

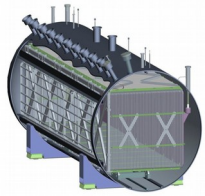
Space Charge Effects in LArTPCs

Michael Mooney

Colorado State University

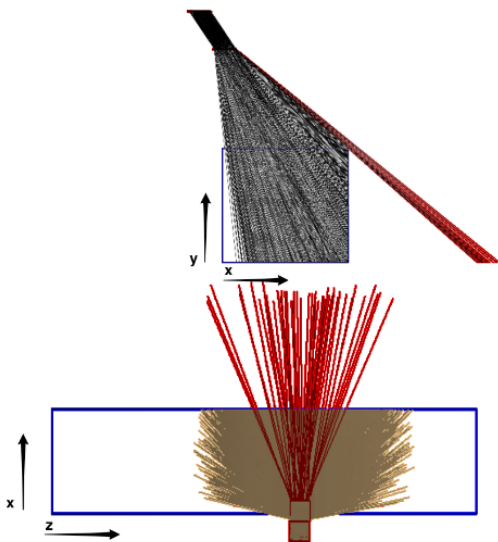
Workshop on Calibration and Reconstruction for LArTPC Detectors

December 10th, 2018

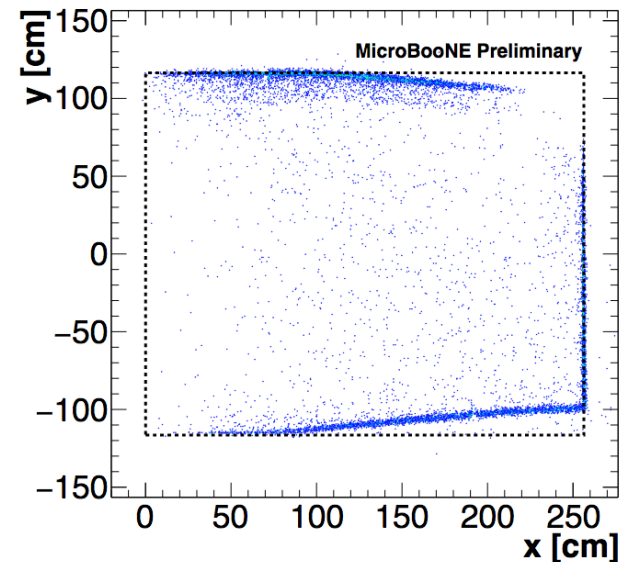


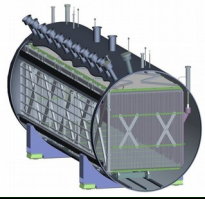
Introduction

- ◆ Space Charge Effect (SCE): distortion of E field and ionization drift trajectories due to build-up of slow-moving argon ions produced from e.g. cosmic muons impinging TPC → modifies dQ/dx , track angles
 - E field distortions impact recombination (**dQ** bias)
 - Spatial distortions lead to squeezing of charge (**dx** bias)
- ◆ See **MicroBooNE public note on SCE** for more details



t_0 tags
from
MicroBooNE
MuCS
→
plot TPC track
start/end points

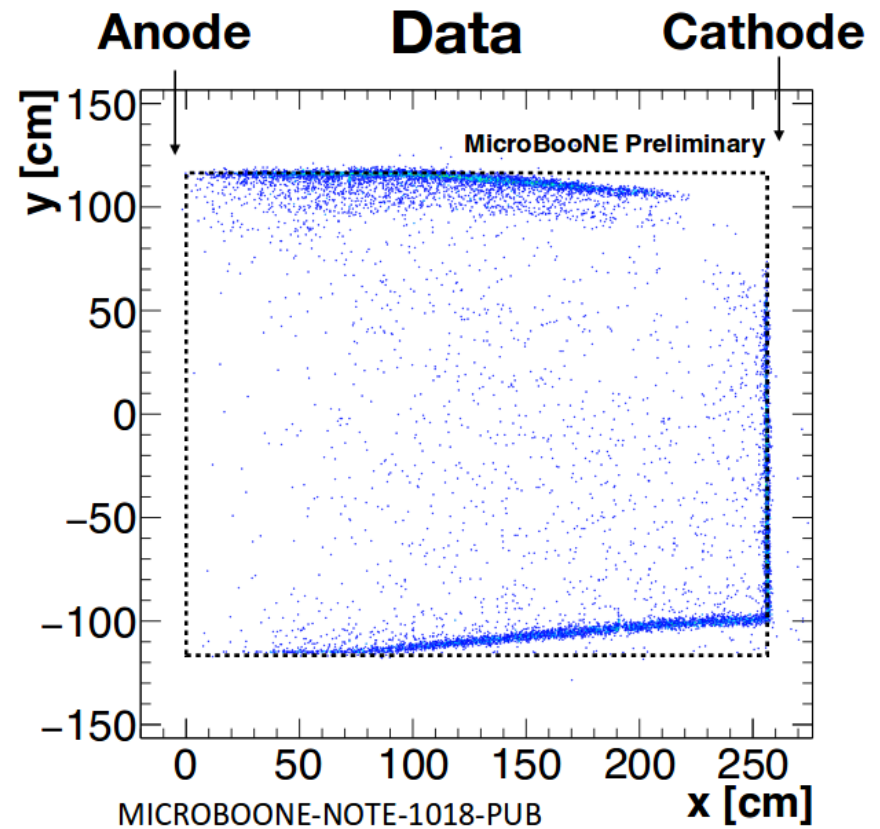


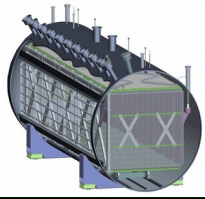


SCE at MicroBooNE



- ◆ Reminder: nominal electric field at μ BooNE is **273 V/cm**
- ◆ Argon ions take **~ 8 minutes** to drift from anode to cathode
- ◆ Maximum E field distortion: **$\sim 15\%$**
- ◆ Maximum spatial distortion: **~ 15 cm**
 - Complicates TPC containment cuts
- ◆ Impact on dQ/dx : **$\sim 10\%$**
 - Complicates particle ID

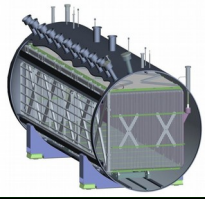




SCE Simulation



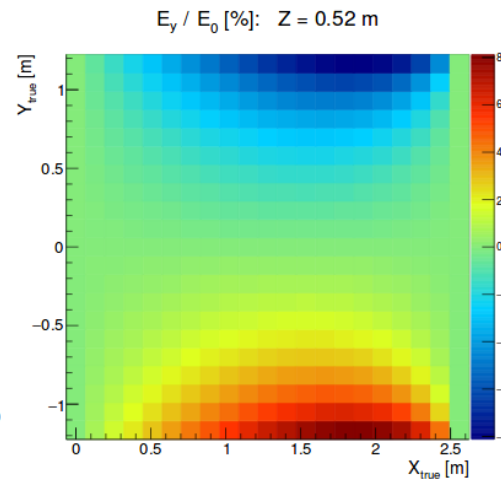
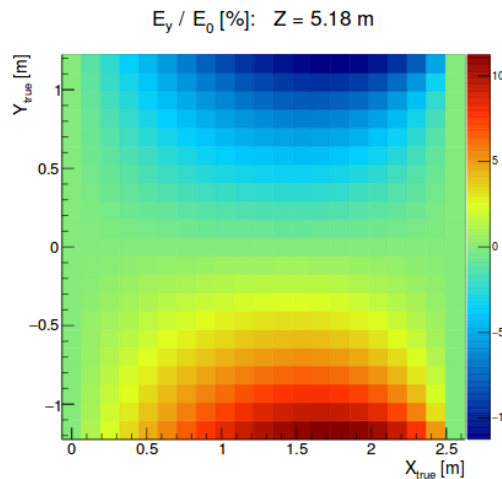
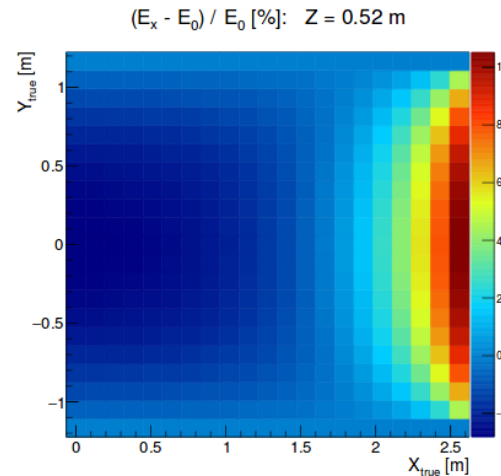
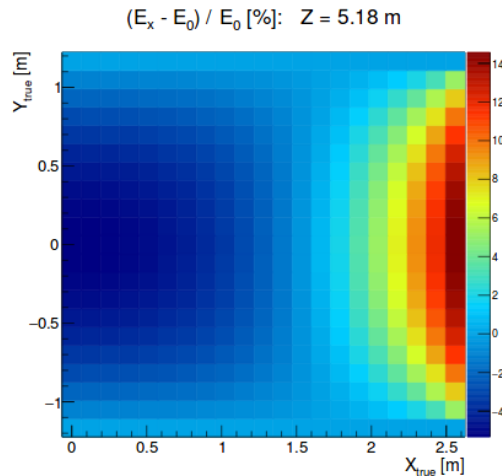
- ◆ In order to comprehensively study SCE at LArTPC experiments, developed dedicated SCE simulation
 - **SpaCE** - Space Charge Estimator
- ◆ Primary features:
 - Obtain E fields analytically on 3D grid via Fourier series
 - Interpolate between grid points using radial basis functions to find E field distortion map throughout TPC
 - Use ray-tracing with RKF45 to obtain spatial distortion map (Δx , Δy , Δz) throughout TPC
- ◆ Standard use: assume linear positive ion distribution (zero at anode, maximum at cathode)
 - Also works with arbitrary space charge density map as input; useful for fluid-flow studies



