# Laser Beam Location System

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Calibration and Cryogenic Instrumentation Workshop
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# Outline

- Motivation for the LBLS systems
- Mirror system
- PIN diode system
- Answers to charge

# Motivation

# Ionization laser system requirements

- IoLaser measures distortions of drift velocity (and so, indirectly, E-field) by comparing
  - laser tracks as reconstructed by the TPC
  - "true" laser tracks as predicted by the mechanical/optical system
- Drift velocity precision measurement requirement: 0.5 % (@CPA)
  - Example: 0.5 % drift velocity distortion over a 1 m (3.5 m) region, leads to 5 mm (18 mm) track shifts
- Requirement on beam position uncertainty: 5 mm
  - Why? In order for beam uncertainty to not dominate over TPC wire spacing
- Challenge since DUNE is big!
- Mechanical precision of calibration laser periscope should do it, but how do we check it? How do we align it in the first place?

# Beam position uncertainty factors

- Movement of the cryostat due to pressure swings
  - inclinometer close to each periscope
  - periodical theodolite surveys ?
- Precision of IoLaser periscope mechanics
  - MicroBoone precision
    - wire pitch: 3 mm
    - encoder precision: O(1) mm @ 10m
    - overall precision: 5 mm @ 10 m
- Precision of laser alignment procedure
- Accuracy of relative periscope/TPC position
  - warm surveys
  - accuracy of cool-down calculations?

**Need in-situ validation!**

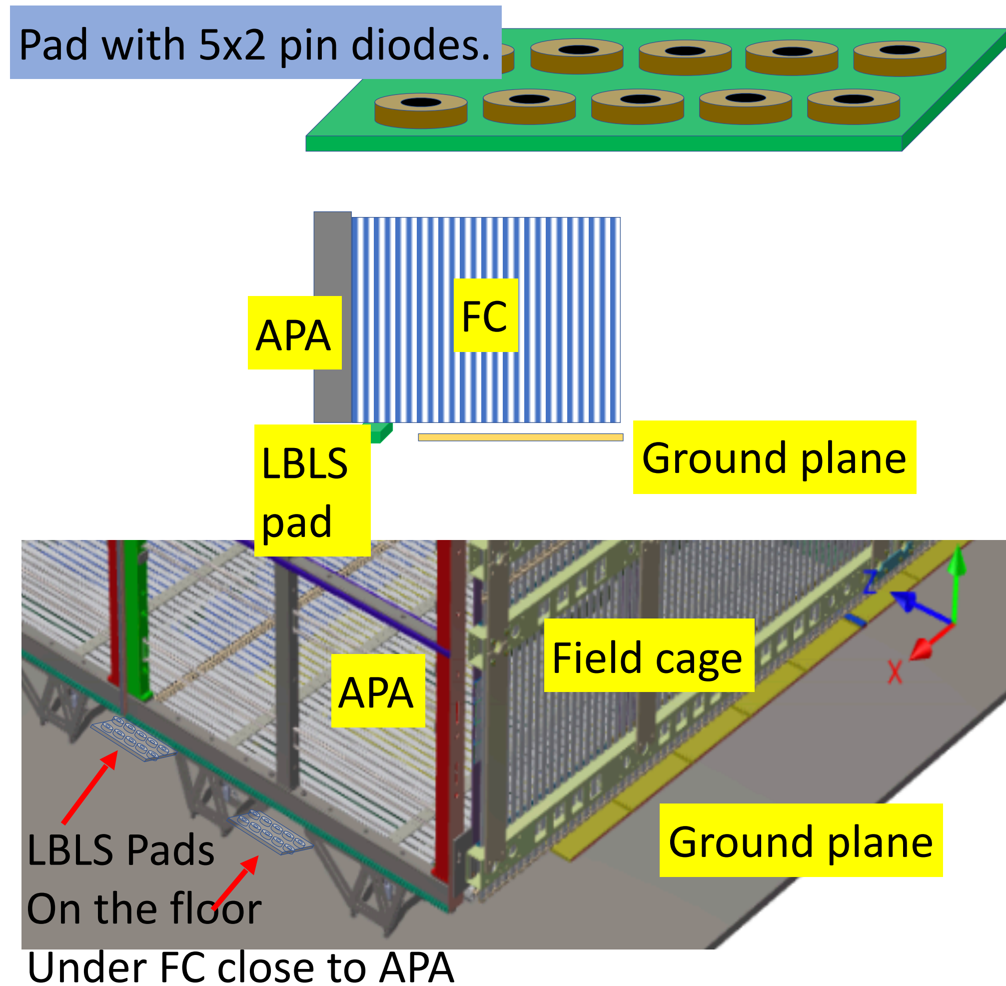
# Two proposed in-situ systems

- PIN diode pads
  - PIN diode gives pulse when hit by laser
  - similar to mini-CAPTAIN system. needs to be outside FC
- Mirror pads
  - new idea for DUNE
  - reflected beam identifies hit mirror. mounted on FC profiles
- Why use both?
  - PIN pads can be used early on, before LAr fill and HV
  - Mirrors are fully passive, no cables. Inside FC.
  - Check position in two different reference frames: FC and cryostat
- Expected precision similar
  - 5 mm precision from a simple yes/no check on signal/reflection
  - better precision may be possible with fine scan and comparing intensity

# Pin diode system

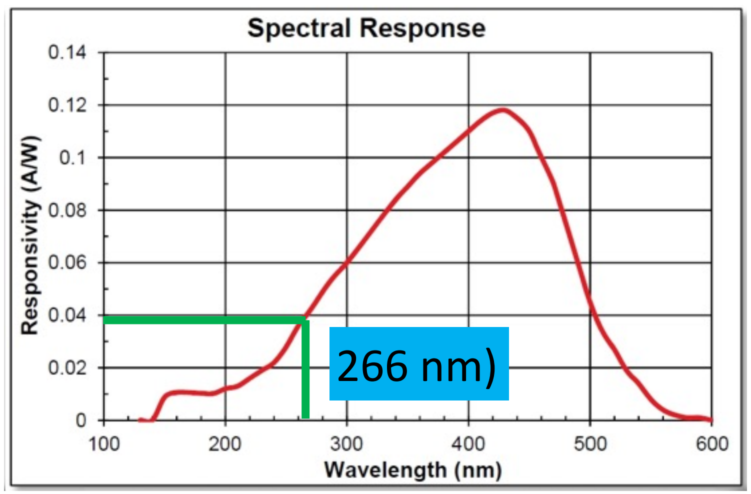
# Purpose of Laser Beam Location System (LBLS)

- Determine IO laser track direction **in-situ** by detecting the beam spot.
- Simple passive system – laser illuminated photodiodes generate electric pulse.
- **LBLS placed on the cryostat floor** under the FC, close to APA plane to avoid high electric field region and obstruction from the ground plane; choose location so each can be seen by two lasers across from it (consulted Bo Yu)
- Signal cables routed along the floor, grouped together with the cryogenic pipe structure.
- Carefully measure locations of LBLS after installation with respect to APA and CPA



