

3DST - A 3D scintillator detector

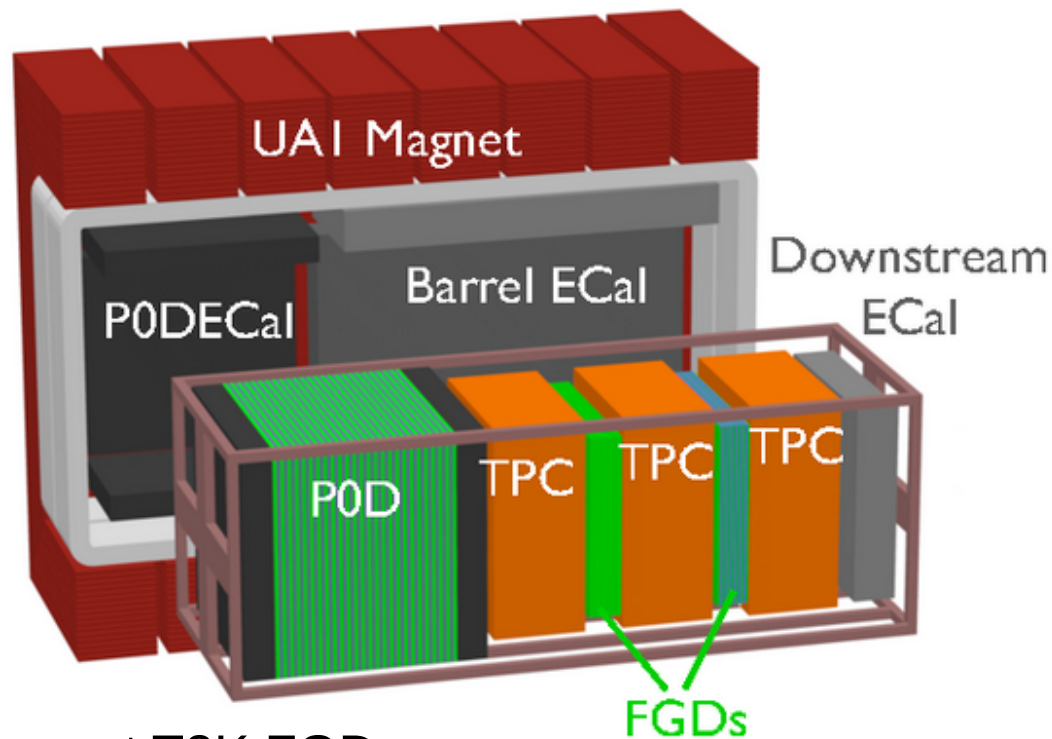
Guang Yang
on behalf of
Jose Palomino, Kevin Wood
Clark McGrew, Chang Kee Jung (Stony Brook)
Davide Sgalaberna (U. of Geneva)

Outline

- Motivation and benefits from a 3D scintillator detector (3DST) in the multi-purpose tracker (MPT)
- Review of 3DST in T2K upgrade
- 3DST hit simulation
- Studies on 3DST
 - muon detection efficiency vs. angle
 - muon angular resolution

Inspired from T2K upgrade

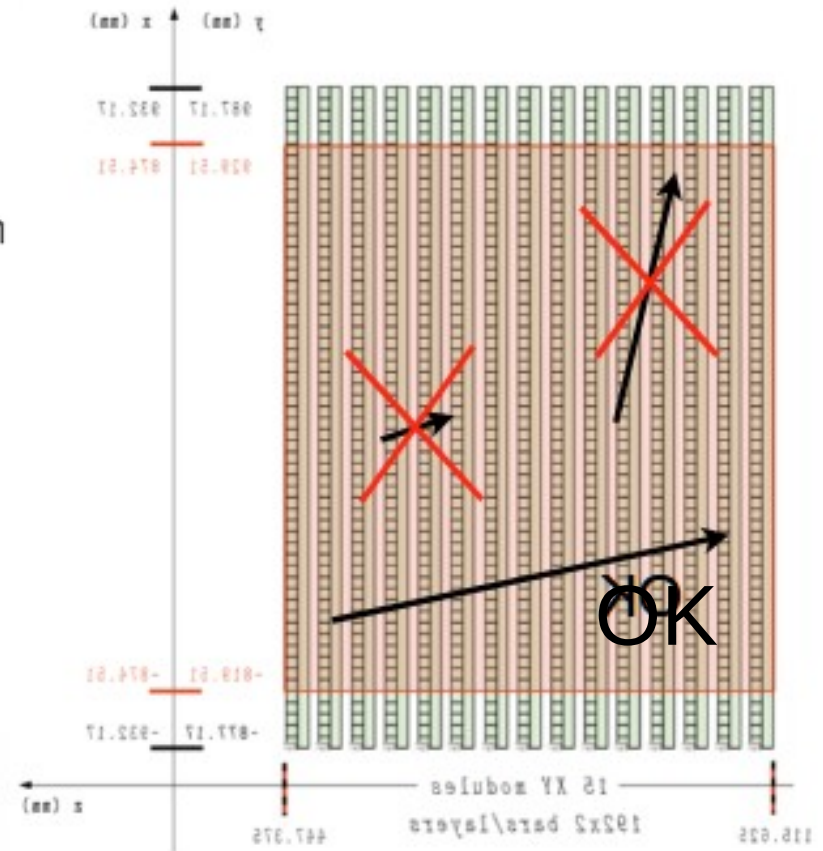
T2K ND280



- Current T2K FGD:

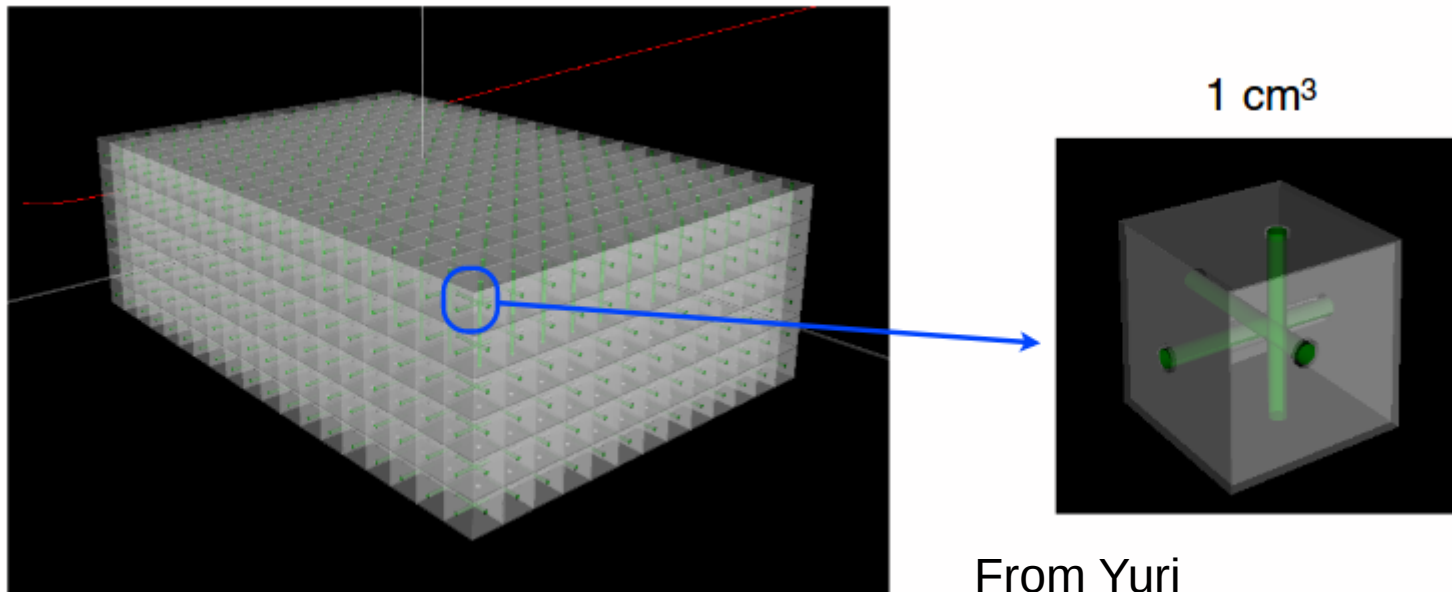
- Classical XY layer bar structure
- Track length threshold 5-6 cm \rightarrow miss low momentum particles.
- Limited high angle coverage \rightarrow 30% events are missing.
- Ambiguity in 3D track reconstruction.
- Not optimized for gamma \rightarrow ee measurement.

ND280 tracker angle coverage



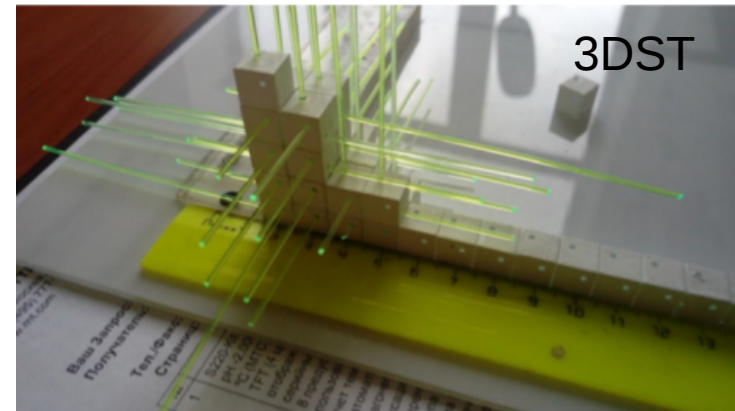
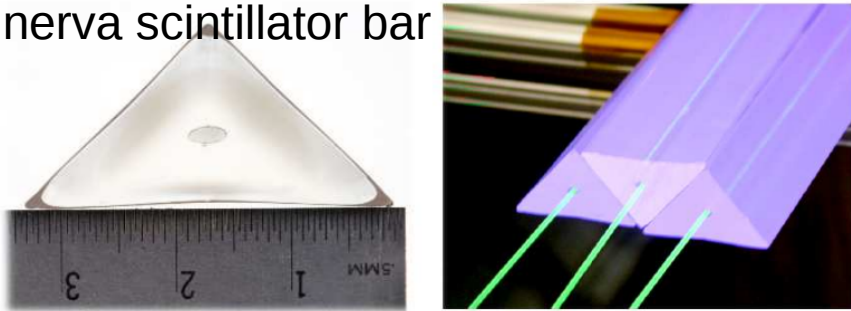
3DST (Super FGD in T2K)

- ~Fully active target
- Full angle coverage
- Direct 3D vertex reconstruction
- Fine granularity allows proton momentum measurement down to 300 MeV
- Connect to world scintillator measurements (xsec, flux etc.)
- Possibly coating Li on the cubes, in order to tag neutrons (to be studied)

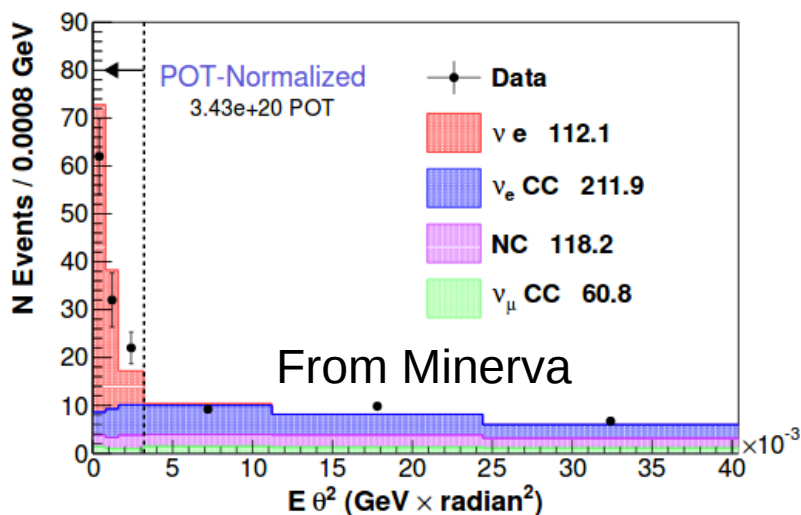


- Large statistics
 - allows early measurements of various neutrino interactions.
- Minerva demonstrated potential for using nu-e scattering and low-nu method to constrain the flux.

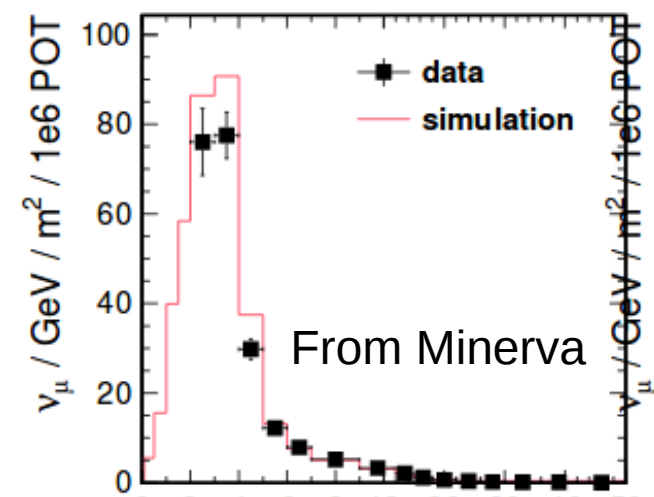
Minerva scintillator bar



Minerva selected nu-e scattering events

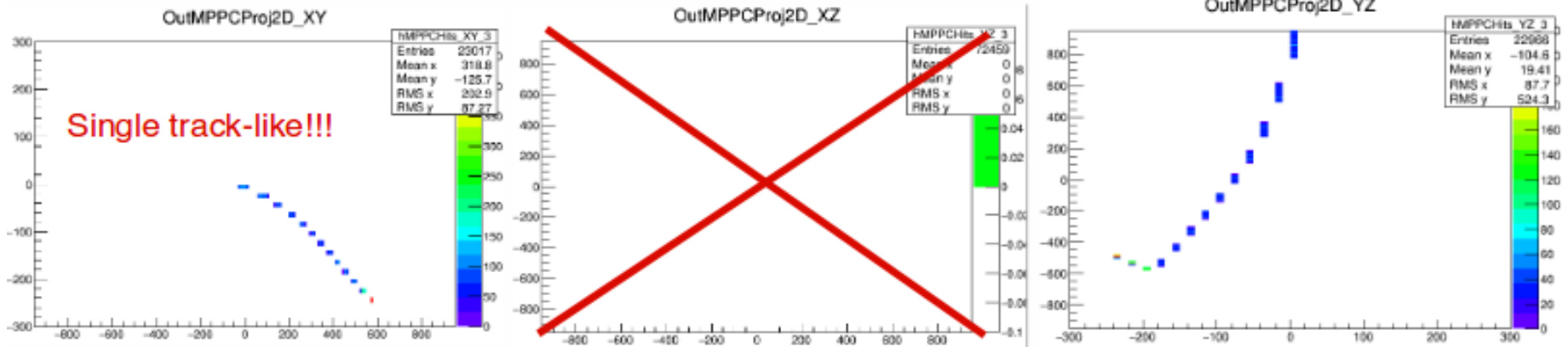


Minerva flux measurement (FHC nu)



