De-noising using Deep Learning on COMET experiment

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Outline

- Motivation
- Detector
- Analysis flow (and how to make image)
- Algorithms: What is Segmentation
- Making images for segmentation
- About random, sim noise
- Results

Motivation

- quantum number for lepton species
- Upper right ：muon decay

muon number and electron number between initial and final state

⇒ conserved

- right：mu – e conversion

Muon num and electron num between initial and final

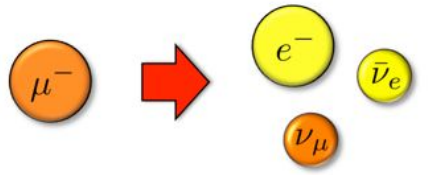
⇒ violated！

rate of charged lepton flavor violation from neutrino oscillation is too small.

Best discovery potential for new physics beyond the Standard Model

一般的にはミューオンは以下の様な崩壊をします

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

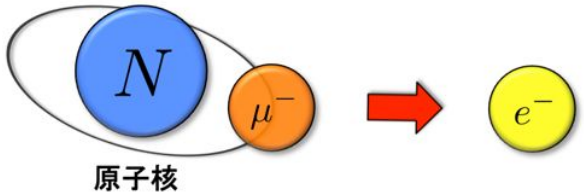


ミューオン数：1
電子数：0

ミューオン数：1
電子数：0=+1-1

ミューオン電子転換過程

$$\mu + N \rightarrow e + N$$



ミューオン数：1
電子数：0

ミューオン数：0
電子数：1

Comet Experiment: Detector

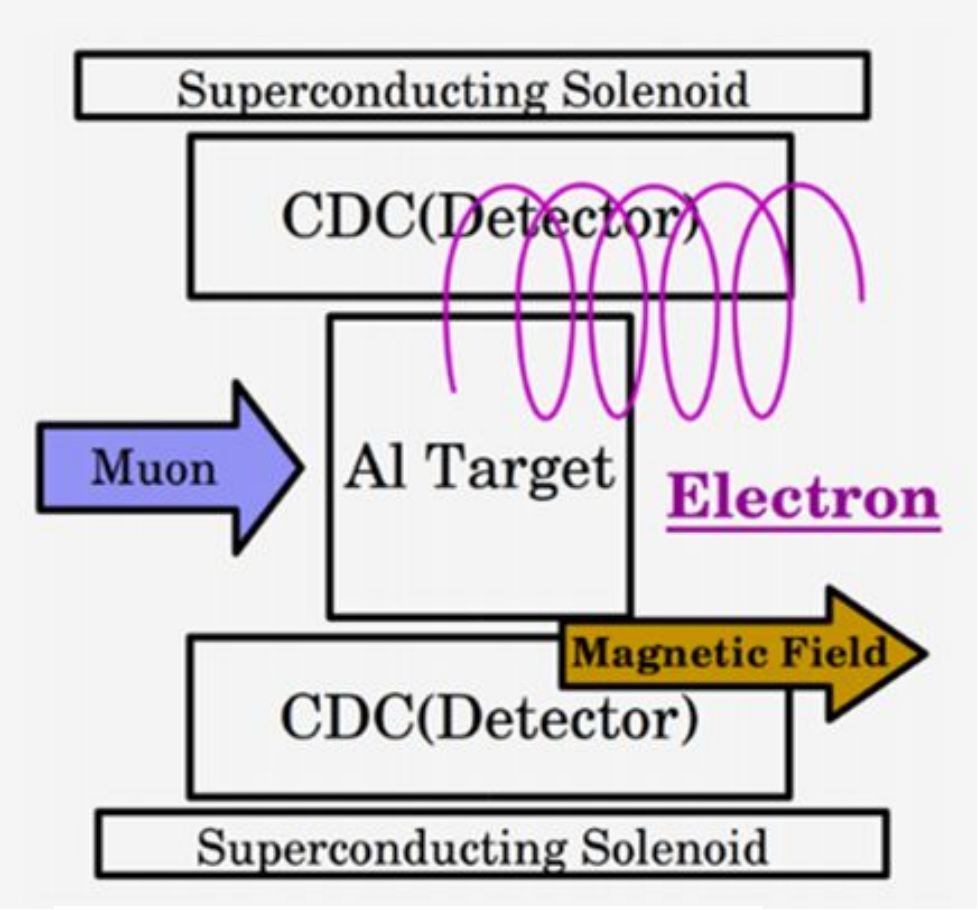
- Alminium target to generate muonic atom
- Cylindrical Drift Chamber（CDC）

