Light Detector Concept(s) for the VD

PoF + SiPM + (X)ARAPUCA on HV surfaces

Flavio Cavanna, Bill Pellico, Francesco Terranova

(and Francesco P, Dante, Ettore, Ana, Franciole, Laura, Serhan, Umut, Bo)

Why a Photon Detector in VD layout for DUNE UG-FD

- Energy deposition in liquid argon yields two signals:
    - ***free charge*** from ionization
    - fast ***scintillation light***.

- Photon detectors (PD) are implemented in LArTPC experiments and light signals are used for *t0* determination and Triggering purposes (detecting a minimal fraction of emitted light)

- With an efficient photon detector ⇒ calorimetric energy reconstruction with good resolution (demonstrated by ARAPUCA in ProtoDUNE-SP and LArIAT)
- With a sufficient coverage, ~4π distributed ⇒ Precise pointing in space (and rough tracking)
  Lower detection threshold

- Potentially, **TWO DETECTORS in one Volume**: LArTPC and PDS complementary for improved detection efficiency, enhanced energy resolution and maximal LiveTime - particularly important for detection & reconstruction of low energy underground events and background rejection

Conceptual design for VD PD basic System:
"SP mirror solution"

- PDS cannot be located at the Anode Plane (as in the SP Module)
- If a solution for operating a PD on HV surfaces is found:

PD active coverage distributed into the Cathode side (mirror solution of SP w/ PD into APA)

+

PD passive coverage (reflector) onto Anode side (laminated on perforated PCB facing LAr)

+

Xe doping (minimize Rayleigh scatter for light at far distance)

*compared w/ 1st SP Module this solution **would allow*** for comparable LY/Energy resolution, better Uniformity of response and some pointing capability at a lower fabrication cost*

** need simulation study*

- Operating PD on HV surface: requirements, base solutions, alternatives
    - ✳ PD based on SiPM (low Bias V, minimal occupancy)
    - ✳ Bias Voltage Supply (IN), Transmit Signal (OUT)
        - ✳ **PoF (Bias V) Receiver & PoF (Signal) Transmitter**
        - ✳ **PoF Receiver (Bias V) & WiFi (Signal) Transmitter**
    - ✳ **SiPM Cold Electronics** (if used, it also requires Power => more from PoF receiver)

R&D Major

- Detector design and coverage: (X)ARAPUCA technology with SiPM photosensors is suitable for this application (flexible design opposite to PMT, **optimization for Xe light**)] **R&D** Major

- Fiber Routing (IN and OUT)] **Design Effort**

*How to **supply bias voltage** to the photo-sensors (in the range of 50 V or less) on the HV surfaces and to **read-out the signal** out of HV surface*

POF Technology for VD application

Two Parts

Warm

- **(1) Power to fiber**
  - Convert electrical power to light
    - Four Laser modules to generate 48 V
    - Each are **4 watt** laser systems
    - Individual adjustable output power
    - Interlocked – to protect laser/personnel
  - Transmit via fiber

Cold

- Fiber optic Receivers
  - Four receivers tied in series ⇒ 48 volt for SiPM and power for LEDs for calibration
  - Typical conversion efficiency 22 %
  - 14 W dissipation (heat)

Cold

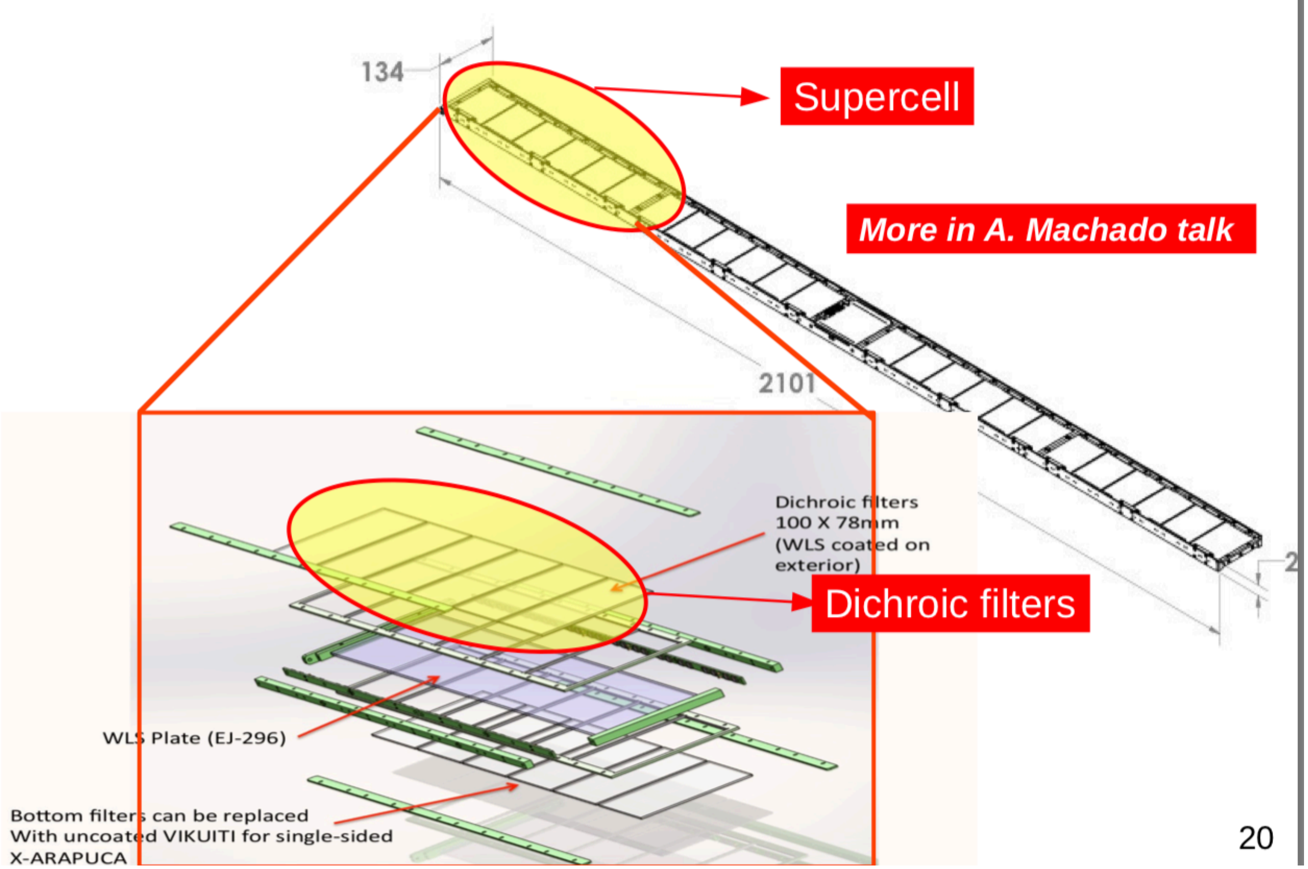
- SiPMs cold electronics module
  - Gang some number of SiPMs
  - Passive or/and Active (w/ preAmp&Shaping)
  - **(2) Signal to fiber**
    - Convert electrical to light
    - Eleds – analog light Transmitters
  - Transmit via fiber

Warm

- SiPMs warm electronics module
  - Fiber to copper
  - Signal conditioning
  - Signal processing

