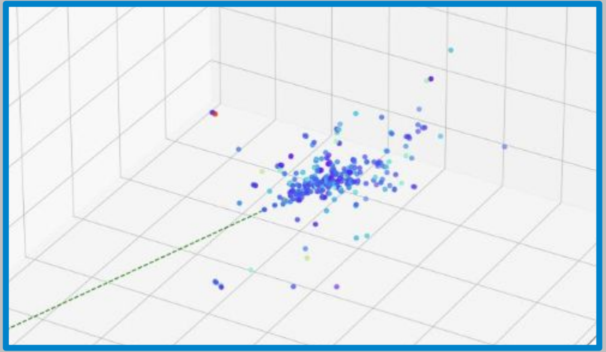
Argonne NATIONAL LABORATORY

Barrel ECal Calorimetry Performance Studies



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U.S. DEPARTMENT OF ENERGY
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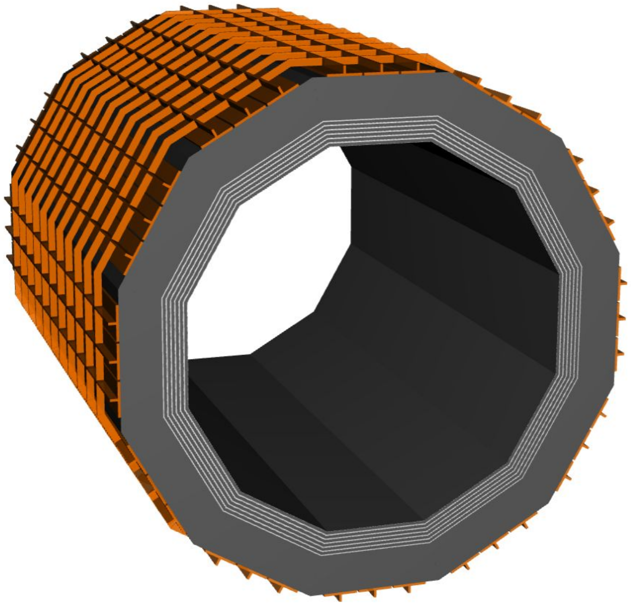
10/10/2021

ScFi + Imaging Calorimeter



- Imaging layer: 0.155 cm + 1 cm of air = **1.155 cm**
- Imaging layers separated with 13*1.22 mm = **1.586 cm** wide layers of ScFi (13 layers of fibers)

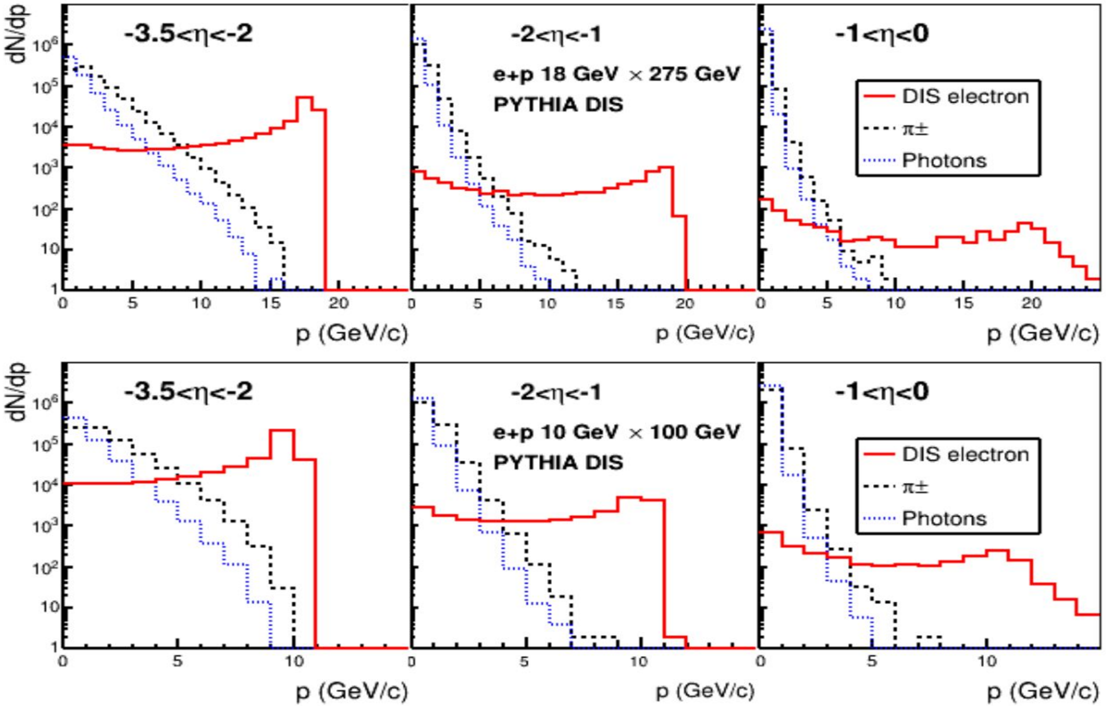
[cm]	9 Img layers	6 Img layers
thickness of SiFi with Img layers	13.09	8.18
thickness of SiFi w/o Img layers	19.63	24.54
total SiFi	32.72	32.72
thickness of Img layers	9.40	5.93
total thickness	42.12	38.65

Currently in simulation:

- ECal Barrel r min = 103 cm
- Solenoid r min = 160 cm
- 57 cm for ECal + support (5 cm)

Pion Background in Inclusive DIS

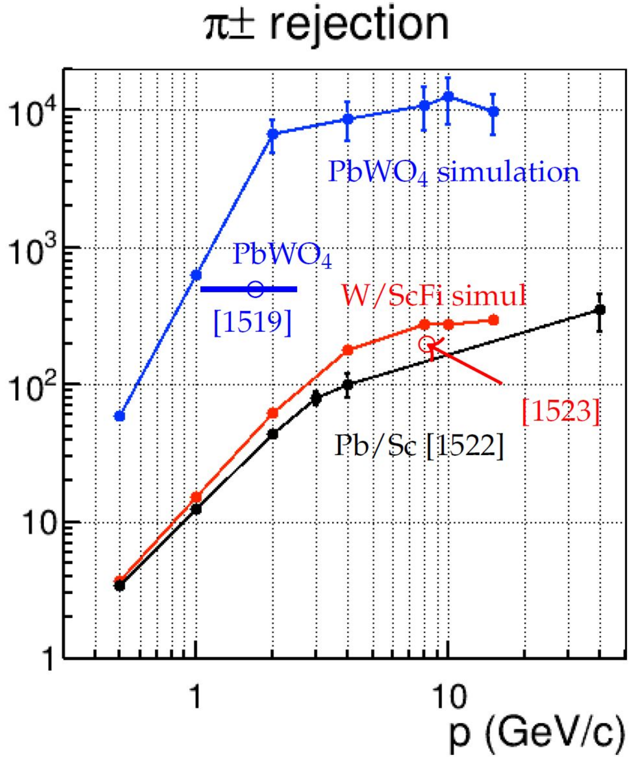
https://indico.bnl.gov/event/8231/contributions/37820/attachments/28257/43445/EIC_EMCal_Pavia_21may20_v2.pdf



18x275 GeV

10x100 GeV

Pion Suppression Plot in YR



Simulation and Data

Standalone Ecal

E/p cut only

95% electron efficiency

Pion Rejection with Machine Learning

- 50k electrons and 50k pions for each momentum point, 80% used for training, 20% for validating.
  - 100k events for benchmarking

- Apply E/p cut first to “clean up” samples

- Combine imaging layer hits and ScFi layer hits
  - 20 hits per layer, sorted by energy deposit, zero padding
  - 5 features per hit (layer_type [0, 1], Edep, Rc, eta, phi)

- Adjust e:pi weighting in cost function to balance efficiency and rejection power

Pion Rejection with Machine Learning

- Simple model
  - Sequential CNN + MLP

- 20 epochs of training

- e-pi classification
  - label with the highest probability is picked

- Final results may be improved
  - More epochs
  - More layers

```
Model: "sequential_75"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_225 (Conv2D)          (None, 29, 20, 48)        1008
_________________________________________________________________
max_pooling2d_225 (MaxPoolin (None, 14, 10, 48)        0
_________________________________________________________________
dropout_225 (Dropout)        (None, 14, 10, 48)        0
_________________________________________________________________
conv2d_226 (Conv2D)          (None, 14, 10, 96)        41568
_________________________________________________________________
max_pooling2d_226 (MaxPoolin (None, 7, 5, 96)          0
_________________________________________________________________
dropout_226 (Dropout)        (None, 7, 5, 96)          0
_________________________________________________________________
conv2d_227 (Conv2D)          (None, 7, 5, 48)          41520
_________________________________________________________________
max_pooling2d_227 (MaxPoolin (None, 3, 2, 48)          0
_________________________________________________________________
flatten_75 (Flatten)         (None, 288)               0
_________________________________________________________________
dense_225 (Dense)            (None, 128)               36992
_________________________________________________________________
dropout_227 (Dropout)        (None, 128)               0
_________________________________________________________________
dense_226 (Dense)            (None, 32)                4128
_________________________________________________________________
dense_227 (Dense)            (None, 2)                 66
=================================================================
Total params: 125,282
Trainable params: 125,282
Non-trainable params: 0
_________________________________________________________________
```

Pion Rejection with Machine Learning

Ideal case to compare with YR plot

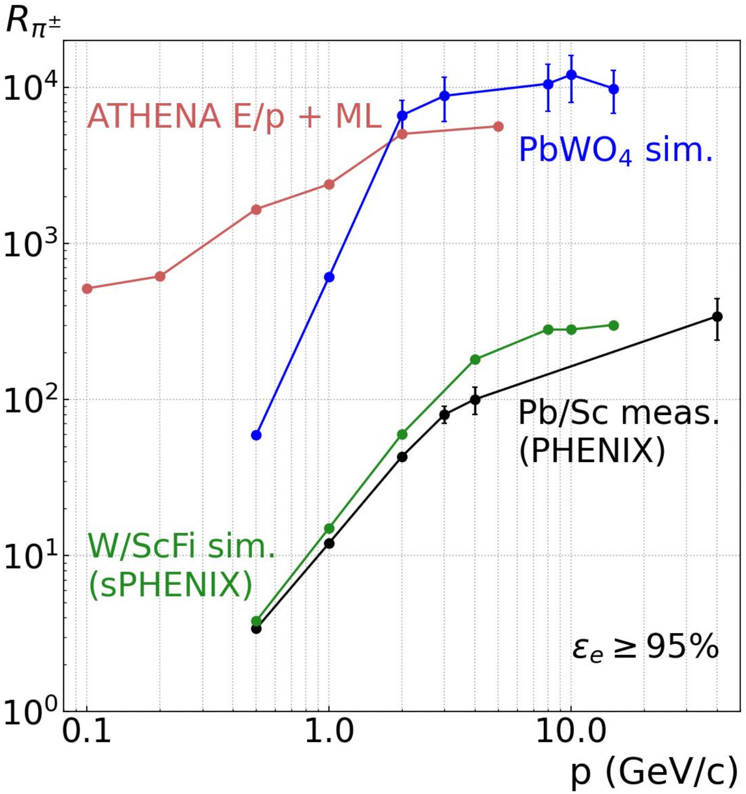
- no materials in front of barrel Ecal, no magnetic field
- eta scan from -1 to 1

p (GeV)	Edep/p cut (9 + 9 layers)			ML			Combined	
	Cut	e Eff.	pion Rej.	e:pion Weighting	e Eff.	pion Rej.	e Eff.	pion Rej.
0.1	> 0.05	99.94%	1.05	1:10	95.55%	489.85	95.49%	514
0.2	> 0.06	99.87%	1.04	1:20	95.36%	590.72	95.24%	614
0.5	> 0.085	98.48%	3.45	1:30	96.47%	479.63	95.00%	1655
1	> 0.085	98.67%	4.72	1:80	97.18%	505.95	95.89%	2388
2	> 0.085	98.08%	6.72	1:100	98.42%	746.00	96.53%	5013
5	> 0.08	98.17%	8.27	1:40	96.77%	678.86	95.01%	5613

