A comparison of feature-based and cell-based classifiers

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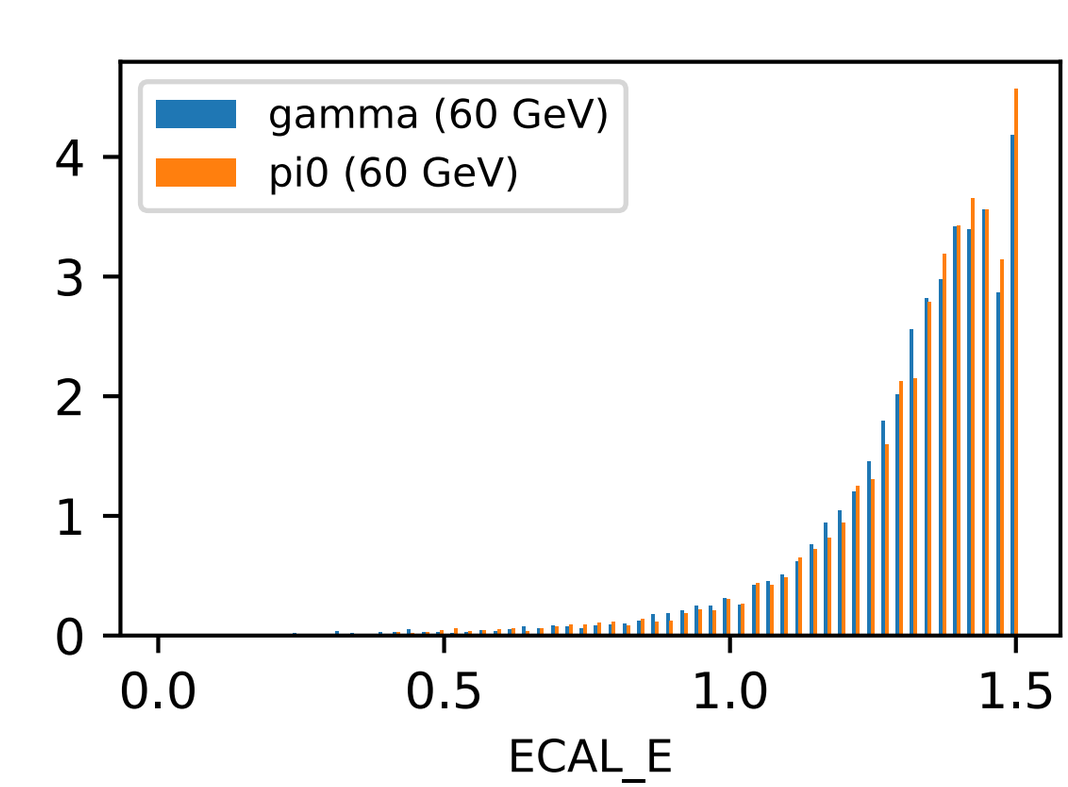
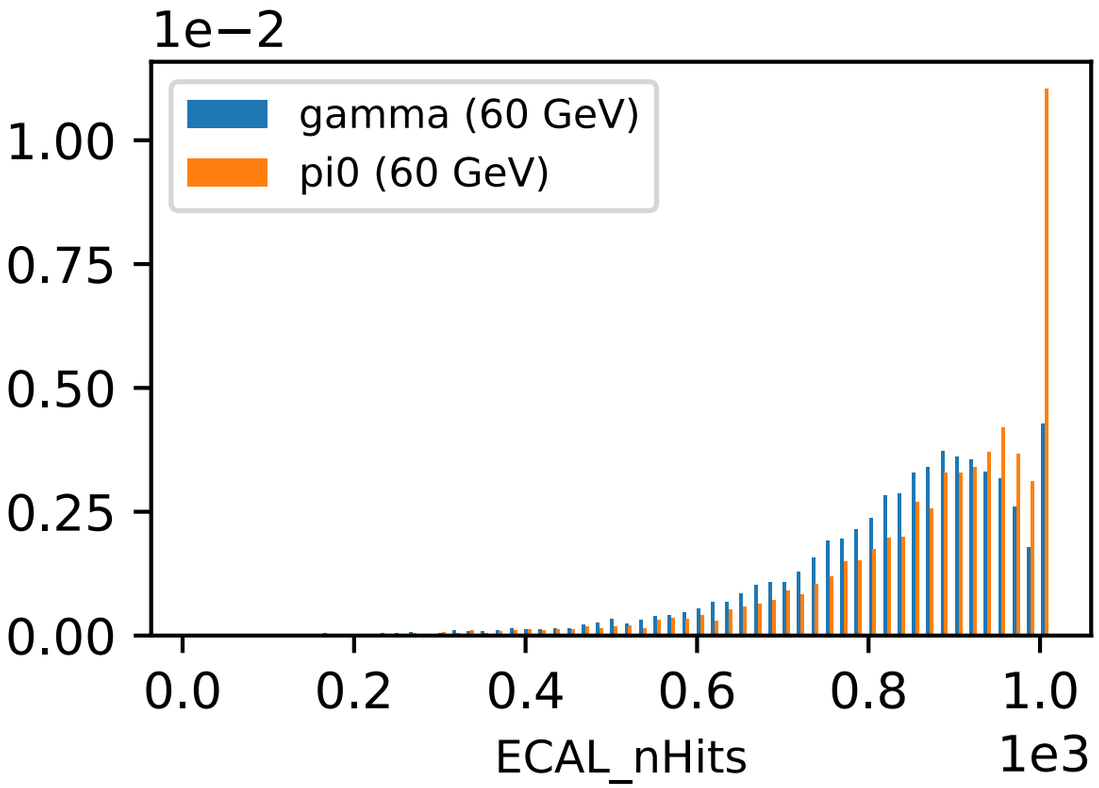
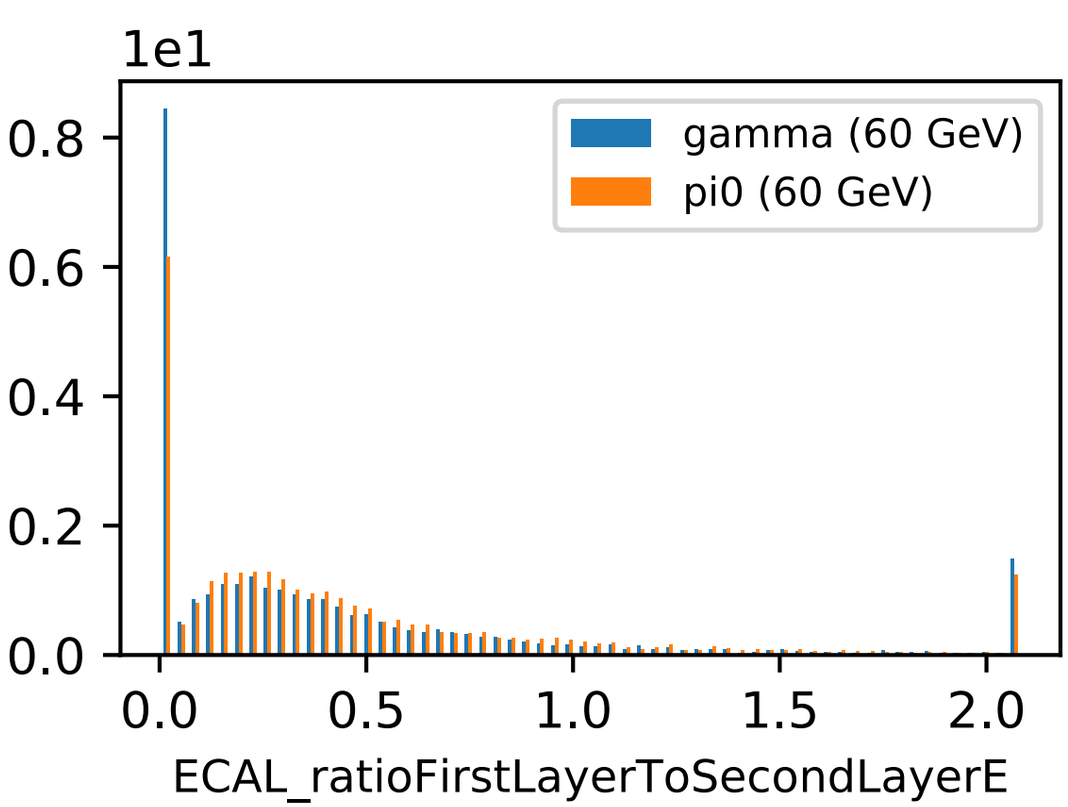
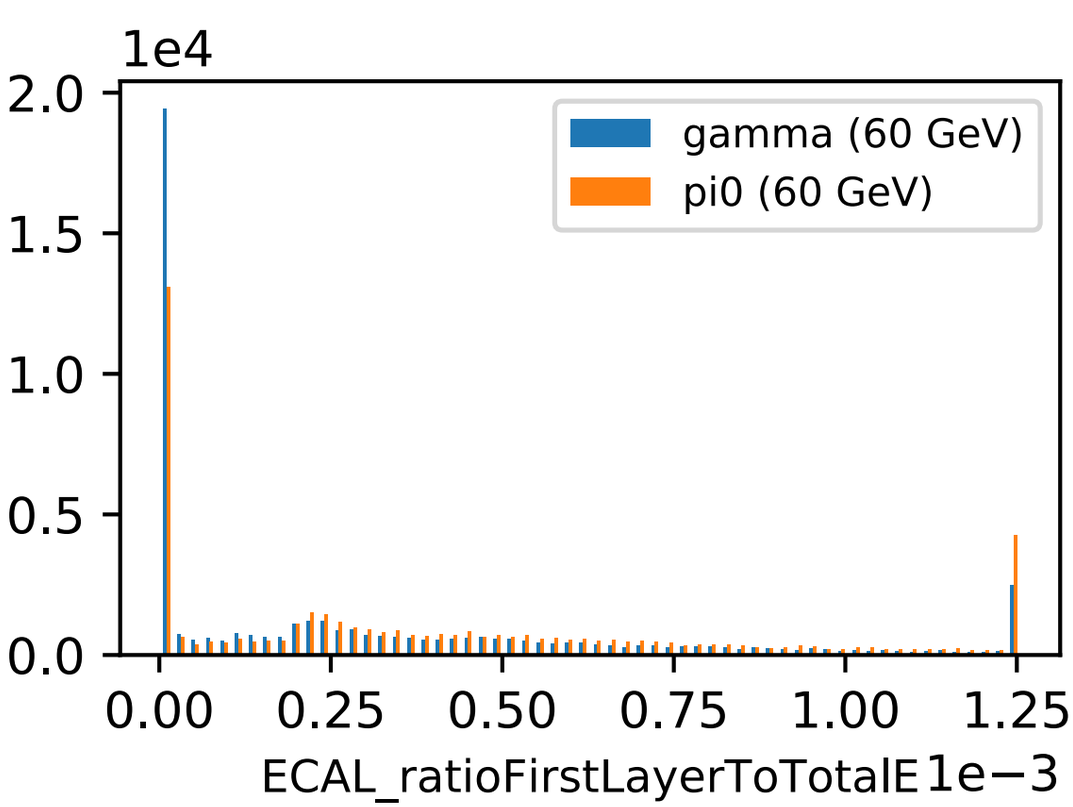
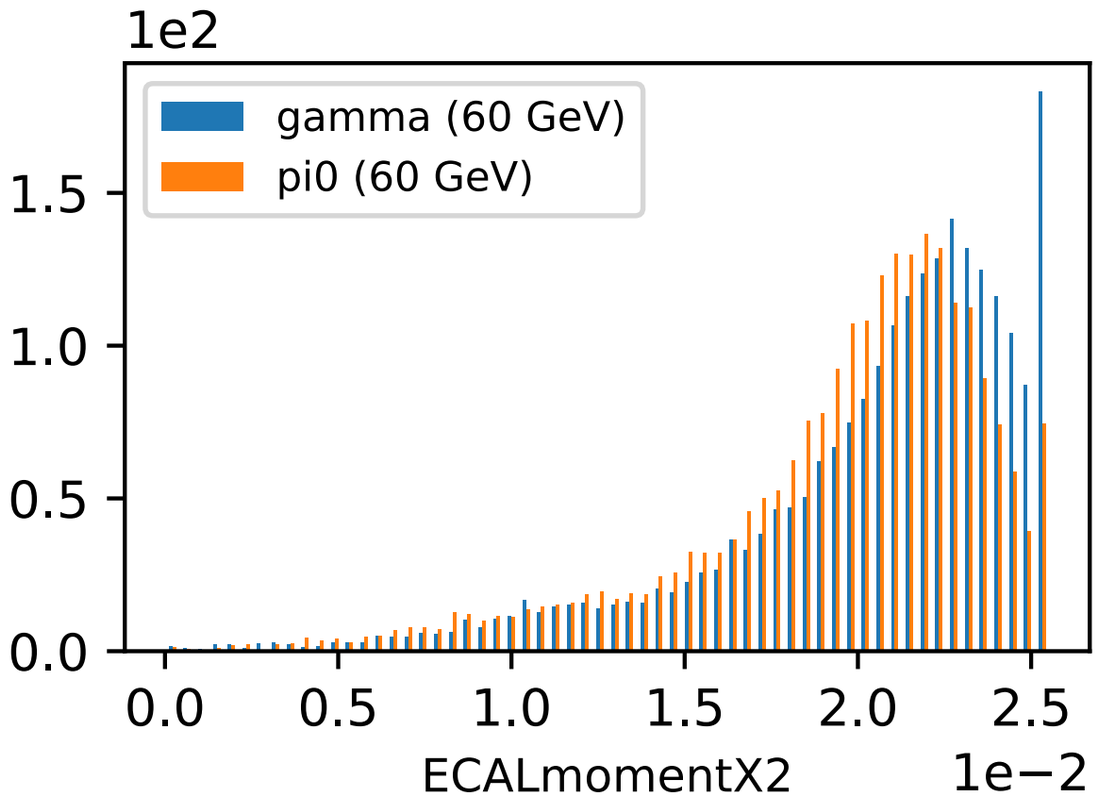
Gamma vs. pi0 classifier

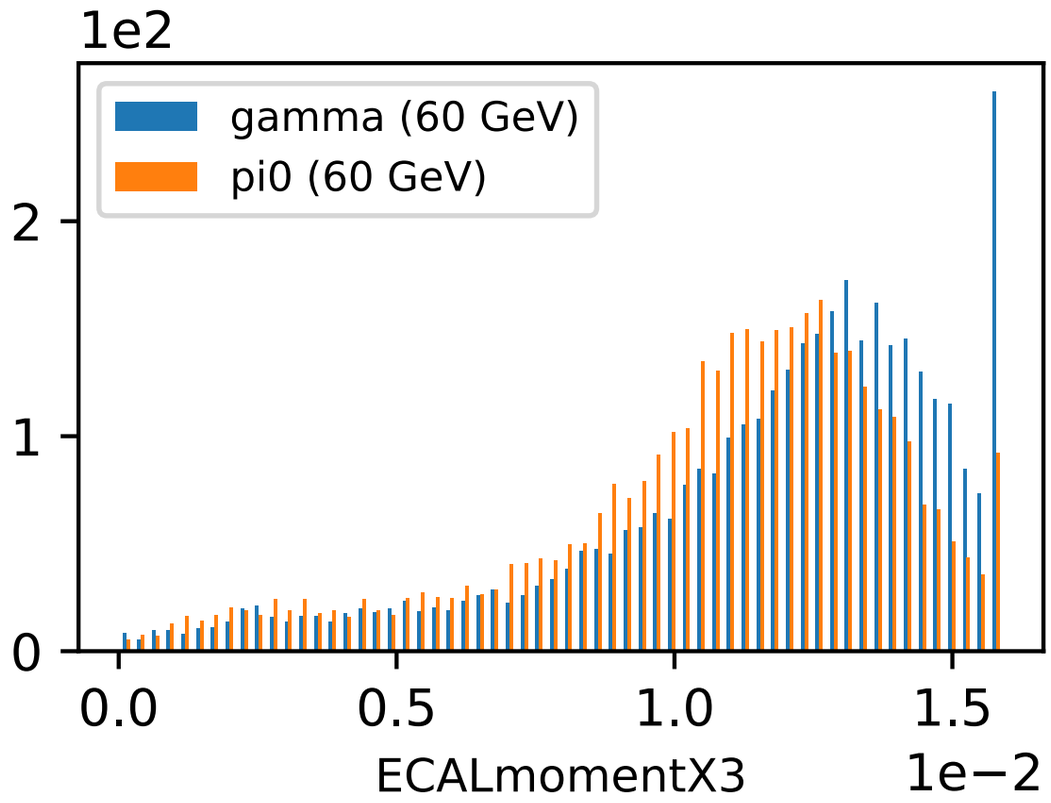


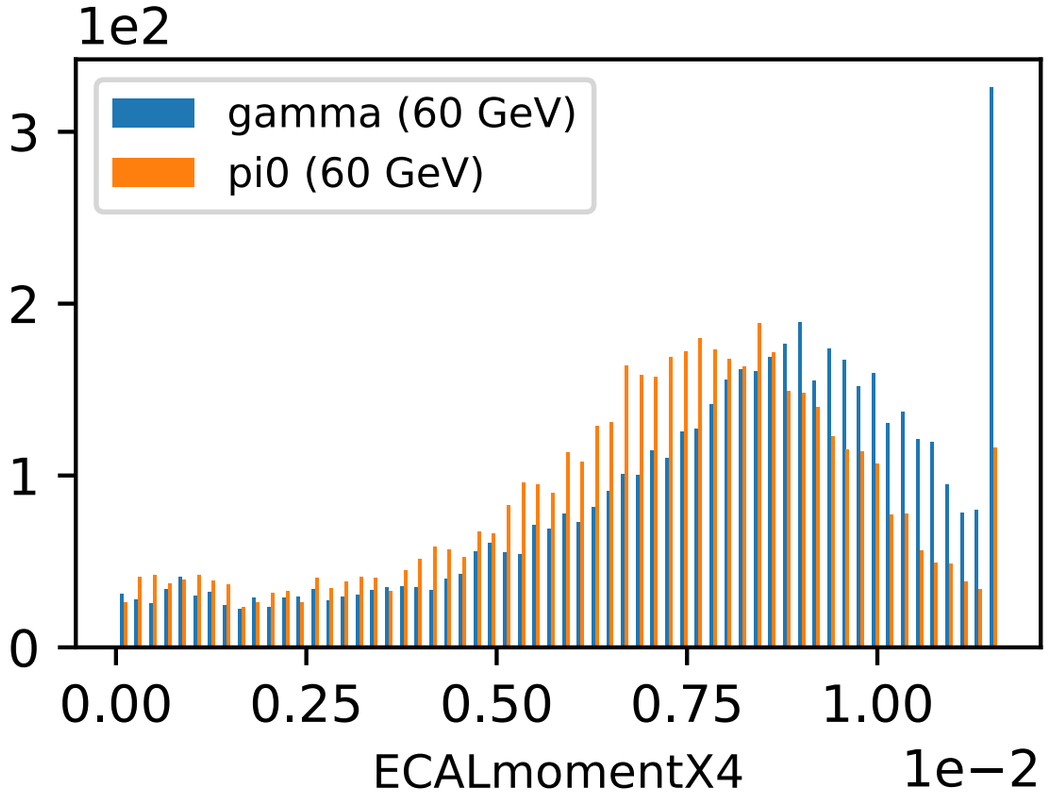


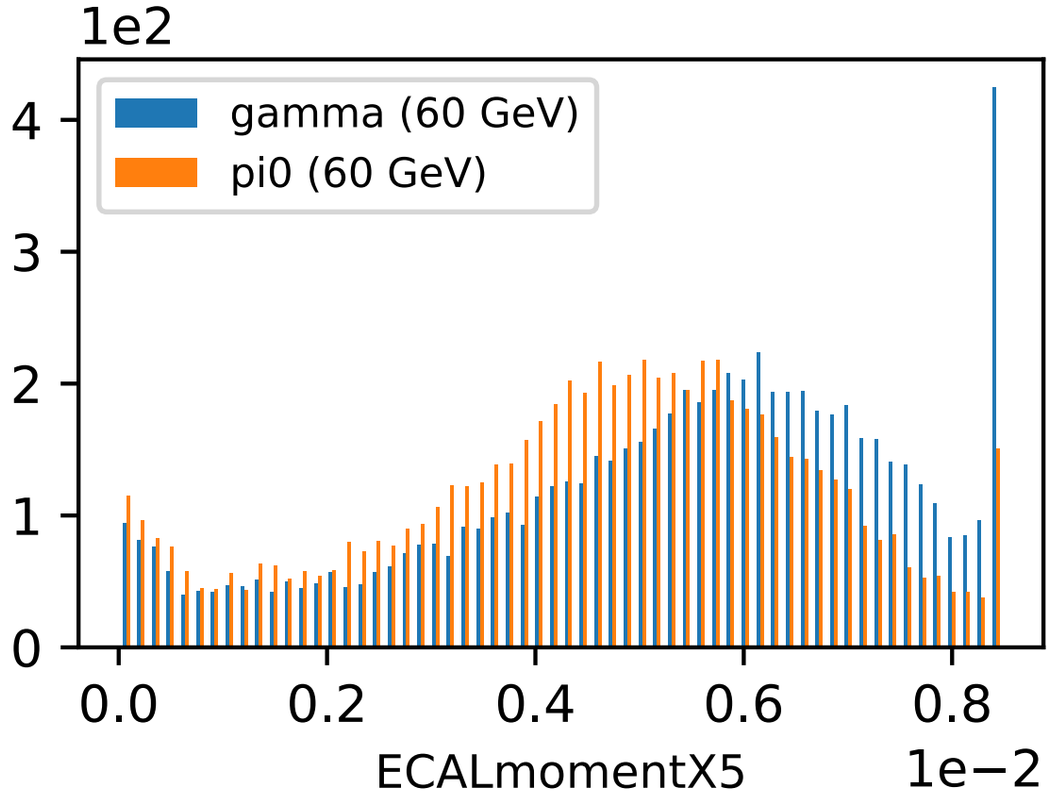


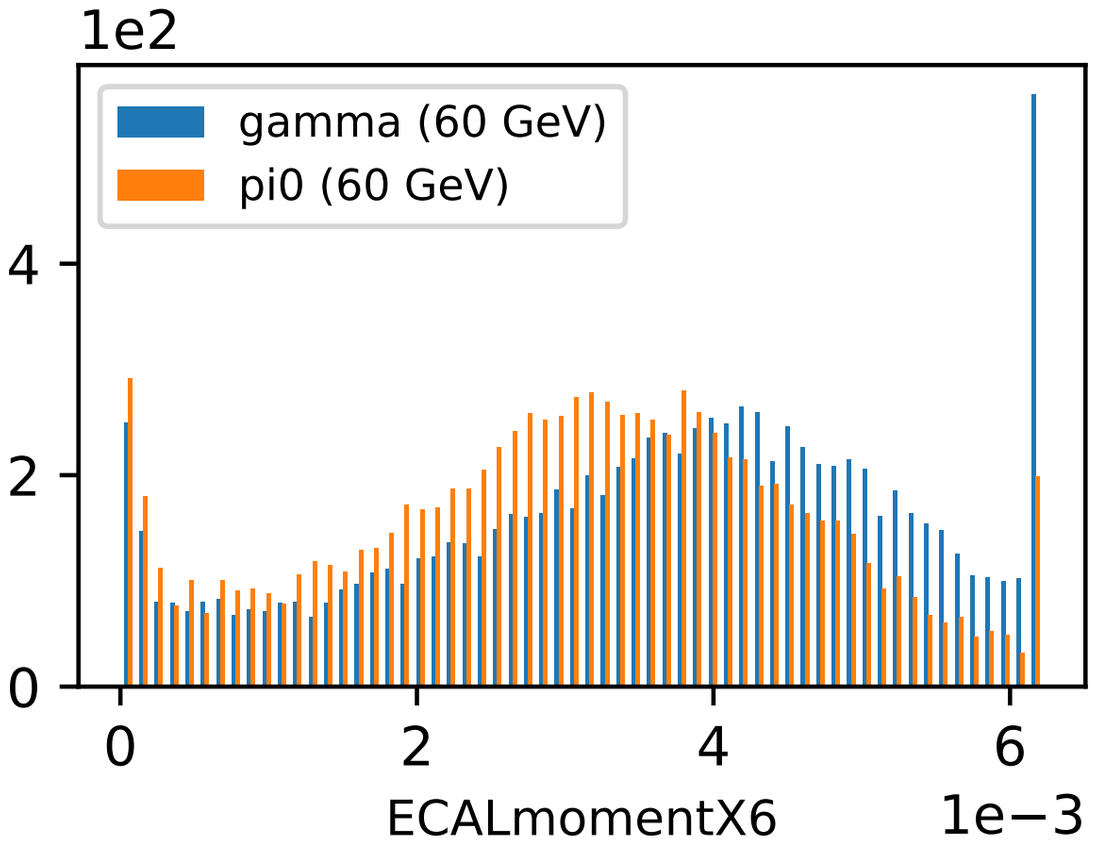


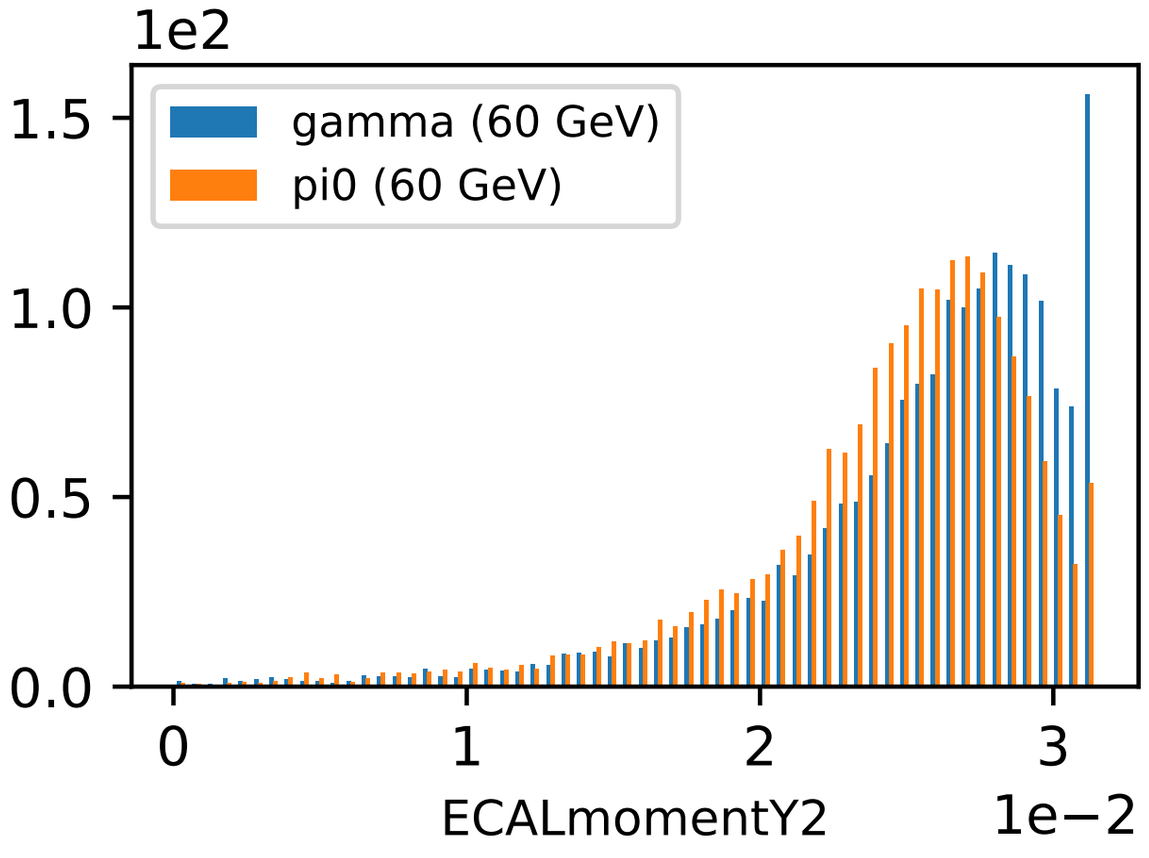

1e2
gamma (60 GeV)
pi0 (60 GeV)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
ECALmomentX2
1e−2

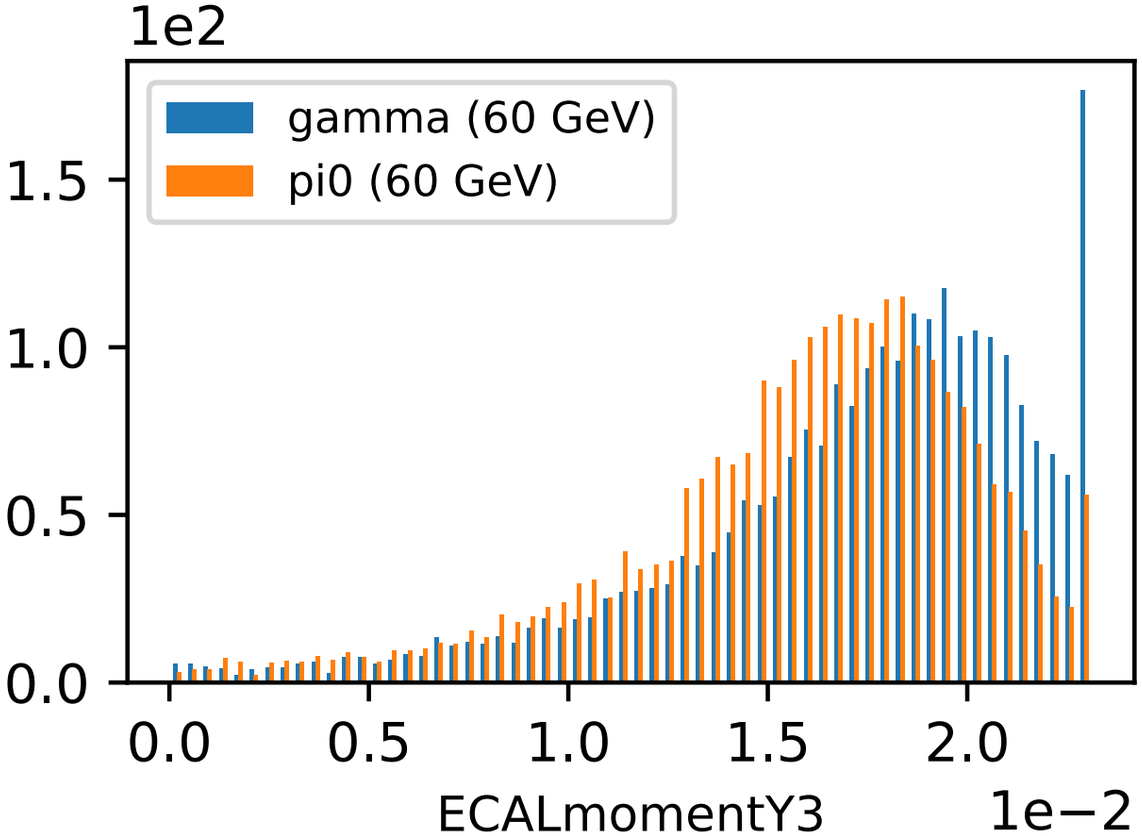

1e2
gamma (60 GeV)
pi0 (60 GeV)
2
1
0
0.0
0.5
1.0
1.5
ECALmomentX3
1e−2

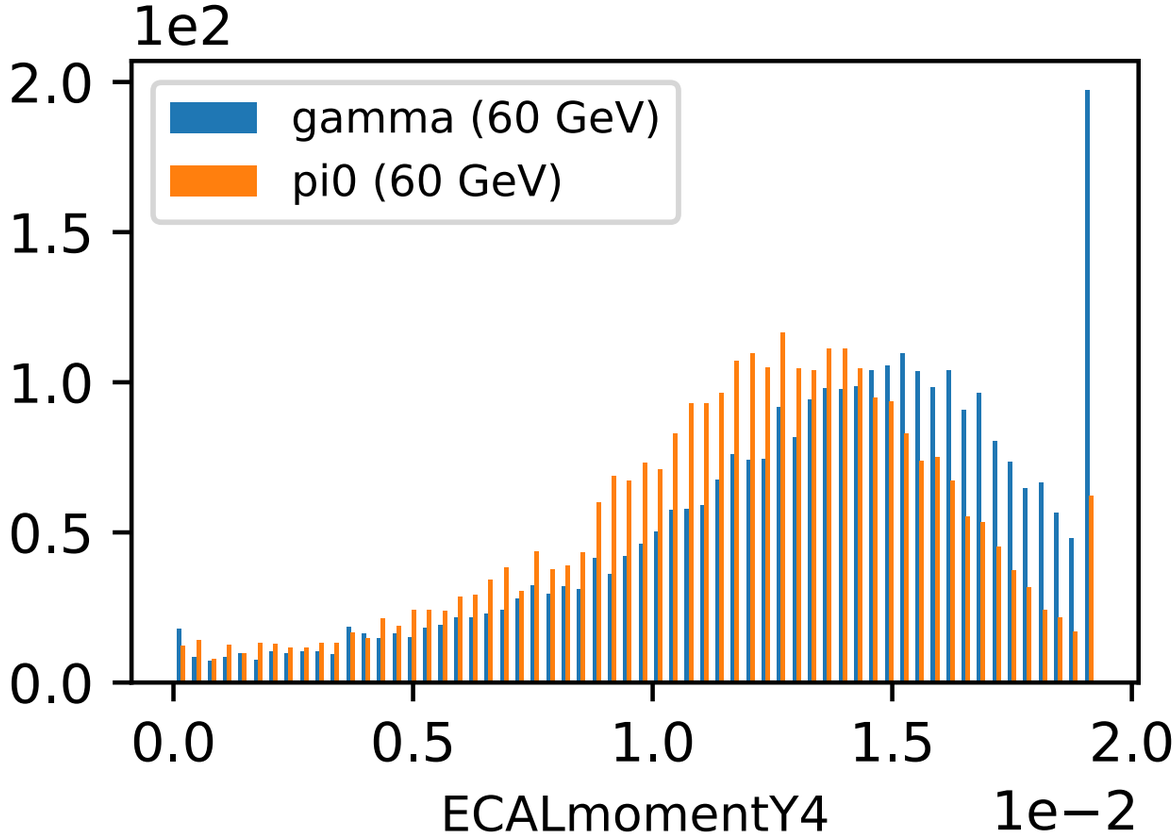

1e2
gamma (60 GeV)
pi0 (60 GeV)
3
2
1
0
0.00
0.25
0.50
0.75
1.00
ECALmomentX4
1e−2

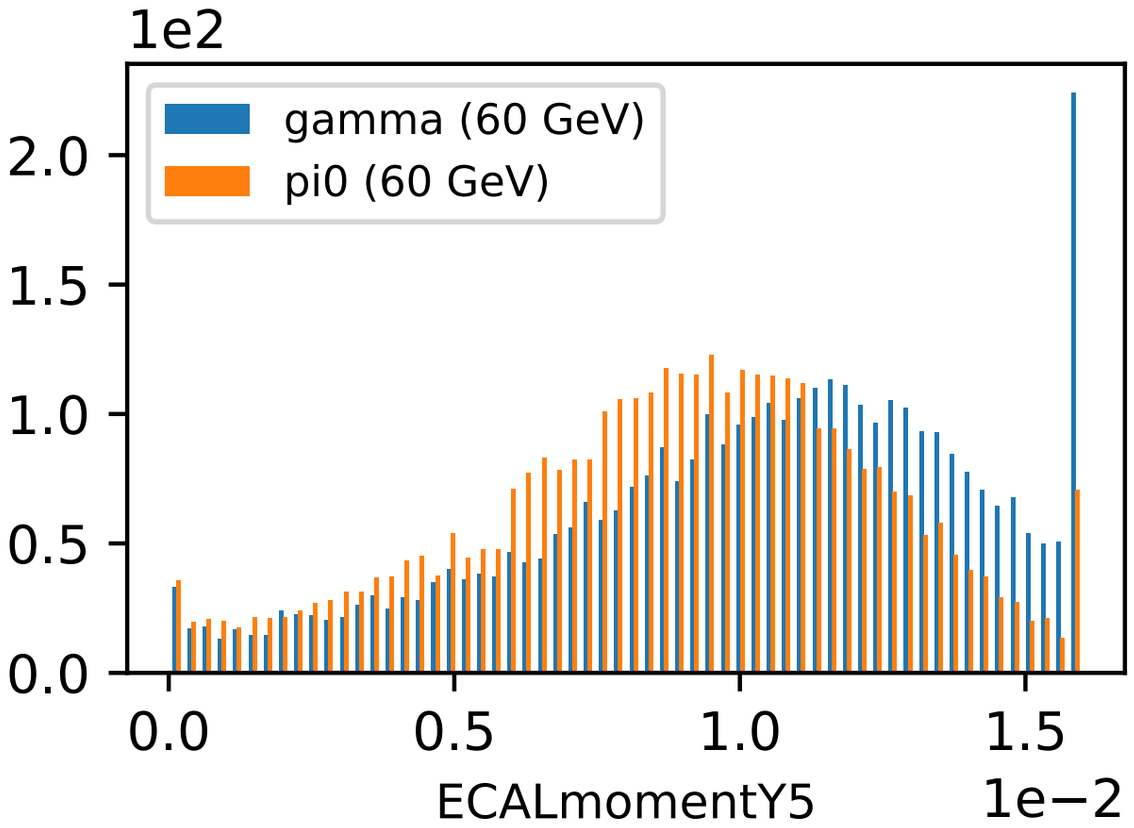

1e2
gamma (60 GeV)
pi0 (60 GeV)
4
3
2
1
0
0.0
0.2
0.4
0.6
0.8
ECALmomentX5
1e−2

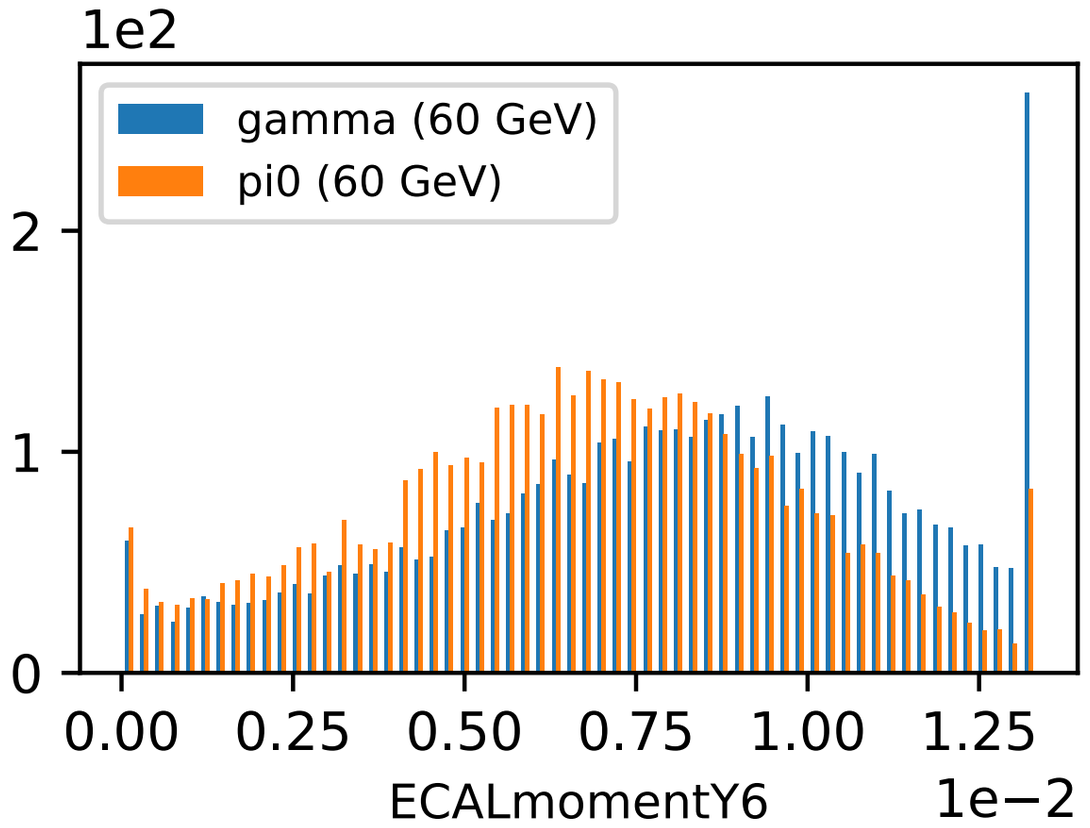

1e2
gamma (60 GeV)
pi0 (60 GeV)
4
2
0
0
2
4
6
ECALmomentX6
1e−3

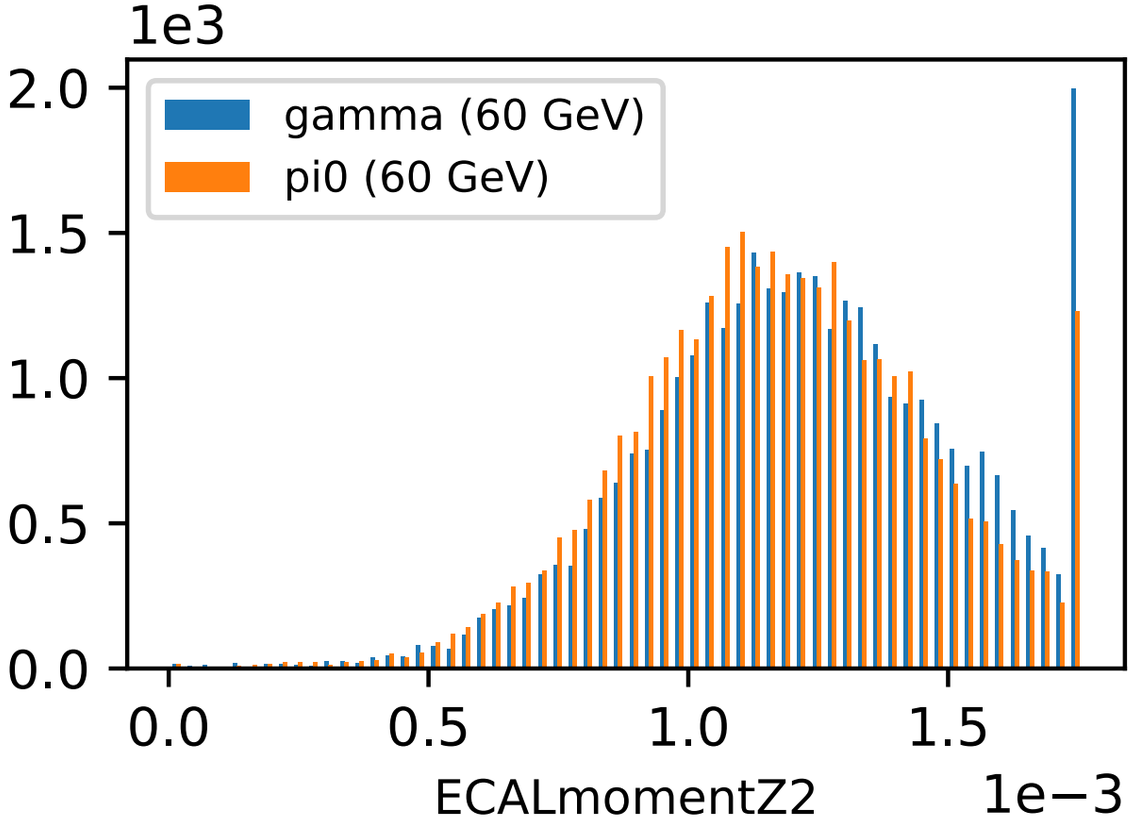

1e2
gamma (60 GeV)
pi0 (60 GeV)
1.5
1.0
0.5
0.0
0
1
2
3
ECALmomentY2
1e−2

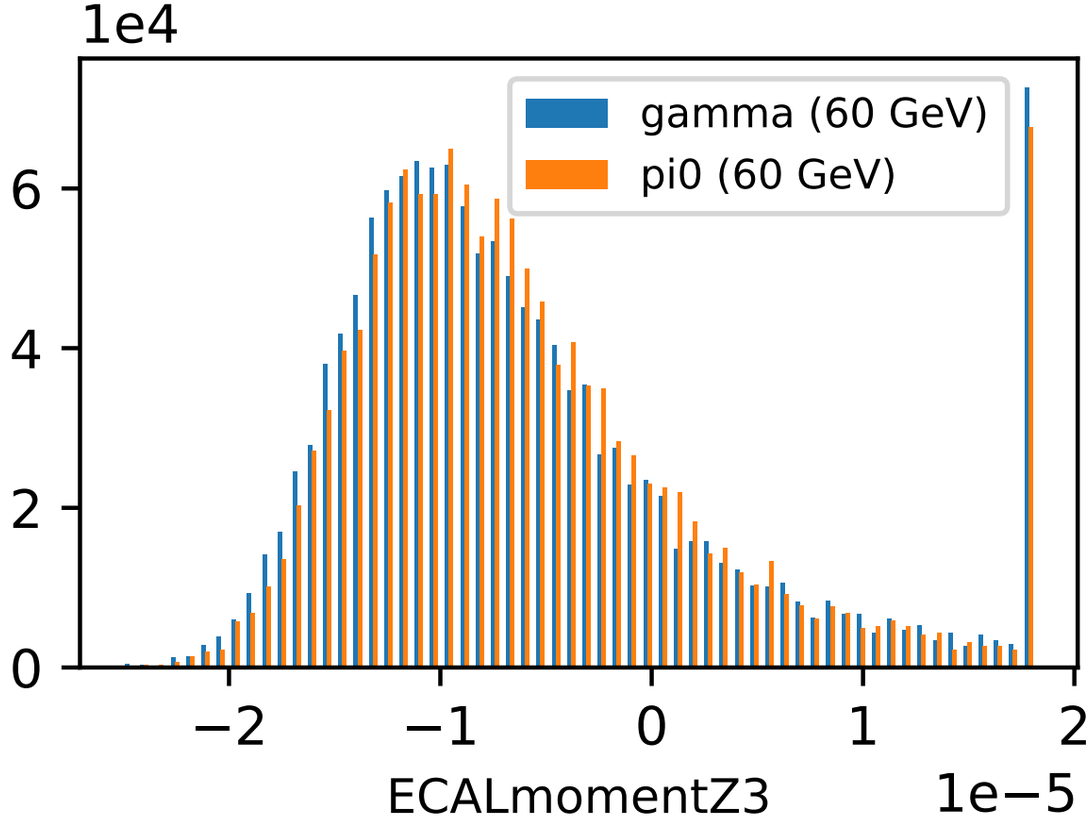

1e2
gamma (60 GeV)
pi0 (60 GeV)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
ECALmomentY3
1e−2

