TRACK IMAGING IN NOBLE LIQUID DETECTORS

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on behalf of the INFN Nu@FNAL Collaboration

LIght Detection In Noble Elements, 14-18 September 2021

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LIQUID ARGON DETECTORS

Cryogenic liquid Argon (and Xenon) Time Projection Chambers are used extensively in neutrino physics and dark-matter searches.

PROS

large target mass

low energy threshold

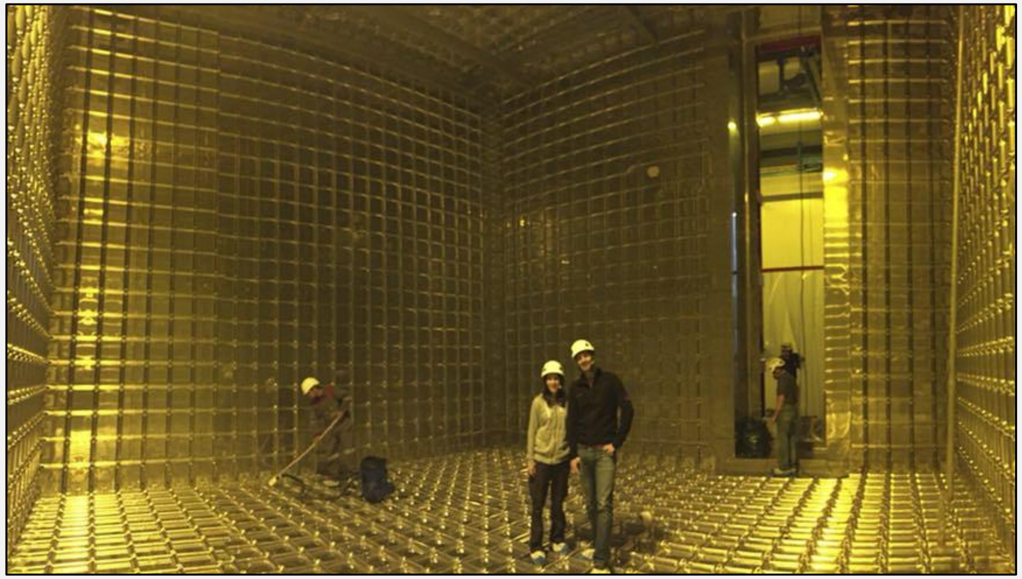
good spatial resolution

low radioactive background

CONS

Long drift time

High purity requirement

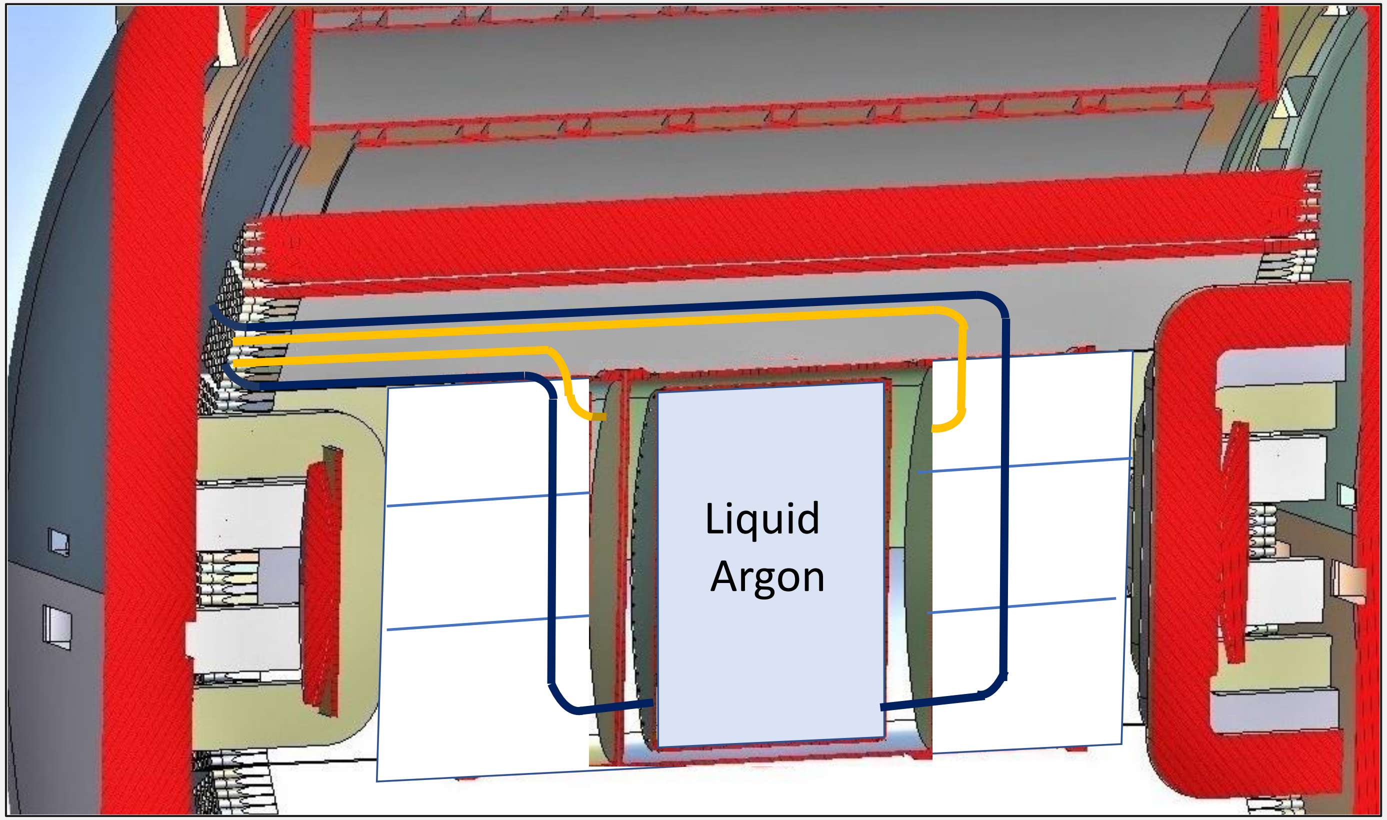


Future accelerator experiments, such as DUNE, will need higher rate capability at the Near Detectors.

AN IMAGING DETECTOR TO SEE PARTICLES

The ultimate goal: take pictures of charged tracks (and measure deposited energy as well).

In the SAND Near Detector for DUNE.
