

# Intersections of Beam Halo and Cosmic Muons in ProtoDUNE

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ProtoDUNE Calibration Meeting  
November 3, 2016

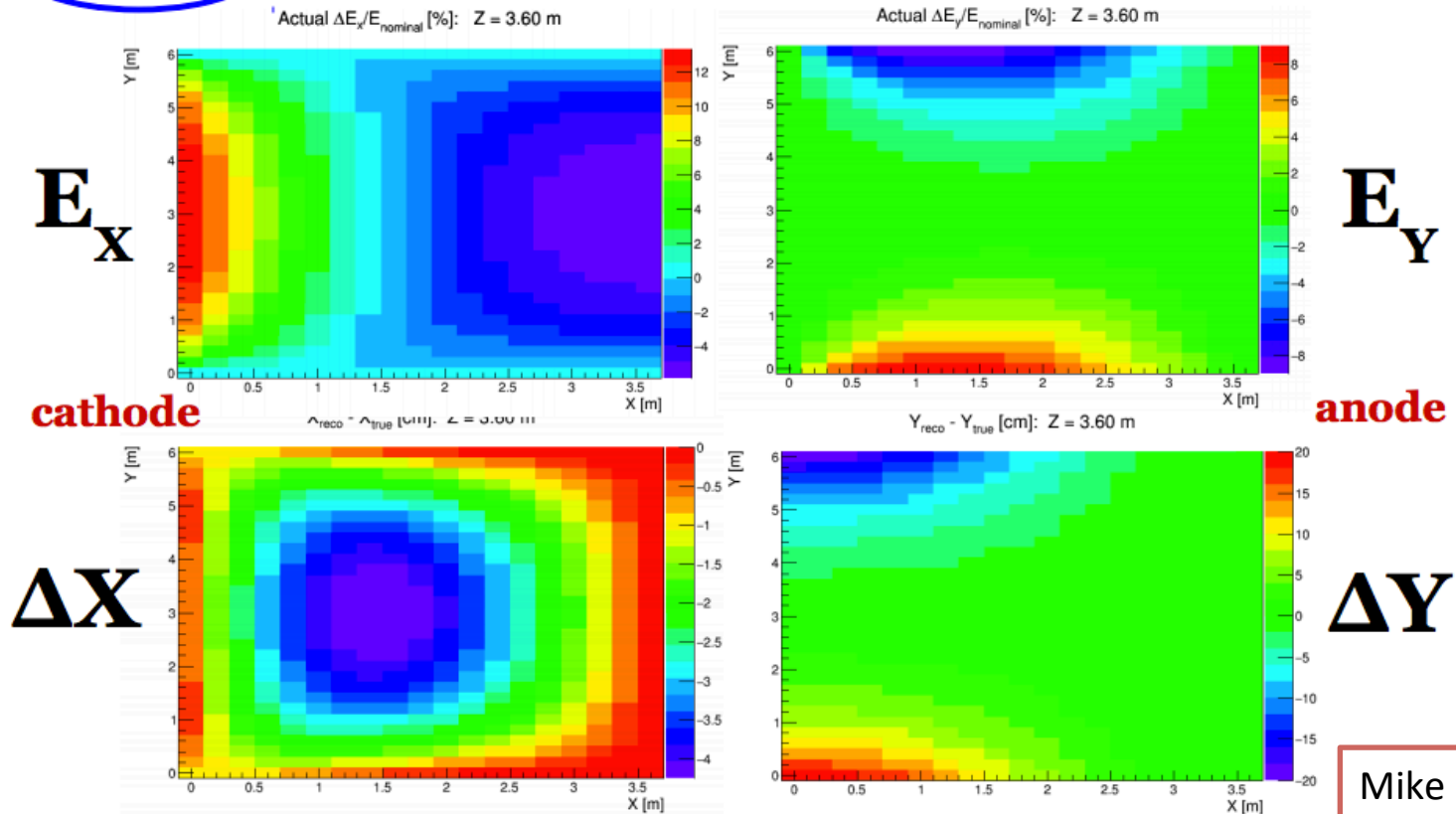
# Outline

- Space charge effect
- Cosmic ray tagger
- MC muon samples
  - Beam halo distribution
  - Cosmic muons
- Tagged muon intersections
  - Single  $t_0$  tag
  - Double  $t_0$  tag
- Summary

# Space Charge Effect (SCE)

Nominal SP Geometry

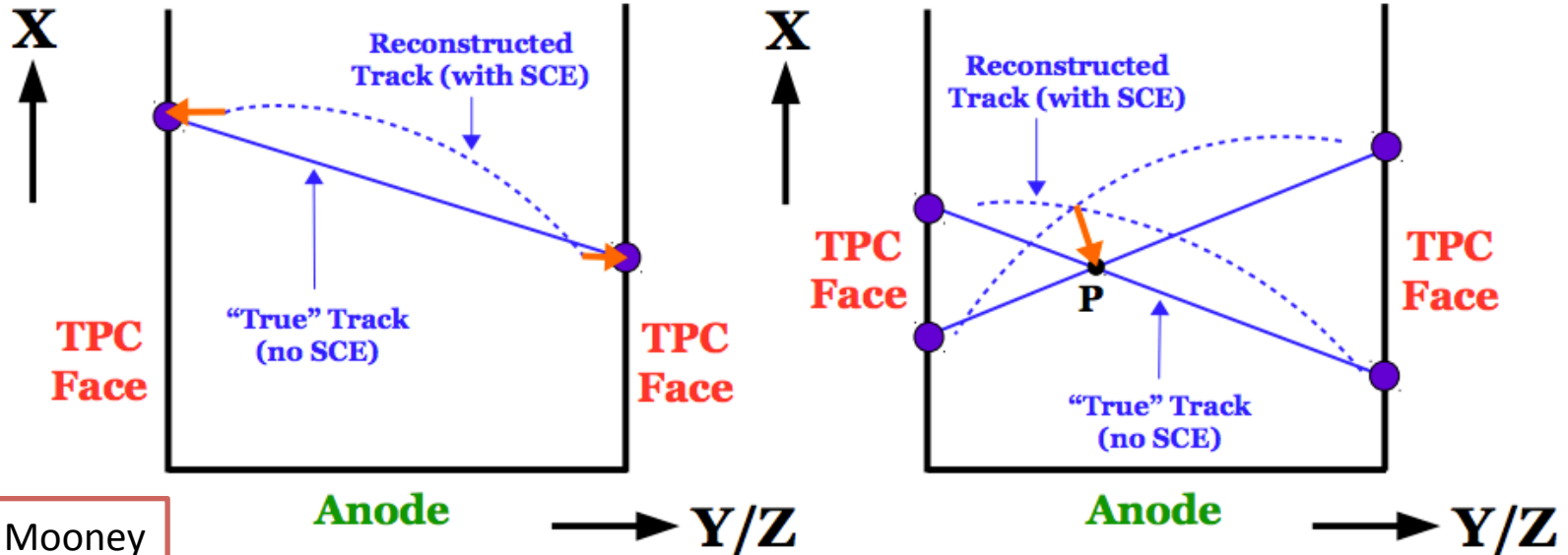
$$E_{\text{nominal}} = 500 \text{ V/cm}$$



