Laser Calibration Topics

Zelimir Djurcic

Argonne National Laboratory

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Introduction

Laser Calibration goals:
Use laser system to calibrate LAr TPC:

- -t0,
- -electron drift velocity,
- -E-field uniformity (i.e. space charge effects),
- -measure electron-lifetime,
- -benchmark simulation/reconstruction.

Plan for ANL involvement:

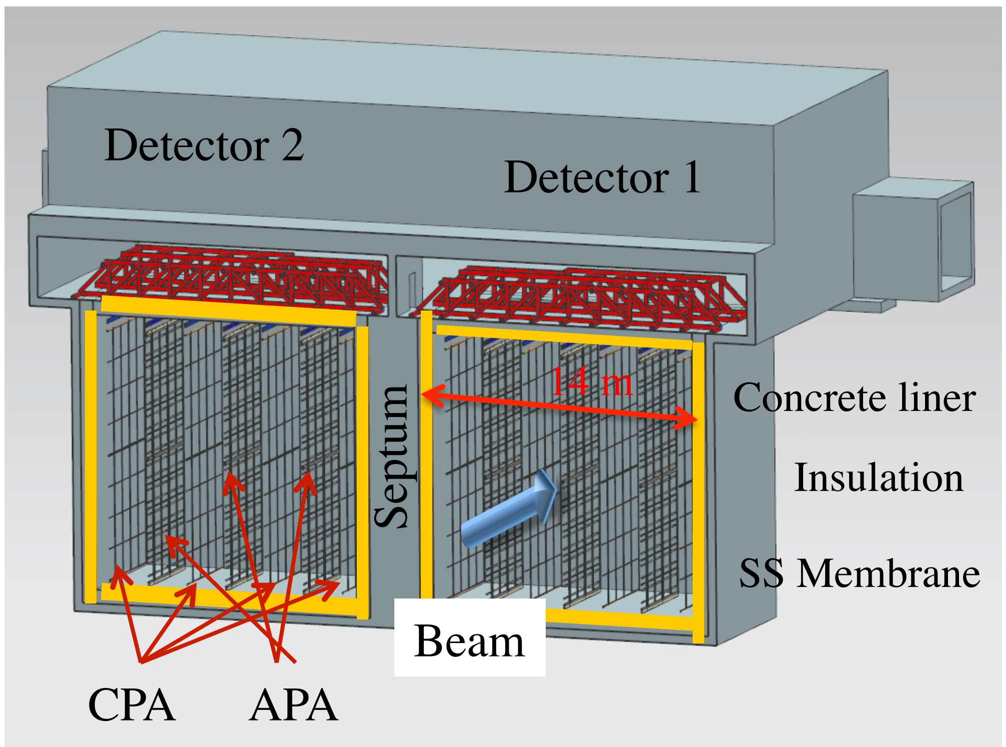
-interested in laser calibration.

-work on LBNE in a synergy with LANL group: Ideally concentrate on 35-ton prototype design, tests, and implementation, later on LBNE far:

- -transport the laser beam into the vessel.
- -develop a system to vary and monitor the laser light level entering the vessel.
- -develop a system to distribute the single laser beam through various entry points of the vessel.
- -improve PD/TPC calibration methods.
- -test laser light influence to photon collection system (PD) by exposing PD paddles coated by different wavelength shifters to laser light: study potential degradation of the wavelength shifter.

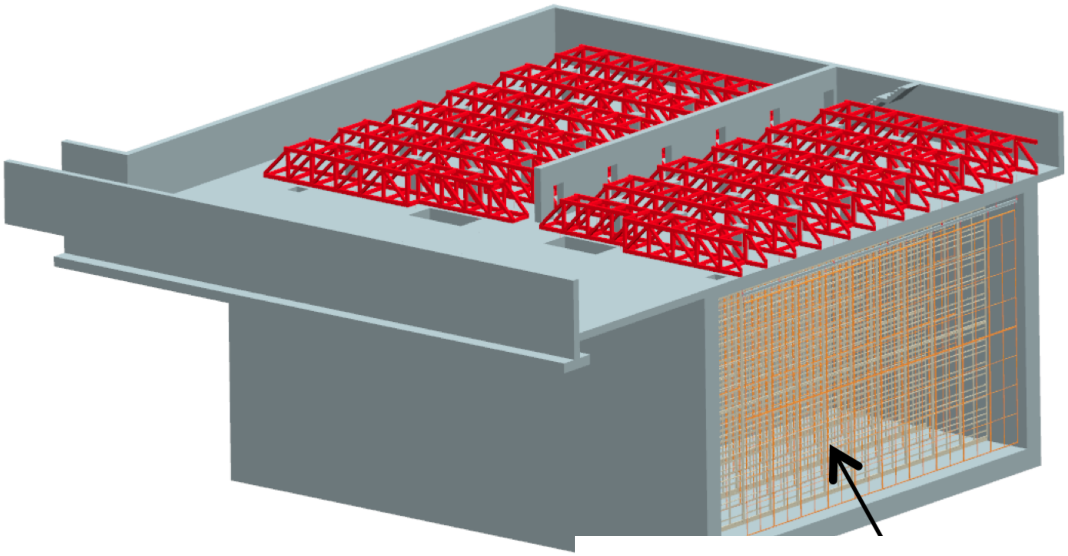
Laser beam transfer above TPC vessel

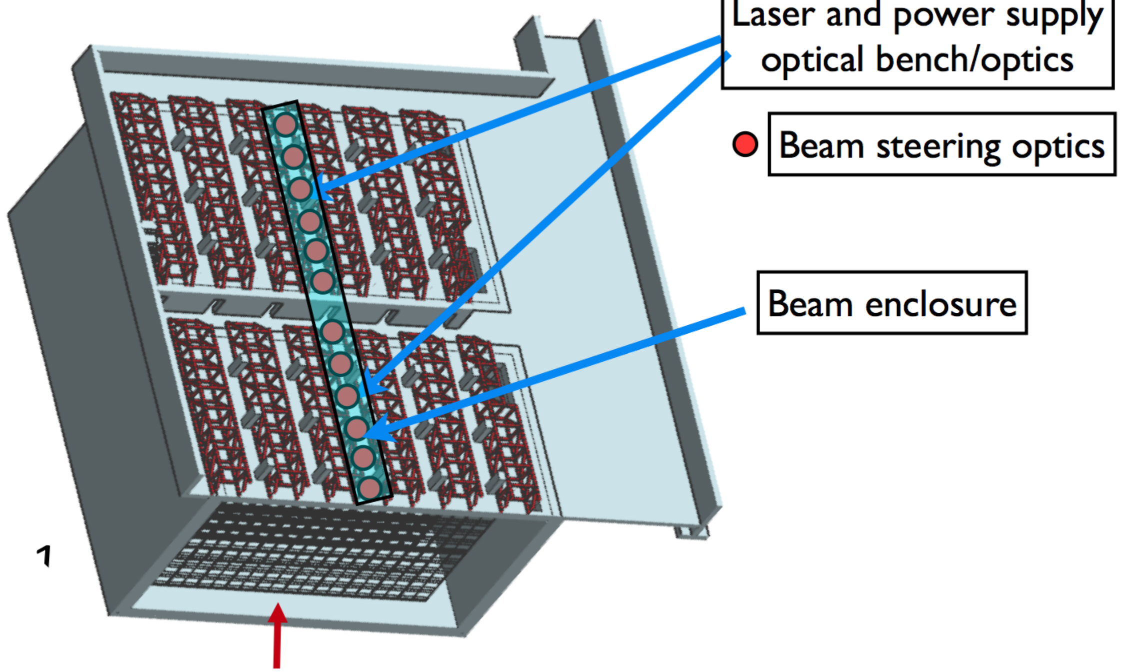
-Planned LBNE (long-baseline neutrino experiment) liquid argon detector.
-Two units: each 5 kton mass.
-Each unit has 4 cathode planes (CPA) and 3 anode planes (APA): these planes make 6 drift volumes each one roughly 2.3 m wide.



Laser beam transfer above TPC vessel

-There will be six laser beam penetration points per detector.





