Feasibility study of Time Projection Chamber detector for CEPC

Haiyun Wang

Huirong Qi, Ling Liu, Zhiyang Yuan, Jian Zhang,

Yuanbo Chen, Qun Ouyang

Institute of High Energy Physics, CAS

16. Oct., 2018, Hengyang

Outline

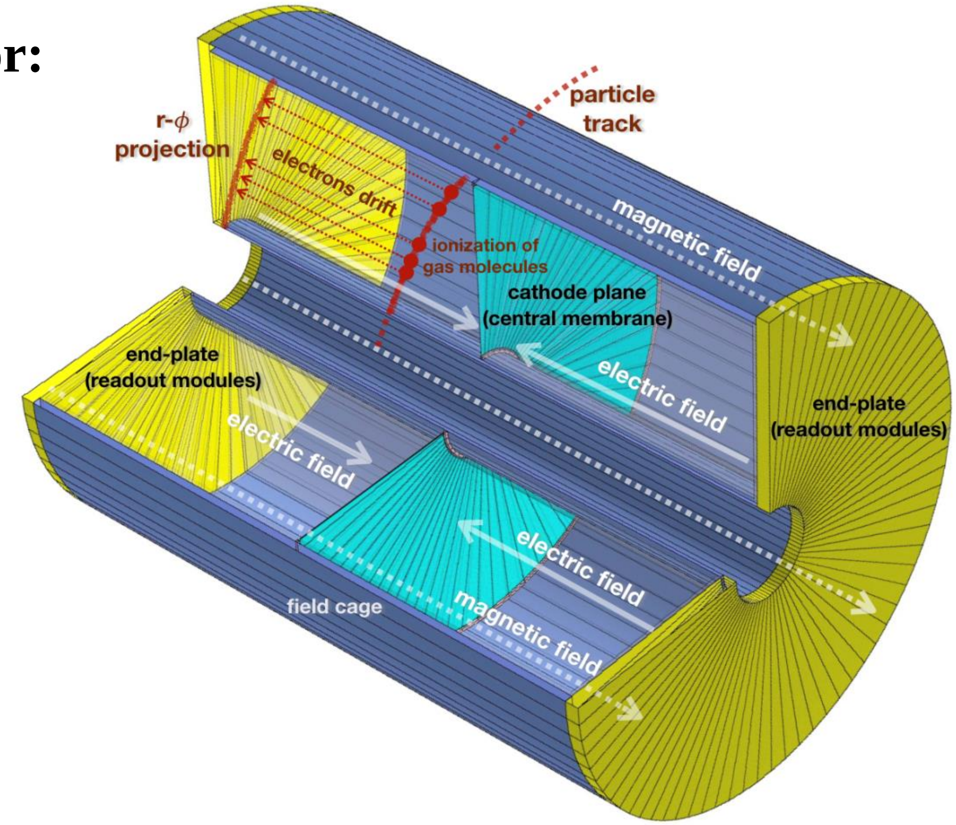
- Requirements
- Baseline design
- Feasibility study of TPC detector
- R&D activities
- Summary

TPC detector for CEPC

TPC could directly provides three-dimensional space points; the gaseous detector volume gives a low material budget; and the high density of such space points enables excellent pattern recognition capability.

TPC detector as the tracker detector:

- Motivated by the H tagging and Z
- High magnetic field
- Full 3-D track reconstruction
- Higher accuracy < 100μm(Overall along the drift)
- Precise dE/dx
- Better two track resolution
- Easily assembled using the modules
- Minimal material budget
- Drift time gives the longitudinal coordinate
- MPGDs as the readout

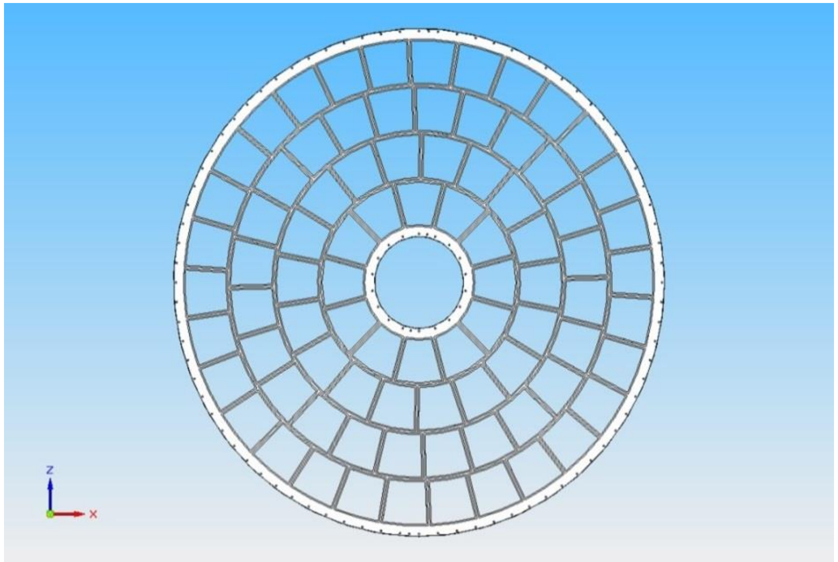


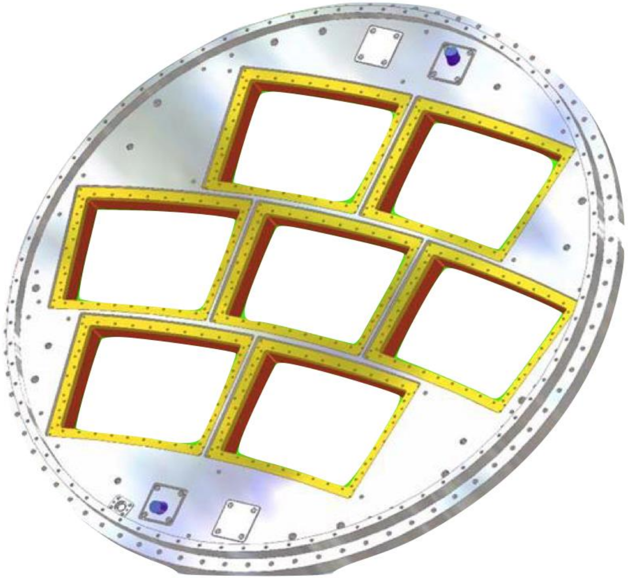
Overview of TPC detector concept

TPC requirements for CEPC

TPC detector concept:

- **Under 3 Tesla magnetic field (Momentum resolution: ~10^{-4}/GeV/c with TPC standalone)**
- **Large number of 3D space points(~220 along the diameter)**
- **dE/dx resolution: <5%**
- **~100 µm position resolution in rφ**
- **TPC material budget**
  - **<1X0 including outer field cage**
- **Tracker efficiency: >97% for pT>1GeV**
- **2-hit resolution in rφ : ~2mm**
- **Module design: ~200mm×170mm**
- **Minimizes dead space between the modules: 1-2mm**





