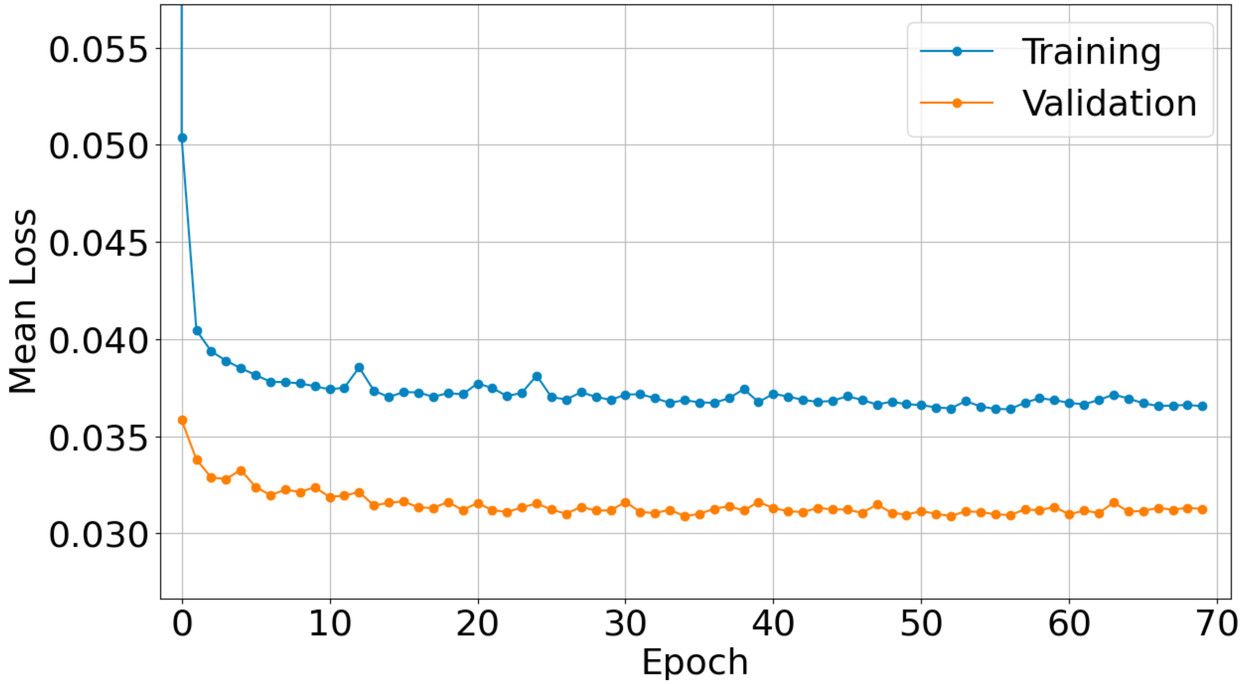
DNNROI for ProtoDUNE-HD

DNN ROI Training

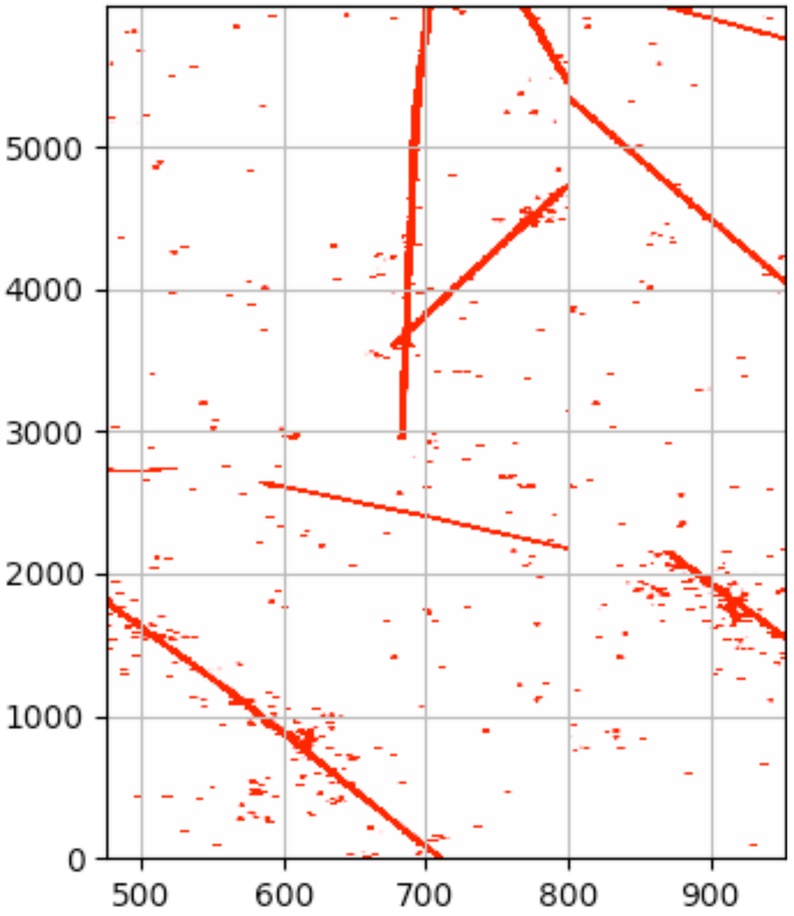
- 400 cosmic events in PDHD (80/20 %training/validation split)
- Loss: cross entropy
- Optimizer: Stochastic Gradient Descent with momentum
- Platform: I9-9900K, 32 GB memory, Nvidia GTX 2080 Ti 11GB, Samsung 970 500GB NVMe SSD [~5h]



