Pin Photodiode
Laser Beam Location System
Design Review

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Goals of the Pin Diode LBLS

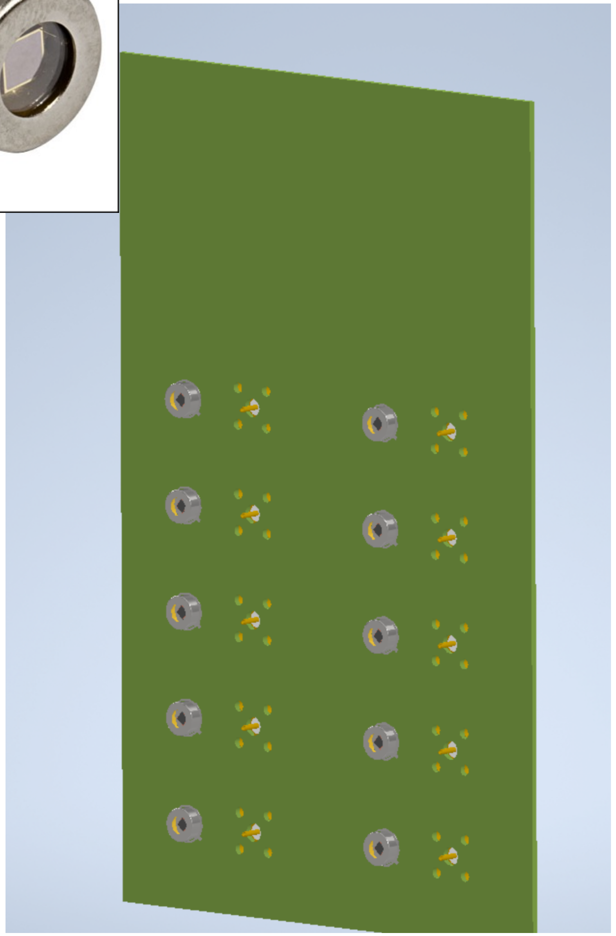
- Subsystem of Iolaser
- Iolaser will be located on top of cryostat, in cryostat reference frame
- Enables measurement of laser beam direction in-situ in reference frame of TPC
- Pin diode system enables positioning feedback early and directly (no need to analyze TPC signals):
  - during Iolaser commissioning, warm phase, as well as regularly during calibration campaigns
- Secondary goal:
  - Constrains cool down effect shifts between cryostat and FC.

Requirements of Pin Diode LBLS

- Size of the laser beam targets determined by the sensitive area of individual pin diodes: not larger than 5 mm.
- Knowledge of the pin-diode strip position w.r.t. the FC - better than 5 mm.
- Positioning: each laser periscope must have at least two LBLS pin diode pads within a distance range of 10 - 20 m (maximum assumed laser beam range).
- Reference frame checks: pin diode LBLS position should be carefully surveyed with respect to cryostat during installation - better than 5 mm.
- Pin diodes must generate strong signal above 0.5 V when hit by beam to easily distinguish signal over background and differentiate between secondary reflections of the field cage and direct hits.
  - (NB: pin diode pads will be located bellow plane of the bottom FC and illuminated by the laser beam passing through gaps between FC profiles).

Overview of Pin Diode LBLS

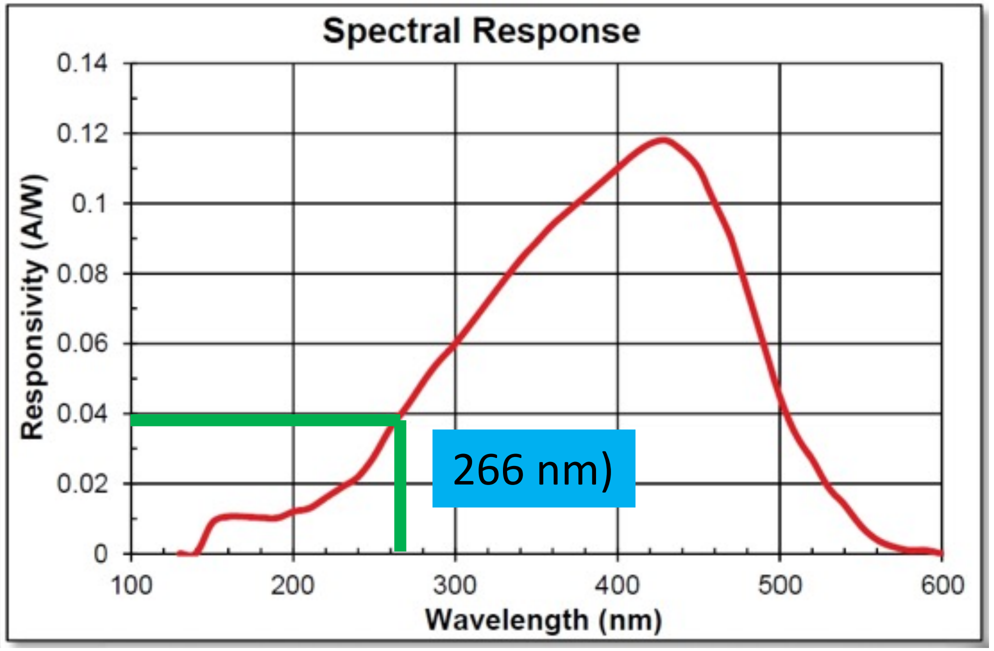
- Pin diode LBLS is envisioned as an array of 2x5 photodiodes to increase area coverage
- When illuminated by laser beam, pin diodes generate electric signal proportional to light flux.
- Placed below field cage to eliminate interference with TPC **E** field.
  - One pin diode pad is attached to G10 I-beam below bottom FC (with alternative on the APA rocker arm)
  - Second location – similar xy, but glued to cryostat floor



CAD design work by Jan Boissevain.

