Laser Beam Location System: Mirror Pads

Laser Calibration Meeting

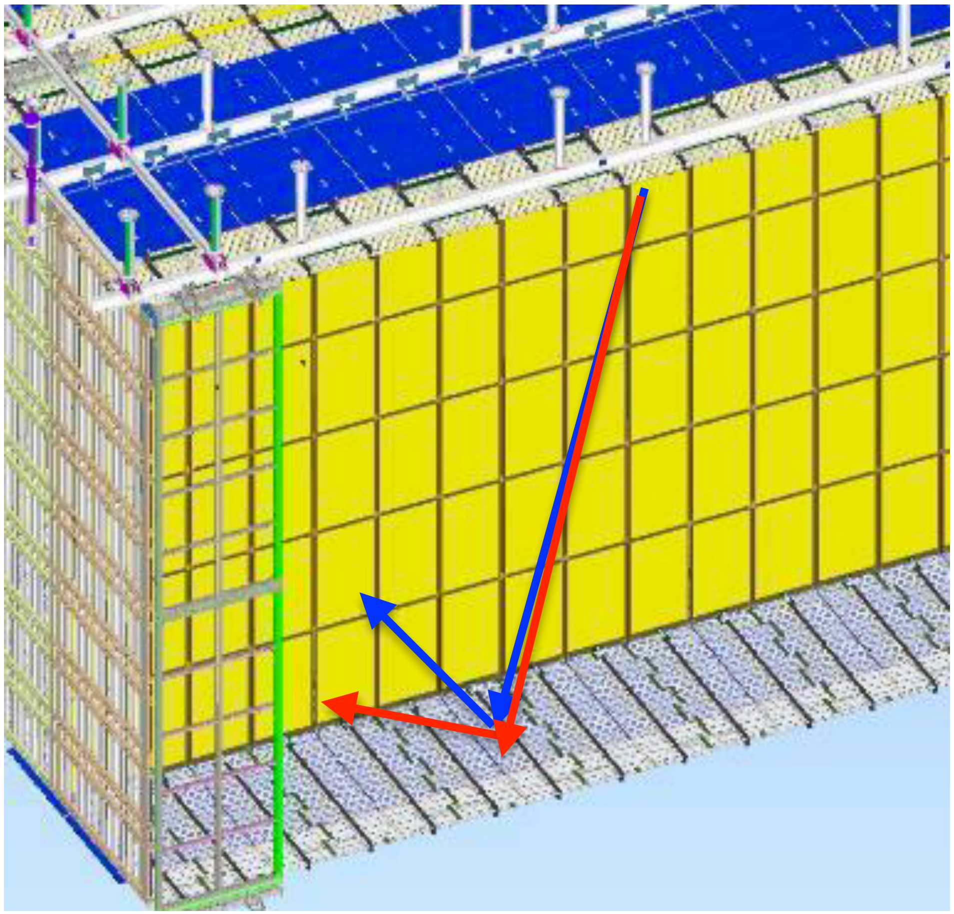
April 16, 2020

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

The problem

- E-field precision measurement requirement: 1%
- Field distortions measured by track path distortions
  - A 1% distortion on E over a 0.5 m region leads to a 5 mm shift
  - Not useful to go much better than 5 mm since that's the wire spacing
- So: need for 5 mm (**Total**) beam position uncertainty
- 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?
  - as a Roman poet said: ***Quis custodiet ipsos custodes?*** ("Who watches the watchmen"?)
  - we say: How do we **calibrate the calibration system**?

The idea



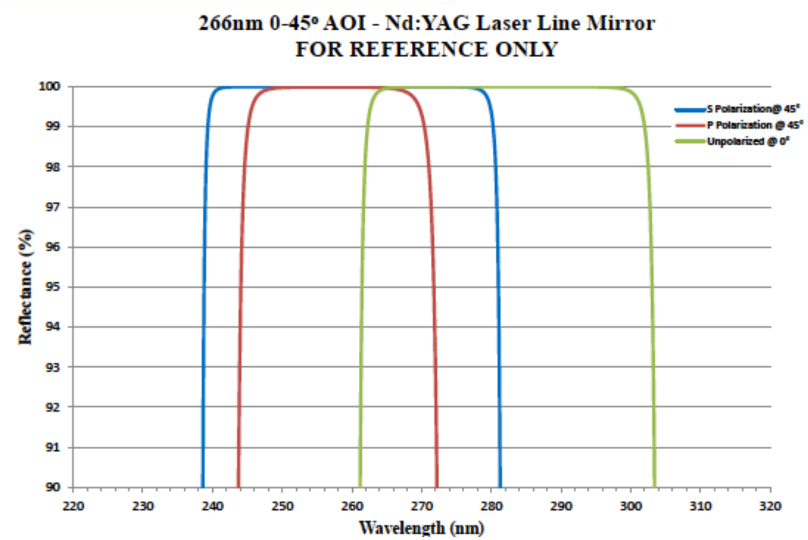
- Aim the beam at a mirror in a known location. Precision ~ size of the mirror.
- We know the beam hit the mirror when we observe the reflection
- Cluster about 5 mirrors together to make it easier to find them
- Each mirror with a different angle
- Reflected beam angle unambiguously identifies which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

Pros and cons

- Fully passive system, no cables
- Easy installation
-

- Works only with the TPC on

The mirrors

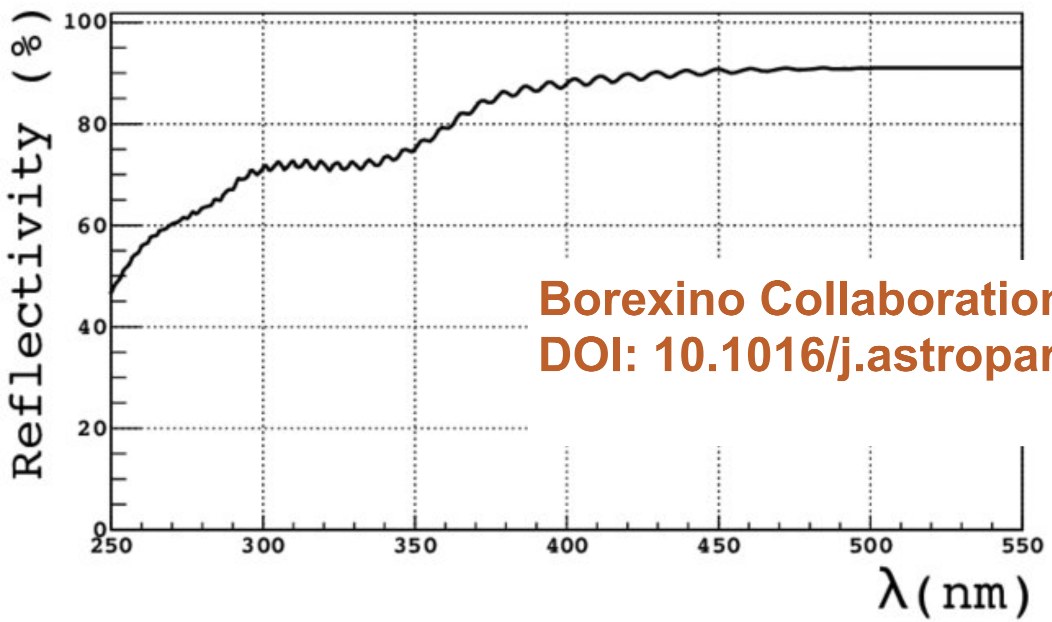


- Edmund Optics Nd:YAG Laser Line
  - substrate: fused silica
  - coating: dielectric
  - surface quality: 10-5
  - wavelength range: 263-268 nm
  - Rabs >99.8% @ 266nm
  - Angle of incidence range: 0 - 45 deg
  - Size (2 options for us)
    - <u>Radius: 6.35 mm, thickness: 4 mm</u>
    - Radius: 4 mm, thickness: 3 mm
  - Cost: ~ 100 € each

