FD2 PDS
State of PoF, SoF, and CE for ProtoDUNE2-VD

23 September 2022
DUNE PDS Consortium
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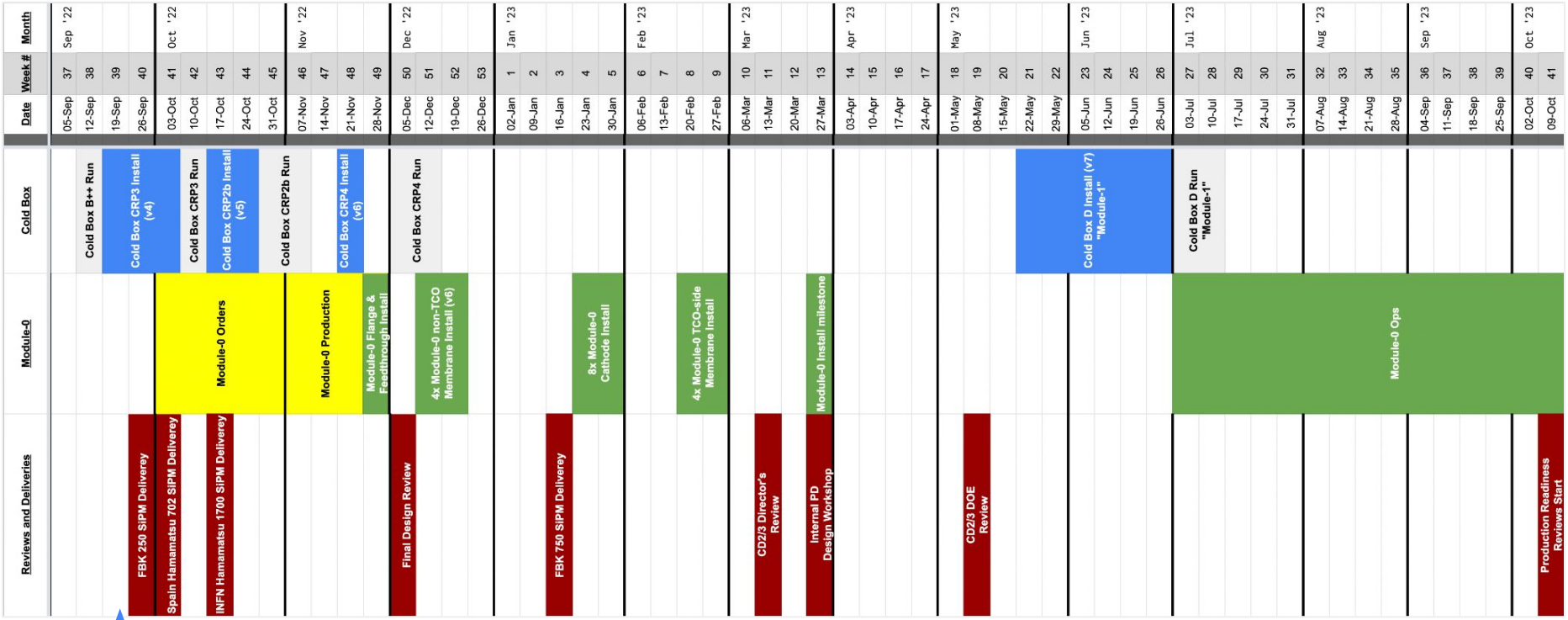
Introduction

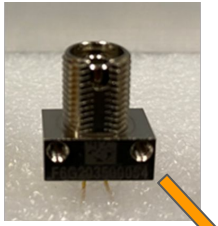
- Goal is to provide an overall picture of…
  - Power-over-Fiber (PoF)
  - Signal-over-Fiber (SoF)
  - Cold Electronics (CE)
- …with regard to Module-0 at ProtoDUNE2-VD including the following:
  - Design status
  - R&D towards Module-0
  - Schedule
    - Production
    - Installation

FD2 PDS Weekly Schedule



We are here

PoF Design State



- Si (971 nm) and GaAs (808 nm) PoF systems have been demonstrated at the Cold Box
  - PoF system components: Transmitter, Fiber, and Receiver
  - Receiver a.k.a. LPC (Laser Power Converter) and PPC (Photovoltaic Power Converter)
  - Favor GaAs for Low Voltage and Si for SiPM Bias Voltage:

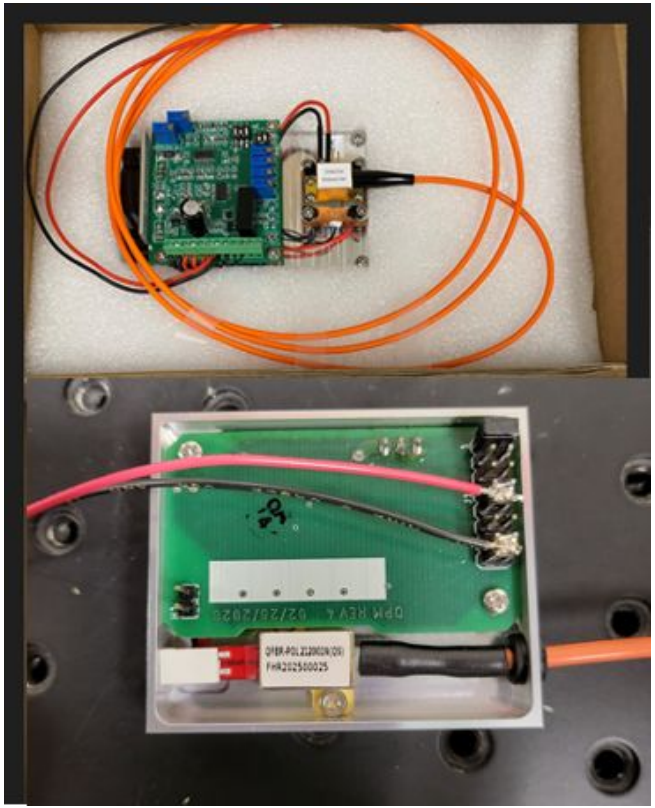
Power Capability*	Type	# of PPC	Current mA	Voltage V**	Power W	Efficiency %
1W	GaAs warm	1	80	5.5	0.45	65
1W	GaAs cold	1	30	6.5	0.20	50
3W	Si warm	1	80	5.5	0.45	50
3W	Si cold	1	15	11.5	0.18	22

* The power delivered is not all converted to usable power; e.g. for Si cold, the efficiency is about 22% in LAr.
** Each PPC module voltage can vary about 3%.

