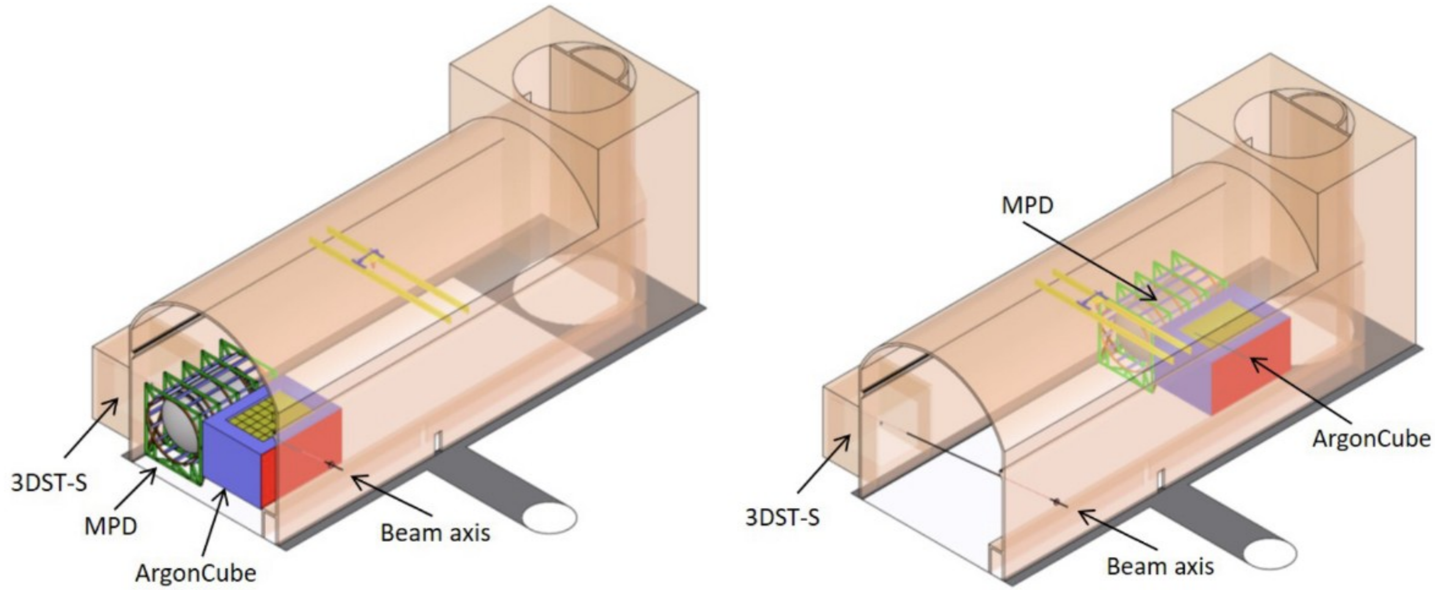
3DST-S as a sub-system in DUNE ND

Guang Yang
On behalf of the DUNE collaboration

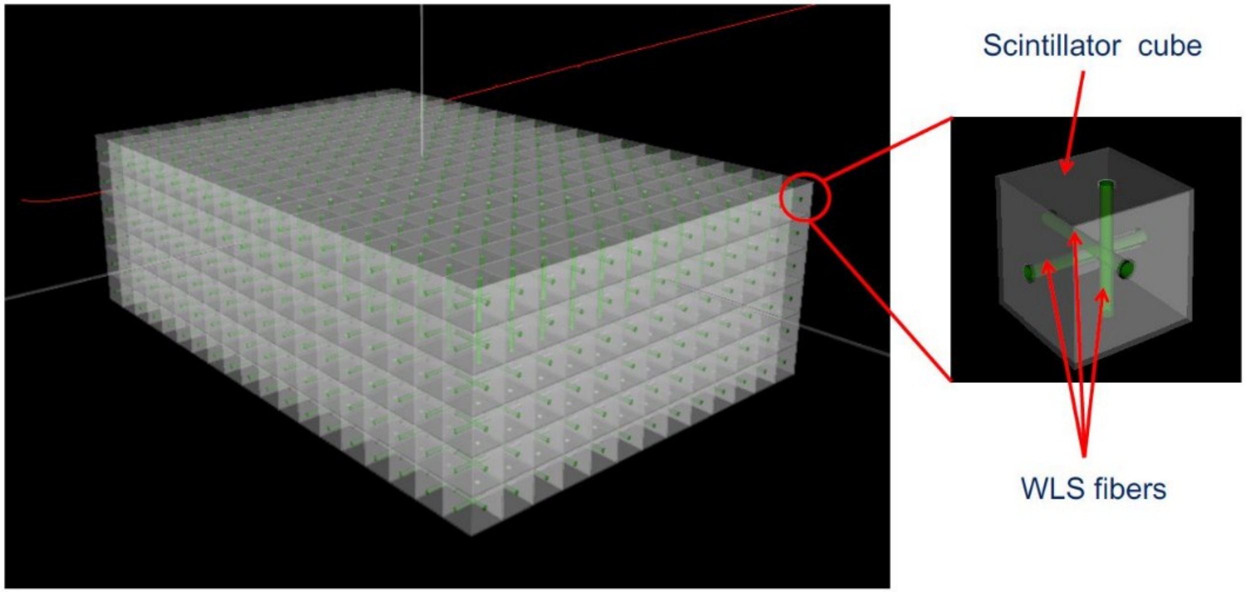
DUNE ND hall

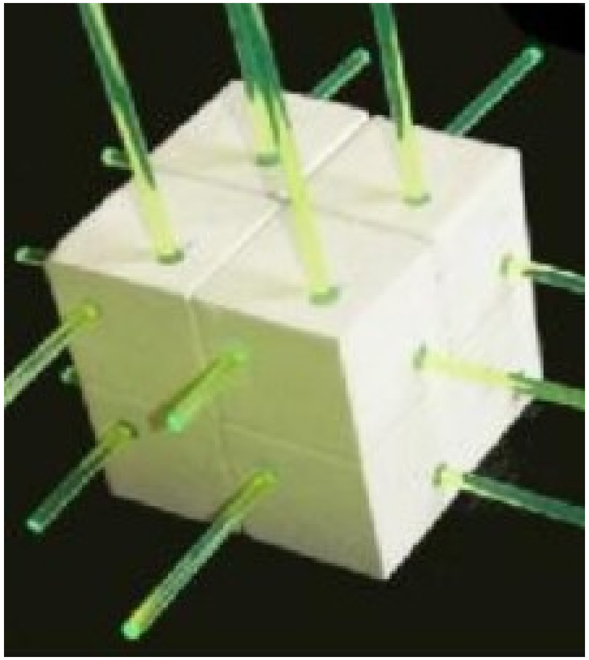


- DUNE ND will consist of a liquid argon detector, a gas argon TPC system which will be surrounded by ECAL and inside a magnetic volume and a 3D projection scintillator tracker.
- DUNE-PRISM is the baseline design.
- DUNE aims at measuring CP violation at five sigma with this ND system.

DUNE ND : 3D projection scintillator tracker (3DST)

- Plastic scintillator detector with 1 cm x 1 cm x 1cm cubes → Fully active
- 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
- Combining with TPC and ECAL, it is named 3DST-S (3DST spectrometer).

