Laser Beam Location System (Mirrors)

José Maneira

Initial Design Review of the Ionization Laser Calibration System

September 18, 2020

Outline

- Motivation/requirements
- Mirror pad system
- Positions in DUNE
- Revisit Requirements
- Plans for ProtoDUNE

Motivation / Requirements

Ionization laser system requirements

- IoLaser measurements of drift velocity/E-field done by comparing
  - laser tracks as reconstructed by the TPC
  - “true” laser tracks as predicted by the mechanical/optical system
- Drift velocity precision 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
  - So that beam uncertainty does not dominate over TPC wire spacing
- Mechanical precision of periscope obeys that, but how do we check it? How do we align it in the first place?

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.
- 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

Cool-down checks

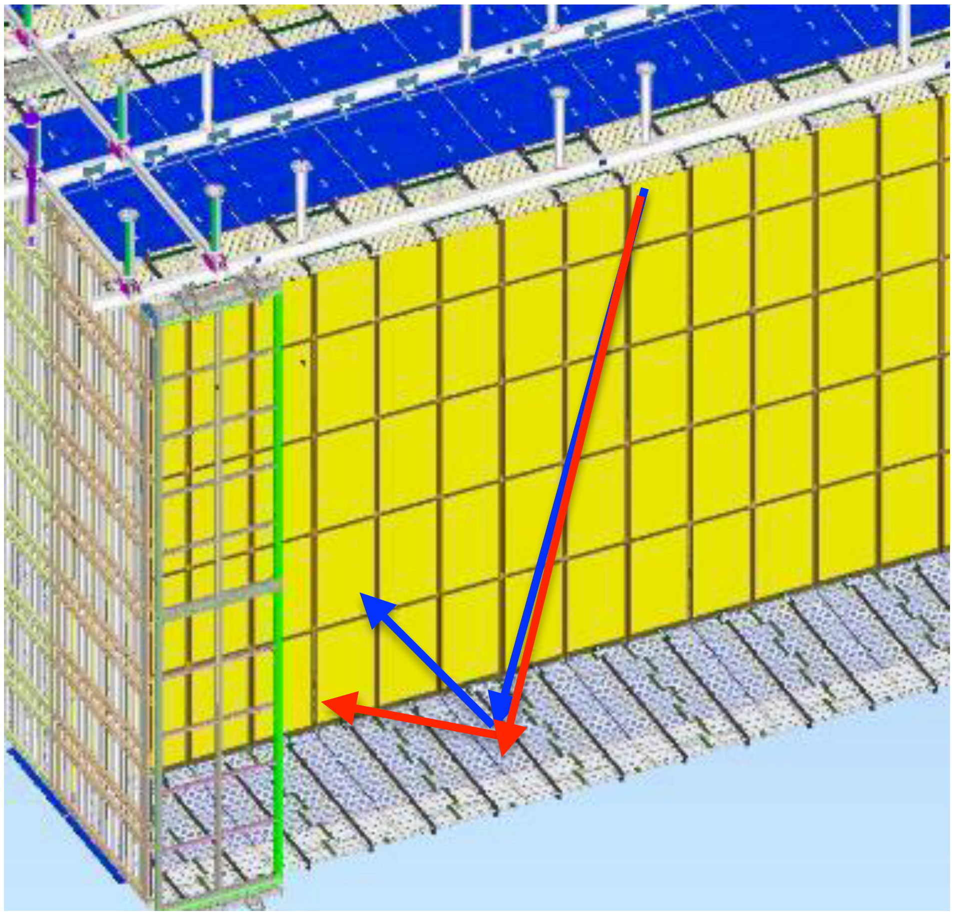
- Example: Expected cool-down 0.1%
    - for instance 3 mm over 3 m
- How do we know exactly where the mirrors are?
    - more general question for DUNE on reference frame of detector after cool-down
- LBLS system can help:
    - eliminate laser alignment uncertainties by measuring two (or more) different 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

Main requirements guiding design

- Size of the laser beam targets: not larger than 5 mm.
- Knowledge of the mirror position w.r.t. the FC: much better than 5 mm.
- Positioning: each laser periscope must have at least two LBLS pads within a distance range of 10 - 20 m (maximum assumed laser beam range).
- Ease of observation 1: the reflectivity and quality of the mirror must be such that the reflected beam is still intense and collimated enough to cause LAr ionization for at least 1 m beyond the mirror.
- Ease of observation 2: the position and inclination of each mirror must be such that the reflected beam is still contained within the TPC for at least 1 m beyond the mirror.
- Photon detector system (PDS) safety: the reflection angle of the mirrors must be such that in no way the reflected beam will hit a PDS module.
- Reference frame checks: as much as possible, different mirrors within view of the same periscope should be placed in different FC modules.

Mirror pad system

The idea

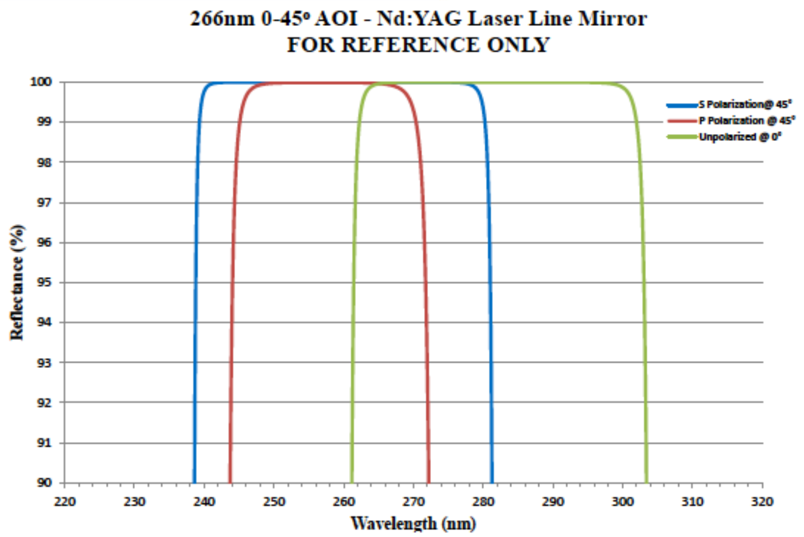


- Aim the beam at a mirror in a known location.
- Precision ~ size of the mirror. Cluster of 5 mirrors together to make it easier to find them
- Each mirror with a different angle
- Reflected beam angle unambiguously identifies which mirror was hit

- 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 flatness: lambda/20
  - Reflectivity >99.8% @ 266nm
  - Angle of incidence range: 0 - 45 deg
  - Size
    - Radius: 6.35 mm, thickness: 4 mm
  - Cost: ~ 100 € each

