The FLArE Experiment for High Energy Neutrino and Dark Matter Searches at LHC

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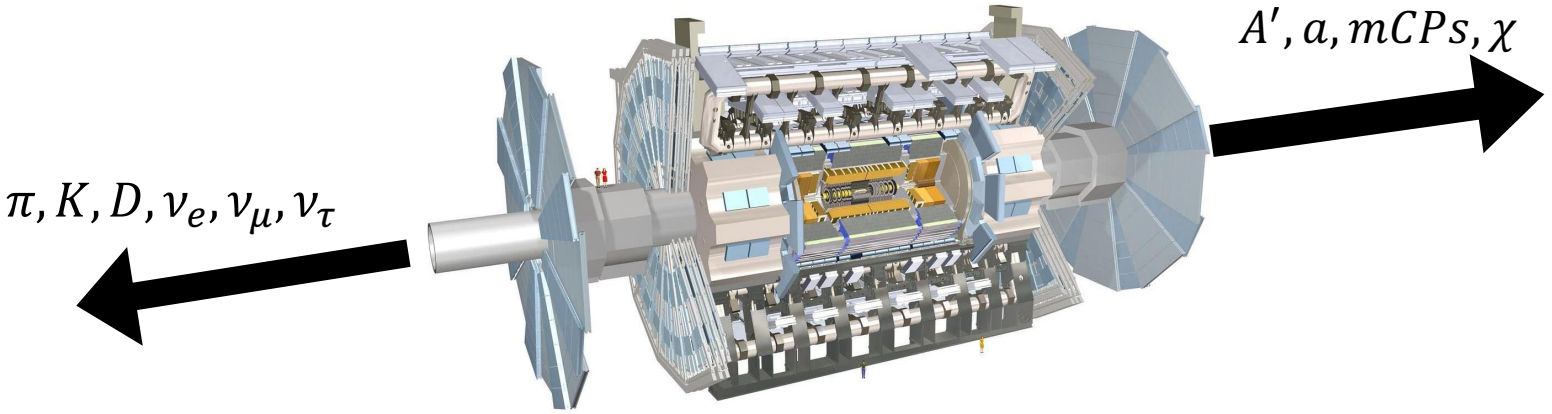
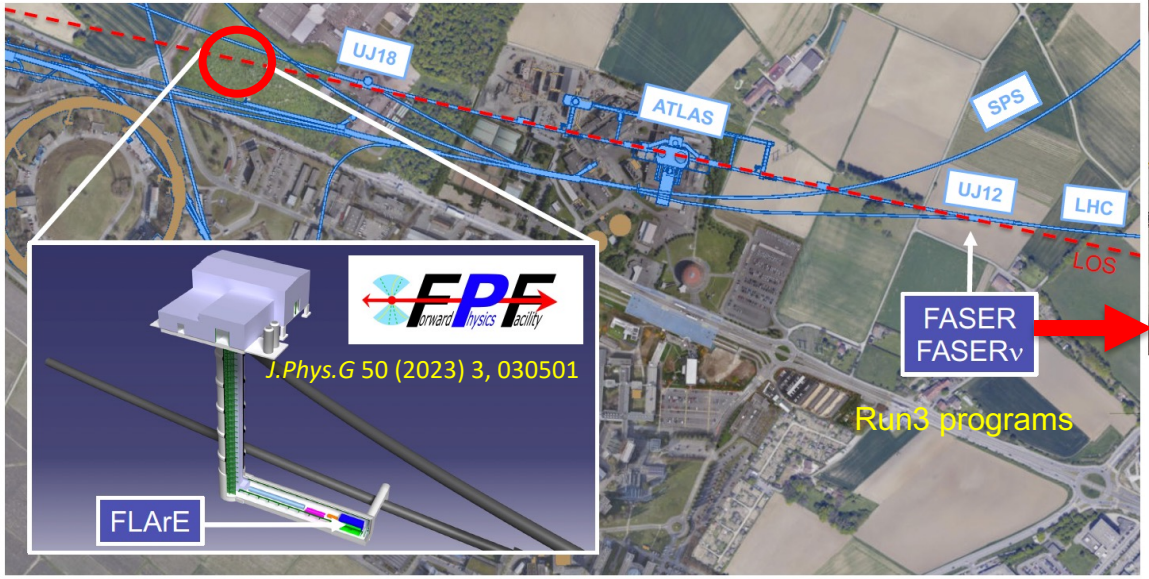
Forward Physics Facility (FPF) and FLArE

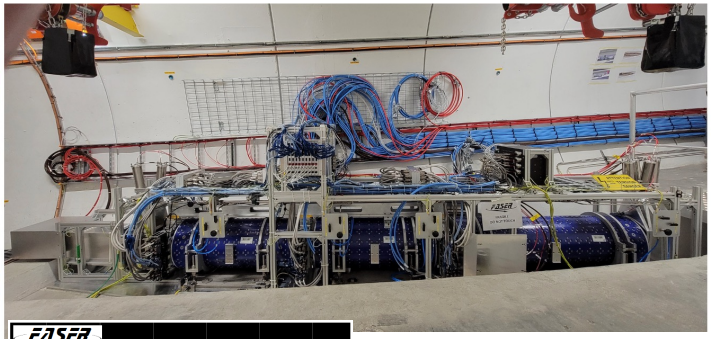


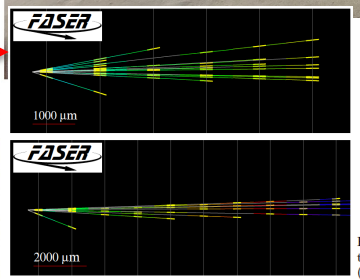
- Most interesting physics is believed to be at high pT, and so are we missing physics in the forward direction?
- The largest flux of high energy light particles, pions, kaons, D-mesons, and neutrinos of all flavors is in the forward direction.
- This could be true of new particles also: dark photons, axion-like particles, millicharged particles, light dark matter, etc.
- The high laboratory energies (>100 GeV), and kinematically focused nature of the particles presents a unique opportunity that should not be missed with the high-luminosity LHC.

