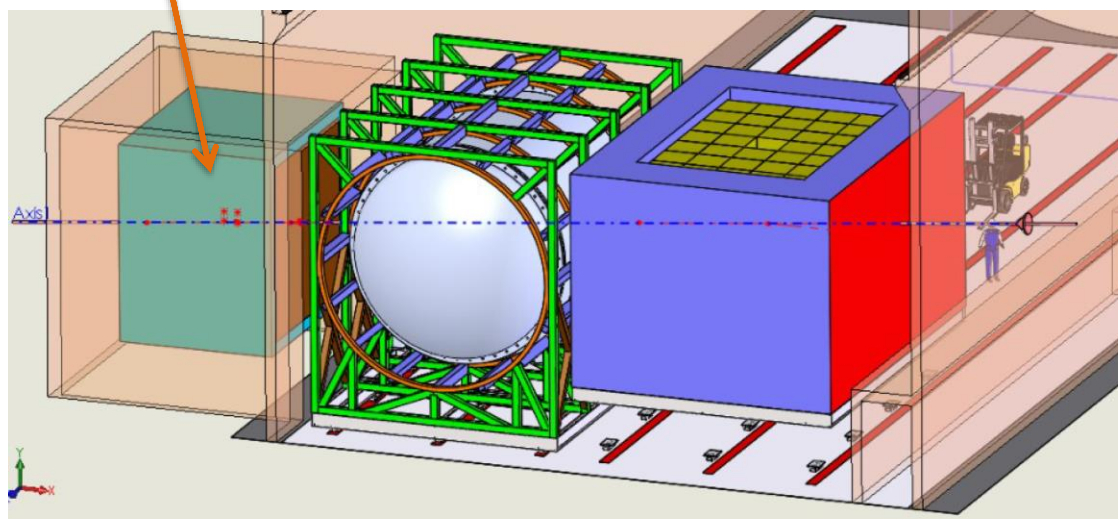
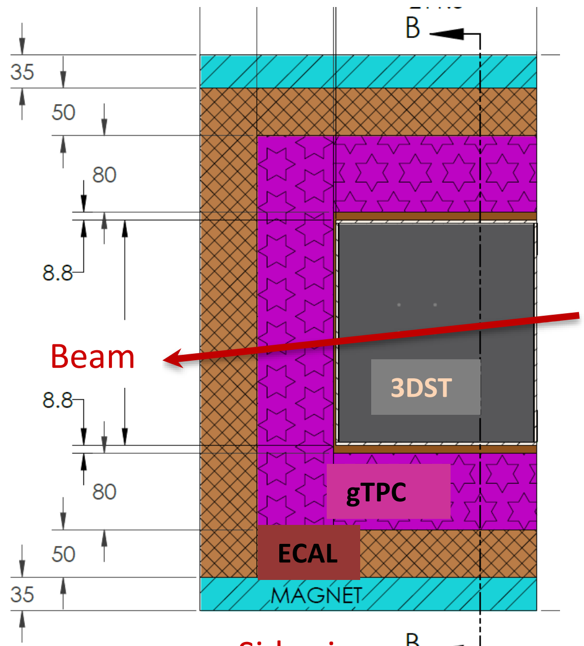
3DST-S in DUNE near detector concept

S. Manly
University of Rochester
LBNC Meeting, Fermilab
June 4, 2019



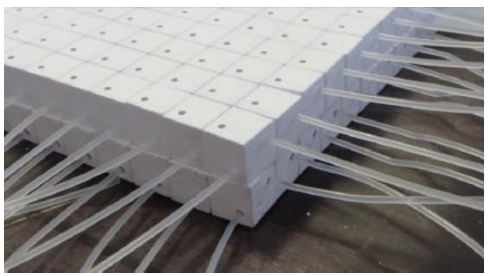
Overview of 3DST-S

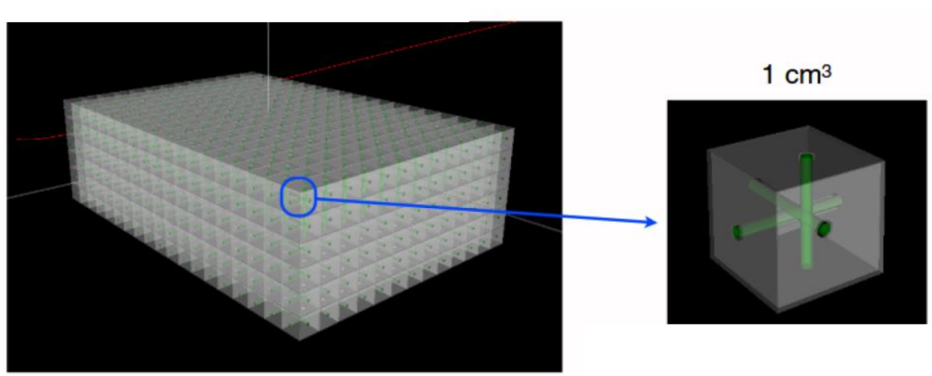


Side view

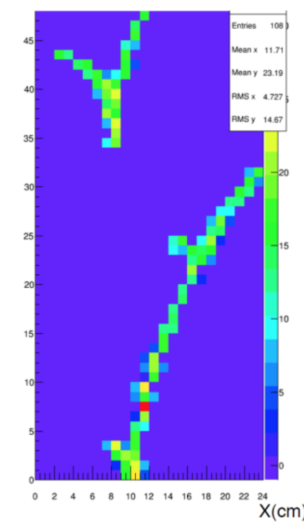
The target is CH, i.e., not argon.
Some of you noticed this ☺.

Complementary to the
Ar parts of the detector





Electron and
radiated/converted photon



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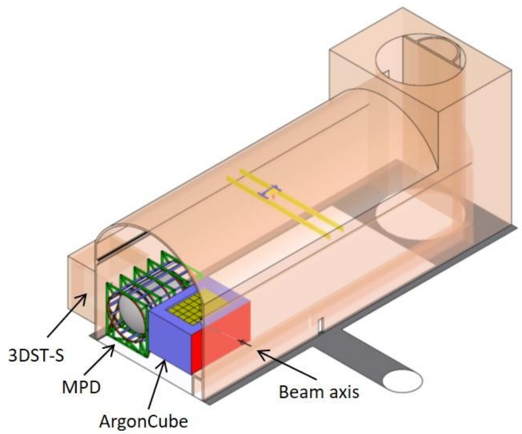


Overarching requirements - from H. Tanaka's talk earlier today

O0 Predict the neutrino spectrum at the FD: The ND must provide a prediction for the energy s provided as a function of the oscillation parameter achieve the required CP coverage. This is the prim	
O0.1	Measure interactions on argon
O0.2	Measure the neutrino energy
O0.3	Constrain the cross section model
O0.4	Measure neutrino flux
O0.5	Obtain data with different neutrino fluxes
O0.6	Monitor the neutrino beam

Not used to tune or constrain model used in oscillation analysis (use Ar for that). Provides information useful for development of model.

