Tracking Studies in Inhomogeneous Magnetic and Electric Fields

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Overview

Inhomogeneities in a Linear Collider TPC

- Inhomogeneous B field (possibly anti-DID)
- E-Field distortions due to charge pileup (high backgrounds at CLIC)

The large prototype

- Inhomogeneous B field of PCMAG ⇒ ideal test case

Data taken has to be corrected for several effects

- Inhomogeneous B field
- TPC position inside PCMAG
- Inhomogeneous E-field near readout
- Alignment

Use MC studies to simulate each of them separately, disentangle the effects

- Deviation of particle trajectory from perfect helix (inh. B)
- E×B effects during drift (inh. B, inh. E, positions of TPC)
- Alignment

What is the impact on the momentum resolution?

Deviation from a Perfect Helix

- Distortions in drift and alignment can be corrected via correction map
- Impact of inhomogeneous B-field on primary trajectory cannot be corrected via map: It never was a helix!
- To fit a trajectory in inhomogeneous B-fields the Kalman filter has to be adapted.

What has to be done?

- Include tracking in inh. B-field into PrimaryIonisationProcessor (✓)
  - Measured PCMAG field map is accessed via GlobalFieldProcessor
  - Runge Kutta helix propagator
- Integrate inh. B-field into the Kalman filter (×)

Integrating an Inhomogeneous B-Field into KalTest

KalTest design:

- Only field value of the magnetic field at the measurement position, no direction
- Coordinates transformation are programmed manually, no geometry framework
- Implicit in the calculations: Cylinder axis and helix axis are the same

Required changes

- Need to extend/change the interface
- Need to implement transformations for intersection calculations of a helix with an arbitrary axis (3D magnetic field)
- Most of the code has to be adapted/checked

Is this the limit of KalTest?

Advantages of redesign from scratch

- Use a geometry framework to describe the shapes and to perform the coordinate transformations
- Overcome some design issues (predefined order of layers)

Changes in the LCTPC KalDet Geometry

Previous version

- LP1 geometry hard coded
- Gas properties, drift velocity and B-field hard coded
- Indices of Kalman layers hard coded in user code
- Many implicit assumptions (layers are cylinders, e.g.)

Reimplementation from scratch: GearTPCKalDetector

- Flexible geometry: Everything that can be described with Gear
- Object pointers and indices can be accessed via interface
- Magnetic field, drift velocity, layer resolution read from Gear file
- Backward compatibility layer to run with old code

Processors in MarlinTPC need to be adapted to take advantage of the new flexibility (work in progress).

Charge Pileup in a TPC at CLIC

High level of beam induced backgrounds for CLIC@3TeV:

- 300.000 incoherent e^+e^- pairs per BX
- 3.2 $\gamma\gamma \rightarrow$ hadrons events per BX
- 1 beam halo muon per BX

Ions drift slowly, TPC integrates up to $\approx$1 second for primary ions:

- 312 bunch crossing per train
- 50 Hz train repetition rate

1. How much space charge is in the TPC?
2. How does this deteriorate the E-field?
3. What is the impact on the reconstructed position?

Calculation of the E-Field and Drift Distortions

Based on Keisuke's *ioneffects* programme

- Use parameterised, factorisable ion density $\rho = \rho_z \rho_r$
- No φ dependence
- Calculate E_r by solving Green's function (see Keisuke's talk at the LCTPC collaboration meeting 2012)
- "Track" electrons along z for constant r
- Calculate $\Delta(r\varphi)$ for fix E_z, B and $\omega\tau$

Ion densities available for

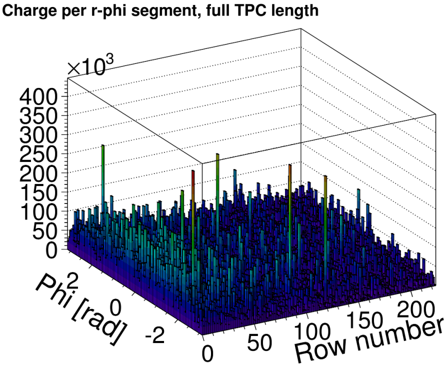
- 1 BT ILC background (fit by D. Arai on A. Vogel's data) $\rho = p_0/(r - p_1)^2$, no z dependence
- 1 BT CLIC background

