# TPC Distortion Calibration Software

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(on behalf of the entire subcommittee*)

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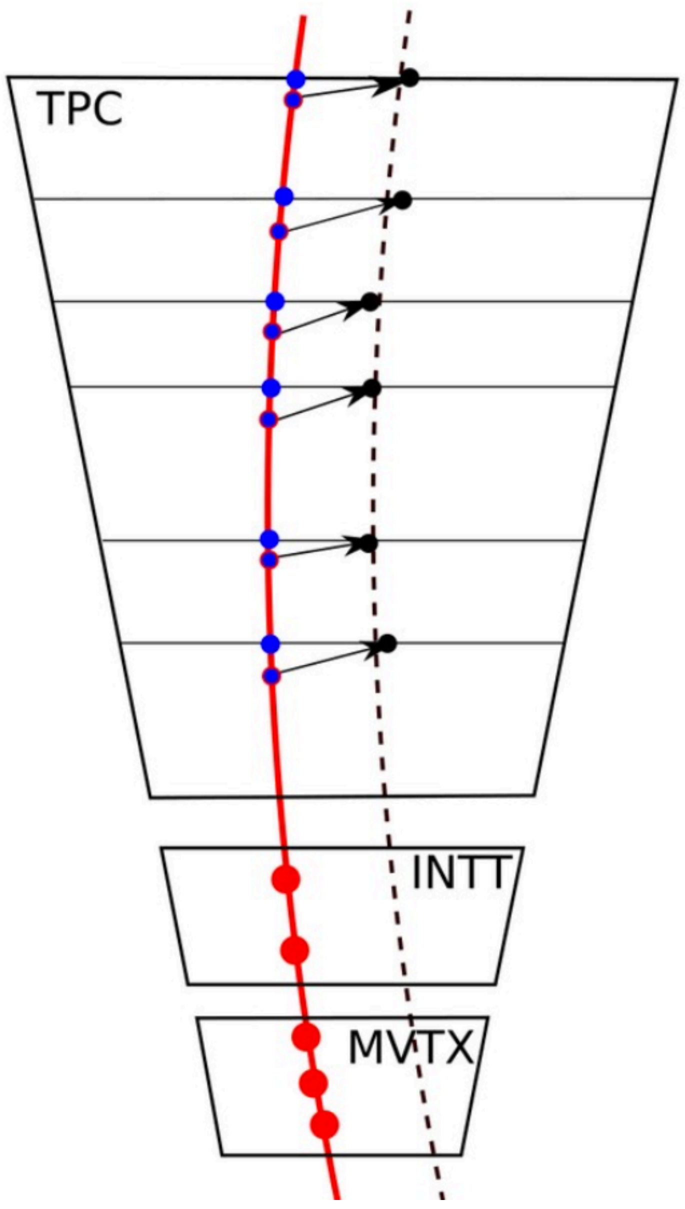
# TPC Distortions

- Due to electric and magnetic fields, electrons do not drift purely in z*
- Deviations from uniform drift must be corrected in order to correctly reconstruct tracks

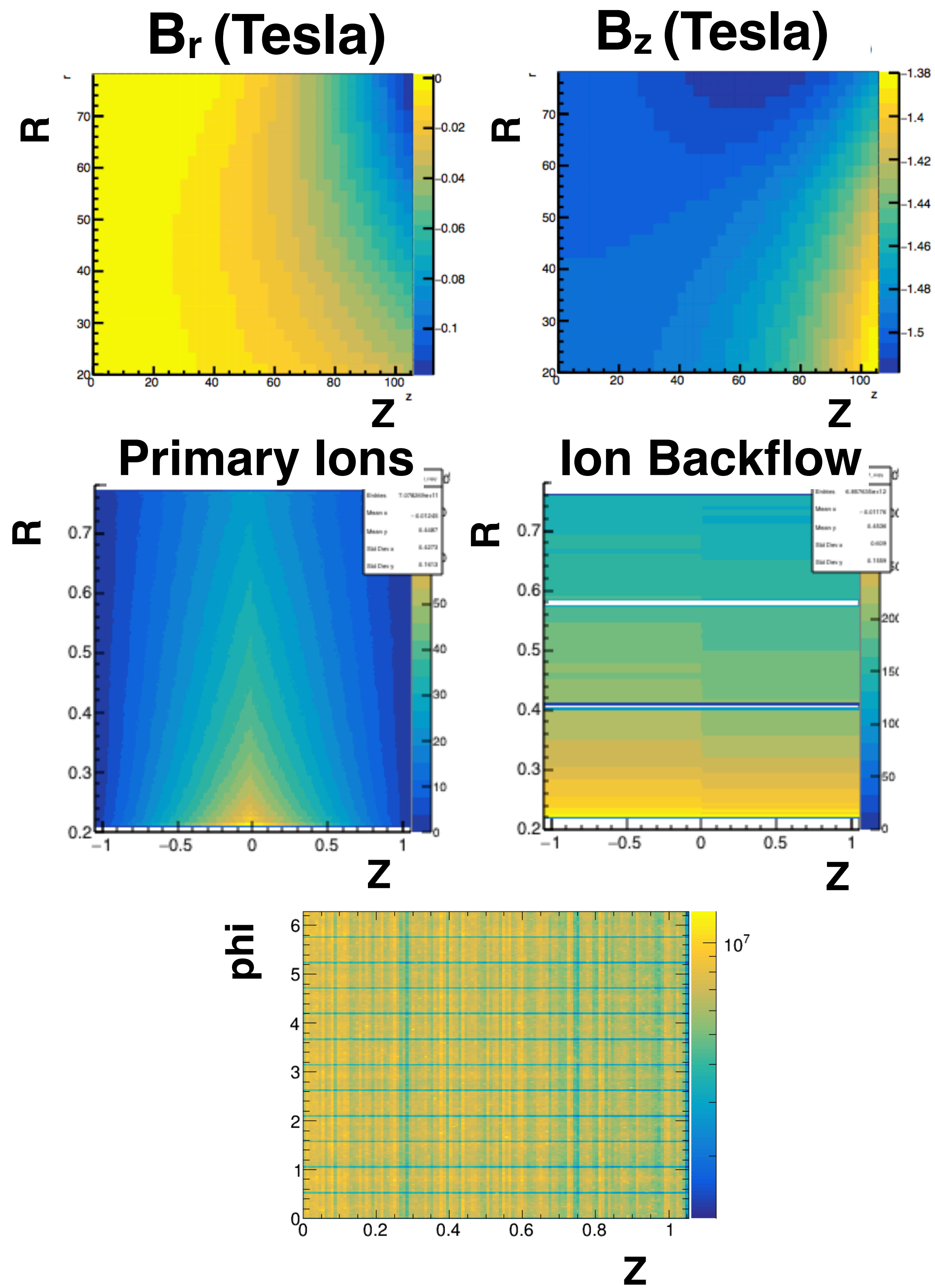



courtesy Hugo

*and their drift speed in z can vary, too

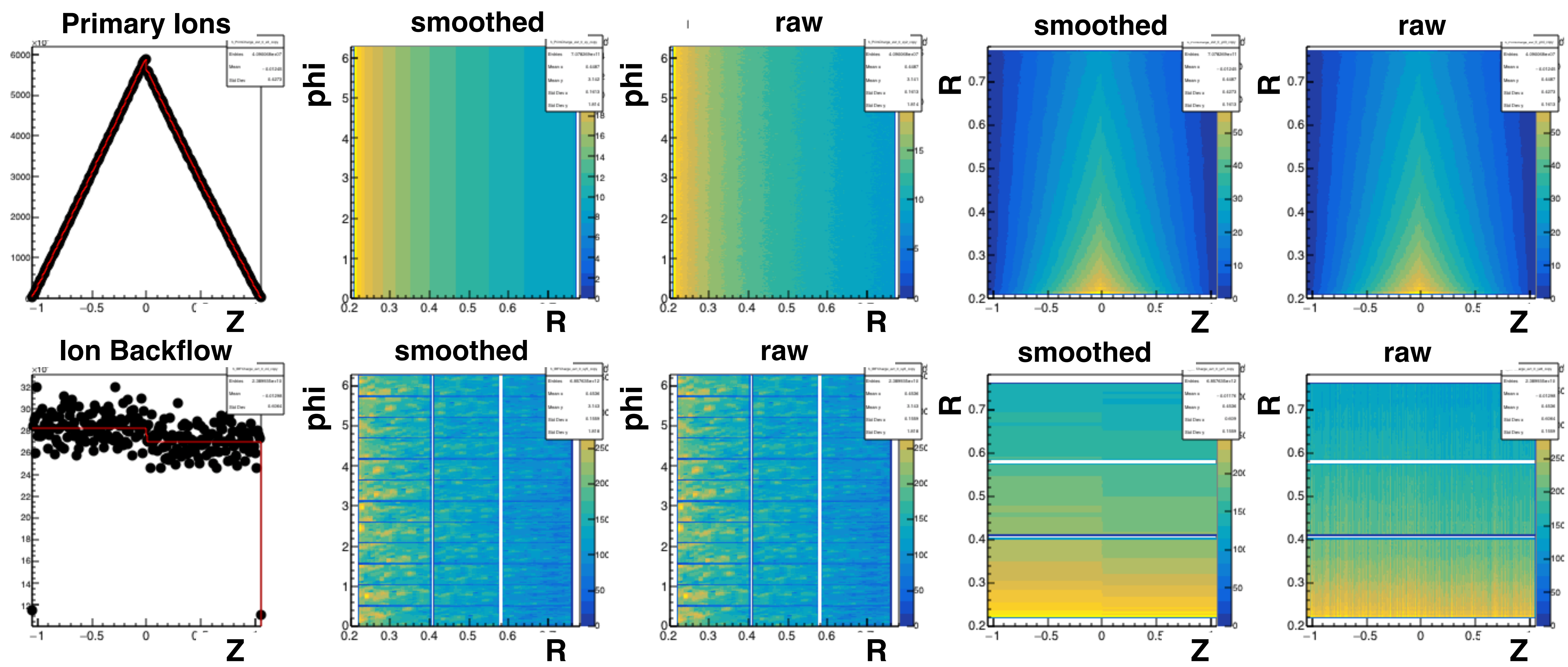
# Structure of TPC Distortions

- Static: fieldmap and alignment, especially field at large z O(cm)
- Quasistatic: variation of gas params and average spacecharge
- Fluctuations: IBF pancakes differ event-to-event, drift for ~78ms



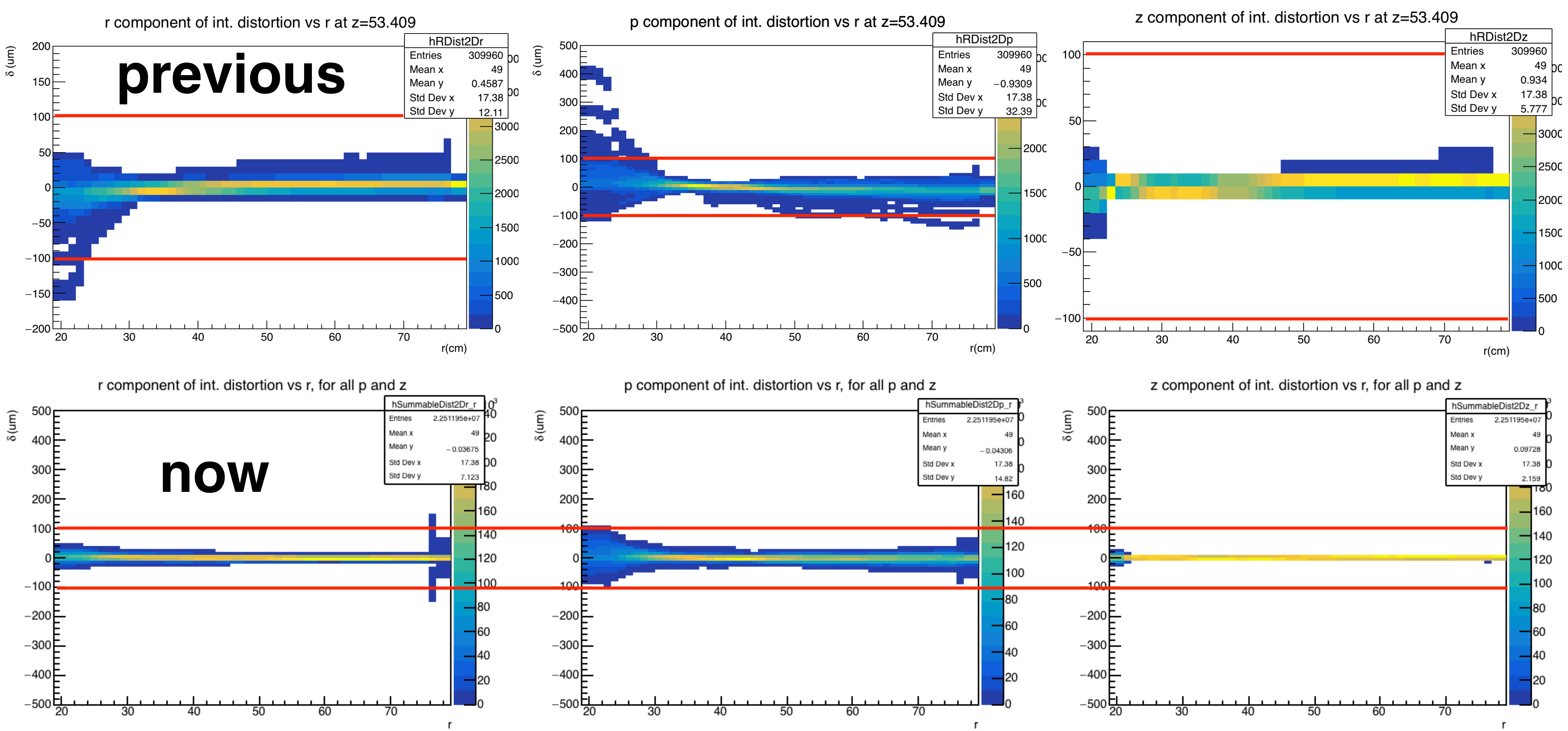
# Generator Status

- Substantially sped up (removed debugging structures)
- post-processing to generate smoother average SC (primaries in phi, IBF in phi and z)



