Graphene as an Ion Blocking Device in the TYL project

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R&D for ILD-TPC within TYL projects

D_RD_2 : The feasibility of a MPGD TPC for the LC was demonstrated.

D_RD_9 : Main issues towards final design were pushed forward with Large Prototype (LP) of the TPC.

- ✓ Performed first test beam experiment of the large -aperture GEM-like gating device
- ✓ Studied key issues of the engineering design: CO_2 cooling, track distortions, etc.

D_RD_18 (2018-2022)

- ✓ design optimization of the GEM-like gating device
- ✓ measurement of position (momentum) and dE/dx resolution of the Large Prototype
- ✓ 2-phase CO_2 cooling
- ✓ GEM gain uniformity and minimization of the GEM discharge
- ✓ mitigation of ExB effects at design level (field distortions) using ERAM design
- ✓ simulation of the effect of the resistive anode layer for MM

Study of Ion Back flow

Ion space charge can worsen the position resolution of the TPC

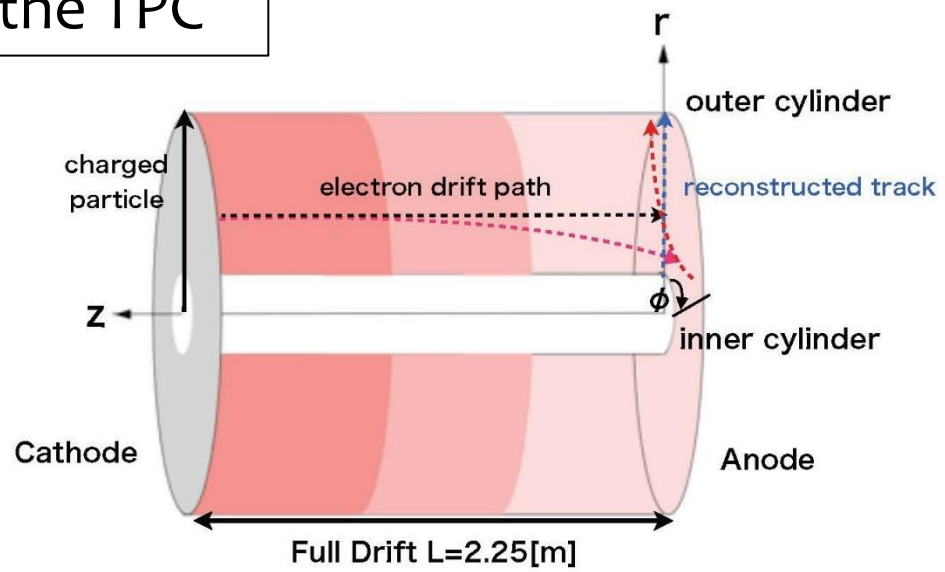
E-field in the drift region can be distorted by the primary and secondary ions.

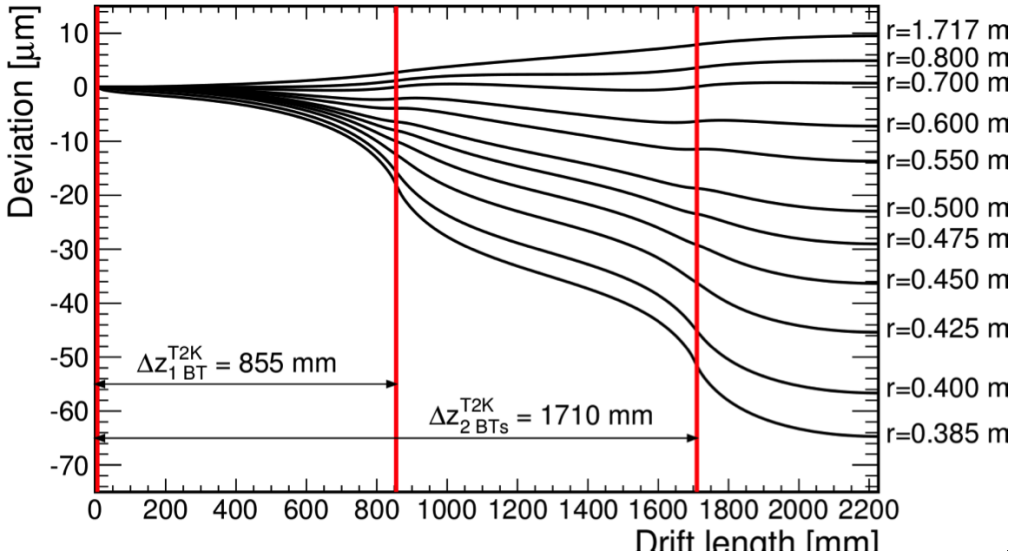
Primary ions come from the ionization by the charged particle and move to the cathode.

