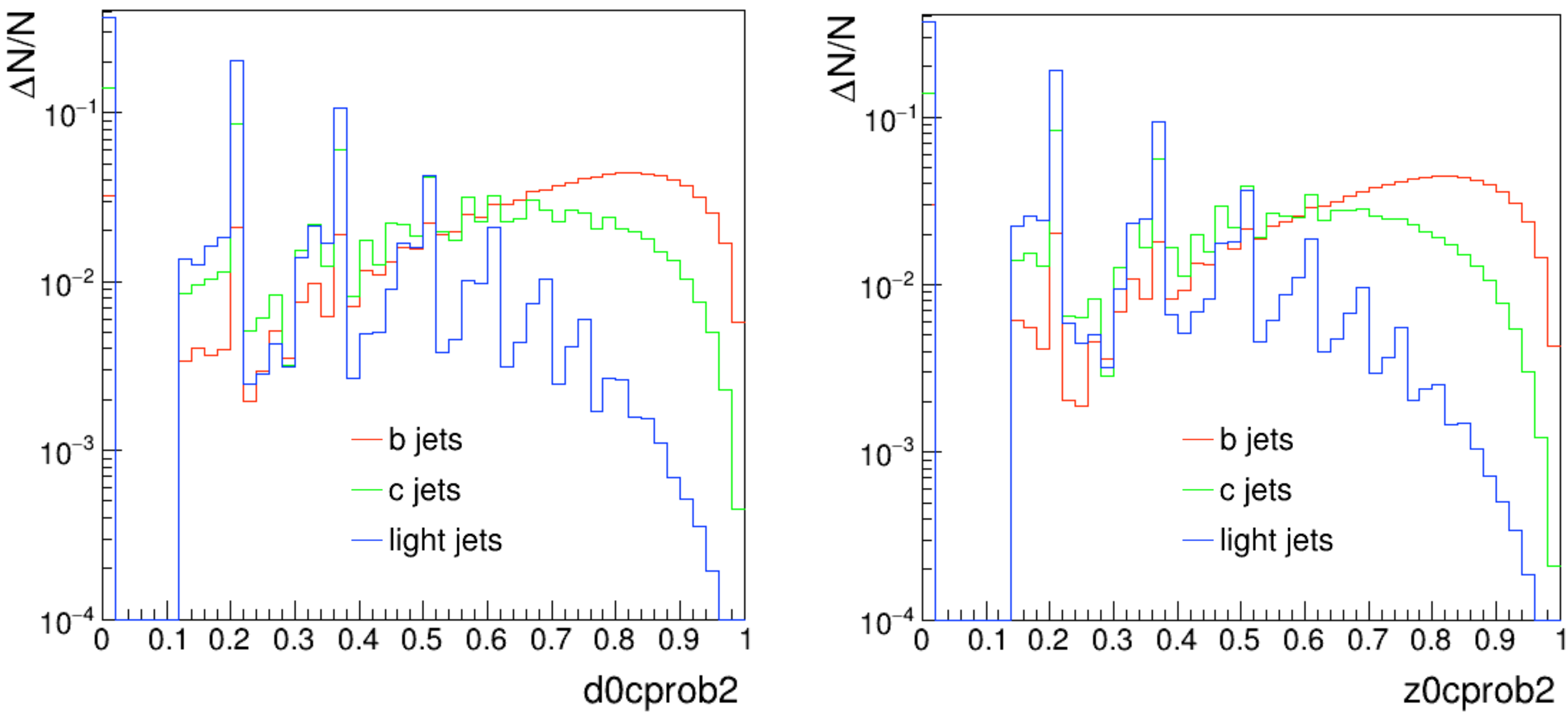
- slightly better performance for b jet identification vs. c jet background
- better performance for c jet efficiencies vs. b jet background below ~90% c jet identification efficiency
- worse performance in b jet / c jet identification vs. light jets (especially for c jets)