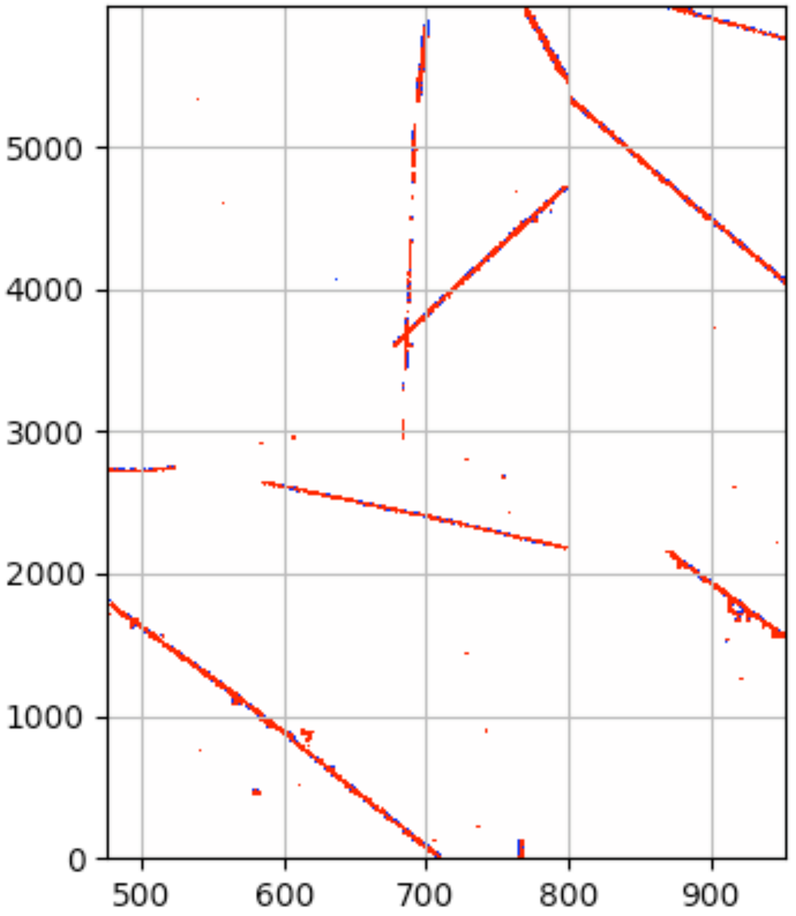
Cosmic event

Clear improvement
for prolonged cosmic track

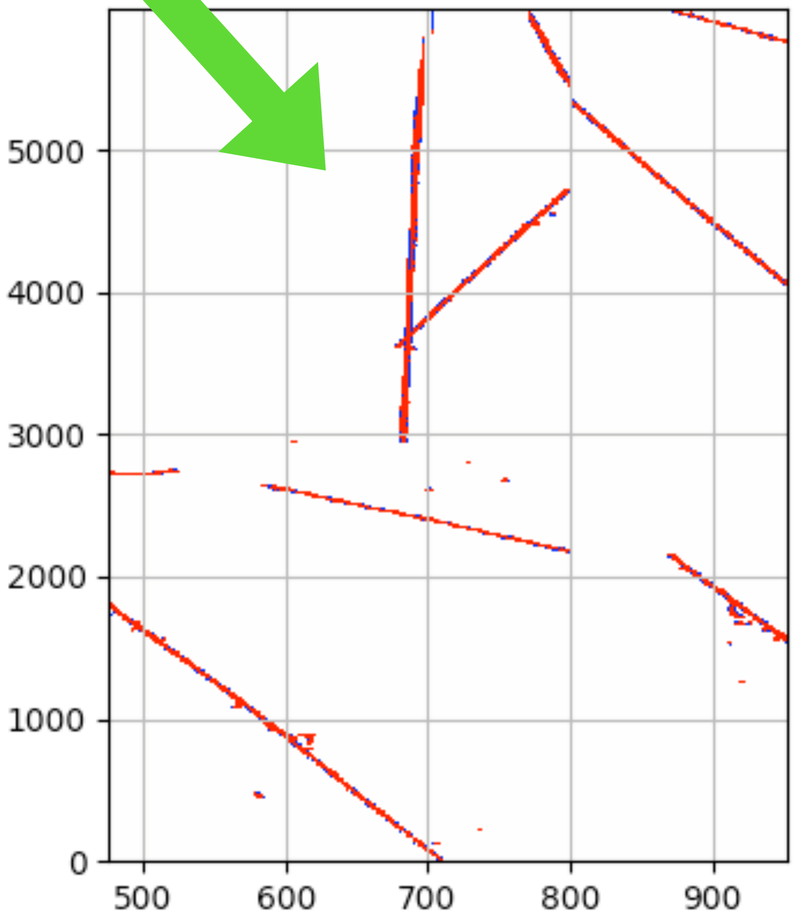
True Info



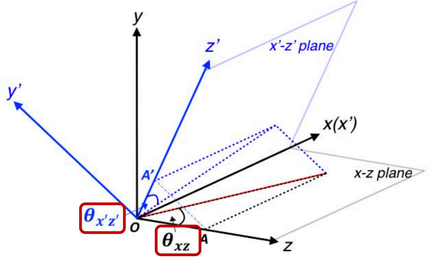
Standard ROI



DNN ROI



Pixel Efficiency/Purity



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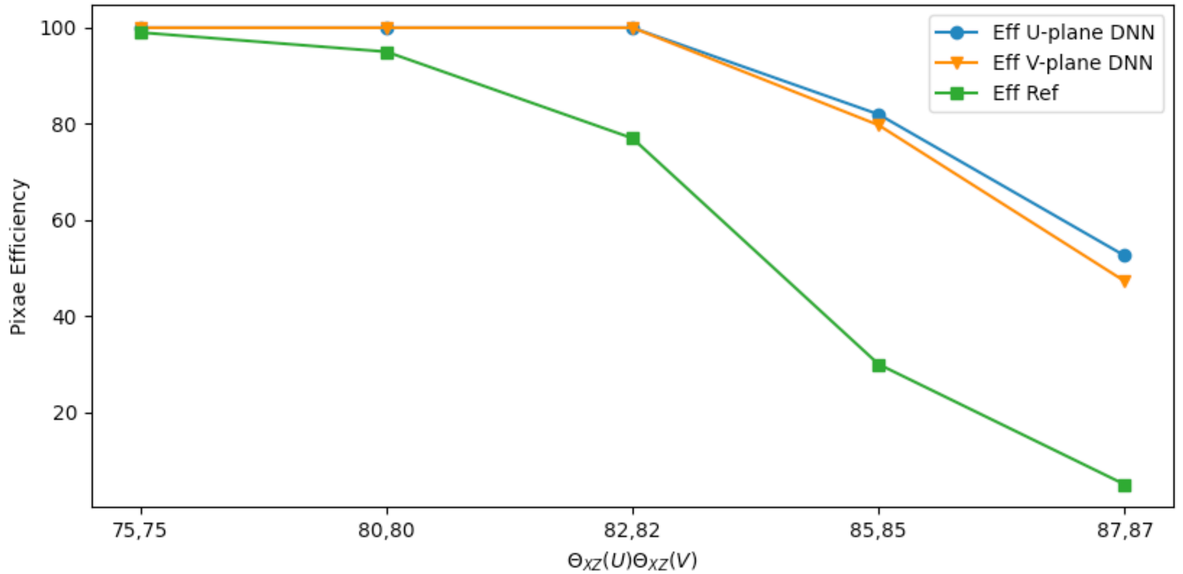
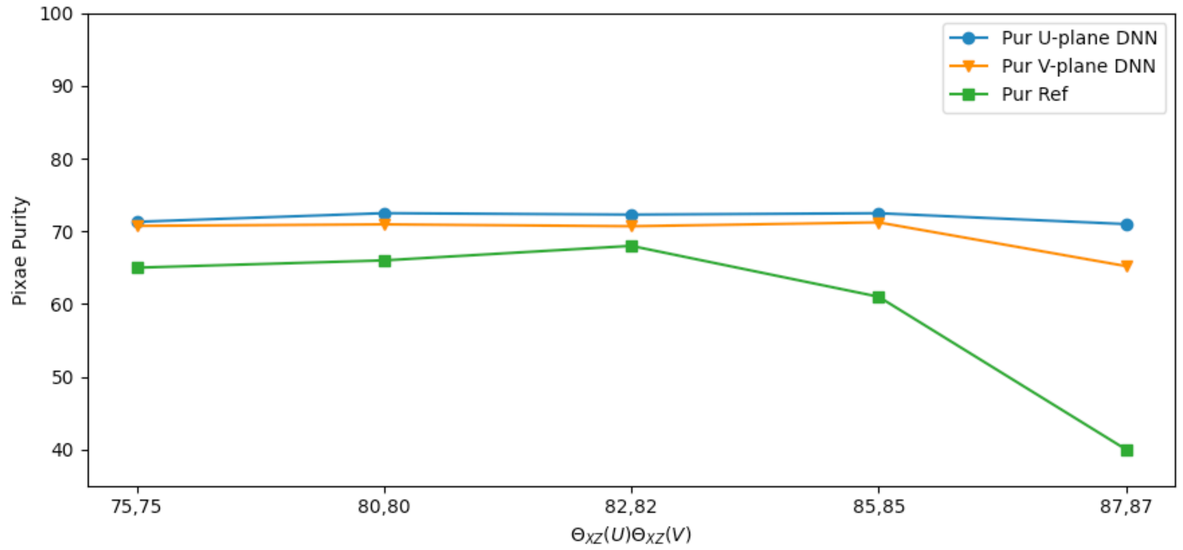
- Test for ideal tracks (1 per event)
- Evaluate network performance using :

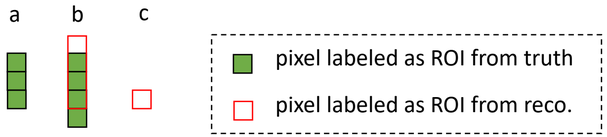
- $Pixel\ Eff. = \frac{\#\ of\ correctly\ abeled\ pixels}{\#\ of\ pixels\ from\ Truth}$
- $Pixel\ Pur. = \frac{\#\ of\ correctly\ labeled\ pixels}{\#\ of\ pixels\ from\ Reco}$



- Similar performance for lower angled tracks between DNN and reference approach
- DNN performs better for higher angled tracks



pixel based evaluation:
eff = (0 + 3 + 0)/(0+3+4) = 3/7
purity = (0 + 3 + 0)/(0+4+1) = 3/5

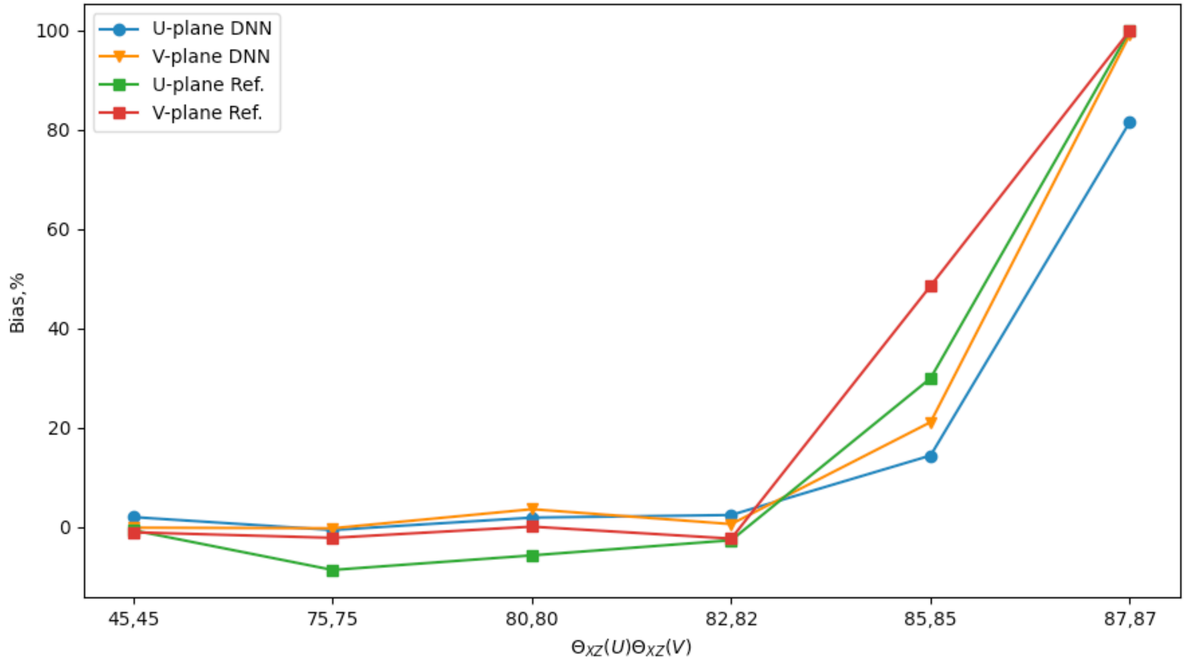


Charge bias

- Bias is 50% quantile of distribution : $100 * (\frac{q_{true} - q_{reco}}{q_{true}})$ per channel [only count channels with charge]