→ O(≤10μm) track distortion

Secondary ions come from the gas amplification and backflow to the drift volume.

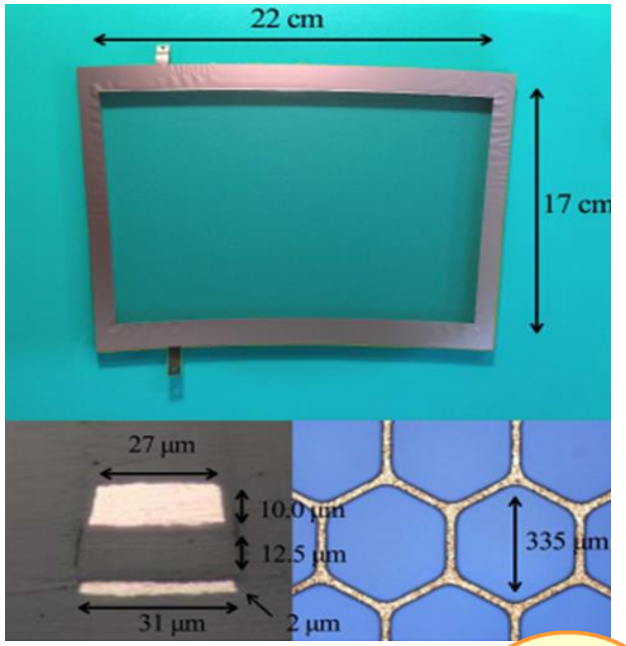
→ 60 μm for IBF x Gain = 3 for the case of 2 ion disks.



