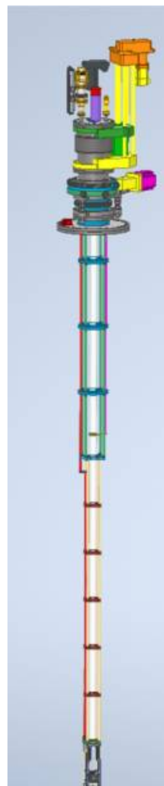
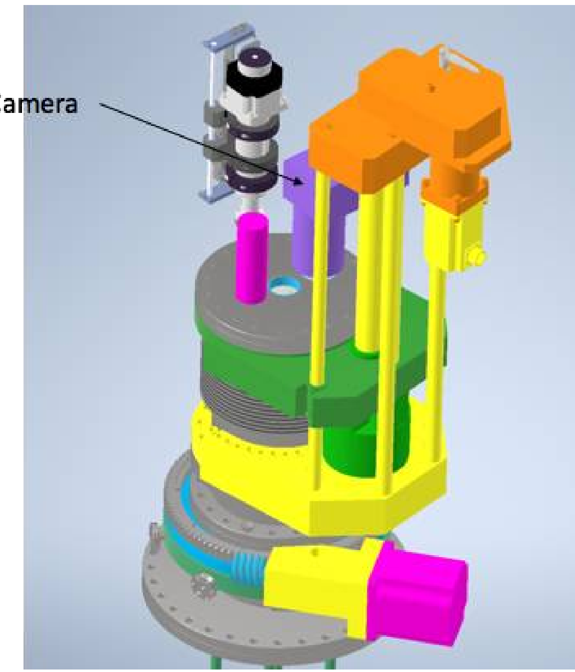
Update on camera for laser, inclinometers, etc.

Glenn Horton-Smith, Kansas State University





Laser WG meeting
February 20, 2020

Purpose for cameras in general

- Monitor "High Voltage Systems"
  - "HVS" = field cage, cathode planes, feedthroughs, grounds
  - "verify the stability, straightness, and alignment of the hanging TPC structures during cooldown and filling" and "ensure that no bubbling occurs near the GPs (SP) or CRPs (DP)" [from TDR]
- Inspect detector components
  - "inspect the state of movable parts in the detector module (calibration devices, dynamic thermometers)" and "closely inspect parts of the TPC after any seismic activity or other unanticipated event" [from TDR]

Detailed purpose of inspection cameras (from TDR, annotations and emphasis added)

"… intended to be as versatile as possible …. likely uses:

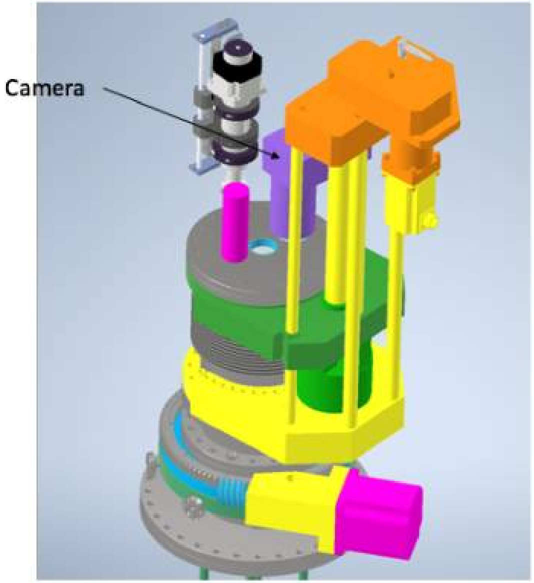
- "status of HV feedthrough and cup,
- **"status of FC profiles, endcaps (0.5 mm resolution),**
- **"y-axis deployment of calibration sources,**
- "status of thermometers, especially dynamic thermometers,
- *"HV discharge, corona, or streamers on HV feedthrough, cup, or FC,* More on this later
- **"straightness and alignment of APA/CRP, CPA/cathode, and FC (1 mm resol.)**
- **"gaps between CPA frames (1 mm resol.),**
- **"relative position of profiles and endcaps (0.5 mm resol.), and**
- **"sense wires** ~~at the top of outer~~ ANYWHERE on ALL **wire planes in SP APA (0.5 mm resol.)."**

[The above resolutions are goals. Specification is 2 mm.]