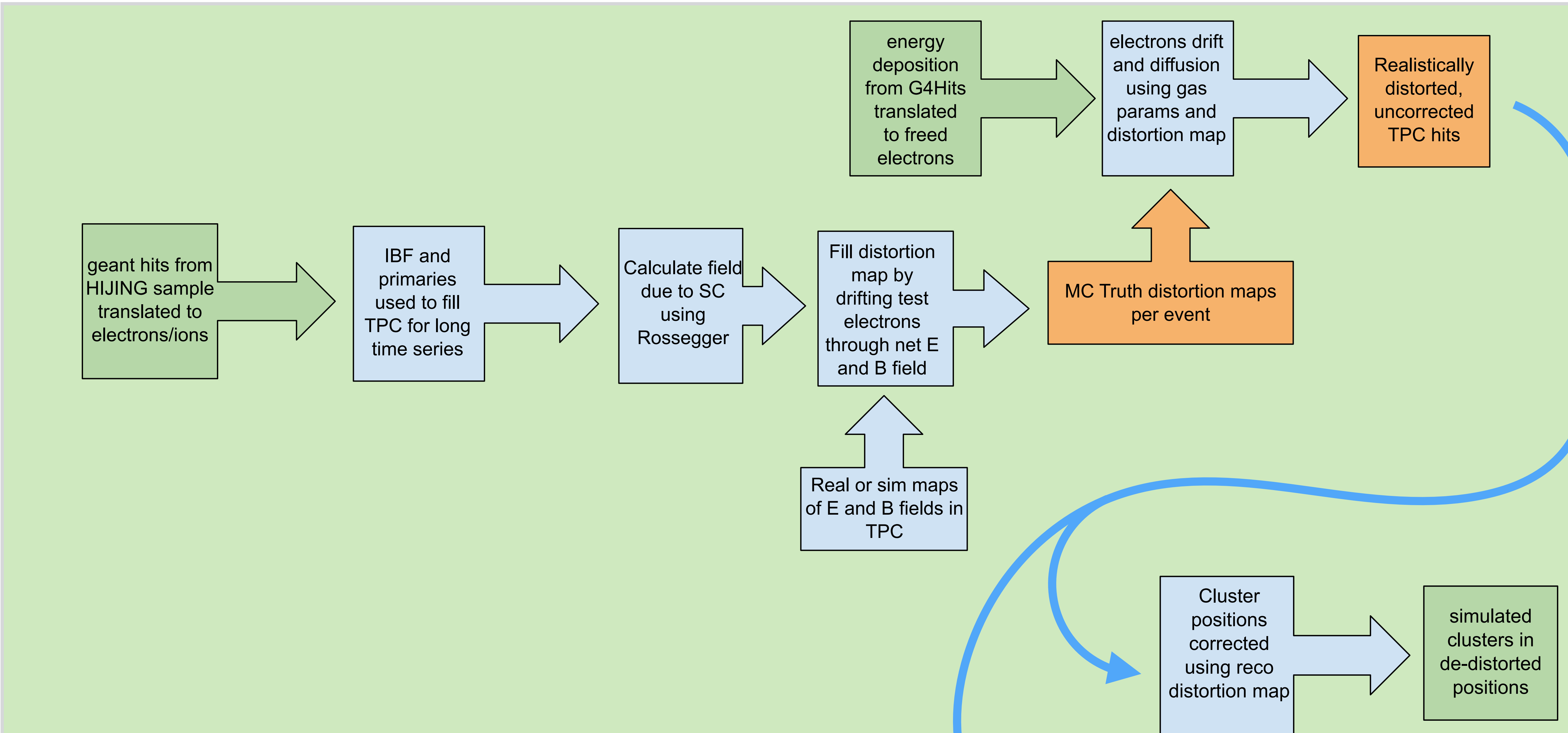
# Generator Status

- Fluctuations now sqrt(2) smaller and symmetric
- Generator checked in

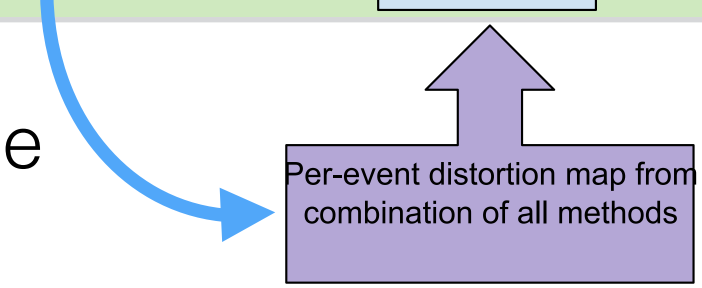


# Generation and Simulation

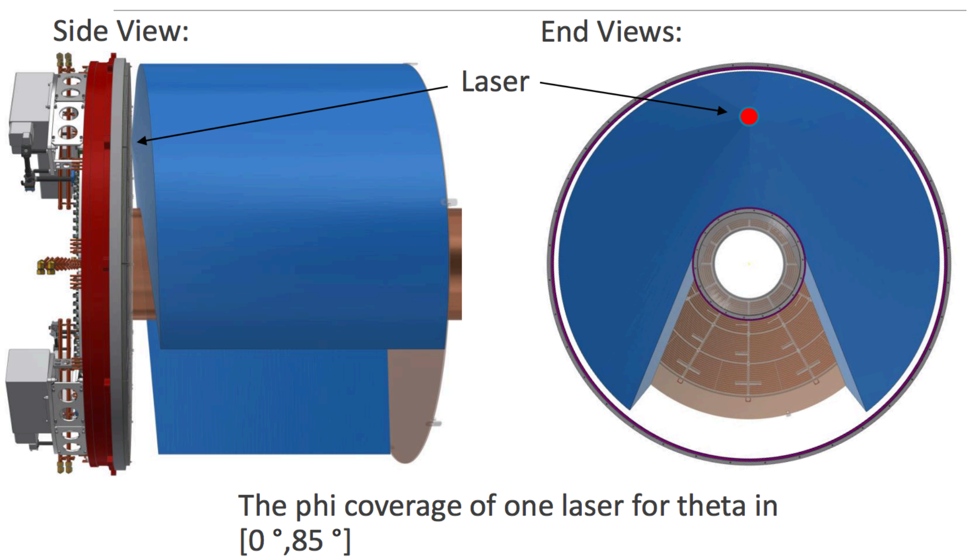
- Framework to generate, apply, and correct distortions is ~in place:

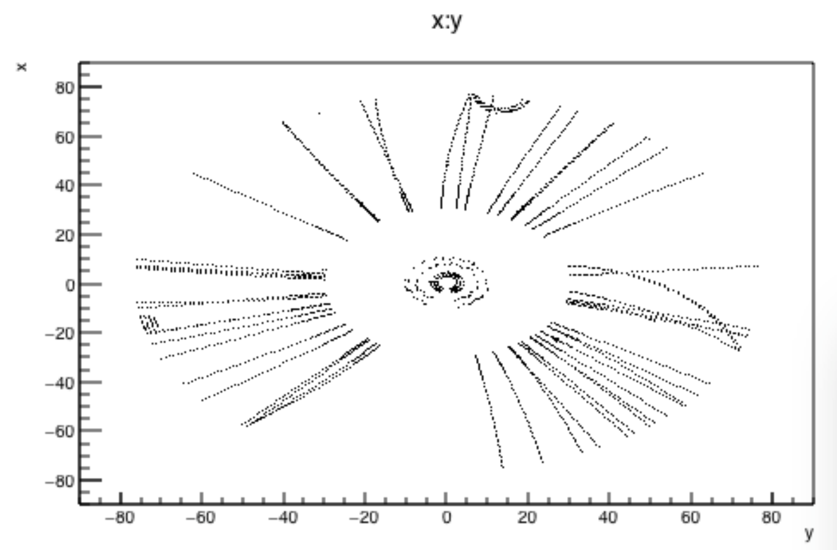


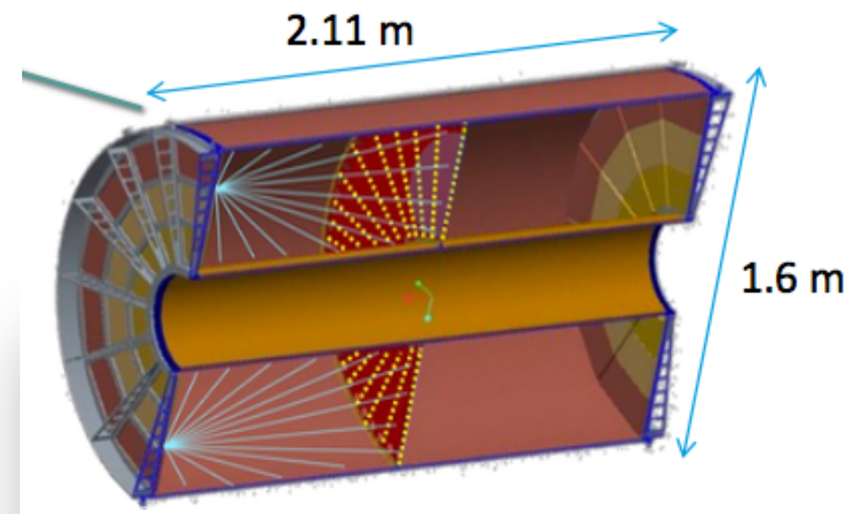

- Focus is now on details of reconstructing the distortion from sim data:



# Monitoring Distortions Directly

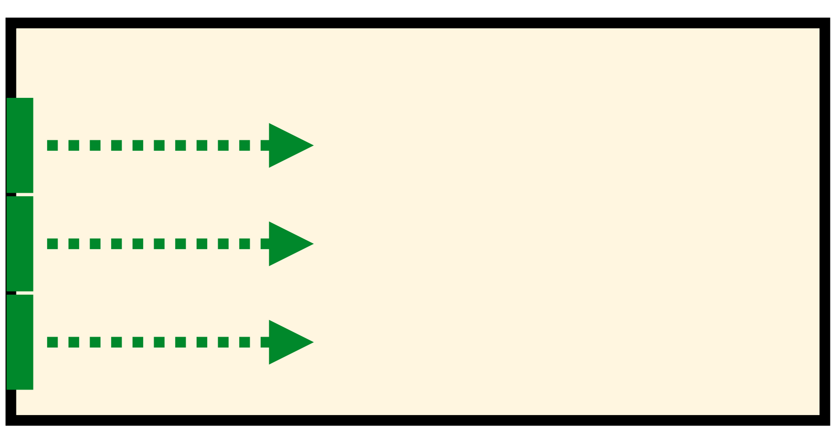


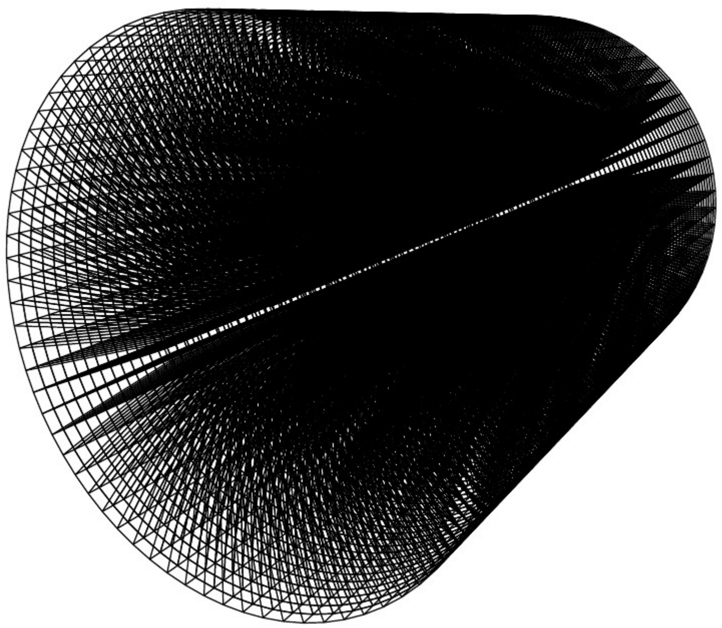




- Static Distortions mapped (full 3D) by **line laser**. B field also mapped directly.
- Average distortions monitored (full 3D) by **tracks** after statics removed.
- Distortion fluctuations monitored (2D) by **CM pattern/diffuse laser** after averages removed.