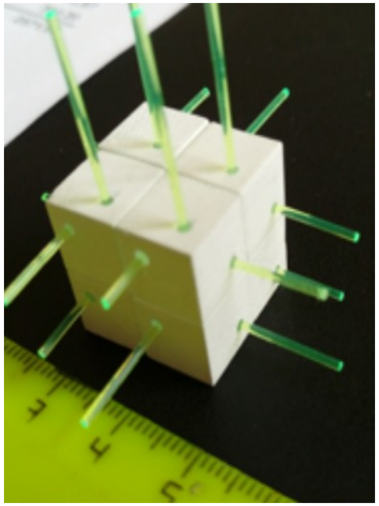


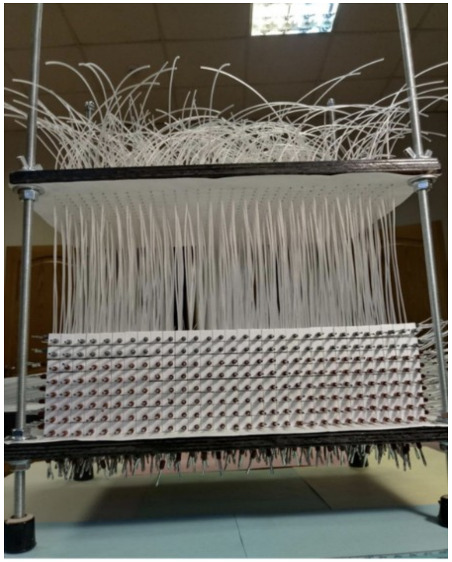


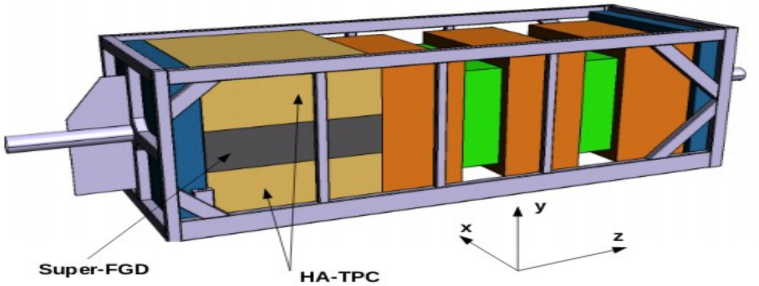
Synergy with T2K upgrade

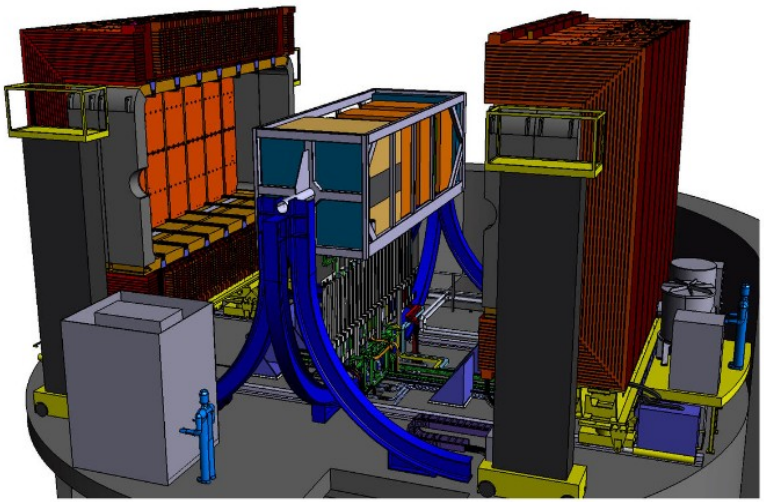
- Functionally identical to the T2K super-FGD in T2K ND280
- Share the effort including hardware and software such as parts production, R&D, neutrino event reconstruction etc.

Super-FGD proto-type
by T2K upgrade group







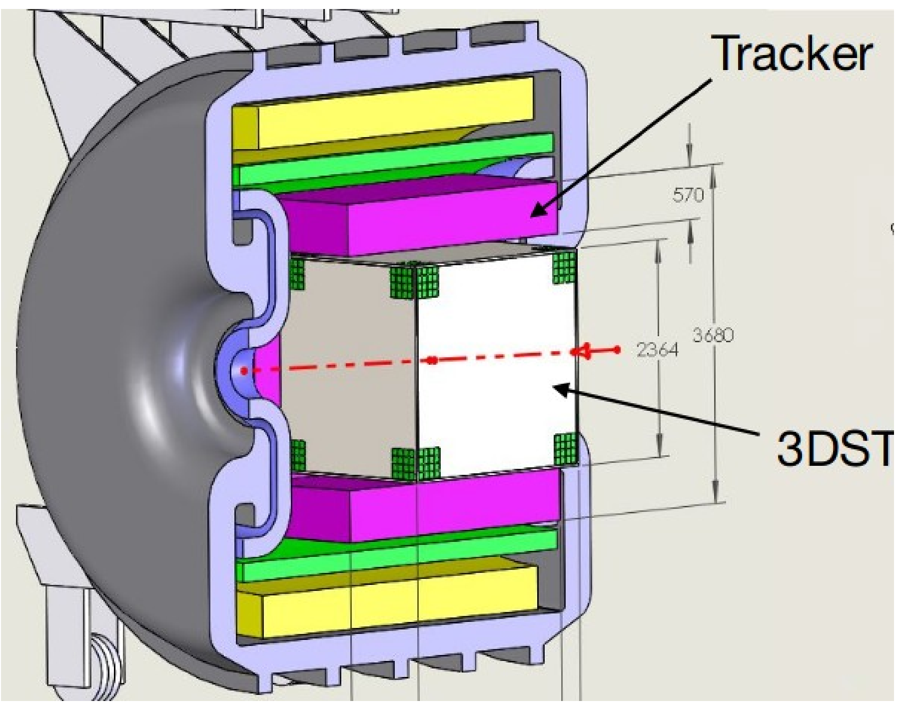


arXiv. 1901.03750

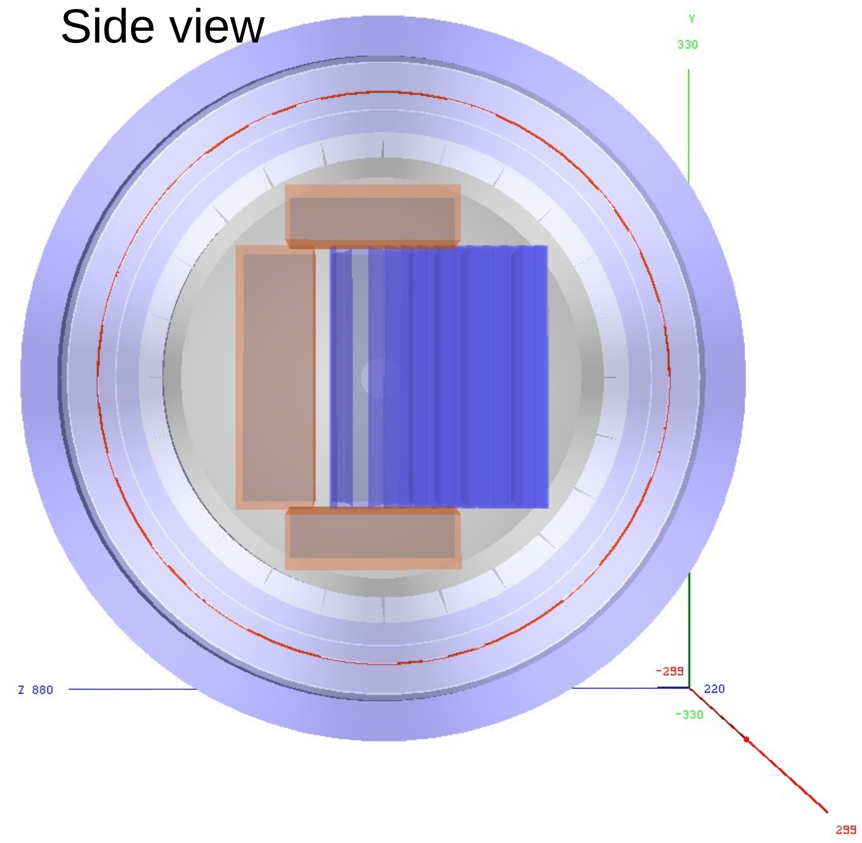
3DST-S

- 3DST-S contains 3DST, TPC and ECAL inside a magnetic field (>0.6 T)

Beam view



Side view



Stony Brook University

Purposes of 3DST

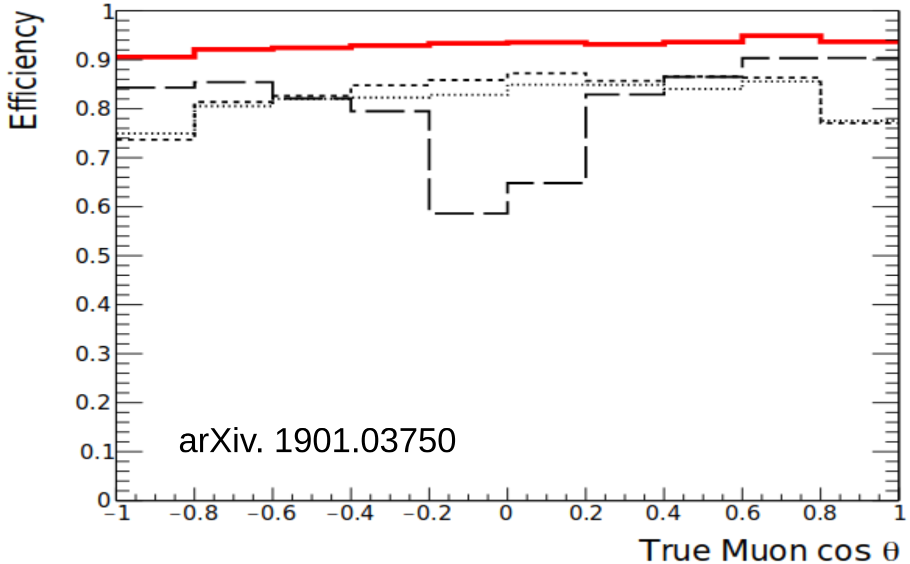
- Beam monitoring:
  - A 2.4m x 2.4m x 2m 3DST can provide daily event rate monitoring with <1% statistical error.
  - As a spectrometer, beam condition changes can be observed in the spectral distortion.
- Neutron tagging and energy measurement: With neutron detection capability, transverse momentum can be used to select hydrogen-enriched samples for both FHC and RHC.
- CH cross section measurement: This measurement can provide us a bridge to the world scintillator cross-section measurements, thus finer tuning the neutrino interaction modeling.

