Photoelectron Laser and Laser Positioning System

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Photoelectron Laser Overview

- Provide well localized electron sources on the cathode at predetermined locations by releasing photoelectrons from metal targets on the CPA by laser light illumination.
- Measure and monitor electron transport in the TPCs, via drifting electrons from the control pattern of locations on the CPA.
- Allows precise determination of electron drift velocity and measurement of distortions in the electron drift due to inhomogeneous and misaligned electric field.
    - Efficient diagnostic tool - measure drift time from the triggered laser pulse to electron cloud detection in the detector.
- Inclusion of the photoelectron target strips enable measurement of transverse size of ionization
- E-field distortions calibration and vertex reconstruction calibration
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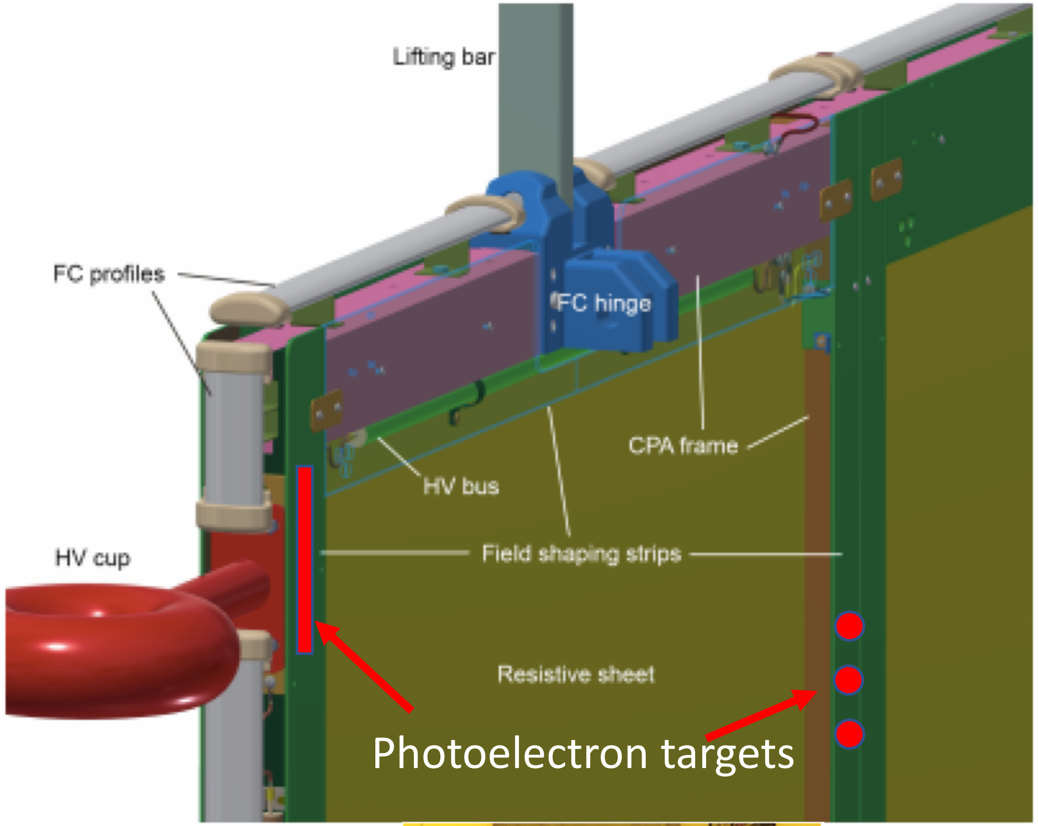
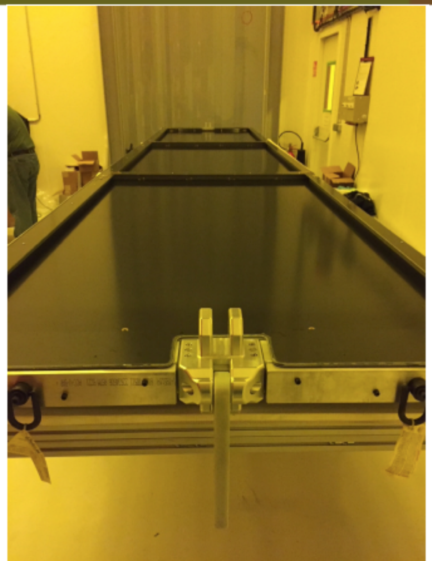
Photoelectron targets

