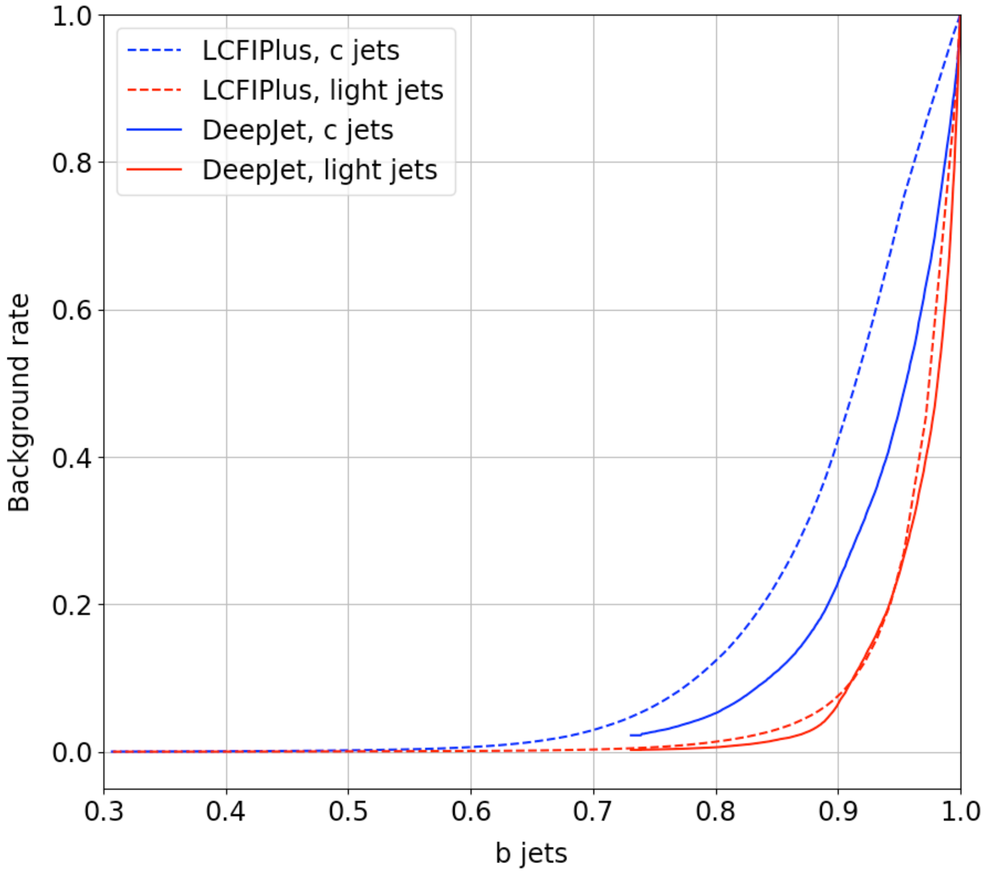
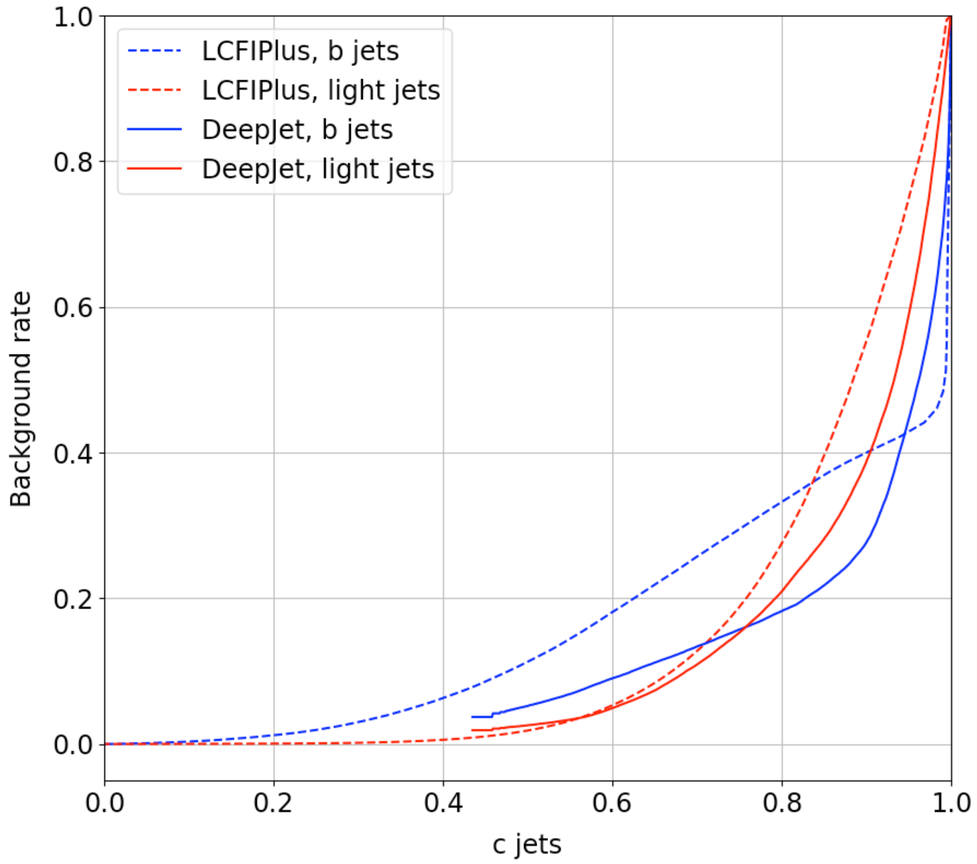
DeepJet



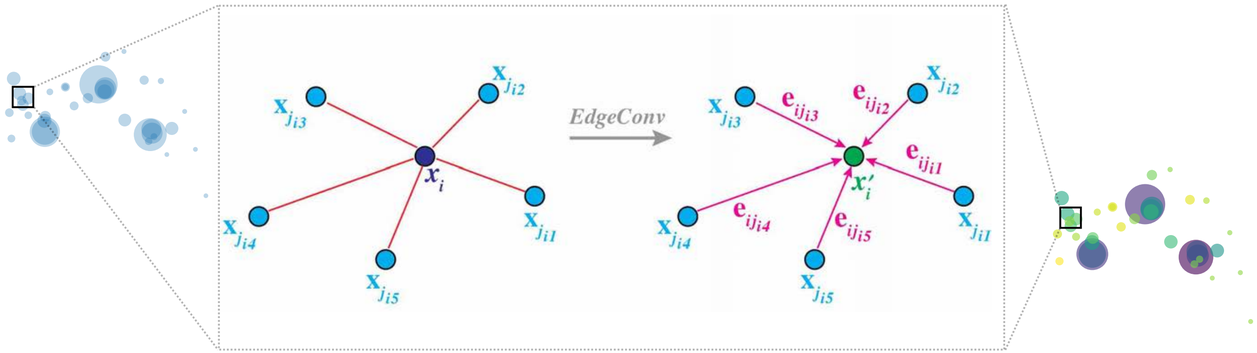


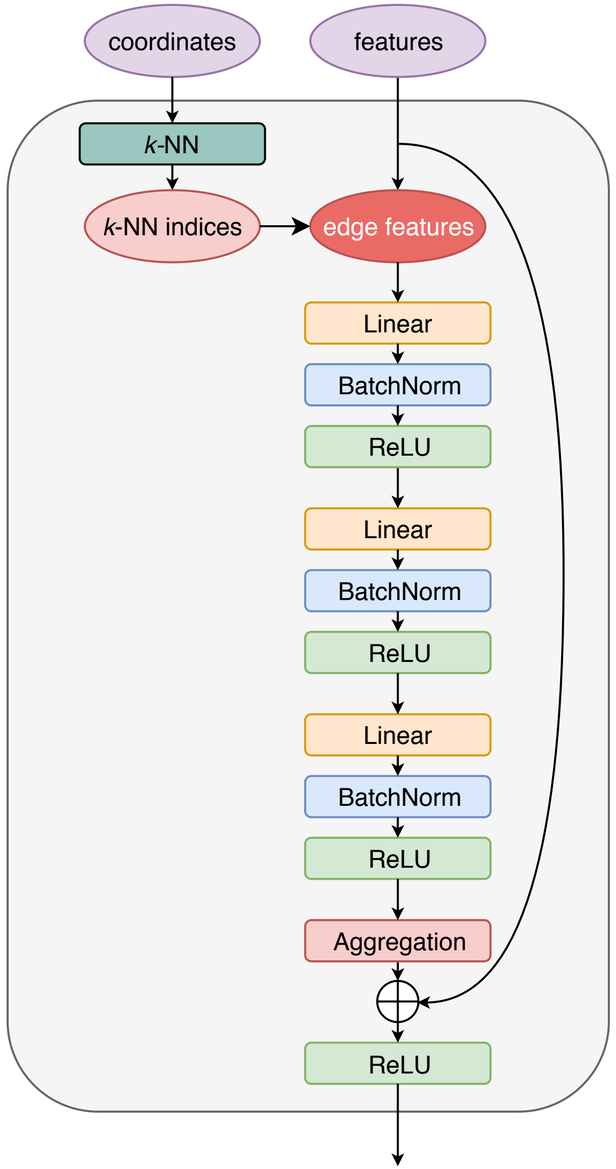
- further optimization of DeepJet architecture
- training: b/c/light jets 1:1:1 (over-sampling of b & c), validation: b/c/light jets 1:1:3
- dropout rate reduced to 5%
- flipped order of the inputs

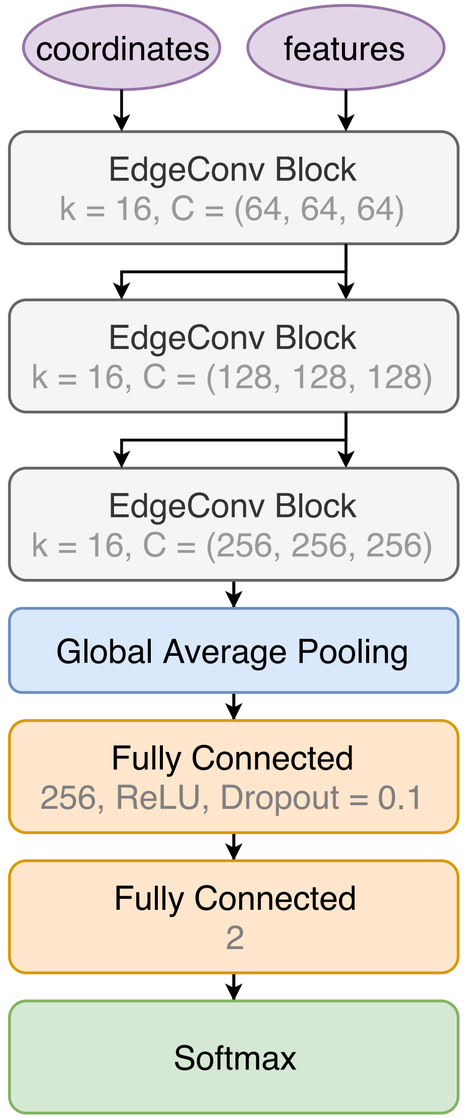
Particle Net: introduction

https://arxiv.org/pdf/1902.08570.pdf, https://indico.cern.ch/event/980214/contributions/4413544/attachments/2277334/3868991/ParticleNeXt_ML4Jets2021_H_Qu.pdf

