Evaluation of the effect of electric field distortion in the TPC on ionized electron position measurement

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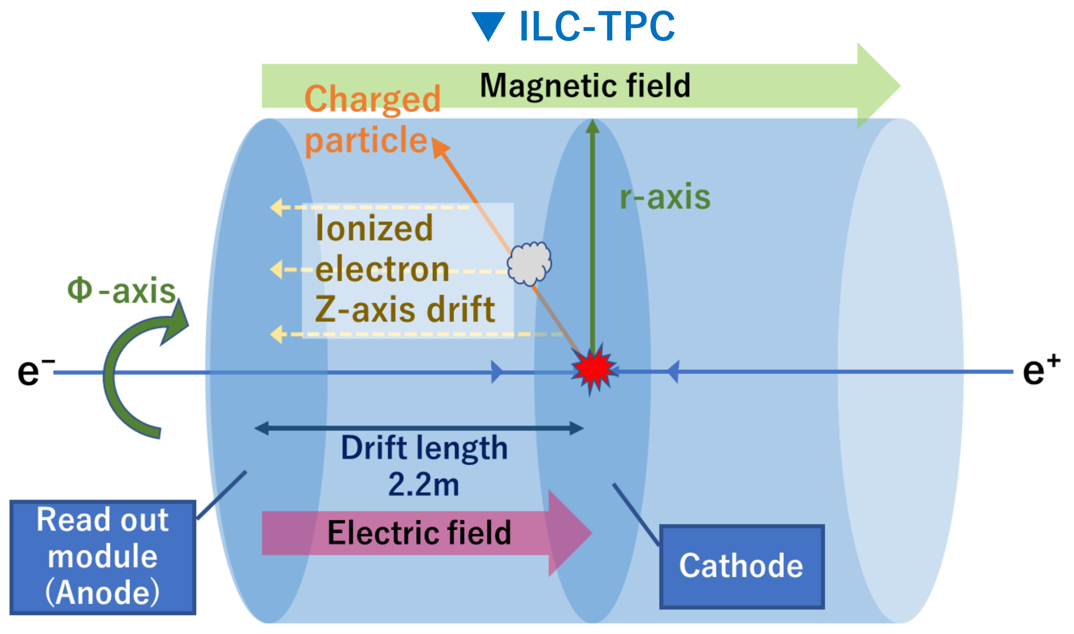
1, Background

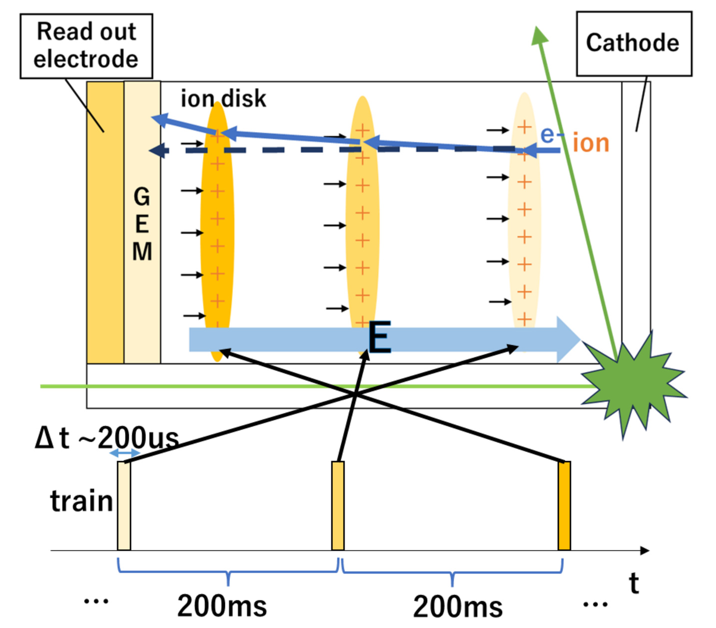
- Since the existence of the Higgs boson was confirmed at CERN in 2012, the realization of the Higgs Factory has been eagerly awaited, and the ILC is one of them. In the ILD detector, which is one of the detector concepts of the ILC project, the use of a (Time Projection Chamber : TPC) is being considered.
- **TPC… A detector that reconstructs the track of a charged particle in 3D.** The particle trajectory is determined by measuring the position of ionized electrons generated from charged particles produced by electron-positron collisions.
- **The trajectories of ionized electrons are disrupted by electric field distortions caused by space-charge in the TPC, as listed below, which affect spatial resolution.**
  - ✓ **Primary ion**
  - ✓ **Secondary ion(Ion Back Flow)**

Ion Back Flow(IBF)
The positive ions generated during electron amplification flow back into the drift space, disturbing the electric field and causing the charged particle trails to be detected incorrectly.