Upstream, between ECAL and inner tracker.



Near Detector requirements:

- Neutrino flux measurement ($\nu/\bar{\nu}$ and flavor discrimination)
- Able to work in high interaction rate environment
- ν/Ar cross section measurement

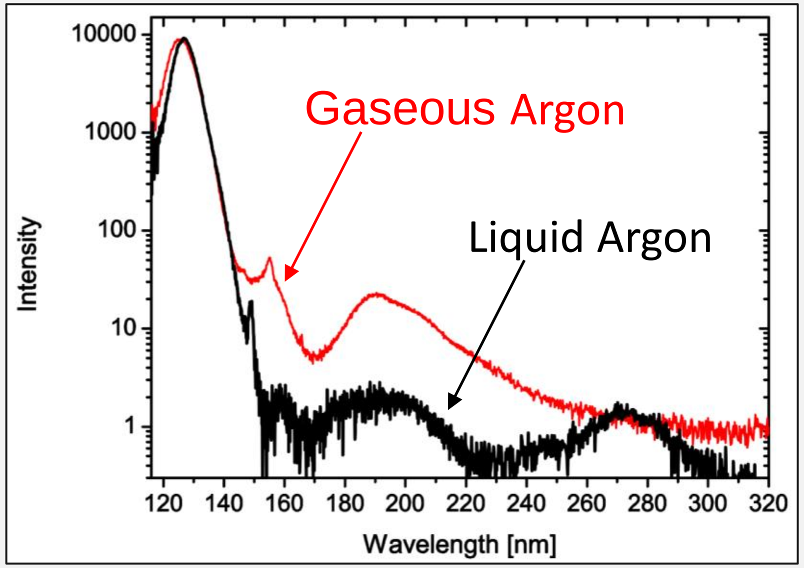
LAr in the Near Detector is needed to study nuclear effects and reduce systematics on the neutrino cross section.

THE IDEA – CHALLENGES AND BENEFITS

Equip a liquid Argon volume with an optical system able to collect the scintillation light and perform a fast 3D reconstruction of the events.

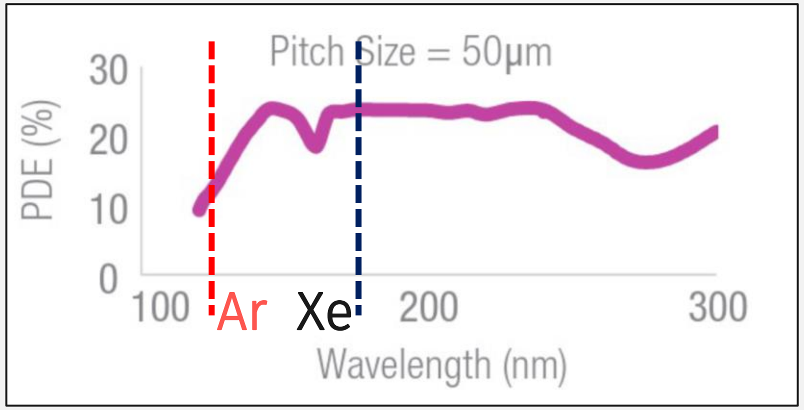
CHALLENGES

- Argon scintillation light @128 nm
  - Most common optical materials are not very transparent
  - Sensors are not very efficient
  - Wavelenght shifting needs to preserve directionality
- Photodetectors need to operate at cryogenic temperatures
- Optics must provide deep and wide field-of-view