Pion Rejection with Machine Learning

9 AstroPix Layers

Ideal case



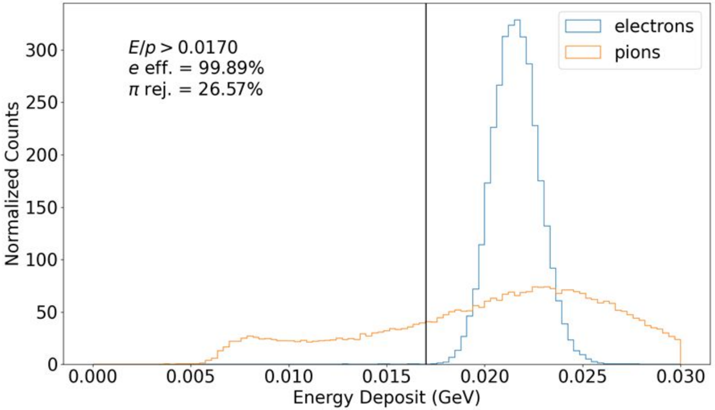
E/p Cut with Current Simulation

Hadron response is being studied, results on E/p cut will change (likely improve)

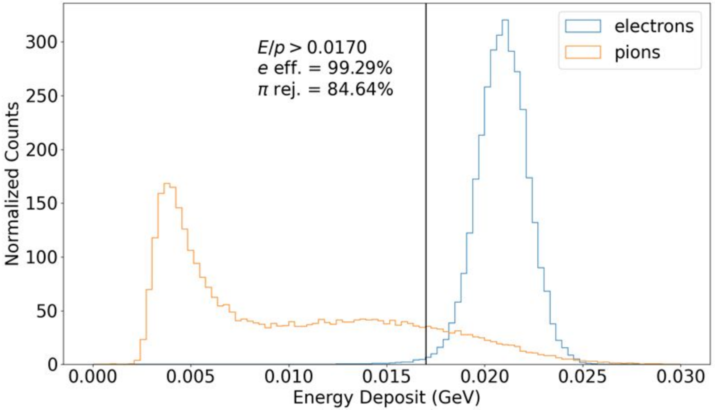
Simple E/p cut for the accumulative Edep over 9+9 layers (sandwich layers)

1 GeV/c particles

Edep on All Layers (scaled by ⅕)

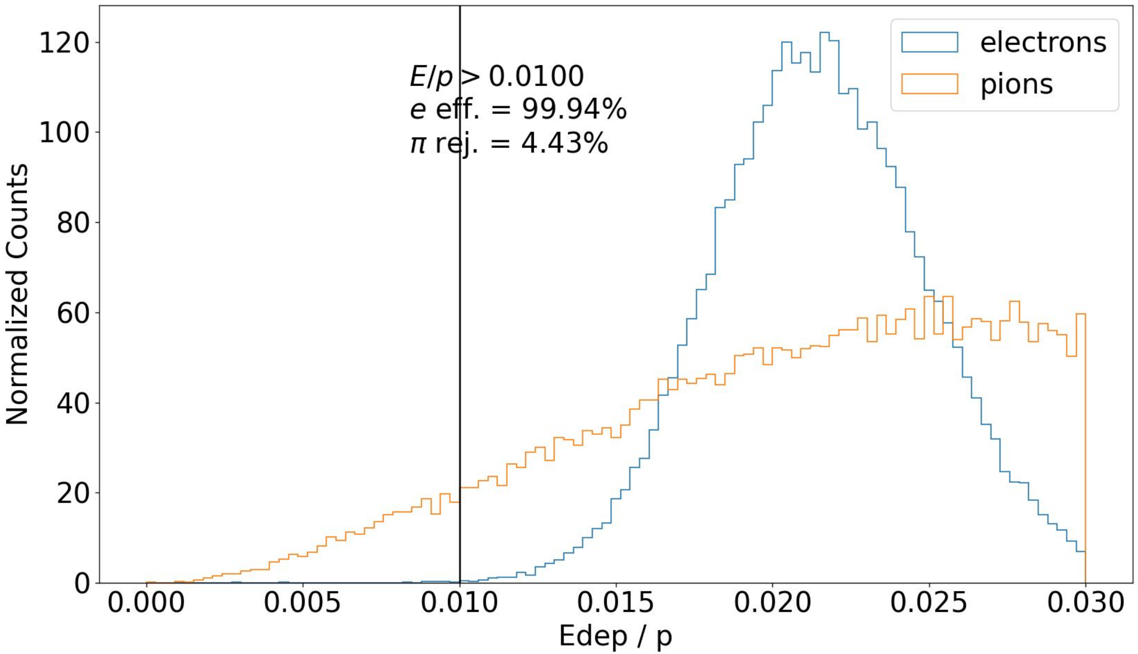


Edep on 9+9 Layers (scaled by ⅕)