(X)ARAPUCA PD technology for VD application

X-ARAPUCA



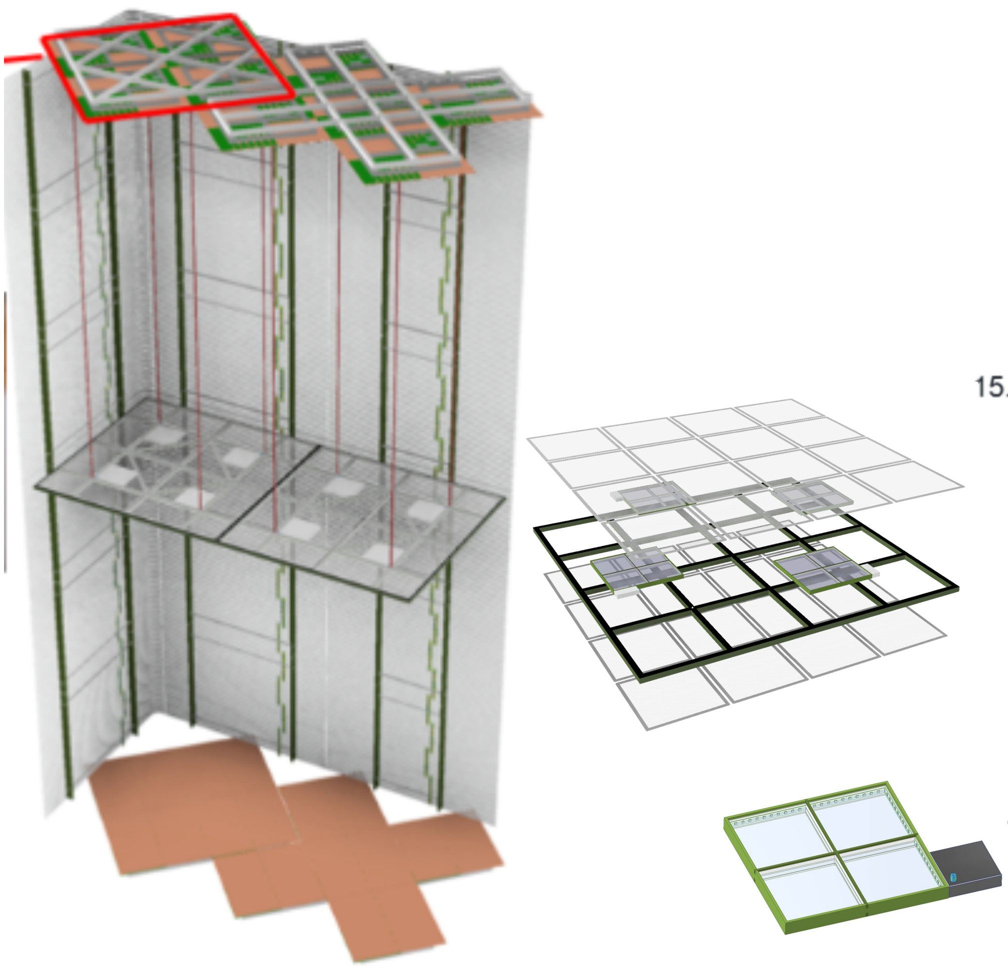
Bar Tot Area: 2101x134=281534 mm2
Bar Active Area: 4x6x(100x78)=187000mm2

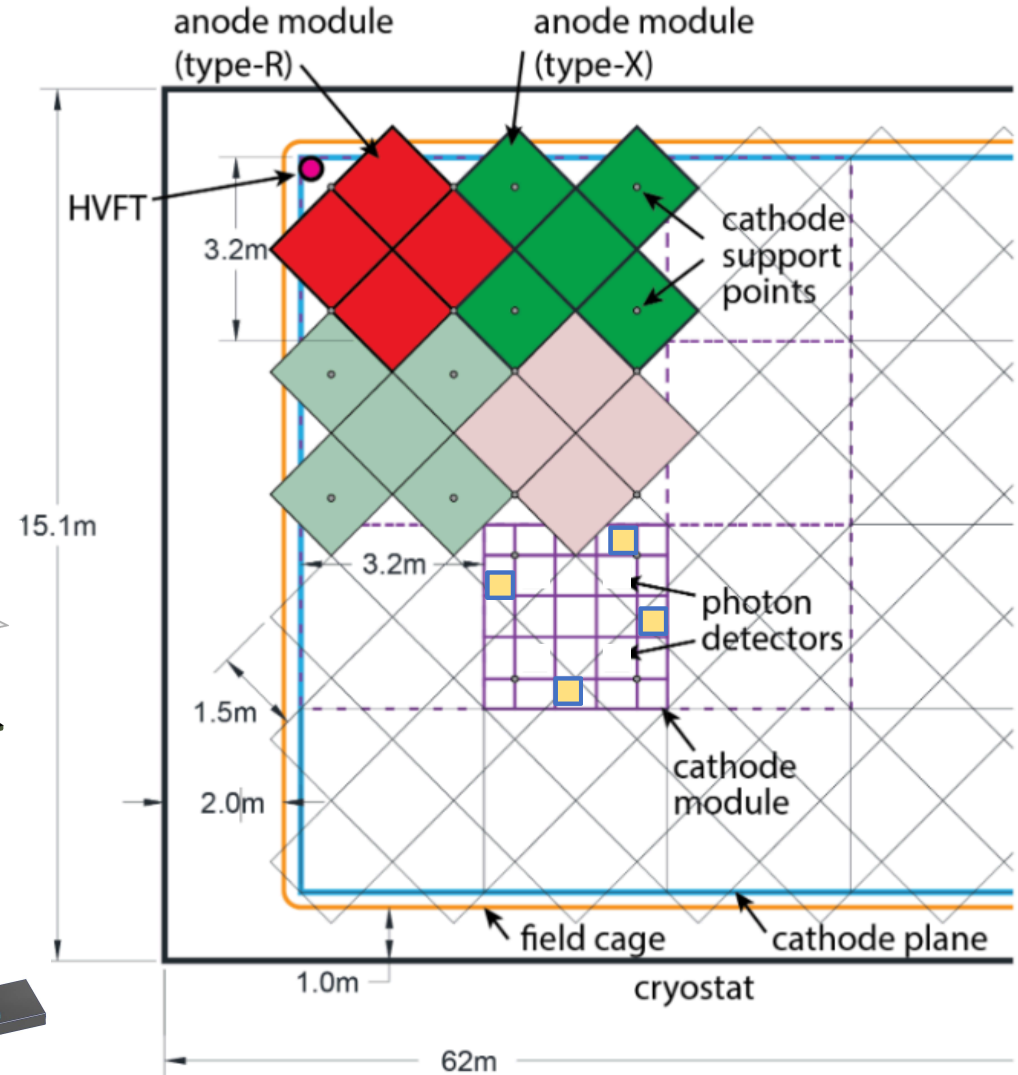
SuperCell: 6x(100x78)=46800 mm2

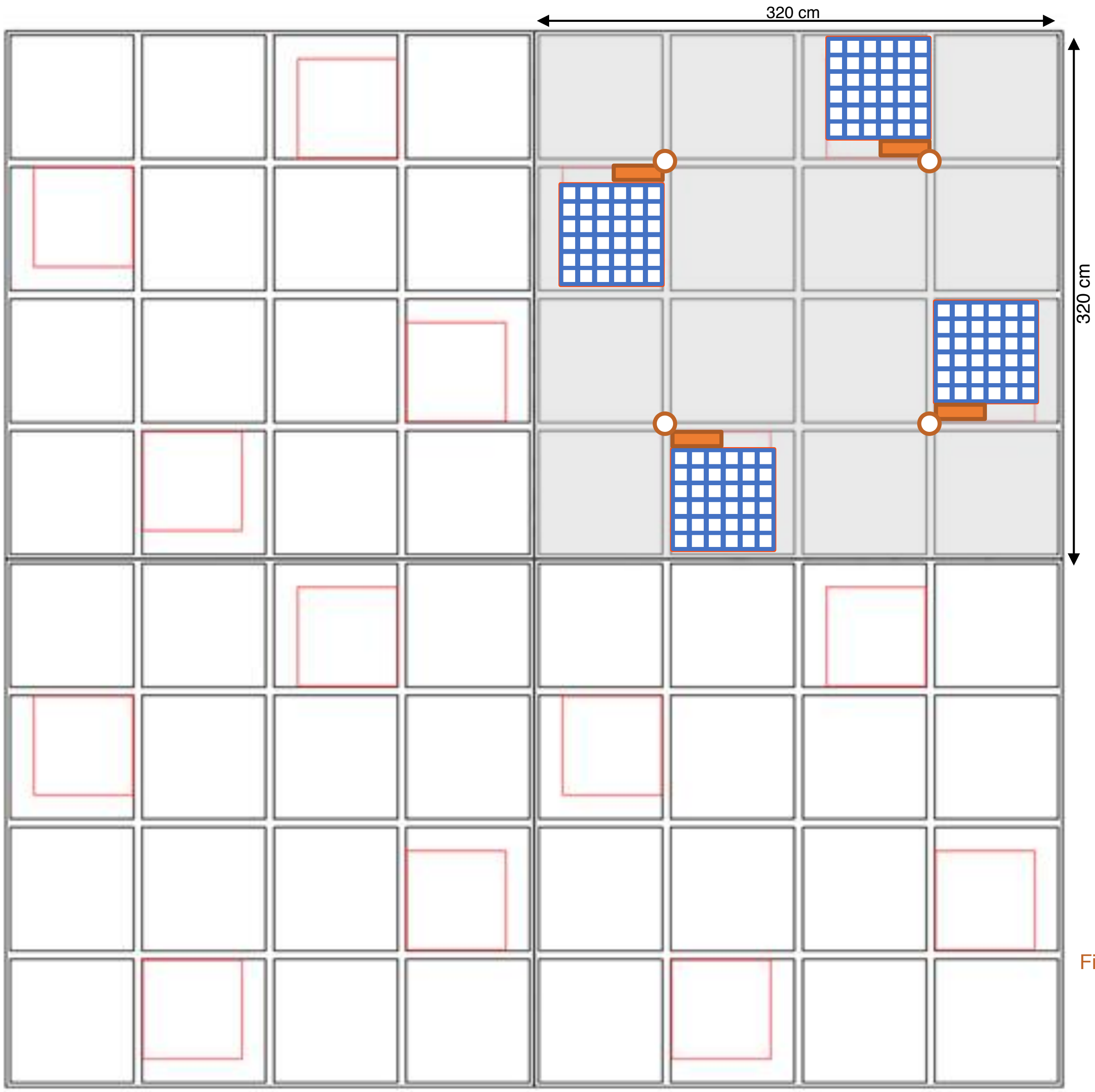
SiPM are passively ganged in groups of 6, 8 groups of 6 are then actively ganged by a cold summing board into one channel of 48 SiPMs

