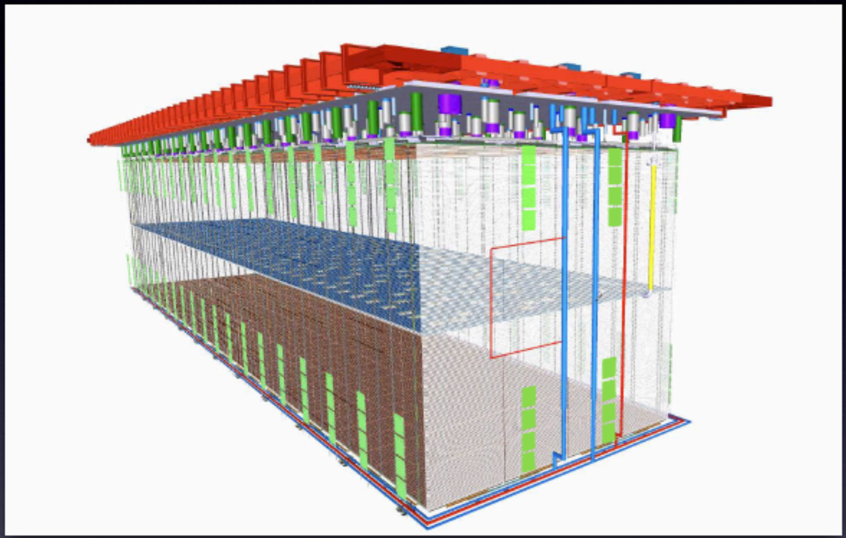
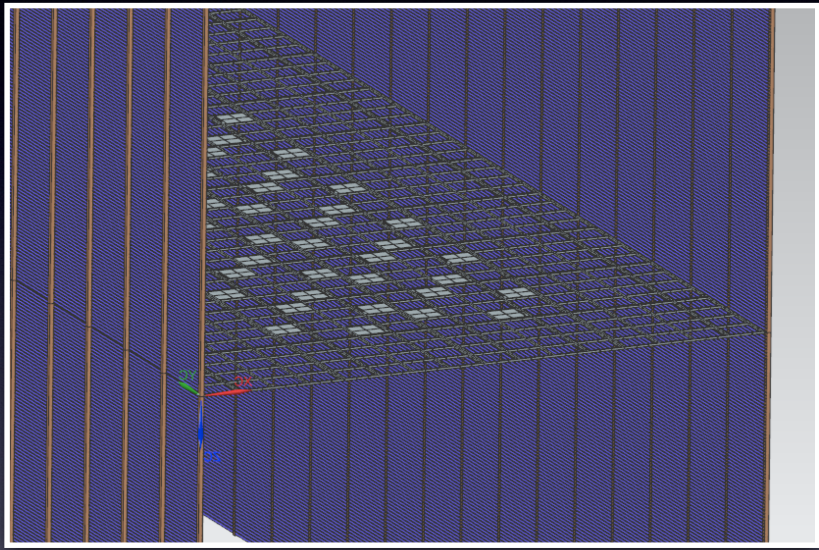
Jun 26 – 28, 2023
Stony Brook University Physics Building

DUNE FD3 Mini-Workshop Toward a Combined Photon Detection and Field Cage System

From this (FD2 - VD)



To this (FD3 - VD Optimized)



“VD Optimized FD3” w/ enhanced PDS Introduction & Goals

June 26, 2023

F. Cavanna
Fermilab

DUNE Phase-2 and Snowmass

- DUNE Phase I should be realized in this decade
  - Every effort should be made to resolve funding profile issues that could delay first physics results into the 2030s
- Realization of the full DUNE Phase II should be the highest priority
  - Pursue upgrades aggressively such that the full DUNE scope is achieved in the 2030s
- R&D work to design detectors that broaden the physics scope while fulfilling the core goals of DUNE should be supported

Snowmass 2021

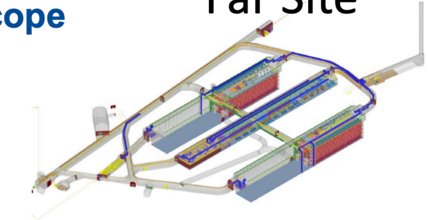
DUNE Phase-2 and P5

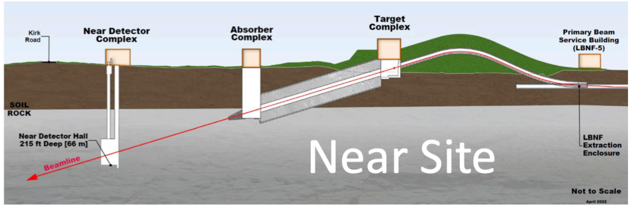
The P5 committee - that reports to HEPAP (the High-Energy Advisory Panel of HEP-DOE and NSF) - is charged to build on the Snowmass US HEP community study to hash out funding priorities for the next 10 years with a 20-year context

DUNE plans for Phase II presented at the Fermilab P5 Town Hall Meeting (all presentations here) March 21-24, 2023.

LBNF/DUNE-US Project Scope

Far Site





LBNF/DUNE-US Project Scope

	Component	DOE Project Scope (meets 2014 P5 minimum to proceed – Phase I)	Phase II Requirements (meets 2014 P5 goal)
Near Site	Conventional Facilities	• Constructed to support 2.4MW primary and neutrino beamline • Constructed to support underground Ph I & II Near Detector	•NONE
Near Site	Neutrino Beamline	• Wide-band output neutrino beam, 1.2MW initially, designed to be upgradeable to 2.4MW	• 2.4MW capable target and new horns • New decay pipe window • Some additional cooling and instrumentation
Near Site	Near Detector	• US contribution to the DUNE Near Detector (Ph I)	• US contribution to more capable Near Detector (Ph II)
Far Site	Conventional Facilities	• Surface and underground facilities & infrastructure for 4 detector modules	•NONE
Far Site	Cryostats	• For 2 detector modules (CERN)	• For 2 detector modules
Far Site	Cryogenics	• 3 x nitrogen units; 35 kton liquid argon for detector modules	• 1 x nitrogen unit; 35 kton liquid argon for detector modules
Far Site	Far Detector	• US contributions to 2 x DUNE LAr TPC modules	• US contributions to 2 x DUNE LAr TPC modules

