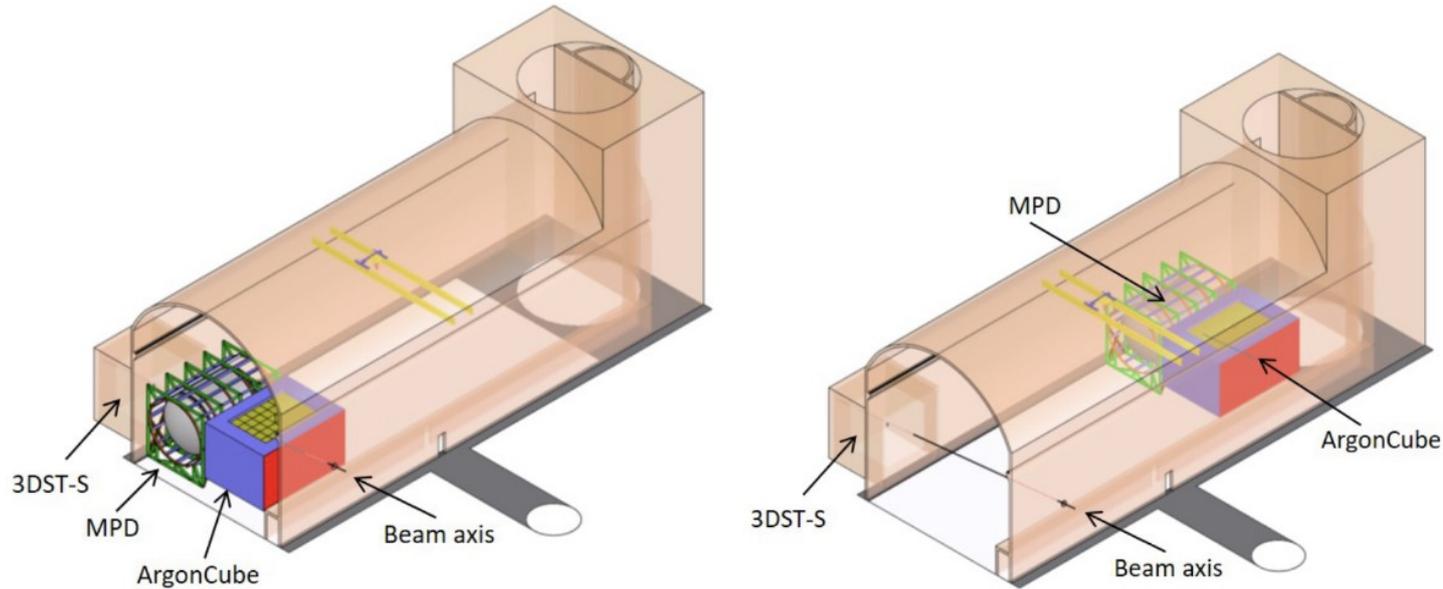




# **3DST - S as a sub-system in DUNE ND**

Guang Yang  
On behalf of the DUNE collaboration

# DUNE ND hall

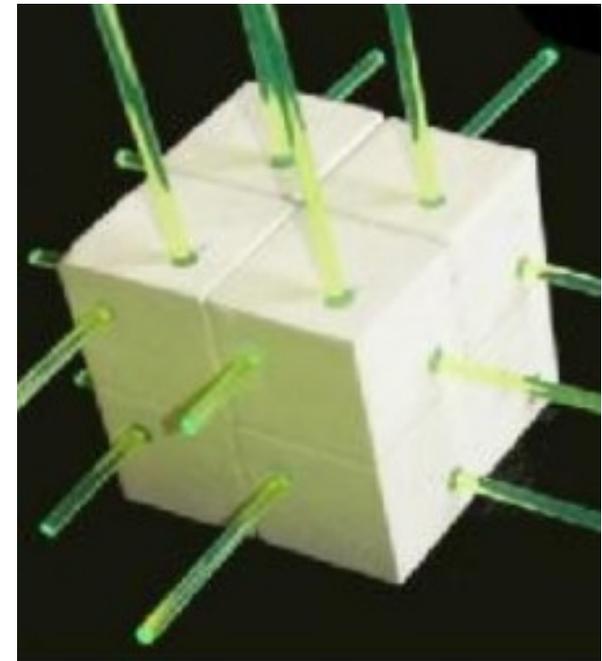
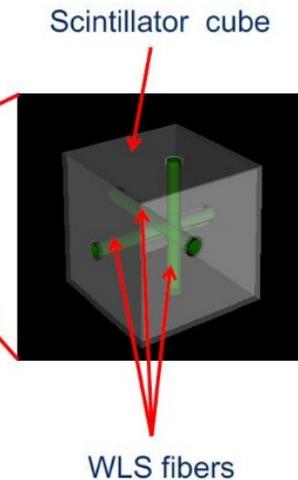
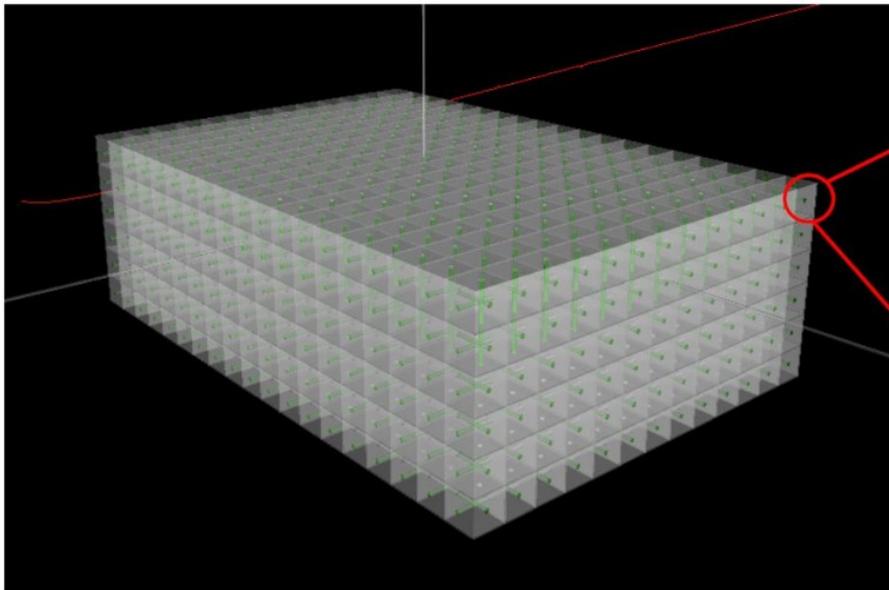


- DUNE ND will consist of a liquid argon detector, a gas argon TPC system which will be surrounded by ECAL and inside a magnetic volume and a 3D projection scintillator tracker.
- Part of the DUNE ND system will be movable.
- DUNE aims at measuring CP violation at five sigma with this ND system.



## 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 TiO<sub>2</sub> 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).

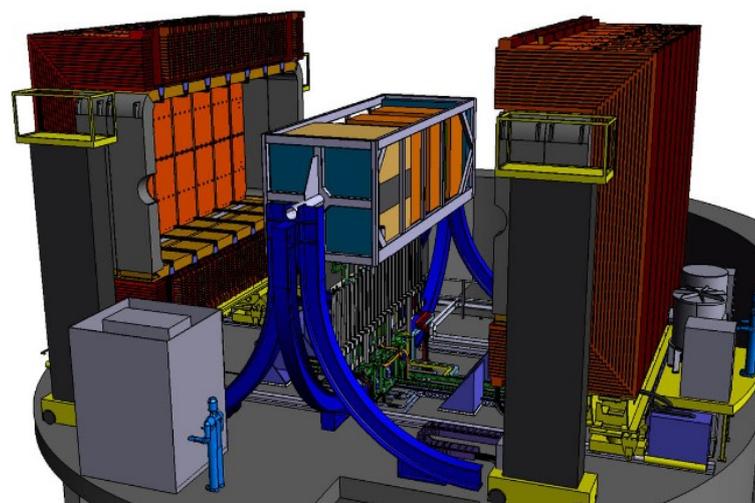
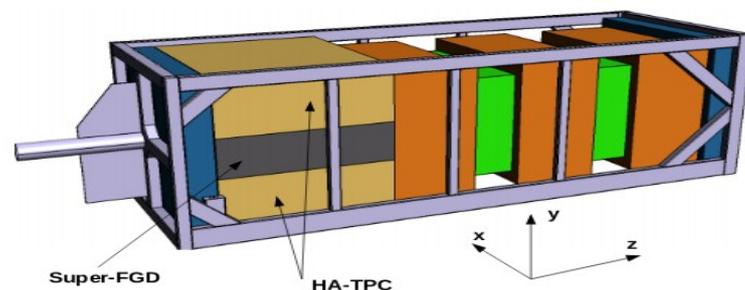
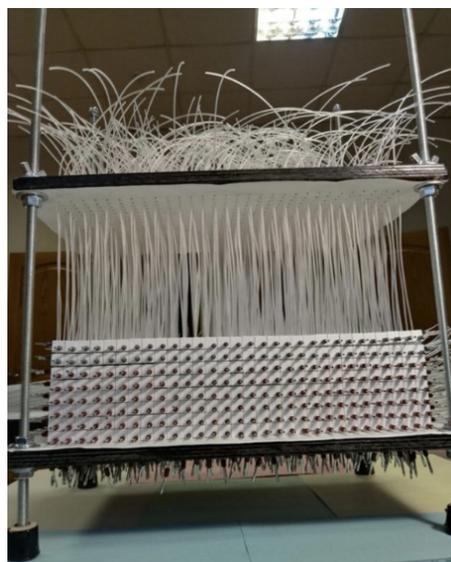
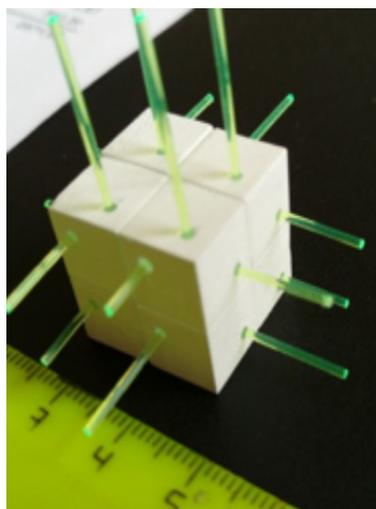




