CDCNN TRG with enriched input information

Yuxin Liu

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Motivation

Trigger menu and rate @ 2022/6/9, exp26r1261

T.Koga-san

-Total L1 rate=~11.5kHz, Luminosity=~4.5 × 10^34

-Rate of standard bits (ffy+fyo+c4+hie) = 4.7kHz: need to keep until end of BelleII

-Others are 6.8kHz

event triggered by upper bits are excluded in lower bits in table

Category	Bit name and condition	Raw rate (kHz)	Exclusive rate (kHz)
CDC ~~B physics~~ standard bits	**ffy**: #full track>=3, |z|<20cm	2.18	2.18
	fyo: #full track>=2, Δϕ>90deg, |z|<20cm	1.77	0.73
ECL ~~B physics~~ standard bits	**c4**: #cluster>=4	0.47	0.26
	hie: Energy sum>1GeV	2.02	1.54
Subtotal		**4.7**	**4.7**
KLM τ/dark	**klmb2b, eklmb2b, beklm**: Back to back sector hits	0.51	0.46
	cdcklm, seklm, ecleklm: #CDC-KLM, ECL-KLM matching>=1	1.11	0.83
CDC τ/dark	**stt**: #full track>=1, |z|<15cm, p>0.7GeV	2.93	1.37
	syo: #full track>=1, #short track>=1, Δϕ>90deg, |z|<20cm	1.93	0.63
	fy30: #full track>=2, Δϕ>30deg, |z|<20cm	2.59	0.22
ECL τ/dark	**lml**: several combination of #cluster and energy	3.92	2.18
	eclmumu: back to back low energy hit	0.63	0.01
Calibration with prescale>1	PID (two photon)	0.35	0.16
	Other (Bhabha, γγ, random, trg)	1.00	0.60
Total L1	**OR of all bits**	**11.5**	**11.5**

CDC TRG rate contribute large part of total L1 trigger

We want to reduce it by 50%

CDC TRG :

CDCTRG Modified Module	Required rate reduction to achieve 50% (status)
CDCFE crosstalk filter, ADC	~10% (not yet)
CDCTRG 2D	~20% (achieved by simulation)
CDCTRG NN, 3D, 3DHough	~30% (not yet)
Total	~50%
(CDC-ECL matching)	30~50% (achieved by data, not used)

What I working on

Need events with |z|<1

→Cut at 20/15cm

→ Better resolution for z could restrict the cut

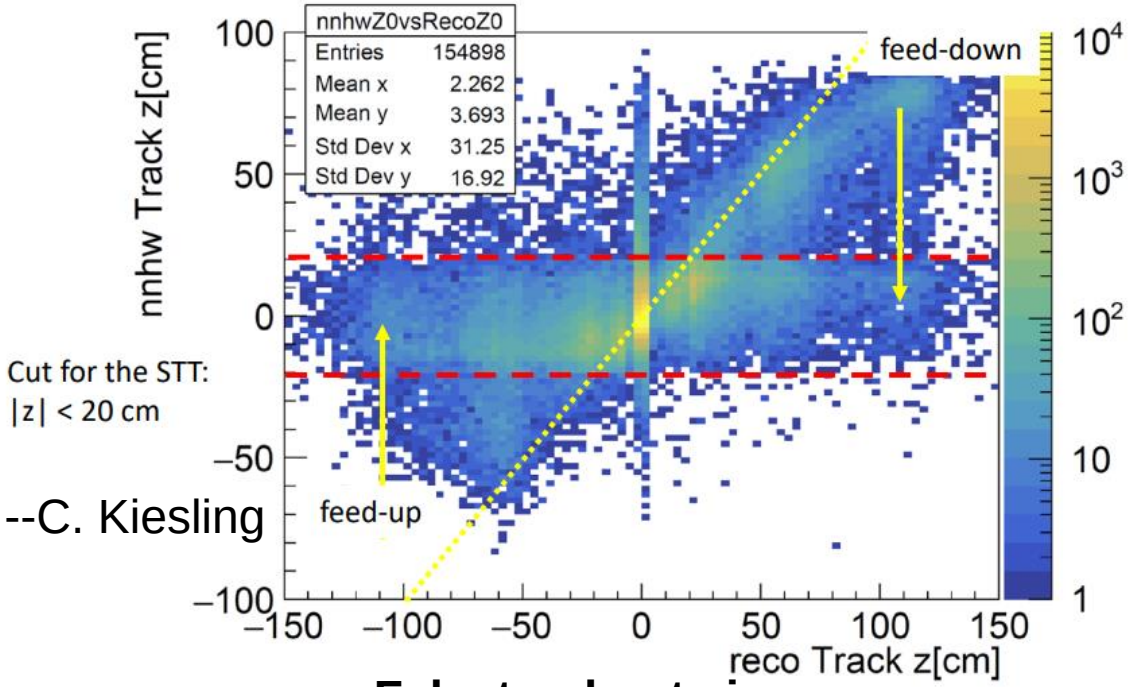
→ reject more Bkg while keeping efficiency

Main idea for NN: Improve z resolution

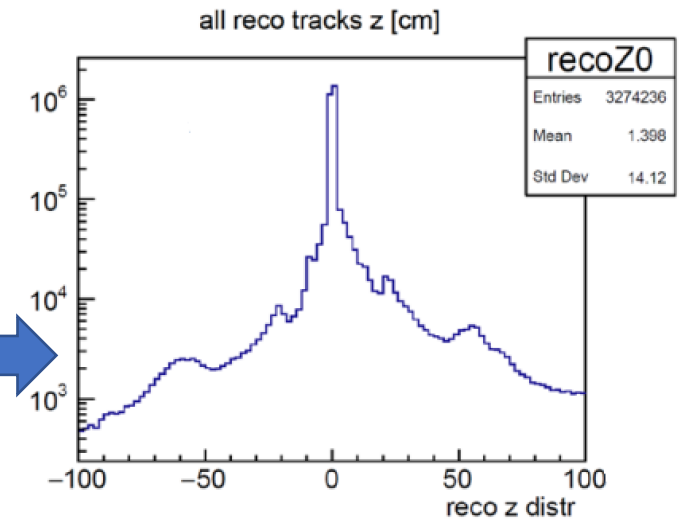
4

Motivation –Problem for CDCNN TRG

“Feed Up” and Feed down in large reco track z area



--C. Kiesling

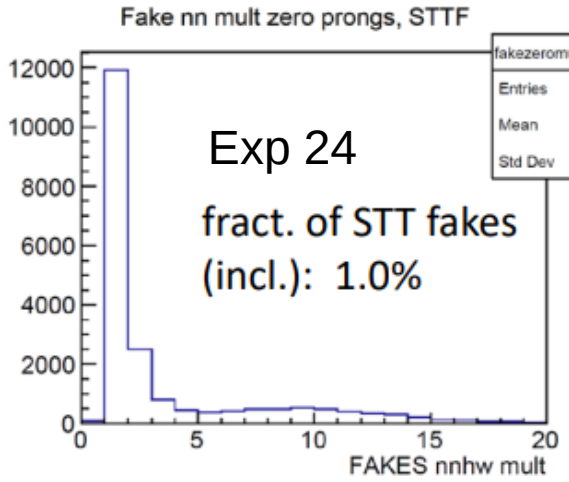


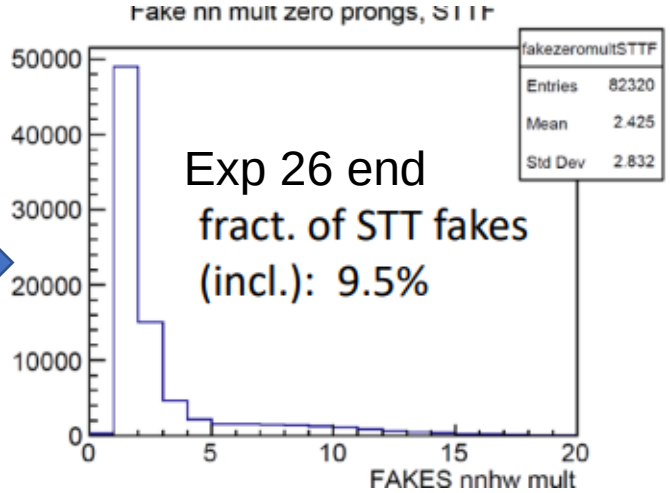
May due to the not proper z distribution for Training set

(Give large weigh on track at IP)

- Could be reduce by better Training set (Or put more weigh on large z area)
- Add extra input may also improve it

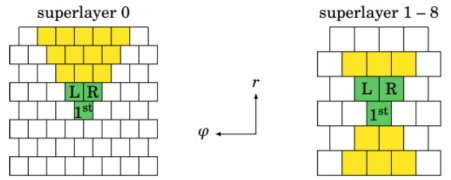
Fake track rate increase



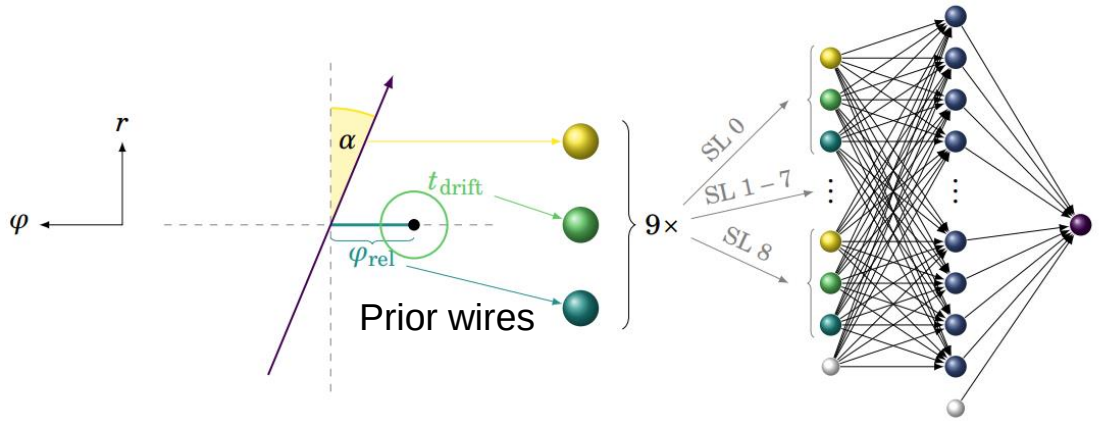


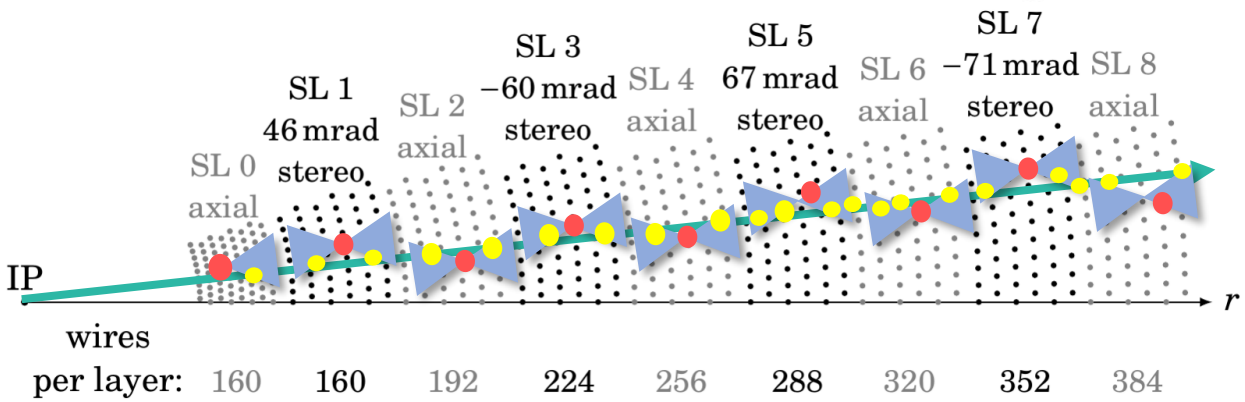
- Not try yet… Will perform detail categorizing for recent data
- Will try to use ADC inform to reject some “Fake Track Segment“ and reduce Fake Track

Motivation



"Track Segment" as a minimal unit CDC TRG





Wires hit in a TS -- Plan to add

Priority wires -- Already used

Present 3D NN use only one prior wire per every Track Segment.

With UT4 Module, more input and larger NN is possible for CDCTRG NN

For extra wire even with $\sigma_{t_{drift}} \sim 32ns$

$$z_0 = z_{cross} - \cot\theta_0 \frac{2\alpha}{\omega}$$

$$\Delta z_{cross} = \frac{r_{wire}}{\sin\psi}\sqrt{(\Delta\phi_{cross})^2 + (\Delta\phi_B)^2}$$

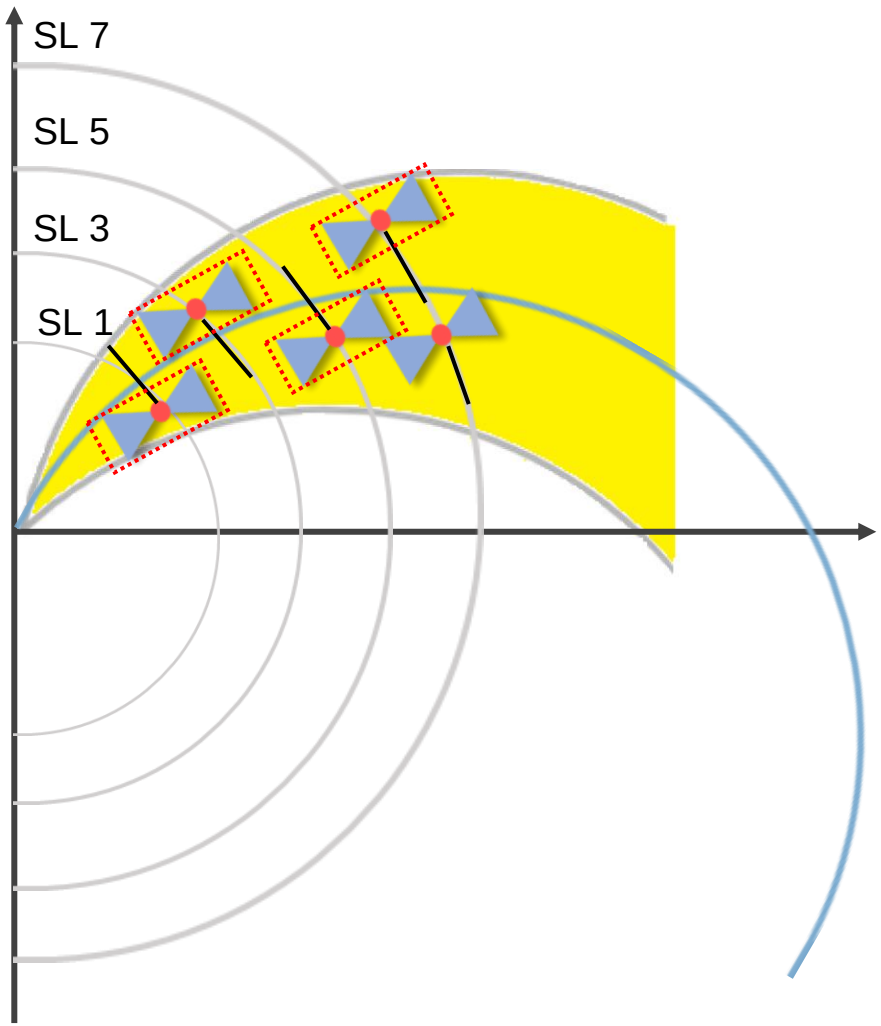
The Δz_{cross} calculated by a single wire is ($P_t > 0.4GeV$)

$$\Delta z_{cross} \sim 2.0 \text{ cm to } 3.4 \text{ cm}$$

In the same order of prior wire (0.4cm ~ 1.4cm)

Can be used to improve the resolution of NN.

How CDCNN TRG work



CDC cross-sectional schematic
(Only stereo layer showed)

1. Get 2D Track from CDC2DHough (Calculate from all axial layer)

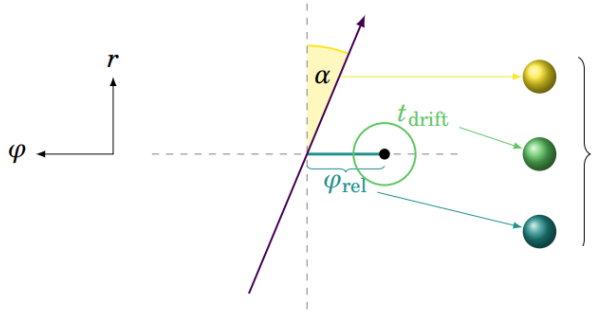
2. Set relative range based on previous RecoTracks

3. Find out all TS in relative range

4. Select out one TS for every SL (first with left/right known; next with smallest drift time)

`if n TS selected >3`

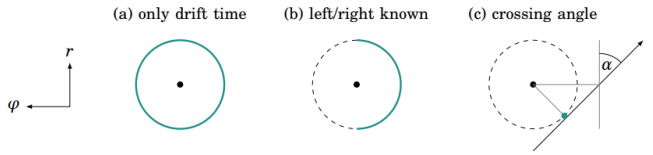
5.1 Use parameter from selected TS and 2D track as input for 5 different NN (for varied missing SL):



$$\phi_{rel} = \phi_{wire} - \phi_{cross}$$

$$\alpha: from\ 2D\ track\ and\ crossing\ SL$$

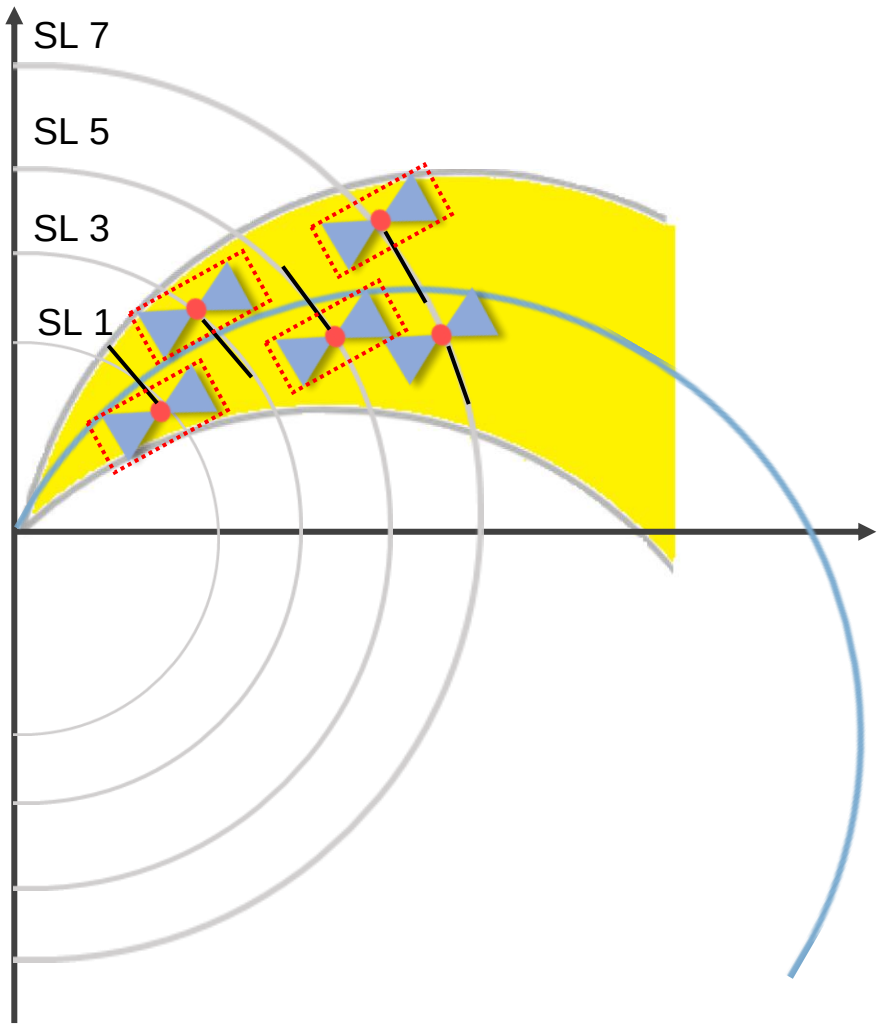
$$t_{drift} = (t_{wire} - t_0) * L/R$$



`else`

5.2 Not build 3D NN track

What we want to add



CDC cross-sectional schematic
(Only stereo layer showed)

1. Get 2D Track from CDC2DHough (Calculate from all axial layer)

2. Set relative range based on previous RecoTracks

3. Find out all TS in relative range

4. Select out one TS for every SL (first with left/right known; next with smallest drift time) Might be improved

```
if n TS selected >3
```

5.1 Use parameter from selected TS and 2D track as input for 5 different NN (for varied missing SL):

5.1.2 Select out 1/2/3 wire(s) for every TS (not prior one; first with left/right known; next with smallest drift time)

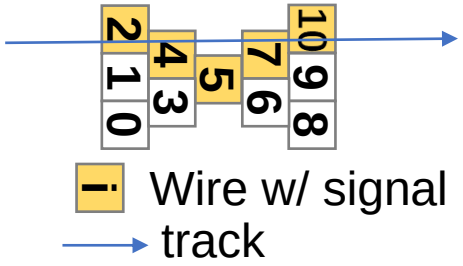
5.1.3 Use parameter from selected TS, 2D Track and selected extra wires

```
else
```

5.2 Not build 3D NN track

Check the L/R impact for NN

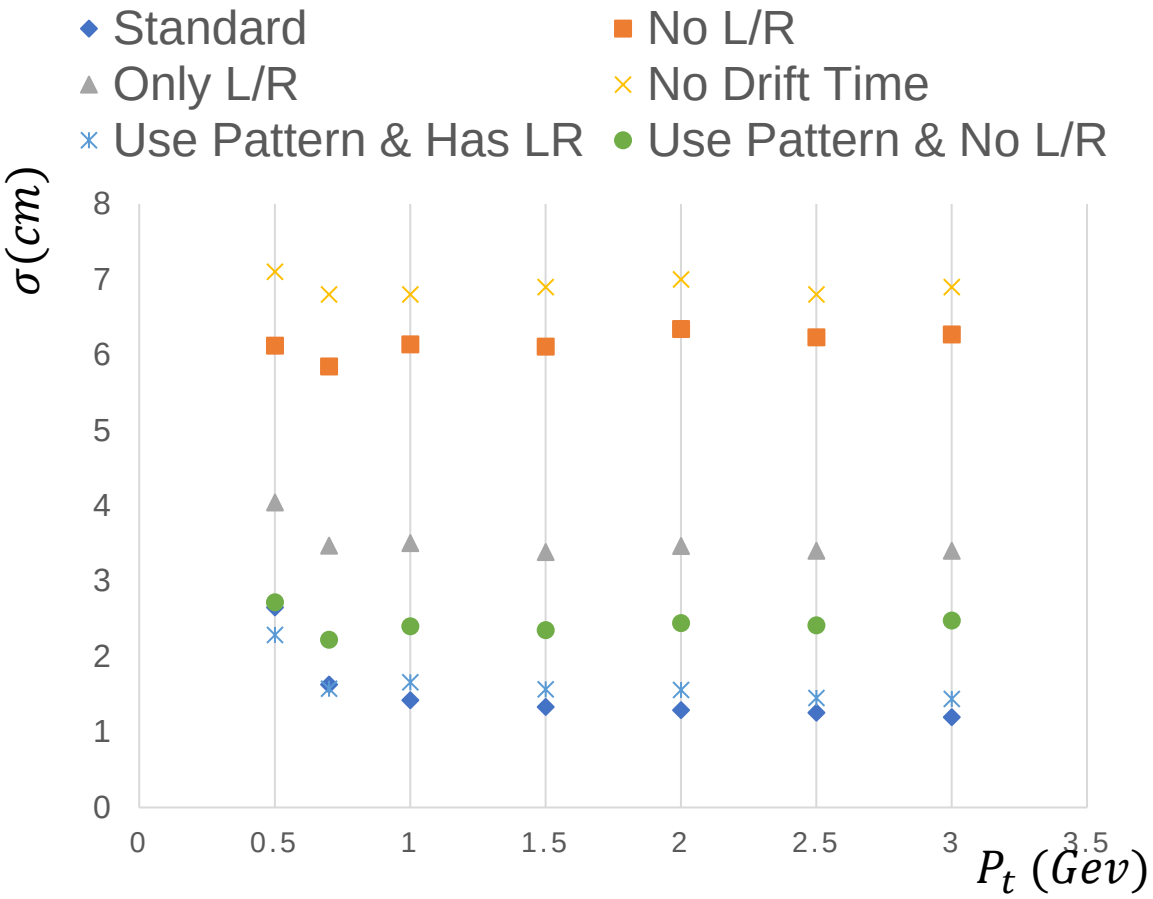
How to determine Left/Right:



A certain pattern →Count over a large number of events and find the most likely L/R

Only for **prior wire,** not available for extra wires

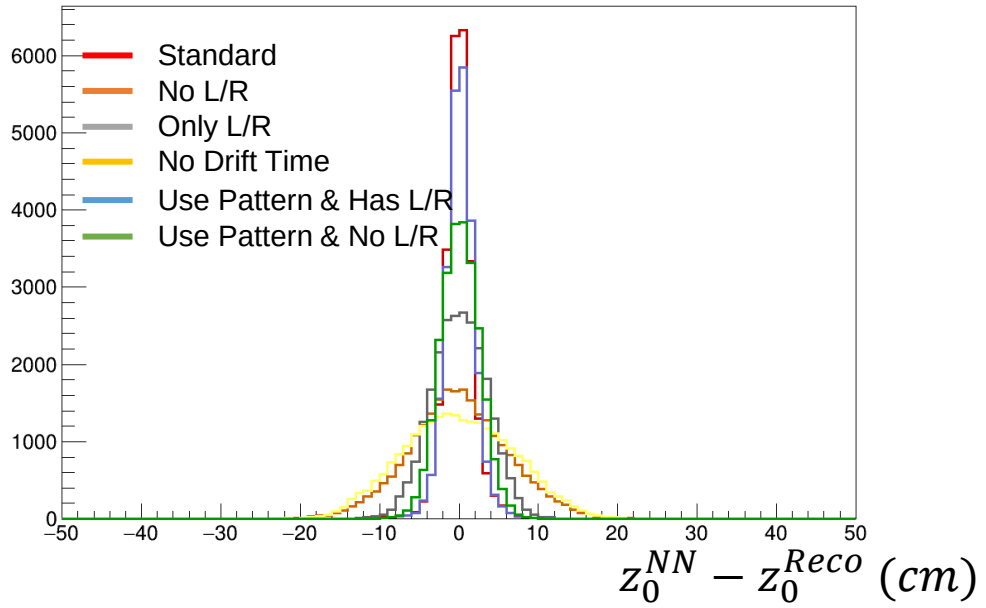
Build a “Full LUT” for every wires?



