# DUNE FD Cameras

DUNE CALCI Scope Workshop/Review

2020-05-14

Glenn Horton-Smith

*(reporting on the work of many people...)*

# Outline

- Recap purpose.
- Recent changes in requirements, approach, scope.
- Fixed cameras
- Periscope cameras
- Other information relevant to charge questions.

# Purpose

- 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]

# Two kinds of cameras envisioned

- **Fixed, "cold" cameras.** (Actually warmed by heaters.) Must work at 13 m depth and last throughout cool–down, filling, and first months of TPC operation (or longer). *These are the cameras that will satisfy the HV system needs.*
- **Movable inspection cameras.** Two designs were being considered as of last review, both designed to be replaceable and deployable through top ports throughout detector lifetime for inspecting anything on top or sides. *Both previous designs conflict with ionization laser needs. A different design can satisfy laser needs and better fulfill the inspection purpose.*

# A change in specification ownership

- The fixed "cold" camera specification is becoming a HV system specification:

| id | Artifact Type | Name | Primary Text | Rationale |
|---|---|---|---|---|
| 2329 | Specification | ~~SP CISC~~ ***SP HV*** Cold camera coverage | The cold cameras are required to cover at least 80% of the exterior of HV surfaces. | To enable detailed inspection of any issues near HV surfaces. |

- I will report on some cold camera developments following up on the last review. Detailed technical questions may need to be deferred to the HV session.

# Detailed purpose and specifications of fixed cameras (TDR)

"The fixed cameras monitor the following items during filling:

- "positions of corners of APA or CRP, cathode plane assembly (CPA) or cathode, FCs, GPs (*1 mm resolution*)
- "relative straightness and alignment of APA or CRP, CPA or cathode, and FC (*<~1 mm resol.*)
- "relative positions of profiles and endcaps (*0.5 mm resol.*)

} HV

- "the LAr surface, specifically, the presence of bubbling or debris."

} Need might continue after filling (e.g. debris suspected)

[The above resolutions are goals for specific locations. The general specification for resolution is 1 cm.]

# Detailed purpose and specifications of inspection cameras (TDR)

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

- "status of HV feedthrough and cup,
- "status of FC profiles, endcaps (*0.5 mm resolution*),
- "straightness and alignment of APA/CRP, CPA/cathode, and FC, and gaps between CPA frames (*1 mm resol.*)
- "relative position of profiles and endcaps *(0.5 mm resol.)*,

HV related. (PE laser can address CPA/APA.)

- "HV discharge, corona, or streamers,

Stretch goal. (UV)

- "sense wires at the top of outer wire planes in SP APA,

Outer top only because we can't see inside.

- "y–axis deployment of calibration sources,
- "precision view of thermometers, especially dynamic thermom."

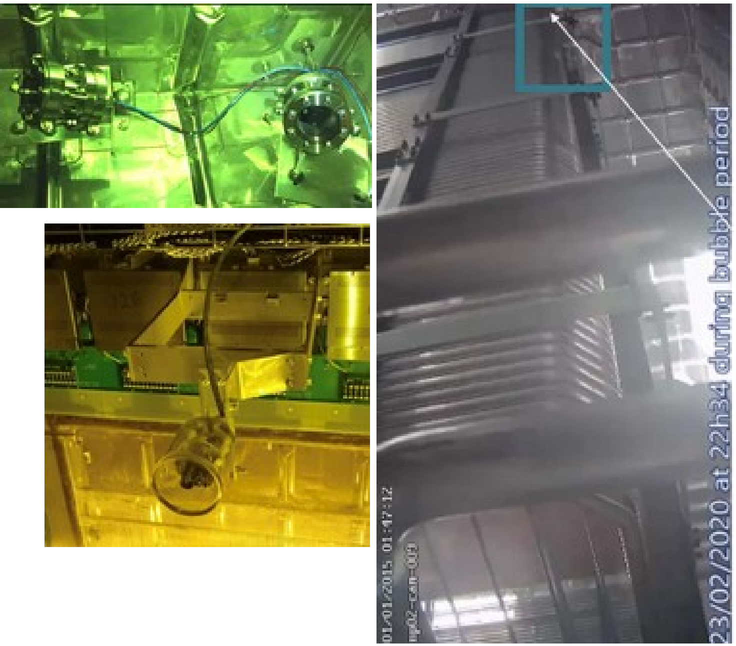
[The above resolutions are goals. Specification is 2 mm.]

Expected throughout experiment.

# Relevant comments from 2019 review

- "There are a limited number of ports available on top of the cryostat which must be shared between CISC and calibration.
- "During the cool down [of the ProtoDUNEs] the cameras were extremely useful to verify what was going on.
- "12 cold cameras in each Far Detector module will provide excellent coverage of the full LBNF cryostat/DUNE detector.
- "The focus of the cameras needs to be remotely adjustable.
- "As further developments: remote optical zoom and the possibility of remotely rotate the camera should be explored.
- "**Recommendation:** Investigate the issue of cold camera lifetime and develop a mitigation strategy if necessary."

# Fixed cameras "in the cold" (HV)




Photos of some cameras in NP04 (left) and a frame from a video taken by an NP02 camera (right).

- Several designs extensively tested in ProtoDUNE–SP and DP.
- Cameras in ProtoDUNE have continued working for >1 year. ✓
- Bo Yu has pressure tested a camera in acrylic housing in LAr at 30 psig, equivalent to 14 m LAr. ✓
- Usefulness of cameras also seen in PD–DP and –SP presentations at the March 6, 2020, general meeting. (https://indico.fnal.gov/event/23466/)

# Fixed camera cost estimates (new)

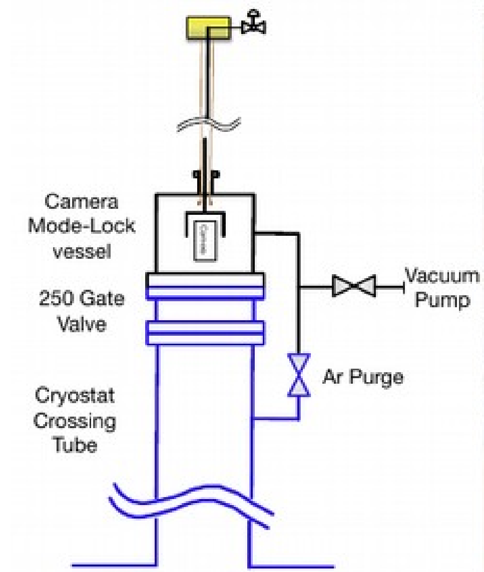
- Cost estimate for proven acrylic enclosure design provided by Bo Yu.

| | | | |
|---|---|---|---|
| M&S: | | *Total:* | $620 |
| | IP camera: | | $ 70 |
| | Heater PCB: | | $ 30 |
| | Acrylic housing: | | $200 |
| | Cold cable: | | $100 |
| | Feedthrough: | | $120 |
| | Integrated light: | | $100 |
| Labor: | | *Total:* | 10 person-hours/camera |
| | Assembly: | | 8 person-hours/camera |
| | Testing: | | 2 person-hours/camera |

- If fixed cameras are needed for more than HV, then they would be made to same design. (E.g., APA–CALCI interface document lists cameras as an APA need to be specified, so far expect periscope cameras to satisfy.)

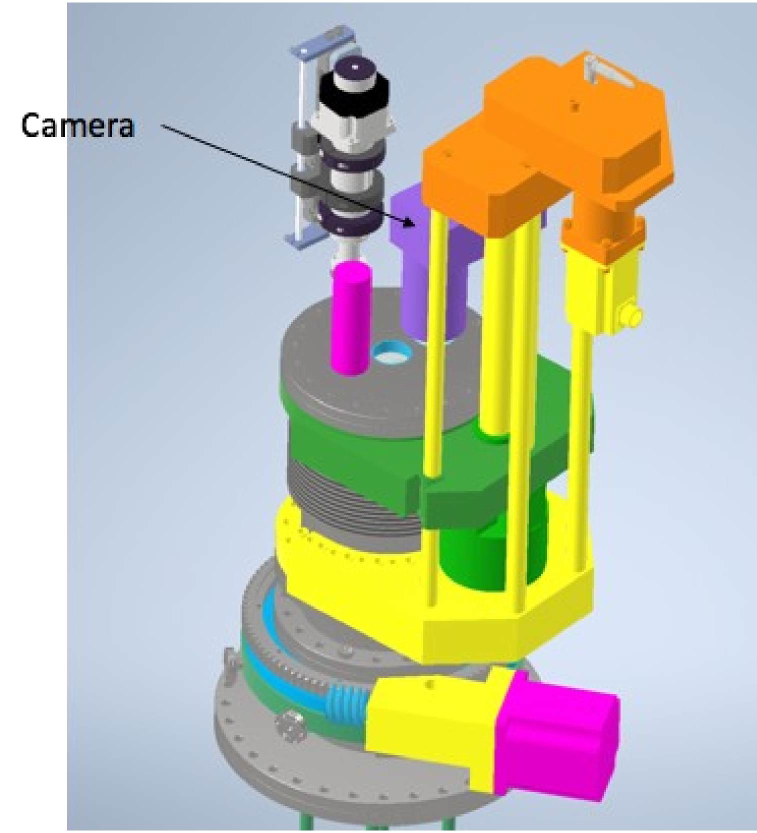
# Movable cameras inserted from "warm" (history)

- Camera–on–a–stick and camera–in–an–intrusion designs considered up until January would need to occupy ports needed for ionization laser periscopes. We can't do that.
- These designs could not view inner CPA, field cage divider boards, or central wire plane features unless deployed through openings in field cage intended for laser.
- These designs require expensive gate valves and/or disruptive removal and insertion process.