- Thresholding in ROI finding is major source of charge bias: signal loss can occur due to its exclusion from the final ROI window

- Larger bias in large angle tracks (as expected)

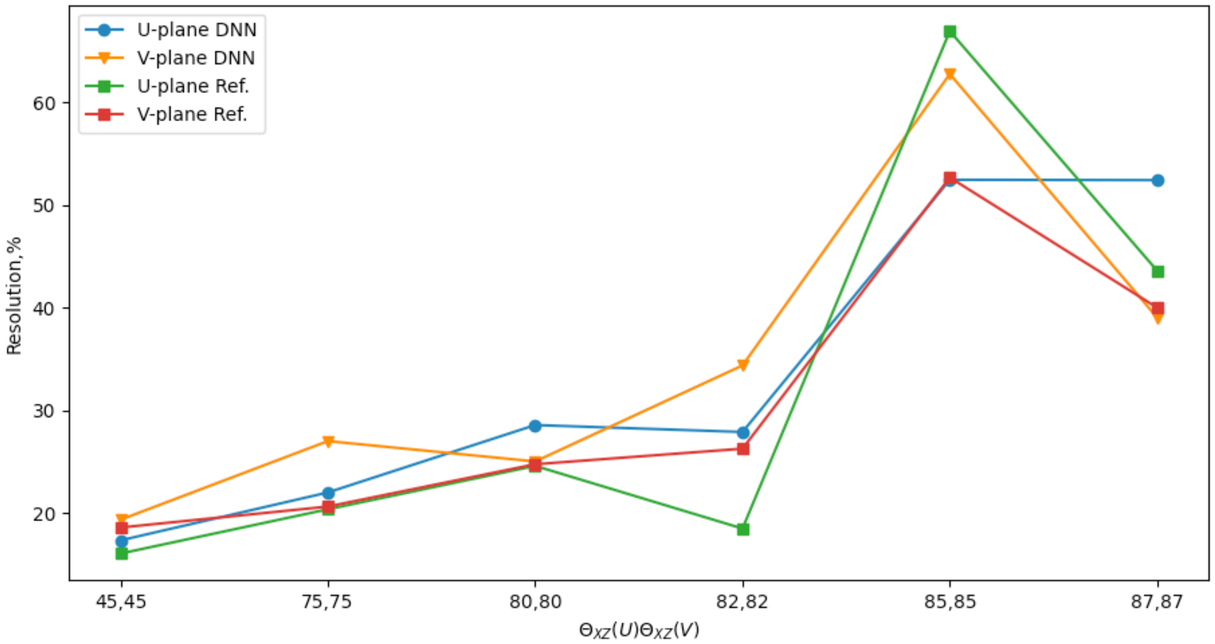


Charge Resolution

- Resolution also drawn from distribution $100 * (\frac{q_{true} - q_{reco}}{q_{true}})$ per channel based on difference between 50% 16%, and 84% quantiles [only count channels with charge]

- electronics noise is the main contributor to the charge resolution

- worse resolution in large angle tracks (as expected)

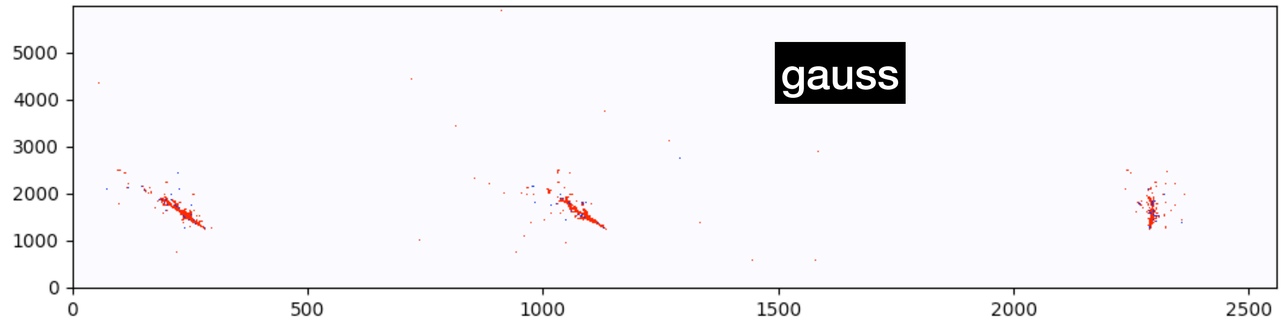


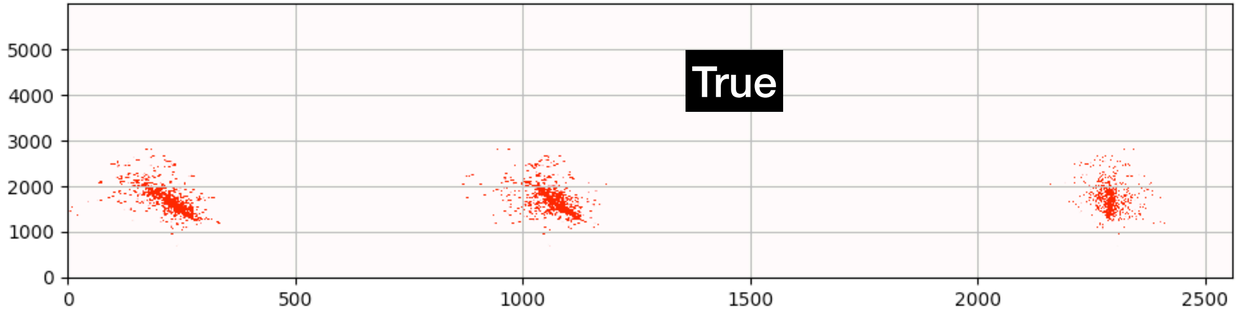
Evaluate showers

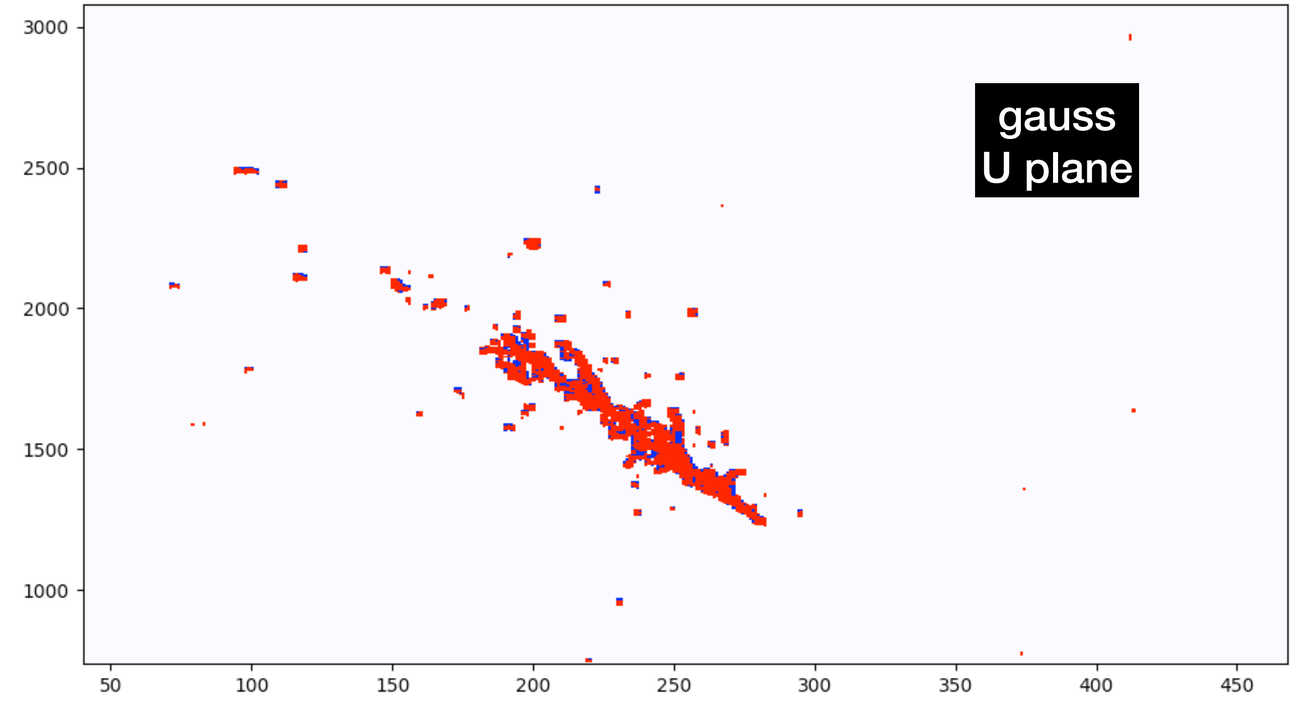
- Check total activity per plane for a single e- simulated in the ~middle of the detector, uniform direction 360 deg. , 1.5GeV, 200 events
- Evaluate on total activity in the event per plane
- Improved bias/resolution with DNN

