Center for Frontiers in Nuclear Science

sPHENIX

# TPC Distortion Calibration Software

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(on behalf of the entire subcommittee*)

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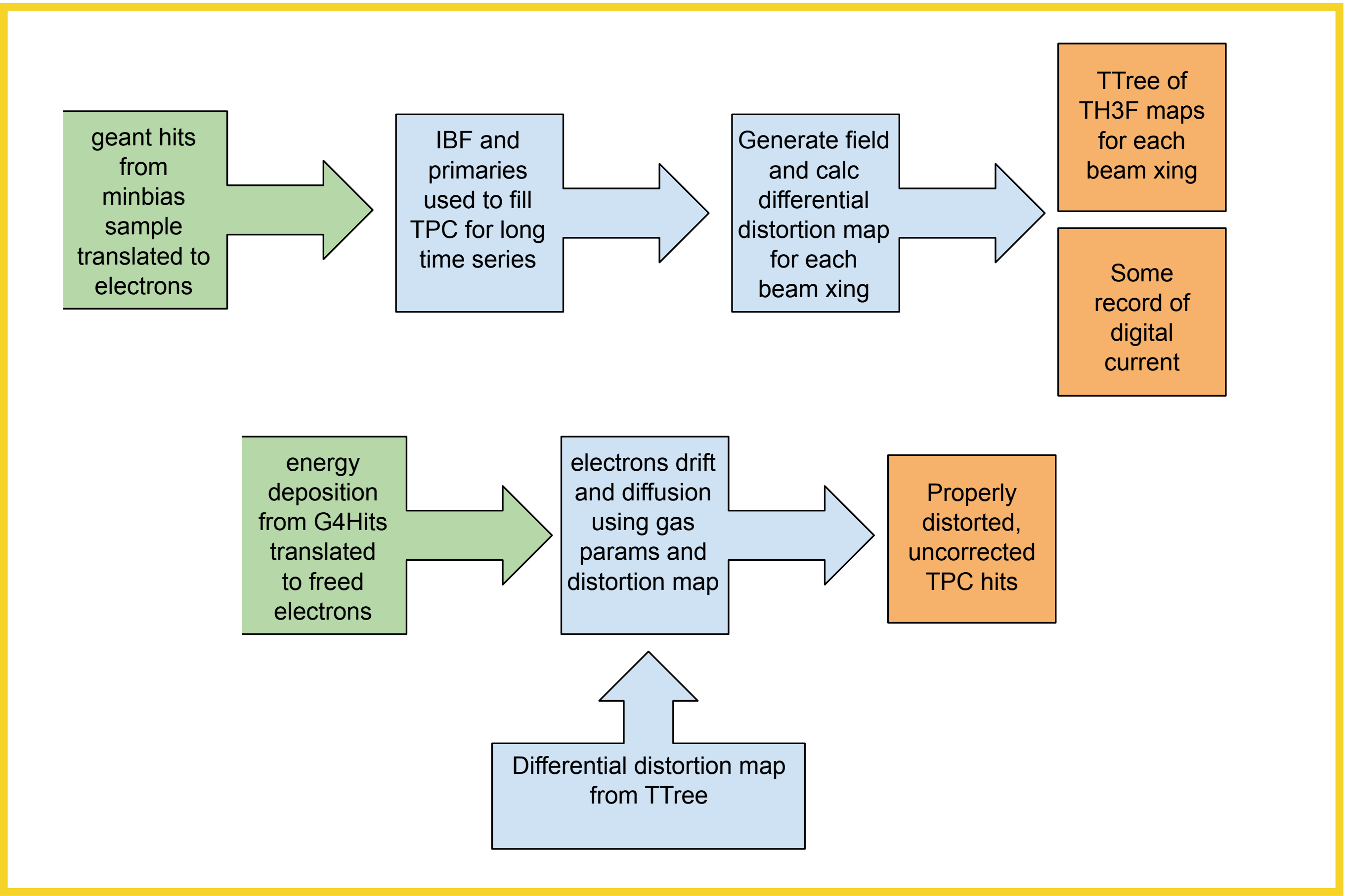
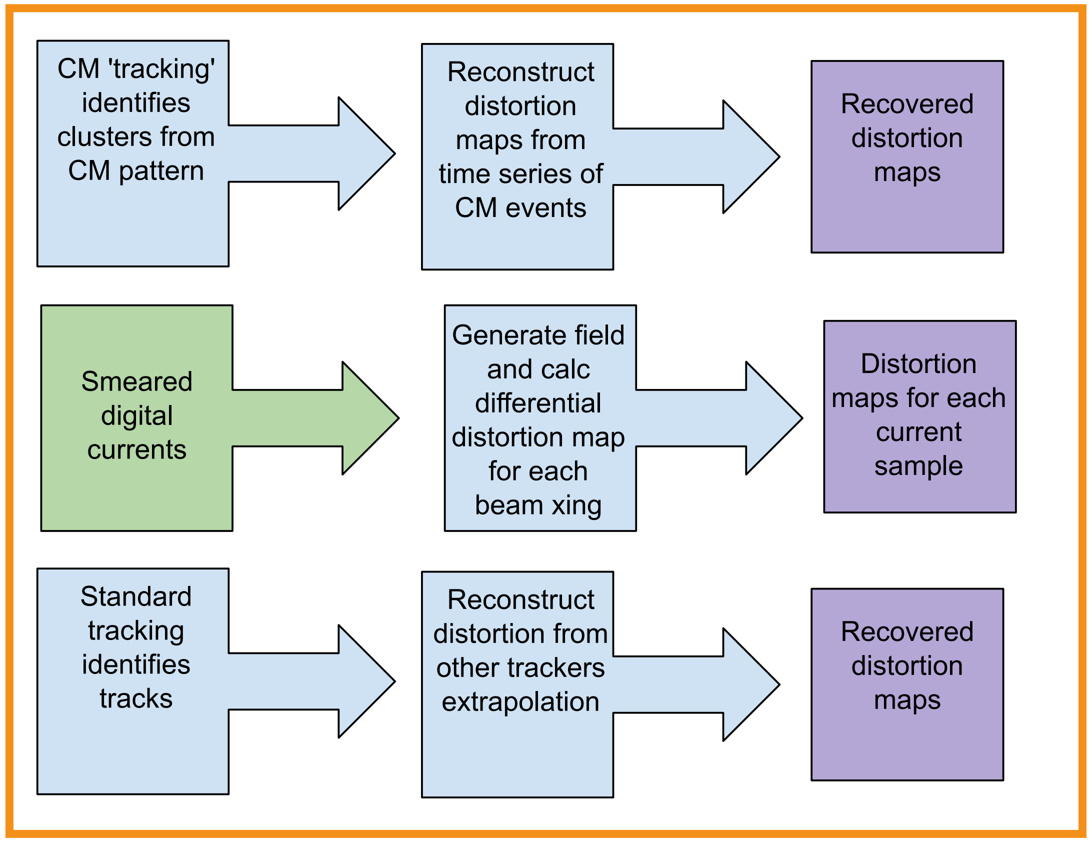
# Overview

- Integrate and expand Spacecharge modeling in Fun4All
- Implement and study Calibration of Spacecharge Distortions through tracking, lasers, and digital current measurements.

