Status of the continuous Ion Backflow suppression detector modules R&D

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Outline

- Physics requirement
- Critical challenges
- Some activities and progress
- Summary

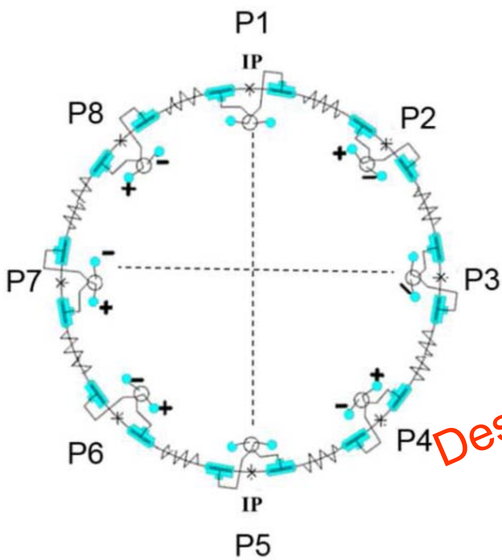
First question:

Why we need continuous IBF suppression in TPC module options?

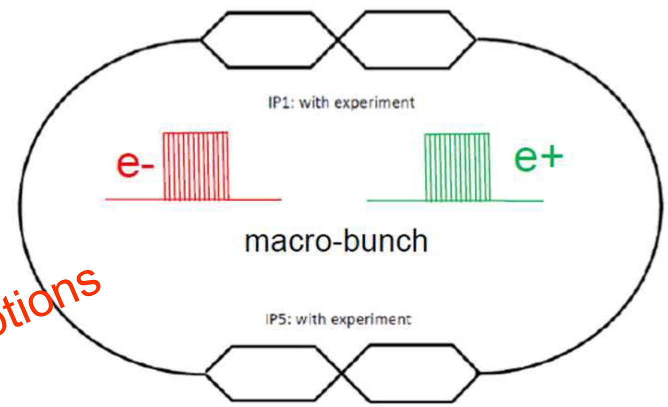
CEPC and its beam structure

Circular e^+e^- Higgs (Z) factory two detectors, **1M ZH events in 10yrs**

$E_{cm} \approx 240$ GeV, luminosity $\sim 2 \times 10^{34}$ $cm^{-2}s^{-1}$, can also run at the Z-pole



Preliminary
Design of the options



Pretzel Scheme

- **Baseline design in pre-CDR**
- **48 bunches / beam**
- **Colliding every 3.6μs, continuously**

→Power pulsing not applicable

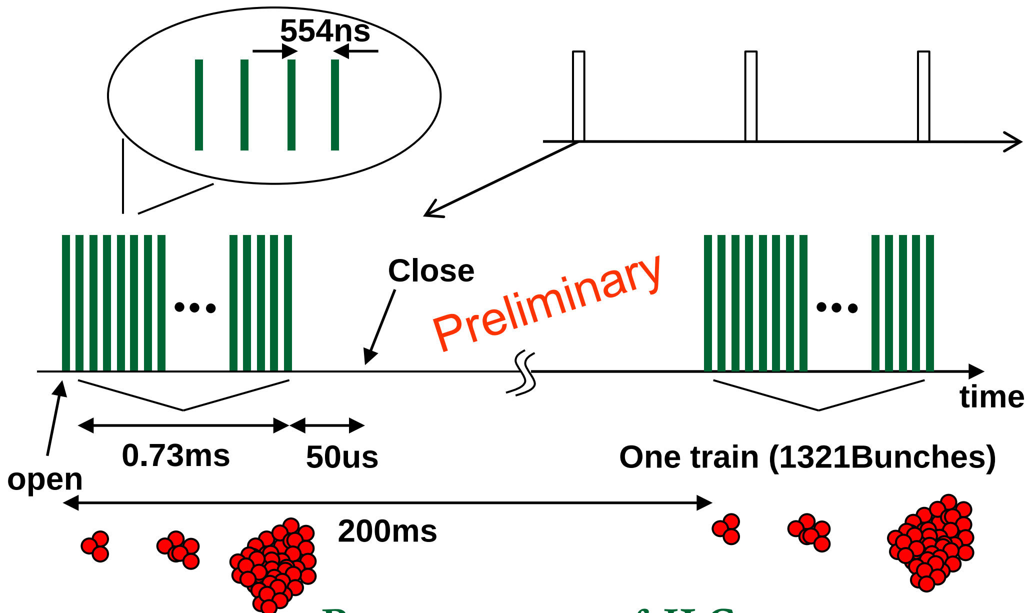
Partial Double-ring Scheme

- **Crab-waist collision to reduce beam and AC power**
- **Avoiding pretzel scheme to increase the flexibility and luminosity**
- **196ns bunch spacing**
- **48 bunches / train**
- **Duty cycle: 9.4μs/181μs**

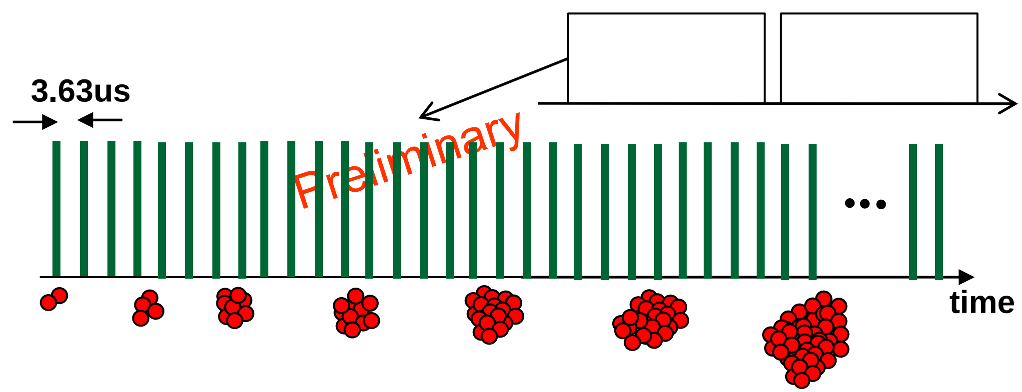
Reference: CEPC/SppC with ILC (FCC), J. Gao, LCWS 2015, Nov. 2-6, 2015, Canada

Compare with ILC beam structure

- In the case of ILD-TPC
  - Bunch-train structure of the ILC beam (one ~1ms train every 200 ms)
  - Bunches time ~554ns
  - Duration of train ~0.73ms
  - Used Gating device
  - Open to close time of Gating: 50μs+0.73ms
  - Shorter working time
- In the case of CEPC-TPC
  - Bunch-train structure of the CEPC beam (one bunch every 3.63μs) or partial double ring
  - No Gating device with open and close time
  - Continuous device for ions
  - Long working time



Beam structure of ILC



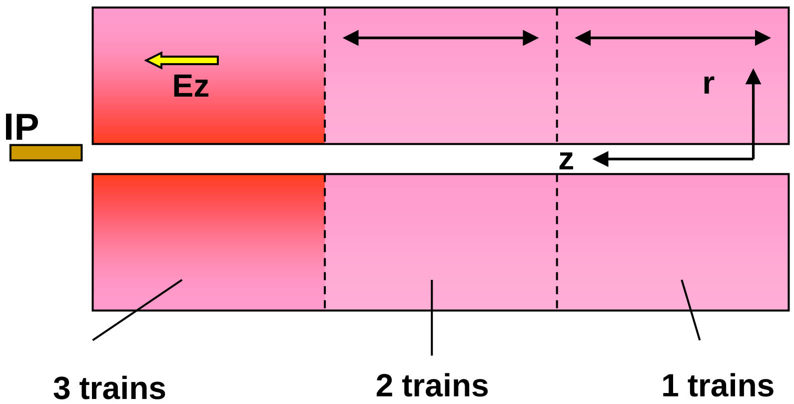
Beam structure of CEPC

Gating device could NOT be used due to the limit time!