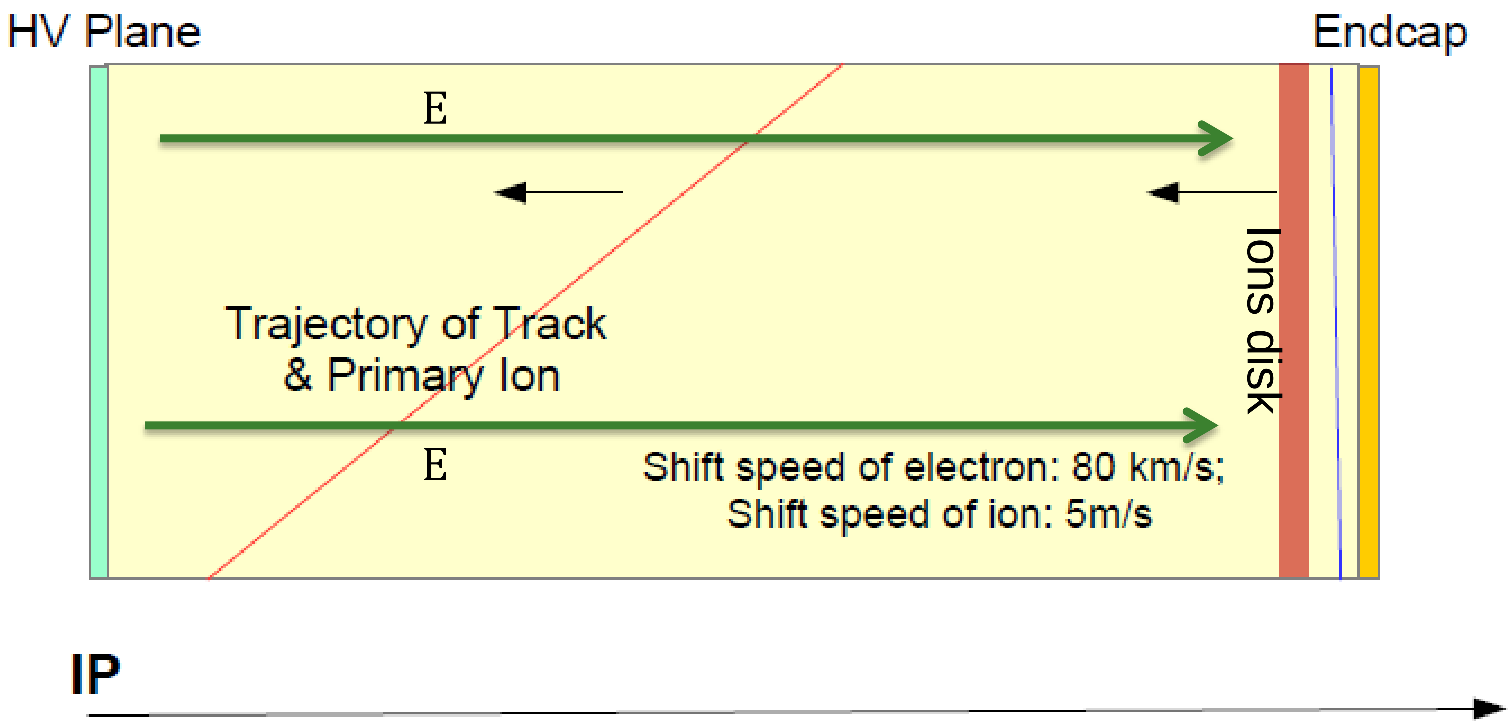
TPC detector endplate concept

Feasibility study of TPC

Voxel occupancy: $\frac{signal\ voxels}{all\ voxels\ in\ the\ TPC}$

Voxel size: 1mm×6mm ×2mm @DAQ/40MHz

- Would it be Limited by
  - Voxel occupancy
  - Primary ions along the track in the chamber
  - Amplification ions create the ions disk back to the chamber (×Gain)
  - Charge Distortion induced by the ions: Mainly from Ion back flow



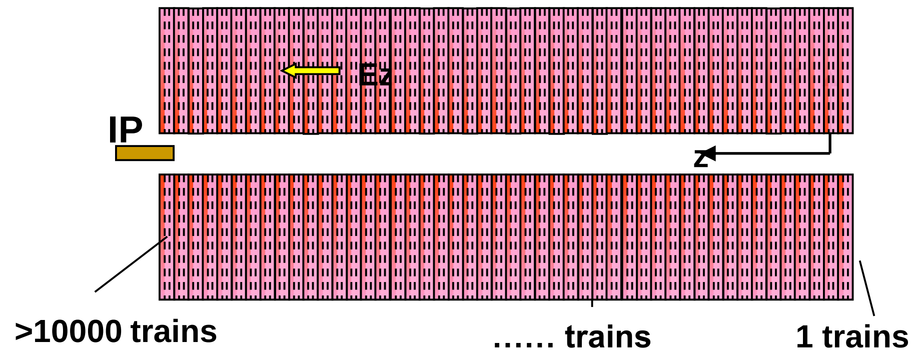
Total ions in chamber: ~ Back flow ions ~(1 + k), k = Gain×IBF + Primary

Technical challenges of TPC for CEPC

ArXiv: 1704.04401

Ion Back Flow and Distortion :

- Distortions by the primary ions at CEPC are negligible
- The ions have to be cleared during the ~us period continuously
- Continuous device for the ions
- Long working time



Amplification ions from the endplate @CEPC

Distortion simulation：

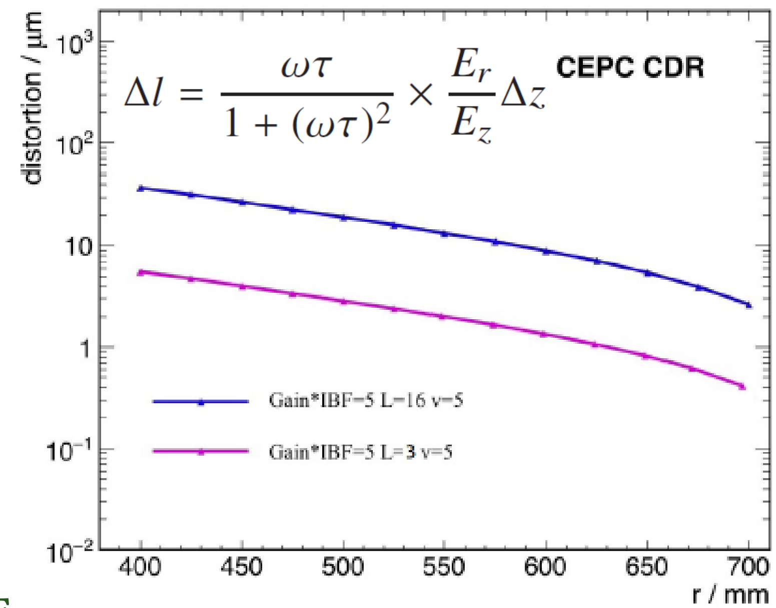
- Full simulation: 9000 events， $Z \rightarrow q\bar{q}$
- Maximal occupancy at TPC inner most layer: ~10^{-5} (safe)
- Background considered (Need careful designed Shielding/detector protection)