Slide from Sowjanya

Cameras + Laser: work in progress

- In discussions with Bern in Jan. 2020, we learnt laser alignment is non-trivial
  - Would like to integrate cameras into the design for safety and alignment purposes
- Cameras also ensure that there is enough clearance of the periscope from FC edges
- Jan + Glenn working together towards this design



Uses

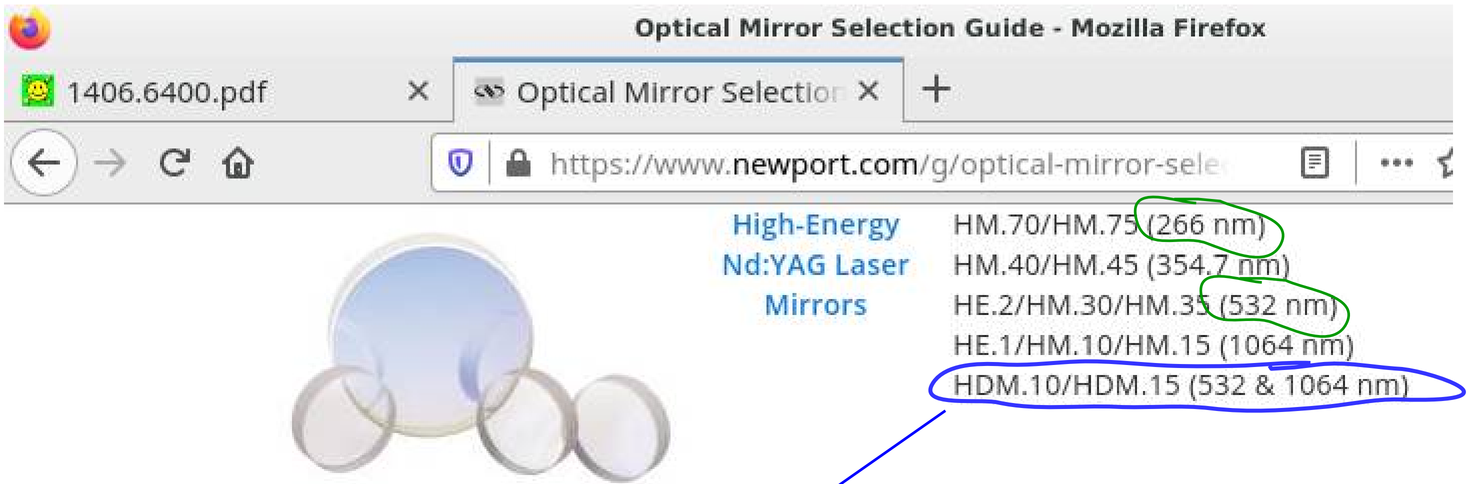
(slide from Glenn)

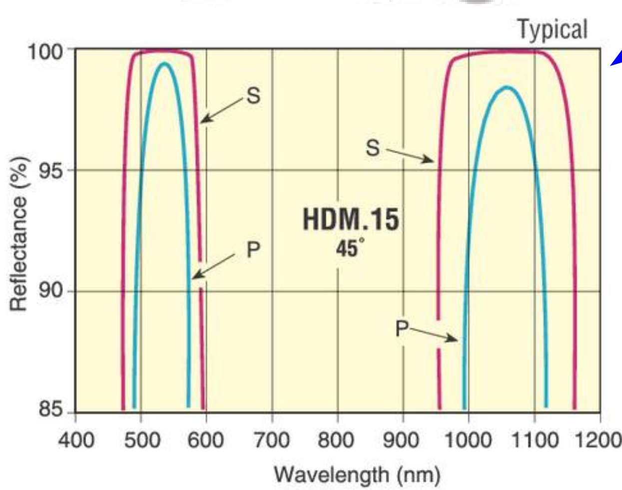
- **As inspection camera:**
  - HV surfaces: CPA, FC, etc.
  - Mechanical alignment check.
  - Surface of liquid argon seen from below, inside and outside
  - APA check (~~viewing from outside endwall only, as central ports are too close to APAs)~~
  - Interior and exterior views!
- **As laser system aid** for aligning and steering the laser on small target (e.g., for photoelectron target studies)
  - 25 mm restriction at top and bottom of vertical path means camera image is somewhat well aligned with laser if camera can see anything.
  - View from camera in laser being set up serves as "viewfinder".
  - One camera can also watch the targeting of another laser. If one system shines a green alignment beam (like MicroBooNE), the camera on the other system can look from a different angle and see exactly where it hits as the system is steered.

