IL NUOVO CIMENTO **45 C** (2022) 15
DOI 10.1393/ncc/i2022-22015-x

COLLOQUIA: SoUP 2021

Liquid argon imaging with Hadamard Masks for neutrino oscillation experiments

V. PIA([1])([2]) on behalf of the INFN NU@FNAL COLLABORATION

([1]) *INFN, Sezione di Bologna - Bologna, Italy*
([2]) *Department of Physics and Astronomy "Augusto Righi", University of Bologna Viale Carlo Berti Pichat 6/2, 40127, Bologna, Italy*

received 4 November 2021

Summary. — Liquid Argon Time Projection Chamber (LArTPC) exploits an electric field to drift and collect charged particles. The drift time may represent a limitation in high interaction rate environments and a different approach is being developed to overcome such limitation. In this paper the first results obtained with a prototype using such approach are presented.

1. – Neutrino oscillation and LArTPC

Near future or future neutrino oscillation detectors, such as the SBN detectors and DUNE, are based on the Liquid Argon Time Projection Chamber (LArTPC) technique. In a LAr TPC an electric field drifts the ionization charges produced in the neutrino interaction toward sensing wire planes where they are read out (fig. 1). A high argon purity is required to minimize charge and light attenuation over the long drift lengths and, depending on the detector dimensions, the drift time of charged particle could be up to some ms. The drift time may be a limitation in high interaction rate environment such as at near site detectors of neutrinos oscillation experiments. A different approach is being developed, aimed at overcoming limitations of LArTPCs. The basic idea is to use the Coded Aperture Technique coupled with VUV-photon detector arrays such as a matrix of Silicon PhotoMultipliers (SiPMs) to collect the LAr scintillation light and thus reconstruct neutrino interactions.

2. – Coded aperture technique

In order to provide the information needed to reconstruct the particles' tracks, a LAr volume has to be instrumented with an optical system and with a fast, segmented photon detector collecting the light. While different optical systems as lenses and mirrors can be considered, the system under study is based on the Coded Aperture Technique [3]. Largely used in the X- and gamma-ray astronomy it is an extension of the simpler pin-hole system: by placing an opaque screen with a pin-hole in front of a highly segmented

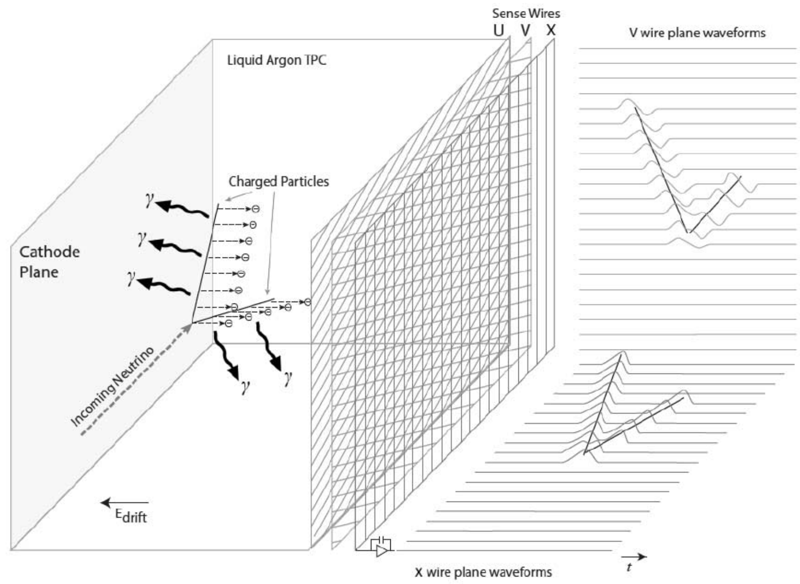

Fig. 1. – Scheme of the operating principle of a LArTPC [2].

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/pinhole 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 with a proper decoding process (fig. 2) [1]. A system of this type has the advantage of a much larger light output compared to the pin-hole and a larger depth of field and field of view than the more traditional systems, such as lens and mirror based 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.