3DST-S capabilities added to ND:

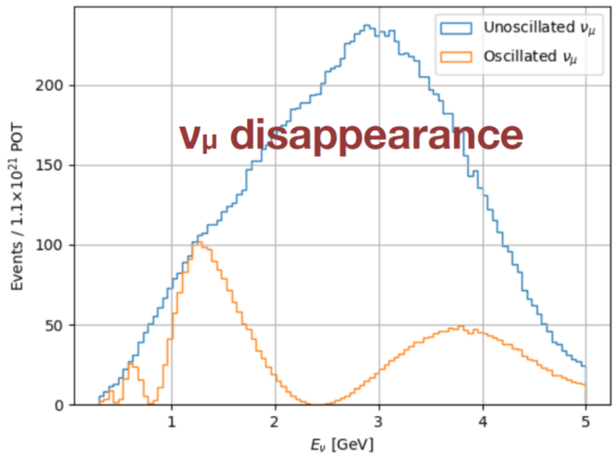
- Beam spectrum/direction monitoring on axis
- Ability to detect neutrons and measure energy
  - Feeds into energy resolution of beam spectrum, flux determination (particularly anti-nu)
  - improvements of interaction model

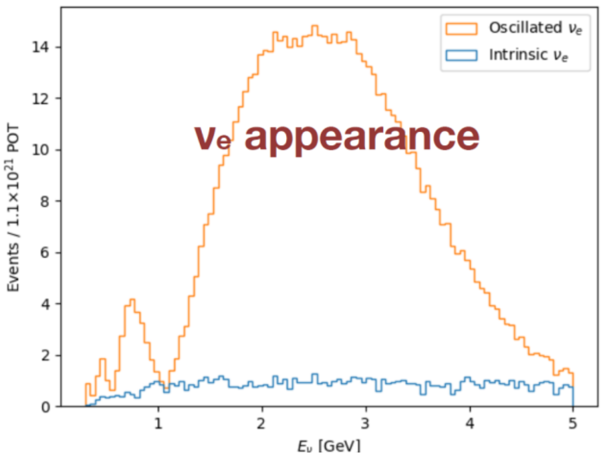
… also contributes to robustness of experiment

From DUNE/LBNF Global Science Requirements

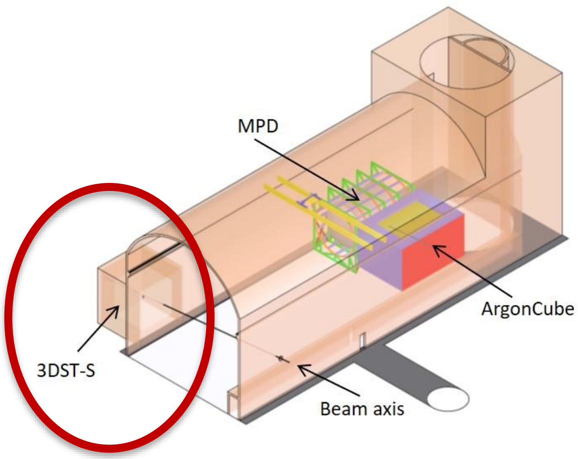
Glo-sci-22: The beam monitoring systems shall have sufficient energy and spatial and temporal resolution that when combined with the detailed knowledge of the beam line geometry, a timely (few hours) feedback of beam performance, stability, as well as a data-driven estimate of the neutrino flux will be obtained.

Beam monitoring with 3DST-S





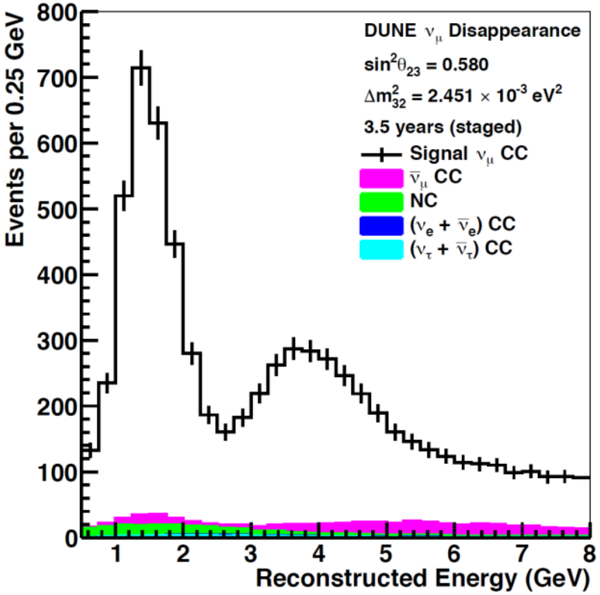
- DUNE aims to measure CP violation via spectral distortion
- 3DST-S provides dedicated on-axis beam spectrum measurement
- Important when PRISM implemented, which introduces flux changes in Ar components of ND

