FD2-VD Photon Detection System Mechanical Design

David Warner

FD2-VD Photon Detector Preliminary Design Review

3-4 May 2022

Preliminary Design Definition

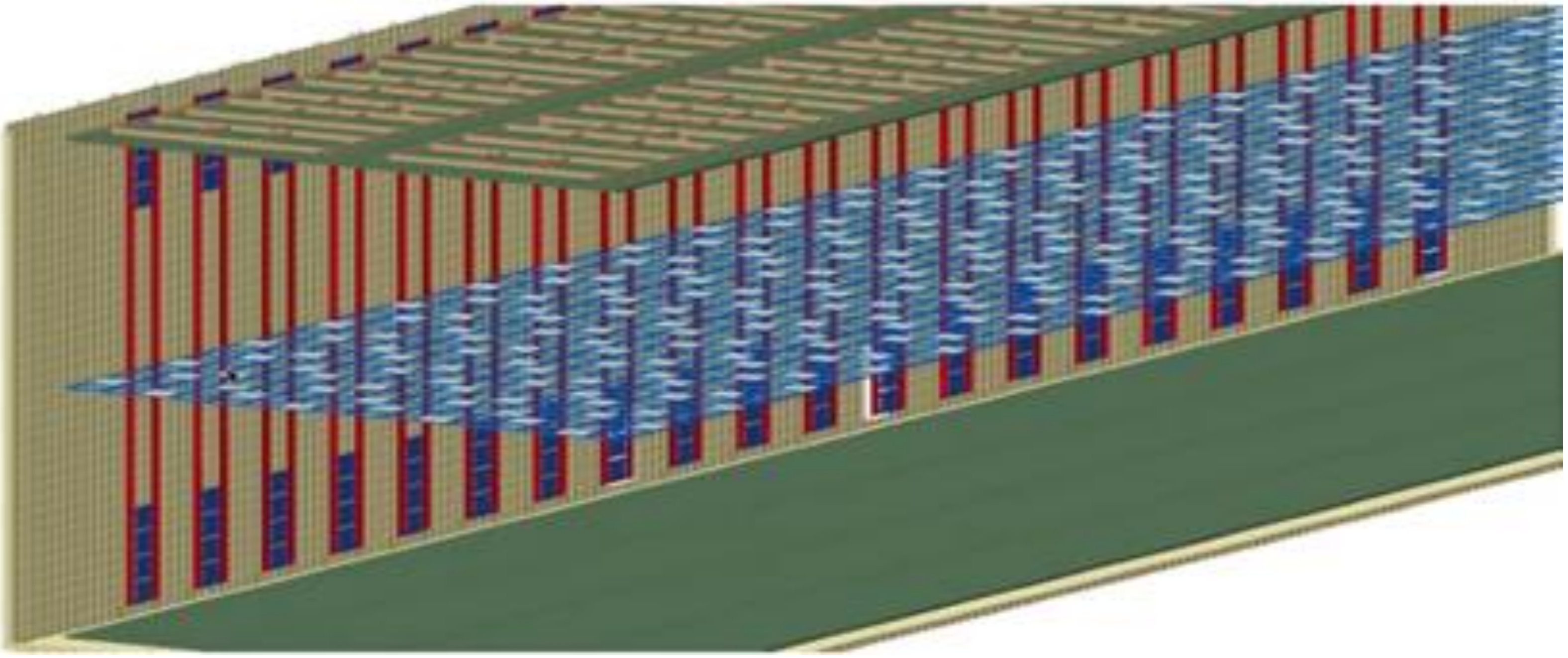
Charge question 5:

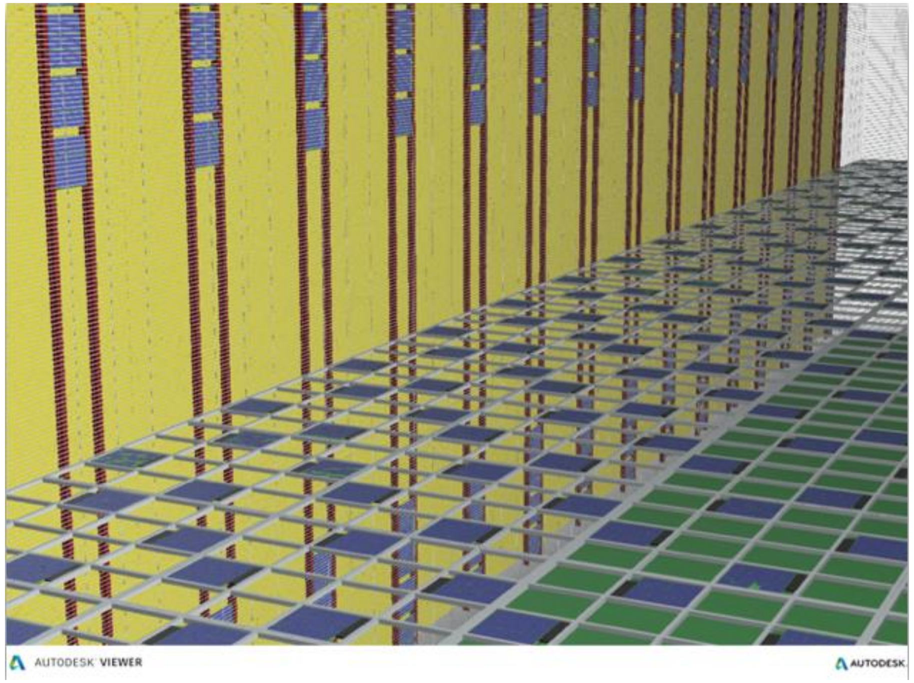
“The preliminary design maturity level for the sub-system to be recommended to proceed to final design is typically 40%-60%. Is the system at this level or is it less (e.g. 30%)?”

1) We present the Cold Box 1 design which meets basic PD system requirements. Drawings and specifications are available for this design.
2) Alternative designs are still in play, both in detector mechanics and other facets of the design. We will show that the CB1 est module is a credible baseline design, and a plan to evaluate the alternates. Drawings and specifications exist where appropriate.
3) We discuss design alternates to be studied in the cold box testing arc prior to presenting a final design in late 2022-early 2023
4) We point out that the project schedule requires very rapid progress which significantly constrains out review schedule
5) We will continue to exploit the similarities between FD1 and FD2 photodetectors both for nearly duplicated components (for example SiPMs and WLS plates) and for testing plans (for example cold electronics validation

Photon Detector System Layout

- Photon detectors mounted in two locations:
  - Inside the cathode plane assemblies “Cathode mount modules”.
  - Behind the cathode planes near the anode planes to increase efficiency far from the cathode “Membrane mount modules”.