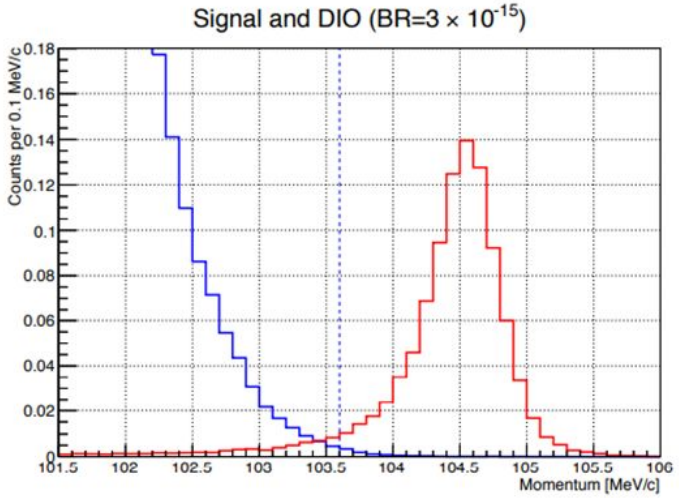
Layer:18, Total cell number:4986

- Solenoid makes Magnetic field

- Helical trajectories

⇒ momentum determination





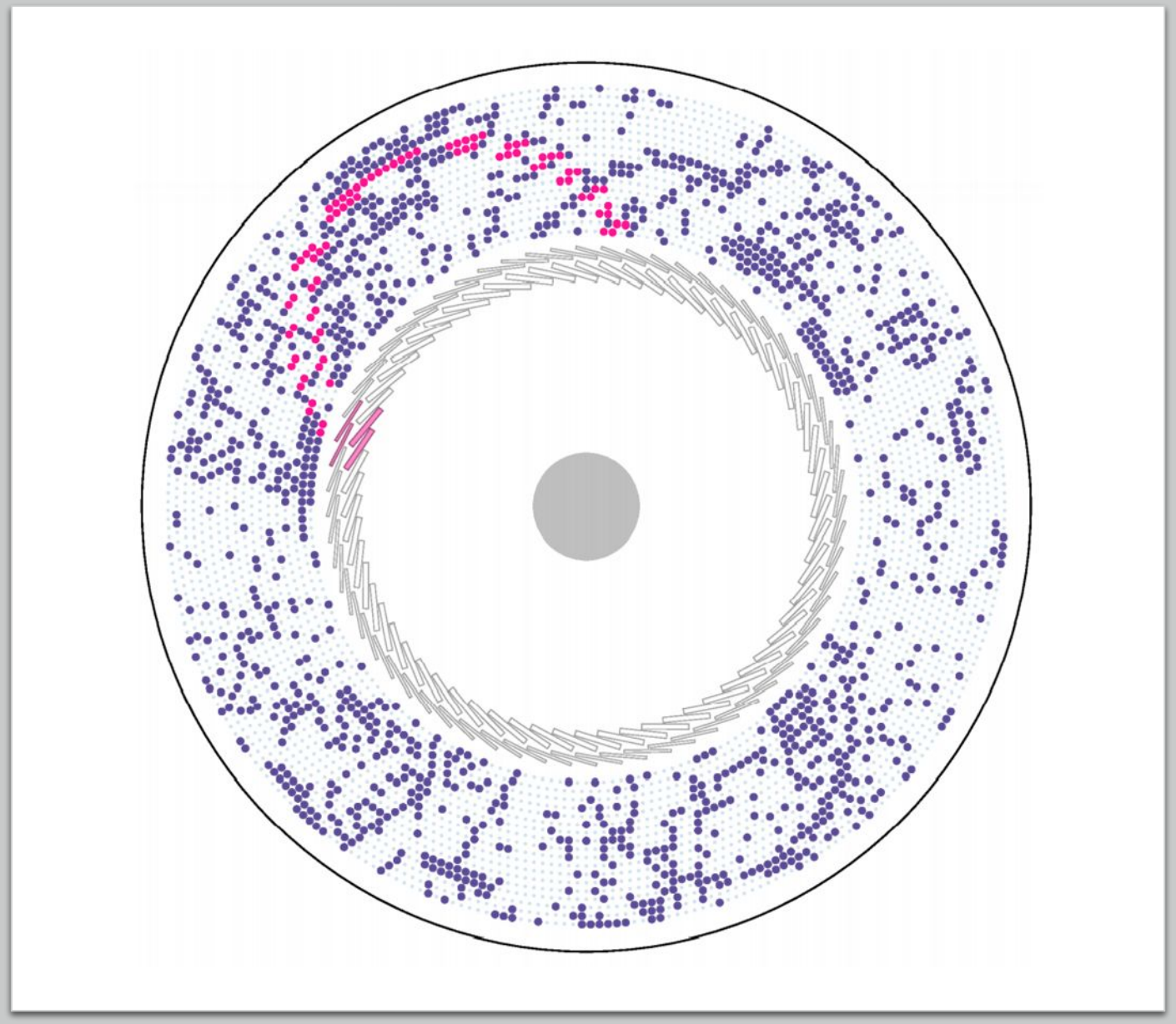
Analysis flow

- ① **background rejection by Neural Network**

  in progress……

- ② 1st-turn-extraction by Neural Network (NN) good

- ③ momentum estimation bad……

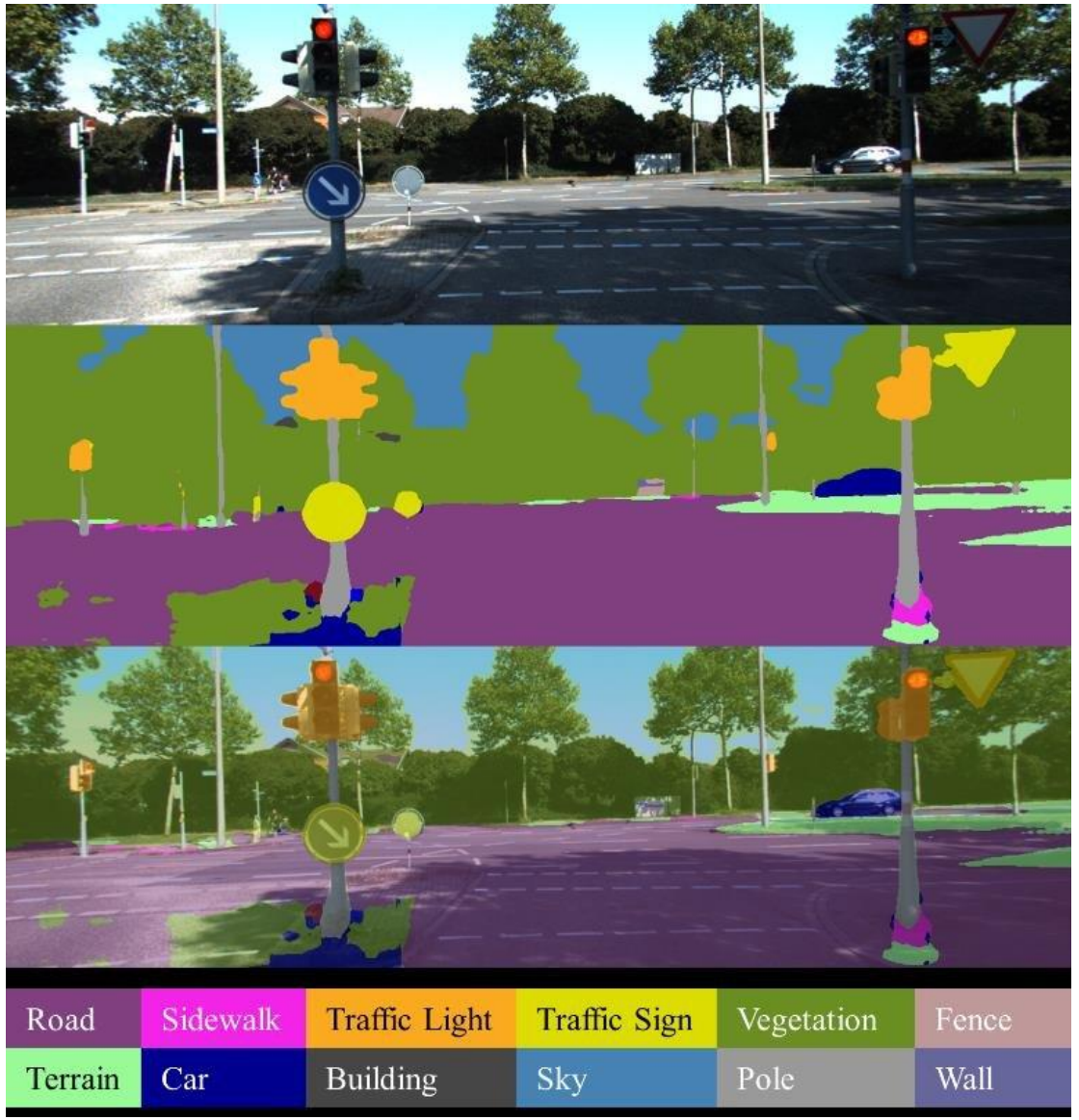


What is segmentation ?

- Feature Pyramid Network (current)

  network for object detection (signal, 1st turn extract)

  object detection means where some object is in image



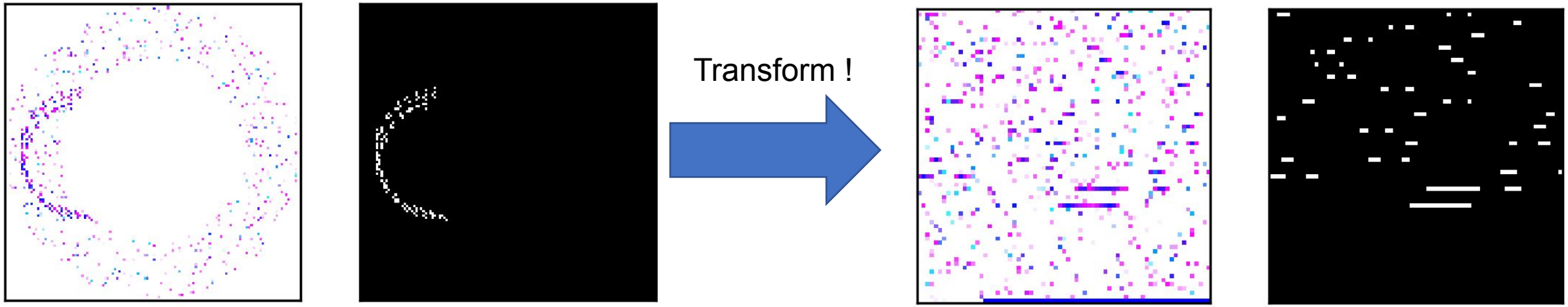
Making Input and label data

- Input and label data are images
- Label data has information like “which cell has true signal hit.”
- Input data has information about Energy deposit and time informaton
- Energy and time information use 2 channels in images.

- If there are multiple hits in one cell, I assign energy and time of only first hits to pixel intensity in image.

Transforming datasets

- The CDC cell-layer structure is converted to a. square image.
- Reduce computation cost.

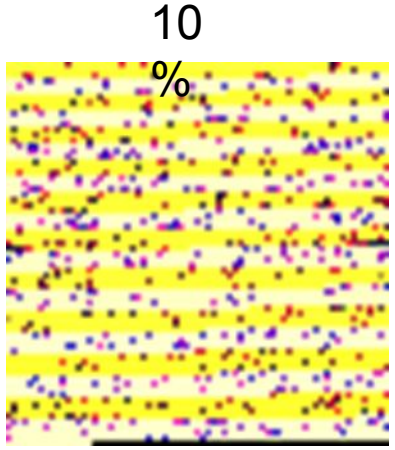


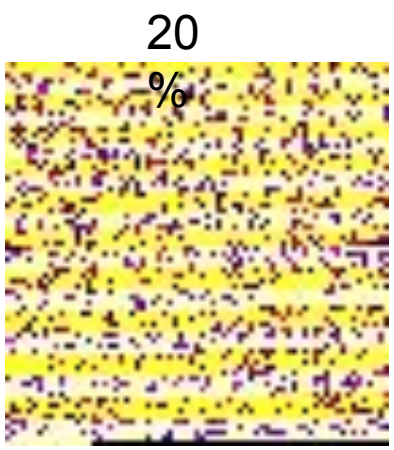
Hit in CDC x-y image

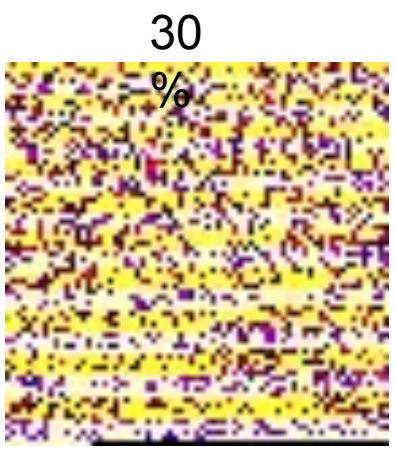
Hit in CDC wireid image

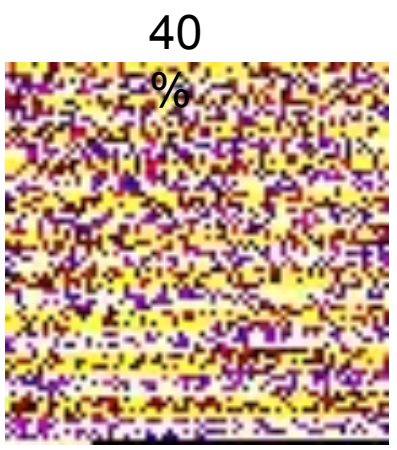
Making of background hits with uniform distribution

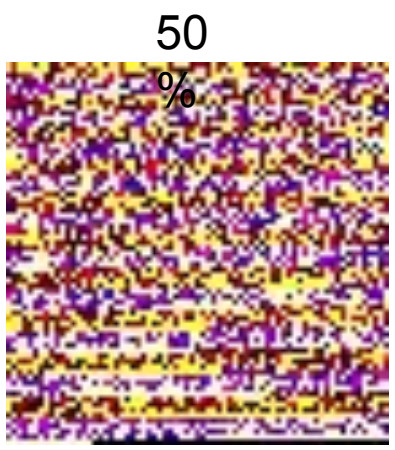
- the distribution of energy_deposit and time information and layer and cell are uniform.
- Time information ~ (0, 900ns)
- Energy deposit ~ (0, 22 keV)