Impact on recombination: ~10%

Impact on spatial distortion: ~5cm (drift), ~20cm (transverse)

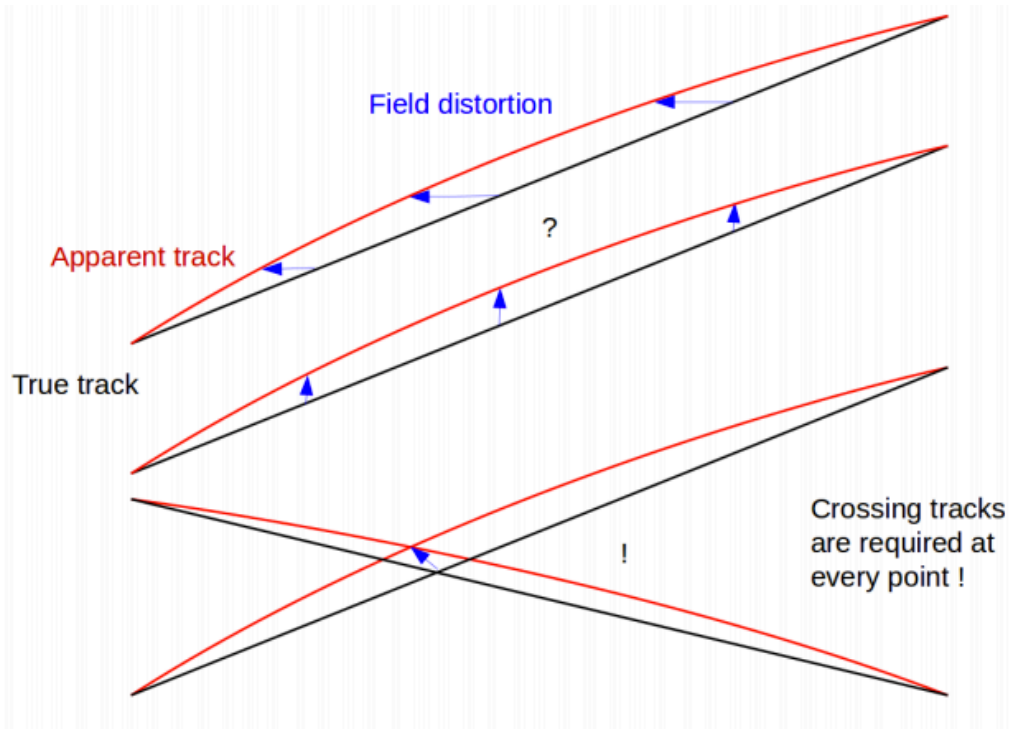
# SCE Calibration with Muons



Mike Mooney

- ◆ Two samples of  $t_0$ -tagged tracks can provide SCE corrections:
  - Single tracks – enable corrections at TPC faces by utilizing endpoints of tracks (correction vector approximately orthonormal to TPC face)
  - Pairs of tracks – enables corrections in TPC bulk by utilizing unambiguous point-to-point correction looking at track crossing points

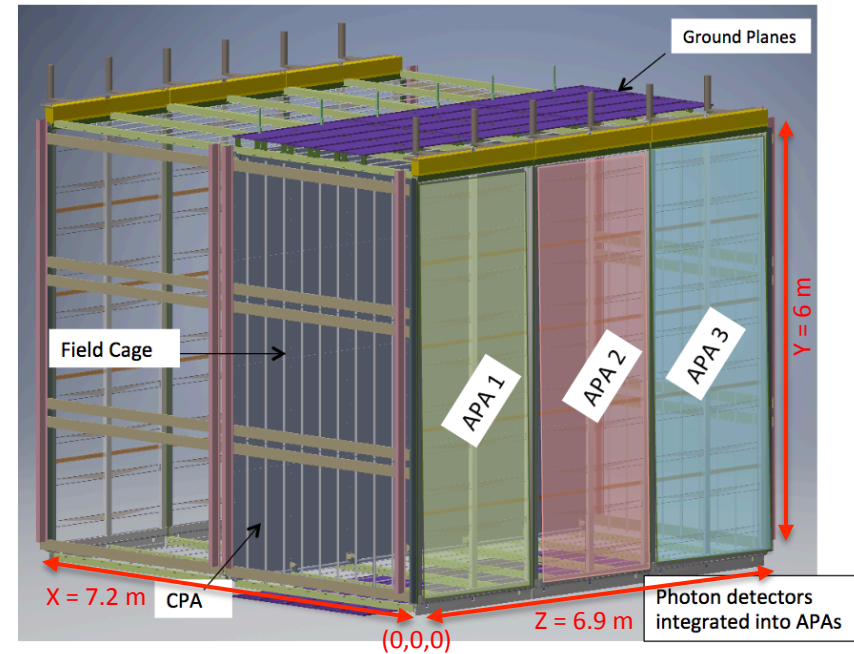
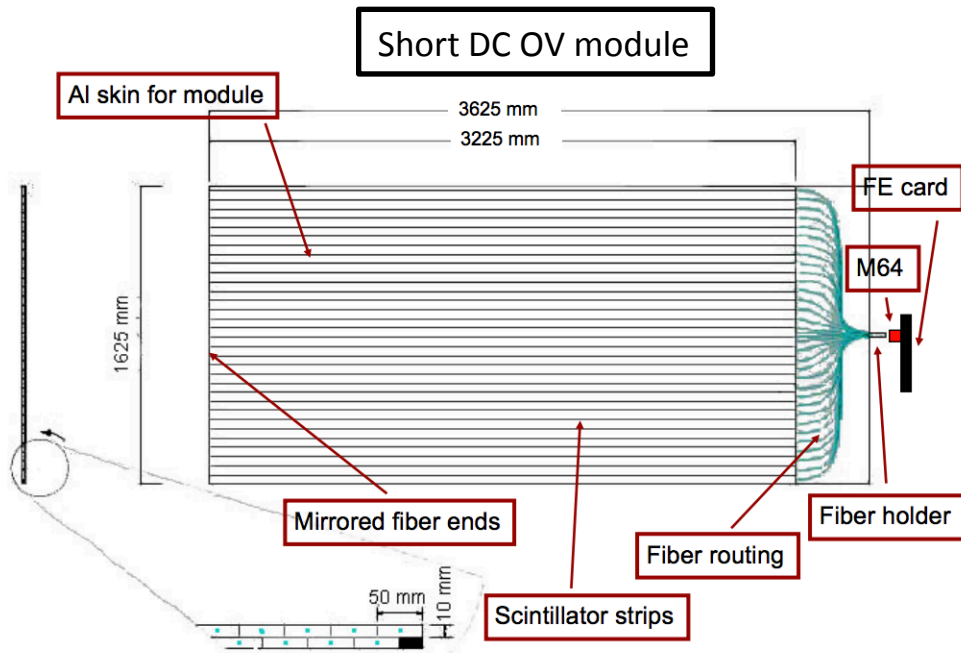
# Crossing Pair Tracks



Mike Mooney

- ◆ As Igor pointed out at protoDUNE Science Workshop, a single laser track is not enough to obtain the SCE correction vector
- ◆ Principle applies to calibration with muon tracks as well!