Phase II FD Baseline and Boundary Conditions

- ***For the purpose of planning the DUNE collaboration will assume FD3 and FD4 are vertical-drift LArTPCs similar to FD2 as the baseline options***
- ***DUNE is actively exploring LArTPC detector options for Phase II with enhanced capabilities that could bring in significant contributions from existing partners and/or new partners.***

Incremental LArTPC R&D on mature options

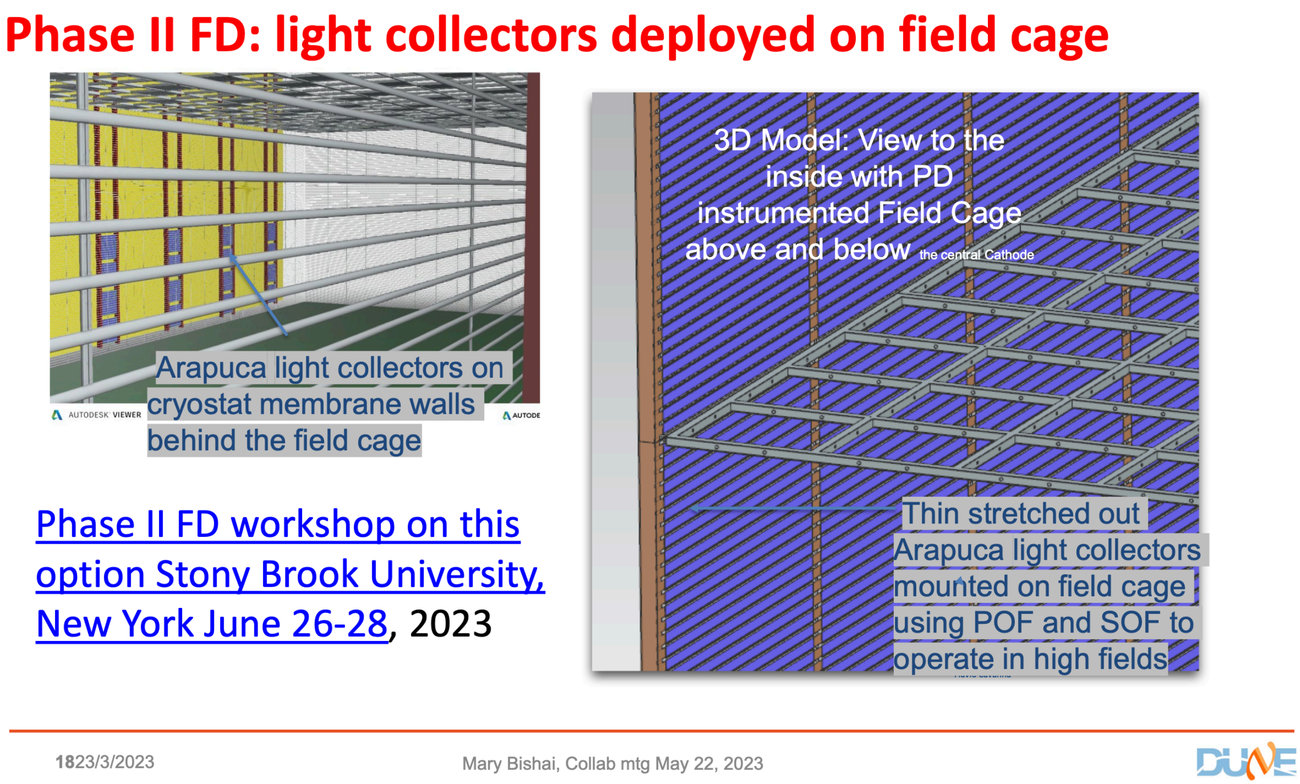
- FD2 like (Vertical Drift) modules with "adiabatic" improvements, mainly in the light detection (baseline option)

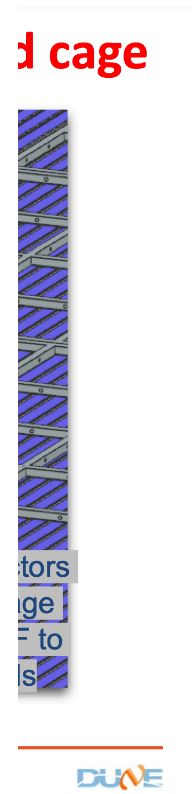
- The DUNE-II Collaboration is planning a phase II "white paper/CDR-light" for the summer 2023.