SCE Sim. Results: E field

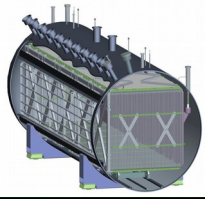


**Near TPC
Center**



**Near TPC
Edge (in z)**

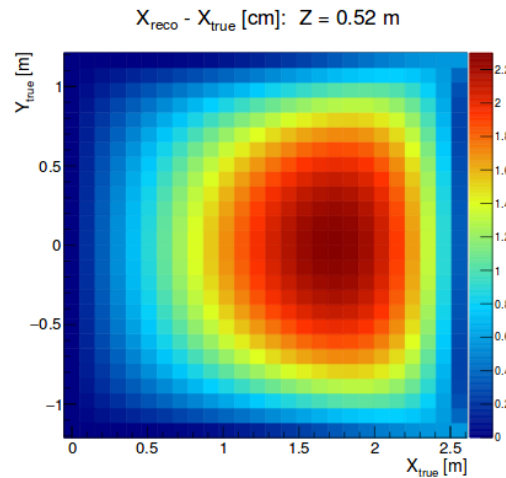
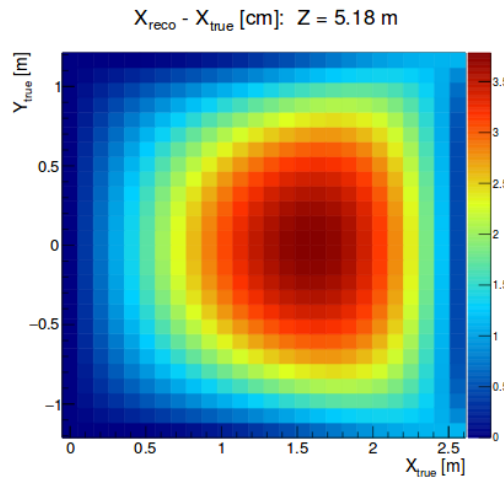
- ◆ Results shown for MicroBooNE (linear SC profile)
 - In these plots, $E_0 = 273$ V/cm; sign flip in E_y/E_0 plots



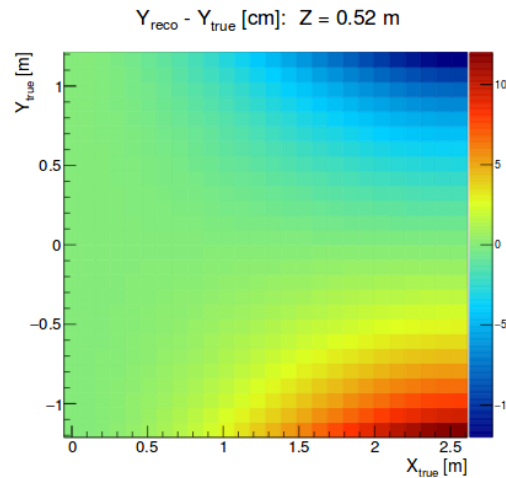
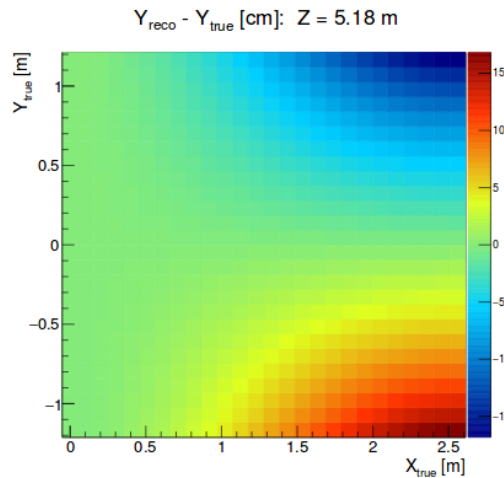
SCE Sim. Results: Spatial



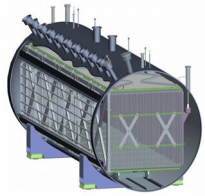
**Near TPC
Center**



**Near TPC
Edge (in z)**



◆ Results shown for MicroBooNE (linear SC profile)

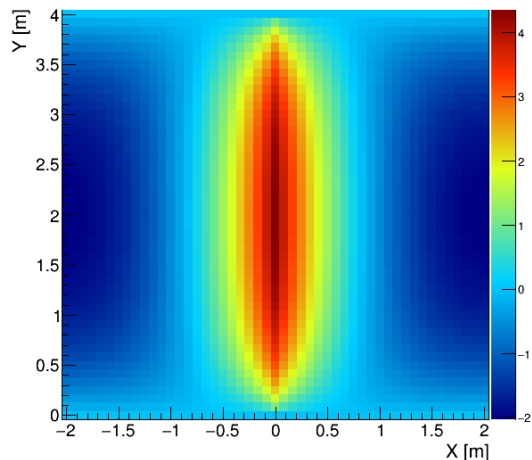


SBN/ProtoDUNE SCE Sim.



SBND

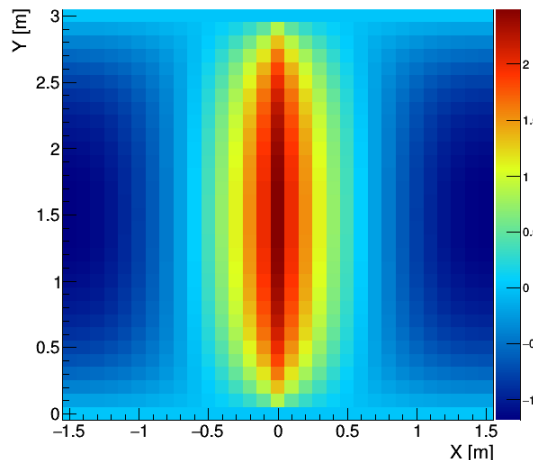
$\Delta E_x/E_{\text{drift}} [\%]: Z = 2.50 \text{ m}$