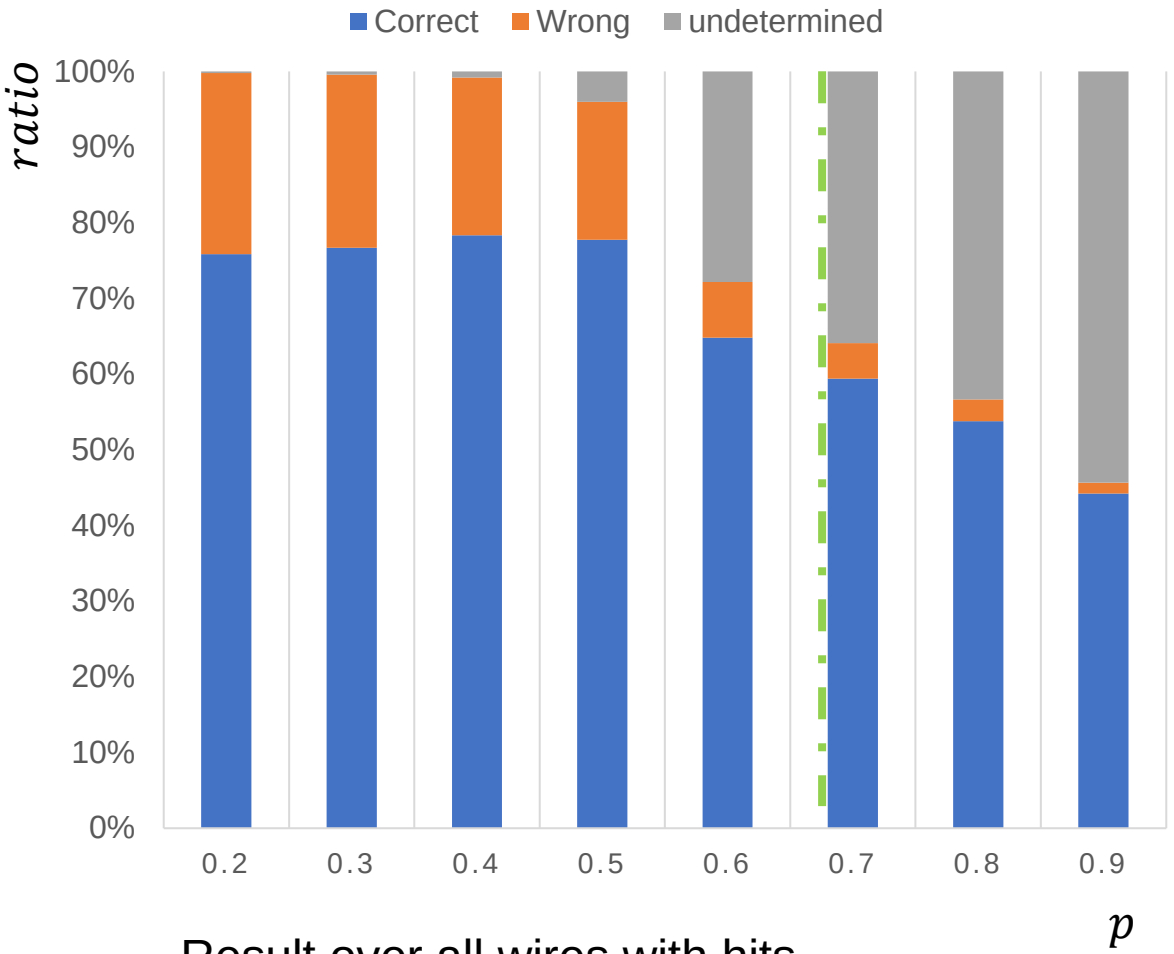
Trained NN based on single track MC w/ fann

L/R is extremely important for currently NN

Pattern input can not fully replace L/R. Even with both pattern and L/R, no improvement for the standard one



Build L/R LUT table for every wires in TS



Result over all wires with hits (exclude prior one)

Following the old way to build up a LUT for **every wires in TS**

Use MC without Bkg first

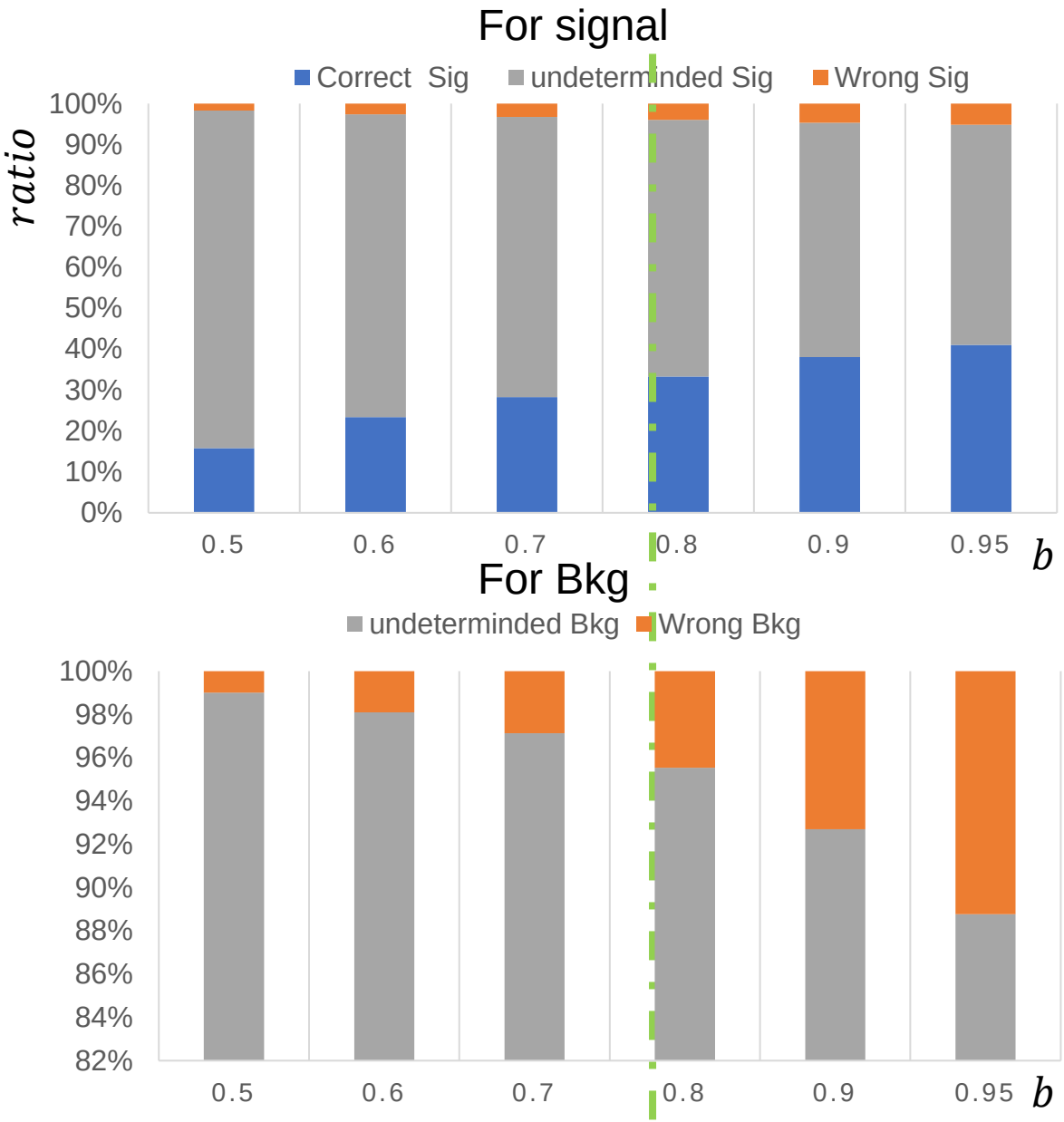
$$L/R\ state = \begin{cases} left & if\ n_L > p(n_L + n_R) + 3\sigma \\ right & if\ n_R > p(n_L + n_R) + 3\sigma \\ undecide & otherwise \end{cases}$$

$$\sigma = \sqrt{(n_L + n_R)p(1-P)}$$

Choose P = 0.7 for LUT.

Since undetermined rate is high, for more wires (>1) case, undetermined events increase

Build L/R LUT table for every wires in TS



build up a LUT include Bkg

Use MC with early Phase III Bkg

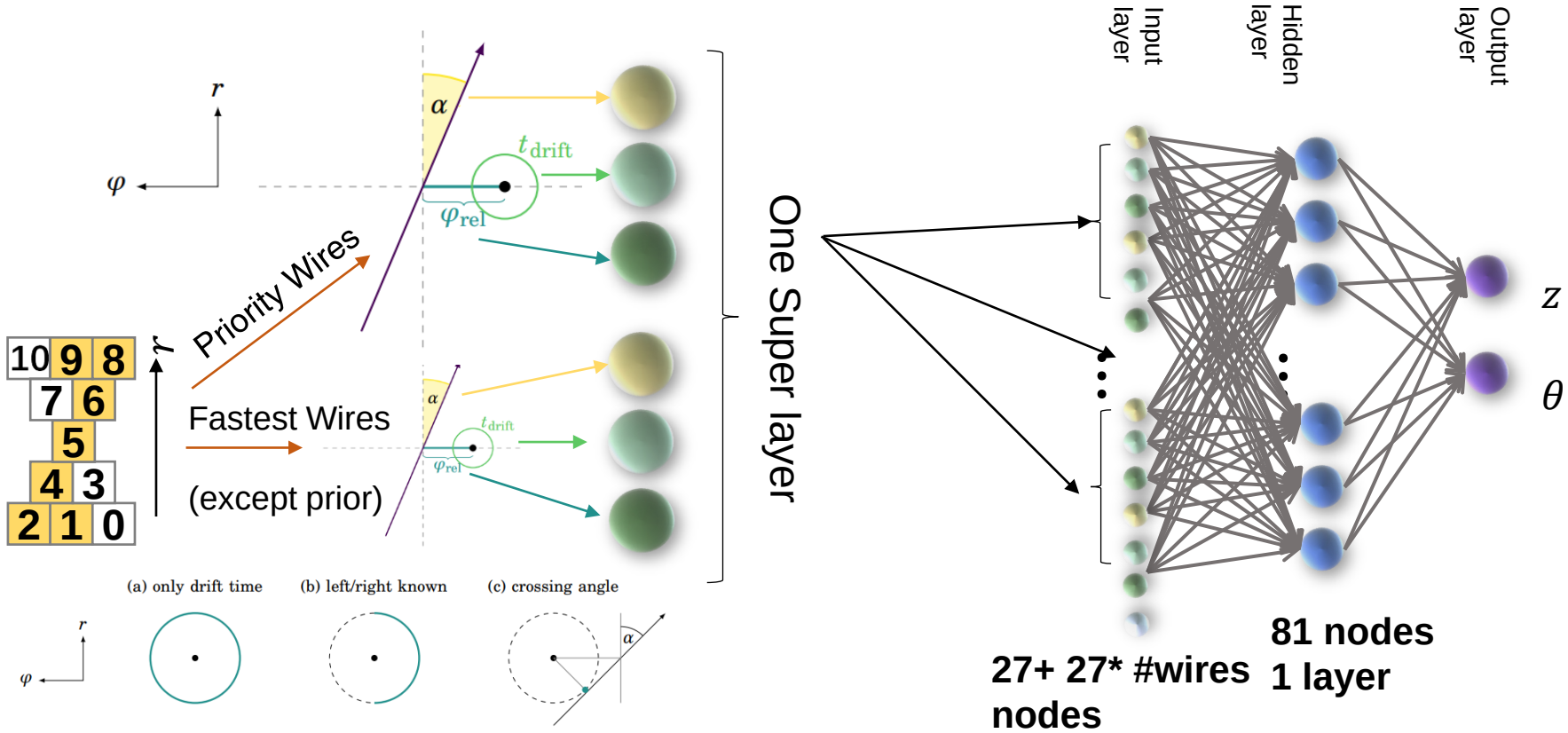
$$L/R\ state(Bkg) = \begin{cases} signal: & otherwise \\ Bkg: & if\ n_b > b(n_{Total}) \end{cases}$$

Want to got correct sig & undetermined Bkg (Which will have a low priority for Bkg hits) as much as possible

Choose b = 0.8 for LUT. To make sure that for a TS, we have large possibility to find at least one extra wires with L/R known

Will generated LUT with Recotrack soon

First attempt: Use extra wire(s) with full information



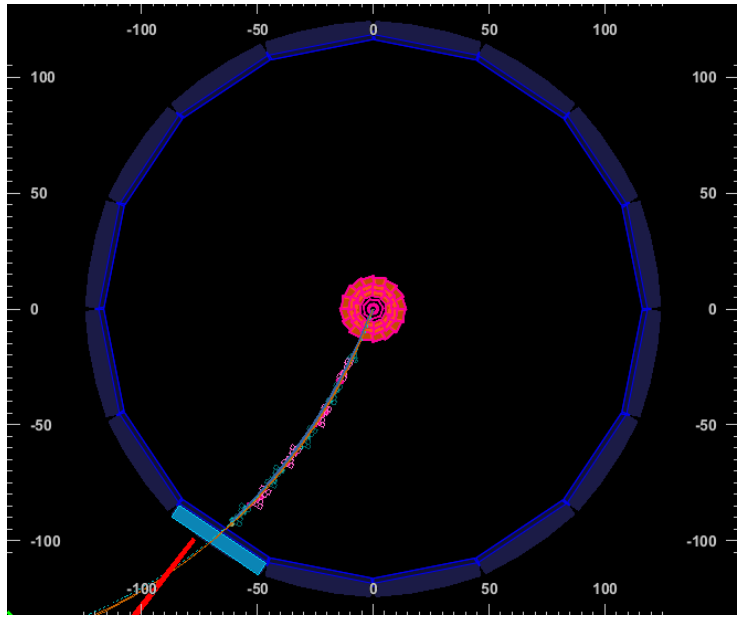
Using wires with no hit as input would decrease resolution significantly

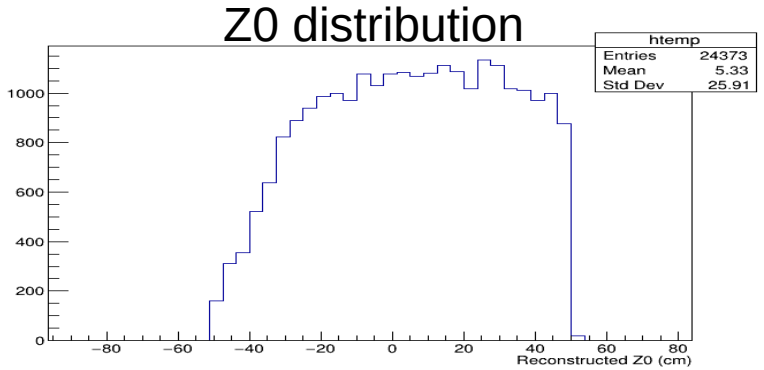
Build up L/R look up table for every wires in TS

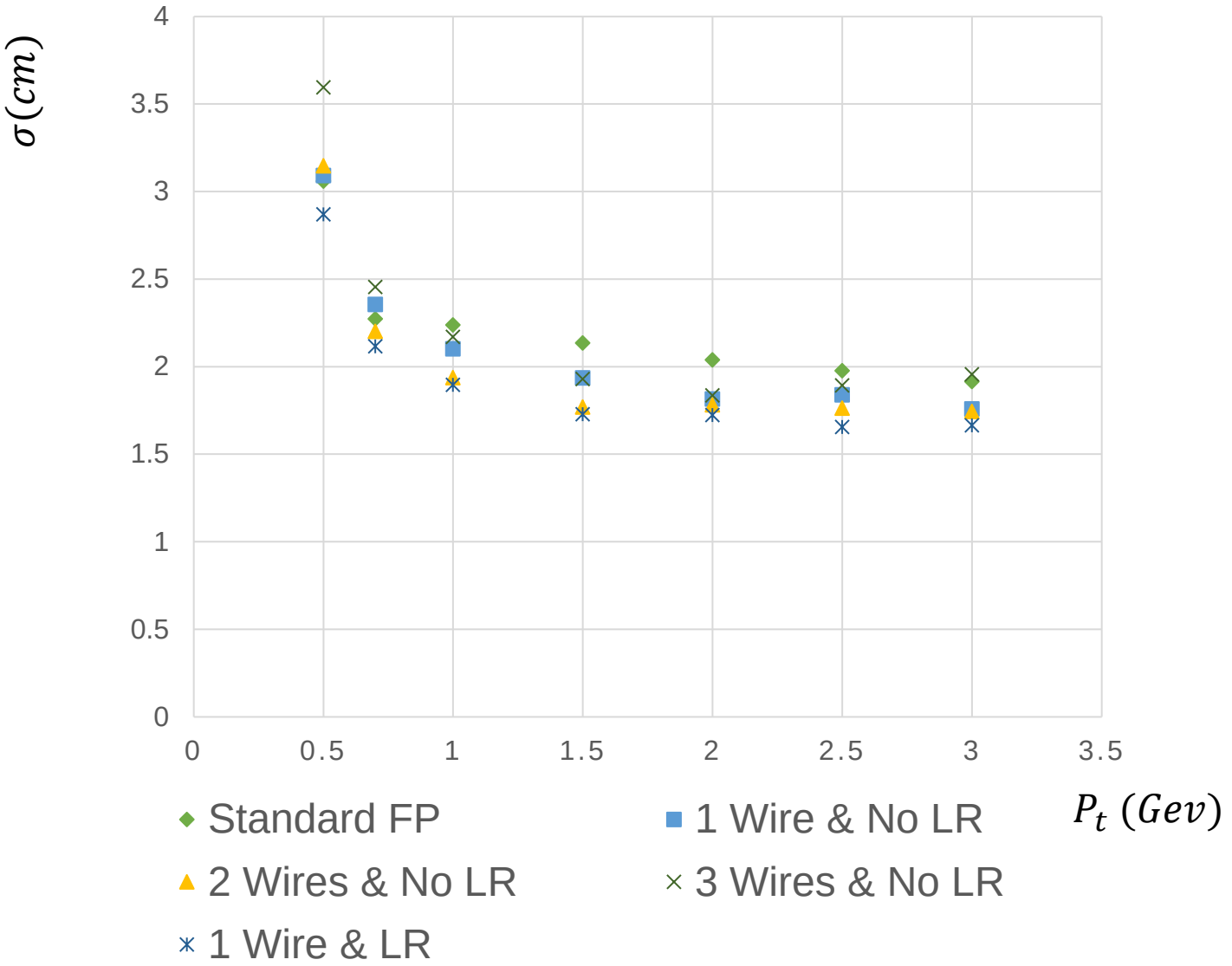
Choose the 1(2,3) wire(s) w**/ L/R know first** (if applied) and fastest t_{drift}

MC Test

MC :
Single track w/o Bkg;
uniform Pt,Φ, θ and vertex z







Not large but could see improvement with L/R known extra wires

Pytorch training with real data

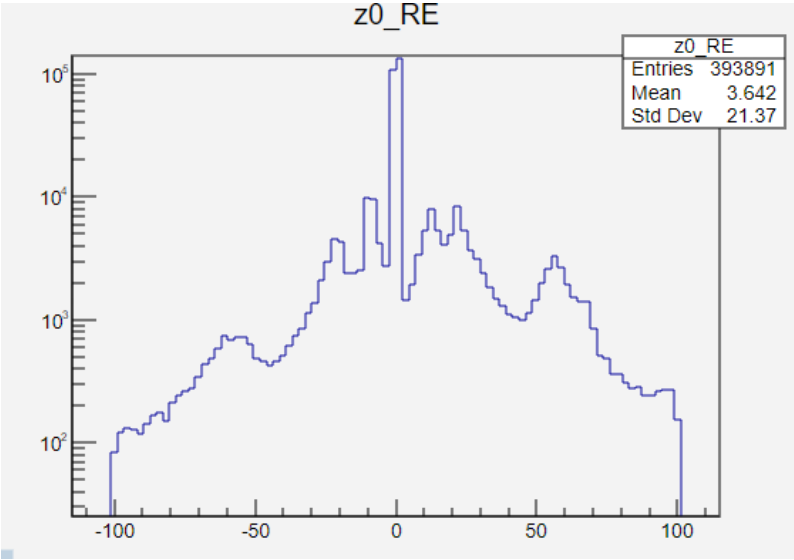
Data: exp26run1756-1780 (w/ beam reco monitor) (random separated to two set)

Generate training data with Extra 3 wires with LUT

Change training method to pytorch → faster convergence and better optimization

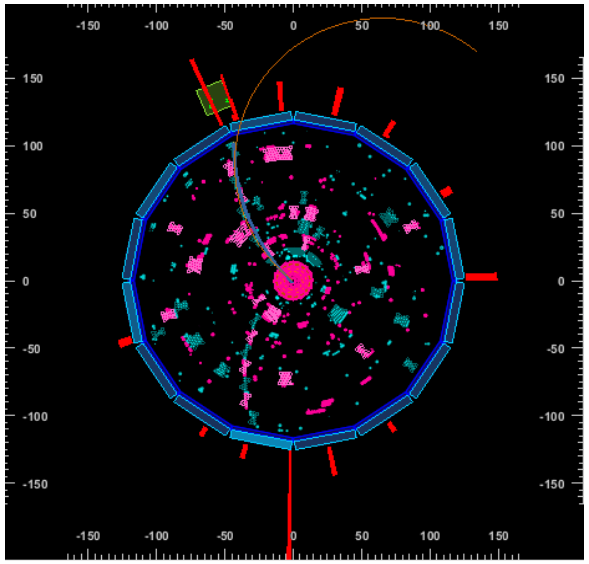
Using simulated ETFHough

Reco Z distribution for data

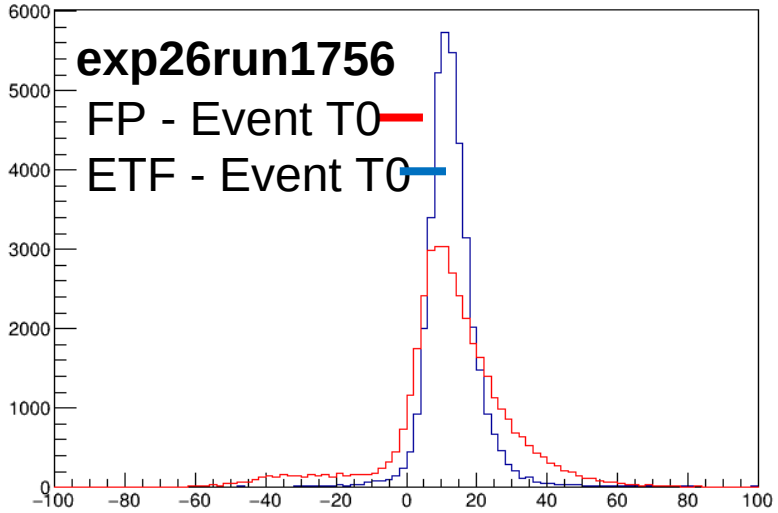


z_{RE} (cm)

Event display



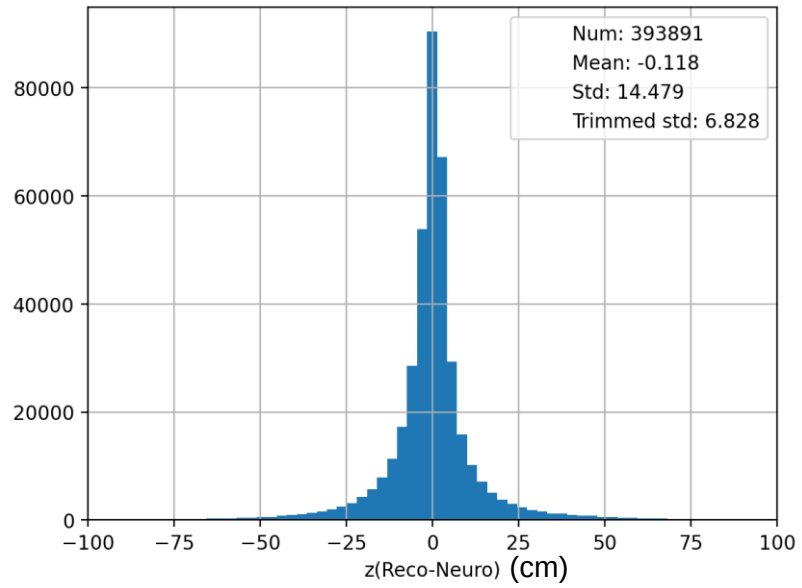
ETF compare with FP

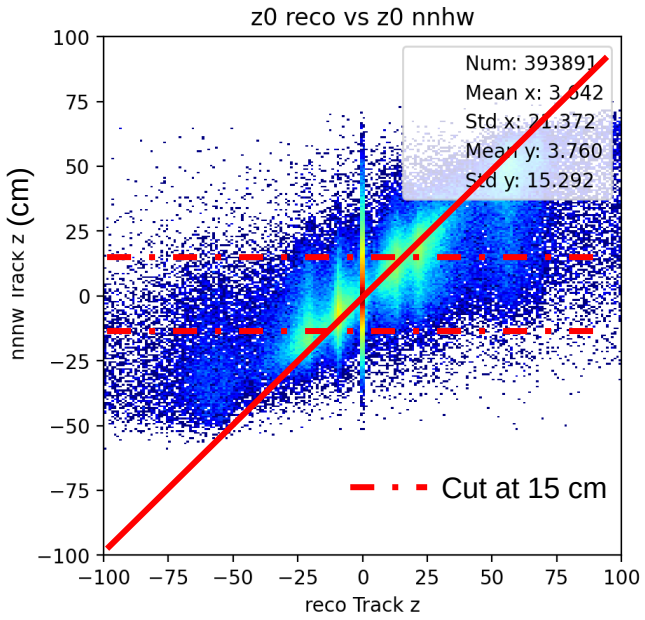


Pytorch training with real data

(Sum over all fives experts)

Standard method





$$\text{Trg efficiency} = \frac{\#|z_0| \text{ from RecoTracks} < 1 \;\&\&\# \; |z_0| \text{ from CDCNNTrack} < \text{cut}}{\#|z_0| \text{ from RecoTracks} < 1}$$

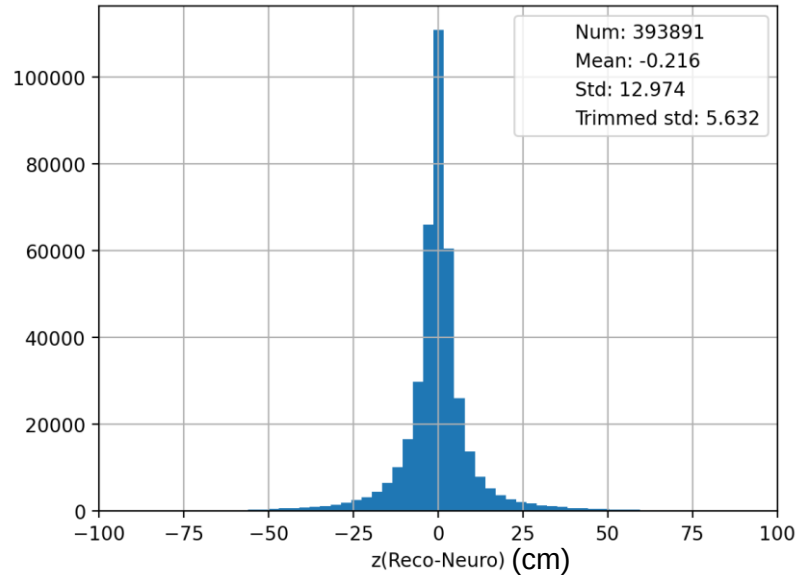
$$\text{Rejected rate} = \frac{\#|z_0| \text{ from RecoTracks} > 1 \;\&\&\# \; |z_0| \text{ from CDCNNTrack} > \text{cut}}{\#|z_0| \text{ from RecoTracks} > 1}$$

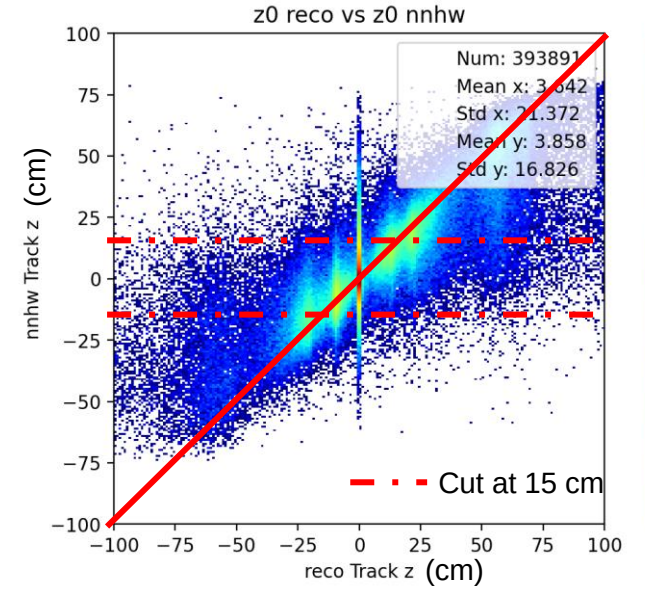
Regarding a needed events as |z0|<1 and z0 cut at 15 cm

TRG Efficiency: 94.6%

Rejected rate: 50.8%

Extra one wire





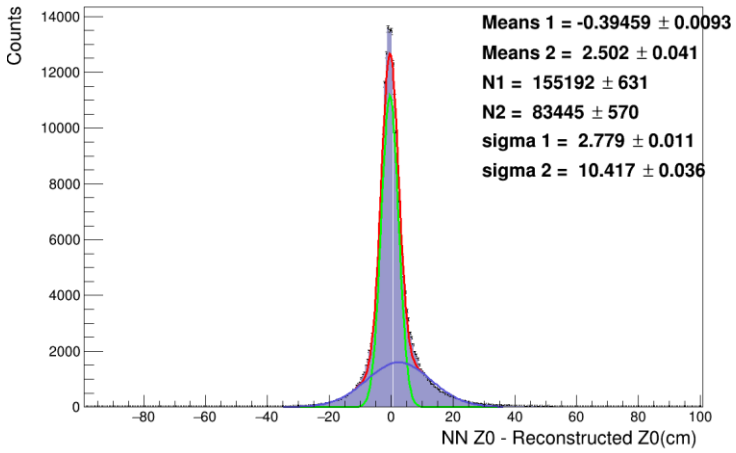
TRG Efficiency: 96.2%

Rejected rate: 53.5%

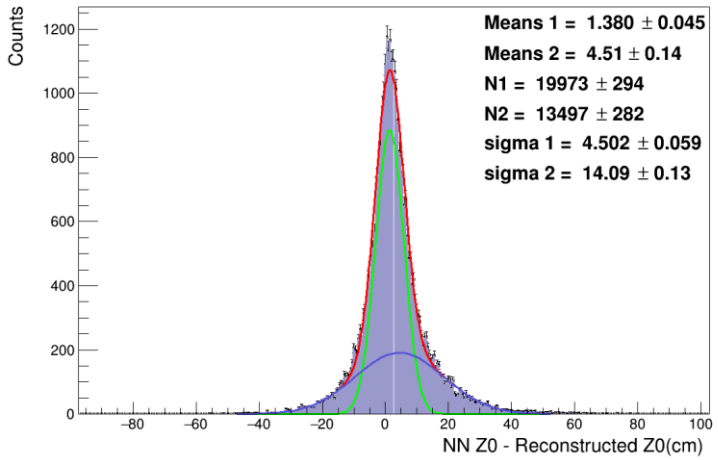
Better performance comparing with standard one, especially for large z0

