Center for Frontiers in Nuclear Science

sPHENIX

TPC Distortion Calibration Software

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(on behalf of the subcommittee*)

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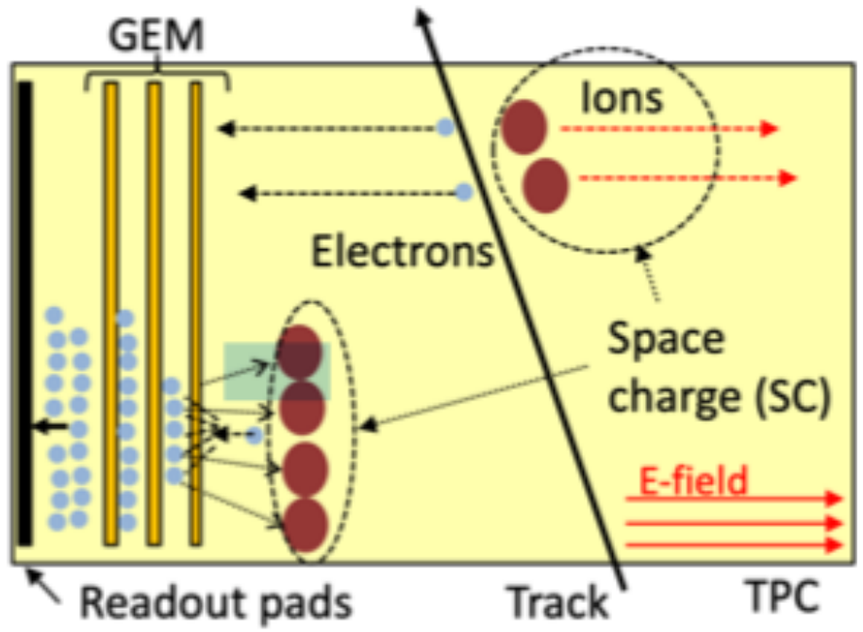
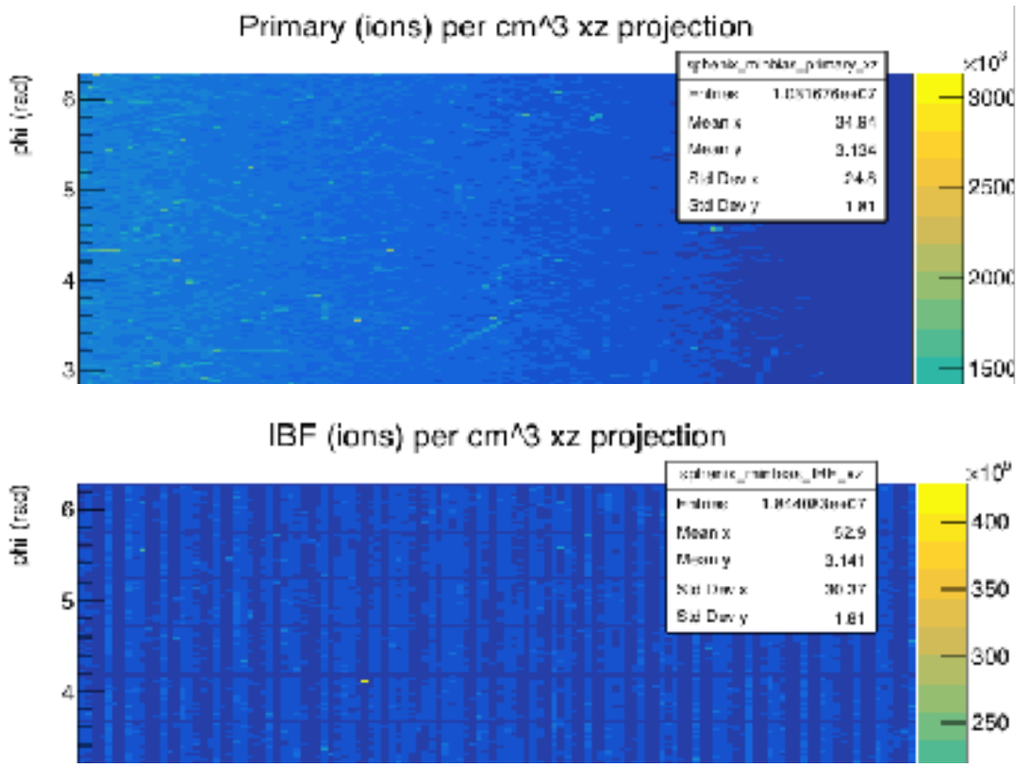
Structure of Spacecharge

$$\rho(r,z) = A\frac{1 - z/z_0 + c}{r^d}$$

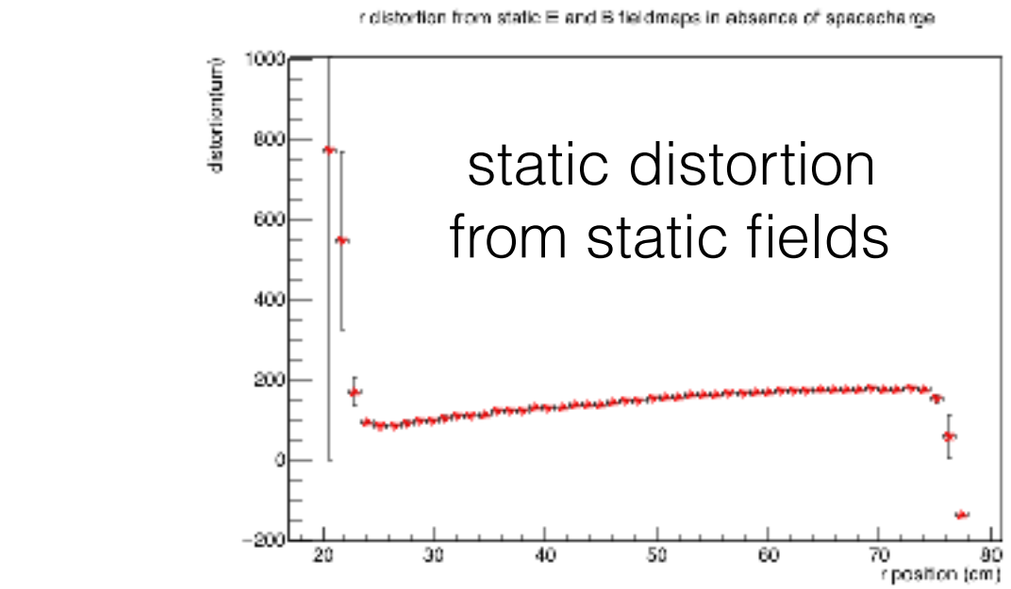
- Heuristic:
  A=Gas and Collider parameters
  z_0=drift length
  c=IBF ions per primary
  d=radial dependence of track density
- Ions drift ~1.3cm/ms (78ms to cross TPC), 5000x slower than electrons
- Pancakes and volume:
  Primary ions are created from charged particles traversing TPC.
  Ion Backflow (IBF) pancakes are created from electrons avalanching at readout.
- Average and fluctuations:
  Average SC governed by luminosity and fixed TPC parameters. Expect few-mm R distortions on average
  Local fluctuations from event-by-event statistics.

