FLArE: Design and Engineering Overview

Steven Linden on behalf of the FLArE Technical Group
FPF5, CERN, 16 November 2022

FLArE Design - Introduction

A FLArE-specific technical group has been formed, organized by me, Milind Diwan, and Jianming Biang.

Focus is on developing a CDR for FLArE by the end of next year.

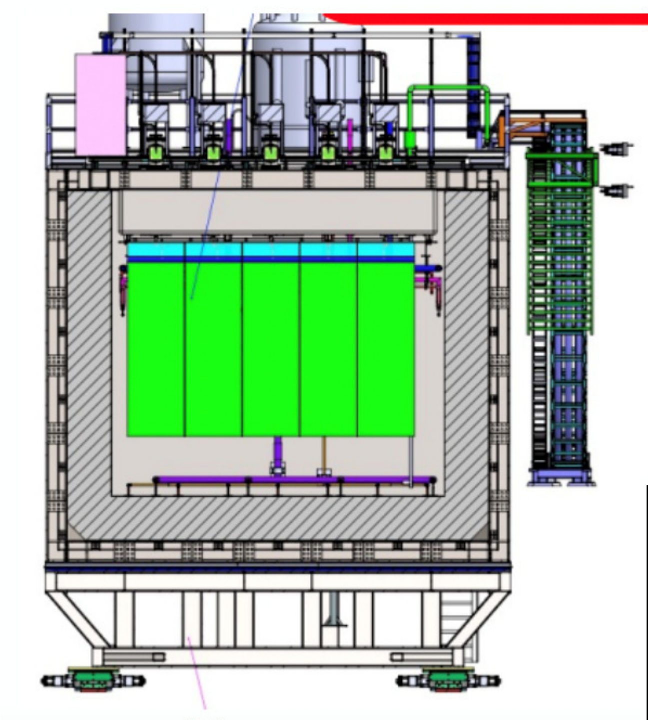
We have begun compiling details of the design in a set of spreadsheets

Will translate these spreadsheets into material for CDR

Also very helpful to look at DUNE ND CDR

Preliminary cost estimates will be based on DUNE ND.

Cryostat



- Space in FPF hall currently is limited to 3.5 m x 3.5 m x 9.6 m for FLArE.

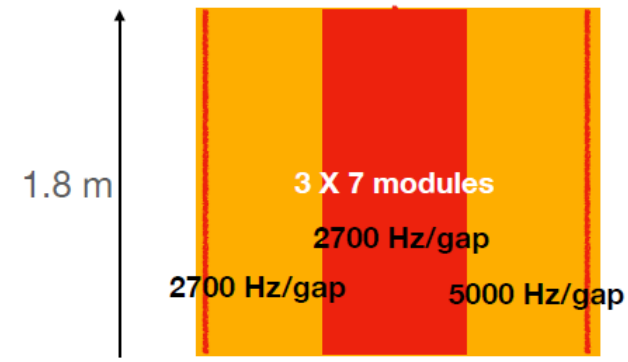
- 80 cm GTT membrane occupies 1.6 m out of 3.5 m.

→ About 1.9 m x 1.9 m cross section allowed for detector.

	Cryostat Inner Dimensions	Insulation Type	Insulation Thickness	Insulation density	Heat leak	Cold shield
MicroBooNE	3.8m dia x 12 m	Polyurethane Foam	**400mm**	32 kg/m³	**~13 W/m²**	No
ICARUS-GS	3.9m x 3.6m x 19.6m	Nomex honeycomb+perforated Al	**665 mm+ (combined)**	25-35 kg/m³	**7-22 W/m²**	Yes
ICARUS-SBN	3.9m x 3.6m x 19.6m	Al extrusion+GTT foam	**665 mm+ (combined)**	25-35 kg/m³	**10-15 W/m²**	Yes
ProtoDUNE	7.9m x 8.55m x 8.55 m	GTT membranc	**800mm**	90 kg/m³	**~8 W/m²**	No
ND-LAr	3m x 5m x7m	GTT membrance	800mm	90 kg/m³	**~8 W/m²**	No
FLArE	~(1m x 1m x 7m)					No?

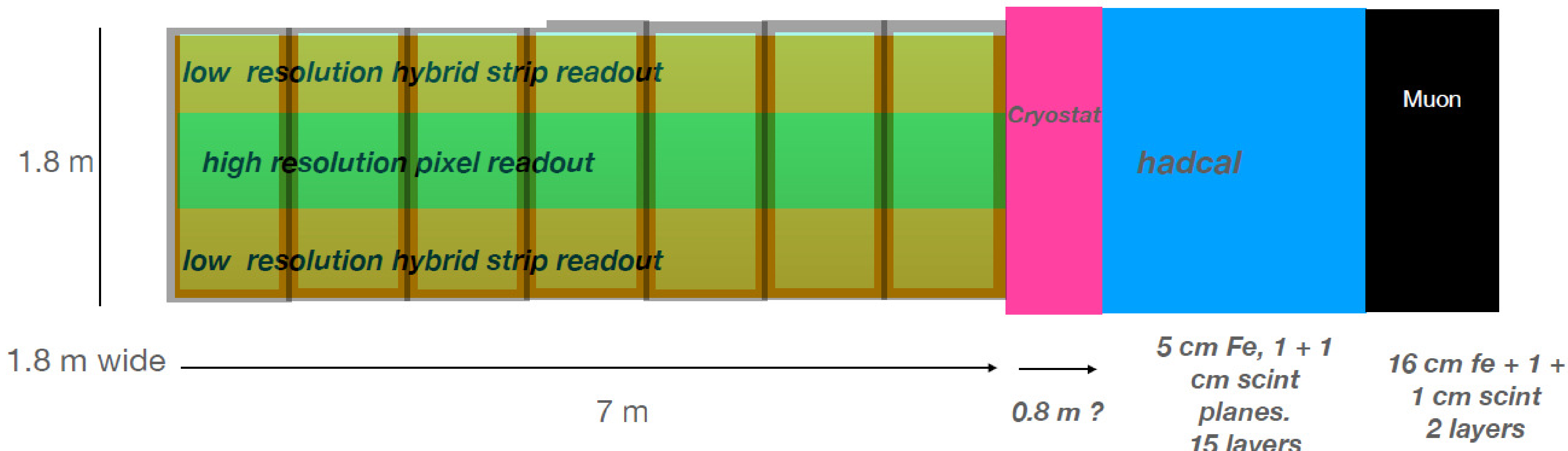
Yichen Li

Detector Dimensions: 3x7 option



Basic requirements:

