Istituto Nazionale di Fisica Nucleare

An imaging detector for Liquid Argon experiments

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on behalf of the INFN Nu@FNAL Collaboration

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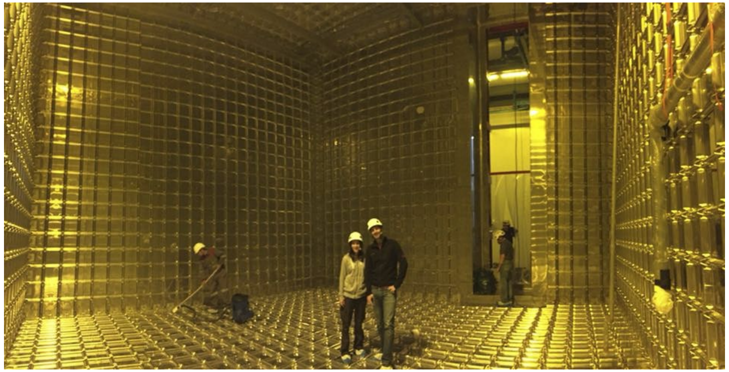
Liquid Argon Detectors

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

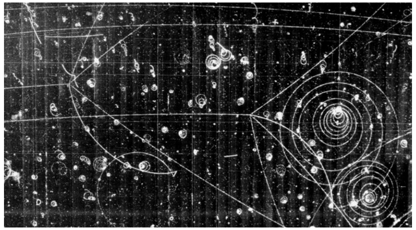
- large target mass
- low energy threshold
- good spatial resolution
- low radioactive background



ProtoDUNE LAr TPC

But, for future accelerator experiments, such as DUNE, the Near Detectors will need *higher rate capability*

An imaging detector to see particles



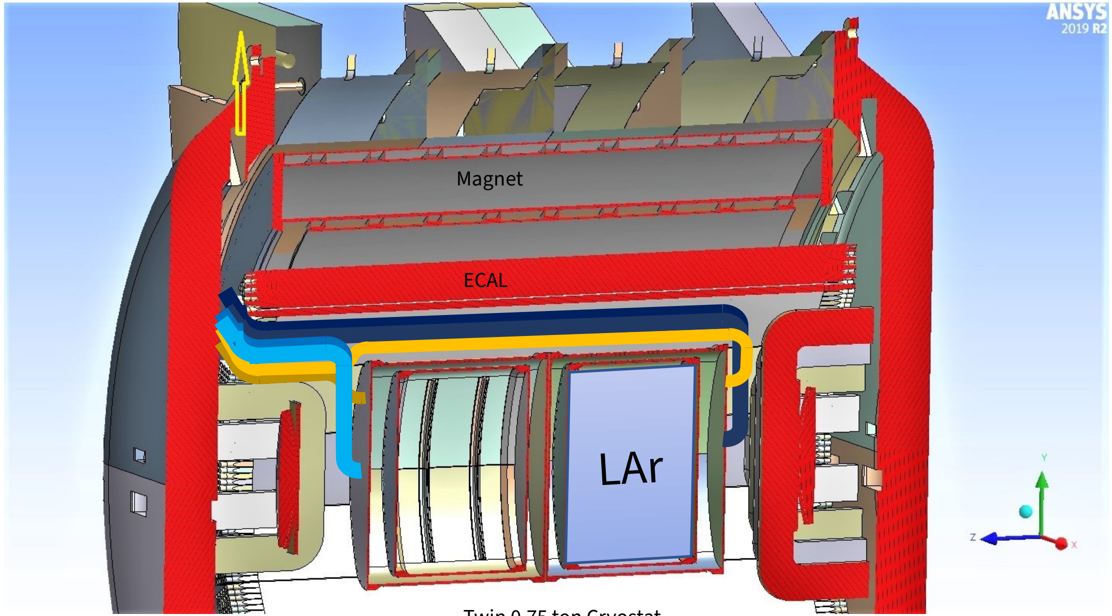
The ultimate goal: take pictures of charged tracks

And measure deposited energy as well

In the SAND Near Detector for DUNE

Formerly KLOE @ INFN LNF

Using LAr in the Near Detector reduces an important systematic to the neutrino cross section



Twin 0.75 ton Cryostat

Main challenges

Argon scintillates at very short wavelenghts (~128 nm)