**Model and Generation**

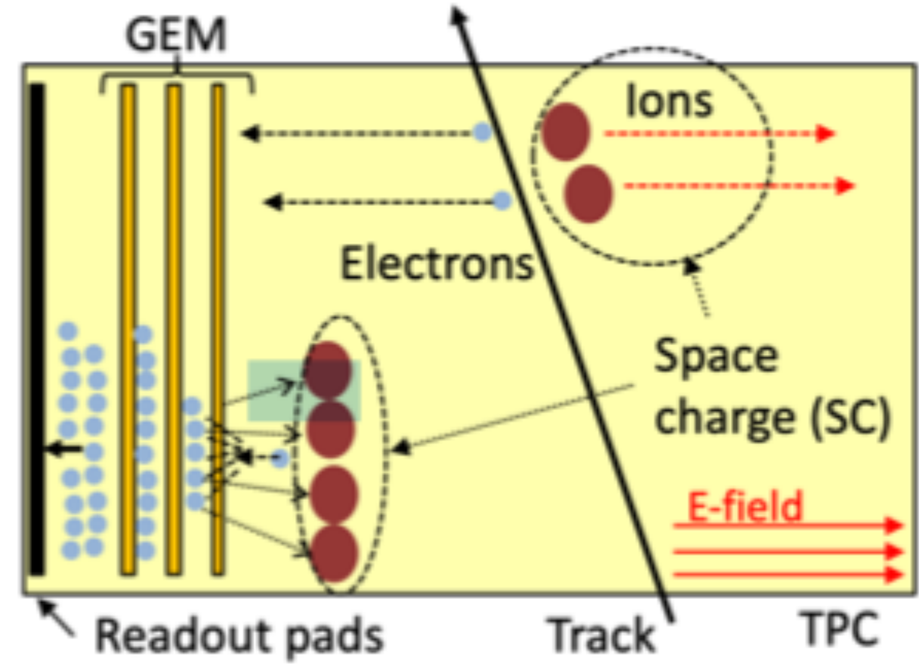



**Reco and Calibration**

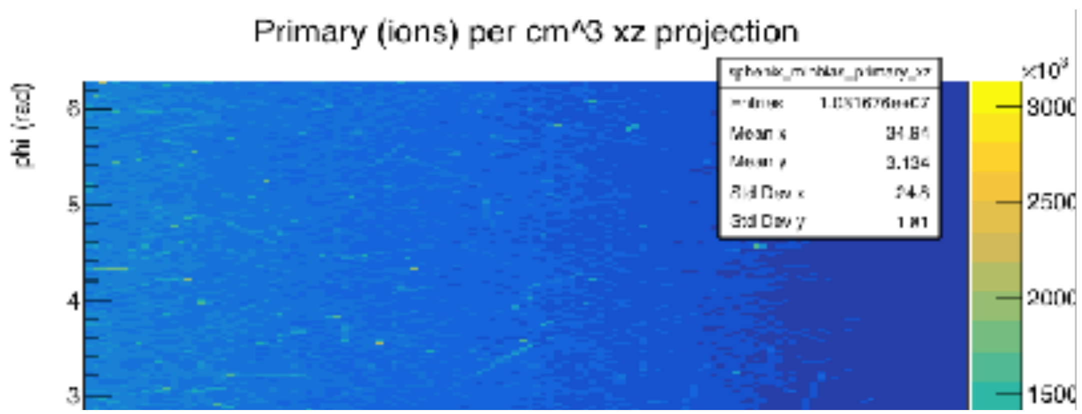


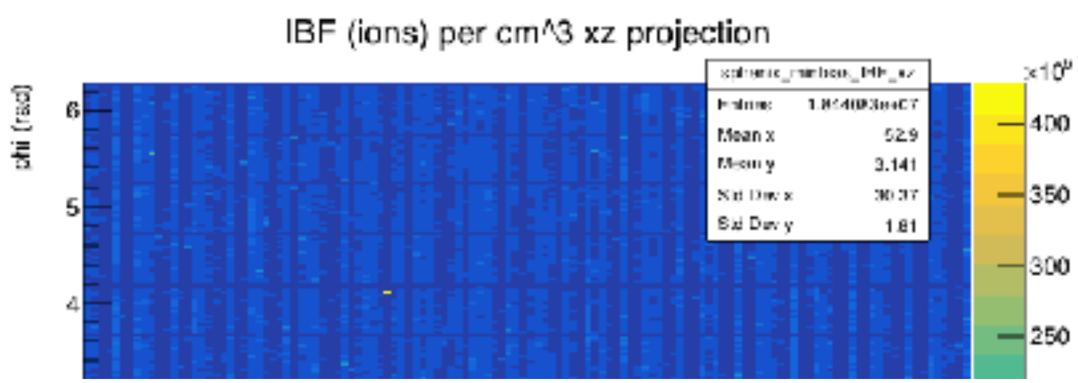
# Structure of Spacecharge

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



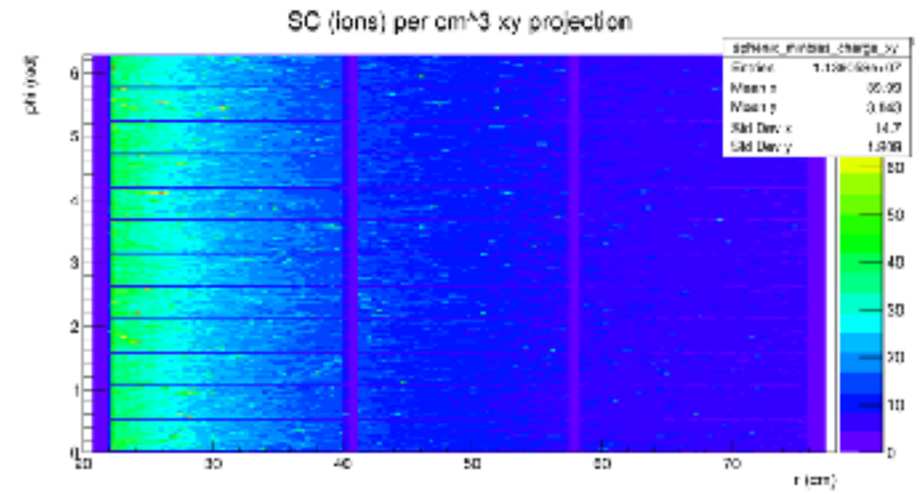

- Heuristic:
  A=Gas and Collider parameters
  $z_0$=drift length
  **c=IBF ions per primary**
  d=radial dependence of track density
- Ions drift ~1.3cm/ms (78ms to cross TPC), 5000x slower than electrons
- Pancakes and volume:
  Primary ions are created from charged particles traversing TPC.
  Ion 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.

