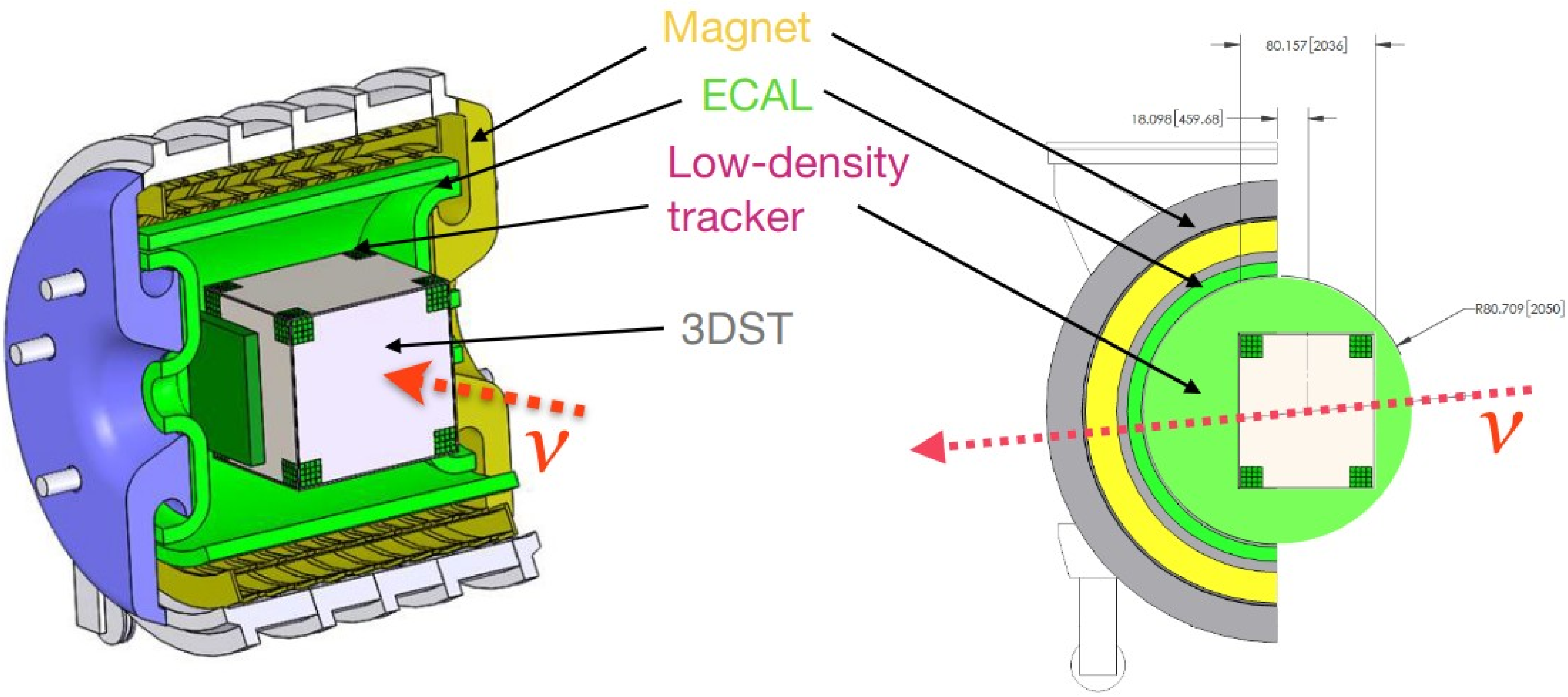
3D projection scintillator tracker (3DST) in SAND

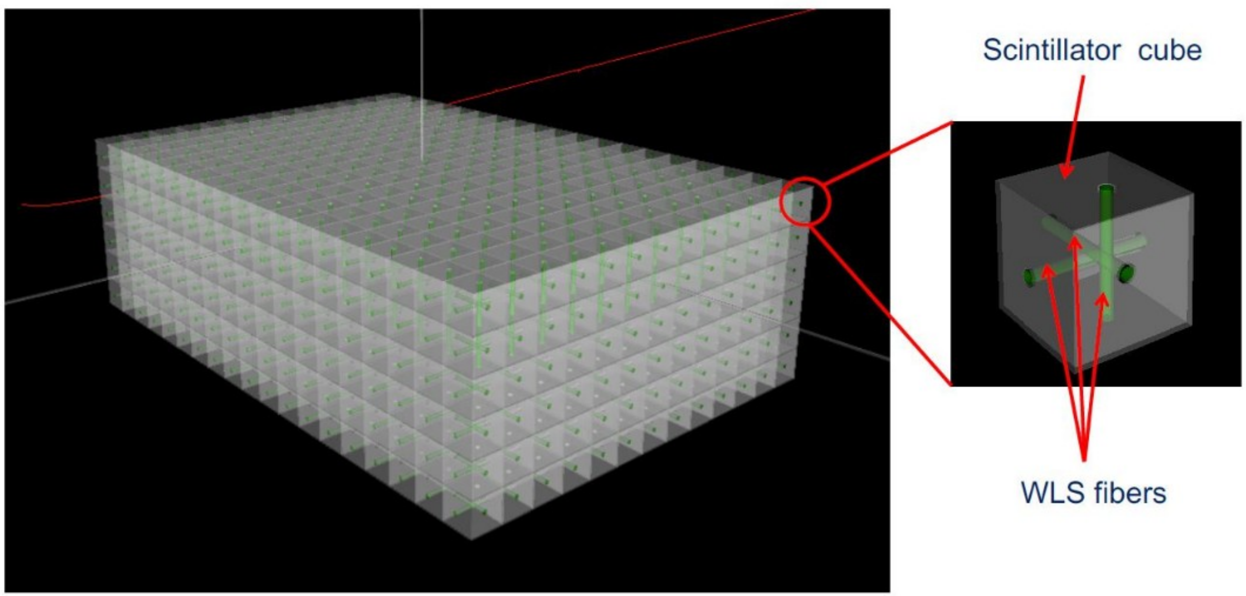
Guang Yang (Stony Brook)

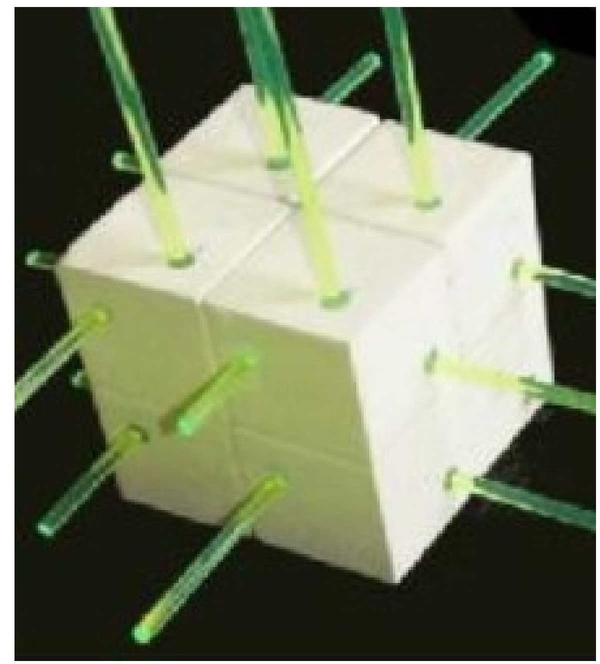
Full SAND reference design



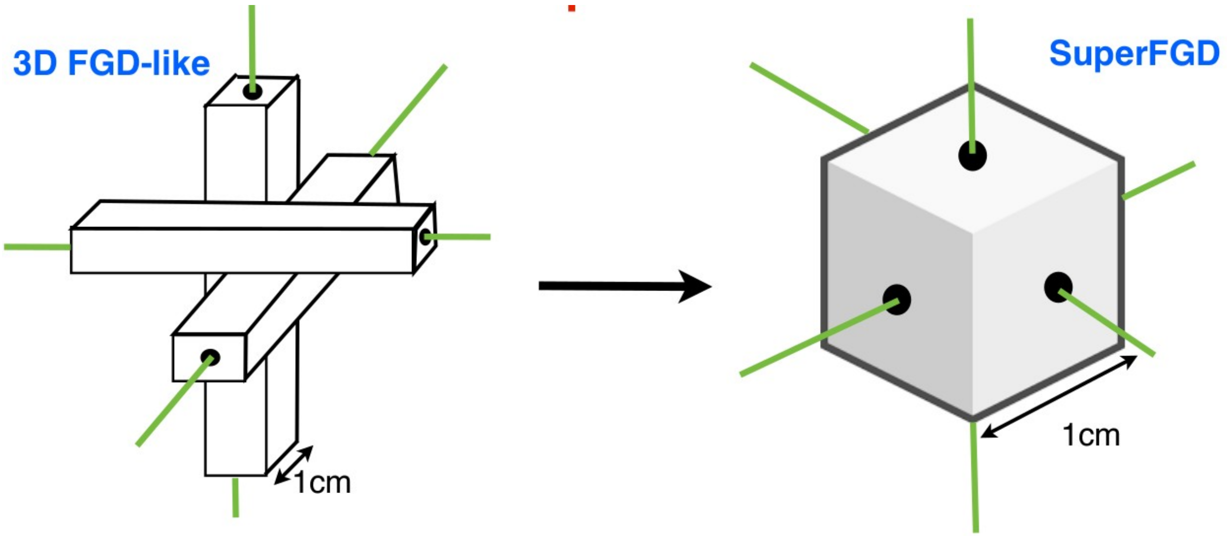
3D projection scintillator tracker (3DST)

- Plastic scintillator detector with 1 cm x 1 cm x 1cm cubes
- Light collected by 3 wavelength shifting fibers
- Each cube coated with TiO2 to keep light entrapped inside the cube
- Read out by MPPC at 3 faces





Scintillator cube technique

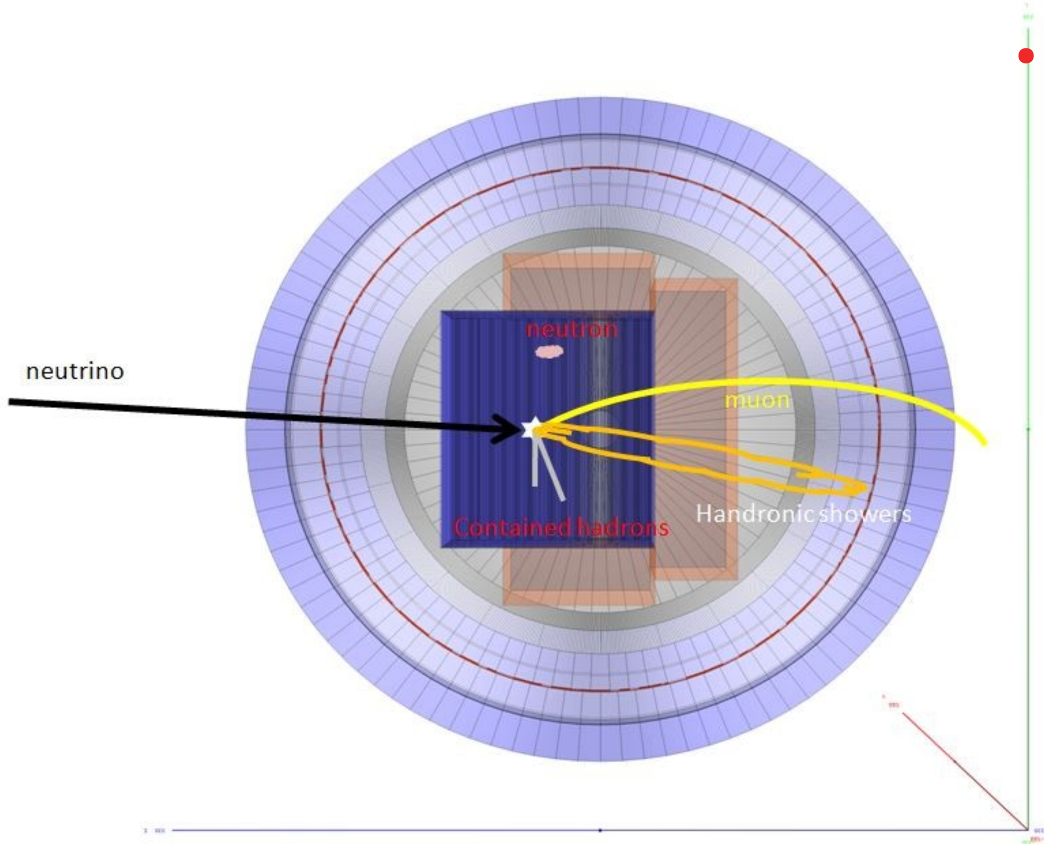


- Coating thickness : 50 um
- WLS fiber diameter : ~1 mm

- Fully active detector : no dead material as a massive target
- Uniform : neutrino interaction is not depending on the interaction location
- Full solid angle acceptance
- Pseudo-3D reconstruction with fine granularity
- Super fast time resolution : NEUTRON!