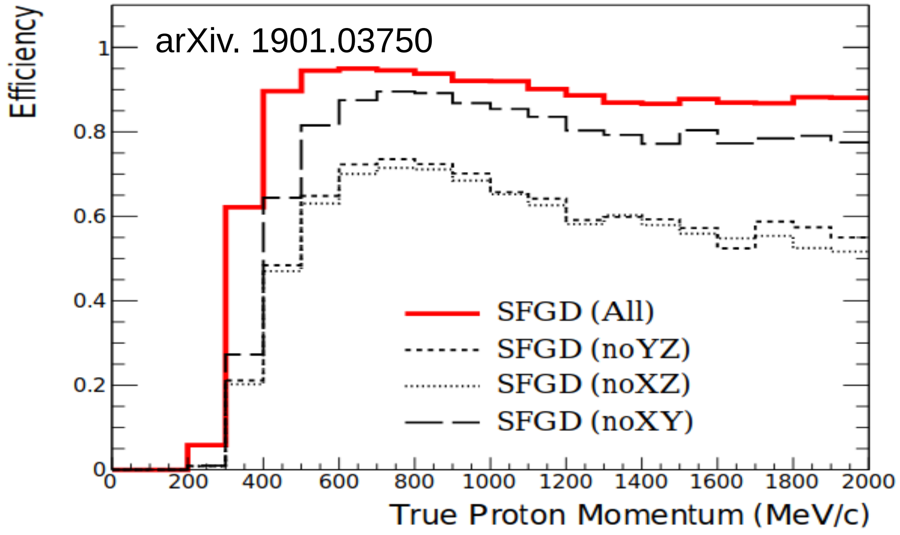
3DST performance

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

For one year

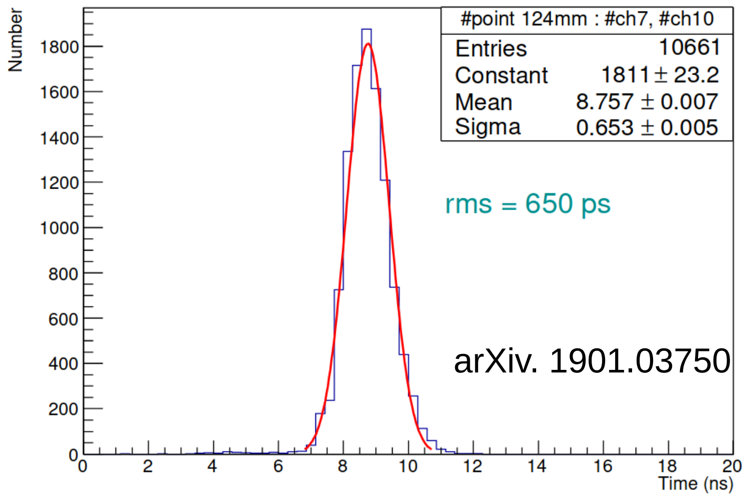
Channel	ν mode	$\bar{\nu}$ mode
ν_μ CC inclusive	13.6×10^6	5.1×10^6
CCQE	2.9×10^6	1.6×10^6
CC π° inclusive	3.8×10^6	0.97×10^6
NC total	4.9×10^6	2.1×10^6
ν_μ-e$^-$ scattering	1067	1008
ν_μ CC coherent	1.26×10^5	8.6×10^4
ν_μ CC low-ν (ν <250 MeV)	1.48×10^6	8.8×10^5
ν_e CC coherent	2.1×10^3	719
ν_e CC low-ν (ν <250 MeV)	2.1×10^4	4.7×10^3
ν_e CC inclusive	2.5×10^5	0.56×10^5

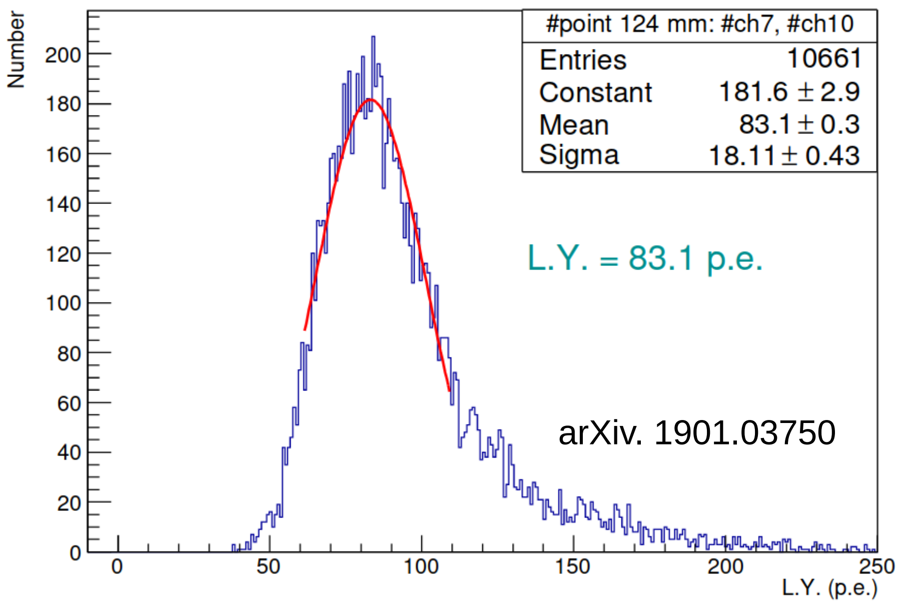


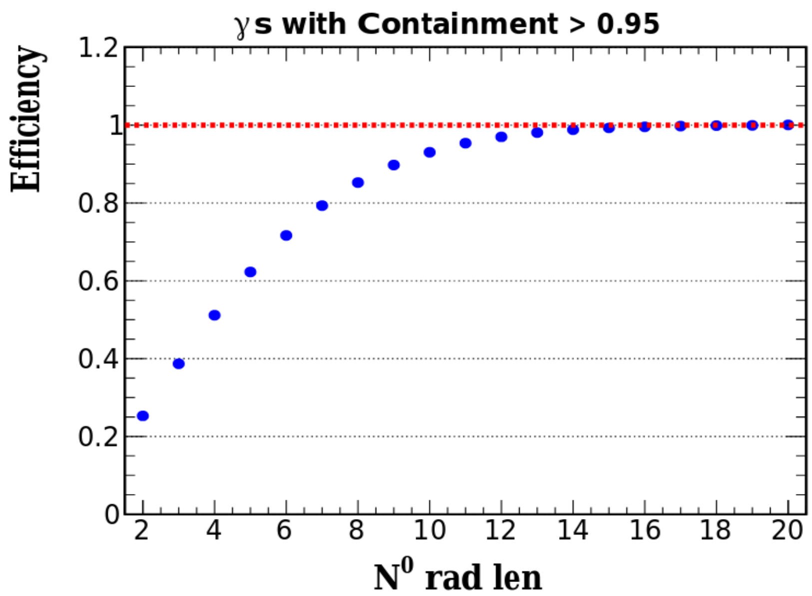


3DST performance

- 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



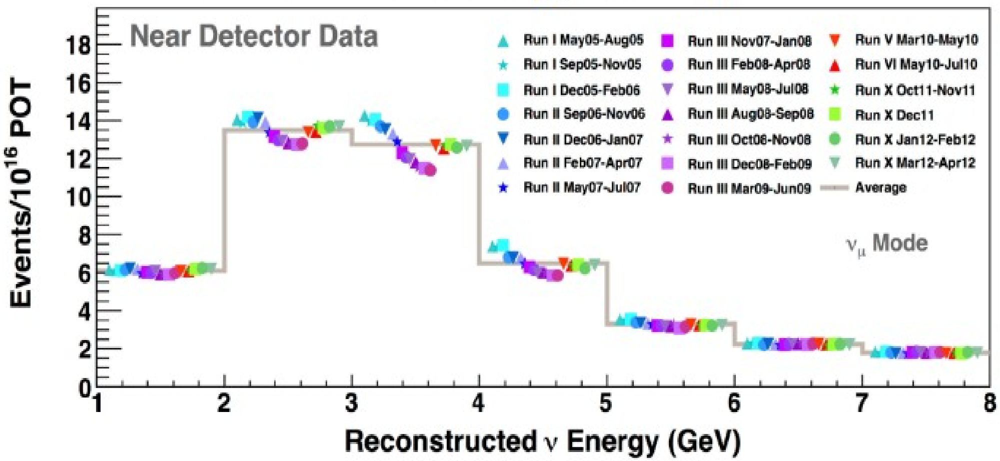




Beam spectrum monitor

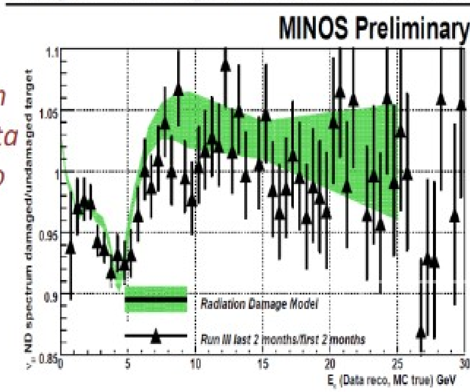
- Beam accidents happened before.