E_x

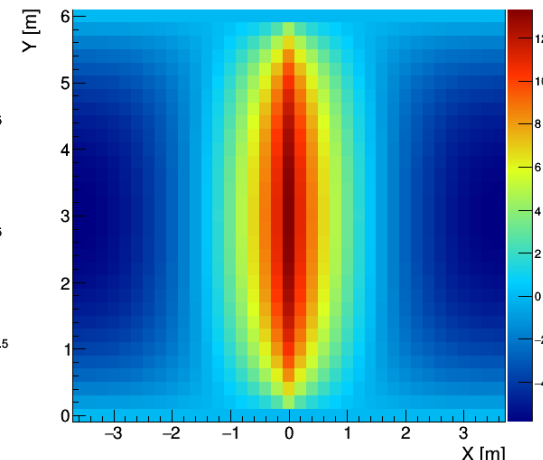
ICARUS

$\Delta E_x/E_{\text{drift}} [\%]: Z = 9.00 \text{ m}$

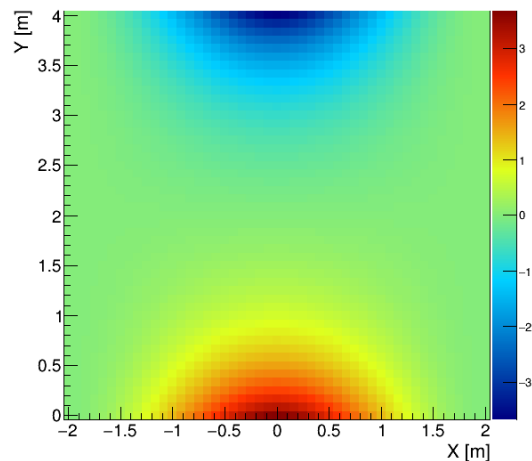


ProtoDUNE-SP

$\Delta E_x/E_{\text{drift}} [\%]: Z = 3.60 \text{ m}$

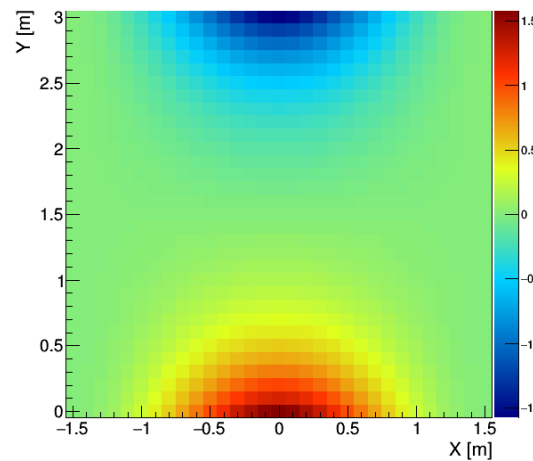


$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]: Z = 2.50 \text{ m}$

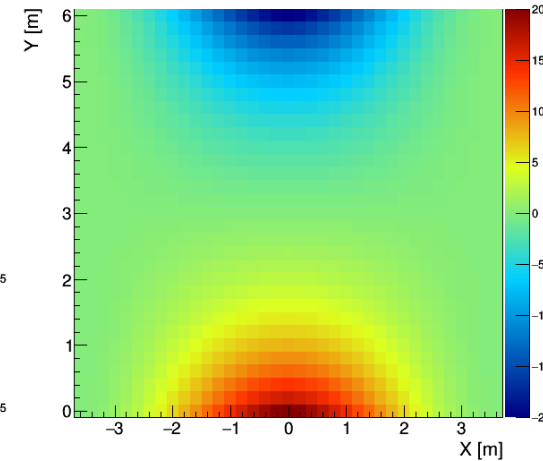


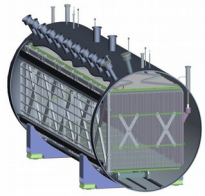
Δy

$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]: Z = 9.00 \text{ m}$



$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]: Z = 3.60 \text{ m}$



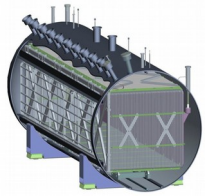


Detector Comparison

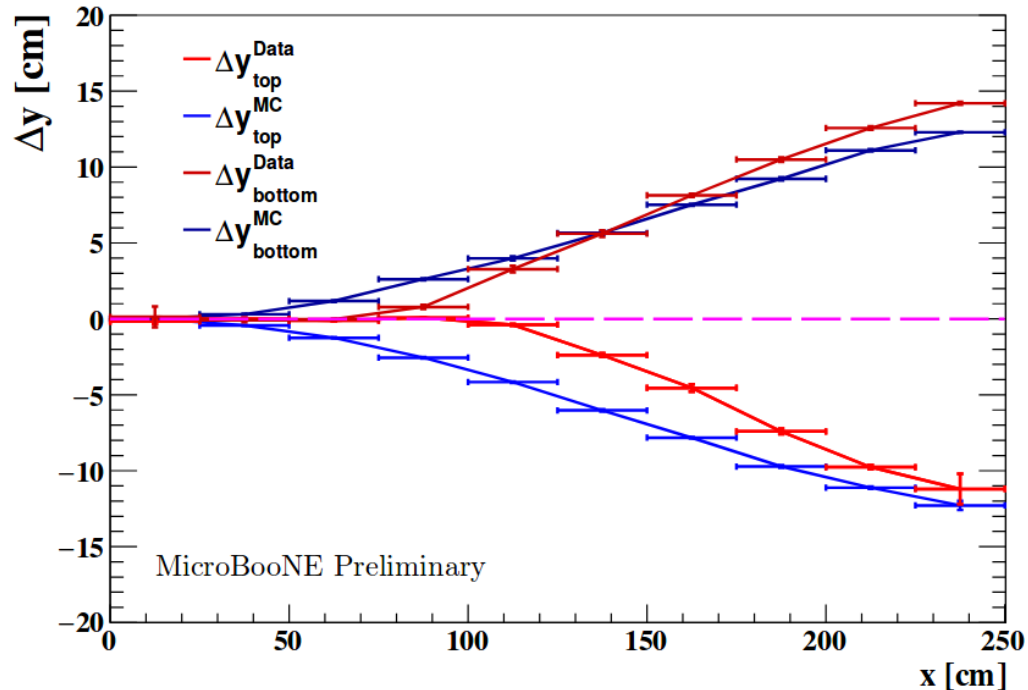


Experiment	E Field	Drift Length	Max E Field Distortion	Max Spatial Distortion
MicroBooNE	273 V/cm	2.5 m	~15%	~15 cm
SBND	500 V/cm	2.0 m	~5%	~5 cm
ICARUS	500 V/cm	1.5 m	~2%	~2 cm
ProtoDUNE-SP	500 V/cm	3.6 m	~15%	~20 cm

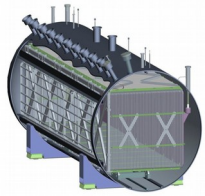
- ◆ Comparison of SCE at different running/future near-surface LArTPC detectors above
 - Roughly, spatial SCE offsets scale with D^3 , $E^{-1.7}$
- ◆ SCE worst at MicroBooNE and ProtoDUNE-SP
- ◆ SCE less bad at SBND and ICARUS, but likely not negligible



μ BooNE Data/MC Comp.



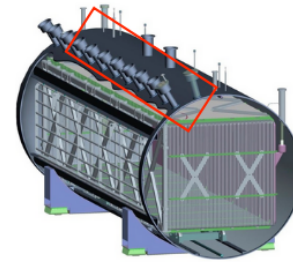
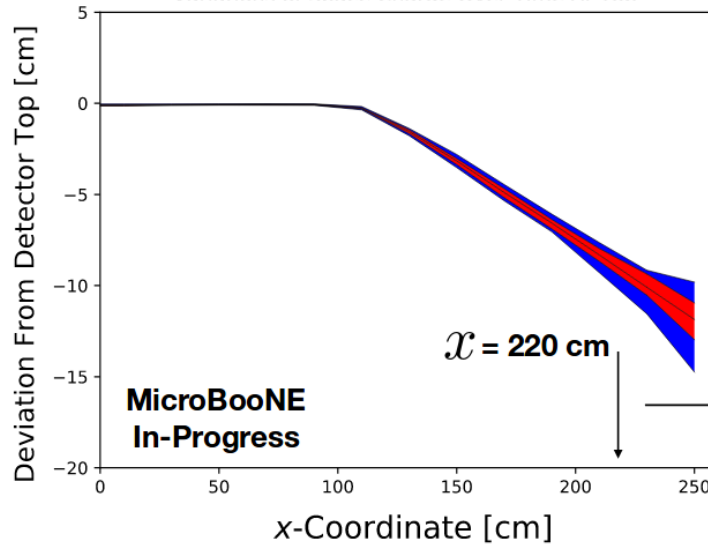
- ◆ Use t_0 -tagged cosmic tracks from MicroBooNE MuCS (Muon Counter System) to validate simulation using data
 - Look at spatial offsets from TPC top, bottom
- ◆ Simulation **close in magnitude and shape**, but some shape differences - effects from **LAr flow**?



Time Dependence @ μ BooNE

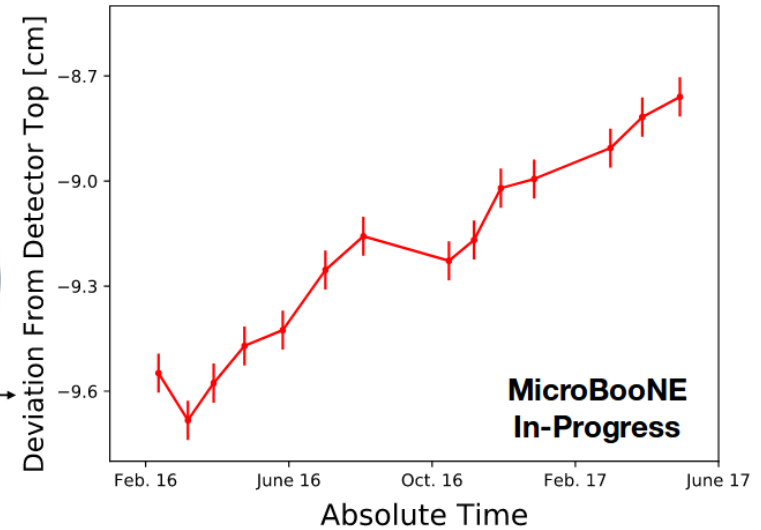


Offsets from TPC Top



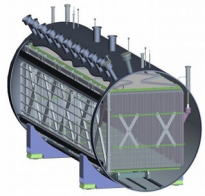
Variation over time shown in the next plot.

C. Barnes - New Perspectives 2018



The track distortions due to SCE are lessening at the detector top as a function of time.

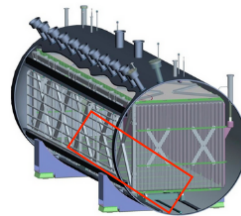
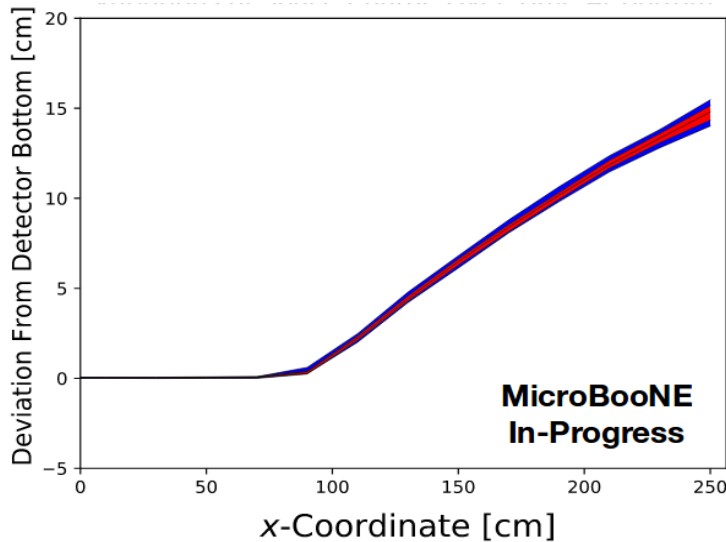
- ◆ Run-to-run variations: $\sim 5\%$ (minimal calib. systematic)
- ◆ Study of time dependence of SCE at MicroBooNE shows gradual mitigation of SCE over time near top of TPC
 - Is this effect the result of LAr flow changing over time?
- ◆ However, no systemic reduction of SCE at TPC bottom...



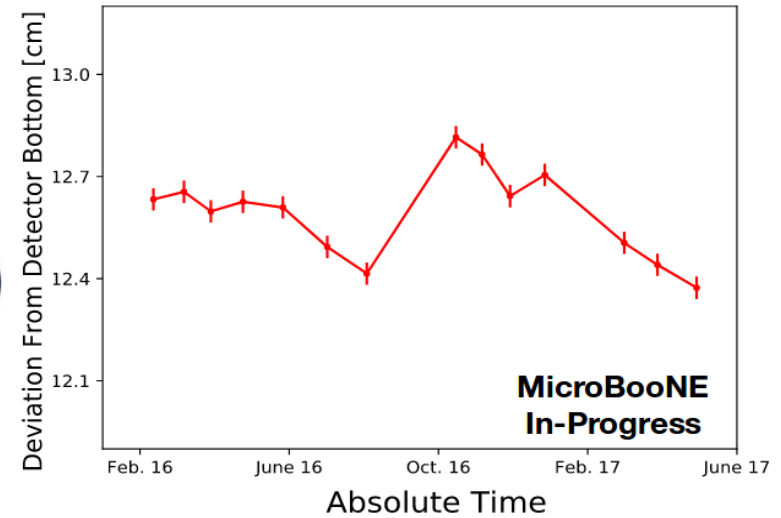
Time Dependence @ μ BooNE



Offsets from TPC Bottom



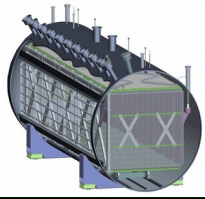
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68% Band
95% Band

There is no noticeable trend for the time dependence of the track distortions from SCE at the bottom in the righthand plot.

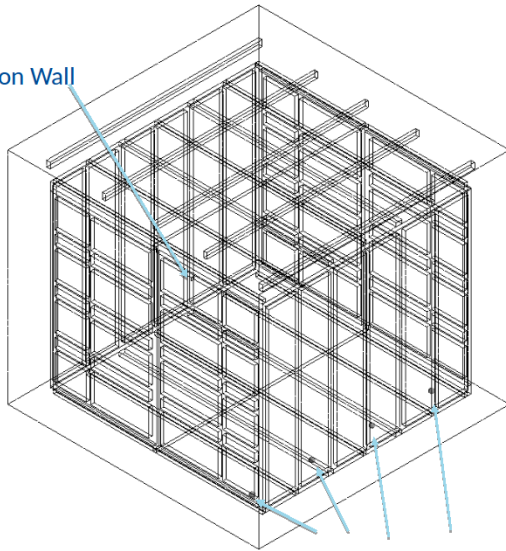
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ProtDUNE-SP LAr Flow Sim.



