Space Charge Effect Simulation with Liquid Argon Flow

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ProtoDUNE Sim/Reco Meeting

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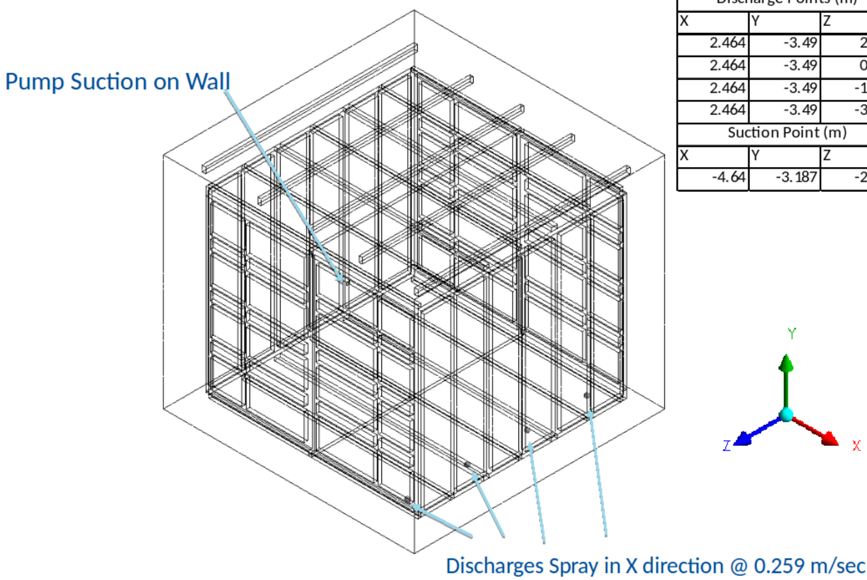
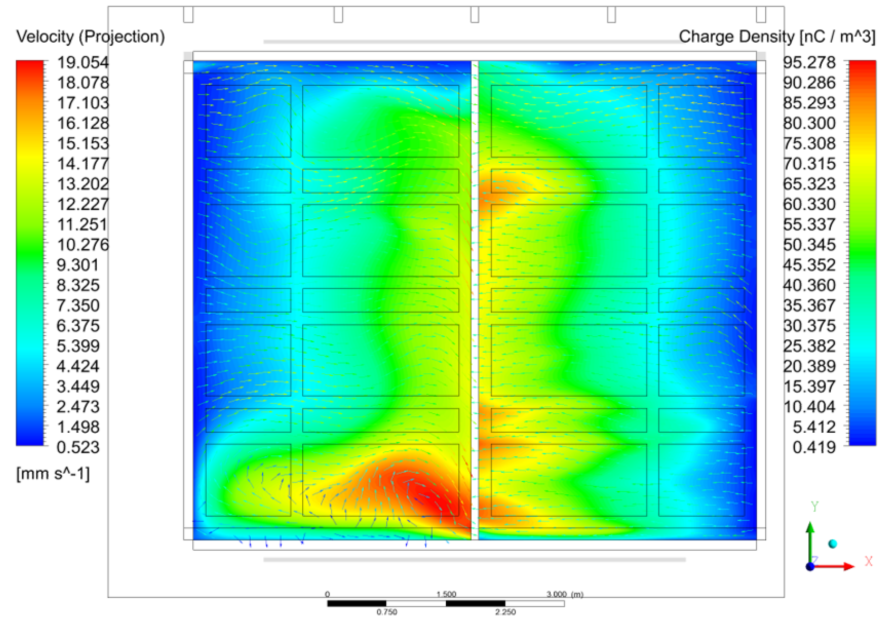
Introduction

- Expect space charge effects (SCE) to be one of two leading detector effects at ProtoDUNE-SP
  - The other: ADC issues (stuck codes, nonlinearity)
  - Important focus of calibration studies prior to first operations of detector
- Open question: how much do we expect flow of liquid argon to impact underlying space charge configuration?
  - Ion drift velocity in electric field and expected liquid argon flow velocity are similar in magnitude
  - Could lead to build-up of space charge in certain parts of detector, or at least modify space charge distribution
- Today: show first study of LAr flow on SCE

Fluid Flow Simulation



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

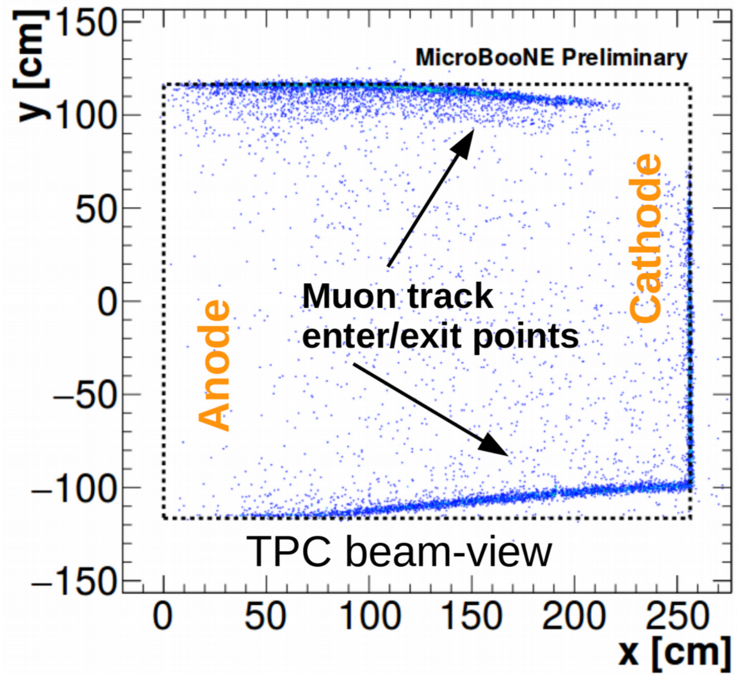


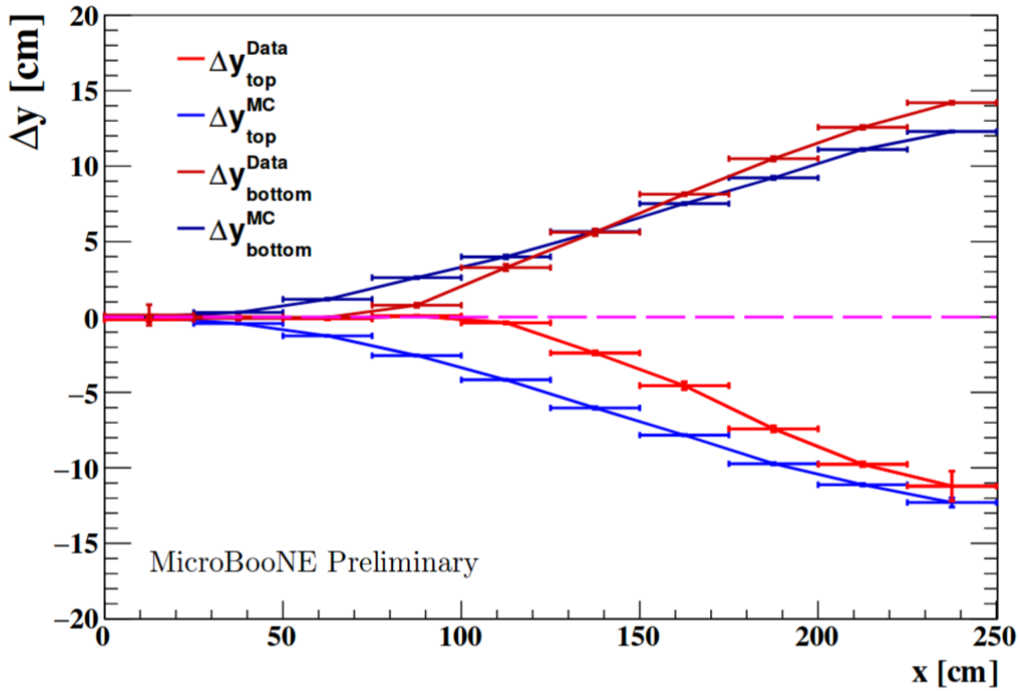
- Developed by Erik Voirin for ProtoDUNE-SP (previously produced for 35-ton) – see **DUNE Doc DB #928**
- 3D simulation of LAr flow, 8 mm/s ion drift @ 500 V/cm, uniform space charge deposition from cosmics
- Ion absorption at field cage, APA, CPA, and all solid objects inside cryostat – see Erik's talk for more info

SCE Simulation

- Make use of code suite developed by M. Mooney for simulation of SCE given space charge density map from Erik's simulation
  - **SpaCE** – Space Charge Estimator
- Fourier series solution for electric field on grid, radial basis functions for interpolation of field between grid points, and ray tracing based on RK45 for determining spatial displacements due to SCE
- Nominally assumes linear space charge distribution (zero at anodes, maximal at cathode), but code suite has capability of using arbitrary space charge distribution as input
  - Compare nominal SCE maps to ones including LAr flow

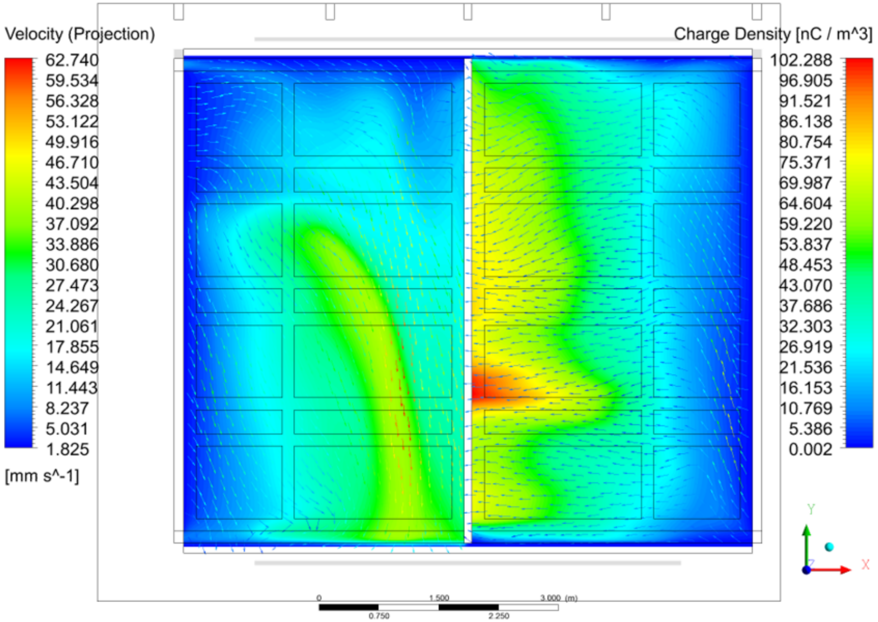
Data/MC Comp. @ μBooNE

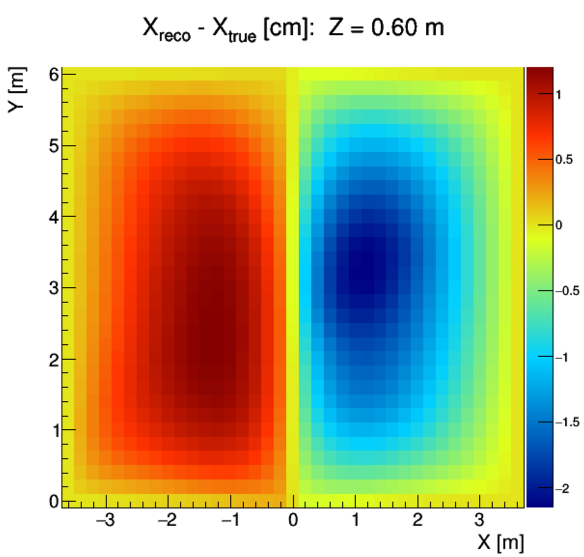


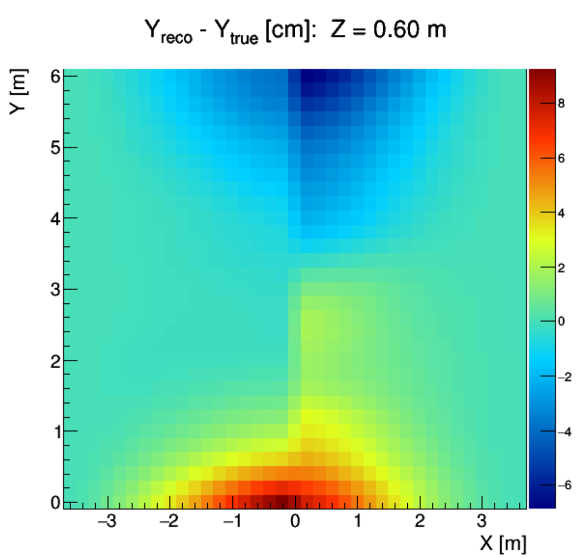


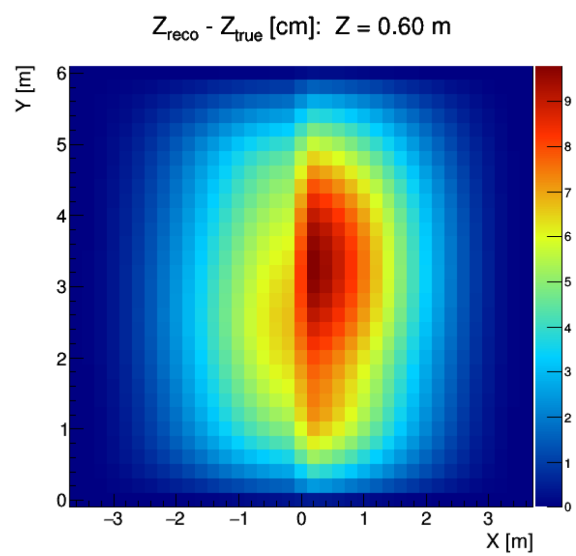
- Transverse spatial distortions (TPC top/bottom) observed in data ~reproduced with SCE simulation
  - MicroBooNE Public Note: **MICROBOONE-NOTE-1018-PUB**
  - Asymmetry in data (not predicted in simulation): smaller distortions at TPC top (see later slides!)