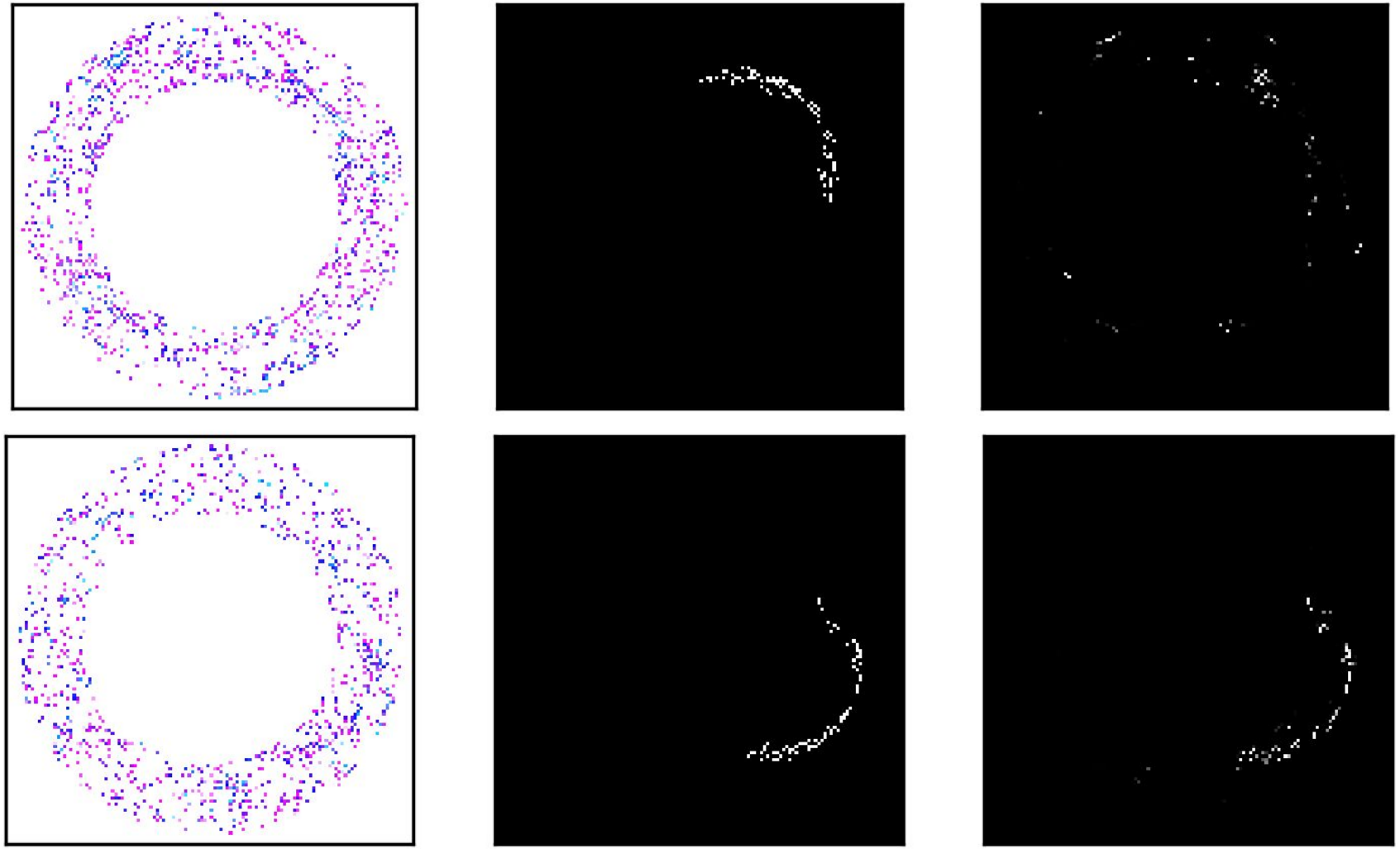
Prediction for full simulated data

a total size of full simulation data is 900 events.

Before the NN study, pre selections were made

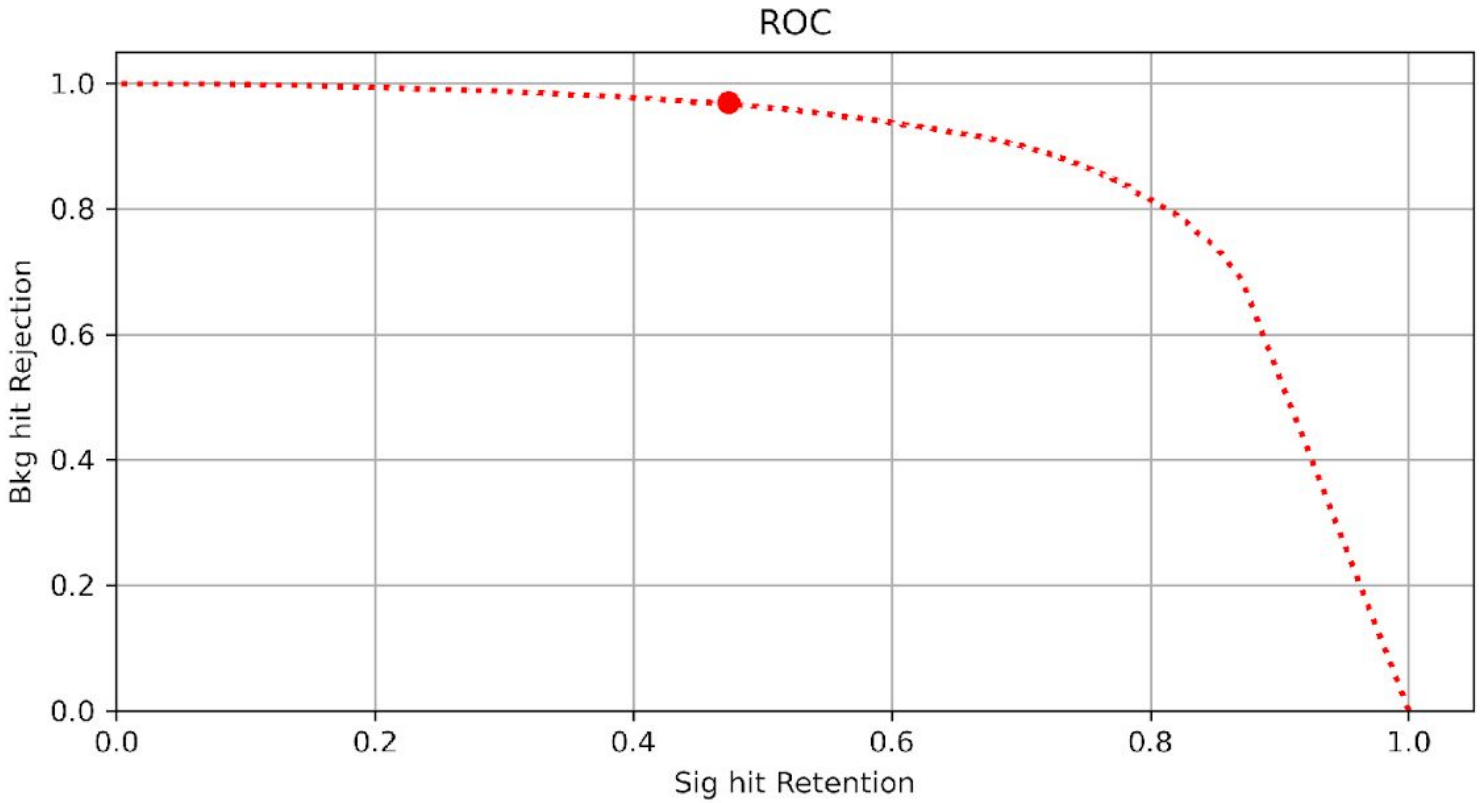
—> time distribution from 0 to 400 ns and energy deposit from 0 to 22 keV.

Prediction sample: by Segmentation



ROC curve

- Traininng Event number: 100000
- Trained by
  50% noisy data
- Red dots means
  Threshold(=0.4)



Summary

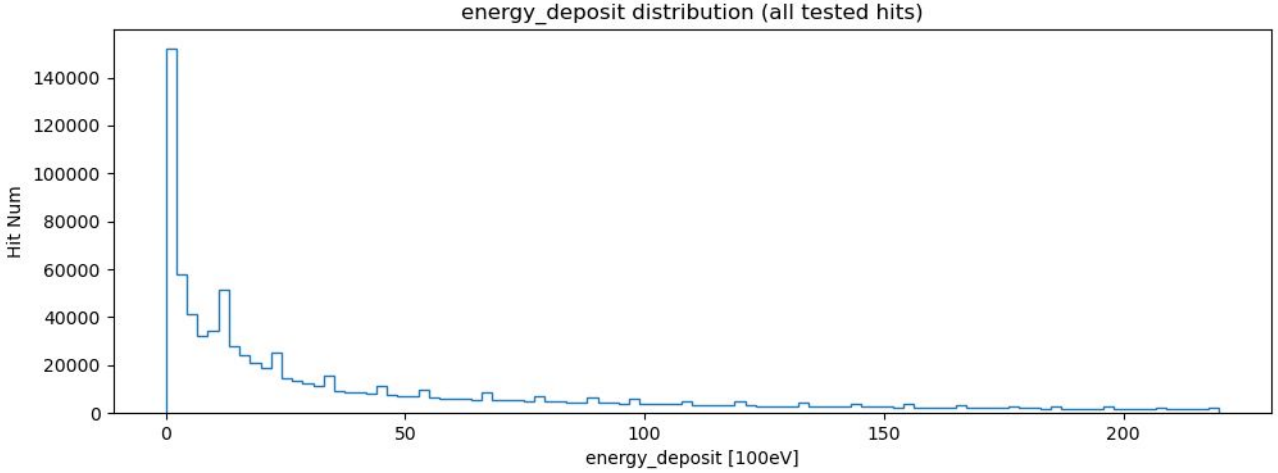
- Segmentation model: FPN
- Time information and Energy_deposit and location information assigned to pixels of image.
- trained by data sample with background hits of random uniform distribution.
- prediction for data sample from the COMET full simulation

