The SAND detector at the DUNE near site

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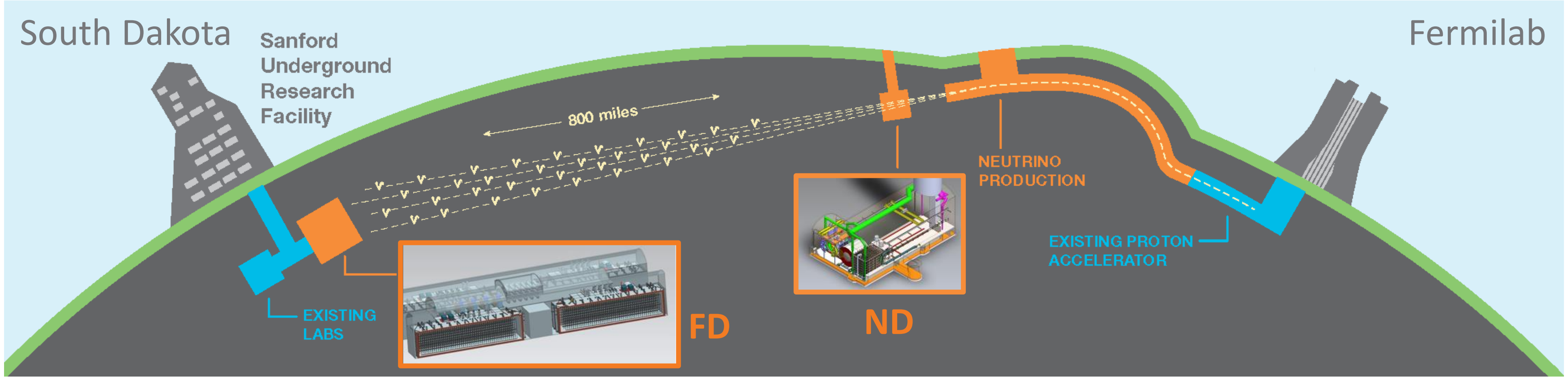
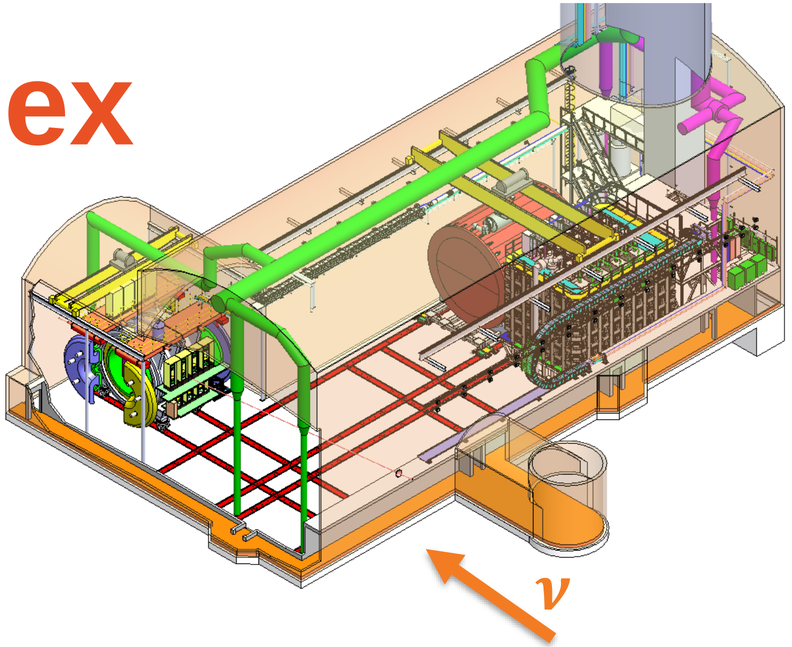
DUNE: Deep Underground Neutrino Experiment