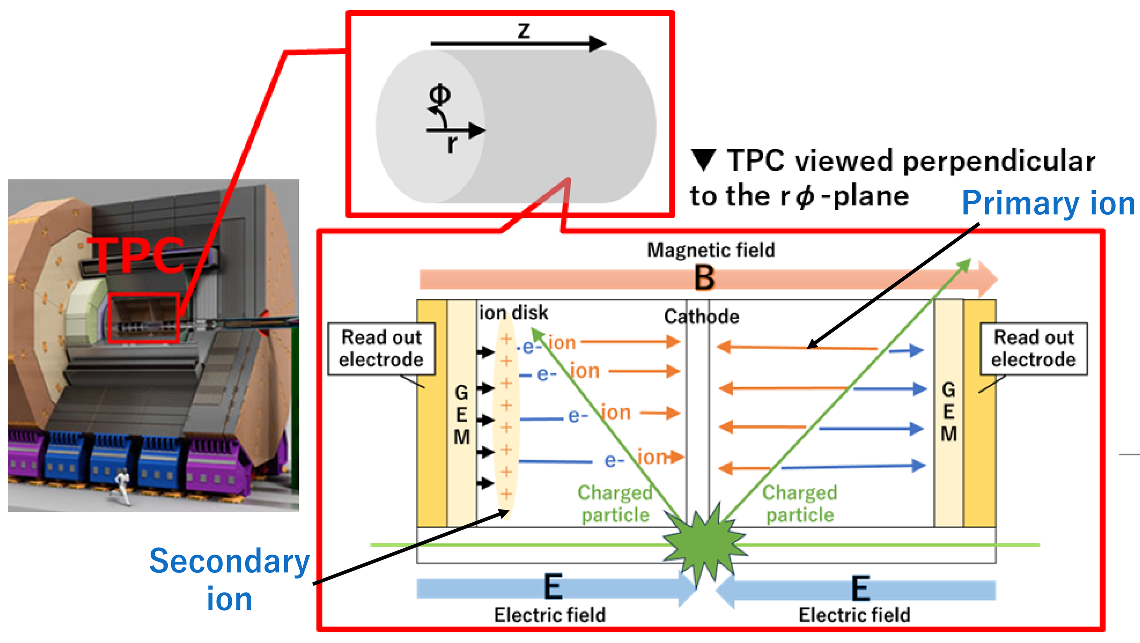
- **Beamstrahlung … a phenomenon in which photons, electron-positron pairs, etc. are emitted when beams cross each other.**
- Beamstrahlung and beam background have a significant effect on TPC electric field distortion.