- Contain neutrino events
- Keep drift lengths short (reduce space charge)
- Fit within cryostat



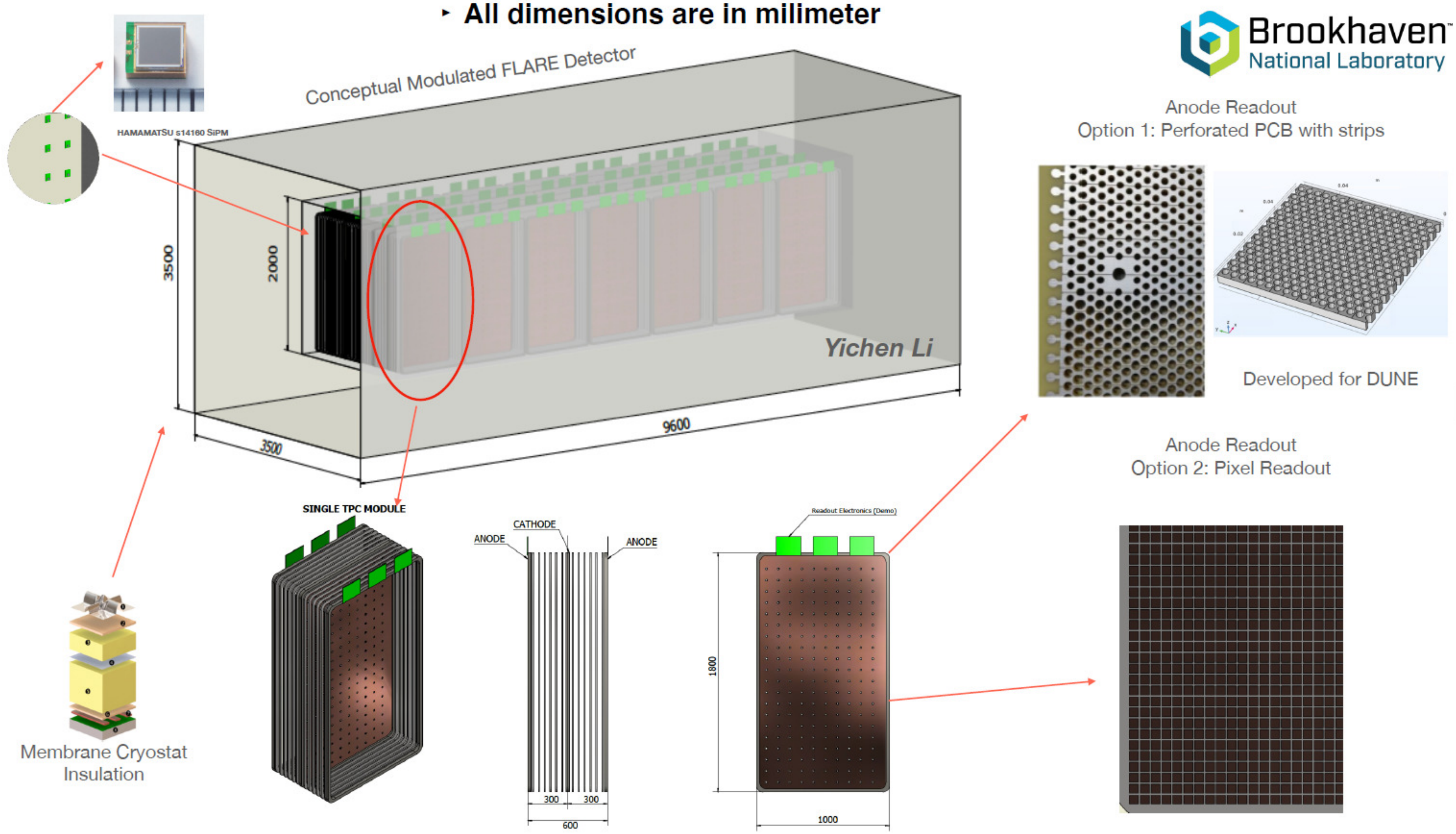
Pixel-based anode → very high number of channels. Reduce channel count by using strip-based anodes in non-fiducial region

Photodetectors needed for triggering – e.g. ARAPUCA (Photon is trapped through wavelength-shifting and dichroic short-pass filters; readout by one or more internal SiPMs.)