# Candidate pin diode: UV sensitive GaP PIN diode operated passively


$$R_\lambda = \frac{I_P}{P}$$

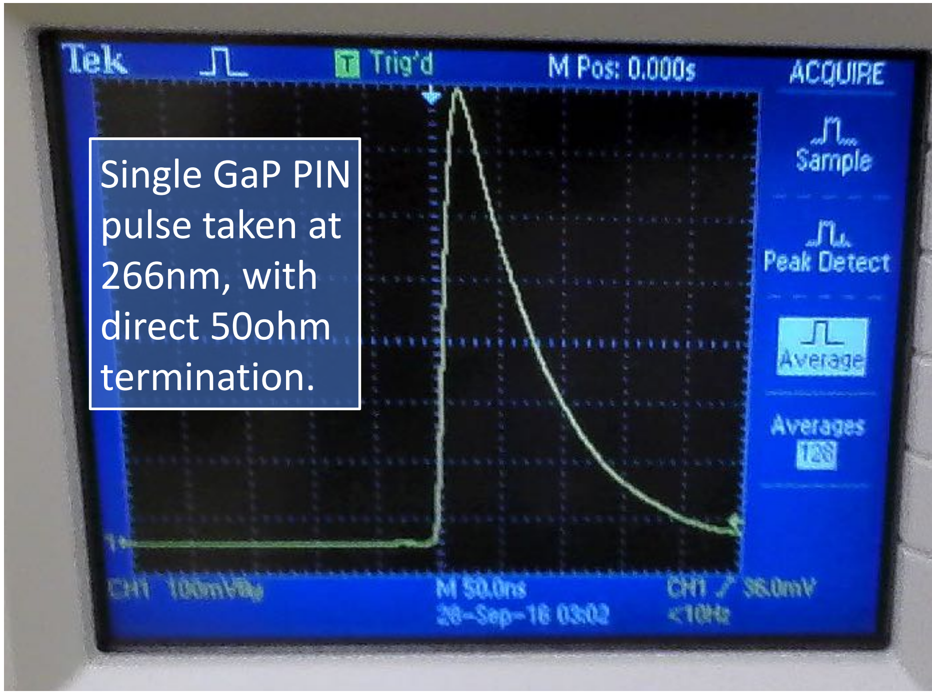



FGAP71 - GaP Photodiode, 1 ns Rise Time, 150-550 nm, 2.2 mm × 2.2 mm Active Area

| Specifications[a] | | |
|---|---|---|
| Wavelength Range | $\lambda$ | 150 - 550 nm |
| Peak Wavelength | $\lambda_P$ | 440 nm |
| Responsivity | $\Re(\lambda)$ | 0.12 A/W |
| Active Area | - | 2.2 mm x 2.2 mm |
| Rise/Fall Time ($R_L$=50 Ω, 5 V, 405 nm) | $t_r/t_f$ | 55 ns / 55 ns (Typ.) |
| NEP, Typical (440 nm, 5V) | W/√Hz | 1.3 x $10^{-14}$ |
| Dark Current (5 V) | $I_d$ | 15 pA (Typ.)<br>40 pA (Max) |
| Capacitance (0 V) | $C_j$ | 1000 pF (Typ.) |
| Package | - | TO-39 |
| Sensor Material | - | GaP |

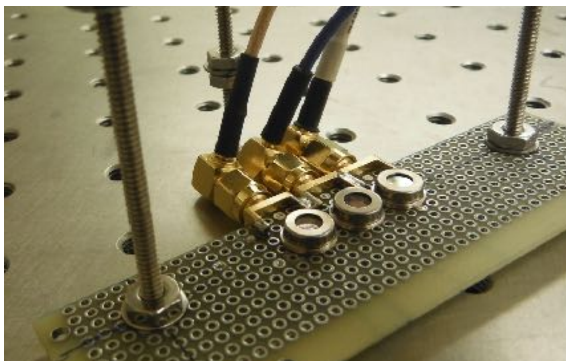
# LBLS testing

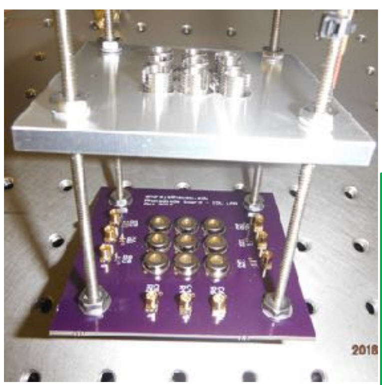
- A single PIN diode soldered directly to a 50 ohm co-ax cable with an SMA termination.
- Very steep rising edge and strong signal – 750 mV
- Pulse duration about 200 ns for the *5 ns* laser pulse.

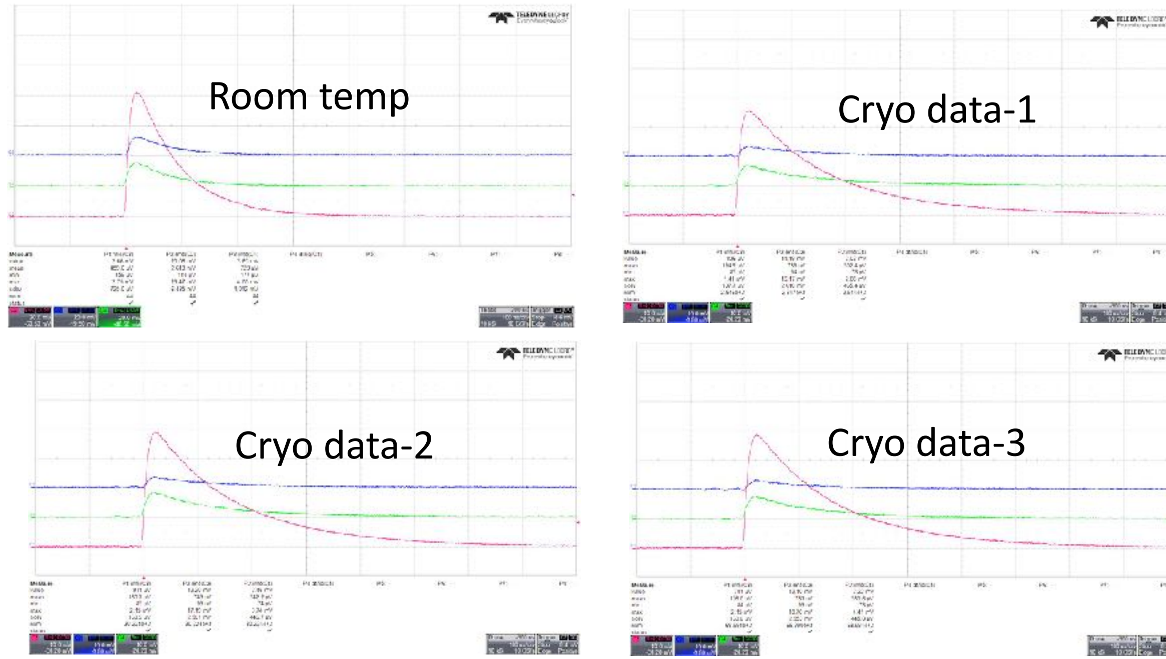



Single GaP PIN pulse taken at 266nm, with direct 50ohm termination.