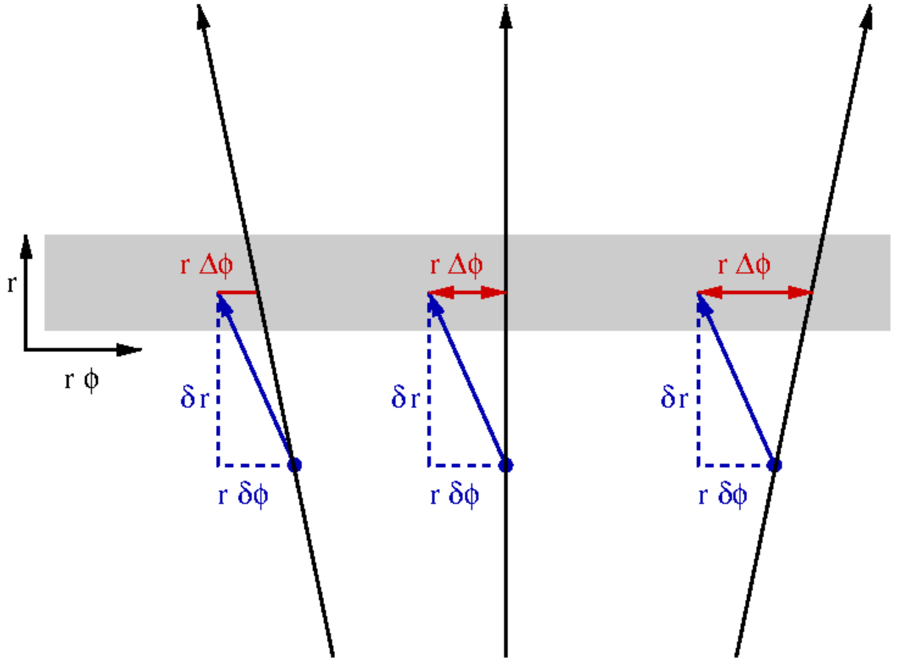
- ***Digital current** provides orthogonal, but indirect, measure of SC distortion*



# Monitoring with Tracks



- Find tracks using all detectors and large search windows
- Fit tracks using the detectors outside of the TPC
- Form residuals (cluster - track) in the TPC along Φ and z
- In each volume element ( > 40000), derive distortions along Φ, r and z from ΔΦ and Δz residuals



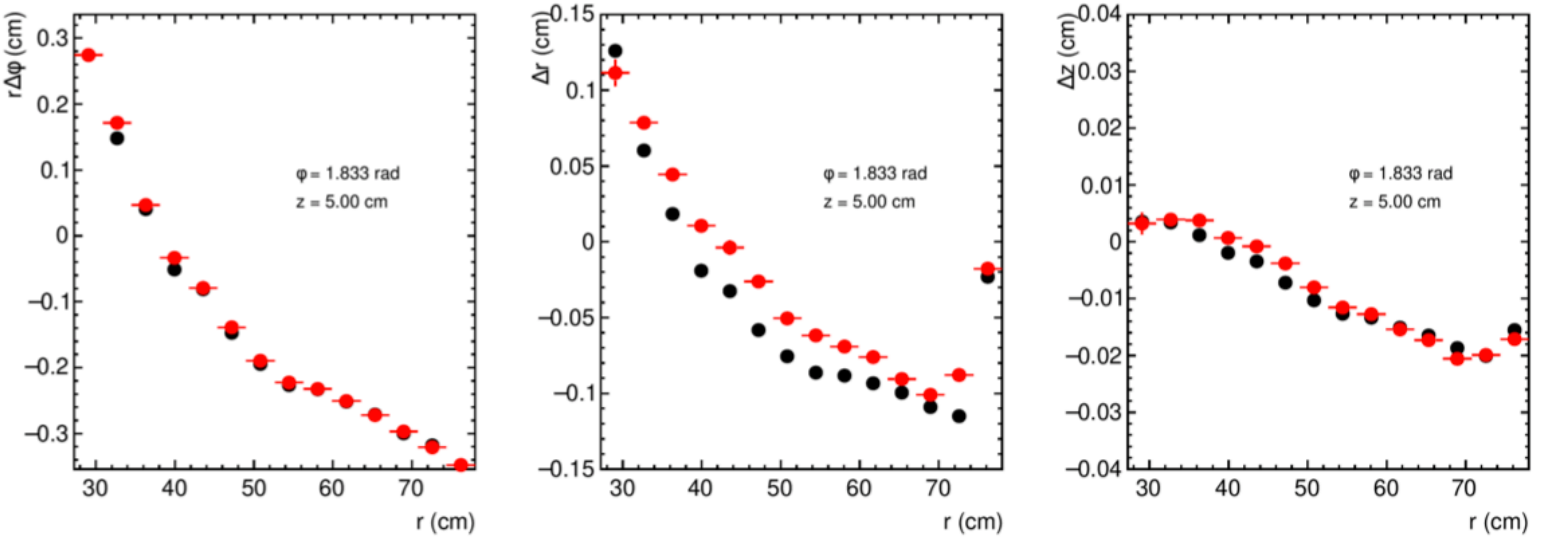

Remarks:

- TPC only measures Φ and z, at a given r. For δr distortions, use correlation between ΔΦ (Δz) and track angle in the (r,Φ) (resp. (r,z)) plane
- Due to large number of volume elements, prefer analytic solution to fit, for getting distortions from residuals
- Same method applicable to line lasers, with the laser, instead of tracking to provide reference track

courtesy Hugo

# Monitoring with Tracks

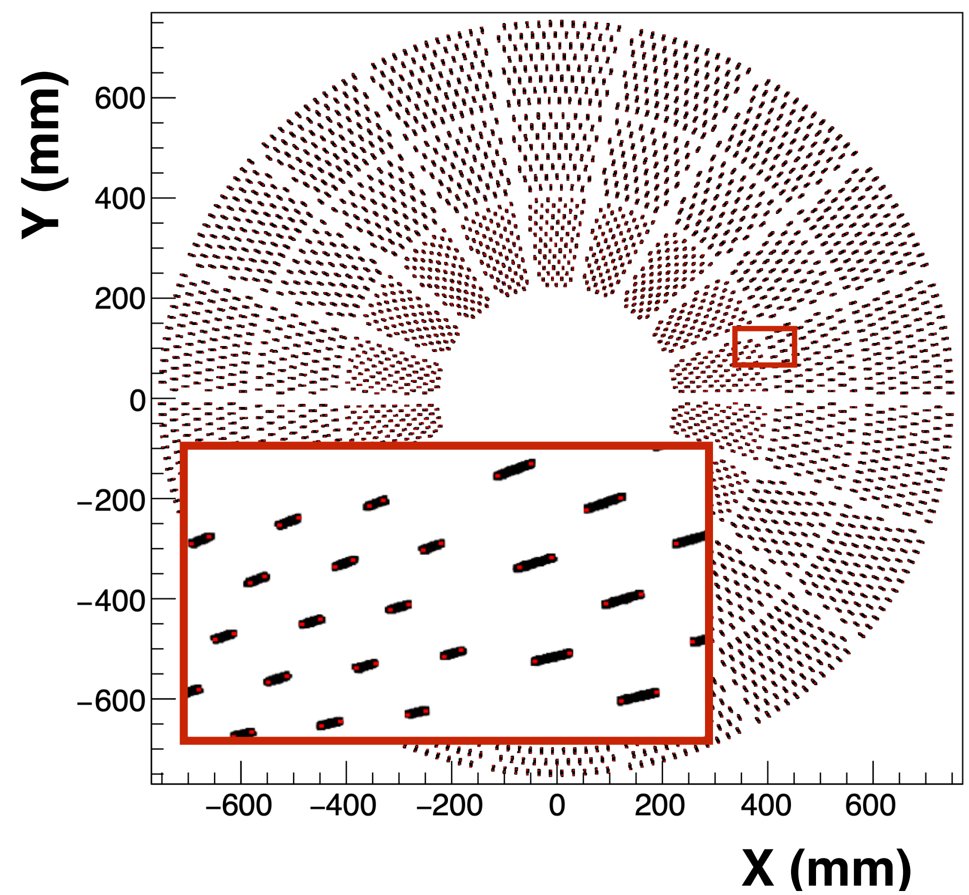
- Many improvements since first demonstration
- Now tracking (ACTS / GenFit) agnostic
- Remaining residuals under investigation



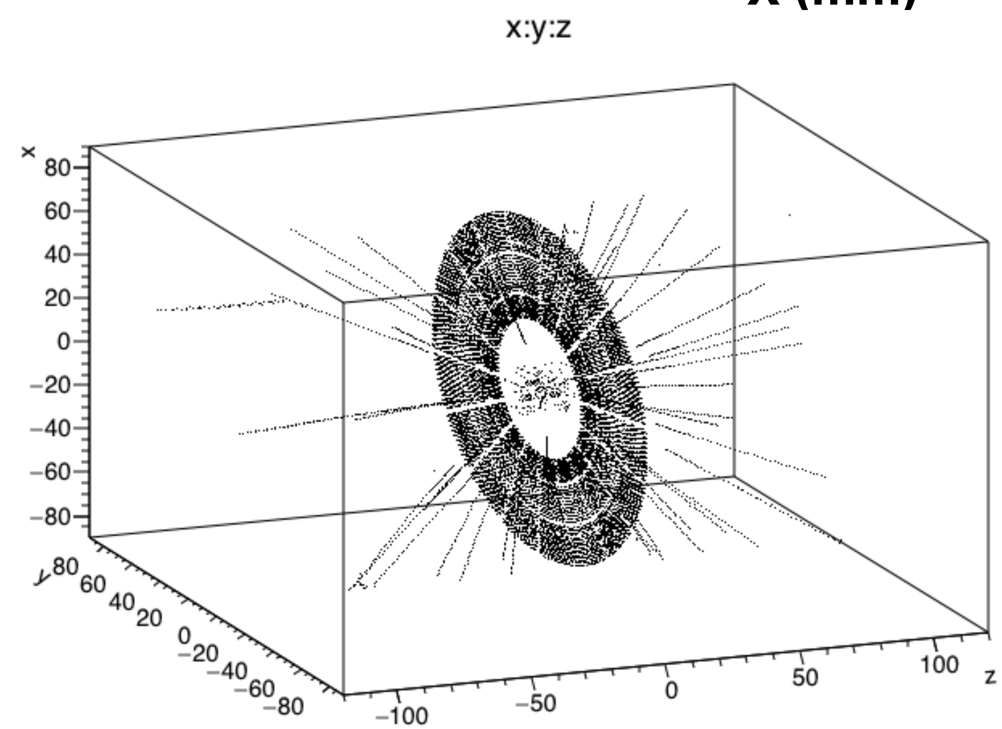

- See Hugo's talk for more details

# Monitoring with CM

- Al pads on CM release charge when strobed with diffuse laser (15kHz), intended to fire after each trigger
- Associate reco cluster to known origin to measure distortion
- Time-average can inform **average distortions**
- Per-strobe used to monitor **fluctuations**