- 30-year qualification?
  - *Literature: Most satellites use GaAs or some version of GaAs, in both near and far orbit, due to their long lifetime. A typical system operates for 15 + years. Lifetime and performance measurements of GaAs photovoltaic match theoretical data predictions. A typical thin cell unit will decrease efficiency by 8% under moderate radiation levels (1 MeV electron exposure tests).*
  - The units being deployed for DUNE VD have nearly 40% overhead to compensate for a decrease in power production or photon conversion. We do not expect the radiation damage modeled in space-based systems and therefore expect very little degradation.
  - GaAs is not new and has been heavily studied since the 1990s for PV use. Their popularity has increased as manufacturing costs have come down. Presently, they are rated nearly the same as Si for power versus weight and therefore are now the default choice for space applications.

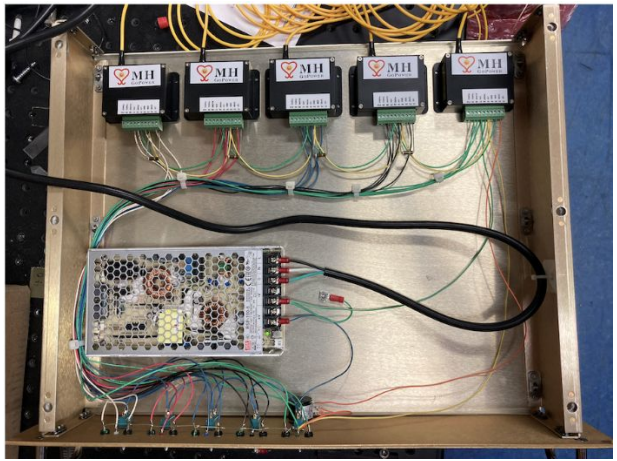
PoF Transmitter State

- Commercial transmitters
- Custom packaging into rackmount unit is design from FNAL and SDSMT
  - Prototypes demonstrated at Cold Box
- Safety surrounding Class-4 lasers is paramount!
  - Wikipedia: "*Class 4 is the highest and most dangerous class of laser... By definition, a class 4 laser can* ***burn the skin****, or cause devastating and* ***permanent eye damage*** *as a result of direct, diffuse or indirect beam viewing. These lasers may ignite combustible materials, and thus may represent a* ***fire risk****... Class 4 lasers must be equipped with a* ***key switch and a safety interlock****..."*



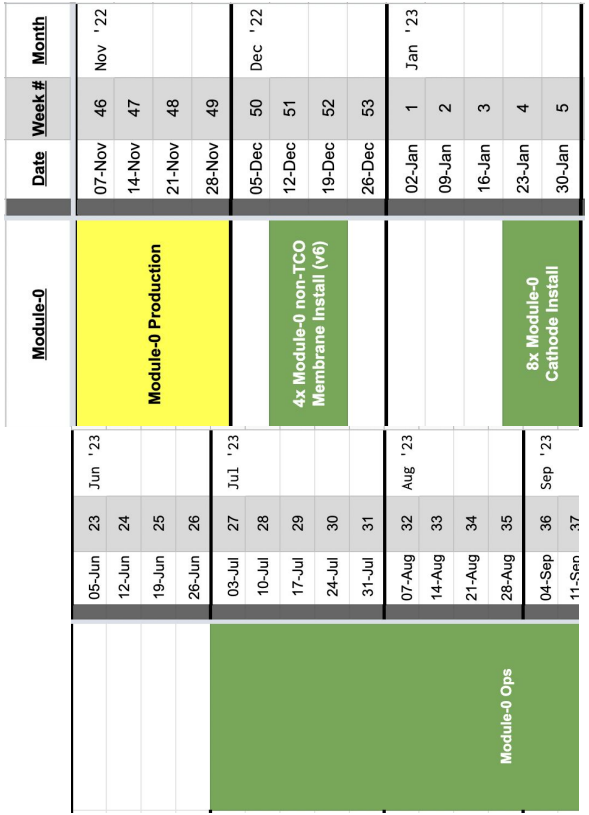
PoF Transmitter R&D towards Module-0

- Transmitter regulation using a feedback loop
  - Could prove critical to walk-up supply voltage over 30-years to compensate for any degradation in the detector or cold-electronics.
    - e.g. to increase the SiPM bias or SoF laser drive bias
    - This could remove the need for cold LDOs and their risk of failure
- Packaging of 8 lasers in 3U rackmount box



PoF Transmitter Schedule (Production/Installation)

- January ‘23 - Cathode Warm Testing
  - Minimum 1 Tx XA unit needed for Warm Testing during installation
    - Already in-hand at Cold Box
- July ‘23 - ProtoDUNE2-VD Operations
  - Full optimized 8 Tx XA units needed for Ops
    - Joint SDSMT/FNAL effort in the spring
- Critical Path Severity: **Low**



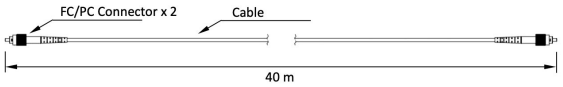
PoF Fiber State

- 2 fiber types ordered: MH GoPower (62.5um) and Polymicro/Molex (105um)
  - Both are black, 1.5mm OD, 40m length FC-FC
  - We have received partial delivery from MH GoPower, none received from Polymicro
    - Expect full delivery by end-of-October (20-week lead times!)

