Space Charge Effects in ProtoDUNE-SP

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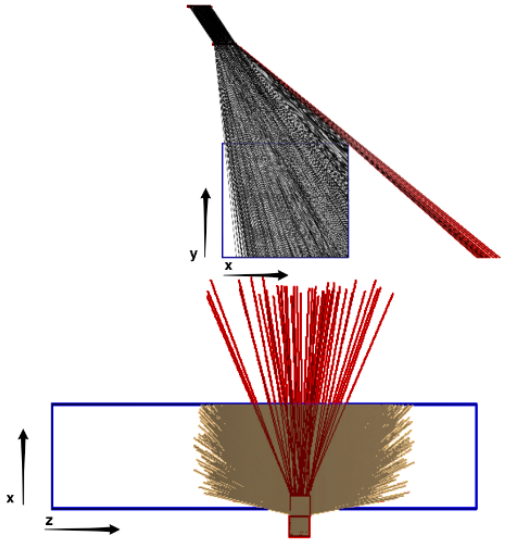
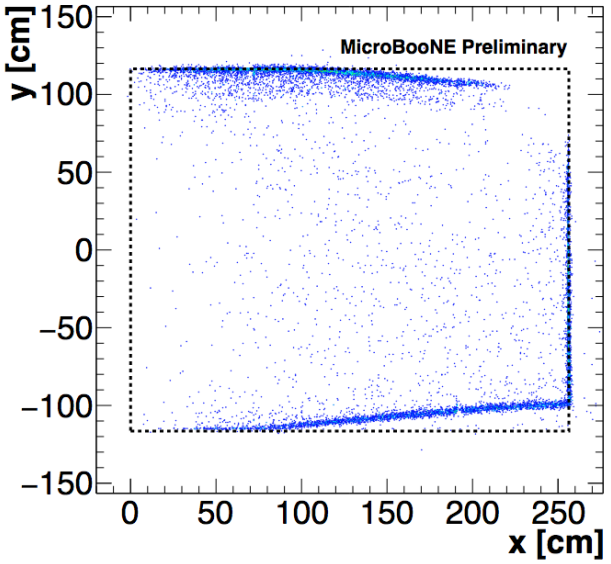
SCE Overview

- 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 dE/dx, track angles
  - E field distortions impact recombination (**dE** bias)
  - Spatial distortions lead to squeezing of charge (**dx** bias)
- See **MicroBooNE public note on SCE** for more details

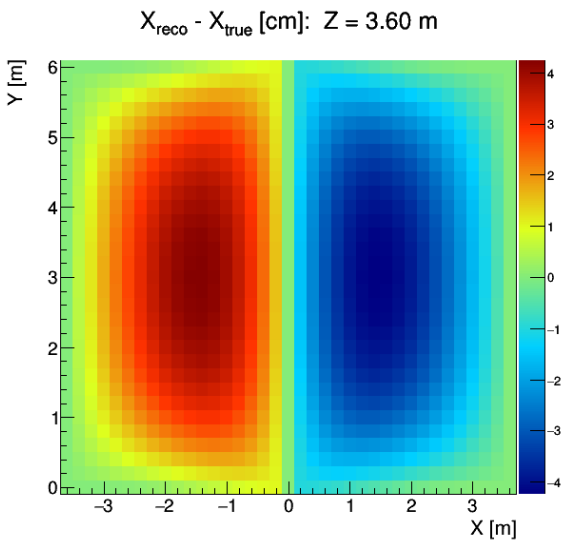


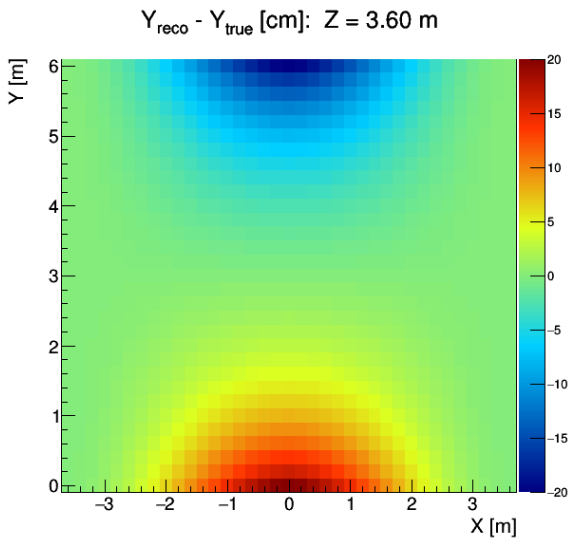
t_0 tags from MicroBooNE MuCS

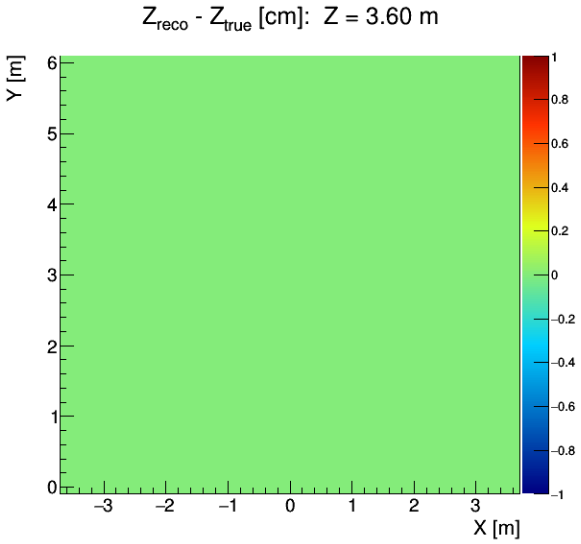
plot TPC track start/end points



ProtDUNE-SP SCE Sim.

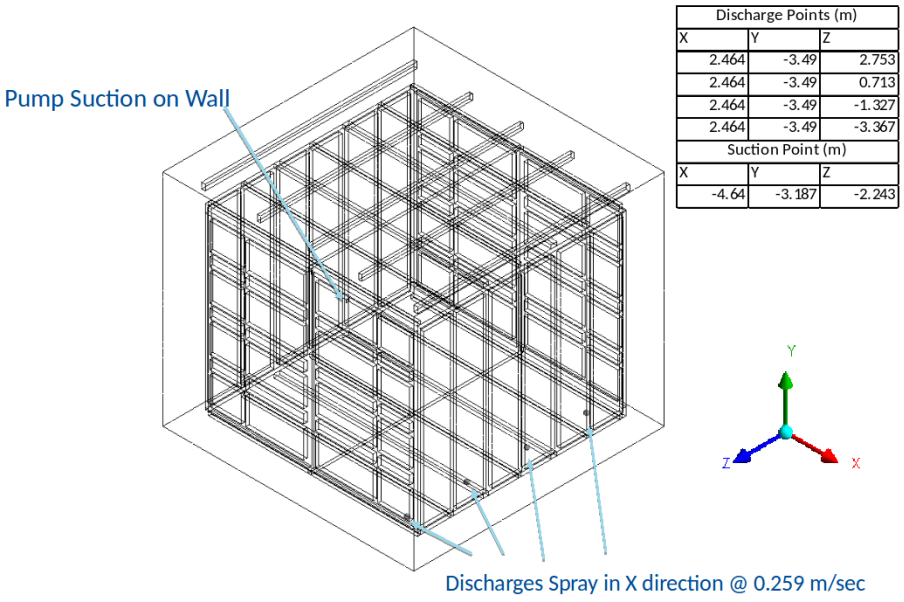




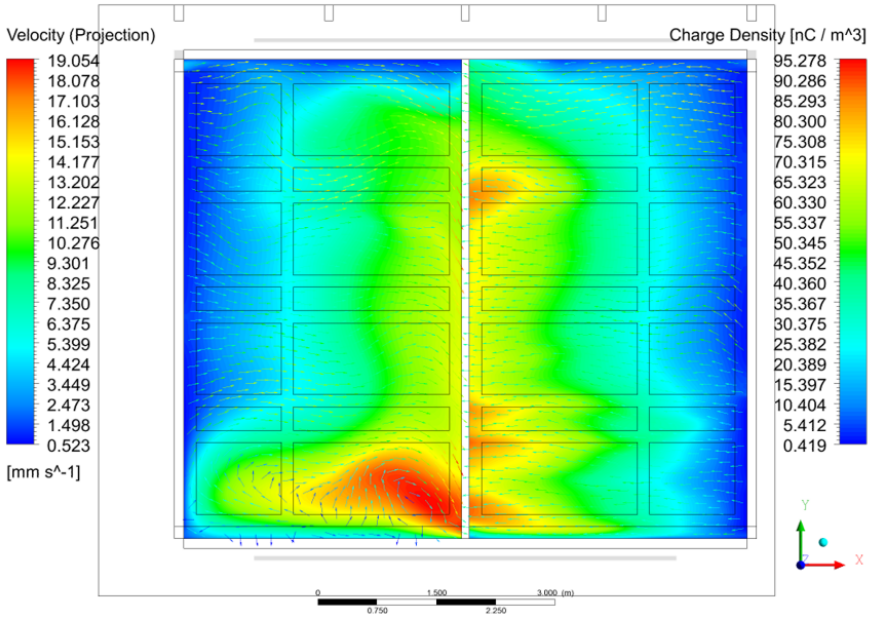


- Home-brewed code developed by Mike M. to study SCE at different LArTPC detectors
  - Solve for E field in detector via Fourier series, interpolation
  - Ray-tracing (RKF45) to obtain spatial distortions
- Result: E field and spatial distortion maps that can be utilized in ionization drift sim. (in LArSoft)

ProtDUNE-SP LAr Flow Sim.

