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The SAND detector at the DUNE near site

F. POPPI on behalf of the DUNE COLLABORATION
Istituto Nazionale di Fisica Nucleare - Viale C. Berti Pichat 6/2, Bologna 40127, Italy

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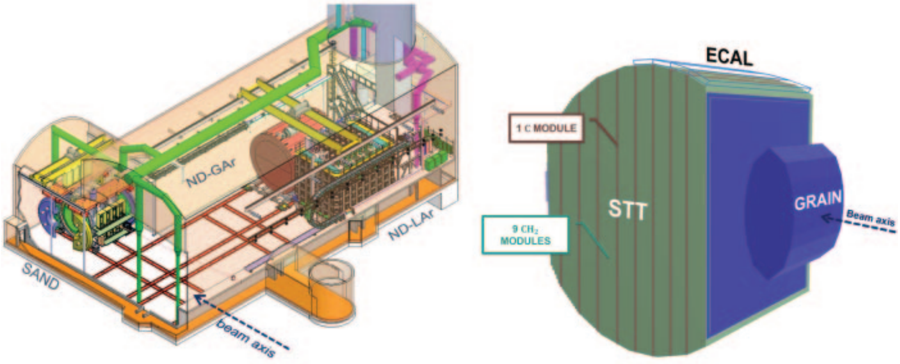
Summary. — DUNE is a next-generation long baseline experiment for neutrino oscillation physics. The SAND detector at the Near Detector complex is designed to perform on-axis beam monitoring, constrain uncertainties in the oscillation analysis and perform precision neutrino physics measurements. SAND exploits a 0.6 T superconductive magnet, an electromagnetic calorimeter made of lead scintillating fibres, a 1-ton novel liquid argon detector (GRAIN) and a modular low-density straw tube target tracker system. In this article, the major components of the SAND detector and their role in the measurements of $\nu/\overline{\nu}$ interactions are presented.

1. – SAND detector

The SAND detector is part of the DUNE Near Detector complex, represented in fig. 1; it is designed to perform on-axis beam monitoring, constrain uncertainties in the oscillation analysis and perform precision neutrino physics measurement.

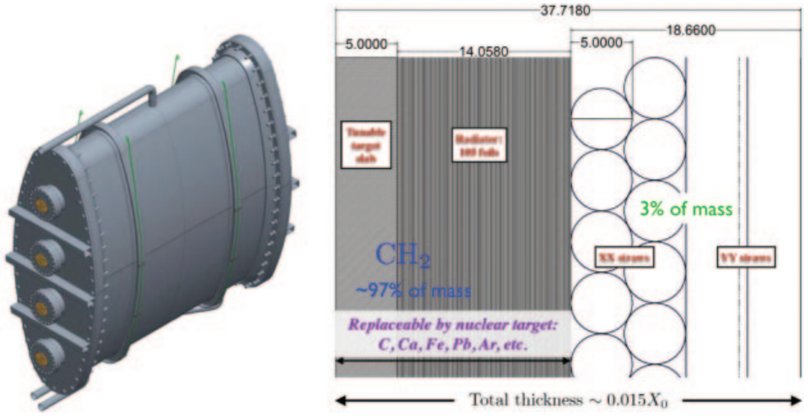
1·1. *The Magnet and the ECAL.* – The SAND detector is based on the repurposed super-conductive magnet and electromagnetic calorimeter of the KLOE experiment [1]. The SAND magnet consists of a super-conductive coil (4.8 m bore) producing a magnetic field of 0.6 T over a 4.3 m length. The magnet is encased in a 475 t iron yoke. The ECAL is a very fine sampling lead-scintillating fibre calorimeter read out by 4800 Photo-Multiplier Tubes (PMTs). Overall, the calorimeter has a mass of 100 t and a thickness of ∼15 radiation lengths. The ECAL is composed of a nearly-cylindrical barrel hermetically closed by two end-caps. The barrel is subdivided into 24 modules each 4.3 m long, 23 cm thick with trapezoidal cross-section of bases 52 cm and 59 cm respectively. Each end-cap consists of 26 C-shaped vertical modules from 0.7 m to 3.9 m in length and 23 cm thick with a rectangular cross-section. The ECAL modules are stacks of ∼200 grooved 0.5 mm thick lead foils alternated with layers of cladded 1 mm diameter scintillating fibres. The calorimeter performances are: i) r-ϕ or x-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 [2].



(a) (b)

Fig. 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˙2. *GRanular Argon for Interactions of Neutrinos (GRAIN).* – The upstream magnetized inner volume of SAND will be instrumented with 1 t liquid argon target called GRAIN, which will act both as passive and active target. GRAIN will study ν-Ar interactions in combination with the STT and the ECAL reconstructed events, constraining nuclear effects and performing complementary measurements to ND-LAr, a movable liquid argon time projection chamber at the DUNE near detector complex. GRAIN will be equipped with arrays of Silicon Photo-Multipliers (SiPMs) to collect Vacuum UltraViolet (VUV) light and perform imaging of the prompt scintillation light. The optical readout system is under study and it is based on ad-hoc lenses and/or Hadamard masks coupled to the SiPMs matrices [3]. The liquid argon cryostat will be made of C-composite materials and stainless steel, to constrain the overall radiation length (in combination with the liquid argon) to $\sim 1\ X_0$. In fig. 2(a) the 3D rendering of GRAIN is presented.