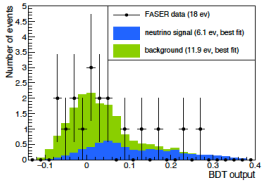
Forward Physics Facility (FPF) and FLArE

- FPF: Proposal to create forward underground space for experiments during HL-LHC
- FLArE: a liquid argon time projection chamber (LArTPC) detector for FPF to detect very high-energy neutrinos and search for dark matter at LHC@CERN
- The central goal of FPF is to extend the current LHC forward physics programs into the HL-LHC era with x10-100 exposure









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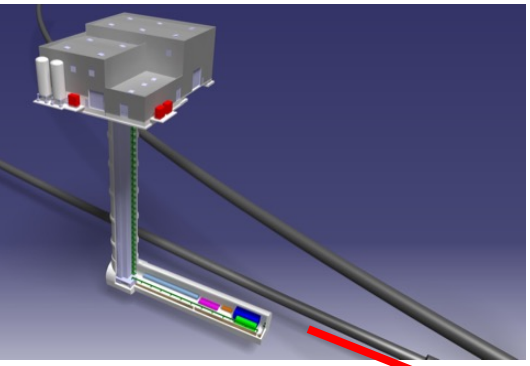
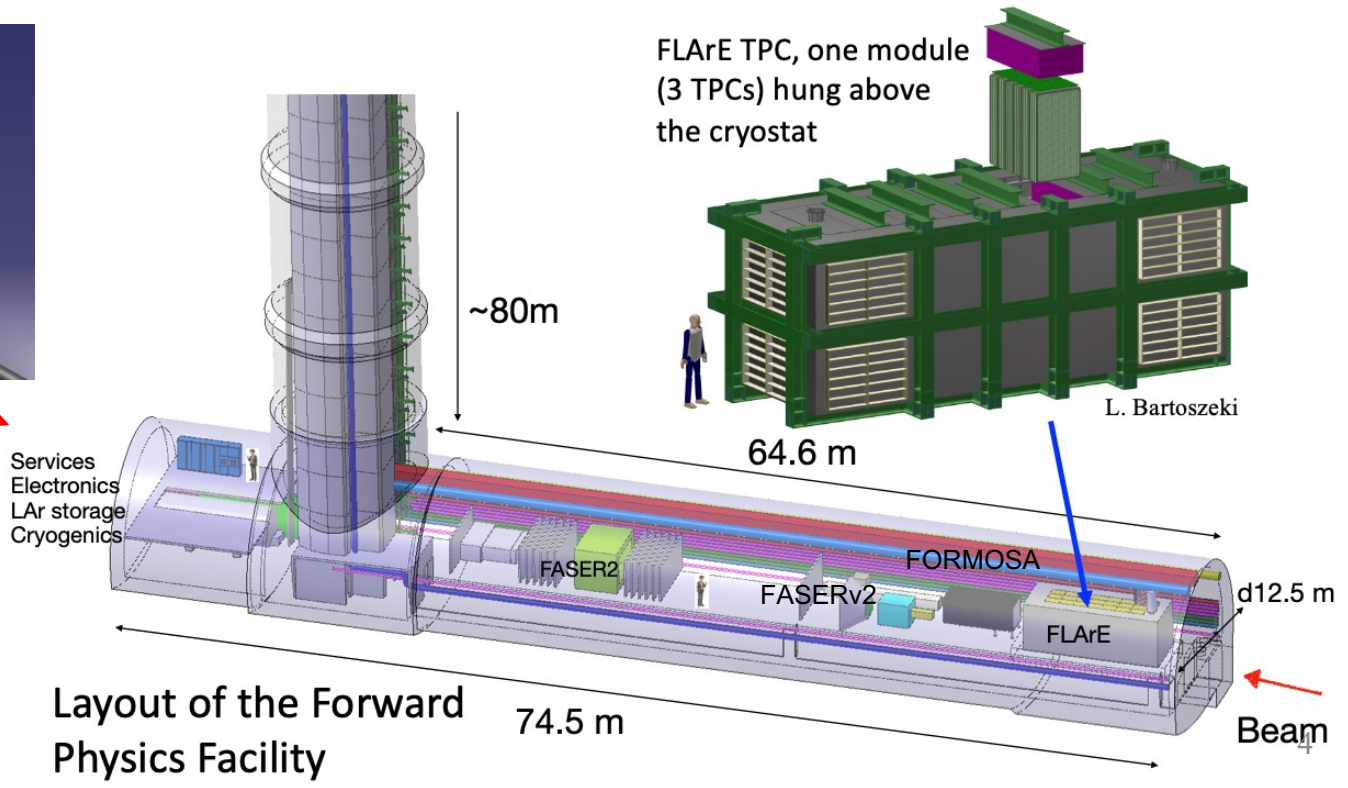
The FPF will be located 620-680 m west of the ATLAS IP along the line of sight (LOS). Also shown is the location of FASER and FASERν, which are also located along the LOS, but 480 m east of the ATLAS IP

