FLArE Update & Status

Steven Linden
FPF7 Workshop
29 February 2024

Outline

- Concept and Reference Design
  - FLArE concept
  - Cryostat
  - TPC
- Engineering Work
- Alternative two-phase design with optical readout (K. Mavrokoridis)
- Simulation (W. Wu, M. Vicenzi)
  - Simulation framework
  - Geometry options
  - Magnet options
  - Muon acceptance
- Summary

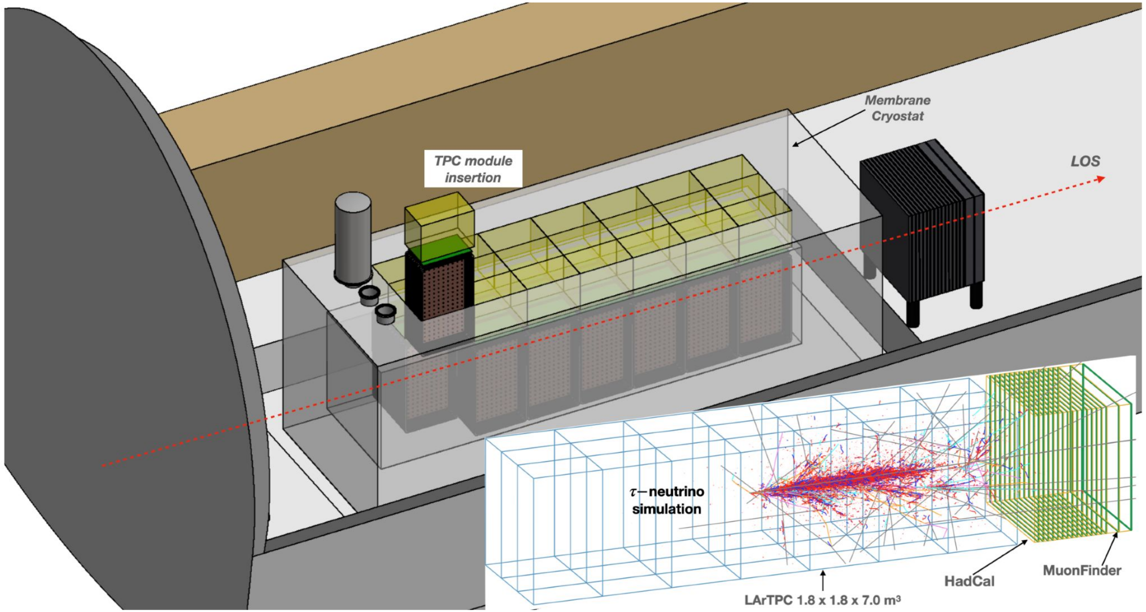
Concept and Reference Design

FLArE: Forward Liquid Argon Experiment

Broad range of physics topics:

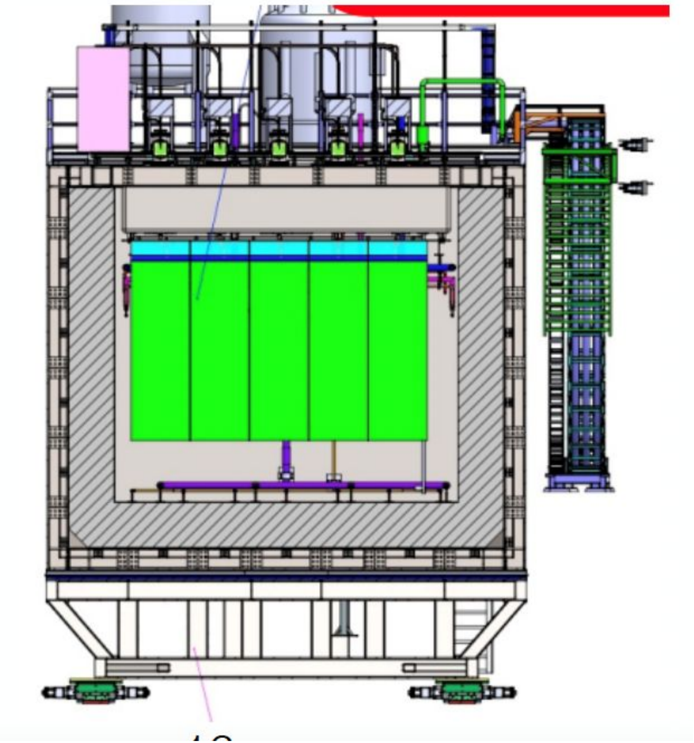
Neutrino physics: high-statistics samples of all flavors, cross-section measurements, neutrino tridents

QCD physics: accessed both in production and in DIS at the FPF; can study small-x proton structure, BFKL dynamics, intrinsic charm, nuclear structure functions



BSM physics: light dark matter scattering (produced by decay of mesons in forward direction), complementary with missing transverse energy collider searches and with direct detection of relic DM

Cryostat Reference Design



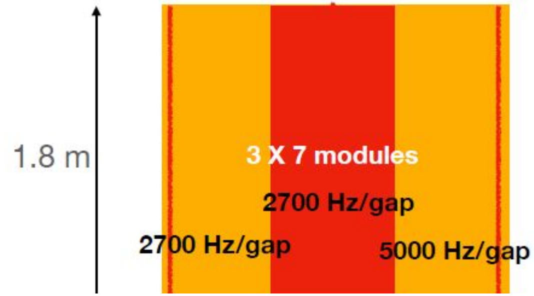
- Reference design is GTT membrane cryostat (used in ProtoDUNE, ND-LAr)

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

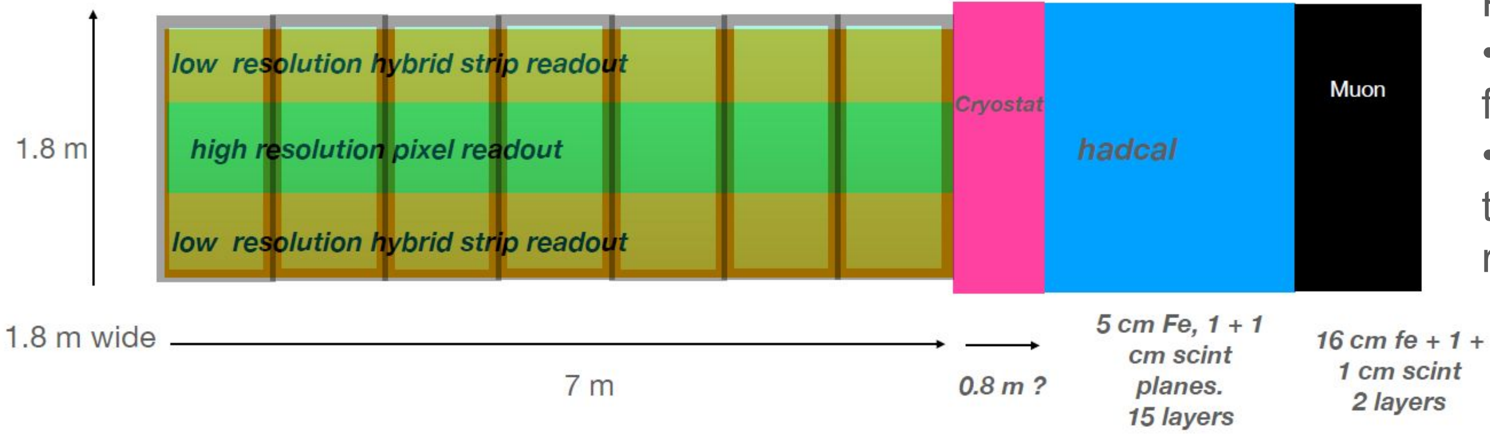
→ About 1.9 m x 1.9 m cross section allowed for detector.

- Is there a compelling reason to use GTT membrane? Can consider single-wall? Vacuum-insulated? These options might decrease the bulk of the cryostat.

TPC Reference Design



3 rows of 7 TPCs
Cathode in center of each TPC → 42 drift volumes
30 cm drift length (good to minimize space charge)



Pixel size?
- Considering options for 2 mm., 5 mm.
- Studies in progress to help set requirements.

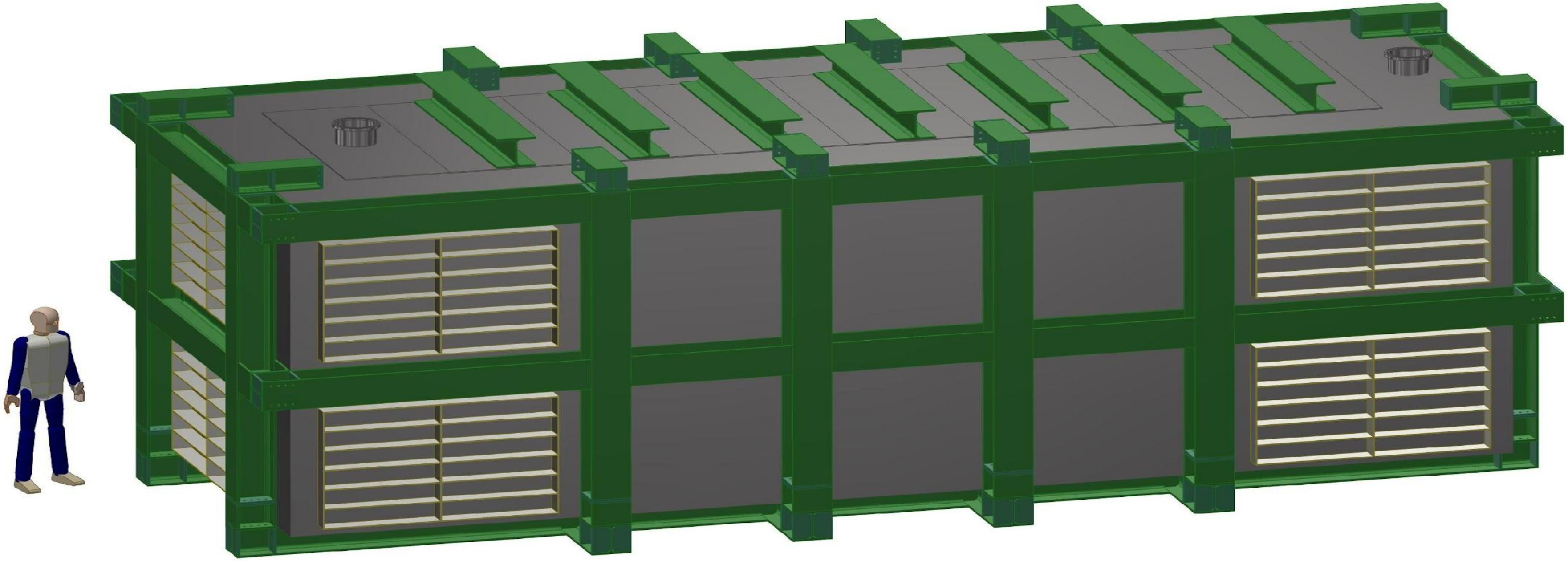
- Pixel-based anode → very high number of channels. Can reduce channel count by using strip-based anodes in non-fiducial region.
- Depending on pixel size and fiducialization, anywhere from ~100k to ~20M channels
- A major constraint will be the heat load per channel - need R&D

