The ICARUS experiment Calibration Analysis

First Annual Workshop - INTENSE

2nd / 3rd of February 2022

MARIA ARTERO PONS

SUPERVISOR: PROF. DANIELE GIBIN

1222·2022 800 ANNI
Università degli Studi di Padova
Dipartimento di Fisica e Astronomia Galileo Galilei
European Commission
Intense
H2020 MSCA ITN
G.A. 858199

Presentation

- I joined the ICARUS Neutrino Group based in Padova on January 2021
- The first part of the PhD position, was intended to the calibration of the ICARUS detector during its commissioning phase at FNAL using either cosmic events or beam data
- In this first year I attended 4 different courses given by the PhD school in Physics
- I also participated in several workshops and conferences, including 3 summer schools

Courses

- Multimessenger Astroparticle Physics by A. De Angelis
  - *"Neutrinos as Multimessenger particles"* March 2021
- Neutrino Physics by R. Brugnera, M. Lattanzi and S. Dusini
  - *"Where are we with sterile neutrinos?"* June 2021
- Statistical Data Analysis by T. Dorigo, D. Bastieri and L. Stanco
  - *"Statistical status on sterile neutrinos"* *July 2021*
- Standard Model & Flavour Physics by G. Simi and M. Tosi
  - *"Test of lepton universality in beauty-quark decays"* *September 2021*

Training

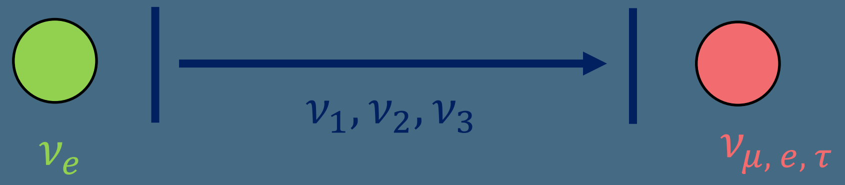
- *Workshops:*
  - *XIX International Workshop on Neutrino Telescopes held online during 18-26 February 2021, organized by INFN Padova*
  - *Calibration Workshop: Ntuples Tutorial held remotely on 27 Sept– 1 Oct 2021, organized by SBN Collaboration*
  - *International Workshop on Cosmic-Ray Muography held in Ghent, Belgium during 24-26 November 2021, organized by Ghent University as part of the European Project Intense-Rise*

Training

- *Workshops:*
  - *XIX International Workshop on Neutrino Telescopes held online during 18-26 February 2021, organized by INFN Padova*
  - *Calibration Workshop: Ntuples Tutorial held remotely on 27 Sept– 1 Oct 2021, organized by SBN Collaboration*
  - *International Workshop on Cosmic-Ray Muography held in Ghent, Belgium during 24-26 November 2021, organized by Ghent University as part of the European Project Intense-Rise*

- *Summer Schools:*
  - *Neutrino Summer Lecture Series held online during June/July 2021 and organized by Fermilab*
  - *Fermilab 2021 Summer Student School at INFN Laboratori Nazionali di Frascati, online attendance during 2-4 August 2021*
  - *FNAL C++ Software School held remotely during August/September 2021*

Neutrinos



- Fundamental particles of SM: fermions, chargeless and weakly interacting particles
- Neutrino oscillations are a well known phenomena, requiring to be massive particles

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}e^{i\alpha_1} & 0 & 0\\ 0 & e^{i\alpha_2} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Atm. + accelerator $\nu_\mu \to \nu_\tau$ | Reactors $\nu_\mu \to \nu_e$ | Reactor + solar $\nu_e \to \nu_{\mu,\tau}$ | Majorana

$c_{ij} = \cos\theta_{ij}$
$s_{ij} = \sin\theta_{ij}$

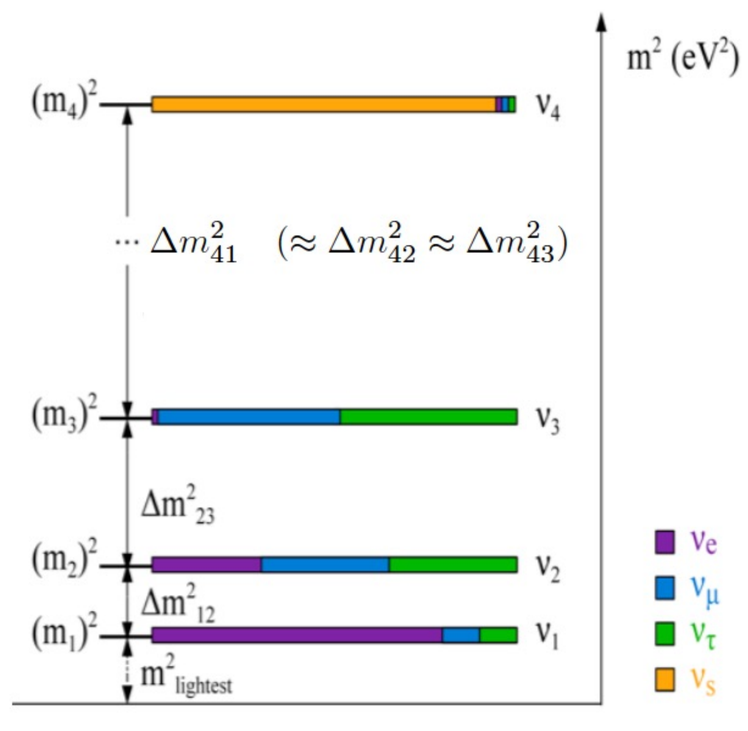
Oscillation probability

$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - \sum_{j>i} U_{\alpha i}U_{\beta i}U^*_{\alpha j}U^*_{\beta j}\sin^2\left(1.27\,\Delta m^2_{ij}\frac{L}{E}\right)$$

- Several anomalies were observed: accelerator experiments such as LSND and MiniBooNE, reactor and solar experiments
- Some of them can be explained by introducing an additional neutrino state with $\Delta m^2 \sim 1\ eV^2$