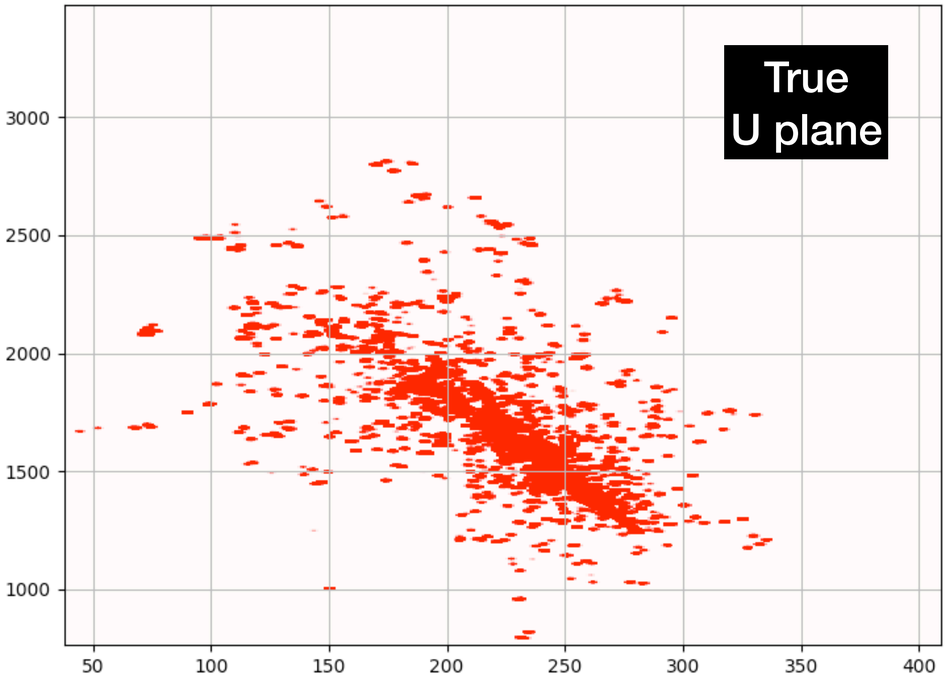
```
U-plane DNN
Bias :  3.2531172037124634
Res :  1.0607194325820335
U-plane Ref
Bias :  8.886434137821198
Res :  3.4793286288036436
V-plane DNN
Bias :  3.1423281878232956
Res :  0.9601534402902031
V-plane Ref
Bias :  10.18589660525322
Res :  3.8509887514298633
W-plane DNN
Bias :  1.203310489654541
Res :  0.4904098169962505
W-plane Ref
Bias :  1.203310489654541
Res :  0.4904098169962505
```

Electron

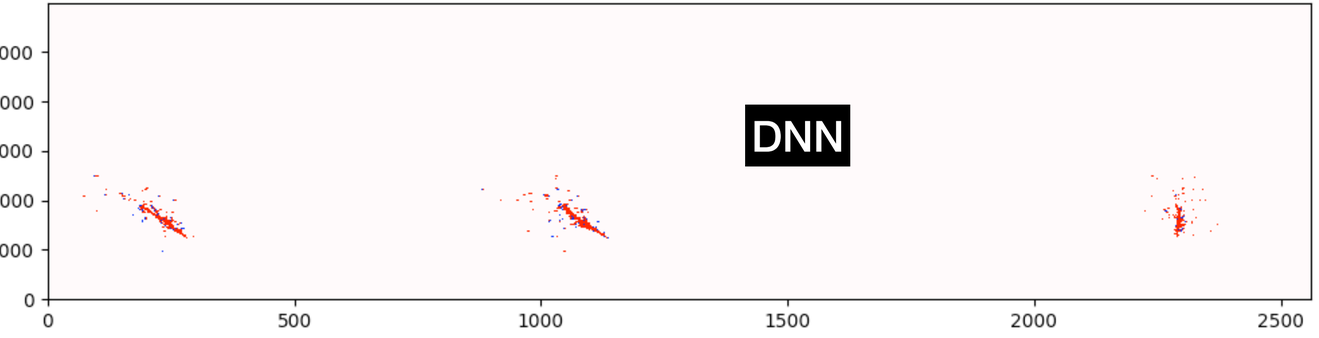

gauss
5000
4000
3000
2000
1000
0
0
500
1000
1500
2000
2500

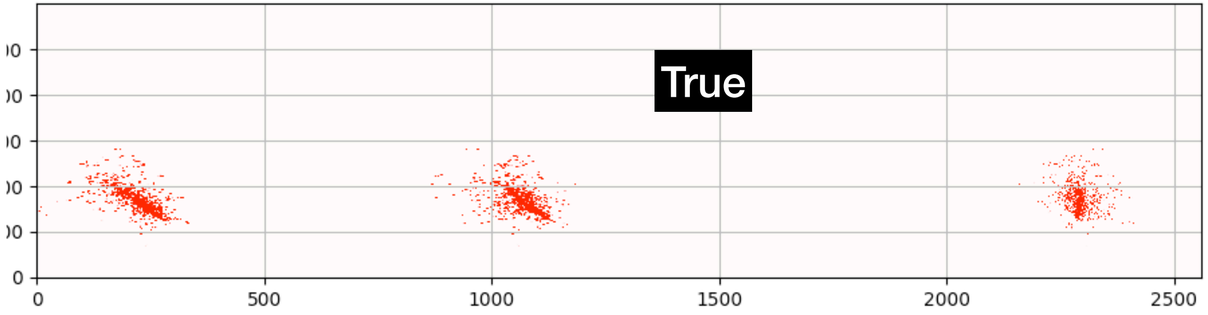

True
5000
4000
3000
2000
1000
0
0
500
1000
1500
2000
2500

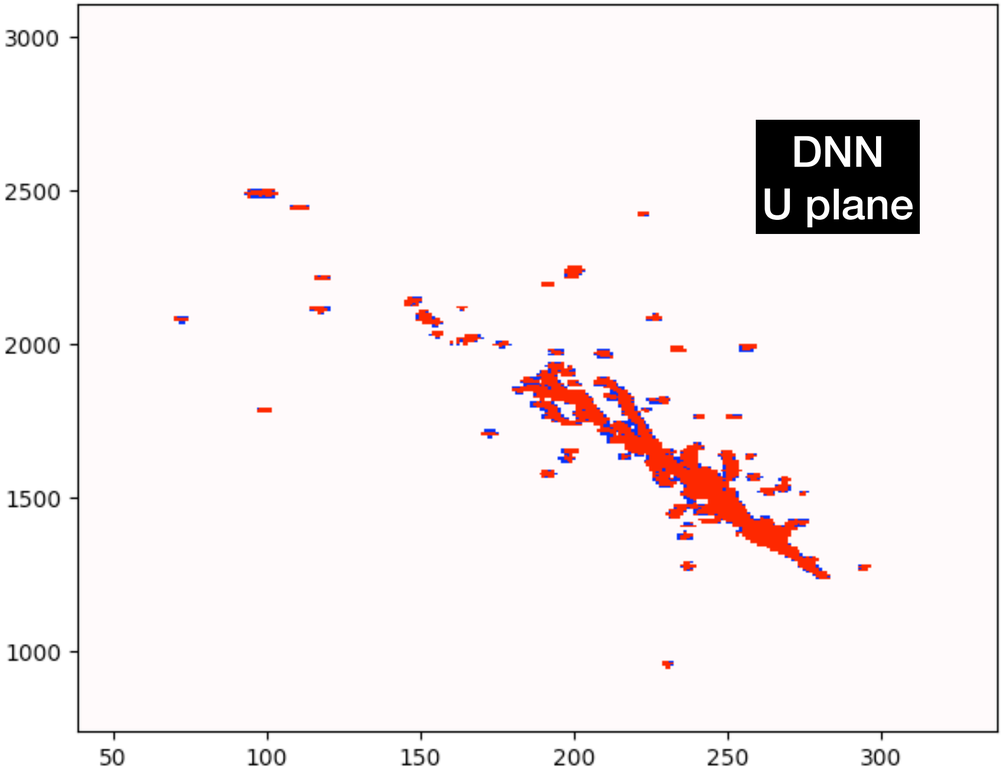

gauss
U plane
3000
2500
2000
1500
1000
50
100
150
200
250
300
350
400
450

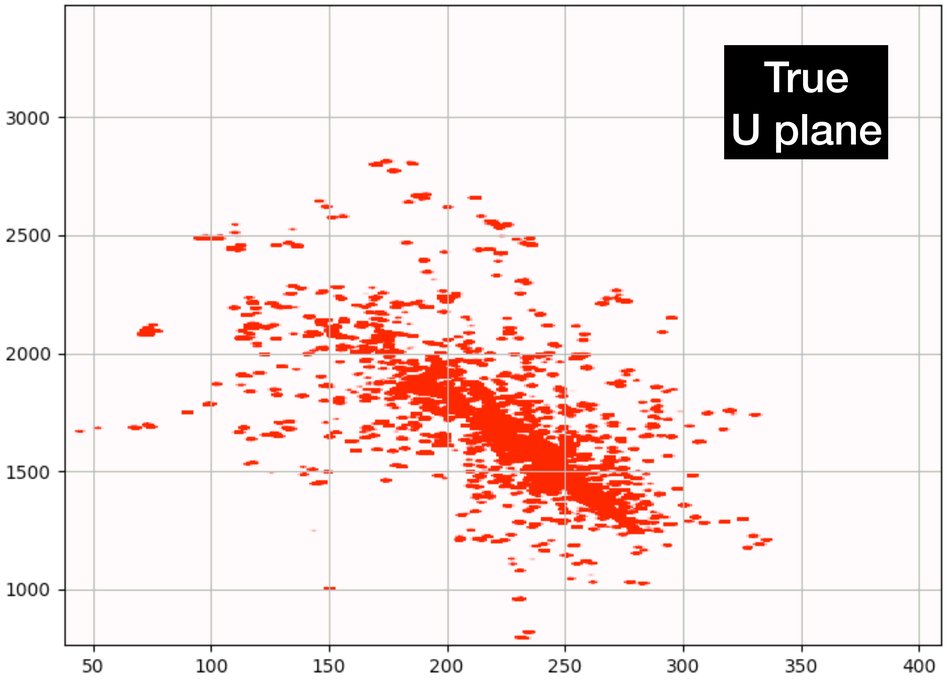

True
U plane
3000
2500
2000
1500
1000
50
100
150
200
250
300
350
400

Electron


DNN
0
500
1000
1500
2000
2500


True
0
500
1000
1500
2000
2500


DNN
U plane
3000
2500
2000
1500
1000
50
100
150
200
250
300


True
U plane
3000
2500
2000
1500
1000
50
100
150
200
250
300
350
400

Evaluate showers

- Retrain with 400 cosmic and 200 single electron events
- All electrons are 1.5GeV starting at center of the detector with uniform angular distribution
- Performance comparison for single e- decreased?