- The DUNE-II project adds additional science reach to LBNF/DUNE-I

News and Updates from DUNE

Mary Bishai
Sergio Bertolucci
Collaboration Meeting
May 22, 2023

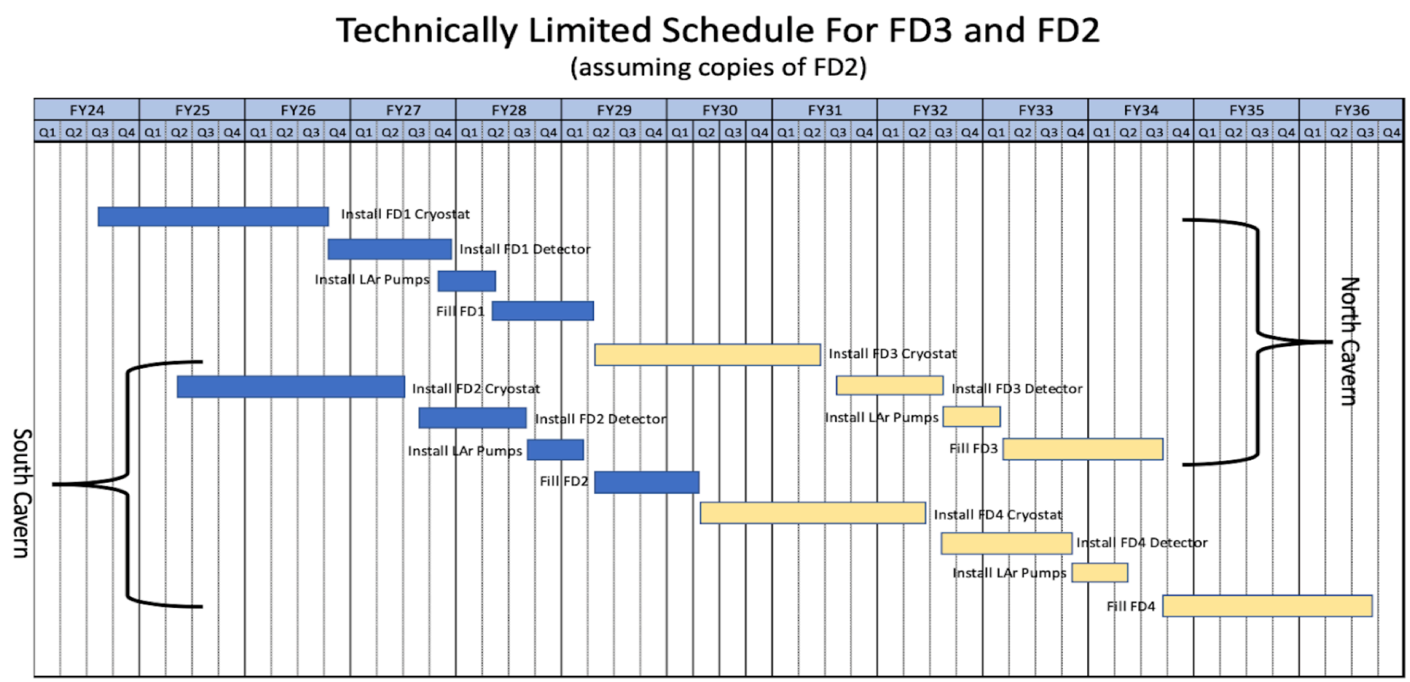




10x light collection for incremental cost. 50% of energy deposited in LAr is in light = improved calorimetry and energy resolution

Mary Bishai
Sergio Bertolucci
Collaboration Meeting
May 22, 2023

FD 3 and 4 Timeline



Earliest installation start in 2029 with FD3 completed in Q4,2034 and FD4 in Q4,2036

DUNE Phase II FD R&D Goals

- *Pursue possible enhancements that make use of recent technological breakthroughs and are well motivated by unique additional physics capabilities.*
- Other considerations are increased funding/resources and/or reduced risk in an international context.
- Enhancements are mainly driven by 1) better energy resolution 2) lower energy thresholds, and 3) lower intrinsic backgrounds,
- Possible expanded physics scope
  - Solar (and supernova) neutrinos in new energy regime.
  - Low-mass dark matter
  - Physics enabled by increased Xe doping

Optimized VD FD3

➡ ***Optimized VD*** Detector solution:

- ➡ Charge R/O (main): LArTPC single phase, vertical drift, CRP based (Top, Bottom planes - 6.5 m drift)
  - ➡ Minimal Optimization: *active volume size* and *PCB perforated strip geometry*
- ➡ Light R/O (enhanced): *x-ARAPUCA modules framed in FieldCage electrodes* for an extended optical coverage (power and signal transmission via optical fiber - PoF and SoF - as for FD2 modules on HV Cathode)

➡ Mature technologies, cost-effective, well defined optimization development path

➡ ***optimized VD*** solution for **FD3-4** modules:

- ➡ meet > 40kT fiducial LAr Volume necessary for DUNE to meet P5 goals
- ➡ retain DUNE unique strengths: excellent PId and energy reconstruction over the entire *beam energy range* **(500 MeV to ~5 GeV)**
- ➡ extend the physics reach to lower energies for SN neutrinos, Solar neutrinos Physics (and improve energy resolution at the Beam energies)
- ➡ Expect moderate overall cost increase and reduced R&D risks

Optimized Vertical Drift FD3-4: Charge R/O technology optimization

LArTPC optimisation options:

- **CRP technology is “close to ideal” (after 4 major generations of developments)**
    - *(1) Wire Planes + Warm Electronics (ICARUS),*
        - *Wire Planes + Cold / Warm Electronics (MicroBooNE)*
    - *(2) APA-Wire Plane + CE - (protoDUNE-SP, SBND, ⇒ DUNE **FD1**) [technologically perfect ! but complicated, labor-intense and expansive]*
    - *(3) CRP-Perforated PCB + CE (⇒DUNE **FD2**) [technologically simpler, based on commercially available components ⇒ fast construction and cost effective]*
  - ***Any possible further CRP optimization step?***
    - Ind, Coll pitch design for LowEn event reco (maybe)
    - expand Active Vol ?
    - Further improve S/N (??)

OR

- **Change core feature of TPC design**
  - **Pixel read-out** to improve charge reconstruction performance

OR

- **Change technology of Charge signal read-out**
  - **Dual Phase Optical read-out** [ARIADNE] to reduce cost and great potential

Optimized Vertical Drift FD3-4: Light R/O technology optimization

Most (if not all) large mass, UG detectors for LowEn (solar) neutrino are Light r/o (scintillator or Cherenkov) based detectors
[featuring 4π coverage for a high & uniform LY - the base for a high detection efficiency and good energy resolution for LowEn events]

LAr-PDS optimization options

- **ARAPUCA(w/ SiPM) technology is still young, with large margins of improvement thanks to well proven flexibility**
  - *ARAPUCA bar w/ few (12)SiPM/channel + Warm Elec [Anode plane coverage] - protoDUNE-SP-2018*
  - *X-ARAPUCA bar w/ more (48)SiPM/channel + Cold & Warm Elec [Anode plane] ⇒ DUNE* ***FD1- 2022***
  - *X-ARAPUCA large tile w/ many (80)SiPM/channel +* ***PoF-CE-SoF*** *& Warm ADC [HV Cathode plane & Membrane Walls] ⇒ DUNE* ***FD2 - 2023***
- **Next "natural" optimization step:**
  - X-ARAPUCA + **PoF & CE(FE+ADC) & SoF** + design flexibility for massive increase of coverage on FieldCage

⇒ **convert TPC Field Cage structure into a fully active PDS**

- extended optical coverage for High and Uniform (Scintillation) LY

OR

- **Change technology of Light signal read-out**
  - **Integrated light pixels in Anode plane (Solar/Q-pix)**
  - **Combine light pixels in Anode plane with X-ARAPUCA tiles on the Cathode plane**

The electric Field Cage (FC), made of walls of thin Al electrodes surrounding 4 sides of the LAr-TPC volume, offers the largest available surfaces ideal for an extended ($\rightarrow 4\pi$) optical coverage.

$\Rightarrow$ FC electrodes geometry instrumented with photon detectors *(for now call this APEX - Al Profile Embedded Xarapuca)*

This would represent the “ultimate step” in LAr detector technology, where scintillation light and free ionization charge signals from energy deposit in the LAr target are both efficiently and uniformly collected by two dedicated detectors (PDS and TPC) fully integrated one into the other.