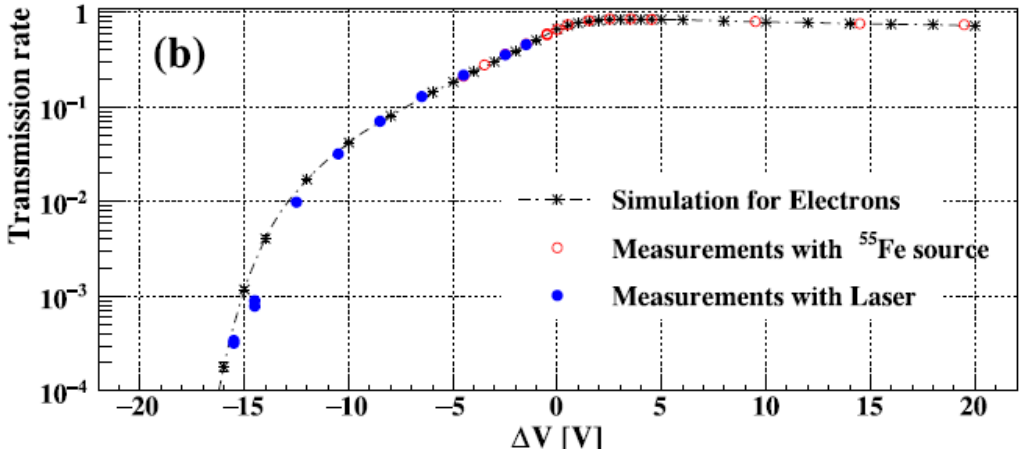


Gating GEM

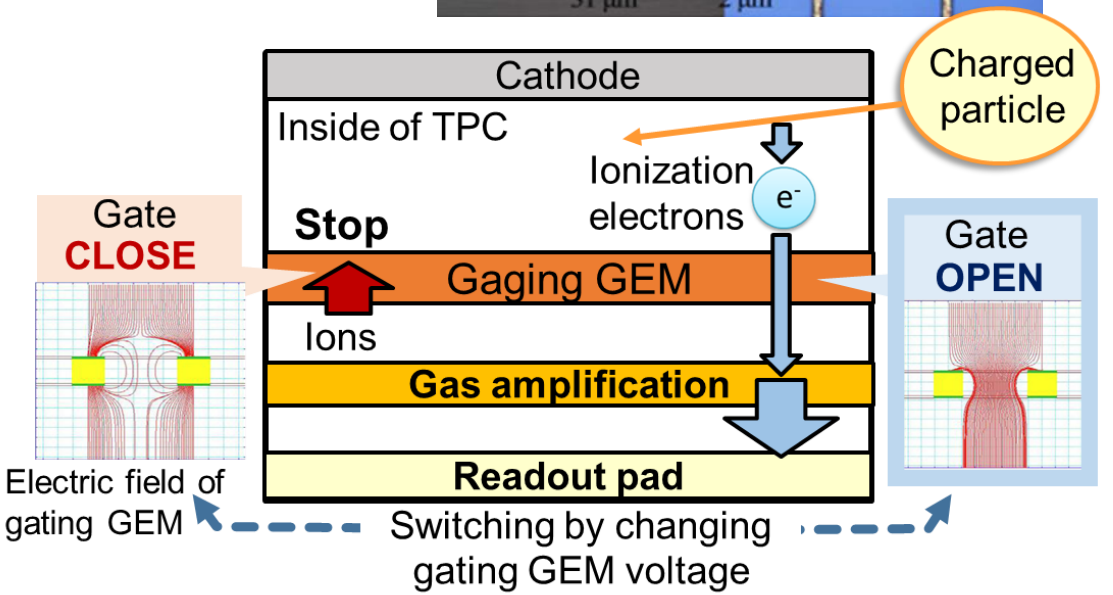
- The gating foil is a thin electrode foil in which GEM-like structure having hexagonal holes with narrow rims.
- It has been manufactured using flexible printed circuit production technology by Fujikura Ltd in Japan.
- The optical aperture ratio is ~ 82 %.
- The gate is opened and closed by changing the polarity and height of the output pulse.



Transmission rate measured with GEM module



- ✓ Electron transmission rate : > 80%
- ✓ Electron blocking power : O(10^{-4}) → expect much better for ion.
- ✓ Consistent results have been obtained with MM.



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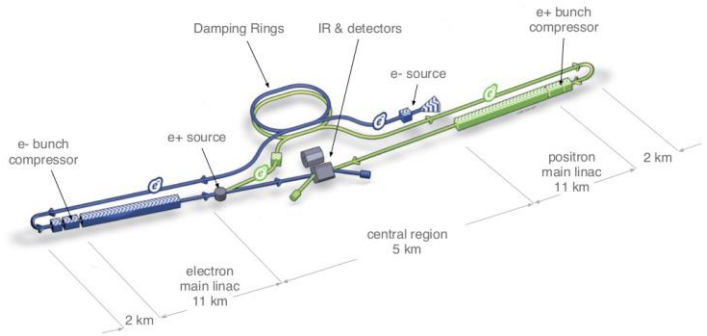
A series of French-Japan joint R&D (*D_RD_2*, *D_RD_9*, *D_RD_18*) has successfully achieved many significant results.

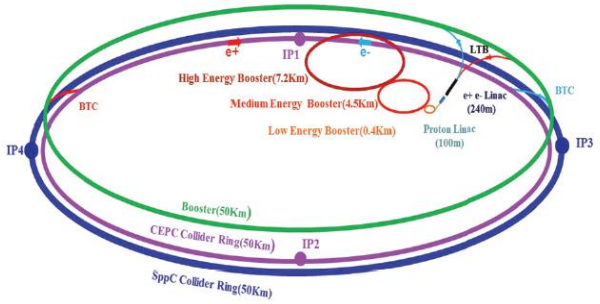
R&D of GEM-like gating device and cooling system.
Understanding the performance of MM/GEM module using test beam data.
There is a synergy with T2K ND280 TPC which applies our design.

