The SAND tracking system at the DUNE Near Detector

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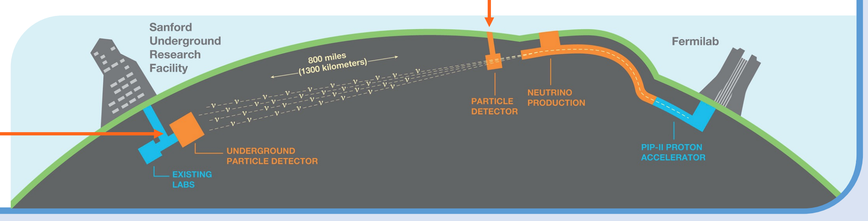
The DUNE experiment

- DUNE (Deep Underground Neutrino Experiment) is a next-generation neutrino physics experiment with an ambitious physics program, which includes [1]:
  - Measurements of δ_{CP}, mass ordering , unitarity of the PMNS matrix
  - Searches for Physics Beyond the Standard Model
  - Measurement of the neutrino flux from galactic supernovae

- DUNE will be located along the LBNF neutrino beamline, the most intense ever built, with a wide-band and an energy peak at 2.5 GeV.
- DUNE will feature a ~1300 km baseline between the Near Detector and the Far Detector experimental sites.

Far Detector
- At SURF, ~1300 km away from the ν-source
- Four innovative 17 kton LArTPCs

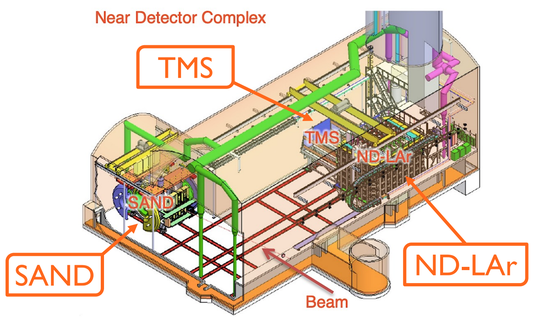
Near Detector
- At Fermilab, 574 m away from the ν-source



The DUNE Near Detector

- The DUNE Near Detector will carry out precision measurements to monitor the neutrino beam, limit its systematics and improve neutrino interaction models [2].

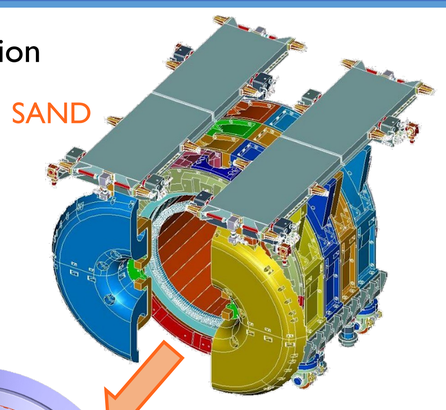
- It will have three components:
  - ND-LAr: a modular LArTPC with a fiducial mass of ~50 ton
  - TMS: a Muon Spectrometer
  - SAND: System for on-Axis Neutrino Detection

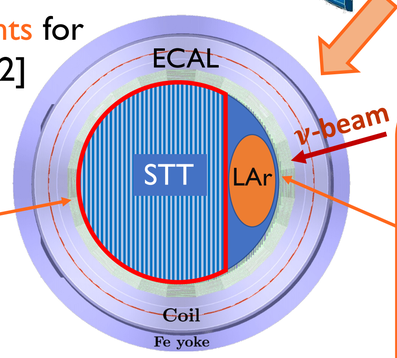


SAND will stand at a fixed position along the beam axis, while ND-LAr and TMS will be movable off-axis, for data-taking in different energy intervals.

The SAND detector

- SAND is a multi-purpose detector, capable of precision tracking and calorimetry, featuring:
  - a 0.6 T superconducting magnet
  - an electromagnetic calorimeter (ECAL) [3]
  - GRAIN: a LAr active target (~1 ton)
  - STT: a low-density tracker based on Straw Tubes with distributed target mass [2]
- SAND will carry out key measurements for the Near Detector physics program [2]





ECAL
- Lead-scintillator fibres, ~15 X_0
- $\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$
- $\sigma_t = 54/\sqrt{E(GeV)}$ ps

GRAIN
- LAr active target (~1 X_0)
- Study of ν-Ar interactions
- Imaging of LAr scintillation light

The SAND physics program

- Constant beam monitoring to detect variations in the energy spectrum and in the spatial distribution of ν_μ-CC events
- Most deviations will be detectable on a weekly basis with $\sqrt{\Delta\chi^2} > 3$ [4]

- Limiting the uncertainties on the $\nu/\bar{\nu}$ flux and on nuclear smearing on the reconstructed energy
- Measurements in hydrogen to unfold the number of detected events in Argon [5]

- Rejection of the background from neutrino interactions with the external material using ECAL and STT
- Multivariate analyses allow to reach 3×10^{-5} rejection factor, 92.7% efficiency and a purity of 99.6% [4]

- Contribution to the Near Detector physics program of precision measurements [4]:
  - measurements of $\sin\theta_W$ and further EW-physics
  - isospin physics tests
  - QCD and nuclear structure studies