# Synergy with T2K upgrade

- 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.
- Talk by Neha Dokania

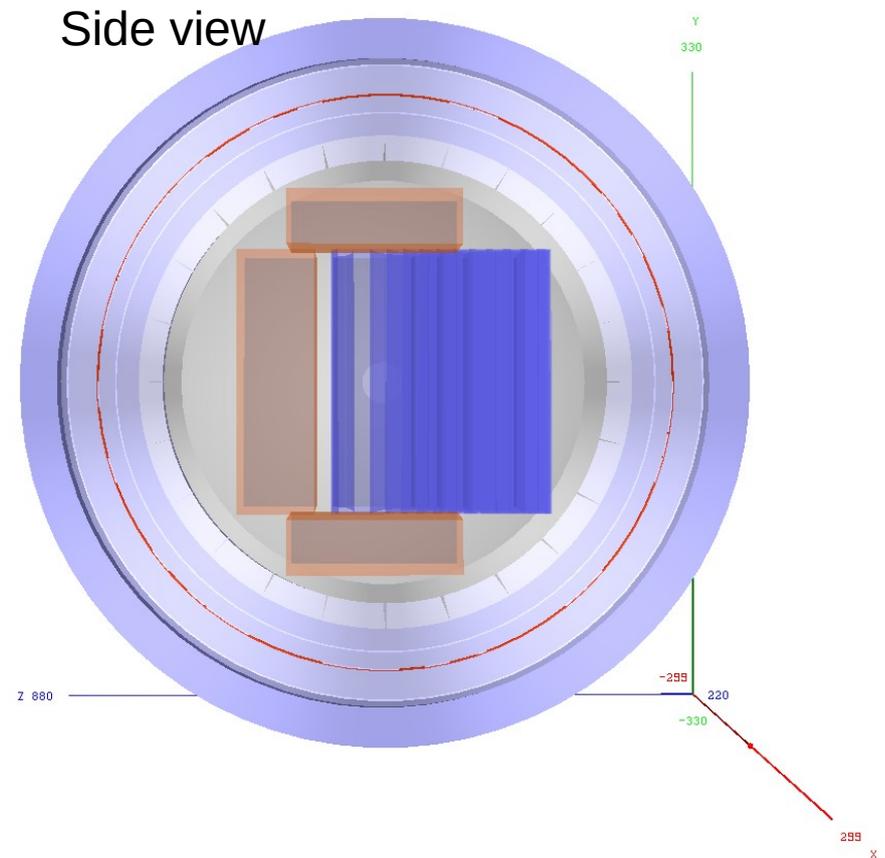
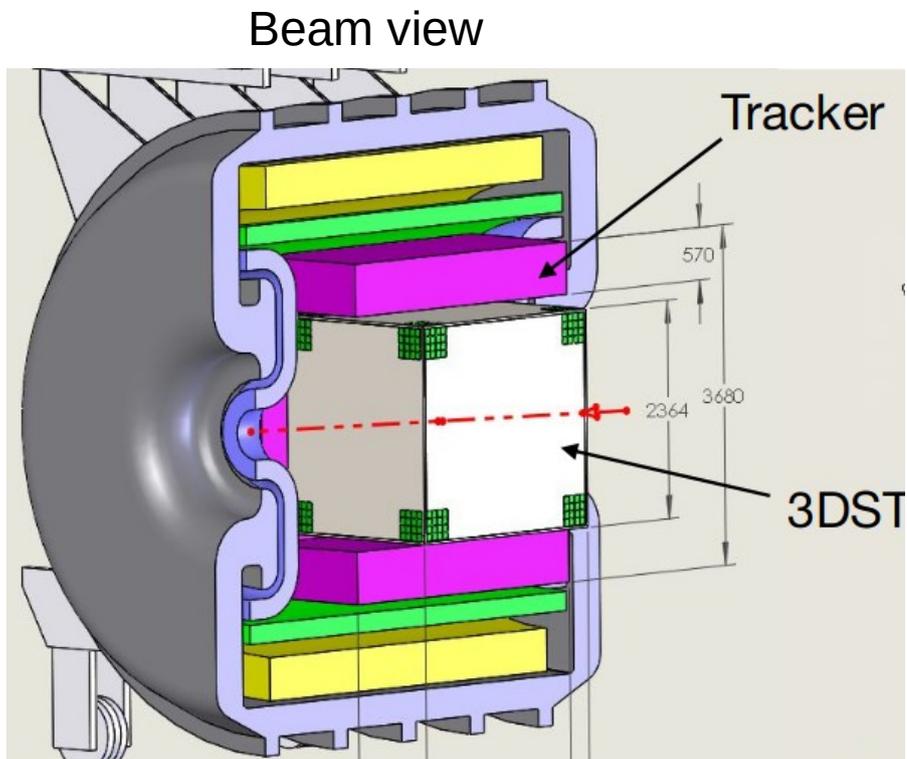
Super-FGD proto-type  
by T2K upgrade group



arXiv. 1901.03750

# 3DST-S

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





# 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.

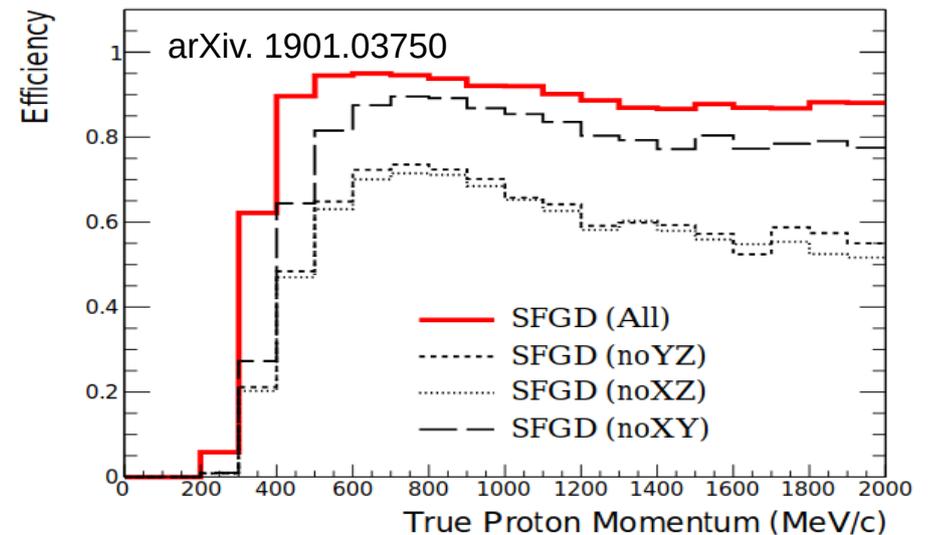
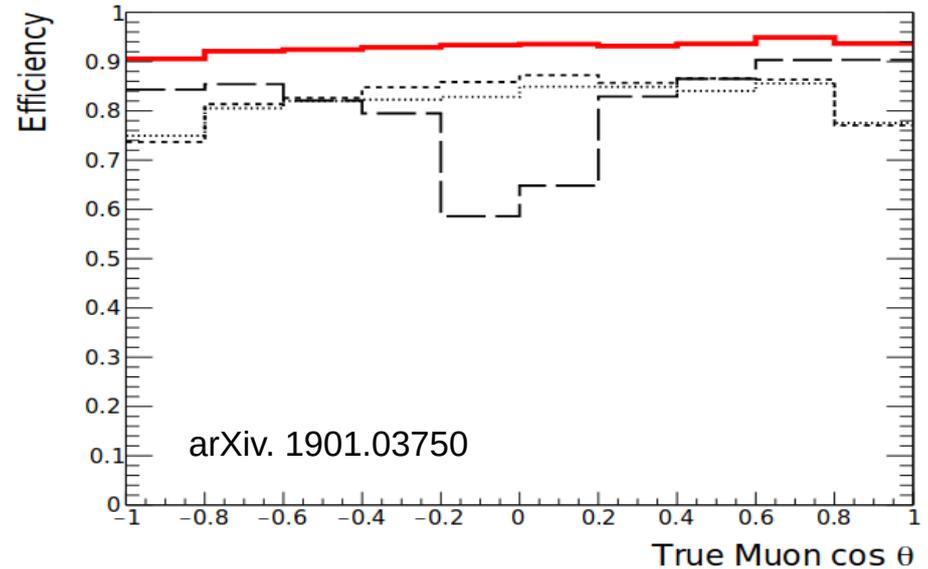