3DST in SAND

- Goal in short: get all final state particle information in good precision for each desired exclusive channel



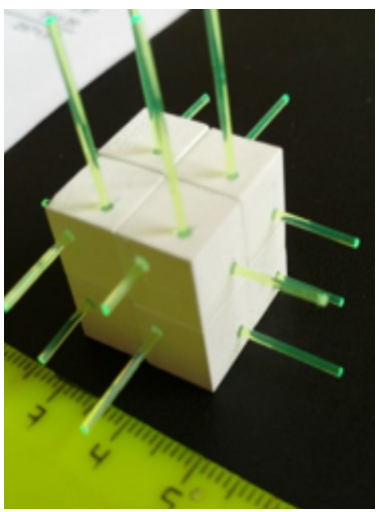
- 3DST provides :

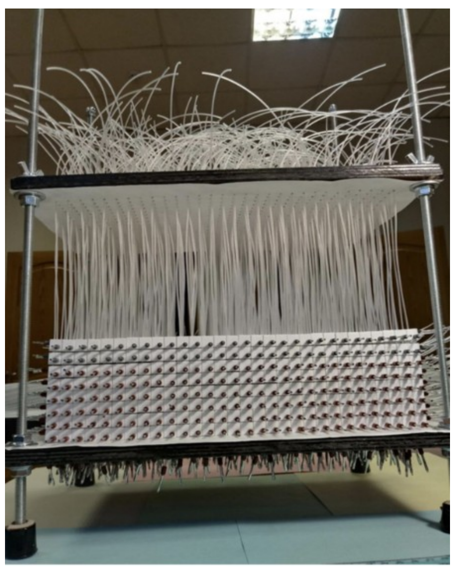
  - Massive fully active CH target
  - Good vertex activity detection
  - Good tracking ability for muons
  - Precise energy and direction for photon/electron
  - Low threshold for hadrons
  - Neutron detection!

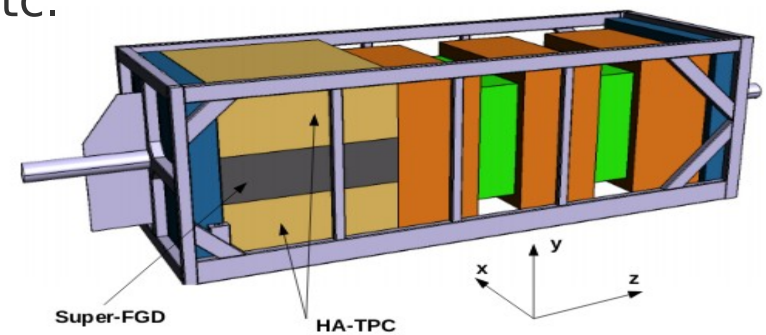
Synergy with T2K upgrade

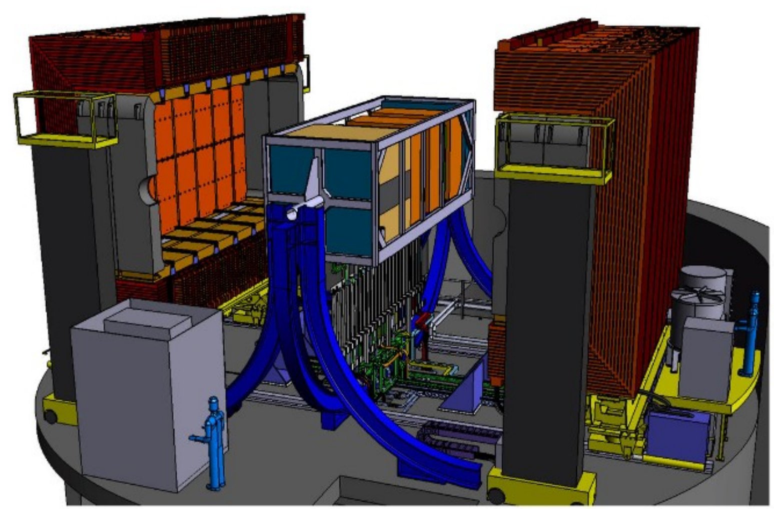
- Functionally identical to the T2K SuperFGD in T2K ND280
- Share the effort including hardware and software such as parts production, R&D, neutrino event reconstruction etc.

Super-FGD proto-type









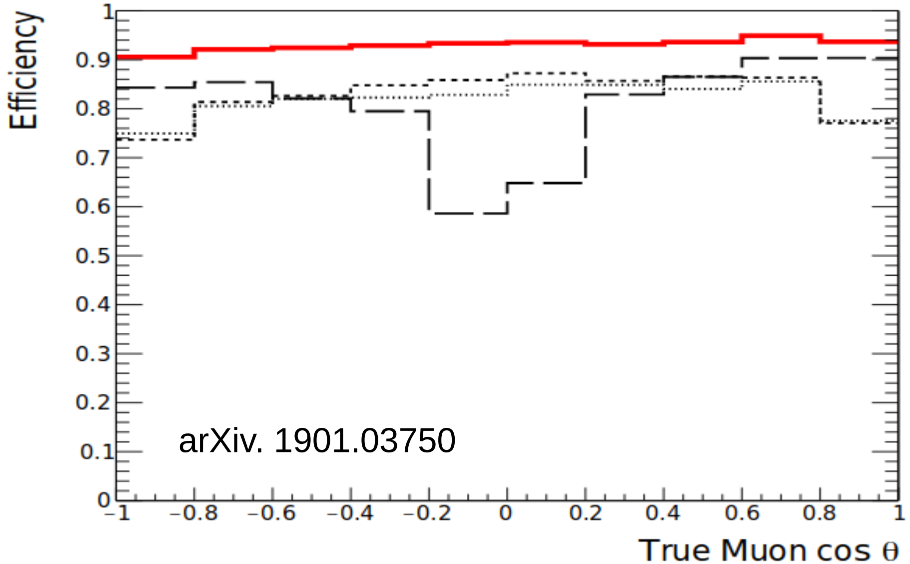
arXiv. 1901.03750

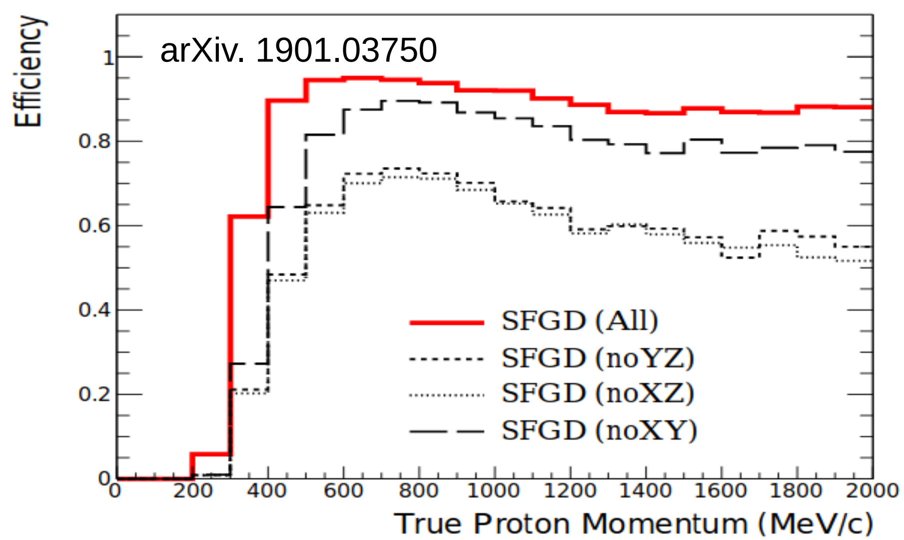
3DST performance

- Relatively high statistics with HydroCarbon target
- Tracking particles over 4pi space
- Low proton threshold

For a year

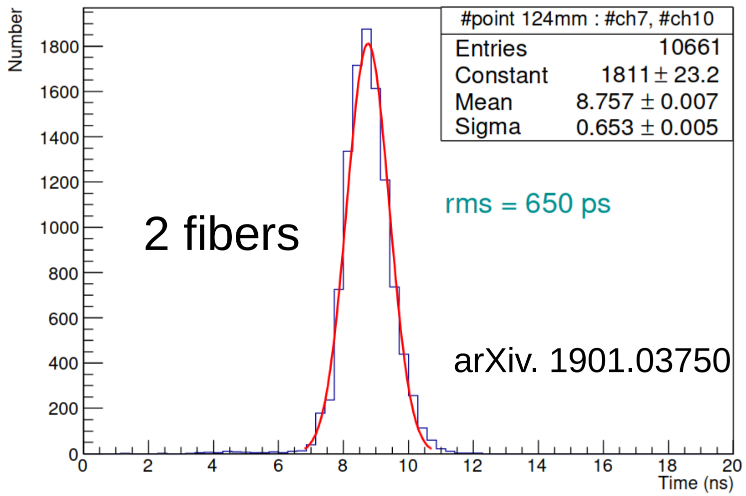
Channel	ν mode	$\bar{\nu}$ mode
ν_μ charged current (CC) inclusive	15.3×10^6	6.1×10^6
CCQE	3.9×10^6	2.4×10^6
CC π° inclusive	5.0×10^6	1.4×10^6
neutral current (NC) total	5.2×10^6	3.3×10^6
ν_μ-e$^-$ scattering	349	190
ν_μ CC coherent	7.49×10^5	4.6×10^5
ν_μ CC low-ν (ν <250 MeV)	1.74×10^6	1.4×10^6
ν_e CC coherent	7.3×10^3	4.3×10^3
ν_e CC low-ν (ν <250 MeV)	1.9×10^4	1.5×10^4
ν_e CC inclusive	2.4×10^5	8.7×10^4

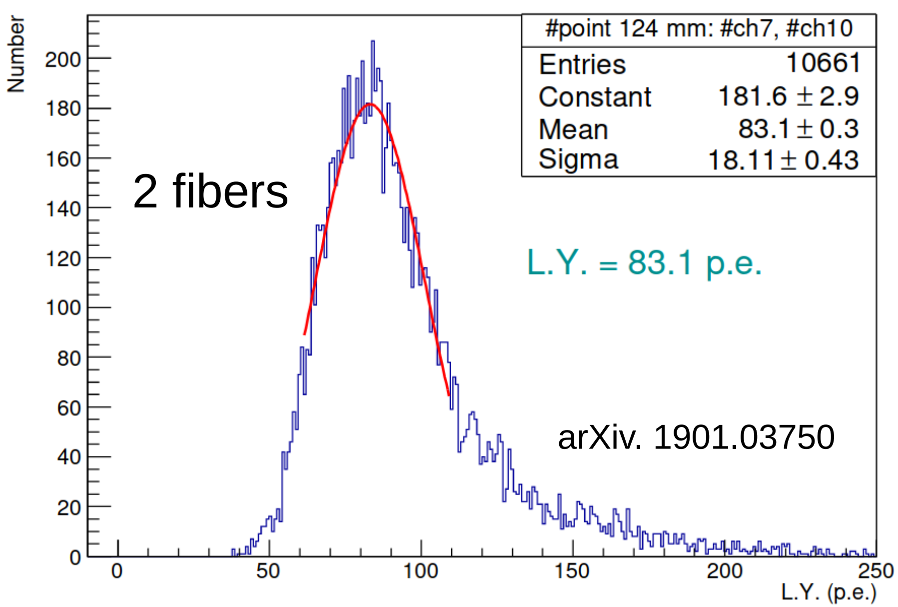


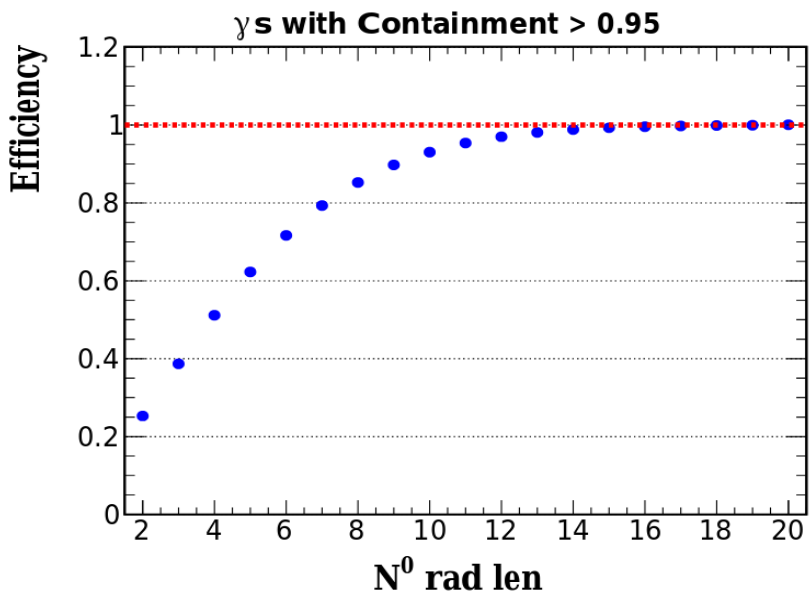


3DST performance

- Super fast and high light yield
- Radiation length ~ 40 cm, TPC and ECAL needed in addition to 3DST
- ~100% charge ID for tracks below 3 GeV







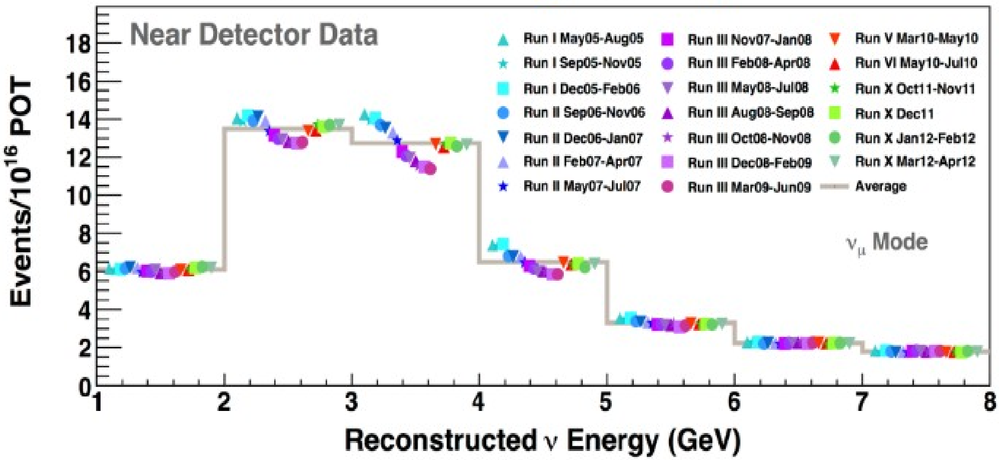
Physics motivation in DUNE ND

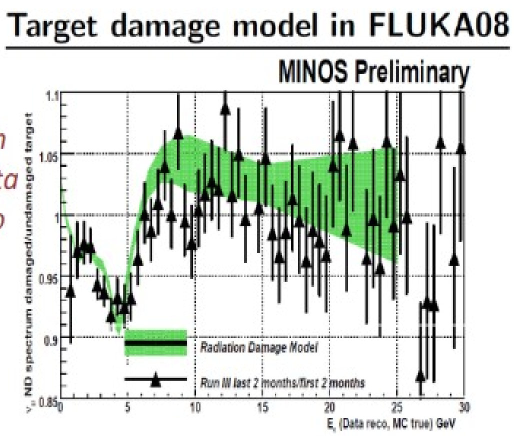
- Monitoring the beam stability : giving alert if any unexpected beam condition change happens
- Neutron detection : providing a flux constraint with neutron measurement
- A different target : providing a unique way to tune the neutrino interaction modeling

Beam accidents

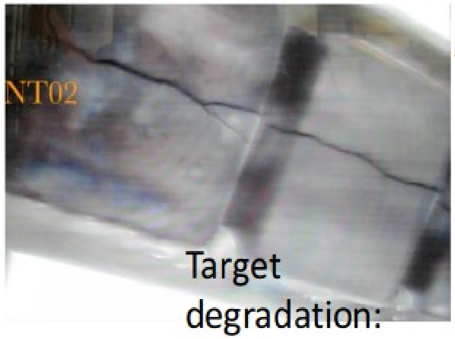
- Beam accidents happened before.