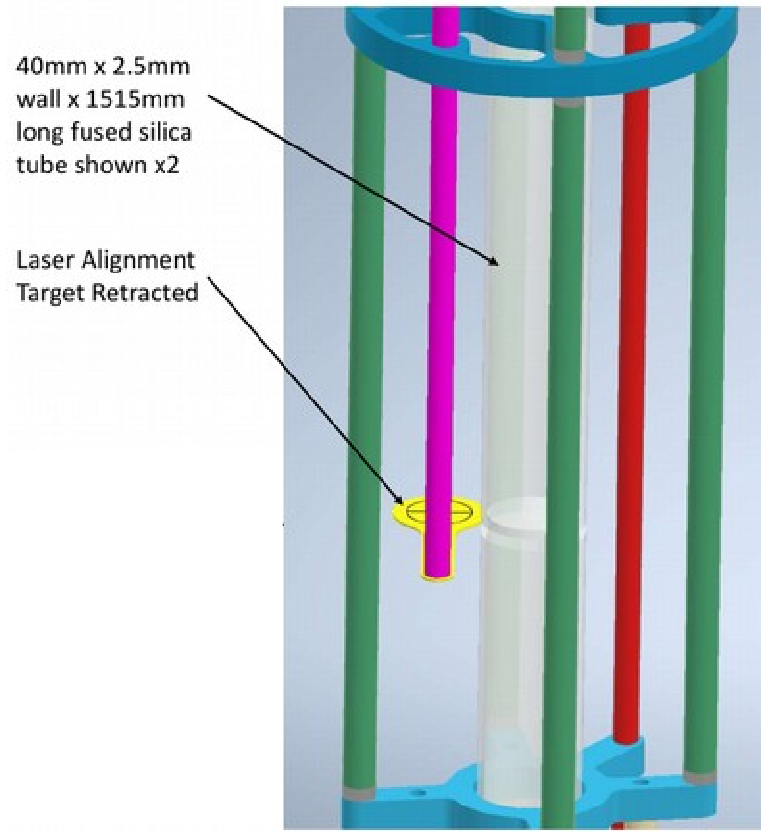

# Laser periscope cameras

- A visible light camera can look through the ionization laser periscope with minimal, low–cost changes to laser design.
- It is very desirable to have a camera for laser alignment operations anyway.
- Camera lives outside cryostat.
- No additional ports needed.
- This is our preferred approach, the only one on which any R&D has happened since January.



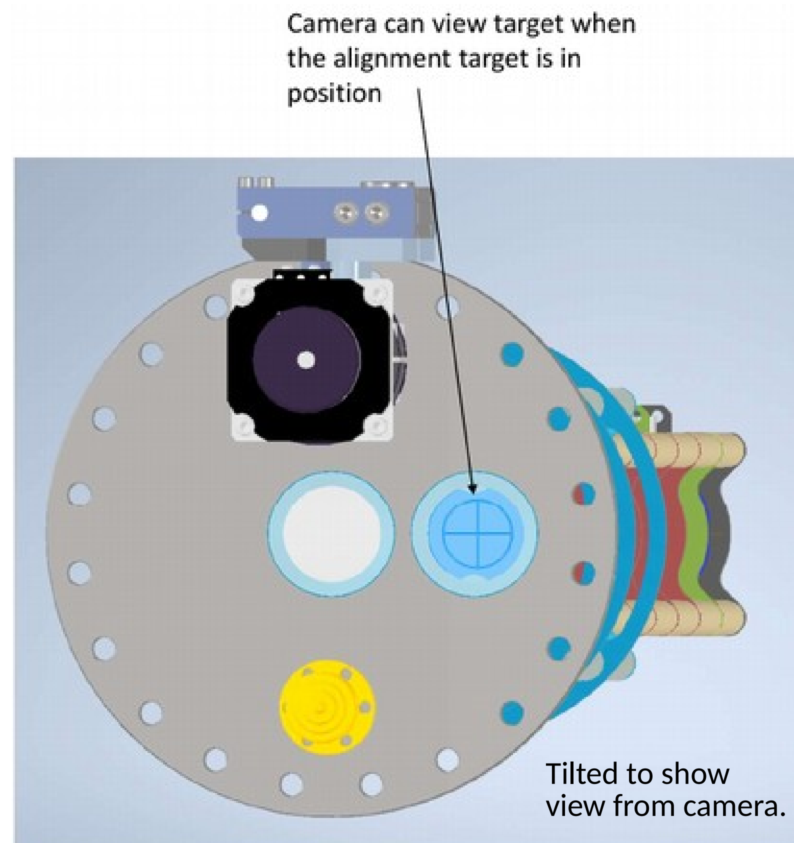
# Alignment camera function 1: align laser beam down periscope axis

- Alignment target already part of design.
- When target inserted into laser path it can be seen through a side–window in top flange while laser goes down central tube.



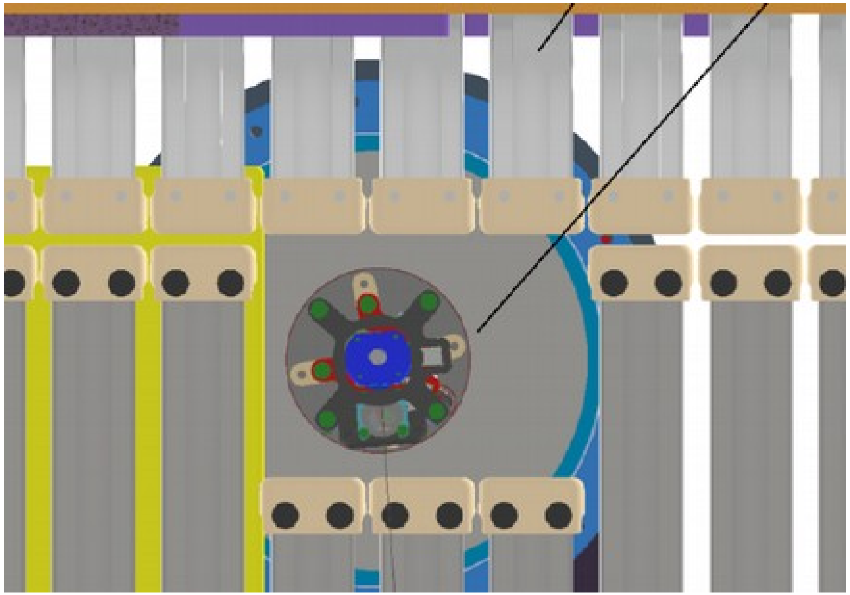
# Alignment camera function 1: align laser beam down periscope axis

- Alignment target already part of design.
- Minimal modification: add camera with remote focus control above side–window.
- Considered essential in order to ensure good centering of beam along periscope optical axis without human eye inside laser box.



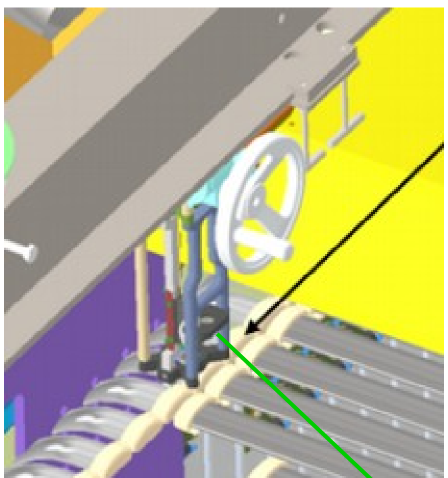
# Alignment camera function 2: verify periscope position in FC opening

- View bottom of periscope from side port, rotate to check all sides.
- No additional modification needed for side view mode.
- Can also be done using “inspection camera” mode.

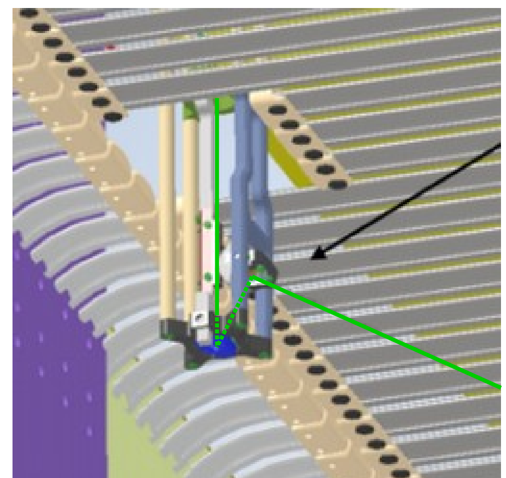


# Inspection camera functions

- Actually look through periscope.
- View exterior features of TPC if periscope above FC.
- View interior features of TPC if periscope inside FC.



Retracted
Looking at outside of TPC



Deployed
Looking inside TPC

# Laser periscope minimal modifications

- Use mirrors that transmits green light as well as UV.
  - Dual–band dielectric mirrors exist.
  - Required to get any visible light reflection.

- Add actuator to slide camera on/off axis.
  - Jan has a design concept.
  - Required to position camera on axis.
- Remote control zoom lens on camera.
  - Commercial off–the–shelf.
- Desirable modifications (beyond minimal scope):
  - 50% larger diameter mirrors.
  - High QE camera sensor. (Astophotography enthusiasts know many.)

# Lighting

- No change in LED lighting system basic design.
- Additional LED selection criteria: spectrum of LEDs *in LAr* must match green band of mirror coating. ("Amber" LEDs in ProtoDUNE–SP were green.)
- New opportunity at no additional cost: green alignment laser of one periscope can "spotlight" a region viewed by another with beam up to 3 cm in diam. (Good option for interior lighting, not so good above TPC.)

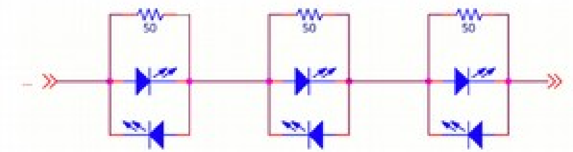
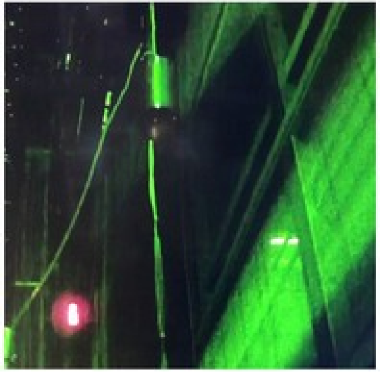



Figure 1.26: Example schematic for LED chain, allowing failure tolerance and two LED illumination spectra.



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

# Added risk to detector if implemented?

- No increased risk since all modifications are exterior to the detector except mirror coating (no mechanical effect) and optionally the mirror size (stays within envelope).

## Risk decrease opportunities:

- Decreased risk to detector due to extra checks on positioning of each periscope relative to FC opening.
- Improved efficiency of alignment operation reduces risk of time lost to laser calibration setup.