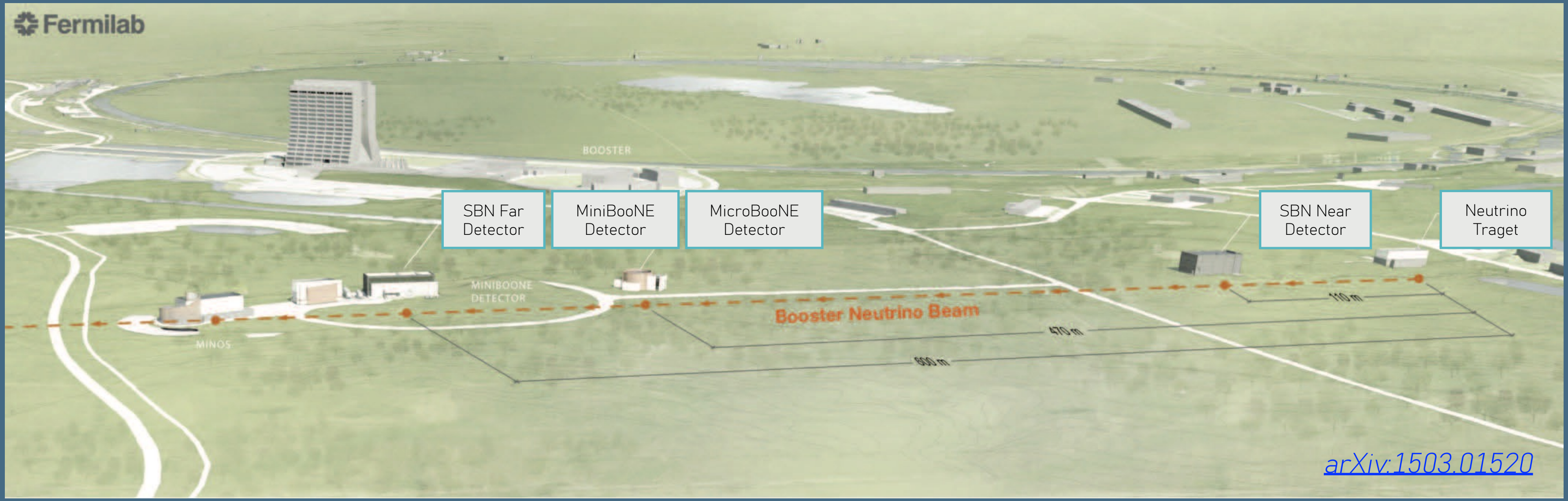
Neutrinos

- The simplest model to accommodate the anomalies found is the 3+1 model , which is an extension of the standard model with a new 4x4 neutrino mixing matrix
- The new particle should be massive and sterile, interacting only through gravity
- Since they will not interact electromagnetically, weakly or strongly they are extremely difficult to detect
- Neutrinos only leave hints indirectly and rarely, since their cross-section is really small
- It is essential to use large detectors to overcome this feature. A huge scientific effort is currently ongoing to search for anomalous neutrino signals using dedicated neutrino sources and beams



Research

- *The Short Baseline Neutrino Program (SBN) is a 3 detector setup experiment aiming to definitely solve the "sterile neutrino puzzle", looking for* ν_e *appearance and* ν_μ *disappearance in a* ν_μ *beam*
- *The experiment is designed to be able to confirm or exclude the allowed parameter space by MiniBooNE and LSND results with at least* 5σ *confidence. Thus SBN has some similarities with MiniBooNE, using the same neutrino beam line at Fermilab (Booster Neutrino Beam - BNB)*



Short-Baseline Neutrino Program

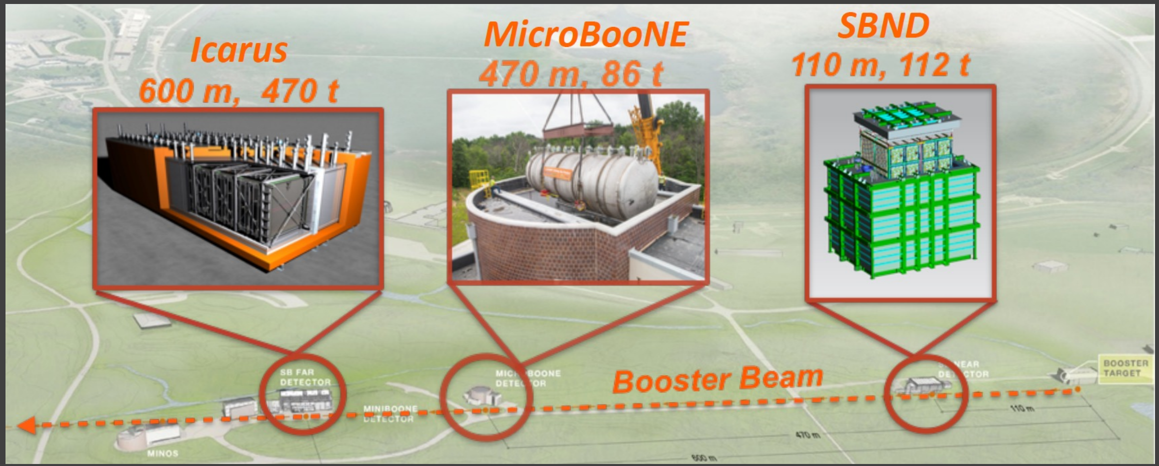
- SBN Program will be crucial to verify the possible existence of sterile neutrinos thanks to the combination of the far and near detectors, which are providing enough statistics and control of the systematics respectively
- In order to minimize systematic uncertainties when comparing event distributions, the three detectors are kept as similar as possible: using the same detection technique (LArTPC) and operation conditions
- The SBN detectors will also record events from the off-axis flux of the NuMI neutrino beam with its higher electron neutrino content and different energy spectrum

MicroBooNE:
- Has been taking data since 2015 ⟶ study the low energy excess anomaly

Run completed

ICARUS:
- Collect higher statistics to search for short baseline oscillations

Commissioning



Fava, Angela. *The Short Baseline Neutrino Program at Fermilab*. February 2021. PowerPoint Presentation.

BNB:
- Well characterized beam
- Able to produce ν and $\bar{\nu}$ beams
- 700 MeV peak energy
- 0.5% ν_e contamination

SBND:
- Characterize the unoscillated BNB neutrino flux

Construction/installation

Short-Baseline Neutrino Program

- SBN Program will be crucial to verify the possible existence of sterile neutrinos thanks to the combination of the far and near detectors, which are providing enough statistics and control of the systematics respectively
- In order to minimize systematic uncertainties when comparing event distributions, the three detectors are kept as similar as possible: us
- The SBN de … eutrino content and

*As part of the **ICARUS Collaboration** we are focusing on the calibration of the detector. It is a first step towards a precise and controlled performance to enable an optimal reconstruction and analysis of neutrino events*