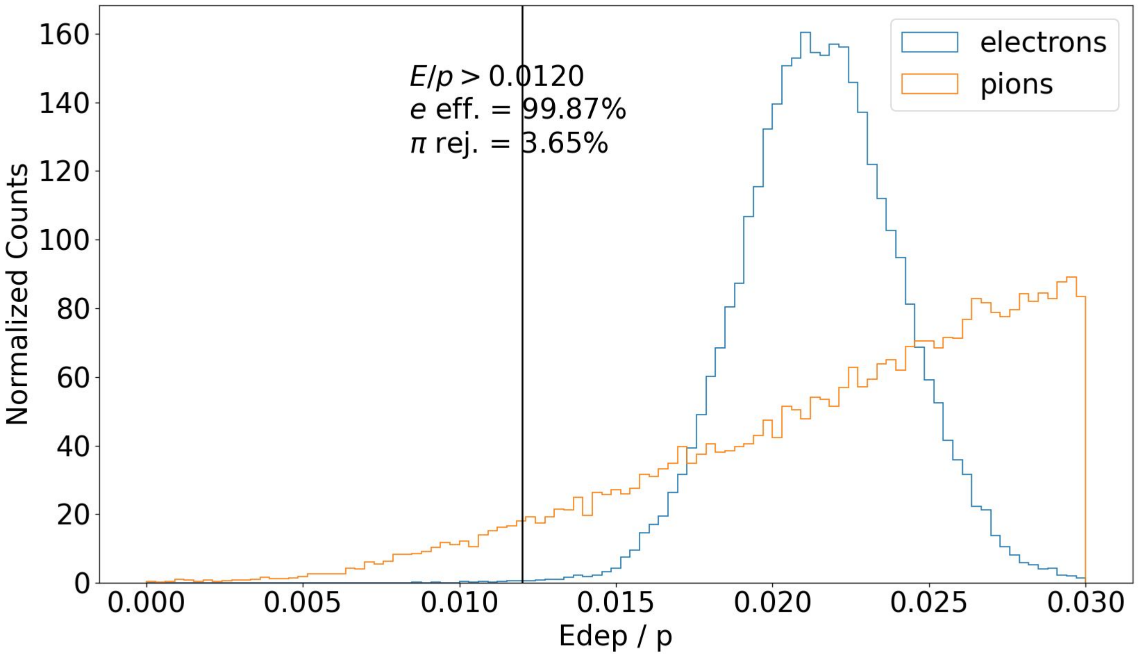
E/p Cuts

0.1 GeV/c



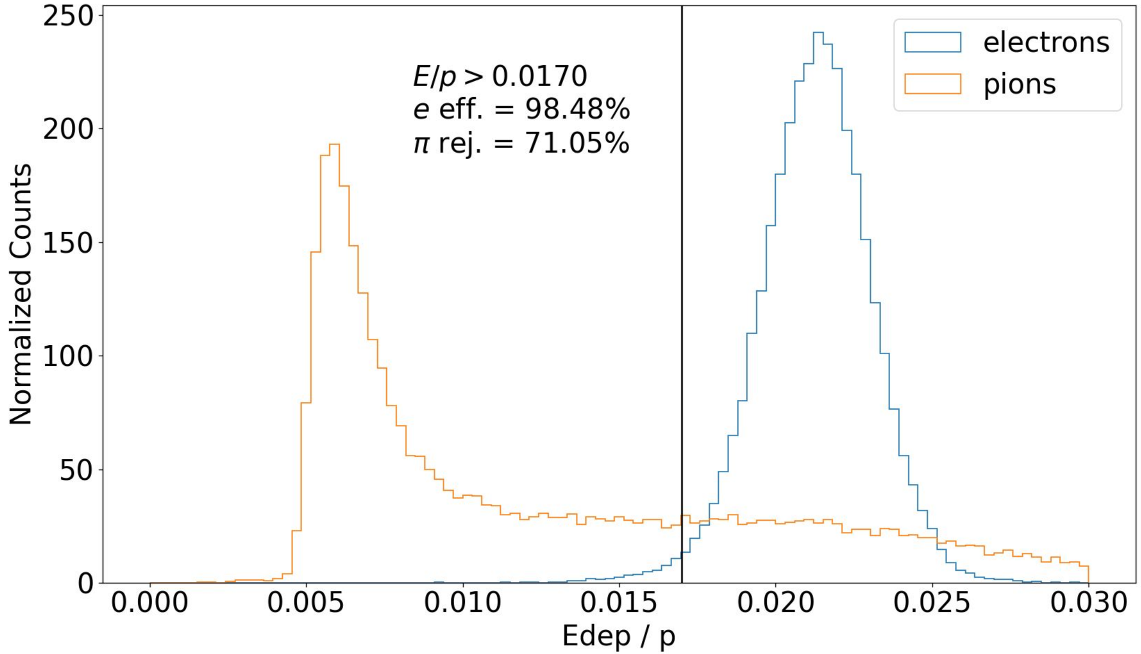
E/p Cuts

0.2 GeV/c



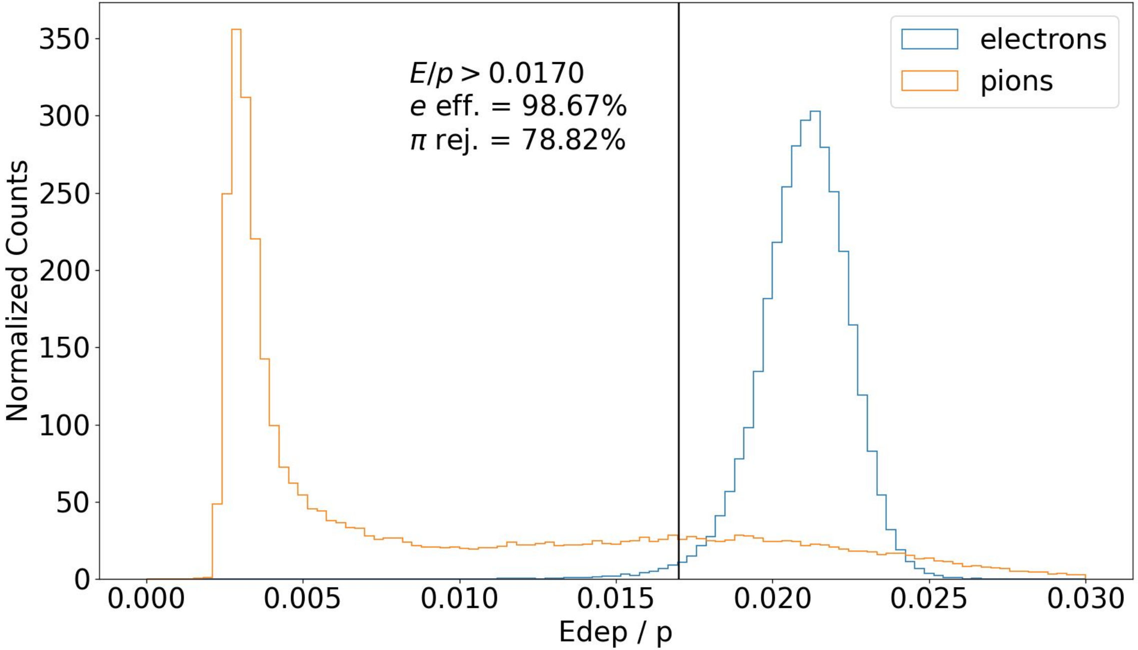
E/p Cuts

0.5 GeV/c



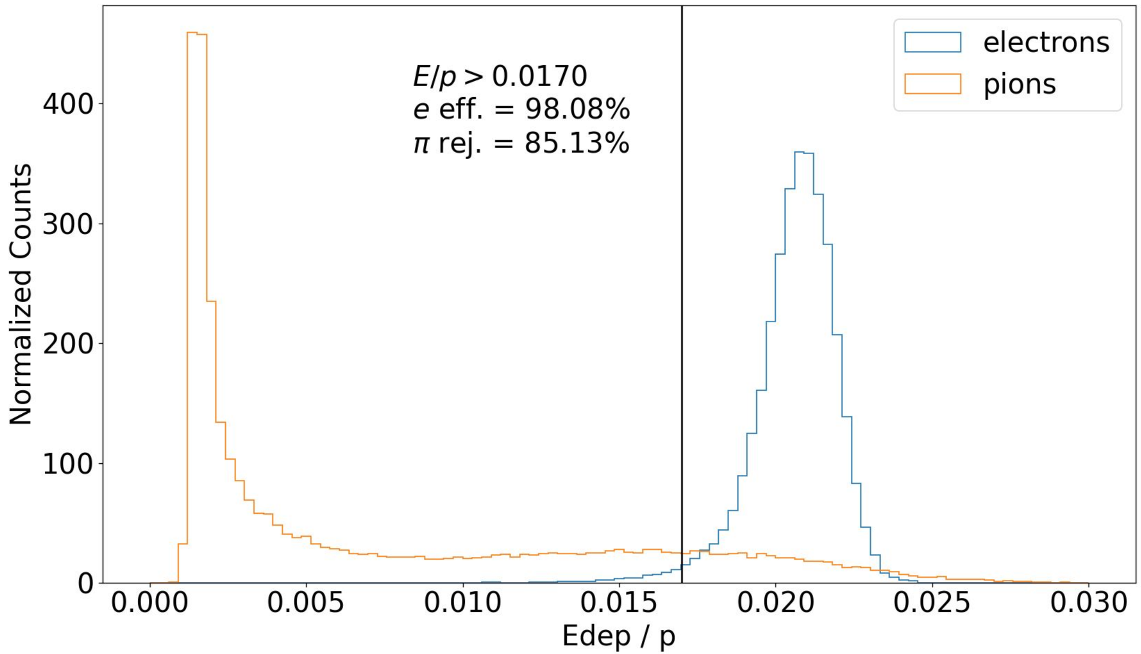
E/p Cuts

1.0 GeV/c



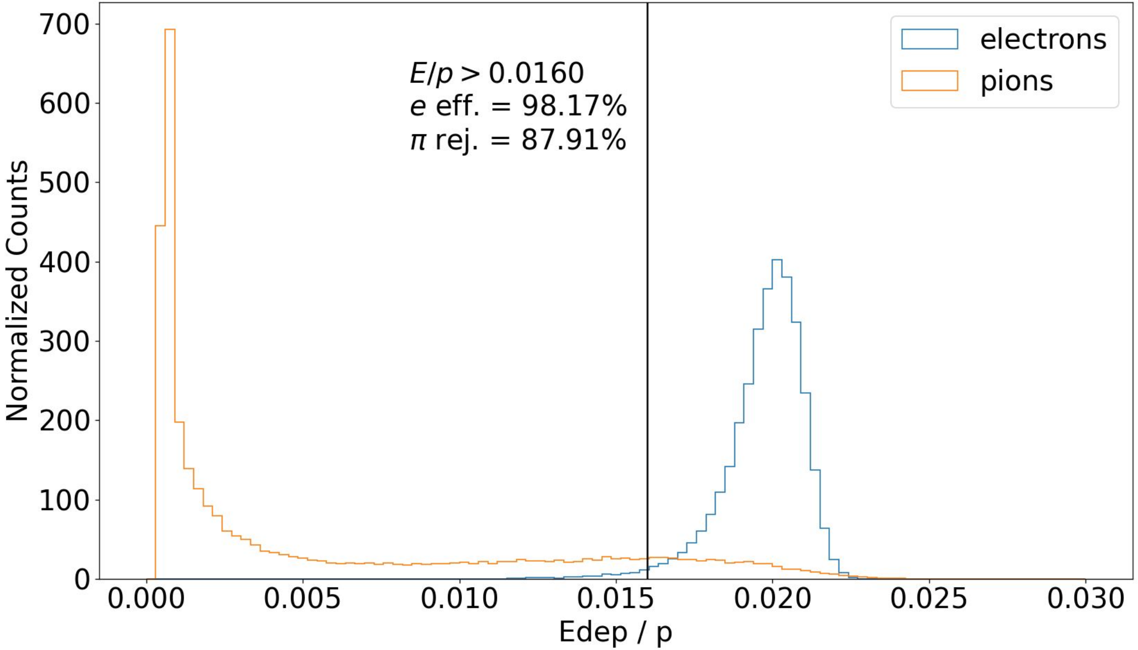
E/p Cuts

2.0 GeV/c



E/p Cuts

5.0 GeV/c



Numbers of Imaging Layers

Disable signals of latter layers (they are still in simulation)

E/p cut is the same, weighting was adjusted to maintain > 95%

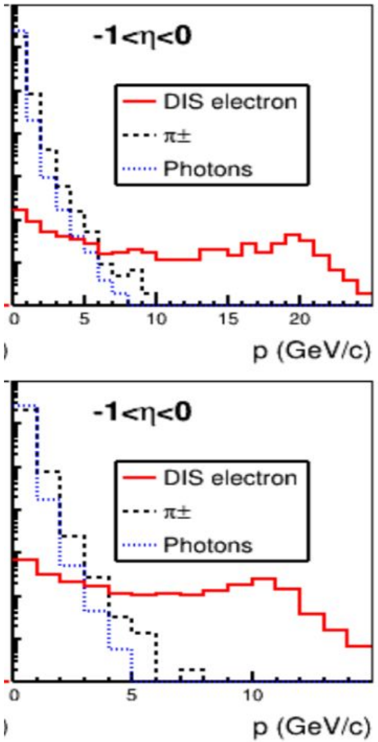
Both eff. and rej. are worse with less number of layers

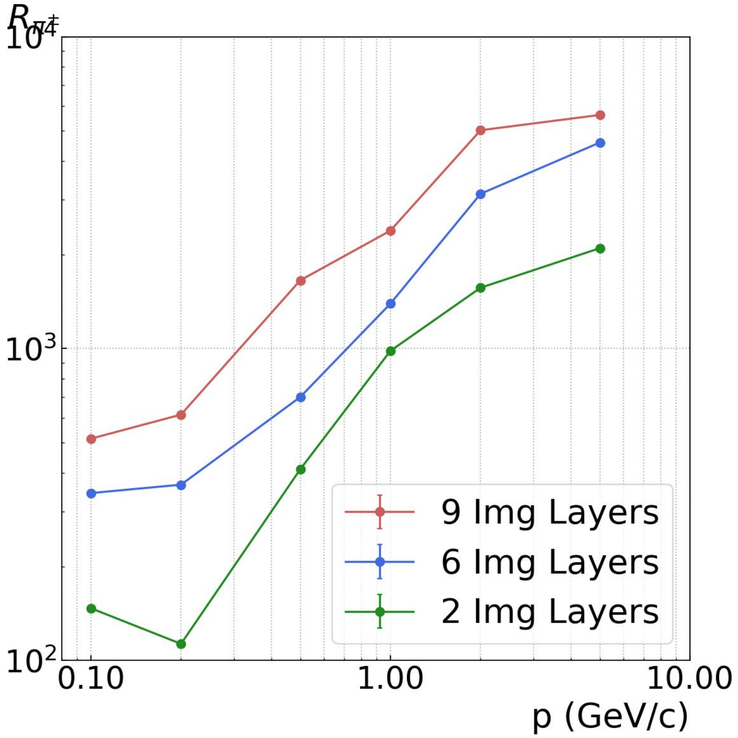
p (GeV)	Pion Rejection Power (e Eff. >= 95%)		
	2 AstroPix layers	6 AstroPix Layers	9 AstroPix Layers
0.1	147	344	514
0.2	113	366	614
0.5	410	699	1655
1	983	1393	2388
2	1567	3135	5013
5	2098	4578	5613

Numbers of Imaging Layers

18x275

10x100





Further possible improvements

2D cut on dE/dx

Higher rejection factor before using ML

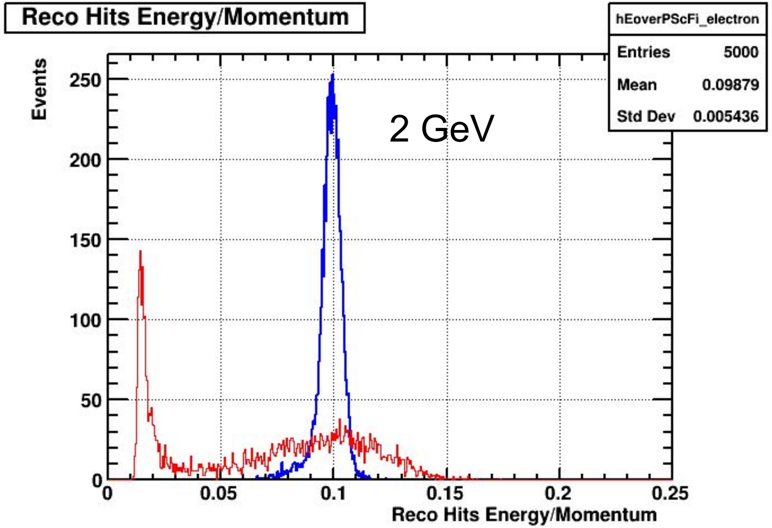
More complicated NN structure

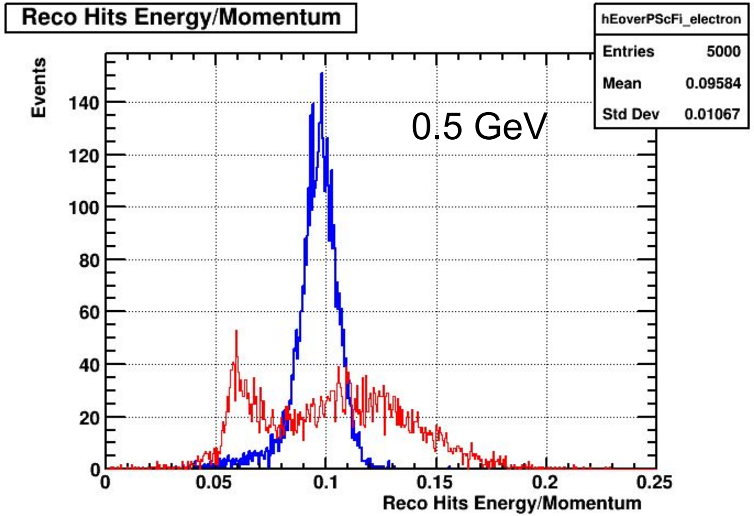
Multi-views classification

electron/pion PID

Cut of Energy deposit from ScFi layers

All particles generated for **eta = 0, no MF**, energies: 0.1, 0.2, 0.5, 1, 2, 5, 10 GeV
Plots for all scanned energies in the backup slides



