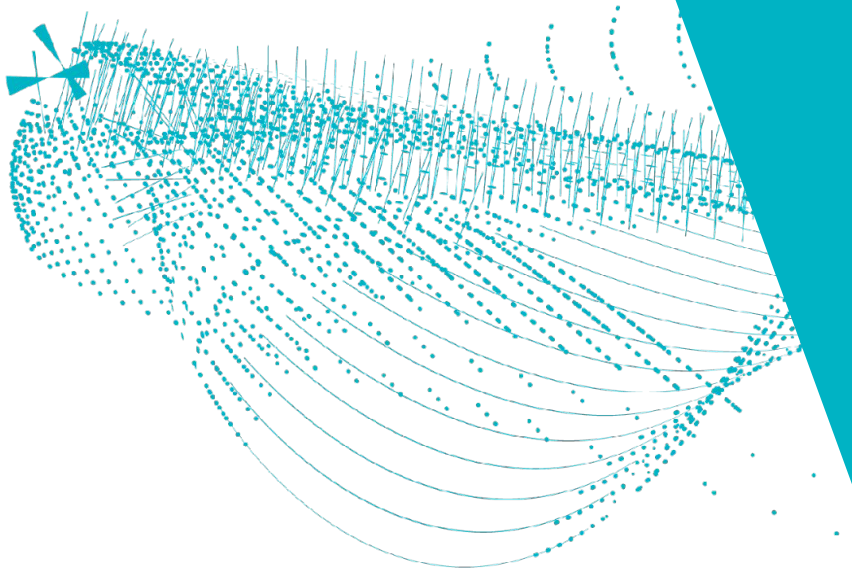
Nikhef

Radboud University



A NuTeV like detector
Or something else?

FPF7, 1.3.2024

Mengqing Wu and
Lydia Brenner

Motivation

FLArE - planned as 10-ton-scale liquid argon time projection chamber (LArTPC), that offers the possibility to precisely determine particle identification, track angle and kinetic energy over large dynamic range from 10 MeV to many hundreds of GeV

➔ snowmass 2021: https://arxiv.org/pdf/2203.05090.pdf
➔ Physics motivation: neutrino detection and light dark matter searches

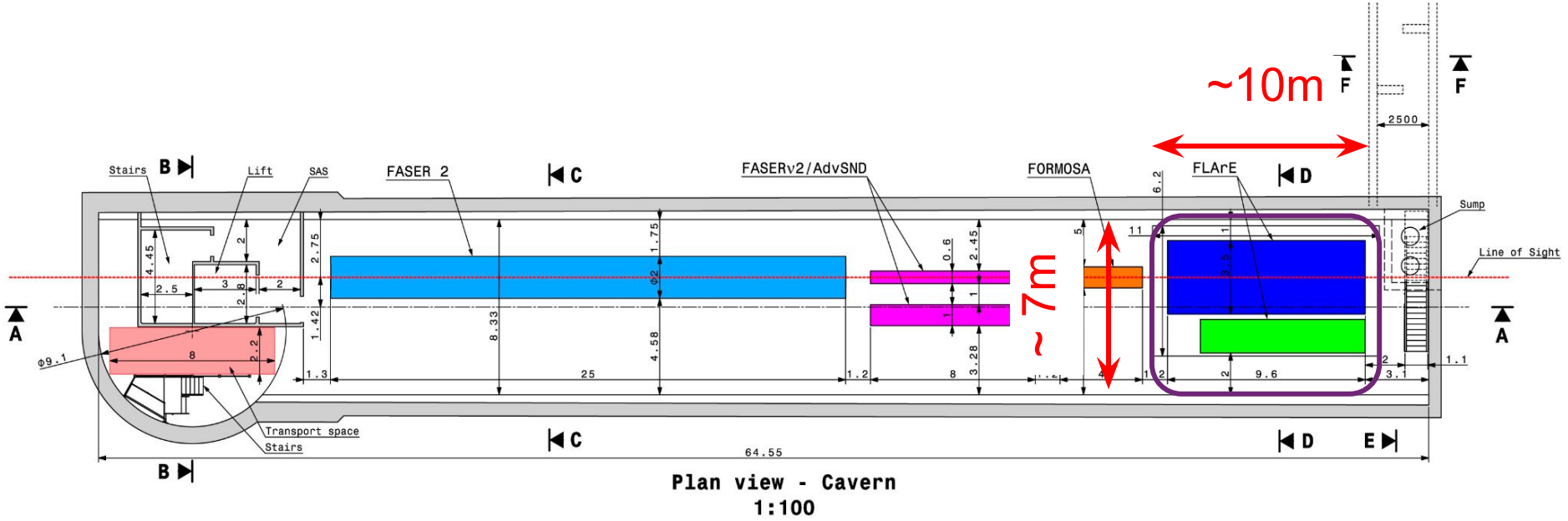
P5 report indicates concerns on high cost of the detector

➔ https://www.usparticlephysics.org/2023-p5-report/

Detector performance wishlist

- Ability to trigger and collect particles that come from an LHC IP and produce an event within the fiducial volume of the detector
  - in the presence of large muon backgrounds from the high luminosity running of the LHC.
- The detector must also be able to contain the events, reconstruct the kinematics, and identify the neutrino type.
- Identification of **tau neutrinos** presents a particular challenge, requiring both high spatial and kinematic resolution.
- In the case of **dark matter events**, an energetic, isolated, forward-going electron must be identified and its energy measured.