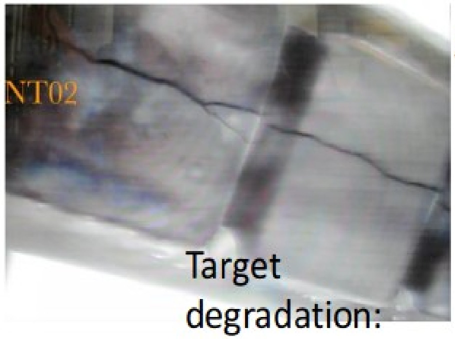
MINOS ND low energy running



Target damage model in FLUKA08

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

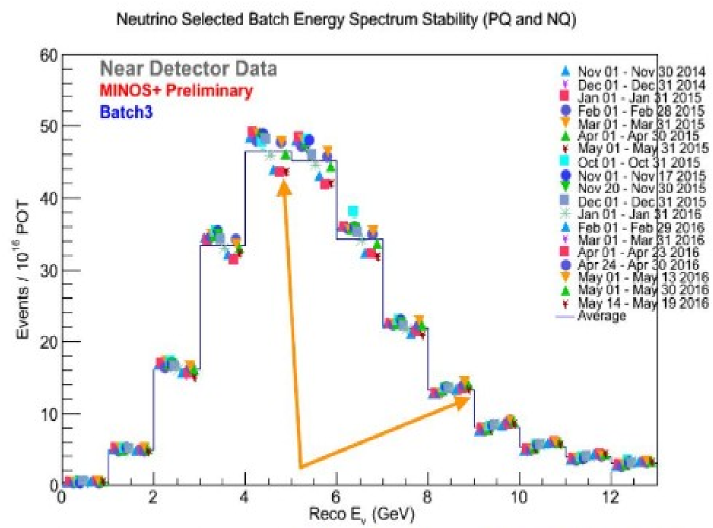




Target degradation: Broken upstream target fins

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

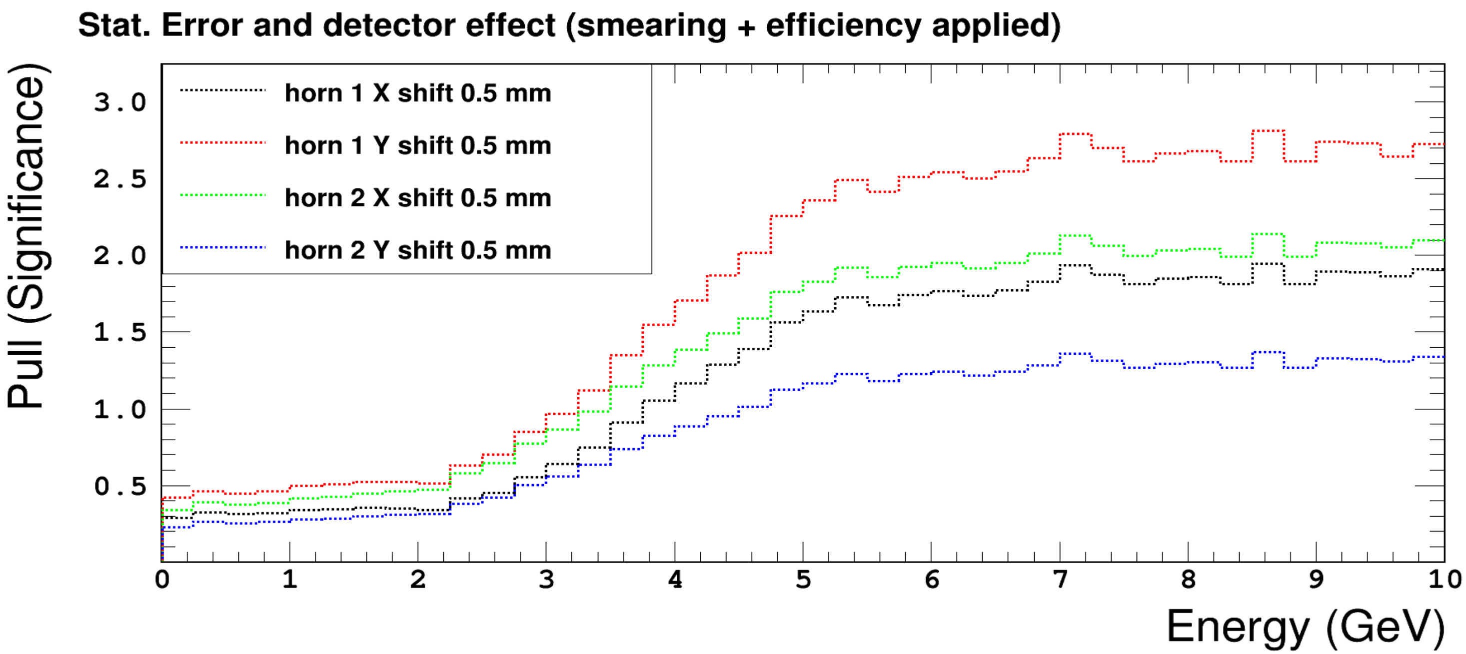
Unexpected horn Tilt discovered by Change in ND flux (due to corroded part)



Jim Hylen, NuMI OPS, Nov 2016

Beam spectrum monitor

- The 3DST has the ability to detect FS particles.
- With the shape measurement over a time period, 3DST is sensitive to beam parameters.
- An example: With only muon energy measurement, 3DST provide good sensitivity to the beam condition changes.
- Major beam variations have been tested.



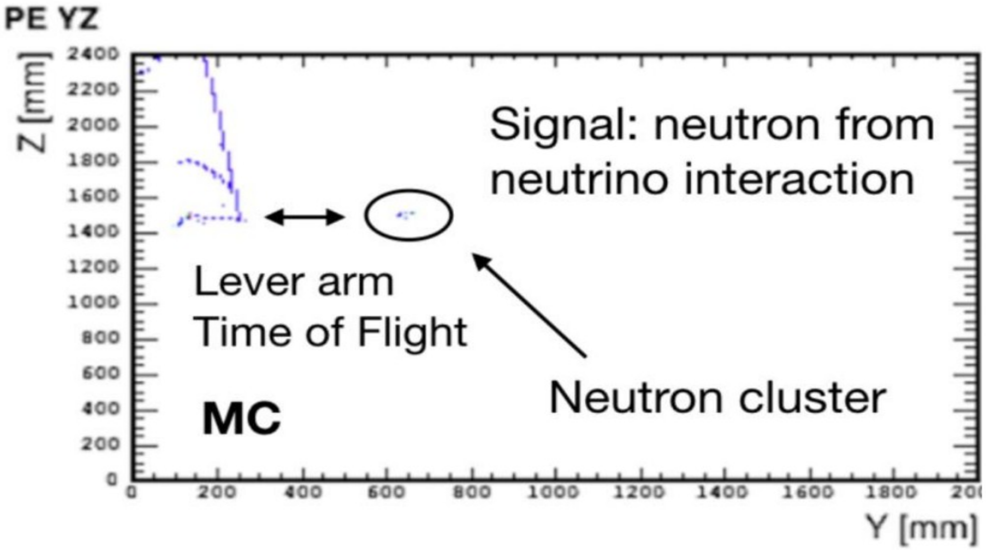
4% muon momentum resolution at 1 GeV

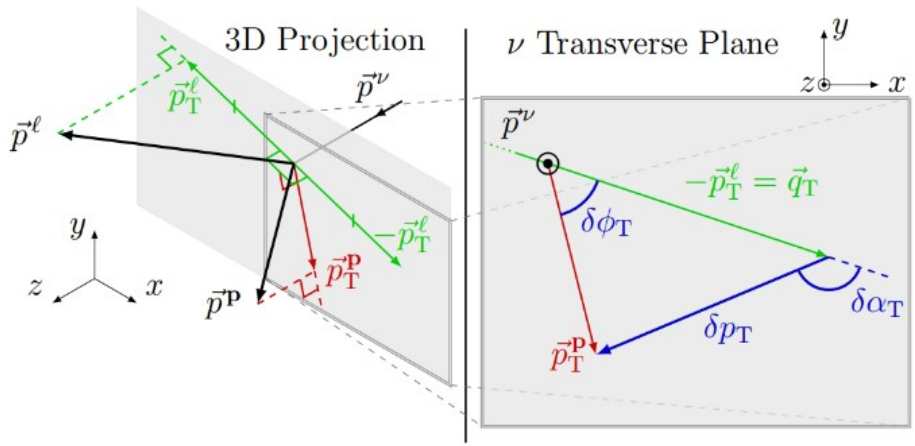
Flux constraint with transverse variable