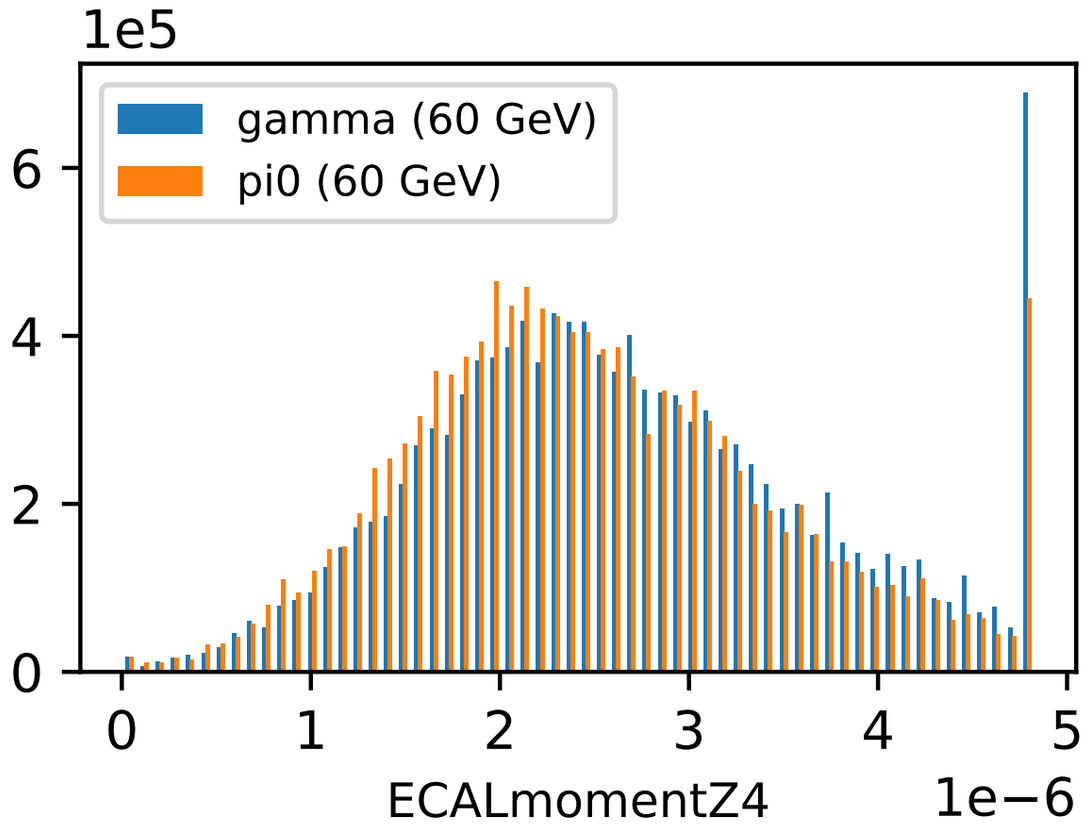

1e2
gamma (60 GeV)
pi0 (60 GeV)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
ECALmomentY4
1e−2

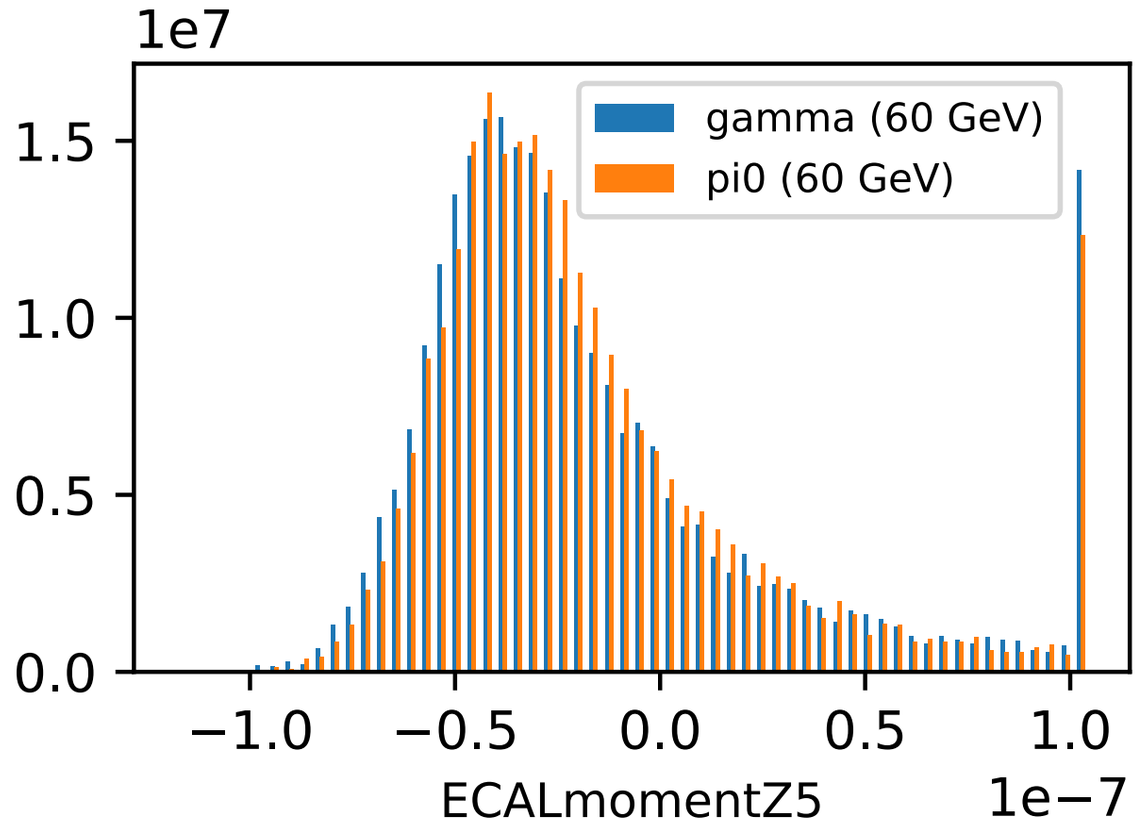

1e2
gamma (60 GeV)
pi0 (60 GeV)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
ECALmomentY5
1e−2

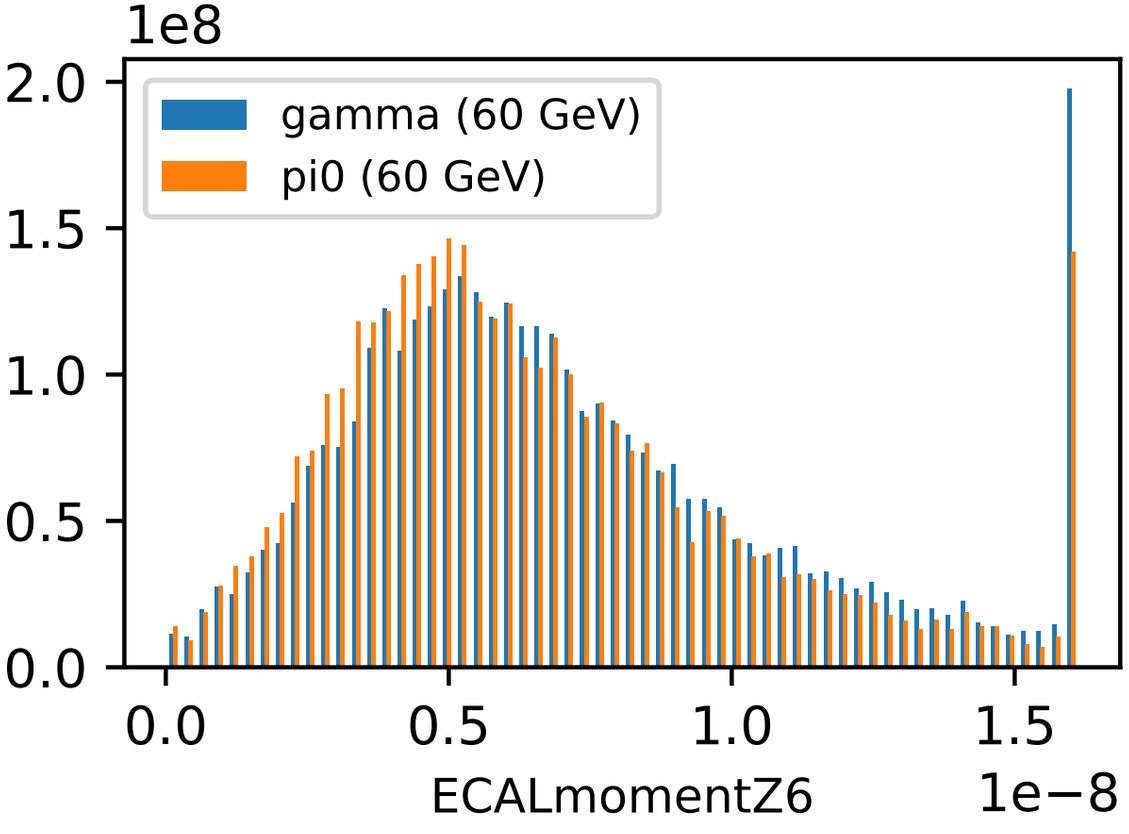

1e2
gamma (60 GeV)
pi0 (60 GeV)
2
1
0
0.00
0.25
0.50
0.75
1.00
1.25
ECALmomentY6
1e−2

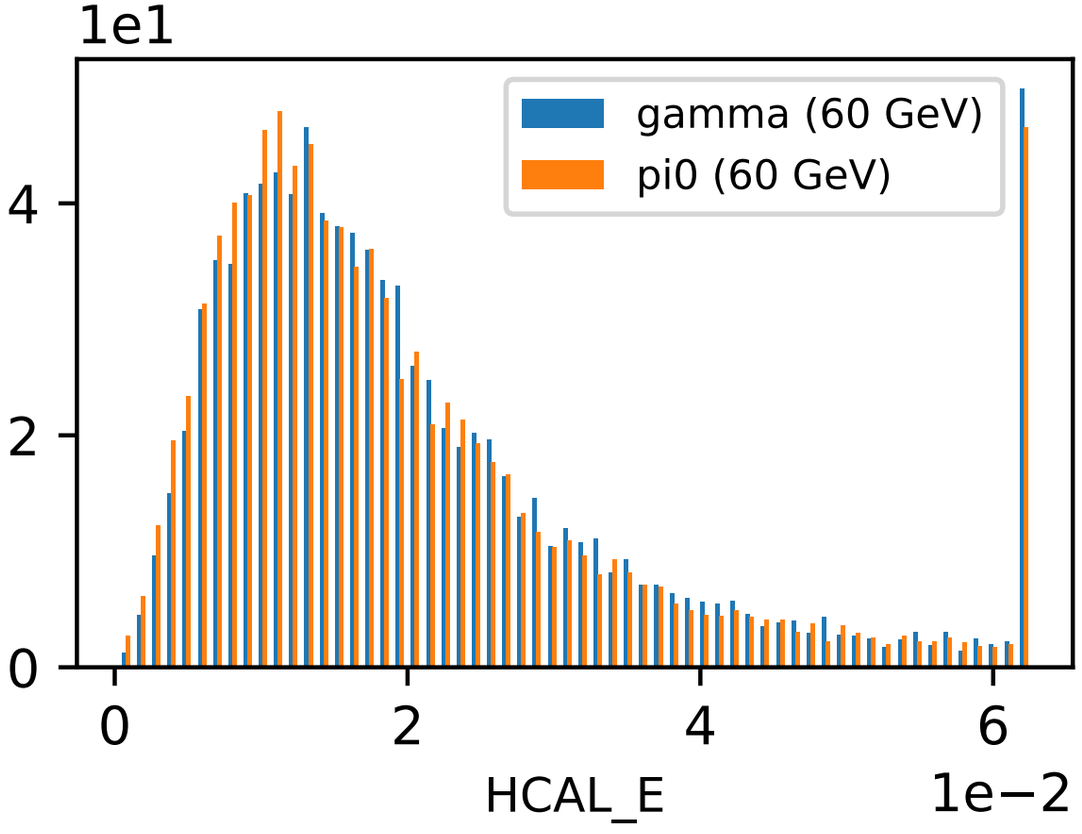

1e3
gamma (60 GeV)
pi0 (60 GeV)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
ECALmomentZ2
1e−3

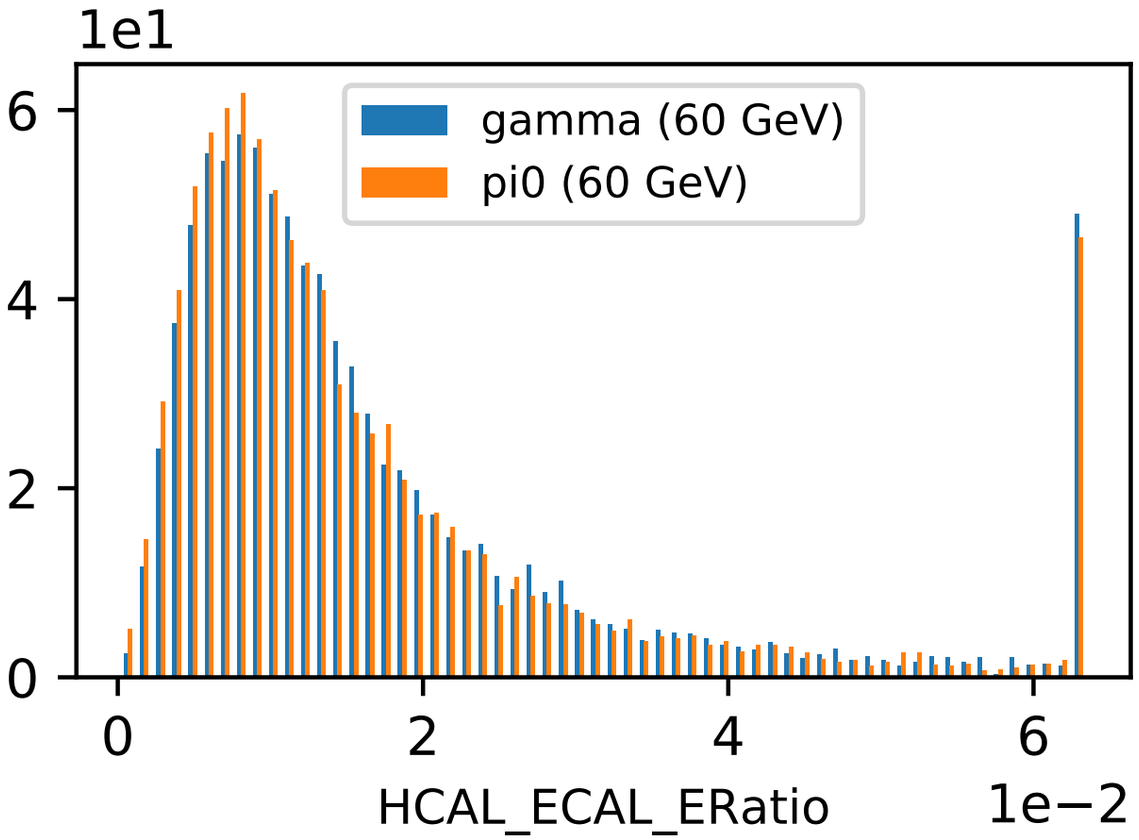

1e4
gamma (60 GeV)
pi0 (60 GeV)
6
4
2
0
−2
−1
0
1
2
ECALmomentZ3
1e−5

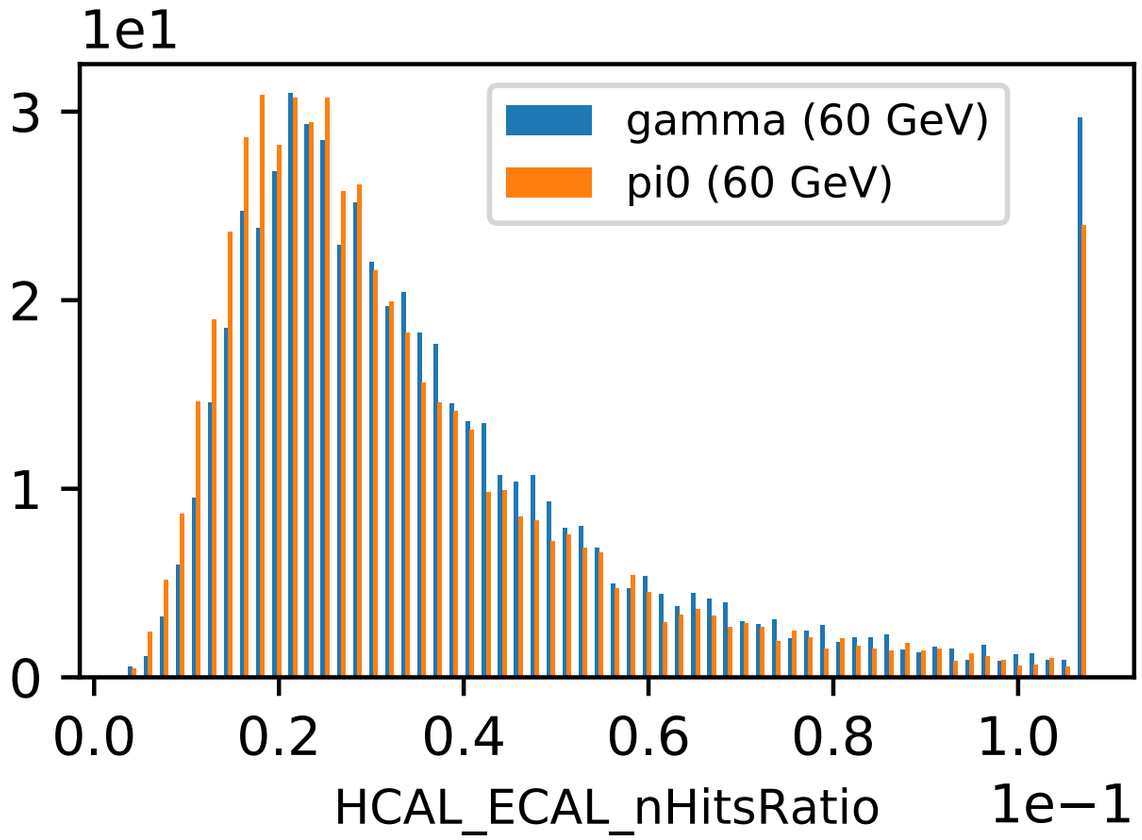

1e5
gamma (60 GeV)
pi0 (60 GeV)
6
4
2
0
0
1
2
3
4
5
ECALmomentZ4
1e−6

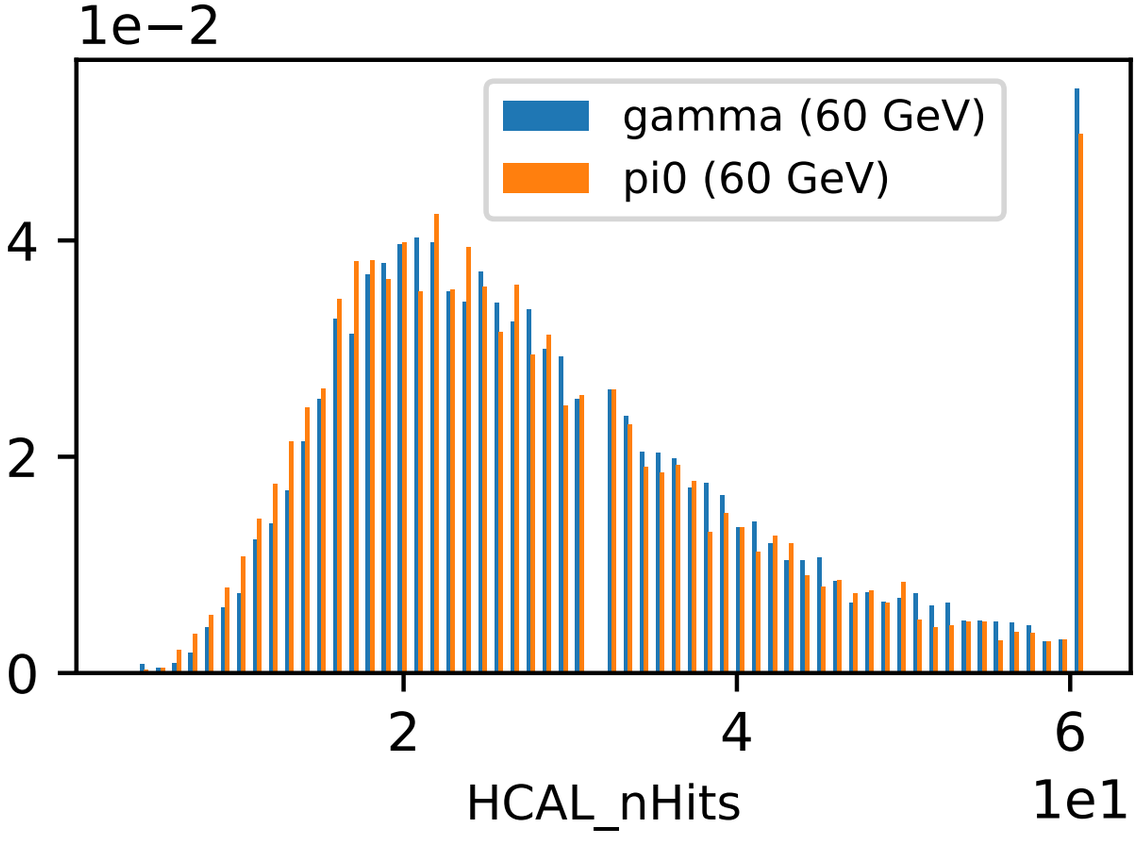

1e7
gamma (60 GeV)
pi0 (60 GeV)
1.5
1.0
0.5
0.0
−1.0
−0.5
0.0
0.5
1.0
ECALmomentZ5
1e−7

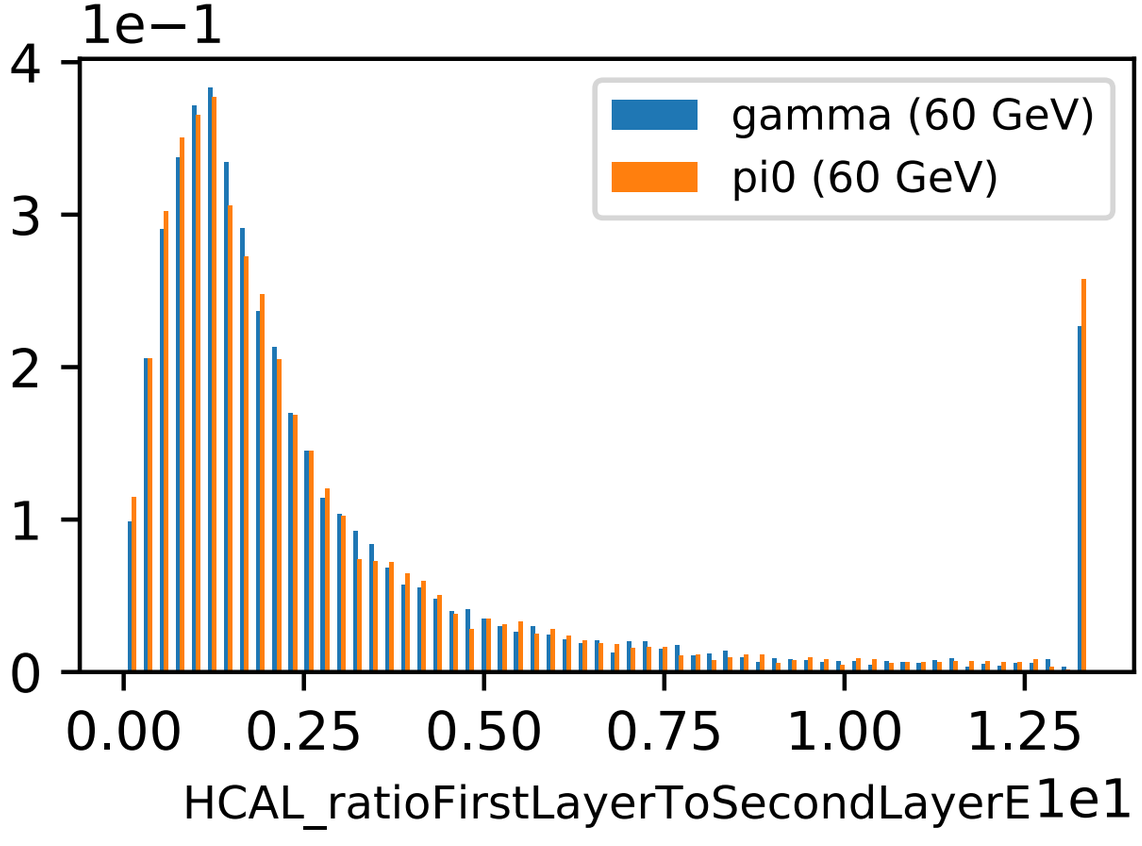

1e8
gamma (60 GeV)
pi0 (60 GeV)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
ECALmomentZ6
1e−8

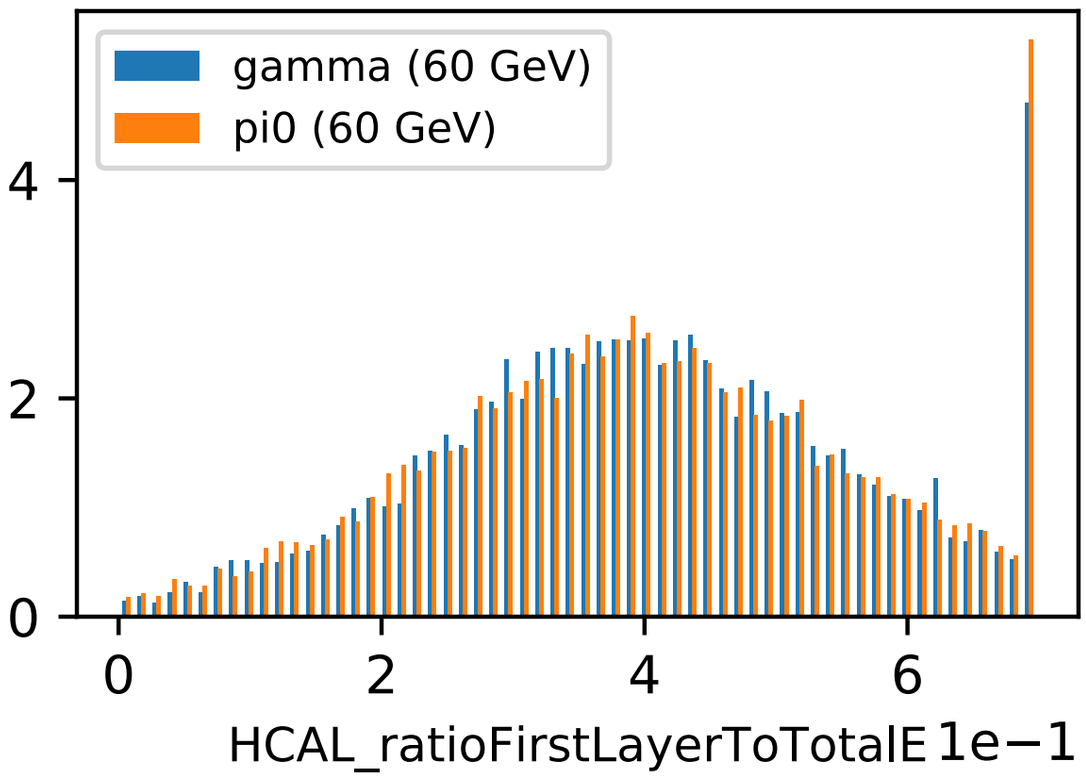

1e1
gamma (60 GeV)
pi0 (60 GeV)
4
2
0
0
2
4
6
HCAL_E
1e−2

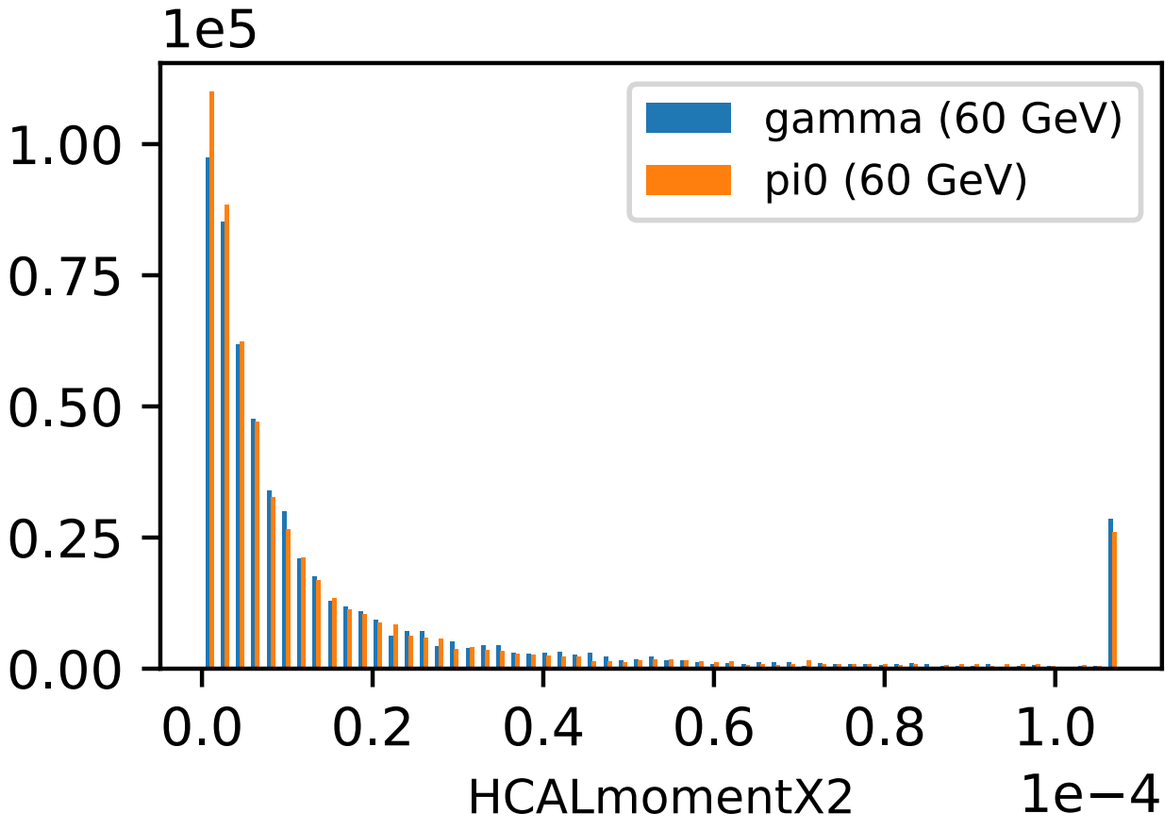

1e1
6
4
2
0
gamma (60 GeV)
pi0 (60 GeV)
0
2
4
6
HCAL_ECAL_ERatio
1e−2

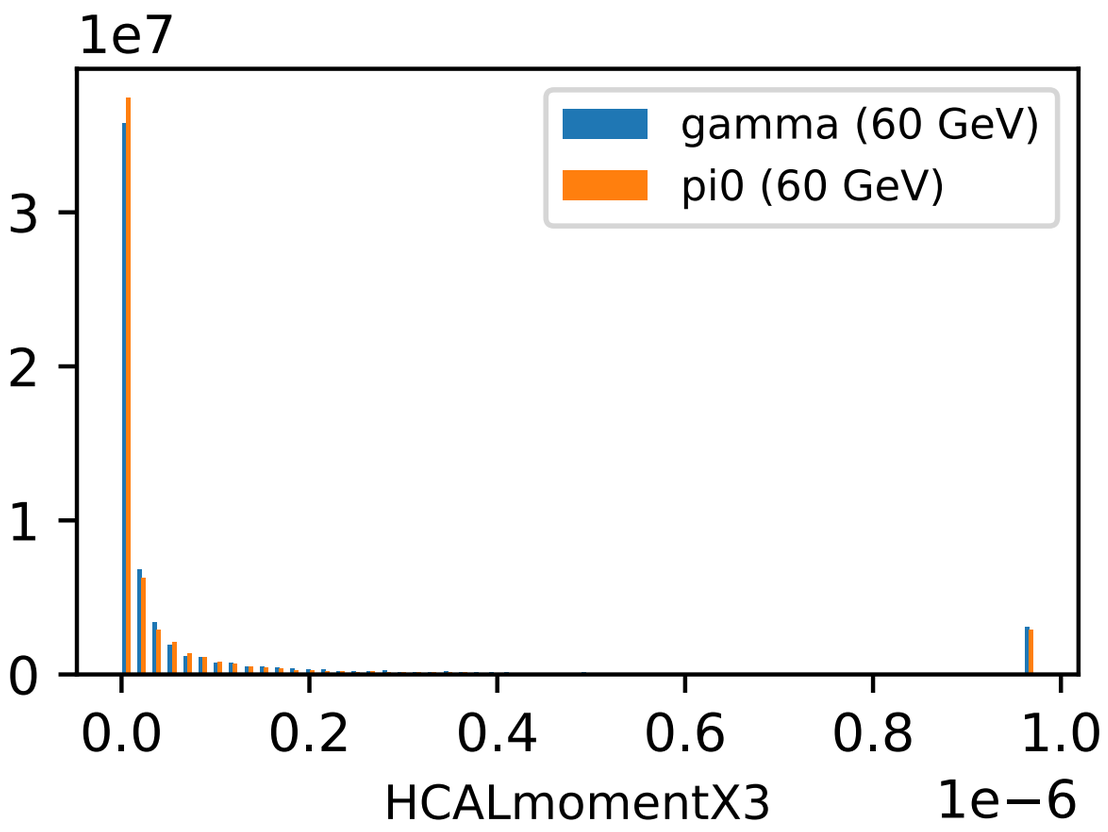

1e1
3
2
1
0
gamma (60 GeV)
pi0 (60 GeV)
0.0
0.2
0.4
0.6
0.8
1.0
HCAL_ECAL_nHitsRatio
1e−1