Detector cavern



Avenues explored in this talk

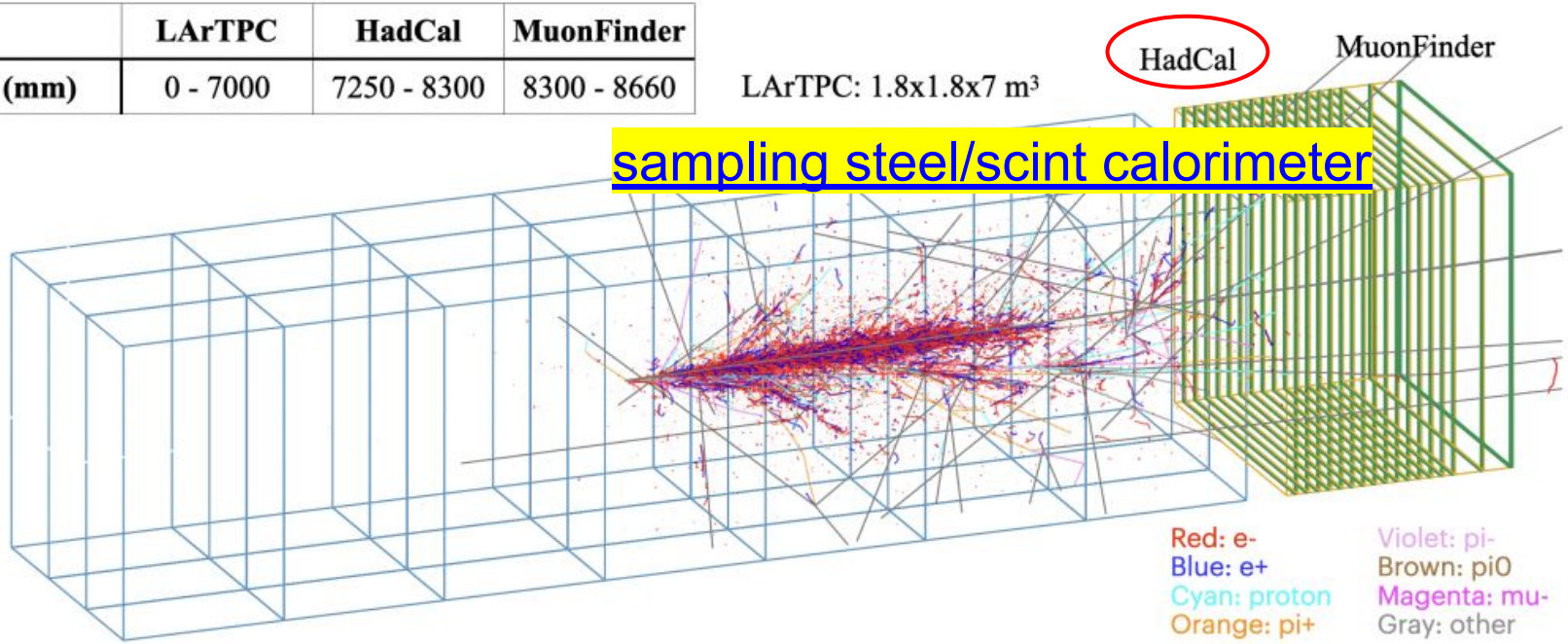
1. Recap: Latest FLArE development
    a. Is it possible to continue with least changes?
2. One alternative proposed: a NuTeV-like detector
    a. “Simple” iron/liquid scintillator sampling calorimeter
    b. Classic, can we modernize to adapt for our usage?
3. A wild proposal: a new detector concept, that
    a. Combines FLArE + NuTev, i.e. TPC + sampling calorimeter
    b. By recycling to-be-retired detector + mature detector concept

Thanks Wenjie Wu!

Recap: the FLArE design

[example simulated neutrino event]

	LArTPC	HadCal	MuonFinder
Z (mm)	0 - 7000	7250 - 8300	8300 - 8660



FLArE design performance

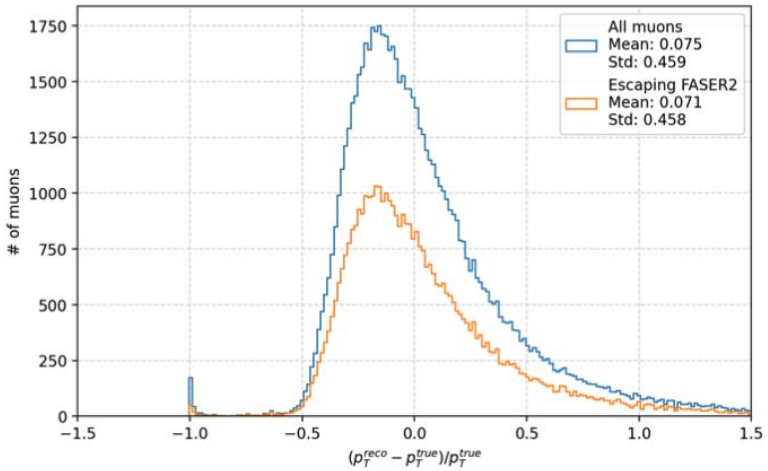
For muons crossing FLArE HadCat and MF at B=1T

Pro

- Designed to meet the performance wishlist:
  - TeV neutrinos
  - all flavors

Con

- Needs to be designed and build from scratch (prototypes to make)
- Concerns on the cost



(b) $(p_T^{\text{reco}} - p_T^{\text{true}})/p_T^{\text{true}}$

Figure credit: FLArE technote see Steven's talk

A NuTeV-like detector?

Raised in the community Dec. 2023
i.e. turn the FLArE HCal to the major detector.