# Cosmic Ray Tagger (CRT)



4

Active CRT module volume = 3.225m x 1.625m in two layers of plastic scintillator  
 This study: cover the active TPC volume with two rows of 5 modules with no overlap:  
 front (Z = -202cm) and back (Z = 944cm):  
 top (Y = 861cm):

$$-404\text{cm} < X < 408\text{cm}$$

$$24\text{cm} < Z < 670\text{cm}$$

$$-404\text{cm} < X < 408\text{cm}$$

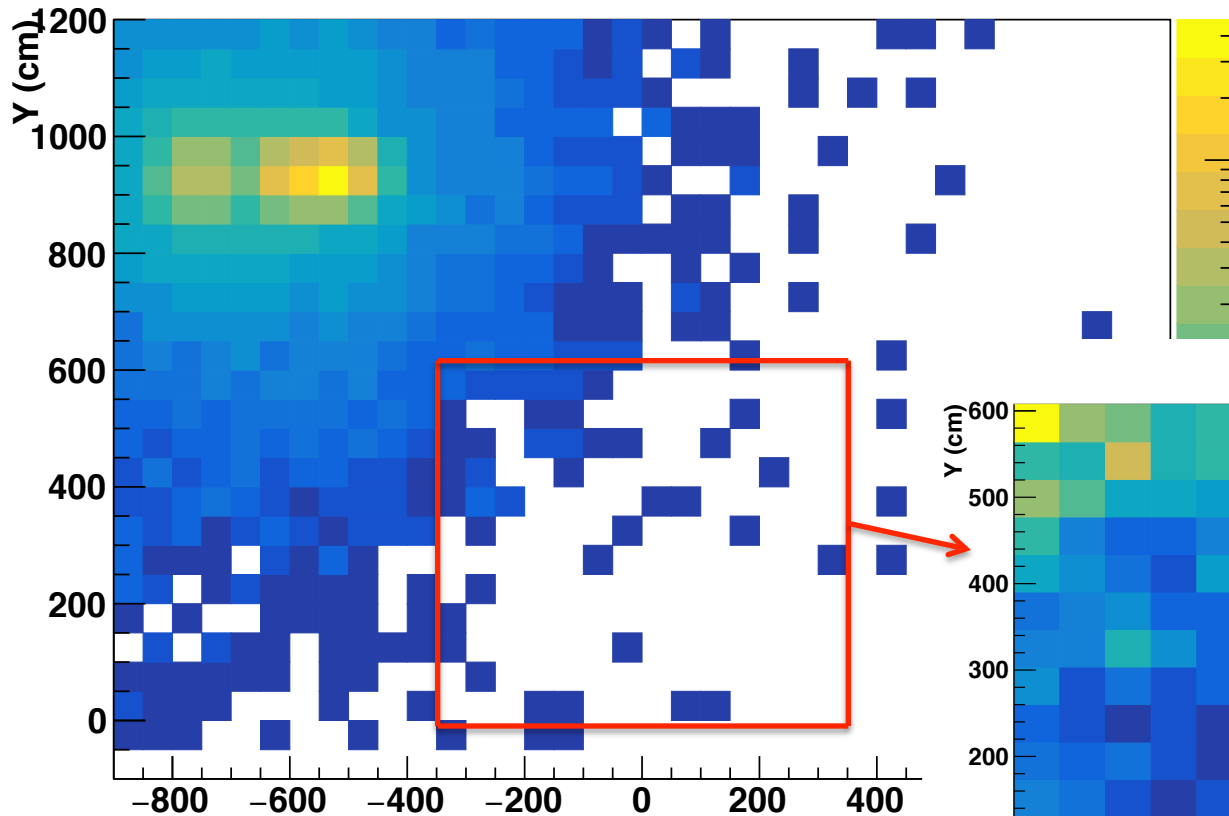
$$-19\text{cm} < Y < 626\text{cm}$$

# MC Muon Samples

- Beam halo muons
  - Untagged generated distribution from beam spill
- Cosmic muons
  - Generated with CORSIKA in LArSoft
- From cosmic muons select  $t_0$ -tagged track samples
  - Single tagged tracks at one TPC face
    - $X = +380$  cm and  $X = -380$  cm anodes
    - Each CRT panel ( $Z = -202$  cm,  $Z = 944$  cm, and  $Y = 861$  cm)
  - Double tagged tracks
    - Anode to anode crossing cosemics
    - All combinations of CRT panel cosmic tags
- Find intersection points in TPC between tagged cosmic samples and beam halo distribution

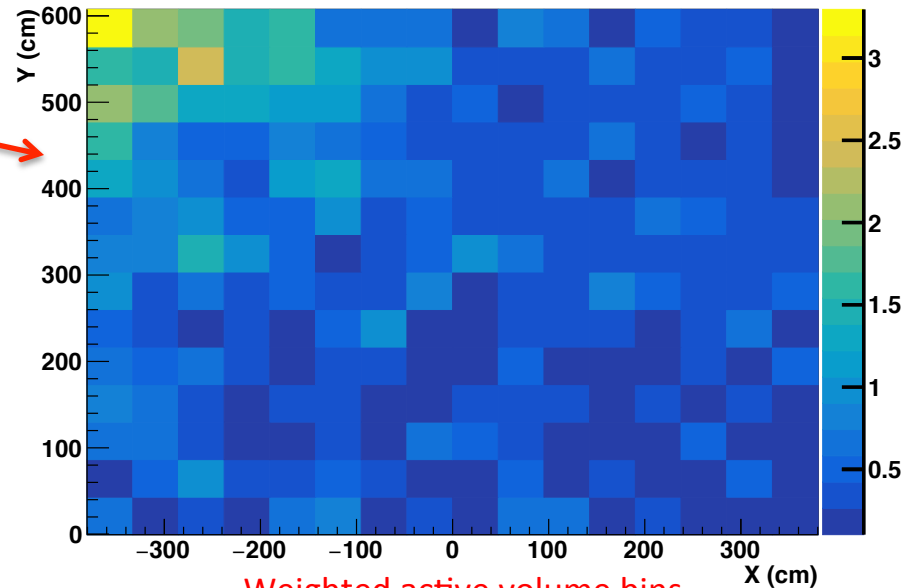
# Beam Halo Distribution

beamhalo: larsoft units



Raw beam halo distribution from Paola converted to LArSoft coordinates:  
Corresponds to 194 muons/spill in active volume