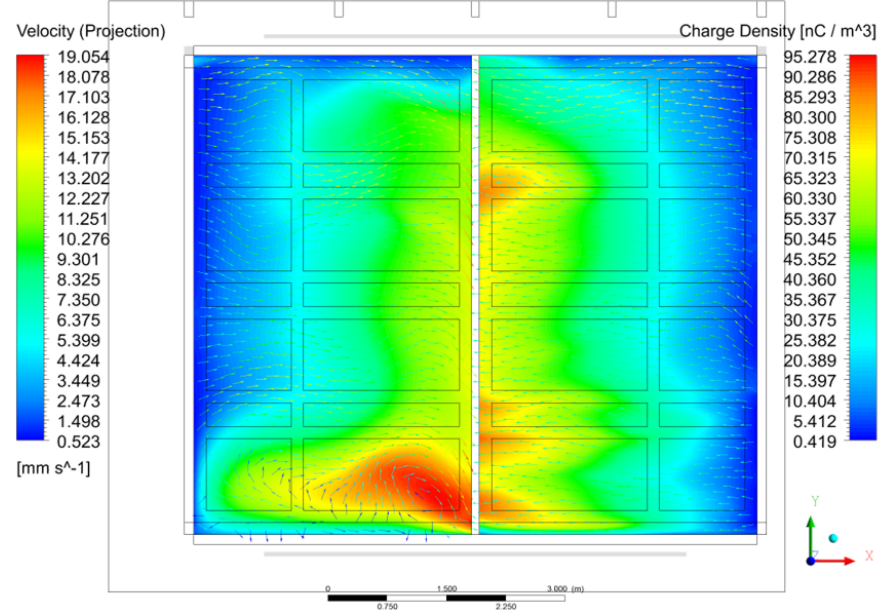
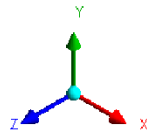
Pump Suction on Wall



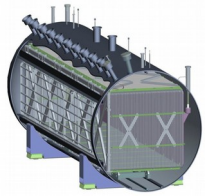
Discharges Spray in X direction @ 0.259 m/sec

Discharge Points (m)		
X	Y	Z
2.464	-3.49	2.753
2.464	-3.49	0.713
2.464	-3.49	-1.327
2.464	-3.49	-3.367

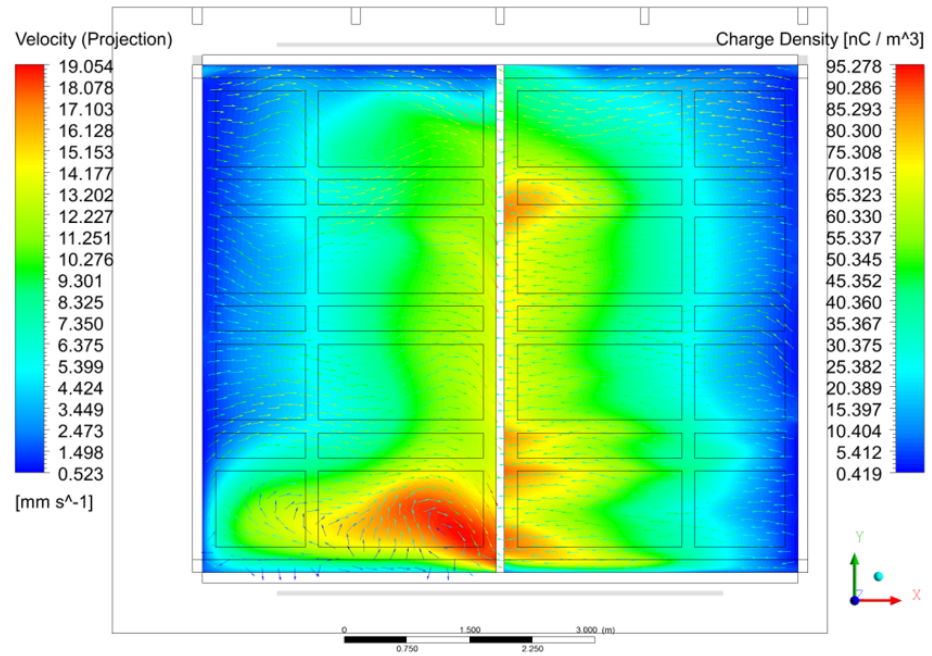
Suction Point (m)		
X	Y	Z
-4.64	-3.187	-2.243



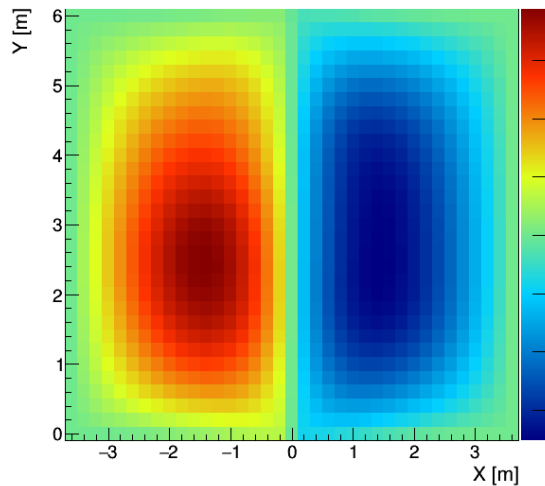
- ◆ Developed by Erik Voirin for ProtoDUNE-SP – better prediction of space charge density (input to **SpaCE**)
- ◆ 3D simulation of LAr flow, 8 mm/s ion drift @ 500 V/cm, uniform space charge deposition from cosmics
- ◆ Ion absorption at field cage, APA, CPA, and all solid objects inside cryostat



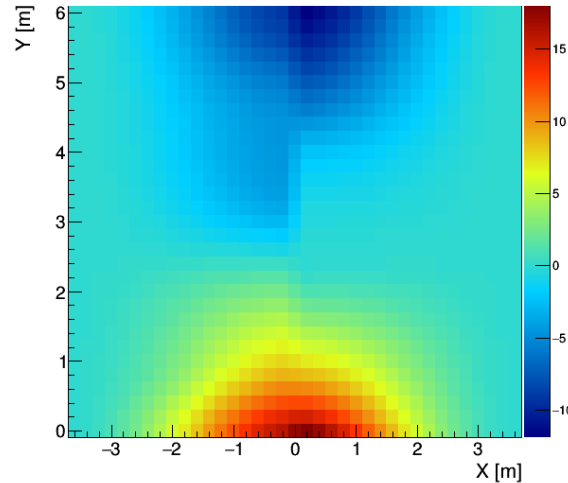
PD-SP Spatial Offsets: $Z = 3.6$ m



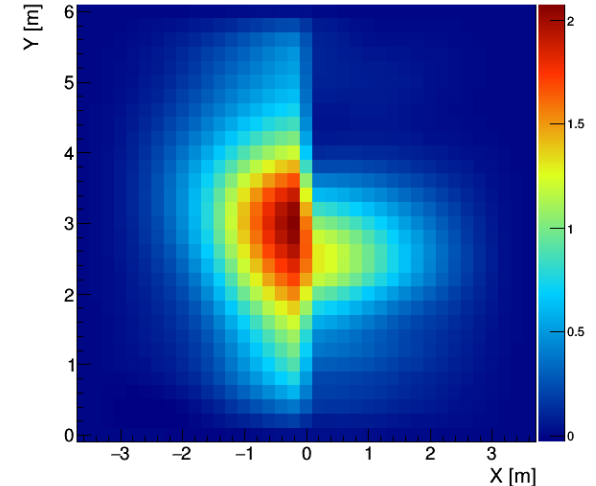
$X_{\text{reco}} - X_{\text{true}}$ [cm]: $Z = 3.60$ m

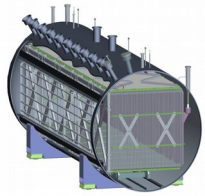


$Y_{\text{reco}} - Y_{\text{true}}$ [cm]: $Z = 3.60$ m



$Z_{\text{reco}} - Z_{\text{true}}$ [cm]: $Z = 3.60$ m

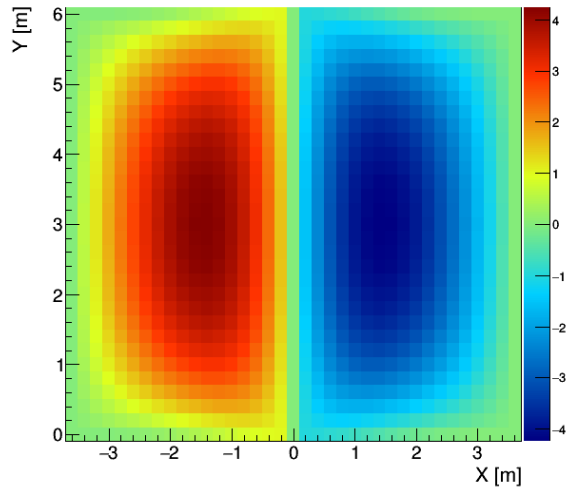




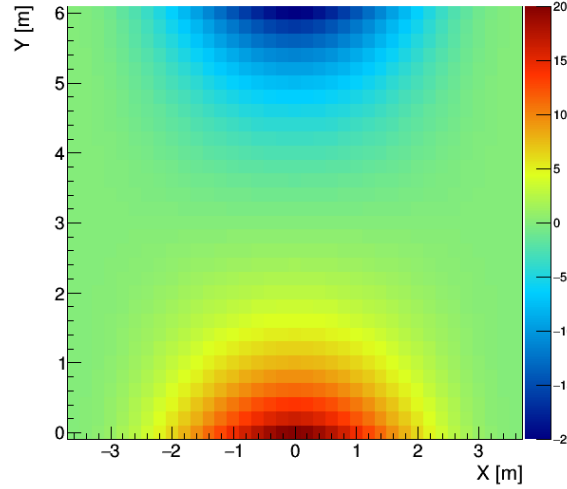
PD-SP Vs. No Flow: $Z = 3.6$ m



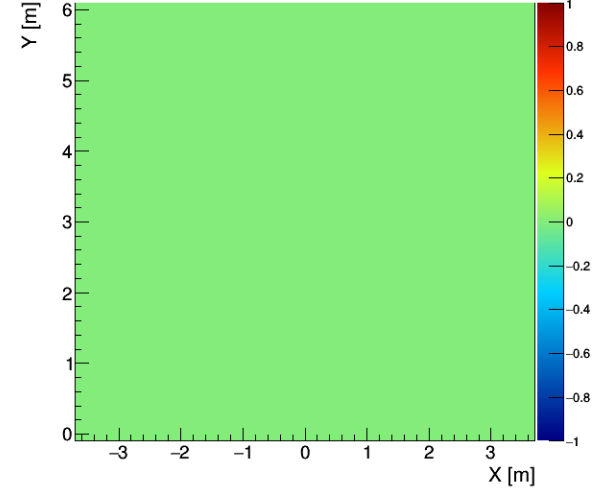
$X_{\text{reco}} - X_{\text{true}}$ [cm]: $Z = 3.60$ m