MINOS ND low energy running





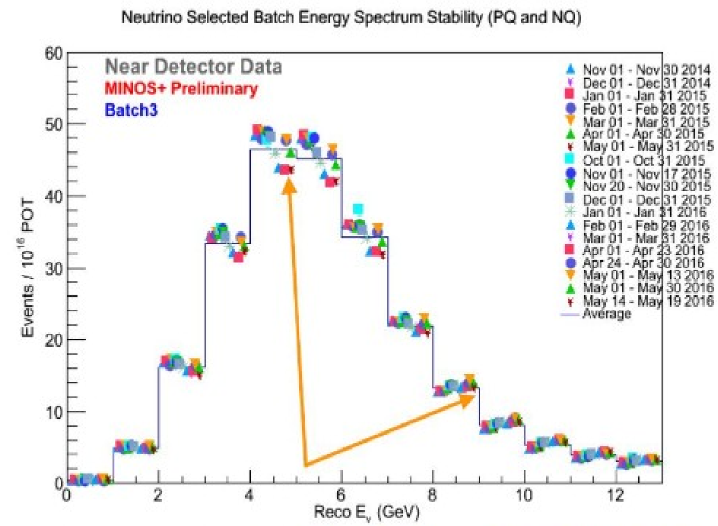
Target degradation modeled by ND data M. Bishai (Neutrino 2010)



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

Target degradation: Broken upstream target fins

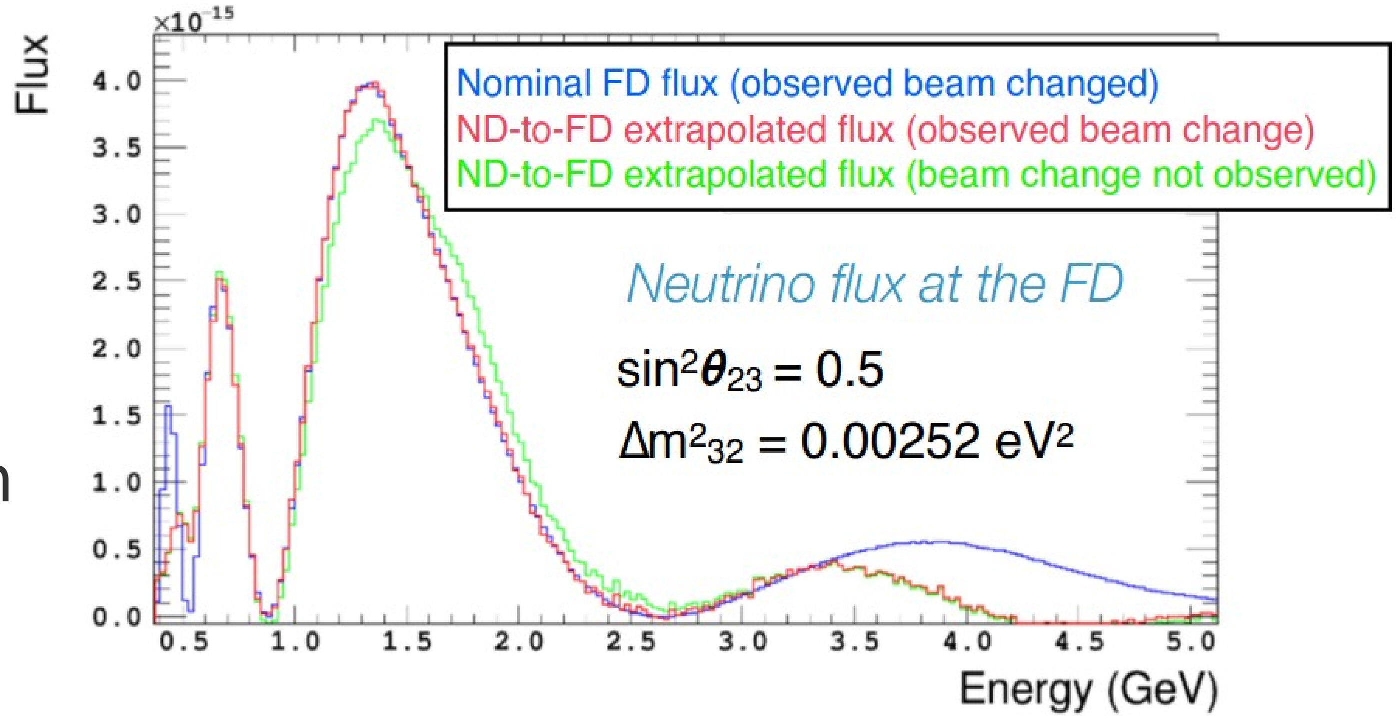
Unexpected horn Tilt discovered by Change in ND flux (due to corroded part)



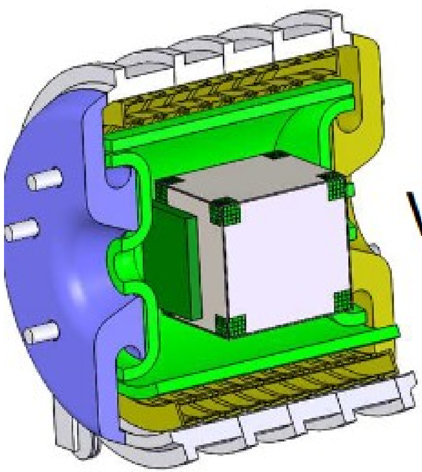
Jim Hylen, NuMI OPS, Nov 2016

Necessity of a nu beam monitor

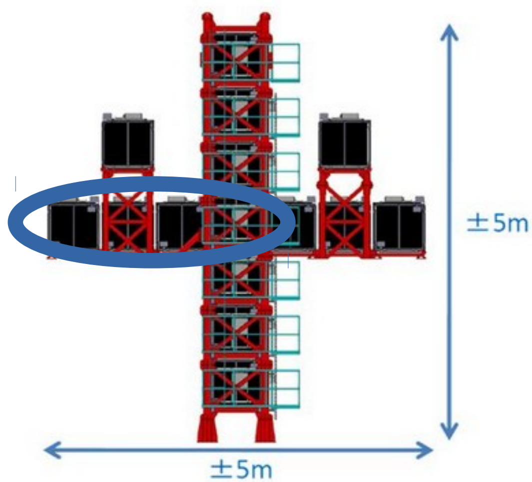
- DUNE-PRISM needs a good knowledge of the neutrino flux at all time
- Flux fit in DUNE-PRISM can be biased if we misunderstand the beam condition
- Faking with a case that when ArgonCube and MPD off-axis beam starts to change



Rate monitor → 7 ton each module
Spectrometer → 8.7 FV



VS



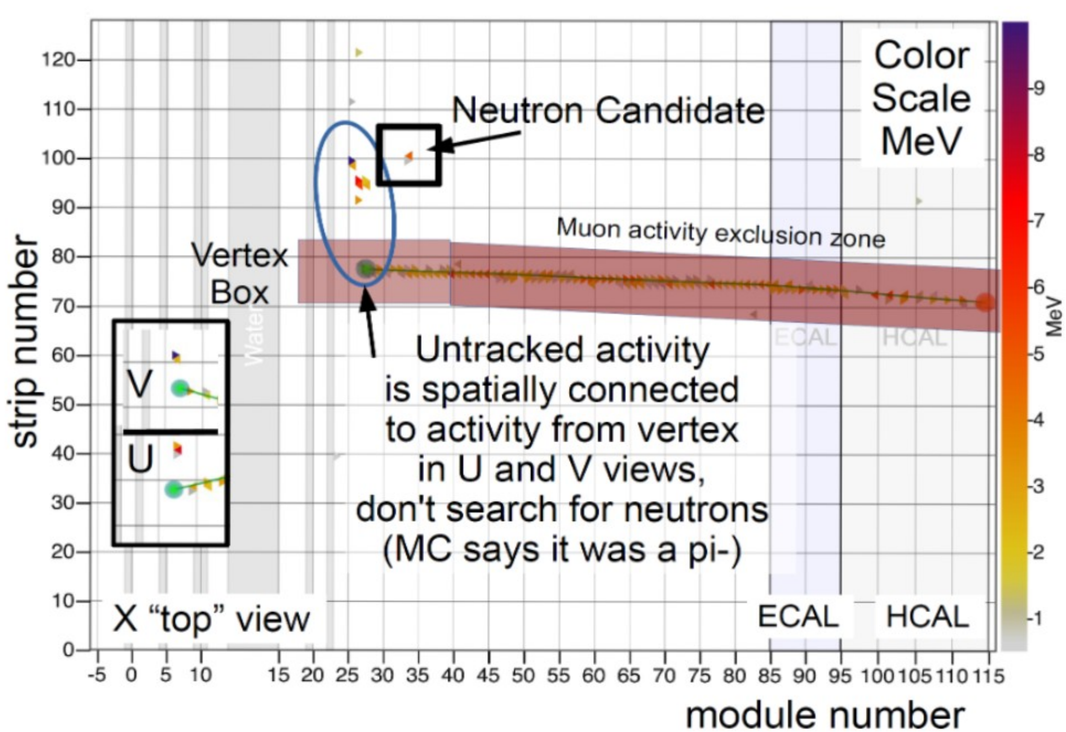
- 3DST spectral measurement much more sensitive to the beam condition changes

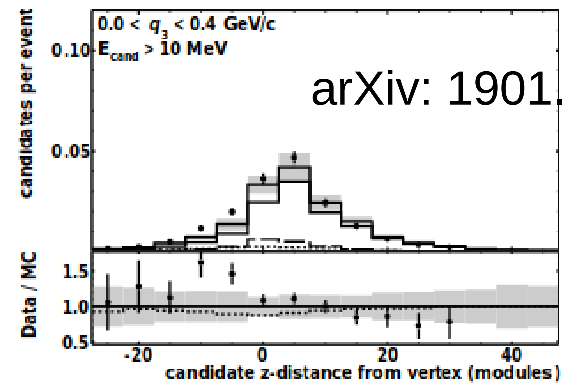
Needs an update!

	Parameter description		Significance, $\sqrt{\chi^2}$	
Beam parameter	Nominal	Changed	Rate-only monitor	SAND
proton target density	1.71 g/cm^3	1.74 g/cm^3	1.9	7.8
proton beam width	2.7 mm	2.8 mm	3.0	6.7
proton beam offset x	N/A	-0.45 mm	0.7	19.9
proton beam $\theta\phi$	N/A	0.07 mrad θ and 1.5707 ϕ	0.2	12.5
horn 1 along x	N/A	0.5 mm	1.9	8.8
horn 1 along y	N/A	0.5 mm	0.7	12.8
horn 2 along x	N/A	0.5 mm	0.2	9.9
horn 2 along y	N/A	0.5 mm	0.4	6.3

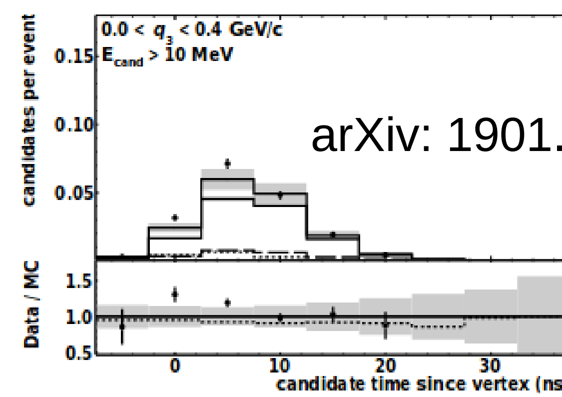
Neutron detection in Minerva

- Minerva sees neutrons.
- Neutron multiplicity, energy and spatial distributions, timing all fairly well described by simulation in Minerva.





