A light & charge readout technology for low-energy physics in DUNE Far Detector

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Photo: The empty interior of ProtoDUNE. Source: CERN

The DUNE Experiment

Object of Study

- (mainly) Neutrinos

Light Leptons with small mass, 2nd most abundant particle in the universe and interact very weakly

- Neutrino sources that DUNE will probe: "artificial" neutrinos from accelerator, solar neutrinos, C.C. Supernovae neutrinos

Scientific Motivation

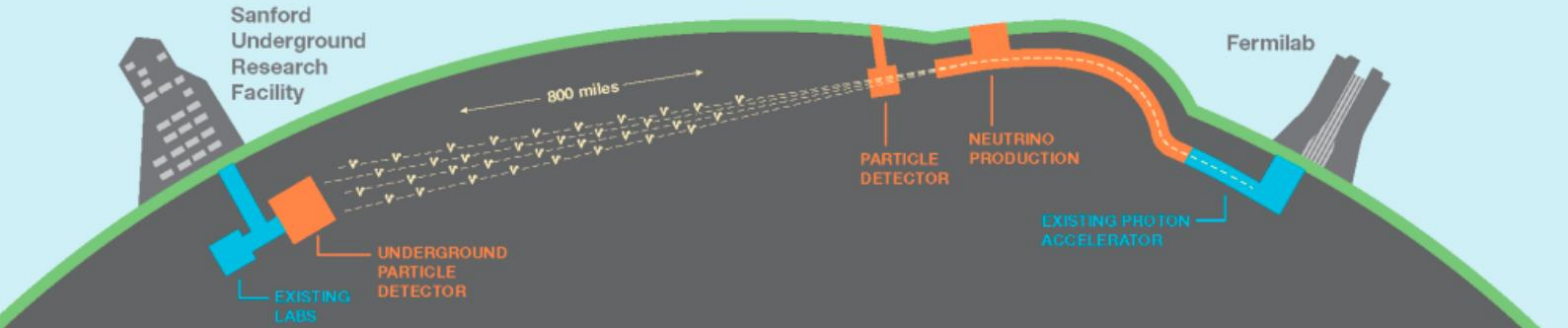
- Origin of matter-antimatter asymmetry
- Neutrino Mass Hierarchy Problem
- Proton Decay
- Observation of Core Collapse Supernovae
- and more…

The People of DUNE

> 1000 Collaborators
> 200 institutions
> 30 countries

Technologies

- High intensity neutrino source generated from MW proton accelerator at Fermilab
- Composite argon-based Near Detector (ND) downstream of the neutrino source
- Massive Far Detector 1.5 km underground, 1300 km downstream of the neutrino source with an active fiducial mass of 40 kt of liquid argon