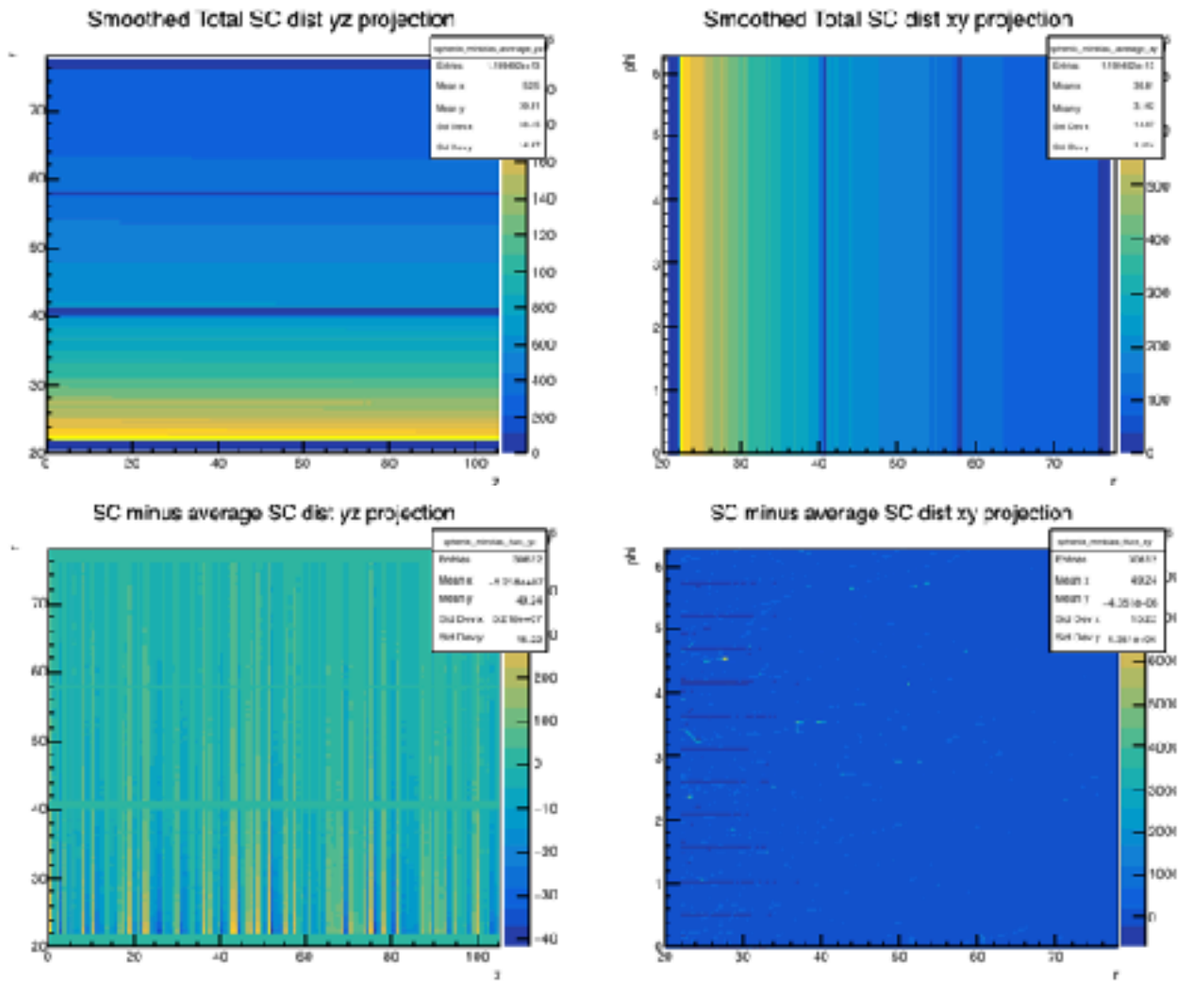




Distortion Timescales

- Static: Arise from alignment w.r.t realistic magnetic and electric fields
- "Long term": external fields change with temperature, pressure, gain, etc.
- "Short term": time-averaged fields from spacecharge change with beam properties
- "Fluctuations": specific charge layout of individual events differ from the average