BENEFITS

- Rate capability
- Possibility to work in a magnetic field
- Reduced sensor noise at low temperature



OPTICAL SYSTEMS

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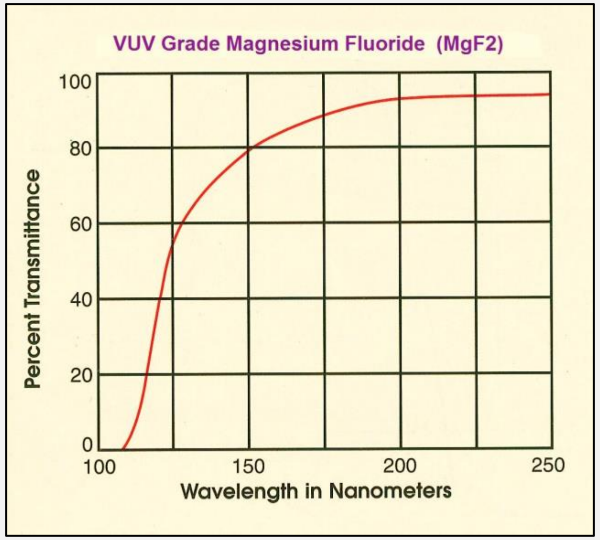
Different types of optical systems are being considered.

Thin VUV-grade lenses lose 50% or more light at 128nm



For Lenses, Fresnel lenses and metallic mirrors performance has not been satisfactory and projected complexity and cost are generally high.

We choose to focus on the Coded Aperture Mask thecnique.

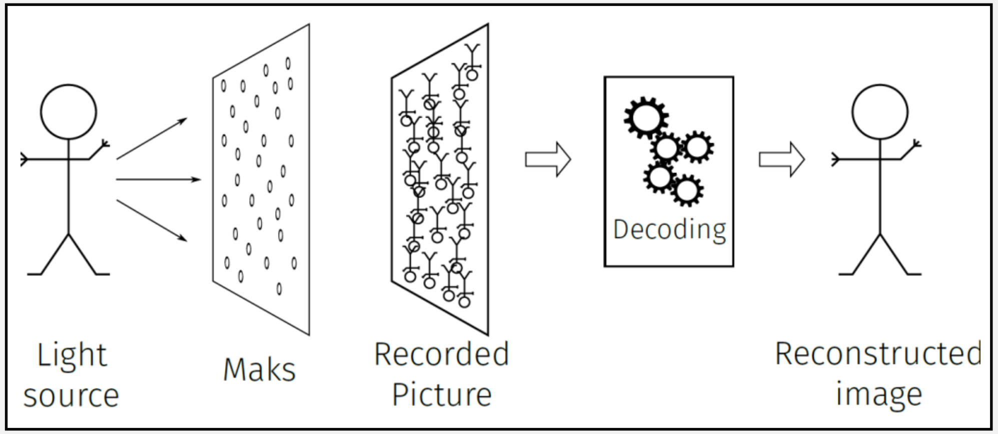
- relatively limited number of acquisition channels
- multiple reconstruction techniques with same setup
- 50% light collected by construction (not depending on the wavelength)
- good field of view
- simple to make

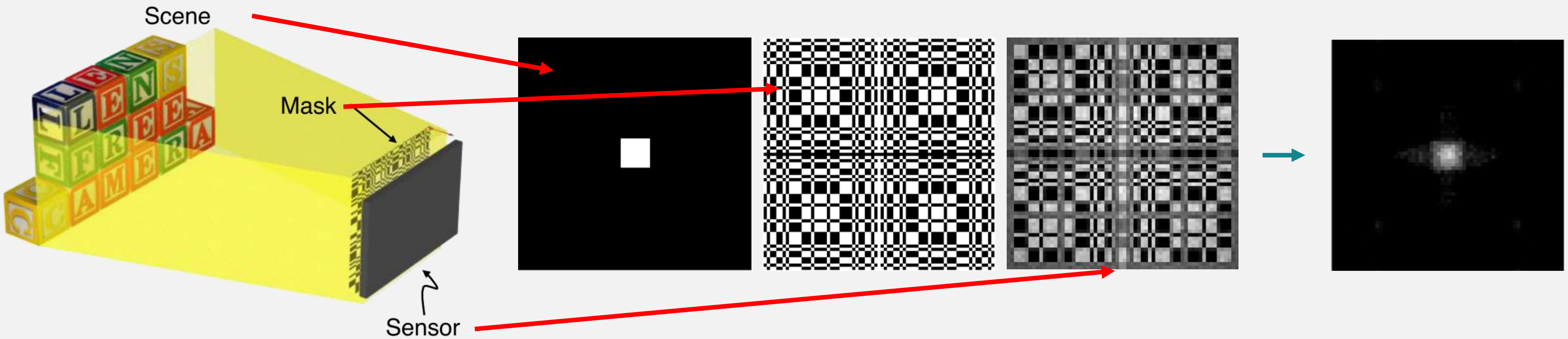
CODED APERTURE TECHNIQUE

Single pinhole can be used to reconstruct images with high spatial resolution.
Single pinhole requires long exposure time or intense light sources.