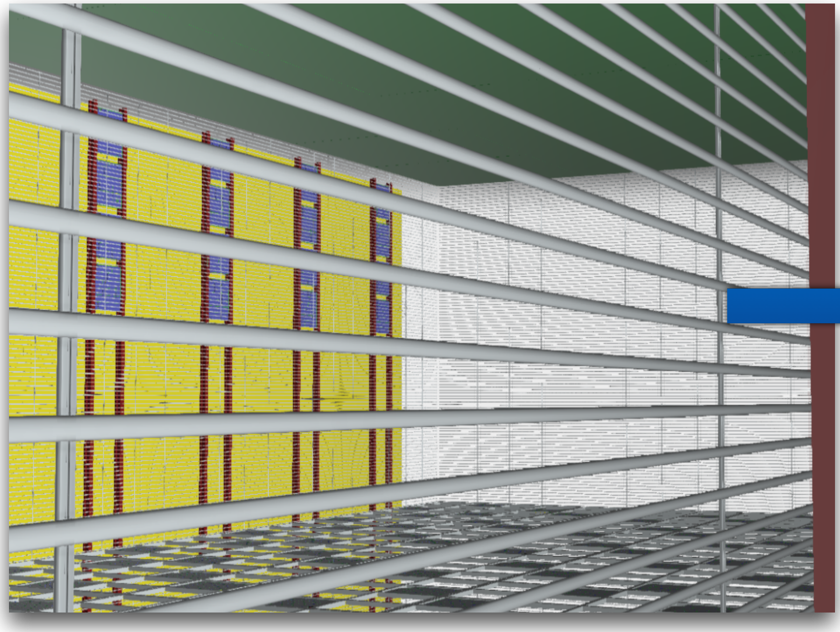
The challenge is from redesigning a light trapping system with PoF-powered SiPM r/o into the FC structure of the TPC, without altering its electrical functionality (possibly, improving it).

The large number of PD channels from an expanded optical coverage will also require the development of new generation large bandwidth SoF transmission and low-cost cold electronics solutions.

The development of this very large-area breakthrough **FC-PD system** for next generation LArTPC detectors is addressed here.

LArPDS from FD2 to FD3-4 (conceptual design)

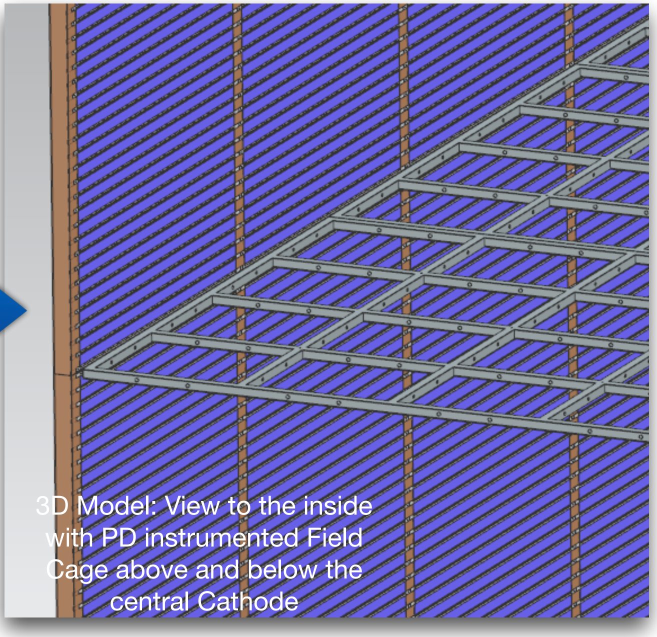
FD2



FC - 70% T

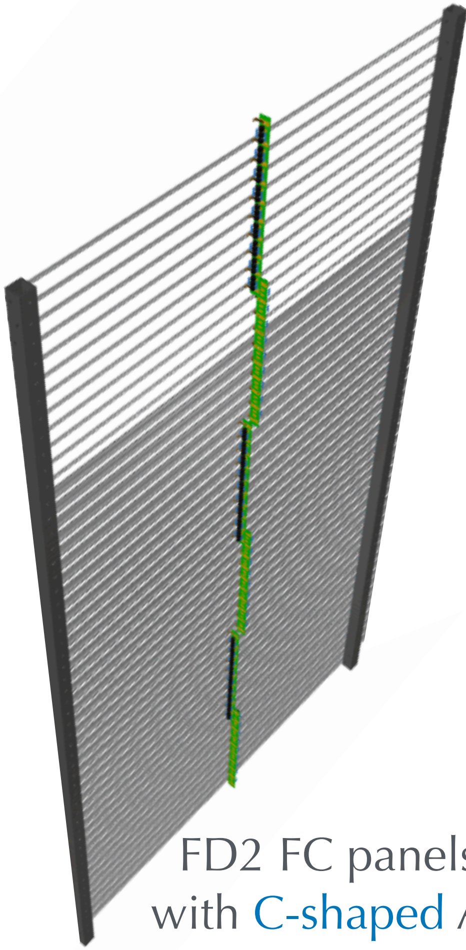
View of the FD2 Lower Volume from behind the FC, as seen by the Membrane PD modules