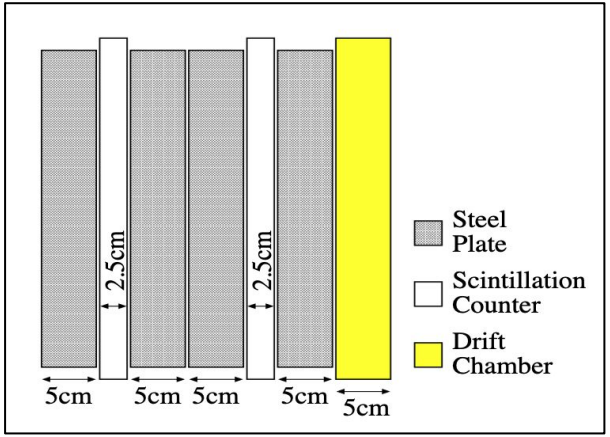
Pro

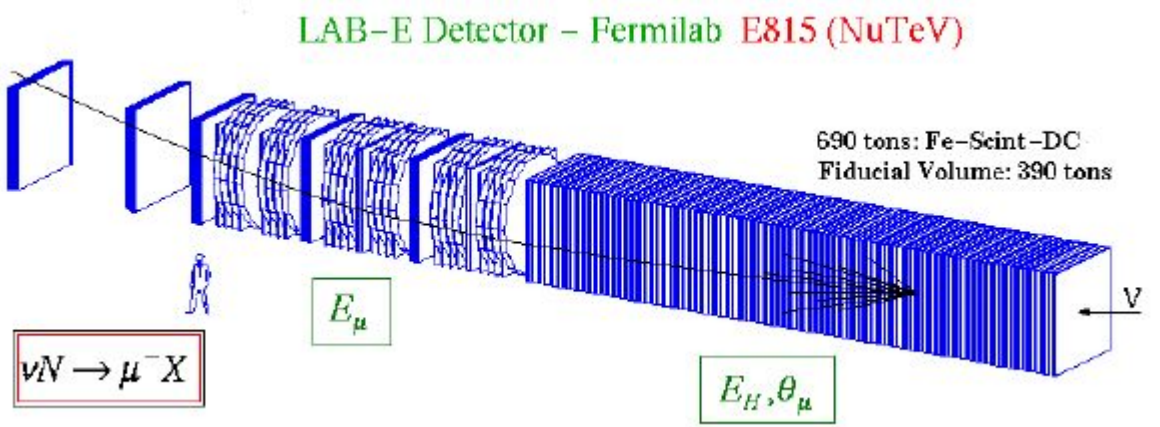
- Large volume (NuTev~400tons) with a good price

Con

- Limited performance Compared to FLArE, e.g. calibrated energy range: 4.5 to 190 GeV

note: keep the steel absorber but change the readout techniques and geometry/segmentation?





NuTeV-like: Neutrino physics potential

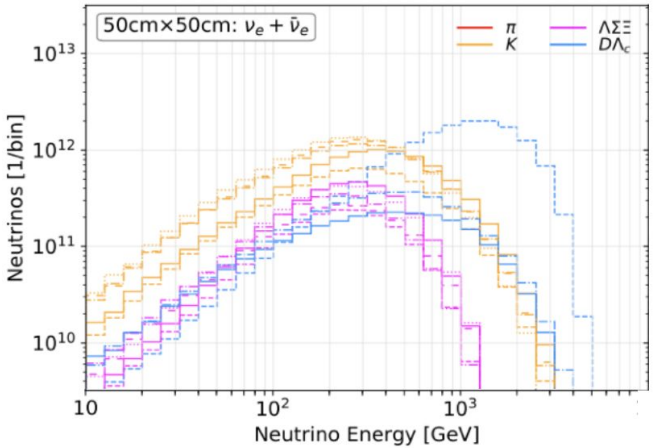
Thanks Felix Kling!

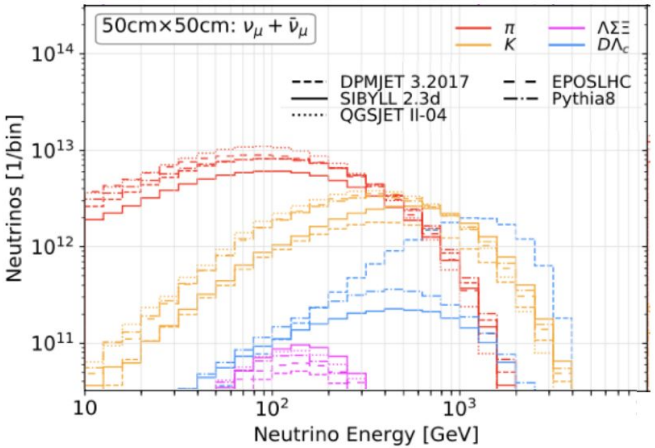
Neutrino energy spectrum sensitive to forward pion / kaon / charm production.

larger rapidity coverage interesting but requires large detectors:
* 1m off-axis: η=7
* 2m off-axis: η=6.5

ideally achieved with cheap detectors

NuTev-style detector should be able to distinguish ν_e CC, ν_μ CC, and NC.

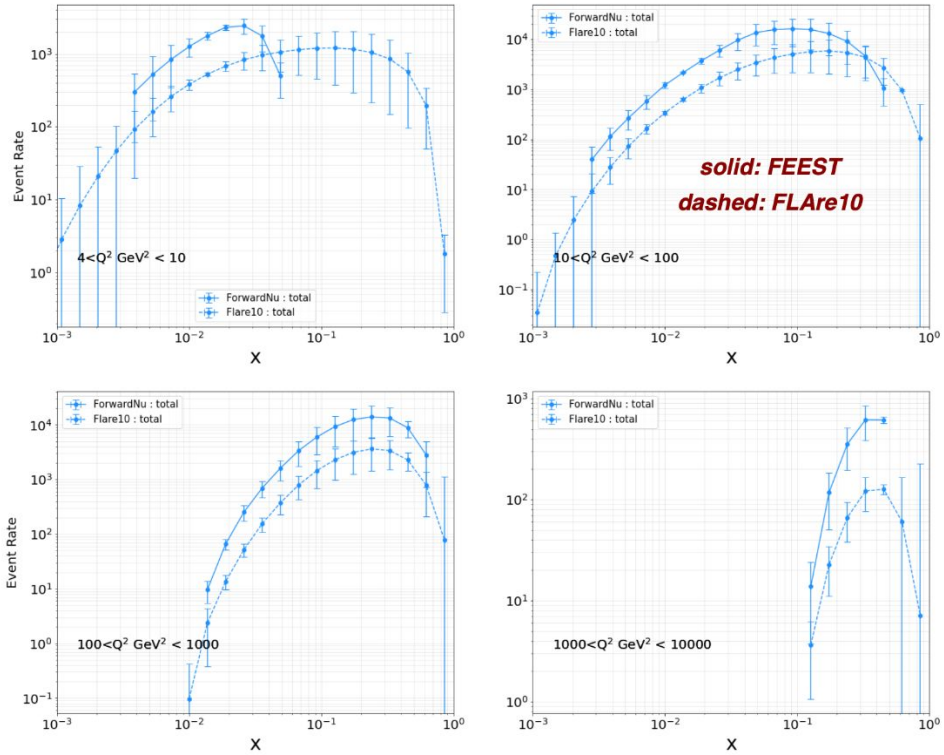




NuTeV-like: Neutrino DIS potential

Thanks Juan Rojo!