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

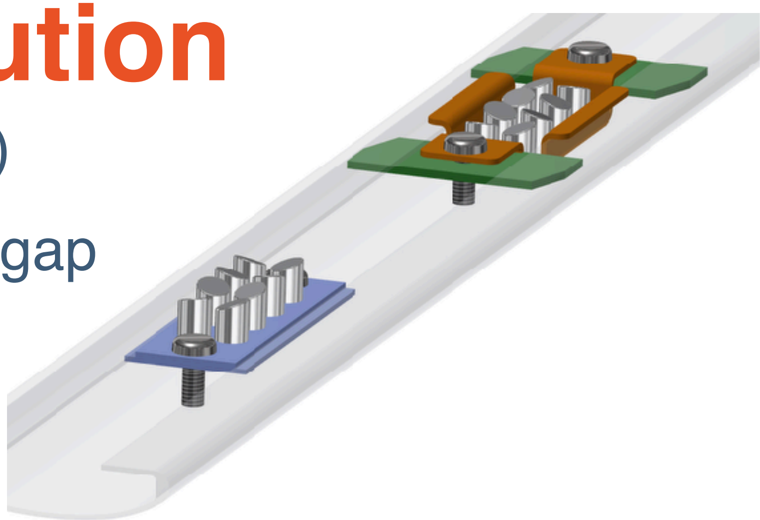
Cheaper alternative

- 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 ?