MicroB

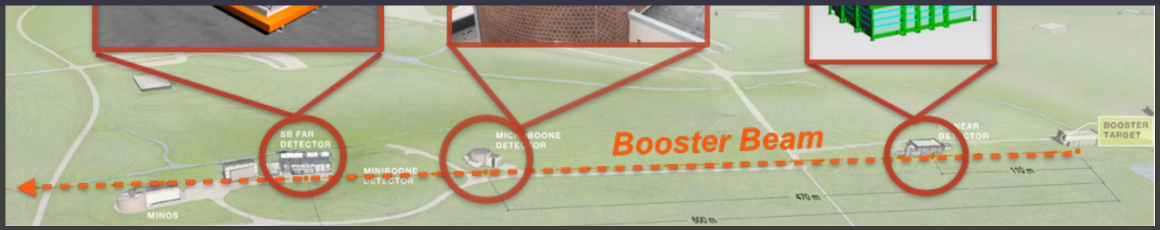
- Has been ta since 2015 low energy anomaly

Run completed

ICARUS:

- Collect higher statistics to search for short baseline oscillations

Commissioning



Fava, Angela. *The Short Baseline Neutrino Program at Fermilab*, February 2021. PowerPoint Presentation.

d beam ν and $\bar{\nu}$

ergy ation

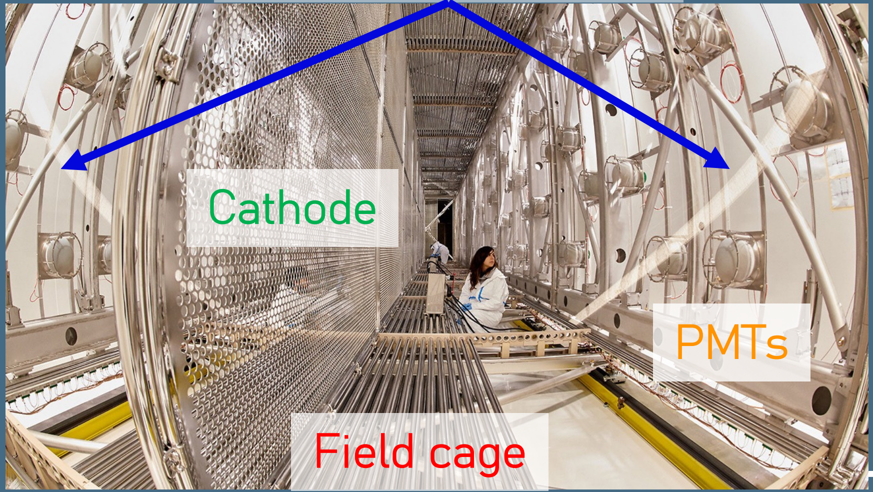
SBND:

- Characterize the unoscillated BNB neutrino flux

Construction/installation

ICARUS detector

Wire planes (Anode)

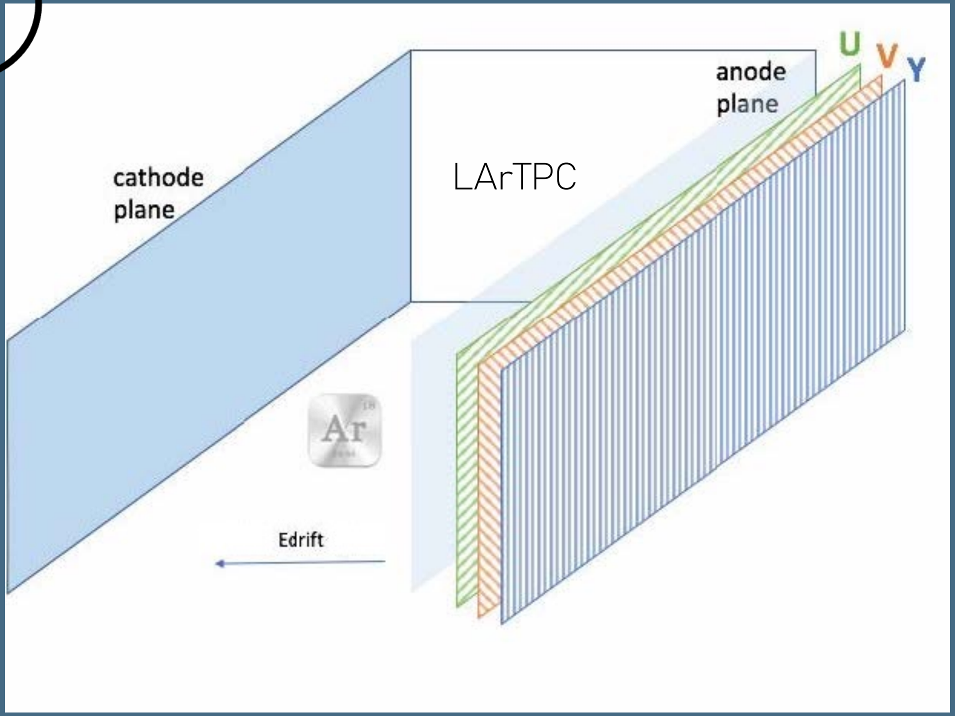


- ICARUS-T600 Lar TPC is a high precision self-triggering detector with 3D imaging and calorimetric capabilities, perfect for neutrino physics
- It allows an accurate reconstruction of a wide variety of ionizing events with complex topologies
- During 2010-2013 the detector was operational at the underground LNGS laboratory, confirming the feasibility of this technique
- The detector is composed of 2 identical cryostats, each one hosting 2 TPCs with a common central cathode allowing a maximum drift length of 1.5 m
- The ionization charge is continuously read by 3 non-destructive readout wire planes with different orientations, and behind the wires there are 90 PMTs per TPC providing the interaction time of each particle and the trigger
- Finally the detector is surrounded by the Cosmic Ray Tagging (CRT) system that helps to reject incoming cosmic particles

