

# Measurement of Space Charge Effects in ProtoDUNE-SP

**Michael Mooney (Colorado State University)**

**On behalf of the DUNE Collaboration**

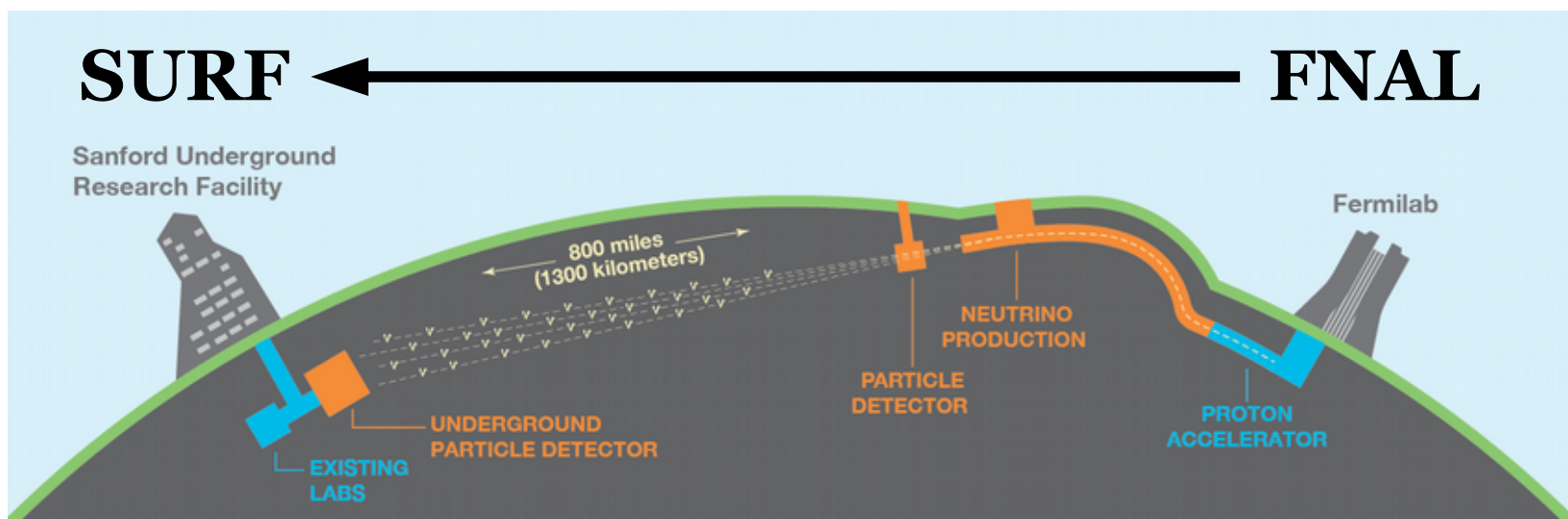
*40<sup>th</sup> International Conference on High Energy Physics  
July 28<sup>th</sup>, 2020*

◆ “Deep Underground Neutrino Experiment”

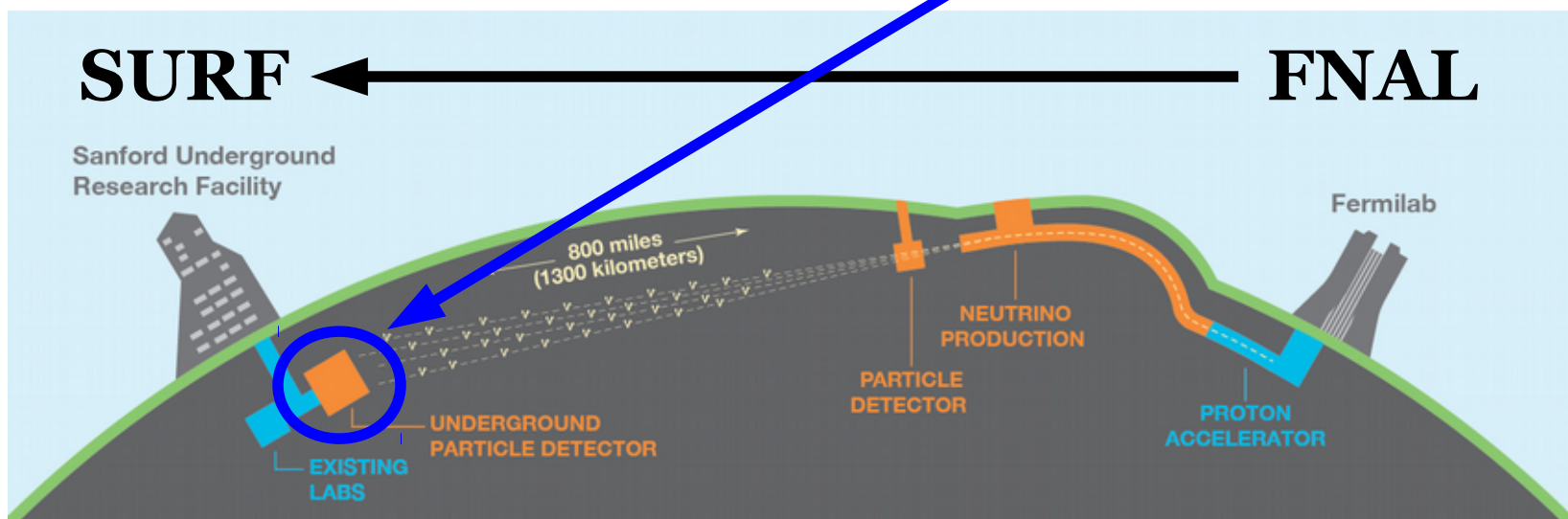
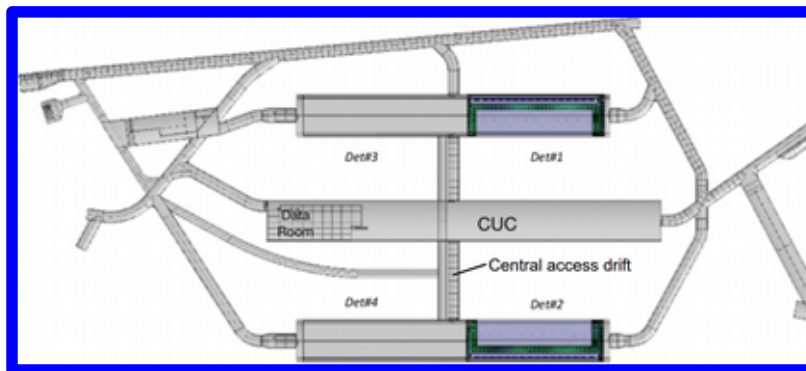
- 1300 km baseline
- Large (70 kt) LArTPC **far detector** 1.5 km underground
- **Near detector** w/ LAr component