FD3-4



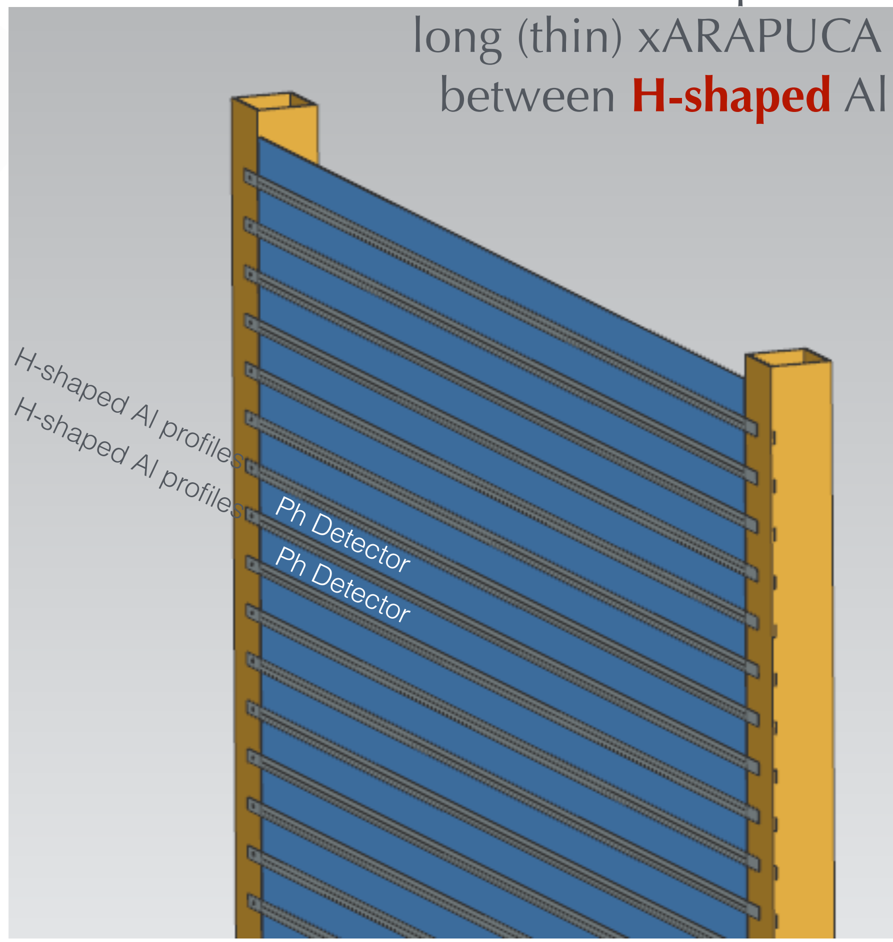
- Naturally expand x10 optical coverage (wrt FD2 PDS)
- Provide optimal mechanical frame structure for xARAPUCA bars in between (reduce fabrication & installation complexity (and costs))
- Retain FC electrical functionality for TPC

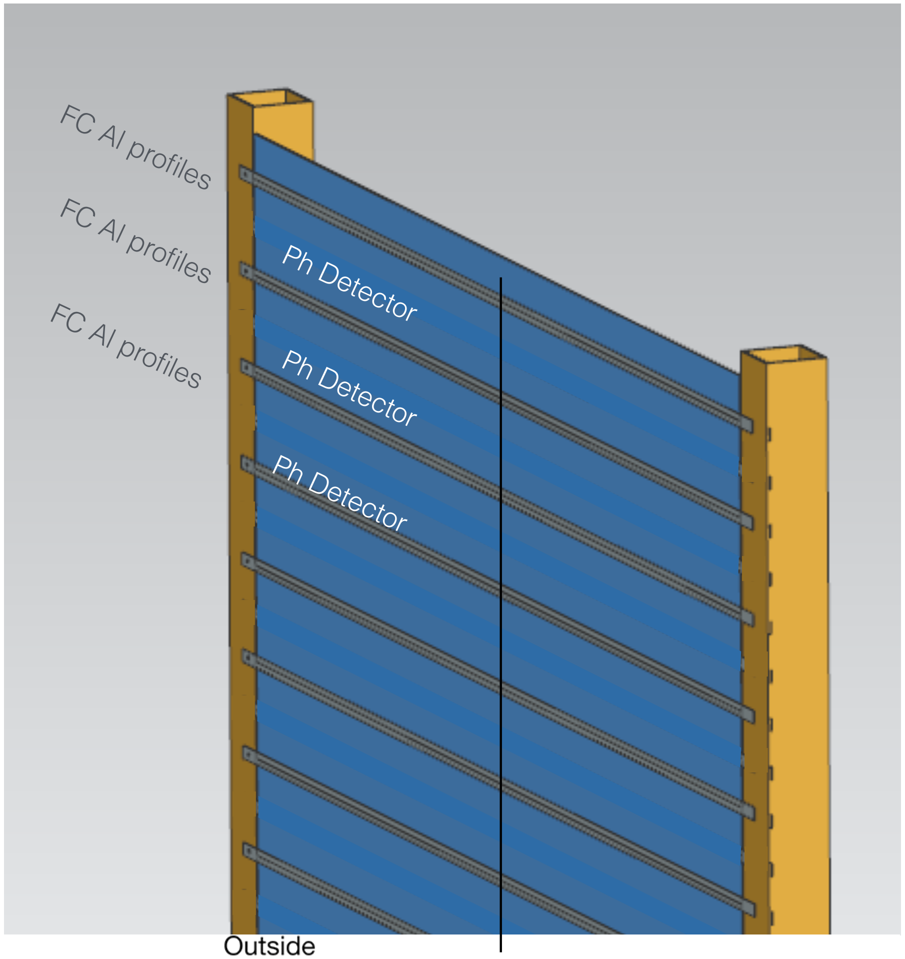
convert TPC Field Cage structure into a fully active PDS