▼ ILC-TPC

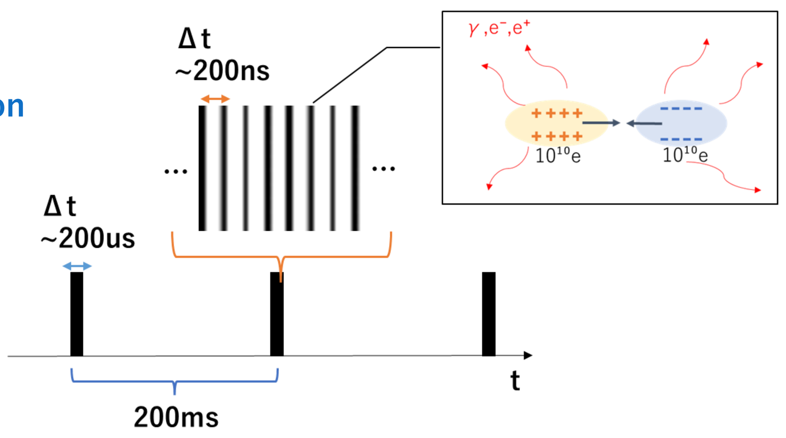




▲ Positive Ions are generated at the timing when beam crossing occurs every 0.2s



▼ TPC viewed perpendicular to the rϕ-plane

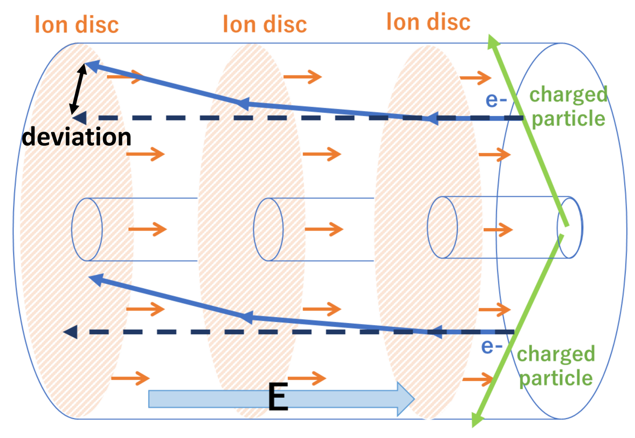


▲ 10^{13} electrons and positrons cross each other every 0.2 seconds

2, Purpose

To accurately measure the momentum by precise position measurement for precise measurement of the Higgs.
➡The effect of electric field distortion due to ion distribution in the TPC on the positional measurements of ionized electrons was evaluated.

Plot the charge distribution of ions at points of the same radius r in the TPC on a histogram along the ϕ-z axis and calculate the electric field distortion at each point.
➡Repeat this for each arbitrary r width (dr) and sum up.

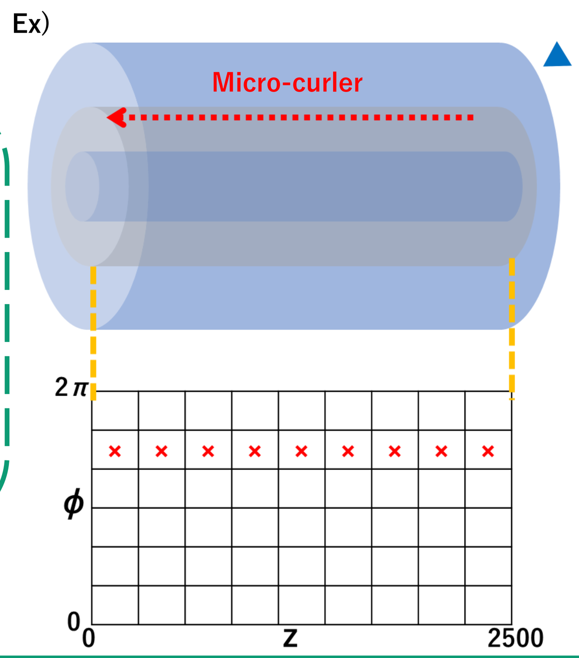


◀ Distortion at the ion disk. Electron generation and arrival positions are shifted by ions.

Blue line: Curved trajectory due to electric field distortion
Dotted line: Trajectory when drifting straight

3, Simulation

Poisson equation
Create ion distribution in 3D space and calculate electric field distortion
⇩
Langevin equation
Evaluate ionized electron arrival position deviation