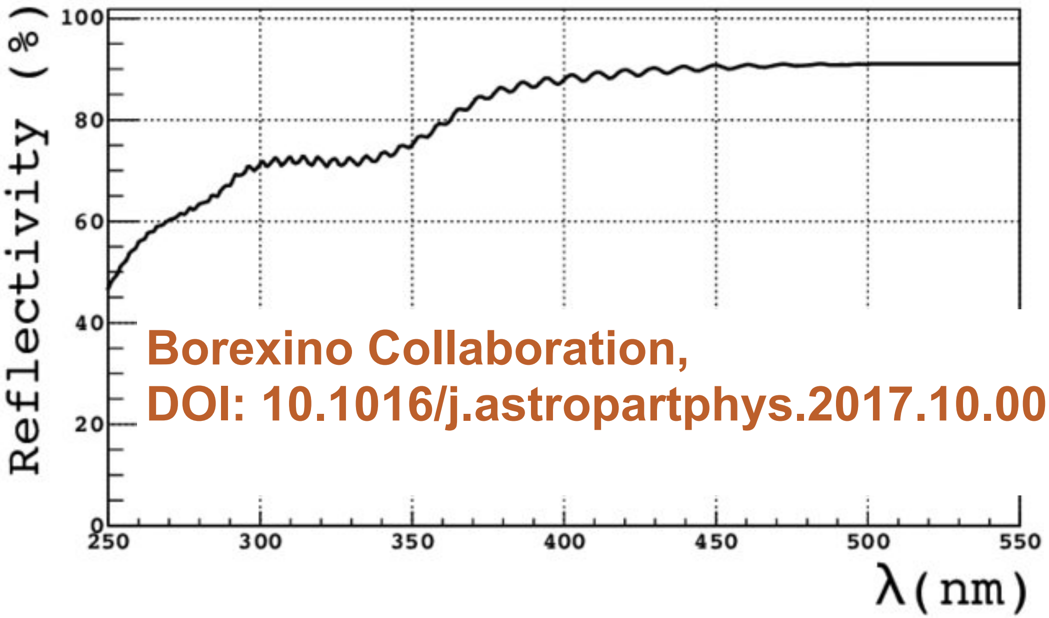


We have 2 at LIP

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

Cheaper alternative

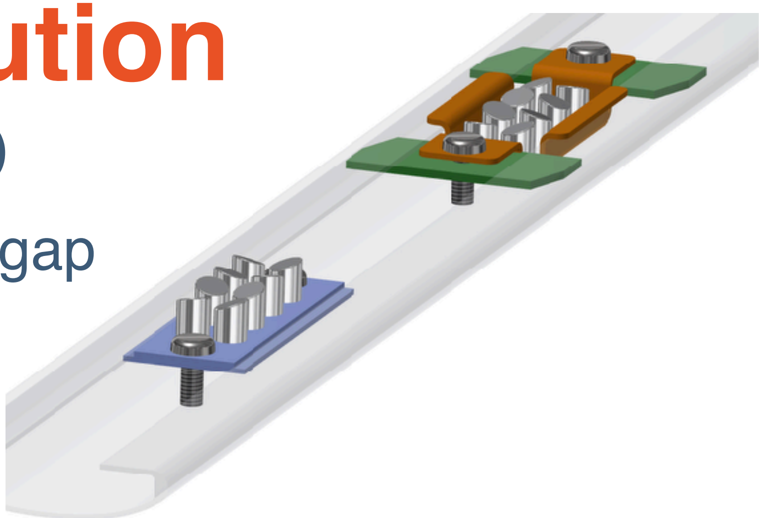
- Polished aluminum discs. Reflectivity at 266 nm is ~ 50%.
- Is it enough:
  - to see the reflected beam?
  - to distinguish from reflections on the FC itself ?



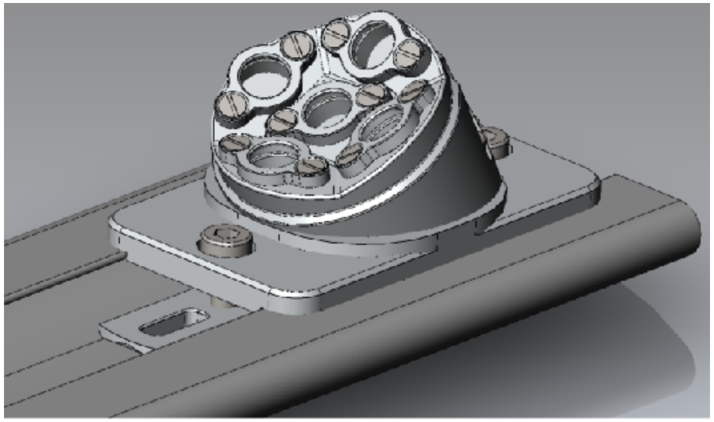
Borexino Collaboration,
DOI: 10.1016/j.astropartphys.2017.10.003

Machined at LIP, same size as mirrors. Will test a few at LIP and PD2

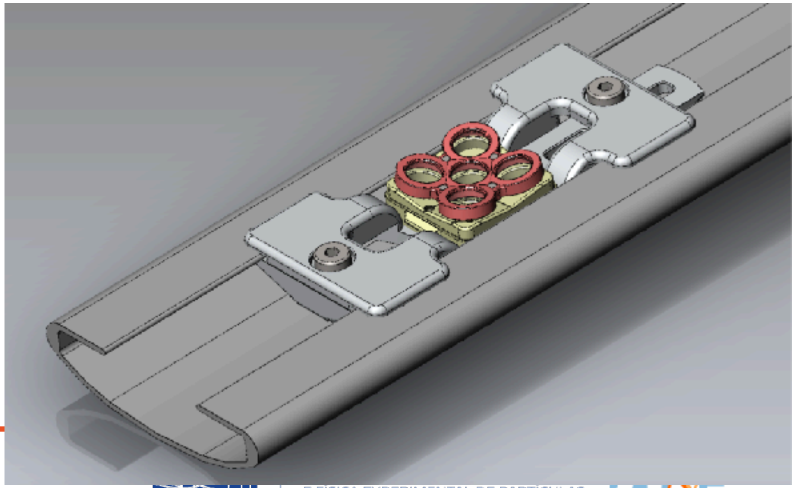
Holder design evolution



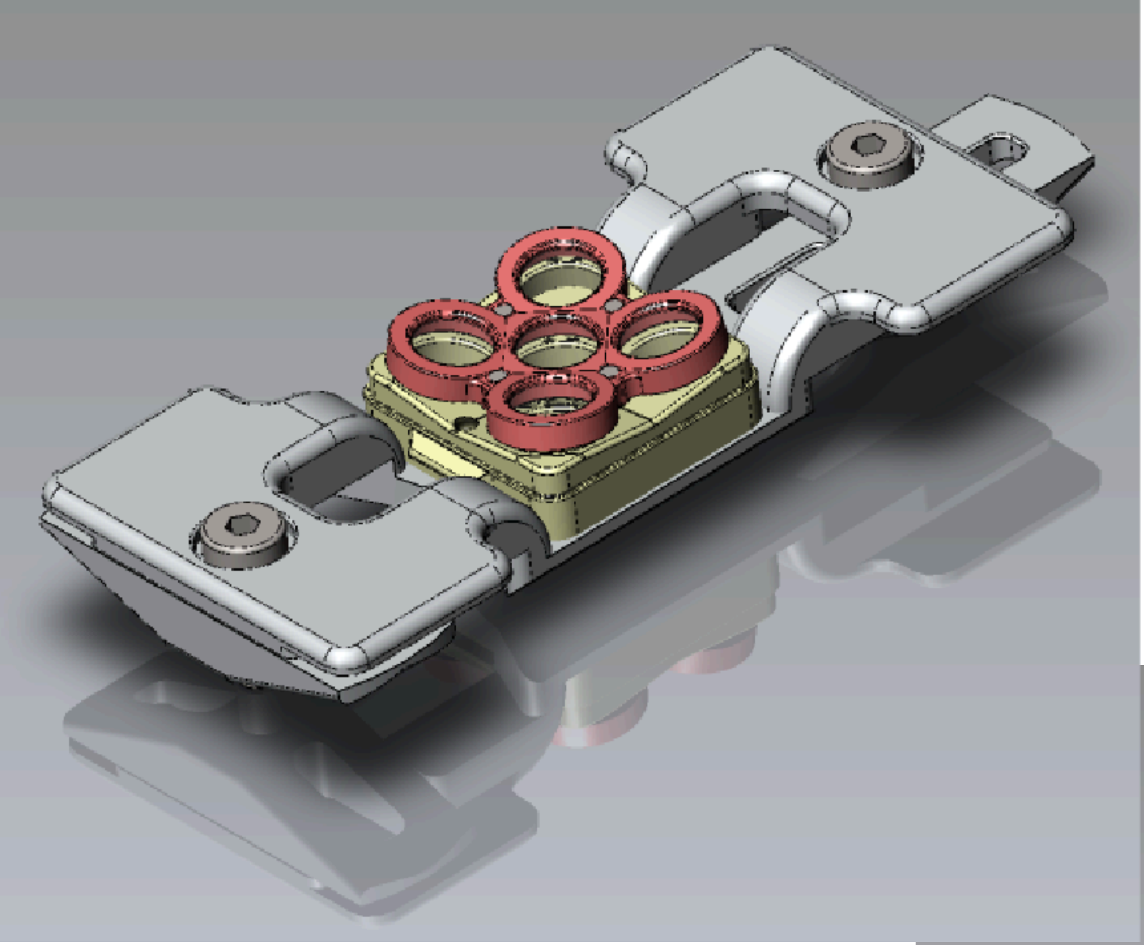
- Initial drawings by Bo Yu (BNL)
- ✔ Attached to inner FC profile gap
- ✘ Polished aluminum surfaces (maybe not reflective enough)