◆ Primary physics goals:

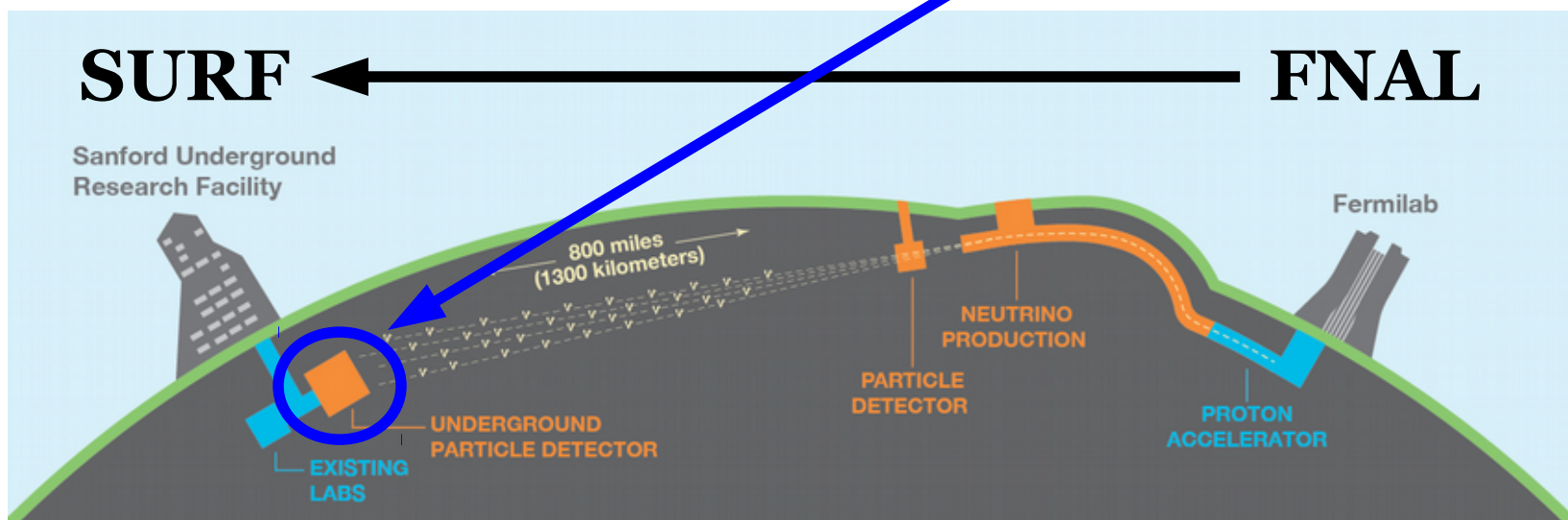
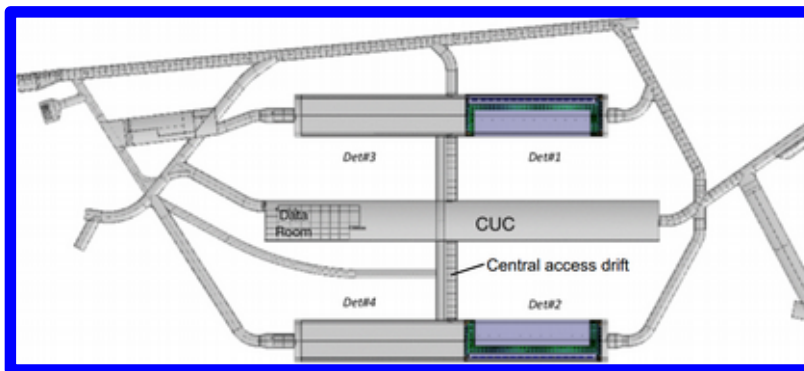
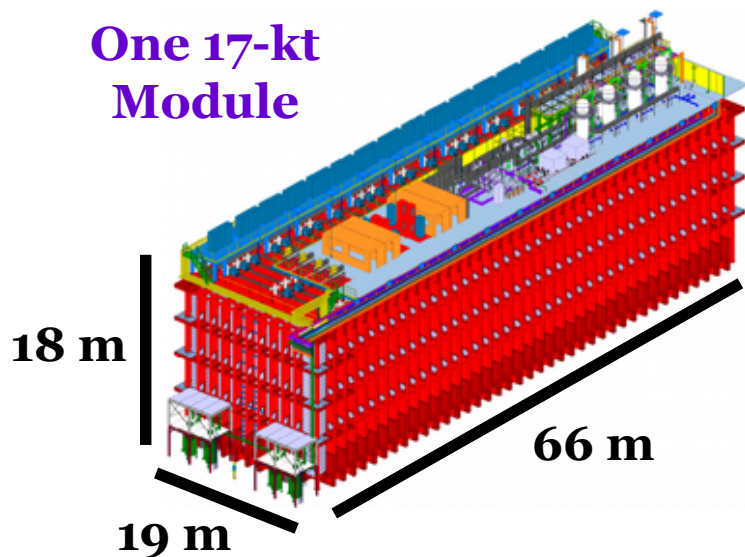
- $\nu$  oscillations ( $\nu_\mu/\bar{\nu}_\mu$  disappearance,  $\nu_e/\bar{\nu}_e$  appearance)
  - $\delta_{CP}, \theta_{23}, \theta_{13}$
  - **Ordering of  $\nu$  masses**
- Supernova burst neutrinos
- BSM processes (baryon number violation, NSI, etc.)