- based on Dynamic Graph CNN (Y. Wang et al., arXiv:1801.07829)
- treat jet as „particle cloud“, input are all jet constituents
- key building block of Particle Net: EdgeConv
  - treat point cloud as a graph, each point is a vertex, edges are constructed as connections between each points and k nearest neighboring points
  - learn an „edge feature“ for each pair $e_{ij} = \mathrm{MLP}(x_i, x_j)$
  - MLP: parameters are shared among all edges
  - aggregation of edge features: $x_i' = \mathrm{mean}_j\, e_{ij}$







(a) ParticleNet

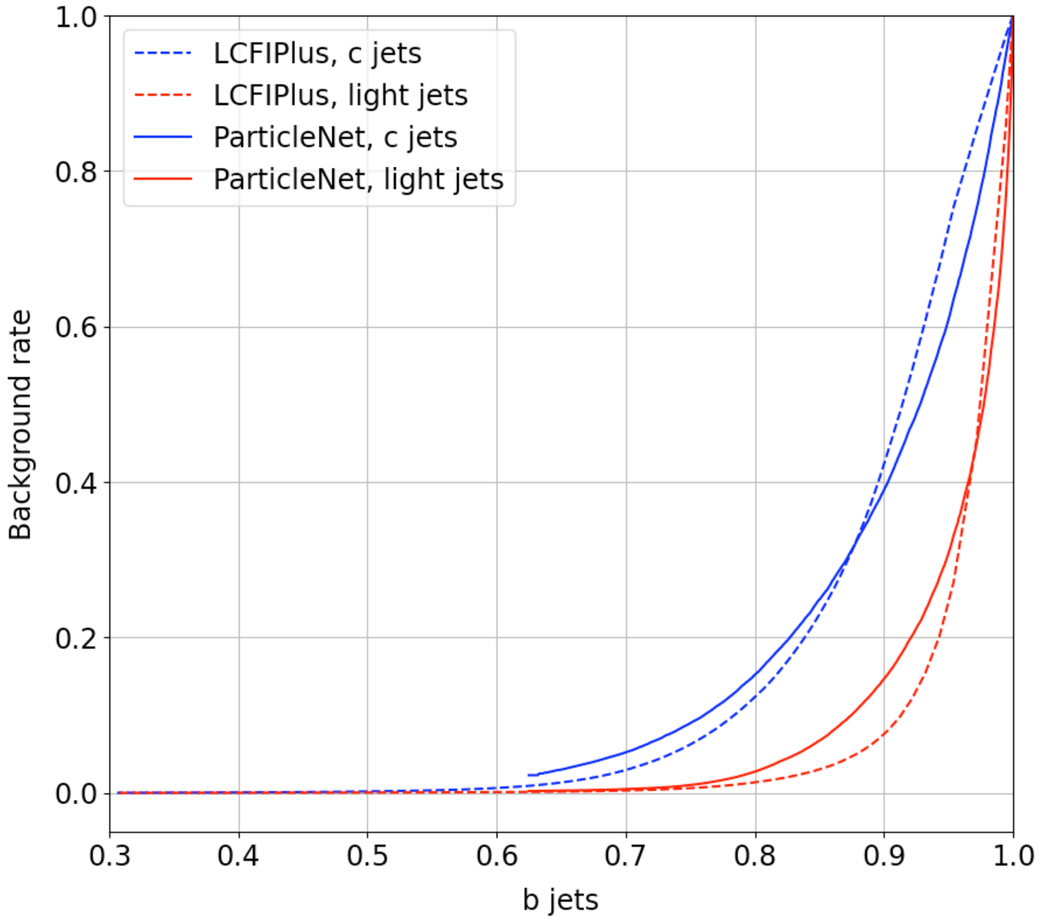
Particle Net: introduction

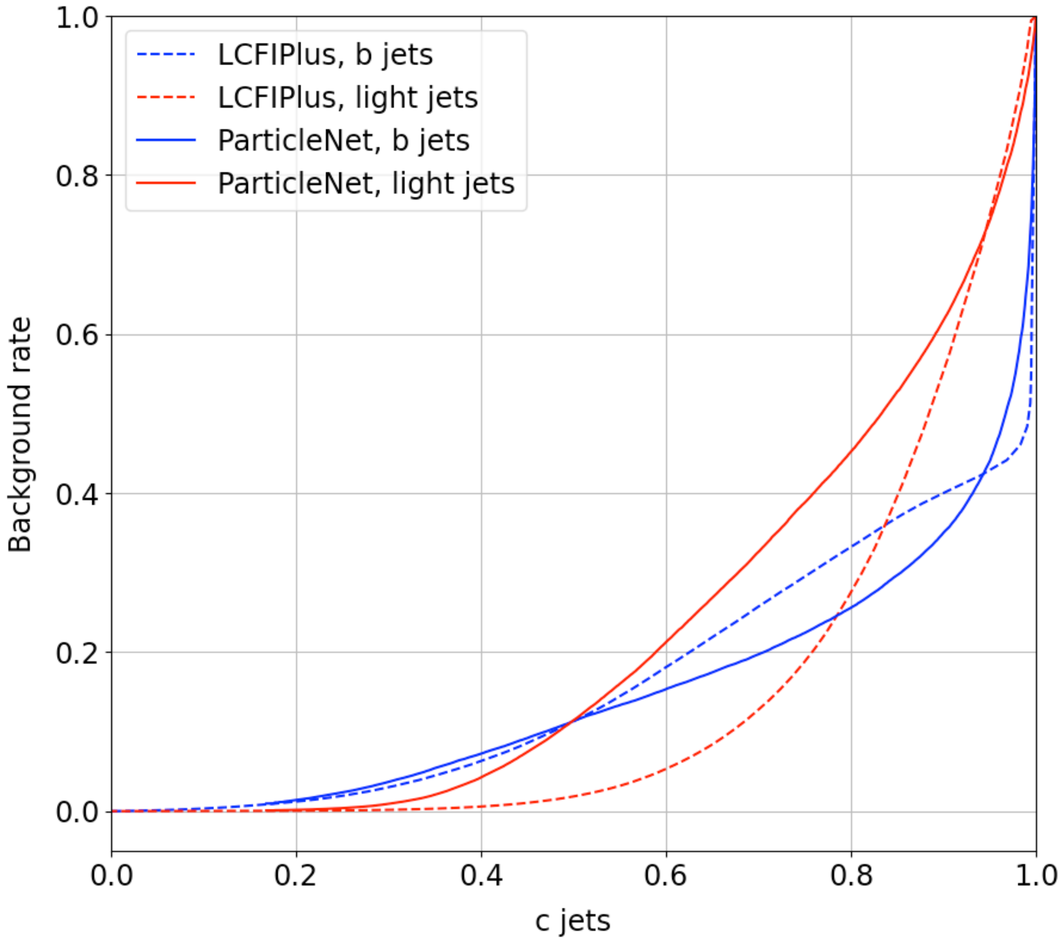
Variable	Definition
$\Delta\eta$	difference in pseudorapidity between the particle and the jet axis
$\Delta\phi$	difference in azimuthal angle between the particle and the jet axis
$\log p_T$	logarithm of the particle's p_T
$\log E$	logarithm of the particle's energy
$\log \frac{p_T}{p_T(\text{jet})}$	logarithm of the particle's p_T relative to the jet p_T
$\log \frac{E}{E(\text{jet})}$	logarithm of the particle's energy relative to the jet energy
ΔR	angular separation between the particle and the jet axis ($\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$)
q	electric charge of the particle
`isElectron`	if the particle is an electron
`isMuon`	if the particle is a muon
`isChargedHadron`	if the particle is a charged hadron
`isNeutralHadron`	if the particle is a neutral hadron
`isPhoton`	if the particle is a photon

- secondary vertices:
  - coordinates: Δη, ΔΦ
  - features: log(pT), mass, number of tracks, χ2/ndf, 2D & 3D IP and their significances