- Photoelectron candidates for targets based on different experiences used in the past:
  - Gold, aluminum, nickel, silver
- Plan to use the same NdYag laser 266 nm with 4.66 eV photons
- Gold (5.1 - 5.47 eV) and nickel (5.04 – 5.35 eV) – work function > 4.66 eV – requires much higher laser intensity or different wavelength light source
- Aluminum (4.06-4.26 eV) and silver (4.26-4.74 eV) – work function < 4.66 eV – 1 photon required to release 1 electron (prior to reduction due to quantum efficiency)
- ~70 angstrom thick Al_2O_3 layer develops on the surface of Al when exposed to air; does not change over time (Al_2O_3 work function 3.9 eV from the literature)
- Aluminum is the preferred candidate – excellent experience from T2K TPC where photoelectron laser was implemented and successfully utilized.

Photoelectron Laser Implementation

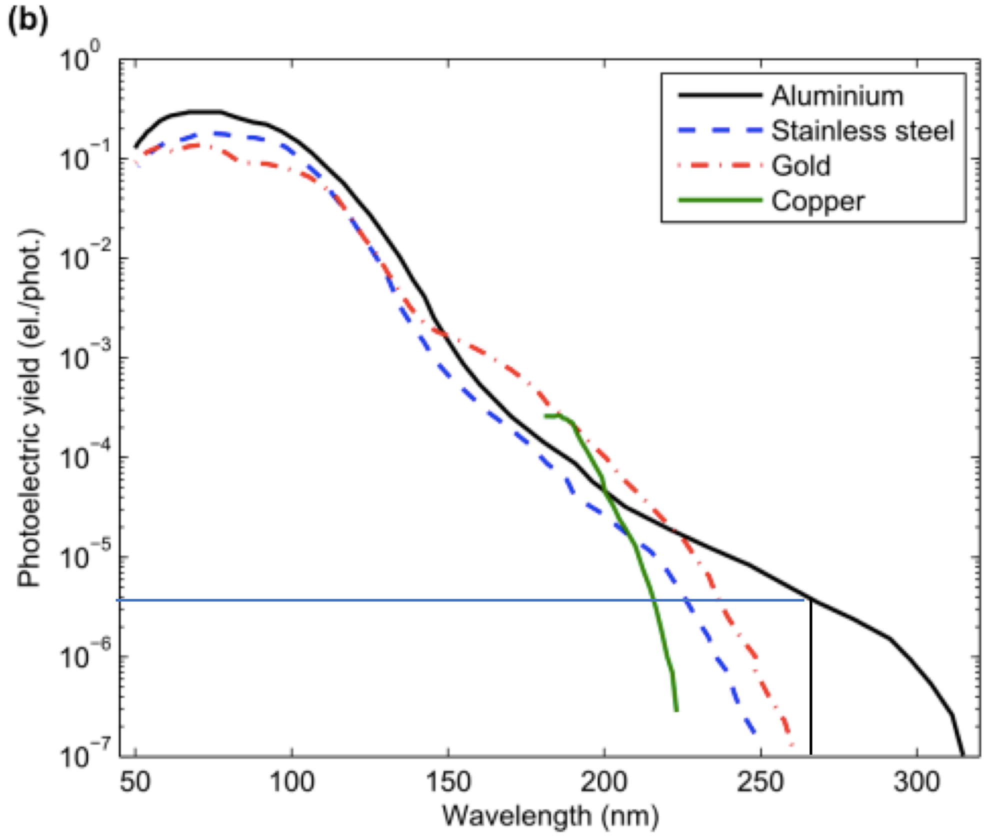
- 7 mm radius target discs placed on the field shaping strips on CPA
- 0.7 x 20 cm target strips placed on the field shaping strips on CPA
- Optical fibers with diffuser routed to APA and fastened between APA planes to illuminate the photoelectron targets located across the TPC on the CPA
- Utilize DSS ports to insert the fibers in the TPC