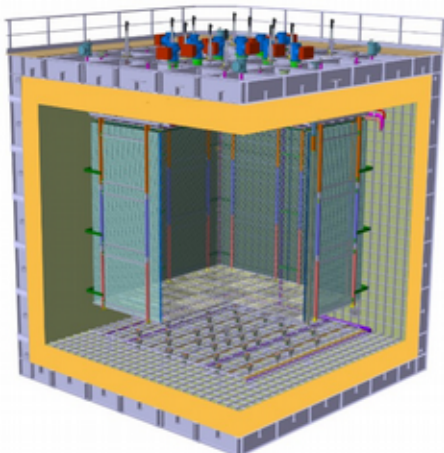
## The DUNE Far Detector: Four LArTPC Detector Modules



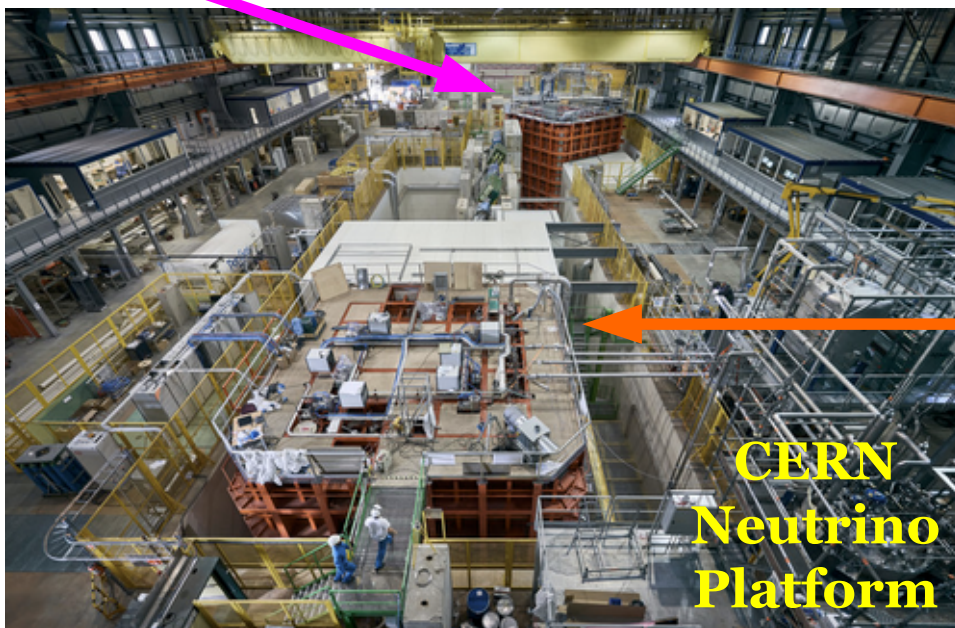
One 17-kt Module



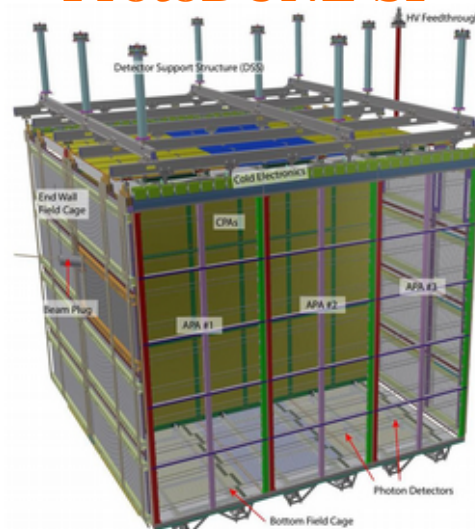
## ProtoDUNE-DP

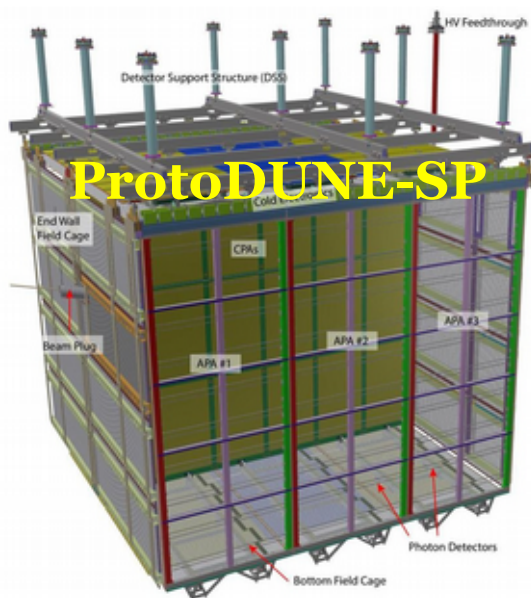


- ◆ Two 1-kt “ProtoDUNE<sub>s</sub>” in charged test beam at CERN (one per FD design)
- ◆ Test of component installation, commissioning, and performance
- ◆ ProtoDUNE-SP operating since 2018; ProtoDUNE-DP since 2019