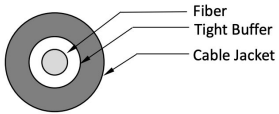
MIH® Fiber Patch Cord

FPC-062CDFC-04015BB **Datasheet**

1. Cable Figures



Cable Structure



2. Fiber Characteristic

Fiber type	Item	Description
MM	Numerical Aperture (NA)	0.27
	Index Profile	GI
	Core Diameter	62.5 ± 3 μm
	Cladding Diameter	200 ± 4 μm
	Coating Diameter	230 ± 10 μm
	Diameter of Buffer	500 ± 50 μm
	Fiber Attenuation	< 3.5 dB/km (@980nm)

FIA105125250 BLACK

Estimated Shipping Cost - FedEx Ground

Fused Silica Optical Fiber

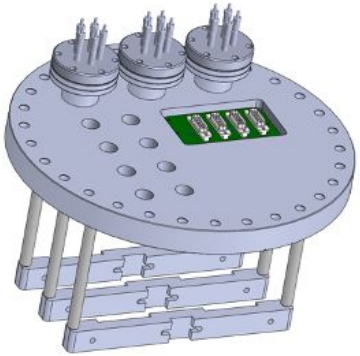
Low-OH Core: 105 ± 2μm
Doped Silica Clad: 125 +1/-3μm
Black Acrylate Buffer: 250 ± 15μm
NA: 0.22 ± 0.02

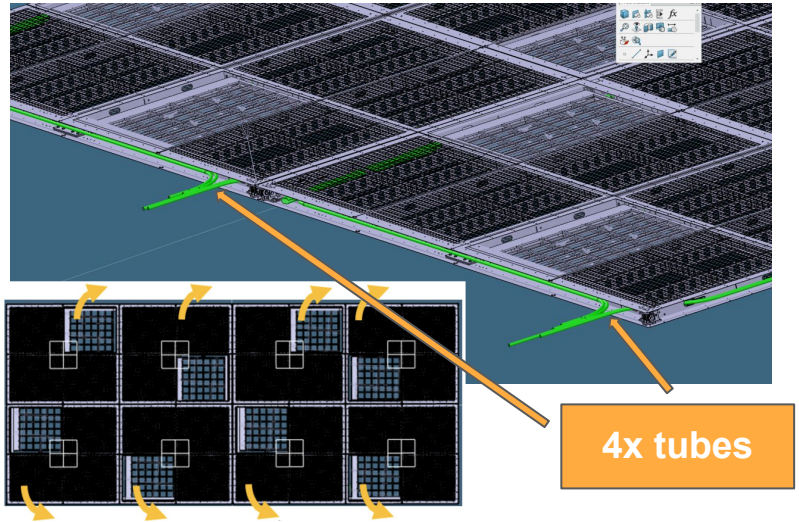
PoF Routing State

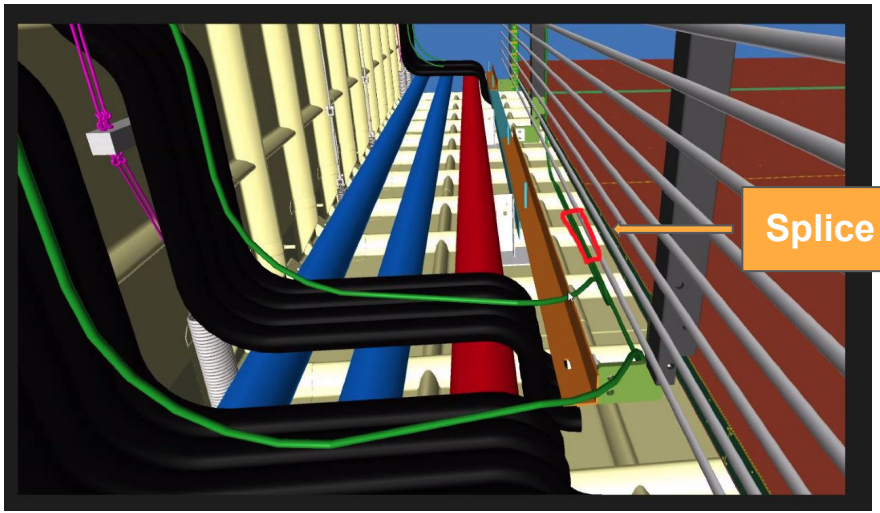
- PTFE ⅜” ID ½” OD black tubing ordered
  - Enforces min bending of 10cm
  - Procedure is slit and install 8 fibers

