Status of the 3DST software & selected physics studies

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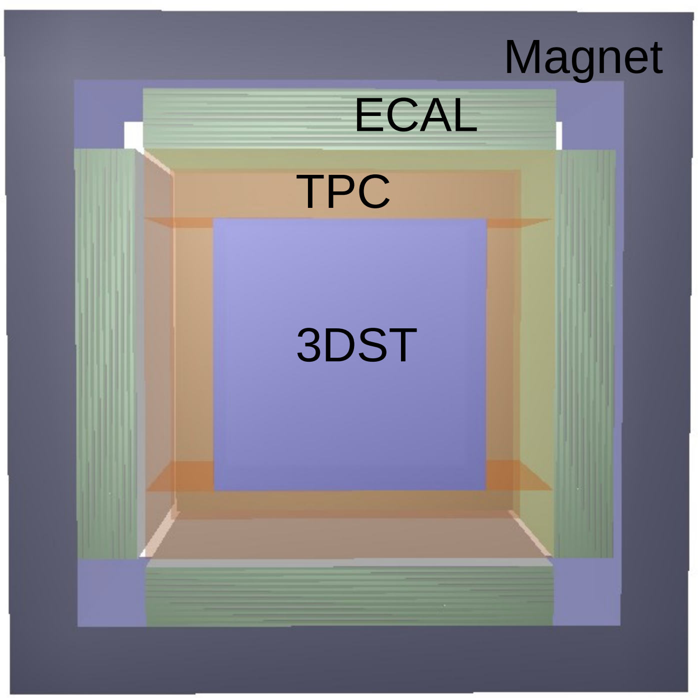
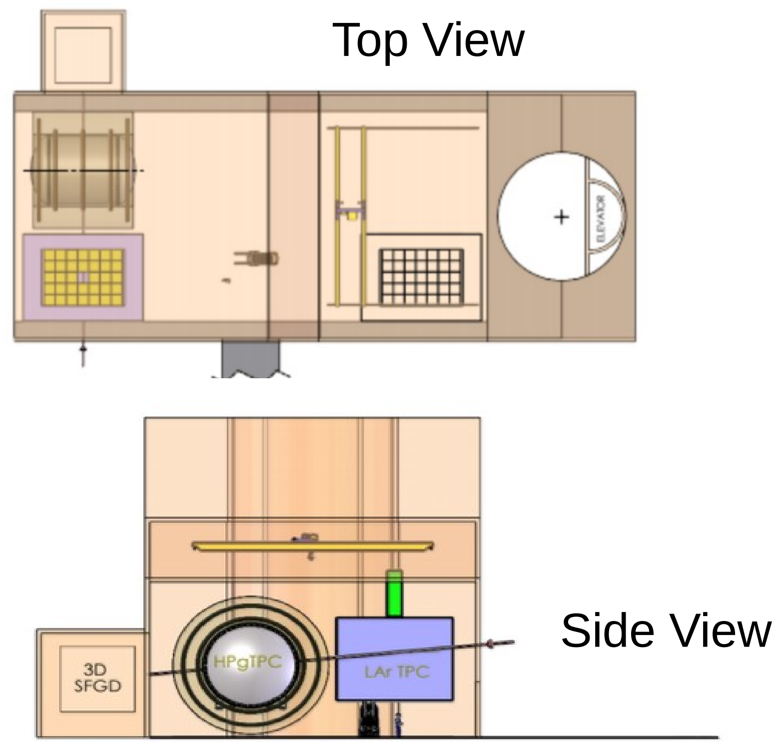
Flow

- Geometry
  - independent → DUNENDGGD
- Neutrino flux generation
  - consistent with LBNF → G4LBNF
- Neutrino interaction generation
  - consistent with LBL → GENIE
- Energy deposition of final state particles
  - consistent with LBL → edep-sim
- Electronics simulation - independent tool
- Reconstructio - independent tool
- Analyses - independent tools

Original design - geometry

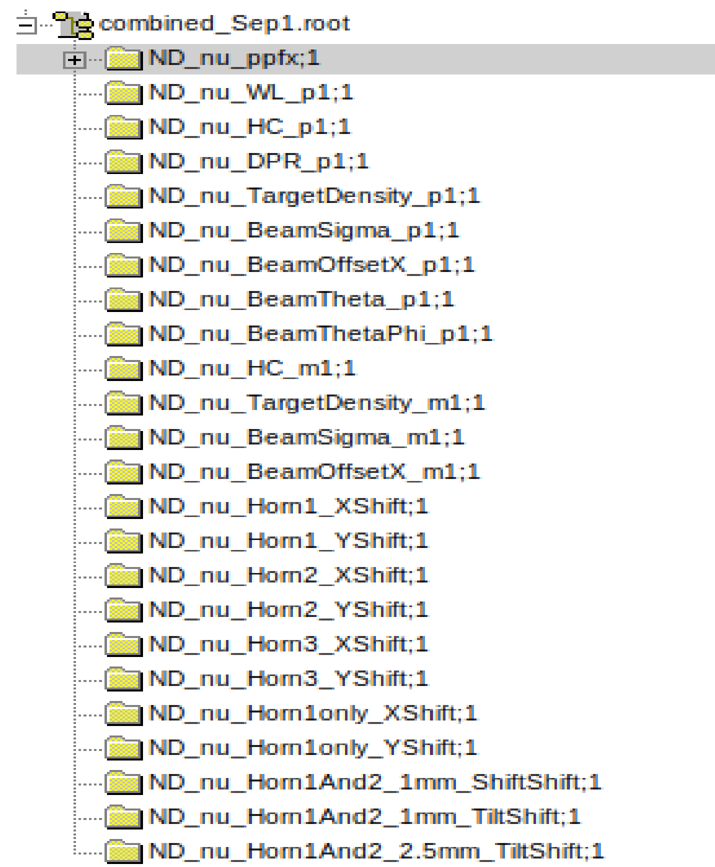
- We set up a basic 3DST concept in DUNE ND system: 3DST surrounded by TPC, ECAL and magnet
- Generated with DUNENDGGD: https://github.com/gyang9/dunendggd
- Layer structure: active volume → component volume → sub-detector → detector → detector hall → Rock world





Neutrino flux generation

- One of the main tasks for 3DST is to do the beam monitoring. Therefore, we will have some self-generated neutrino flux samples with variations of the beam conditions.
- Some of these are available from the samples that used for the beam uncertainty evaluation for the LBL, but some are not.
- To generate the shifted spectrum, we will need to generate beam simulation from the geant level, which means g4lbnf will be used.
- A tool existing created initially for PRISM can help us on some of the tasks : https://github.com/luketpickering/DUNEPrismTools/
- If you would like to run it, contact me.



Neutrino flux generation

- Steps:

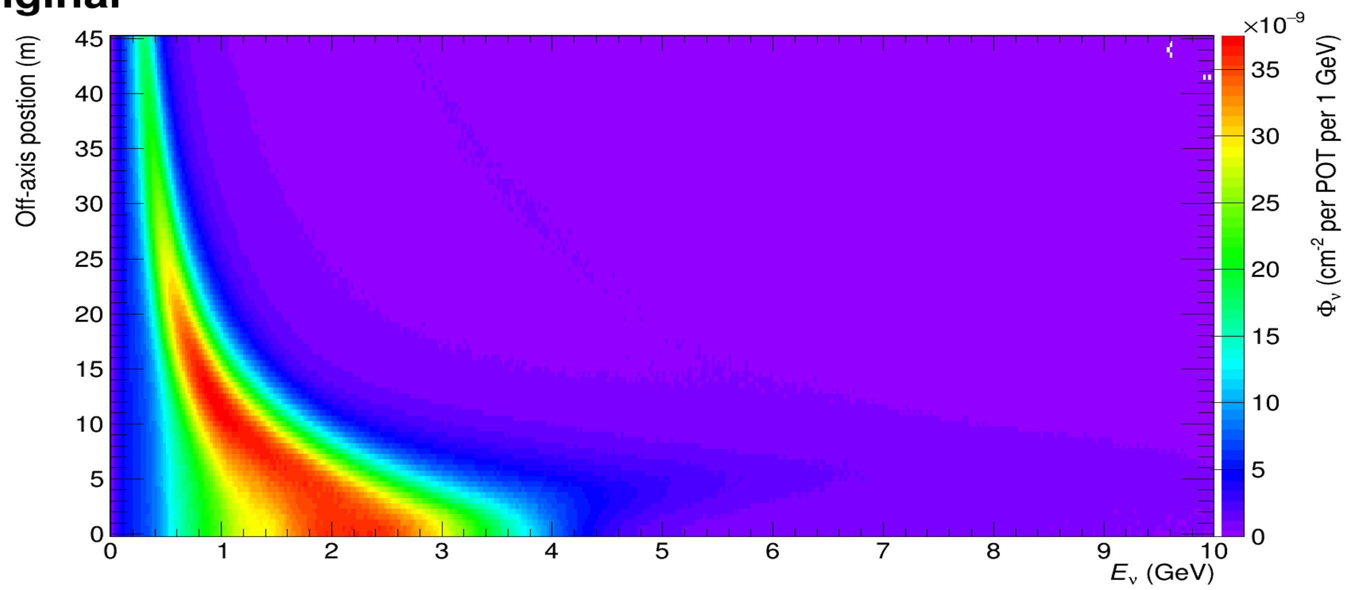
  1. dk2nu generation: dk2nu is a ntuple tree containing hadron decay and neutrino information, with beam parameter set we need.

