PROCEEDINGS OF SCIENCE

# Measurement of space charge effects and energy calibration in ProtoDUNE-SP

**Mitch W. Mote for the DUNE Collaboration**[a,*]

[a] *Louisiana State University,*
*202 Nicholson Hall, Baton Rouge LA 70803, United States of America*

*E-mail:* mmote3@lsu.edu

The single-phase liquid argon prototype at CERN (ProtoDUNE-SP) acts as a validation of the design for the DUNE single-phase far detector. With a total mass of 770 tons, it is the largest monolithic liquid argon single-phase time projection chamber in the world. ProtoDUNE-SP collected test-beam in autumn of 2018 and has been collecting cosmic and special calibration data since the end of 2018.

The accumulation of positive ions in a LArTPC located on the surface can distort the electric field and the reconstructed particle trajectories. It is critical to understand and correct for this space charge effects in order to achieve the desired spatial and calorimetric resolutions in the LArTPC. This talk will present the measurement of space charge effects and the calorimetric calibration of the detector in ProtoDUNE-SP.

**** The 22nd International Workshop on Neutrinos from Accelerators (NuFact2021) ****
**** 6–11 Sep 2021 ****
**** Cagliari, Italy ****

*Speaker





PoS(NuFact2021)175

## 1. Introduction

The ProtoDUNE single phase (SP) experiment is a 770 ton Liquid Argon Time Projection Chamber (LArTPC) designed to test components that will be used in the Deep Underground Neutrino Experiment (DUNE). The detector uses a constant electric field of 500 $V/cm$ in it's fiduciary volume to drift ionization electrons to receiving wires at the edges of the volume, and in this way reconstruct events in a three dimensional picture. ProtoDUNE-SP has been taking data since 2018.

This detector is located at surface level, and so experiences a large flux of cosmic rays. These cosmics often ionize Argon atoms, leading to Argon ions and ionization electrons. Since the Argon ions are much more massive than the ionized electrons, they move around $2 \times 10^5$ times slower in our drift field [1]. As a consequence, these Argon ions will often build up in the detector, leading to a large positive space charge effect (SCE).

SCE manifests in various ways. The most clear manifestation is in the distortion of the electric field in the detector. This leads to changes in ionized electron drift paths, seen in figure 1. SCE can also affect electron-ion recombination rates at the energy deposition points in the detector. These distortions change where points in a track are reconstructed, as well as effect the amount of energy reconstructed at these points, possibly leading to particle misidentification [2].

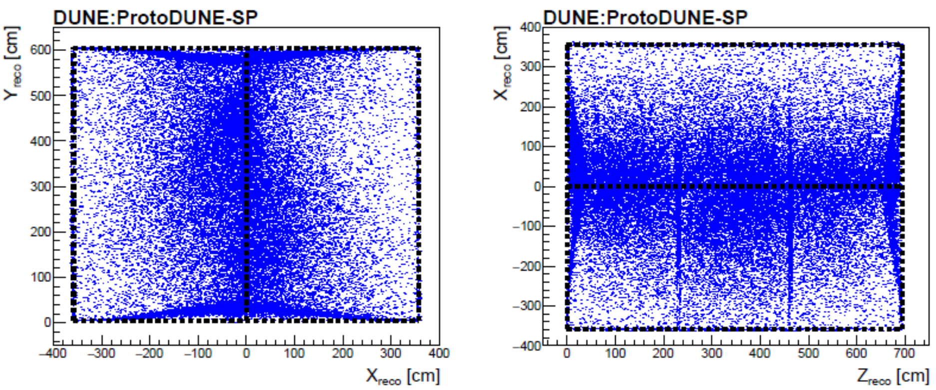


**Figure 1:** Projections of cosmic ray track end points in the x-y and x-z planes in ProtoDUNE-SP data. Edges of the detector represented by dashed lines, where x=0 is the cathode. Reproduced from [1].

## 2. Measurement of SCE in ProtoDUNE-SP

SCE in ProtoDUNE-SP was measured at each face of the detector. In order to measure SCE, the population of cosmic tracks that cross the cathode (at $x = 0$) are used. These tracks are $t_0$-tagged by identifying when they crossed the cathode. From this time identification, their position in the drift direction (defined as x) can be determined, and compared with the reconstructed x position to evaluate the size of the SCE at detector faces in the x direction. For the transverse to the drift direction (y-z) detector faces, we can use the fact that our cosmic tracks should be through-going. Therefore, we can determine the spatial distortion by measuring the distance between the end of the track and the edge of the detector in the direction orthogonal to the detector face in question

[1]. By using these methods, we are able to produce the distortion maps in data shown in the left portion of figure 2.