Δl, distortion along r-direction

Δz, drift length along the z-direction

τ, is the mean free time of electrons

$\omega = {}^{eB}/_{m}$



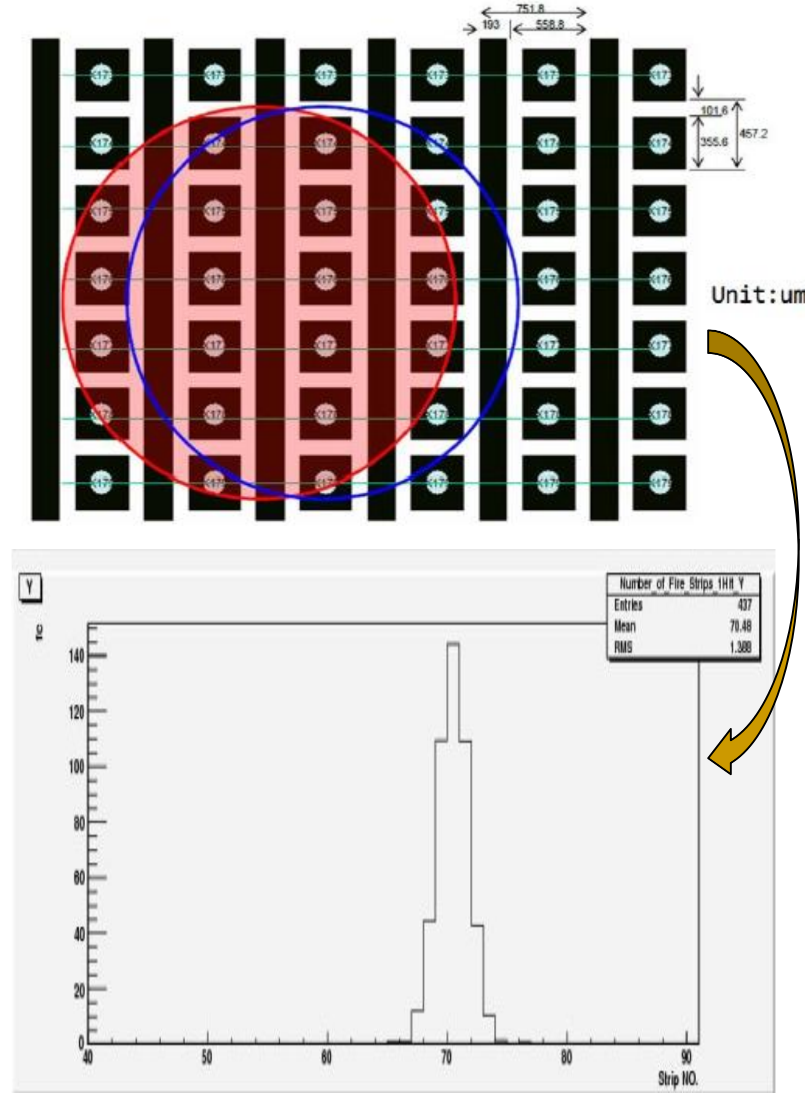
L : the luminosity in units of $10^{34}cm^{-2}s^{-1}$

- TPC will be could be used if the Gain×IBF can be controlled to a value smaller than 5.

Gas amplification detector module and pad size

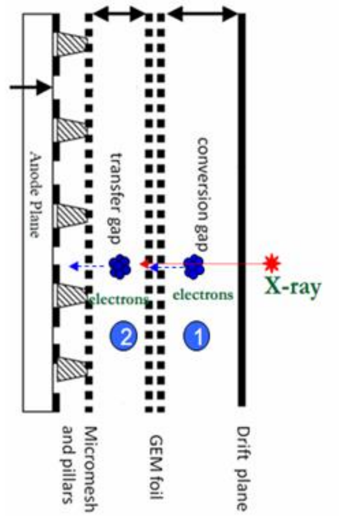
Micro pattern detector:

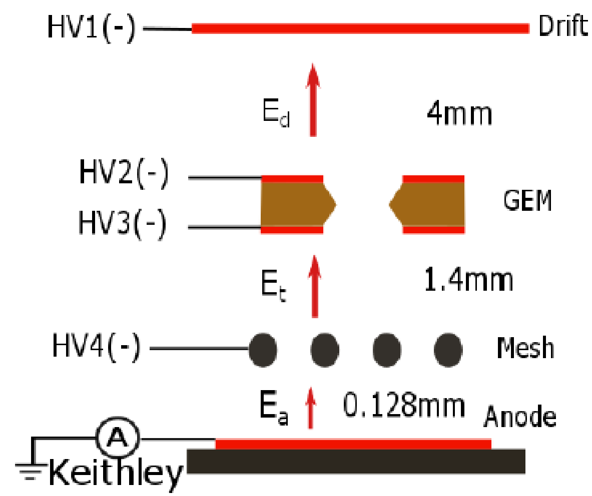
- **GEM and Micromegas detector**
- **Electron cluster using Center-of-Gravity**
  - **Pitch: ~1mm**
  - **Pad Size: ~1mm×6mm**
- **High gain (5000-10000)**
- **High rate capability: MPGDs provide a rate capability over 10^5 Hz/mm^2 without discharges that can damage electronics.**
- **Intrinsic ion backflow suppression: Most of the ions produced in the amplification region will be neutralized on the mesh or GEM foil and do not go back to the drift volume.**
- **A direct electron signal, which gives good time resolution (< 100 ps) and spatial resolution (100 μm).**



The profile of an electron cluster in GEMs detector

Technical challenges of TPC for CEPC





Continuous IBF prototype and IBF×Gain

Hybrid micro-pattern gaseous detector module: GEM plus a Micromegas (GEM+MM)

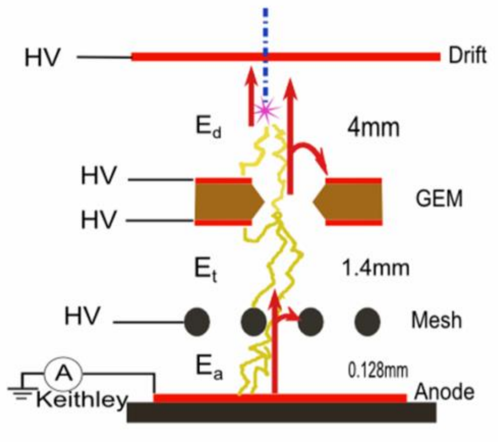
Continuous IBF module:

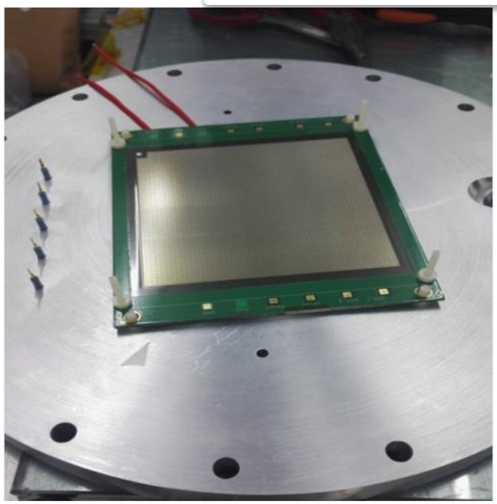
- Continuous Ion Back Flow due to the continuous beam structure
- Low discharge and spark possibility
- Space charge effect for IBF
- Gain: 5000-6000
- Good energy resolution: <20%

TPC detector module@ IHEP

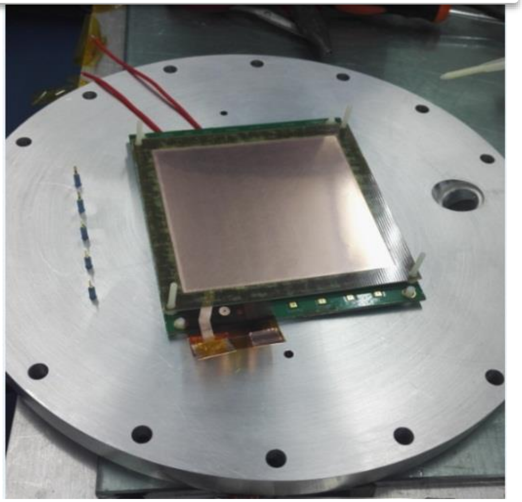
DOI: 10.1088/1748-0221/12/04/P0401 JINST，2017.4
DOI: 10.1088/1674-1137/41/5/056003 , CPC,2016.11
DOI: 10.7498/aps.66.072901Acta Phys. Sin. 2017,7