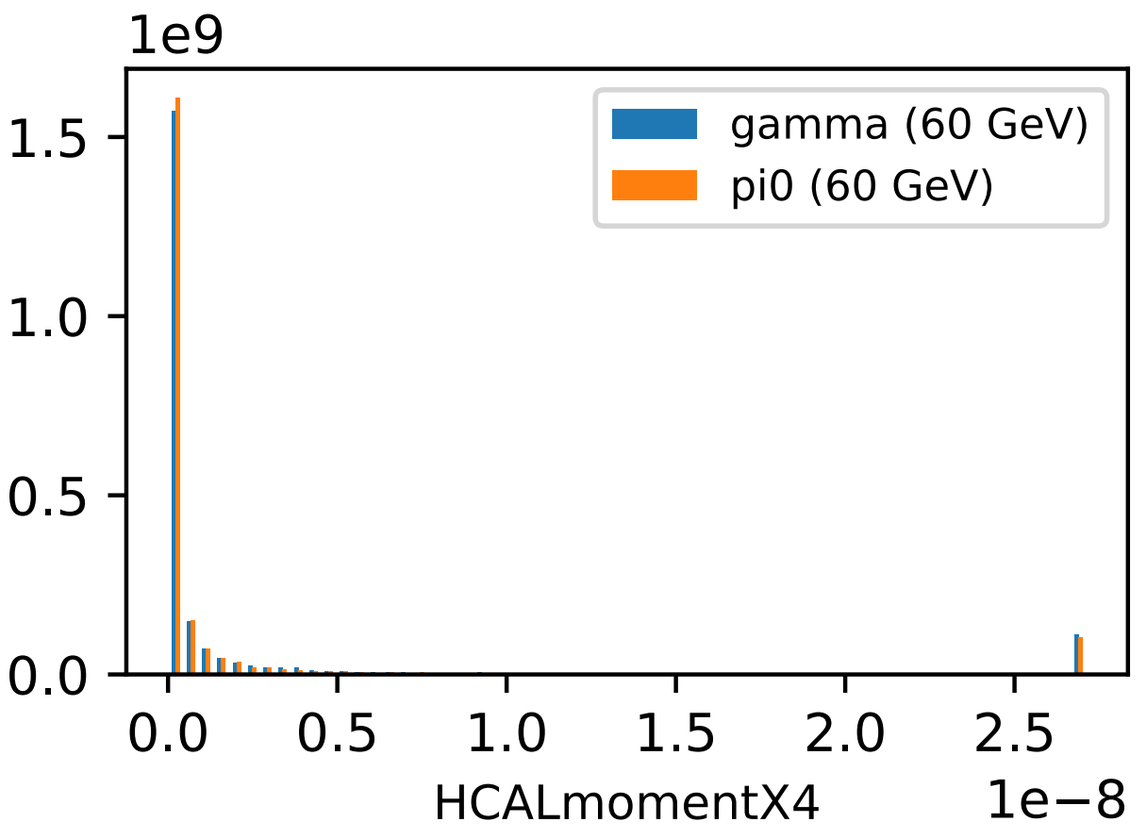

1e−2
4
2
0
gamma (60 GeV)
pi0 (60 GeV)
2
4
6
HCAL_nHits
1e1

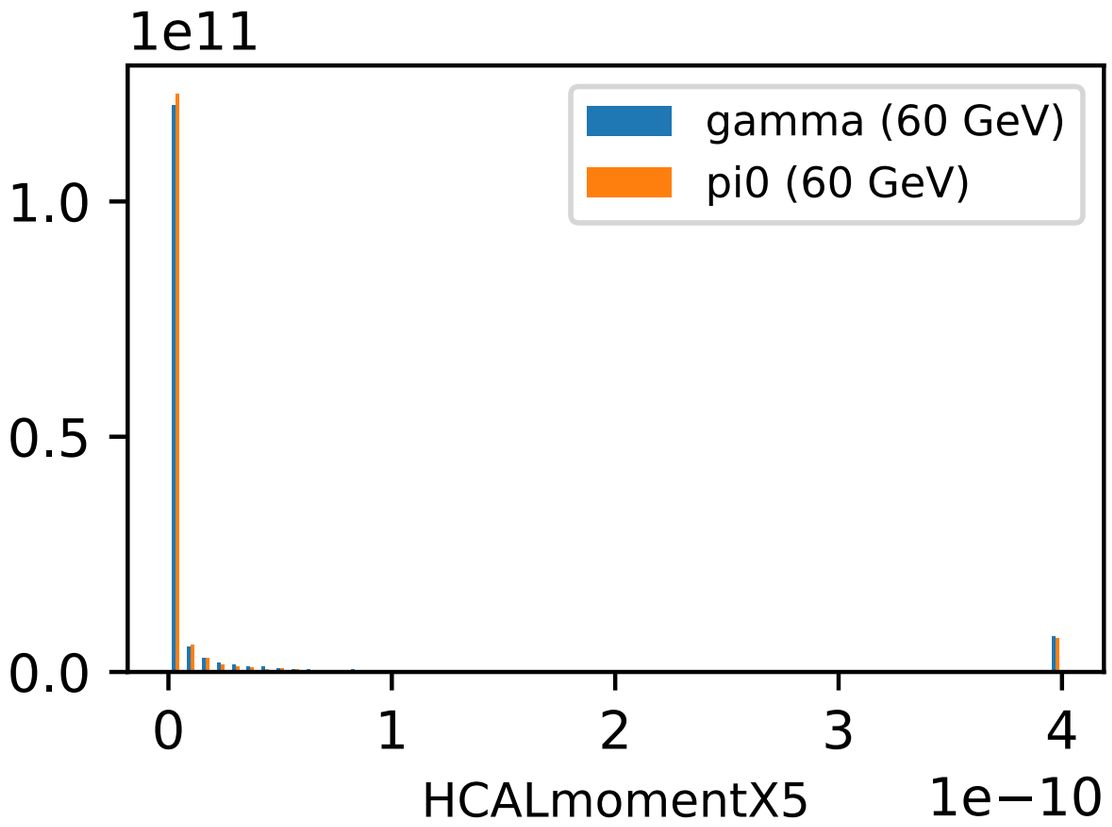

1e−1
4
3
2
1
0
gamma (60 GeV)
pi0 (60 GeV)
0.00
0.25
0.50
0.75
1.00
1.25
HCAL_ratioFirstLayerToSecondLayerE
1e1

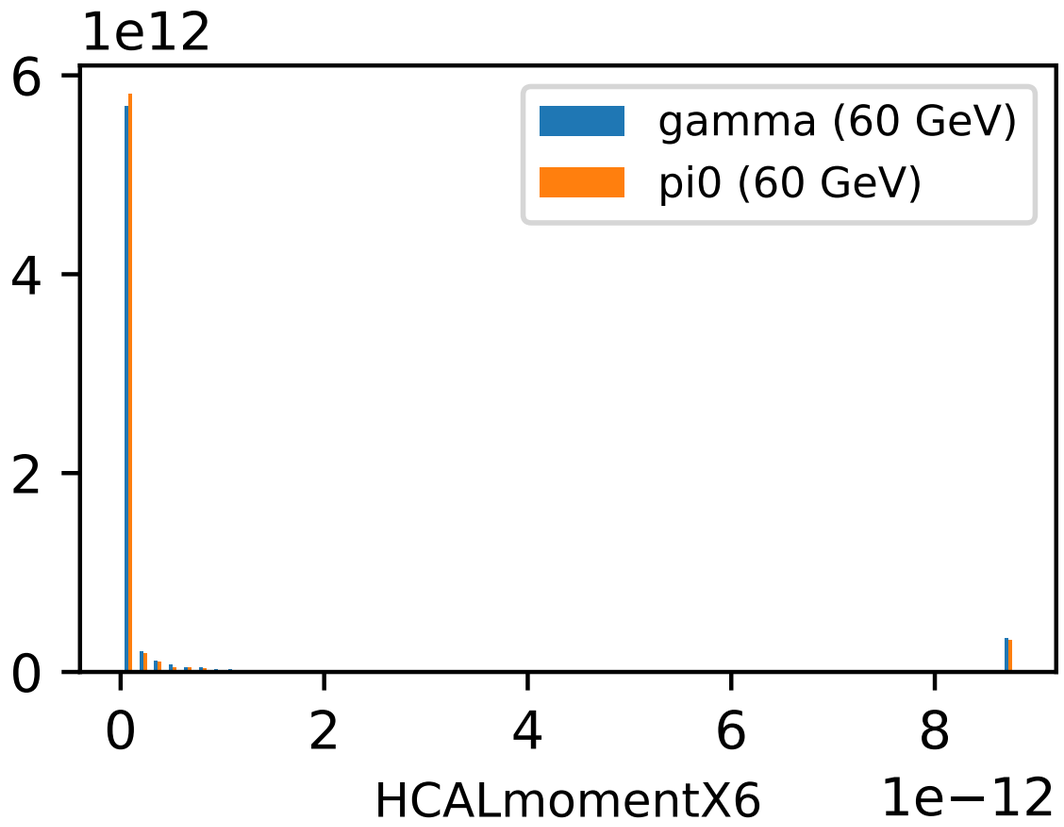

gamma (60 GeV)
pi0 (60 GeV)
0
2
4
0
2
4
6
HCAL_ratioFirstLayerToTotalE
1e−1

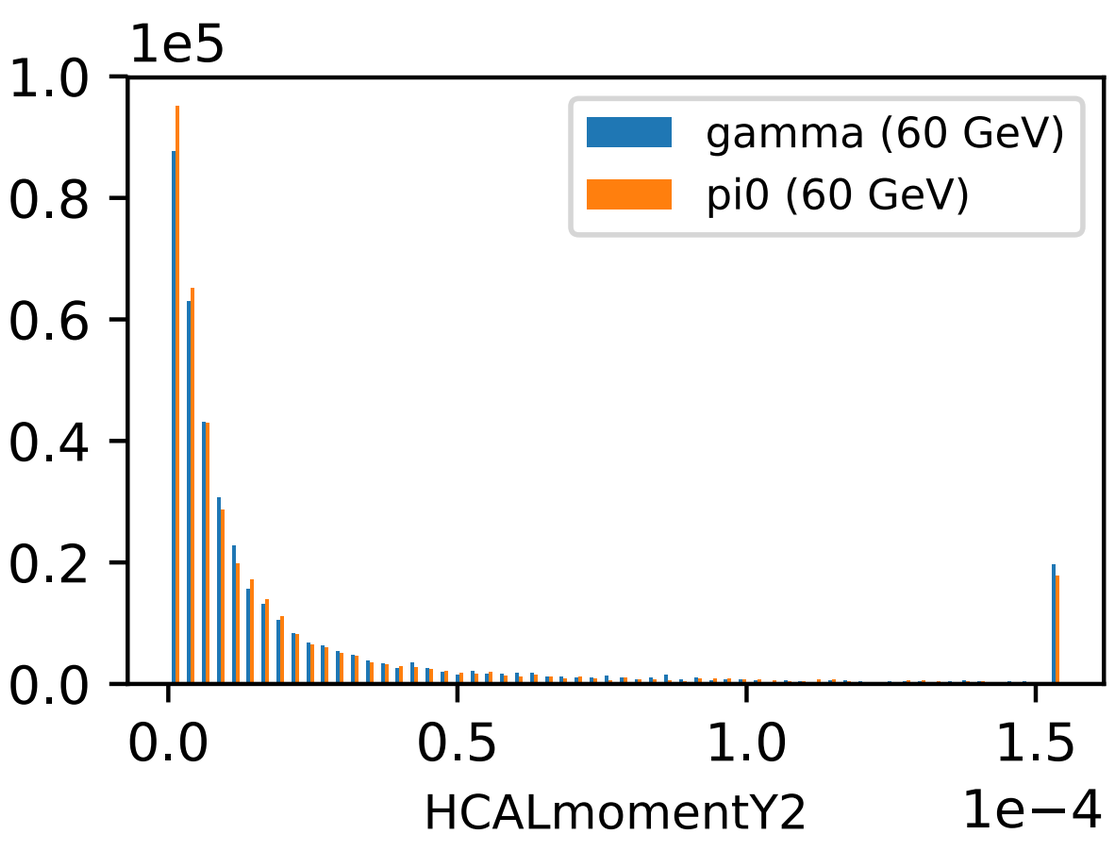

1e5
gamma (60 GeV)
pi0 (60 GeV)
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
0.6
0.8
1.0
HCALmomentX2
1e−4

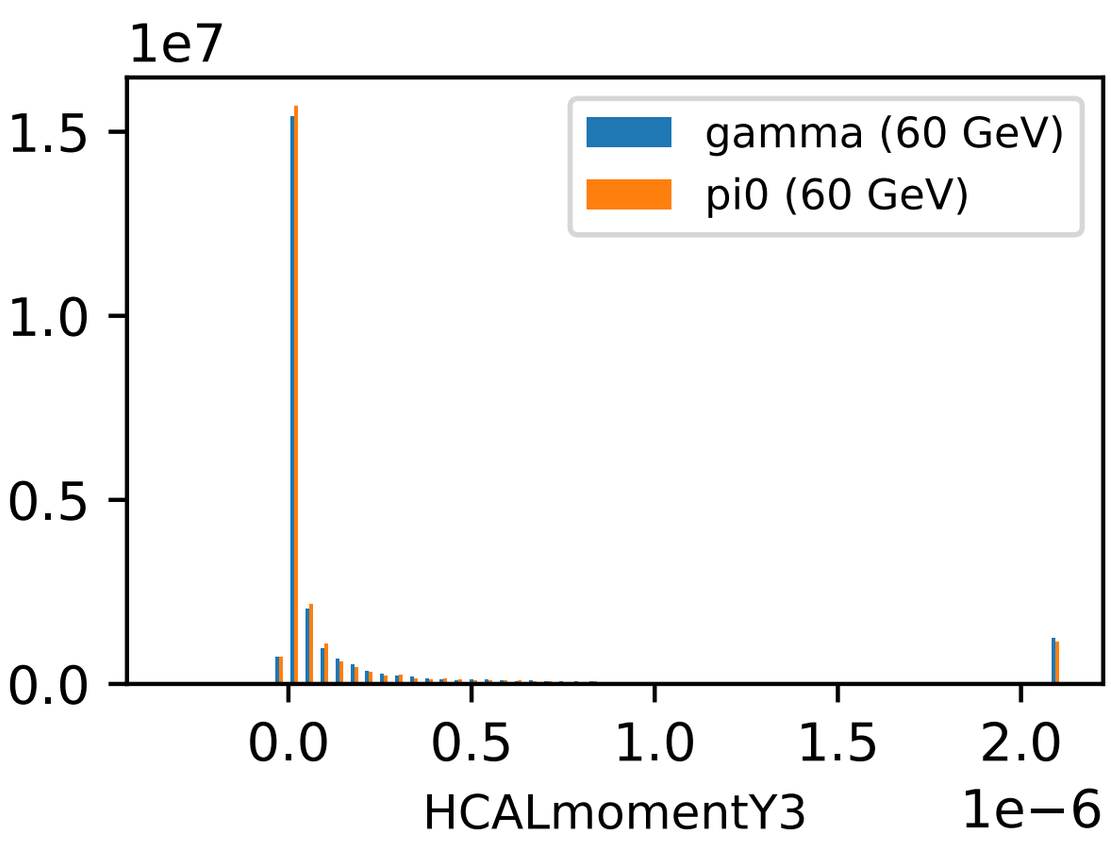

1e7
gamma (60 GeV)
pi0 (60 GeV)
0
1
2
3
0.0
0.2
0.4
0.6
0.8
1.0
HCALmomentX3
1e−6

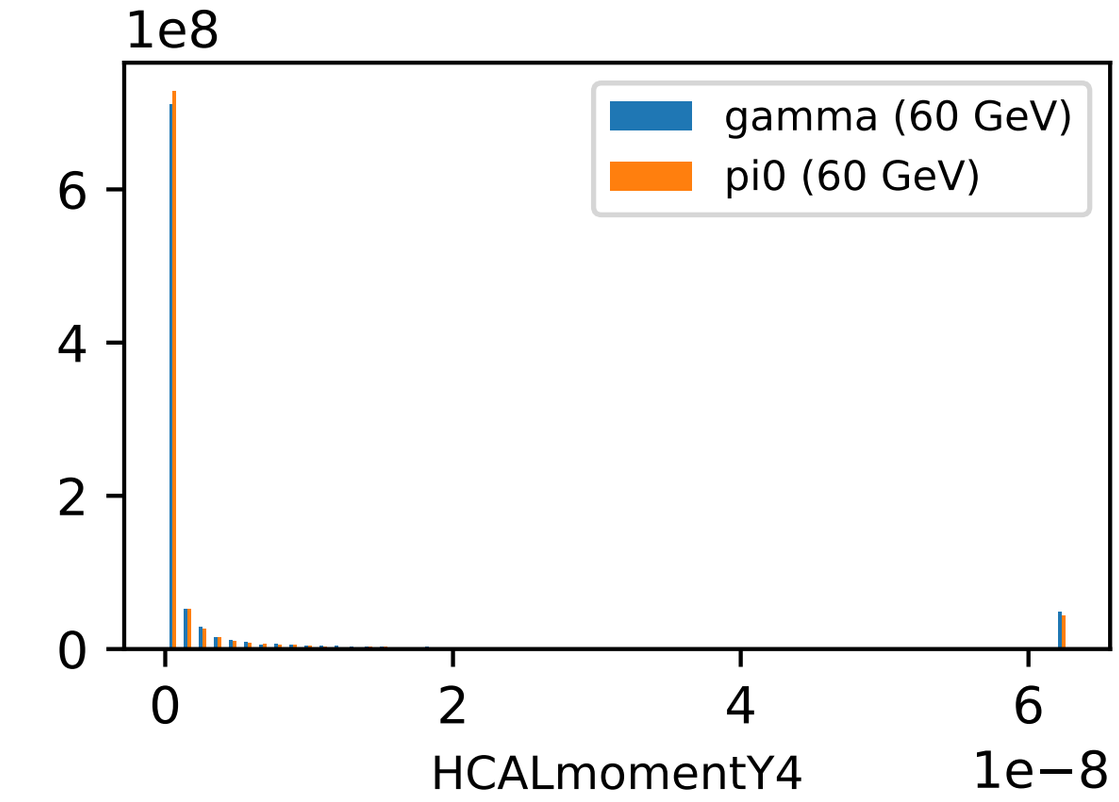

1e9
gamma (60 GeV)
pi0 (60 GeV)
0.0
0.5
1.0
1.5
0.0
0.5
1.0
1.5
2.0
2.5
HCALmomentX4
1e−8

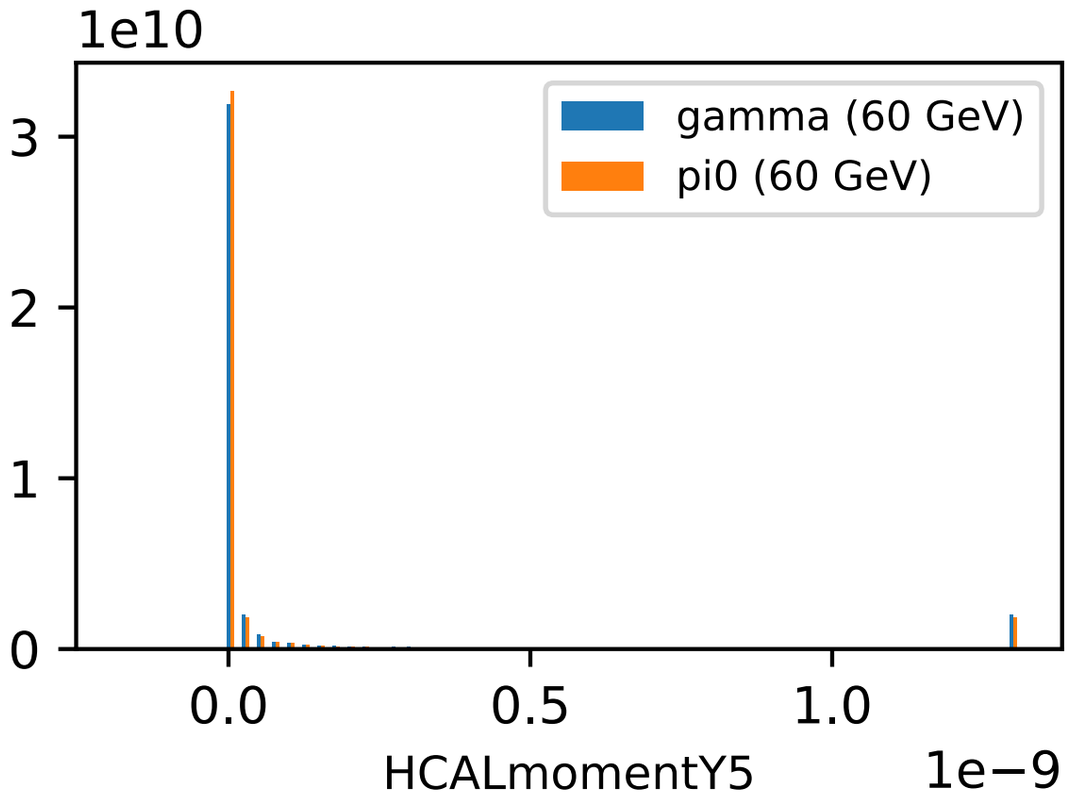

1e11
gamma (60 GeV)
pi0 (60 GeV)
1.0
0.5
0.0
0
1
2
3
4
HCALmomentX5
1e−10

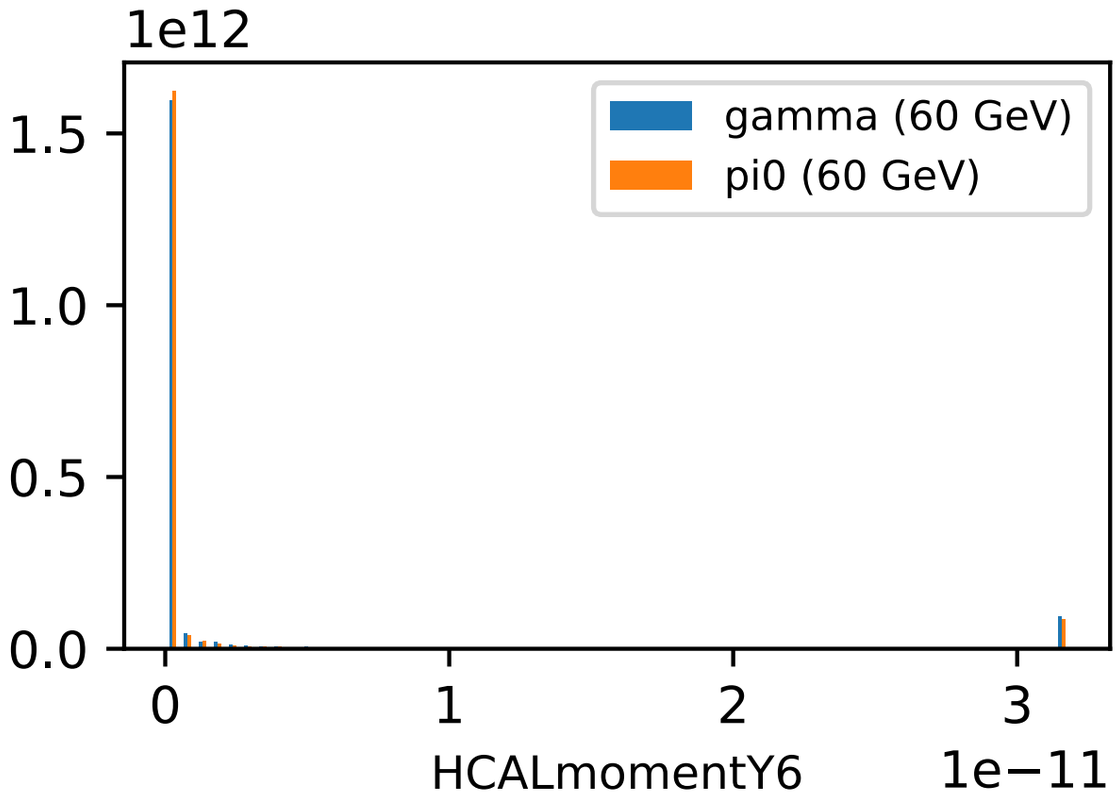

1e12
gamma (60 GeV)
pi0 (60 GeV)
6
4
2
0
0
2
4
6
8
HCALmomentX6
1e−12

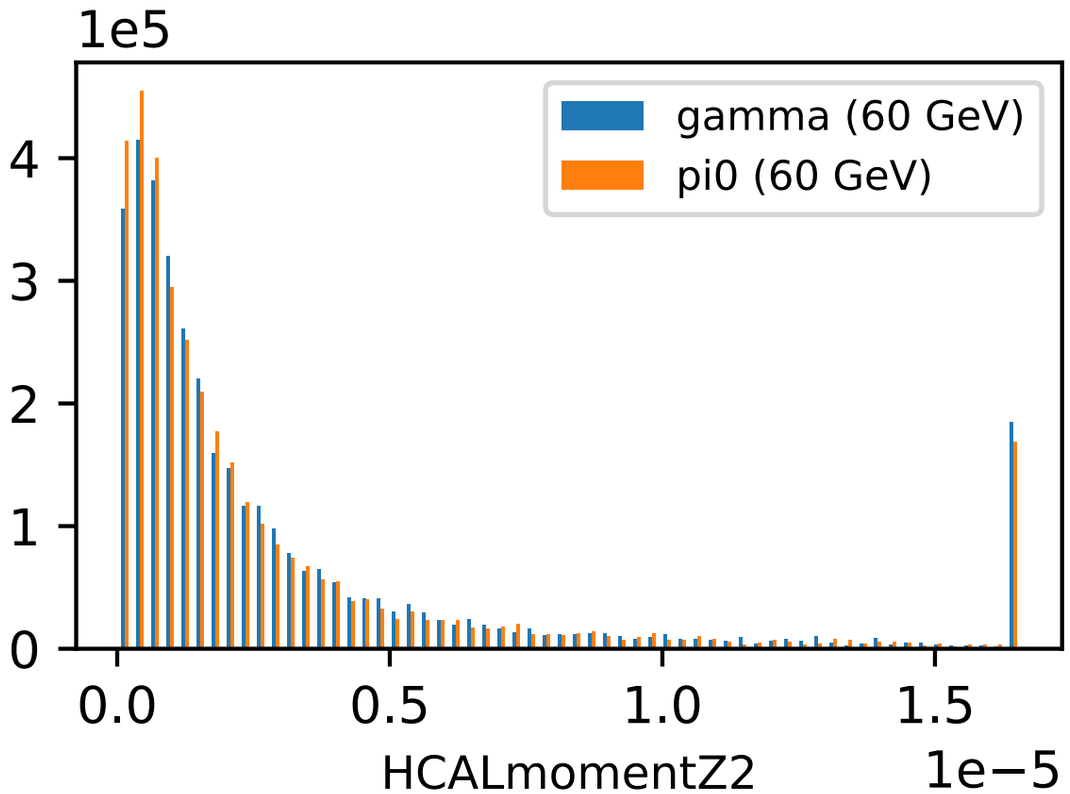

1e5
gamma (60 GeV)
pi0 (60 GeV)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
HCALmomentY2
1e−4

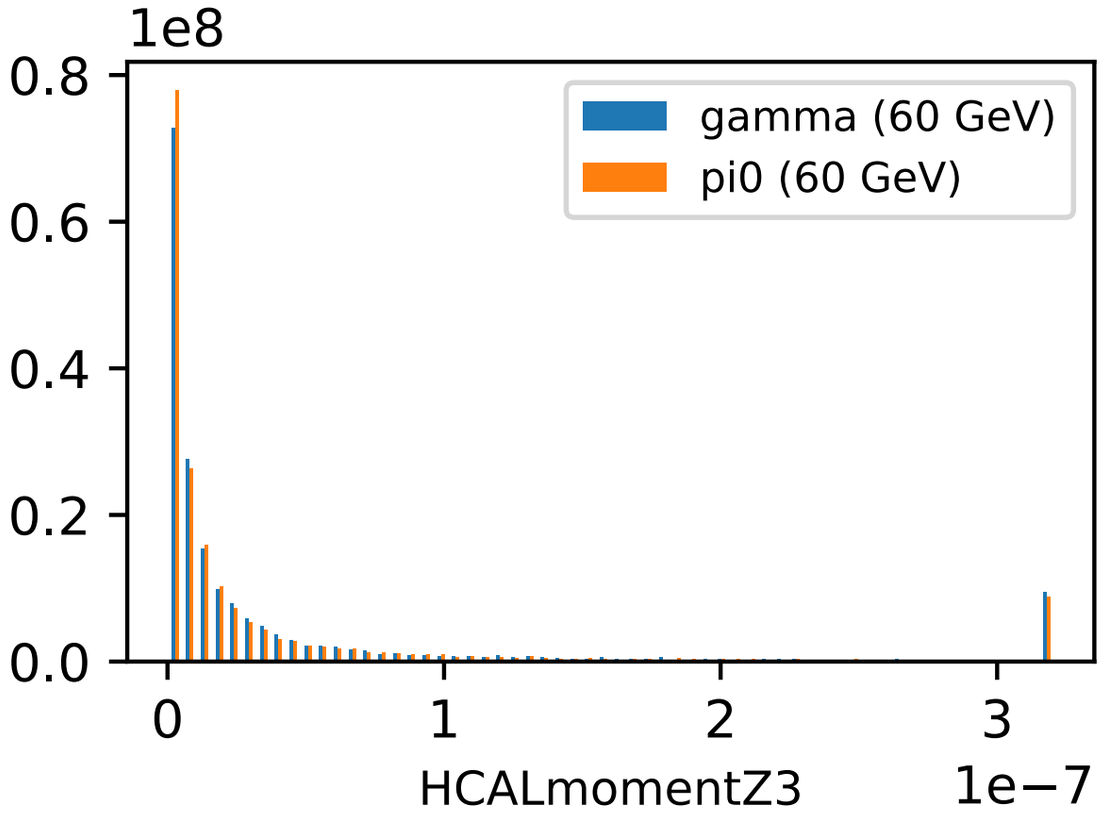

1e7
gamma (60 GeV)
pi0 (60 GeV)
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
HCALmomentY3
1e−6

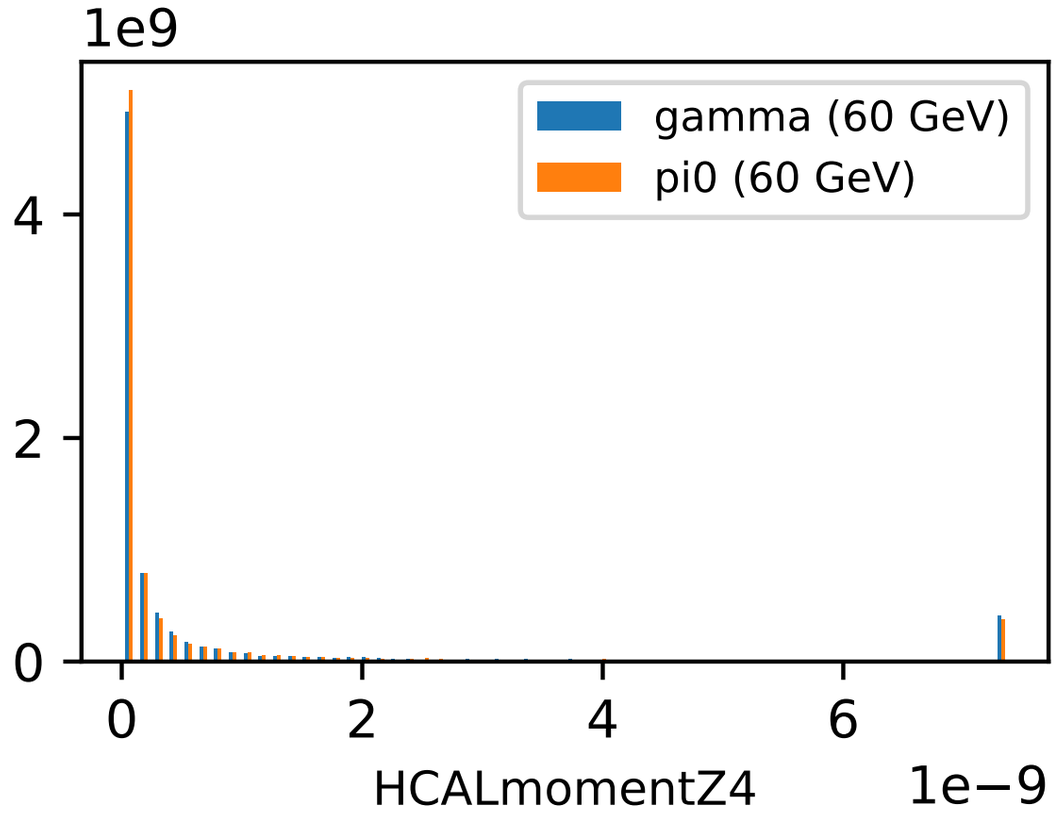

1e8
gamma (60 GeV)
pi0 (60 GeV)
6
4
2
0
0
2
4
6
HCALmomentY4
1e−8

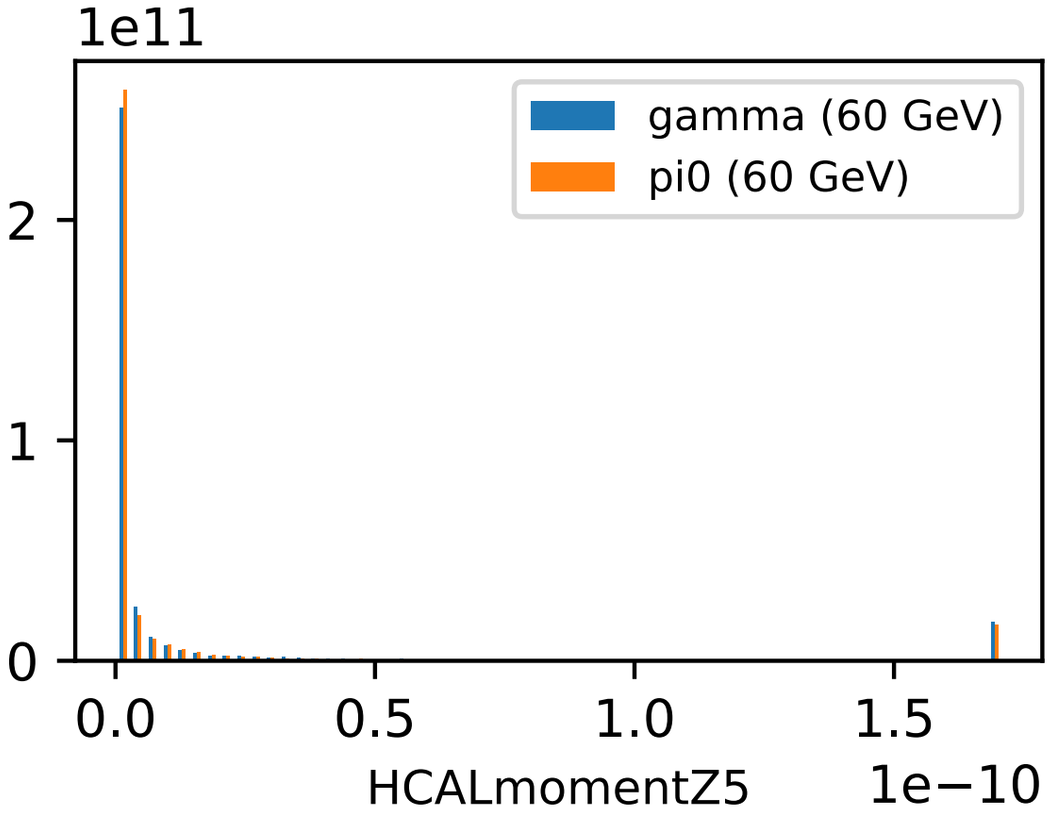

1e10
gamma (60 GeV)
pi0 (60 GeV)
3
2
1
0
0.0
0.5
1.0
HCALmomentY5
1e−9

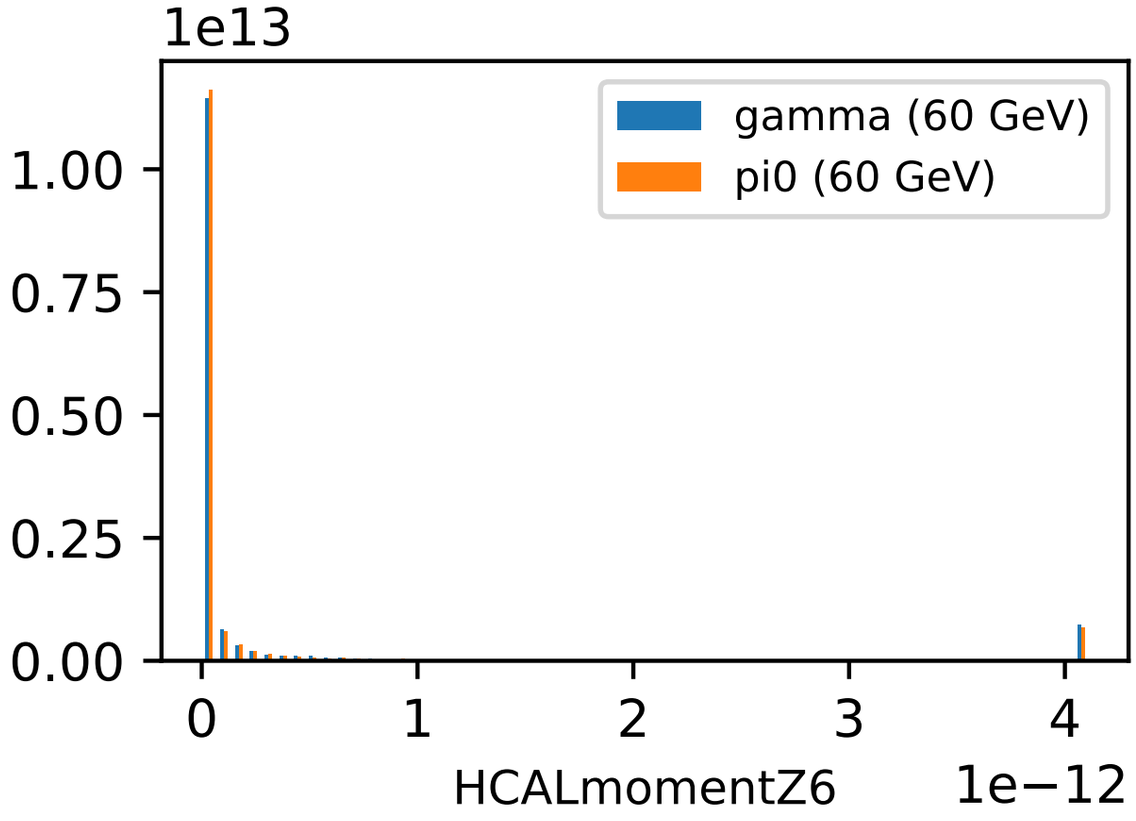

1e12
gamma (60 GeV)
pi0 (60 GeV)
1.5
1.0
0.5
0.0
0
1
2
3
HCALmomentY6
1e−11


1e5
gamma (60 GeV)
pi0 (60 GeV)
4
3
2
1
0
0.0
0.5
1.0
1.5
HCALmomentZ2
1e−5

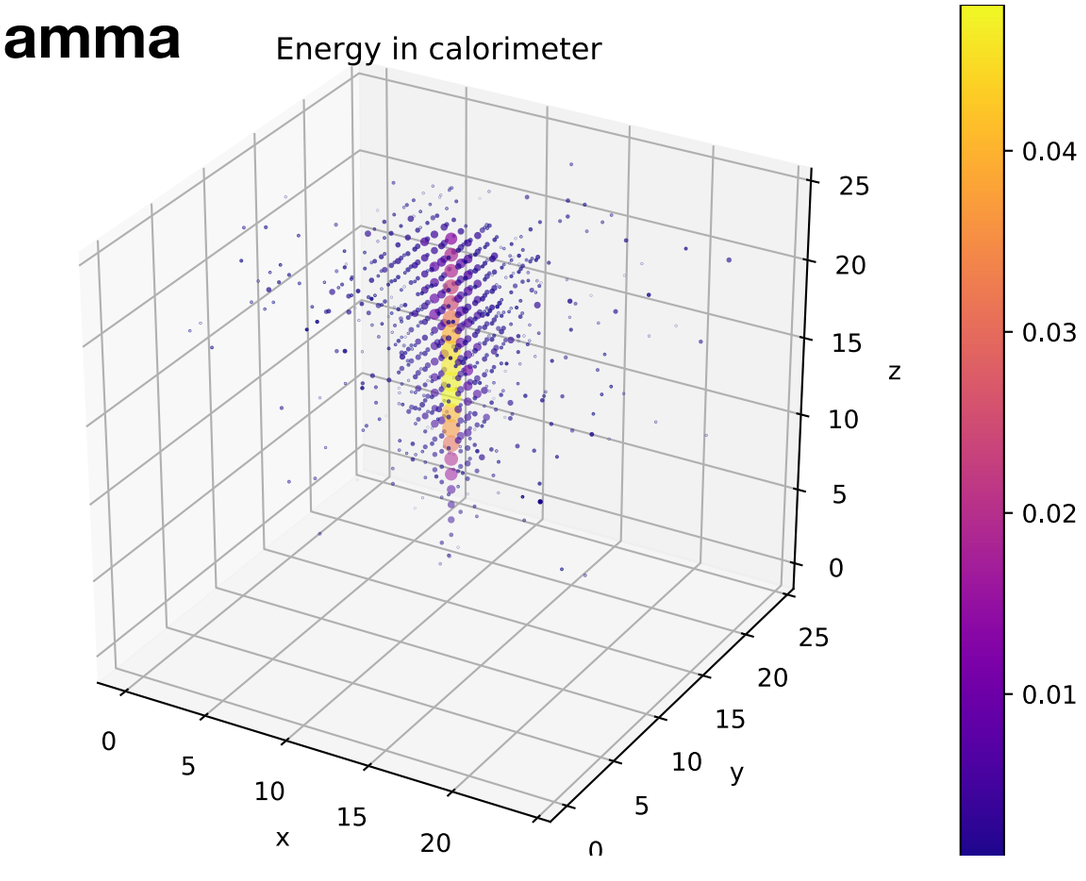

1e8
0.8
0.6
0.4
0.2
0.0
0
1
2
3
1e−7
HCALmomentZ3
gamma (60 GeV)
pi0 (60 GeV)


