DEEP UNDERGROUND NEUTRINO EXPERIMENT

CALCI CI WG meeting
09/04/2020

temperature sensors
Preparation for the May workshop

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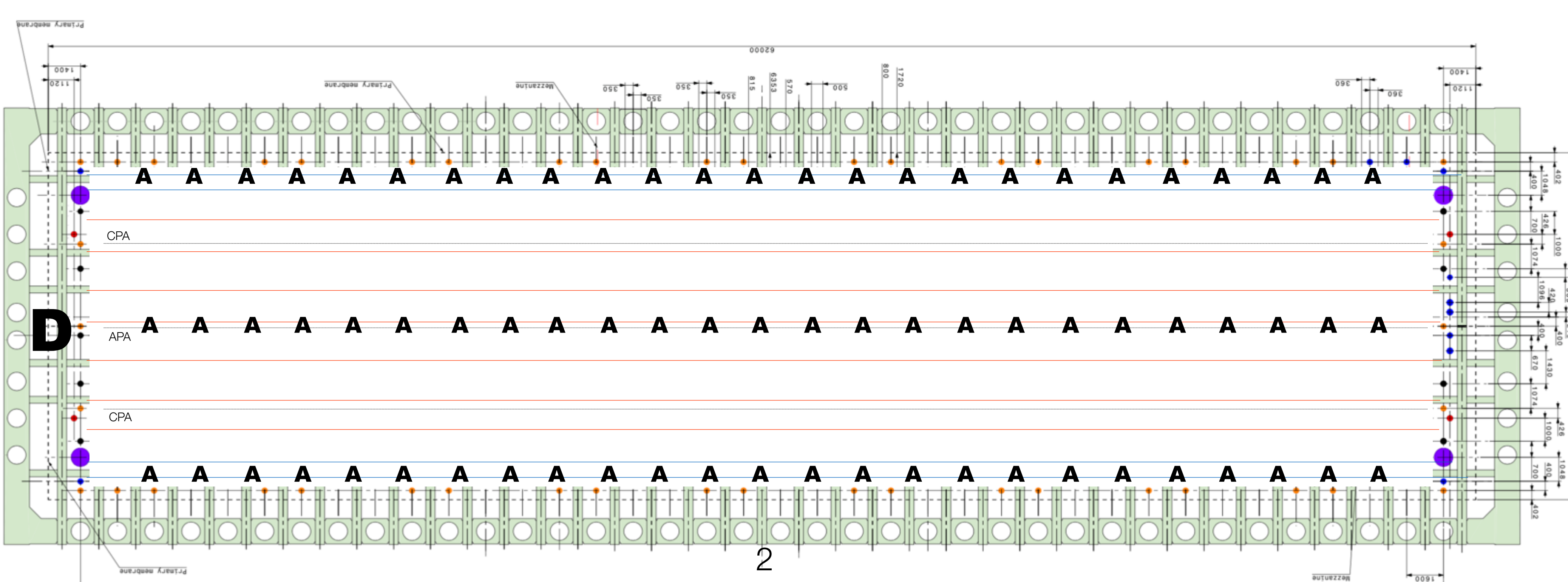
Vertical arrays