Extrapolate to 1 second ≈ max. ion drift time

- 5 BT ILC background
- 50 BT CLIC background

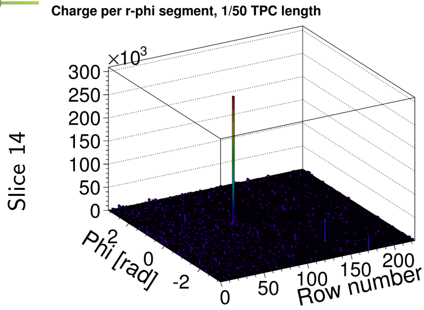
Charge per r-φ Segment

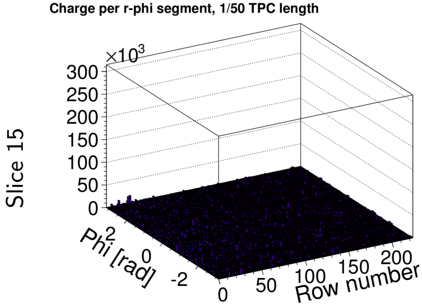
Integrated 1 CLIC BT over the full drift length



- Not flat in φ
- Distribution has spikes

Charge per r-φ Segment and z Slice for 1 BT





- Local depositions in 1 voxel only
- MC truth list shows they originate from pions
- Is this plausible?

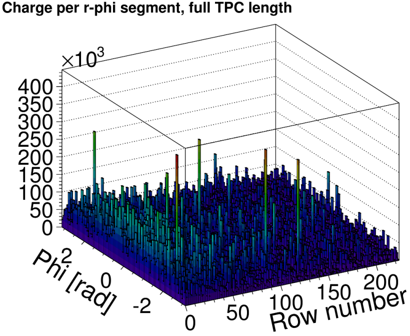
- Pion interaction length in Ar ≈900 m.
- 4500 pions in the $\gamma\gamma \rightarrow$hadrons background (1 BT)
- Low angle (≈2 m track length)

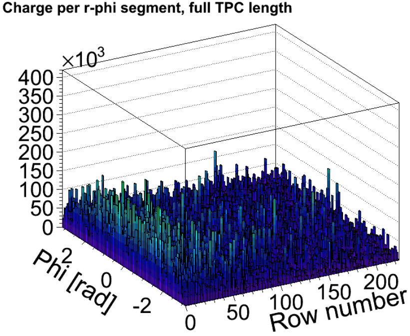
$\Rightarrow$ 9000 pion-TPC-meters = 10 interaction lengths

- Fits with the number of peaks in the histogram

Charge per r-φ Segment

Integrated 1 CLIC BT over the full drift length





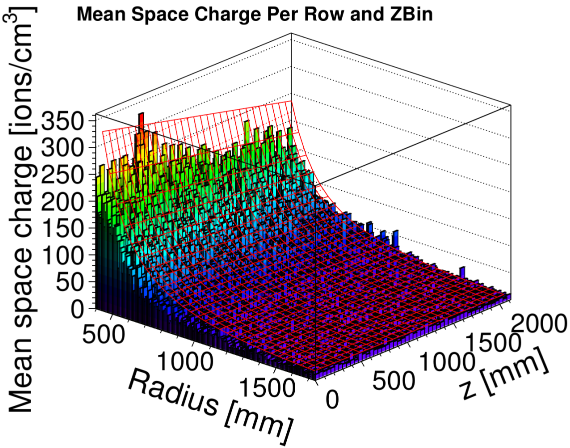
Without cut

- Not flat in φ
- Distribution has spikes

With cut on highest voxels charges

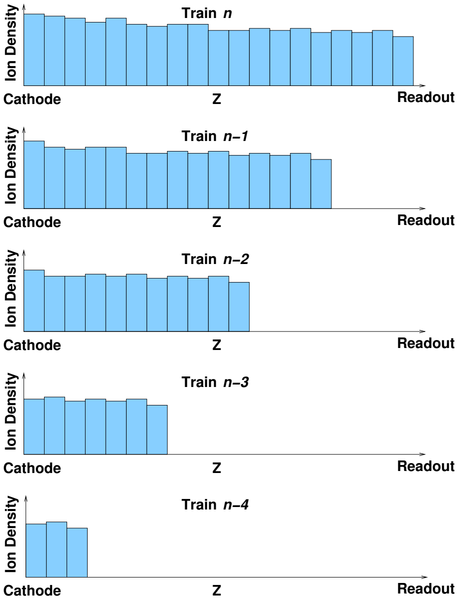
- Huge spikes are gone
- Still a bit bumpy
- Good enough to assume φ independence