1e9
4
2
0
0
2
4
6
1e−9
HCALmomentZ4
gamma (60 GeV)
pi0 (60 GeV)

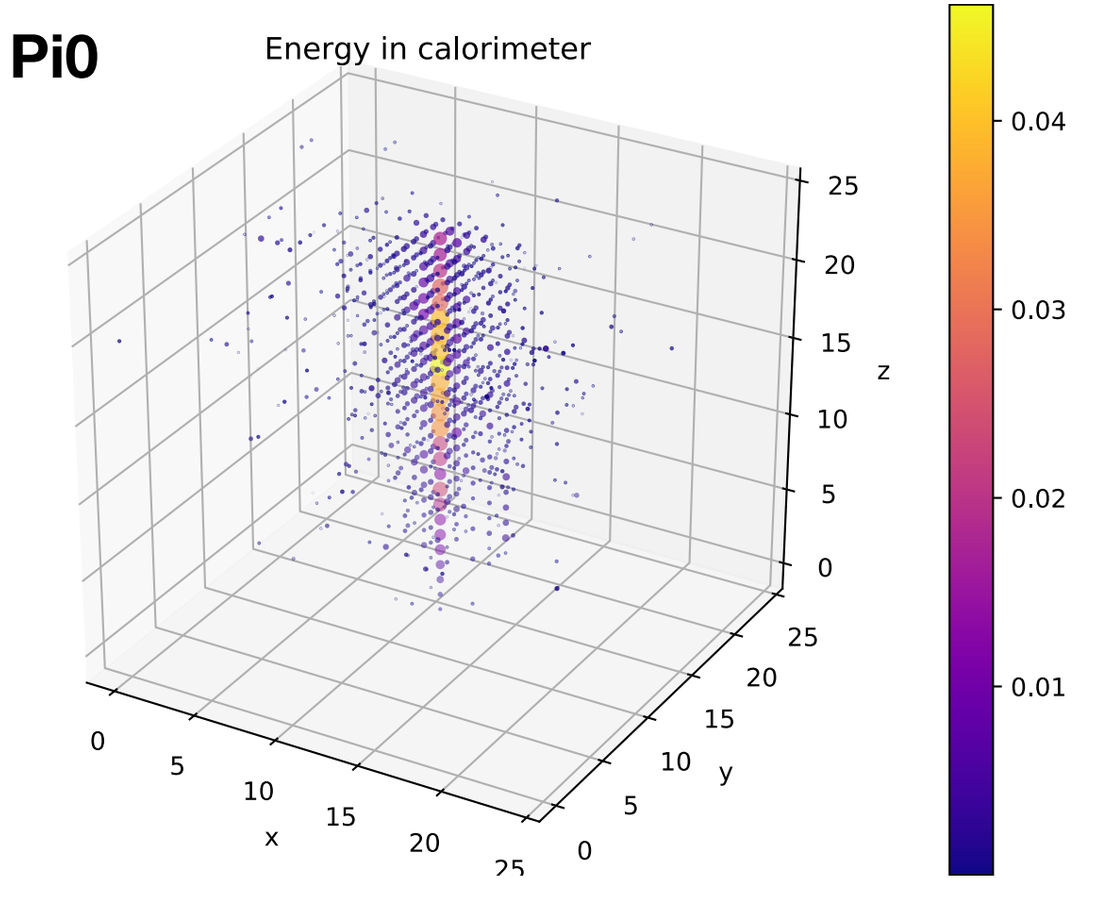

1e11
2
1
0
0.0
0.5
1.0
1.5
1e−10
HCALmomentZ5
gamma (60 GeV)
pi0 (60 GeV)

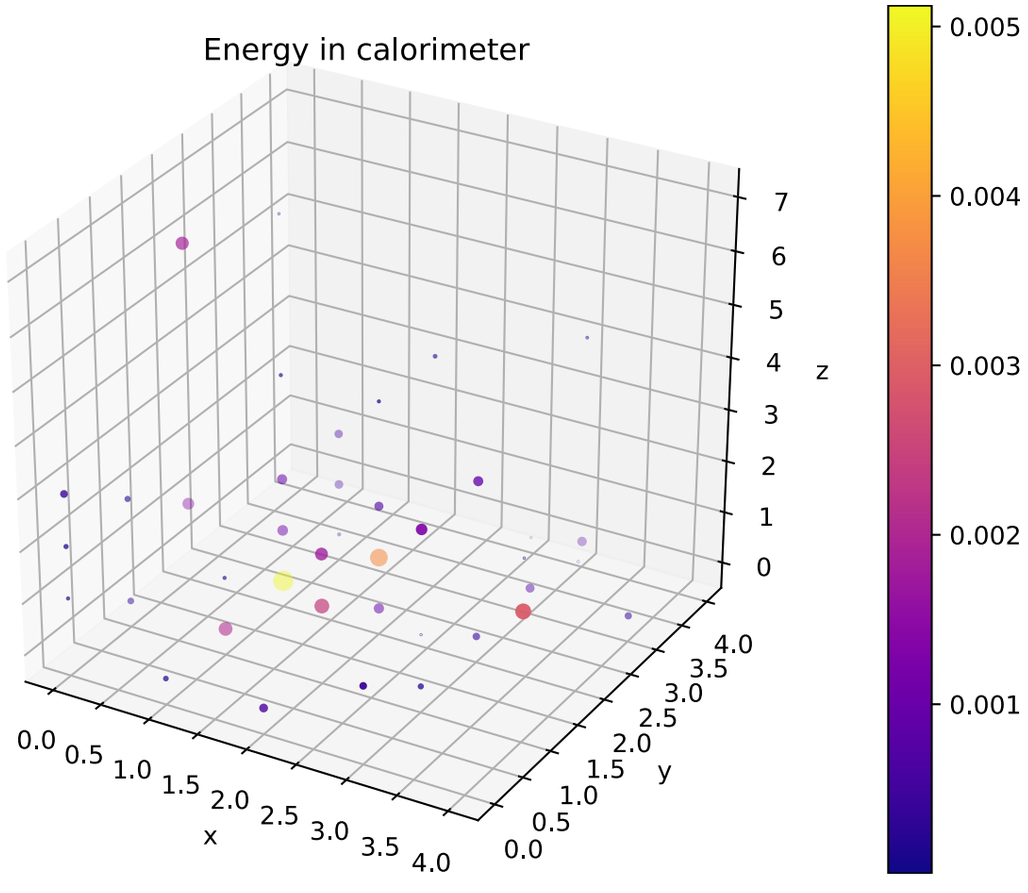

1e13
1.00
0.75
0.50
0.25
0.00
0
1
2
3
4
1e−12
HCALmomentZ6
gamma (60 GeV)
pi0 (60 GeV)

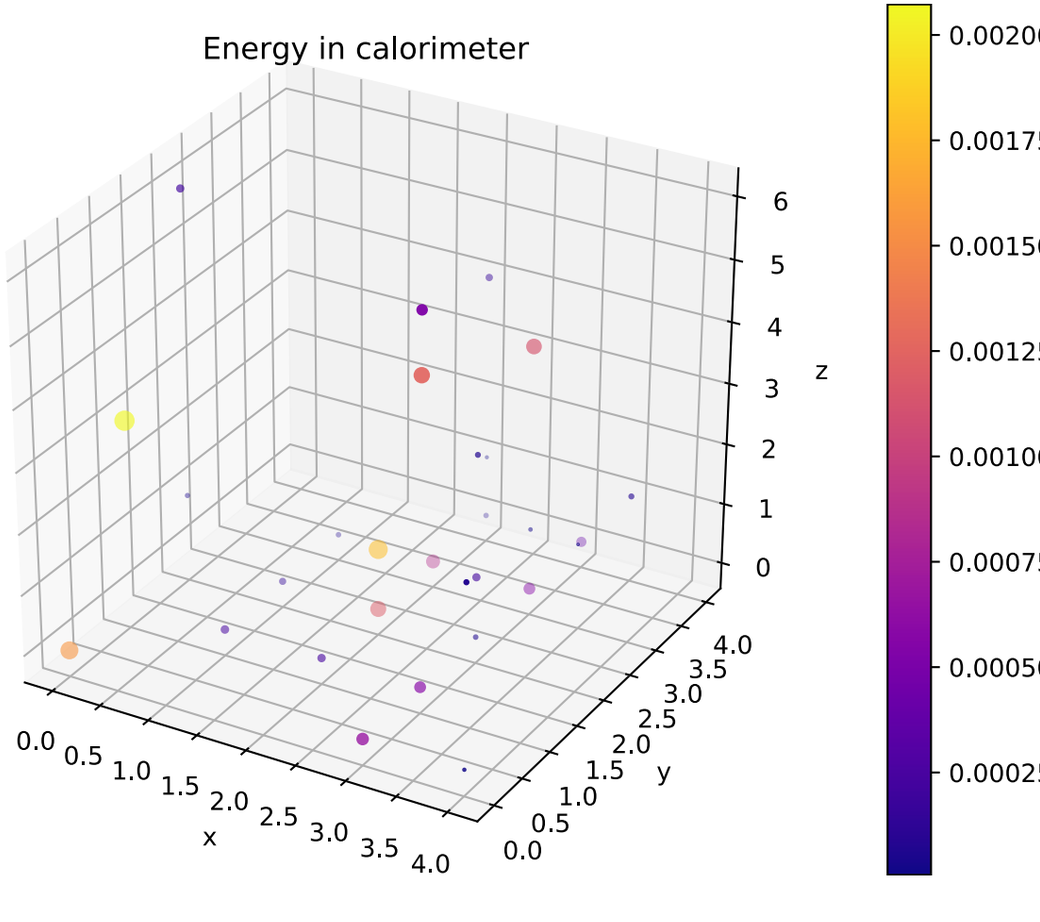
Gamma


Energy in calorimeter
x
y
z
0
5
10
15
20
25
0.04
0.03
0.02
0.01

Pi0

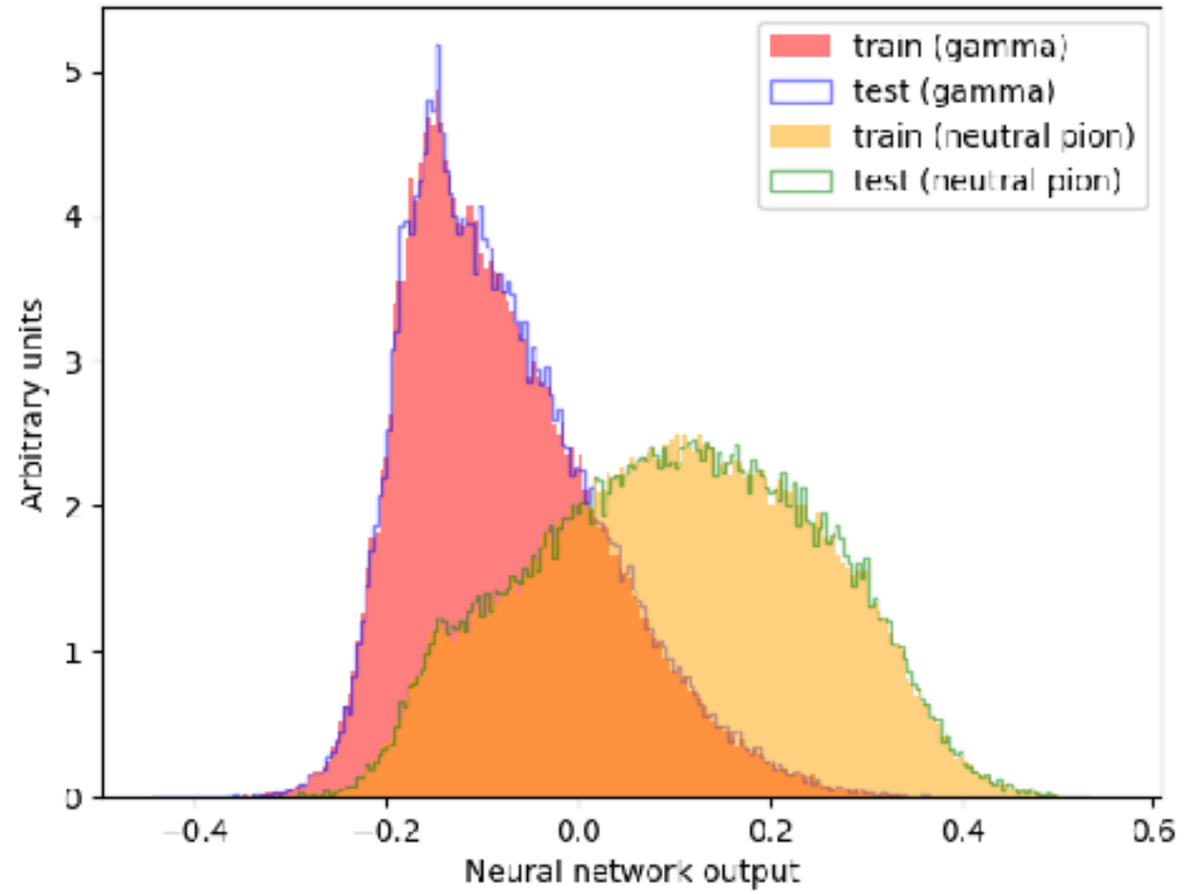

Energy in calorimeter
x
y
z
0
5
10
15
20
25
0.04
0.03
0.02
0.01


Energy in calorimeter
x
y
z
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
1
2
3
4
5
6
7
0.005
0.004
0.003
0.002
0.001


Energy in calorimeter
x
y
z
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
1
2
3
4
5
6
0.00200
0.00175
0.00150
0.00125
0.00100
0.00075
0.00050
0.00025

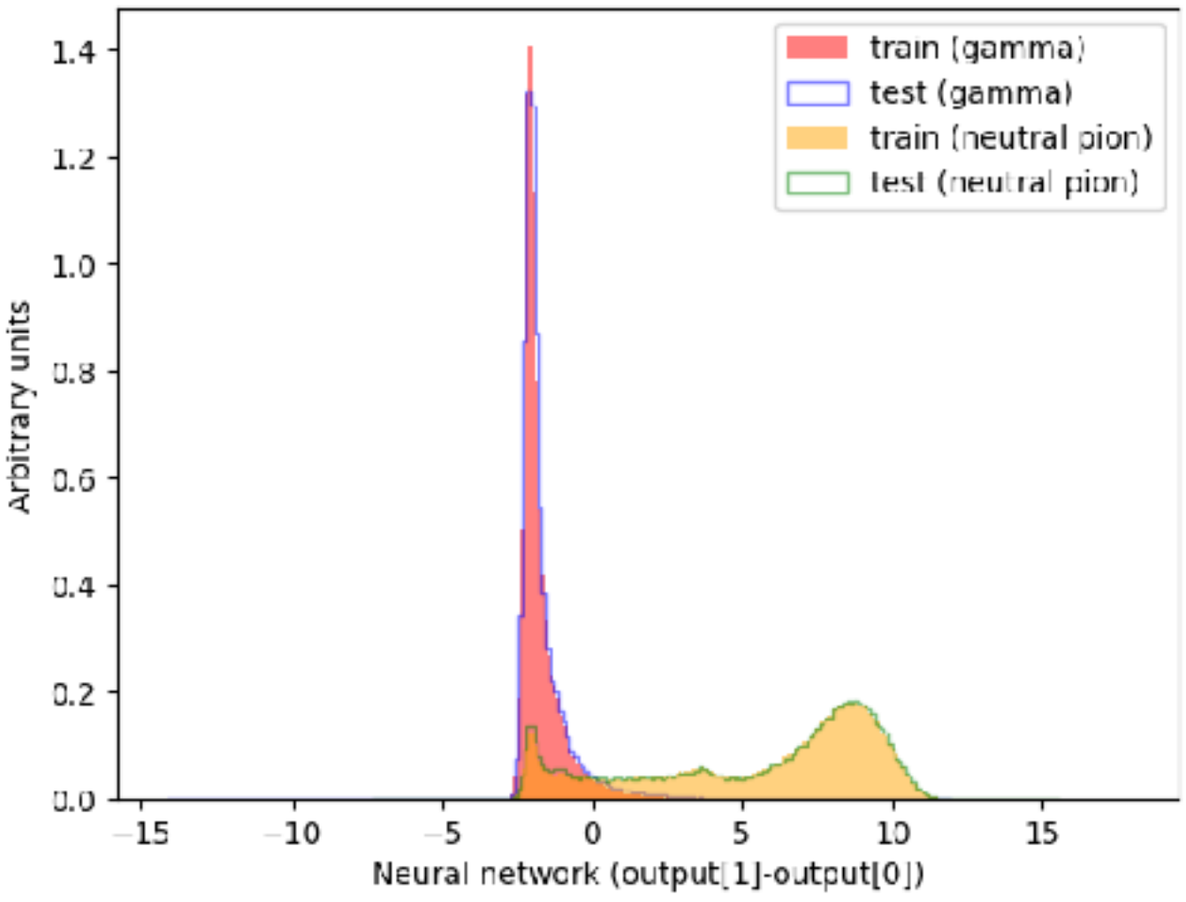
BDT (Depth=3, 400K training samples and 200K testing samples)

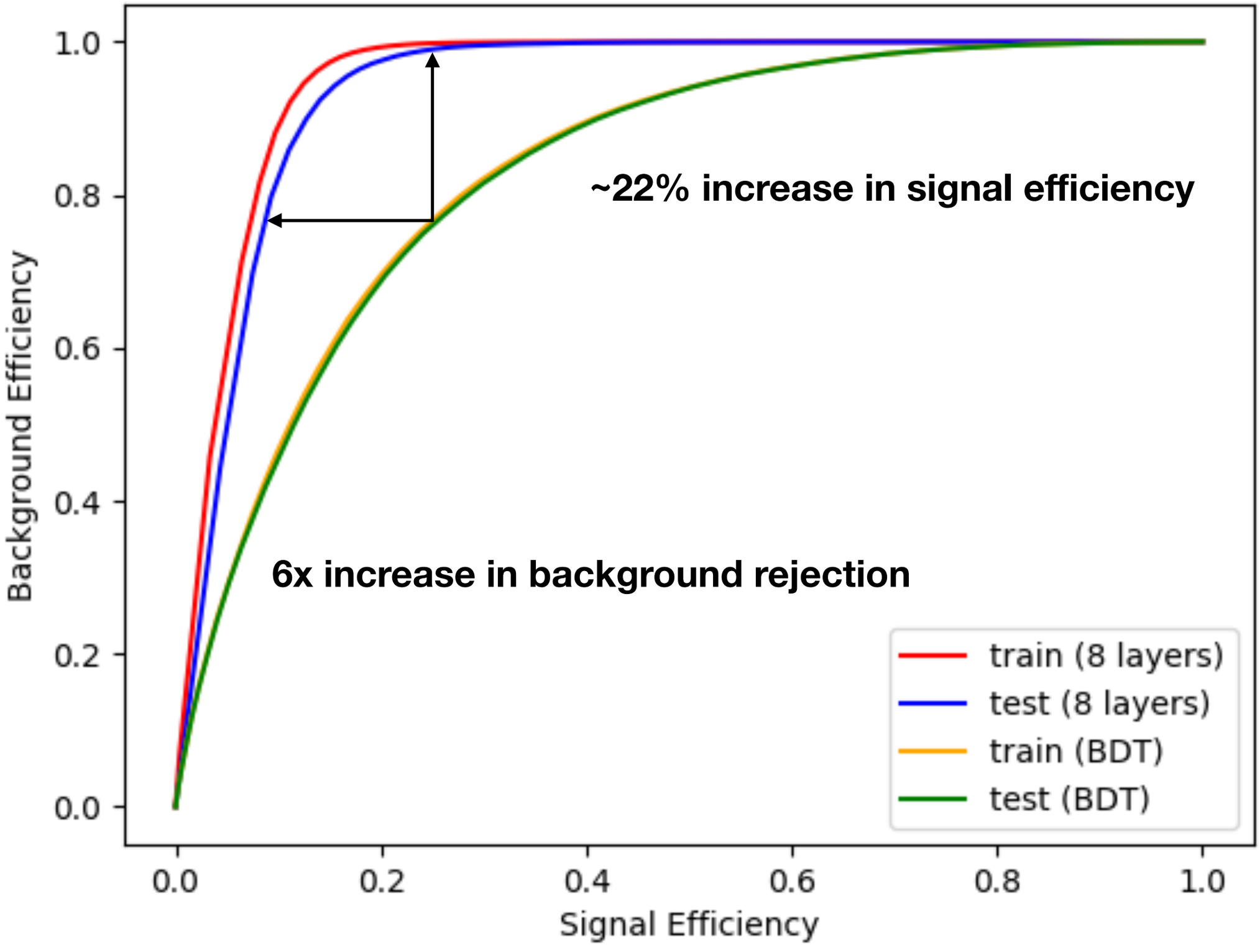
BDT Accuracy 76%

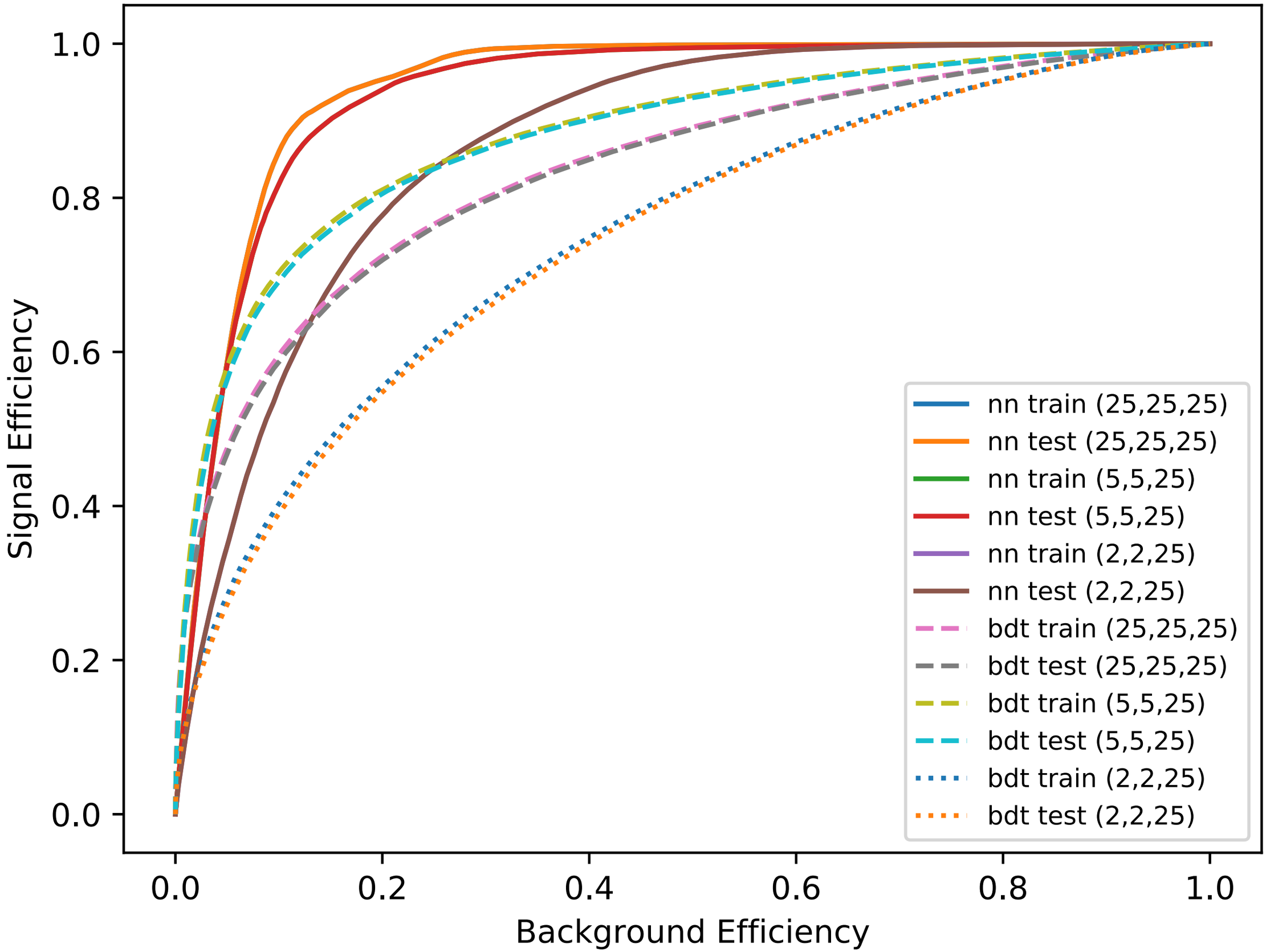


Fully connected NN (Depth=8, width=96, 400K training samples and 200K testing samples)

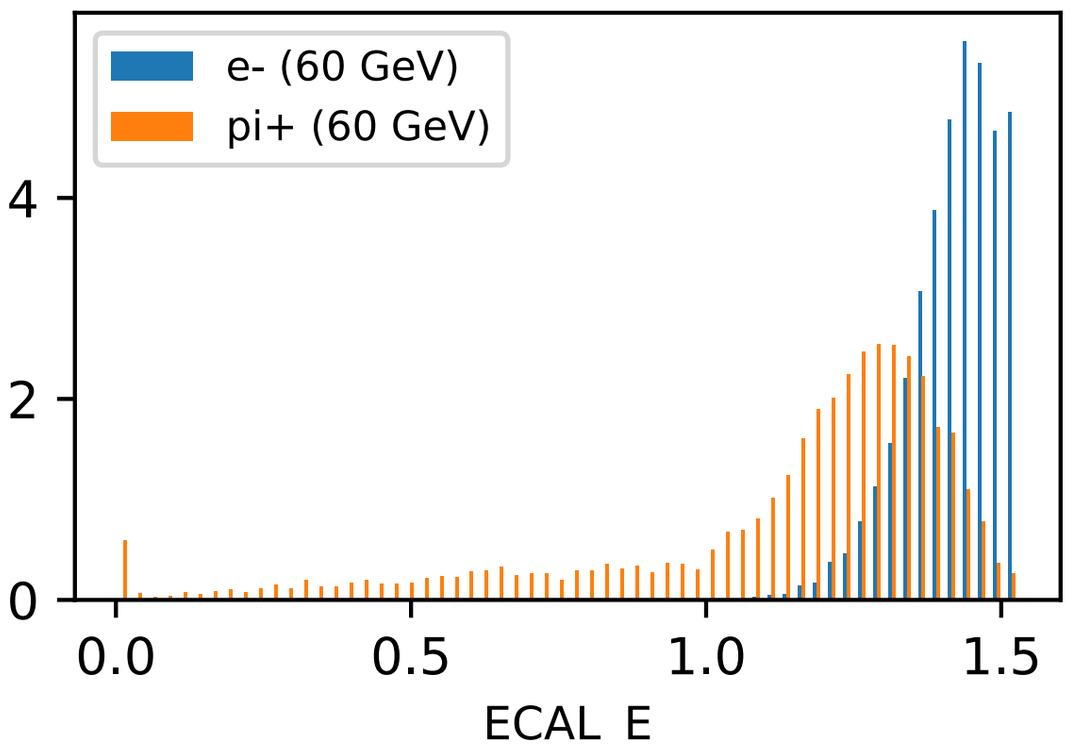
NN Accuracy: 90%

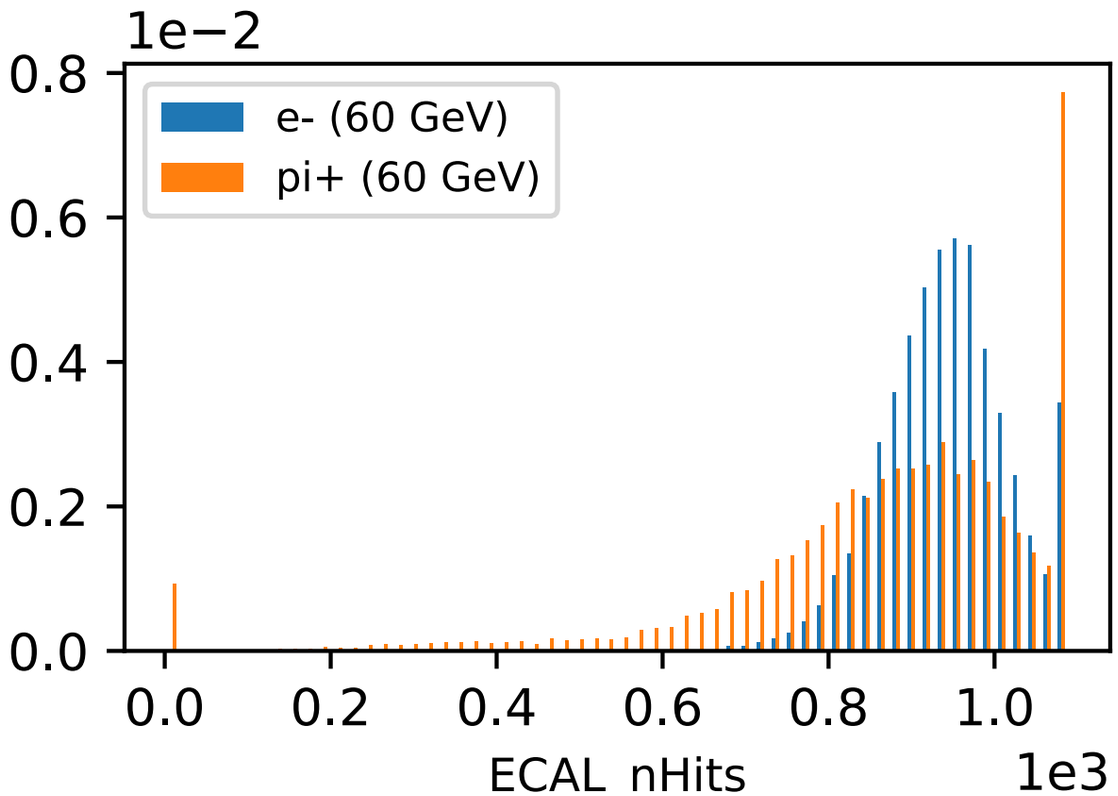


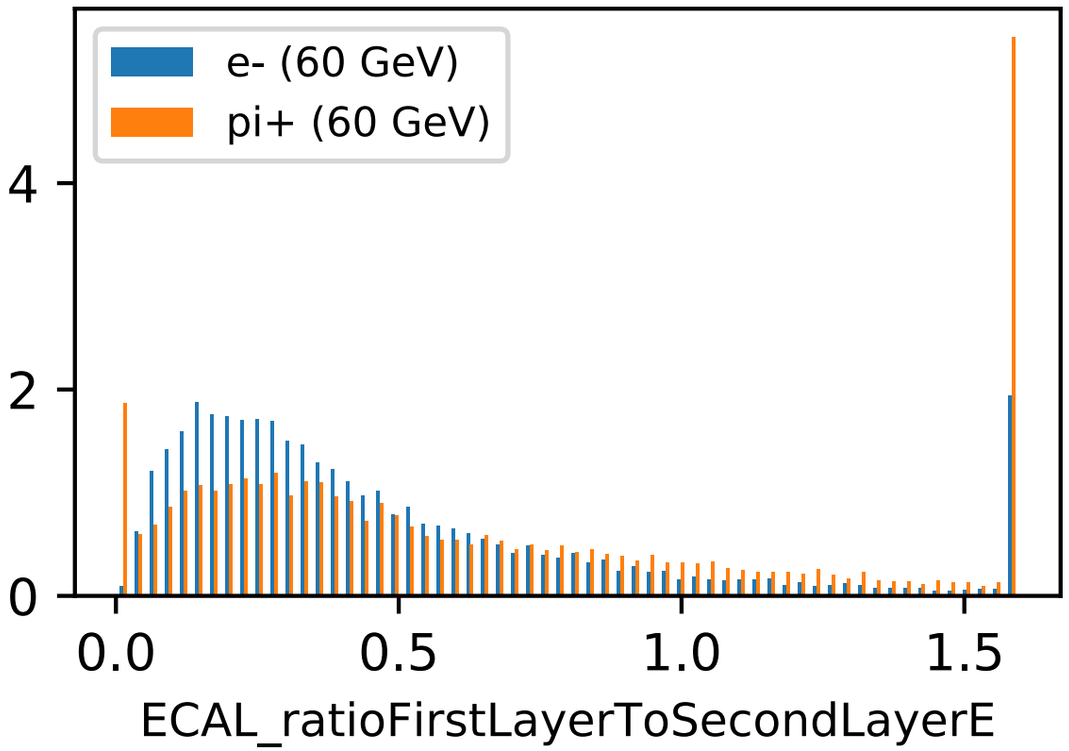

~22% increase in signal efficiency
6x increase in background rejection
train (8 layers)
test (8 layers)
train (BDT)
test (BDT)
Background Efficiency
Signal Efficiency
0.0
0.2
0.4
0.6
0.8
1.0

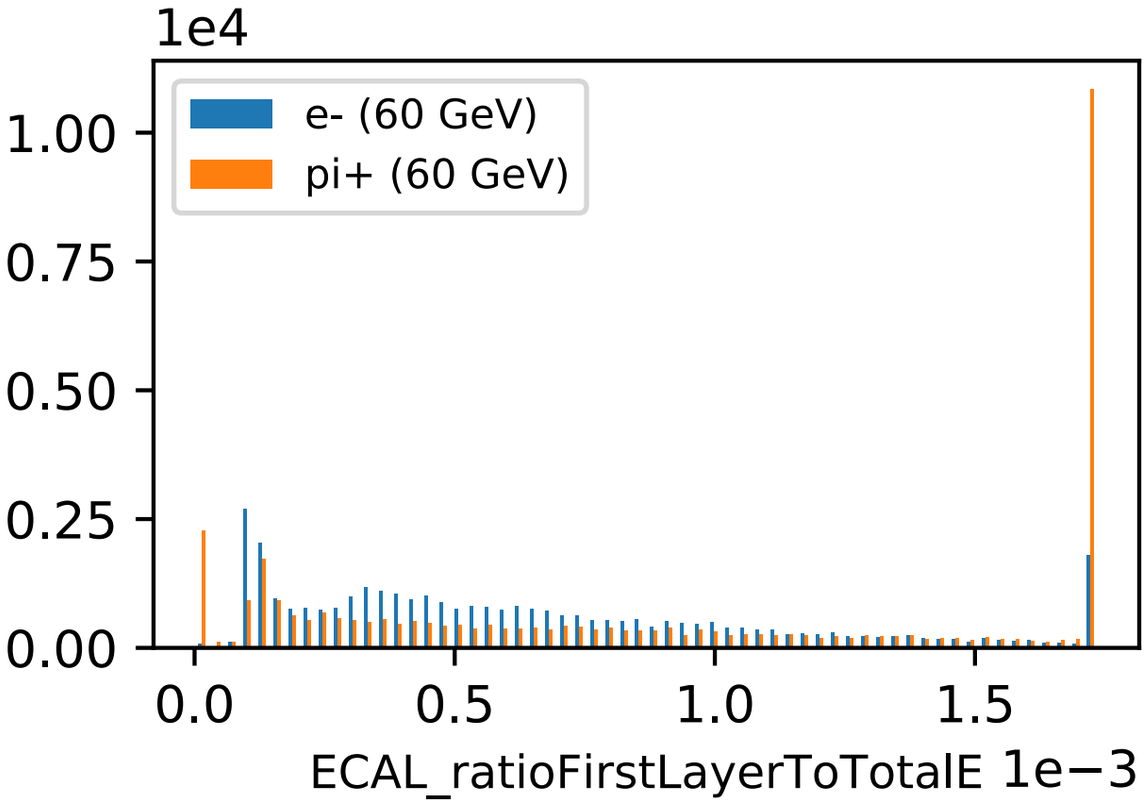

1.0
0.8
0.6
0.4
0.2
0.0
Signal Efficiency
0.0
0.2
0.4
0.6
0.8
1.0
Background Efficiency
nn train (25,25,25)
nn test (25,25,25)
nn train (5,5,25)
nn test (5,5,25)
nn train (2,2,25)
nn test (2,2,25)
bdt train (25,25,25)
bdt test (25,25,25)
bdt train (5,5,25)
bdt test (5,5,25)
bdt train (2,2,25)
bdt test (2,2,25)