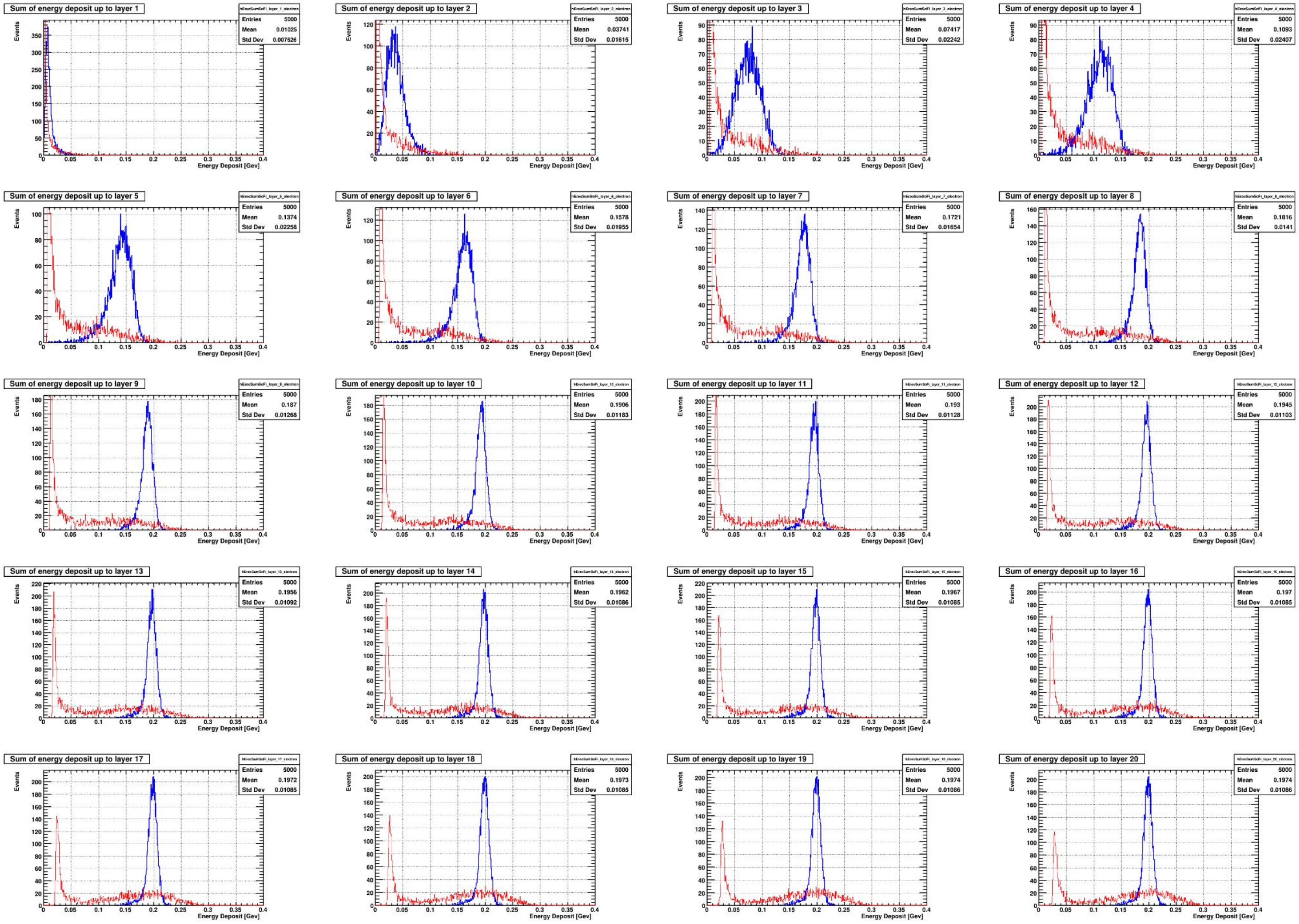


electron/ pion PID

Plots: deposited energy **summed up to** the particular layer

Example for 2 GeV

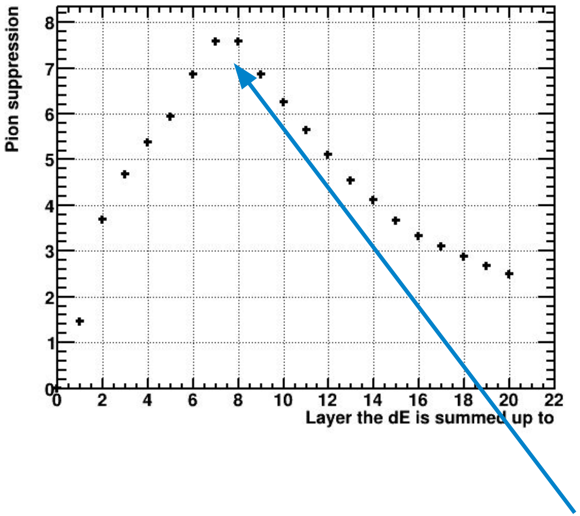
Plots for all scanned energies in the backup slides

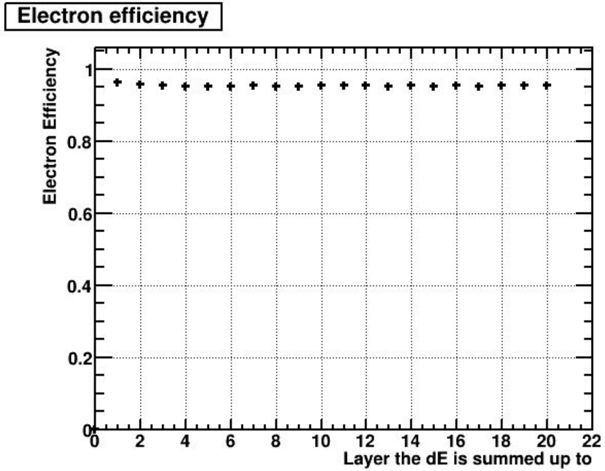


electron/pion PID

Example for 2 GeV

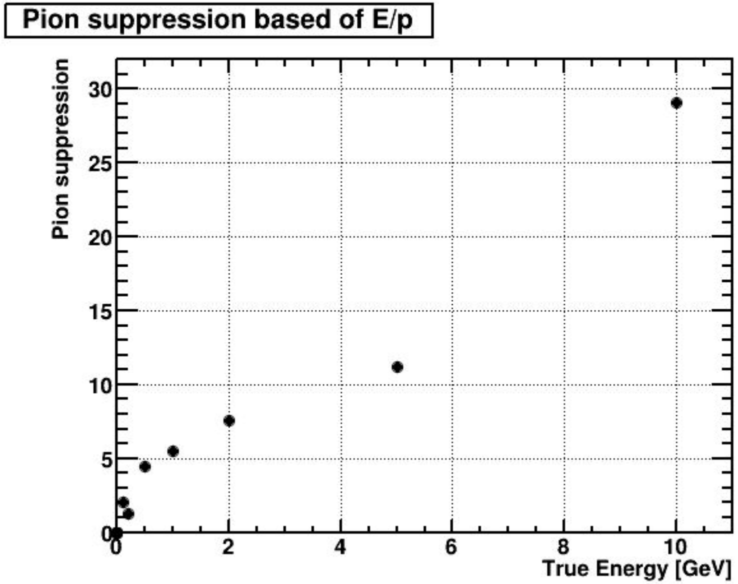
Left: **Pion suppression** vs the layer that the deposited energy is summed up to
Right: **Electron efficiency** for the cut on the deposited energy up to the particular layer

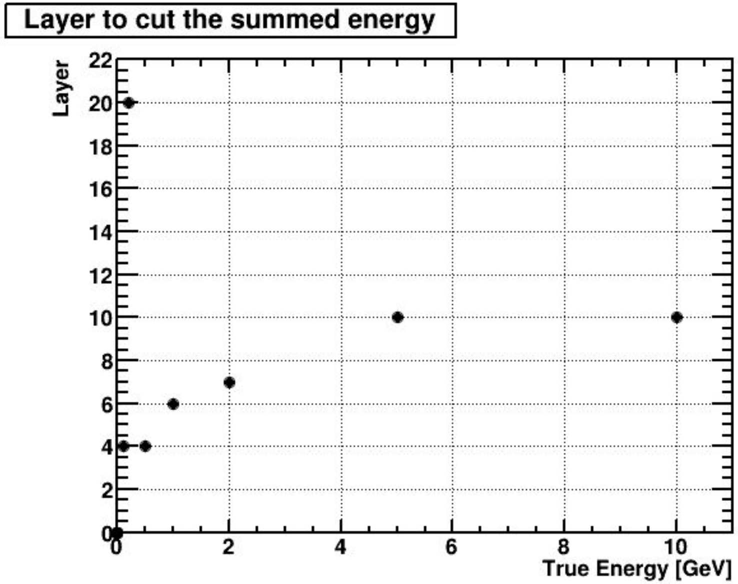




For 2 GeV electrons/pions, cut on energy summed up to 6th or 7th layer.

electron/pion PID





Energies: 0.1, 0.2, 0.5, 1, 2, 5, 10 GeV

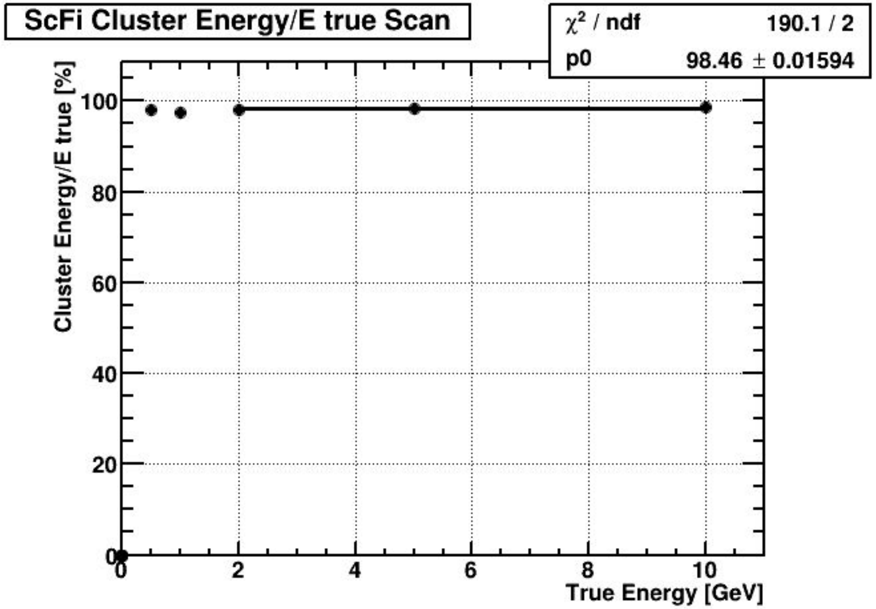
Please ignore point (0,0)