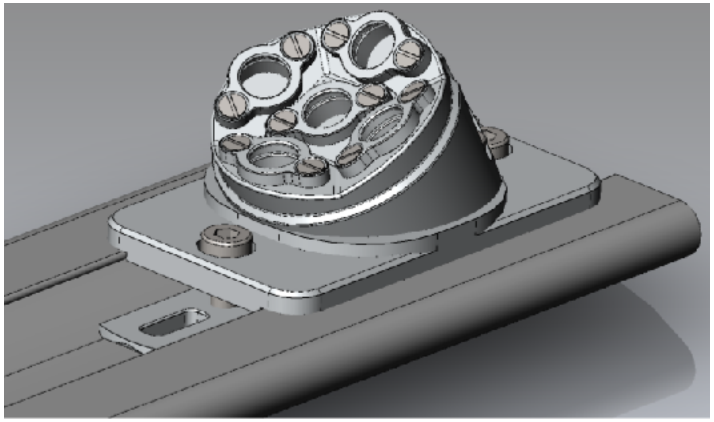


Borexino Collaboration,
DOI: 10.1016/j.astropartphys.2017.10.003

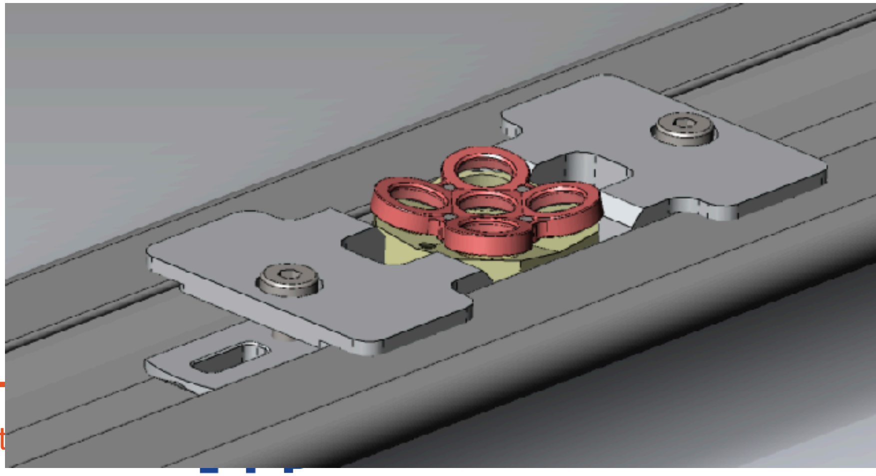
Holder design evolution



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

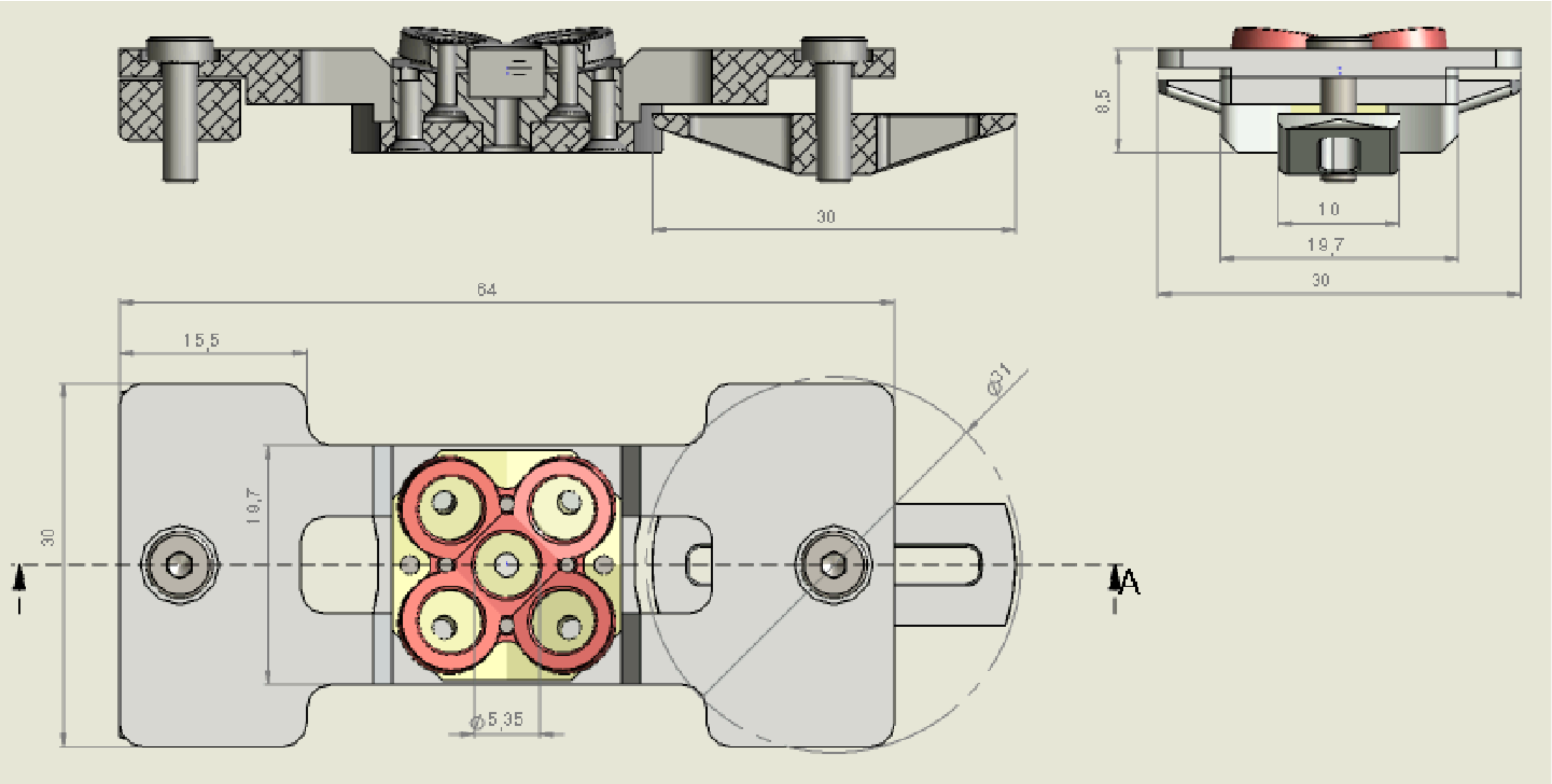


- First version from Rui Alves (LIP)
- ✔ Holder for commercial mirrors
- ✘ Standing too much out from FC