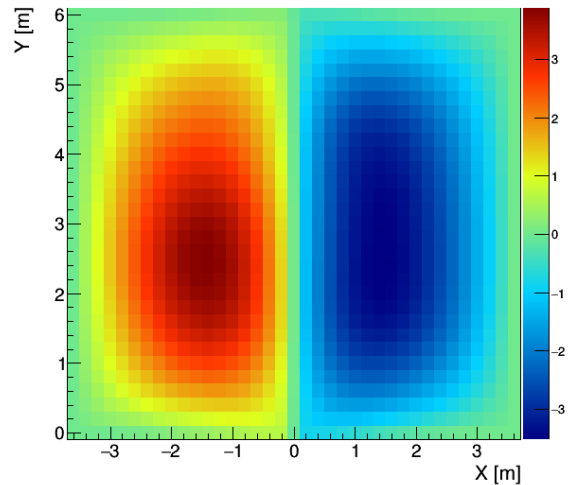
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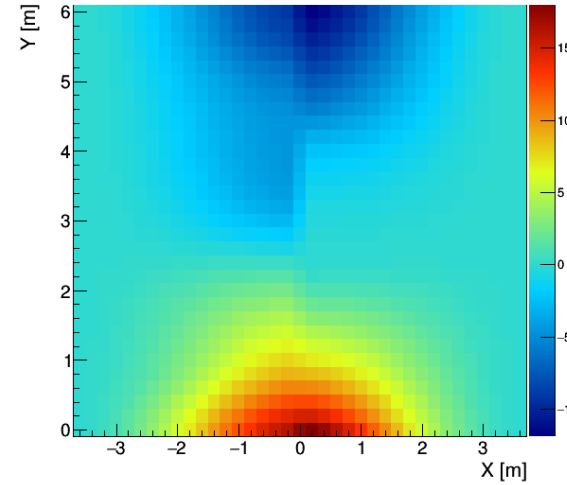
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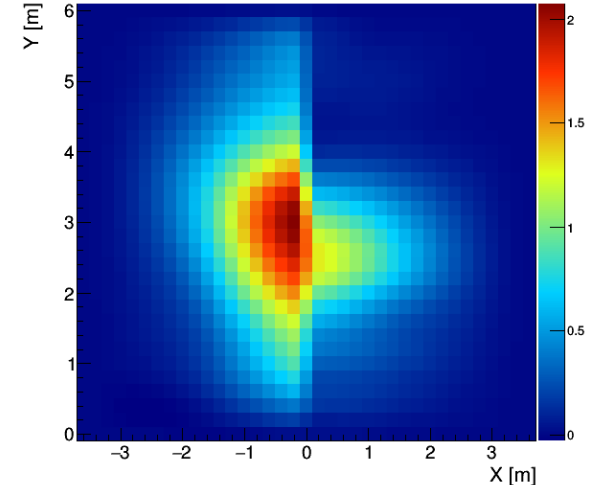
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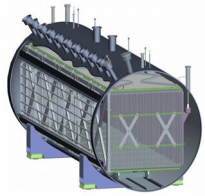


$Y_{\text{reco}} - Y_{\text{true}}$ [cm]: $Z = 3.60$ m

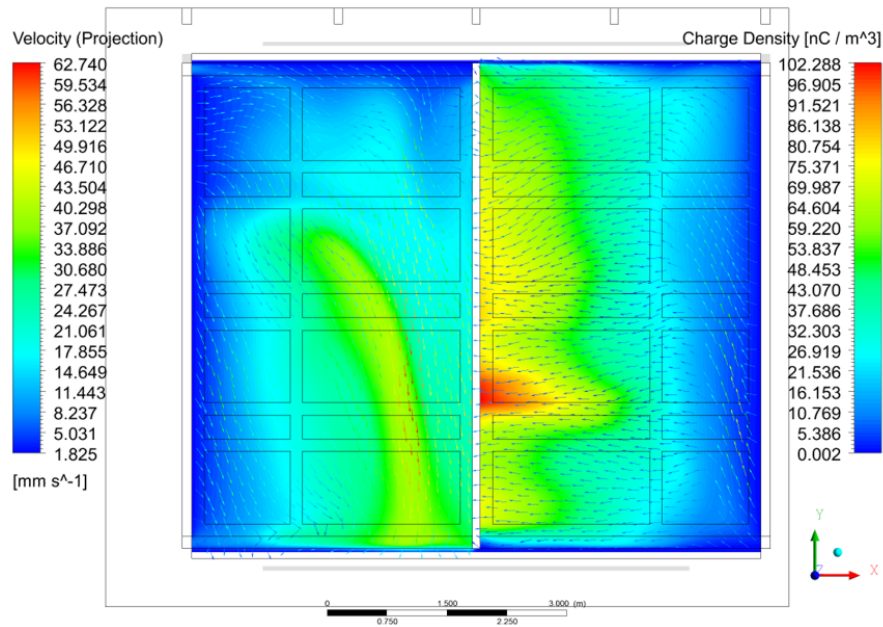


$Z_{\text{reco}} - Z_{\text{true}}$ [cm]: $Z = 3.60$ m

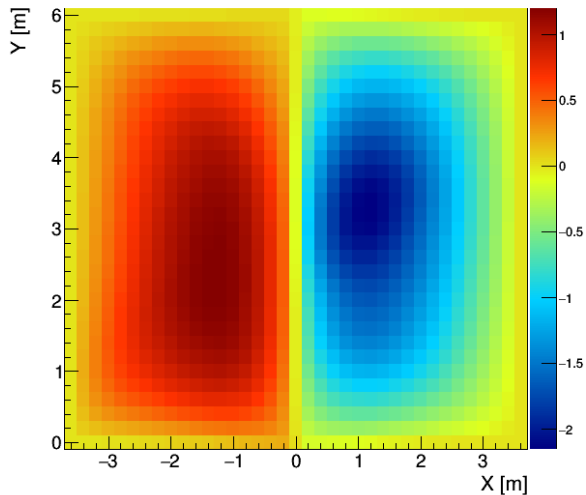




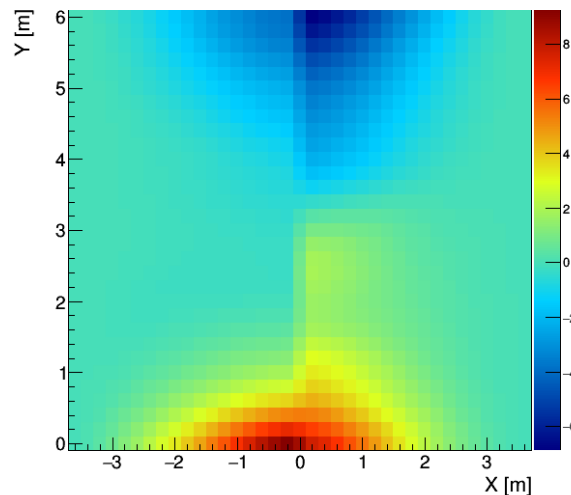
PD-SP Spatial Offsets: $Z = 0.6$ m



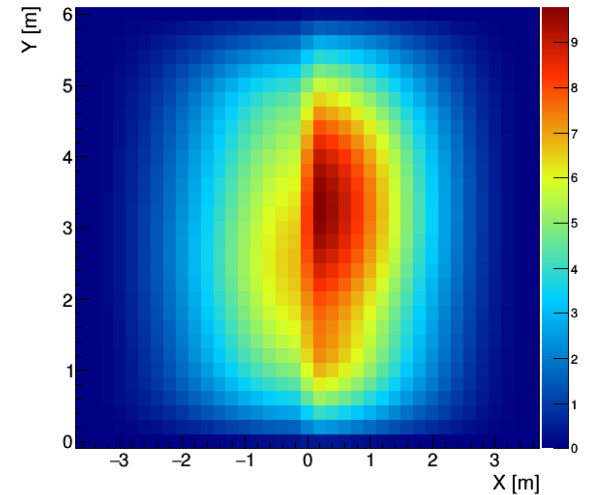
$X_{\text{reco}} - X_{\text{true}} [\text{cm}]$: $Z = 0.60$ m

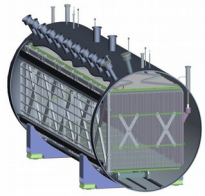


$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]$: $Z = 0.60$ m



$Z_{\text{reco}} - Z_{\text{true}} [\text{cm}]$: $Z = 0.60$ m

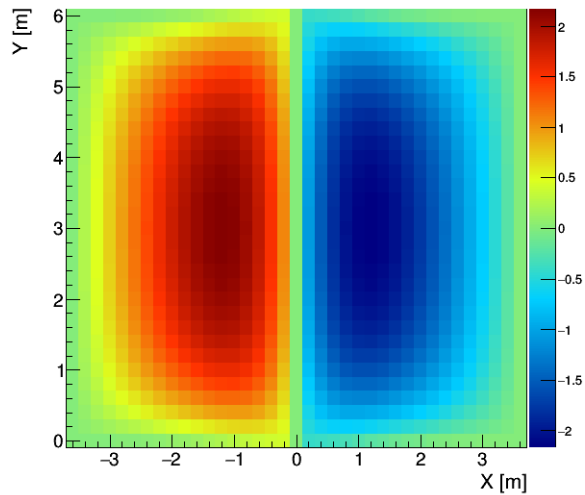




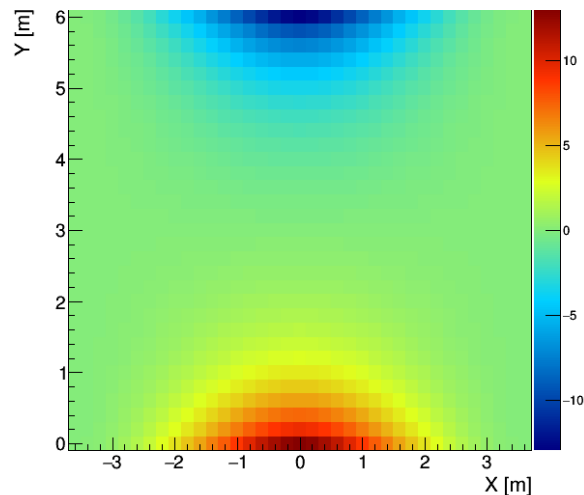
PD-SP Vs. No Flow: $Z = 0.6$ m



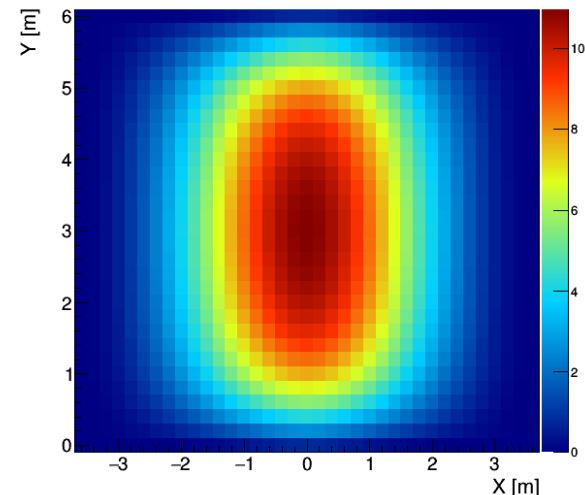
$X_{\text{reco}} - X_{\text{true}}$ [cm]: $Z = 0.60$ m