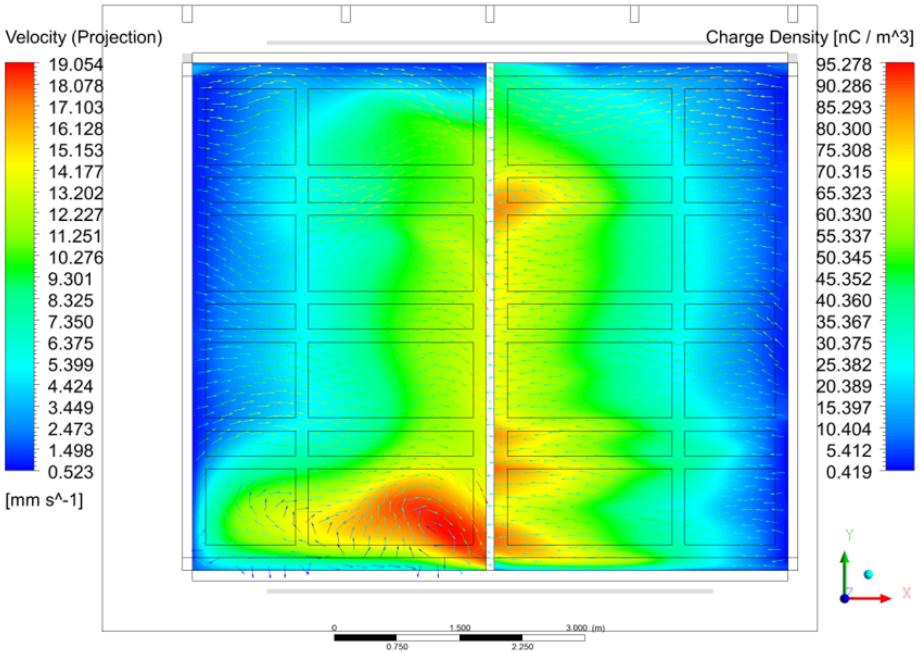


Discharge Points (m)		
X	Y	Z
2.464	-3.49	2.753
2.464	-3.49	0.713
2.464	-3.49	-1.327
2.464	-3.49	-3.367
Suction Point (m)		
X	Y	Z
-4.64	-3.187	-2.243

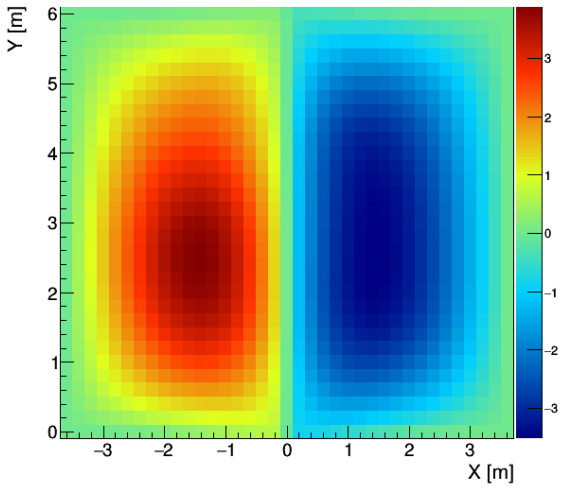


- Developed by Erik Voirin for ProtoDUNE-SP; better prediction of space charge density → improve E field sim.
- 3D simulation of LAr flow, 8 mm/s ion drift @ 500 V/cm, uniform space charge deposition from cosmics
- Ion absorption at field cage, APA, CPA, and all solid objects inside cryostat