# Inspection camera expected performance

- For worst–case tilt of small mirror reducing effective aperture to 15 mm in vertical direction:

  Diffraction limit: $\theta_{\mathrm{A}} = 1.22\,\lambda / D_2 = 40\,\text{microradians}$

  Field of view (FWHM): $\theta_{\mathrm{V}} = D_1 / L = 13\,\text{milliradians}$

  Feature resolution for object 15 m from mirror:

  $$(15\text{ m}) \cdot \theta_{\mathrm{A}} = 0.6\,\text{mm}$$

  FOV for object 15 m from mirror:

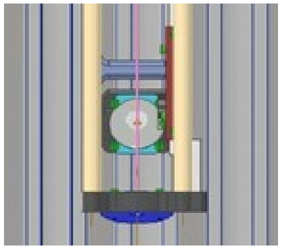
  $$200\ \ \text{mm}$$

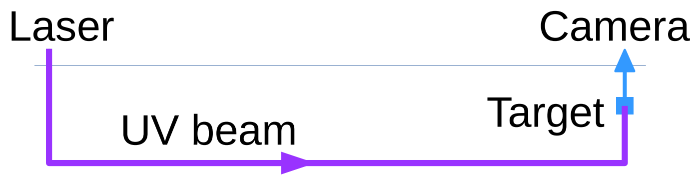
- The resolution meets the inspection camera requirement.
- Although field of view is small in any given image, the periscope scan system makes it possible to acquire multiple overlapping images to form a mosaic.

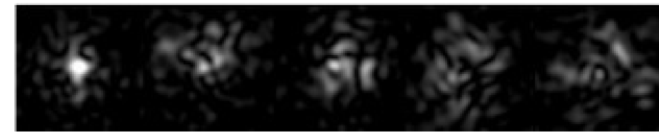
# Plan to demonstrate performance

- Initial calculations done analytically and using a JPL-written Fourier optics package normally used for advanced telescope design, minimally extended to include LAr refraction. Takes into account refraction, mirror quality, and diffraction through elliptical (tilted circular) apertures.
- Next steps are to fully implement simulations of complete design, room temperature mock-up, then tests in LAr as part of periscope development.
- One undergraduate and one new graduate student (still taking classes) interested in doing more detailed design and simulations. Plan was for that to start this spring, but COVID-19 disruption made it hard to get started. Both will be available this summer.

# Bonus: Laser–camera spot size and beam quality check





“Speckle” due to temperature fluctuations in turbulent gas flow. (In air, not LAr.)

- Set two periscopes so each one’s camera sees the other.
- Insert (translucent) UV alignment target in one periscope.
- Remove camera from other and shoot laser.
- Observe beam spot size and pulse–to–pulse shape of beam propagated through LAr.
- Quantifies wavefront quality, combination of laser and LAr effects.
- Stringent periscope alignment check.
- Beam spot imaging is a standard technique used in other contexts.

# Need for inspection cameras

- They provide the only way to see the state of FC profile exterior and interior, resistor boards, HV bus, etc.
  - PE laser can tell if APA/CPA are tilted or misplaced, but cannot give information about mechanical state. Inspection camera can see CPA buckling, hinge state, APA–FC latch...
  - Inspection camera would allow direct visual inspection to guide ideas for corrective actions in case of any change. (E.g., exterior manipulation of HV feedthrough or DSS, etc.)
- Inspection camera can also monitor RSDS & thermometer motion.
- They also provide continuation of surface imaging and most HV imaging capabilities as long as laser periscopes function, which should be throughout life of experiment.

# Periscope camera system costs (M&S)

| Hardware | Qty. | Inst. | Resp. Person | Cost est. | Source | Status |
|---|---|---|---|---|---|---|
| ProtoDUNE-SP-2: Cameras in Laser periscope (full system) | 2 | KSU | G. Horton-Smith | 10000 | DUNE US project | Approved (LANL) |
| DUNE FD1: Camera in Laser periscope (full system) | 12 | KSU | G. Horton-Smith | 21000 | DUNE US project | Aspirational |
| DUNE FD1: Computers | 2 | KSU | G. Horton-Smith | 4000 | DUNE US project | Aspirational |
| DUNE FD1: Light system | 15 | Drexel | C. Lane | 3900 | DUNE US project | Aspirational |

* DUNE FD M&S based on CISC Warm Camera estimate, includes camera cost, camera electronics, 10 m of cables.

# Periscope camera system costs (labor)

- ProtoDUNE–II: Cameras on Laser Periscope: hardware design, production, commissioning: faculty (**0.2 FTE.yr**), grad students (**0.3 FTE.yr**), engineer (**0.05 FTE.yr**), technician (**0.02 FTE.yr**)
- DUNE FD1: Cameras on Laser Periscope: hardware design, production, commissioning: faculty (**0.5 FTE.yr**), postdocs (**1 FTE.yr**), grad students (**1 FTE.yr**), engineer (**0.06 FTE.yr**), technician (**0.05 FTE.yr**)
- DUNE FD1: light system: hardware design, production, commissioning: faculty (**0.5 FTE.yr**), grad students (**0.25 FTE.yr**), Technicians (**0.01 FTE.yr**)

# FD–SP HV cups, endwalls, and FD–DP

- So far we only have designs integrating cameras into the FD–SP FC–penetrating ionization laser periscopes. Endwall periscopes would add more parallax views and expand coverage.
  - HV: need to image the HV cups may extend past the proven life of the fixed cameras.
  - Endwall inspection: same consideration.
  - Without endwall periscopes, another long–lived solution is needed. (E.g., permanent viewport intrusion via a dedicated port.)
- Similar considerations apply to long–term FD–DP HV and inspection needs.

Intrusion photo courtesy Francesco Pietropaolo

# Justification in safeguarding FD, facilitating operation?

## Fixed cameras:

- Essential for verifying CPA/FC/APA state during cool-down, prior to filling, during filling, prior to HV ramp-up, throughout commissioning.
- No ProtoDUNE has ever been cooled, filled, or ramped up HV without cameras.

## Periscope cameras:

- Alignment function considered essential for safe and efficient laser alignment, periscope deployment.
- Long-term inspection ability will aid diagnosis and solution of any situations not addressable by fixed cameras.

# Minimum scope needed to fulfill role?

## Fixed cameras:

- 12 wide–field cameras with lighting gives full coverage.
- HVS consortium evaluating needs more carefully.

## Periscope cameras:

- Alignment function: each periscope system needs one camera with remote focus.
- Inspection function: each periscope system needs dual–band mirrors, one camera with remote focus and zoom, and actuator to slide camera on/off axis.

# Technical issues of feasibility resolved?

## Fixed cameras

- Yes. Most aspects of design well proven in PDSP.
- Improvements reflecting lessons–learned seem straightforward, will be tested in PDSP2

## Periscope cameras

- No apparent problems of feasibility.
- Detailed mechanical design in progress.
- Plan in place for verifying expected performance prior to PDSP2 deployment, then in PDSP2.

# Risks to detector performance associated with implementation? (repeating slide 19)

- No increased risk. All modifications are exterior to the detector except mirror coating (no mechanical effect) and optionally the mirror size (stays within envelope).

## Risk decrease opportunities:

- Decreased risk to detector due to extra checks on positioning of each periscope relative to FC opening.
- Improved efficiency of alignment operation reduces risk of time lost to laser calibration setup.

# Credible plan in place for demonstrating system performance?

- We think so.
- Most aspects of fixed camera design well proven in PDSP, improved design to be tested in PDSP2. (HVS leading.)
- Periscope camera plans include room temperature mock–up, tests in LAr as part of periscope development, and use in PDSP2.

# Functionality of system justifies its overall cost?

- Unit cost of fixed camera in acrylic has come down to $620/camera. Very low cost for essential functionality.
- Added cost to periscope design is ~$2400/unit for cameras + computers + lighting. (About 1.4% of unit cost of laser+periscope+control.)

# Essential, highly desirable, or what?

## Fixed cameras:

- Essential: full HVS coverage, currently considered as 12 cameras for full coverage at nominal TDR specifications.
- HVS consortium evaluating needs further.

## Periscope cameras:

- Essential: beam alignment functions, periscope mechanical alignment check w.r.t. field cage.
- Highly desirable (very): inspection functions.

APA consortium will also communicate needs. (CALCI–APA interface.)

# Summary

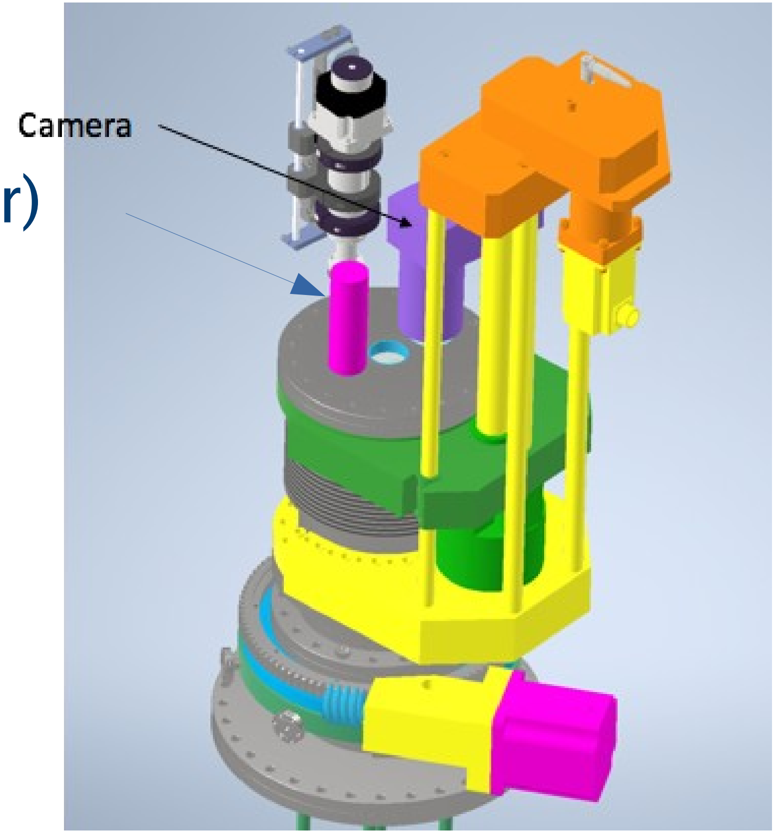
- No change in fixed cameras other than progress in validating lifetime and pressure resistance. Specification transfered to HV consortium. Fixed cameras will be used in FD–DP and –SP.
- Laser periscope cameras facilitate operation of lasers and provide for inspection of exterior top TPC surfaces, LAr surface, and all interior TPC surfaces. Minimum scope is off–the–shelf cameras, addition of camera mover, and change of mirror coating. No added risk, expected to decrease risk.