# Candidate pin diode: UV sensitive GaP PIN diode operated passively





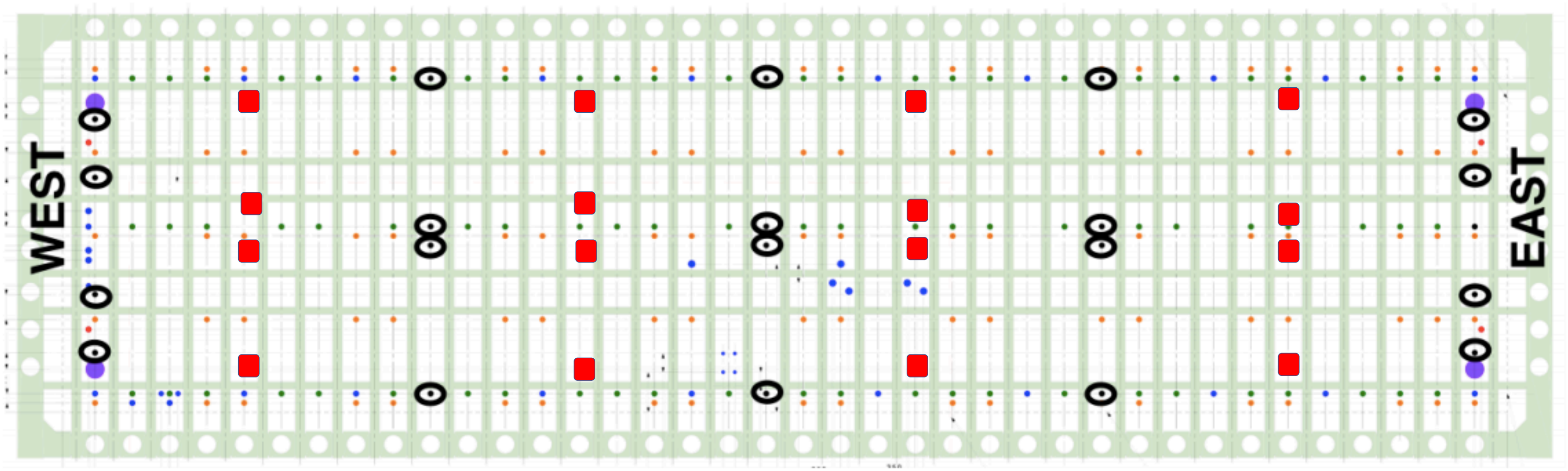



Data from the 3x1 LBLS array exposed to 266 nm laser beam before and after cryo cycling. The magenta trace is the center PIN, blue and green are outer ones.

***Thus: LBLS is able to detect the brightest region of the laser beam. No signal degradation after multiple cryo cycles.***

# Laser Beam Location System Locations and Planning

- Each pad consists of 10 pin diodes, placed in 2 rows (5x2) for easier localization, imaging and redundancy.
- Total of 16 LBLS sensor pads with 4 LBLS pads per drift volume.
- Each LBLS pad will be visible by two lasers.
- LBLS placed on the floor near APA to limit exposure to HV.
- Locations carefully surveyed prior to detector closing.



# LBLS Cost

- The cost of the system is modest.
- The main cost of the system is the pin diodes ~$90/each
- The cost of a single LBLS pad is $1,000
- For 16 modules + 3 spares, the cost is $19k
- Other cost include cables to be routed to the surface, but are minor.

- Cost of the ProtoDUNE II system would be of the order of ~$4k and would include 2 pads and routing cables.

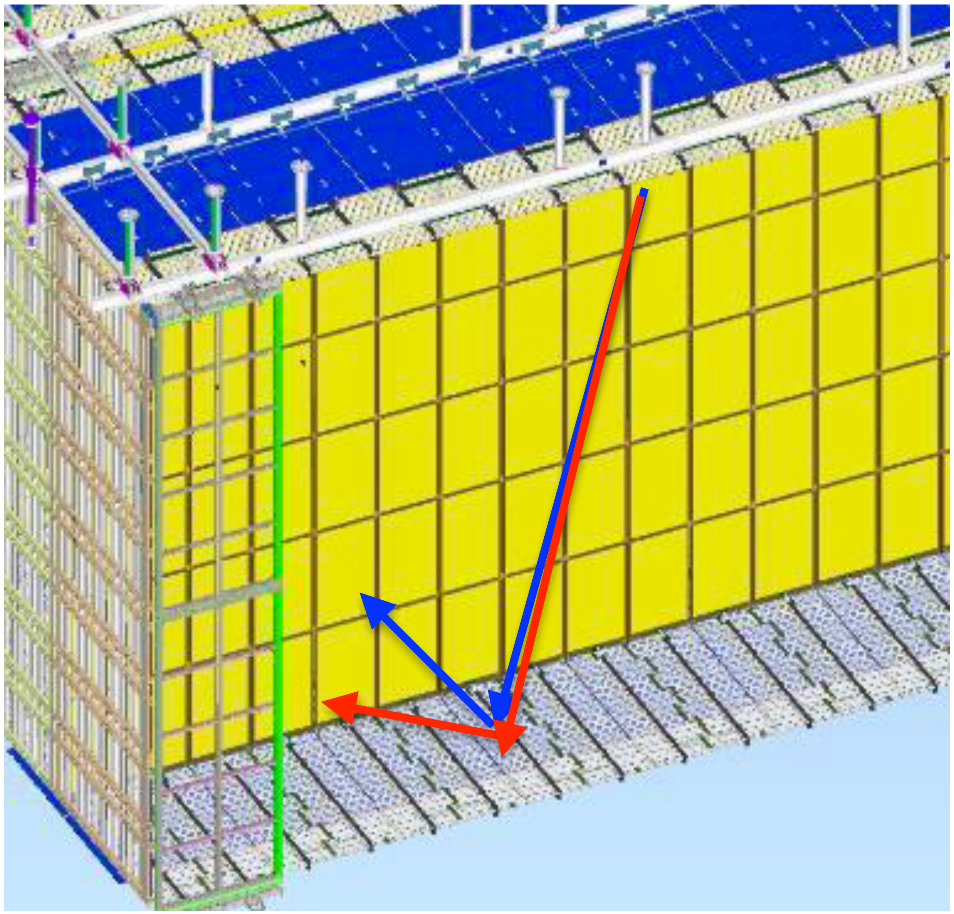
# Planning for installation in ProtoDUNE-2

- Two dedicated locations, close to APA (because of HV), under the field cage, but not under the ground plane, to avoid obstructed view. Attachment method to the floor – cryogenic glue? (should be OK)
- Routing of cables on the floor and along the wall, following cryogenic pipes
- Allocating (sharing) exit port for the cables – to be determined. 2 Dsub connectors would suffice.
- Read out system for the LBLS will be integrated with the Slow Control

- The system can be fabricated and tested prior to the end of 2020 and installed in 2021. Flange allocation for taking out signal cables is the main issue to be solved.