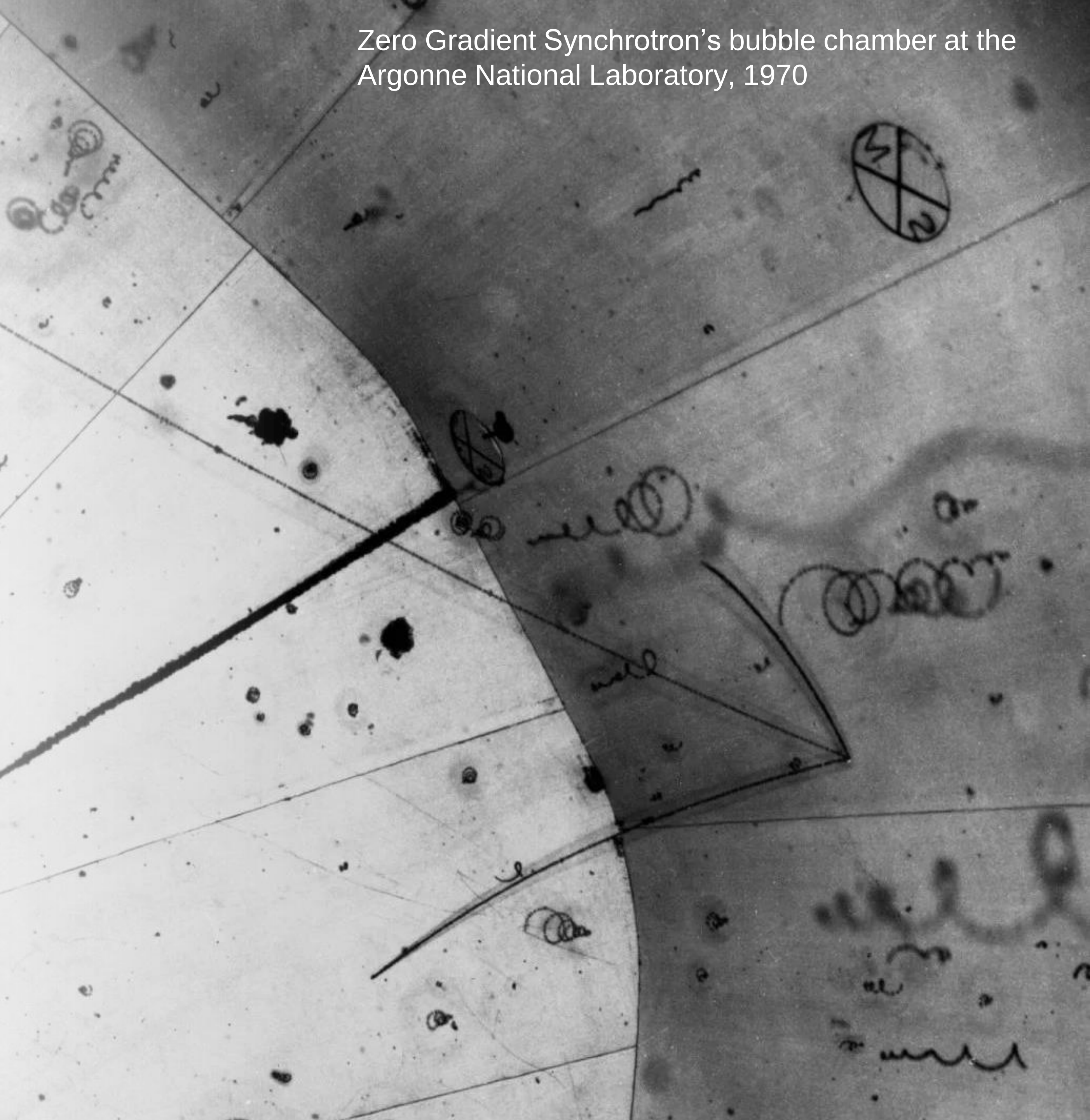


Neutrinos

- Lightest particle known (with mass)
- No Electrical or Color Charge
- Only interacts via Weak Force
- Exists in three flavours

Known sources:

1. Nuclear Reaction in the Sun
2. Cosmic Rays interacting with Earth’s Atmosphere
3. The Earth itself
4. Nuclear Reactors (anti-neutrinos)
5. Core Collapse Supernovae
6. “The Big Bang” (Relic Neutrinos)



Zero Gradient Synchrotron’s bubble chamber at the Argonne National Laboratory, 1970

Known and Unknown Facts about Neutrinos

We know that they oscillate

We know that they could violate CP

δ_{CP} Value
We don't know if it's actually there and if it is enough to explain matter-antimatter asymmetry

We know that they have mass

We know that two mass species have similar mass

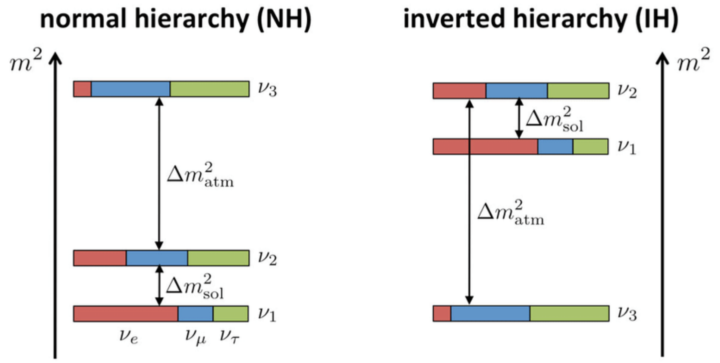
We don't know their mass

Hierarchy Problem
We don't know if the «outcast» mass is higher or lower than the other two

Dirac or Majorana
We don't know how they gain mass

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

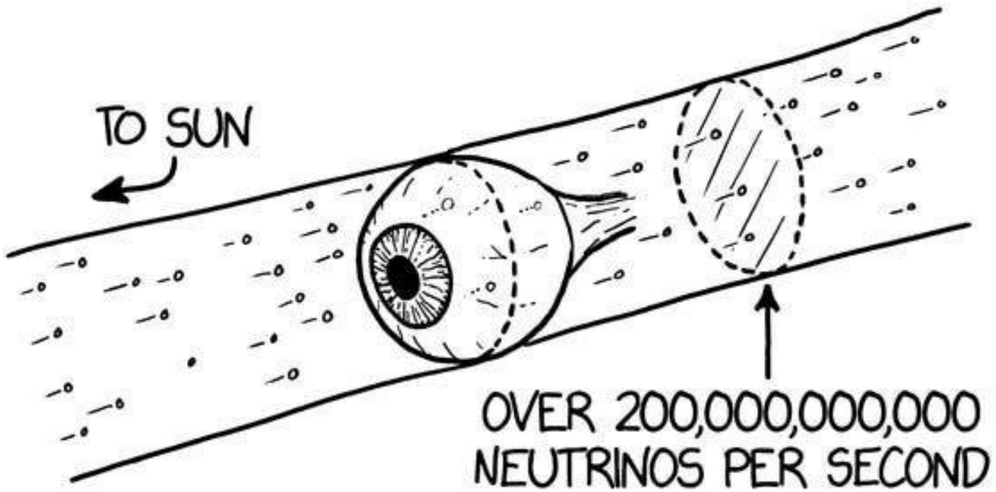


Why study neutrinos?