Candidate Pin Diode: UV Sensitive GaP PIN Diode Operated Passively

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



Measurement: Thorlabs

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

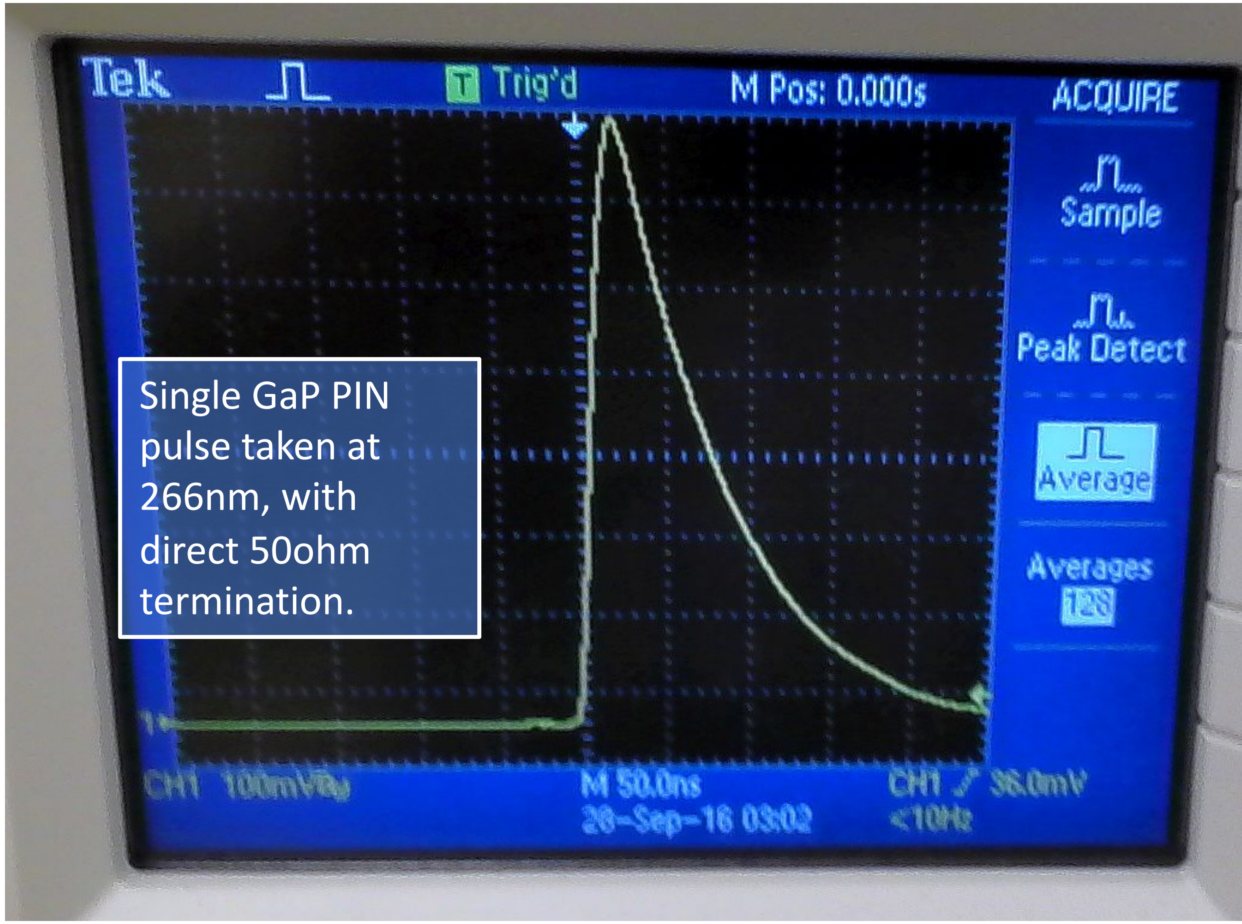
Specifications[a]		
Wavelength Range	λ	150 - 550 nm
Peak Wavelength	λ_P	440 nm
Responsivity	$\Re(\lambda)$	0.12 A/W
Active Area	-	2.2 mm x 2.2 mm
Rise/Fall Time (R_L=50 Ω, 5 V, 405 nm)	t_r/t_f	55 ns / 55 ns (Typ.)
NEP, Typical (440 nm, 5V)	W/√Hz	1.3×10^{-14}
Dark Current (5 V)	I_d	15 pA (Typ.) 40 pA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

Specifications: Thorlabs

Available from Thorlabs:
https://www.thorlabs.com/thorproduct.cfm?partnumber=FGAP71

Pin Diode Testing

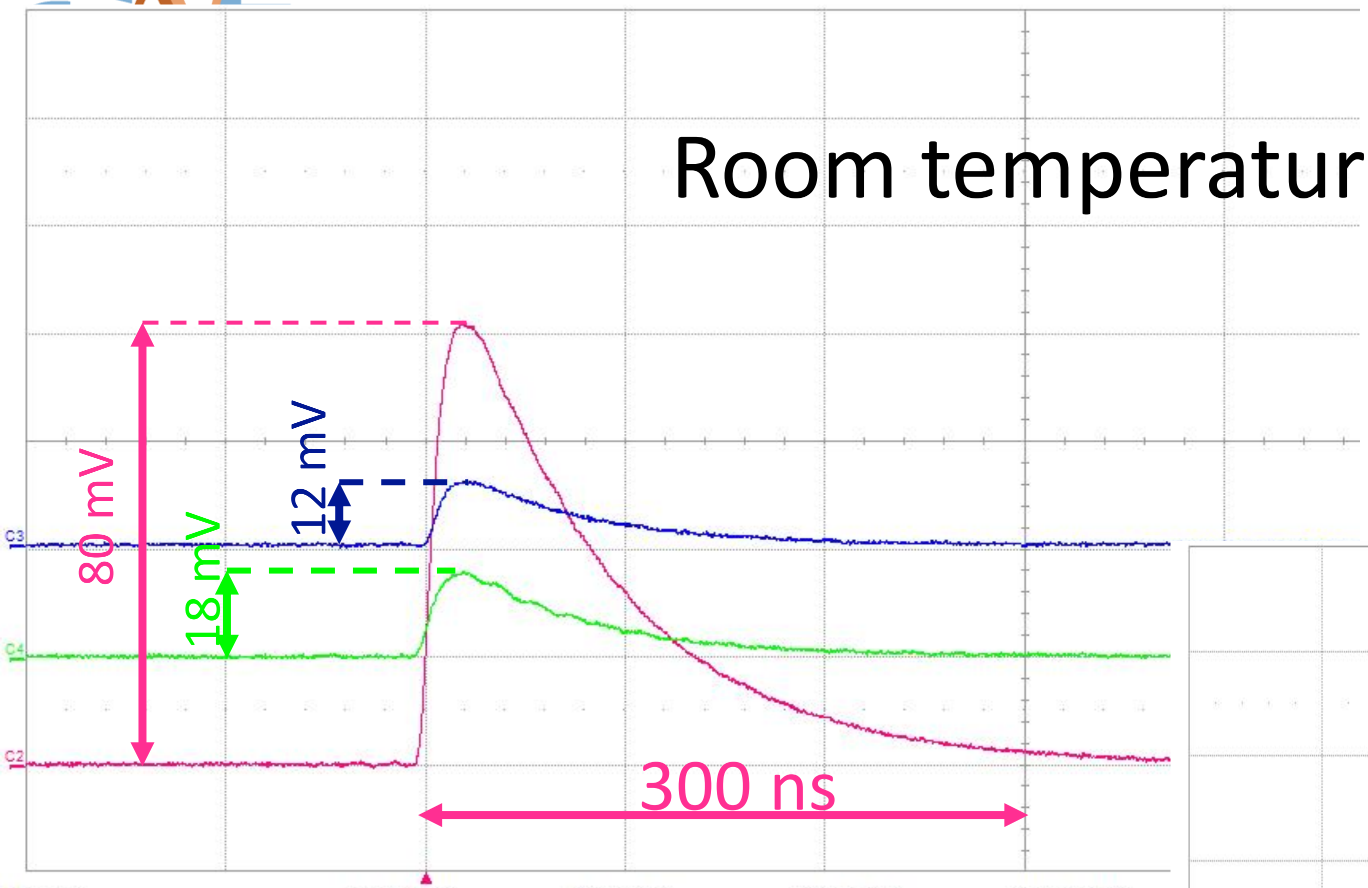
- A single PIN diode soldered directly to a 50ohm co-ax cable with an SMA termination.
- Very steep rising edge and strong signal – 750 mV
- Pulse duration about 200 *ns* for the *5 ns* laser pulse.

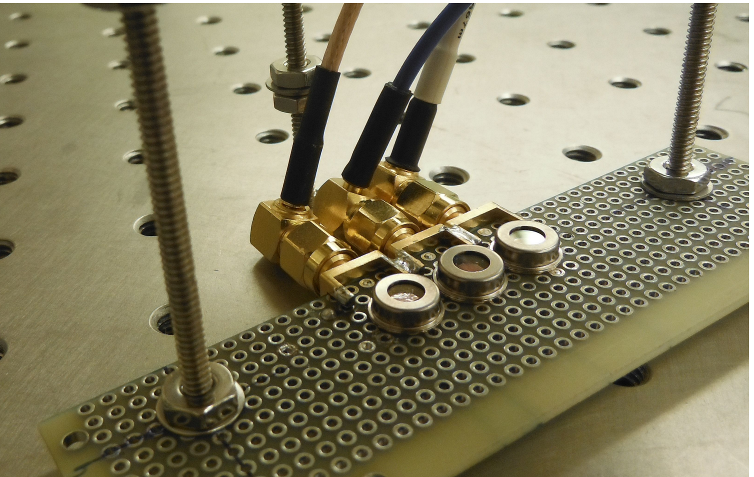


Single GaP PIN pulse taken at 266nm, with direct 50ohm termination.