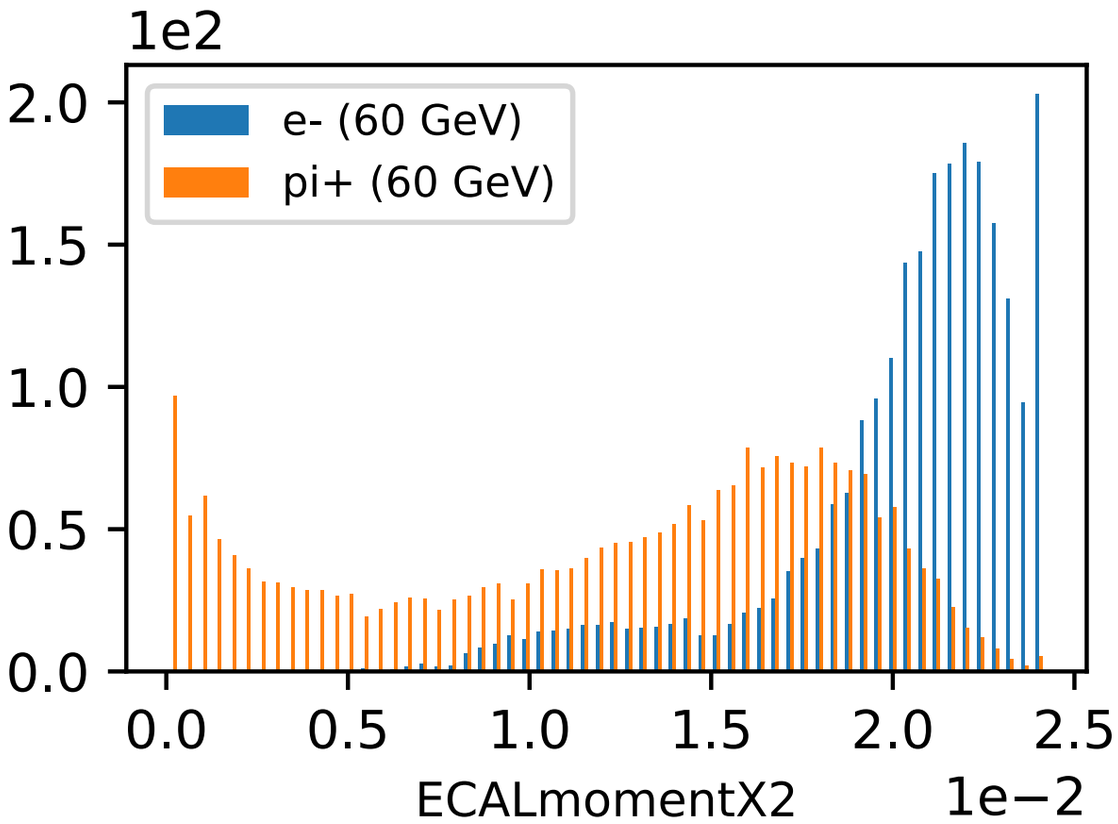
e- vs. pi+ classifier

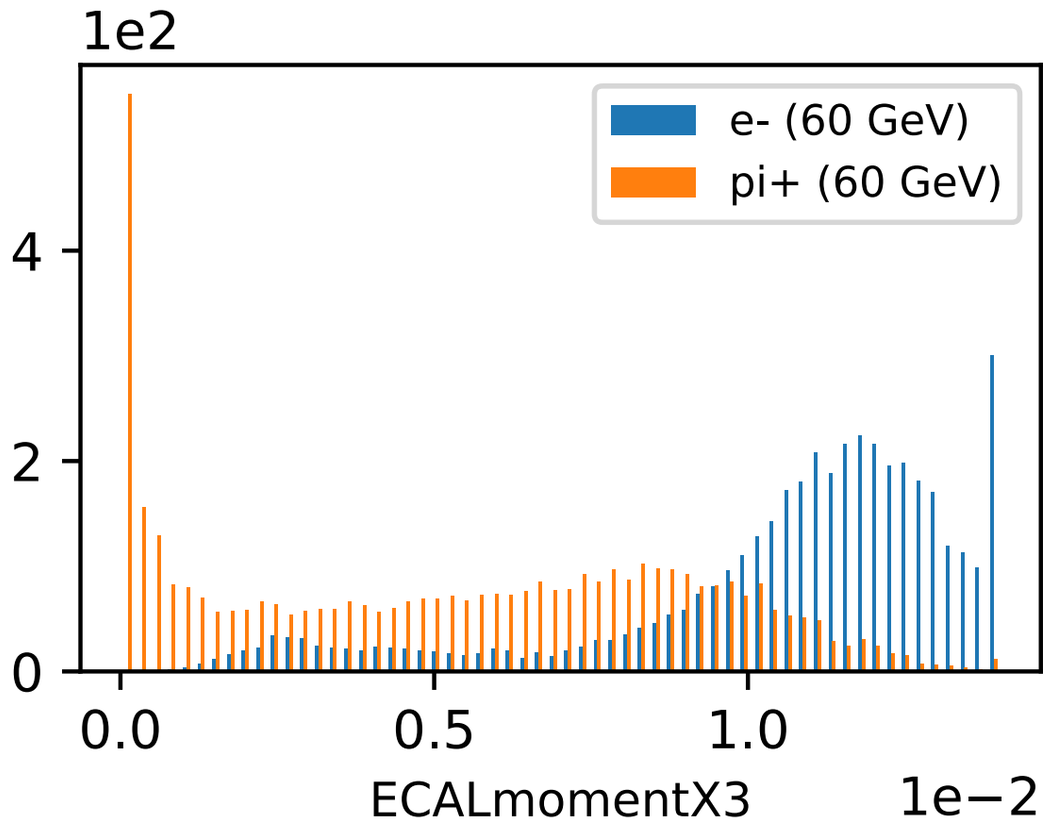


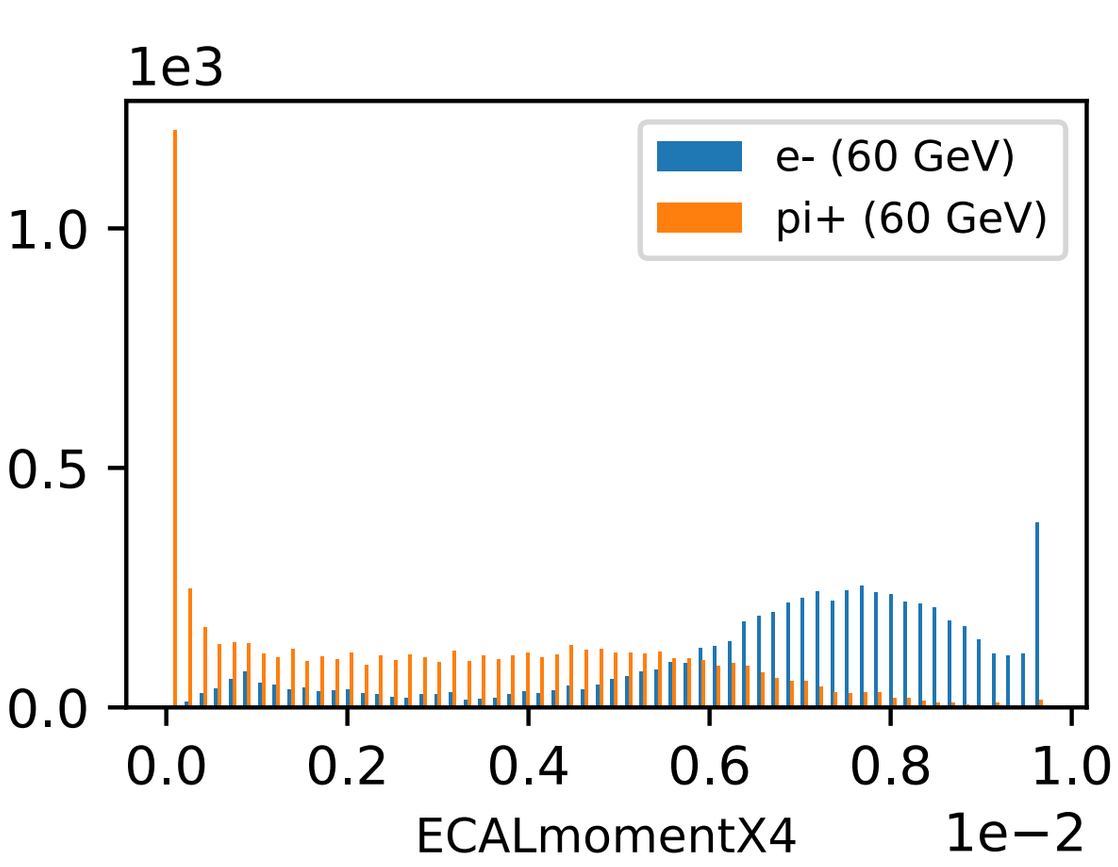


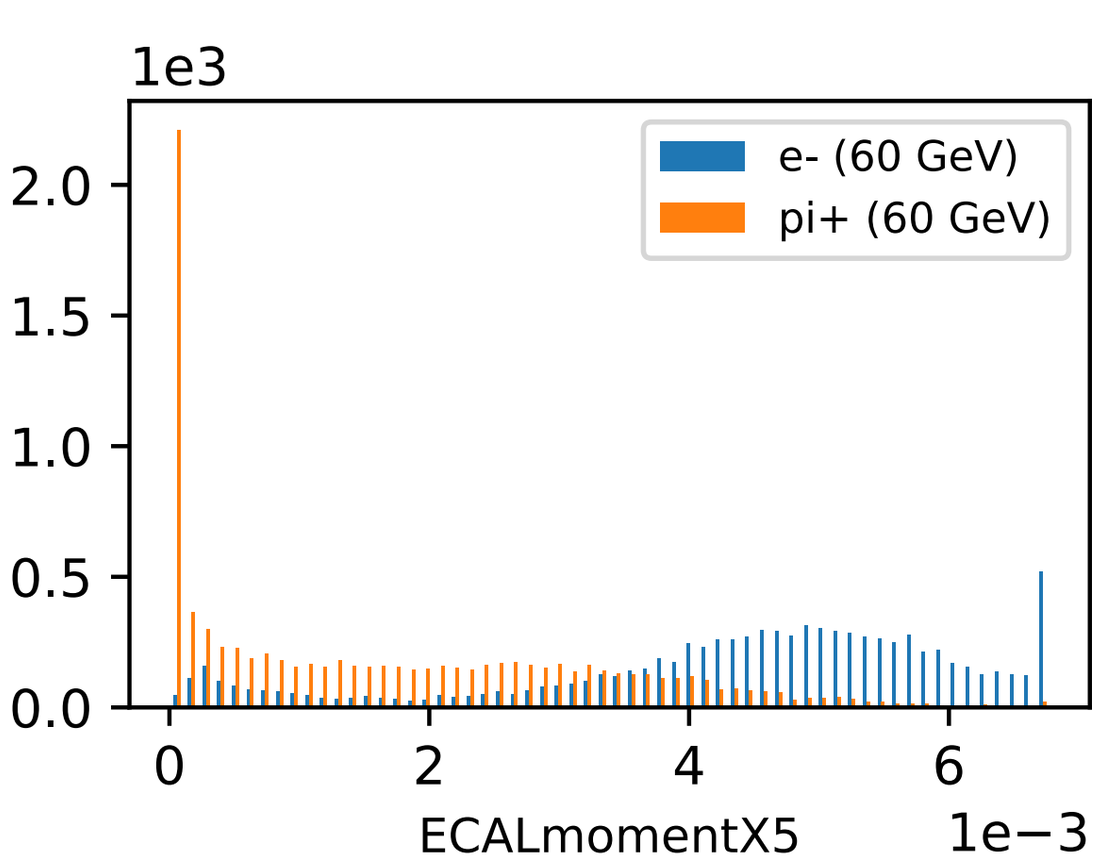


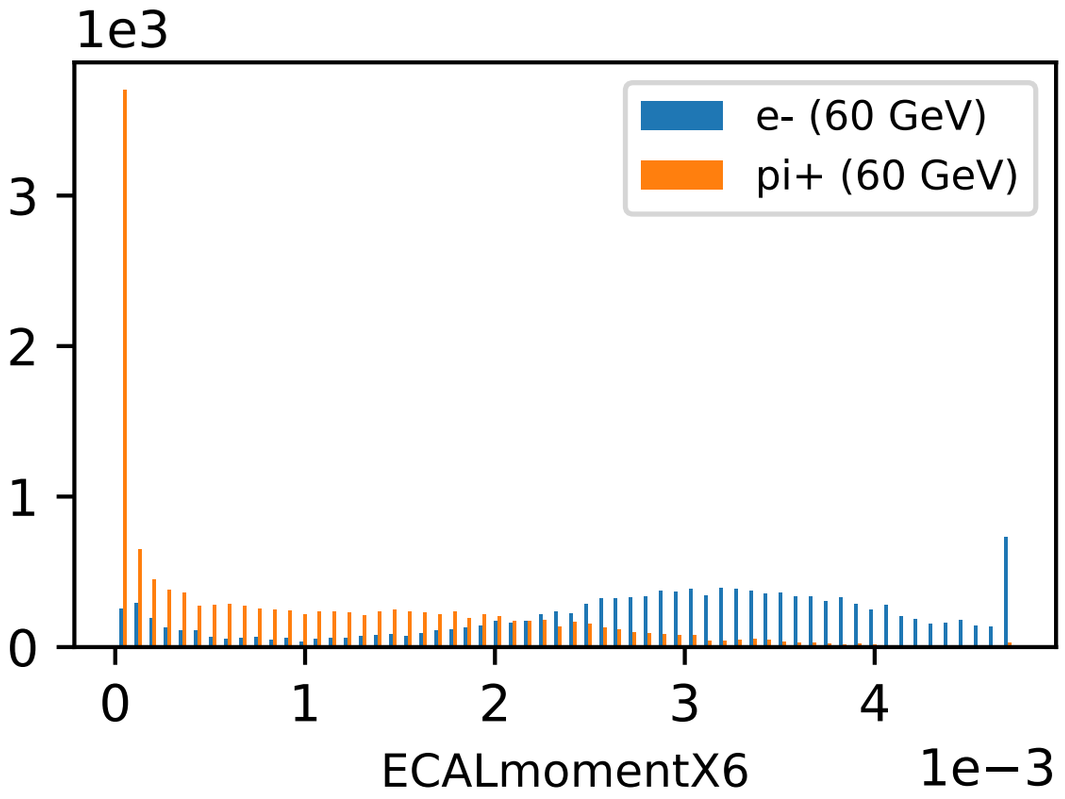


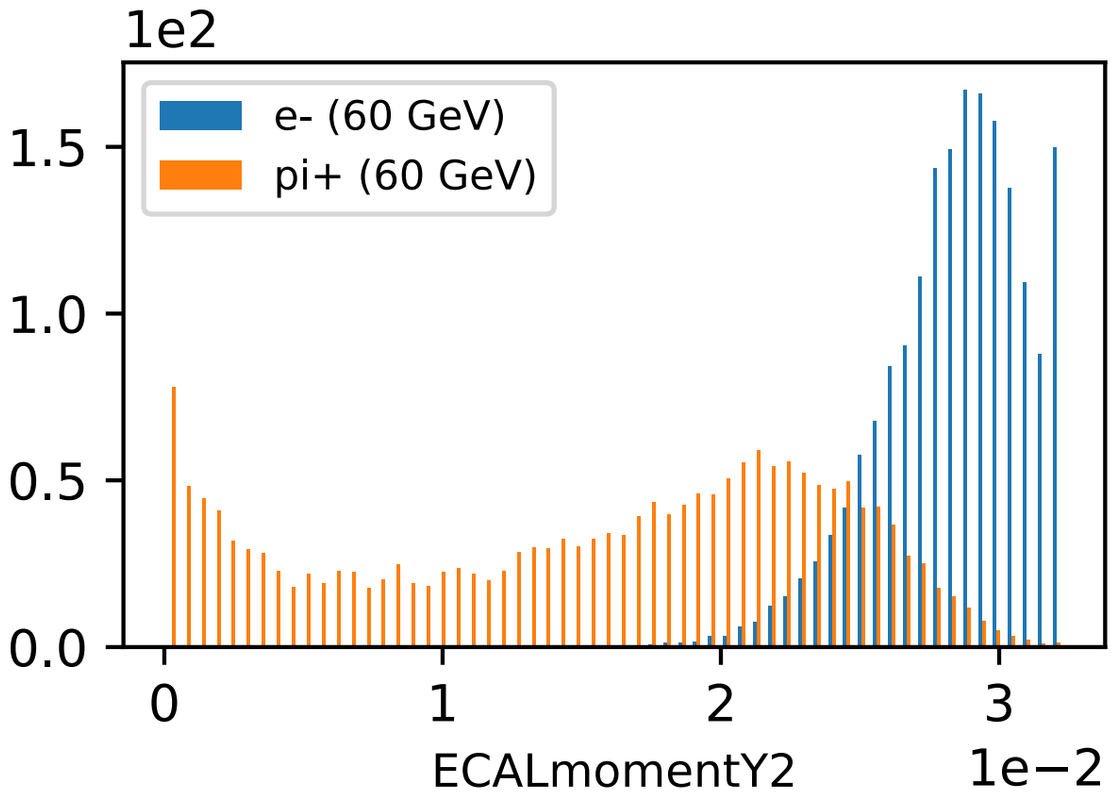

1e2
2.0
1.5
1.0
0.5
0.0
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
2.0
2.5
ECALmomentX2
1e−2

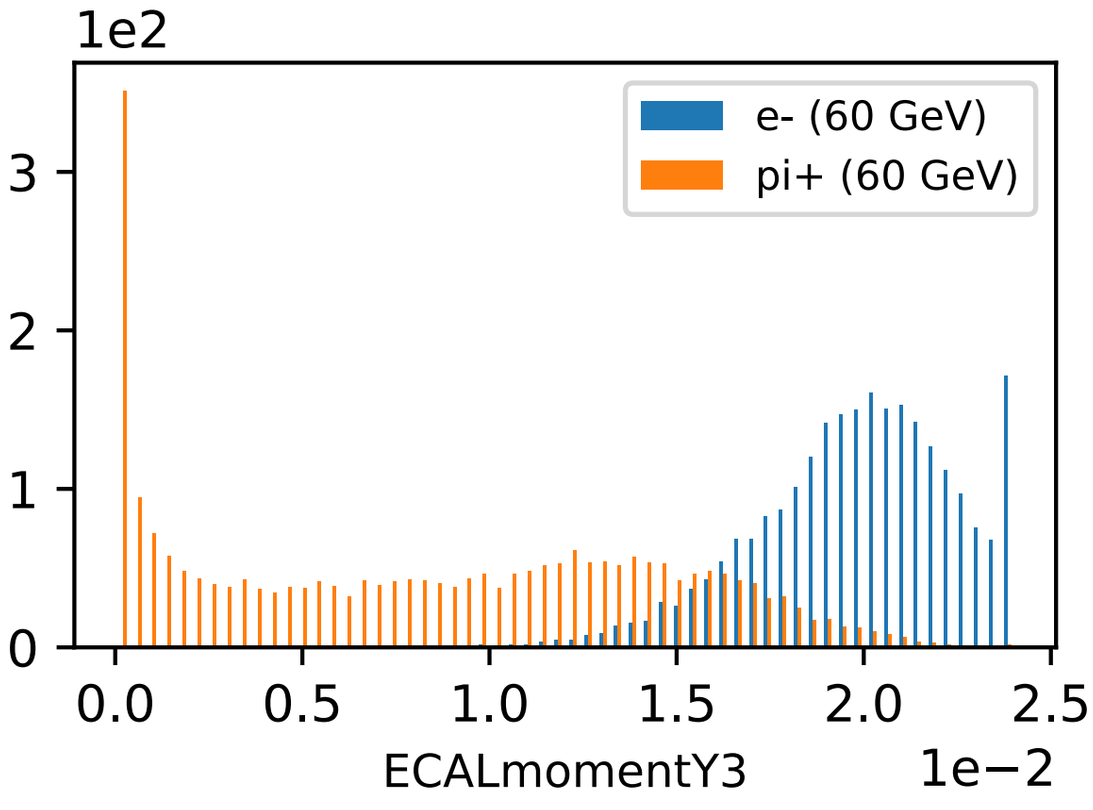

1e2
4
2
0
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
ECALmomentX3
1e−2

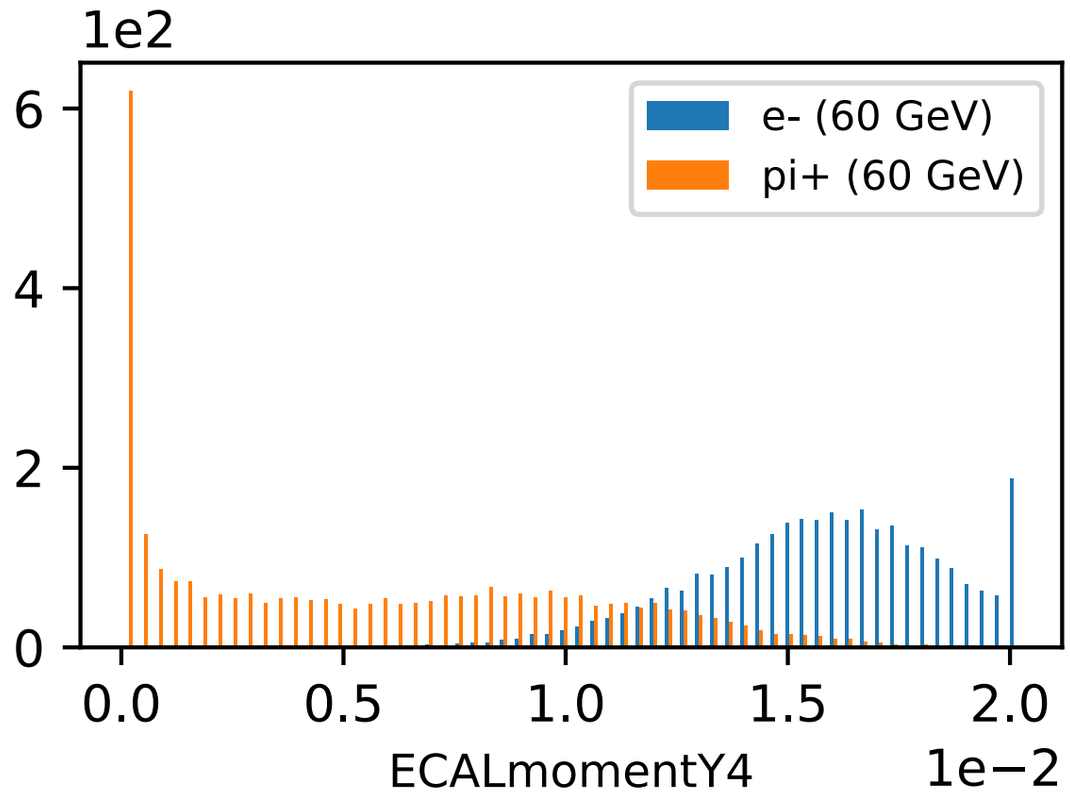

1e3
1.0
0.5
0.0
e- (60 GeV)
pi+ (60 GeV)
0.0
0.2
0.4
0.6
0.8
1.0
ECALmomentX4
1e−2

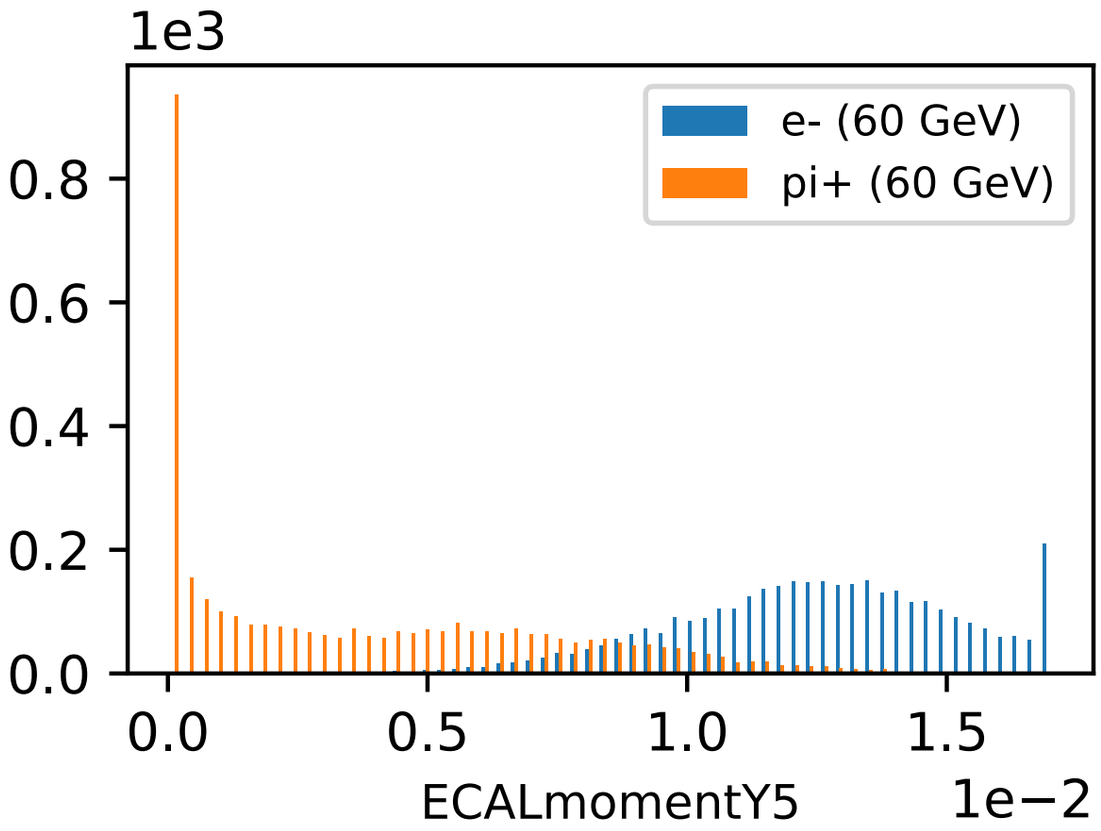

1e3
2.0
1.5
1.0
0.5
0.0
e- (60 GeV)
pi+ (60 GeV)
0
2
4
6
ECALmomentX5
1e−3

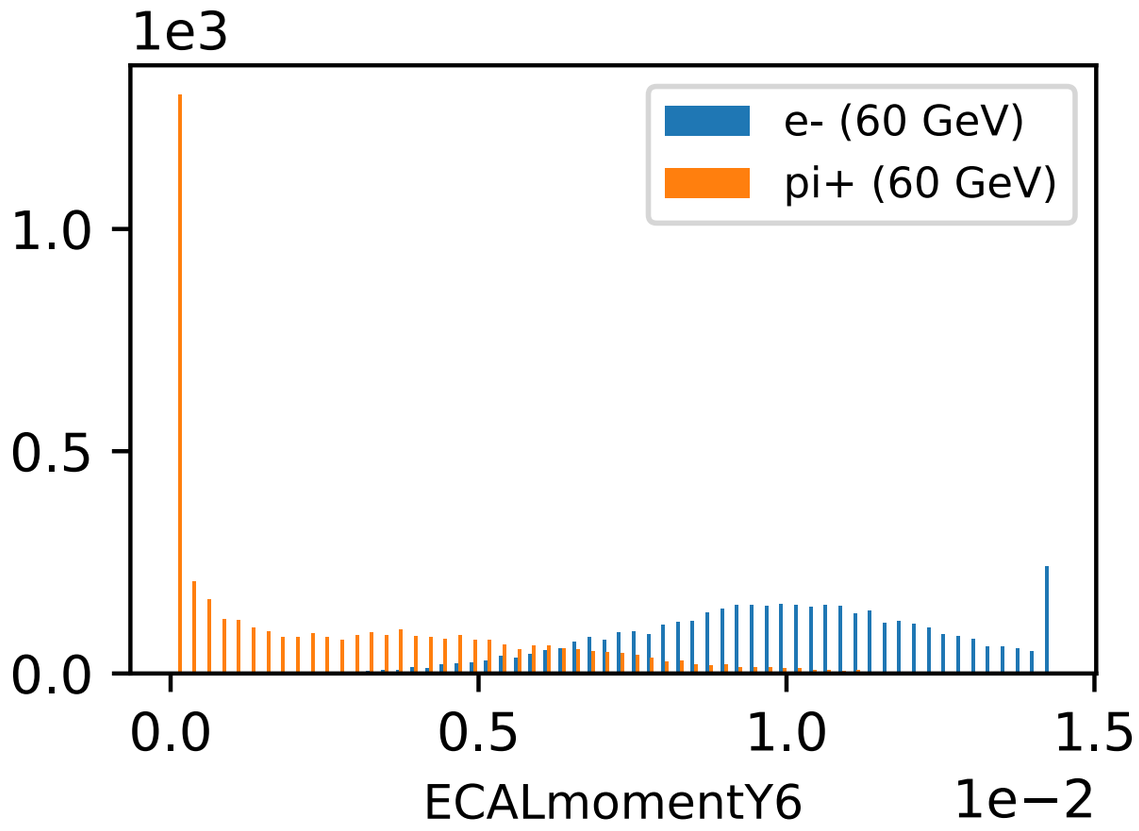

1e3
e- (60 GeV)
pi+ (60 GeV)
0
1
2
3
0
1
2
3
4
ECALmomentX6
1e−3

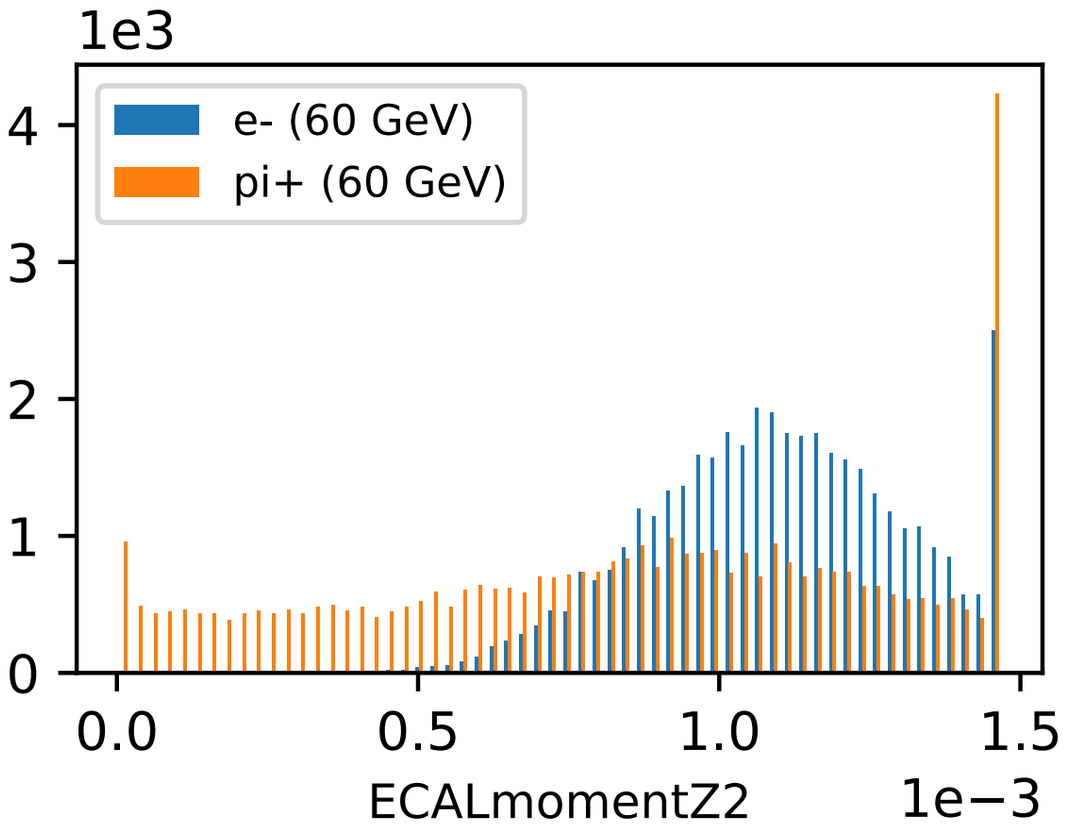

1e2
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
0
1
2
3
ECALmomentY2
1e−2

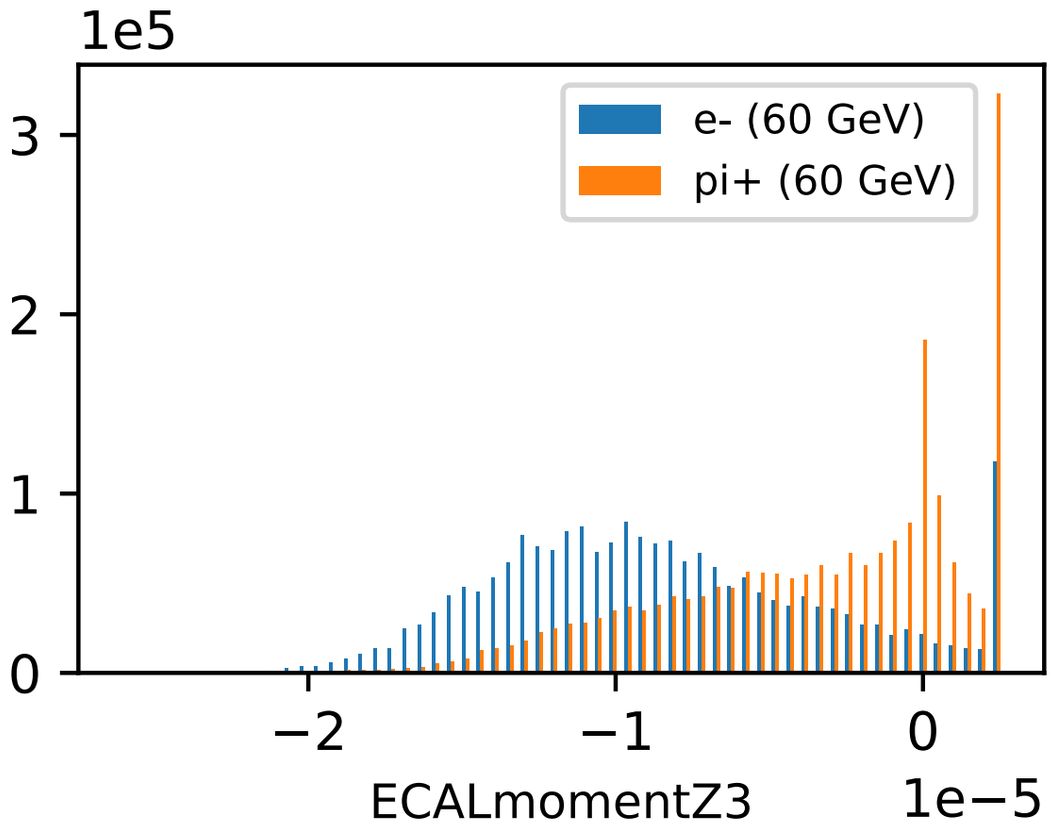

1e2
e- (60 GeV)
pi+ (60 GeV)
0
1
2
3
0.0
0.5
1.0
1.5
2.0
2.5
ECALmomentY3
1e−2

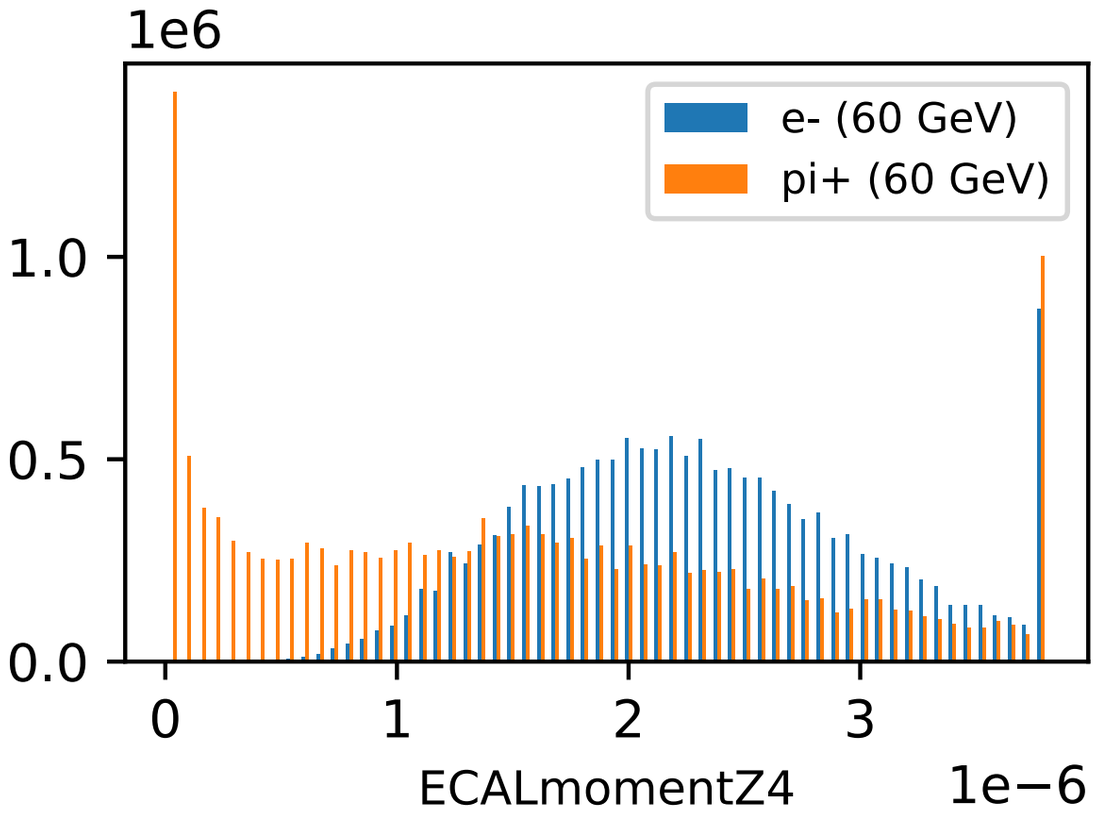

1e2
e- (60 GeV)
pi+ (60 GeV)
0
2
4
6
0.0
0.5
1.0
1.5
2.0
ECALmomentY4
1e−2

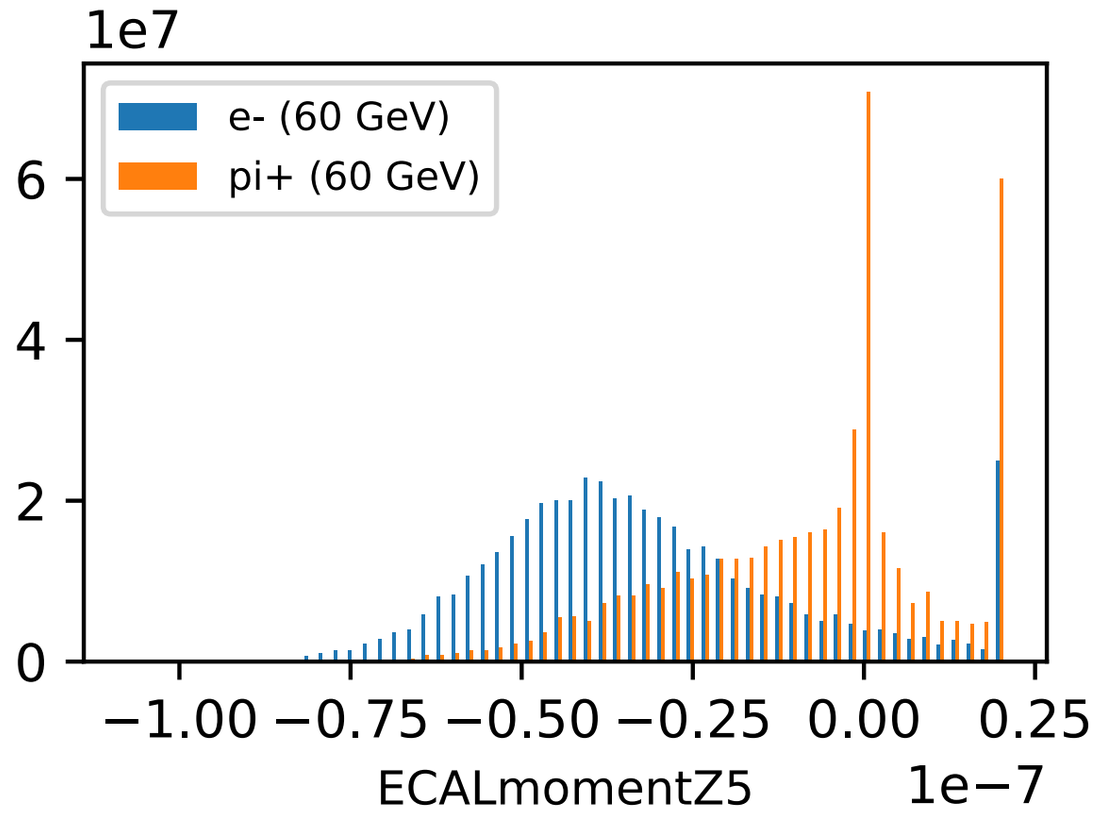

1e3
e- (60 GeV)
pi+ (60 GeV)
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
ECALmomentY5
1e−2