Details performance at different z0

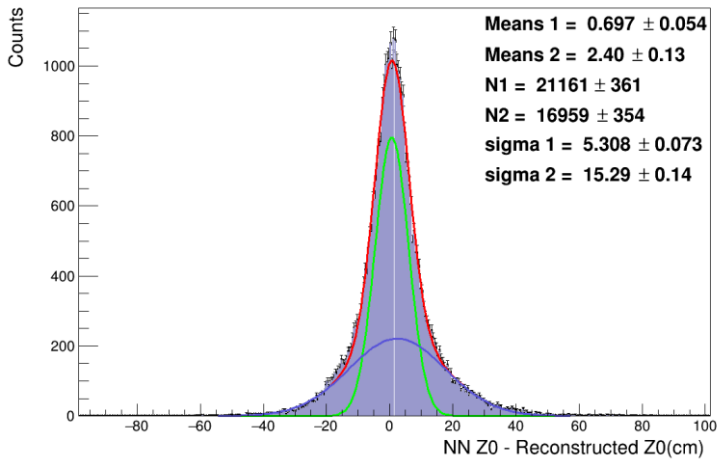
Standard method



Z<1

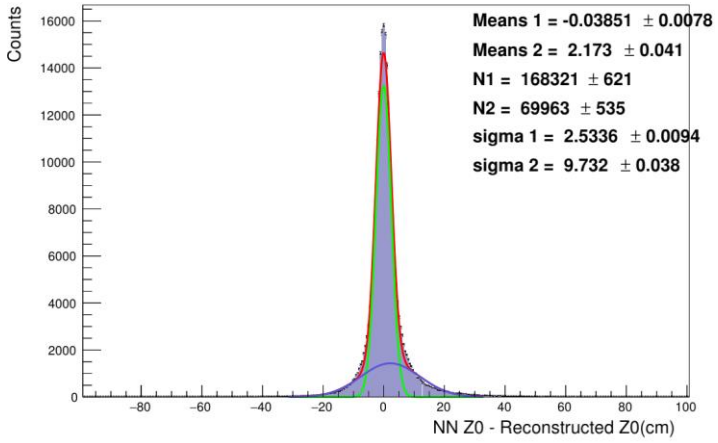


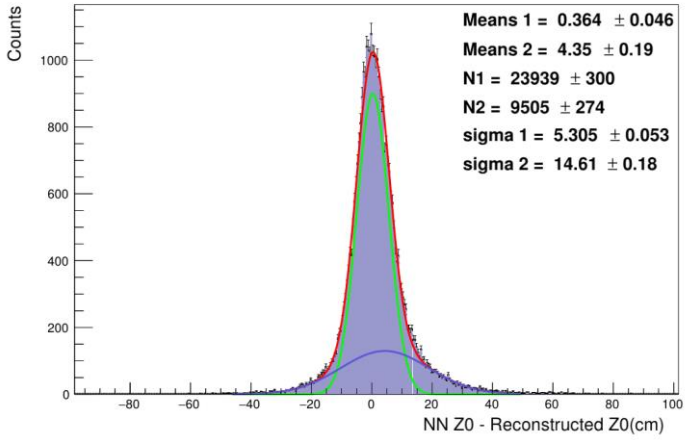
1<Z<10

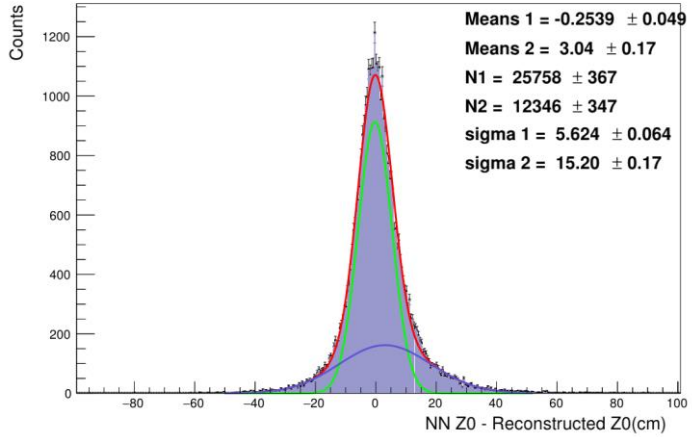


10<Z<20

Extra one wire

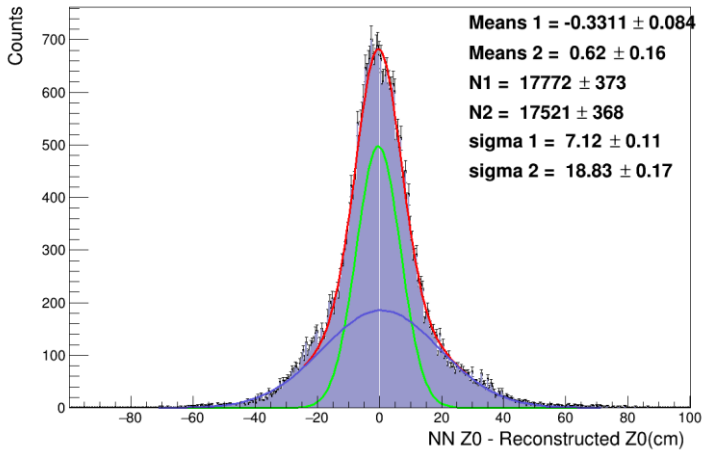




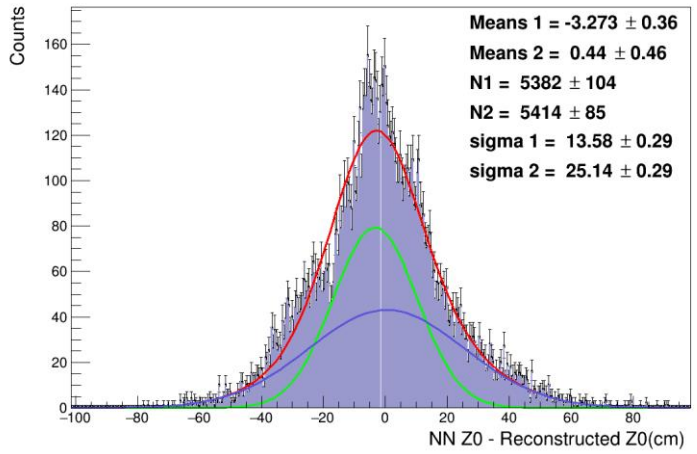


Details performance at different z0

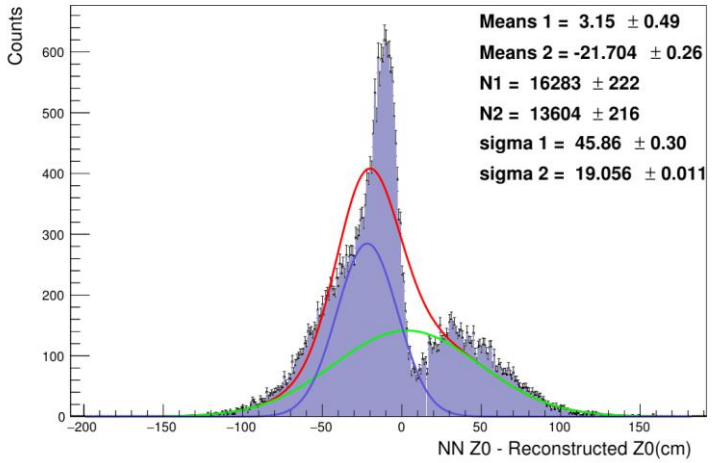
Standard method



20<Z<30

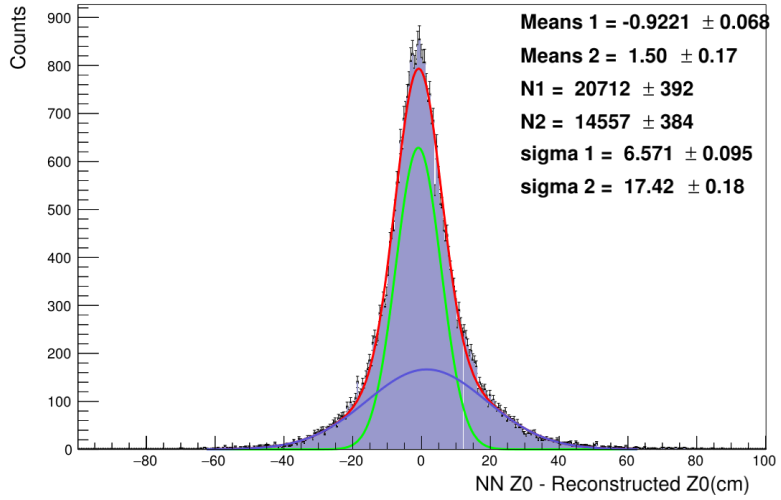


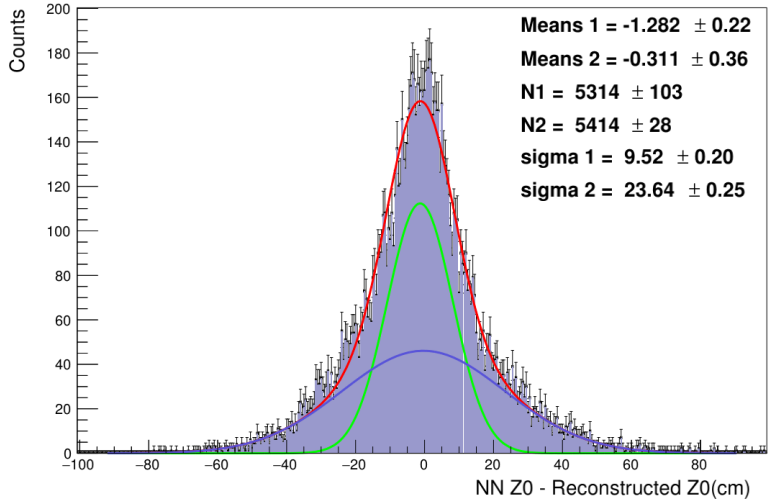
30<Z<40

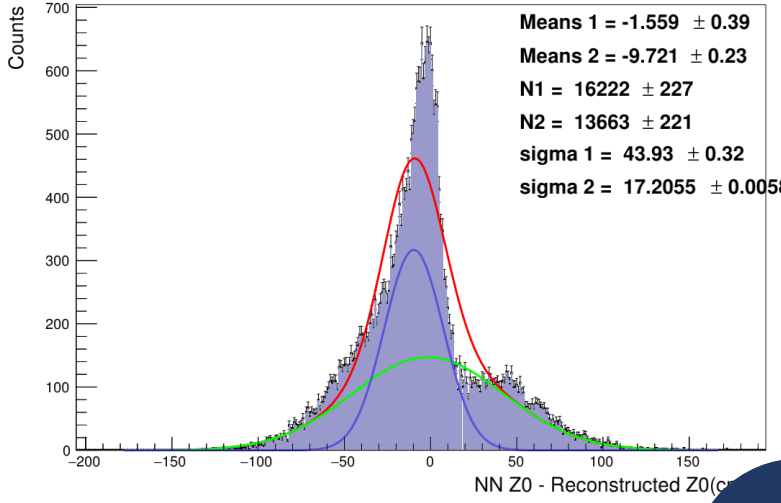


40<Z

Extra one wire



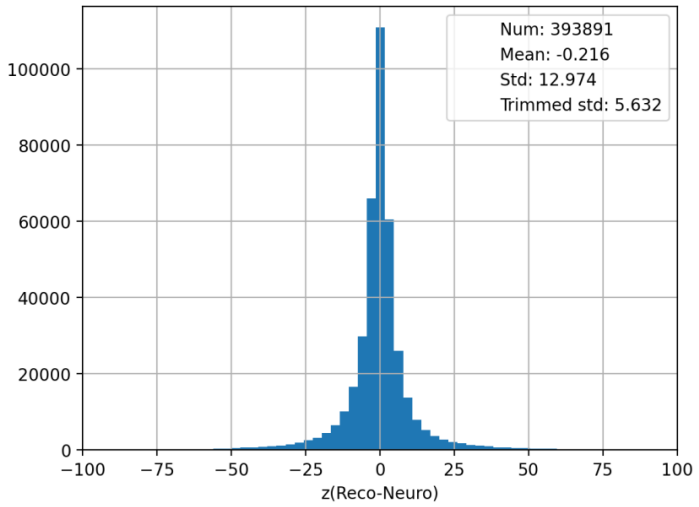


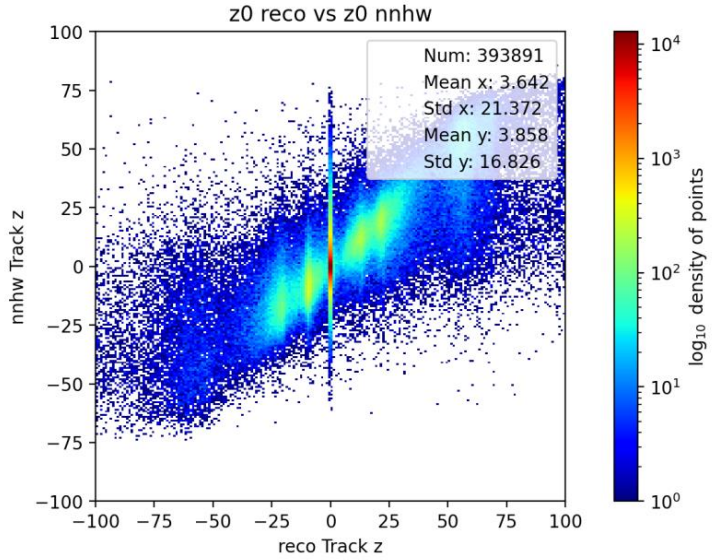


Still some “feed down” and feed up → leakage of training data?

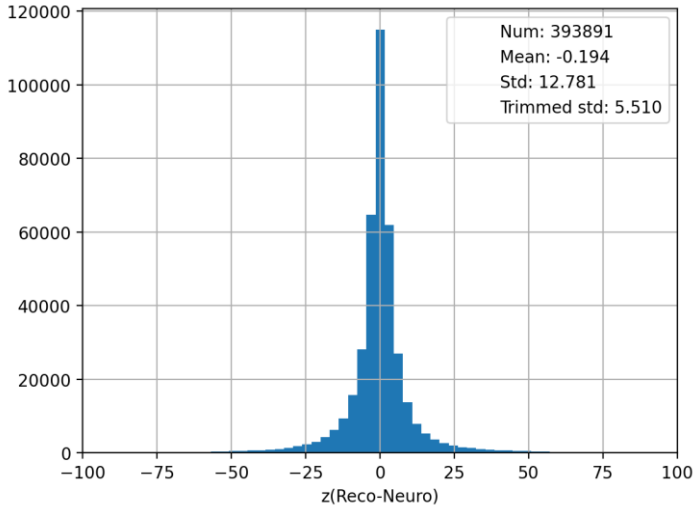
More Extra wires?

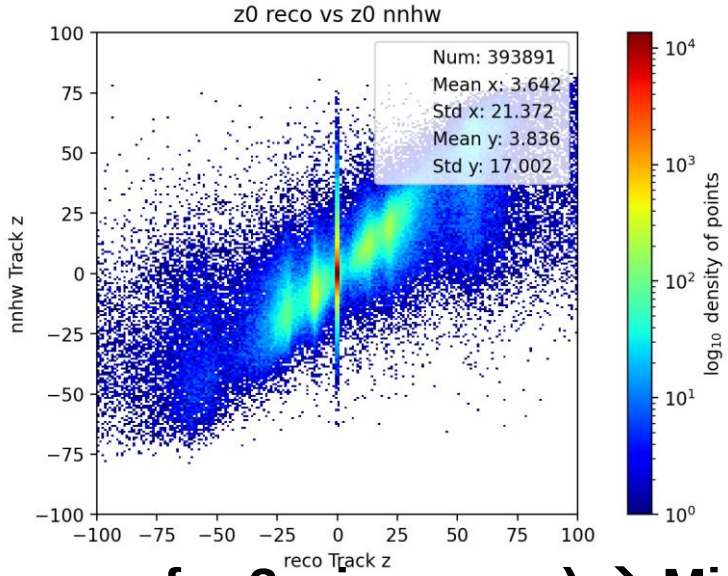
Extra one wire



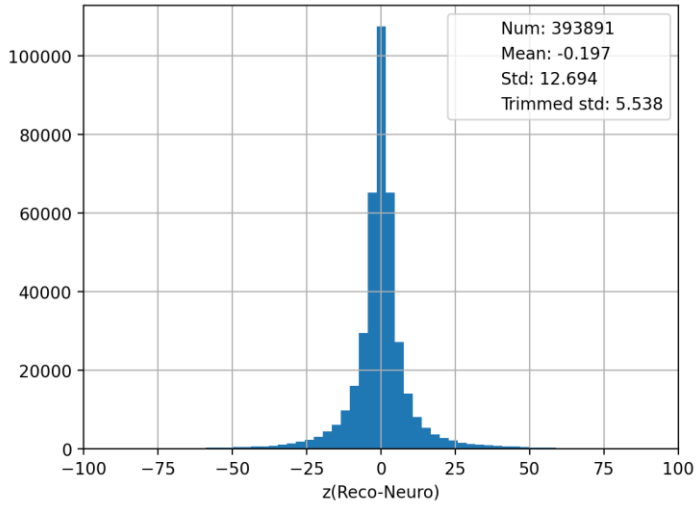


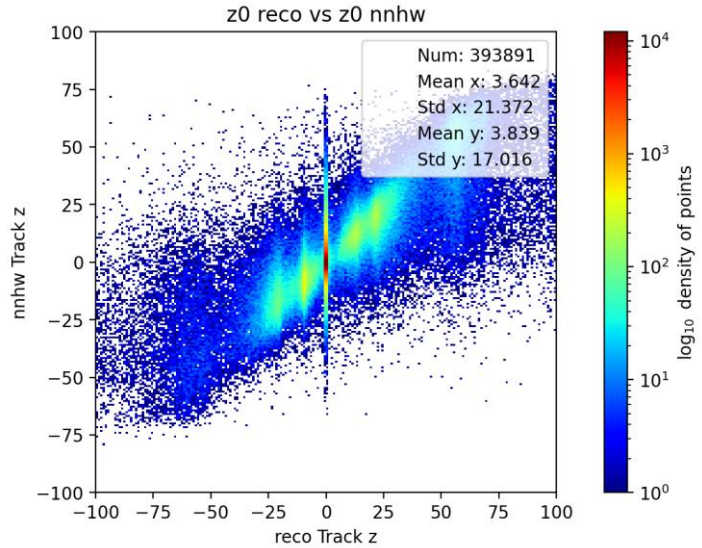
Extra two





Extra three

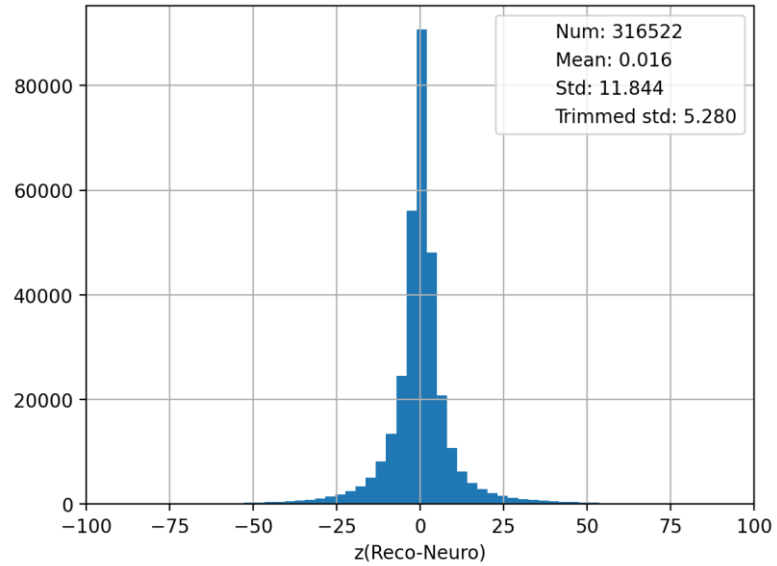




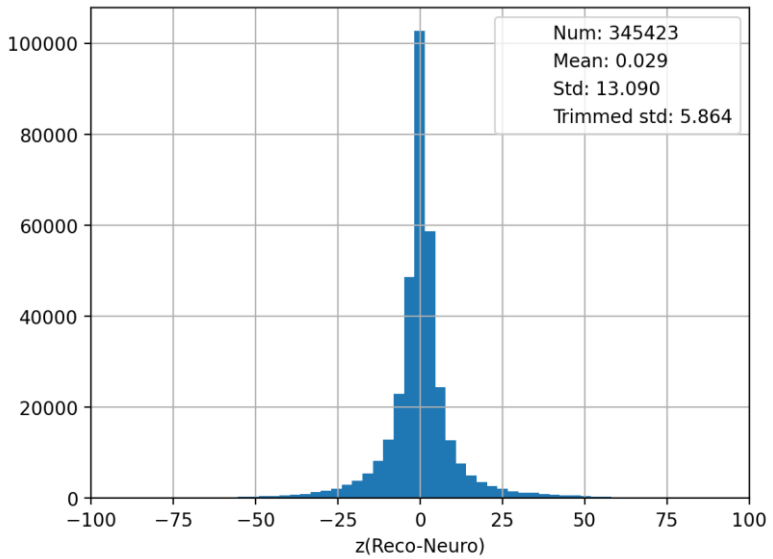
No large improvement (even worse for 3 wires case) → Might due to the L/R undetermined wires or not enough hidden layer/ hidden nodes

Difference between experts for extra 1 wire case

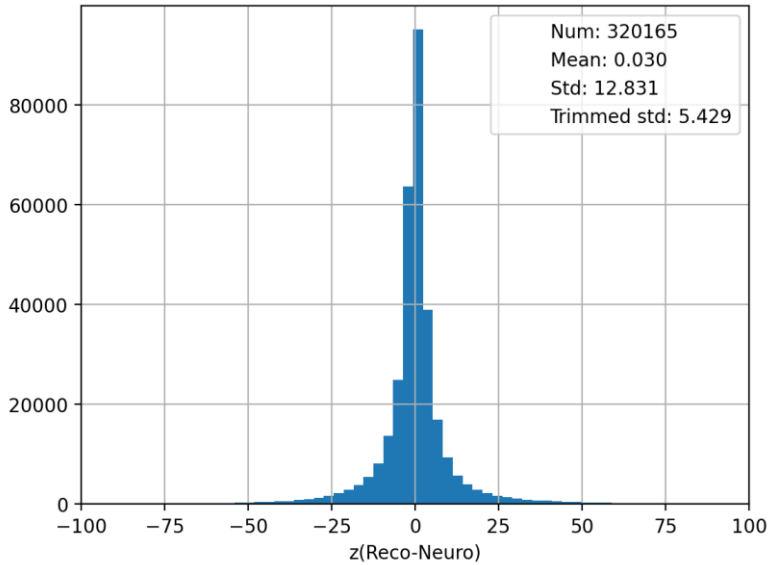
All SL have TS



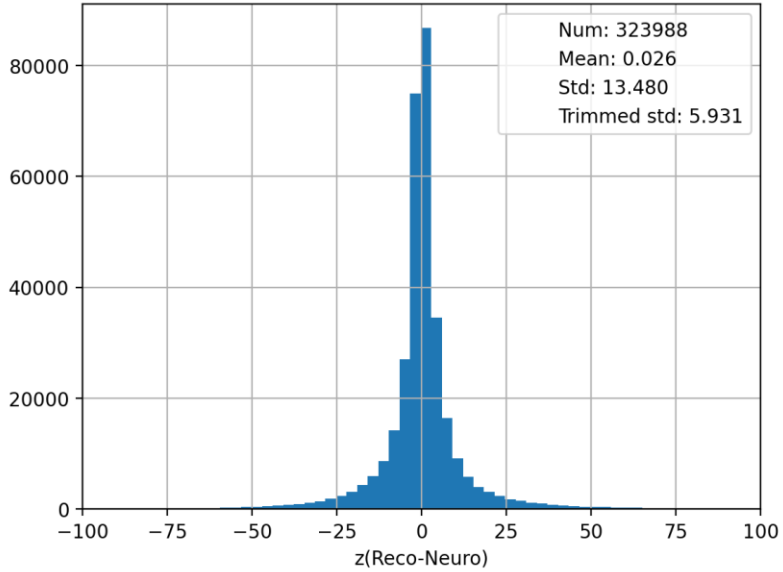
Missing SL 7



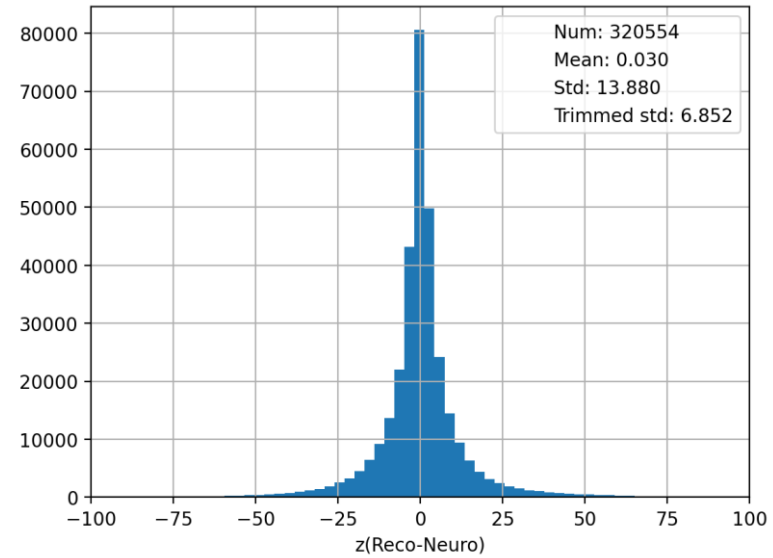
Missing SL 5



Missing SL 3



Missing SL1



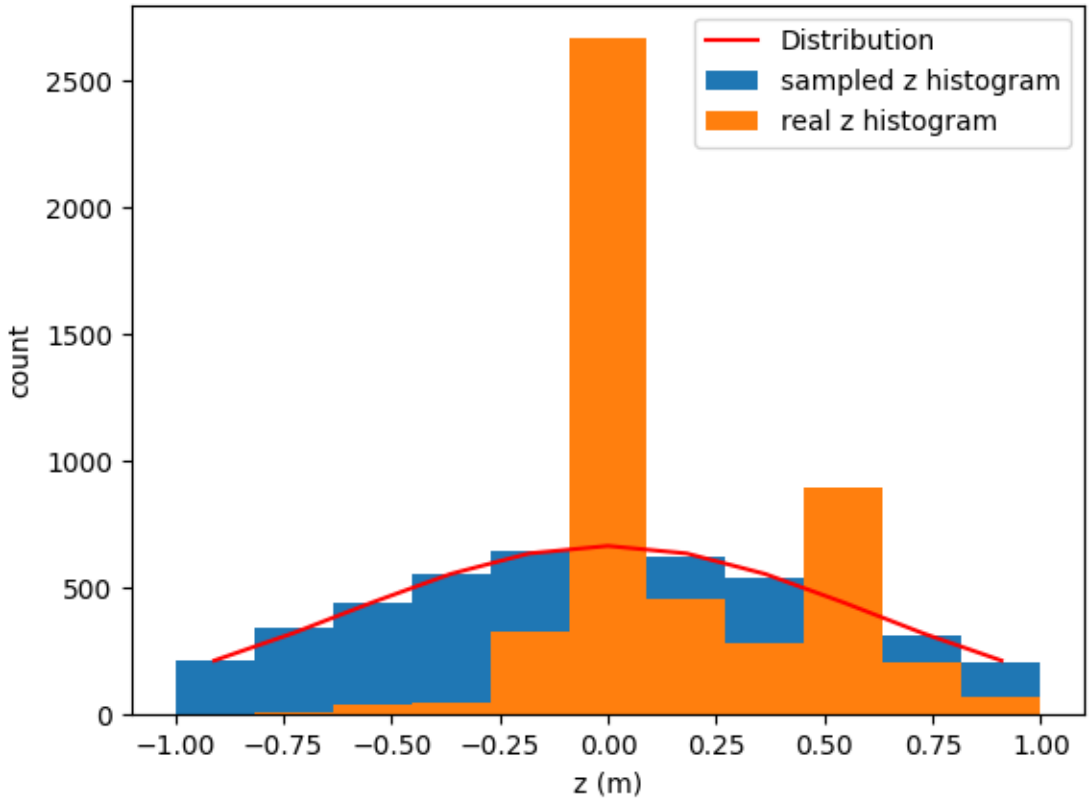
w/ missing SL1 still got worst result.

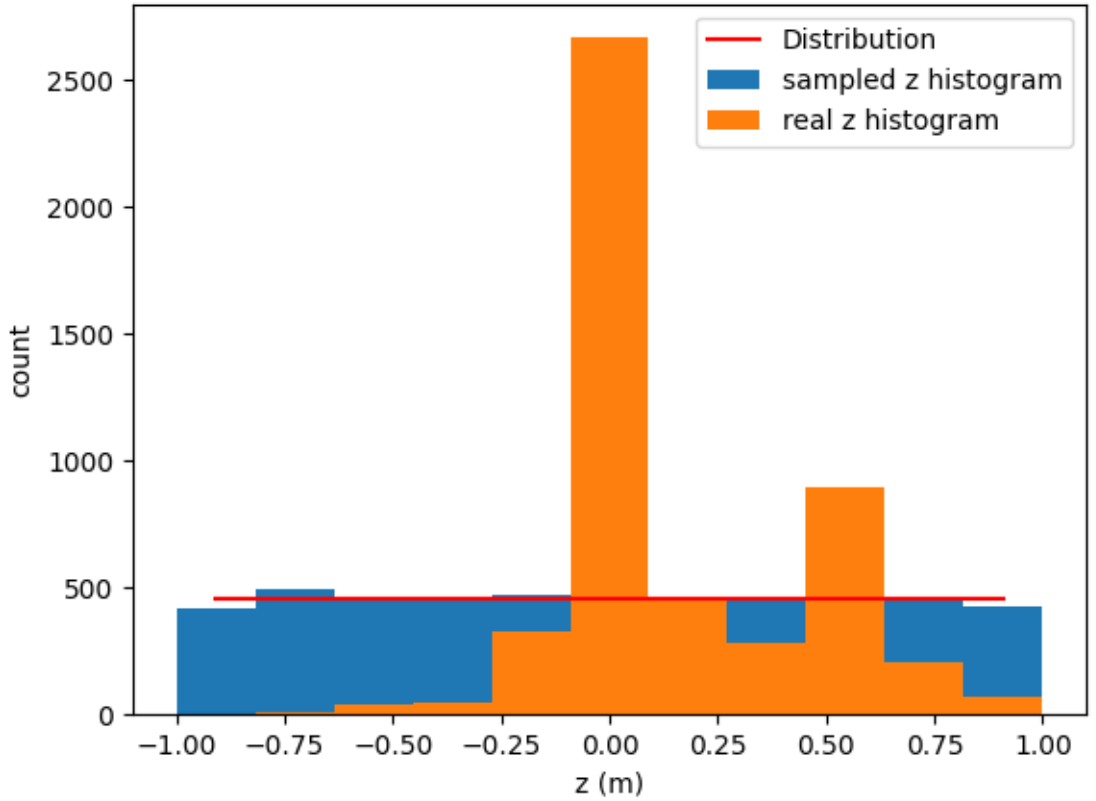
(However, expert 0 case dominate the events in exp26run1756-1780 >80%)

Reshape the training set?