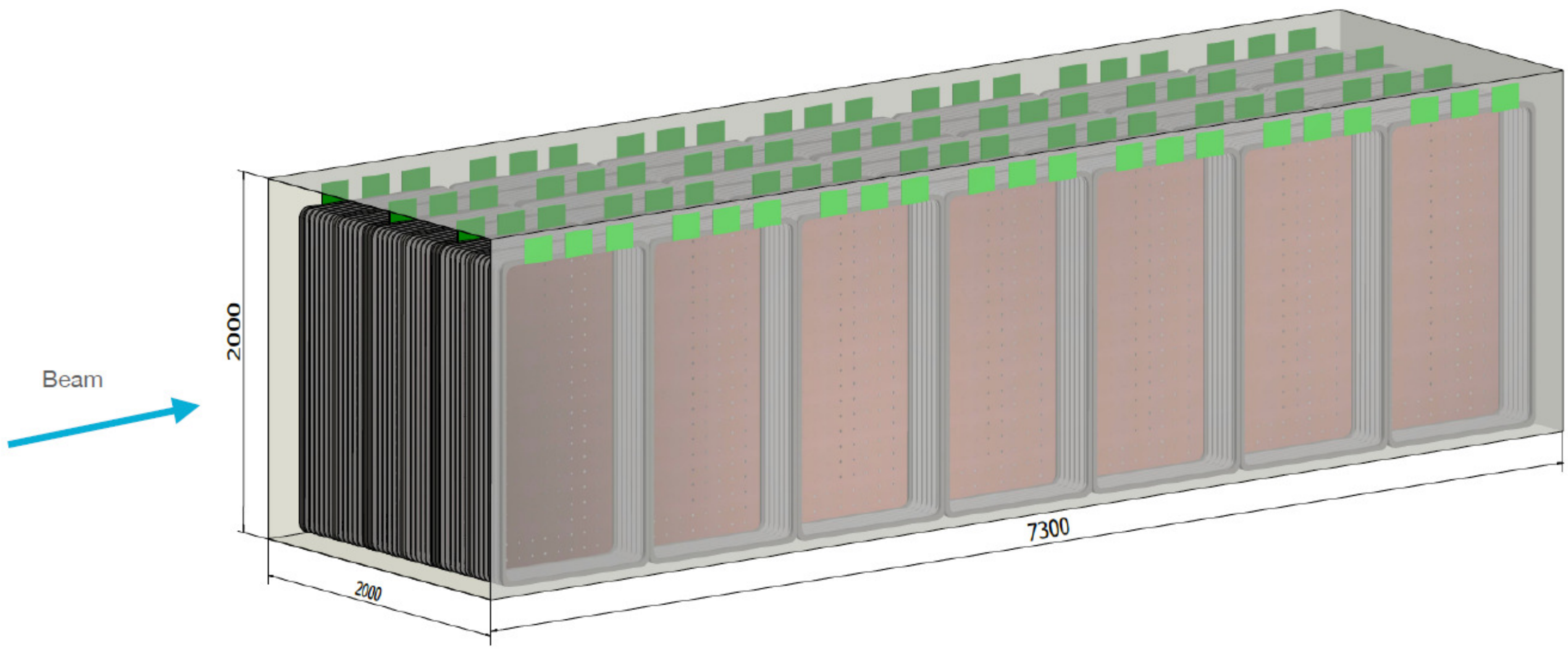
None of this has been optimized yet – all numbers are preliminary!

Preliminary Models

- **All dimensions are in milimeter**



Preliminary Models: TPC



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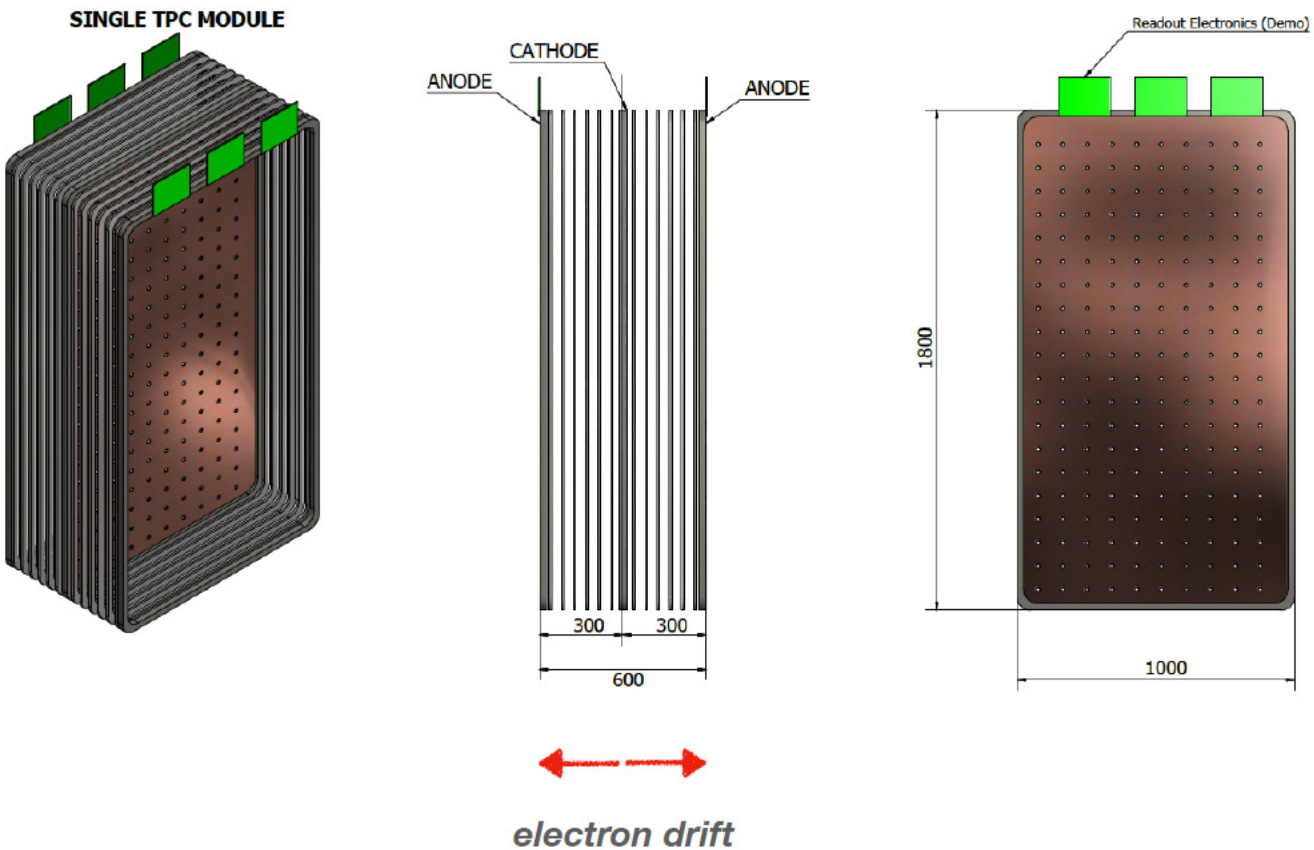
Preliminary Models: Modules



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30 cm. drift length, ~1 kV/cm., ~0.5 Hz/cm^2 muons → ~1 muon per drift time

Detector Parameters: 3x7 option

	Most Aggressive	**Least Aggressive**
# of modules	21	21
Module height	180 cm	180 cm
Module width	60 cm	60 cm
Module depth	100 cm	100 cm
Total TPC height	180 cm	180 cm
Total TPC width	180 cm	180 cm
Total TPC depth	700 cm	700 cm
# of cathodes	21	21
# of anodes (pixel)	42	14
# of anodes (strip, two planes)	0	28
Pixel/pitch size	2	5
Channels per anode (pixel)	450,000	72,000
Channels per anode (strip)	-	1,120
Total channels	18,900,000	132,160

We may be looking at a very high number of channels!