# 3DST performance

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

For one year

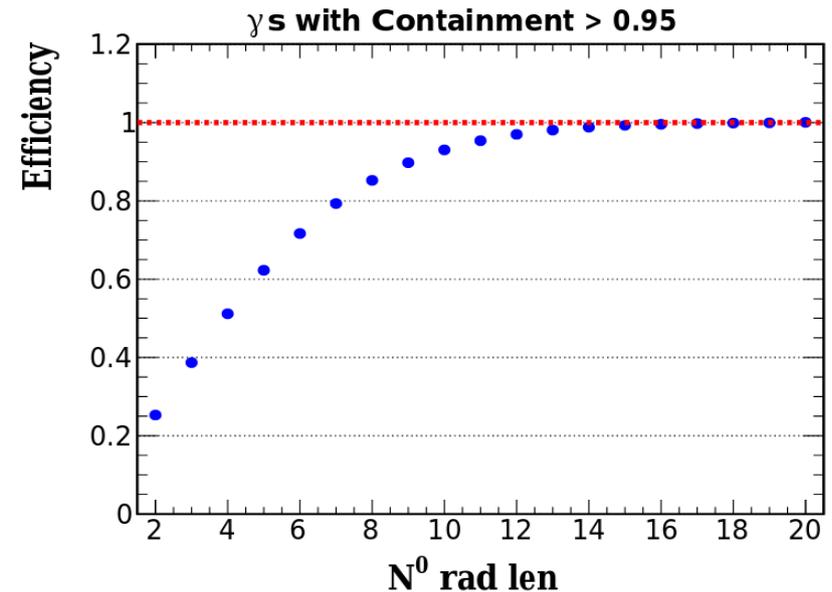
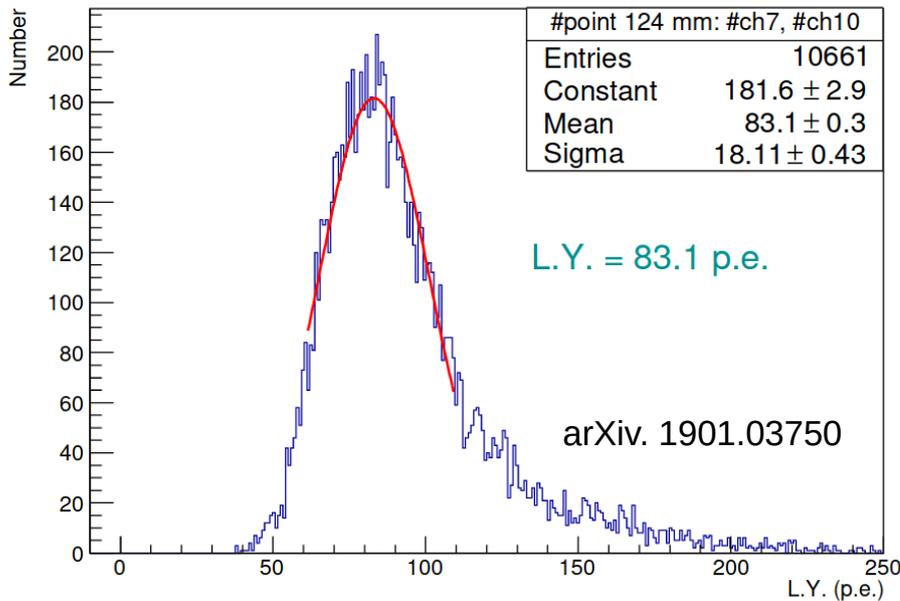
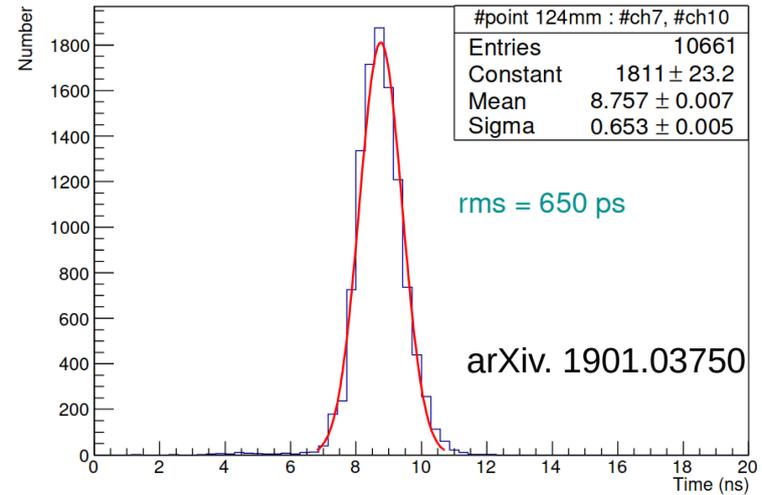
Channel	$\nu$ mode	$\bar{\nu}$ mode
$\nu_\mu$ CC inclusive	$13.6 \times 10^6$	$5.1 \times 10^6$
CCQE	$2.9 \times 10^6$	$1.6 \times 10^6$
CC $\pi^0$ inclusive	$3.8 \times 10^6$	$0.97 \times 10^6$
NC total	$4.9 \times 10^6$	$2.1 \times 10^6$
$\nu_\mu$ - $e^-$ scattering	1067	1008
$\nu_\mu$ CC coherent	$1.26 \times 10^5$	$8.6 \times 10^4$
$\nu_\mu$ CC low- $\nu$ ( $\nu < 250$ MeV)	$1.48 \times 10^6$	$8.8 \times 10^5$
$\nu_e$ CC coherent	$2.1 \times 10^3$	719
$\nu_e$ CC low- $\nu$ ( $\nu < 250$ MeV)	$2.1 \times 10^4$	$4.7 \times 10^3$
$\nu_e$ CC inclusive	$2.5 \times 10^5$	$0.56 \times 10^5$





# 3DST performance

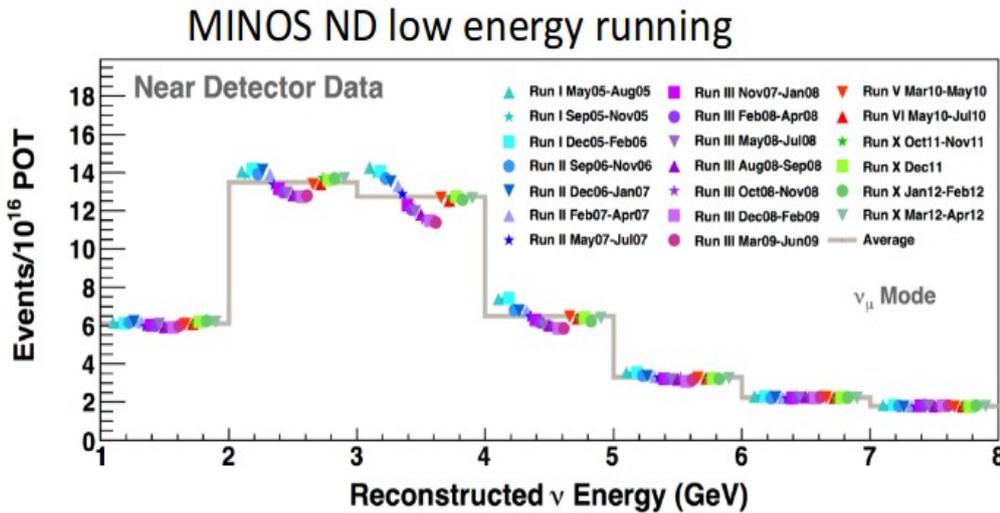
- Super fast and high light yield
- Radiation length  $\sim 40$  cm, TPC and ECAL needed in addition to 3DST
- $\sim 100\%$  charge ID for tracks below 3 GeV



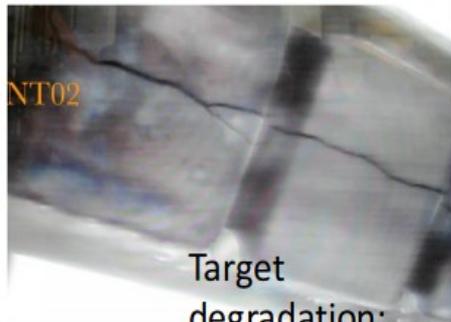
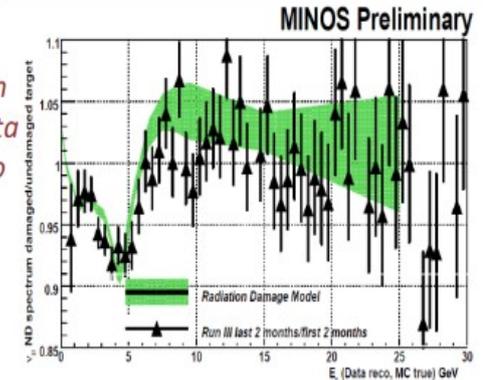
# Beam spectrum monitor

- Beam accidents happened before.