Engineering Work

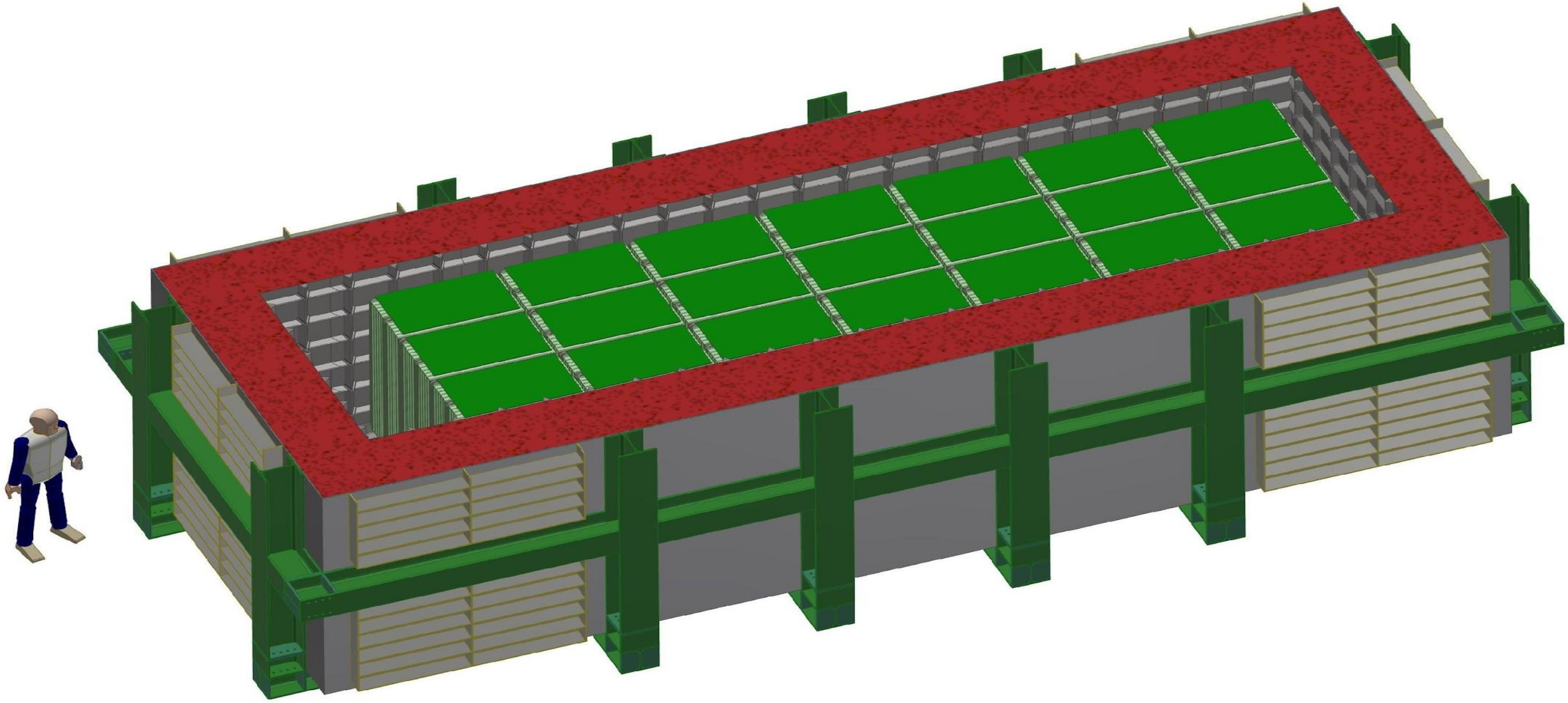
Engineering team and goals

- We now have an engineering contractor (Larry Bartoszek) working with us, as well as some time from two BNL engineers (Connor Miraval and Steve Trabocchi).
- This group has been working toward a conceptual design of the TPC, cryostat, and installation plan.
- The largest issues remaining to be worked out in detail are the specifics of the cryogenic system and the plan for installing TPC modules.
- Bartoszek has created a preliminary 3D model for the detector.
- The model was cobbled together from parts of the SBND detector, morphed to fit around our TPC modules.
- There are significant elements missing, as would be expected of this stage of design
  - Seals are not shown
  - No HV feedthroughs are shown
  - No signal feedthroughs are shown
  - Hadron calorimeter, muon tracker not included

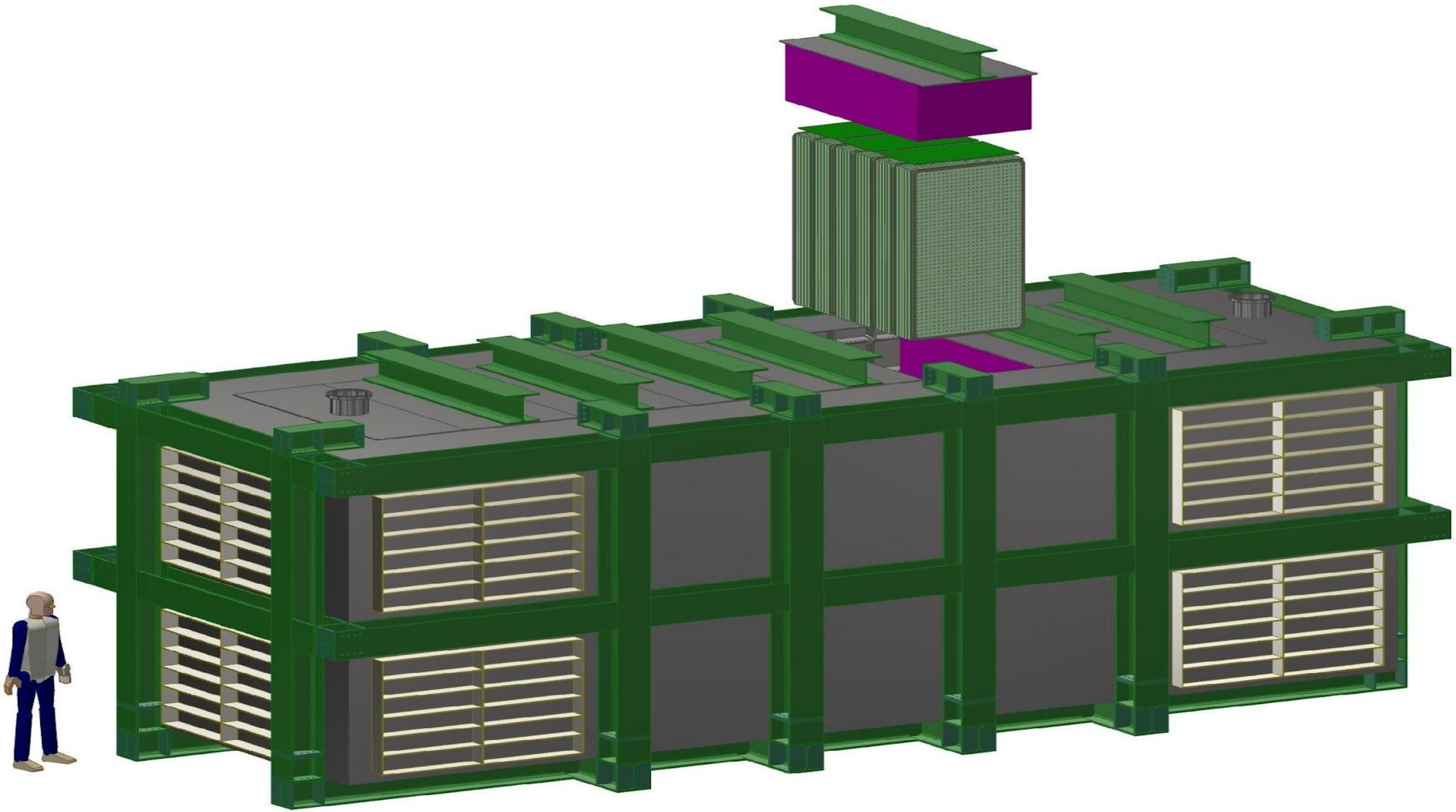
Overall outside view of the membrane cryostat