Noise in the Detector and Photoelectron Quantum Efficiency Yield

- Reflection coefficient at 266 nm from Al is 90%
- Abundant scattered light will hit exposed aluminum surfaces such as FC
- Photoelectron Quantum efficiency for aluminum is of the order 10^{-6} therefore emission of photoelectrons from aluminum surfaces in the TPC is negligible



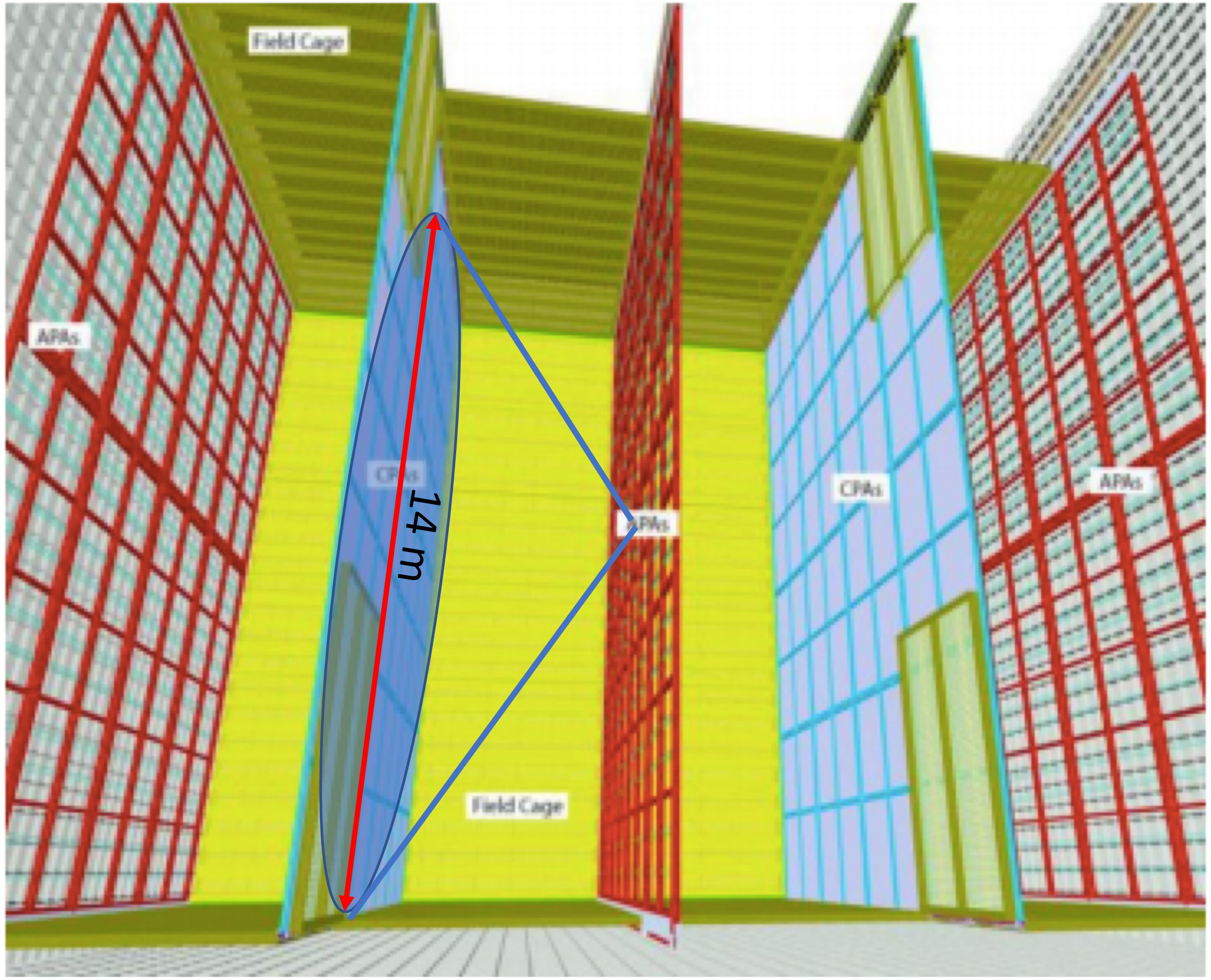
Area illumination from a single fiber

- Pulse power 50 mJ (can go up to 100 mJ without large cost increase), pulse length 5 ns
- Efficiency of injecting light in the UV fiber 2% (conservative estimate)
- Number of photons per pulse 6.7×10^{14} photons/pulse
- Assume 7 m radius illumination on CPA (optical element diffusing light coming out of fiber)
- Phototarget radius 7 mm
- Quantum efficiency 5×10^{-6} at 266 nm
- Attenuation in 20 m of optical fiber ~ 7.5 at 0.22 dB/m at 266 nm
- Number of photoelectrons from a single target 9000