Target damage model in FLUKA08



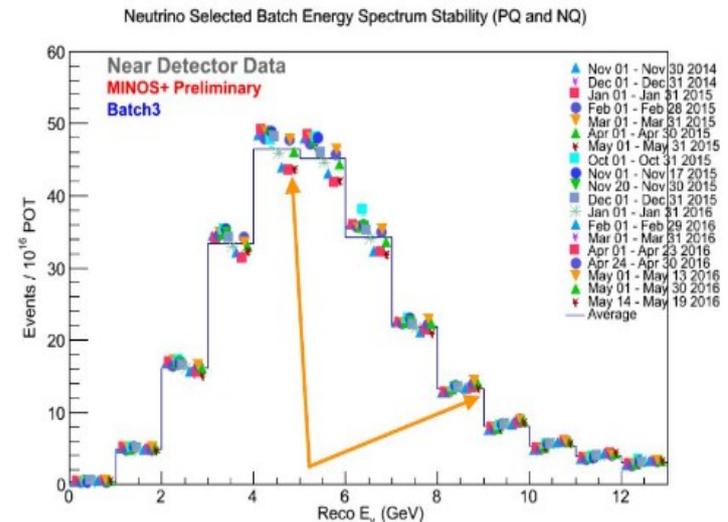
Target degradation modeled by ND data  
M. Bishai (Neutrino 2010)



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)



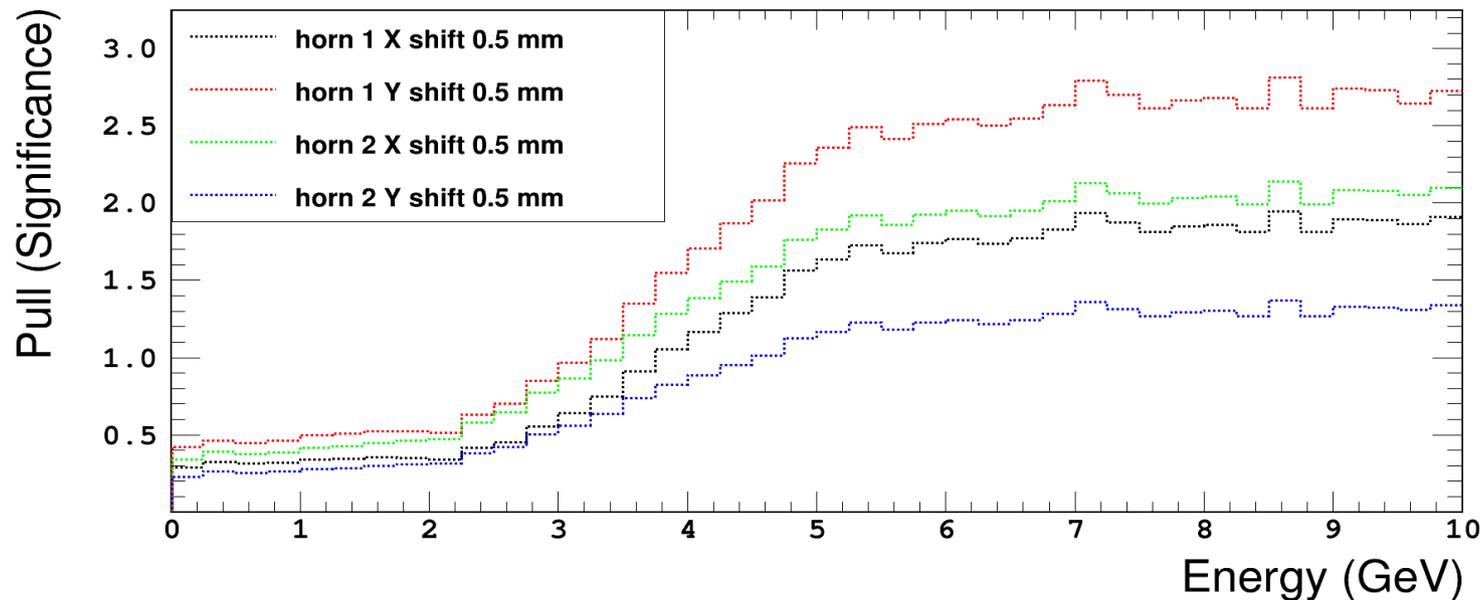
Jim Hysten, NuMI OPS,  
Nov 2016



# 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.

Stat. Error and detector effect (smearing + efficiency applied)

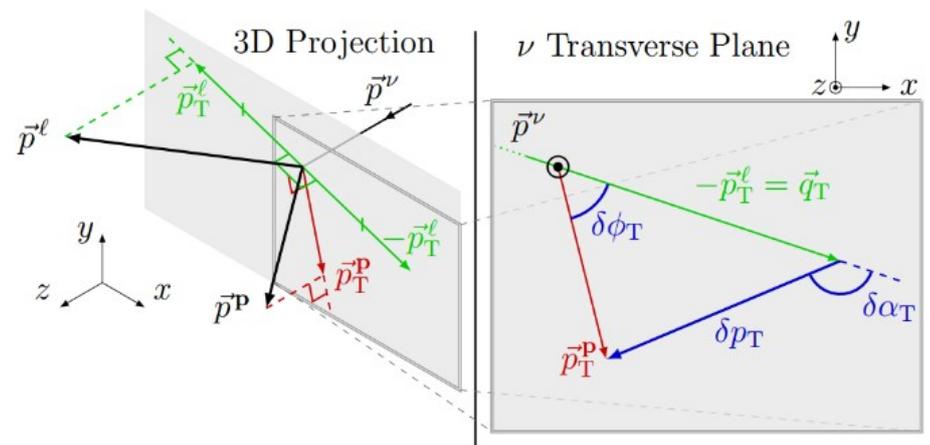
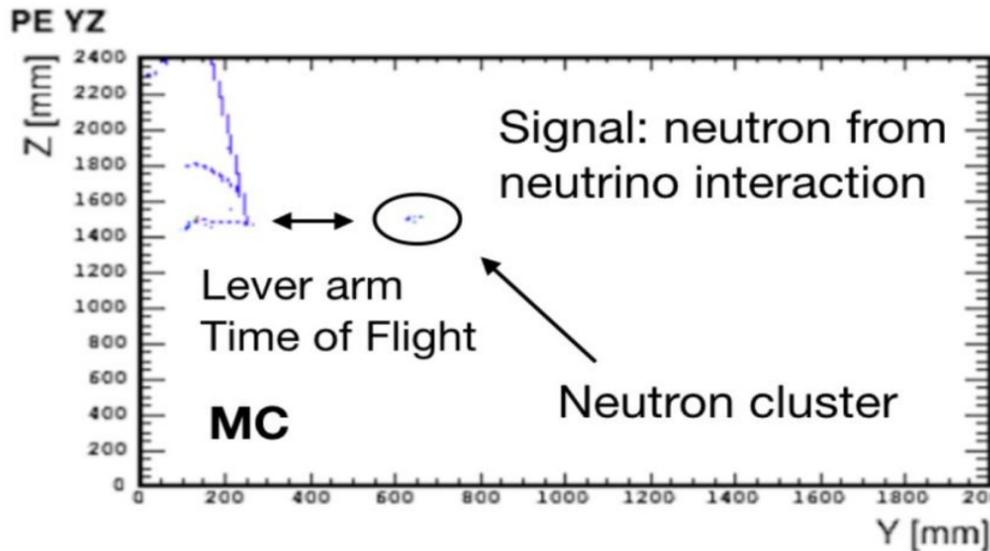


4% muon  
momentum  
resolution at  
1 GeV



# Flux constraint with transverse variable

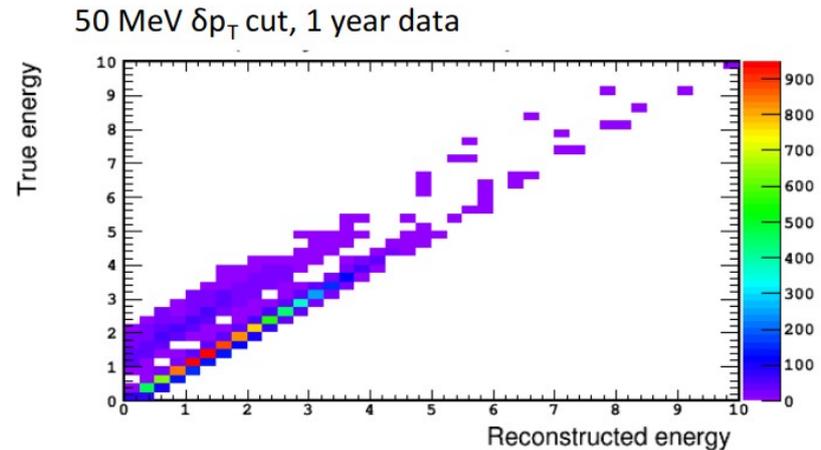
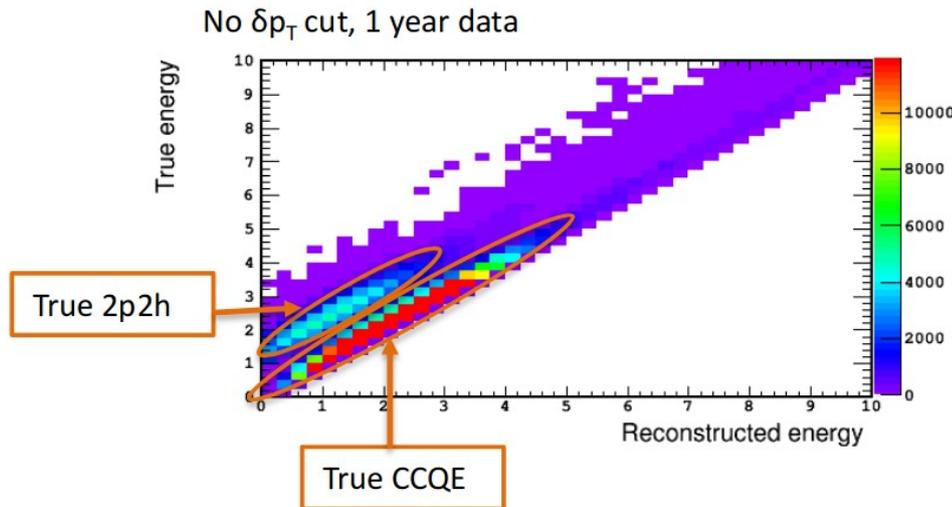
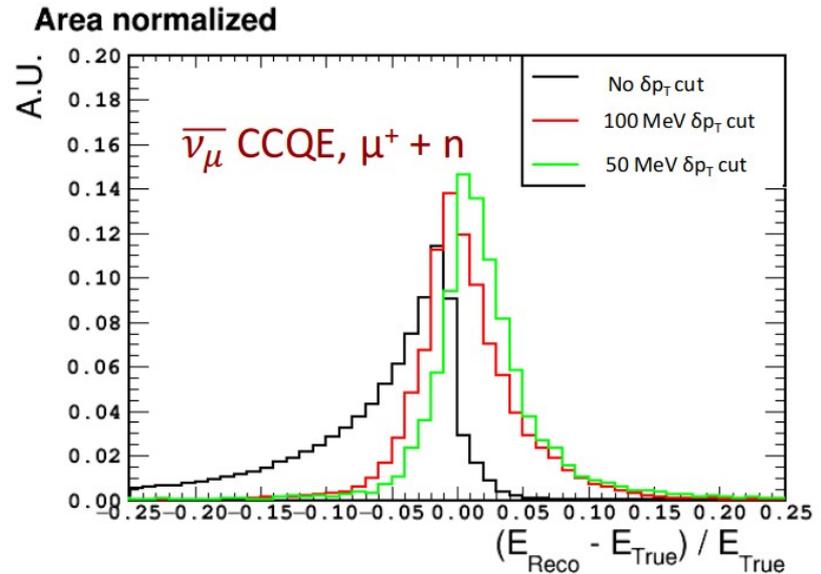
- Neutron energy can be measured with fast timing.
- Out-of-FV (fiducial volume) background can be controlled.
- With the neutron measurement, both FHC and RHC transverse variables can be measured:
  - tune the model
  - select FSI (final state interaction) free samples.