Fiber Routing State

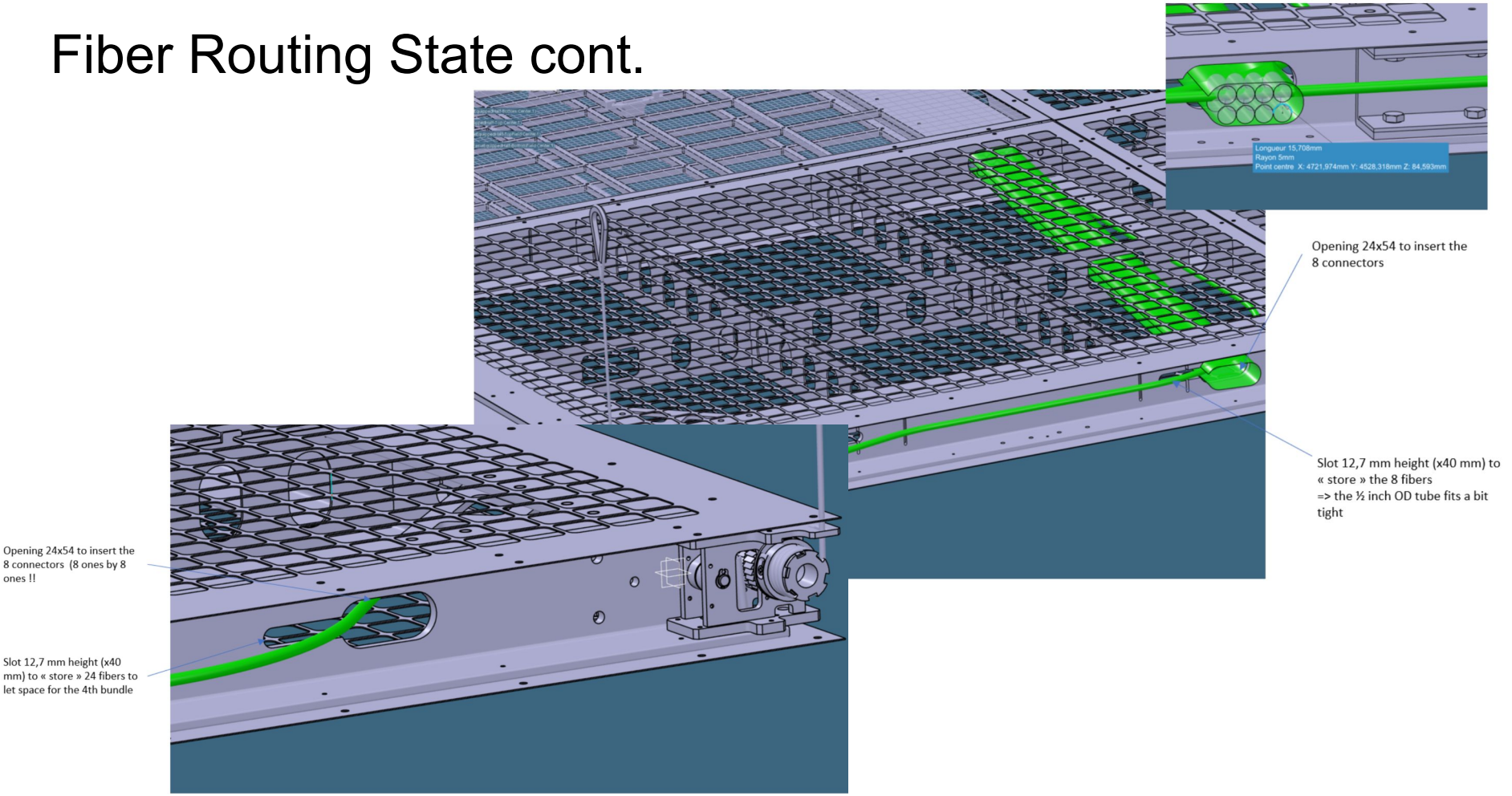
- 8 fibers per XA (2 PoF + 2 SoF + 4 spare)
- 8 fibers per ¾” feedthrough
- 8 fibers per PTFE tube
- Fiber spliced on floor **or** pulled all the way to feedthrough





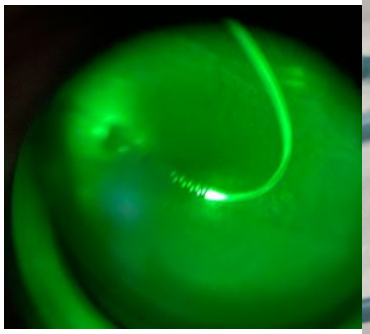


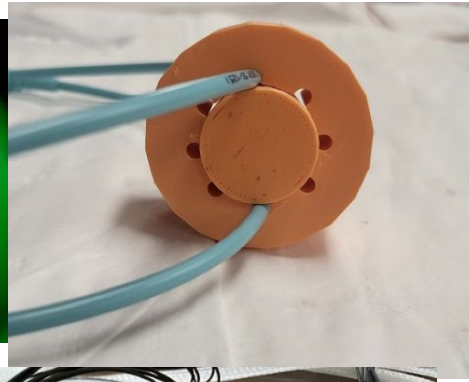
Fiber Routing State cont.

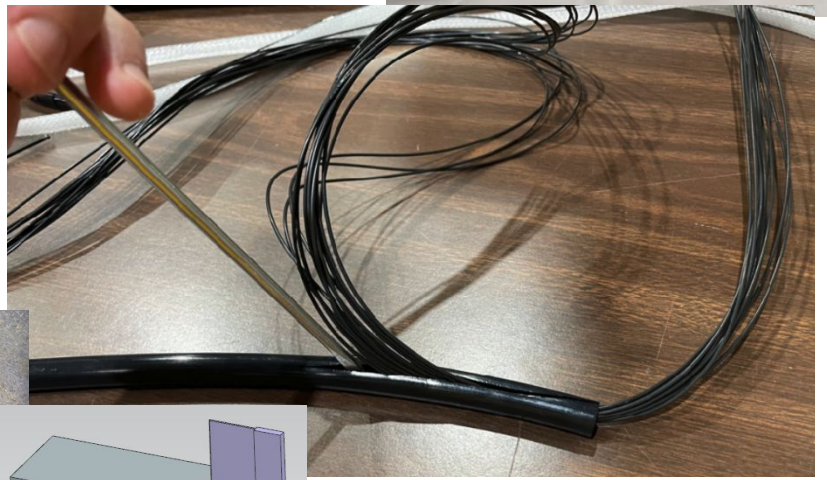


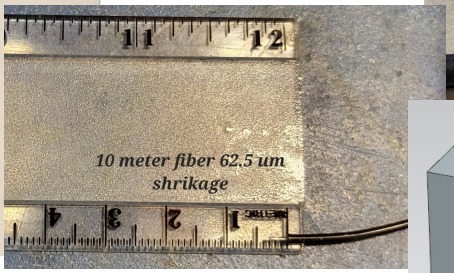
Fiber R&D towards Module-0

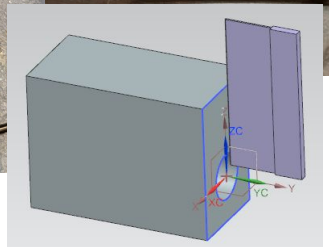
- Resolution needed on SoF fiber selection (MMF is what is ordered!)
- Resolution needed for light leakage at bends and connectors of PoF and SoF.
- Automated jig for slicing tubing needed.
- Gain confidence in relative CTE of all materials and connectors.
- Splicing R&D at SDSMT.
- Feedthrough R&D to avoid in-situ termination.
- Fiber and tube labeling scheme needed.
    - E.g. Binary code using 3x wide/thin tie wraps. 8x colored fiber tip covers.