- 2 SVs, all jet constituents

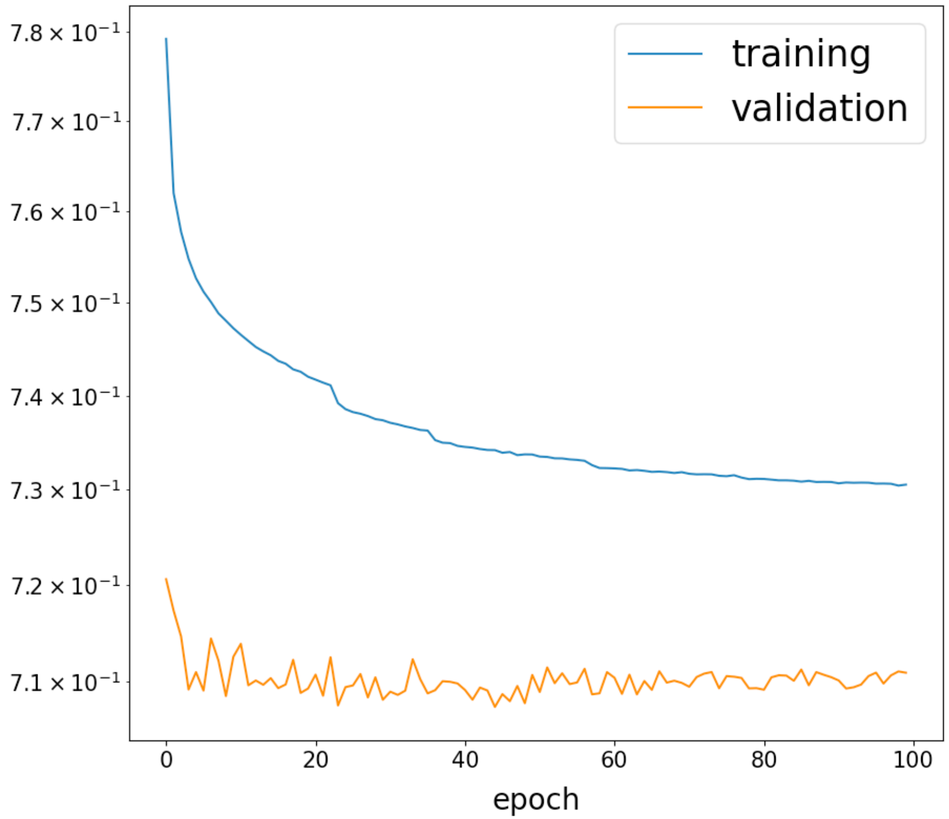
Particle Net : first results

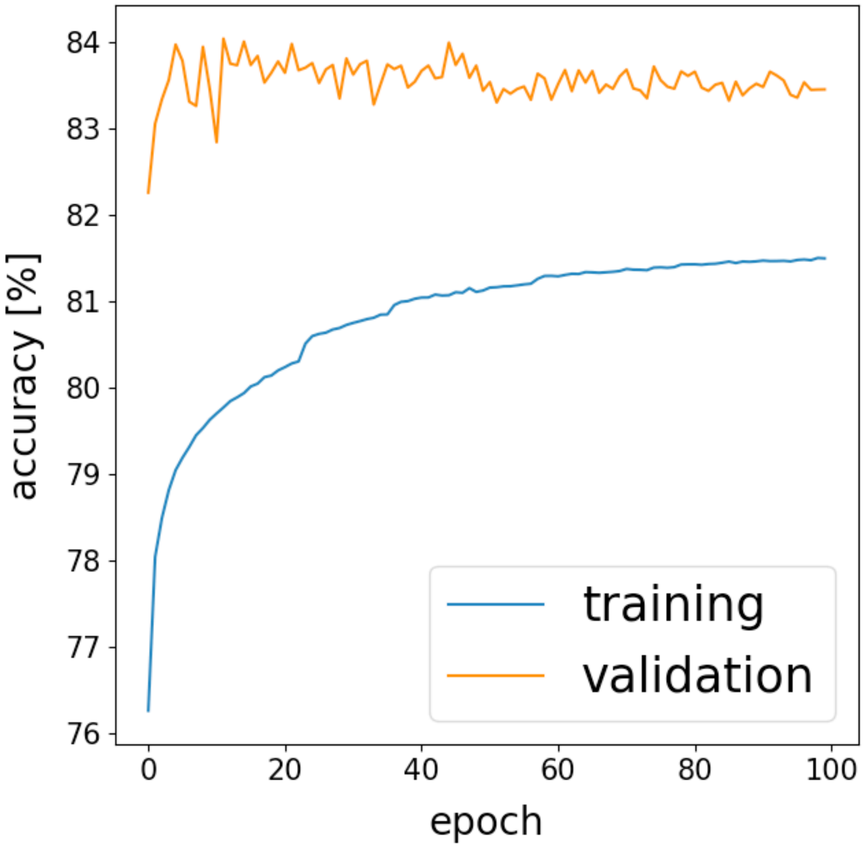




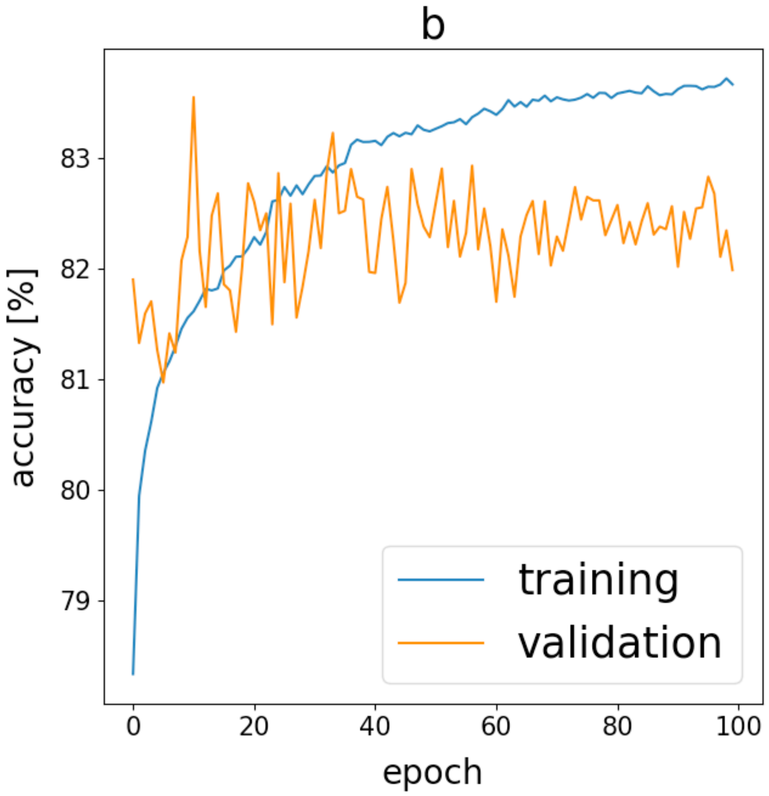
Backup

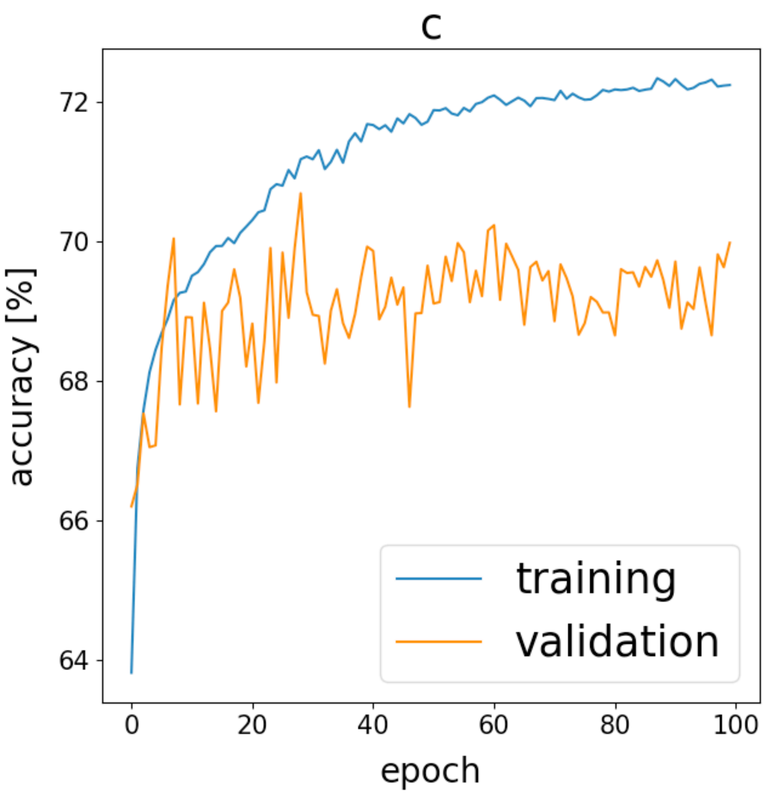
DeepJet

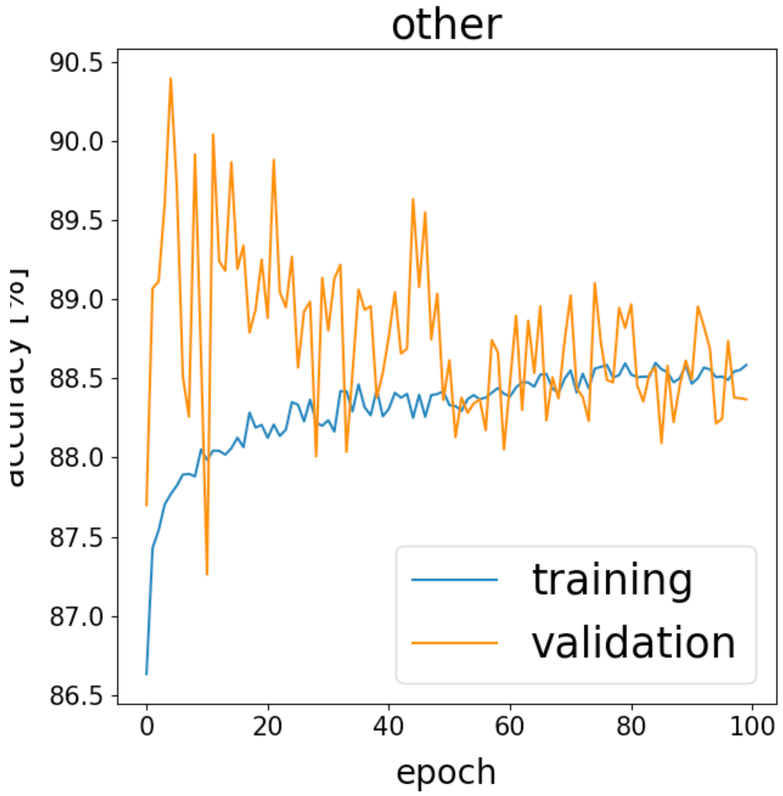

7.8×10^{-1}
7.7×10^{-1}
7.6×10^{-1}
7.5×10^{-1}
7.4×10^{-1}
7.3×10^{-1}
7.2×10^{-1}
7.1×10^{-1}
0
20
40
60
80
100
epoch
training
validation


accuracy [%]
84
83
82
81
80
79
78
77
76
0
20
40
60
80
100
epoch
training
validation

