Stony Brook University

System for on-Axis Neutrino Detection (SAND) as part of the DUNE near detector

Guang Yang for the DUNE collaboration

Stony Brook University

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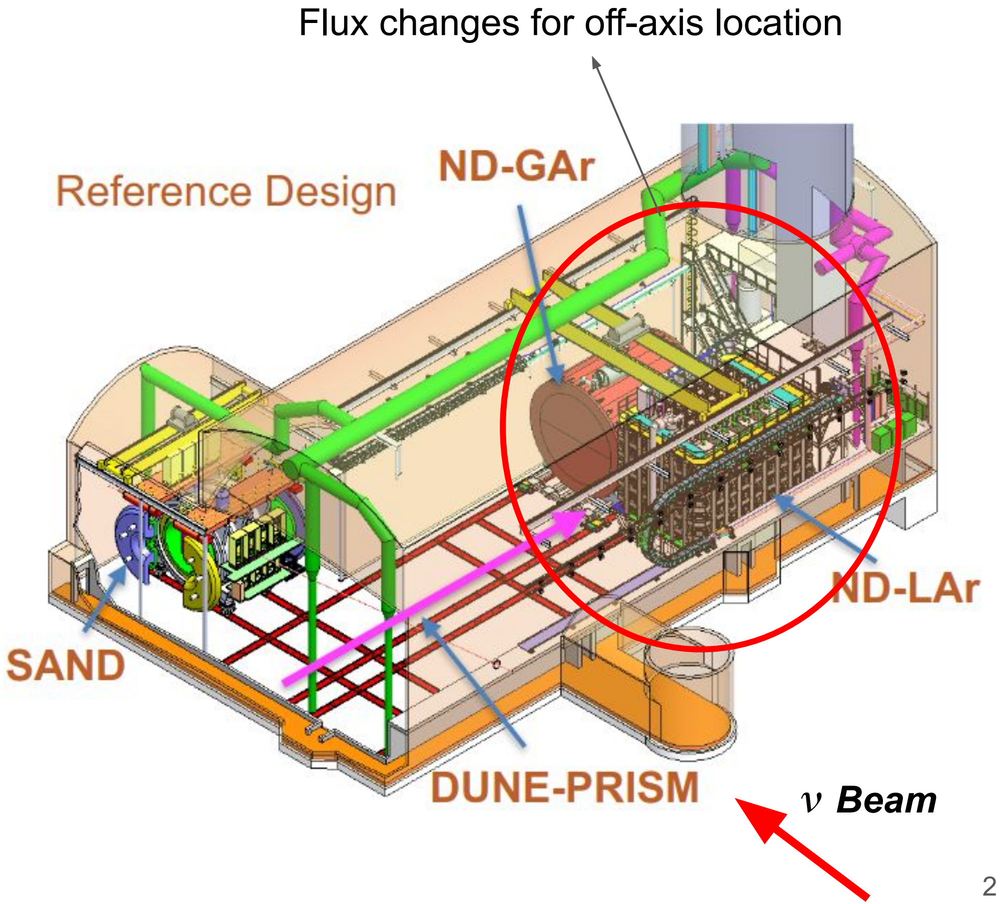
DUNE ND complex design

DUNE has a broad band beam peaked around 2.5 GeV -> CP measurement relying on the spectral change between ND and FD

SAND is the only system on-axis all the time to ensure the beam spectral stability -> Need good neutrino and antineutrino energy reconstructions

SAND is the only non-Argon target for the neutrino interaction measurement -> Need enough mass and a variety of interaction channels



SAND (System for on-Axis Neutrino Detection)