- Test with GEM-MM module
  - New assembled module
  - Active area: 100mm×100mm
  - X-tube ray and 55Fe source
  - Bulk-Micromegas from Saclay
  - Standard GEM from CERN
  - Avalanche gap of MM:128μm
  - Transfer gap: 1.4mm
  - Drift length:2mm~200mm
  - Mesh: 400LPI

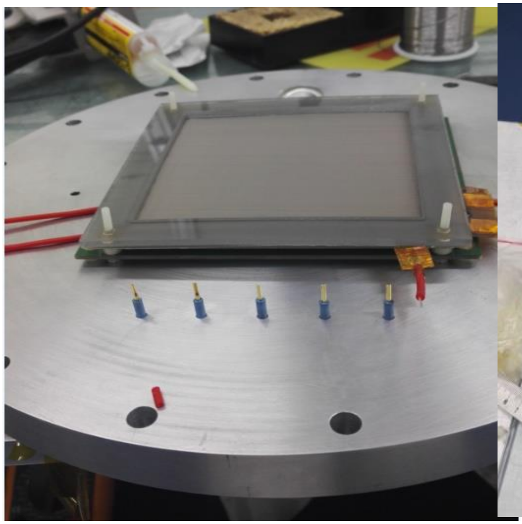




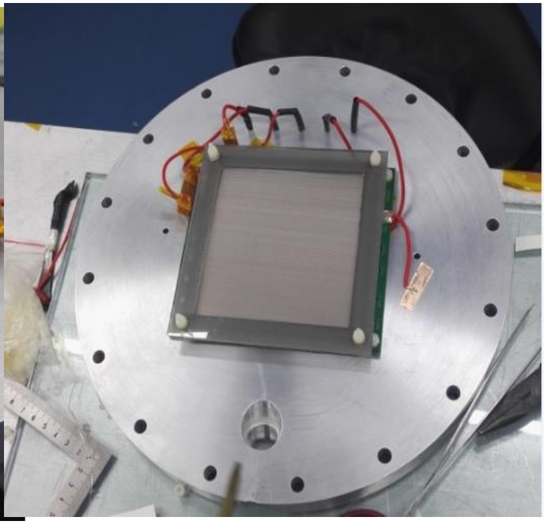
Micromegas(Saclay)



GEM(CERN)



Cathode with mesh

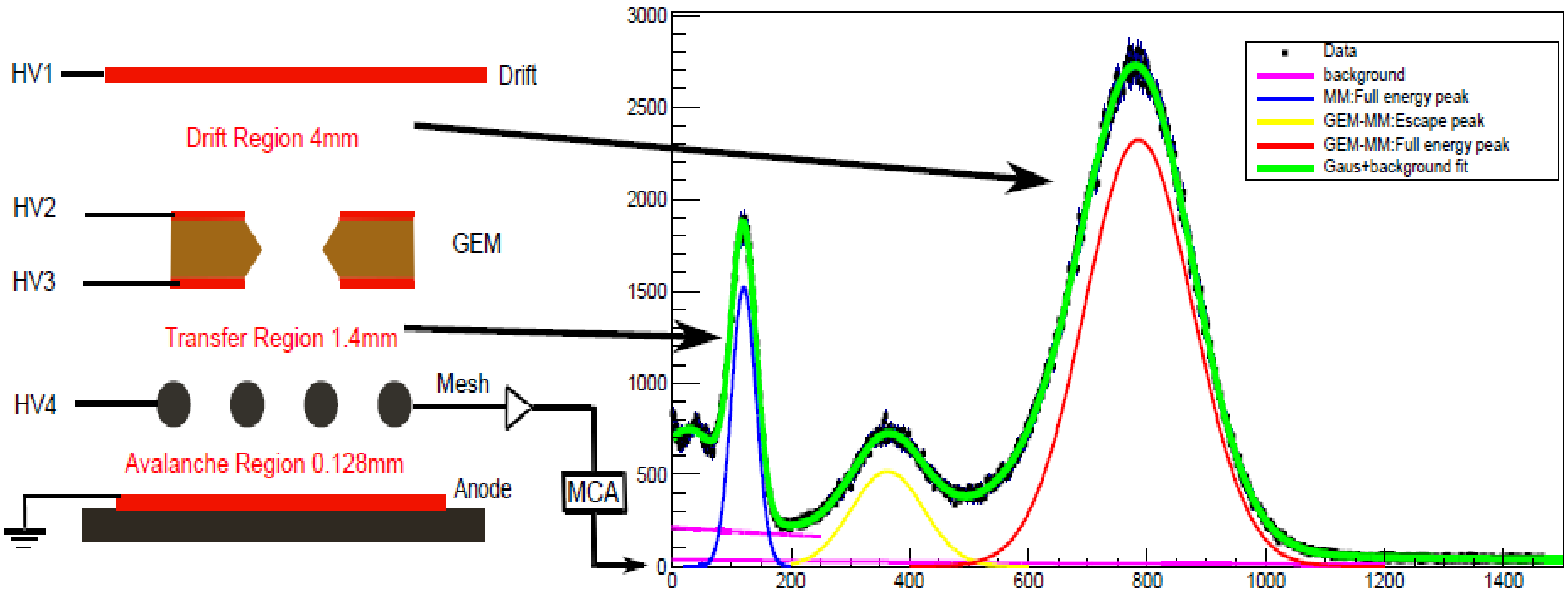


GEM-MM Detector

GEM+MM@CEPC R&D

Peak	Mean	Sigma	Resolution(%)
MM Photo Peak	120.9	20.6	40.1
GEM-MM Escape Peak	362.9	60.8	39.4
GEM-MM Photo Peak	785.9	91.1	27.3

Source: ^{55}Fe, Gas mix: Ar(95) + iC4H10 (5)

