The Temperature Monitoring System for the Phase-I DUNE Far Detector Modules

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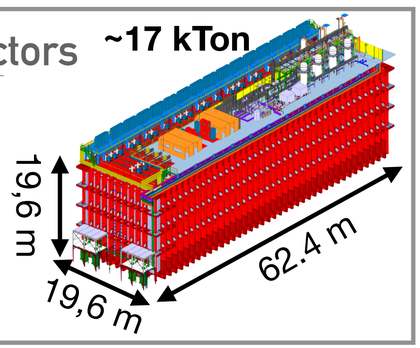
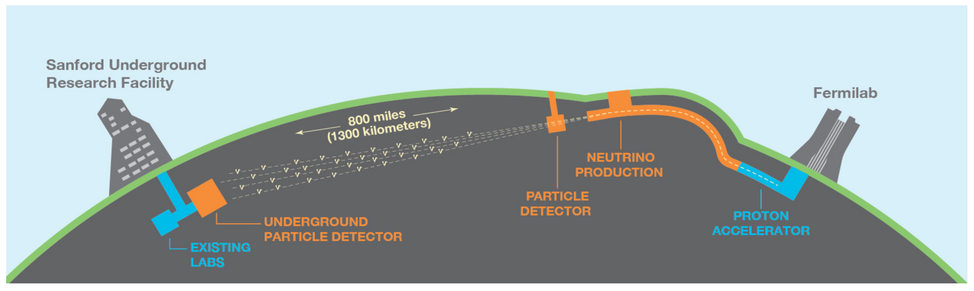
The ***Deep Underground Neutrino Experiment*** (DUNE) is an on-axis long-baseline accelerator-based ***neutrino oscillation experiment*** with the most powerful neutrino beam to date, *starting operation on 2029*.

DUNE Far Detectors

For the ***Phase-I two*** of the four ***FD-modules***, a Near Detector (ND) and a 1.2 MW neutrino beam will be installed.



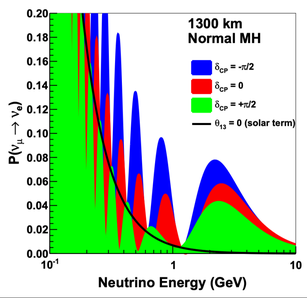


A 2.4 GeV average muon neutrino beam is sent from Fermilab to SURF (South Dakota), 1300 km away.

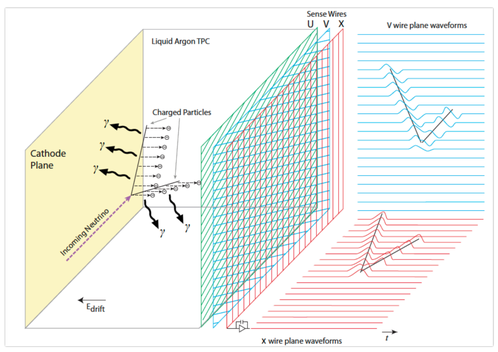
DUNE Physics Goals

DUNE aims at a precision measurement of the ***oscillation parameters***, ***proton decay*** searches and ***neutrino astrophysics***.

- DUNE has been designed to have ***unprecedented resolution to*** δ_{CP}
- DUNE will be also leading the determination of the θ_{23} octant and will resolve the ***mass hierarchy***.



DUNE FD Technology: Liquid Argon Time Projection Chamber (LArTPC)



TPC operating principle

Liquid Argon (LAr) is used as ***target and detector material*** since it has higher density than water, large ionisation and scintillation capabilities and is relatively cheap.

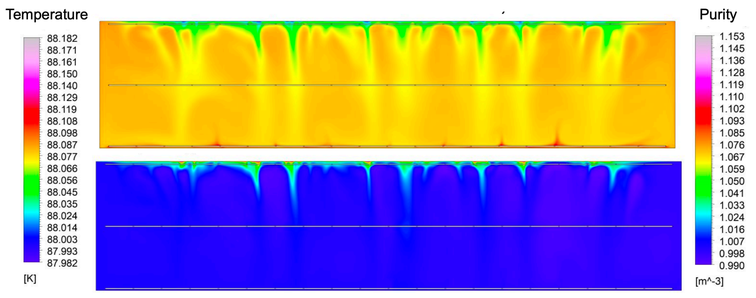
The base technology of the Phase-I DUNE FD Modules is the ***Liquid Argon Time Projection Chamber*** *(LArTPC)*.

- **Ionisation electrons** produced by traversing charge particles drift towards the anode and produce a **3D image** (*3rd coordinate given by drift time*).
- A ***very high LAr purity*** is key to avoid absorption of those electrons in their way to the anode.
- A dedicated ***recirculation system*** purifies the LAr, resulting in a high ***correlation between concentration of impurities and temperature***.