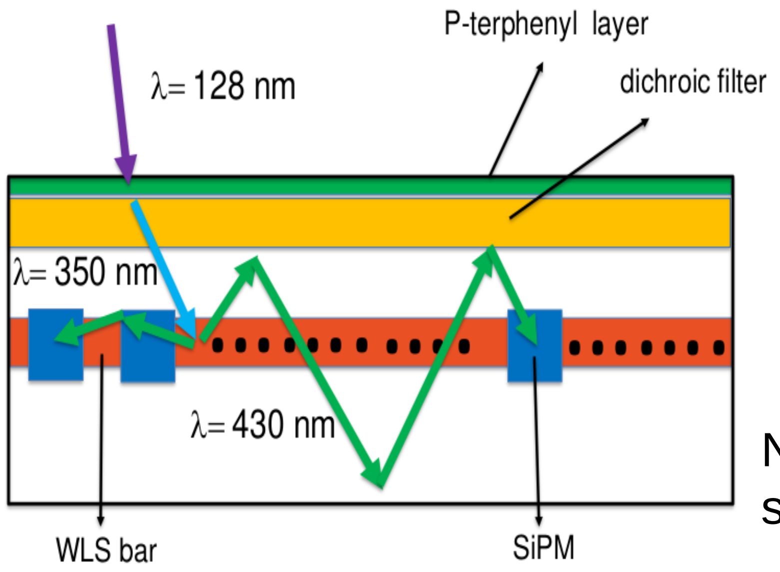




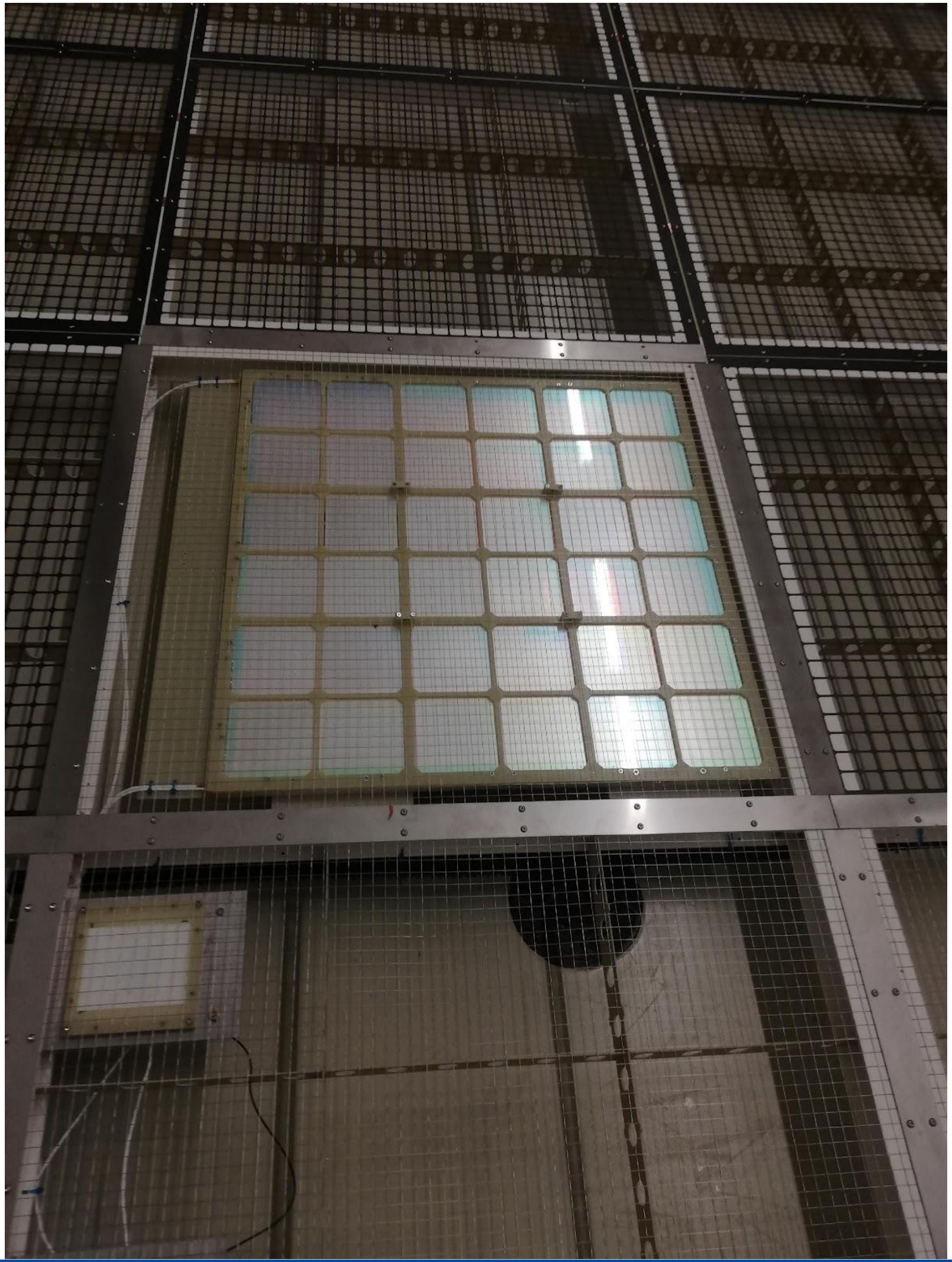
- Configuration details:
  - 320 cathode mounted double sided X-ARAPUCAs (detect light from both sides). These utilize power and readout over fiber.
  - 320 membrane mounted single sided X-ARAPUCAS (detect light just from one side). May use conventional readout. 70% transparent field cage to increase photon collection through field cage.

FD2-VD X-ARAPUCA Concept

- 60 cm X 60 cm active area X-ARAPUCA
- Light detected with 160 SiPMs (ganged in groups of 80 to two channels.
  - *Groups of 20 SiPM passively ganged (hybrid series-parallel scheme).*
  - *4 groups of 20 SiPMs actively ganged to a single readout channel.*
  - *SiPMs mounted to kapton flexible board to better match WLS plate thermal contraction.*
- Dichroic filter coated with pTP.
- High efficiency light guide developed by G2P and INFN (Milano Bicocca).



Note: Not to scale)



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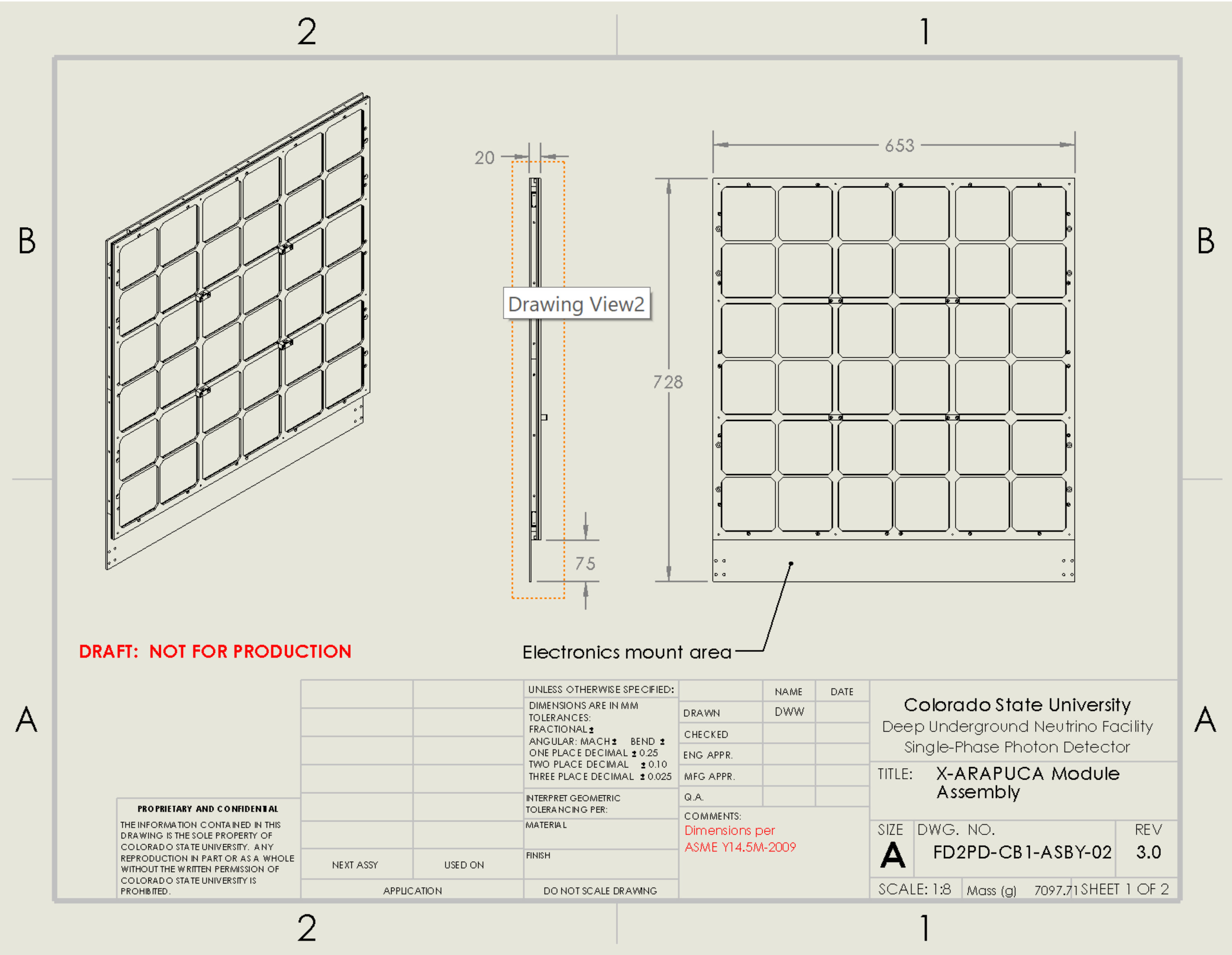
Module Assembly Drawing (CB1)

Mechanical drawings and .STEP models of initial prototype (Cold Box 1) available in review documentation. Initial .STEP model of CB3-4 module (but no drawings) also available

- FR-4 frame housing 653 X 728 X 20mm^3 frame.
- Approximately 7.1 kg mass (dry) neglecting electronics (< 15kg required by cathode).
- Approximately 600 X 600mm^2 active area (36 dichroic filter plates ~100 X 100mm^2).
- Electronics mounting platform integral to design.