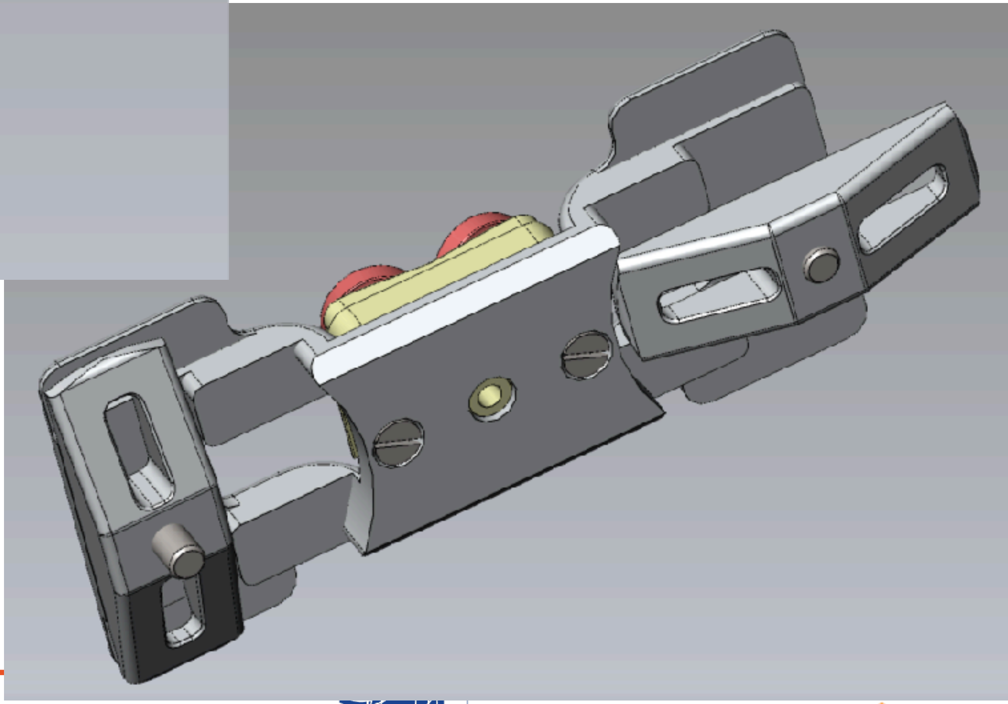
- First version from Rui Alves (LIP)
- ✔ Holder for commercial mirrors
- ✘ Standing too much out from FC



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



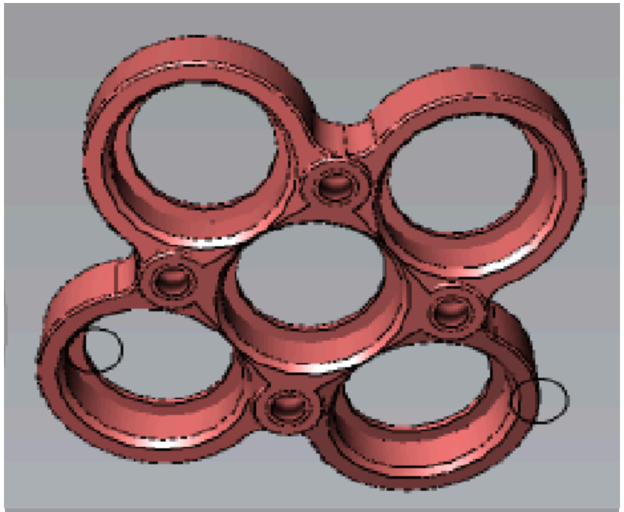
Overview

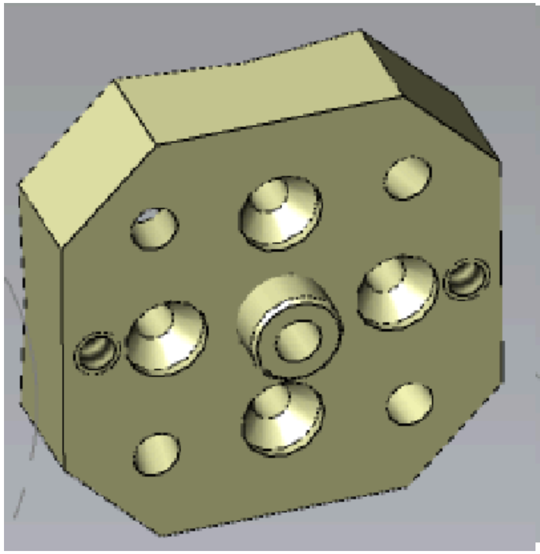


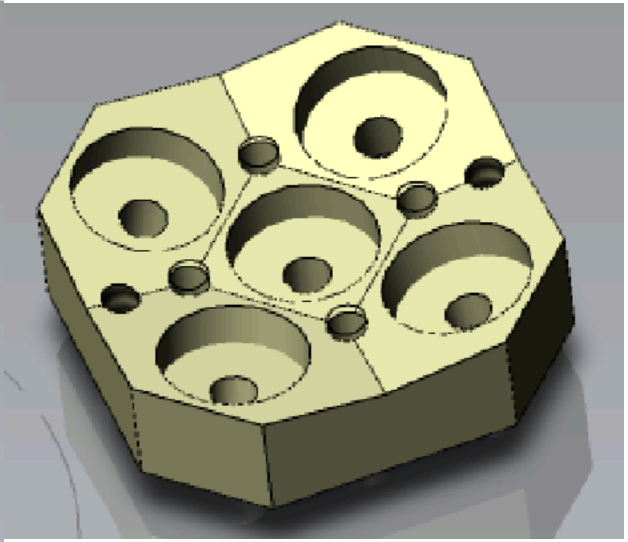
- all machined parts in aluminum
- screws in stainless steel
- removable cap in plastic