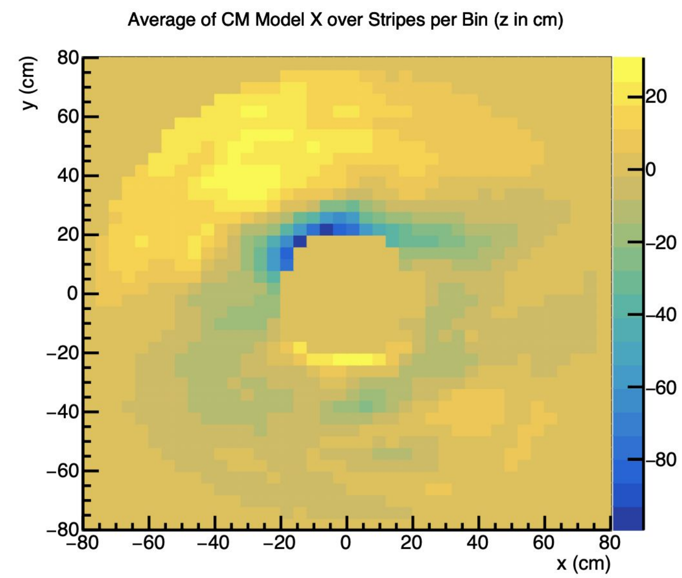



- phony g4hits for each pad injected into hitcontainer before drift step PHG4TpcElectronDrift
- Truth-free cluster association algortihm in progress

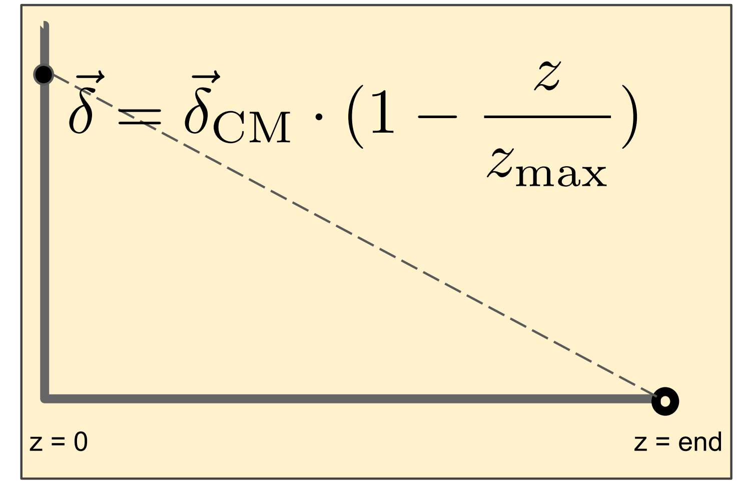


# Monitoring with CM

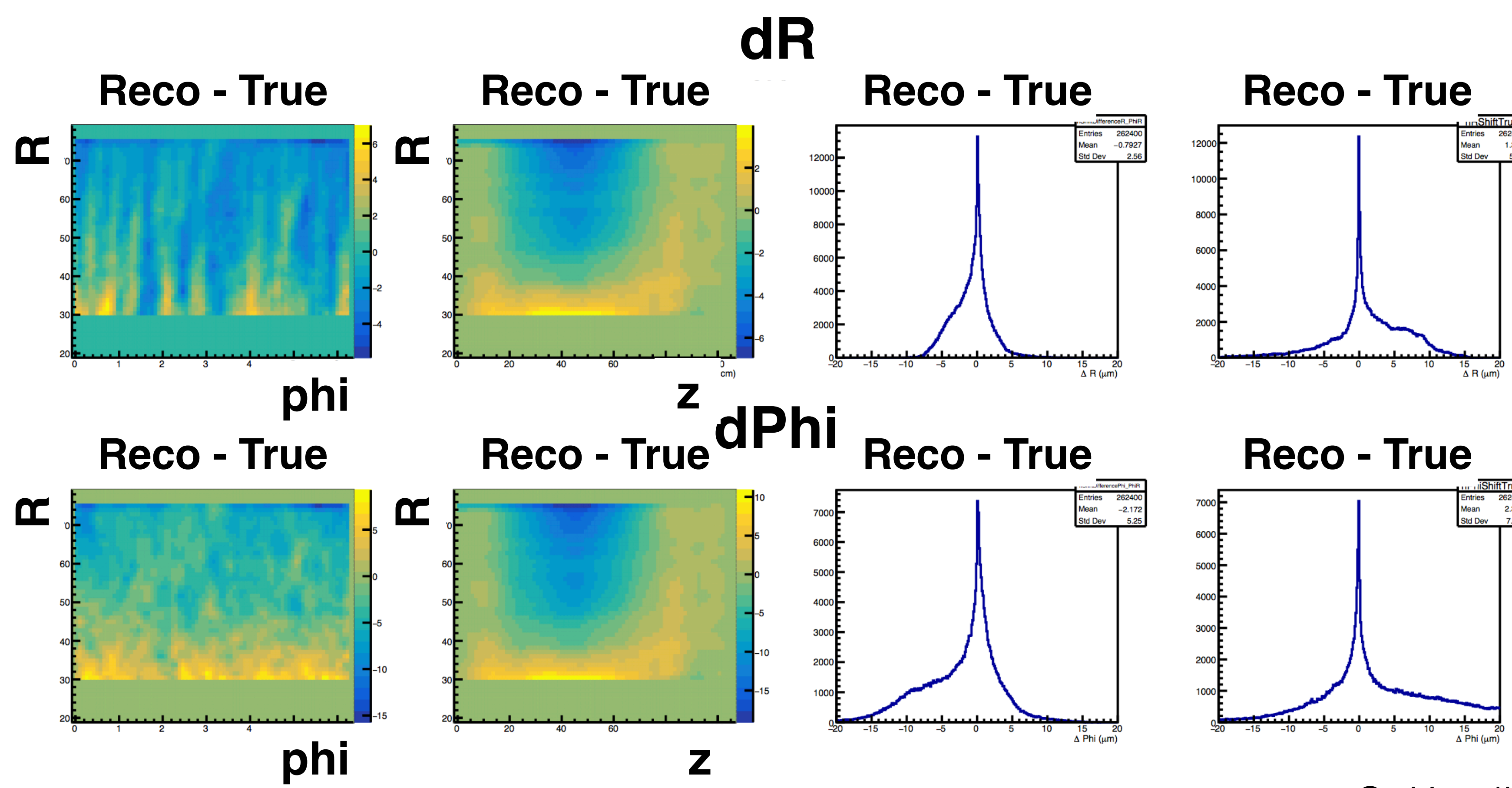
- Select TH2F binning so that >0 strips in each bin, average measured distortion in each cell
- Extend to volume with linear model




x

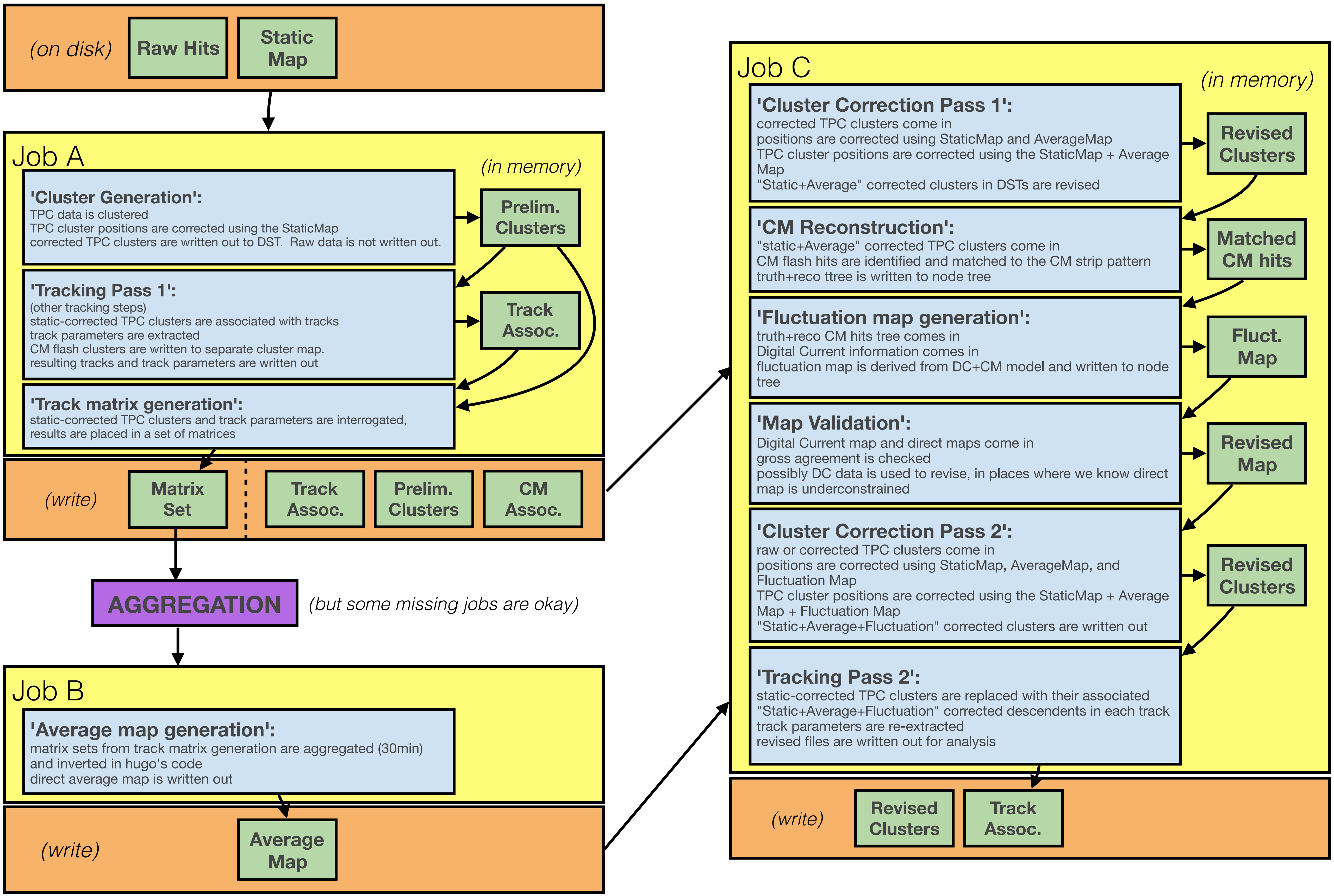



- Toy data generator separated from reco
- Converted from cartesian to polar binning
- pulled to main repo