A matrix of multiple pinholes can increase the light collection, but the recorded image is a superimposition of the images from every hole.

By a proper pinhole arrangement (mask), it is possible to decode the image of the source.

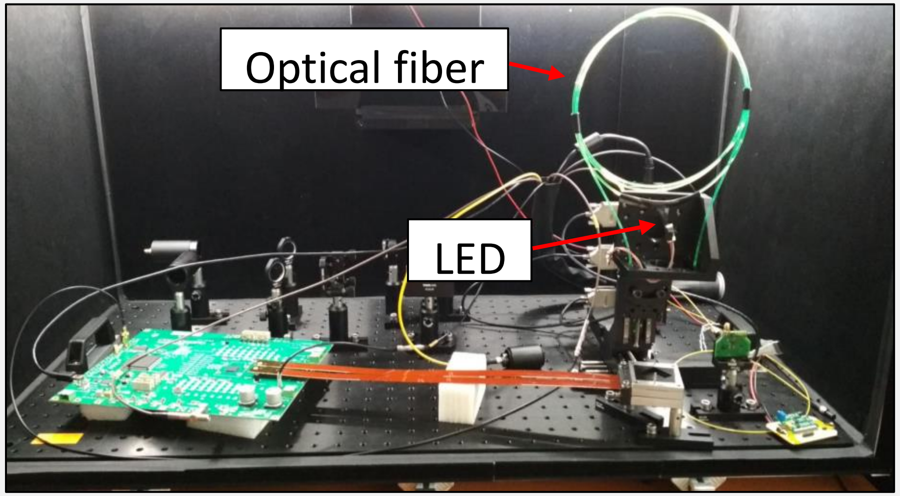


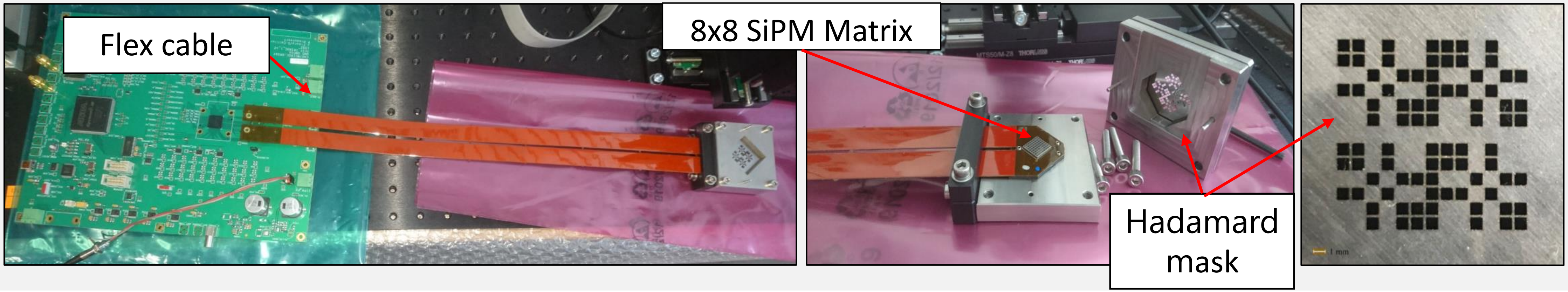


A PROOF OF CONCEPT PROTOTYPE

Assembled the 8x8 sensor with a Coded Aperture Mask

- Rank 7 MURA, 2x2 mosaic.
  Provides a wide field of view, but spatial resolution is limited.
- 4-layer, 50 cm long flexible PCB to extract the signals.
  Hosts one Hamamatsu S13615-1050N-08 with 64 separate SiPMs.
  SiPM end works in liquid nitrogen (77K).
- Signals read out by TRIROC Evaluation Board
- Blue LEDs used as point sources



