Simulation and analysis of low energy Michel electrons in ProtoDUNE

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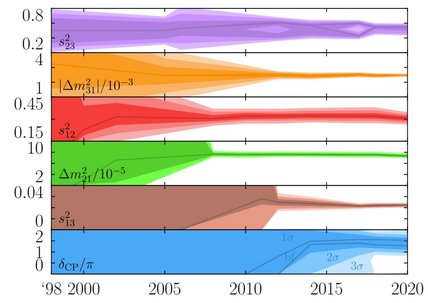
Low energy (MeV) electron for caracteristion of the LarTPC detector response in the DUNE experiment

1. Neutrinos

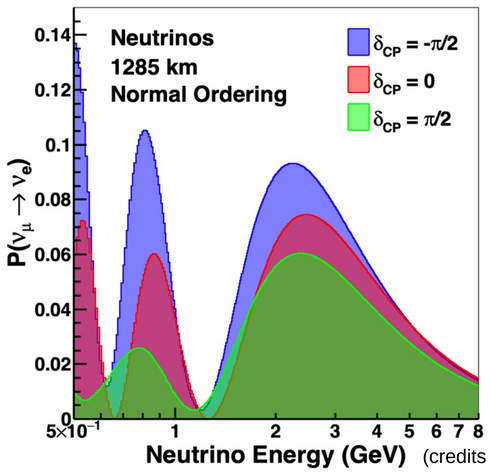


- **Elementary particle** of the Standard Model (SM)
- Neutral lepton sensitive to weak interaction
- **Very abundant but** not yet completly understood
- Discovery of their **oscillation:**
  - is not predicted by the SM
  - is described by PMNS matrix (3 mixing angles, 1 CP phase)
  - implies the existence of masses terms

Neutrino is a privileged probe to investigate the **matter/antimatter asymetry (δ_{CP})** as well as dark matter nature.

2. The DUNE experiment

Principles



(credits to [3])

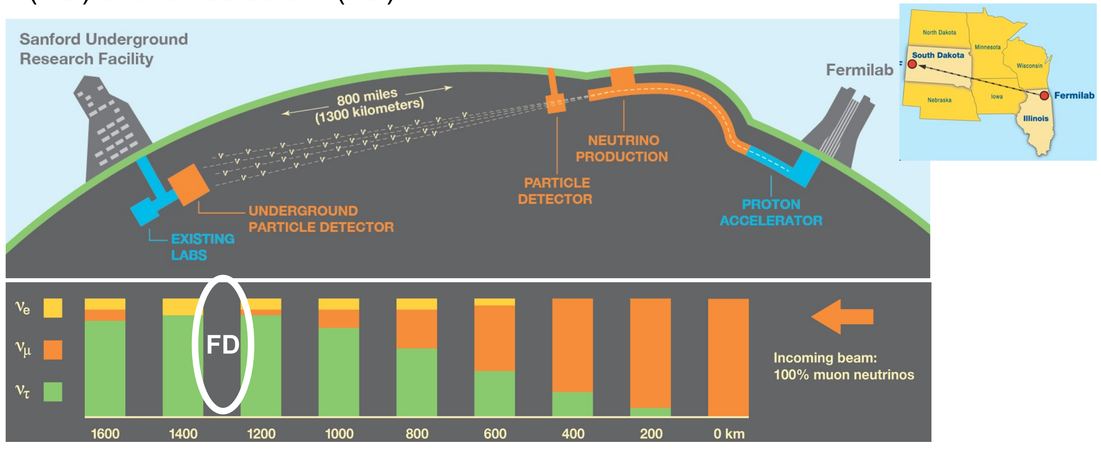
The DUNE collaboration aims to:

- measure **oscillation parameters** precisely, notably δ_{CP} but also the octant of θ_{23}
- determine the **neutrino mass hierarchy**
- observe the **proton decay**
- detect a **galactic supernova**

Also: test the unitarity of PMNS, look for sterile neutrinos and dark matter [2].

Experiment

To reach these objectives, DUNE is made of an accelerator (neutrino beam), a near (ND) and far detectors (FD).