- Most common optical materials are not very transparent
- Sensors are not very efficient
- Wavelength shifting can be done, but needs to preserve directionality

Photodetectors need to operate at cryogenic temperatures

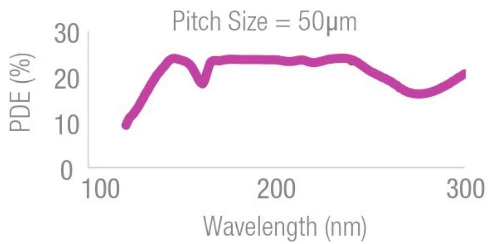
- It is impractical to extract light from the cryostat…
- ... and also thousands of analog signals: a cryogenic ASIC is needed
- On the other hand low temperatures reduce sensor noise

Optics must provide deep and wide field-of-view

Photodetectors

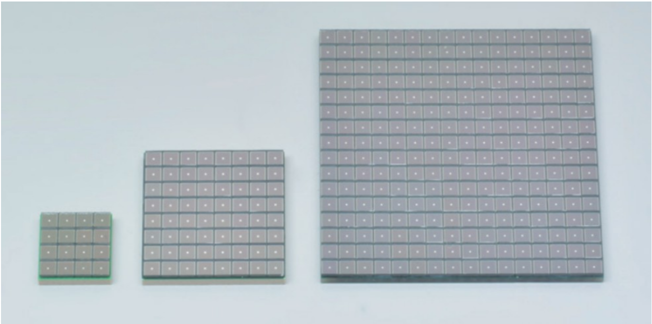
Several vendors have pushed SiPMs sensitivity in the *Deep* and *Vacuum* Uv

> 25% at Lxe and > 10% at LAr peaks reported

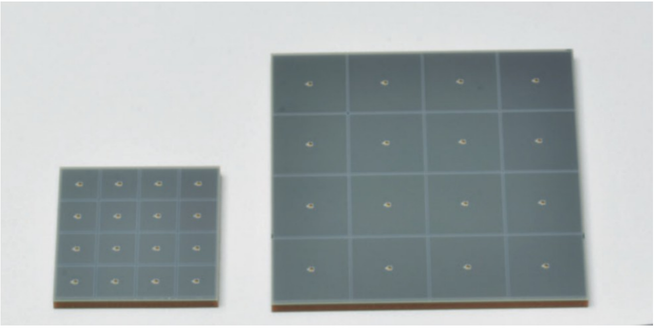


Tightly packed matrices of up to 16 x 16 pixels are available commercially with standard wavelength SiPMs

Not quite for VUVs



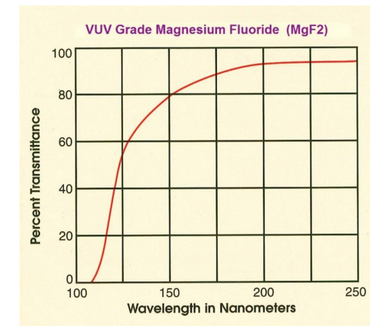
Hamamatsu S13615 and S14161



Optical Systems

Thin VUV-grade lenses made of MgF_2 and CaF_2 lose 50% or more light at 128nm

LAr refractive index is > 1.4, which would require fairly thick lenses for short focal lengths



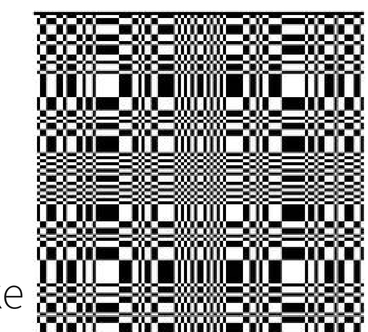
eSourceOptics Catalog

We have investigated several systems based on lenses, Fresnel lenses and metallic mirrors.