Critical challenge: Ion Back Flow and Distortion

In the case of ILD-TPC

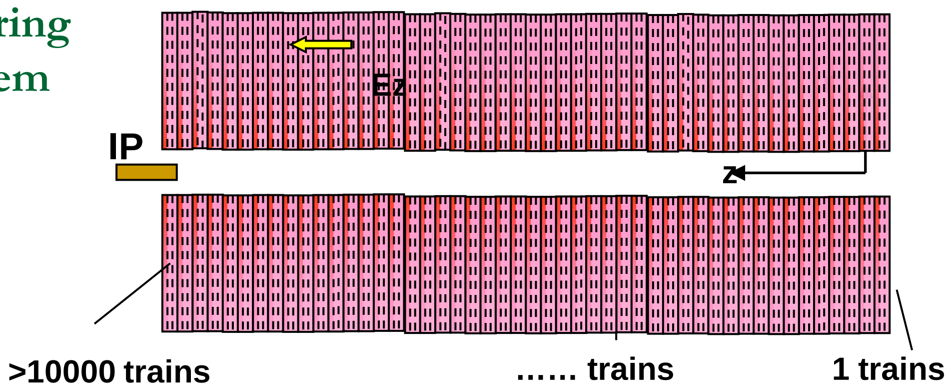
- Distortions by the primary ions at ILD are negligible
- Ions from the amplification will be concentrated in discs of about 1 cm thickness near the readout, and then drift back into the drift volume Shorter working time
- 3 discs co-exist and distorted the path of seed electron
- The ions have to be neutralized during the 200 ms period used gating system



Amplification ions@ILC

In the case of CEPC-TPC

- Distortions by the primary ions at CEPC are negligible too
- More than 10000 discs co-exist and distorted the path of seed electron
- The ions have to be neutralized during the ~4us period continuously



Amplification ions@CEPC

Requirements of Ion Back Flow /estimation

- Electron:
  - Drift velocity ~6-8cm/us@200V/cm
  - Mobility μ ~30-40000 cm^2/(V.s)
- Ion:
  - Mobility μ ~2 cm^2/(V.s)

  in a "classical mixture" (Ar/Iso)

$$S_N = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 S_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 S_{x_2}^2 + \left(\frac{\partial f}{\partial x_3}\right)^2 S_{x_3}^2}$$

Standard error propagation function

$$\sigma_{r\varphi/z}(z) = \sqrt{\sigma_{0,r\varphi/z}^2 + \frac{D_{t/l}^2}{N_{\mathrm{eff}} \cdot e^{-Az}} z}$$

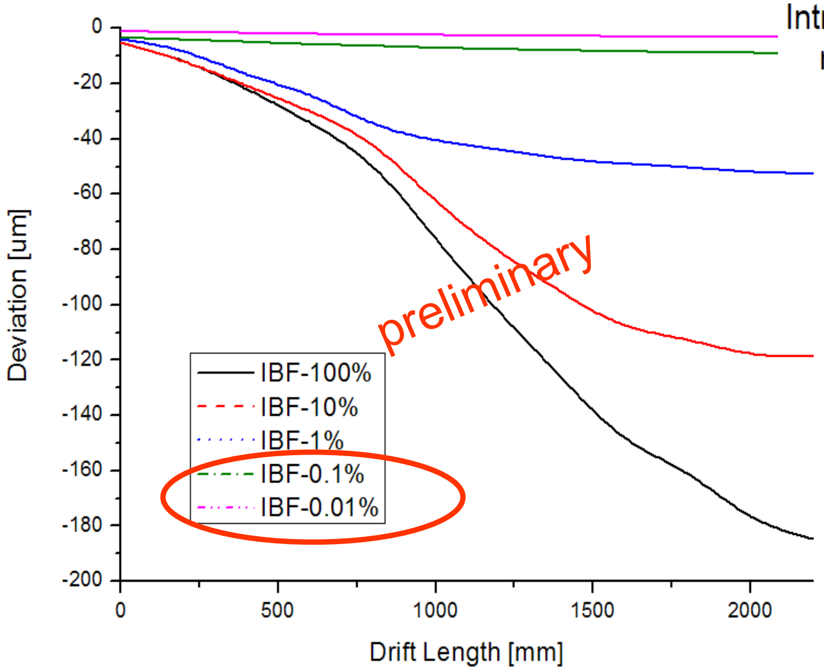
Transverse and

Intrinsic resolution of the readout at zero drift distance in rφ/z

Effective number of primary signal electrons

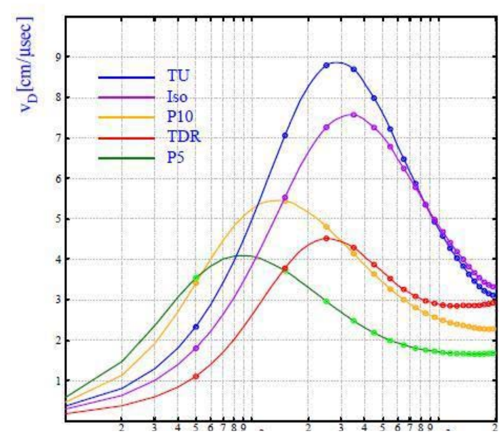
molecules during drift

Position resolution of the TPC function



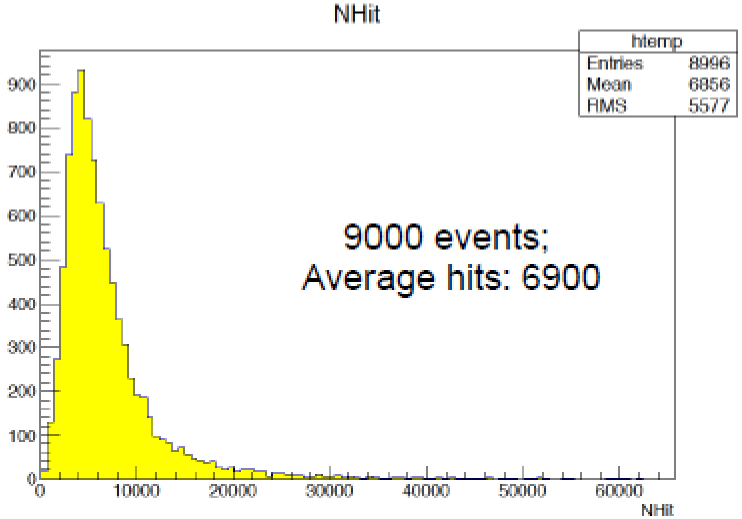
Neff=33
Gain=5000
Ar/Iso=95/5
5-6Tracks/Branch
r=400mm

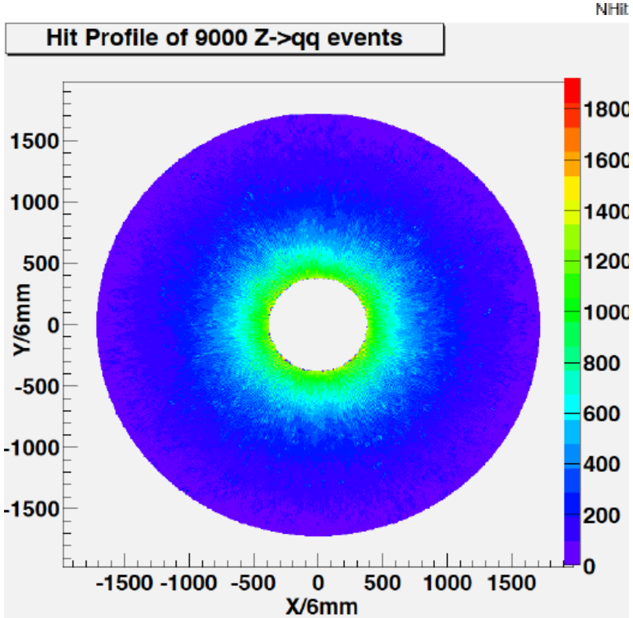
Evaluation of track distortions due to space charge effects of positive ions