PhDetectors into the Cathode

a) 13-m vertical drift





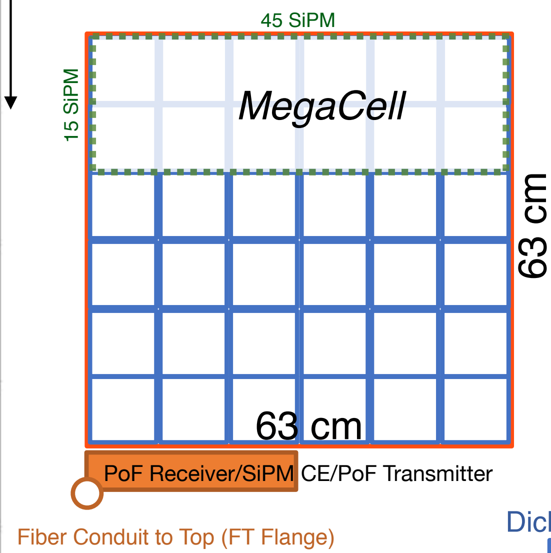


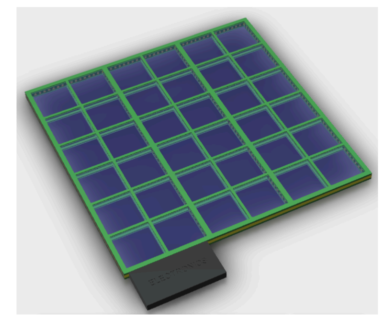
more economical to increase the area of a PD than to increase the number of PD modules

sketch of using 4x 60cm x 60cm tiles
on a cathode module (active Area)
[4 x 63cm x 63cm total Area]

1 Tile (active area)=
1.9 Bar (active area)

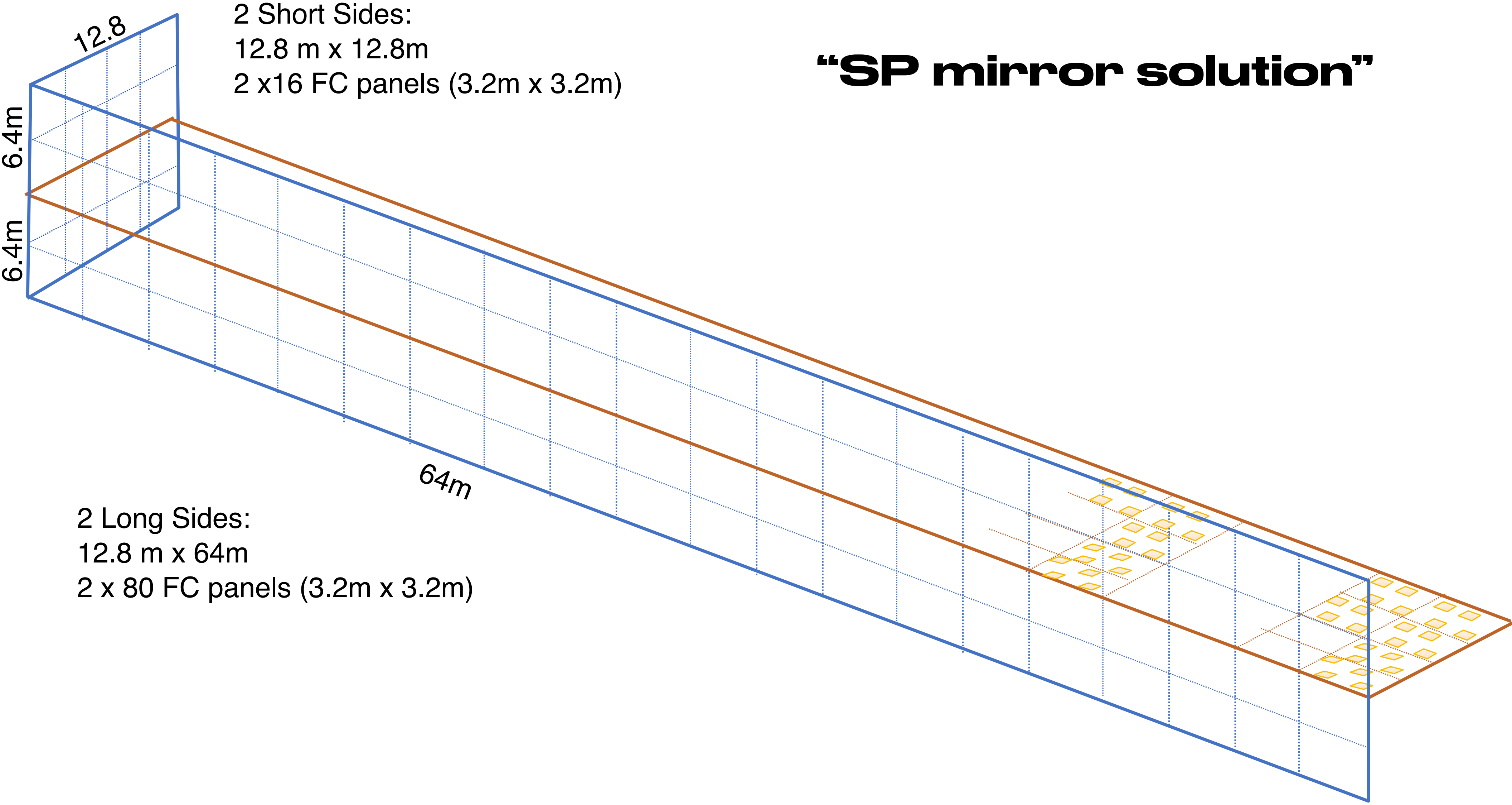
X-ARAPUCA Tile



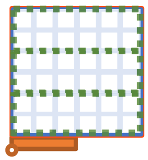


“SP mirror solution”

2 Short Sides:
12.8 m x 12.8m
2 x16 FC panels (3.2m x 3.2m)



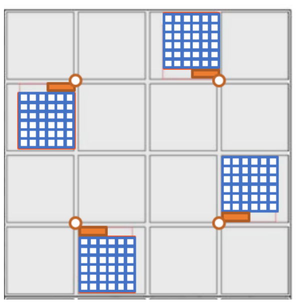
2 Long Sides:
12.8 m x 64m
2 x 80 FC panels (3.2m x 3.2m)



1 PD Tile

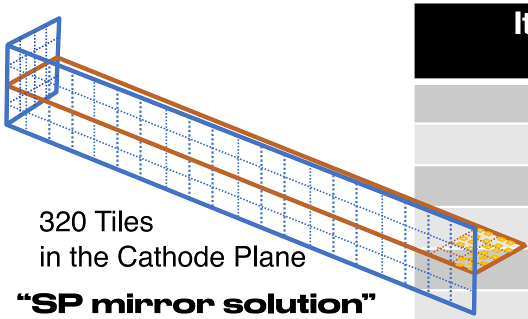
Item (per Tile)	Number	Dimensions (Area)
Tot. Area	1	630 x 630 mm^2 = 0.4 m^2
Active Area	1	600 x 600 mm^2 = 0.36 m^2
WLS plates *("MegaCell")*	3	600 x 200 mm^2 = 0.12 m^2
Dichroic Filters	36+36 (two-sided)	100 x 100 mm^2
PhotoSensors (SiPM)	360 (120 per *MegaCell)*	
ReadOut Channels	6 (2 per *MegaCell*)	
SiPMs per Channel	60	
Weight	~ 4.5 kg	

***Single Phase** (Xarapuca bar)*
2101 x 134 mm^2 = 0.28 m^2
4x6x(100x78) mm^2 = 0.19 m^2
6x(100x78) mm^2 = 0.05 m2
24+24 (100 x 78) mm^2
192
4 (1 per SuperCell)
48



4 Tiles in a Cathode Module

Item (per Cathode Module)	Number
PD Tiles	4
MegaCells	12
Dichroic Filters	144+144
SiPMs	1440
R/O Ch.s	24
PD Active/Cathode ModuleTotal Area Ratio	14%
PD Weight	18 kg



320 Tiles
in the Cathode Plane

"SP mirror solution"

Item (per Cathode Plane)	Number	Dimensions (Area)
Cathode Modules	80	3200 x 3200 mm^2
PD Tiles	**320**	
MegaCells	**960**	
Dichroic Filters	**23,040**	
SiPMs	**115,200**	
R/O Ch.s	**1920**	