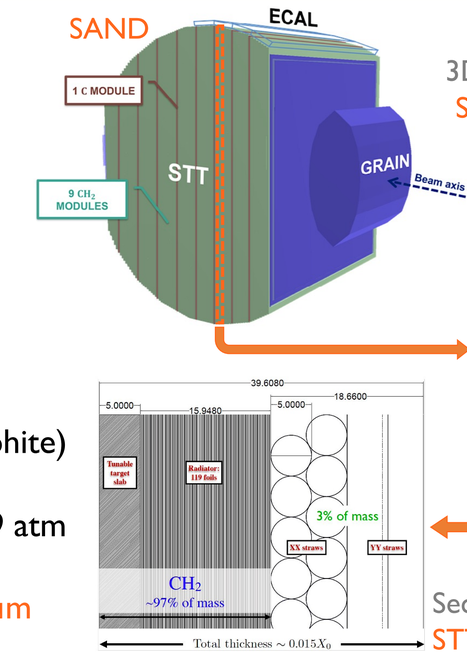
The SAND Straw Tube Tracker (STT)

- Low-density tracker based on 5 mm diameter Straw Tubes [2]

84 modules, each with:
1. thin layers ($1-2\%\ X_0$) of target materials
2. Transition Radiation Detector
3. four straw tube layers in a XXYY configuration

- Base layout: one layer of C (graphite) every nine of CH_2 (polypropylene)
- Gas mixture: Xe/CO_2 (70%/30%) at 1.9 atm

- Single-point spatial resolution < 200 μm



3D view of an STT module

Section of an STT module

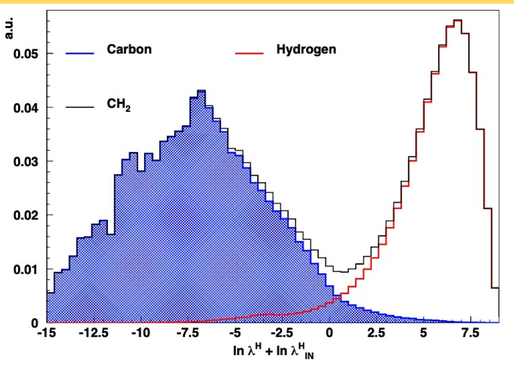
"Solid" Hydrogen Measurements

- Critical measurements for DUNE:
  - determination of the systematic error on $\nu/\bar{\nu}$-flux reconstruction
  - reduction of the smearing from nuclear effects on the reconstructed energy

- Studying CC $\nu(\bar{\nu})$-hydrogen interactions [5]:

  $\nu_\mu p \to \mu^- p\pi^+$, $\bar{\nu}_\mu p \to \mu^+ p\pi^-$ and $\bar{\nu}_\mu p \to \mu^+ n$
  - overall accuracies of $< 1\%$ can be reached in the DUNE beam energy range
  - model-independent constraints on nuclear effects on initial and final states can be set

- A high statistics of ν-CC interactions on H can be reached subtracting measurements on C – targets from those on CH_2–targets ("Solid" Hydrogen) [6]



Kinematic identification of $\nu_\mu p \to \mu^- p\pi^+$ interactions on H in STT [7].

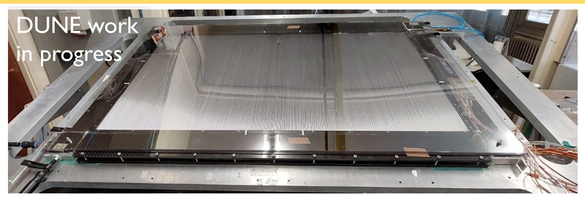
1.2 MW beam statistics		
Interaction	CH_2	H
ν_μ-CC (FHC, 5 yrs.)	$35 \cdot 10^6$	$3.6 \cdot 10^6$
$\bar{\nu}_\mu$-CC (RHC, 5 yrs.)	$13 \cdot 10^6$	$2.9 \cdot 10^6$
2.4 MW beam statistics		
Interaction	CH_2	H
ν_μ-CC (FHC, 5 yrs.)	$66 \cdot 10^6$	$6.5 \cdot 10^6$
$\bar{\nu}_\mu$-CC (RHC, 5 yrs.)	$24 \cdot 10^6$	$4.3 \cdot 10^6$

STT CC-event statistics for the planned beam power options and modes [6].

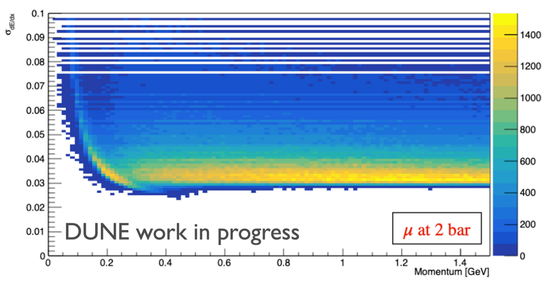
STT prototype: construction and testing

- A prototype STT module (120 x 80 cm^2) has been successfully built and tested at CERN
- Construction procedures and mechanical design have been validated
- Straw and readout performances were tested at a muon testbeam

- Ongoing work on the design of the final SAND modules
- Design of a back-up tracker based on Drift Chambers is ongoing



120 x 80 cm^2 prototype of an STT module.



Measured prototype dE/dx resolution

Conclusions and prospects

- SAND will measure the variation in the LBNF neutrino beam spectrum at the DUNE Near Detector and will carry out a broad physics program
- The SAND STT tracker will enable precision measurements on the neutrino flux
- Solid Hydrogen measurements will allow a significant reduction of the systematics due to neutrino-nucleus interactions
- The prototyping phase is ongoing, with positive results
- The design of the STT modules and the setup of production sites are in progress

References

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2. Abud, A. Abed, et al. "Deep underground neutrino experiment (DUNE) near detector conceptual design report." *Instruments* 5.4 (2021): 31.
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5. Duyang, H., et al. "A precise determination of (anti) neutrino fluxes with (anti) neutrino-hydrogen interactions." *Physics Letters B* 795 (2019): 424.
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7. Duyang, H., et al. "A Novel Approach to Neutrino-Hydrogen Measurements. *arXiv:1809.08752*.