- Neutron energy can be measured with fast timing.
- Out-of-FV (fiducial volume) background can be controlled.
- With the neutron measurement, both FHC and RHC transverse variables can be measured:

  - tune the model

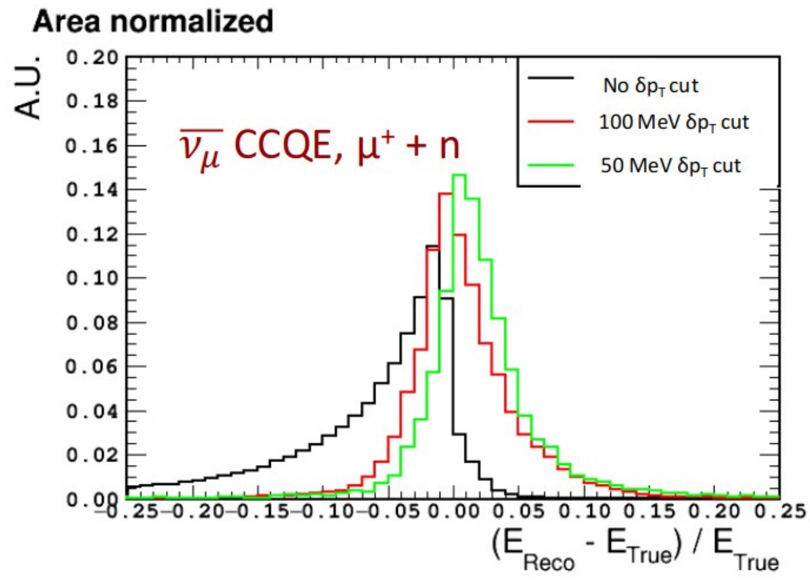
  - select FSI (final state interction) free samples.

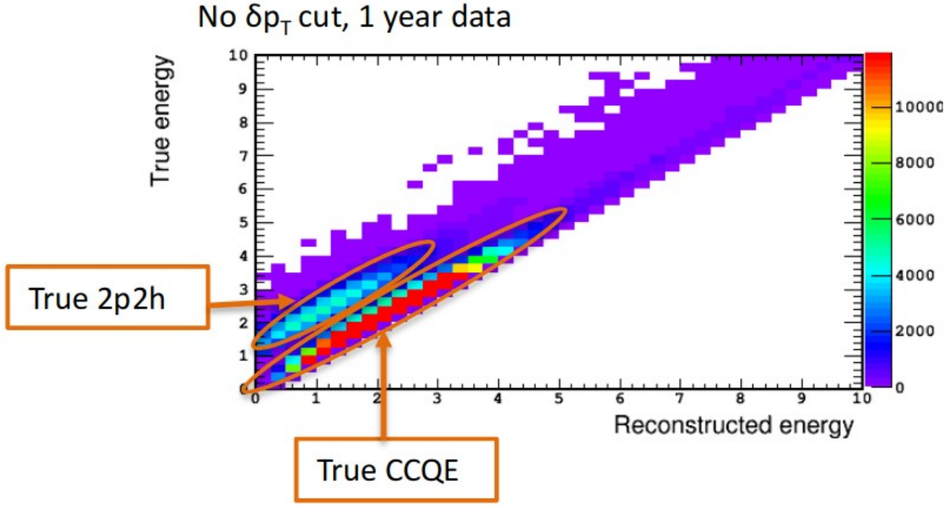


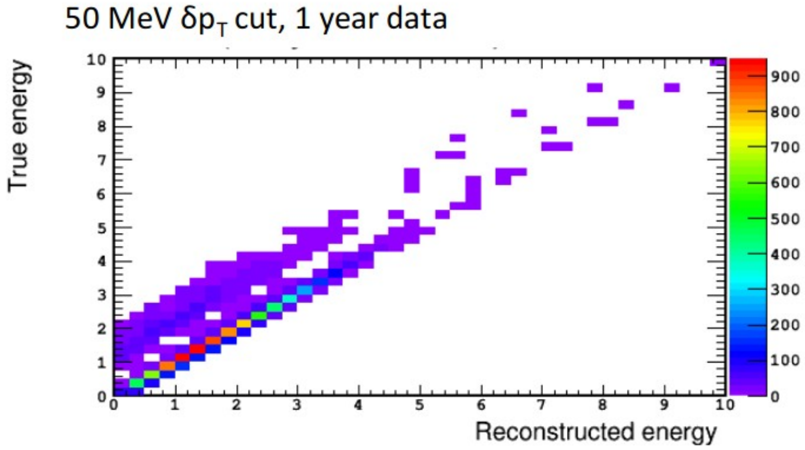


Flux constraint with transverse variable

- Cut on missing Pt → Sample with less nuclear/FSI effects
- Improved energy resolution for flux determination
- RHC CCQE as an example
- Potentially expand-able to n and pi0 final state

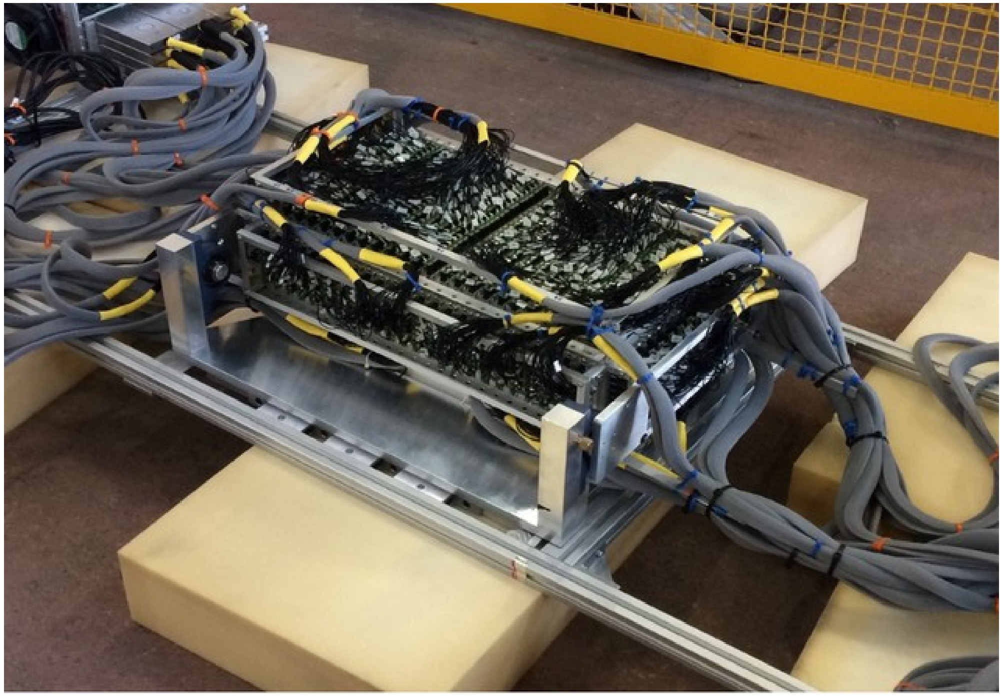






CERN prototype

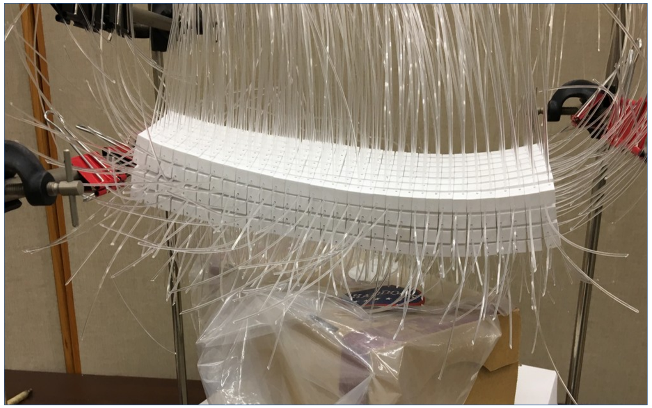
- 9216 cubes (48 width x 24 length x 8 height 1 x 1 x 1 cm^3 cubes)
- 1728 channels
- Ceramic type MPPCs and CITIROC-based electronics
- MPPCs calibrated with LED before the test beams.