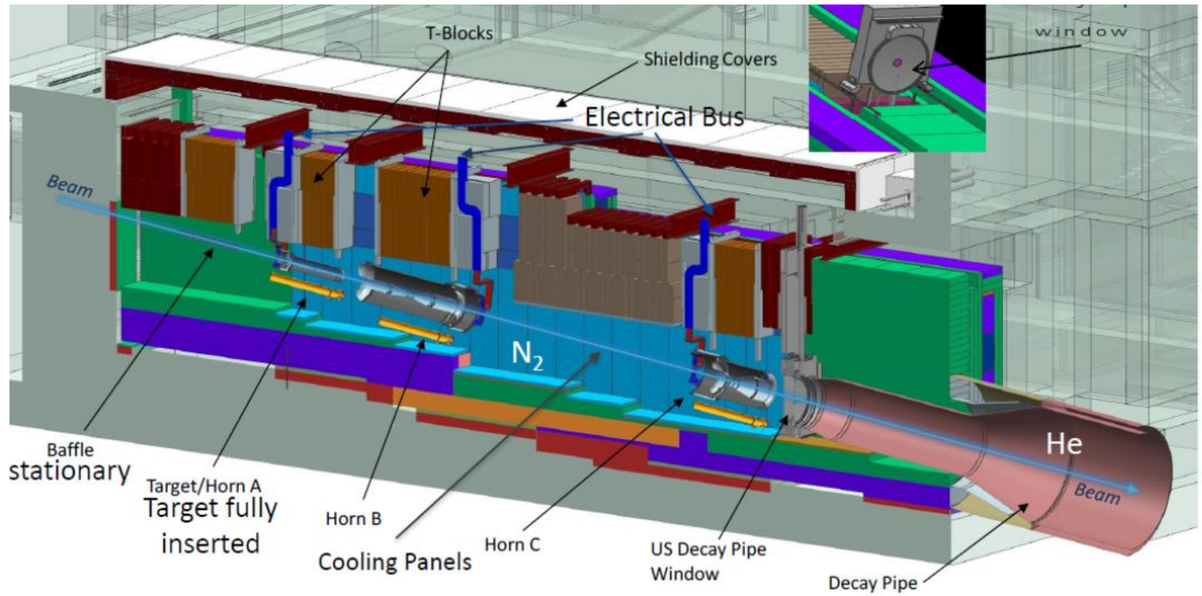


3DST-S stays on axis

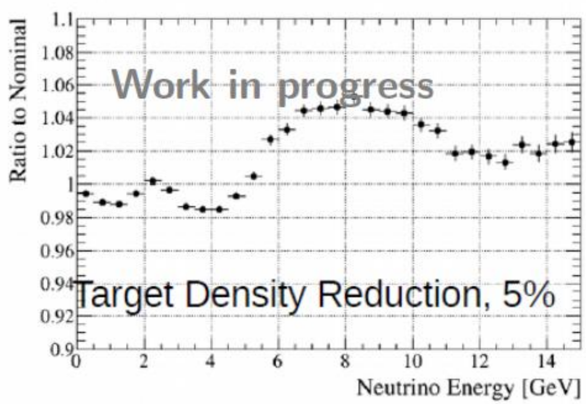
Beam monitoring with 3DST-S

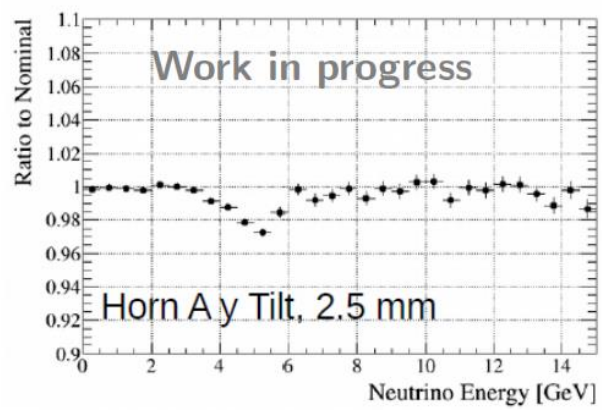
Stuff can happen





M. Bishai, NuFACT 2018



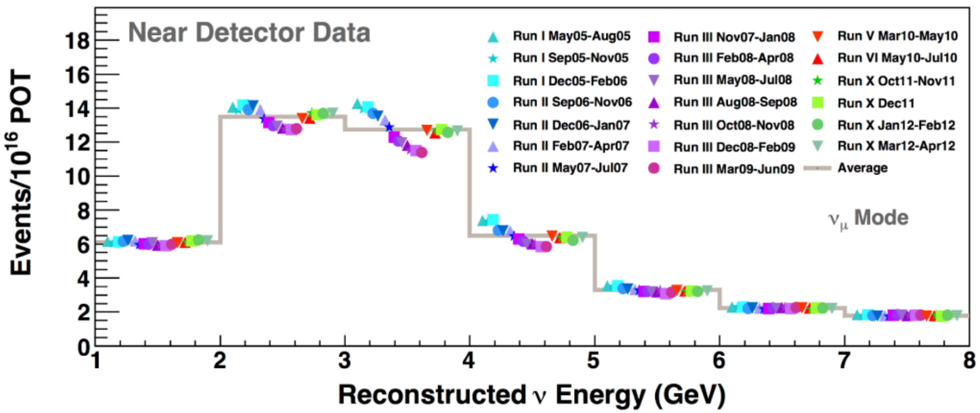


Can produce spectral wiggles (not just a rate issue) → Bad

Beam monitoring with 3DST-S

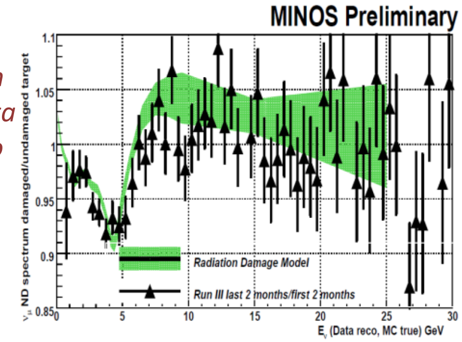
Stuff has happened

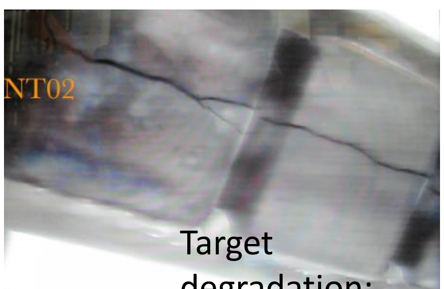
MINOS ND low energy running



Target damage model in FLUKA08

Target degradation modeled by ND data M. Bishai (Neutrino 2010)

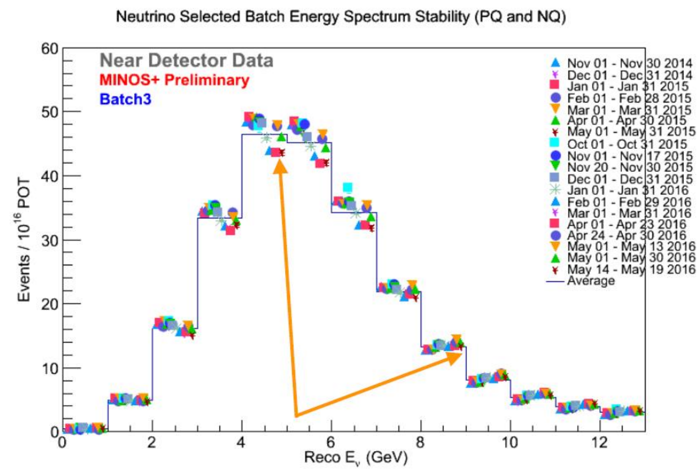




A. Holin, CERN CENF-ND meeting, Nov 2017

Target degradation: Broken upstream target fins

Unexpected horn tilt discovered by change in ND flux (due to corroded part)