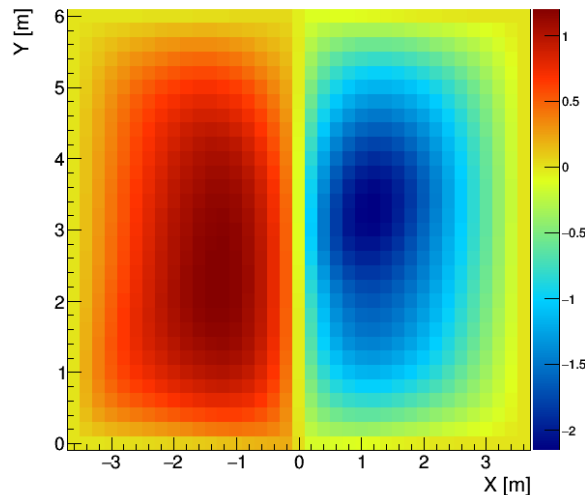
$Y_{\text{reco}} - Y_{\text{true}}$ [cm]: $Z = 0.60$ m



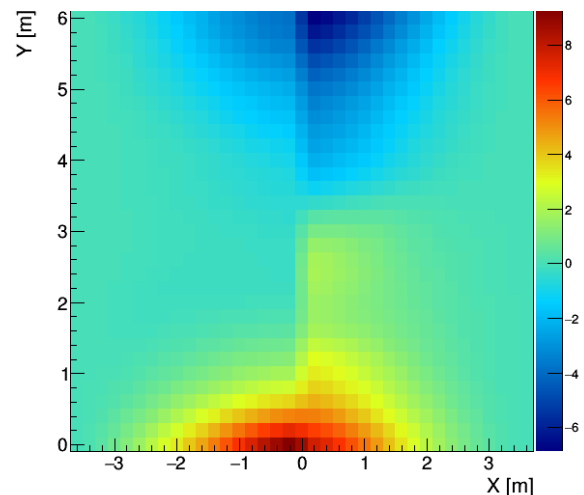
$Z_{\text{reco}} - Z_{\text{true}}$ [cm]: $Z = 0.60$ m



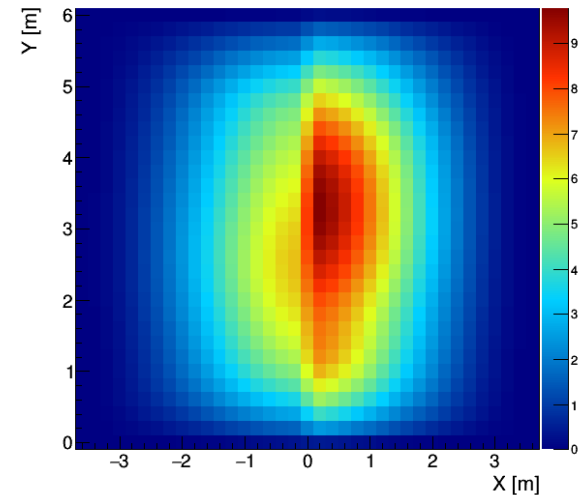
$X_{\text{reco}} - X_{\text{true}}$ [cm]: $Z = 0.60$ m

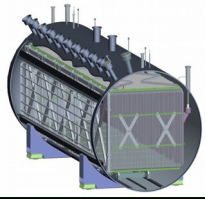


$Y_{\text{reco}} - Y_{\text{true}}$ [cm]: $Z = 0.60$ m



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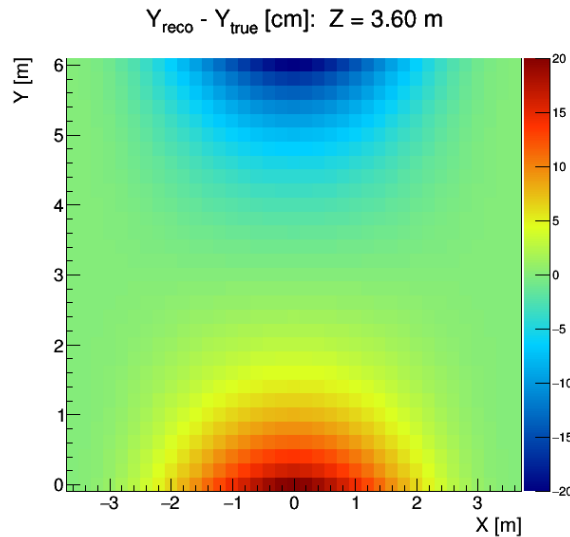




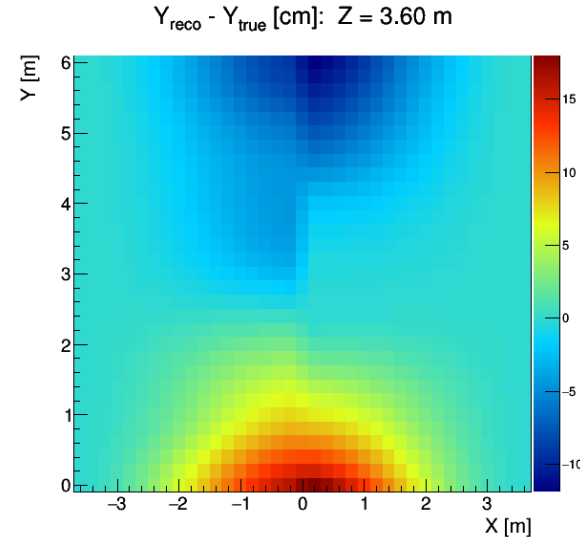
Fluid Flow Study Results



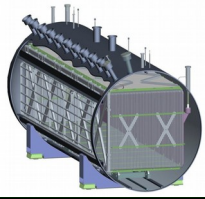
**No Fluid
Flow Sim.**



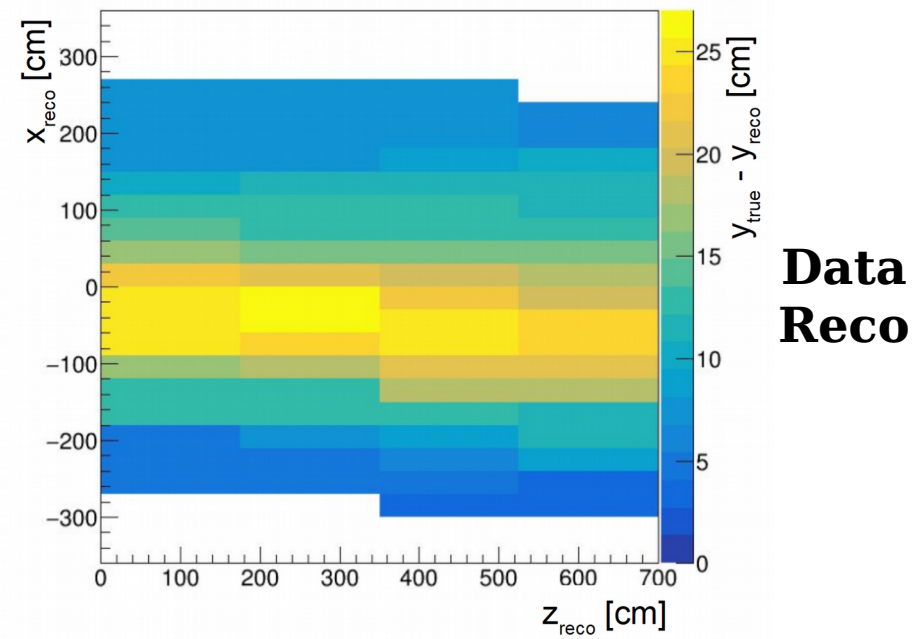
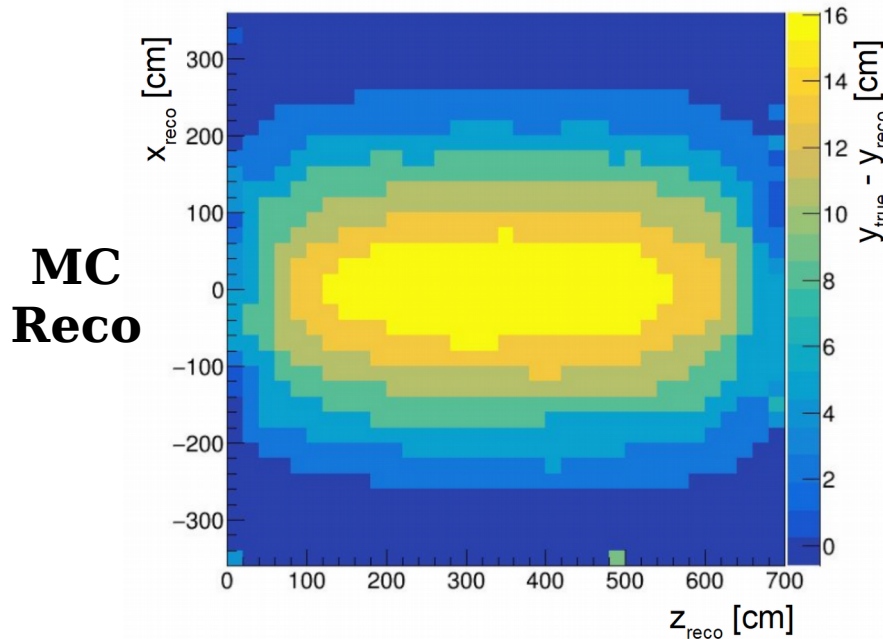
**With Fluid
Flow Sim.**



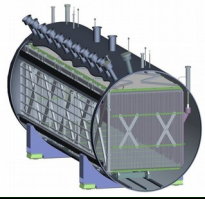
- ◆ Principal observations from fluid flow study:
 - Asymmetry in comparing two drift volumes (shared cathode is at $x = 0$)
 - Up/down asymmetry emerges as well – less SCE at top
 - Overall reduction in magnitude of SCE
- ◆ Need to look at ProtoDUNE-SP **data** to validate fluid flow model (use to tweak model?)