Testing part of development for miniCAPTAIN detector in 2017.

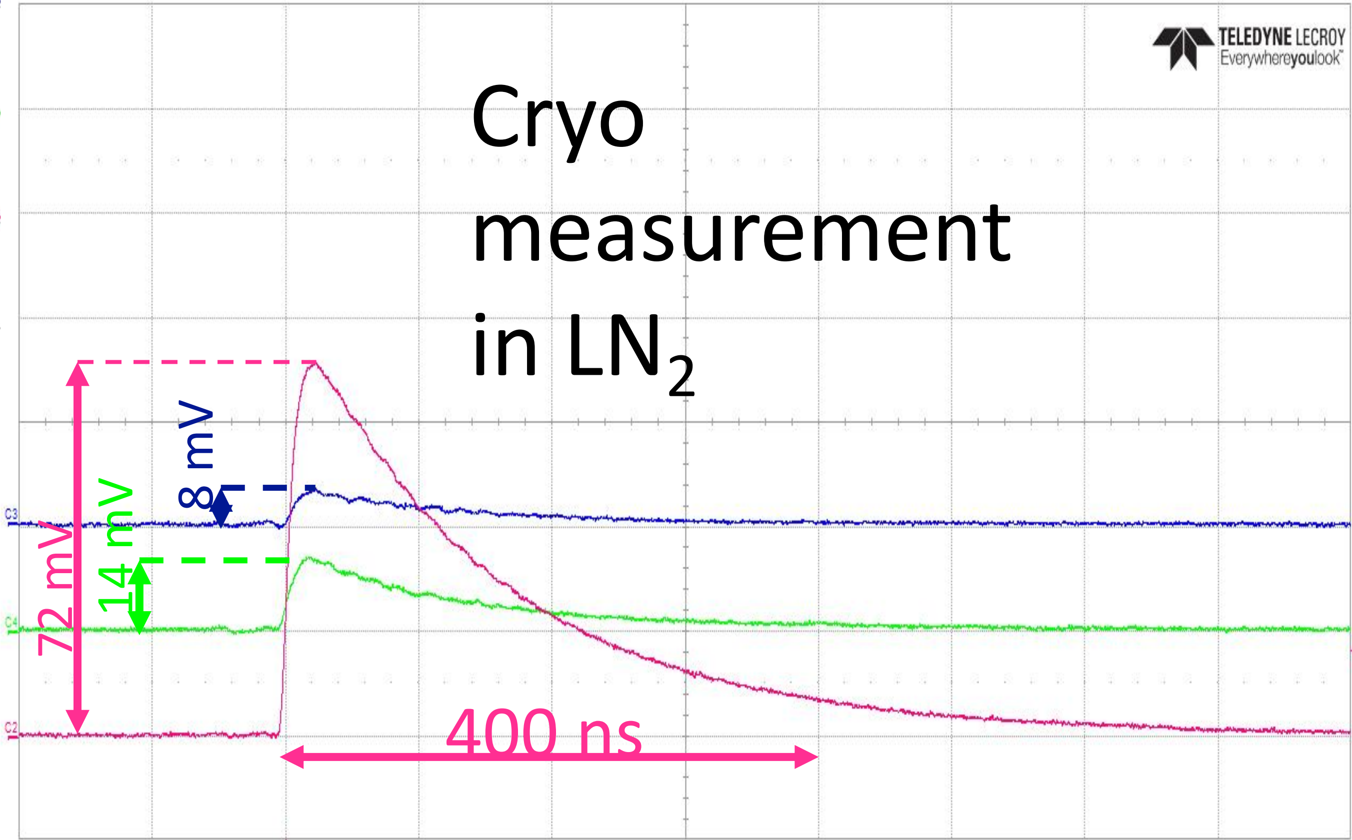
Warm and Cryo Operation for 3 Pin Diodes