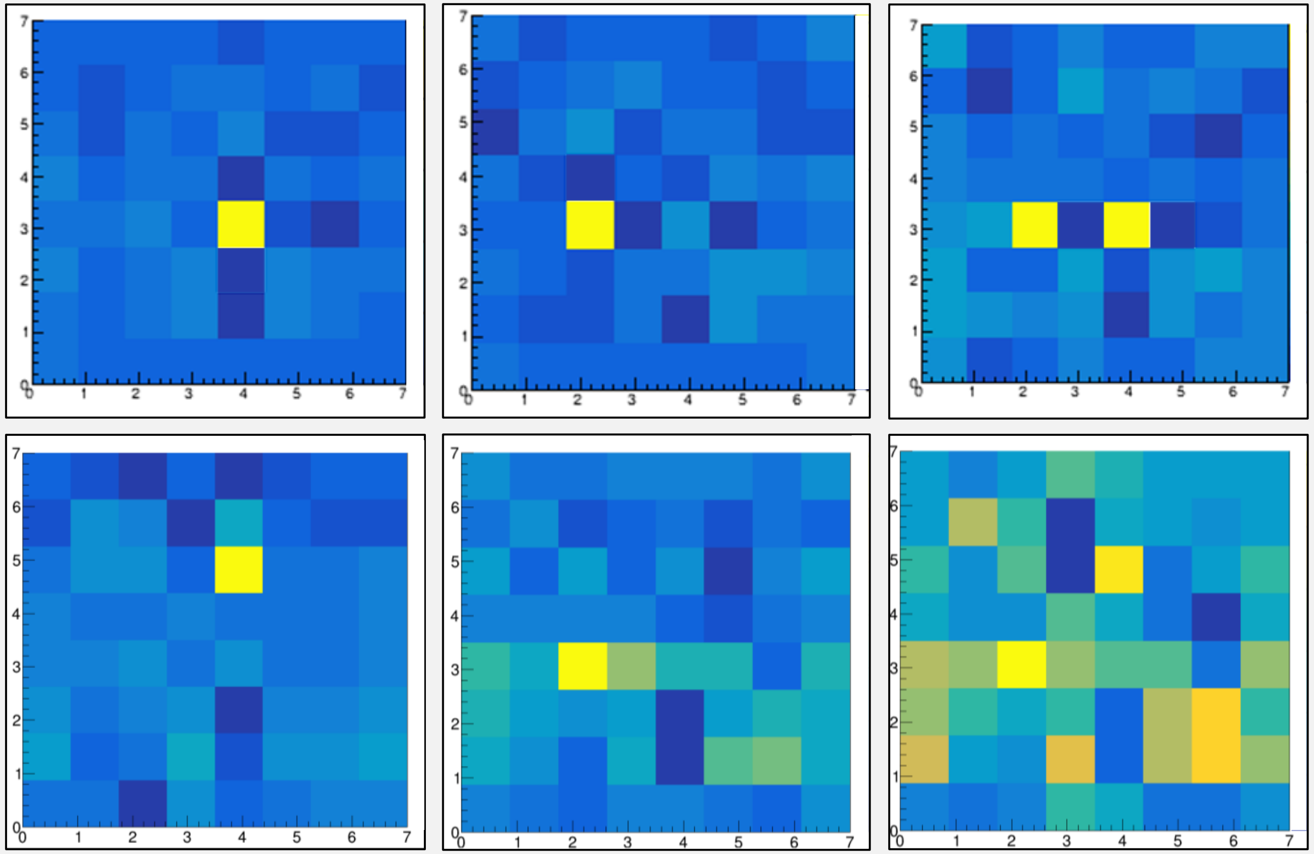


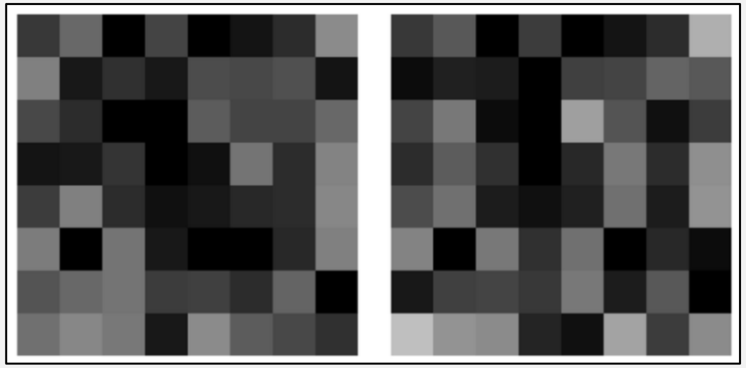
RECONSTRUCTION OF POINT SOURCES

LED A | LED B | LED A +B

SIMULATION

PROTOTYPE MEASUREMENTS





RAW SENSOR IMAGE

Both points are still visible.

Some noise signal is clearly visible on the prototype results. This is likely generated by:

- misalignment of mask and sensor
- SiPM associated noise (DCR, afterpulse , crosstalk)