SuperFGD/3DST vs. FGD-like XZ

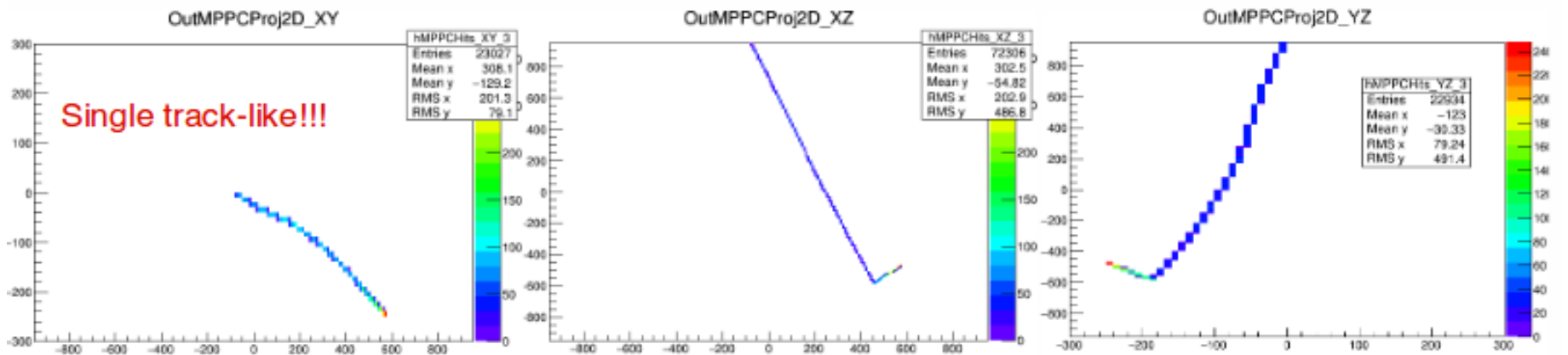
FGD scint bars along XZ



- The proton track is not detected in the FGD

SuperFGD

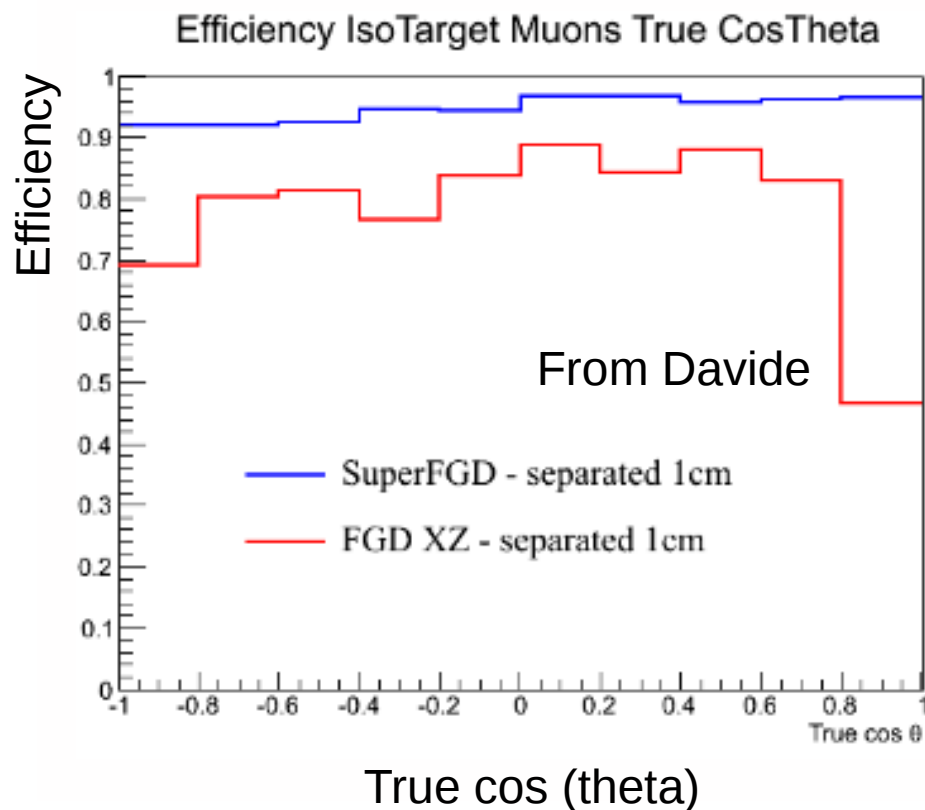
From Davide



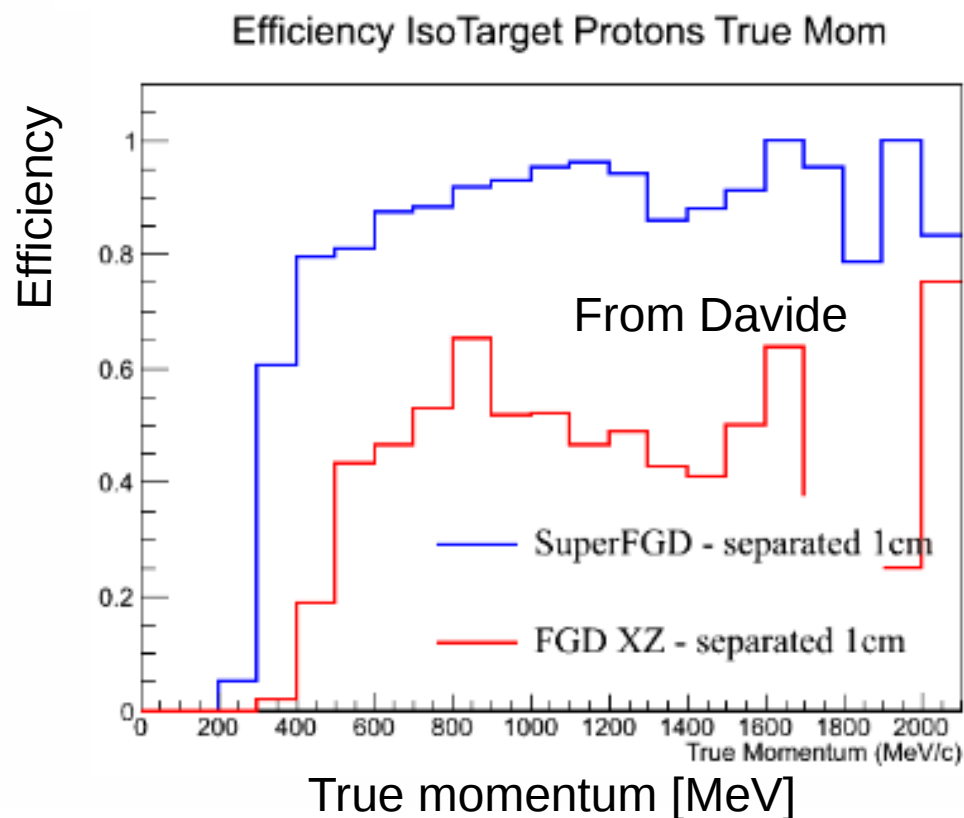
- 3DST has a better 4π acceptance and lower particle momentum threshold than a FGD-like detector.

Expected performance of 3DST

3DST vs. FGD-like XZ



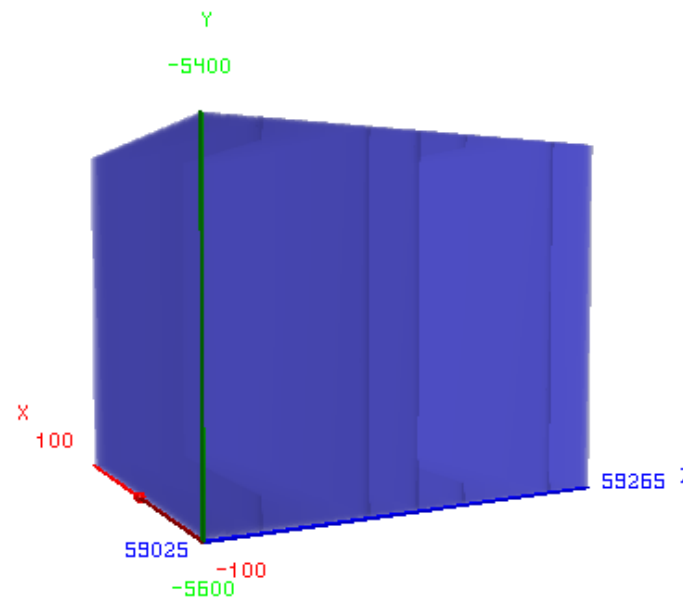
3DST vs. FGD-like XZ



- 3DST has a better 4π acceptance and lower particle momentum threshold than a FGD-like detector.

Hit Simulation status

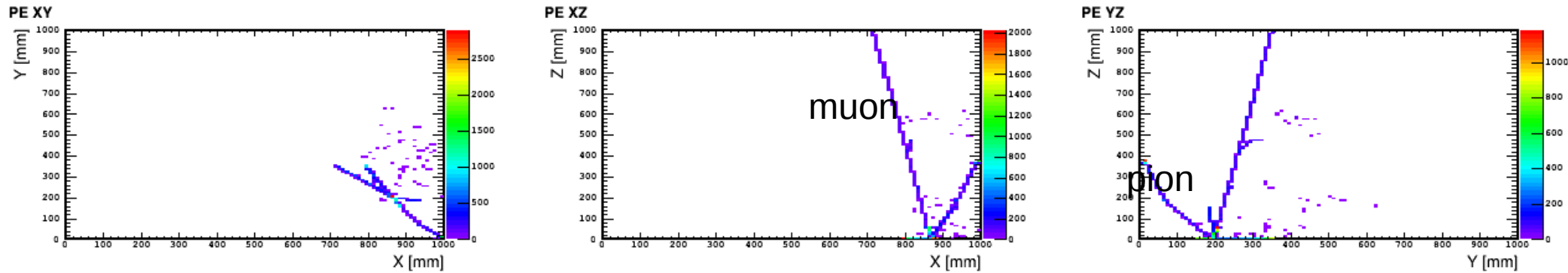
- I have modified the T2K upgrade package for 3DST to adopt our simulation tool and beam flux.
- Things considered:
 - 1 cm scintillator cube
 - Birk's saturation (dedx)
 - edep to number of photons in scintillator
 - light collection in each fiber (3 in a cube)
 - light attenuation in fiber (11926 mm)
 - MPPC efficiency (0.38)
 - ADC response (including noise)
- Now those are based on typical FGD calibration, 3DST expects 30% light collection in each fiber comparing to FGD. (test beam ran on Oct. in CERN)



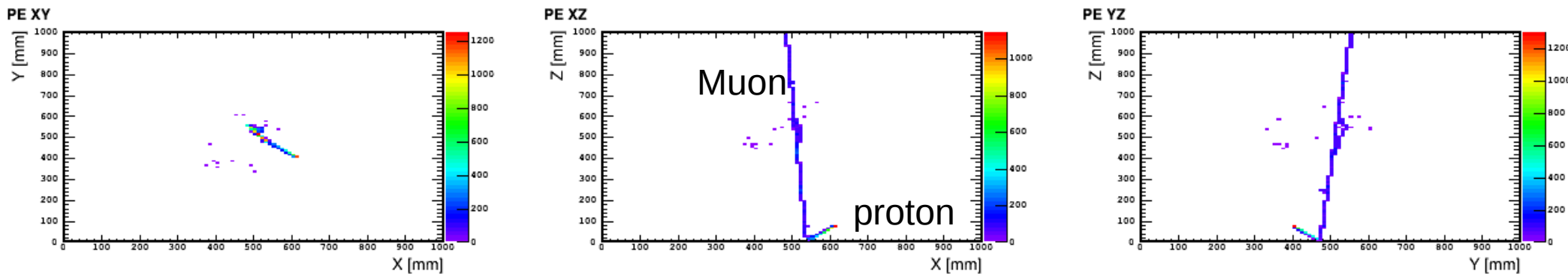
3DST 2x2x2.4 m module
(from DUNENDGGD)

Hit simulation (particle gun)

Example event: CC1pi



Example event: CCQE

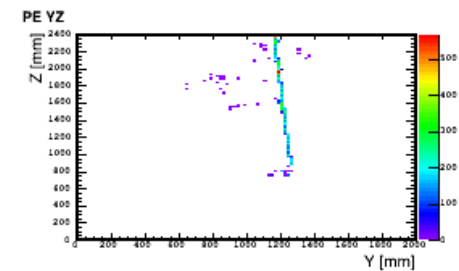
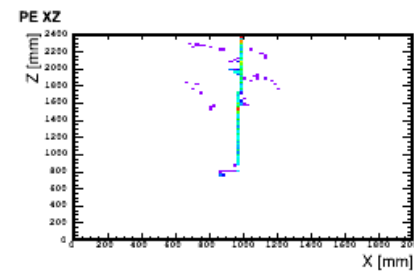
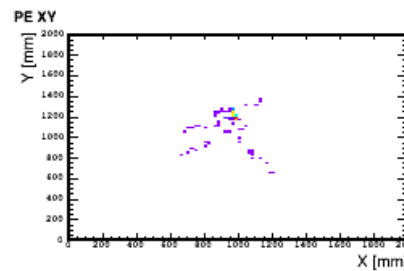
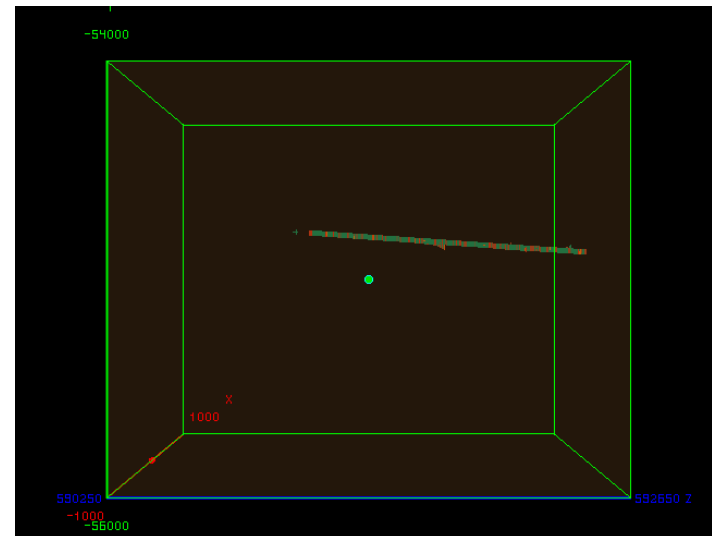
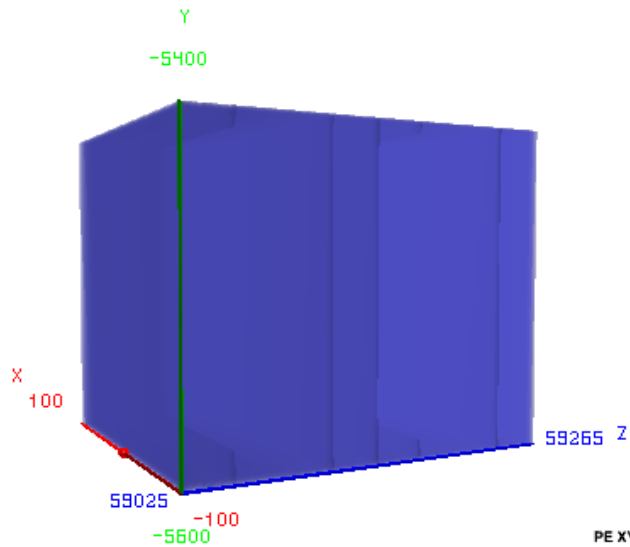


- 3 2D projections give time, track length, direction and energy deposit information for event reconstruction.