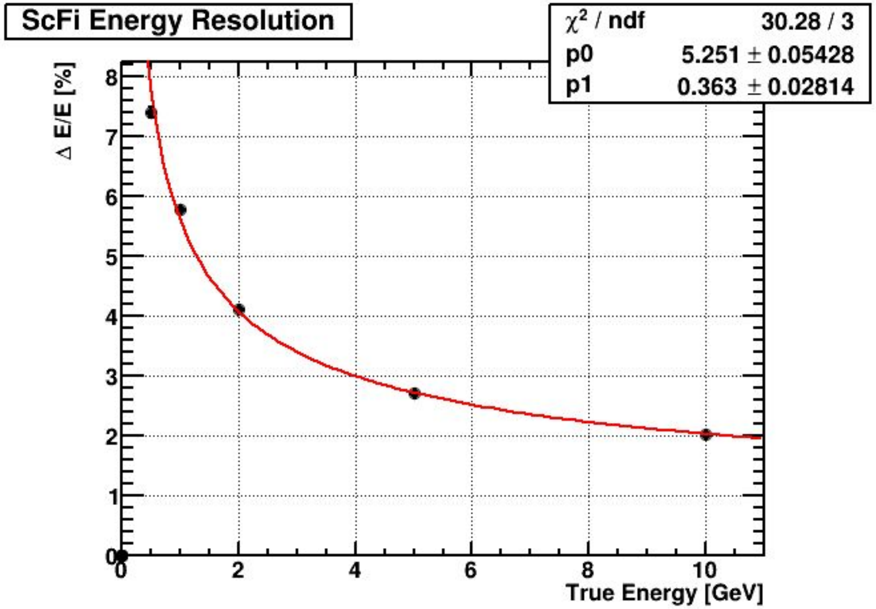
Backup

Energy resolution

photons

$5\%/\sqrt{E} + 0.36\%$

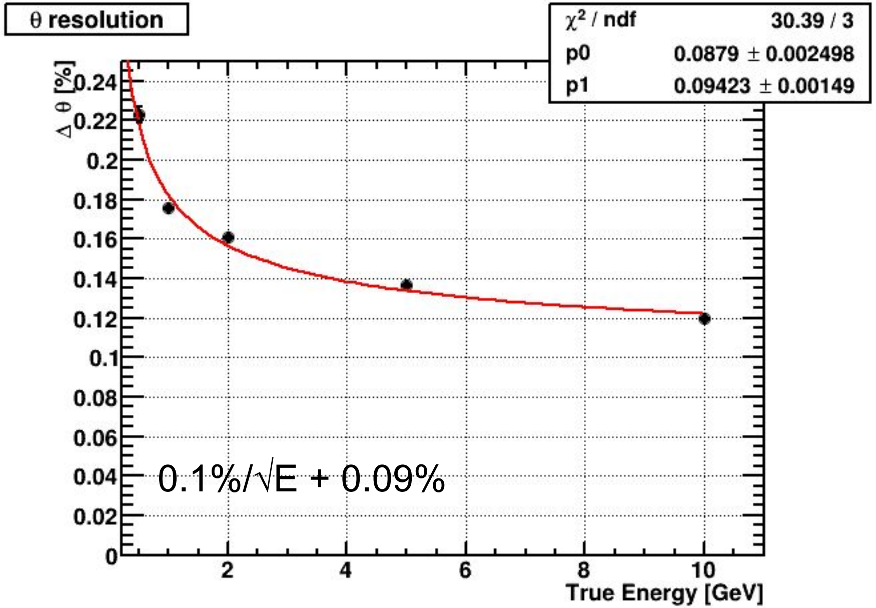


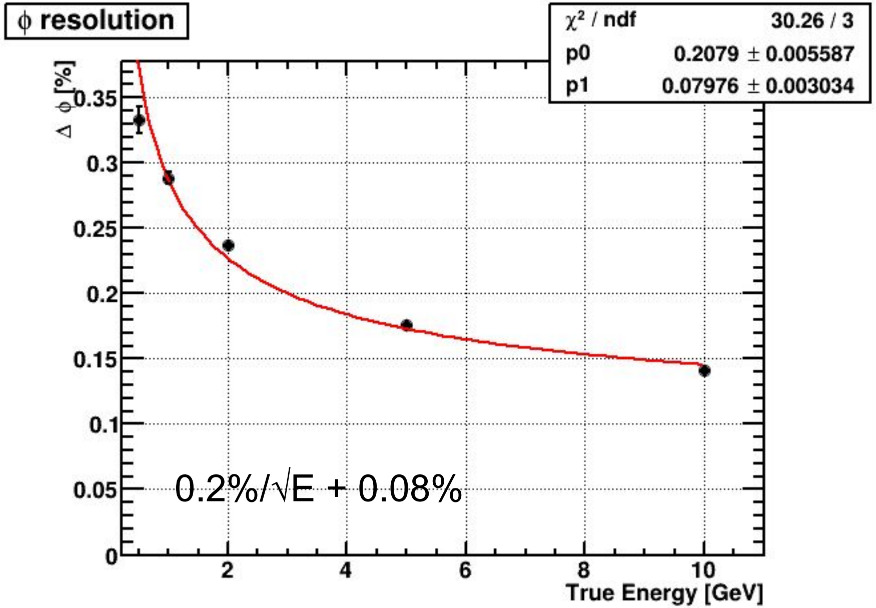


Spatial resolution

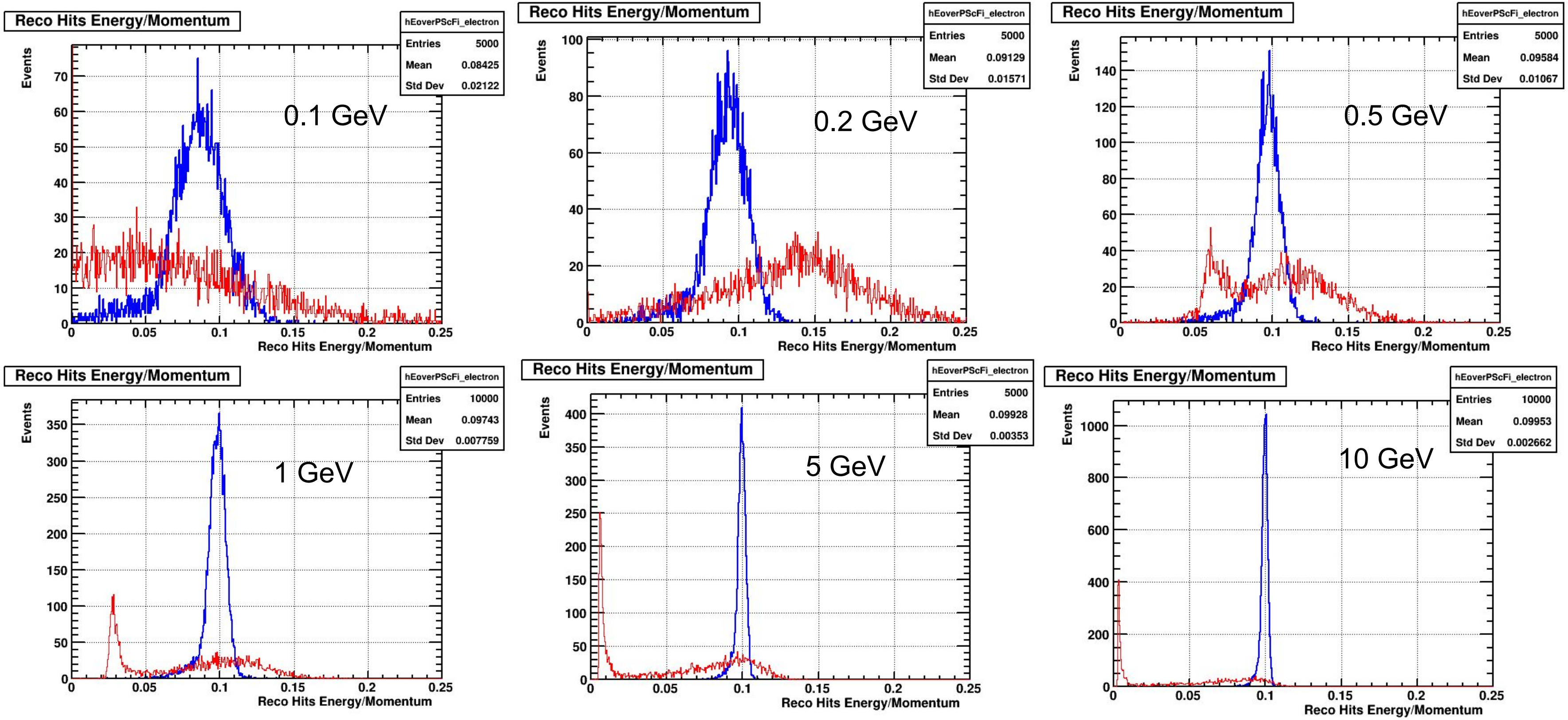
photons

generated with eta=0, phi=(0,360) deg





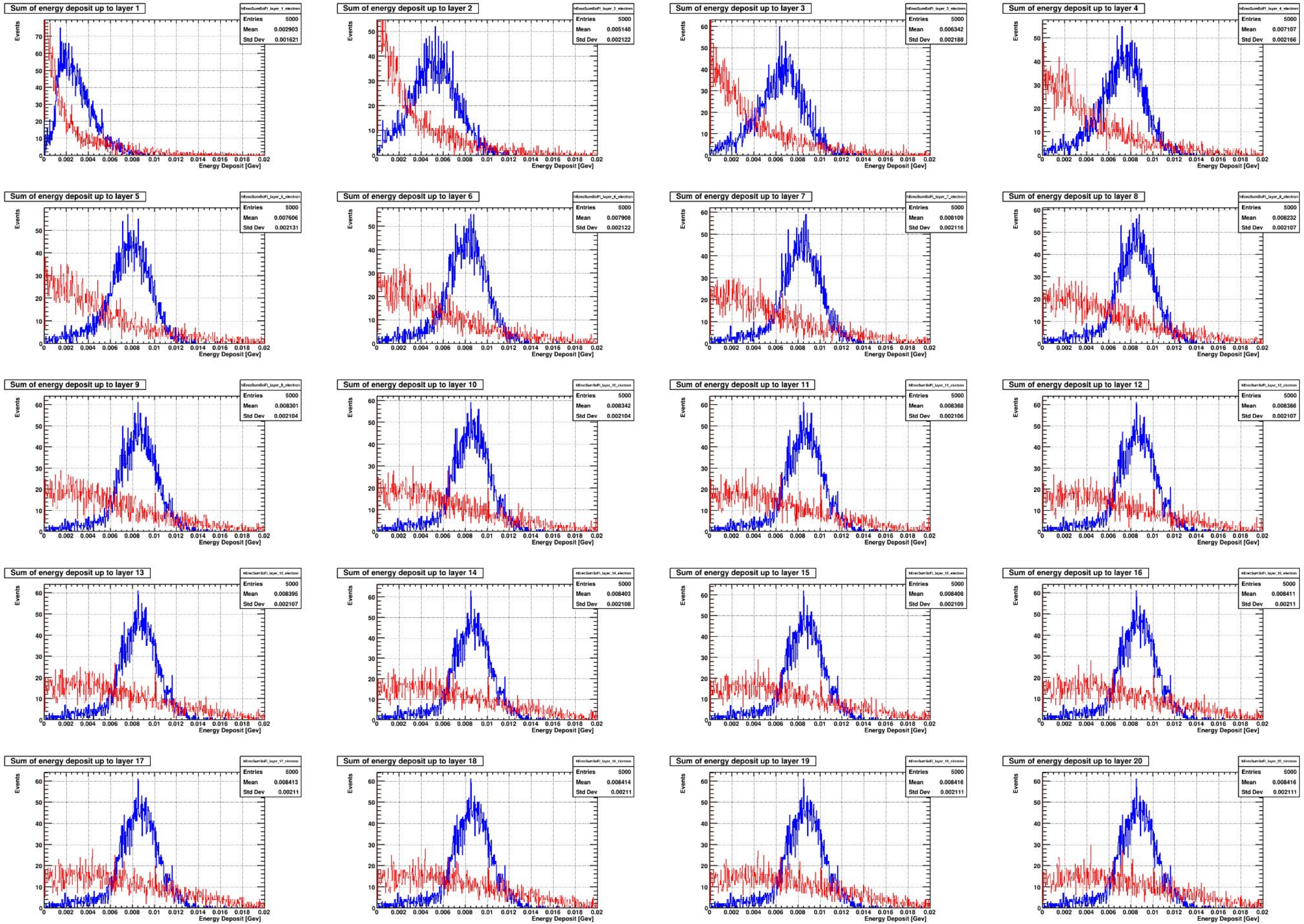
electron/pion energy loss in all ScFi layers