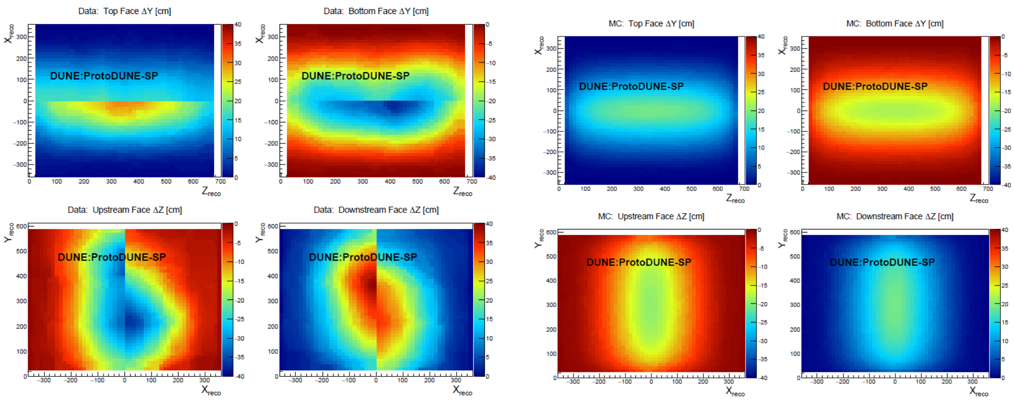


**Figure 2: Left:** Spatial distortions measured normal to the top, bottom, upstream, and downstream faces of the detector in data. The color map indicates the correction (in cm) that must be added to the starting/ending point of a track in order to correctly identify it's true entrance/exit position. **Right:** Simulation of spatial distortions measured normal to the top, bottom, upstream, and downstream faces of the detector, originally developed for MicroBOONE. Reproduced from [1].

In order to correct these effects, a full map of SCE and therefore electric field distortions is needed throughout the detector. To build this map, we can start with a Monte Carlo (MC) simulation of SCE originally developed for MicroBOONE [3]. By dividing the data map correction with the MC map corrections, we can make a correction for each volume element in the detector. Using a method originally developed at MicroBOONE [4] the SCE map can also give us a map of electric field distortions across the volume of the detector.

## 3. Validation of SCE using CRT

To validate the distortion map results, we can use the Cosmic Ray Tagger (CRT) modules in ProtoDUNE-SP. The CRT modules are an array of scintillator strips at the front and back of the detector. These identify the start and end point of our throughgoing cosmic tracks, which are also $t_0$-tagged to give us a reconstruction of these tracks through the detector [5]. These can then be compared to the reconstruction at detector faces in the same way as described in section 2 to independently verify the distortions at detector faces (results for the upstream detector face can be seen in figure 3).

We can also select for two CRT tagged tracks which intersect, and by measuring the difference in the CRT crossing point and reconstructed crossing point, estimate SCE at that point in the detector, further verifying the 3D maps.

## 4. Calibrating Calorimetric Constants

Our main goal is to correct the energy deposition per unit length of the reconstructed particles (referenced here as $\frac{dE}{dx}$) in order to avoid misreconstruction of particles. This is a function mainly

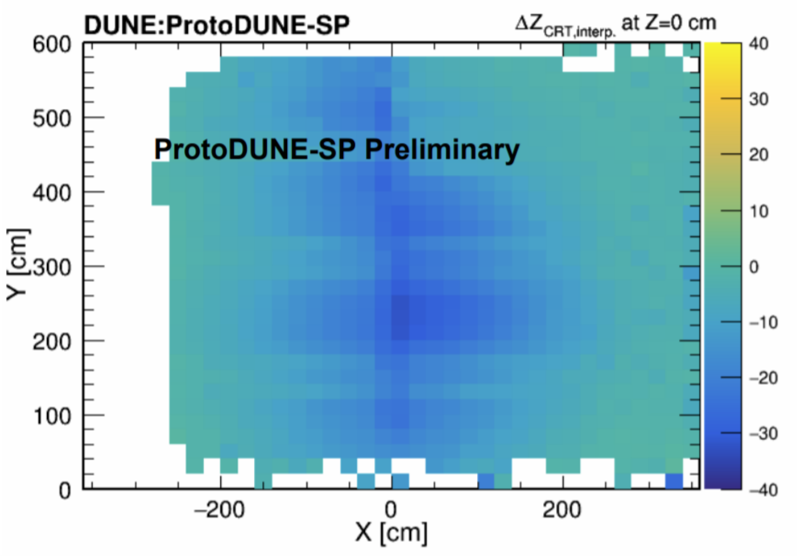


**Figure 3:** Measurement of SCE in data normal to the upstream face of the detector using the CRT module method. The color gradient indicates the correction (in cm) one must add to the reconstructed entrance/exit of the cosmic track to accurately describe its true entry/exit point. Reproduced from [5].