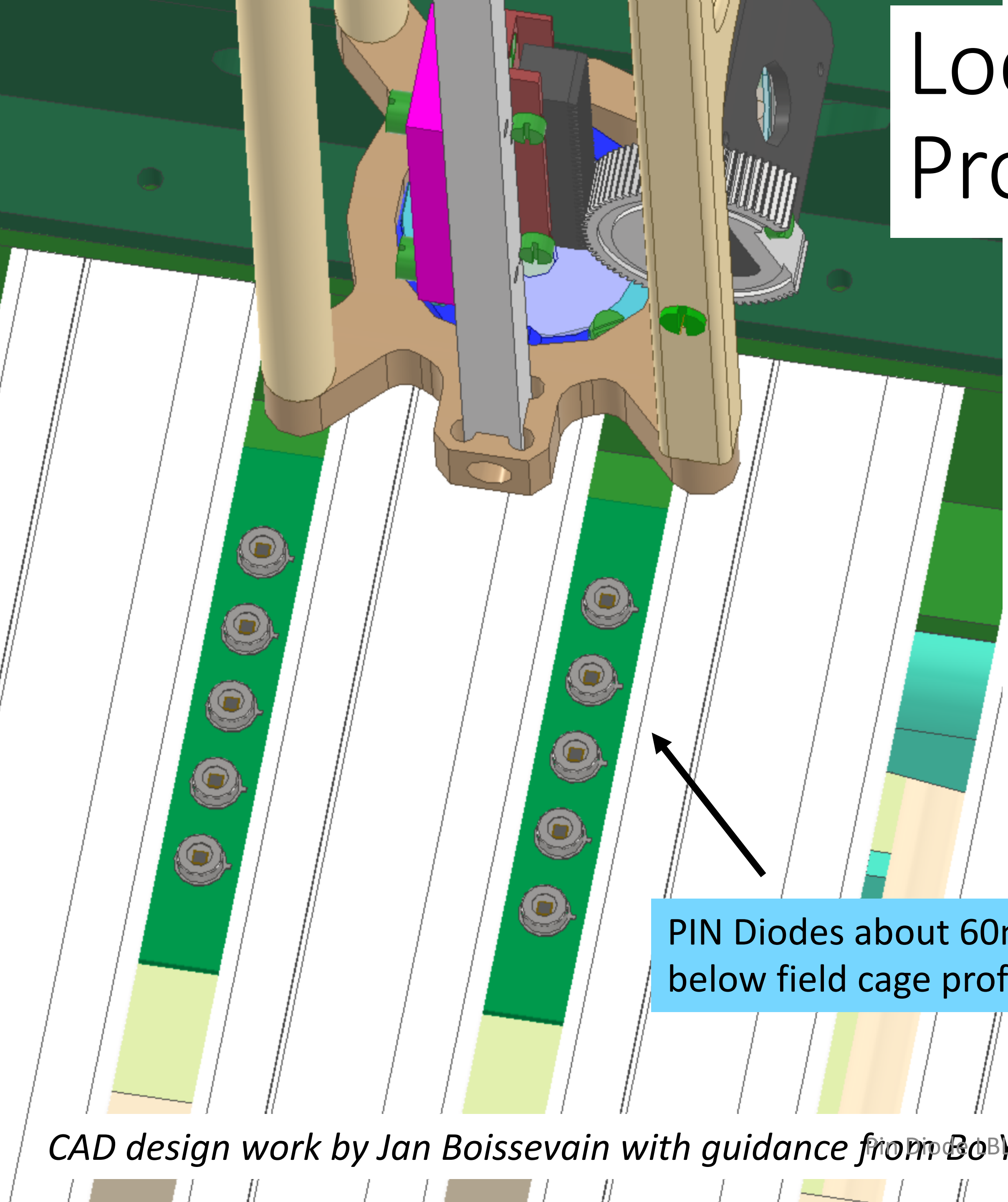


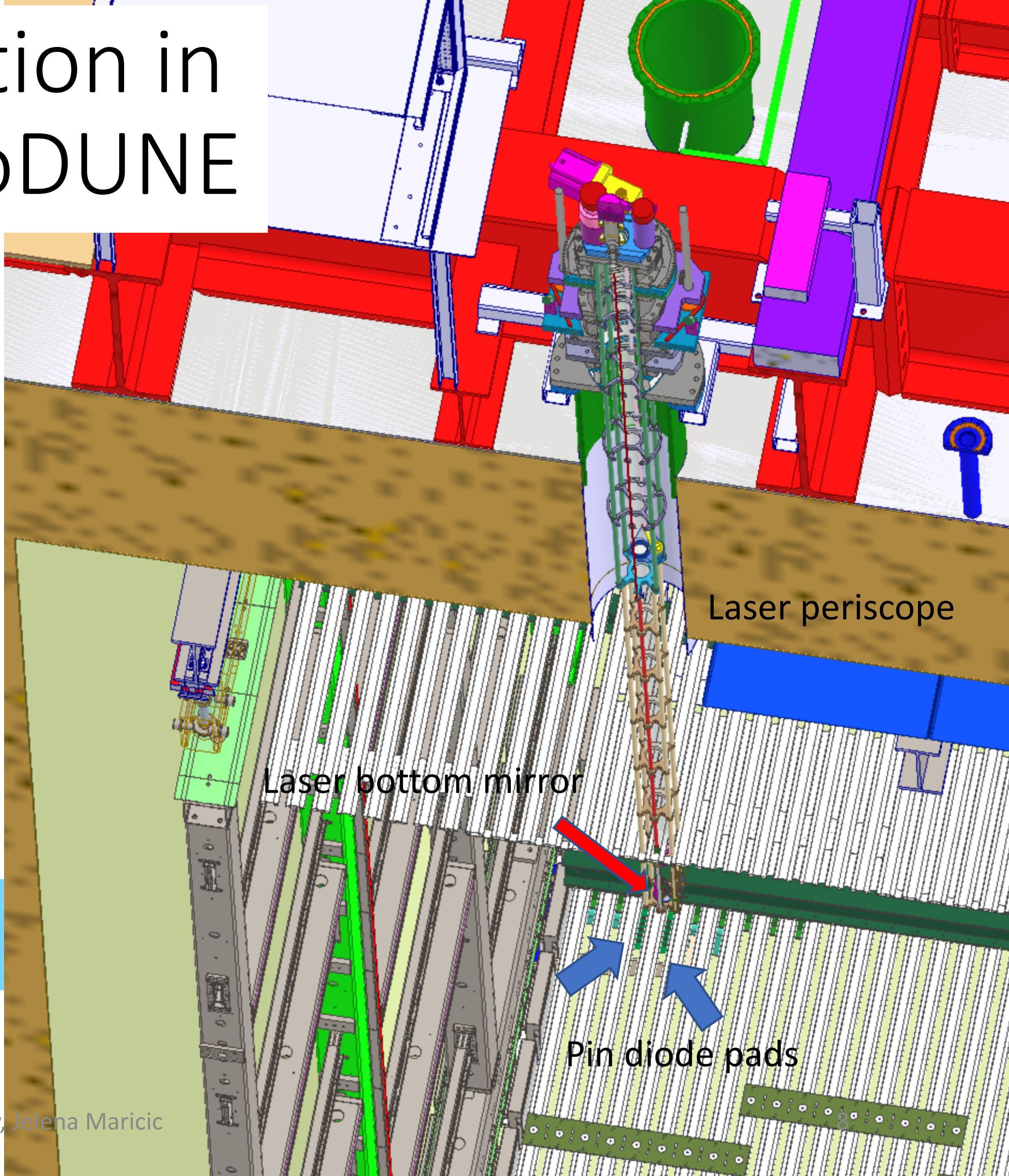
Oscilloscope traces
For 3 PIN diodes
Illuminated with
266 nm NdYag laser
pulses.

Prototype built for miniCAPTAIN detector in 2017.