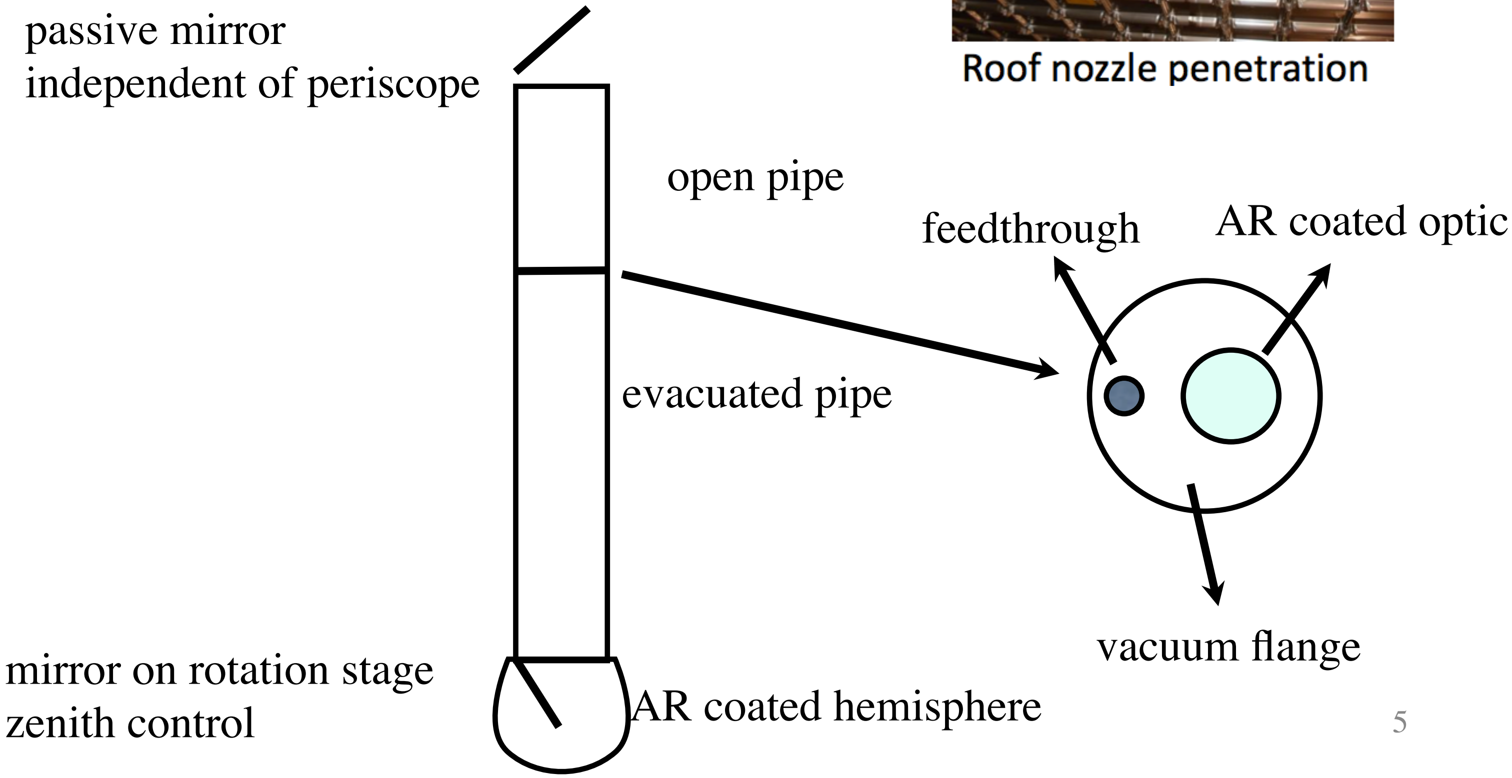
Laser beam transfer above TPC vessel

-Preliminary LANL design on how to transfer the laser beam into the TPC.
The periscope will penetrate from above the detector into the detector above the LAr level.

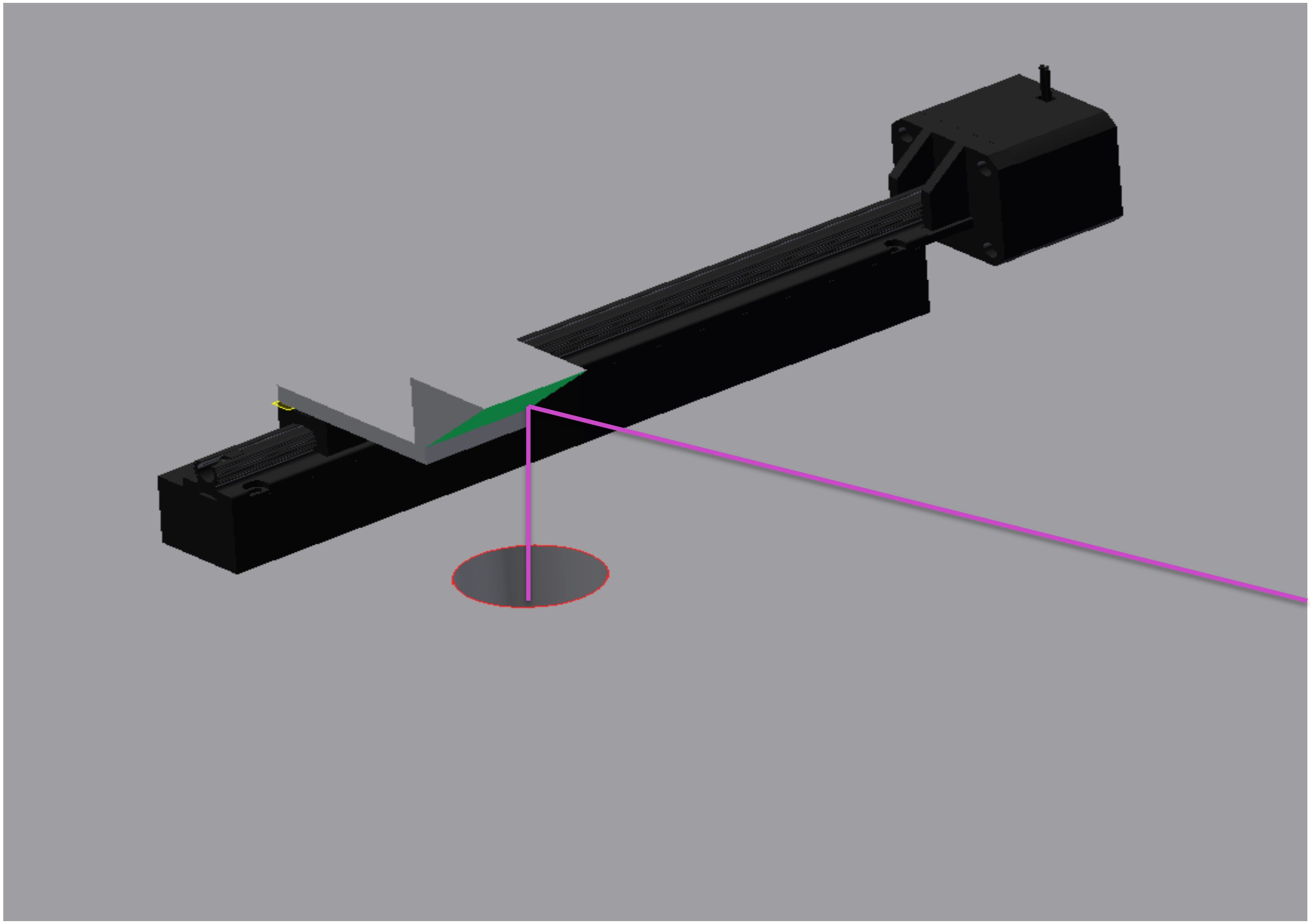
- ~10 cm aperture (perhaps smaller if needed)
- ~2.6m long (penetrate insulation, ullage, inactive LAr volume)