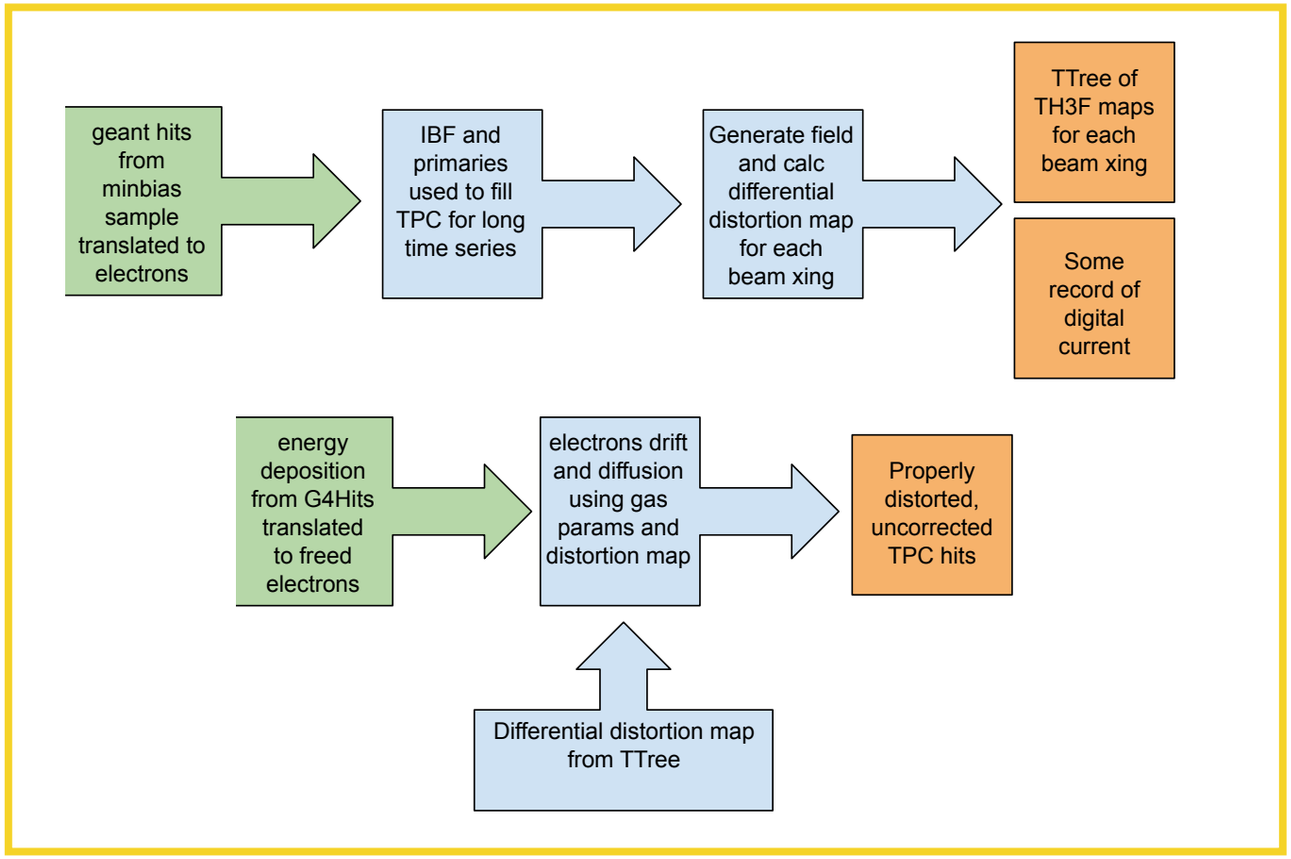




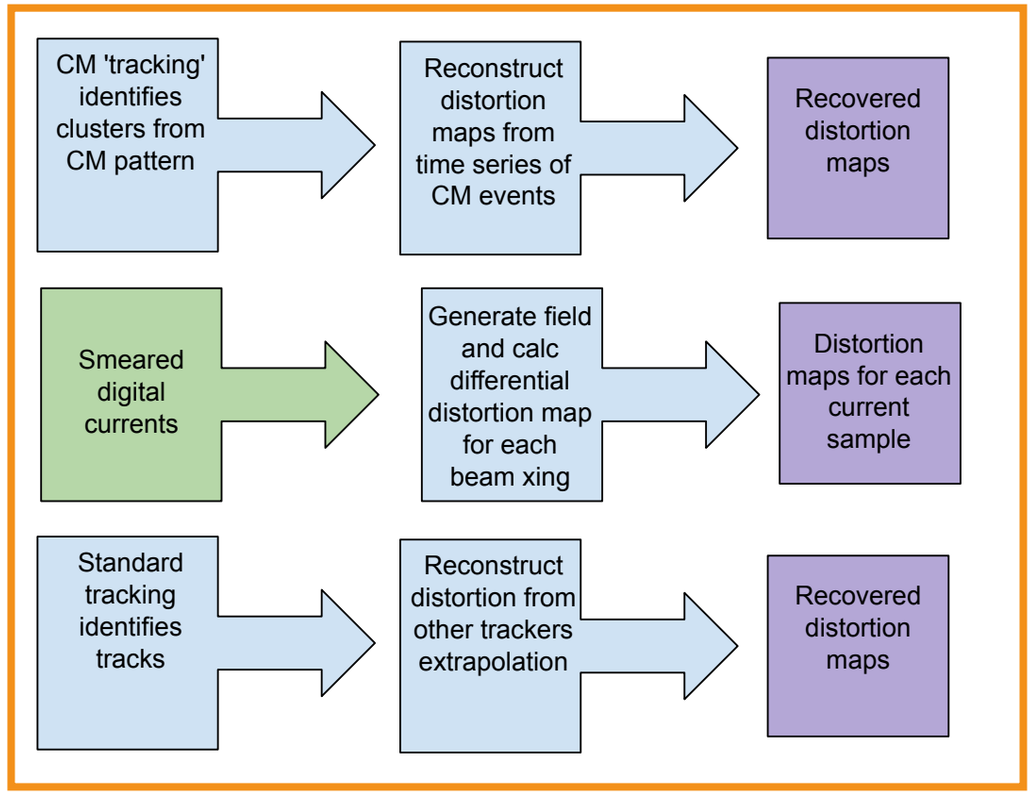
Overview

- Integrate and expand spacecharge modeling in Fun4All
- Implement and study calibration of spacecharge distortions through tracking, lasers, and digital current measurements.

Model and Generation



Reco and Calibration

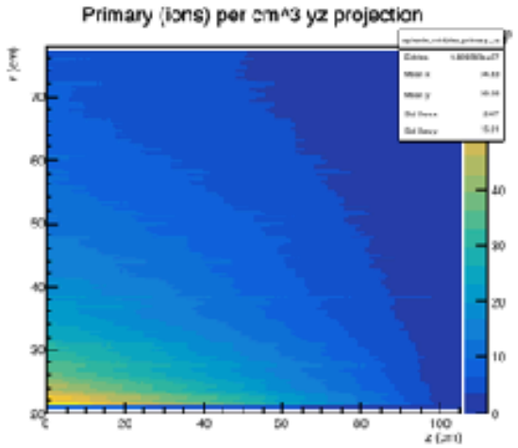


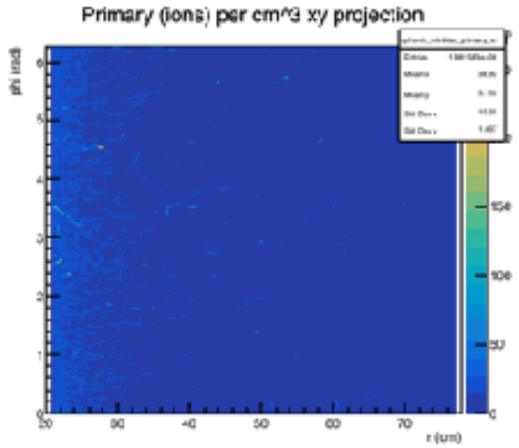
Projects and Milestones

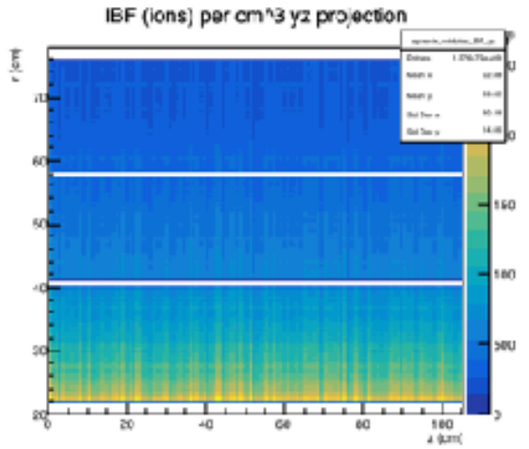
Brainpower	Task	*Early July*	*Mid July*	*Late July*	*Early August*	*Mid August*	*Late August*
Chris P	generate HIJING events	***improved HIJING with backsplash from Cal?***					
Ananya P, Evgeny S	current / SC maps from HIJING	***low-res SC maps for early distortion studies***		*tool to gen. SC time series for desired luminosity and IBF factors*			
Jordan S, Ross	generate distortions from SC maps	*compare and select tiling scheme for field calc*		*study and select MC truth resolution*		*validate with analytic model*	
Henry K	implement MC truth distortions	***static dist. map in sim.***	*time series distortion maps in simulation.*				
Jordan S, Evgeny S	distortions from currents				*Reconstruct SC from dig.current*	*Reconstruct distortion map from digital current, study*	
Sara K	Simulate laser events	***generate CM stripe G4Hits in event***					
Sara K	Reconstruct laser events			*reconstruct CM hits*			
Sara K, Ross	distortions from laser events				*implement CM calibration loop; extract distortion maps*		
in collab. with other Subcom	Distortions from tracks	*repeat Hugo's analysis with static distortion map*		*study with time-varying map, look at correlations*			
TBD	Cross-validate methods					*study fast distortion maps with slow already subtracted*	
Ross, Chris P, Others	Define MC-truth and correction formats	***revise format for slow+fluctuations***					
Joe	Corrections in reco	*implement movable hits in ACTS...*			*distortion maps in reco.*		
Tony, Hugo, Others	Tracking w/wo correction	*prepare diagnostic tools.*			*check tracking eff. w/ and wo/ distortions and corrections.*		
TBD	Studies of Physics Impact		*develop analysis modules to track physics observables w/wo corrections*				