Mirror holder piece

- Separate from FC attachment
- Different angles possible

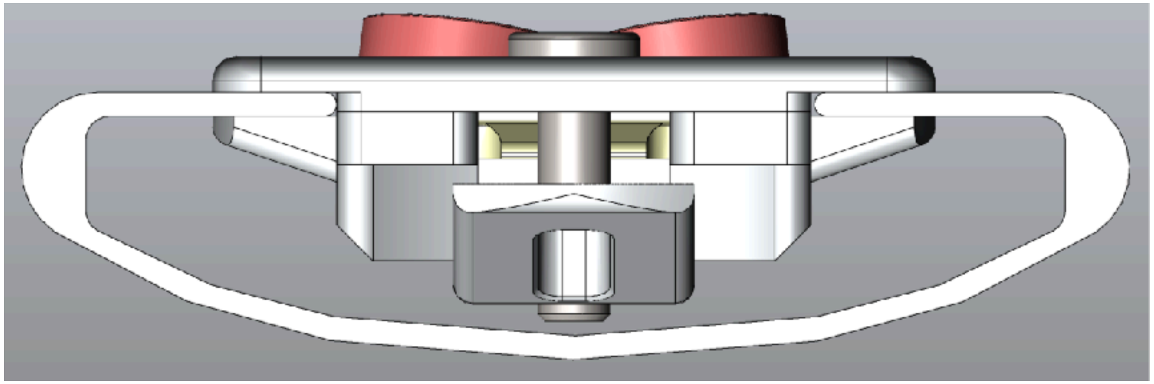




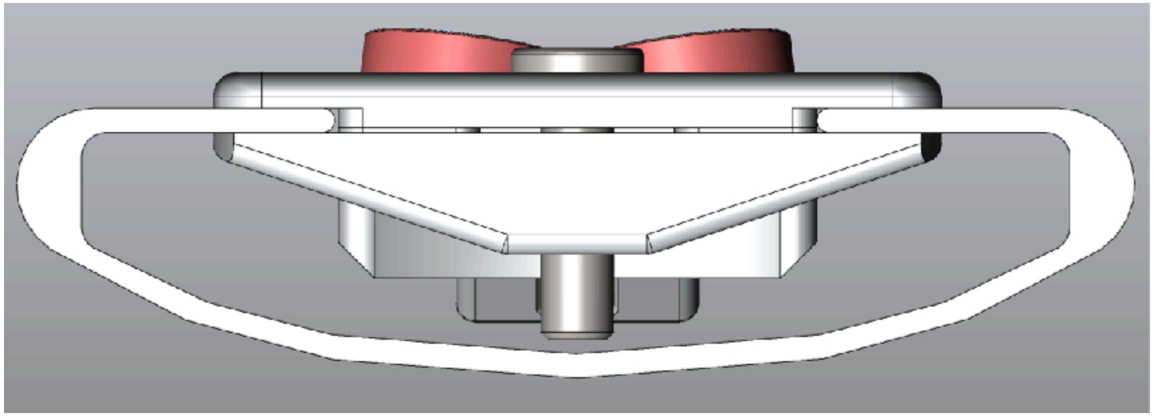


Fixation to FC

- First, enter the gap



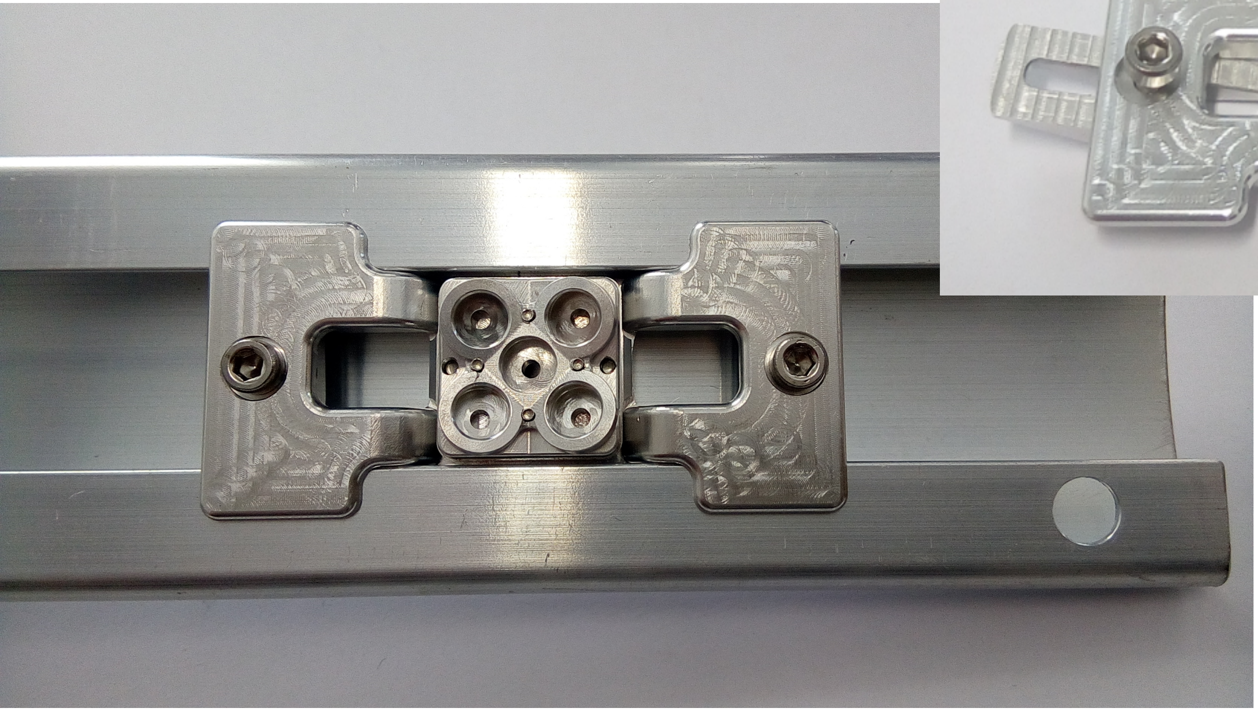
- Second, rotate bracket into place and tighten screw



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

First prototype

Machined at LIP mechanical workshop
Coimbra, August 2020



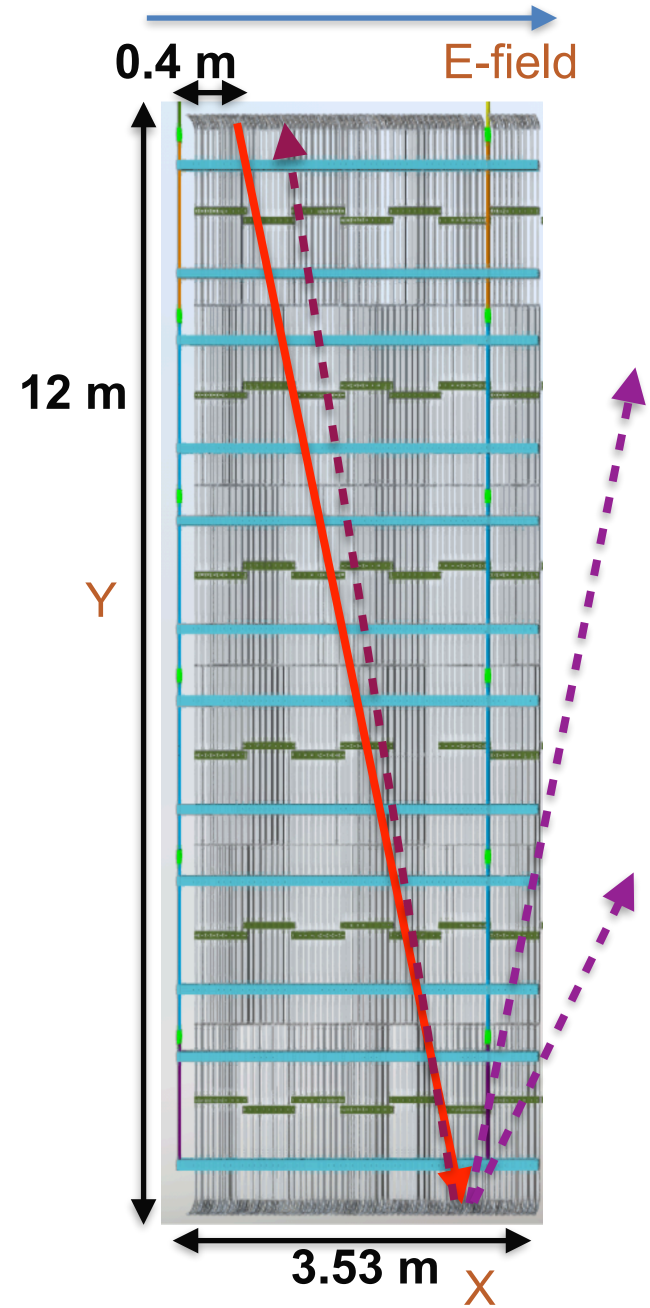
Positions, DUNE

Define the positions/angles

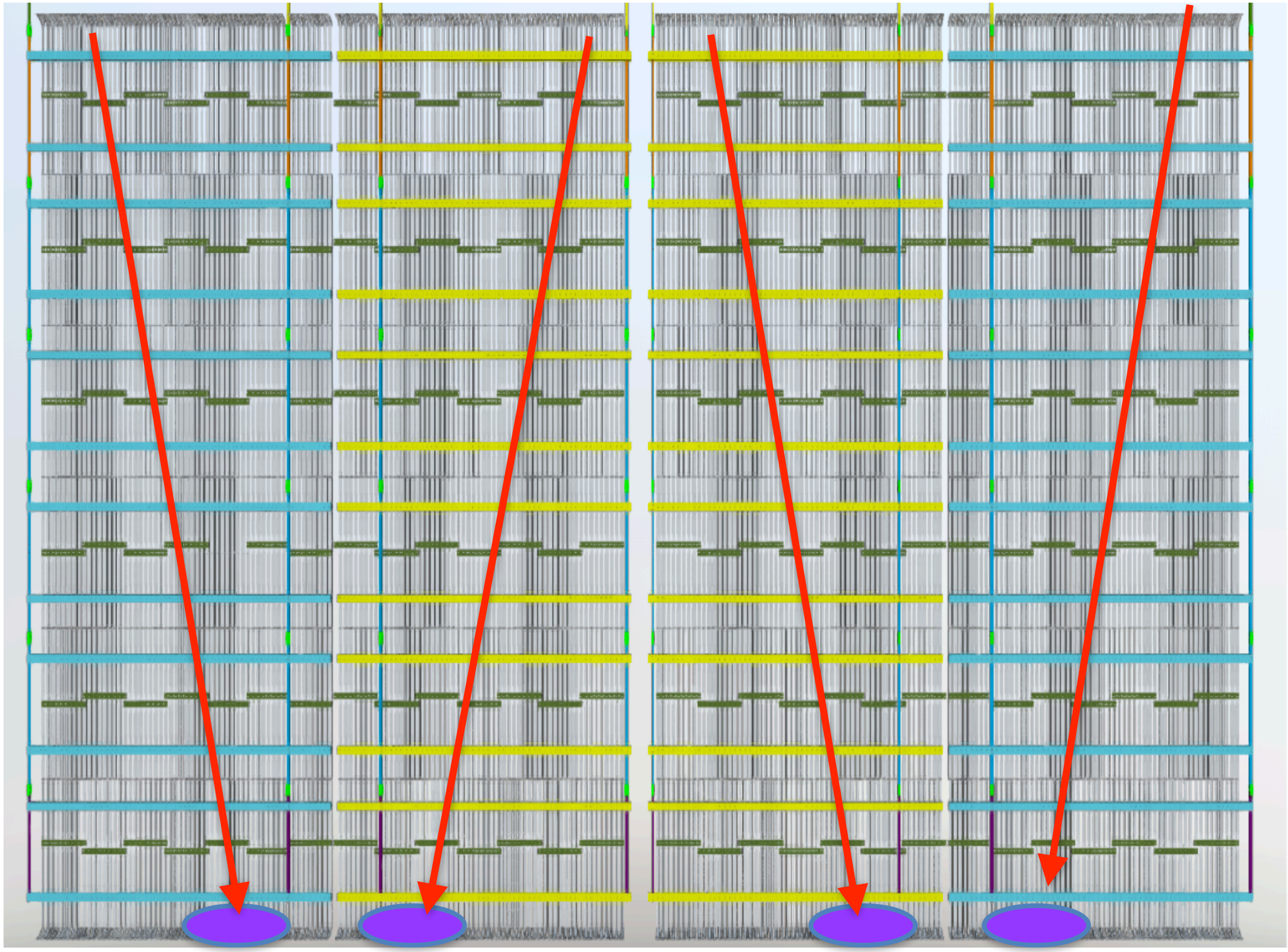
- Requirements
  - Not more than 20 m away. Preferably less, due to beam divergence
  - Reflection at least 1 meter long
  - Reflections should never hit PDS
  - Piece should be rotation symmetric (to avoid installing it wrongly)