Event rate

Project CDR number to a $1 \times 1 \times 1 \text{ m}^3$ module, we can expect to have 179,000 events with 10^{20} POT at 574 m.

DUNE Geometry and event generation



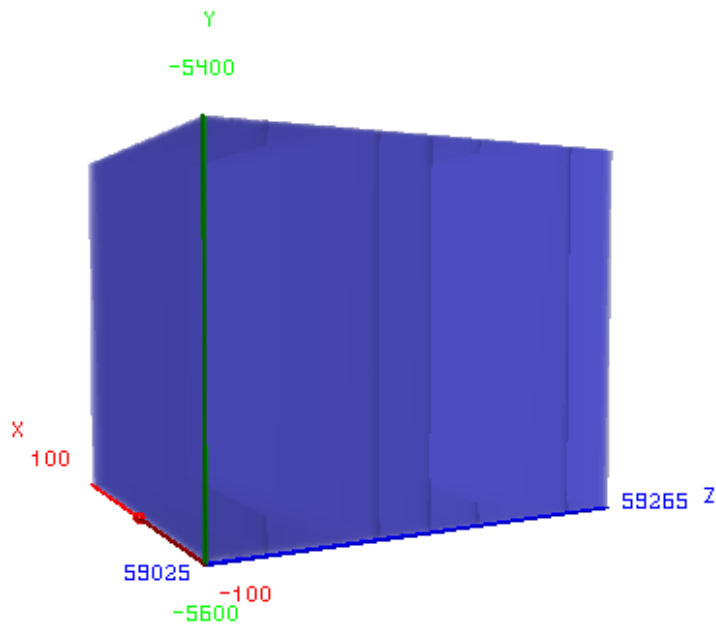
DUNE Geometry and event generation

DUNENDGGD:

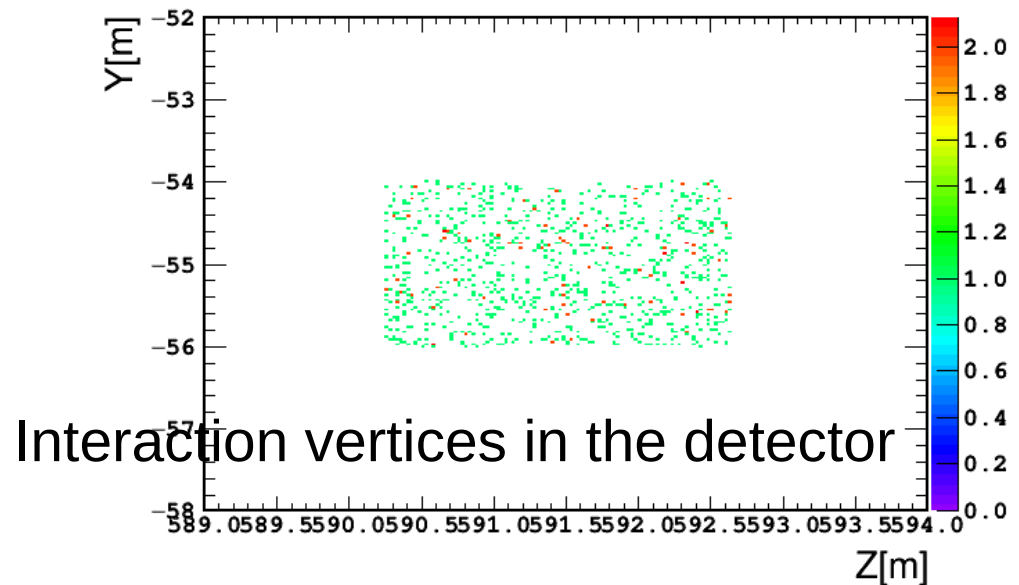
Multiple layers:

Boxes \rightarrow row \rightarrow plane \rightarrow 3D

- GENIE with DUNE flux Ntuple, Geometry is at the realistic place.
- Edep-sim for energy deposit.
- CC events only.



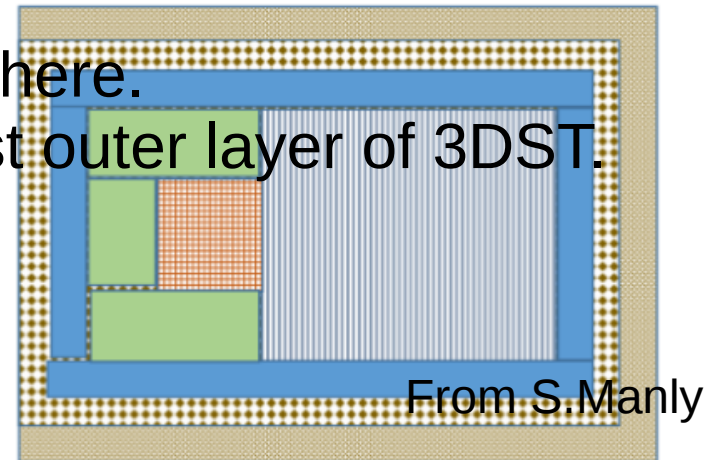
3DST module
 $2 \times 2 \times 2.4 \text{ m}^3$



Interaction vertices in the detector

Muon detection efficiency vs. muon angle

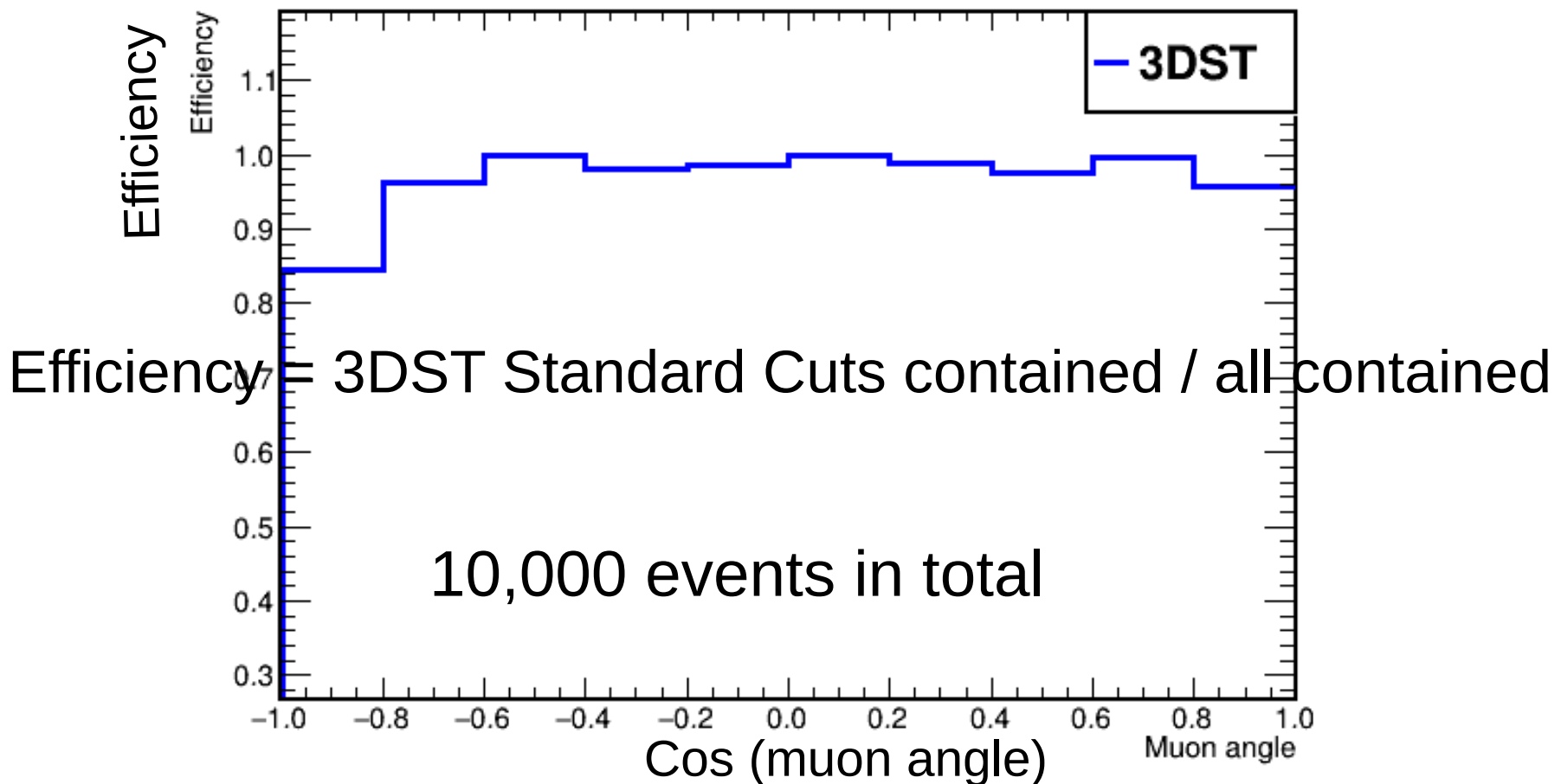
- Only consider CC events.
- Assume muons that going into TPC will be fully reconstructed (100% efficiency).
 - Only contained muons are considered here.
 - Contained muon: no true hit in the most outer layer of 3DST.
- Defining the efficiency:
Cuts:
 - Events that have two 2D projections that have at least 3 hits.
 - All three 2D projections have at least 6 hits.
 - second long track is separated from the longest one.
- For contained events, low momentum and merged muons cannot be reconstructed. This is the definition being used in T2K upgrade.



Defining the efficiency for muon CC events:

Cuts:

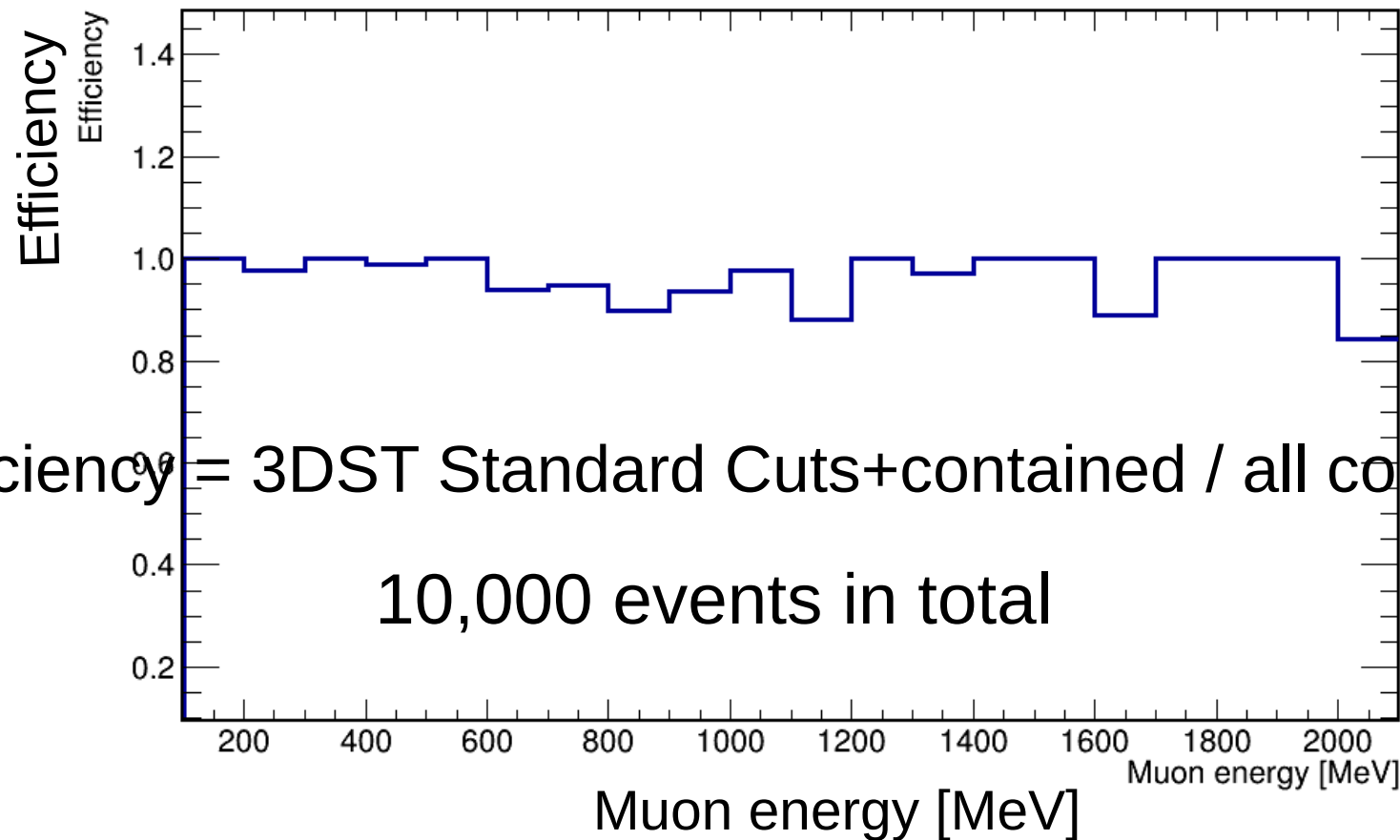
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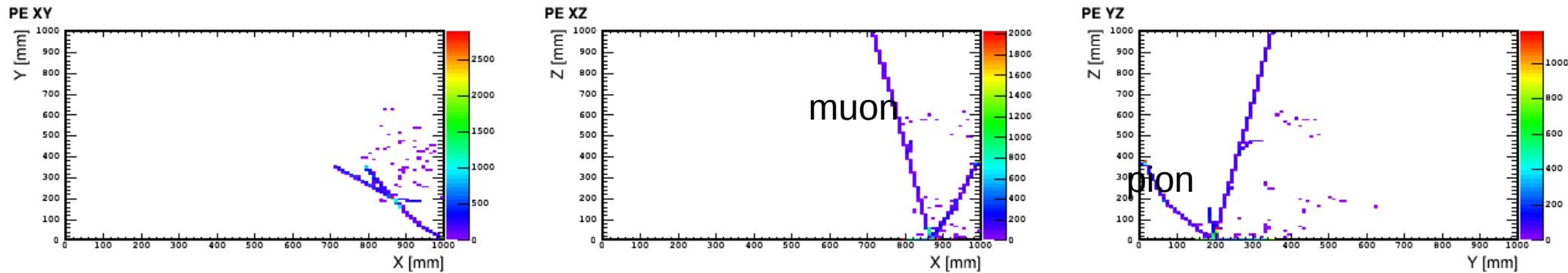
Defining the efficiency for muon CC events:

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Muon angular resolution (without B field)

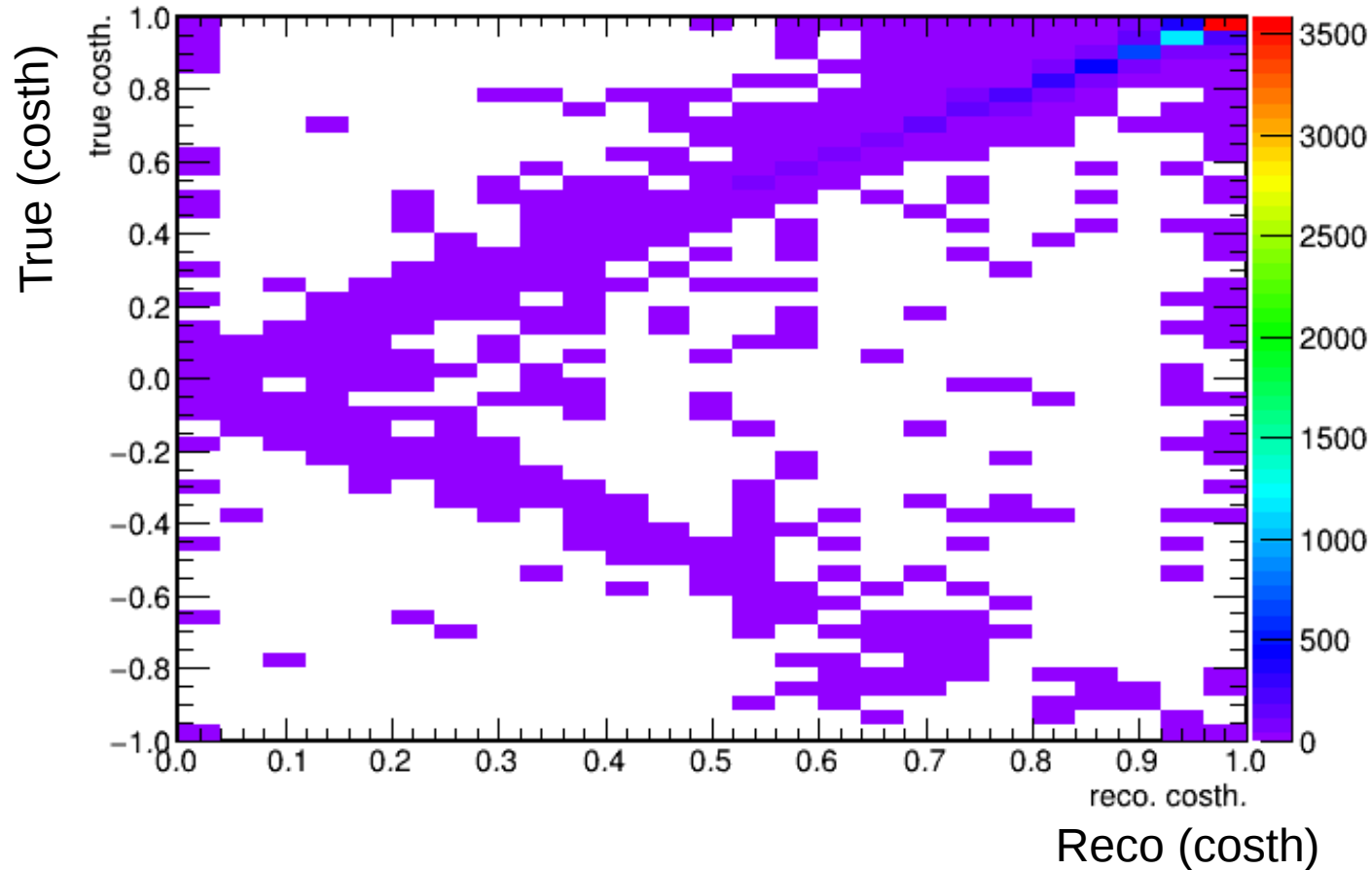


Two ways have been implemented:

1. connect the first and last hits.
2. Consider the charge collected in neighbor cubes.
 - n PE in each cube is treated as “n hits”.
 - get the mean of x, y and z.
 - obtain a covariance matrix for all “hits”.
 - eigenvector with largest eigenvalue gives direction.

(simple tutorial: <https://www.geometrictools.com/Documentation/LeastSquaresFitting.pdf>)

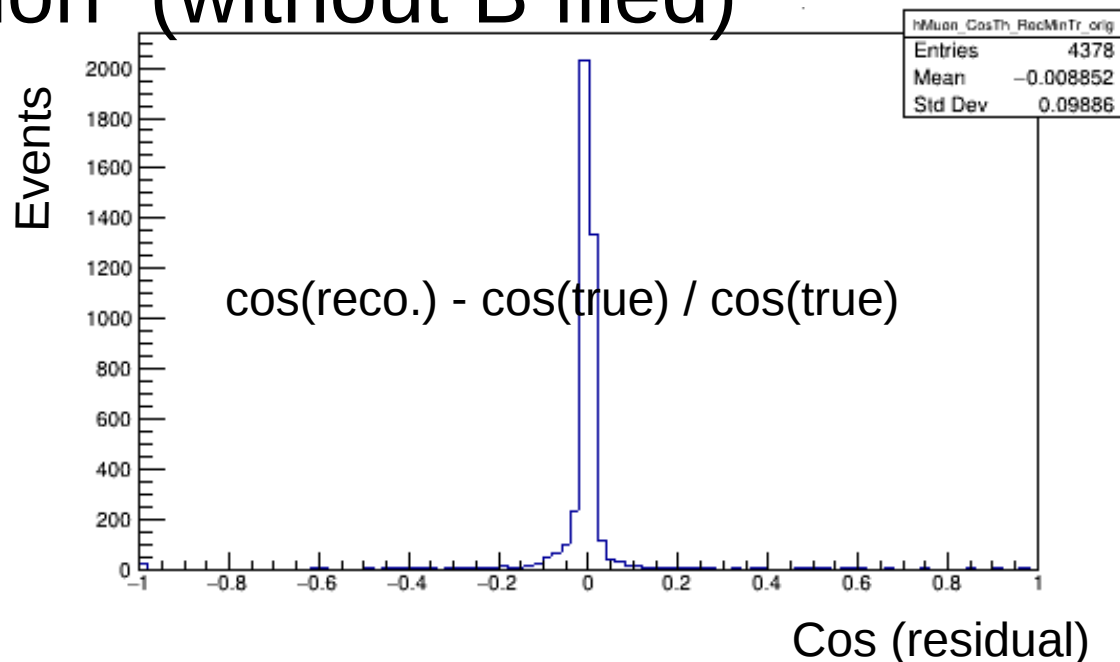
Muon Angular resolution (without B filed)



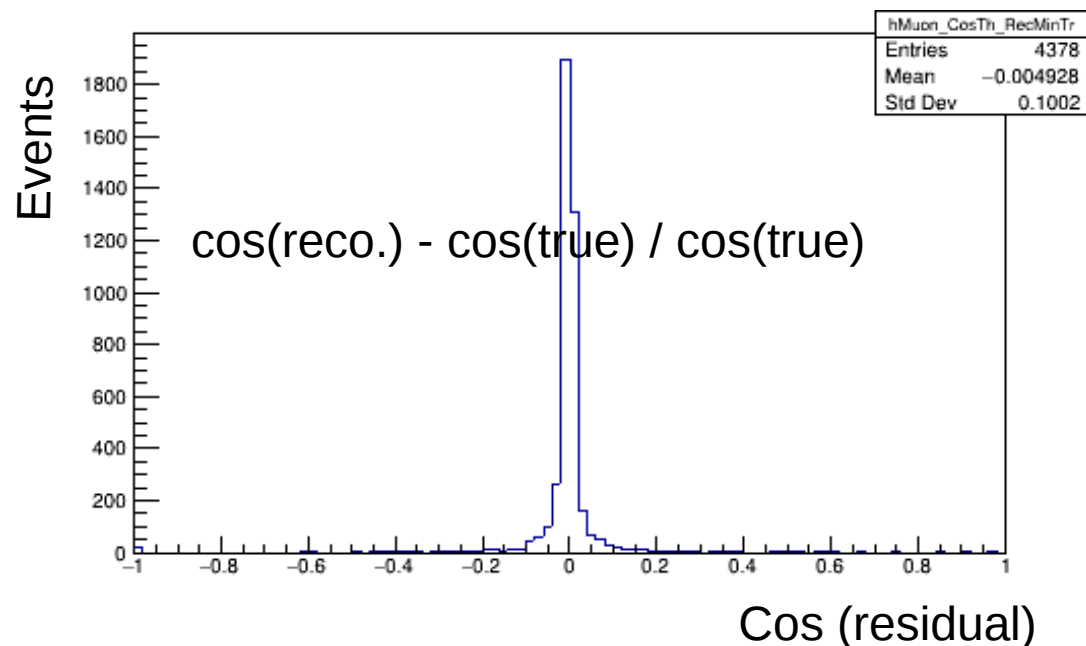
- all events, no selection applied.
- No backward events, no time information yet.

Muon angular resolution (without B filed)

First way:
Connect first and last points

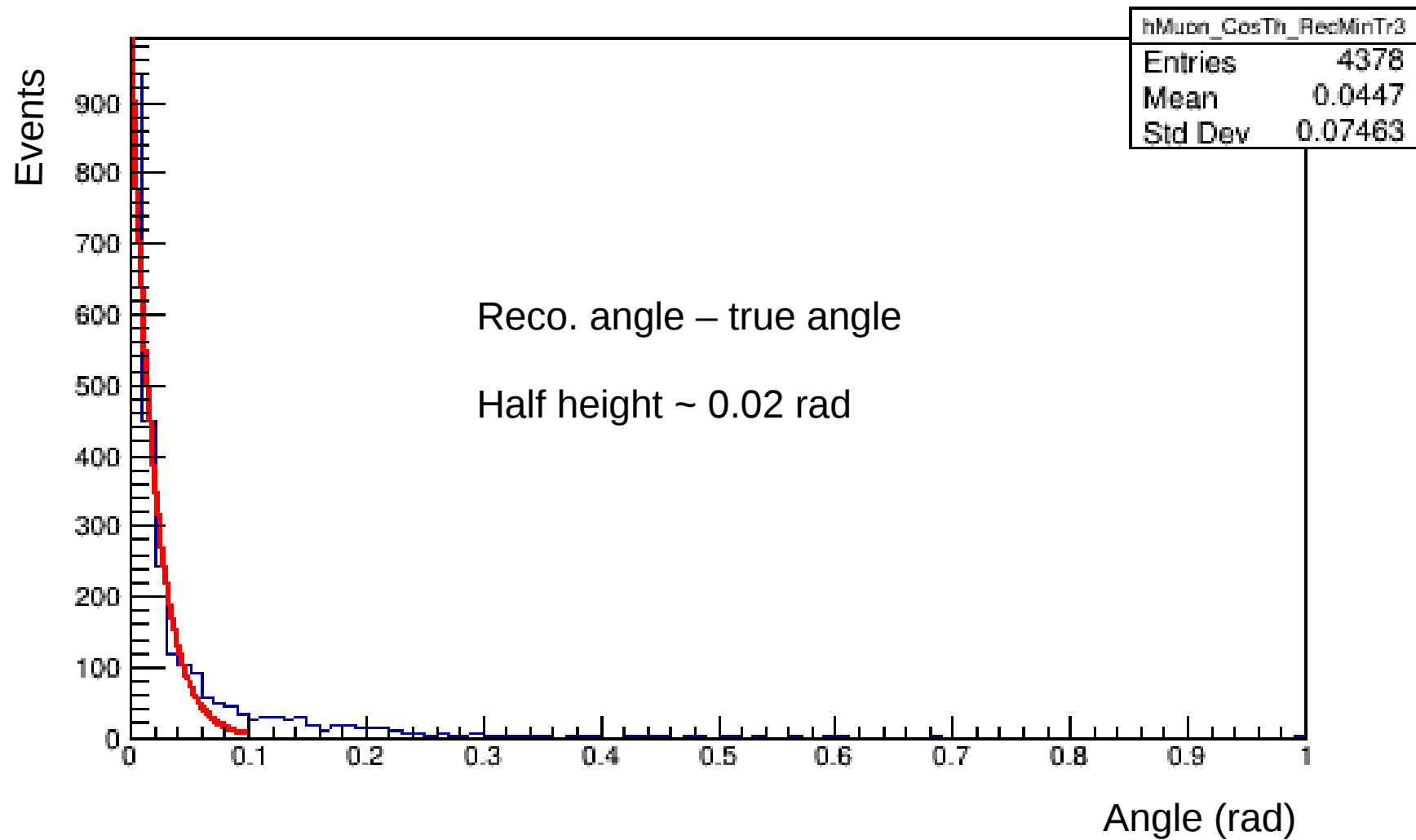


Second way:
Consider the charge collected
in neighbor cubes.