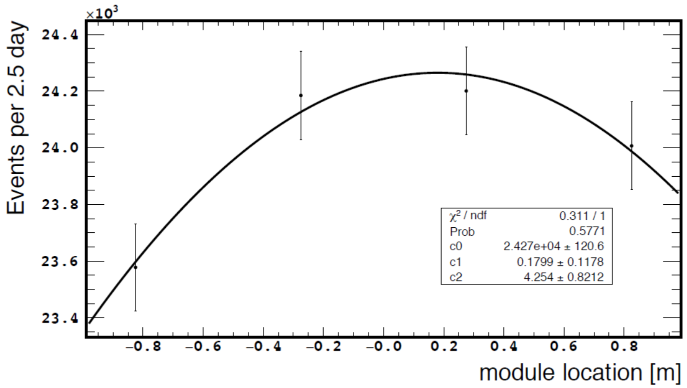
Jim Hylen, NuMI OPS, Nov 2016

MINERvA's "*&^% medium energy flux wiggle" saga

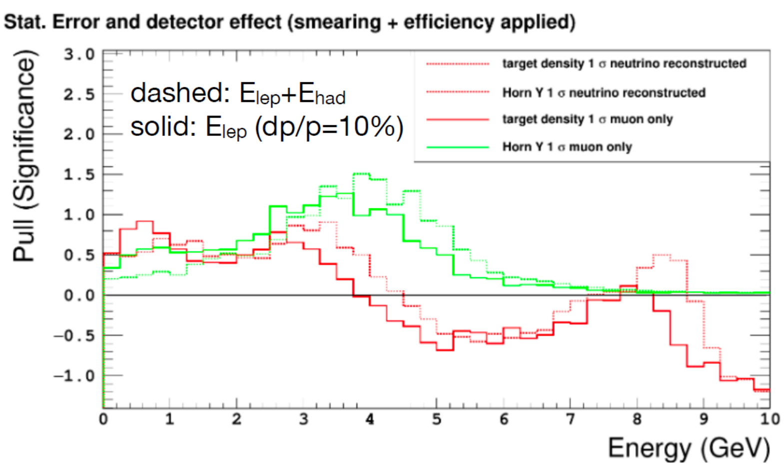
Beam monitoring with 3DST-S

Stuff will happen

2.4x2.4x2 m^3 3DST-S
beam center to 11 cm
2.5 days of running



Shape pull in muon energy or neutrino energy spectrum for 1 week of running



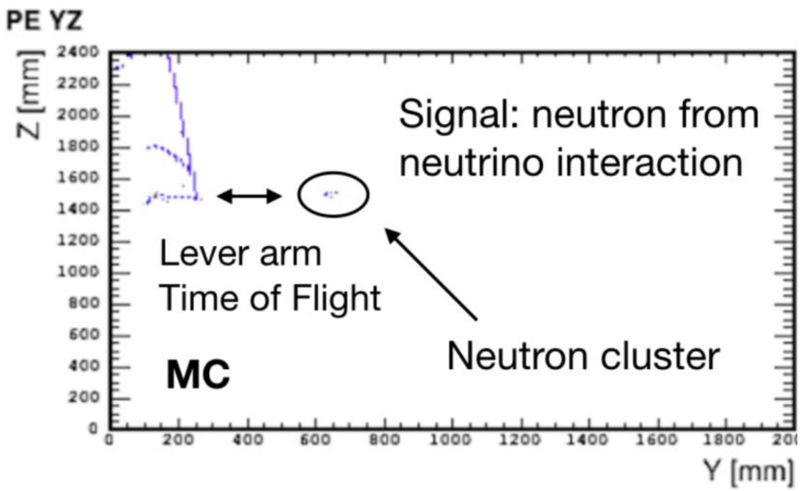
- Monitoring the stability of the LBNF flux and energy spectrum at the ND crucial to achieving goals.
- Muon monitor capabilities limited by removal of low energy muons due to sculpting by hadron absorber at end of beam pipe.
- Changes in on-axis energy spectrum likely to be only indication of certain problems such as shifts in horn position, miscalibrations of currents, changing target density, etc..
- Total rate much less sensitive to changes.
- Effects of problems typically large on-axis and die out off-axis (NOvA ND data relatively insensitive to things picked up on-axis).
- Common for beam parameters to change, particularly after long downtimes.

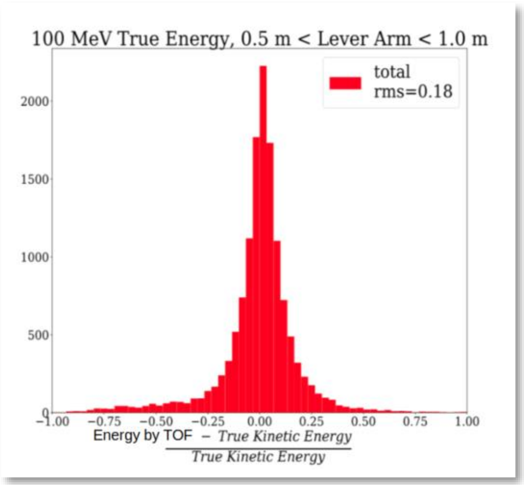
Paraphrased from a few paragraphs written by Laura Fields and Zarko Pavlovic in response to LBNC ND exec. summary feedback last week

Neutrons and 3DST-S

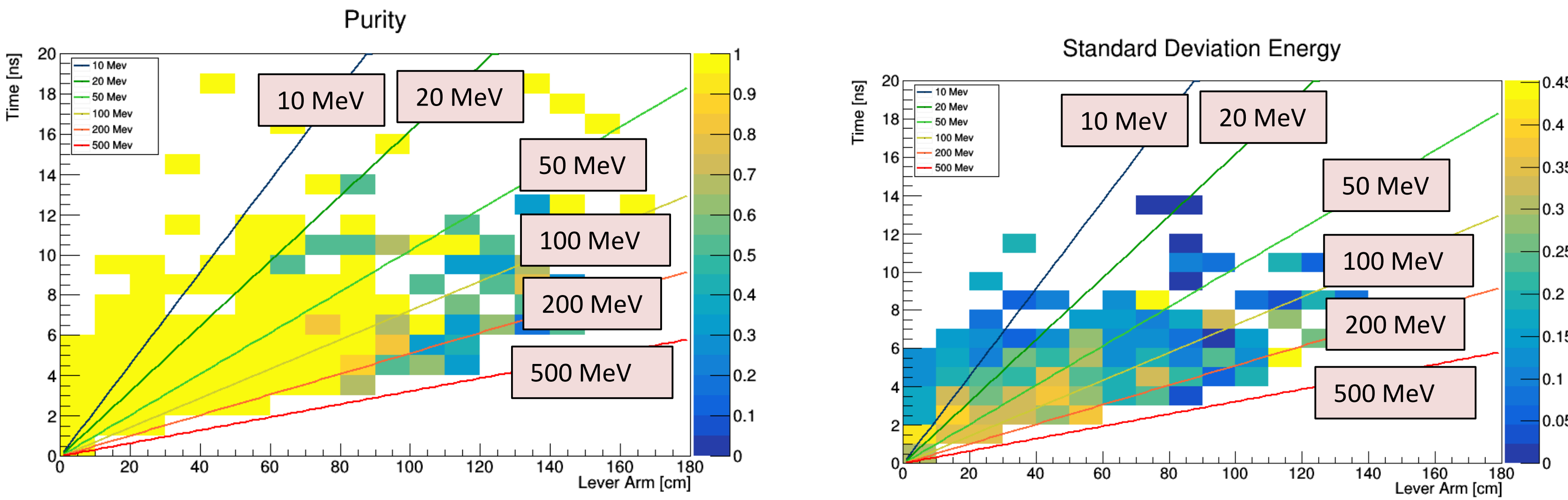
DUNE ND design aims to see and use things invisible to past neutrino experiments: Low momentum pions & protons, and neutrons