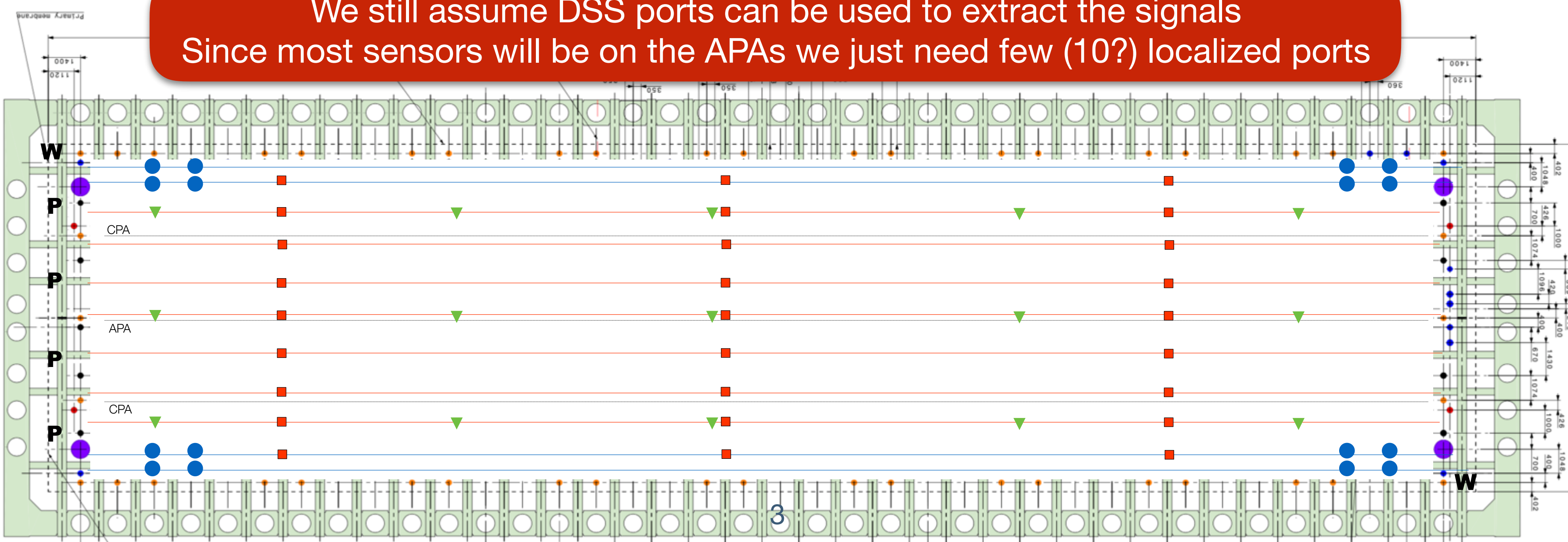
- **Sensors on APAs (A):**
  - 8 precision sensors in half of the APA doublets and 4 in the other half (452 in total), cross-calibrated in the laboratory. For 3D temp. maps
  - 4 standard sensors in half of the APAs, for APA frame T measurement
- **Dynamic T-Gradients (D):** A fix array of 48 sensors cross-calibrated with a movable set of 5 sensors. For 3D temperature maps



Other temperature sensors

- **LAr pumps (P) and inlets (●):** Important input for CFD simulations
- **Top GP sensors (■):** Several transverse arrays of sensors to better know what happens between two APA rows
- **Floor sensors (▼):** Standard sensors epoxied to the floor for detecting the presence of LAr when filling starts
- **Wall sensors (W):** Standard sensors to measure the vertical gradient of the cryostat membrane during cool-down

We still assume DSS ports can be used to extract the signals
Since most sensors will be on the APAs we just need few (10?) localized ports



The charge I

Review Committee Charge – Part I: The review committees are asked to look at each of the proposed systems and evaluate the following:

- Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role? (Cryogenic Instrumentation only)
- Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?
- Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?
- Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?
- Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?
- Does the functionality of the system justify its overall cost?

Question I

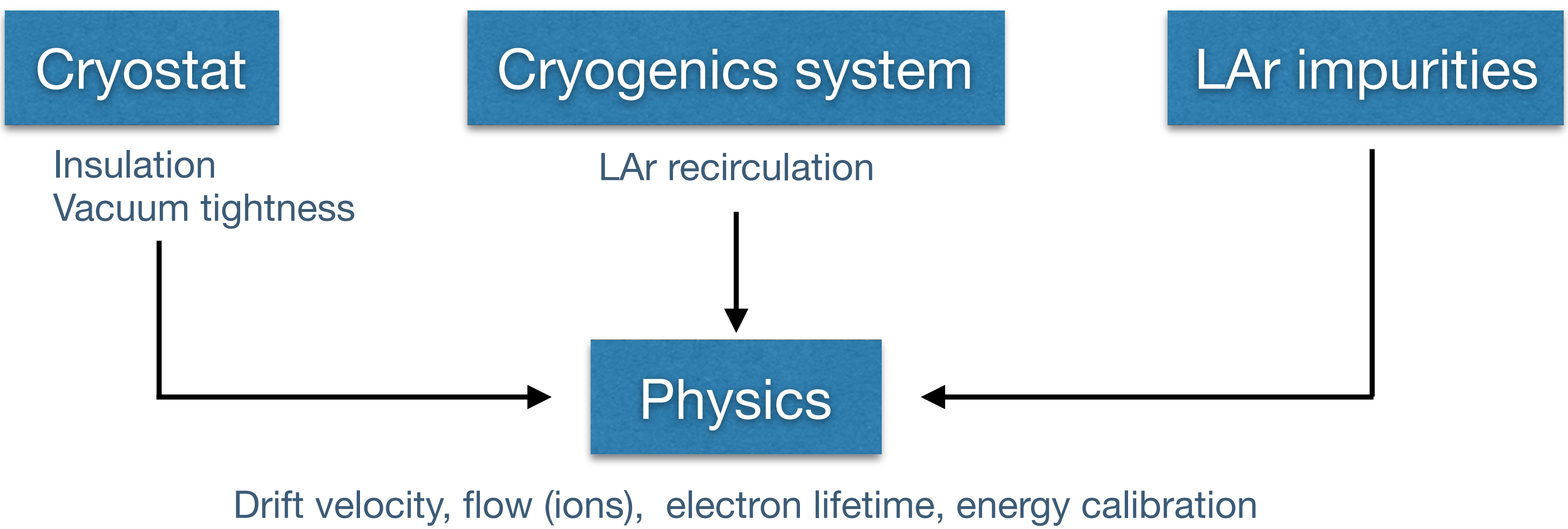
- **Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role? (Cryogenic Instrumentation only)**
- The first DUNE far detector module will use the largest cryostat ever built (20xProtoDUNE) for a TPC
- At least for this module a sufficiently dense 3D grid of temperature sensors should allow us to understand the behaviour of the system. A precision 3D temperature map will demonstrate that the cryostat and the cryogenics system are working well:
  - Incoming LAr temperature as expected in all inlets
  - LAr mixing as expected: gradients as expected everywhere