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

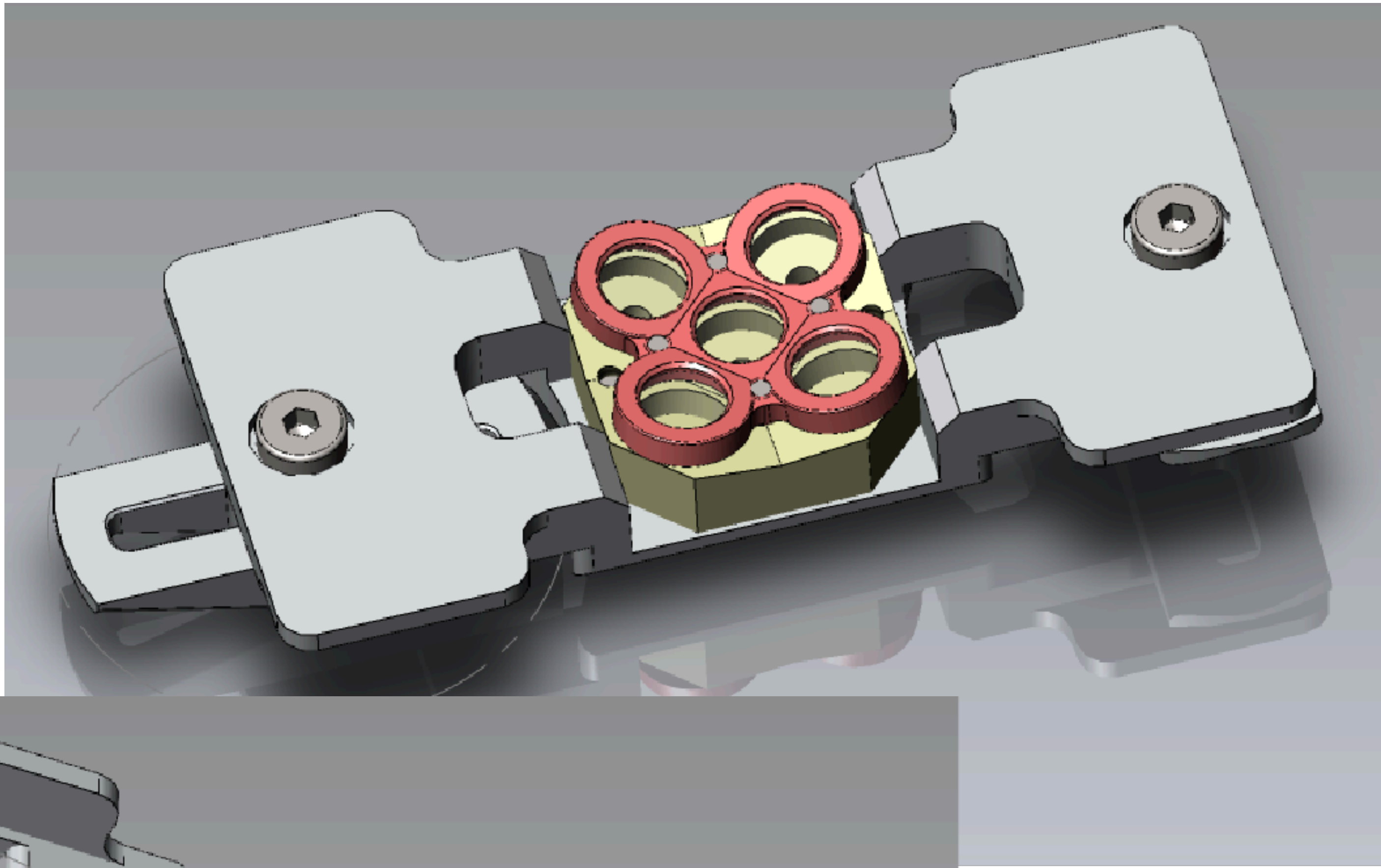
Current mirror holder design

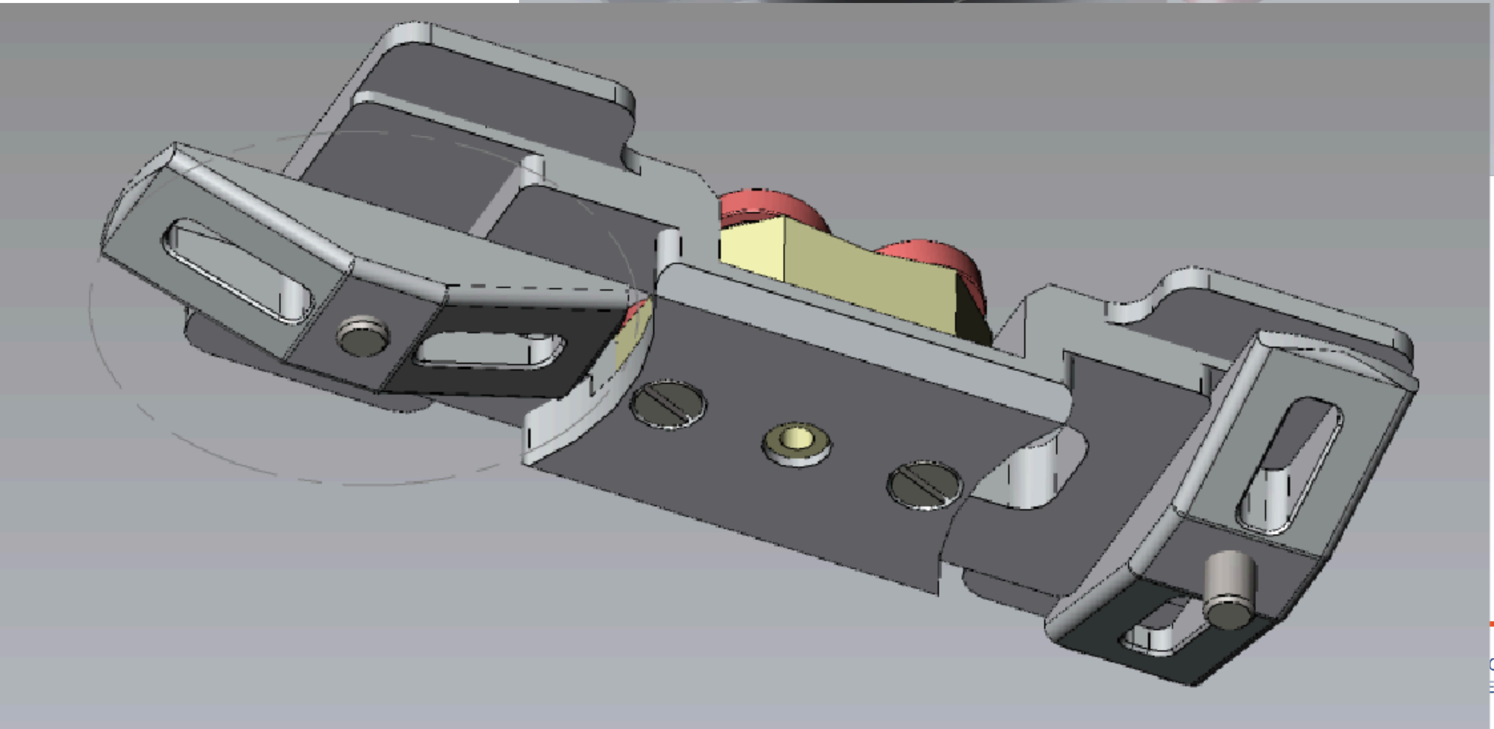


- all parts in aluminum

Angle: 10 deg

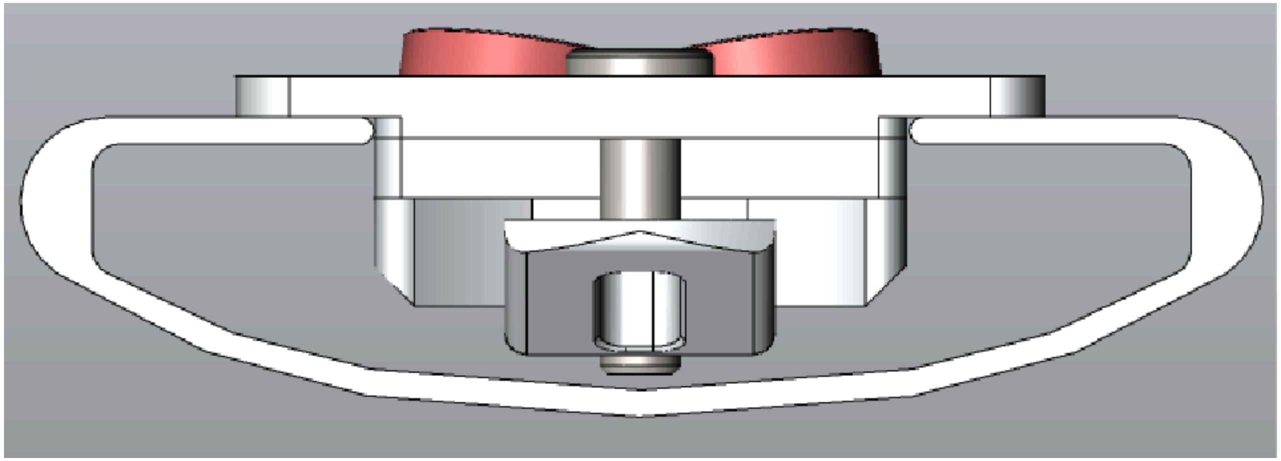
Overview



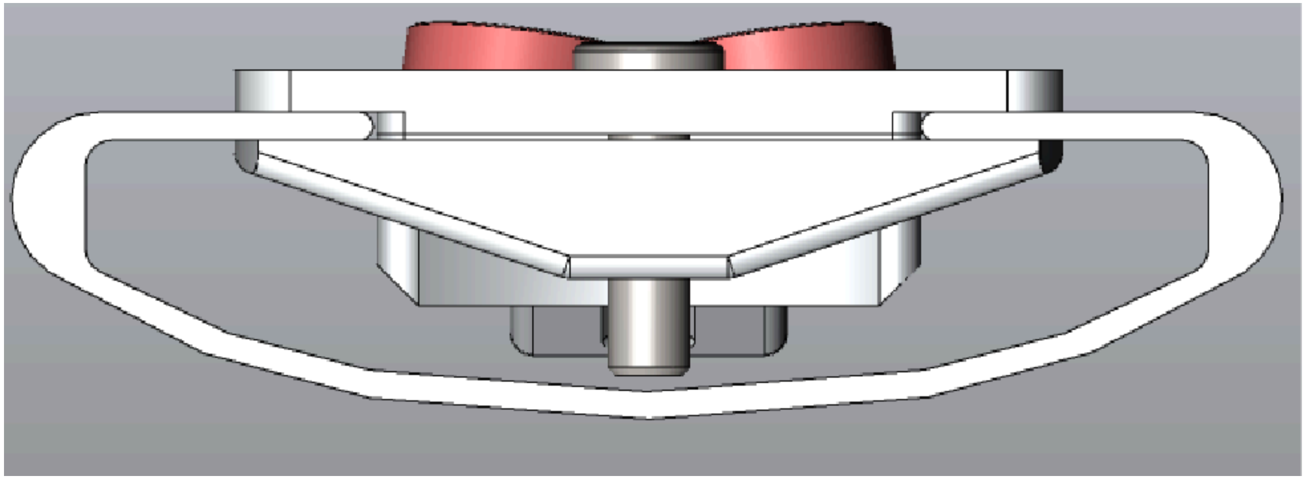


Fixation to FC

- First, enter the gap



- Second, rotate bracket into place and tighten screw

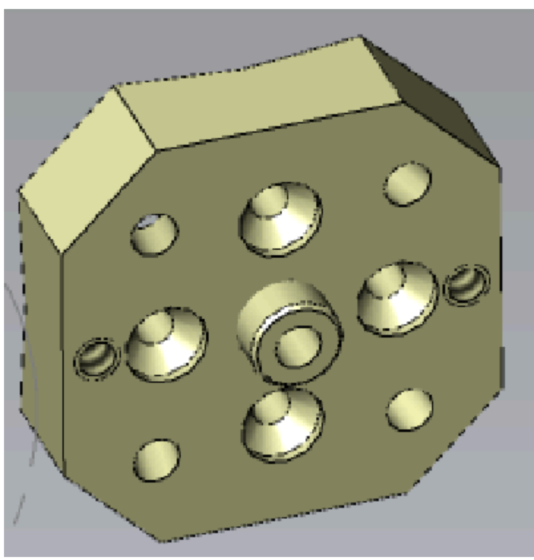


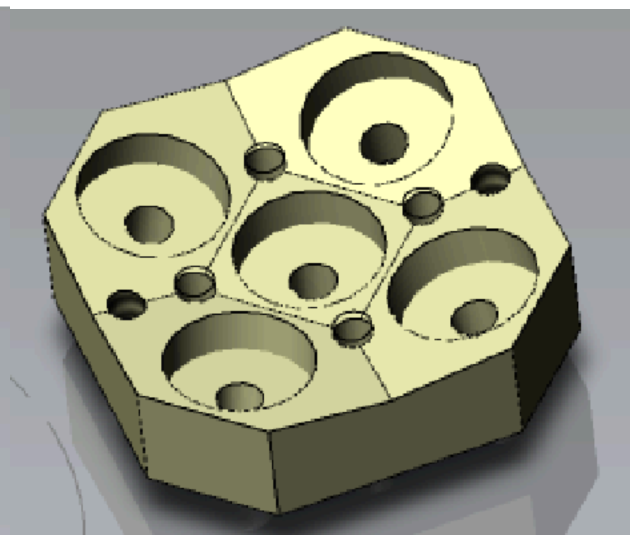
- Tighten only the edges, avoid pressing against the bottom of the FC

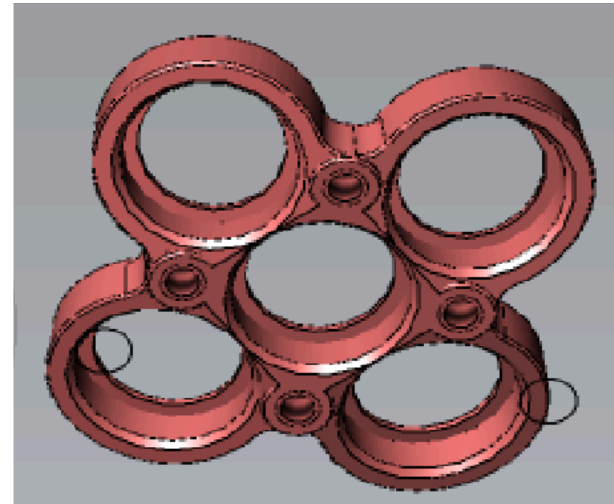
LIP LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS DUNE