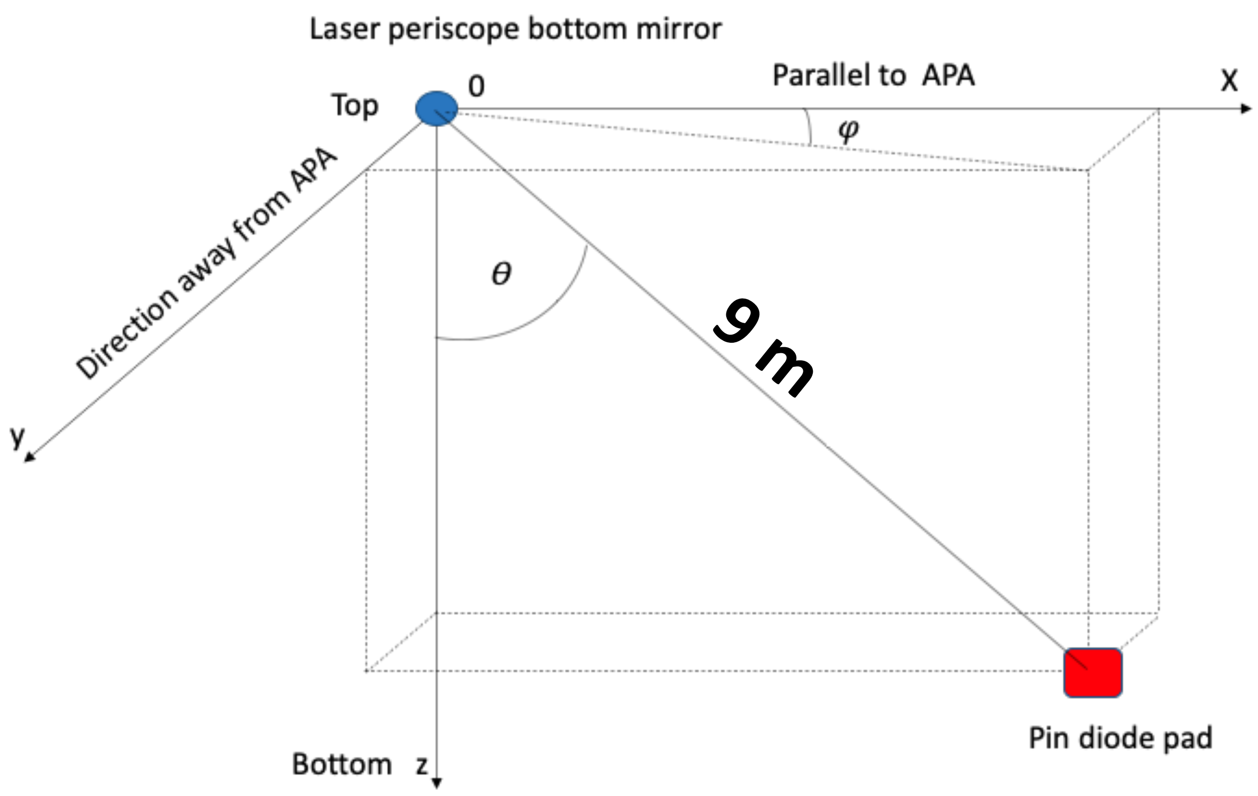
Location in ProtoDUNE



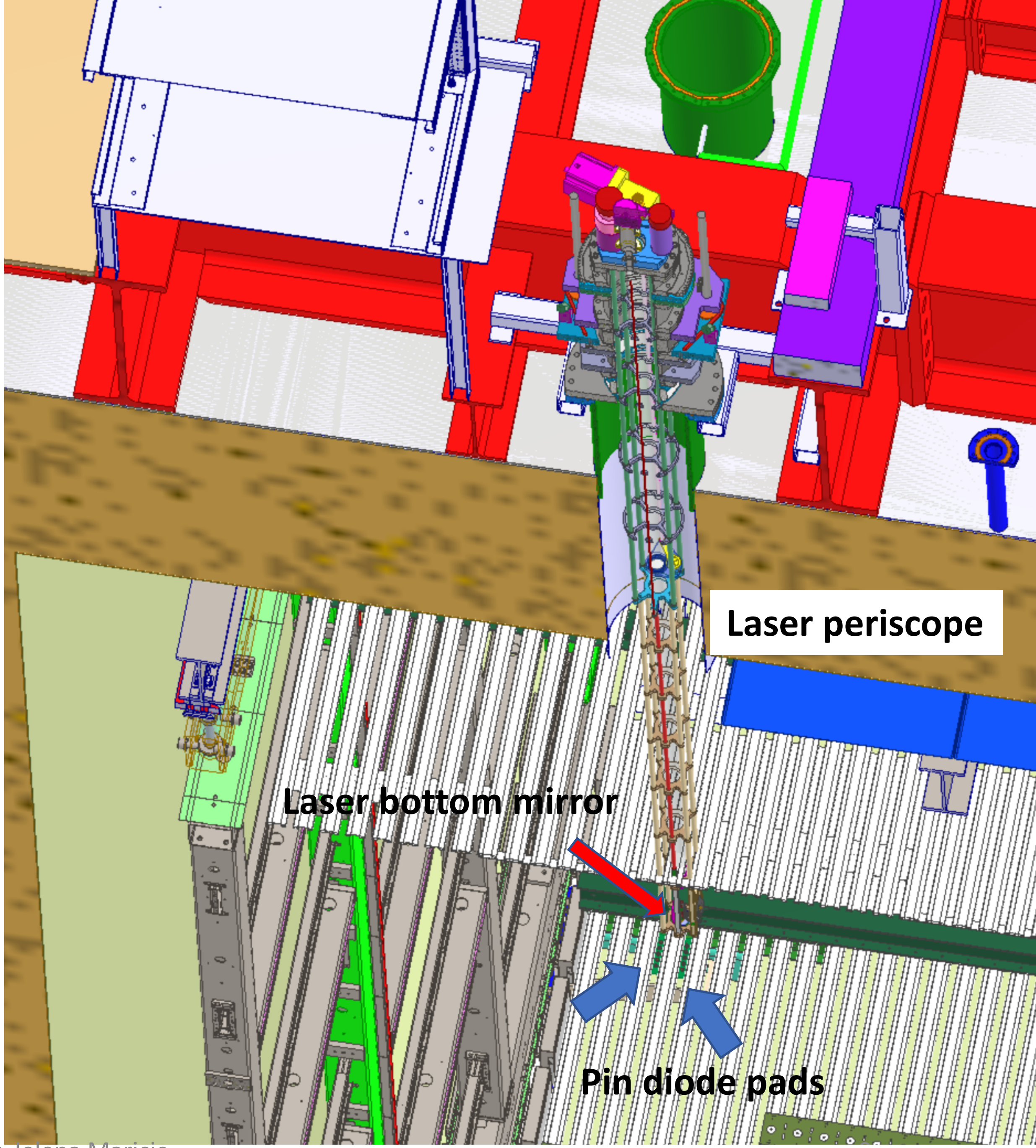


CAD design work by Jan Boissevain with guidance from Bo Yu.

Viewing the Pin Diode Pad from the Periscope Bottom Mirror



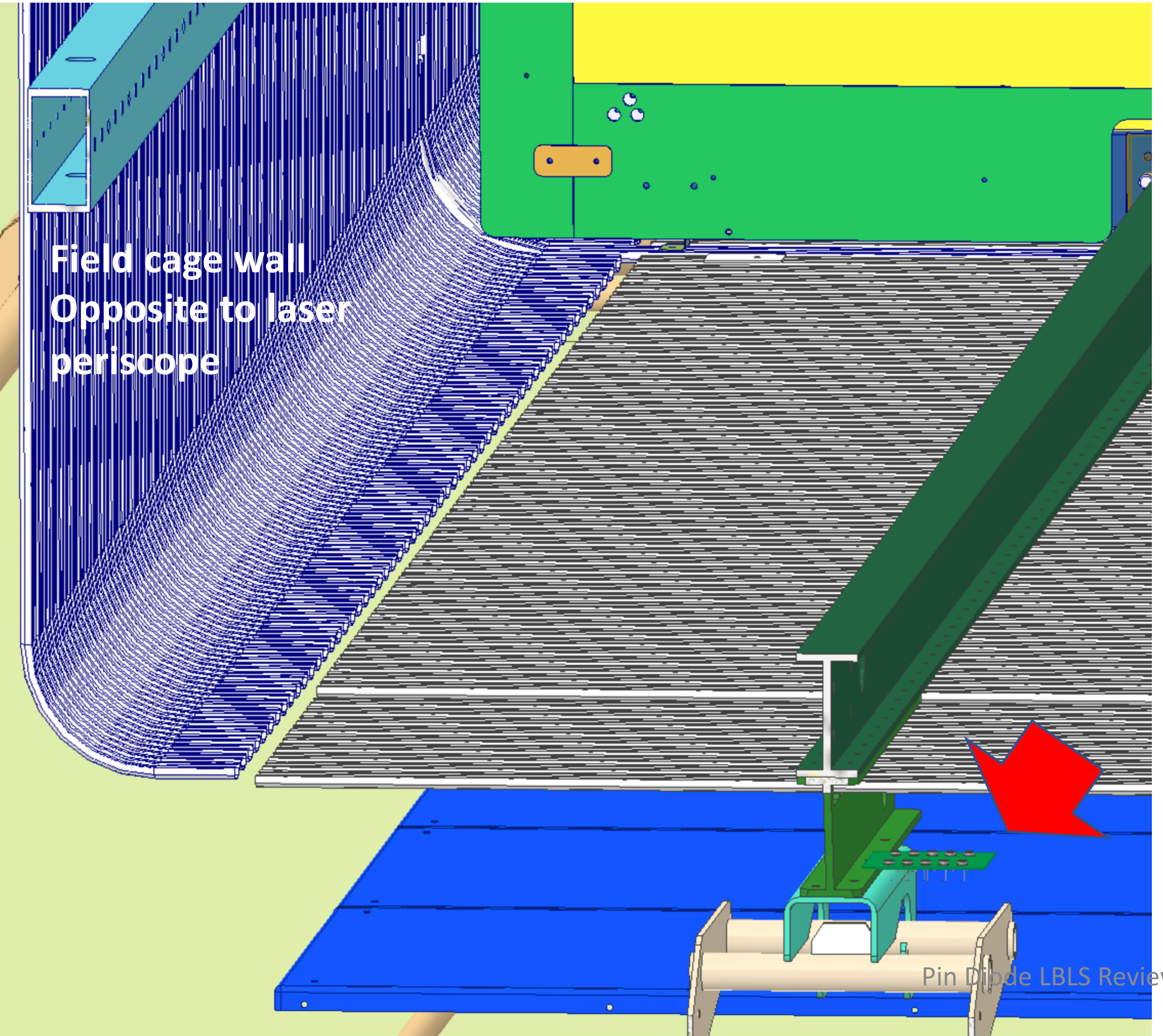
Beam views the pin pad from roughly 45° and 6° toward the APA.