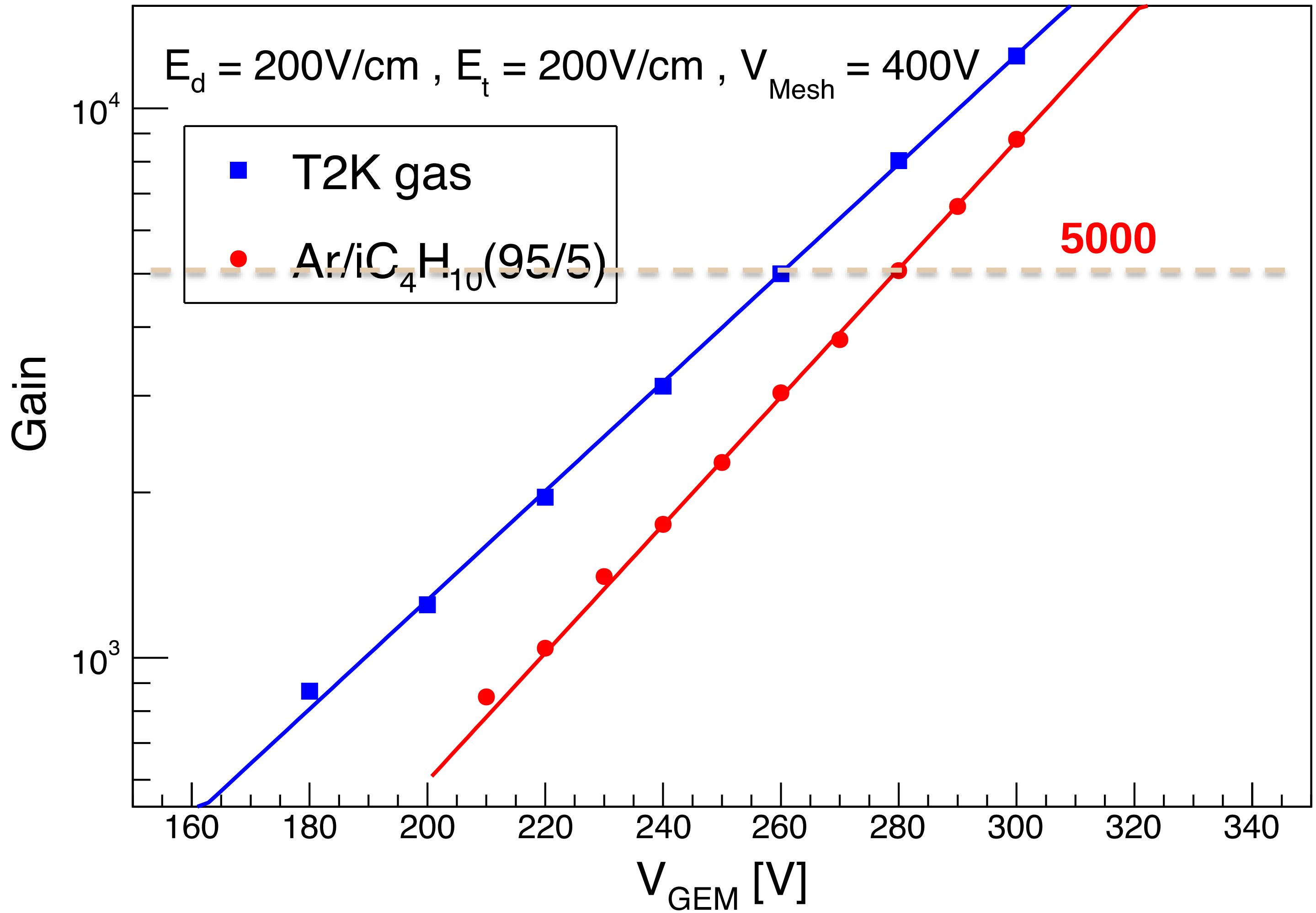


GEM-MM configuration(left) and pulse height spectrum on 5.9 keV for a GEM-MM showing each peak and the corresponding location of primary ionization(right)

Ed=250 V/cm, Vgem=340 V, Et=500V/cm, Vmesh=420 V

k=Gain×IBF, k~5 Gain? IBF?

Gain of the hybrid structure detector



Measurement of GEM-MM module

- Test with GEM-MM module
  - Keithley Electrometers for Ultra-Low Current Measurements: pA~mA
  - Keithley: 6517B
  - Test of cathode of the module
  - Test of readout anode of the module
  - Labview interface of the low current to make the record file automatically

Keithley 6517B

Electrometer/High Resistance Met

- 20mA, 10μV - 200V, 100Ω - 10PΩ

Brand:	Keithley
Model No:	6517B

KEITHLEY
A Tektronix Company

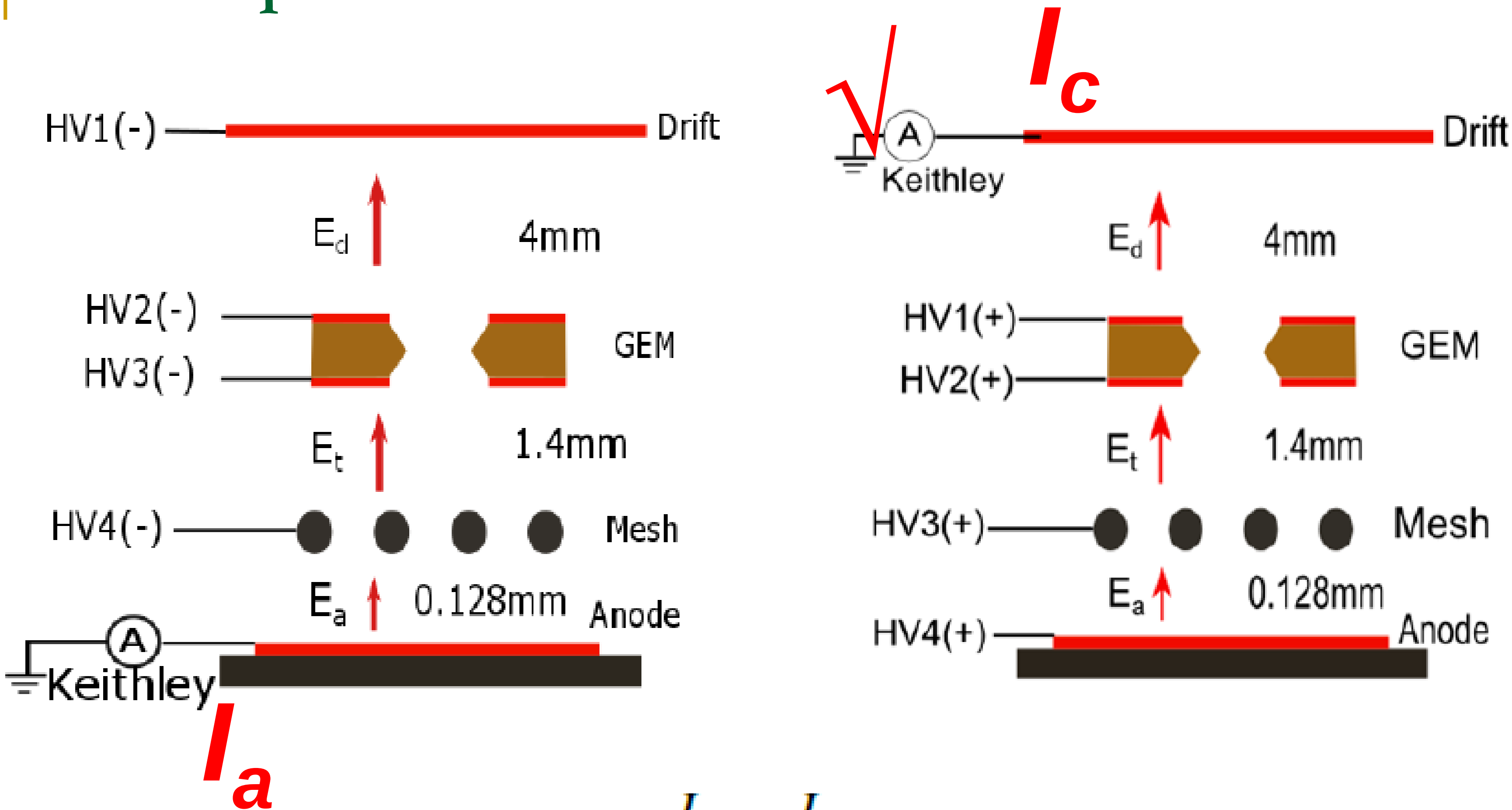
Labview interface of the current with Keithley

➤ 皮安表：**Keithley(6517B[13])**

$$IBF = \frac{I_c - I_{prim}}{I_a}$$

I_c,阴极电流（drift cathode），正比于阴极收集离子数
I_{prim}，漂移极初级电离电流（primary ion current）
I_a，阳极电流（anode pad），正比于阳极收集电子数