Roof nozzle penetration

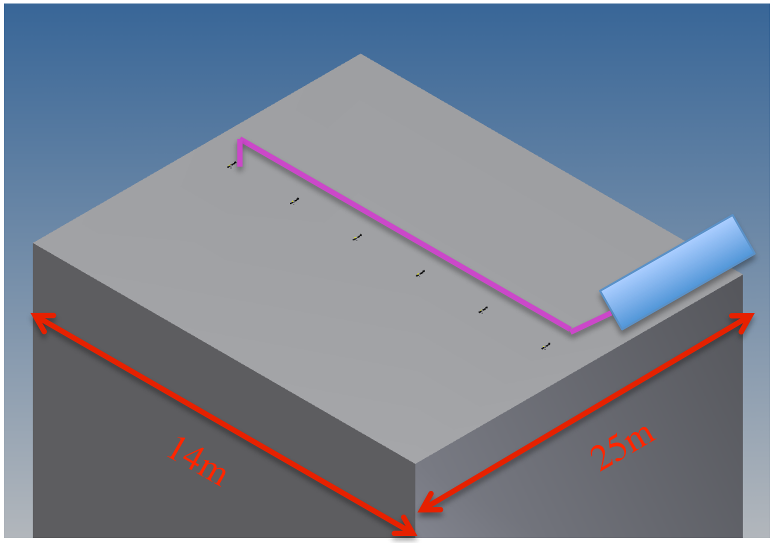
(from Gus)

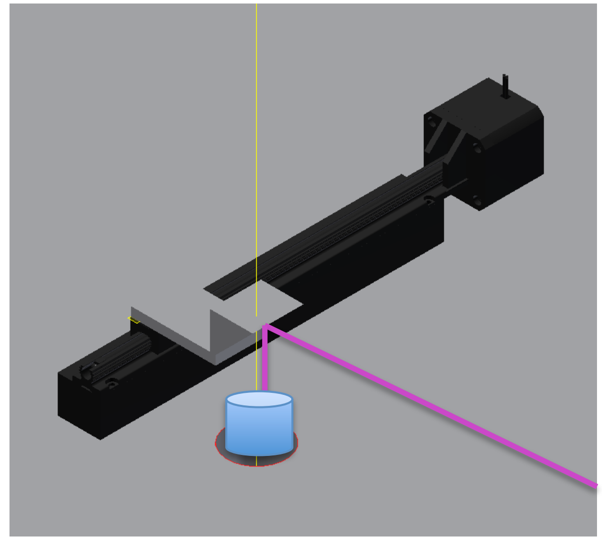


Laser beam transfer above TPC vessel

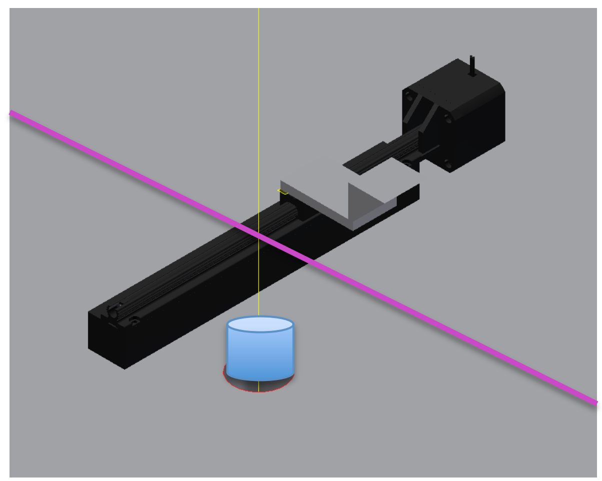


Laser beam transfer above TPC vessel





Reflect laser



Pass laser
to next spot

M&S cost estimate (by Allen Zhao, ANL):
Materials Total = 6226:
6 slides + motors: 471*6=2826
6 step controllers: 200*6=1200
Stepper Power Supply: 200
Adaptor/mount: 2000
Labor = ?:
Design: Requires Engineering
Control: Requires Engineer
(only basic mechanics, no optics)

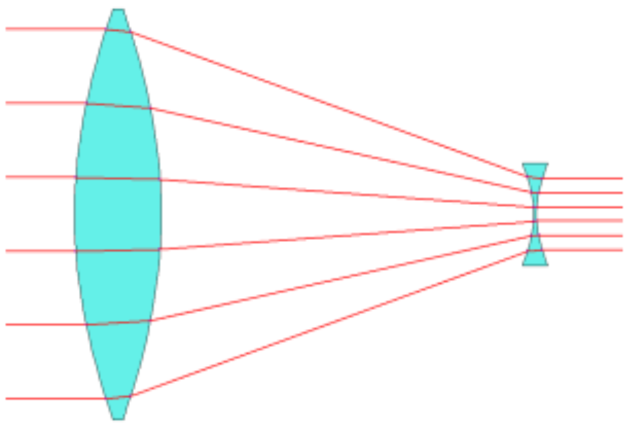
Laser beam transfer above TPC vessel

-Want to control the distribution of the laser beam remotely.

-May need re-focusing:

When using such a technique for large TPC in which the beam path is of the order of 5-10 m or even longer: very important parameter to check is the divergence of the laser.

The divergence is found on the data sheet of the laser model but usually only the 1st harmonic of the laser is reported.
It therefore important to measure it (expect 0.5 mrad) and improve it using "Galilean telescope optics"
⇒ prepare the beam to be steered into TPC.

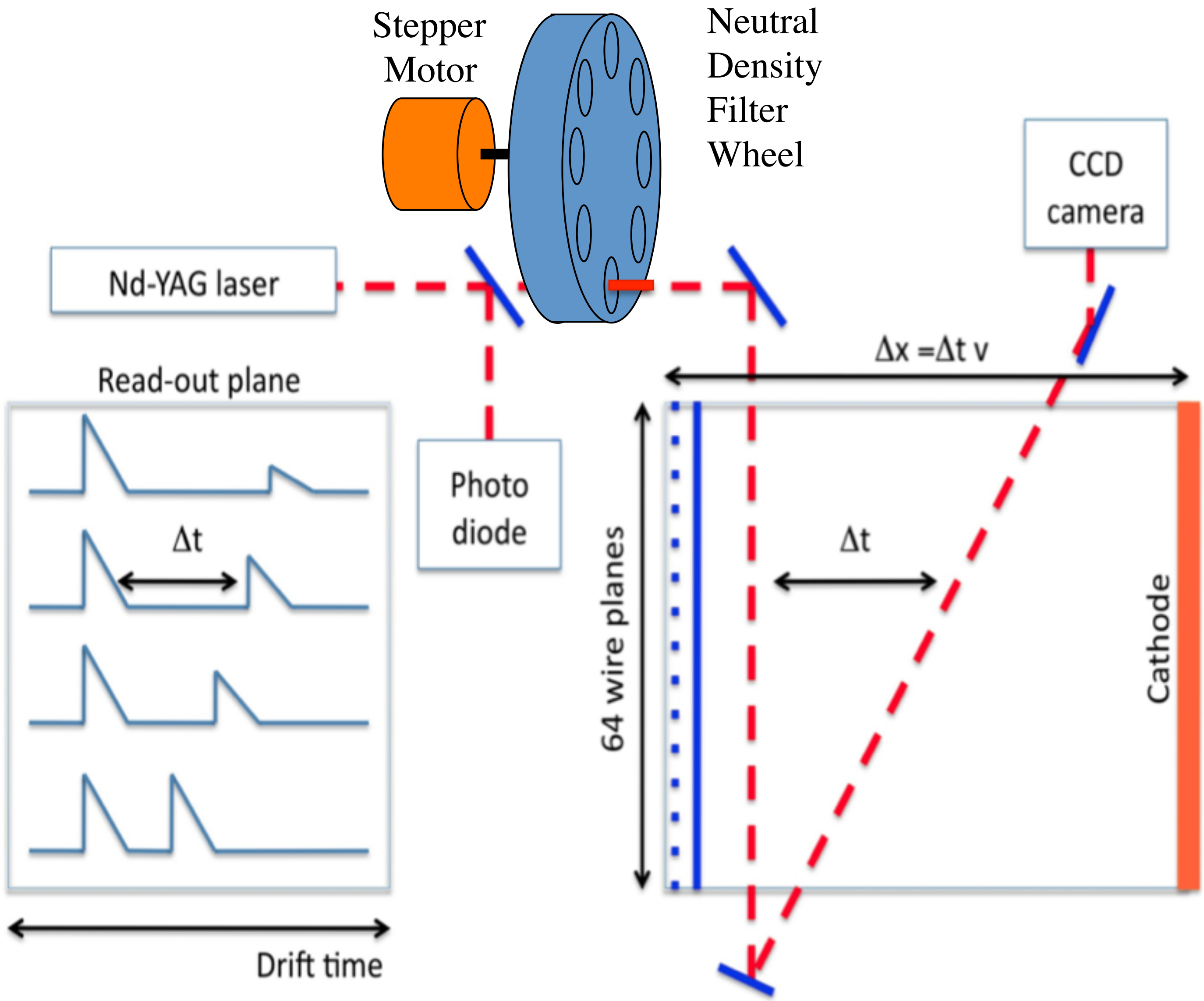


The divergence is a key point because the electron yield is a function of the flux of photons and NOT of the total number of photons.