beamhalo: larsoft units



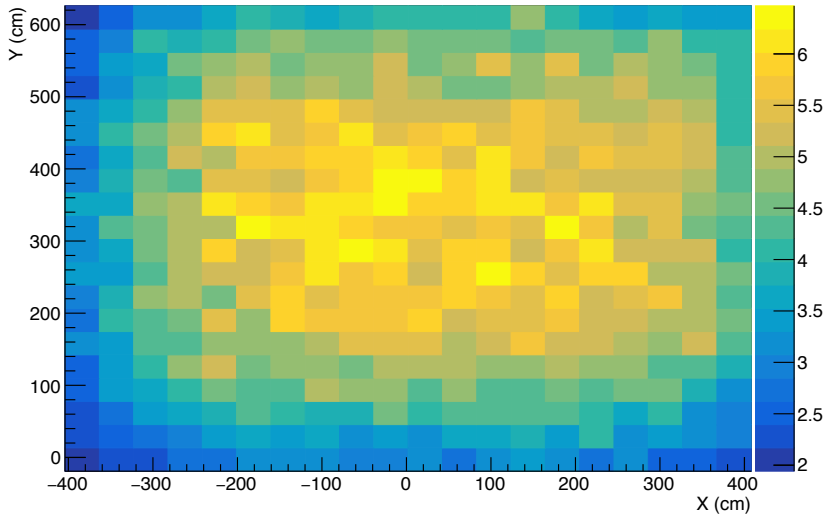
Can only record 120 beam triggers per spill,  
weight bins by number of muons/spill:

$$N_{\mu/\text{spill}} = N_{\text{bin}} \times 4.8 \text{ sec/spill} \times 25 \text{ Hz} \div 194$$

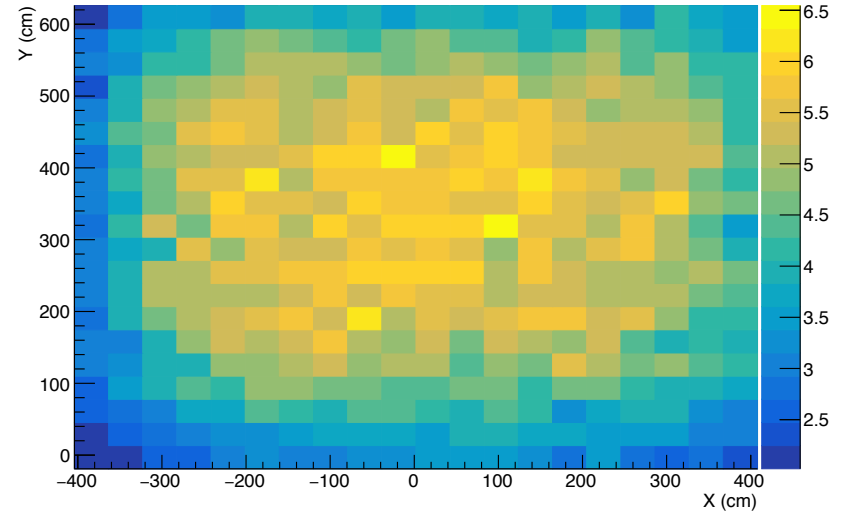


# CRT Cosmic Hits

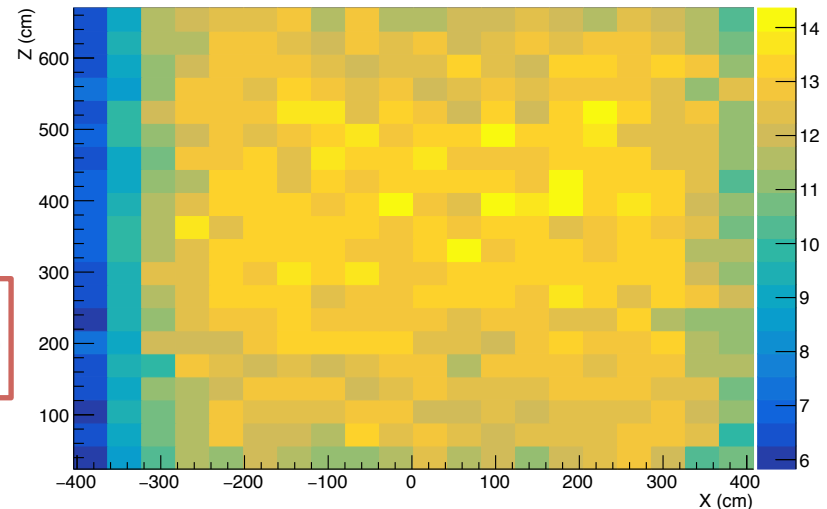
Front CRT muon hits (Z = -202cm) /spill **1855 muons**



Back CRT muon hits (Z = 944cm) /spill **1844 muons**



Top CRT muon hits (Y = 861cm) /spill **4831 muons**



## Normalize cosmic muon sample to spills:

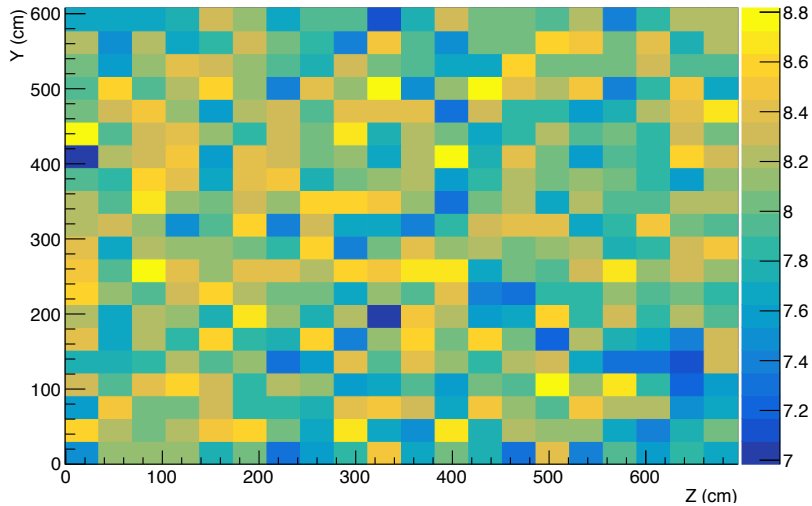
- 1,401,886 simulated muons in 9.5k triggers
- Use both on- and off-spill cosmics
- $N_{\text{trig}} = 2 \times 4.8 \text{ sec/spill} \times 25 \text{ Hz} = 240 \text{ trig/spill}$
- 4 ms per readout window/6.45 ms simulated

$$N_{\mu/\text{spill}} = 240 \frac{\text{trig}}{\text{spill}} \times \frac{4 \text{ ms}}{6.45 \text{ ms}} \times \frac{1}{1.40 \text{ M } \mu} \times 147 \frac{\mu\text{on}}{\text{trig}}$$