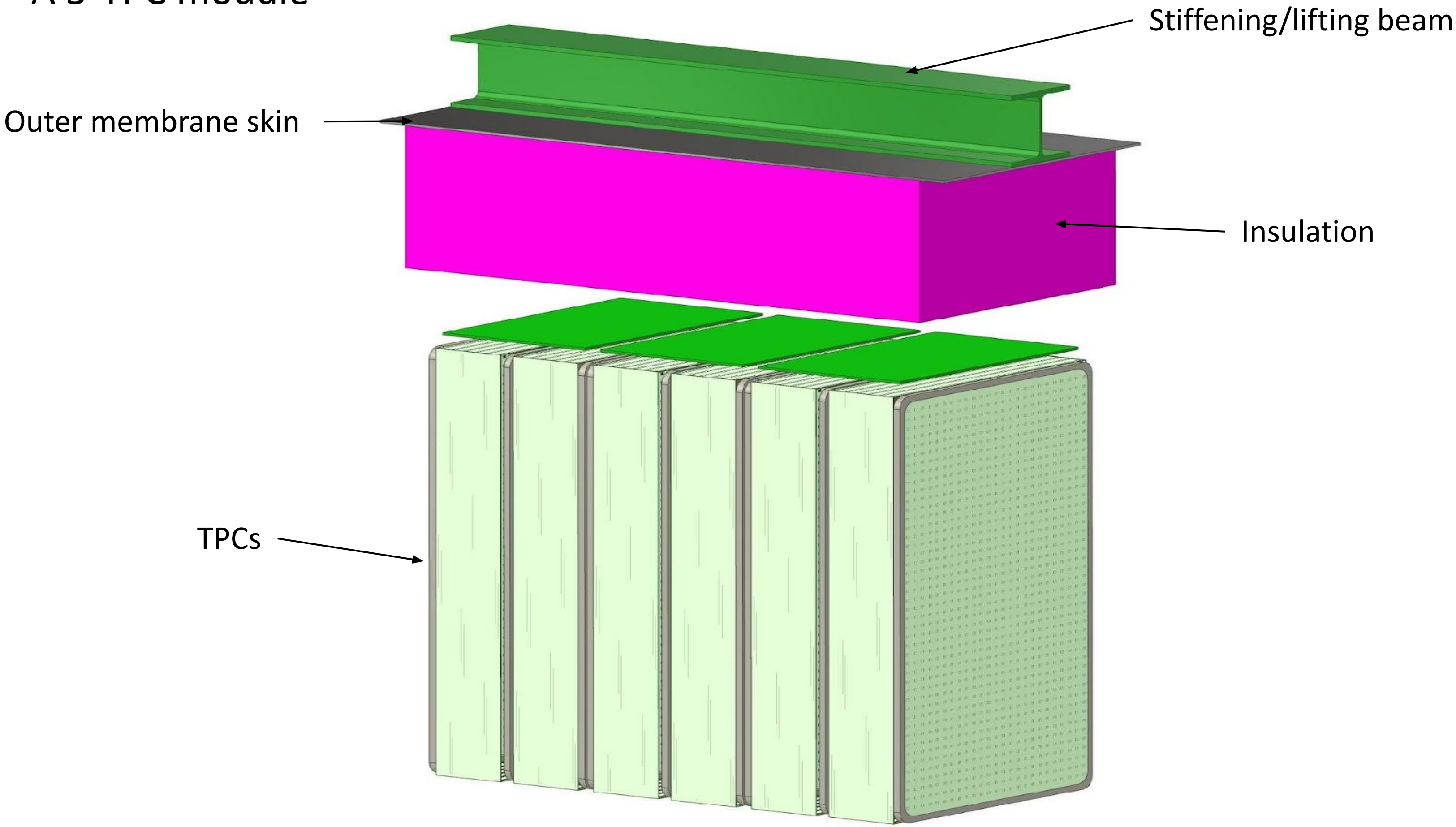
Cross-section using a horizontal cutting plane



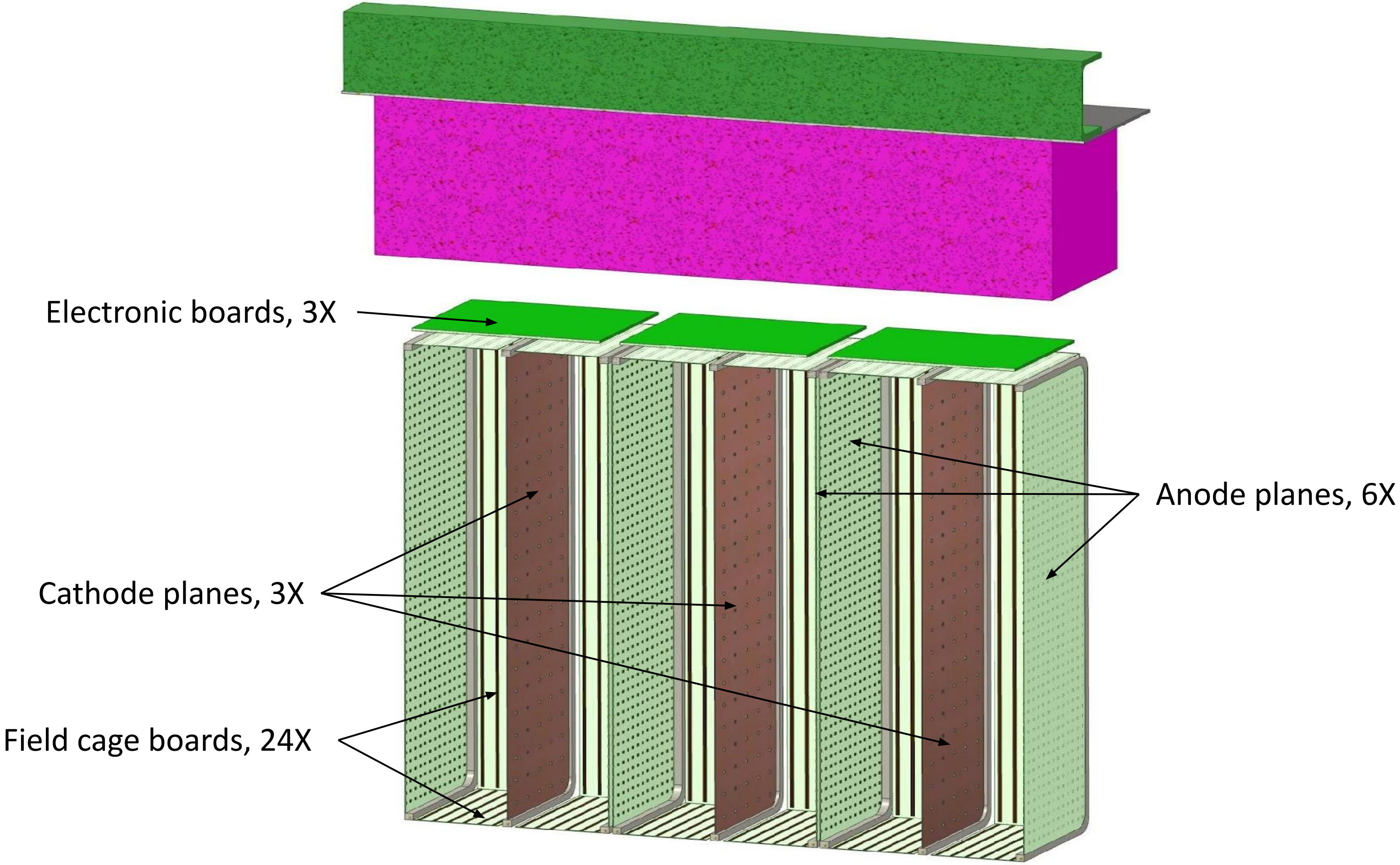
One detector module (3 TPCs) hung above the cryostat



A 3-TPC module



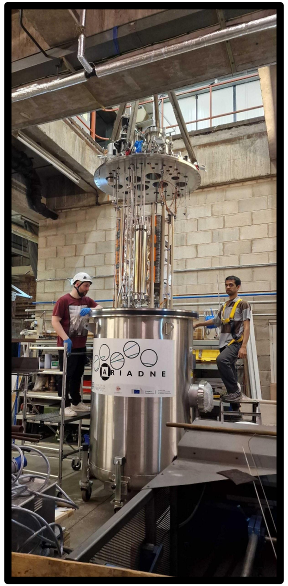
Section view through 3 TPC module

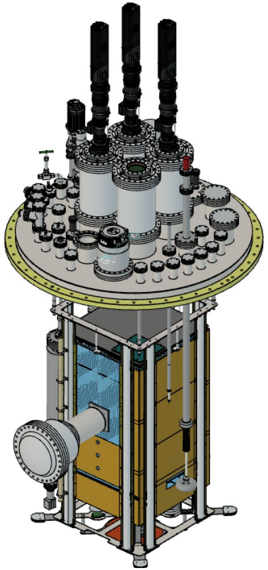


FLArE TPC based on ARIADNE optical readout technology

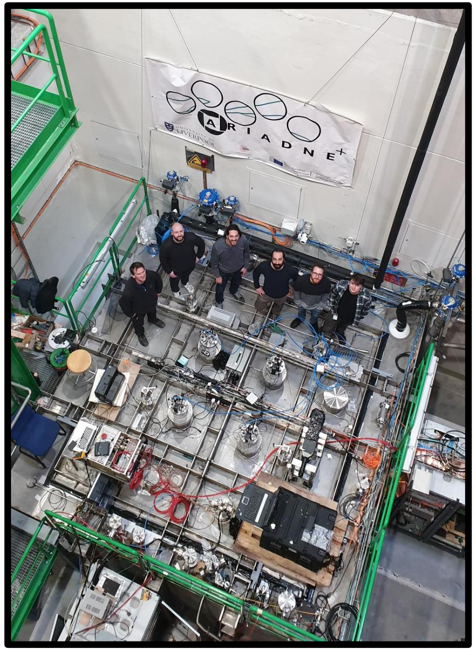
At Liverpool a fast 3D optical TPC readout (TPX3CAMs) was matured with the ARIADNE program, mainly within the framework of DUNE detectors.