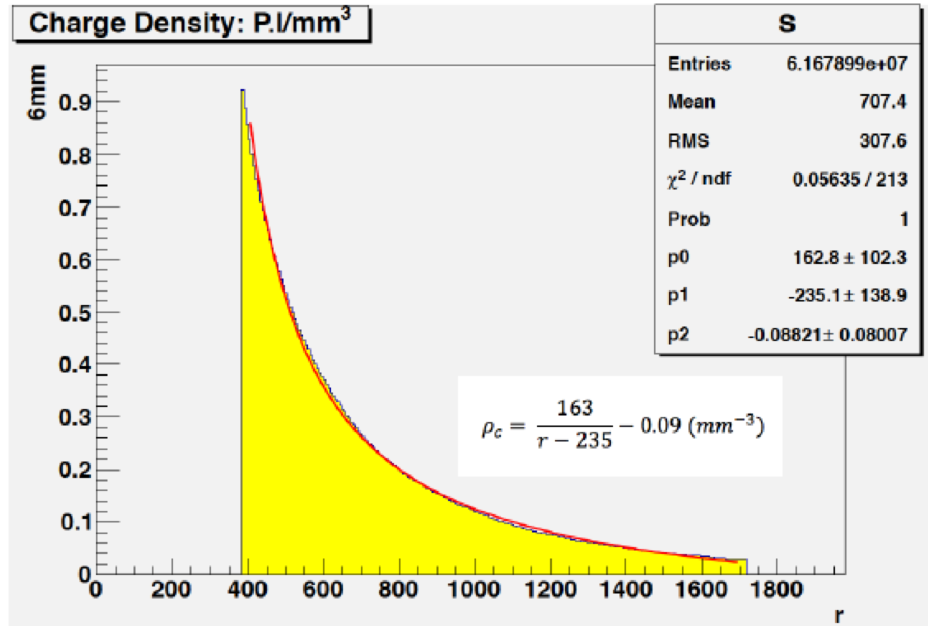


Simulated the drift velocity in different gas mixture

More further estimation for Z-pole /starting





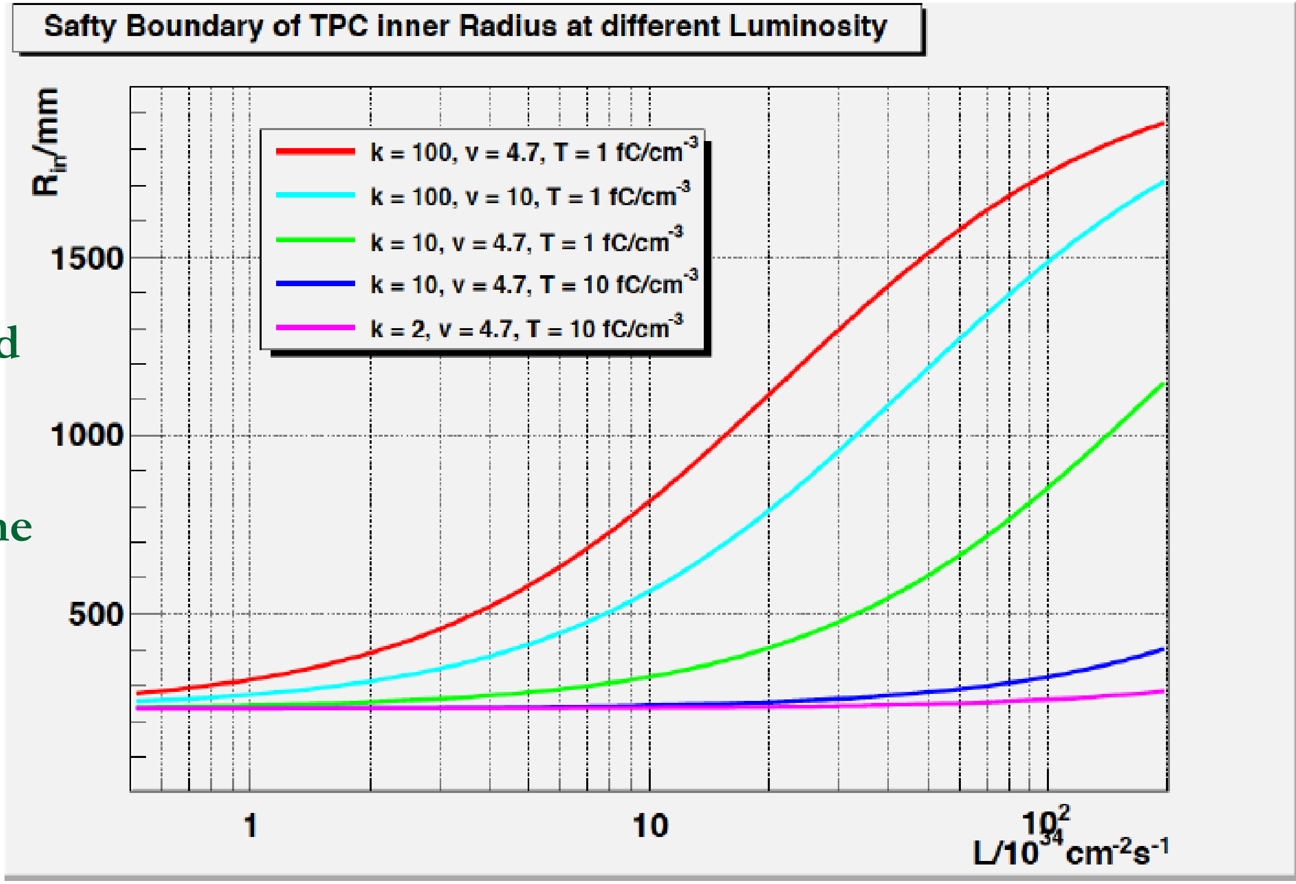


TPC Hit Profile of Full Simulated Z->qq events From Manqi's simu.

More further estimation for Z-pole /starting

If the Tolerance level ~1fC/cm^3 & k < 10 (the back flow ion is controlled to be less than 1 order of magnitude more than the P.I), should seemed be fine to use even at 2E36.

Very preliminary!
Other parameters need estimate carefully!