Proposed Detectors for FPF

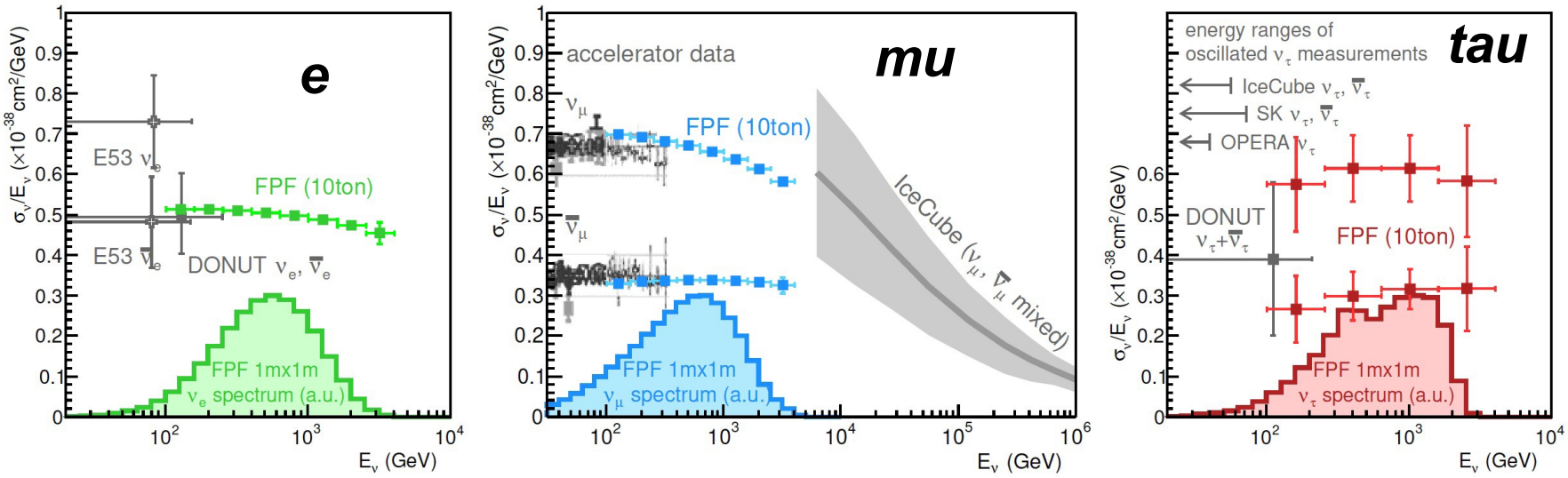
Experiment	Science Priority	Technology
FASER 2	Long-live neutral particles decay	Large decay volume (super-conducting) magnetic spectrometer
FASERnu2	Neutrino Interactions	Tungsten/Emulsion 20 tons. Veto and interface tracker for muons
FORMOSA	Milicharged particles	Scintillation bars with photomultiplier readout.
FLArE	DM scattering and neutrino interactions	Liquid Argon TPC 10-20 tons

The experimental program is getting better integrated with clear scientific goals and requirements for each of the components





Neutrino physics

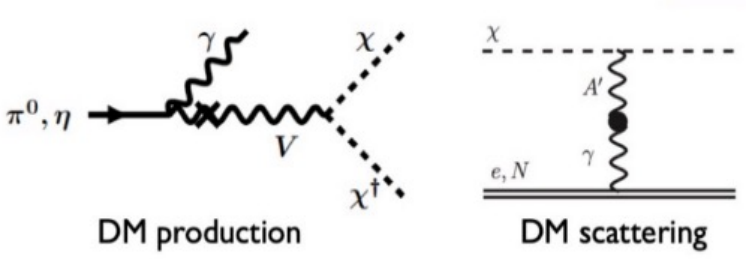


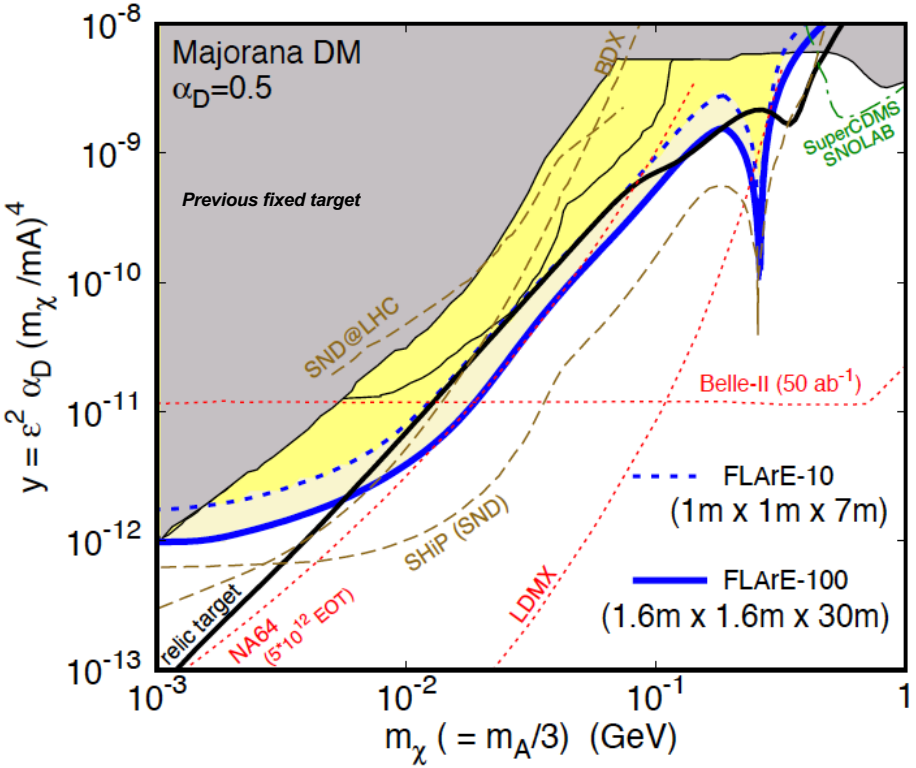
- The current data from accelerators ends around 300 GeV. FPF would provide data that fills in the gap between accelerators and atmospheric neutrinos.
- Total rate will be ~100k electron neutrinos, ~1M muon, and ~few thousand tau neutrino events.

Light Dark Matter scattering

Elastic scattering from electrons or nuclei

- Mass of the χ alters the kinematics of the outgoing electron or nucleus.
- Signal is at low energy (~1 GeV)
- Background is from neutrino interactions and muons.
- The sensitivity plot assumes reasonable cuts for background suppression
- Makes use of the huge flux of mesons for this ***direct detection*** technique to get to the relic density target.