Minimum amount of system scope

- **Sensors on APAs:** difficult to establish a minimum, probably 4 sensors in vertical at 5 different locations along the cryostat could be sufficient to make sure the system is not malfunctioning
- **Dynamic T-Gradient**: essential to validate the calibration of all other systems at any time. One system is the minimum
- **Other sensors:**
  - **LAr inlets**: important to immediately detect an issue with the LAr delivered to the cryostat. **Two (for redundancy) in each side of each of the four pipes**
  - **LAr pump**: not essential for this purpose
  - **Ground planes**: not essential for this purpose
  - **Floor**: **15 sensors** (requested by cryogenics system)
  - **Wall**: **one every three corrugations (13) in two opposite corners** (requested by cryogenics system)

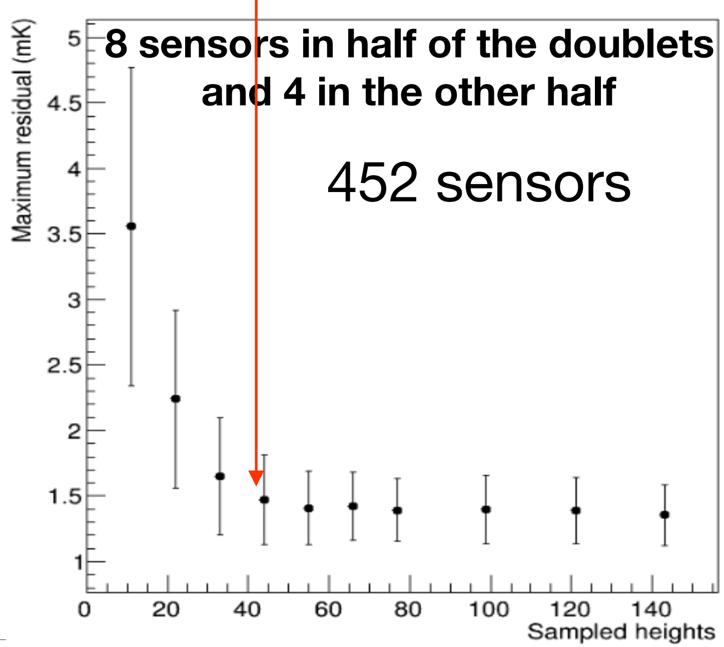
Question II

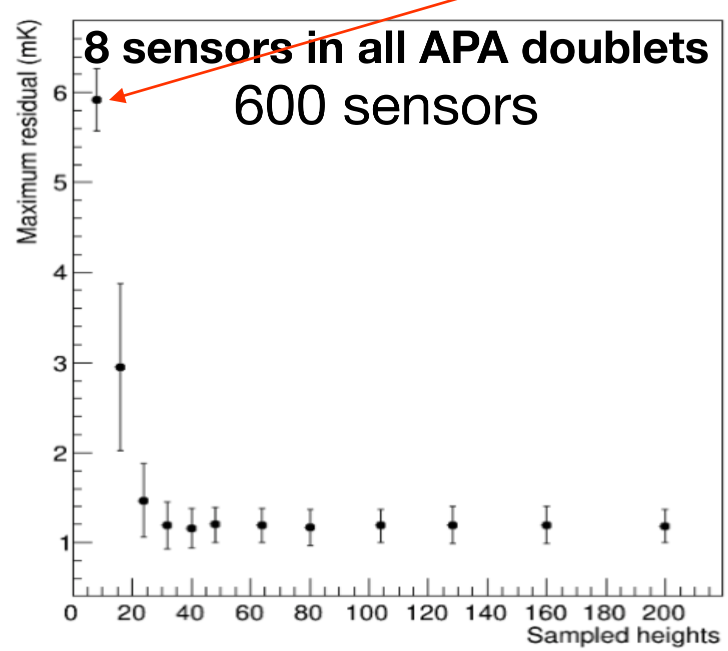
- **Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfil this role?**
- A sufficiently dense 3D grid of temperature sensors should allow us to ensure that lack of understanding of LAr velocity, density & purity does not compromise physics