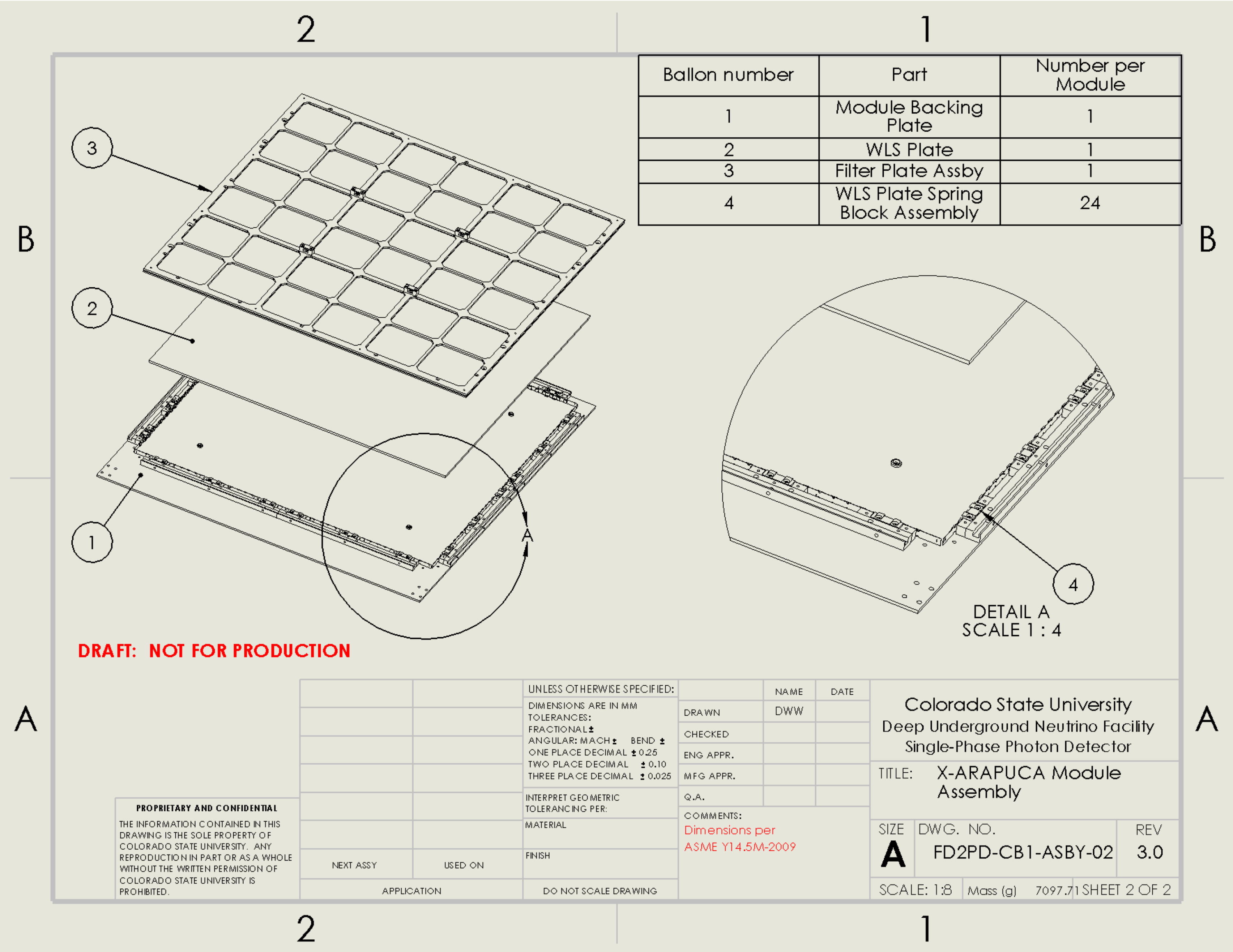


Module Assembly Exploded (CB1)

Major mechanical elements of module include:

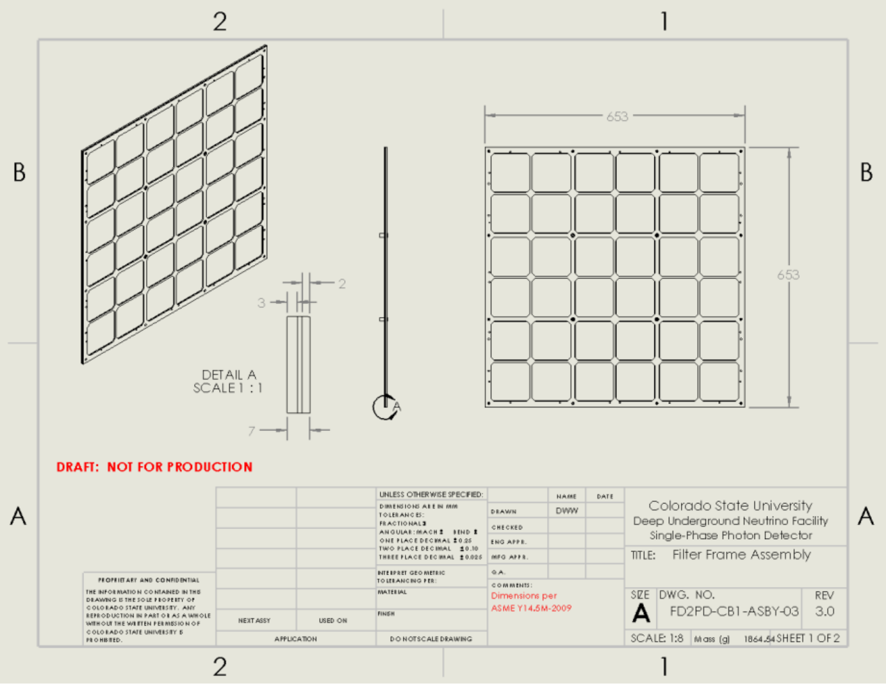
- (1) Module backing plate (can be replaced by second filter plate assembly for 2-sided readout).
- (2) 599 X 599 X 4mm^3 WLS plate.
- (3) FR-4 frame housing and locating 36 dichroic filters (separate sub-assembly).
- (4) Spring-loaded SiPM mounting system for ensuring contact with WLS plate warm and cold.

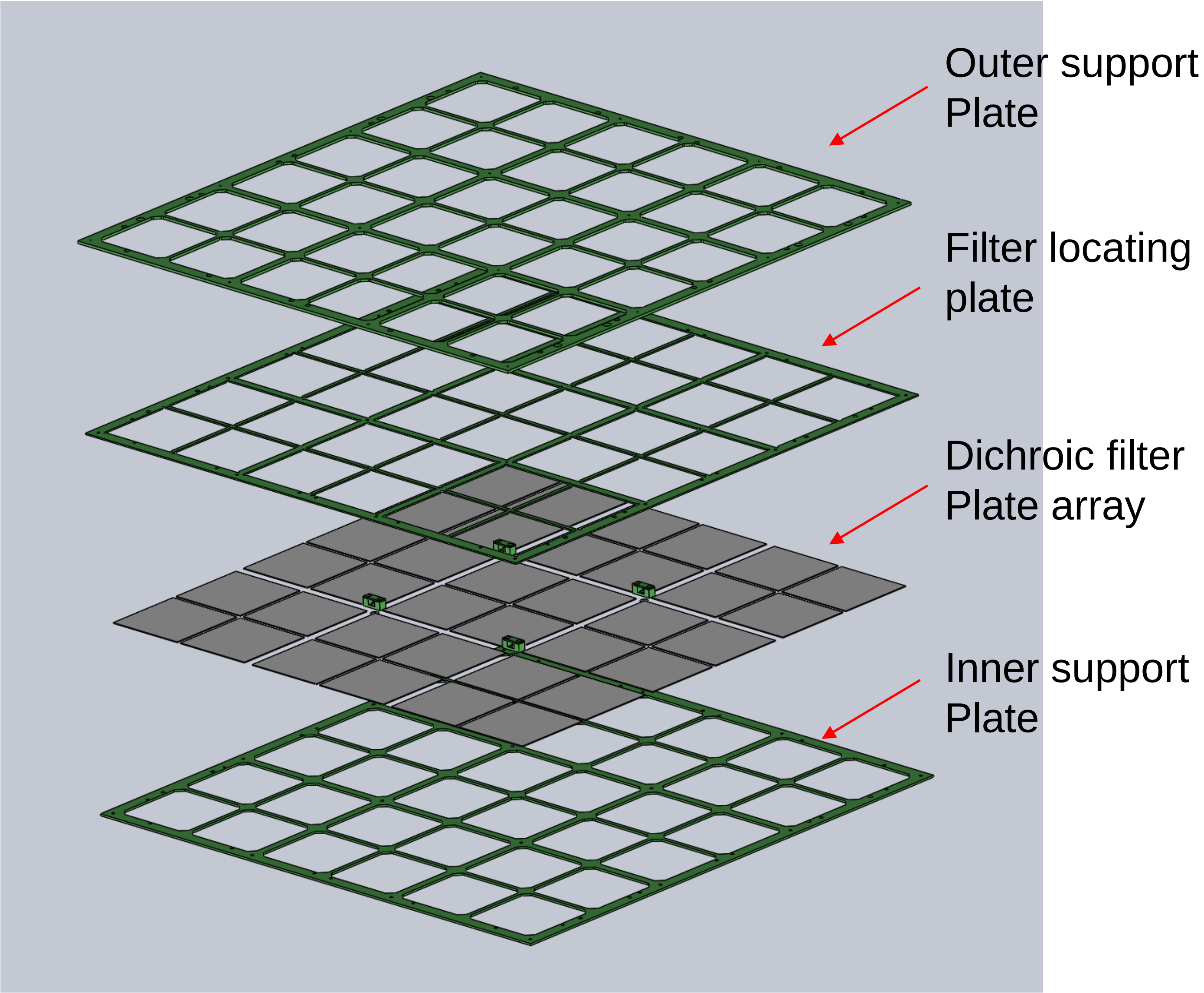
Interesting point: ~6mm relative contraction



Dichroic Filter Plate Assembly

- Independent support frames for filter plates.
- Can be installed on one side (membrane mount) or both sides (cathode mount) of a PD module.