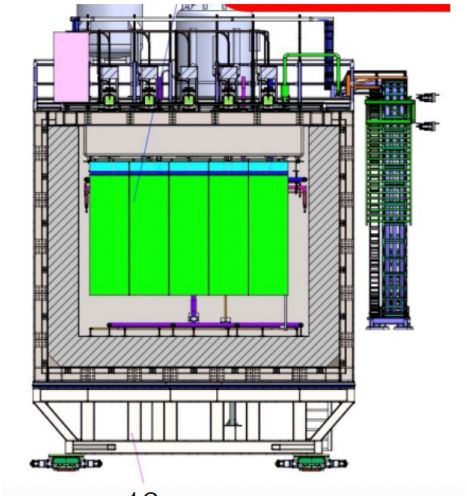




Batell, Feng, Trojanowski (2021)

Cryostat options for FLArE

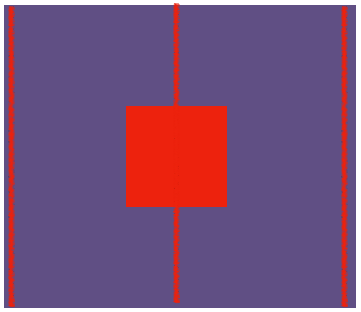
Very important for space considerations.



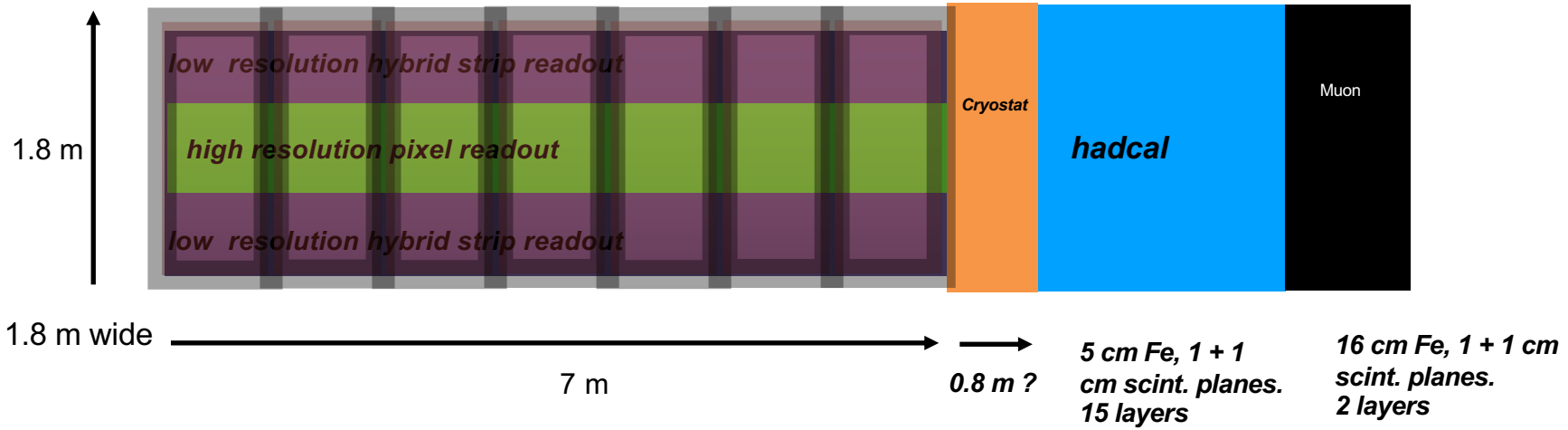
	Cryostat Inner Dimensions	Insulation Type	Insulation Thickness	Insulation density	Heat leak	Cold shield
MicroBooNE	3.8m dia x 12 m	Polyurethane Foam	**400mm**	32 kg/m^3	**~13 W/m^2**	No
ICARUS-GS	3.9m x 3.6m x 19.6m	Nomex honeycomb+perforated Al	**665 mm+ (combined)**	25-35 kg/m^3	**7-22 W/m^2**	Yes
ICARUS-SBN	3.9m x 3.6m x 19.6m	Al extrusion+GTT foam	**665 mm+ (combined)**	25-35 kg/m^3	**10-15 W/m^2**	Yes
ProtoDUNE	7.9m x 8.55m x 8.55 m	GTT membranc	**800mm**	90 kg/m^3	**~8 W/m^2**	No
ND-LAr	3m x 5m x7m	GTT membrance	800mm	90 kg/m^3	**~8 W/m^2**	No
FLArE	~(1m x 1m x 7m)					No?

- 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. More space might be needed for corrugations.
- GTT is easy to install, DUNE ND-LAr design has installation from top, this would also simplify things.

FLArE Detector



Simulations have confirmed that these dimensions allow reasonable containment of neutrino events in LAr and total energy measurement.
They also fit within the cryostat allowed transverse space.