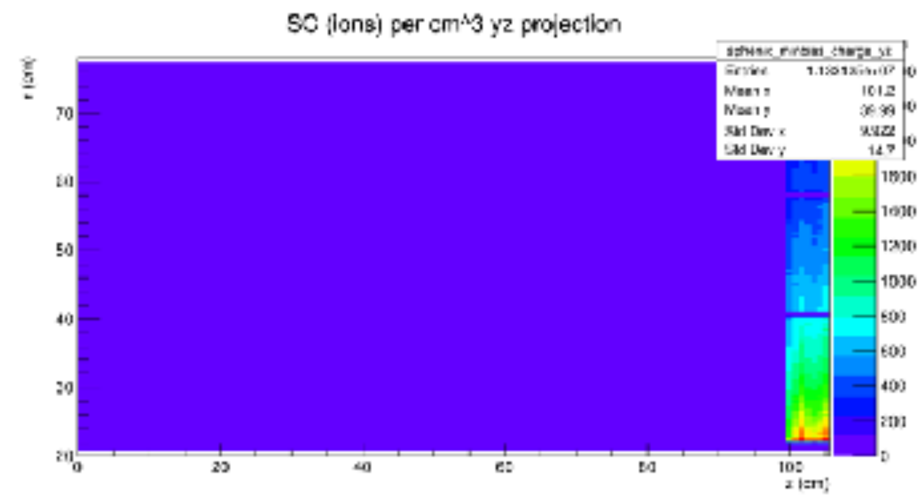


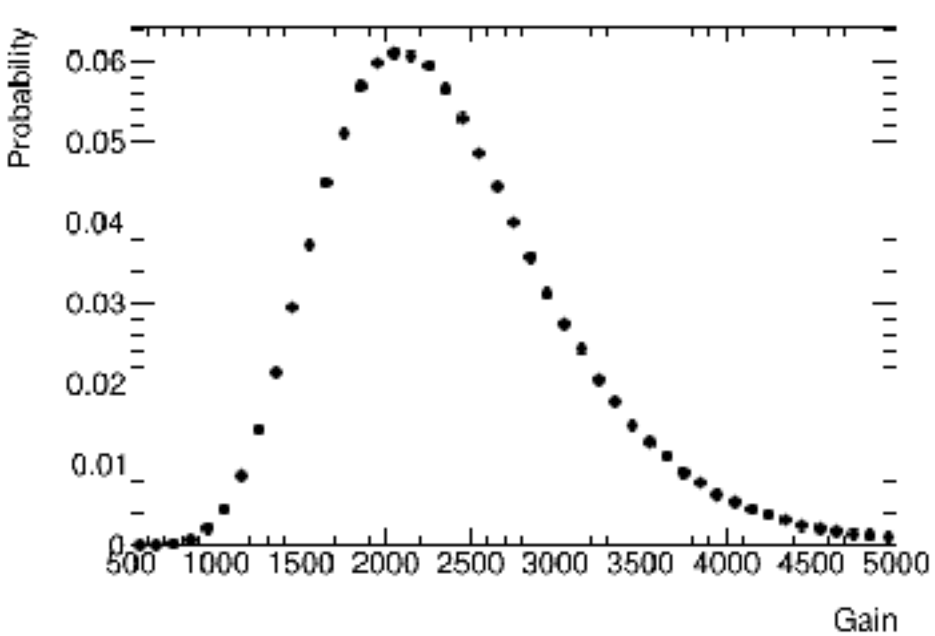



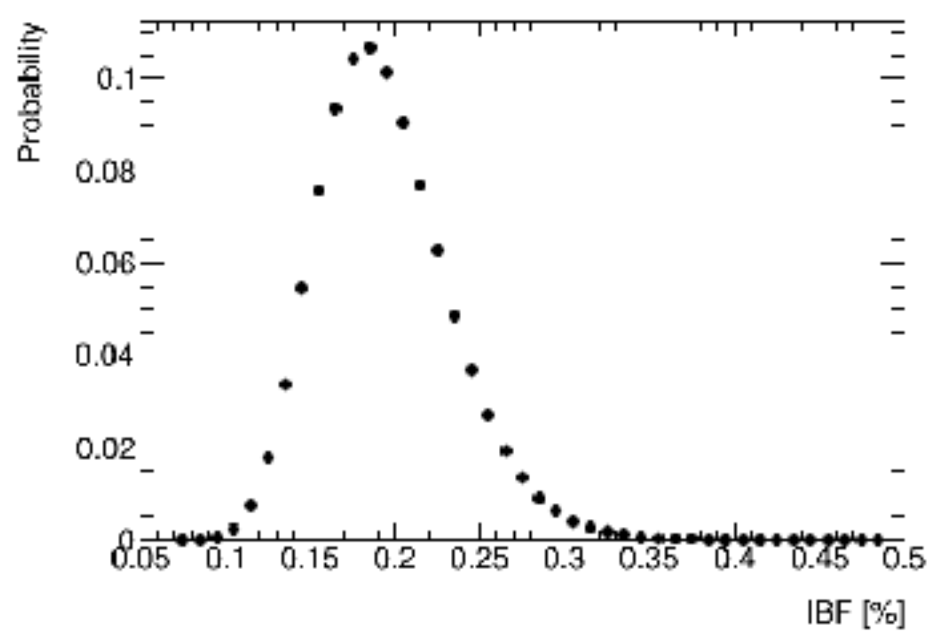
# Generating Spacecharge Models

- 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.
- Evgeny Shulga (Weizmann) developing IBF and gain models needed in MC-truth and reco smearing.