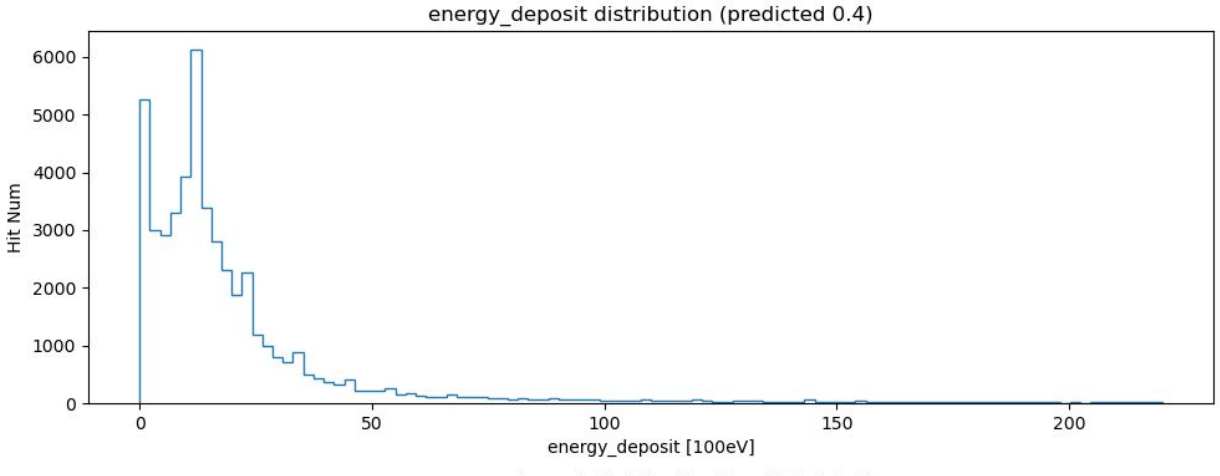
Improving performance

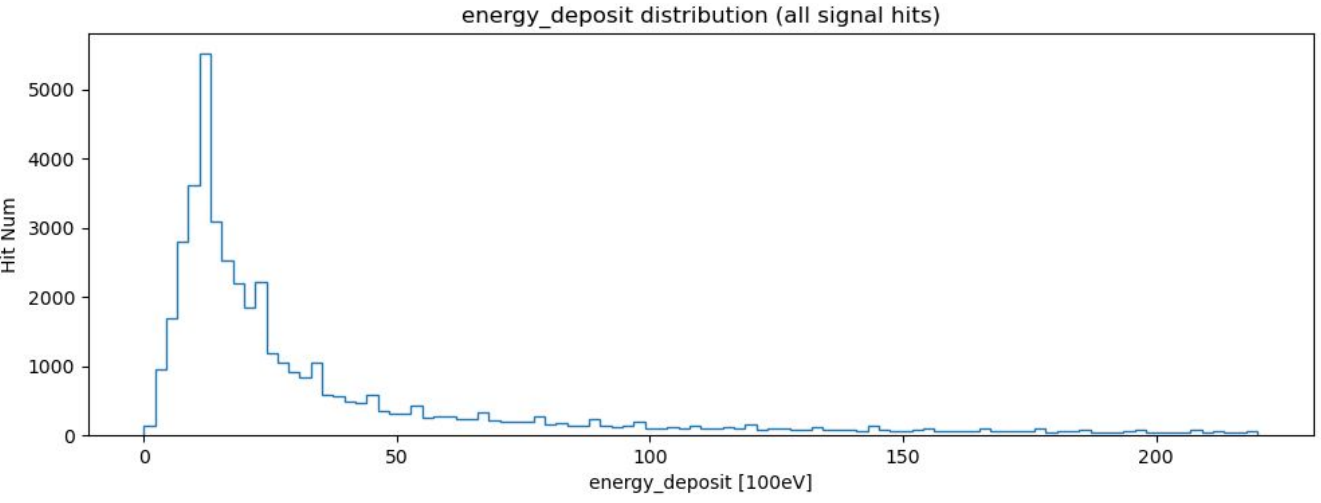
- distribution of training sample should include realistic distributions of simulated events.
- Third channels (or more higher) for input image
- Other better model ?

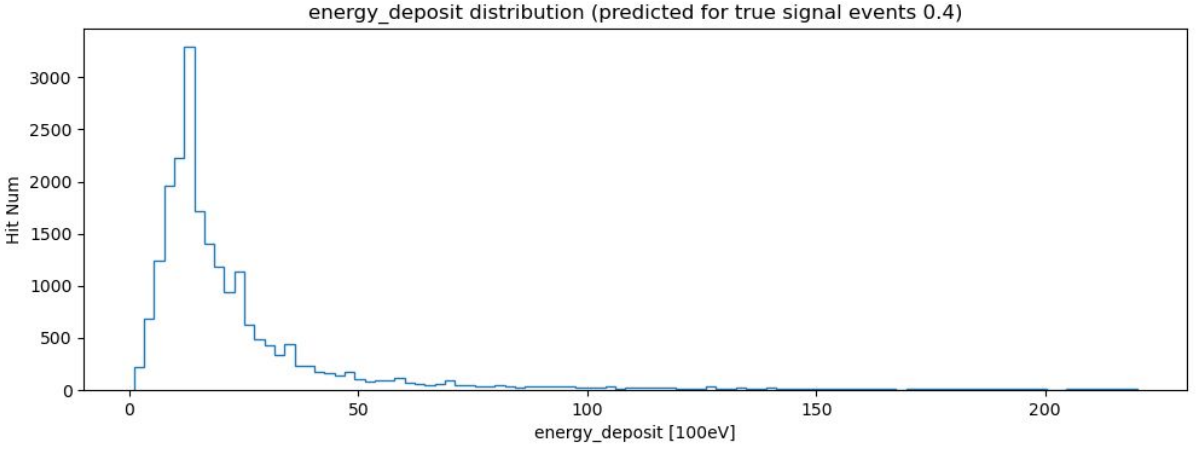
Thank you for your attention.

Histogram of predicted sample(Energy)