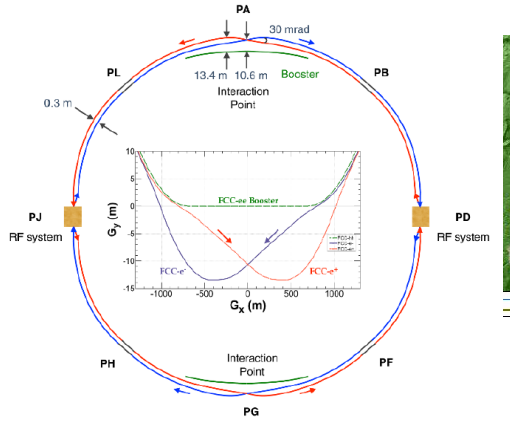
Current project : D_RD_28 (2023 ~)

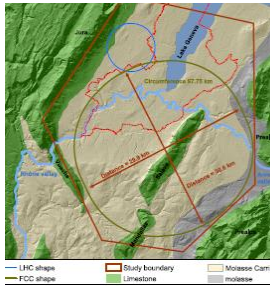
Background

- The ILC is the most advanced project for the future Higgs factory.
  → We will continue to develop the ILD-TPC for coming engineering design phase.
- Circular colliders such as the Circular Electron Positron Collider (CEPC) and the Future Circular Collider (FCCee) has been recently proposed as the Higgs Factory (and for EW/top physics).









We proposed to study the issues for using a TPC designed for a linear accelerator with a circular machine, focusing on …

- ✓ Impact for the degradation of spatial resolution caused by the field distortion.
- ✓ Modifying the design of readout module to suppress the IBF without the gating device.
- ✓ Development of efficient cooling system without power pulsing.

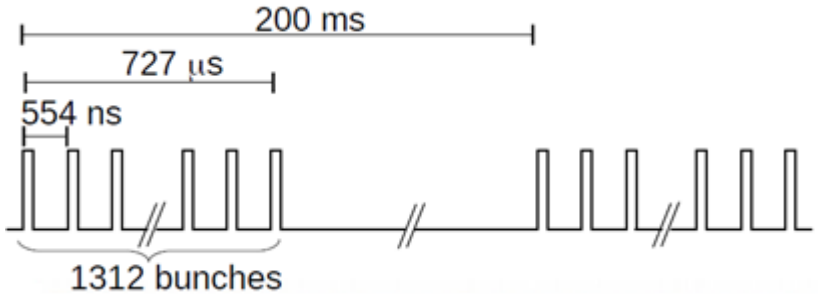
Study for using a TPC for a circular machine

- Circular colliders such as the Circular Electron Positron Collider (CEPC) and the Future Circular Collider (FCCee) has been recently proposed as the Higgs Factory.
- The operating conditions are absolutely different from ones for a linear collider.

  Bunch crossing

  ILC: certain time intervals

  CC : extremely high frequency



- The luminosity of the circular machine can reach much higher when operated at lower center of mass energies. Especially, we should consider conditions at Z-pole running.

Luminosity/IP (10^{34} $cm^{-2}s^{-1}$)

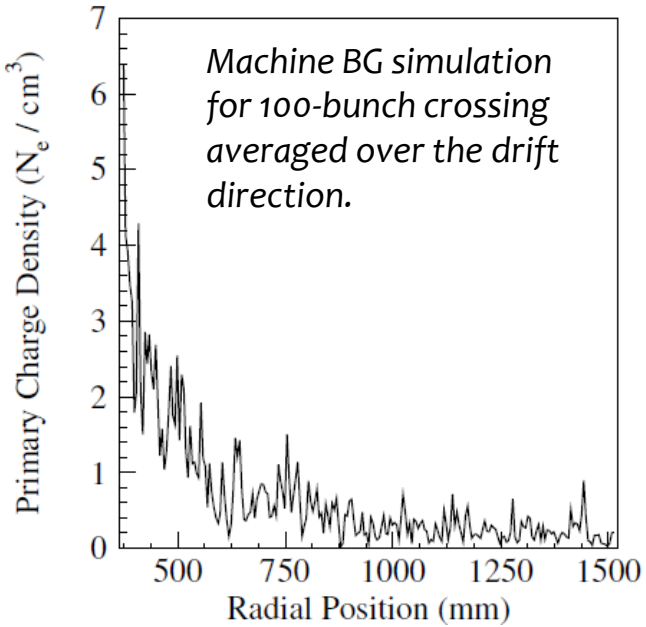
	Z (91GeV)	H (240-250 GeV)
ILC	0.2	1.4 (2.7)
CEPC (50 MW option)	~200	~8
FCCee	~200	8.5