LArTPC

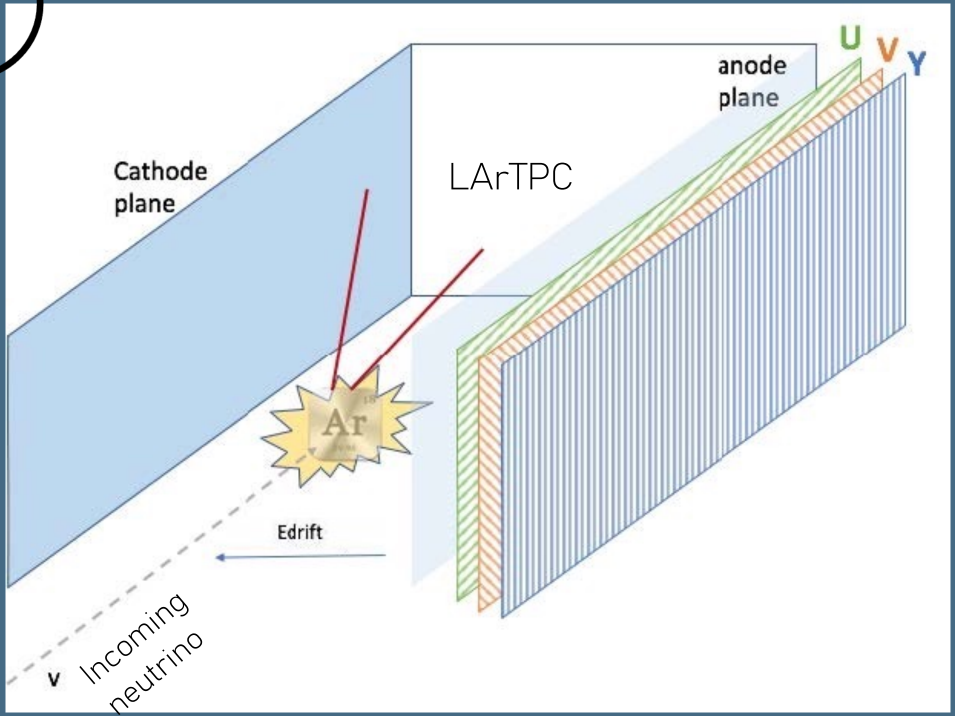
Wospakrik, Marianette, Detector Performance of the MicroBooNE LArTPC, February 2021, PowerPoint Presentation

1



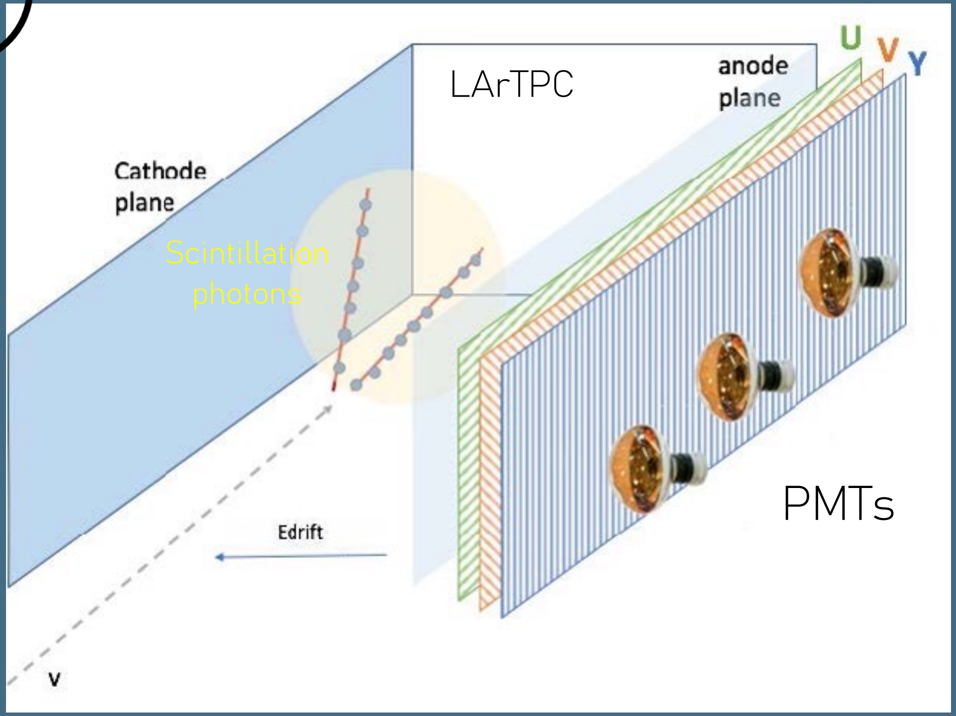
Large volume of ultra pure liquid argon (to avoid signal attenuation) surrounded by a high-voltage cage

2



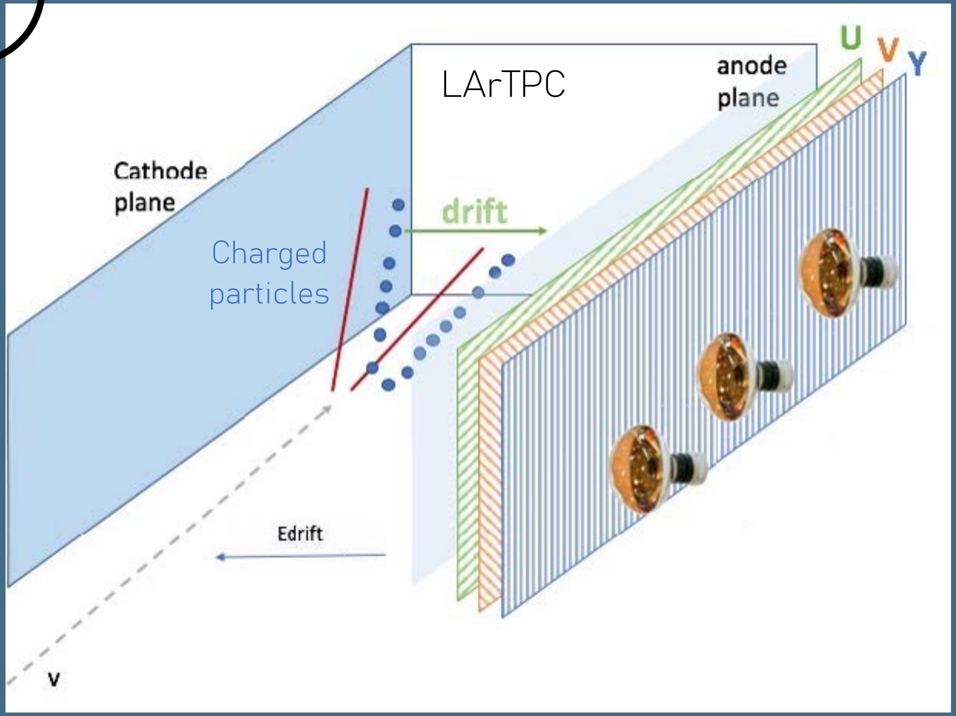
When a neutrino enters the large volume of liquid argon it interacts with the argon producing charged particles that deposit their energy, producing ionization electrons and scintillation light

3



The LAr is transparent to its own scintillation light, so it propagates inside the detector until collected by the arrays of PMTs. This signal is fundamental to recognize the time at which the interaction occurred (Trigger)