LCFIPlus variables

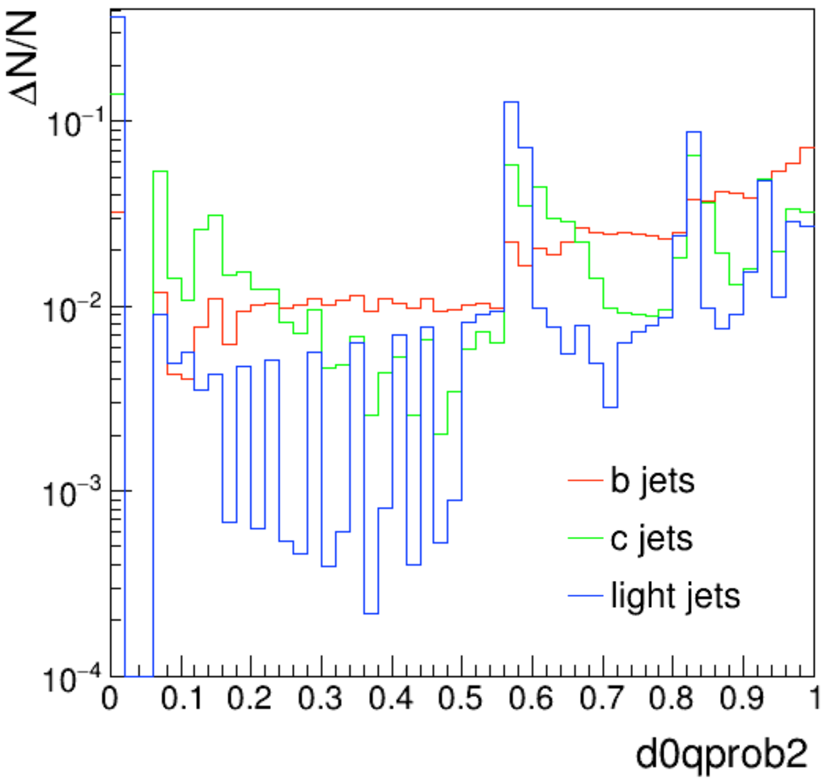


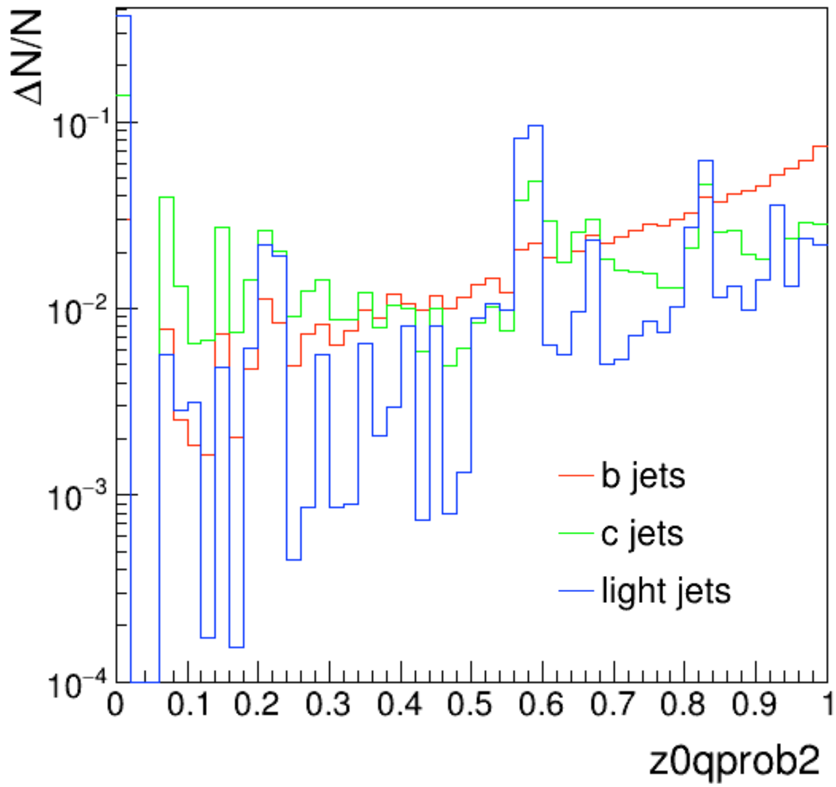


LCFIPlus variables

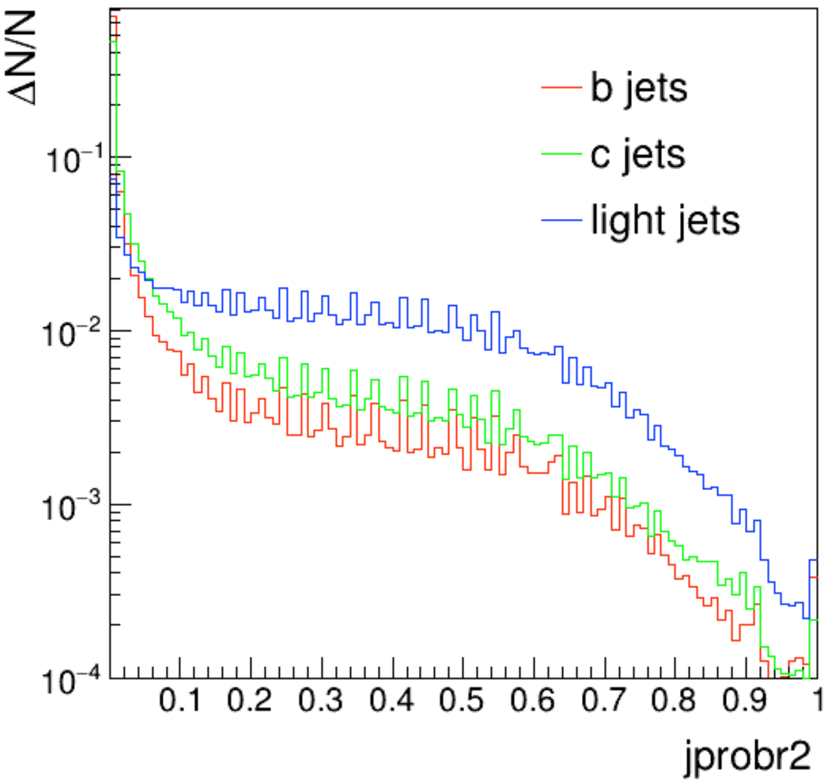


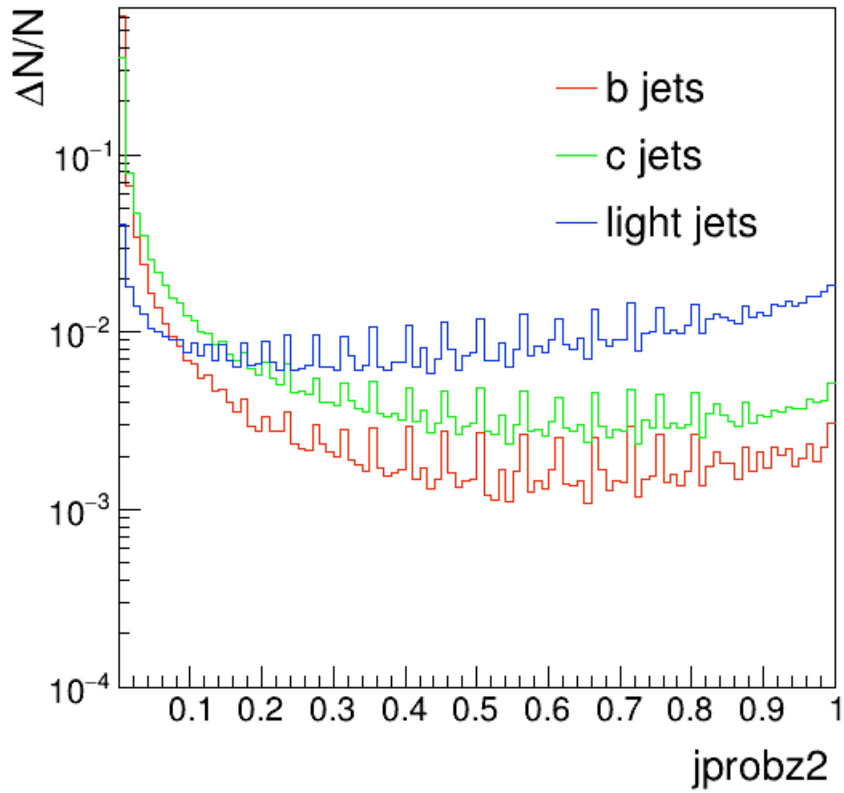
LCFIPlus variables



