CEPC AHCAL PID

Use Artificial Neural Network

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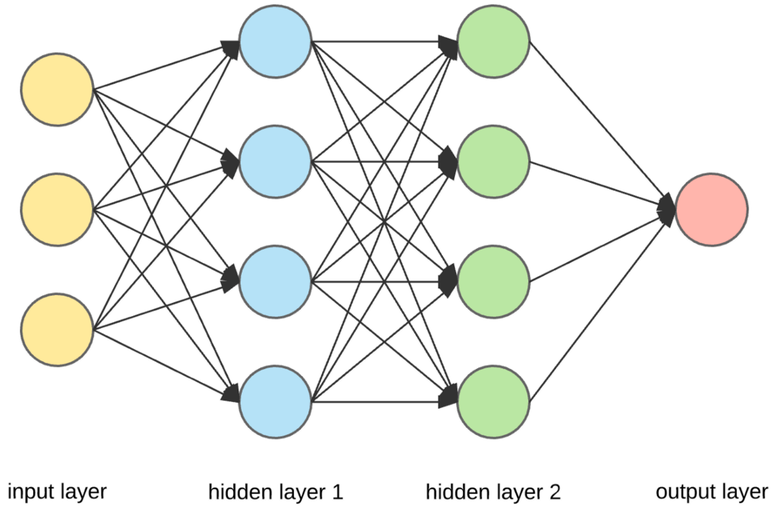
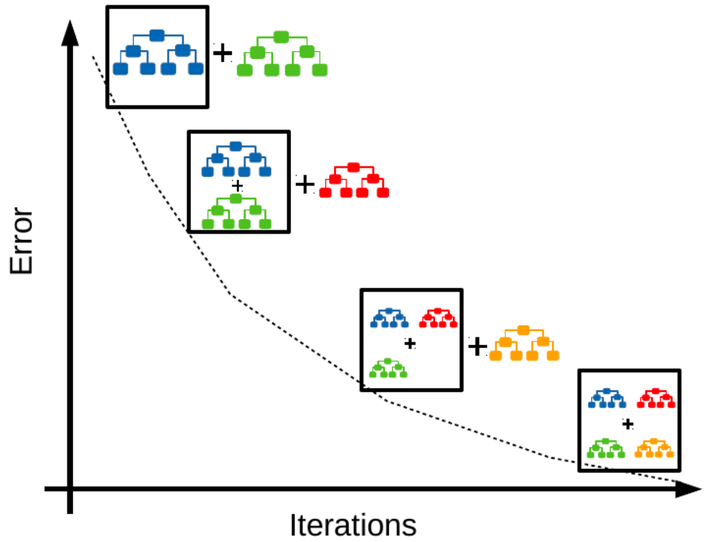
Technical route

- **A**rtificial **N**eural **N**etwork:
  Siyuan SONG



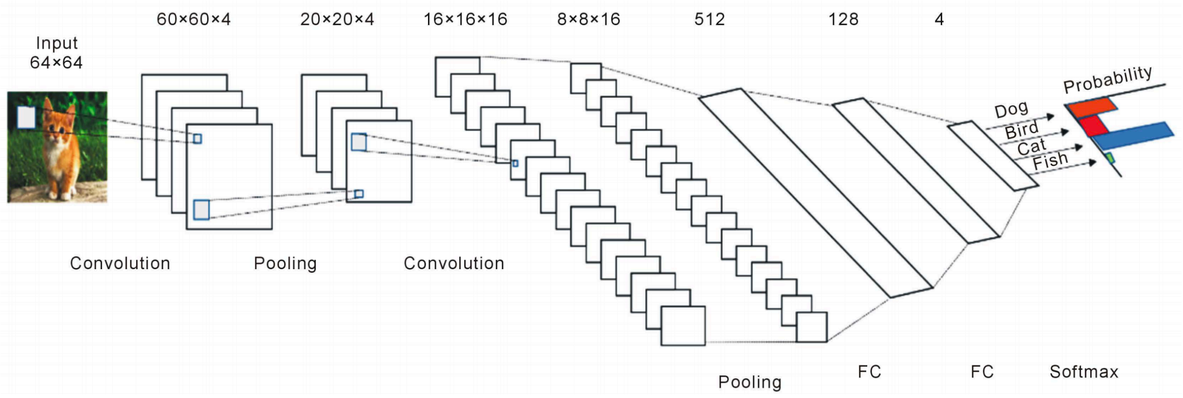
- **B**oosted **D**ecision **T**ree:
  Zhen WANG



ANN Fundamental principle

- Need an Image (Tensor) and a label (Tensor).
- Output could be a normalized Tensor storing several probabilities.
- Net actually is a very complicated function:
  - Output = Net(image, net parameters)
- Lose function would guide optimizing parameters of the net in Gradient Descent way.
  - Loss = L(output, label)

Net



Forward: get classification probability.