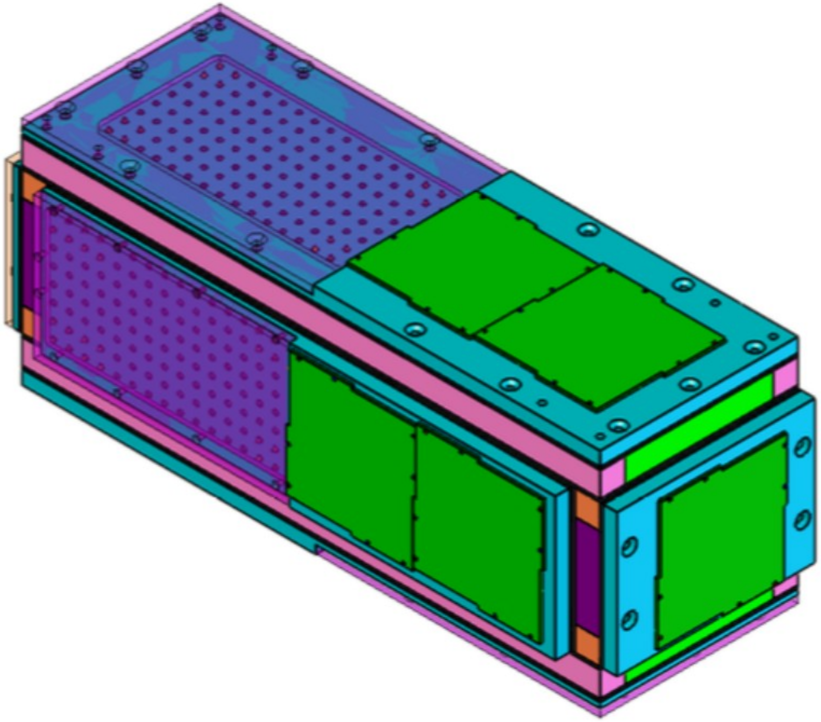


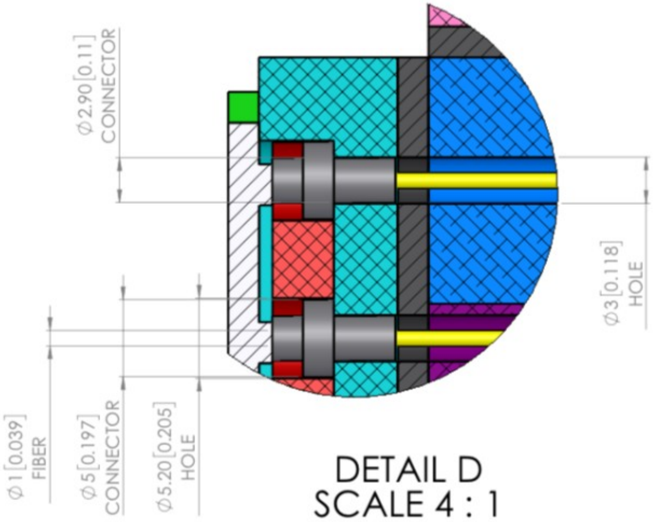
- It was used in CERN charged particle beam test in 2018.
- Data are being analyzed.

3DST US-Japan prototype

- 8 (width) x 32 (length) x 8 (height) cubes
- 2048 cubes and 576 channels
- CITIROC-based electronics supported by the US-Japan Cooperative Research funds

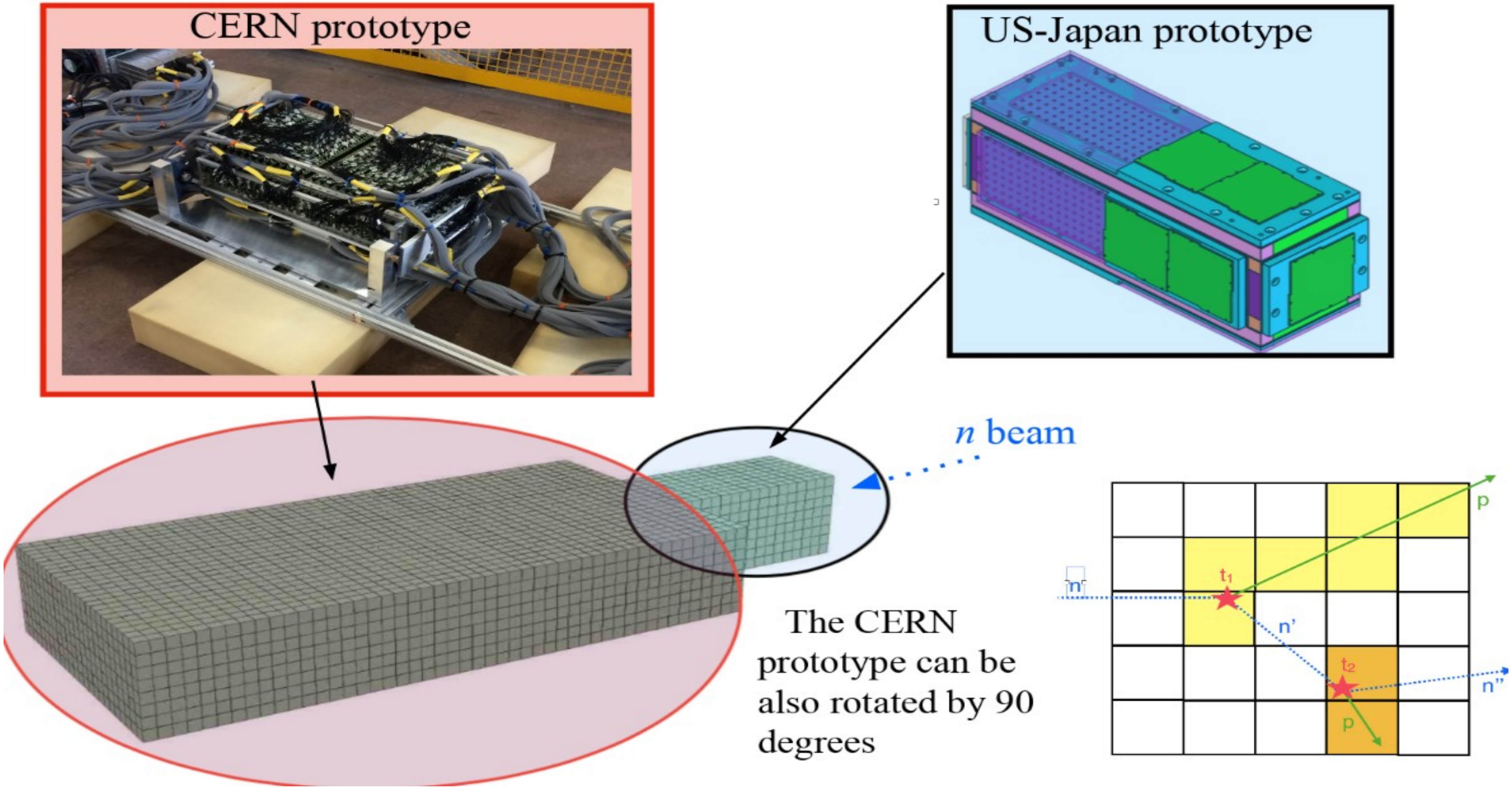






3DST neutron beam test with a prototype

- A neutron beam test planned for the 3DST US-Japan prototype at LANL
- With TOF, neutron energy is known at a great precision



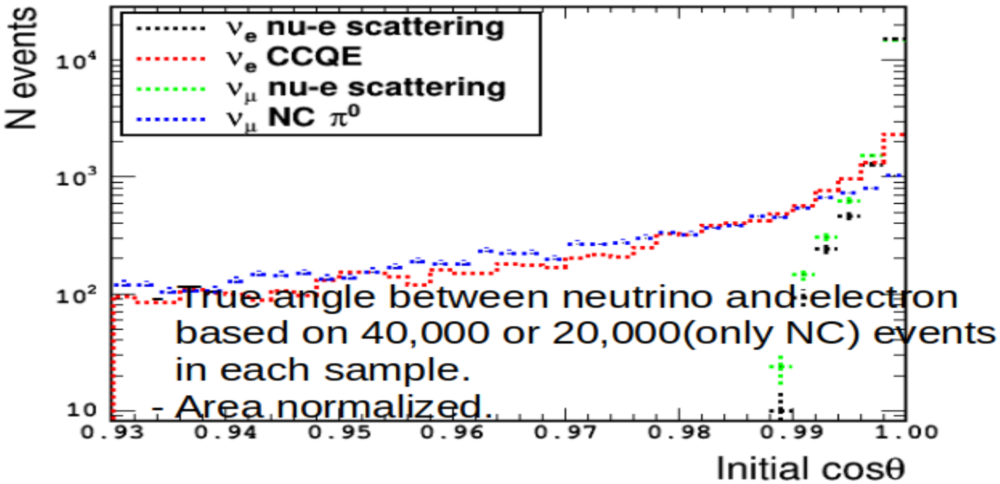
Conclusion

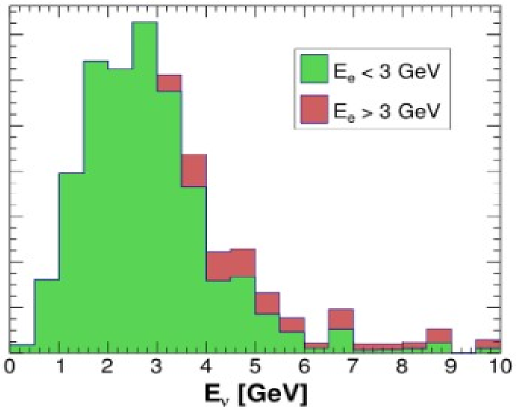
- 3DST-S is part of the DUNE ND reference design and will likely be on-axis.
- 3DST-S will provide various measurements including beam monitoring, flux measurement and neutrino interaction model tuning.