Important to consider heat load per channel and optimize

Other Geometry Options

We can consider other options besides the 3x7, transverse drift option.

One option is 2x7 modules – increases drift length to 45 cm., reduces number of channels.

Another option is to have the drift direction parallel to the beamline – trade anode resolution for electronics sampling time in beam direction.

We still have a lot of free parameters in this design. These options will all be refined, but will be carried through into the CDR.

Magnetic Spectrometer

Muons above ~2 GeV are not contained in FLArE.

→ A magnetic spectrometer is likely needed in the FPF not just for FASER2, but also for muon momentum measurement in FLArE.

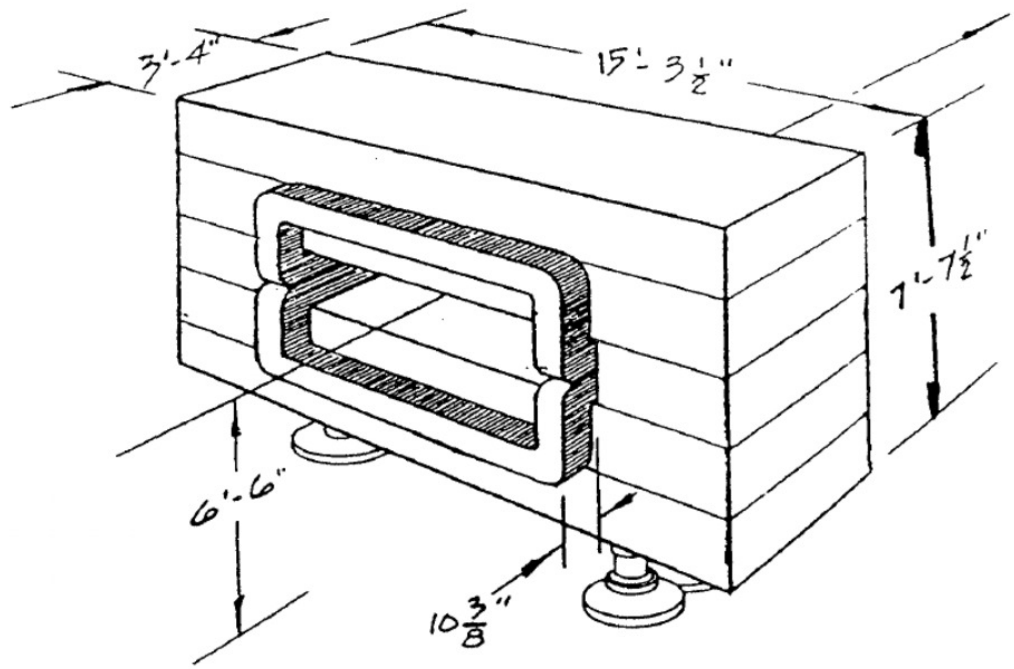
Example: 96D40 magnet (available at BNL)

About 4.5 m wide by 2.4 m high

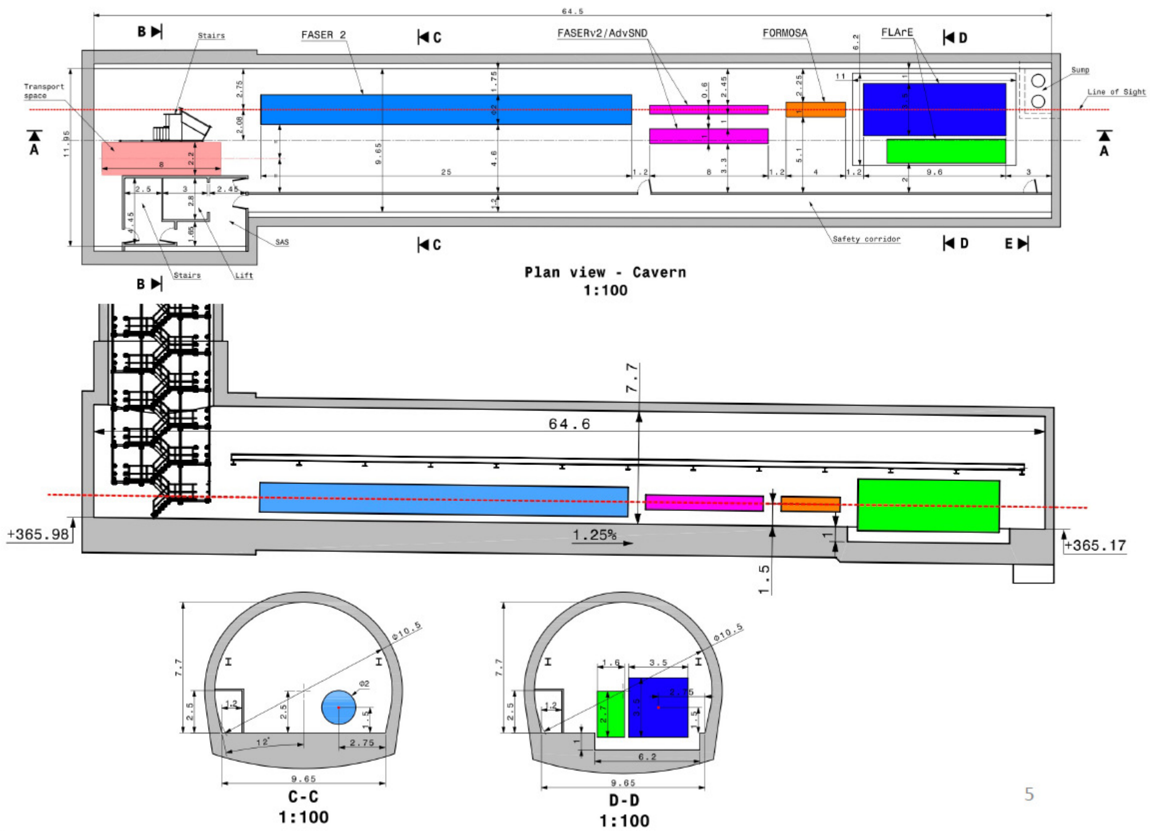
But this is with a ~0.5 m gap; we need a gap of ~1 m.