Mirror holder piece

- Separate from FC attachment
- Different angles possible





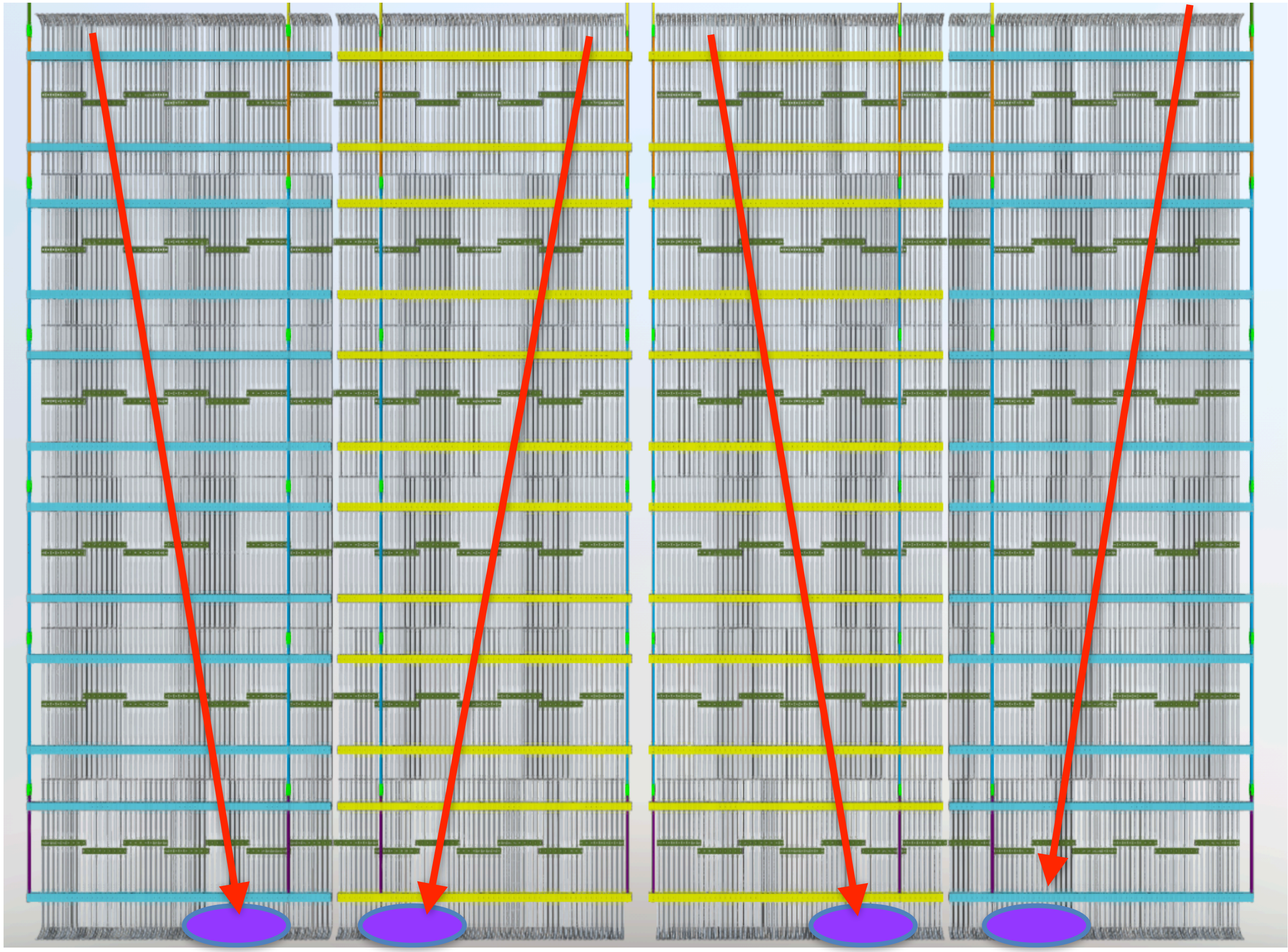


Define the positions

- Requirements
  - mirror on bottom FC
  - not more than 20 m away. Preferably less, due to beam divergence
  - The positions/angles should be such that the reflection is at least 1 meter long
  - Reflections should never hit PDS
  - piece should be rotation symmetric (to avoid installing it wrongly)
  - Options
    - Minimum: each baseline laser sees only one (-> 8)
    - Medium: each baseline laser sees 2 (-> 16)
    - Maximum: Have different distances, and/or end-wall (32)