We could reshape the data set to **randomly (uniform of follow gaus dist.)** pick up events at different z ↓

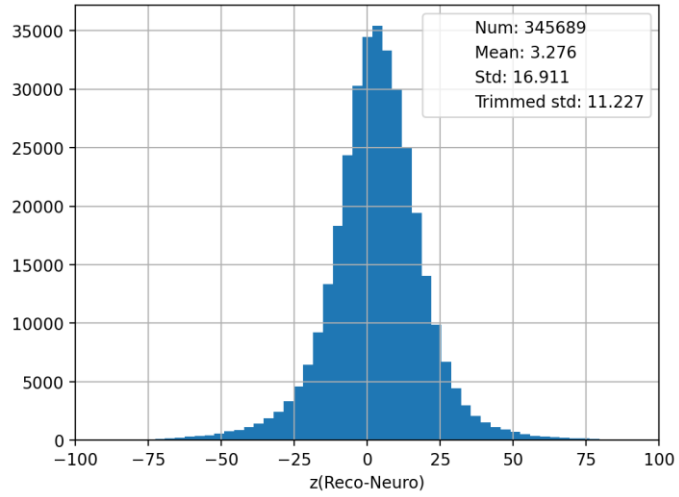
Still want to keep good resolution at IP→ not modified validation set

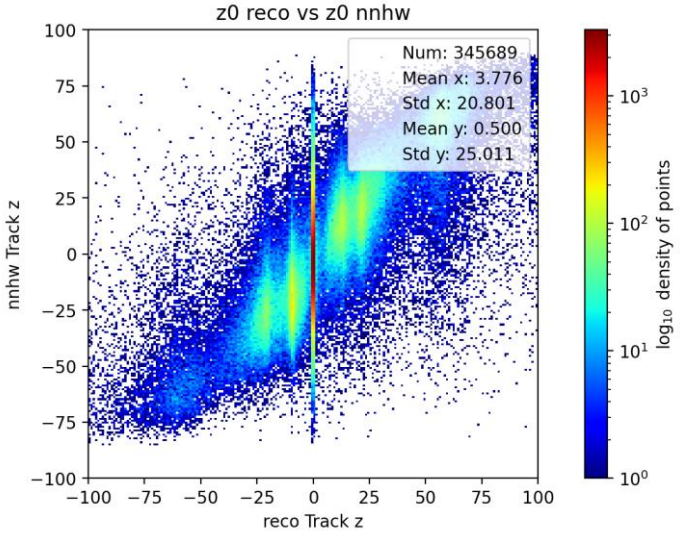




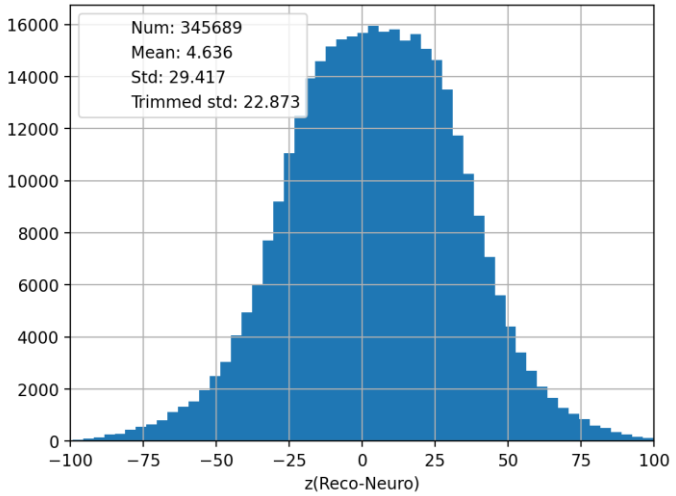
Reshape the training set?

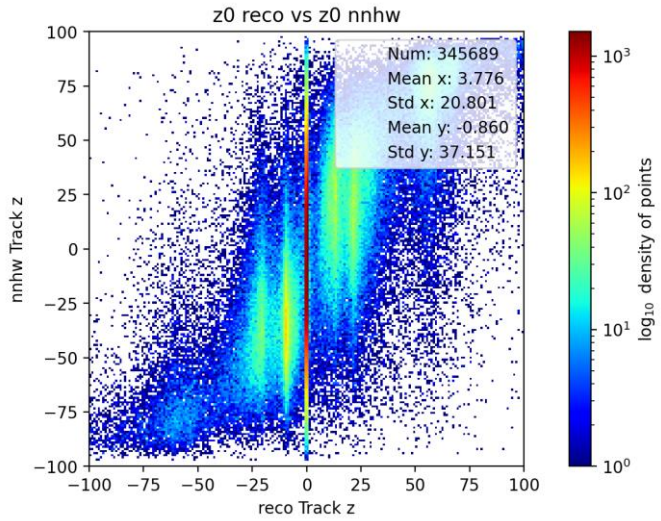
Norm distribution



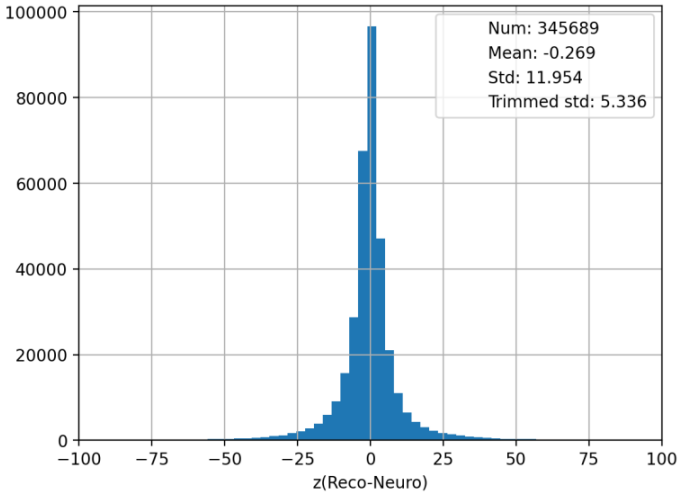


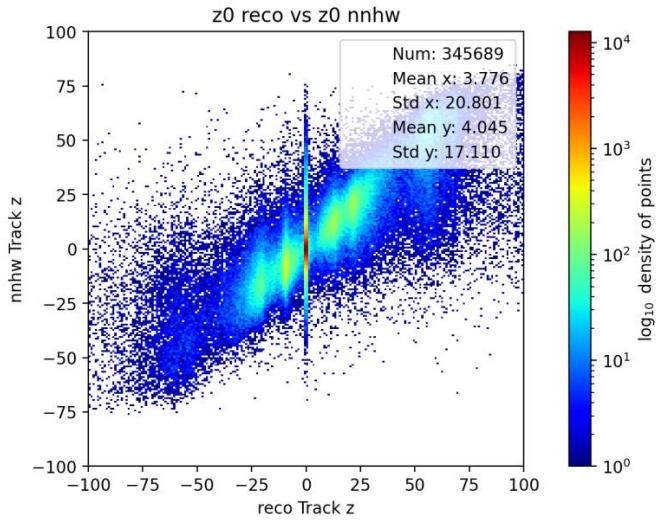
Uniform distribution





Norm Extra 1 Wires





Converge soon due unexpected increasing error in validation set…

Summary & Plan

Summary

a)Add 1 extra wire could make improvement for the CDCNN TRG

b)Retraining with recent data & pytorch would also improve CDCNN TRG

b) Feed down and feed up still exist –(reshape of dataset needed?)

c) More than one wire make little difference at current NN structure.

Plan

a) Adding ADC into data selection for TS or even wires

b) Try different Hidden layer & Hidden nodes for 2(3) extra wires case

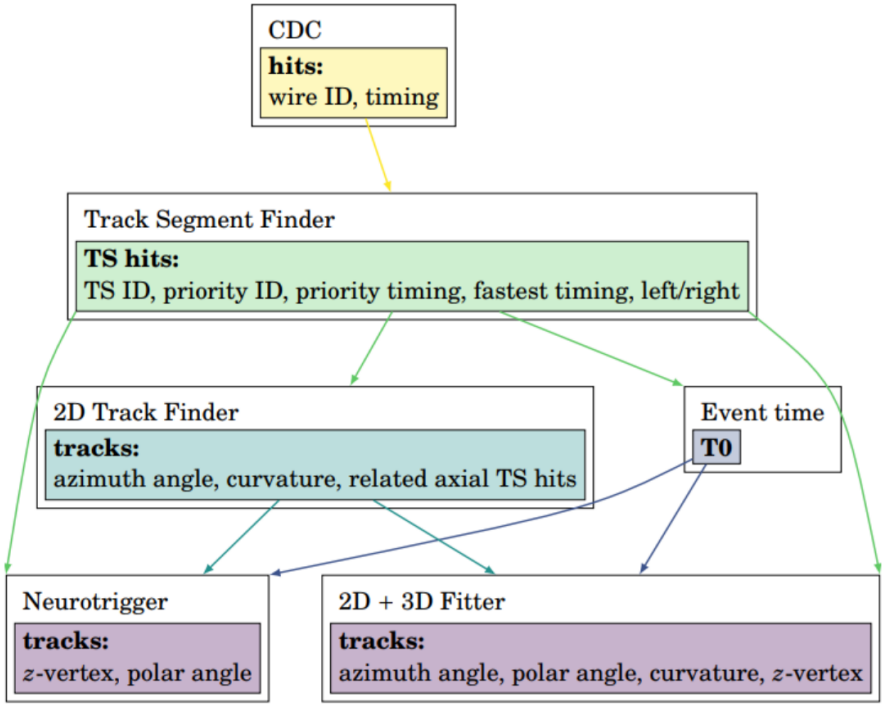
c) Categorize each parts contribution to trigger rate

d) Try to train a parallel NN for fake track

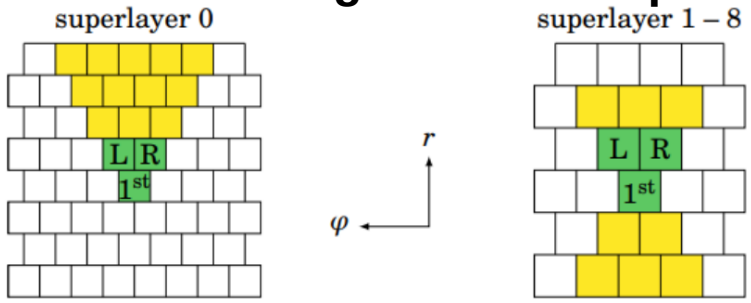
Thanks for your listening and attention!

BACK UP

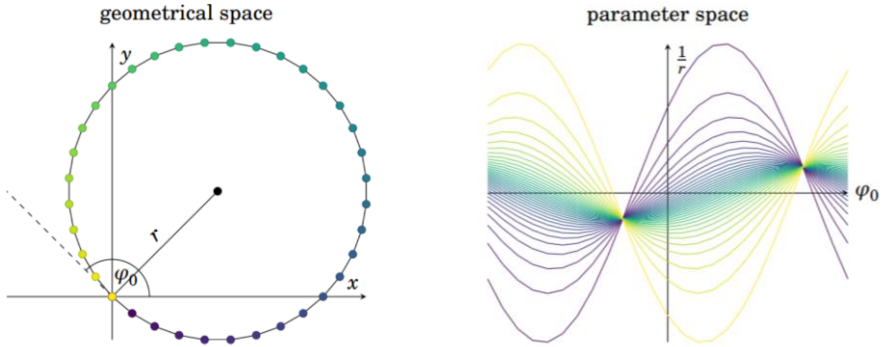
Introduction-CDC first level TRG



Track Segment build up



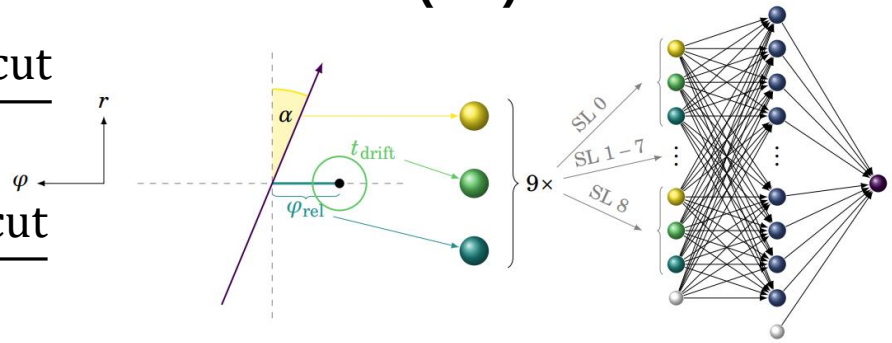
2D Track reconstructed (using hough transformation



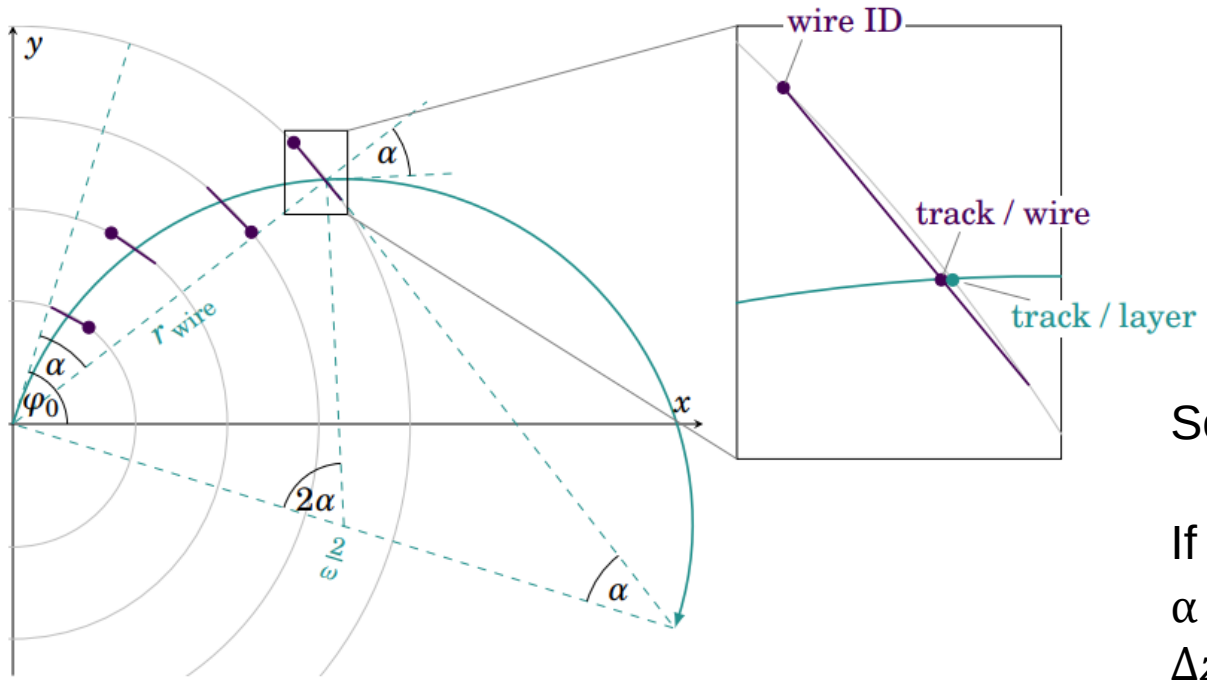
3D Neural Network (NN) to calculated z / θ

$$\text{g efficiency} = \frac{\#|z_0| \text{ from RecoTracks} < 1 \;\&\&\#\; |z_0| \text{ from CDCNNTrack} < \text{cut}}{\#|z_0| \text{ from RecoTracks} < 1}$$

$$\text{jected rate} = \frac{\#|z_0| \text{ from RecoTracks} > 1 \;\&\&\#\; |z_0| \text{ from CDCNNTrack} > \text{cut}}{\#|z_0| \text{ from RecoTracks} > 1}$$



How to calculate out z0&z0 uncertainty



With direct cross stereo wire:

$$\phi_{cross} \sim \phi_0 - \arcsin\left(\frac{1}{2} r_{wire}\omega\right) \equiv \phi_0 - \alpha(r,\omega)$$

$$\frac{z_{cross} - z_B}{Z_F - Z_B} = \frac{\phi_{cross} - \phi_B}{\phi_F - \phi_B}$$

$$z_0 = z_{cross} - \cot\theta_0 \frac{2\alpha}{\omega}$$

Drift time would influence:

$$\phi_{hit} = \phi_{wire} \pm \arcsin\left(\frac{v_{drift} t_{drift} cos\alpha}{r_{wire}}\right)$$

$$r_{hit} = r_{wire} \pm v_{drift} t_{drift} sin\alpha$$

So the δt_{drift} would influence ϕ_{cross} and r_{wire}

If we ignore r_{wire} comparing with δt_{drift}, (with small α and large P_t)
Δz_0 could be consist of Δz_{cross} (from 3D Fitter /NN)
And $\Delta(\cot\theta_0 \frac{2}{\omega})$ (From 2D track)

And: $$\Delta z_{cross} = \frac{r_{wire}}{\sin\psi}\sqrt{(\Delta\phi_{cross})^2 + (\Delta\phi_B)^2}$$

Still, ignore r_{wire} comparing with δt_{drift},

$$\Delta\phi_{cross} \times \sim 0.03° - 0.08° \ (varied\ from\ r_{wire})$$

$$\Delta\phi_B \sim \frac{v_{drfit} cos\alpha}{r_{wire}} \Delta t_{drift}$$

MC Test

MC :

Train Sample

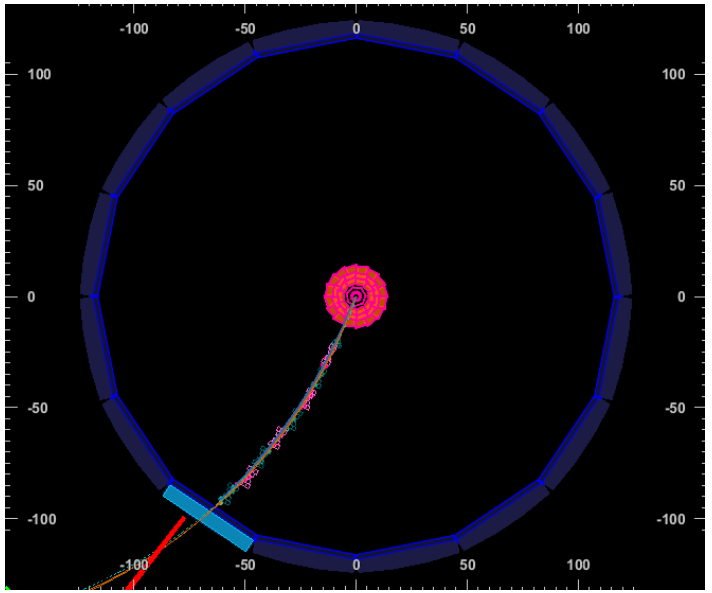
- **Particle gun:**
- **muons; single tracks;**
- **Pt :[0.3 GeV,3 GeV], uniform;**
- **Φ: [0, 360],uniform;**
- **θ: [0,170], uniform;**
- **Vertex z0: [-50, 50], uniform;**
- **N events: 300k**

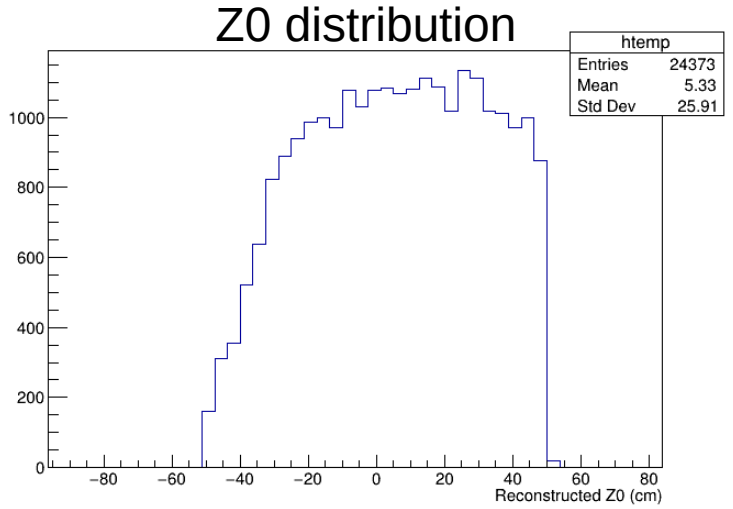
Validation Sample:

- **Same config;**
- **N events: 20k**

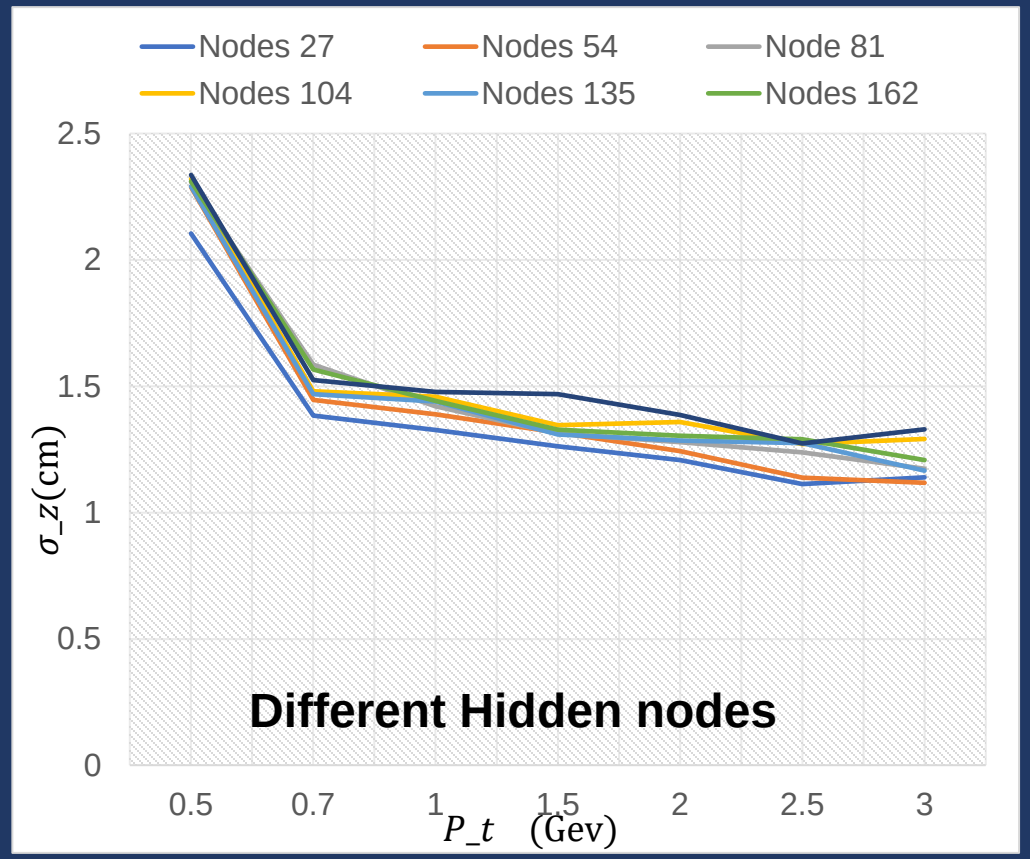
Test Sample:

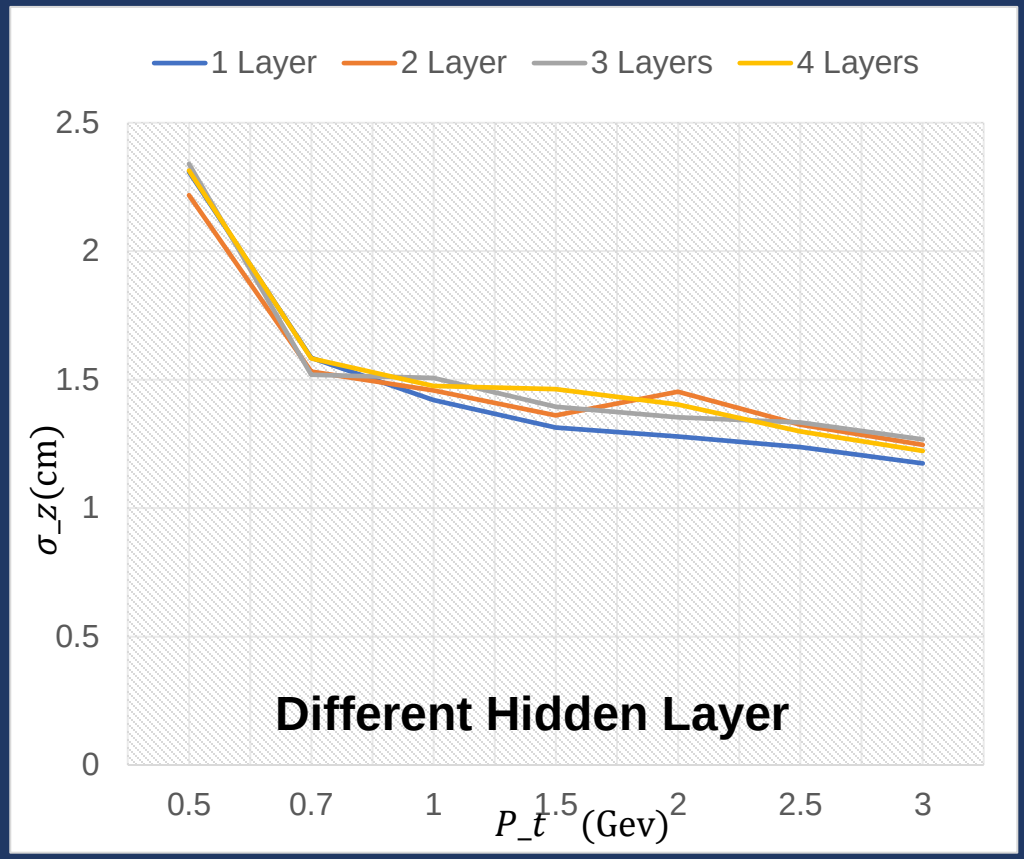
- **Same config;**
- **N events: 50k**





Hidden Layer



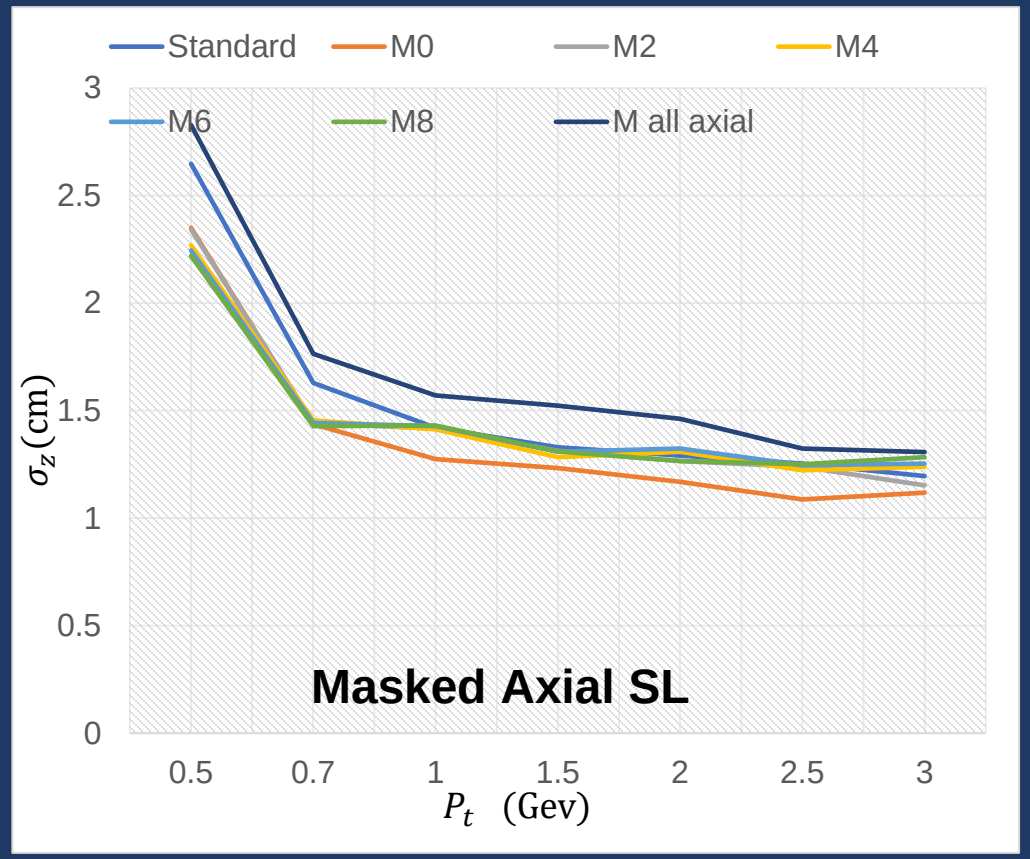


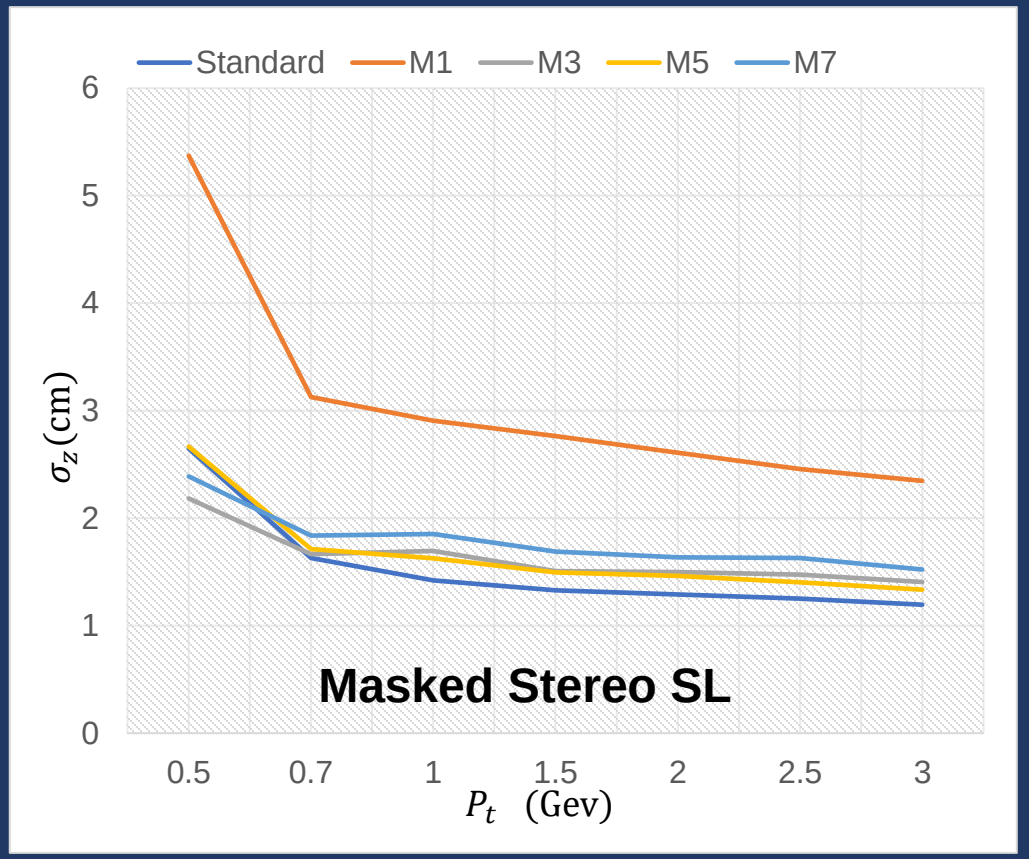
Trained with MC, event t0 =0.