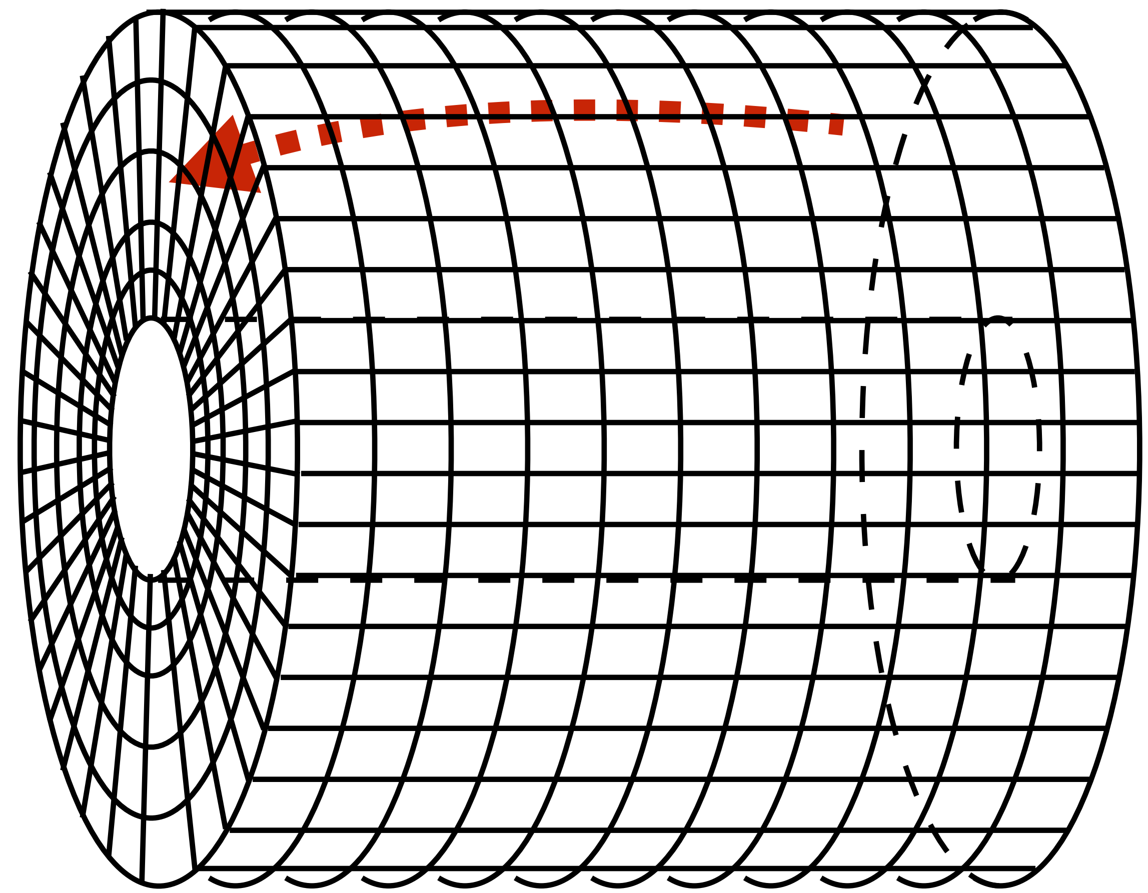



# From Spacecharge to Distortions

- Divide TPC into Pieces of Cake (POC) grid
- Compute cell-to-cell Green's functions
- Use SC distribution to sum field vector per cell*
- Propagate each electron using 2nd order Langevin eqn.
  - pre-compute integrals
  - interpolate between r,phi adjacent cells



Cartesian Coordinates:

$$\begin{pmatrix}\delta_{xE}\\ \delta_{yE}\end{pmatrix} = \begin{pmatrix} c_0 & c_1 \\ -c_1 & c_0 \end{pmatrix} \begin{pmatrix} \int \frac{E_x}{E_z}\, dz \\ \int \frac{E_y}{E_z}\, dz \end{pmatrix}$$

$$\begin{pmatrix}\delta_{xB}\\ \delta_{yB}\end{pmatrix} = \begin{pmatrix} c_2 & -c_1 \\ c_1 & c_2 \end{pmatrix} \begin{pmatrix} \int \frac{B_x}{B_z}\, dz \\ \int \frac{B_y}{B_z}\, dz \end{pmatrix}$$

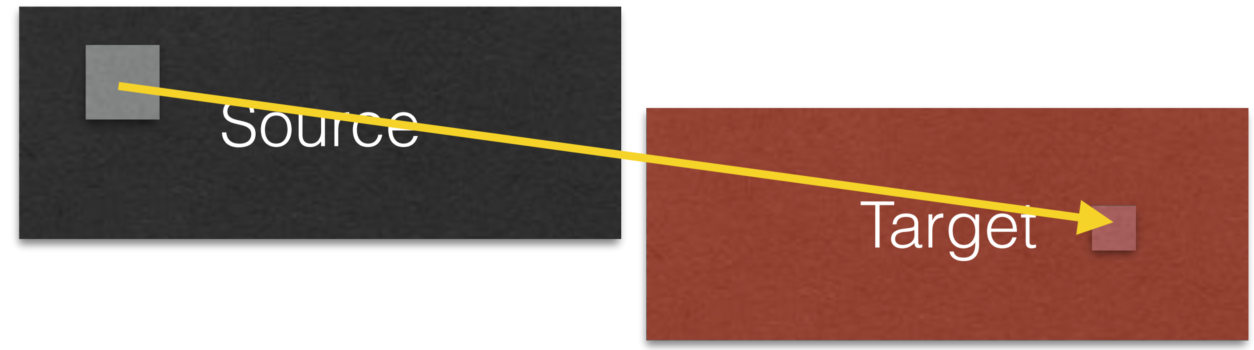
and the z distortion, to first order, is:

$$\delta_z = \int \frac{v'(E)}{v_0} (E - E_0)\, dz$$

# Computing Distortions

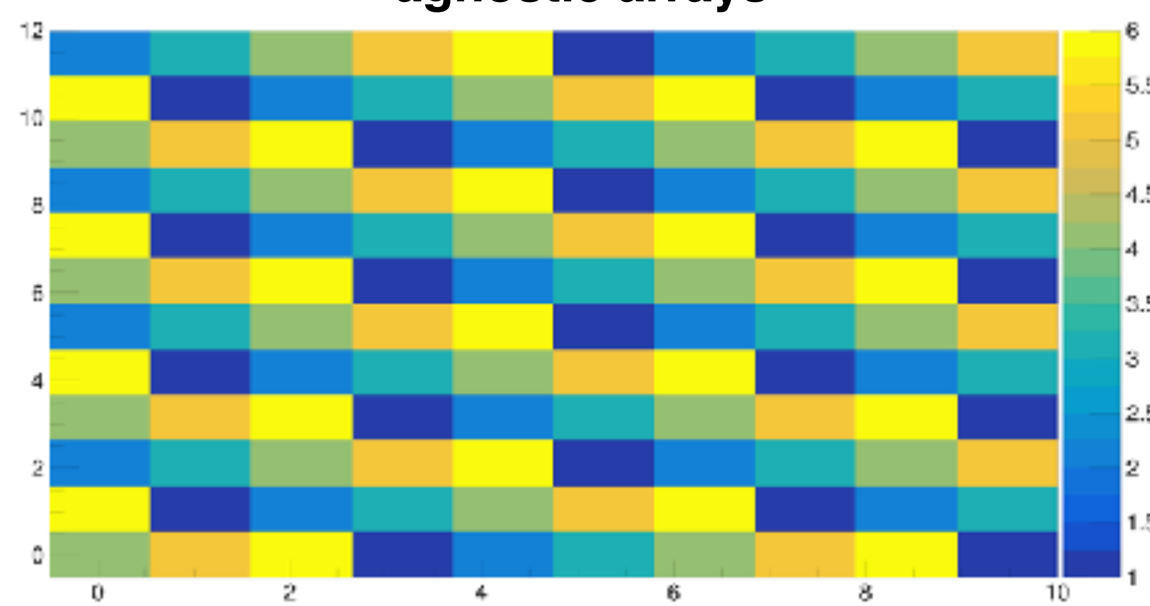
- Jordan Sprague (MIT) and RC implementing more efficient calculation and storage of distortion model from SC
- Refactoring code to be table-layout agnostic.  Supply unique index into flat array for given point in the **target** (field calc'd at) and **source** (unit charge placed at) discretizations of the TPC volume.
- Exploit symmetry, distance hierarchy to beat memory and compule scaling