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

End-wall view



LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

All: inc. angle (α_i) on pad: 10 deg

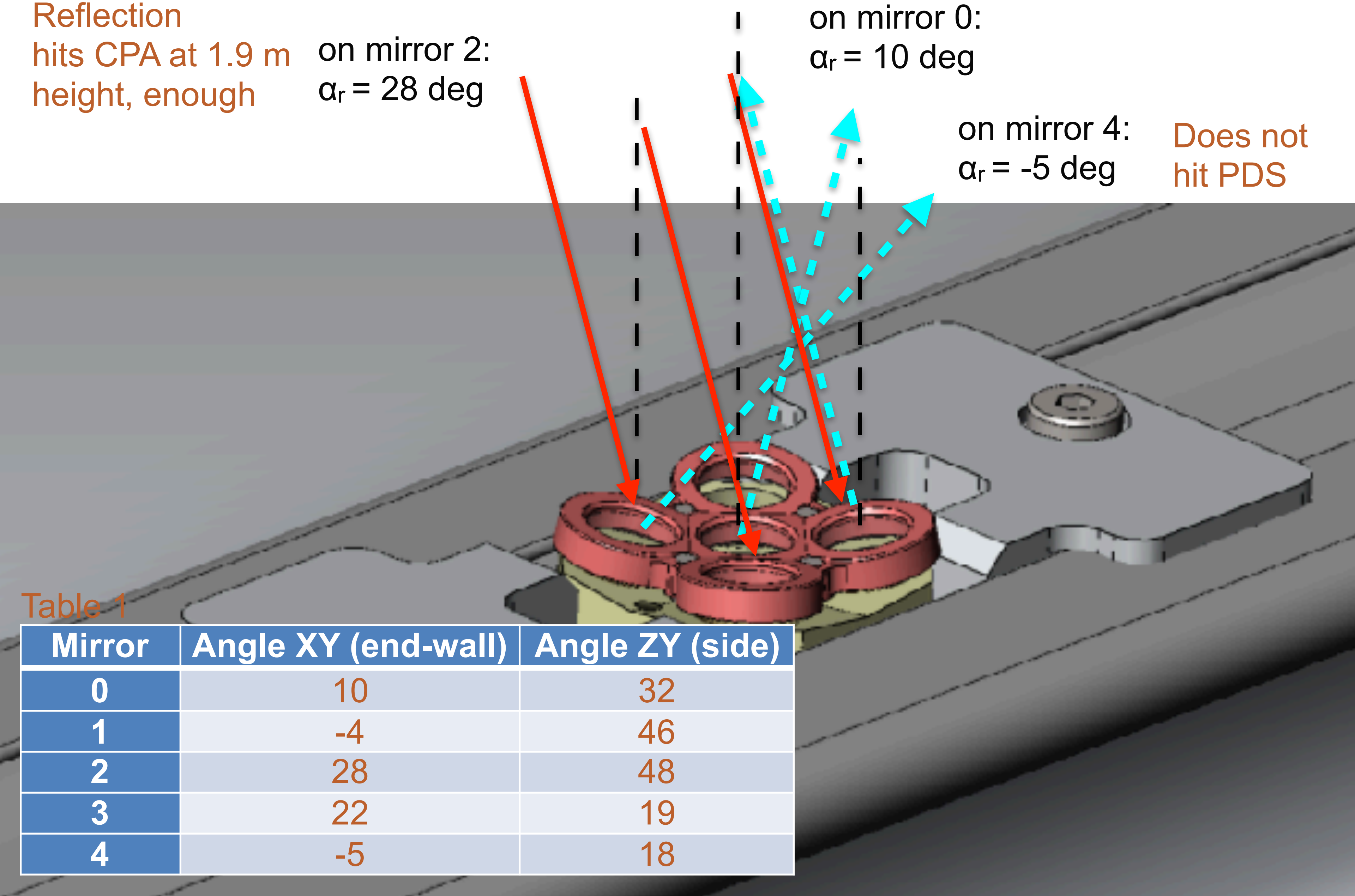
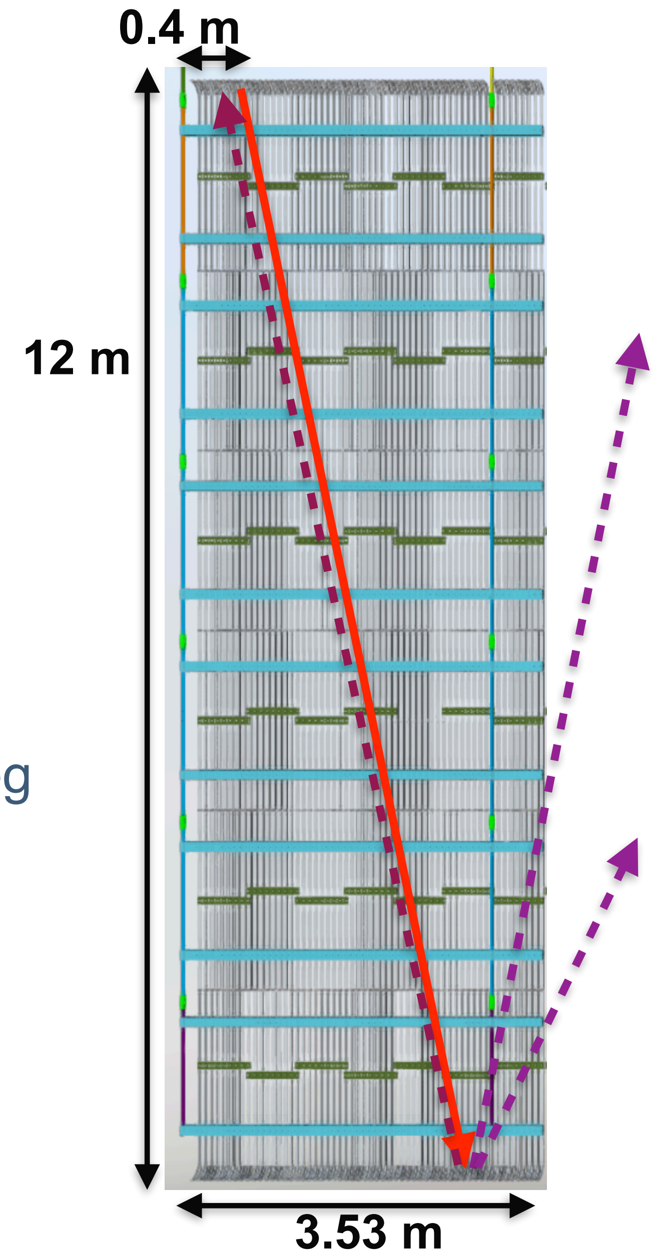


