PROCEEDINGS OF SCIENCE

The SAND detector at the DUNE near site

G. Ingratta [a,*] on behalf of the DUNE collaboration

[a] *Istituto Nazionale di Fisica Nucleare,*
Viale C. Berti Pichat 6/2, Bologna 40127, Italy

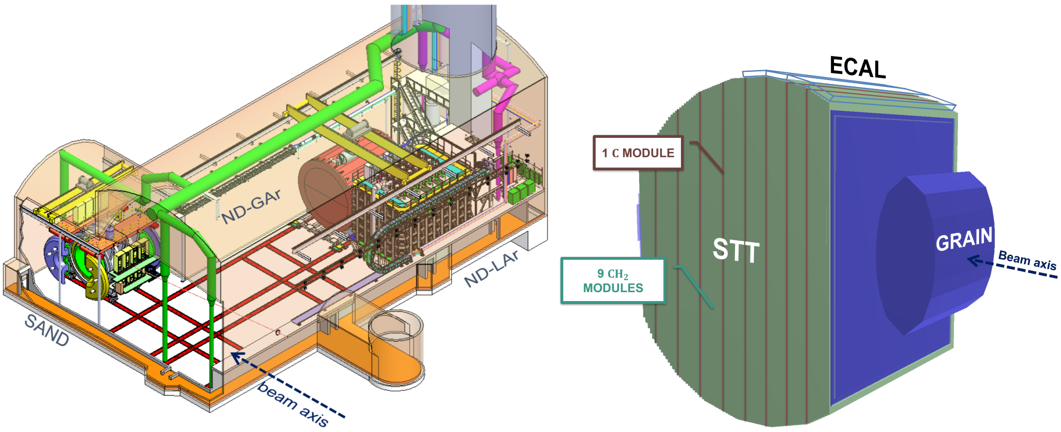
E-mail: ingratta@bo.infn.it, gianfranco.ingratta2@unibo.it

DUNE is a next-generation long baseline experiment for neutrino oscillation physics. The Near Detector complex aims at constraining the systematic uncertainties to ensure high precision measurements of neutrino oscillation parameters. The SAND apparatus is one of the three components of the Near Detector complex permanently located on-axis to monitor the neutrino beam stability, measure its flux and perform precise neutrino physics. SAND exploits a 0.6 T superconducting magnet coupled with an electromagnetic calorimeter made of lead scintillating fibers. The inner magnetized volume is provided with a novel LAr detector and a low-density Straw Tube Target tracker. In this article the major components of the SAND apparatus and their role in the measurements of (anti)neutrinos interactions are presented.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

PoS(ICHEP2022)998



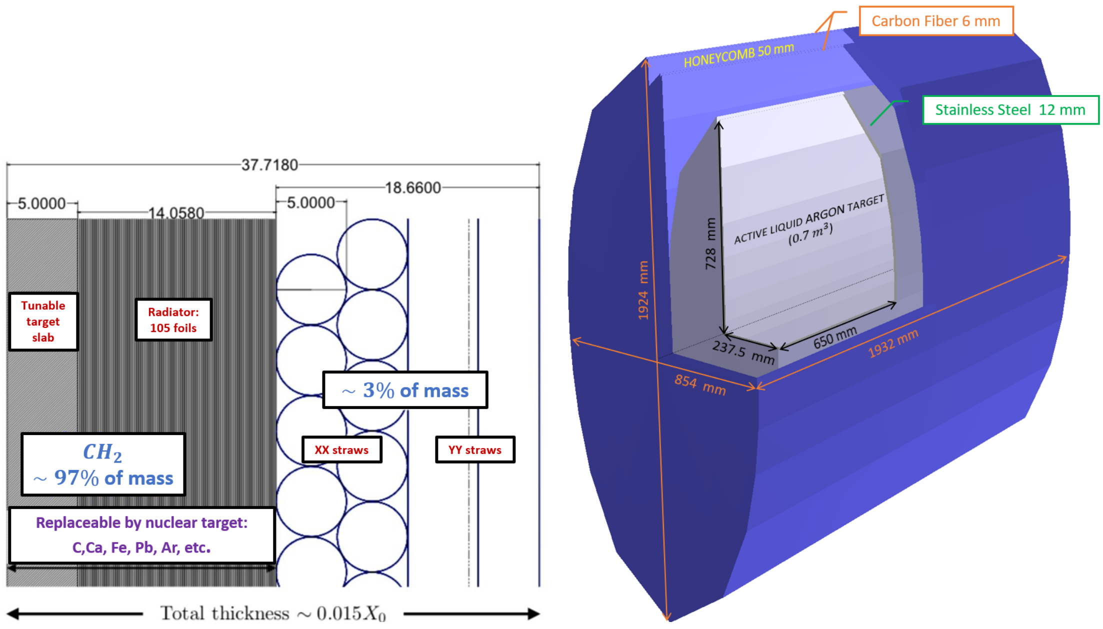
(a) (b)