(a) (b)

Fig. 2. – (a) 3D rendering of GRAIN. (b) Drawing of an STT module made of: (i) tunable CH$_2$ target; (ii) radiator foils for $e^{\pm}$ ID; (iii) four straw layers XXYY.

1˙3. *The Straw Tube Target Tracker (STT).* – The inner volume of SAND will be instrumented with a diffuse target tracker system, which combines the need for a large mass to collect enough statistics, still retaining high momentum ($\sigma(1/p)/(1/p) \sim 4\%$ for $1\,\mathrm{GeV}\ \mu$) and space ($< 200\,\mu\mathrm{m}$) resolutions. The STT is composed of 84 modules with an overall mass of ∼5 t. Each module is equipped with: i) tunable neutrino passive target; ii) a thin radiator made out of polypropylene foils for e/π separation via transition radiation; iii) 4 planes of straw tubes arranged in XXYY layers. The design of one $\mathrm{CH_2}$ STT module is shown in fig. 2(b). The current configuration foresees 8 carbon target modules, 70 $\mathrm{CH_2}$ target modules and 6 tracking modules with no target. The straw tubes have 5 mm diameter and different lengths up to 4 m, operating with $\mathrm{Xe/CO_2}$ 70/30 gas at 1.9 atm. A model independent subtraction of measurements on graphite (pure C) targets from those on the $\mathrm{CH_2}$ targets will provide high statistic $\nu/\overline{\nu} - \mathrm{H}$ CC interactions sample. This technique, called "solid hydrogen target", is thoroughly discussed in the literature [4].

2. – SAND physics program

2˙1. *$\nu/\overline{\nu}$ beam monitoring.* – SAND will provide continuous monitoring of the on-axis neutrino beam, in order to identify potential variations that could directly affect the oscillation analysis at the Far Detector. The neutrino beam will be monitored by reconstructing the neutrino interactions energy spectrum and spatial distribution from the particle momenta produced in the ν_μ CC interactions. SAND will have enough sensitivity ($\sqrt{\Delta\chi^2} > 3$) to detect most of the beam variations with one week of data collection [5].

2˙2. *Flux measurements.* – Neutrino flux measurements is a mandatory condition to extract the oscillation probability from measured neutrino interactions. The solid hydrogen target will enable 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 [4]. 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 are below the sub-percent level [5].

2˙3. *Constraining nuclear effects.* – The complex modelling of ν-nucleous interactions in argon can be largely improved by a direct comparison with ν-hydrogen. SAND will exploit such a comparison within the same detector. The number of events detected at the Near/Far Detectors for the exclusive process X can be written as

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

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. The unfolding of $\sigma_X R_{phys}$ in argon is obtained from the direct comparison with hydrogen for which $R_{phys} \equiv 1$ [4]; accounting for the large expected statistic, an accurate measurement of σ_X on hydrogen is foreseen, constraining the neutrino energy dependence on the detector response R_{det} only, which can be calibrated to 0.2% from the K_0 mass peak [6].

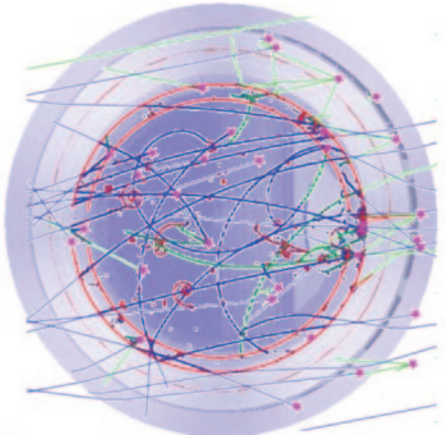


Fig. 3. – Simulation of ν interactions in a beam spill.

2˙4. *Background rejection.* – By requiring an *in-time* coincidence with the beam spill, the cosmic radiation and the ambient radioactivity backgrounds can be suppressed. The most critical background source is the activity induced by beam-related interactions in the material surrounding the detector. The expected CC+NC event rate per spill is 84 (45) events/spill for $\nu/\overline{\nu}$ mode. Figure 3 shows the simulation of ν interactions within the SAND volume for one beam spill. The background can be rejected by combining timing and topological information in both ECAL and STT using a multivariate analysis [5] 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] Adinolfi M. *et al.*, *Nucl. Instrum. Methods A*, **482** (2002) 364.

[2] Ambrosino F. *et al.*, *Nucl. Instrum. Methods A*, **598** (2009) 239.

[3] Andreotti M. *et al.*, *Eur. Phys. J. C*, **81** (2021) 1011.

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

[5] Adamov G. *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`.

[6] DUNE Collaboration (Abed Abud A. *et al.*), *Instruments*, **5** (2021) 31.