# Flux constraint with transverse variable

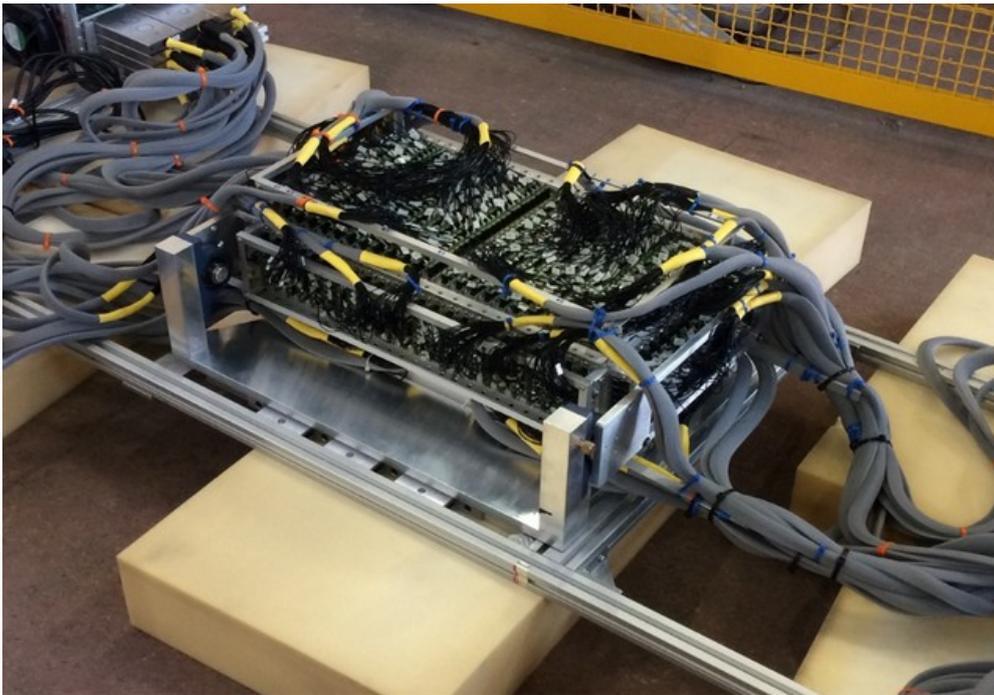
- Cut on missing  $P_t$  → Sample with less nuclear/FSI effects
- Improved energy resolution for flux determination
- RHC CCQE as an example
- Potentially expand-able to  $n$  and  $\pi^0$  final state





# CERN prototype

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



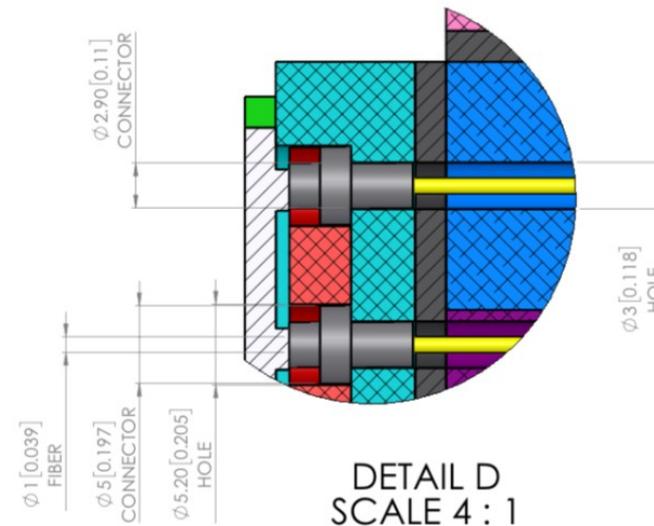
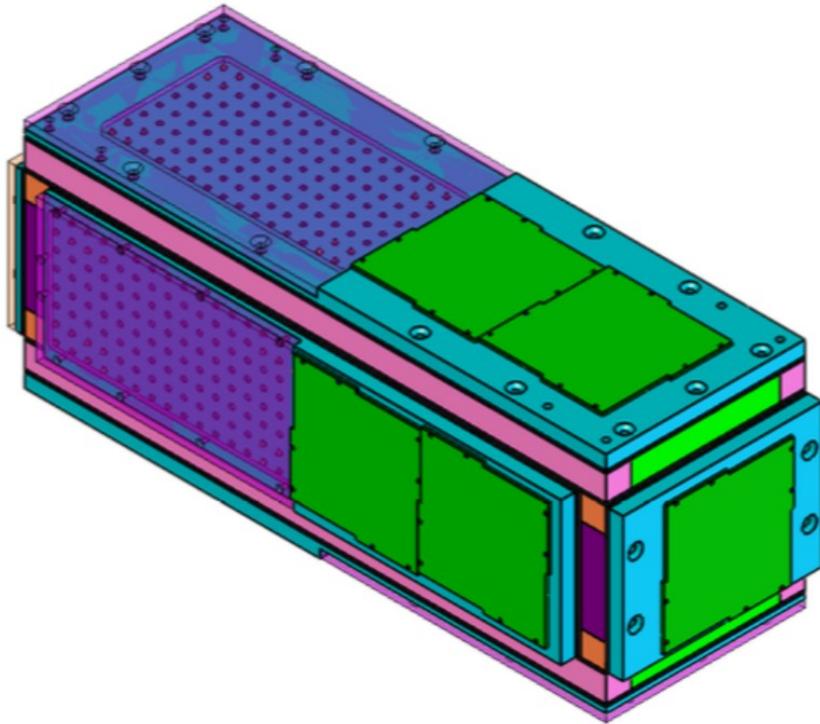
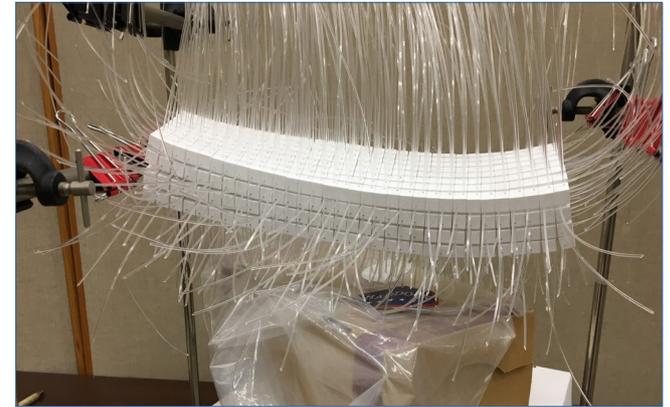
- It was used in CERN charged particle beam test in 2018.
- Data are being analyzed.