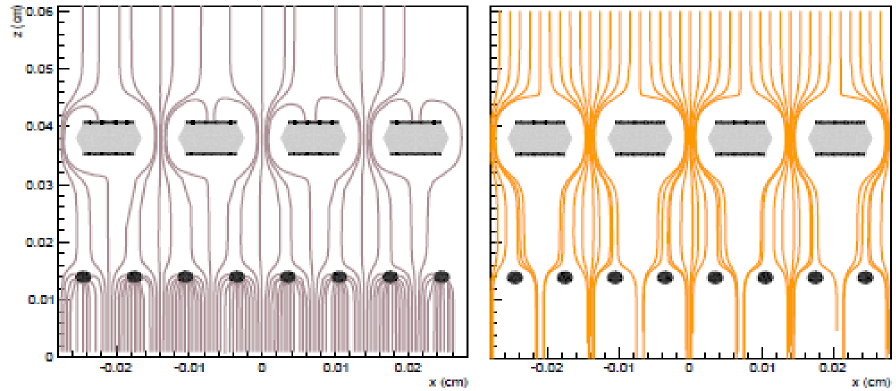


- k: ratio between back flow ion to the primary ionization;
- L: Luminosity Unit in $10^{34}cm^{-2}s^{-1}$;
- v: Drift velocity of ion, unit in $m{*}s^{-1}$;
- r: radius of the TPC test point, for instance TPC inner radius, unit in mm

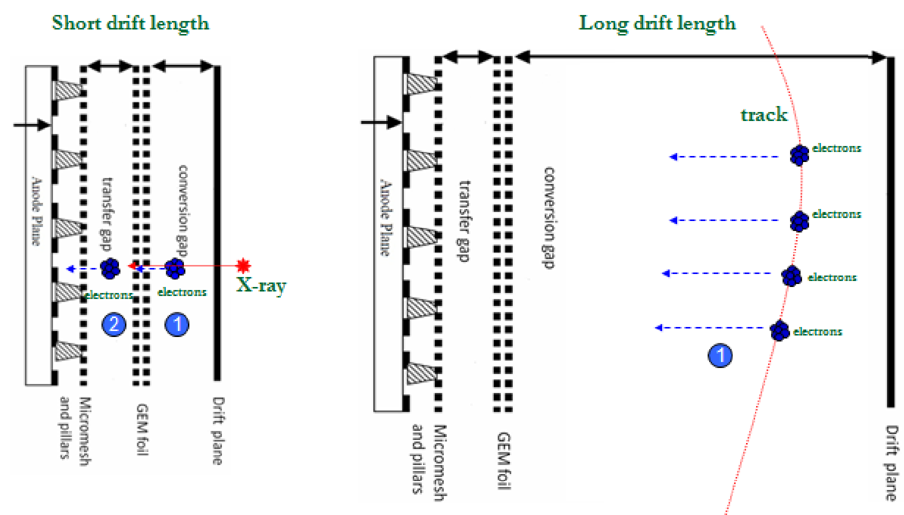
New ideas for the ions?

- Our group was asked to "think" on an alternative option for CEPC TPC concept design
- And we did our best …
- We proposed and investigated the performance of a novel configuration for TPC gas amplification: GEM plus a Micromegas (GEM+Micromegas)
- Hybrid micro-pattern gaseous detector module

- GEM+Micromegas detector module
  - GEM as the preamplifier device
  - GEM as the device to reduce the ion back flow continuously
  - Stable operation in long time
  - Low material budget of the module



ANSYS-Garfield++ simulation
(0T, Left: ions; Right: electrons)

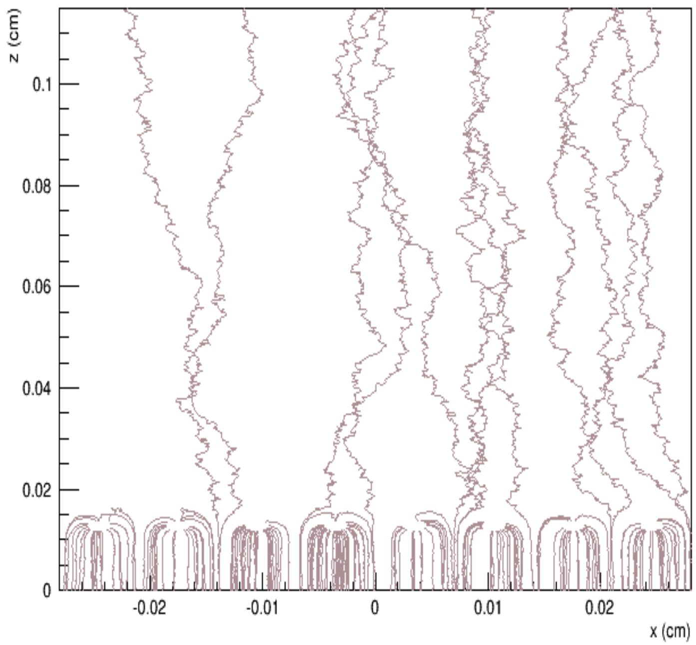


Hybrid detector

IBF simulation

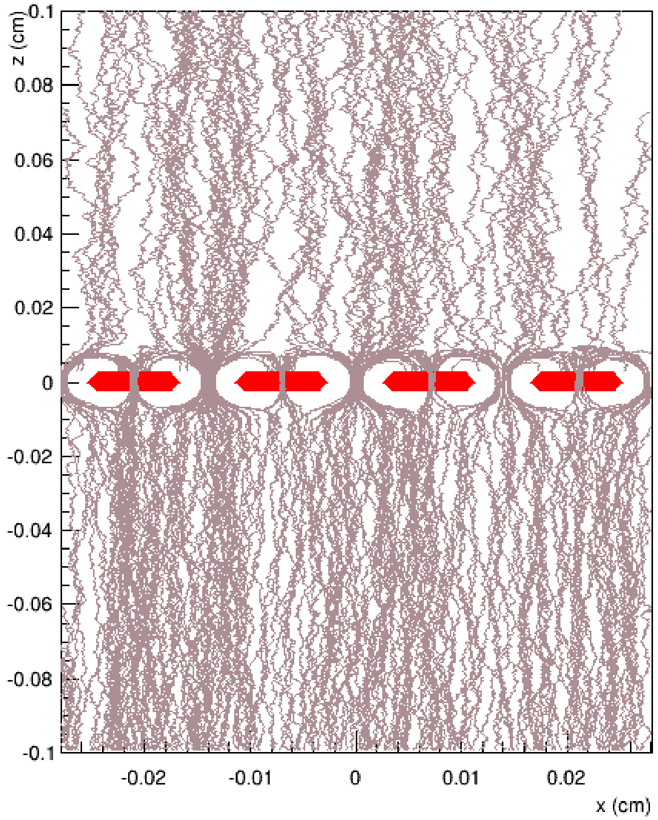
- Garfield++/ANSYS to simulate the ions back to drift
  - GEM and Micromegas Module using ANSYS
  - Record the ions to drift layer, mesh layer, and sensitive layer

Micromegas standalone



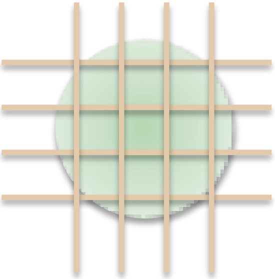
Ions not actually drift along electric field lines