Can add more steel.

Need to consider space constraints and whether it is necessary to fully contain the field.



Installation Challenges



Preliminary design of the FPF cavity aims for minimum size that can satisfy experiment requirements.

This means we need to think carefully about how everything can be installed within the space constraints.

Two major issues for FLArE:

1. Will we be able to install TPC from above?
2. Will the large magnet prevent installation access to FLArE?

Ideally, want to be able to remove and replace modules after installation.

We must study the design and installation and iterate with CERN civil engineering.

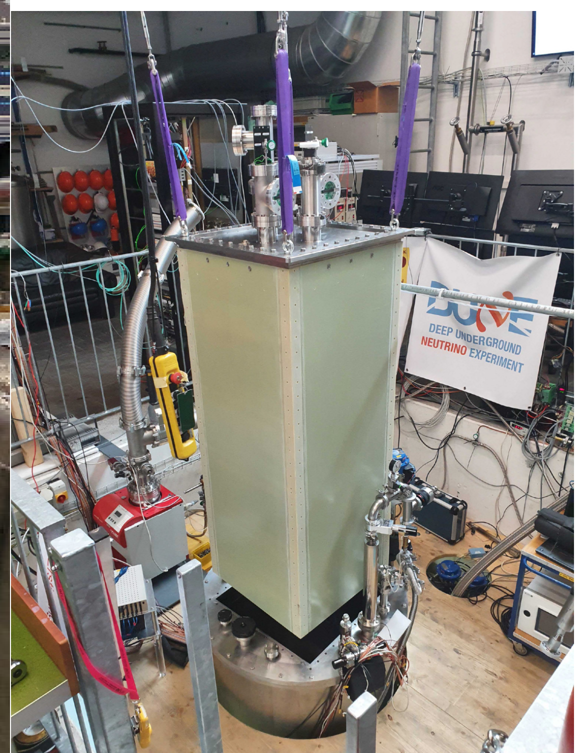
Resources are available to hire contractors to study these issues, but the problems need to be clearly defined.

TPC/Anode Design

Significant expertise with TPCs exists in the Instrumentation Division at BNL.

Several instrumentation experts (Bo Yu, Sergio Rescia, Aleksey Bolotnikov) are involved with our technical design group.

We benefit from the work on DUNE, particularly the near detector concepts.



Several test stands exist or are under development in the U.S. (FNAL, Irvine, BNL).

These can support readout R&D.

TPC Production and Testing

Tremendous resources exist at CERN for building and testing LAr TPCs

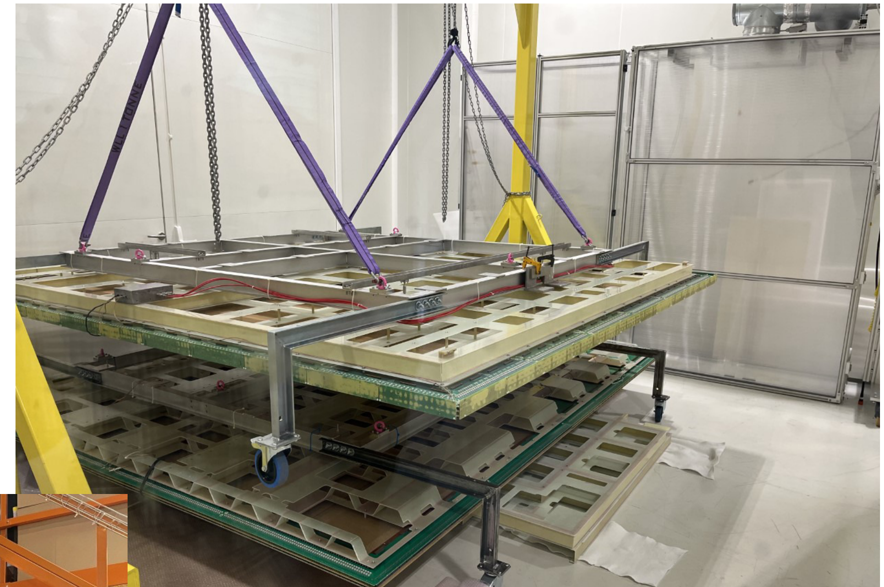
We should take full advantage of these resources!

Vigorous and well-established LAr R&D program is ongoing in building 182 (Francesco Pietropaolo)

Mature production process for ProtoDUNE anode and cathode assemblies exists

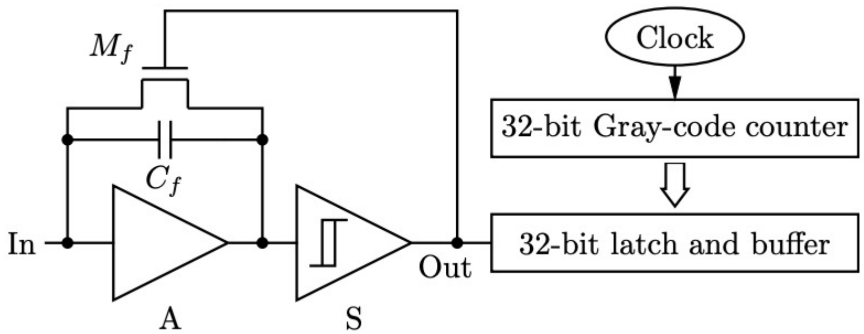
When ProtoDUNE effort is complete and focus shifts to building DUNE – whither the cryostats and infrastructure?