Assume 100% CRT tagging efficiency

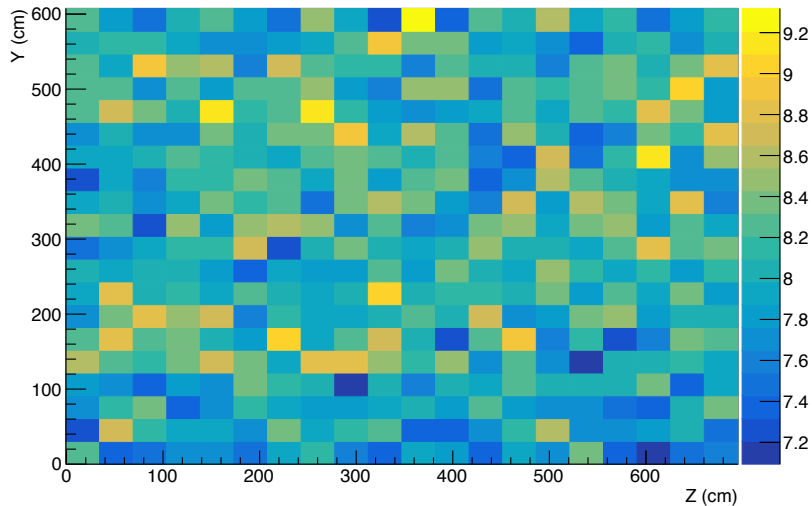
# Cathode and Anode Cosmic Hits

Cathode muon hits (X = 0cm) /spill

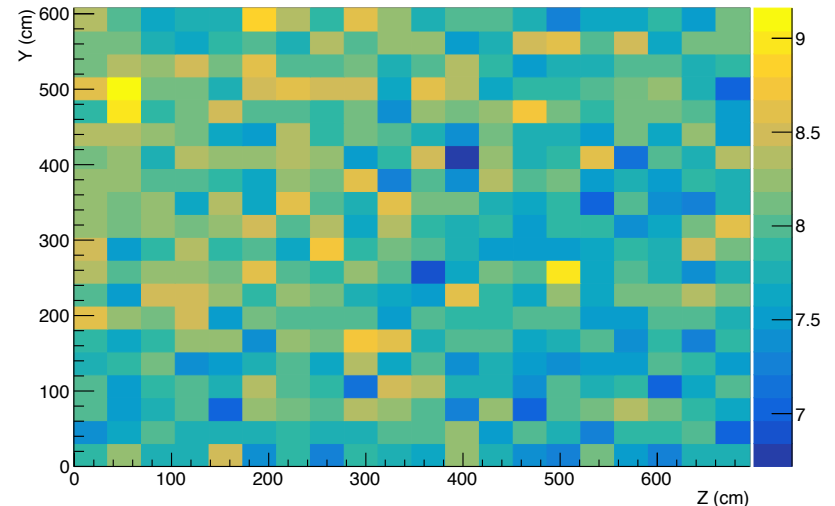


~3.2k muons per spill  
Assume 100% anode tagging efficiency

Anode muon hits (X = -380cm) /spill

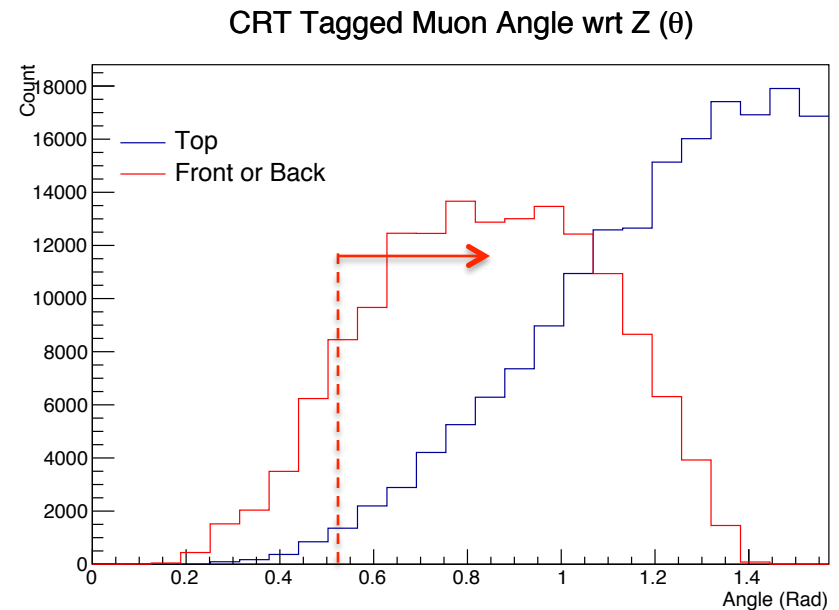
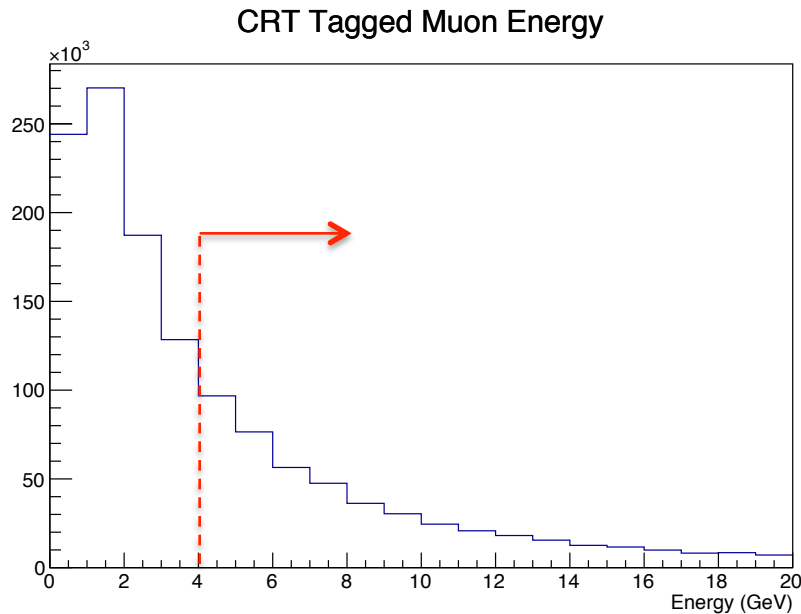