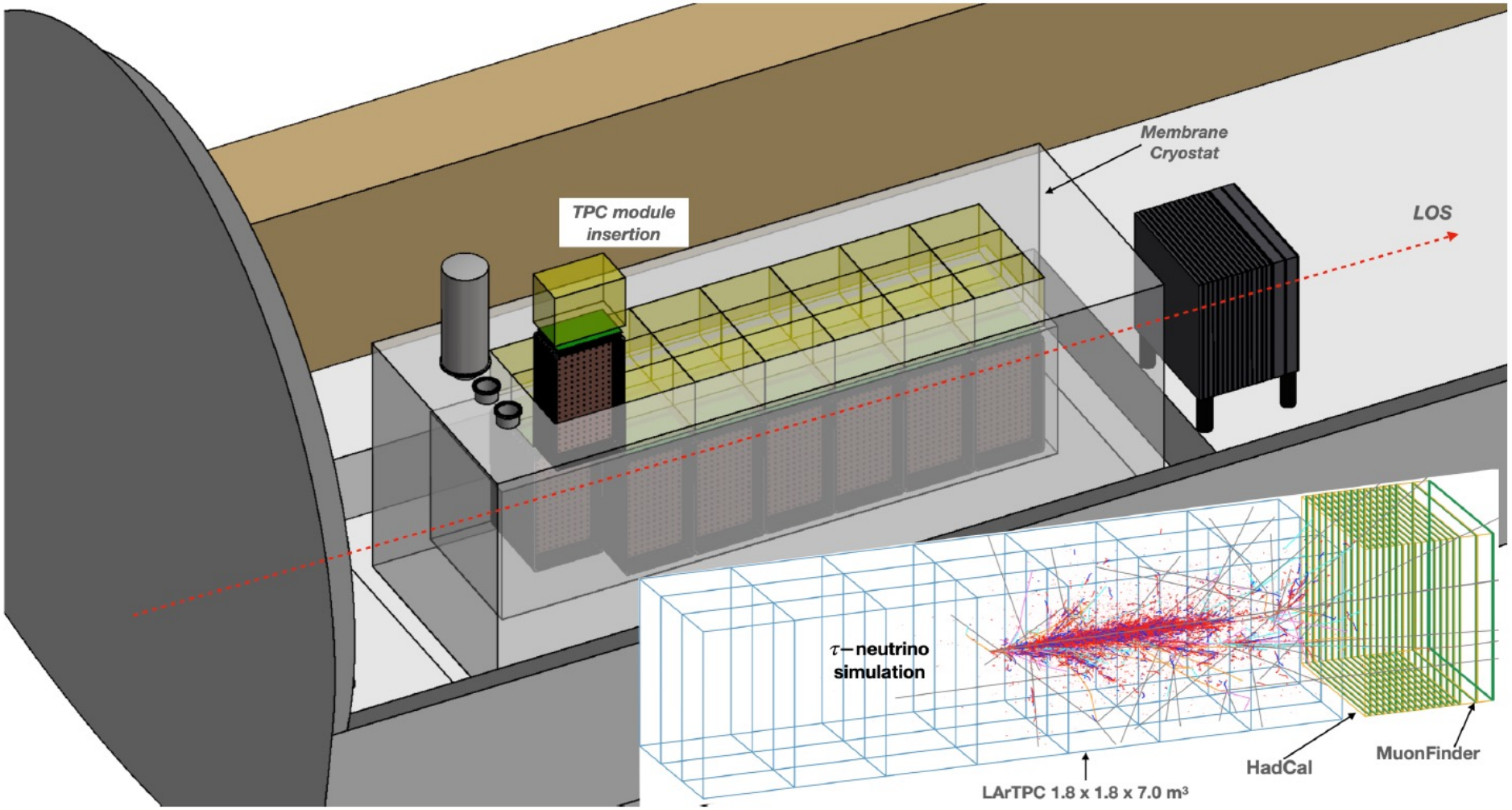
(Preliminary Parameters)

Geometry options in Conceptual Design:

- ***2 X 7 vertical modules***
- ***3 X 7 vertical modules***
- ***0.45 m or 0.3 m gap***

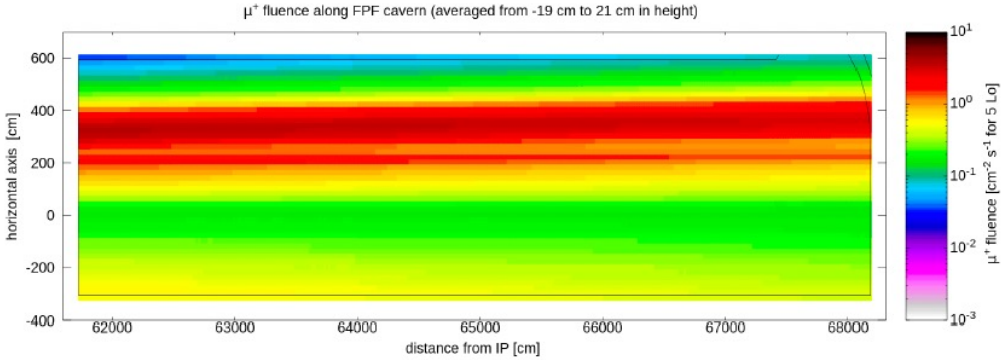
Option to use combined high / low resolution pixel and strip TPCs

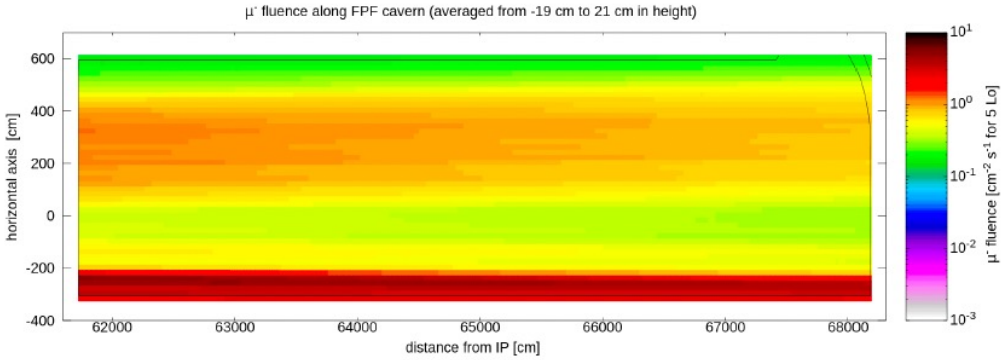
FLArE Detector Simulation



Experimental Condition Simulation

Muon Rate (main background) vs. horizontal position and distance from IP, 0 is the ATLAS axis.





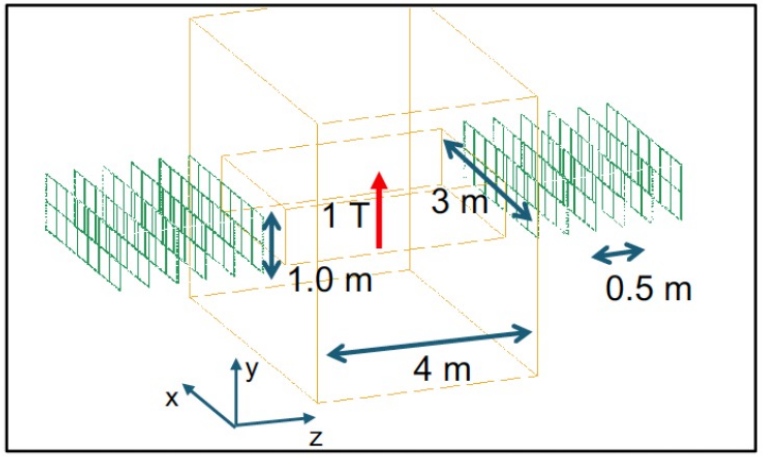
Minimum distance	612 m
Total Lumi/max lumi	3000/fb ; $5x10^{34}$ /cm2/sec
Lumi per day	~1 /fb assuming 10 year running
pseudorapidity coverage	>6.4, (~5.4-6.0 for off-axis)
track density (from data)	1.7x 10^4/cm²/fb^{-1}
max track density per sec (per crossing)	0.85/cm²/sec (2x10^{-8}/cm2/crossing)
Tracks in detector/1 ms	8.5/m^2/1msec
Neutral hadron flux > 10 GeV (10^{-4} of muons)	~3 /cm²/fb^{-1}
Total neutrino rate (all flavors)	~50/ton/fb^{-1}