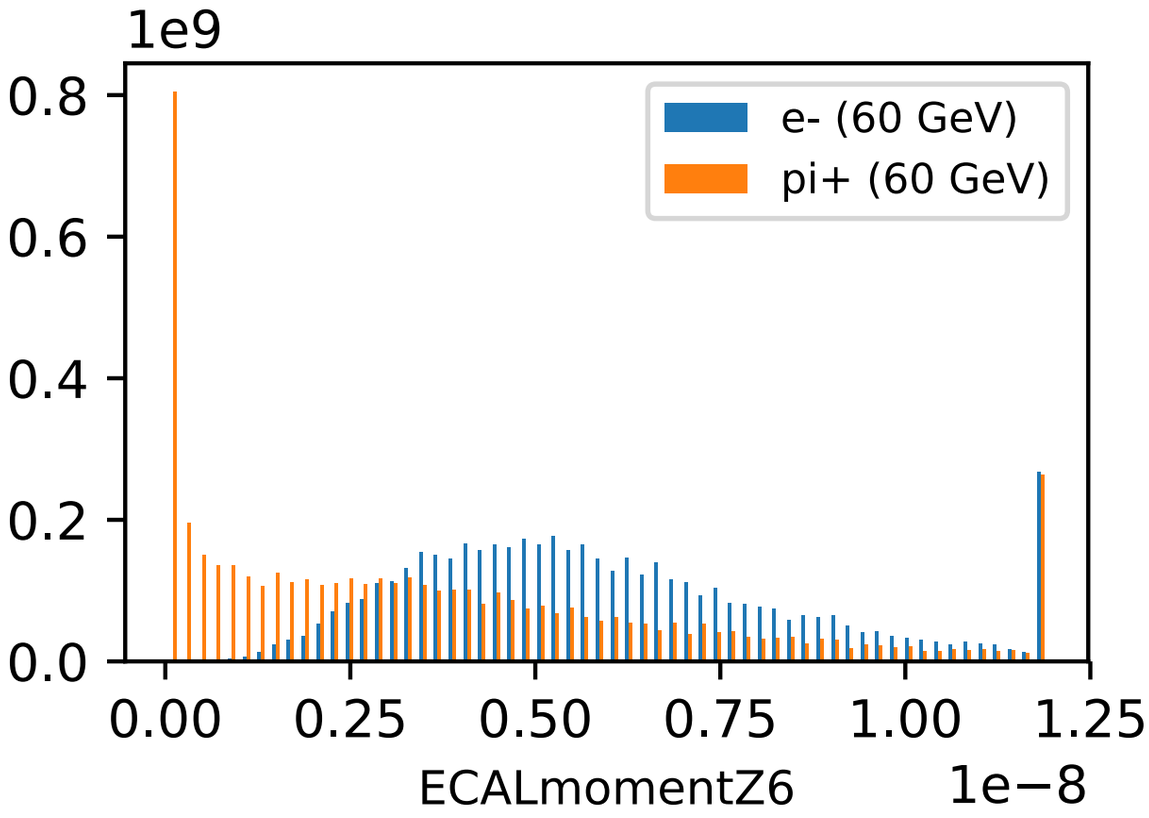

1e3
e- (60 GeV)
pi+ (60 GeV)
1.0
0.5
0.0
0.0
0.5
1.0
1.5
ECALmomentY6
1e−2

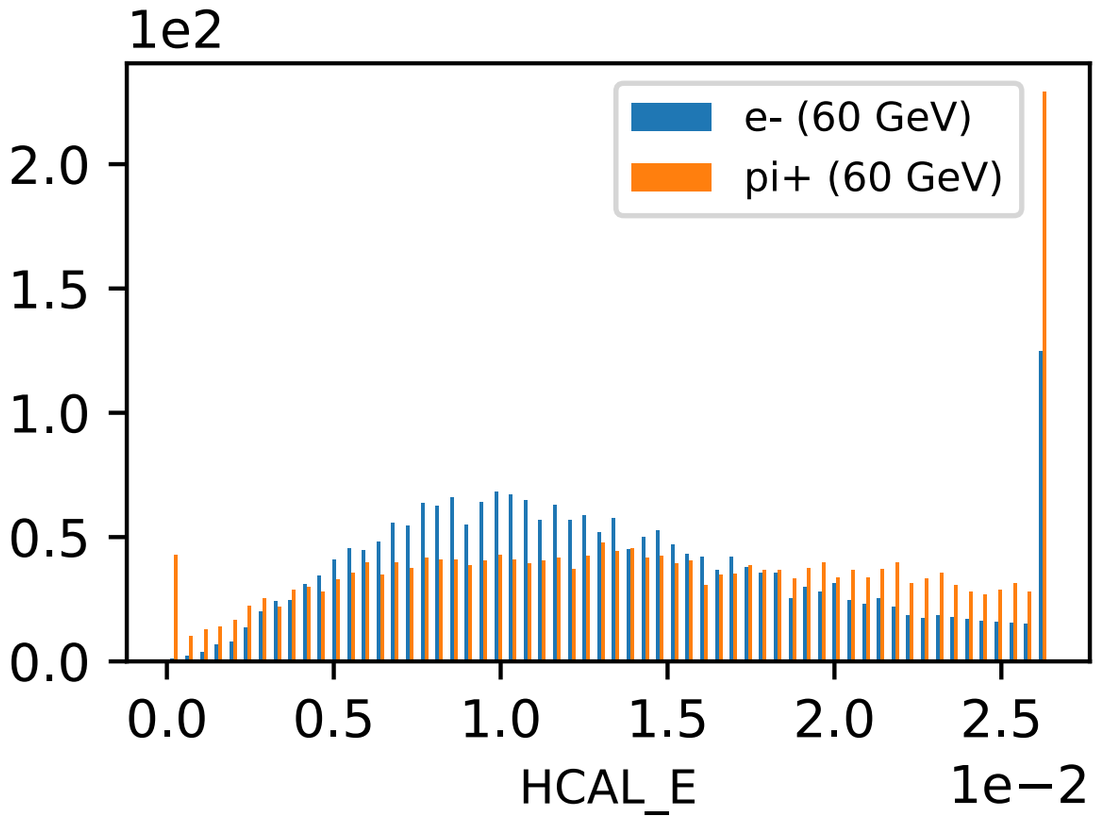

1e3
e- (60 GeV)
pi+ (60 GeV)
4
3
2
1
0
0.0
0.5
1.0
1.5
ECALmomentZ2
1e−3

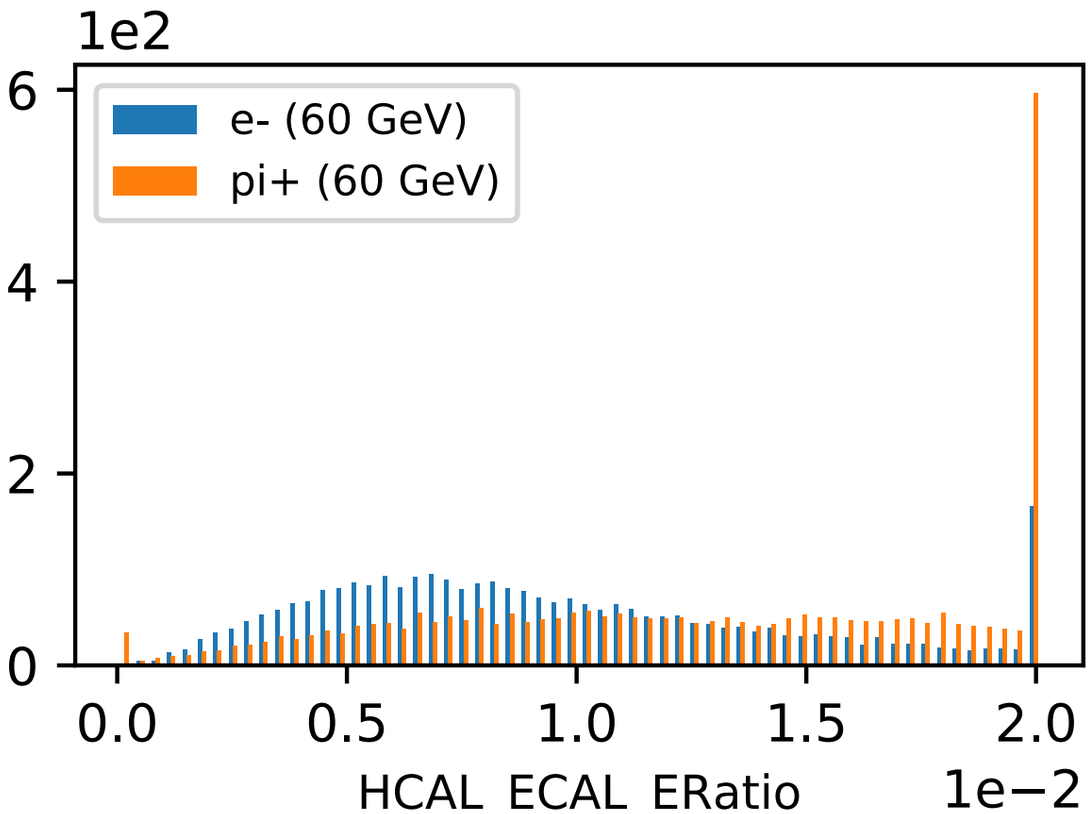

1e5
e- (60 GeV)
pi+ (60 GeV)
3
2
1
0
−2
−1
0
ECALmomentZ3
1e−5

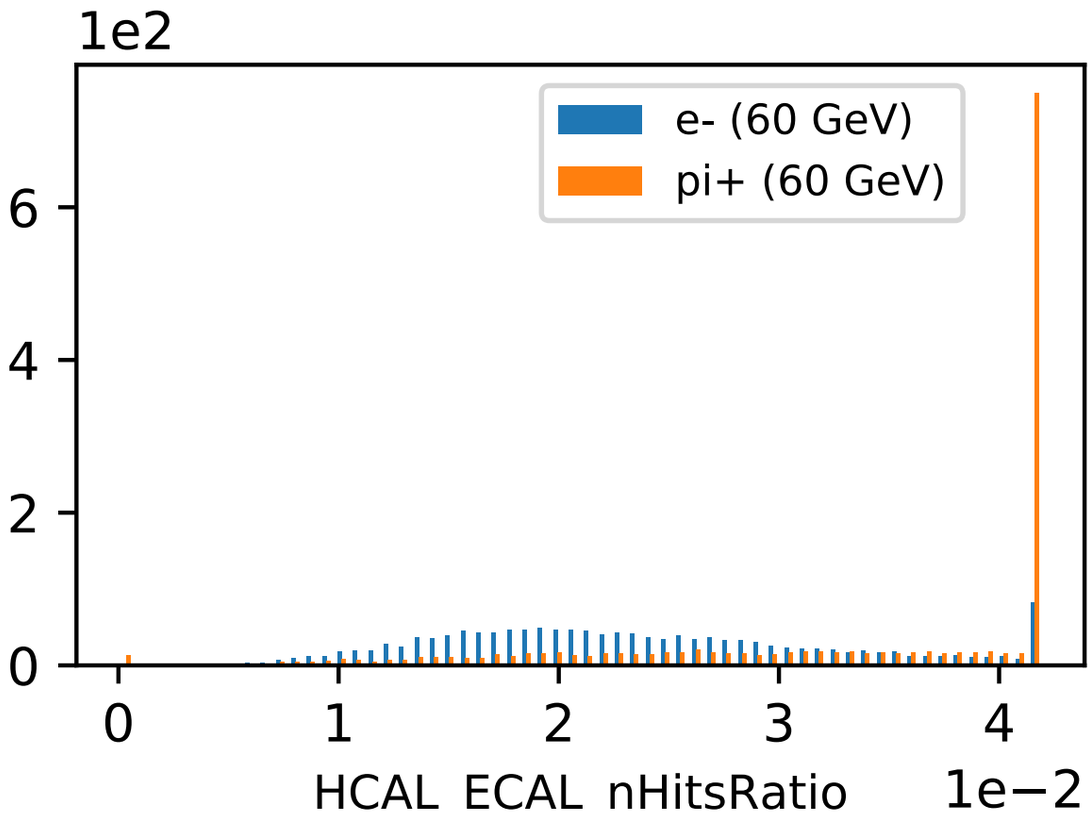

1e6
e- (60 GeV)
pi+ (60 GeV)
1.0
0.5
0.0
0
1
2
3
ECALmomentZ4
1e−6

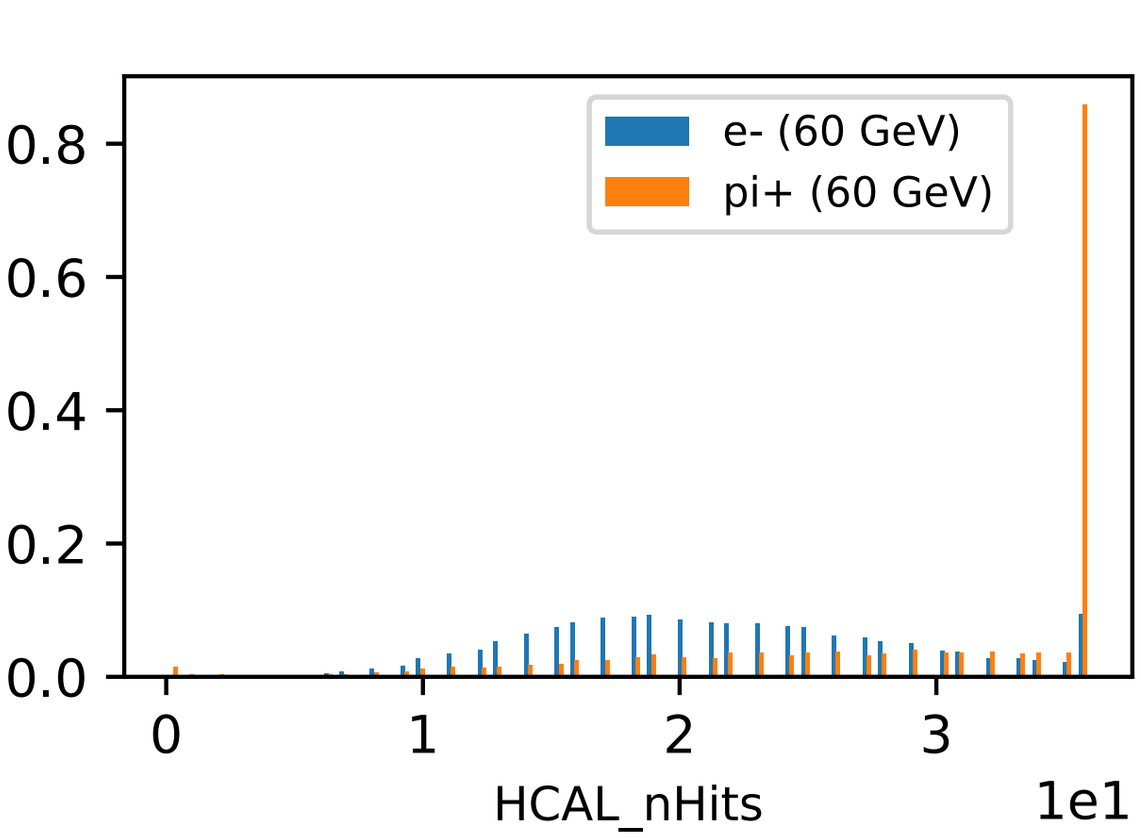

1e7
e- (60 GeV)
pi+ (60 GeV)
6
4
2
0
−1.00
−0.75
−0.50
−0.25
0.00
0.25
ECALmomentZ5
1e−7

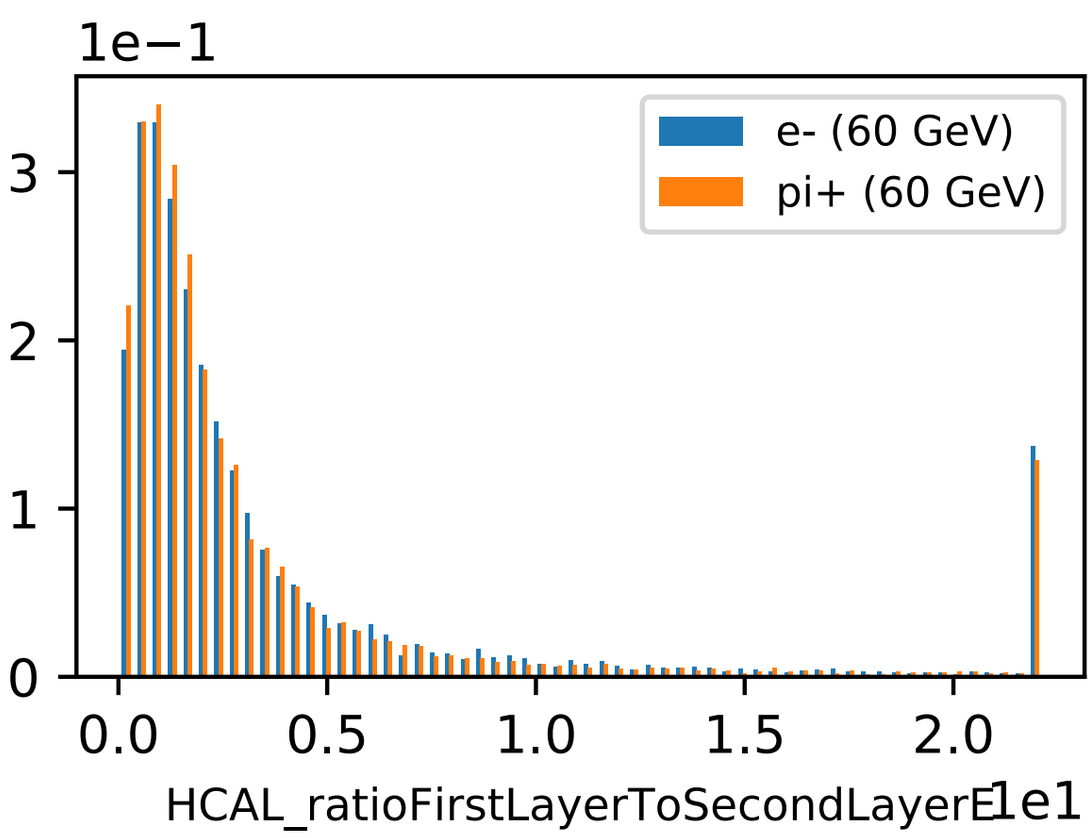

1e9
e- (60 GeV)
pi+ (60 GeV)
0.8
0.6
0.4
0.2
0.0
0.00
0.25
0.50
0.75
1.00
1.25
ECALmomentZ6
1e−8

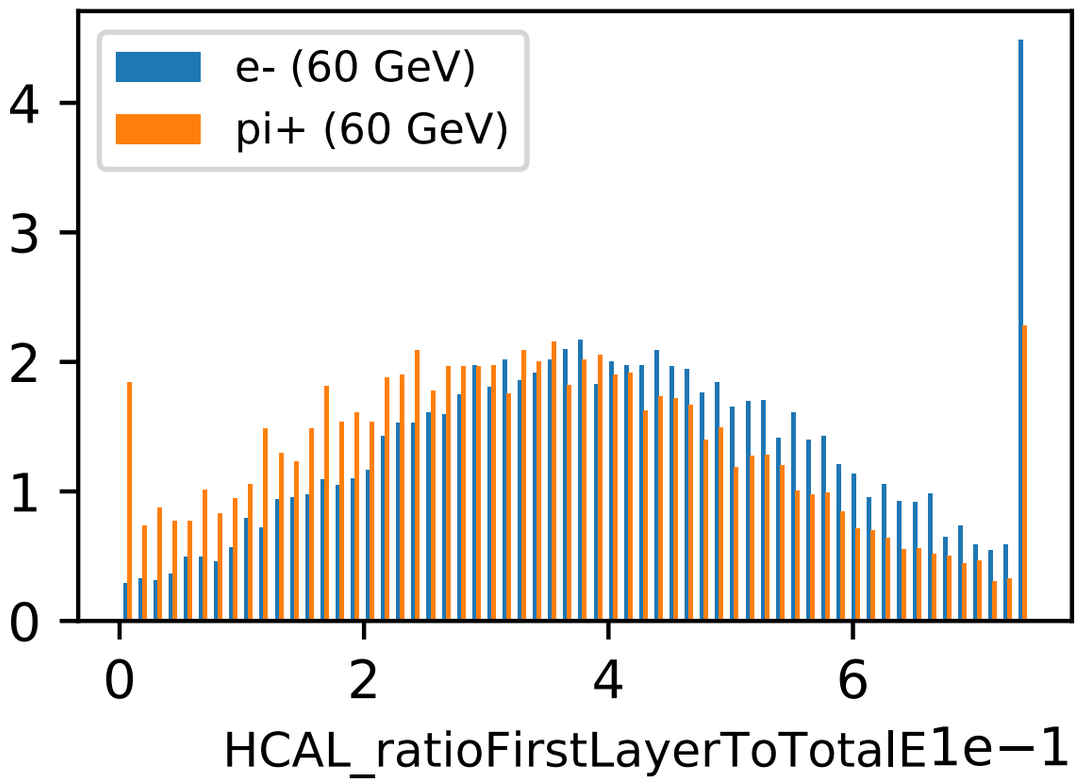

1e2
e- (60 GeV)
pi+ (60 GeV)
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
HCAL_E
1e−2

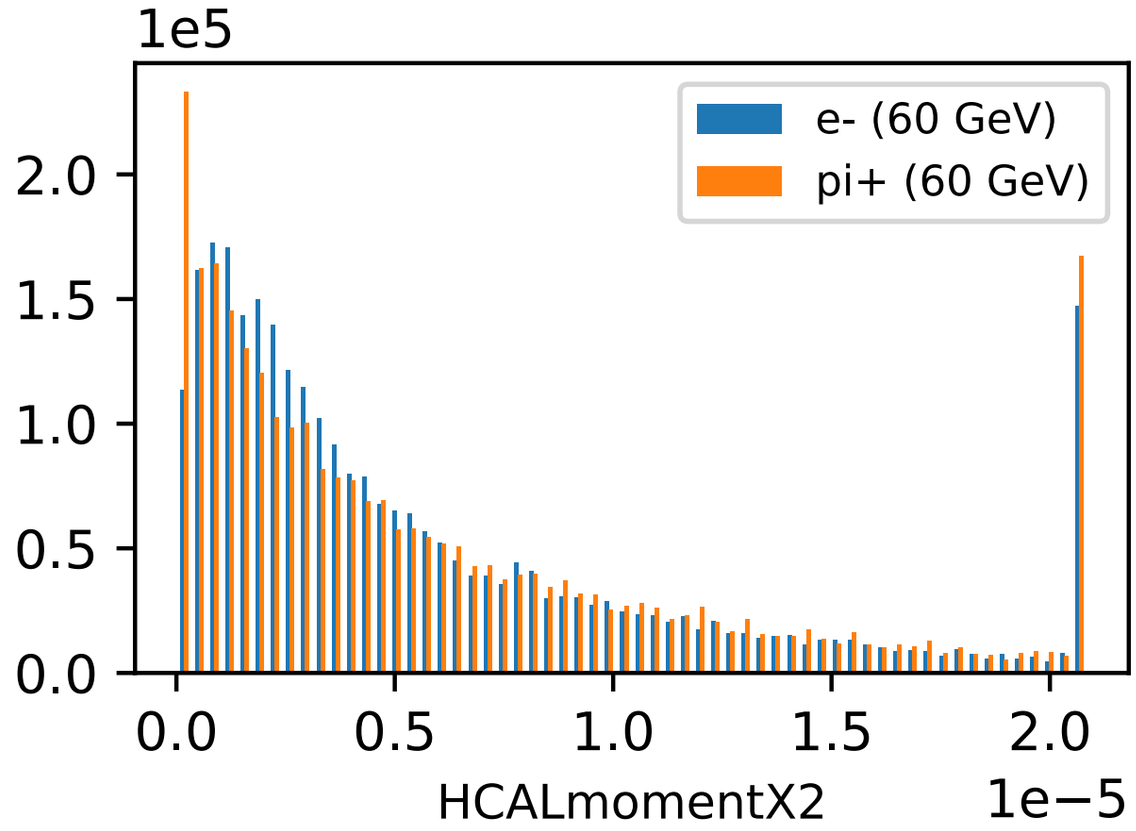

1e2
e- (60 GeV)
pi+ (60 GeV)
HCAL_ECAL_ERatio
1e−2

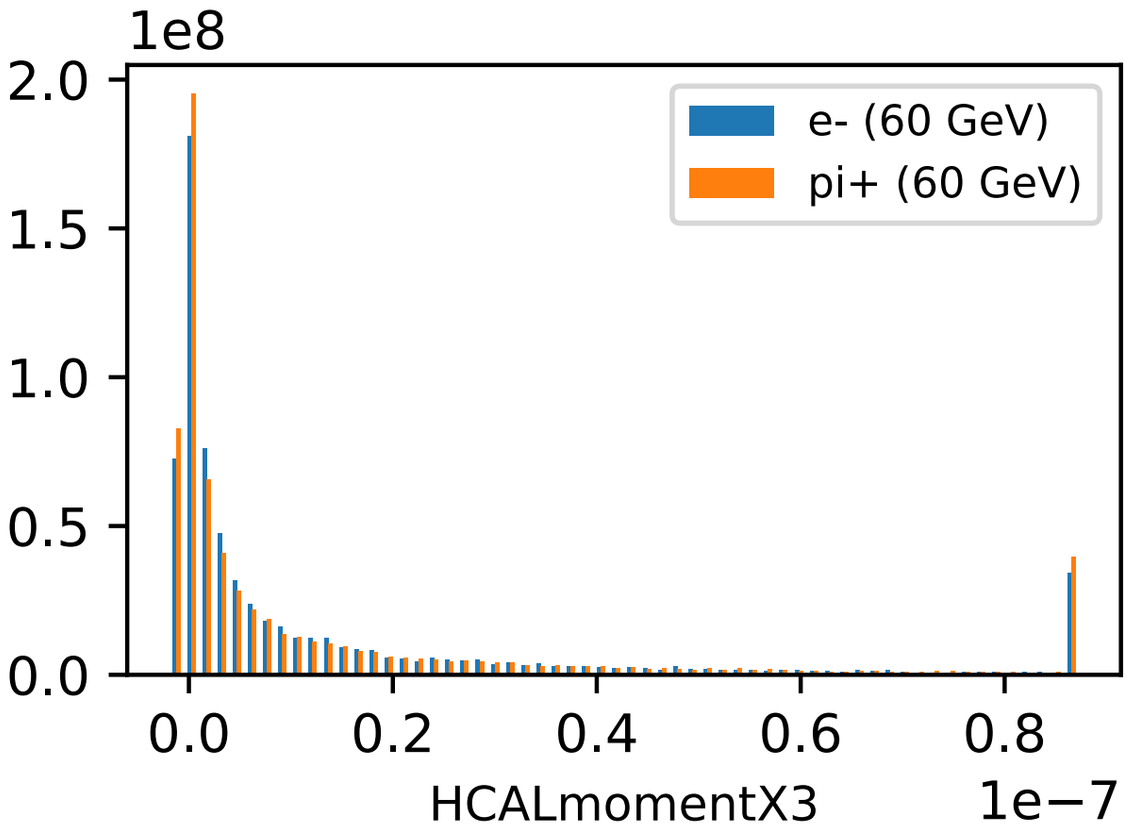

1e2
e- (60 GeV)
pi+ (60 GeV)
HCAL_ECAL_nHitsRatio
1e−2

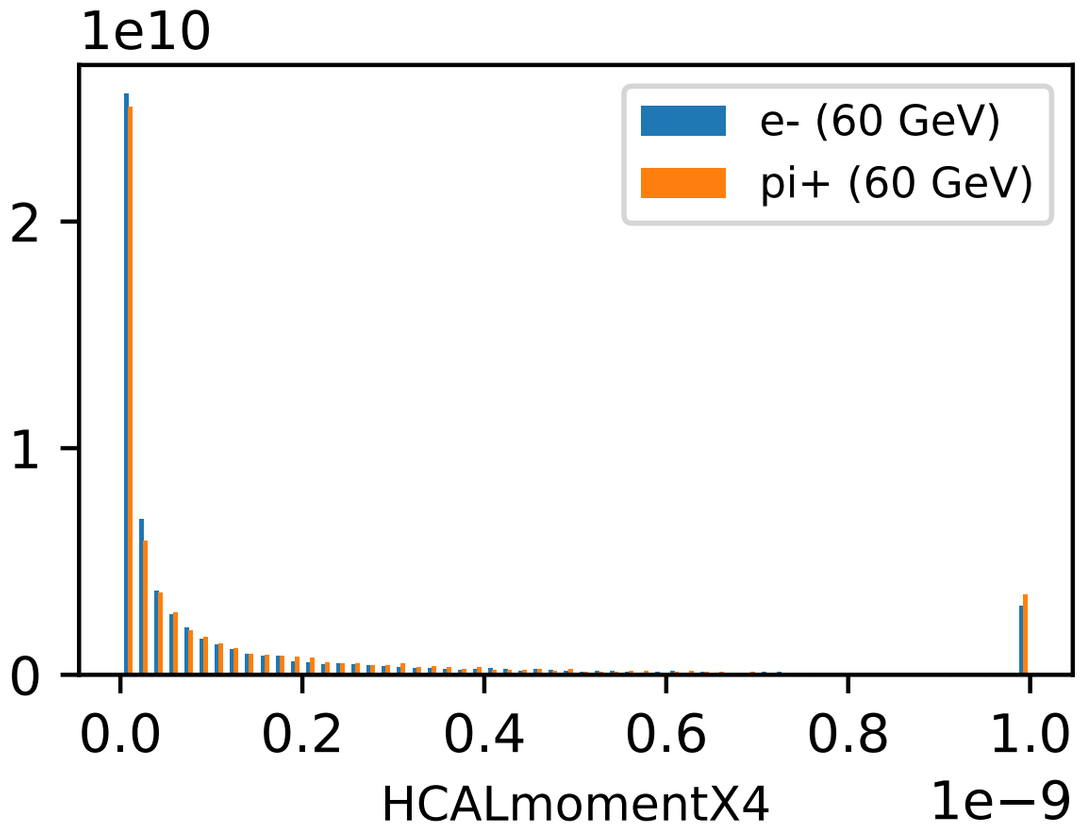

1e−1
e- (60 GeV)
pi+ (60 GeV)
HCAL_nHits
1e1

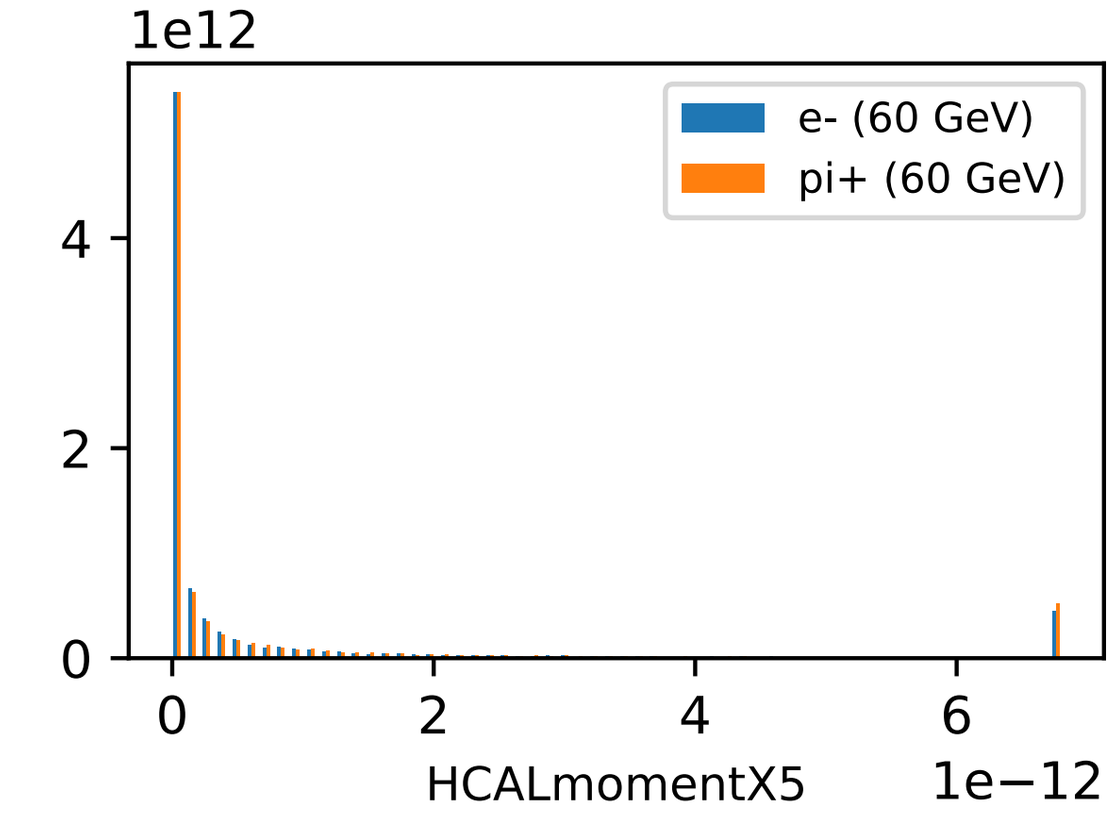

e- (60 GeV)
pi+ (60 GeV)
HCAL_ratioFirstLayerToSecondLayerE
1e1

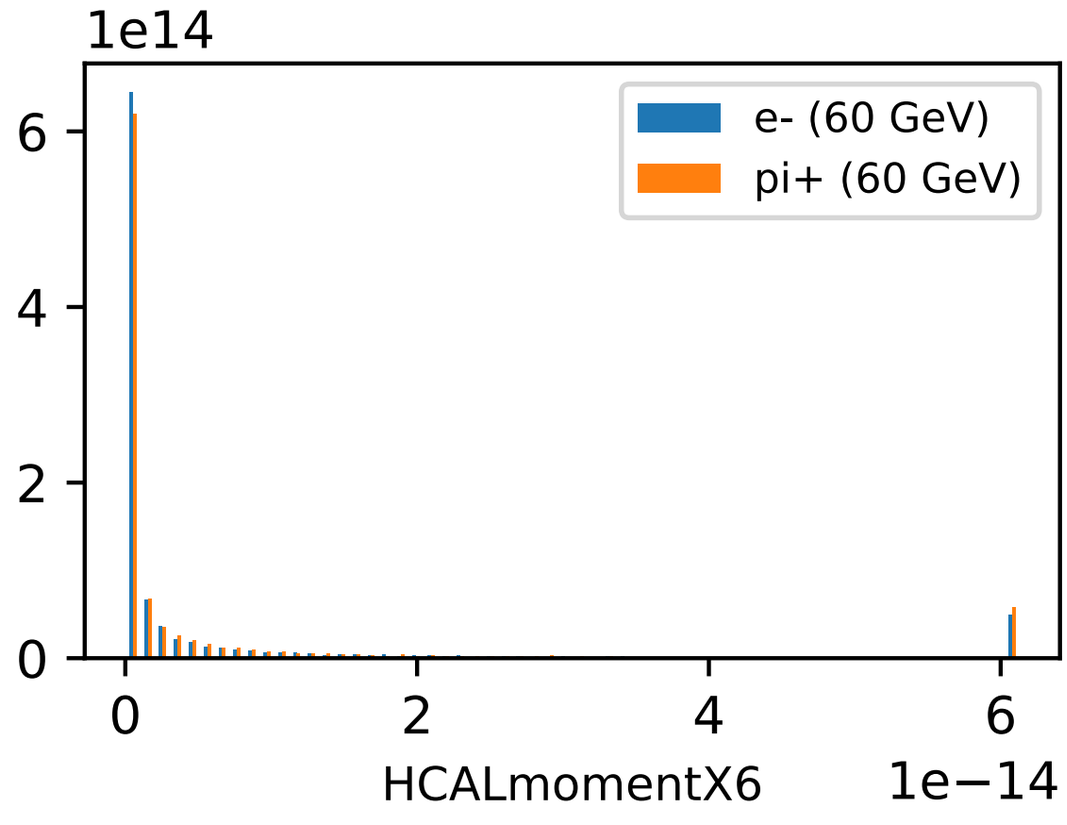

e- (60 GeV)
pi+ (60 GeV)
0
1
2
3
4
0
2
4
6
HCAL_ratioFirstLayerToTotalE
1e−1

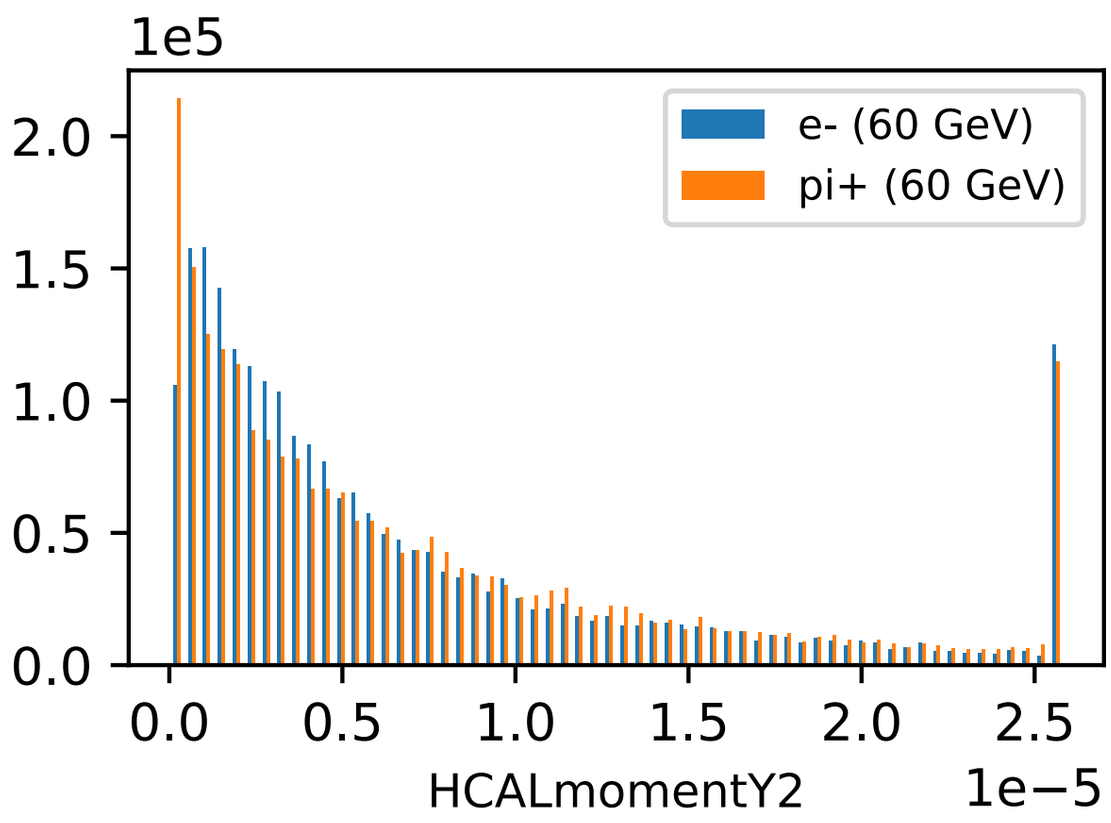

1e5
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
2.0
0.0
0.5
1.0
1.5
2.0
HCALmomentX2
1e−5

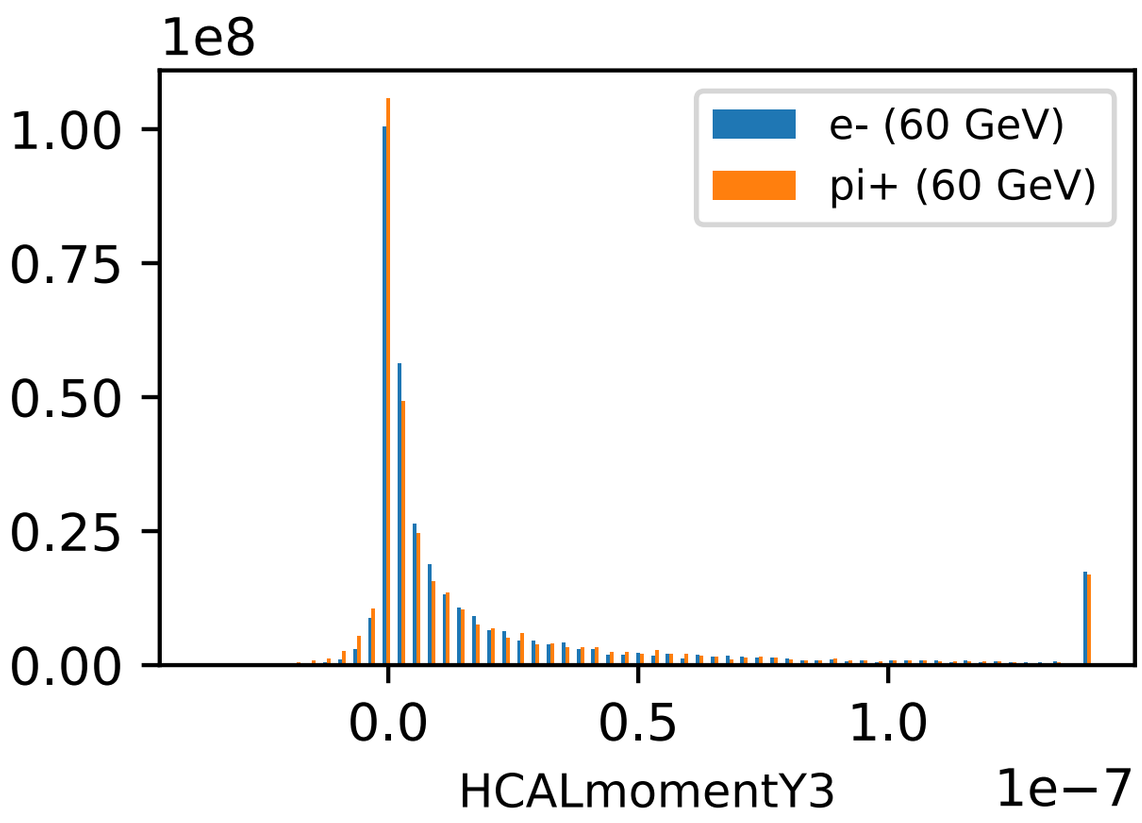

1e8
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
2.0
0.0
0.2
0.4
0.6
0.8
HCALmomentX3
1e−7