Minimum amount of system scope

- **Sensors on APAs:** The current baseline (agreed with APA and PD consortia) assumes 8 sensors in half of the APA doublets and 4 in the other half. Less sensors do not simplify things !!!! Then the question is how many different configurations.
  - For the 8+4 configuration the FOM saturates a 40 different heights (FOM=1.5 mK). For 8 sensors that means **5 different configurations**
  - A single configuration (8 sampled heights) would have FOM>6 mK

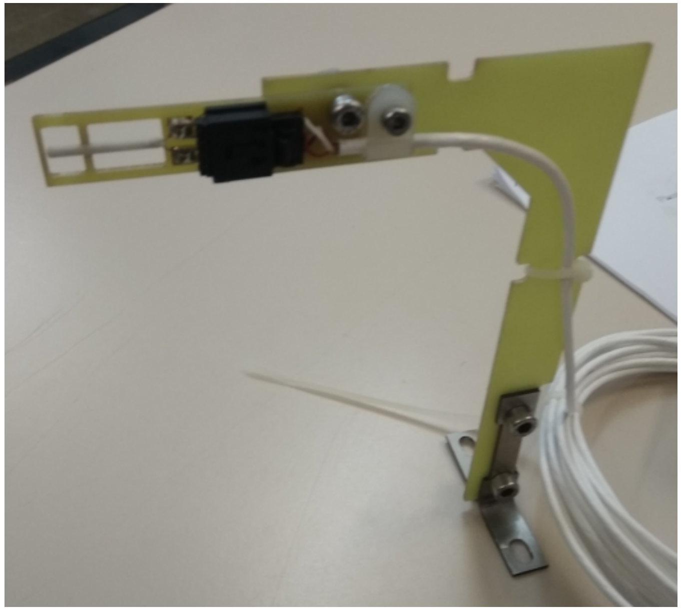




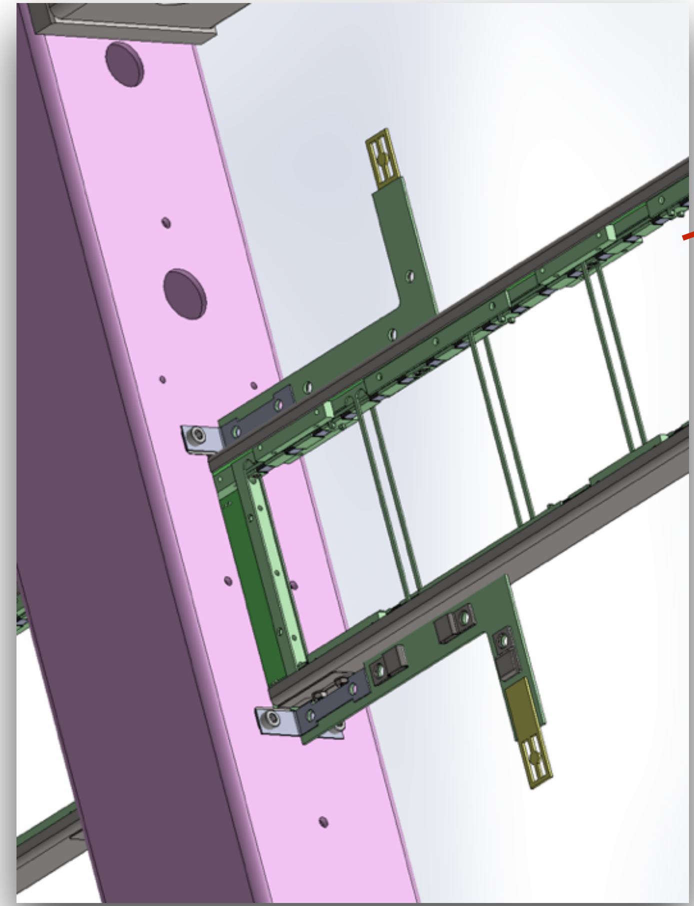
Sensors on APAs

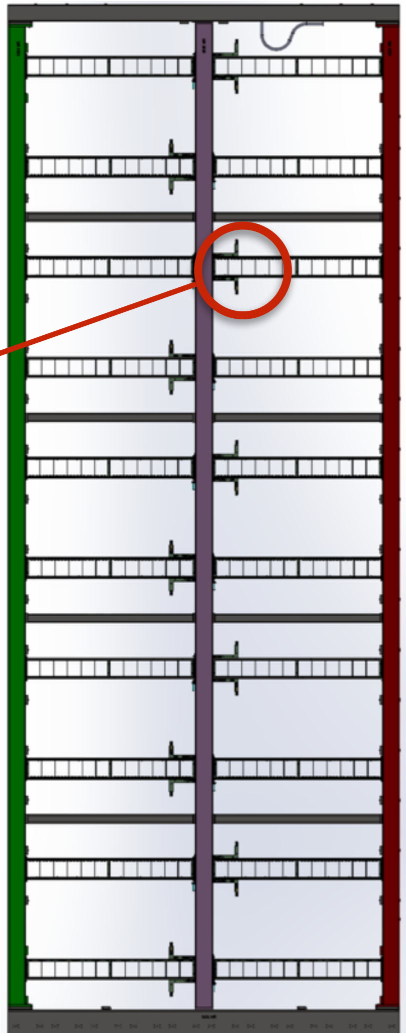
- Each APA will have only 4 of those sensors, uniformly spaced, but there are 20 possible anchoring points