- 3DST
  - Highly granular 3D capability
  - Very good timing resolution (500 ps, 3 fiber, 1.3 m)
  - Sensitive to small energy depositions by neutrons
- High potential to reconstruct neutrons on event-by-event basis via Time-of-Flight





Neutrons and 3DST-S



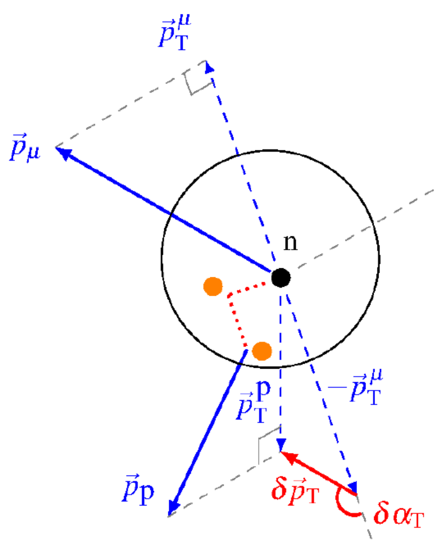
Purity (left) and energy resolution (right) as function of flight distance and ToF. Lines showing different KE_n shown.

Neutrons are a new tool:

- New handle for flux measurements
- New handle to explore interaction physics/modeling

Neutrons as a new tool

- Studies using single transverse variables (STV) showing up in recent publications from MINERvA and T2K
- Being used to improve neutrino energy reconstruction and deconvolve initial and final state processes
- Having access to neutrons in reconstruction will make this even more useful

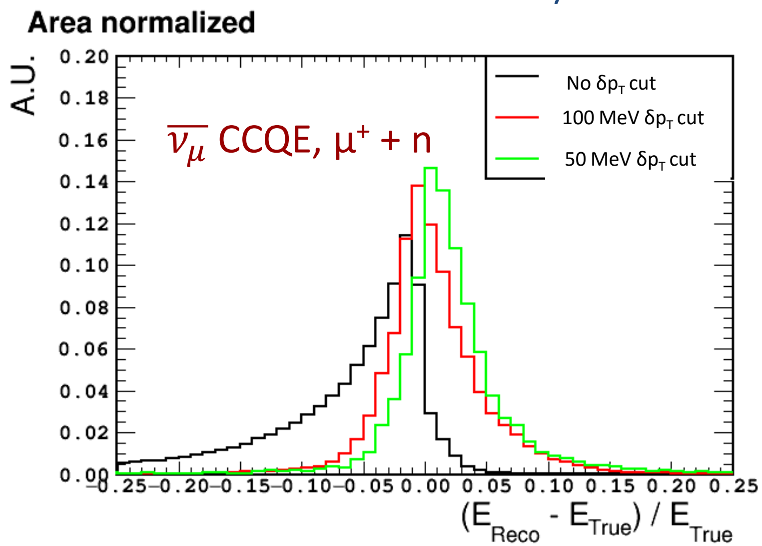


Momentum imbalance in transverse plane, δp_T

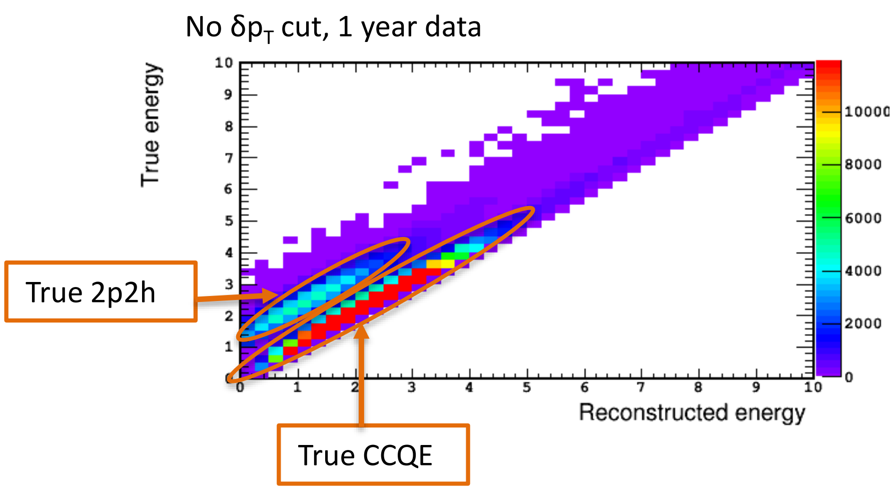
Figure from MINERvA collab., PRL 121, 022504 (2018)

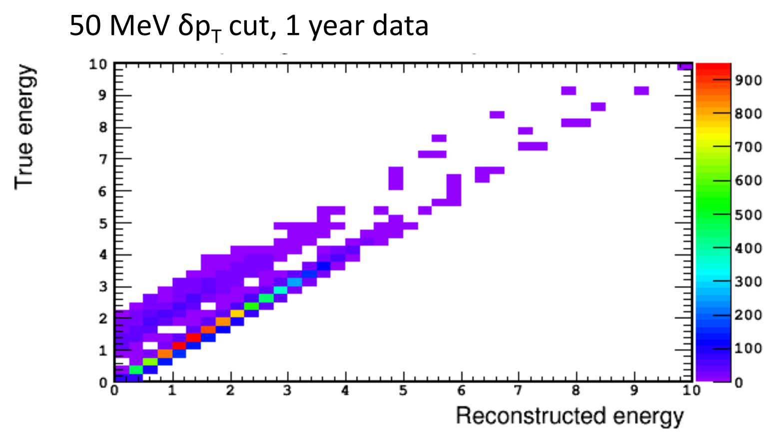
Neutrons as a new tool

- Add neutrons to analysis event-by-event, looking at δp_T
- Particularly of interest for $\overline{\nu_\mu}$ flux determination