Spatial Offsets: Z = 0.6 m

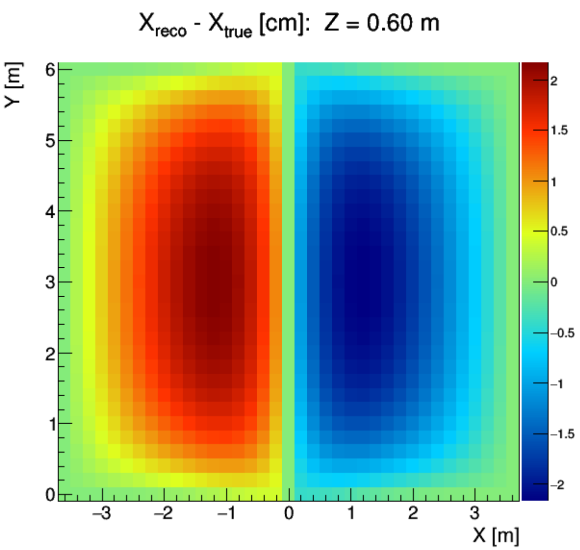


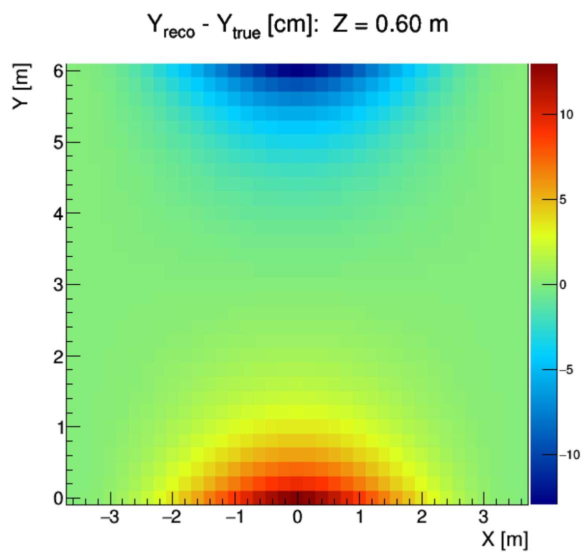


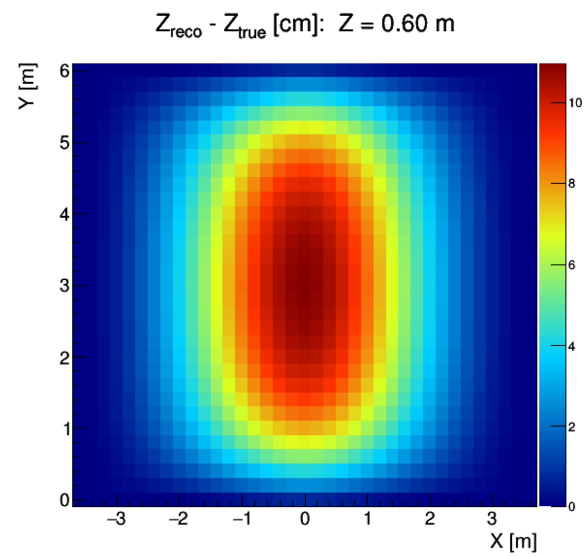


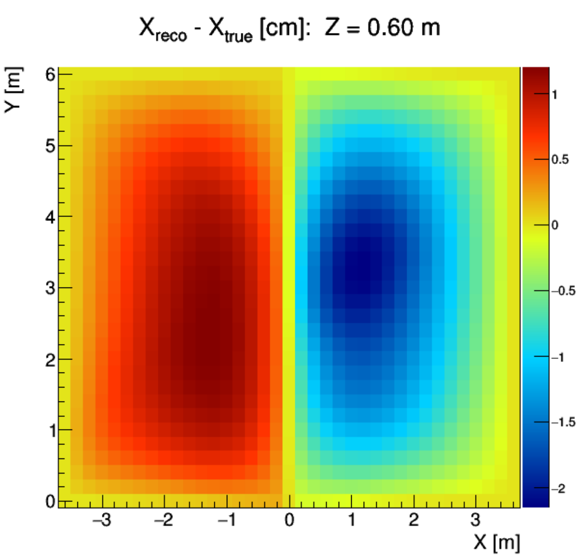


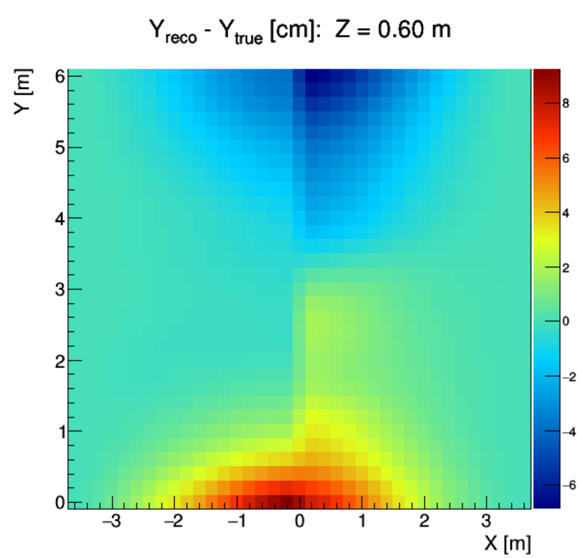
Vs. No Flow: Z = 0.6 m

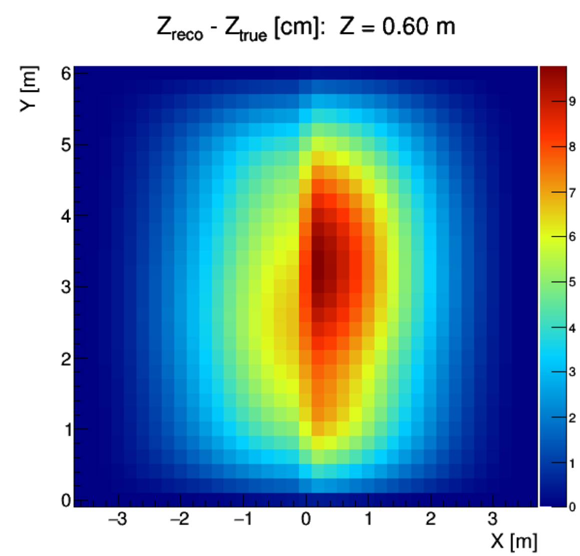




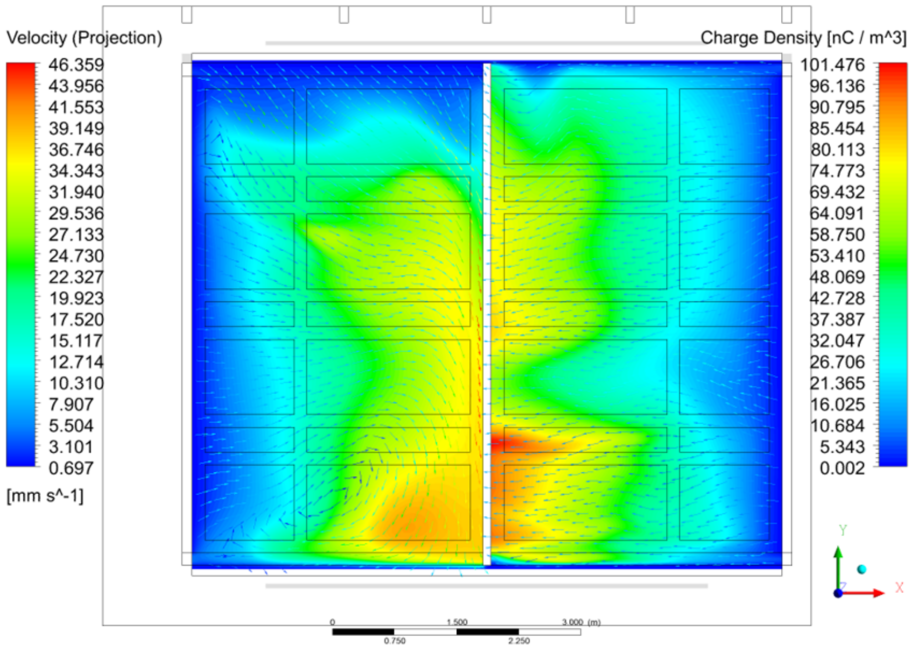


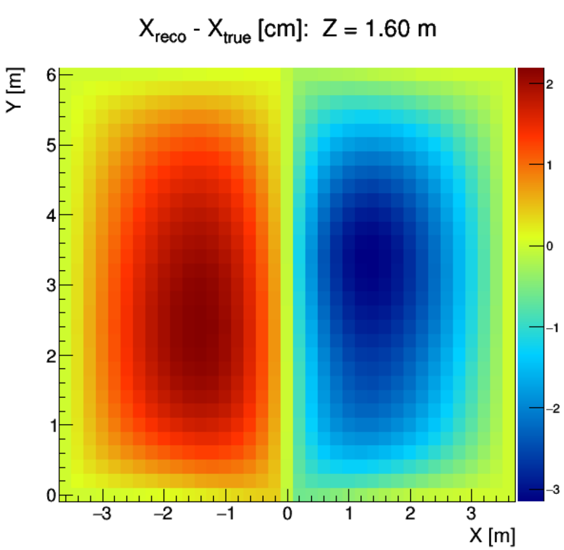


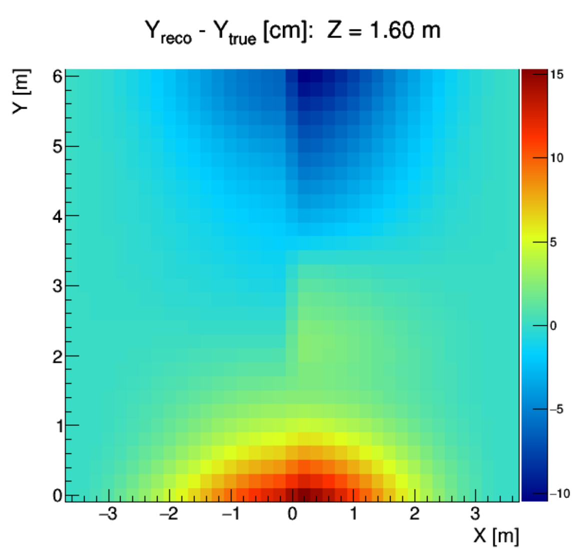


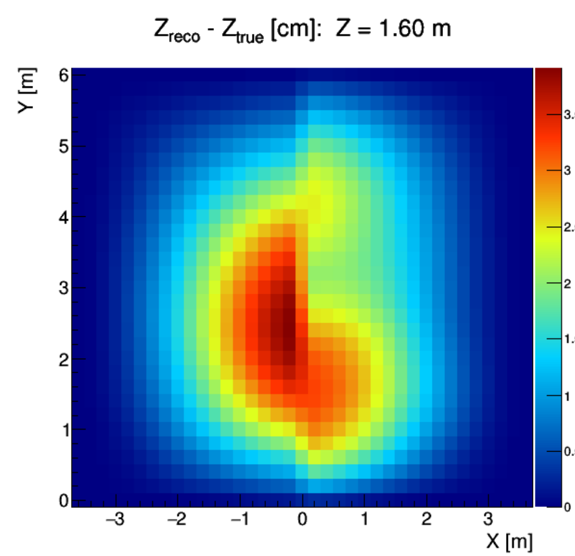


Spatial Offsets: Z = 1.6 m

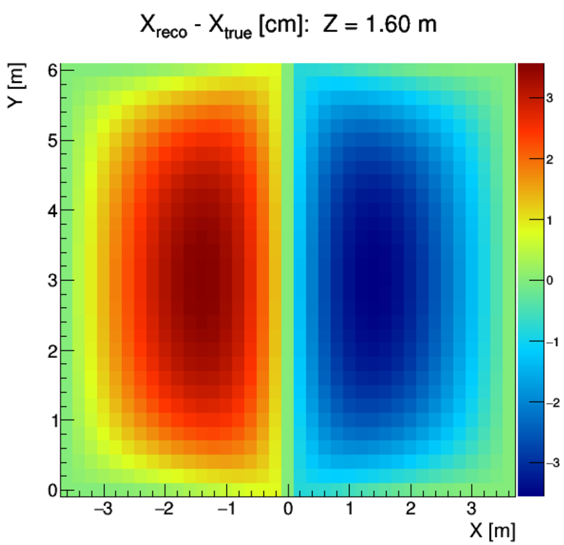


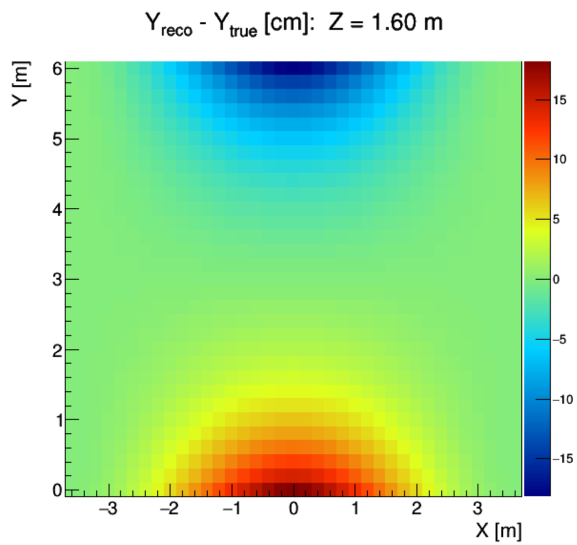


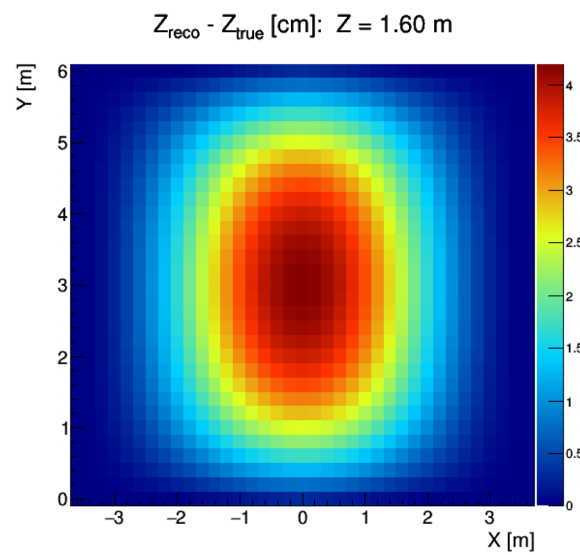