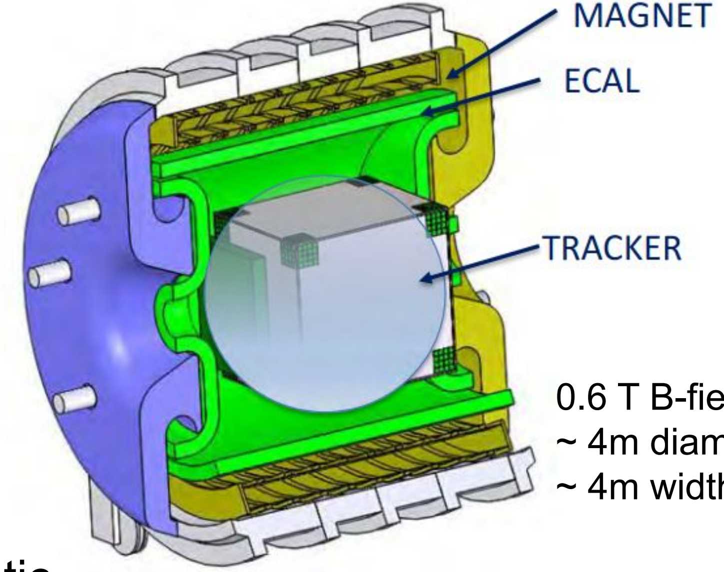
On-axis permanently

Better-known target and well-established technologies

Diversity in the SAND consortium: > 100 people from 9 countries

KLOE magnet + ECAL + inner tracking system + LAr target

- A Superconducting magnet + electromagnetic calorimeter re-purposed from the KLOE experiment in Italy
- A newly built inner tracker system capable for precise neutrino and antineutrino energy determination



0.6 T B-field
~ 4m diameter
~ 4m width

SAND inner tracker design

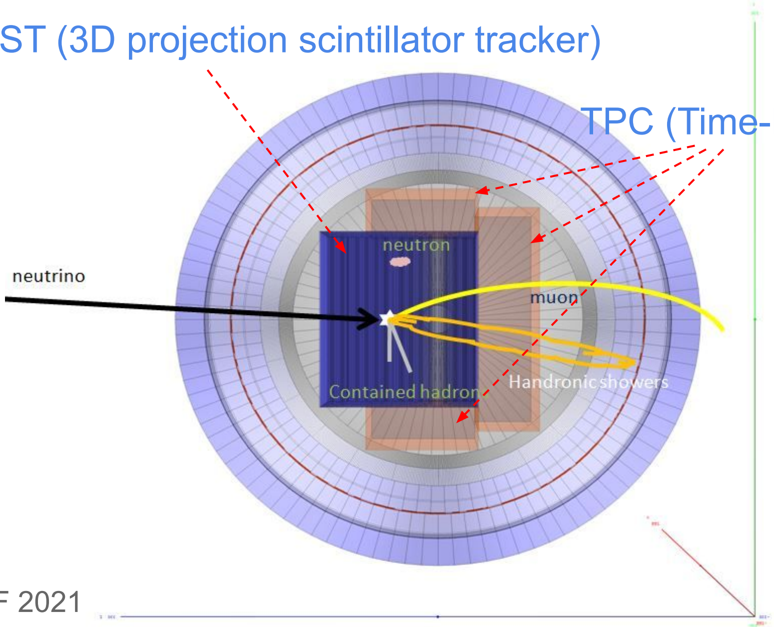
Reference design: ECAL + 3DST + low density tracking system (either TPC or STT) + LAr

Alternative design: ECAL + STT + LAr

The inner tracker design finalization is ongoing.

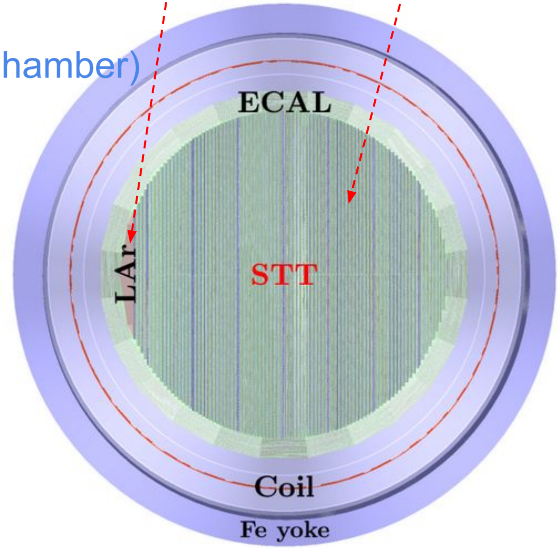
3DST (3D projection scintillator tracker)

TPC (Time-Projection Chamber)



Liquid Ar meniscus

STT (Straw Tube Tracker)



ECAL in SAND

24 barrel modules

60 cells (5 layers)

4.3m total length

2 x 32 endcaps modules

Operated from 1999 till March 2018 in KLOE experiment with good performances and high efficiency