**~6D Lookup Table**



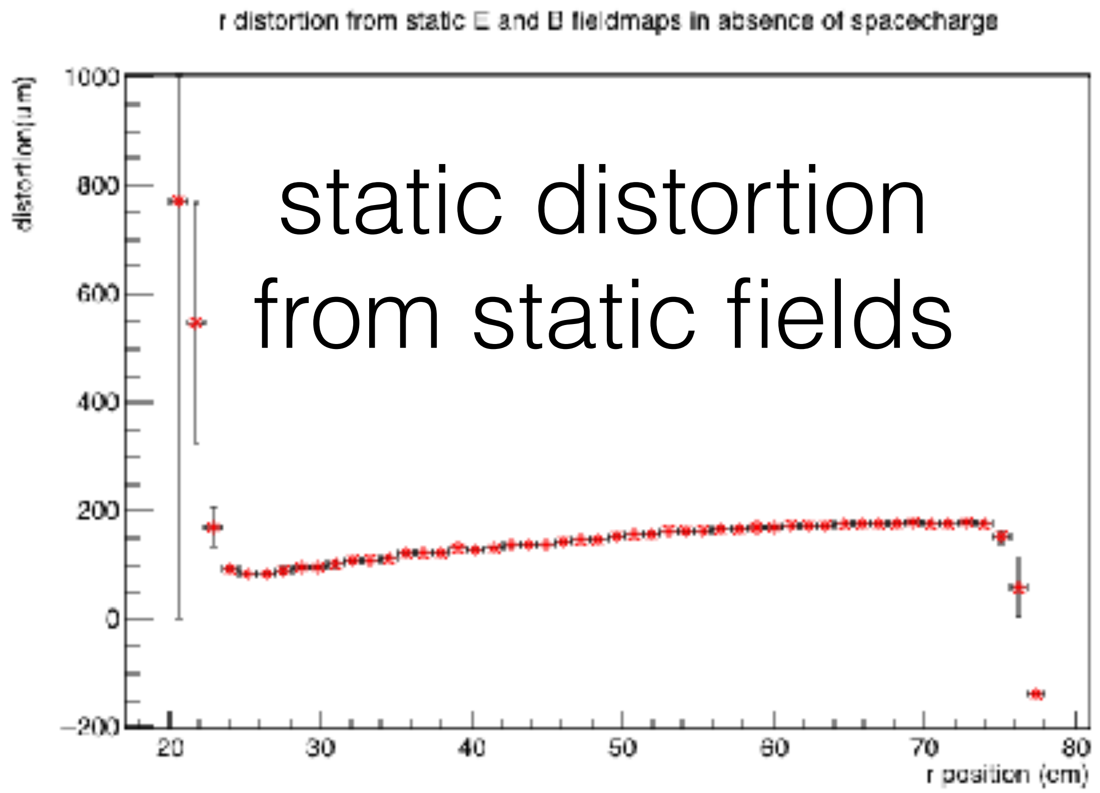

| Element | memory scale | compute scale | timing |
|---|---|---|---|
| Lookup Table | $(n_r \times n_\Phi \times n_z)^2$ | $(n_r \times n_\Phi \times n_z)^2$ | startup |
| Field from SC | $(n_r \times n_\Phi \times n_z)$ | $(n_r \times n_\Phi \times n_z)^2$ | per event |
| Swim | 1 | $n_z$ | per cluster |

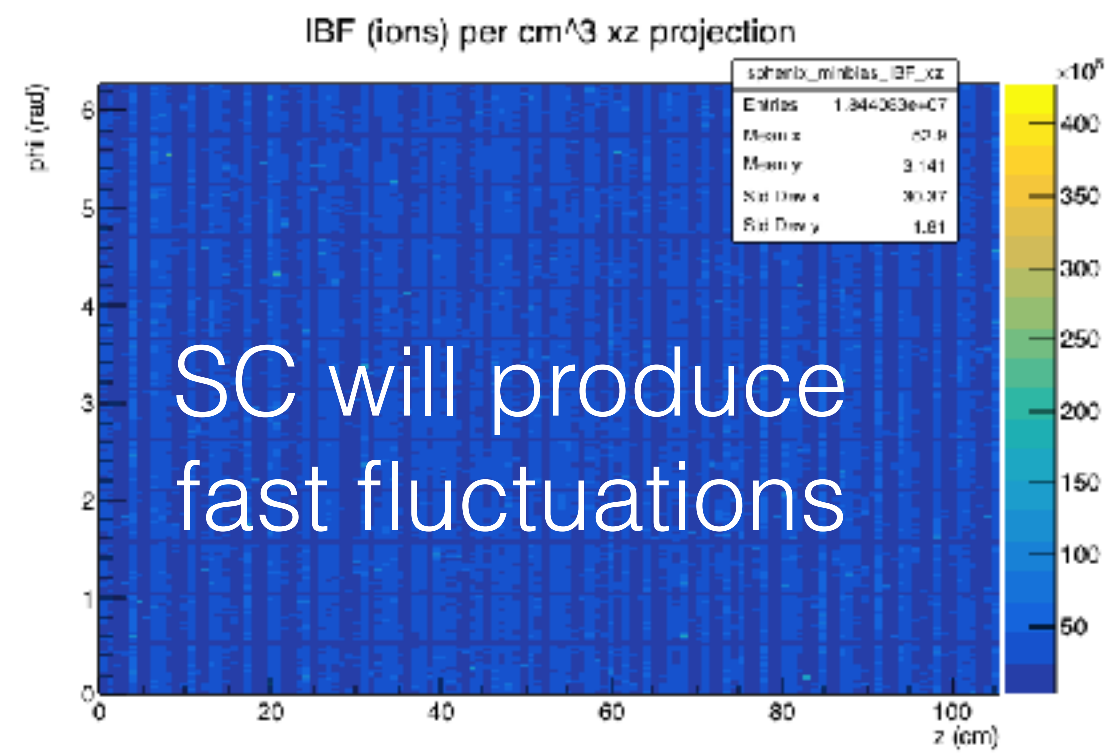
**Index % 6 of 'Target' grid cells for agnostic arrays**