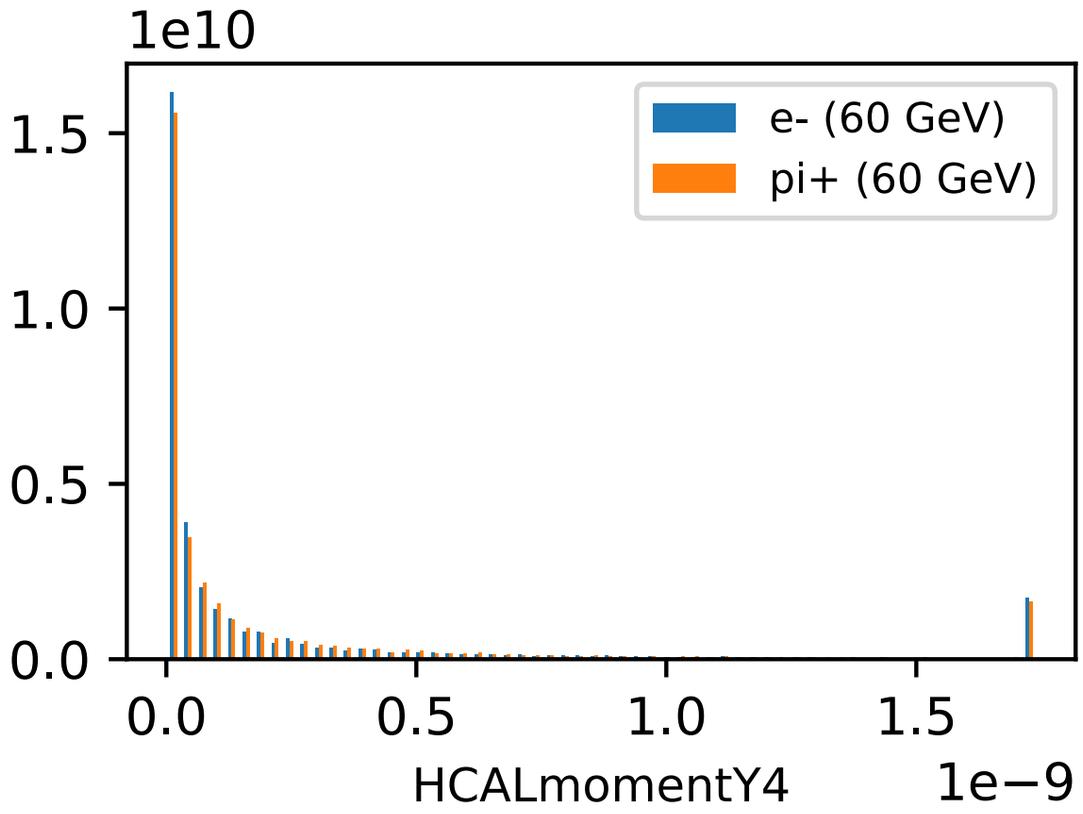

1e10
e- (60 GeV)
pi+ (60 GeV)
0
1
2
0.0
0.2
0.4
0.6
0.8
1.0
HCALmomentX4
1e−9

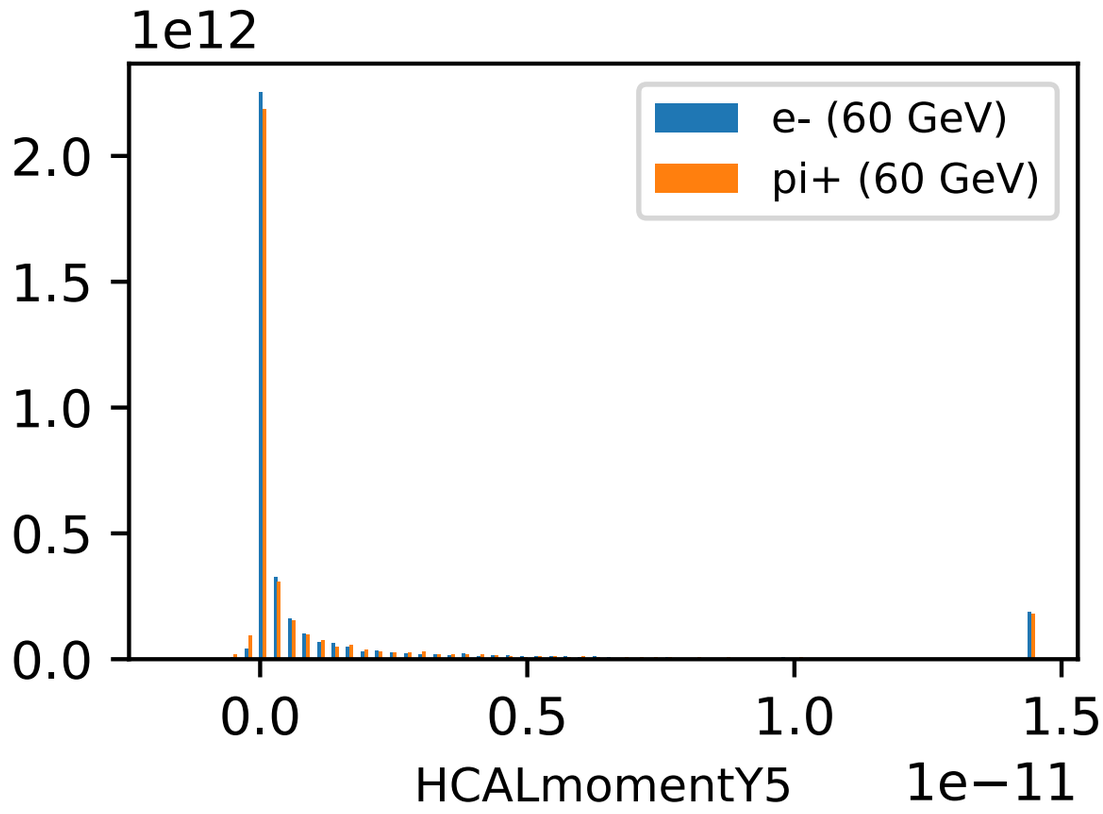

1e12
e- (60 GeV)
pi+ (60 GeV)
0
2
4
0
2
4
6
HCALmomentX5
1e−12

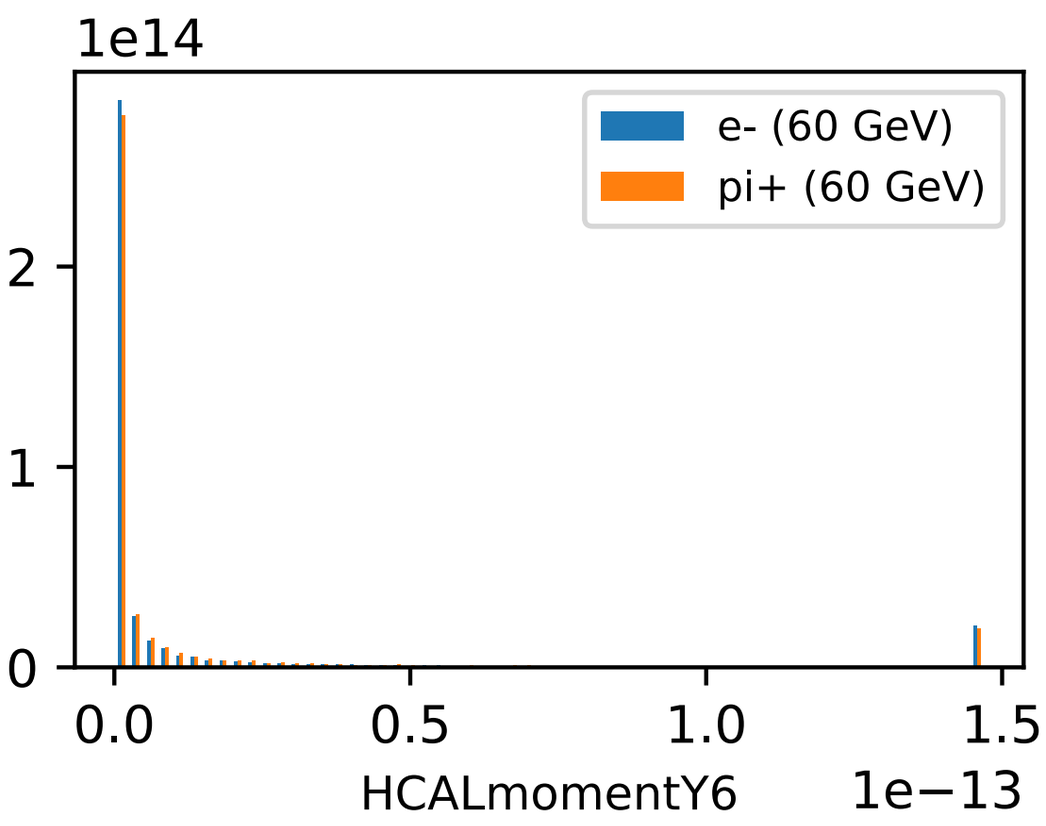

1e14
e- (60 GeV)
pi+ (60 GeV)
0
2
4
6
0
2
4
6
HCALmomentX6
1e−14

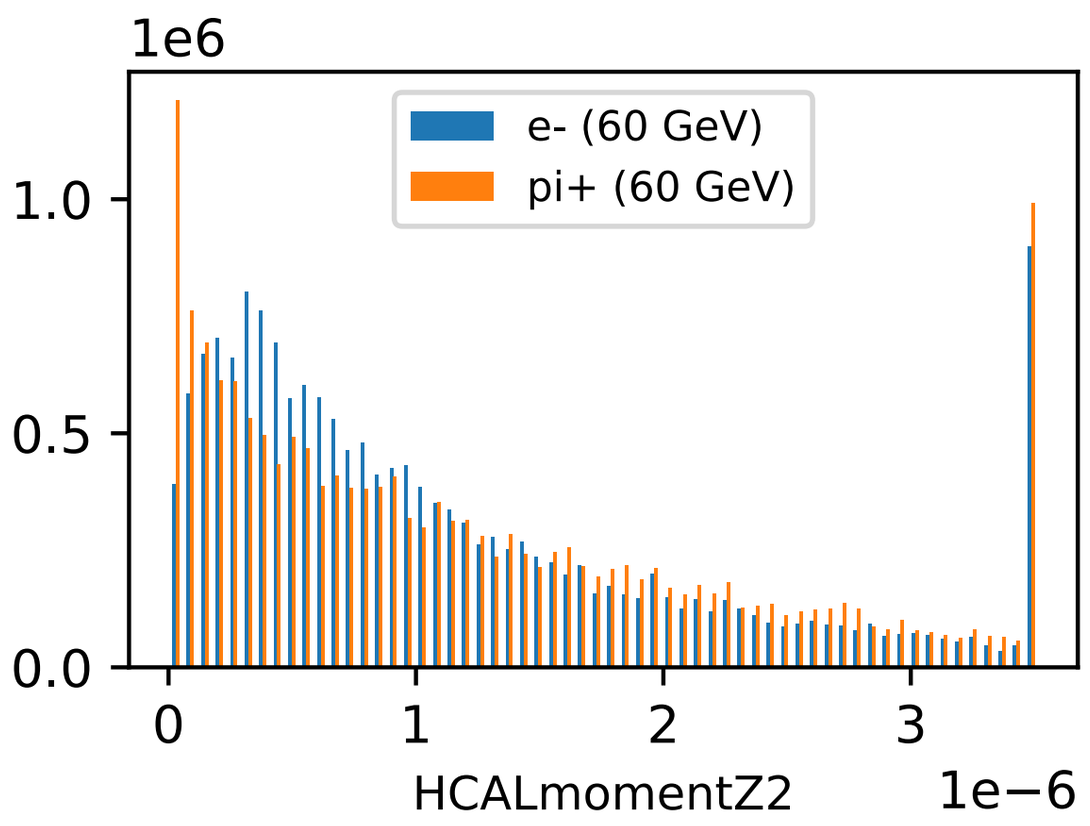

1e5
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
2.0
0.0
0.5
1.0
1.5
2.0
2.5
HCALmomentY2
1e−5

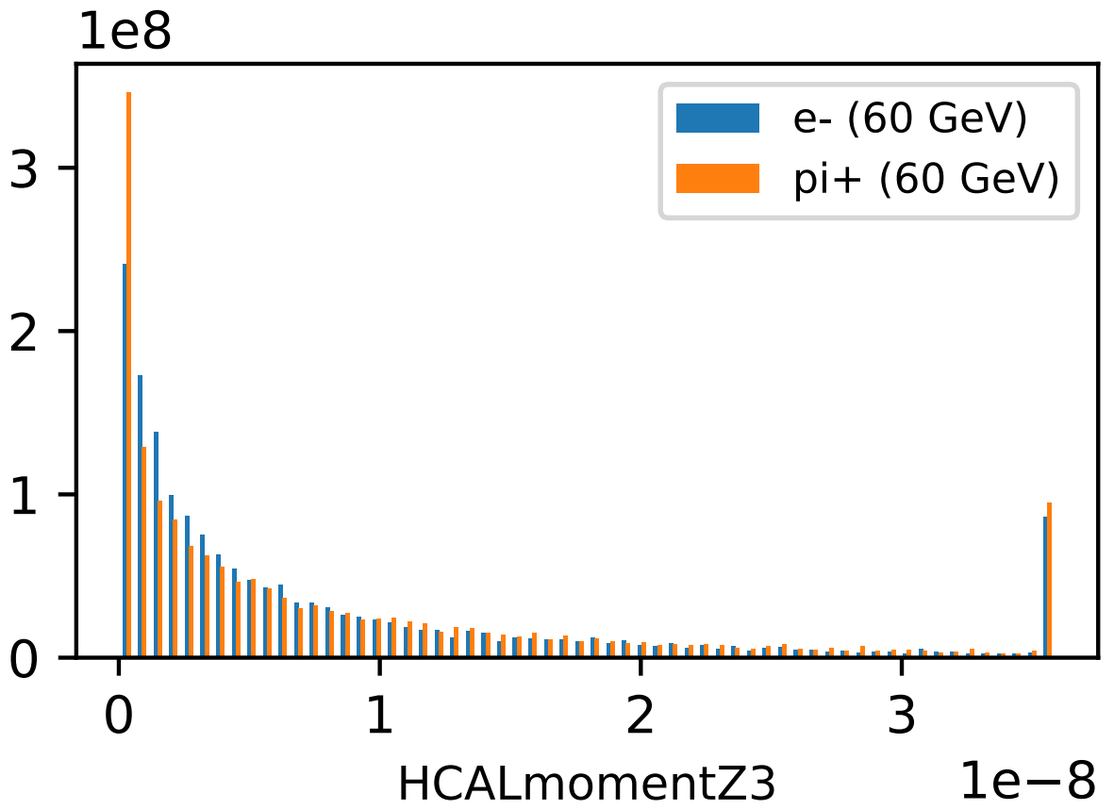

1e8
e- (60 GeV)
pi+ (60 GeV)
0.00
0.25
0.50
0.75
1.00
0.0
0.5
1.0
HCALmomentY3
1e−7

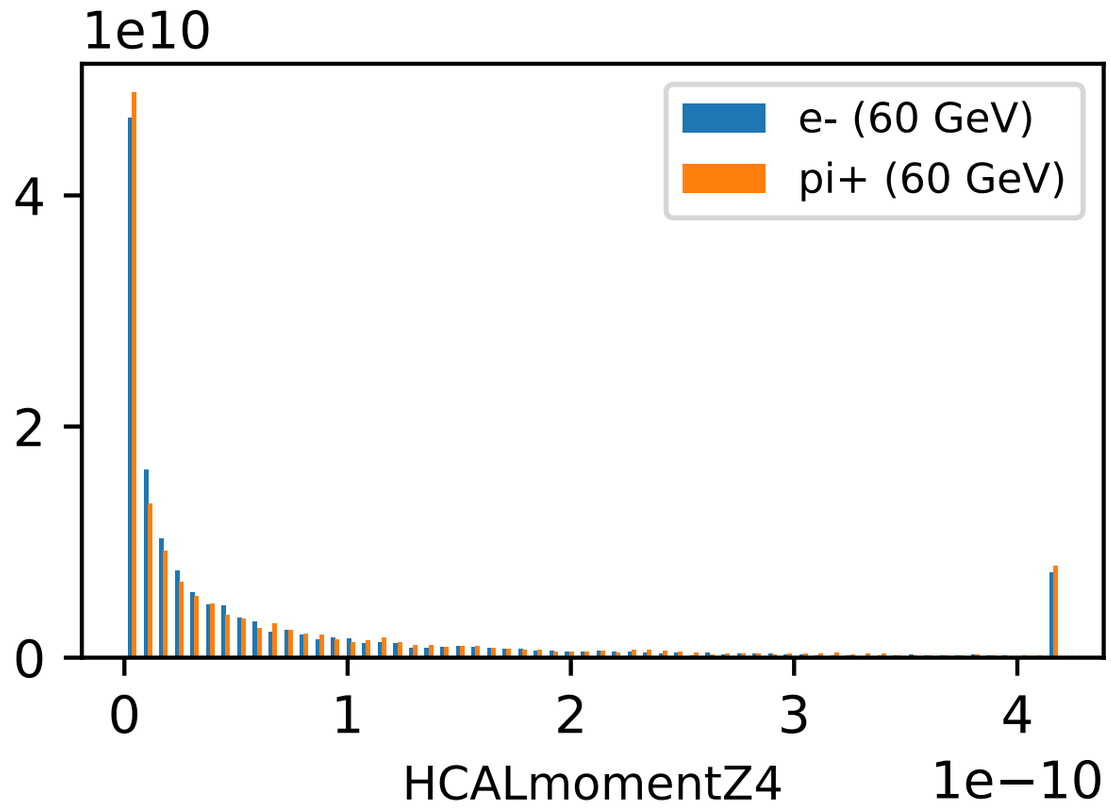

1e10
1.5
1.0
0.5
0.0
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
HCALmomentY4
1e−9

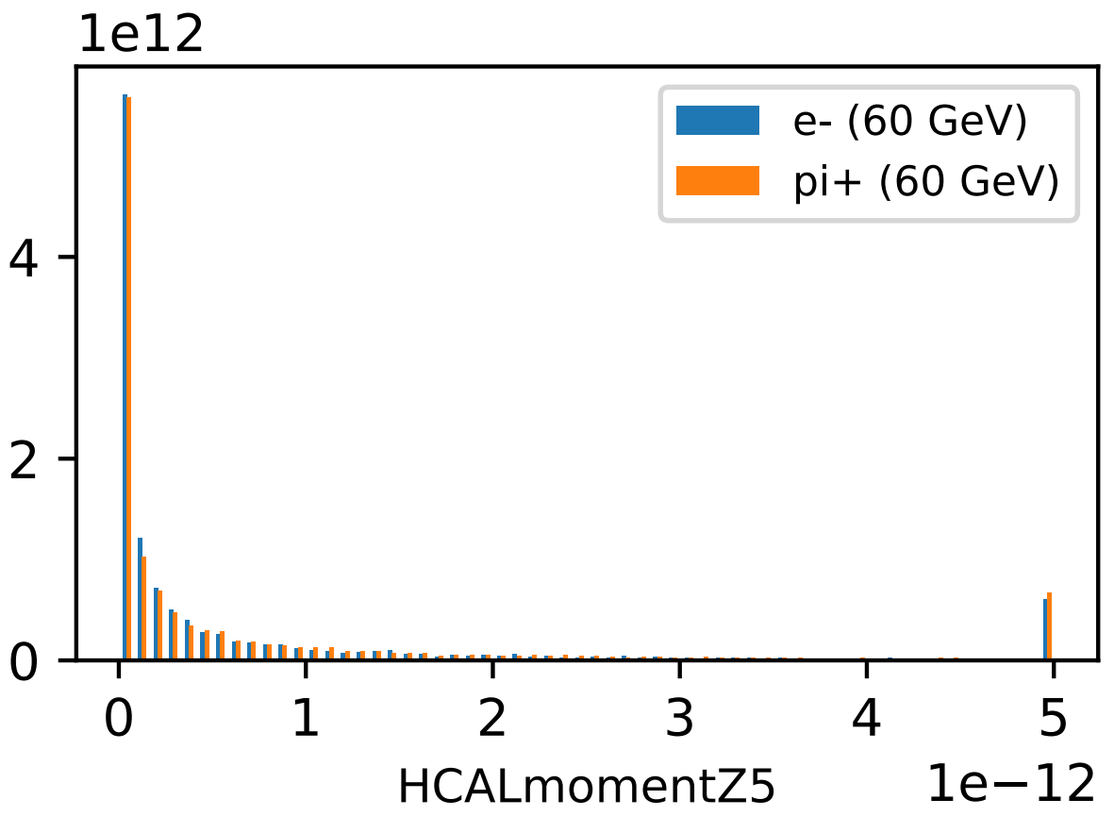

1e12
2.0
1.5
1.0
0.5
0.0
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
HCALmomentY5
1e−11

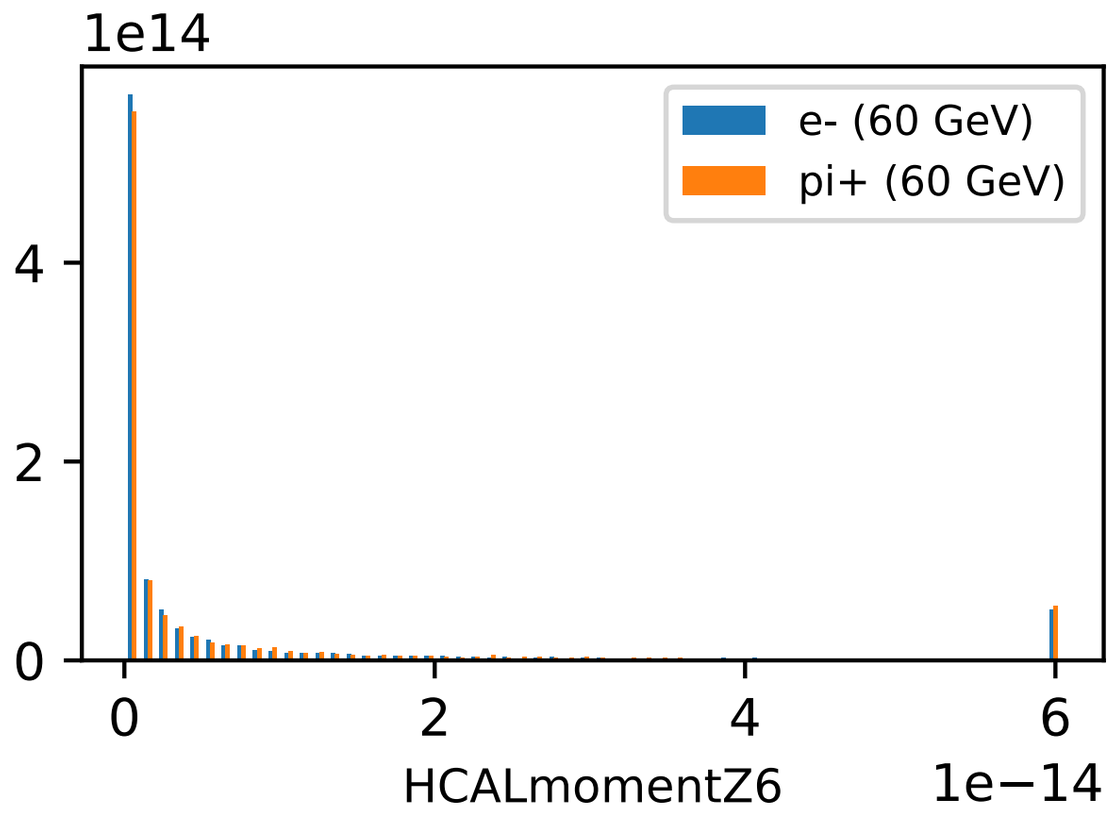

1e14
2
1
0
e- (60 GeV)
pi+ (60 GeV)
0.0
0.5
1.0
1.5
HCALmomentY6
1e−13


1e6
1.0
0.5
0.0
e- (60 GeV)
pi+ (60 GeV)
0
1
2
3
HCALmomentZ2
1e−6

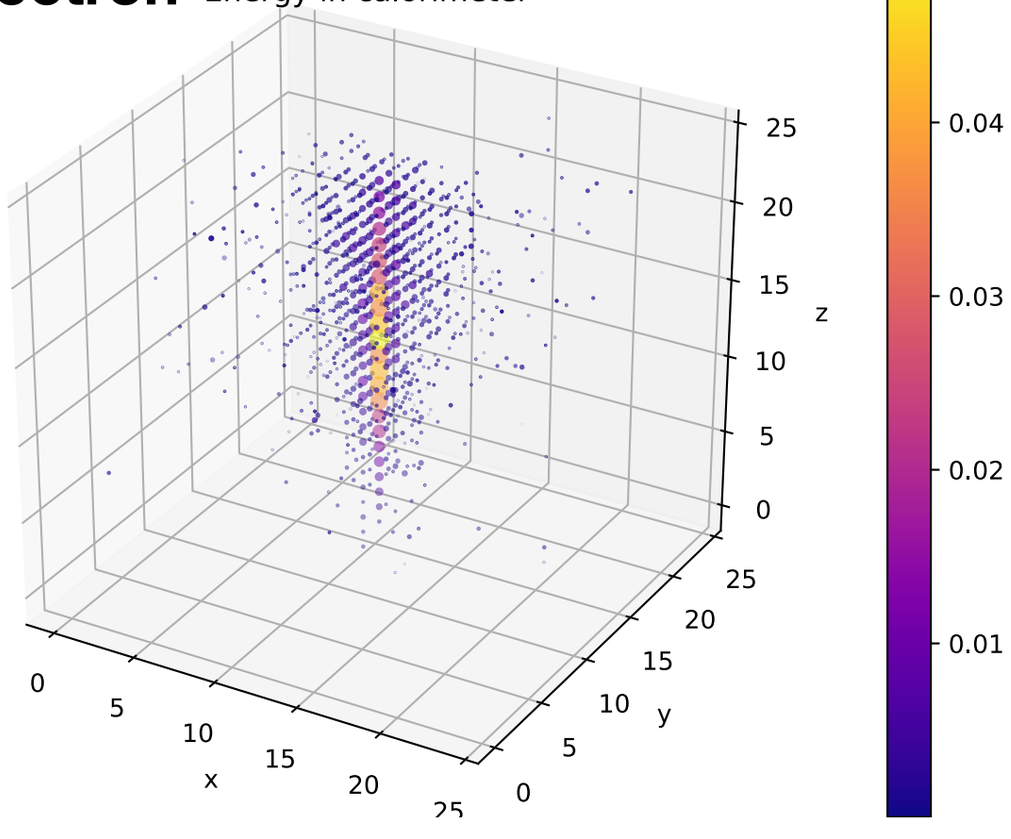

1e8
e- (60 GeV)
pi+ (60 GeV)
0
1
2
3
0
1
2
3
HCALmomentZ3
1e−8

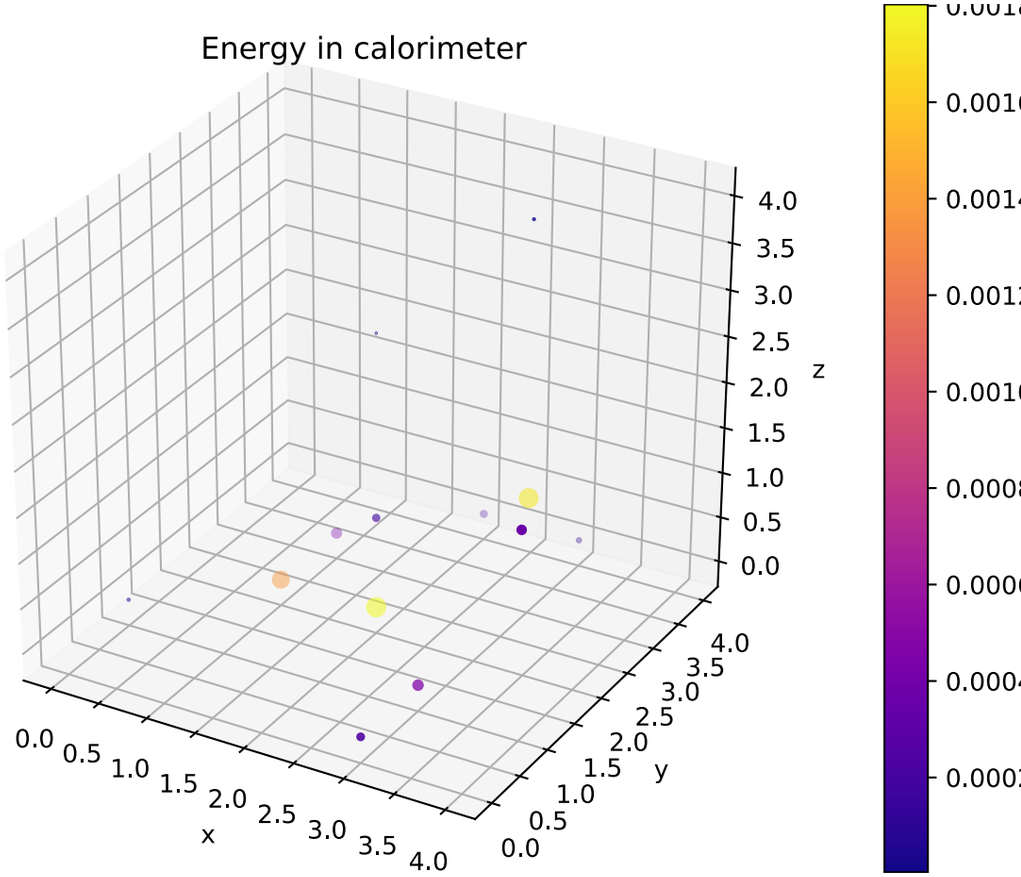

1e10
e- (60 GeV)
pi+ (60 GeV)
0
2
4
0
1
2
3
4
HCALmomentZ4
1e−10


1e12
e- (60 GeV)
pi+ (60 GeV)
0
2
4
0
1
2
3
4
5
HCALmomentZ5
1e−12

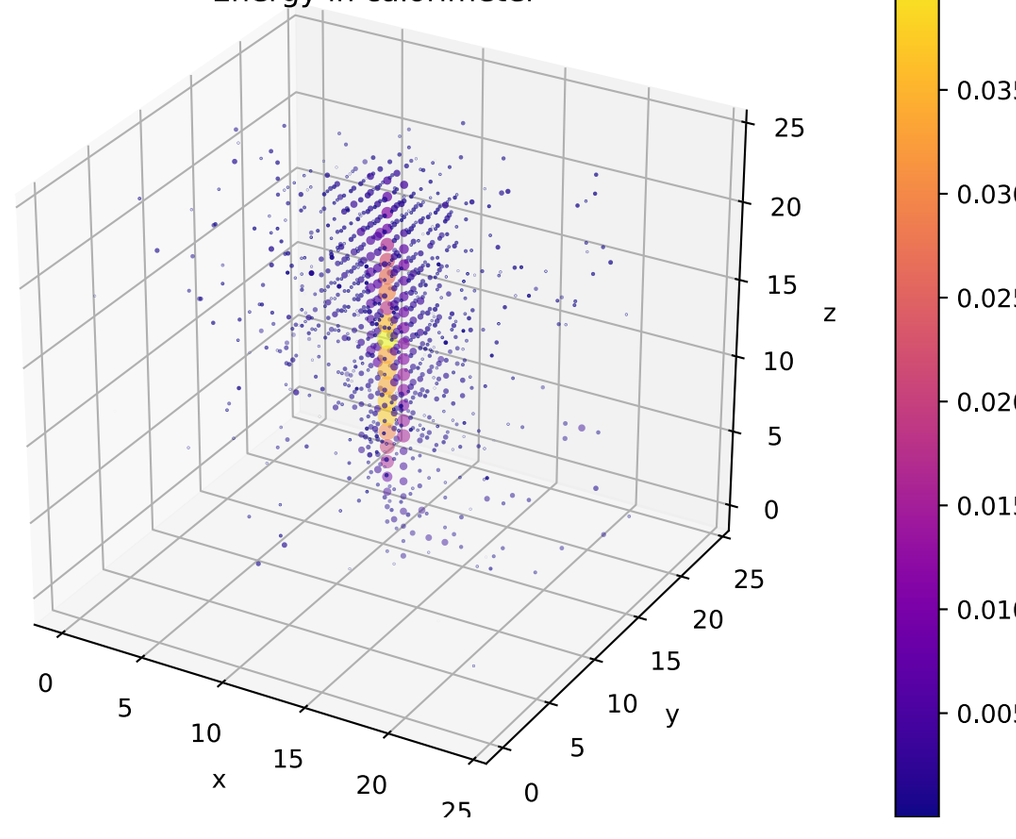

1e14
e- (60 GeV)
pi+ (60 GeV)
0
2
4
0
2
4
6
HCALmomentZ6
1e−14

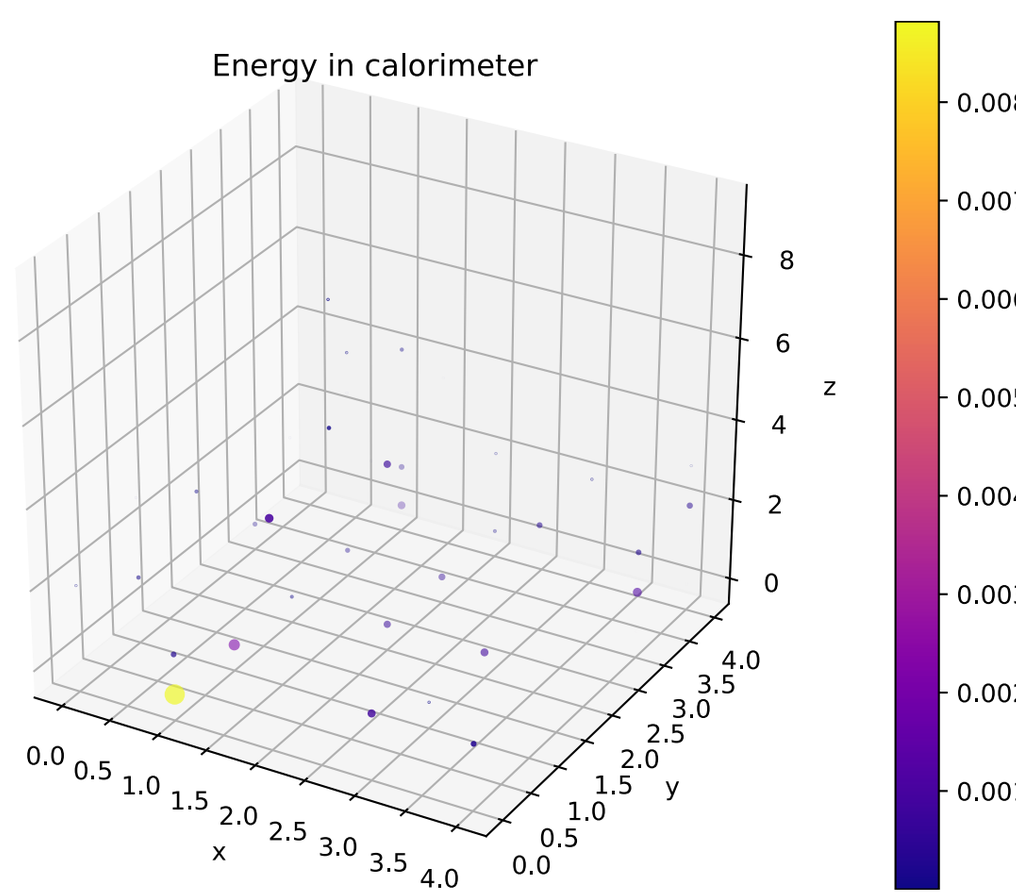
Electron


Energy in calorimeter
x
y
z
0
5
10
15
20
25
0.05
0.04
0.03
0.02
0.01


Energy in calorimeter
x
y
z
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002

Pi+


Energy in calorimeter
x
y
z
0
5
10
15
20
25
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005

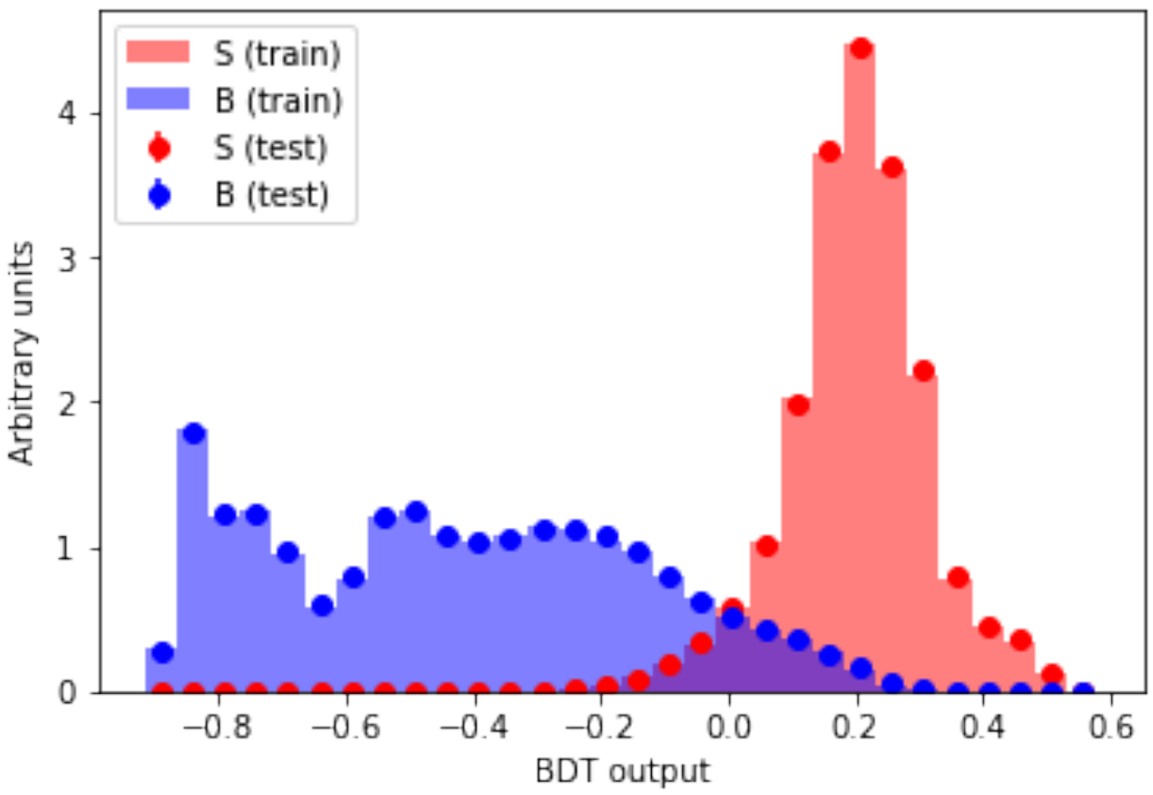

Energy in calorimeter
x
y
z
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
2
4
6
8
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001

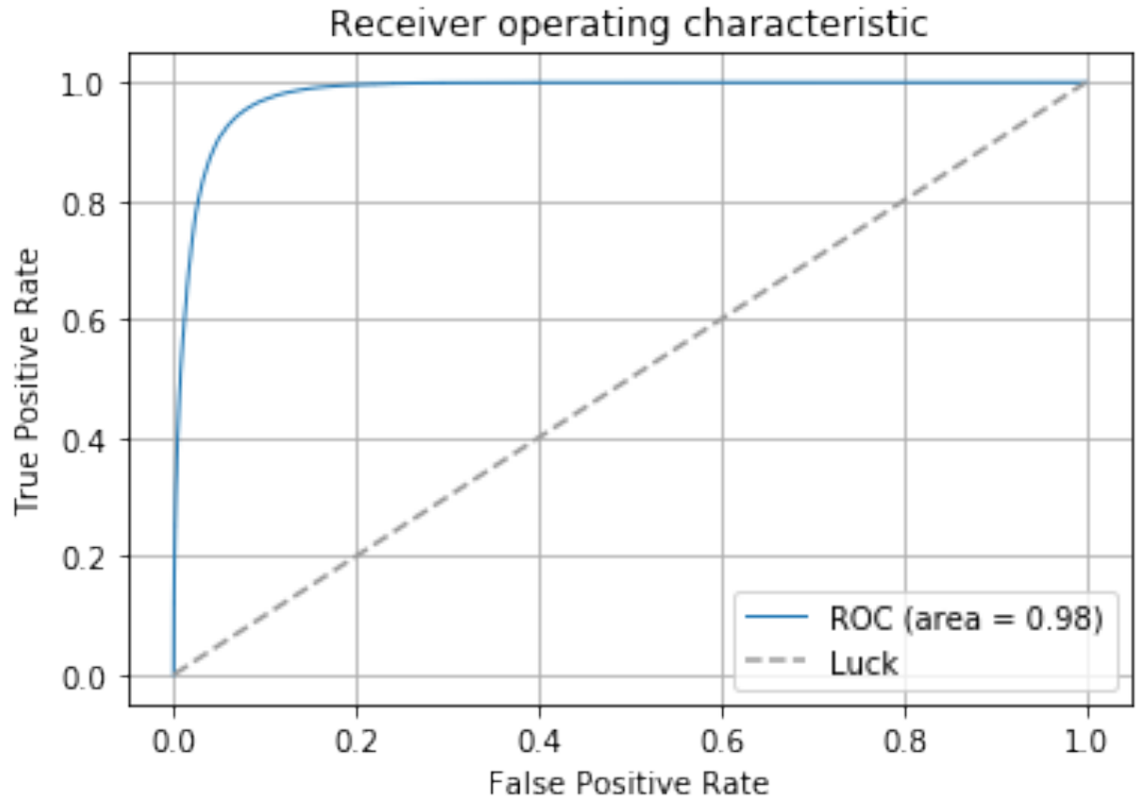
BDT (depth= 3, estimator = 800, learning rate = 0.5, algorithm = SAMME, trained on 400K images and tested on 200K images)

	precision	recall	f1-score	support
charged pion	0.95	0.92	0.94	98944
electron	0.92	0.96	0.94	100153
avg / total	0.94	0.94	0.94	199097

Area under ROC curve: 0.9815

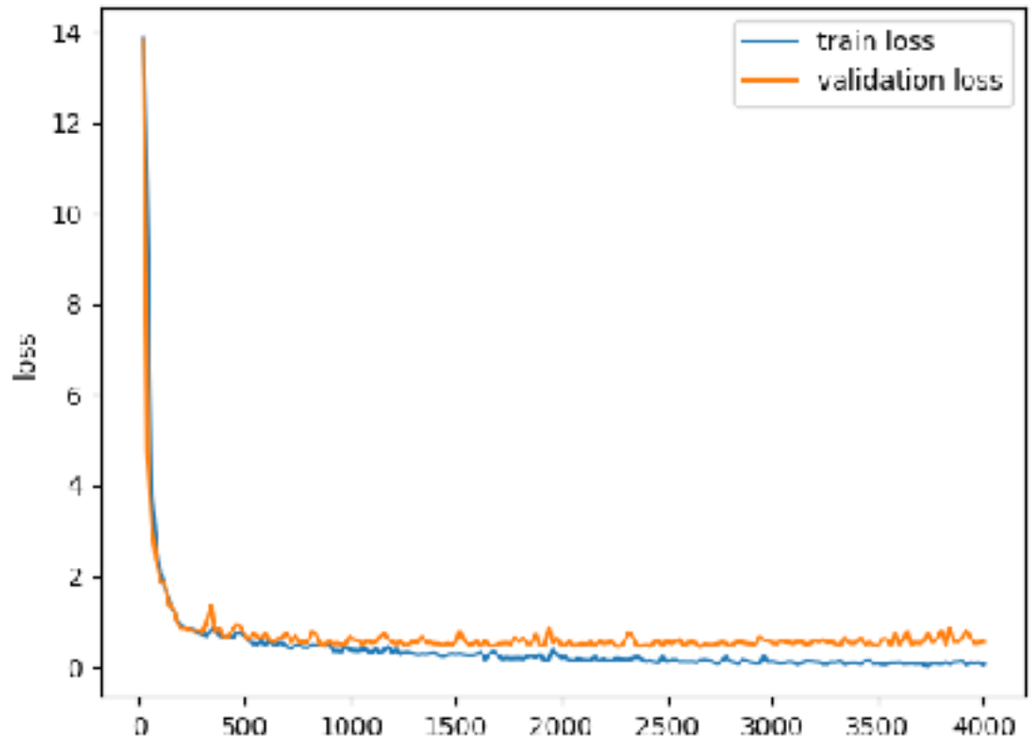
Precision = TP/(TP+FP)
Recall=TP/(TP+FN)
F1-score = 2*P*R/(P+R)