Two steps



$$IBF = \frac{I_C - I_P}{I_A}$$

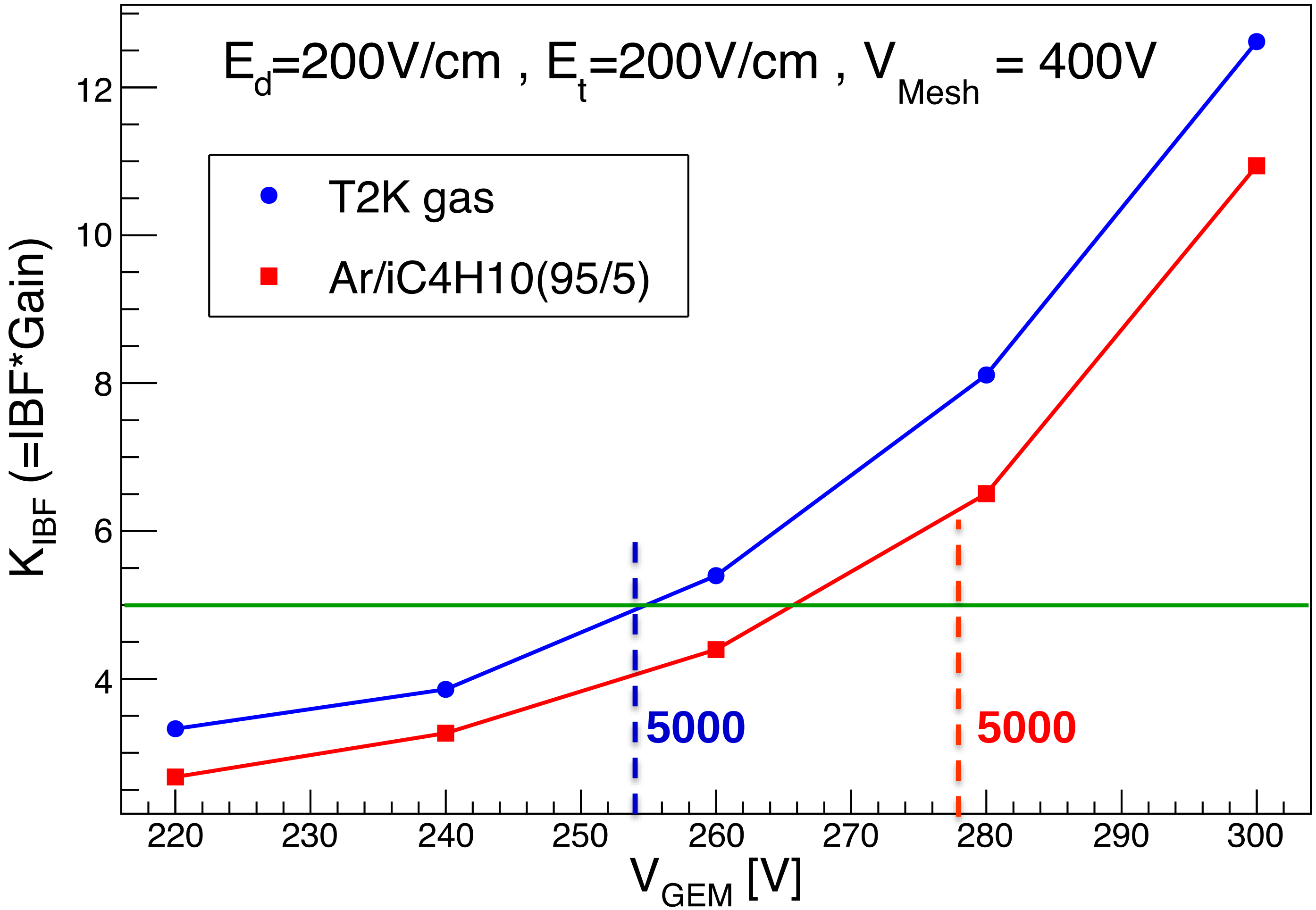
I_c,阴极电流（**drift cathode**），正比于阴极收集离子数

I_{prim}，漂移极初级电离电流（**primary ion current**）

I_a，阳极电流（**anode pad**），正比于阳极收集电子数

Key IBF factor: IBF × Gain

Results in 2018



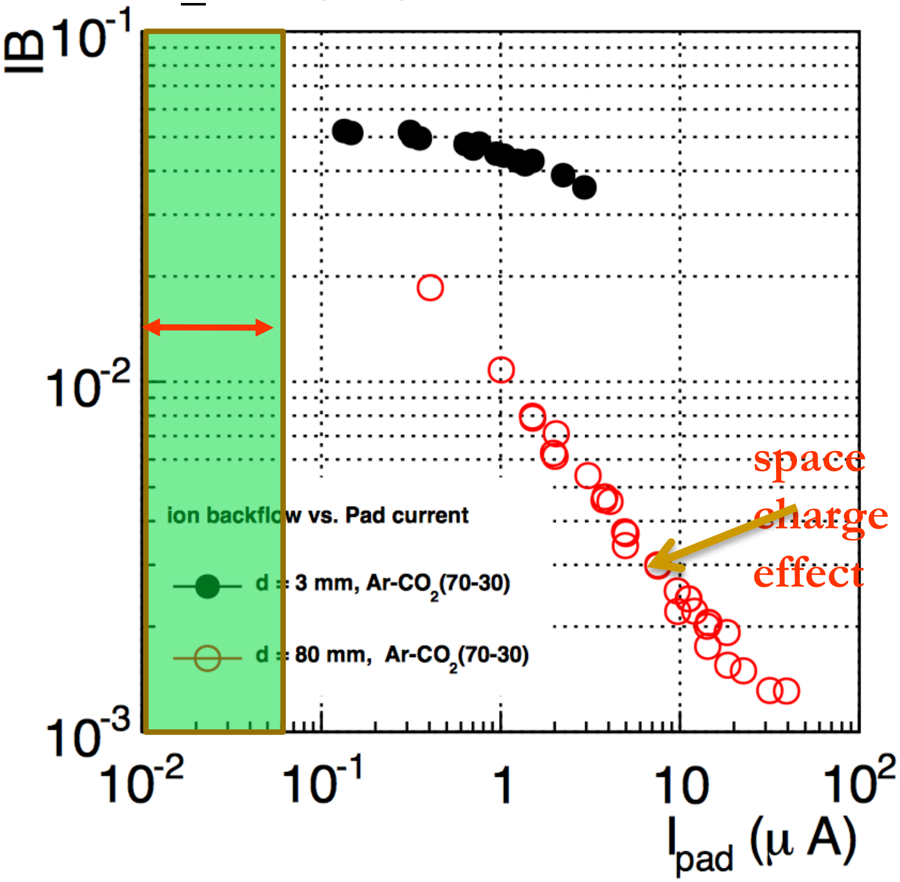
Space charge effect in MPGD

- Lots of ions make space charge effect to decrease IBF value significantly in the high rate