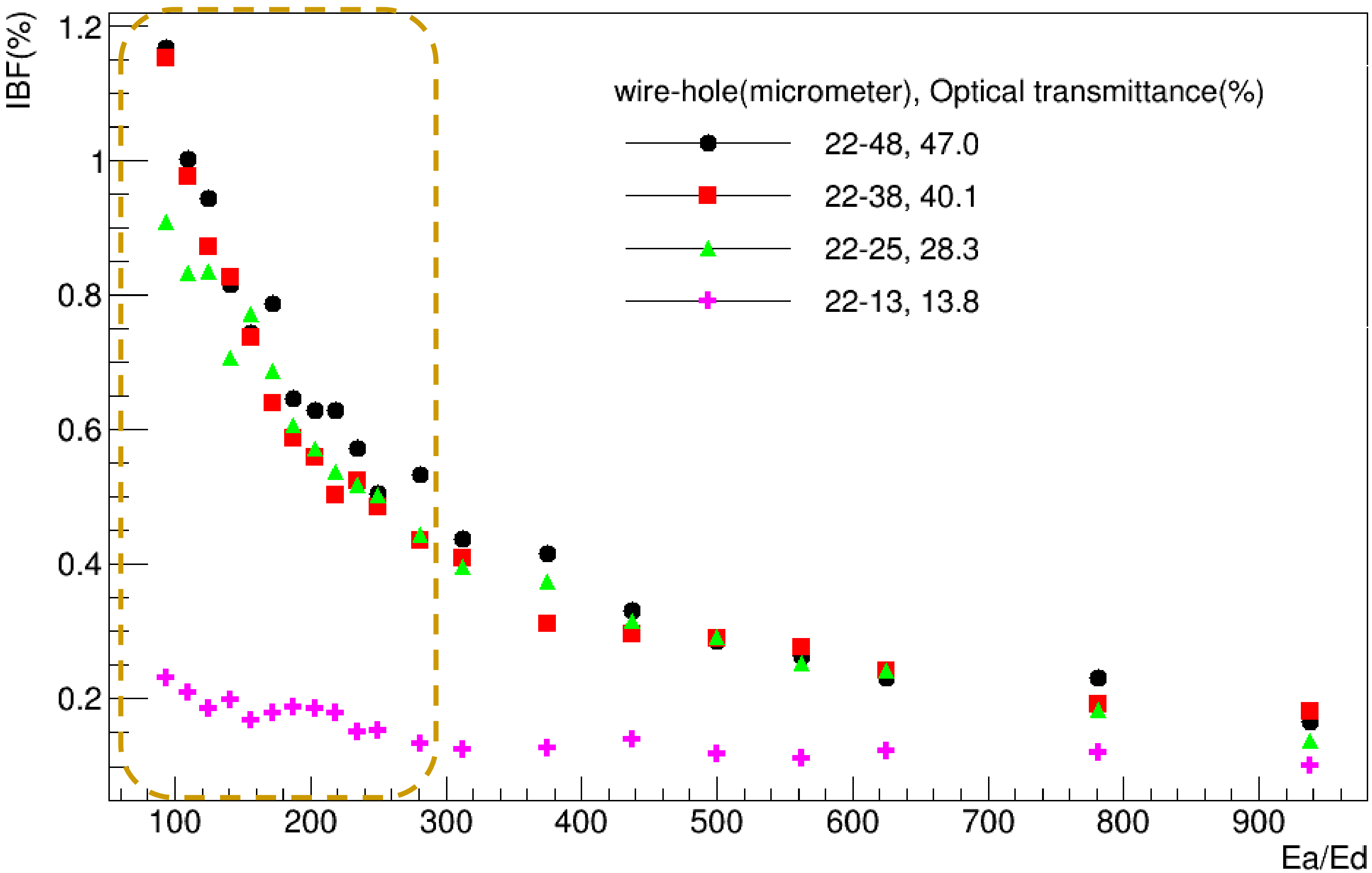
GEM Standalone



IBF simulation

- Garfield++/ANSYS to simulate the ions back to drift
  - 350LPI/ 420LPI/ 500LPI/ 1000LPI
  - Ea is electric field of amplifier of Micromegas

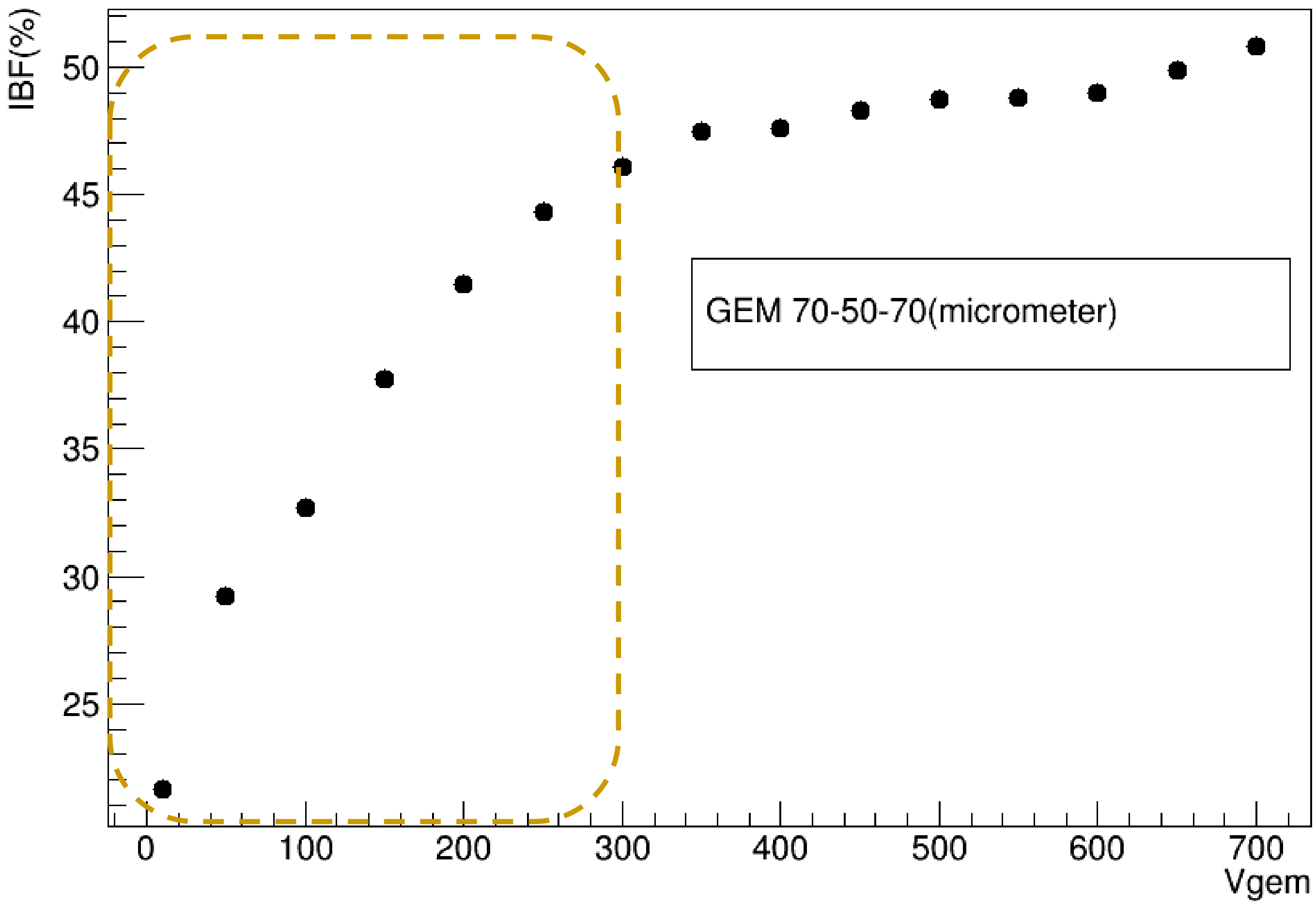




Electric field of amplifier VS Electric field of Drift

IBF simulation

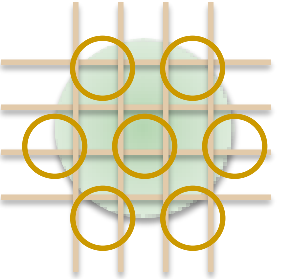
- Garfield++/ANSYS to simulate the ions back to drift
  - Standard GEM module (70-50-70)