Backward: optimize net parameters.

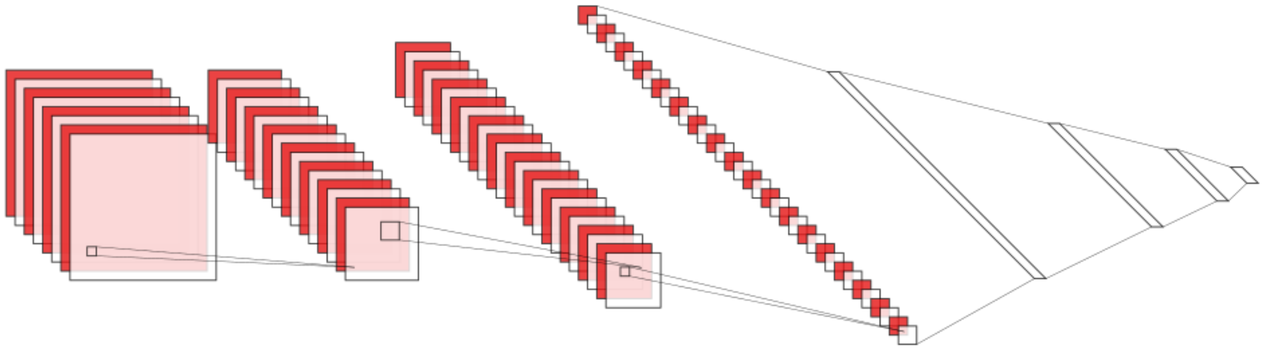
$$L_{\mathrm{CE}} = -\sum_{i=1}^{n} t_i \log(p_i), \quad \text{for n classes,}$$

where t_i is the truth label and p_i is the Softmax probability for the i^{th} class.

Loss function

ANN

- Input: tensor(40, 18, 18), energy deposits.
- Output: tensor(3,), probability.
- 6,660,723 trainable paramaters in Net.