# 3DST US-Japan prototype

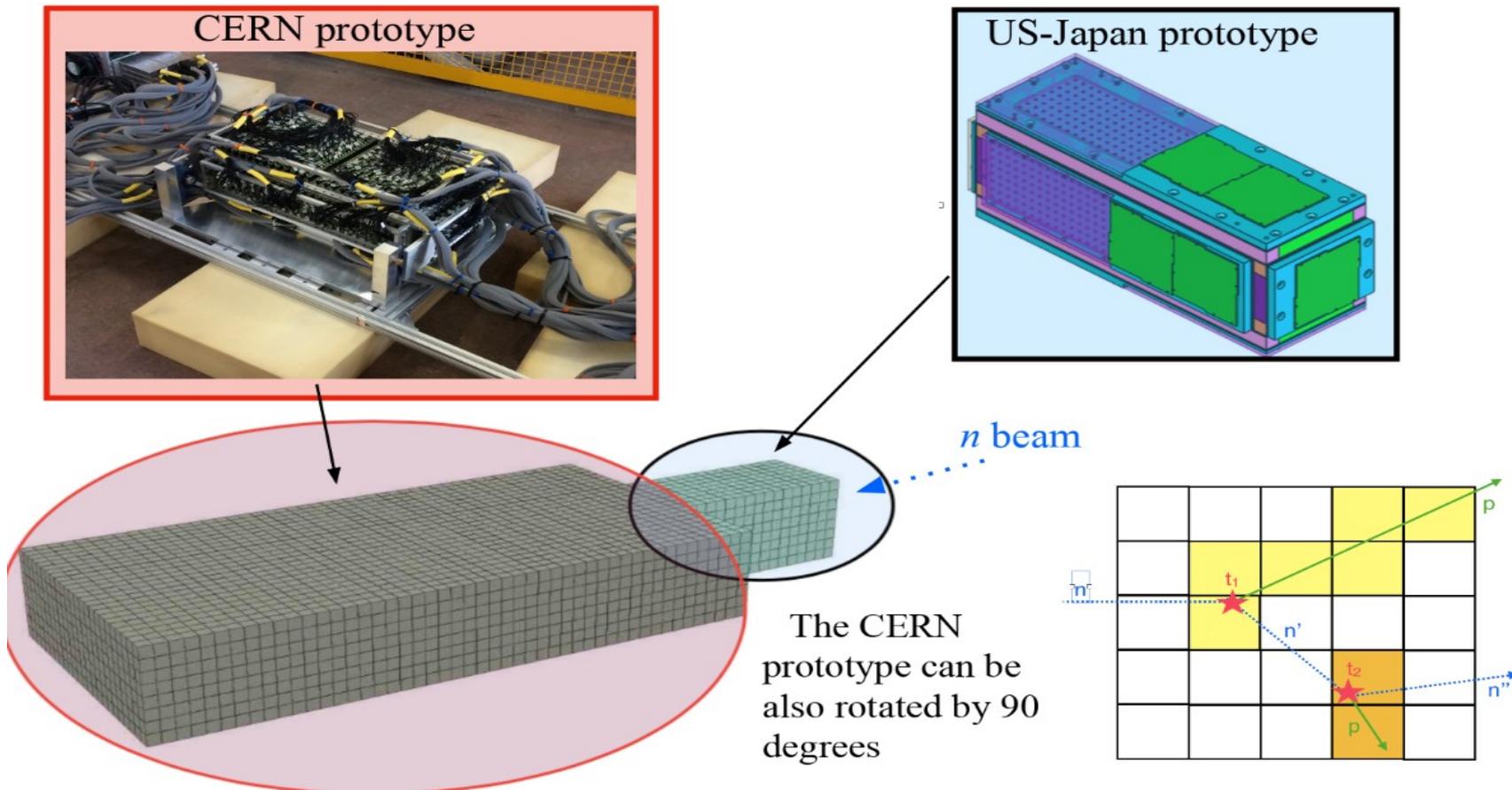
- 8 (width) x 32 (length) x 8 (height) cubes
- 2048 cubes and 576 channels
- CITIROC-based electronics supported by the US-Japan Cooperative Research funds





# 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.

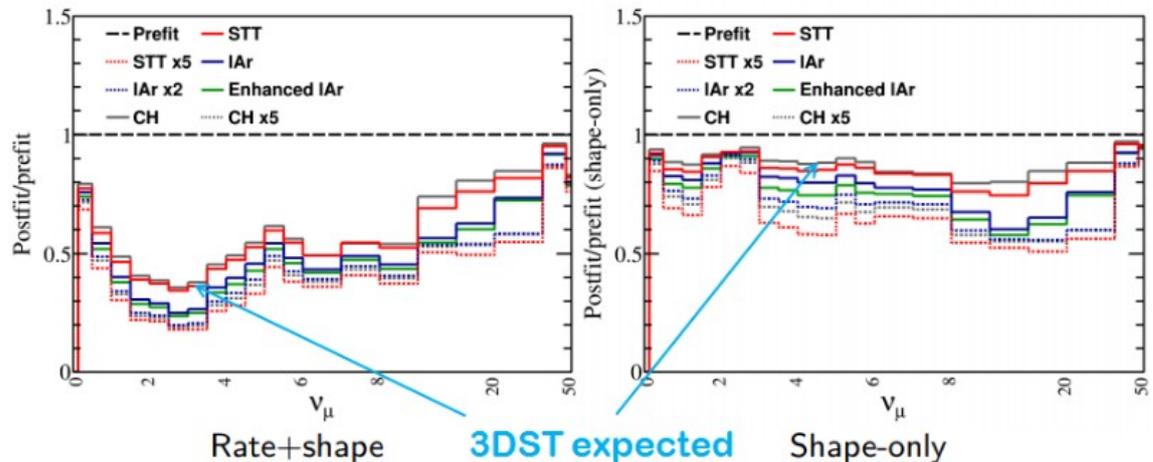
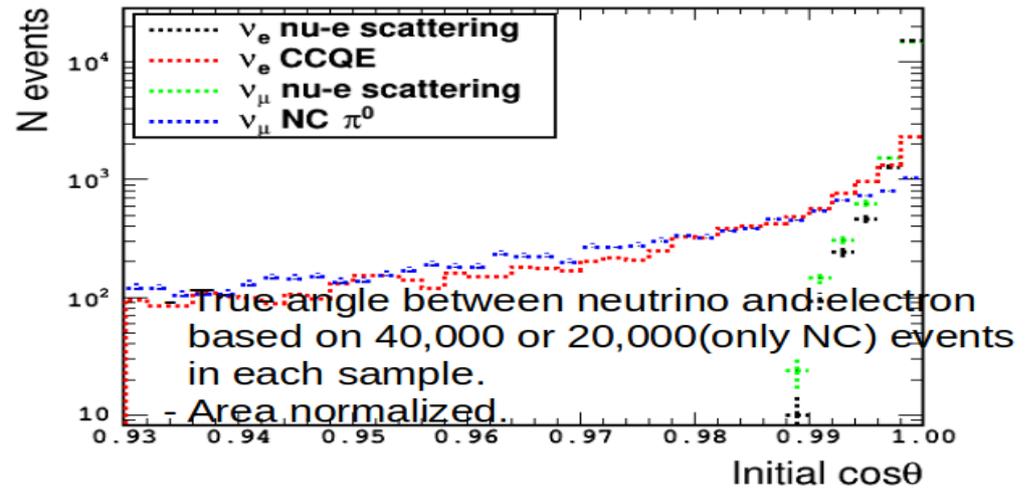
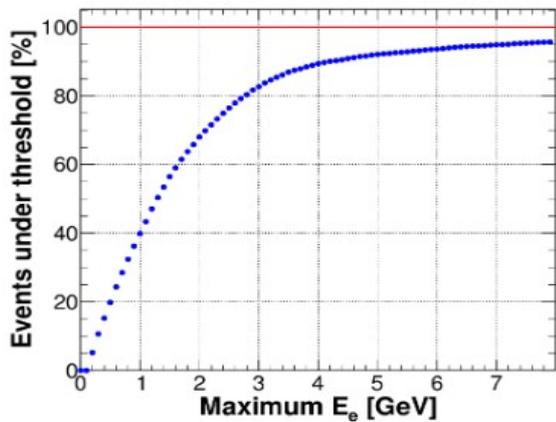
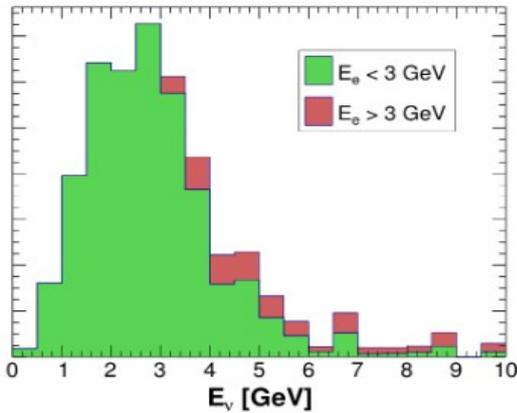