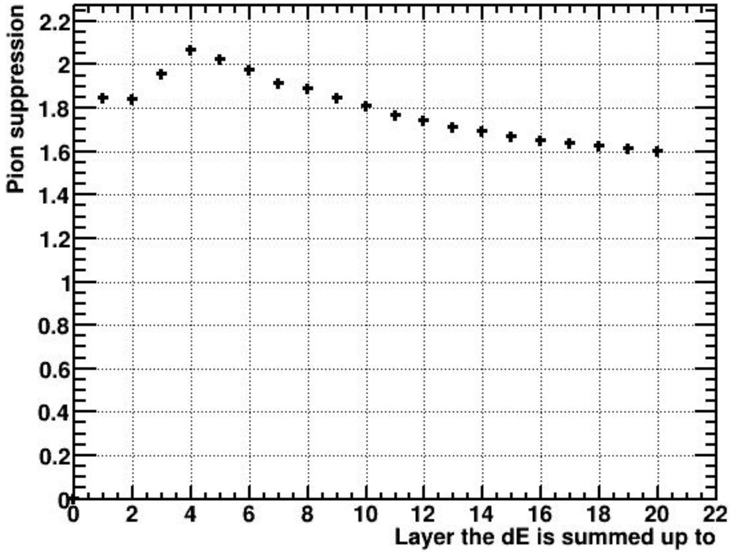
electron/ pion PID

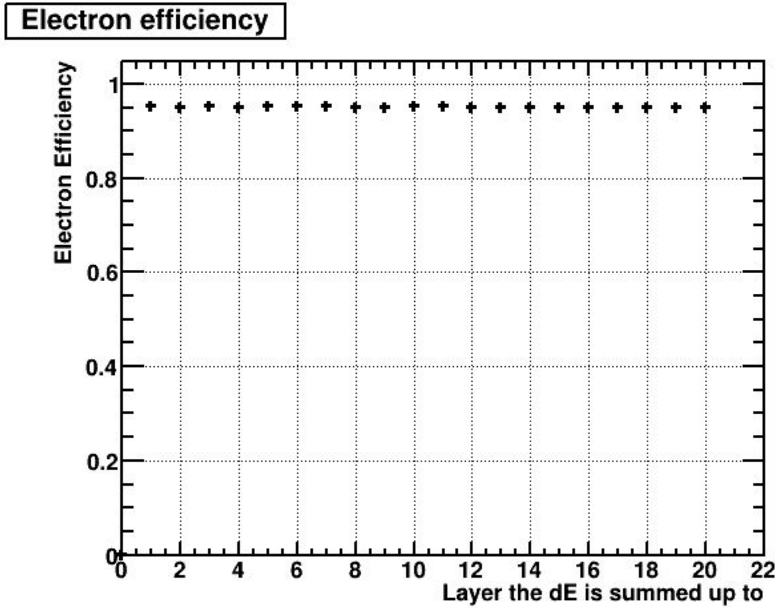
Plots: deposited energy **summed up to** the particular layer

Example for 0.1 GeV



electron/pion PID - cut investigation



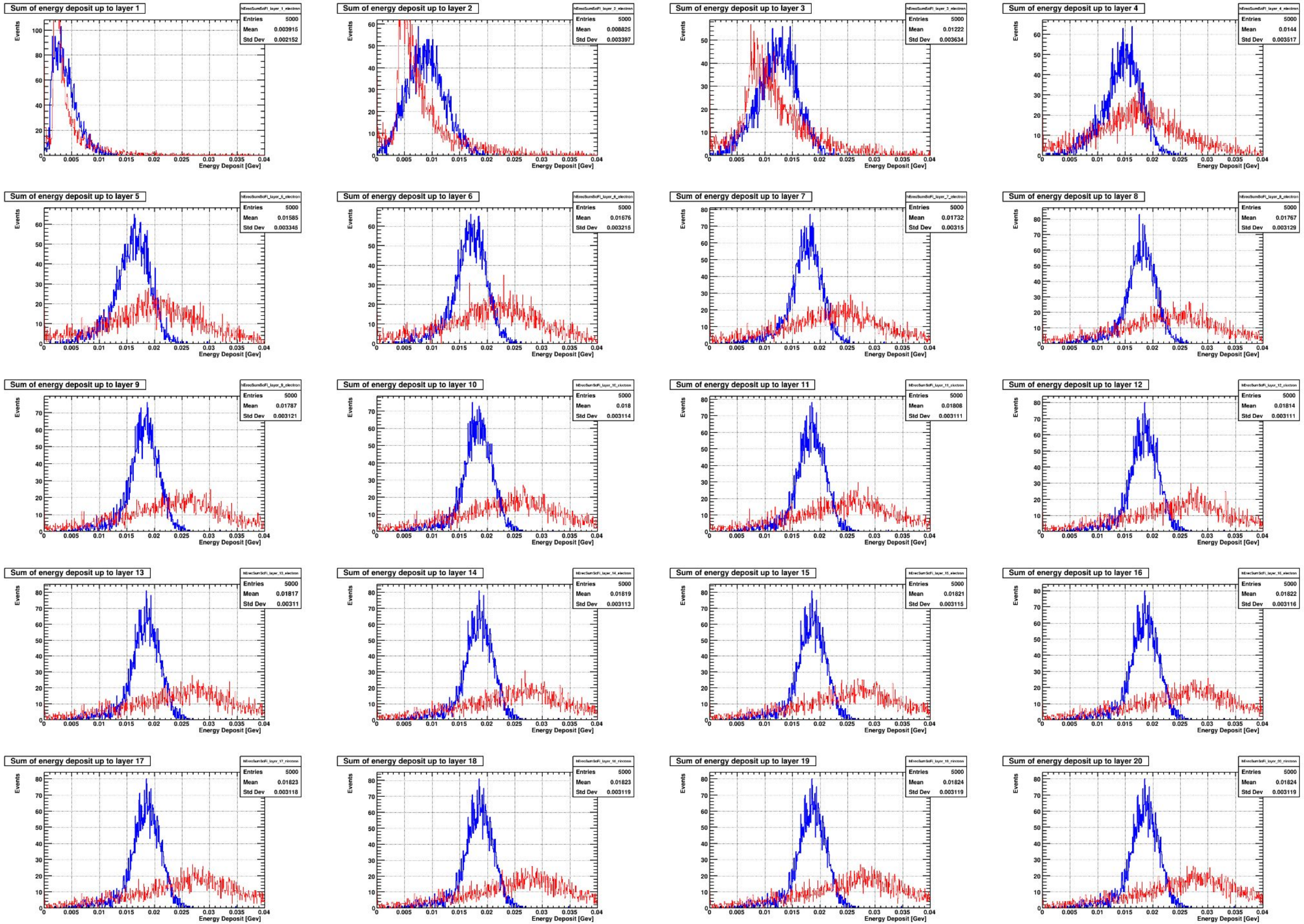


Example for 0.1 GeV

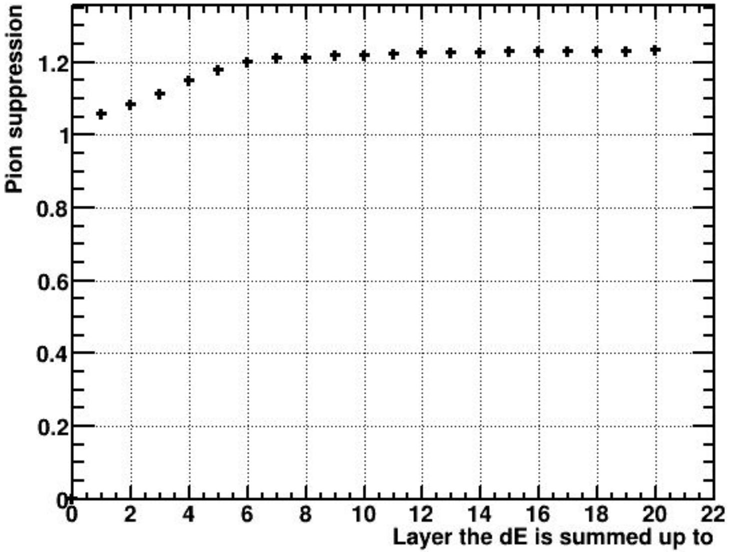
electron/ pion PID

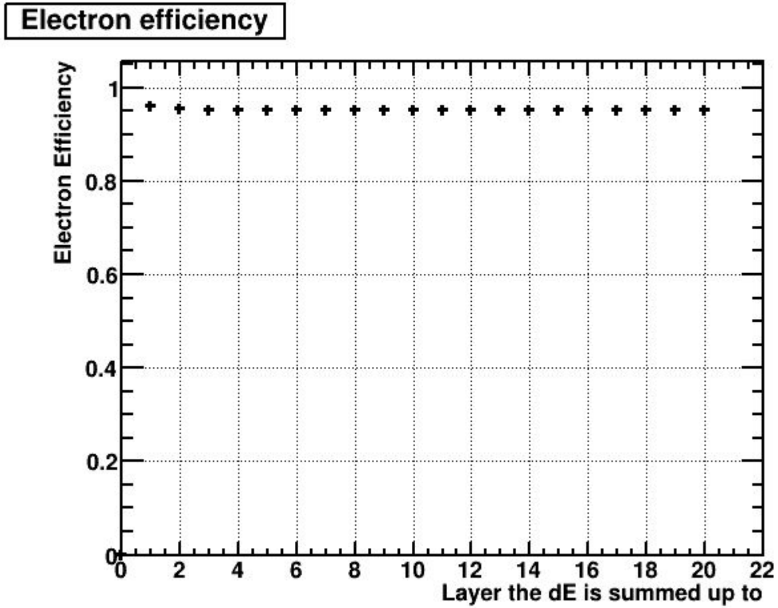
Plots: deposited energy **summed up to** the particular layer