# Extra: links to interesting presentations

- Collaboration monthly call Mar 6, 2020: https://indico.fnal.gov/even/23466/
  - Dominique Duchensneau presentation: includes recent interesting and revealing use of cameras in NP02
  - Roberto Acciarri presentation: shows camera intrusion being removed without unfilling NP04 cryostat (replaced with Xe light sensitive detector)
- DUNE-doc-16034: "Report of the Cryogenic Instrumentation Workshop held at CERN on 19 June 2019"
- DUNE-doc-8318, -8615, -8190, -8942: lots and lots of PD-SP/NP04 camera installation, design, and testing information from 2018.
- DUNE-doc-9826: "Movie of stuff moving in the argon"
- DUNE-doc-9934 "recordings from filling of NP04 cryostat"

# Extra bonus: UV sensitive PMT

- TPB–coated PMT could see UV light in the bandpass of the periscope mirrors (same as laser)
- Possibly see HV corona?
- We envision trying that in PDSP2.
- For FD–SP system we would need an actuator.



# Extra slides: from CALCI presentations

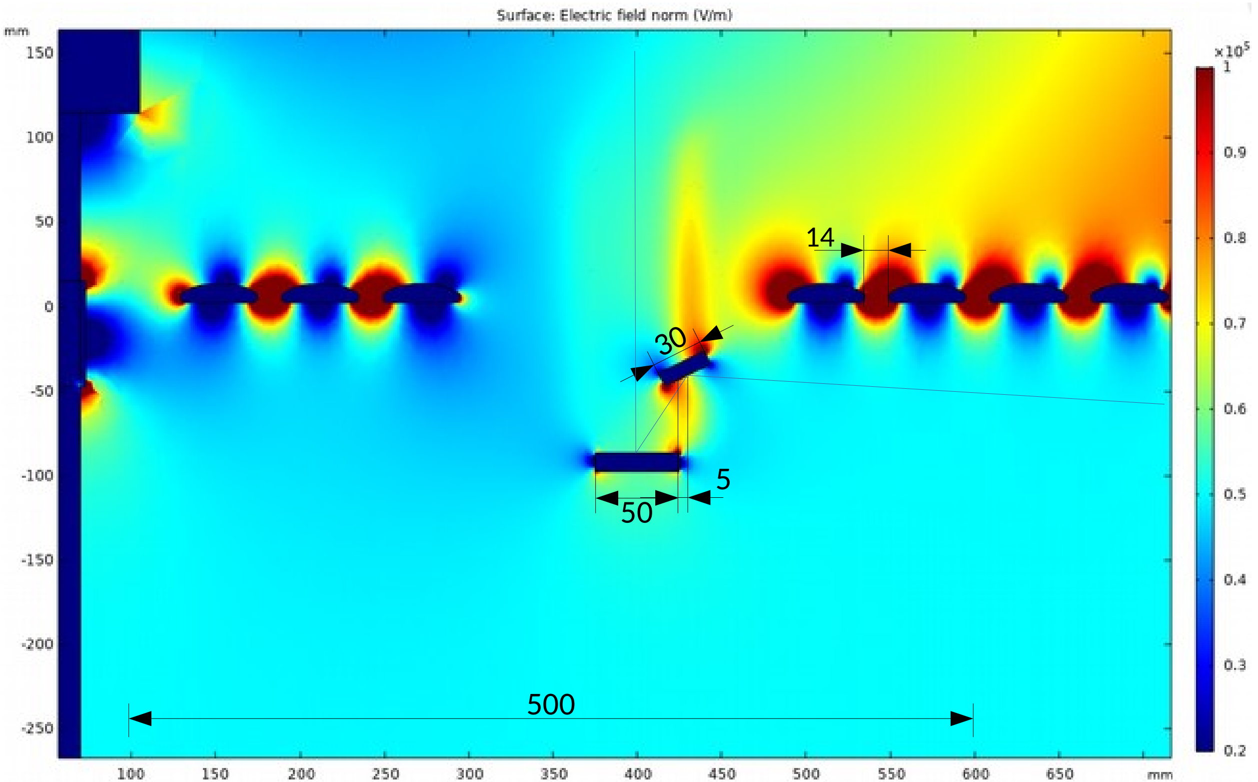
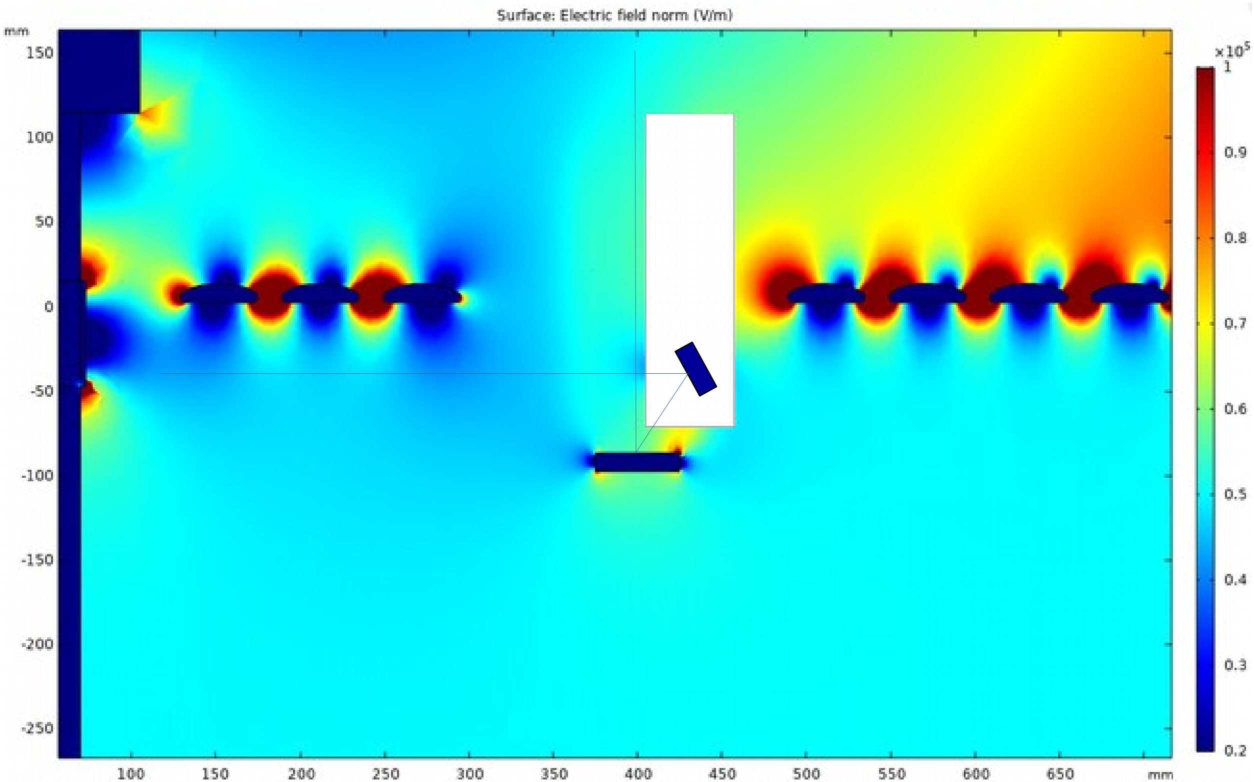
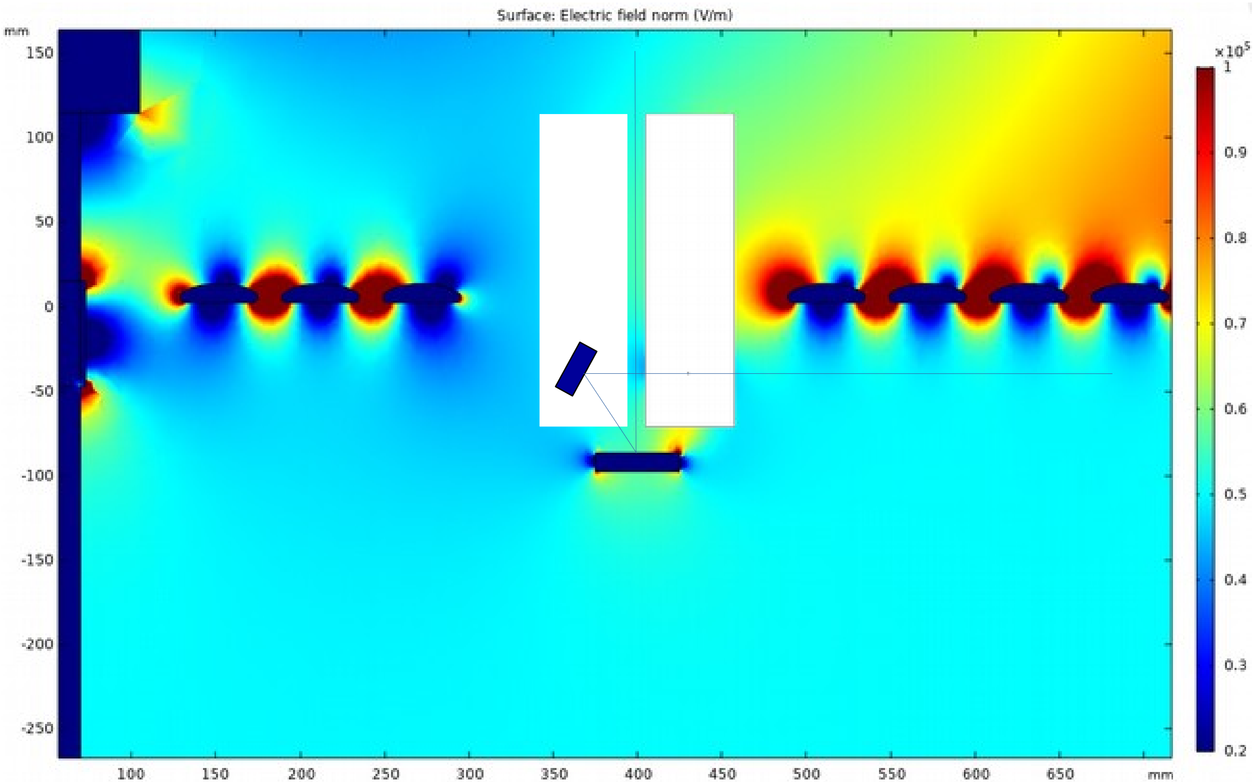



Image from Bo Yu https://indico.fnal.gov/event/20996/session/2/contribution/15/material/slides/0.pptx
Dimension lines added by Glenn H-S. Do not trust dimensions except for FC spacing.