Single Phase Module
1500
6000
48,000
288,000
6000

Conceptual design for TWO DETECTORS in one VD Volume

- If a solution for operating a PD on HV surfaces is found:

PD active coverage distributed onto 5 sides of the LAr Volume (Cathode side and 4 Field Cage sides)

+

PD passive coverage (reflector) onto Anode side (laminated on perforated PCB)

+

Xe doping (minimize Rayleigh scatter for light at far distance)

*This would allow **4π coverage**: full uniformity of response, energy resolution, low threshold and pointing capability*

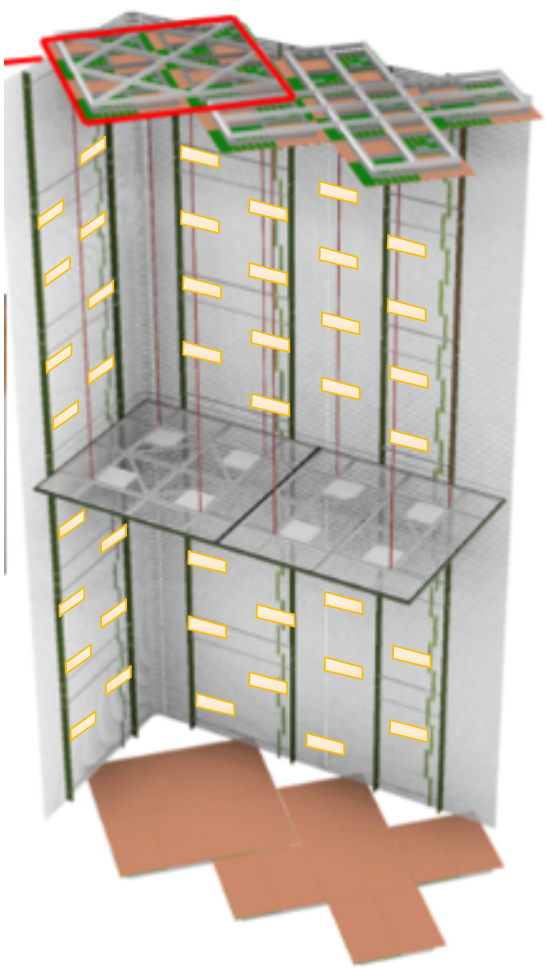
It would be a second detector - for Ar Light Signals - complementary to LArTPC:

- *complete exploitation of LAr (collect all energy deposited)*
- *Guarantee highest Live Time (active also when LArTPC is OFF for purity drop, HV issues,..) very relevant for UG Physics*
- *Start data taking (SN observer) six months/one year before LArTPC (while LAr filling)*

TWO DETECTORS in one

PhDetectors onto the FieldCage

a) 13-m vertical drift



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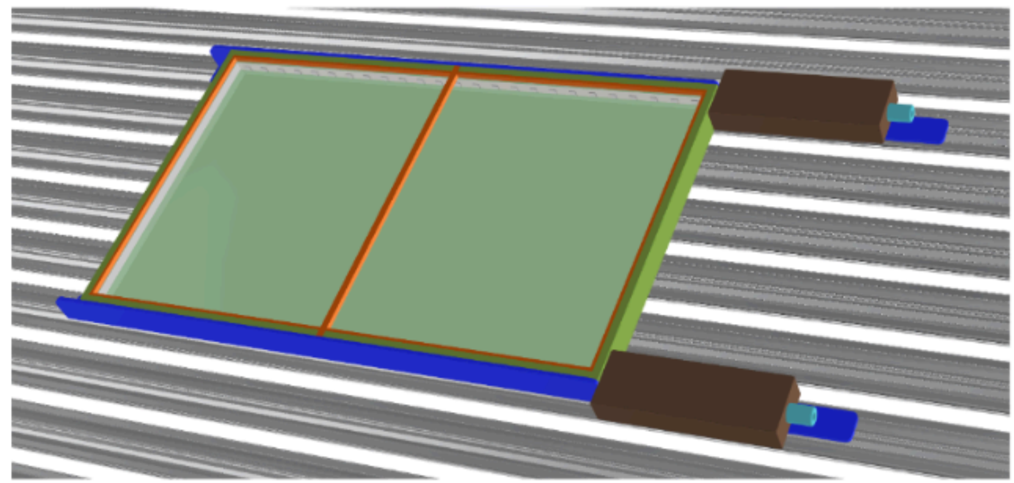
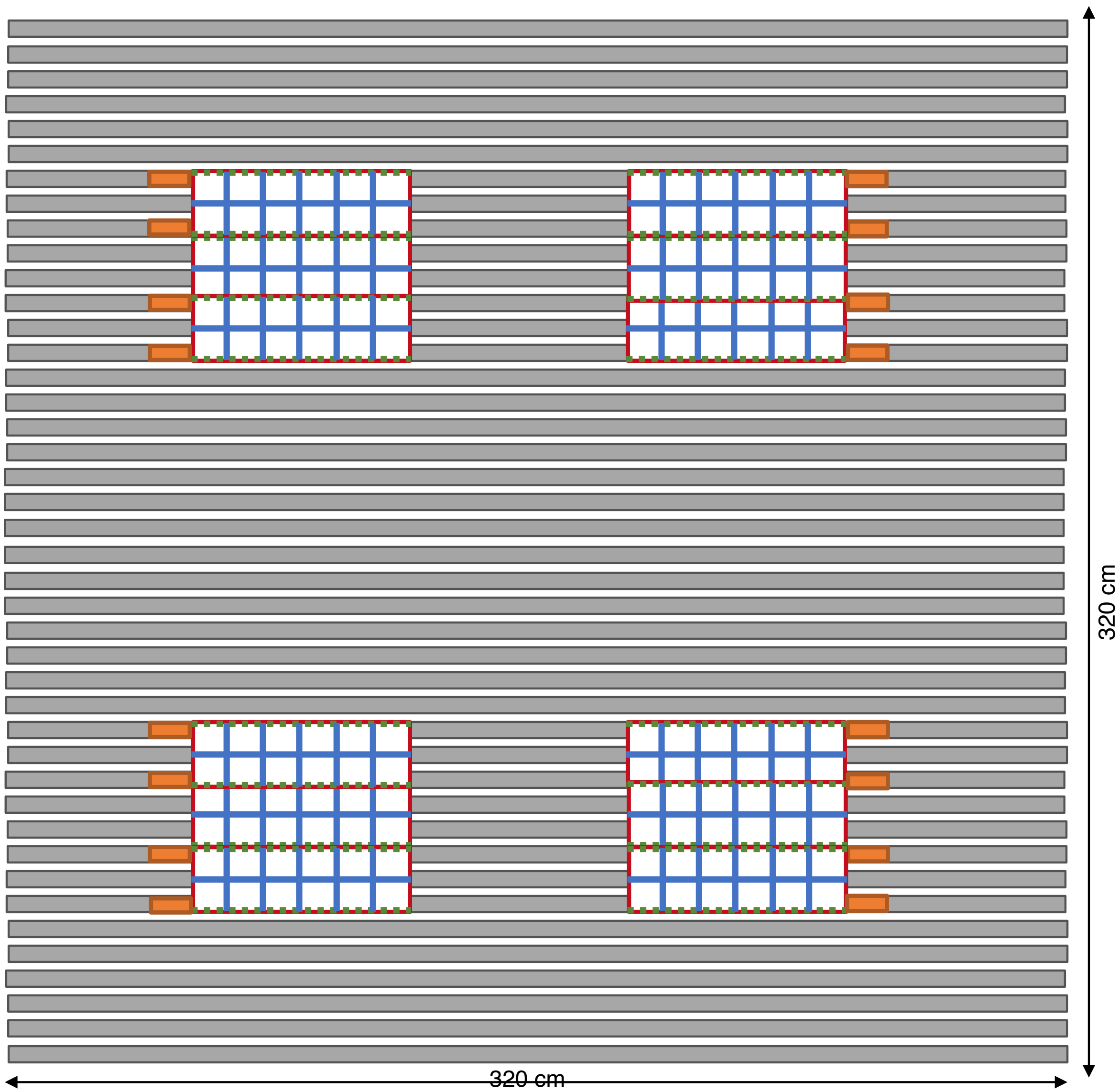
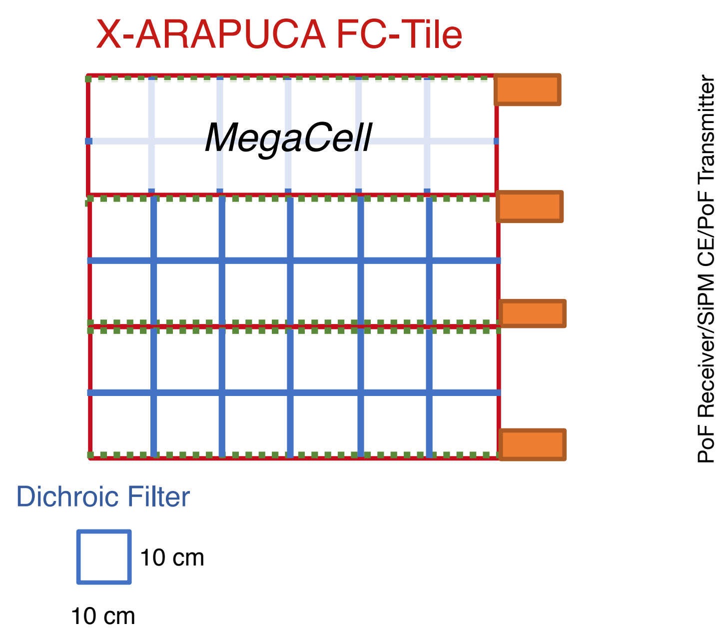