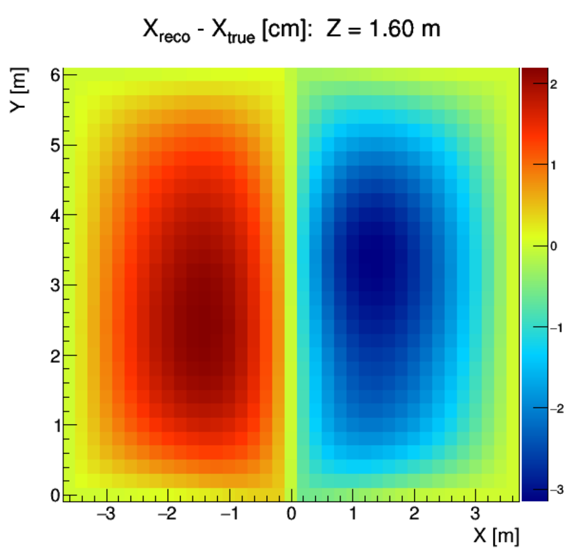


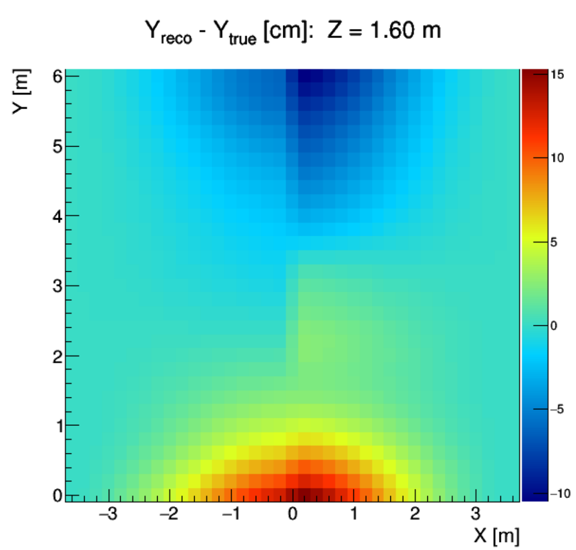
Vs. No Flow: Z = 1.6 m

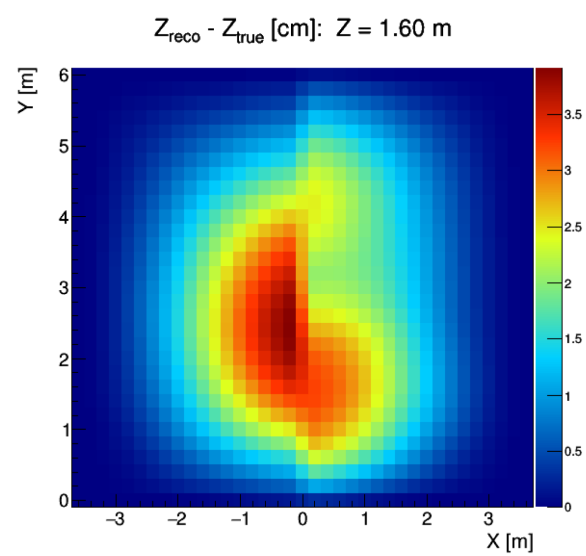




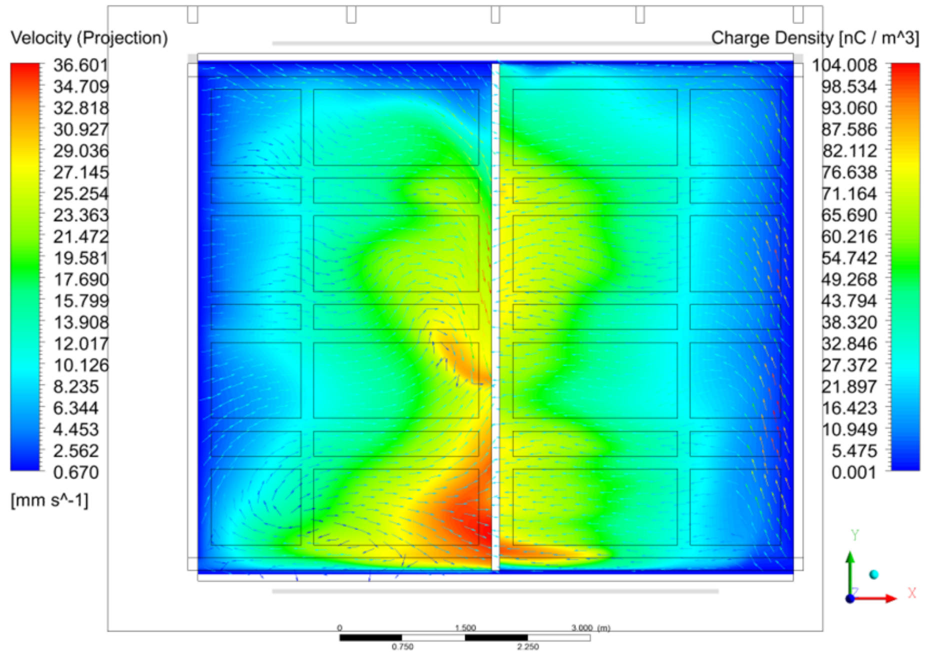


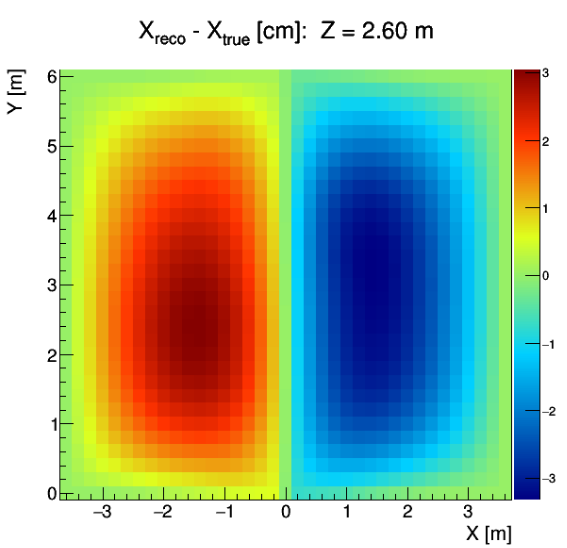


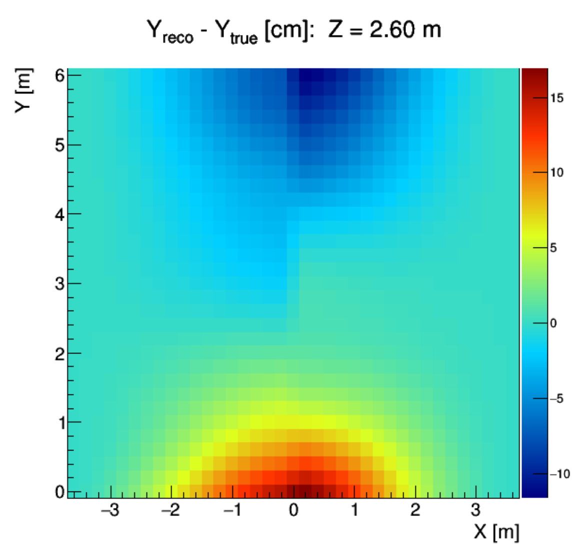


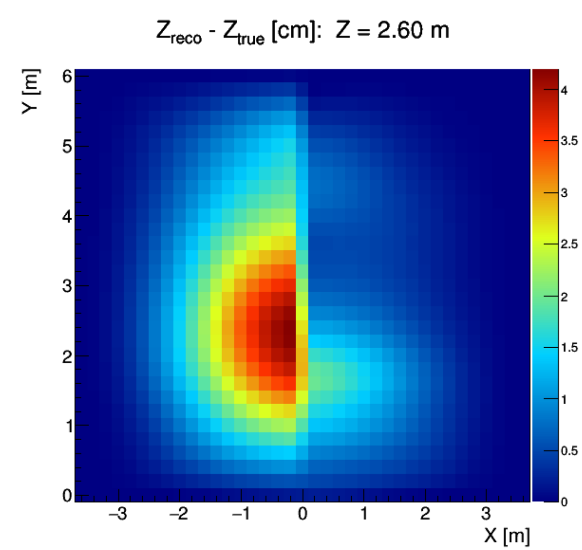


Spatial Offsets: Z = 2.6 m

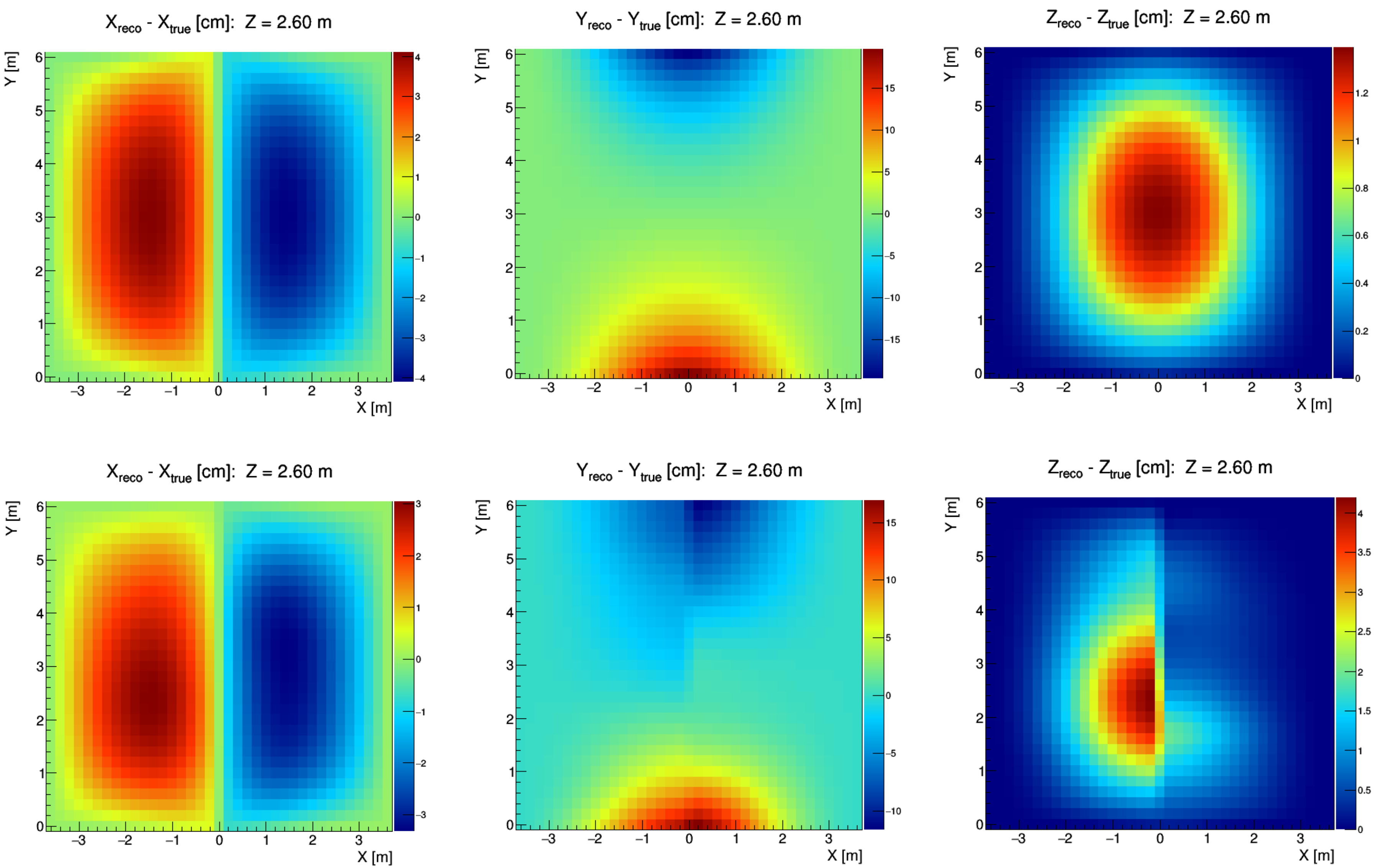




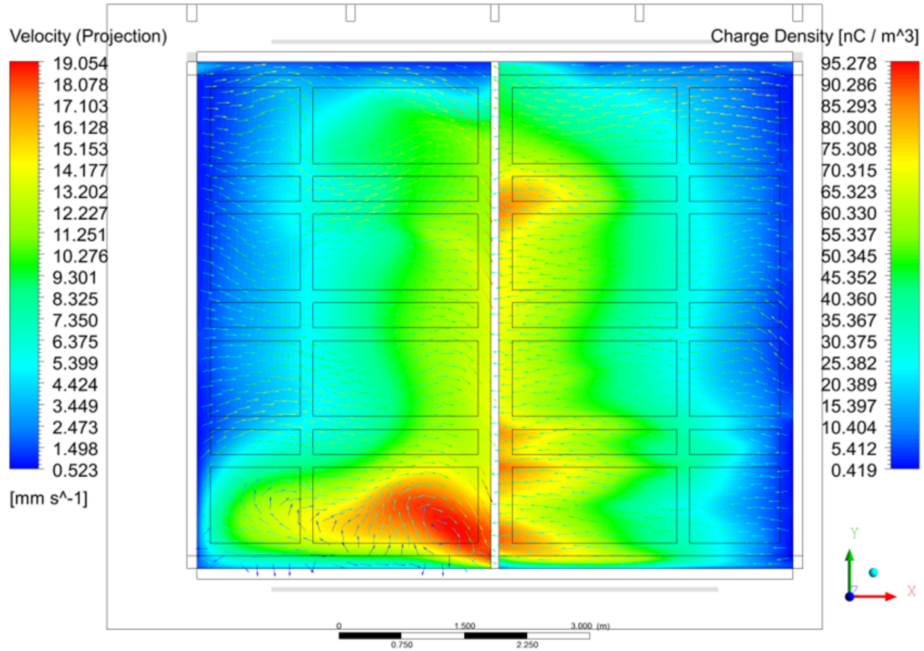


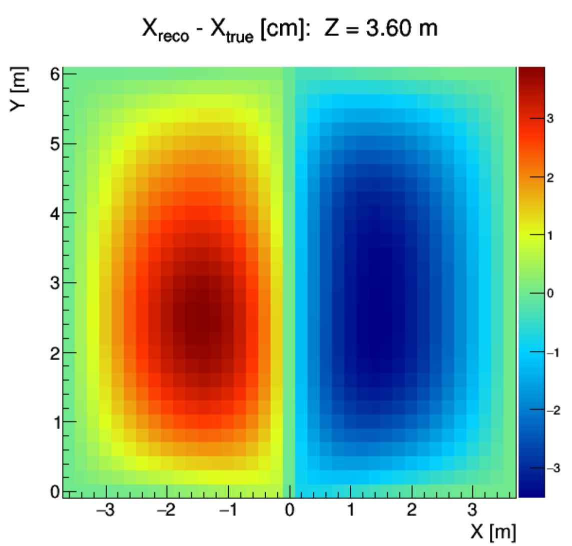


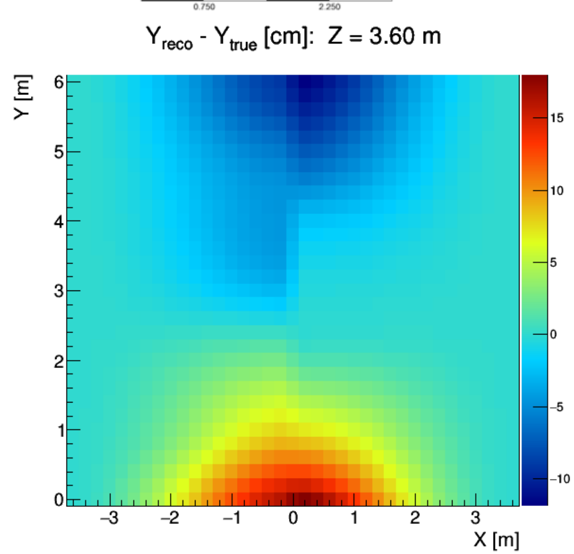
Vs. No Flow: Z = 2.6 m

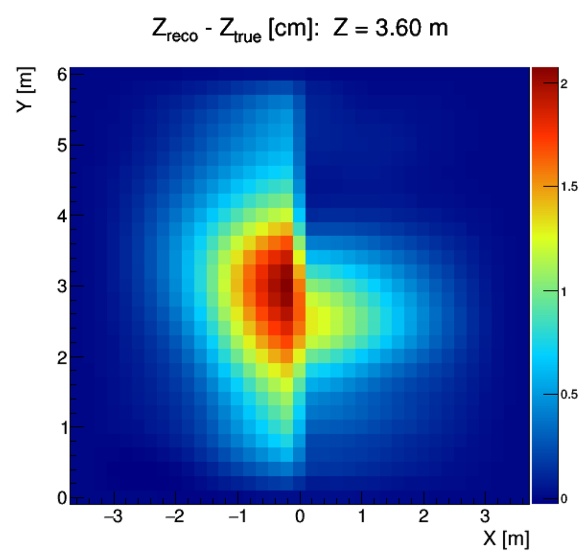


Spatial Offsets: Z = 3.6 m

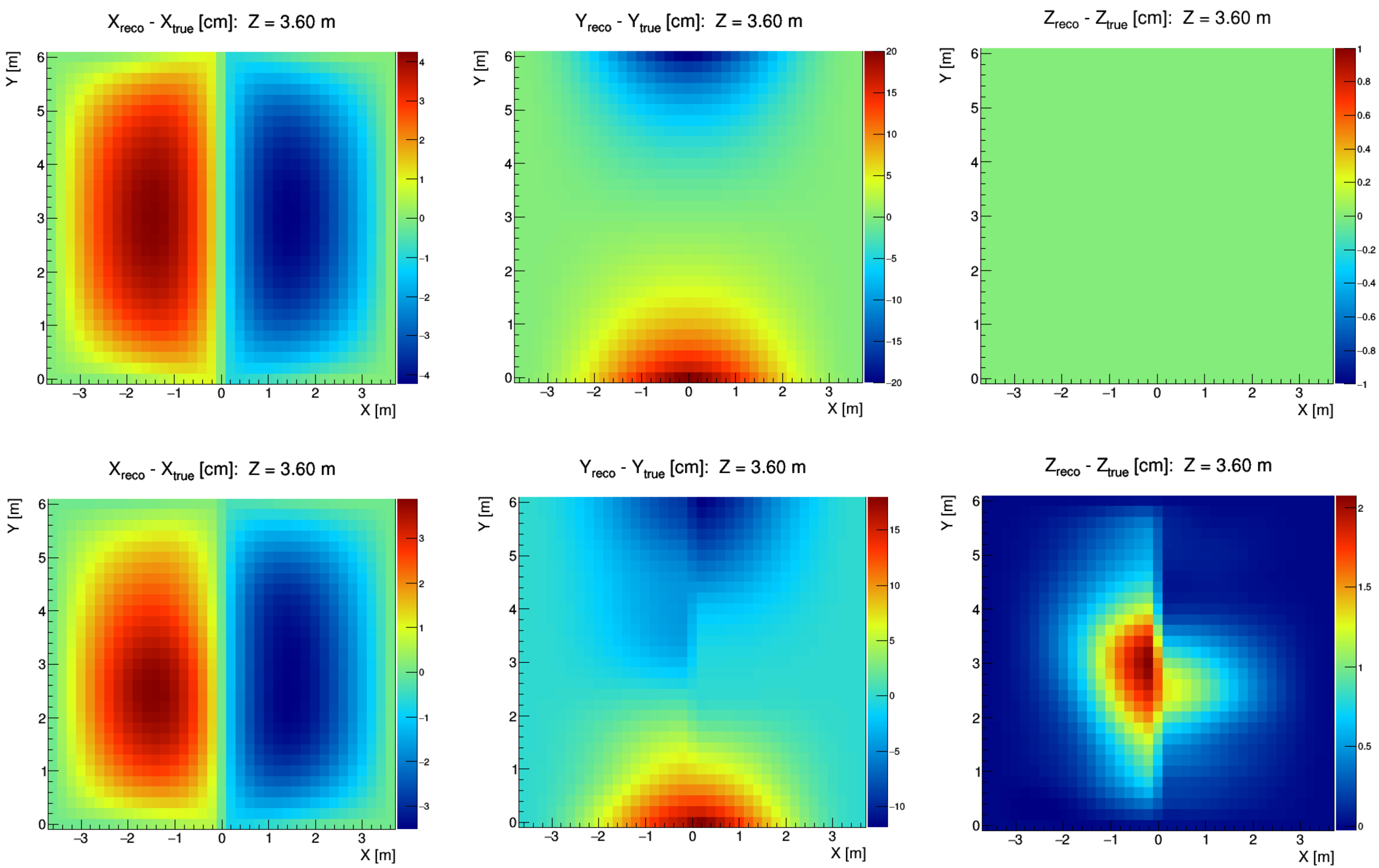