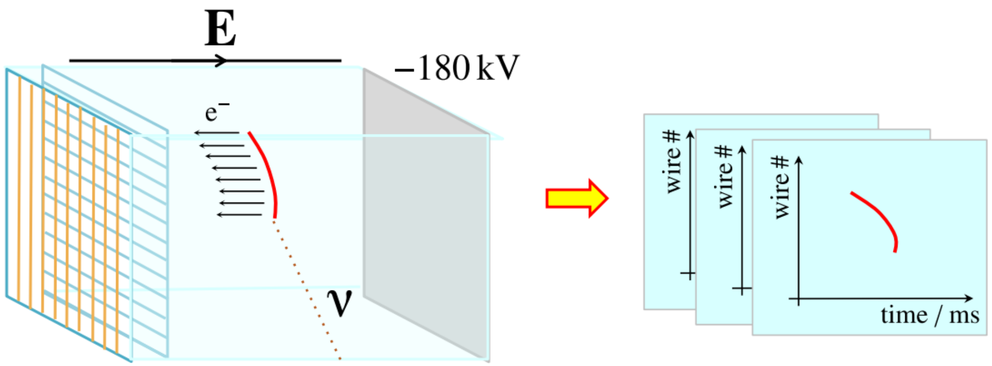
- They may reveal the cause of the matter-antimatter asymmetry (CPV in the leptonic sector)
- They can be used to probe core collapse supernovae and the formation of a neutron star / black hole
- They can enrich our comprehension of stars and nuclear reaction in stars
- They can allow us to see the universe before the last scattering surface
- They can be used to probe the Earth's interior

But also: any experiment sensible enough to detect neutrinos can also look for…

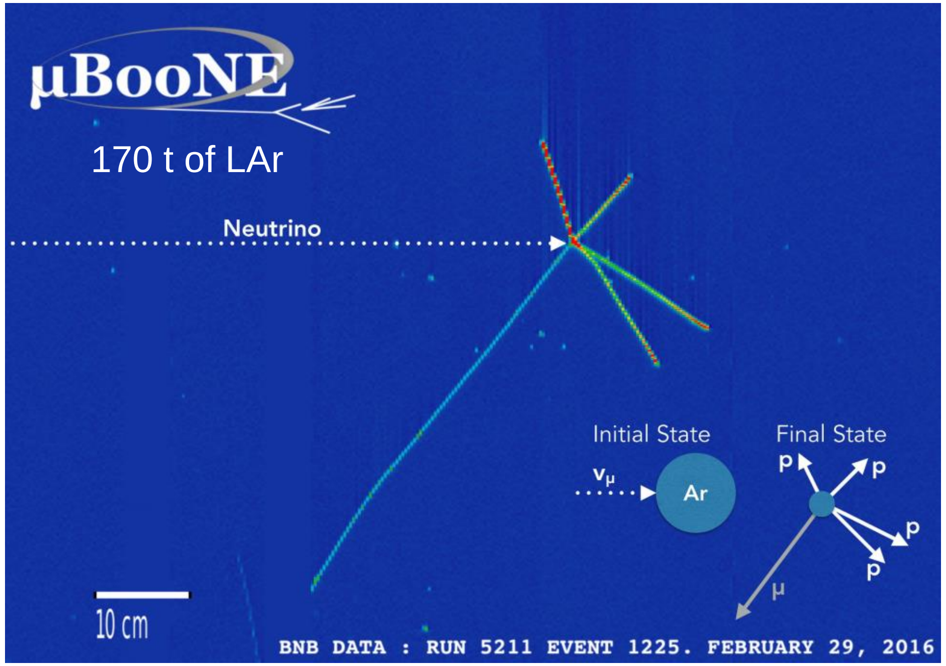
- Proton Decay
- Dark Matter
- Many more BSM Processes