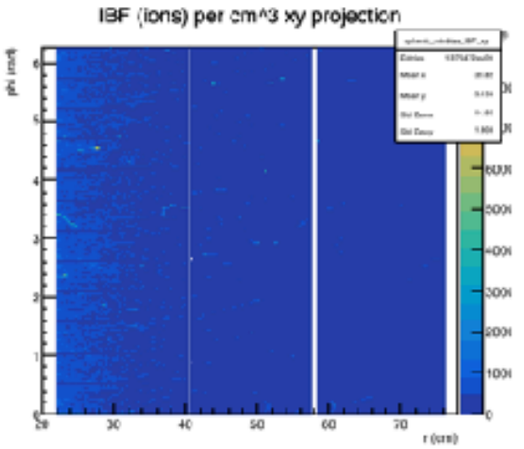
Generating Spacecharge Models

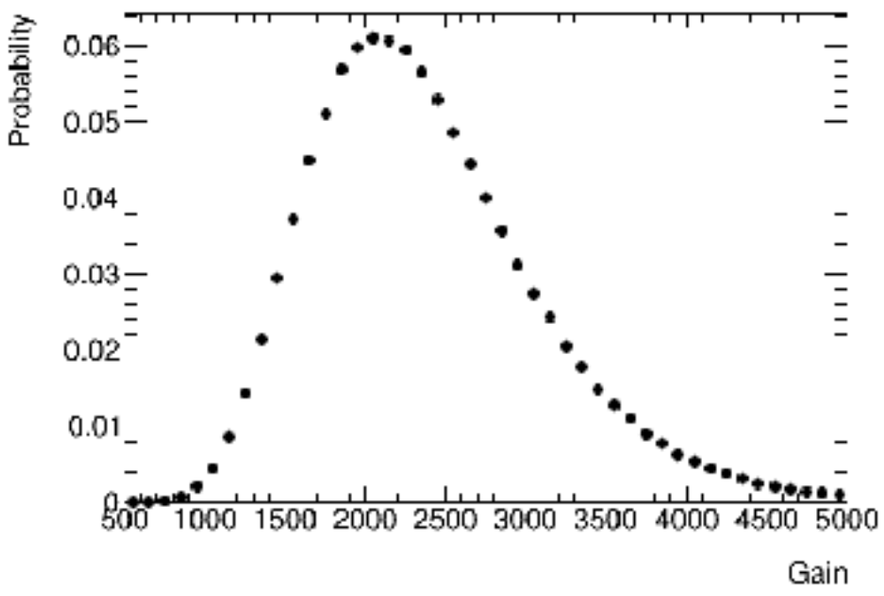
- Ananya Paul (SBU) is implementing full Poisson statistics in the SC model
- Generating high-res samples (150MB per full TPC 'frame'). Working on efficient storage of larger time-series sets.
- Next step: Evgeny Shulga (Weizmann) developing IBF and gain models to combine with new synchronized timestamp sample