End-wall view

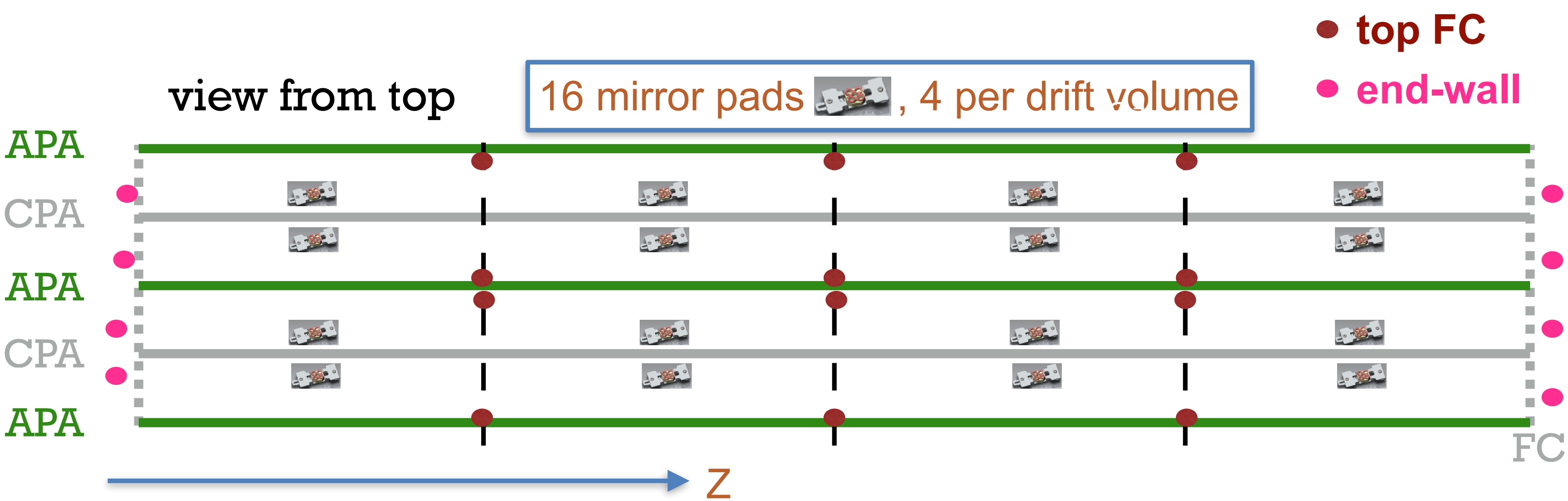
- Maximum angle if mirror pad close to CPA: atan (3.13/12) = 15 deg
- If mirror ~ 1 m distant from CPA: atan(2.13/12) = 10 deg
- So, place pad 1m away from CPA
  - Incidence angle in pad (XY plane) = 10 deg
  - Still enough room to see reflection
  - Max reflection (-10 deg) does not hit PDS