Different hidden Layers / nodes do not make large difference in standard model

Add more wires do not induce other relationship, keep hidden layer as before.

Masked Super Layer

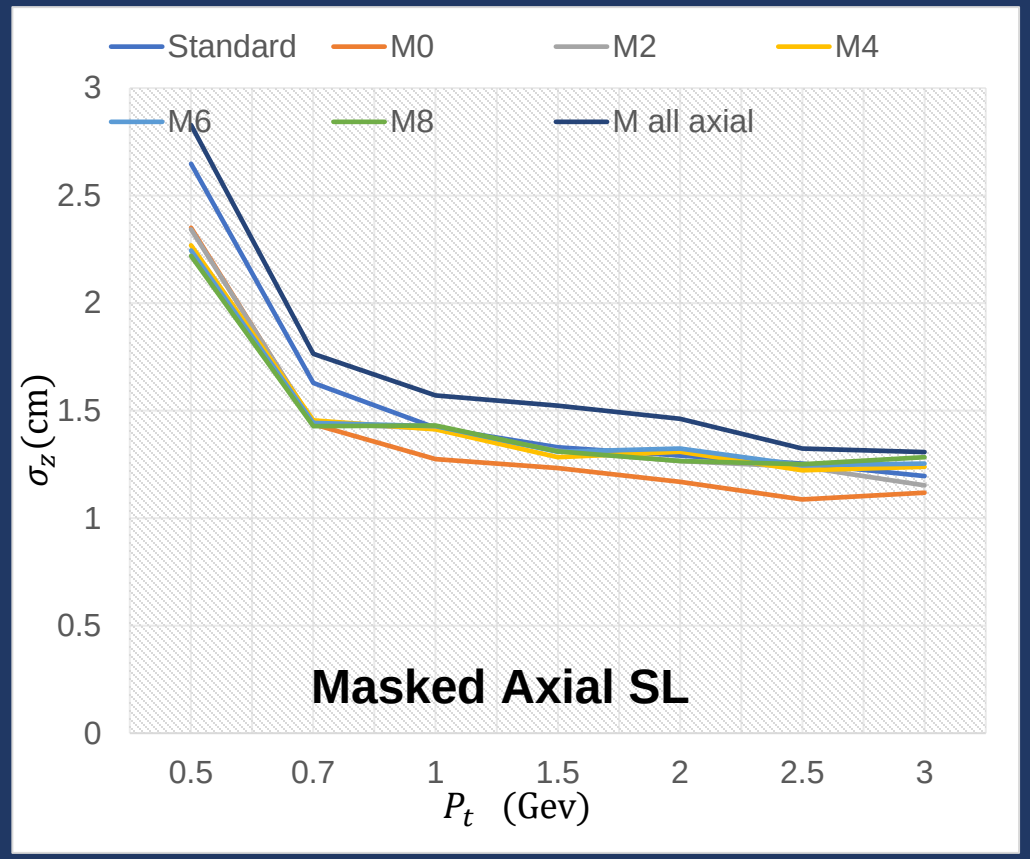


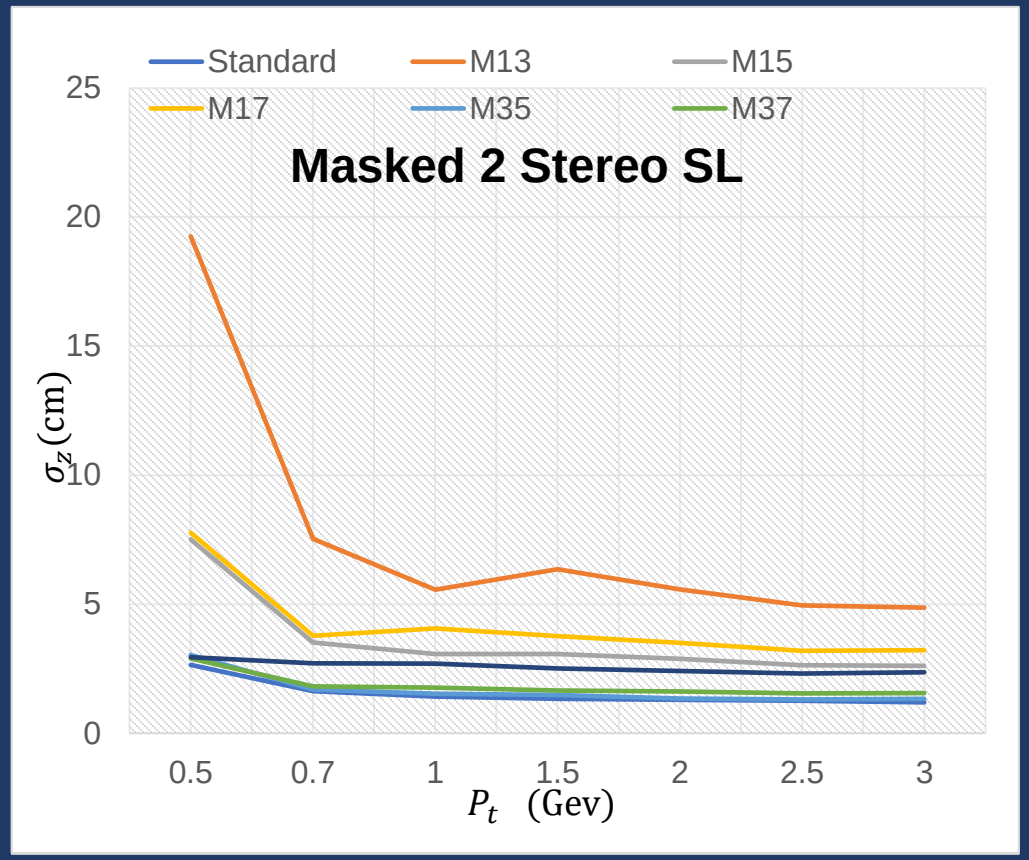


To see the importance of each super layer, masked each one for the training & testing for NN.

Axial layer contribute little to the NN, even masked all, resolution decrease little

Masked Super Layer

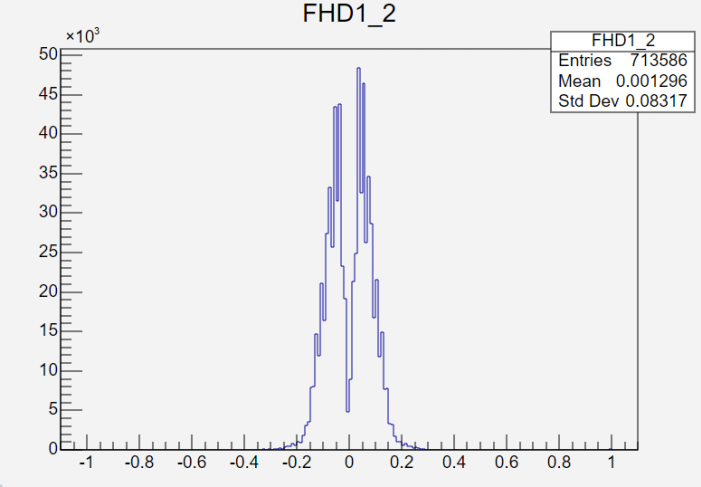




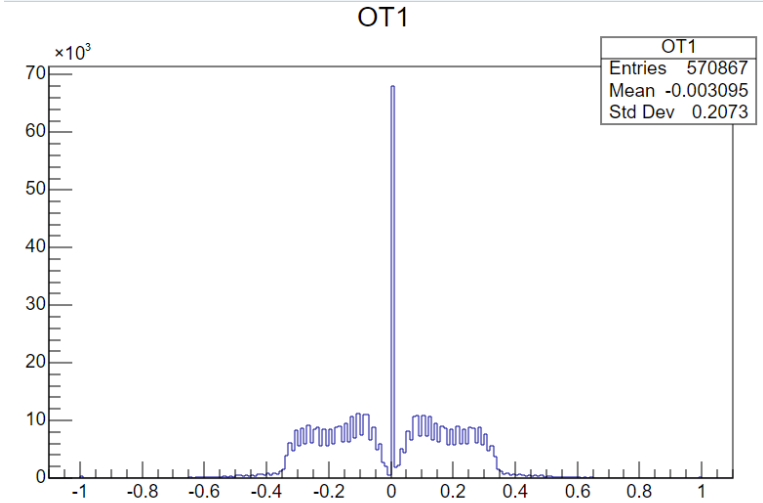
To see the importance of each super layer, masked each one for the training & testing for NN.

Axial layer contribute little to the NN, even masked all, resolution decrease little

Input Parameters

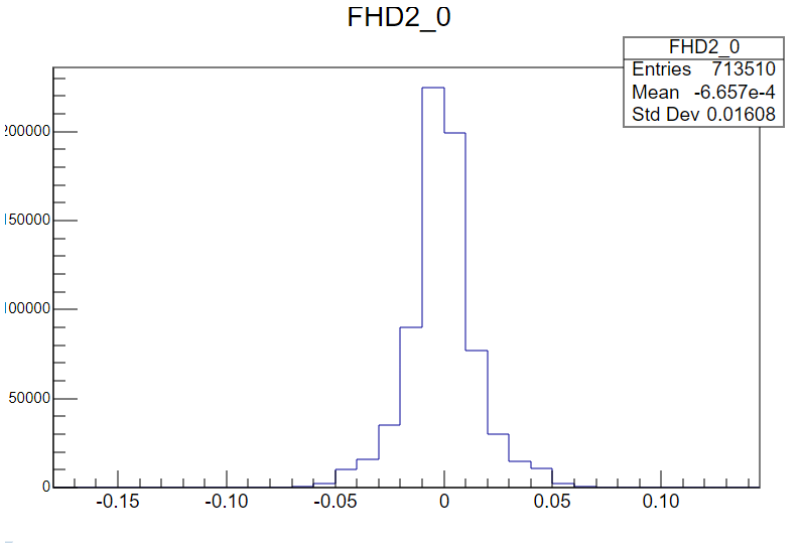


Extra T

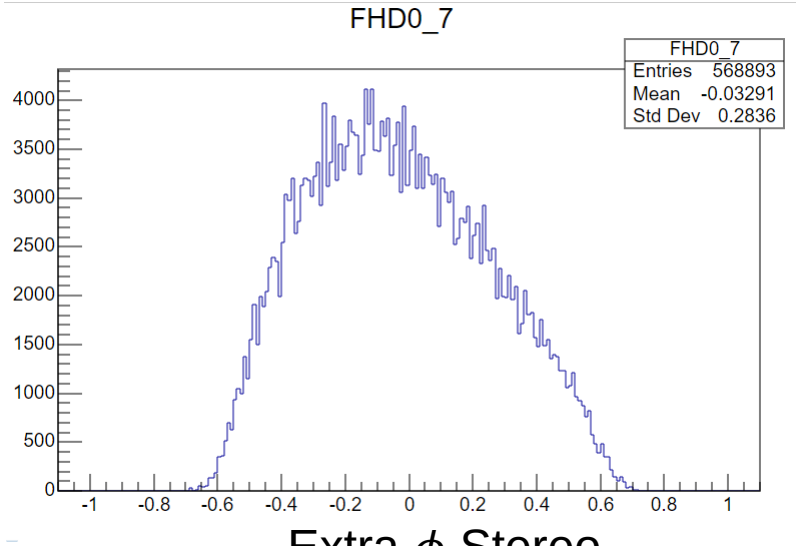


Origin T

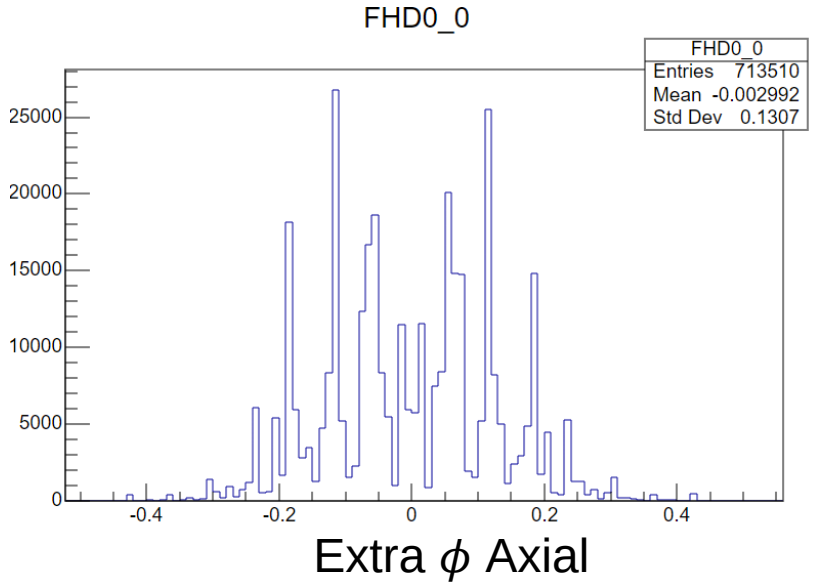
For exp26run1771



Extra α



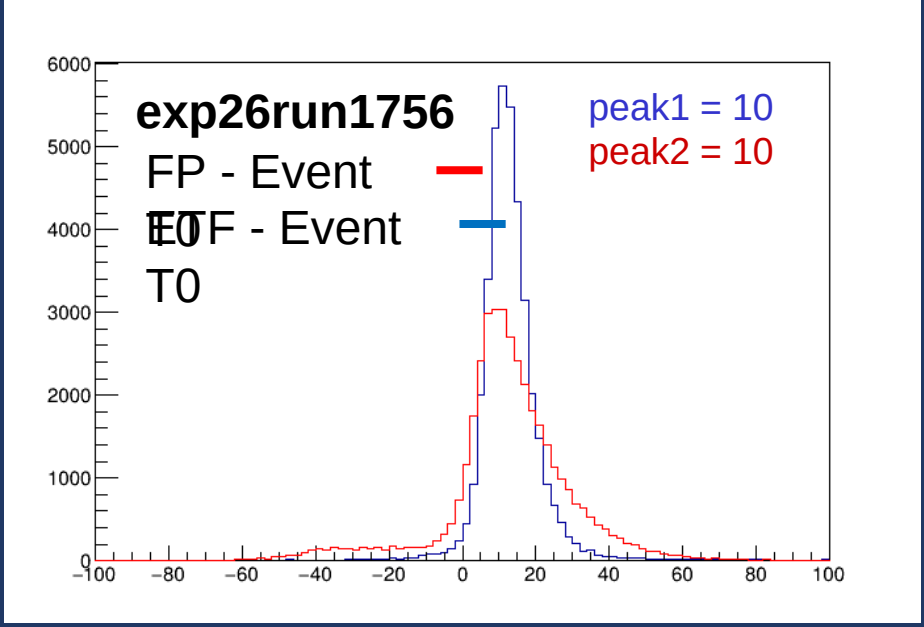
Extra ϕ Stereo



Extra ϕ Axial

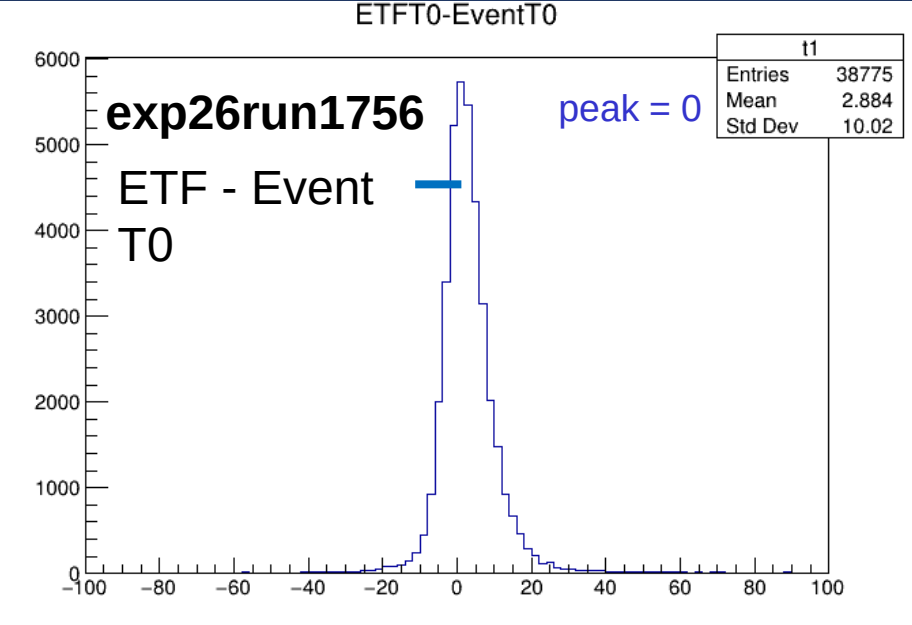
ETF-offset

```
addParam("offset", m_offset,
         "Set certain time offset for ETFHough simulation"
         "Default as 0", 0);
```



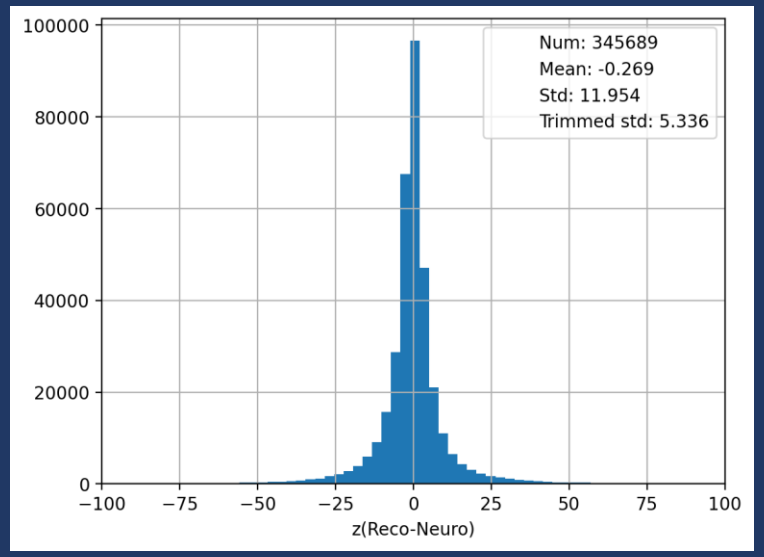
After

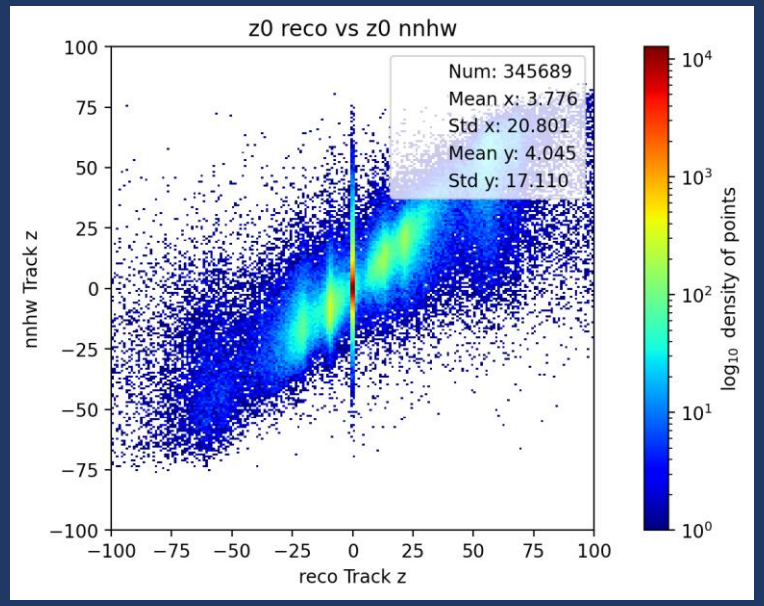
Offset = -10 ns



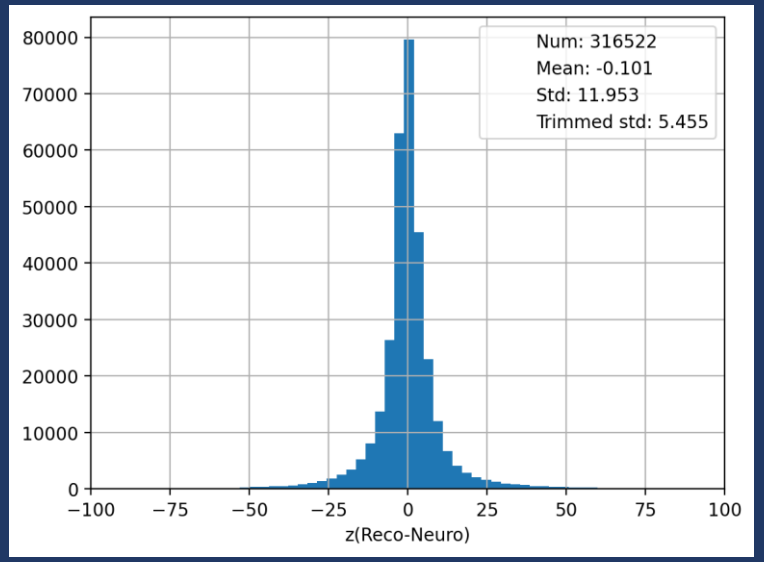
After ETF offset 1 wires expert 0

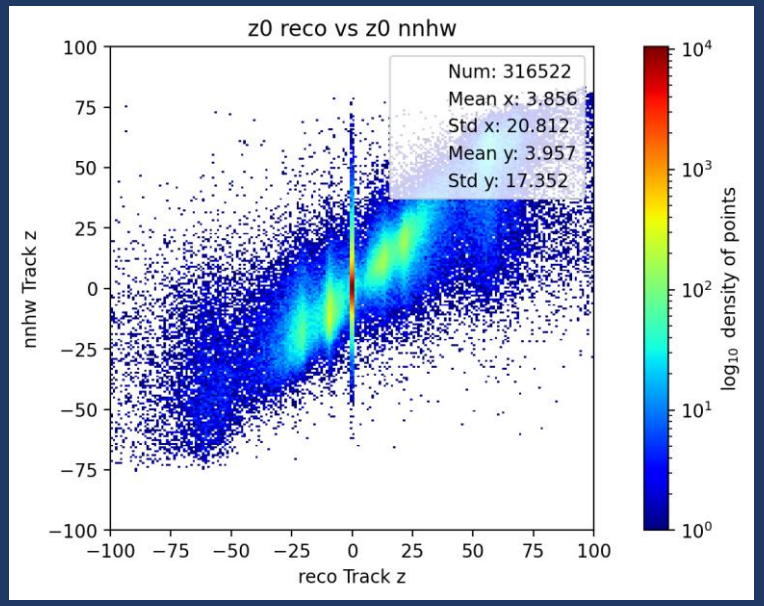
Before offset





After offset





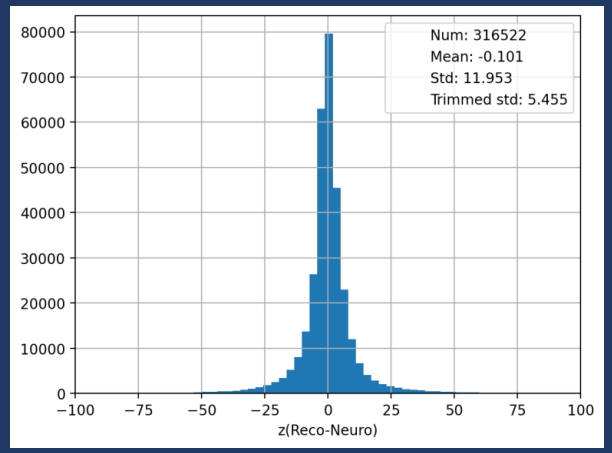
No difference
--As expected: NN could learn the offset

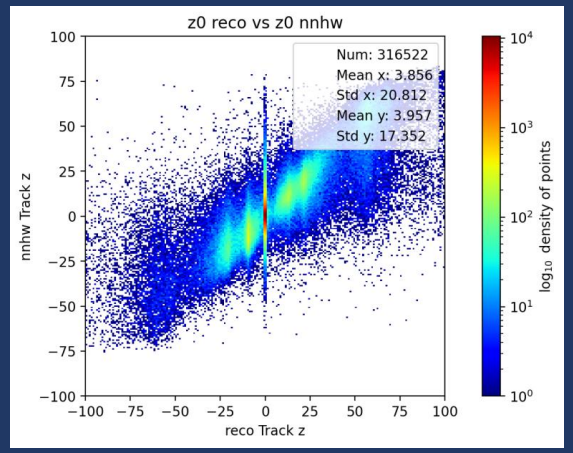
Step learning rate?

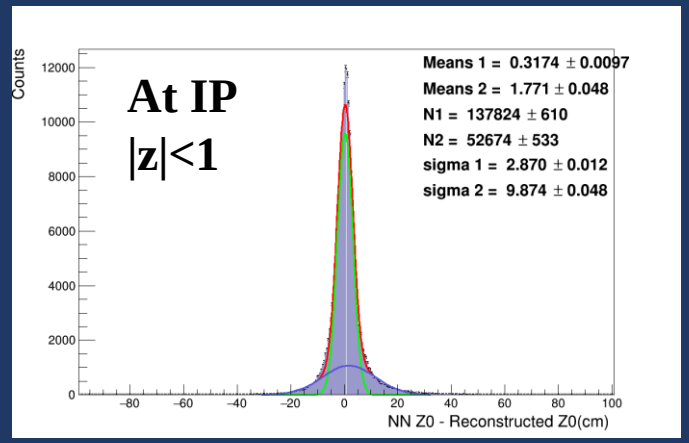
Question: Training error will start to oscillate after a few hundreds epoch → try to adjust learning rate to improve it more deeply.