Input Tensor

Output Tensor

Feature Layer

Classification Layer

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1          [-1, 80, 16, 16]          28,880
       BatchNorm2d-2          [-1, 80, 16, 16]             160
            Conv2d-3         [-1, 160, 14, 14]         115,360
       BatchNorm2d-4         [-1, 160, 14, 14]             320
            Conv2d-5          [-1, 320, 5, 5]         461,120
       BatchNorm2d-6          [-1, 320, 5, 5]             640
            Conv2d-7          [-1, 480, 3, 3]       1,382,880
       BatchNorm2d-8          [-1, 480, 3, 3]             960
            Linear-9                [-1, 960]       4,148,160
      BatchNorm1d-10                [-1, 960]           1,920
           Linear-11                [-1, 480]         461,280
      BatchNorm1d-12                [-1, 480]             960
           Linear-13                [-1, 120]          57,720
           Linear-14                  [-1, 3]             363
================================================================
Total params: 6,660,723
Trainable params: 6,660,723
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.05
Forward/backward pass size (MB): 1.00
Params size (MB): 25.41
Estimated Total Size (MB): 26.46
----------------------------------------------------------------
```

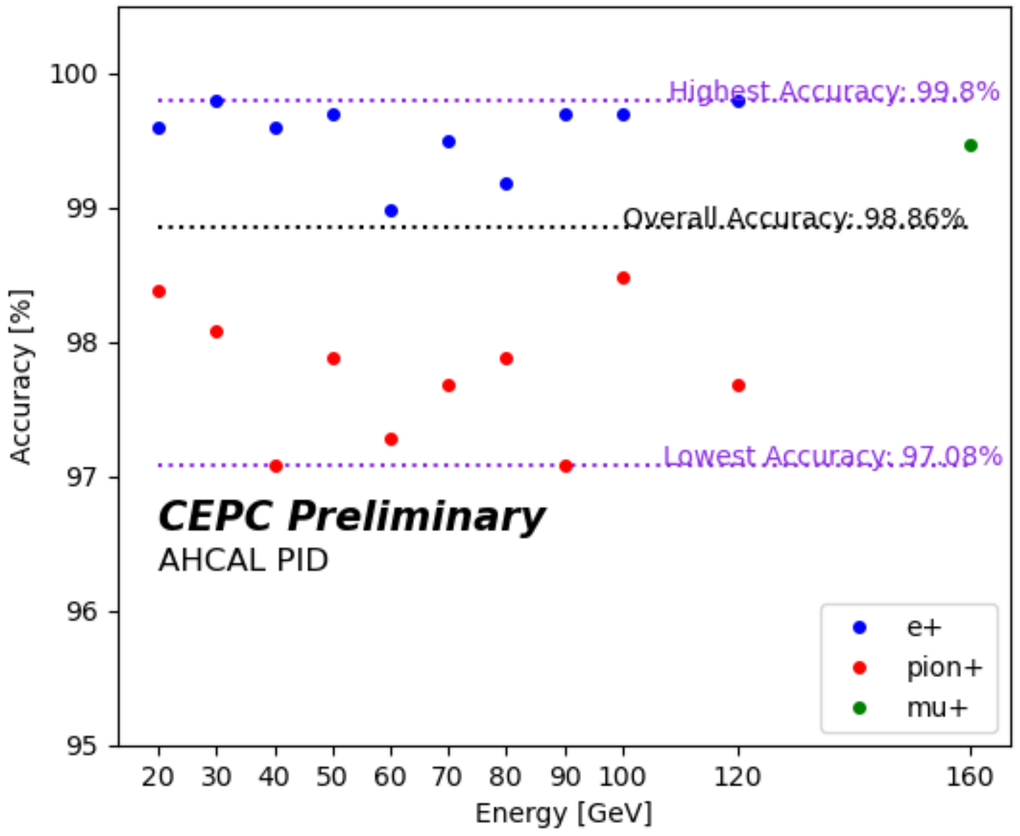
Data preparation

Particle\E (GeV)	20	30	40	50	60	70	80	90	100	120	160	Total	Finished
mu+											100k	100k	100k
e+	10k	10k	10k	10k	10k	10k	10k	10k	10k	10k		100k	100k