of charge deposition ($\frac{dQ}{dx}$) and the magnitude of the electric field. Throughgoing cosmic muons can be used as a standard candle to normalize the charge deposition, as they should distribute charge evenly through the TPC. After this, we can use stopping cosmic muons for our energy deposition calibration as the energy loss of a minimum ionizing particle is very well known [6]. $\frac{dE}{dx}$ is modeled by the Modified Box Model [7]:

$$\left(\frac{dE}{dx}\right)_{calibrated} = \left(exp\left(\frac{\frac{dQ}{dx}_{calibrated}\beta' W_{ion}}{C_{cal}\rho\varepsilon}\right) - \alpha\right)\left(\frac{\rho\varepsilon}{\beta'}\right) \tag{1}$$

where $C_{cal}$ is a calibration constant used to convert from ADC to number of electrons, $W_{ion}$ is the Work function of Argon ($23.6 \times 10^{-6} \frac{MeV}{electron}$), $\varepsilon$ is the electric field given by our SCE map, $\rho$ = 1.38 $g/cm^3$, $\alpha$ = 0.93 and $\beta'$ = 0.212 kV/cm $g/cm^3$/MeV are two model parameters measured at Argoneut, and $\frac{dQ}{dx}_{calibrated}$ is calibrated charge deposition per unit length. The values to be determined (after using the SCE electric field distortion maps to determine $\varepsilon$) are $\left(\frac{dQ}{dx}\right)_{calibrated}$ and $C_{cal}$.

First, the $\frac{dQ}{dx}$ response is normalized across the transverse (YZ) plane, and then normalized in the drift (X) axis. An additional time normalization factor is also applied that deals with the 3 different planes in ProtoDUNE-SP that a hit can land on. For each of these planes, a reference value over the whole data taking run is determined, and then this reference value is divided by a value determined from the specific dataset in question to account for any variation in hitplane response across datasets. The corrections are then applied to get a normalized detector response using the formula

$$\left(\frac{dQ}{dx}\right)_{calibrated} = \left(\frac{dQ}{dx}\right)_{uncalibrated} * Normalization(y,z) * Normalization(x) * N_{time} \tag{2}$$

With this, the only remaining variable left to determine is $C_{cal}$. This is determined by using the sample of stopping cosmic muons in data to measure the Bragg peak in their energy deposition as a function of residual range. This is then used to fit $C_{cal}$ to the value that makes these peaks best agree with Landau-Vavilov theory for energy deposition of stopping particles. Results for data and comparing data to MC predictions can be seen in figure 4.

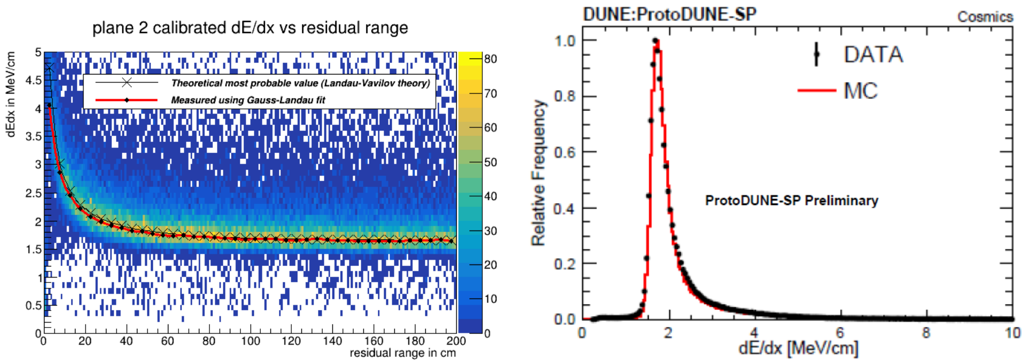


**Figure 4: Left**: Measured $\frac{dE}{dx}$ versus residual range for stopping muons in data run 5387 collection plane at 1 GeV after calibration. The theoretical curve is plotted with the crossed points, while the measured values using the determined calibration constant is plotted in red. **Right**: $\frac{dE}{dx}$ versus relative frequency after calibration, using data run 5387 and MC samples from Production Run 4.

## References


[1] D. Collaboration, *First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform*, *J. Inst.* **15** (2020) .

[2] M. Mooney, *Measurement of space charge effects in protodune-sp*, Presented at the 40th International Conference on High Energy Physics, 2020.

[3] M. Collaboration, *Study of Space Charge Effects in MicroBooNE*, Tech. Rep. MICROBOONE-NOTE-1018-PUB (2016).

[4] C. Adams and et. al., *A Method to Determine the Electric Field of Liquid Argon Time Projection Chambers Using a UV Laser System and its Application in MicroBooNE*, *JINST* **15** (2019) 7.

[5] R. Diurba, *Evaluating protodune single phase detector response with a cosmic ray tagger (crt)*, Presented at the CPAD Instrumentation Frontier Workshop 2019, 2019.

[6] D. Groom, N. Mokhov and S. Striganov, *Muon Stopping Power and Range Tables 10 MeV - 100 TeV*, Tech. Rep. http://pdg.lbl.gov/2019/AtomicNuclearProperties/adndt.pdf.

[7] A. Collaboration, *A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC*, *Journal of Instrumentation* **8** (2013) .