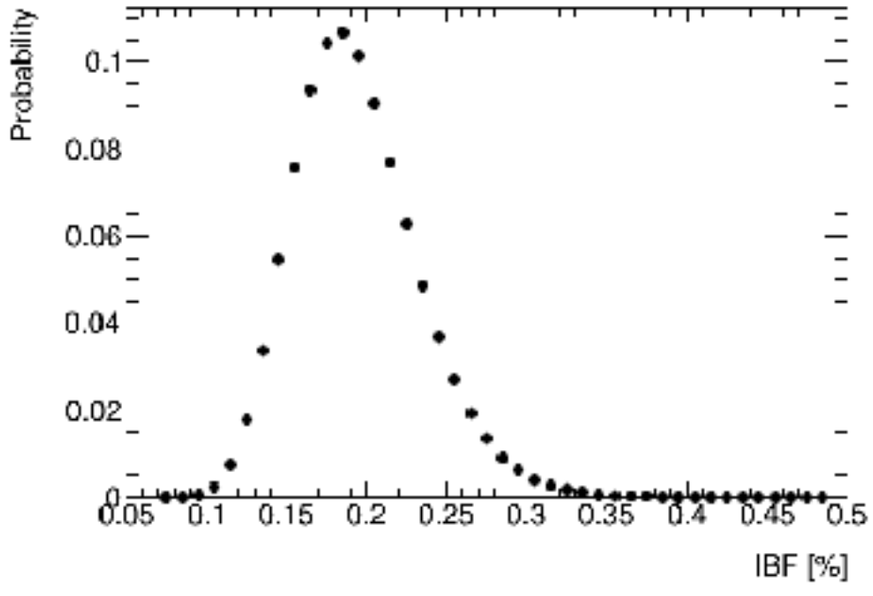






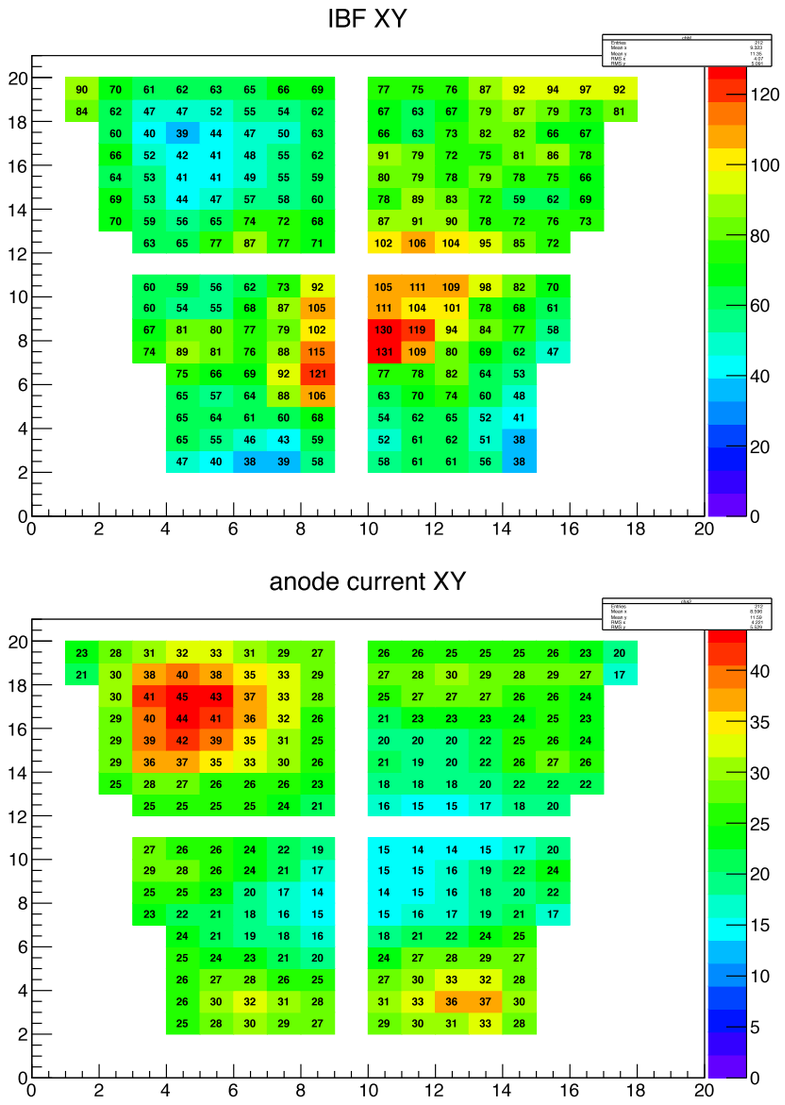


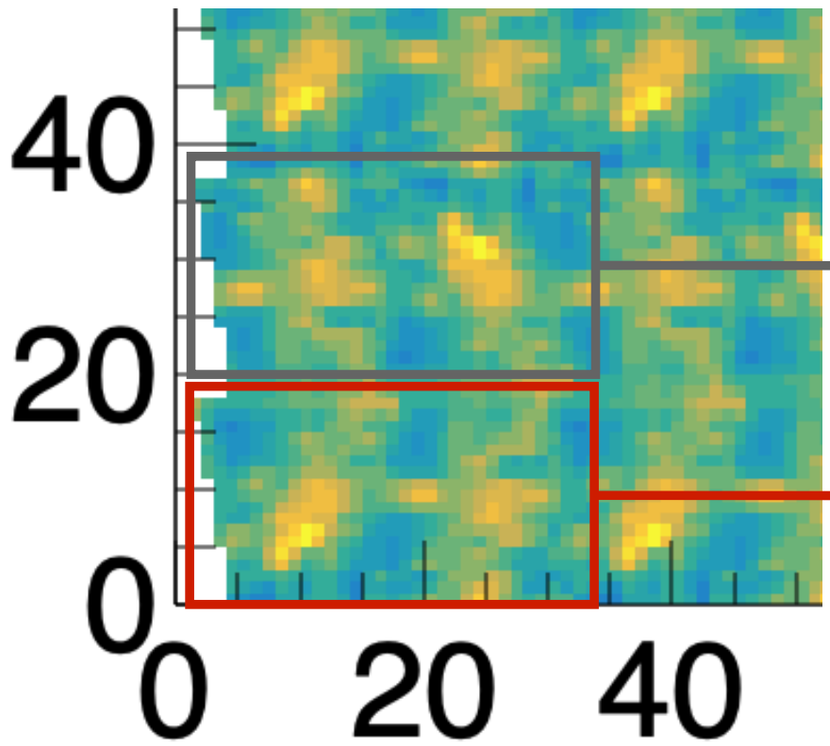


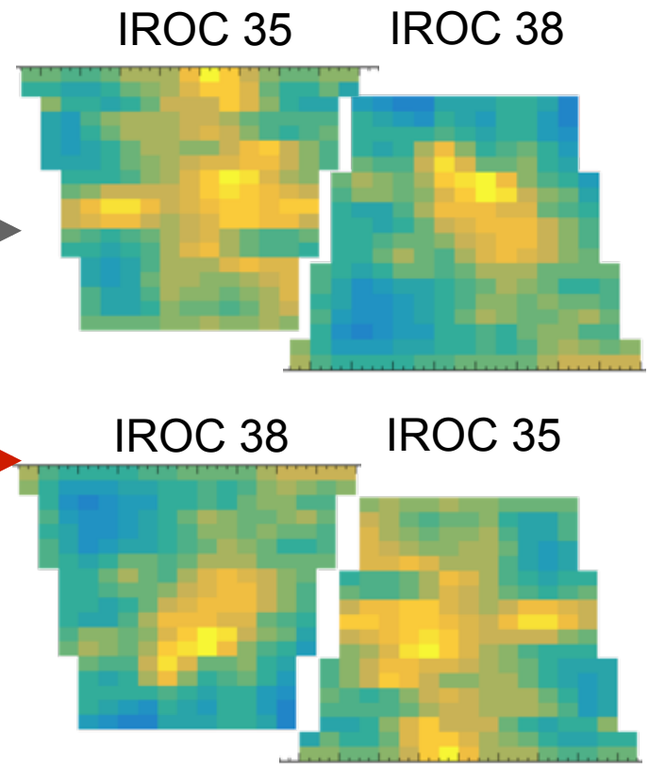


Gain Maps for SC and Digital Current

- Developing gain/IBF maps based on ALICE IROC single-GEM studies
- In addition to spatial correlation, IBF hot spots correlate with gain cool spots in some cases, so independent variation probably worst-case.
- Create large map by tiling from IROC studies