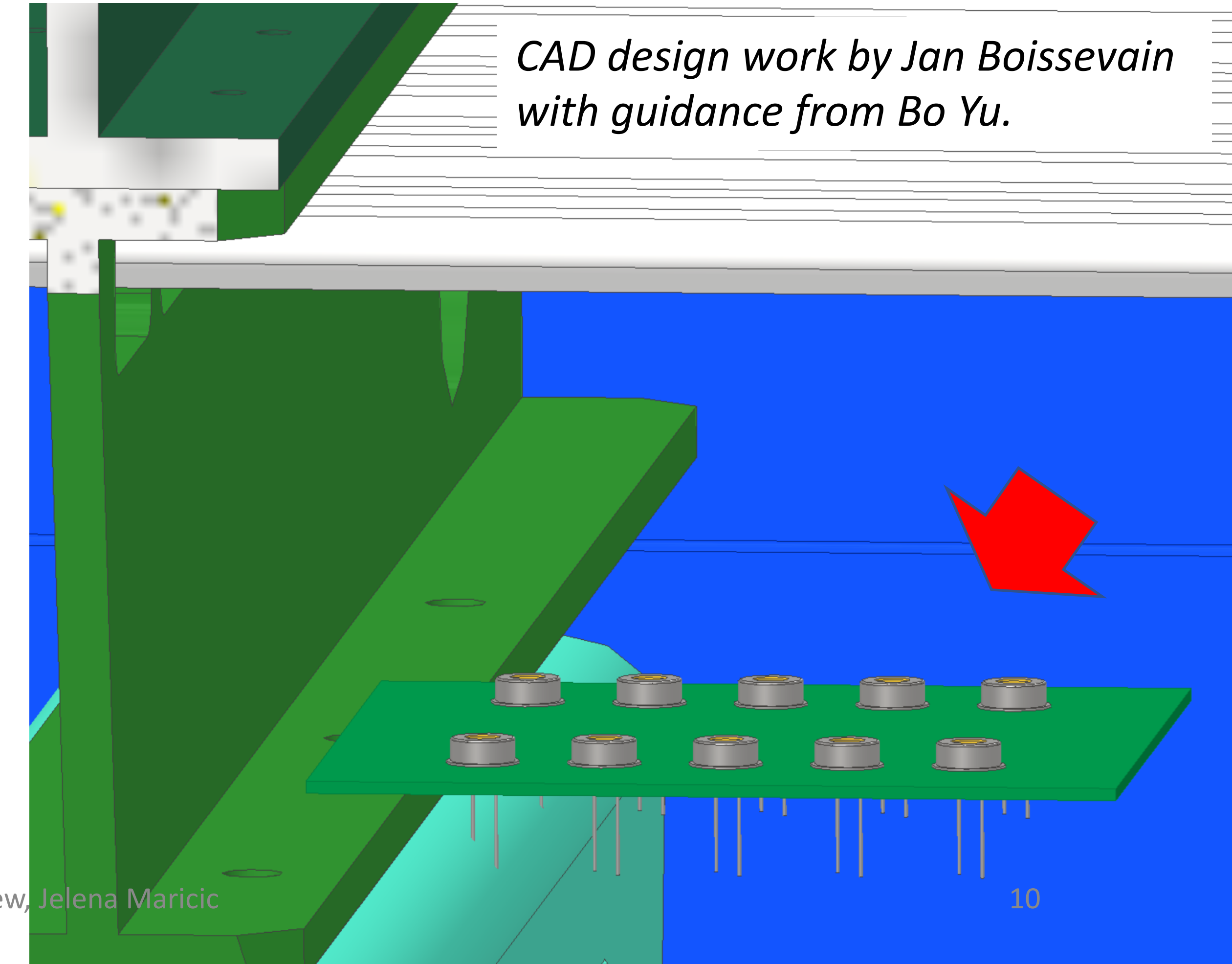


CAD design work by Jan Boissevain with guidance from Bo Yu.

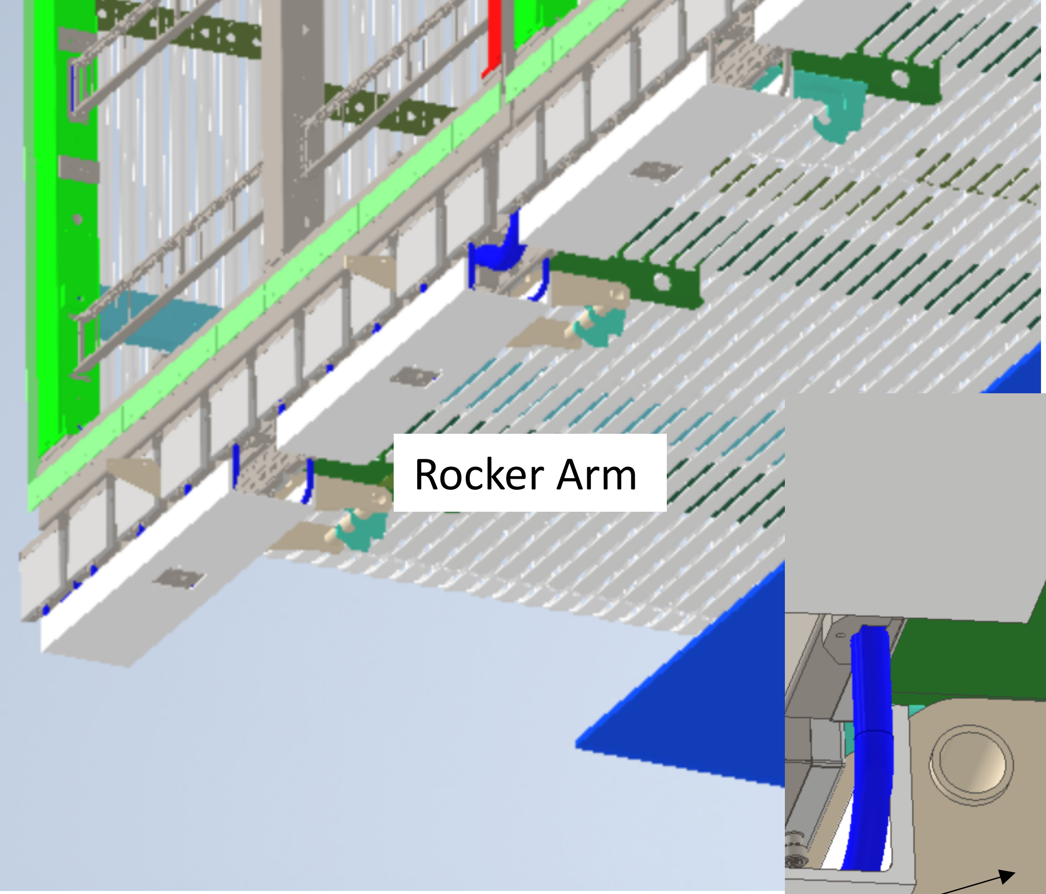
Side View of PIN diode location

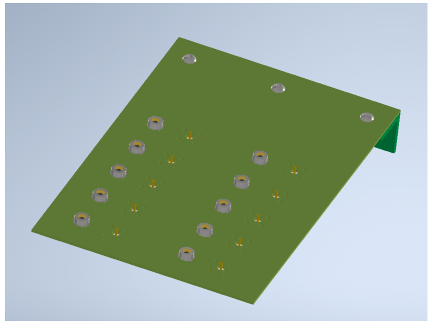
Pin diode pad mounted on G10 I-beam
6 cm bellow the bottom frame of the FC.
24 cm away from APA plane
6 m away from the periscope side of the field cage
Same position is available in ProtoDUNE and FD