Liquid Argon TPCs: an excellent choice



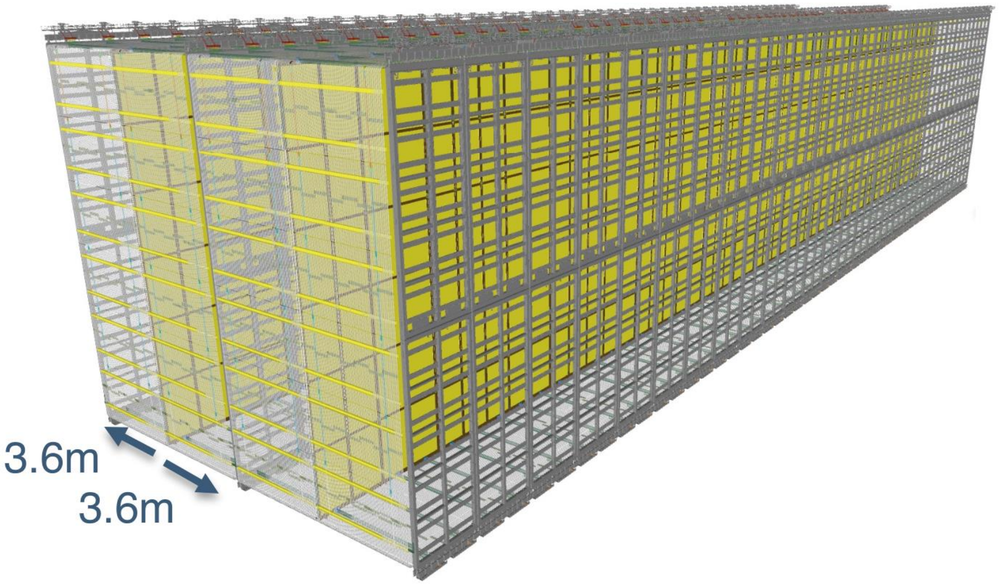
- Physical events in argon produce ionization, and scintillation with powerful PSD «compliant» characteristics
- Scintillation (128 nm) is detected by photosensors (SiPMs in DUNE)
- Ionization electrons are drifted with an electric field to a collection region
  - They can be collected by either anodic wires (as in pictures), converted to light in gas argon (dual phase tpc), collected by charge pads…
- Can achieve excellent track reconstruction and energy measurement (fully active calorimeter)
- Particle ID by: dE/dx, Argon Scintillation, Range, Topology…



Dune Far Detector

The first phase of Dune (Phase I) will see the construction of two (out of four) modules with 17kt of Lar each, the biggest LAr TPCs ever built

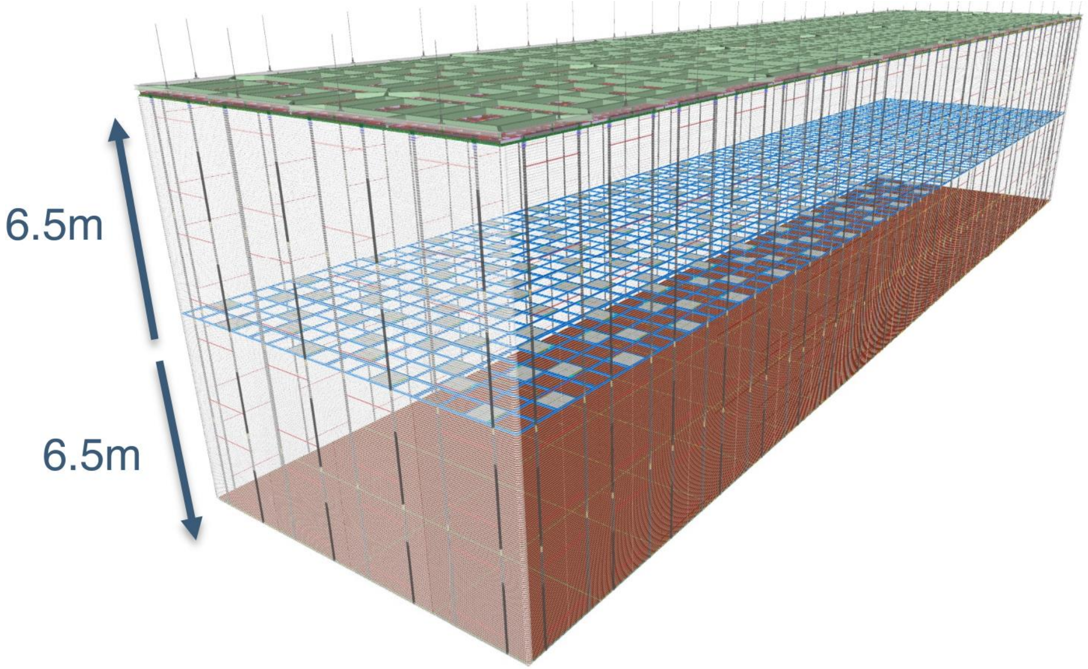
Horizontal Drift



TPC Size: (12 m) x (14 m) x (58.2 m)
Charge redout with APAs (Anode Plane Assemblies):