CHARGED TRACKS SIMULATION AND RECONSTRUCTION

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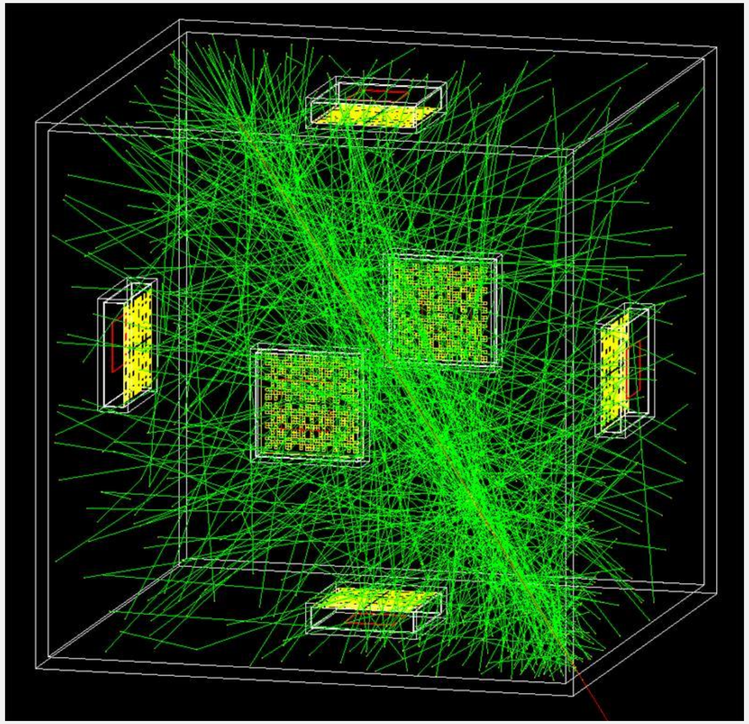
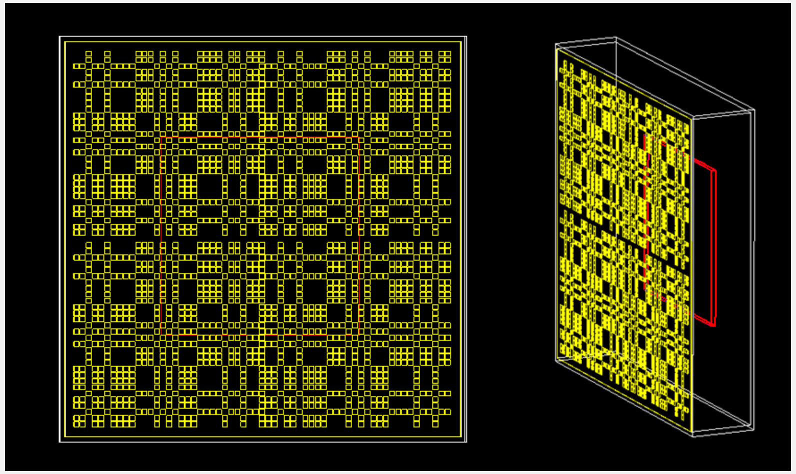
Extensive simulation campaign before scaling up the hardware

- Modelled neutrino events in GENIE, as well as simple cosmics etc…
- Charged tracks and photons propagated with Geant4
  Implemented the details of masks, sensors, LAr self attenuation and scattering, …
- Custom code to model SiPM and electronics response
  Initially concerned about effect of Crosstalk and afterpulse on very low signals





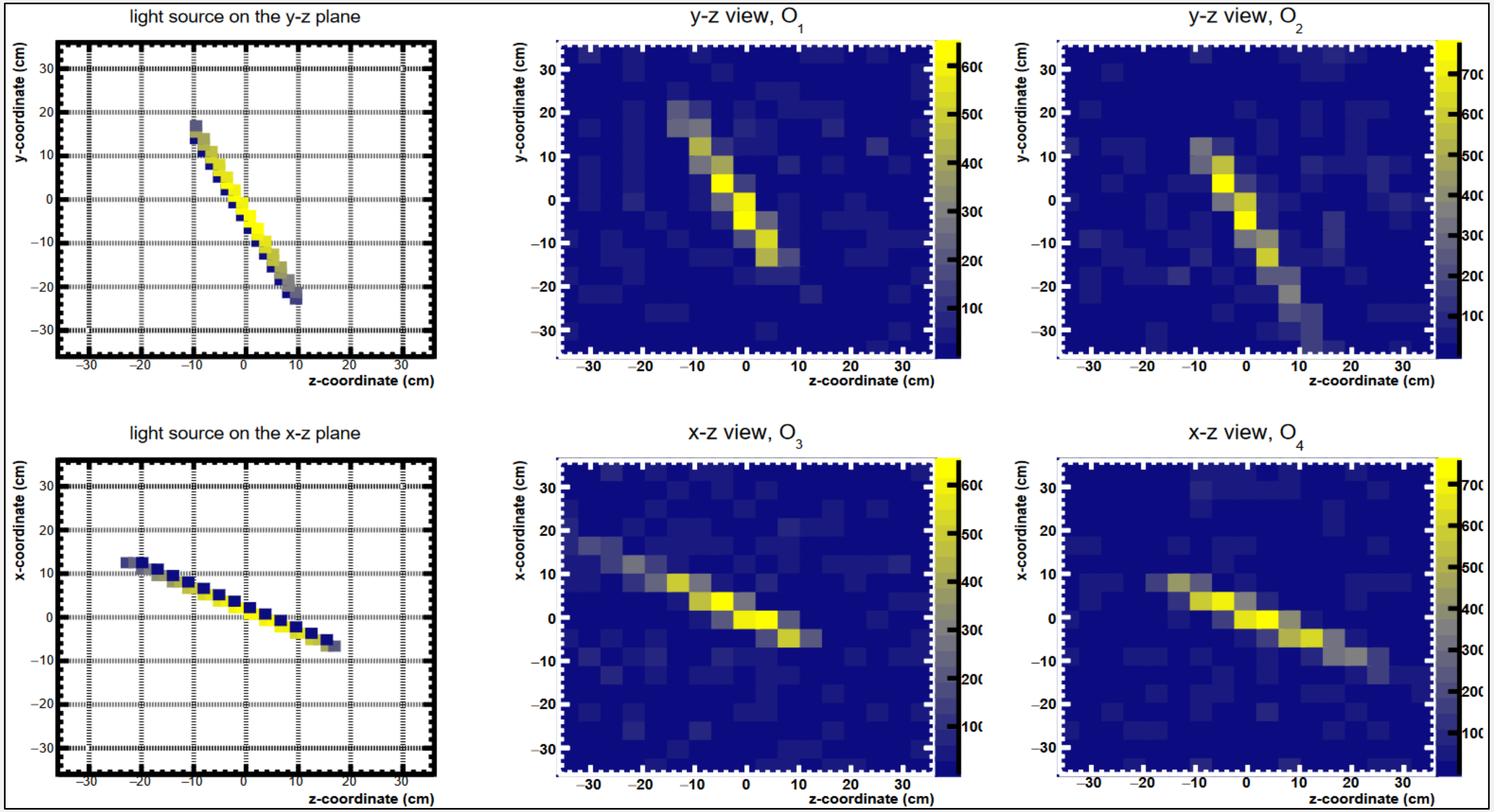
For details about the algorithms and the method for combining multiple images of the same event, see our paper [Preprint https://arxiv.org/abs/2105.10820]