# Mirror pad system

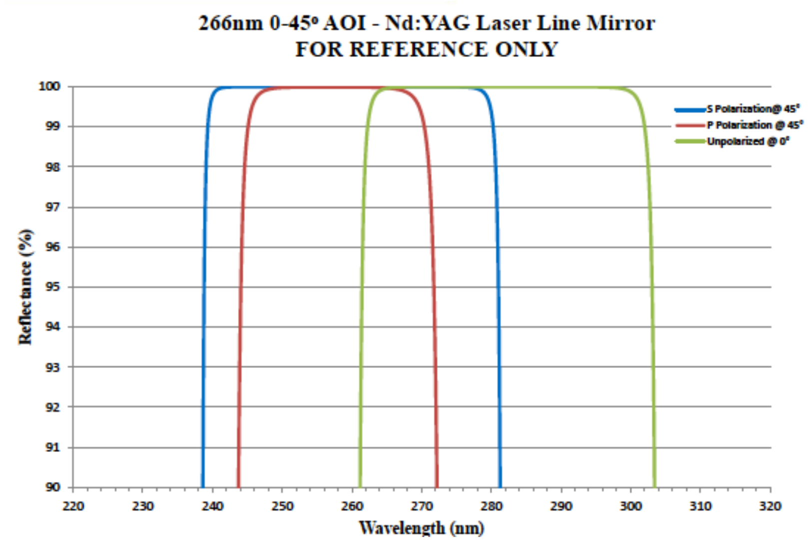
# The idea



- Aim the beam at a mirror in a known location.
- Precision ~ size of the mirror. Cluster of 5 mirrors together to make it easier to find them
- Each mirror with a different angle
- Reflected beam angle unambiguously identifies which mirror was hit

- To be carried out at the start of any IoLaser scan.
- Initial alignment may take a few shots. Automated scan.

# The mirrors

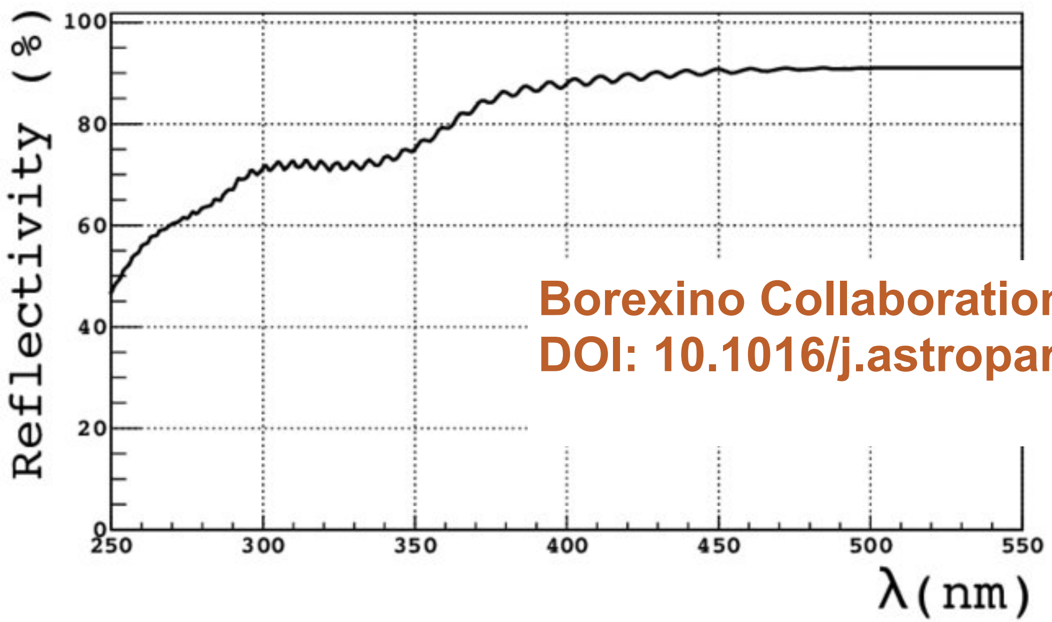



- Edmund Optics Nd:YAG Laser Line
  - substrate: fused silica
  - coating: dielectric
  - surface quality: 10-5
  - wavelength range: 263-268 nm
  - Rabs >99.8% @ 266nm
  - Angle of incidence range: 0 - 45 deg
  - Size
    - Radius: 6.35 mm, thickness: 4 mm
  - Cost: ~ 100 € each

https://www.edmundoptics.eu/f/ndyag-laser-line-mirrors/39566/

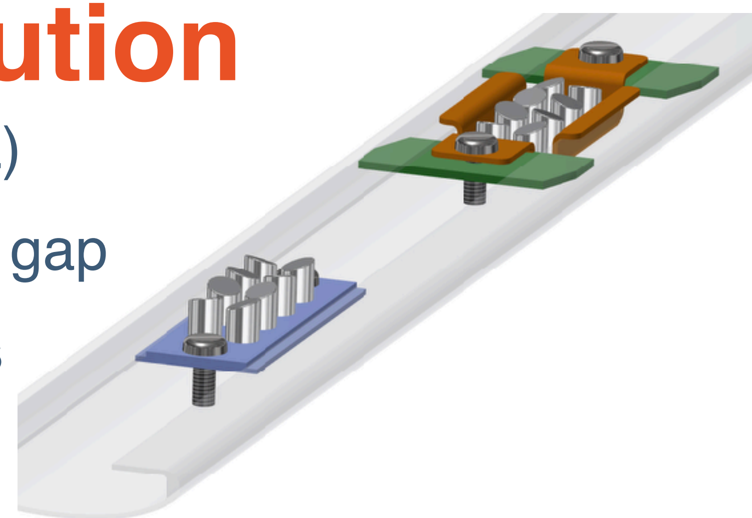
# Cheaper alternative

- Polished aluminum discs. Reflectivity at 266 nm is ~ 50%.
- Is it enough:
  - to see the reflected beam?
  - to distinguish from reflections on the FC itself ?