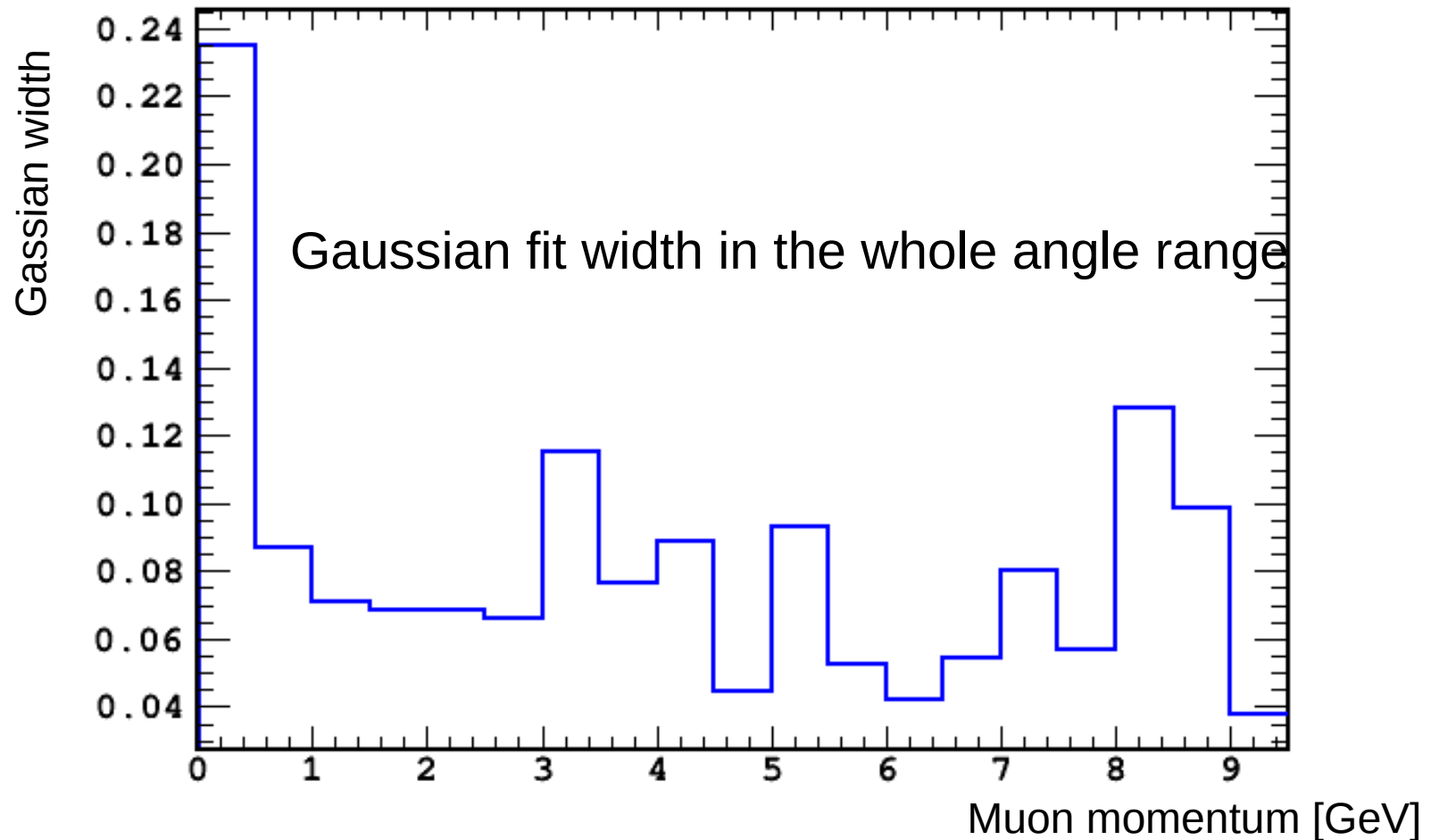


They are so similar..

Muon angular resolution



Muon angular resolution vs. momentum



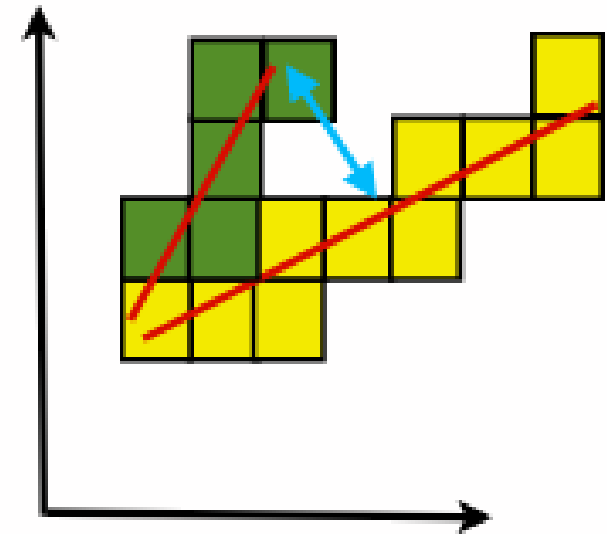
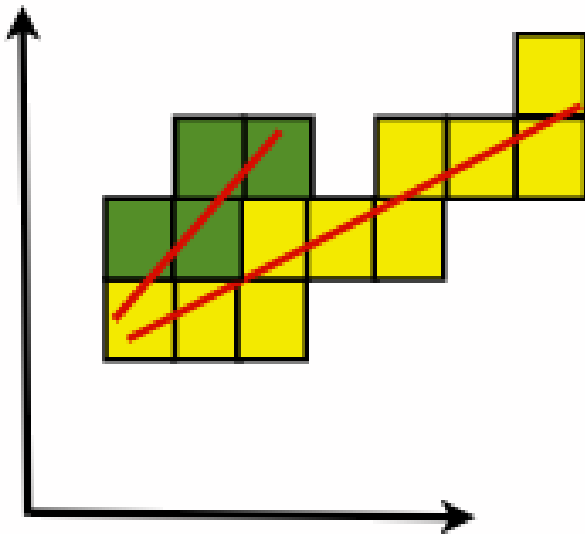
- After 500 MeV, it is flat distributed.
- Low momentum muons have worse resolution.

Conclusion

- A mass target is important for DUNE early measurement as well as the connection to the outside measurements.
- Hit simulation and true-based reconstruction tool has been built for DUNE.
 - Kevin Wood and myself will continue this study in the collaboration with T2K upgrade group.
- 3DST gives good and flat muon angular coverage.
- 3DST preliminary angular resolution calculated (comparable to Minerva).
 - Kevin Wood is going to do detailed nu-e scattering study with 3DST.

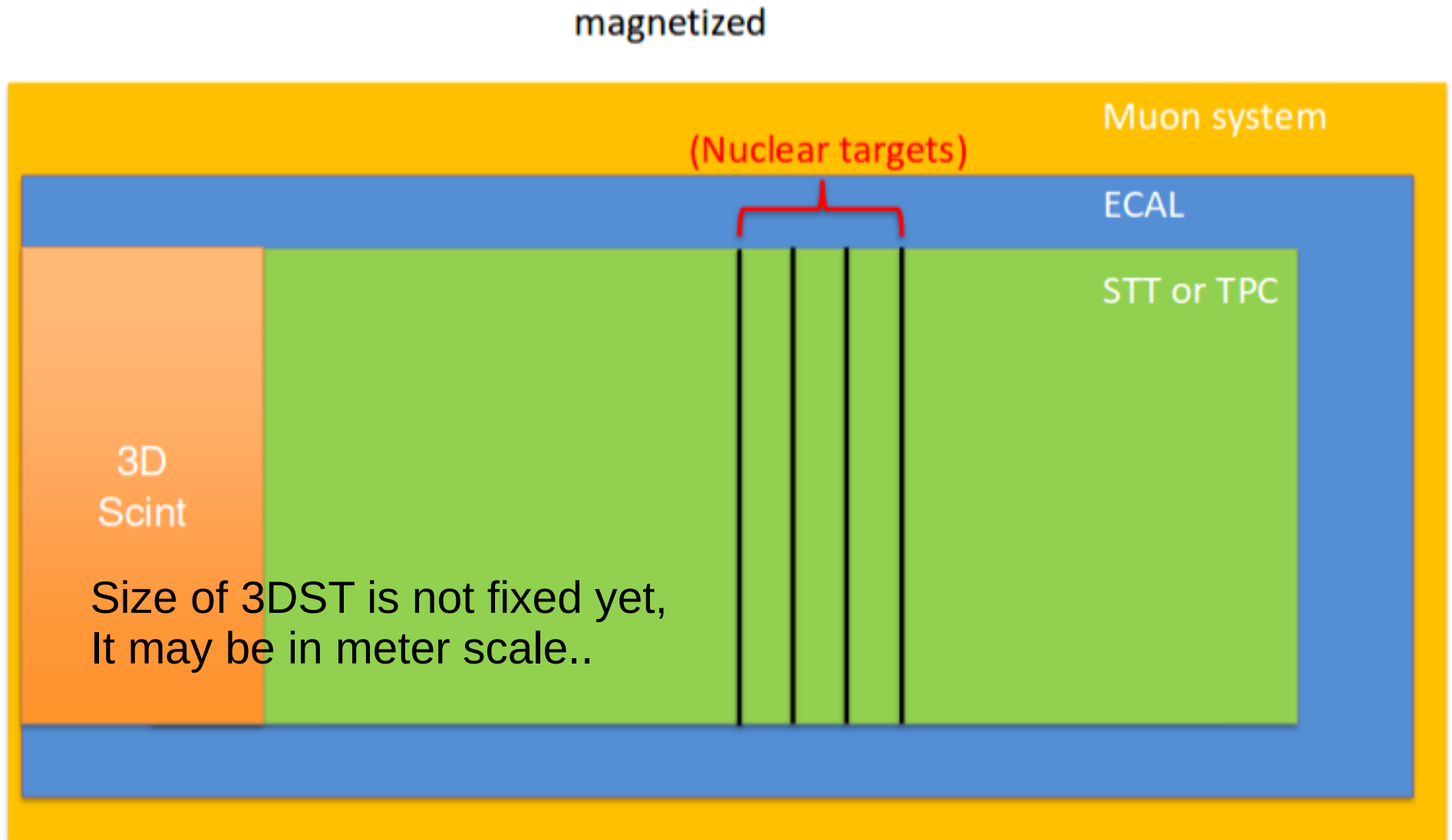
BACKUP

Track separation



Project the shorter track to the longer track, if the blue arrow cross more than one unfired cube, the two tracks are separated.