Anode muon hits (X = +380cm) /spill



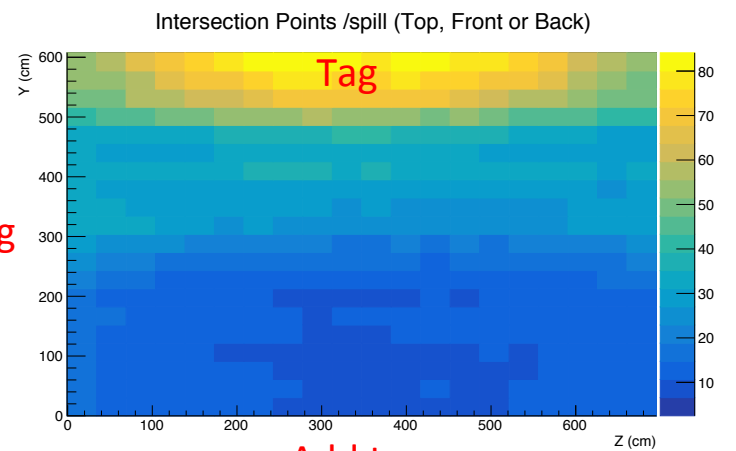
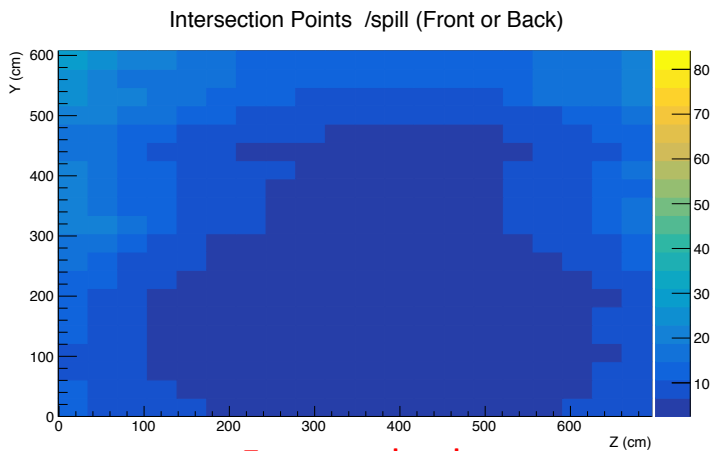
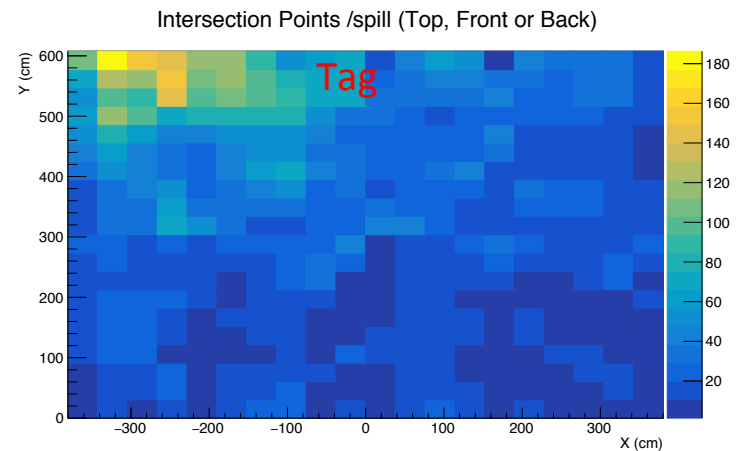
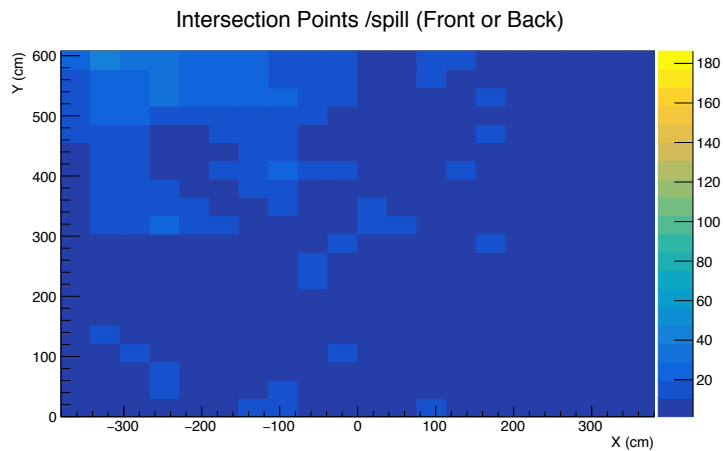
# Cosmic Muon Cuts

- Using initial muon momentum to extrapolate track: require  $E_\mu > 4 \text{ GeV}$
- Using beam halos assumed to be in  $\hat{Z}$  for crossing tracks: require  $\theta_z > \pi/6$



# CRT Single Tag Crossings

For single  $t_0$ -tagged crossing points we are mostly interested in occupancy near the TPC face. Each bin is the number of intersections between single CRT  $t_0$ -tagged cosmics with beam halo muons.

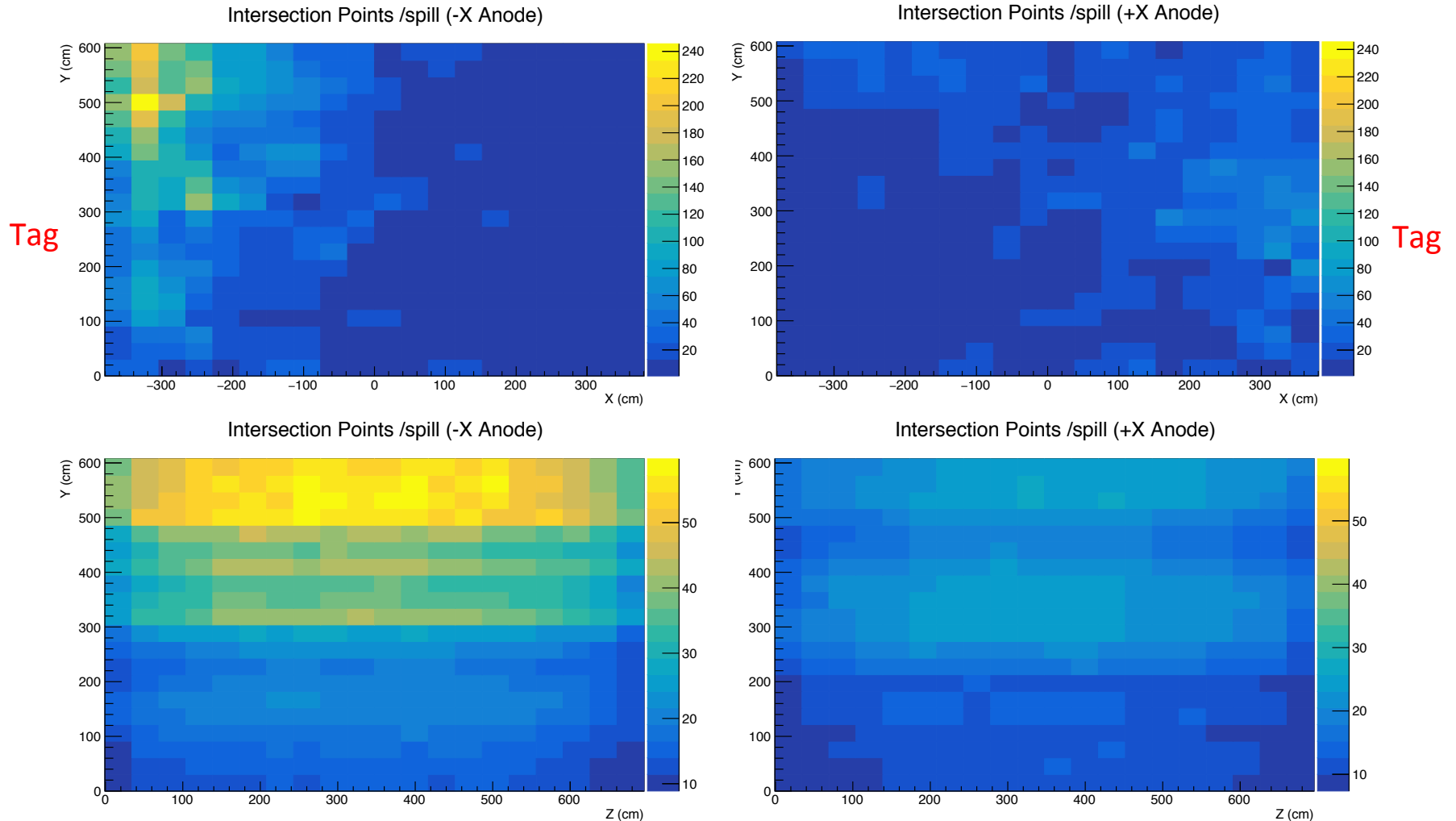


Front or back

Add top

# -X or +X Anode Crossings

Each bin is the number of intersections between single -X or +X anode  $t_0$ -tagged cosmics with beam halos.