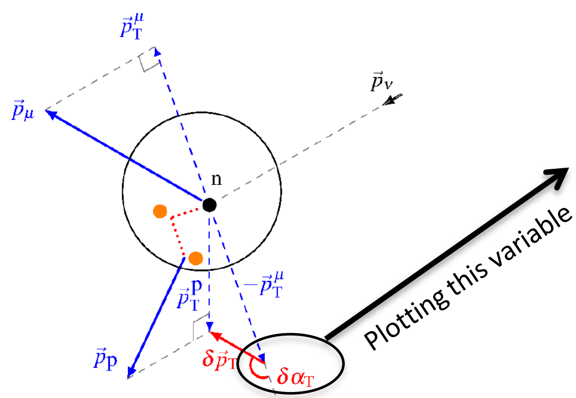
- Cut on missing p_T → sample with less nuclear/FSI effects (H enhanced)
- Gives improved energy resolution for flux determination.
- $\overline{\nu_\mu}$ CCQE (30% of events at DUNE)
- Expanding study to $n\pi^o$ final state



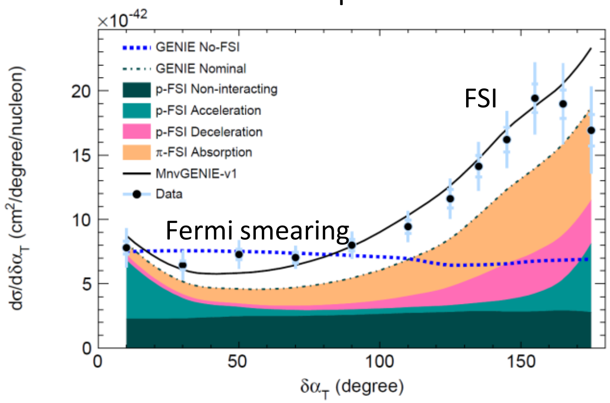


STV studies, recent work

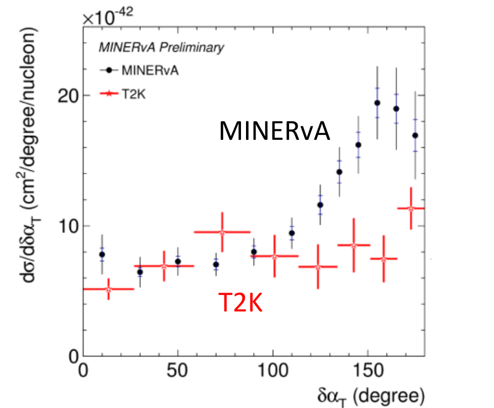
- Deconvolving initial state and final state and CCQE from resonance (even where detector sees same final state)



ν_μ + CH → μ^- + p + 0π



MINERvA collab., PRL 121, 022504 (2018)



X. Lu, FNAL Wine and Cheese, March 2018

Incorporation of neutrons in STV studies likely to be helpful

- Neutrino interaction model: not reality, requires tuning
- DUNE will tune with argon data from LArTPC, MPD

But

- Model development will use all handles
- Neutrons in 3DST-S promising new handle

2p2h/MEC is a case study for surprising physics seen/studied in CH
Generators include something (imperfect) for it
DUNE will use and tune with Ar data

Contribution to robustness of experiment

Admittedly a somewhat fuzzy topic, but robustness is important.

Dedicated on-axis neutrino spectrum monitoring

Minimal technology risk
Very fast detector

Inclusion of neutrons improved STV analyses may help model evolution

Flux measurements:

- Anti-ν_μ with n
- Sign-separated (anti-)ν_e CC flux measurement (before MPD gets the stats)
- Low-ν and ν-e^-, different background systematics from Ar detectors

Confidence in parts of model may be bolstered by studying A dependence

Provides tight connection to world CH data catalog

Beam and interaction models feed into oscillation analysis:

Imperfect model does not agree with Ar data

Tweak with Ar data constraints
Beam model tuning

Tweaked model agrees better, still not perfect

Set systematic error
- Residual disagreement (Ar data)
- Parameter adjustment range
- Confidence, input from all sources welcome

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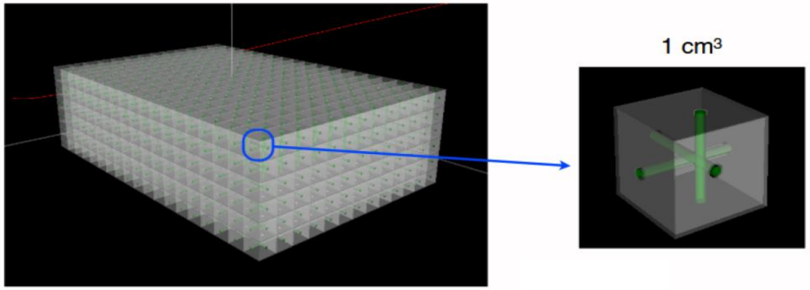
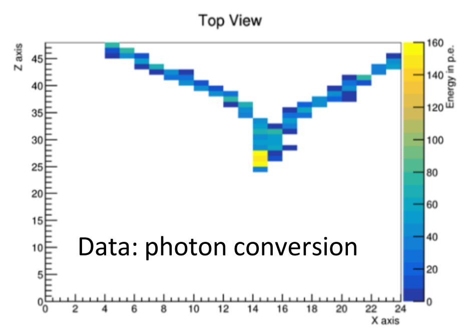
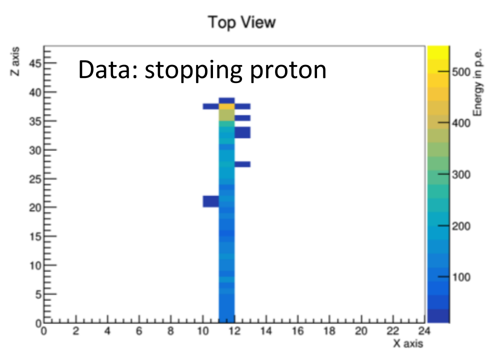
Technical status of 3DST