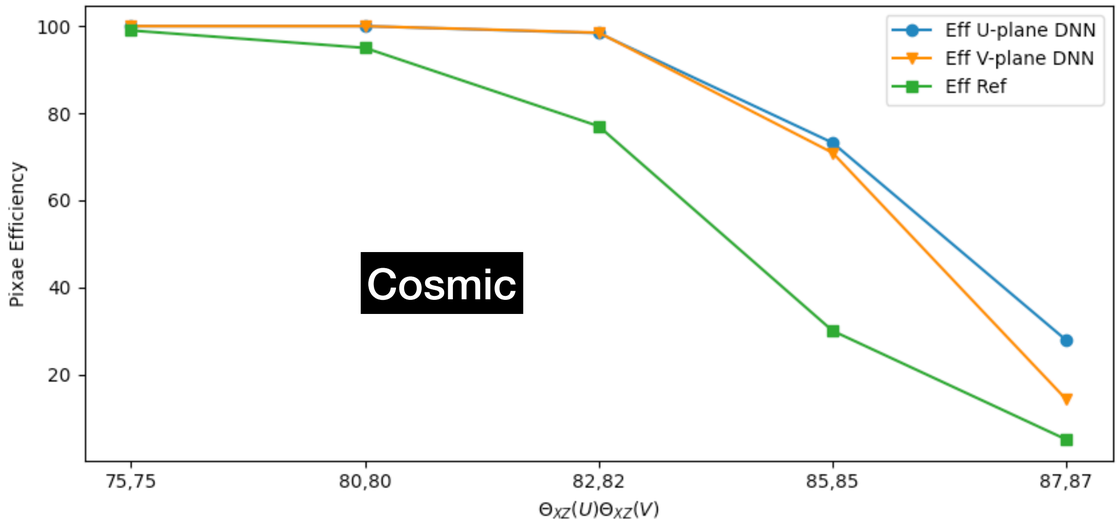
With e- in training

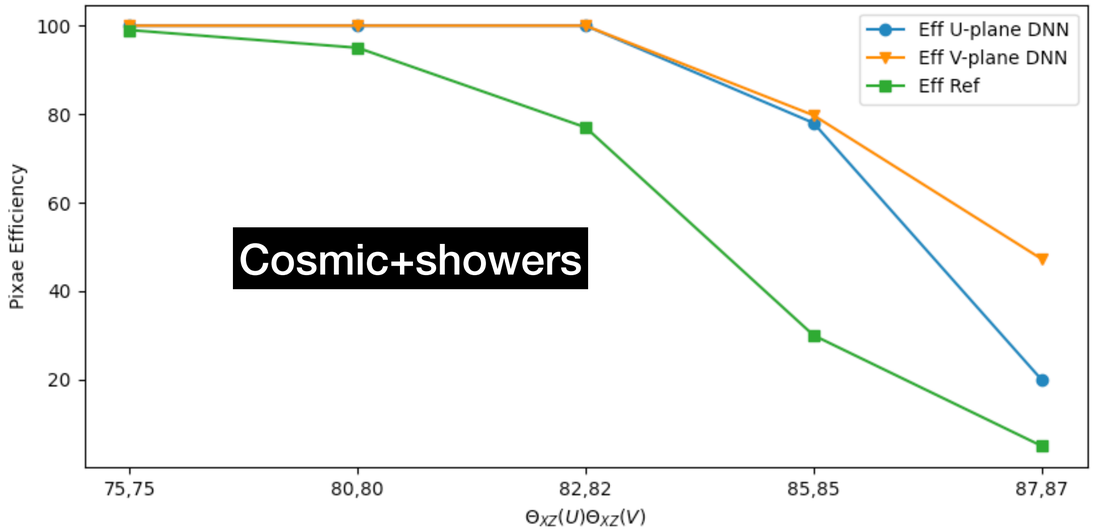
```
U-plane DNN
Bias :  4.571162536740303
Res :  1.417400815510866
U-plane Ref
Bias :  9.097599983215332
Res :  4.137159809065387
V-plane DNN
Bias :  4.422864690423012
Res :  1.1390361945515728
V-plane Ref
Bias :  9.208225458860397
Res :  3.232712530770866
W-plane DNN
Bias :  1.2475624680519104
Res :  0.5364315777831199
W-plane Ref
Bias :  1.2475624680519104
Res :  0.5364315777831199
```

No e- in training

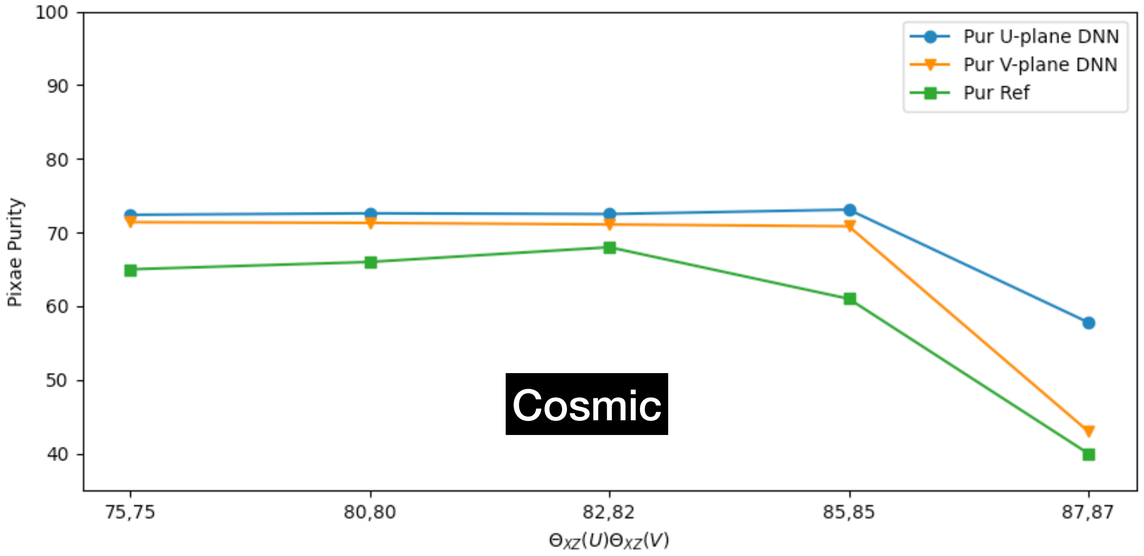
```
U-plane DNN
Bias :  3.2531172037124634
Res :  1.0607194325820335
U-plane Ref
Bias :  8.886434137821198
Res :  3.4793286288036436
V-plane DNN
Bias :  3.1423281878232956
Res :  0.9601534402902031
V-plane Ref
Bias :  10.18589660525322
Res :  3.8509887514298633
W-plane DNN
Bias :  1.203310489654541
Res :  0.4904098169962505
W-plane Ref
Bias :  1.203310489654541
Res :  0.4904098169962505
```