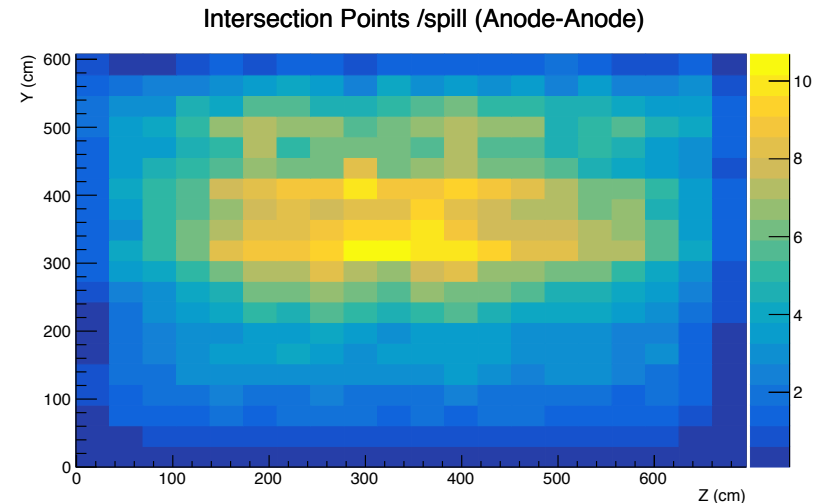
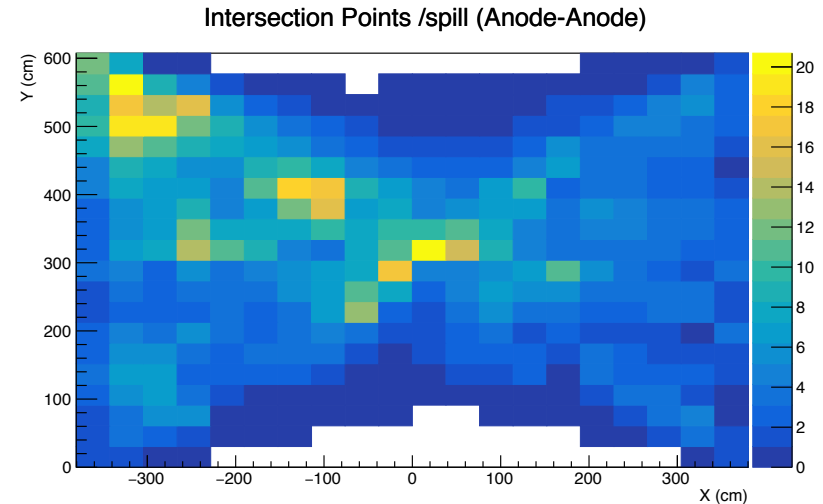


# Anode-Anode Double Tags

Double-tagged crossing points (one  $t_0$  tag at each TPC face) improve SCE corrections in the TPC volume.

Each bin is the number of intersections between anode to anode cosmuics, which have one  $t_0$  tag in each anode face, with the beam halo muons.

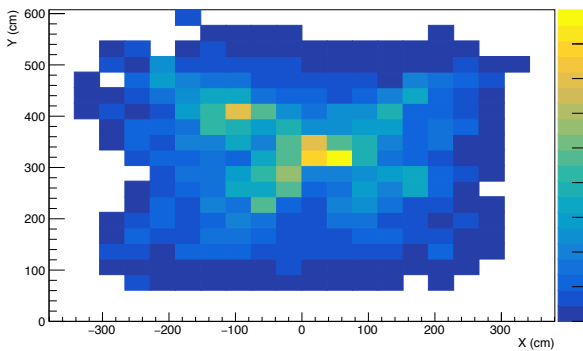
Normalized to one spill.



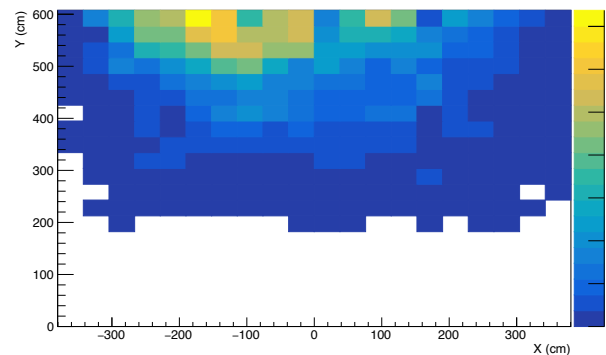
# CRT Double Tags

Each bin is the number of intersections between CRT double-tagged cosmics, which have one  $t_0$  tag in each panel, with the beam halo muons. Normalized to one spill.

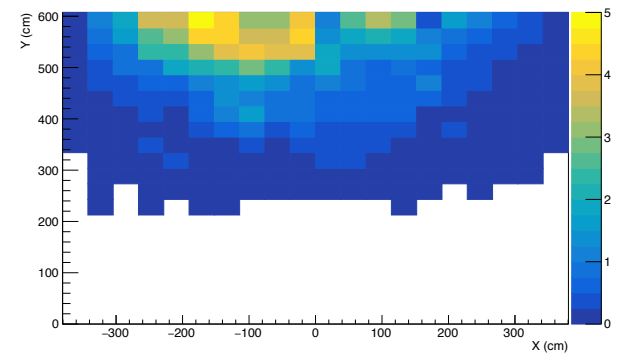
Intersection Points /spill (Front and Back)



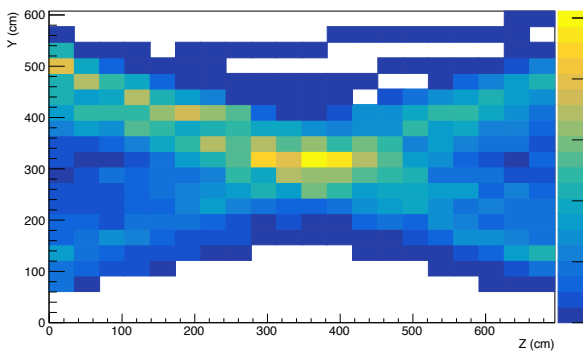
Intersection Points /spill (Front and Top)