- Rich research program:
  - **neutrino oscillations** (leptonic CP violation, Neutrino Mass ordering, PMNS matrix measurements)
  - **Supernova neutrino physics**
  - **BSM physics** (baryon number violation and others)
- **New neutrino ($\nu/\bar{\nu}$) beam**: wide band, peak at 2.5 GeV and high power proton beam (1.2 MW upgradable to 2.4 MW)
- Near and Far Detector:
  - **Far Detector (FD):** four Liquid Argon Time Projection Chambers (LArTPC) of 17kton, located 1.5 km underground and 1300 km away from the neutrino source
  - the **Near Detector complex (ND)**

The Near Detector complex



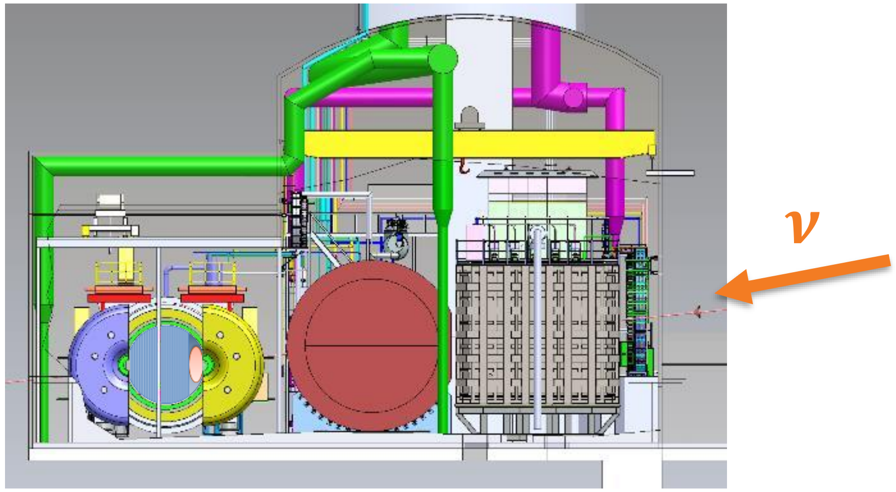
Near detector will be located 575 m from the neutrino source

Three main detectors:

- **ND-LAr**: a 67 t modular LArTPC

- **TMS / ND-GAr**: Temporary Muon Spectrometer (Phase 1) / high pressure gaseous argon TPC, surrounded by an electromagnetic calorimeter in a 0.5 T magnetic field (Phase 2)

- **SAND (System for on Axis Neutrino Detection)**: a magnetized multi-purpose detector



SAND

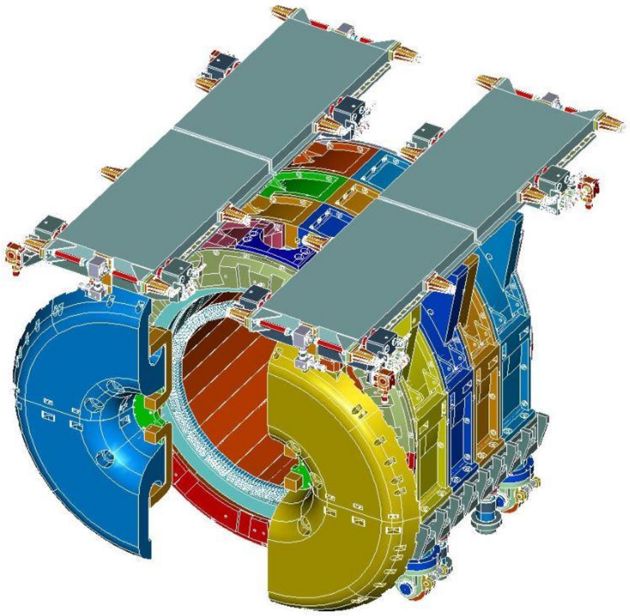
SAND goals:

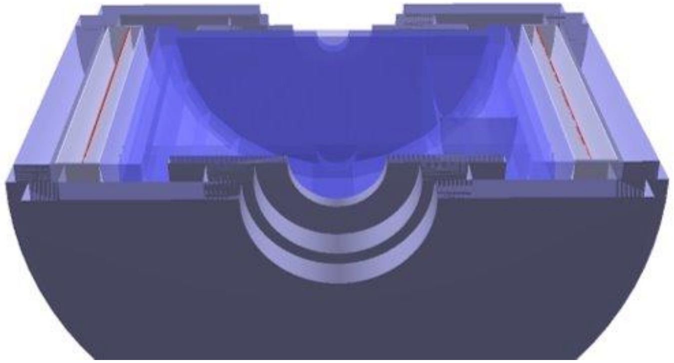
- **beam monitoring**
- **flux measurements**
- **constrain nuclear effects systematics**