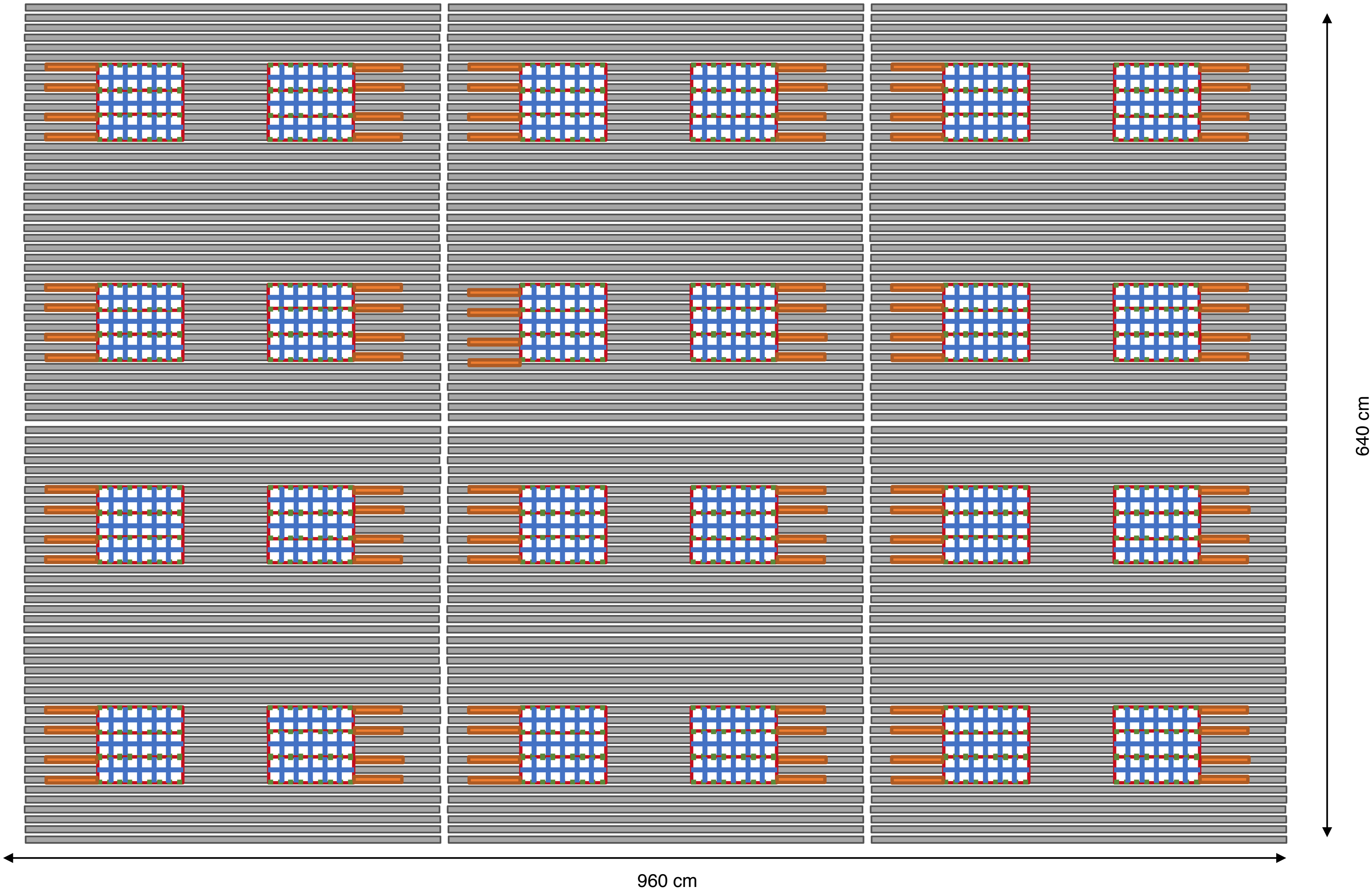
FIG. 10. Conceptual design of a PD module mounted on the inside of the field cage facing the active volume. The SiPMs are mounted on either the top or the bottom edges of the PD module, with no conductors in between. These SiPMs are powered by two sets of independent PoF and readout modules biased at different voltages as defined by the top and bottom most field cage profiles they are attached to.



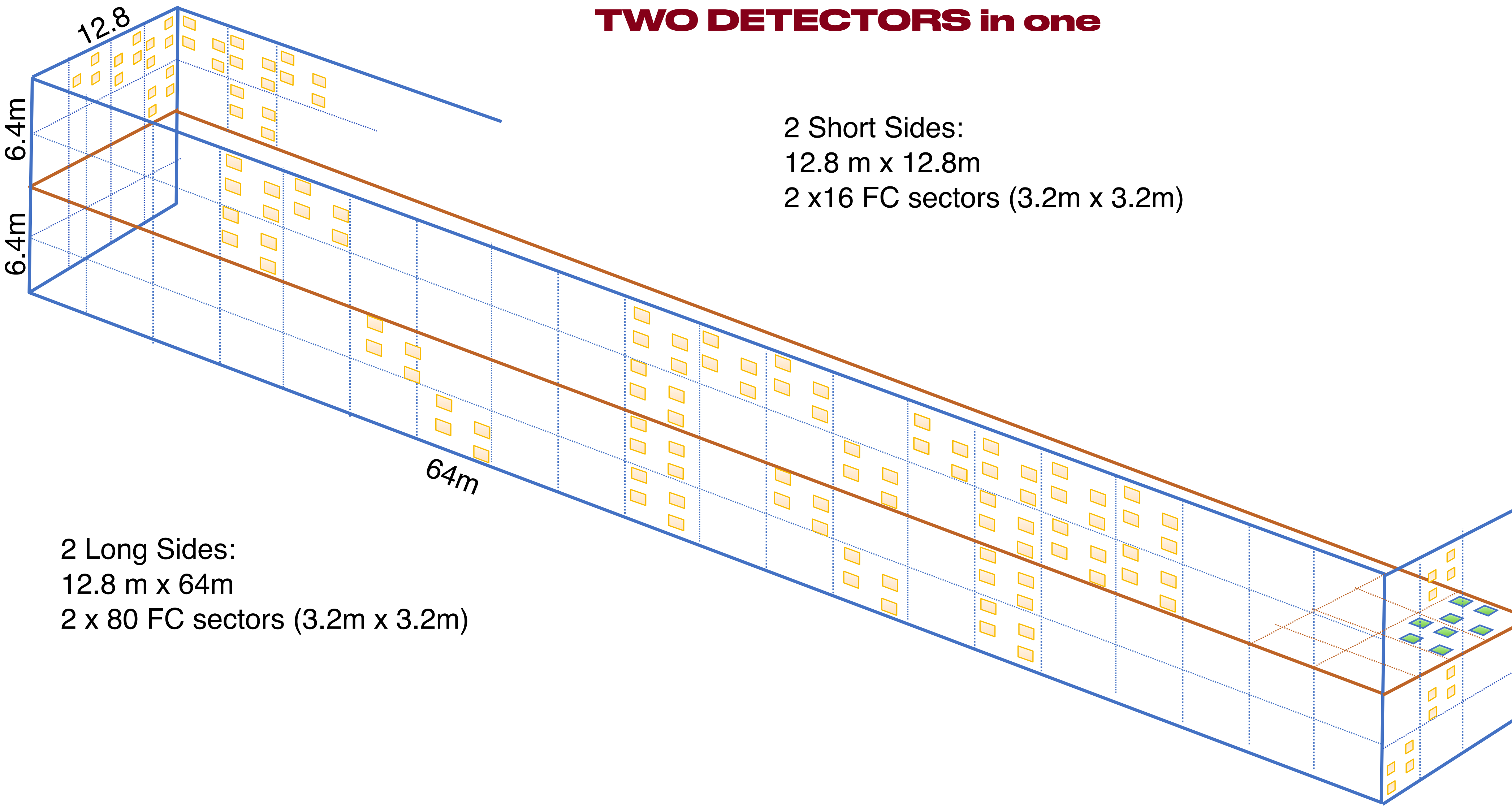
sketch of using 4x 60cm x 60cm tiles
on a cathode module (active Area)
[4 x 63cm x 63cm total Area]