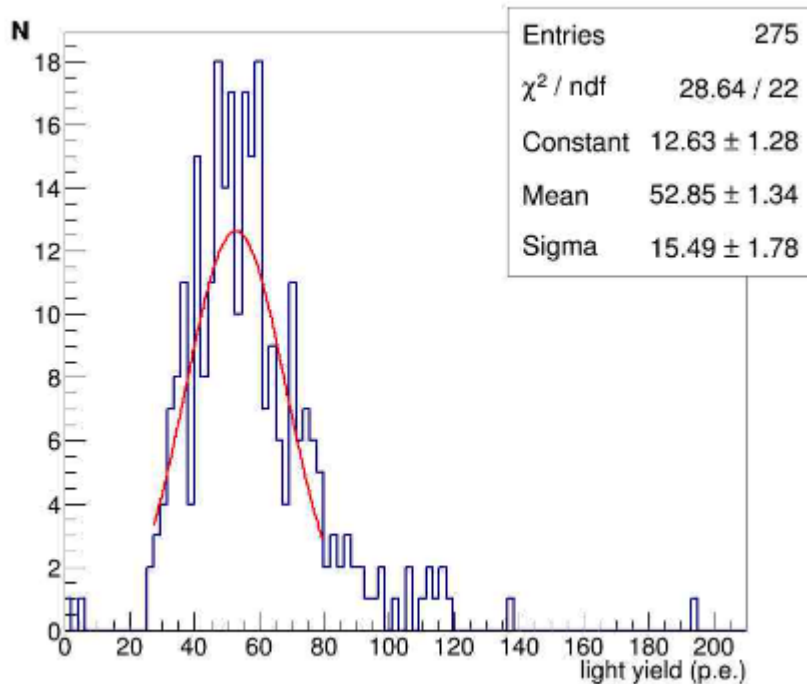
Possible position



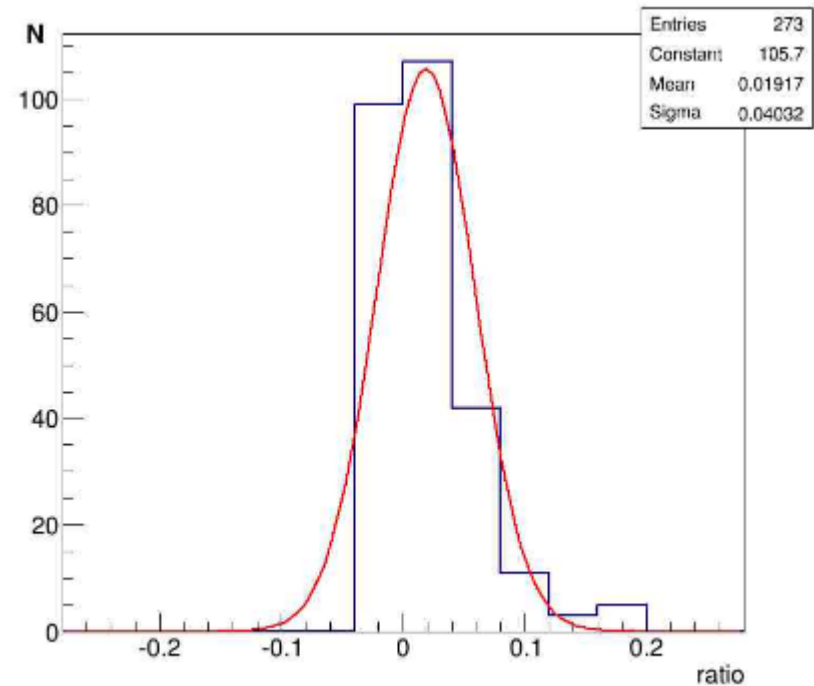
From Alfons Weber

Measured performance of 3DST

Light yield per MIP per fiber
at 1m from MPPC

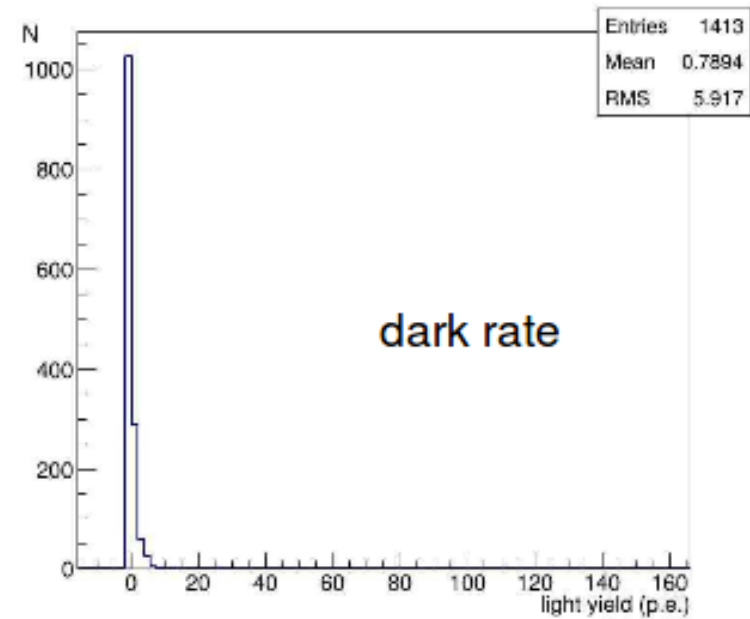
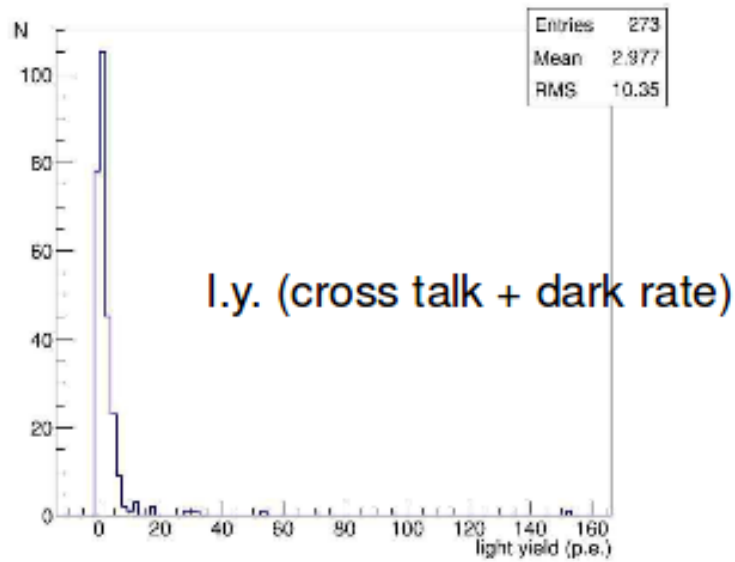


Ratio of signal in a adjacent cube to
Fired cube



- Good light yield for MIP in single cube.
- Low signal cross talk from cube to cube.

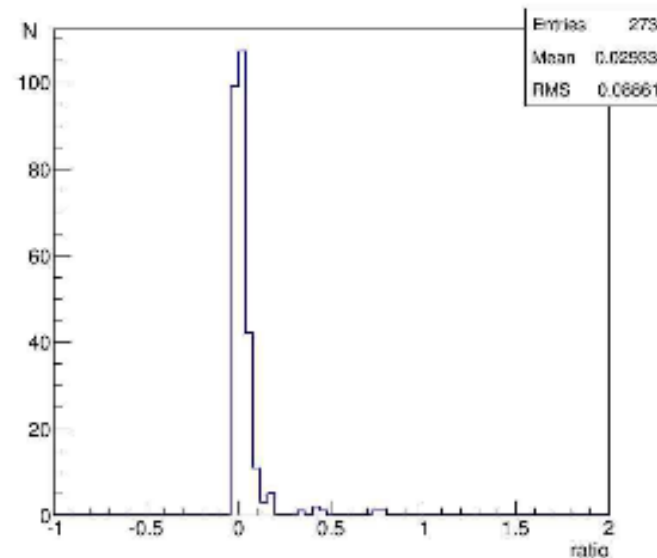
Expected performance of 3DST



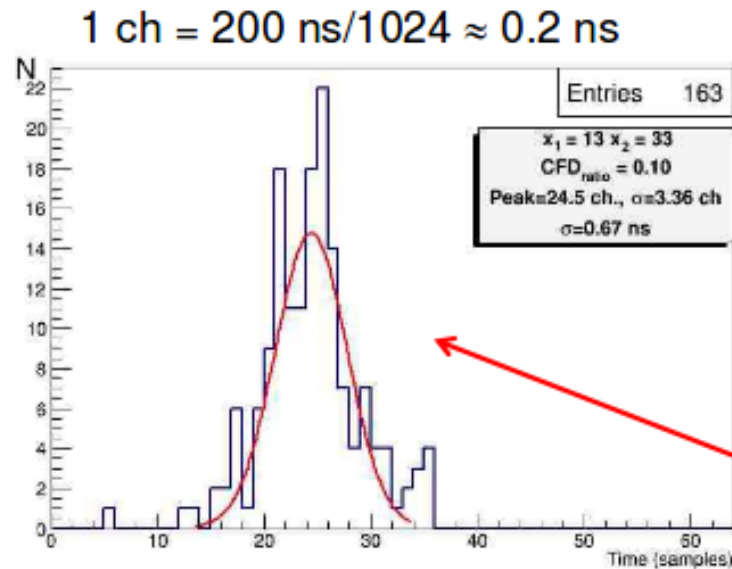
Ratio:
(cross talk - dark rate)/signal



Cross-talk $\leq 3\%$



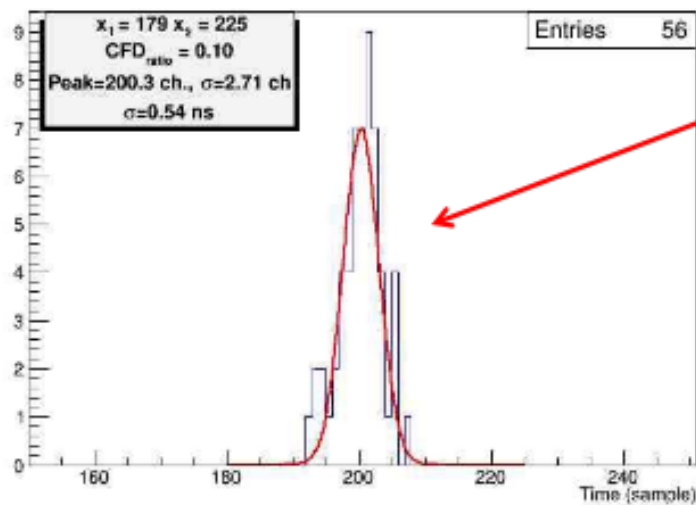
Expected performance of 3DST



1 fiber readout (1D)

$\sigma = 0.67$ ns

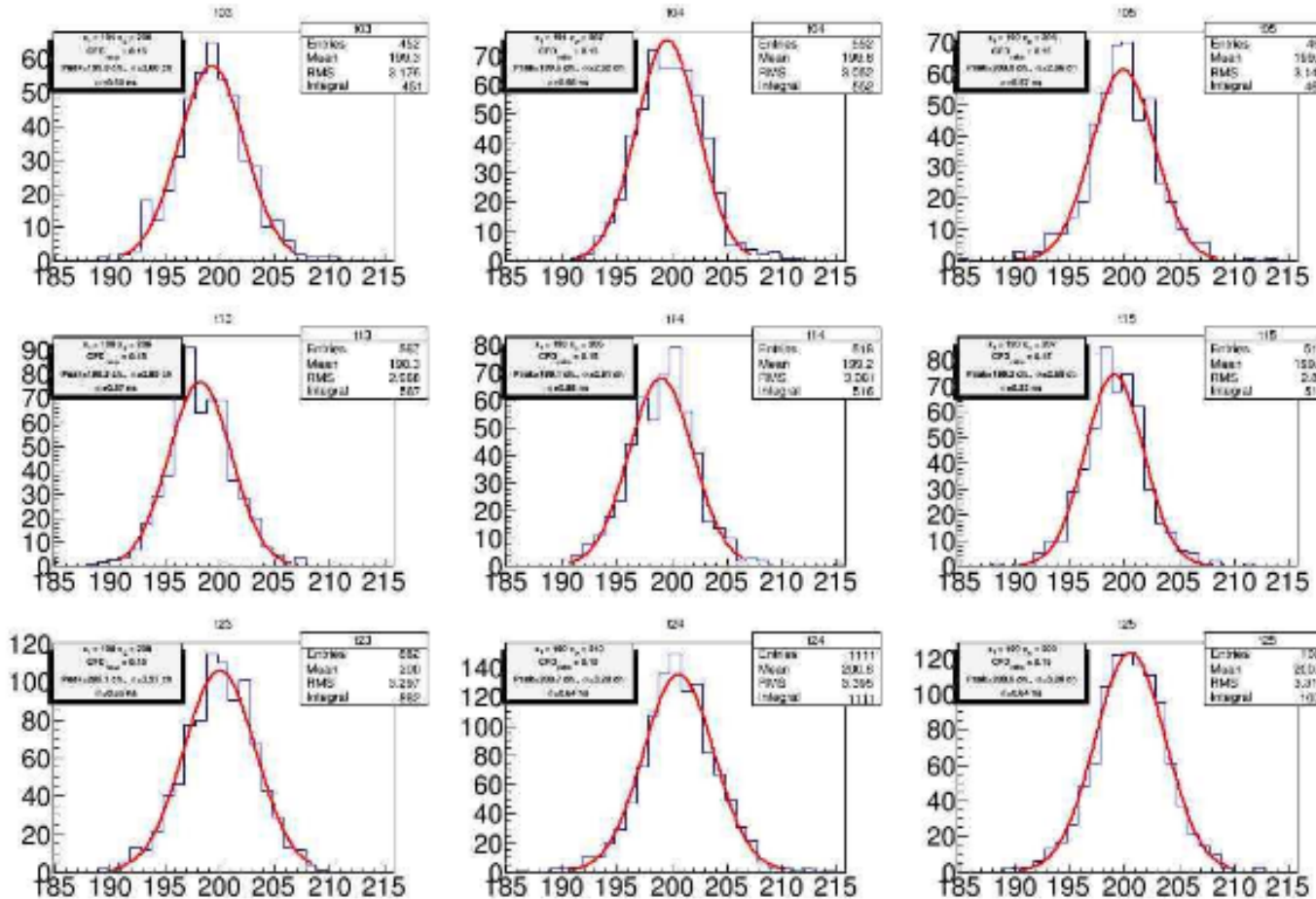
the same cube



2 fiber readout (2D)