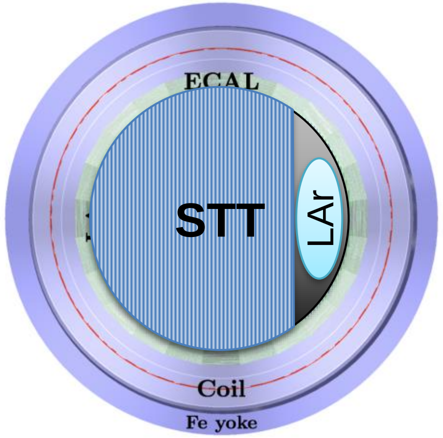
The SAND detector:

- **superconducting magnet**
- **Electromagnetic Calorimeter (ECAL)**
- **Straw-Tube-Tracker (STT)** complemented with CH_2 and C targets
- **1-ton LAr active target (GRAIN)**

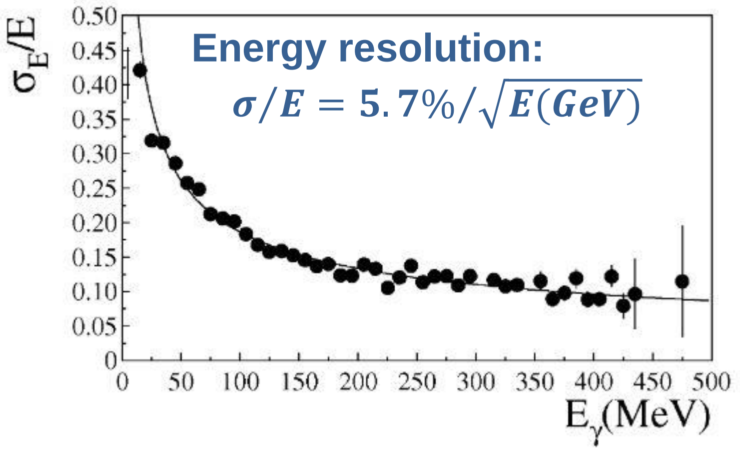
} Repurposed from the KLOE experiment at Frascati National Laboratories