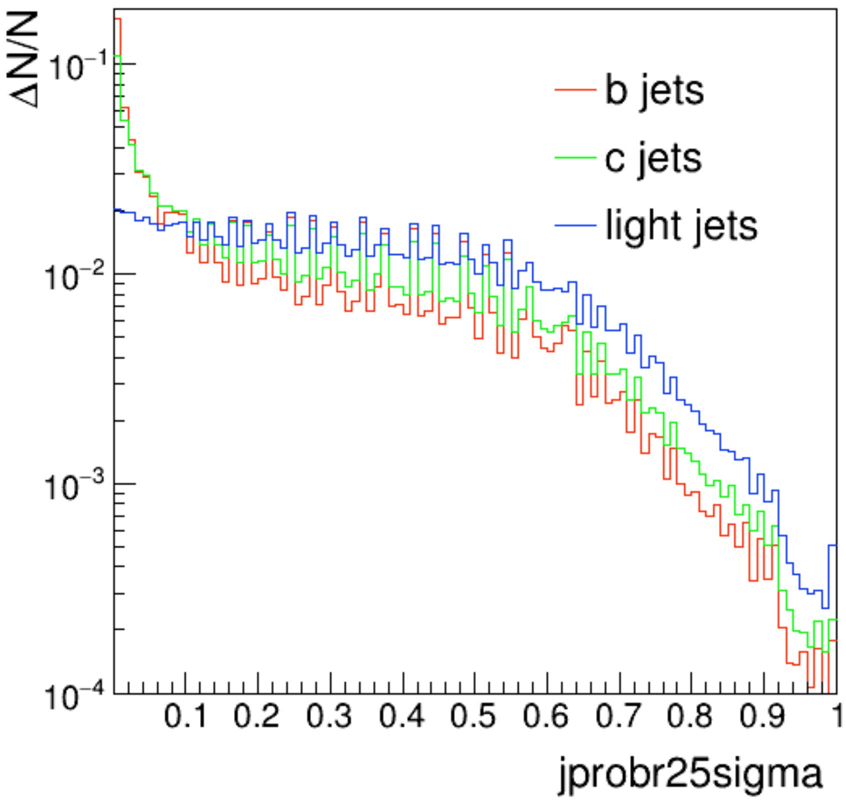


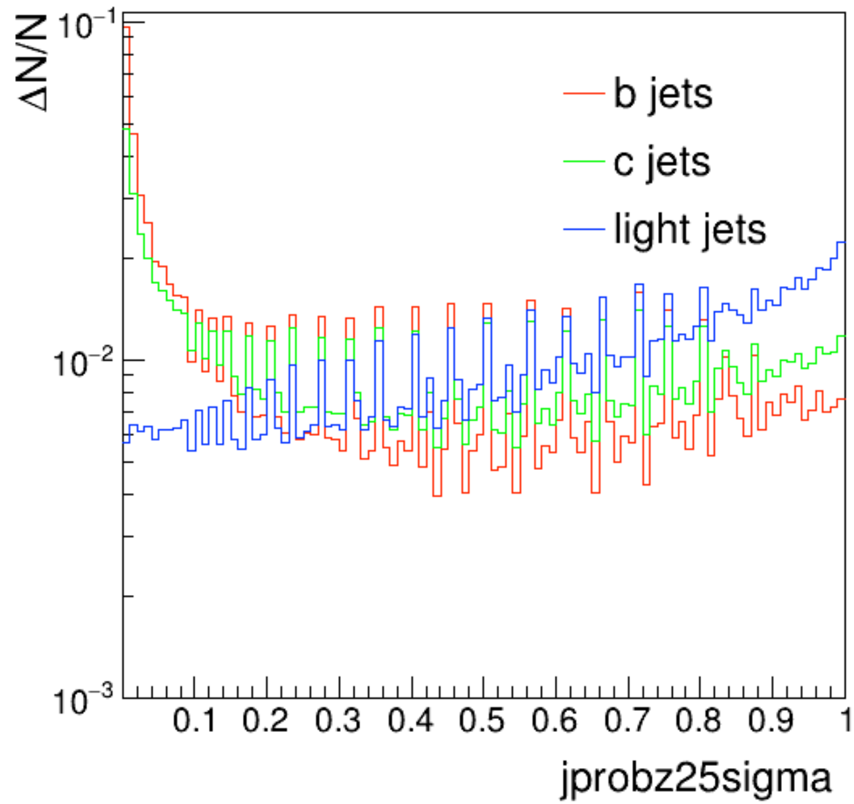
LCFIPlus variables



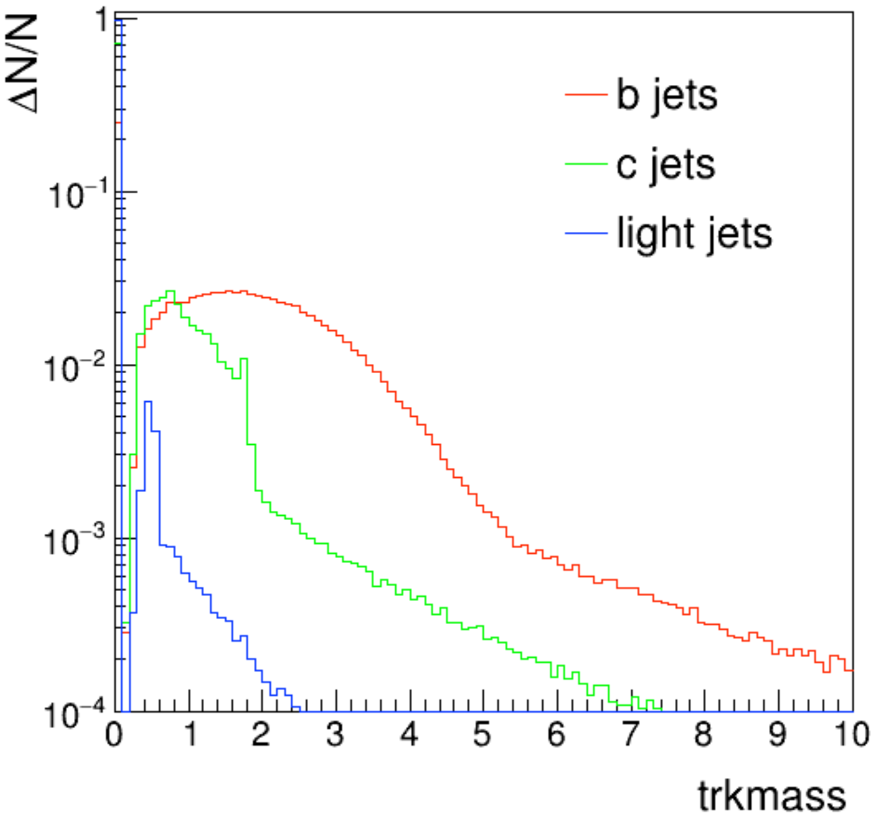


LCFIPlus variables

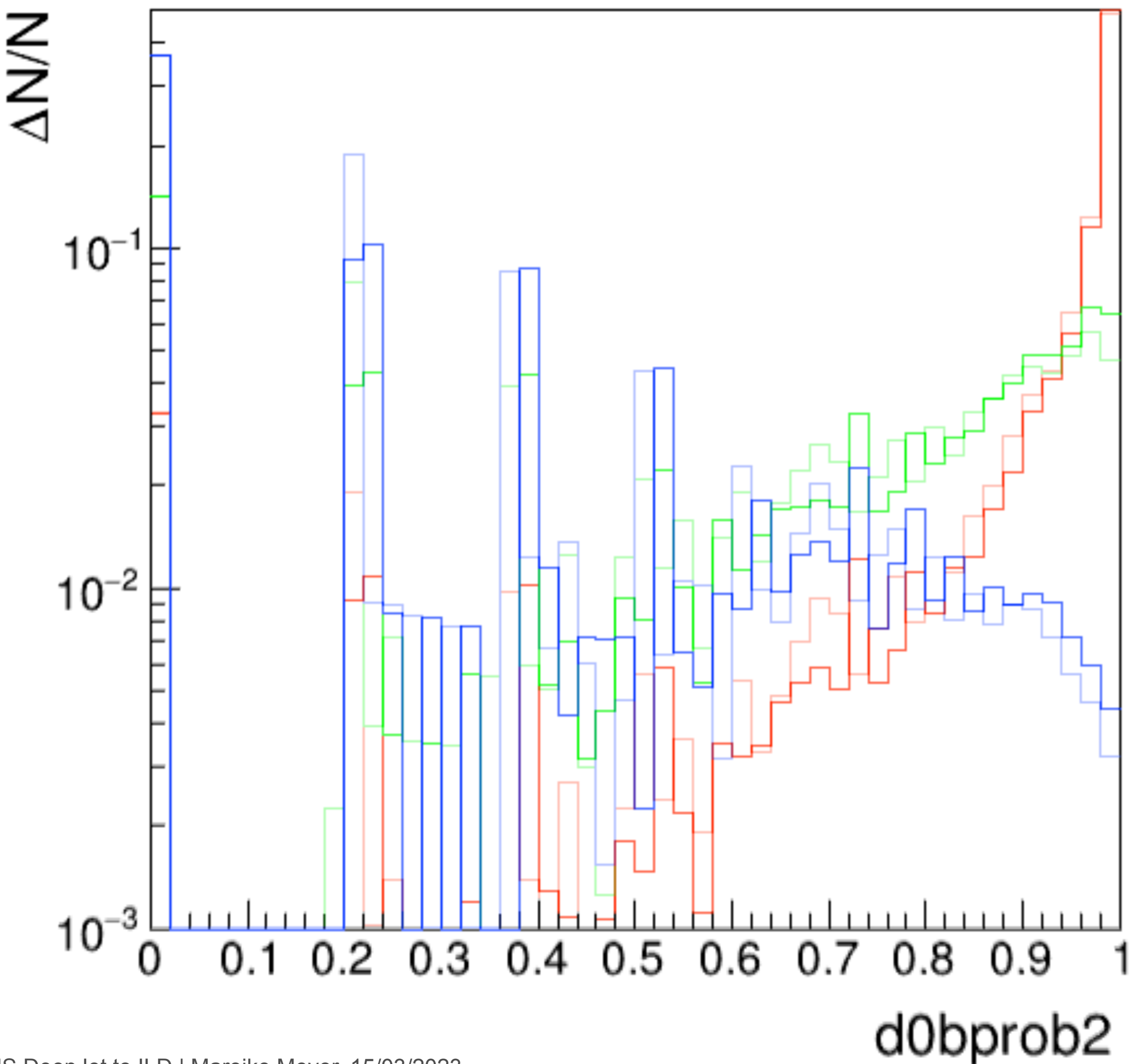




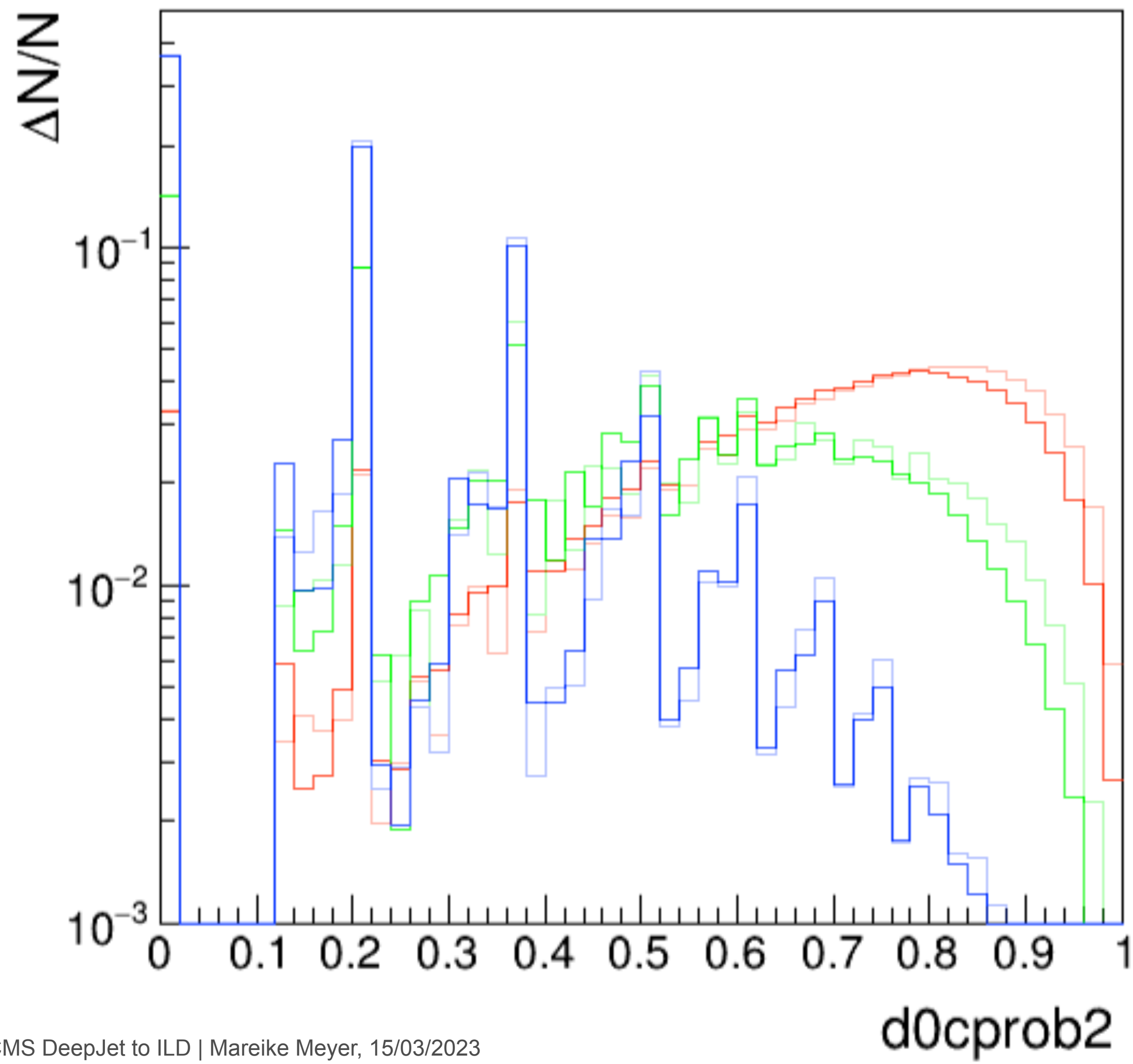