First attempt: learning rate * 0.2 at every 200 epoch

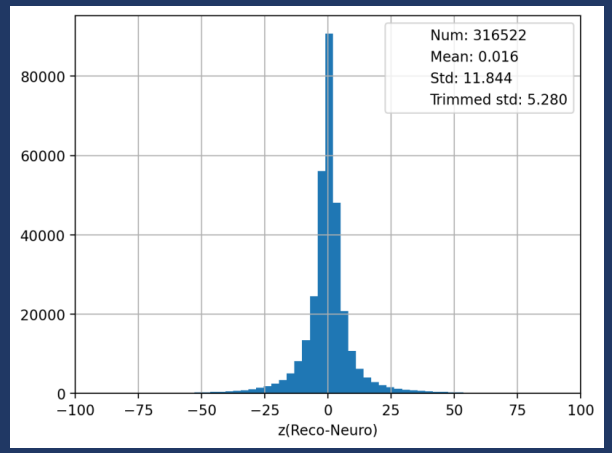
before

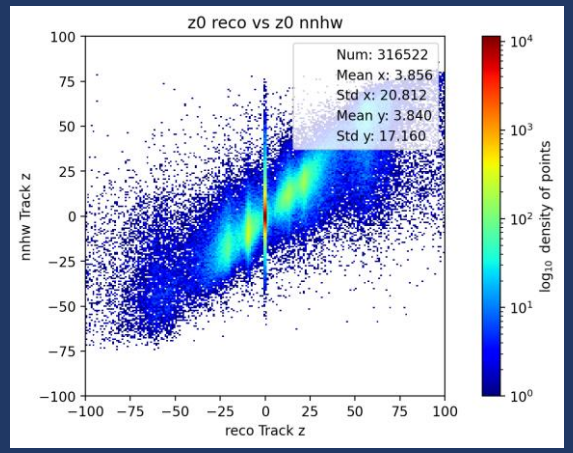


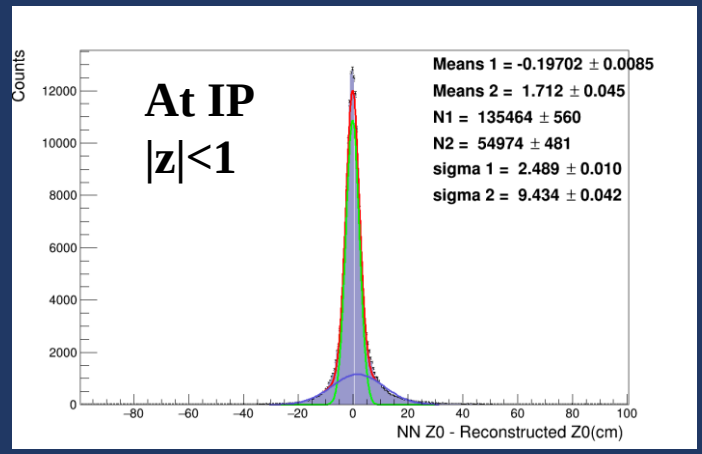




After

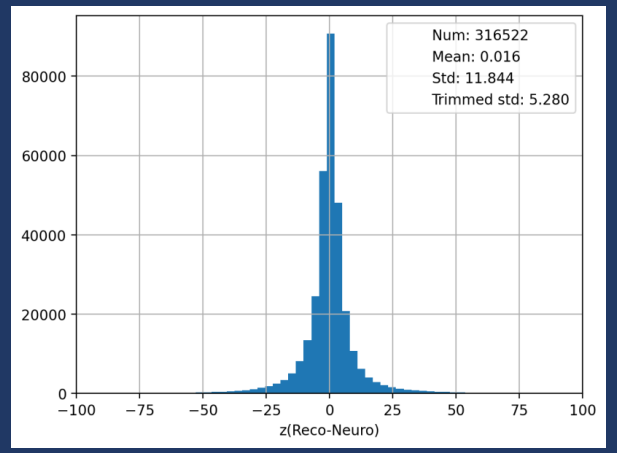


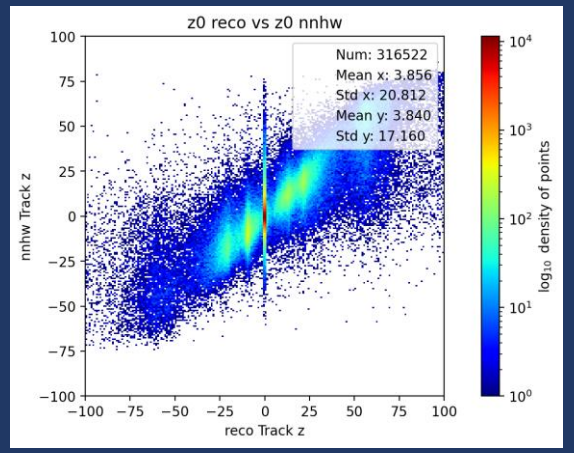


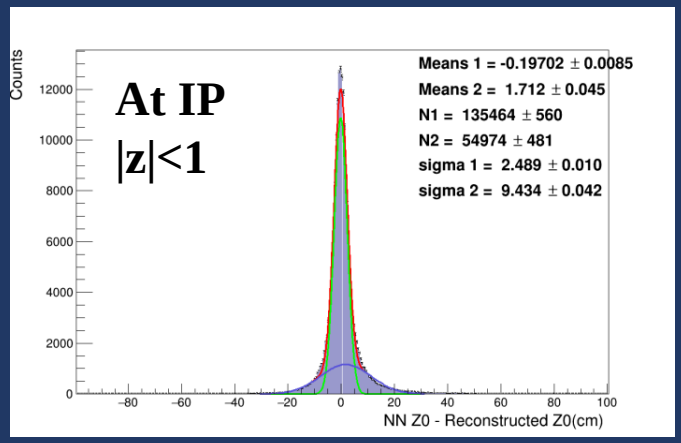


More wires?

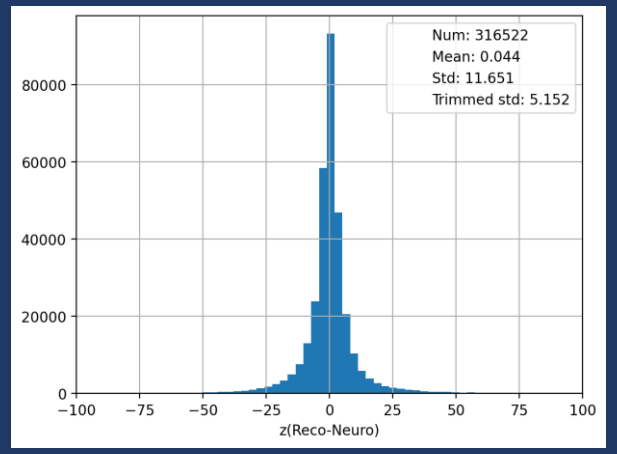
Wire 1

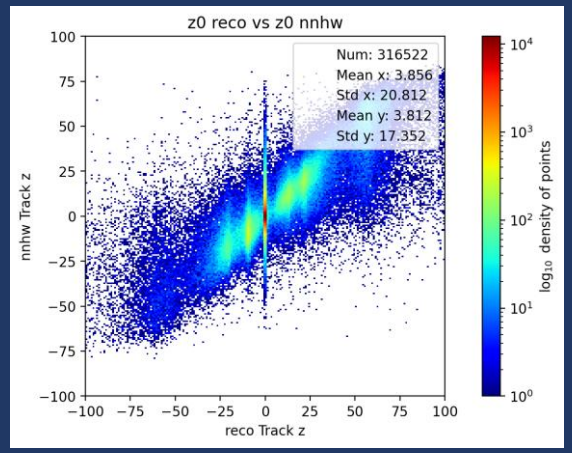


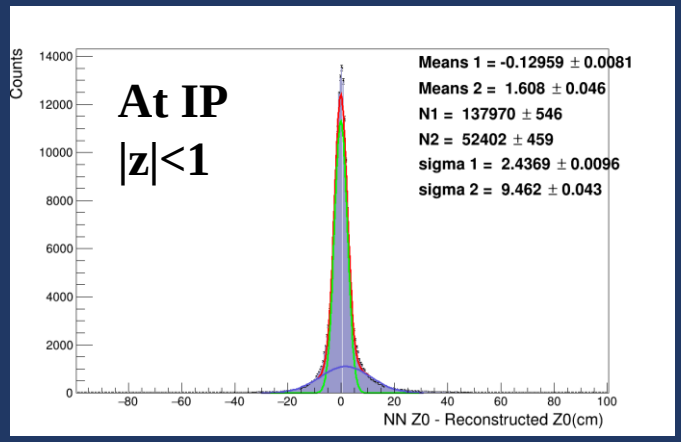




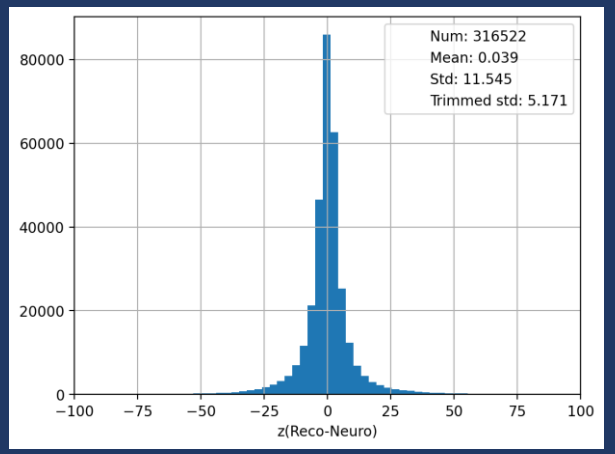
Wire 2

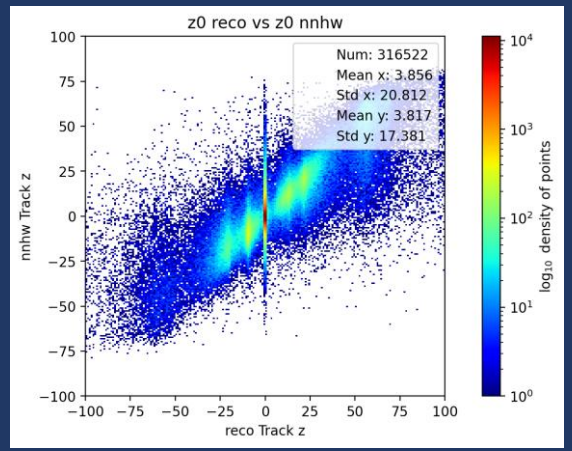


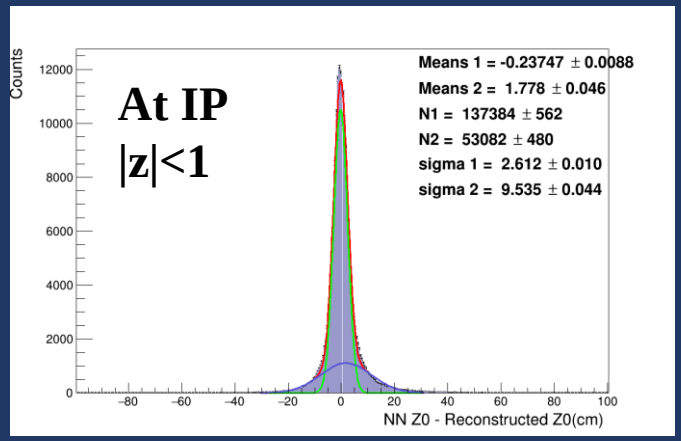




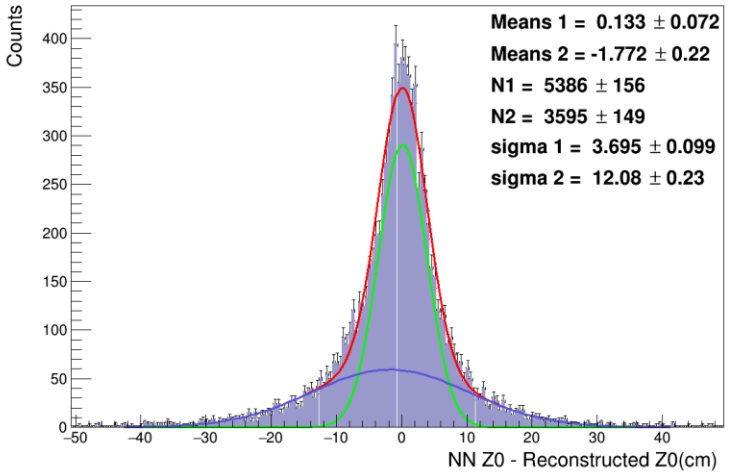
Wire 3

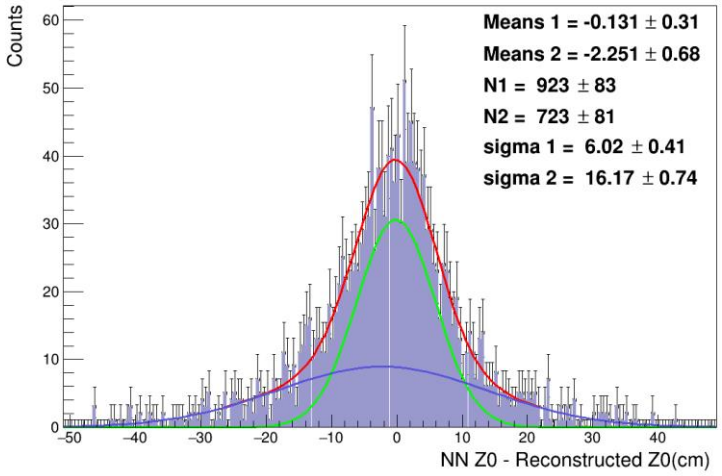


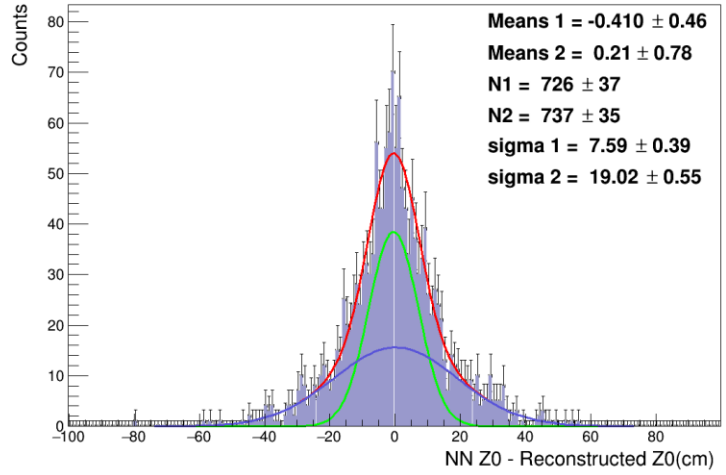




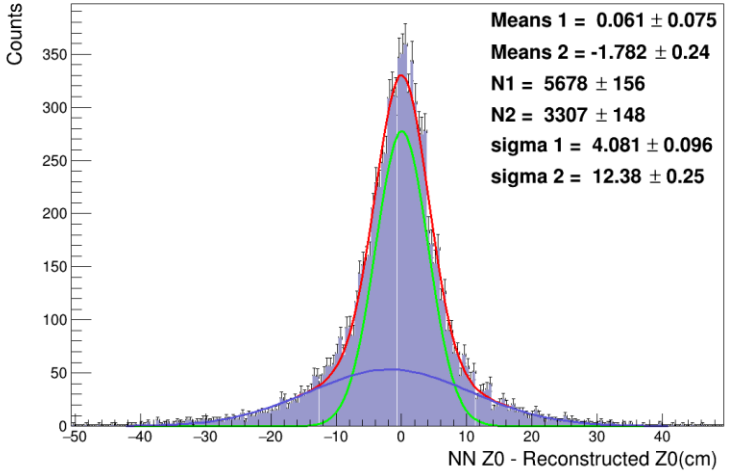
Detail result compare with z0 -- OLD FANN

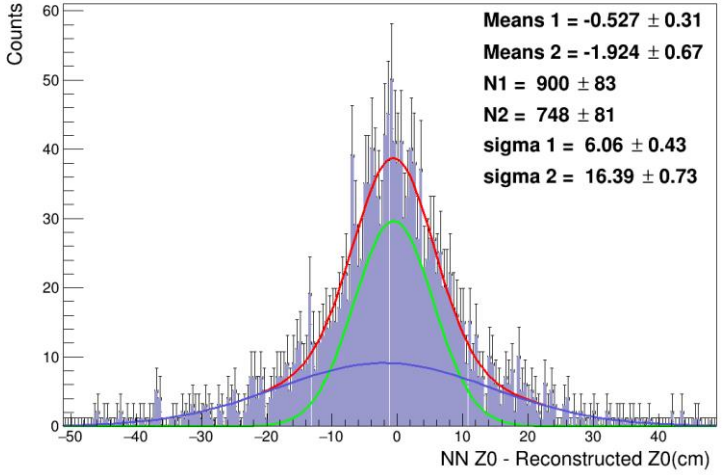


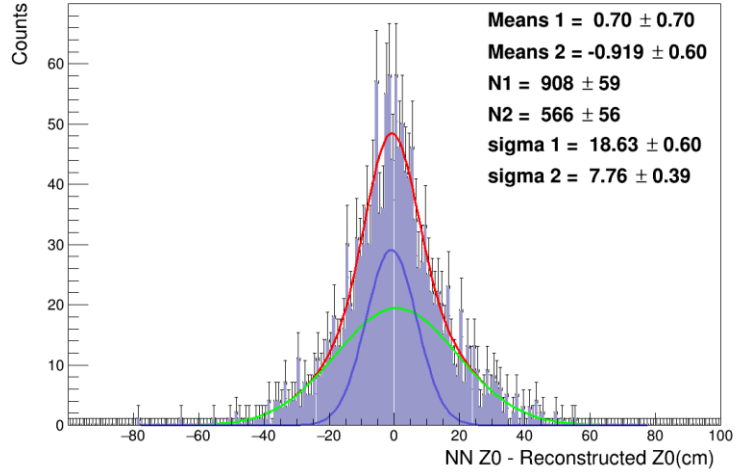




Wire1







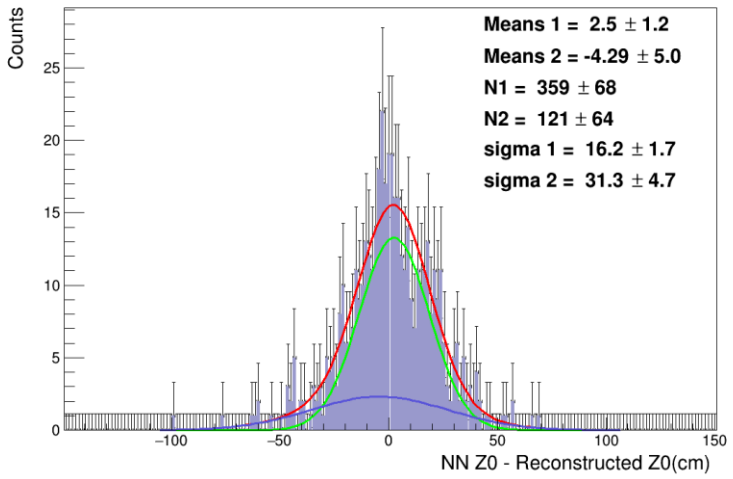
Standard

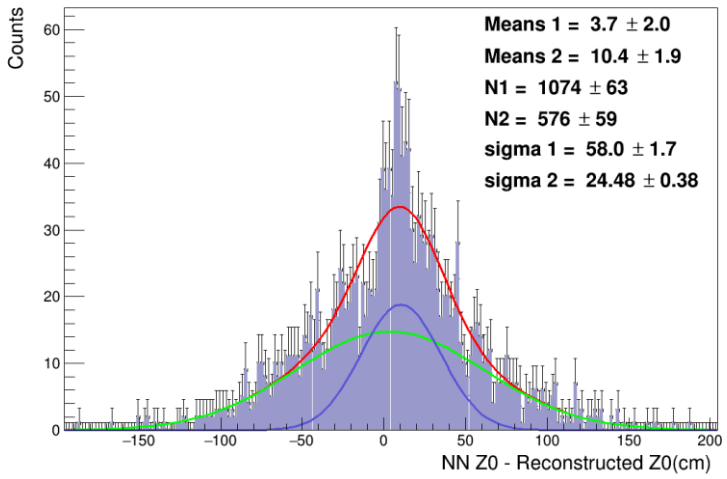
0-10

10-20

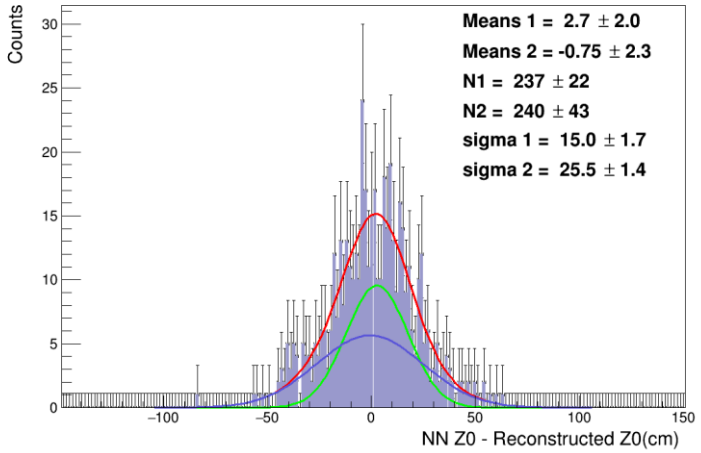
20-30

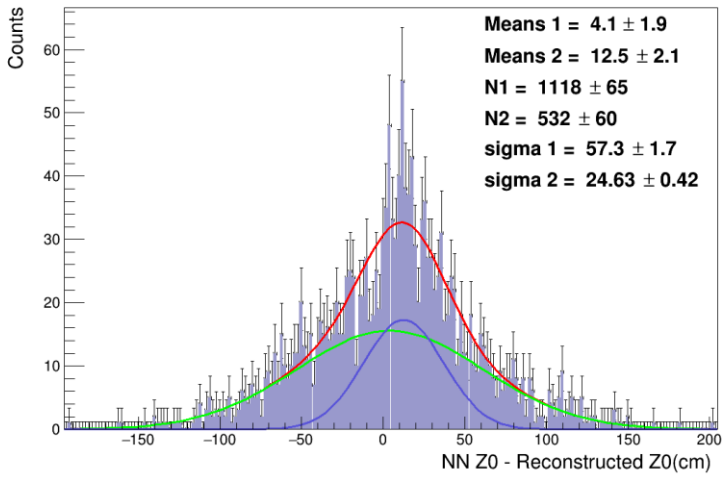
Detail result compare with z0-- OLD FANN





Wire1





Standard

30-40

40+

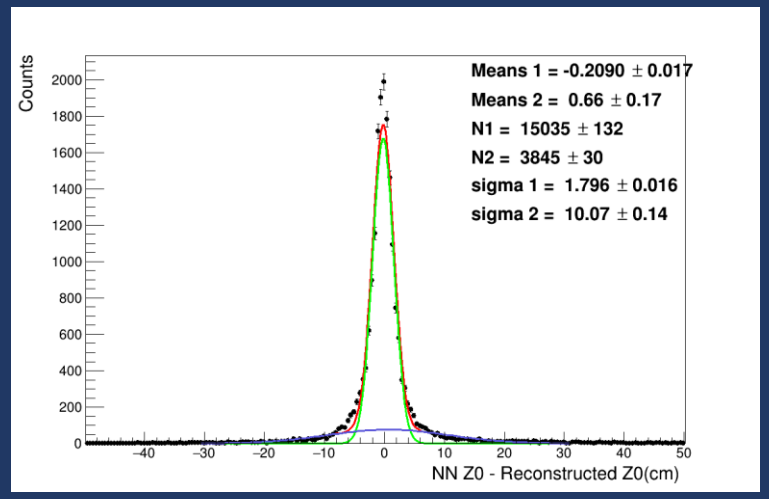
Real data test –Train with exp24 run 2004

Train NN with exp24 run2004 and exp26r1968

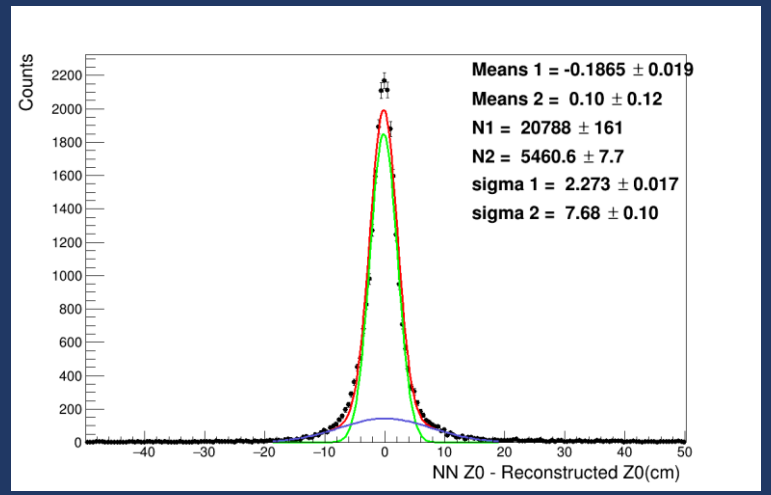
Test with exp24 run2004(sorry not unpacked another one for test)
And exp26 run 1777 (which use for trigger study with z0 in any range)

exp24 run2004

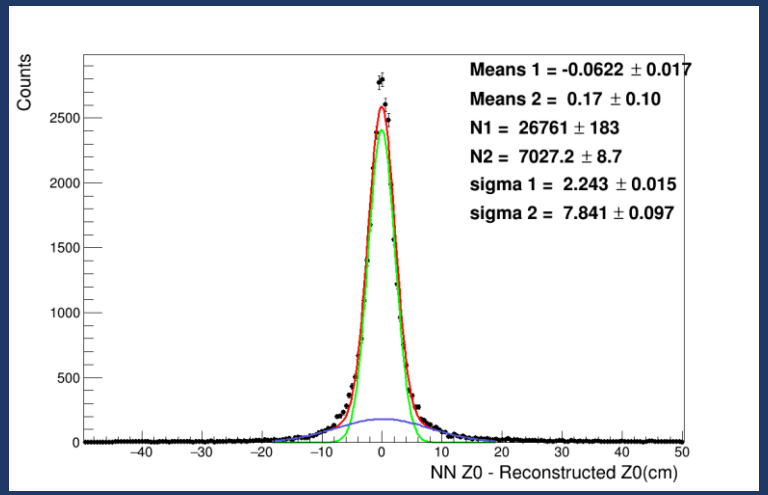
Origin with ETFHough



Wire 1 with ETFHough



Wire 2 with ETFHough



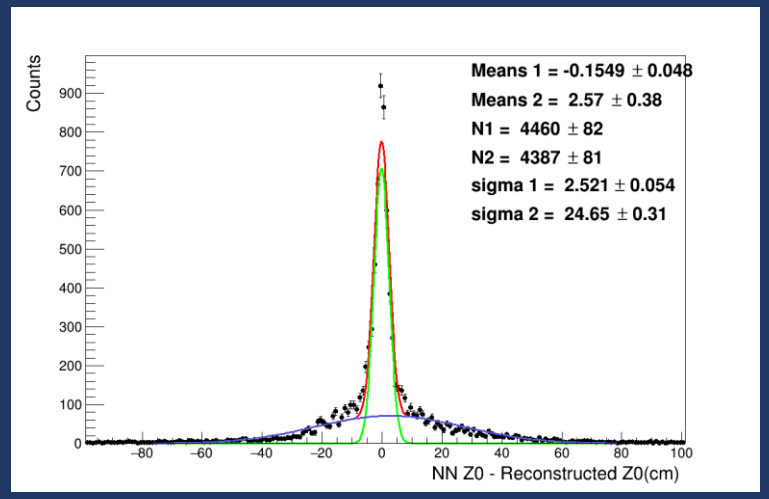
Real data test –Train with exp24 run 2004

Train NN with exp24 run2004 and exp26r1968

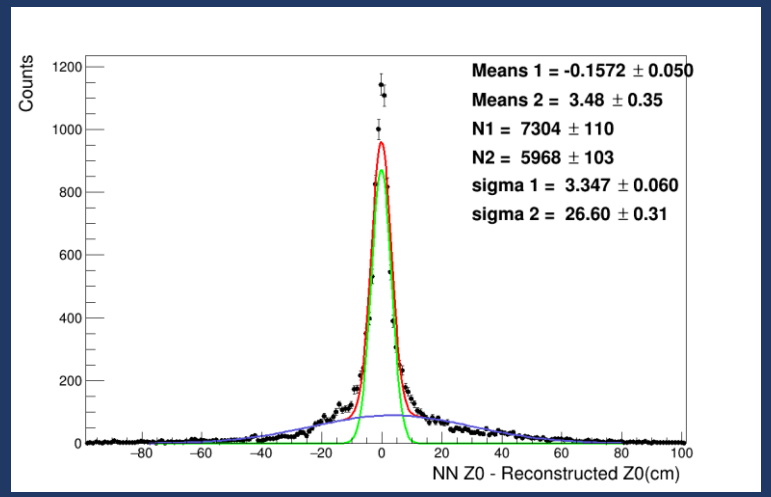
Test with exp24 run2004(sorry not unpacked another one for test)
And exp26 run 1777 (which use for trigger study with z0 in any range)

exp26 run 1777

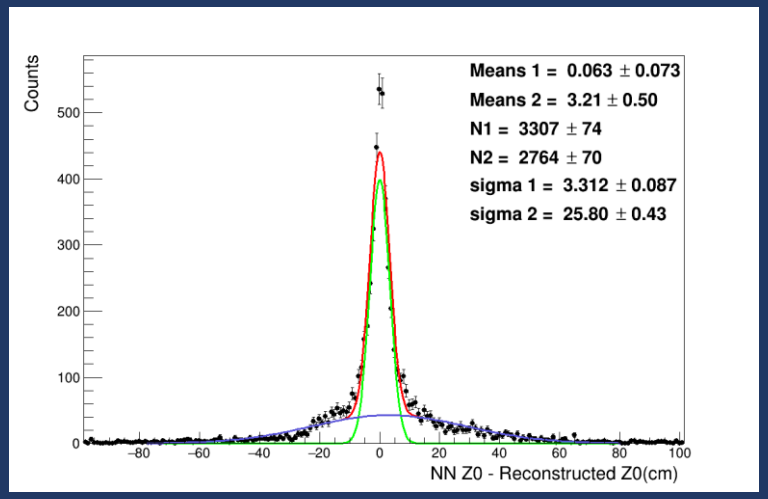
Origin with ETFHough



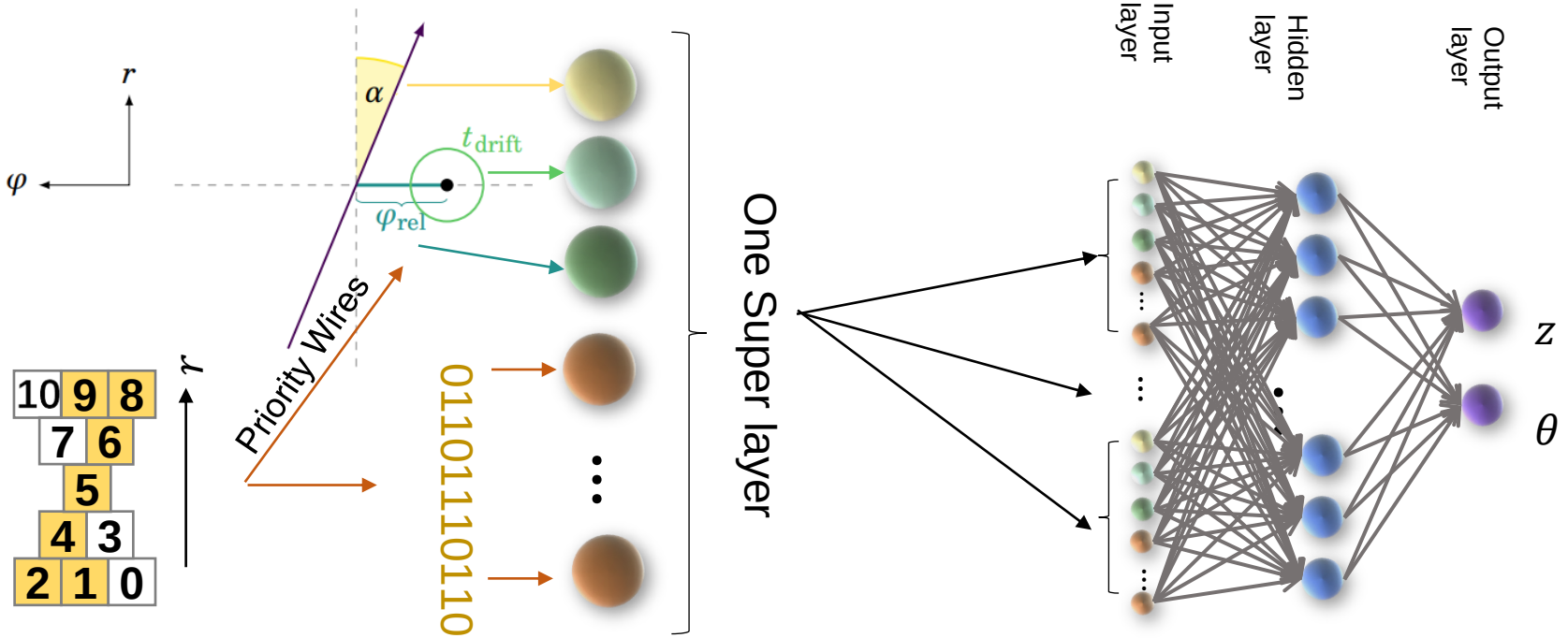
Wire 1 with ETFHough



Wire 2 with ETFHough



First attempt: Directly use TS pattern as input



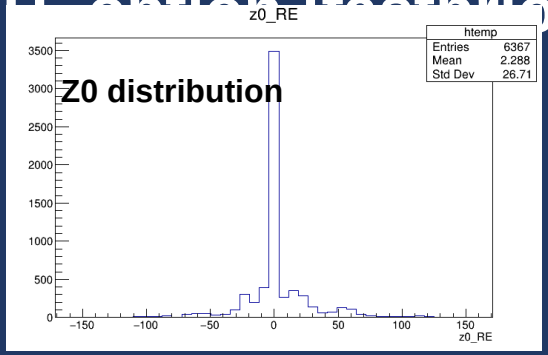
Directly use 11/15 bits pattern as input

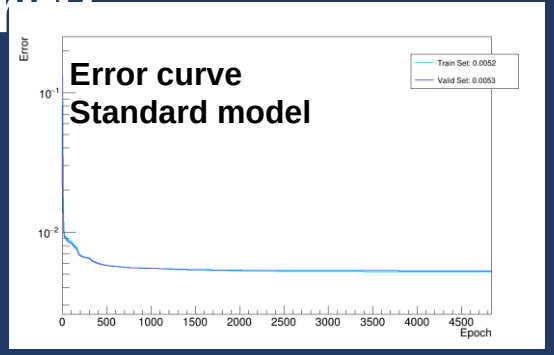
Since L/R information are got from pattern, hoping could replace L/R with it

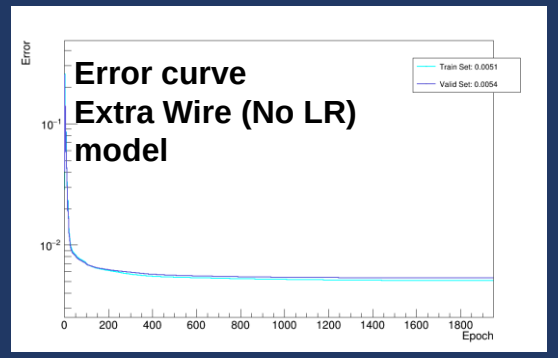
Train with real data

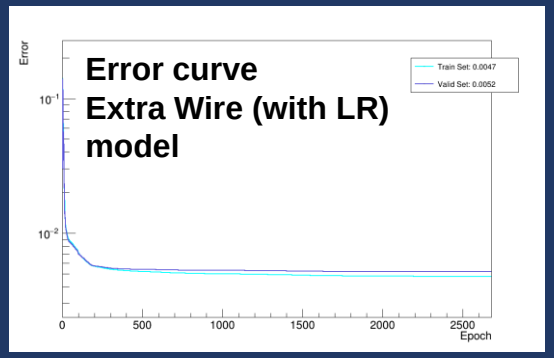
Train Standard model and one extra wire model (with/without LR) with exp26 run1771 & exp26 run1762; beam-reco-monitor.