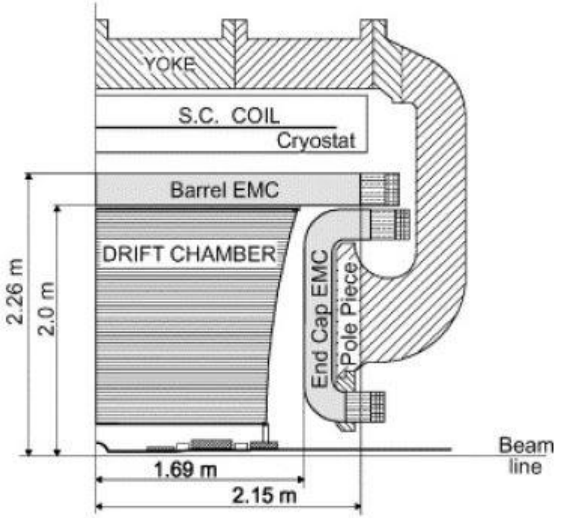


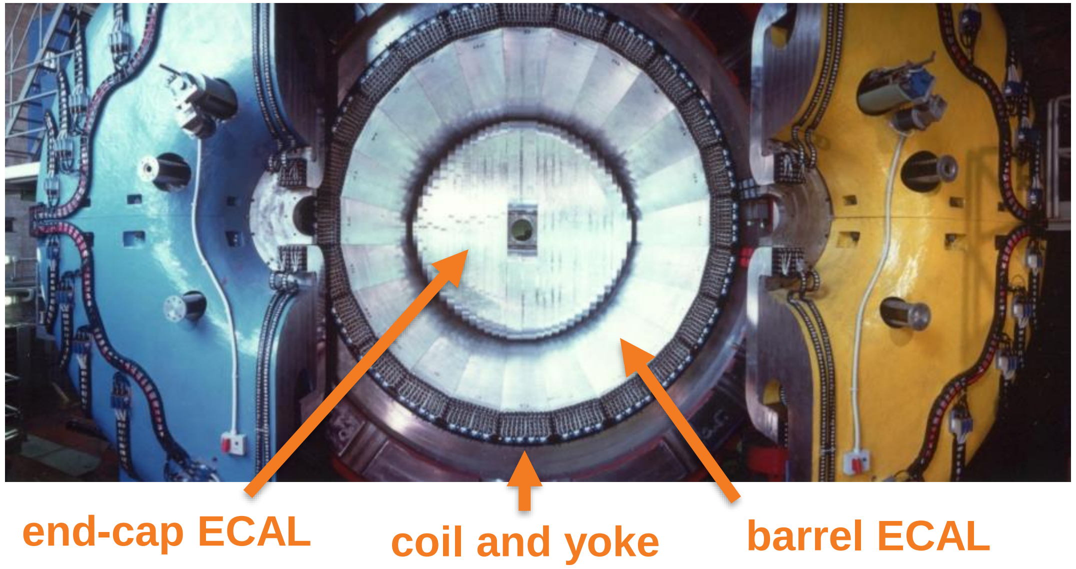


SAND – magnet and ECAL

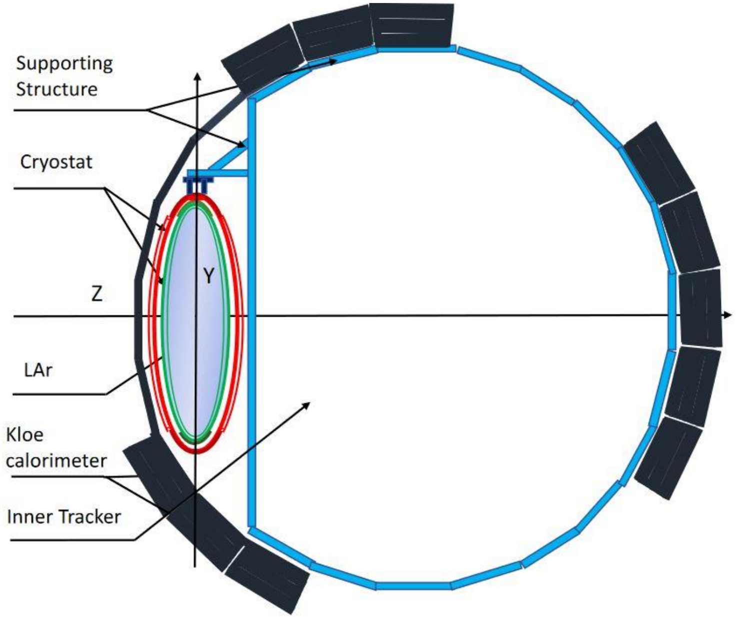


- ECAL:
  - fine **sampling calorimeter** made of **lead-scintillating fibres**
  - readout on both ends by **4800 PMTs**
  - **barrel ECAL** composed of 24 trapezoidal sectors, 4.3 m long
  - **end-caps ECAL** composed of 26 «C» shaped vertical modules
- Magnet:
  - superconducting coil
  - 5m bore
  - magnetic field of 0.6 T
  - 475 tons iron yoke