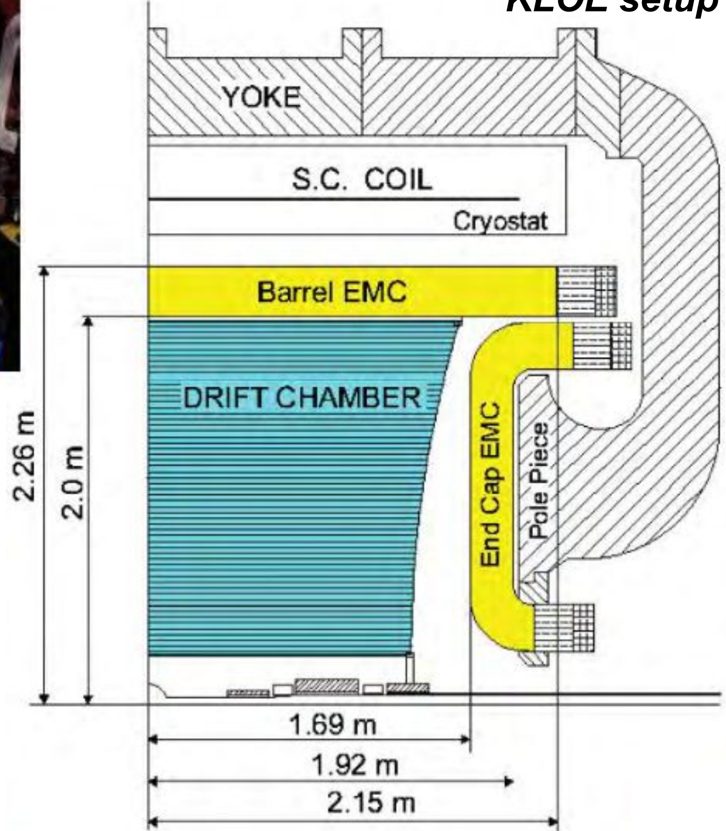
Energy resolution: σE/E=5.7%/√E(GeV)

Time resolution: σt=54ps/√E(GeV)⊕50 ps

Nucl. Instrum. Meth. A482 (2002) 364-386

~ 100 ton total mass

KLOE setup



Drift Chamber to be replaced by SAND inner tracker

3D Projection Scintillator Tracker (3DST)

4π angle coverage
High light yield (50 pe single fiber)
Fast timing (0.9 ns single fiber)
Fine granularity

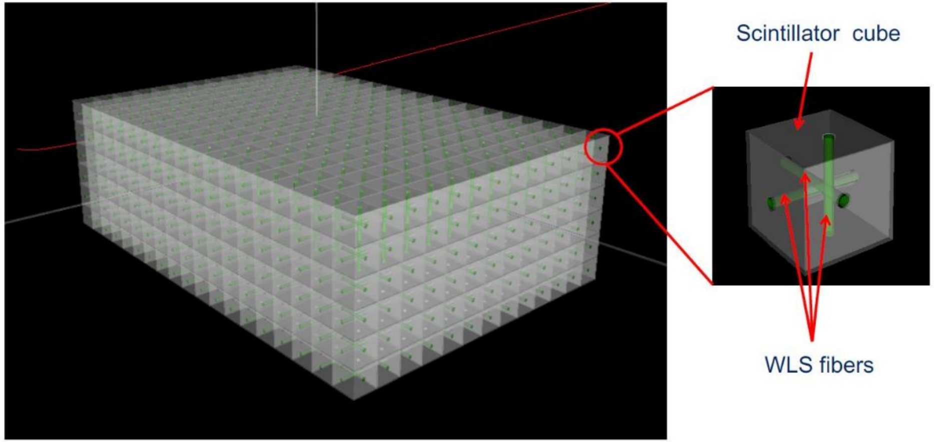
Plastic scintillator detector with 1.5 cm x 1.5 cm x 1.5 cm cubes

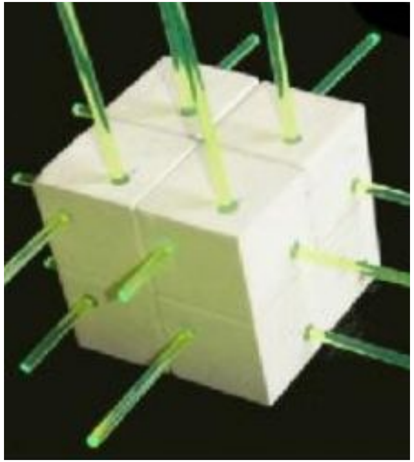
Light collected by 3 wavelength shifting fibers

Ecah cube etched to keep light entrapped inside the cube => no different materials

Read out by MPPC at 3 faces

Functionally identical to T2K superFGD detector (CERN-SPSC-2019-001)