I retract this caveat!

Los Alamos National Laboratory | Sowjanya Gollapinni 2/19/2020

Type of mirror: dielectric coated (no metal)





Dielectric mirrors can be made to reflect more than one band of color. 532&1064nm is available off the shelf, we need 266&532nm to reflect UV for the laser and green light for the camera. (And possibly an alignment beam?) Custom coating designs can be ordered. (There's even a program to design them.)

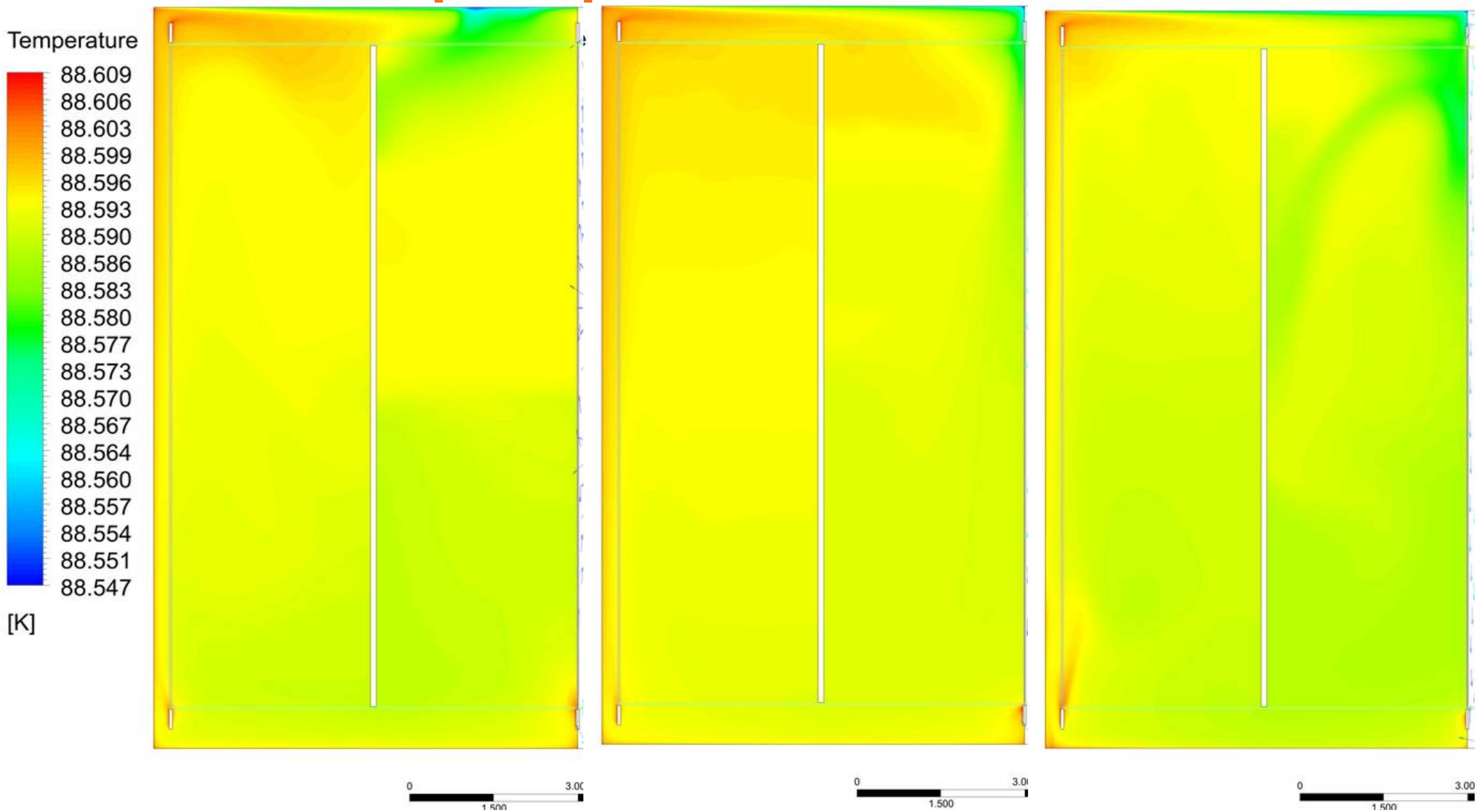