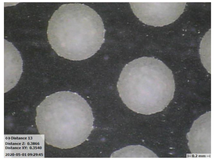
ARIADNE 1ton LAr detector @Liverpool



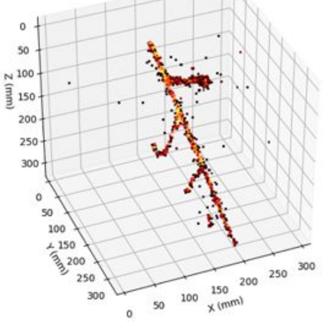


ARIADNE^{+} 15ton LAr detector





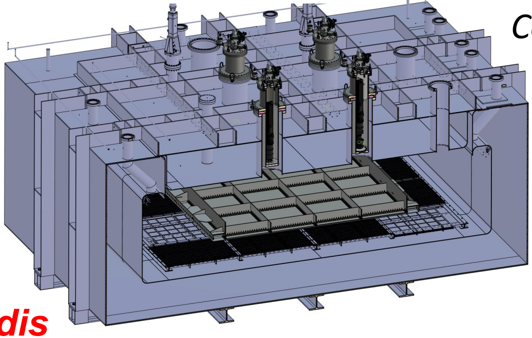
Glass THGEM



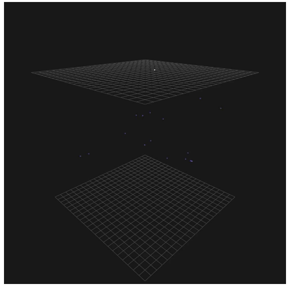
Technology already demonstrated at large scale.

TPX3Cams capture the S2 light produced in novel glass THGEMs

Offers high granularity 3D reconstruction and low energy thresholds



Continuous streaming



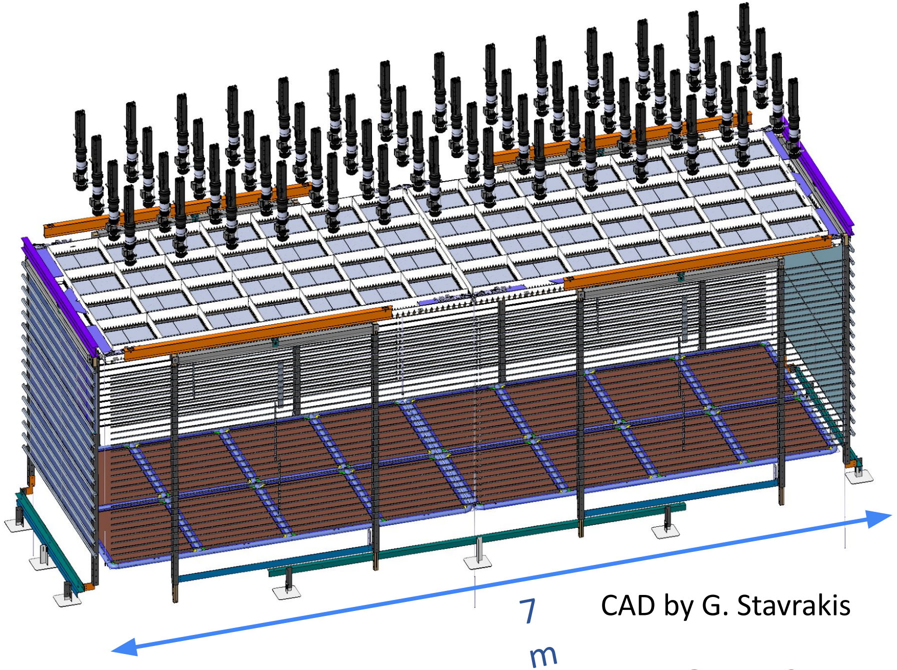
http://hep.ph.liv.ac.uk/ariadne

Slide from Kostas Mavrokoridis

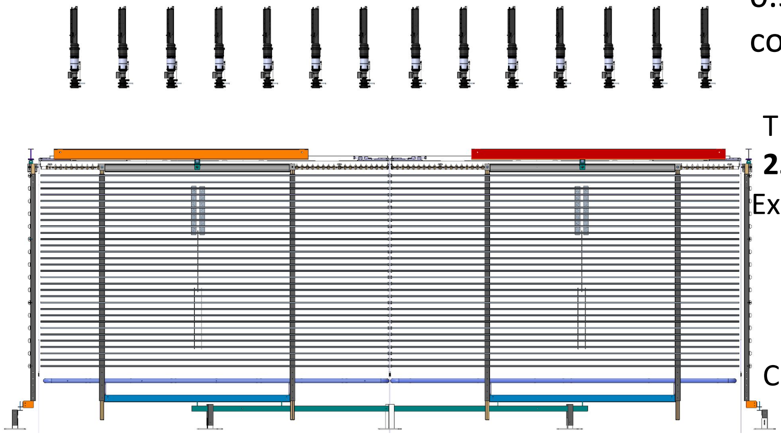
ARIADNE technology can meet the requirements for a FLArE TPC at Low Cost

UNIVERSITY OF LIVERPOOL

A conceptual FLArE LAr TPC using 56 TPX3cams providing 1.8mm/pixel resolution and 1.6ns time resolution for the electron drift



CAD by G. Stavrakis



An opportunity to bring a cost effect innovate fast 3D optical readout to the FPF.
Technology already well developed and demonstrated.
Liverpool is interested in delivering the light readout plane and the optical system for FLArE

Slide from Kostas Mavrokoridis

Simulation

Simulation overview

We have a tech note ready for review - comments and suggestions are welcome: https://www.overleaf.com/1625521614bgrvrfzsgqhx#2c82dd

Topics covered in the tech note are:

- Detector geometry (including the whole FPF hall)
- Muon acceptance for FLArE muons in FASER2
- Muon momentum reconstruction
- Tau neutrino identification
- Effects of pixel size on particle ID

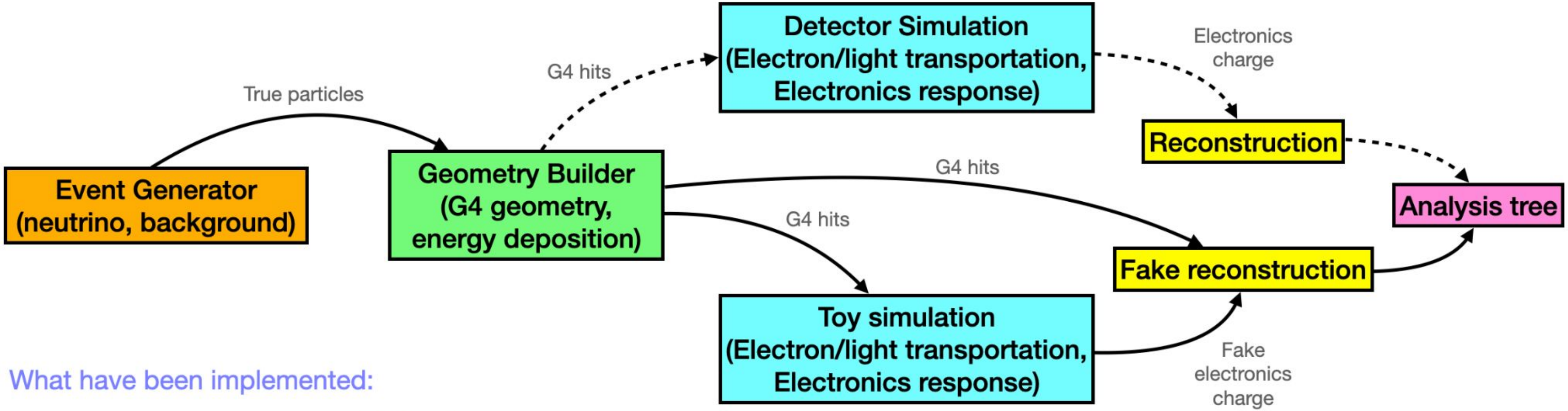
I will only cover the first two items here, but for details on the status of each of these studies, please see the tech note.

Thanks to Matteo and Wenjie, who have done a lot of work on these studies and provided the next set of slides.

Simulation framework

→ Current working strategy

- - -→ Ultimate goal



What have been implemented:

GENIE

Single Particle { Muon, Neutron, …

TPC volume

HadCal

MuonCatcher

FORMOSA

FASERnu2

FASER2 Magent { SAMURAI, Crystal Pulling

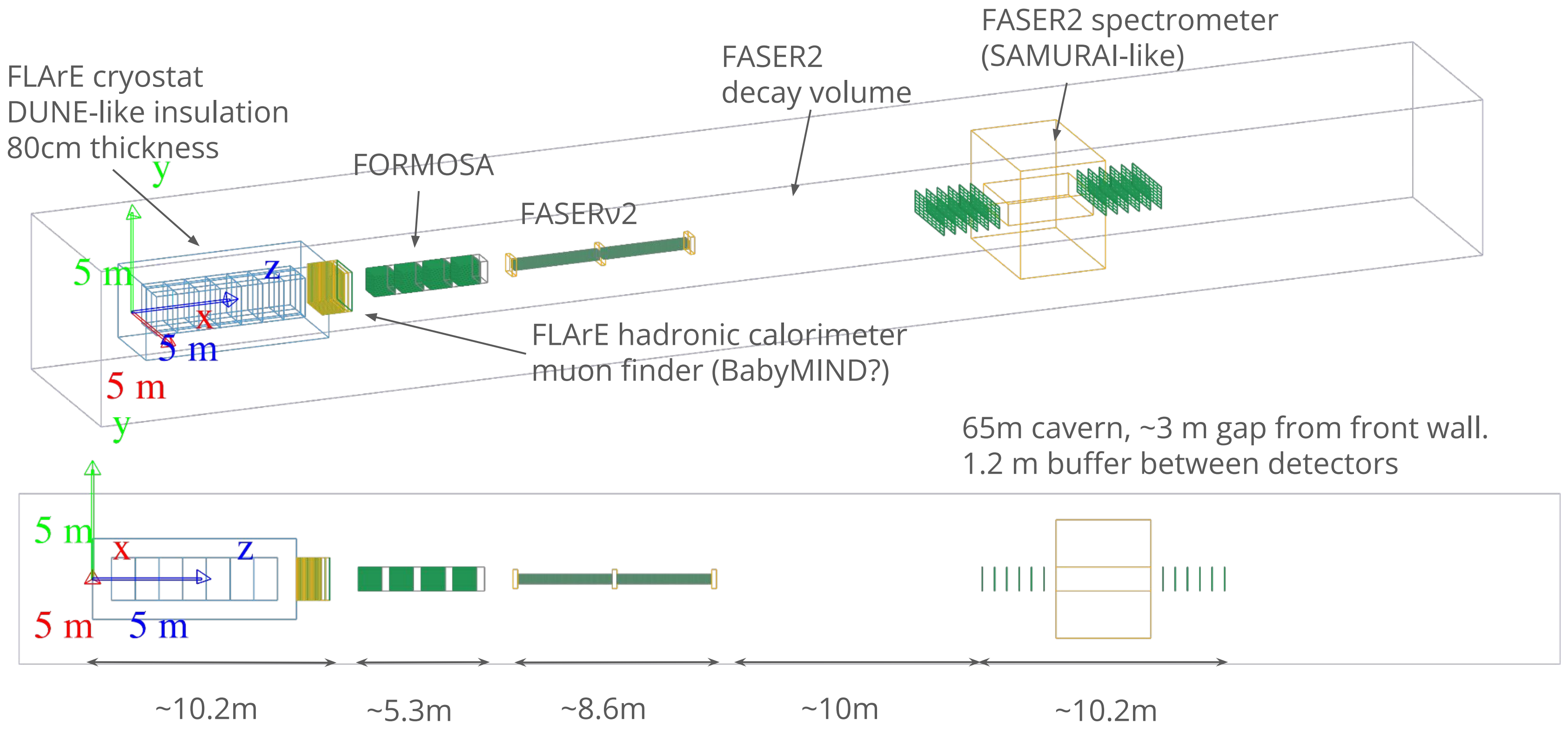
Toy diffusion of electrons

Pseudo variables

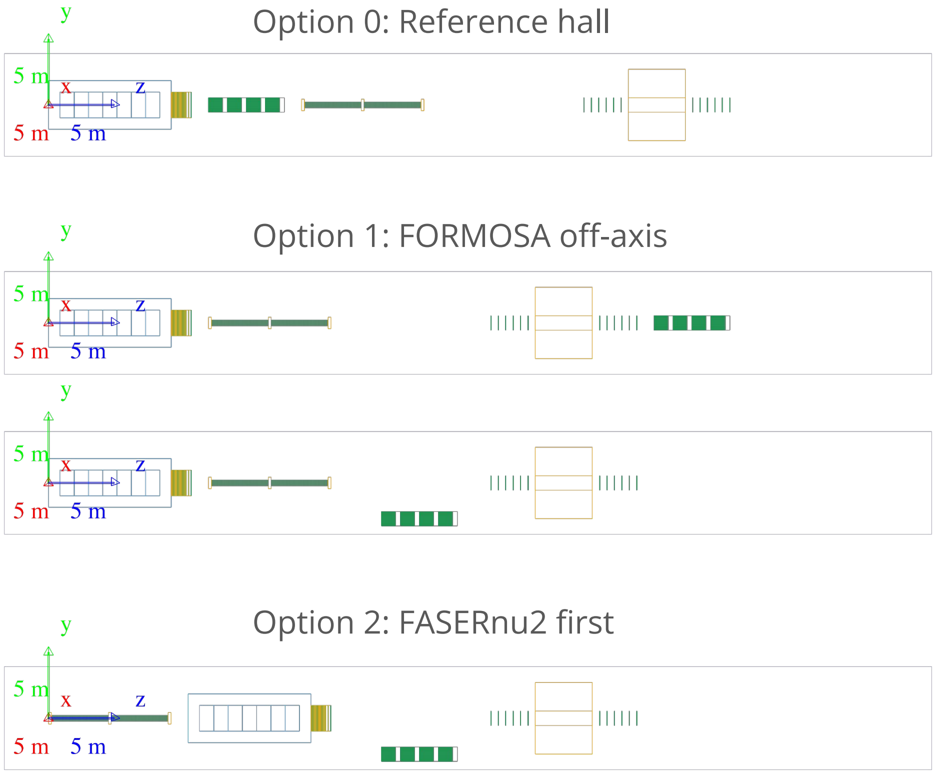
Muon momentum fit

Ntuple

FPF cavern in simulation



Alternative hall options



Detector	Total length [m]
FLArE	10.2
FORMOSA	5.3
FASERν2	8.6
FASER2 (SAMURAI-like)	10.2
FASER2 (Crystal-pulling)	6.3

Several alternative FPF configurations have been proposed. Each option can accommodate both FASER2 magnet designs.

FPF hall configurations

Name	Comment	FLArE (y, z) [m]	FORMOSA (y, z) [m]	FASERν2 (y, z) [m]	FASER2 (y, z) [m]
Option 0	Reference hall	$(0, 4.3)$	$(0, 13.9)$	$(0, 22.0)$	$(0, 42.6)$
	...with CrystalPulling magnets	$(0, 4.3)$	$(0, 13.9)$	$(0, 22.0)$	$(0, 40.7)$
Option 1a	FORMOSA behind FASER2	$(0, 4.3)$	$(0, 45.1)$	$(0, 15.5)$	$(0, 36.1)$
	...with CrystalPulling magnets	$(0, 4.3)$	$(0, 41.1)$	$(0, 15.5)$	$(0, 34.1)$
Option 1b	FORMOSA below decay volume	$(0, 4.3)$	$(-2.5, 26.0)$	$(0, 15.5)$	$(0, 36.1)$
	...with CrystalPulling magnets	$(0, 4.3)$	$(-2.5, 26.0)$	$(0, 15.5)$	$(0, 34.1)$
Option 2	FASERν2 before FLArE	$(0, 14.1)$	$(-2.5, 26.0)$	$(0, 4.3)$	$(0, 36.1)$
	...with CrystalPulling magnets	$(0, 14.1)$	$(-2.5, 26.0)$	$(0, 4.3)$	$(0, 34.1)$

Table 1: Summary of the FPF configurations. The (y, z) positions of the on-axis detector centers are reported. A 1.2 m buffer between each experiment is assumed. The center of the coordinate system always corresponds to the front of the first detector, 3.1 m from the cavern wall. The z-axis represents the line of sight, while y is the vertical direction. The full length of the cavern is 65 m.

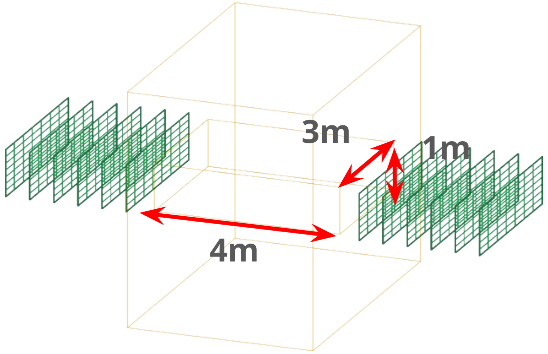
Magnet options

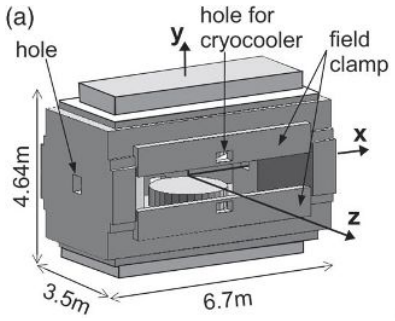
Two magnet designs for the FASER2 spectrometer magnet.

SAMURAI-style:
<u>Pro</u>: 4 Tm, great Pt resolution.
<u>Con</u>: Huge yoke, procurement time and cost, installation.

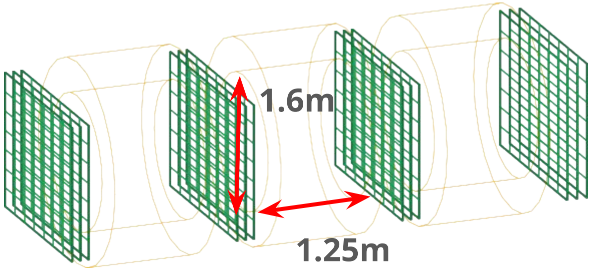
Crystal-pullers:
<u>Pro</u>: Cheap, readily available, small and modular.
<u>Con</u>: 0.75 Tm each, worse Pt resolution.