- *Note: Assumed conservative light injection efficiency; neglect Rayleigh scattering (40 m at 266 nm in Ar)*

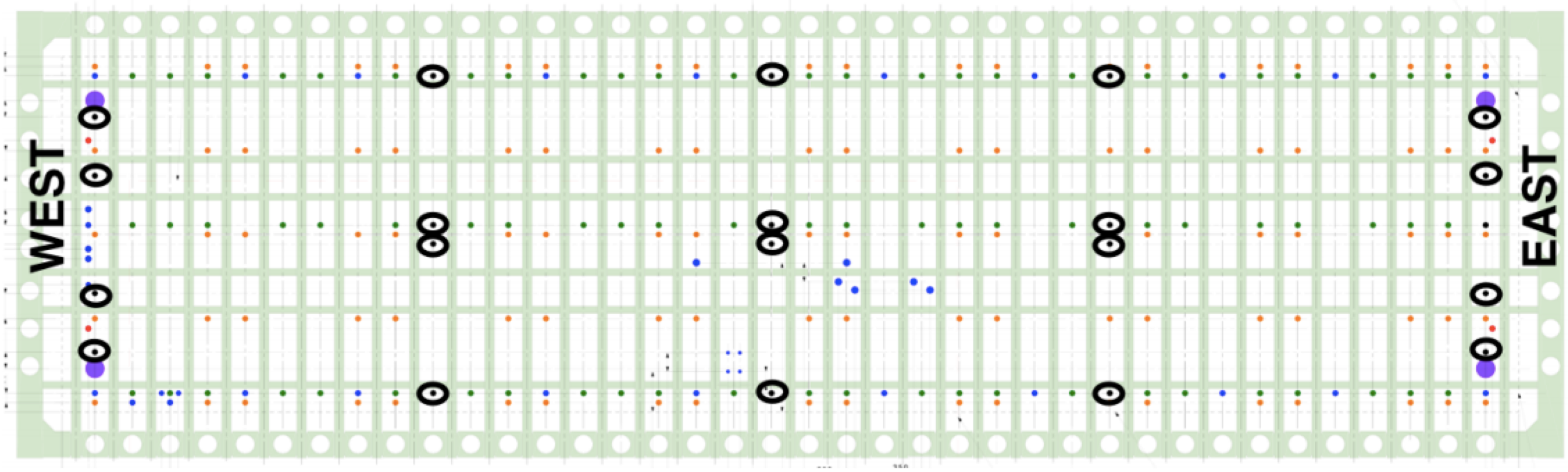
Required number fibers

- We need several thousand photons per target
- Single fiber from a single laser can be used to illuminate 14 m diameter area
- Fibers will be placed along central line between upper and lower level APAs for best illumination