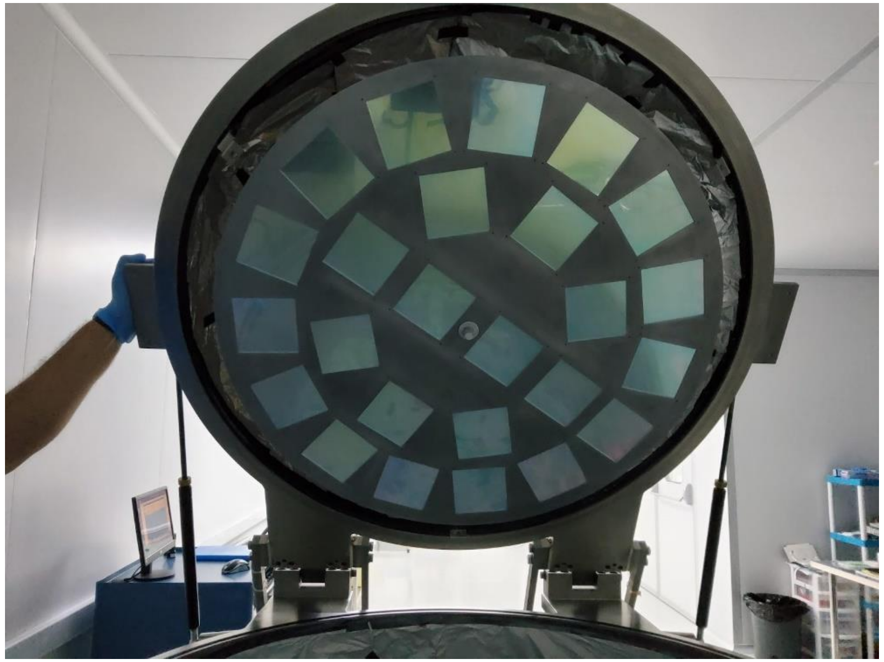




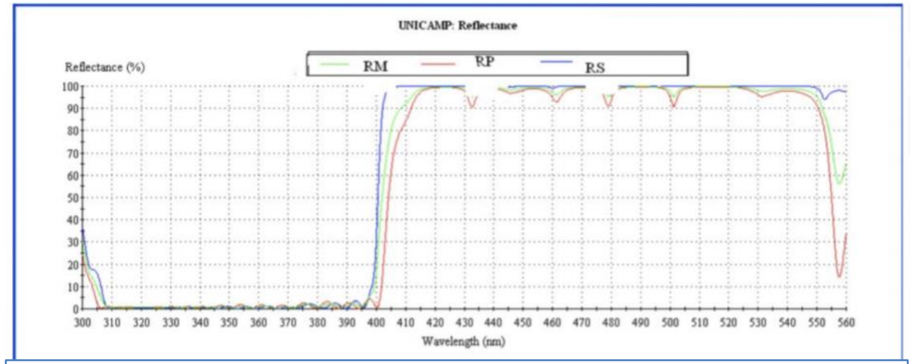
Dichroic filters (CB1) *A. Machado, UNICAMP*

CB 1 filters:

- Dimensions: 97mmX97mmX1mm
- Subtrate: Schott B270
  - (https://www.schott.com/en-ua/products/b-270-p1000313)
- Dichroic film produced by OPTO (Brazil) - 40 layers of Tantalum Oxide (Ta2O5) and Silicon Dioxide (SiO_2)
- Cutoff: 400nm
- Designed for a angle of incidence of 45º
- Coated on the glass side with p-Terphenyl by a vacuum evaporator chamber at UNICAMP (average thickness 400 ug/cm^2)
- Evaporation production: 25 filters per cycle (3hours)



Vacuum deposition station at UNICAMP



- Cut-off: 400 nm – It transmit between 300nm and 400nm, and reflects between 400nm and 500nm. See bellow spectral response;
- Incidence angle – 45 degrees
- Spectral Curve

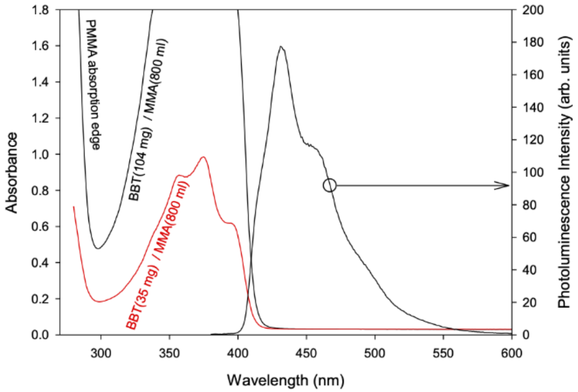
Dichroic filters (optimizations for CB3 and 4)

Filter optimizations for CB3, 4

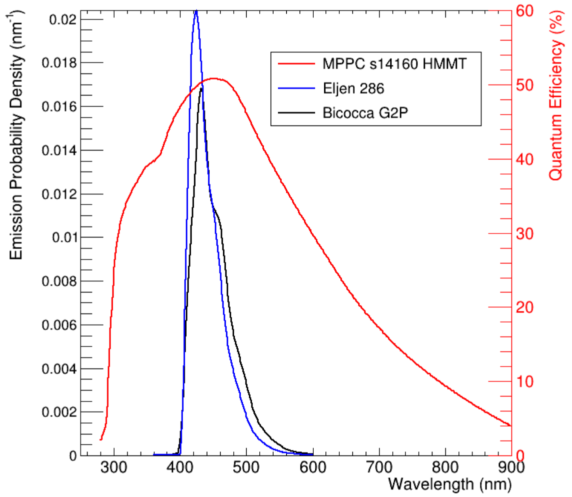
- Comparison tests between multiple vendors: OPTO (BR) – ZAOT (IT) – Photon Export (SPA)
- Examine filters optimized to different AOI → Improve the trapping efficiency of X-ARAPUCA
- different substrate (B270, B33) → to optimize the transmission and adhesion of the pTP film
- different dimension and thickness (e.g 200mm X 200mm X 2mm) to optimize the fill factor of the X-ARAPUCA tile and robustness