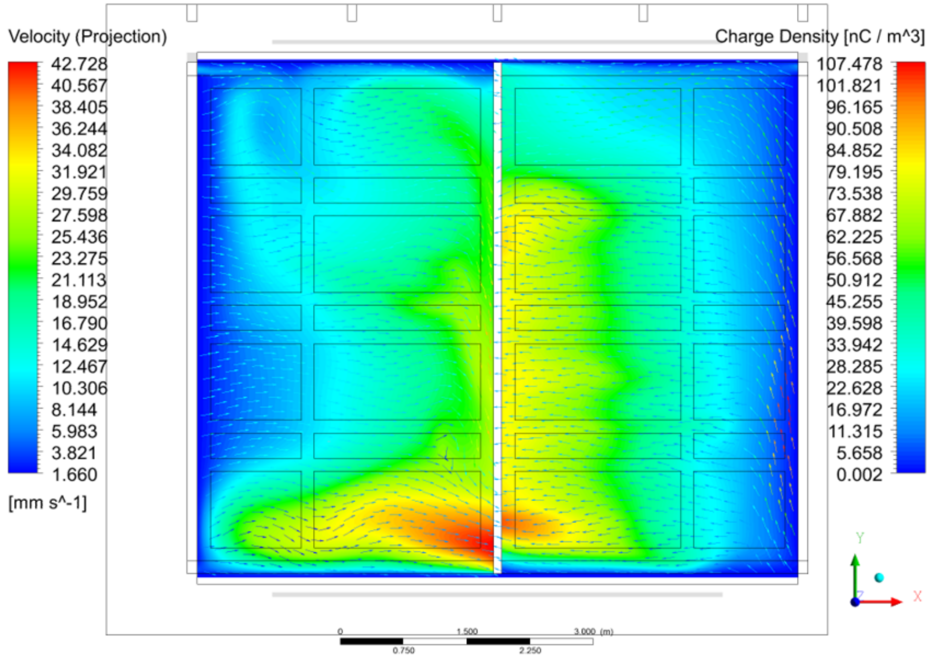




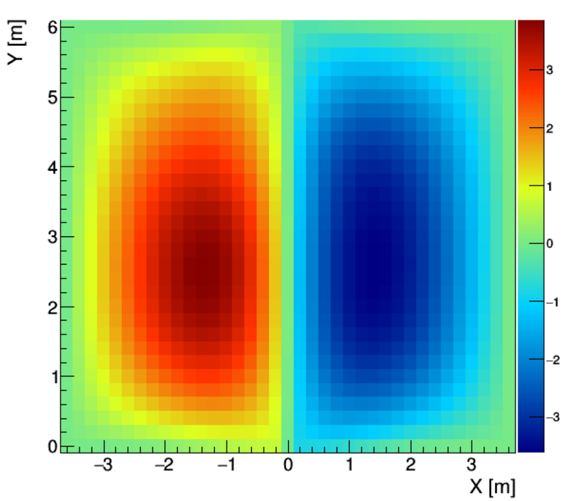
Vs. No Flow: Z = 3.6 m



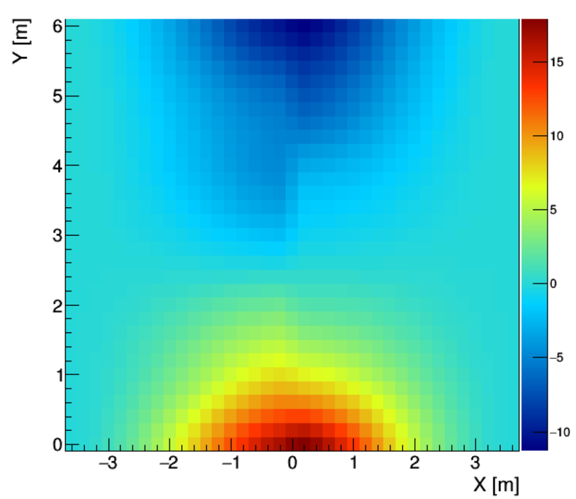
Spatial Offsets: Z = 4.6 m



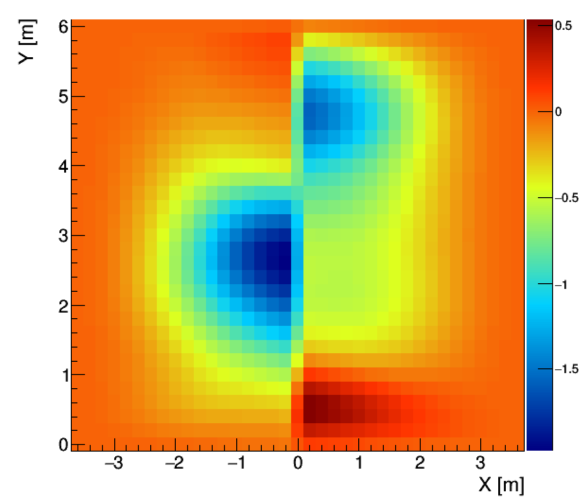
X_{reco} - X_{true} [cm]: Z = 4.60 m



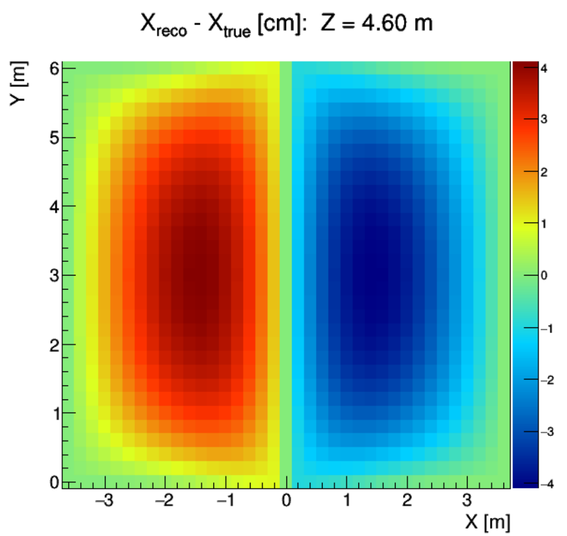
Y_{reco} - Y_{true} [cm]: Z = 4.60 m

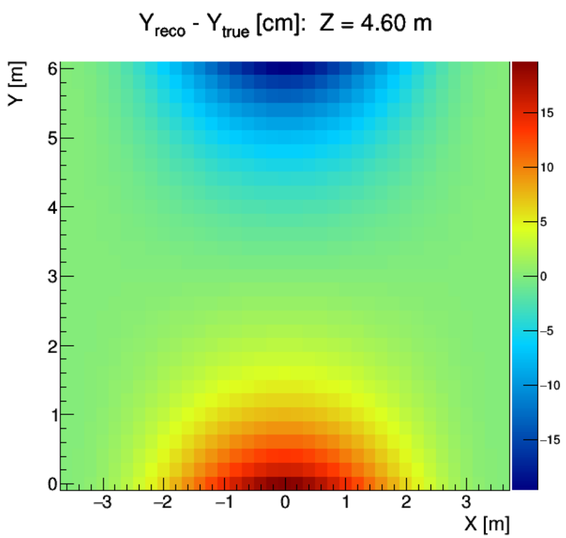


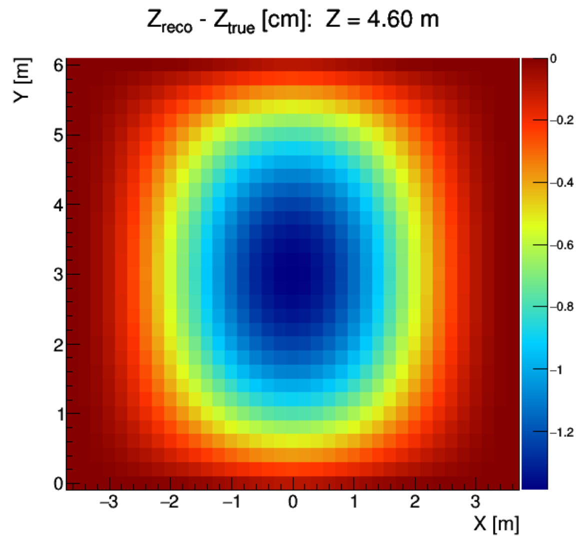
Z_{reco} - Z_{true} [cm]: Z = 4.60 m

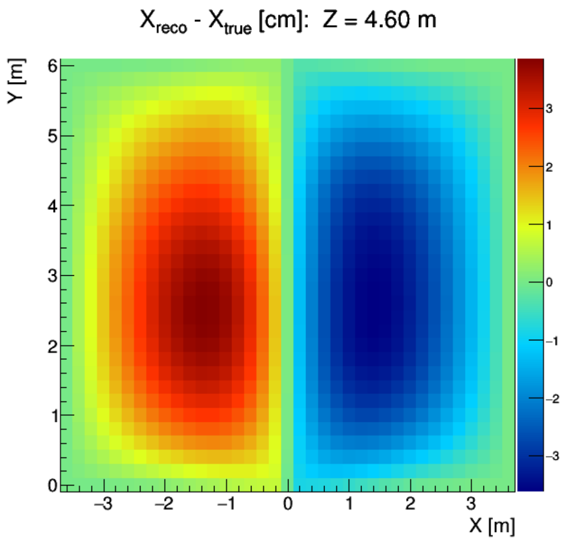


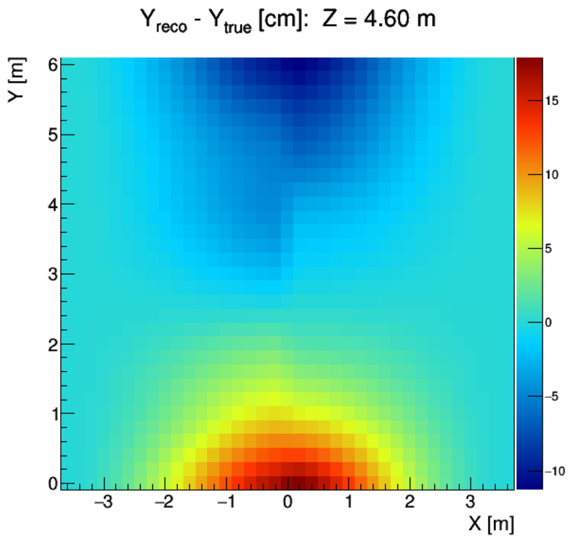
Vs. No Flow: Z = 4.6 m

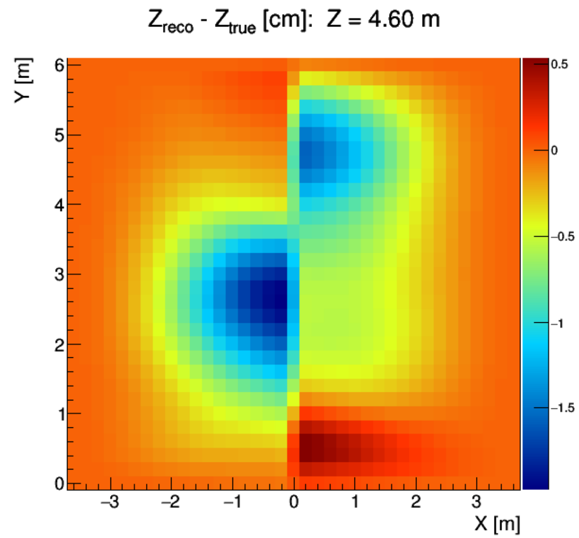




