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Study of a novel VUV-imaging system in liquid argon for neutrino oscillation experiments

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Summary. — DUNE, a dual site long-baseline neutrino experiment, currently being built, will aim to measure some of the still unknown neutrino oscillation parameters. The near site will be composed by three detectors. One of them, the SAND detector, will include a liquid argon volume instrumented with an innovative detection technique. In this paper the first results obtained with a prototype are presented.

1. – DUNE experiment

Precise measurements of the neutrino oscillation parameters have been performed in the last decade by short- and long-baseline experiments on neutrino beams. Current experiments are aiming to answer open questions, like the neutrino mass hierarchy and the CP violation in the leptonic sector, which in turn could be connected to the matter-antimatter asymmetry in the Universe. In this context the DUNE experiment will play a key role. DUNE will be a dual site experiment with a Near Detector (ND) system located few hundred meters from the neutrino source at Fermilab, and a multi-kiloton LAr TPC, the Far Detector (FD), located 1300 km away from the source [1]. In order to perform the measurements in the appearance and disappearance neutrino oscillation channels, it is necessary to characterize the unoscillated neutrino beam with high precision, as systematic uncertainties would limit the sensitivity to both the CP-violation and mass ordering. Moreover, the neutrino interaction and cross section on liquid argon have to be studied with unprecedented accuracy. These measurements will be performed by the ND complex, allowing the extrapolation of the neutrino flux to the FD and constraining the systematic uncertainties at the required level.

The DUNE Near Detector complex will be composed by three systems: two of them moving on- and off-axis the neutrino beam, and one staying always on-axis. The fixed system (System for on Axis Neutrino Detection, SAND) will reuse some of the KLOE detector components, *i.e.*, the electromagnetic calorimeter and the superconducting magnet. The magnetic volume will be instrumented with 1 t LAr detector and a tracking

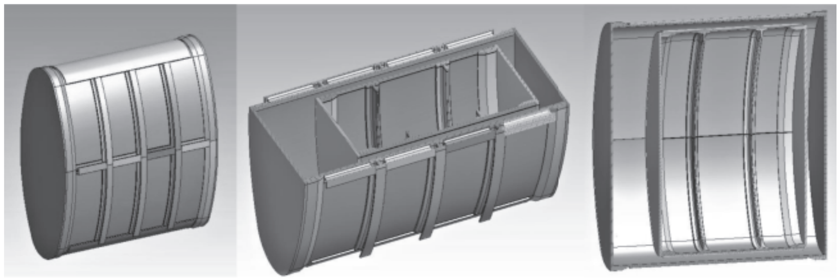

Fig. 1. – Scheme of the external volume of the meniscus (left) and internal volume cross sections (center and right).

system, including different nuclear targets. This configuration will allow the study of nuclear effects in different materials, in particular in argon, the Far detector target. In the LAr "meniscus" (fig. 1) an innovative detection technique will be implemented aimed at overcoming some limitations of LAr TPCs as the event pileup and the argon high purity. The basic idea is the use of the Coded Aperture Technique coupled with arrays of VUV-photon detectors such as a matrix of Silicon PhotoMultipliers (SiPMs).

2. – Liquid argon meniscus and coded aperture technique

The main novelty is to use exclusively the LAr scintillation light to reconstruct neutrino interactions. To this end the LAr volume has to be instrumented with an optical system and with a fast, segmented photon detector collecting the light to provide the information needed to reconstruct the particles' tracks. While different optical systems as lenses and mirrors could be used, the system under study is the Coded Aperture Technique [2]. This technique, largely used in the X- and gamma-ray astronomy, is an extension of the simpler pin-hole system: by placing an opaque screen with a pin-hole in front of a highly segmented photodetector, the light originating from a source will hit the detector on a pixel at a position related to the source distance and light direction. The location of the hit is therefore in one-to-one correspondence with the source of the photons, and the photodetector/pin-hole system acts as an imaging camera. Expanding this idea, it is possible to demonstrate that a system of multiple holes (a mask) produces a pattern on the light sensor array that can be used to reconstruct the original image. A system of this type has the advantage of a much higher light output compared to the pin-hole and a larger depth of field and field of view than the more traditional systems. Using multiple systems of this type arranged in a stereo view, one could be able to perform a complete 3D reconstruction of the event.

3. – Simulations and event reconstruction

In order to study the performance of a detector based on the coded aperture technique a complete simulation using the Geant4 toolkit has been developed. Two different setups have been studied: a SAND-like LAr meniscus subdivided in smaller volumes, and a room temperature prototype. Simulations include the geometry of both the mask and the sensor, which we refer to as camera, and the light source. The camera and ligh source components are setup dependent. The meniscus is simulated as a cube, 50 cm side, filled with LAr. Five cameras are included, one on each side of the box (upstream

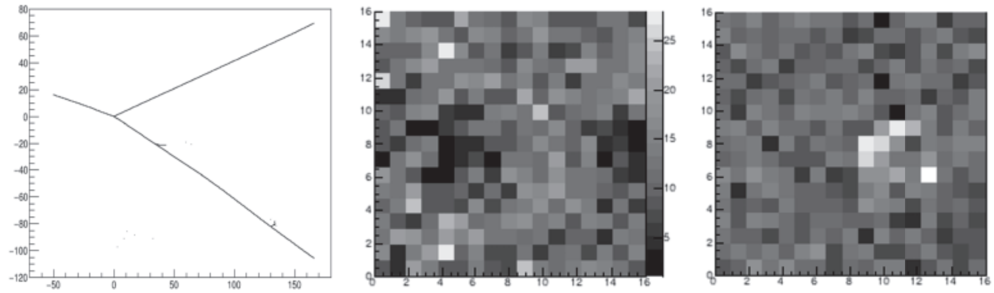

Fig. 2. – Monte Carlo simulation of neutrino interaction in LAr (left). Sensor response as the number of photons reaching every SiPM (center). Reconstructed image obtained from the deconvolution of the sensor response (right).