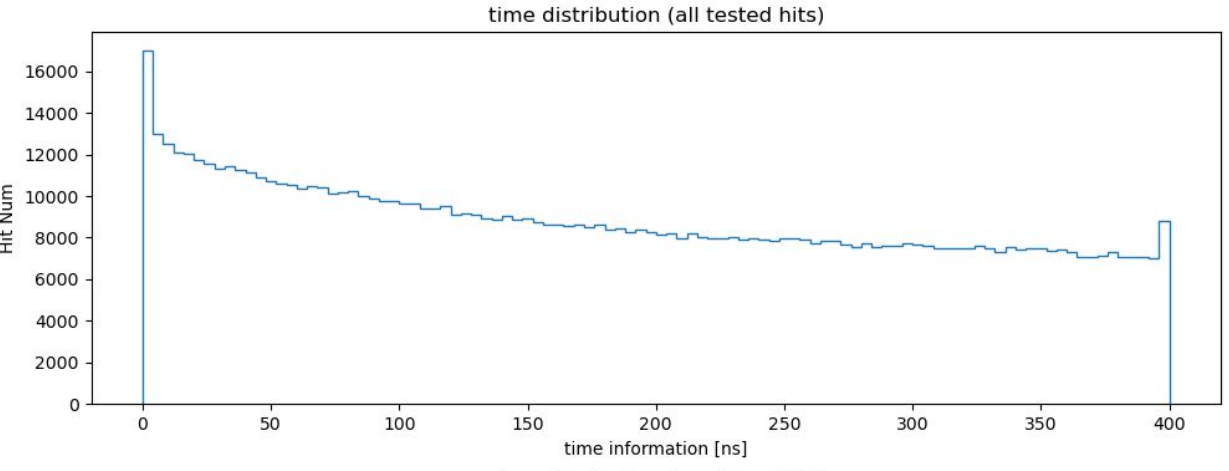


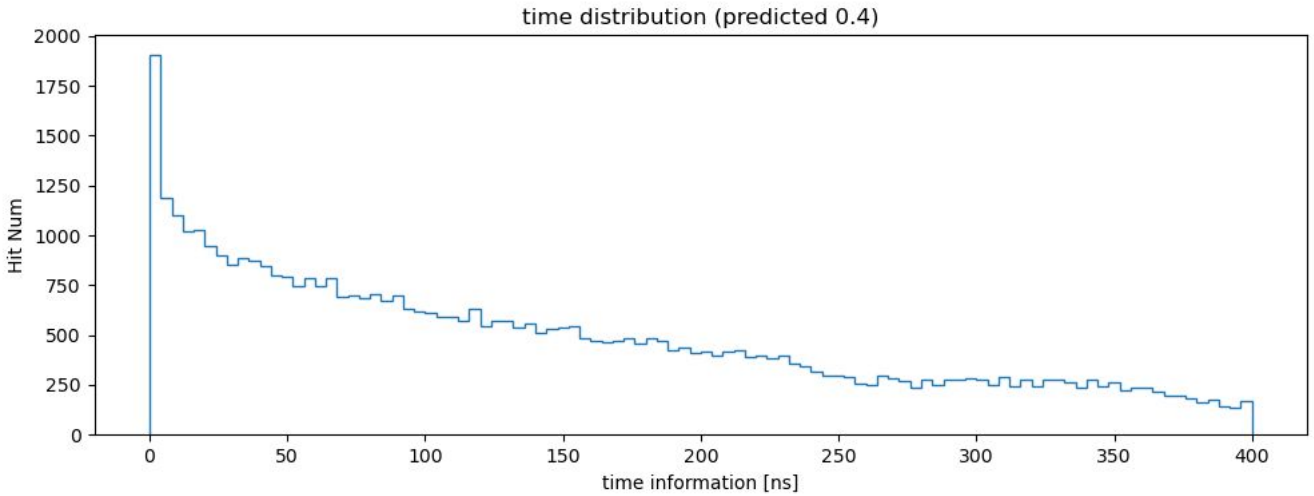


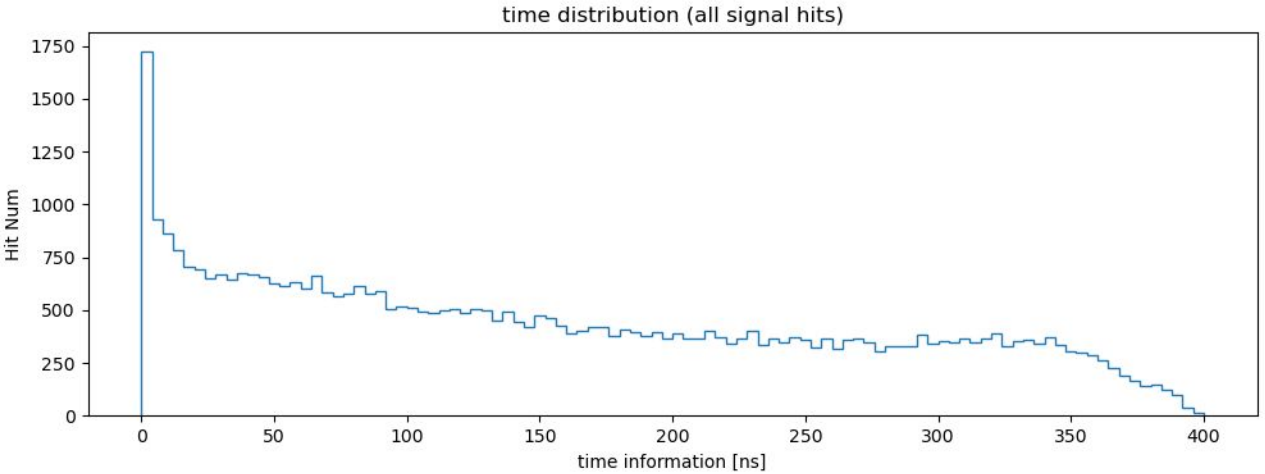


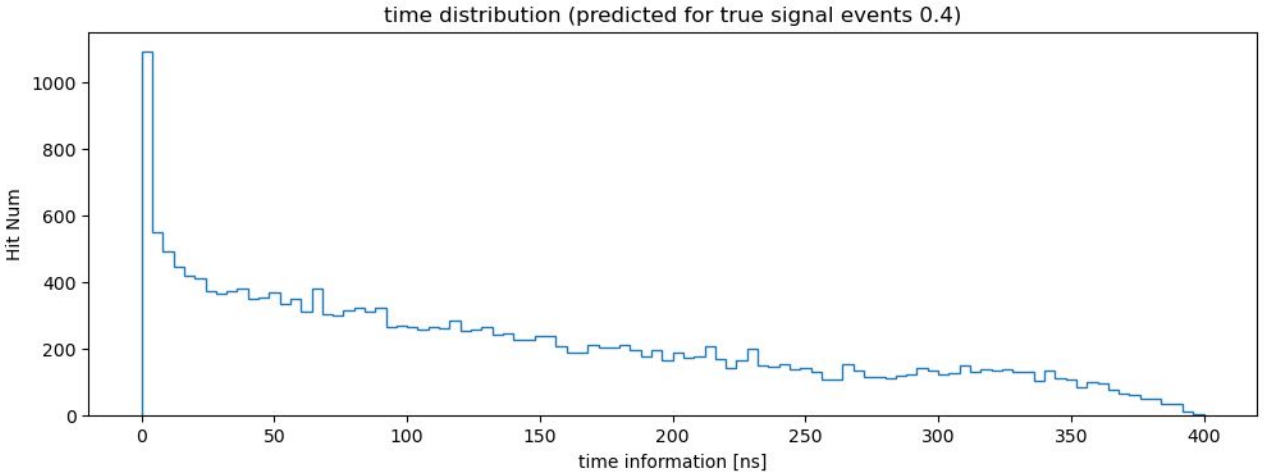


Histogram of predicted sample(time)