pion+	10k	10k	10k	10k	10k	10k	10k	10k	10k	10k		100k	100k

- Train set: Validation set: Test set = 8 : 1 : 1.
- Source: Geant4 simulation data, provided by Zixun XU.

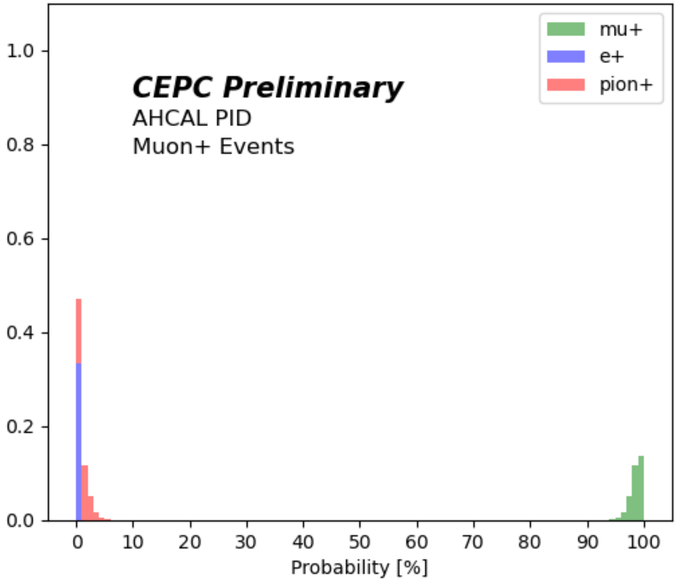
Preliminary results

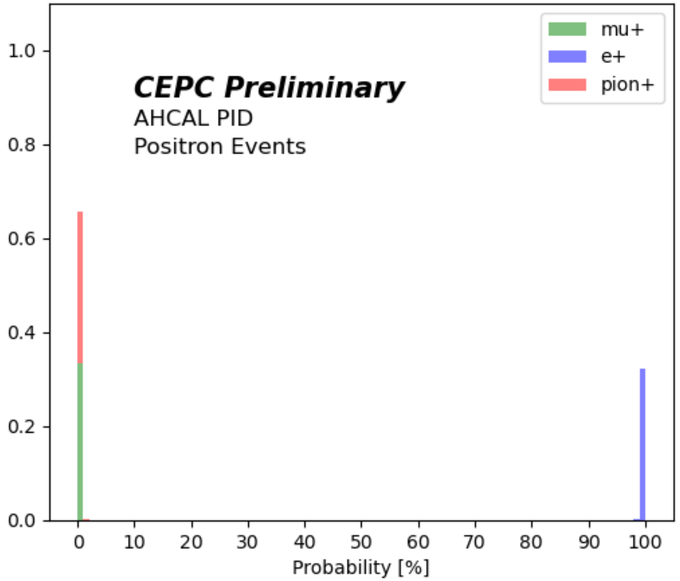
- Reached an encouraging overall accuracy: 98.86%.
- Each energy point: 1000 Events.
- e+ and muon+ can be classified with higher accuracy.
- pion+ events identification get a relative lower accuracy, but still > 97.08%.

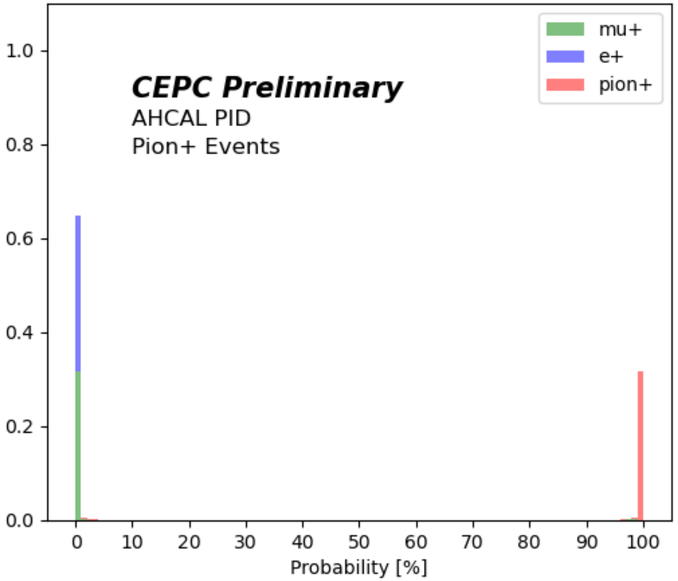


Preliminary results

- Net output probability distribution.
- Each kind of particle: 10,000 Events.
- From left to right, incident particles are Muon+, Positron+, and Pion+.
- The distinction is obvious.