Final design (J.V Civera), prototyped at IFIC



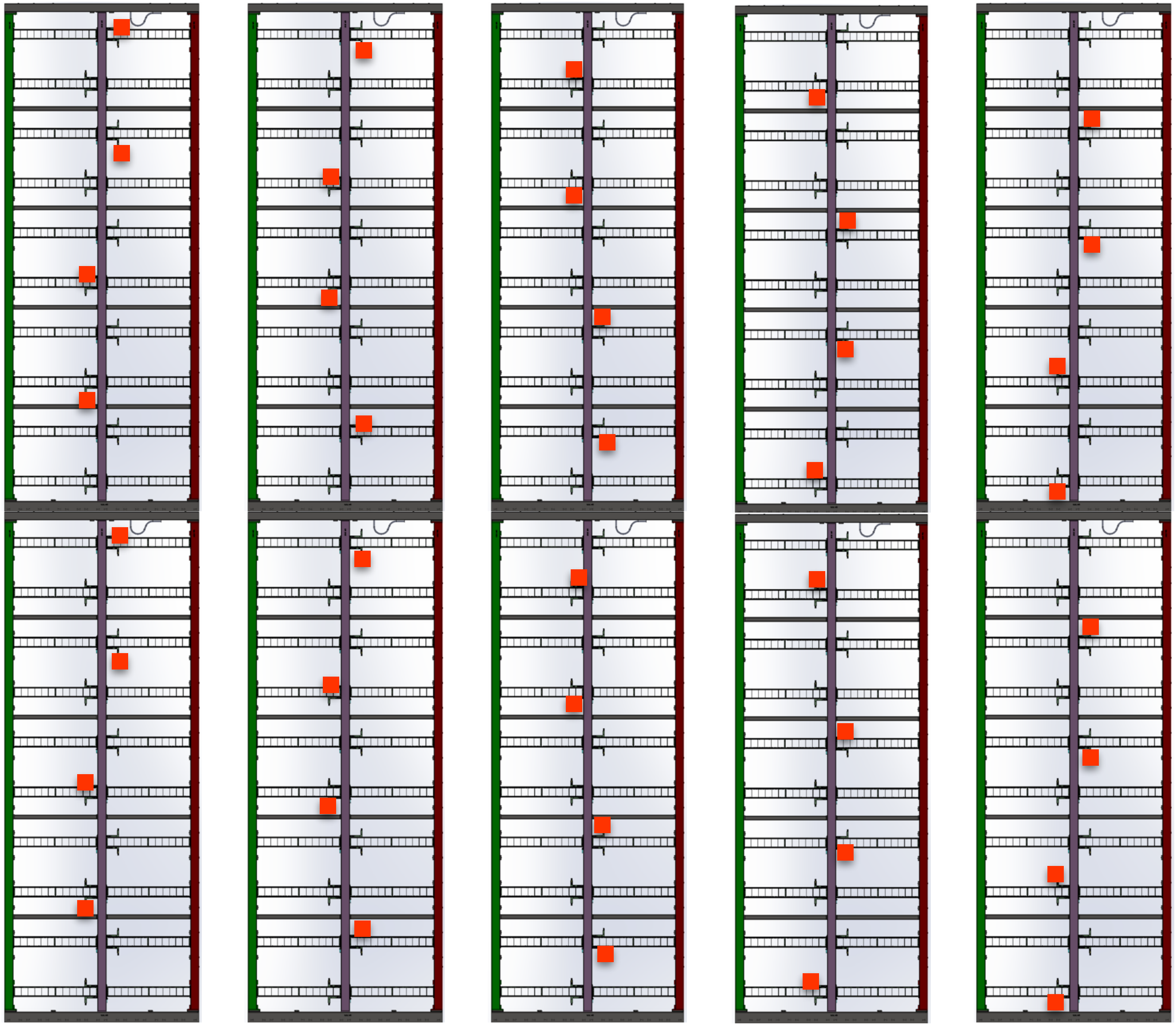
Initial design by D. Warner





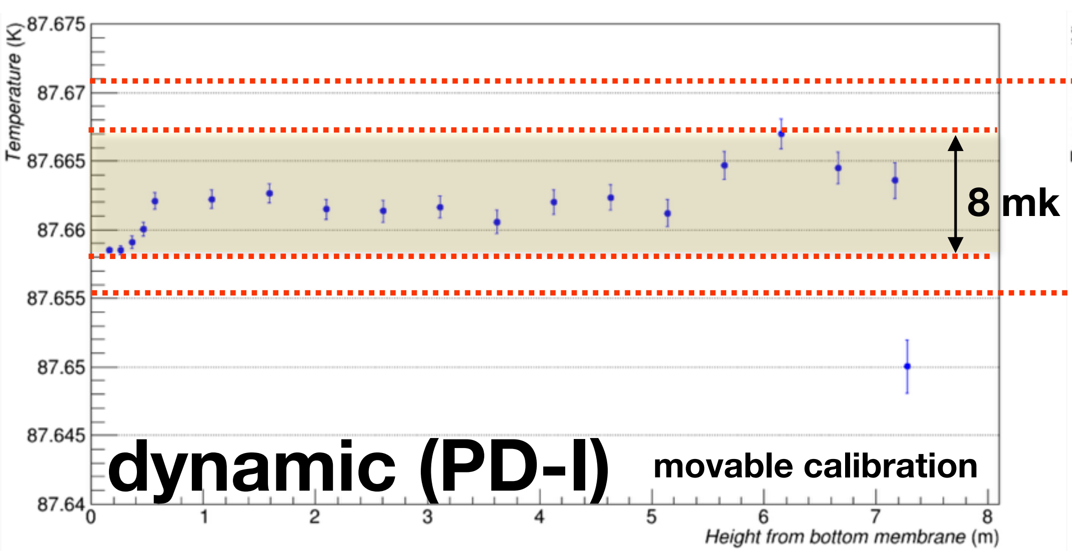