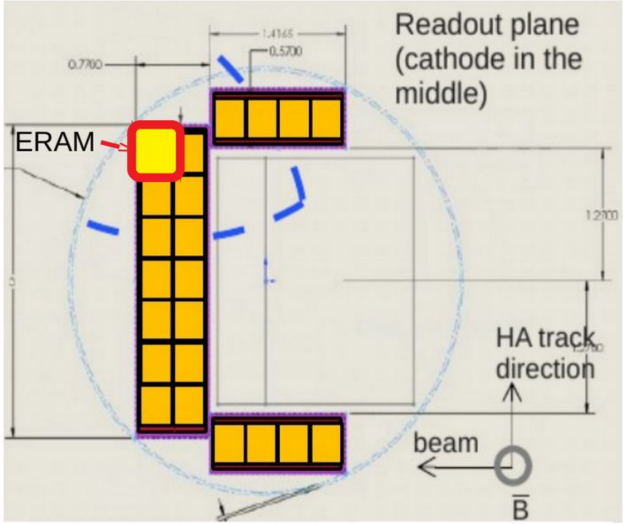
Gaseous TPC

Momentum resolution: ~4 % depends on magnetic field, pads numbers and size

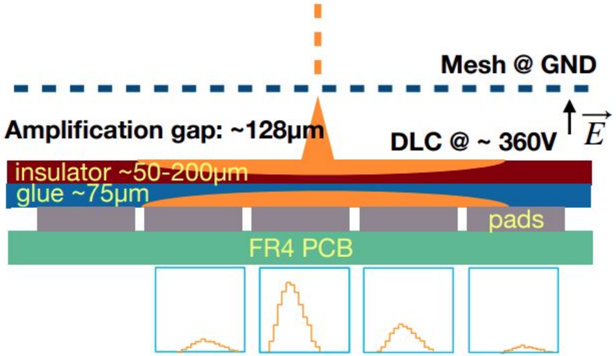
Momentum scale: ~2 % depends on uniformity of B-field, E-field, alignment → can be calibrated

Detectors which we know how to build and proved stable over time

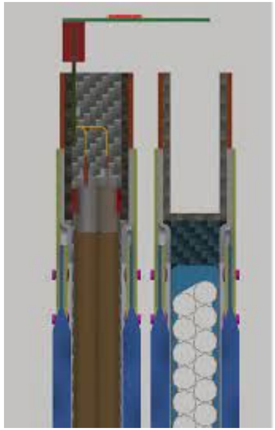
Several detector prototypes tested on dedicated cosmic test bench at Saclay (France) → available for SAND prototypes test



resistive anode MicroMegas



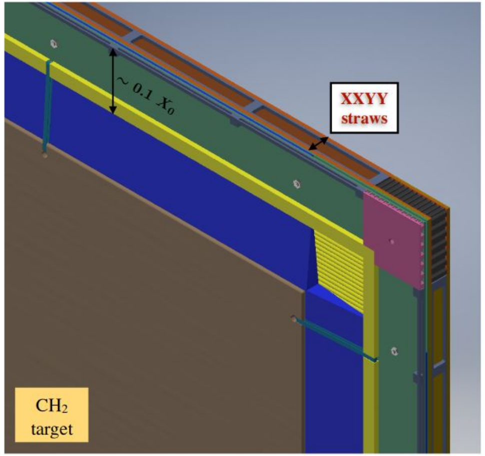
Straw Tube Tracker (STT)

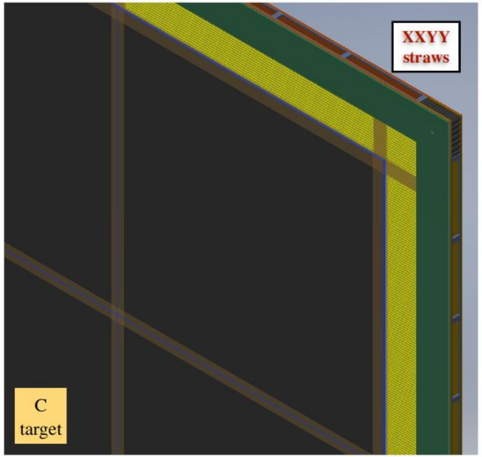


Thin (1-2% X0) passive targets (~97% of STT mass) of high purity interleaved with 4 XXYY straw layers of negligible mass: 0.005 ≤ ρ ≤ 0.18 g/cm3

"Solid" hydrogen target from a model-independent subtraction CH2 and graphite (C) targets after kinematic selection of H

Front-end readout with VMM3 ASICs, back-end readout based on FELIX (DUNE FD)