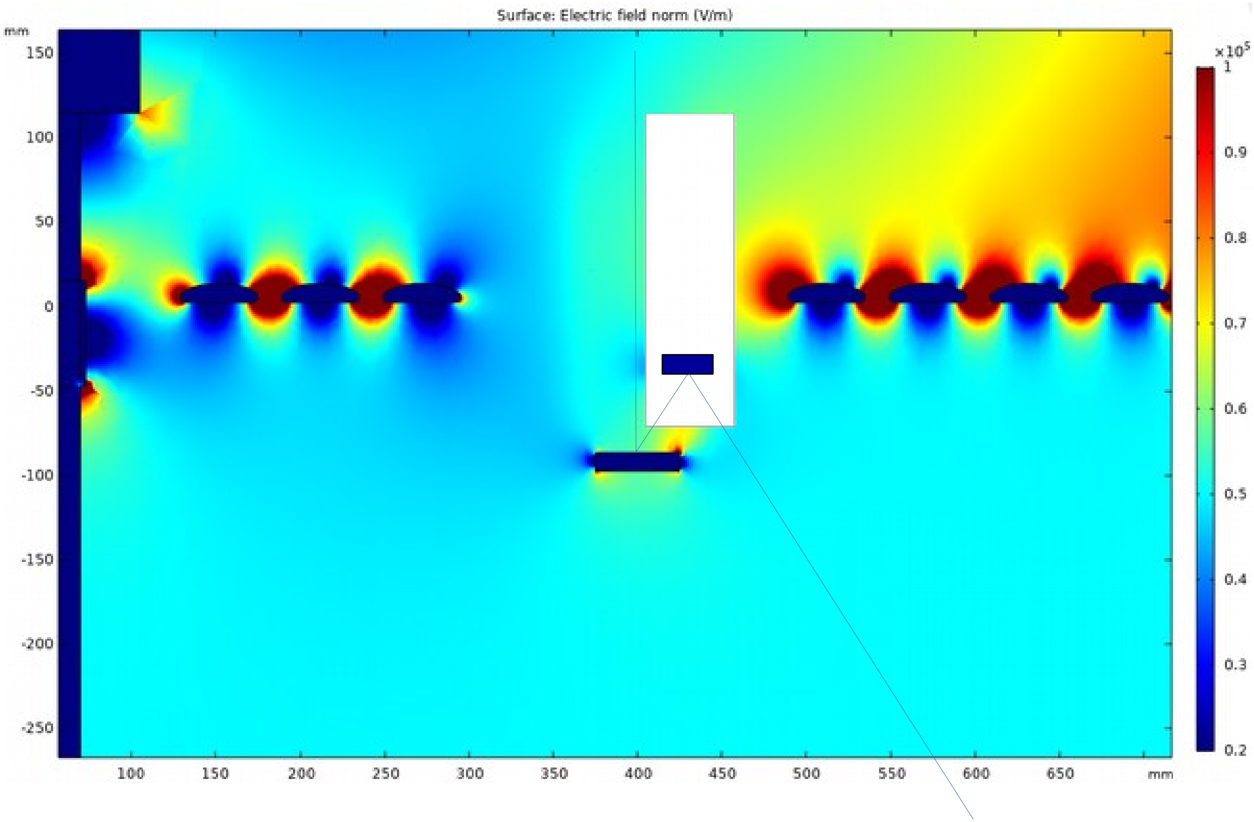
Effective aperture of 25 mm mirror (in 30 mm holder) would be seriously foreshortened in this configuration. However, it is not the best configuration for near-horizontal aim..




Better way to obtain near-horizontal pointing.
Angle of tilting mirror to optical axis is apx 30 degrees.
Effective aperture of 25 mm mirror is ~21 mm.
A good configuration to use with camera.




An more correct way to aim the laser.
(APA is at left in this picture.)




Optical path ideally on this side of bottom mirror for more vertical aims. Worst case angle of tilt mirror to optical axis is ~45 degrees, effective aperture ~18 mm still assuming 25 mm mirror.

# Image resolution

Assume 532 nm wavelength, $D_1$ = 50 mm aperture at top, $D_2$ = 15 mm effective size mirror at bottom, 5 m from camera to mirror, 1280x960 pixel camera, field of view restricted by lower mirror.

Airy disk size: $\theta_A = 1.22\,\lambda / D = 40$ microradians

Field of view: $\theta_V = D / L = 10$ milliradians

Feature resolution for object 15 m from mirror:

$$(15\text{ m} + 5\text{ m}) \cdot \theta_A = 0.8\text{ mm}$$

FOV for object 15 m from mirror:

200 mm

# Extra slides (mostly left over from 2019 review)

| Purpose | Operational phase |
|---|---|
| Monitor ullage gas, LAr, detector mechanical structures during filling. | Cryogenics commissioning and filling. |
| Monitor movable devices such as thermometers, detector calibration, CRPs. | Detector commissioning. (Goal: Maintain ability during long term operations.) |
| Investigate unexpected events. (E.g., suspected mechanical or HV problems) | Both detector commissioning and long-term operations, as needed. |

# Two types for DUNE FD modules (SP and DP)

- **Fixed, “cold” cameras.** (Actually warmed by heaters.) One enclosure design needs to be chosen. Must work at 12 m and last throughout cool–down, filling, and first months of TPC operation (or longer).
- **Movable, “warm”, inspection cameras.** Two designs being considered, one to be chosen: camera enclosure on “fork” in sealed deployment system, or PDSP–style tube–with–dome. Replaceable and deployable through top ports throughout life of detector for inspecting anything on top or sides.

# Specifications (official)

| Label | Description | Specification (Goal) | Rationale | Validation |
|---|---|---|---|---|
| SP-FD-18 | Cryogenic monitoring devices | | Constrain uncertainties on detection efficiency, fiducial volume. | ProtoDUNE |
| SP-CISC-27 | Cold camera coverage | $>80\%$ of HV surfaces ( 100% ) | Enable detailed inspection of issues near HV surfaces. | Calculated from location, validated in prototypes. |

# Detailed purpose and specifications of cold cameras (TDR)

"The fixed cameras monitor the following items during filling:

- "positions of corners of APA or CRP, cathode plane assembly (CPA) or cathode, FCs, GPs (*1 mm resolution [goal]*)
- "relative straightness and alignment of APA or CRP, CPA or cathode, and FC (*<~1 mm resol. [goal]*)
- "relative positions of profiles and endcaps (*0.5 mm resol. [goal]*)
- "the LAr surface, specifically, the presence of bubbling or debris."

[The above resolutions are goals for specific locations. **The general specification for resolution is 1 cm.**]

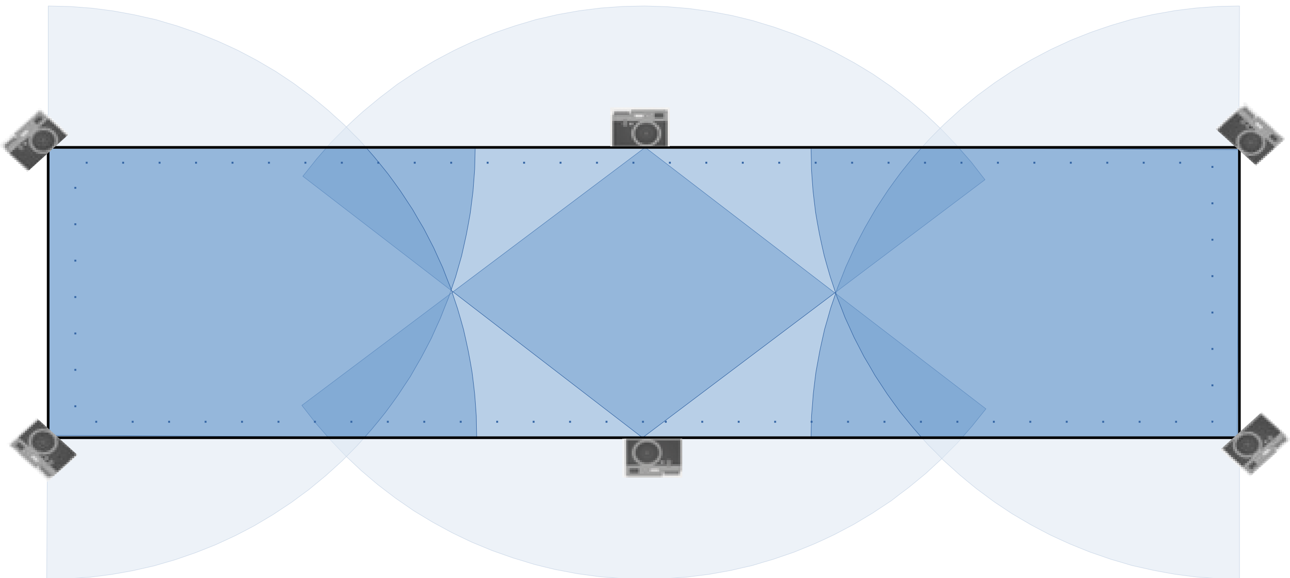
# Detailed purpose and specifications of inspection cameras (TDR)

"… 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,
- "precision view of thermometers, especially dynamic thermometers,
- "HV discharge, corona, or streamers on HV feedthrough, cup, or FC,
- "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 wire planes in SP APA *(0.5 mm resol.)*."