LCFIPlus variables



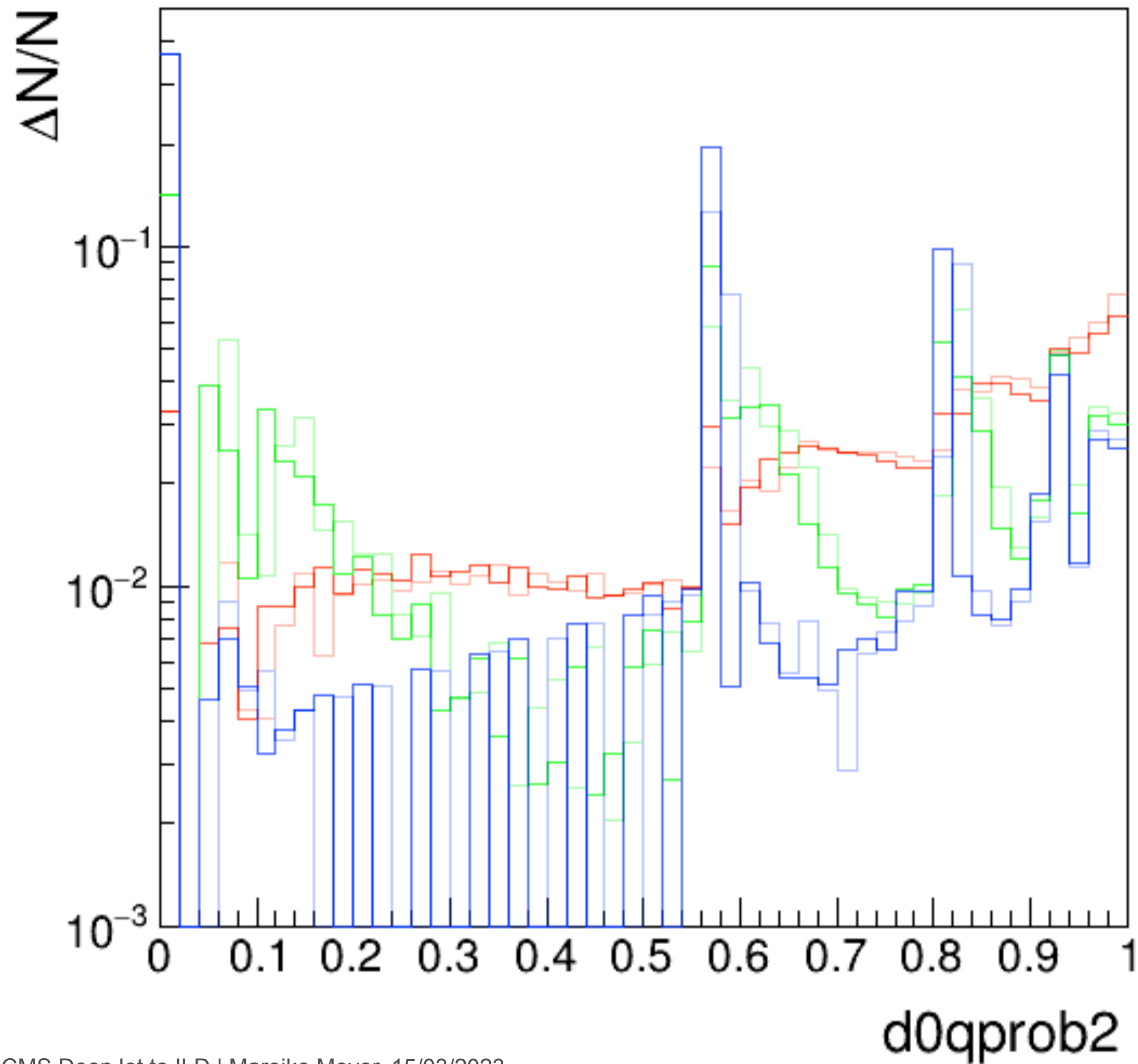
LCFIPlus variables



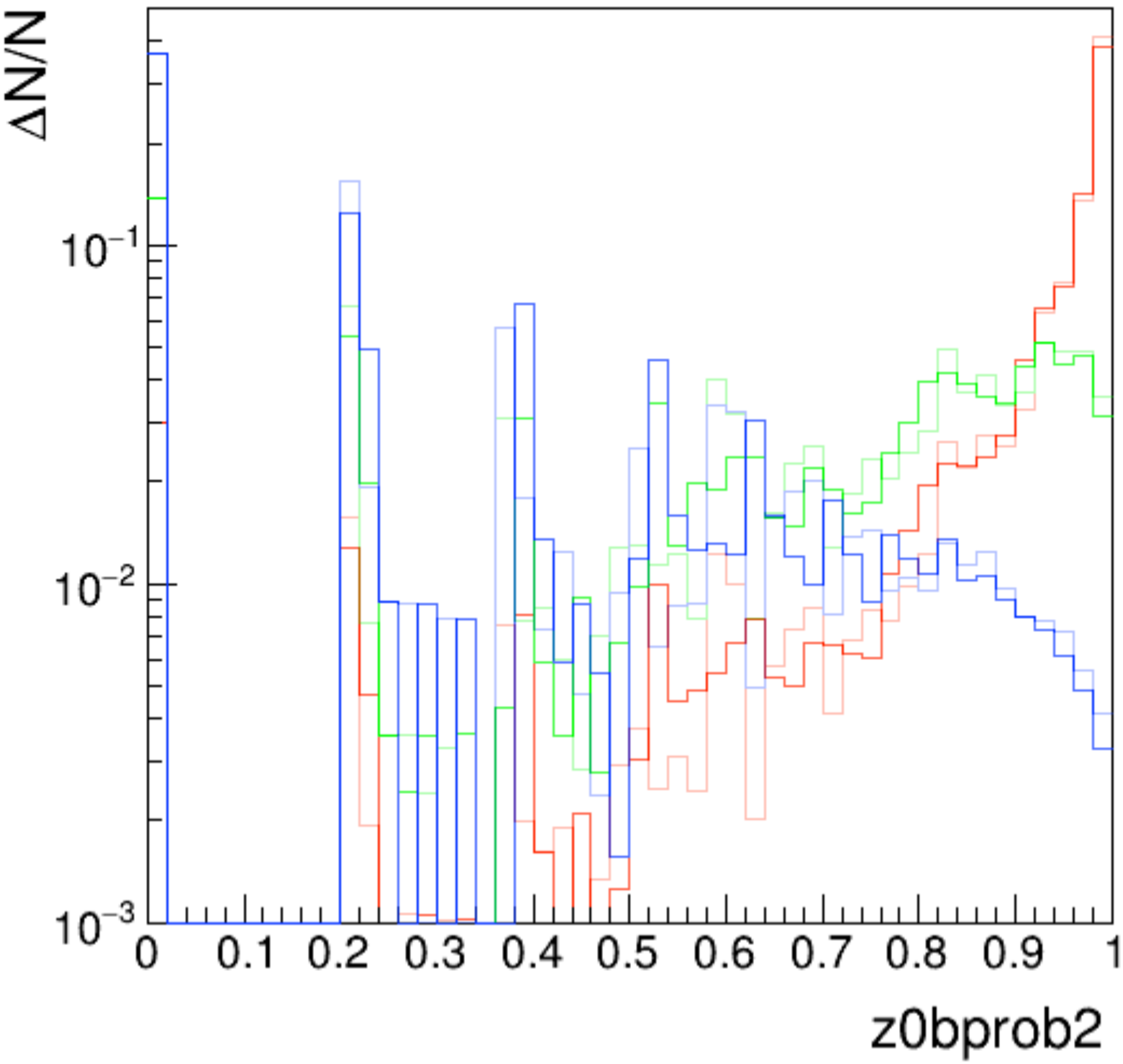
LCFIPlus variables



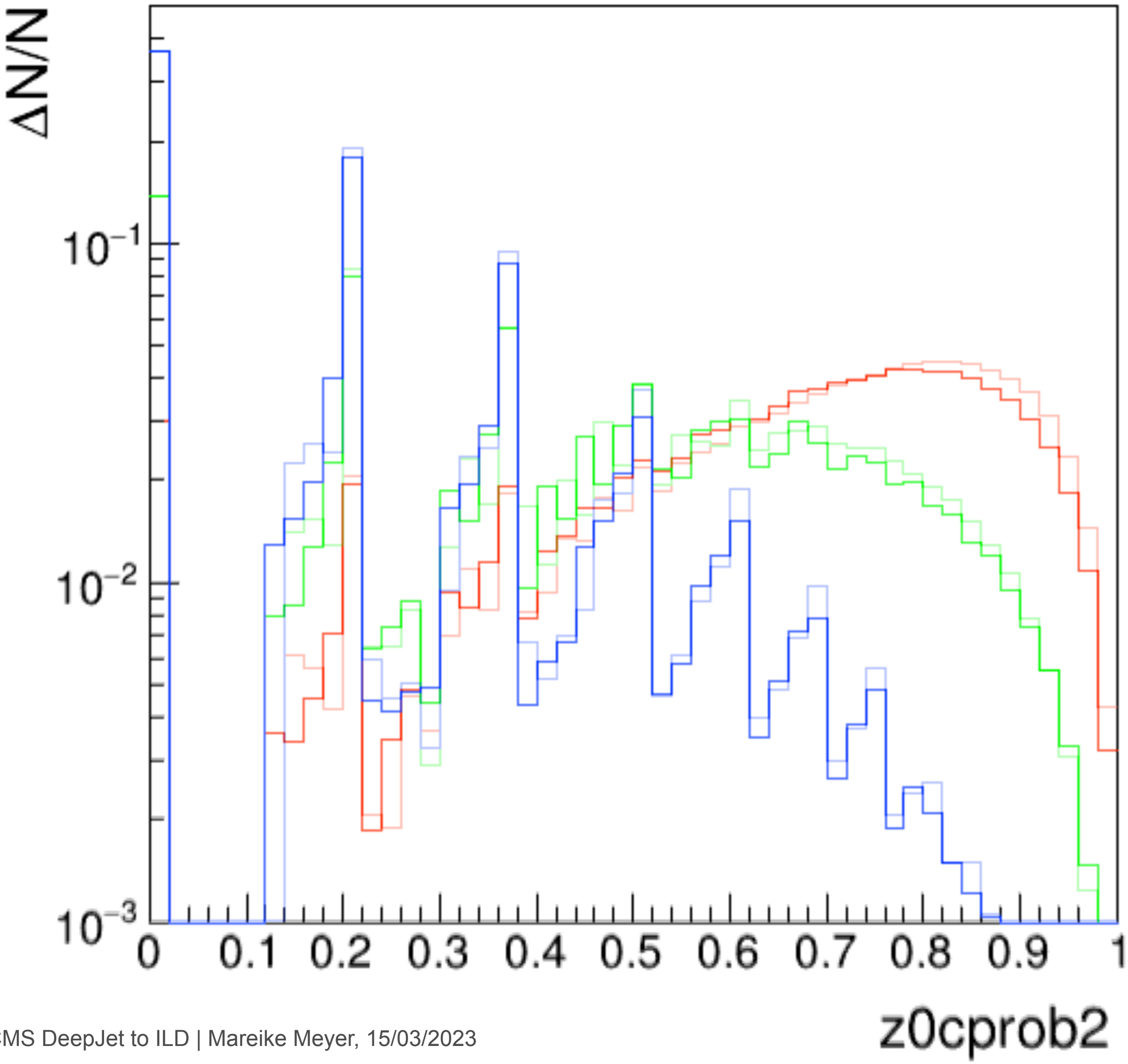
LCFIPlus variables



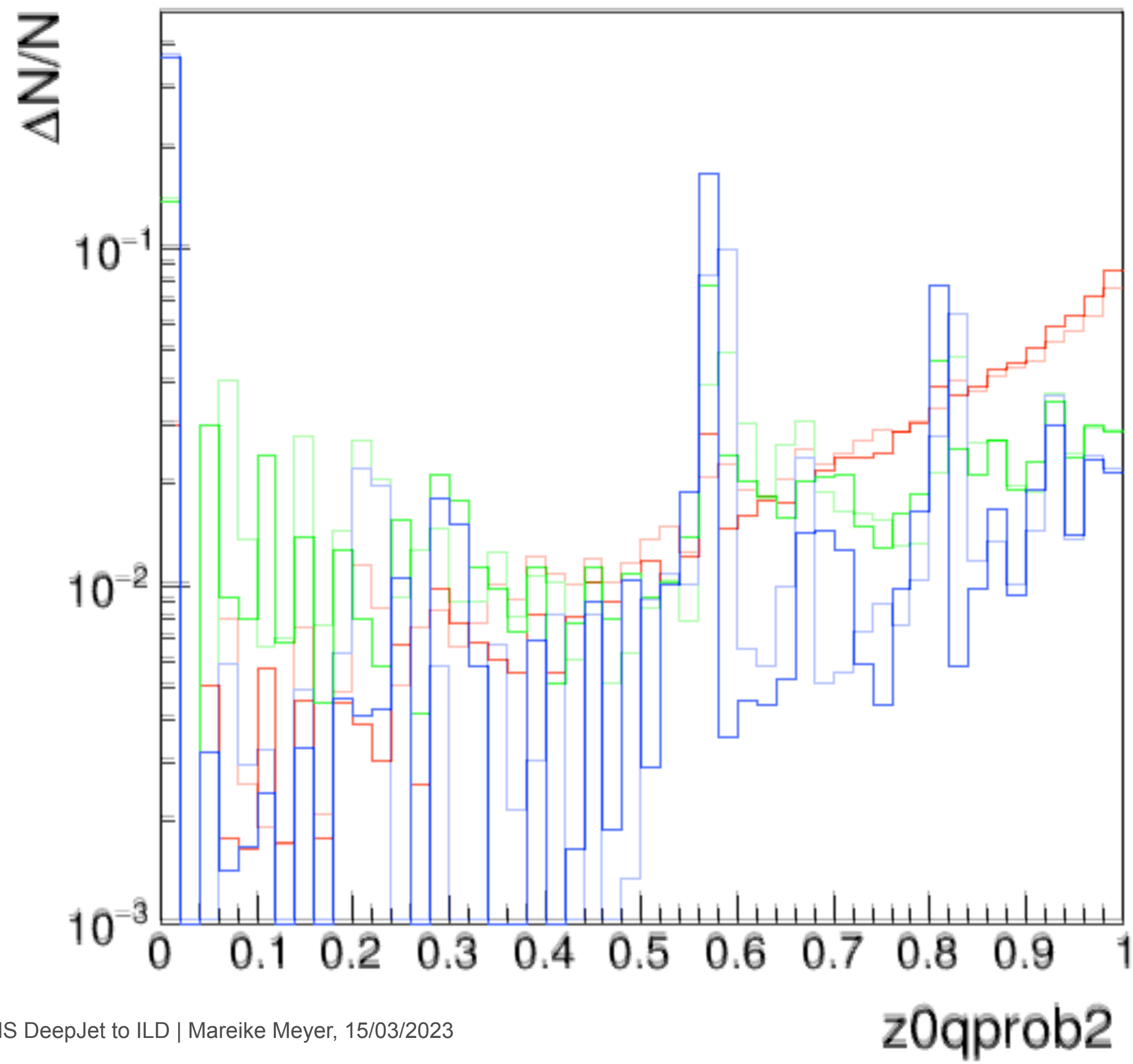