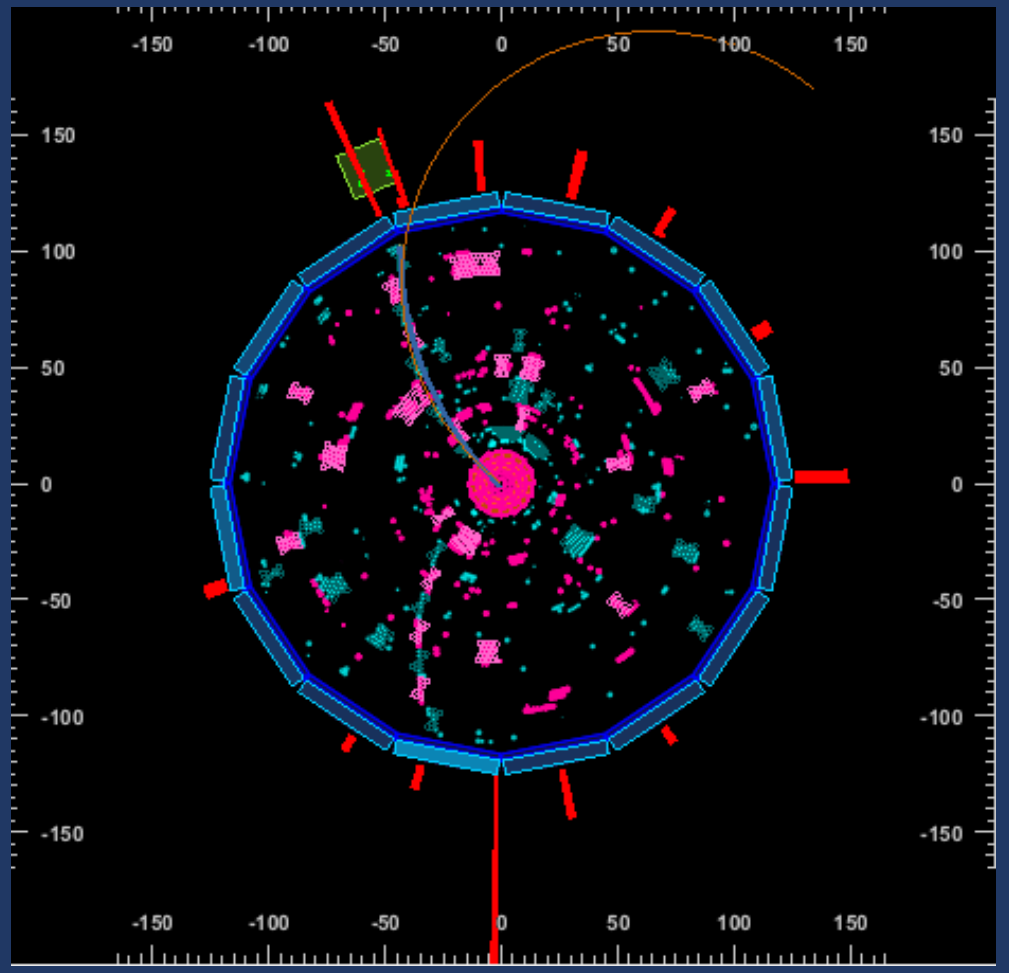
ETF option: footprint





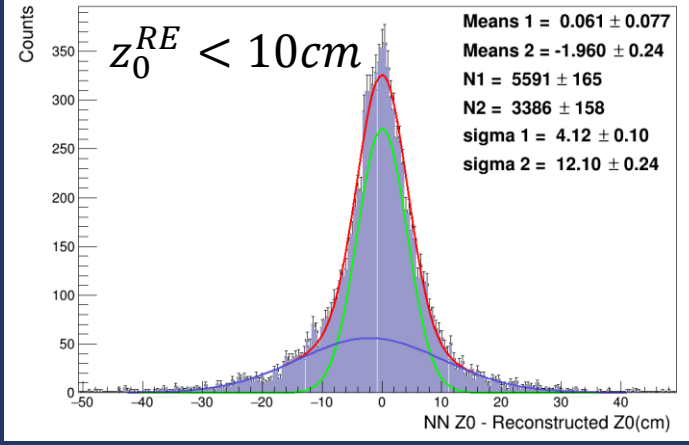


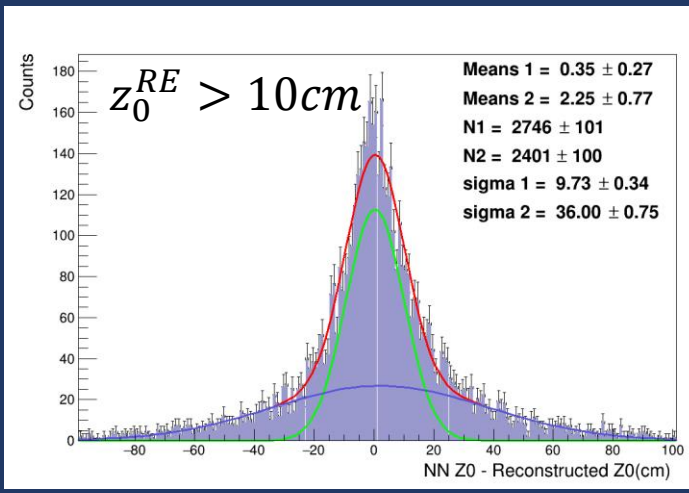




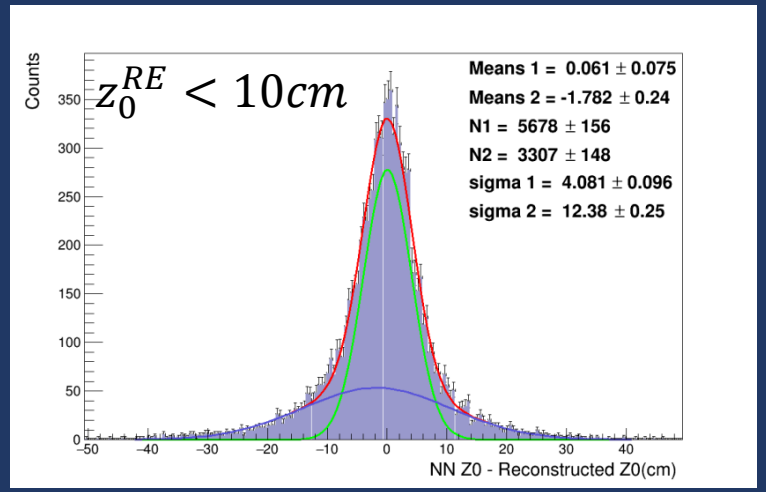
Test with real data exp26 run1771

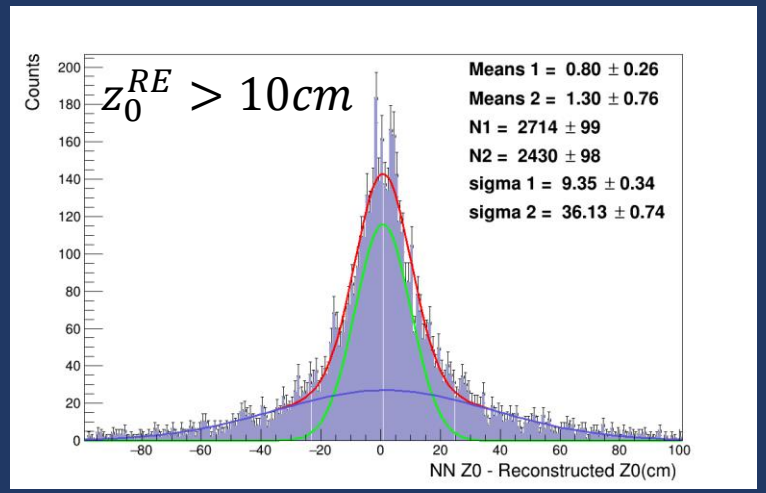
Standard Model



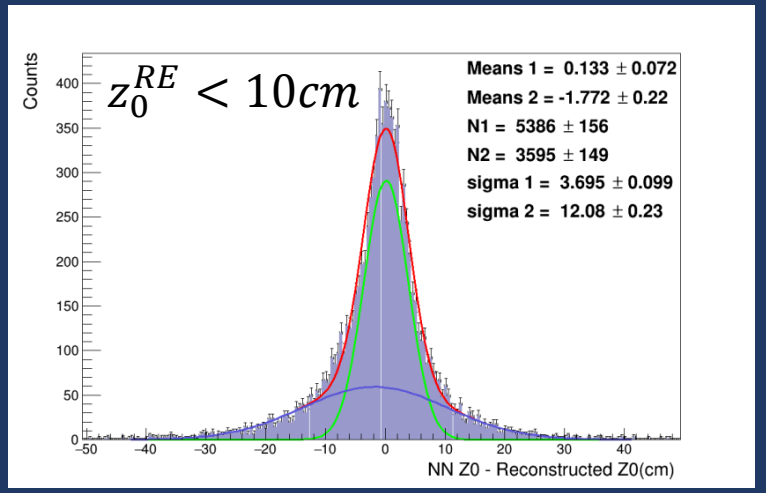


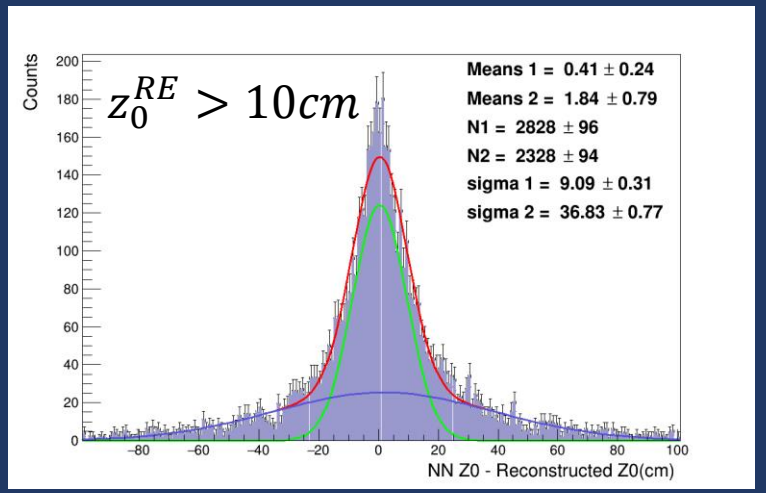
Extra Wire 1 No L/R





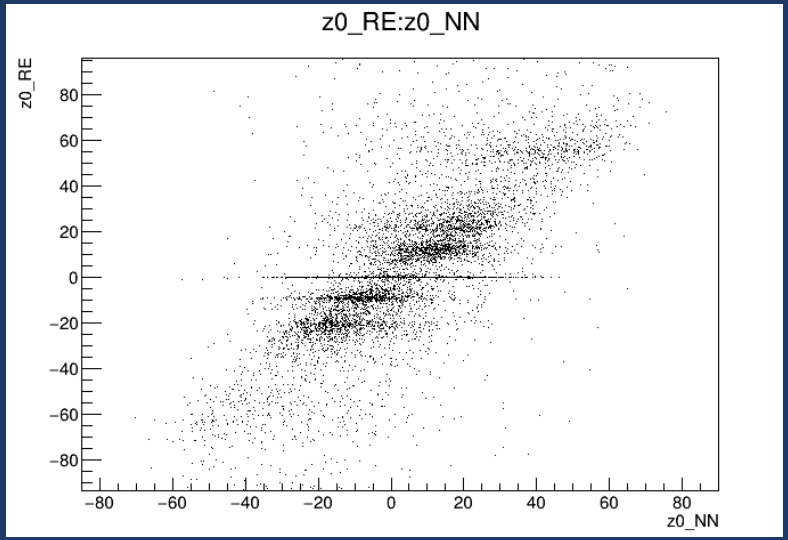
Extra Wire 1 with L/R



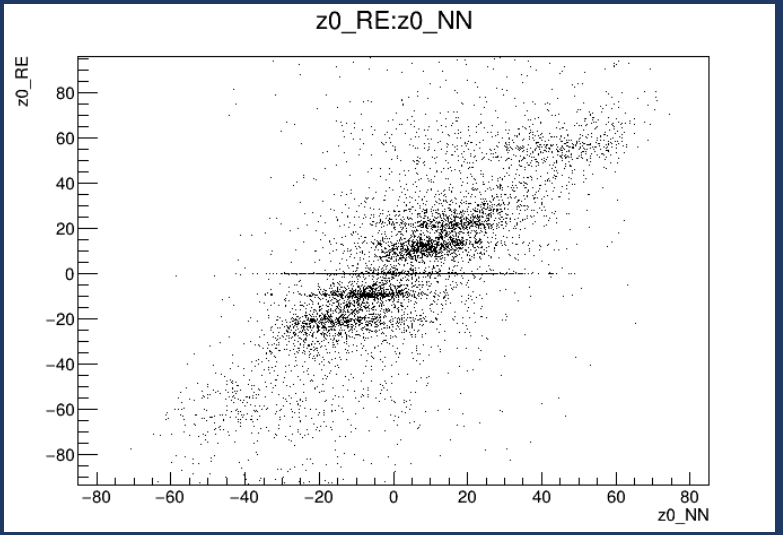


Test with real data exp26 run1771

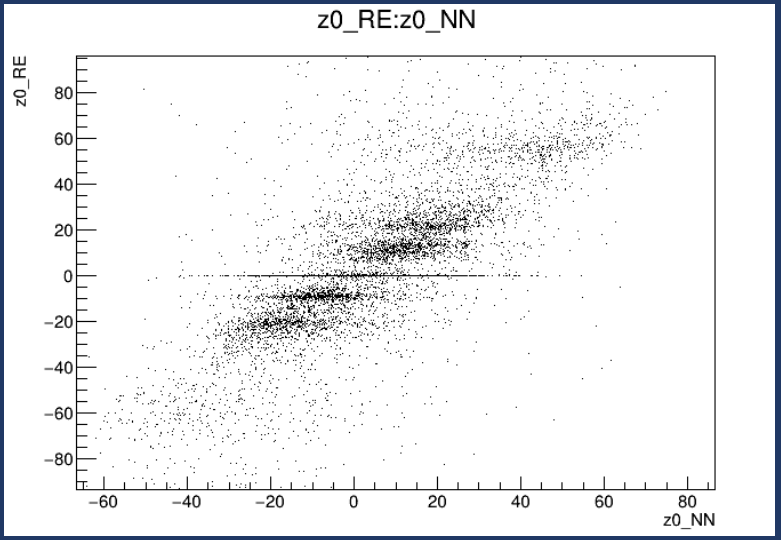
Standard Model



Extra Wire 1 No L/R



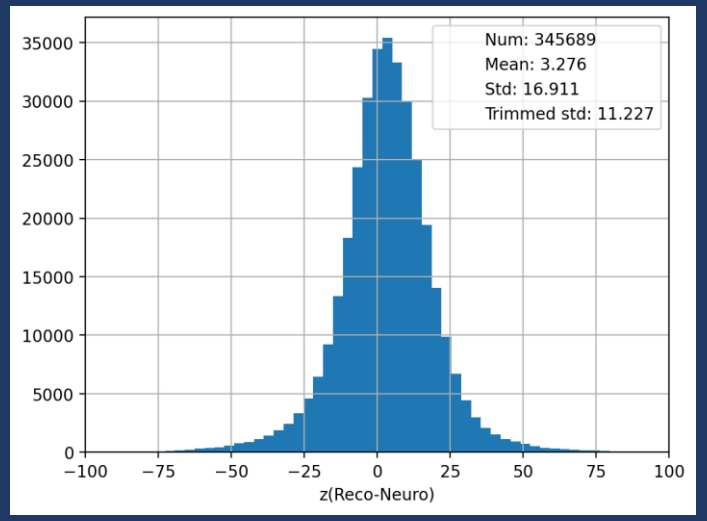
Extra Wire 1 with L/R

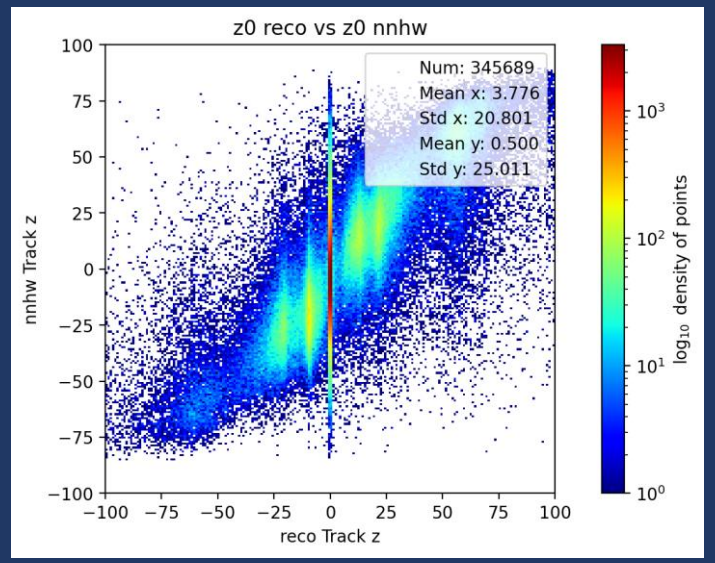


Training still need to be improved.

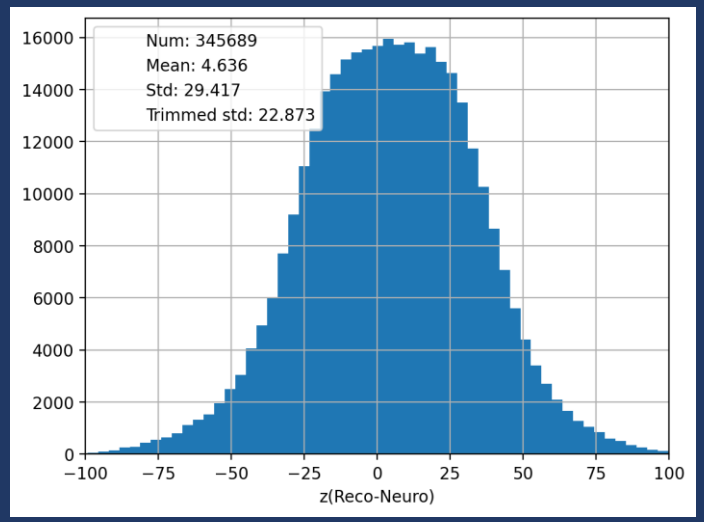
Pytorch training result -Uniform / norm distribution