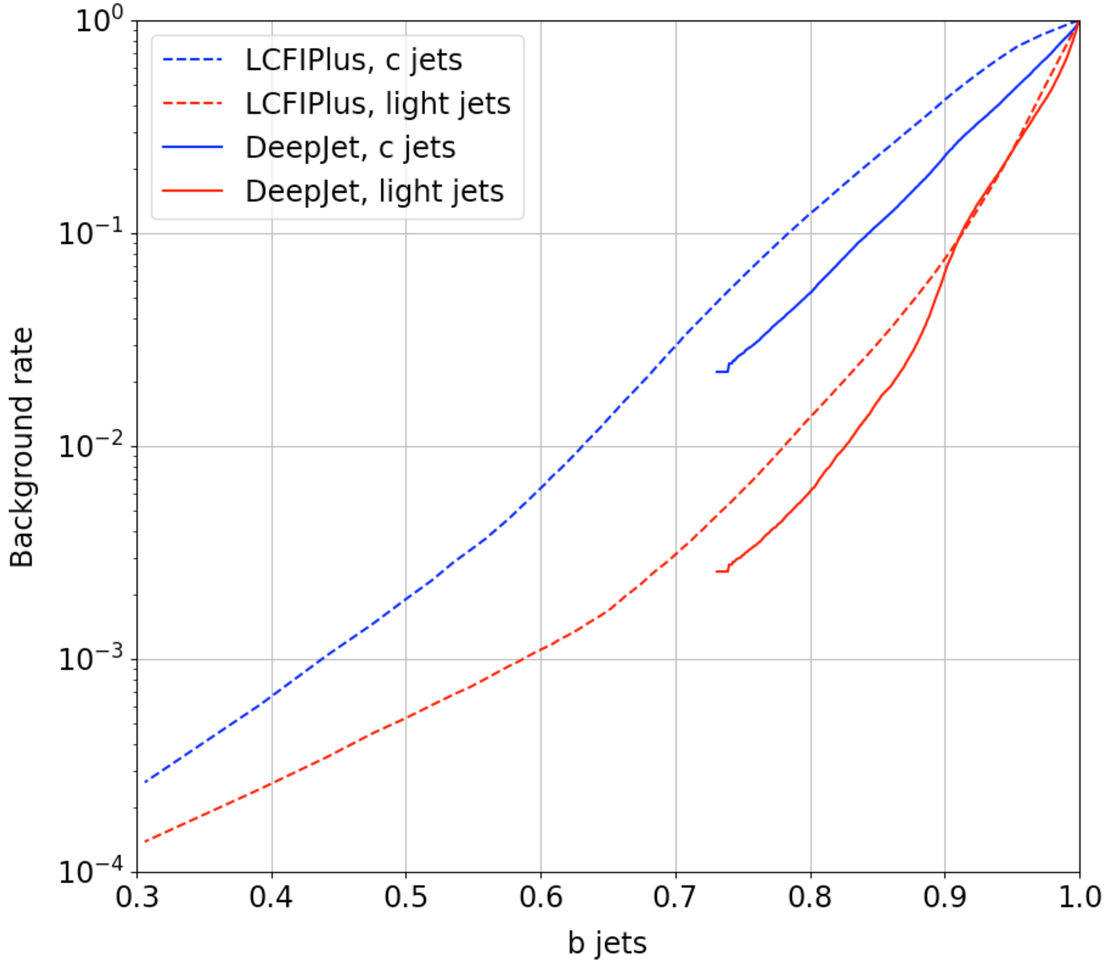
DeepJet

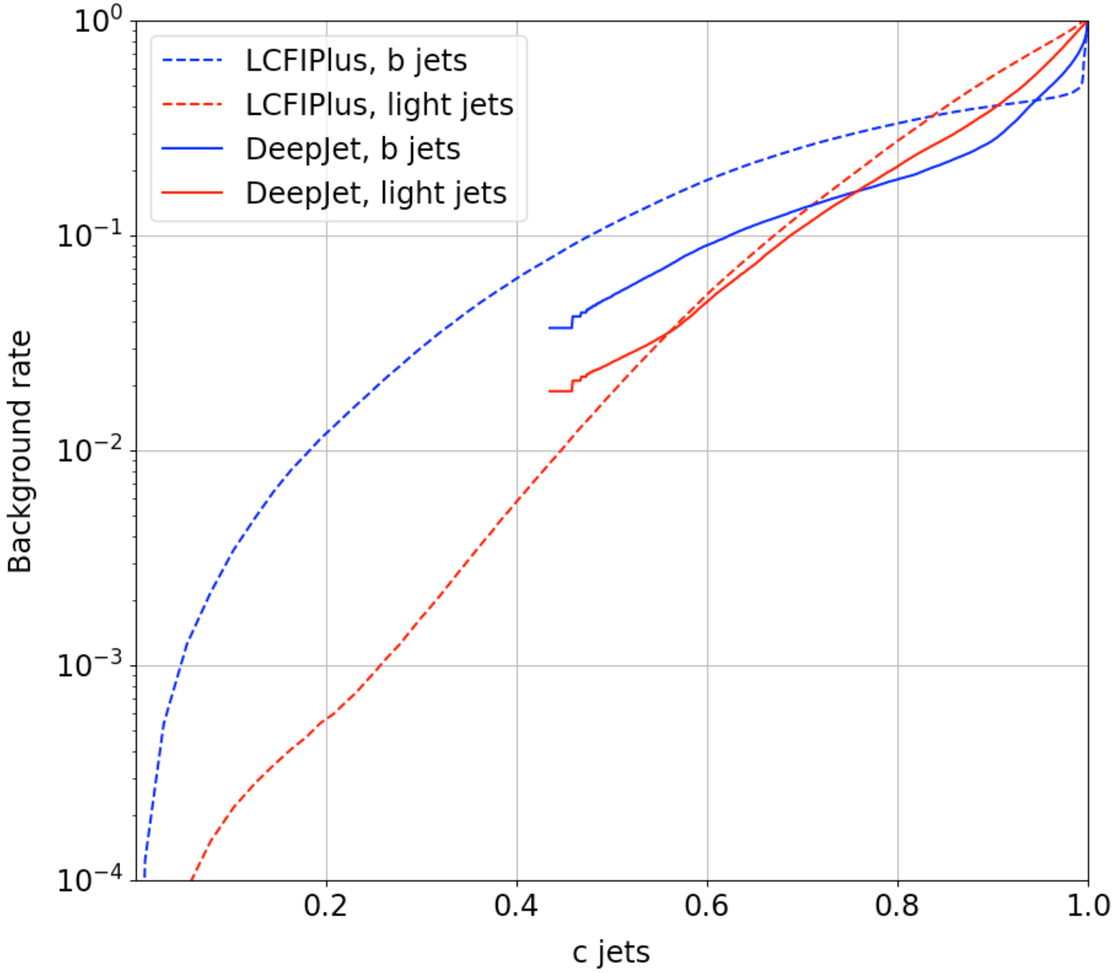

b
accuracy [%]
epoch
training
validation


c
accuracy [%]
epoch
training
validation

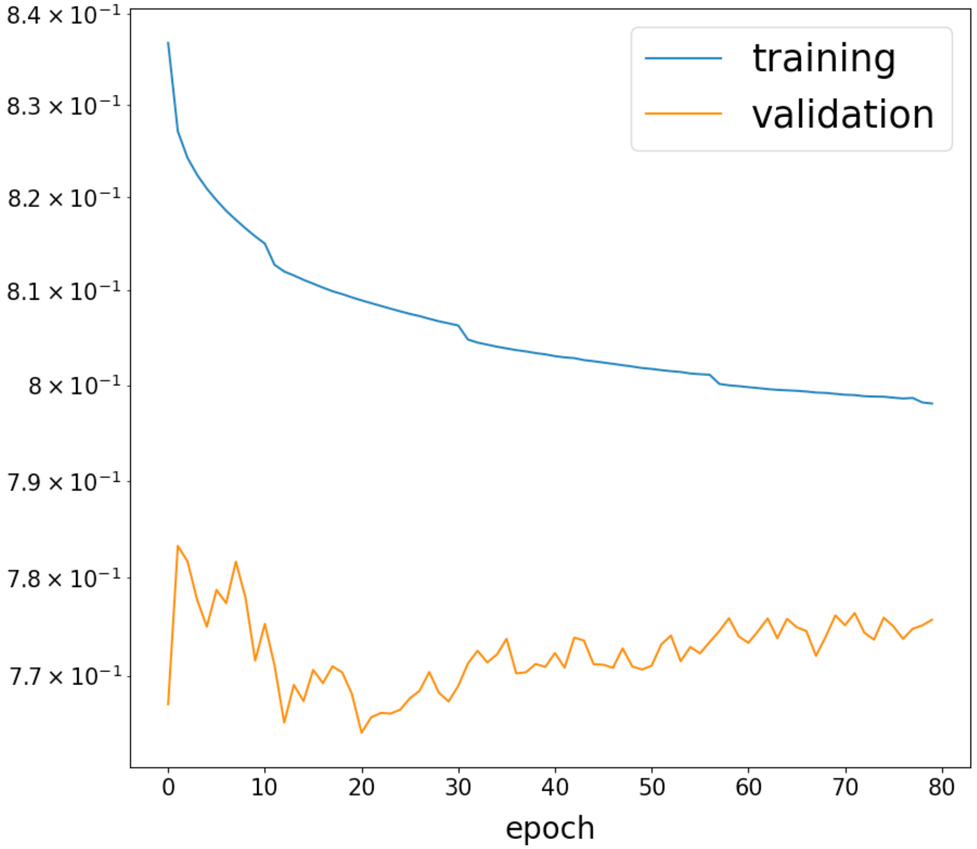

other
epoch
training
validation

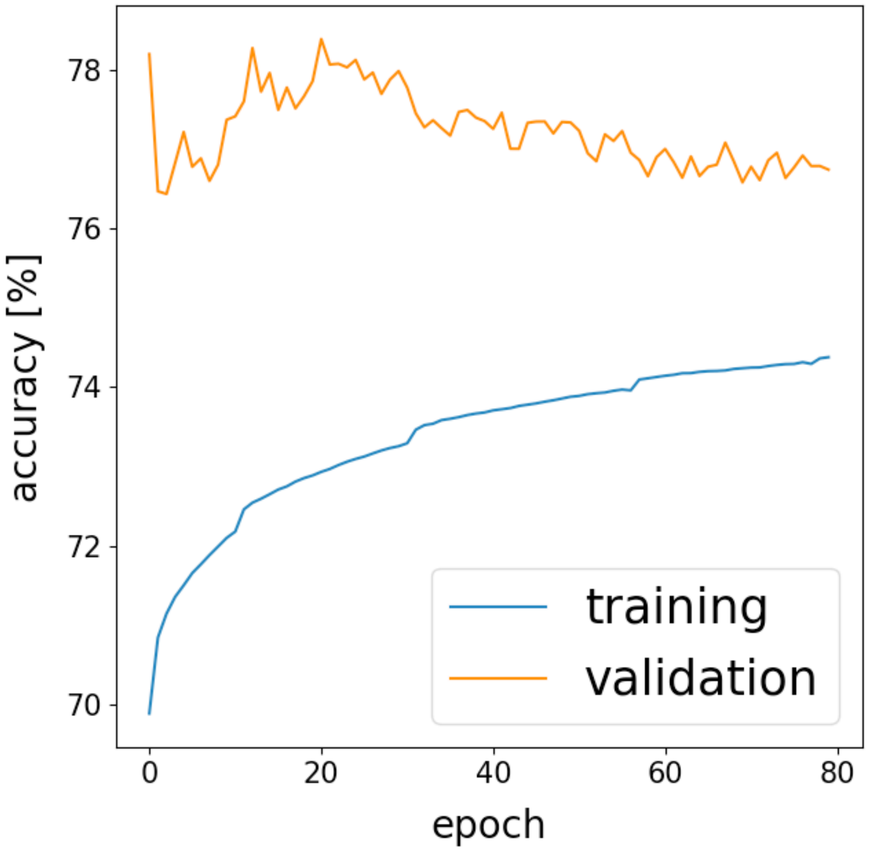
DeepJet


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

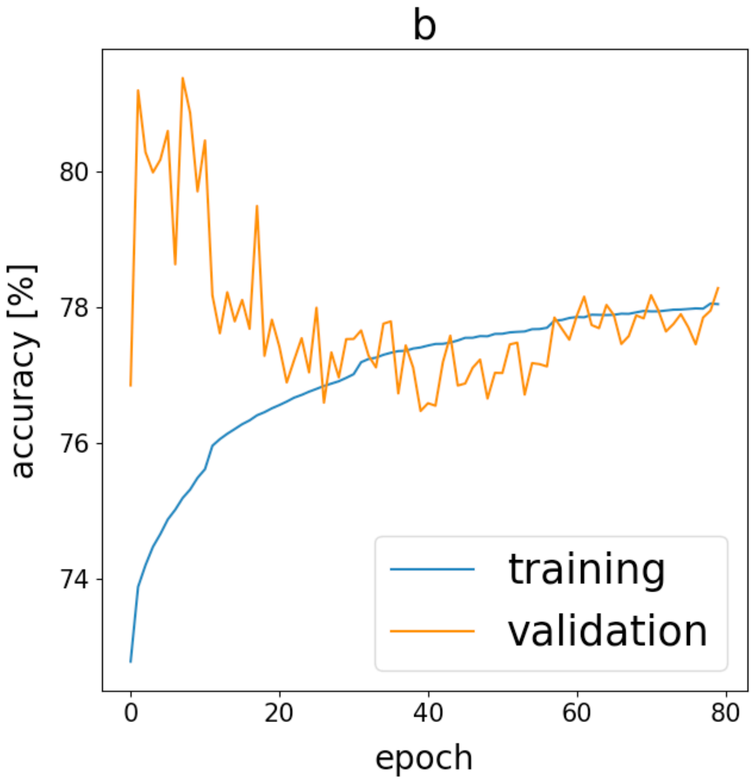

LCFIPlus, b jets
LCFIPlus, light jets
DeepJet, b jets
DeepJet, light jets
Background rate
c jets
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0.2
0.4
0.6
0.8
1.0