WLS Plate detail *C. Cattadori, Milano Bicocca*

Large size High efficiency WLS Tiles

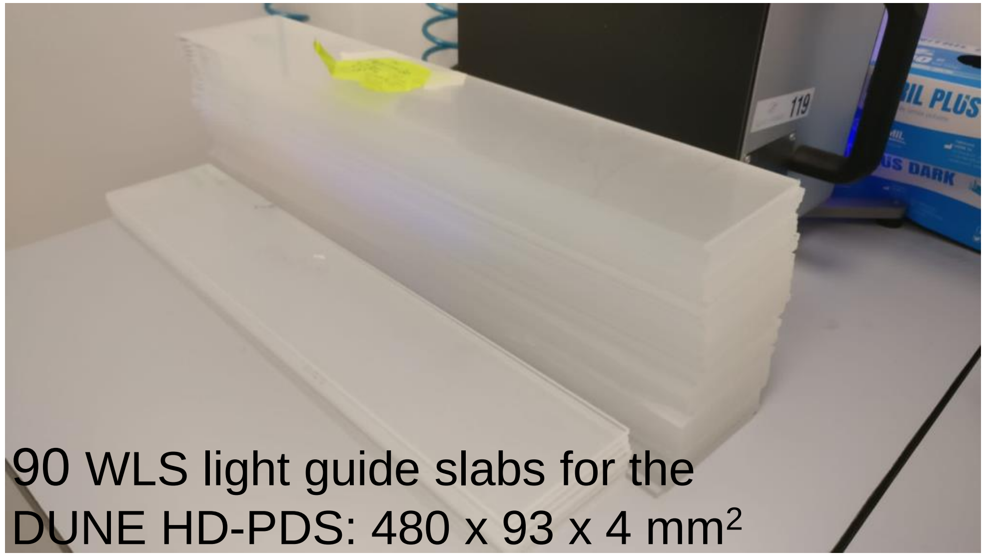


Optimized for dichroic filters…

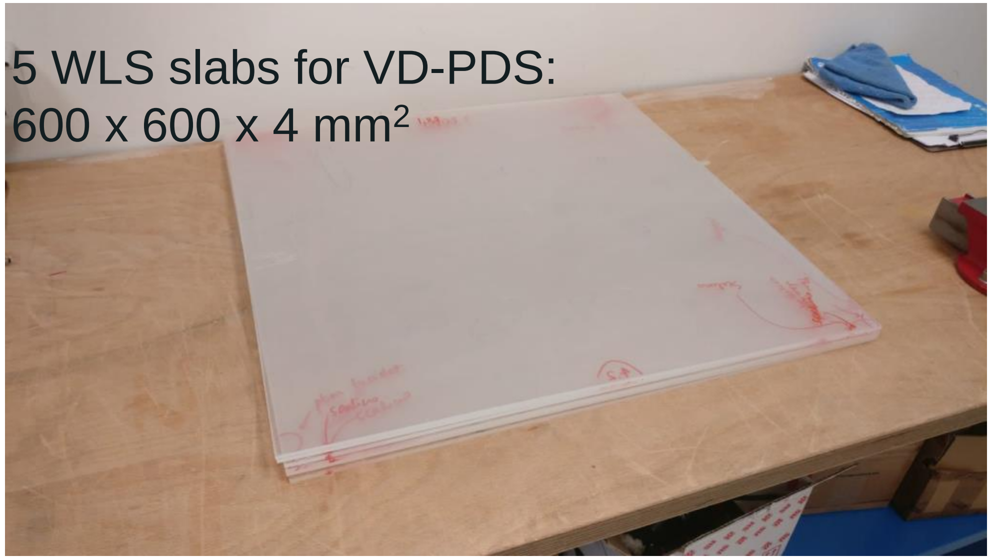


…and for SiPMs

- Fabricated from PMMA base resin:
  - Proven to be cryoresiliant in FD1-HD testing.
  - Cast from monomer syrup.
- Cromophore tuned to minimize absorption/emission spectra overlap.
- Absorption length >=1 m.
- Laser cut and polished at the edges.

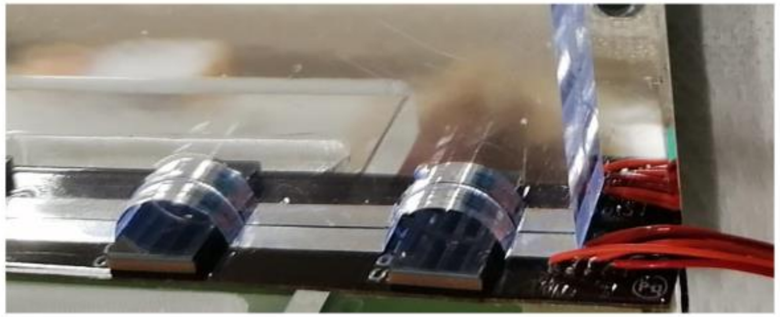


90 WLS light guide slabs for the DUNE HD-PDS: 480 x 93 x 4 mm^2

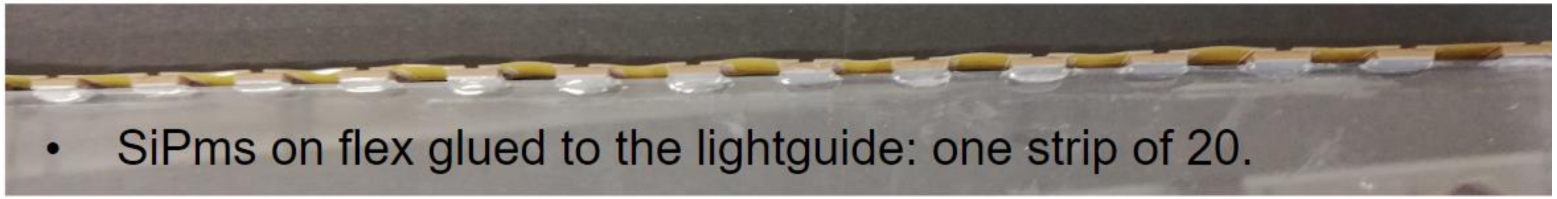


5 WLS slabs for VD-PDS: 600 x 600 x 4 mm^2

Optimization of SiPMs to WLS Optical coupling

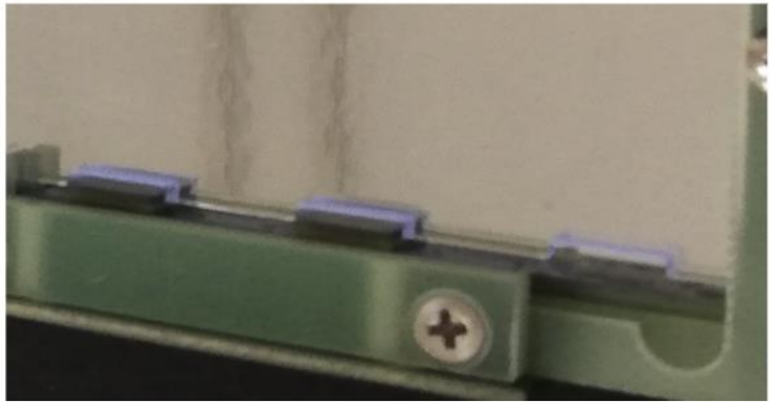


SiPMs on flexible Kapton PCB: supports the SiPMs acting as routing board as same time



- SiPms on flex glued to the lightguide: one strip of 20.

Edges of the lightguide machined with cylindrical (for spring loading) and flat (for gluing) divot to improve SiPMs optical coupling by spring loaded/gluing

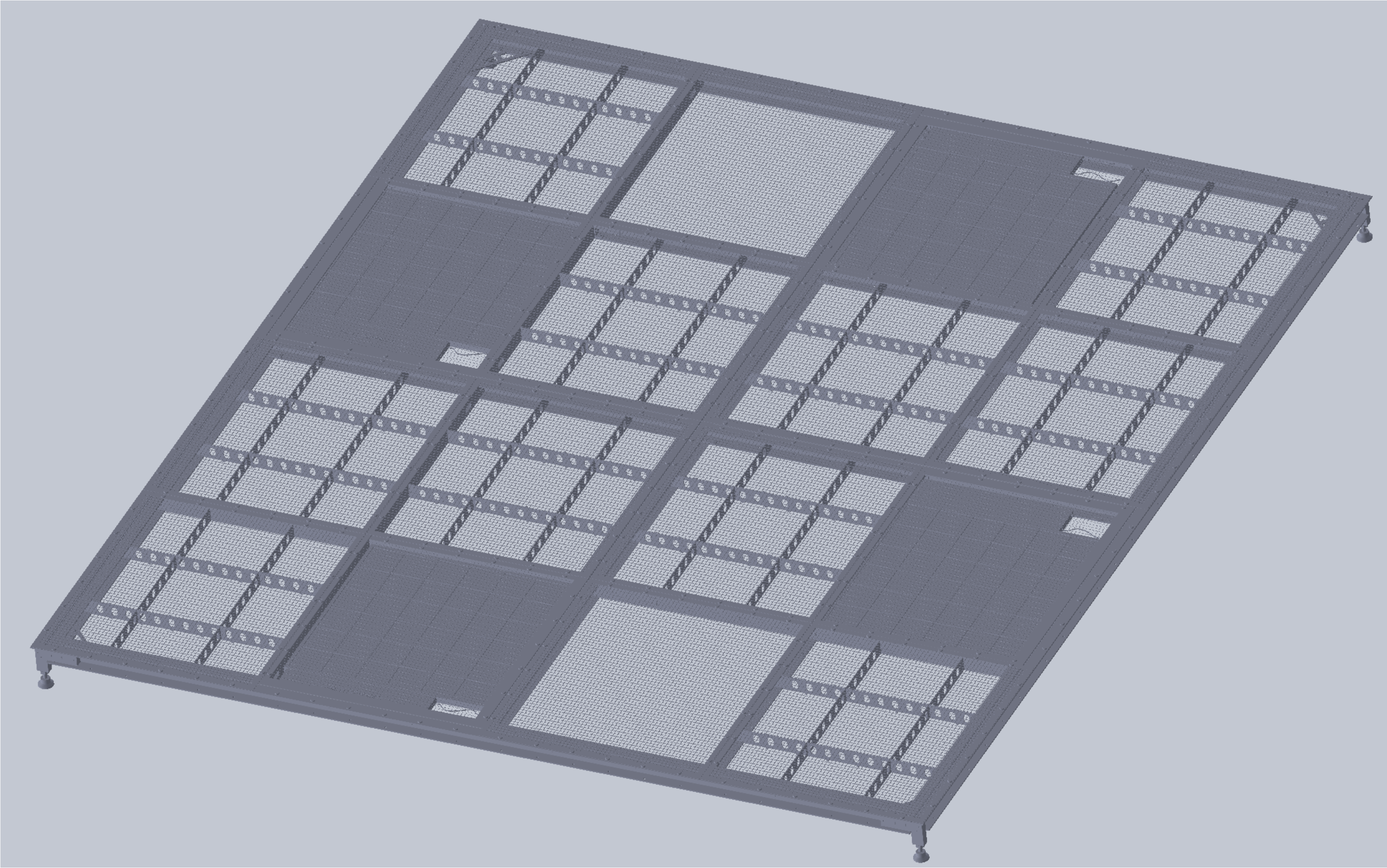


- SiPms on flex: zoom of one string of 24

Module frame support-- Cathode

Cathode-mount PD modules are supported on the G-10 cathode frames (inside mesh), 4 modules per frame.