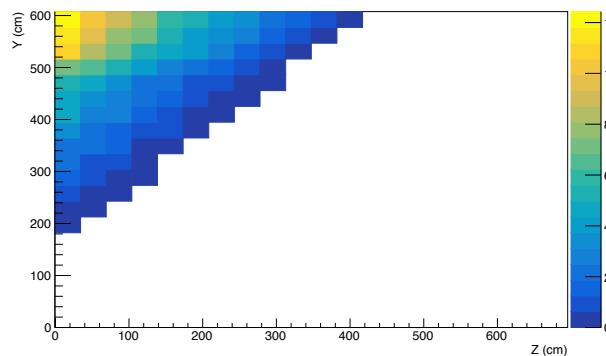
Intersection Points /spill (Back and Top)



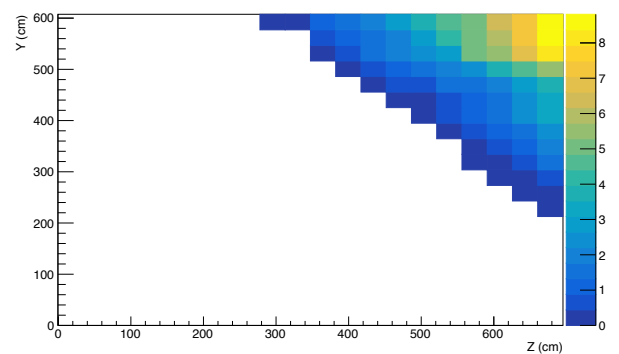
Intersection Points /spill (Front and Back)



Intersection Points /spill (Front and Top)

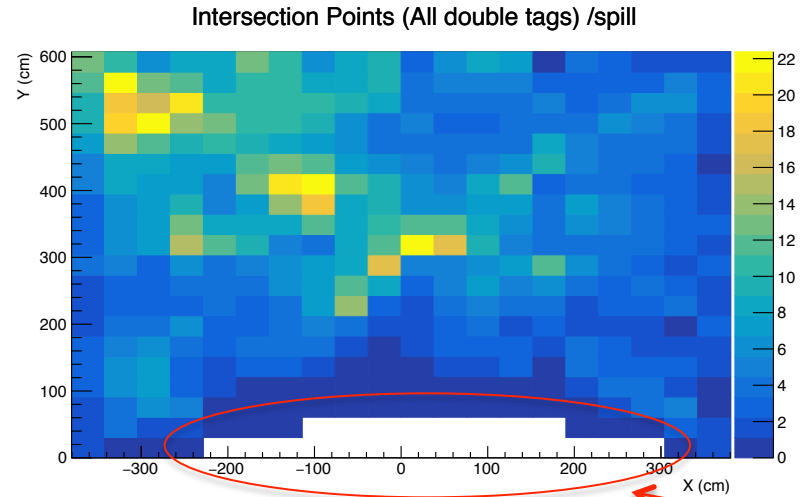
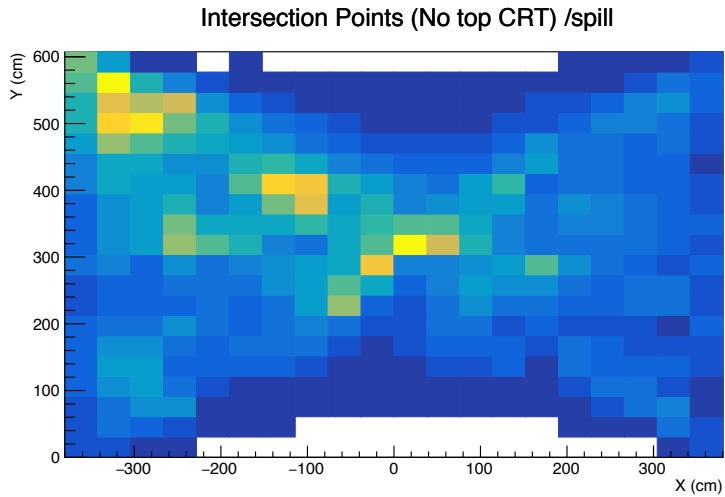


Intersection Points /spill (Back and Top)

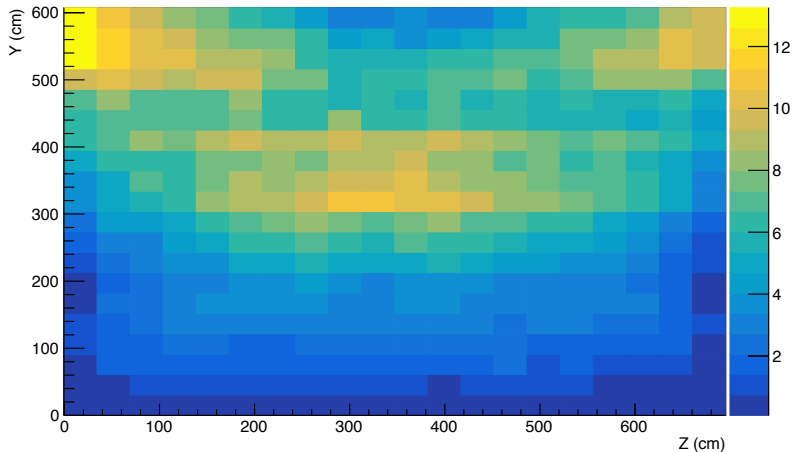
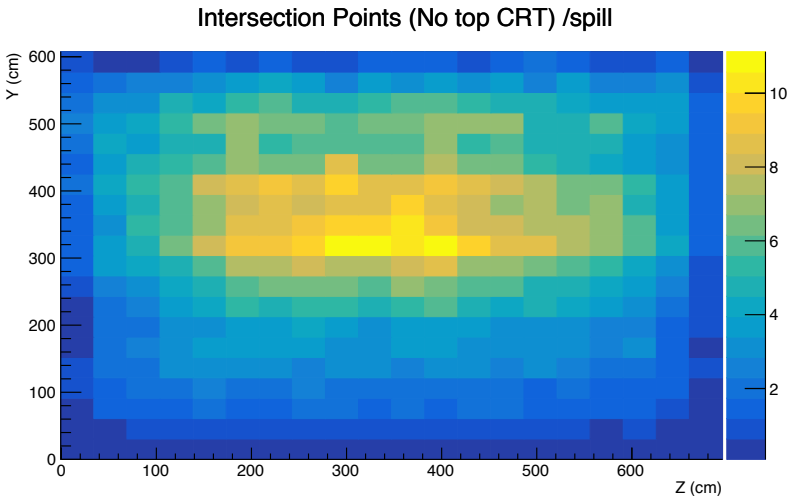


# All Double Tags

Front/back and anode/anode tags  $\longrightarrow$  Add front/top and back/top tags



Final gap





# Summary

- Updates since August
  - Correct beam halo distribution has been included
  - Increased cosmic muon statistics by 10x
- Have single  $t_0$ -tagged muons near 5/6 TPC faces if we include top CRT
- Double  $t_0$ -tagged cosmic muon intersections with the beam halo can cover almost all of ProtoDUNE TPC bulk
  - Can fill in the final gap with single-tagged muons
- Still to be considered
  - Anode-CRT double tag combinations intersection points with beam halo
  - Anode-anode double tags intersection with CRT double tags (no beam halo required)