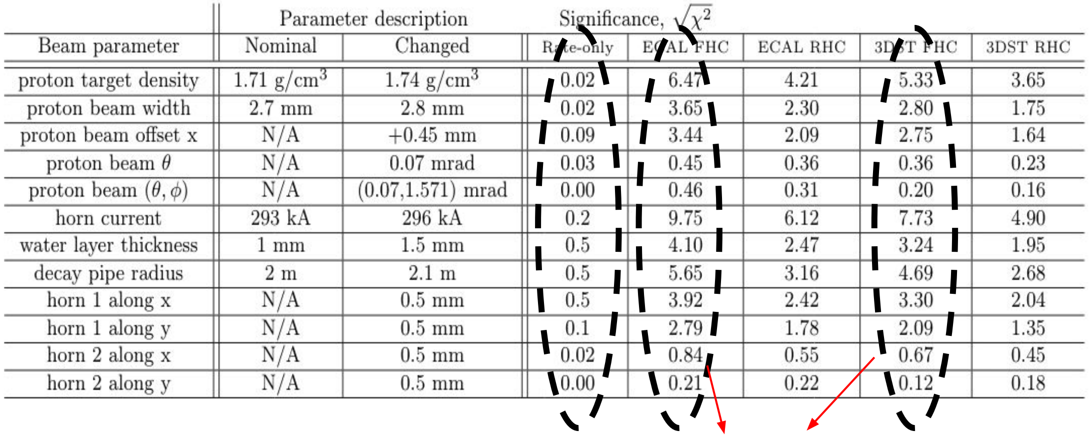
Beam spectral monitoring

PRISM requires the Ar detectors changing flux from time to time.

Two cases are compared :

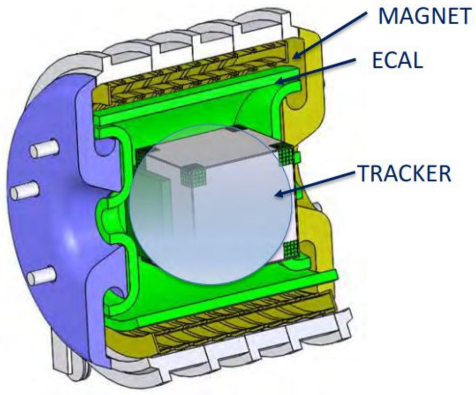
- SAND with 3DST+TPC
- T2K INGRID-like rate-only detector array (4 with each 7 tons)

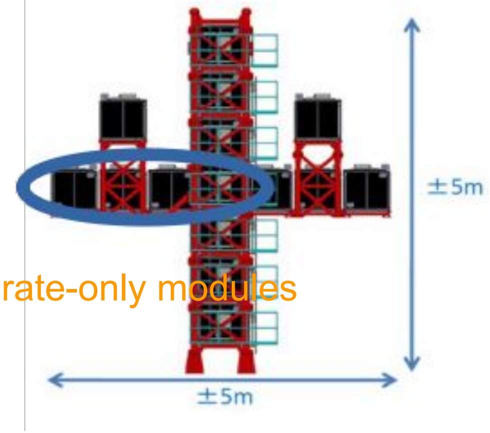
-> Precise spectral monitoring can provide both trouble-finding and diagnosis.