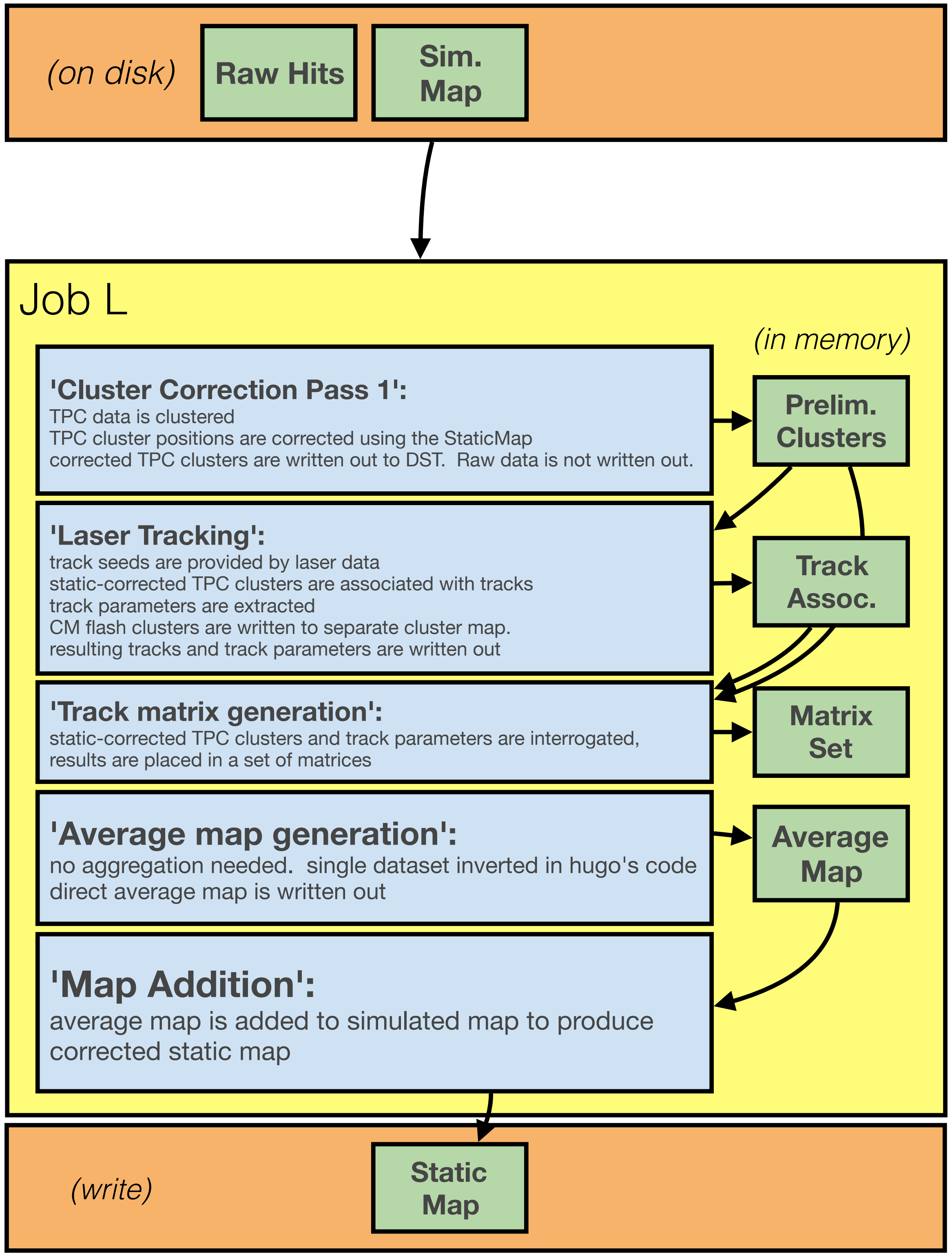



courtesy S. Kurdi

# Distortion Reco in Track Reco

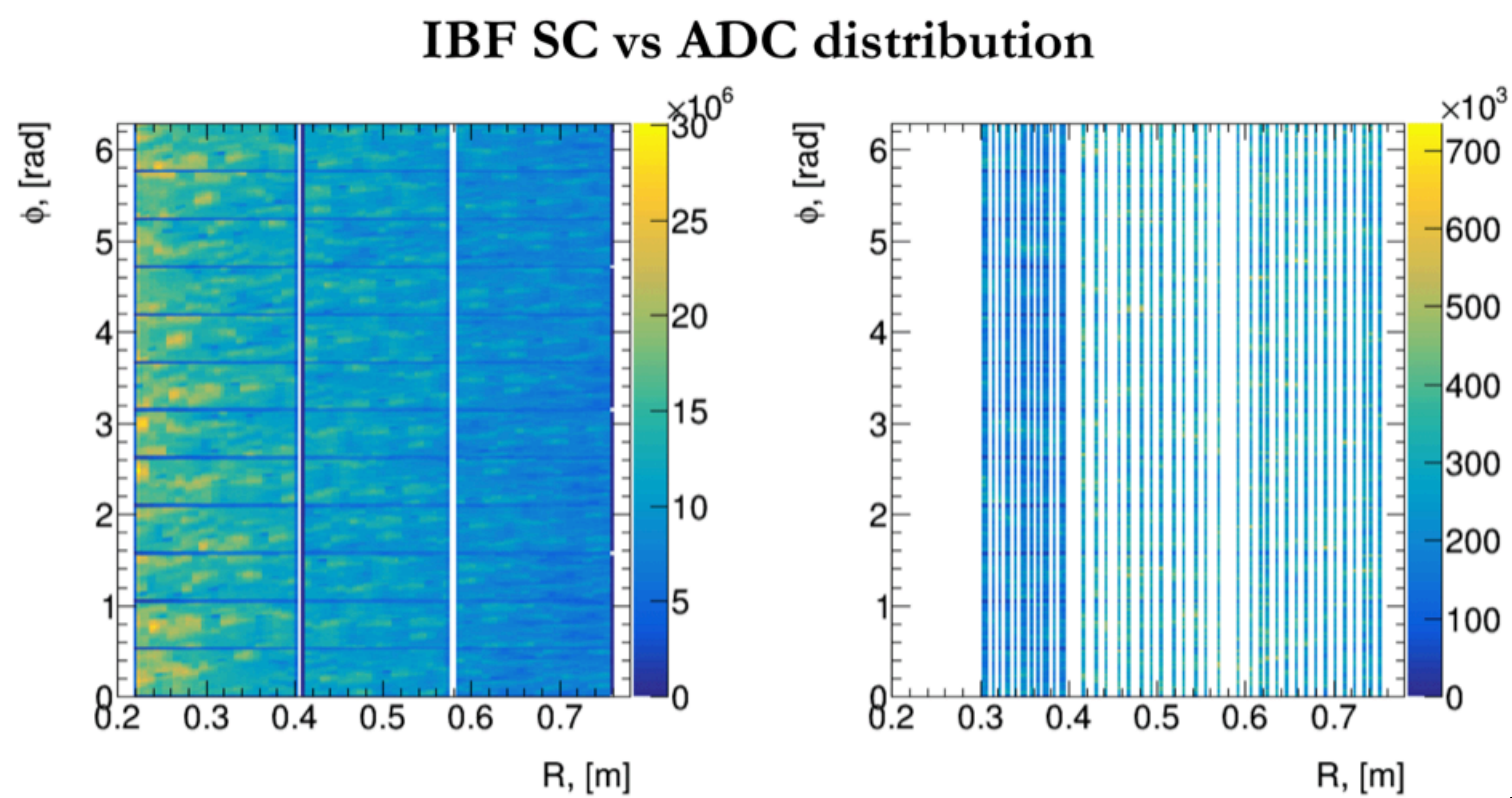


# Generating the Static Map



# Digital Current Modeling

- in data:  separate data channel from FEEs feeds into distortion generator
- in sim: generate DC from minbias events with readout response and digitization
  - Driving more realistic TPC response in MC -- gain maps now applied
- Under active development




courtesy E. Shulga

# Path forward

- Working on data flow in discussion with SDCC (Doug et al.) -- assembling the full mock-up chain
- Existing:
  - Track-based average distortion reco
  - CM-based fluctuation distortion reco
- Early stages:
  - Realistic Digital Current from event digitization for indirect distortion
  - Directed lasers + laser-tracking for static distortion

- Develop alignment (many similiarities to distortions)
- Realistic distortions and corrections in next MDC

# Thanks!

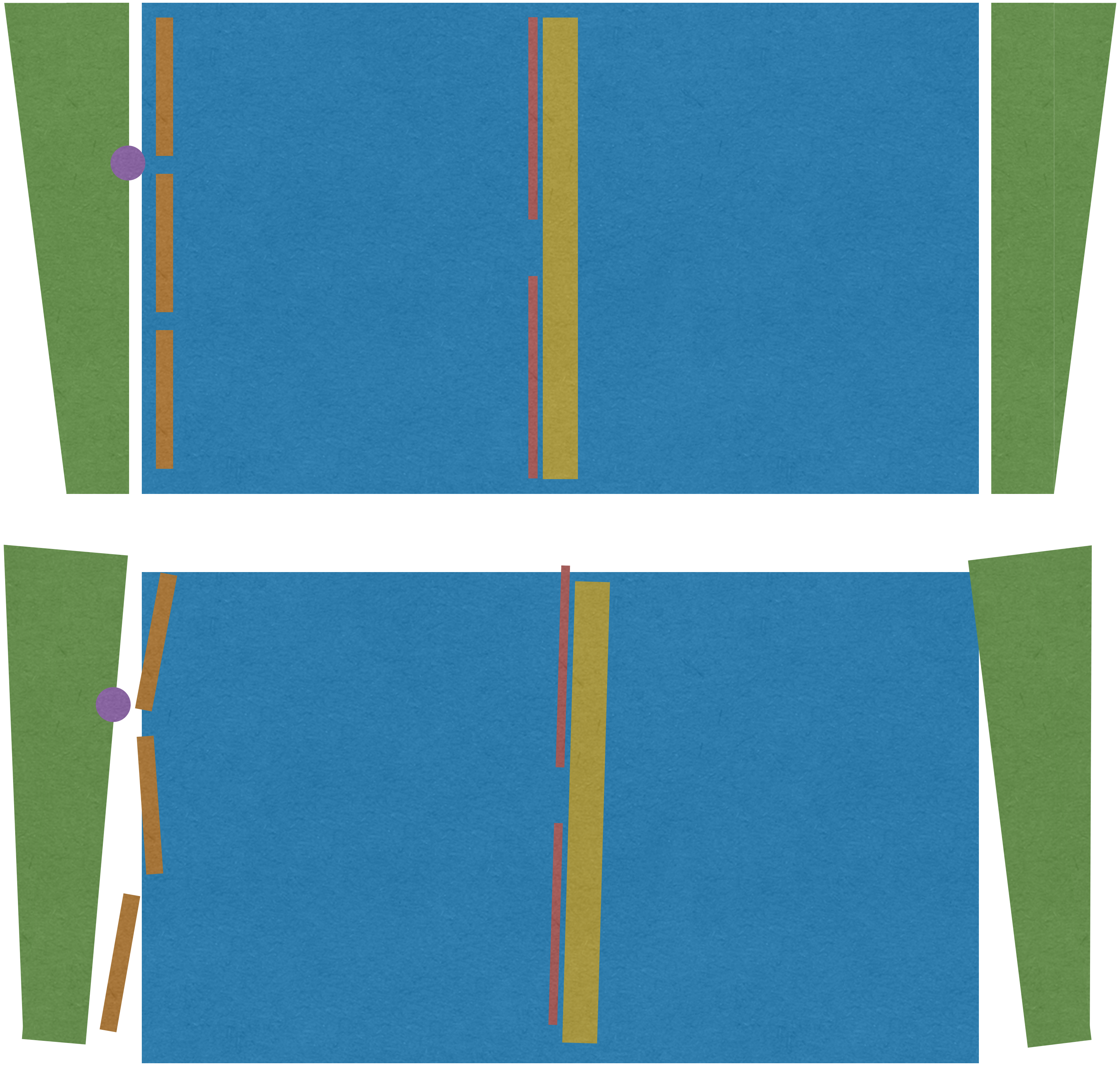
- Just a subset of the folks working hard on distortions (and tracking and all the other software tasks)


Room for more!

# Alignment

- Many of the same tools (lasers, CM, tracks) can be used for alignment as well
- Want to separate alignment and distortion effects as much as possible

- *TPC global: 5 params -- limits? What defines the TPC?*
- Wagon Wheels x 2: 5 params wrt sPHENIX global
- CM (side x2?): 5 params wrt WW
- CM petals x 36: 3 params wrt CM (coplanar?)
- Modules x 72: 5 params wrt wagon wheel



# Monitoring with Tracks

For each volume element, form $\chi^2$ from linear relation between residuals and track angles, weighted by relevant uncertainties:

$$r\,\Delta\phi = r\,\delta\phi + \delta r\,.\tan\alpha$$
$$\Delta z = \delta z + \delta r\,.\tan\beta$$
$$\chi^2 = \sum \frac{\left[r\,\Delta\phi - \left(r\,\delta\phi_0 + \delta r_{0.}\tan\alpha\right)\right]^2}{\sigma_{r\phi}^2} + \frac{\left[\Delta z - \left(\delta z_0 + \delta r_{0.}\tan\beta\right)\right]^2}{\sigma_z^2}$$

With:

- $\Delta\Phi$ and $\Delta z$ residuals in the TPC (measured)
- $\alpha$, $\beta$ local track angles in ($\Phi$,r) and (z,r) planes (measured)
- $\delta\Phi_0$, $\delta r_0$ and $\delta z_0$ the distortions (unknown)