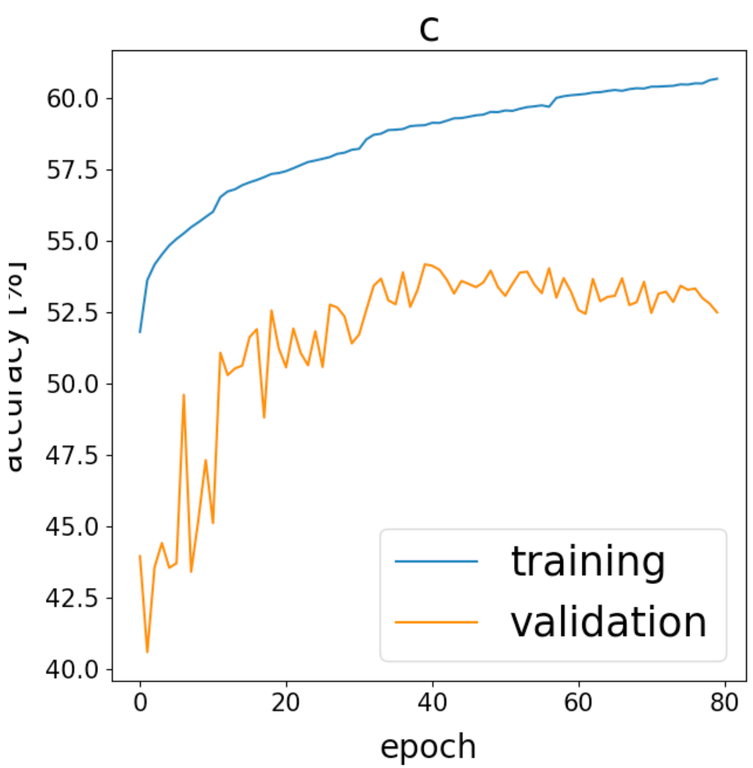
Particle Net : first results

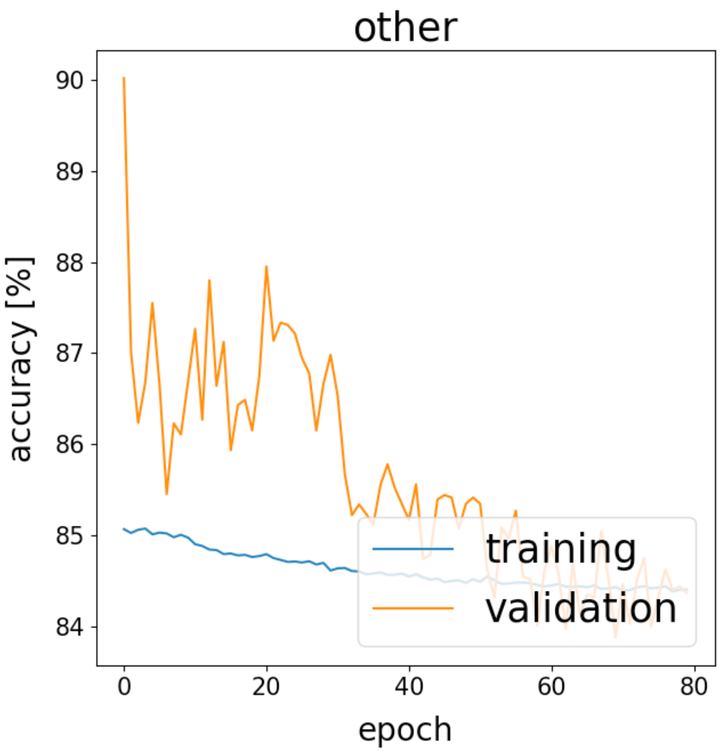




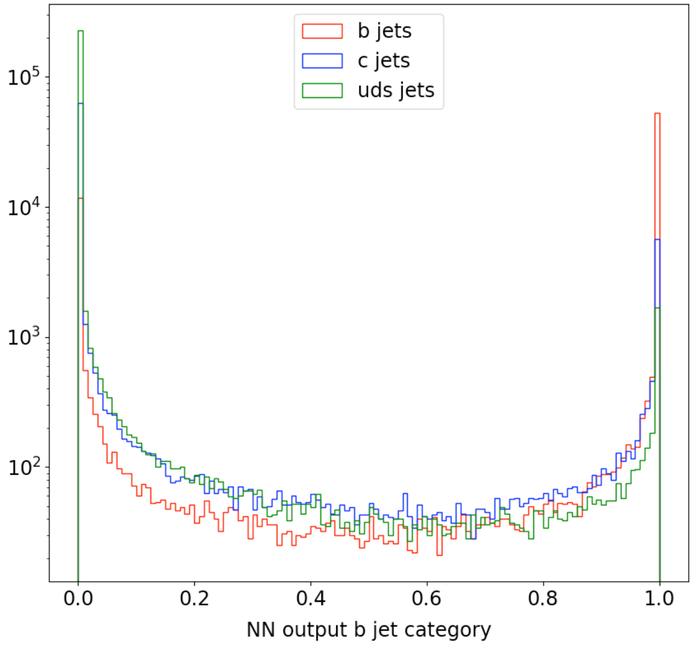
Particle Net : first results

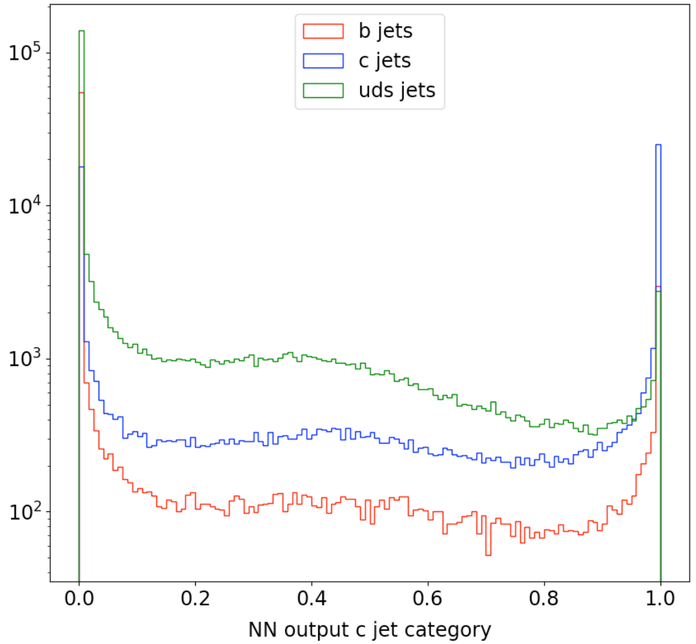


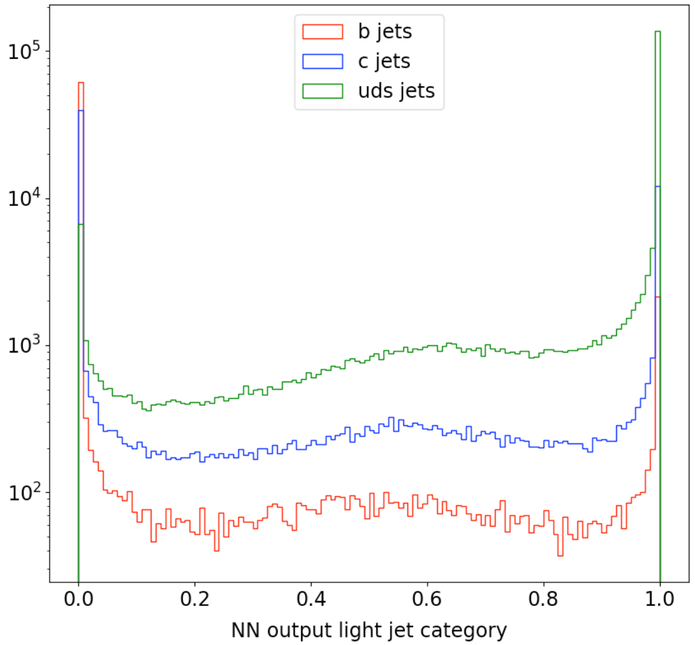