End-wall view



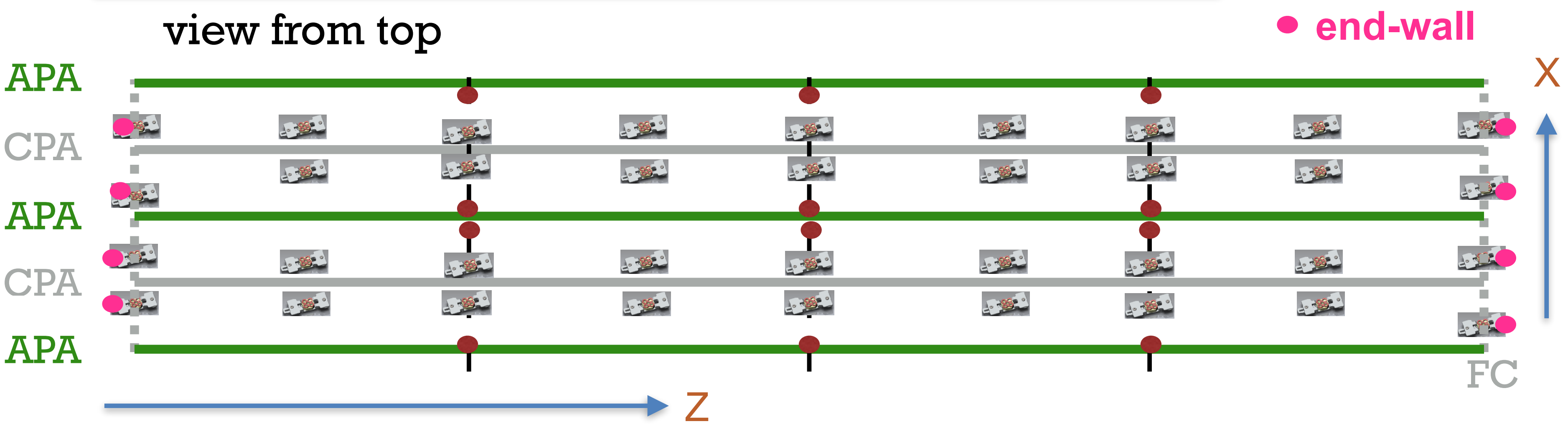
Proposed locations: baseline

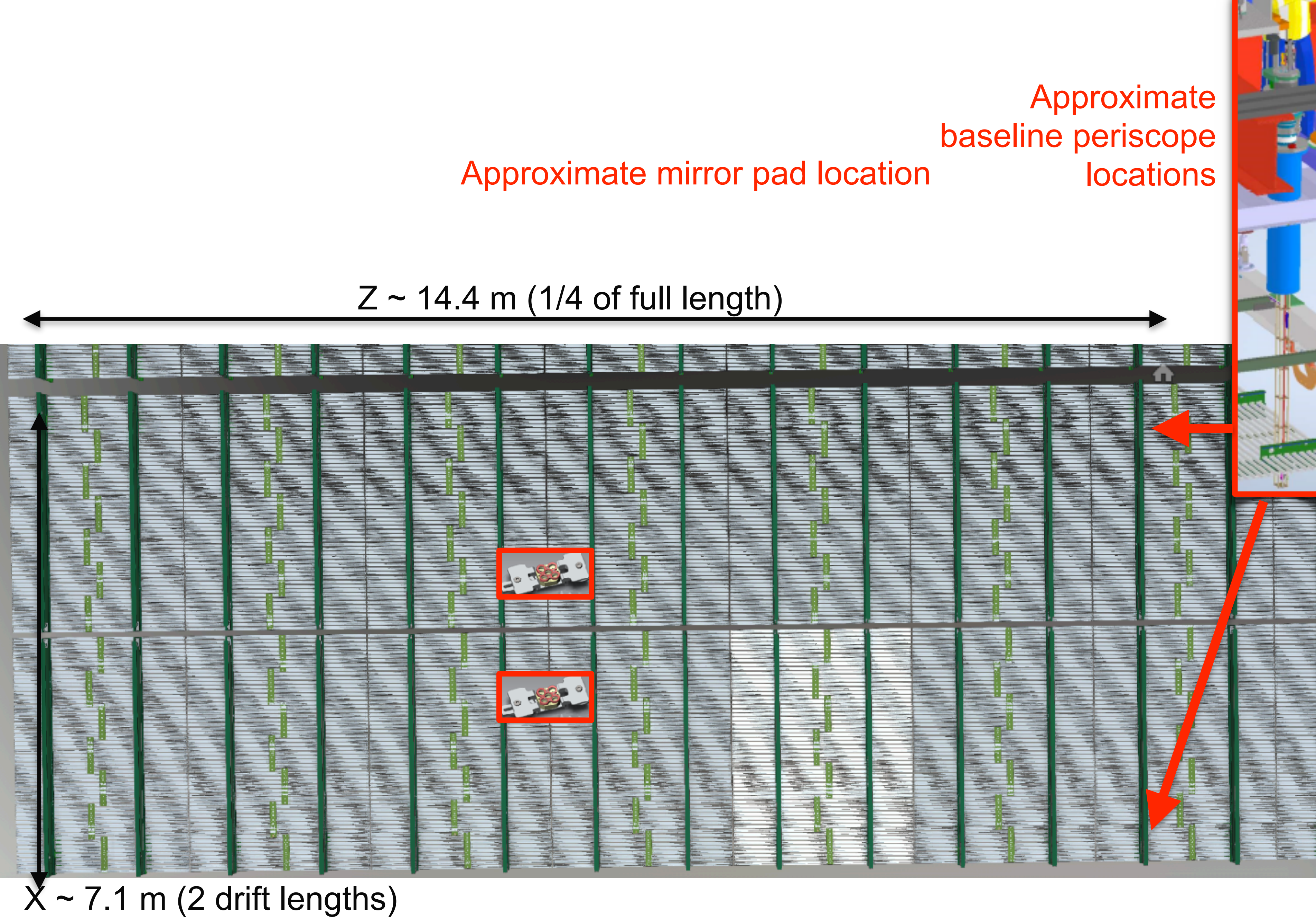


- Along X (drift): closer to CPA ~ 1 m away, i.e. profile #17 counting from CPA
- Along Z (beam): Roughly half-way between laser periscopes
  - ideally: -21.8 m, -7.3 m, +7.3 m, +21.8 m from the detector center.
  - in practice: next to end cap closer to TCO of modules 3/25, 9/25, 16/25, 22/25 (with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

Proposed locations: extended

36 mirror pads, 9 per drift volume (of which 2 in end-wall)




Approximate mirror pad location
Approximate baseline periscope locations
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**

Revisit Requirements

Consortium-held, integration

Artifact Type	Name	Primary Text
Specification	SP CALCI attachment of laser beam location systems (LBLS) to FC	LBLS will be attached to FC components in ways to ensure HV safety and E-field uniformity.

✓ Design developed in close contact with HV. Attachment tested with prototype.

Specification	SP CALCI Max. E field near calibration/instrumentation devices	EB-held req. 2264 applies here.

✓ FEA done with initial design, should be done again with final.

Specification	SP CALCI Noise from calibration/instrumentation devices	EB-held req. 2265 applies here.

✓ Fully passive device. No electronics.

Consortium-held, design

Name	Primary Text	Value
SP CALCI laser beam location precision	The laser system shall have independent beam location systems capable of measuring the laser beam direction with a precision of 0.5 mrad or smaller.	0.5 mrad

✓ Precision achievable with 5 mm mirrors at > 10 m distance. Survey needed.

IoLaser periscopes and location system survey	The extremity of the periscopes and the laser beam location systems must be part of a warm survey at the end of installation.

✓ A survey must be included in the installation plan.

Laser beam location system (mirrors) positioning	The LBLS mirror pads should be installed at a distance of at least 40 cm away from the HV system support I-beams.

✓ Positions close to end-caps are OK for HV. In case of ProtoDUNE, installation close to resistor plates requires further discussion.

Plans for ProtoDUNE

ProtoDUNE plans

1. Design, Organization
    1. Produce and test prototype
        1. Machining at LIP workshop, two prototypes ✓
        2. Two mirrors bought for initial tests ✓
        3. Test attachment to FC profile sent from CERN (thanks Francesco!) ✓
        4. Test mechanics/mirrors in liquid nitrogen ~Fall 2020
    2. Converge on installation plan with HV (pre-mounting or inside TCO) ~Fall 2020
2. Procurement/ fabrication of 3 additional mirror pads (1 spare) ~Early 2021
    1. Fabricate 3 mirror pads and ~ 10 polished aluminum discs
    2. Procure additional 10 mirrors (LIP)
3. Installation at ProtoDUNE
    1. Date pads need to arrive at CERN ~July 2021
    2. If pads pre-mounted on modules ~August 2021
    3. If pads installed inside TCO ~October 2021

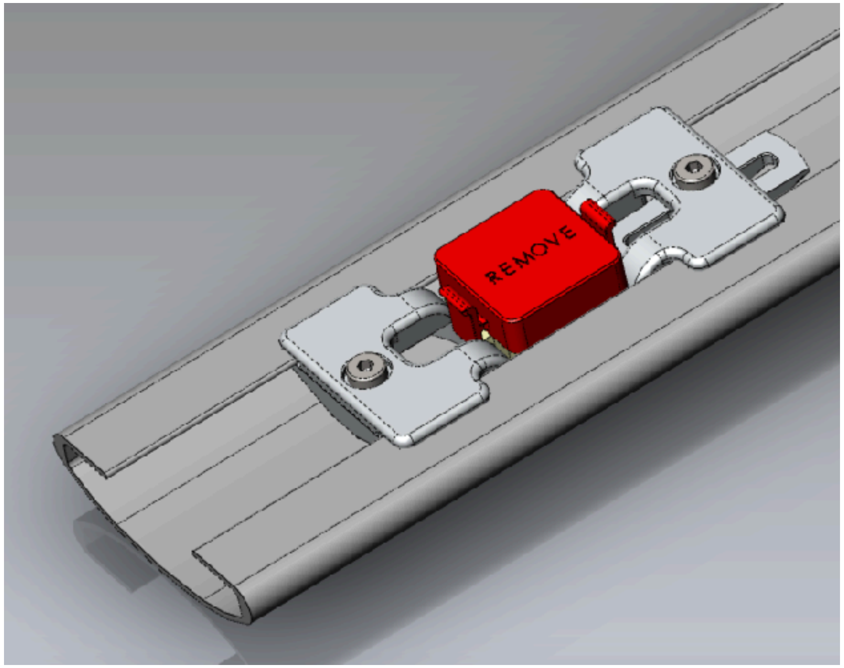
Testing Plans (all @LIP)

1. Basic mechanical functionality. Insert pads in profile. Qualitative check on ease of installation and robustness.
2. Cryogenic cycle. Immerse the pad in LN, check for cracks or bends, and repeat #1. Insert mirrors in place, immerse pad again in LN. Inspect mirrors for visible cracks or surface deterioration.
3. Mirror reflectivity at LN temperature, relative to the quoted reflectivity at room temperature. In a nitrogen gas atmosphere (not LN), and using a UV LED with a narrow band-pass filter.
4. Reflectivity of polished aluminum. Repeat measurement #3, with the discs.

Problems with tests #2 or #3, might lead to changes in the design or fabrication procedure. Tests #3 and #4 should not influence the decision to go ahead for PD2, but provide knowledge for the PD-2 data analysis, and possibly cost savings for DUNE.