  2. following plots: extract flux from each dk2nu beam parameter setup

  3. Combining all those variations

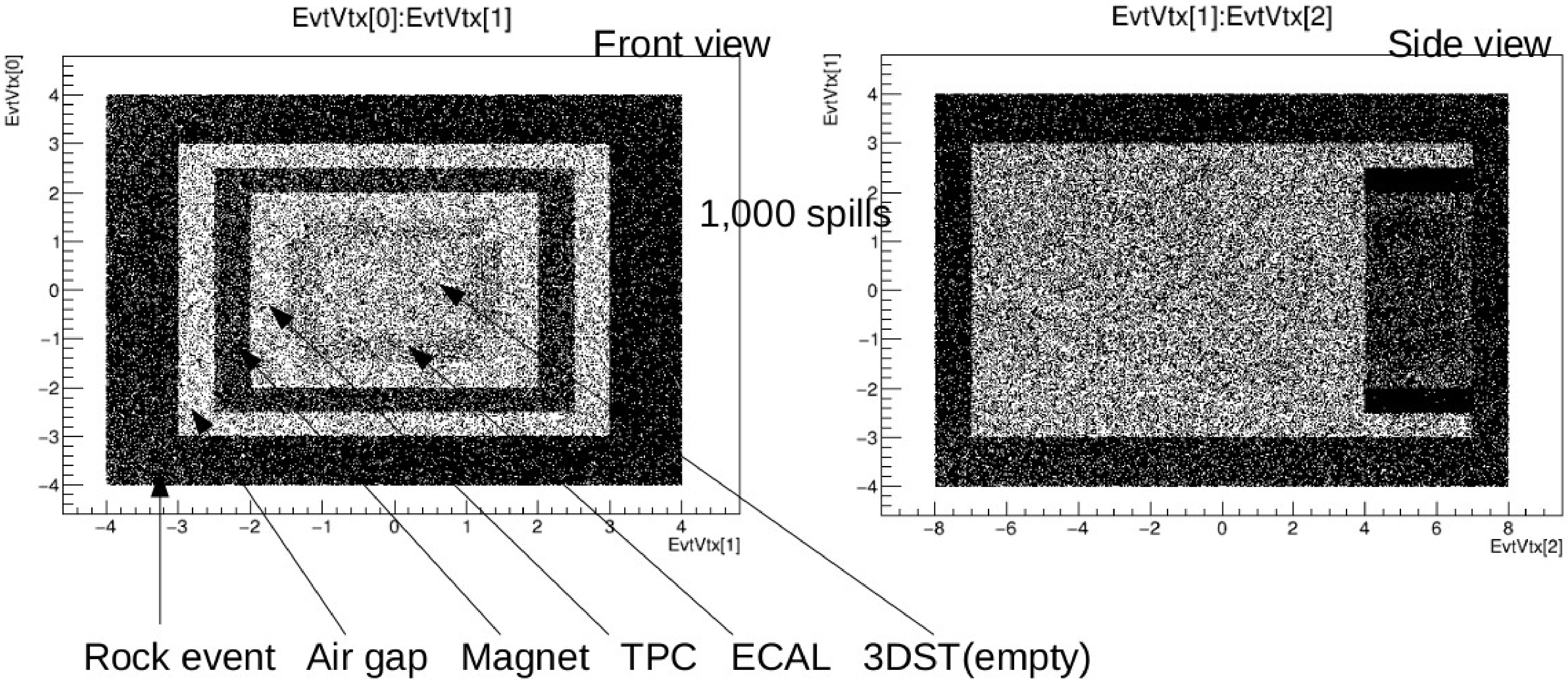
  4. Demonstrate the usefulness of 3DST with our studies

Original



Neutrino interaction

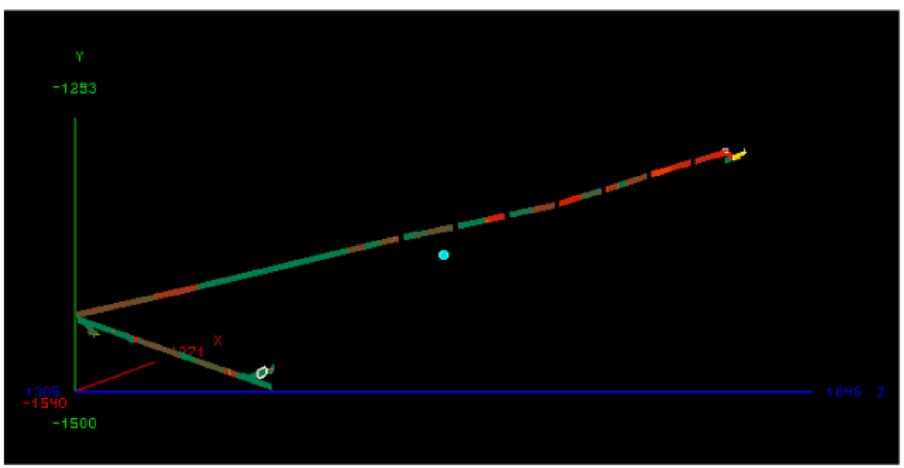
- GENIE (v2_12):
  - whichever version used for the LBL should be used here.
  - running on fermi grid, software consistent with LBL



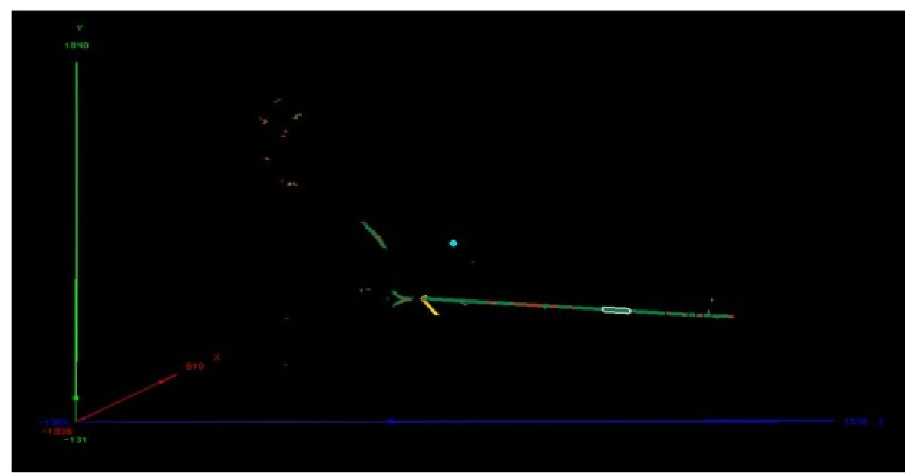
Energy deposition

- Edep-sim:
  - GEANT4 based. Usually set all volumes to be active in order to do detailed final state particle studies.
  - running on Fermi grid, consistent with LBL
- You can run it locally: https://github.com/ClarkMcGrew/edep-sim

CC pi+ in TPC



CC pi0 in 3DST



Electronics simulation

- Electronics reposnses:

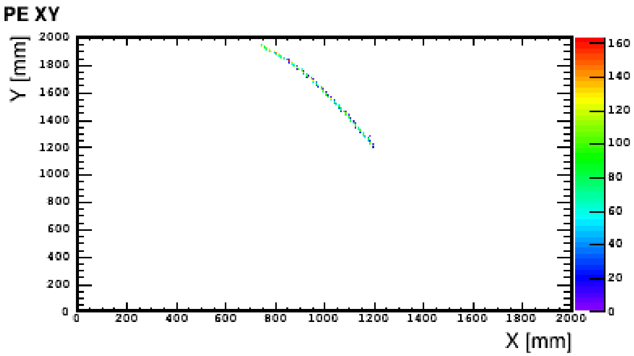
  Conversion chain edep → photon captured in fiber → light attenuation → MPPC response

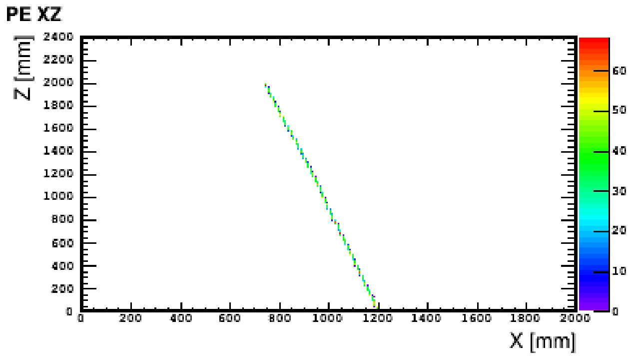
- Input edep-sim and output :

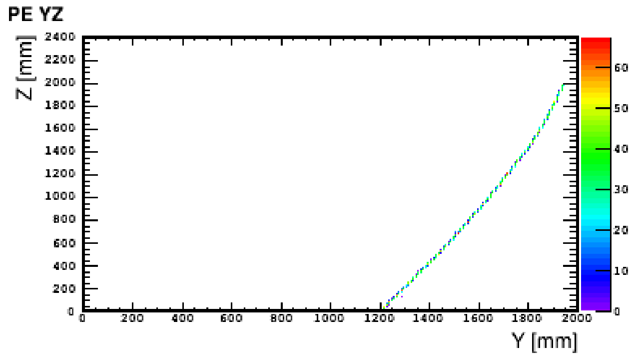
  - analysis tree containing final state particle high-level information

  - three 2D readout maps with electronics response applied

- In a sub-location of a package: https://github.com/gyang9/DUNE3dstTools/tree/master/src/elecSim







Reconstruction

- Developing a new reconstruction tool dedicated for 3DST and superFGD by Clark McGrew and Sergey Martynenko

- Functioning packages:
  - Read the input file containing fiber hit information;
  - Create 3D Hits from fiber hits;
  - Adjust charge for 3D Hits;
  - Cluster 3D Hits (DB Scan);
  - Define hits order inside each cluster (Minimum Spanning Tree);
  - Split clusters into Track-Like objects (find vertices);

- In development:
  - Track fit;
  - Shower search;
  - Other?