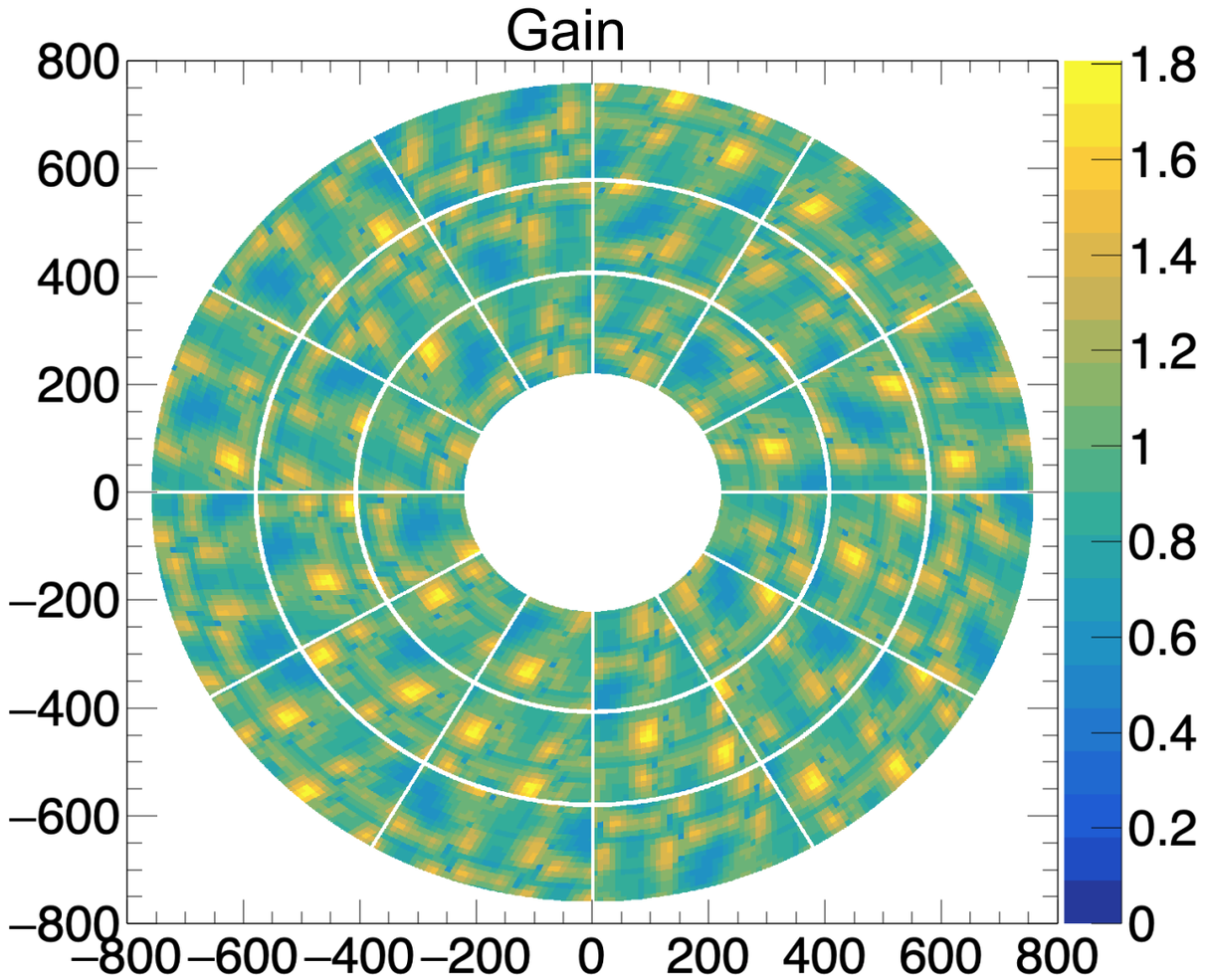


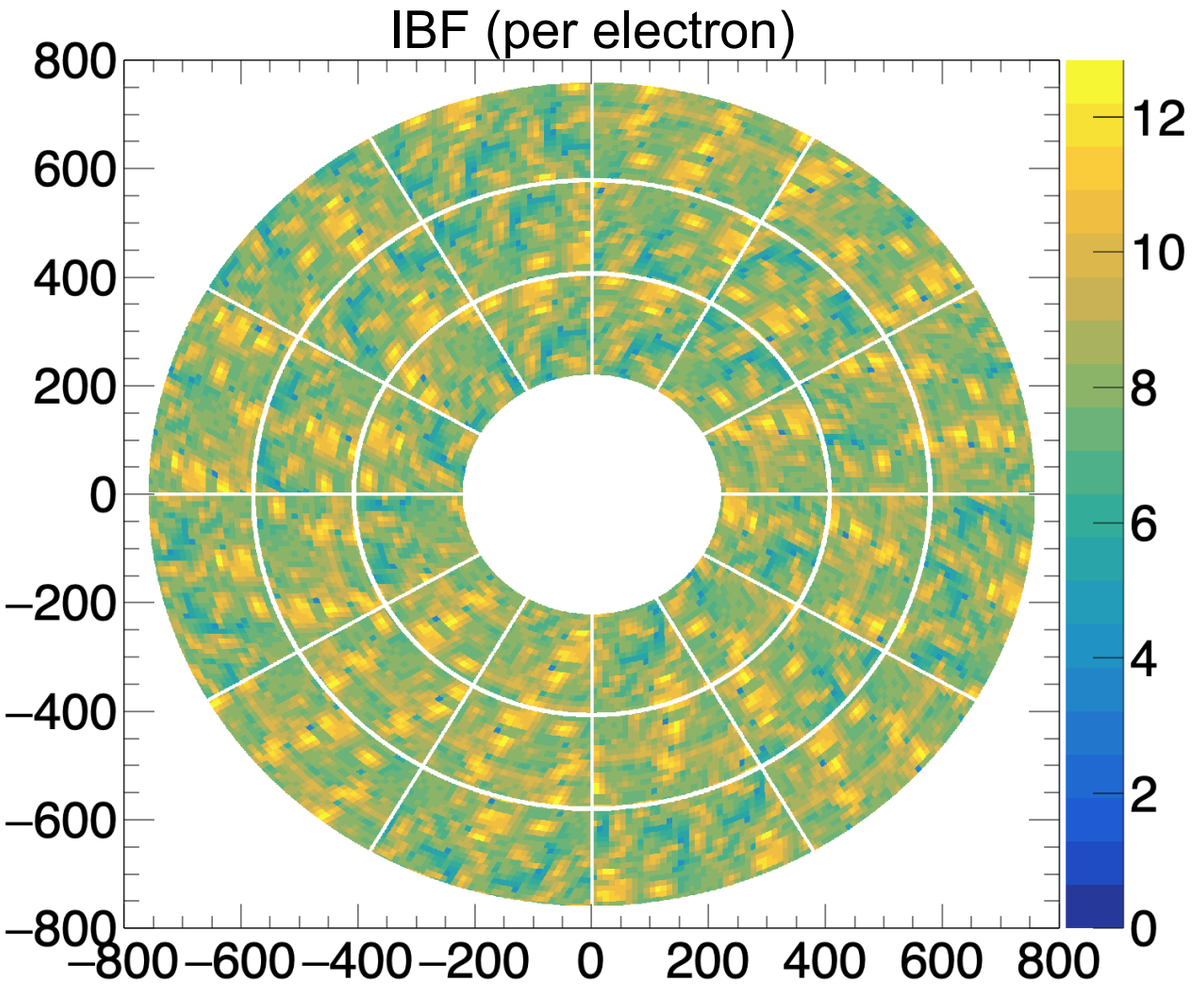




Gain Maps for SC and Digital Current

- Cookie-cutter randomly from that map to populate each sPHENIX TPC module separately for gain and IBF