Fabrication and Installation Plan

- Fabrication of all aluminum parts at LIP; mirror procurement by LIP
- 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



LBLS Cost: ProtoDUNE-II

Hardware

Deliverable	Quantity	Institution	CORE Cost	Funding Source	Status of funding
ProtoDUNE: Pads with 10 PIN diodes and cables	2	Hawaii	$2,000.00	DUNE U.S. Project	approved
ProtoDUNE: LBLS Pad DAQ interface	2	Hawaii	$3,000.00	DUNE U.S. Project	approved
ProtoDUNE: Mirror LBLS prototypes	4	LIP	$3,000.00	Portugal	approved

Costs include R&D and testing planned

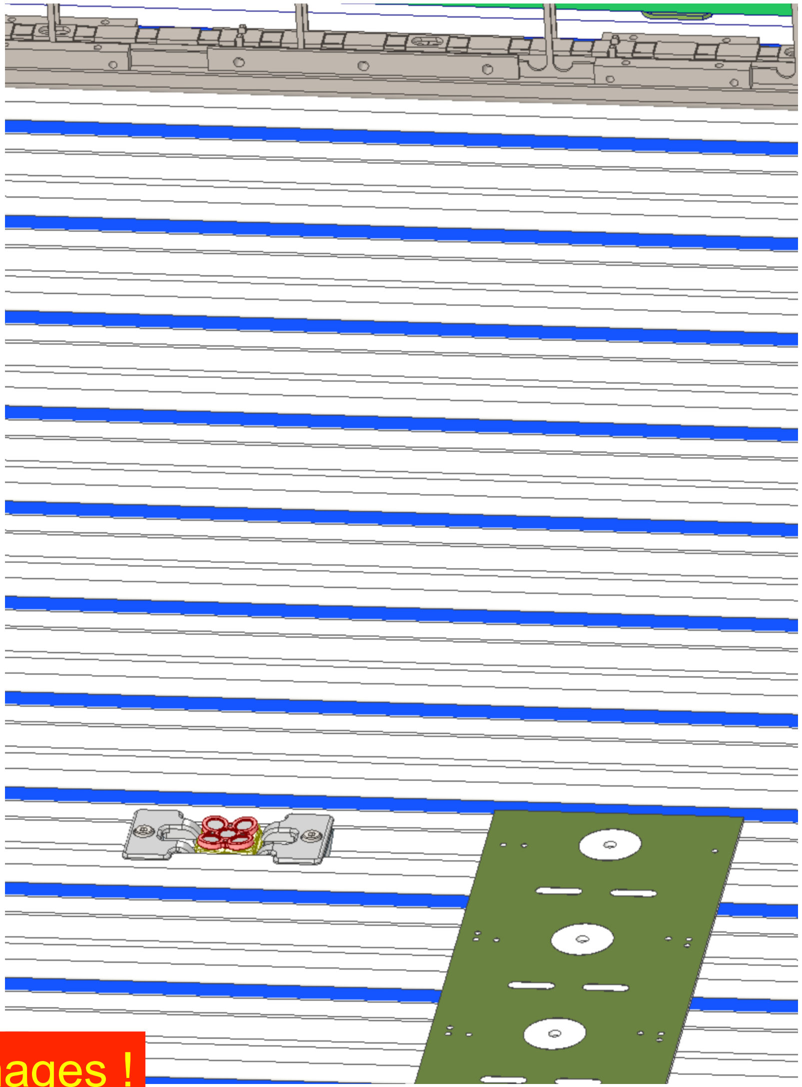
Labor

Deliverable		Institution		Funding Source	Status of funding
ProtoDUNE : Person-power for mirror pads hardware design, production, commissioning: faculty (1/12 FTE.yr), engineer (1/12 FTE.yr), technician (1/6 FTE.yr)		LIP		Portugal	Approved
ProtoDUNE : Person-power for PIN diode pads hardware design, production, commissioning: faculty (1/3 FTE.yr), postdocs (0.3 FTE.yr), grad students (0.5 FTE.yr), engineer (1/12 FTE.yr), technician (0.3 FTE.yr)		Hawaii, LANL		DOE IF Base, DUNE US Project	Approved

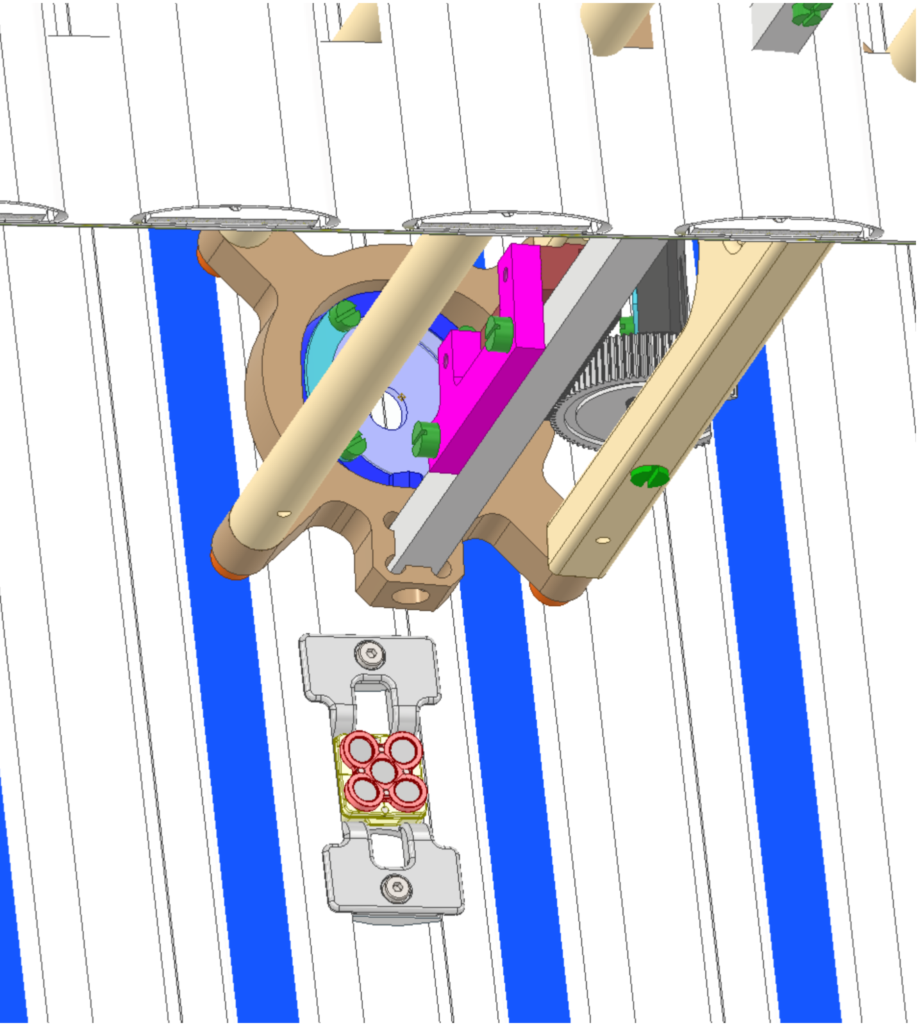
Pretty modest costs

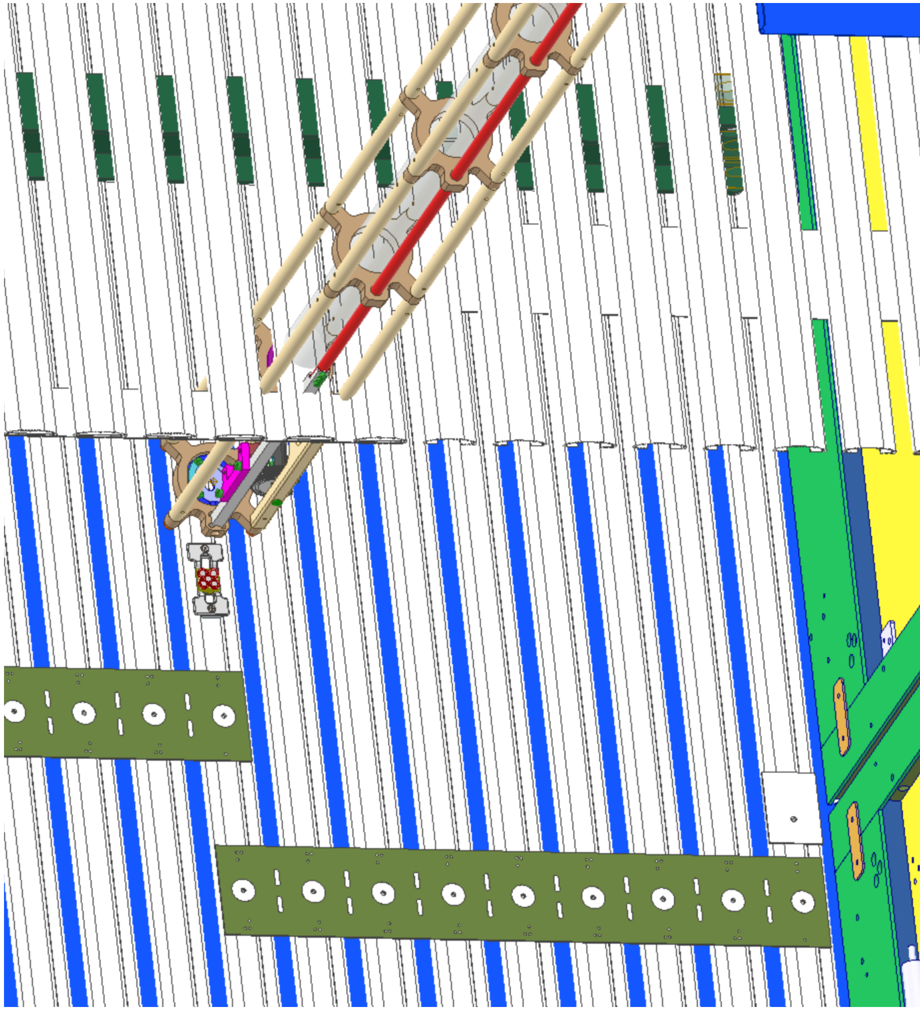
Positions in ProtoDUNE

- In ProtoDUNE there are only two FC modules, so if we use only the location close to the end-caps, we have basically only one position (useless to put mirrors close to corners)
- It would be good to also have a position close to resistor pad (middle of module)
    - need to discuss with HV best way to install this.
- Plan to install 4 pads
    - 2 in bottom FC, 2 in end-wall