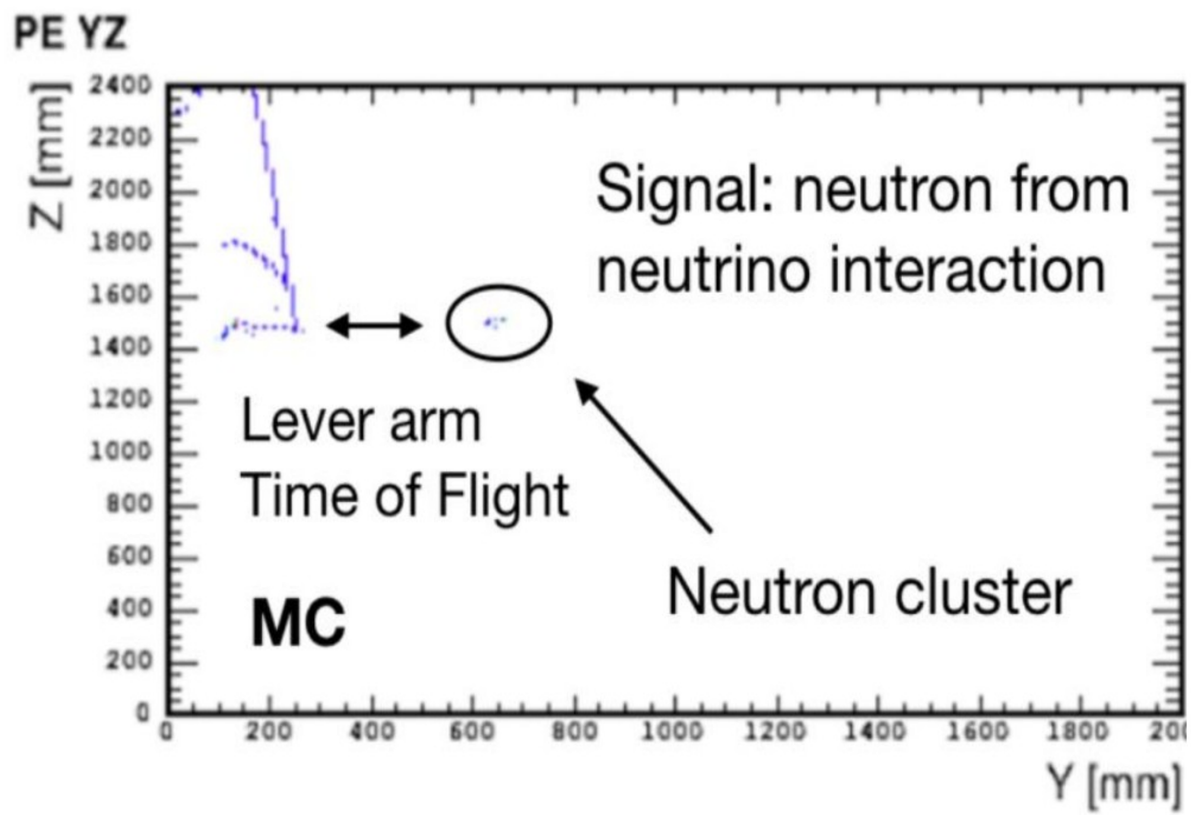
arXiv: 1901.04892



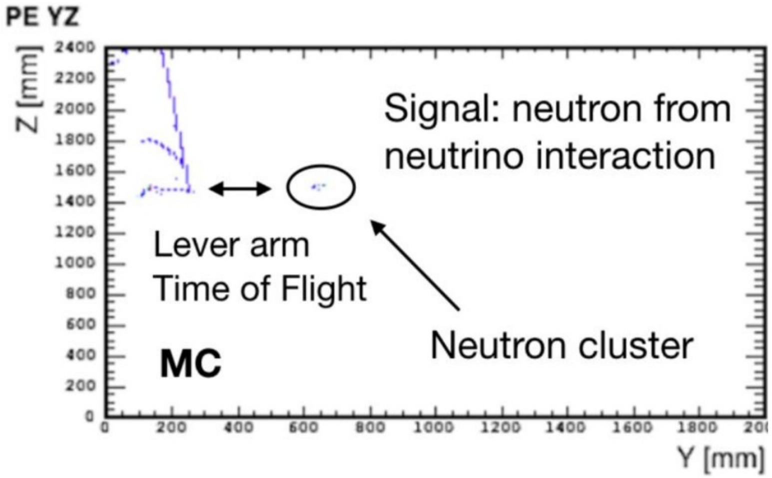
arXiv: 1901.04892

Neutron detection in 3DST

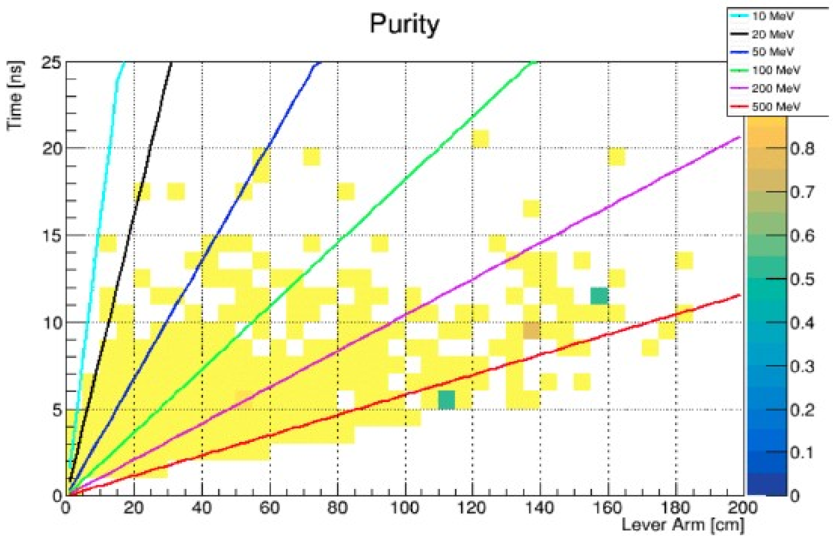
- Neutron is the last and important piece to fully reconstruct the neutrino energy
- With super good time resolution, time-of-flight can be used to measure the neutron kinetic energy.
- Thus, we can do flux constraint and cross section model tuning with this neutron energy measurement.

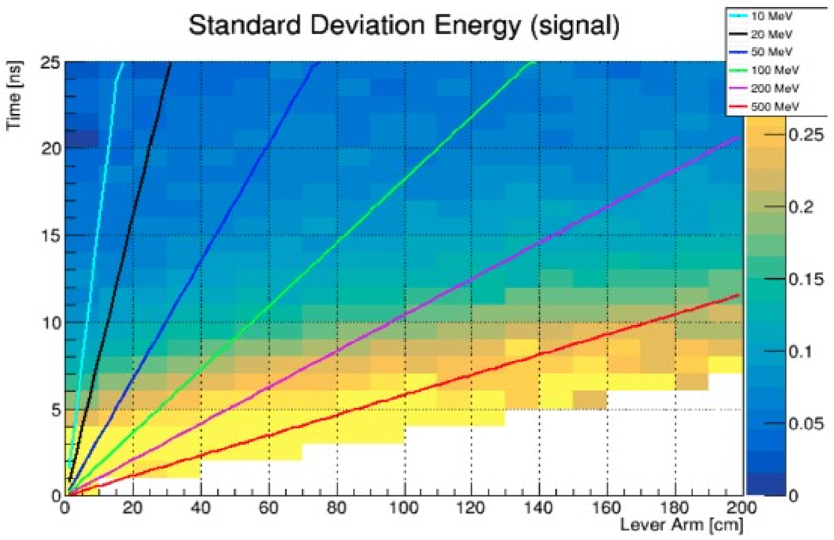


Neutron detection in 3DST



- Out-of-FV background is below 2% due to the tight time cut
- Secondary neutron and gamma background is being studied
- Signal neutron energy resolution mostly at 20-30% level

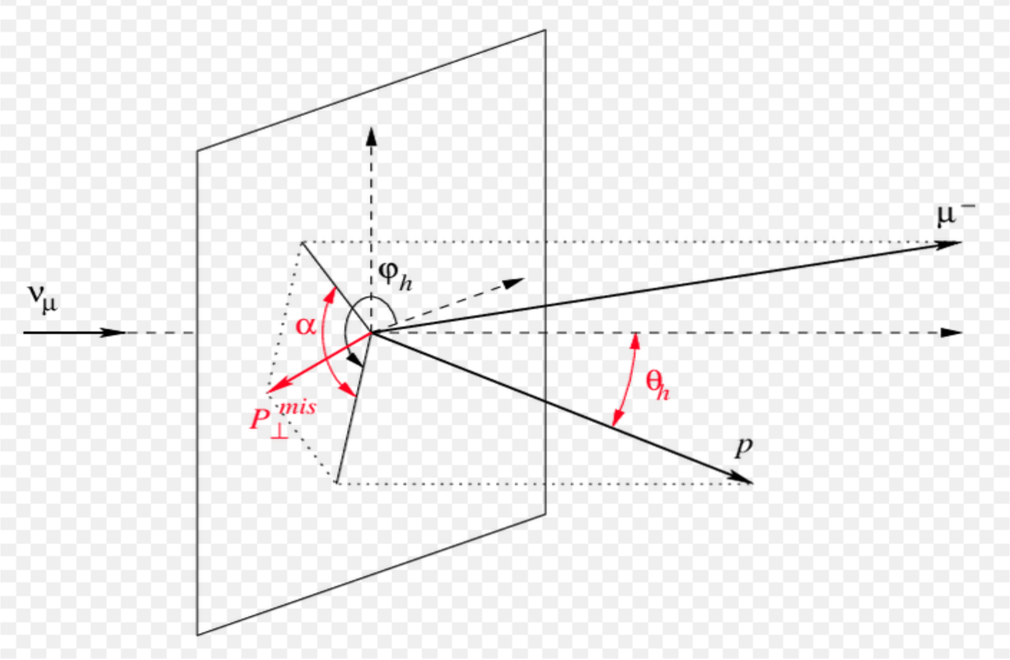


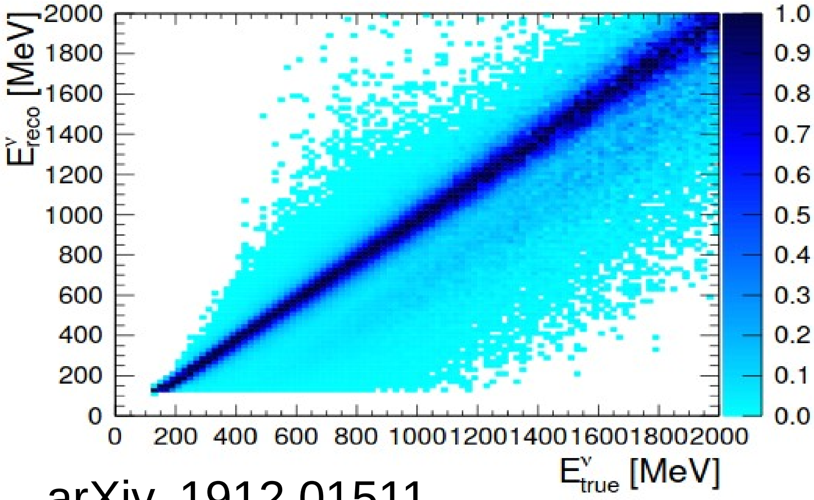


Stony Brook University

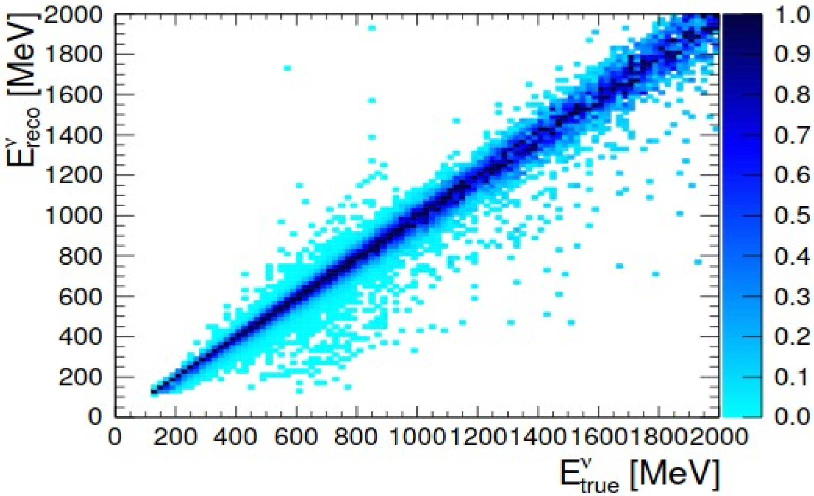
Flux constraint – Single transverse variable

- Single transverse variable (dpt) cut provides a less-FSI sample.
- Selecting CC0pi as a demonstrator; can potential do single pion channels as well.