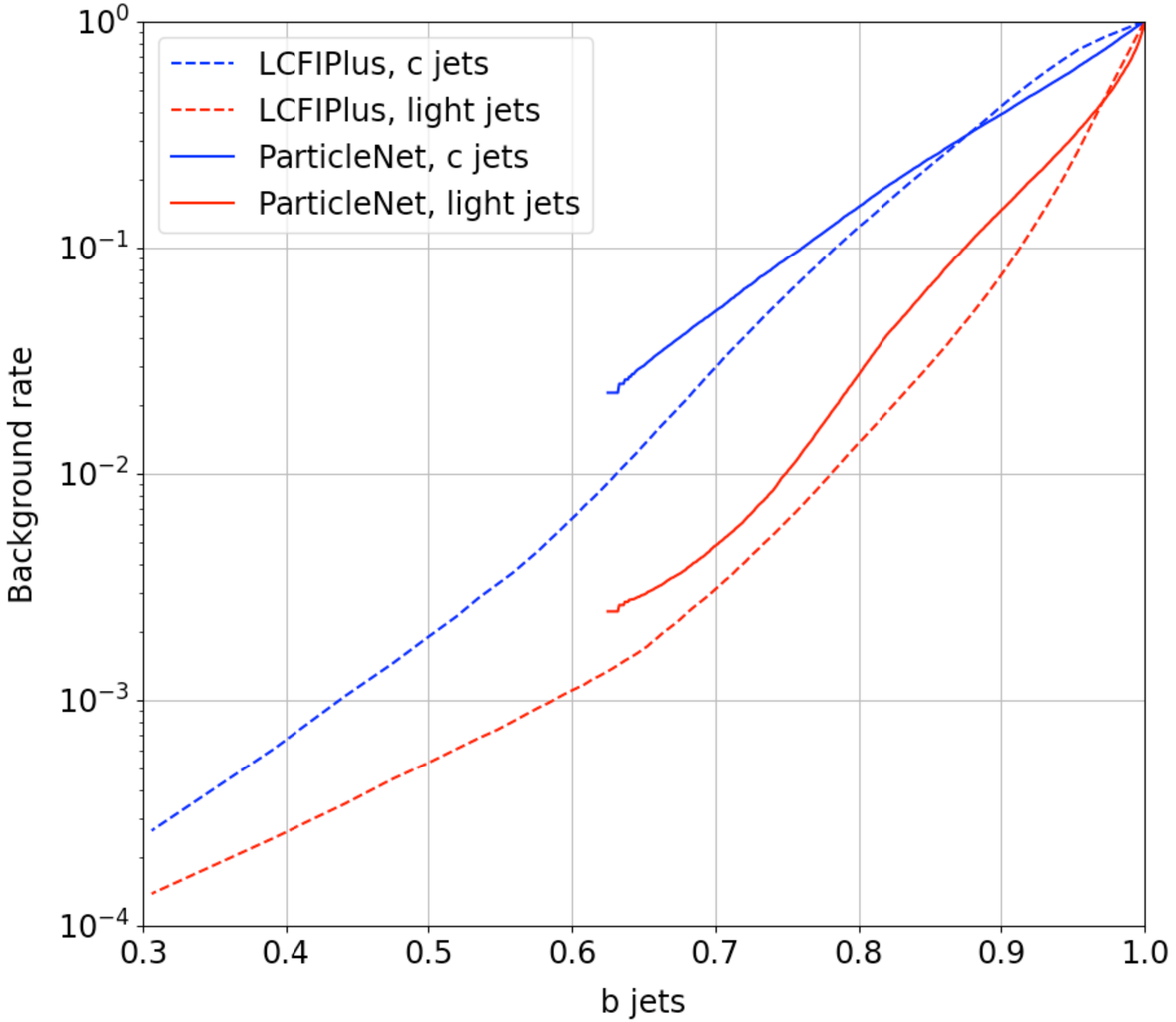
Particle Net : first results

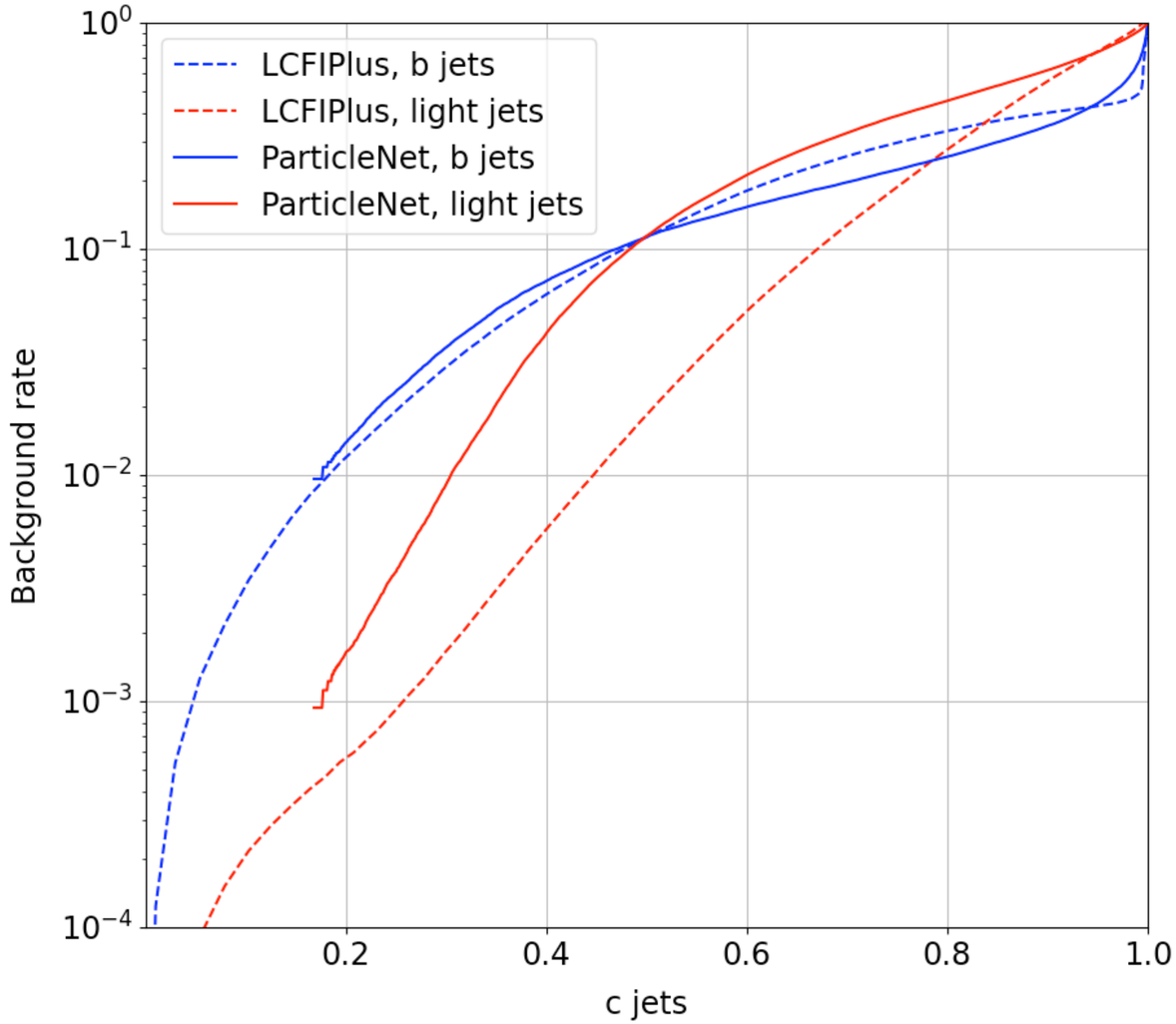






Particle Net : first results



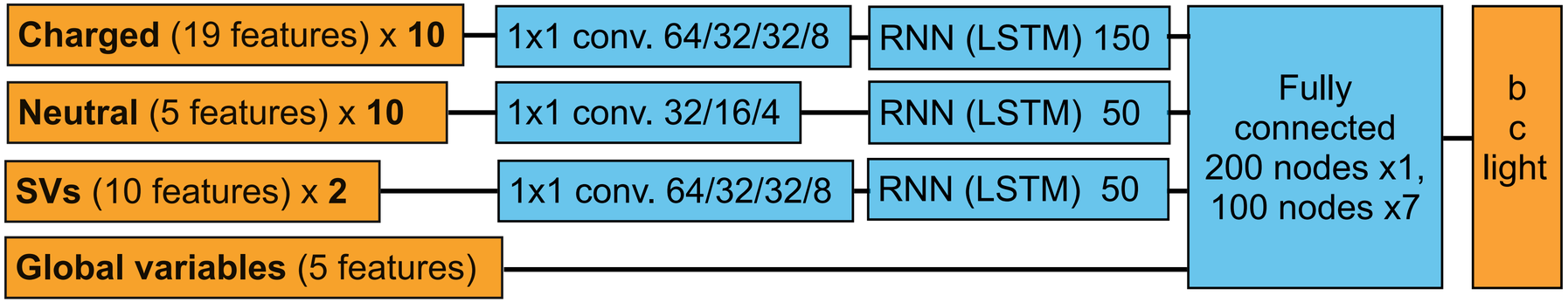


Next steps

- optimize Particle Net:
  - NN complexity, LR
  - more input features
  - less jet constituents?