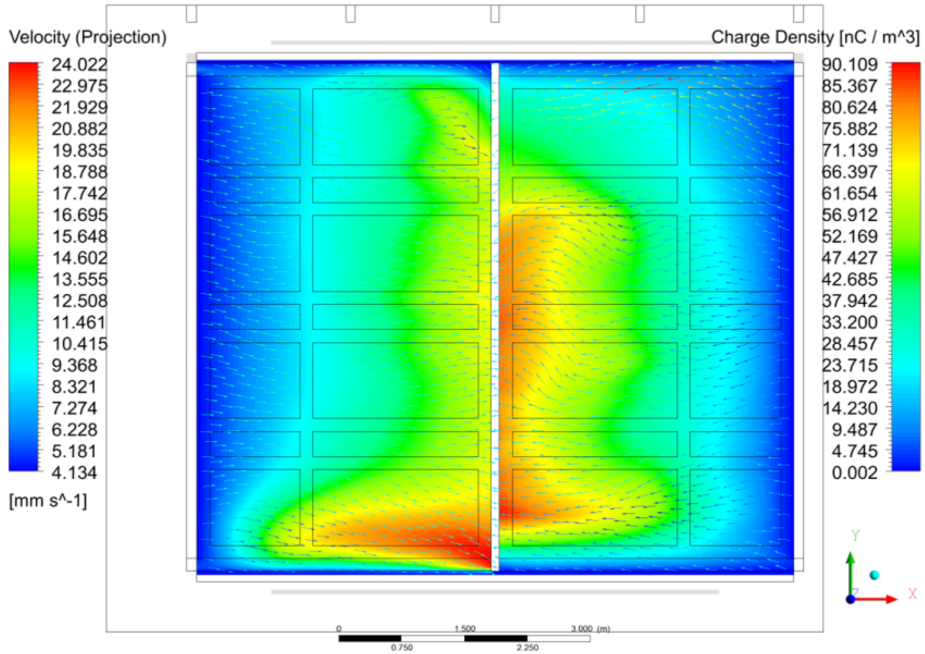


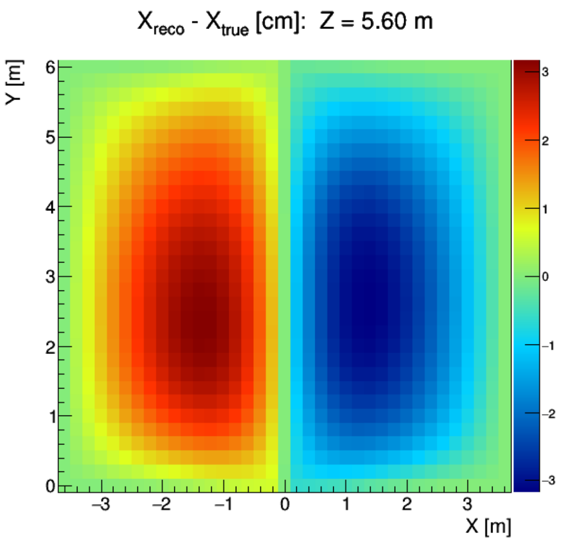


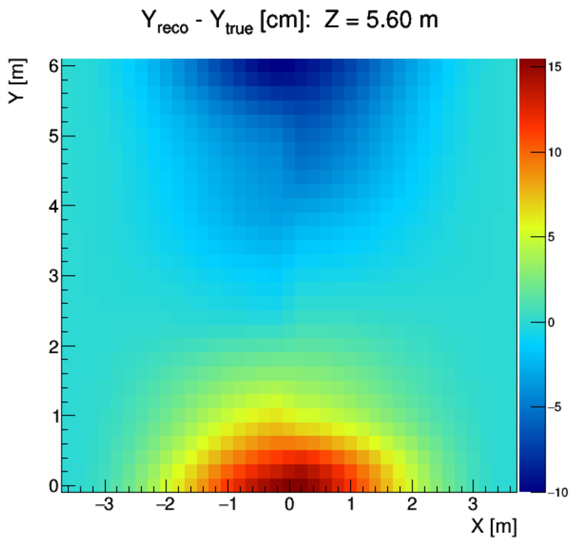


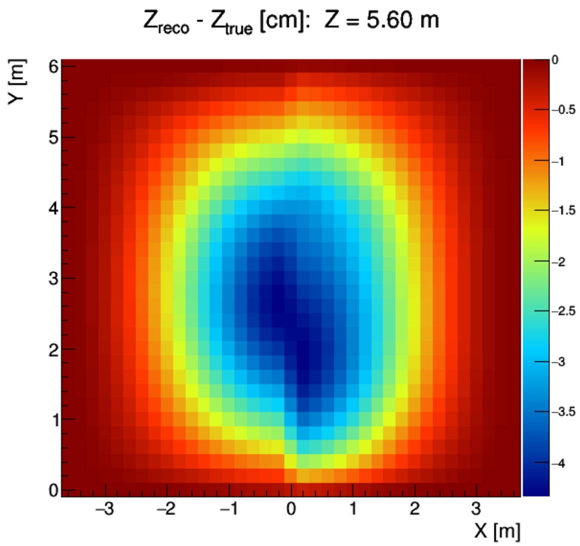


Spatial Offsets: Z = 5.6 m

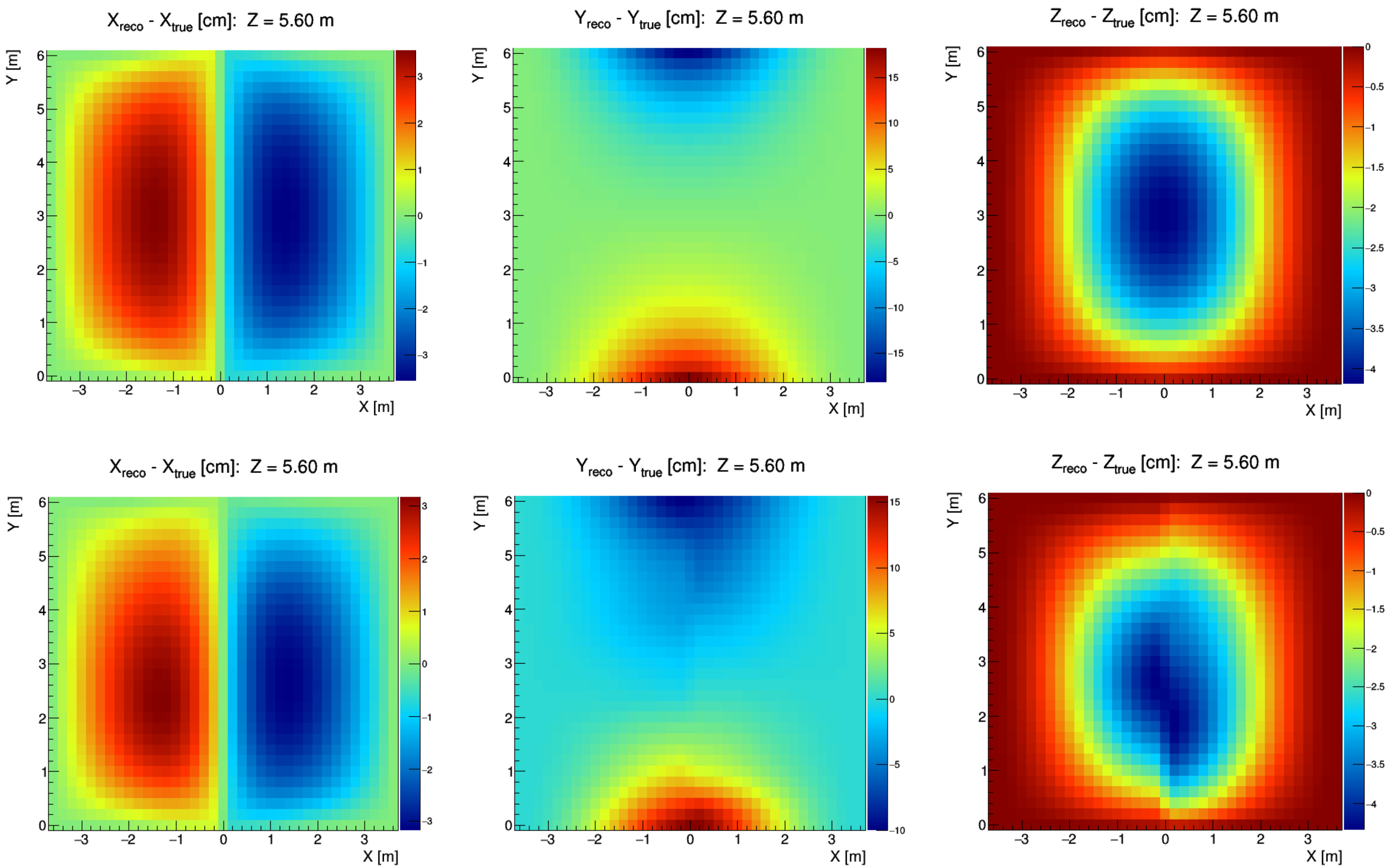




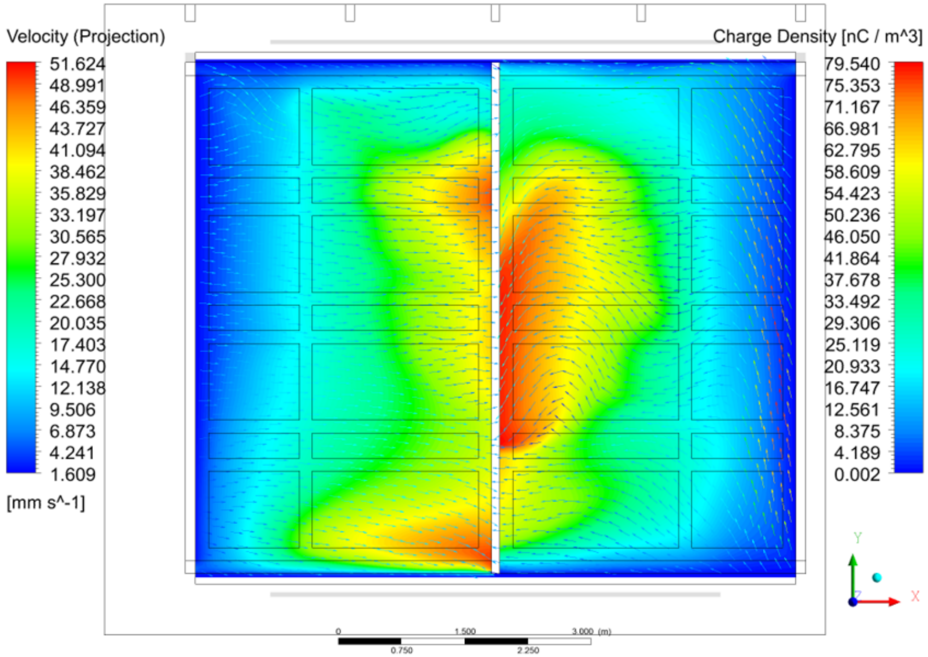


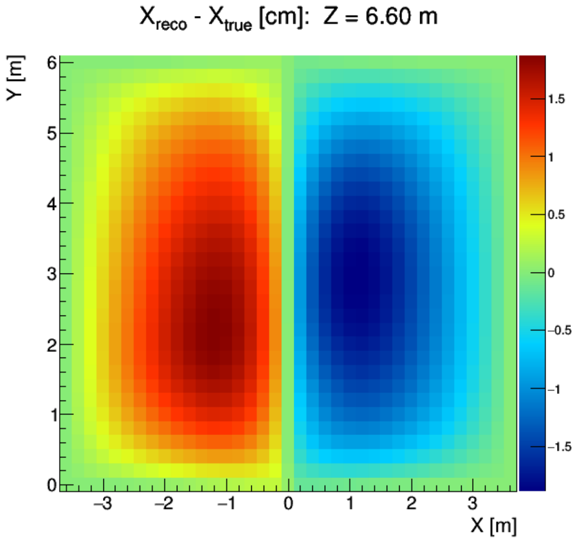


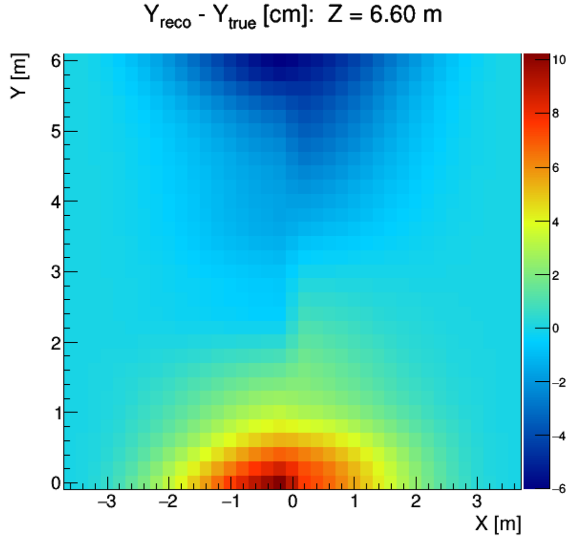
Vs. No Flow: Z = 5.6 m

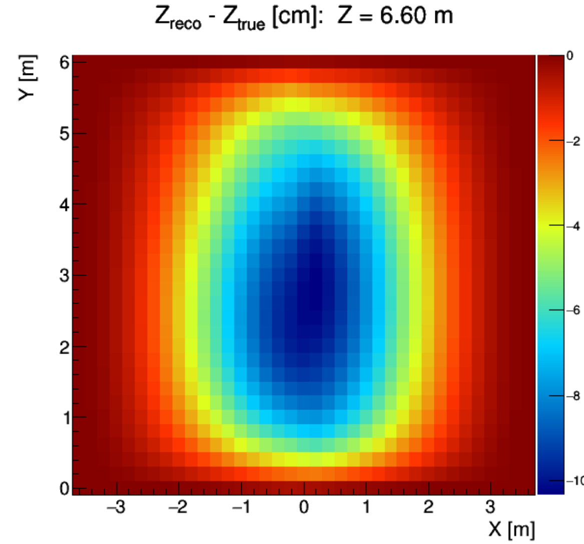


Spatial Offsets: Z = 6.6 m

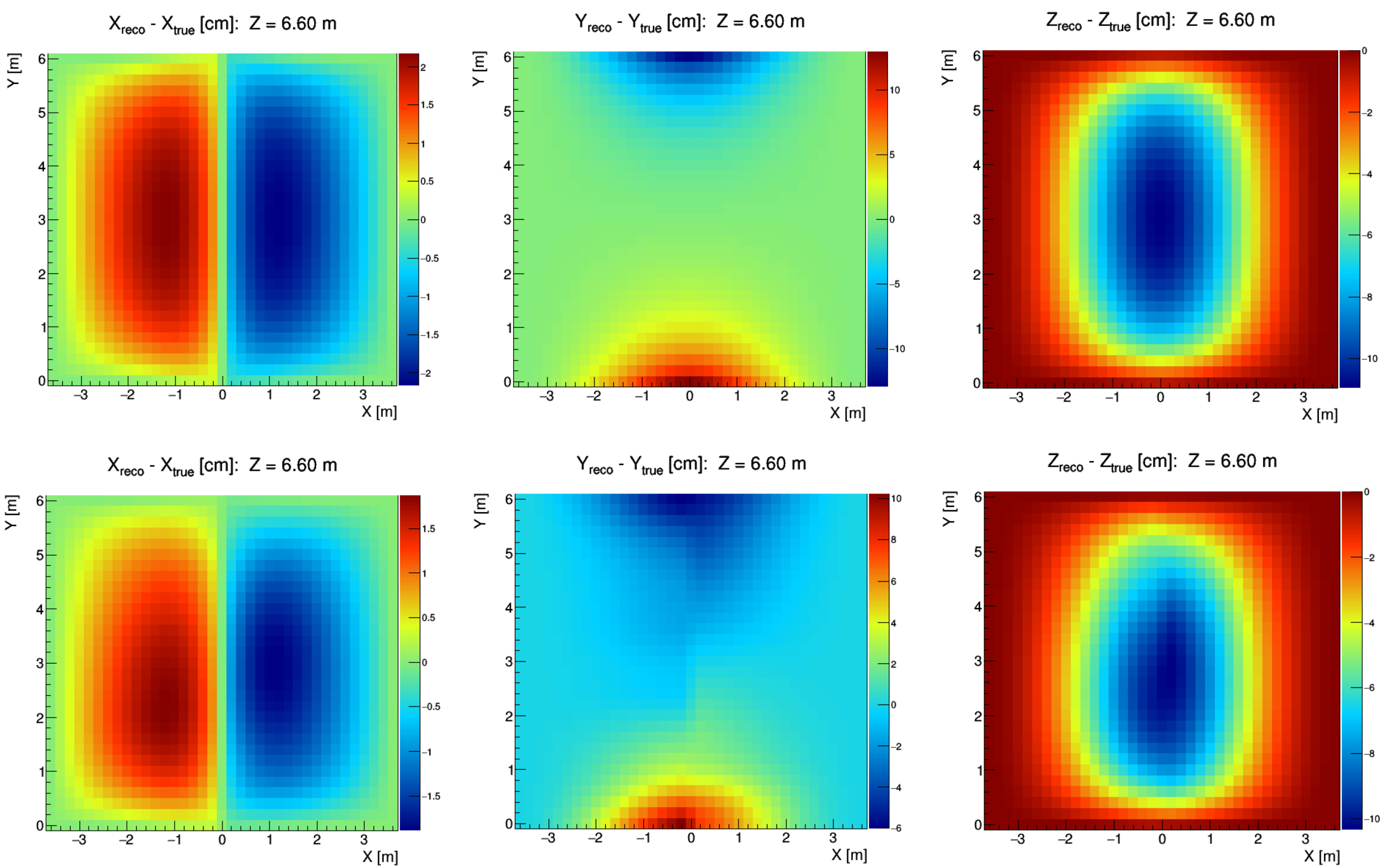








Vs. No Flow: Z = 6.6 m

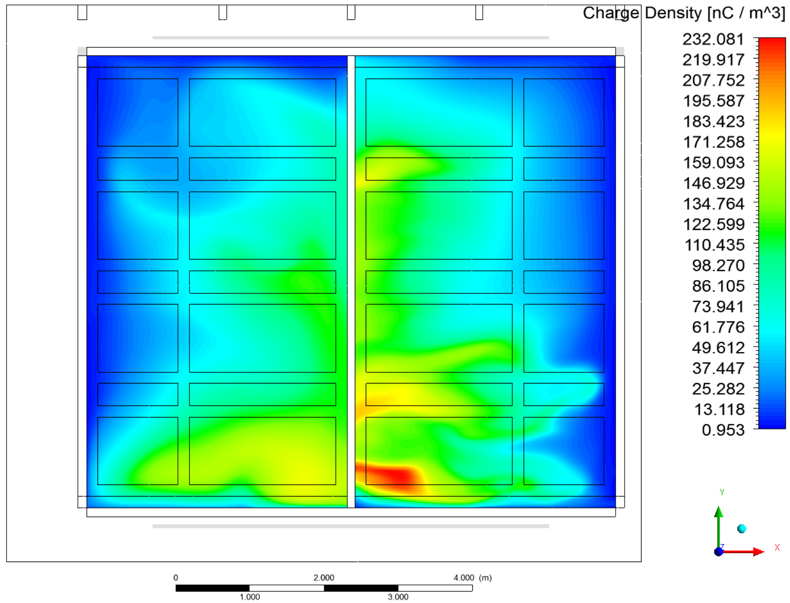


Discussion

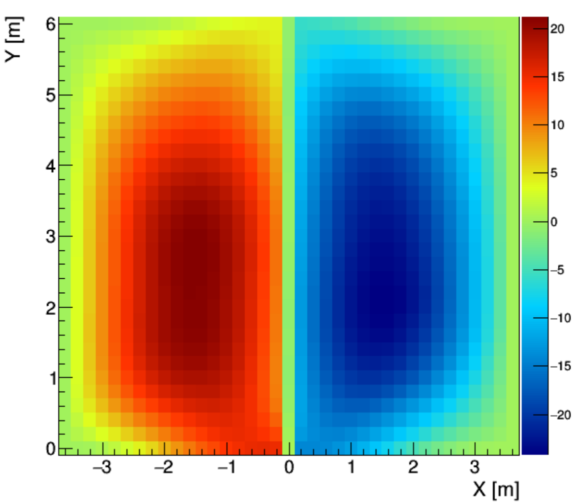
- Main effects of liquid argon flow on SCE:
  - Magnitude of distortions roughly **2/3** in comparison to nominal case (no flow)
    - Ion deposition rate used by M. Mooney and Erik are almost identical: **$\sim 2\times10^{-10}$ C/m^3/s**
  - Very different distributions in the two drift volumes
  - SCE smaller at top of TPC (also seen at MicroBooNE)
- Distributions still smoothly vary across drift volumes, as in nominal case
- Noteworthy: no large build-up of space charge predicted in any one place when including effects of fluid flow
- Useful case study for qualitative understanding, but may be very different in reality
  - Essential to have **data-driven calibration**