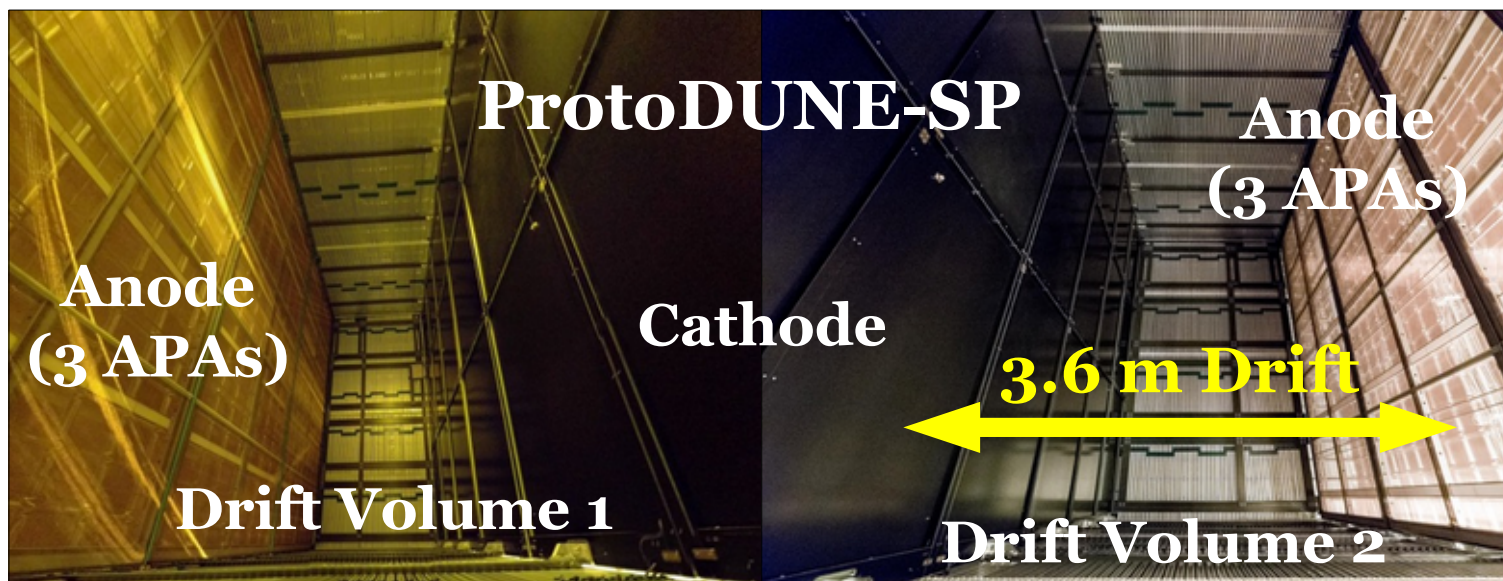


## ProtoDUNE-SP

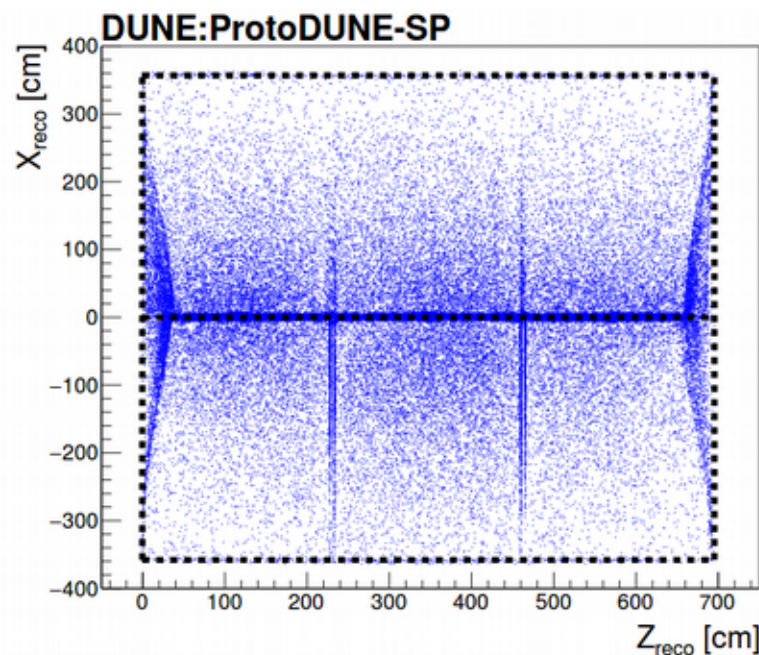
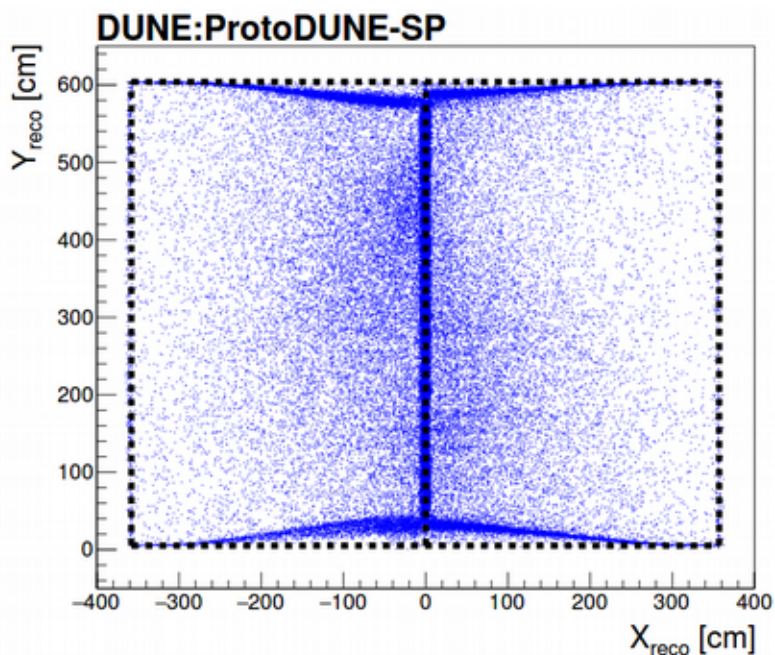




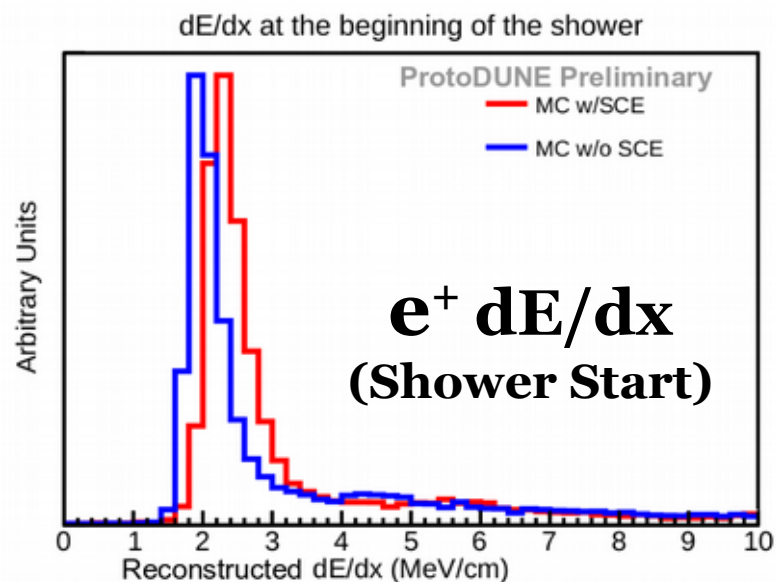
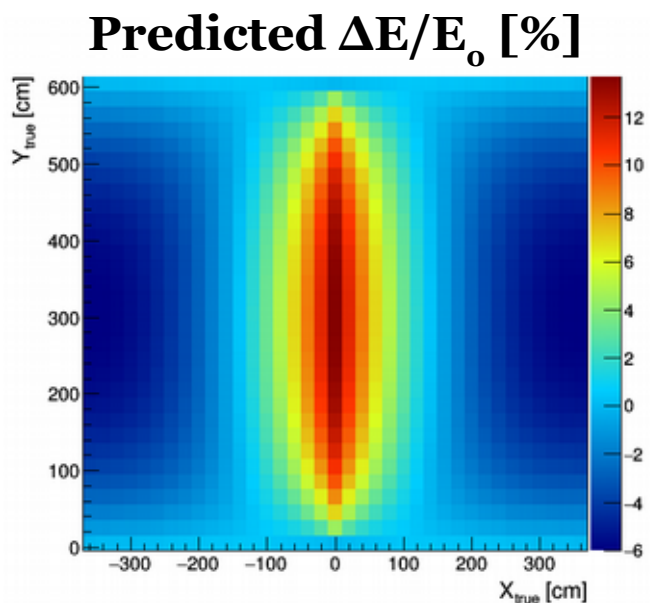
- ◆ Two 1-kt “ProtoDUNE<sub>s</sub>” in charged test beam at CERN (one per FD design)
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- ◆ Looking at first cosmic data, notice offsets in track entry/exit points from top/bottom of TPC
  - Very suggestive of space charge effects (SCE) **as expected** given that ProtoDUNE-SP is located near the surface
  - **Space charge:** build-up of slow-moving  $\text{Ar}^+$  ions due to e.g. cosmic muons impinging active volume of TPC (via ionization)