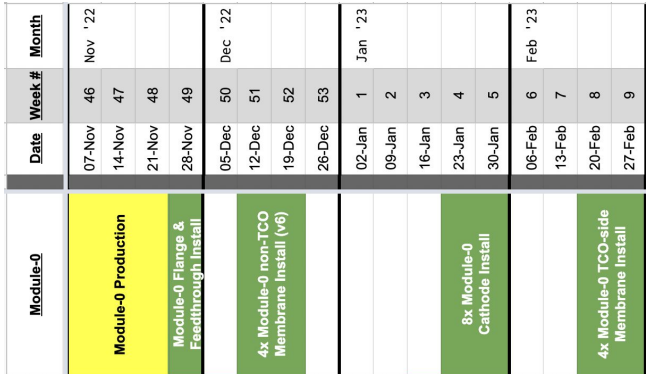


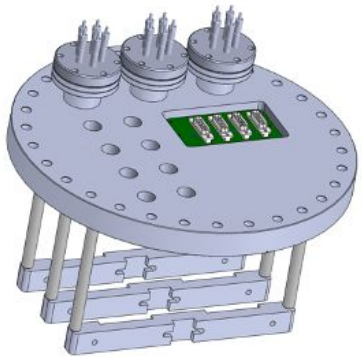




Fiber Schedule (Production/Installation)

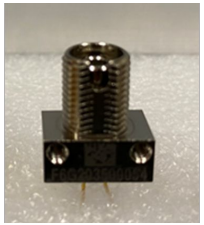
- 10x 100’ Tubing order to be placed 29-Sept + 4 weeks⇒ 28-Oct
- 10-Oct: Finalize Flange **Design**
- 07-Nov: Complete Flange **Fabrication**
- 28-Nov: Flange & Feedthrough **Installation**
- 05-Dec: **Dress** fibers/tubing on membrane
- 30-Jan: **Splice** fibers
- Need to plan personnel travel!
- Critical Path Severity: **Medium**

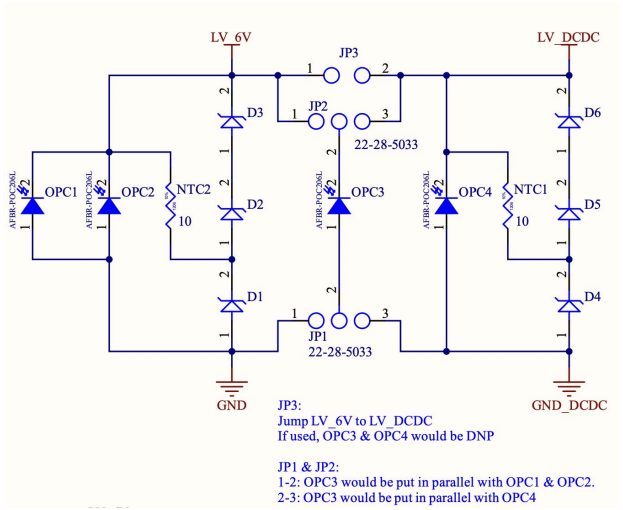




PoF Receiver State

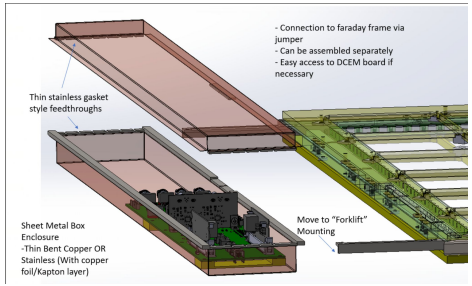
- 20 GaAs (200mW/LPC) LPCs in-hand.
- Opportunity for InGaAs (UIUC) or large area GaAs LPC (Broadcom) for higher power (~400mW/LPC).
- Parallel redundant scheme final.

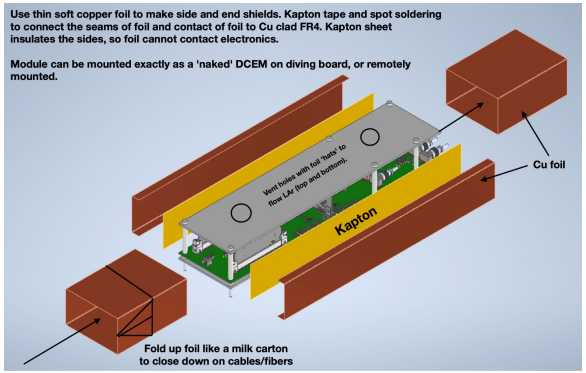




PoF Receiver R&D towards Module-0

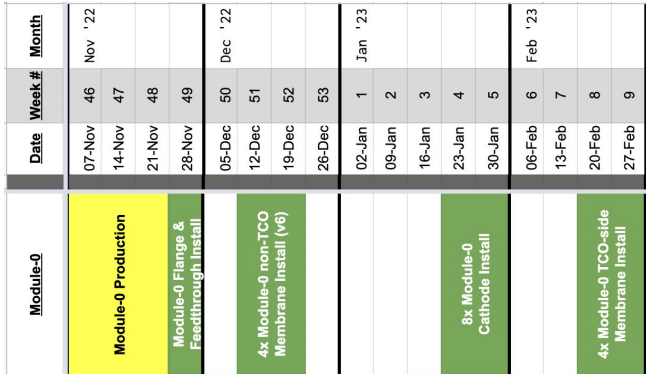
- 3 potential receiver optimizations on the horizon (but may be too late):
  - UIUC packaging of InGaAs lower-series-resistance LPC solution
  - Broadcom wide area LPC for increased efficiency and power delivery
  - Broadcom InGaAs LPCs
- Light leakage mitigation is critical
  - E.g. Copper-clad G10 box
  - E.g. Silicon/potting