Performance has not been satisfactory

Projected complexity and cost is generally high

There is an alternative, the Coded Aperture Mask



Frequently used in X-ray astronomy and γ detection

Still loses 50% of light, but good field of view, simple to make

A proof of concept prototype

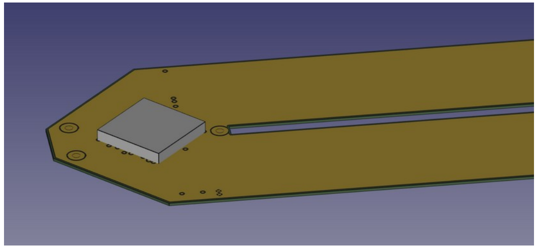
Primary goal: test SiPM matrix connectivity and functionality in LAr

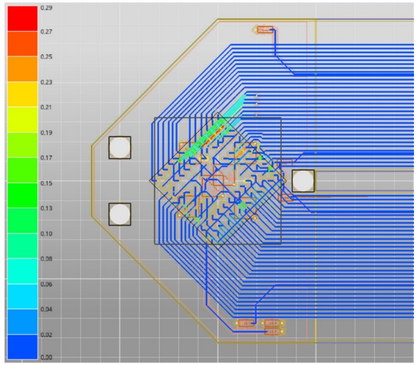
At this stage no cold electronics is viable, need to extract the analog signals from the cryostat

Designed and built a flexible PCB

Hosts one Hamamatsu S13615-1050N-08 with 64 separate SiPMs

4-layer, 50 cm long, as little copper as possible to minimize heat transport into the cryostat





SiPM end was tested in liquid nitrogen (77K) – Works!

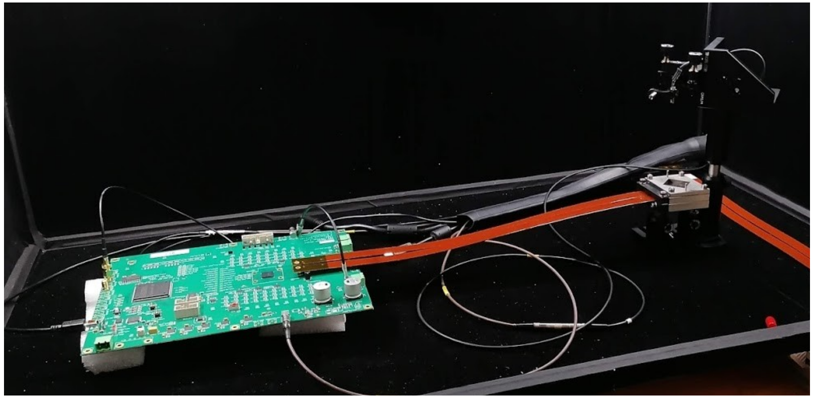
Experienced no issues with a few thermal cycles

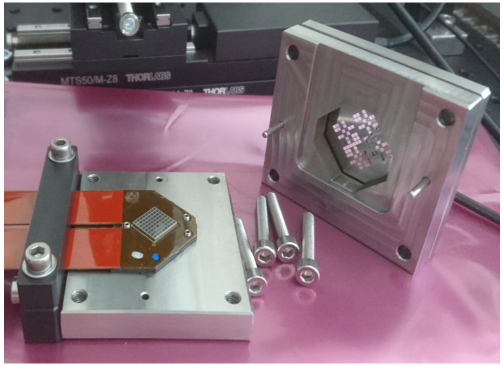
Assembled the 8x8 sensor with a Coded Aperture Mask

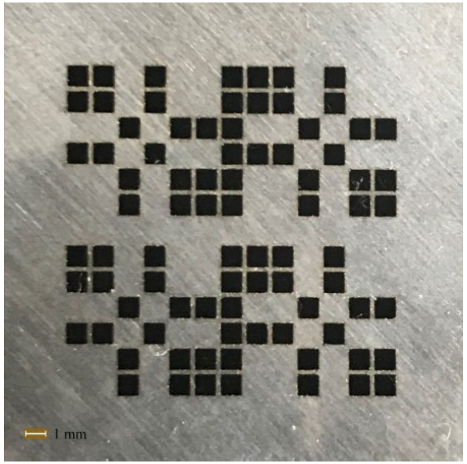
Rank 7 MURA, 2x2 mosaic. Provides a wide field of view, but spatial resolution is limited