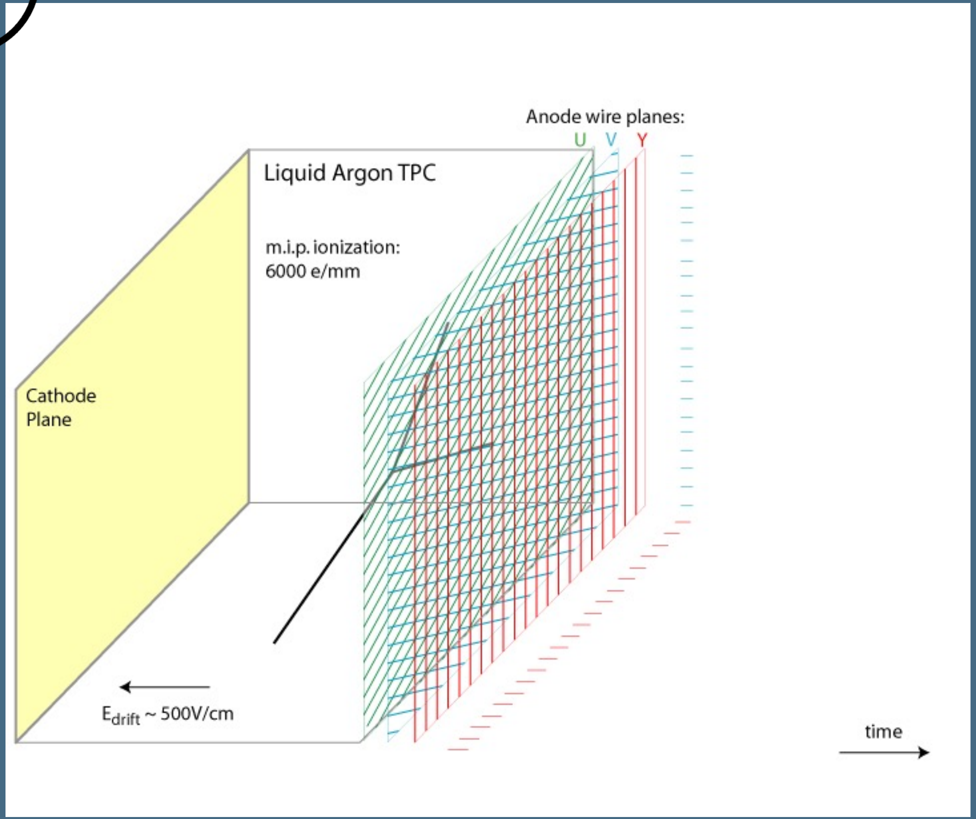
4



The uniform electric field set up between the cathode and the anode drift the ionized electrons to the wire chamber planes on the anode side of the detector

Wospakrik, Marianette. Detector Performance of the MicroBooNE LArTPC. February 2021. PowerPoint Presentation

5



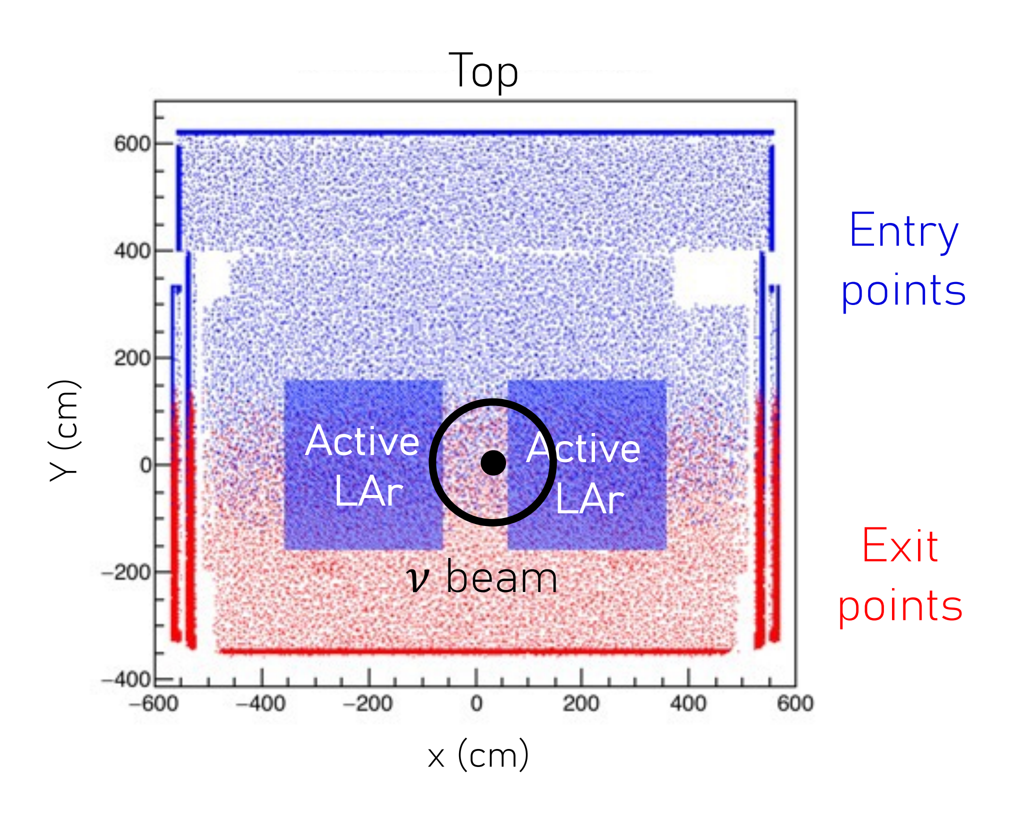
https://lar.bnl.gov/wire-cell/

The ionization electrons are then detected by the 3 anodic wire planes providing simultaneous different projections of the same event and allowing a full 3-dimensional image of the event

This information allows a precise reconstruction of the recorded particle trajectories and a fine calorimetric measurement

Research

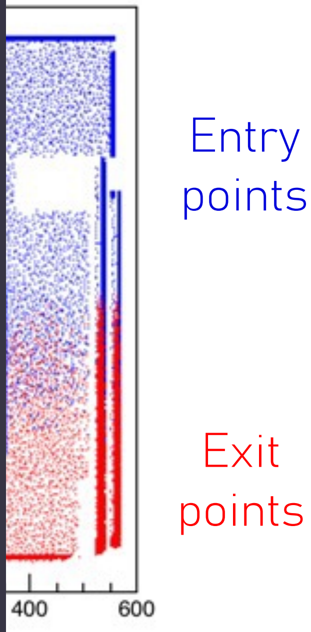
- Since the detector is located on the surface we expect to have a large background, around 15 cosmic particles per trigger event
- The detector is equipped with several instruments to provide useful information: PMTs, CRTs and TPCs
- Our first approach is to use the Cosmic Ray Tagger (CRT) to select events fully contained inside the detector, highly suppressing cosmic noise
- In order to characterise its efficiency we performed a geometrical coverage study of the CRT using MC simulated events
- Latest version of the CRT geometry was used but no surrounding materials were considered
- The coverage was computed only for tracks crossing the Liquid Argon active volume