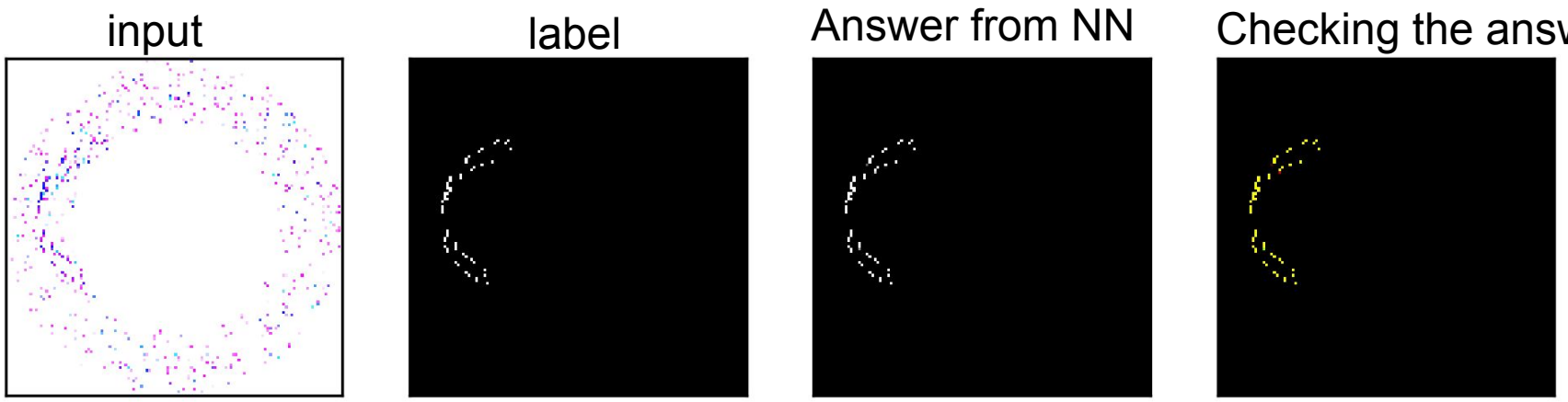




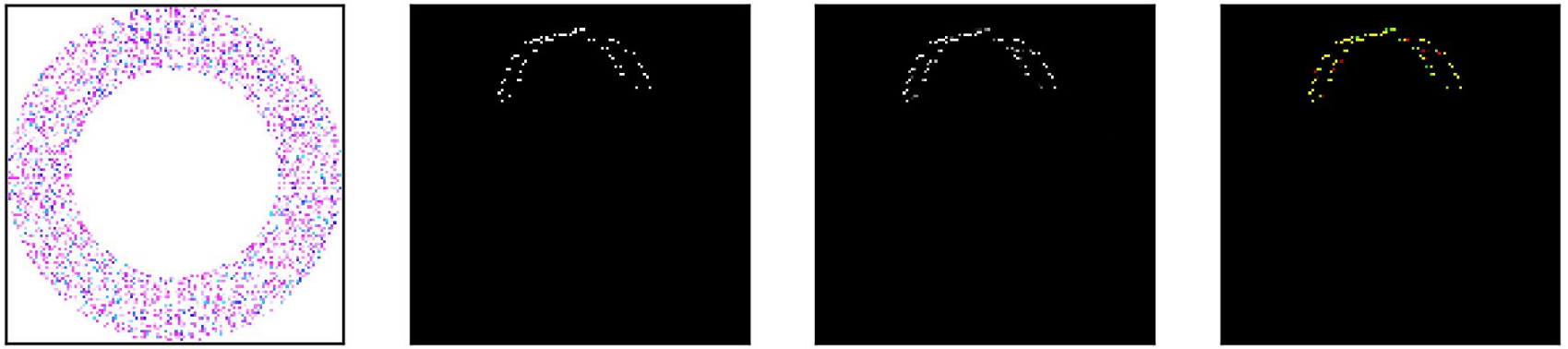
backup

Test Example: denoising

- 10%

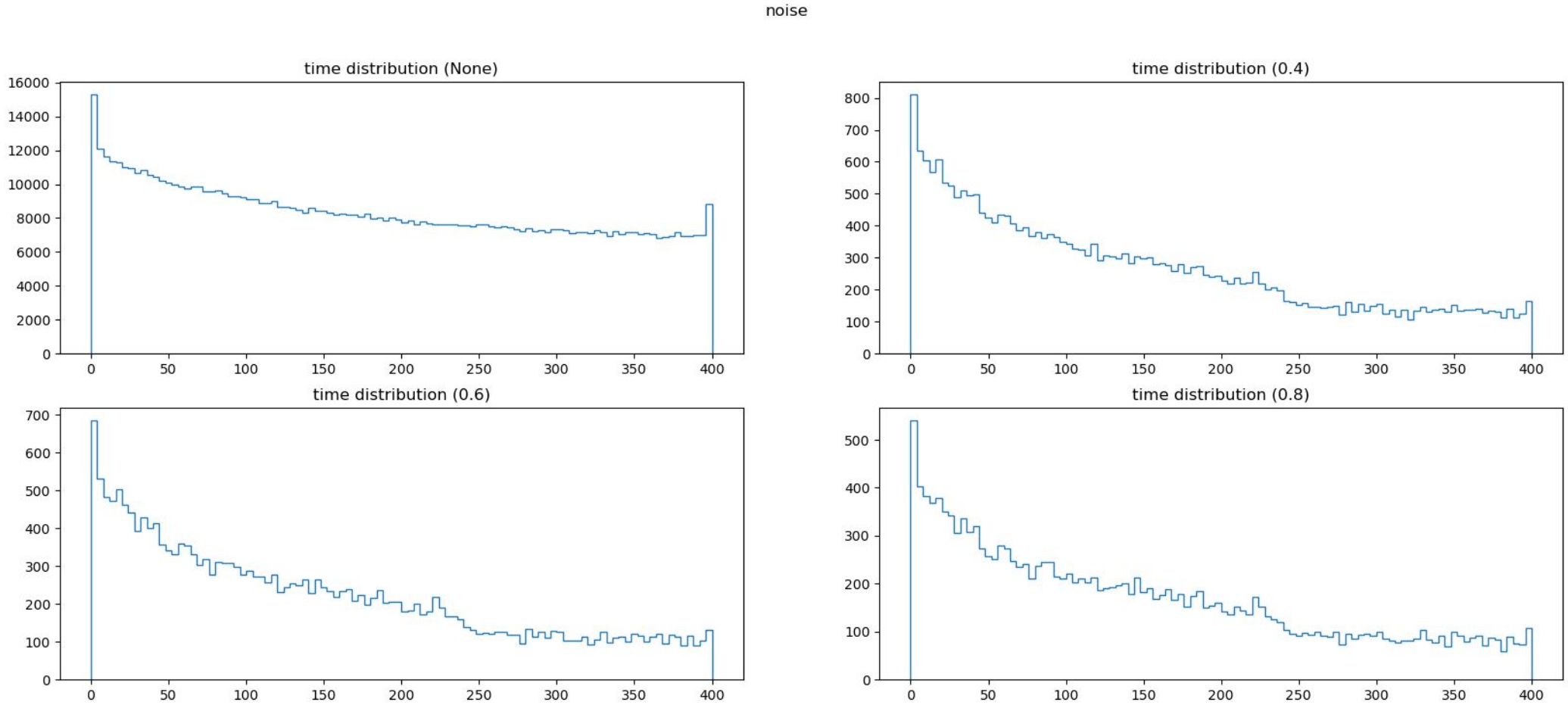


- 50%

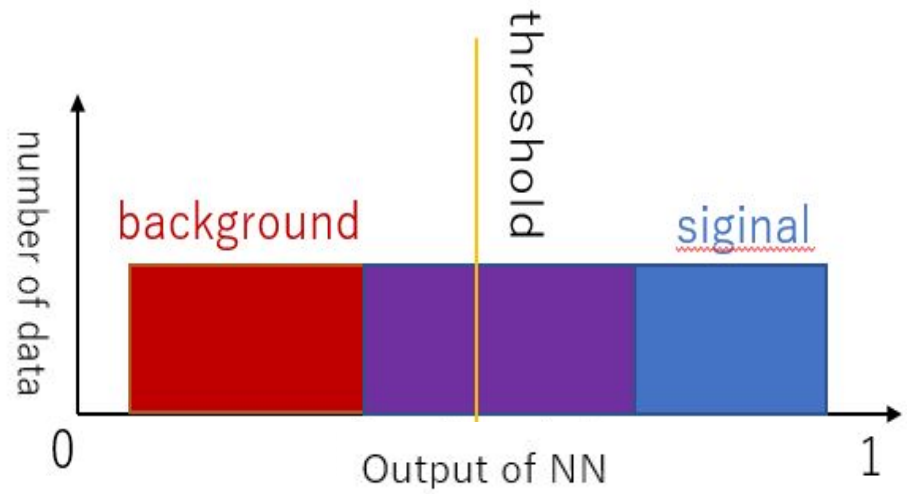


Histogram of predicted sample (noise)

- Time distribution

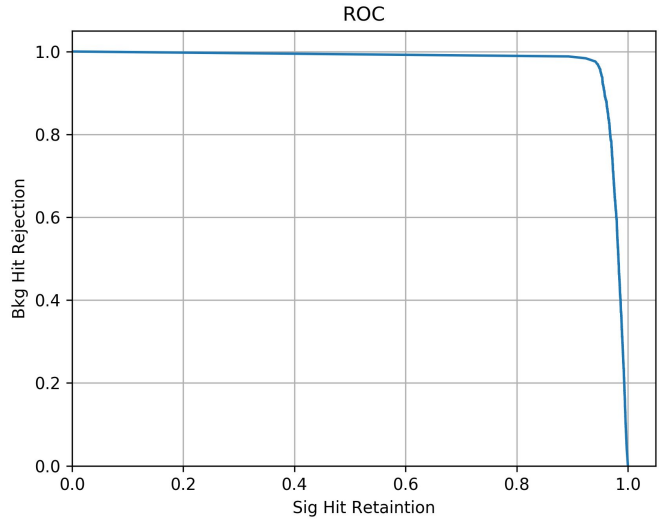


How to evaluate（ROC）



- ROC(Receiver Operating Characteristic)
  output of the NN is 0 ~ 1
  needs any threshold for prediction
  horizontal axis : signal *acceptance*

$$\left(= \frac{True\ signal}{True\ signal\ + False\ background} \right)$$

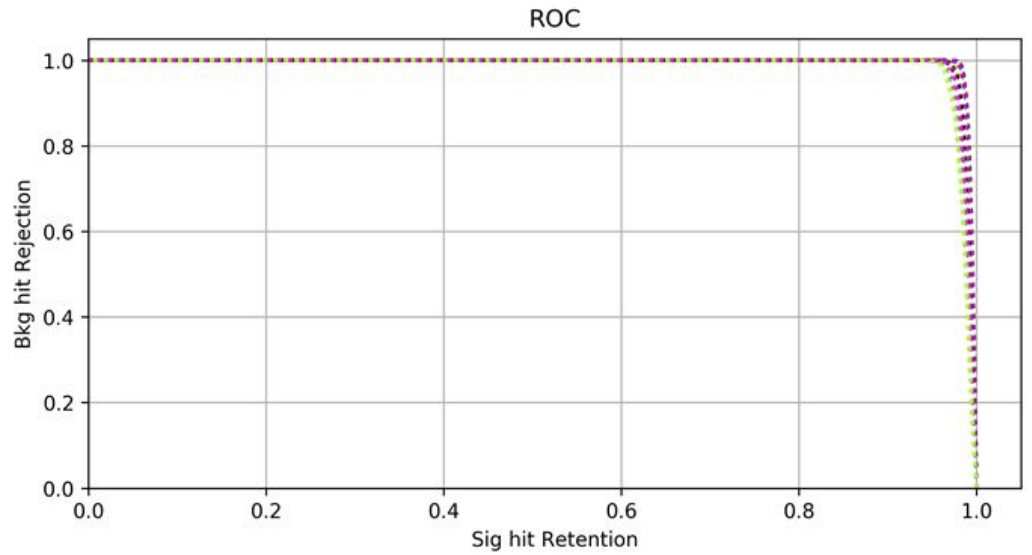


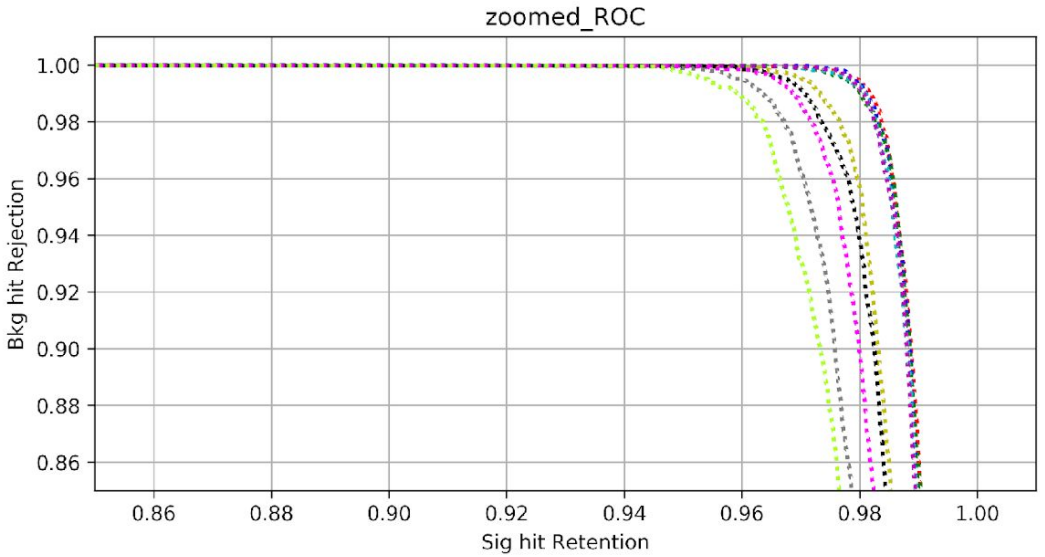
vertical axis : background rejection

$$\left(= \frac{True\ background}{False\ signal\ + True\ background} \right)$$

Result: Test with 10% noisy data

- FPN Trained 10%
- FPN Trained 20%
- FPN Trained 30%
- FPN Trained 40%
- FPN Trained 50%
- DnCNN Trained 10%
- DnCNN Trained 20%
- DnCNN Trained 30%
- DnCNN Trained 40%
- DnCNN Trained 50%





Additional Try: label-change

- Changing how to label when I make label data,

  from “Whether true signal hit is contained in each cells”

  (we call this “way①”)

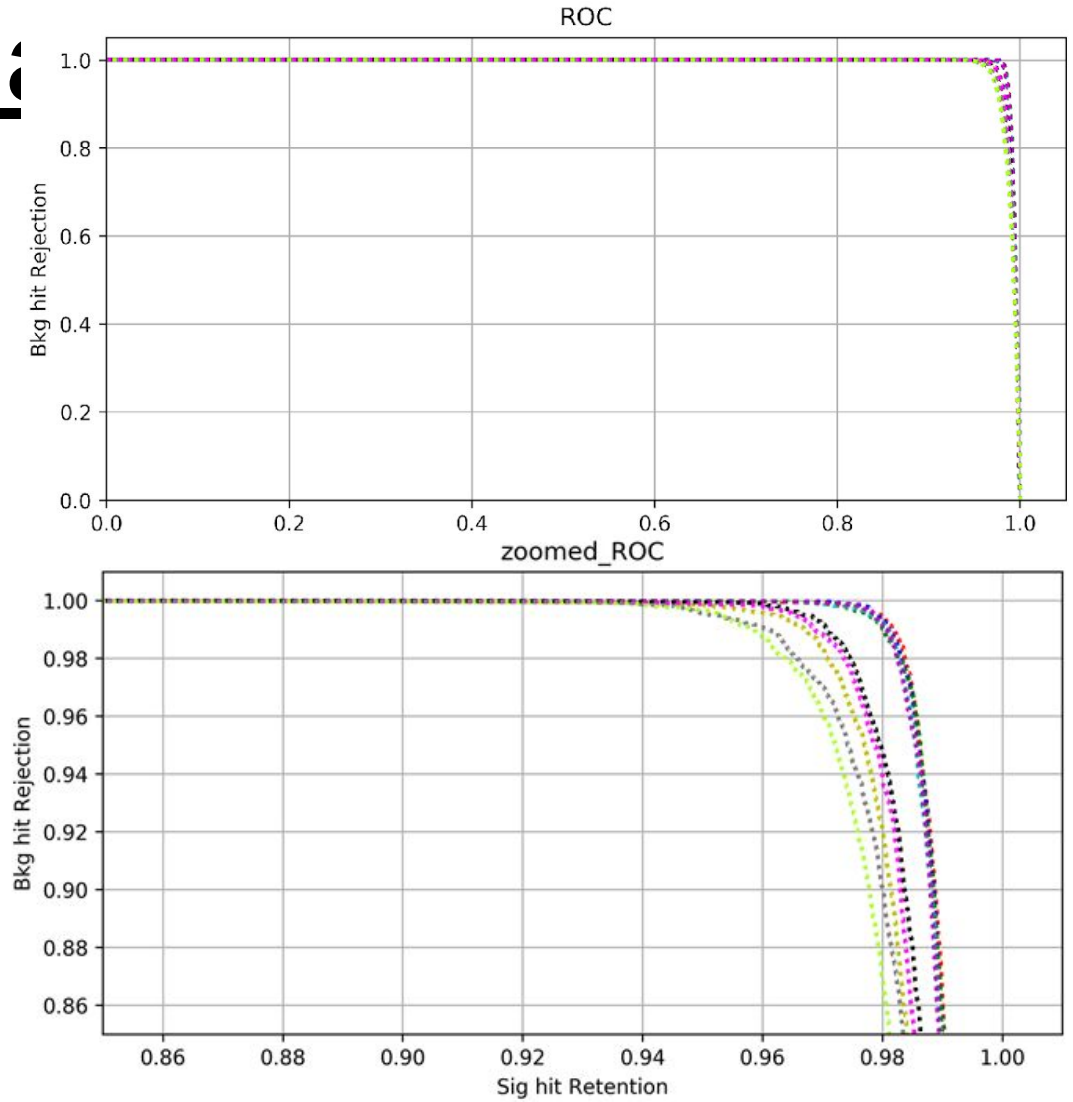
  to “Whether first hit is true signal hit in each cells”