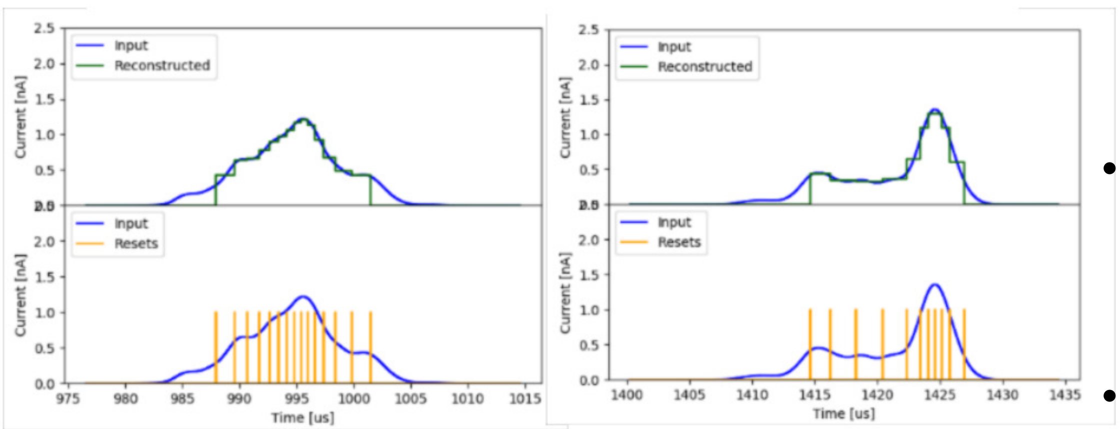
It seems natural and synergistic to build and test the FLArE modules using all this existing infrastructure and expertise.



Pixelized Anode: Q-Pix

Charge Integrate/Reset (CIR) circuit





Q-Pix Collaboration, arXiv:2203.12109v1 [physics.ins-det]

- Charge amplifier continuously integrates incoming current
- When the charge reaches a certain threshold, the amplifier resets
- The reset time is captured and stored and used for charge signals reconstruction as illustrated
- However, Charge/Reset circuit stops following input signals if polarity changes
- This happens when a pixel captures the induced signal generated by an electron cloud collected on a neighboring electrode
- For Q-Pix approach, it is important to have electrode designs that minimize induced signals

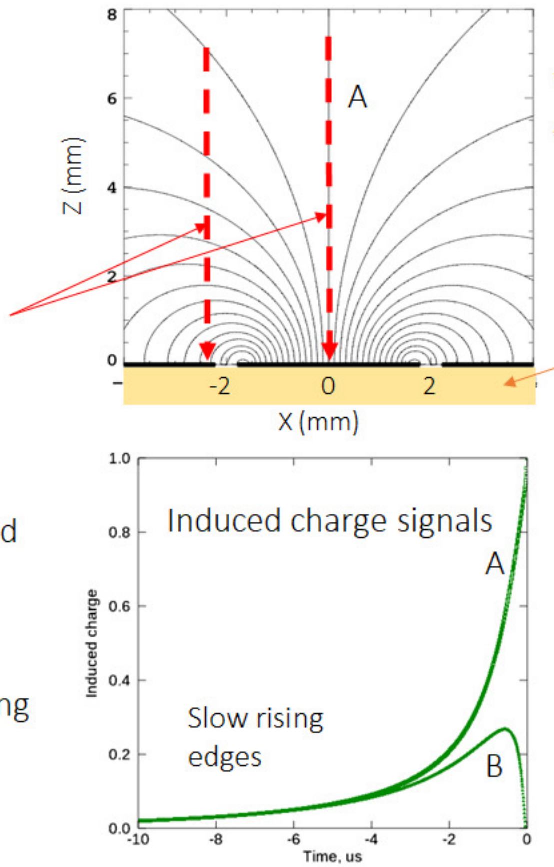
Pixelized Anode: Q-Pix

From A. Bolotnikov (BNL):