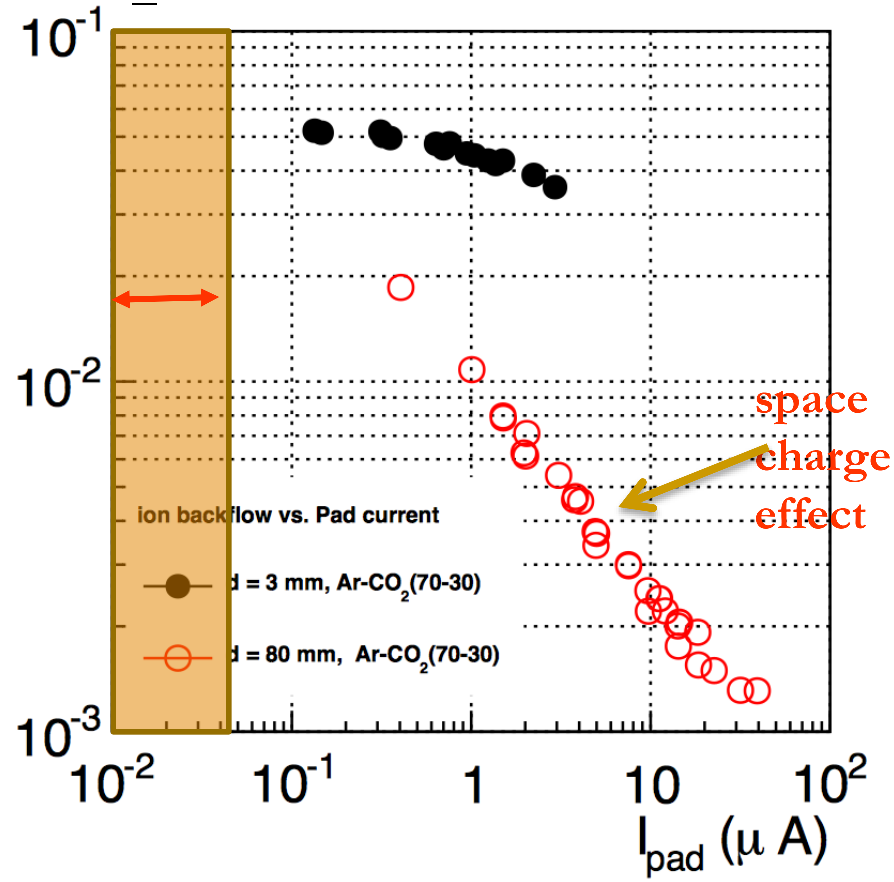
Obvious space charge effect to reduce IBF？

Check I_{pad}

Green， T2K， Et=200V/cm, Ed=200V/cm, V_mesh=400V, V_Gem:30~300V



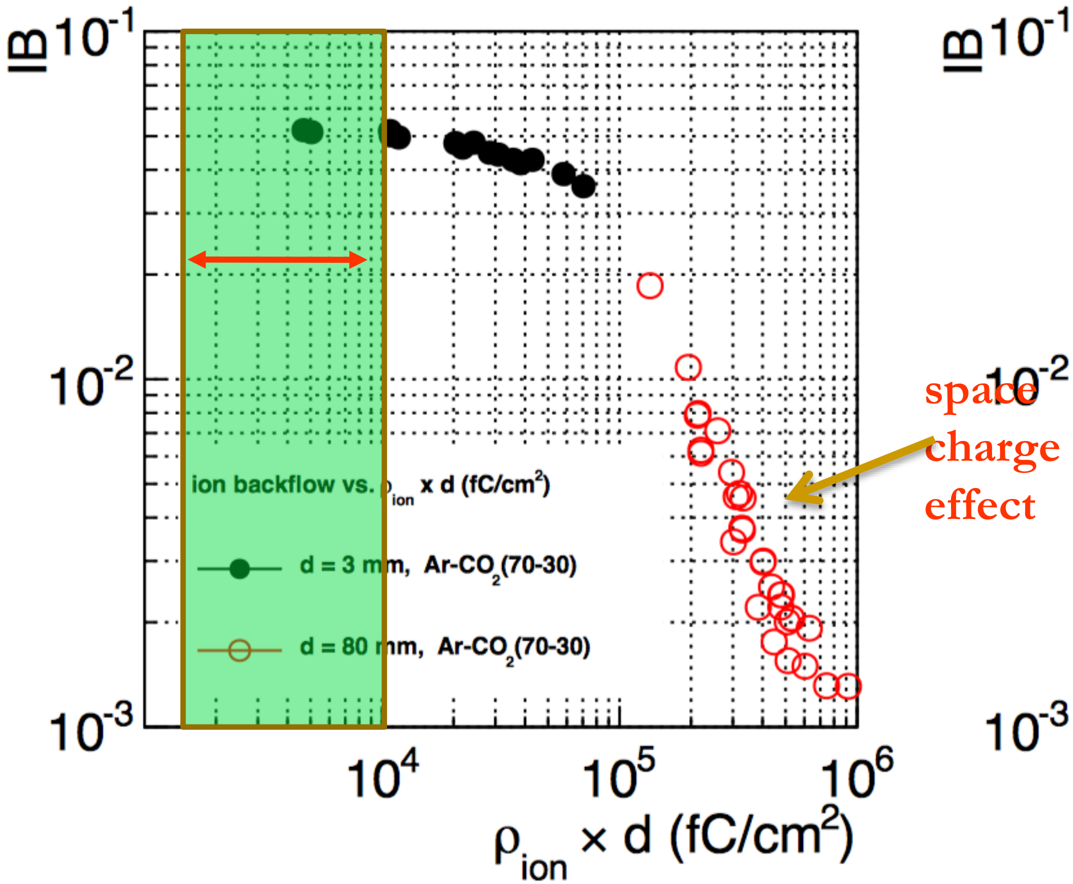
Yellow， Ar/iso(95/5) ， Et=200V/cm, Ed=200V/cm, V_mesh=400V, V_Gem:30~300V



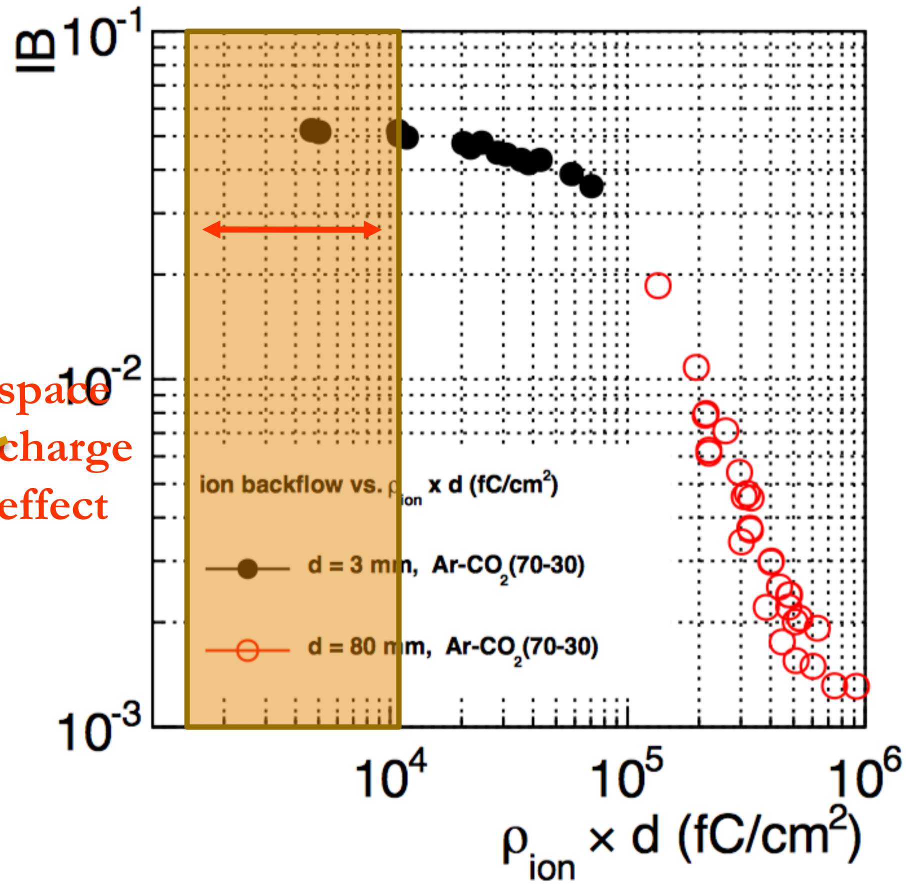
Current of Pad is very low in our Exp. No space charge effect！

Check $\rho_{ion} \times d$

Green: T2K， Ic: 4pA～59pA，～10^3 （fC/cm²）



Yellow: Ar/iso(95/5) Ar/iso gas Ic : 3.5pA~53pA, ～10^3 （fC/cm2）



Current of Pad is very low in our Exp.No space charge effect！

Summary

The Time Projection Chamber presented here provides an good starting point for TPC research and development in the context of the CEPC beam environment.