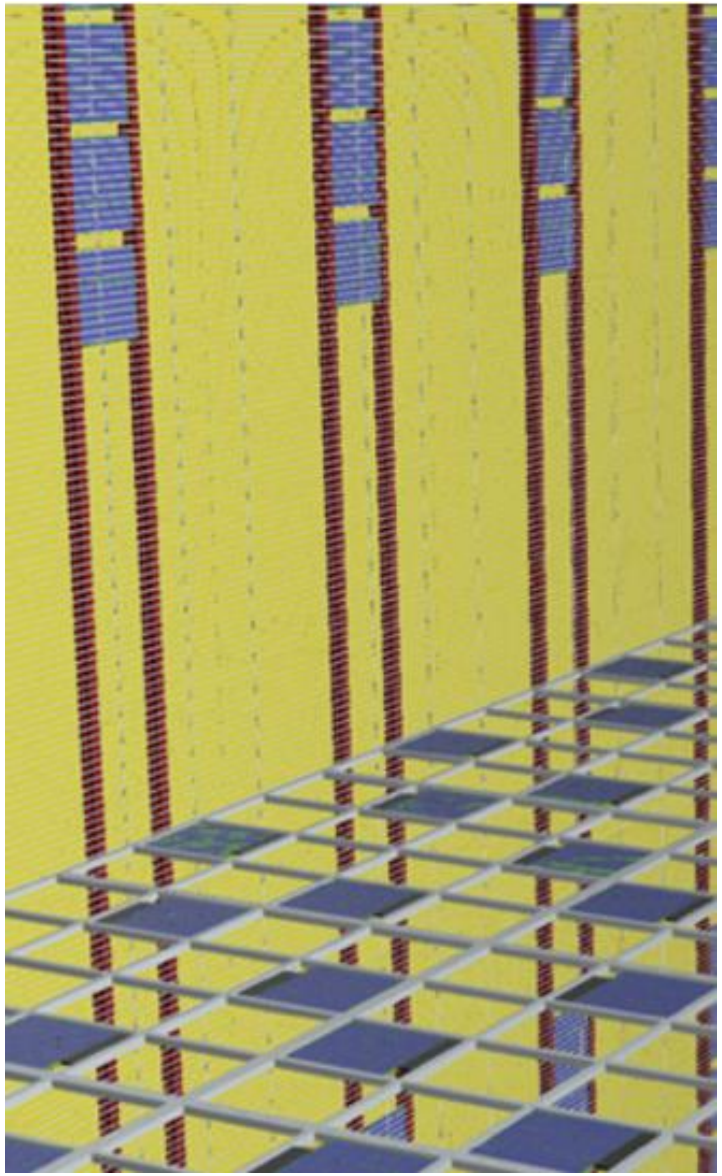
- Four G-10 supports will be mounted to the inside of the cathode frame and the module mounted to those (exact positions TBD).
- Exact module configuration within the cathode plane is still under discussion (See R. Rivera talk), but is not foreseen to impact the design.
- PD Module frame and cathode frame both manufactured from G-10 to minimize CTE issues.
  - G-10 fiber plane configuration considered.
- Power and signal fibers routed through frame (see D. Pushka presentation.



Membrane Mount Module Design and Mounting

Membrane mount modules are primarily a EU responsibility, and as such are only just beginning to move into the design phase.

- P6 costing and cold box test planning foresee using a very similar module design and mounting scheme for the membrane mount modules.
- Since membrane mount modules are single-sided, we have significant flexibility to add mounting points to the rear side of the modules.
- Infrastructure for cable trays exists in this region of the detector. Significant effort will be taken to leverage this infrastructure to support the PD modules. Additional supports will be added if needed.
- Since the membrane mount modules do not need to mount inside the cathode frame nor operate at HV, additional flexibility for module design exists. Design teams in Spain and Italy are beginning to study if we want to leverage this flexibility to re-optimize the module design.



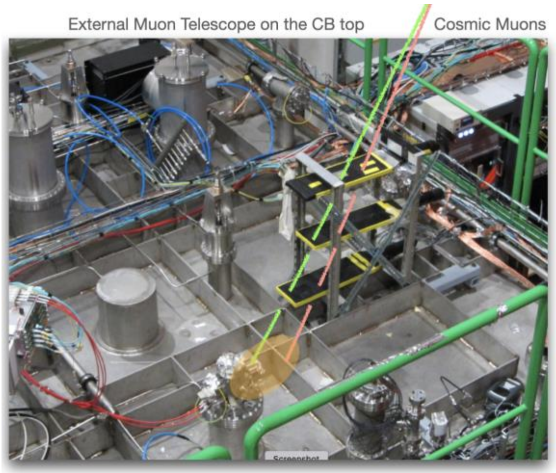
Shared cable trays (with bottom CE) or independent supports

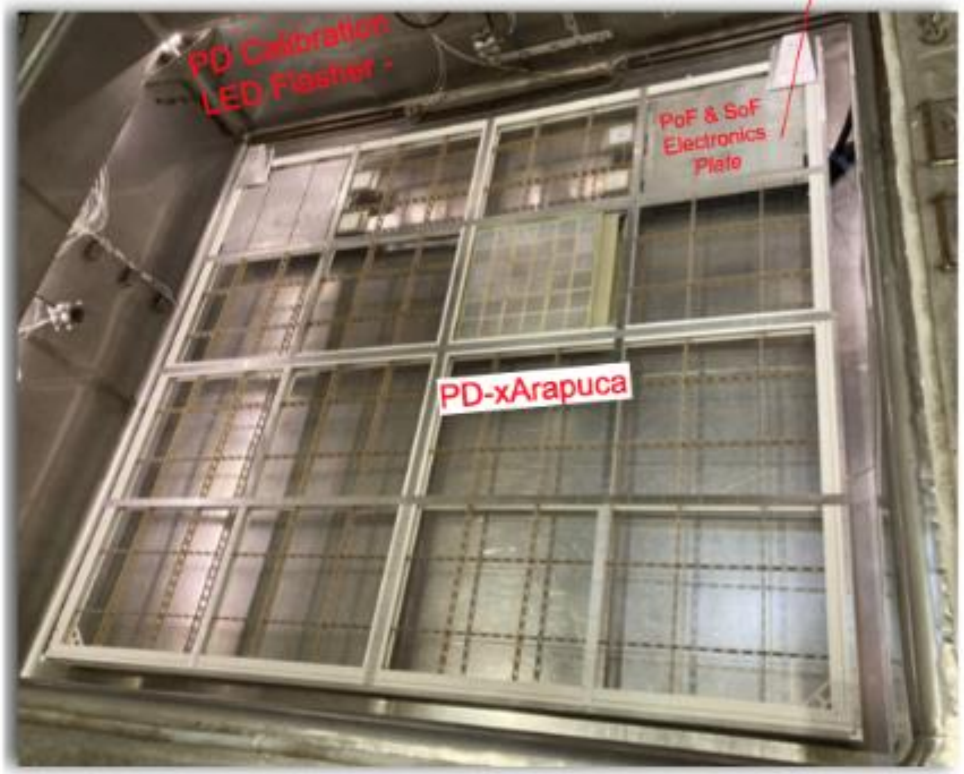
Mechanical Prototyping Path

Cold Box 1 at CERN:

Demonstration of full scale X-ARAPUCA

- *One 60 cm X 60 cm X-ARAPUCA tile installed on the cathode.*
- *Successful operation in LAr at HV on cathode represents initial design validation.*
- *Validation of spring-loaded SiPM mounting concept for SiPMs (with significant lessons learned!).*
- *Will inform continuing designs.*