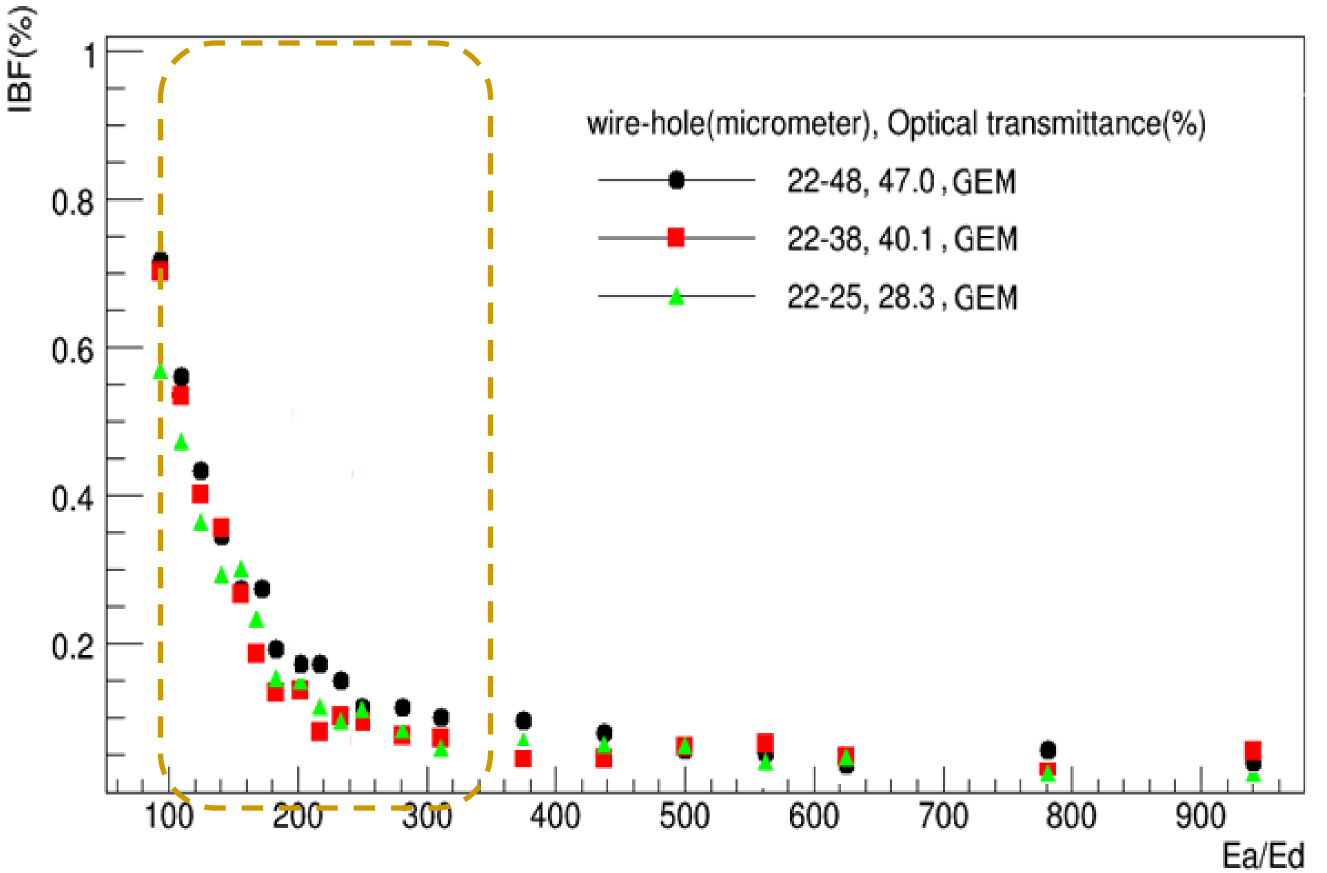


Voltage of the GEM detector

IBF simulation

- Garfield++/ANSYS to simulate the ions back to drift
  - 350LPI/ 420LPI/ 500LPI with GEM detector@150V
  - Ea is electric field of amplifier of Micromegas



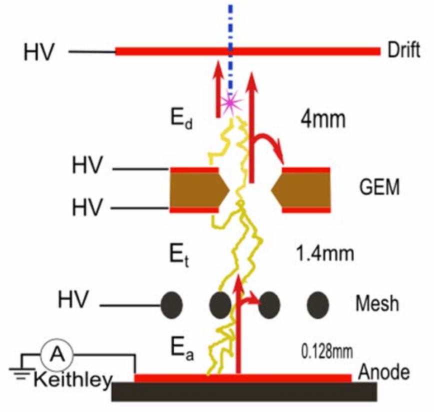


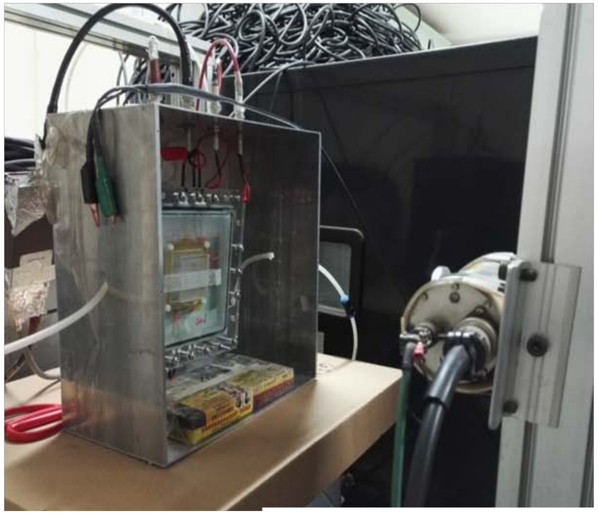
Electric field of amplifier VS Electric field of Drift

Test of the new module

Supported by 高能所创新基金

- Test of GEM+Micromegas module
  - Assembled with the GEM and Bulk-Micromegas
  - Active area: 50mm×50mm
  - X-tube ray and X-ray radiation source
  - Simulation using the Garfield
  - Ion back flow with the higher X-ray: from 1% to 3%
  - Stable operation time: more than 48 hours
  - Separated GEM gain: 1~10





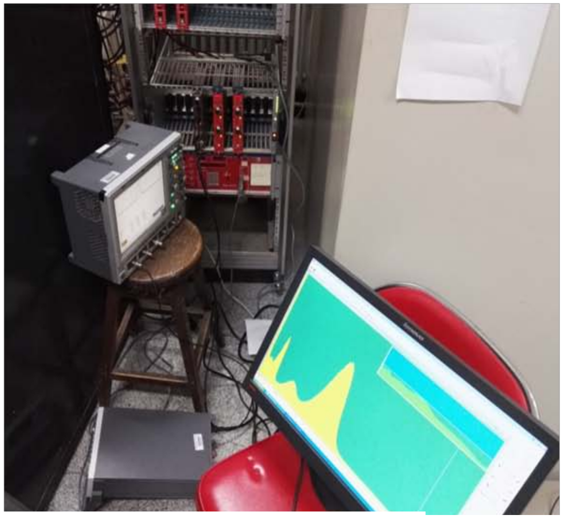
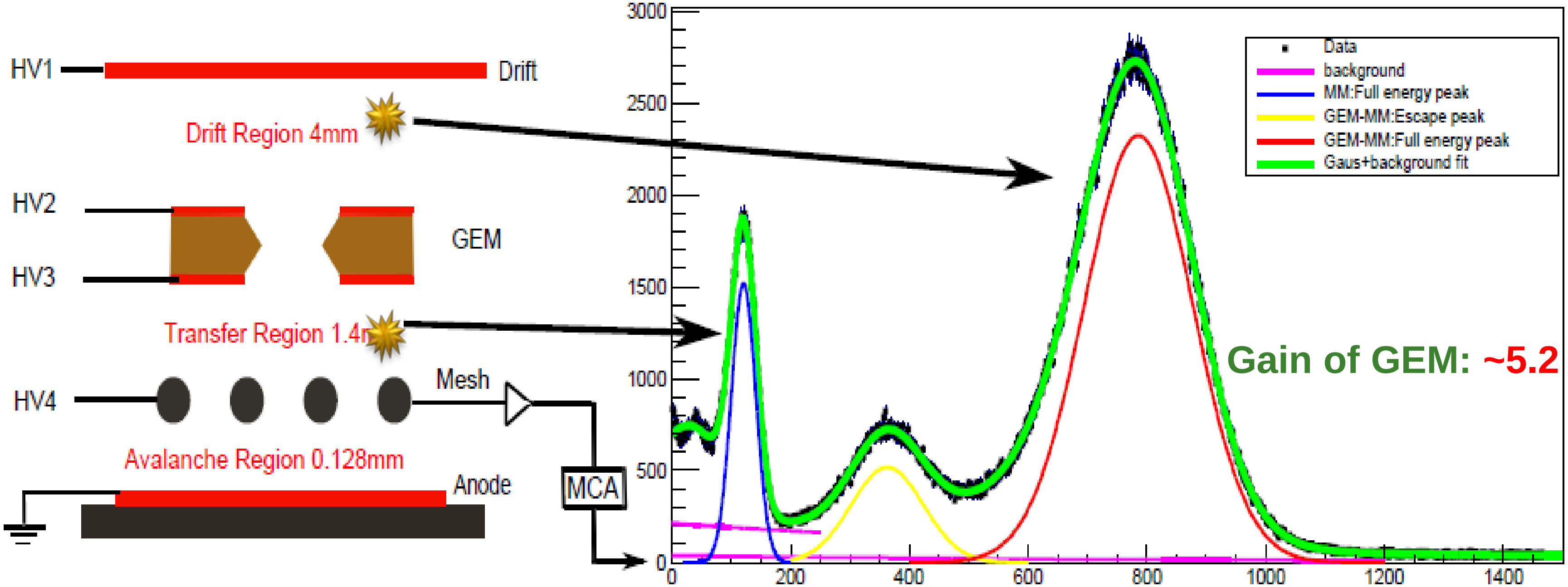