Several critical challenge issues have been identified in pre-studies

- **TPC is promising for the CEPC (e+e- collider with High event rate Z pole operation**
- **Validation of the preliminary results from the combination GEM+Micromegas detector module: (IBF×Gain=5)**
- **No obvious space charge effect to reduce IBF**

Collaboration with international teams (LCTPC collaboration group, Japan-KEK group, France-Saclay group)

Going to TDR for next step

Thanks.

Check and answer

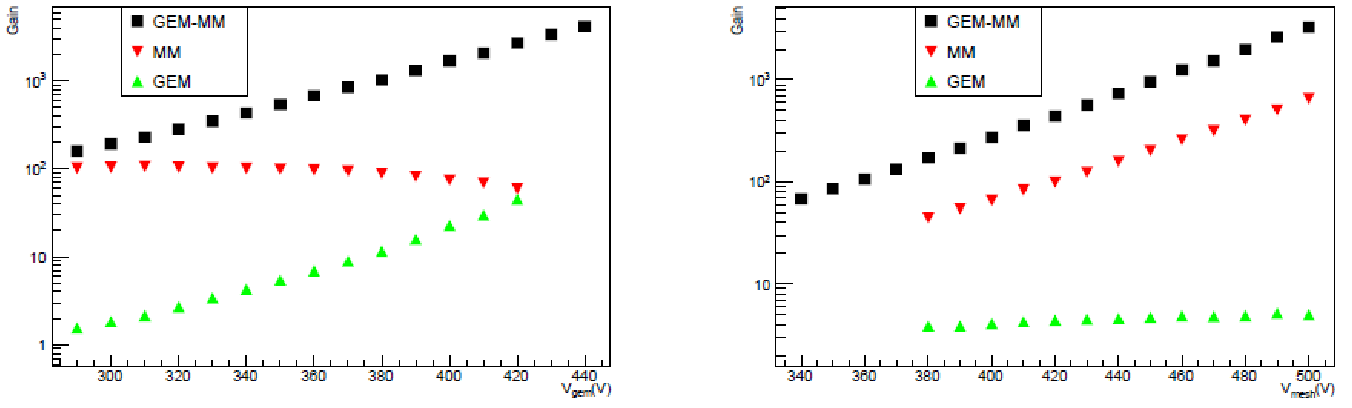
http://iopscience.iop.org/article/10.1088/1748-0221/9/04/C04025/pdf

https://www.sciencedirect.com/science/article/pii/S0168900216308221

High rate and lots of ions make space charge effect to decrease IBF value !!!

复合结构探测器（Hybrid detector）的选择

GEM+Micromegas模块测试：



(a) (b)

Gas gain versus GEM voltage, micromesh $V_{mesh} = 420V$ (a) and micromesh voltage, $V_{GEM} = 340V$ (b). $E_d = 250V/cm$, $E_t = 500V/cm$.

- 电荷灵敏前放：ORTEC 142IH
- 主放： ORTEC 572 A
- 多道：MCA of ORTEC ASPEC 927

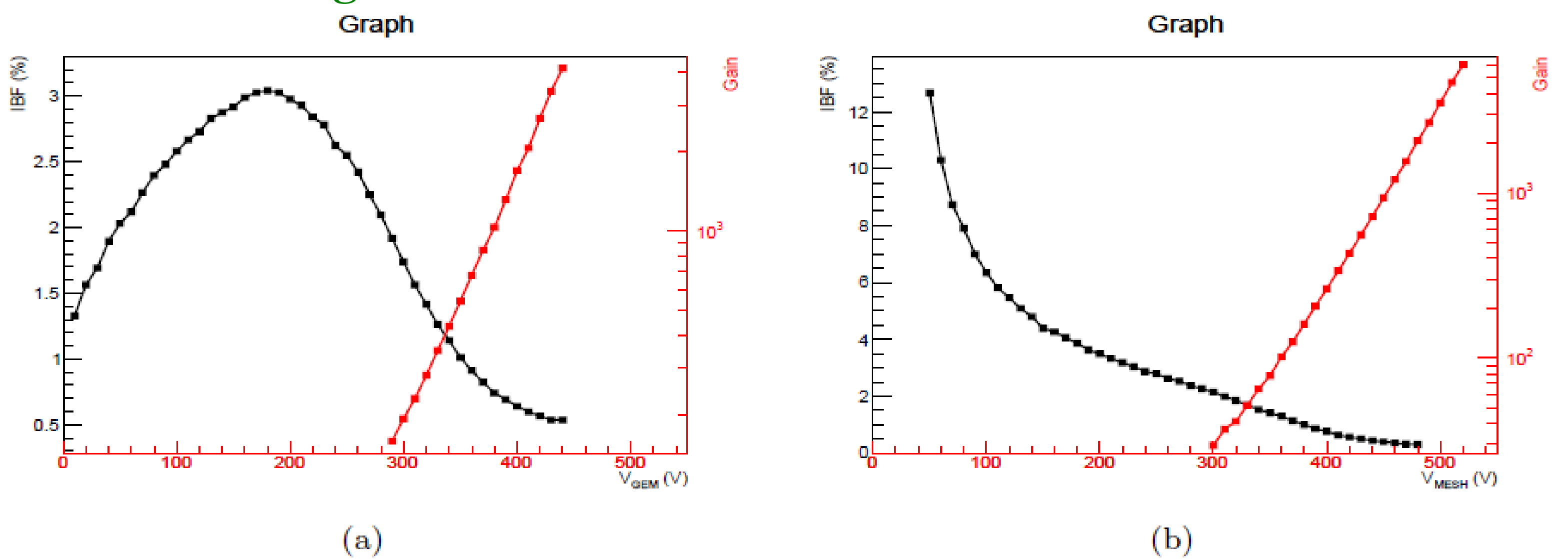
$$G_{GEM} = \frac{G_{GEM-MM}}{G_{MM}}$$

➡ G_{MM}，MM 全能峰
G_{GEM-MM}，GEM-MM 全能峰

- GEM的预防大保证GEM-MM可以达到较高增益
- 同时保证Micromegas工作在相对较低电压下
- 高增益下打火率显著降低
  增益5000时没有明显打火现象

复合结构探测器（Hybrid detector）的选择

GEM+Micromegas模块测试：



Gas gain and IBF versus (a): GEM voltage, micromesh $V_{mesh} = 420V$ and (b): micromesh voltage, $V_{GEM} = 340V$. $E_d = 250V/cm$, $E_t = 500V/cm$.

- 皮安表：**Keithley(6517B[13])**

$$\mathrm{IBF} = \frac{\mathrm{I_c} - \mathrm{I_{prim}}}{\mathrm{I_a}}$$

I_c,阴极电流（drift cathode），正比于阴极收集离子数
I_{prim}，漂移极初级电离电流（primary ion current）
I_a，阳极电流（anode pad），正比于阳极收集电子数

- **Micromegas的加入，提高增益的同时，降低了IBF**
- **IBF~0.2%，增益~5000**