- ◆ SCE leads to E field distortions, distortions in reconstructed ionization position
- ◆ Can bias particle reconstruction in several ways:
  - Location of reconstructed charge – from spatial distortions
  - Particle energies – from E field distortions (recombination impact)
  - Particle  $dE/dx$  – from both E field and spatial distortions





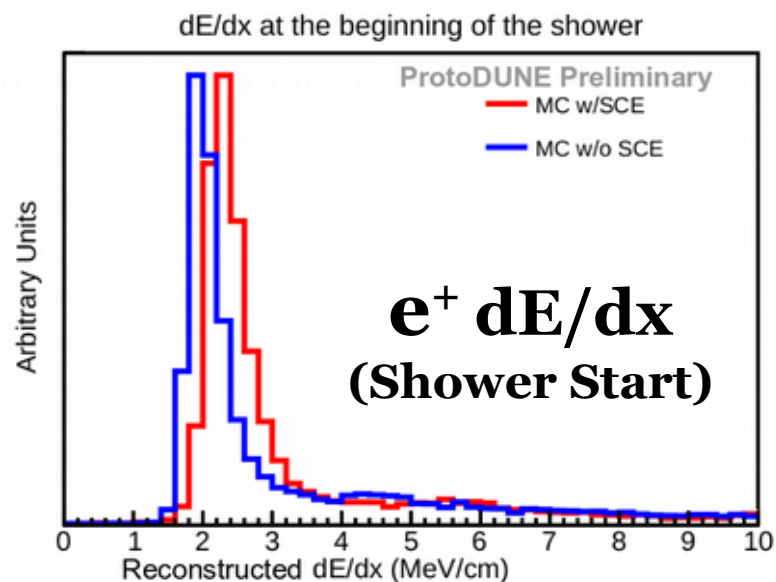
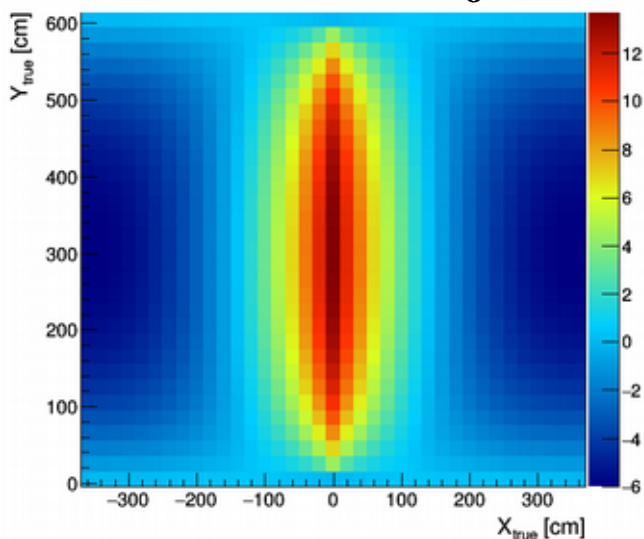
# Impact of SCE

$$\frac{dE}{dx} = f \left( \frac{dQ}{dx}, |\vec{E}| \right)$$

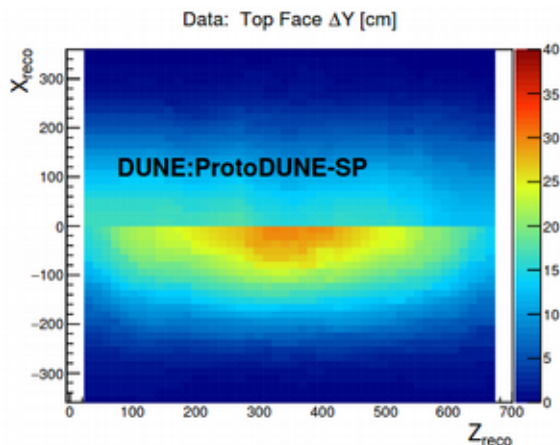
Impacted by SCE via  
*Spatial Distortions*

