An imaging detector for liquid scintillator experiments

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on behalf of the PRIN 2017KC8WMB group
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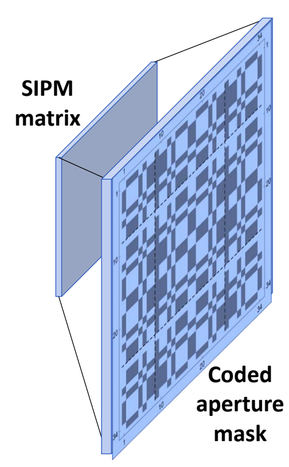
INTRODUCTION

Noble elements in the liquid phase (LAr, LXe) constitute an excellent medium for the detection of Neutrino interactions and for Dark Matter searches. We are developing an optical system that collects the **scintillation light** produced by charged particles in this medium to perform a **fast 3D reconstruction** of events, as an alternative or complement to Time Projection Chambers.

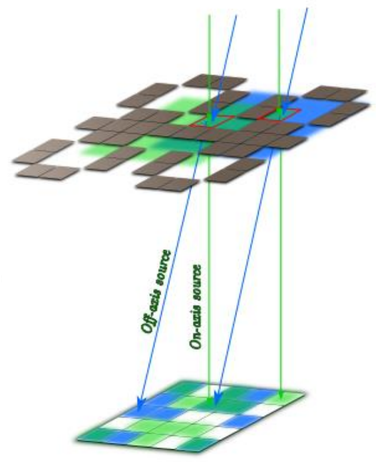


The base unit system consists in a "Camera" composed by a **Coded Aperture Mask** and a **Silicon Photomultiplier** (SiPM) matrix.

Properties:

- High rate capability
- Possibility to work in a magnetic field
- SIPM VUV models can detect scintillation LAr scintillation light (PDE ~ 15 % @ 128 nm)
- High noise reduction at low temperature
- Coded mask have ~50% photon transmissivity by construction
- Deep and wide field of view

CODED APERTURE MASKS



Coded aperture mask techniques were developed as the evolution of a single pinhole camera

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A matrix of multiple pinholes improves light collection and reduces exposure time

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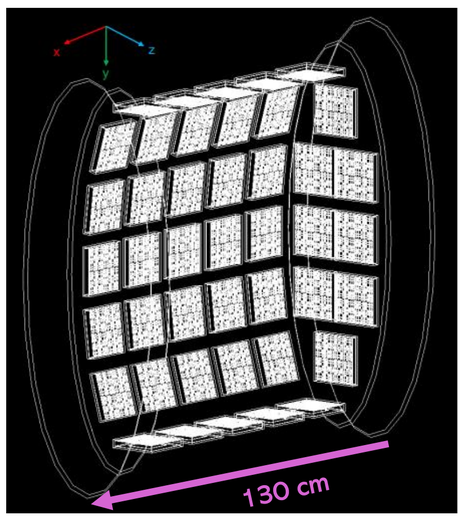
The image formed on the sensor is the superimposition of multiple pinhole images.

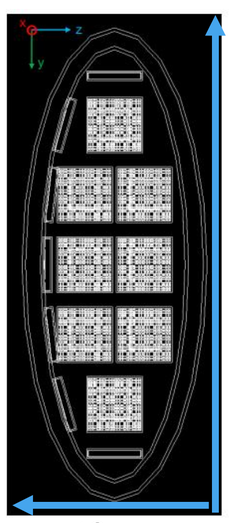
The original image is obtained with a simple deconvolution process where the kernel is derived from the mask pattern.

The detailed technique and preliminary results with simulated neutrino events are described in: *M. Andreotti et Al. "Coded masks for imaging of neutrino event", European Physical Journal C (2021) 81:1011*

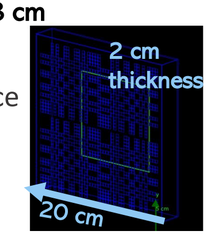
EXAMPLE DETECTOR GEOMETRY

Neutrino events have been simulated in an example detector geometry of **~1 ton LAr target volume**.