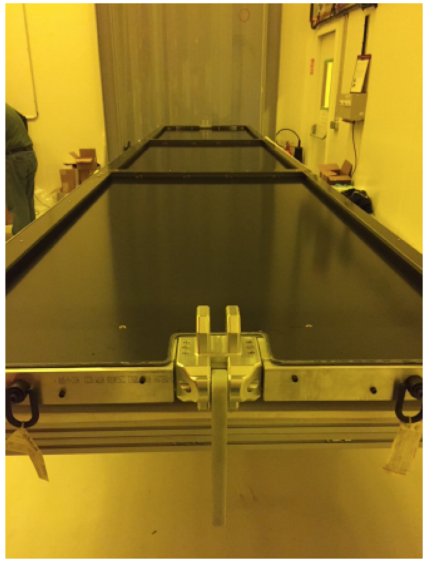
Locations

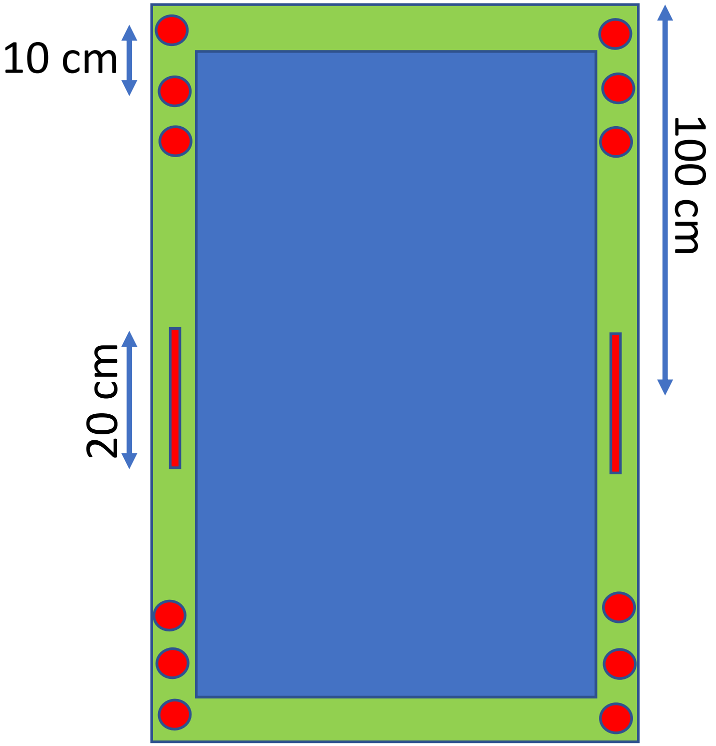
- Utilize existing track lasers for illumination of photoelectron targets.
- One fiber per target
- 20 laser fibers with 20 m fiber length (5 m in warm + 15 m in cold) for a total of 100 m of warm and 300 m of cryogenic fibers.
- Excellent TPC resolution allows for illumination of all targets in parallel.



Target locations

- Targets will be placed on the corners of Resistive Panels (RPs) that are 1.2 x 2 m in dimensions on field shaping strip surfaces.
- 12 dot targets with 10 cm spacing placed as shown
- 2 0.7 x 20 cm strips per RP
- Targets placed on ever other RP
- Total number of RPs per SP module is 600
- Total number of RPs with targets attached is 300, resulting in total of 3600 dot targets and 600 strip targets.





Calibration Campaign

- Assuming parallel running of lasers, all photoelectron targets can be illuminated at once, assuming that laser firing can be coordinated or calibrated with sufficient precision.
- Lasers operate at 10 Hz frequency.
- Assuming 10000 pulses per laser, about 15 minutes is needed per laser.
- Depending whether the lasers are run in parallel or series, the entire calibration campaign will take between 1 – 5 hours.

Is Random Argon Scintillation Light (9.68 eV) Problem for Photoelectron Laser?

- Used photon simulation to estimate noise coming from scintillation photons (from radiological backgrounds) hitting the photocathode target.

- Used photon detector simulations and unfolded number of photons per surface area based on number of photoelectrons detected in SiPM.

Photon Rate Calculation

The length of the time window per event :

4.492 ms

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T0:        [ -2246000 ]
T1:        [  2246000. ] # ending time in ns
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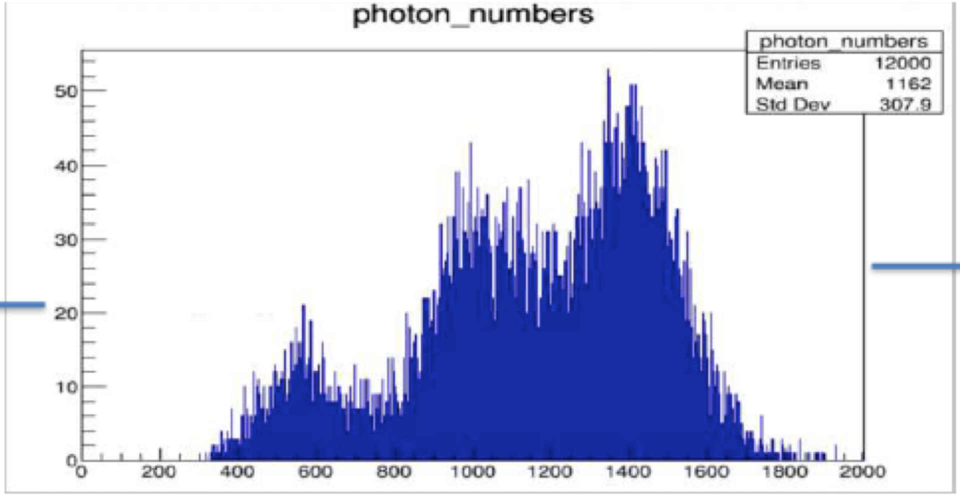