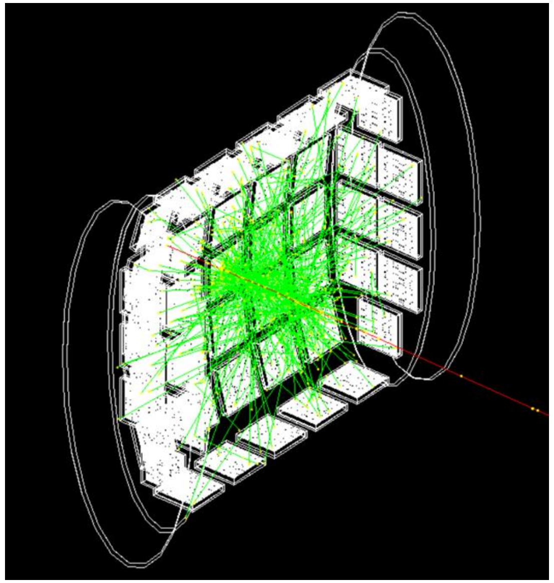




SAND - GRAIN



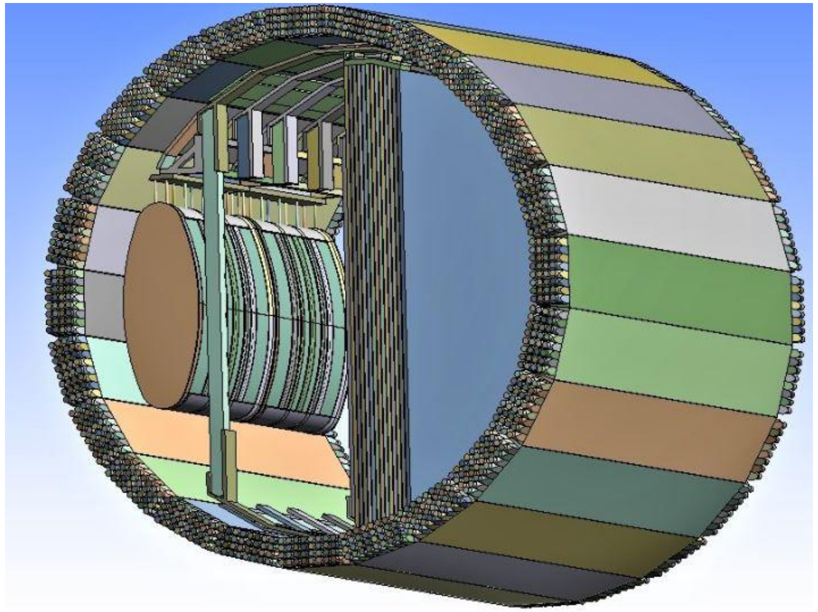
- **1-ton LAr target: GRAIN** (GRanular Argon for Interactions of Neutrinos)
- cryostat made of C-composite materials and Aluminum, overall radiaton length to $\sim \mathbf{1}\, \boldsymbol{X_0}$ (cryostat+LAr)
- GRAIN will be used as:
  - **passive target:** to study $\nu - Ar$ interactions, in synergy with STT and ECAL
  - **active target:** to perform imaging on prompt VUV scintillation light (readout by arrays of Silicon Photo-Multipliers)



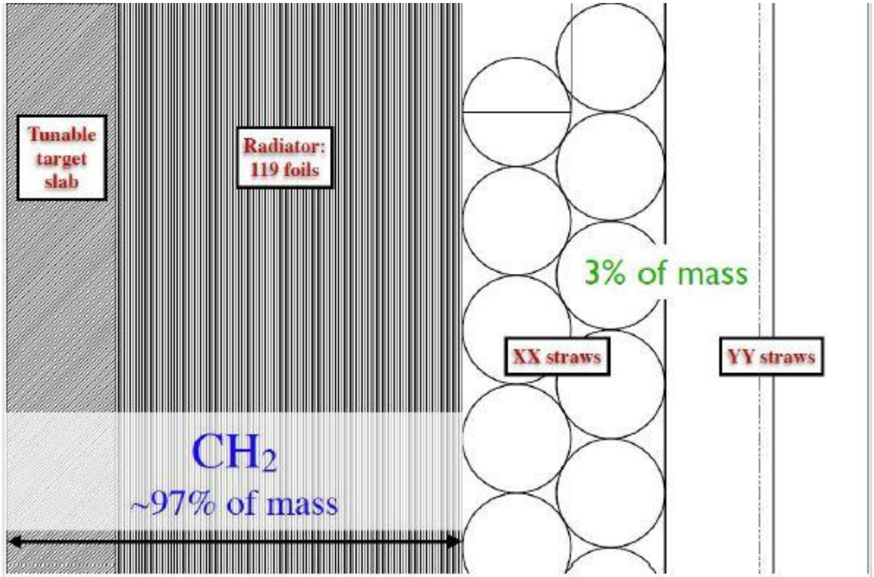
See M. Vicenzi's talk on neutrino event reconstruction in GRAIN