# backups



# 3DST performance

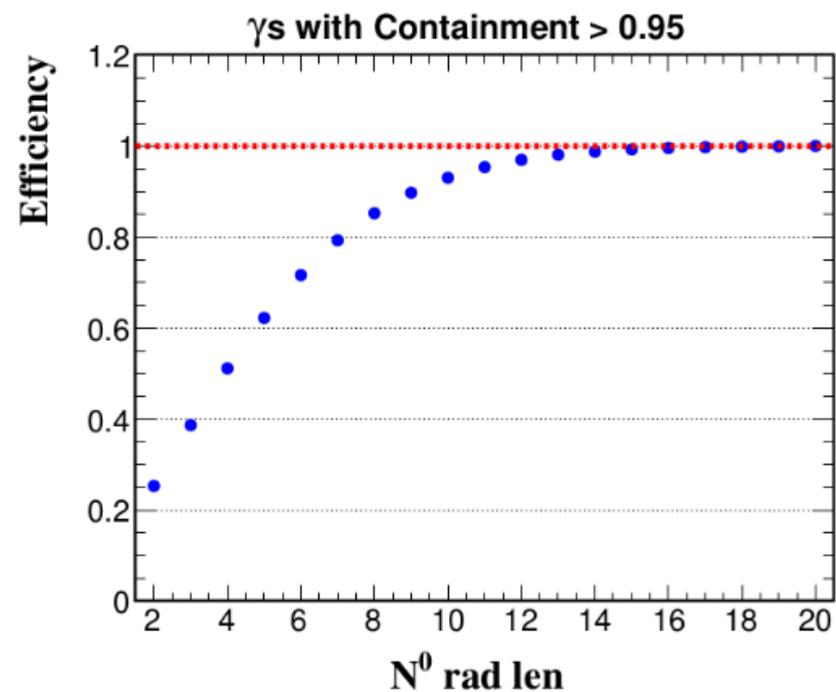
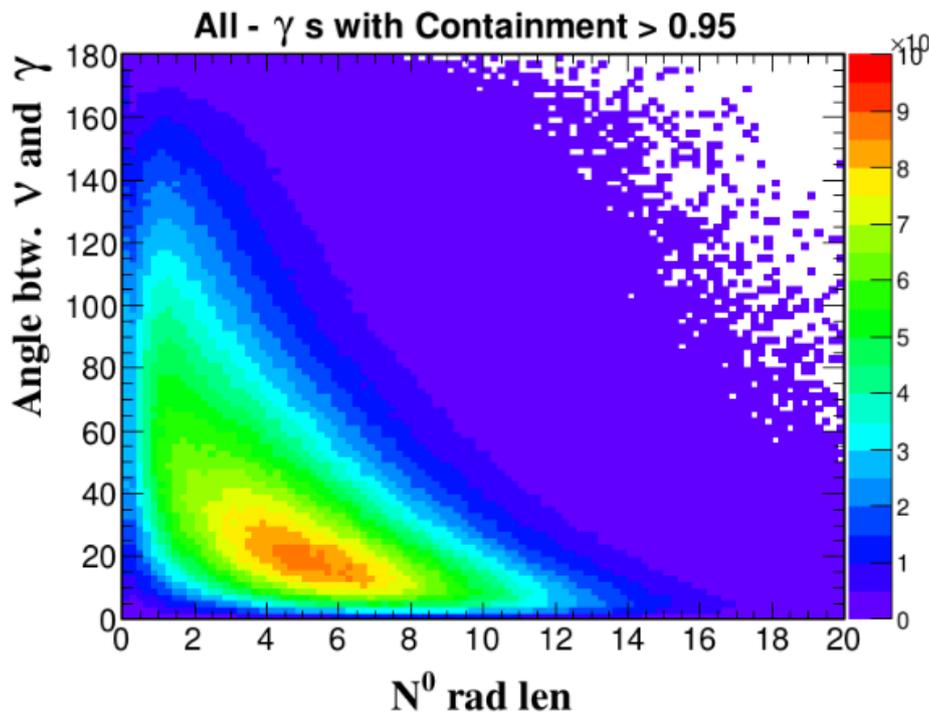
- Good angular resolution let 3DST having good ability to do neutrino-electron scattering. Not full electron containment might be still fine for this channel





# 3DST performance

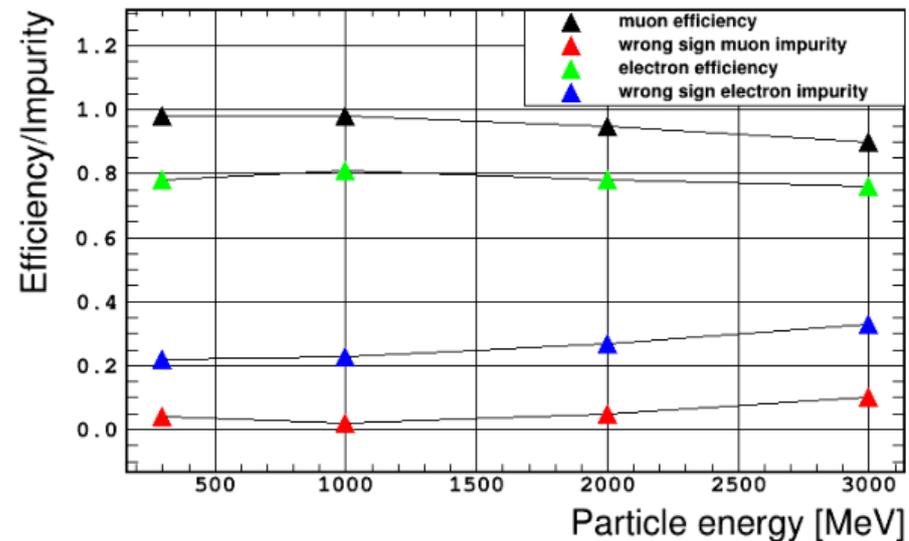
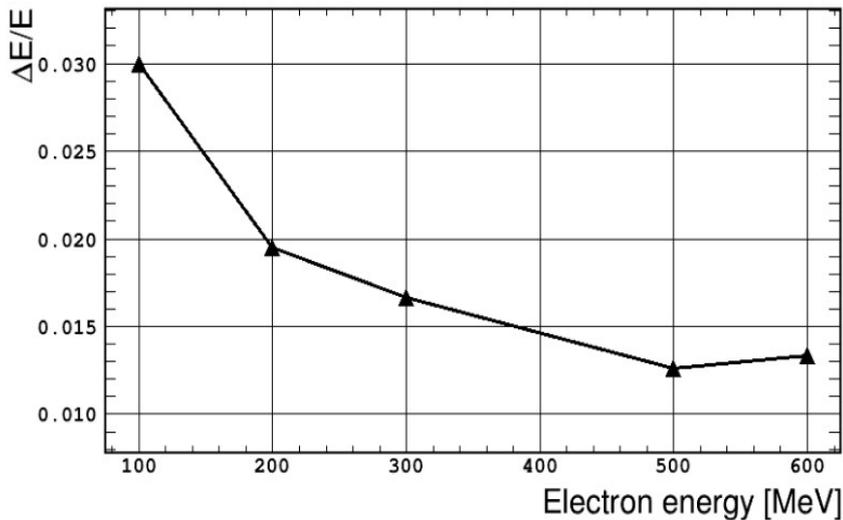
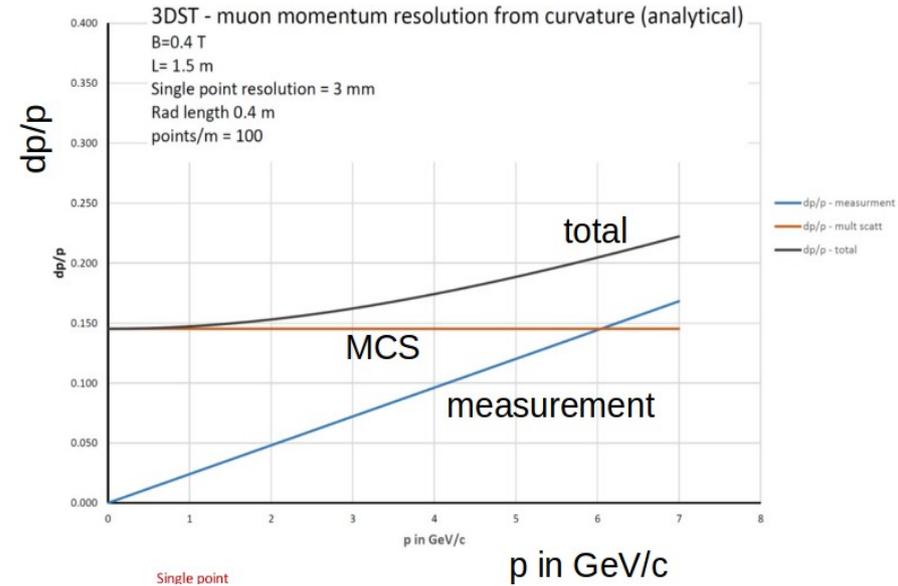
- Radiation length  $\sim 40$  cm, for all  $\pi^0$  and electron containment, may need downstream or side ECALs.
- 2 m depth 3DST contains 60%  $\pi^0$  which deposits  $> 95\%$  energy.