Research

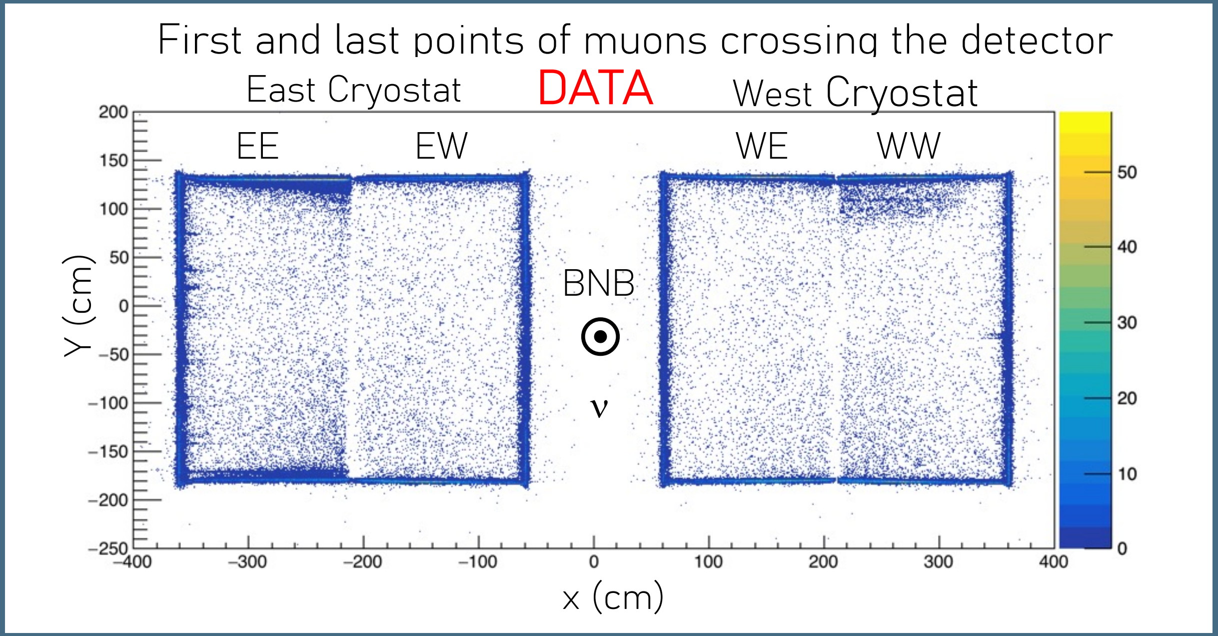
- Since the detector is located on the surface we expect to have a huge backgrou
- The dete informati
- Our first events fu
- Geometri efficiency
- Latest ve were con
- The coverage was computed only for tracks crossing the Liquid Argon active volume

- *The geometrical coverage for observing either the entry or the exit point is 98.4%*
- *Instead for observing both entry and exit points is ~49%, as we know that the bottom face is not fully covered by scintillator panels*
  - *~18% of the total were crossing top and bottom CRT panels*

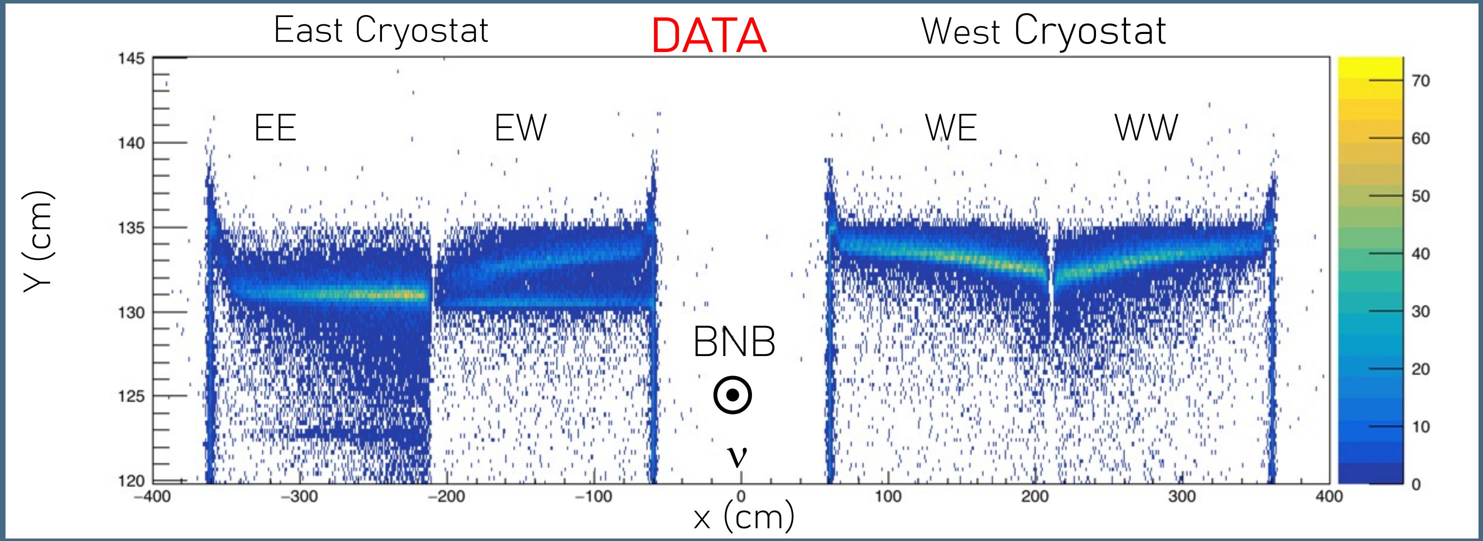


Research

- First analysis of Anode to Cathode tracks
  - Information provided by the TPCs
  - The tracks selected are cathode piercing cosmic rays for which is possible to reconstruct the interaction time (t_0) of the track with respect to the trigger time
  - In addition we used Anode to Cathode tracks, that are characterized by having a projected length along the drift direction within a TPC equal to the maximum drift distance (1.5 m)
  - The main goal: use these tracks to study the details of the detector performance and pinpoint possible problems in the reconstruction phase
  - Several differences were seen between the different TPC