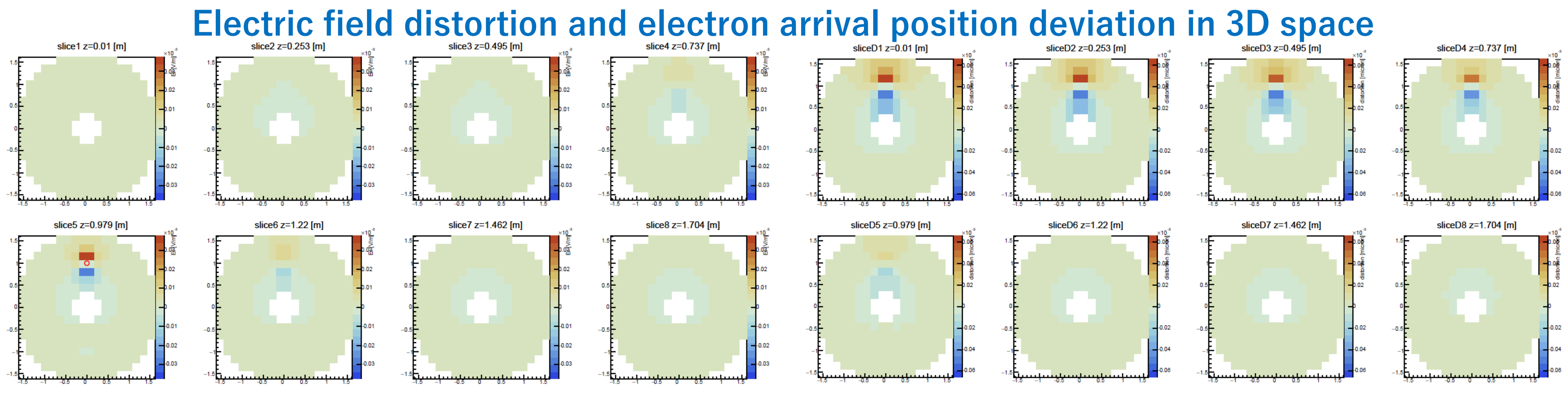
4, Results

To understand the step-by-step process, the following cases of charges present in the TPC considered.
(1) Point charge
(2) Micro-curler
(3) Ions produced at the timing of beam crossings
The distortion in the rΦ direction was checked at the z point of a certain interval.

(1)Point charge

When there is only one ion at **R=1000 mm, ϕ=1570 mrad, z=1010 mm, 1000e**

Electric field distortion and electron arrival position deviation in 3D space



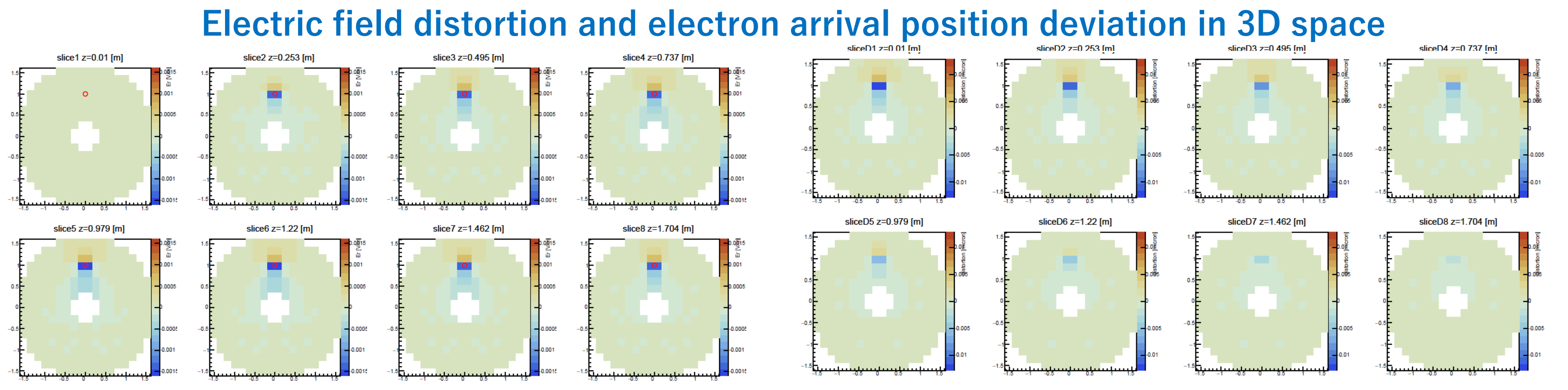
Electric field distortion(Er) Electron arrival position deviation(Δrϕ)

- Electric field distortion : ±0.03 ×10^{-3} V/m, Arrival position deviation : ±0.06 ×10^{-3} μm
- It is distorted only around the charge.