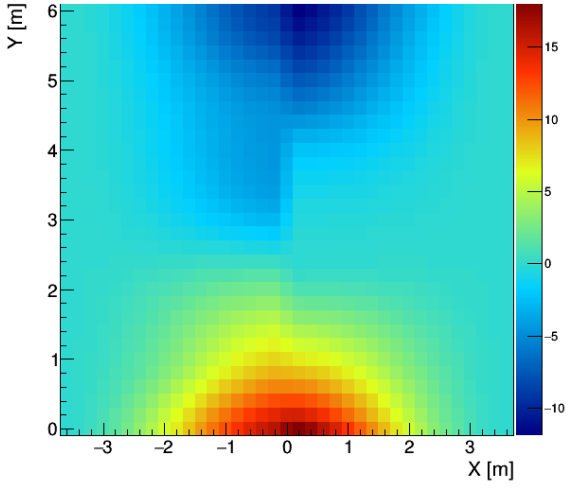
PD-SP Spatial Offsets: Z = 3.6 m



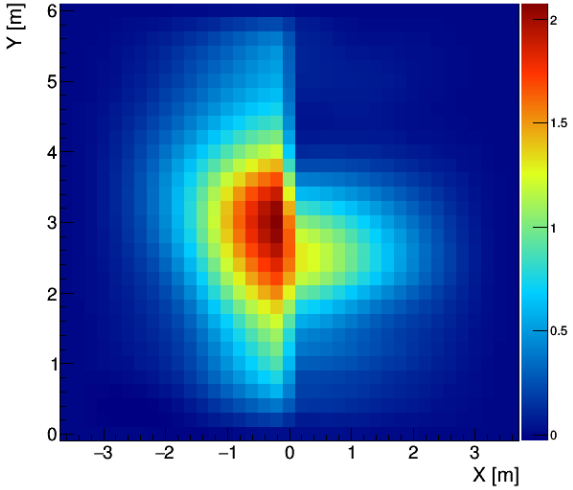
$X_{reco} - X_{true}$ [cm]: Z = 3.60 m



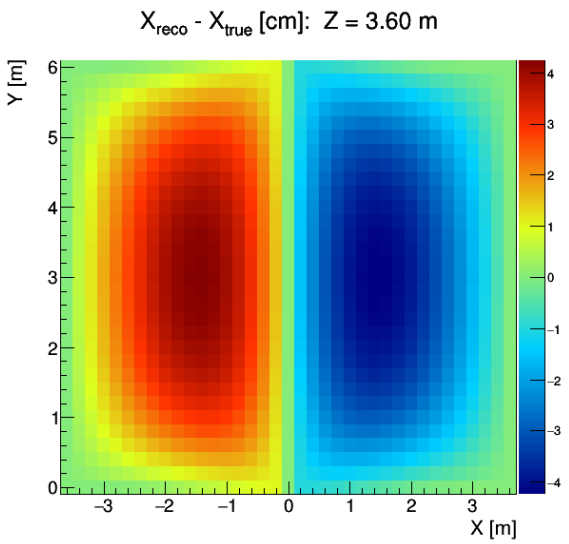
$Y_{reco} - Y_{true}$ [cm]: Z = 3.60 m

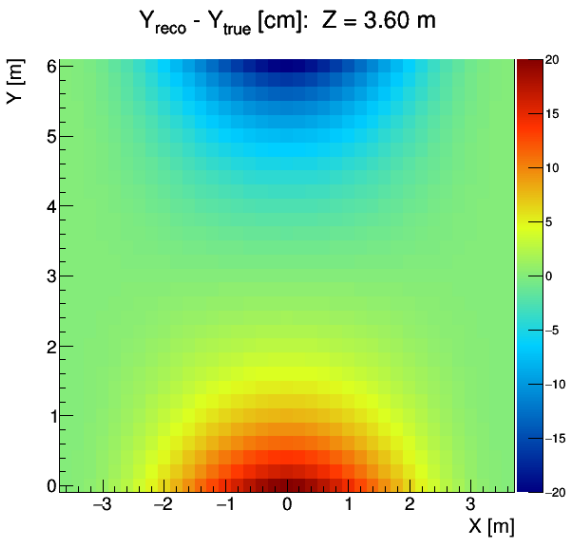


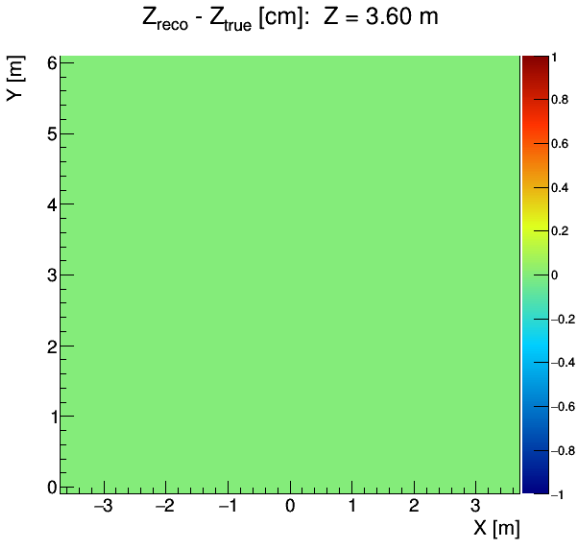
$Z_{reco} - Z_{true}$ [cm]: Z = 3.60 m

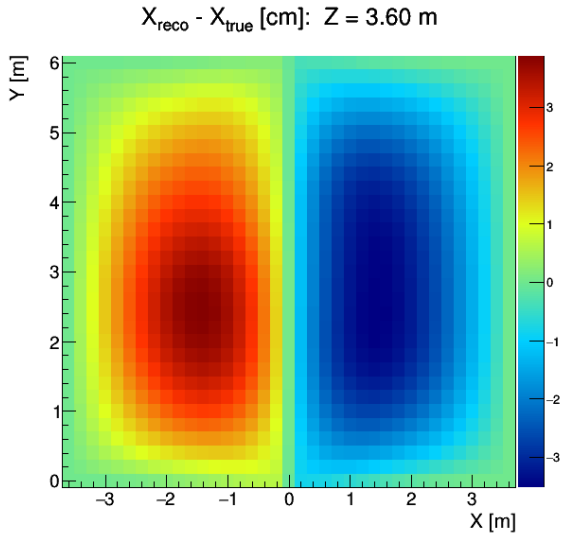


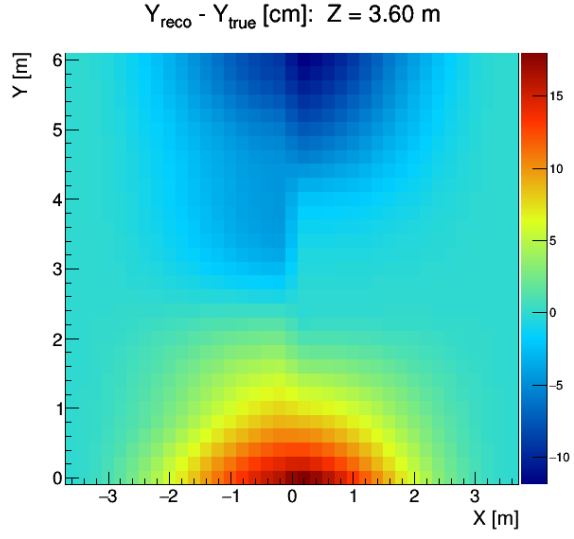
PD-SP Vs. No Flow: Z = 3.6 m

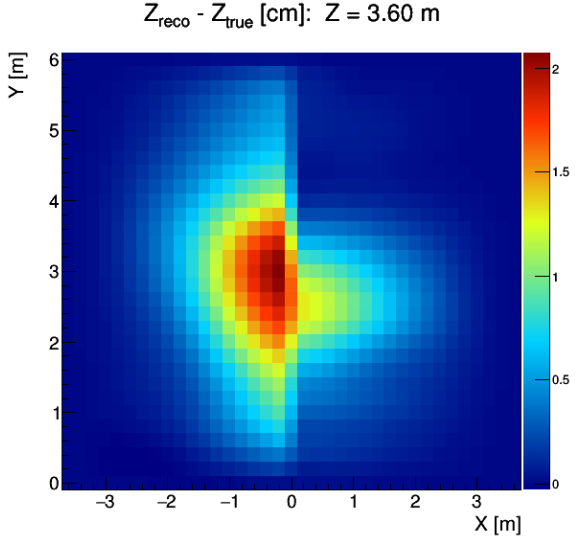






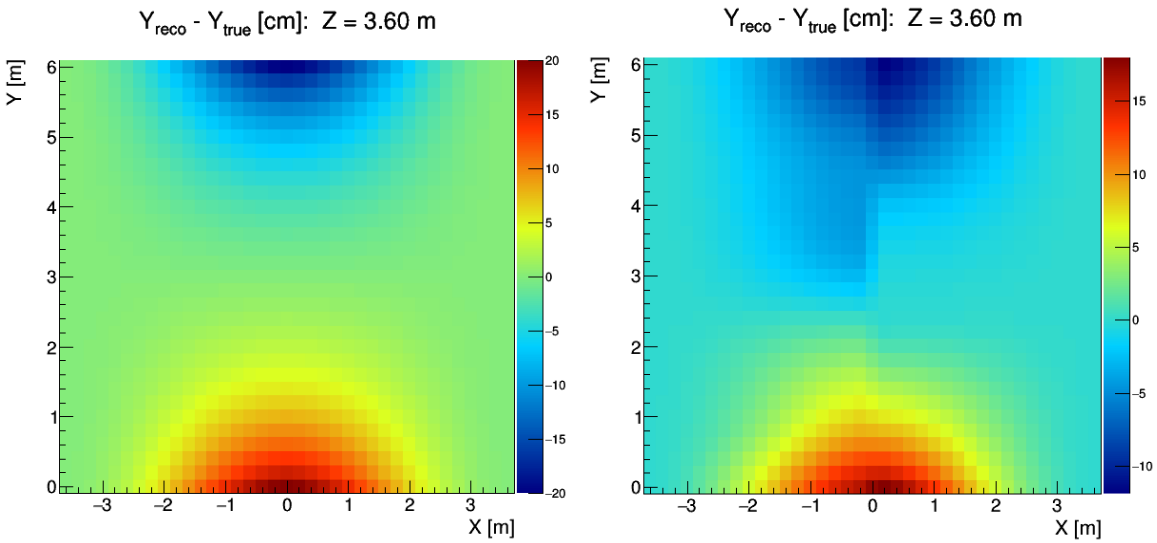






Tuning Fluid Flow Model

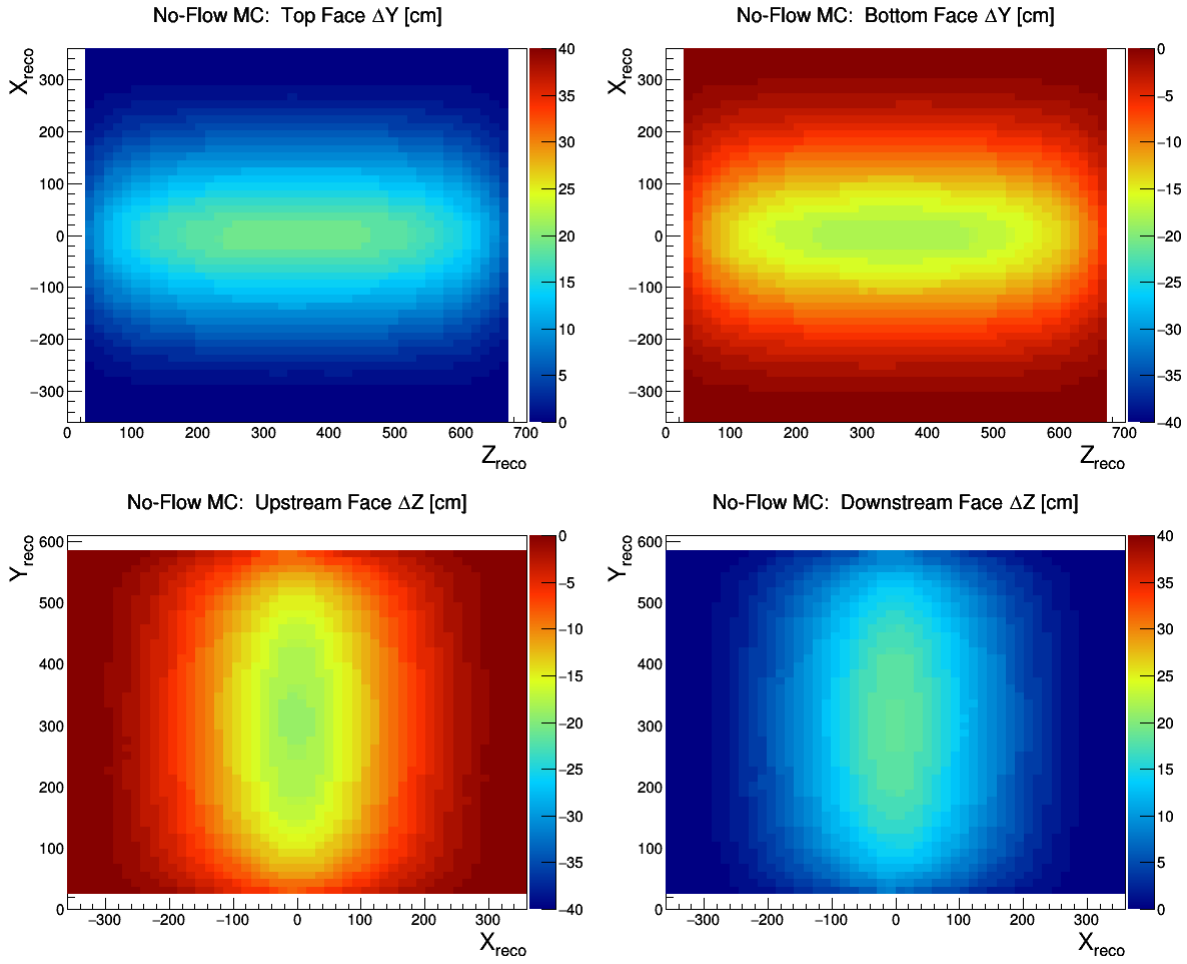
No Fluid Flow Sim.



With Fluid Flow Sim.