Research

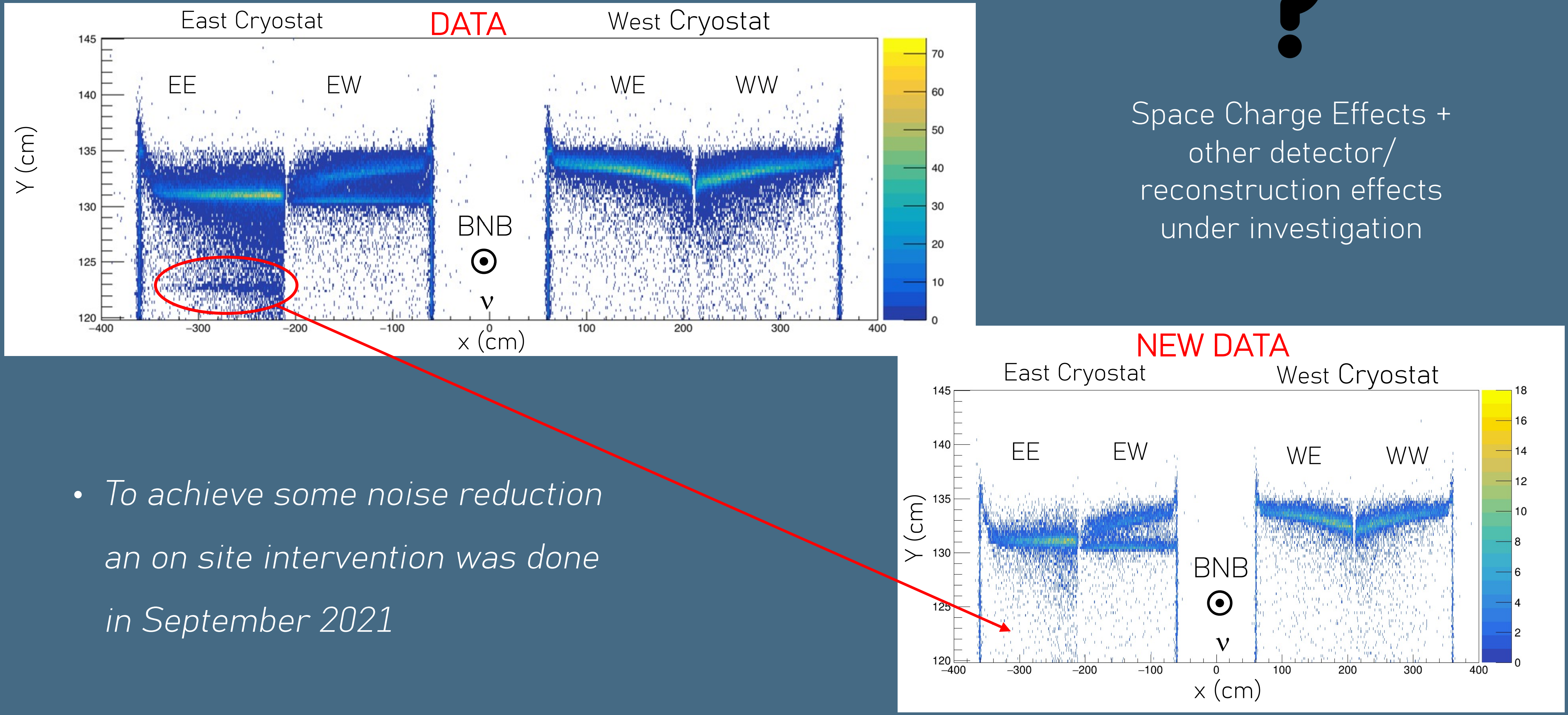


Space Charge Effects + other detector/ reconstruction effects under investigation

What are the Space Charge Effects?

Electrons and positive ions drift along the same electric field lines towards the anodic wire plane and the cathode. However, their drift velocities are quite different: $v_{Ar\ ions} \sim 5 \cdot 10^{-6}\ mm/\mu s$ while $v_{e^-} = 1.55\ mm/\mu s$ (considering $E = 500\ V/cm$). Due to their reduced mobility argon ions will drift much slower than electrons, causing a not negligible distortion of the drift field. This effect is caused by the accumulation of positive charge in the active volume detector due to ionizing events, mainly cosmic rays