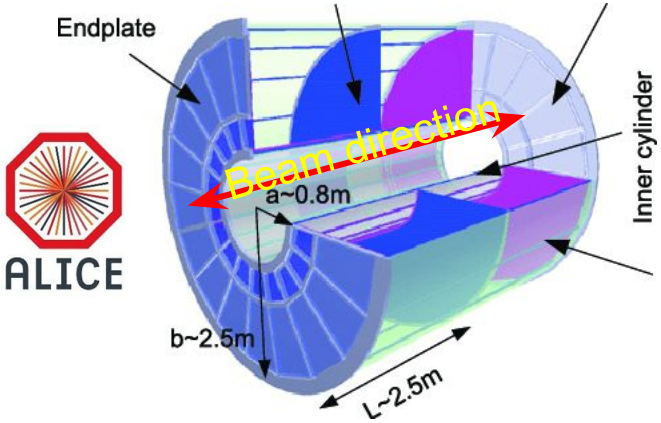
- Dashed for FLArE10 while solid for NuTeV-like detector
- Comparable performance with FLArE



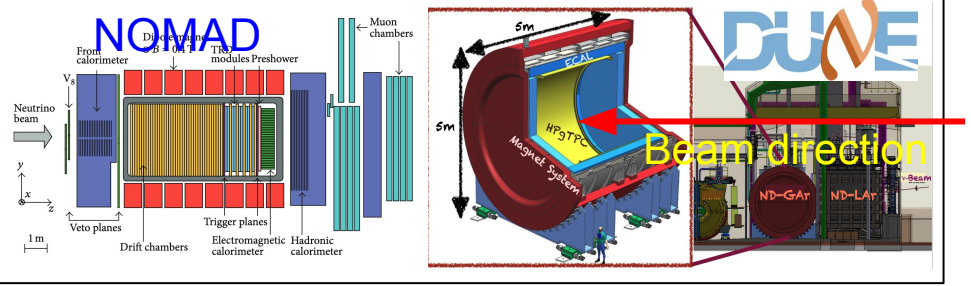
FAIRIE = Forward Anomalous lIght particle Reconstruction and Identification Experiment

New detector concepts - brainstorming

- Can we recycle detectors to continue with FLArE with minimal changes? **Gas** TPC
- ALICE TPC will retire after run-4



- ALICE is gas TPC, to compensate the volume, sandwiched by sampling ECal (inspired by NOMAD)
- ECal technology shopping list: DUNE ND ECal? (same technology in CMS HGCal, CALICE AHCal)
- DUNE ND TPC is high pressure **gas** TPC – inspired by ALICE TPC



The Alice TPC

Alice will retire their TPC in LS 4

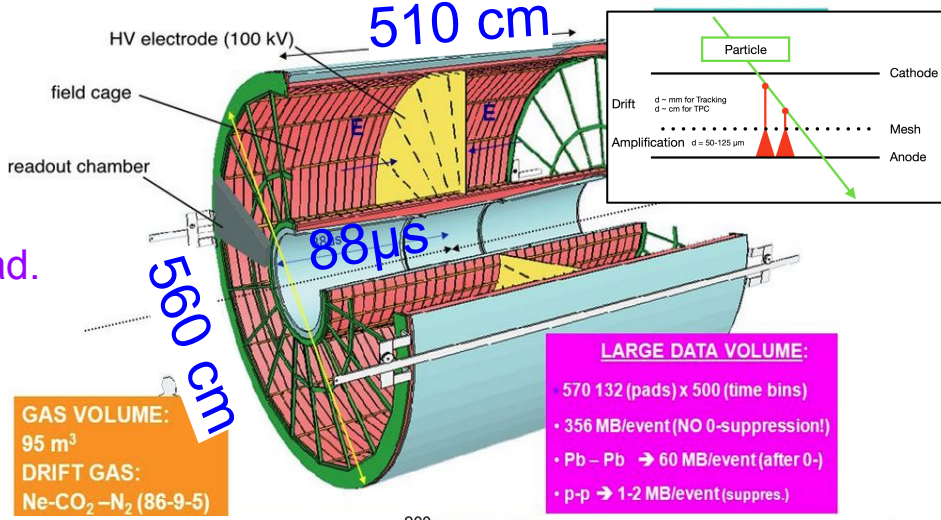
➔ Initial discussions with ALICE colleagues had.