LCFIPlus variables



LCFIPlus variables



LCFIPlus variables



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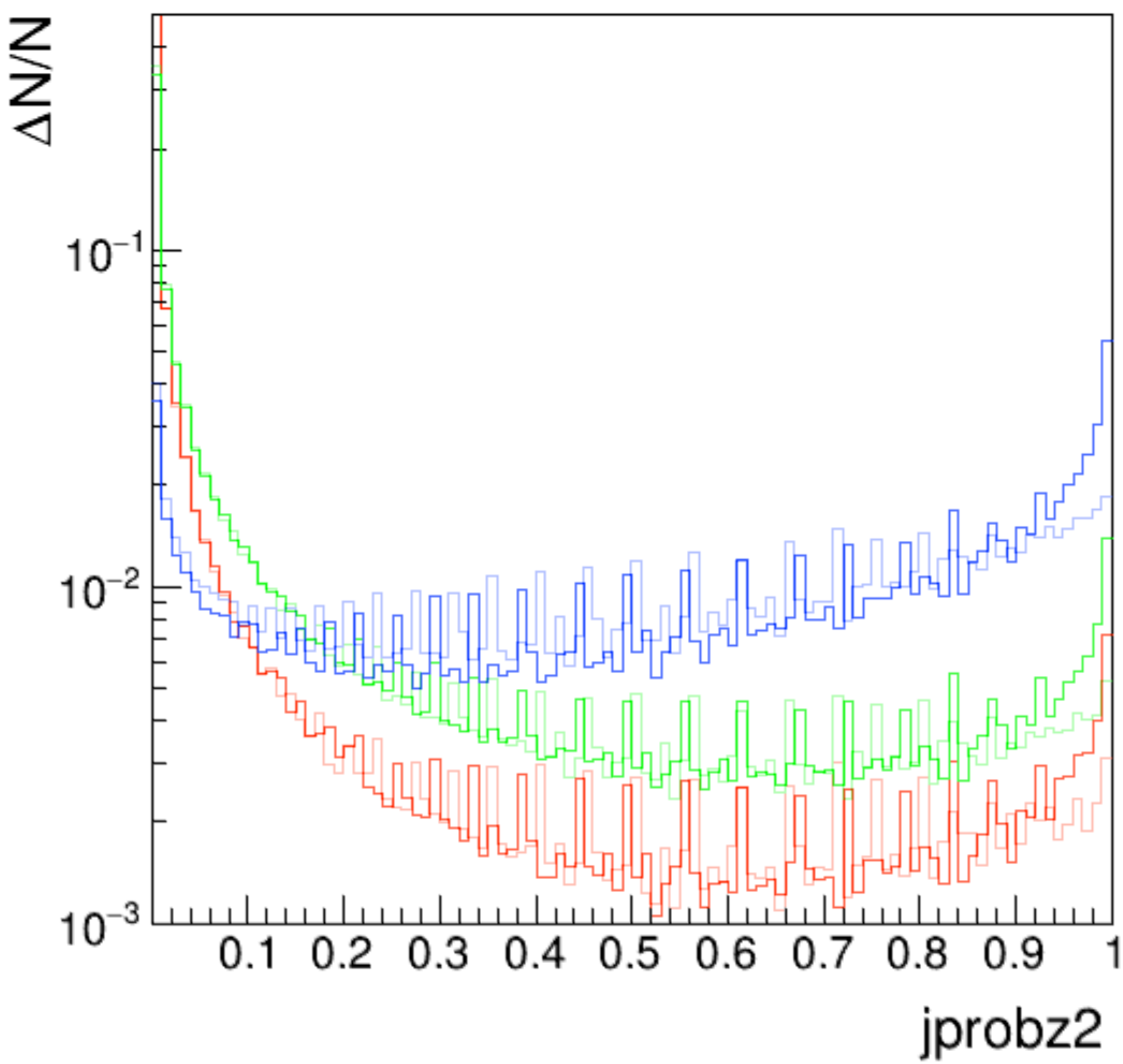
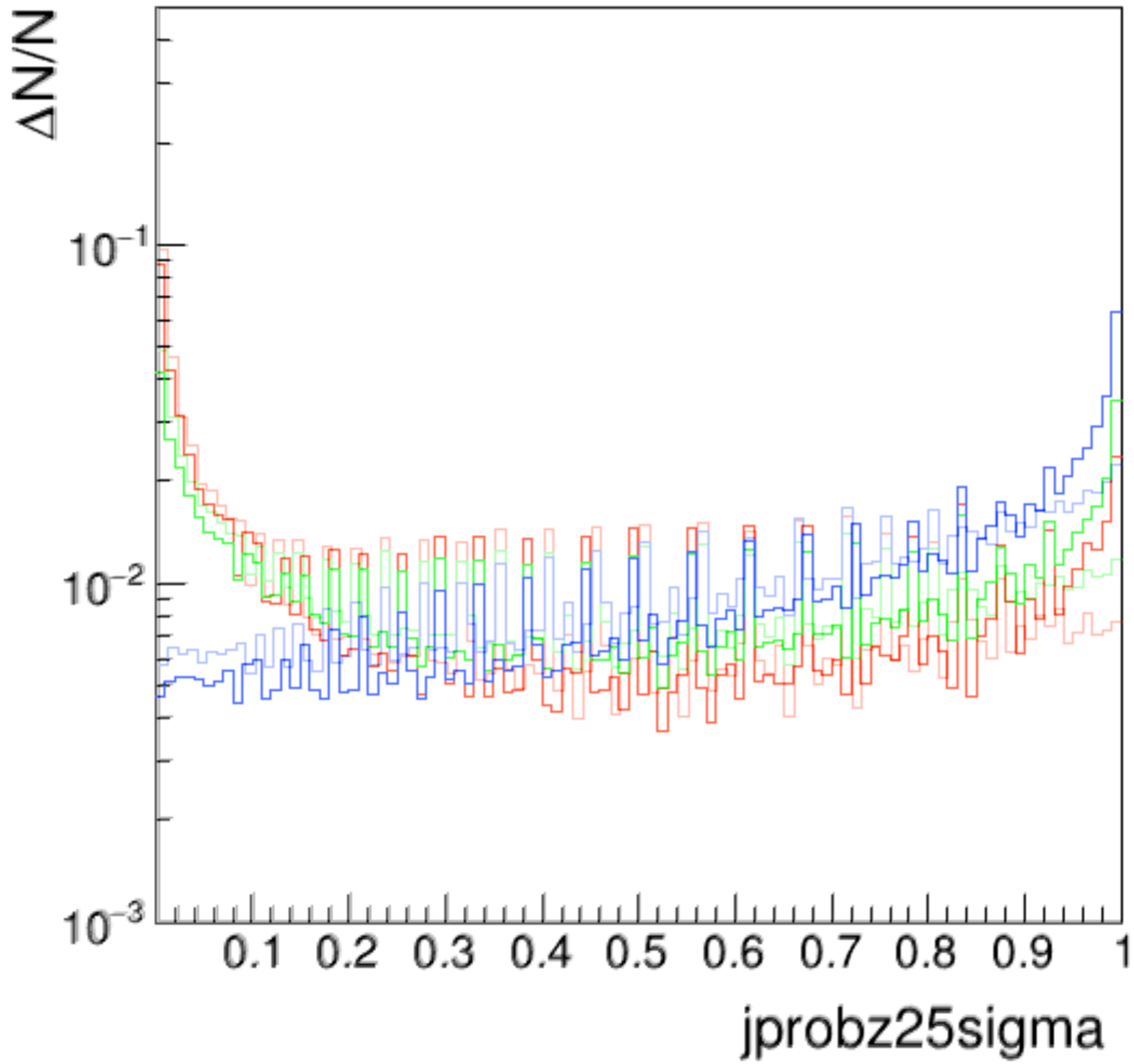
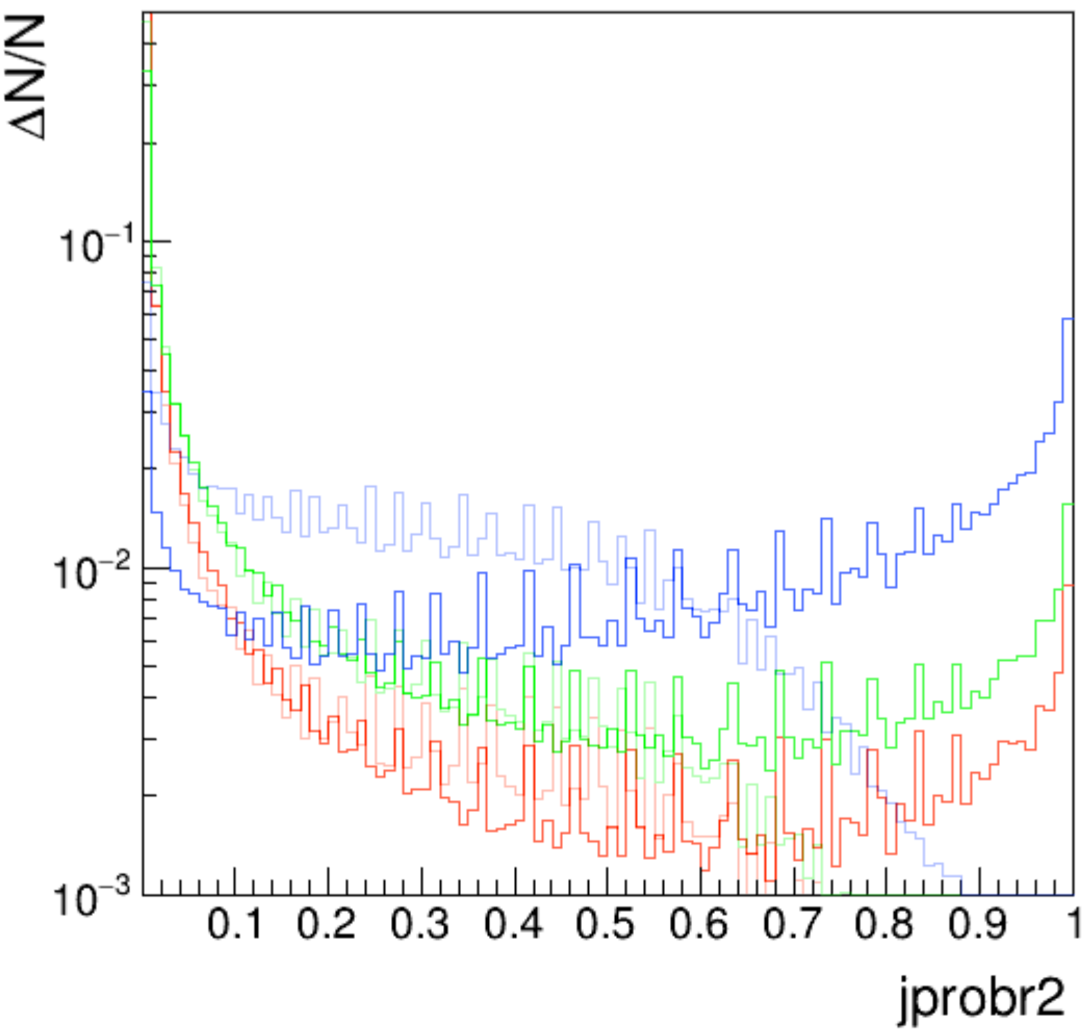