Charge Fit in r-z (1 CLIC BT)



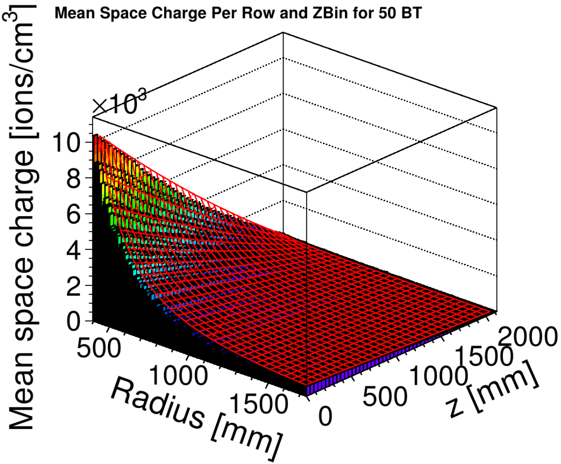
- Slight dependence on z
- Parametrisation $(p_0 + p_1 z)/(r - p_2)^2$
- Charge up to 350 ions/cm^3
- A bit more than 1 ILC BT

Summing Up Multiple Bunch Trains



- Ions slowly drift towards the cathode
- Previous bunch trains partly drifted out
- Region near the readout only contains 1 BT
- Ion density is highest near the cathode

Charge Fit in *r*-*z* (50 CLIC BT)[1]

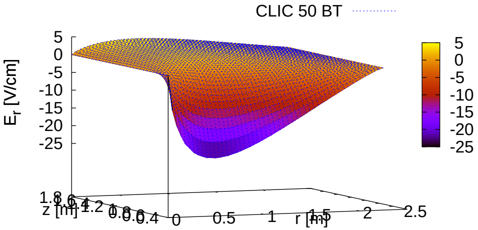


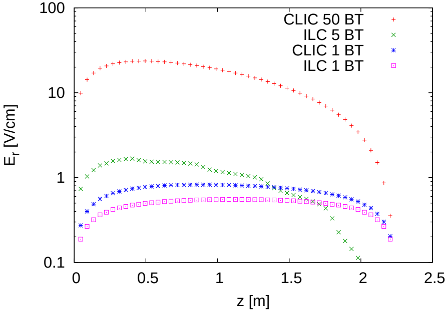
- Strong dependence on z
- Parametrisation $(p_0 + p_1 z + p_2 z^2)/(r - p_3)^2$
- Very high charge near the cathode
- Charge up to 10,000 ions/cm^3

[1] I used 50 times the same bunch train.

E-Field

Electric field near the inner field cage

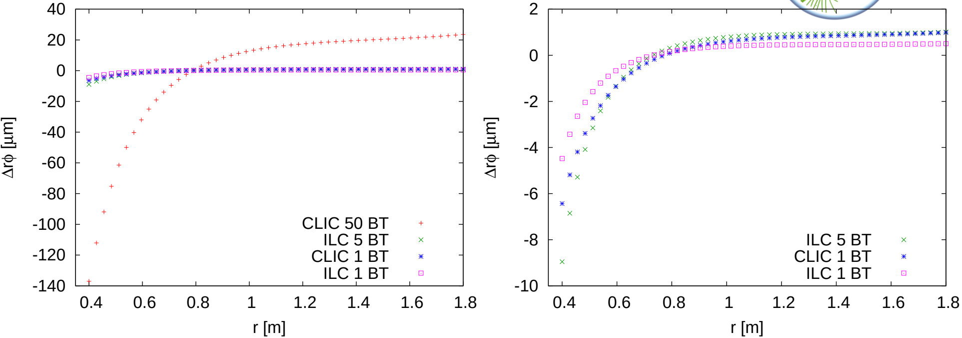




- E_r is largest near the inner field cage
- E_r changes sign towards outer field cage

- E_r for 50 BT at CLIC is up to 25 V/cm
- E_z component will not be negligible
- Effects on drift velocity and diffusion
- Simulations have to be adapted to include these effects!