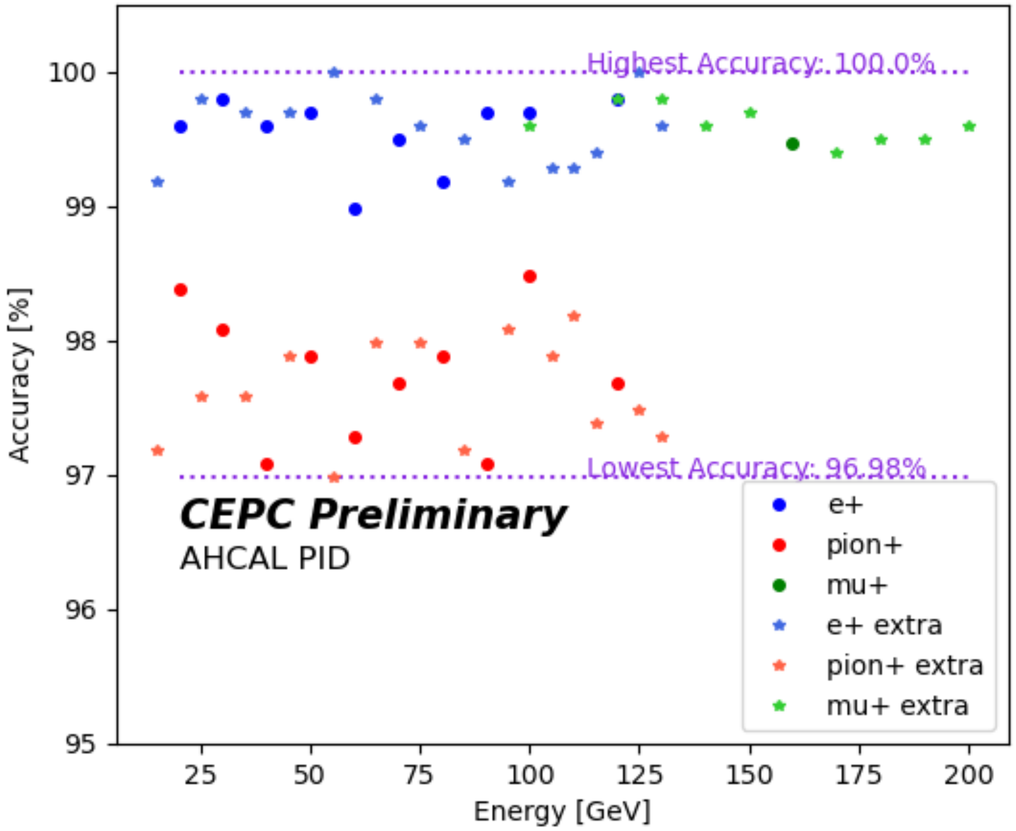






Preliminary results

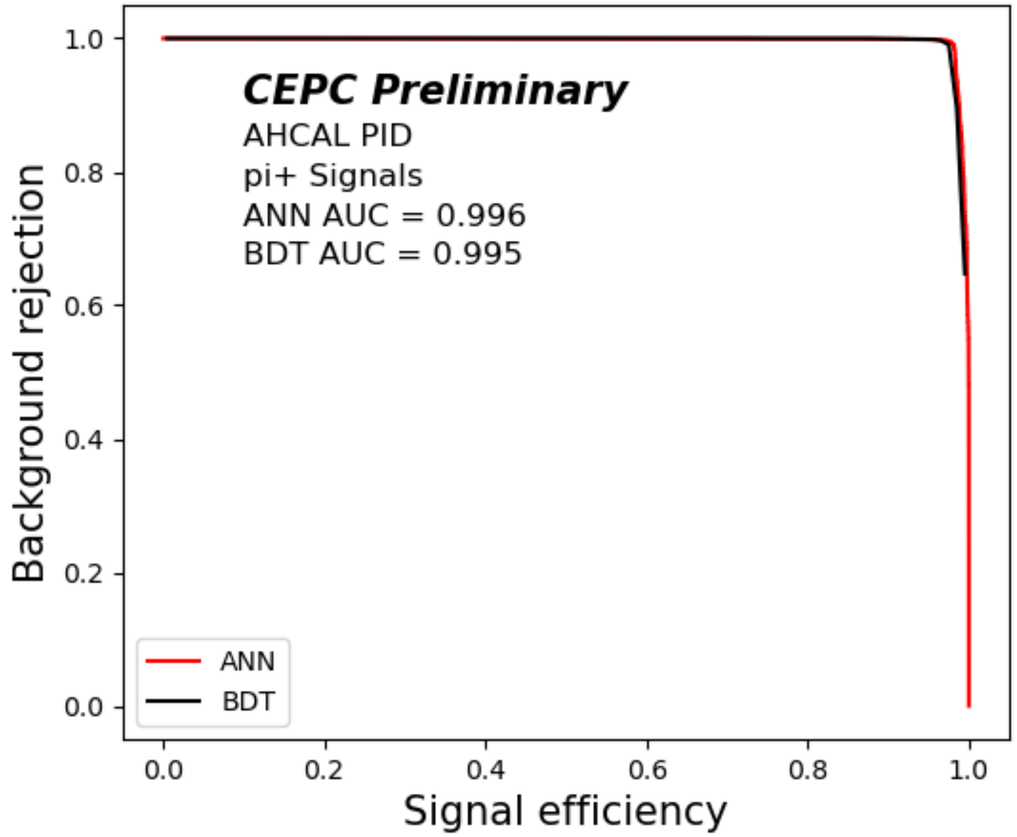
- Include muon+, e+, pion+ events with extra energy.
- Each energy point: 1000 Events.
- This net could still identify “unseen” particles.
  - e+: 15, 25, 35, 45, 55, 65, 75, 85, 95, 105, 110, 115, 125, 130 GeV.
  - pion+: 15, 25, 35, 45, 55, 65, 75, 85, 95, 105, 110, 115, 125, 130 GeV.
  - muon+: 100, 120, 130, 140, 150, 170, 180, 190, 200 GeV.



Preliminary results

ANN vs BDT

- Their ROC curve is very close in Pi+ signals.
- AUC stands for "Area under the ROC Curve.” Classifier is better if AUC is closer to 1.
- ANN AUC = 0.996 , when signal: Pi+, background: e+ & mu+ .



BDT ROC is provided by Zhen WANG.