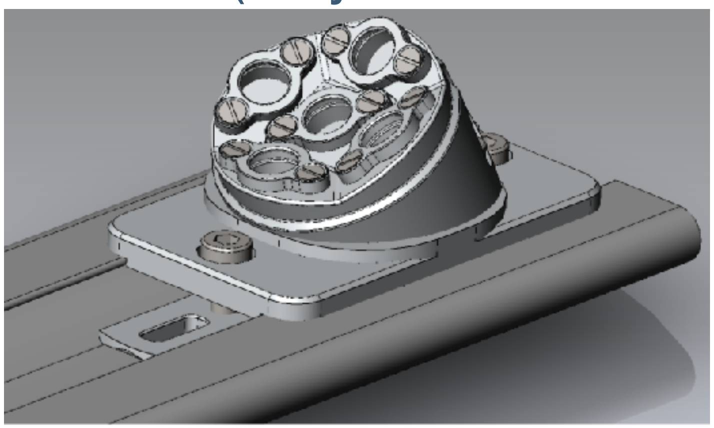



**Borexino Collaboration,**
**DOI: 10.1016/j.astropartphys.2017.10.003**

# Holder design evolution

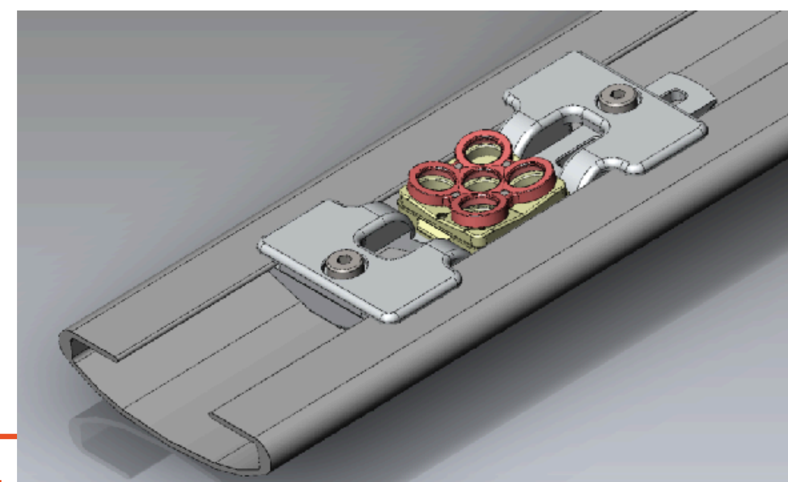


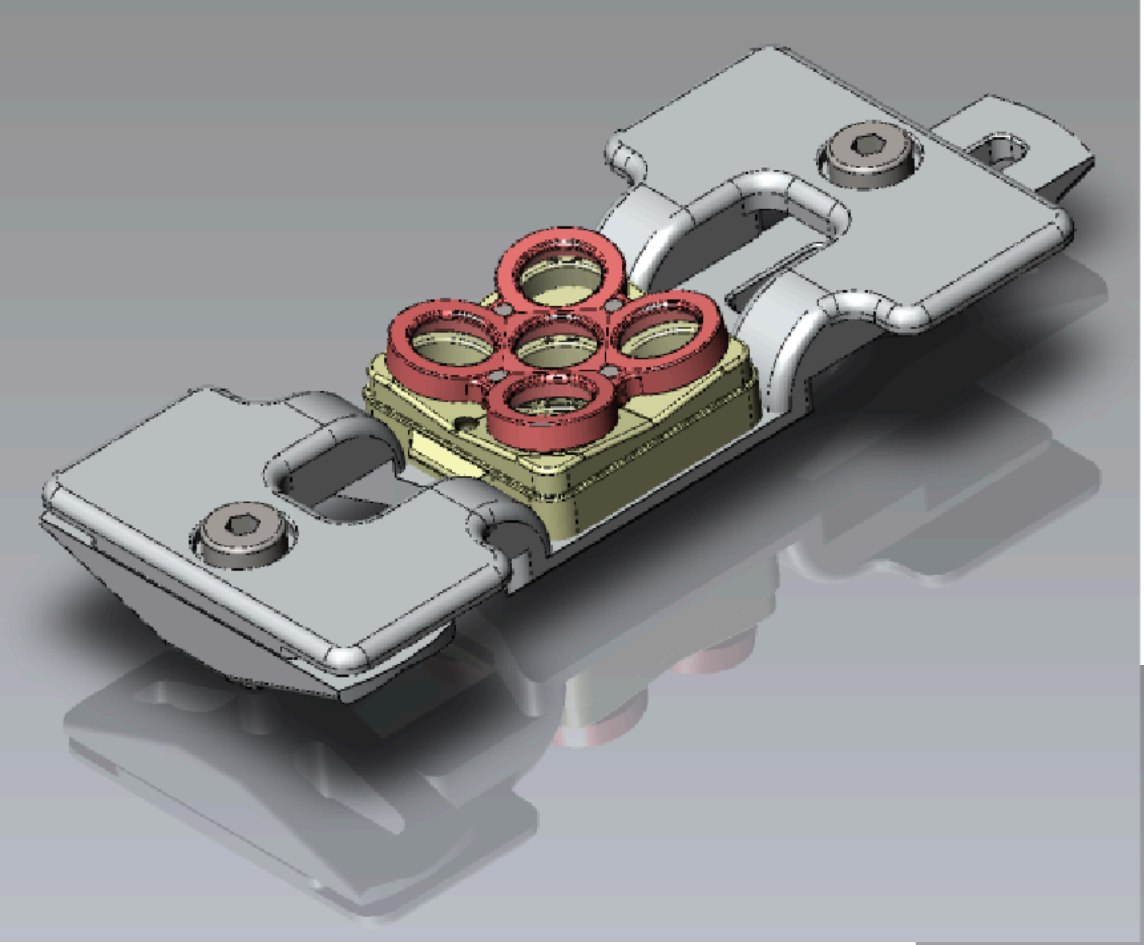
- Initial drawings by Bo Yu (BNL)
- ✔ Attached to inner FC profile gap
- ✘ Polished aluminum surfaces (maybe not reflective enough)



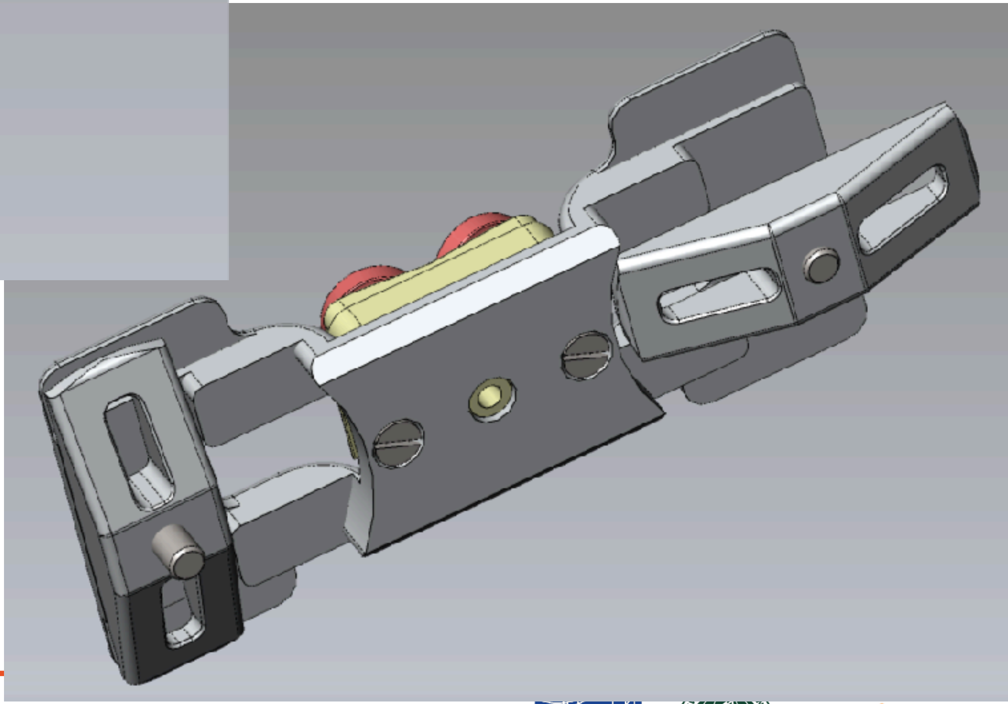
- First version from Rui Alves (LIP)
- ✔ Holder for commercial mirrors
- ✘ Standing too much out from FC