Field distortion by positive ions

- In high-rate running at the circular collider, distortion in the drift volume is a significant issue, which is caused by
  - a large amount of the primary ions from ionization of the tracks from both Z-pole events and the machine background
  - the backflowing ions generated in amplification.
    ← This issue is common to all the amplification devices.
    (gating device does not work with continuous beam)
- It is necessary to evaluate how much it affects the tracking performance and eventually the momentum resolution.

Note:

At the ILC, primary charge density is assumed to be 1-5 ions/cm³ resulting in the distortion of < 5um.



A. Vogel, 10.3204/DESY-THESIS-2008-036

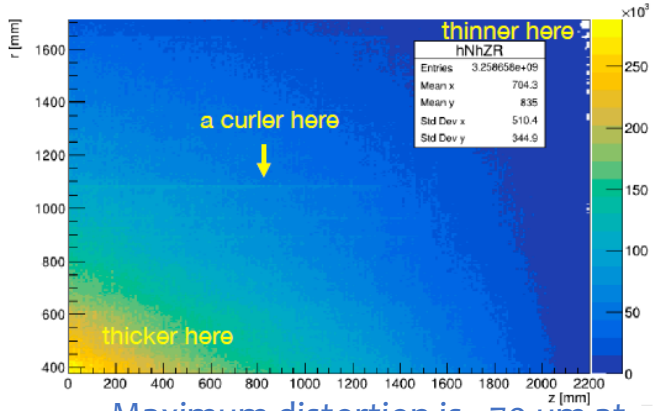
Estimation of TPC distortion at Z-pole run

- Both French and Japanese teams have started the simulation study for the TPC operated at Z-pole experiment.
- Then, we will try to adapt the simulation results to the ILD and evaluate the impact on the physics events.
- In addition, correction of the track distortion using well known tracks (such as $Z \rightarrow \mu\mu$) is another subject to be considered, and it should be also investigated in the simulation study.

Study for Z-pole run with toy MC as a starting point.
by K. Fujii and D. Jeans from Japanese group.

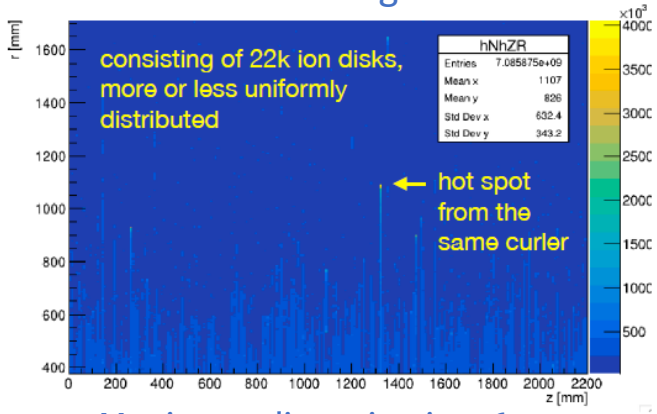
Z-pole 50 Hz → 22k events in the 0.44 s time frame.

Primary ions



Maximum distortion is ~70 um at the innermost region

Backflowing ions



Maximum distortion is ~160 um at the innermost region

TPC size
r_{in} = 375 mm, r_{out} = 1720 mm, length = 2200 mm
B field 2 T
Ion drift velocity v_{ion}=5 m/s

- Further study is needed with full simulation in ILD/TPC condition.
- We may learn from experience of ALICE (50kHz, Pb-Pb collision) where the TPC is used for tracking.
  Evaluation of the track distortion and it's correction method.