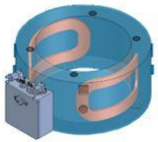
SAMURAI-like magnet





TOSHIBA Crystal-pulling magnets





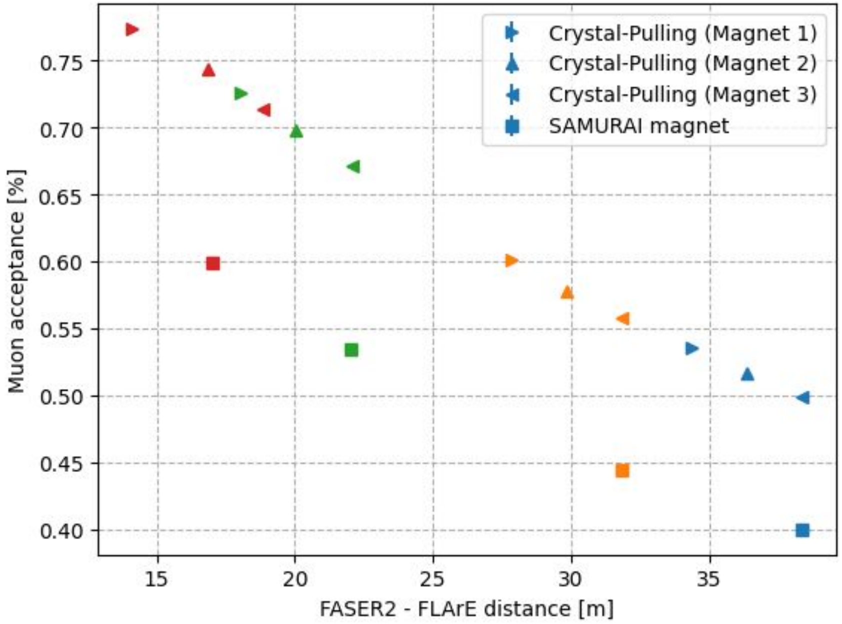
Magnet option	Qnty	Size	Window	Length	Field	Field integral
SAMURAI-like	1	6 m × 5 m × 4 m	3 m × 1 m	4 m	1 T	4 Tm
Crystal-pulling	3	2.4 m × 2.4 m × 1.25 m	⌀1.6 m	1.25 m	0.6 T	0.75 Tm
Tracking stations	**Sets**	**Number per set**	**Size**	**Thickness**	**Gap to magnet**	**Spacing**
SAMURAI-like	2	6	3 m × 3 m	2 cm	0.5 m	0.5 m
Crystal-pulling	4	3	1.6 m × 1.6 m	2 cm	0.25 m	0.1 m

Muon acceptance vs. distance

Acceptance is mainly driven by the FLArE-FASER2 distance, which depends on the FPF configuration.

- Blue: reference option
- Orange: option 1a/1b
- Green: option 2
- Red: option 2 “squeezed”

The circular window of the crystal-pulling magnets works better.

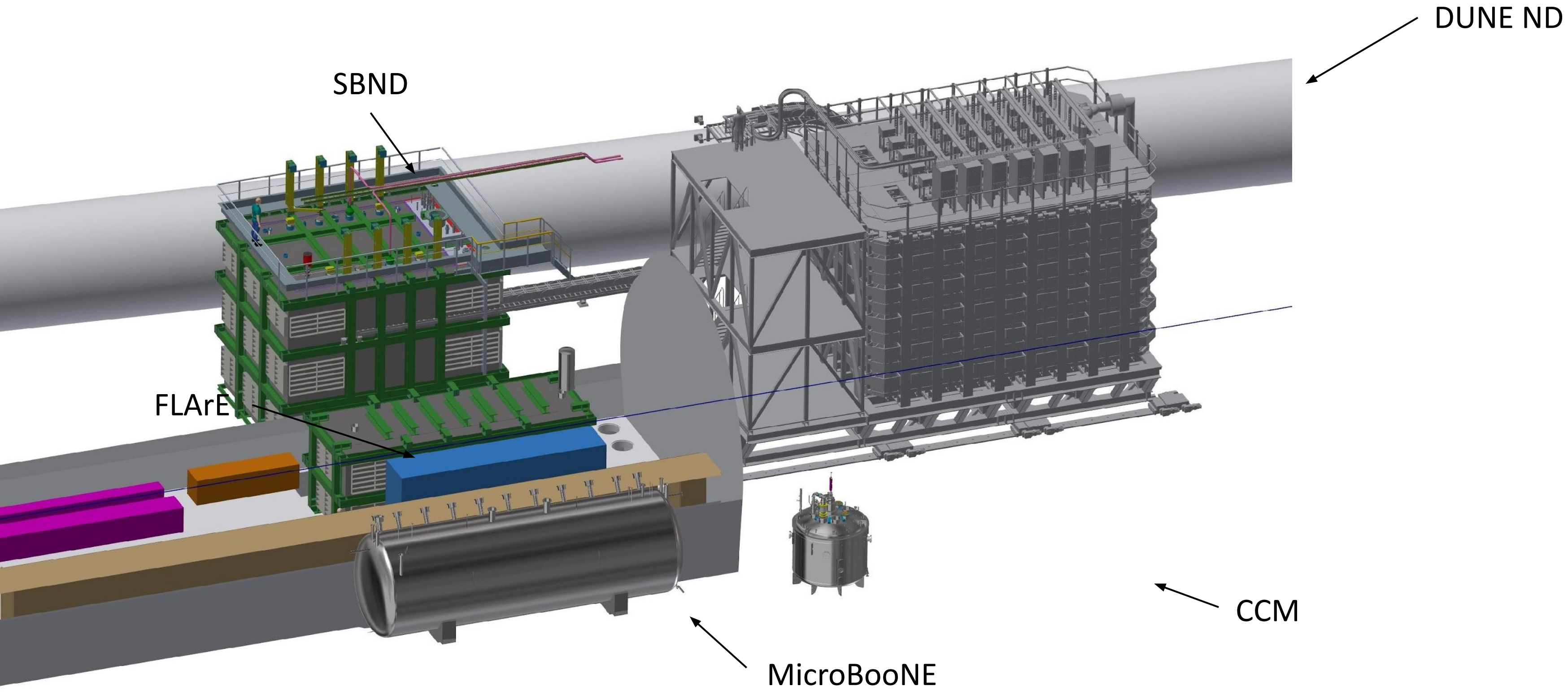


Summary

- We now have a preliminary version of a 3D design for the TPC.
- Conceptual installation plan and cryogenic design are underway.
- An alternative two-phase design is also being considered (will keep this as an option in PBC report).
- Simulation now includes the whole FPF, with options for configurations
- Demonstration of bunch separation and beam tagging (see Matteo's talk this afternoon in parallel session 1).
- Tech note on simulations is in draft form.
- Tech note on conceptual design is planned.
- The next major effort will be R&D and conceptual design for electronics readout and photosensors.