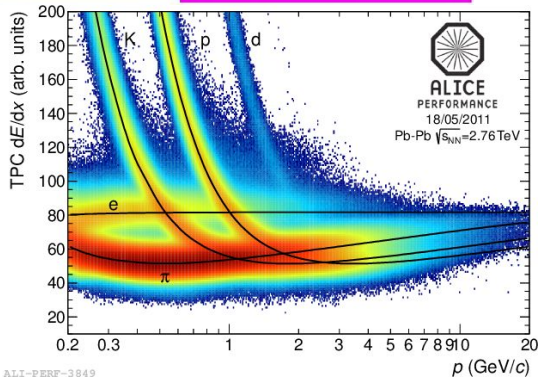
Pro

- It fits! – 5.6m x 5m cylinder
- Good energy/momentum measurement for dE/dx (PID)
- Spatial resolution shall fit well for us as it serves at the busy LHC environment

Con

- Available later than the envisioned FPF installation
- Hollow concentric cylinder (not ideal case)
- Gas detector: good volume but not massive

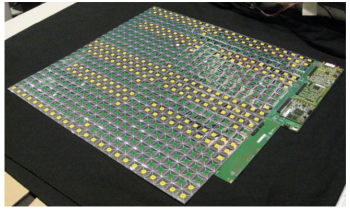


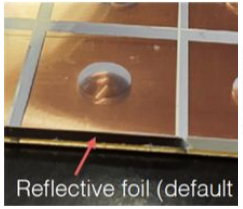


CALICE AHCAL detector concept - DUNE ND ECal, CMS HGCal

Similar to the NuTeV, or FLArE HadCal, an absorber-scint sampling calorimeter:

- SiPM-on-tile: Plastic scintillator + commercial SiPMs
  - Large order of this SiPM costs ~10€/piece
- ASIC (SPIROC2, IJCLab)
  - Self trigger with buffer - fit our low data rate
- Mature detector concept with high granularity, offering
  - Shower shape studies
  - Reconstruction using particle flow algorithm
  - BDT based particle ID





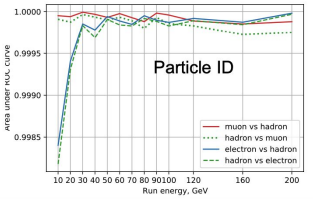
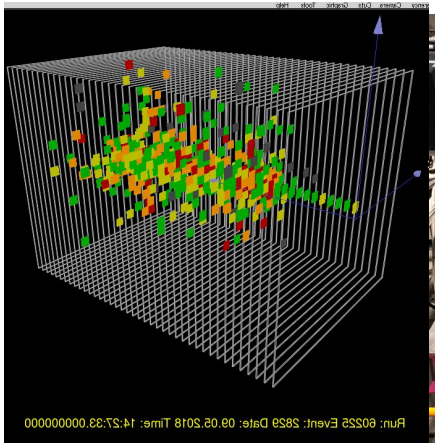
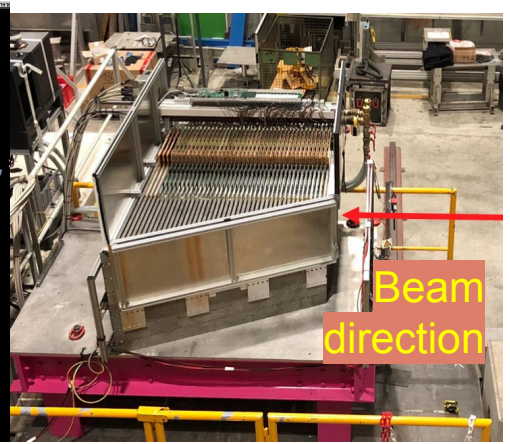


Figure credit: Katja Krueger





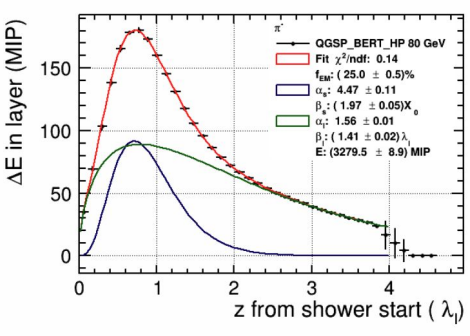
Initial discussions with CMS HGCal & CALICE colleagues had.

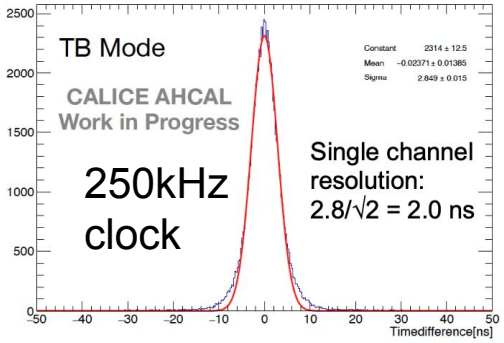
A prototype to recycle?

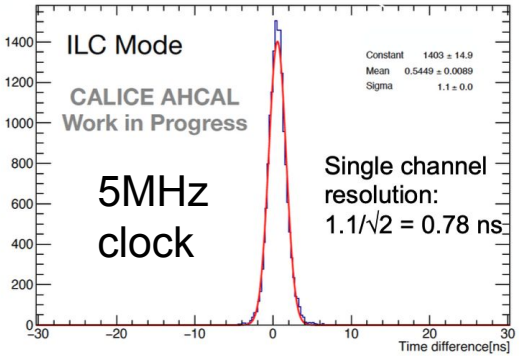
Figure credit: Katja Krueger

Recycle prototype from CMS HGCal?
or recycle prototype design from **CALICE AHCal prototype**?

- 38 active layers of 72*72 cm^2, large enough to contain hadron showers
- Steel absorber stack with SiPMs (HPK S13360-1325PE)
- *In total:* 608 SPIROC2E ASICs, ~22000 channels
- All modules interchangeable
- Built with scalable production techniques in ~2 years
- *Bonus:* hit time resolution ~1ns*







**depending on the application scenario (e.g. trigger rate, clock freq)*

Absorber and geometry choice inspired by DUNE ND ECAL

- Large sampling ECAL with good energy and angular resolution, neutron sensitivity and sub-ns time resolution for ToF (important for TPC)
  - background rejection
  - particle catcher + muon id/tracker for TPC
- Very thin absorber due to very low energies
  - not our case, reducing system complexity
- Absorber material & granularity drives the cost, which decides:
  - calorimeter energy resolution
  - angular resolution