Example for 0.2 GeV



electron/pion PID - cut investigation



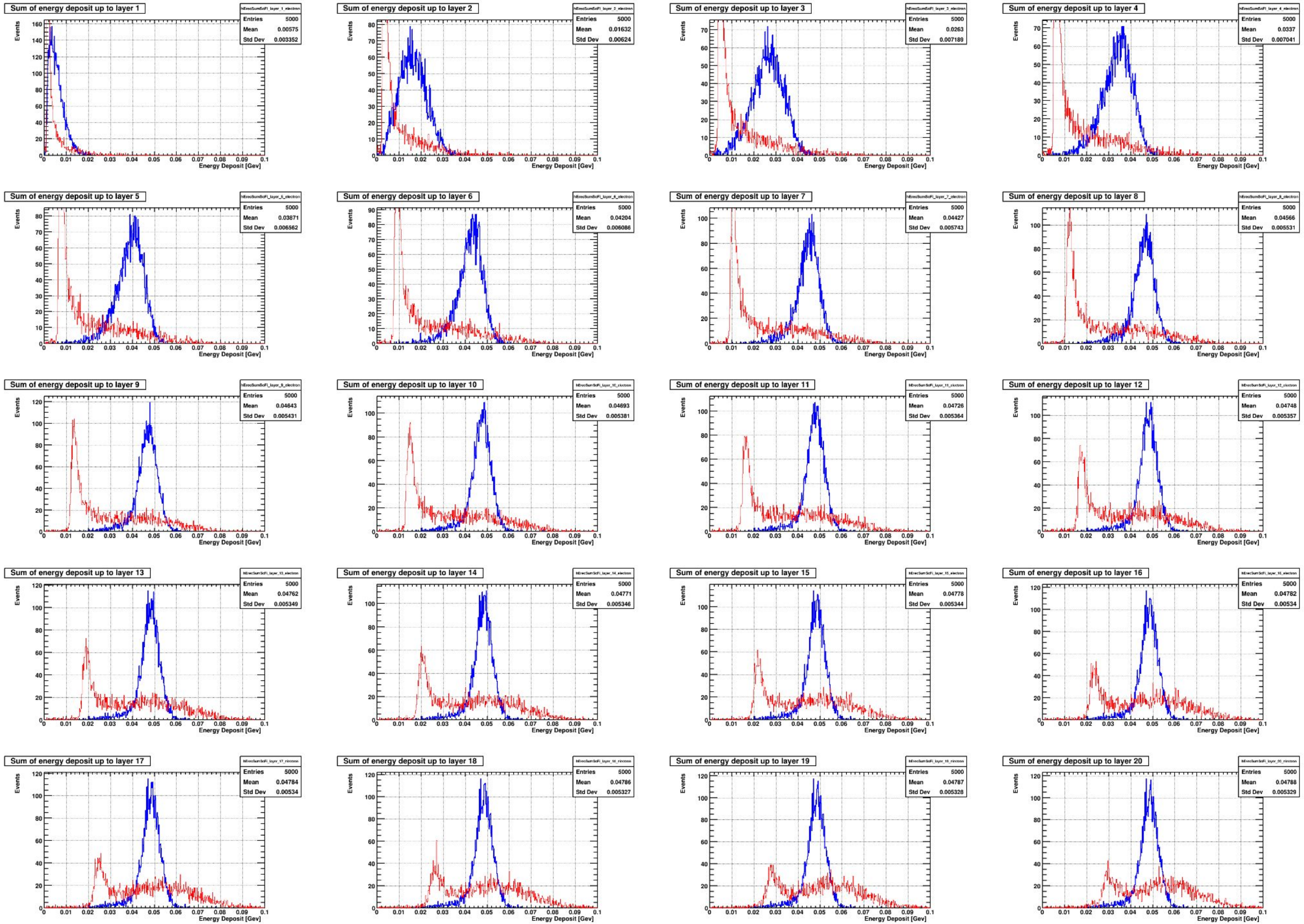


Example for 0.2 GeV

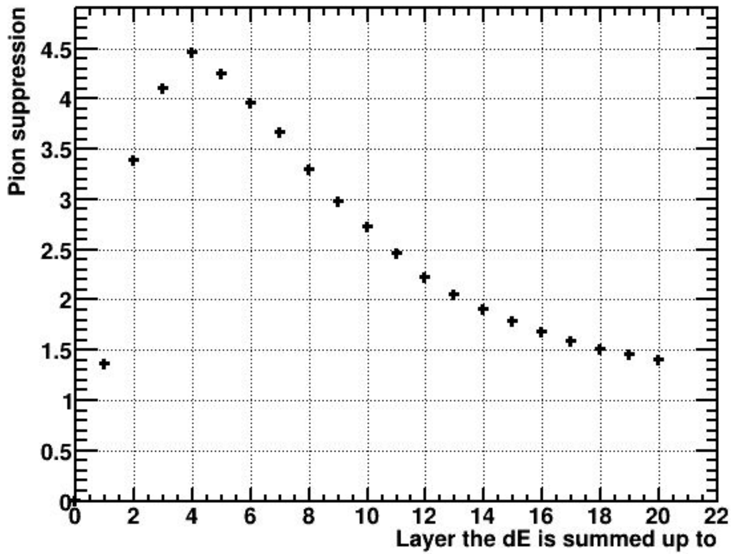
electron/ pion PID

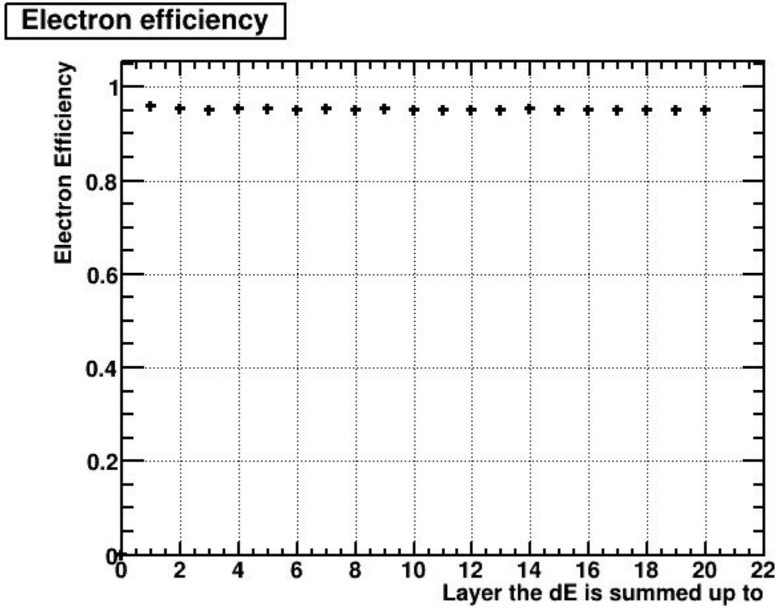
Plots: deposited energy **summed up to** the particular layer

Example for 0.5 GeV



electron/pion PID - cut investigation



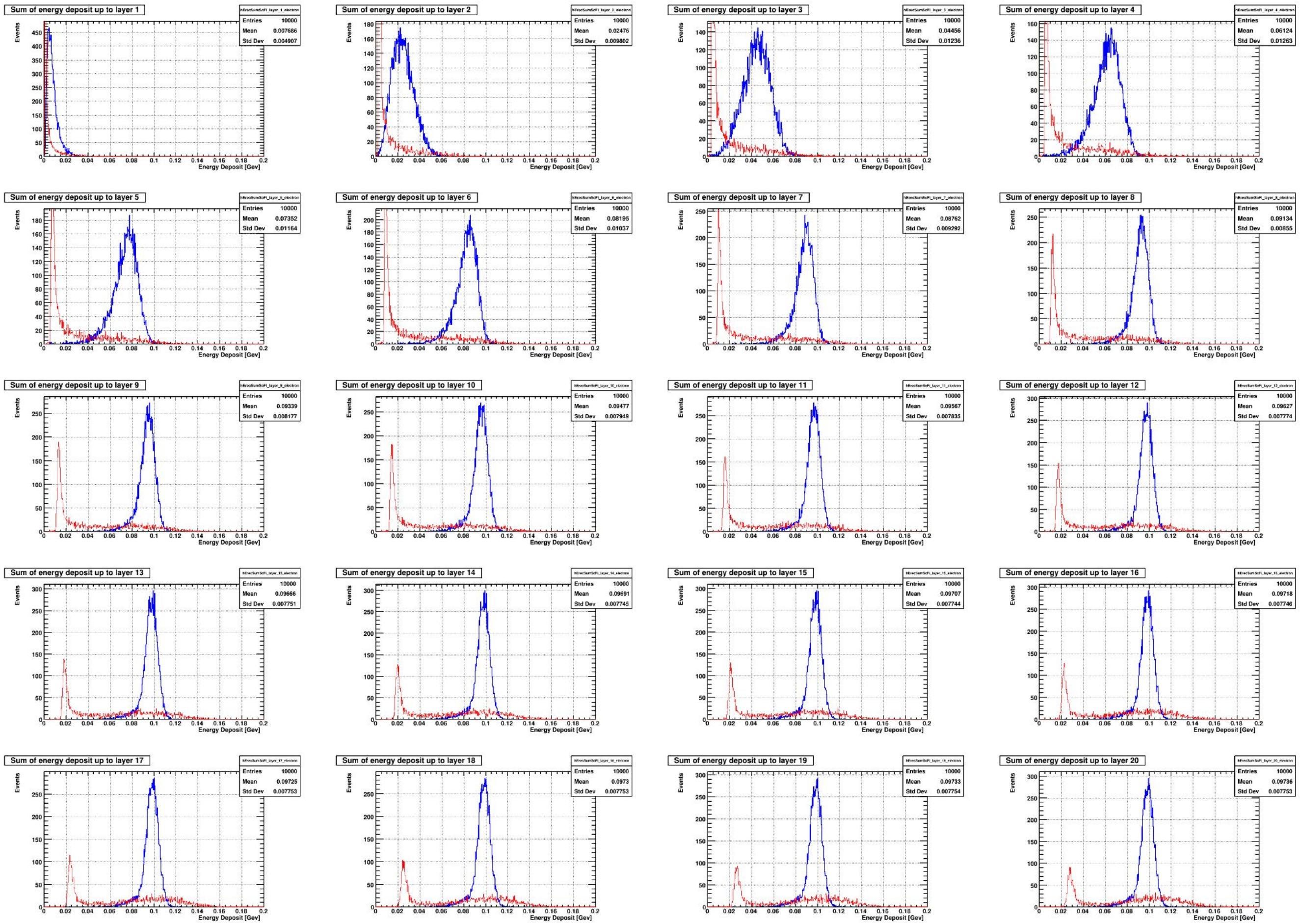


Example for 0.5 GeV

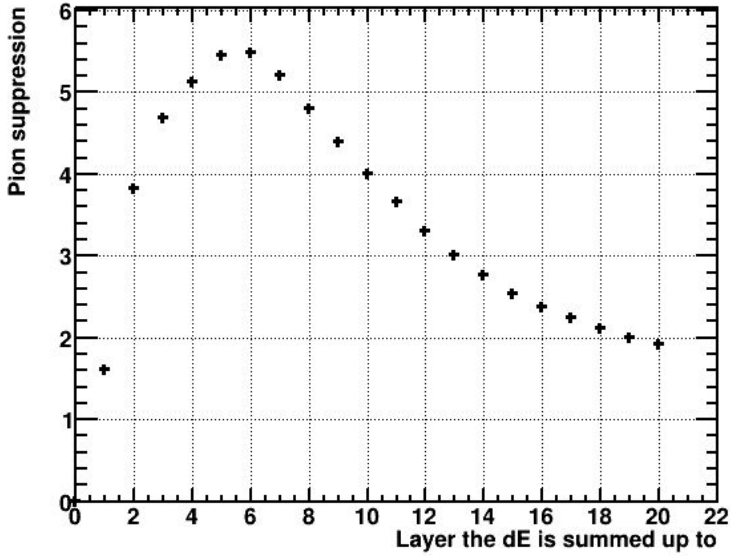
electron/ pion PID

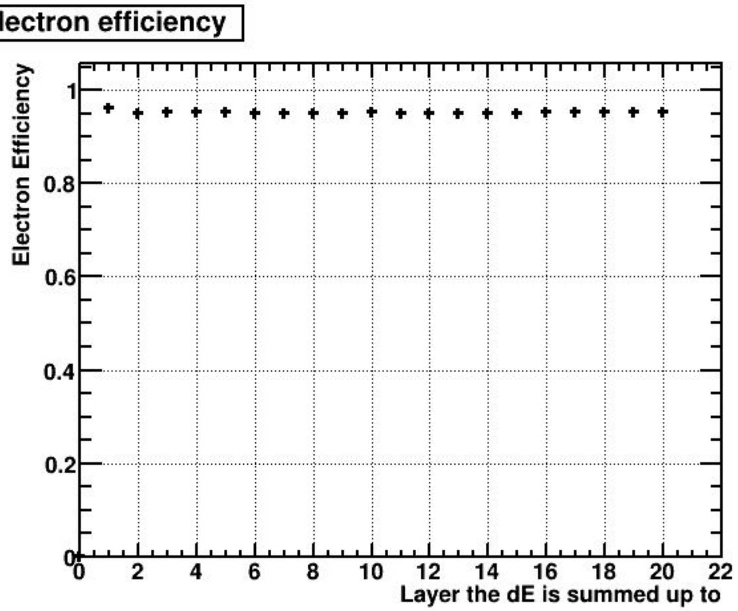
Plots: deposited energy **summed up to** the particular layer