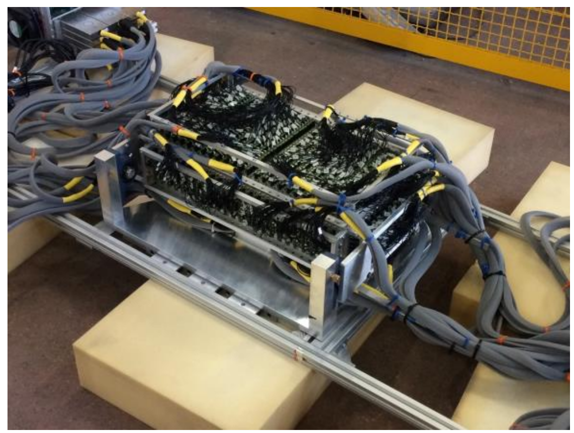


Technology R&D well along since also being used for SuperFGD in T2K upgrade

SuperFGD is a 3DST prototype

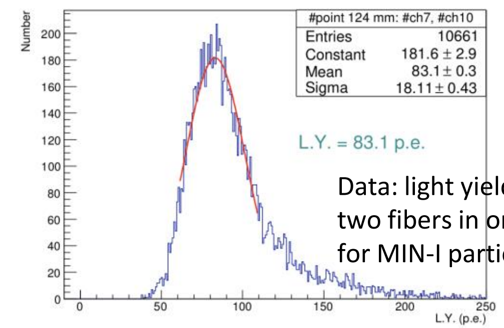


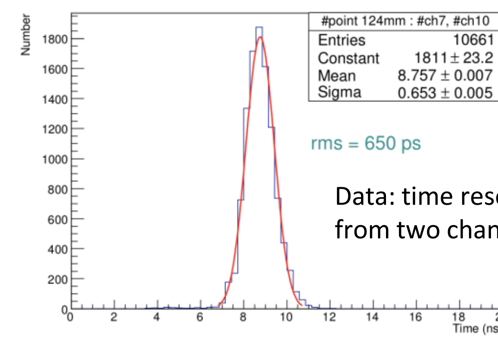




Several beam tests at CERN

Many DUNE collaborators involved in 3DST are also involved with SuperFGD

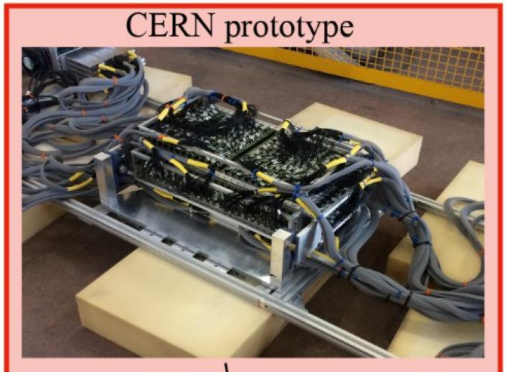


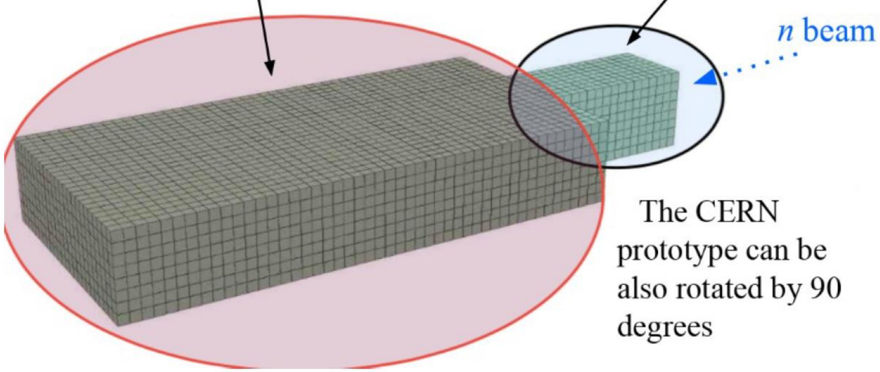


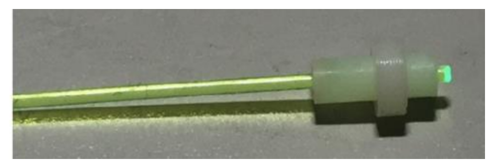
Technical status of 3DST

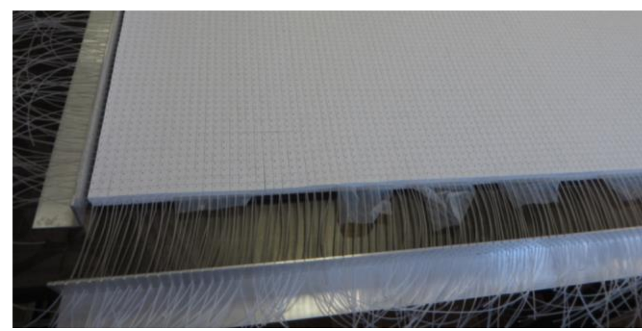
3DST and SuperFGD collaborators planning to run devices in neutron beam test at LANL this summer/fall

8x24x48 cubes









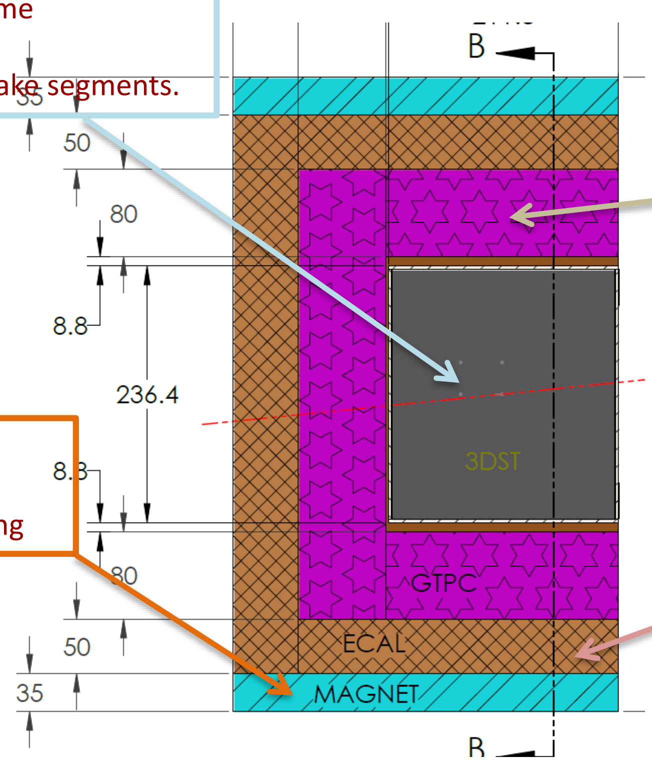
Work proceeding with expectation to construct SuperFGD in 2020, install in 2021

Technical risks for 3DST-S

➢ 3DST-S component technologies prototyped and/or proven → low risk

- Construction of 12 ton device significantly more challenging than the 2 ton SuperFGD.
- May require some automation.
- May need to make segments.