(2)micro-curler

When there is only one micro-curler at **R=1000 mm, ϕ=1570 mrad, 125×10³e**

Electric field distortion and electron arrival position deviation in 3D space

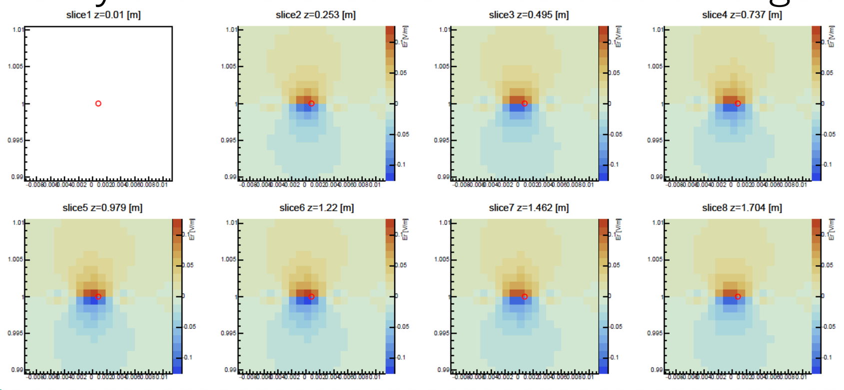


Electric field distortion(Er) Electron arrival position deviation(Δrϕ)

- Electric field distortion : - 1.5 ×10^{-3} V/m, Arrival position deviation : ±0.01 μm
  ➡ The distortion is about 10 times larger than that of the point charge.
- Distortion remains continuously in the Z-axis direction.

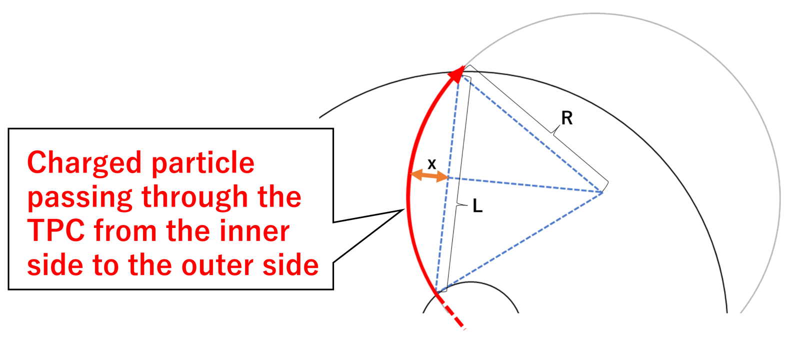
What's micro-curler?
…Since the curvature varies with the magnitude of the momentum, very low momentum forms a helix with a fairly small radius. This is called a micro-curler, which forms a line along the magnetic field.

Only the micro-curler area was enlarged to confirm the electric field distortion.



- Electric field distortion : ±0.1 V/m, Arrival position deviation : ±1 μm
  ➡ The distortion is about 100 times larger than that of the whole TPC.

Estimation of deviation tolerance



Particles with large momentum have difficulty distinguishing differences in curvature.

$$Pt = 0.3B[T]R[m]$$

Assuming B=3.5 T, L=1.4 m, when a charged particle of 125 GeV(Maximum momentum that can be produced by ILC250GeV) is flying, the allowed range of x is

$$x = \frac{0.3}{8} \cdot \frac{(1.4)^2 \cdot 3.5}{125} \approx 2[\mathrm{mm}]$$

The target performance for rΦ directional momentum is

$$\frac{\sigma_{Pt}}{Pt} = 1\times10^{-4} Pt[GeV/c]$$

Then, $Pt = 125[GeV/c]\sim10^2[GeV/c]$

$$\frac{\sigma_{Pt}}{Pt} \cong 1\times10^{-2} \cong 1\%$$

The allowable range of deviation of the ionized electron arrival position is

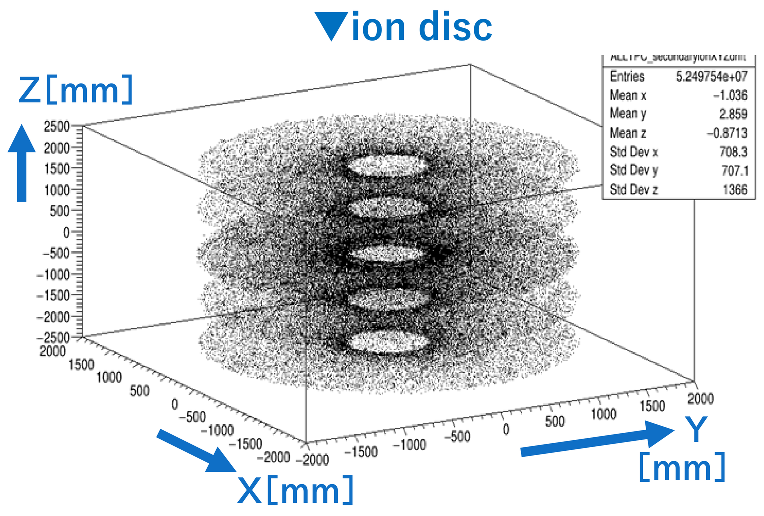
20um (1% for 2mm)

➡ Only at one point where x is the largest, ≦20um is allowed.