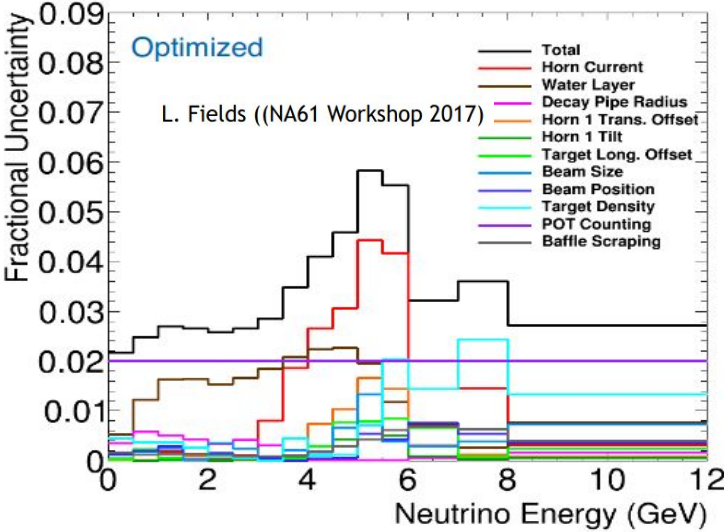
Beam parameter	Parameter description		Significance, $\sqrt{\chi^2}$				
	Nominal	Changed	Rate-only	ECAL FHC	ECAL RHC	3DST FHC	3DST RHC
proton target density	1.71 g/cm^3	1.74 g/cm^3	0.02	6.47	4.21	5.33	3.65
proton beam width	2.7 mm	2.8 mm	0.02	3.65	2.30	2.80	1.75
proton beam offset x	N/A	+0.45 mm	0.09	3.44	2.09	2.75	1.64
proton beam θ	N/A	0.07 mrad	0.03	0.45	0.36	0.36	0.23
proton beam (θ, ϕ)	N/A	(0.07,1.571) mrad	0.00	0.46	0.31	0.20	0.16
horn current	293 kA	296 kA	0.2	9.75	6.12	7.73	4.90
water layer thickness	1 mm	1.5 mm	0.5	4.10	2.47	3.24	1.95
decay pipe radius	2 m	2.1 m	0.5	5.65	3.16	4.69	2.68
horn 1 along x	N/A	0.5 mm	0.5	3.92	2.42	3.30	2.04
horn 1 along y	N/A	0.5 mm	0.1	2.79	1.78	2.09	1.35
horn 2 along x	N/A	0.5 mm	0.02	0.84	0.55	0.67	0.45
horn 2 along y	N/A	0.5 mm	0.00	0.21	0.22	0.12	0.18

Two independent samples with spectral information



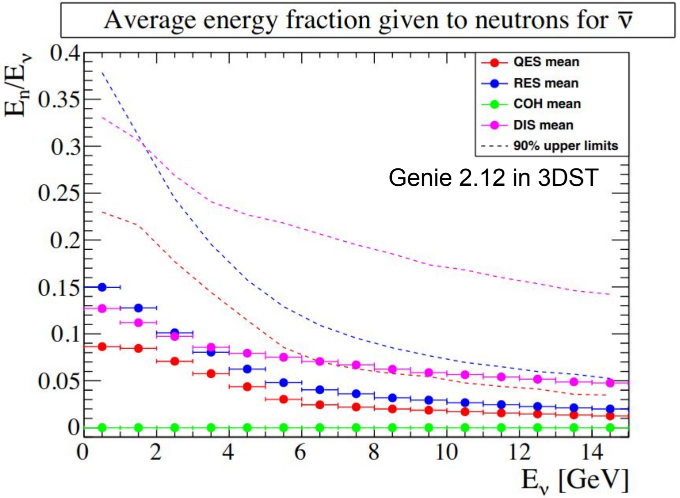


4 rate-only modules

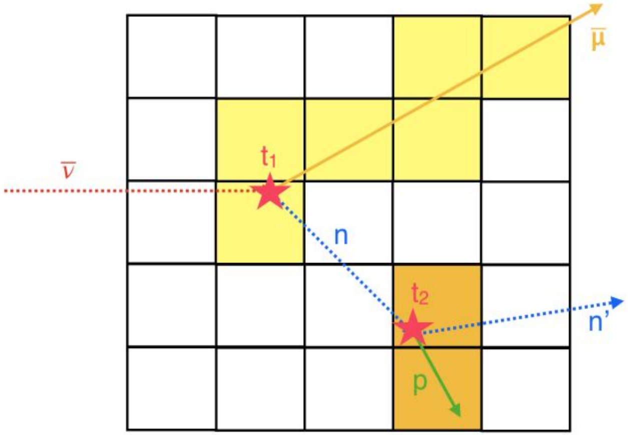


L. Fields ((NA61 Workshop 2017)

Neutron detection in 3DST



Time-of-flight technique



Neutron carrying out a large fraction of energy in antineutrino interaction

Time of flight and travel distance between the vertex and neutron induced hit cluster can be obtained.