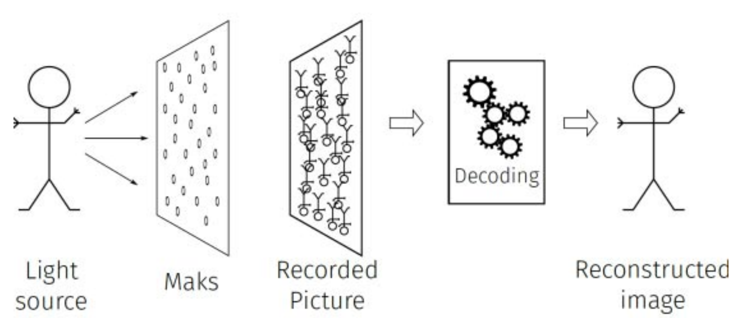

Fig. 2. – Scheme of the encoding and decoding of the signal of a coded aperture camera.

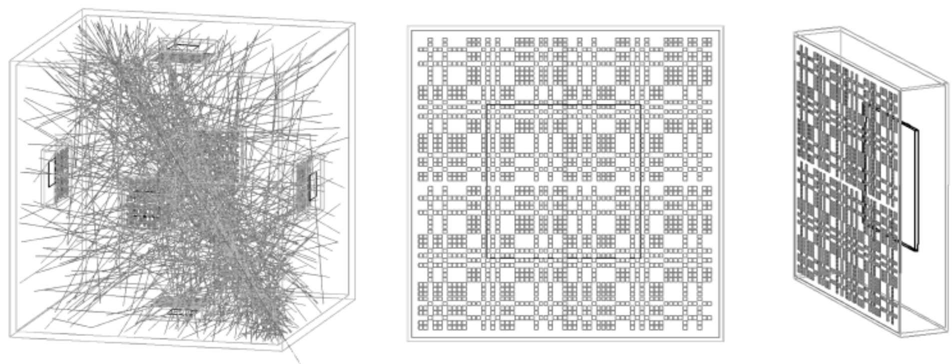

Fig. 3. – Example of charged particle crossing the cold demonstrator volume (with reduced light output) and details of the camera geometry.

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 was developed. Two different setups have been studied: a cryogenic temperature LAr volume (cold demonstrator), 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 light source components are setup depending. The cold demonstrator is simulated as a cube, 50 cm side, filled with LAr. Six cameras are included, one on each side of the box looking at the center of the volume. The sensor of each camera is a matrix 16×16 of 3×3 mm^2 SiPMs, located 20 mm beyond the mask. Muons and neutrino interactions have been simulated with GENIE [4]. 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. Figure 3 shows an example of a charged particle passing through the cold demonstrator and the details of a single camera geometry.

For both configurations the simulation yields the number of photons passing through each hole of each mask and reaching the sensor. A custom tool simulates the SiPM response and the major sources of noise such as dark current rate, crosstalk and afterpulses, the quantum efficiency, the rise time and the saturation of the SiPMs. 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. 4 for the cold demonstrator geometry with a simulated neutrino interaction.

4. – Experimental setup and results

An experimental setup was built at the INFN Bologna laboratory. In fig. 5 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.

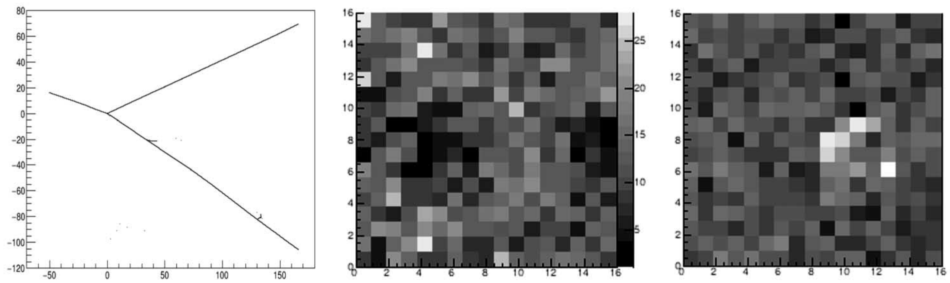

Fig. 4. – Monte Carlo simulation of neutrino interaction in LAr (left). Sensor response as the number of photons reaching every SiPM (center). Reconstructed image obtained from the deconvolution of the sensor response (right).