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

# Cold camera number and locations: Full coverage with 12 cameras



4032×3024 pixel cameras
45° half angle at 8 corners
53° half angle at 4 long edge centers
12 cameras total

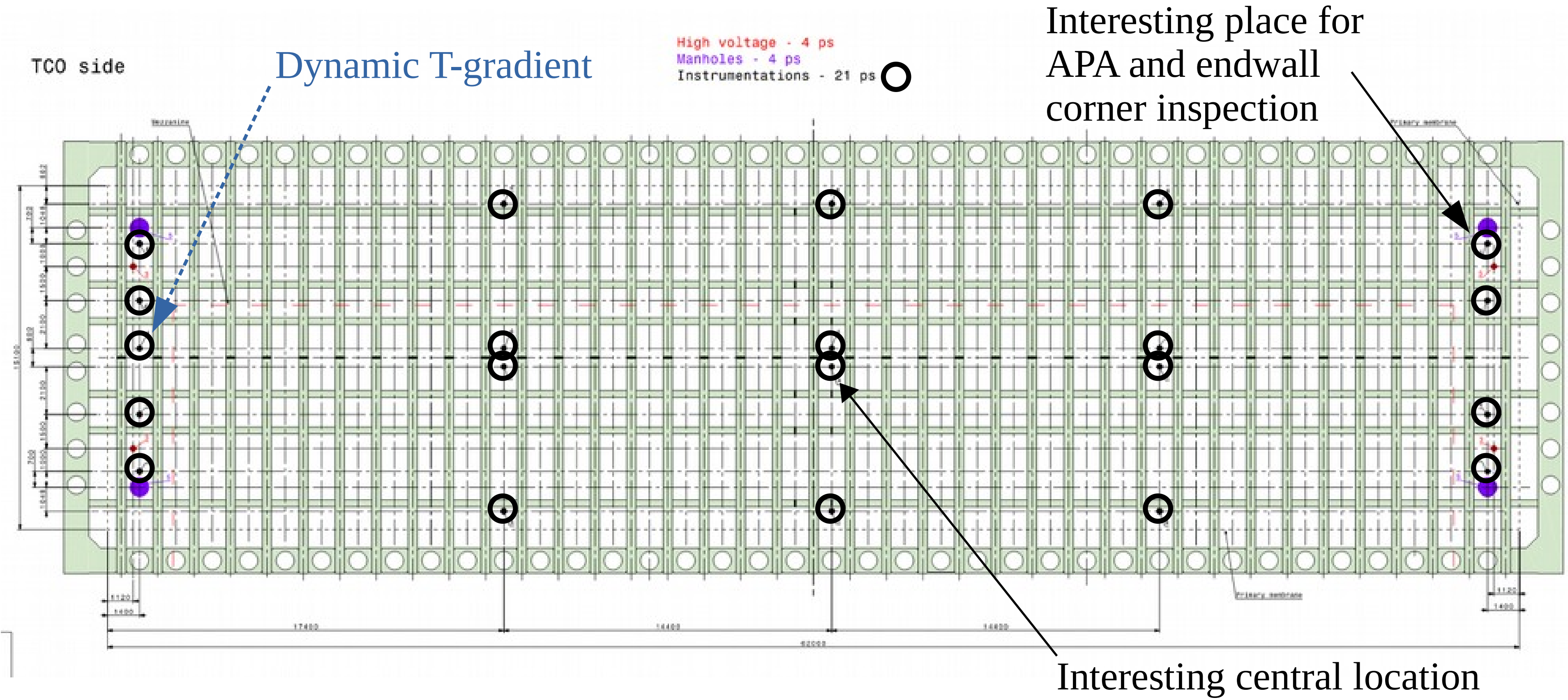
At viewing distance 22.3 m (shown):
0.8 cm/pixel for corner cameras,
0.9 cm/pixel for edge cameras.

Note: We have to carefully consider geometric projection when surface feature of interest is not perpendicular to view direction. Also diffraction limit, lens projection, etc.

# Inspection camera number and location

- They are designed to be movable.
- Deployable through any instrumentation port with a clear aperture. (Cables can come in through side feedthroughs.)
- Optimal number depends on how easily we think we can move the system from penetration to penetration, which depends on various factors, in particular which penetrations have gate valves.
- Currently budgeting for 3 cameras with complete deployment apparatuses, and 3 gate valves.
- We could have many gate valves and one movable camera, or many cameras in well chosen locations without extra gate valves (which would limit moveability to exceptional circumstances), or something in between. E.g., 7 gate valves and 2 inspection camera systems would cost the same as the current 3+3 plan.

# Inspection cameras deploy through instrumentation penetrations



# Specific questions in committee charge

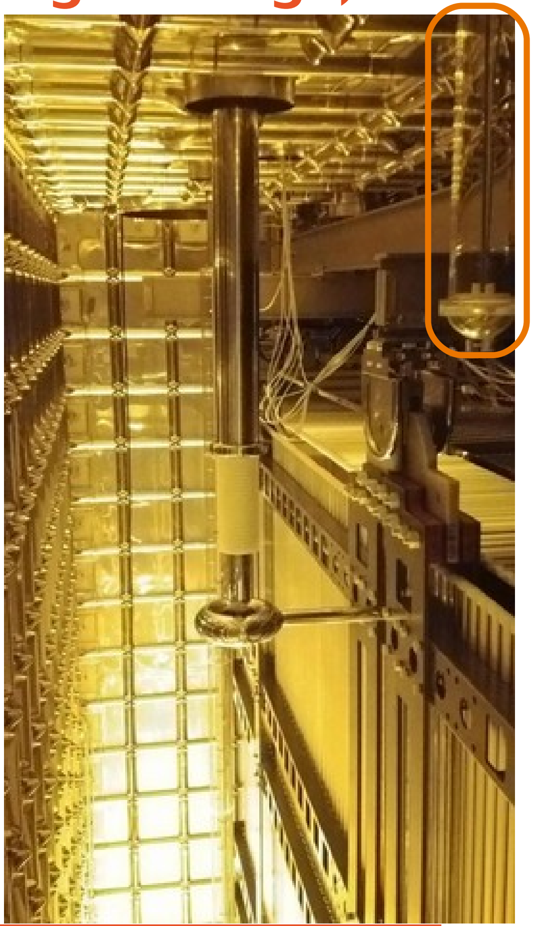
- How did the two types of cameras implemented in the ProtoDUNE-SP cryostat (cold inside the liquid and warm in the gas ullage) perform relative to one another?
- What are the important uses of cameras and what level of coverage is needed to provide the required functionality?
- Do warm cameras need to be permanent or can they be moved from one port to another to investigate potential issues? If the cameras can be moved, what is the correct number to have on-hand?
- What sorts of improvements are being considered for the camera designs used in the ProtoDUNE cryostats and is there confidence that cameras installed in the DUNE far detector modules can survive over the operational lifetime of the detector and is this in fact necessary?
- Are the proposed mechanisms for supporting the cameras within the cryostat and connecting them to the outside of cryostat mechanically sound and cost effective?

# How did the two types of cameras implemented in the ProtoDUNE–SP cryostat … perform relative to one another?

- No two cameras had identical perspectives on any part of ProtoDUNE.
- All cameras gave views that were useful in filling, operation, or both.
- Performance criteria are still being established.
- Keeping good focus is a known performance issue.
- Presentation at May collaboration meeting by Dominique Duchesneau on "CRP TDR update and camera studies for ProtoDUNE–DP" represents of state of the art in quantitative performance evaluation.

# … two types of cameras implemented in the ProtoDUNE-SP cryostat (cold inside the liquid and warm in the gas ullage) …

- Note: the camera part of both “cold” and “warm” cameras operate in enclosures warmer than LAr. The camera element is not directly exposed to the ullage.
- It is intended that the “warm” inspection camera enclosures could be positioned in either liquid or ullage as needed.
- Fixed “cold” cameras could also be positioned in either liquid or gas, or even right at the liquid-gas interface.



# From "ProtoDUNE Lessons Learned" talk at June 4 HV Review

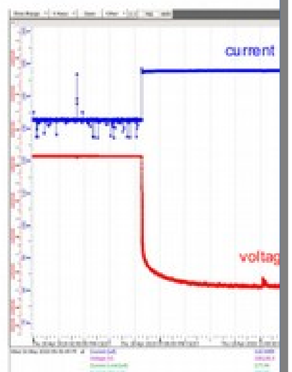
## System Monitoring & Regular Checks

**System Monitoring**

- The available components like ground plane monitoring and cameras were of great help → USE in DUNE
- Additional ideas:
  - PMT
  - IR PMT?

## HV Streamer Self Quenching?

- April 2019: deactivated auto recovery, let streamer go on while it lasts
  - Lasted 12h → self quenched after
- No evidence of light emission in the visible spectrum from cameras
- After that, no steamers for the following 2 weeks!
  - Only, short self healing current blips
- Last 40 days only 4 streamer events of longer duration O(6h)




33 June 4, 2019 ProtoDUNE: Lessons Learnt From Beam and Stability Runs

https://indico.cern.ch/event/813154/contributions/3403388/

## What are the important uses of cameras and what level of coverage is needed to provide the required functionality?

- Monitor "High Voltage Systems"
  - 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]
- Need full coverage of HV surfaces and movable devices.

## Do warm cameras need to be permanent or can they be moved from one port to another to investigate potential issues? If the cameras can be moved, what is the correct number to have on-hand?

- They don't need to be permanent, will be movable.
- If moving a camera is made trivial, then the correct number is probably one or two.
- *However*, moving a camera is an "open heart operation" *unless* we put a permanent gate valve on every port that we might want to use.
- We need either many gate valves and one movable camera, or several cameras in well chosen locations with movability reserved for exceptional circumstances.
- ProtoDUNE will perform the "open heart operation" to replace one warm camera with a UV directional detector.

## What sorts of improvements are being considered for the camera designs used in the ProtoDUNE cryostats ...

- The main *functional* improvement needed is remotely adjustable focus. (See talk by D.Duchesneau referenced earlier.)
- More R&D needed to ensure *operational* requirements can be met, in particular lifetime and pressure resistance of cameras.
  - ‣ Fixed–position "cold cameras" at bottom must withstand twice the pressure and remain non–contaminating for ~30 times longer than the full ProtoDUNE run.
  - ‣ The insertable inspection camera design is untested. A PD–SP acrylic intrusion had condensation freeze inside it, although the idea seems sound, and indeed the camera was later removed successfully.

and **is there confidence that cameras installed in the DUNE far detector modules can survive over the operational lifetime of the detector and is this in fact necessary?**

- Different answers for cold and warm.
- Cold cameras need only operate over duration of filling. (See TDR.) This is necessary. High confidence that they will survive this time based on ProtoDUNE.
- Warm camera system should be functional over lifetime of experiment, but maintenance could include replacement.