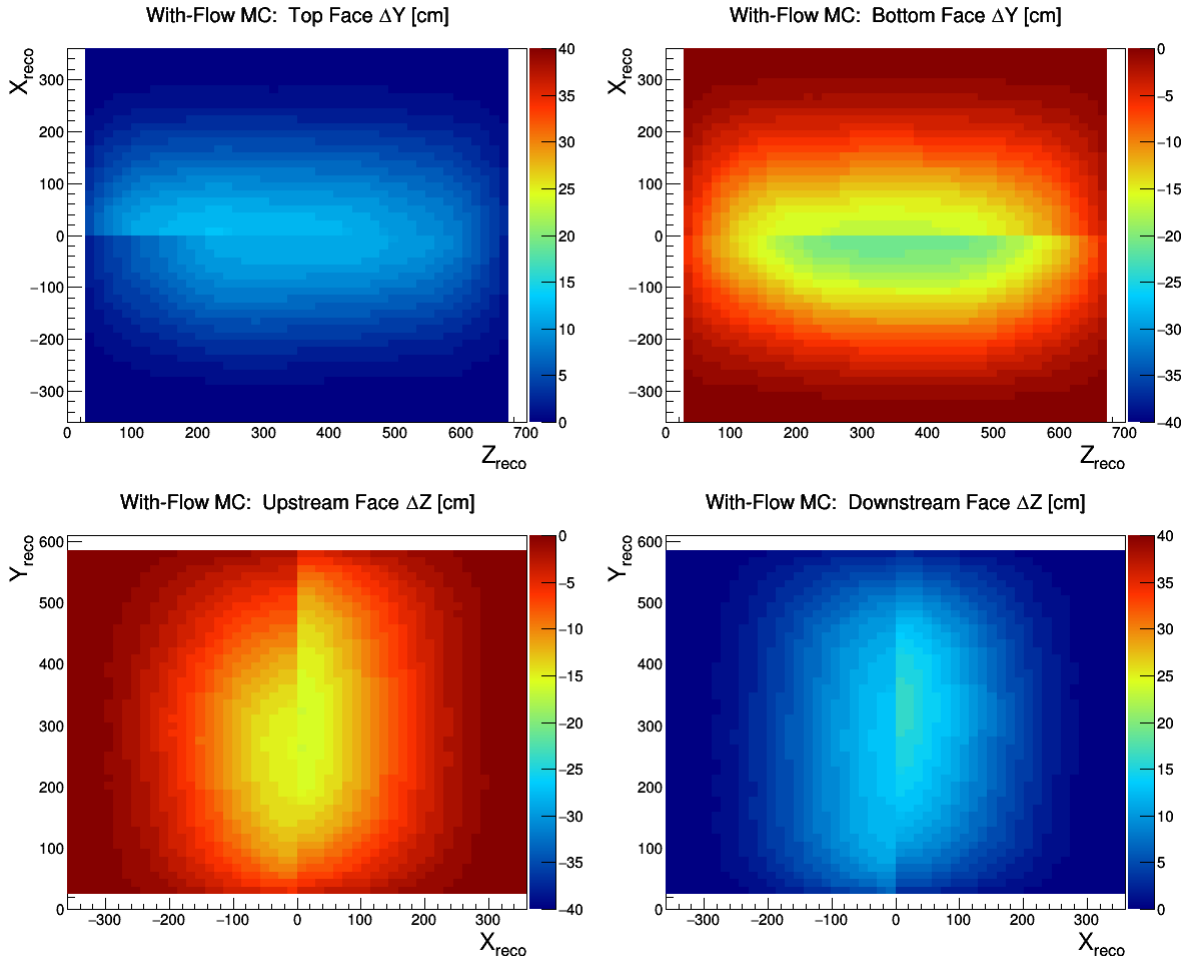
- Principal observations from fluid flow study:
  - Asymmetry in comparing two drift volumes (shared cathode is at x = 0)
  - Up/down asymmetry emerges as well – less SCE at top
  - Overall reduction in magnitude of SCE
- Can use ProtoDUNE-SP **data** to validate fluid flow model (use to tweak model?)

No-Flow MC at TPC Faces



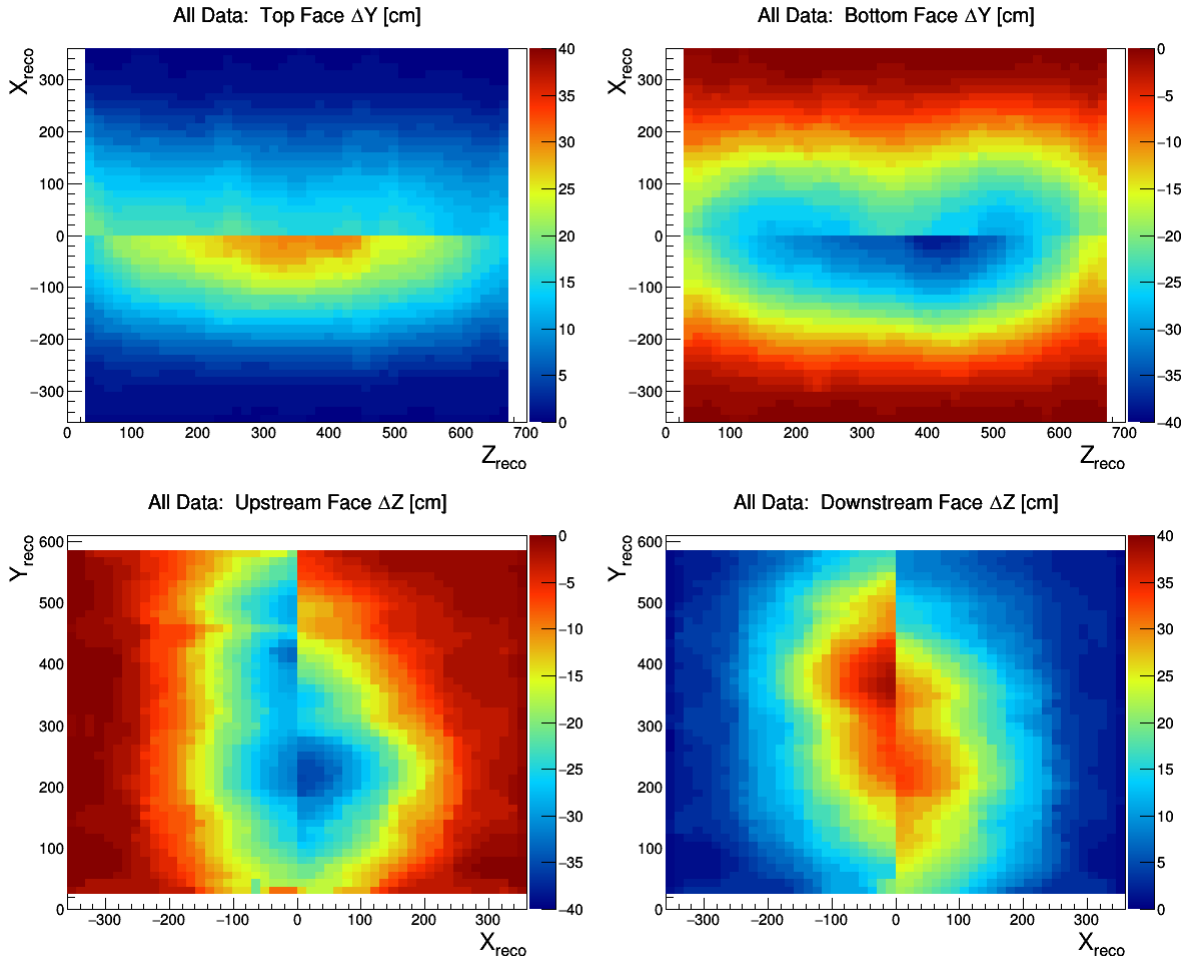
- Comparing MC to data, offsets from TPC faces much larger in data! Drift ion velocity wrong?

With-Flow MC at TPC Faces



- Comparing MC to data, offsets from TPC faces much larger in data! Drift ion velocity wrong?