- Each plane has 1 collection wire plane and 2 induction wire planes at different angles
- Sub-cm granularity

Vertical Drift



TPC Size: Same as HD
Charge redout with CRPs (Charge Readout Planes):

- Central Cathode suspended
- SiPMs PhotoDetectors on cathode and walls

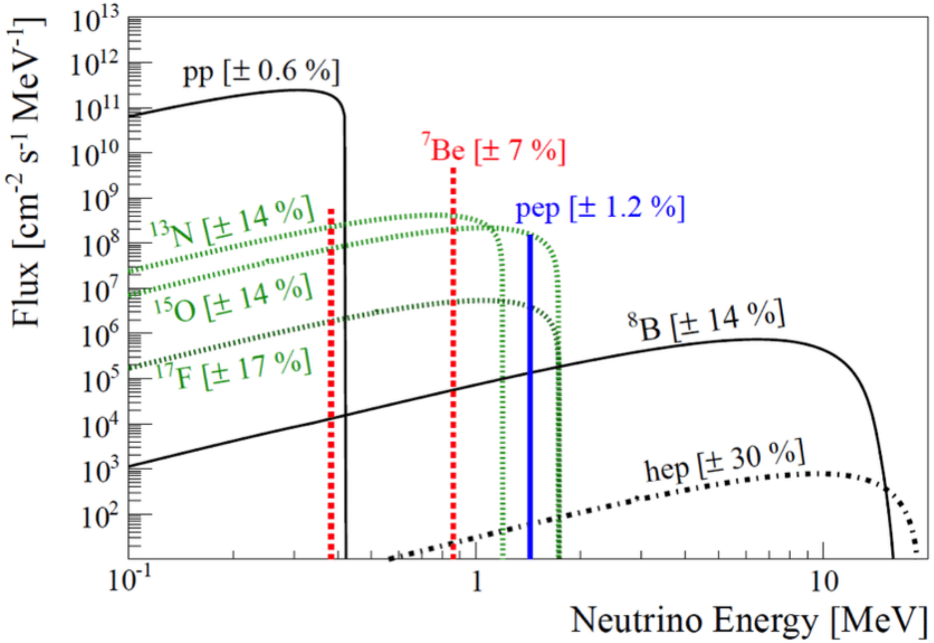
Photon detection system: Both detectors will use the X-Arapuca technology (with different geometries / form factors)

Dune Far Detector: Modules of Opportunity

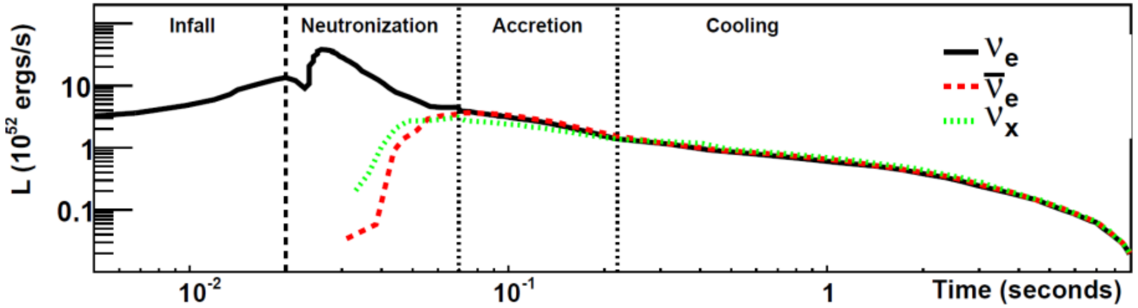
The DUNE Collaboration invites the broader particle physics community to participate in this OPEN WORKSHOP (DUNE collaboration membership not required) to explore options for expanded physics opportunities and novel detector technologies for these "modules of opportunity" that will be part of DUNE's Phase II. The meeting will address how to improve the DUNE's primary physics program and how to broaden the physics scope of the experiment.