-Need control of "input" parameters i.e. pulse width (usually FWHM ~ 5-7 nm) and the beam energy.

Laser beam transfer above TPC vessel

-Example how one may split the laser beam in order to monitor laser power and pulse width with a photo-diode device, before sending it into the detector.



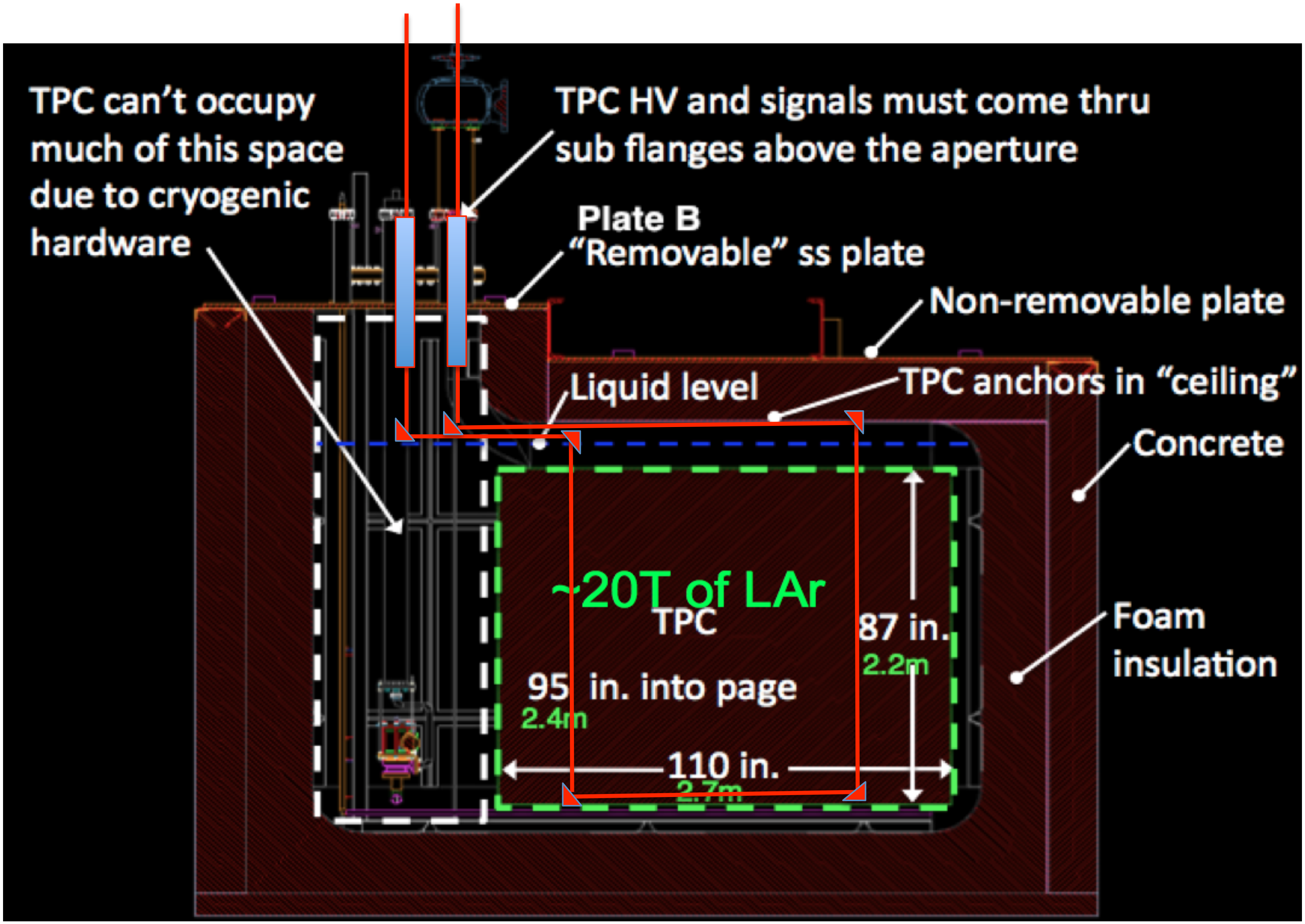
Laser beam transfer above TPC vessel

-Try these schemes in the 35-ton? The 35-ton is the LBNE-like prototype.
-It would be an unique opportunity to perform the laser run there:
leverage LANL investment in optical feed-through design, exercise beam transport into the vessel with input parameter control.
-Image laser track in TPC.

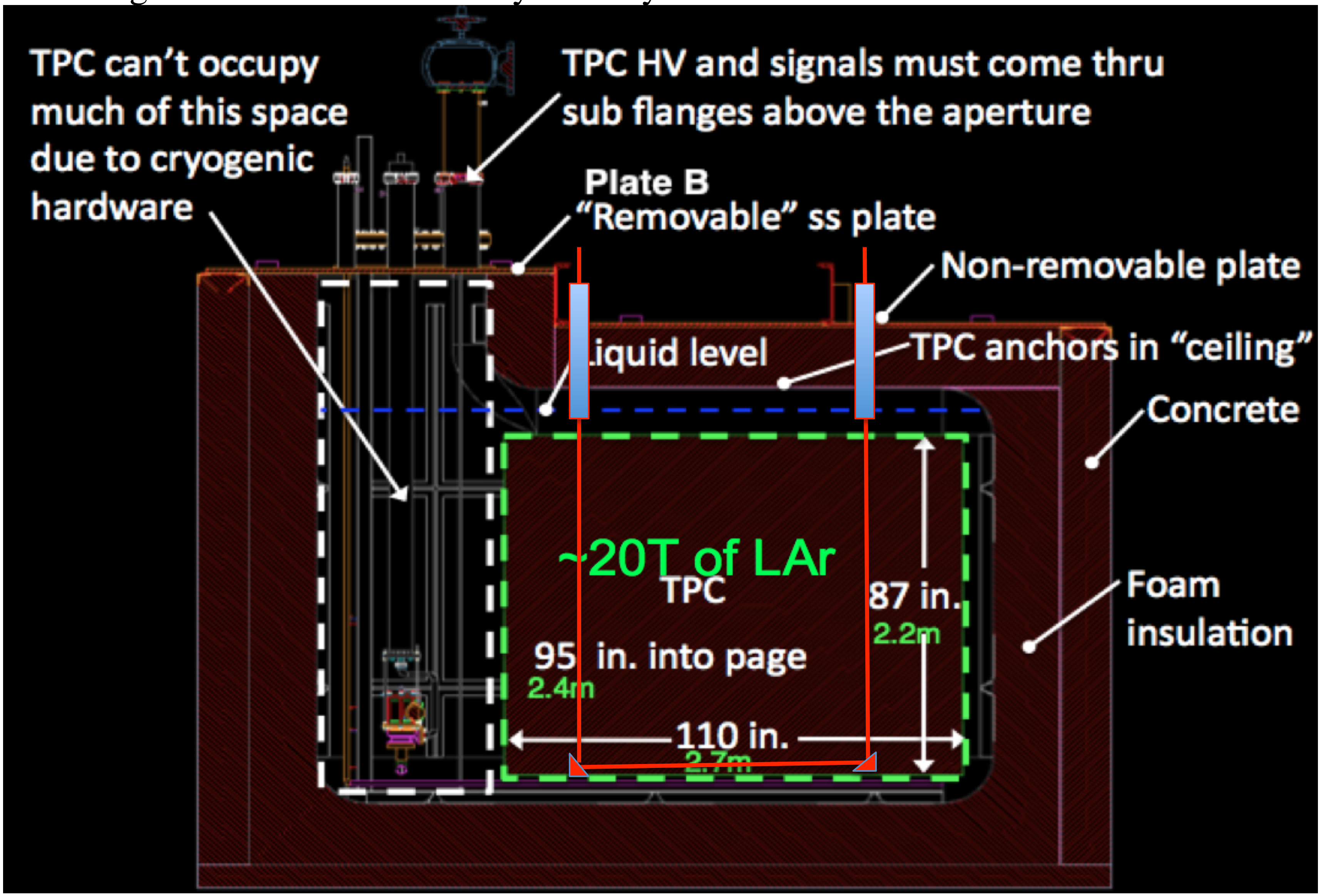
-Ultimate test for LBNE?