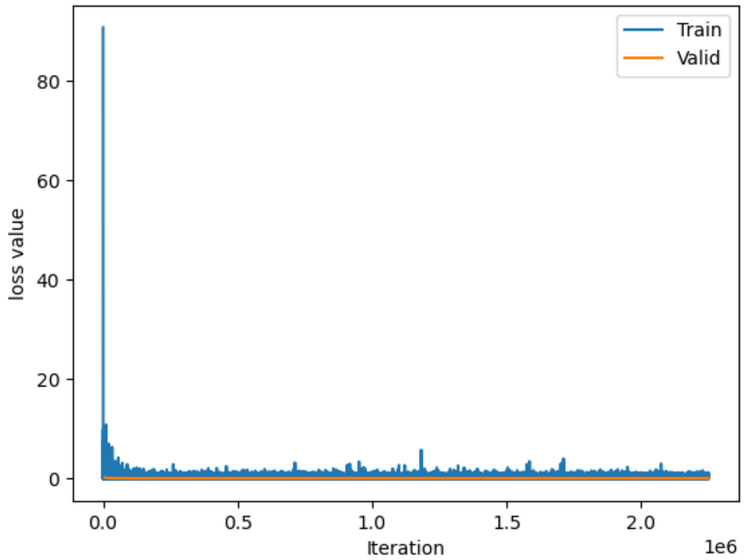
Ref: Park S H, Goo J M, Jo C H. Receiver operating characteristic (ROC) curve: practical review for radiologists[J]. Korean journal of radiology, 2004, 5(1): 11-18.

Future plan & Conclusion & Reflection

- Overall accuracy reached 98. 86%, ANN $\mathrm{AUC}_{\pi_{\mu e}}$ reached 0.996.
- Tune hyper-parameters; Optimize ANN structure.
- Compare with BDT method.
- Add ANN PID module into EventDisplay tool: PyShow.

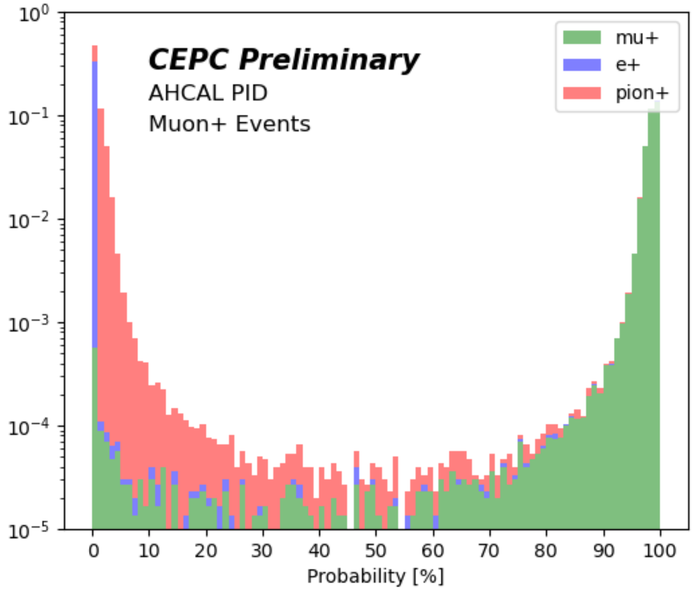
Backup

- Code: https://github.com/Tom0126/CEPC-AHCAL-PID.git

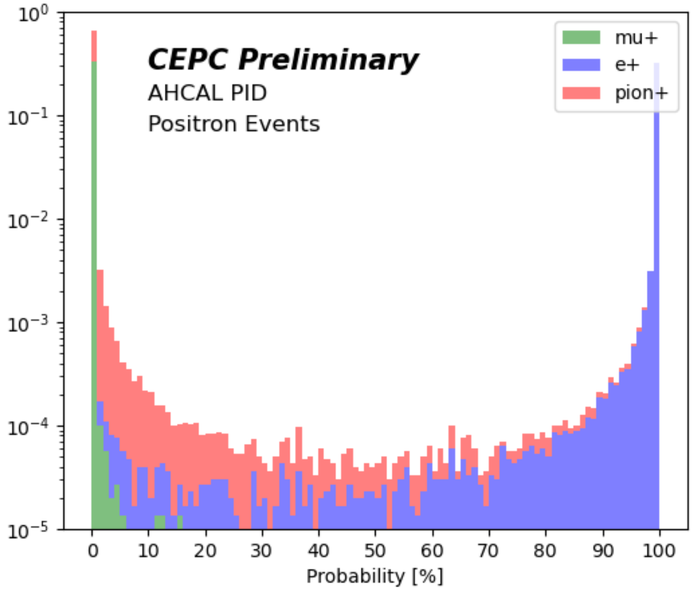


Loss function

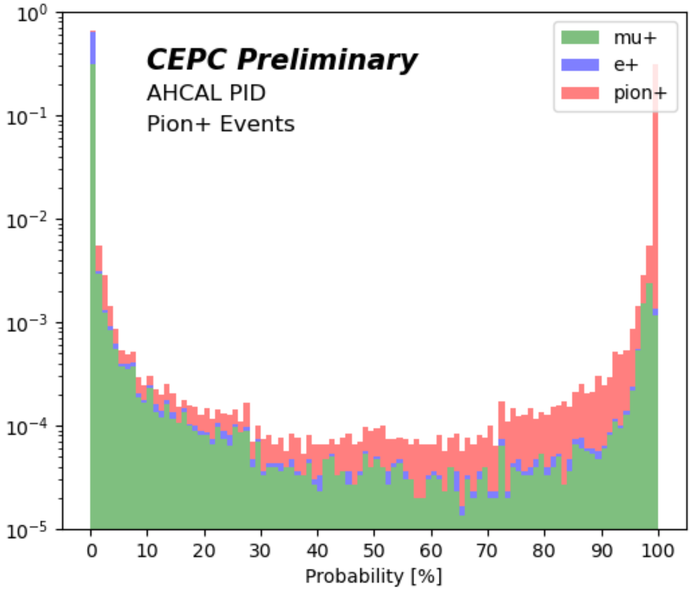
Backup



mu+



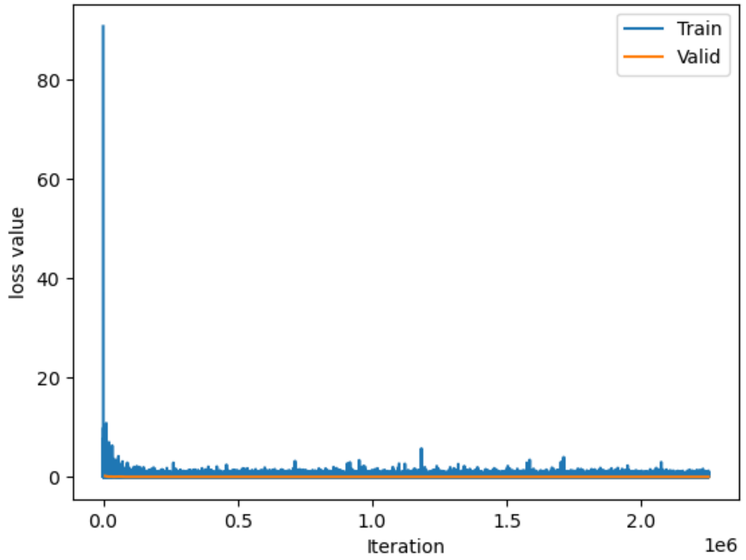
e+



pi+

Log scale

Backup



Loss function