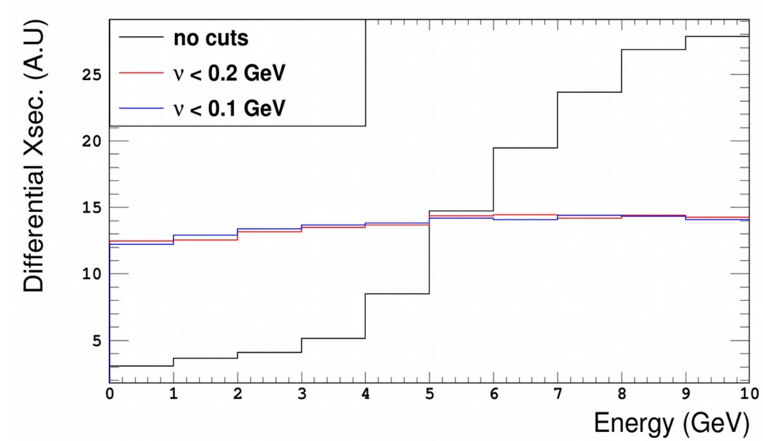


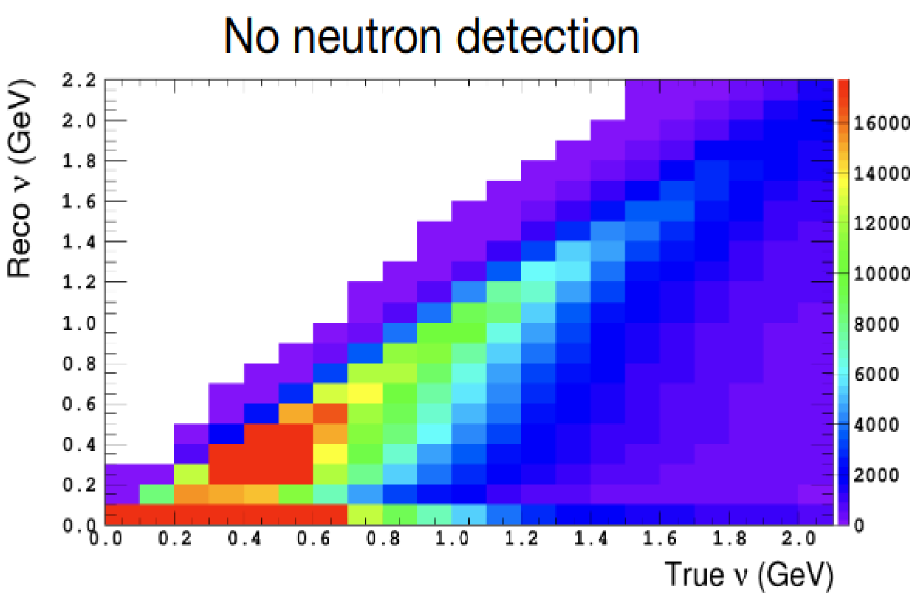
arXiv. 1912.01511

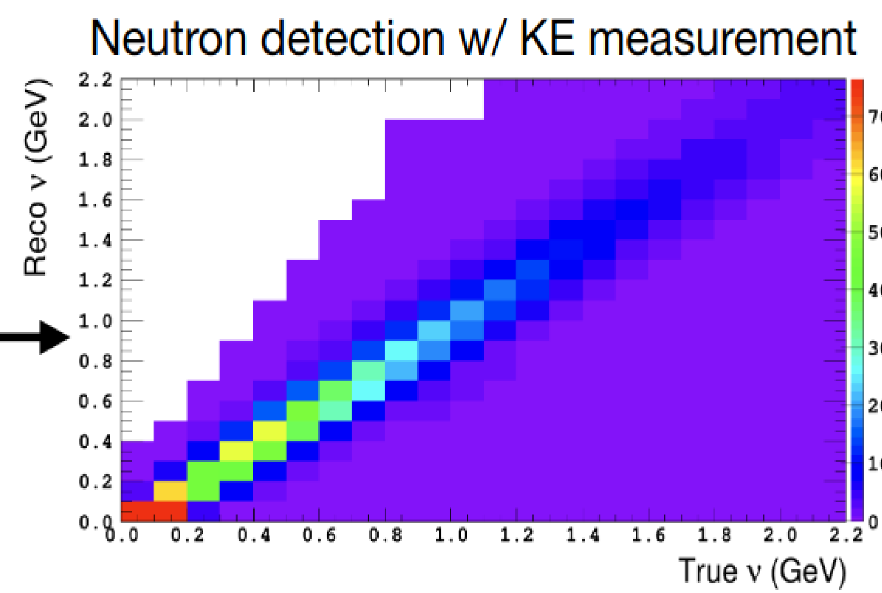


Flux constraint – low nu

- Here nu defined as energy transferred to the nucleus
- Low nu cross section is flat along neutrino energy → flux shape info. can be constrained.



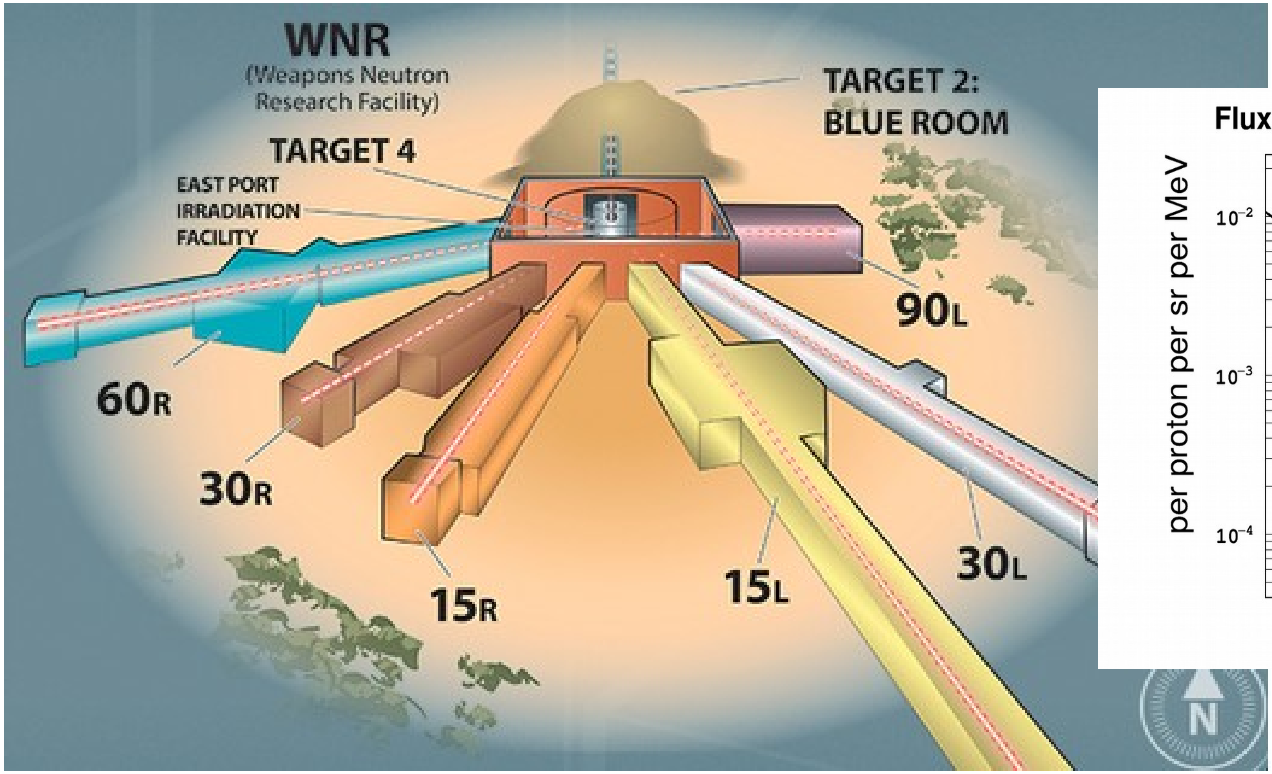


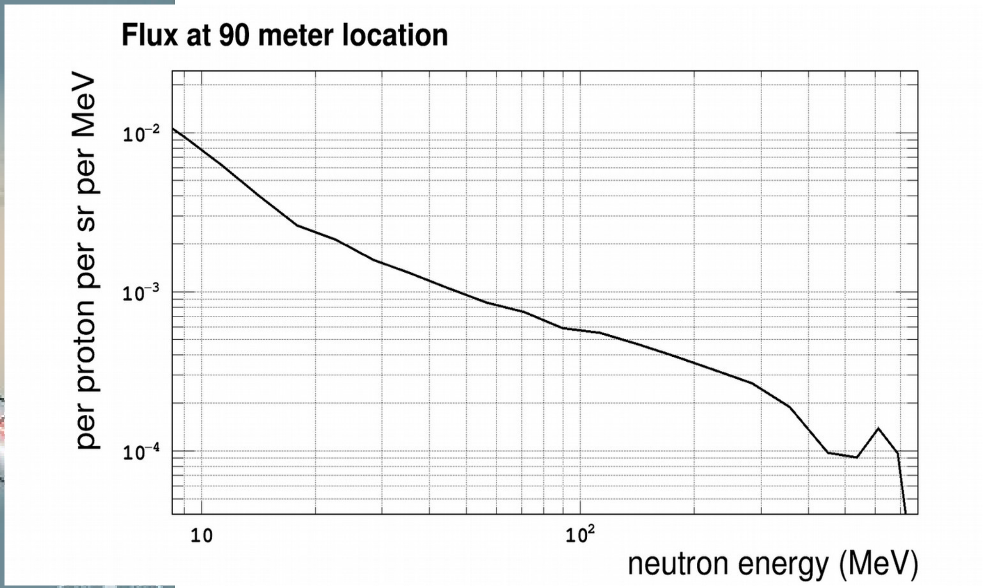


Neutron beam test

- Los Alamos National Laboratory provides neutron beam ranged from 0 -800 MeV
- We have two run time: ~ 3 weeks at 15L 90 m location

  ~ 3 days at 15R 20 m location

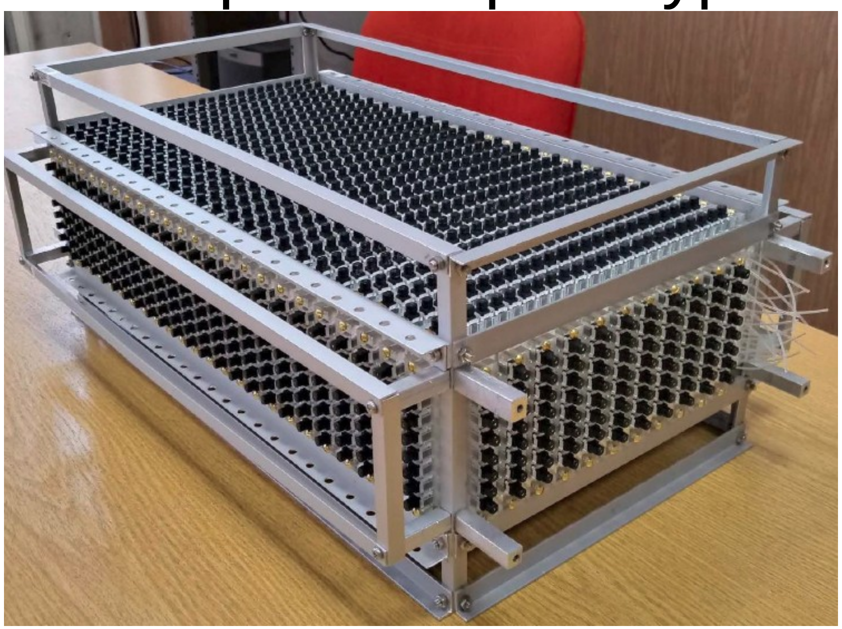




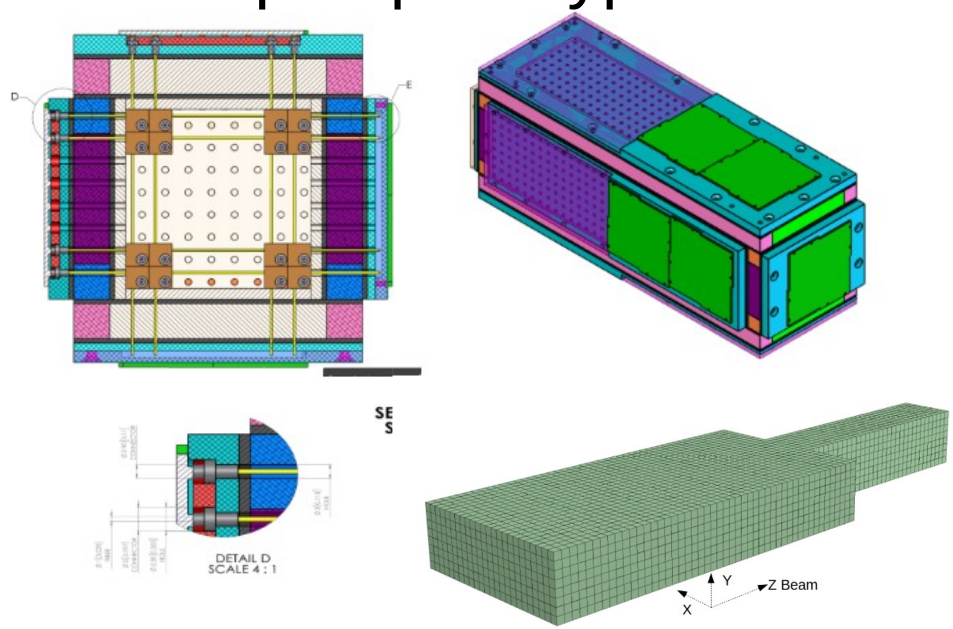
Two prototypes

- SuperFGD prototype being used for the charged particle beam test in CERN (24x8 48)
- US-Japan prototype uses some new designs that will be used in the T2K upgrade, probably 3DST (8x8x32)
- They can be combined in a number of ways