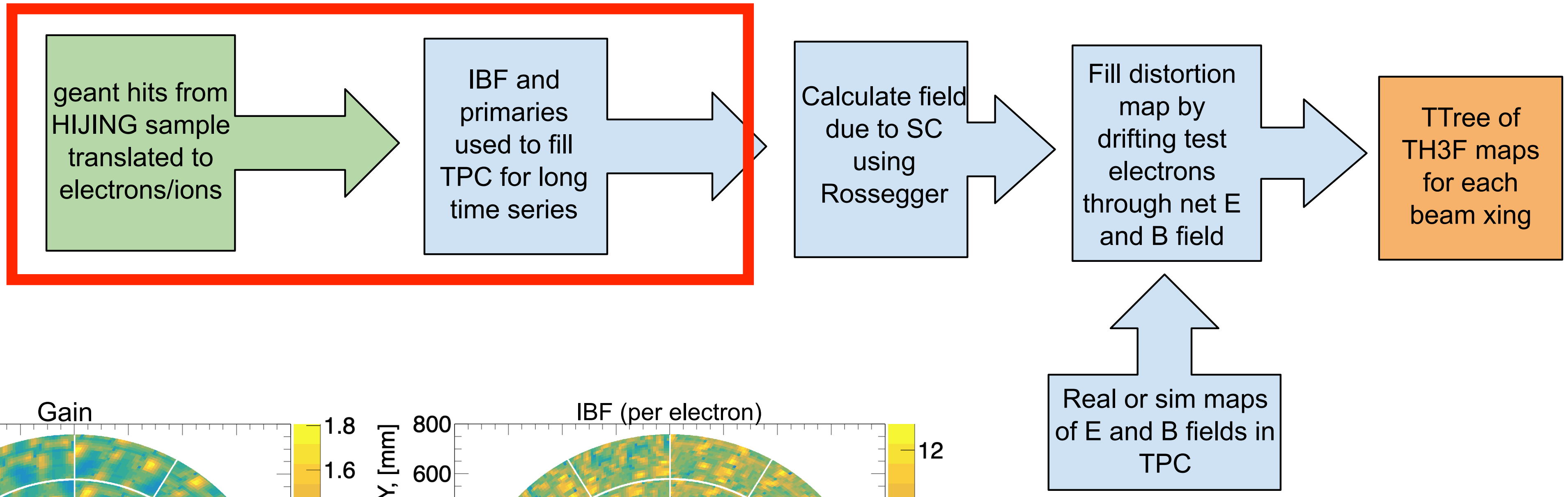
To minimize, set the partial derivatives on the three unknown quantities $\delta\Phi_0$, $\delta r_0$ and $\delta z_0$ to zero. Since $\chi^2$ is quadratic in $\delta\Phi_0$, $\delta r_0$ and $\delta z_0$, this results in three linear equations:

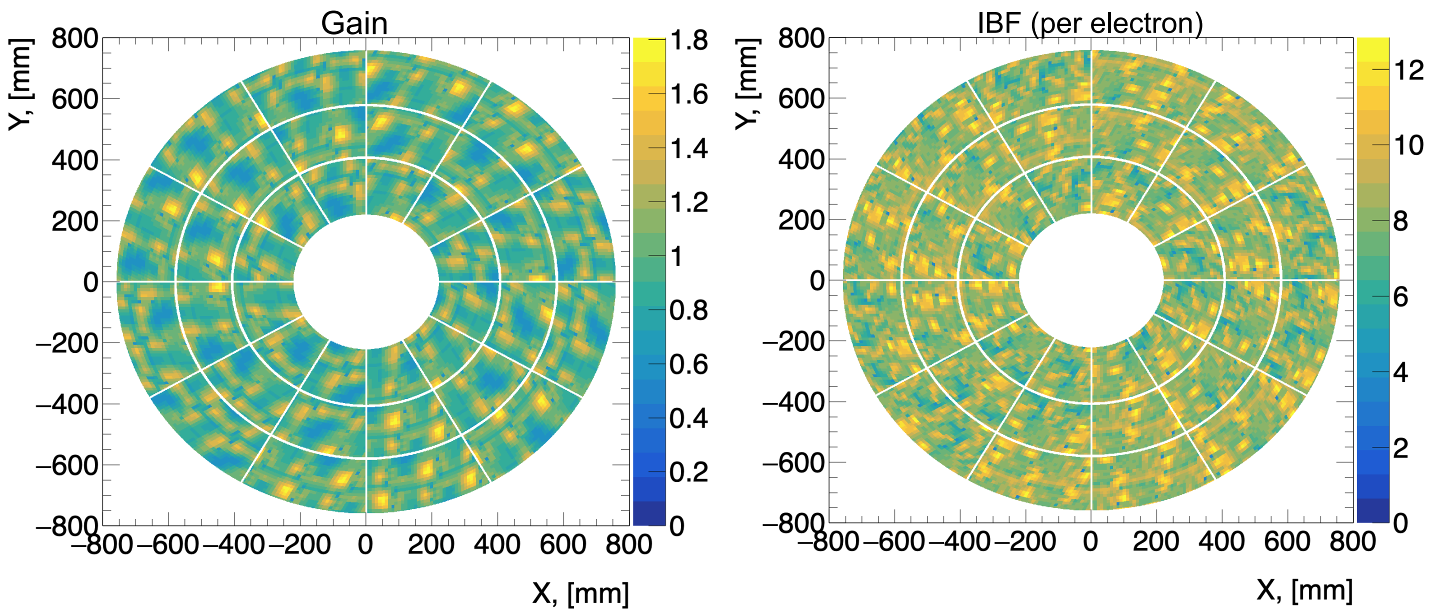
$$\begin{pmatrix} \sum \frac{1}{\sigma_{r\phi}^2} & 0 & \sum \frac{\tan\alpha}{\sigma_{r\phi}^2} \\ 0 & \sum \frac{1}{\sigma_z^2} & \sum \frac{\tan\beta}{\sigma_z^2} \\ \sum \frac{\tan\alpha}{\sigma_{r\phi}^2} & \sum \frac{\tan\beta}{\sigma_z^2} & \sum \frac{\tan^2\alpha}{\sigma_{r\phi}^2} + \frac{\tan^2\beta}{\sigma_z^2} \end{pmatrix} \cdot \begin{pmatrix} r\,\delta\phi_0 \\ \delta z_0 \\ \delta r_0 \end{pmatrix} = \begin{pmatrix} \sum \frac{r\,\Delta\phi}{\sigma_{r\phi}^2} \\ \sum \frac{\Delta z}{\sigma_z^2} \\ \sum \frac{r\,\Delta\phi\,.\tan\alpha}{\sigma_{r\phi}^2} + \frac{\Delta z\,.\tan\beta}{\sigma_z^2} \end{pmatrix}$$

Minimization results in inverting a 3x3 matrix for each volume element

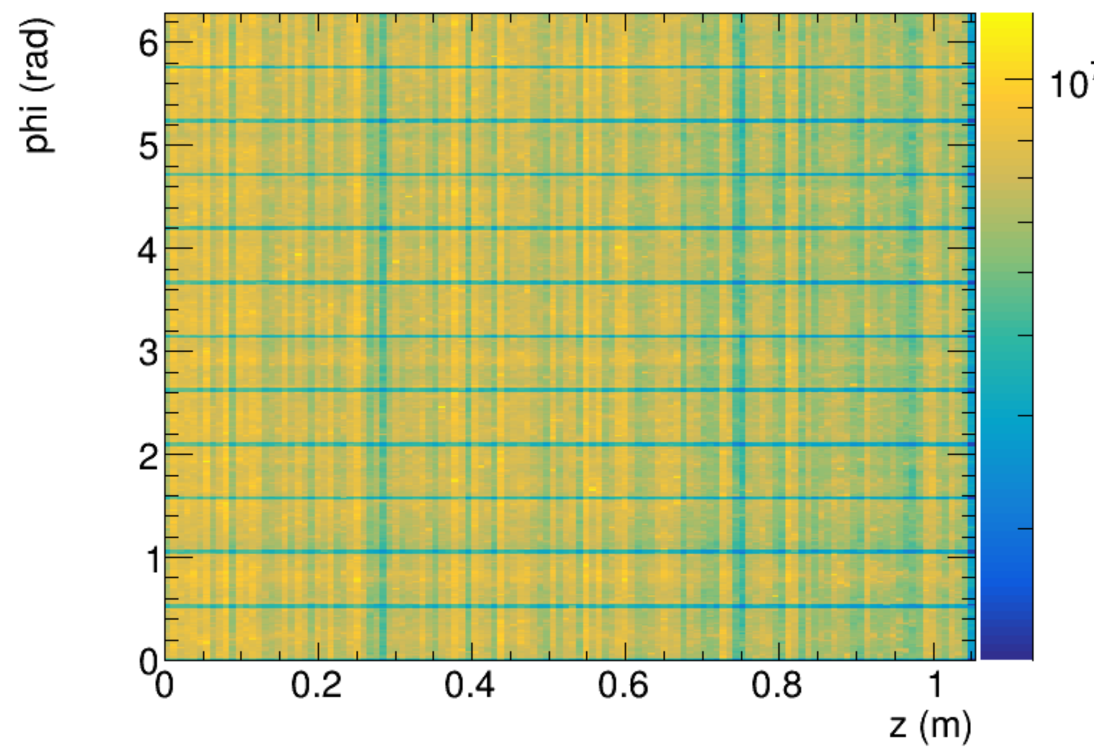
courtesy Hugo

# Generating Distortions



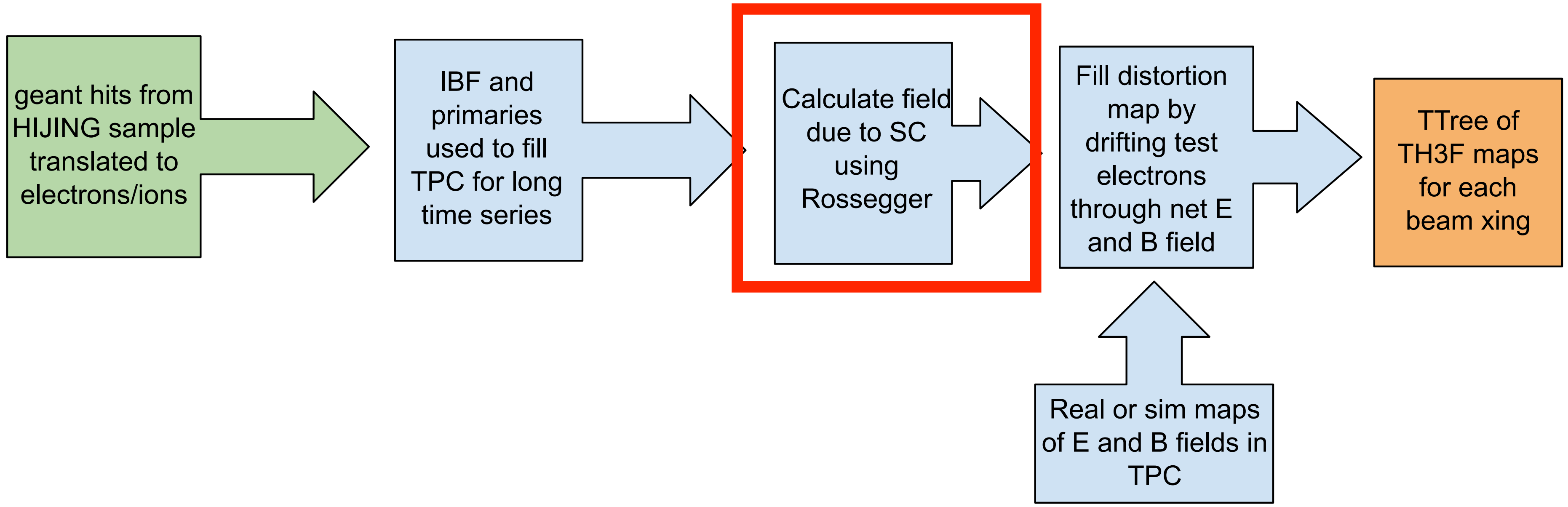

IBF (per electron)=Gain*IBF*2000*0.44%



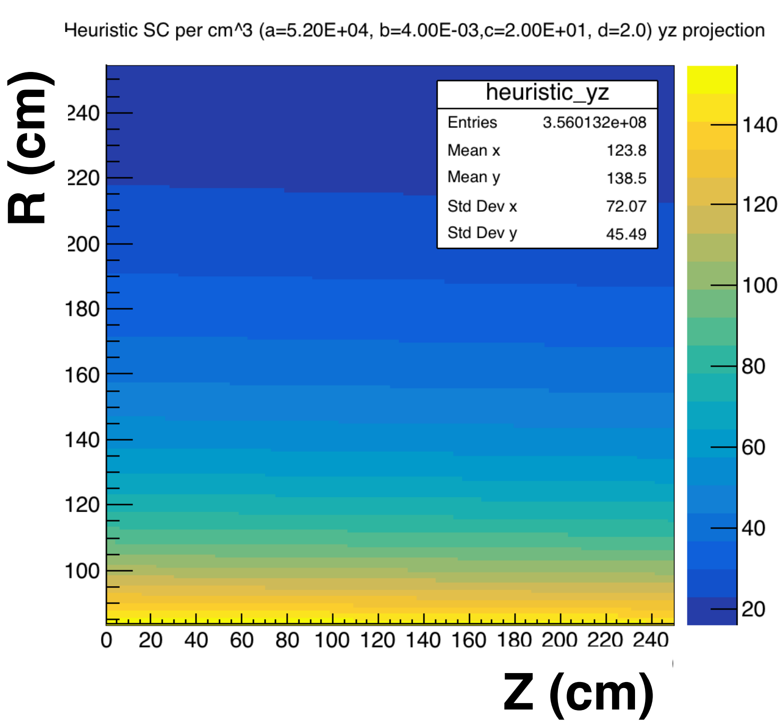

- MC gain/IBF maps sampled from ALICE modules
- Time-ordered HIJING events sync'd to reconstruction
- average and per-event TPC snapshots with IBF + primaries