Optical simulations

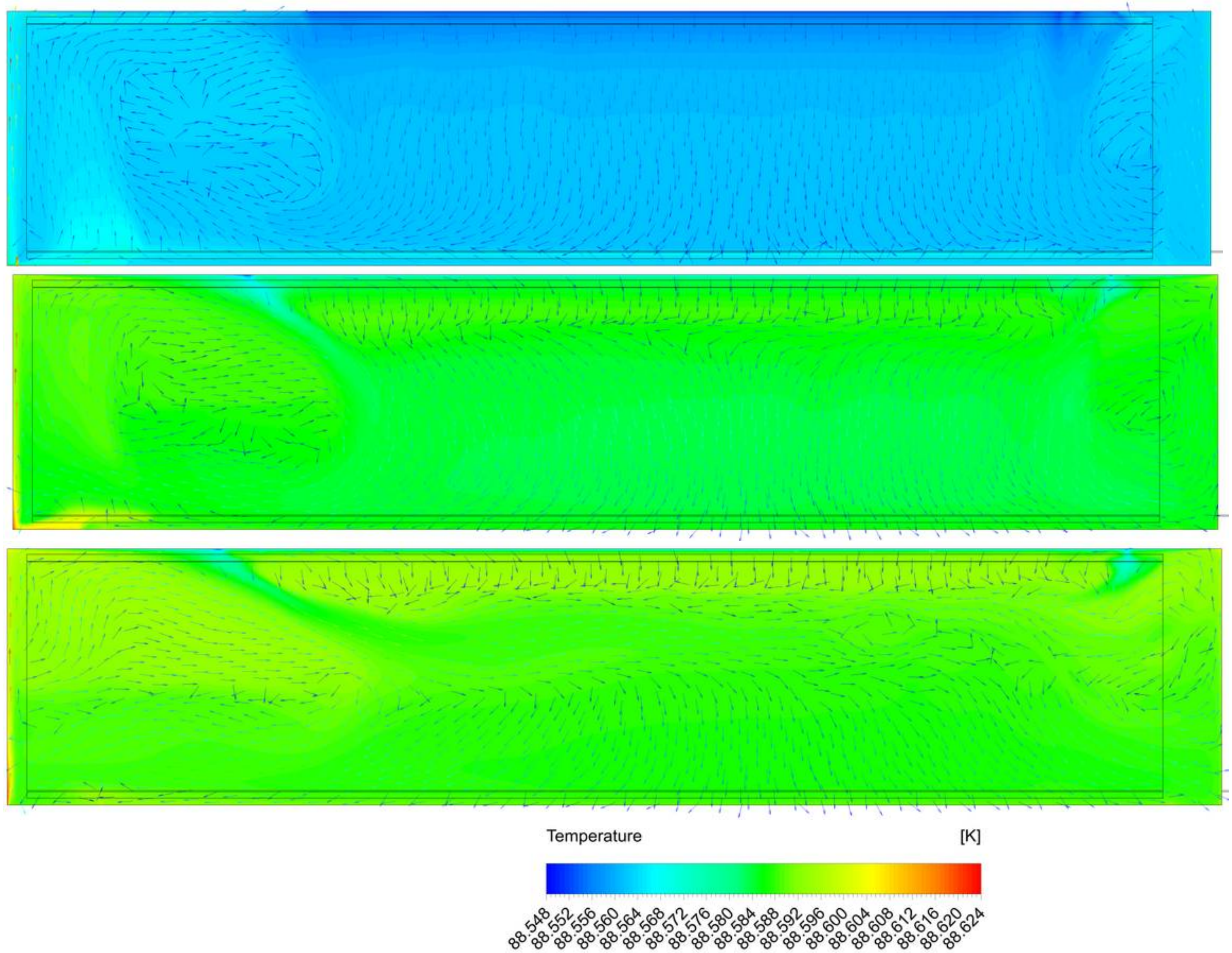
- Using a wavefront simulator from NASA/JPL called PROPER.
- Used for designing telescopes and other instruments.
- Confirms resolution estimates for the mirror sizes we have.
- Have included liquid argon index of refraction effects.
- Next step is to add variable phase due to variations of index of refraction due to temperature. (The same phenomenon as "seeing" in astronomy.)