First Look: PD-SP Data



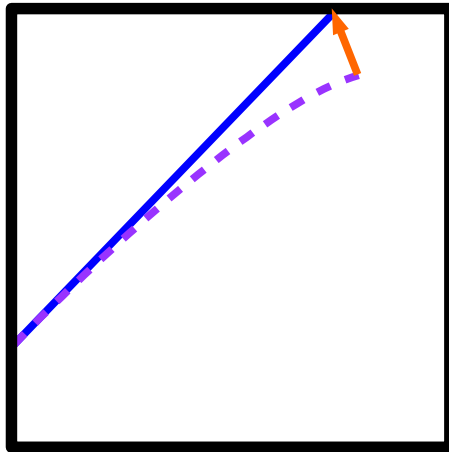
- ◆ Using cathode-crossing cosmic tracks (provides t_0 tag) in ProtoDUNE-SP data to study spatial offsets at TPC top
 - Coarse binning due to low statistics; processing more data, should have extensive study of TPC faces by end of year
 - Spatial offsets slightly larger than expected: **25+ cm**
 - Hints of correlation w/ electron lifetime... negative ions?



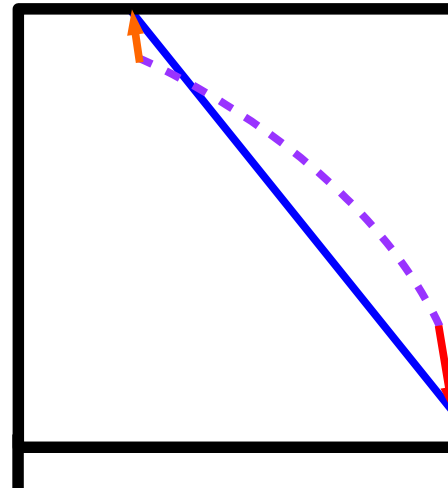
Cosmics Calibration Strategy



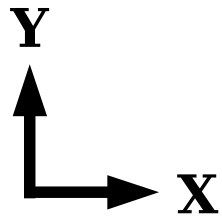
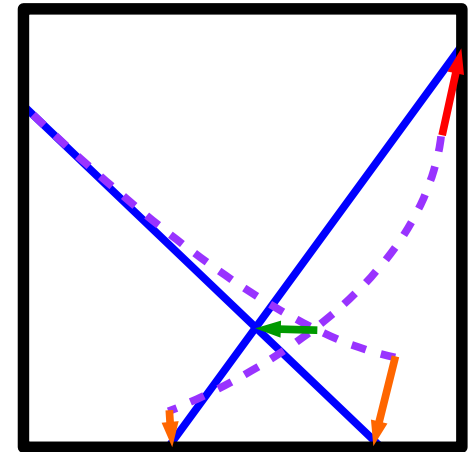
**Anode-Piercing
Face Calibration**



**Cathode
Calibration**



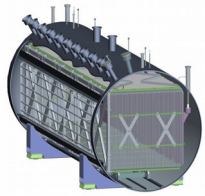
**Bulk
Calibration**



Anode

Cathode

- ◆ Cosmics calibration strategy has multiple steps:
 - Anode-piercing face calibration: finds “truth track” ends
 - Cathode calibration: finds “truth track” ends at cathode
 - Bulk calibration: uses track pairs to get offsets in TPC bulk
- ◆ Combine with UV laser calibration at MicroBooNE; results in forthcoming SCE paper

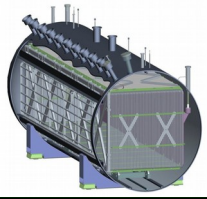


Summary

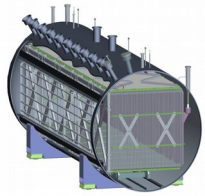


Experiment	E Field	Drift Length	Max E Field Distortion	Max Spatial Distortion
MicroBooNE	273 V/cm	2.5 m	~15%	~15 cm
SBND	500 V/cm	2.0 m	~5%	~5 cm
ICARUS	500 V/cm	1.5 m	~2%	~2 cm
ProtoDUNE-SP	500 V/cm	3.6 m	~15%	~20 cm

- ◆ Space charge effects expected in large LArTPCs that reside near the surface
 - Observed at MicroBooNE and ProtoDUNE-SP - not small!
 - Less bad for SBND/ICARUS, but not negligible
- ◆ Some evidence of LAr flow impact at MicroBooNE
- ◆ Negative ions playing a role at ProtoDUNE-SP?
- ◆ **Expected to be negligible in DUNE SP FD**



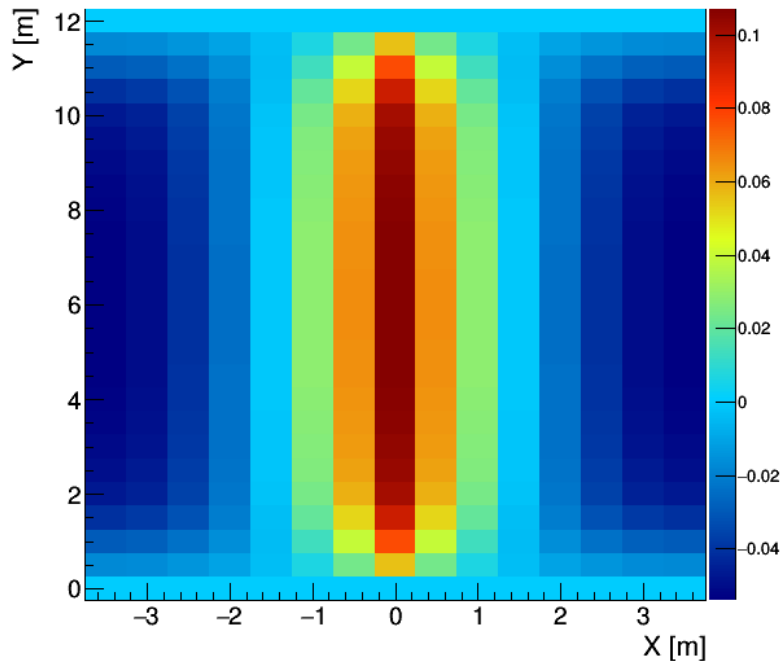
BACKUP SLIDES



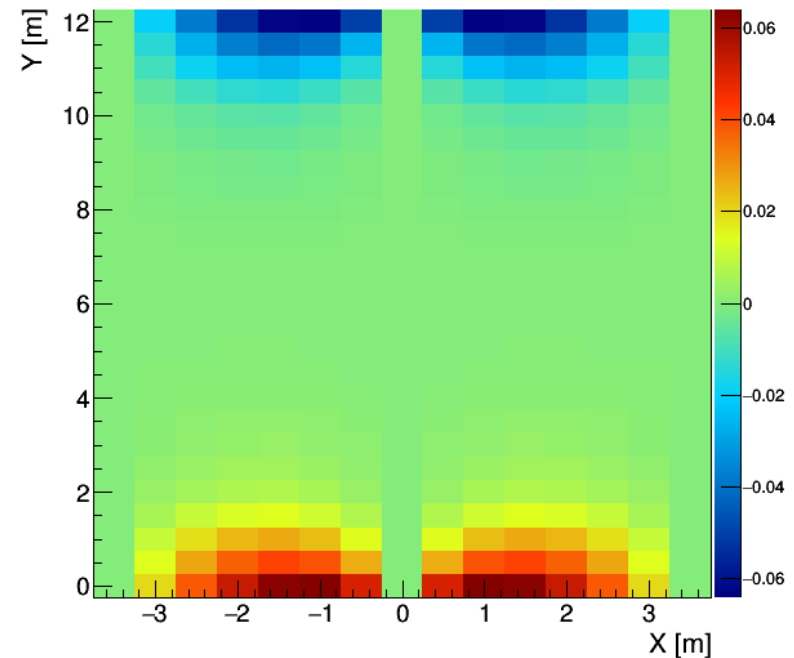
SCE for DUNE SP FD



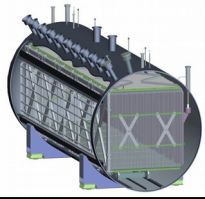
$\Delta E_x/E_{\text{drift}}$ [%]: Z = 29.00 m



$\Delta E_y/E_{\text{drift}}$ [%]: Z = 29.00 m



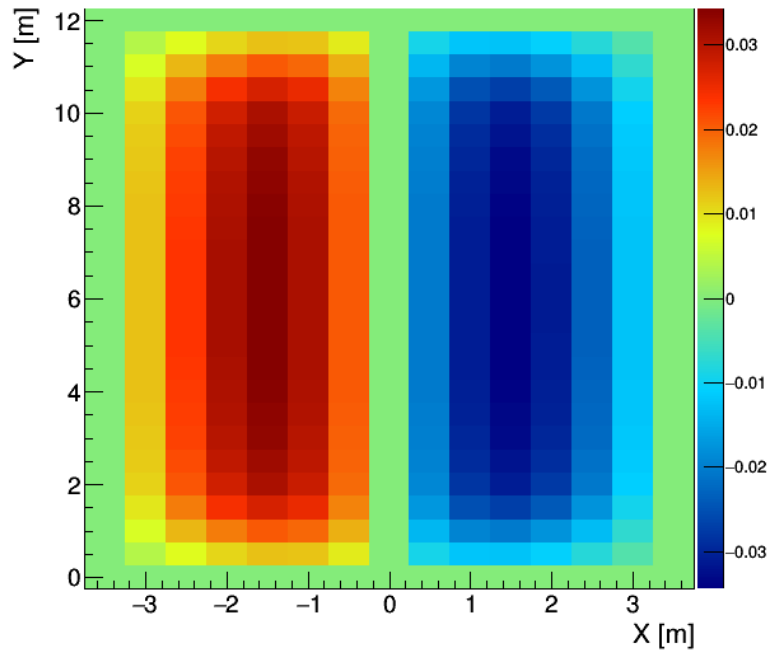
- ◆ DUNE SP FD – looking at one half of central Z slice
 - APA+CPA+APA
- ◆ E field distortions on order of **0.1%** – very small!
 - Impact on dQ/dx from recombination \sim **0.03%**