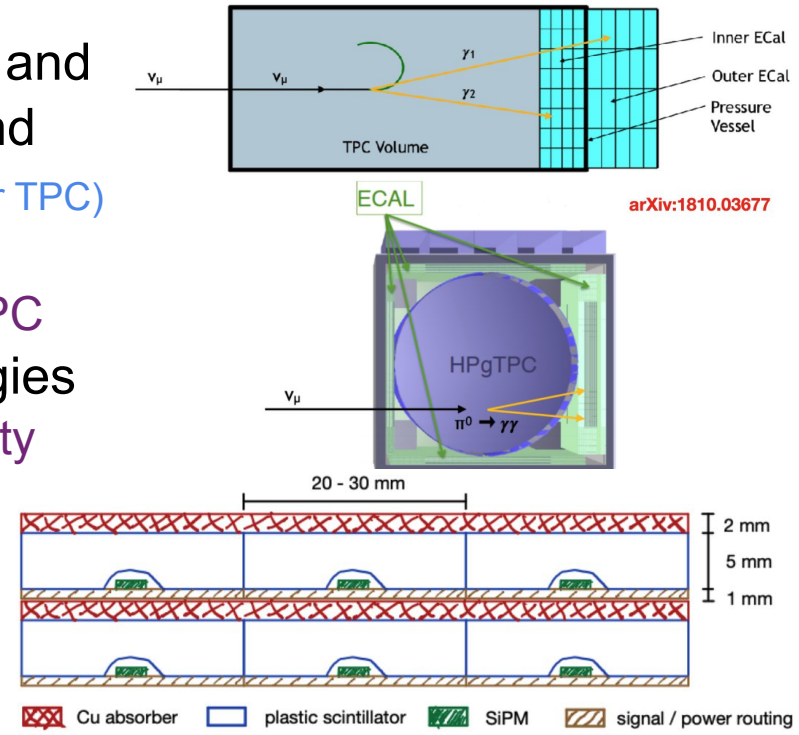


Figure credit: Eldwan Brianne

The idea and a very rough estimation of the cost

Assuming we do 38 layers of 5m*2.5m (H*L) SiPM-on-Tile calorimeter plate, with average tile size of 10*10cm^2:

SiPM on large quantity order

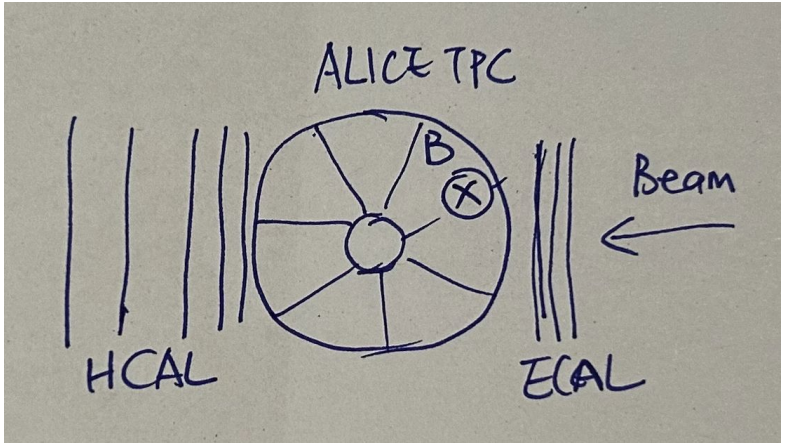
➔ 1250 channels per plate

➔ x 20 plates for HCal = 250kCHF

➔ x 4 plates for ECal = 50kCHF

Steel price driven by dimension and flatness: cheapest option is industrial product size

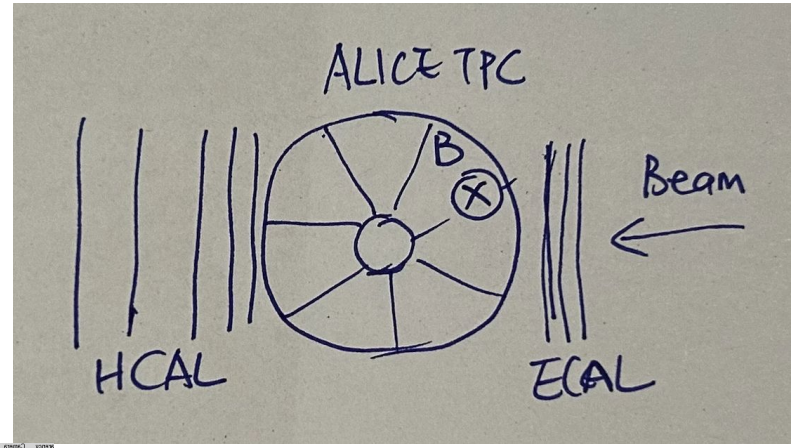
ASIC & carrier board: hard to retrieve, needs to check with IJCLab.

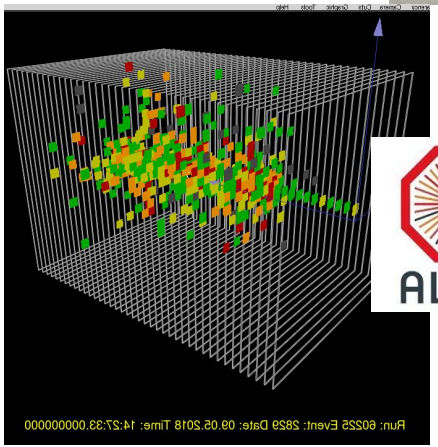


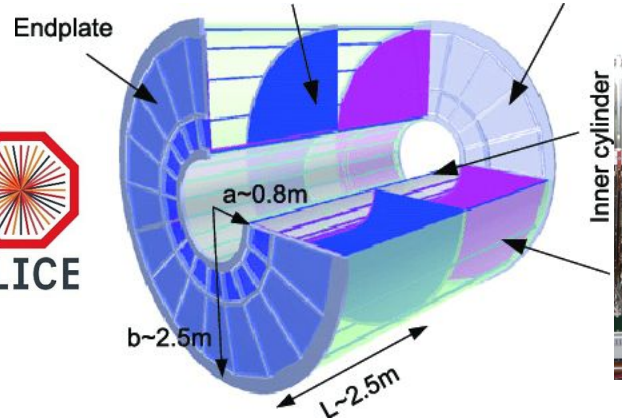
Summary

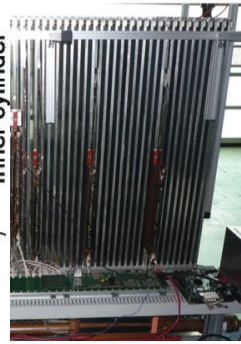
Various options explored
➔ Feedback welcome!