-ANL close to FNAL: I would naturally collaborate with LANL but be active in implementation of laser calibration techniques to detectors at FNAL.

-Try this scheme at LANL TPC, or 35-ton prototype?
-May need penetrations through multiple structures (CPA, etc).



-Try this scheme at LANL TPC, or 35-ton prototype?
May need penetrations through multiple structures (CPA, etc).
-This scheme needs a penetration through the cryostat membrane and insulation.
-Doing it here costs some money but may alleviate risk with Far LBNE detector.



Photon detection system?

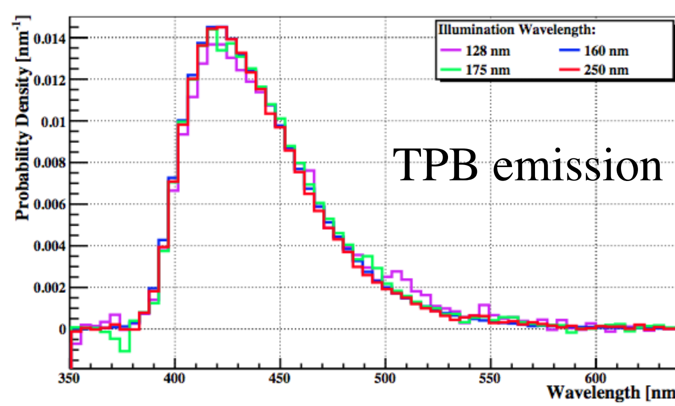
-What is the photon detection system for LBNE?
-A subsystem consisting of acrylic light guides coated with wave-length shifter;
Placed between the APA wire planes;
Goal: enable absolute event timing by detection of VUV scintillation photons (128nm).

-Scintillation light production in LAr: two processes contributing:

$$\mathrm{Ar}^* + \mathrm{Ar} \rightarrow \mathrm{Ar}_2^* \rightarrow 2\mathrm{Ar} + \gamma$$

$$\mathrm{Ar}^+ + \mathrm{Ar} \rightarrow \mathrm{Ar}_2^+ + e \rightarrow \mathrm{Ar}_2^* \rightarrow 2\mathrm{Ar} + \gamma$$

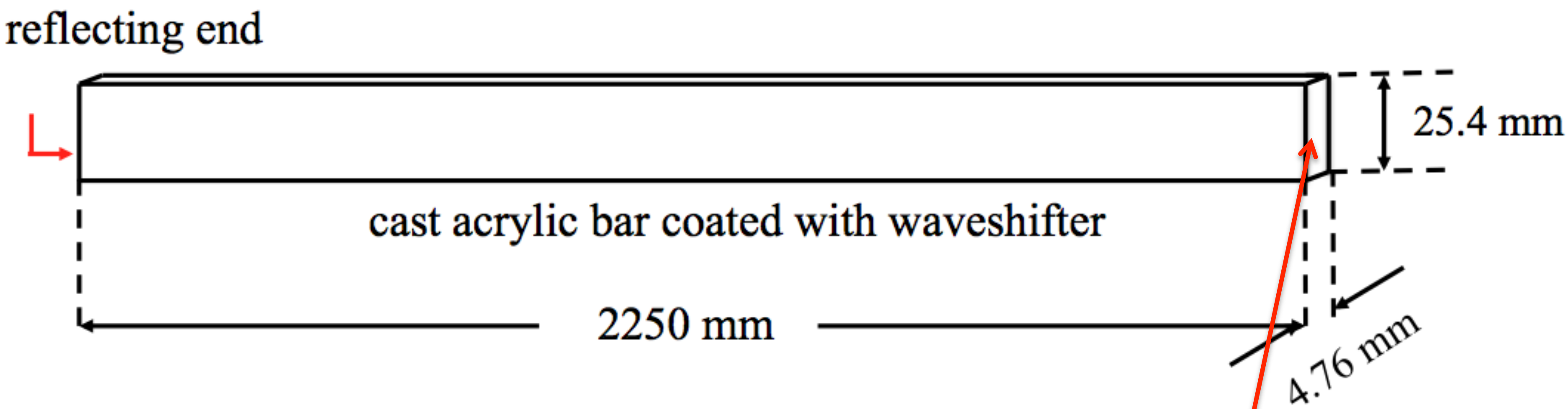
-Result: two light components i.e. prompt light with 6 ns decay constant (~1/4) and late light with 1.6 μs (~3/4).
LAr scintillation photons emitted at 128nm where photosensors (PMTs, SiPMs, …) inefficient;
-Practical Solution: wave-length shift the VUV light by TPB (Tetraphenyl Butadiene) or bis-MSB (p-bis-(o-methylstyryl)-benzene) to absorb UV photons and re-emit in optical range (~400 nm).

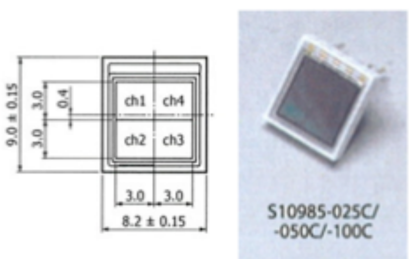


TPB emission spectrum

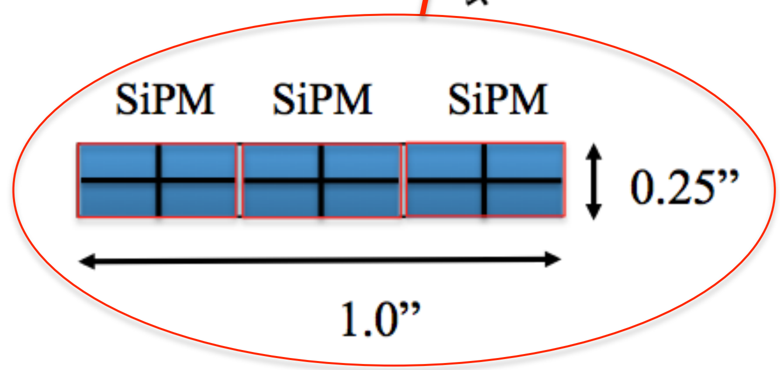
Preliminary design of Light Guides

-Showing one photon paddle here.
-Current design plans 10 photon paddles/APA plane.