Mean: 1162
Maximum: 2000
Center of the 3rd peak :1400

N_photons	Area (cm^2)	Time window Length(ms)	Per Area(cm^2) Per event time window	Per Area (cm^2) Per ms
2000	2130.3742	4.492	0.938802207	0.208994258
1400			0.657161545	0.146295981
1162			0.545444082	0.121425664

The average photon rates is therefore 0.146 photons per cm^2 per ms

Noise in the detector induced by photoelectron targets is negligible considering low quantum efficiency of .

Test program for Photoelectron Laser in ProtoDUNE Phase II

- Glue targets in predetermined locations on the CPA – several targets sufficient to validate system
- Use different target materials to compare their performance
- Verify the potential of targets to generate several 1000 electron clouds and their potential to diagnose electric field distortions and vertex reconstruction
- Allocate port to insert laser fibers used for illumination
- Interface with track laser in order to inject 266 nm photons into fibers
- Validate light attenuation in fibers
- Validate design interface with APA and optimized locations of fibers between top and bottom APAs

Budget Estimate of the Photoelectron Laser

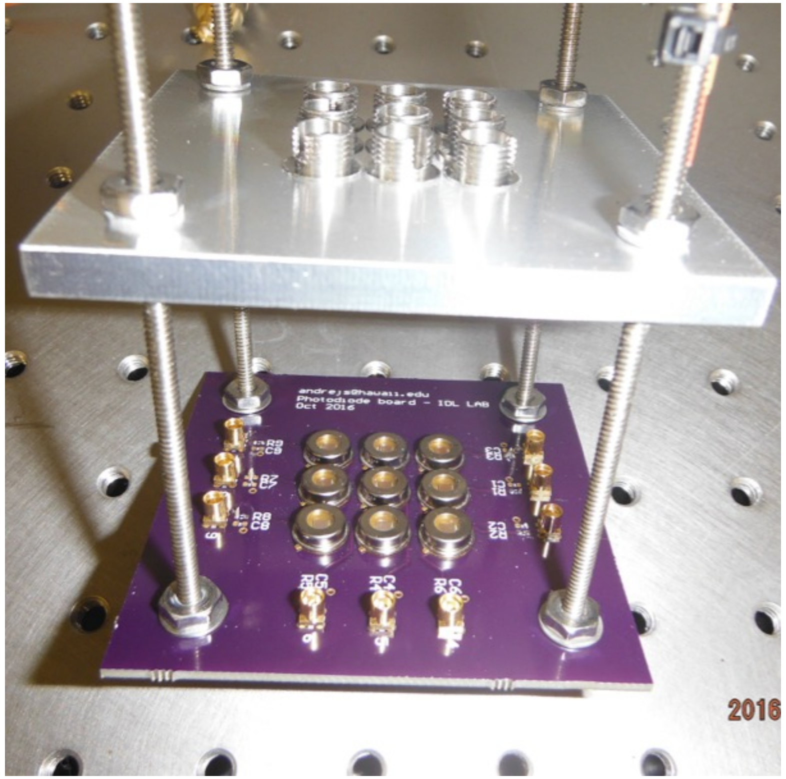
- Given the ability to use track laser for the photoelectron calibration, the main cost of the system are fibers

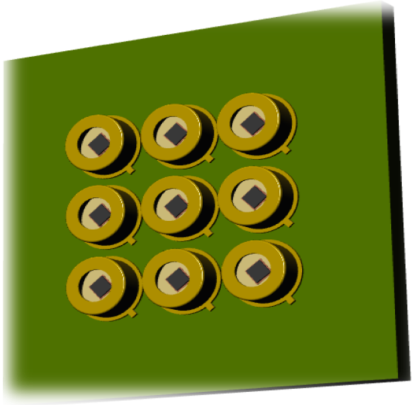
Fiber core (um)	Cost per meter ($)	Total cost for 300 m ($)
300	19	5700
400	29	8700
600	50	15000

- Other costs include target production, diffusers and fiber attachment to APAs that should be of the order of $5000.