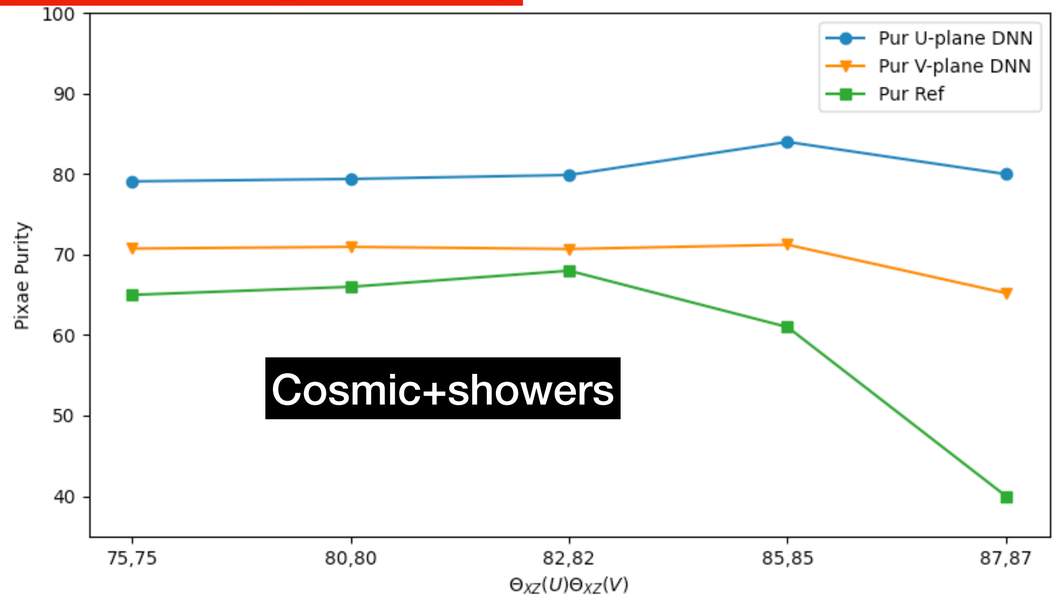
Repeat track validation





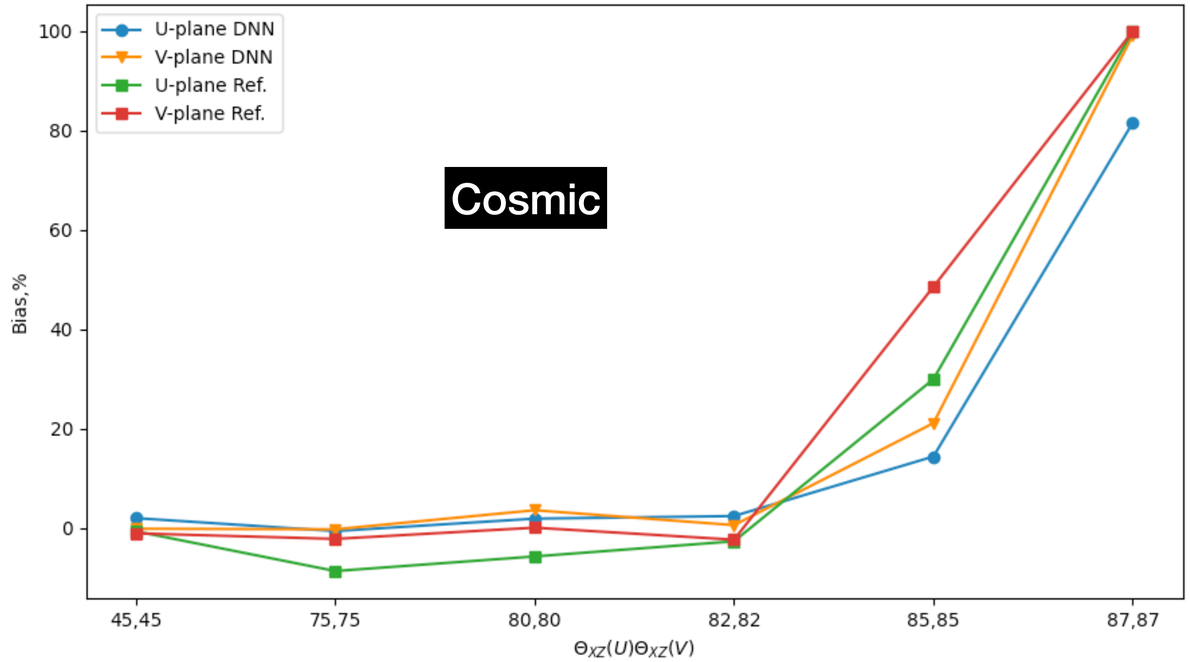
V plane Efficiency and U plane purity increased signifficantely

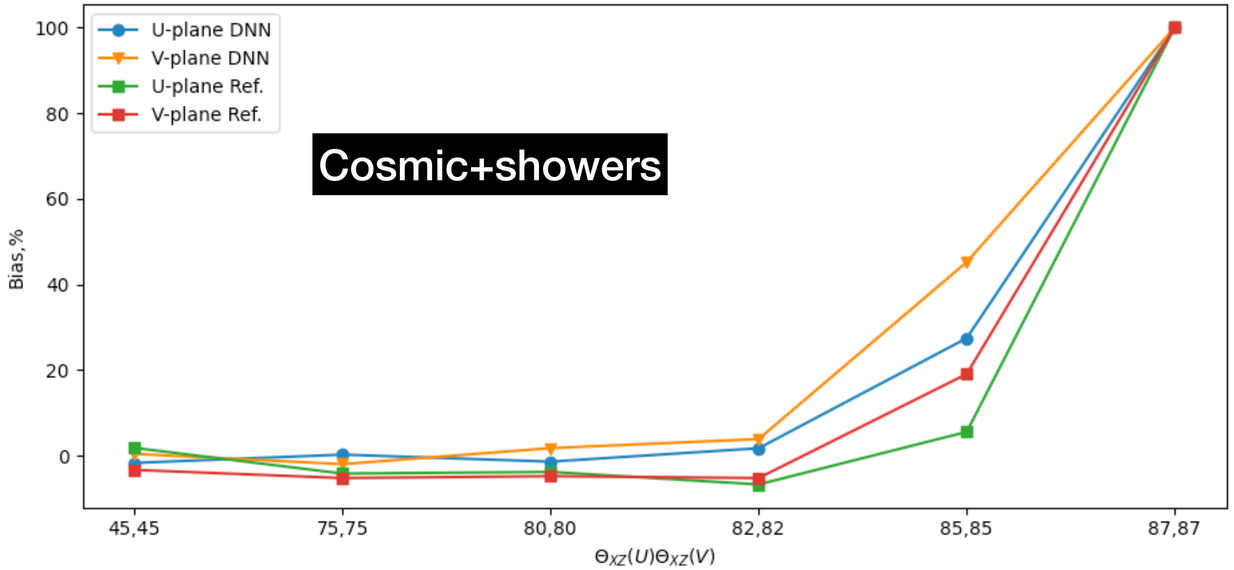




Charge bias

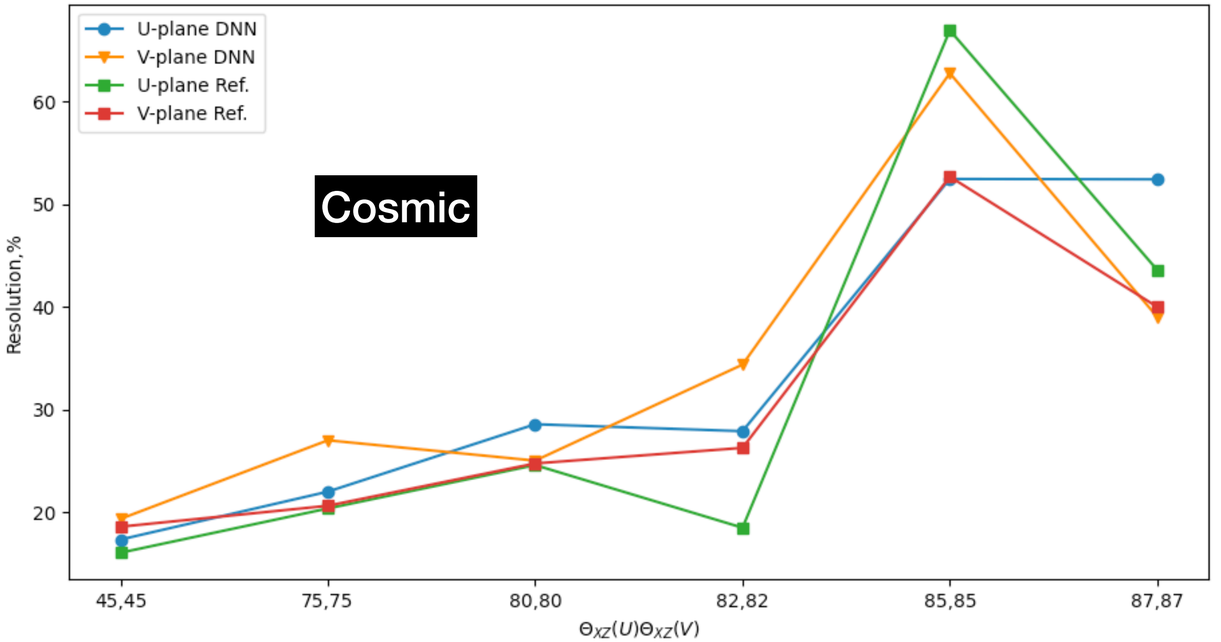
- Bias increased at higher angles

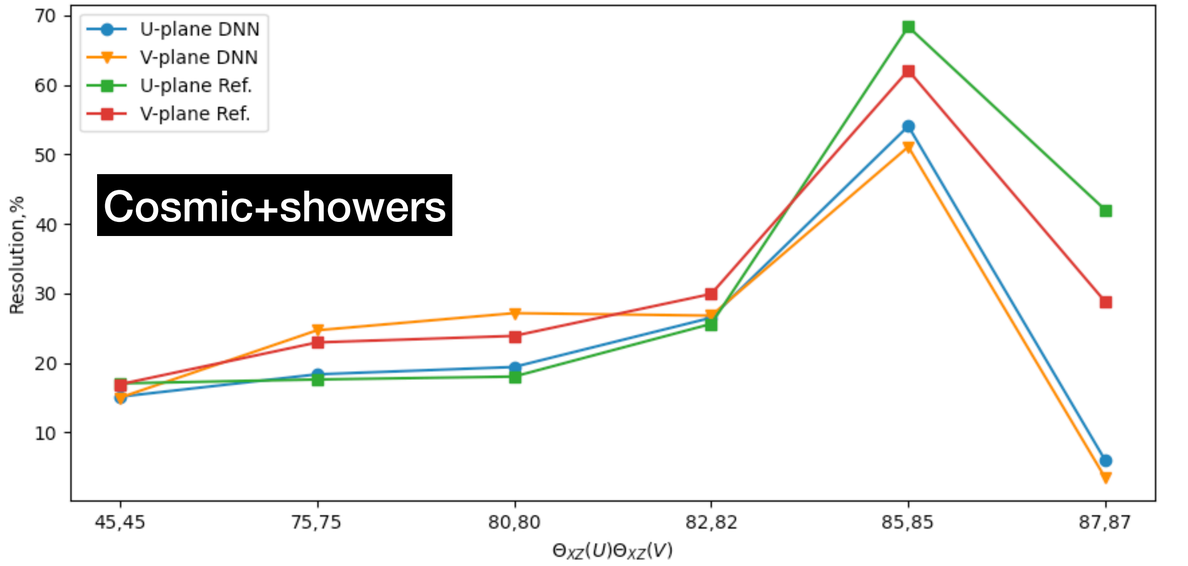




Charge Resolution

- Resolution ~similar
- 87/87 angle reduced, but with high bias might be a small number of hits for resolution calculation