  (we call this “way②”)

- I got five and five roc curves according to above two ways.

Additional Result: label change with 10% noisy test da

- FPN Trained 10%(way①)
- FPN Trained 20%(way①)
- FPN Trained 30%(way①)
- FPN Trained 40%(way①)
- FPN Trained 50%(way①)
- FPN Trained 10%(way②)
- FPN Trained 20%(way②)
- FPN Trained 30%(way②)
- FPN Trained 40%(way②)
- FPN Trained 50%(way②)



Interpretation: label change

- "Whether first hit is true signal hit in each cells": To decide what to label, it depends on dirft time (time information)

  ⇒ if the number of hits is bigger, the number of hits labeled as signal may be smaller.(noisy hits can interrupt trus signal hits)

- "Whether true signal hit is contained in each cells": To decide what to label, it depends on whether the signal hits is contained in multiple-hits or not.

  ⇒ even if the number of hits is bigger, nothing wouldn't smaller.

Summary

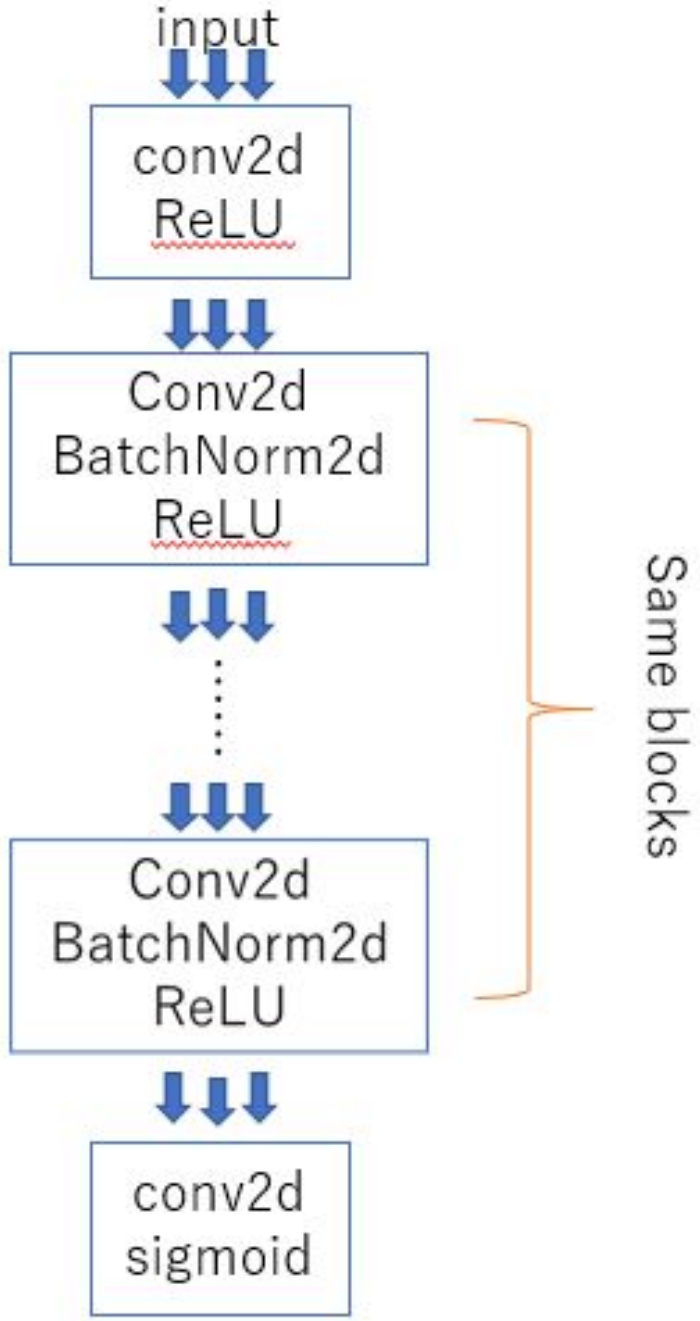
- Uniform distribution of time and energy
- FPN is better than DnCNN
- FPN look only true signal hits.
- But DnCNN look noise hits to denoise.

DnCNN architecture

- Denoising CNN

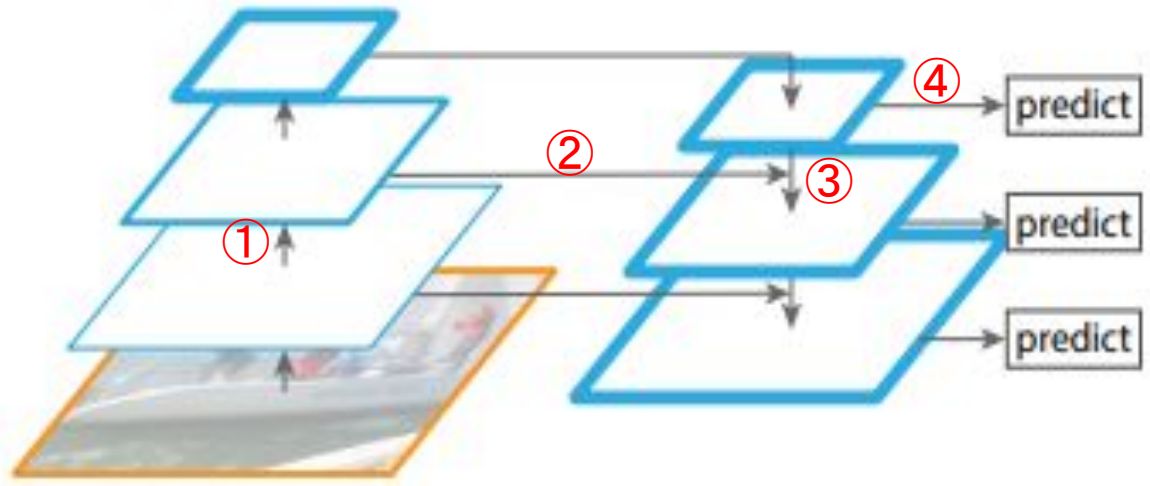
convolution (getting feature)
batch normalization
(non-linear function)

Unlike FPN, image isn't extended.