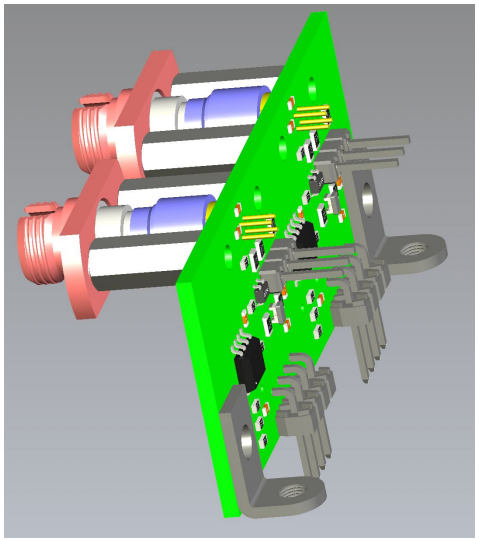
PoF Receiver Schedule (Production/Installation)

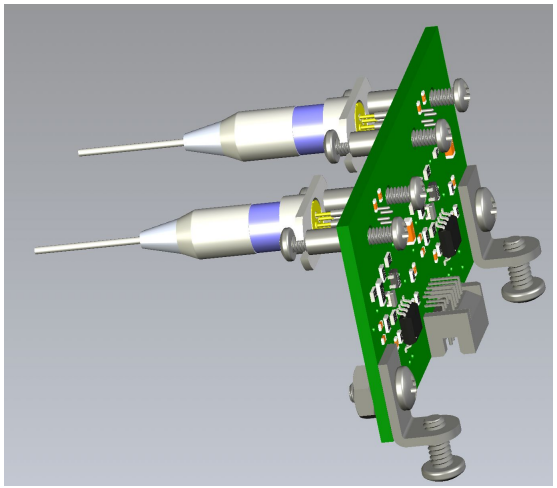
- If cathode CE power remains <200mW, we have sufficient GaAs LPCs in-hand
- If power requirements increase, PoF receiver lead-times becomes critical path!
  - Broadcom hopes to deliver high power (400mW) units in December
- 21-Nov: install and test on CE motherboards
  - 8 motherboard kits
- 23-Jan: install CE kits w/XA on cathode
- Critical Path Severity: **Low**

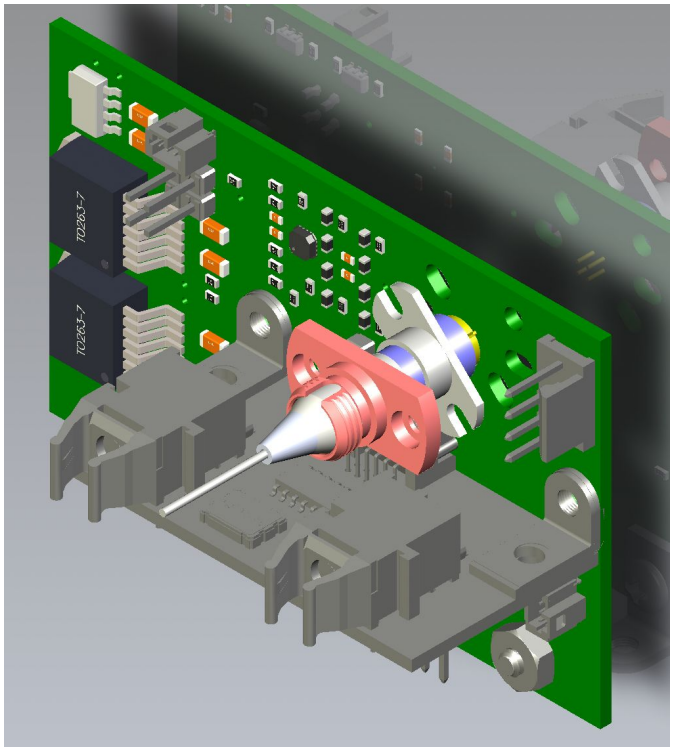


SoF Design State

- 3 signal conditioning flavors: ‘ARGON2x2’ ‘Simp3x’ and ‘digital’
- Critical issue is lasers flooding