- Second version from Rui Alves (LIP)
- ✔ Holder for commercial mirrors
- ✔ Lowered into gap
- ✔ Rounded edges





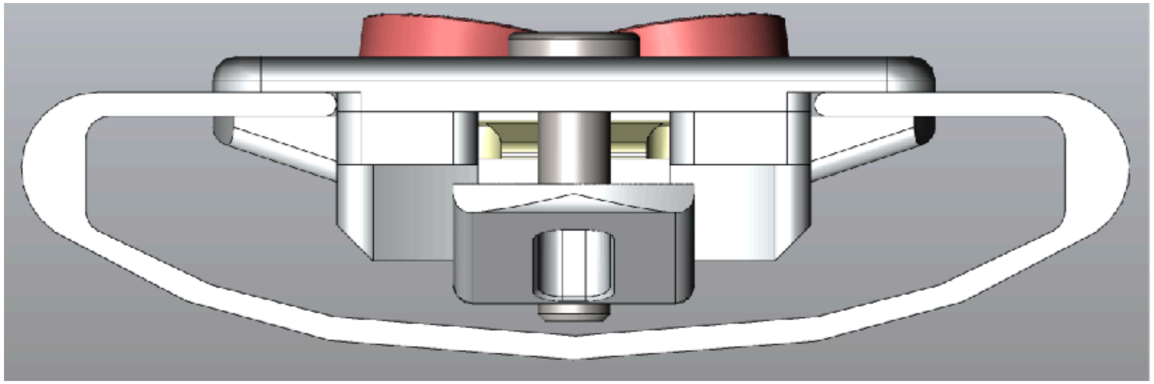
# Overview



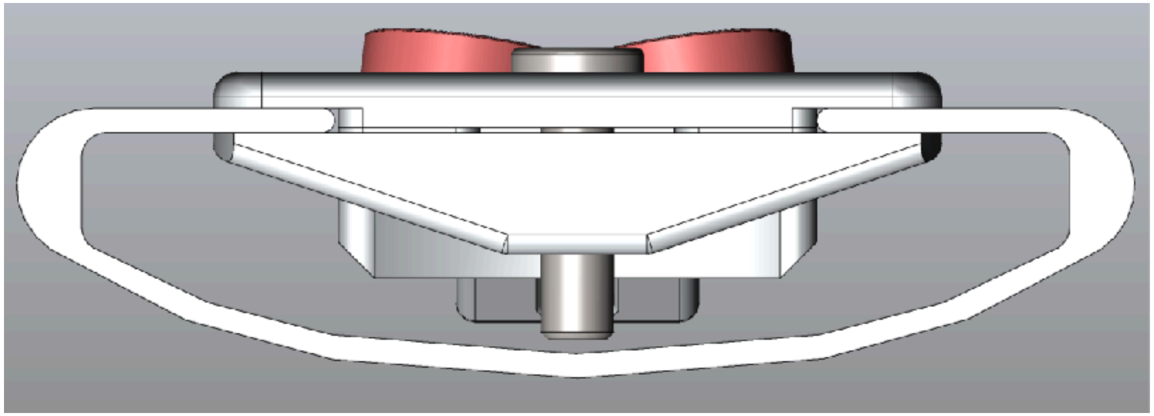
- all machined parts in aluminum
- screws in stainless steel
- removable cap in plastic

# Fixation to FC

- First, enter the gap



- Second, rotate bracket into place and tighten screw



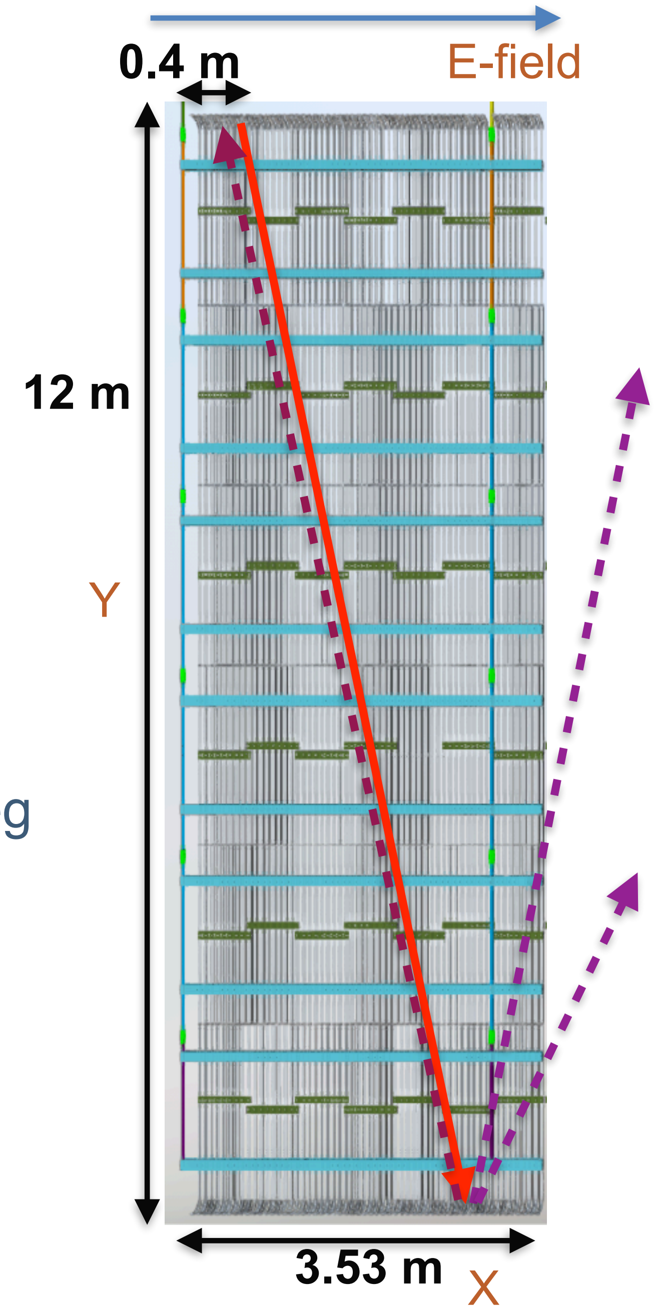
- Tighten only the edges, avoid pressing against the bottom of the FC