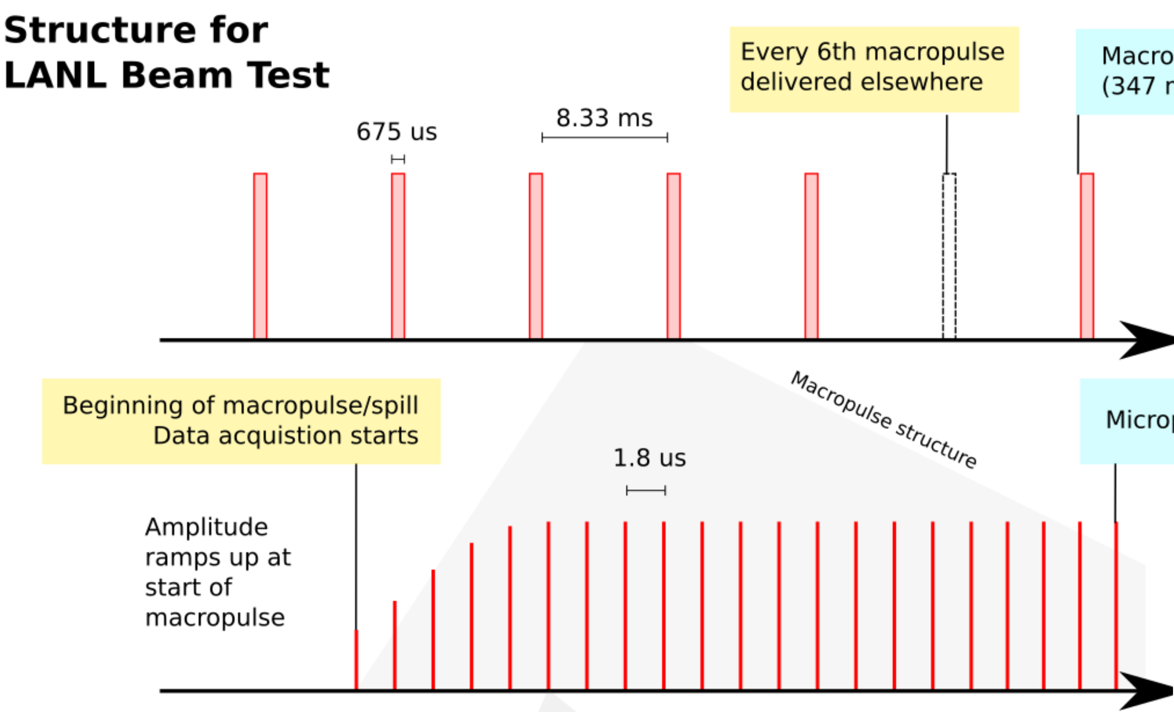
SuperFGD prototype



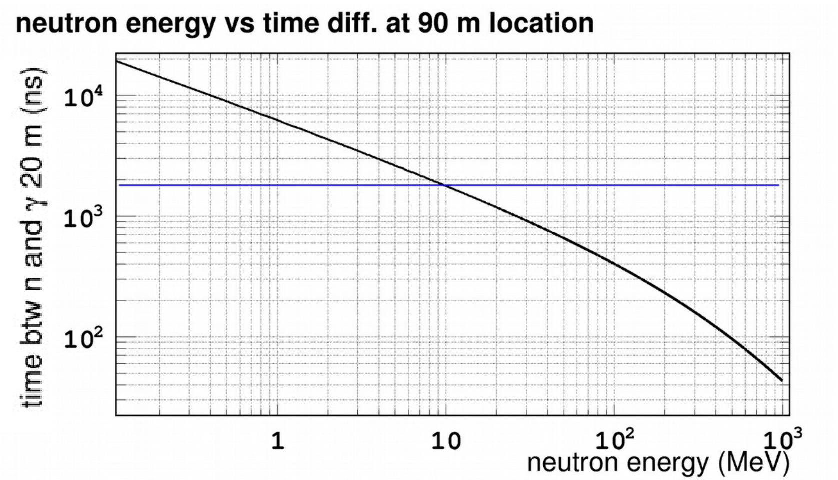
US-Japan prototype



Neutron beam time structure



- We have 675 us trigger window to cover each macropulse
- Gamma flash + micropulse t0 are available



- Wrap-around can be handled with cut on low energy deposit
- Statistically wrap-around is not significant

Run plan

- Our data rate is several kHz at 90 m location
- 20 m location is higher with larger solid angle and slightly smaller collimator setting
- SFGD prototype:

  - 90 m for 16 days : z axis aligned with beam 10 days

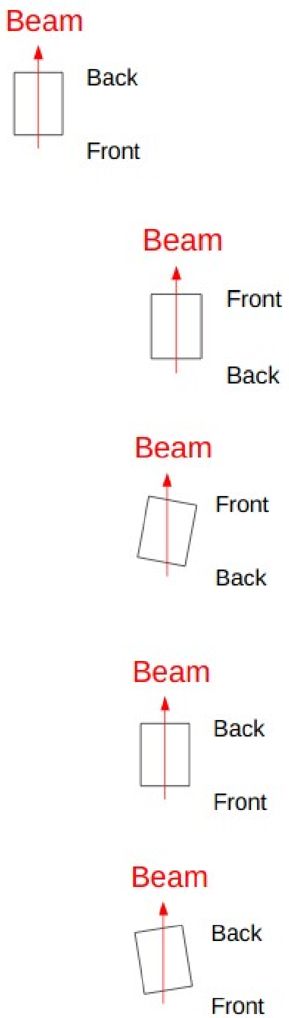
    rotated 180 about y for 4 days

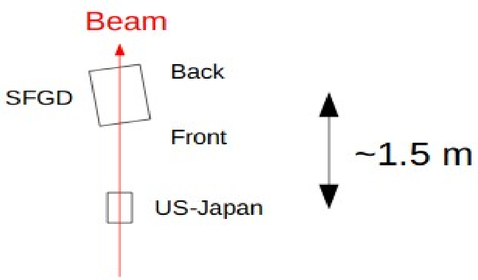
    rotated another 10 for 2 days

  - 20 m for 5 days: z axis aligned for half a day

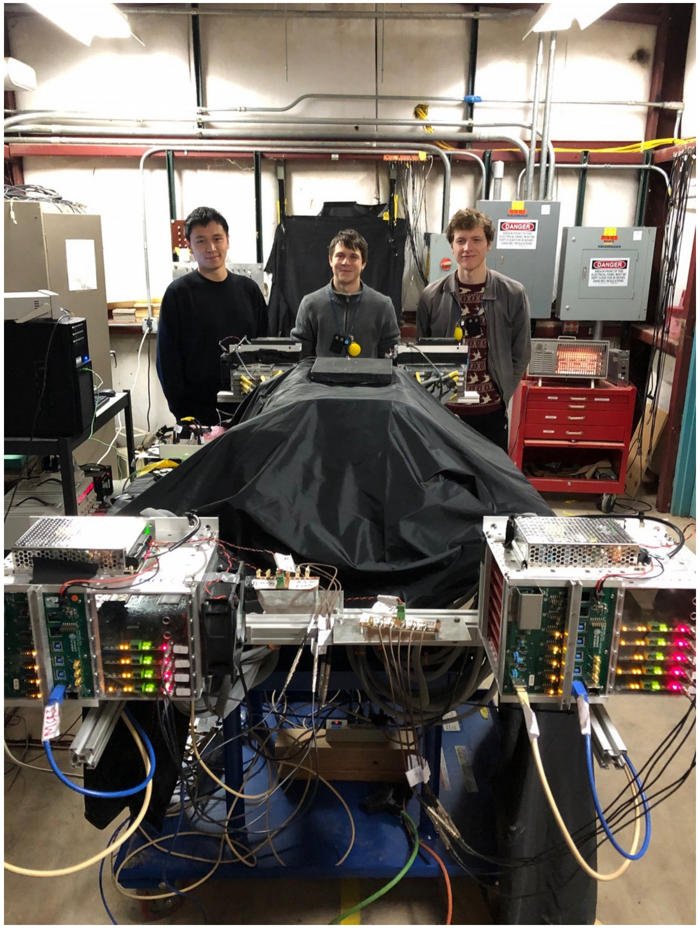
    rotated 5 for 4 and a half days
- US-Japan prototype:

  - 20 m for 4 hours : rotated 5 clockwise





SuperFGD at 90 m location



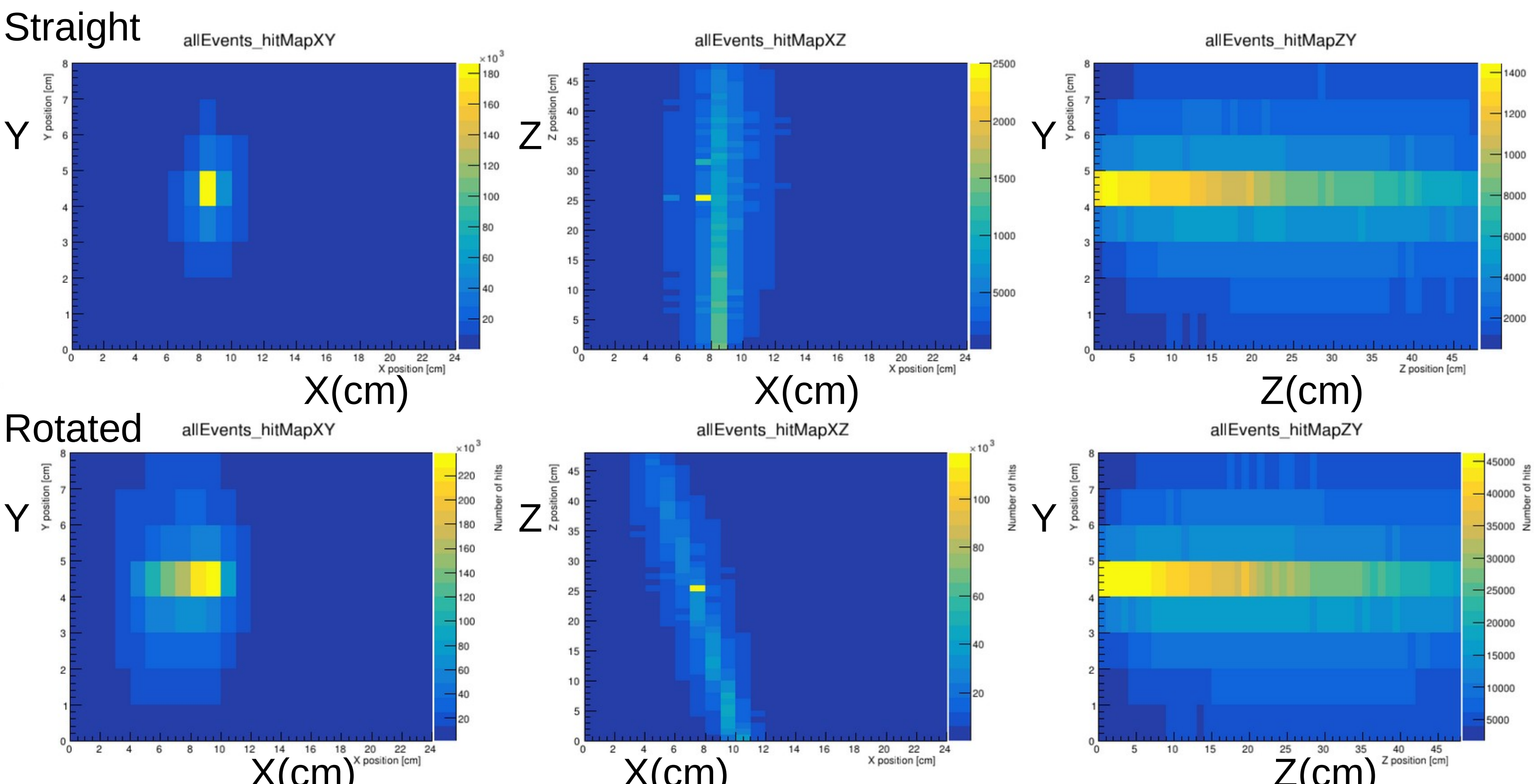
- SuperFGD prototype in the 90 m shed

US-Japan prototype

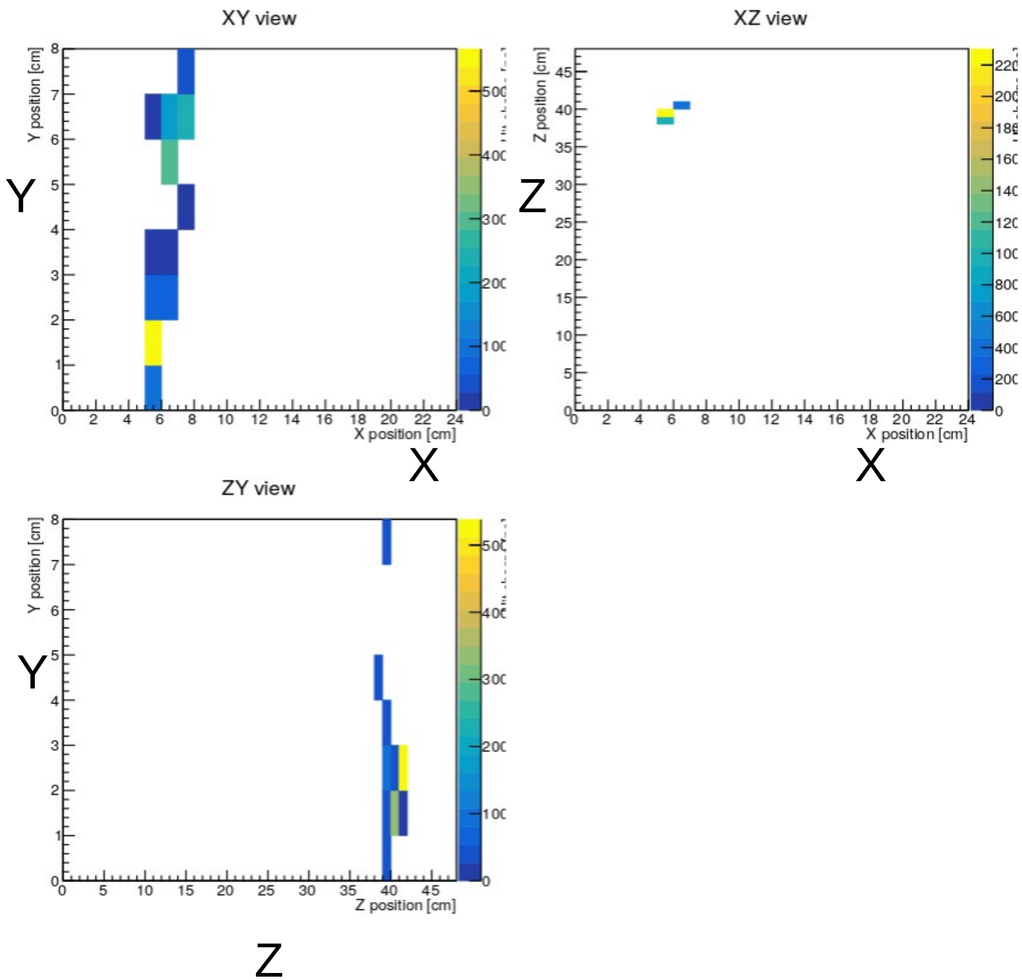
- 8x8x32 with novel mechanical box and MPPC; same FEBs to superFGD prototype