Drift Distortions Near the Inner Field Cage



Drift over the full TPC drift length

- Distortions for ILC are small (9 µm for 5 BT)
- Distortions for 1 BT CLIC are OK (7 µm)
- Distortions for 50 BT CLIC not negligible: 137 µm need to be corrected for
- Changes in E_z, drift velocity and diffusion are not included
- Local distortions from large charge depositions not included yet

Summary

Inhomogeneous B-field

- Integrated into PrimaryIonisationProcessor
- Kalman filter needs to be adapted

KalDet

- New flexible geometry for LCTPC
- Processors currently being adapted

Charge pileup for 50 BT of CLIC background

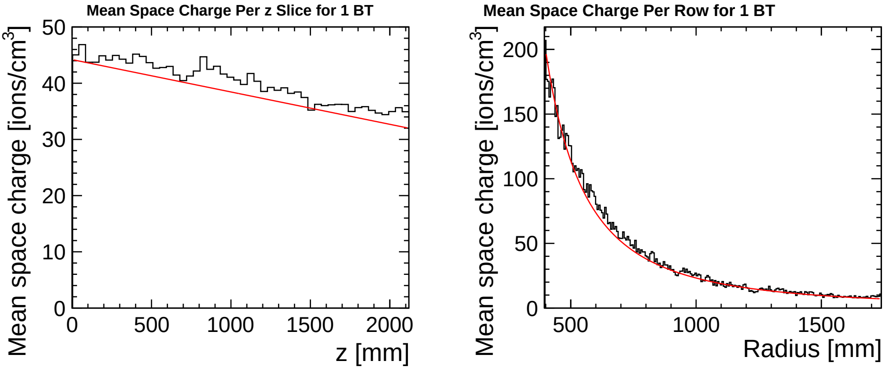
- Huge electric field distortions $\mathcal{O}(10\ \%\ E_z)$
  - Change in drift velocity and diffusion
- Distortions in $r\varphi$ $\mathcal{O}(140\ \mu\text{m})$ have to be corrected for

Next steps

- Runge Kutta drifter
  - Drift in inhomogeneous E and B fields
  - Include nonparametrisable peaks
  - Calculate correction map

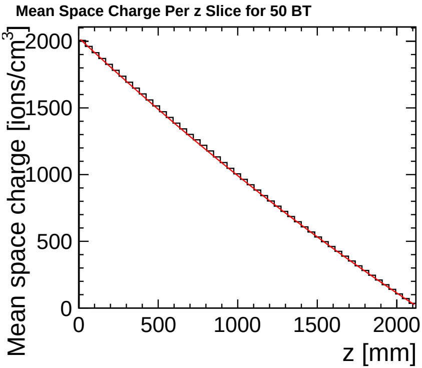
Backup

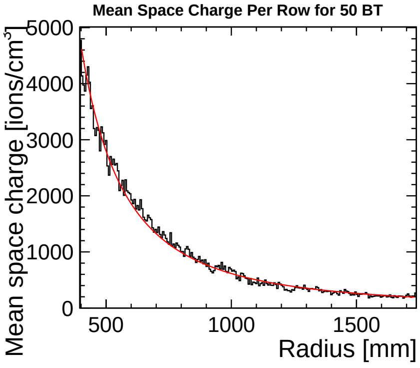
Mean Space Charge for 1 CLIC BT



The fit is not a fit to the 1D histogram.
It is the analytical integral of the 2D parametrisation,
while the histogram is the projection of the 2D histogram.

Mean Space Charge for 50 CLIC BT





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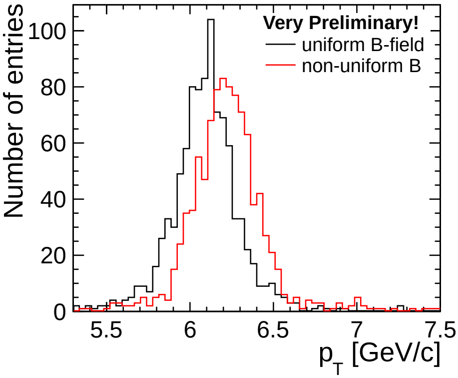
Simulation with Inhomogeneous B-Field

Simulation (charge deposition)

- Uniform magnetic field
- Measured PCMAG field map

Reconstruction

- Always uniform magnetic field



- Reconstructed p_T for non-uniform B-field is shifted and broader

$\Rightarrow$ We have to include inh. B in the track fit (Kalman filter)