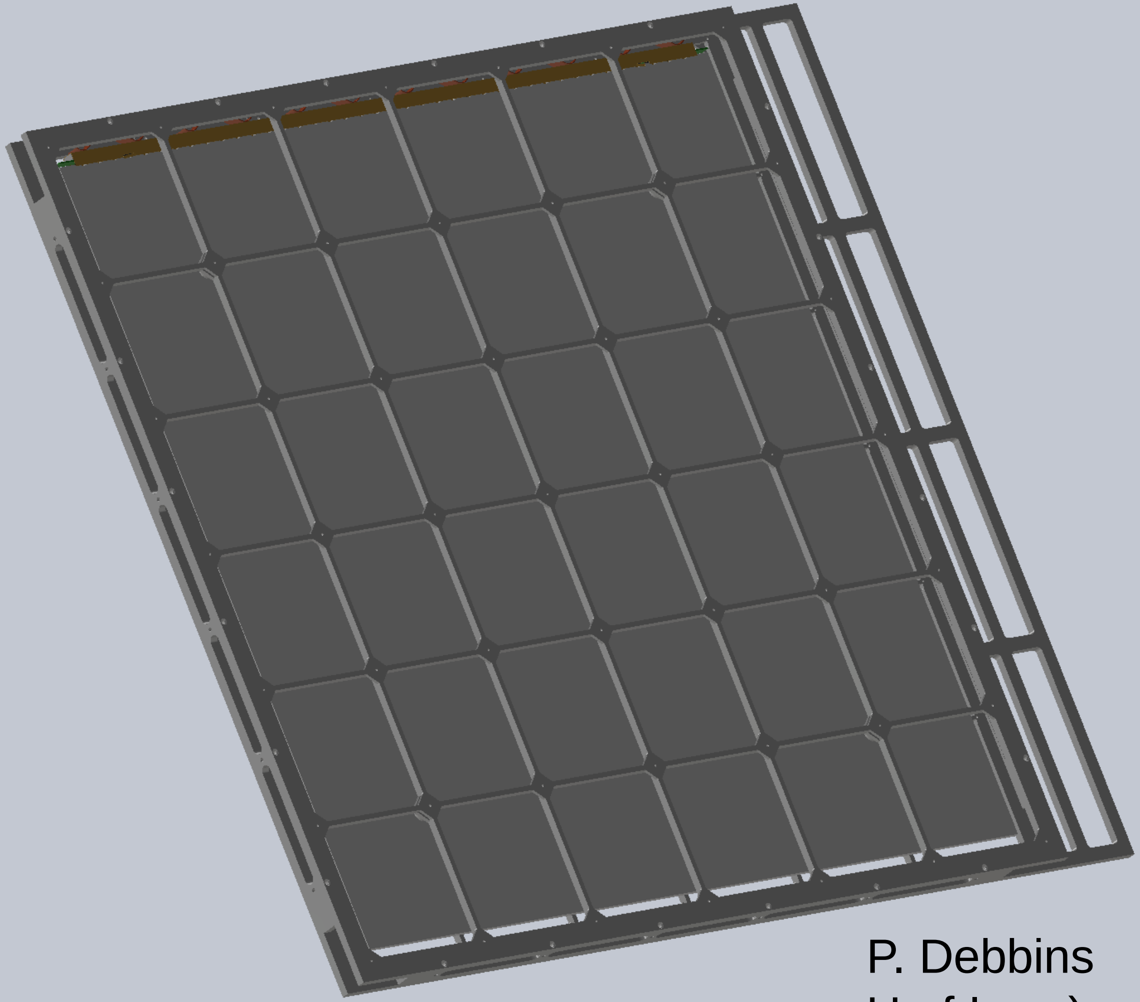




Towards a Final Module: Cold Box 3 and 4

Proposed module improvements to be tested in CB 2 and 3 include:

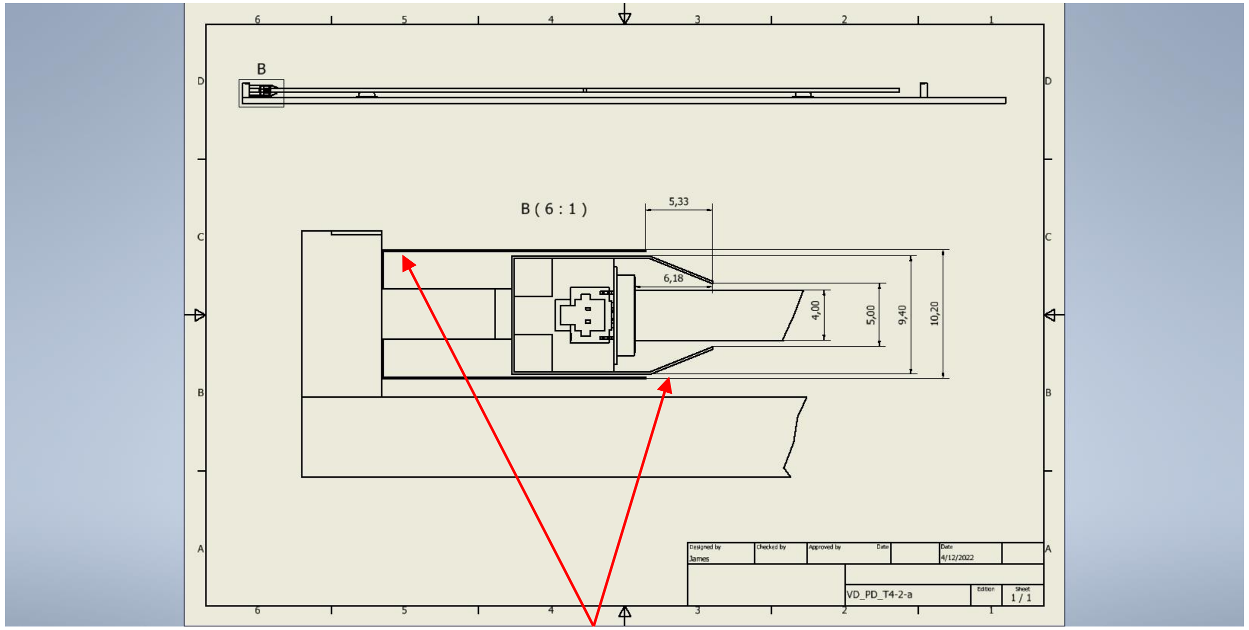
- Larger dichroic filters (200 X 200mm^2, 2mm thick) to minimize mechanical light loss (*Has impacts of frame strength, mass. Under investigation*)
- Direct optical coupling (epoxying) of SiPMs to WLS plate (*Requires validation of epoxy performance cryogenically*)
- Light-focusing cutouts ("Divots") in the side of WLS plates to improve spring-loaded light collection (*Thermal expansion issues. Under investigation*)
- Mechanical improvements to reduce part count, reduce mechanical dead areas, and improve manufacturability.



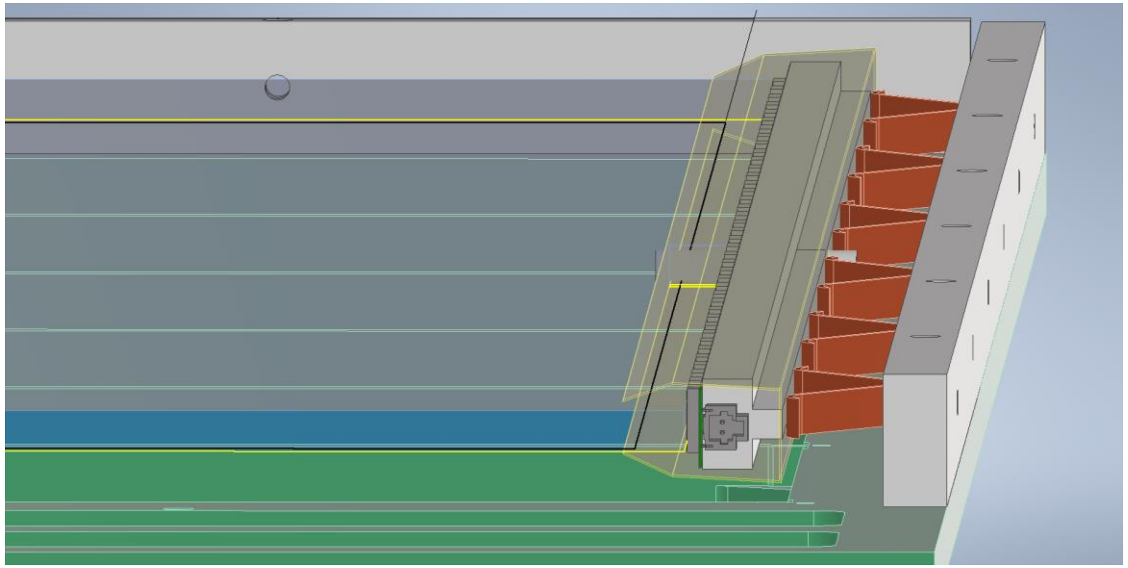
P. Debbins
U of Iowa)