face excluded) looking at the center of the volume. The sensor of each camera is a 16×16 matrix of 3×3 mm^2 SiPMs, 5 mm beyond the mask. Muons and neutrino interactions have been simulated with GENIE [3]. The light source is the LAr scintillation light emitted by the liquid argon with scattering, absorption and emission spectrum parametrized. For the warm prototype geometry only one camera is considered and its parameters are defined by the detector used in the experimental setup (sect. 4). The sensor is a 8×8 matrix of 1×1 mm^2 SiPMs 10 mm beyond the mask and the camera is placed in a box filled with air. The light source emulates two LEDs with no parametrization of light scattering or absorption.

For both configurations the simulation yields the number of photons passing through a hole of a mask and reaching the sensor. This information is then used to reconstruct the image of the light source by a deconvolution algorithm in which a decoding kernel is defined by the geometry of the mask. An example of the result is shown in fig. 2 for the meniscus geometry with a simulated neutrino interaction.

4. – Experimental setup and results

To validate the results obtained with the simulation an experimental setup was built at the INFN Bologna laboratory. In fig. 3 a picture of the main components is shown: the SiPM matrix, the mask mechanical support, the mask itself, and an optical fiber coupled with a laser used as light source. The camera was lightened and the number of photons on every SiPM of the sensor was saved. The reconstructed images obtained from the deconvolution of these data were then compared with the simulation. Results

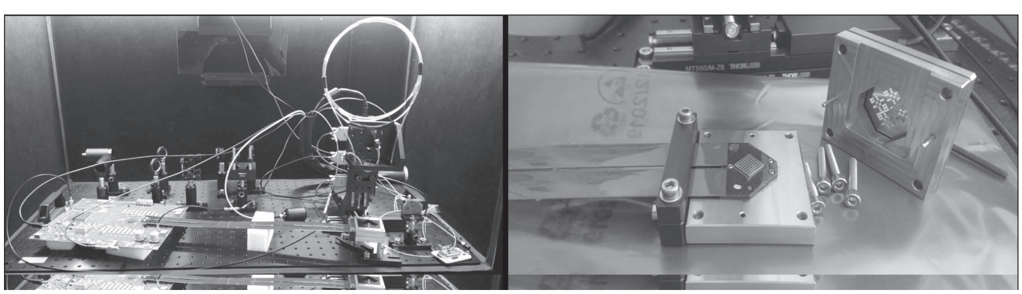

Fig. 3. – Experimental setup and focus on the sensor and mask support.

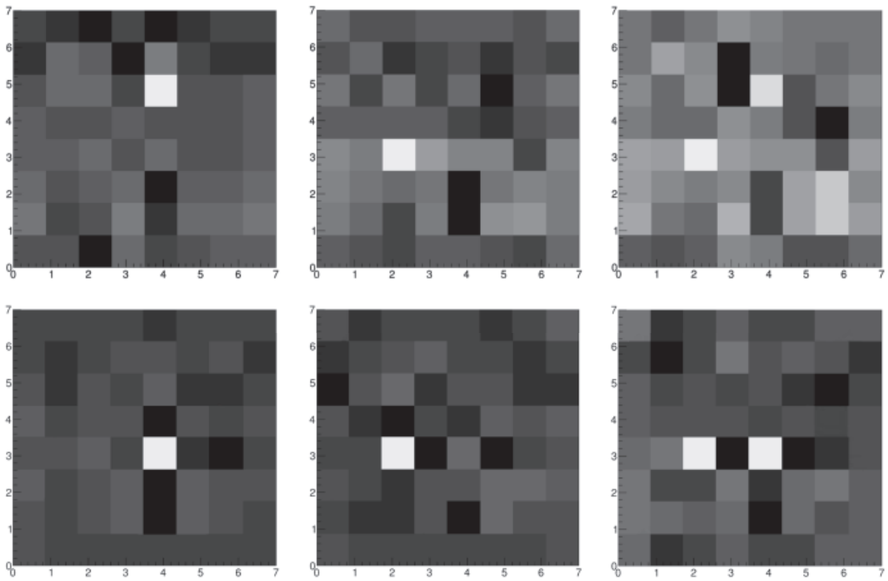

Fig. 4. – Reconstructed images of simulation (bottom row) and experimental (top row) data for one (first two columns) and two (last column) light sources.

with one or two light sources are shown in fig. 4. Similar images are reconstructed using data from the simulation and the experimental setup, respectively, as shown in fig. 4. Two main differences concern the position of the light source, and a larger background for the experimental data based images. The first difference is due to the rotation of the detector (45 degrees compared to the geometry simulated). The reason of the different background is under study.

5. – Conclusions

The DUNE Near Detector will be composed of different systems to perform all the measurements needed to constraint the systematic uncertainties at the Far Detector. To this end, a volume (meniscus) of liquid argon will be included in the ND SAND system. An innovative approach, exploiting the Coded Aperture Technique and LAr scintillation light, will be implemented to reconstruct the neutrino interaction events. A simulation of the LAr meniscus has been developed as well as that of an experimental setup used as a preliminary first validation of the technique. The preliminary results are promising and in agreement with the simulation. Further studies and test are needed to fully assess the limits and advantages of this technique.

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