More detailed studies to be done.







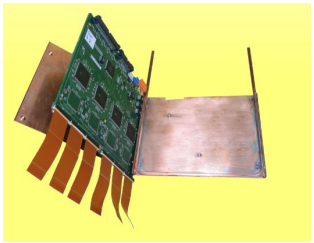


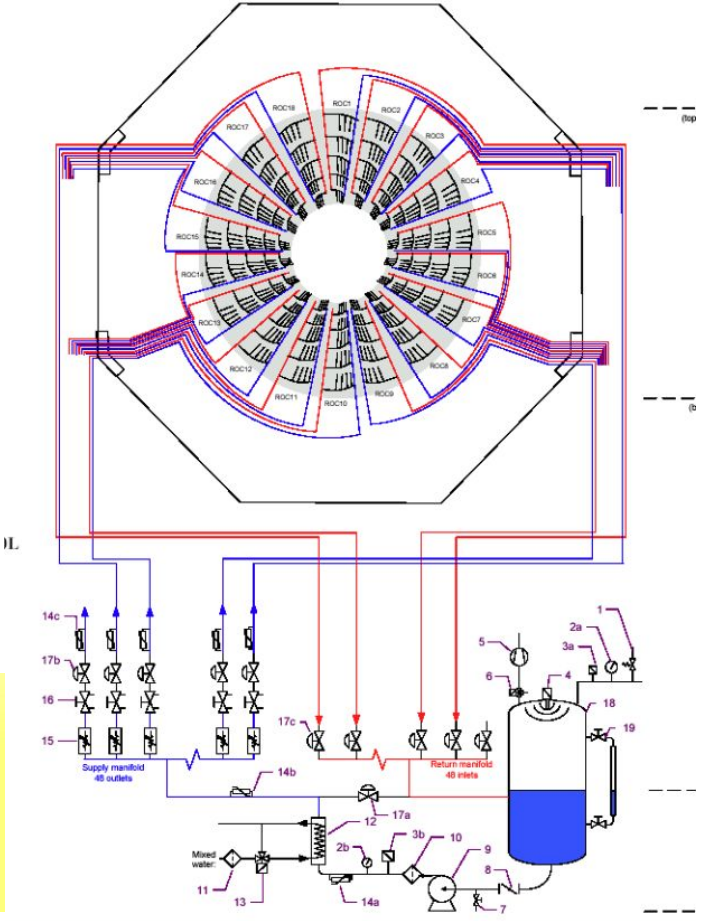
Back-up

ALICE TPC Cooling system

About 60 adjustable cooling circuits:

- leakless under pressure system
- cooling of ROC bodies
- FEE enveloped in copper plates (≈ 27kW)
- thermal screens towards ITS and TRD
- service Support Wheel closed with copper shields





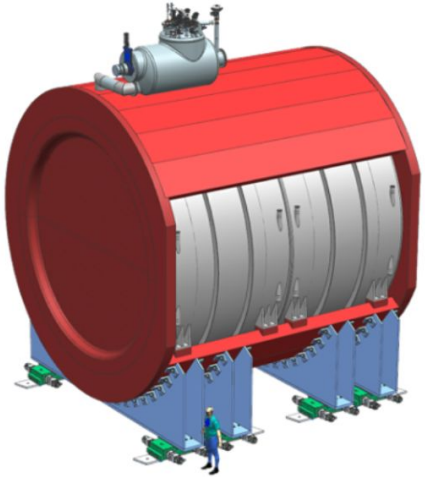
Slide credit: Jens Wiechula

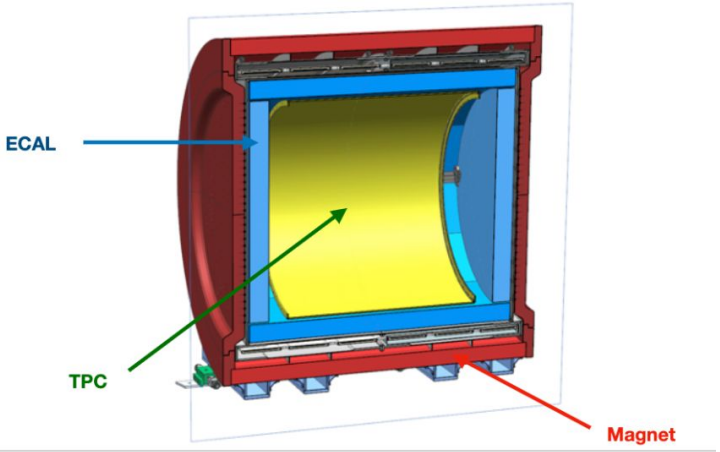
Nikhef

The DUNE Near Detector: ND-GAr.