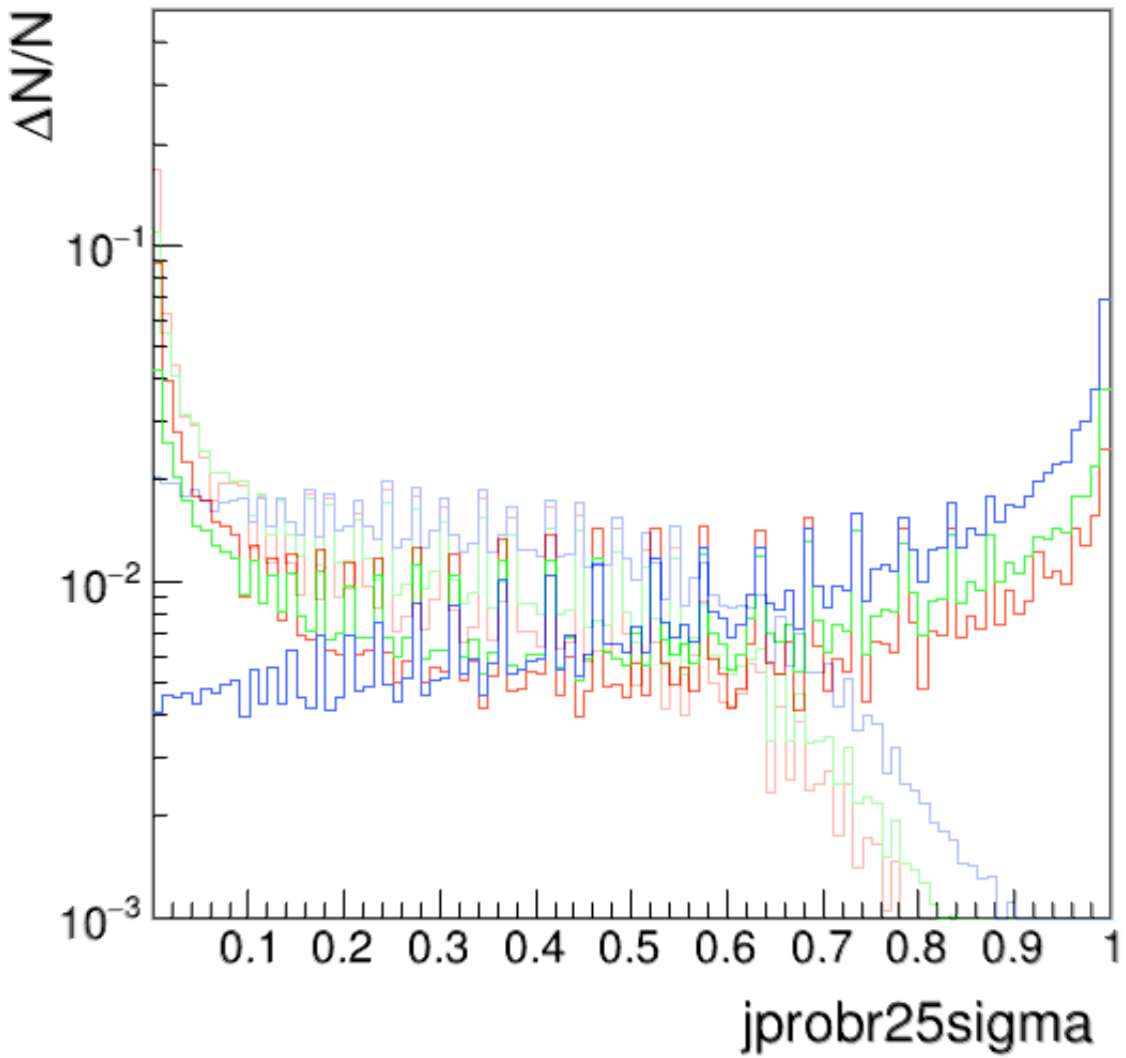
LCFIPlus variables

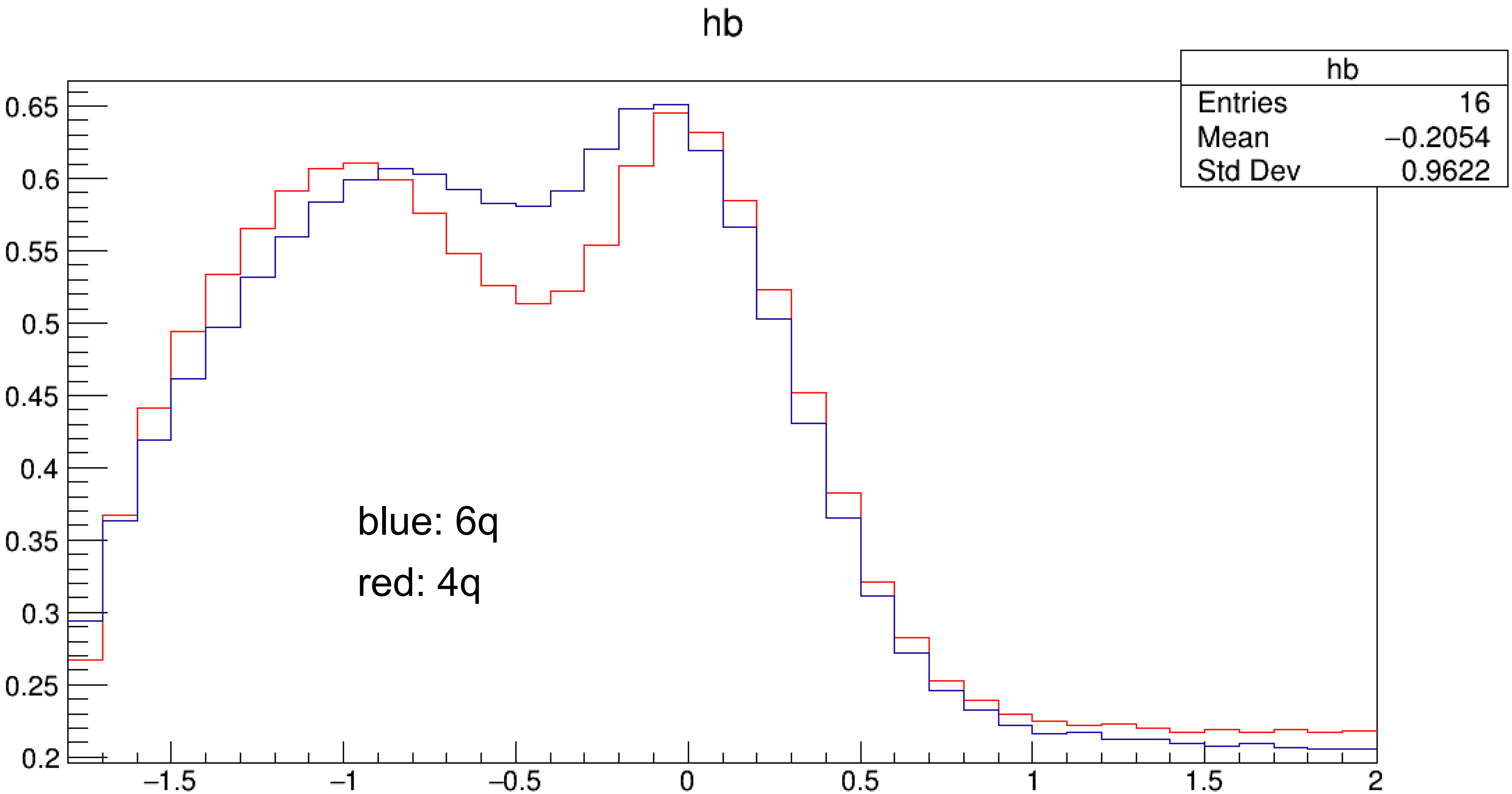


LCFIPlus variables

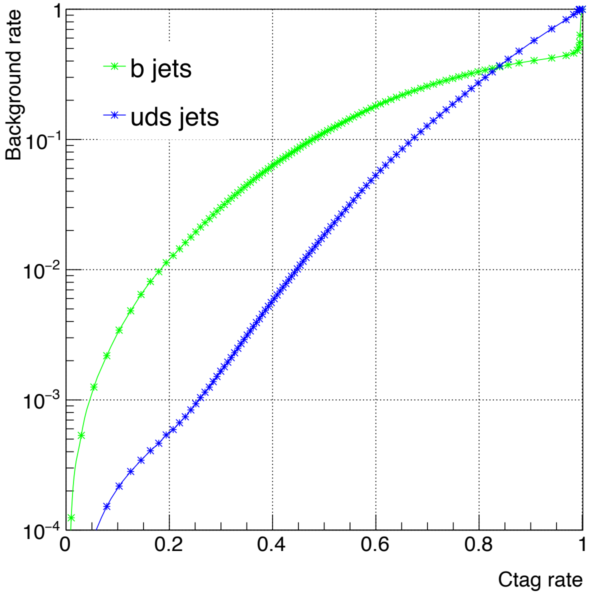


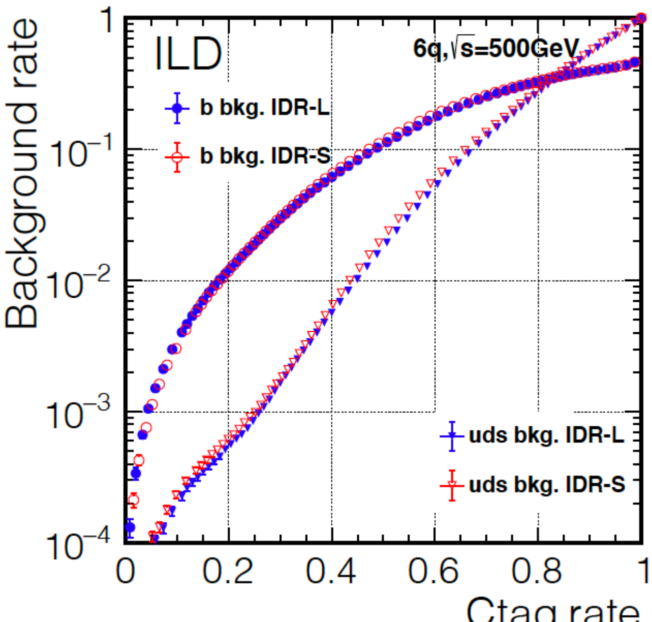
LCFIPlus variables

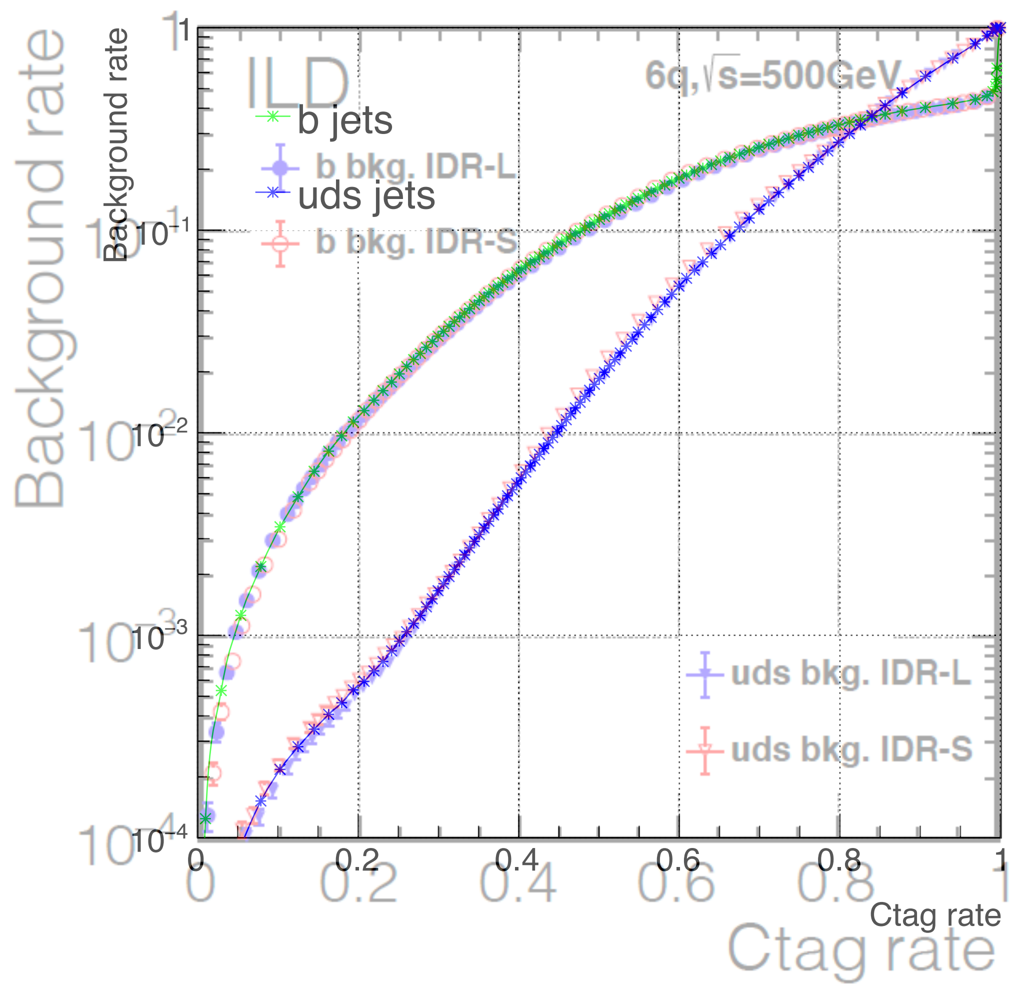



hb
hb
Entries 16
Mean −0.2054
Std Dev 0.9622
blue: 6q
red: 4q
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
−1.5
−1
−0.5
0
0.5
1
1.5
2