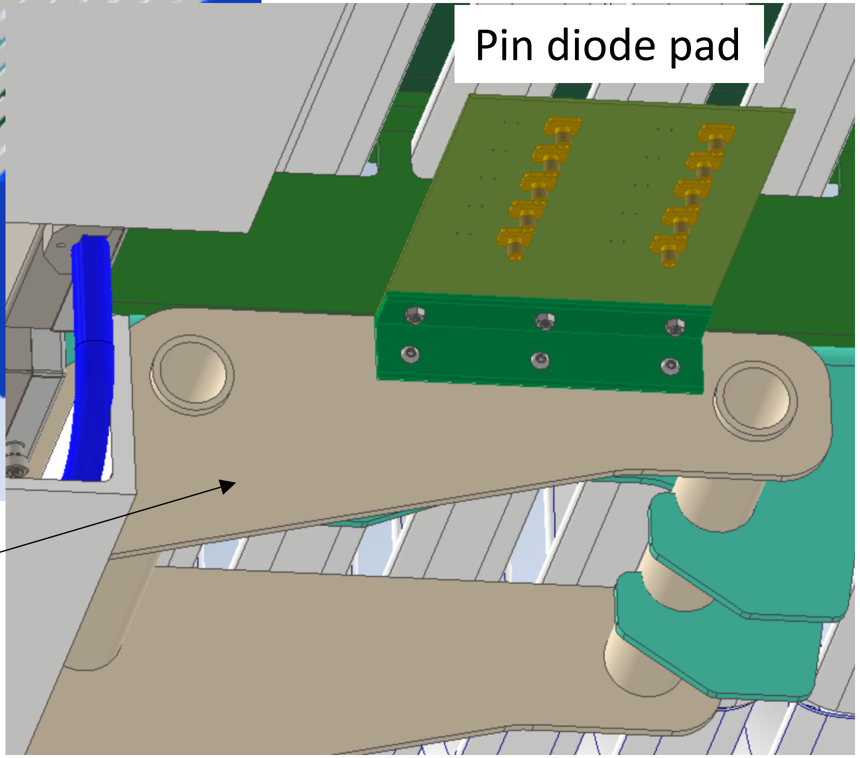




Alternative Placement

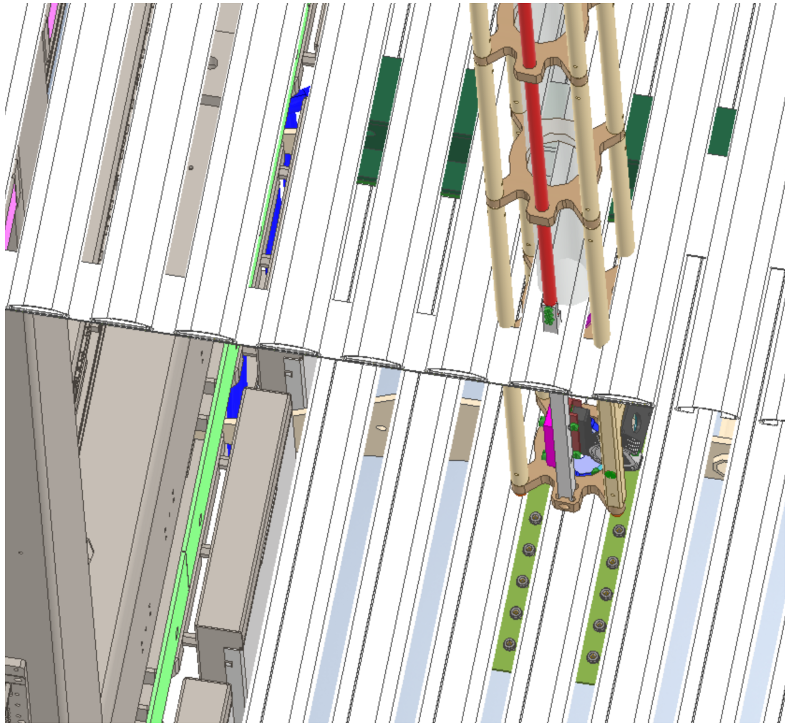






Rocker Arm

Place pin diode pad attached to APA rocker arm 153 mm below FC.
Easier installation and cabling – installed together with APA.



Pin diode pad observed from top through FC.

CAD design work by Jan Boissevain with guidance from Bo Yu.

Pin Diode LBLS Cost

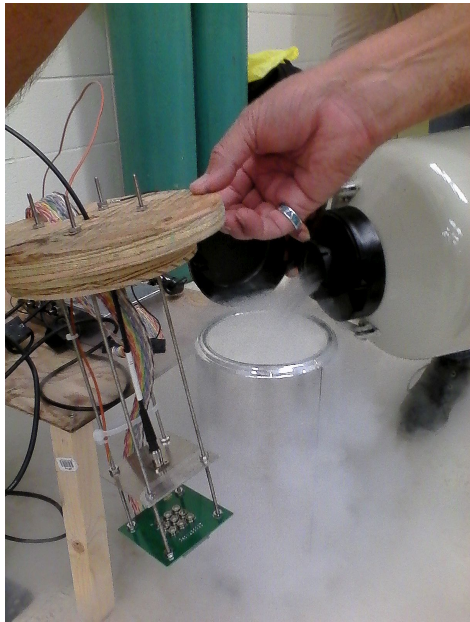
- The cost of the system is modest.
- The main cost of the system is pin diode ~$90/each
- The cost of single LBLS pad is $1,000
- For 16 modules + 3 spares, the cost is $19k
- Other cost include cables to be routed to the surface, but are minor.

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

Testing plans I – cryogenic endurance and characterization

- Cryogenic tests of all pin diodes that will be used to characterize and calibrate their signals as initial reference both in warm and cold (in LN2)
  - NdYag laser and dewar available at UH for warm and cold testing including the feedthrough for laser to inject light into dewar
- Cycling and aging tests
  - While the tests performed in the past showed pin diodes to perform well under cool down, warm up cycling tests and for prolonged duration, the tests must be repeated at the UH lab prior to module production.
- Manpower:
  - Ranjan Dharmapalan (postdoc – 100% DUNE),
  - Alex Dvornikov (graduate student – 100% DUNE),
  - Undergraduates (difficult now due to COVID-19)
  - myself

Quantel
Q-smart (850 mJ)
4w NdYag laser



At UH lab

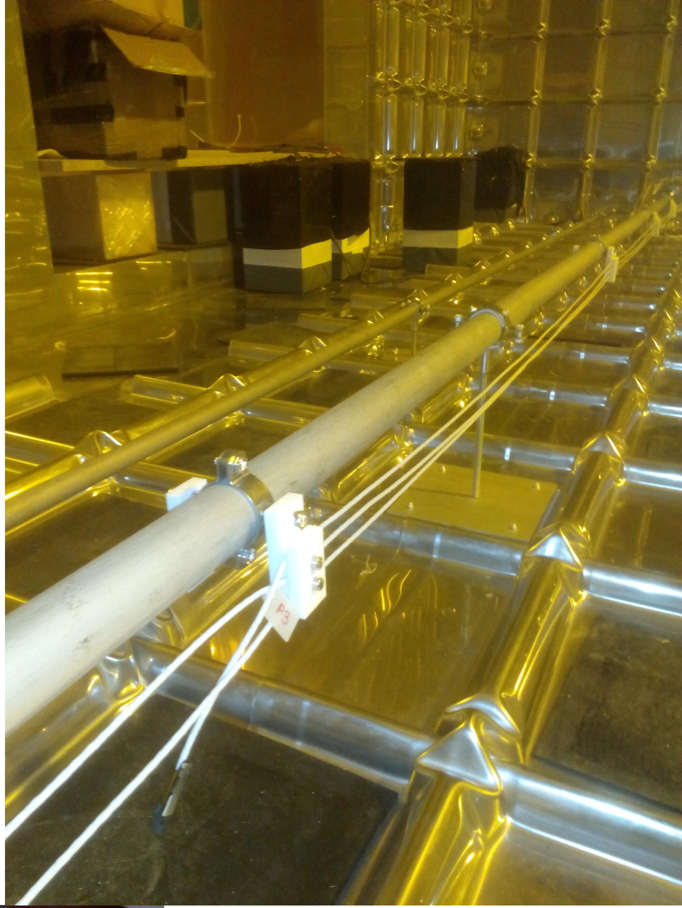
Testing plans II – electronics testing

- Cross-talk characterization among pin diodes on the same pad.
  - Cross-talk between signals must be measured and characterized, and mitigated in case of strong interference.
- Signal attenuation in the cables as well as signal degradation when exciting the cryostat
- Exposure of pin diodes to high laser power to develop safe limits that will prevent damage of the pin diodes by the laser beam
- Test signal cables and connections for integrity after pin diode pad has been fabricated