Low Energy SM *ν* Physics in DUNE Phase-2

Two fields of low energy research…



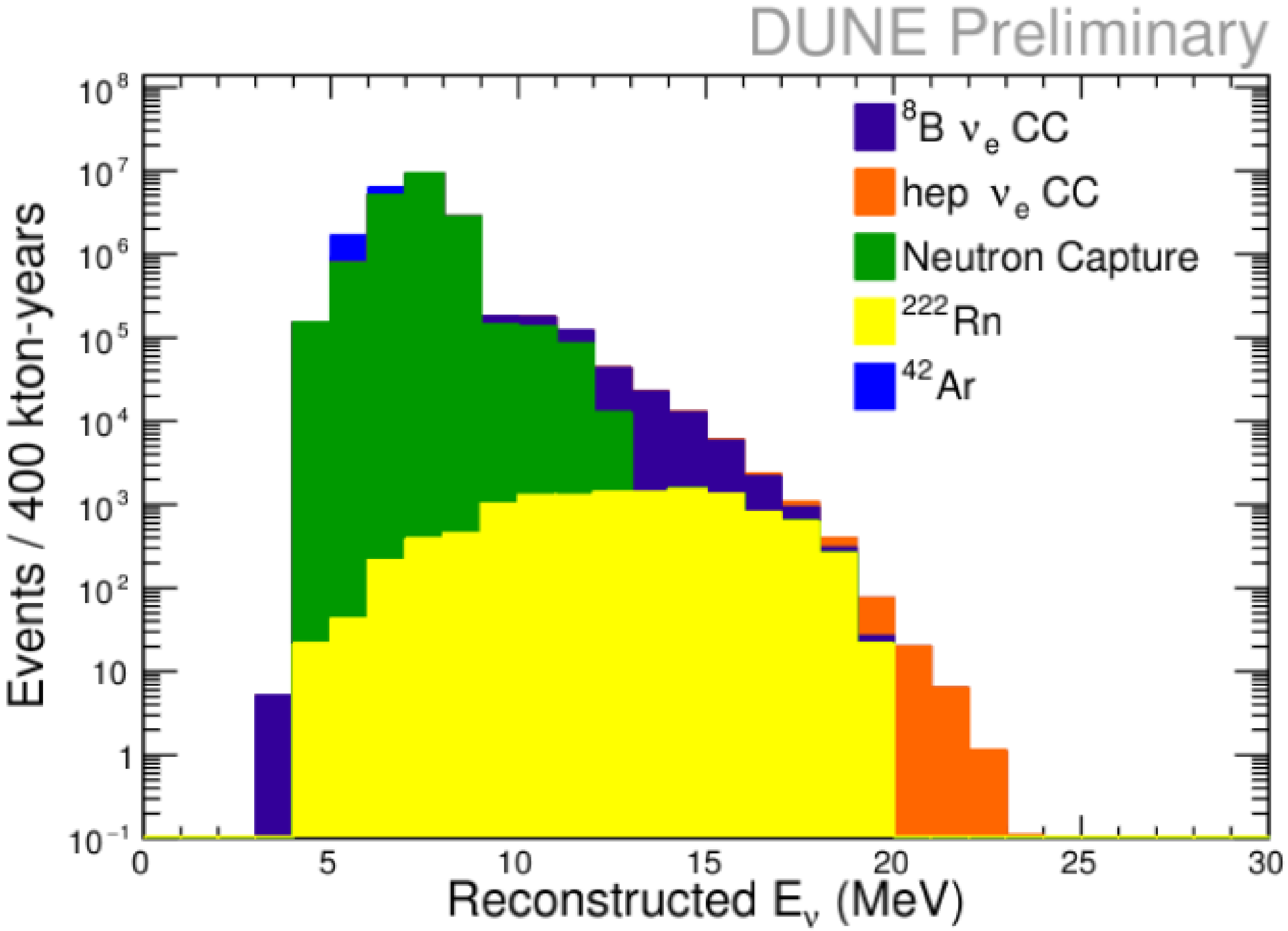
Solar Neutrinos:
hep (3He + p –> e+ + ve) neutrinos have never been measured, whie 8B neutrinos suffer from great uncertainty due to neutrino oscillation
A measurement would help validate the solar model



Supernovae Neutrinos: validate Core Collapse models, observe the birth of a black holes through neutrinos

Low Energy SM *ν* Physics in DUNE Phase-2

Challenges:
- Significant backgrounds
- Limited energy resolution @ low-energy
- Difficult reconstruction @ low-energy