Motivation for Monitoring Temperature

The ***Temperature Monitoring System*** (TMS) is designed to resolve the temperature map:

- When stationary conditions are reached, ***impurities*** concentration and ***temperature*** become ***very stable*** over time. The expected ***vertical gradient*** is about ***15 mK***.
- A precision on the temperature measurement better than 5 mK is needed to **determine the impurities concentration based on CFD simulations**.
- The TMS, providing a 3D temperature map every 3 seconds, can immediately detect any ***failure of the recirculation system***.



CFD simulation at the stationary regime at x=0 m

Required precision on the temperature map for different values of the normalised impurity range and electron lifetime.

ΔI_{max} (%)	τ_0^t (ms)	σ_T (mK)
1	3	6.5
	10	-
	100	-
2	3	3.3
	10	11
	100	-
5	3	1.3
	10	4.3
	100	-

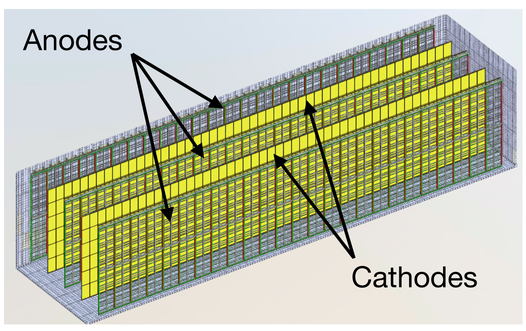
$$\sigma_T\,(mK) < \frac{\tau_0^t(ms)}{2.3}$$

In the ***worst scenario*** of 5% impurity variation and 3 ms electron lifetime, the ***required precision*** on the temperature map is ***1.3 mK***.

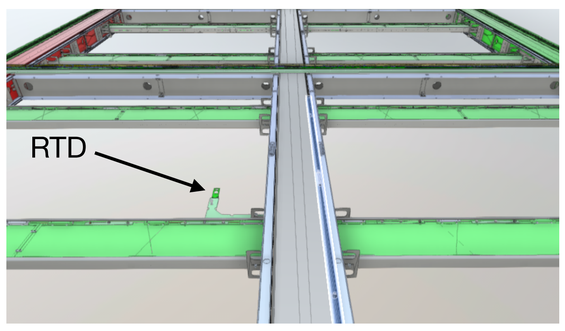
Far Detector I: RTD-based TMS

The ***DUNE FD-I*** will be a ***Horizontal Drift*** (HD) TPC:

- 150 Anode Plane Assemblies (APA) constitute the three ***Anode Planes***.
- 100 Cathode Plane Assemblies (CPA) constitute the two ***Cathode Planes***.



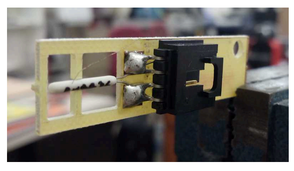
600 Resistance Temperature Detectors (RTD) are installed on the APAs, covering the entire active volume.



A sensor installed on one APA. There are 4 RTDs installed on each APA.

RTD measurement technique

- RTDs are ***Pt-100*** temperature sensors fed in series with a 1 mA current.
- The voltage drop is measured using the 4-wire termination.
- The signal is ***multiplexed*** and digitised through a 24 bits Analog to Digital Converter (ADC), with 1 V dynamic range.

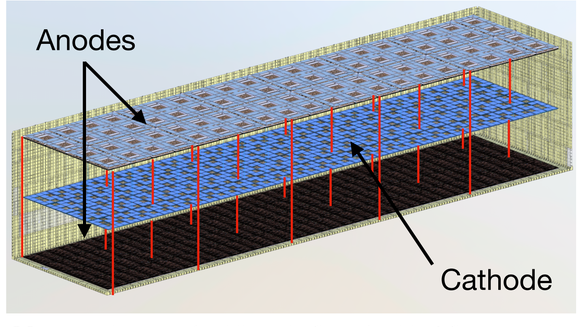


RTD sensor for the HD prototype at CERN

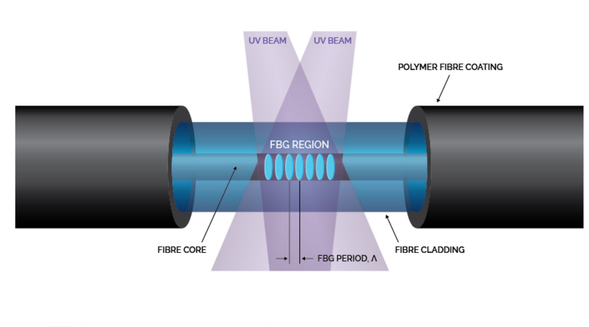
Far Detector II: FBG-based TMS

The ***DUNE FD-II*** will be a ***Vertical Drift*** (VD) TPC:

- Two planes of ***Perforated Anode PCBs*** form the two anodes at 300,000 kV
- A ***cathode*** containing the Photon Detection System is interleaved at ~6 m.