arxiv 2105.06197

- Muon flux: 0.6 Hz/cm^2 at 5*10^{34}/cm^2/sec
- Neutron flux ~0.1 Hz/cm^2 is mostly at low energies
- Radiation and vibration has been considered and there are no issues.

Muon momentum measurement

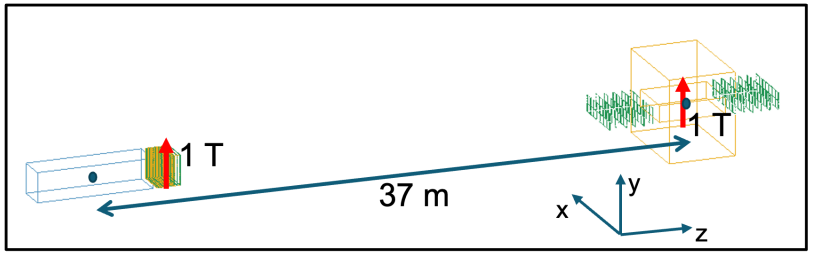
- Muons can easily pass through the detector, with a small portion of the energy deposited in the detector
- Propose to cooperate with FASER2's magnet, along with the magnetized HadCal and MuonFinder, in order to precisely reconstruct the muon momentum



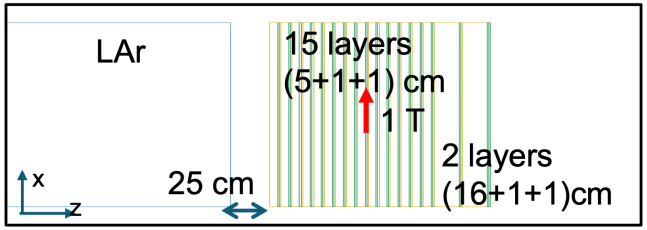
FASER2 magnetic volume (rectangular window): 3 m x 1 m (4 Tm)

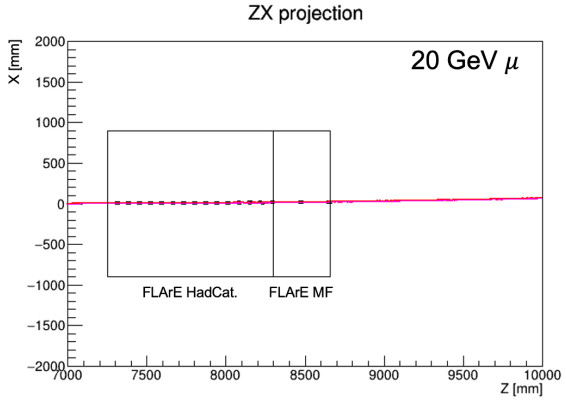
6 tracking stations, 50 cm apart, B = 1 T (fixed)

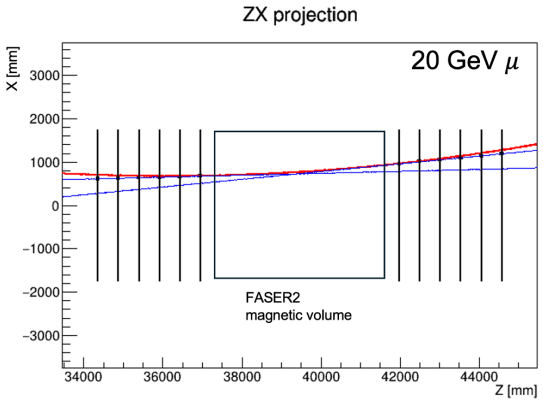
Complete geometry in the simulation:



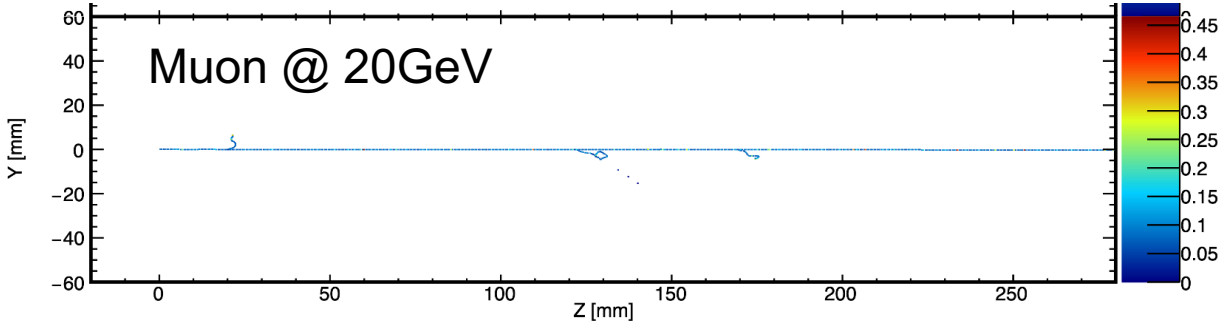
FLArE center to magnet center: 36.9 m
Magnetized HadCatcher and MuonFinder
B = 1 T (default, but still open to optimization)