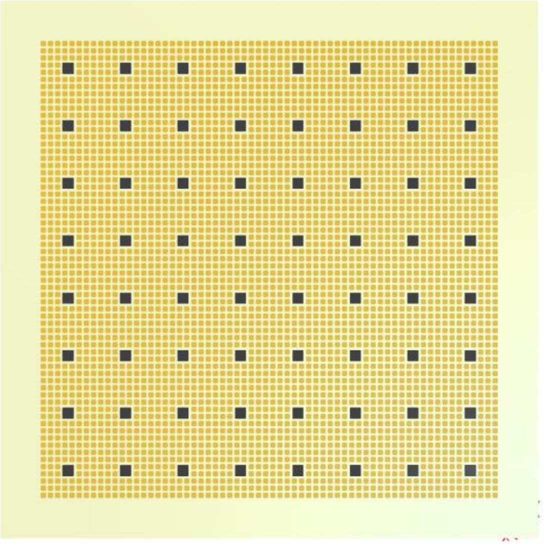


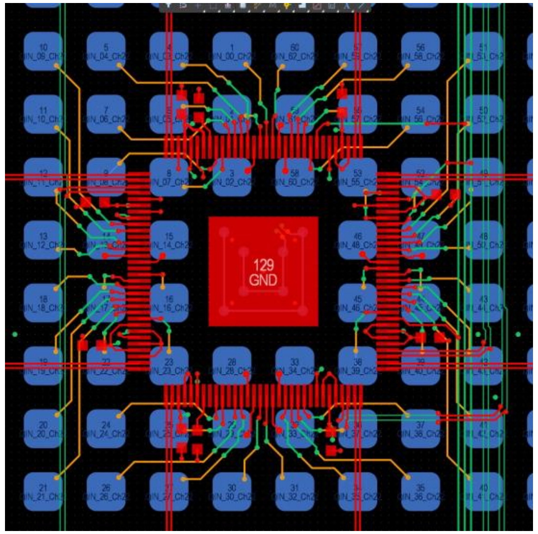
The SoLAr Proposal

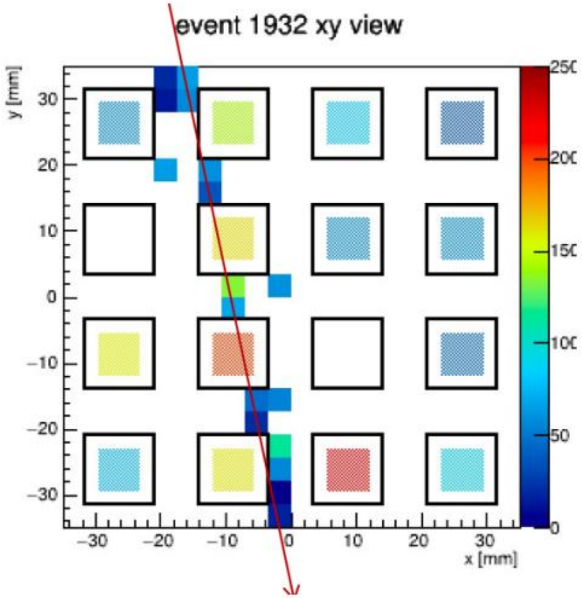
Target
$\Delta E/E \approx 7\%$

2.5% measurement of 8B
and 11%; measurement of hep flux

- Pixellated Q-L Calorimetric Readout replacing wires
  - VUV SiPMs integrated on the Anode (+ Arapuca on Walls)
  - SoLAr Tile prototype (V2) ready for testing (July):
    - Tile dimension: 32 × 32 cm2
    - Divided into 8 × 8 regions (64 − 4 pixel, 1 SiPM)
    - 64 LArPix (60 ch. used)
    - 64 Hamamatsu VUV MPPCwith independent readout
    Complete re-design of the PCB
- Background suppression with material choice, passive shielding, PSD, direction reconstruction