# Define the positions/angles

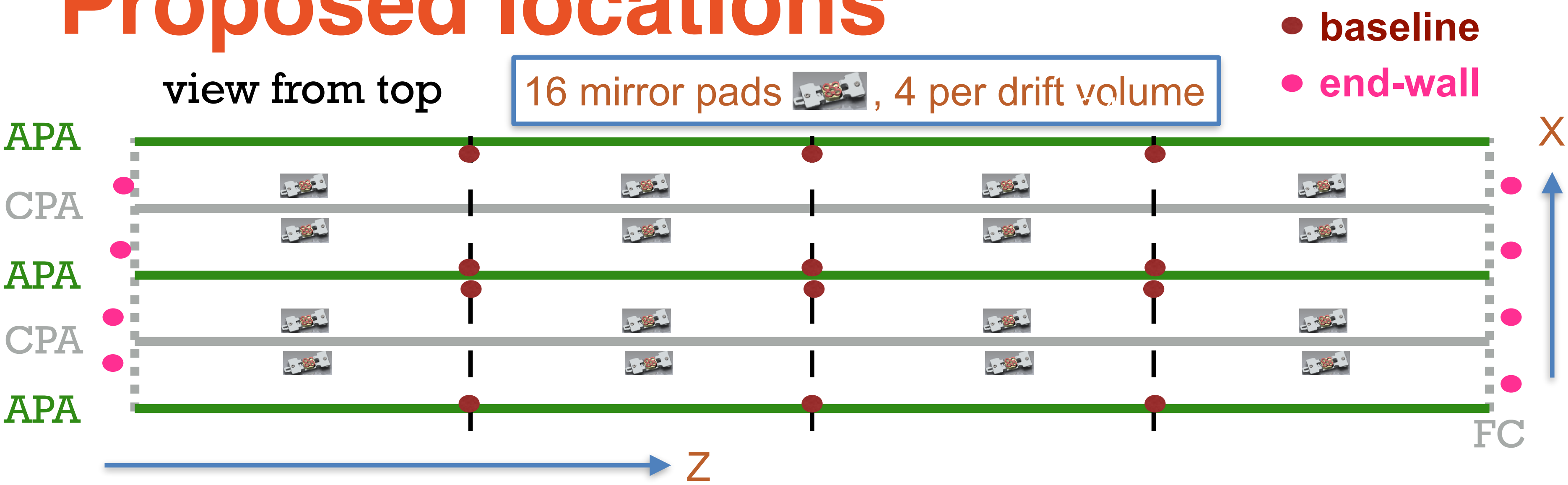
- Requirements
  - Not more than 20 m away. Preferably less, due to beam divergence
  - Reflection at least 1 meter long
  - Reflections should never hit PDS
  - Piece should be rotation symmetric (to avoid installing it wrongly)

# End-wall view

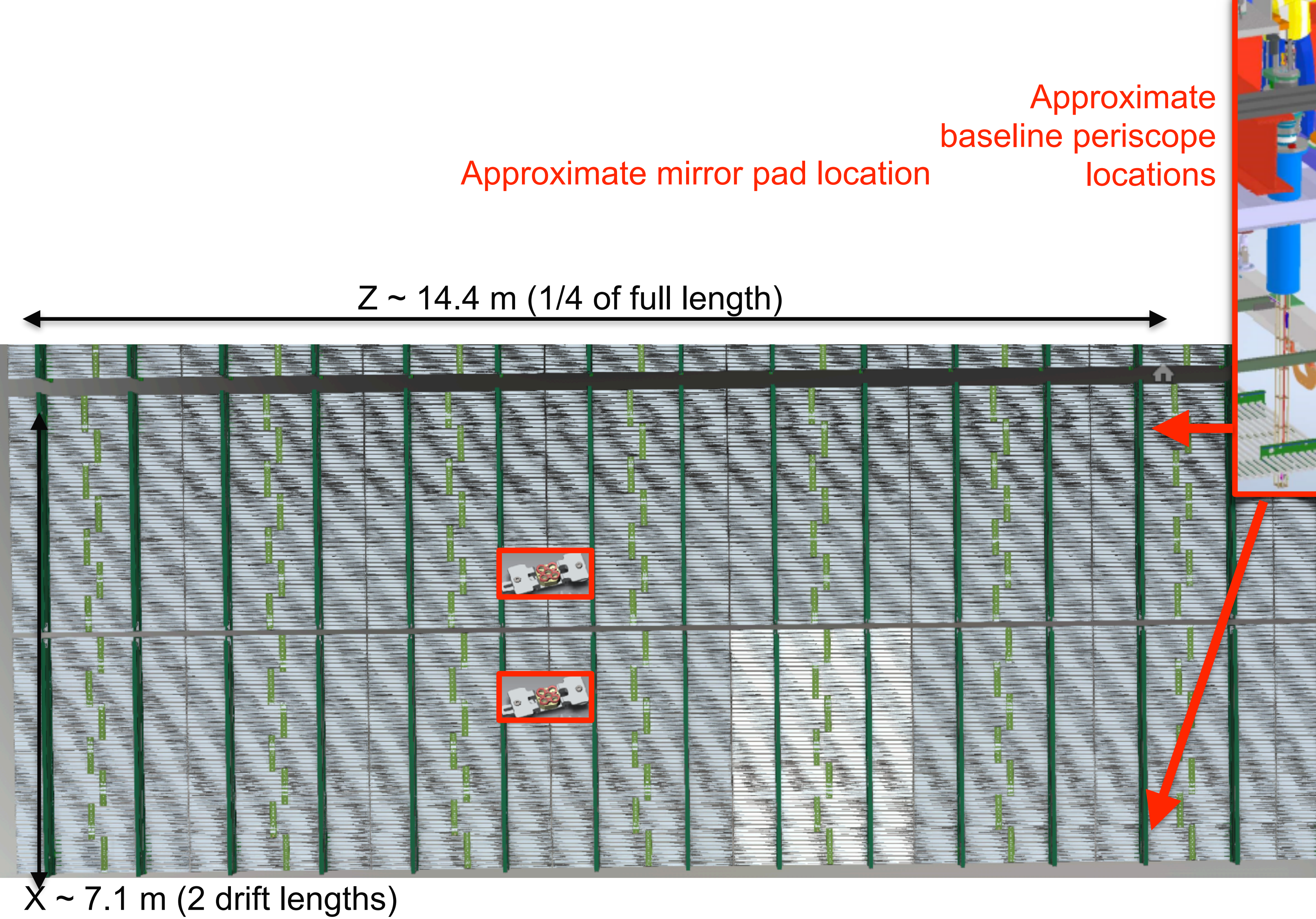
- Maximum angle if mirror pad close to CPA: atan (3.13/12) = 15 deg
- If mirror ~ 1 m distant from CPA: atan(2.13/12) = 10 deg
- So, place pad 1m away from CPA
  - Incidence angle in pad (XY plane) = 10 deg
  - Still enough room to see reflection
  - Max reflection (-10 deg) does not hit PDS