# 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": from specific charge layout of individual events differing from the average



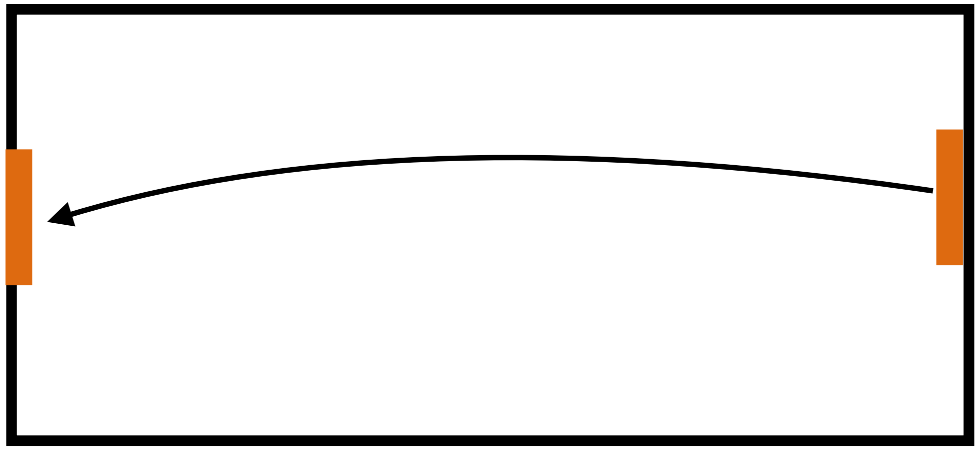



# Creating Distorted Events

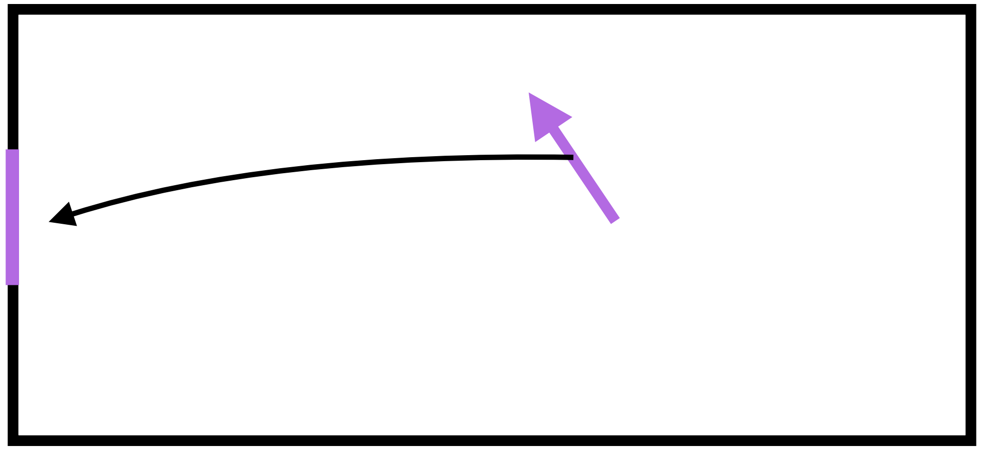
- Currently, z-independent distortions can be applied at the electron drift or cluster reconstruction stage
- Henry Klest (SBU) is implementing proper 3D distortions from computed maps
- Two routes for how to associate these maps:
    1. Simulated events do not affect distortions:
       Distortions can be treated like embedding. Generate distortions independently from minbias MC sample, drift events and TPC pile-up tracks through distortion map selected from pre-computed time series.
    2. Simulated events impact distortions:
       MC sample generated with time stamps. Pile-up is reflected in SC and hence distortion map. Simulated events appear downstream in time series.

# Distortion Handles

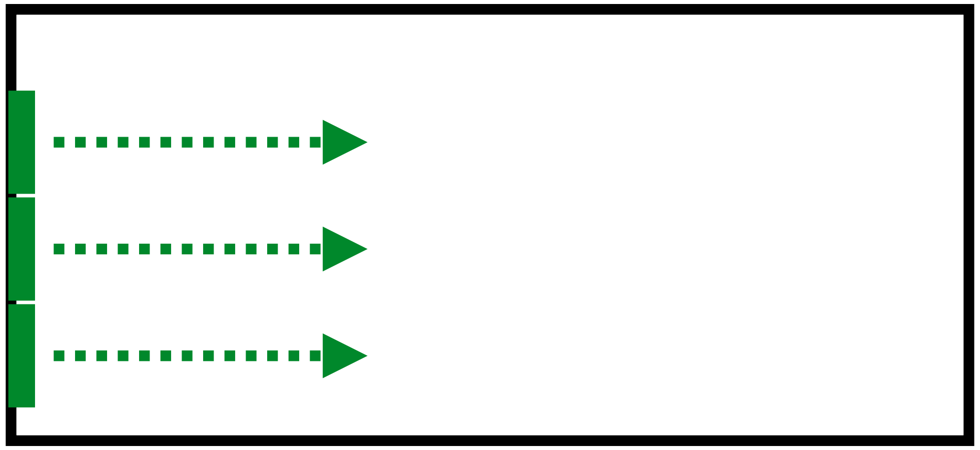
- Central Membrane Stripes: illuminated with laser (kHz), produces clusters at known position, integrates over entire distortion column



- Tracks: (*eff. ~Hz) produces clusters at uncertain position extrapolated from inner tracking, integrates over partial distortion column



- Digital current: infers spacecharge current directly from electrons at readout (kHz), computes distortions from charge



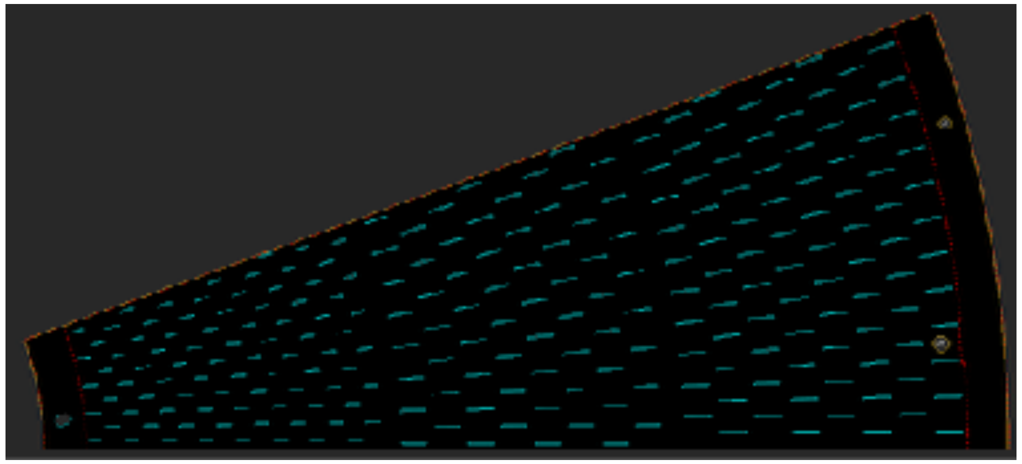
- *Simulation: model expected average spacecharge shape, compute distortions for a given luminosity*