## … [warm cameras] survive over the operational lifetime of the detector and is this in fact necessary? [continued]

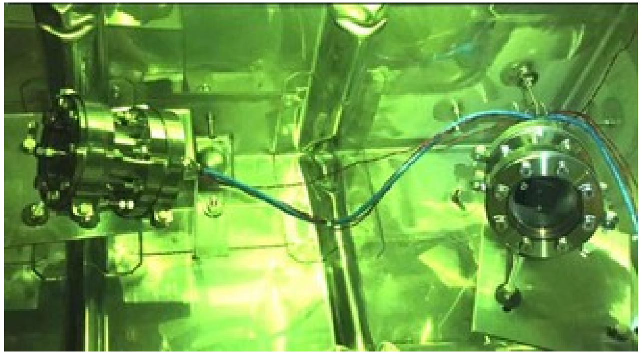
- In the ProtoDUNE–style warm camera system, the “camera part” can be replaced without removing the enclosure. (No open heart.)
- A given warm “camera part” only needs to operate long enough that replacement is not too frequent. (~ few years)
- Required warm camera enclosure lifetime depends on replaceability:
  - Many gate valve, easily movable case: Enclosure needs to last for ~few year frame. Medium confidence in this from PD.
  - “Open heart replacement” only case: enclosures should last for lifetime of experiment. Engineering R&D needed for confidence.
- May not be necessary to last so long: after several years, we may have learned all we need, barring some catastrophe (earthquake). (Still need 1 gate valve per deployed camera for safe removal.)

## Are the proposed mechanisms for supporting the cameras within the cryostat and connecting them to the outside of cryostat mechanically sound and cost effective?

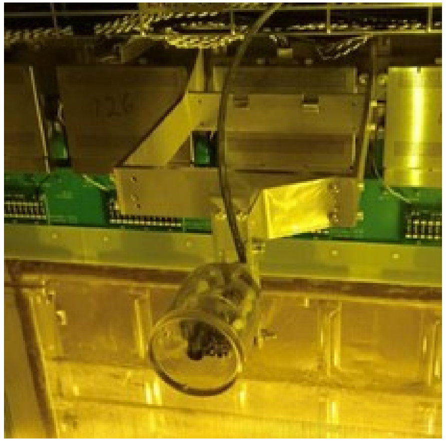
- EDMS 2145174 describes the planned cable interfaces, which are similar to other systems: cables run on DSS I-beams and side cable trays, exit through side flanges on DSS and non-DSS penetrations.
- Inspection cameras will be supported by the top flanges on the instrumentation feedthroughs.
- Fixed camera supports expected to be similar to those in ProtoDUNE-SP. (Pictures next slide.)

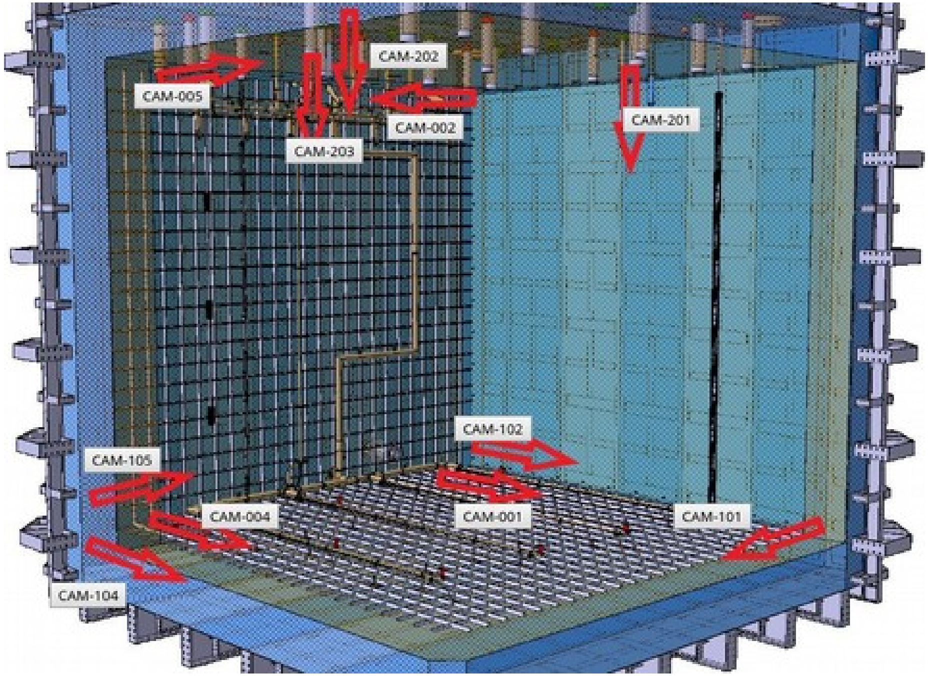
# ProtoDUNE fixed camera mounting

Cryo pipes, corner plates



APA





# Inspection camera deployment: "glove box" or "periscope" designs

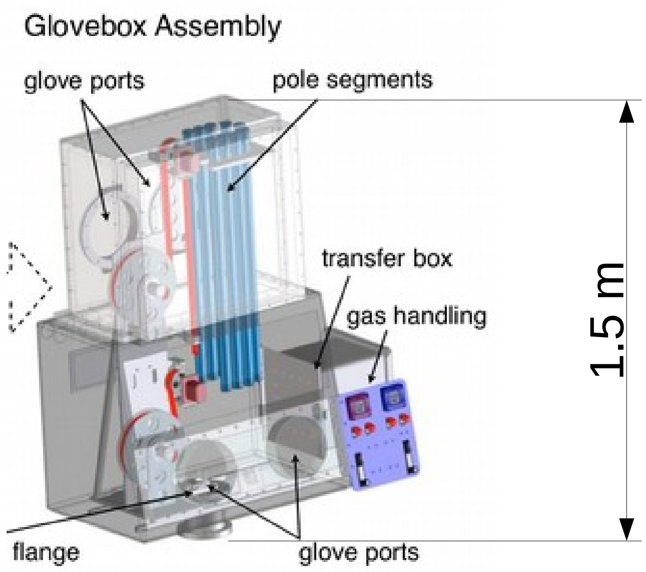



Figure from JINST 4:P04017,2009 (KamLAND full-volume calibration)

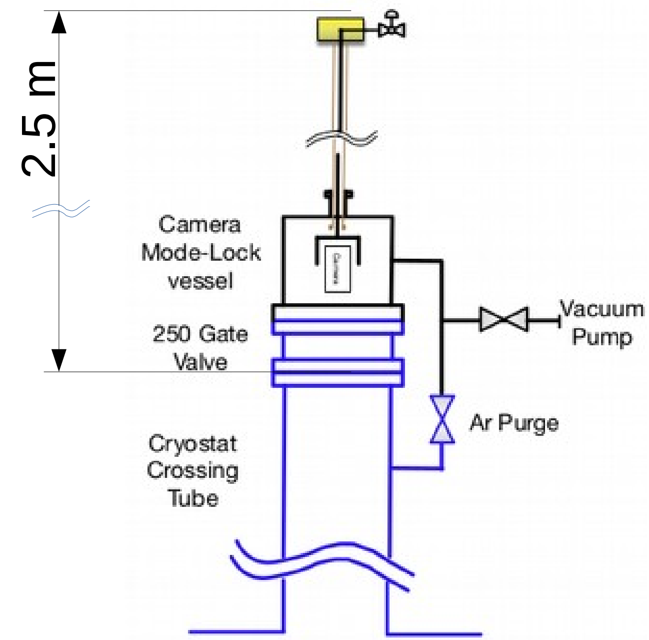
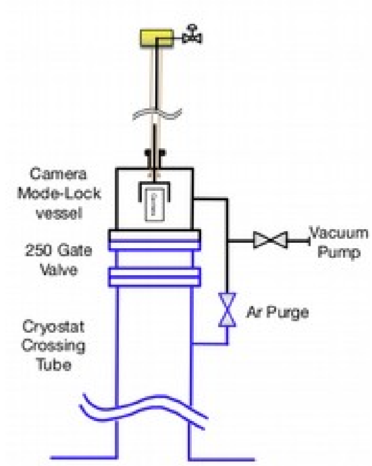
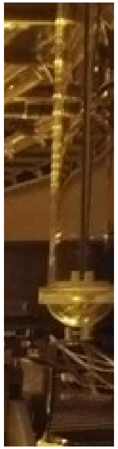



Figure from TDR – baseline design

## Are the proposed mechanisms ... cost effective?

- Fixed cold camera designs are as minimal as they can be. (Still to confirm pressure resistance.)
- PDSP acrylic intrusion design could turn out to be cheaper than fork, but longevity less clear, deployment/removal more difficult.



# Summary

- I've tried to address
  - purpose and required functionality in the 3 operational phases;
  - proposed types, numbers, and locations of cameras;
  - information related to specific charge questions.
- Further questions?

# Yet more extra slides

# CISC Scope: Purpose

**Maintain detector live time: S**low **C**ontrol alerts on bad detector system conditions.

**Constrain uncertainties on detection efficiency and fiducial volume: C**ryogenic **I**nstrumentation measures relevant LAr conditions.

Plus various **special cases**.