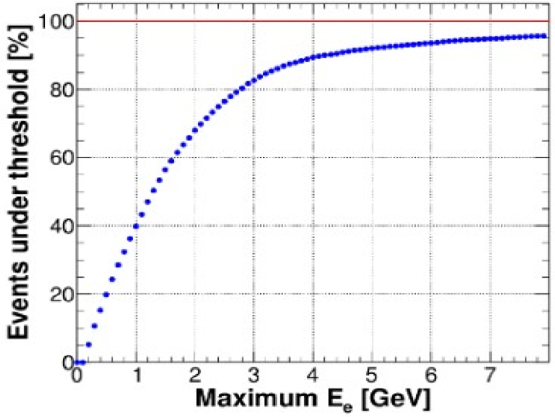
backups

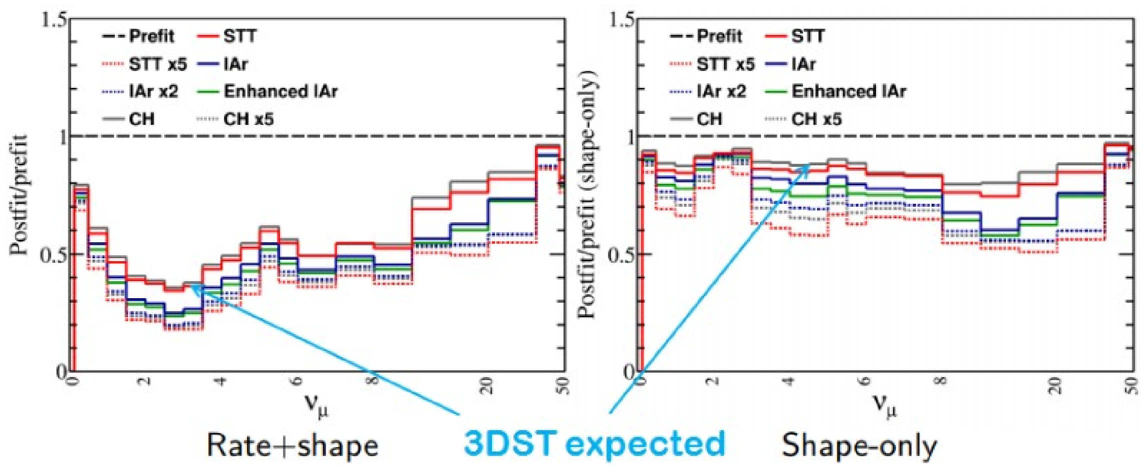
3DST performance

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



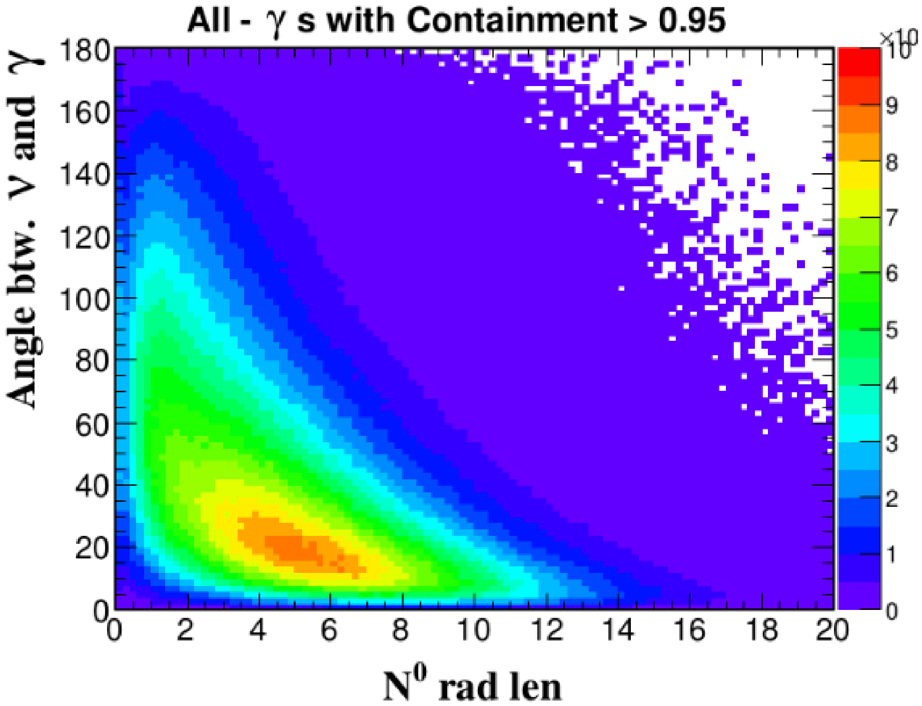


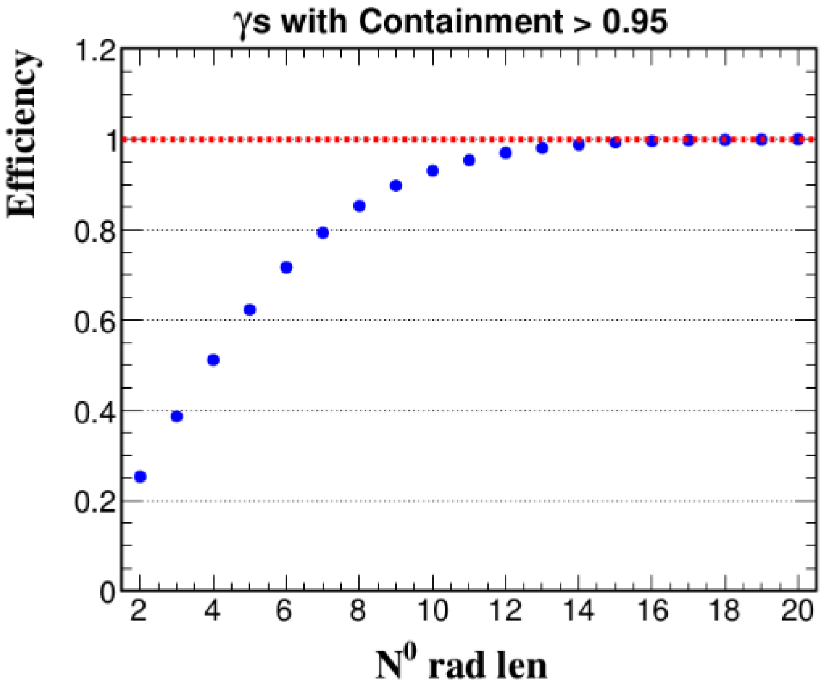




3DST performance

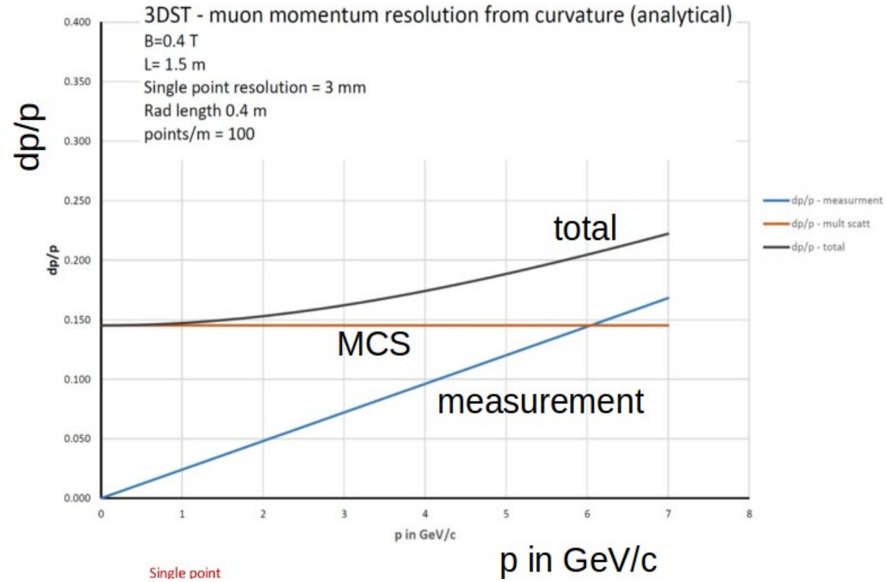
- Radiation length ~ 40 cm, for all pi0 and electron containment, may need downstream or side ECALs.
- 2 m depth 3DST contains 60% pi0 which deposits > 95% energy.