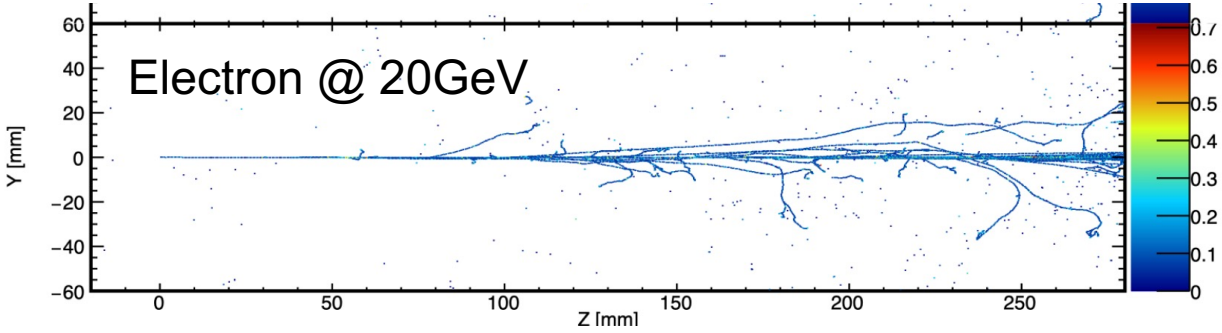


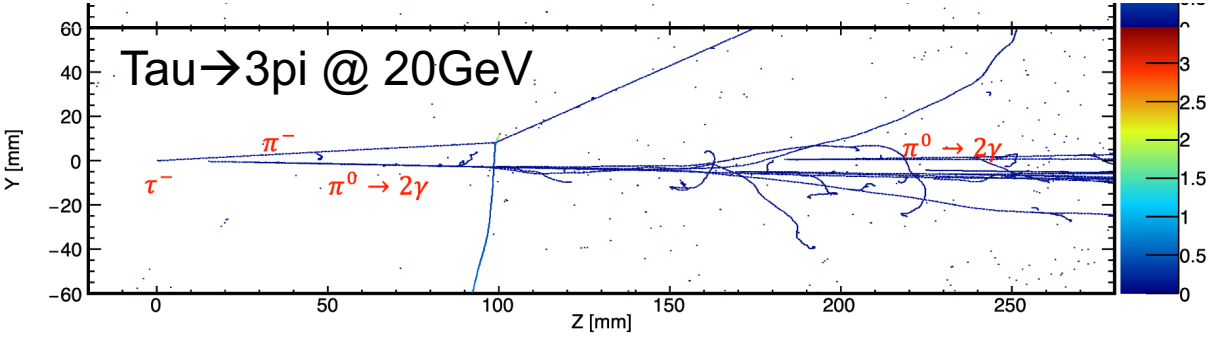




Event simulation in FLArE

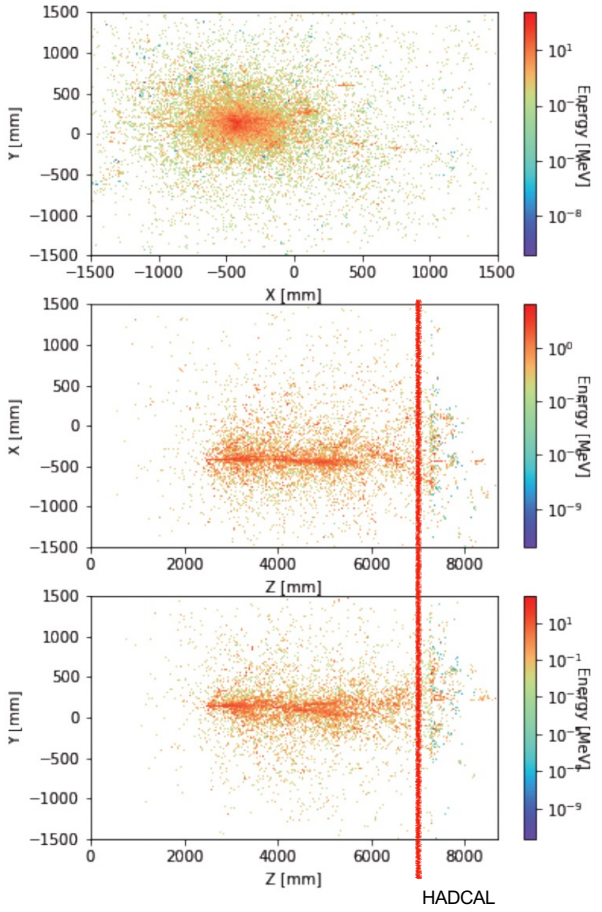






ν_τ CC (E_ν = 230.7 GeV)

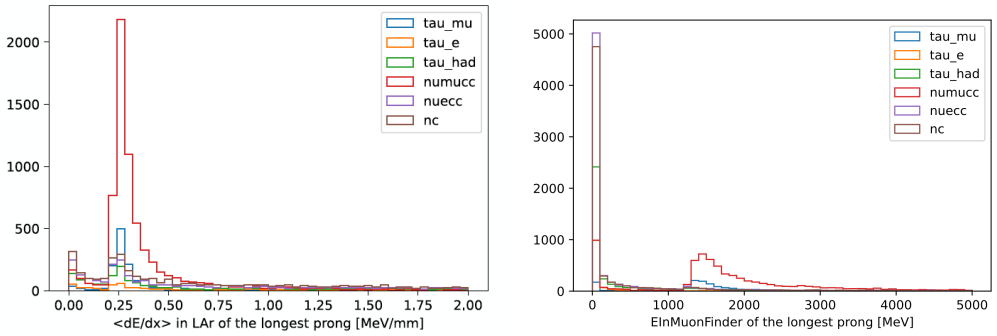
$\tau^-(102.9\ \text{GeV}) \to \nu_\tau + \bar{\nu}_\mu + \mu^-(74.7\ \text{GeV})$