Case 1: large contacts, 0.4 mm gaps

DUNE near detector TPC

Two electron cloud trajectories

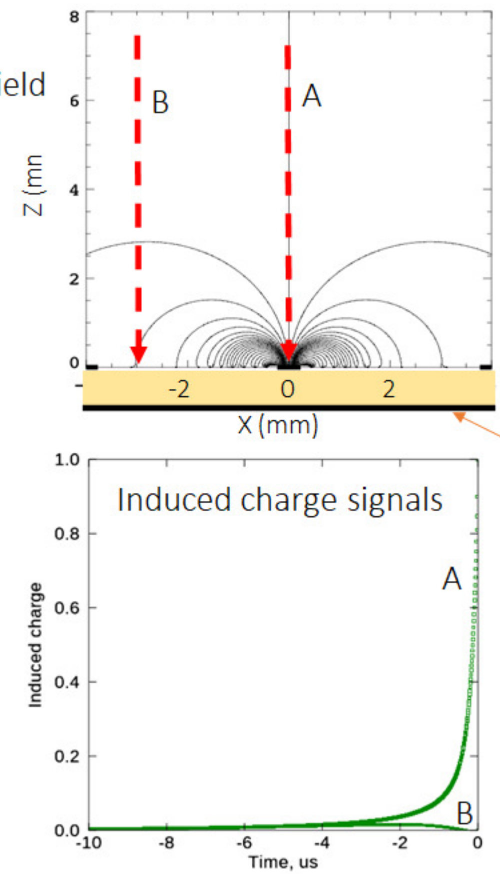


Weighting field 4-mm pitch

PCB

- Strong induced signals from neighboring pixels
- Long slow rising edges

Case 2: 0.4-mm contacts, large gaps



Design considered by Q-Pix team

Shielding plate

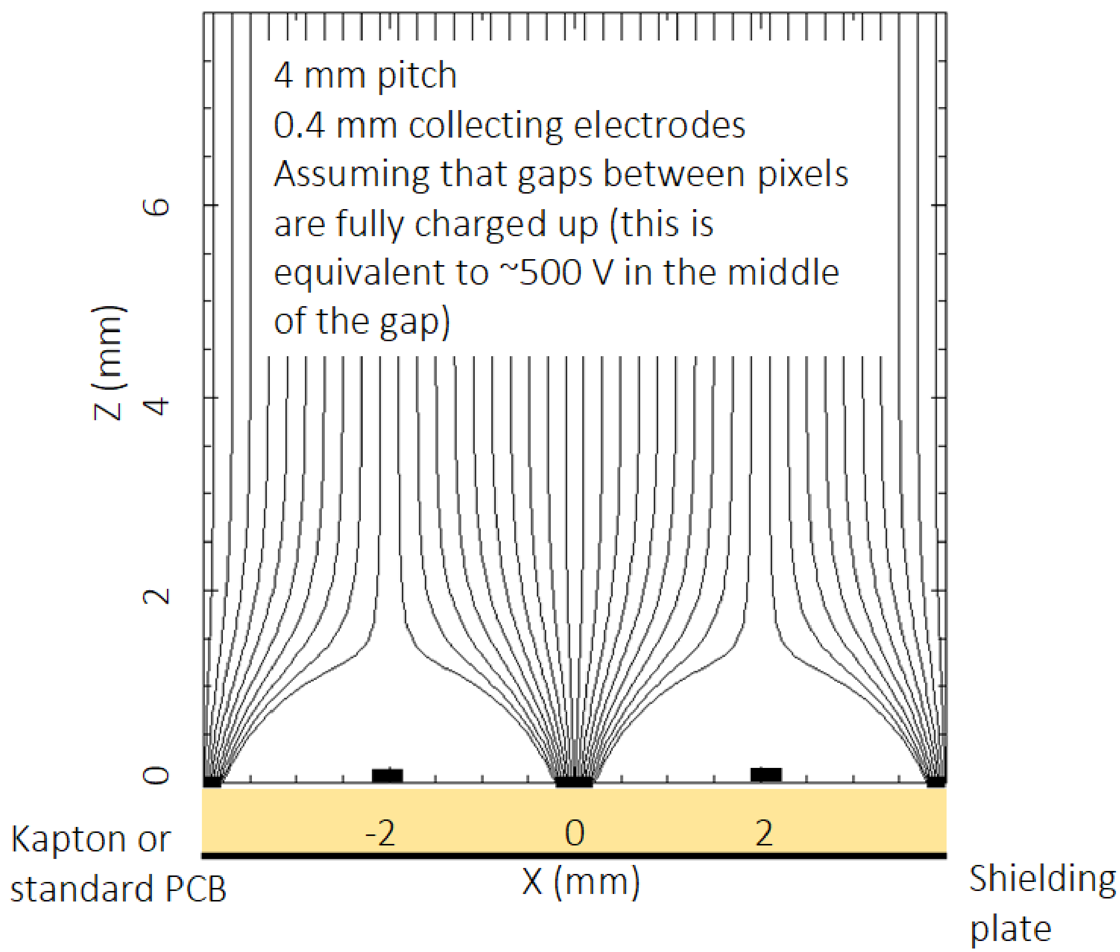
- Small induced signal from a neighboring pixel
- Fast rising edges

Pixel with Small Contacts: Field Shaping

As shown in the previous slide, the "small pixel – large gaps" geometry works well for Q-Pix readout, however:

- Field-lines are strongly bent - different drift times
- If gaps are not fully charged, then some charge losses are expected between pixels
- One can try to use field-steering electrodes to avoid charge losses in the gaps – increase electronic noise