Refraction in liquid argon (laser and camera)

- Index of refraction varies with temperature.
- Nice paper on how to calculate refraction in general case.
  Mahdiyar Noorbala and Reza Sepehrinia 2016 Eur. J. Phys. 37 025301
- In simple case with variation of temperature only in vertical direction, 10^{-3} kelvin/m, causes 10^{-6} radians per meter change in beam direction. 5×10^{-3} kelvin/m in top 1 m causes 8 mm deflection over 40 m. Still ok, but starts to be interesting.
- These temperature variations are for recirculation stopped.
- With recirculation on, simulations show larger gradients distributed over the entire detector.

From 2015 1-pump simulation, EDMS 2154414




Temperature
[K]
88.548
88.552
88.556
88.560
88.564
88.568
88.572
88.576
88.580
88.584
88.588
88.592
88.596
88.600
88.604
88.608
88.612
88.616
88.620
88.624

Inclinometer

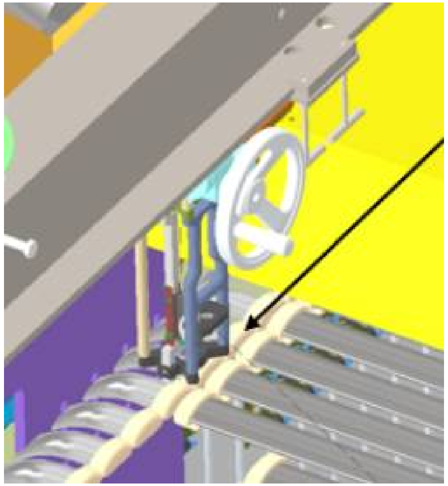
- Flanges are attached to membrane, may tilt with changes in pressure.
- 100 microradian (0.002 degree) tilt of flange would make 1 mm shift of beam over 10 m. But we don't know flanges are that stable.
- We want to get a high precision inclinometer and try it on ProtoDUNE.
- If tilt is slow enough, we can feed back on the inclinometer and adjust the periscope.

TILT-3x Series

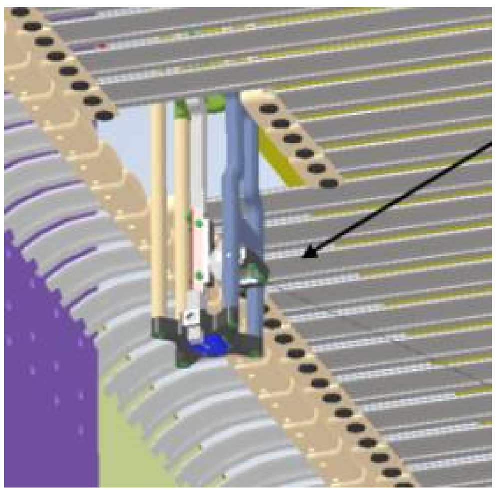
High Precision Inclinometer

- Size: 2.14" x 1.64" x 0.85"
- High Resolution: up to 0.001° | 0.05 mg
- High accuracy: < 0.05°
- Single or Dual-Axis Inclinometer
- Three-axis accelerometer
- Multiple Interface Options(USB, RS232, RS422, RS485, etc)
- Robust Aluminum Housing

Coronas and streamers? Look for UV!