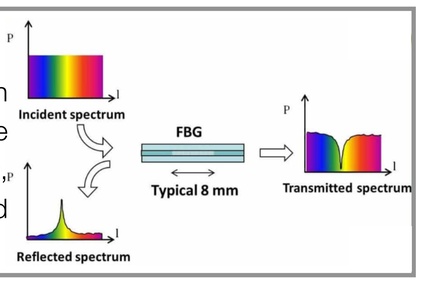
20 vertical arrays (red lines in figure) with 4 fibres each, containing 30 FBGs per fibre (2400 sensing points in total) will de deployed.



FBG sensors are refractive index modulations creating a repeating pattern in the fibre core.

FBG Interrogation Technique

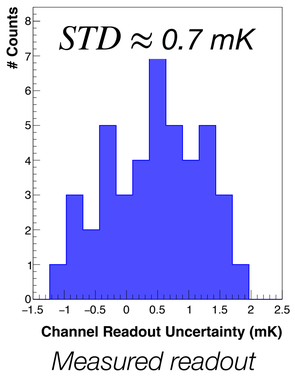
An ***interrogator*** sends IR laser light with different wavelength (WL) to each FBG. The ***reflected light*** is analysed by the same device. The ***displacement in WL*** depends on temperature, humidity and strain, at each FBG. By keeping humidity and strain under control, **temperature** can be inferred.



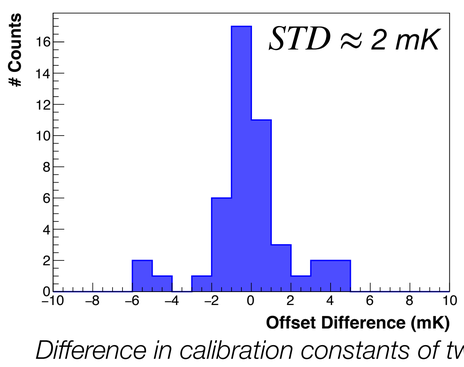
Relative Calibration Results

159 RTDs have been successfully installed in ***ProtoDUNE-HD***:

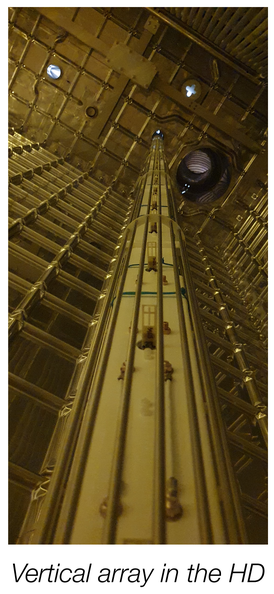
- A vertical array with 48 sensors allows to resolve the vertical temperature gradient with a precision of ***~2 mK***.
- Sensors at other locations measure key inputs for CFD simulations: inlets, outlet, ullage…



Measured readout uncertainty.



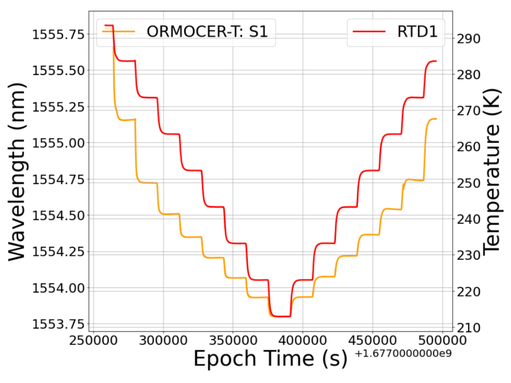
Difference in calibration constants of two independent calibrations of the vertical array.



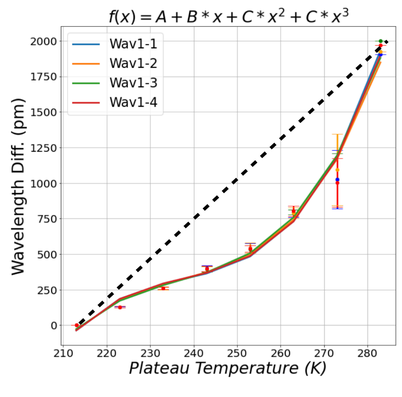
Vertical array in the HD prototype a CERN

R&D Status & Current Achievements

The resolution of the interrogator is ***~30 fm***, meaning that to achieve the required ***< 5 mK*** temperature precision, FBG sensors must have a **sensitivity** better than **6 *pm/K***.



Calibration run under a controlled atmosphere, in a climatic chamber at IFIC.



The sensitivity is presented as the mean over the temperature range (dotted line).

$$\frac{\Delta\lambda}{\Delta T} \approx 13\ pm/K$$

Bibliography