APA configurations

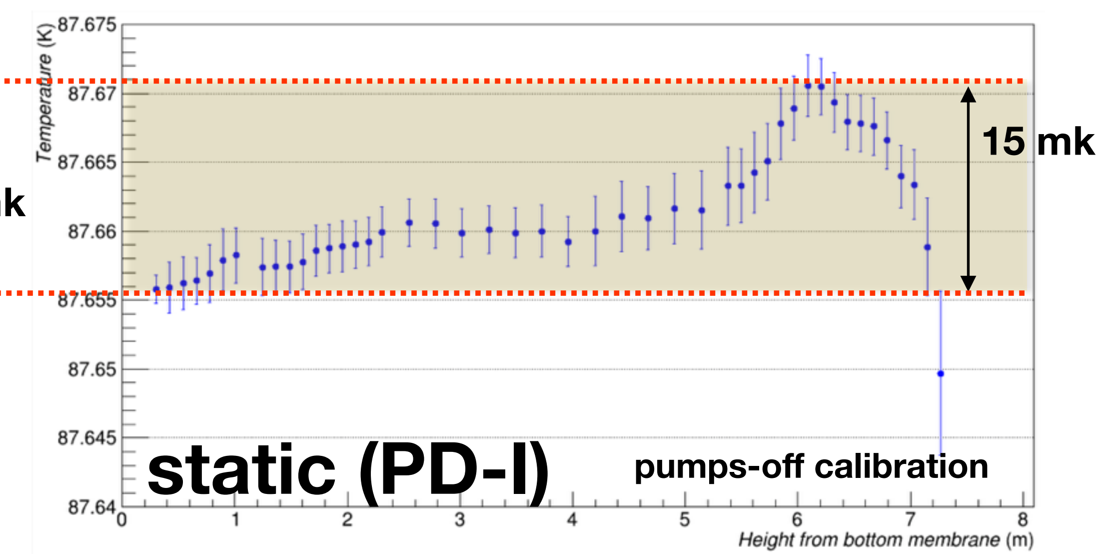
- 5 posible APA configurations (to be agreed with APA consortium)