BACKUP SLIDES

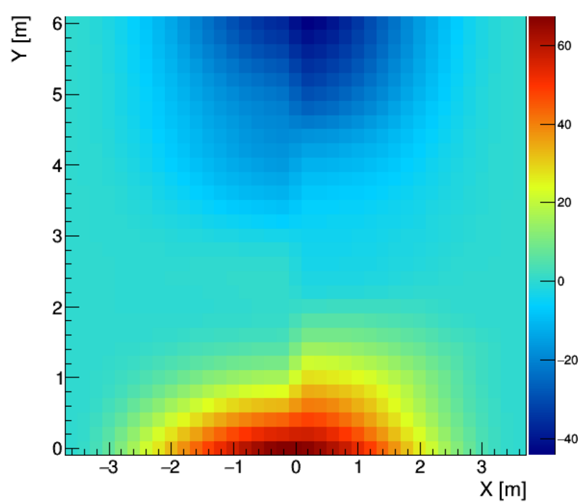
Half Field Offsets: Z = 3.6 m



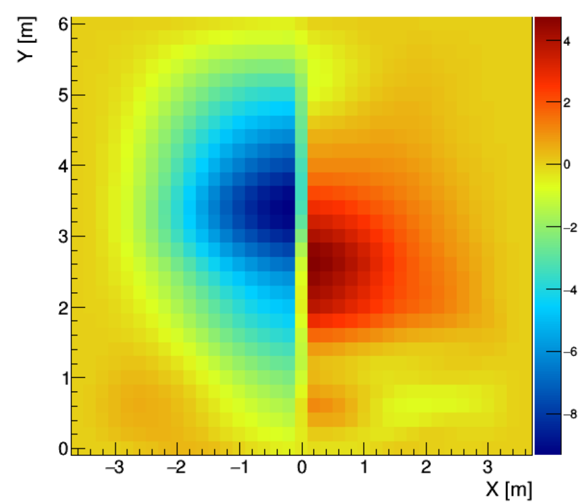
X_{reco} - X_{true} [cm]: Z = 3.60 m



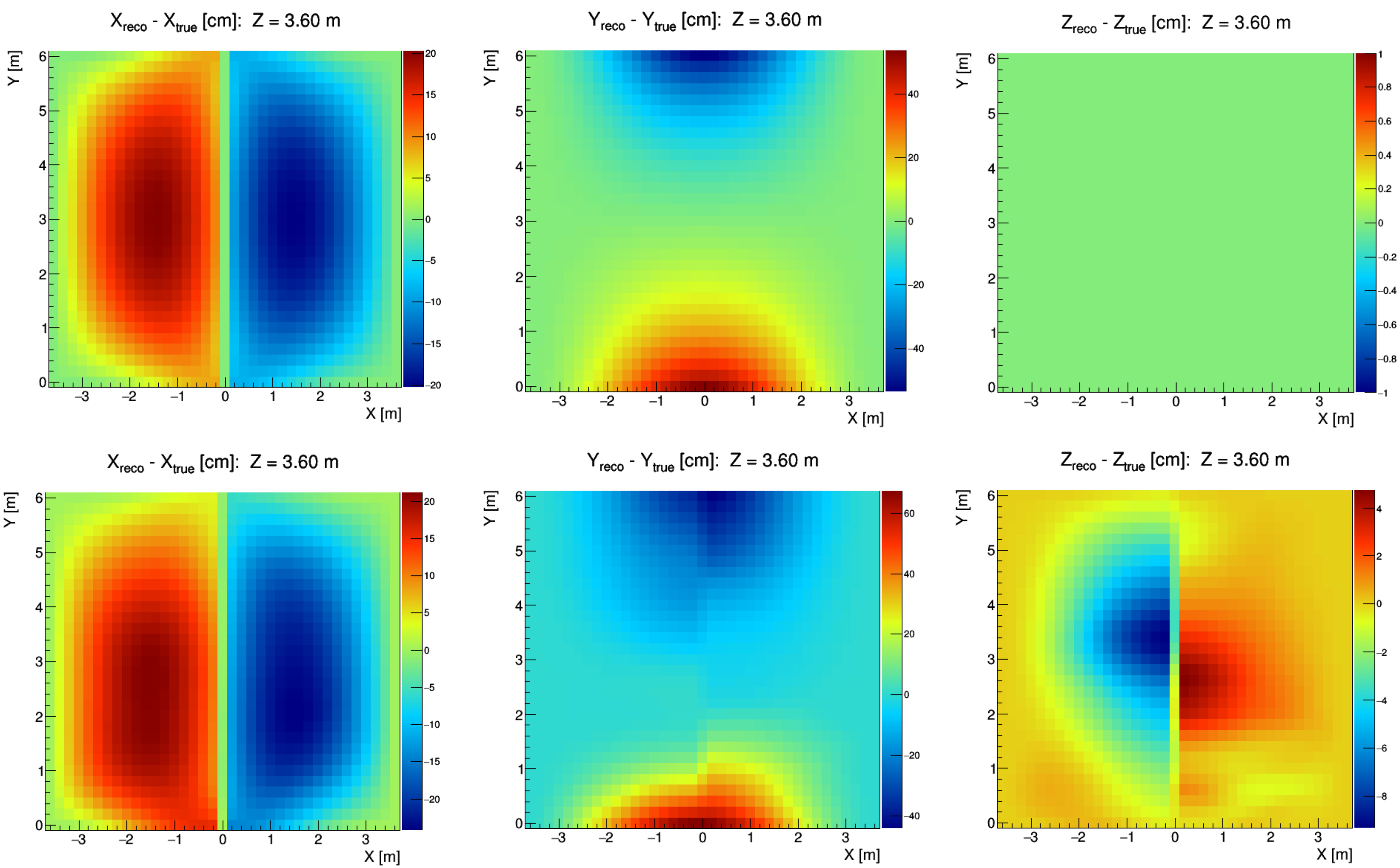
Y_{reco} - Y_{true} [cm]: Z = 3.60 m



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

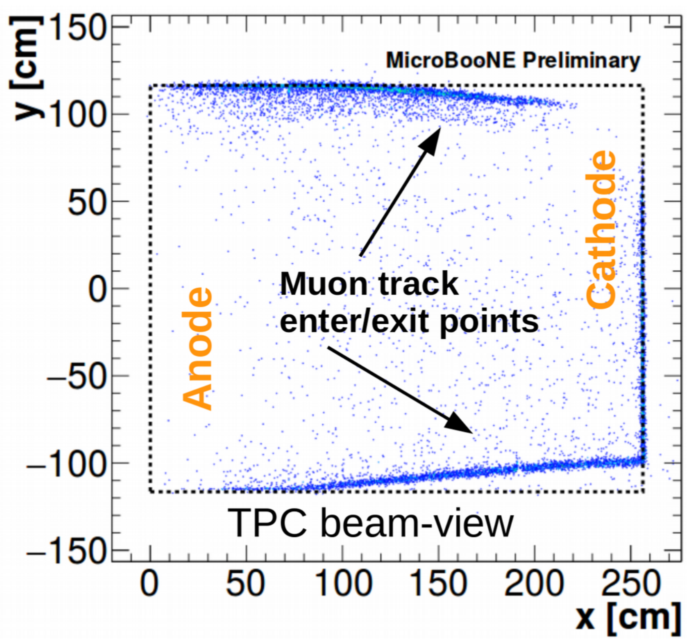


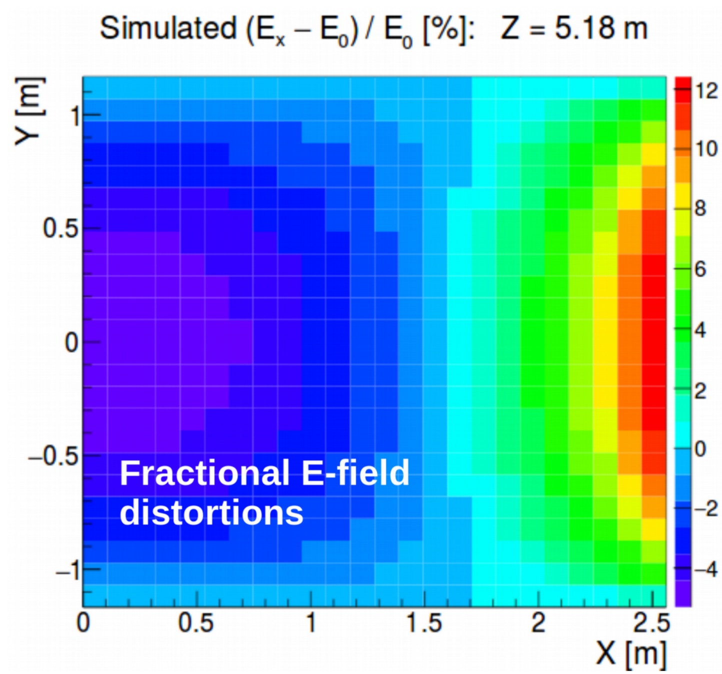
Half Field Vs. No Flow: Z = 3.6 m



Space Charge Effects

- Space charge effects: build-up of slow-moving argon ions in TPC volume due to large cosmic flux (afflicting near-surface LArTPCs, e.g. ProtoDUNEs)
  - Observed at MicroBooNE: **MICROBOONE-NOTE-1018-PUB**
  - Distorts E field (recombination smearing), leads to spatial distortions in position of reconstructed ionization charge





SCE Predictions

ProtoDUNE SP

ProtoDUNE DP

DUNE SP Far Detector

DUNE DP Far Detector

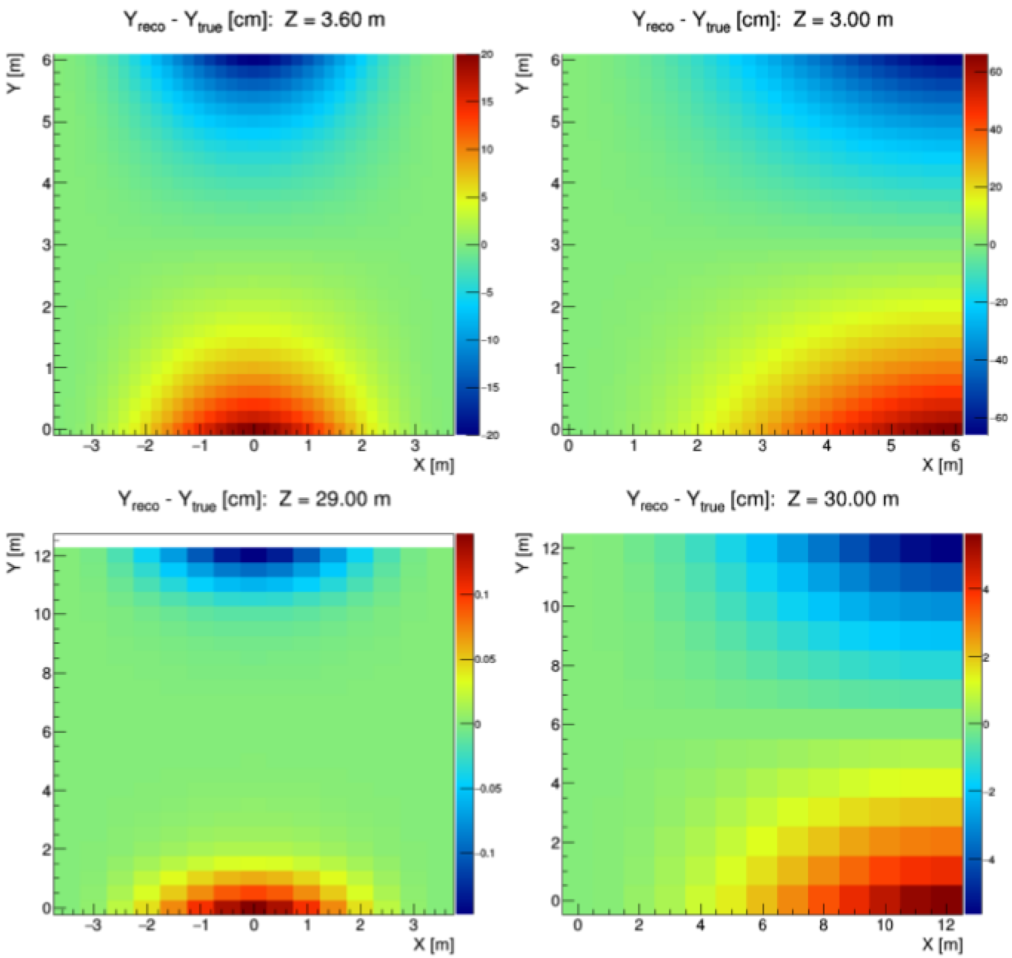
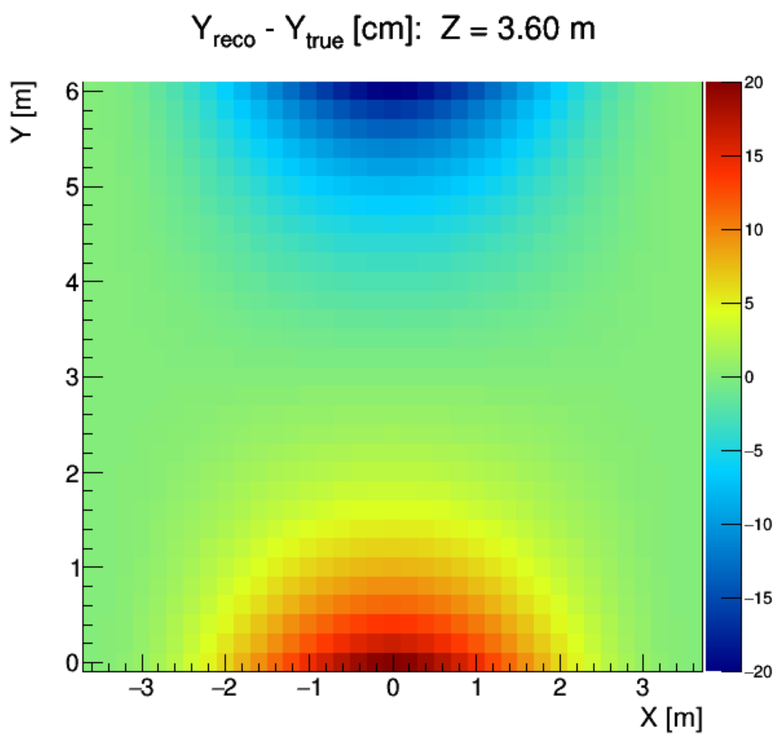


Figure 4: Predictions of spatial distortions (in the vertical direction, y) due to space charge effects at the ProtoDUNE detectors and DUNE far detectors, making use of a dedicated simulation incorporated into LArSoft. Shown is a central

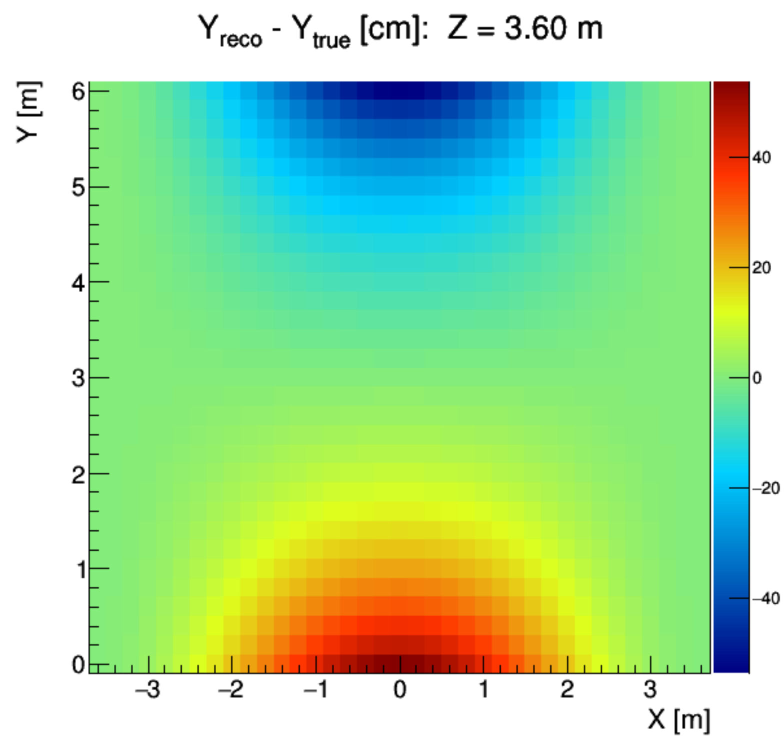
ProtoDUNE-SP @ 250 V/cm?