IBF (per electron)=Gain*IBF*2000*0.44%

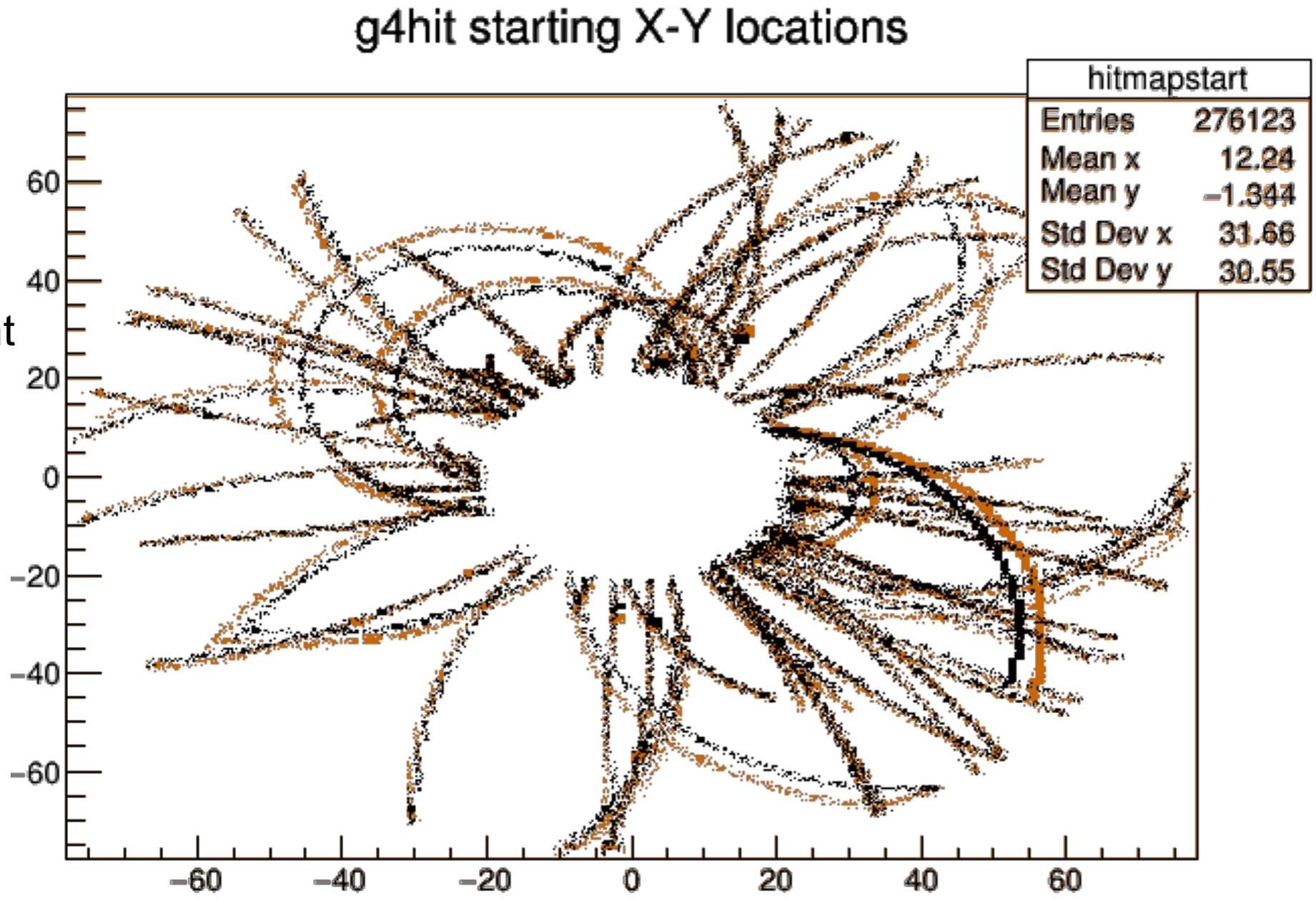
Distortions in Fun4All

- Henry Klest (SBU) implemented distortion maps in event generation
- (and created a punchlist of corrections needed in the next set of maps)

Black = start
Orange = end

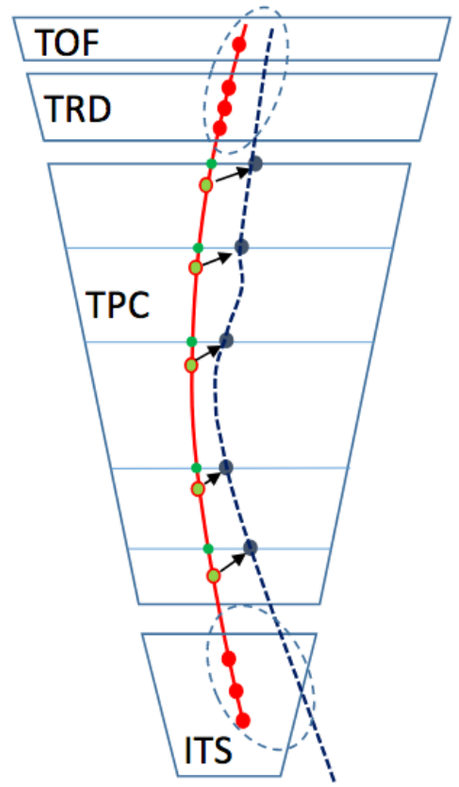
Full Pythia event

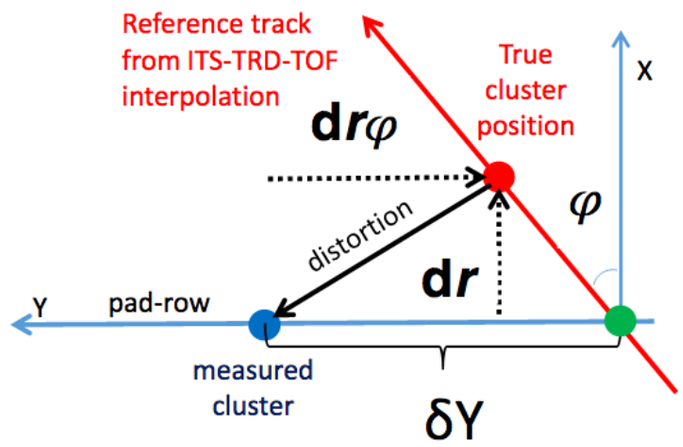
Space charge distortion, and diffusion



Calibration from Tracking

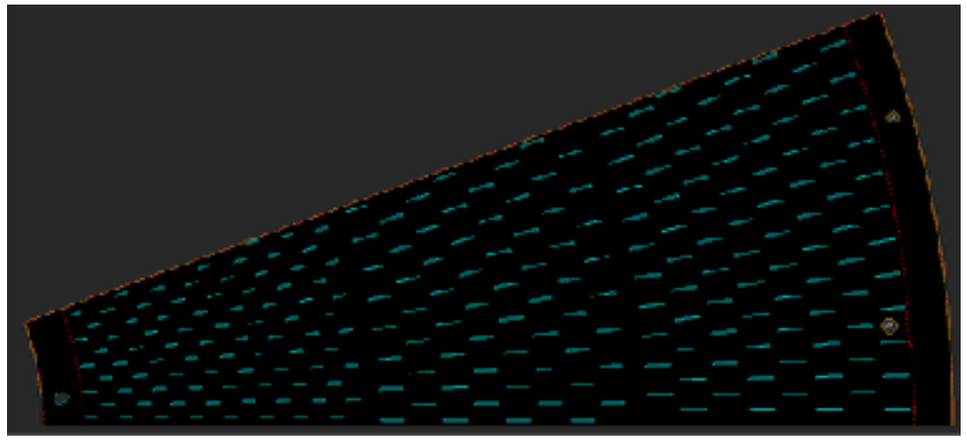
- (Per Hugo's work) Use best-fit parameters without TPC data to constrain true position of reco clusters in the TPC.
- Extracting 2D distortion requires large sample of tracks -- don't know what point along track should map to hit.
- Treat each voxel independently. Accuracy depends on time scale of distortion vs time to accumulate tracks in voxel.