Research

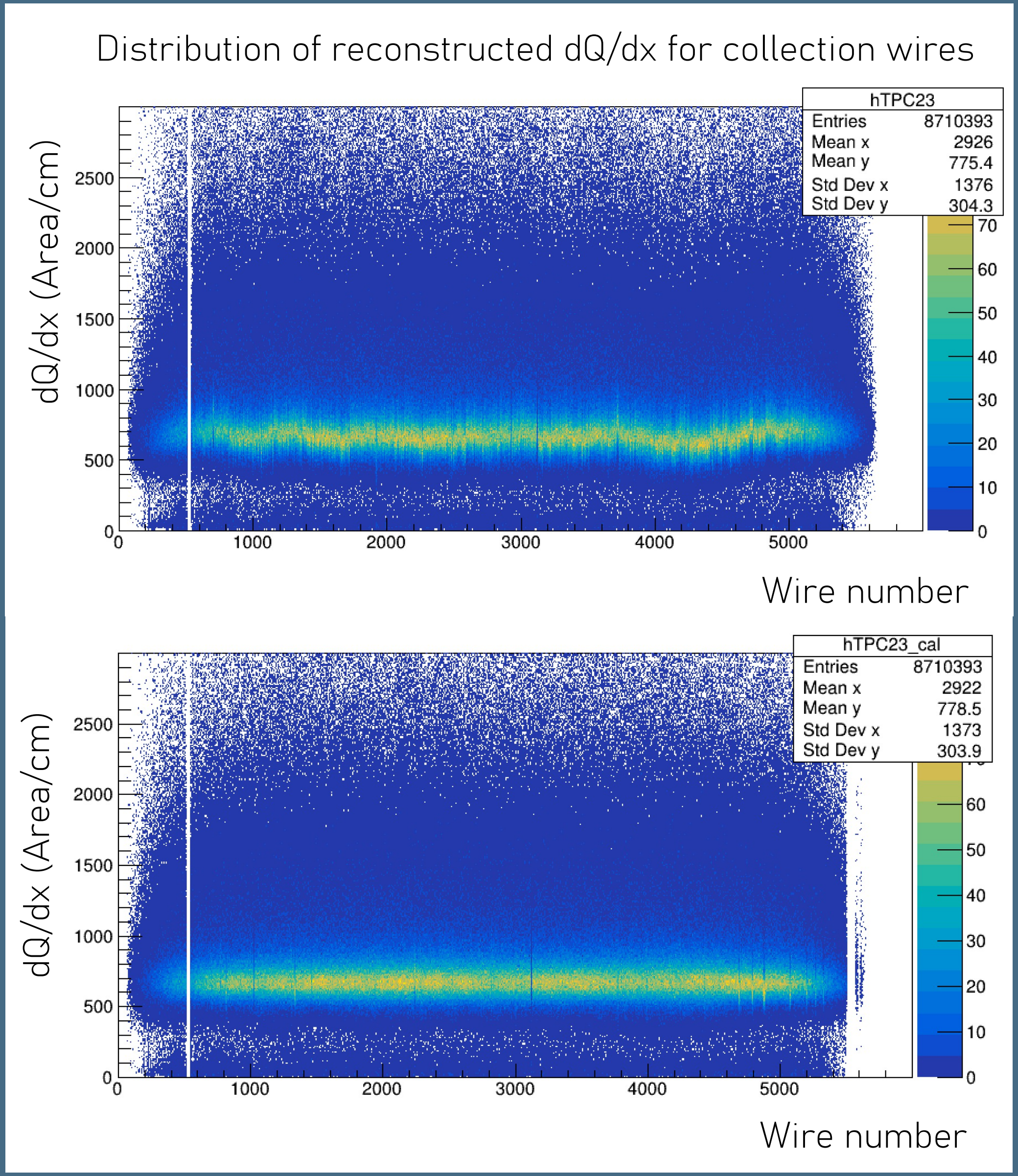


Space Charge Effects + other detector/ reconstruction effects under investigation

- *To achieve some noise reduction an on site intervention was done in September 2021*

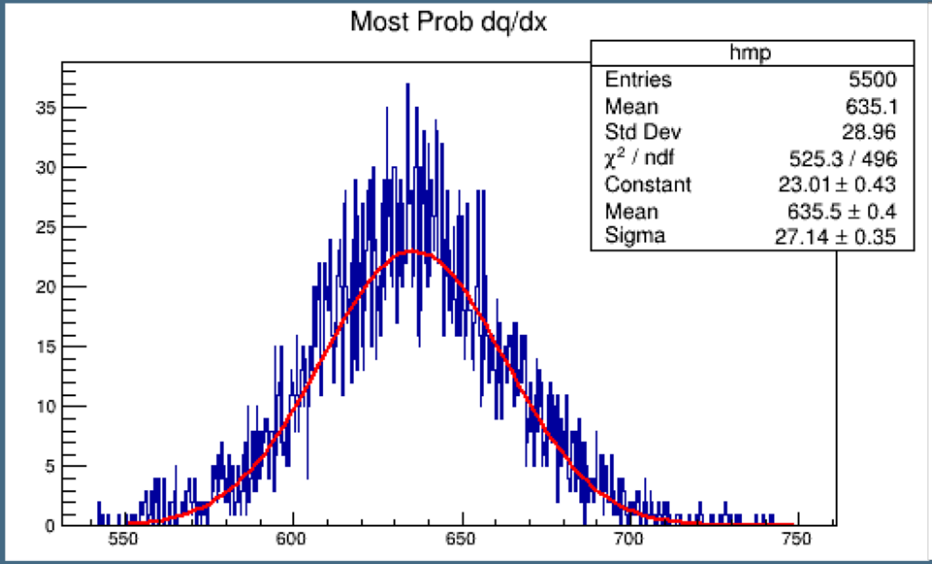
Research

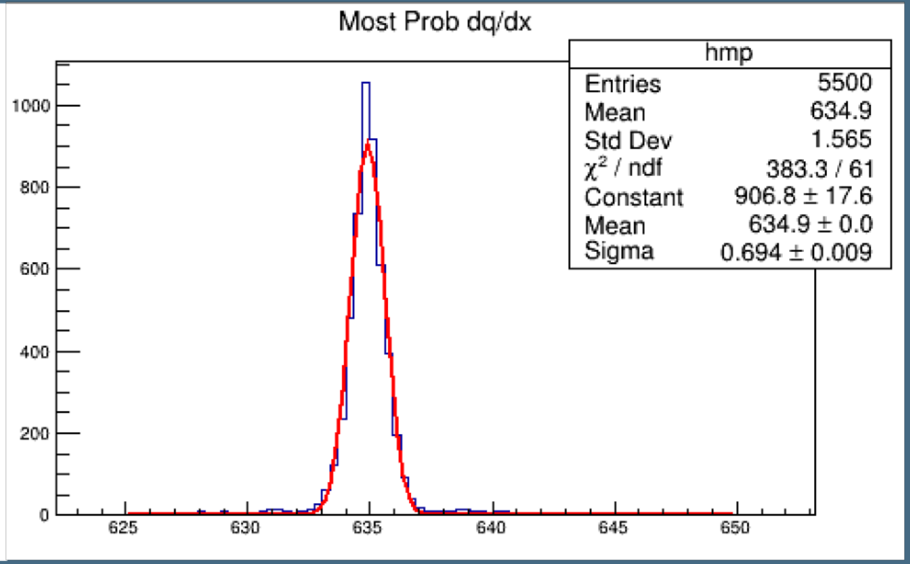
- *Charge calibration using TPC information*
  - *The aim of the TPC Calibration is to identify the global calibration constant, used to convert the recorded signals into deposited energy, and to obtain an equalize response for each channel*
  - *Currently using Anode to Cathode tracks to study the deposited charged along the tracks*
  - *As a first approximation, the variation of the dE/dx along the track can be considered small, hence the recombination is almost constant along the track and dQ/dx will behave as dE/dx*
  - *dQ is the integral of the wire signal associated to an energy deposition in the TPC, while dx is the length of a particle trajectory seen by a given wire*
  - dQ/dx *is corrected with the electron lifetime to account for the signal attenuation due to the electronegative impurities*



Research

- *Once each channel has the dQ/dx corrected, the idea is to fit the obtained distribution with a Landau + Gaussian in order to extract the most probable value*
- *The calibration factor is then computed as the ratio between* MPV_{median} *and* $MPV_{channel}$
- *The width of the MPV distribution provides an estimation of the precision of the method*
- *In previous studies it was seen that the RMS of the distribution of MPV was around 1.5% for MC data and 4.5% for real data*





- *We have a std/mean of 4.56% before calibration, while after the value decreases to 0.25%*

PRELIMINARY !!

Future prospects

- *Near term*
  - *Finalize analysis for the dQ/dx calibration: study the impact of different lifetimes, typologies of tracks, incident angles, …*
  - *Calibration of the light response: there are also future plans to use the light produced during the interactions to achieve a higher track reconstruction precision*

- *Long term*
  - *Once the detector is calibrated the main physical goal is to perform a reconstruction analysis of the neutrino interactions*

THANK YOU FOR THE ATTENTION !!