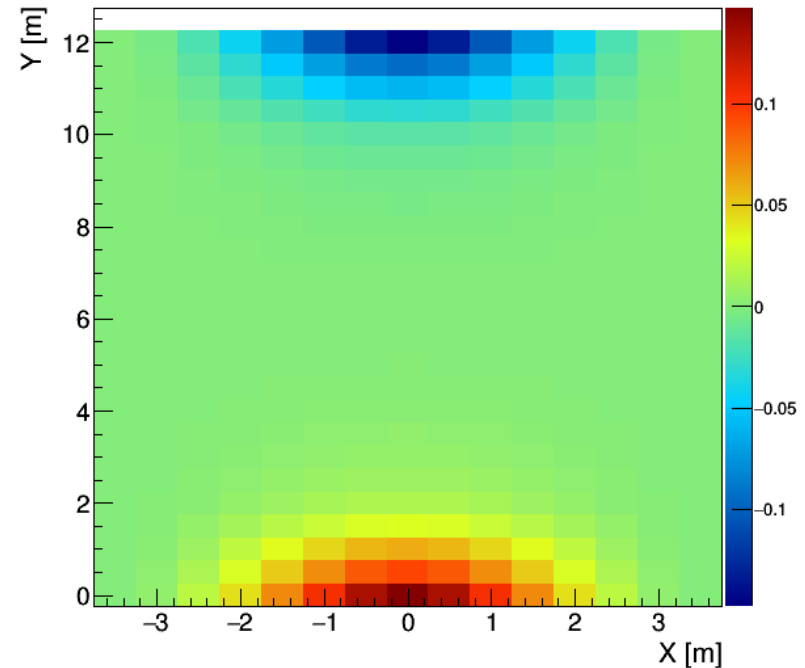
SCE for DUNE SP FD (cont.)



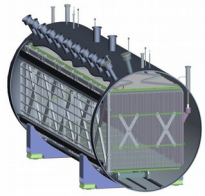
$X_{\text{reco}} - X_{\text{true}} [\text{cm}]$: $Z = 29.00 \text{ m}$



$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]$: $Z = 29.00 \text{ m}$



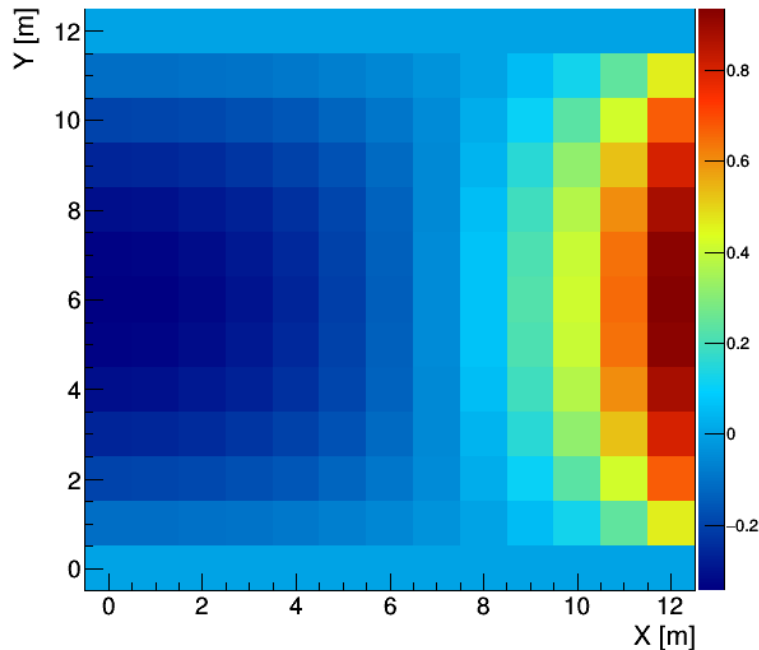
- ◆ DUNE SP FD – looking at one half of central Z slice
 - APA+CPA+APA
- ◆ Spatial distortions on order of **1.0-1.5 mm** – small!
 - Total impact on dQ/dx (including recomb.) **< 0.1%**



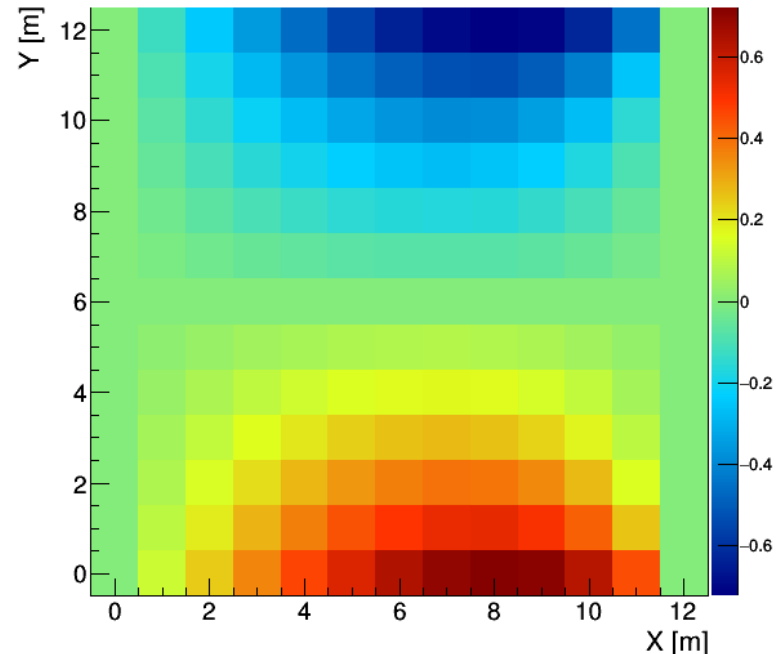
SCE for DUNE DP FD



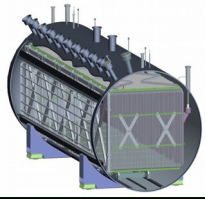
$\Delta E_x/E_{\text{drift}}$ [%]: Z = 30.00 m



$\Delta E_y/E_{\text{drift}}$ [%]: Z = 30.00 m



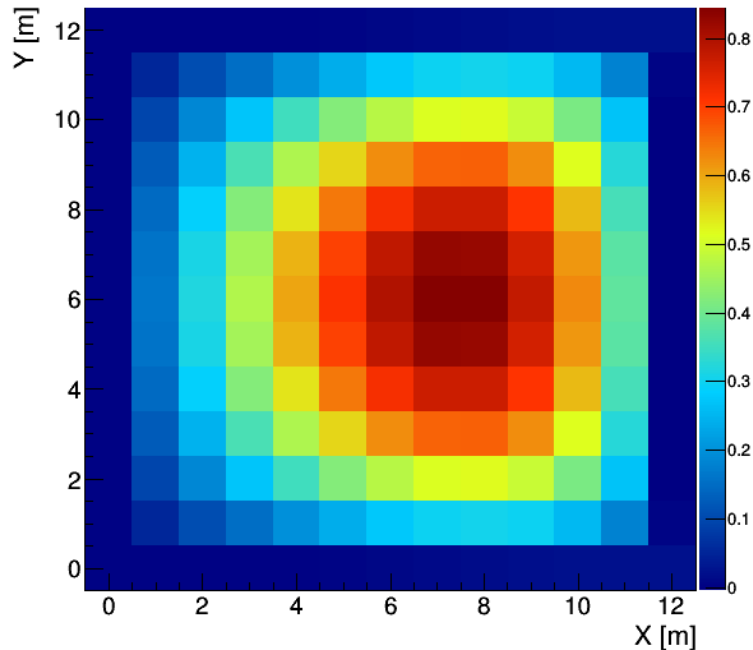
- ◆ DUNE DP FD – full detector, central Z slice
 - Ionization **drift is to left** (anode on left, cathode right)
- ◆ E field distortions roughly **1%** – larger than for SP
 - Impact on dQ/dx from recombination **~ 0.3%**
 - Neglects liquid/gas interface effects – can be large!



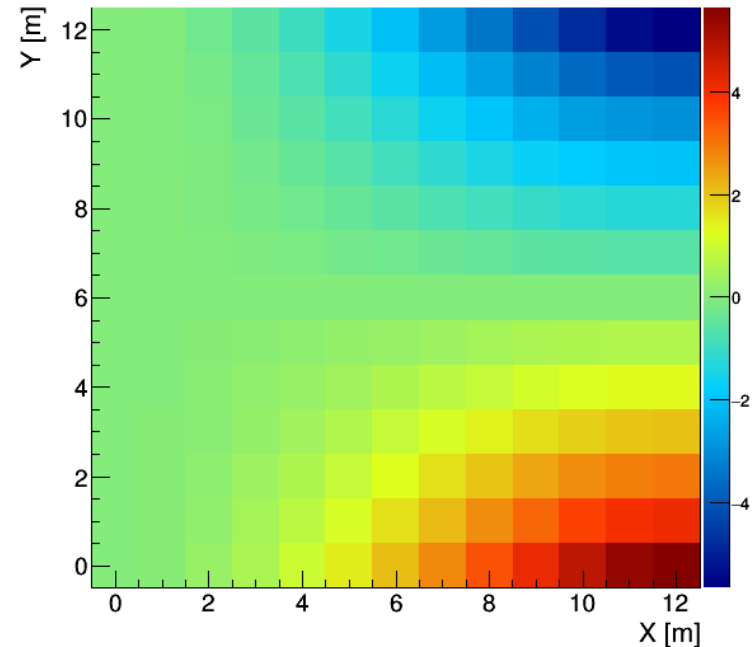
SCE for DUNE DP FD (cont.)



$X_{\text{reco}} - X_{\text{true}} [\text{cm}]: Z = 30.00 \text{ m}$



$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]: Z = 30.00 \text{ m}$



- ◆ DUNE DP FD – full detector, central Z slice
 - Ionization **drift is to left** (anode on left, cathode right)
- ◆ Spatial distortions roughly **5 cm** – not negligible!
 - Total impact on dQ/dx (including recomb.) **~ 2-3%**
 - Neglects liquid/gas interface effects – can be large!