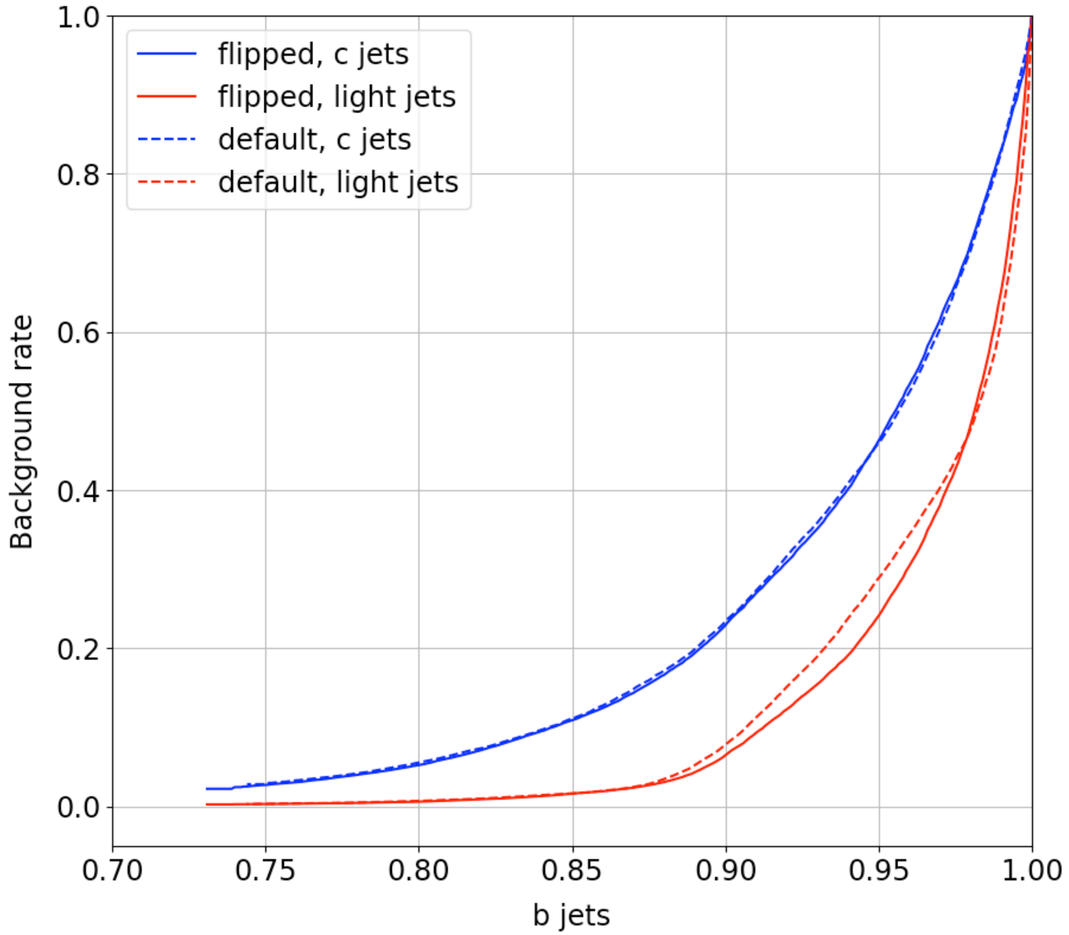
- study sensitivity of identifying s jets
- integration into iLCSoft

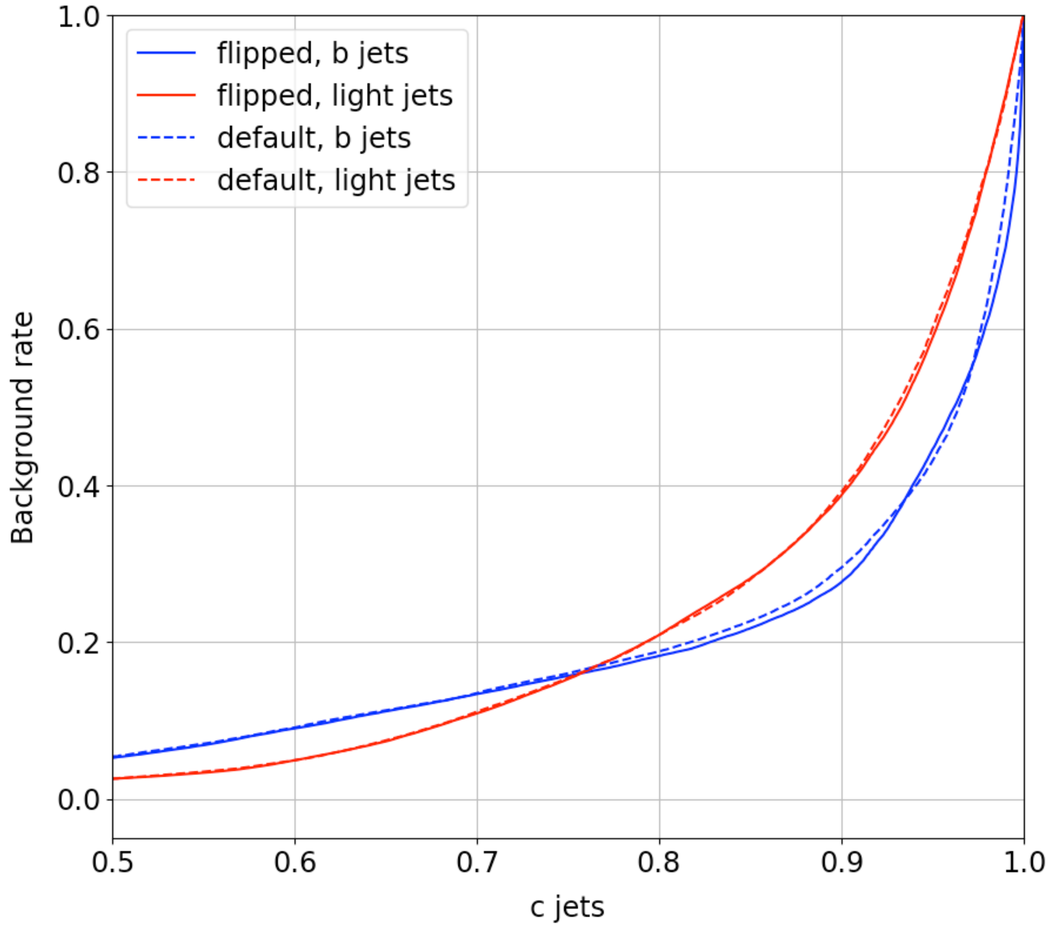
Architecture & data pre-processing



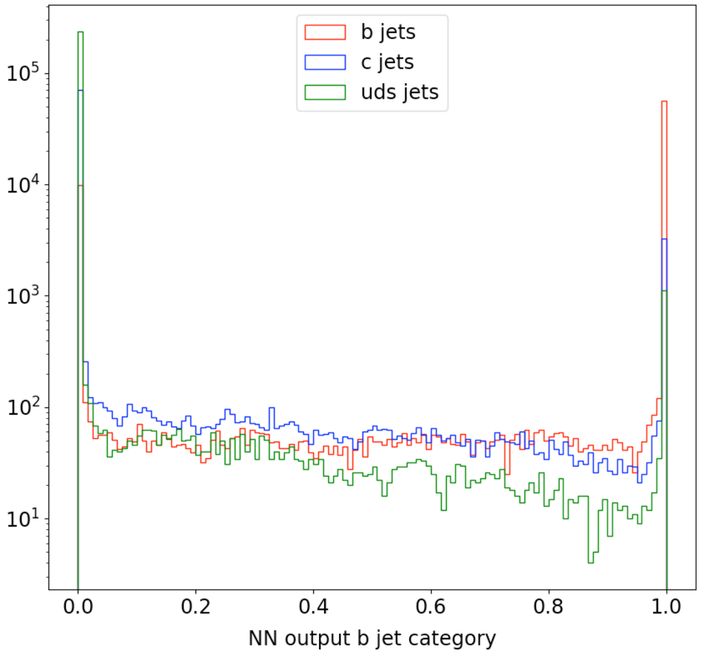
- classify jets into **three classes**: b jets, c jets & light jets
- **ordering of input particles** by (as applied in CMS)
  - impact parameter significance for charged jet constituents
  - shortest angular distance to a secondary vertex (by momentum if there is no secondary vertex) for neutral jet 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

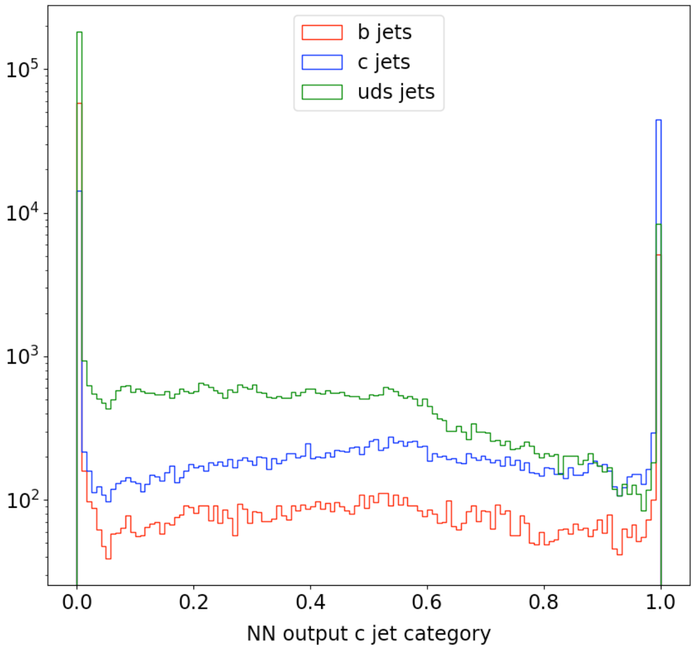
DeepJet

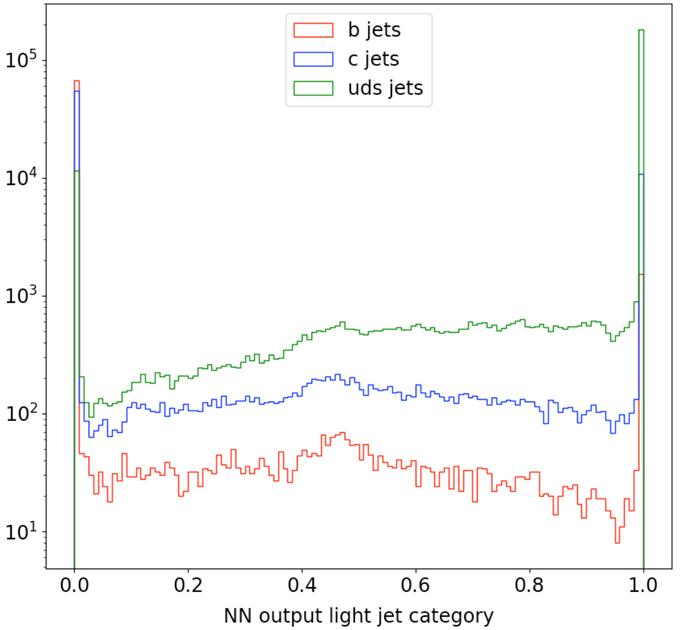

flipped, c jets
flipped, light jets
default, c jets
default, light jets
Background rate
b jets
1.0
0.8
0.6
0.4
0.2
0.0
0.70
0.75
0.80
0.85
0.90
0.95
1.00


flipped, b jets
flipped, light jets
default, b jets
default, light jets
Background rate
c jets
1.0
0.8
0.6
0.4
0.2
0.0
0.5
0.6
0.7
0.8
0.9
1.0