1 FC-Tile =
1 Cathode-Tile



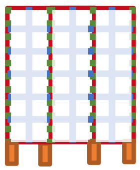

640 cm
960 cm

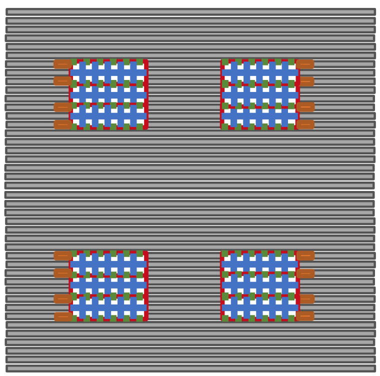
TWO DETECTORS in one



2 Short Sides:
12.8 m x 12.8m
2 x16 FC sectors (3.2m x 3.2m)

2 Long Sides:
12.8 m x 64m
2 x 80 FC sectors (3.2m x 3.2m)





FC Coverage

Item (per FC-Tile)	Number	Dimensions (Area)	*Single Phase*
Tot. Area	1	630 x 630 mm^2 = 0.4 m^2	*2101 x 134 mm^2 = 0.28 m^2*
Active Area	1	600 x 600 mm^2 = 0.36 m^2	*4x6x(100x78) mm^2 = 0.19 m^2*
WLS plates *("MegaCell")*	3	600 x 200 mm^2 = 0.12 m^2	*6x(100x78) mm^2 = 0.05 m2*
Dichroic Filters	36	100 x 100 mm^2	*24+24 (100 x 78) mm^2*
PhotoSensors (SiPM)	270 (90 per *MegaCell)*		*192*
ReadOut Channels	6 (2 per *MegaCell*)		*4 (1 per SuperCell)*
SiPMs per Channel	45		*48*
Weight	~ 4.5 kg		*2.3 kg*

Item (per FC Module)	Number
PD FC-Tiles	4
MegaCells	12
Dichroic Filters	144
SiPMs	1080
R/O Ch.s	24
PD Active/FC ModuleTotal Area Ratio	14%
PD Weight	18 kg

Item (per FC)	Number	FC Module Dimensions (Area)
2 Long Side FC Modules	2 x 80	3200 x 3200 mm^2
PD FC-Tiles	640	
MegaCells	1920	
SiPMs	172,800	
R/O Ch.s	3840	
2 Short Side FC Modules	2 x 16	
PD FC-Tiles	128	
MegaCells	384	
SiPMs	34,560	
R/O Ch.s	768	

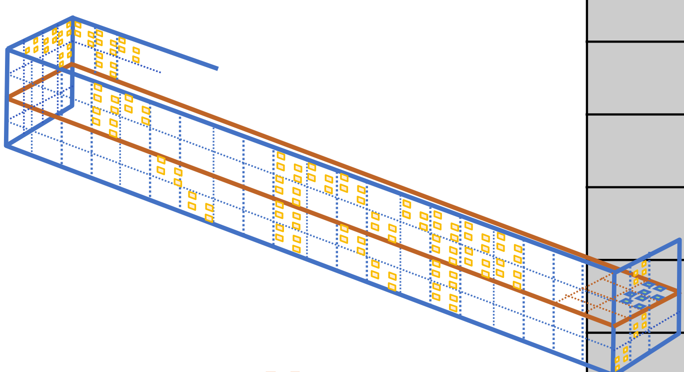
Cathode Coverage

Item (per Cathode Plane)	Number
Cathode Modules	80
PD Tiles	320
MegaCells	960
Dichroic Filters	23,040
SiPMs	115,200
R/O Ch.s	1920
Active Coverage	14%

FieldCage Coverage

Item (per FC - 4sides)	Number
FC Modules	192
PD FC-Tiles	768
MegaCells	2268
Dichroic Filters	27,648
SiPMs	207,360
R/O Ch.s	4608
Active Coverage	14%

VertDrift
"TWO DETECTORS in one"