Signals read out by TRIROC Evaluation Board

Blue LEDs used as point sources

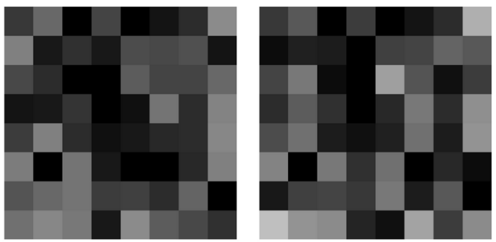






Steel mask, 100um thick, 1 mm holes, 1.2 mm pitch

Reconstruction of point sources



Raw sensor image

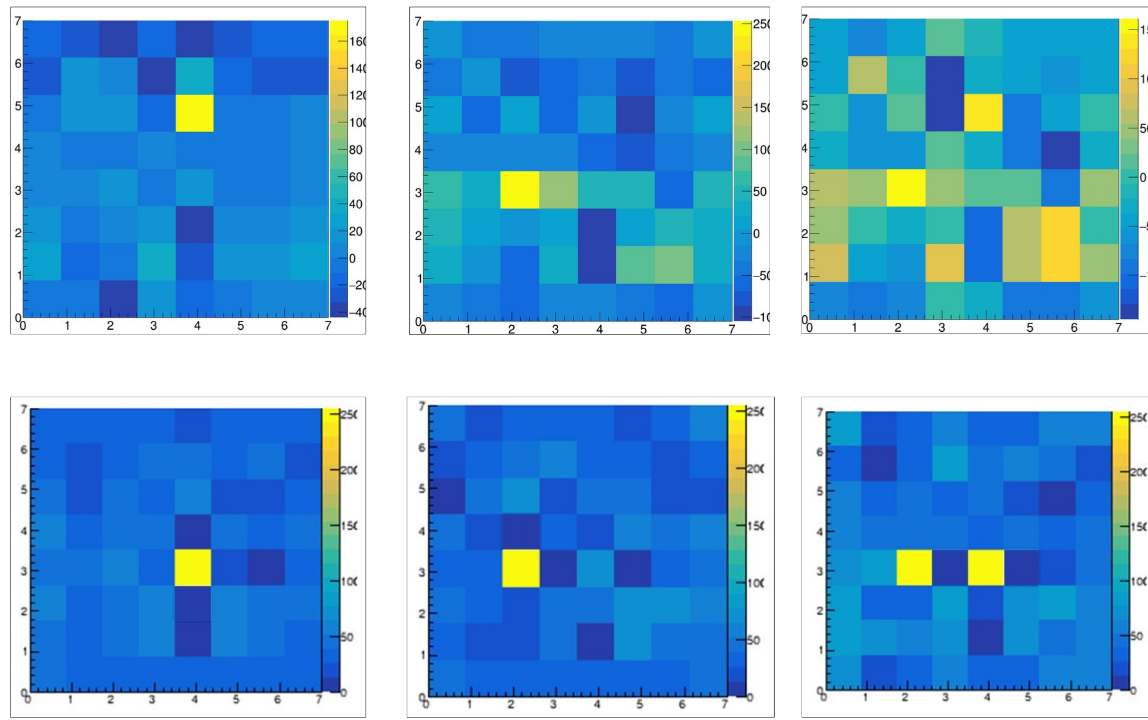
Reconstructed image

Many artefacts from SiPM noise, quantization, etc...