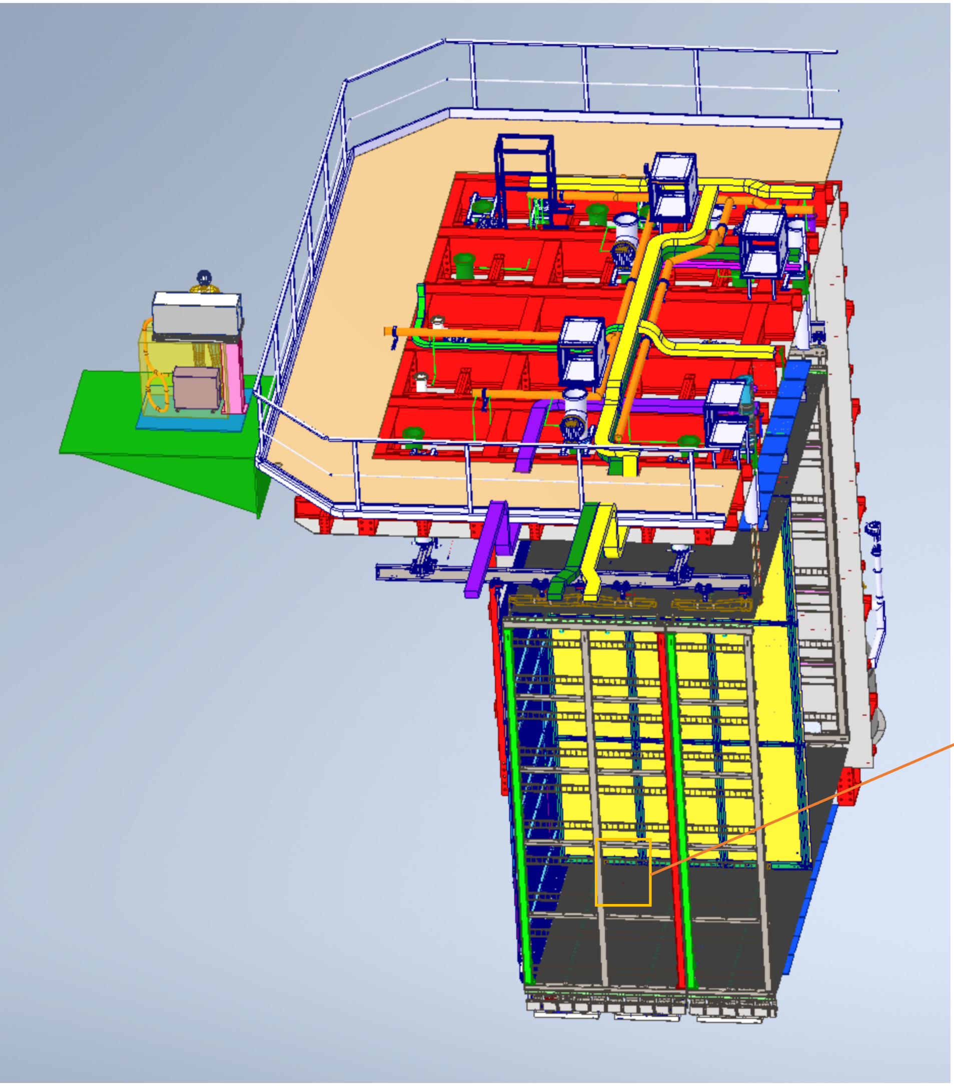


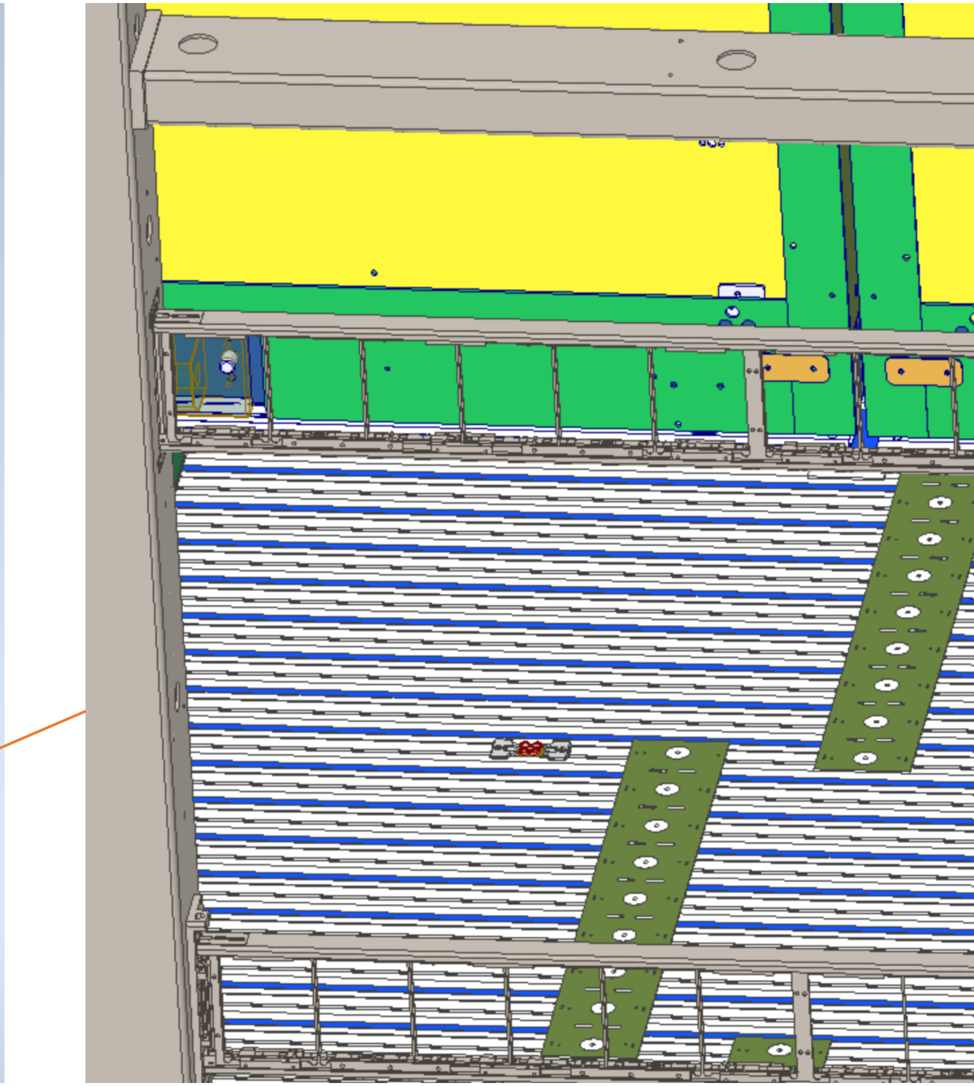
Thanks to Jan Boissevain for these images !





Thanks to Jan Boissevain for these images !





Thanks to Jan Boissevain for these images !

LIP team on LBLS

Lisbon

- José Maneira, Scientist, design, overall supervision

Coimbra

- Rui Alves, Mech. Eng., design, procurement, testing
- Francisco Neves, Scientist, testing, software for PD analysis
- Vladimir Solovov, Scientist, testing

- Thanks also to the LIP machine shop for parts production
  - Alberto Blanco, Scientist, LIP machine shop coordinator
  - Nuno Dias, Technician, LIP machine shop