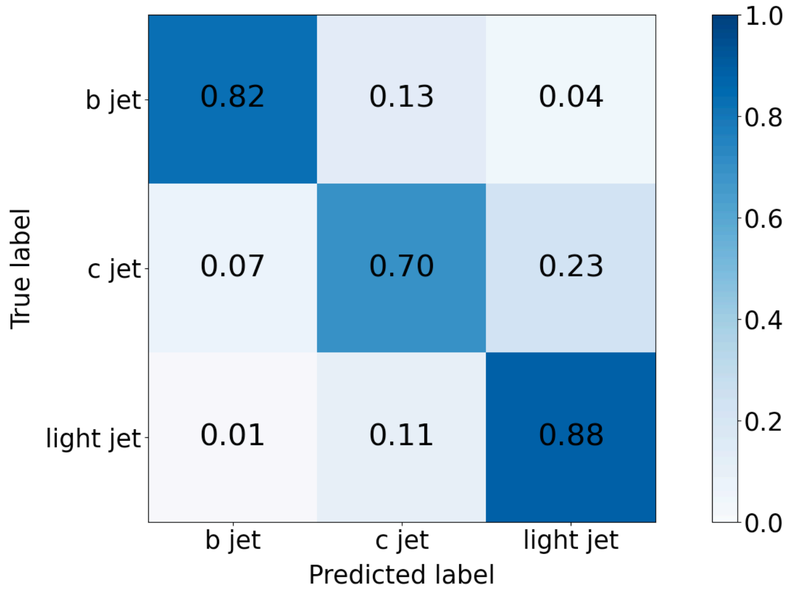
DeepJet

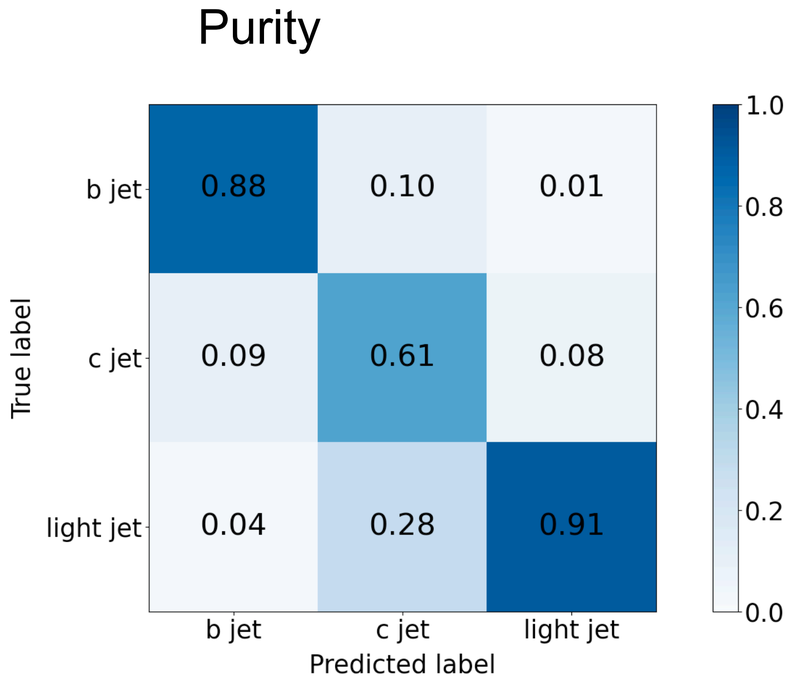

b jets
c jets
uds jets
10^5
10^4
10^3
10^2
10^1
0.0
0.2
0.4
0.6
0.8
1.0
NN output b jet category


b jets
c jets
uds jets
10^5
10^4
10^3
10^2
0.0
0.2
0.4
0.6
0.8
1.0
NN output c jet category

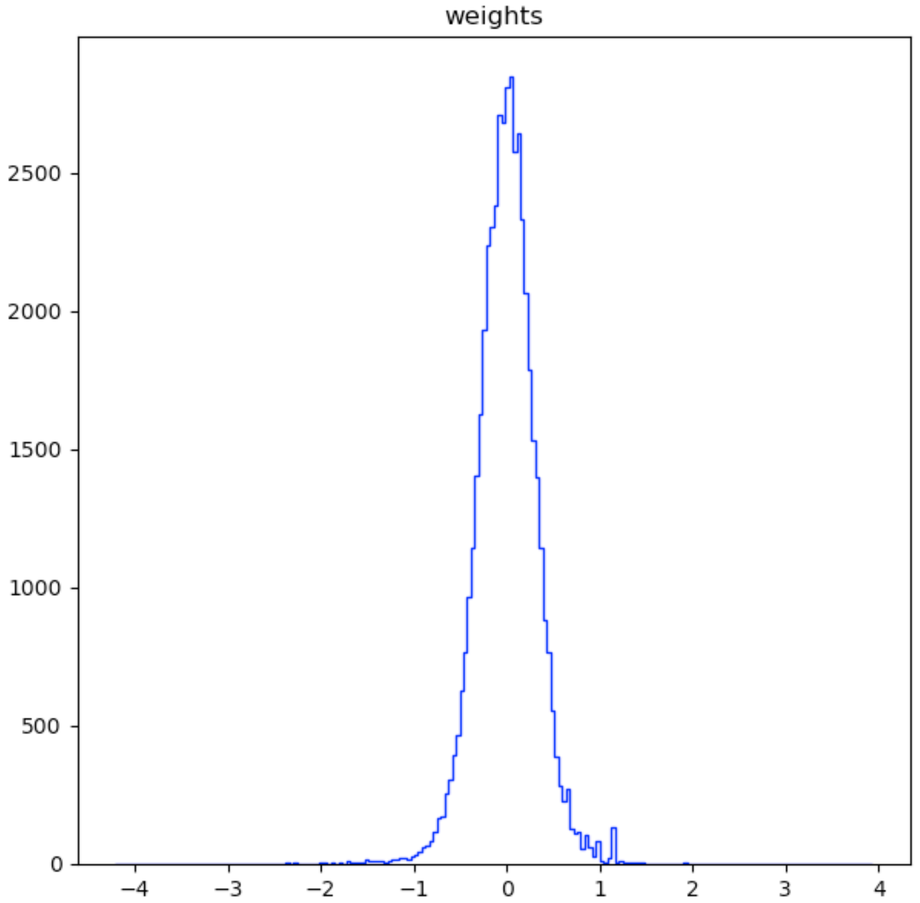

b jets
c jets
uds jets
10^5
10^4
10^3
10^2
10^1
0.0
0.2
0.4
0.6
0.8
1.0
NN output light jet category

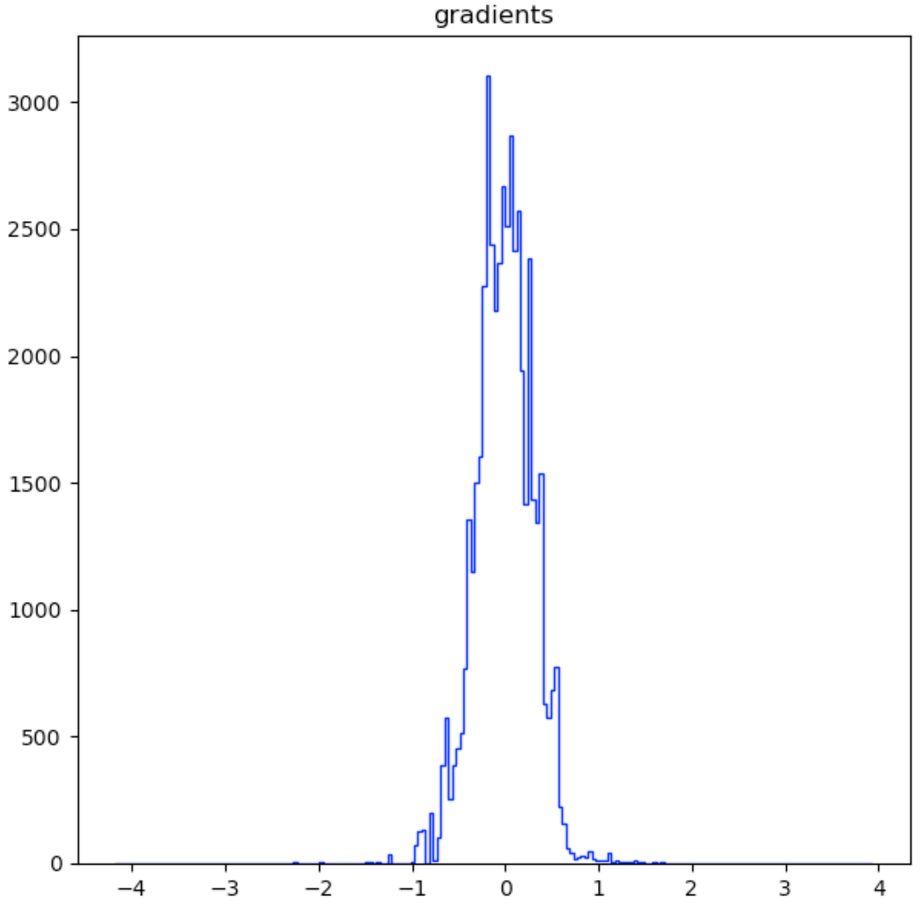
DeepJet


b jet
c jet
light jet
True label
0.82
0.13
0.04
0.07
0.70
0.23
0.01
0.11
0.88
b jet
c jet
light jet
Predicted label
1.0
0.8
0.6
0.4
0.2
0.0


Purity
b jet
c jet
light jet
True label
0.88
0.10
0.01
0.09
0.61
0.08
0.04
0.28
0.91
b jet
c jet
light jet
Predicted label
1.0
0.8
0.6
0.4
0.2
0.0

Particle Net





Particle Net