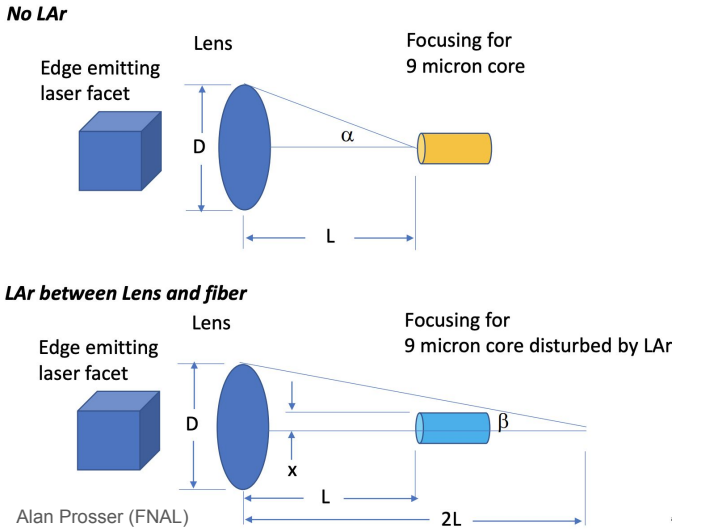


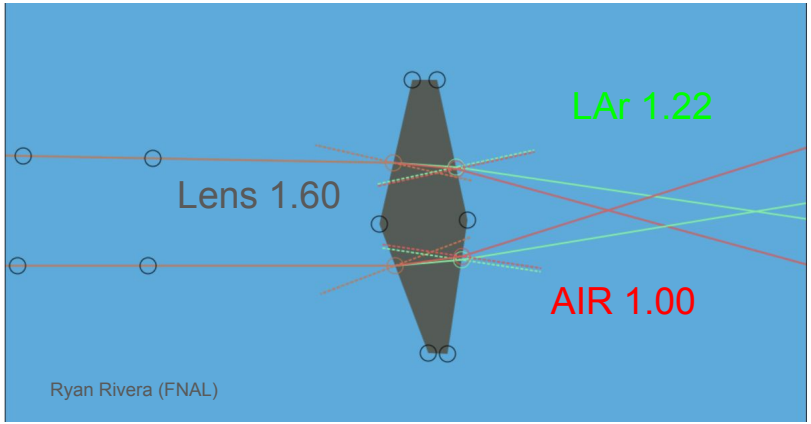




SoF Laser Flooding R&D

- Signal-over-Fiber fiber coupling
  - Compensate for LAr refractive index
- Attempts which have flooded:
  - FNAL potting
  - APC potting
  - IOC vendor ‘hermetic seal’
  - Lasermate vendor ‘hermetic seal’
- Attempts that remain:
  - Allow flooding and overdrive (20mA > 3mA)
  - Lasermate seal + potting
  - Lasermate defocus fiber stub
  - Broadcom defocus fiber stub
- **Repercussions!**
  - Power requirement impact on PoF (+85mW)
  - Constrains fiber coupling options and ability to mitigate modal noise



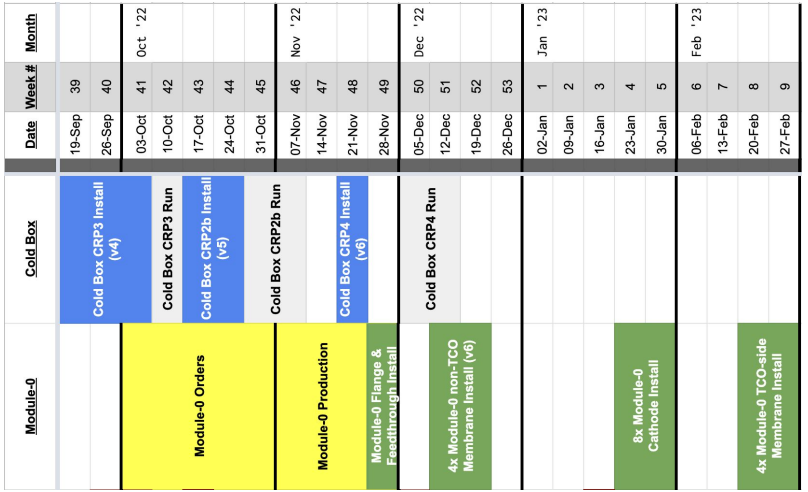


General SoF R&D

- LDO selection (vs regulated PoF) needed
- Full BOM Component selection (including vendor) needed
  - Trust issues with manual component installation and change tracking
- Digital SoF implemented anywhere?
  - Due to power needs of 500mW, and risk of HV discharge distributing signals across XAs, may only make sense at the membrane (where HD has already shown >6 S/N)
  - Worth it for redundancy? Built in noise isolation?
  - DAPHNE only supports 250mW per cable! (not enough power for digital readout!)

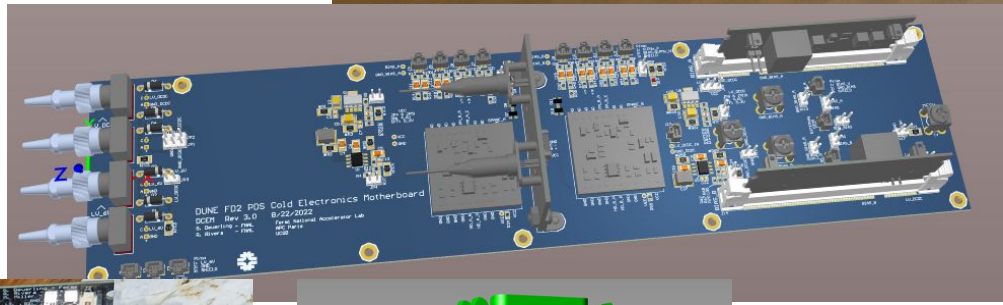
SoF Schedule (Production/Installation)

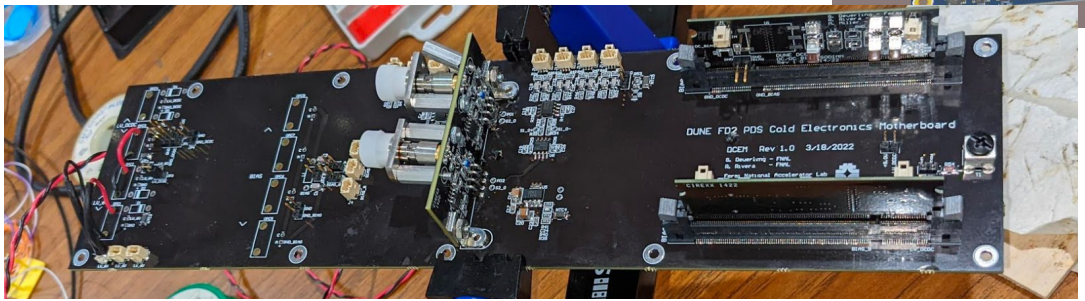
- 8-week lead times on lasers implies last order is 29-Sep.
  - Working on Lasermate defocus order
- 20-week lead times on fibers implies must use PoF black MMF.
- 6-week turnaround for Laser Adapter daughtercard design to turnkey delivery implies last design change is 10-Oct.
- Critical Path Severity: **High**

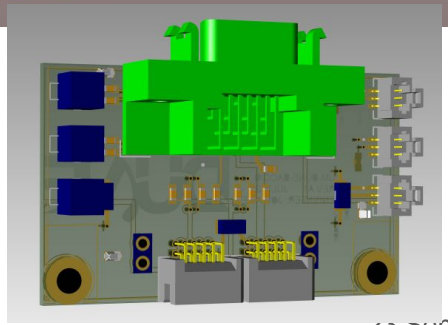


Cold Electronics (CE) State

- SiPM Flex circuits are in production
- 3 flavors of cathode motherboards
  - ‘ARGON2x2’, ‘Simp3x’, and ‘HD+Simp3x’
- 2 flavors of membrane motherboards
  - ‘w/SiPM bias gen’ and ‘w/out bias gen’
- 4 flavors of DC-DC SiPM bias gen
  - PICO, LBL-DCDC, LBL-Opto, and INFN