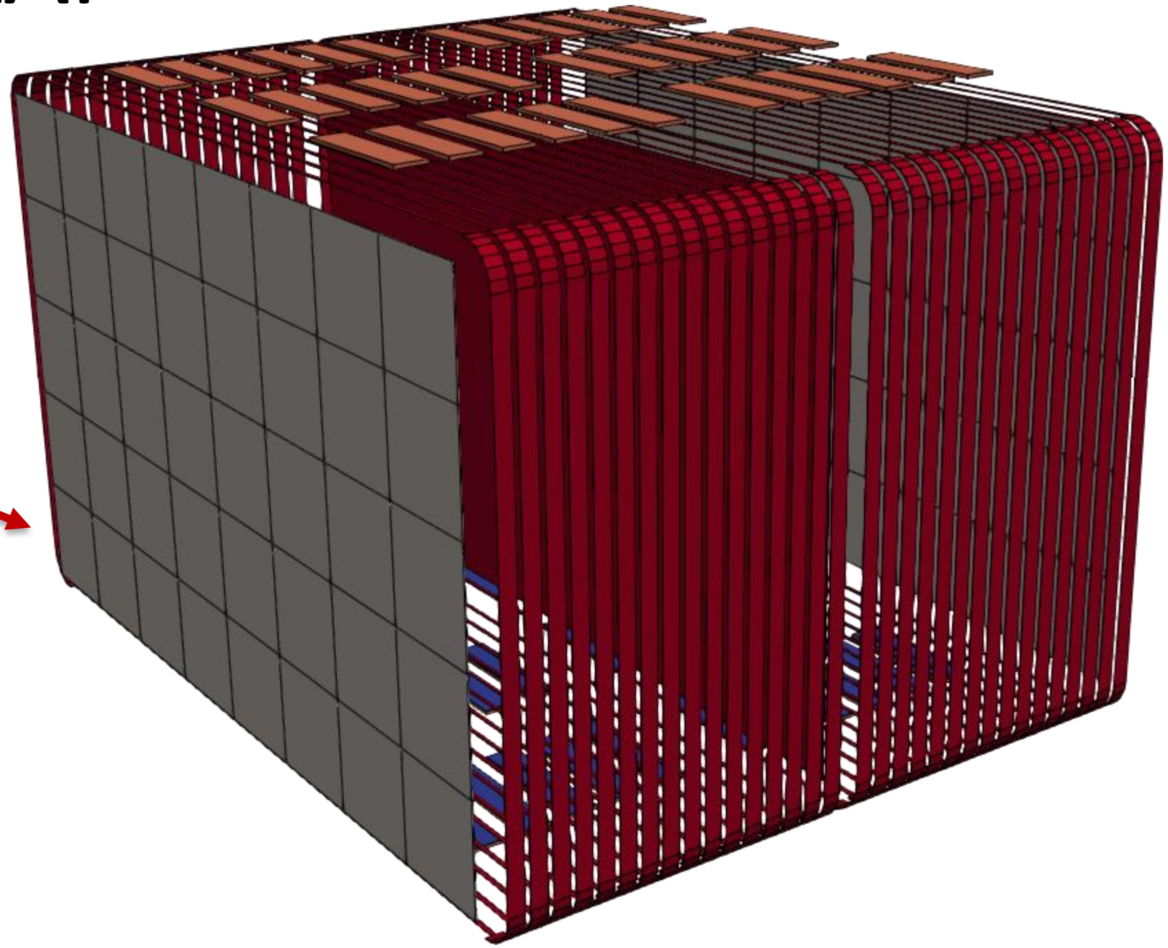






Status and future of SoLAr

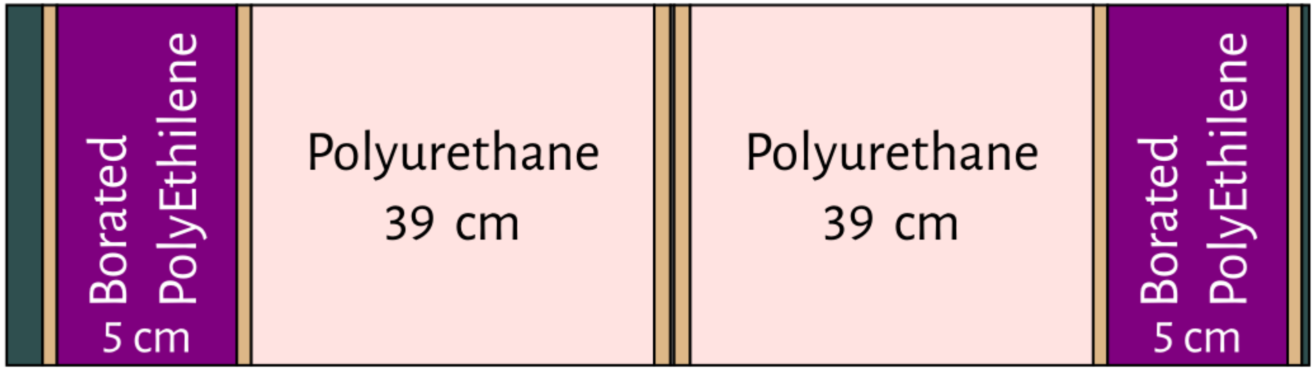
- Phase I: Prototyping
  - R&D on integrated charge + light readout
    → in v2 phase with new multi-layer pcbs, different SiPM/Pads layout
- Phase II: Medium Scale Experiment
  - Prove low-energy performance
  - Validate target energy resolution
  - Test background suppression methods
- Phase III: DUNE MoO



Planned in Boulby Underground Laboratory (UK)
• 1100 m rock overburden
Dimensions
• 1.6 x 2.6 x 2 m3 (1 m drift length)

Geant4 for simulating SoLAr

- Proof-of-concept for 7% resolution target
- Event reconstruction (dE/dx, ...)
- Backgrounds and mitigation strategies
  - One example: Radiogenic Neutrons mitigation by sandwiching the cryostat walls within Borated Polyethilene



$$n + {}^{10}\mathrm{B} \rightarrow {}^{11}\mathrm{B}^{*} \rightarrow {}^{7}\mathrm{Li} + \alpha + \gamma$$