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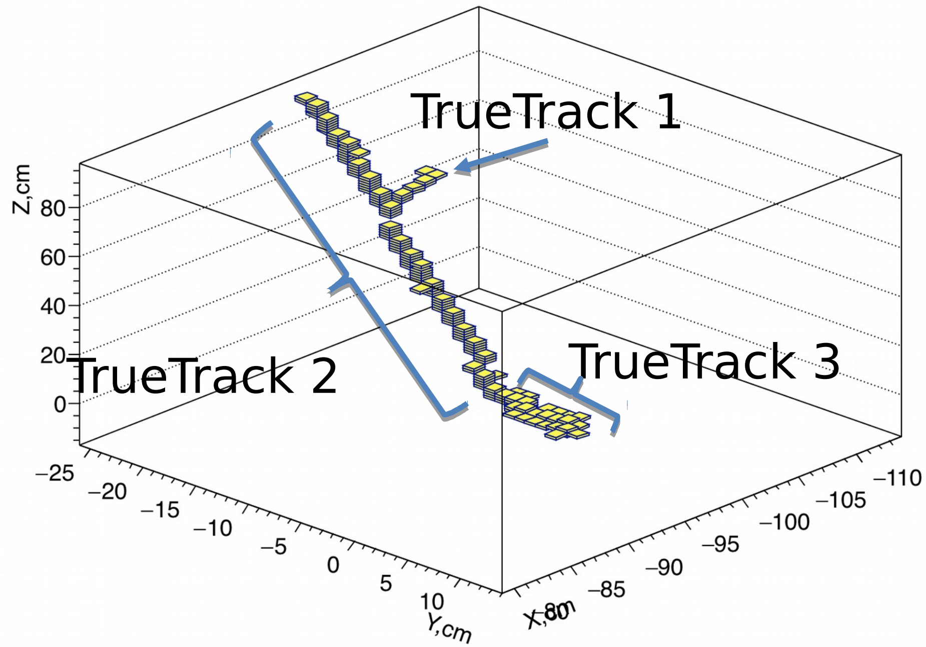
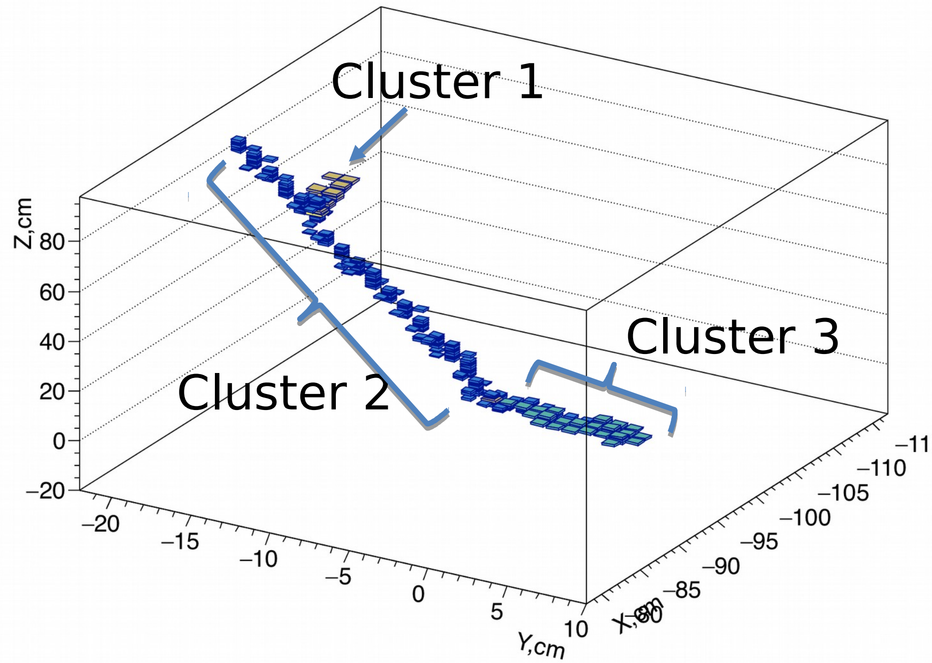
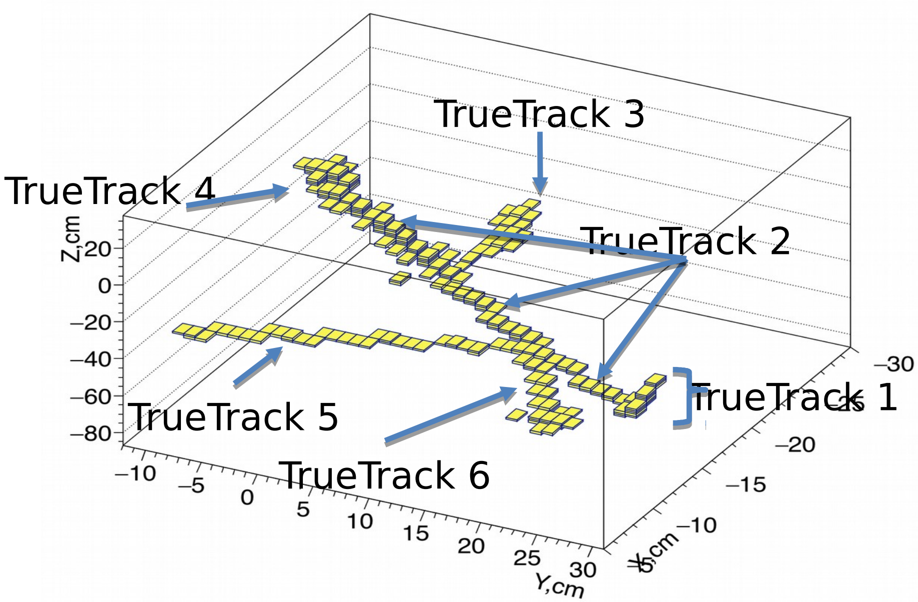
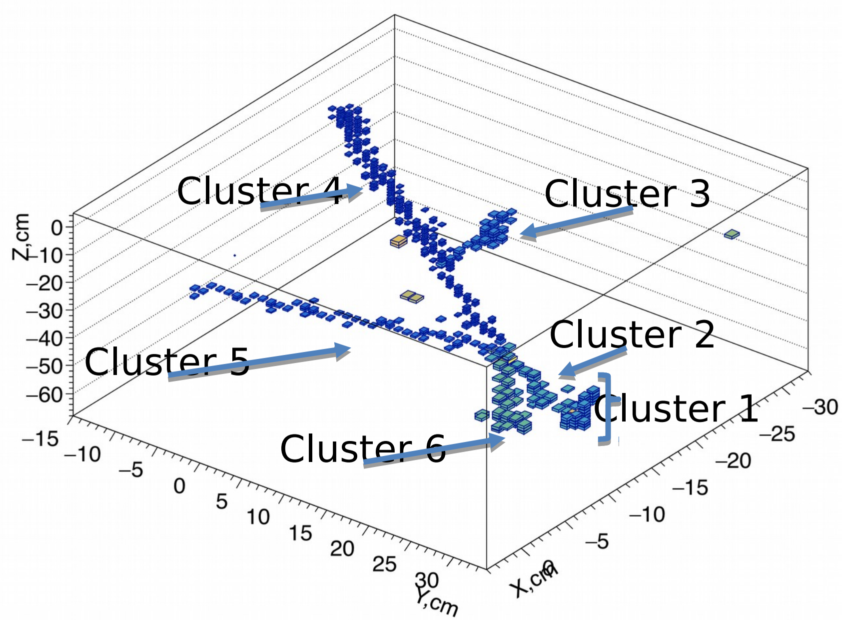








Reconstruction

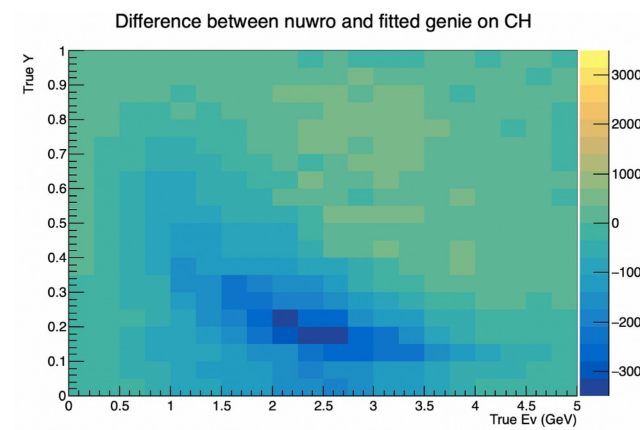
Stony Brook University

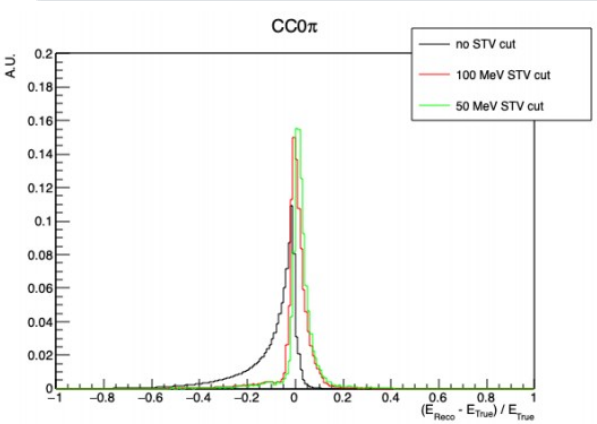
- Work is being done by Sergey Martynenko
- Sergey's conclusion at this point:
    - Test reconstruction techniques as a set of separate root scripts:
        - 3D hits are created and clustered;
        - Clusters are split into track-like objects;
    - First look at the effectiveness of pattern recognition algorithms:
        - Hit finding works well with crosstalk(small amount of Ghost Hits);
        - Charge Adjustment works with crosstalk;
        - Clustering and track splitting works well with crosstalk, but quantitatively tested only without crosstalk
    - Temporary code is on GitHub:
        - https://github.com/rennney/CubeRecon
    - Future:
        - Understand True information in MC with crosstalk to quantify clustering properly;
        - Define efficiency for complex events;
        - Continue working on Track fitting and Shower search algorithms

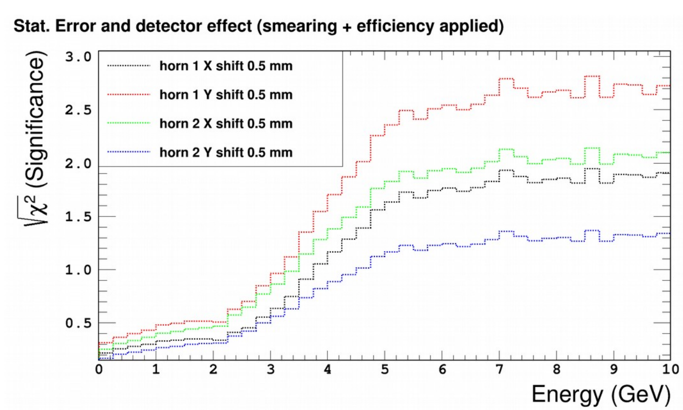
Analysis

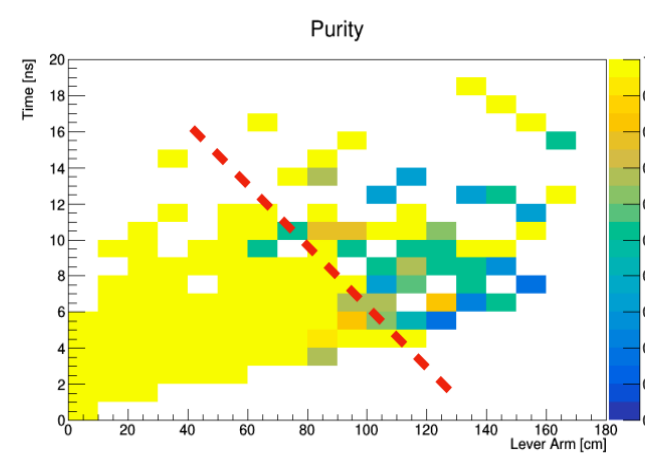
- A package has been created compiling all current analysis tools: https://github.com/gyang9/DUNE3dstTools