A high performance gas detector

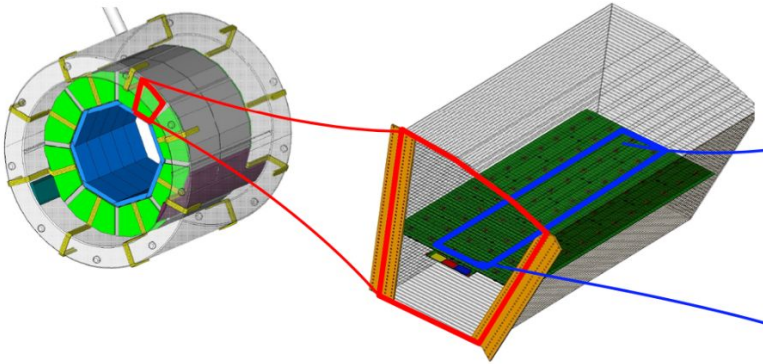
- Placed behind the ND-LAr
  - Acting as a **spectrometer** for particles exiting the ND-LAr
  - Provides its **own physics program** for ν interactions on gas argon
- Key components
  - High Pressure (**10 bar**) GArTPC as tracker with 1 tons Ar target mass
  - Surrounded by a **high performance calorimeter**
  - Inside a superconducting magnet and partial return Yoke (0.5 T)
- **Challenges**
  - Calorimeter integration inside the pressure vessel (PV)
  - Cryostat and yoke acting as the PV
  - Minimise fringe field and material budget

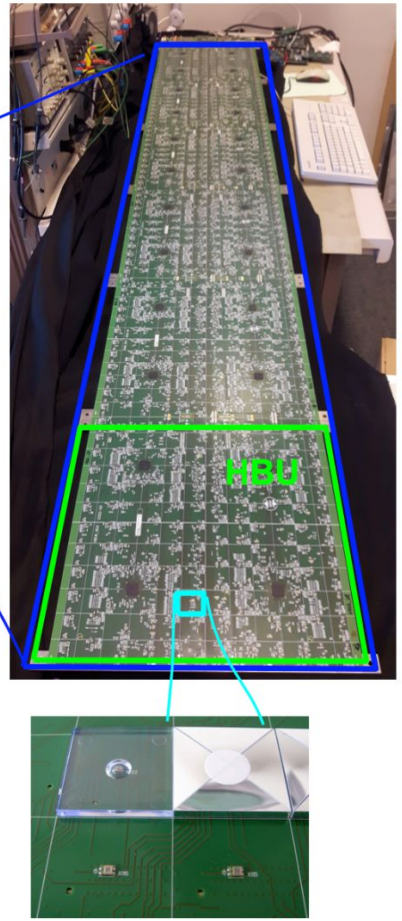




Slide credit: Eldwan Brianne

AHCAL Technological Prototype





- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- **fully integrated design**
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers -> **power pulsing**
- **scalable** to full detector (~8 million channels)
- geometry inspired by ILD, similar to SiD and CLICdp
- HCAL Base Unit: 36*36 cm^2, 144 tiles, 4 SPIROC2E ASICs
  - slabs of 6 HBUs, up to 3 slabs per layer

Slide credit: Katja Krueger

Alternative names

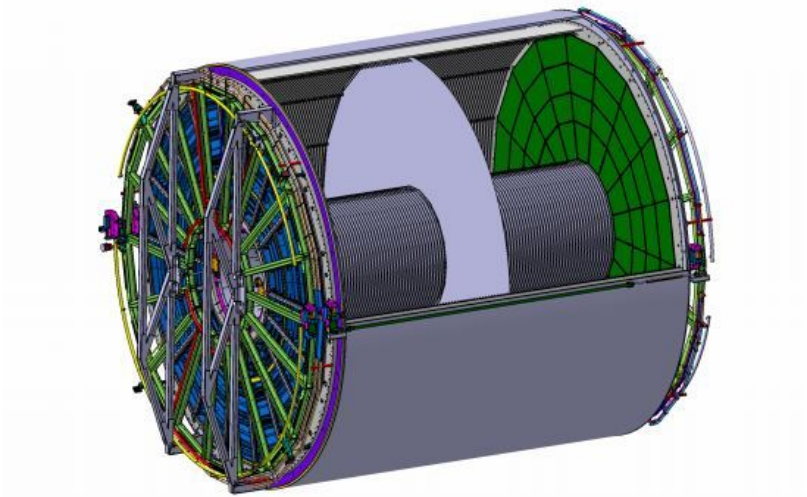
FABIOLA = Forward from Alice to Bob Identification Of LHC pArticles

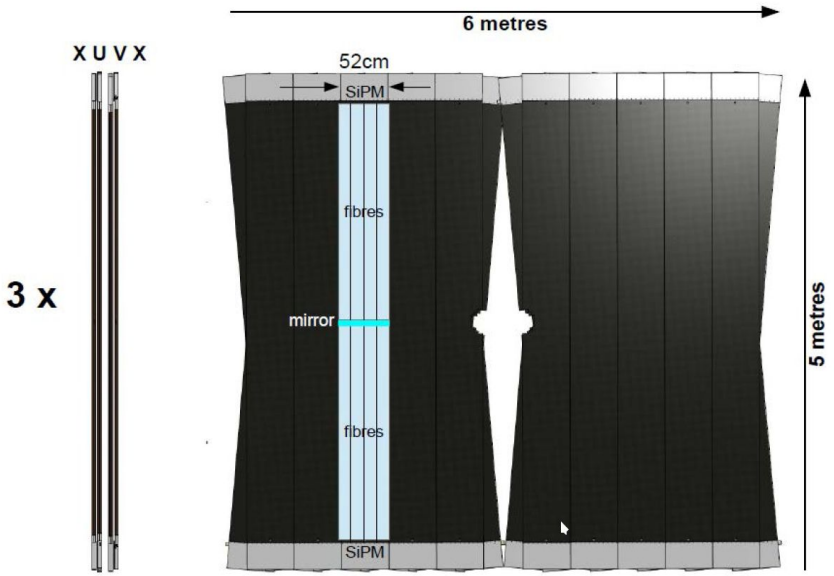
FAWN = Forward Array for Weakly interacting particles and Neutrinos

FANTASTIC = Forward Anomalous particles and Neutrino Tagging adopted from Alice based on Scintillator Tracker In Calorimetry

FRONTIER = FoRward Observatory for Neutrino Tagging and Invisible Entity Research

MISC




X U V X
3 x
6 metres
52cm
SiPM
fibres
mirror
fibres
SiPM
5 metres

FLArE costs picture

?