Figure 1: (a) DUNE ND complex components. (b) Simulation of the SAND inner volume, with an active LAr target (GRAIN) upstream, followed by the tracking system (STT). The electromagnetic calorimeter (ECAL) surrounds the STT and GRAIN offering a 4π coverage.

1. SAND components

The Magnet and the Lead/Scintillating-Fiber Calorimeter: SAND will exploit the superconducting magnet and calorimeter refurbished from the KLOE experiment. The magnet was designed in conjunction with its iron yoke to produce 0.6 T over a 4.3 m long, 4.8 m diameter volume. The ECAL is a lead-scintillating fiber sampling calorimeter of about 100 tons [4] with radiation length X_0 = 1.6 cm and density of 5.3 g/cm^3. The overall calorimeter thickness is ~ 15 radiation lengths. The nearly-cylindrical calorimeter barrels consist of 24 modules each 4.3 m long, 23 cm thick with trapezoidal cross-section of bases 52 and 59 cm respectively. Each end-cap consists of 32 vertical modules from 0.7 m to 3.9 m length and 23 cm thick. Their cross-section is rectangular, of variable width. All ECAL modules are stacks of approximately 200 grooved 0.5 mm thick lead foils alternating with 200 layers of cladded 1 mm diameter scintillating fibers. Each ECAL module is read out on both ends by phototubes through a light guide for a total of 4880 phototubes. The calorimeter performances are: (i) $\mathrm{r}-\phi$ or $\mathrm{x}-\mathrm{r}$ space resolution of 1.3 cm, (ii) energy resolution of $\sigma/\mathrm{E} = 5.7\%/\sqrt{\mathrm{E(GeV)}}$ and (iii) time resolution of $54/\sqrt{\mathrm{E(GeV)}}$ ps [5].

The Straw Tube Target Tracker (STT): The STT is a diffuse target tracker system [2] which combines the need for a large mass (~5 tons) to collect enough statistics, still retaining high momentum ($\sigma(1/\mathrm{p})/(1/\mathrm{p}) \sim 4\%$ for 1 GeV μ) and space (< 200 μm) resolutions. The straw tubes have 5 mm diameter, 12 μm mylar walls plus 70 nm aluminum coating, 20 μm gold-plated tungsten wire, operated with Xe/CO_2 70/30 gas at 1.9 atm. Figure 2(a) shows the design of one STT module, equipped with three main components: (i) the neutrino target layers; (ii) a series of thin, polypropylene foils (radiator) for e/π separation via transition radiation; (iii) 4 planes of straw tubes arranged in XXYY layers. The target and radiator can be dismounted/replaced so that the average density of the detector can be tuned between a maximum of 0.18 g/cm^3 and a minimum of 0.005 g/cm^3. The current configuration foresees 8 carbon target modules, 70 CH_2 target modules and 6



(a) (b)

Figure 2: (a) Drawing of an STT module (xy section, z is the beam axis and x the B field axis) made of: (i) tunable CH_2 target; (ii) radiator foils for $e^{\pm}$ ID; (iii) four straw layers XXYY. (b) GRAIN cryostat simulation with: (a) inner vessel in stainless steel, (b) external vessel combination of honeycomb and carbon fiber layers.

tracking modules with no target. A model independent subtraction of measurements on graphite (pure C) targets from those on the CH_2 targets will provide high statistic $\nu(\overline{\nu}) - \mathrm{H}$ CC interaction sample. This technique, called "solid hydrogen target" is fully discussed in [3]. Assuming a beam power of 2.4 MW and 2 years of data taking, the expected accumulated statistics in STT is about 66×10^6 ν_μ CC in CH_2 and 6.5×10^6 ν_μ CC in H.