NuModel	Ar-C model tuning
beamMonitoring	Beam monitoring
elecSim	Electronics simulation
fluxSTV	Single transverse variable with neutron measurement
nBKG	Neutron out-of-FV background evaluation (from Manoa)
reco	Reconstruction (from Sergey)
CMakeLists.txt	









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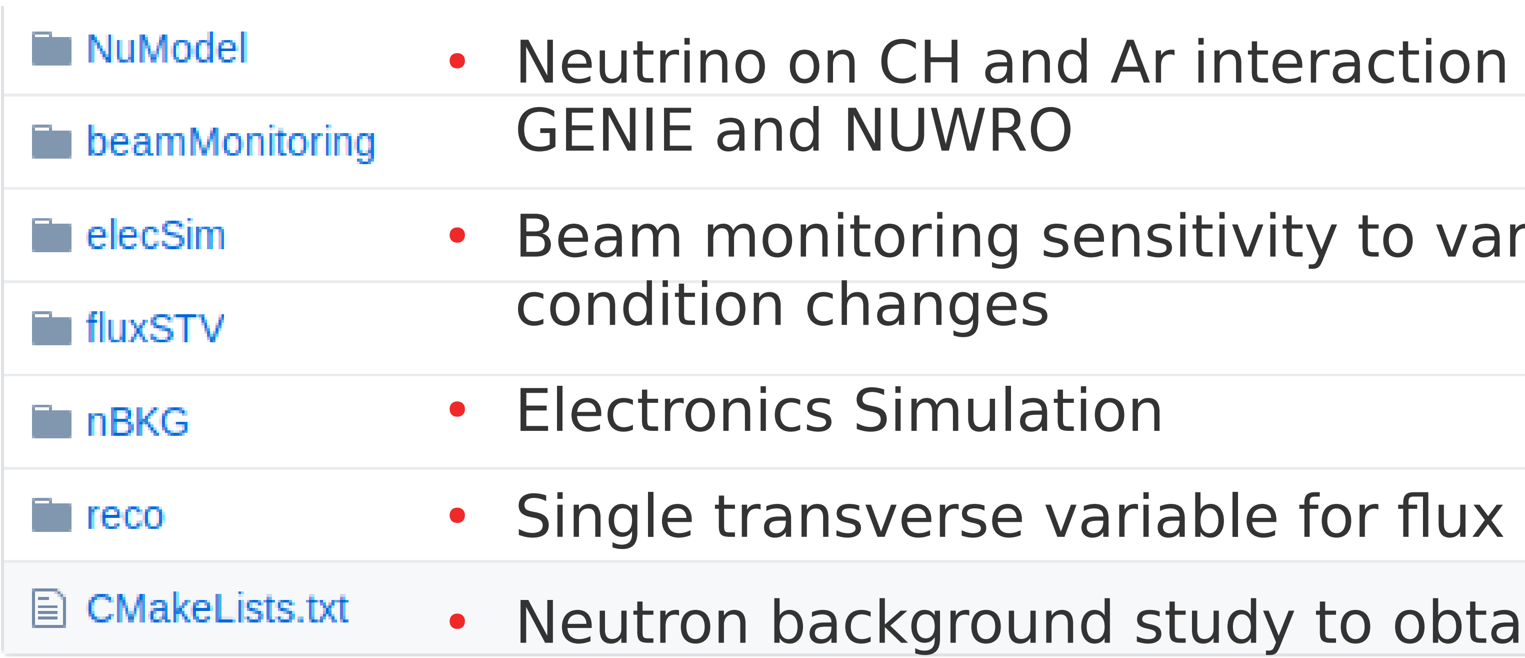


- Neutrino on CH and Ar interaction tuning with GENIE and NUWRO
- Beam monitoring sensitivity to various beam condition changes
- Electronics Simulation
- Single transverse variable for flux constriant
- Neutron background study to obtain pure neutron sample on the space of arm and time
- Reconstruction from 3 2D maps

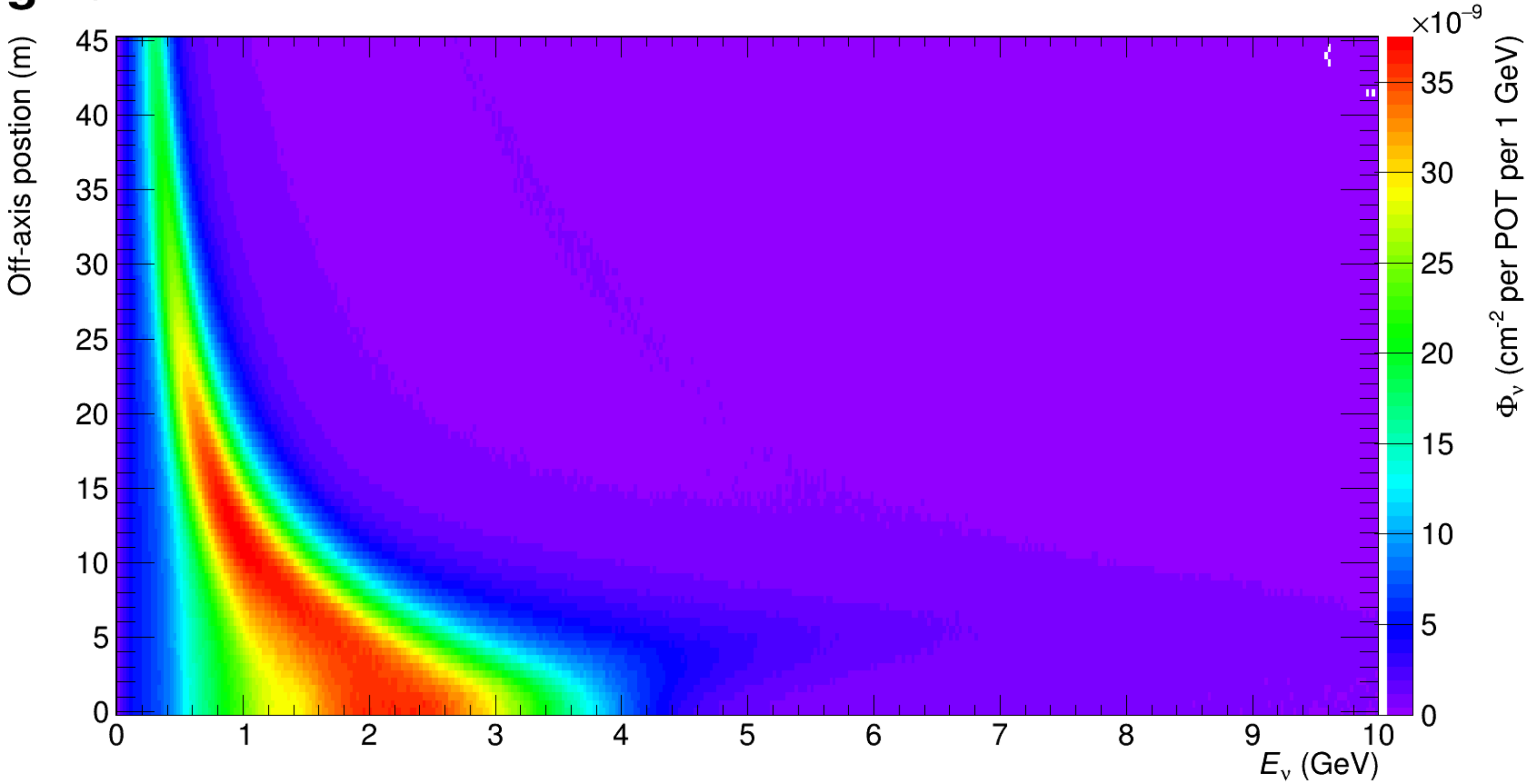
Example usage of 3DST (least but of course, not last)

- Beam monitoring
- Flux constraints

Nominal PRISM flux fit

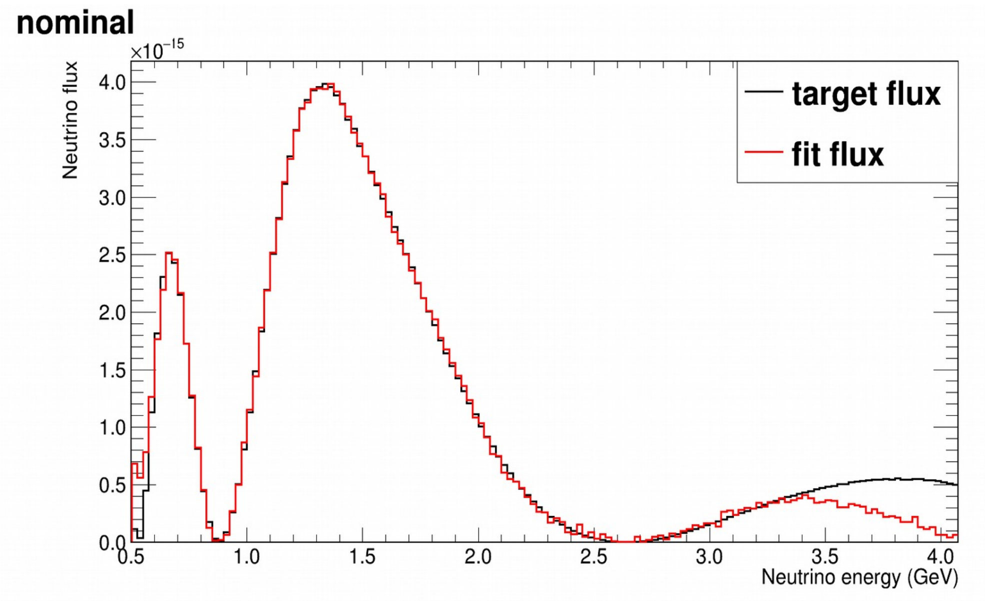
- Use off-axis ND flux to match FD oscillated flux