SAND - STT

- **Diffuse target tracker system:**
  - 90 modules with an overall fiducial mass of ~5 t.
  - Each module is composed of **4 planes of straw tubes** (5 mm diameter) in XXYY disposition, a tunable passive **target** ($CH_2, C, \ldots$) and a **radiator** of polypropylene foils



- The STT design grants:
  - reconstruction of **transverse plane kinematics** variables
  - $\boldsymbol{e/\pi}$ **separation** (transition radiation) and $\boldsymbol{p/\pi/K}$ **identification** (dE/dX and range)
  - $\boldsymbol{4\pi}$ **detection of** $\boldsymbol{\pi^0}$ from γ conversion within the STT volume
  - **neutron detection**, in synergy with ECAL proven capabilities



SAND – beam monitoring

- **Continuous monitoring** of the neutrino beam is necessary to identify potential variations that could directly affect the FD oscillation analysis
- monitoring performed by reconstructing the **neutrino interaction** (**energy spectra** and **spatial distribution**)

- SAND will have enough sensitivity to **detect most of the beam variations** with **1 week** of data taking

Proton beam parameter	1σ deviation as given by beam group	New $\sqrt{\Delta\chi^2(E_\nu)}$ true	New $\sqrt{\Delta\chi^2(E_\nu)}$ rec
Horn current	+3 kA	12.57	9.44
Water layer thickness	+0.5 mm	4.69	3.58
Proton target density	+2%	5.28	4.07
Beam sigma	+0.1 mm	4.41	3.53
Beam off set X	+0.45 mm	5.11	3.54
Beam theta phi	0.07 mrad θ, 1.57 ϕ	0.62	0.28
Beam theta	0.070 mrad	0.91	0.58
horn 1 X shift	+0.5 mm	4.70	3.42
horn 1 Y shift	+0.5 mm	5.27	3.87
horn 2 X shift	+0.5 mm	1.18	0.69
horn 2 Y shift	+0.5 mm	1.31	0.77