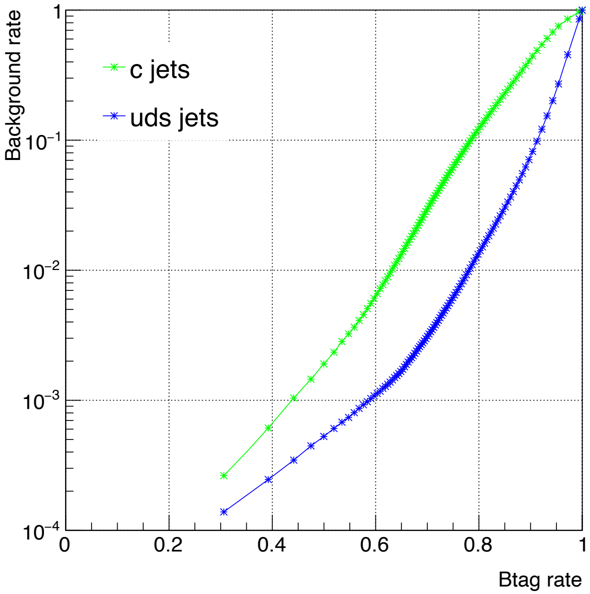
Performance LCFIPlus

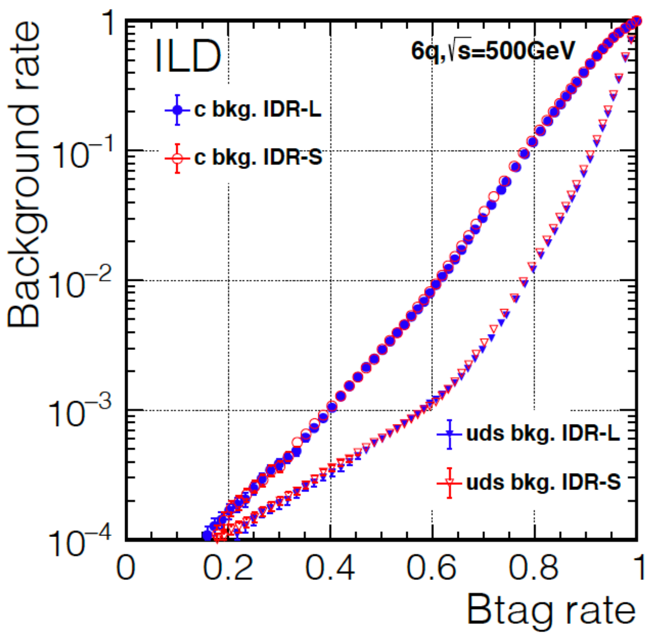


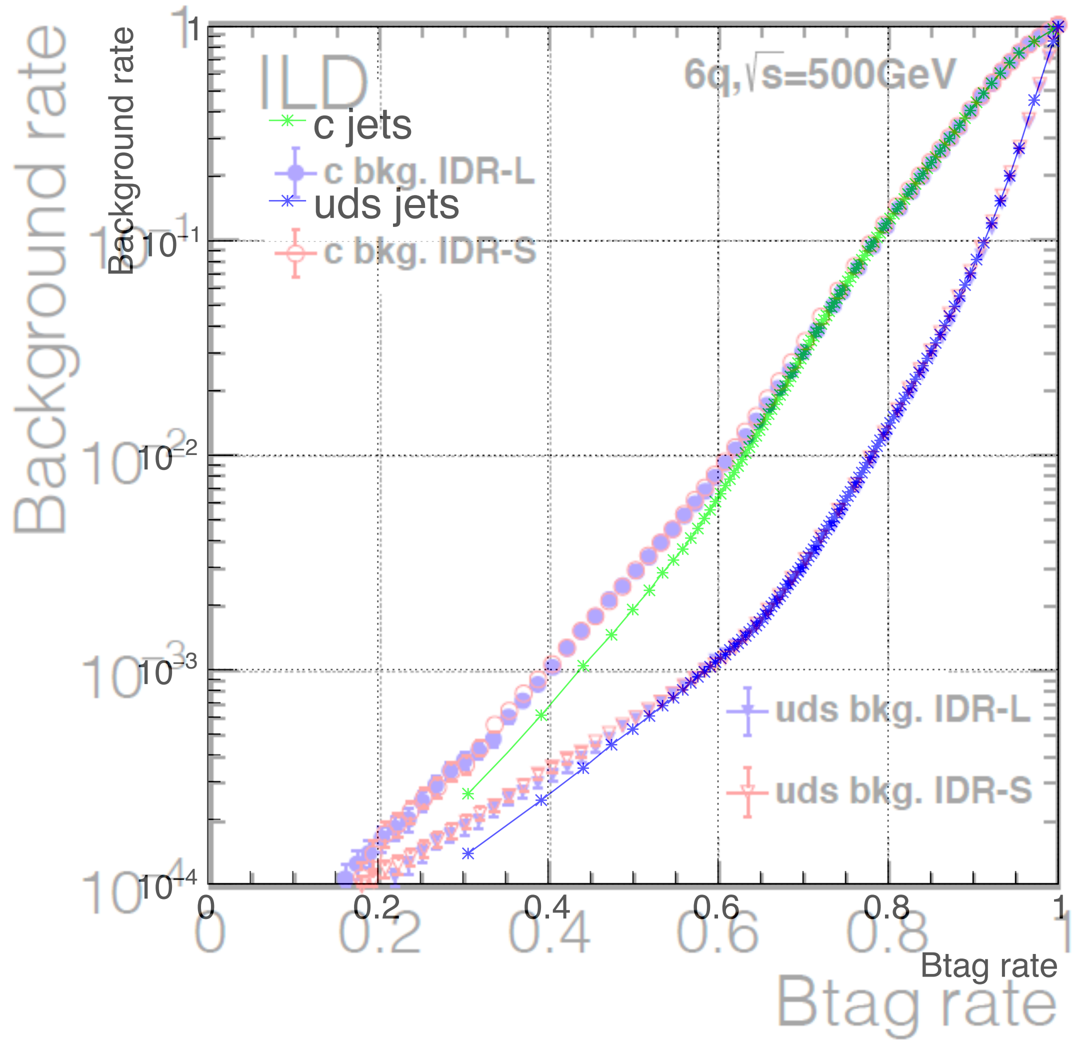




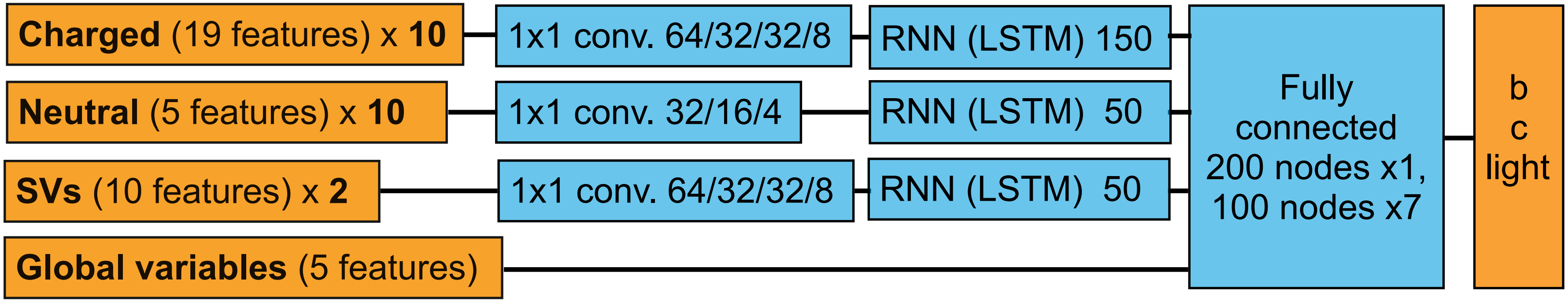
Performance LCFIPlus







Architecture & data pre-processing

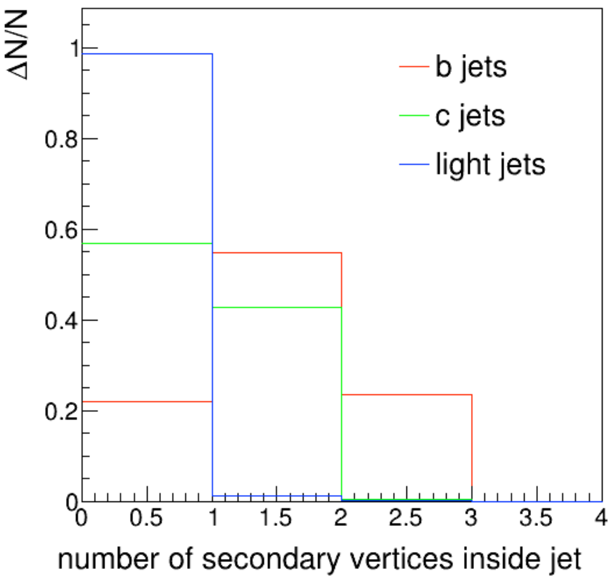


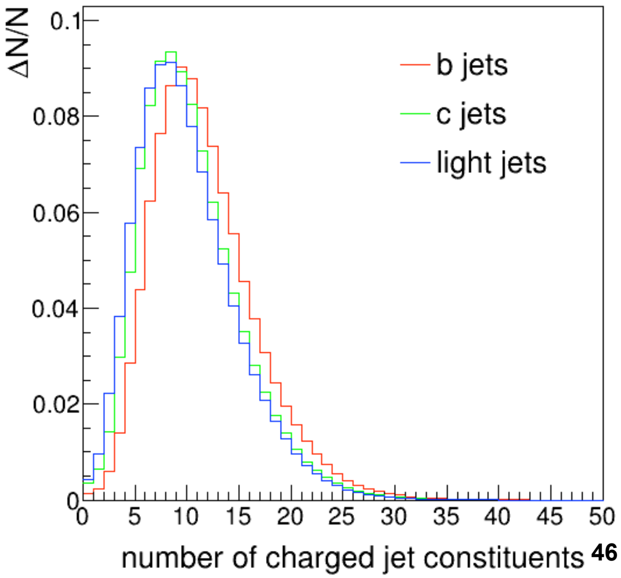
- classify jets into **three classes**: b jets, c jets & light jets
- **ordering of input particles** by (as applied in CMS)
  - impact parameter significance for charged jet constituents
  - shortest angular distance to a secondary vertex (by momentum if there is no secondary vertex) for neutral jet constituents
  - flight distance significance for secondary vertices
- if a value of a features is not available, the value is set to -10
- **normalize input features** to mean 0, std 1

Input features - global variables

- jet momentum
- jet transverse momentum
- number of charged jet constituents
- number of neutral jet constituents
- number of secondary vertices

5 input features

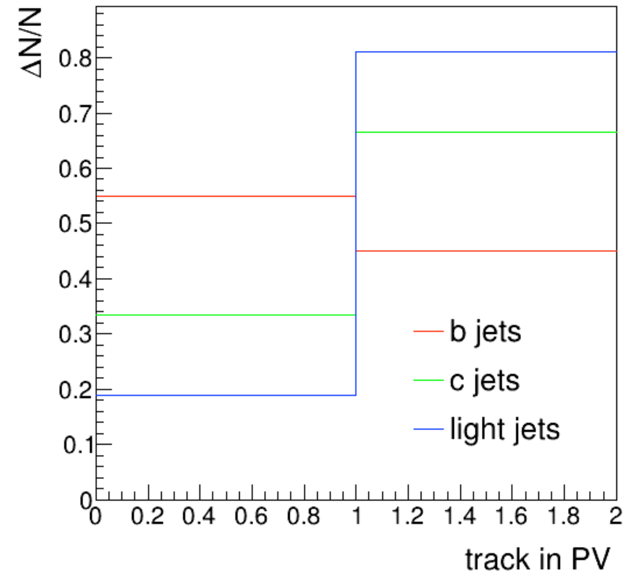


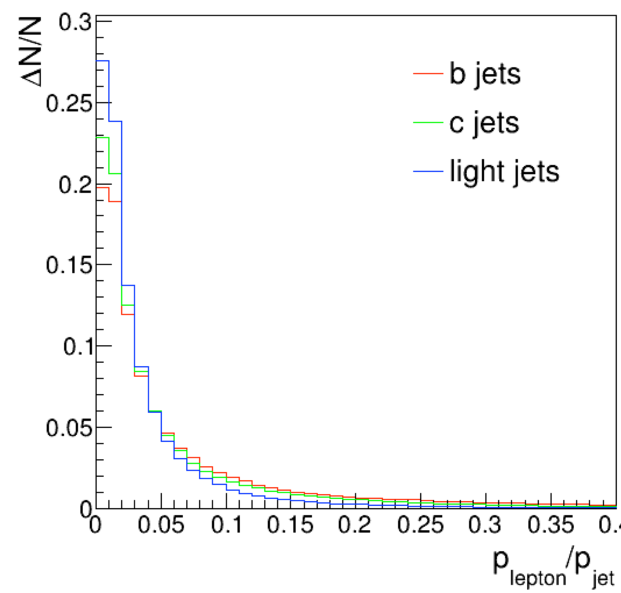


Input features - charged jet constituents

- track momentum / jet momentum
- transverse track momentum relative to jet
- dot product of jet and track momentum w.r.t. jet momentum
- ΔR(track, jet),
- d0, d0 significance
- Z0, Z0 significance
- 3D impact parameter, 3D impact parameter significance
- track reconstructed in PV?
- is electron?, is muon?, lepton momentum relative to jet, lepton transverse momentum relative to the jet, lepton momentum / jet momentum
- kaon-ness of charged particles, track momentum fraction weighted with kaon-ness
- χ2/ndf

19 input features

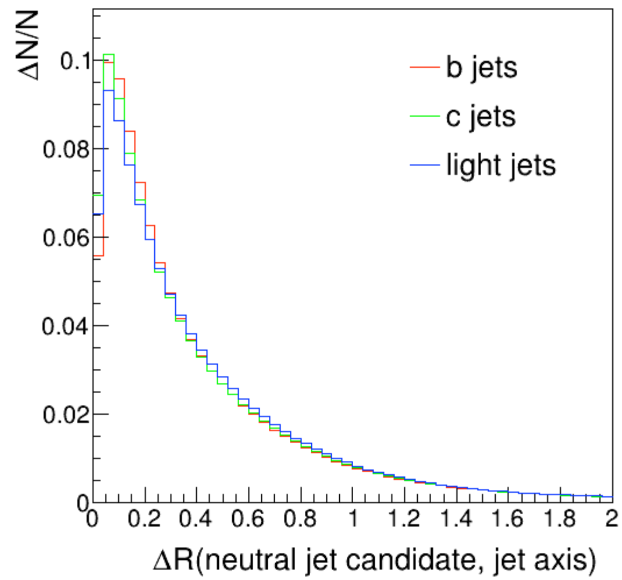


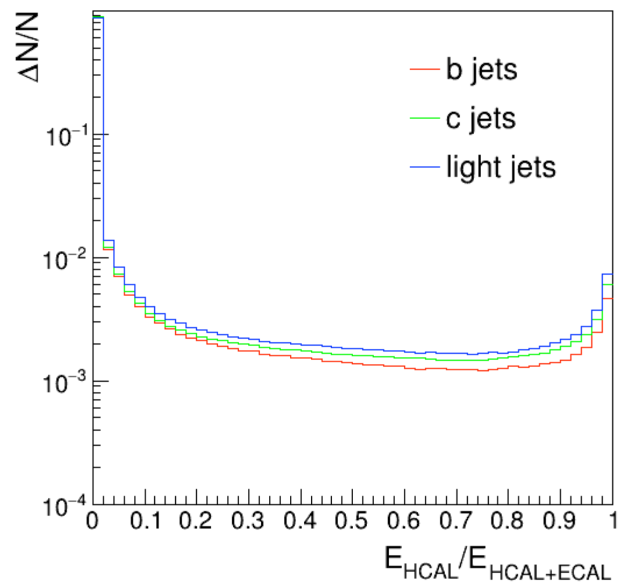


Input features - neutral jet constituents

- momentum of neutral jet constituent
- fraction of the jet momentum carried by neutral jet constituent
- ΔR(jet axis, neutral candidate),
- is photon?
- fraction of neutral candidate energy deposited in the hadronic calorimeter