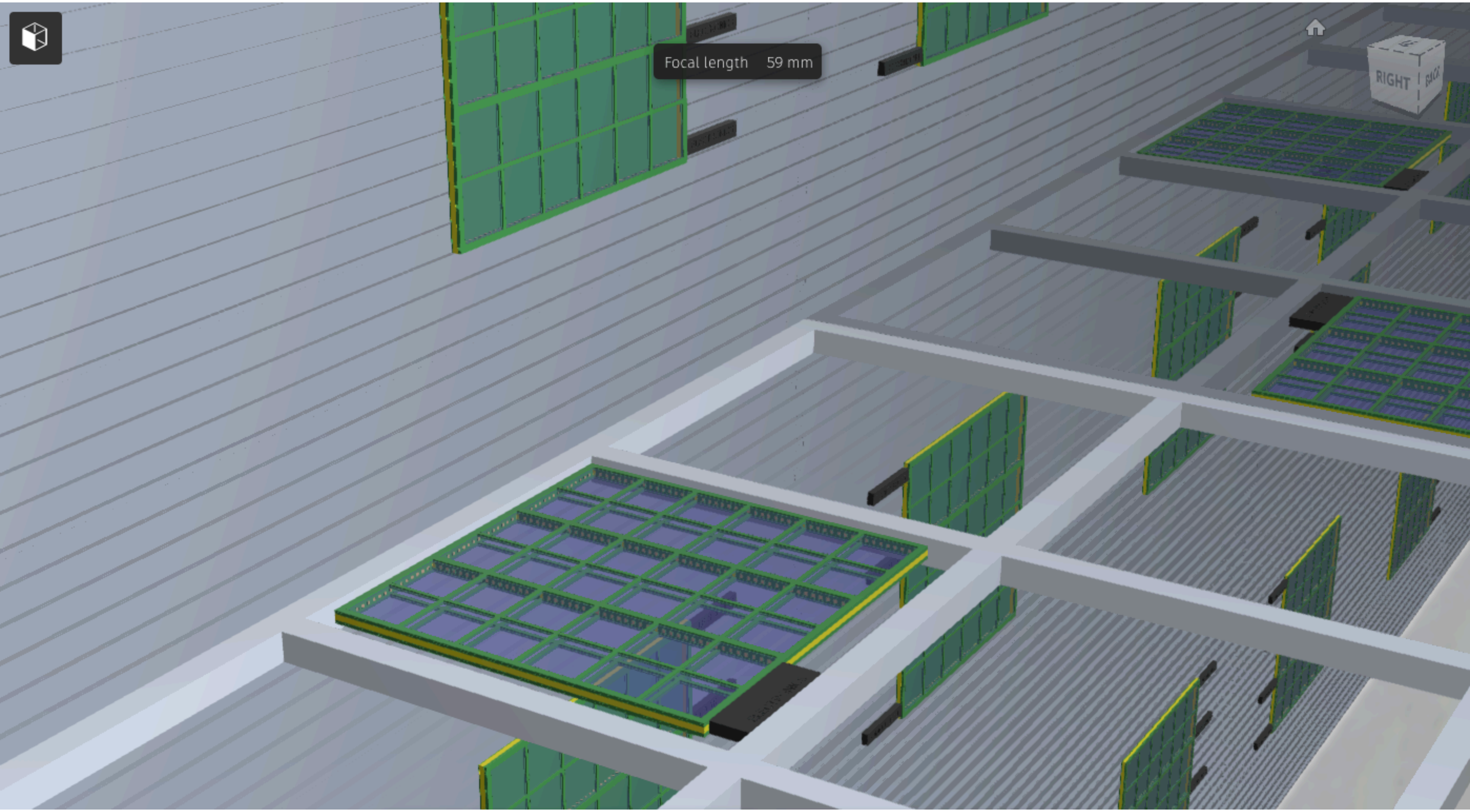


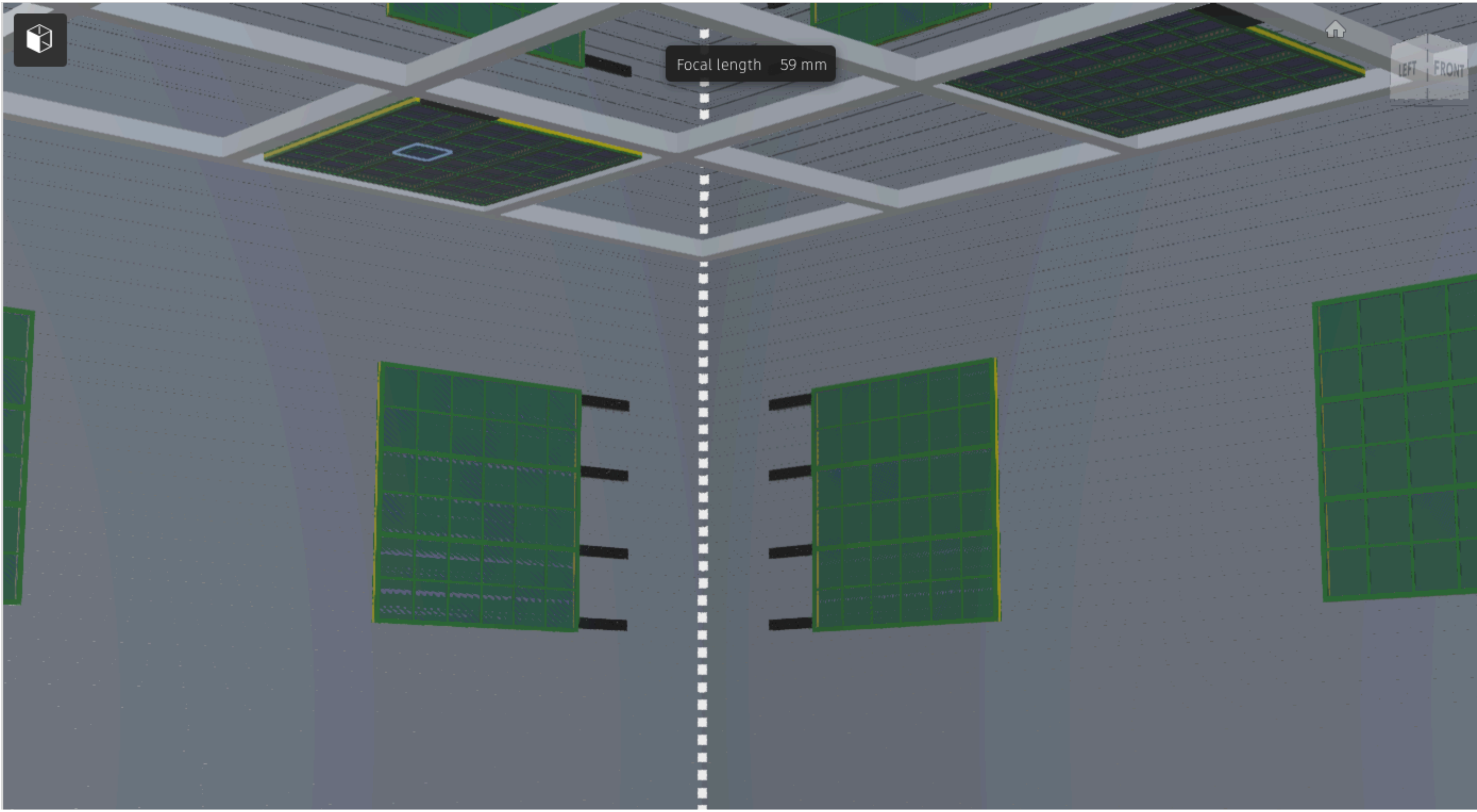
Vs

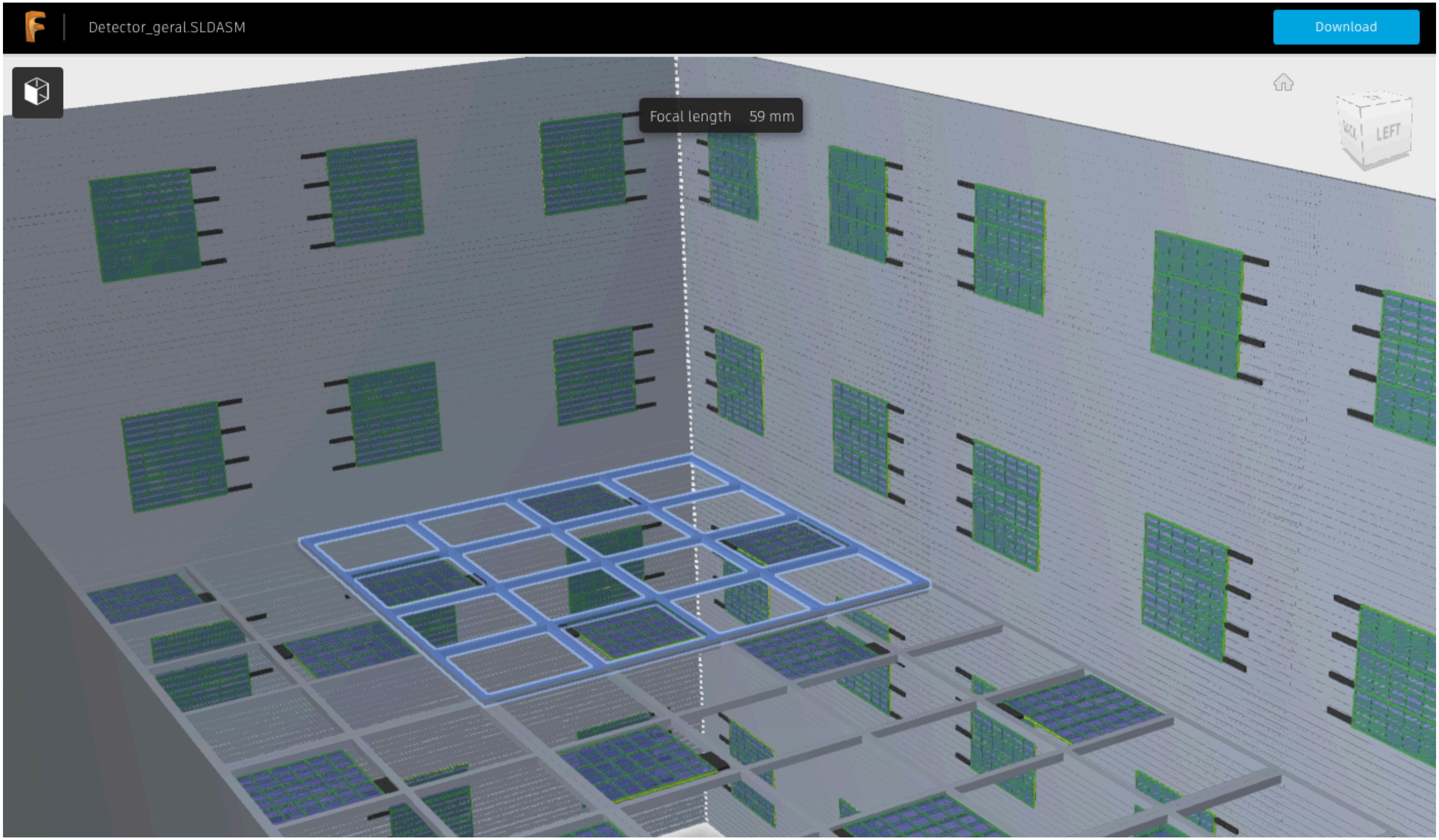
Single Phase

Item (Cathode+FC)	Number	*Single Phase Module*
PD Tiles	1088	*1500*
MegaCells	3228	*6000*
Dichroic Filters	50,688	*48,000*
SiPMs	322,560	*288,000*
R/O Ch.s	6528	*6000*
Active Coverage	14% (Cathode + FC sides)	*12% (anode side only)*

4π avg. coverage = 10.% (including Anode surface w/out active coverage)