You can still see both points

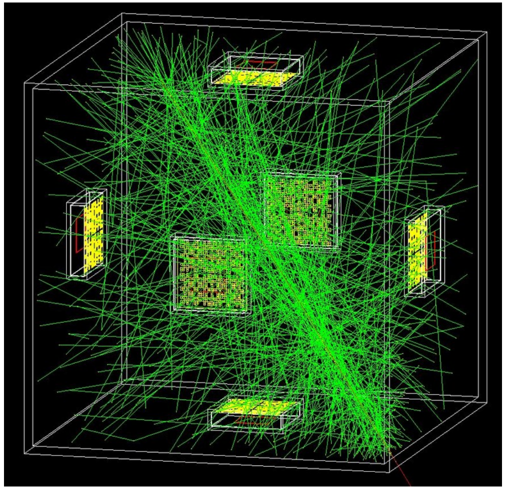
Simulation of the same

Led 1 Led 2 Both



Charged tracks simulation and reconstruction

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

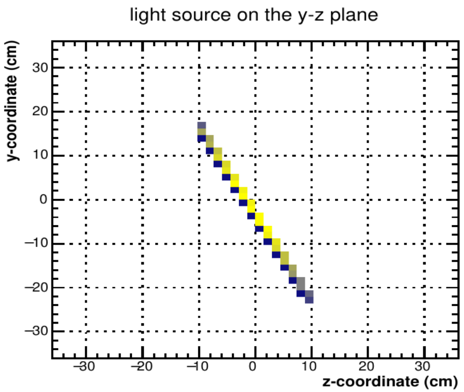
Reconstruction of raw sensor data

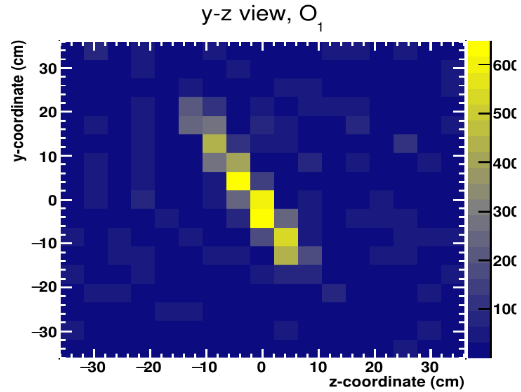
- For details about the algorithms and the method for combining multiple images of the same event, see our paper [Preprint https://arxiv.org/abs/2105.10820]

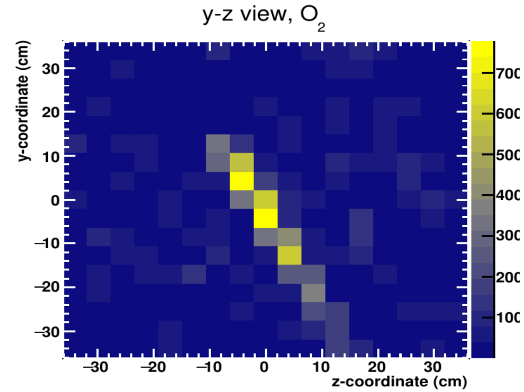
Charged tracks simulation and reconstruction