Fabrication and testing schedule

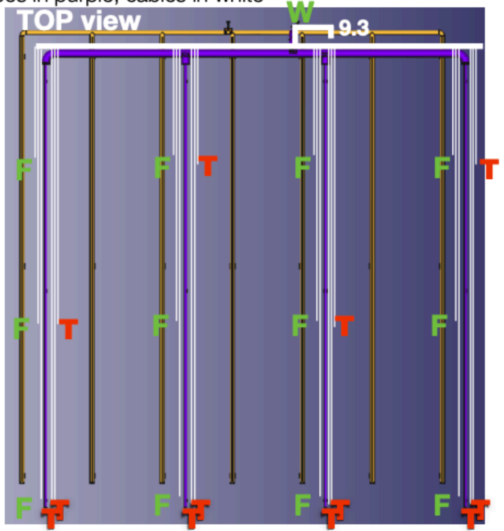
- October – December 2020
  - Cryogenic testing and characterization of pin diodes – 1 month
  - Prototype pin diode pad production (at UH – in house and using our machine shop) and characterization – 1.5 months
  - Cycling and aging testing – 3 months
- January 2021 – March 2021
  - Cross-talk characterization – 1 month
  - Signal attenuation in cables and damage of pin diodes by high laser power – 1 month
- April 2021 – August 2021
  - Fabrication of two pin diode pads and characterization
  - Integration testing at LANL
- Possible schedule delay due to COVID-19 – minor risk)

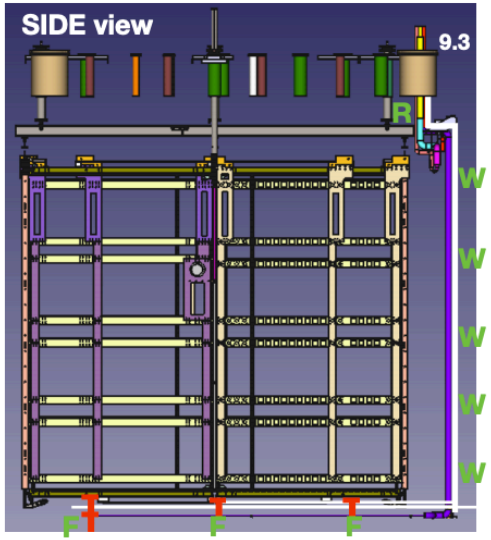
Installation in ProtoDUNE-2



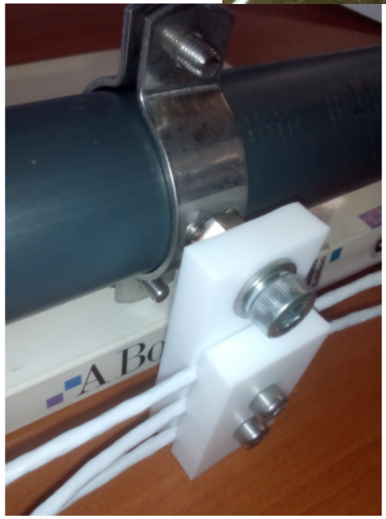
- Two dedicated locations, one attached to FC and another on the floor
- Installation along with APA or prior to bottom FC
- Routing of cables on the floor and along the wall, following cryogenic pipes – employ cabling similar to temperature sensors
- Impact of introduced electronic noise to be studied.
- Allocating (sharing) exit port for the cables – to be determined.
- Read out system for the LBLS will be integrated with the Slow Control
- *Flange allocation for taking out signal cables is the main issue to be solved.*

Pipes in purple, cables in white





Example cabling scheme for temperature sensors from Anselmo Cervera UFIC, Valencia



Example cable support On small pipe in ProtoDUNE for temperature sensors from Anselmo Cervera UFIC, Valencia

Are there a set of well understood and documented requirements for the prototype laser penetration system stemming from the systems being considered for the DUNE Far Detector?

- Positioning: each laser periscope must have at least two LBLS pin diode pads within a distance range of 10 - 20 m (maximum assumed laser beam range) → **current distance from bottom periscope mirror to pin diode pad is 9 m.**
- Knowledge of the pin-diode strip position w.r.t. the FC - better than 5 mm. Size of the laser beam targets determined by the sensitive area of individual pin diodes: not larger than 5 mm.
- Knowledge of the pin-diode strip position w.r.t. the FC - better than 5 mm.
- Reference frame checks: pin diode LBLS position should be carefully surveyed with respect to cryostat during installation - better than 5 mm.
- Pin diodes must generate strong signal above 0.5 V when hit by beam to easily distinguish signal over background and differentiate between secondary reflections of the field cage and direct hits. Planned testing will encompass these measurements.

Establish 1.5 cm position precision

Does the design address the documented requirements? Is the design feasible?

- Photodiodes that are selected have 2.2 x 2.2 mm^2 sensitive area and therefore provide required granularity of better than 5 mm.
- Careful survey of the installation location needs to be conducted prior to installation to satisfy positioning requirements.
- Electric signals above 0.5 V from these pin diodes have been measured in the past, and will be measured again with the current setup.

Are plans for prototyping sufficient to validate the viability of the design? In particular, is the plan for testing of the prototype at LANL adequate for validating its use in ProtoDUNE-II?

- Pin diode LBLS will be tested at Los Alamos with the Iolaser to:
  - record signals as expected in ProtoDUNE,
  - verify beam spot reconstruction capabilities
  - check the resiliency of the pin diodes to laser beam exposure to avoid damage during calibration system commissioning and campaigns.

  - Build mock-up field cage profiles with correct spacing and record signals on pin diodes from the laser light reflected off the field cage profile for reference in ProtoDUNE.

Have issues related to the grounding and shielding of electrical connections within the laser penetration system been properly accounted for in the design? Does the proposed testing plan for the prototype allow for validation of proposed grounding and shielding scheme for the DUNE Far Detector?

- One pin diode pad will be at least 6 cm (15.3 cm) below the FC which is fine for a grounded conductive plane according to Bo Yu, as long as we keep it in the area close to APA where HV is lower.
- We will need additional study to confirm this for the specifics of the pin diode pad and make an adaptation as needed.
- The second pin diode pad will be on the cryostat floor, thus sufficiently far from the FC.
- Cables will be routed on the floor and wall, following cryogenic piping

Summary

- Pin diode LBLS will pinpoint the laser beam direction in TPC during IoLaser commissioning and detector calibration
- Requirements will be satisfied by a combination of testing and detector survey.
- Production plan in sync with IoLaser preparation and integrated test planned for next year
- Cabling plan will be developed using the example from temperature sensor cabling scheme used in ProtoDUNE