The collaboration follows a phase approach:

Phase I

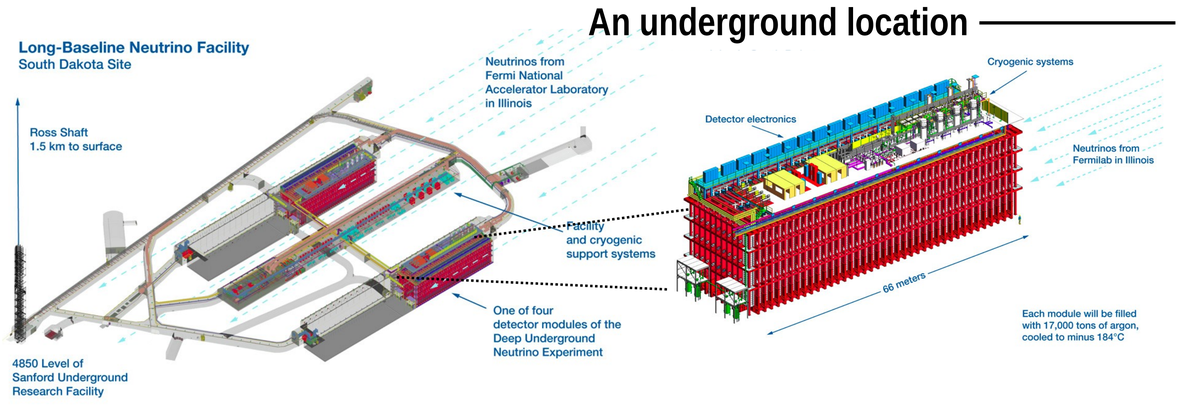
- Ramp to **1.2 MW** beam intensity
- **2x17kt** (10kt+) of LAr TPC modules
- Near detector: ND-LAr + TMS (steel/scint. range stack) + SAND

Phase II

- Proton beam increases to **2.4 MW**
- **4x17kt** LAr TPC FD module
- Upgrade of ND from TMS to ND-Gar

3. The Far Detector

An underground location

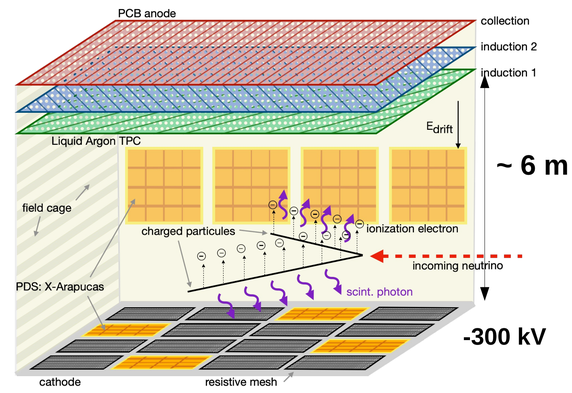


A giant LArTPC

The far detector will use two different concepts/designs based on LArTPC technology:

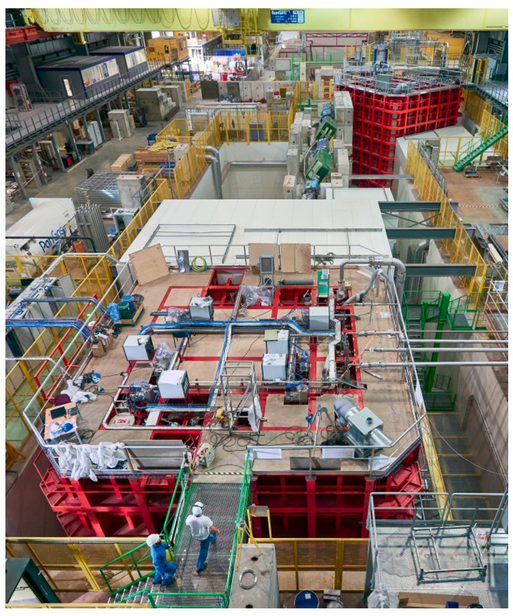
- **Horizontal drift** (wire TPC using APA)
- **Vertical drift** (drilled PCB using CRP)

Each of these technologies are being tested at CERN using the DUNE prototypes: ProtoDUNE.



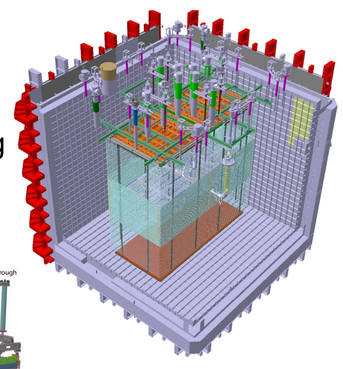
LArTPC principles (credits to E.Lavaut)

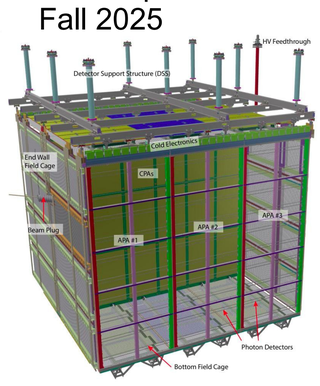
4. ProtoDUNEs at CERN



ProtoDUNE-VD

- Filled with LAr
- Electronics is being commissionned
- Data expected in Fall 2025