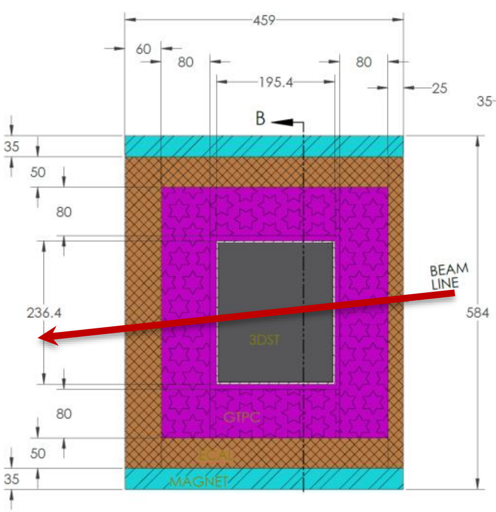
- TPCs expected to be similar to those in ND280 upgrade



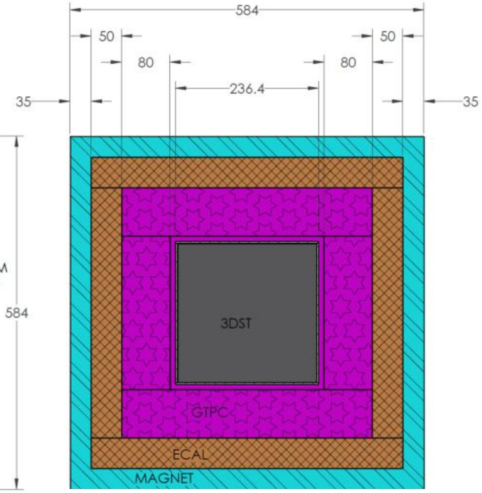
- Magnet design starting
- Aiming for 0.6T
- Probably normal conducting

- ECAL design not expected to be challenging or particularly high in channel count (pointing criteria not extreme)

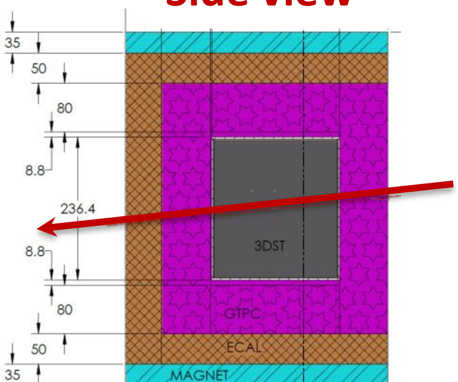
3DST-S: different configurations under study

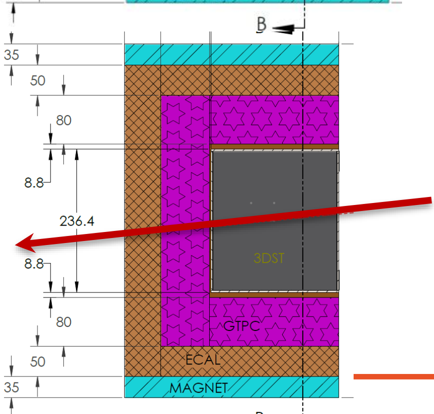


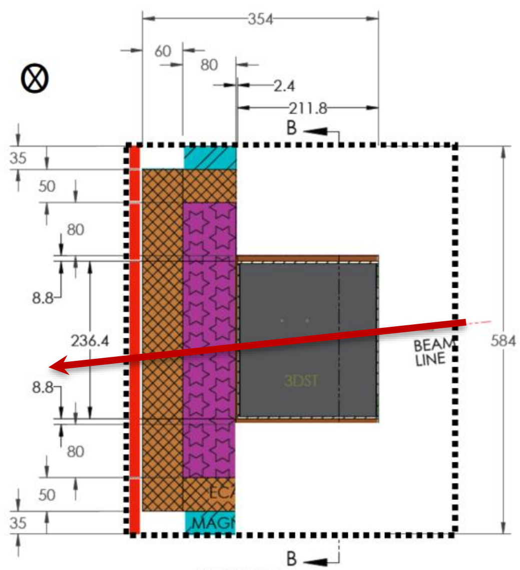
Side view



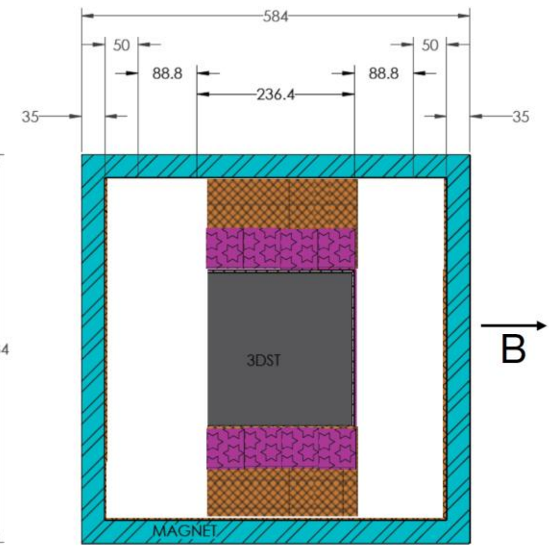
Beam's eye view





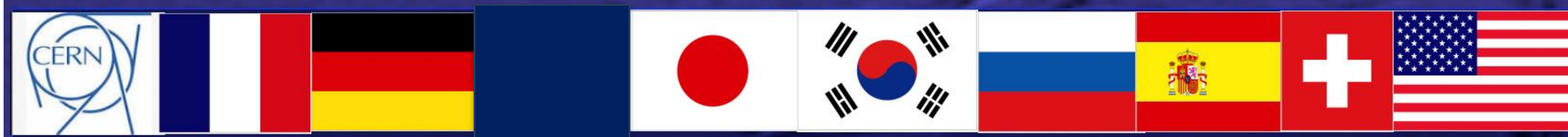


SECTION A-A



SECTION B-B

The SuperFGD/3DST Group
(19 institutions, 9 countries + CERN)



CERN

France
CEA Saclay

Germany
MPI Munich

[redacted]

Japan
KEK
Tokyo Metropolitan U.
U. Kyoto
U. Tokyo
Yokohama National U.

Korea
Chung-Ang U.

Russia
INR

Spain
IFAE, Barcelona

Switzerland
U. Geneva

USA
BNL
Fermilab
Louisiana S. U.
S. Dakota School of Mining and Technology
Stony Brook U.
U. California, Irvine
U. Colorado
U. Minnesota, Duluth
U. Pennsylvania
U. Pittsburgh
U. Rochester

* Institutions in yellow have expressed specific interests in DUNE ND 3DST-S

* Two students from Madagascar are very actively involved in the 3DST studies.

* Monireh (Minoo) Kabirnezhad, Oxford, just joined the 3DST effort