Suppress the IBF without gating

- It is absolutely difficult to use an active gating system for the circular machine.
- We should consider to modify the design and configuration of the MPGD readout system to suppress the backflowing ions.
  - It has been reported recently that a combined Micromegas with GEM readout module can suppress ion backflow*.
  - Graphene membrane might be useful**.
- It might be possible to suppress the ion backflow by optimizing field conditions although the collection efficiency of primary ions can be also affected.

The French and Japanese teams have developed the Micromegas and GEM readout, respectively.

Additionally, the Japanese team has developed gating device for the ion backflow.

⇒Based on our findings obtained through these studies, we will consider a new readout module and detector configurations.

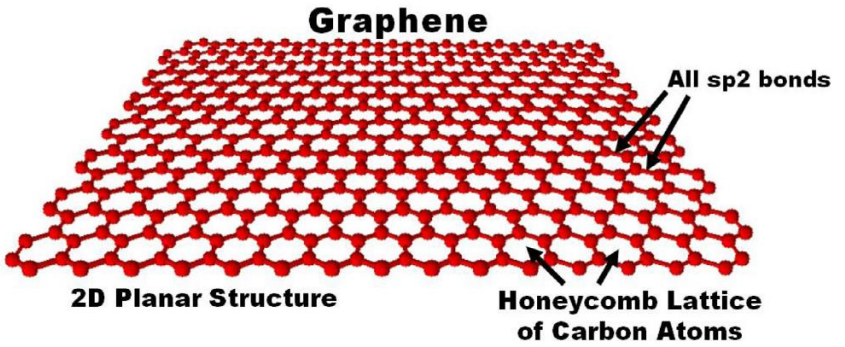
** https://indico.desy.de/event/33640/contributions/128390/attachments/77557/100324/ECFA_LCTPC_IHEP__Huirong_20220930.pdf*

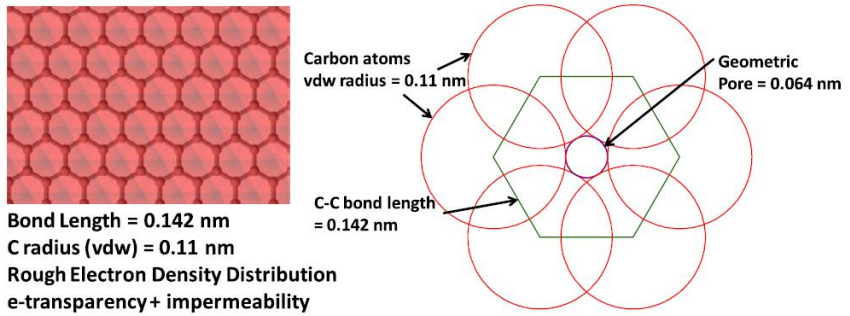
*** Nuclear Inst. And Methods in Physics Research, A824 (2016) 571.*
Nuclear Inst. and Methods in Physics Research, A 1031 (2022) 166521.
https://indico.cern.ch/event/1219224/contributions/5130761/attachments/2567723/4427337/MPGD_Conference_2022_CERN.pptx

Suppress the IBF with graphene

Graphene …

- A single layer of SP2 hybridized carbon atoms arranged in honeycomb lattice with pore size ~ 0.06 nm.
- Transparent to electrons, but impermeable to ions.
- Can separate different gas volume in the same detector.
- Mechanically strong.