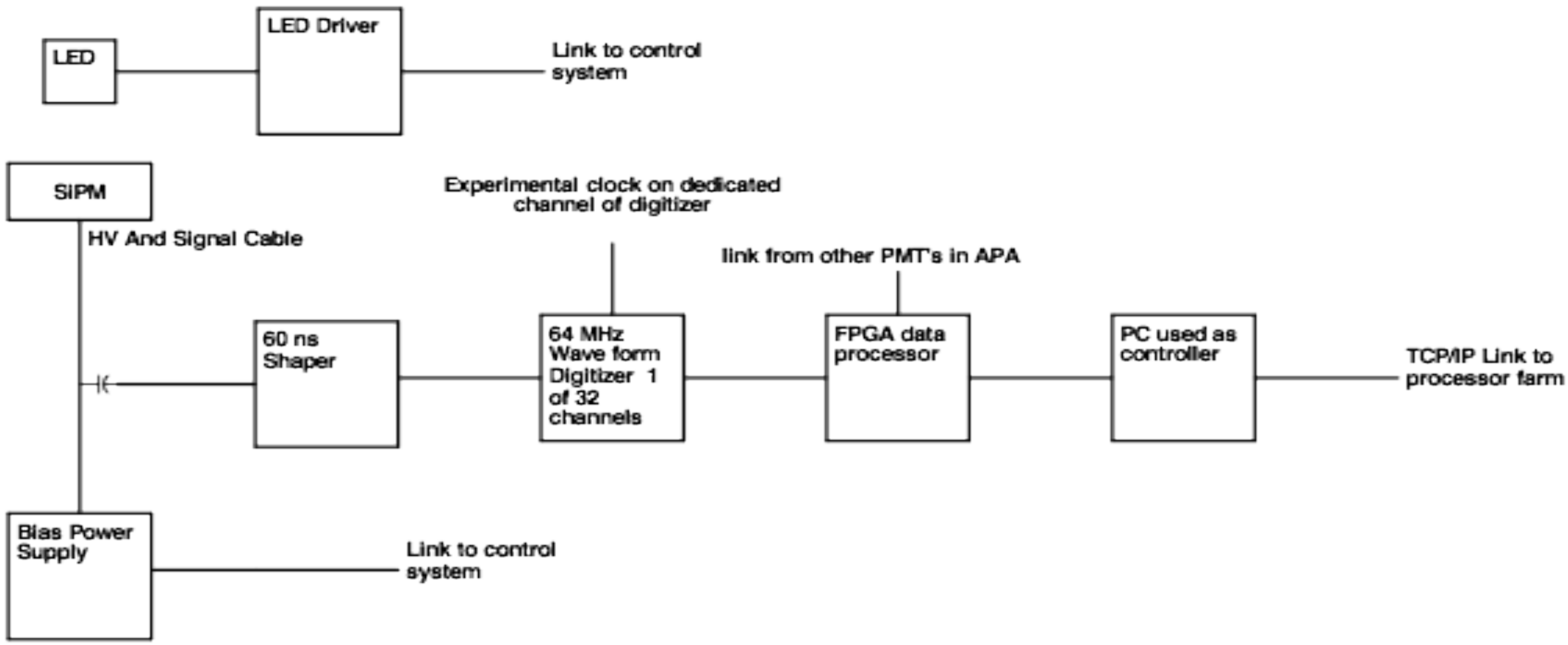
2x2 ch array SiPM
active area 3x3 mm
3 x SiPMs per end



-There is also at least one alternative design considered: replace acrylic light guide with optical fibers for light collection.

PD front-end electronics

-Initial design discussed by Marvin Johnson.

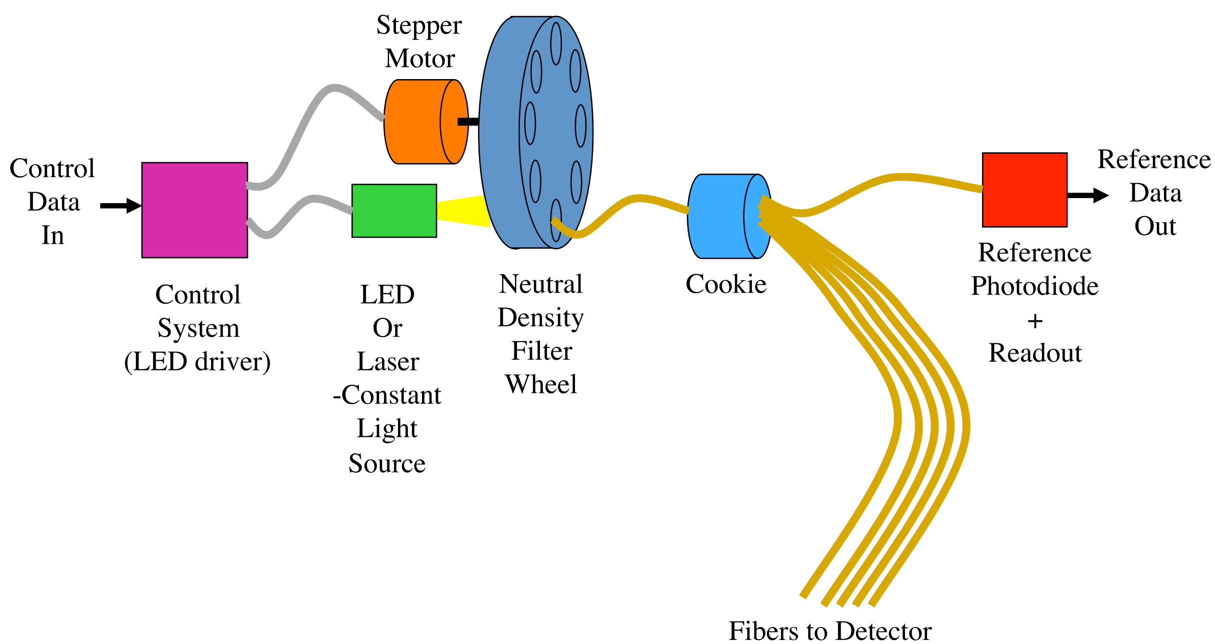


-Based on our interest it was decided that ANL will take responsibility for the photon detector electronics: Gary Drake will be the engineer and Zelimir will be the coordinating physicist.

Calibration of the light collection system

-General goal of a calibration system for PD system: understand properties of the photon detection system, including
- -time offset (t0) for each channel,
- -timing resolution of the PD system, and
- -channel-to-channel gains of the photo-sensor with with readout electronics.

-An initial LED calibration will be implemented in a test prototype (at IU/CSU), then in the LAPD/35-ton prototypes.



Can we use the laser for simultaneous TPC (charge) and PD calibration?

Use 266 nm photons for the PD calibration?

-A ~20,000 of 128nm photons per MeV in liquid argon. In a 10MeV interaction one then expects roughly 10 x 20000 ~ 2 x 10^5 photons.

-What happens if shooting 1mJ laser beam into the vessel?
=> expect ~1.3 x 10^{15} photons of 266 nm per pulse (less with lower pulse power).

-Can we use these? How much 266nm photons scatters off the beam?

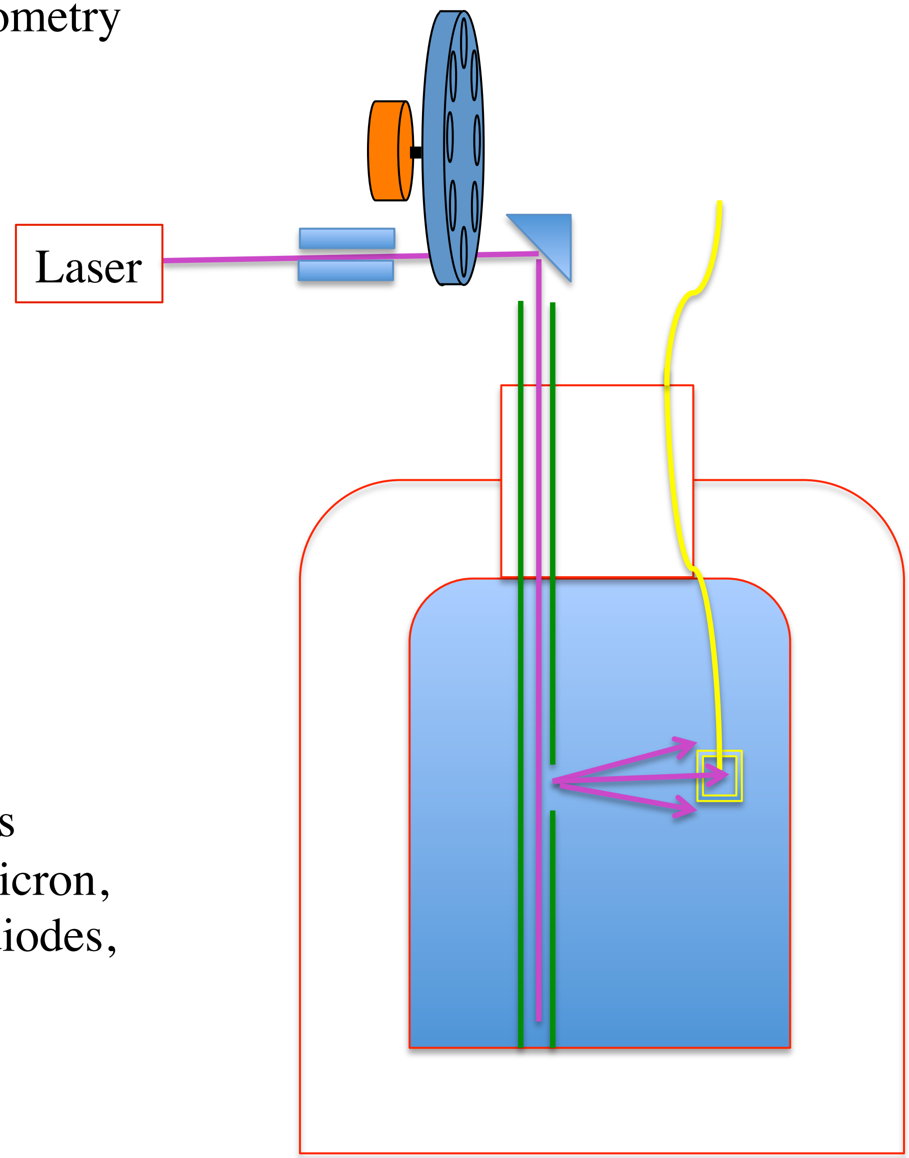
-Investigate alternative photon detection scheme with Nd:YAG: use 266nm Rayleigh scattered light (Ar atom size ~0.2nm << 266nm so Rayleigh scattering dominates).