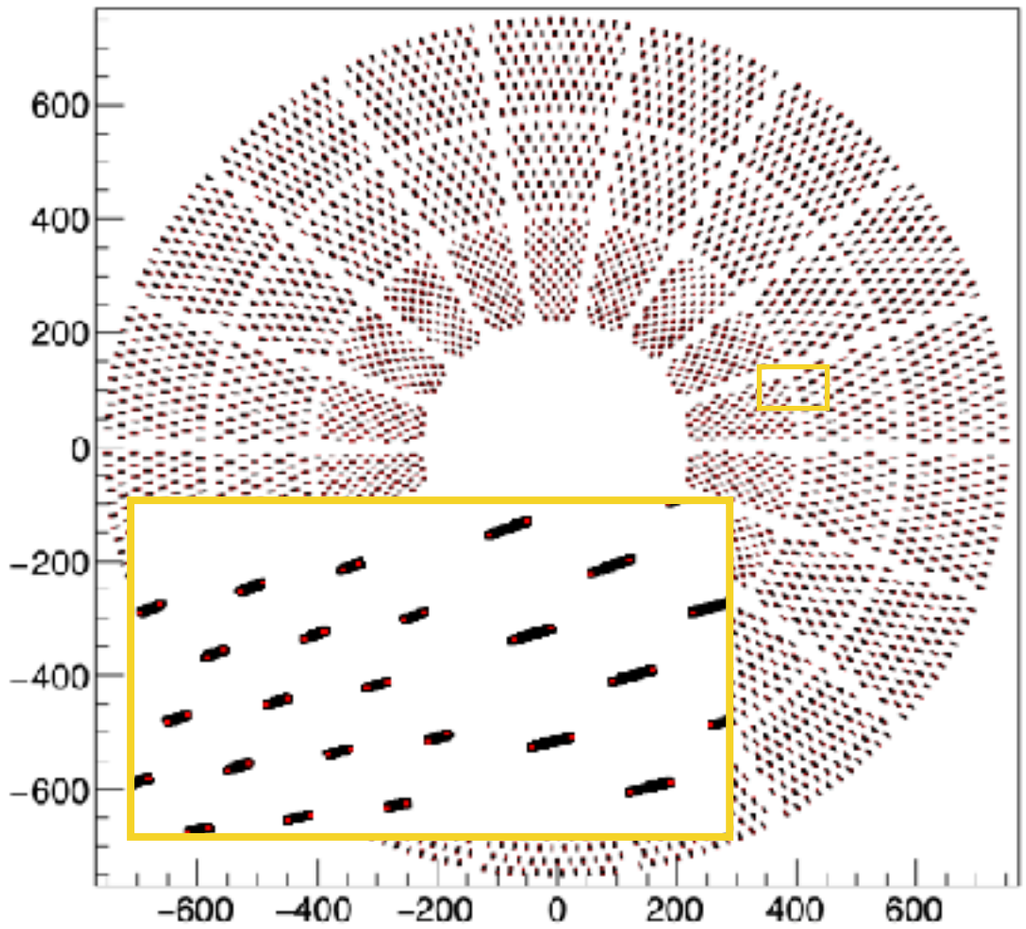




Calibration from Central Membrane

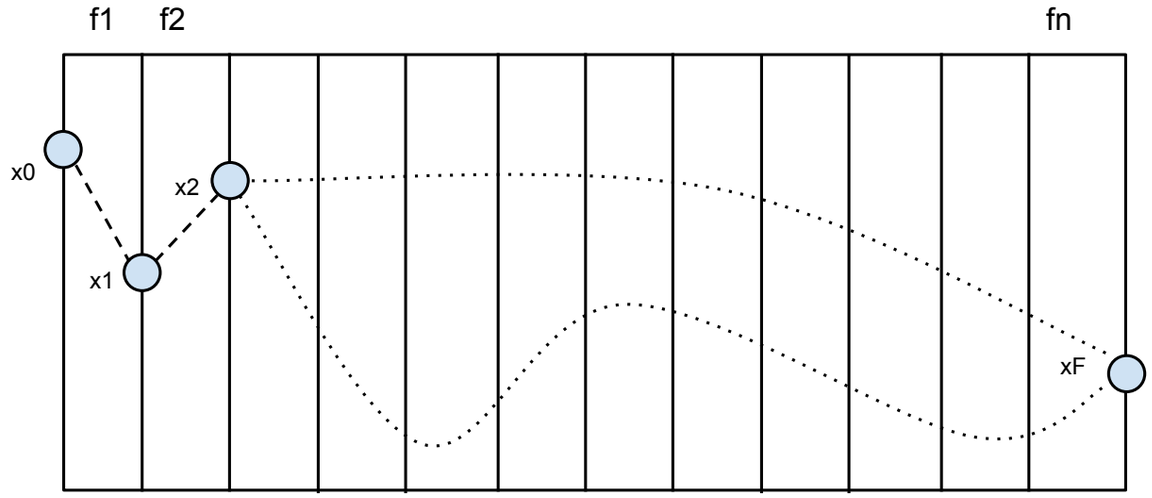
- Sara Kurdi (SBU) implementing CM stripe model into Fun4All for 'laser events' and laser event reco
- Easy reconstructions: known positions yield 2D distortion with single shot
- ...but all have same z: z=0
- Mock PHG4Hits use stripe extent for start and end of hit, back-calculate eion needed to get correct # electrons
- Converting this into 'g4laser' module





Extracting differentials?

The position of an electron at readout is the sum of the distortion in each z-step along the way. Electrons from the CM stripe pattern integrate over the entire z-column (and tracks over a partial column):



The distortions evolve with the motion of the ions (primary<<IBF):

(improved drawing courtesy Sara Kurdi)

By comparing the reconstructed CM stripe position at two consecutive times, we learn about the portions of the z-column they do not have in common, and can use this to extract differential information about the distortions. The number of iterations where you can link differential information is limited by intrinsic detector resolutions.

Summary

- Distorted event generation maturing steadily -- but many cross-checks still to complete
- Laser/CM event generation almost ready
- First studies of distortion *reconstruction* from MC data getting started.

- But time flies (when you're having fun, or waiting for power to be restored)

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Greens functions

- Free Space: $\vec{E}(\vec{x}_{at}, \vec{x}_{from}) = \frac{\vec{x}_{at} - \vec{x}_{from}}{|\vec{x}_{at} - \vec{x}_{from}|^3}$
- Analytic: $\vec{E}(\vec{x}_{at}) = \mathrm{ChargeModel} \rightarrow \mathrm{GetE}(\vec{x})$
- TPC Boundary Solutions (Rossegger thesis):

$$\frac{\partial}{\partial\phi}G(r,\phi,z,r',\phi',z') =$$

$$\frac{1}{L}\sum_{k=1}^{\infty}\sum_{n=1}^{\infty}\sin(\beta_n z)\sin(\beta_n z')\frac{R_{nk}(r)R_{nk}(r')}{N_{nk}^2}\frac{\partial}{\partial\phi}\left(\frac{\cosh[\mu_{nk}(\pi-|\phi-\phi'|)]}{\mu_{nk}\sinh(\pi\mu_{nk})}\right) \quad (5.66)$$

$$\text{with} \quad \frac{\partial}{\partial\phi}\left(\cosh[\mu_{nk}(\pi-|\phi-\phi'|)]\right) =$$

$$= \begin{cases} -\mu_{nk}\sinh[\mu_{nk}(\pi-(\phi-\phi')), & \text{for } 0 \le \phi' < \phi \le 2\pi \\ \mu_{nk}\sinh[\mu_{nk}(\pi-(\phi'-\phi)), & \text{for } 0 \le \phi < \phi' \le 2\pi \end{cases}$$

+ R,Z terms through clever choice of basis.

Computing Distortions

- Jordan Sprague (MIT) and RC implementing more efficient calculation and storage of distortion model from SC
- Sanity-checking distortion maps using test charge and low-resolution maps from Ananya