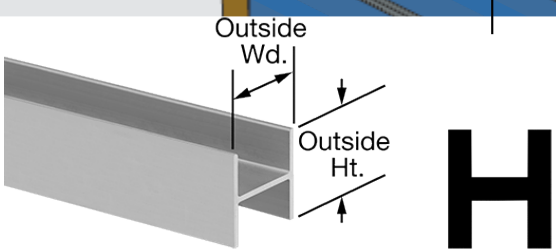


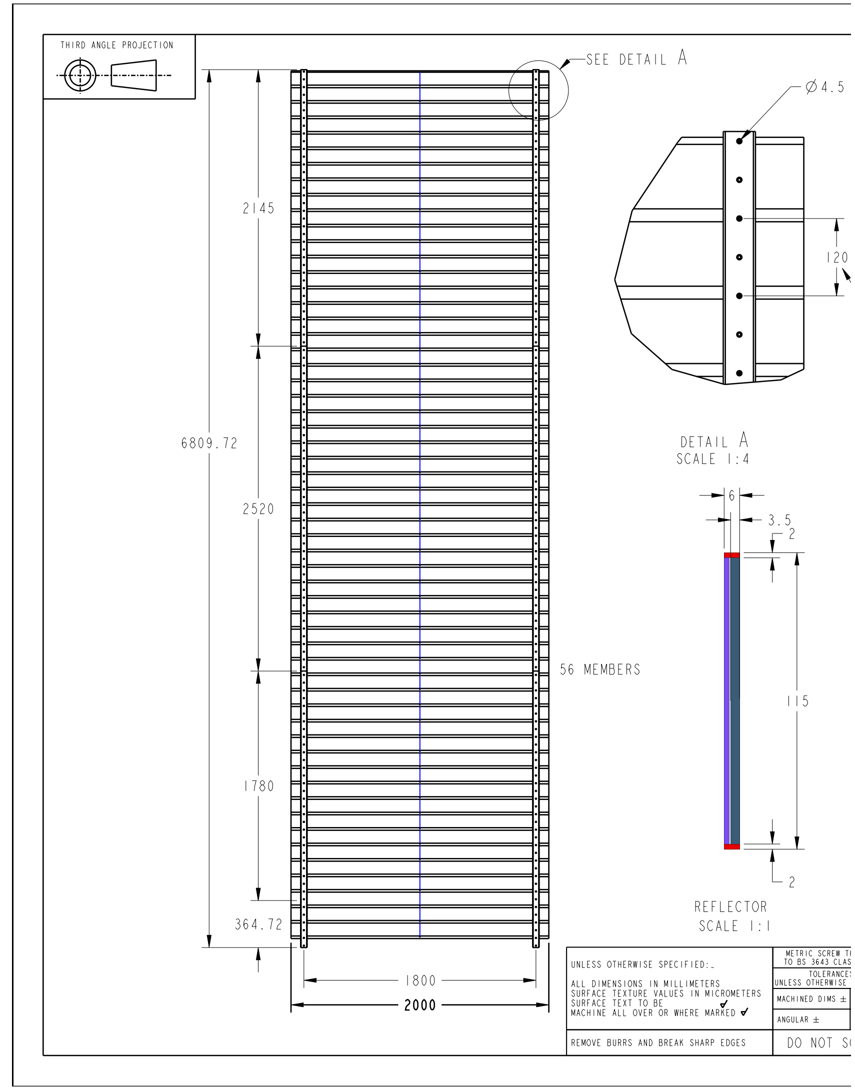
FD2 FC panels formed with C-shaped Al profiles

FD3-4 FC panels with long (thin) xARAPUCA detectors between **H-shaped** Al profiles