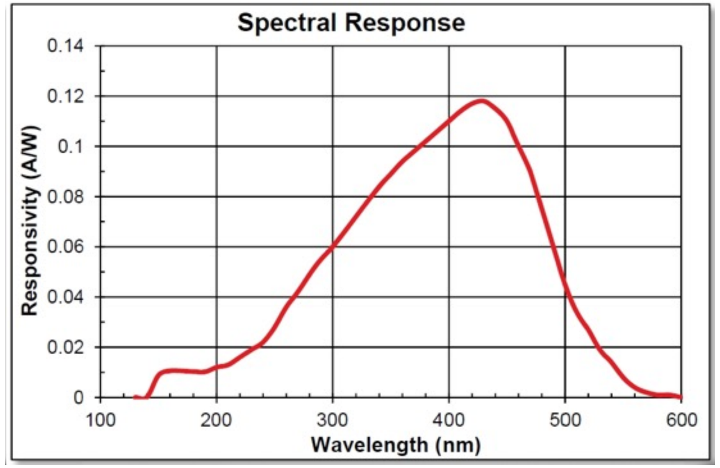
Purpose of laser positioning system (LPS)

- Pinpointing the laser track in-situ can be achieved by detecting the beam spot on the opposite side from the laser injection point.
- It is a simple passive system utilizing photodiodes that generate electric signal, when laser light shines on them.
- Place a single LPS for each laser across its nominal direction – ideally, under the FC
- Carefully measure locations of LPS after installation with respect to APA and CPA

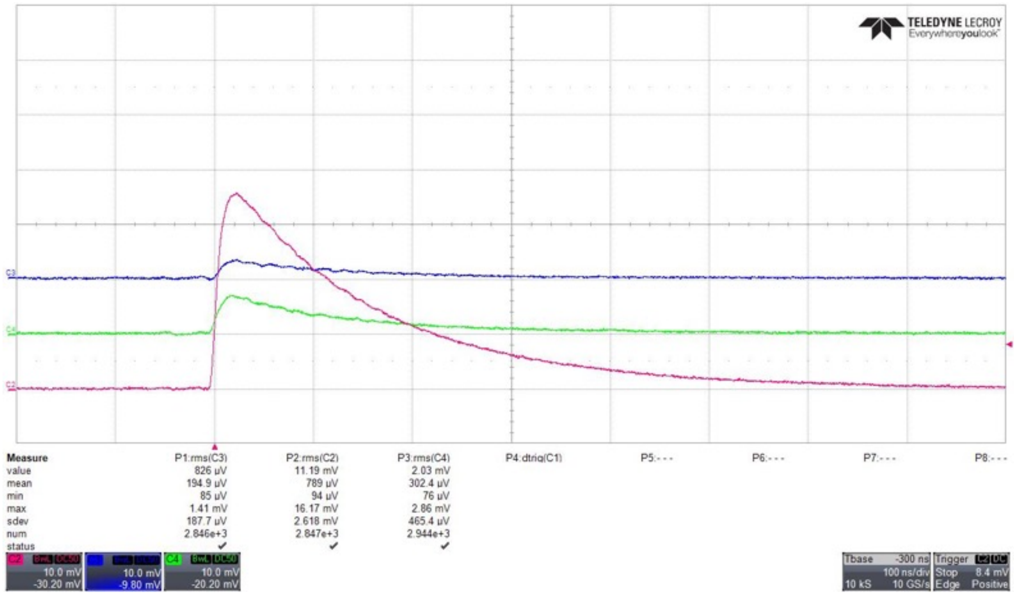




Candidate pin diode: UV sensitive GaP PIN diode operated passively



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



Data of the latest LPS array before and after cryo cycling. The magenta trace is the center PIN, blue and green are outer ones.
Thus: LPS is able to detect the brightest region of the laser beam.