$\sigma = 0.54$ ns

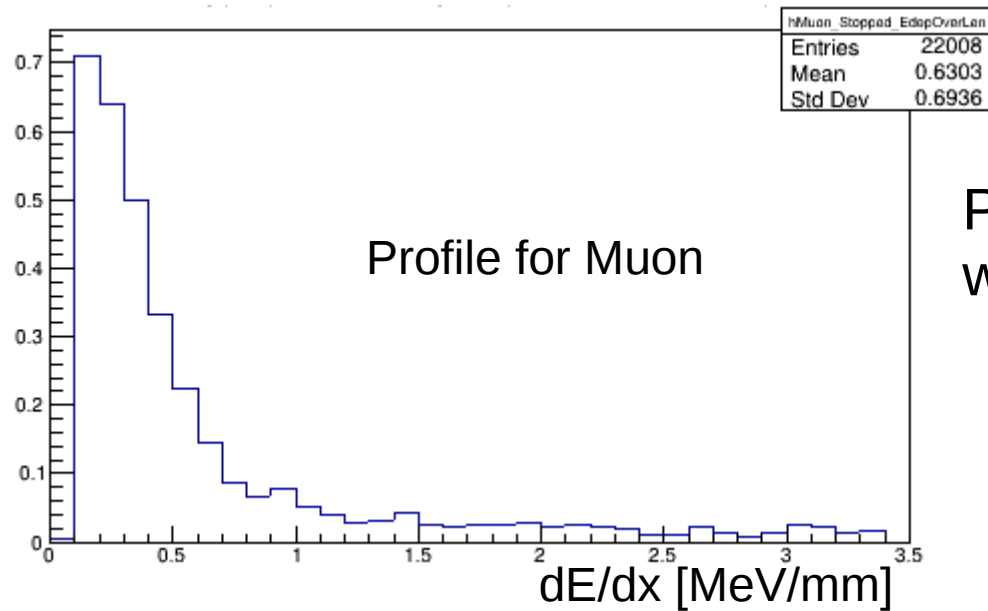
Expected performance of 3DST



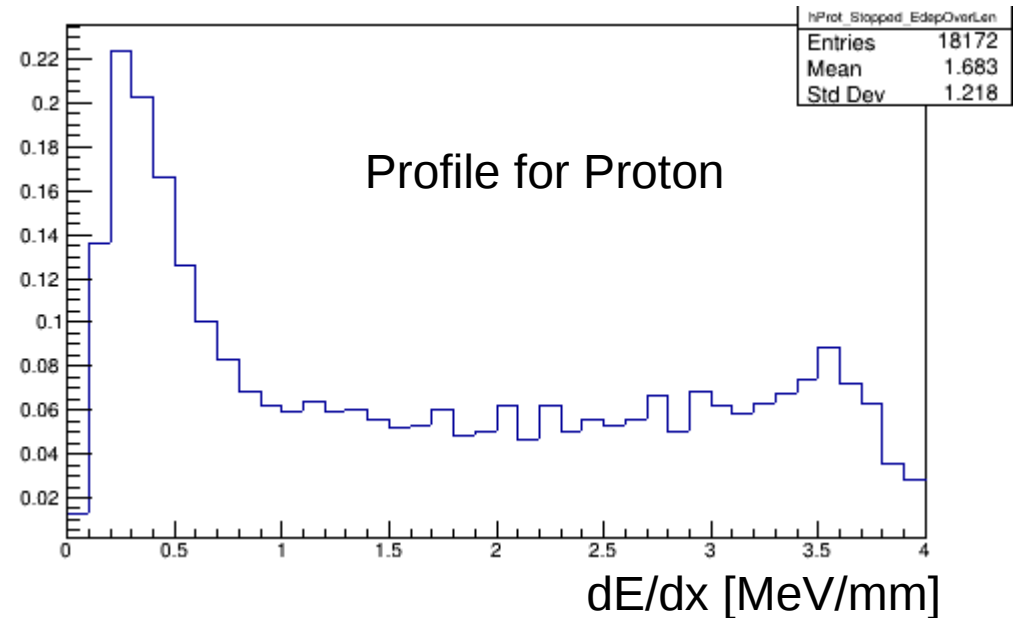
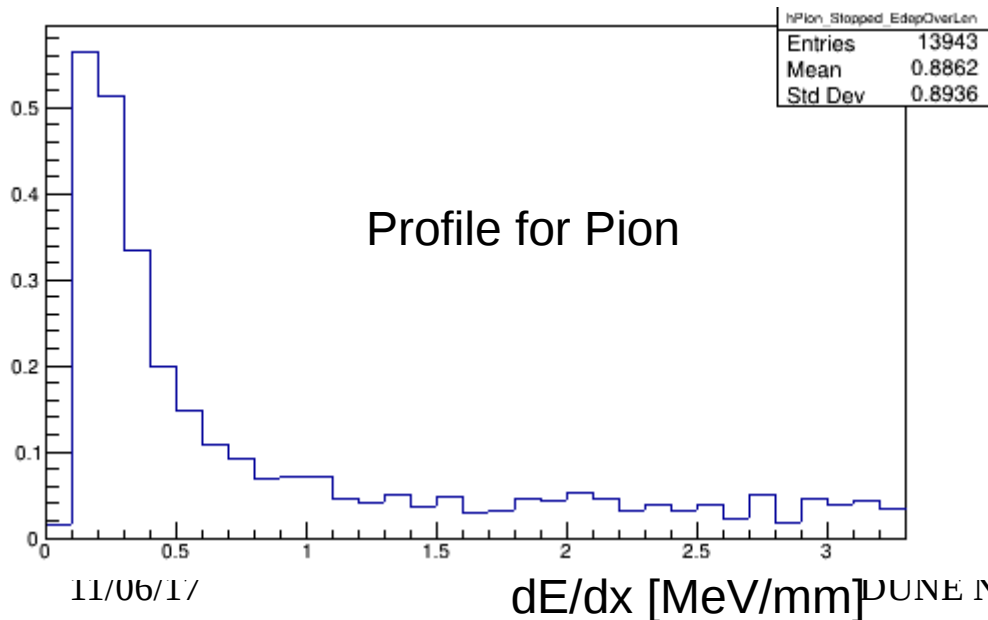
9 cubes
2D readout
 $\sigma_t = 0.5-0.6$ ns

We can expect $\sigma < 0.5$ ns for 1 cube with 3 D readout

PID – just use dE/dx at this point, not really used in analysis



PDFs for different particles are obtained with MC truth.

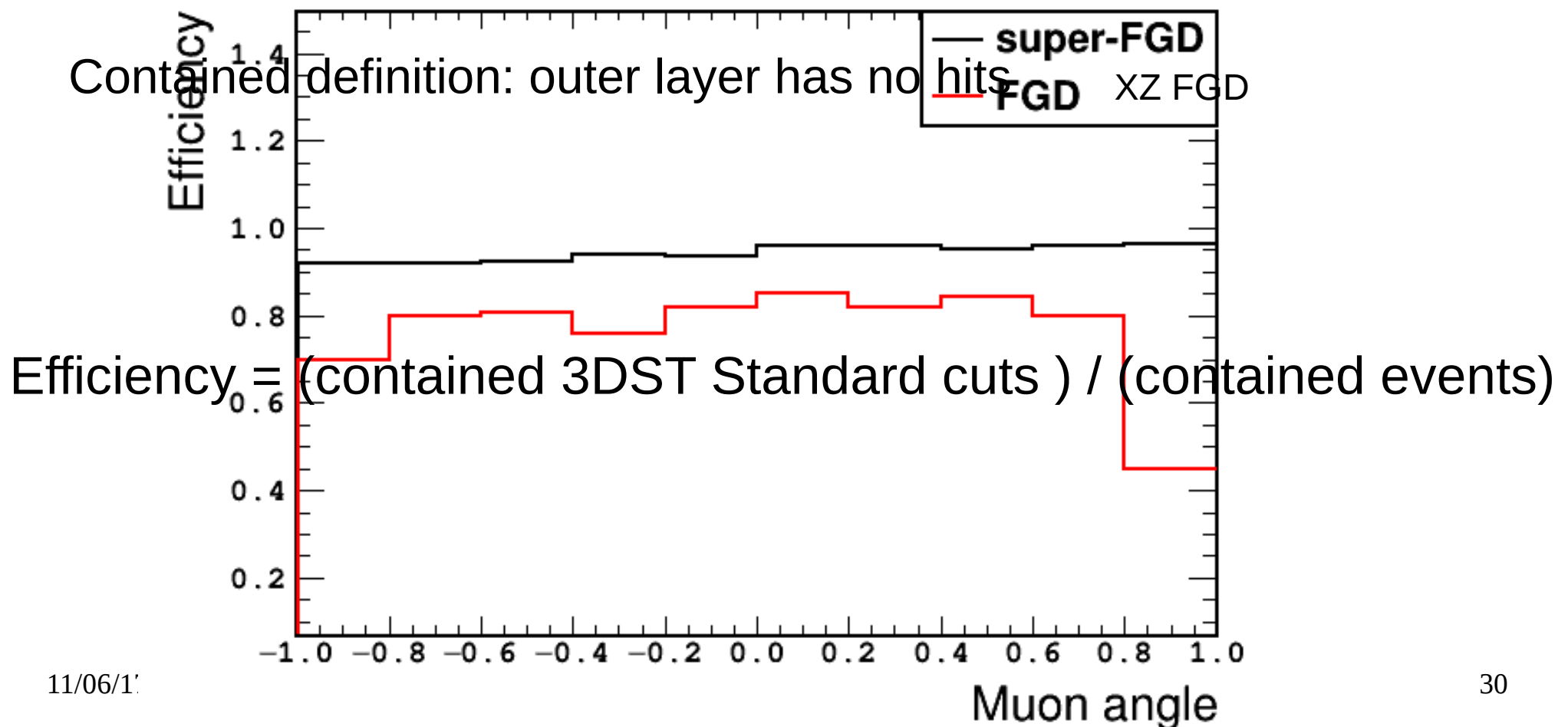


Detection efficiency

Defining the efficiency for contained events:

3DST Standard cuts:

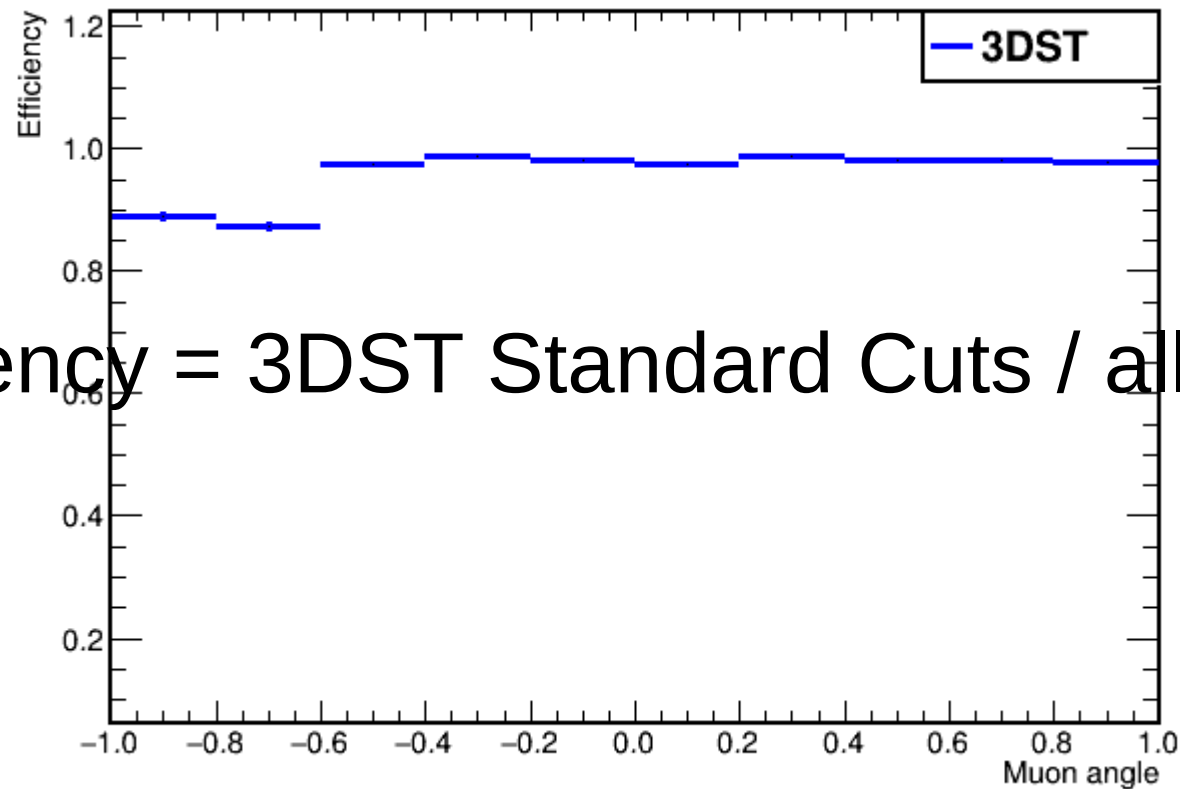
- Events that have two 2D projection successfully reconstructed.
- 2D projection reconstructed if :
 - in each plane at least 3 hits and in total at least 6 hits.
 - second long track is separated from the longest one.



Defining the efficiency:

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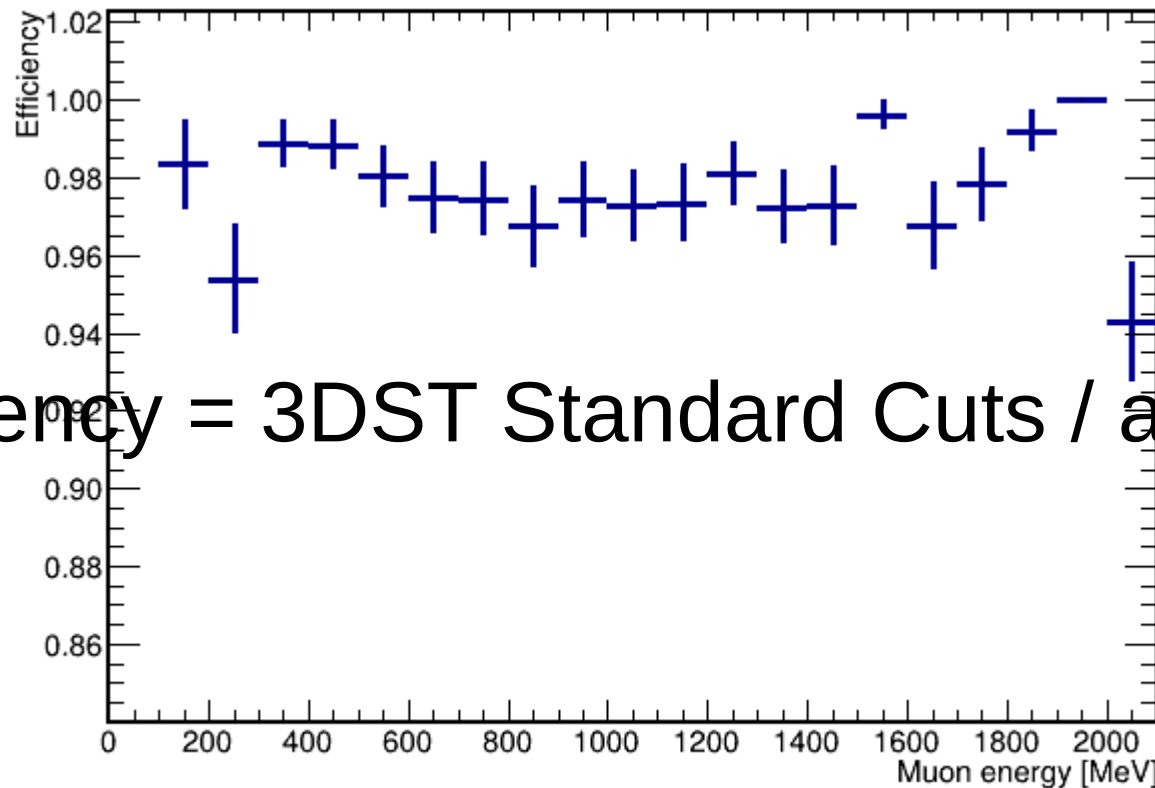


Efficiency = 3DST Standard Cuts / all events

Defining the efficiency:

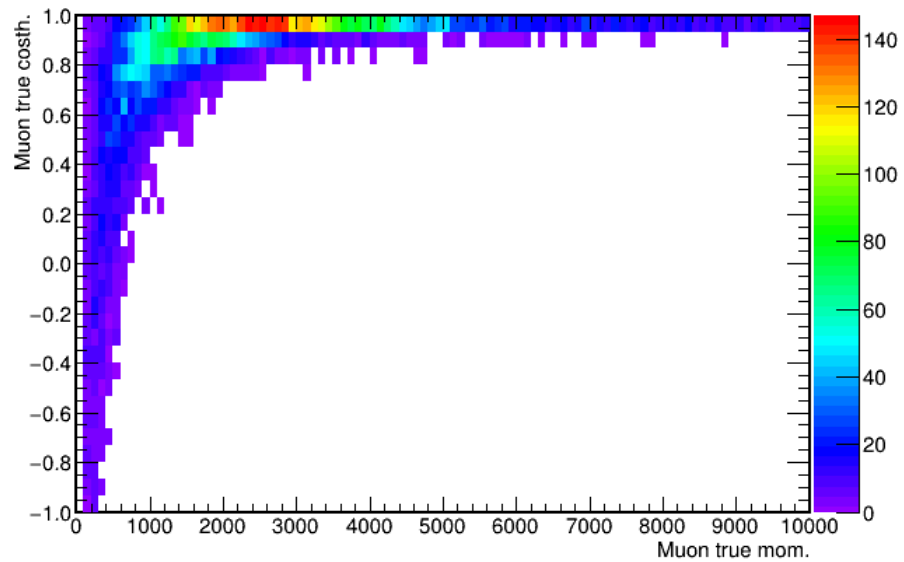
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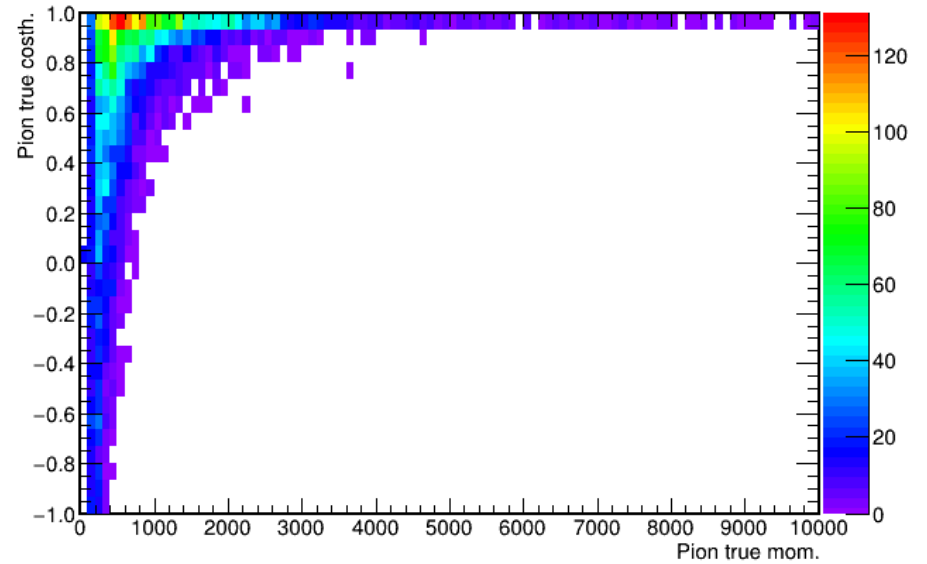


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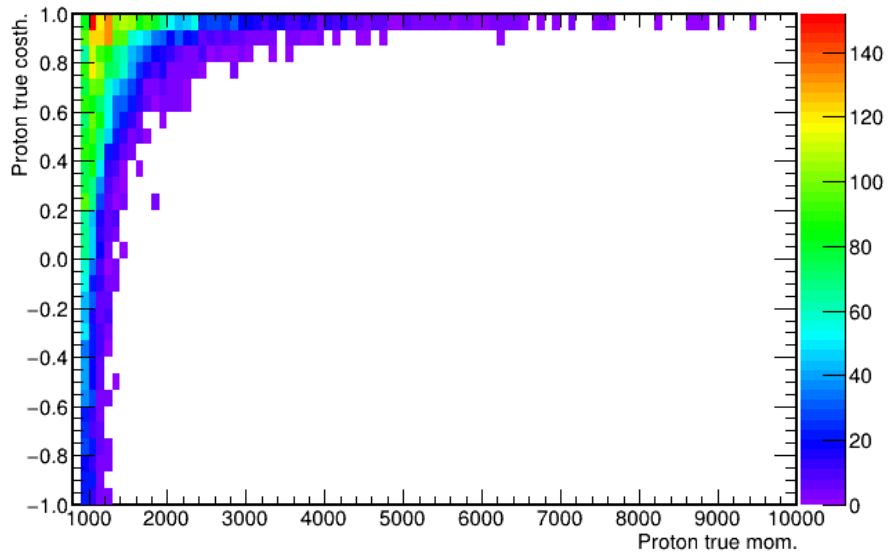
All Muons True Mom Vs CosTheta



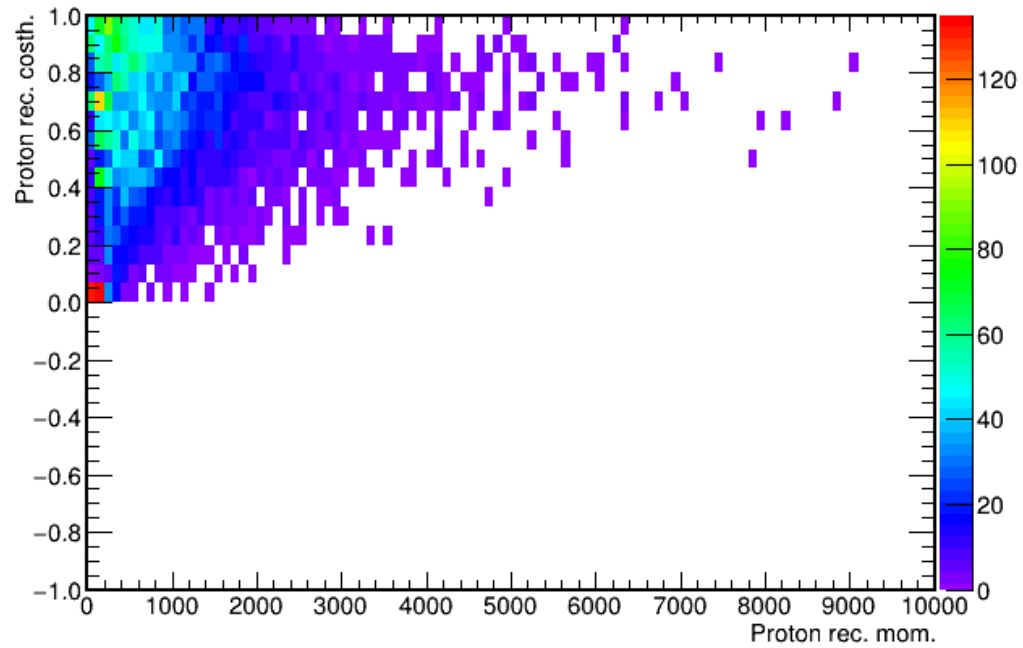
All Pions True Mom Vs CosTheta



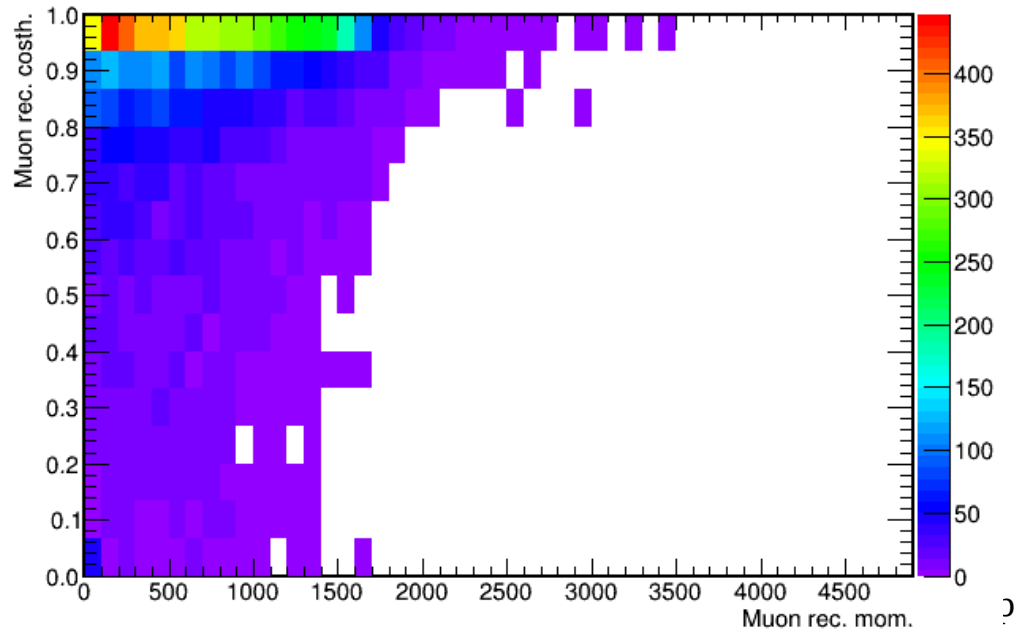
All Protons True Mom Vs CosTheta



All Protons Rec Mom Vs CosTheta



All Muons Rec Mom Vs CosTheta



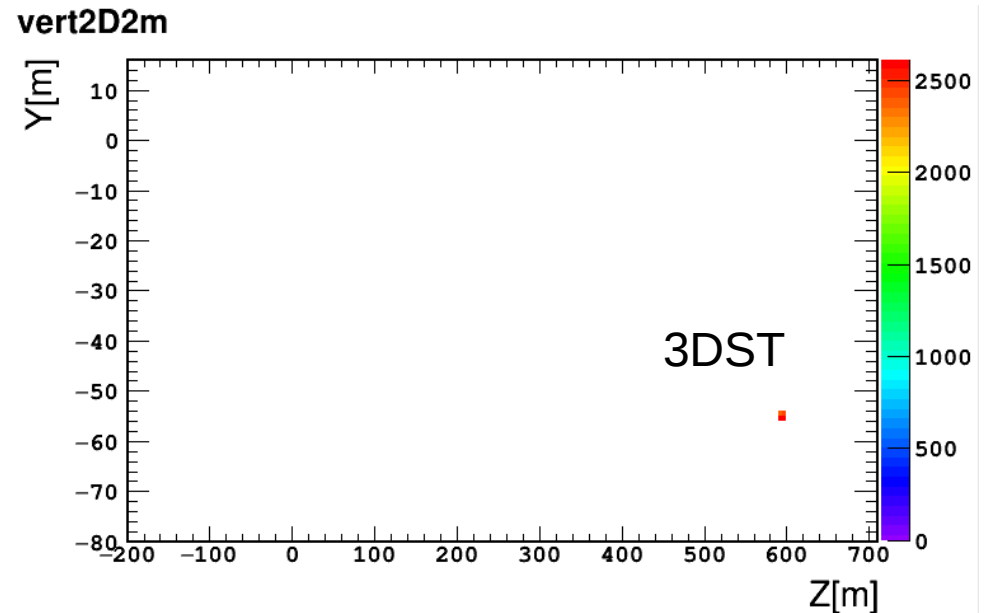
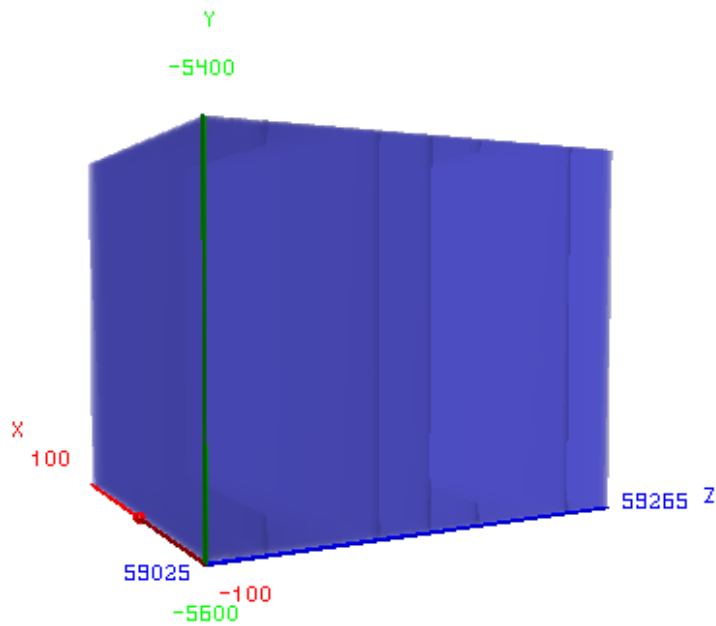
DUNE Geometry and event generation

DUNENDGGD:

Multiple layers:

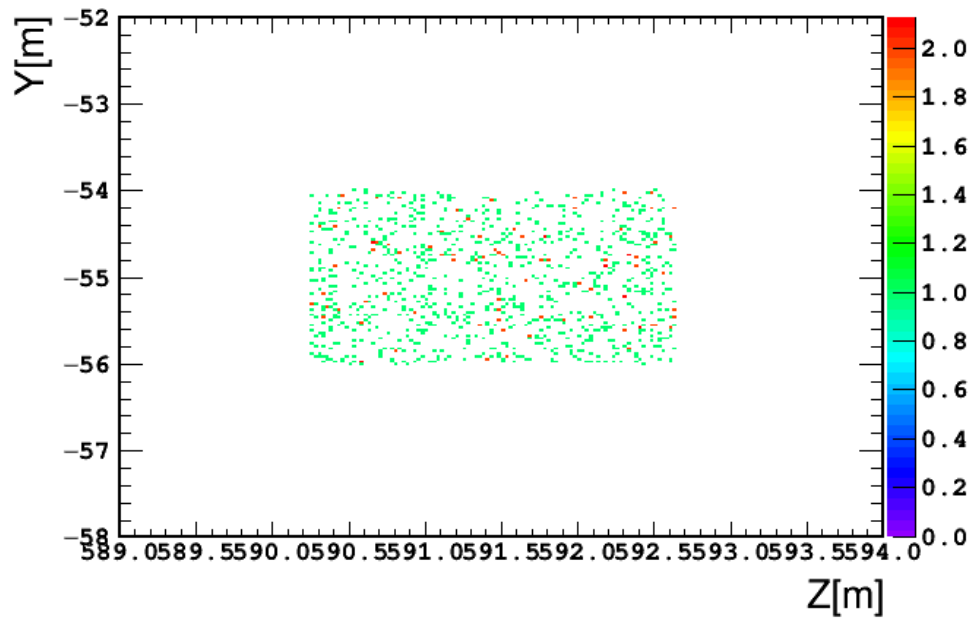
Boxes \rightarrow row \rightarrow plane \rightarrow 3D

- GENIE with DUNE flux Ntuple, Geometry is at the realistic place.
- Edep-sim for energy deposit.
- CC events only.



3DST module
 $2 \times 2 \times 2.4 \text{ m}^3$

Events in the detector



Zoom-in of previous plot.
Interaction vertices in the detector.

Two random example events