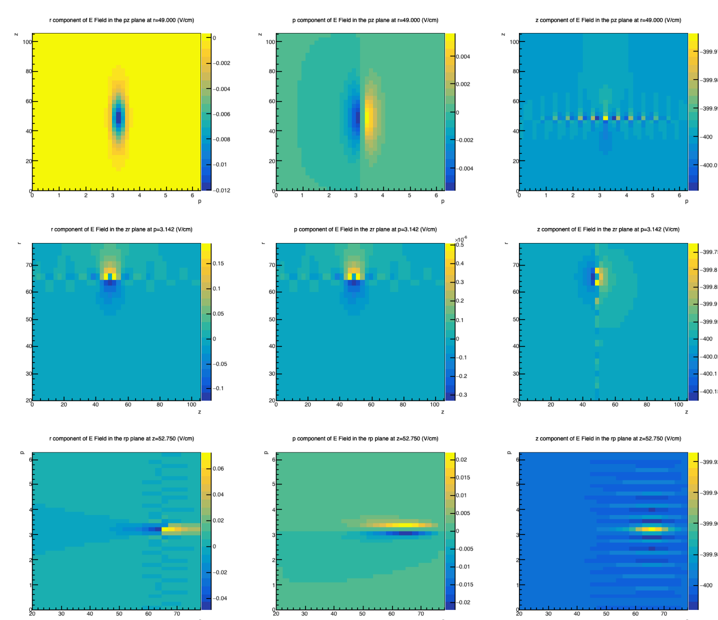
(Evgeny Shulga (WIS))

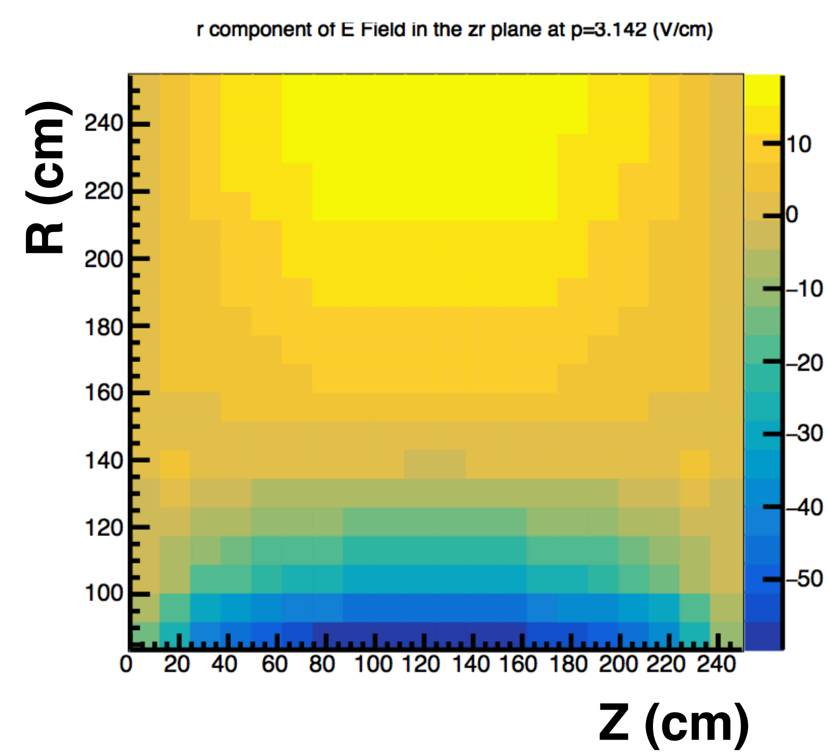
# Generating Distortions



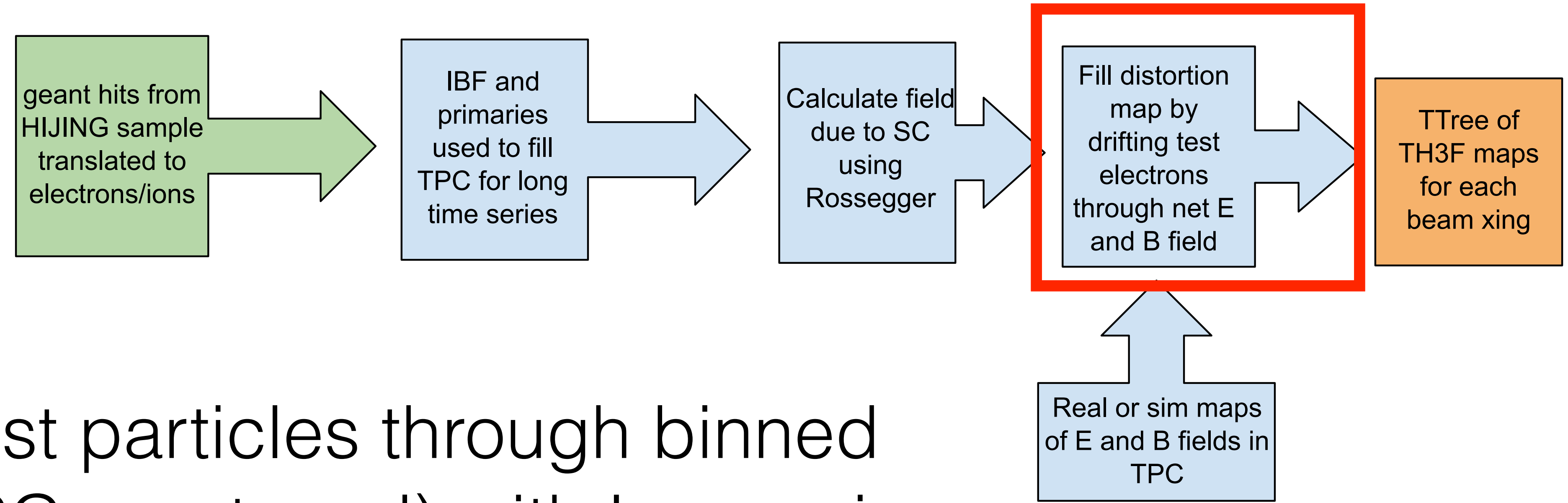

Charge Density (3D, Scalar) x Greens functions (6D, Vector) = 3D Electric Field Map (3D, Vector)



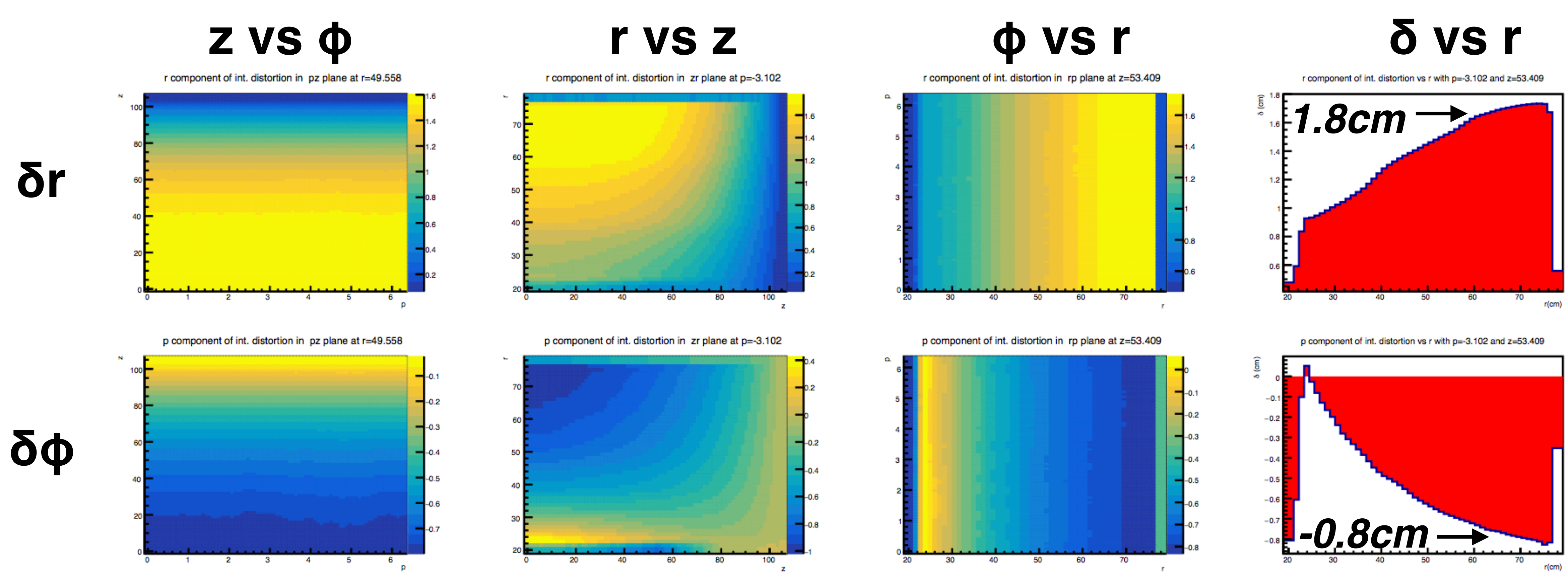





# Generating Distortions



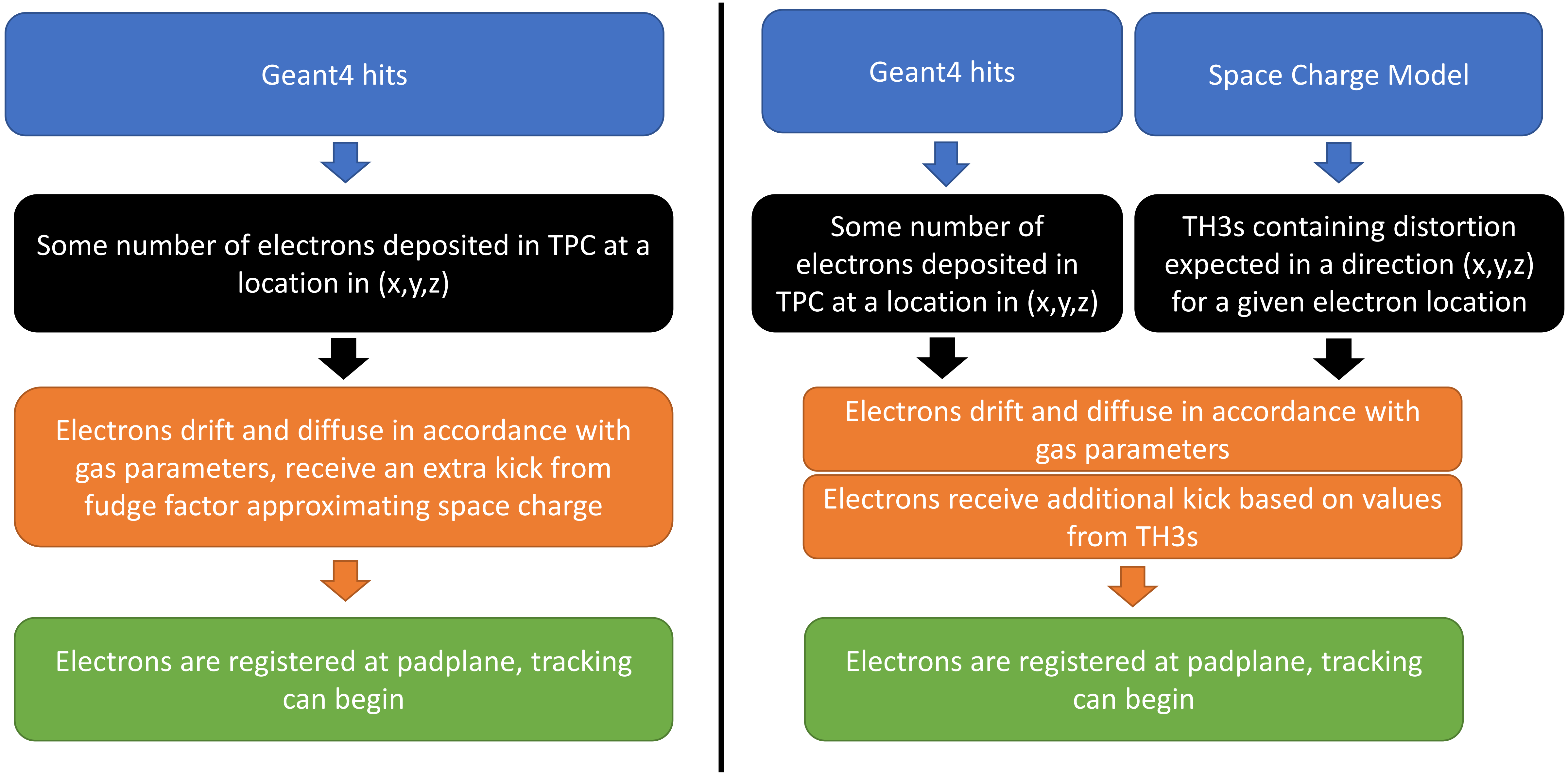

- Swim test particles through binned fields (SC + external) with Langevin Eqn, store results in TH3F:



# Applying Distortions in Fun4All

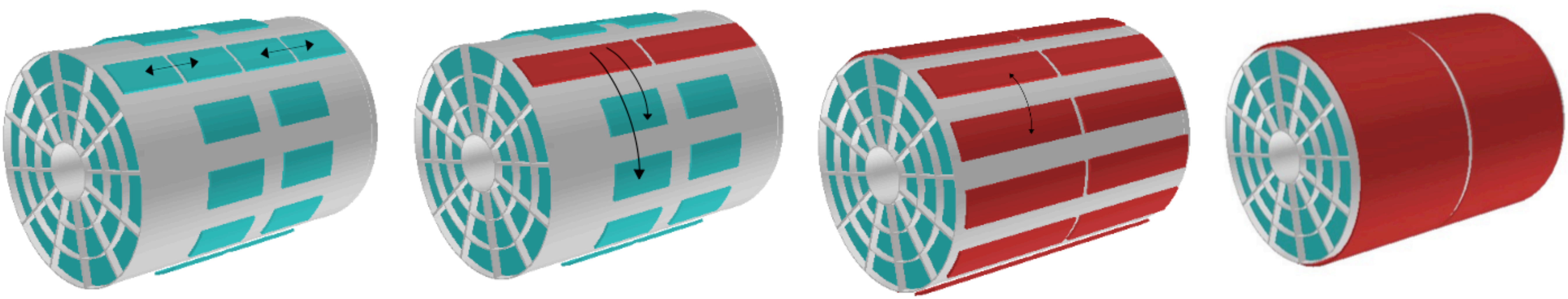
- PHG4TpcElectronDrift reads external maps, applies shifts to each deposited electron (Henry Klest (SBU))

Previously in Simulation | Currently in Simulation



# Interpolating with Outer Tracker

- TPOT allows measuring track residuals precisely
- Matrix inversion procedure extracts average distortions (Hugo Pereira Da Costa (LANL))
- Extension to full TPC demonstrated in stand-alone code and in Fun4All:



1. small z interpolation between MM modules

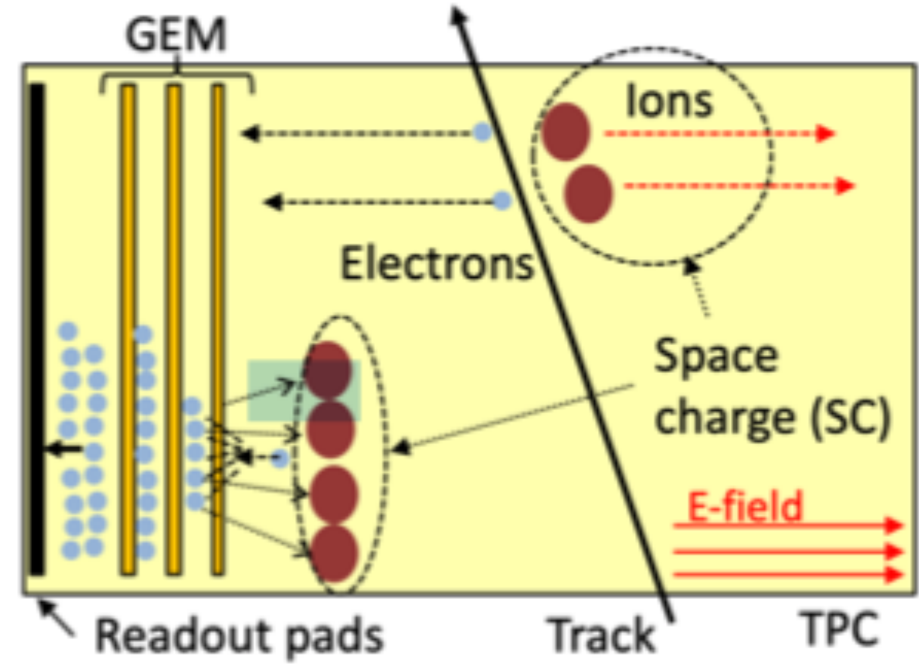
2. copy z dependence in fully equipped sector to other sectors, normalized by local measurement

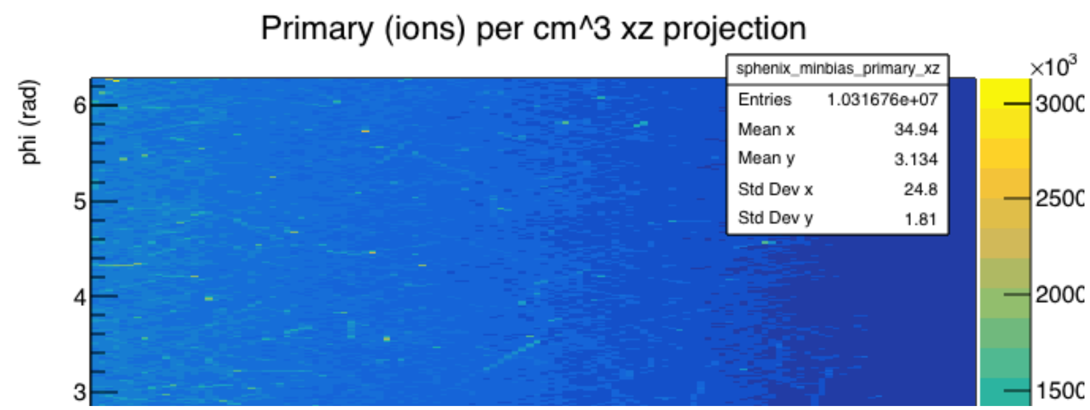
3. interpolate between sectors to cover full acceptance, **normalized by time-averaged CM measurement**

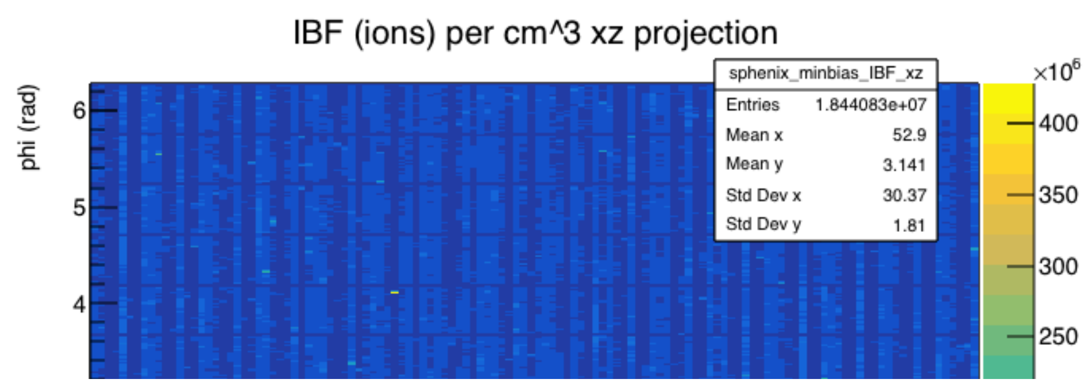
# Structure of Spacecharge

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

- Heuristic:
  A=Luminosity, multiplicity, TPC 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.

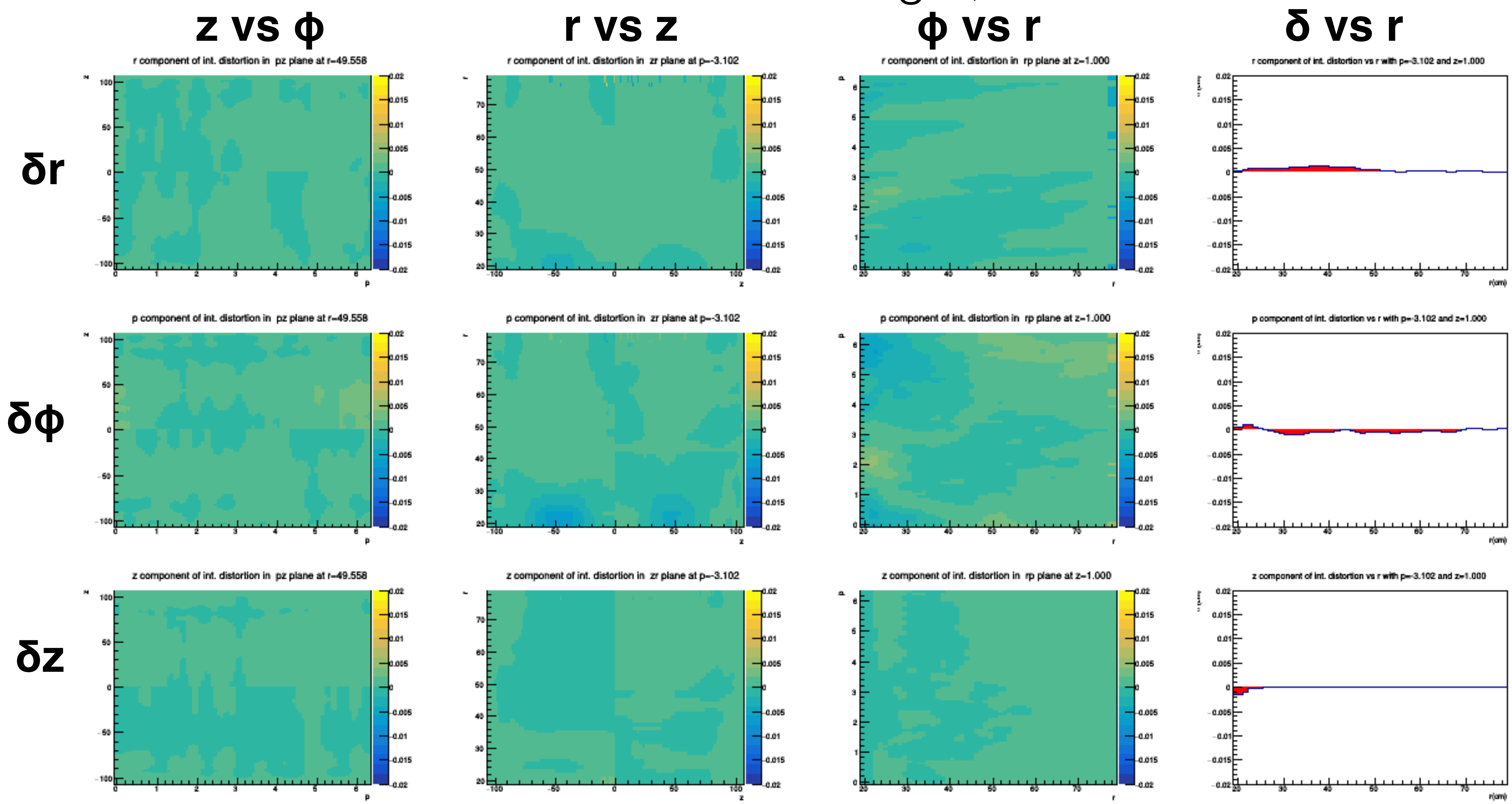


# Surveying Fluctuations

- Fluctuations are correlated across z (particles share partial path)
- 20 frames = 78 ms = 1 TPC driftlength; scale=±200um




**Post-hoc slices of integral distortion**
**Drifting grid of (rp)=(54 x 82) electrons with steps per file**
**Lookup per file: apr07_maps_fluct/fluct_apr07.file0.h_Charge_0.real_B1.4_E-400.0.ross_phi1_sphenix_phislice_lookup_r26xp40xz40.distortion_map.hist.root**
**Gas per file: apr07_maps_fluct/fluct_apr07.file0.h_Charge_0.real_B1.4_E-400.0.ross_phi1_sphenix_phislice_lookup_r26xp40xz40.distortion_map.hist.root**