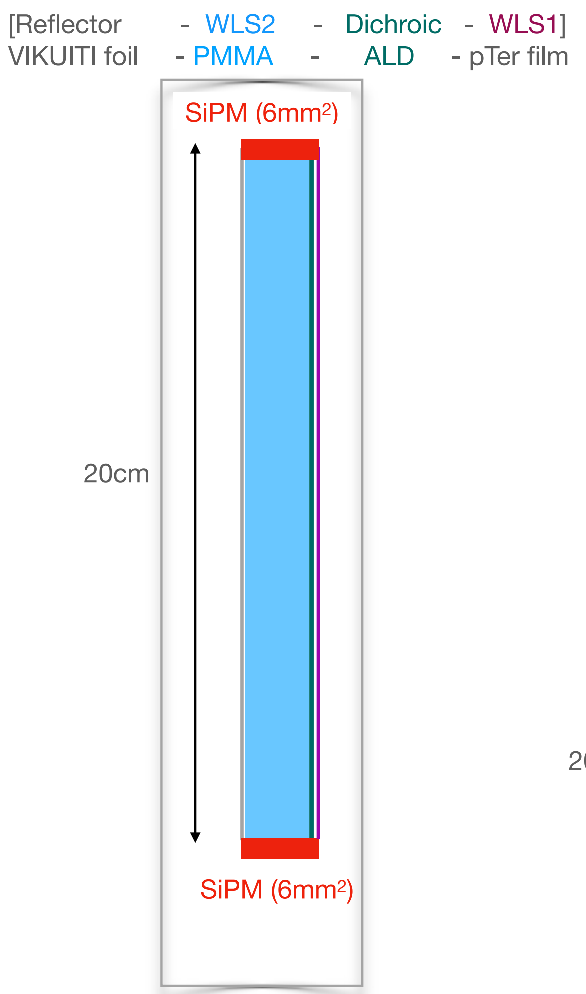


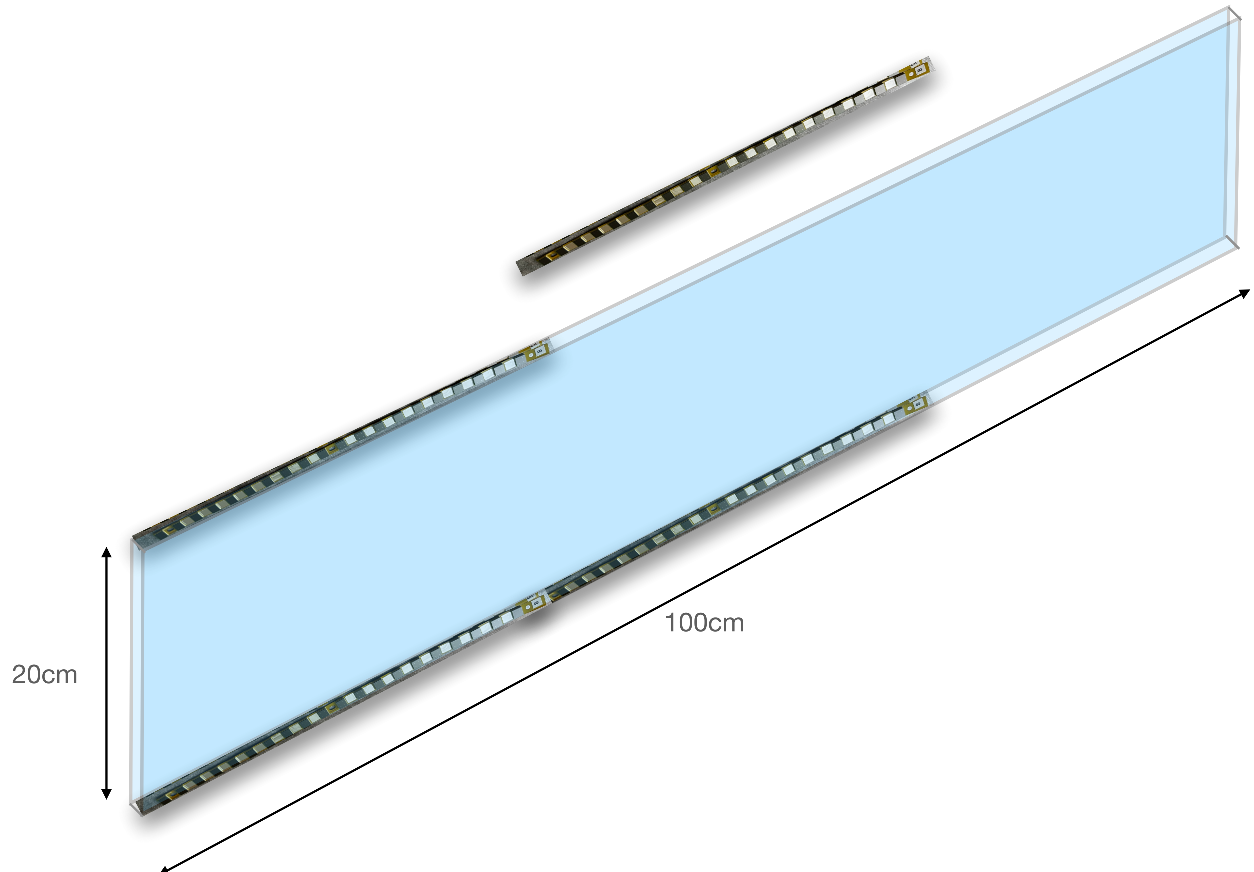


Courtesy - George Stavrakis [Liverpool, UK]

Simplified **ARAPUCA*** concept

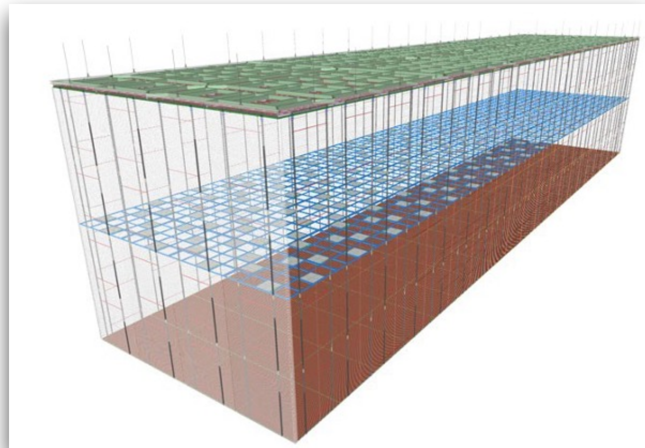
(One-sided)

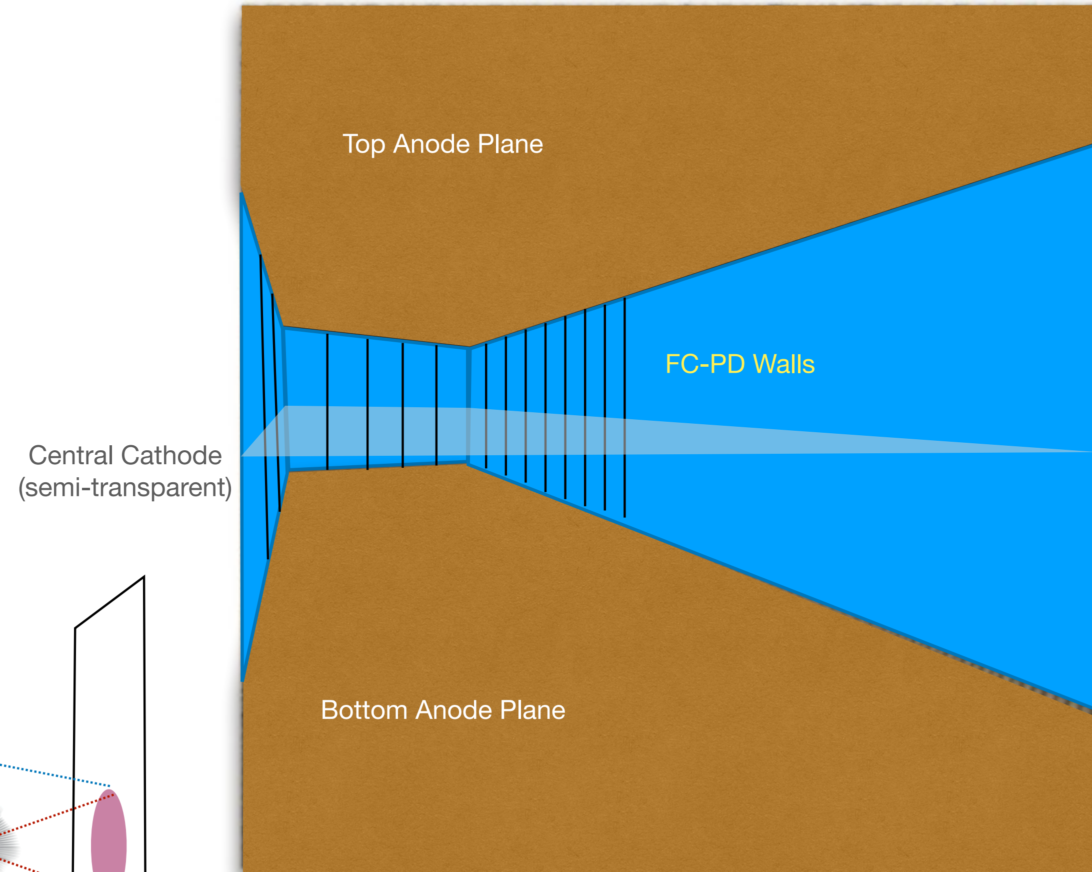




* from XARAPUCA (FD1-2), to original ARAPUCA concept (only if overall convenient)

Detector main components: Al Profiles and PMMA plates (radiopure, low emanation materials)