Photon detection test with laser

-Design a cheap experiment in a small dewar by varying laser power and control scattered light by geometry (i.e. use light over a short path).

-Rayleigh scattering attenuation long i.e. 17m: through 1cm section one gets only ~10^{-4} fraction coming out.
-At 10 cm distance from the light source one gets another factor ~10^{-4}.
for a photo-sensor with 3mm x 3mm area.

-Then vary the light intensity at input by neutral density filter.
(need to study
-consider MPPC with a large number of pixels (i.e. wide dynamic range): if you have a 50micron, the 3x3 mm version is actually 60*60 photodiodes,
i.e. 3600 individual photo-detectors.



Photon detection test with laser

-Craig Thorn indicated a new photo-sensor sensitive down to 128 nm, and sensitive to 266 nm => could help improve performance of the photon detection system.

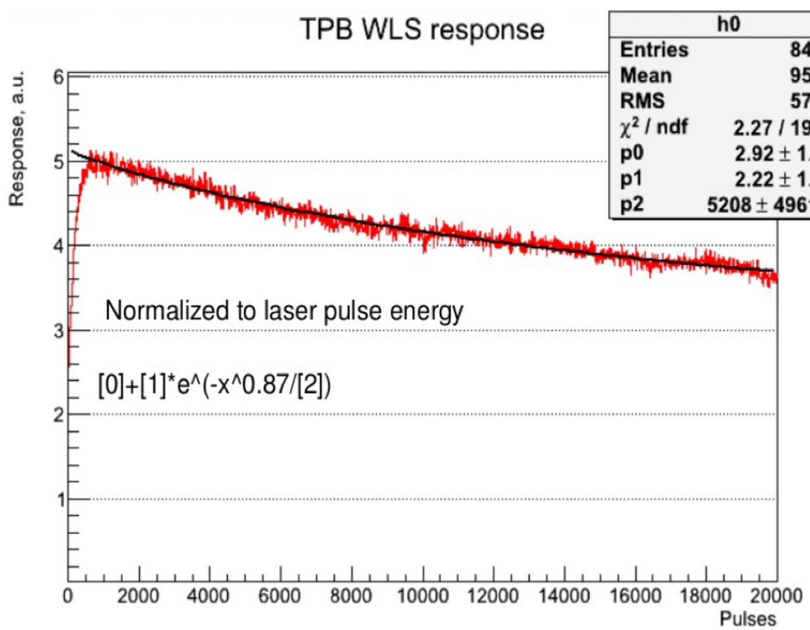
-If the small experiment provides understood results then try the calibration scheme in LANL TPC, later in other detectors (i.e. 35-ton).

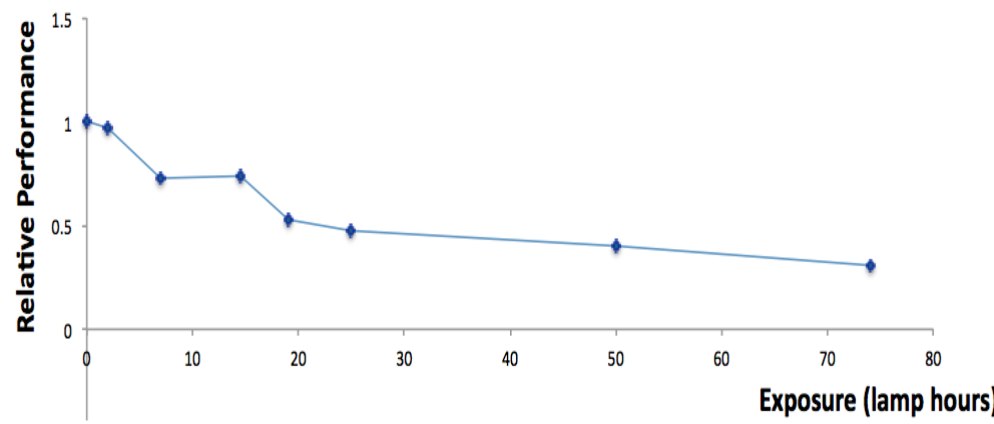
-Ultimately one could calibrate both TPC and the PD system by producing a long track (muon-like) and a short track (e-like) within desired time interval mimicking a realistic experimental scenario.

Issues with TPB degradation when exposed to laser light?

-Potential laser side effects?
Remember laser light from Nd:YAG has λ = 266 nm.