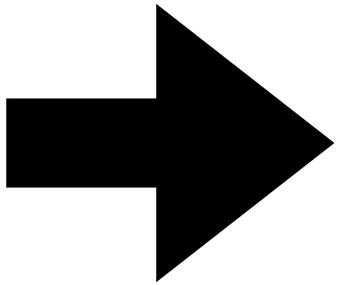
Data Performance

Full stage 2 chain without dnn :

- Peak virtual memory usage (VmPeak) : 6038.05 MB
- Peak resident set size usage (VmHWM): 2041.58 MB
- ~2 min

With DNN ROI [thanks to Wenqiang configs are available in dunereco]:

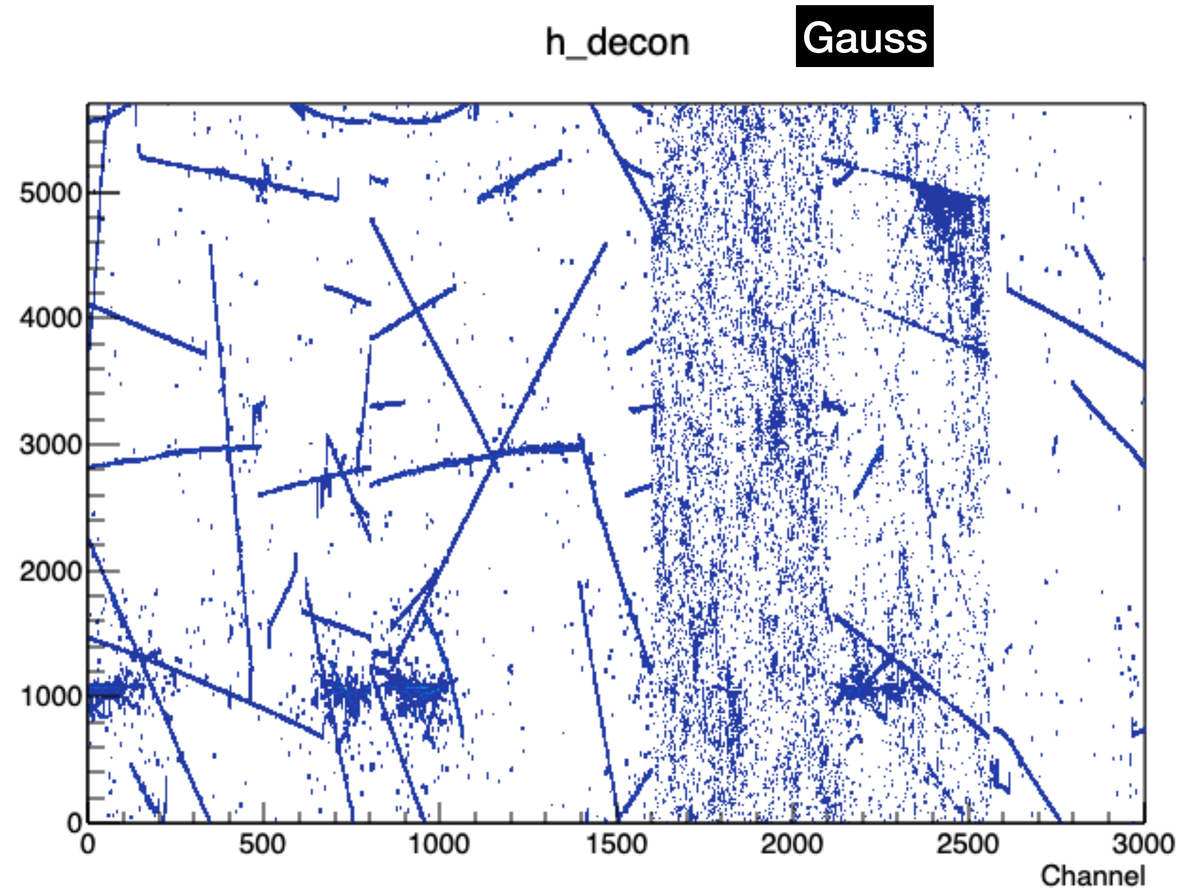
- Peak virtual memory usage (VmPeak) : 9489.81 MB
- Peak resident set size usage (VmHWM): 4997.28 MB
- ~5min

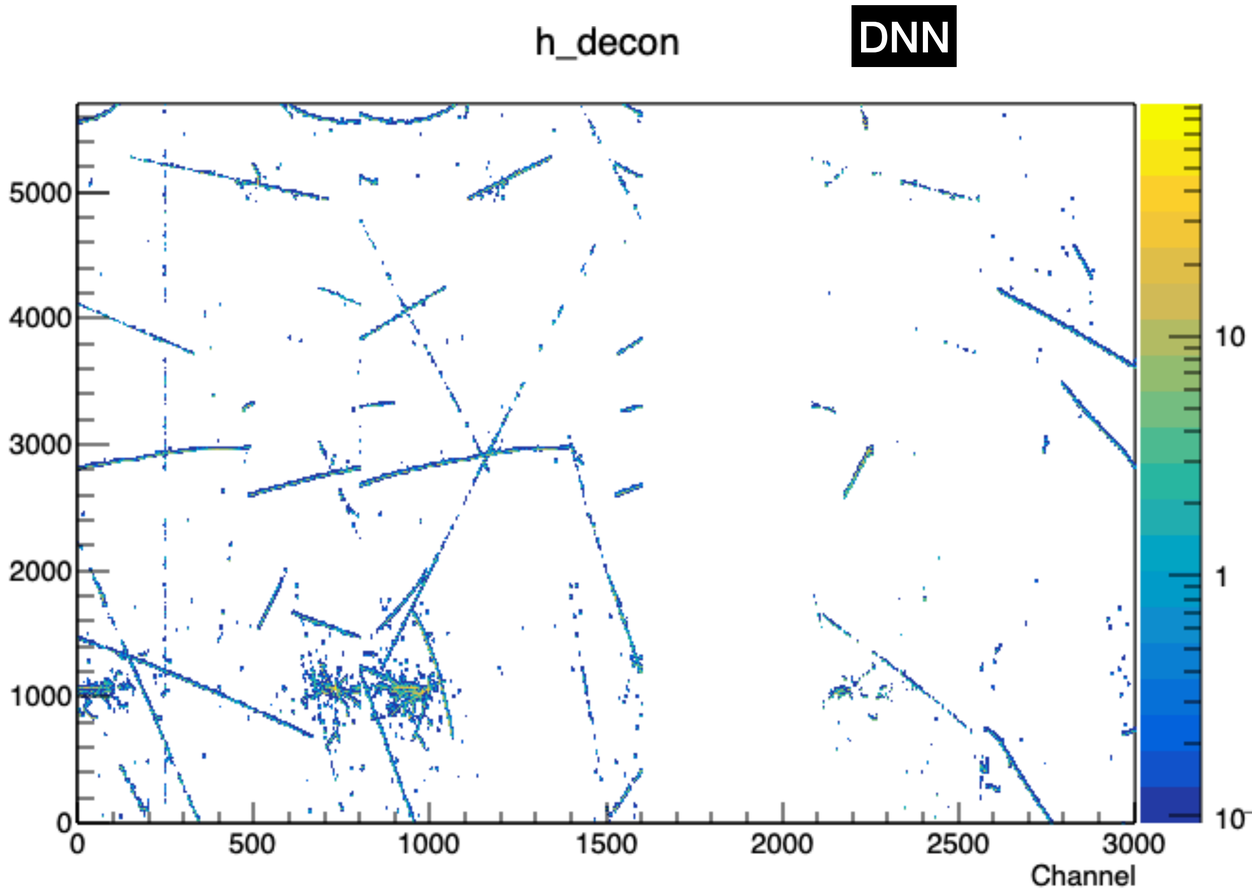


Adding DNN gives:

- 2.5 time longer
- 3.5G more memory
- Gray’s fix [multimap->unordered_multimap] should improve time
- Memory fix?