Data at TPC Faces

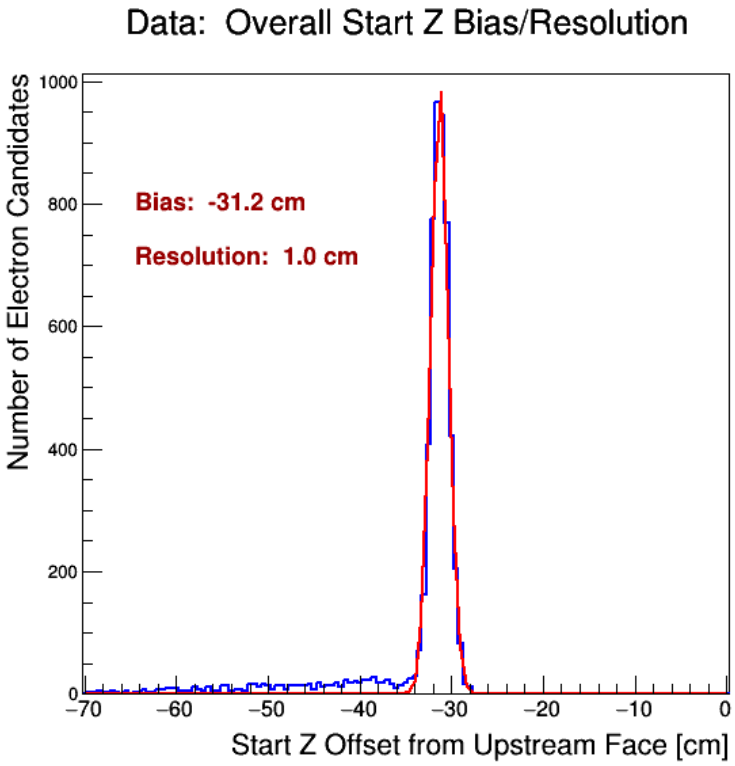


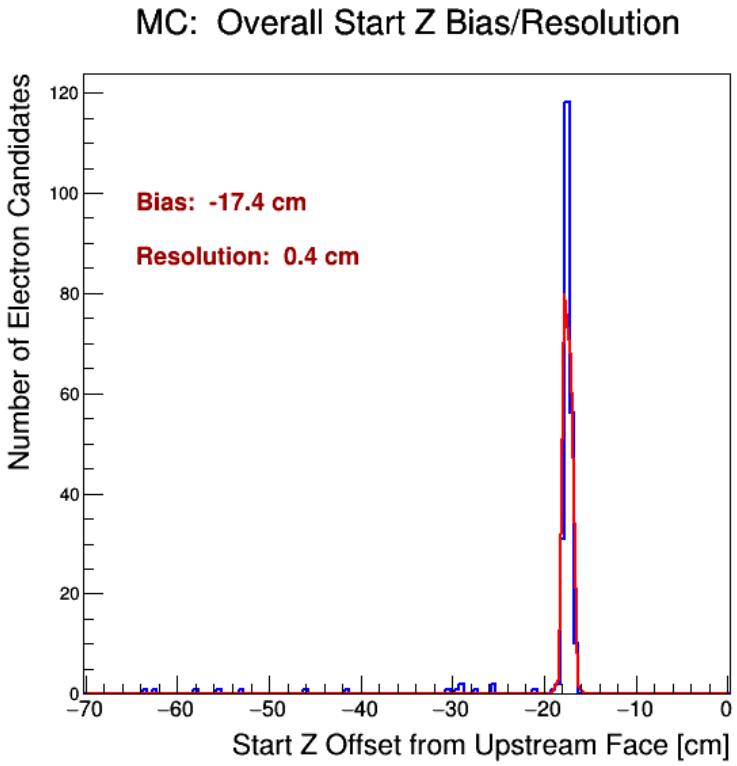
- Comparing MC to data, offsets from TPC faces much larger in data! Drift ion velocity wrong?

SCE Time Dependence

- Use sample of beam electrons (e^+), provided by Aaron Higuera, to probe SCE time dependence at **short timescales**
  - First look by Mike M.
  - Look at width of ΔZ distribution in data, compare to MC
  - Broadening in MC due only to reconstruction effects
  - Broadening in data due to reconstruction and SCE
- Also study offsets in different runs using end points of cosmic tracks to study **long timescales**
  - Preliminary study by Hannah Rogers
  - Also can use high-rate runs (triggering at 30-40 Hz) to study shorter timescales with this sample – effort led by Francesca Stocker

SCE at Short Timescales

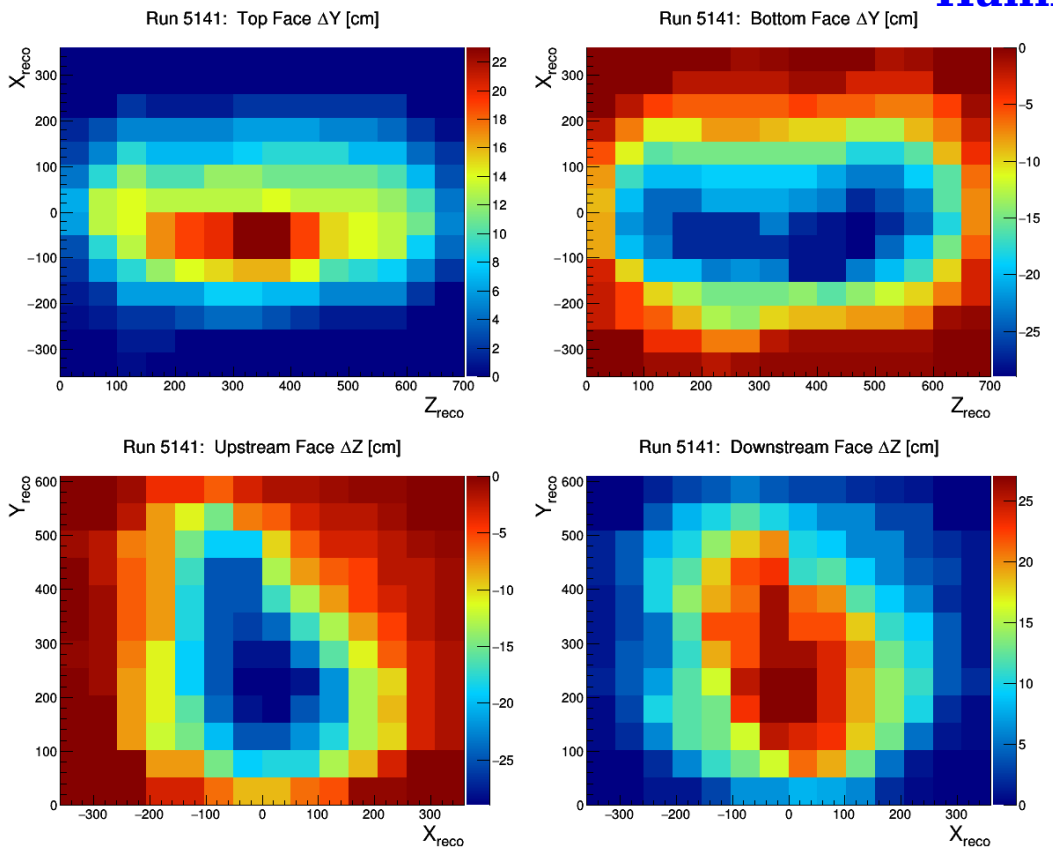




- Look at Z offset dist. (all e^+ candidates, single run)
  - Data: -31.2 ± **1.0 cm**
  - MC: -17.4 ± **0.4 cm**
- Implies SCE time dependence < 1 cm (< **3%** effect)

SCE at Long Timescales

Hannah Rogers (CSU)

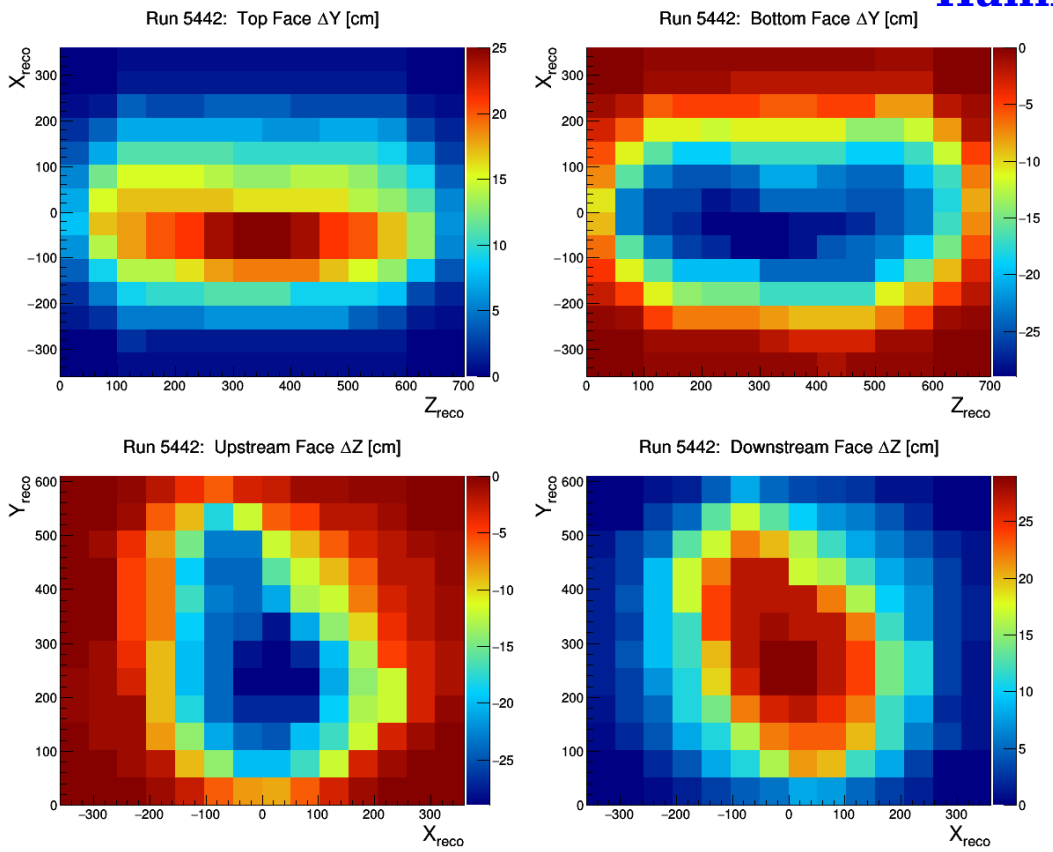


Run 5141

- No significant time dependence over O(month)
  - No more than 5% variation
  - Needs more precise study with higher statistics

SCE at Long Timescales

Hannah Rogers (CSU)