500 V/cm



~20 cm spatial distortions

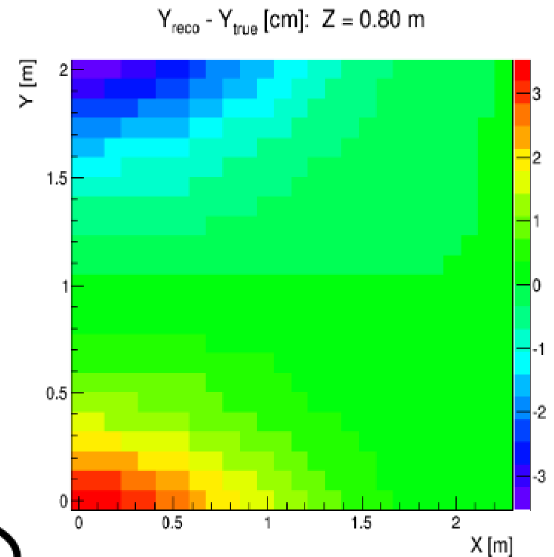
250 V/cm

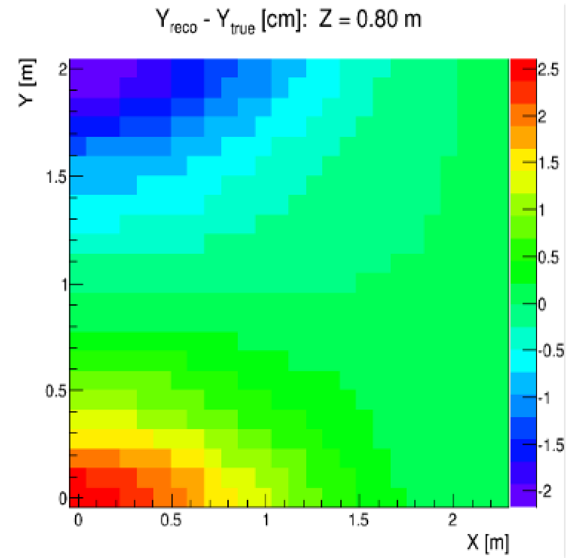


~60 cm spatial distortions

SCE w/ Fluid Flow (35 ton)

Δy
Without
LAr Flow



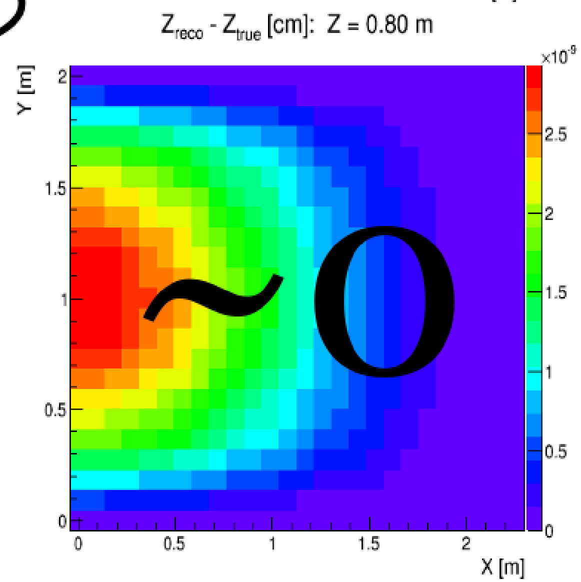


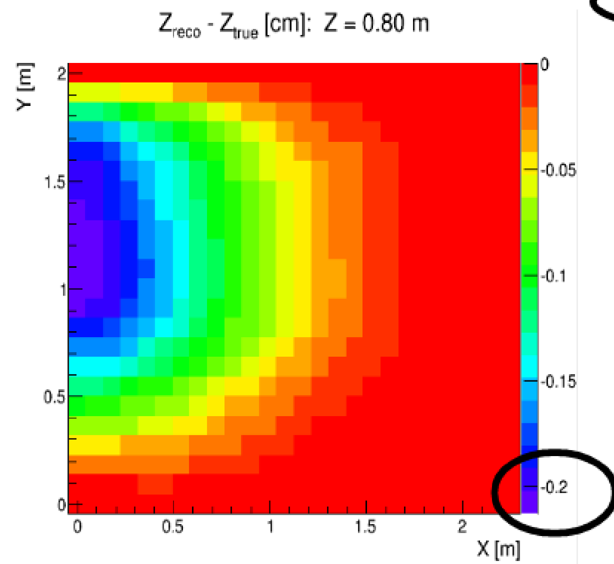
Δy
With
LAr Flow

Q map from E. Voirin

central z slice

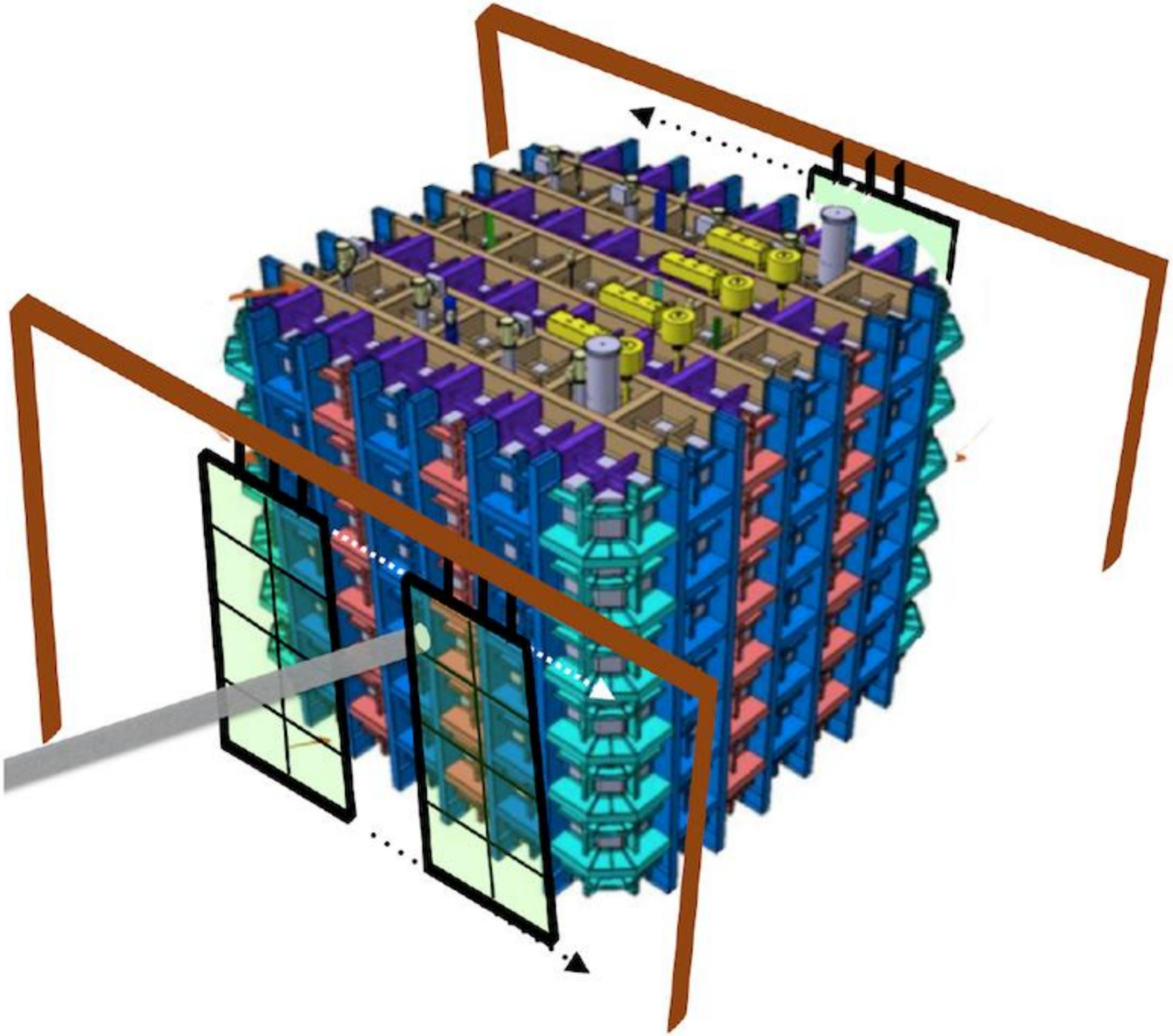
Δz
Without
LAr Flow



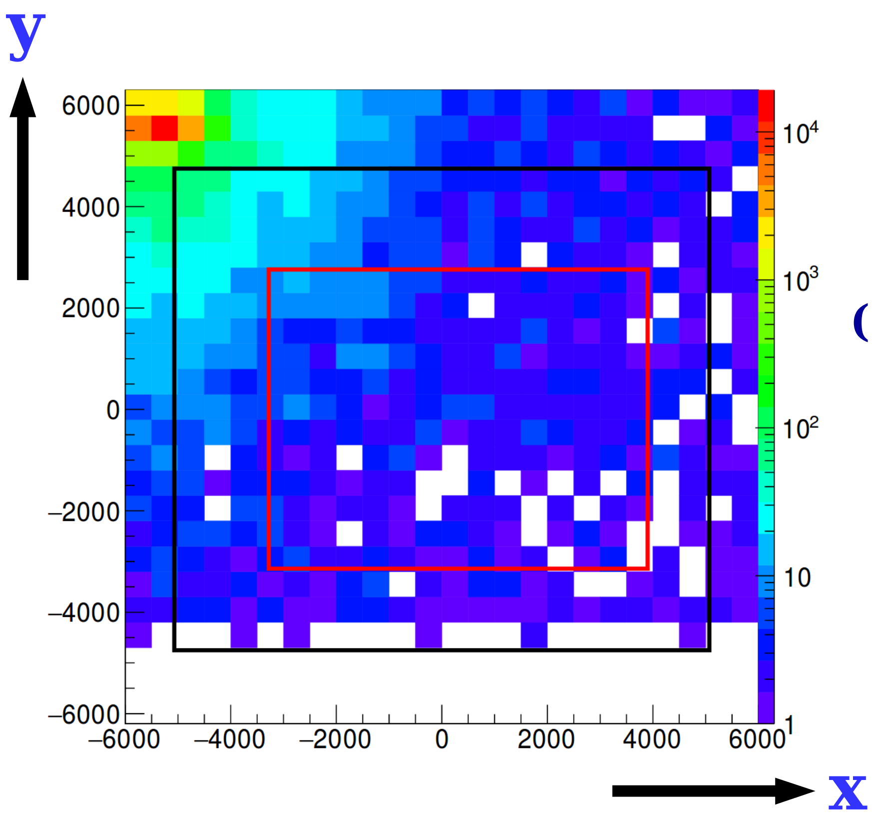


Δz
With
LAr Flow

CRT Layout



Using Muon Halo



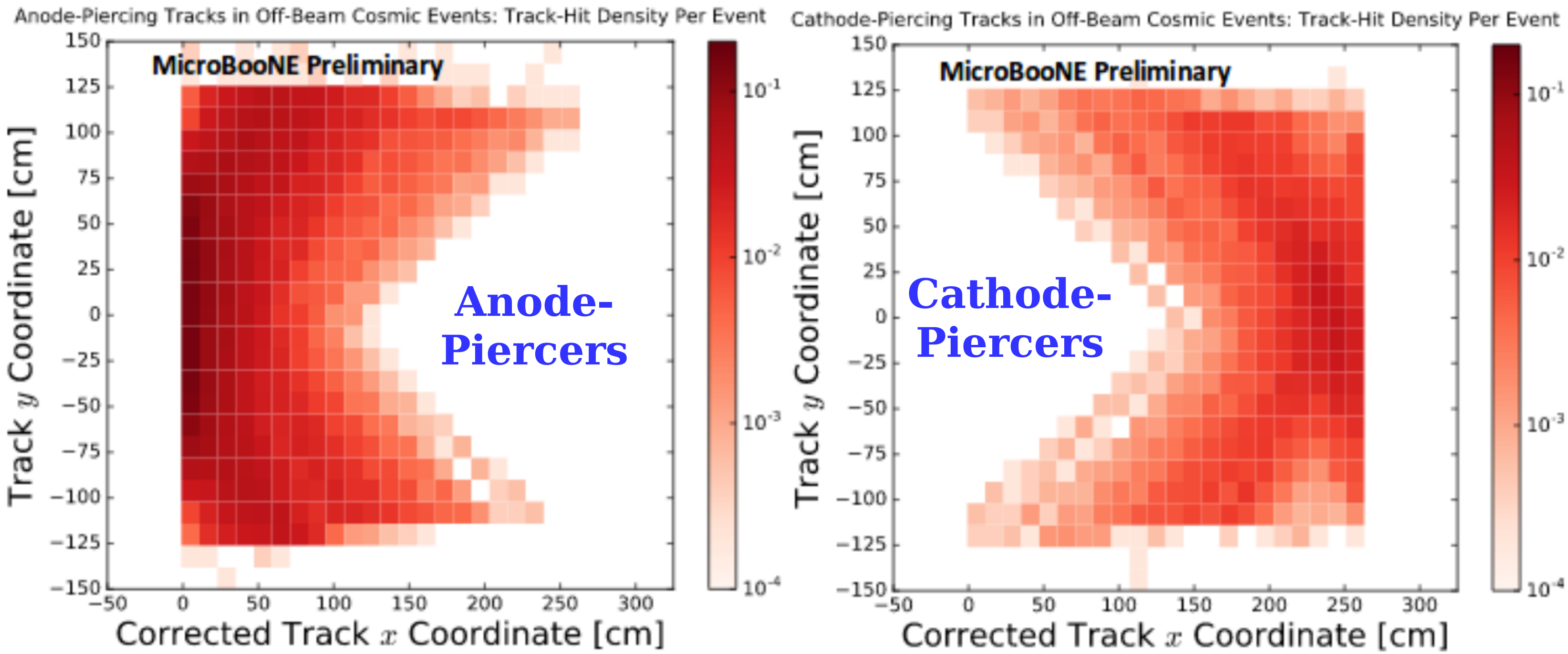
Muon Halo Coverage Map (ProtoDUNE-SP TDR)

units: $\mu/m^2/spill$

(spill length: 4.8 s)

- Muon halo can fill in gap (active volume in red, above)
- However, relative to cosmics, rate is low: **O(100)/spill**
- Need **CRT triggers** to save as many as possible

Other t_0-tagging Methods



- What about using other t_0-tagging methods to fill gaps?
- For example, MicroBooNE's anode/cathode piercers:
  - See public note: **MICROBOONE-NOTE-1028-PUB**
- But this sample still sees a gap in the middle of TPC...