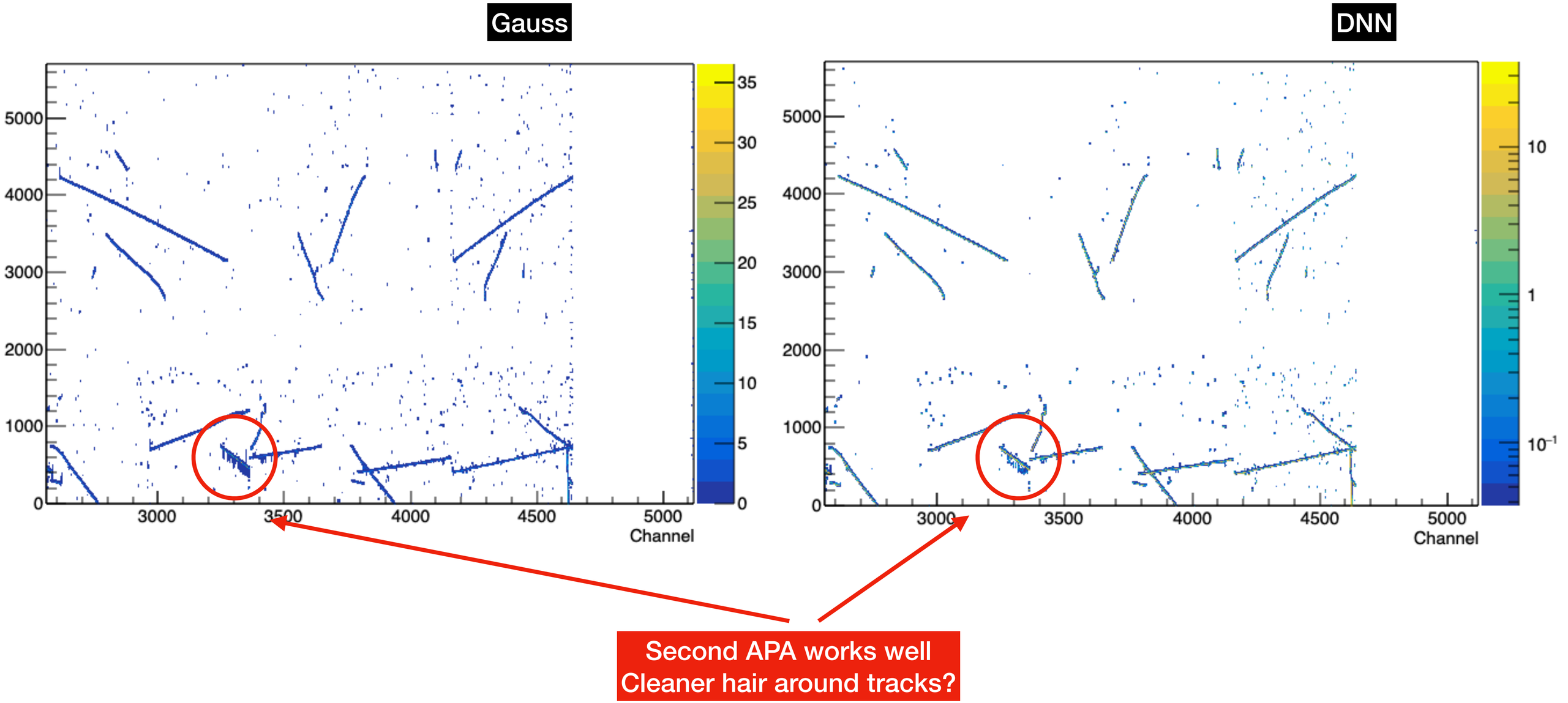
Data [model trained with e- included]





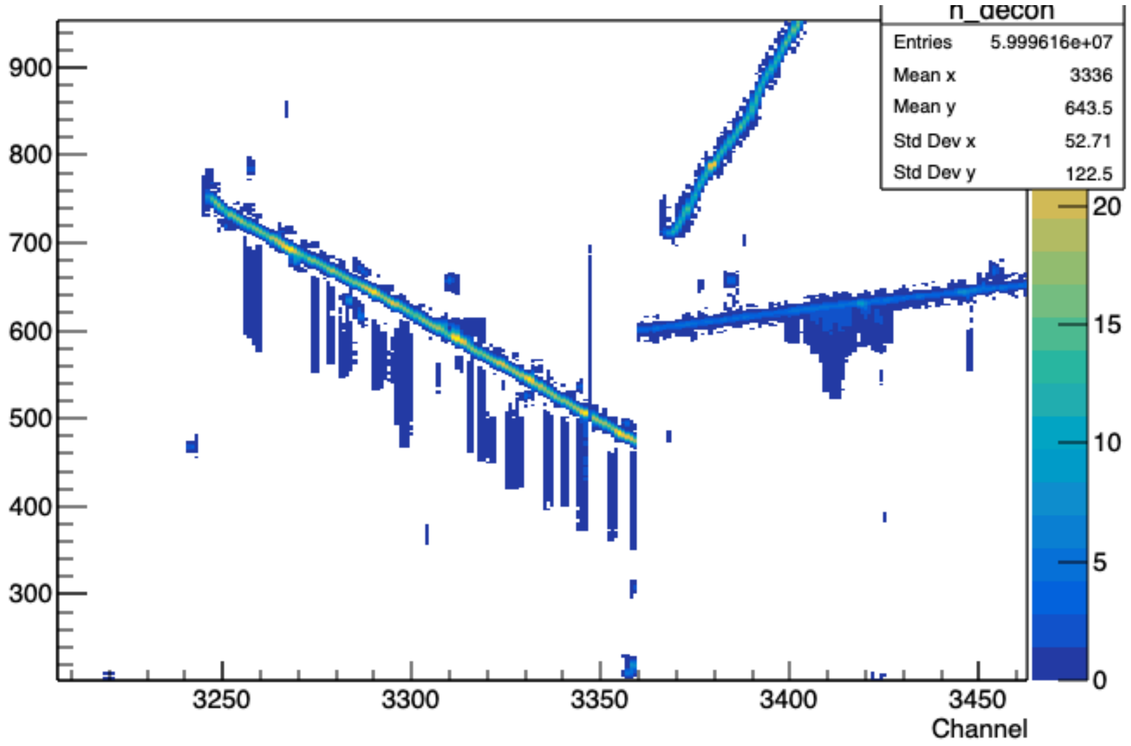
First APA does not work with DNN - > problems with field response

Data [model trained with e- included]

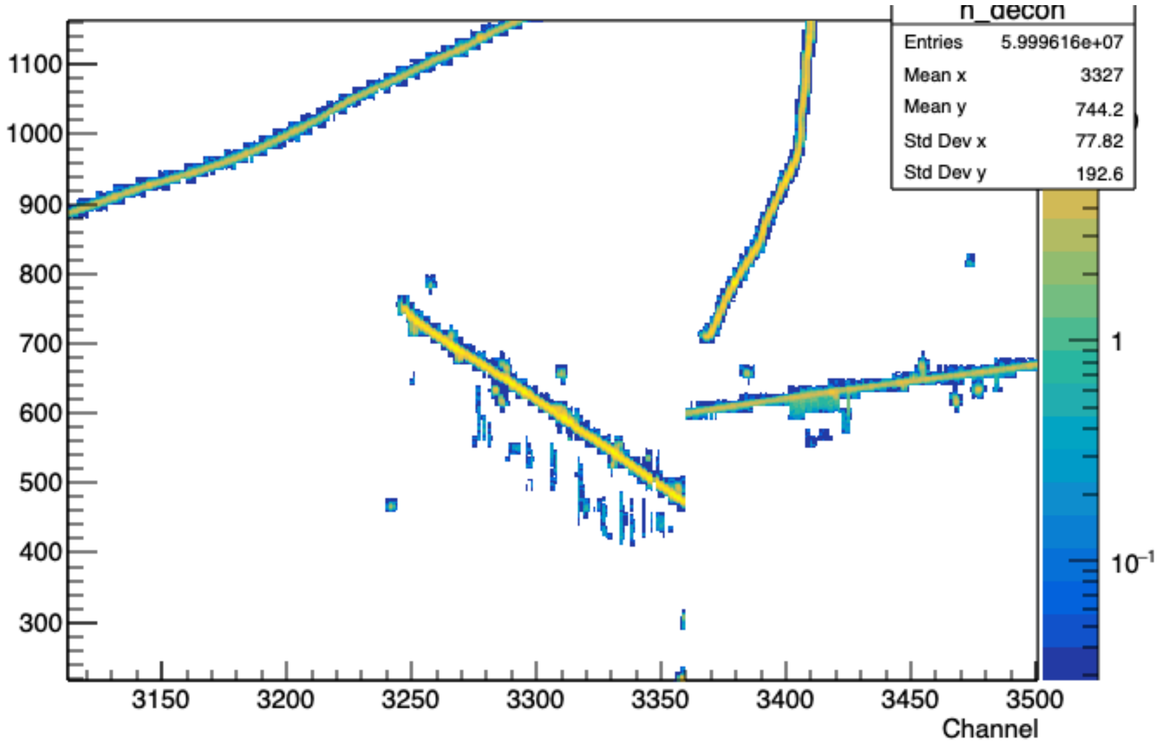


Data [model trained with e- included]

Gauss



DNN



Second APA works well
Cleaner hair around tracks?

Summary

- Model trained on cosmic works with showers
  - Adding showers to the training does not provide signiffican improvement -> may be need more stat.

- DNN ROI implemented for data processing for PDHD and works well
  - However software version for training and data are far apart -> not a problem now, but will be in a future [APA1 sim. changes] -> solution to hio ?
  - Take x2.5 more time and +3.5G of memory -> needs solution
  - APA 1 does not work well -> using two separate models or standard sp for it