Example for 1 GeV



electron/pion PID - cut investigation



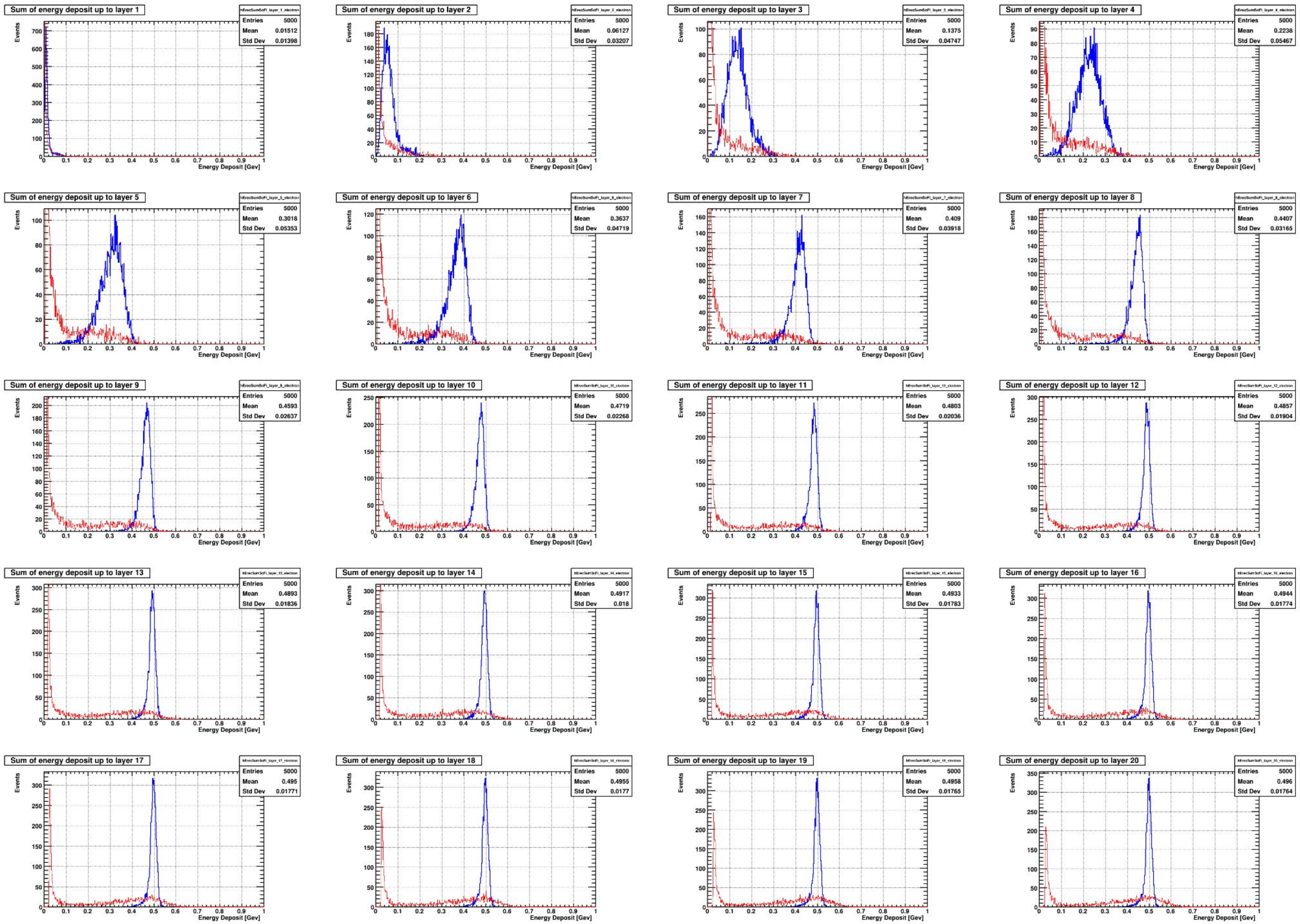


Example for 1 GeV

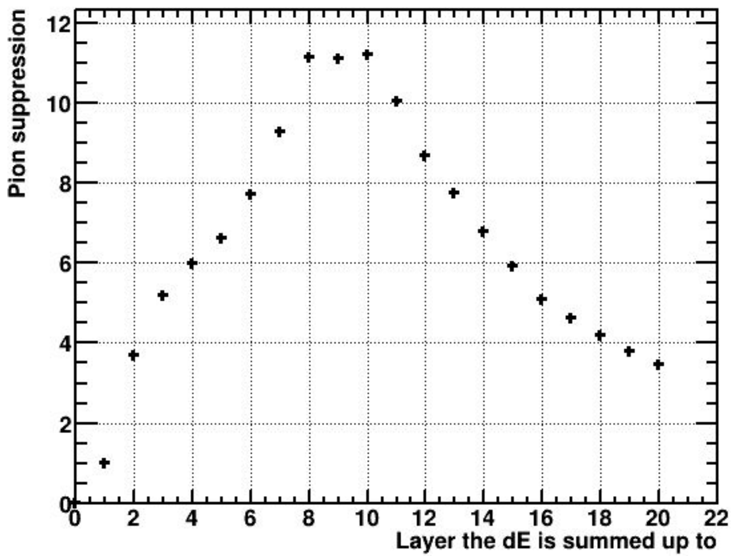
electron/ pion PID

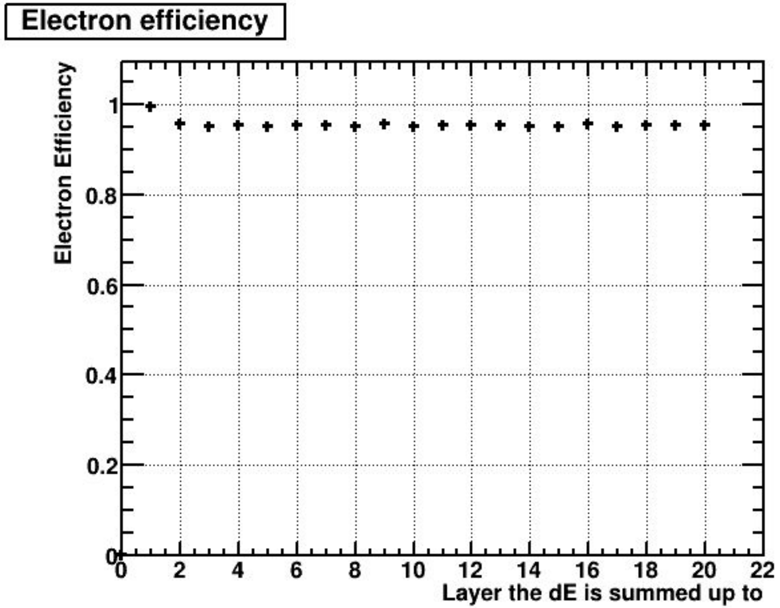
Plots: deposited energy **summed up to** the particular layer

Example for 5GeV



electron/pion PID - cut investigation



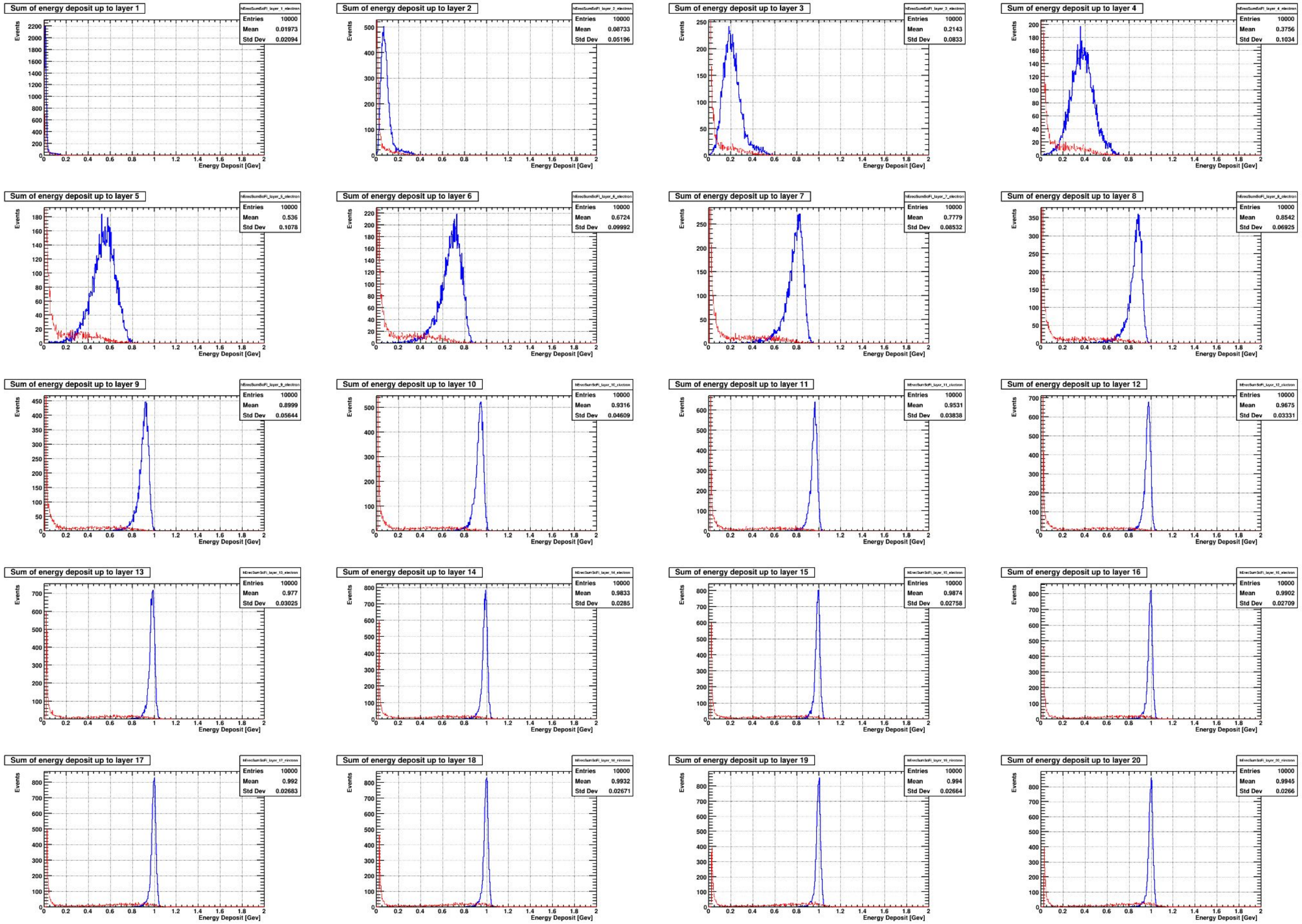


Example for 5 GeV

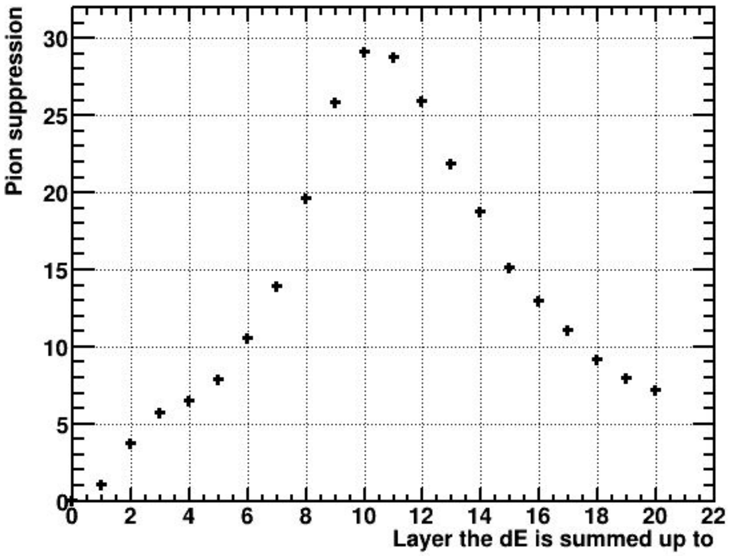
electron/ pion PID

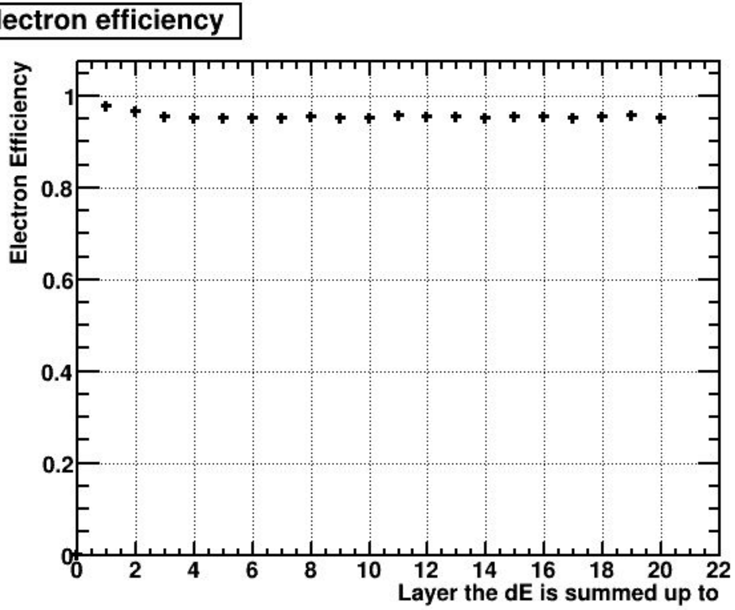
Plots: deposited energy **summed up to** the particular layer

Example for 10 GeV



electron/pion PID - cut investigation





Example for 10 GeV