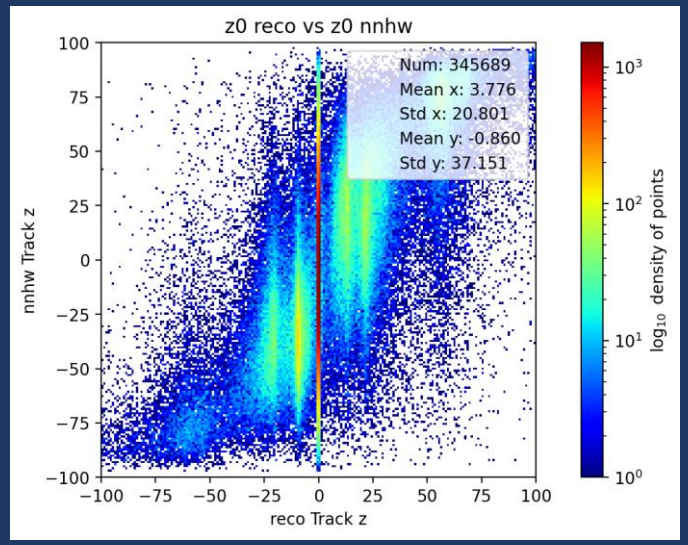
Norm



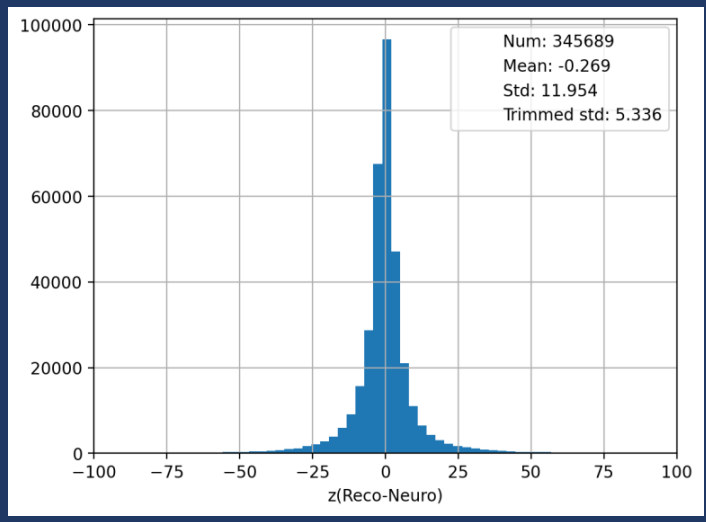


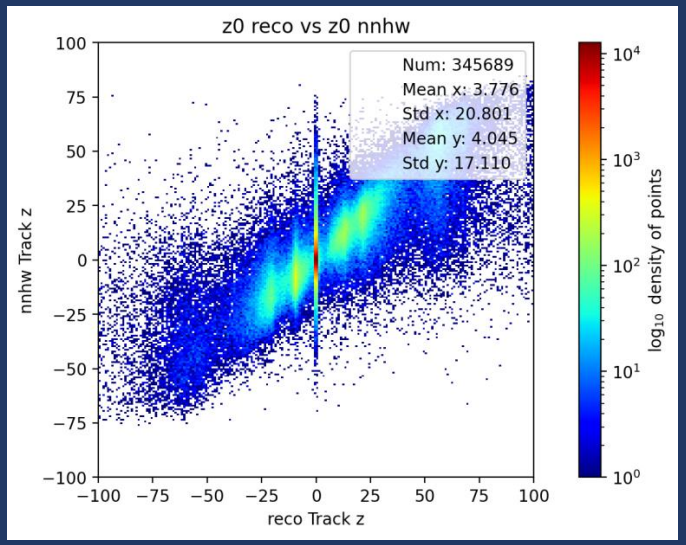
Uniform



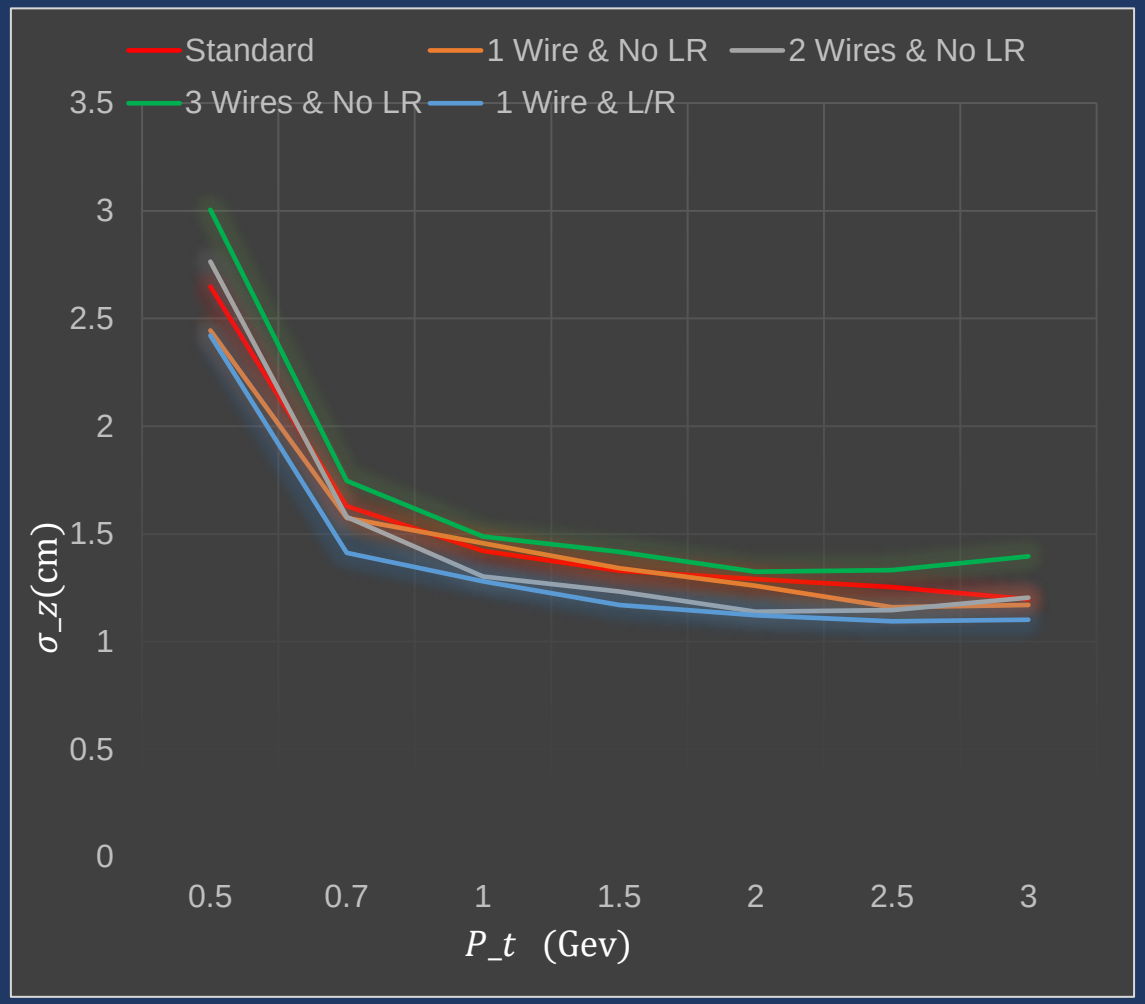


ExtraWires





Extra wire as input

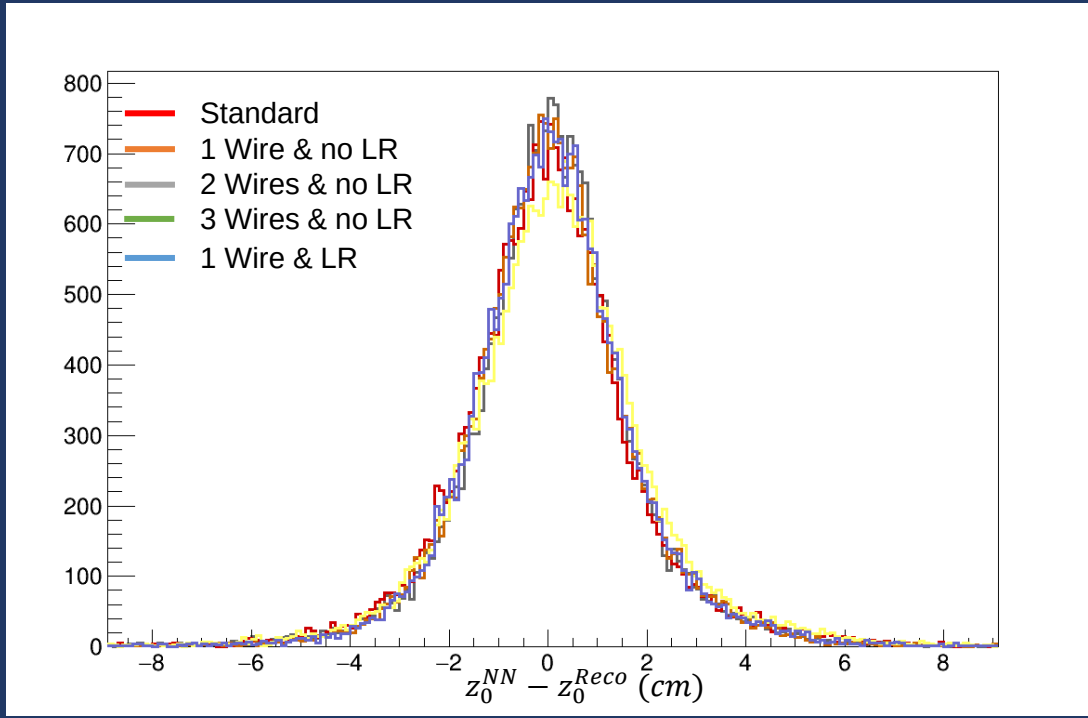


Trained NN based on MC

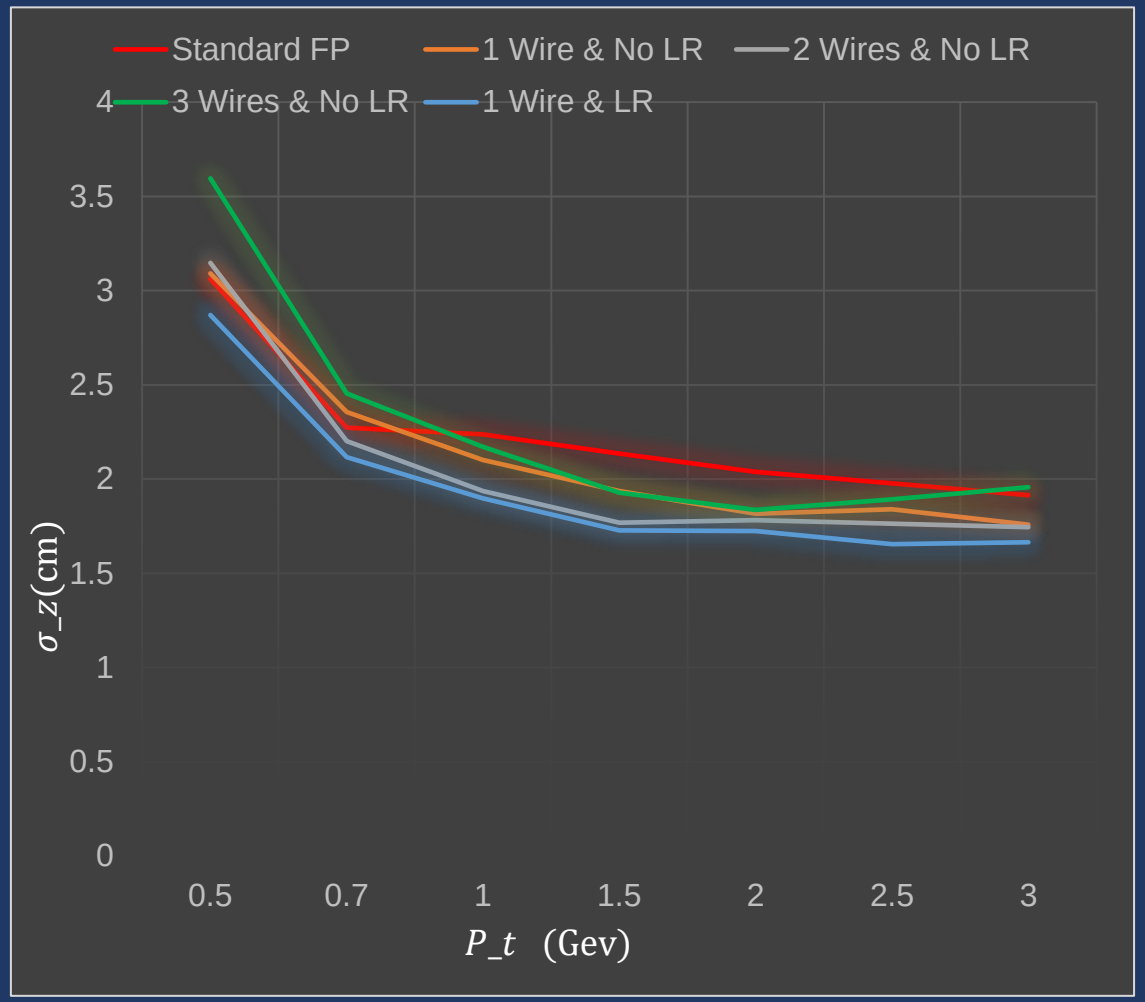
ETF : Set Event T0 as zero for precise t_{drift}

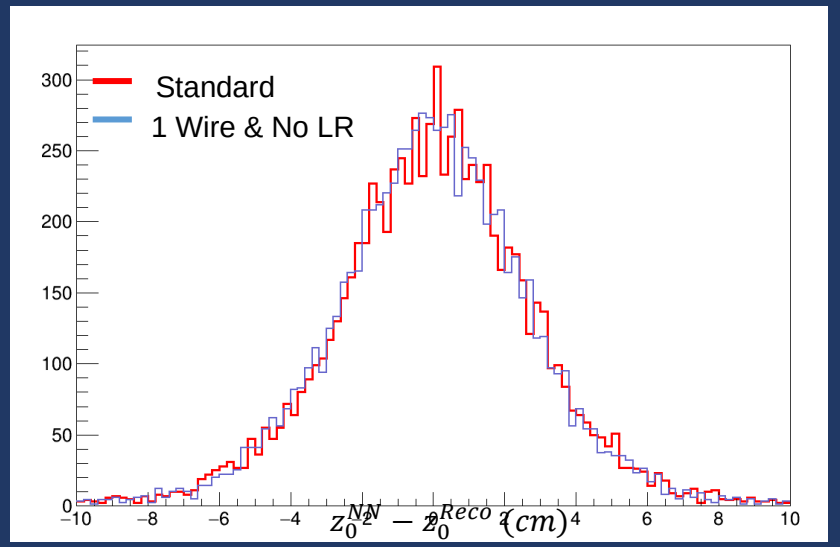
Add More wires without L/R make little improvement

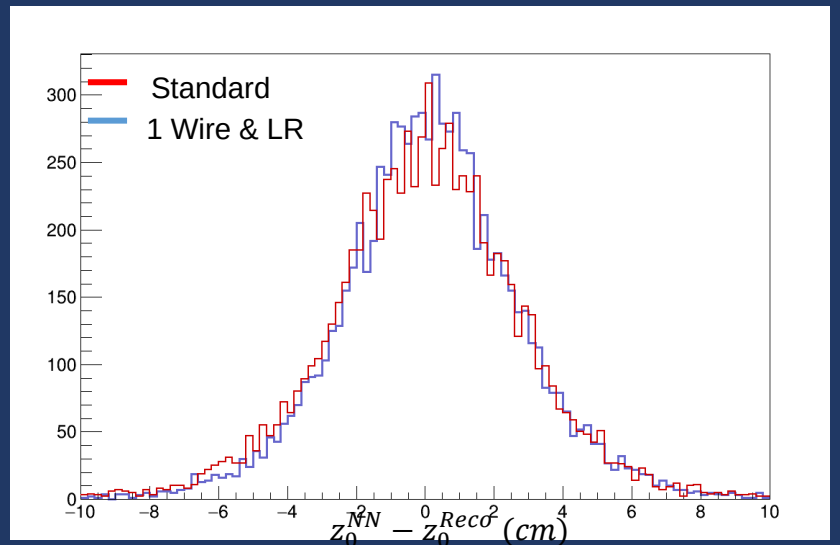
Add wire with L/R could make slightly difference in MC



Extra wire as input -- fastpriority

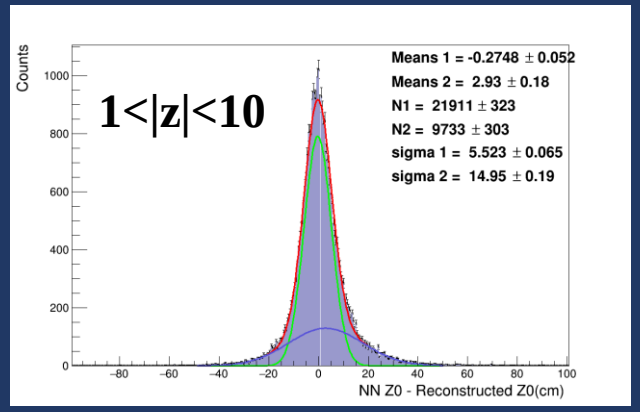


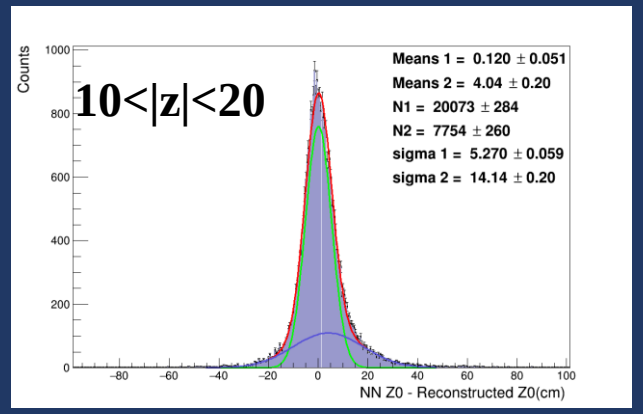


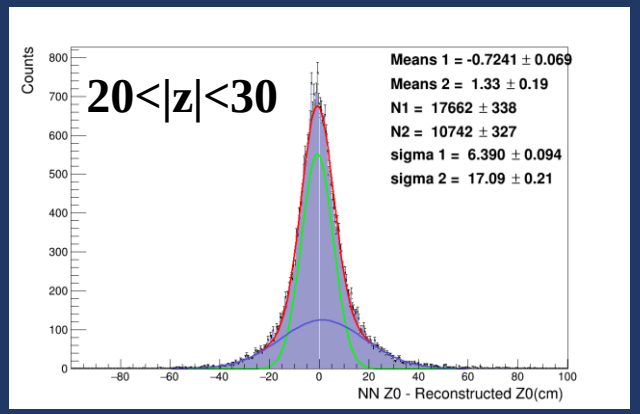


More wires?

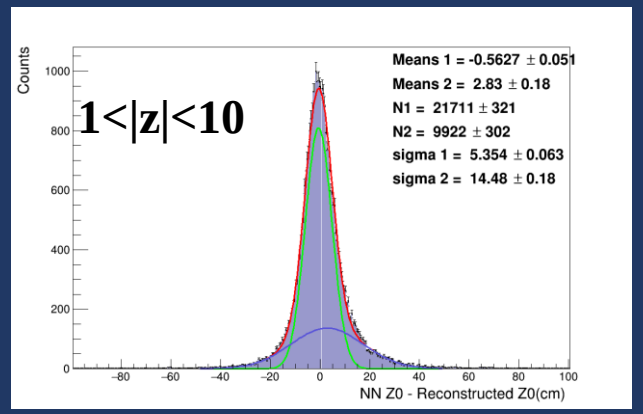
Wire 1

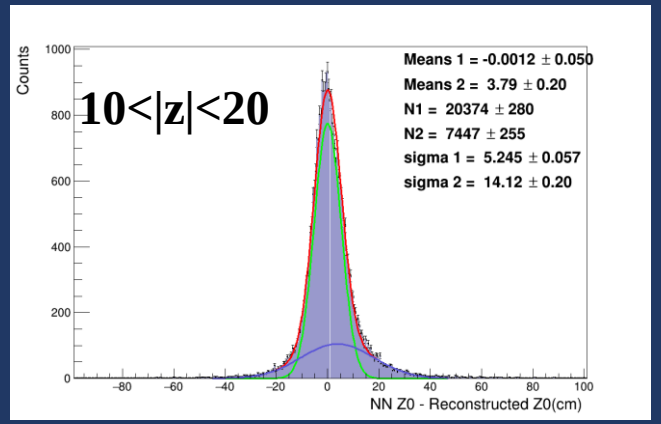


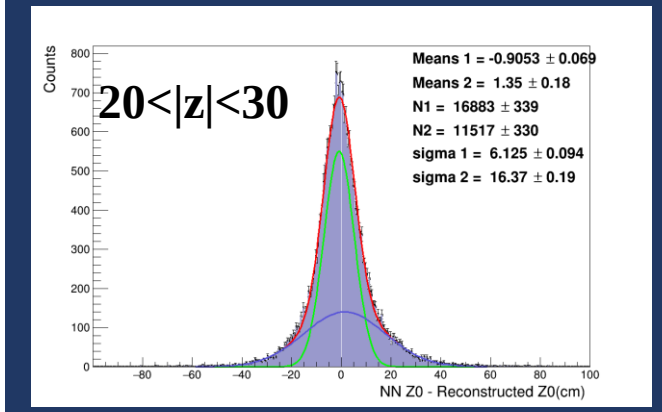




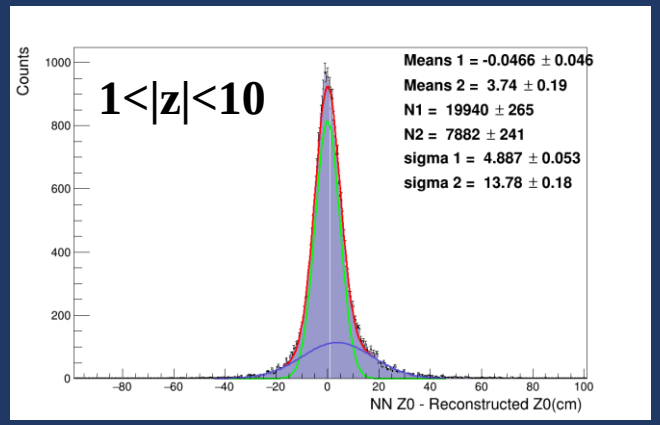
Wire 2

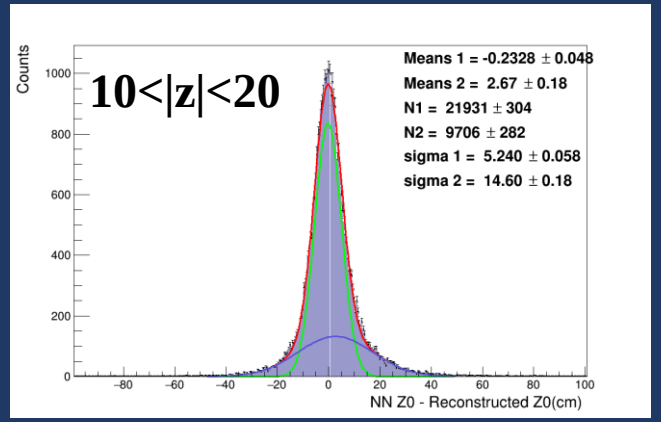


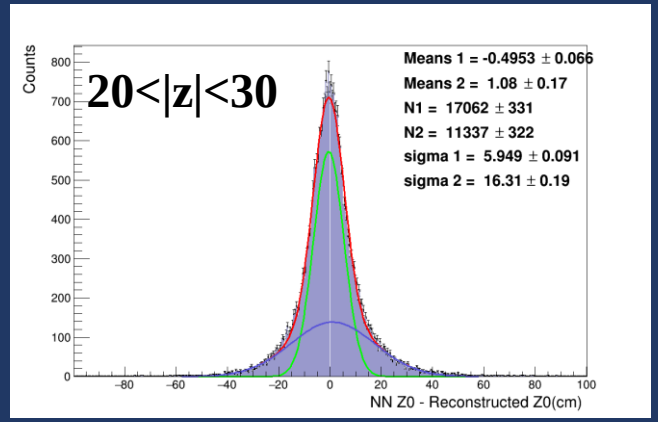




Wire 3

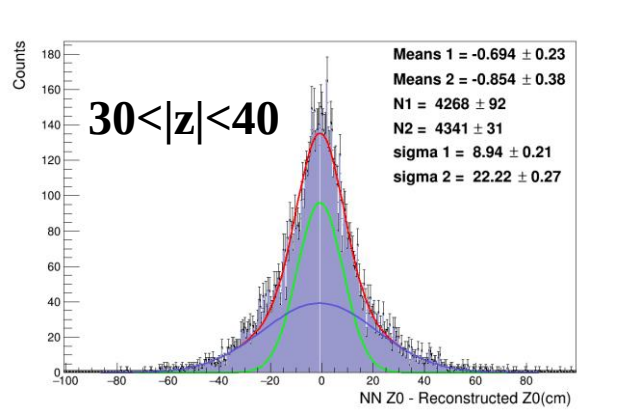


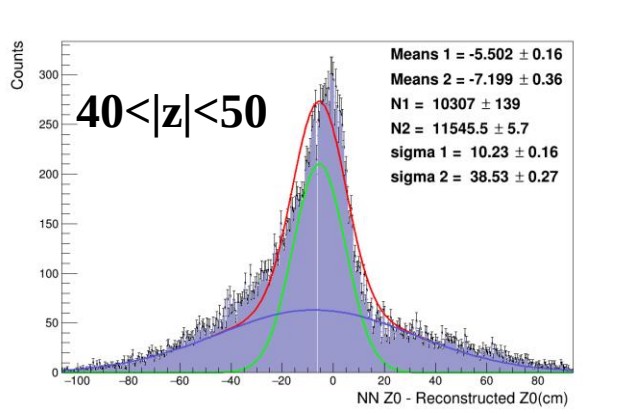




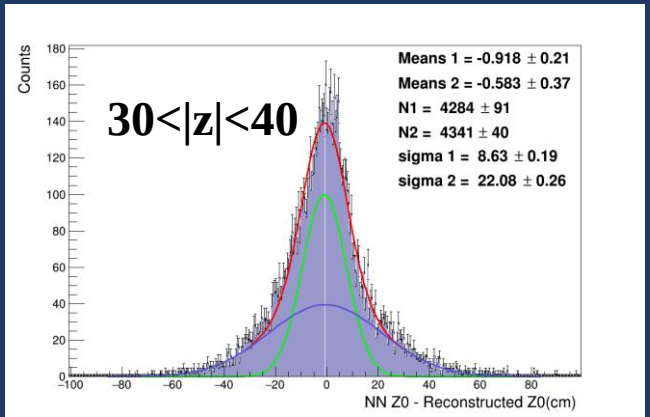
More wires?

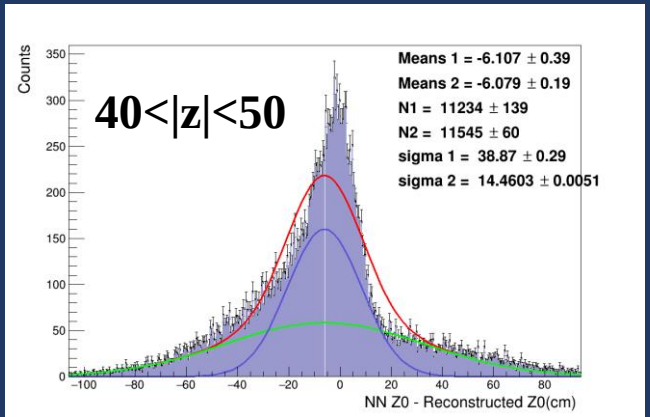
Wire 1



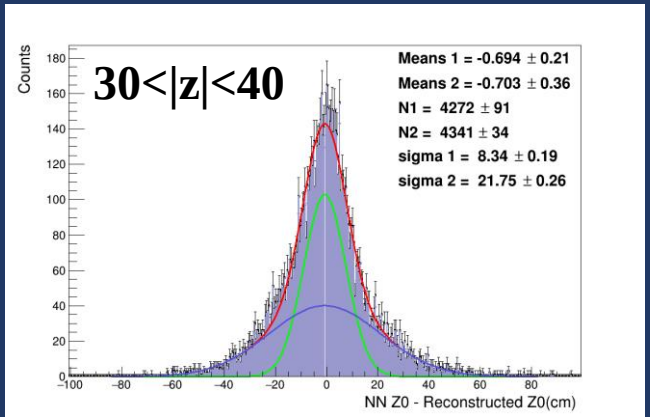


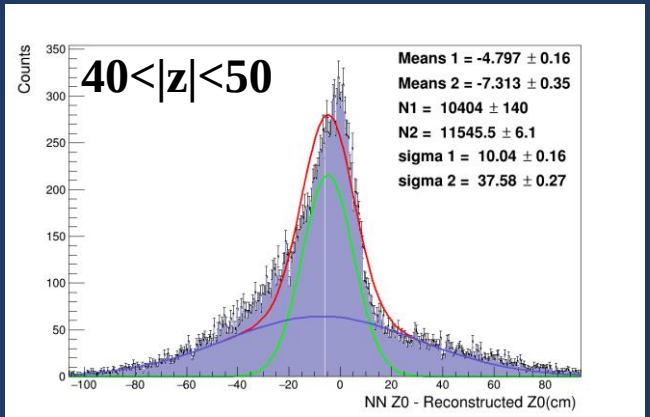
Wire 2





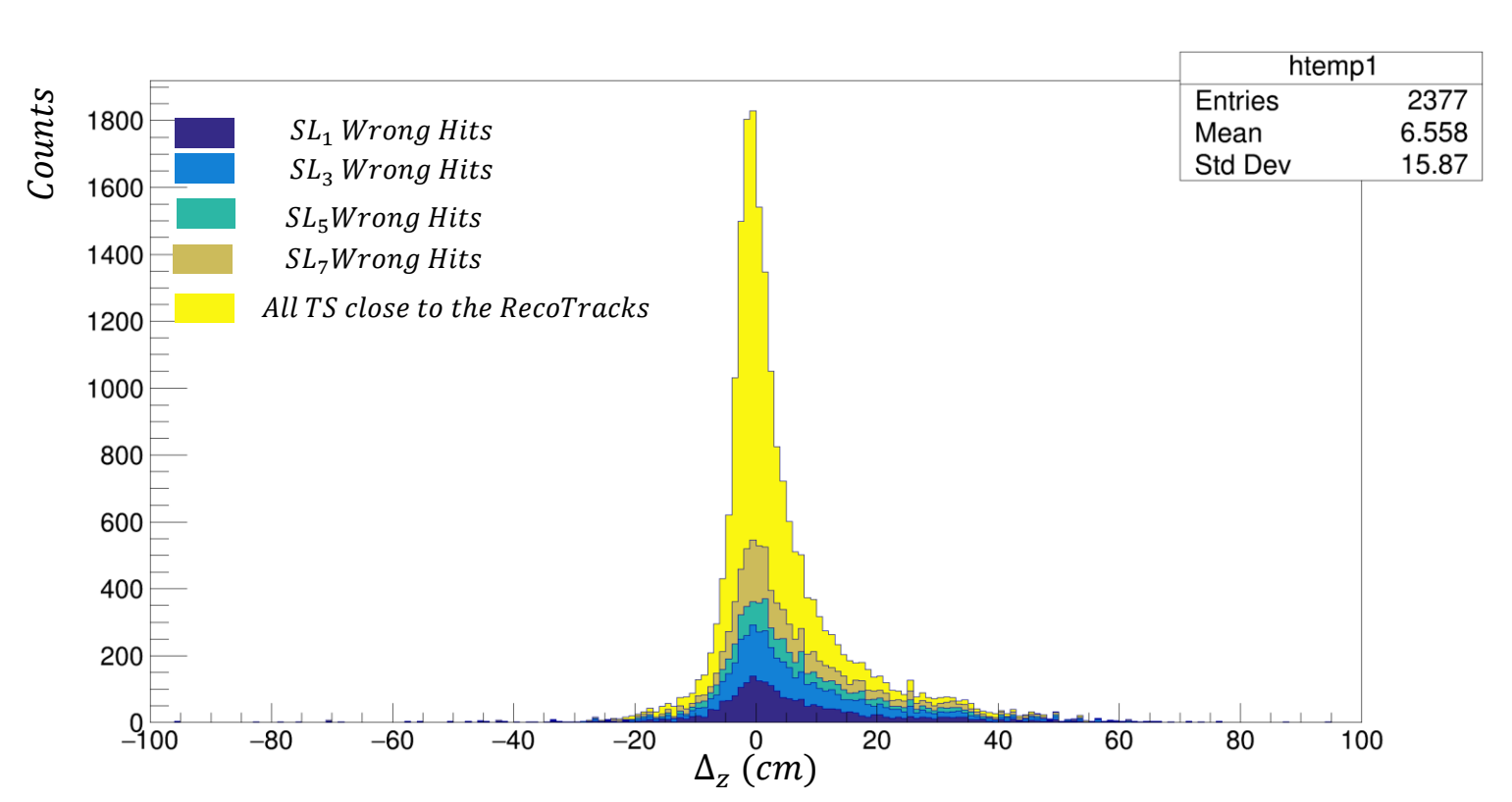
Wire 3





Track Segment ID

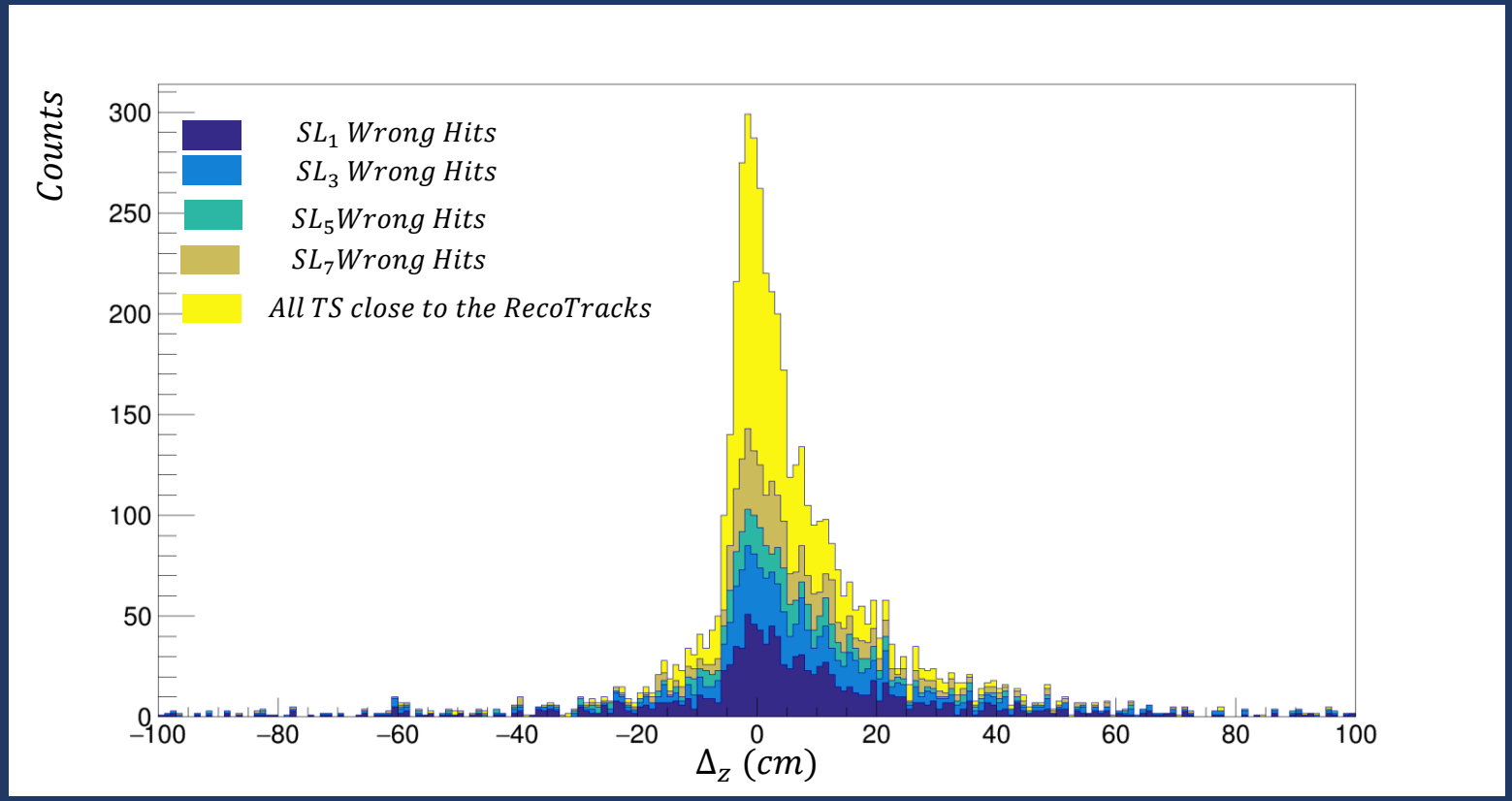
Consider the Delta Z distribution of those NN choose wrong hit



exp024run2004

Track Segment ID

Consider the Delta Z distribution of those NN choose wrong hit



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