# Proposed locations




- Along X (drift): closer to CPA ~ 1 m away
  - i.e. profile #17 counting from CPA
- Along Z (beam): Roughly half-way between laser periscopes
  - ideally: -21.8 m, -7.3 m, +7.3 m, +21.8 m from the detector center.
  - in practice: next to end cap closer to TCO of modules 3/25, 9/25, 16/25, 22/25 (with module 1/25 being the furthest away from TCO)
  - easier for installation, within arms reach of module edge


Approximate baseline periscope locations
Approximate mirror pad location
Z ~ 14.4 m (1/4 of full length)
X ~ 7.1 m (2 drift lengths)

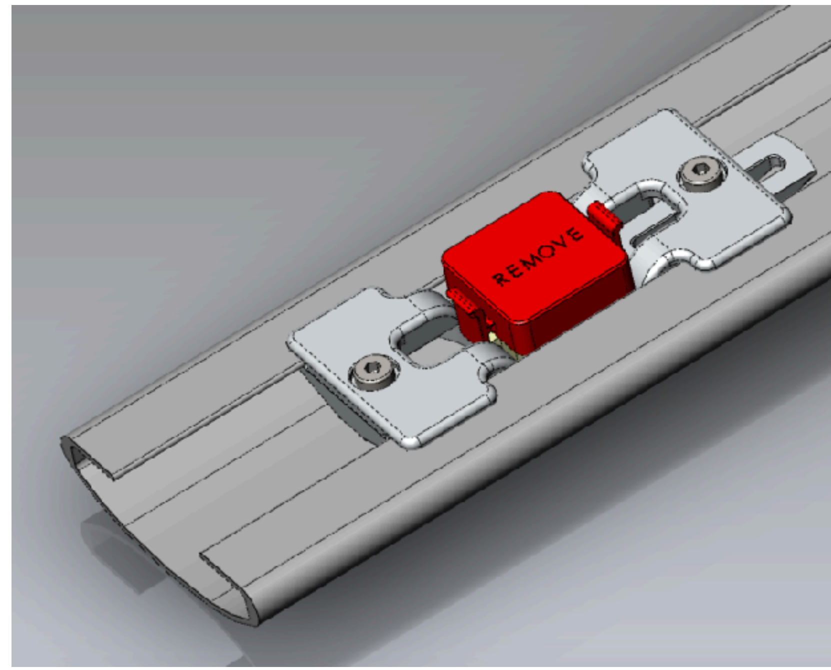
**away from TCO side** **TCO side**

Close to FC #17 ~ 1.02 m away from CPA

**away from TCO side** **TCO side**

# Installation Plan

- Ship pad from Portugal
- QA & Pre-assemble with plastic pad to protect mirrors
- Option 1)
  - Mount on FC module outside cryostat
  - Operator in cryostat just removes cap before lowering of the next module
- Option 2)
  - Operator in cryostat mounts and removes cap before lowering of the next module



# Cool-down checks

- Example: Aluminum cool-down expected ~< $3x10^{-3}$ (0.3%)
  - for instance 3 mm over 1 m
- How do we know exactly where the mirrors are?
  - more general question for DUNE on reference frame of detector after cool-down
- LBLS system can help:
  - eliminate laser alignment uncertainties by measuring two (or more) different mirror pads with the same laser periscope
  - check FC/cryostat ref. frame shift by measuring LBLS mirror pads and LBLS PIN diode pads with same laser periscope

# ProtoDUNE plans

1. Design, Organization
    1. Produce and test prototype
        1. Machining scheduled for July at LIP workshop
        2. Two mirrors bought for initial tests
        3. FC profile sent from CERN (thanks Francesco!)
        4. Test mechanics in liquid nitrogen/ test attachment to FC profile
    2. Converge on installation plan details with HV consortium
2. Procurement/ fabrication of 2 mirror pads, 1 Al disc pad (all @LIP)
    1. Fabricate ~ 10 polished aluminum discs ~Summer 2020
    2. Procure additional 10 mirrors (LIP) ~Fall 2020
    3. Fabricate 4 mirror holders (1 spare)
3. Installation at CERN could be early 2021

# Answers to charge

# Review Charge - Part I

- Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?
  - This system is ancillary to the Ionization Laser calibration system, with a well-defined role in the alignment of the beam and the validation that the position precision requirements are met. Without an LBLS system, it may be hard to demonstrate that the beam position precision is really ~ 5 mm @ 10m distance

# Review Charge: Scope scenarios

- Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?
    - 1) Absolute minimum scope: each baseline laser within less than 15 m from a LBLS pad, i.e. 8 pads (choosing either mirror or PIN).
        - No allowance for redundancy, inter-pad checks, no possibility of reference frame checks, so this is not recommended
    - 2) “Baseline” scope: 16 mirror + 16 PIN pads. Allow some redundancy, inter-pad checks, inter-frame checks, end-wall laser coverage.
    - 3) “Extended” scope, allowing further consistency checks for cool-down effects, including the DC end-walls would require 8 mirror pads per drift volume (32 total), in addition to the 16 PIN pads.

# Review Charge - Part I

- Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?
  - The system is quite simple to build and install, no technical issues have been raised.
  - Methodological question raised in the previous WS: How do we distinguish a laser beam misalignment and FC cool-down effects?
    - we combine information from multiple mirror pads and/or with the PIN diode pads to remove ambiguity.
- Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?
  - Risk: laser beams reflecting on the mirrors towards the PDS. The mirror angles are chosen to be well away from the APAs. Stray reflections can be checked in PD-II
- Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?
  - Yes. The designs are advanced in both cases and the necessary contacts with the HV consortium have been established.

# Review Charge - Part I - Cost

- Does the functionality of the system justify its overall cost?
  - The M&S cost is mostly just the mirrors and the PIN diodes themselves. ~500€/mirror pad or 1000 $/ PIN pad.
    - Scope 1) 8 pads: 5 k€ mirror, 10k$ PIN
    - Scope 2) 16 pads ~ 30k$
    - Scope 3) 16 PIN + 32 mirrors ~ 40 k$
  - Quite minimal.

including a few spares

# Review Charge - Part II

- Essential:
  - To have at least one LBLS, otherwise the laser ionization data risks being very uncertain. Scope 1
- Highly desirable:
  - It is “Highly desirable” to have both.
    - LBLS PIN-diode system can be used for checks still in the warm.
    - Mirror system is fully passive, and in a different reference frame — very important to constrain cool-down effects
    - Scope scenario 2 is very highly recommended and with minimal cost.
    - Scope scenario 3 is a small stretch from 2.