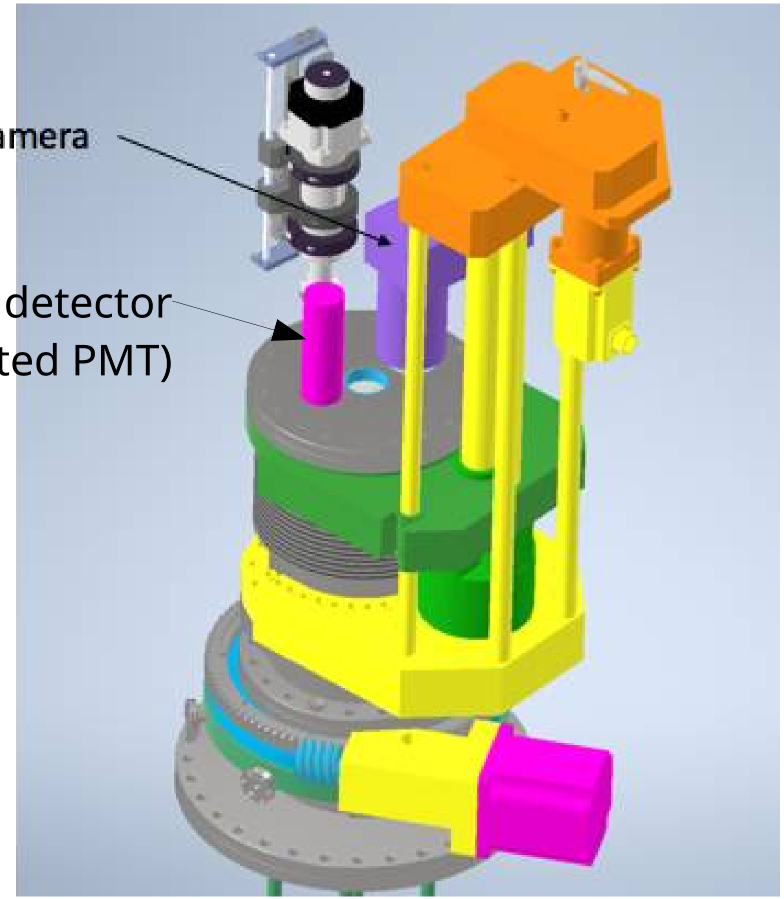
Retracted
Looking at outside



Deployed
Looking at inside

Camera

UV detector
(TPB-coated PMT)



Extra slides

Specifications (detailed, CISC consortium)

Quantity/Parameter	Specification	Goal
Cold cameras		
Coverage	80% of the exterior of HV surfaces	100%
Frames per second	yet to be defined	
Resolution	1 cm on the TPC	yet to be defined
Duty cycle	yet to be defined	
longevity	> 18 months	> 20 years
Inspection cameras		
Coverage	80% of the TPC	yet to be defined
Frames per second	yet to be defined	
Resolution	2 mm on the TPC	yet to be defined
heat transfer	no generation of bubbles	
longevity	> 18 months	> 20 years
Light emitting system		
radiant flux	> 10 mW/sr	100 mW/sr
power	< 125 mW/LED	
wavelength	red/green	IR/white
longevity	> 18 months (for cold cameras)	> 20 years

Lighting with LEDs

- Cameras will have light rings around lenses for nearby objects.
- For distant objects, lighting close to the object is better. ($1/r^2$ instead of $1/r^4$)
- Beware of shift to shorter wavelength due to bandgap change in cold.

JINST 8 (2013) T12001, arXiv:1310.6601

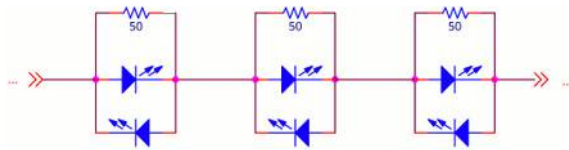
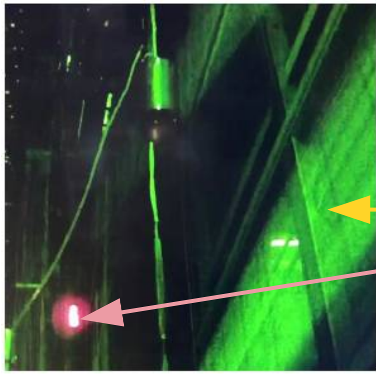


Figure 1.26: Example schematic for LED chain, allowing failure tolerance and two LED illumination spectra.