# 3DST performance

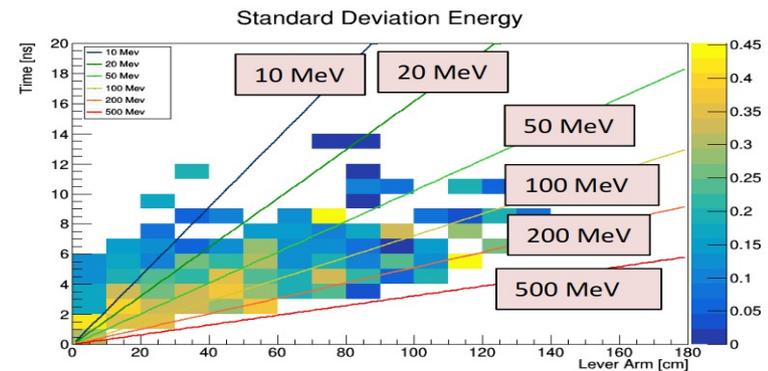
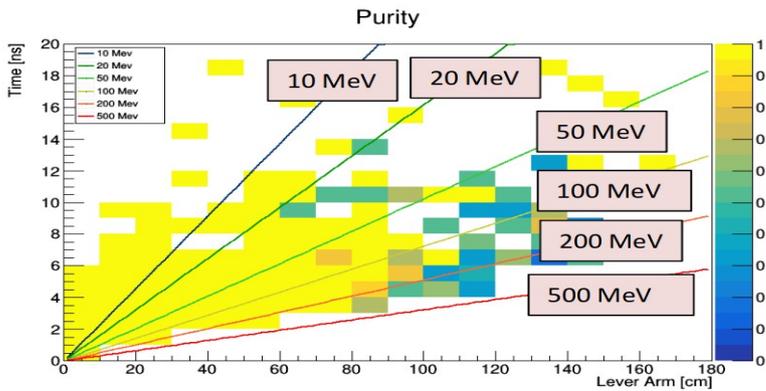
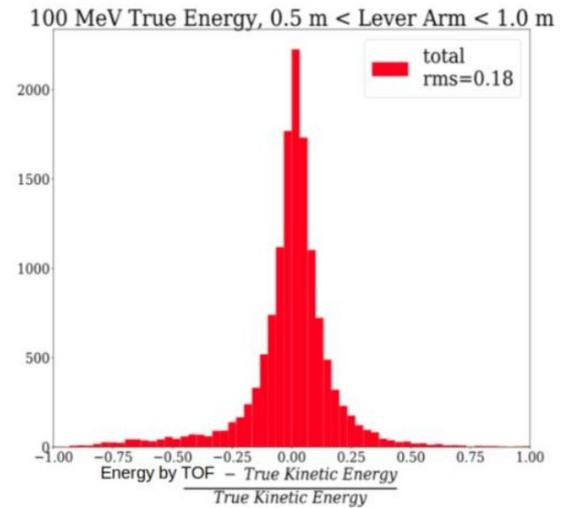
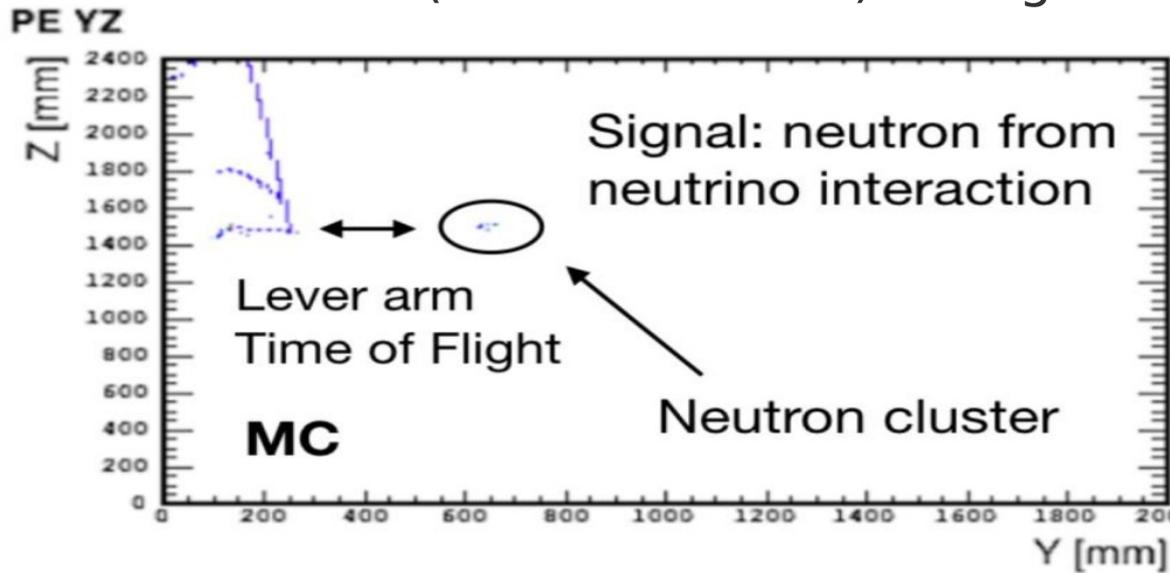
- Few percent resolution can be achieved for contained electrons.
- 15%-20% track momentum resolution with 0.4 T B-field in interested energy region.
- Good charge ID for tracks below 3 GeV.





# Flux constraint with transverse variable

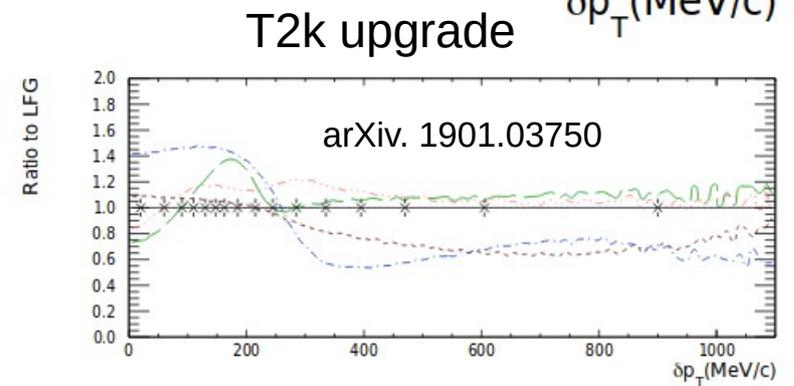
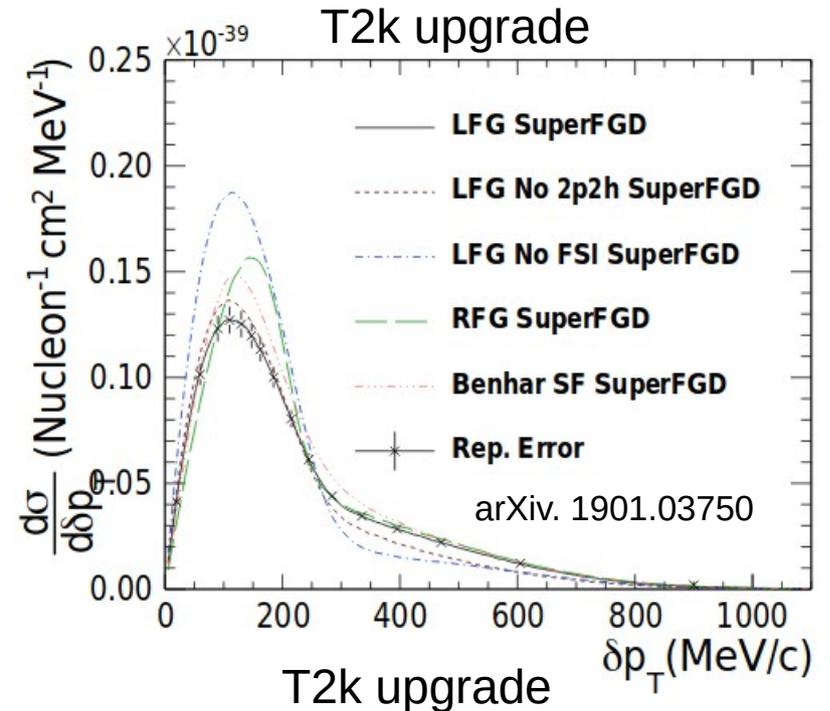
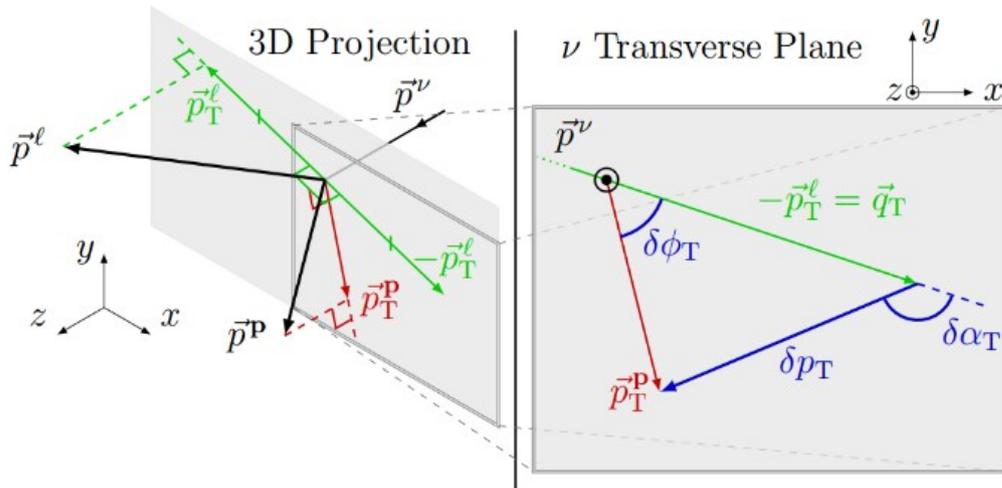
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# Flux constraint with transverse variable

- With the neutron measurement, both FHC and RHC transverse variables can be measured:
  - tune the model
  - select FSI (final state interaction) free samples.





# Materials

Item	Specification
Effective photosensitive area	1.3 mm x 1.3 mm
Pixel pitch	25 $\mu\text{m}$
Number of pixels	2668 pixels
Fill factor	47%
Package type	Surface mount
Breakdown voltage ( $V_{\text{BR}}$ )	53 $\pm$ 5 V
Peak sensitivity wavelength	450 nm
Photo detection efficiency	25%
Gain	7.0 x 10 <sup>5</sup>
Dark count	70 kcps (typ.)
Crosstalk probability	1%

**Table 2.2:** Specifications of the S13360-1325PE MPPC. The characteristics are measured at ( $V_{\text{BR}}+5$ ) V and 25 degree C.