CHARGED TRACKS SIMULATION AND RECONSTRUCTION

SIMULATION RECONSTRUCTION

Y-Z PLANE

X-Z PLANE



DESIGN OF A REALISTIC CRYOGENIC DEMONSTRATOR

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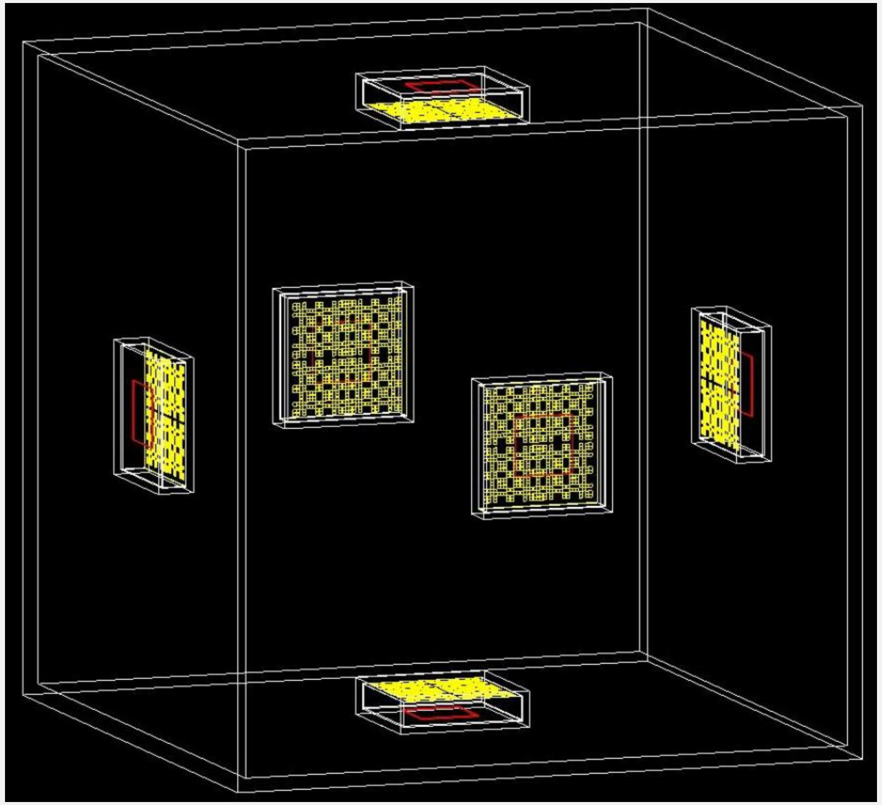
MINIMAL SPECIFICATIONS FROM SIMULATION
For a 0.1 ton LAr demonstrator

At least 3x3 mm pixel size, assuming a 25% PDE
Only reachable with WLS at present

At least 16x16 channels per "Camera"

At least 3 cameras, 6 better
Two facing each other, one orthogonal
Not much use for cameras crossed by particles



DESIGN OF A REALISTIC CRYOGENIC DEMONSTRATOR

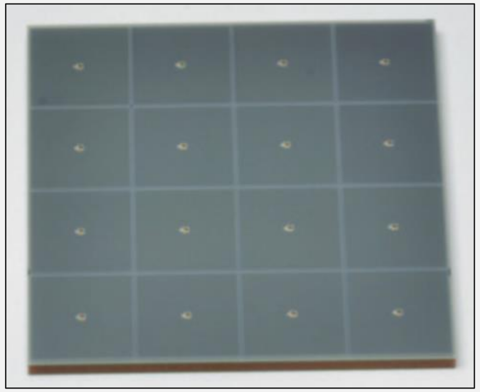
A new cryogenic ASIC has been developed and is under testing.