Impacted by SCE via  
*E Field Distortions*

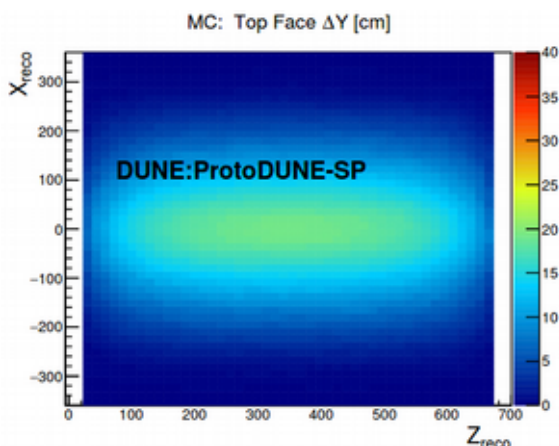
**Predicted  $\Delta E/E_0$  [%]**



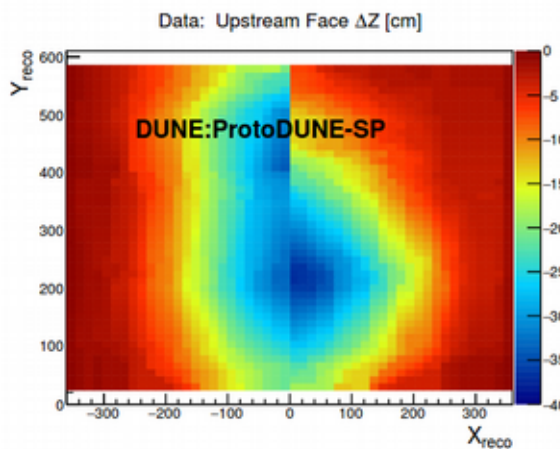
**Data:**  
TPC Top



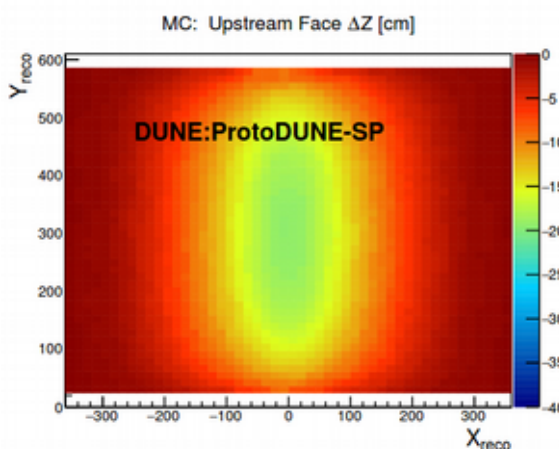
**Prediction:**  
TPC Top



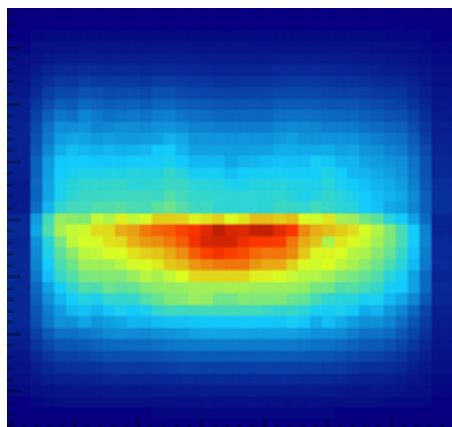
**Data:**  
TPC Front



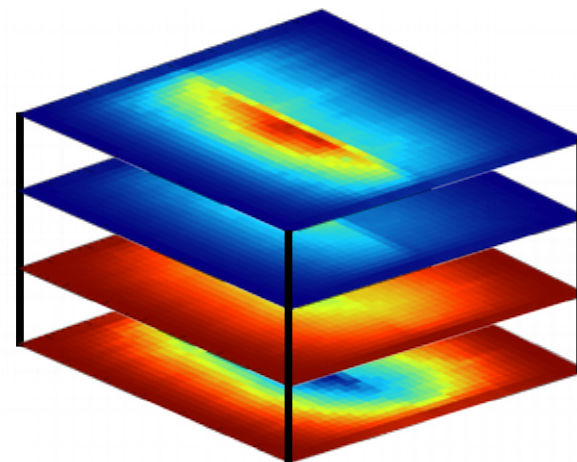
**Prediction:**  
TPC Front



- ◆ Probe spatial offsets at TPC faces w/ cosmic track entry/exit points
- ◆ SCE **50-75% larger** than initial prediction – up to 35 cm
  - Asymmetries likely due to argon flow (not included in prediction)

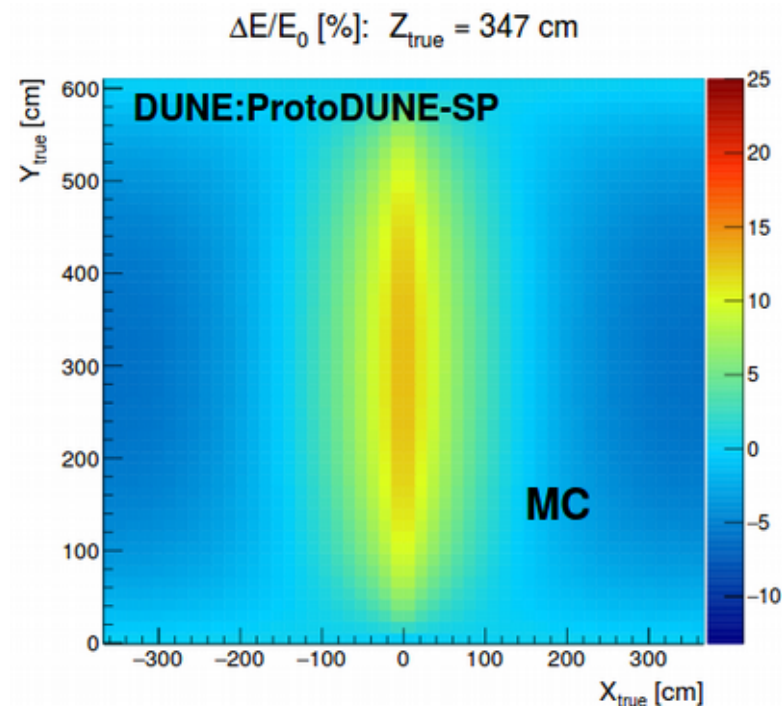
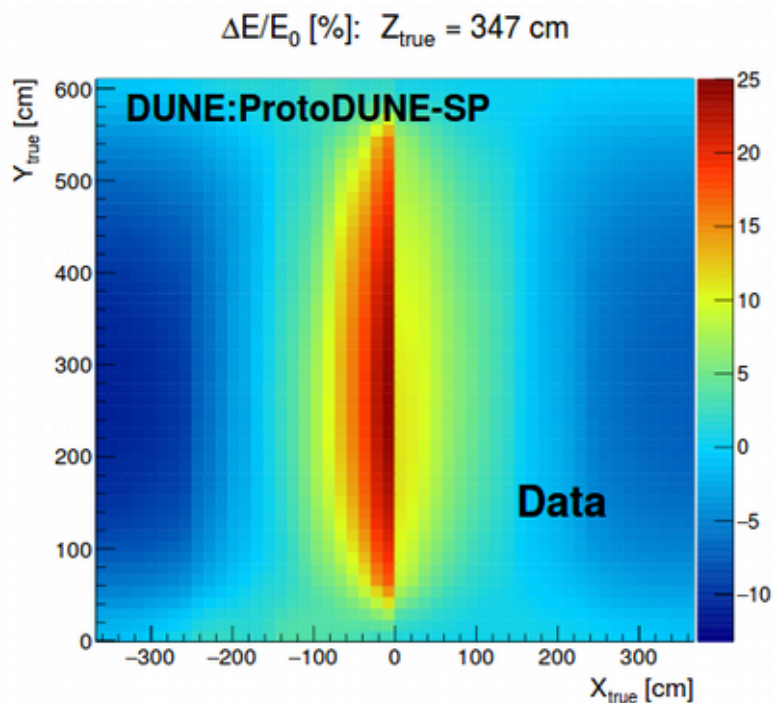