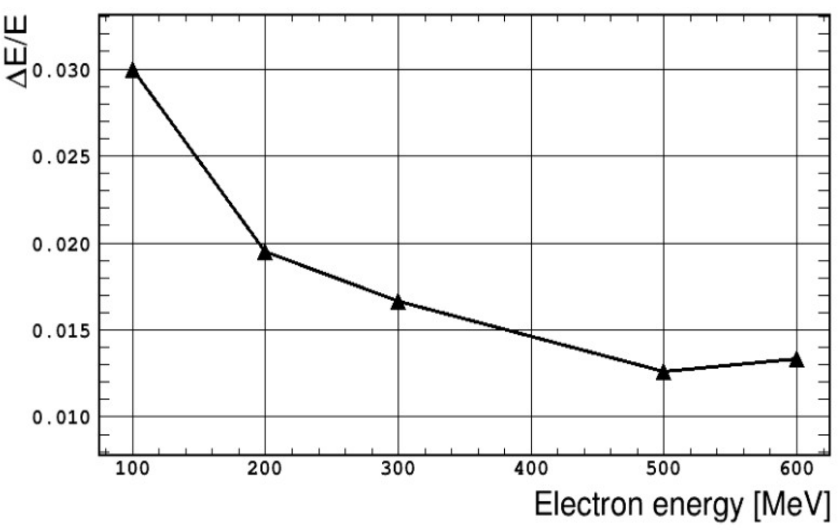


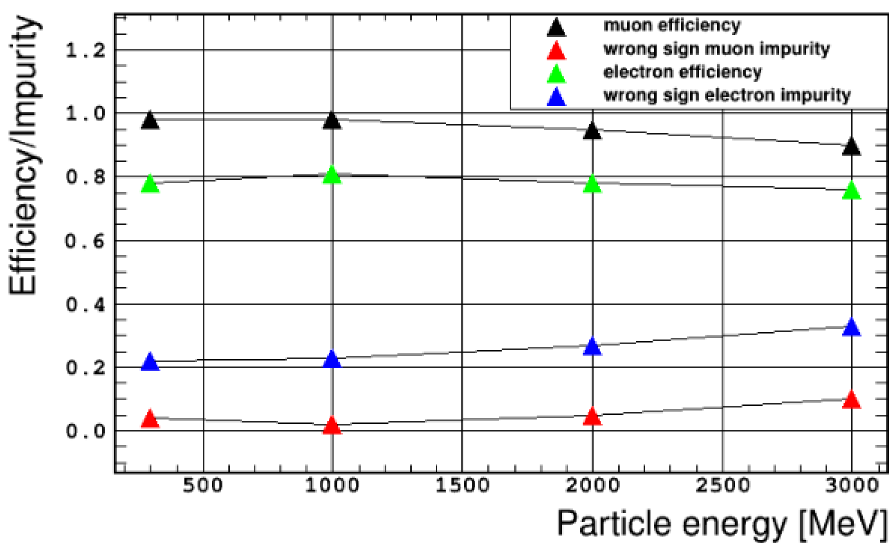


3DST performance

- 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.







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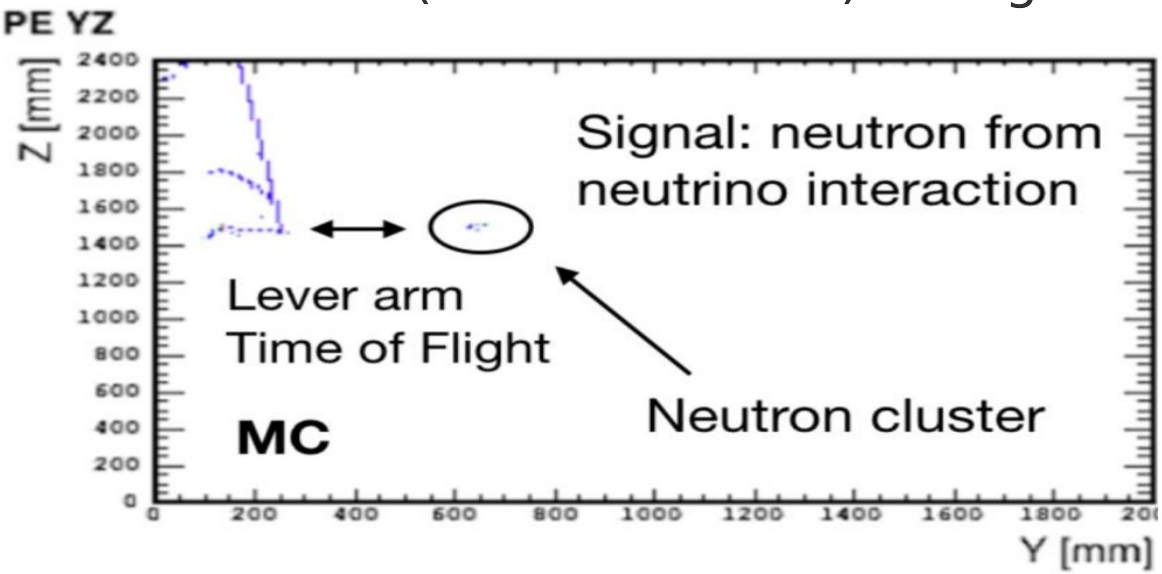

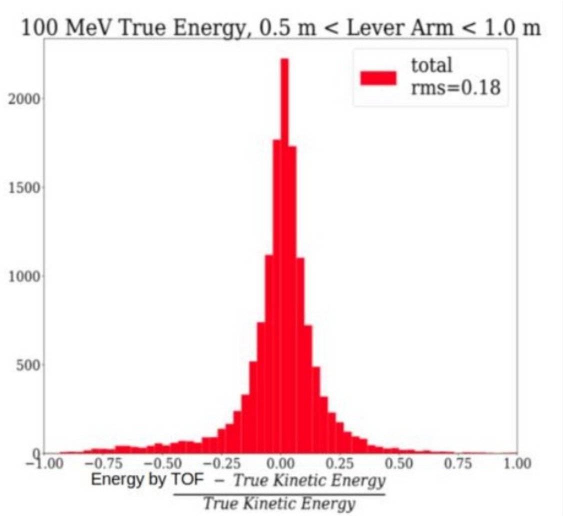

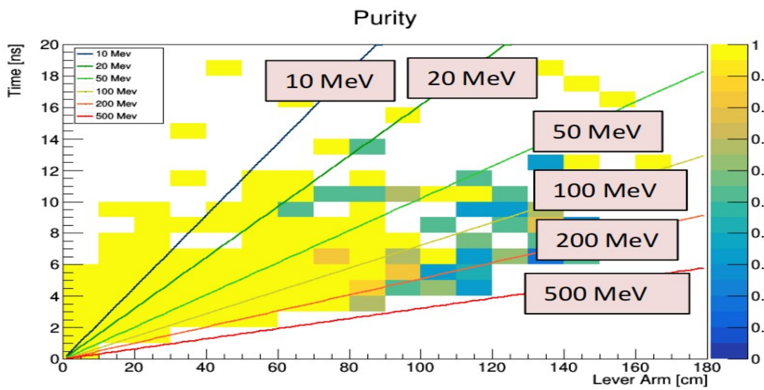

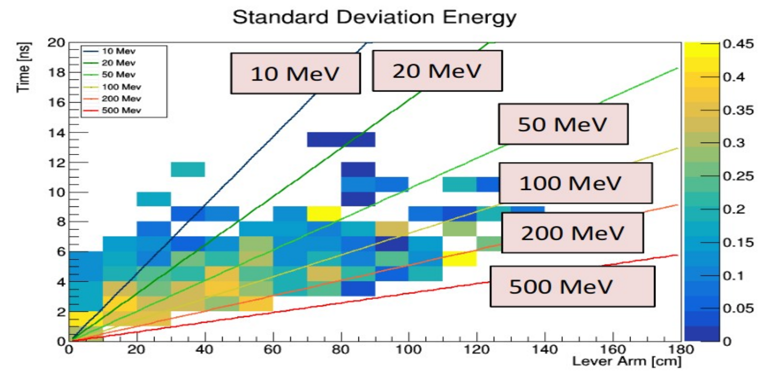

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