I. Kreslo, LAGUNA talk (November 2012):

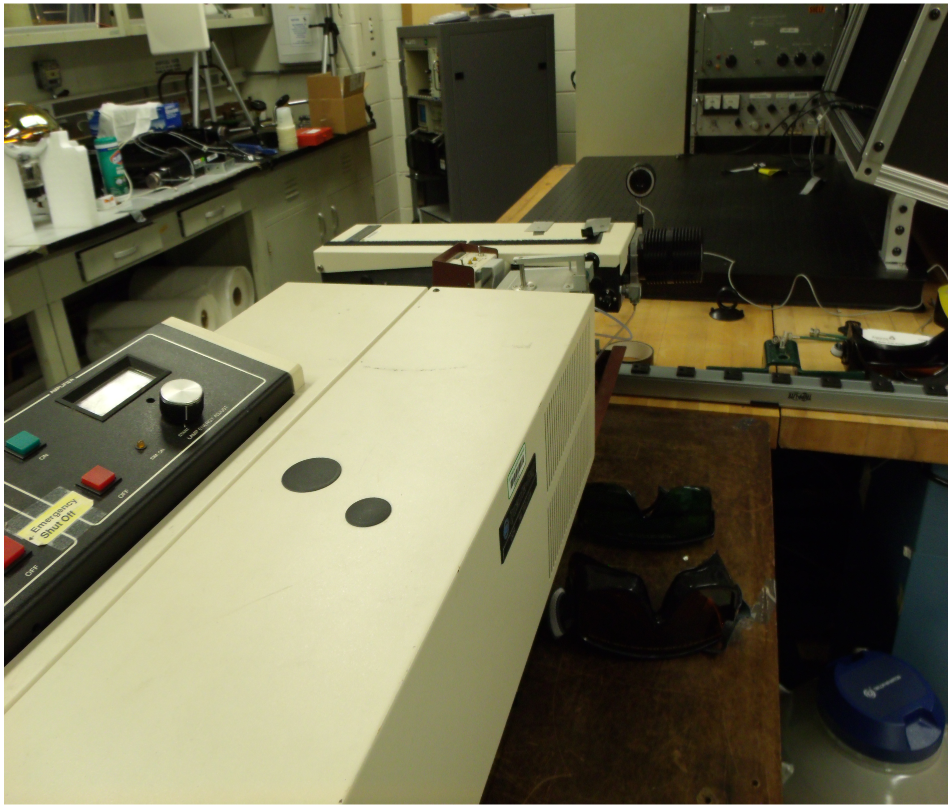




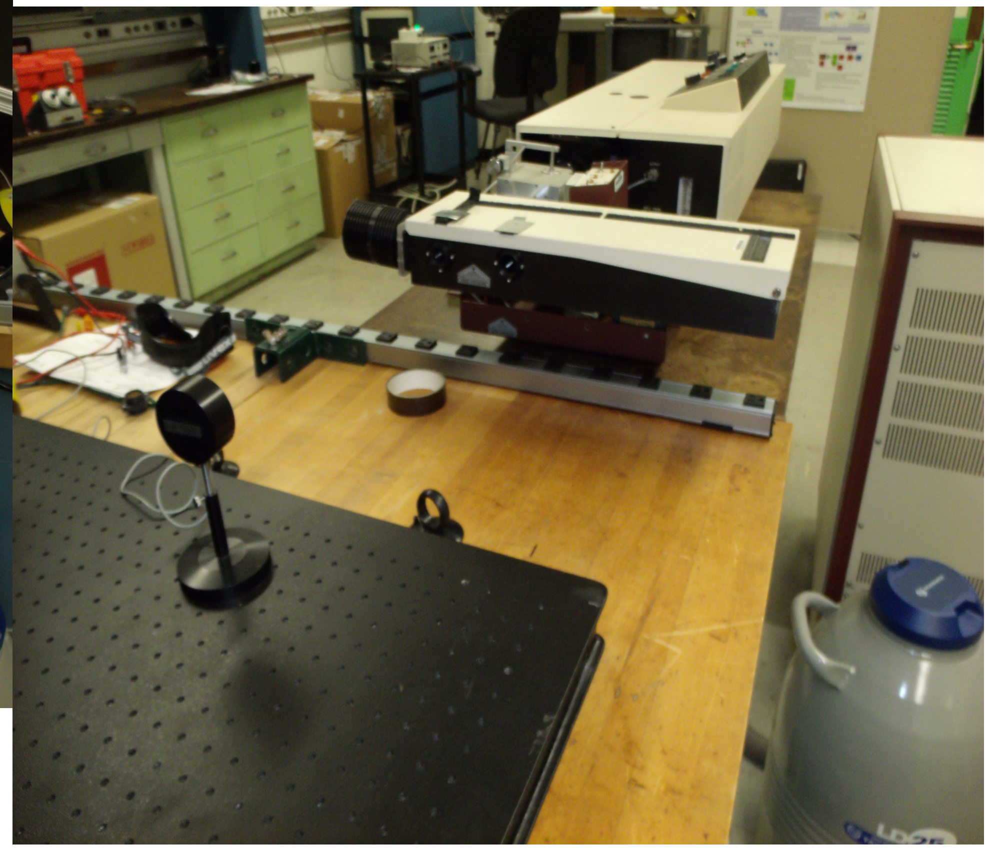
Degradation measured at λ=300 nm in B. P. Jones et al., arXiv:1211.7150

Loss of 20% is reached after exposure of 14000 laser pulses with 10mJ/20cm^2
i.e. total exposure of 7J/cm^2.
⇒ Such exposure not expected from laser calibration: usually ~100(s) pulses per calibration run with isotropic light.

Nd:YAG laser setup/equipment at Argonne HEP



-laser moved to new location (HEP), currently tested; operational procedures put in place.



Currently available equipment:

-Laser: Quanta-Ray Model DCR-2A-20 P.S.

wavelength = 532 nm, energy/pulse 110-260mJ (oscillator/amplifier), pulse width = 6-7ns

@266 nm expect energy/pulse 45-60mJ, pulse width = 4-5ns

-Various laser optics, power-meter, optical tables, etc.

-Expertise with lasers and laser optics within division and lab.

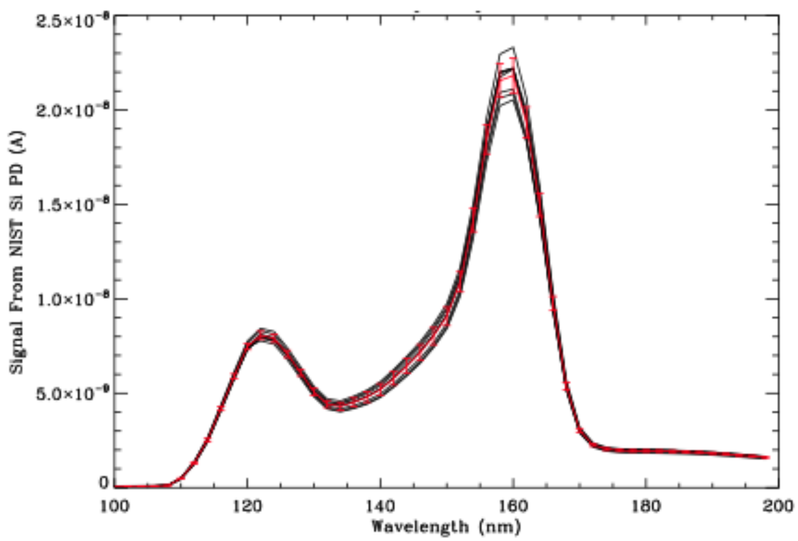
-A large LAr dewar (closed top), and a small open top dewar for tests.

-Extensive engineering support mechanical/electronics, glass-blower at the lab.

Backups

PD System Calibration with 128nm light

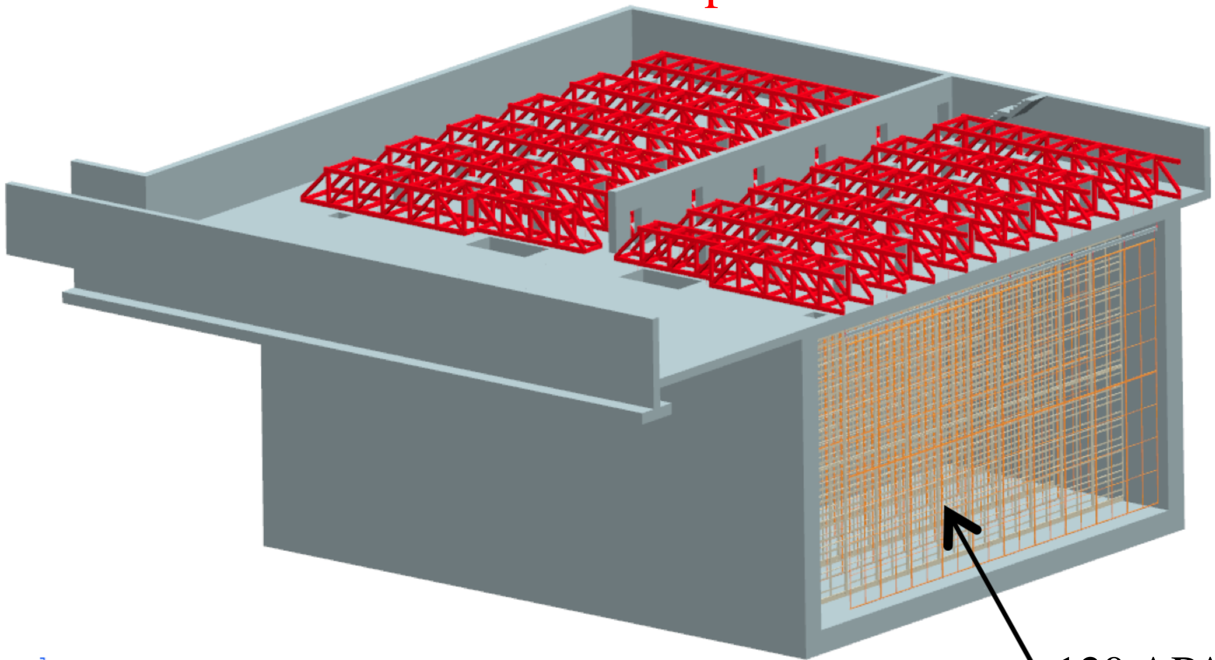
-LED at ~250-430 nm perhaps sufficient to monitor the light collection time response, but LAr scintillation photons emitted at photons emitted in VUV at 128 nm.
-Ideally provide 128 nm light for real physics calibration.
-Options D2 lamp (used in VUV mono-chromator), or frequency tuned Nd:YAG laser.
-Don't know how to transport 128nm light from mono-chromator?



-D2 (deuterium) lamp spectrum: power density is weak in the spectral range in question.

-Another solution: 118-nm radiation generated by frequency-tripling of the third harmonic of a Nd:YAG laser.
-For both solutions: is it possible to transport light into LAr volume?

Potential Implementation in 10 kton LBNE LAr



Current design:

- -120 APA planes
- -10 photon paddles per APA plane.
- -12 SiPMs per paddle.
- -Total 14400 SiPMs total (at maximum).