2D Maps at TPC Faces



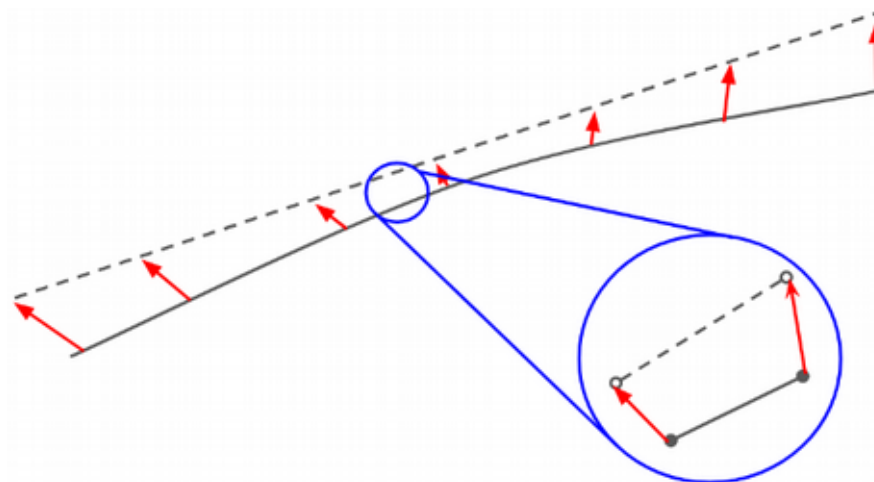
3D Maps in TPC Bulk

- ◆ Have robust estimation of spatial offsets at TPC faces (2D) using cosmic muon entry/exit points
- ◆ Scale **predicted** 3D spatial distortion map with data/MC scale factors at TPC faces, linearly interpolated across TPC
- ◆ With 3D spatial distortion map in hand, simple to calculate local drift velocity everywhere (**arXiv:1910.10430**)
  - Then use drift velocity model,  $v(E)$ , to extract E field distortions



- ◆ Product of 3D calibration: E field map throughout TPC
  - Use this “data-driven” E field map in **improved MC simulation**
- ◆ Nearly 25% higher E field near cathode than nominal E field
  - Reminder: nominal E field is 500 V/cm
  - That means E field near cathode **greater than 600 V/cm!**

- ◆ Case study: SCE corrections to particle  $dE/dx$ 
  - $dE/dx$  vs. residual range used for particle ID – important to eliminate bias in this quantity
- ◆ Correct two separate impacts of SCE:
  - **Spatial distortions** – correct for spatial “squeezing/stretching” of reconstructed charge (impacts “ $dx$ ” in calculation)
  - **E field distortions** – correct for E field dependence of electron-ion recombination (reduces “free charge” that drifts to wire)



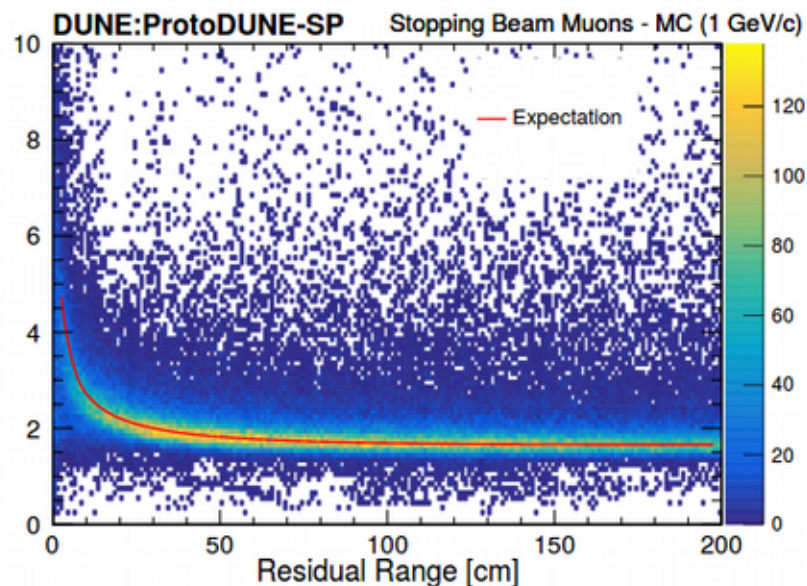
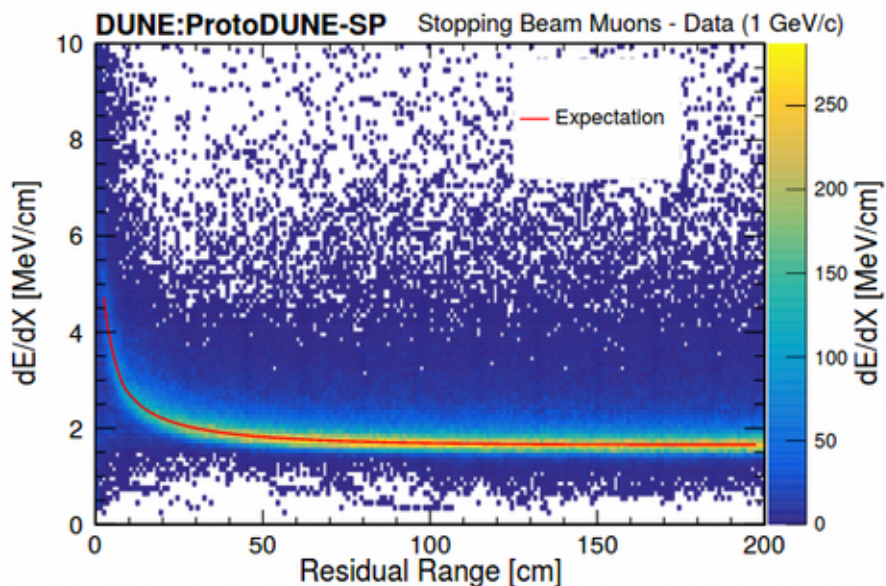
**Spatial  
Distortion  
Correction**