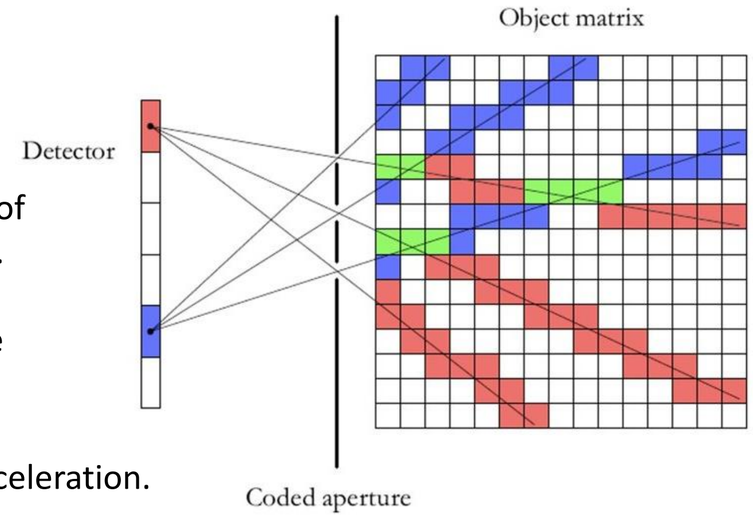
- 130 x 146 x 48 cm^3
- 76 cameras, covering most of the available surface
- **32x32 matrix sensors, 3x3 mm^2 pixels**
- Full SiPM waveform simulation and readout electronics included in event reconstruction



3D DIRECT RECONSTRUCTION ALGORITHM

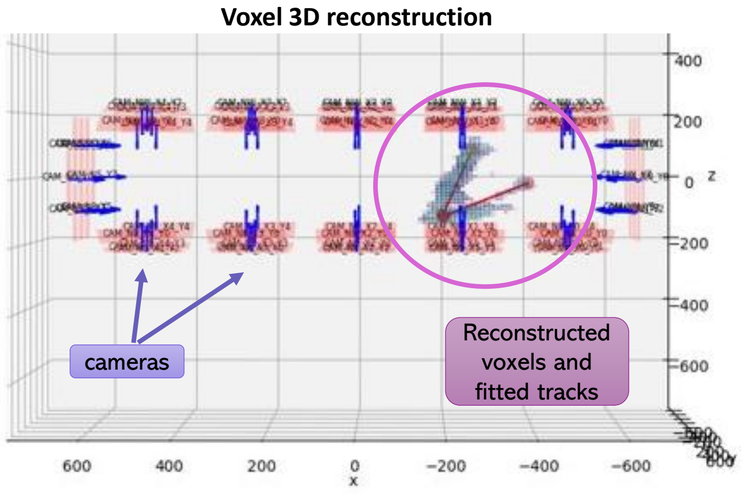
- Each hit on the SiPM matrix is propagated back into the inner volume through every hole in the mask, with an appropriate **weight** assigned to voxels.
- This weight represents the **Bayesian probability** of the voxel to be a source of the detected photons.
- A score in the segmented reconstruction volume is calculated by adding these weights.

Software written in Python and openCL for GPU acceleration.