Fig. 5. – Experimental setup and focus on the sensor and mask support.

The camera was illuminated and the number of photons on every SiPM of the sensor was saved. The reconstructed images, obtained from the deconvolution procedure, were then compared with the simulation. Results with one or two light sources are shown in fig. 6. The different position of the reconstructed points is due a 45 degrees rotation of the camera compared to the simulated geometry, as shown on the right image of fig. 5. A large background for the experimental data based images is also visible and its origin is under study.

5. – Conclusions

A new imaging system to be exploited in neutrino detectors is being developed. This innovative approach exploits the Coded Aperture Technique and LAr scintillation light and will be implemented to reconstruct neutrino interactions. A simulation of two geometries has been developed, one based on an experimental prototype and one based on a future LAr volume prototype. An experimental setup was used as a preliminary 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.

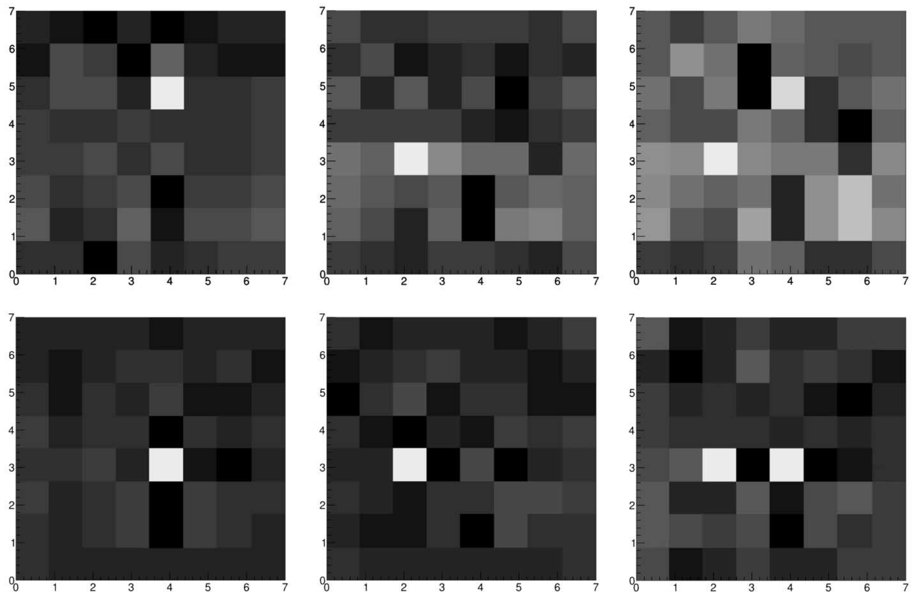

Fig. 6. – Reconstructed images of simulation (bottom row) and experimental (top row) data for one (first two columns) and two (last column) light sources.

REFERENCES

[1] NU@FNAL Collaboration (Andreotti M. *et al.*), arXiv:2105.10820 [physics.ins-det].

[2] DUNE Collaboration (Abi B. *et al.*), *JINST*, **15** (2020) T08008, arXiv:2002.02967 [physics.ins-det].

[3] Fenimore E. E. and Cannon T. M., *Appl. Opt.*, **17** (1978) 337.

[4] Andreopoulos C., Bell A., Bhattacharya D., Cavanna F., Dobson J., Dytman S., Gallagher H., Guzowski P., Hatcher R., Kehayias P. *et al.*, *Nucl. Instrum. Methods A*, **614** (2010) 87, arXiv:0905.2517 [hep-ph].