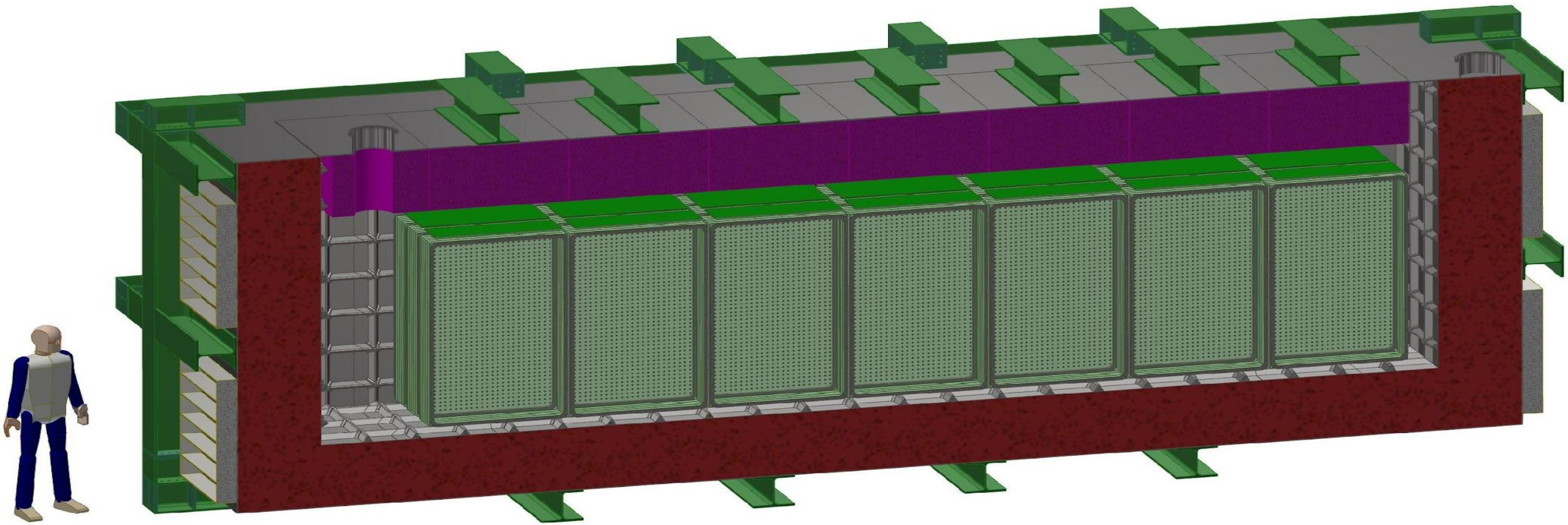
Backup

Other detectors near FLArE for scale

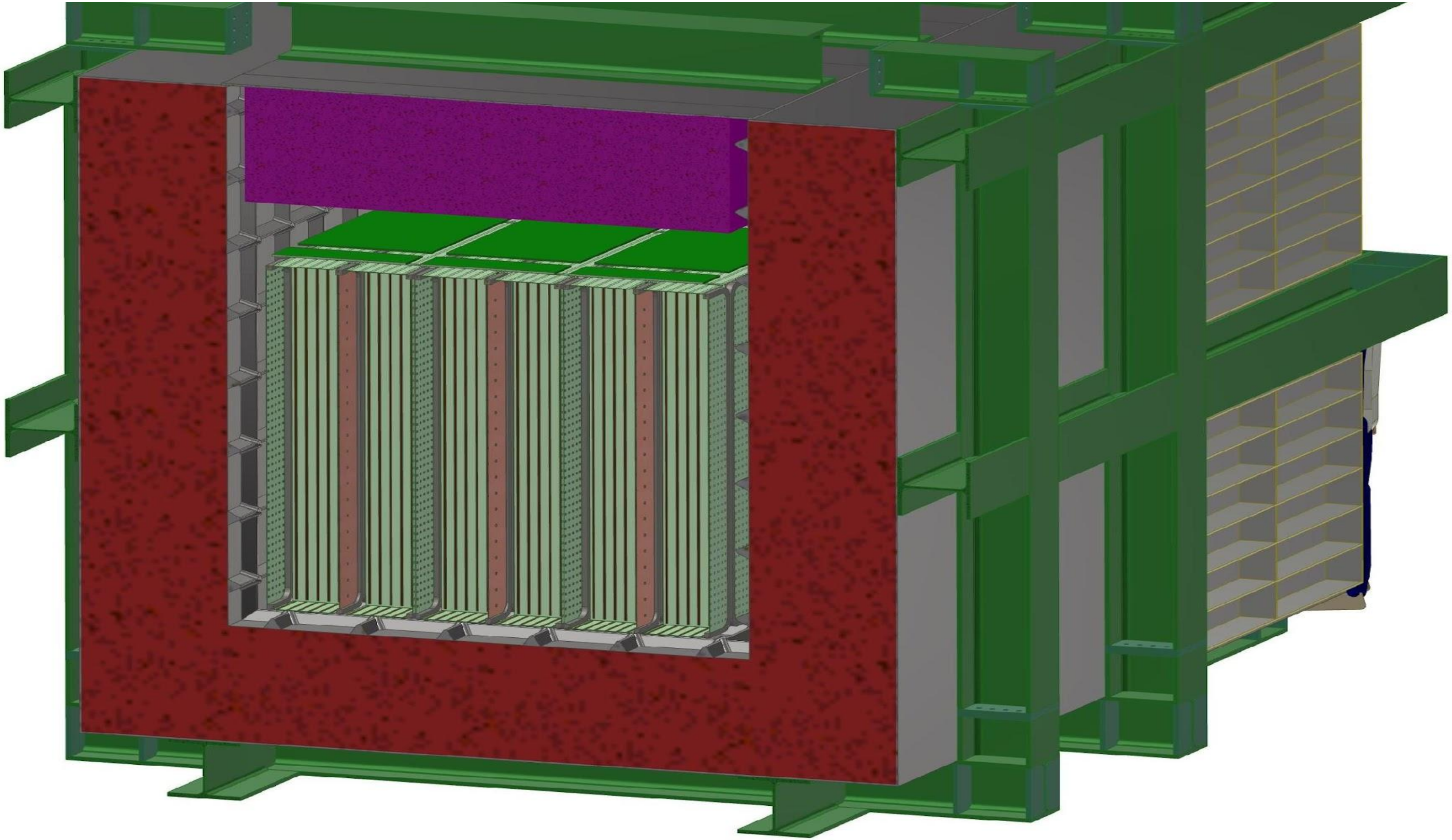


Parts of SBND were used to construct the FLArE model

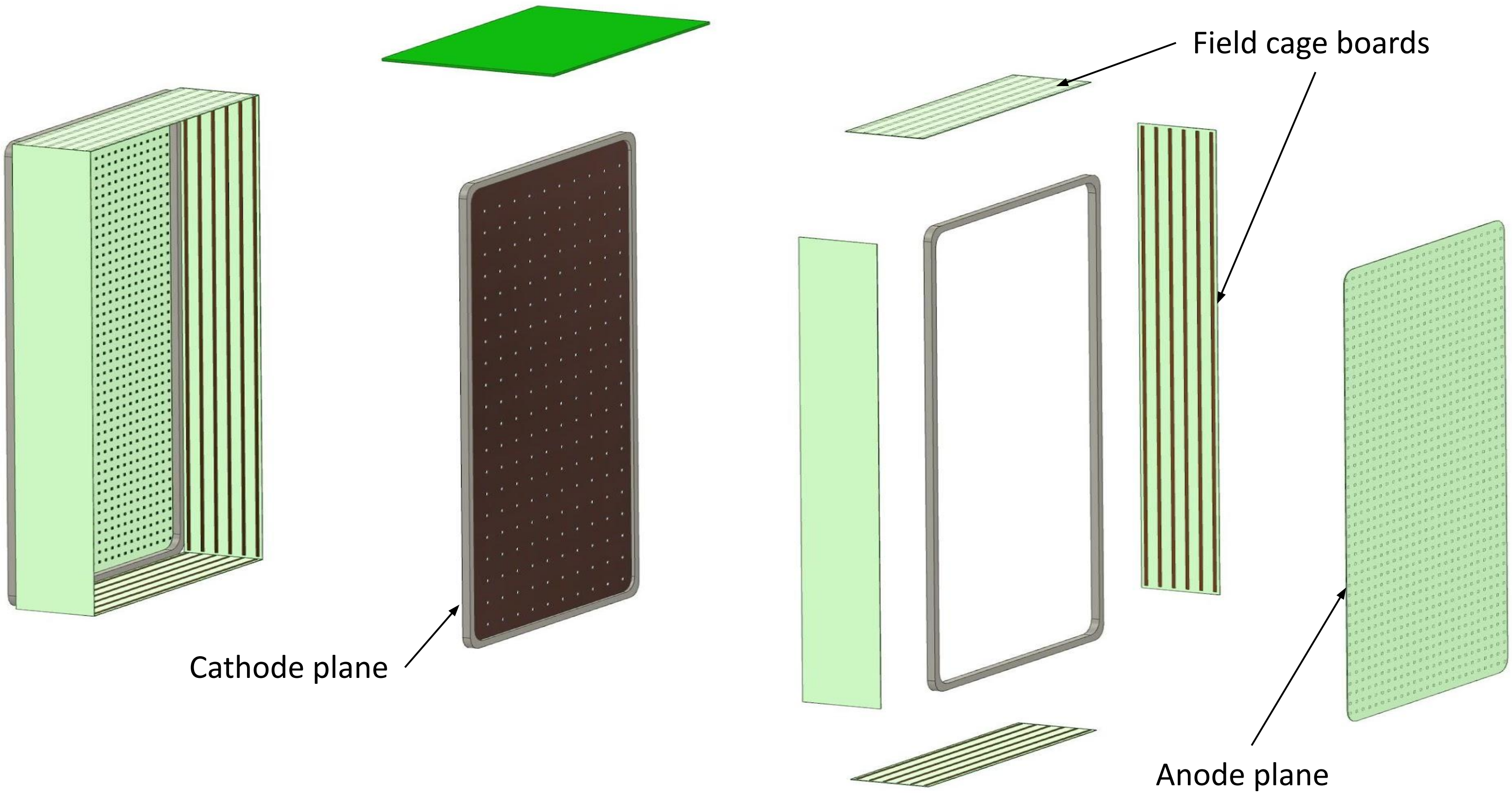
Section view along the vertical mid-plane of the detector



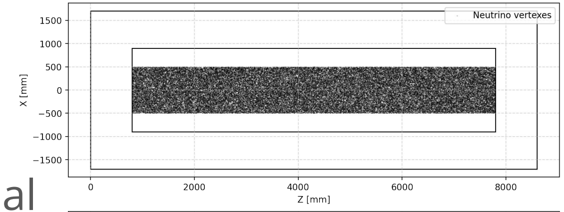
Cross-section transverse to the beam direction

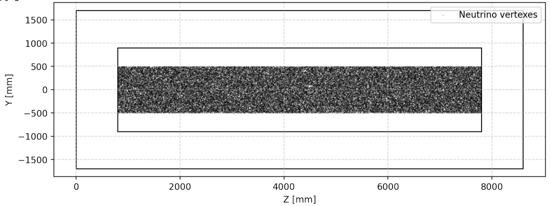


Exploded view of a single TPC module



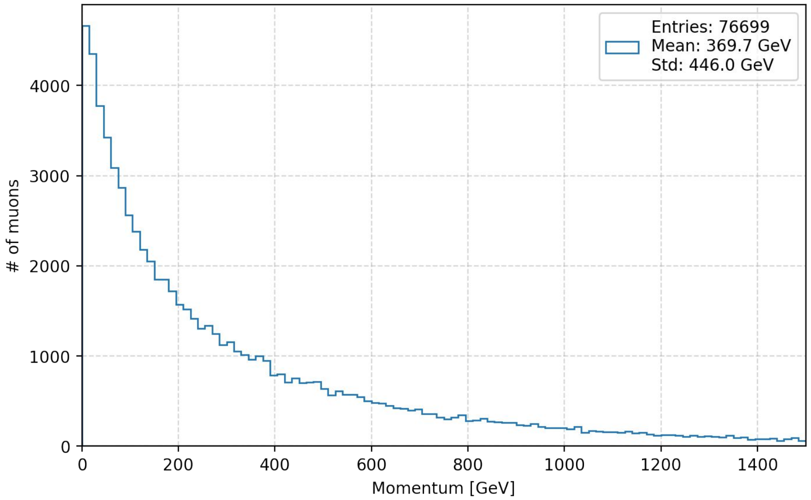
Input sample



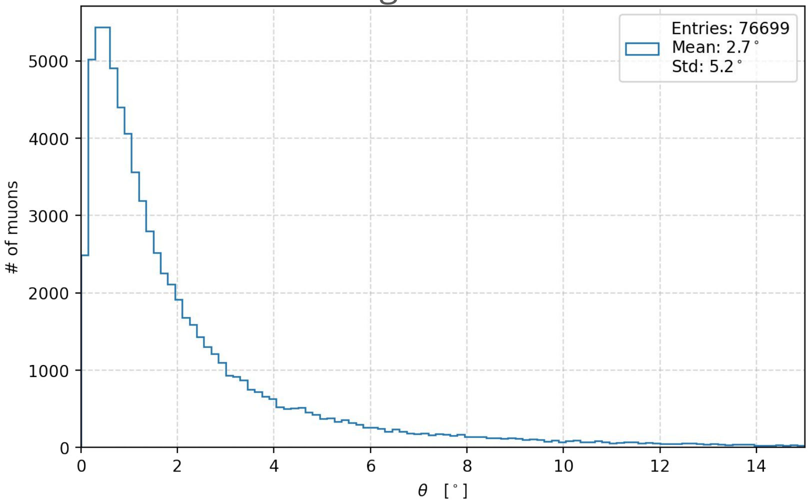


- Muons from numu interactions in FLArE fiducial volume (1m x 1m x 7m).
- 100k numu → 76.7k muons (CC fraction)
- Average muon momentum ~370 GeV