Dynamic T-Gradient

- It has been used in PD-I to establish the overall scale insitu and to test the validity of other calibration methods (pumps-off and laboratory). This is the only system able to perform a model-independent insitu calibration.
    - Ideally one system in each side of the cryostat. Given the ports availability only one is foreseen
    - The number of sensors in the fix array could be debated. In PD-I it had 24 sensors, which it a bit at the limit to detect local variations. Since DUNE is double in height we estimate **48 sensors is the minimum**





Other sensors

- **LAr inlets**: a precious input for CFD simulations. **Two (for redundancy) in each side of each of the four pipes.** In PD-I, sensors at inlets are not at the right position.
- **LAr pump**: a precious input for CFD simulations. **Two (for redundancy) in each pump.** In PD-I there was no sensor at the pump
- **Ground planes**: At least **two sensors in each active volume at 3 different positions along the cryostat.** Important to have few points between APA rows.
- **Floor**: not needed for analysis
- **Wall**: not needed for analysis

Question III

- **Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?**
- **Sensors on APAs**: This is a new system. The largest issue is having different APA configurations. This poses some problems in terms of APA manufacturing and installation. Those issues are being discussed with the APA consortium. **Having a baseline distribution for the review would be desirable**
- **Other sensors:** sensors in pumps and LAr inlets are new. They will need a proper encapsulation to avoid detachment. **We need at least a conceptual design for the review, although a 3D model would be better**

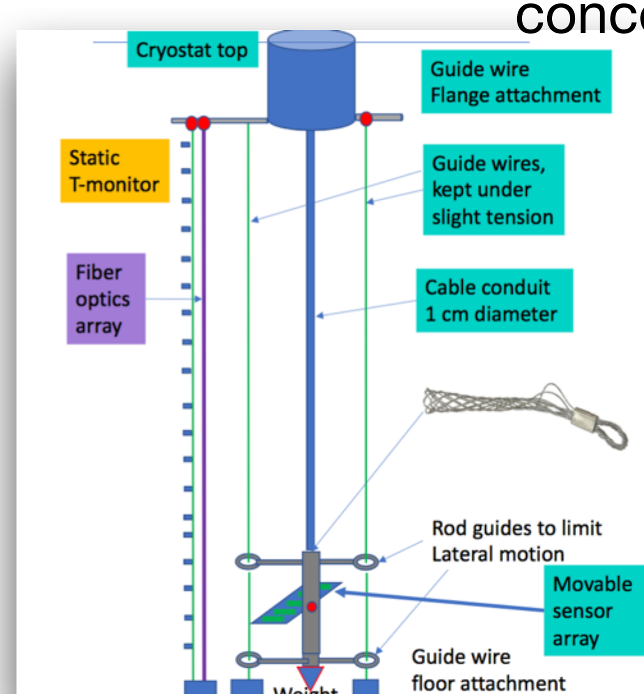
Dynamic T-Gradient

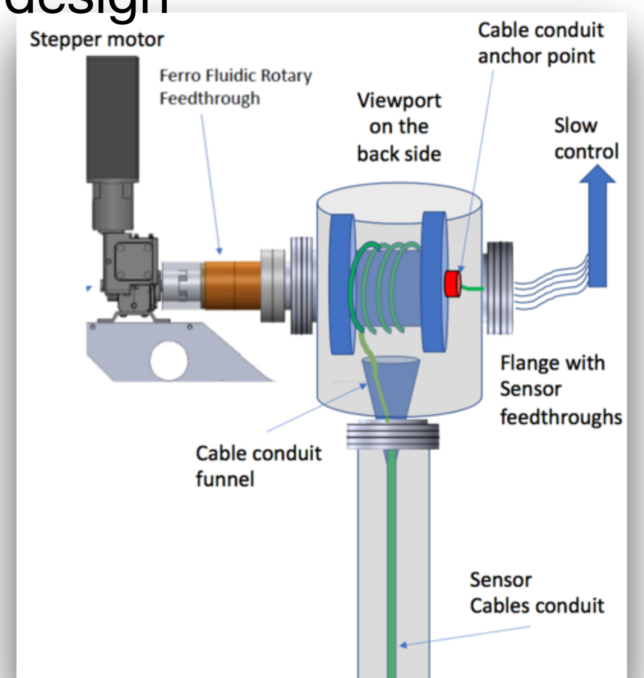
- **Dynamic T-Gradient:** The design is completely new, and resolves some issues raised at the previous review.