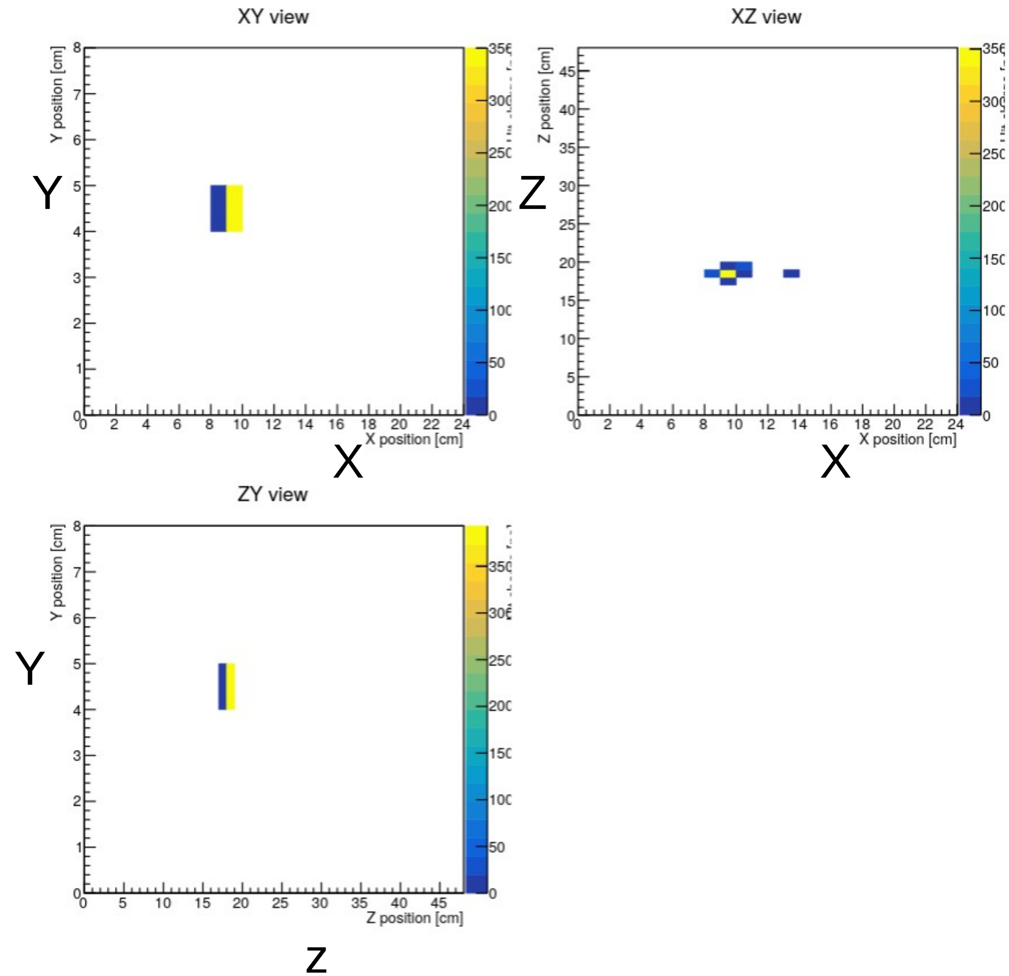
Event topology

- We rotated detector for various angles to understand the fiber/MPPC behaviour

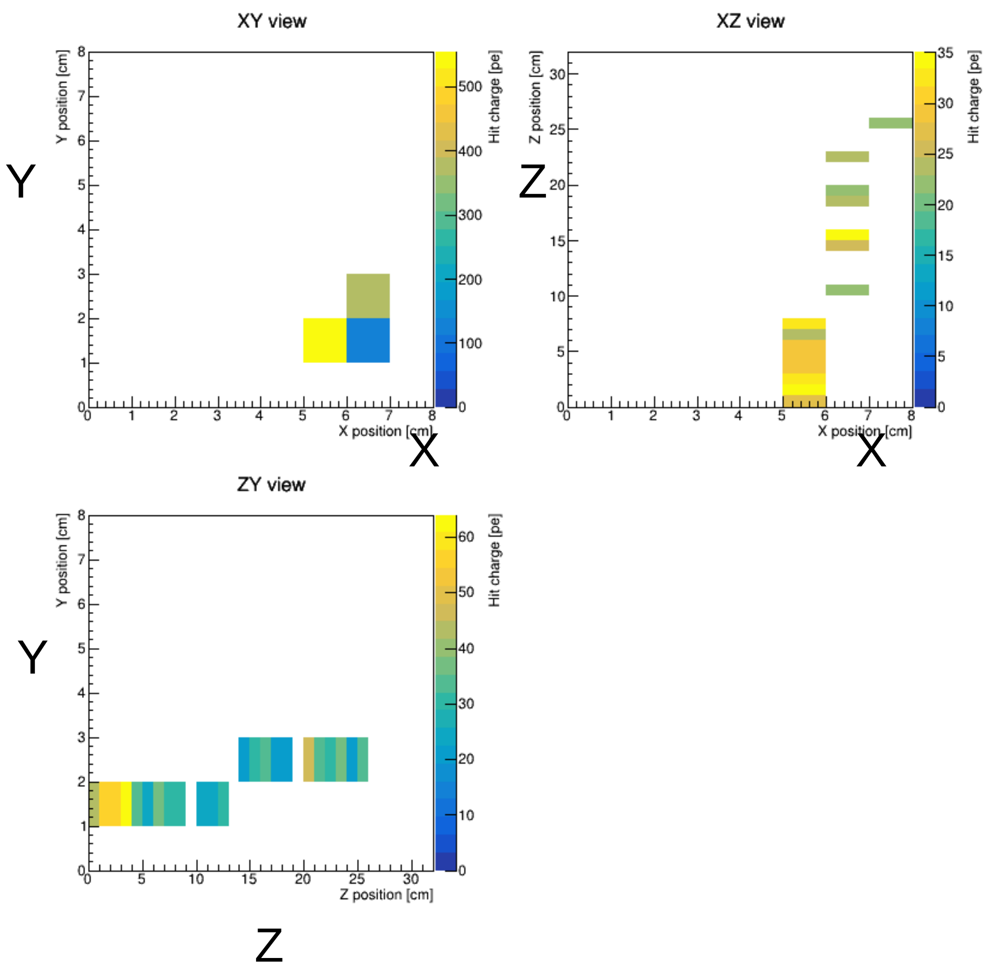


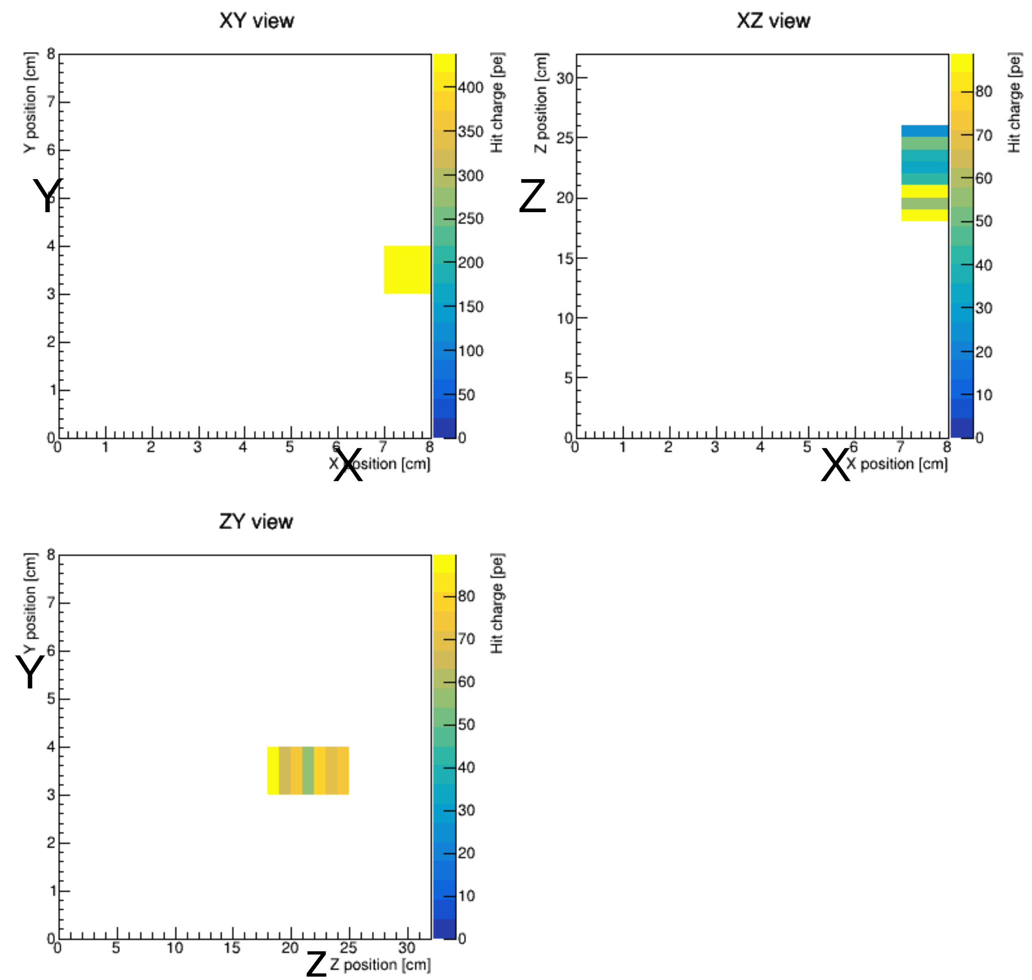
Some event displays



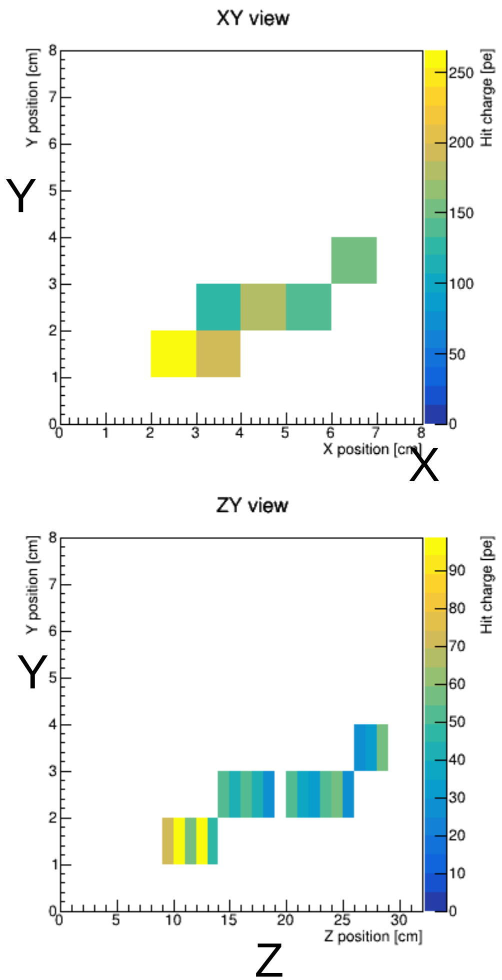


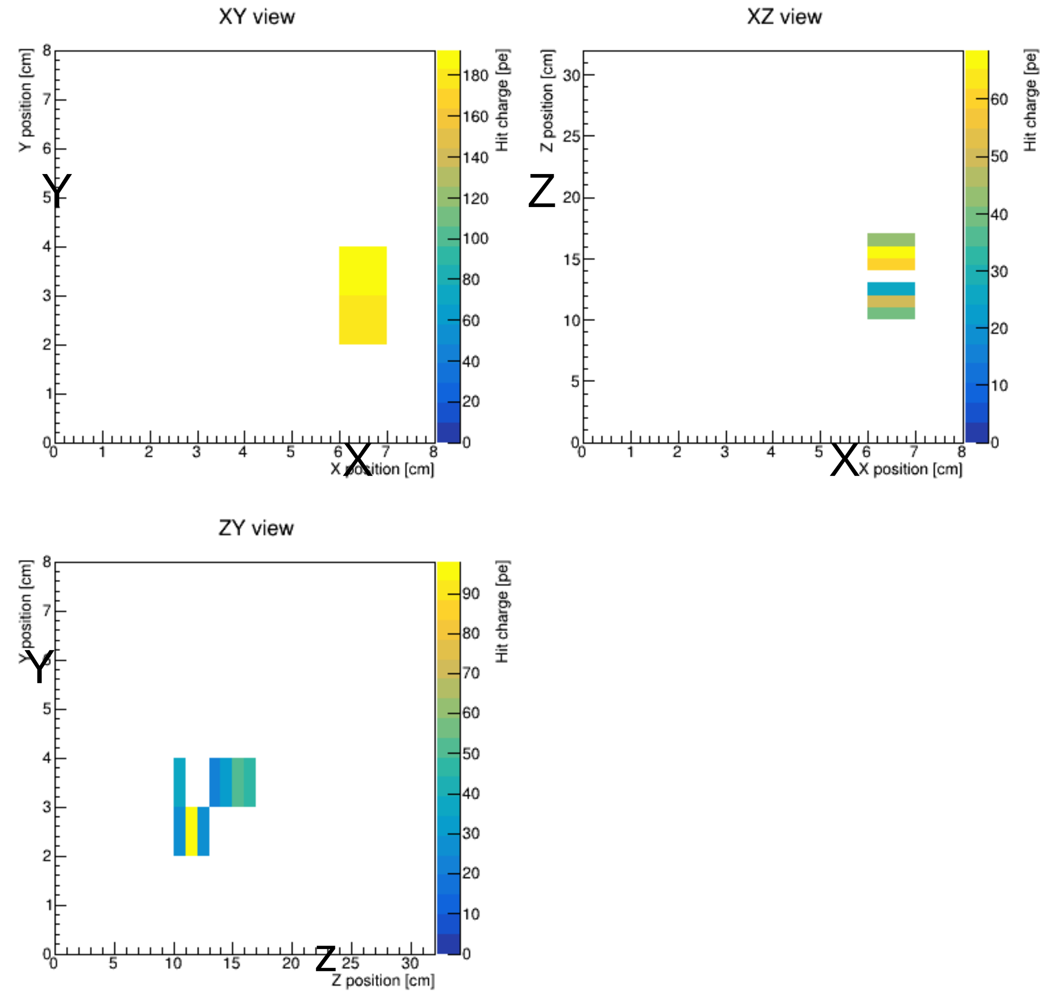
US-Japan Neutron candidates





US-Japan Neutron candidates



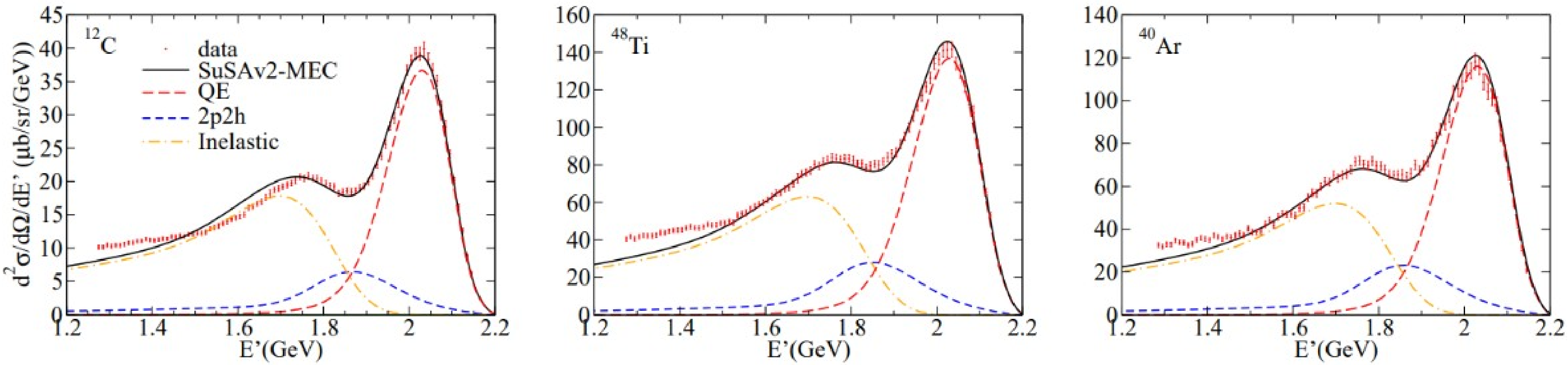


Tuning xsec model

- Models that moves beyond simple Fermi-gas approximations on the timescale of DUNE are expected: An example is the Relativistic Mean Field (RMF) model

  https://arxiv.org/pdf/nucl-th/9905060.pdf

- RMF calculates interaction cross section on different nuclear targets in the same framework using the same physics
- Working great with electron scattering data



Out-going electron energy (GeV)

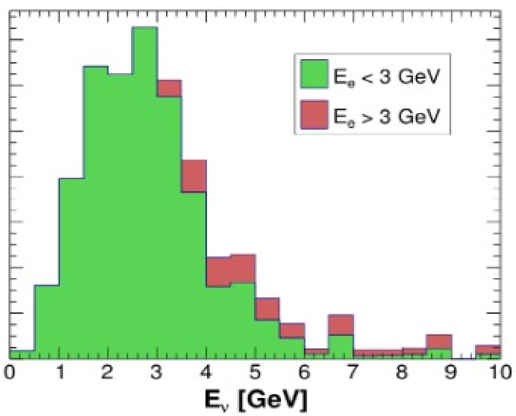
Summary

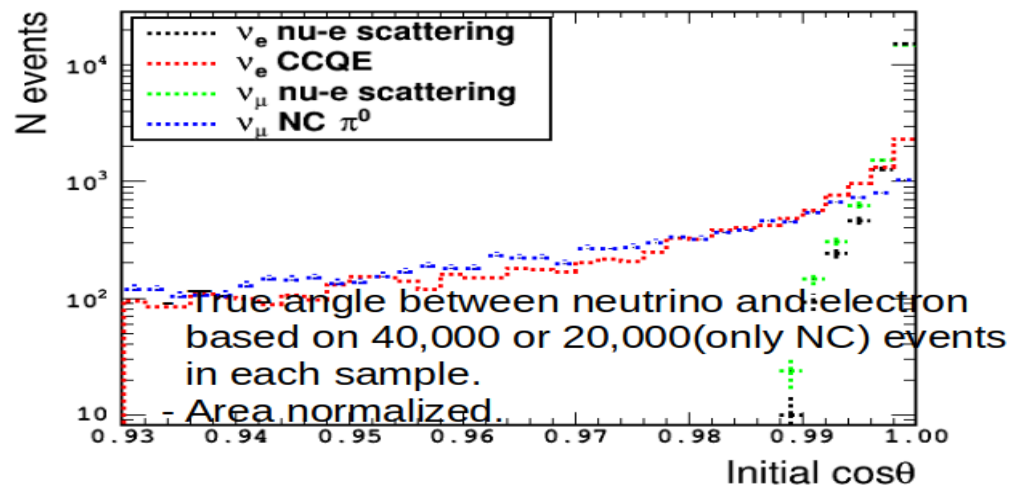