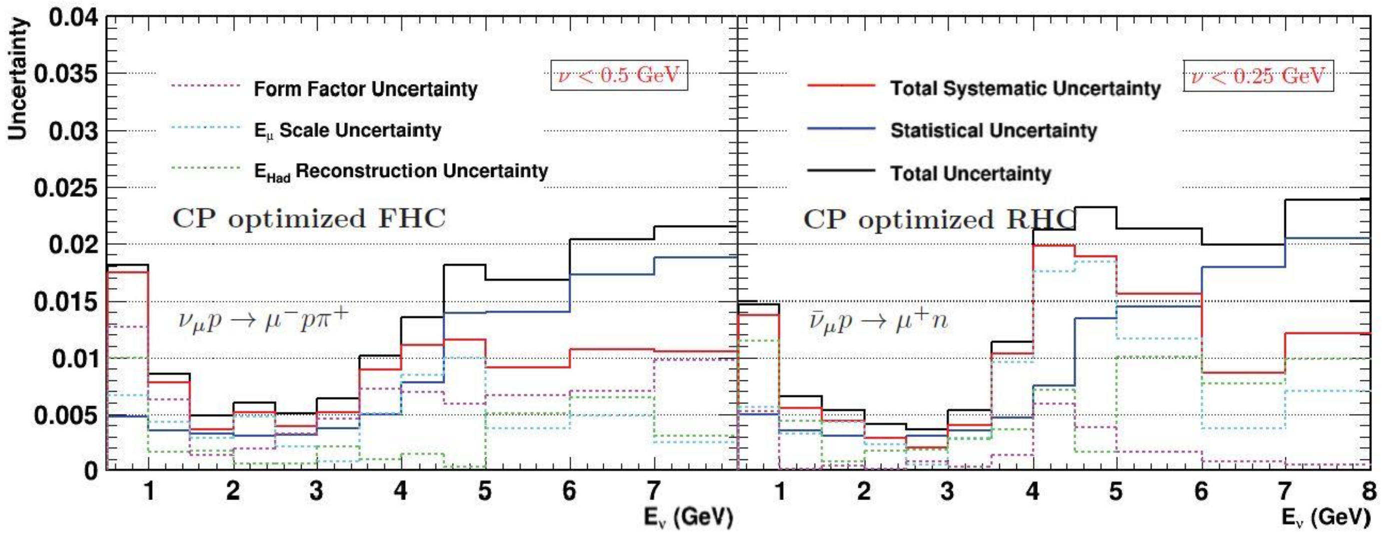
1 week of data taking

SAND – flux measurements

- neutrino flux measurements $\phi(E_\nu)$ is a mandatory condition to **extract oscillation probability** from measured neutrino interactions:

$$N_X = \int P_{osc}(E_\nu) * \phi(E_\nu) * \sigma_X(E_\nu) * R_{phys}(E_\nu, E_{vis}) * R_{det}(E_{vis}, E_{rec}) dE_\nu$$

- **absolute and relative ν fluxes** evaluated by a large sample of $\nu/\overline{\nu}$ interactions on H within the STT



Systematic uncertainties on flux measurement (5 years data-taking, STT-only)

SAND – constrain nuclear effects

- complex modelling of neutrino interaction in argon can be improved by **direct comparison of neutrino interactions with hydrogen**

$$N_X = \int P_{osc}(E_\nu) * \phi(E_\nu) * \sigma_X(E_\nu) * R_{phys}(E_\nu, E_{vis}) * R_{det}(E_{vis}, E_{rec}) dE_\nu$$

known to 1% on H

Measured with large statistic

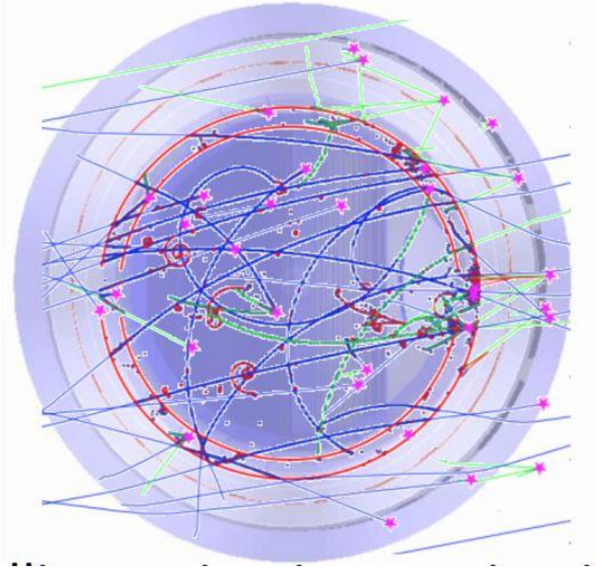
$R_{phys} \equiv 1$

$\delta p/p$ 0.2%
calibrated from
$K_0 \longrightarrow \pi^+ \pi^-$
in STT volume

- SAND allows to **constrain the product** $\sigma_X(E_\nu) * R_{phys}(E_\nu, E_{vis})$ on Ar by a direct comparison with H within the same detector

SAND – background rejection

- **cosmic radiation** and **ambient radioactivity** backgrounds can be suppressed by requiring in-time coincidence with beam spill
- the most critical background: **beam related interactions** in the material surrounding the detector
- the expected CC+NC event rate per spill is 84 (45) events/spill for neutrinos (anti-neutrinos)



Simulation of ν interaction in a spill

The external background can be rejected by means of simple cuts to timing and topological information from the subdetectors

Signal efficiency (%)	Background efficiency (%)	Purity (%)
92.8	0.003	99.6

Conclusions

- DUNE is a new generation long baseline neutrino experiment that will exploit a Near and Far Detector structure

- the SAND detector is a key element of the DUNE experiment. It is expected to start data taking operation since Day 1 of the DUNE program, foreseen for 2030

- the excellent beam monitoring capabilities will significantly contribute to the long-baseline oscillation measurements

- SAND also offers the possibility to further constrain flux and nuclear effects systematics