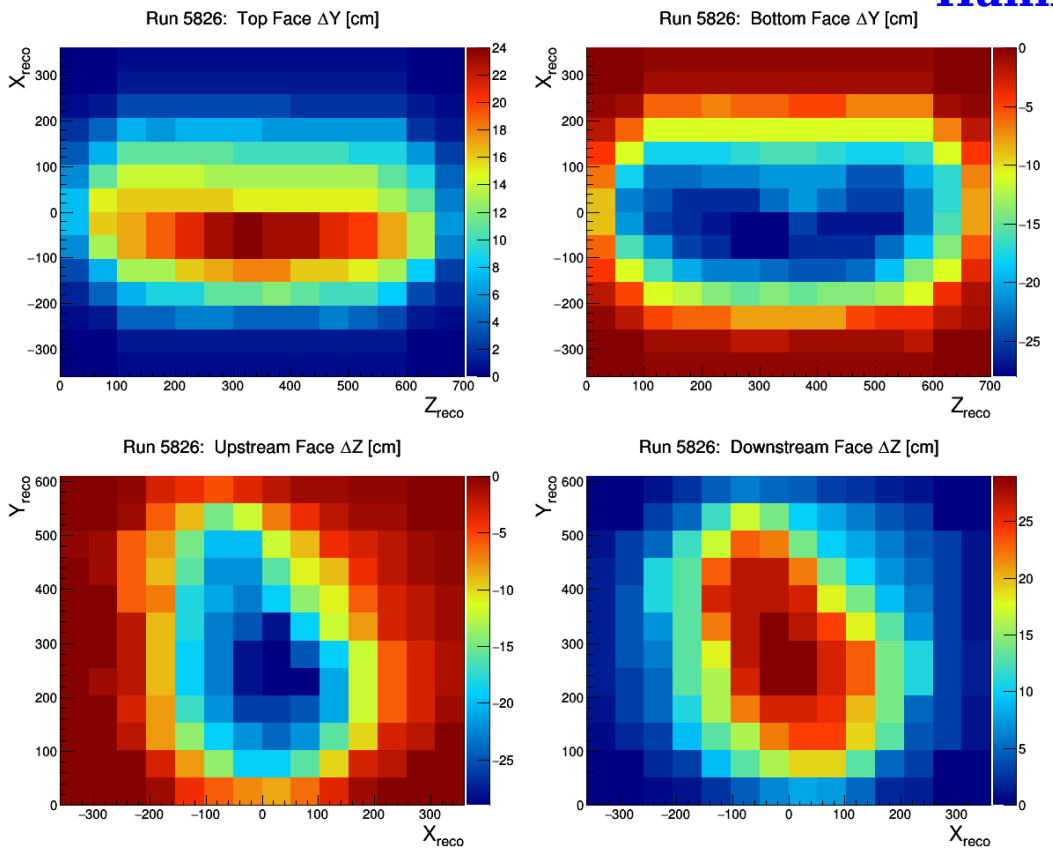


Run 5442

- No significant time dependence over O(month)
  - No more than 5% variation
  - Needs more precise study with higher statistics

SCE at Long Timescales

Hannah Rogers (CSU)



Run 5826

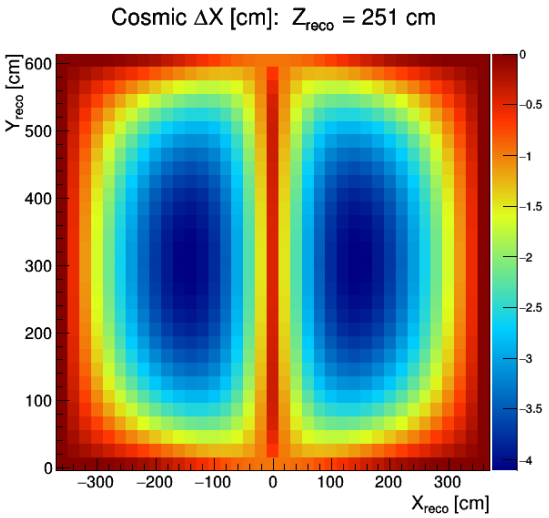
- No significant time dependence over O(month)
  - No more than 5% variation
  - Needs more precise study with higher statistics

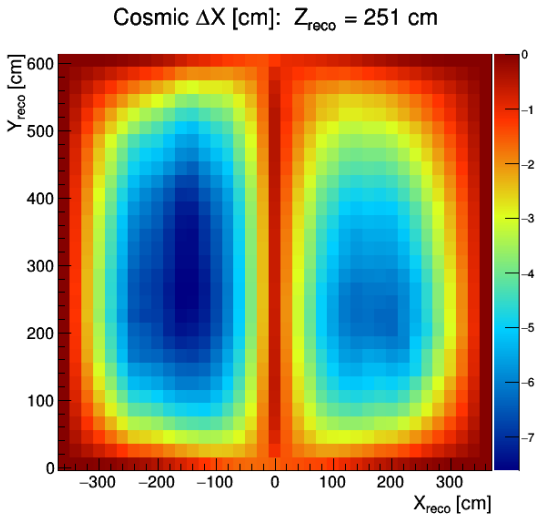
Data-Driven SCE Sim.

- Goal: use **data-driven SCE simulation maps**
  - Uses spatial offsets at boundaries, obtained from data, to scale simulation
  - Eventually, once t_0-tagged sample larger (introducing anode-piercing tracks, CRT-tagged tracks) use **crossing points of track pairs** to improve estimation of SCE
- Procedure:
  - 1. Measure reco. spatial offsets at top, bottom, upstream, and downstream TPC faces in both data and MC
  - 2. Form 2D scale factor map at TPC faces w/ data/MC ratio
  - 3. Interpolate scale factors across 3D volume to scale MC truth spatial map everywhere
  - 4. Compute E field using straightforward calculus

Data-Driven Maps (Z = 251 cm)

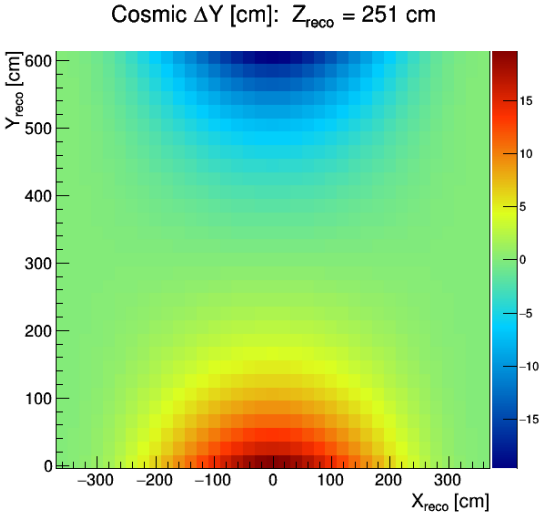
Orig. ΔX

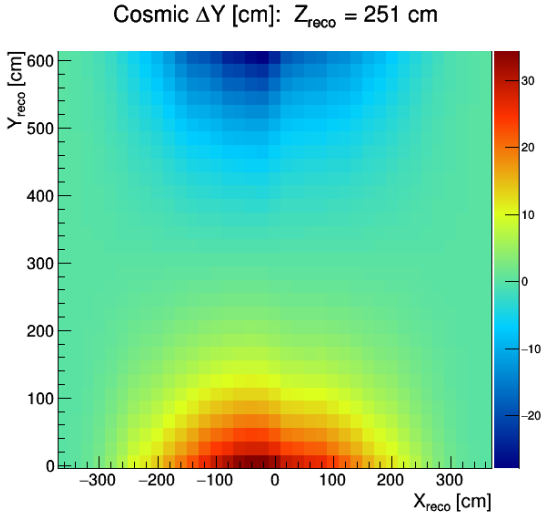




Data-Driven ΔX

Orig. ΔY



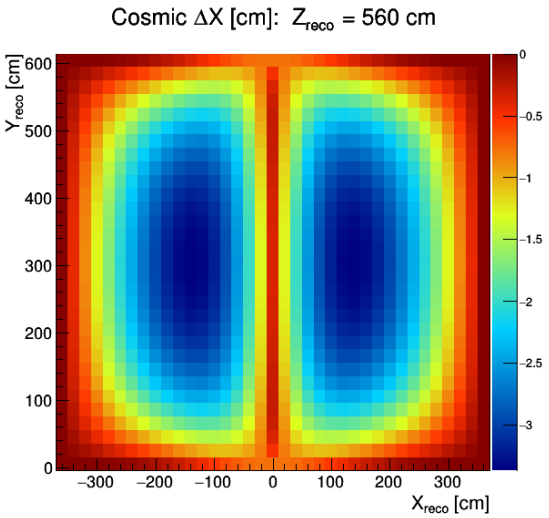


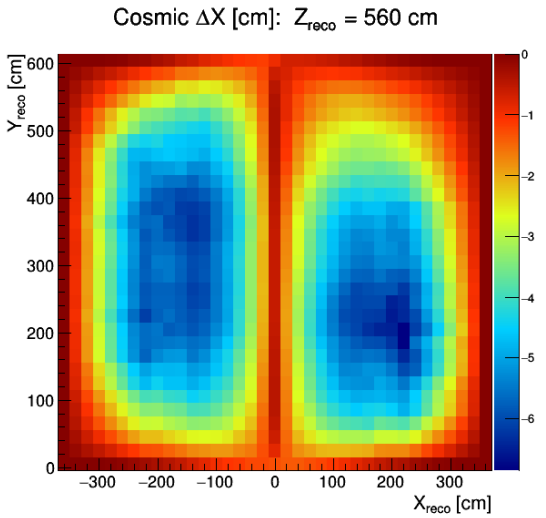
Data-Driven ΔY

- E field maps coming next week → produce new MC

Data-Driven Maps (Z = 560 cm)