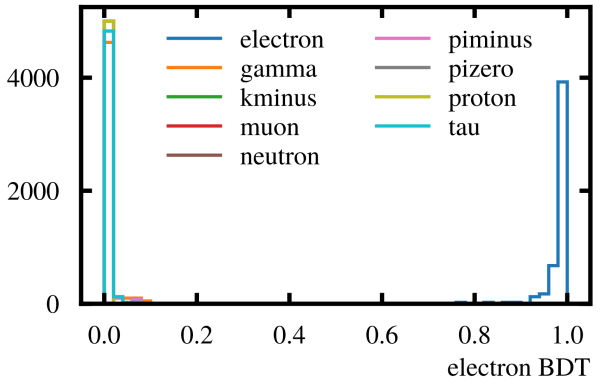
HADCAL

Reconstruction and Event Identification

ν_τ CC, $\tau \rightarrow \mu$ and ν_μ CC are distinct from other channels in dE/dx and energy deposit

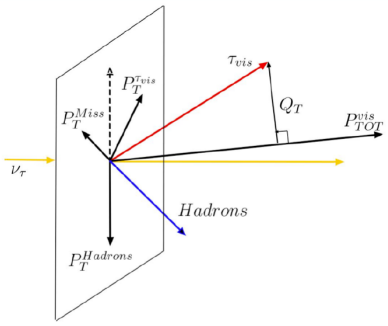


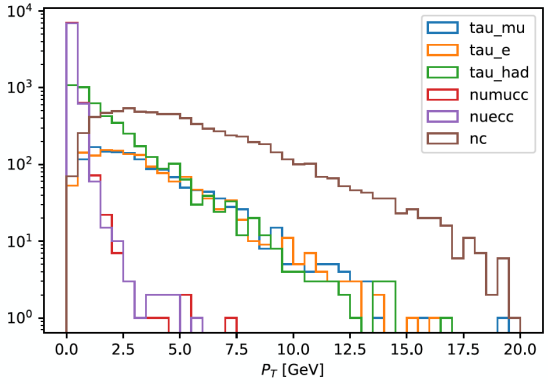
Singe Particle BDT

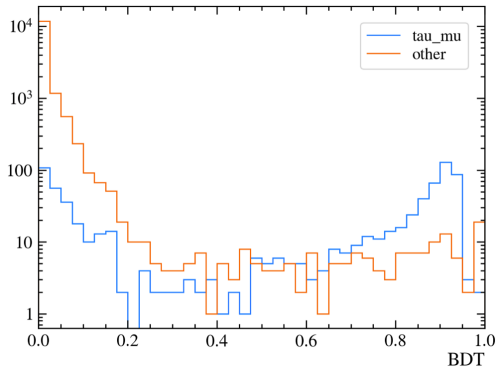


ν_τ CC, $\tau \rightarrow \mu$ have more neutrinos in the final state than ν_μCC, thus more missing momentum in the transverse plane

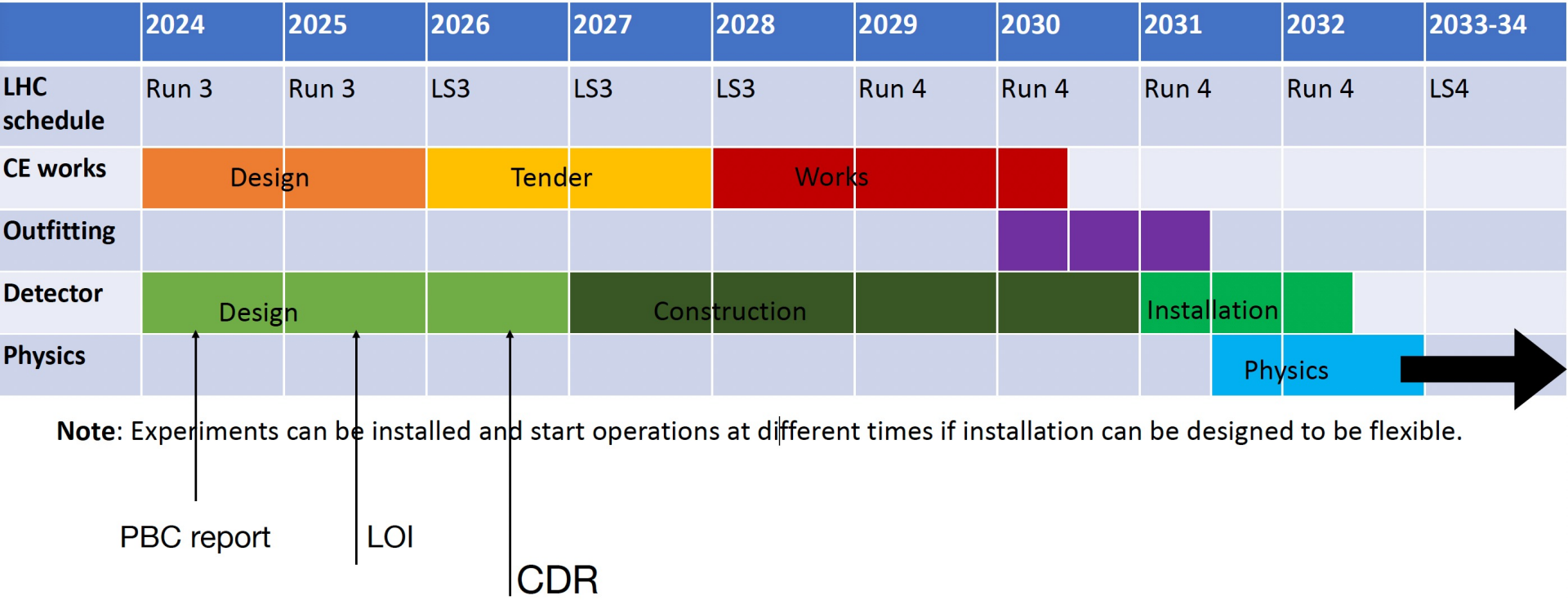
A BDT shows promising results to select ν_τ CC, $\tau \rightarrow \mu$ from backgrounds, working on other τ decay modes







Possible FPF Timeline



Aim to fit US FLArE efforts into the ASTAE portfolio

Summary

- A forward physics facility FPF is being considered at CERN for neutrino and dark matter physics
- Liquid Argon detector FLArE for FPF is being considered
- Detector capability, event rate and backgrounds of FLArE are preliminarily studied, showing that a LAr detector is feasible
- Engineering and simulation work towards a CDR is underway

Thank you!