Focal length 59 mm
RIGHT


Focal length 59 mm
LEFT
FRONT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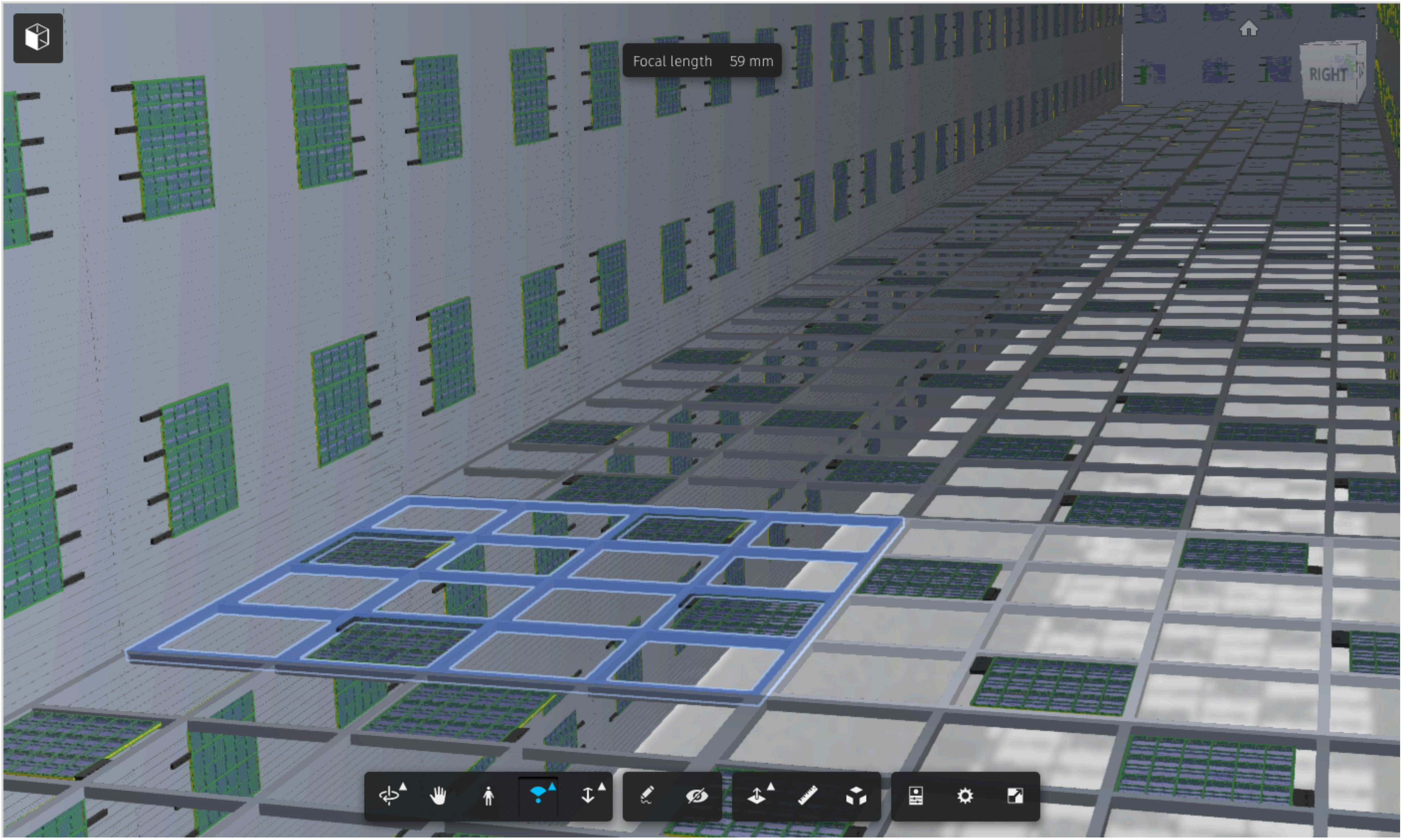
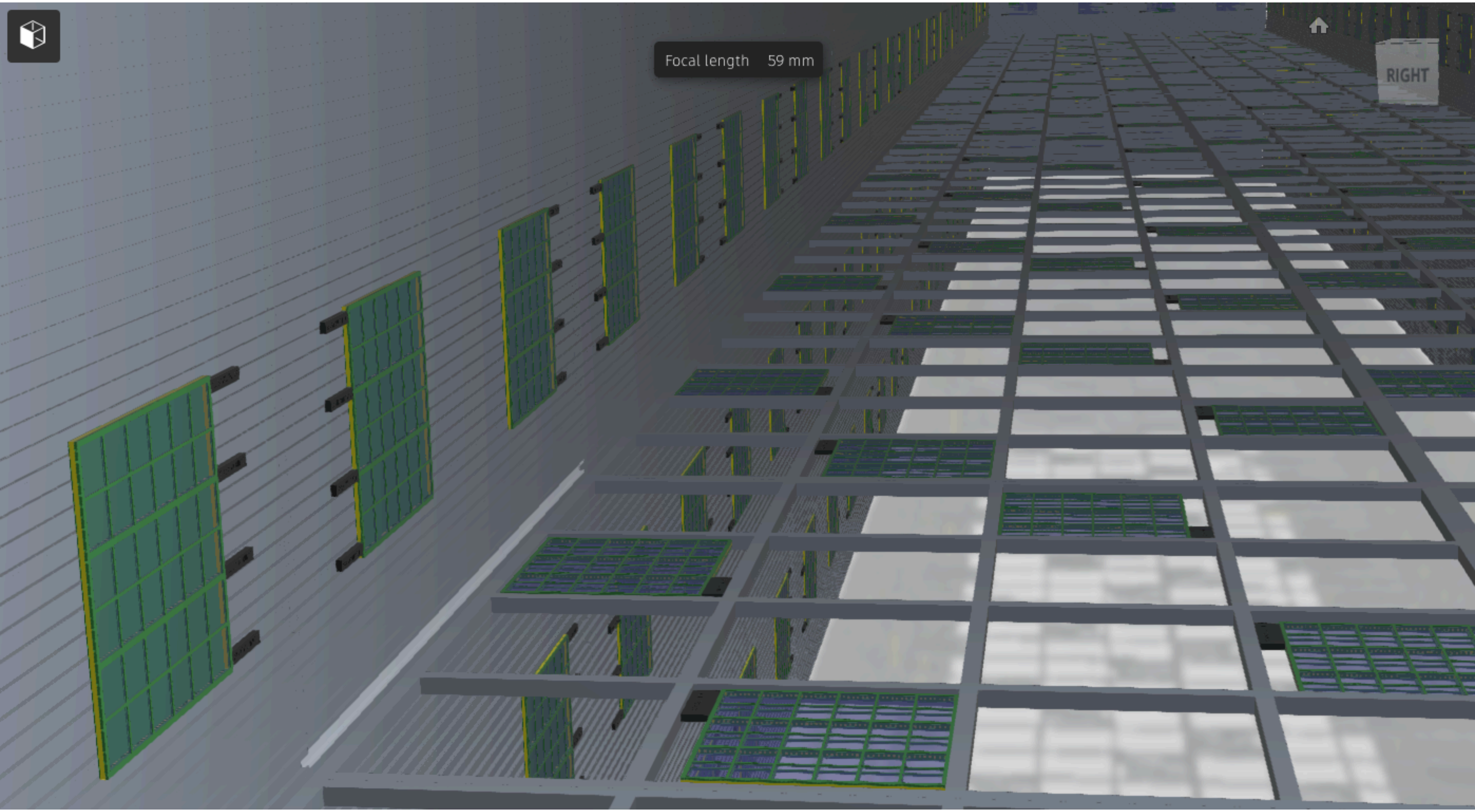
Download
Focal length 59 mm
LEFT



Focal length 59 mm
RIGHT


Focal length 59 mm
RIGHT

SUMMARY:

assuming PoF Technology ok for Bias V/IN and Signal/OUT of surface at HV, PDS is based on (X)ARAPUCA technology design. Two options are presented for VD-PDS:

- *basic solution "SP mirror":*

- ✴ XARAPUCA Cathode coverage (~15%) + Xenon + Reflector on Anode (to compensate for longer drift)
- ✴ Same "poor" SP-design, same goals/requirements, similar performance of SP PhDet solution
- ✴ Much lower cost (from 1/3 to 1/2 of SP)

- *new^{++} solution "TWO DETECTORS in one":*

- ➡ Cathode Coverage + FieldCage Coverage + Xenon + Reflector on Anode
- ➡ Same detector (tile) distributed over 5 HV surfaces (instead of over only one as in "SP Mirror")
- ➡ Standard **4π coverage** design as for Large Volume Scintillator Detectors for UG Physics
- ➡ Standalone detector, complementary to LArTPC
- ➡ Full exploitation of available LAr signals
- ➡ Max Live Time insurance (active also when LArTPC is OFF for purity drop, HV issues,..)
- ➡ Early Start data taking (SN active)
- ➡ Same cost as for SP PDS if in the 10-15% coverage range.
    - Cost & Coverage are tunable

- *Either cases require dedicated R&D phase to develop PoF Technology for Bias V/IN and Signal/OUT*
- *…. either cases look relatively "simple and economic"*
- *but engineering effort for fiber routing IN/OUT may be not negligible (next step in conceptual design)*

Physics with Photon Detectors

- **Determination of T0 in all non-beam physics.**
  - T0 $\rightarrow$ absolute distance from the readout plane
  - Useful for:
    - Fiducial volume selection (e.g. exclude nucleon decay backgrounds)
    - Correcting for attenuation in TPC signals
- **Triggering**
  - An alternative “trigger primitive” for identifying supernova bursts.
  - Combine with the TPC for a sophisticated solar neutrino trigger.
- **Calorimetry**
  - A complimentary energy measurement, even at a few MeV.
- **And possibly more:**
  - Michel tagging, pulse shape discrimination for PID…

SPPD – High Level Requirements

Label	Description	Specification (Goal)	Rationale	Validation
SP-FD-3	Light yield	$>$ 20 PE/MeV (avg), $>$ 0.5 PE/MeV (min)	Gives PDS energy resolution comparable to that of the TPC for 5-7 MeV SN νs, and allows tagging of $>$ 99 % of nucleon decay backgrounds with light at all points in detector.	Supernova and nucleon decay events in the FD with full simulation and reconstruction.
SP-FD-4	Time resolution	$< 1\,\mu s$ ($< 100\,ns$)	Enables 1 mm position resolution for 10 MeV SNB candidate events for instantaneous rate $< 1\,m^{-3}ms^{-1}$.	
SP-FD-15	LAr nitrogen contamination	< 25 ppm	Maintain 0.5 PE/MeV PDS sensitivity required for triggering proton decay near cathode.	In situ measurment