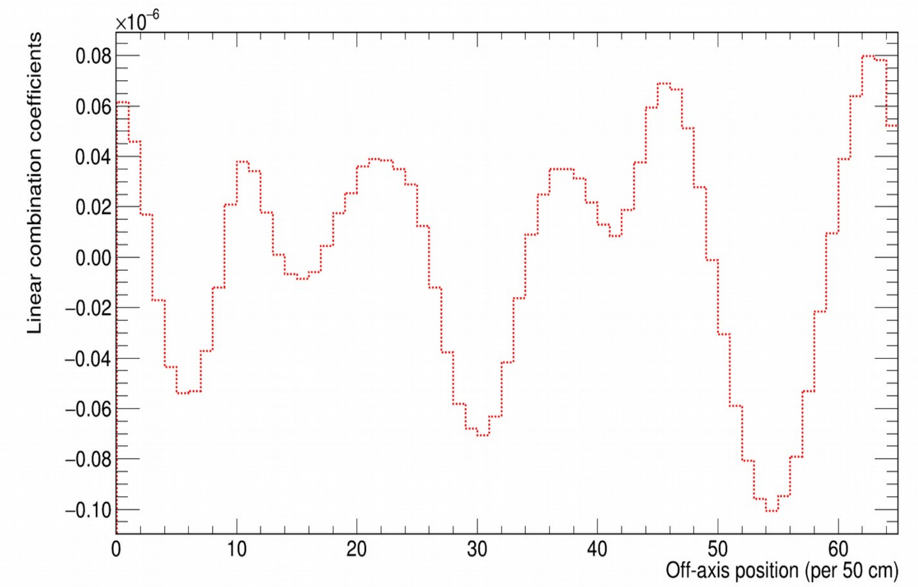
Original



Nonimal PRISM flux fit

- ND flux matching FD flux → Linear combination coefficients tell oscillation

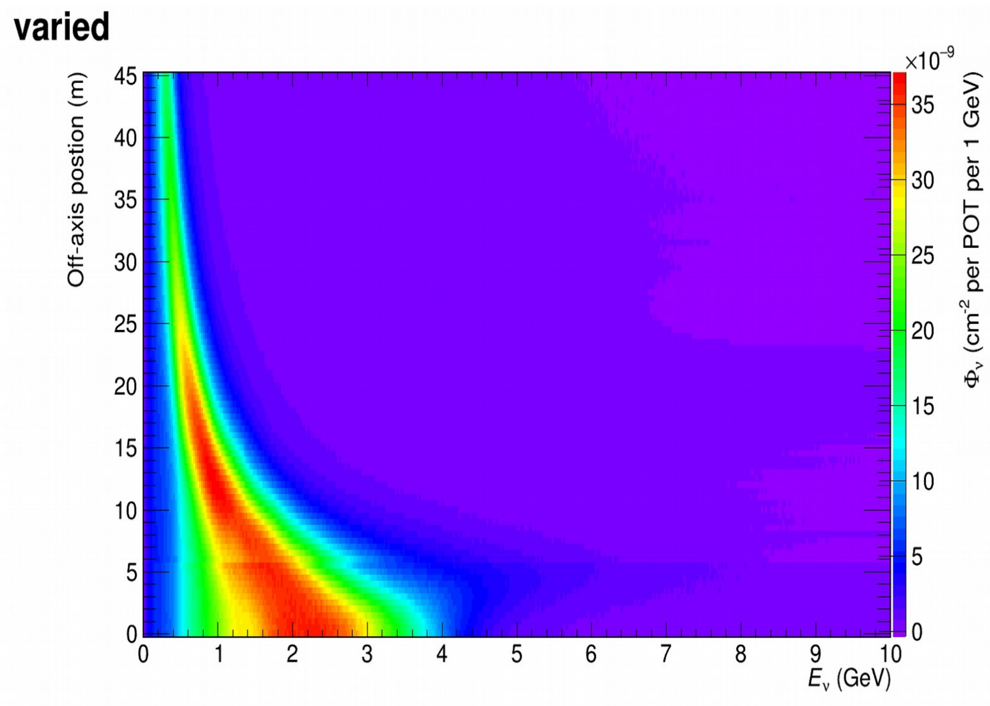


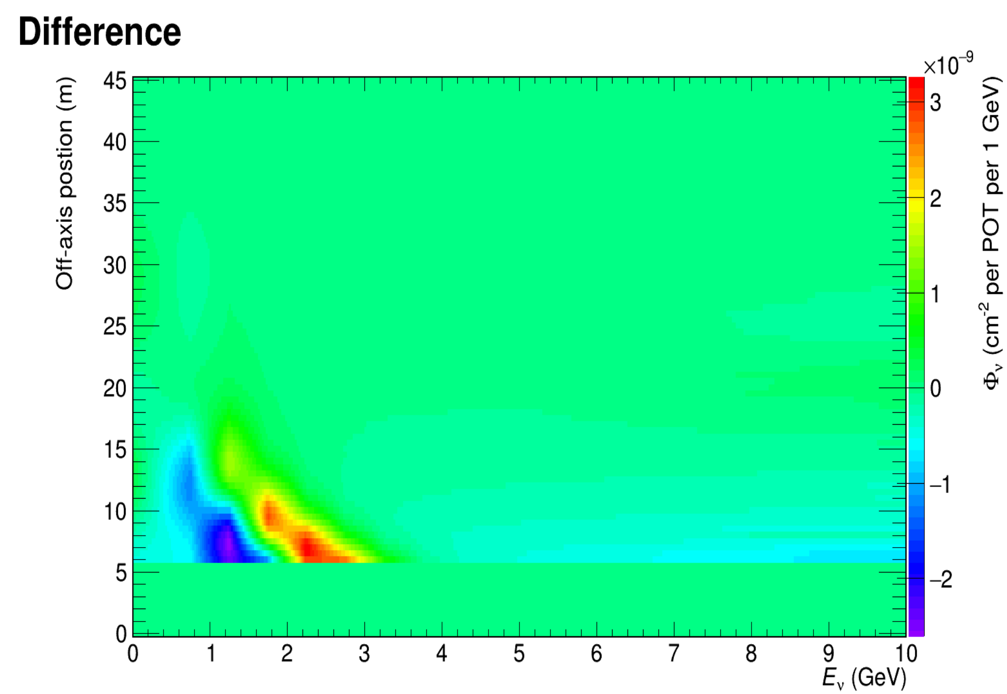


- Each coefficient list corresponds to one oscillation parameter set.
- Apply this map to ND and FD data, without xsec model, find the oscillation parameters.

Beam changes at off-axis positions

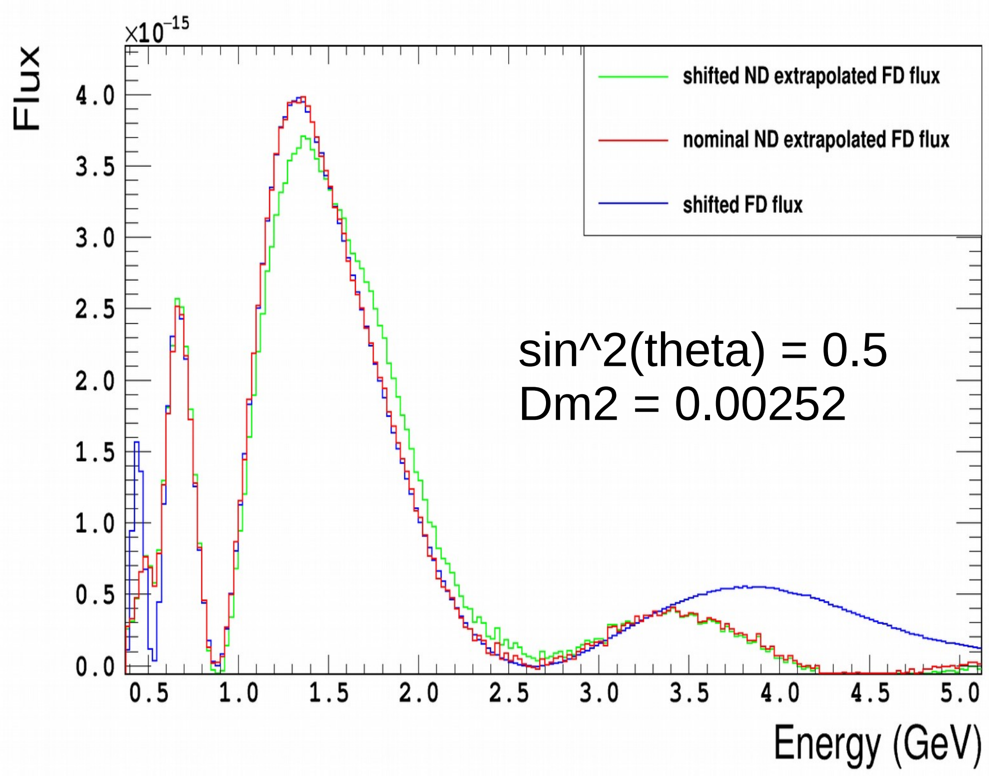
- When detector goes off-axis at 6 meters, beam changes in shape.
- Total rate over energy not changed
- This case was made with ~6 mm horn 1 X shift + overall rate compensation.