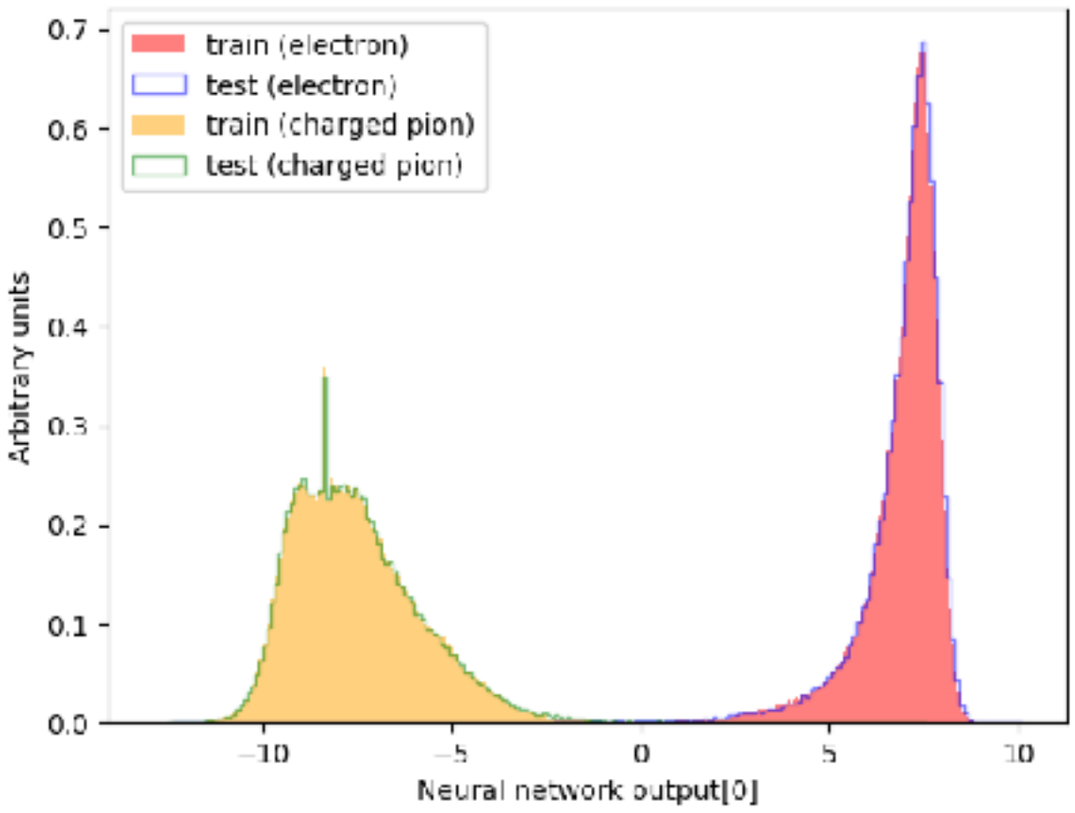


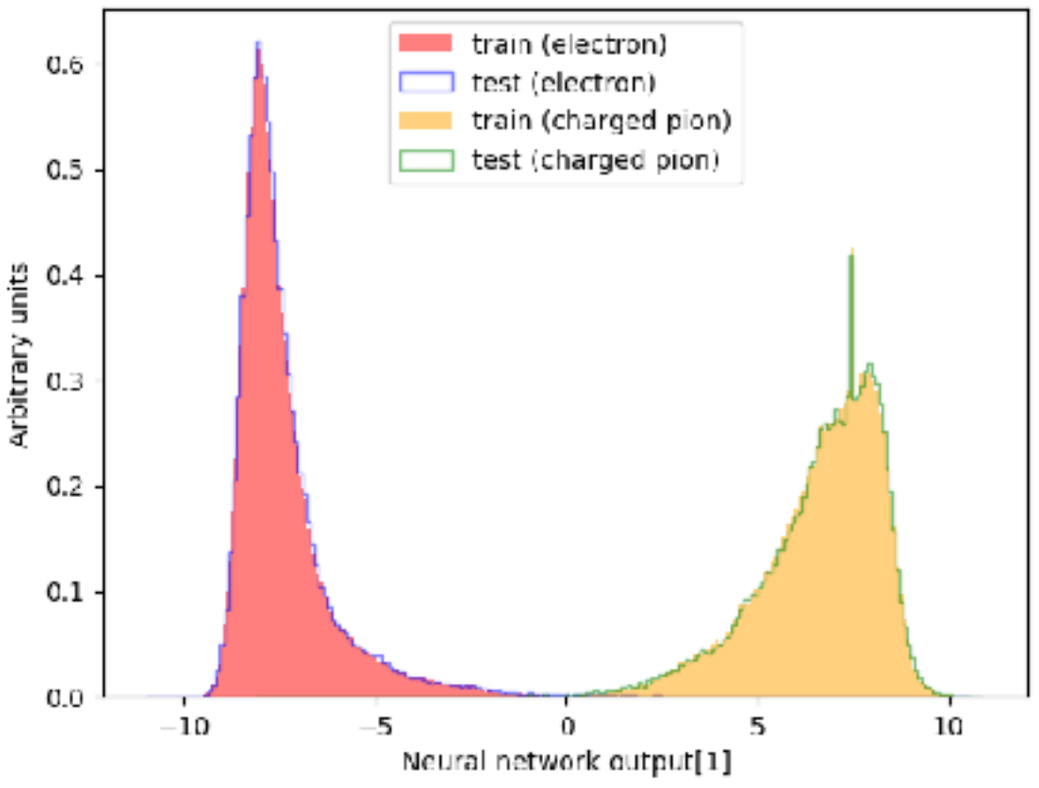


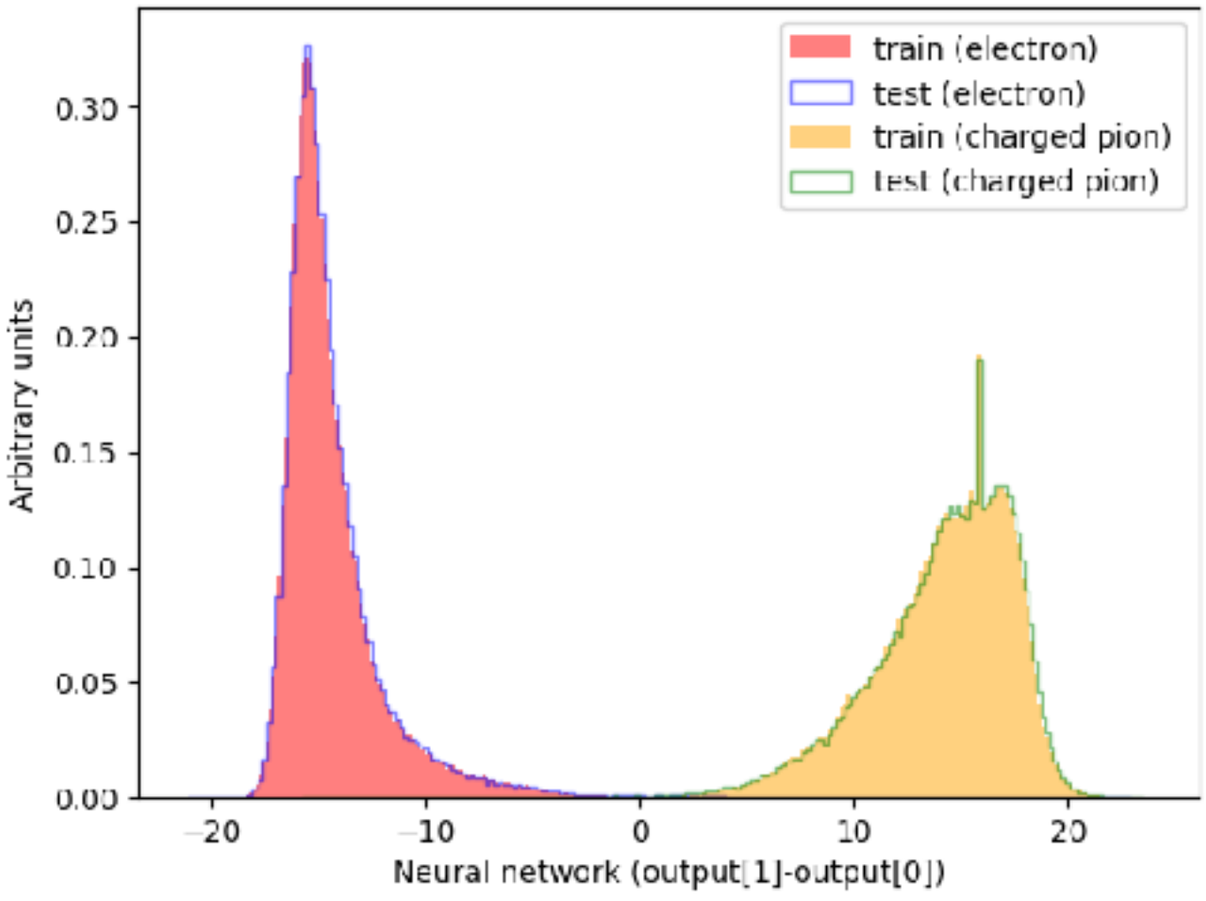
Fully connected neural network (depth = 7, width = 64, learning rate = 0.01, decay rate = 0, optimizer = Adam, trained on 400K images and tested on 200K images)

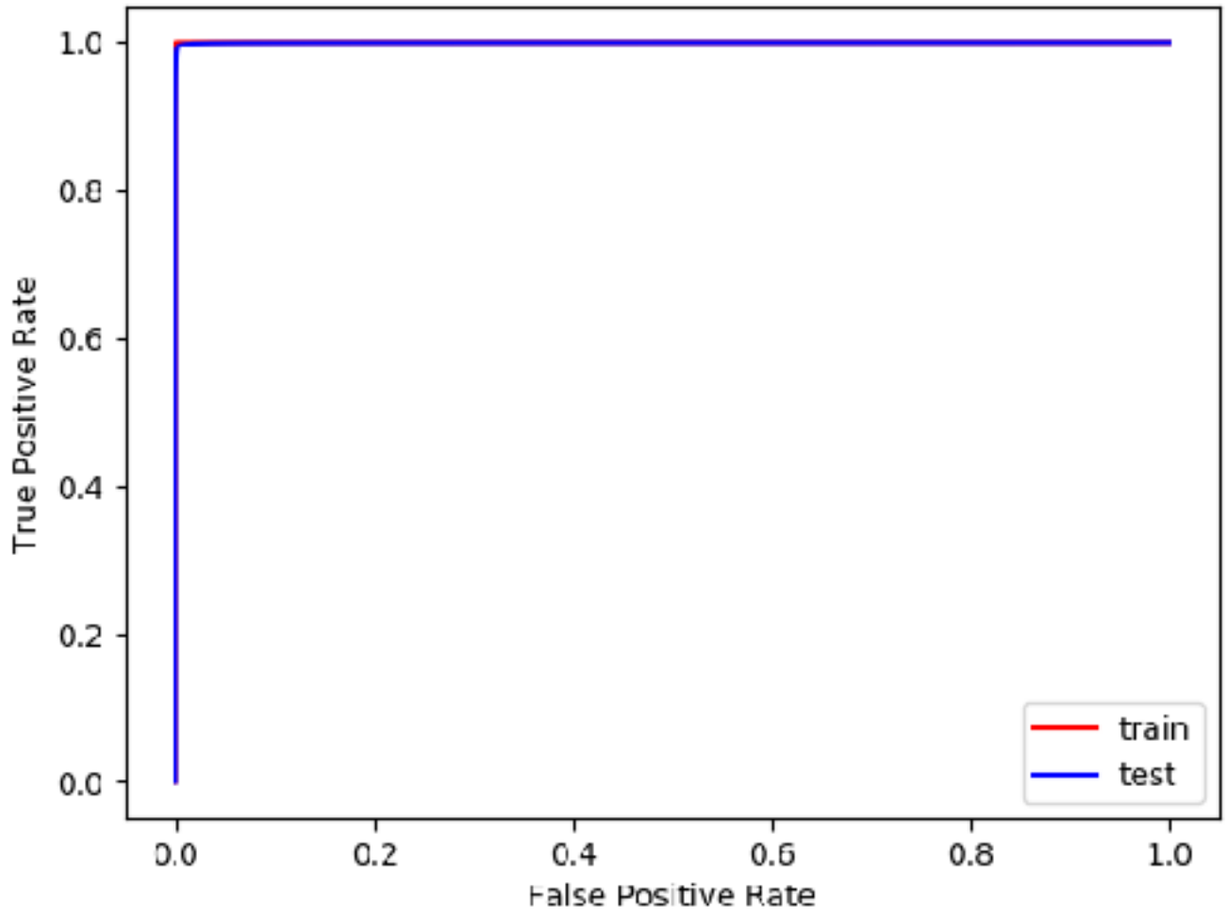
```
Accuracy on test images:  99.574500 %
```





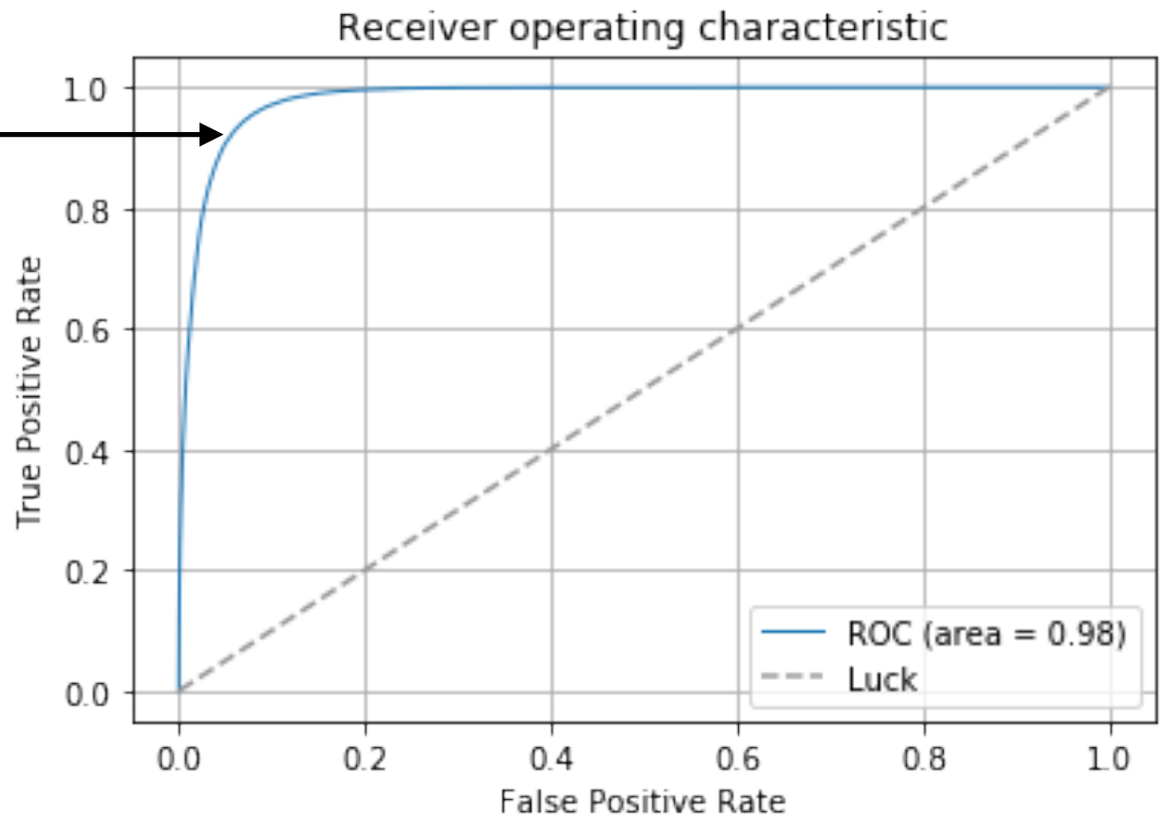






5~7% increase in TP

BDT =>

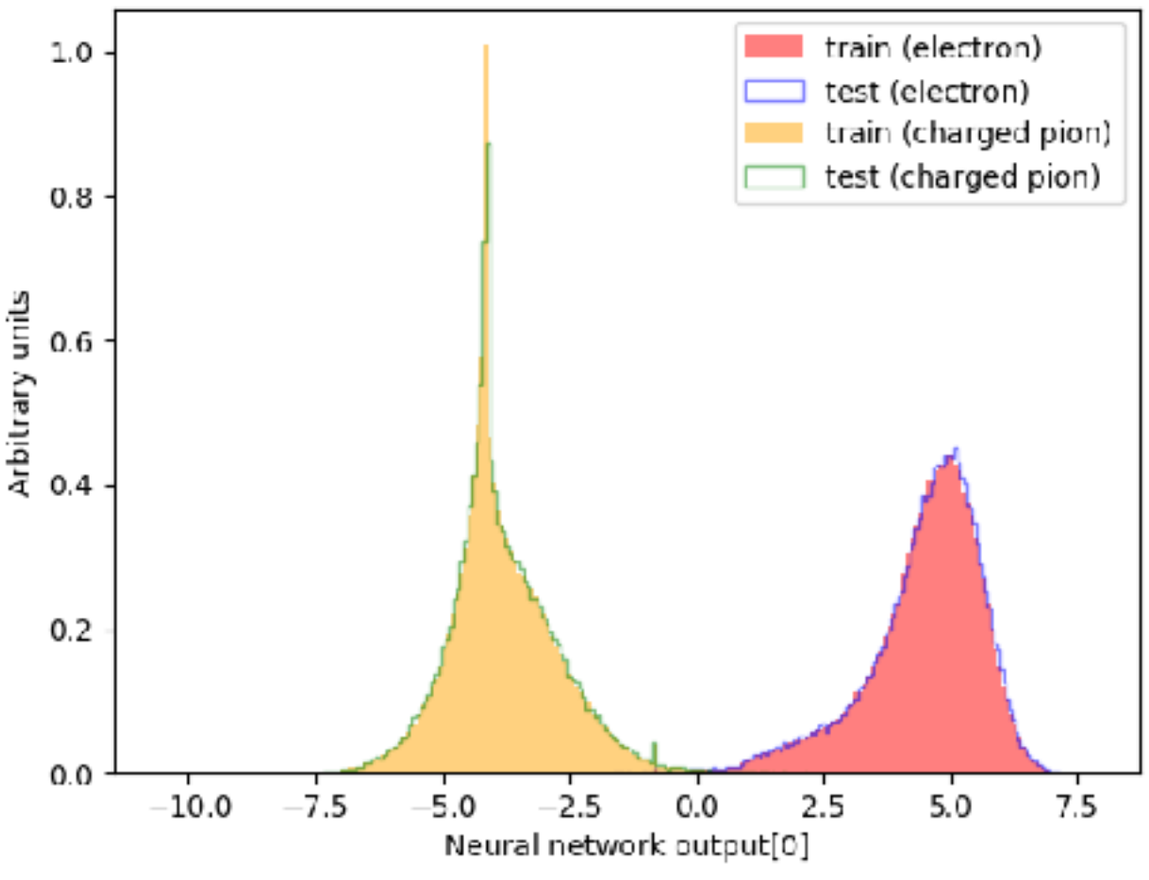


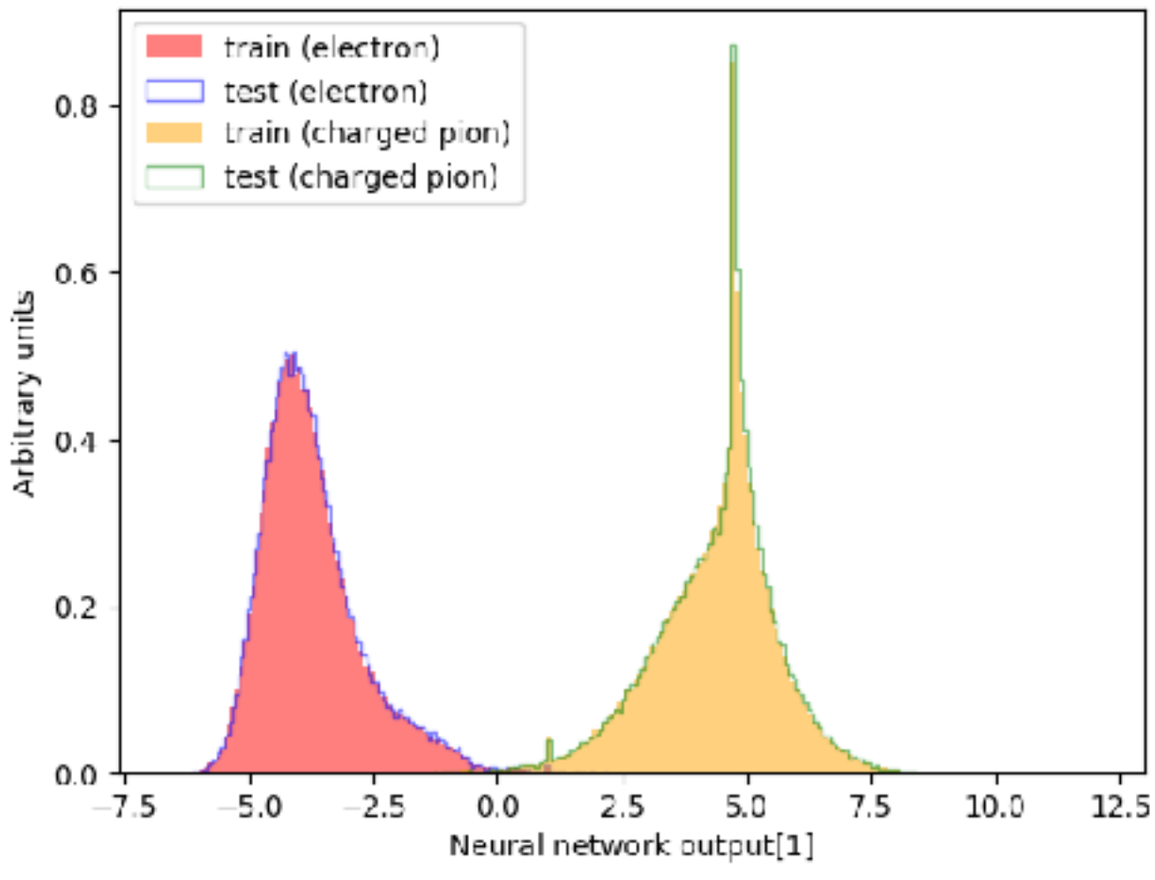
CNN

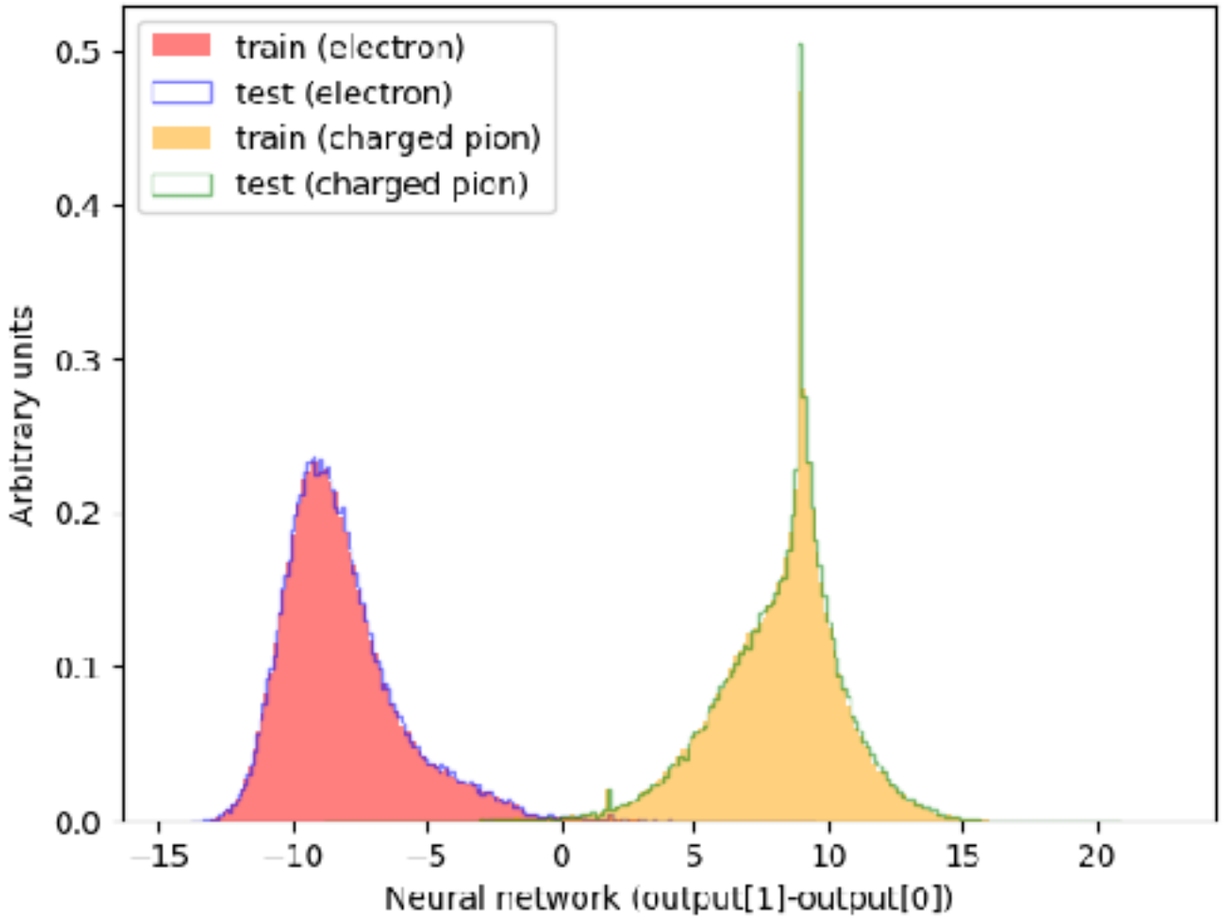
ECAL: Conv3d (1, 4, 10)->MaxPool3d(2)->Con3D(4, 8, 5)->MaxPool3d(2)->FC(64, 8)— — — — — —>|
|->FC(16, 16)->FC(16, 2)
HCAL: Conv3d (1, 4, (2, 2, 41))->MaxPool3d(2)->Con3D(4, 8, (1, 1, 3))->MaxPool3d(2)->FC(32, 8)->|

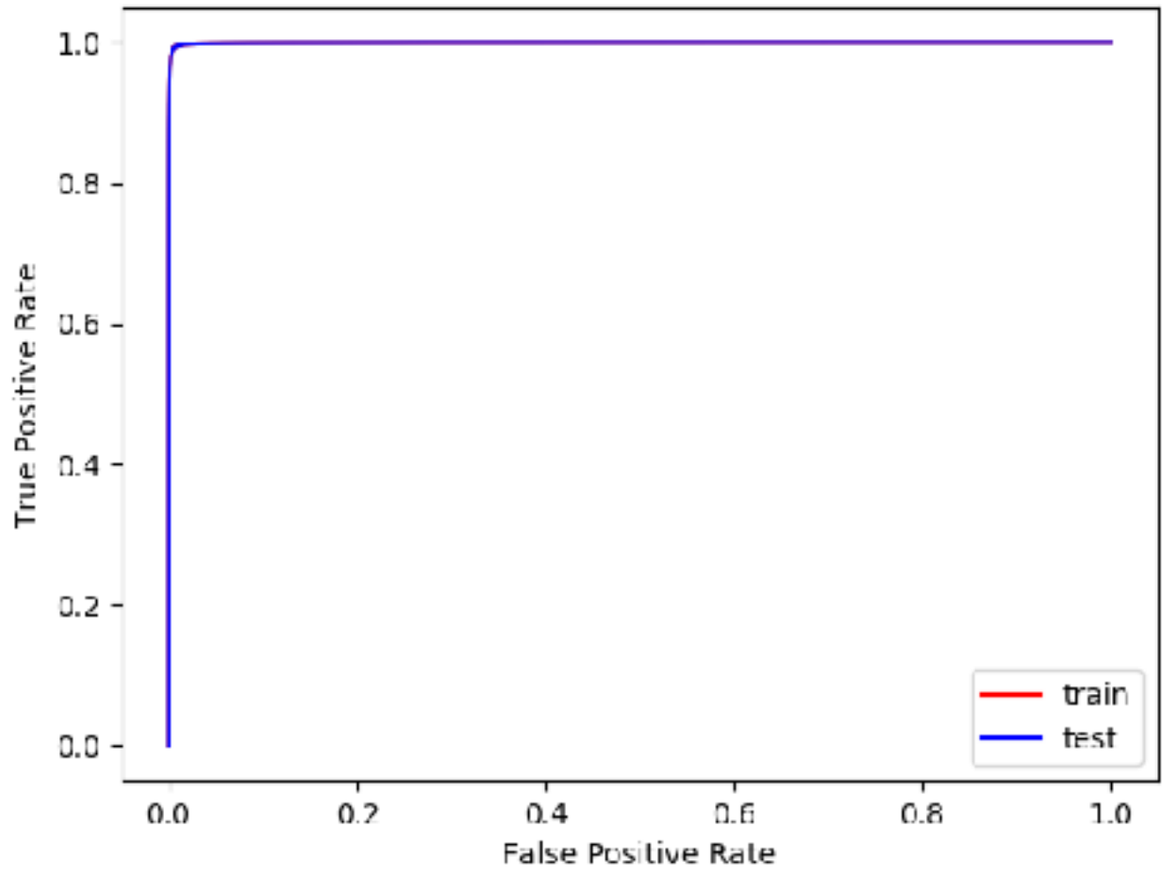
Trained on 400K images, tested on 200K images

```
Accuracy: 99.300000 %
```

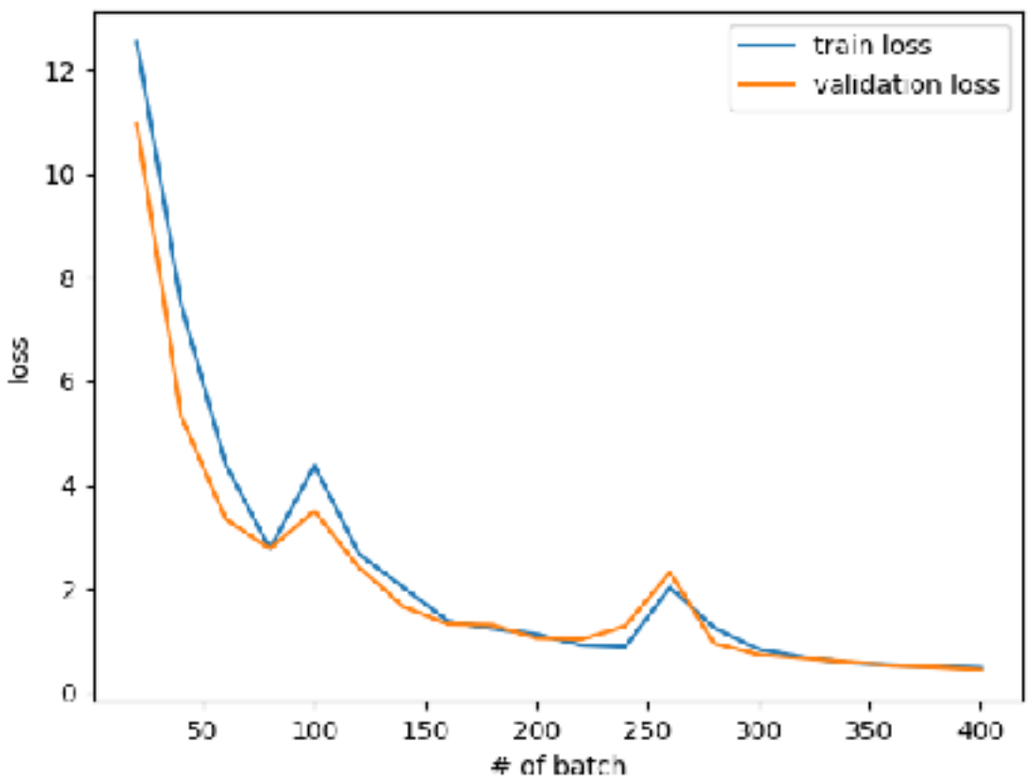




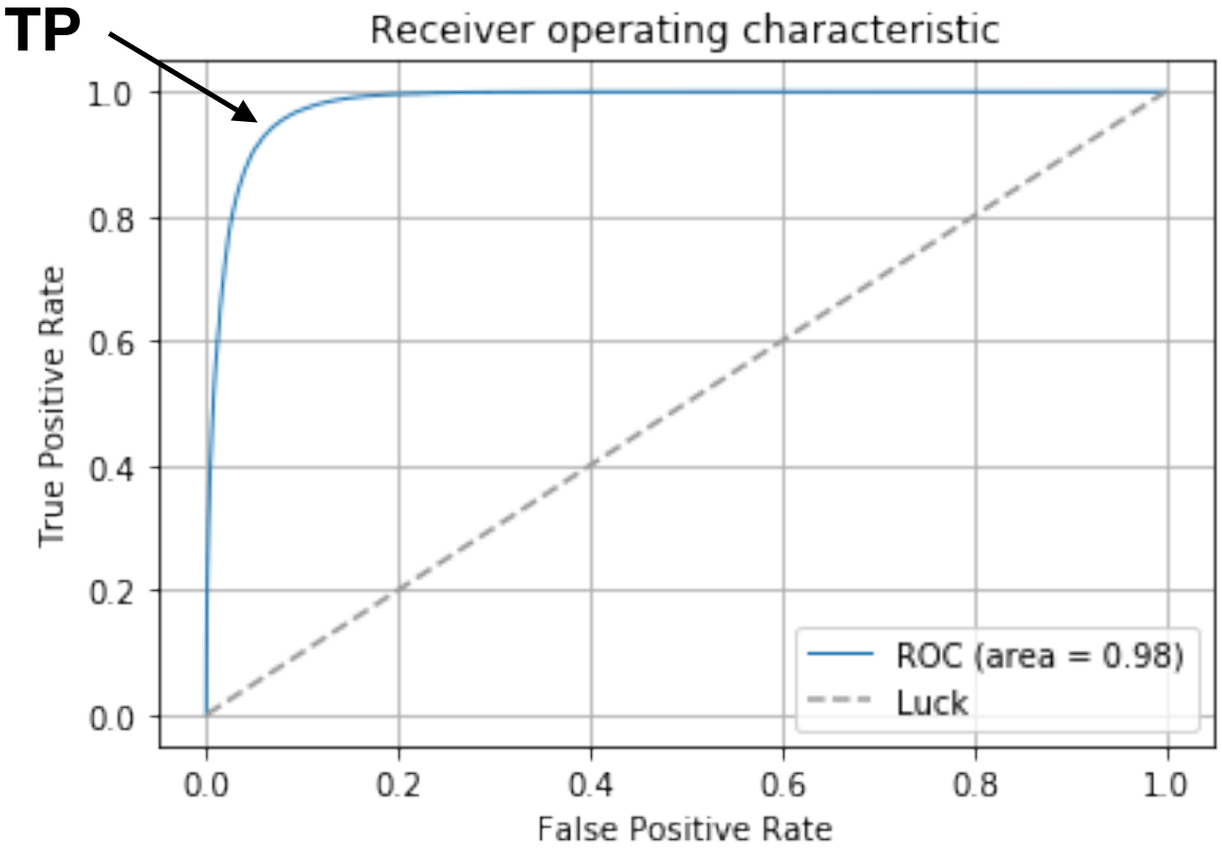


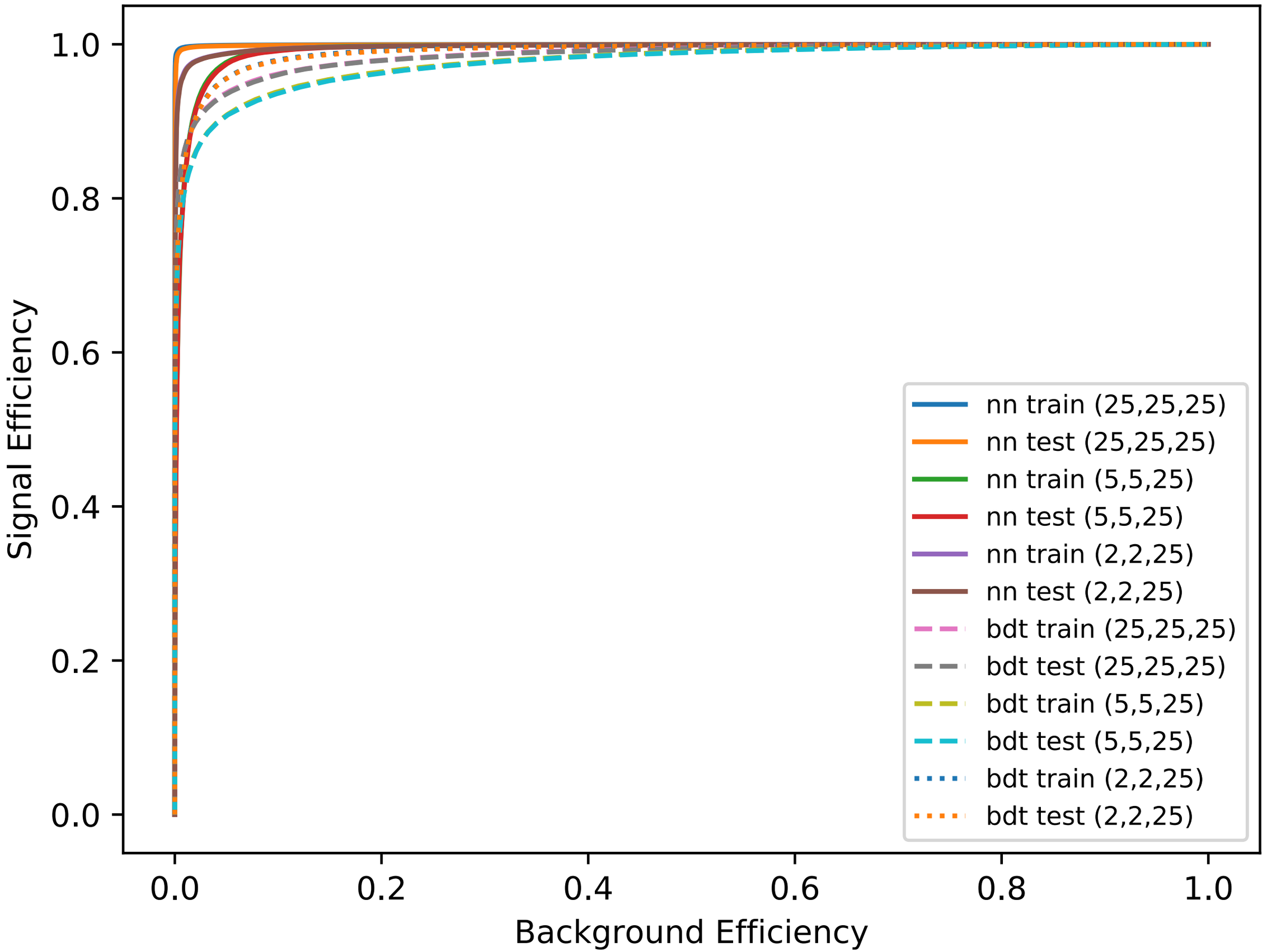


5~7% increase in TP



BDT =>




Signal Efficiency
Background Efficiency
0.0
0.2
0.4
0.6
0.8
1.0
nn train (25,25,25)
nn test (25,25,25)
nn train (5,5,25)
nn test (5,5,25)
nn train (2,2,25)
nn test (2,2,25)
bdt train (25,25,25)
bdt test (25,25,25)
bdt train (5,5,25)
bdt test (5,5,25)
bdt train (2,2,25)
bdt test (2,2,25)