GRAIN: An active liquid argon target of about 1 ton will be installed in the upstream part of the SAND inner magnetic volume to constrain nuclear effects on Ar and perform complementary measurements to ND-LAr. Figure 2(b) shows a simulation of the currently studied GRAIN cryostat in which the LAr volume will be hosted. GRAIN LAr volume will be instrumented with an optical system able to perform tracks reconstruction using the UV scintillation light on fine segmented focal planes. The optical systems under study are based on ad-hoc designed lenses and Hadamard masks coupled to SiPM matrices.

2. SAND physics program

$\nu/\overline{\nu}$ beam monitoring: SAND will continuously monitor the on axis (anti)neutrino beam. The neutrino energy spectrum is reconstructed from the measured particle momenta produced in the ν_μ CC interactions, requiring a minimum number of STT hits ($\geq$ 6 for interactions in ECAL and GRAIN, $\geq$4 for those in STT) in the plane parallel to the beam directions. Dedicated studies on the expected sensitivity to beam variations, show that SAND will have enough sensitivity ($\sqrt{\Delta\chi^2} > 3$)

to detect most of beam variations on 1 week of data taking [2].

Flux measurements: The "solid hydrogen" target allows the determination of ν_μ and $\overline{\nu}_\mu$ relative fluxes with an accuracy better than 1% using exclusive $\nu_\mu p \to \mu^- p \pi^+$, $\overline{\nu}_\mu p \to \mu^+ p \pi^-$, and $\overline{\nu}_\mu p \to \mu^+ n$ processes on hydrogen with small energy transfer ν, thus reducing the uncertainties from the energy dependence of the cross-sections [3]. The expected statistical and systematic uncertainties in the ν_μ and $\overline{\nu}_\mu$ relative fluxes achievable in 5 years of data taking assuming 2.4 MW beam power and SAND inner volume filled only with STT tracker are below the sub-percent level [2].

Constraining nuclear effects: The smearing introduced by nuclear effects directly affects the reconstruction of the (anti)neutrino energy. The number of events detected at the Near or Far Detectors for the exclusive process X can be written as:

$$N_X(E_{rec}) = \int_{E_\nu} dE_\nu \Phi(E_\nu) P_{osc}(E_\nu) \sigma_X(E_\nu) R_{phys}(E_\nu, E_{vis}) R_{det}(E_{vis}, E_{rec}) \tag{1}$$

where $\Phi(E_\nu)$ is the incoming (anti)neutrino flux, P_{osc} is the survival probability (1 at the Near detector), σ_X is the process X cross-section, R_{phys} is the nuclear smearing and R_{det} is the detector response. Once the fluxes are measured in the STT, we are left with the convolution of the three terms $\sigma_X R_{phys} R_{det}$. The unfolding of $\sigma_X R_{phys}$ in argon is obtained from the comparison with hydrogen for which $R_{phys} \equiv 1$ [3]; given the large expected statistics, one can accurately measure σ_X on hydrogen so that the unfolding of the neutrino energy only depends on the detector response R_{det}, which is essentially defined by the value of $\delta p/p$ calibrated to 0.2% from the K_0 mass peak [1].

Background rejection: Cosmic radiation and ambient radioactivity backgrounds are suppressed to negligible levels by requiring a time coincidence with the beam spill. Background from beam-related neutrino interactions in the material surrounding the detector are partially eliminated combining timing and topological information in both ECAL and STT using a multivariate analysis [2] to achieve a rejection factor of 3×10^{-5} against CC+NC external interaction with an efficiency of 92.7% and a purity of 99.6%.

References

[1] A. Abed Abud *et al.* [DUNE collaboration], *Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report*, *Instruments* **5** no. 4 (2021)

[2] G. Adamov *et al.*, *A Proposal to Enhance the DUNE Near Detector Complex,* DUNE doc 13262, 2019. https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=13262

[3] H. Duyang, B. Guo, S.R. Mishra and R. Petti, *A Precise Determination of (Anti)neutrino Fluxes with (Anti)neutrino-Hydrogen Interactions,* ArXiv:1902.09480v2 [hep-ph].

[4] M. Adinolfi *et al.*, *The KLOE electromagnetic calorimeter*, *Nucl. Instrum. Meth.* A482 (2002) 364-386.

[5] F. Ambrosino *et al.*, *Calibration and performances of the KLOE calorimeter*, *Nuc. Instrum. Meth.* A598 (2009) 239–243.