Muon momentum



Muon angle w.r.t. z-axis



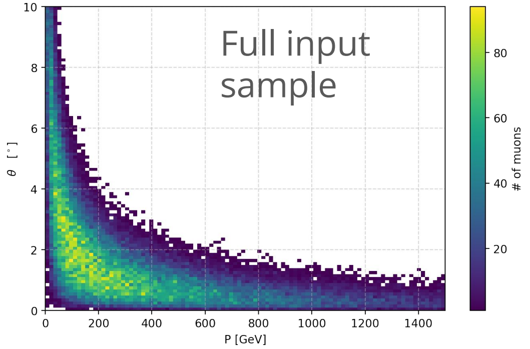
Muon acceptance: SAMURAI

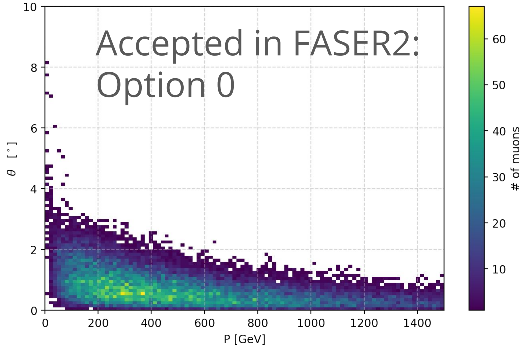
Muons is accepted into FASER2 if:

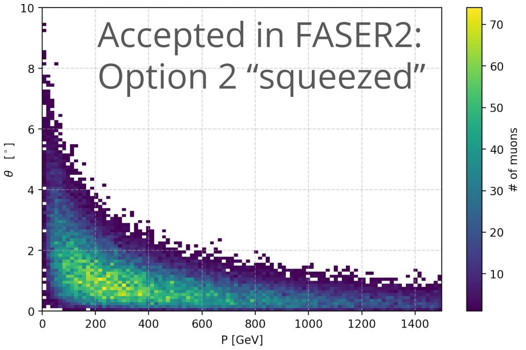
1. >0 pre-magnet trackers crossed
2. >2 post-magnet trackers crossed

FASER2 rectangular SAMURAI-like magnet					
Option	Distance [m]	FLArE volume	Total	HadCat + MF	FASER2
FLArE + FASER2 only	38.3	All fiducial	76699	66899 (87.2%) 73486 (95.8%)	23760 (31.0%) 30808 (40.2%)
Option 0: Reference hall	38.3	fiducial	76699	73486 (95.8%)	30668 (40.0%)
Option 1a: FORMOSA last Option 1b: FORMOSA below	31.6	fiducial	76699	73486 (95.8%)	34188 (44.5%)
Option 2: FASERν2 first	22	fiducial	76699	73461 (95.8%)	41027 (53.5%)
Option 2 "squeezed"	17	fiducial	76699	73309 (95.6%)	45952 (59.9%)

Table 5: Muon acceptances for the FLArE magnetized spectrometer and the FASER2 "SAMURAI-like" magnet for different configurations of the FPF cavern. FLArE fiducial volume is $1\,\text{m} \times 1\,\text{m} \times 7\,\text{m}$. The magnetic field both in the FLArE spectrometer and in the FASER2 magnet is 1 T. The distance is computed from the center of the FLArE liquid Argon volume to the center of the FASER2 magnet window.







Muon acceptance: Crystal-pullers

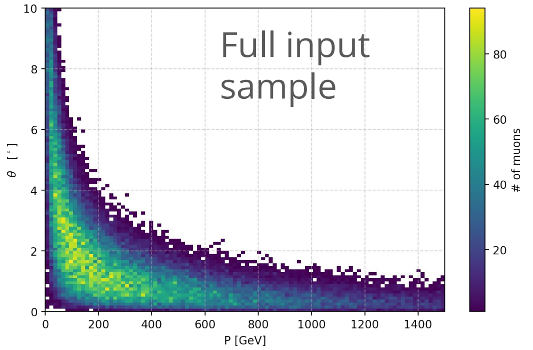
Muons is accepted into FASER2 if:

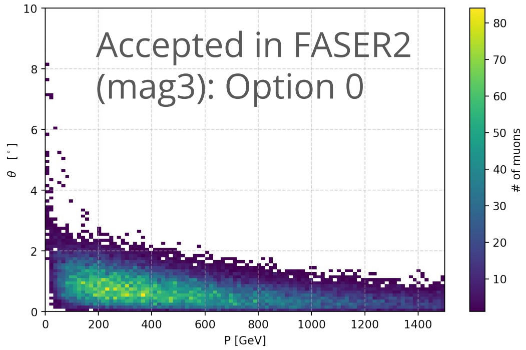
1. >0 pre-magnet trackers crossed
2. >2 post-magnet trackers crossed

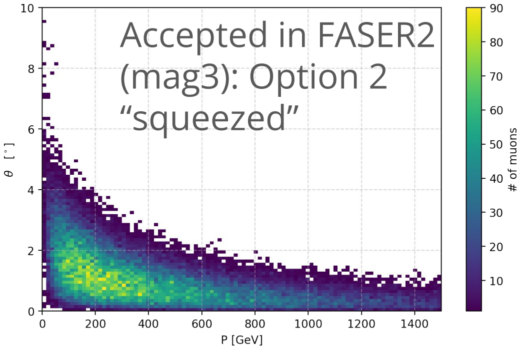
FASER2 cylindrical crystal-pulling magnets					
Option	Distance [m]	Total	FASER2 Mag. 1	FASER2 Mag. 2	FASER2 Mag. 3
Option 0: Reference hall	36.4	76699	41048 (53.5%)	39645 (51.7%)	38281 (49.9%)
Option 1a: FORMOSA last Option 1b: FORMOSA below	29.8	76699	46077 (60.1%)	44360 (57.8%)	42764 (55.7%)
Option 2: FASERν2 first	20	76699	55689 (72.6%)	53514 (69.8%)	51502 (67.1%)
Option 2 "squeezed"	16.8	76699	59351 (77.4%)	57001 (74.3%)	54749 (71.4%)

Table 6: Muon acceptances for the FASER2 "crystal-pulling" magnets for different configurations of the FPF cavern. FLArE fiducial volume is $1\,\text{m} \times 1\,\text{m} \times 7\,\text{m}$. The magnetic field in the FLArE spectrometer is 1 T, while the field in each FASER2 magnet is 0.6 T. The distance is computed from the center of the FLArE liquid Argon volume to the center of the FASER2 magnet assembly.

Each magnet is independent.
However mag3 ≡ mag3 && mag1 && mag2



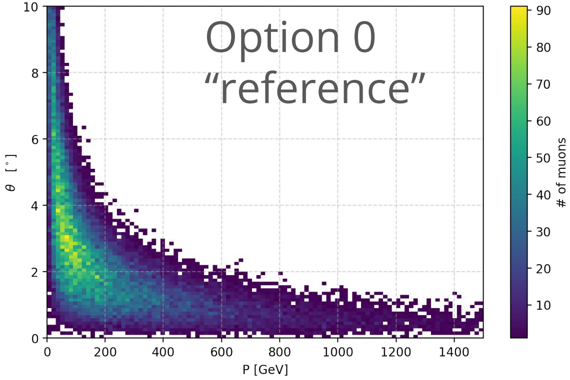


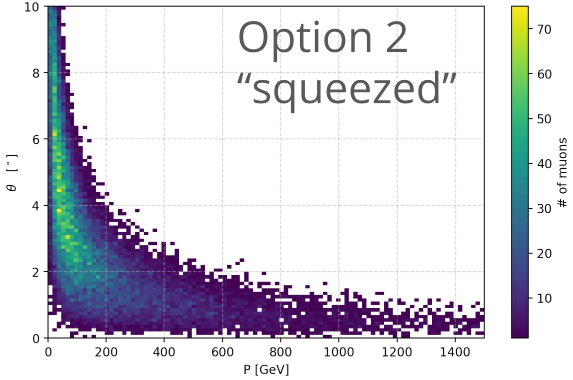


Comparison

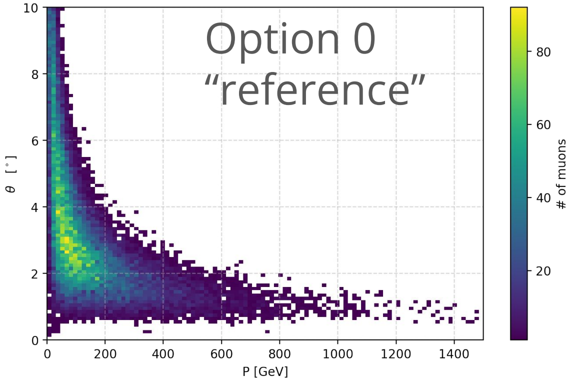
Phase space of muons escaping FASER2

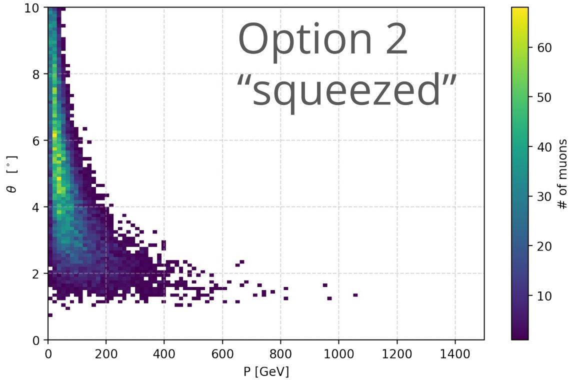
SAMURAI-like magnet (3 m x 1m)





Crystal-pulling magnets (1.6 m diameter)





Crystal-pullers fully recover straight-going muons!