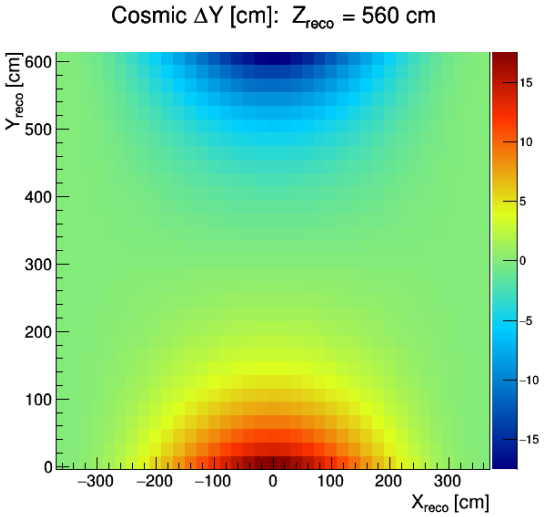
Orig. ΔX

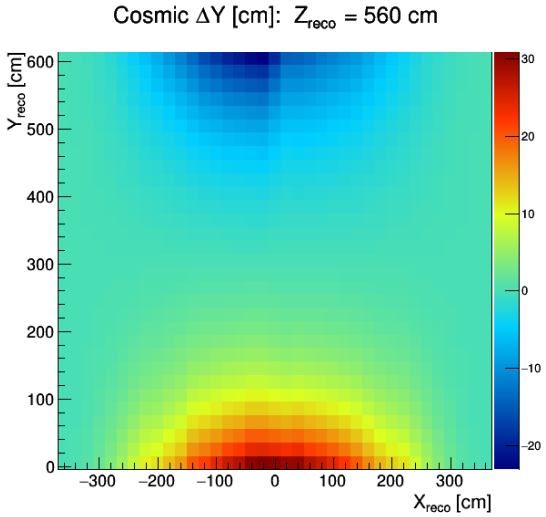




Data-Driven ΔX

Orig. ΔY



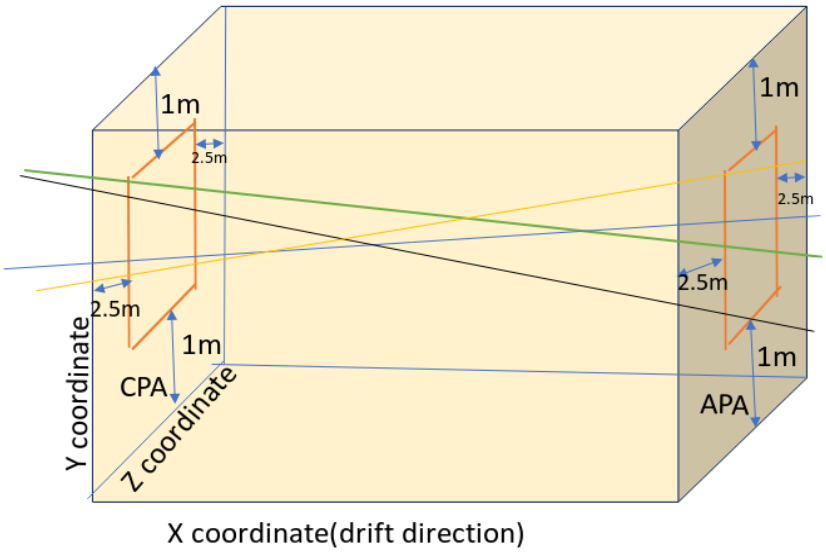


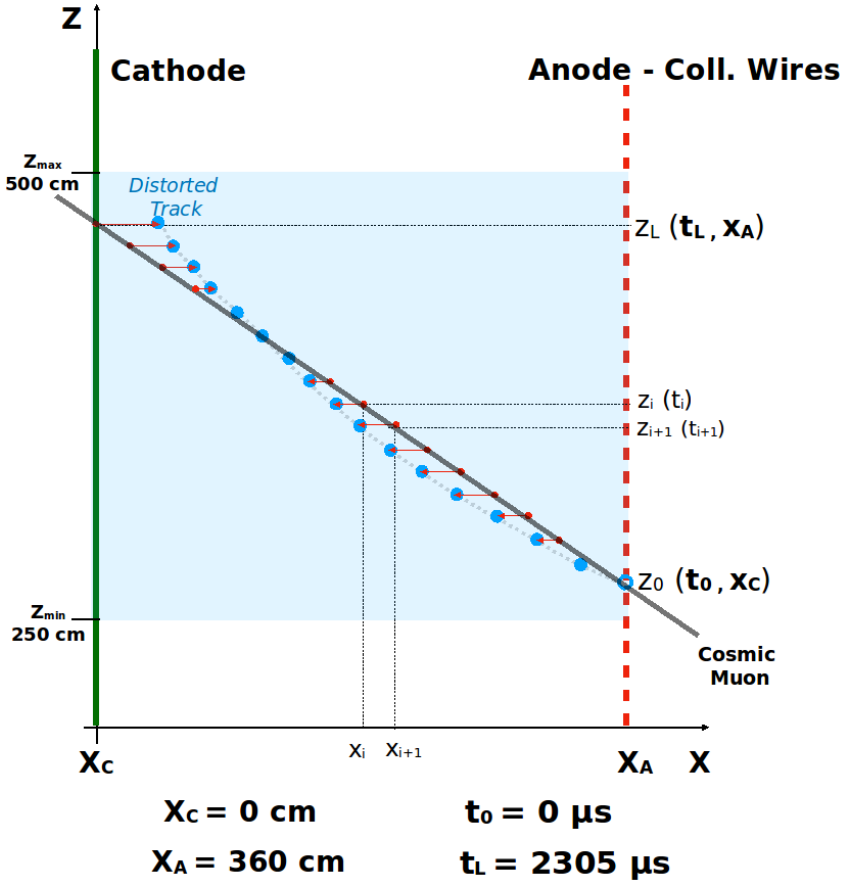
Data-Driven ΔY

- E field maps coming next week → produce new MC

First Look at E Field

Ajib Paudel (KSU)

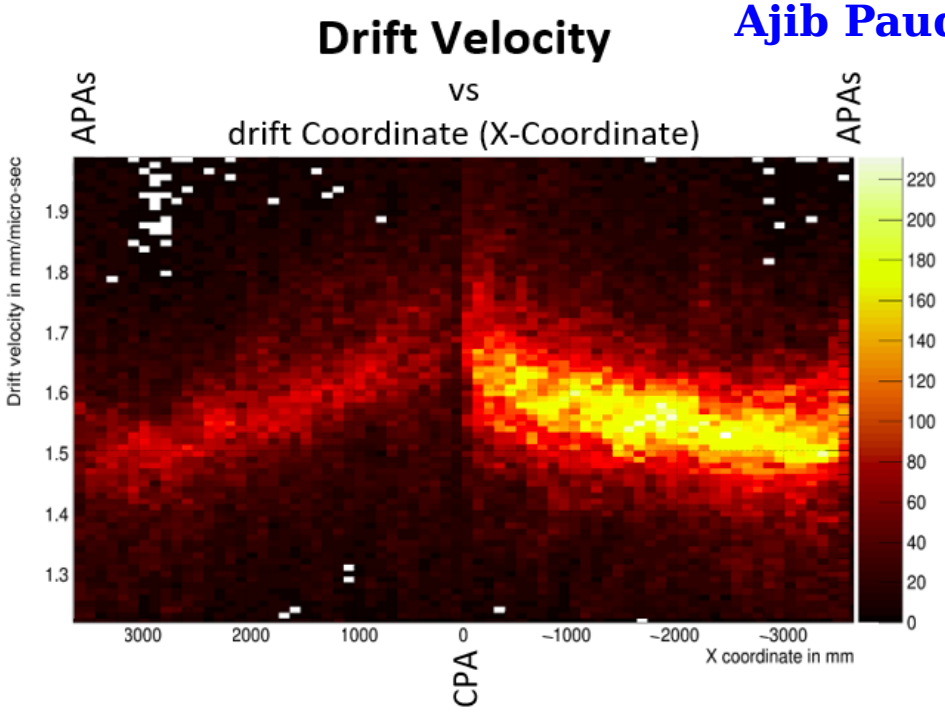


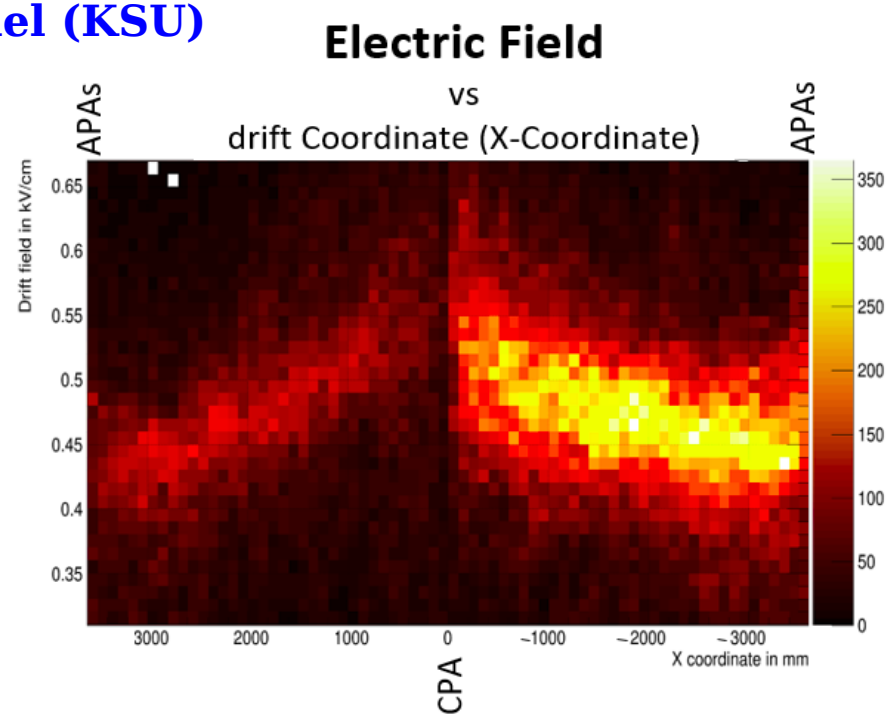


- First study of E field:
  - Use C-A crossing tracks
  - Restrict to central Y/Z values
  - Measure distance **in x** between reconstructed track and assumed track trajectory → extract E field (simple math)