Photo of the GEM+Micromegas Module with X-ray

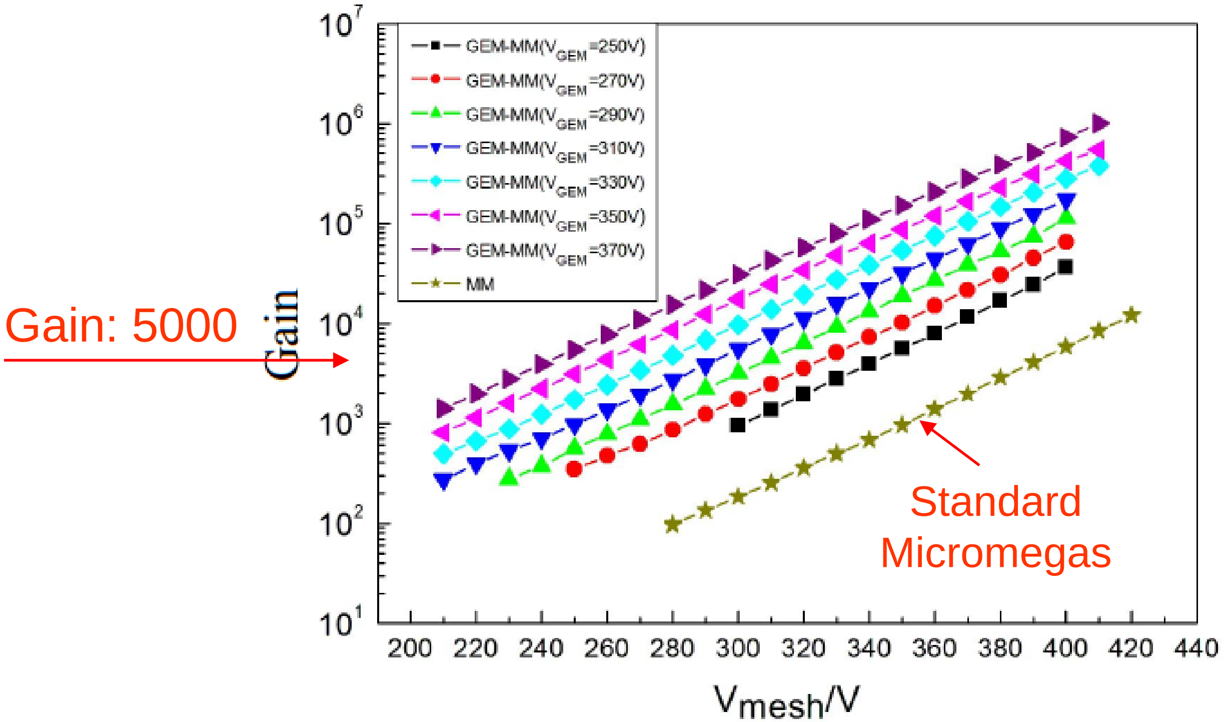
Energy spectrum@^{55}Fe

Source: ^{55}Fe, Gas mix: Ar(97) + iC_4H_{10}(3)



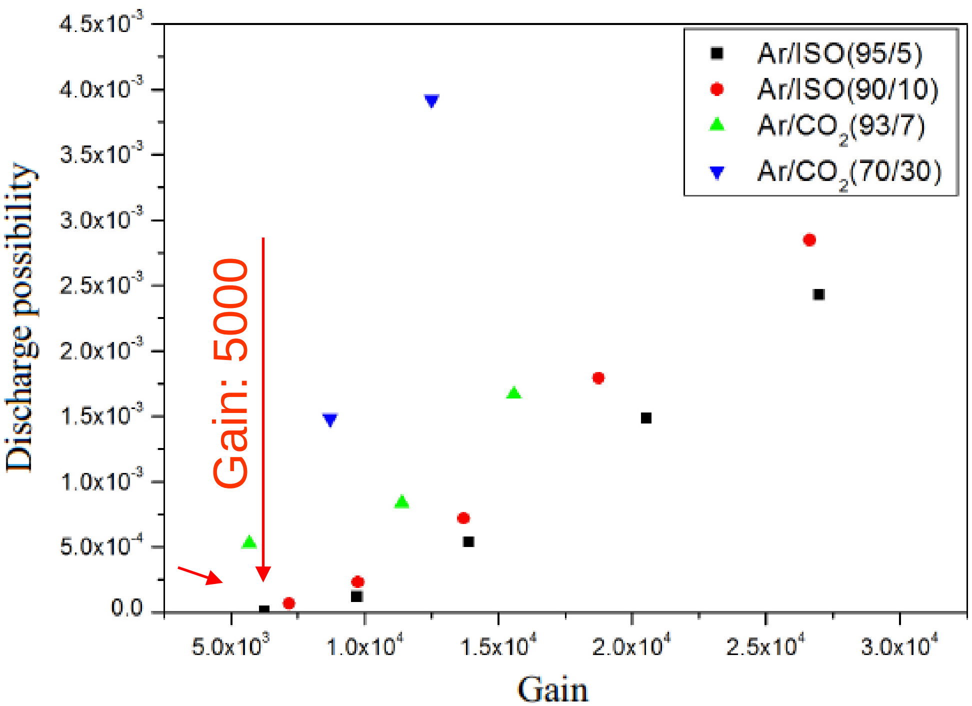
An example of the 55Fe spectra showing the correspondence between the location of an X-ray absorption and each peak.