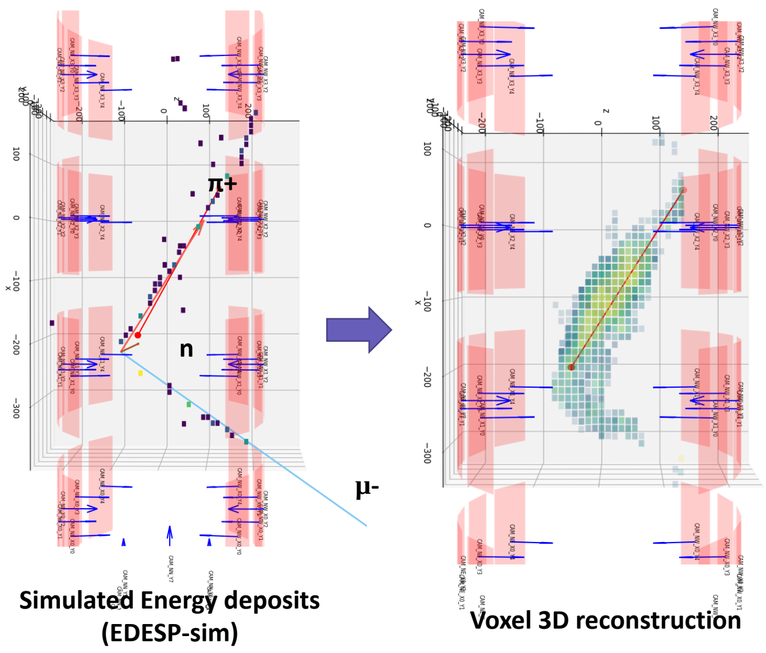


Compared to traditional techniques, this algorithm is well suited to deal with low light yields.

Voxel 3D reconstruction



NEUTRINO EVENTS RECONSTRUCTION



Simulated Energy deposits (EDESP-sim)

Voxel 3D reconstruction

The algorithm reconstructs a map of the deposited energy in the volume, where a higher voxel score corresponds to a higher probability of being the source of the scintillation photons.

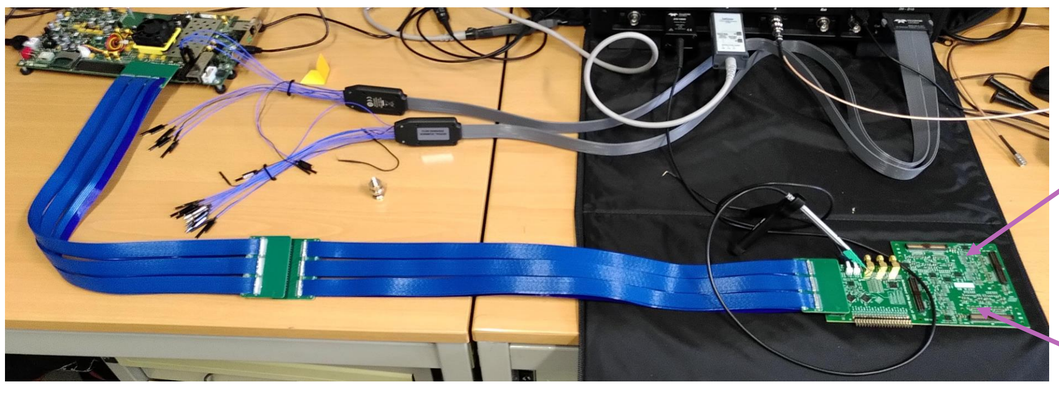
Challenges:

- Cameras crossed by particles loose information → ML algorithm under development to detect and exclude these cameras;
- Low contrast between signal and background voxels: voxel selection cut is not trivial;
- Track points extraction with *local principal curves* algorithm.

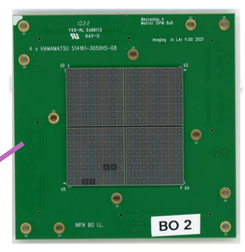
PROTOTYPE

We're building a prototype demonstrator with 3 cameras based on available SiPM matrices on the market, with cryogenic electronics.
Each camera consists in:

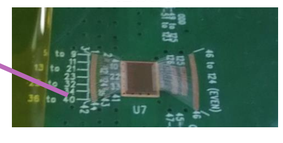
- 4 Hamamatsu S14161 8x8 matrices, with 3x3 mm^2 SiPM, coated in TPB wavelength shifter.
- 8 ALCORs, a 32-channel cryogenic ASIC with multiple TDCs, developed by INFN Torino microelectronics group



SiPM matrix board



ALCOR



This prototype will be tested in a Liquid Argon cryostat for imaging of simple light sources and cosmic rays, at ARTIC facility in INFN Genova. Expected Q2 2023.

Cameras placement scheme inside cryostat