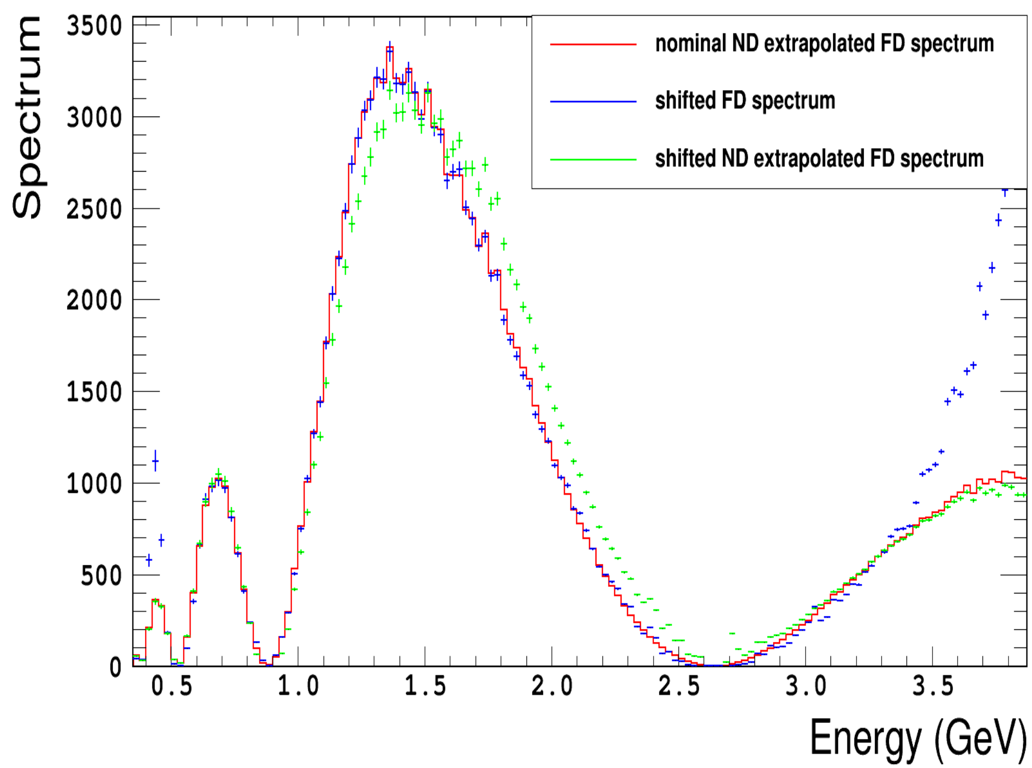




Flux fit biased

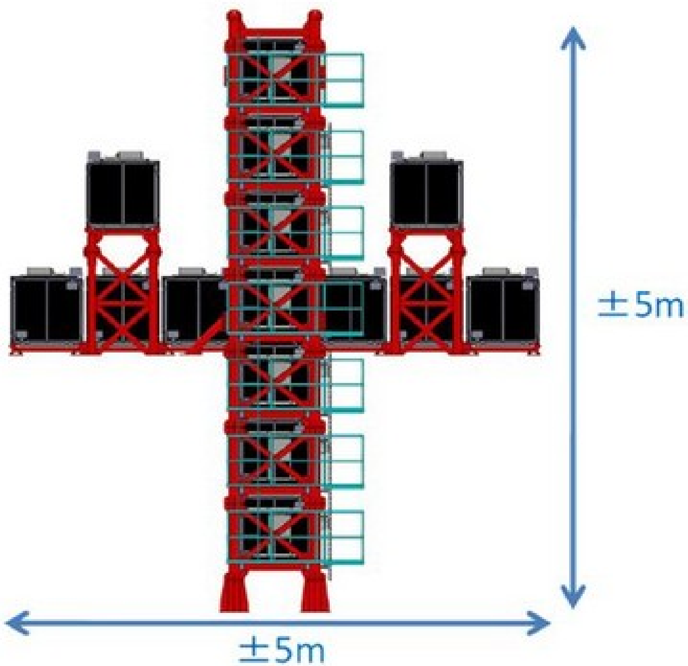
- Applying the linear combination coefficients to the changed ND; FD shifted as well (50% of time)

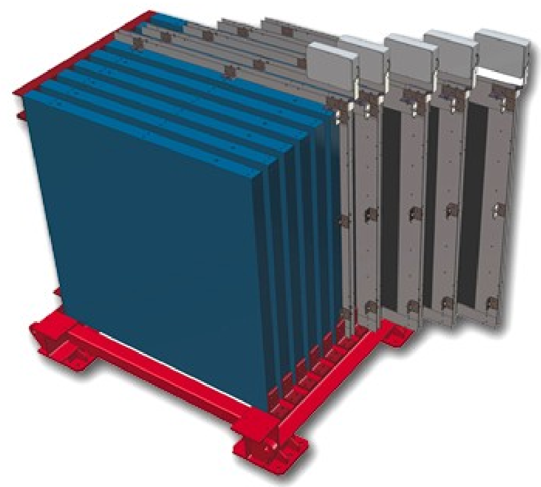


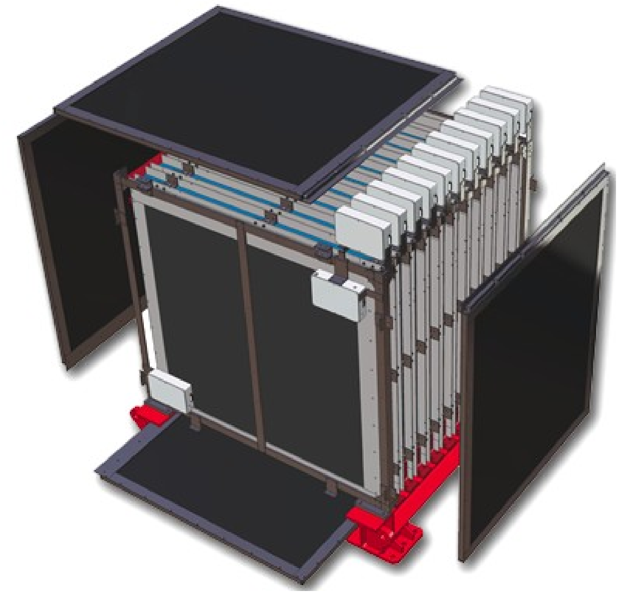


INGRID-like → rate only

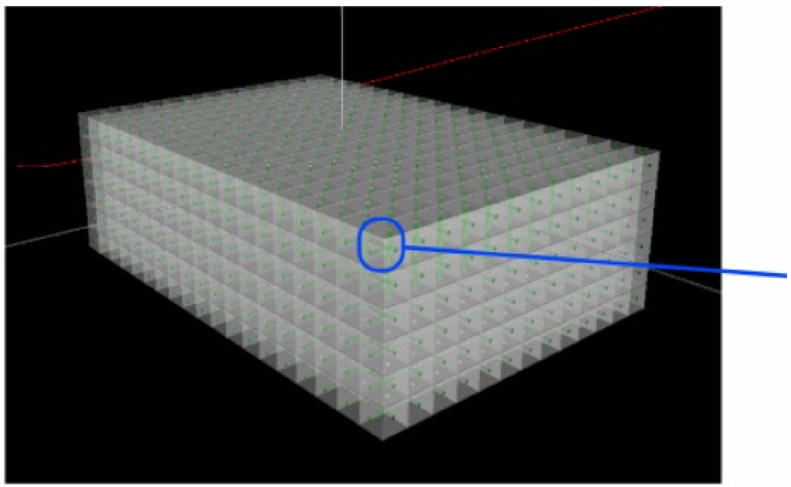
- ~7 tons per module array along X and/or Y
- 4 modules considered at 0,1,2,3 meters
- Target: scintillator and iron
- Ranged over few meters

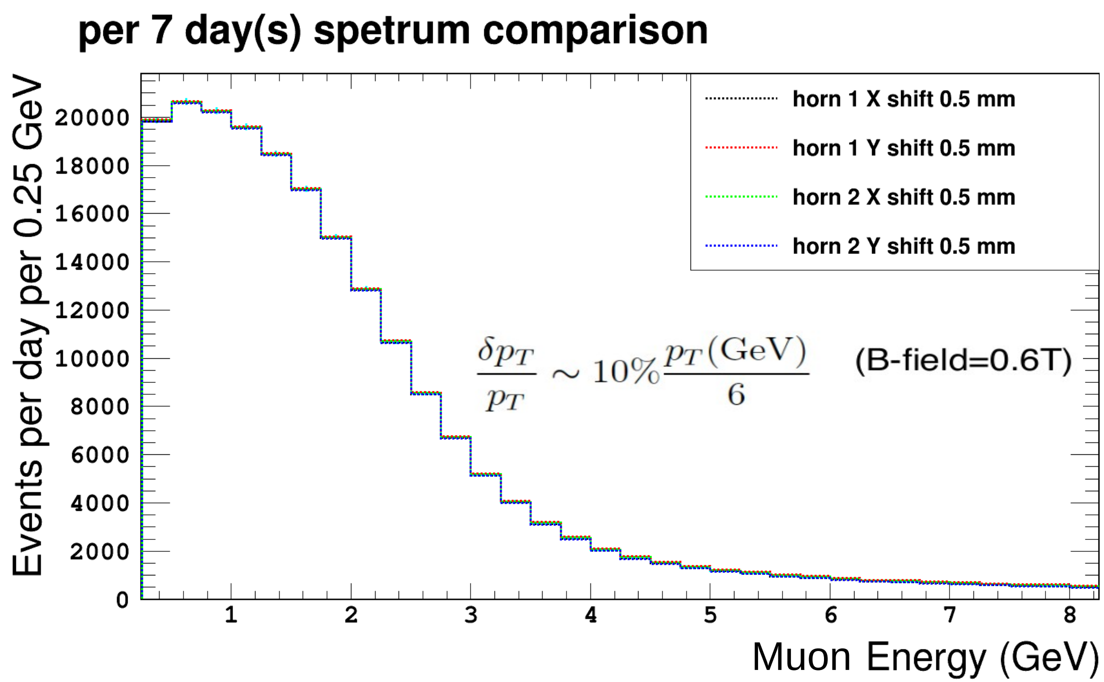


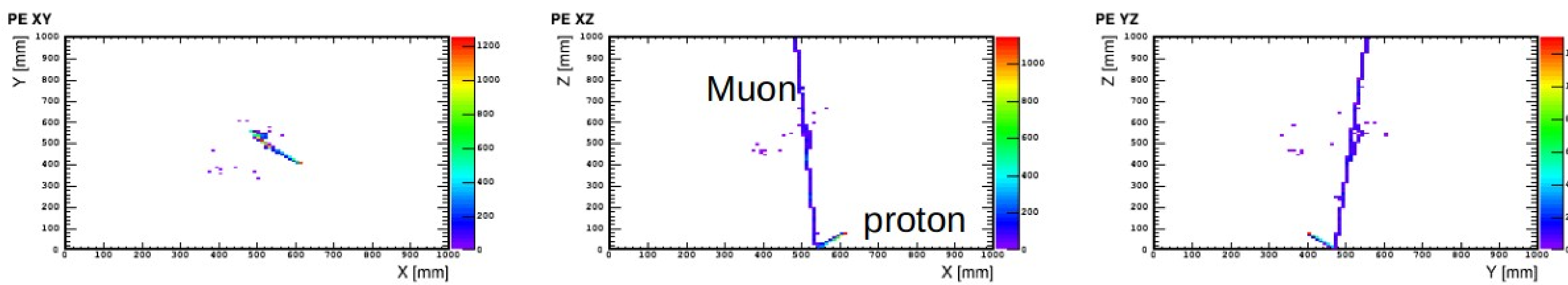




3DST-like (8.7 tons on-axis) → shape available







- Muon detection acceptance in the TPC has been considered.