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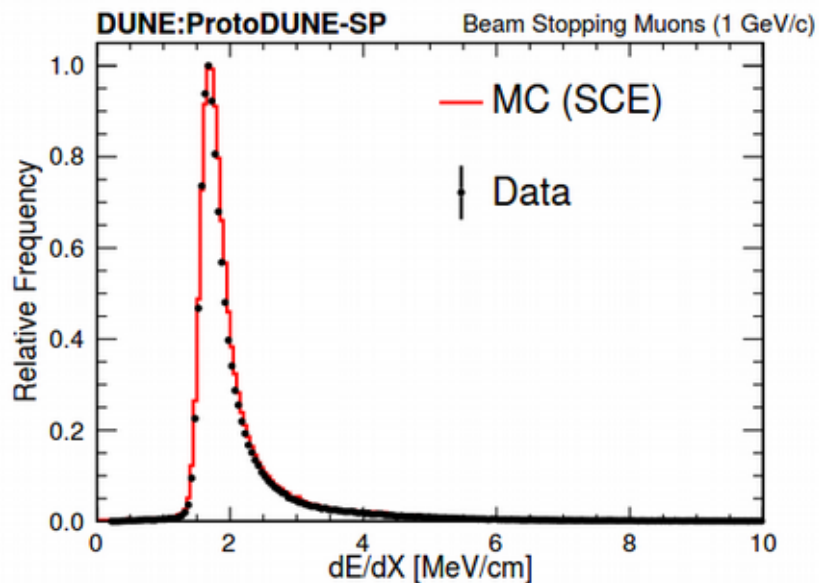
Impacted by SCE via  
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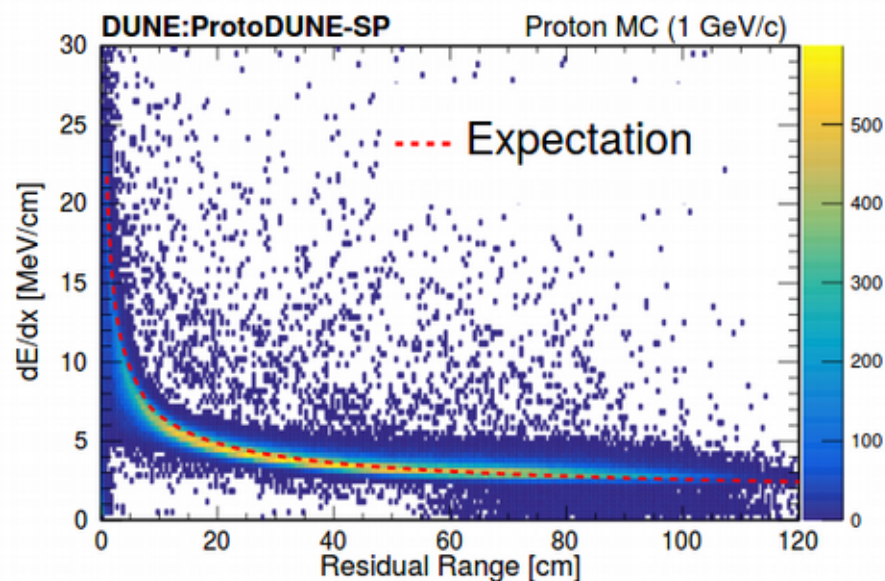
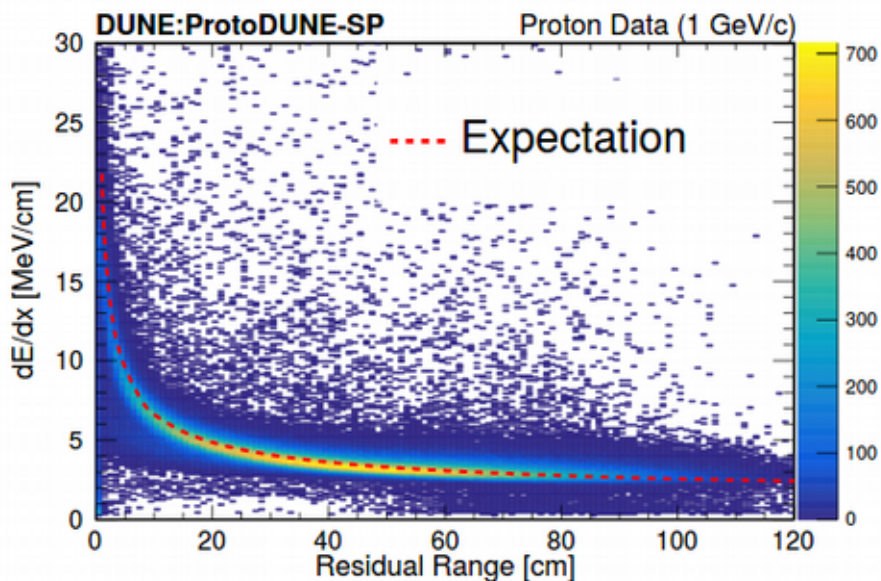
Impacted by SCE via  
*E Field Distortions*



**Other Energy Scale  
Corrections Included**

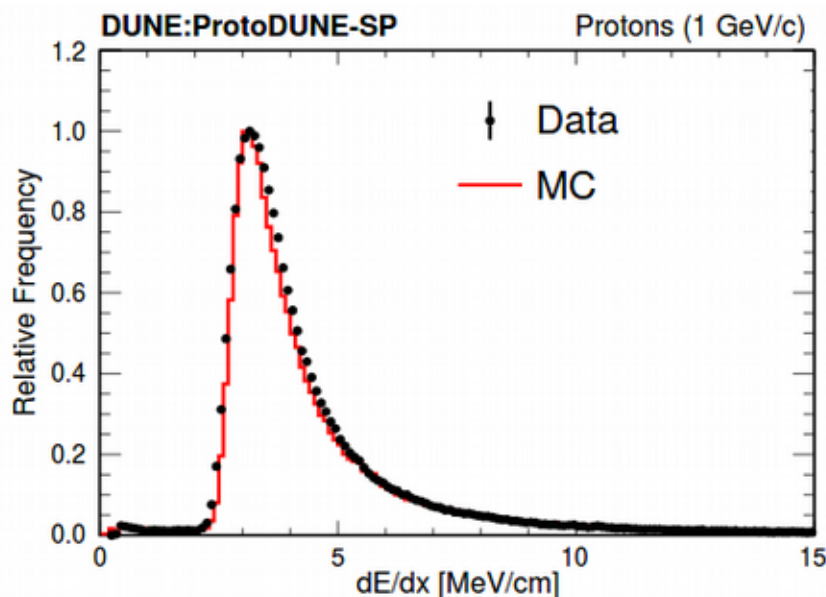
**See Richie Diurba's  
Talk on Energy Scale  
Calibrations at  
ProtoDUNE-SP**





**Other Energy Scale  
Corrections Included**

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Talk on Energy Scale  
Calibrations at  
ProtoDUNE-SP**





- ◆ Presented first measurement of space charge effects at ProtoDUNE-SP
  - Up to 35 cm of transverse spatial distortions from TPC edges
  - E field distortions as large as 25% of nominal E field near cathode
- ◆ SCE calibration for particle  $dE/dx$  presented – performs well
- ◆ Results presented here summarized in forthcoming paper
  - “First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform” – [arXiv:2007.06722](https://arxiv.org/abs/2007.06722) (submitting to JINST)
- ◆ Preparing dedicated SCE publication including improved 3D calibration, systematic uncertainty analysis, and time dependence studies