5 input features

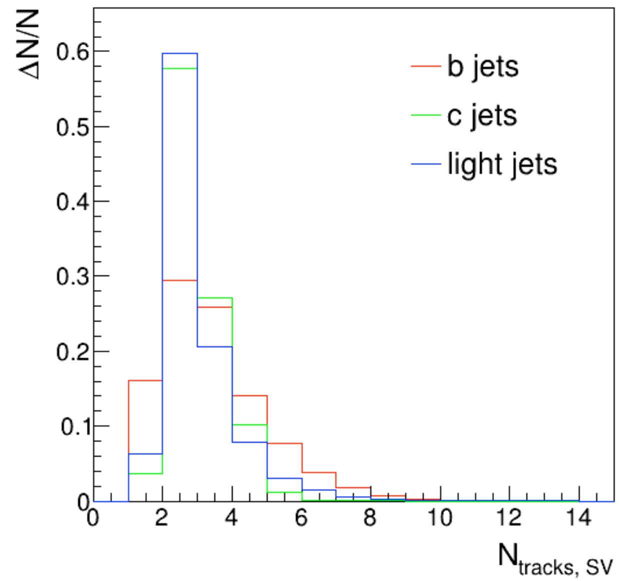


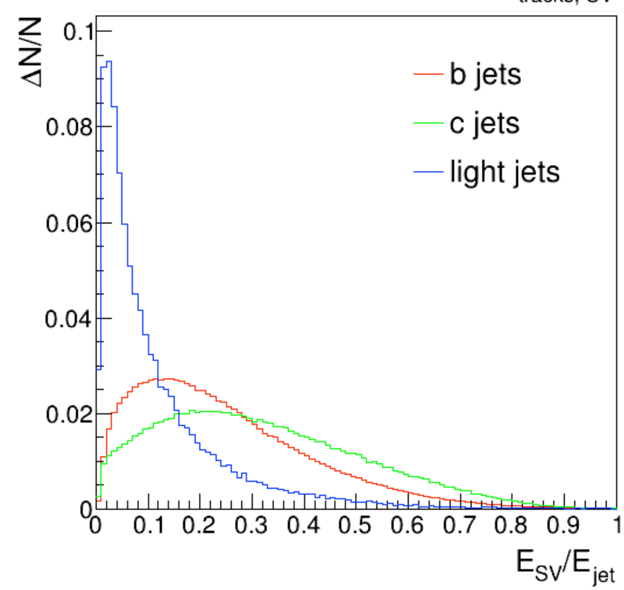


Input features - secondary vertices

- SV mass
- number of tracks in SV
- ΔR(SV, jet)
- SV energy / jet energy
- SV energy
- cosine of the angle between the secondary vertex flight direction and the direction of the secodary vertex momentum
- 3D impact parameter, 3D impact parameter significance
- χ2, ndf

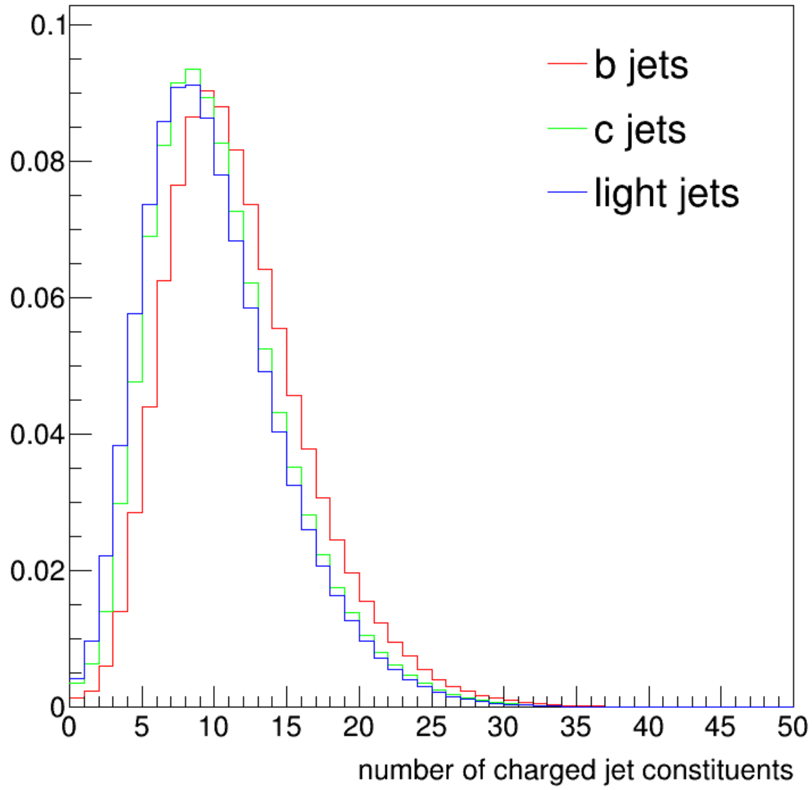
10 input features

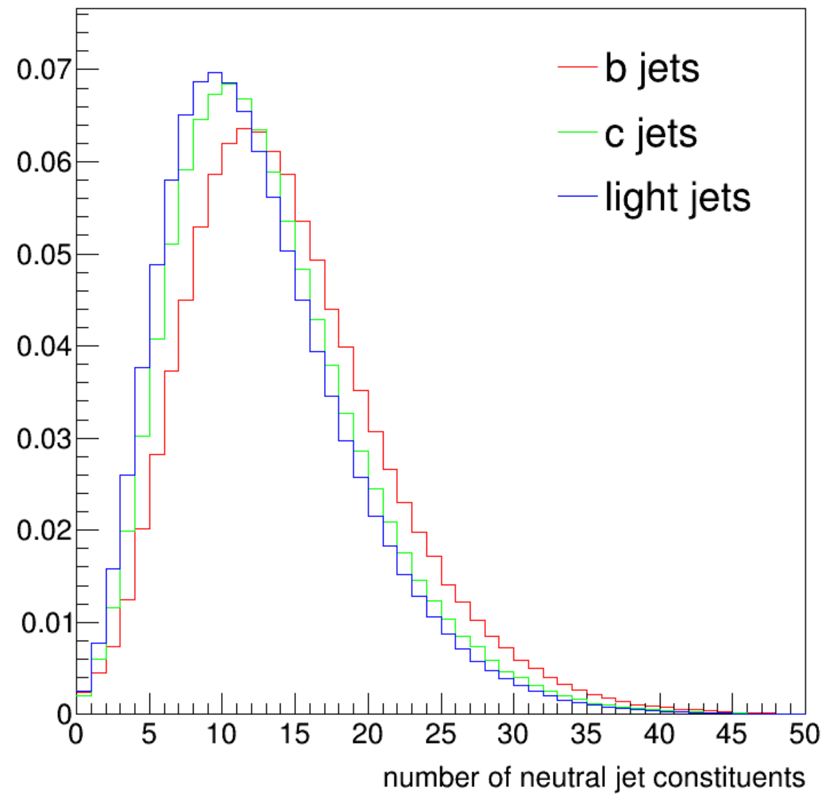




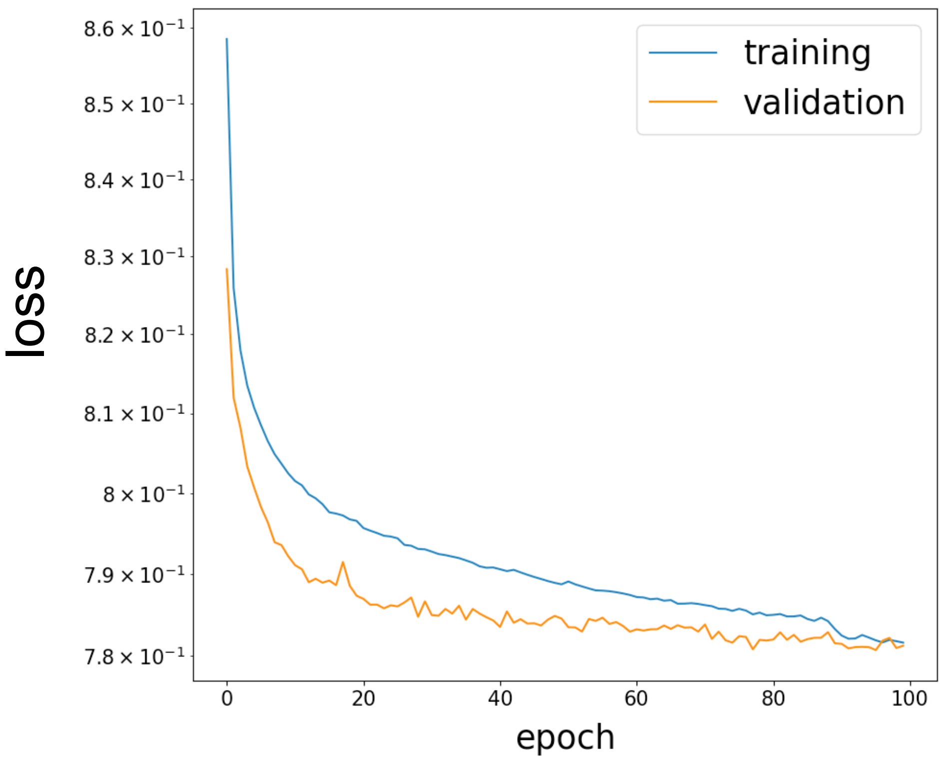
Training

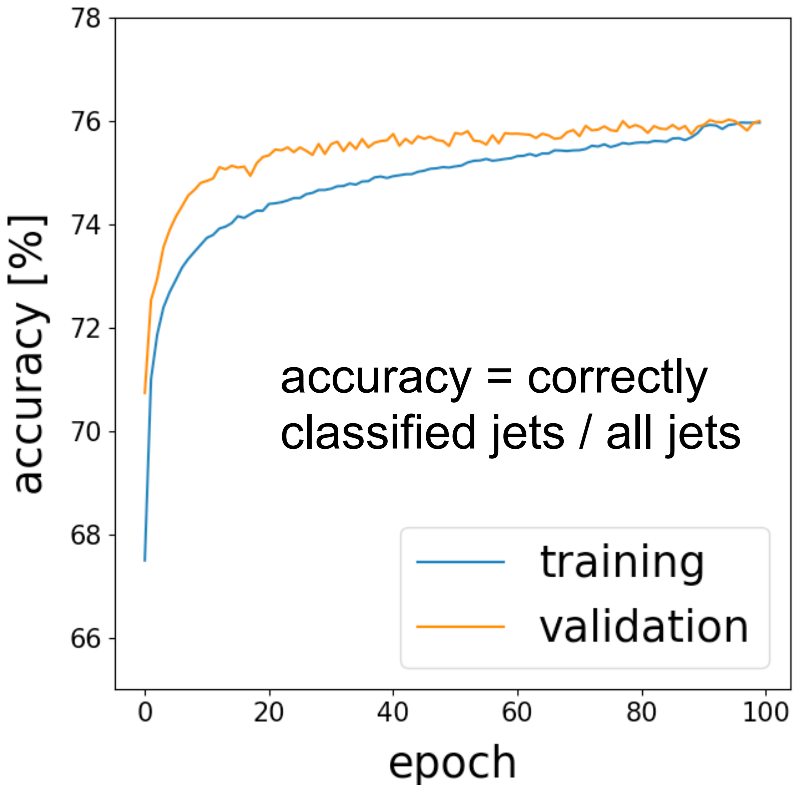
- activation functions: relu / softmax (last layer)
- cross entropy loss
- optimizer: Adam
- regularization: batch normalization, dropout (0.1)
- batch size: 200
- learning rate: 0.0003
- learning rate is halved if validation loss stagnates for 10 epochs
- number of epochs: 100
- Xavier weight initialization


b jets
c jets
light jets
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
40
45
50
number of charged jet constituents


b jets
c jets
light jets
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
20
25
30
35
40
45
50
number of neutral jet constituents

Results: loss & accuracy





- accuracy ~76% in training & validation data
- epoch 89: learning rate halved
- train longer? decrease dropout rate?