Table 1

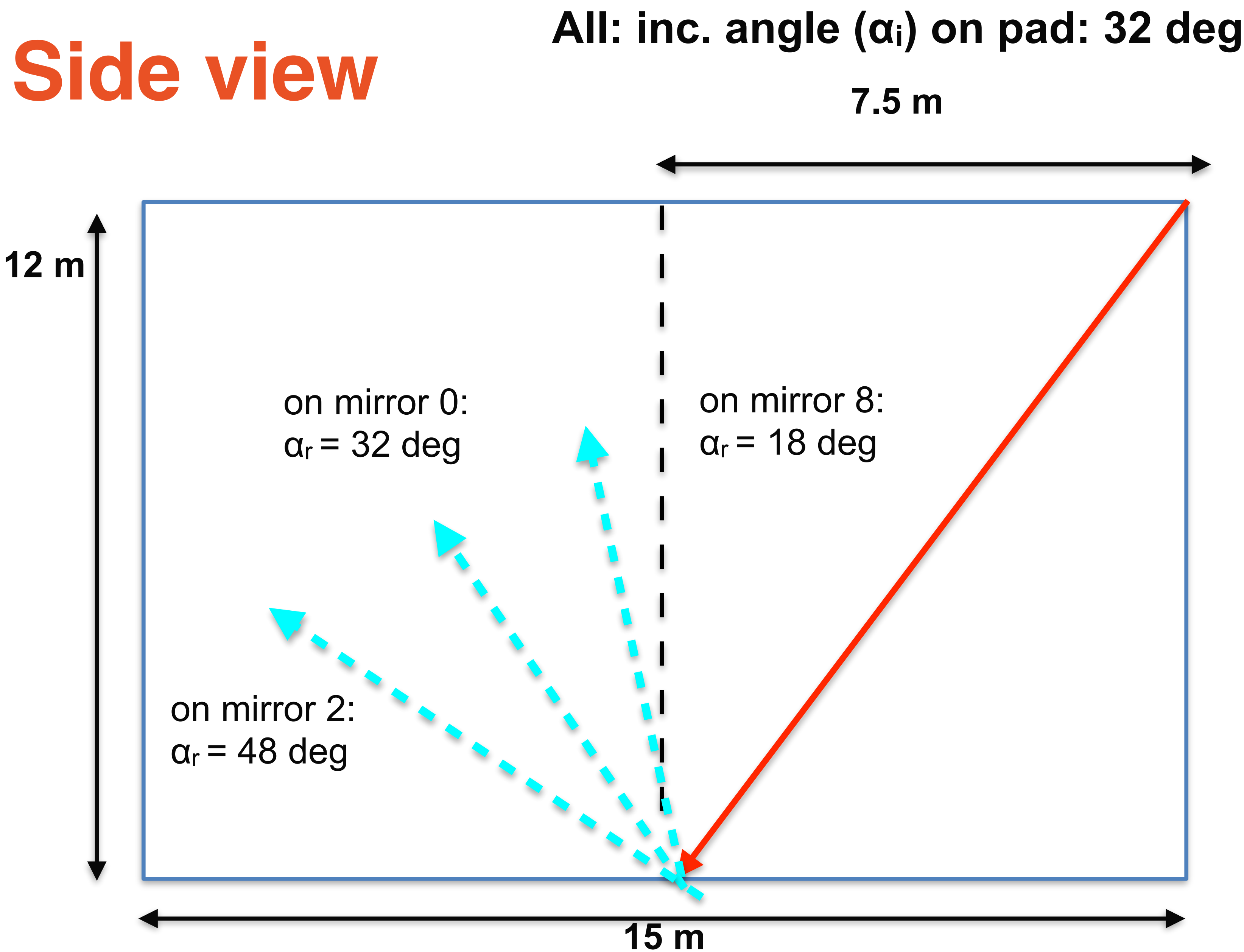
Mirror	Angle XY (end-wall)	Angle ZY (side)
0	10	32
1	-4	46
2	28	48
3	22	19
4	-5	18