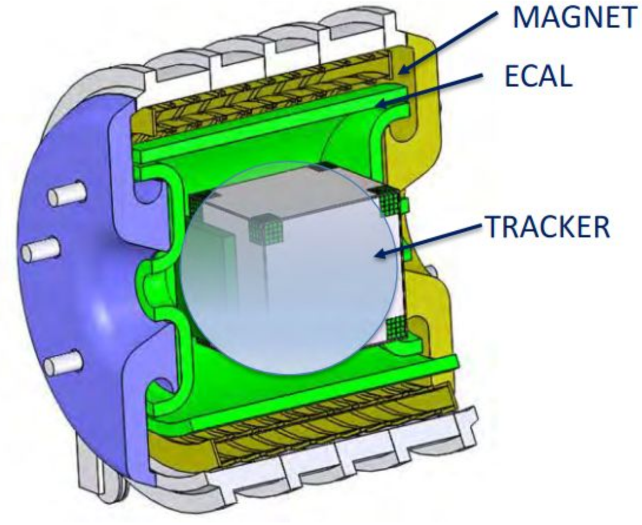
- Not only tagging, we can detect the neutron kinetic energy on an event-by-event basis!
  - ***Wednesday 15:30 to 16:00 (Eastern) two talks about a neutron beam test by Andriaseta Sitraka (SDSMT) and Eric Chong (UPenn)***

Summary

SAND (System for on-Axis Neutrino Detection) as part of the DUNE ND complex can provide strong physics programs:

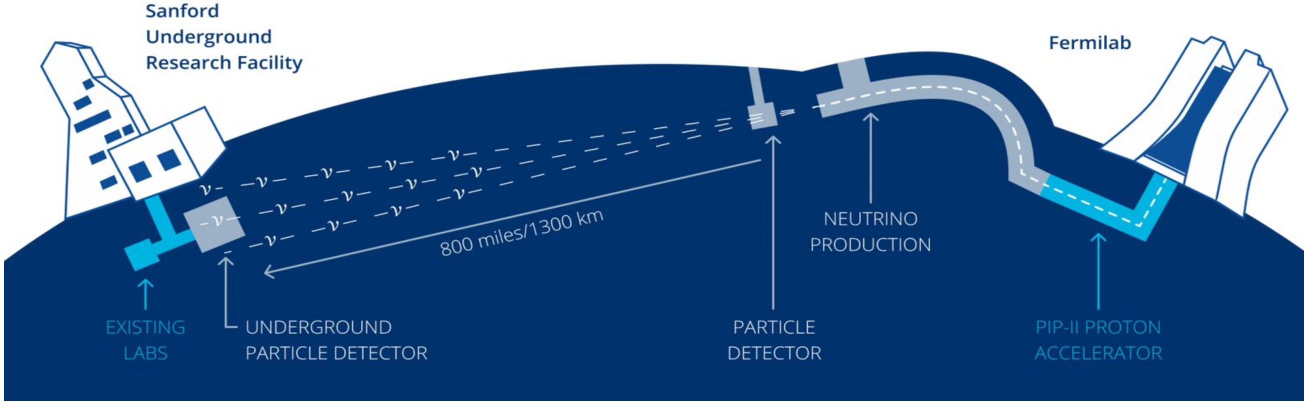
- Monitor the beam
- Measure the absolute flux for all neutrino flavors
- Constrain the cross section models

Inner tracker redesign is ongoing.



Backups

Deep Underground Neutrino Experiment (DUNE)



Neutrinos generated from hadron decays caused by proton hitting targets

Two opposite horn currents changing focused hadron charge resulting in neutrino (FHC) and antineutrino (RHC) modes

A FD (far detector) with a very long baseline to measure the oscillated neutrino spectrum and a ND (near detector) to measure un-oscillated flux and control the systematic uncertainties

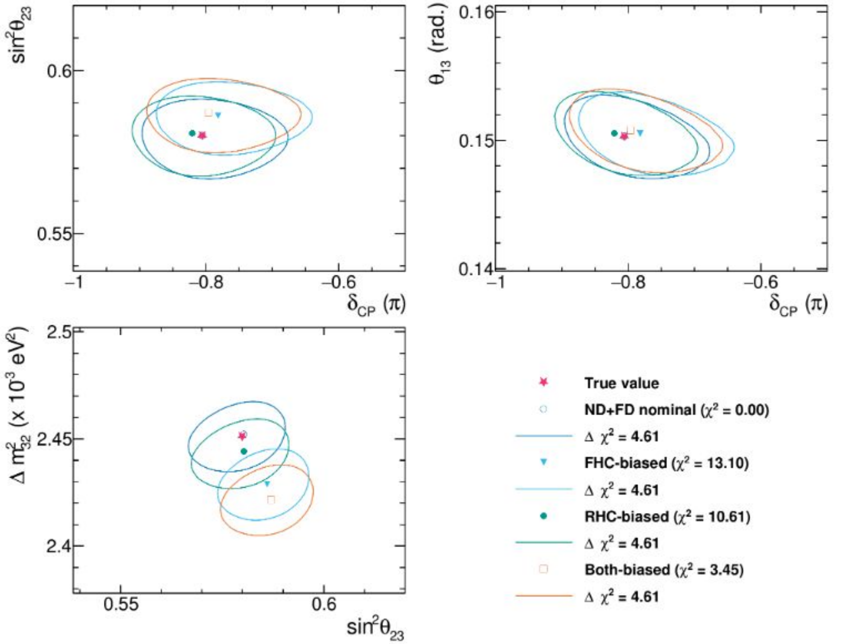
Beam monitoring necessity

PRISM requires the Argon detectors change fluxes from time to time -> insensitive to the beamline changes