Variations considered

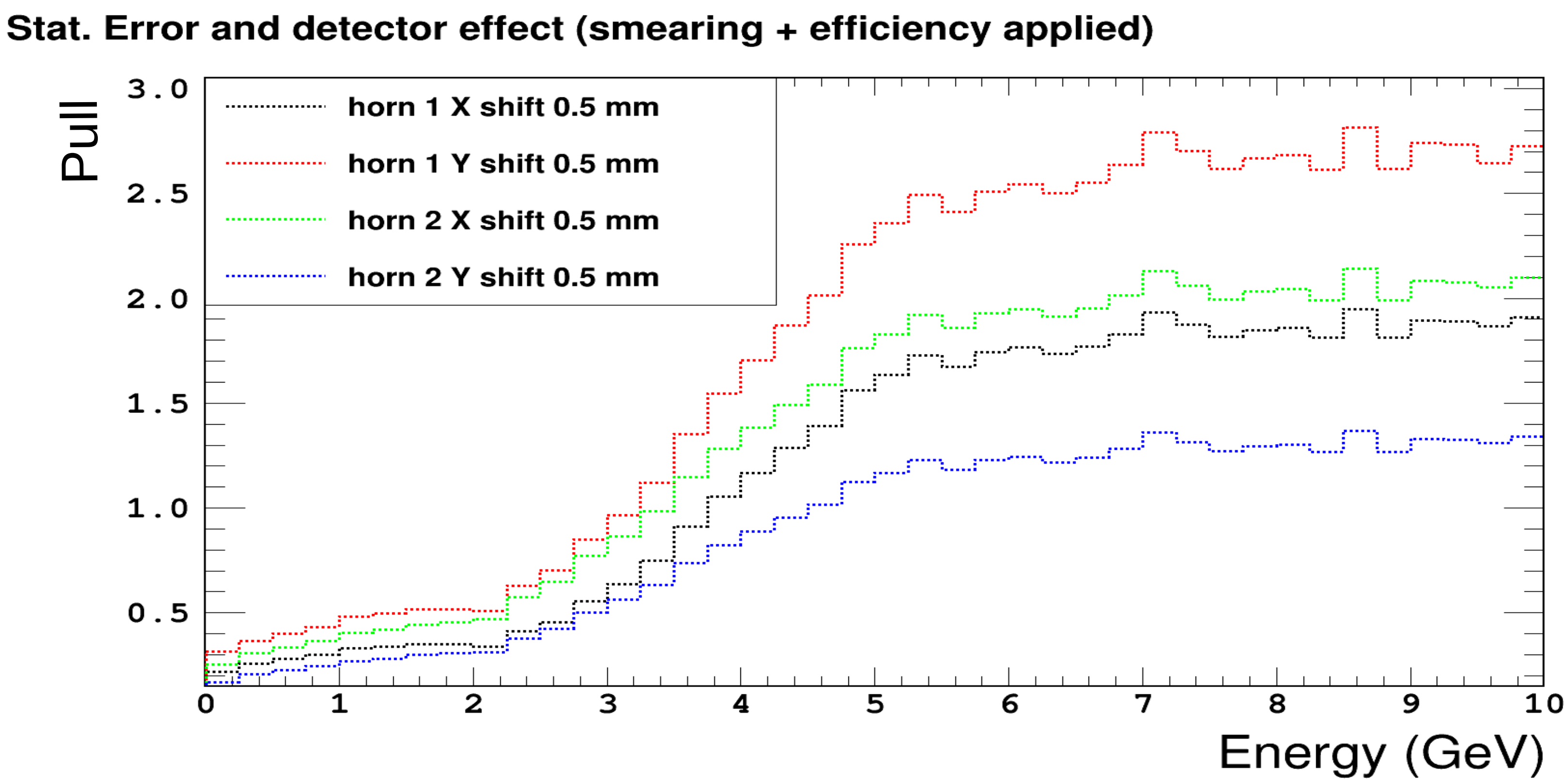
12 available shifts:
(proposed by the beam group, more will come soon)

- Proton Target Density: 1.71 → 1.74 g/cm3
- Proton Beam Offset X: -0.45 mm
- Proton Beam width: 2.7 → 2.8 mm
- Proton Beam theta: beamtheta 0.07 mrad
- Decay Pipe radius: 2.0 m → 2.1 m
- Horn current: -293 → -290 kA
- Water Layer thickness: 1 → 1.5 mm
- Horn 1 or 2 along x or y : shift 0.5 mm

The way to compare

- Rate-only: At a location, for a given mass scenario (one on-axis plus few off-axis modules) and a time period, if we vary one parameter above, what is the sqrt(chi2) ((shift – nominal)/stat.) we will get. Shift and nominal are one single rate numbers. A Sum in quadrature is calculated if considering multiple modules at different locations.
- Spectrometer: On-axis; For a given mass scenario (one on-axis spectrometer) and a time period, if we vary one parameter as above, what is the sqrt(chi2) ((shift – nominal)/stat.) we will get with the spectral information.
- We call the quantity of sqrt(chi2) a pull.

On-axis shape sensitivity with 8.7 ton for a week



- On-axis; if we vary one parameter as above, what is the sqrt(chi2) ((shift – nominal)/stat.) we will get with the spectral information

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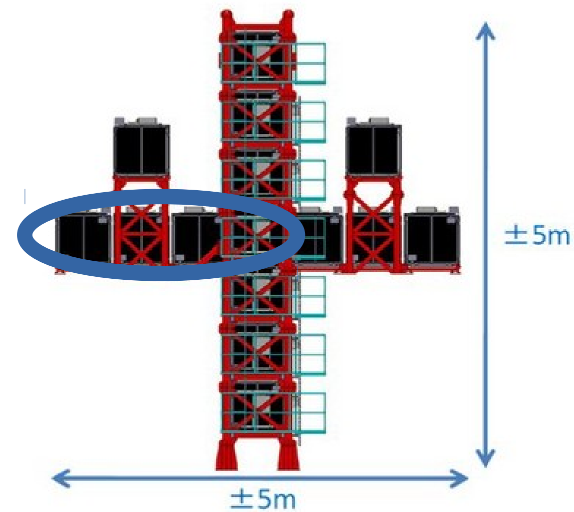
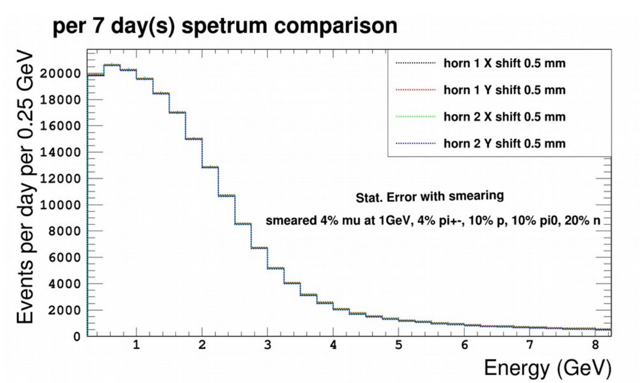
Rate monitor → 7 ton each module
Spectrometer → 8.7 FV in total

sqrt(chi2)	4 modules One-side rate	Muon spectrometer
Beam targ. dens.	1.9	7.8
Beam offset x	0.7	6.7
Beam theta	0.2	19.9
Horn 1 X 0.5 mm	1.9	8.8
Horn 1 Y 0.5 mm	0.7	12.8
Horn 2 X 0.5 mm	0.2	9.9
Horn 2 Y 0.5 mm	0.4	6.3



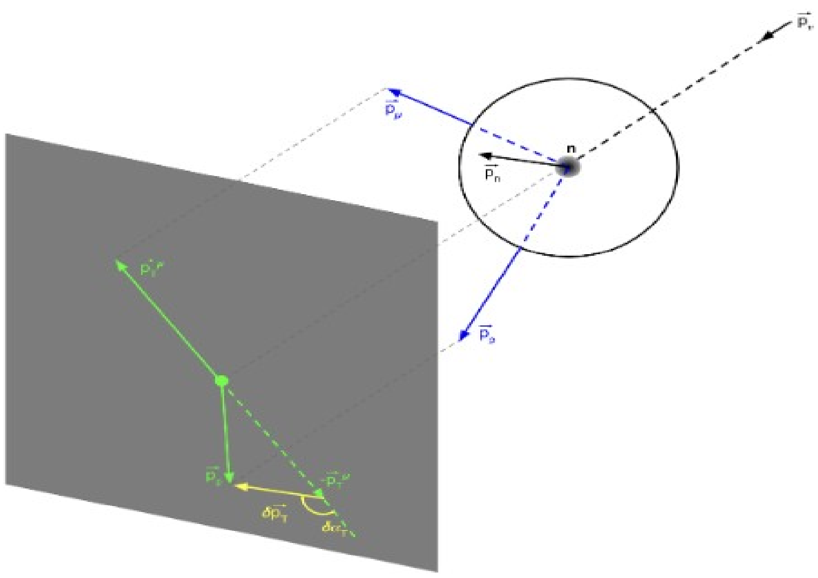


- Summary of the cases that rate-only monitoring is not very sensitive.

Flux constraint - STV

- Single transverse variable: momentum imbalance in the transverse plane to the neutrino direction
- STV cut provides a less-FSI sample.
- RHC sample with selection of CC0pi0p1n channel

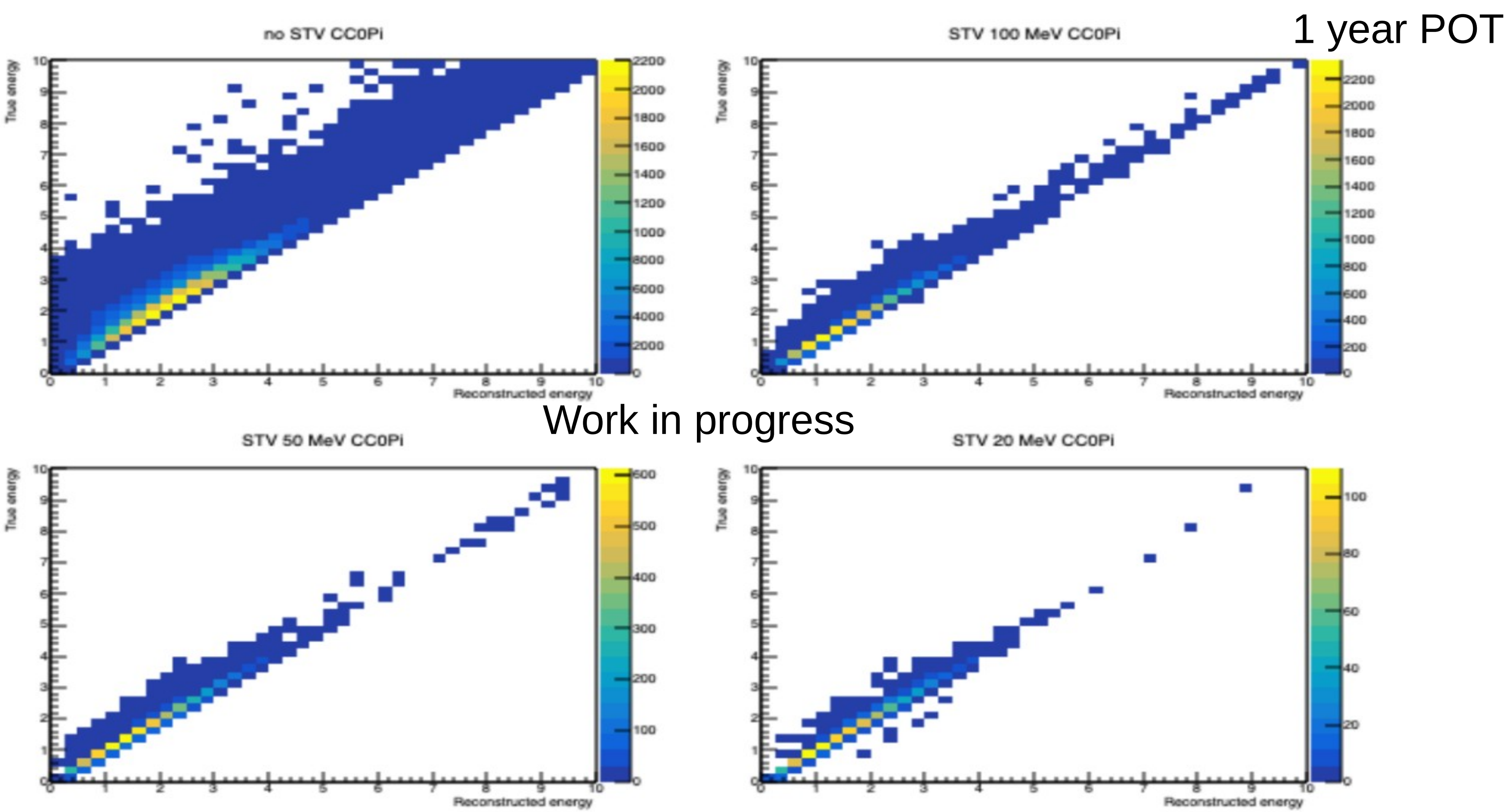
    - muon > 100 MeV/c ; pion > 5 MeV KE rejected