# Physics connections

## **High level:** maintain detector live time, measure LAr conditions

| | Maintain live time | LAr conditions | Special use cases | Notes |
|---|---|---|---|---|
| **CFD Model** | / | / | | Predicts LAr conditions throughout detector using measurements outside field cage |
| **Purity monitors** | / | / | | Independent of TPC, works at low&high purity, detect purity issues early, input to CFD |
| **Thermometers** | / | / | | Input to CFD, detect recirculation malfunction |
| **Liquid Level** | / | / | / | HV interlock, input to CFD, filling |
| **Gas Analyzers** | / | | / | Can detect purification issues before LAr enters cryostat during filling and top-off |
| **Cameras** | | / | / | Monitor filling, calibration deployment, investigate after seismic or mechanical event |
| **Cryo. Test Fac.** | | | / | Test devices before installation |
| **Slow Control** | / | / | / | Provides status and alerts, recorded history, real time data |

# Mechanical event gallery

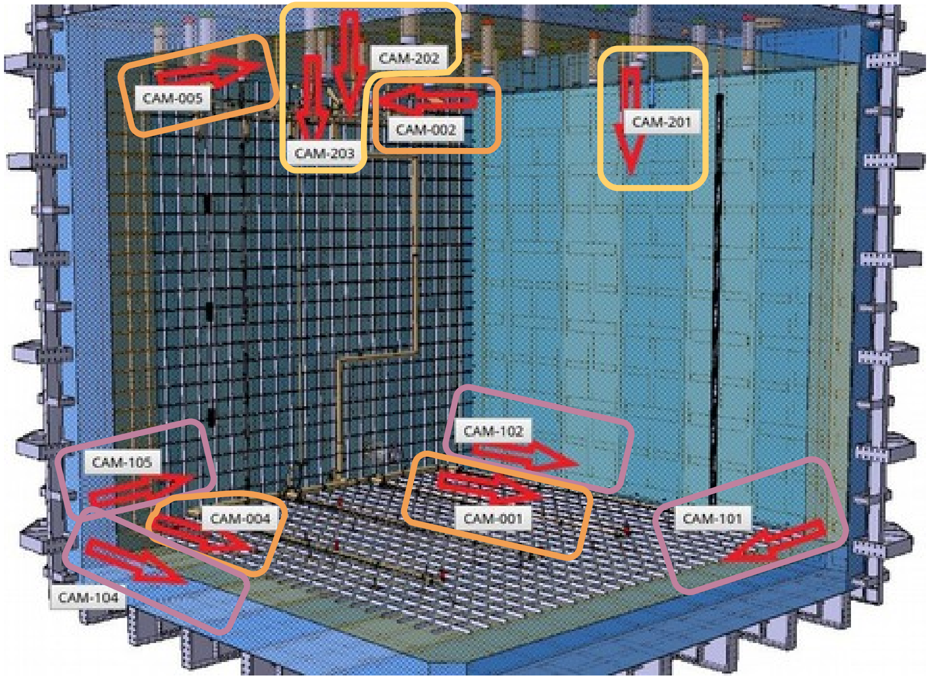

From HV Review Mechanical Design, Interfaces, and Installation 4 Jun 2019, 11:00
https://indico.cern.ch/event/813154/contributions/3403390/
(System as designed has safety factor 3.75 over the failure mode pictured.)

**Figure 8.** Photograph of a broken wire on the test setup. The wire was cut at its bottom attachment point and can easily be spotted because it is curling up and distorting the wire pattern. Note that only one plane of vertical wires is strung in this particular test.

From MicroBooNE camera paper
JINST 10 T08006 (2015)
(Image from camera test setup shown.)

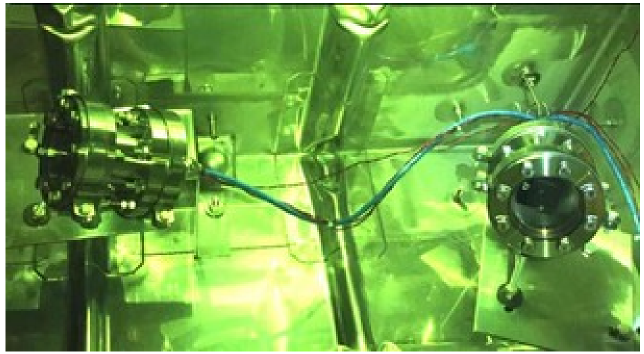
# ProtoDUNE experience

- 11 cameras deployed in ProtoDUNE–SP
  - 101, 102, 104, 105 use vacuum–tight enclosure (see Edgar's talks)
  - 001, 002, 004, 005 use acrylic enclosures (Bo)
  - 201, 202, 203 deployed in acrylic tubes from outside cryostat (Francesco)

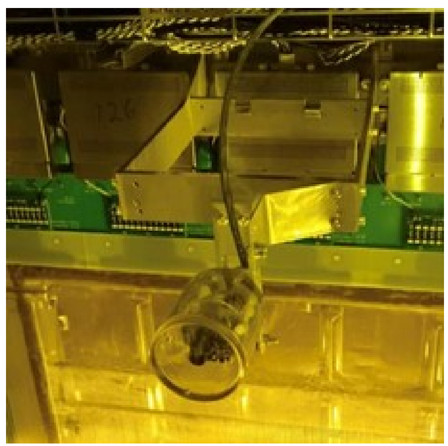


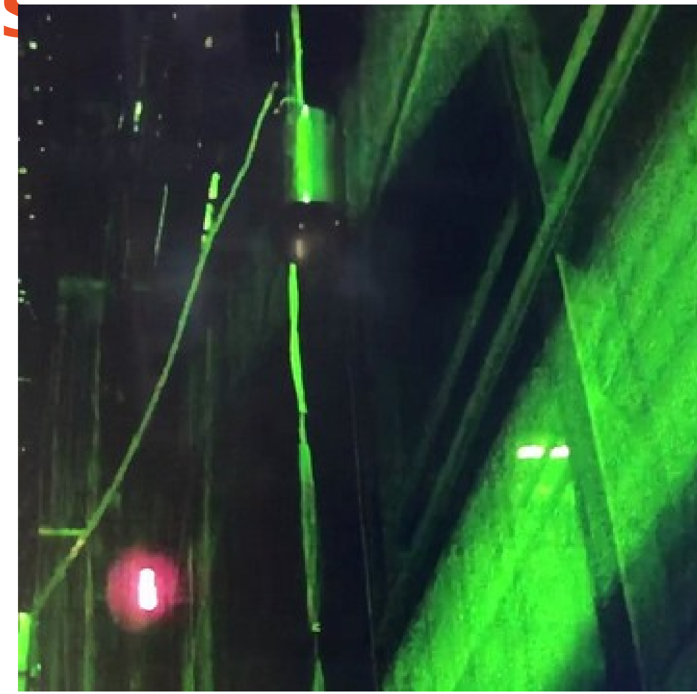
# ProtoDUNE fixed cameras

vacuum-
tight



acrylic

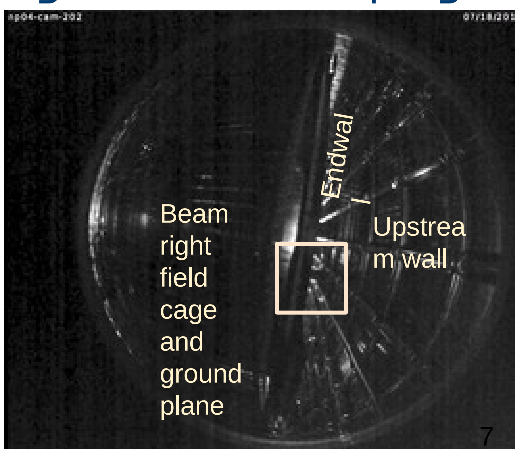




Part of a video from camera 105 showing purity monitor mounted outside the APA on the beam left side, ProtoDUNE-SP filled. (David Rivera PDSP elog 6303, 2018-09-15 03:01)

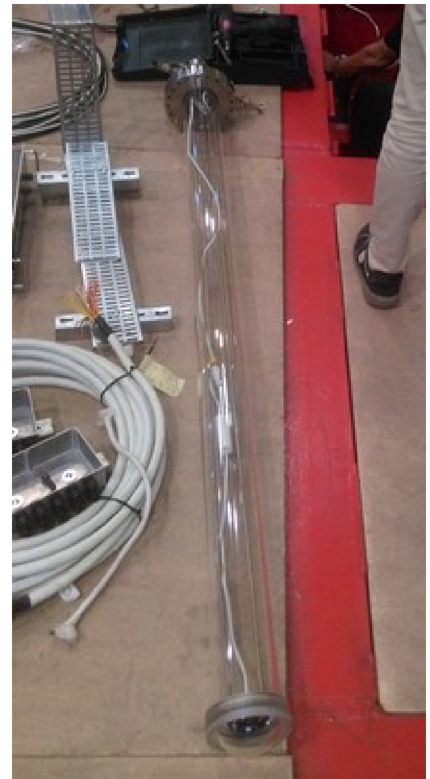
# ProtoDUNE removable cameras

Cameras 201, 202, and 203 are fisheye cameras installed in acrylic tubes that intrude into the cryostat from ports 14.2, 18.2, and 9.3 (resp.). **They can be removed and replaced without draining the detector.** Cam-202 is upstream beam right, near beam plug.





View from Cam-202 before filling



PDSP inspection camera in acrylic tube before installation

Photo of steel tube intrusion at bldg 182.

# Cameras – a question from LBNC review

**All camera designs appear to work in ProtoDUNE. How do you choose? (pg. 34) ProtoDUNE cameras worked. Why do we need R&D? (Table 11, item 10)**

▸ Fixed-position “cold cameras” at bottom must withstand twice the pressure and remain non-contaminating for ~30 times longer than the full ProtoDUNE run. ▸ The insertable inspection camera design is untested; a PD-SP acrylic intrusion had moisture freeze the camera in place in operation, although the idea seems sound. ▸ R&D is needed for cold camera design selection and inspection camera design testing.

# More comments and replies from LBNC review

pg 1-34 - line 16 - will you be able to see sub-mm resolution with them? what is the field of view?

- Yes, sub-mm in key places. FOV can be up to 90 x 120 degrees.

cameras section - identify a baseline version- all designs appear to work, so how do you choose between them to come to the final design

- Fixed-position “cold cameras” at bottom must withstand twice the pressure and remain non-contaminating for ~30 times longer than the full ProtoDUNE run.
- The insertable inspection camera design is untested; a PD-SP acrylic intrusion had condensation freeze inside it, although the idea seems sound, and indeed the camera was later removed successfully for replacement.
- R&D is needed for cold camera design selection and inspection camera design testing. This is still ongoing.

# Other useful presentations

- PD–SP camera + HV studies, R&D:
  https://indico.fnal.gov/event/19351/contribution/1/material/0/0.pdf
  https://indico.fnal.gov/event/19122/contribution/2
- PD–DP camera + CRP studies, R&D (D. Duchesneau):
  https://indico.fnal.gov/event/18681/session/15/contribution/75
- HV Systems Review, June 4, 2019, "Lessons Learned," "Mechanical Design and Interfaces," and "Electrical Design and Interfaces" talks.
  https://indico.cern.ch/event/813154/