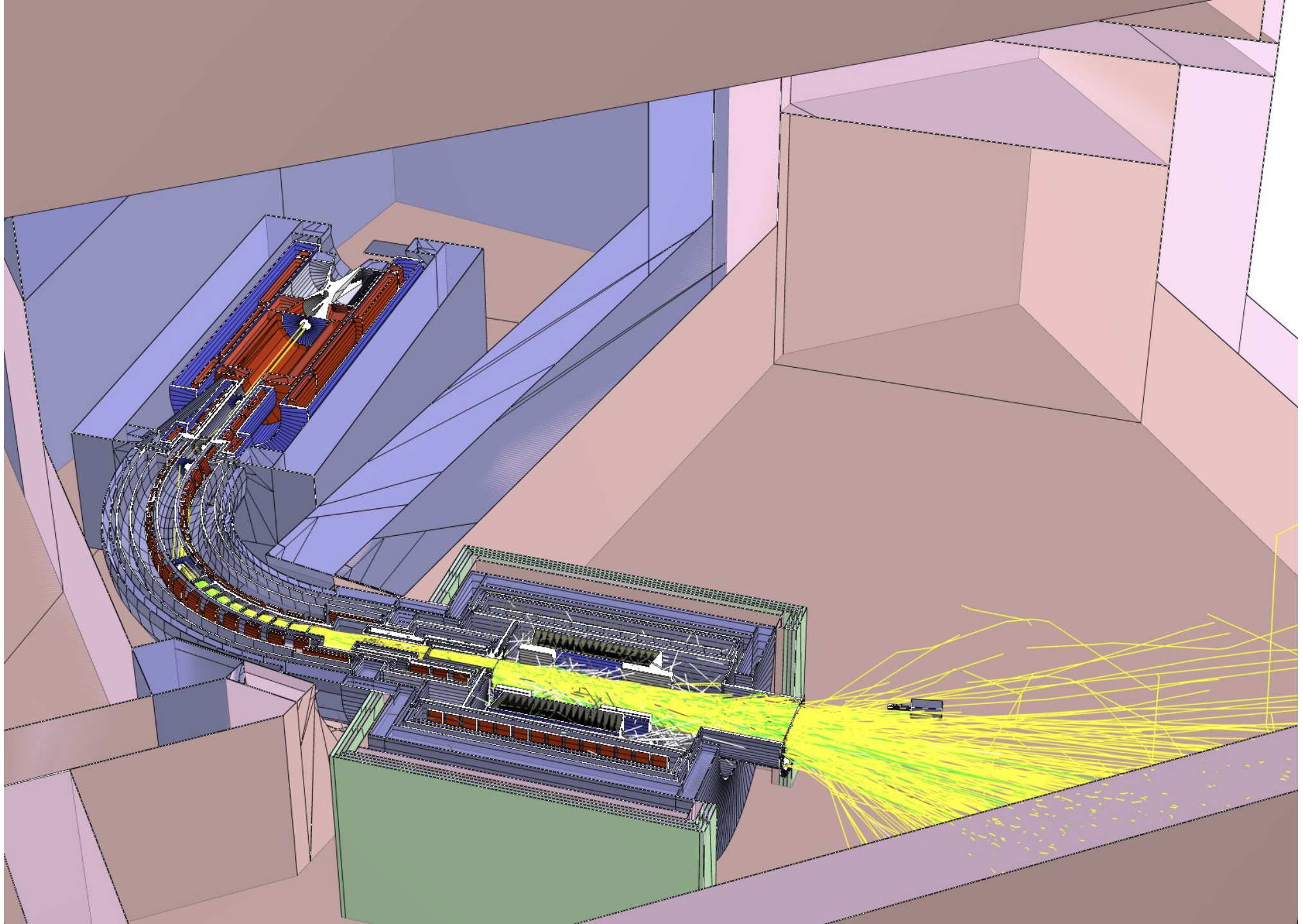
Feature Pyramid Network architecture

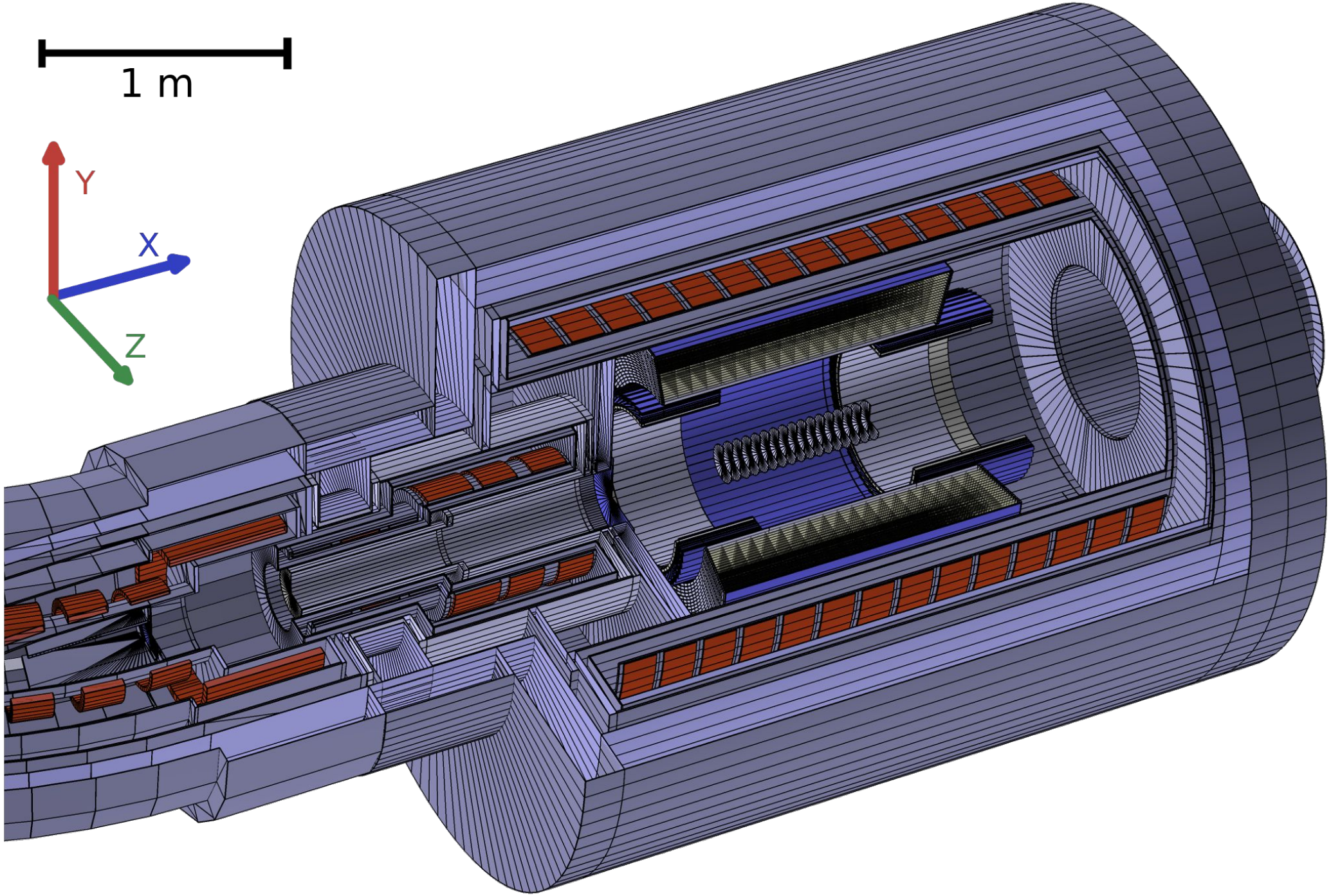
① As step up, size down (conv)
② Feature map in Different scale would be extracted
③ As step down, size up
④ Predicting where the object is

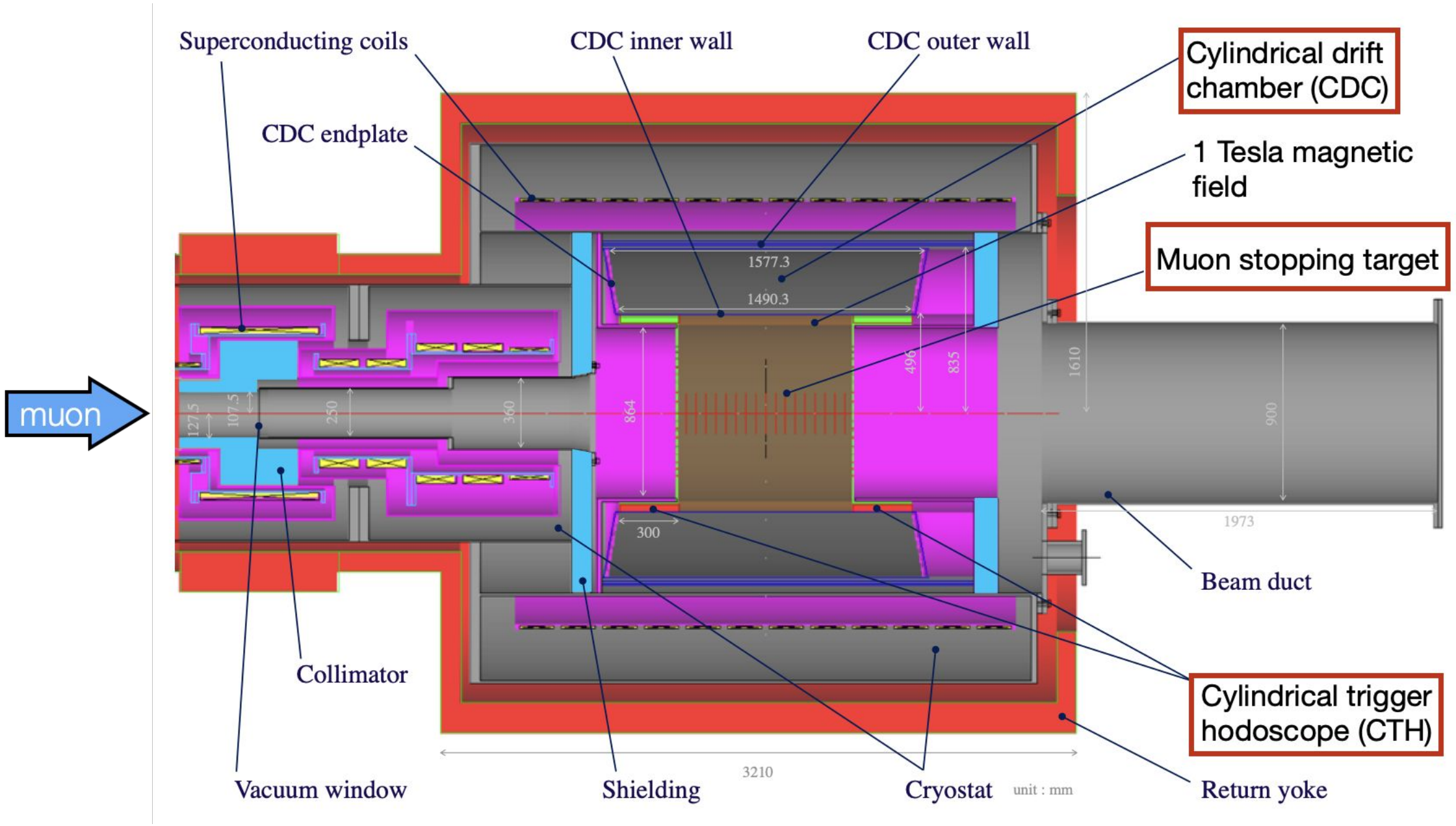


(d) Feature Pyramid Network

https://arxiv.org/pdf/1612.03144.pdf




1 m
Y
X
Z


Superconducting coils
CDC inner wall
CDC outer wall
Cylindrical drift chamber (CDC)
CDC endplate
1 Tesla magnetic field
Muon stopping target
muon
1577.3
1490.3
496
835
1610
900
1973
127.5
107.5
250
360
864
300
Beam duct
Collimator
Cylindrical trigger hodoscope (CTH)
3210
Vacuum window
Shielding
Cryostat
unit : mm
Return yoke