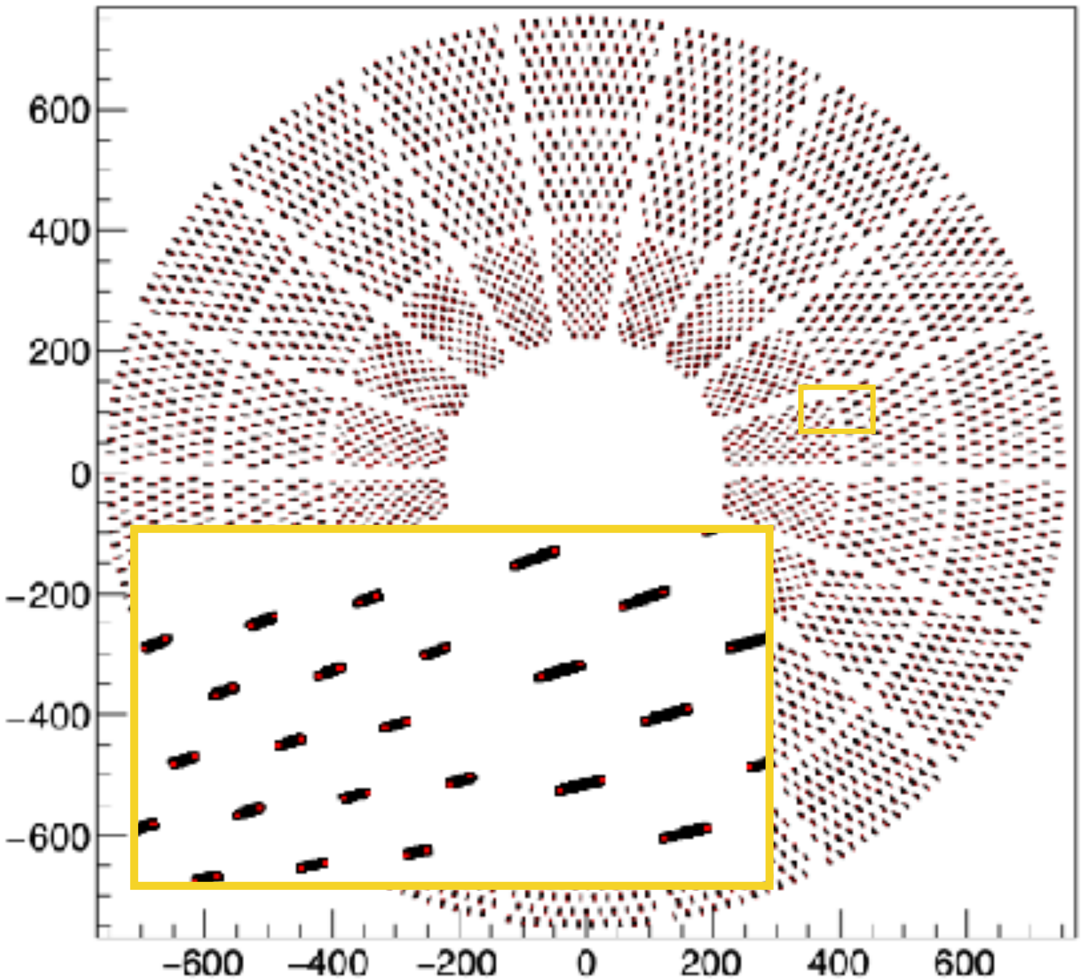
# Calibration from Tracking

- Hugo developed this in the spring:
- Use best-fit parameters without TPC data to constrain true position of reco clusters in the TPC.
- Treat each voxel independently. Accuracy depends on time scale of distortion vs time to accumulate tracks in voxel.

# Calibration from Central Membrane

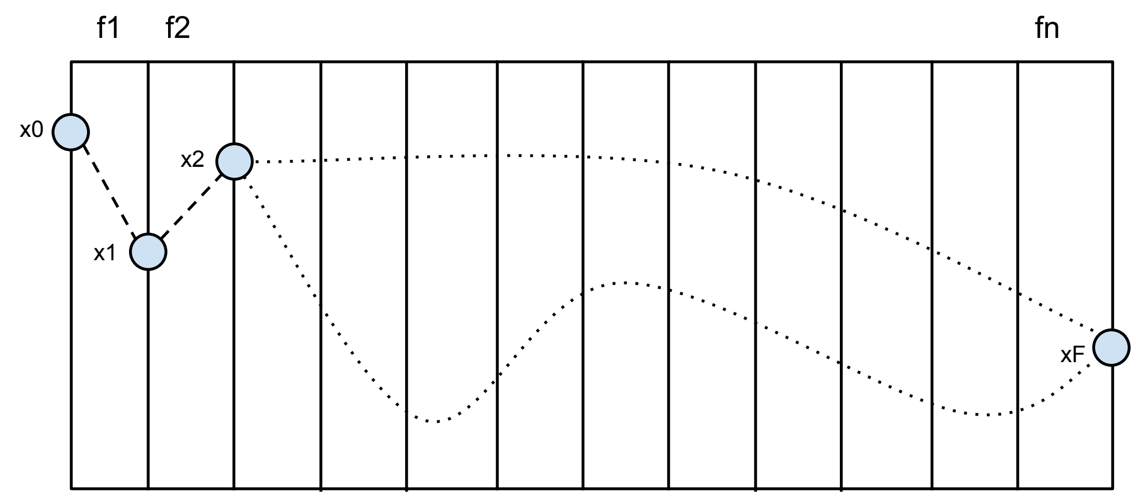
- CM stripes use calibration approach similar to tracks
- Easier reconstructions: known positions > estimated track parameters.
- ...but all have same z: z=0
- Sara Kurdi (SBU) implementing stripe model into Fun4All for 'laser events' and laser event reco
- Mock PHG4Hits use stripe extent for start and end of hit, back-calculate eion needed to get correct # electrons:



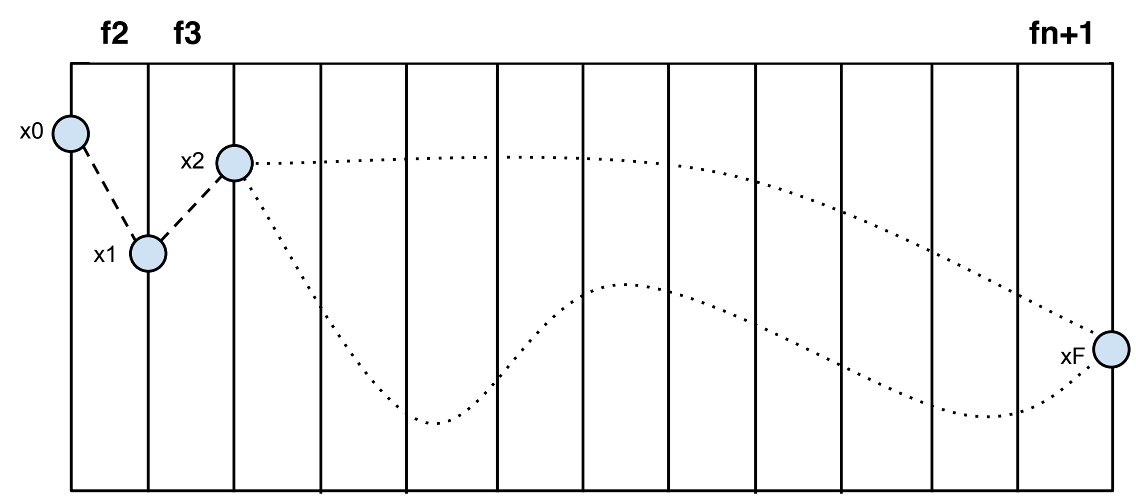


# Extracting differentials?

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):



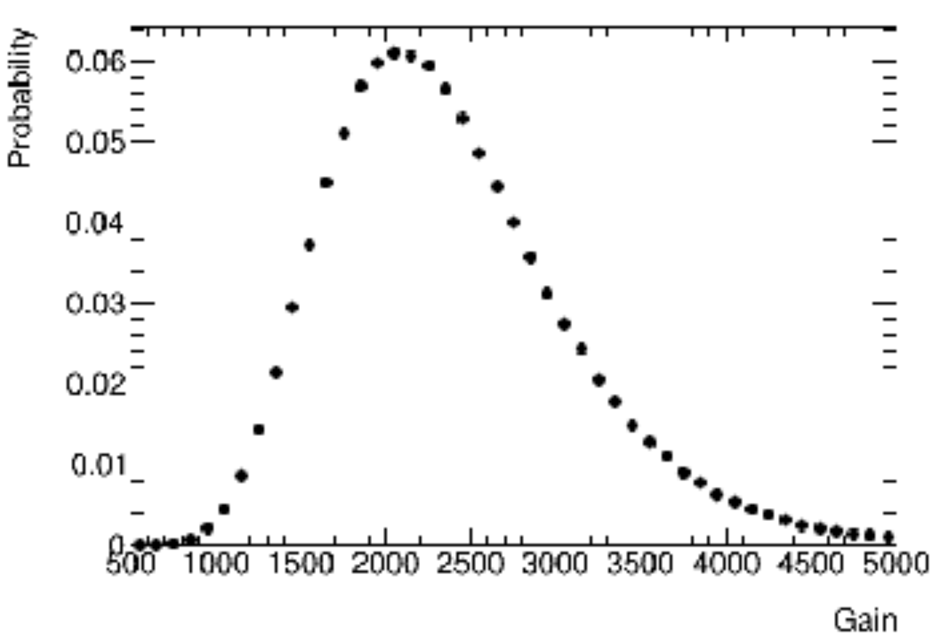

The distortions evolve with the motion of the ions (primary<<IBF):

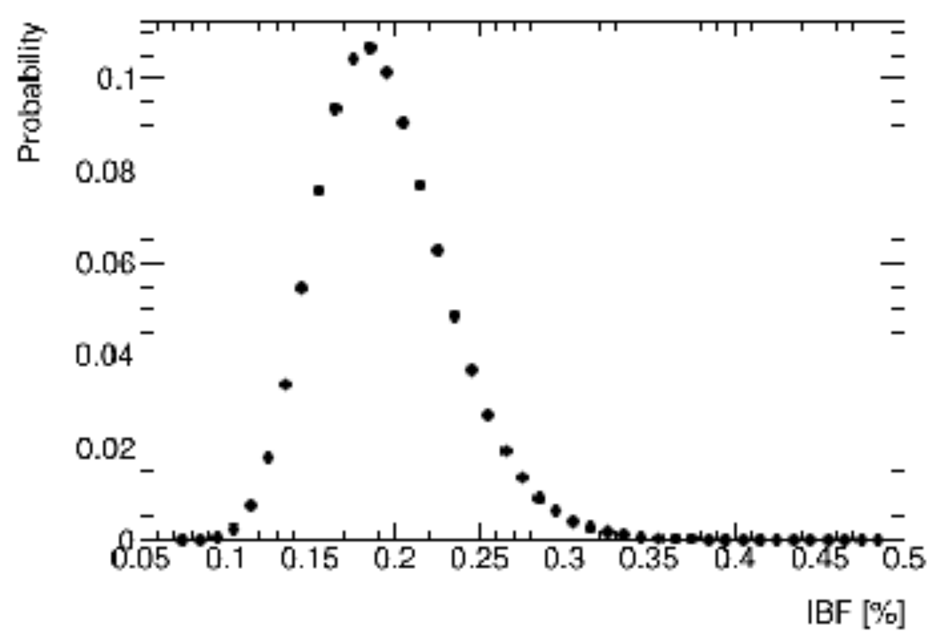



By comparing the reconstructed CM stripe position at two consecutive times, we learn about the portions of the z-column they do not have in common, and can use this to extract differential information about the distortions. The number of iterations where you can link differential information is limited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

# Calibration from Digital Currents

- Calibration will involve computing the distortion maps from digital current (read at 50kHz in ALICE)
- 'Reco' spacecharge needs to reflect proper zero-suppression, saturation, and gain/IBF uncertainty
- Calibration residuals dependent on distortion resolution/model studies.



# 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* | | | | |

# Summary

- By Summer's end:
  - Implement and validate realistic distortion models in MC data
    - SC (Ananya, Evgeny), Model (Jordan, Ross), Implementation (Henry)
  - Implement track-, laser-, and current- based reconstruction of distortion maps
    - Tracks (Hugo+), Lasers (Sara, Ross), Current (Jordan, Ross, Evgeny)
    - Study, optimize and report on performance of each
  - Combine!

# 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: $$\vec{E}(\vec{x}_{at}) = \text{ChargeModel} \rightarrow \text{GetE}(\vec{x})$$
- TPC Boundary Solutions (Rossegger thesis):

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

$$\text{with} \quad \frac{\partial}{\partial\phi} (\cosh[\mu_{nk}(\pi - |\phi - \phi'|)]) = = \begin{cases} -\mu_{nk} \sinh[\mu_{nk}(\pi - (\phi - \phi')), & \text{for } 0 \leq \phi' < \phi \leq 2\pi \\ \mu_{nk} \sinh[\mu_{nk}(\pi - (\phi' - \phi)), & \text{for } 0 \leq \phi < \phi' \leq 2\pi \end{cases}$$

+ R,Z terms through clever choice of basis.