Preliminary E Field Results

Ajib Paudel (KSU)

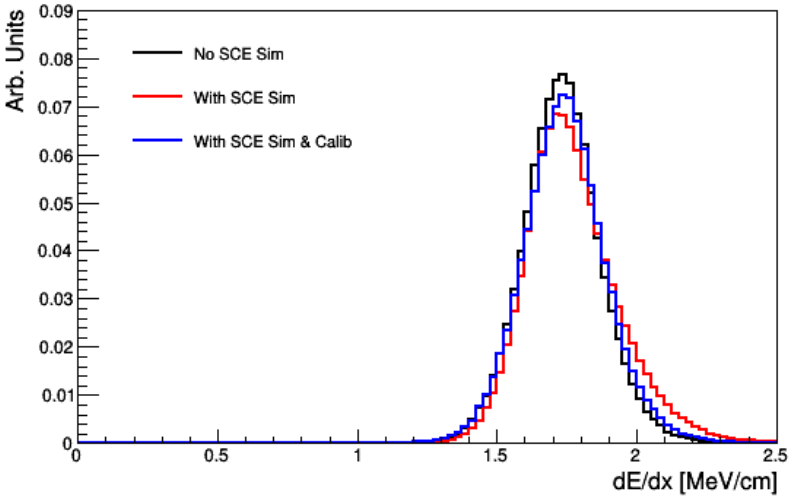


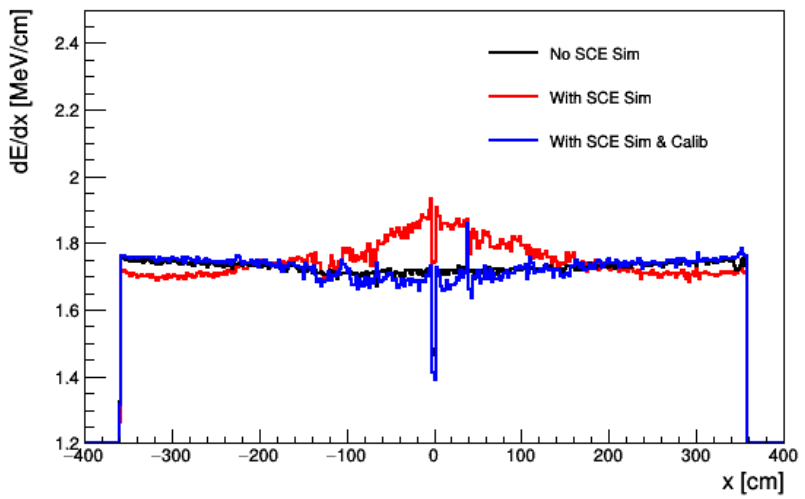


- Reconstructed E field higher at cathode, lower at anode, as expected – O(20%) deviation from nominal
- Some limitations of method toward precision study
  - Cathode point wrong from wrong drift velocity, distortions in Z
  - However, good qualitative check that behavior is as expected!

SCE Calibration: dE/dx

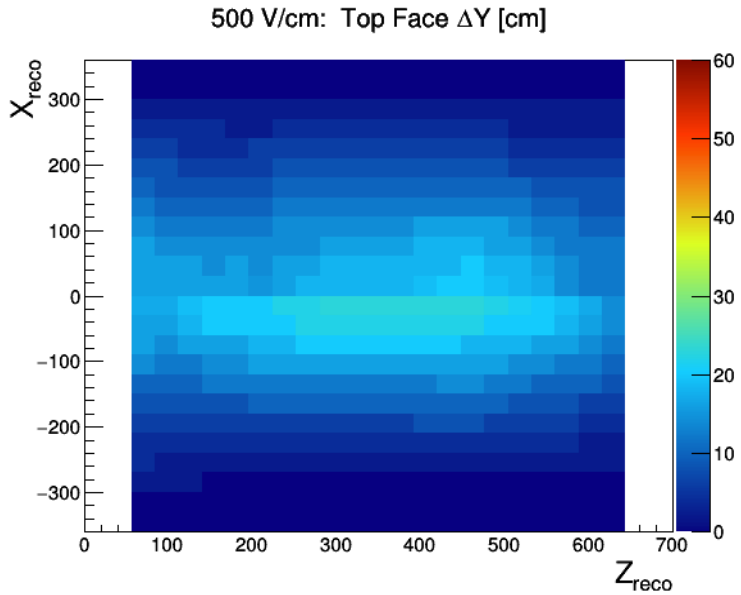
Hannah Rogers (CSU)

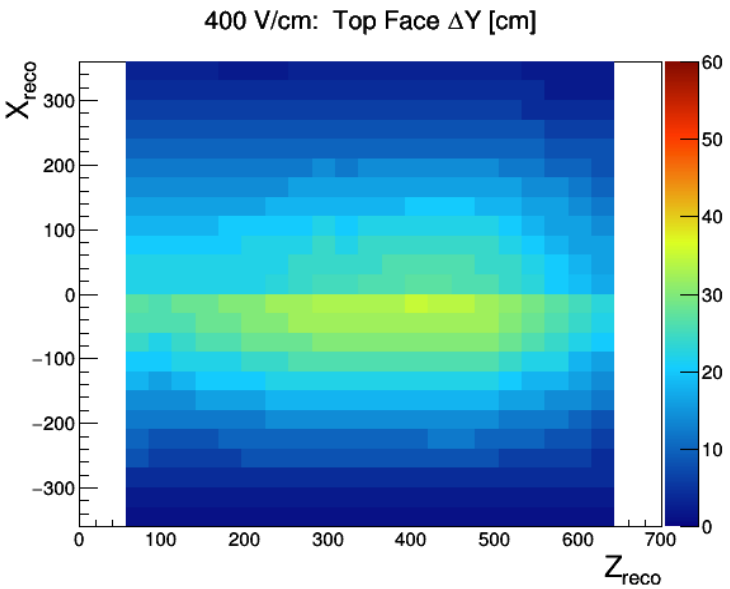


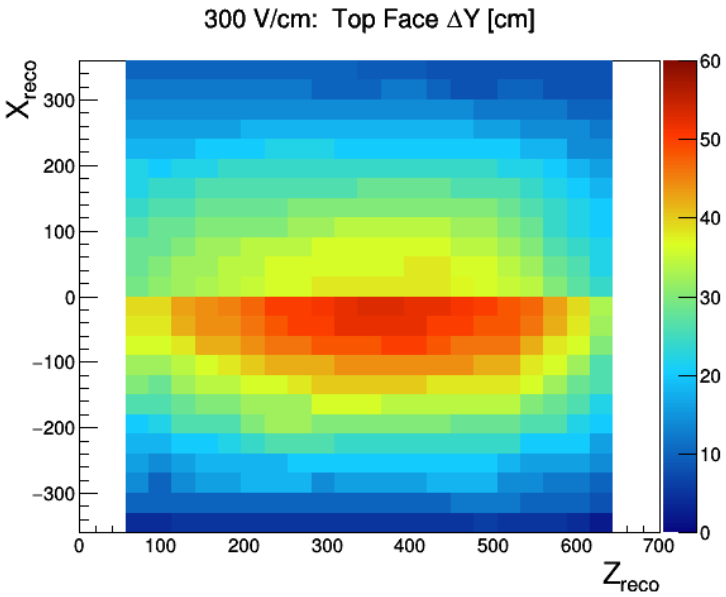


- Implemented in LArSoft by Hannah Rogers (CSU)
- Calibrate dE/dx with both spatial calibration map (charge squeezing/stretching → fix dx) and E field calibration map (correct recombination → fix dE)
- Validate with “perfect calibration” in MC
  - Tail of dE/dx distribution improves
  - dE/dx vs. x distribution becomes more uniform

HV Scan Studies







Francesca Stocker

- Also studying E field dependence of SCE
- Several runs taken at different HV settings
- SCE increases at lower E field, as expected – still under study

Summary

- First studies of space charge effects (SCE) complete
  - But a lot more questions than answers!
- Estimated spatial offsets due to SCE from TPC faces
  - SCE 50%+ worse in data than in simulation
    - Wrong ion drift velocity? Tune LAr flow model?
  - Preliminary: time dependence < 5% (small)
- First data-driven SCE maps ready for use next week
- Calibration framework for SCE nearly ready
- Continuing to study E-field and time dependence of SCE, as well as improve SCE simulation/calibration
  - Thanks to Josh Thompson, Francesca Stocker, Hannah Rogers, Stefania Bordoni, Richie Diurba, and Ajib Paudel for their work!

BACKUP SLIDES