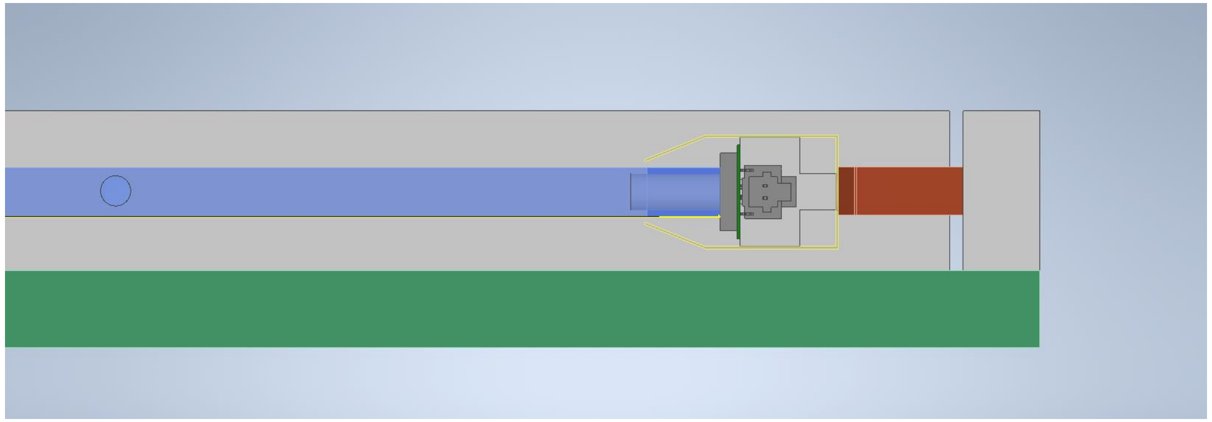
Design improvements: Leaf springs and Cathode HV Shielding

- As a result of CB1 testing, we are in the process of improving the module design for later cold box tests.
- Revisions include HV shielding and improved SiPM spring loading.



Possible shield locations (Outer cover preferred optically, inner cover may be electrically superior).





Drawings from P. Debbins U of Iowa)

LBNF/DUNE

2022/2023 Progression

- Cold Box progression:
  - July ‘22 CRP CB3 ⇒ test of SiPM mounting and improved mechanical design
    - Min Viable product ⇒ one full module works on the cathode
  - **Extra** CB3+ possible -- Sep ‘22 PDS CB ⇒ Flex, Better packaged PoF & readout.
    - Min Viable product ⇒ one full chain works on the cathode
    - Min Viable product ⇒ one full chain works on the membrane
  - Nov ‘22 CRP CB4 ⇒ **Preliminary** module-0; Components moved to module-0.
    - Min Viable product ⇒ one full chain works on the cathode
    - Min Viable product ⇒ one full chain works on the membrane
  - **Extra** CB4+ planned -- July ‘23 PDS CB ⇒ **Final** packaging PoF & readout.
    - Min Viable product ⇒ one full chain works on the cathode
    - Min Viable product ⇒ one full chain works on the membrane
- Module-0 demonstration:
  - Install March ‘23
  - Survival of HV discharge
  - Mechanical installation procedure
- Small-scale Cold Tests:
  - Downselect filter configuration
  - Downselect SiPM mounting

Analysis Plan

Initial draft of analysis plan document (mechanical) is with the compliance office now.

- *Initial (Brief!) conversation with Olga Beltramello held at CERN 4/26. Initially positive discussion.*

- Main PD consortium responsibilities include:

  (LC-2.2.1-A) Loads due to relative thermal expansion of the module relative to the CPA frame, particularly as related to module/frame mechanical tolerances and the need to maintain electrical contact following cool-down
  (LC-2.2.2-B) Loads due to detector masses and support cable self-load of the membrane mount PD system. This load will also include any cable and/or fiberoptic mass (I&I interface).
  (LC-2.2.2-C) Loads due to relative thermal contraction between the cryostat, support cables, and optical fibers due to differential cooling during cryostat filling and different coefficients of thermal expansion (CTEs)

- Critical point: Need to confirm that Cathode consortium and I&I will include PD modules in their analysis of load cases.
  - Expected to be recommendation from compliance office.
  - Will be coordinated through project office.

Analysis Plan

for

DUNE Far Detector 2 Photon Detector Module

and

Support Structure

DRAFT

David Warner - Colorado State University

25 April 2022

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Summary

- A mechanical design has been developed, mounted in a cathode frame, and operated at HV

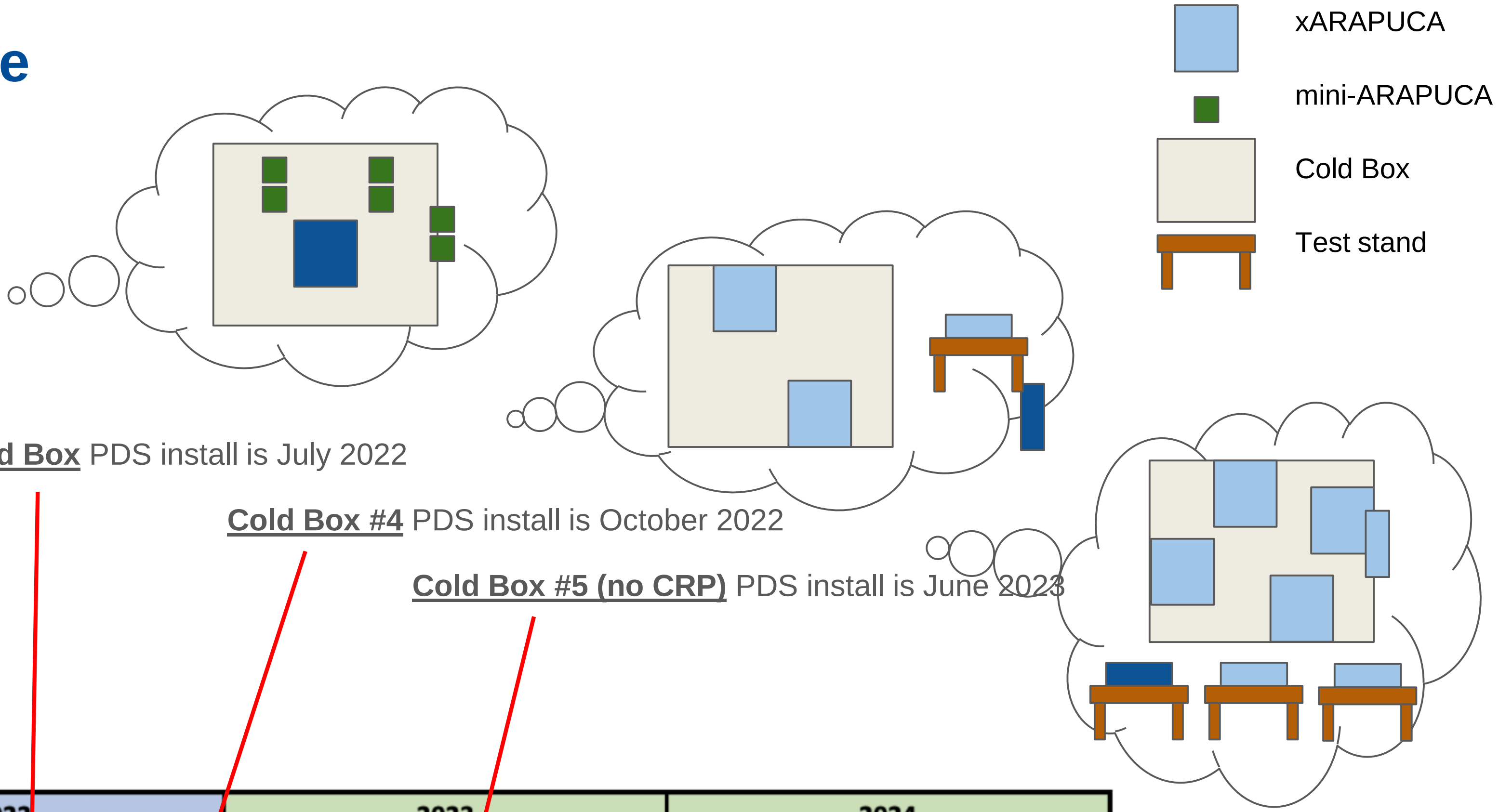
- This design provides the basis of estimate for the FD2-VD PD
  - No “Show-stoppers” were found

- Significant opportunity for improvements exist, and will be tested in the cold box tests at CERN prior to Module 0.

- Membrane mount design optimization is beginning now as additional consortium resources come online. No significant modifications are REQUIRED, but opportunities may exist.

Backup

Cold Box pictorial schedule



Parasitic ARIADNE run

CRP2 PDS install is 18 April 2022

CRP3 Cold Box PDS install is July 2022

Cold Box #4 PDS install is October 2022

Cold Box #5 (no CRP) PDS install is June 2023