- Muon 4% smearing at 1 GeV and proportional to momentum; pions and protons 10%; neutron 30%
- Can potential do single pion channels as well.

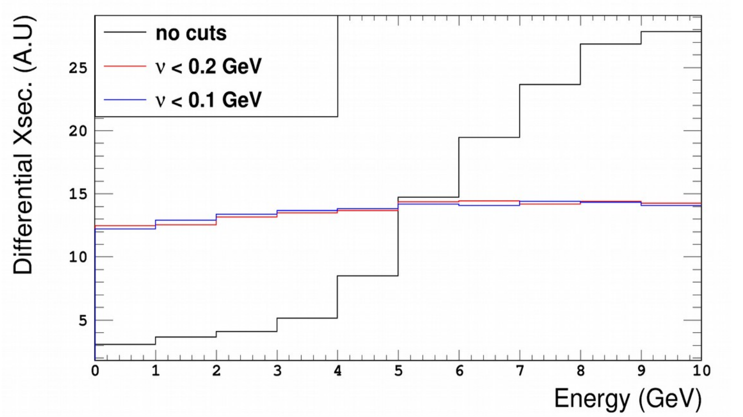
Flux constraint - STV

- Selecting CC0pi0p1n as a demonstrator; can potential do single pion channels as well.

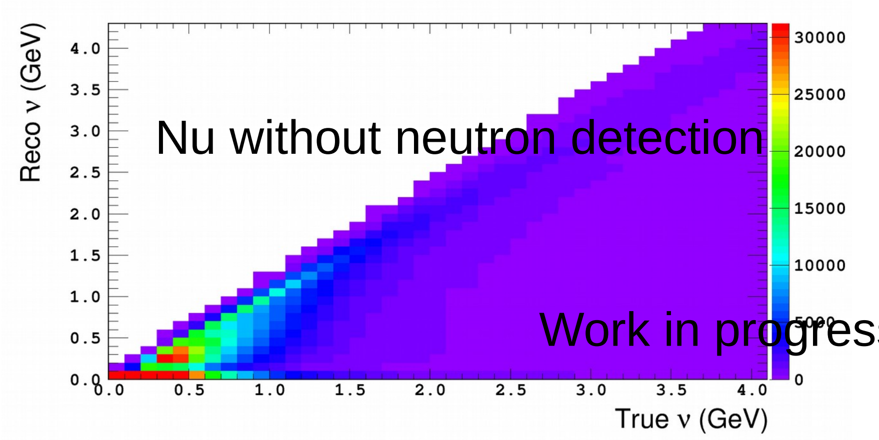


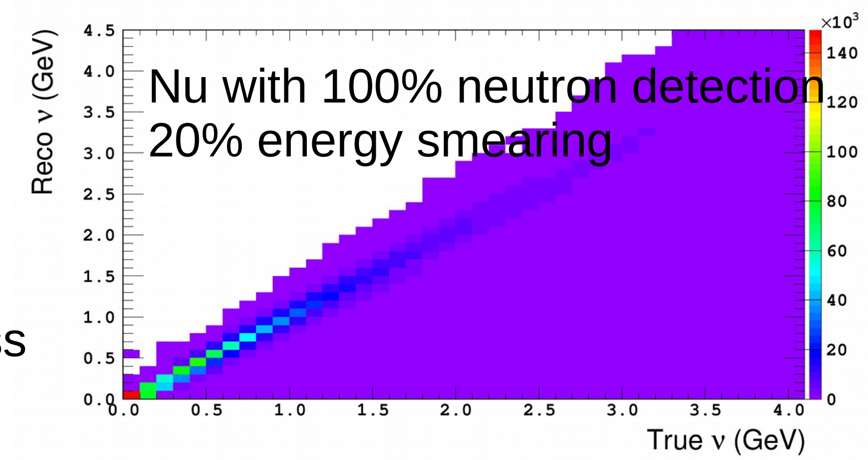
Flux constraint – low nu

- Low nu cross section is flat along neutrino energy → flux shape info. can be constrained.



- Reco. Nu: sum of all energy except muon with the same thresholds and smearings as for the STV study
- True nu : neutrino energy – muon energy
- RHC only as a demonstrator for neutron detection ability
- Plan to assign uncertainty on the left plot

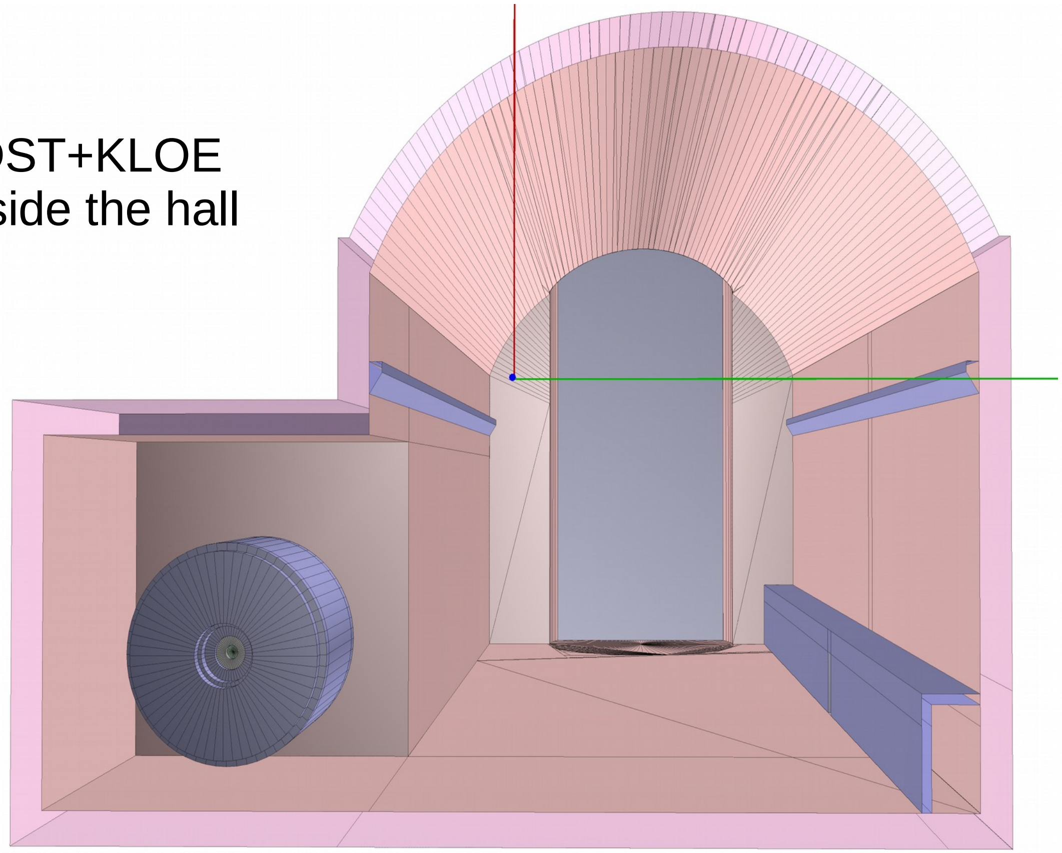




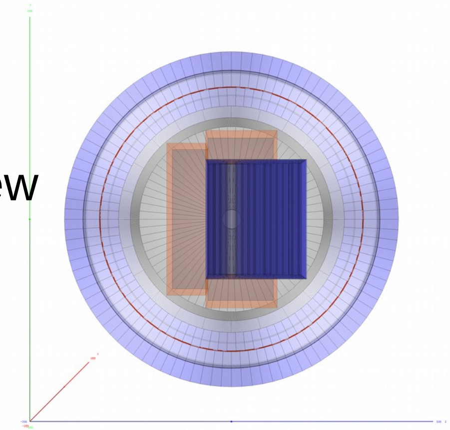
Detector hall and KLOE

- Detector hall is ready (written by 3DST group with DUNENDGGD)
- 3DST + TPC inside KLOE

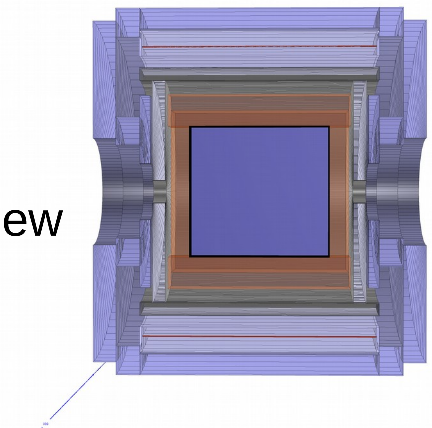
3DST+KLOE
Inside the hall



Side view



front view



Comments

- The 3DST software flow has been built and used for few years → robust.
- 3DST inside KLOE geometry is ready.
- We have some KLOE independent studies done; would be good to have a list of studies that need input from KLOE as well.