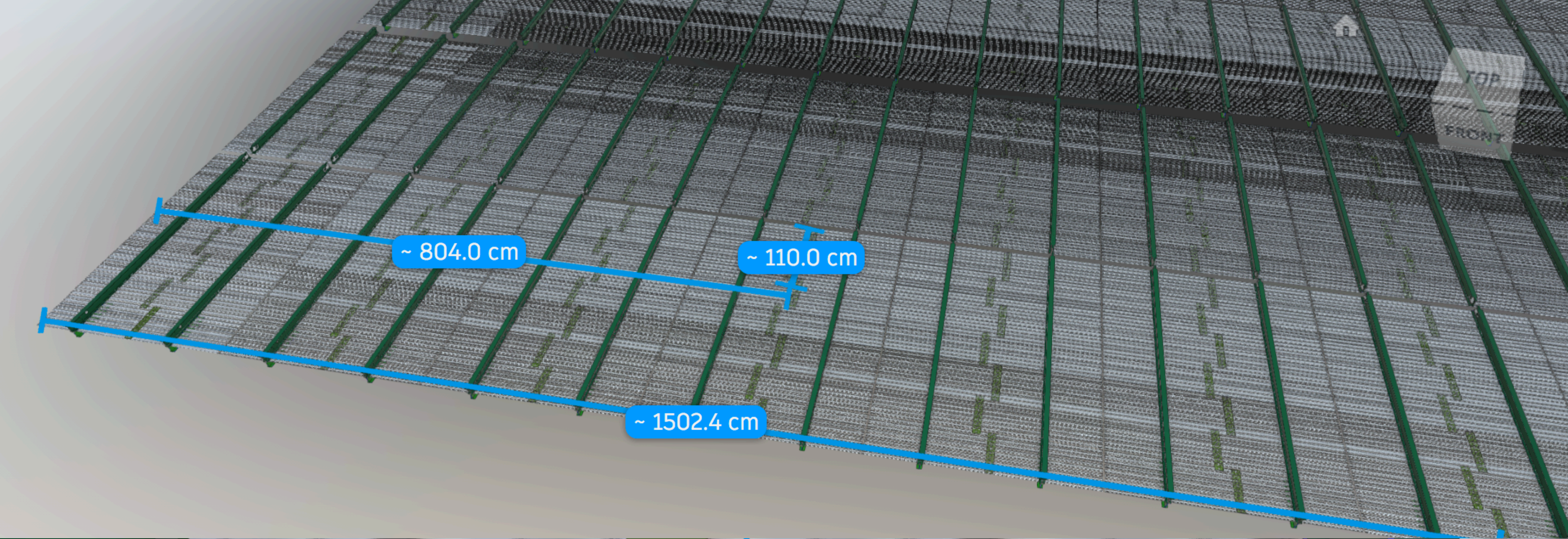
End-wall view

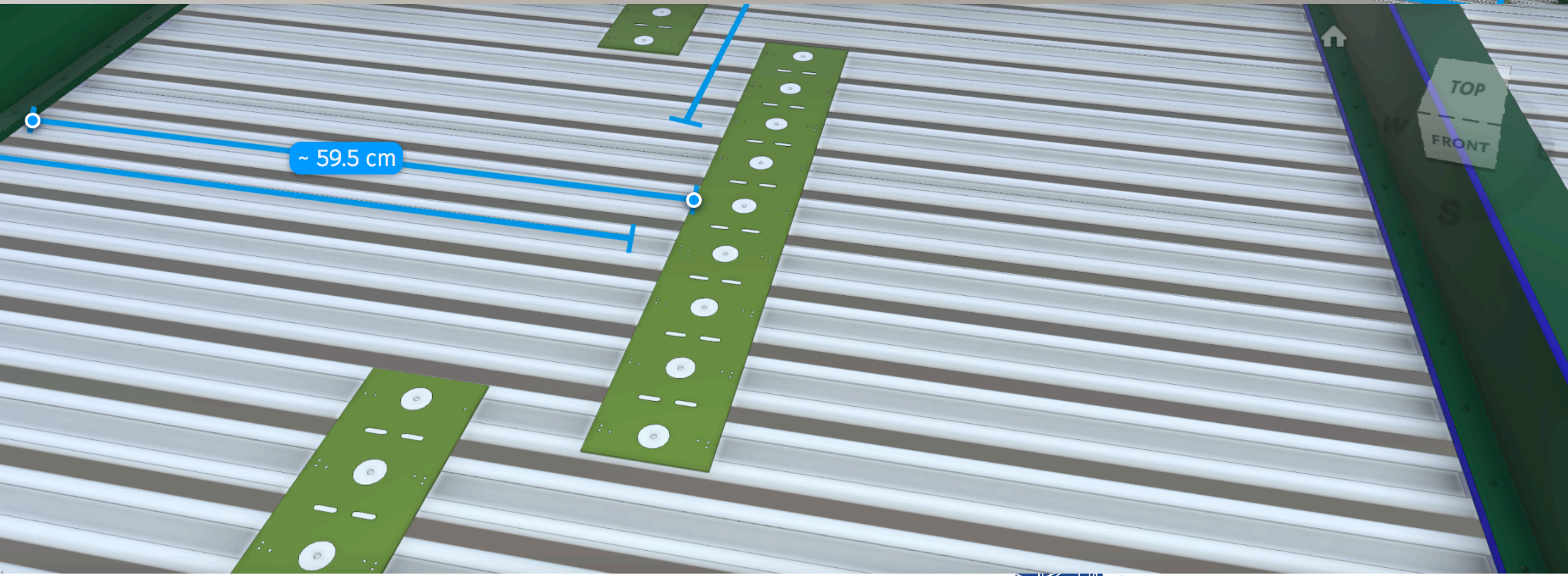
- Maximum angle if mirror pad close to CPA: atan (3.13/12) = 15 deg
- If mirror ~ 1 m distant from CPA: atan(2.13/12) = 10 deg
- So, place pad 1m away from CPC
  - Incidence angle in pad (XY plane) = 10 deg
  - Still enough room to see reflection
  - Max reflection (-10 deg) does not hit PDS

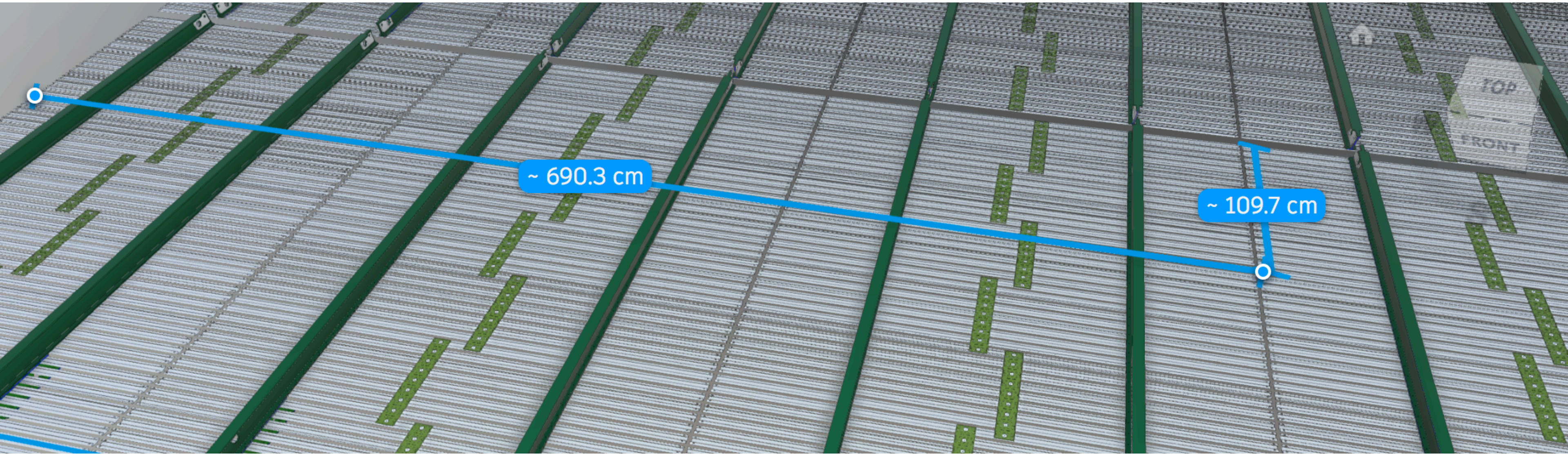


Side view


All: inc. angle (α_i) on pad: 32 deg
7.5 m
12 m
on mirror 0:
α_r = 32 deg
on mirror 8:
α_r = 18 deg
on mirror 2:
α_r = 48 deg
15 m


~ 804.0 cm
~ 110.0 cm
~ 1502.4 cm
TOP
FRONT


~ 59.5 cm
TOP
FRONT


~ 690.3 cm
~ 109.7 cm
TOP
FRONT

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 persicope

Next steps

- Design
  - Round all edges
  - Estimate effects of thermal contraction on mirror
  - Piece to secure cover
- Define the positions
  - Propose additional 16 in case we do a total of 32.
- Installation and survey plan
  - When to mount on FC module?
  - Can we put it close to resistor bar or plastic end-cap?
  - Measure distance w/r to nearest I-beam

ProtoDUNE plans

1. Design, Organization
    1. Complete design of holders and cap
    2. Agree on mirror model/supplier
    3. Discuss and converge on design and installation plans with HV consortium
    4. Approve system scope in May review
2. Procurement/ fabrication of 2 mirror pads, 1 Al disc pad (all @LIP)
    1. Fabricate ~ 10 polished aluminum discs
    2. Procure 12 mirrors (LIP)
    3. Fabricate 4 mirror holders

~Summer 2020

~Fall 2020

3. Installation at CERN could be early 2021

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.
  - The criterion for the absolute minimum scope for this system is to have each baseline laser periscope within less than 15 m from a mirror pad. This would amount to 8 mirror pads in the SP module.
  - Additional scope, allowing end-wall periscope coverage, and improving precision, would have 16 mirror pads.
  - Further scope, allowing consistency checks for cool-down effects, would require 8 mirror pads per drift volume (32 total).

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 (need 32) 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?
- Does the functionality of the system justify its overall cost?
  - The M&S cost is essentially just the mirrors themselves. ~500€/pad. 4 k€ for the minimal scope, 16 k€ for the maximum 32 pads. Quite minimal.

Review Charge - Part II

- Essential:
  - Experiment should not be run without this system in place
- Highly desirable:
  - Strong justification for including this system but not viewed as absolutely necessary
- What should be our statement?
  - It is “Essential” to have at least one LBLS, otherwise the laser ionization data risks being very uncertain.
  - 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