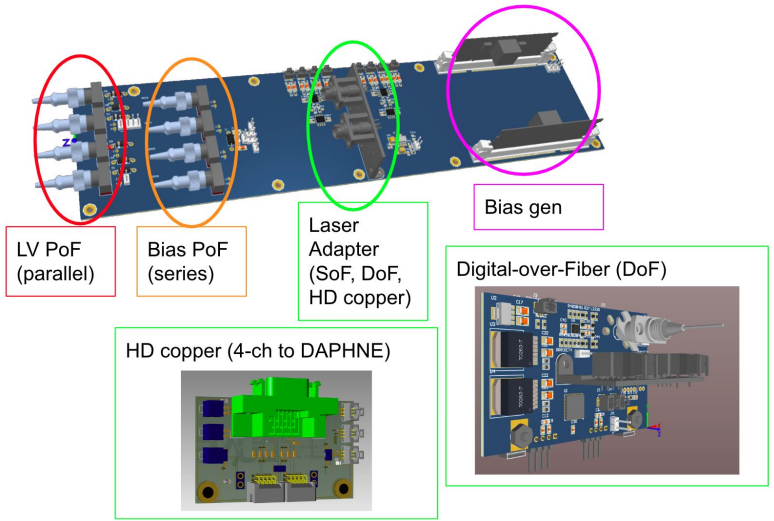






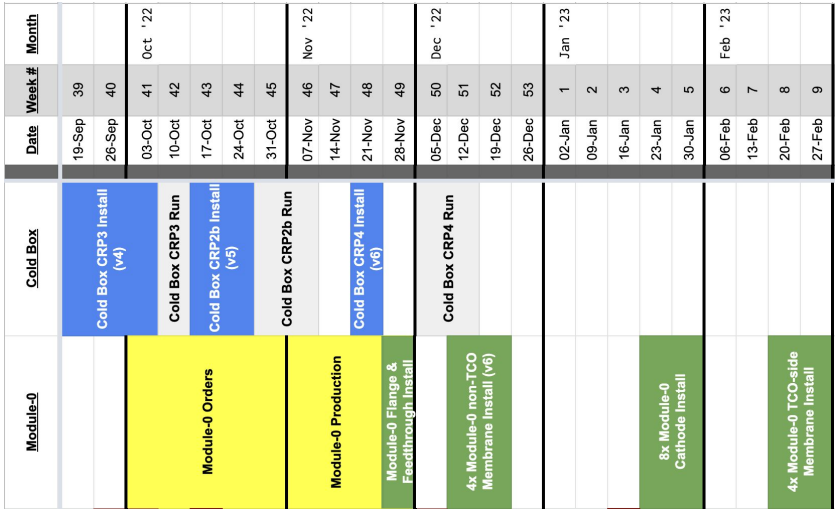
CE R&D towards Module-0

- Downselect motherboard
  - Cathode: Based on SoF pairing, S/N, and power optimization.
  - Membrane: Based on S/N, power optimization (<250mW), and adjustability.
- Downselect SiPM bias gen
  - Based on S/N, cost, adjustability, and 30-year qualification.
- Downselect LDO
  - Based on voltage stability, 30-year qualification, and PoF warm-side regulation.
- Need selection of BOM components (including vendor) for turnkey order
  - Avoid manual population variation and change tracking.



CE Schedule (Production/Installation)

- 60 FBK + 140 HPK **SiPM Flex boards** ordered by UCSB
  - **Flex** expected 14-Oct, then ship to INFN
  - INFN/Spain expect 2652 **SiPMs** by 24-Oct
    - Enough for 16 X-ARAPUCA
    - 250 FBK + 2402 HPK (+750 FBK Jan 23')
  - INFN is planning **SiPM population** order
    - Keep SiPMs for 8x Membrane XA
      - For CERN/Ciemat/INFN XA assembly?
    - Ship NIU SiPMs for 8x Cathode XA
  - **Fallback plan** is use SiPMs from 4x Cold Box XA for non-TCO Membrane XA install
- 17-Oct: Readout/DC-DC **PCB Designs and BOMs frozen**
  - 2-weeks to place order + 4-week lead times on turnkey orders
- Critical Path Severity: **High**



Summary

- PoF/SoF (Response & Monitoring) Fiber Routing
  - Design decision: Fiber route path; dressing/conduit approach; other consortia interfaces
  - Biggest challenge: Order lead-times
  - Critical Path Severity: **Medium**
- PoF
  - Design: GaAs system
  - Biggest challenge: Splicing; adapting to **laser flooding**
  - Critical Path Severity: **Low**
- SoF
  - Design decision: laser and fiber pairing
  - Biggest challenge: **Laser flooding**; order lead-times
  - Critical Path Severity: **High**
- CE
  - Membrane Design decision: Bias gen vs DAPHNE gen
  - Cathode Design decision: ARGON2x2 vs Simp3x; LDO-a vs LDO-b vs regulated-PoF
  - DC-DC SiPM Bias decision: PICO vs LBL-a vs LBL-b vs INFN
  - Biggest challenge: Adapting to **laser flooding**
  - Critical Path Severity: **High**

Organizing FD2 PDS Travel

- For Cold Box, PD team entered unconfirmed/confirmed travel to help everyone plan, should we extend use for Module-0?
  - https://docs.google.com/spreadsheets/d/1qT_wY5rvEtjS2t741bd8TGejxSAtKZlWlWu3m8GozzA/edit?usp=sharing
- Daily ‘FD2 PDS Calendar’ schedule maintained here:
  - https://calendar.google.com/calendar/u/0?cid=bjVmaGNqZ2NhMzM1MmFrbmJtYjNlODRkMmtAZ3JvdXAuY2FsZW5kYXIuZ29vZ2xlLmNvbQ