(3)Ions produced at the timing of beam crossings

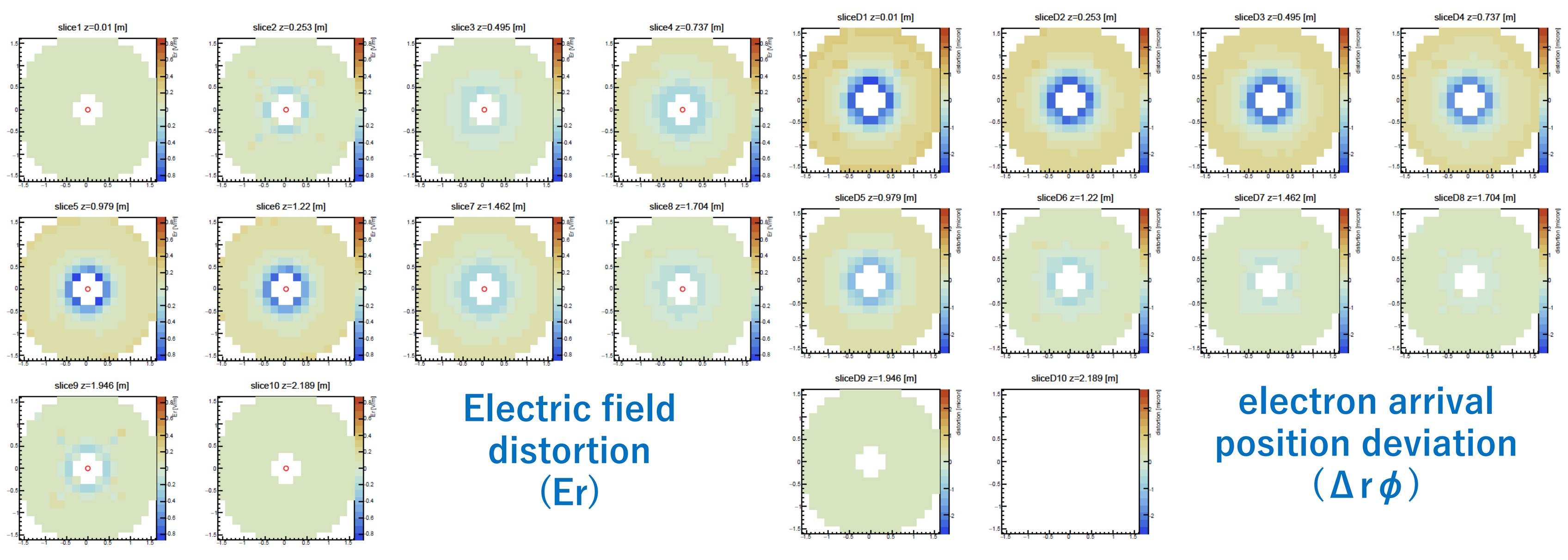
For 3 ion disks

▼ion disc



Ions after amplification by GEM (secondary ions) create a mass of ions called "ion disk".

Electric field distortion and electron arrival position deviation in 3D space



Electric field distortion (Er)

electron arrival position deviation (Δrϕ)

- Electric field distortion : ±0.8 V/m, Arrival position deviation : ±2 μm
  ➡ Electric field distortion is large at z=1.0−1.2 m where the ion disk remains
- Positive ions are concentrated closer to the inner diameter, and the associated electric field distortion and arrival position shift is greater closer to the inner diameter.
- The maximum misalignment is about 2um for the entire TPC, but if we look locally, it could be more than 20um, which is the target.

5, Summary

- ◆ Compared to a single point charge or micro-curler, the distortion and the position deviation were found to be larger in cases such as ion disks with a large number of ions.
- ◆ The misalignment appears to be acceptable when viewed over the entire TPC, but the distortion may be even greater when viewed locally, and will be examined in more detail in the future.
- ◆ FCC will have a different effect on distortion.