A. Bolotnikov

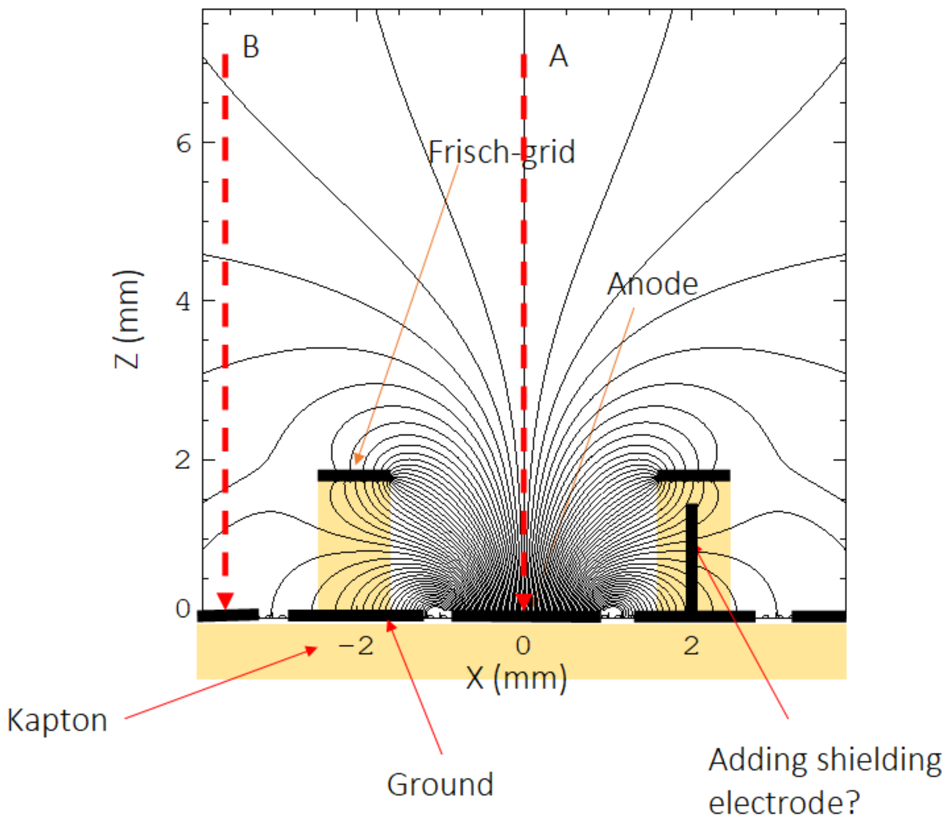


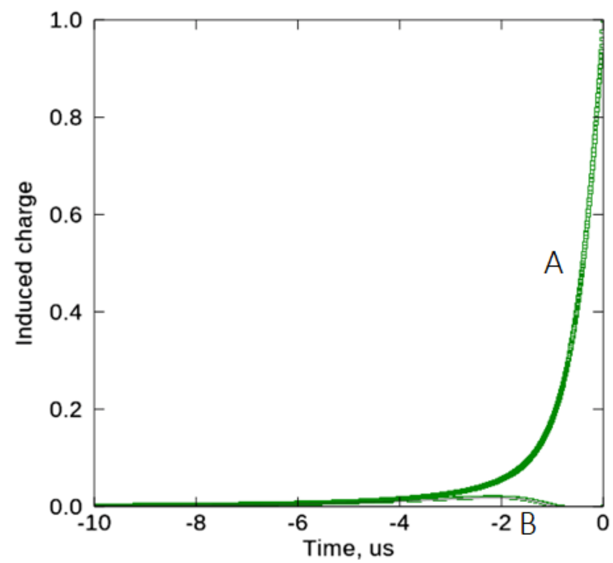
Shielding electrode is important!

Pixel with Small Contacts: Field Shaping

Frisch-grid and vertical shielding electrodes can be added for additional field shaping.

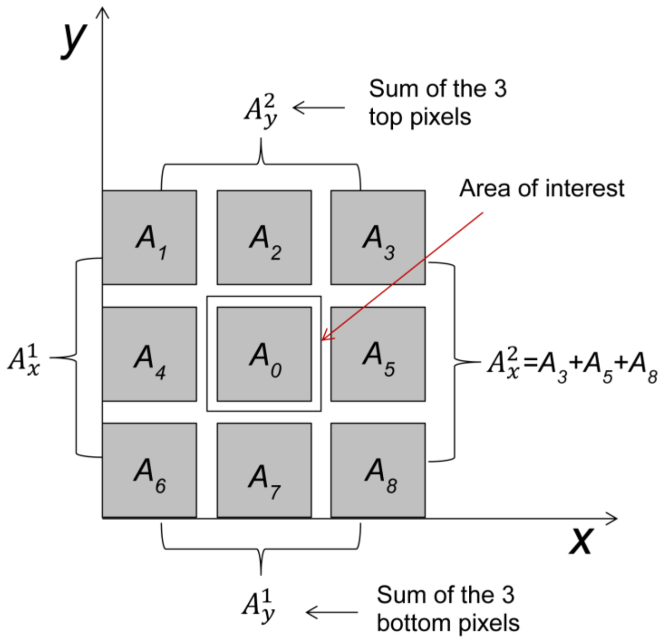
All this needs to be optimized based on full simulations.





Most of the field lines terminate on the grounding electrodes

Subpixel Position Resolution



Very small pixel sizes might lead to impractically large channel counts.

Information from neighboring pixels can be used to achieve resolutions smaller than pixel size.

Similar concept to some noise reduction techniques.

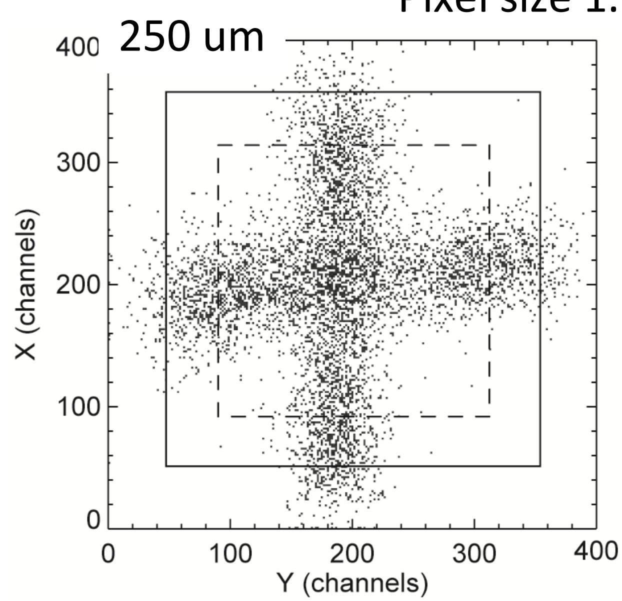
See Giraldo et al., https://doi.org/10.1016/j.nima.2017.04.030

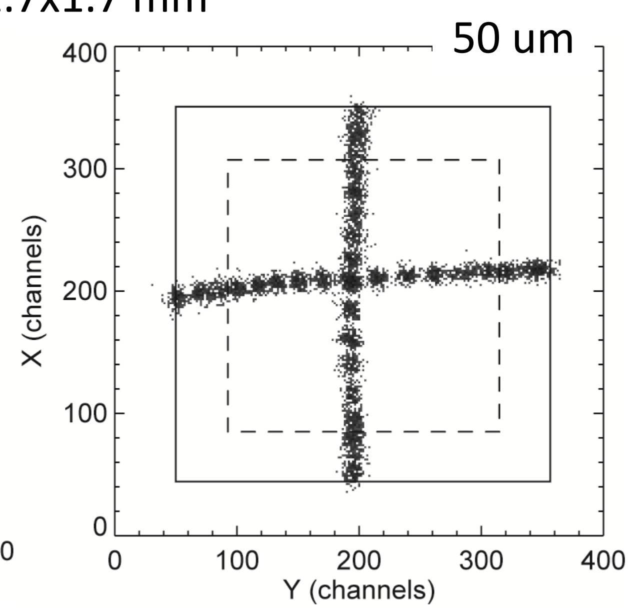
15x15x5 mm CdZnTe pixel detector

Illuminated by a pulsed laser

Resolution down to 250 μm (left, 0.25 MeV) or 50 μm (right, 1 MeV)

Pixel size 1.7x1.7 mm





Summary

• FLArE technical group is actively working on a CDR.

• Broad aspects of the detector design are defined.

• Several detector geometry decisions must be finalized.

• Further simulation and prototyping are needed to inform design decisions – What resolution can we reach? What anode parameters are needed to achieve it?

• The goal is a CDR, including cost estimate, by sometime in 2023.