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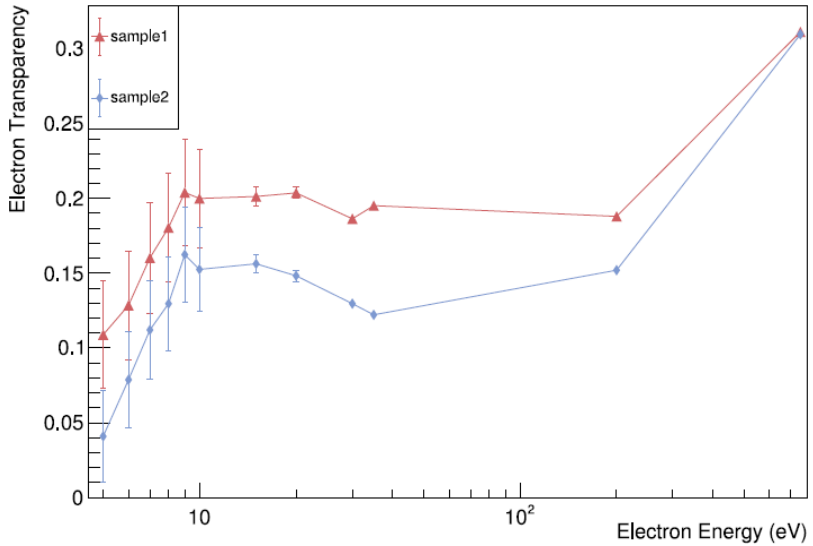

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Summary

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  R&D of GEM-like gating device and cooling system.
  Understanding the performance of MM/GEM module using test beam data.
- Circular colliders such as FCCee and CEPC have been recently proposed as Higgs factory.
- A new project (D_RD_28) in FJPPL started in 2023. Main purpose of the project is to explore the use of TPC in a circular collider ;
  - evaluating field distortion by ions resulting in track distortion
  - modifying the design of the readout module to suppress the IBF
  - improving cooling system
- Graphene is a possible material to suppress the IBF with its specific properties.
  - plan to test graphene coated MM.

Backup

Estimation of TPC distortion at Z-pole run

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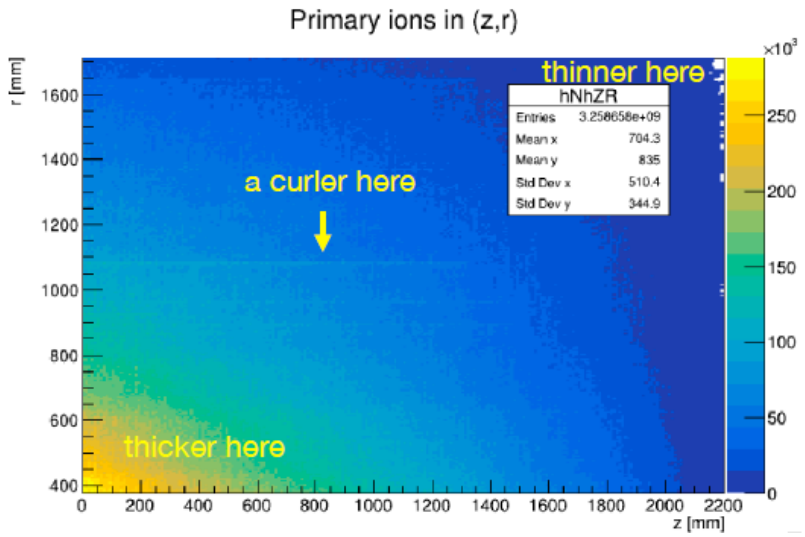

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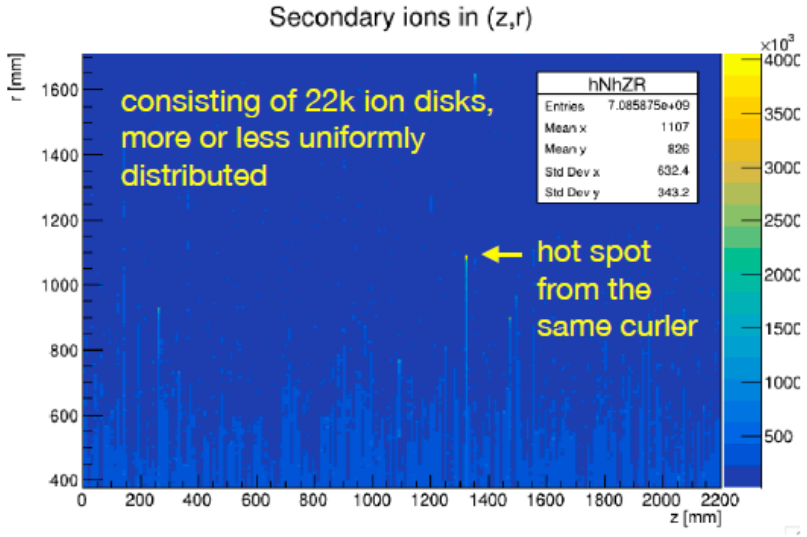

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Obtained by solving the Poisson equation with proper boundary conditions and then estimated the distortion of drift electron trajectory by the Langevin equation.