> **2019 review committee report**
> The in-situ calibration of the Dynamic T-Gradient sensors has been demonstrated in ProtoDUNE –SP. If such a monitor were to be deployed in DUNE several design changes are necessary including segmentation of the pieces due to limited overhead installation space and a re-designed viewport in light of the failure of the initial one installed.

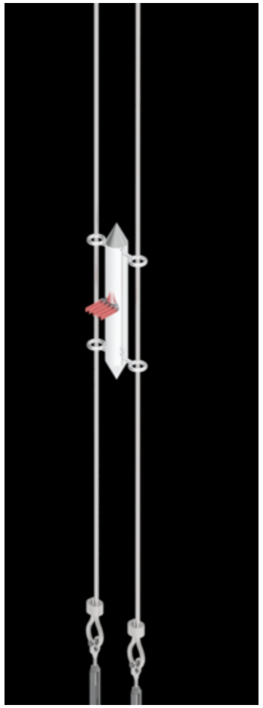
- **A more advanced 3D model for the review** addressing the movable system, potential swinging, etc, would be desirable

conceptual design





3D model



Question IV

- **Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?**

- **Sensors on APAs**: potential noise induced in cold electronics is the largest risk.
  - The risk is low: RTDs receive a **DC** current of **1 mA,** cables are shielded and properly grounded
  - Risk mitigation: only if problems arise
    - Reduce the live time: take measurements only few times a day
    - Disconnect from readout and ground them
  - Risk assessment:
    - Tests in ICEBERG, CERN coldbox and later in ProtoDUNE-SP II

- **Dynamic T-Gradient:** this is a movable system with potential risk related to mechanical stability and swinging. It is also important to address the vacuum tightness of the housing system and the robustness of the view port
  - A detailed 3D model is needed to understand how to solve the problem
  - It should be tested in PD-II and we should have a way for extrapolating to double height (intermediate anchoring point ?)
- **Other sensors**: Mostly for pumps and inlets.
  - The risk is related to potential detachment of the sensor given the proximity to a strong LAr flow
  - Risk mitigation: properly encapsulate the sensor. 3D model needed for the review
  - Risk assessment: the system will be tested in PD-II

Question V

- **Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?**
- **Sensors on APAs**: Each of the 4 APAs will be instrumented with 4 RTDs (2 are precision RTDs) cross-calibrated with all other sensors in the cryostat. Their temperature will be compared with those other sensors, some of them nearby. Also a comparison between pumps off and laboratory calibration will be done.
- **Dynamic T-gradient**: there is a plan to test the new design, which will have a lower calibration error. The dynamic calibration will be compared with pumps on/off calibration, laboratory calibration and sensors in nearby APA. Its performance depends only on the ref. sensor position accuracy
- **Other sensors**: Sensors near LAr pump and directly exposed to incoming LAr will be installed in PD-II. This will be precious information to further advance with CFD simulations. For redundancy, two contiguous sensors will be installed at each of those five locations. Comparison between pumps on and pumps off is a crucial tool in this case

Question VI

- **Does the functionality of the system justify its overall cost?**
- The system is not expensive

Only M&S

	# sensors	cost/sensor	common	TOTAL
sensors in APAs	452	140	10000	73280
dynamic T-gradient	48	140	20000	26720
sensors in LAr inlets	16	140	5000	7240
sensors in pumps	8	140	2000	3120
sensors in GPs	27	140	2000	5780
wall sensors	26	15	1200	1590
floor sensors	15	30	3000	3450
readout	592	8	10000	14736
TOTAL				**135916**

The charge II

Review Committee Charge – Part II: Based on their evaluations of the individual systems, the review committees are asked to classify each of the proposed systems in terms of the following categorizations:

1. Essential – Experiment should not be run without this system in place.
2. Highly-desirable – Strong justification for including this system but not viewed as absolutely necessary.
3. Advantageous – Good arguments exist for why this system might be useful but not fully justified in terms of its contribution to overall detector performance.
4. Debatable – System could potentially be useful but not fully supportable based on current arguments.

- **Sensors on APAs**: Some distribution of precision sensors along the height and length of the cryostat is **essential.**
- **Dynamic T-Gradient: essential** for a model independent in-situ calibration giving a reference for all other sensors
- **Other sensors**:
  - **LAr inlets**: **essential** to immediately detect cryogenics system malfunctioning
  - **LAr pumps**: **highly-desirable** as input/cross-check for CFD simulations
  - **Ground planes**: **highly-desirable** to reduce extrapolation error to region between two APA rows
  - **Floor**: **essential** to detect the presence of LAr when filling starts (probably the more inexpensive way)
  - **Wall**: **essential** to measure the cryostat membrane temperature during cooling down and filling