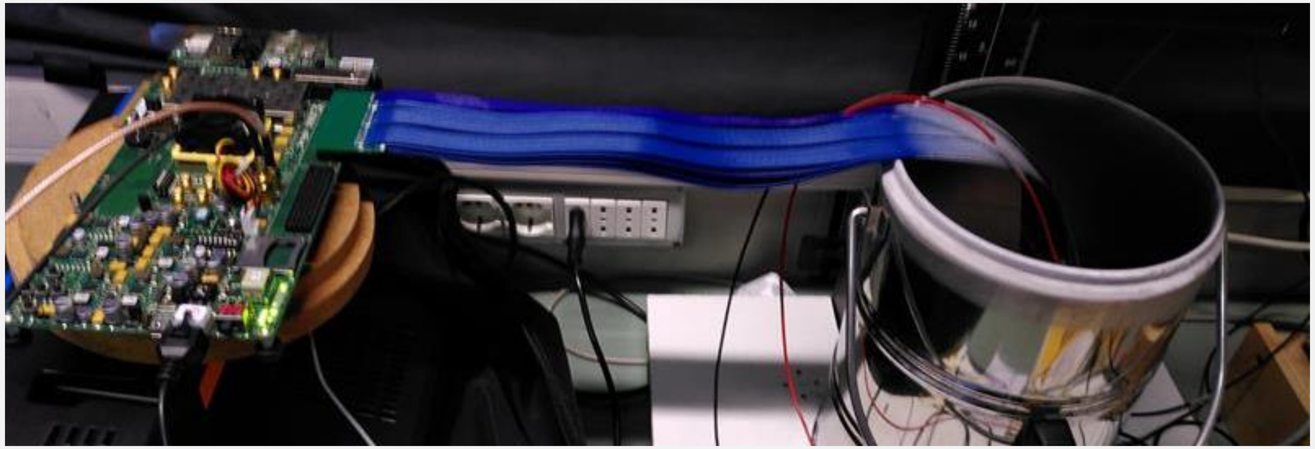
ALCOR, developed by the INFN Torino microelectronics group, 32 channel TDC.

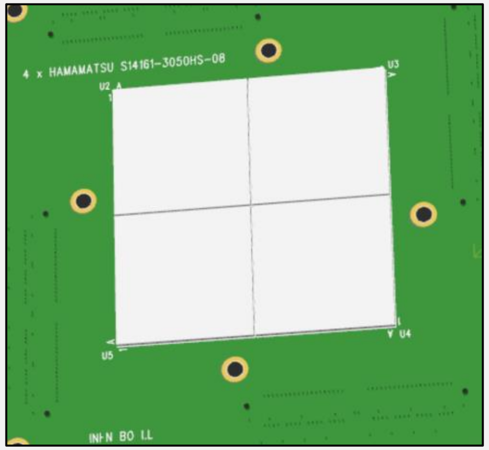
Each camera will use four Hamamatsu S14161-3050HS-08 and 8 ALCORs.

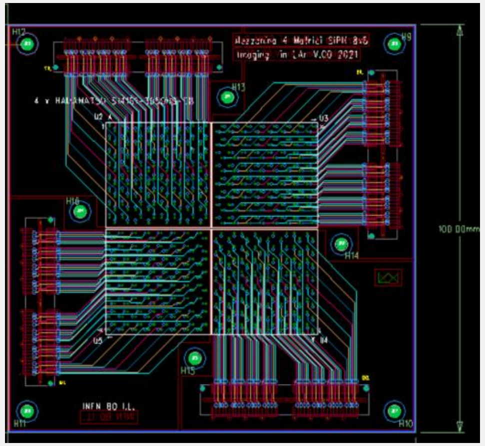
The design can be easily adapted to larger sensors such as -4050 or -6050.

One Xilinx VC707 per camera.









CONCLUSIONS

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A new imaging system to be exploited in neutrino detectors, based on the coded aperture technique, is being developed.

First prototype of cryogenic Coded Aperture SiPM camera
- Can reconstruct simple point sources
- Can work at liquid Argon temperature
- Limited resolution, insufficient for track imaging

Larger prototype with multiple 256-channel cameras designed
- Extensive Geant4 + SiPM response simulations to refine design and establish minimum requirements
- Expected to be operational in Q4 2021