Estimation of TPC distortion at Z-pole run (*cont'd*)

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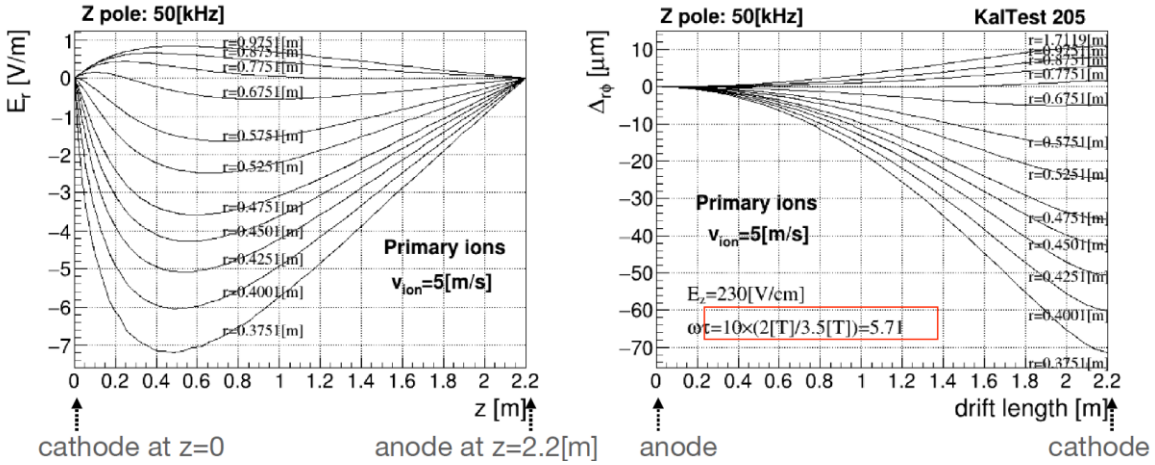

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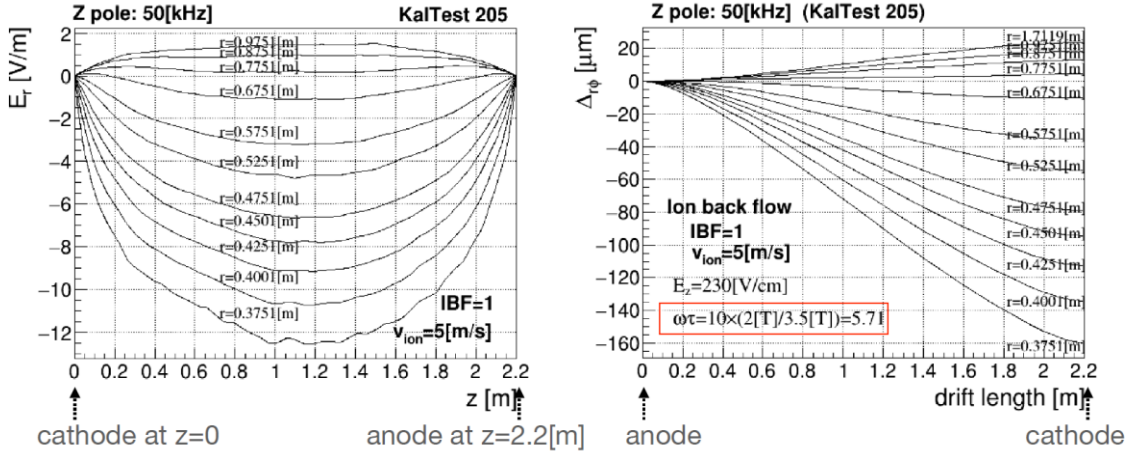

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