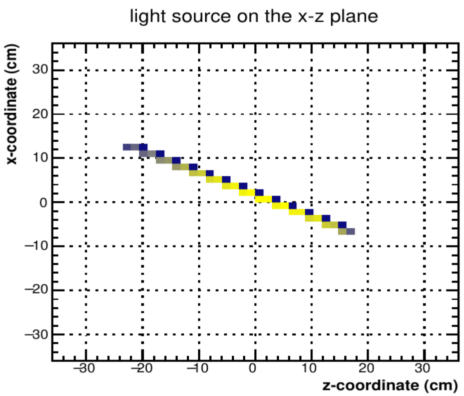
Simulated

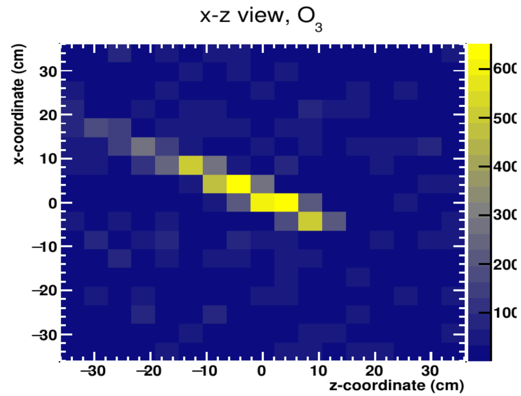
Reconstructed

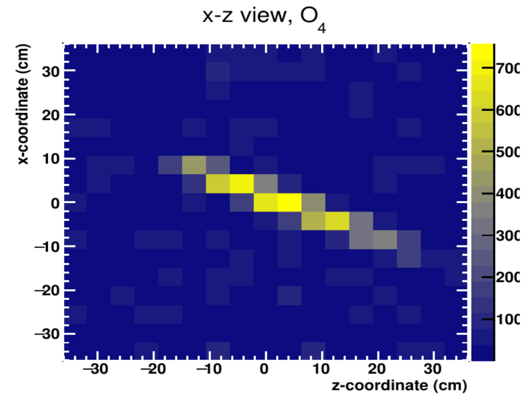








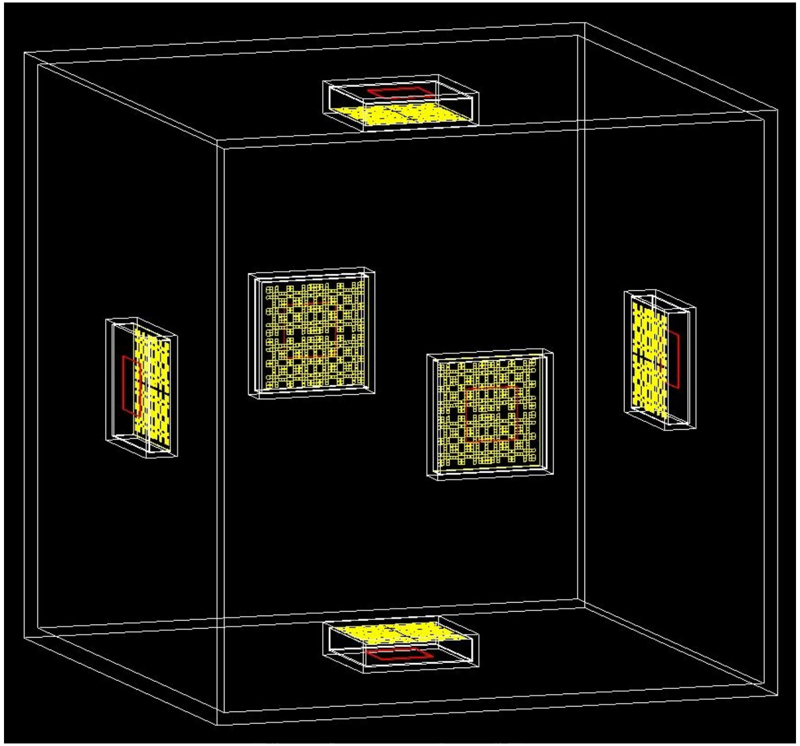




Design of a realistic cryogenic demonstrator

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

Extracting analog signals can be done, but is highly inconvenient

- The demonstrator would require a large number of feed-through ports

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

- ALCOR, developed by the INFN Torino microelectronics group, 32 channel TDC
- This is also a first demonstrator, not yet proven in cryogenic conditions

ALCOR design paper DOI: 10.22323/1.370.0011 https://pos.sissa.it/370/011/

Designed cameras to work both with and without the ASIC

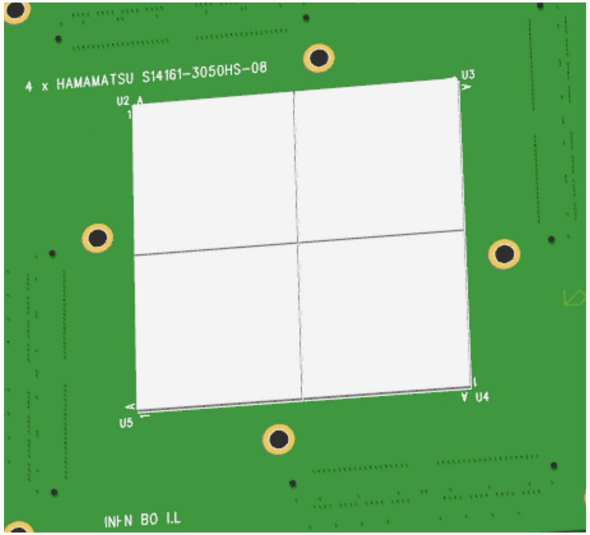
Design of a realistic cryogenic demonstrator

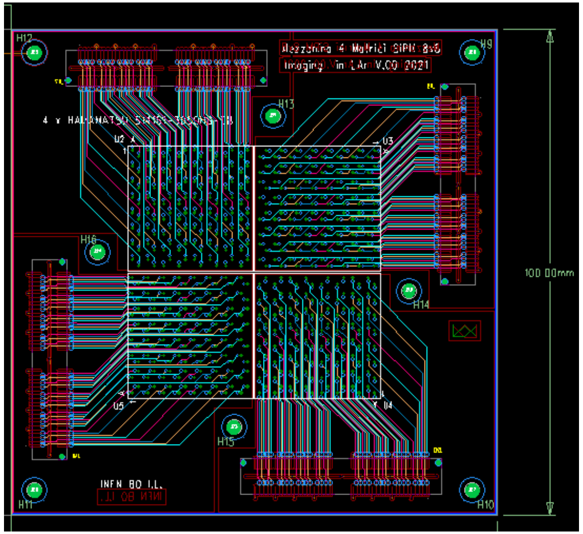
Each camera will use four Hamamatsu S14161-3050HS-08 and 8 ALCORs

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

One Xilinx VC707 per camera

320 MHz LVDS outputs from ASIC





Conclusions

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 simulations to refine design and establish minimum requirements
- Expected to be operational in Q4 2021