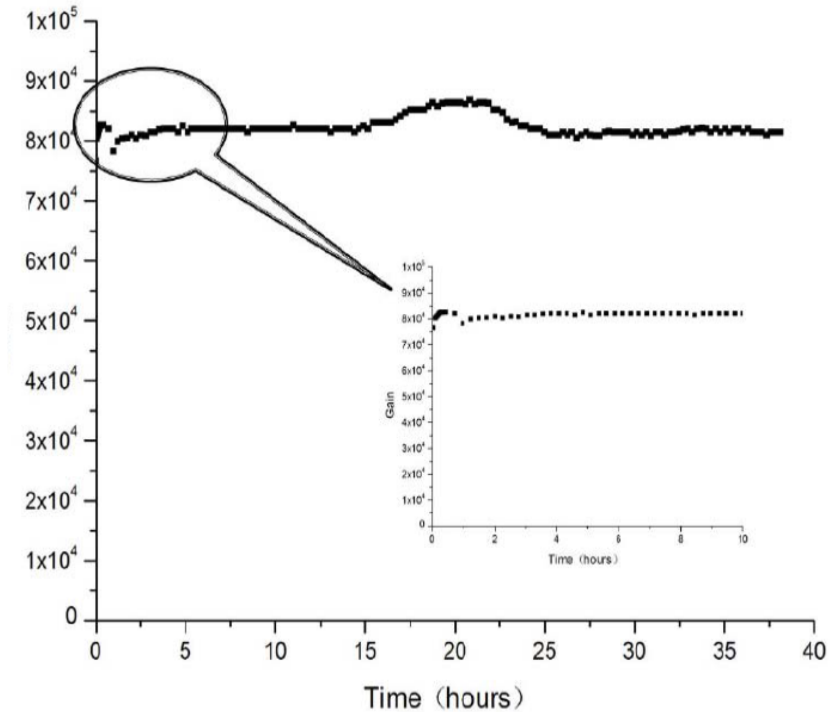
Gain of GEM + MM



- **Test with Fe-55 X-ray radiation source**
  - **Reach to the higher gain than standard Micromegas with the pre-amplification GEM detector**
  - **Similar Energy resolution as the standard Micromegas**
  - **Increase the operating voltage of GEM detector to enlarge the whole gain**

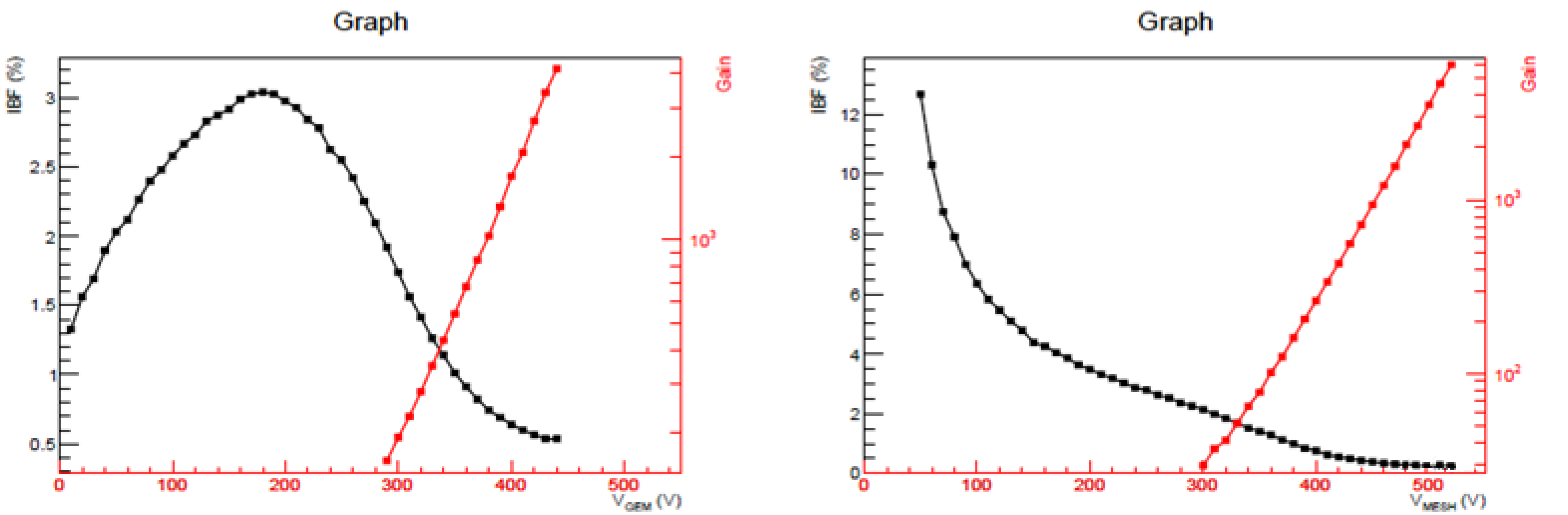
Discharge and working time





- Test with Fe-55 X-ray radiation source
  - Discharge possibility could be mostly reduced than the standard Bulk-Micromegas
  - Discharge possibility of hybrid detector could be used at Gain~10000
  - To reduce the discharge probability more obvious than standard Micromegas
  - At higher gain, the module could keep the longer working time in stable

IBF preliminary result



(a) (b)

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

- Test with X-tube@21kV~25kV using the Hybrid module
  - Charge sensitive preamplifier ORTEC 142IH
  - Amplifier ORTEC 572 A
  - MCA of ORTEC ASPEC 927
  - Mesh Readout
  - Gas: Ar-iC4H10(95-5)
  - Gain: ~6000

Contribution of the ions from the drift region to be γ, calculation of IBF, η:

$$I_{mesh} = G\gamma$$
$$I_c = \gamma + G\gamma\eta = \gamma + \eta\, I_{mesh}$$

G is the gas gain of the detector.

	GEM+MMG 420LPI (IHEP)	2GEMs + MMG 450 LPI (Yale University)	Micromegas only 450 LPI (Yale University)
Ion Back Flow	**0.1-0.2% Edrift = 0.25 kV/cm**	(0.3 –0.4)% Edrift = 0.4 kV/cm	(0.4 –1.5)% Edrift= (0.1-0.4) kV/cm
<GA>	**4000~5000**	2000	2000
ϵ-parameter(=IBF*GA)	**4~5**	6~8	8~30
E –resolution	**~16%**	<12%	<= 8%
Gas Mixture (2-3 components)	**Ar + iC4H10**	Ne+CO2+N2, Ne+CO2,Ne+CF4, Ne+CO2+CH4	X + iC4H10 (Ar+CF4+iC4H10)
Sparking (^{241}Am)	**<10^{-8}**	< 3.*10^{-7}(Ne+CO2) (N.Smirnov report)	~ 10^{-7} (S. Procureur report)
Possible main problem	**Thin frame**	More FEE channel	#
Goals	**CEPC TPC**	ALICE upgrade	#

Summary

- **Critical requirements for CEPC TPC modules**
  - Beam structure
  - Continuous Ion Back Flow

- **Some activities for the module**
  - IBF simulation of the detector have been started and further simulated.
  - The hybrid structure gaseous detector's IBF is just as one option.
  - Some preliminary IBF results of the continuous Ion Backflow suppression detector modules has been analyzed.
  - The IBF value would be estimated and the reasonable value would be studied.

Thanks very much for your attention !

1^{st} limit factor: Charge Density

$$\rho_c = 0.156(1+k)\frac{L}{V}\left(\frac{163}{r-235} - 0.09\right)$$

$$= (1+k)\frac{L}{V}\left(\frac{25}{r-235} - 0.0137\right)(mm^{-3})$$

$$= (1+k)\frac{L}{V}\left(\frac{4}{r-235} - 0.0022\right)\left(\frac{fC}{cm^3}\right)$$

- Quantity & Units:
  - *k: ratio between back flow ion to the primary ionization;*
  - *L: Luminosity Unit in $10^{34}cm^{-2}s^{-1}$;*
  - *v: Drift velocity of ion, unit in $m*s^{-1}$;*
  - *r: radius of the TPC test point, for instance TPC inner radius, unit in mm*