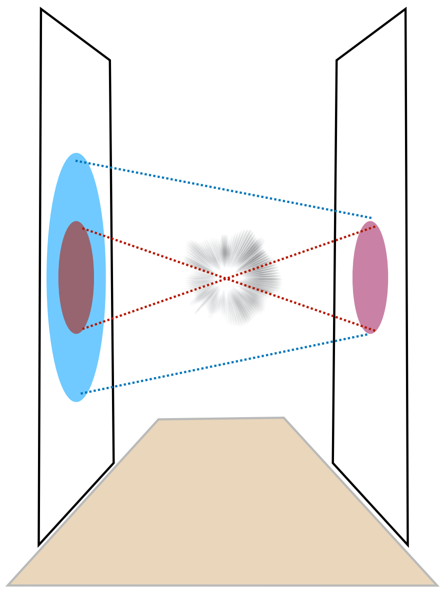


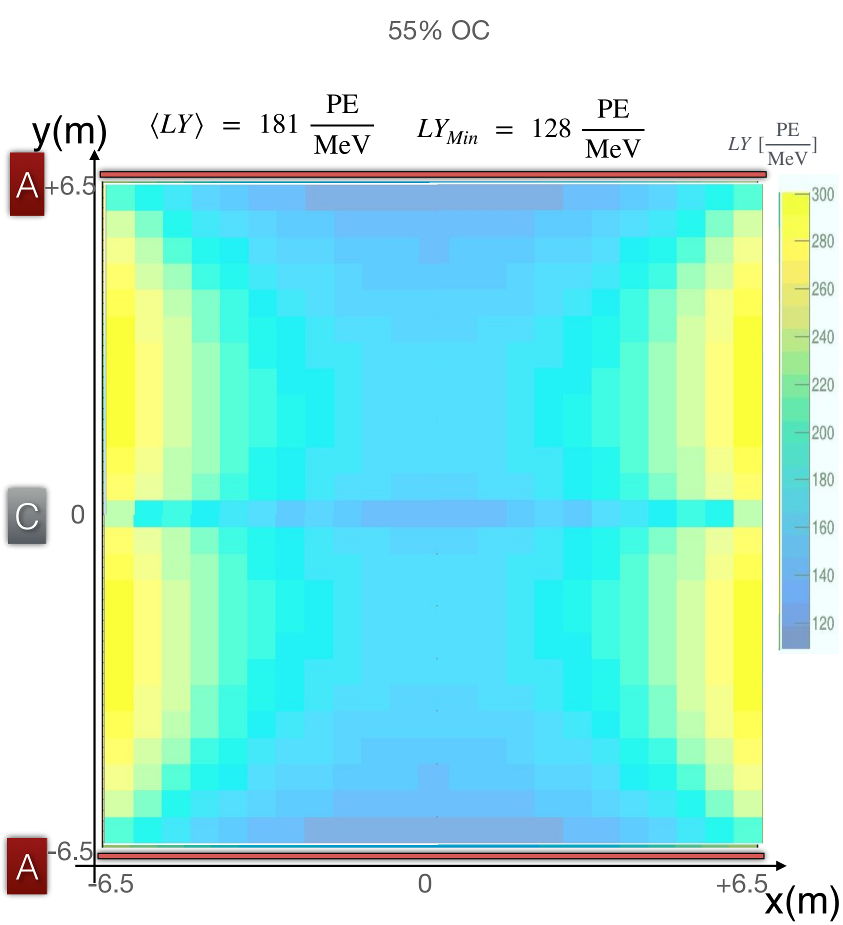


Striking feature of the extended optical coverage:

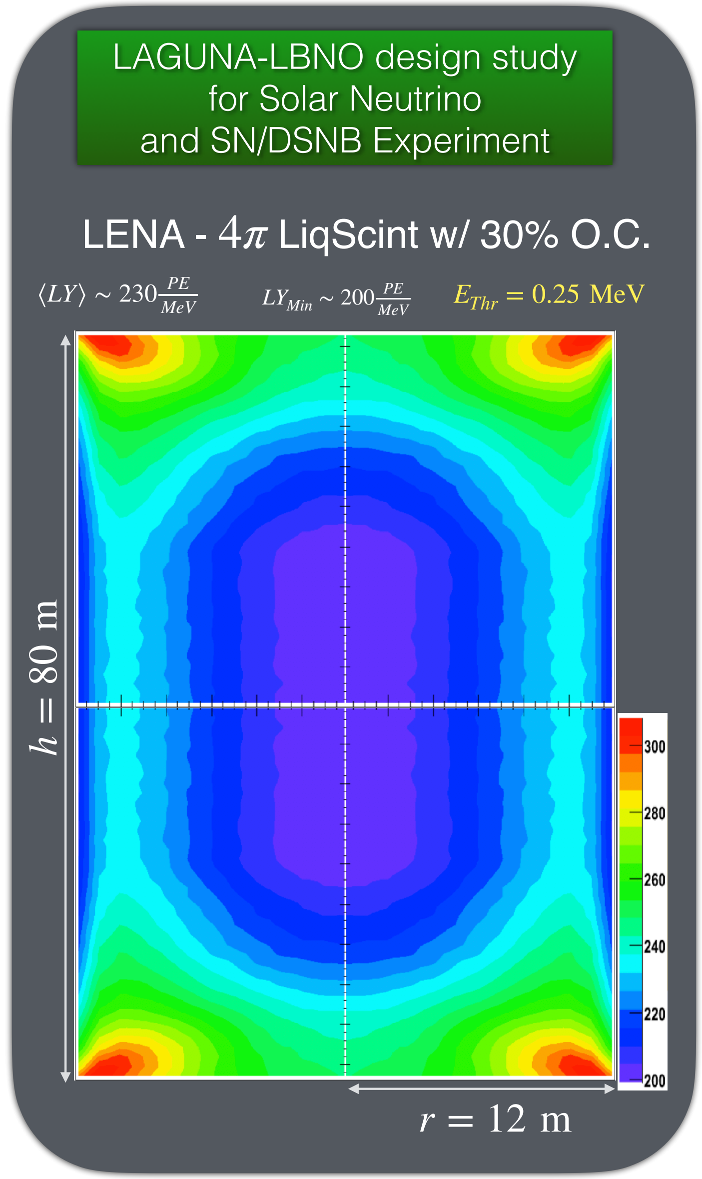
backward emitted WL-shifted light
from a FC wall
collected on opposite FC wall

For an ideal →100% ($\rightarrow 4\pi$) Opt.Coverage
⇒ PCE x 2
(or can reduce n. of SiPM by 1/2)





55% OC
$\langle LY \rangle = 181 \frac{PE}{MeV}$
$LY_{Min} = 128 \frac{PE}{MeV}$
$LY [\frac{PE}{MeV}]$
y(m)
x(m)
A
C
A
+6.5
0
-6.5
-6.5
0
+6.5
300
280
260
240
220
200
180
160
140
120



LAGUNA-LBNO design study
for Solar Neutrino
and SN/DSNB Experiment
LENA - 4π LiqScint w/ 30% O.C.
$\langle LY \rangle \sim 230 \frac{PE}{MeV}$
$LY_{Min} \sim 200 \frac{PE}{MeV}$
$E_{Thr} = 0.25$ MeV
$h = 80$ m
$r = 12$ m
300
280
260
240
220
200