An unnoticed beam change can bias the oscillation parameter measurements -> 9kA horn current shift as an example

SAND able to monitor the spectral change in the beamline

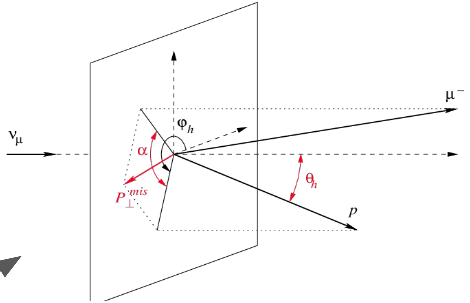
The oscillation parameter postfit 90% confidence contours with true and fake data best-fit values. FHC, RHC and both flux changes were assumed and shown in different colors. The best fit χ^2 values are given in the legend.



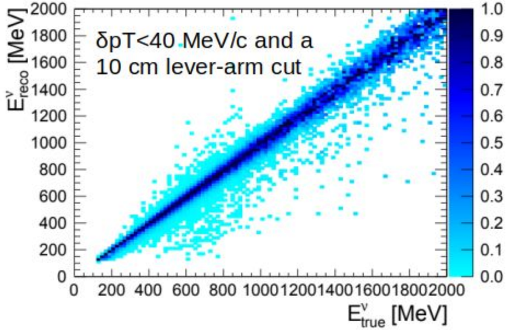
Flux constraints (FHC and RHC)

In RHC, with neutron KE detection, 3DST can immediately provide a number of unique channel selections that can be used to constrain the flux.

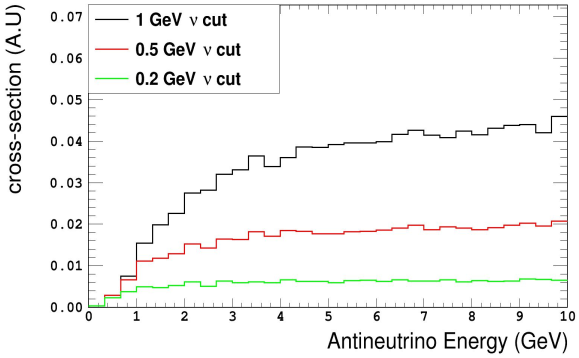
- Low transverse momentum sample
- Low energy transfer sample (low ν)



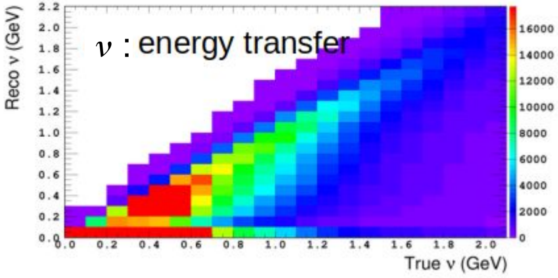
Phys. Rev. D 101, 092003 (2020)



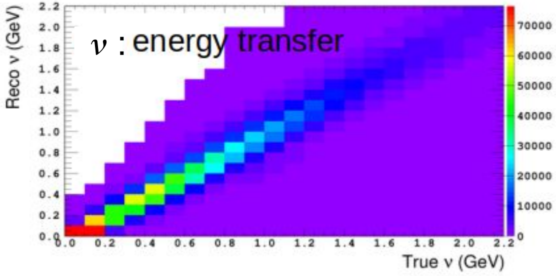
Cross section shape (A.U)



RHC without neutron



with neutron



Different target materials -> model tuning

A Carbon and Hydrogen target

- Neutrino interaction modeling not good enough especially at DUNE energy
- DUNE to be model dependent => unrealistic to expect a model that suitable for an oscillation analysis without proper validation and tuning informed by a different target and even external data
- In the DUNE era, a lot of new models with A-dependency included expected

Relativistic Mean Field model

arXiv.1902.06338

2.2 GeV electron with angle 15.5 deg.