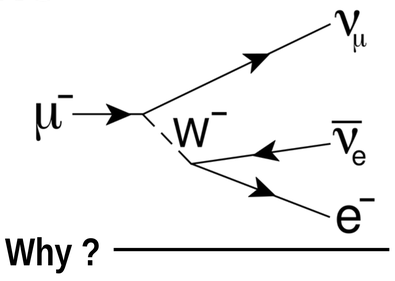
ProtoDUNE-HD

- Cosmics and beam data taken in 2024
- Data and simulations are being analysed

5. Michel electrons

Definition

- Michel electrons are coming from muon decay
- Due to relativistic effect, more probable when muon is almost at rest (hence the Bragg peak)
- A majority of μ- (~73 %) are captured by the nuclei
- Electrons have a known spectrum: [0, 50] MeV [5]

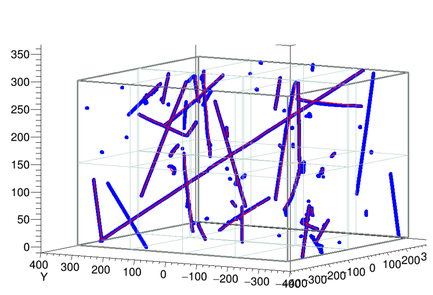


Why ?

- Can be used in ProtoDUNE to caracterise the detector response at low energy.
- Interesting for low energy events like supernovae

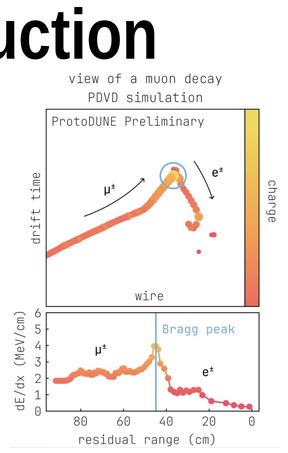
→ Reconstruction and simulation need to be optimized for a new design (PDVD)

6. Cosmic muons reconstruction



Cosmics MC in ProtoDUNE-VD

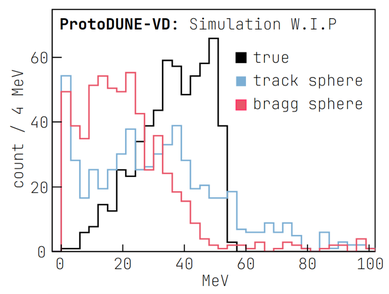
- Cosmics simulation using LArSoft
- LArSoft/Pandora is used for identifiying tracks in the TPC hits
- The end point is also refined using the Bragg peak from the slowing down muon
- This new method allows to clearly tag the muon's end



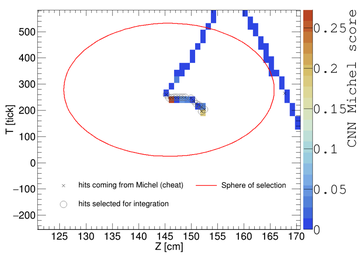
7 . Michel electron ProtoDUNE analysis

The status

- The main challenge of this analysis is to correctly identify the hits belonging to the muon wrt the michel electron or to delta ray.
- This analysis focuses on:
  1) Identifying a crossing muon using standard tools in ProtoDUNE (LarSoft/pandora)
  2) Reclustering and ordering the hits around the extremities of the muon
  3) Searching for a Bragg peak to tagg muon events with a large dE/dx close to the end of the track
  4) Integrating the charge in the collection plane within a 20 cm cylinder around the end point, removing the hits belonging to the mother muon



Michel energy spectrum in ProtoDUNE (work with J.Quelin-Lechevranton)



Michel hits CNN tagging

Next steps

1) Using a neural network to improve the Michel electron hit identification (CNN, Nugraph, on-going)
2) Complexify the michel hits selection by using more adapted shape (conique, free surfaces, on-going)
3) Mapping the response function in the ProtoDUNEs

[1] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I Introduction to DUNE - arxiv :2002.02967
[2] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics - arxiv :2002.03005
[3] Long-baseline neutrino oscillation physics potential of the DUNE experiment - arxiv :2006.16043
[4] The DUNE Vertical Drift - arxiv :2211.11339
[5] Identification and reconstruction of low-energy electrons in the ProtoDUNE-SP detector, https://arxiv.org/abs/2211.01166

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To know more about the group activity : https://phe.ijclab.in2p3.fr/neutrinos/