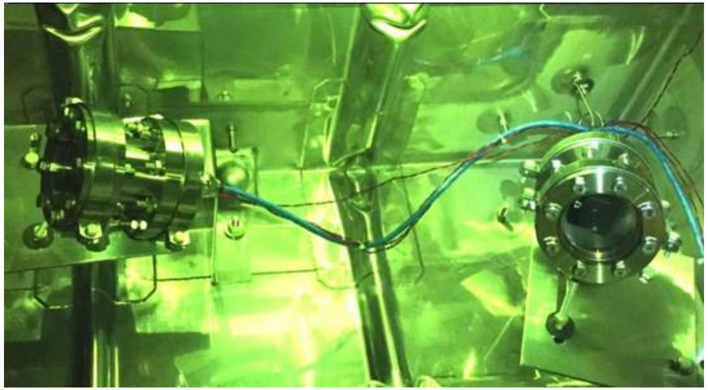
$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta}$$

"Amber LED" illumination
"IR LED"

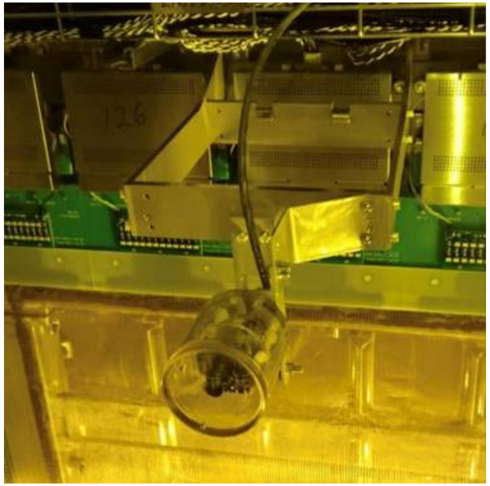
KANSAS STATE UNIVERSITY DUNE

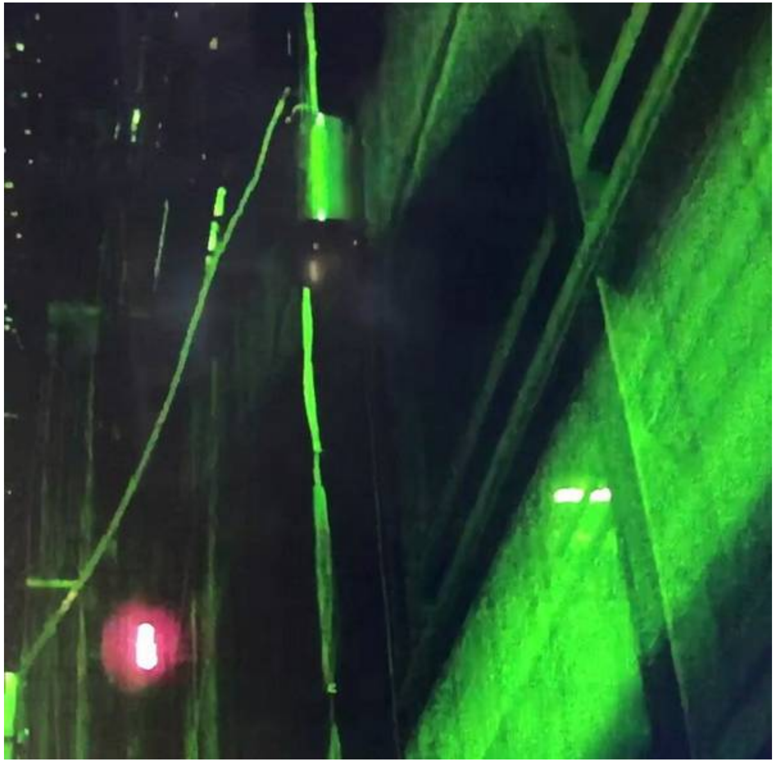
ProtoDUNE fixed cameras

vacuum-tight



acrylic





Part of a video from camera 105 showing purity monitor mounted outside the APA on the beam left side, ProtoDUNE-SP filled. (David Rivera PDSP elog 6303, 2018-09-15 03:01)