- 3DST is a fully active 4pi target that can serve as a nice neutrino beam monitor.
- Neutron detection is unprecedented in 3DST.
- 3DST provides a unique target to tune the neutrino interaction models.

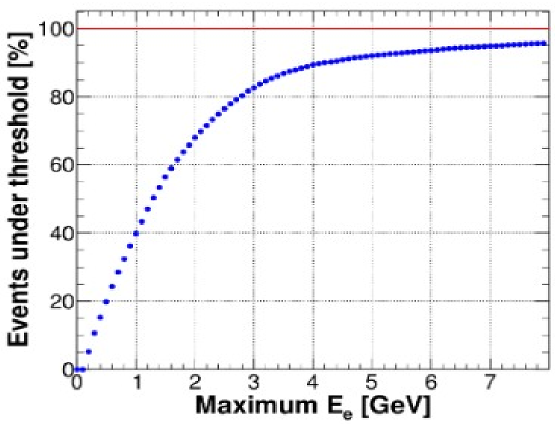
Backups

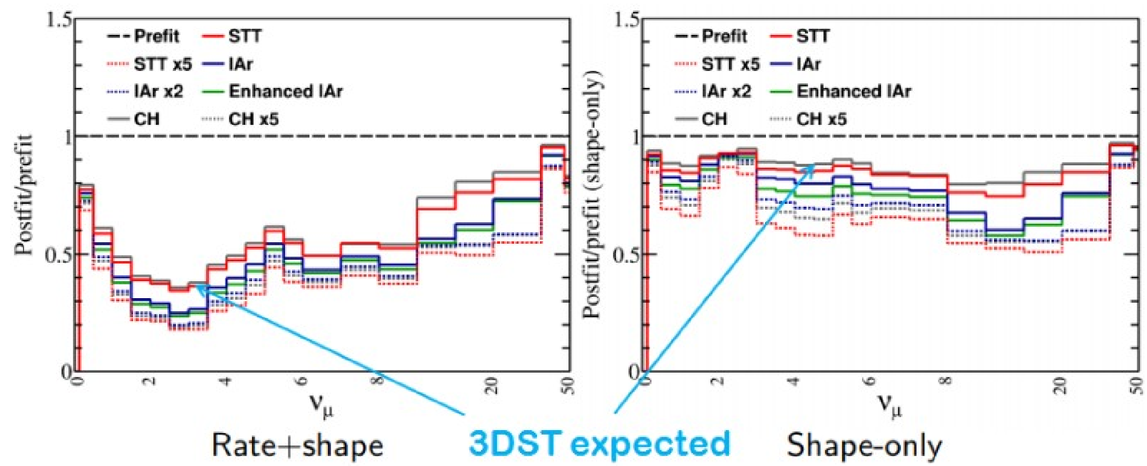
3DST performance

- Good angular resolution let 3DST having good ability to do neutrino-electron scattering. Not full electron containment might be still fine for this channel



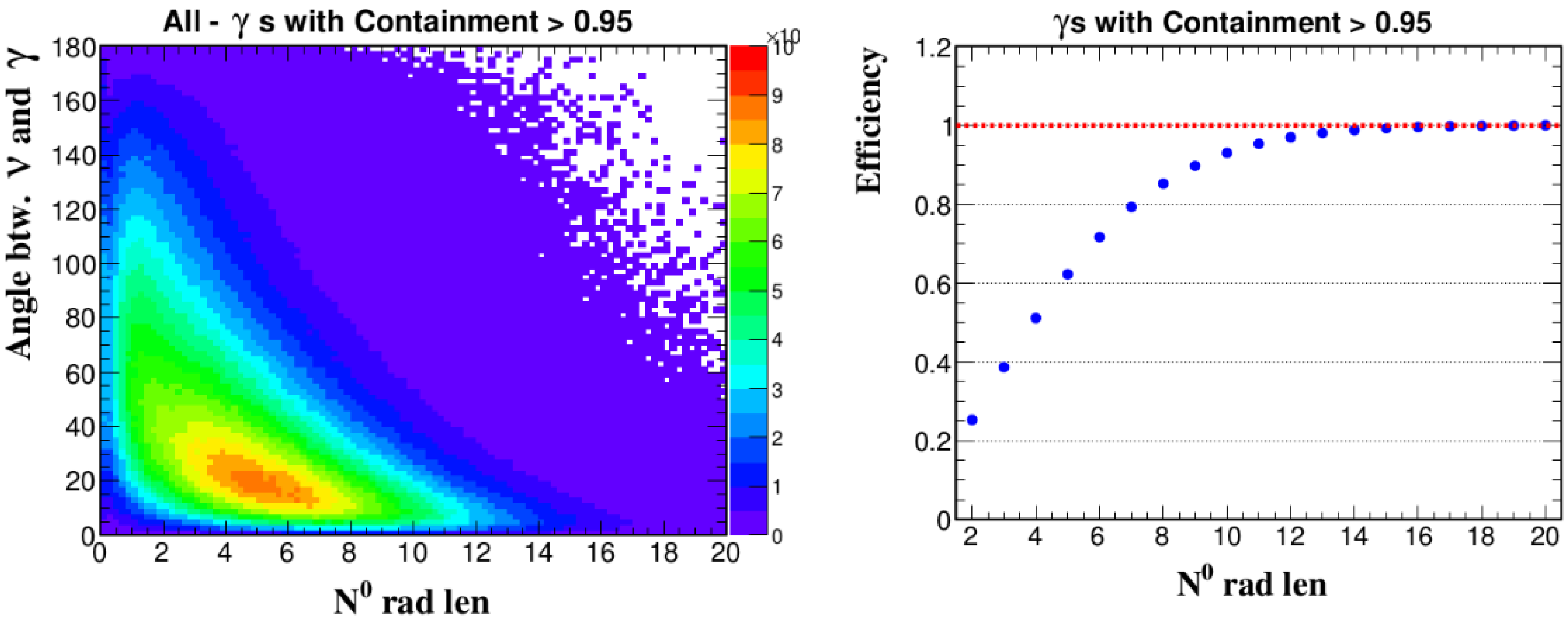






3DST performance

- Radiation length ~ 40 cm, for all pi0 and electron containment, may need downstream or side ECALs.
- 2 m depth 3DST contains 60% pi0 which deposits > 95% energy.



3DST performance

- Few percent resolution can be achieved for contained electrons.
- 15%-20% track momentum resolution with 0.4 T B-field in interested energy region.
- Good charge ID for tracks below 3 GeV.