Simulation and investigation of the gaseous detector module for CEPC TPC

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Outline

- Physics requirements
- Status of TPC module R&D
- Plans and timeline
- Summary

Physics requirements

Collider concept

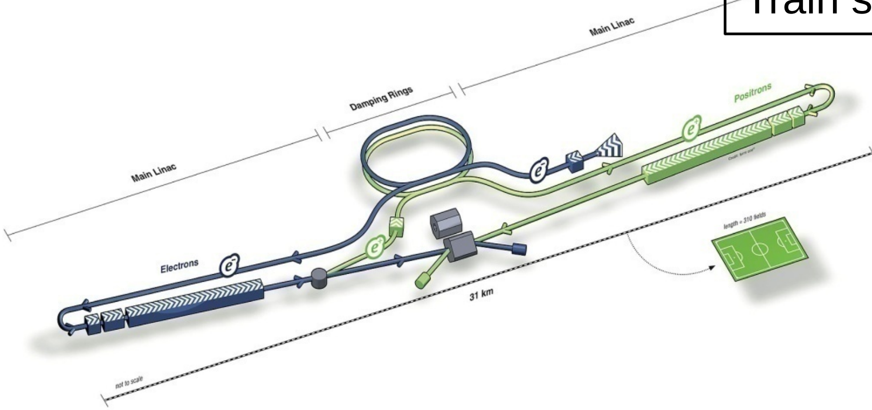
Circular e^+e^- Higgs (Z) factory with two detectors, 1M ZH events in 10yrs

E_{cm} ≈240 GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, can also run at the Z-pole

Circumference: ~100km

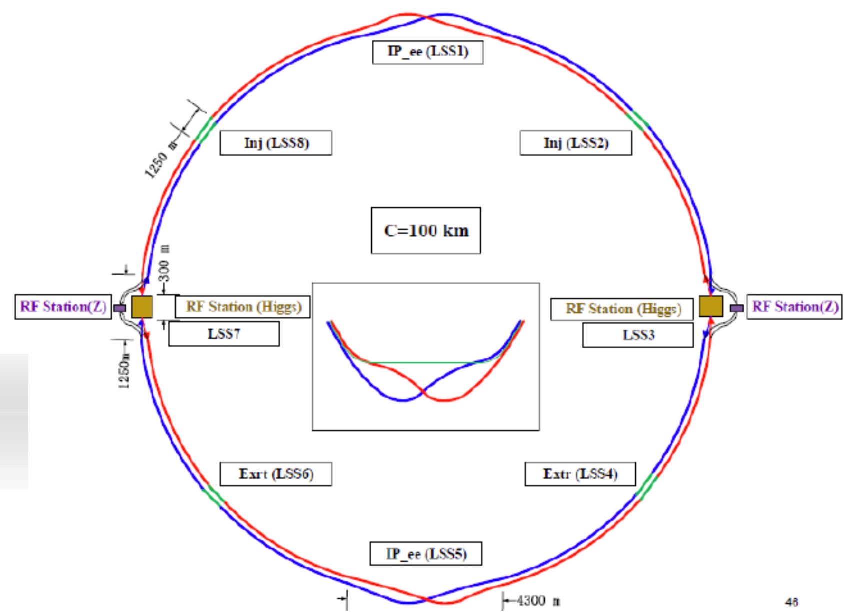
Updated on January, 2017

	tt	H	W	Z
Beam Energy [GeV]	175	120	80	45.5
Bunches / beam	98	555	3000	65716
Train spacing [us]	**83.5**	**83.5**	**84**	**98.6**



international linear collider

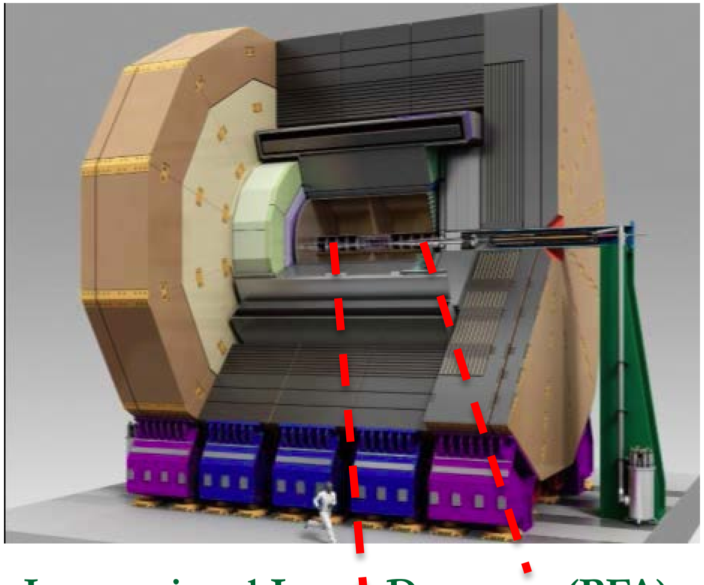
FCC hh ee he



Layout of CEPC Double Ring

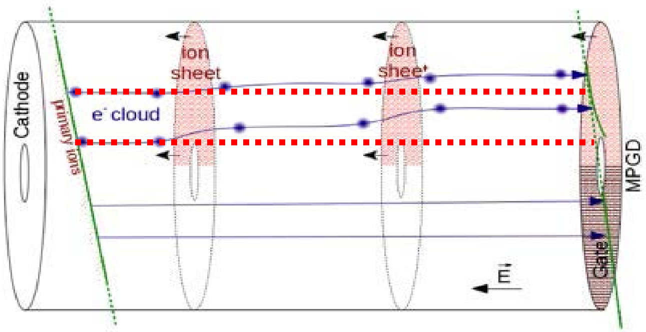
Detector concept

- One option in CEPC detector concept
- Motivated by the H tagging and Z
- Main tracker detector with TPC
- ~3 Tesla magnetic field
- ~100 μm position resolution in rφ
- Systematics precision (<20 μm internal)
- Large number of 3D points(~220)
- Distortion by IBF issues

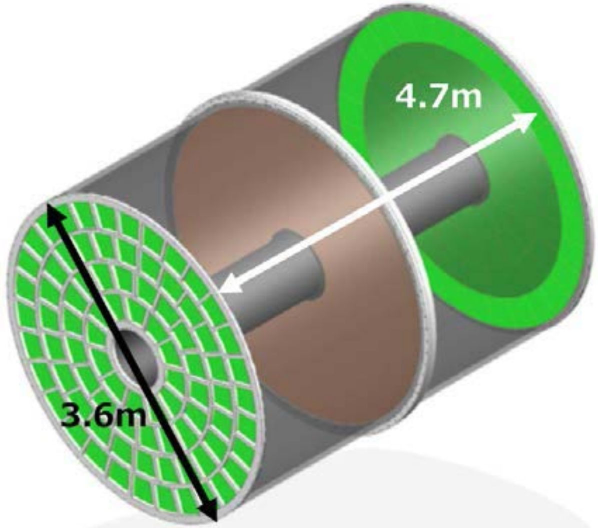


International Large Detector (PFA)

- Momentum resolution:
  - → $\delta(1/p_T) \leq 9 \times 10^{-5}\mathrm{GeV}^{-1}$
- Single hit resolution:
  - → $\sigma(r\phi) \leq 100\mu m$ (overall)
  - → $\sigma(Z) \simeq 400\mu m$ at z=0
- Tracking efficiency:
  - → 97% for $p_T \geq 1\mathrm{GeV}$
- dE/dx resolution: 5%



Ions backflow in drift volume for distortion

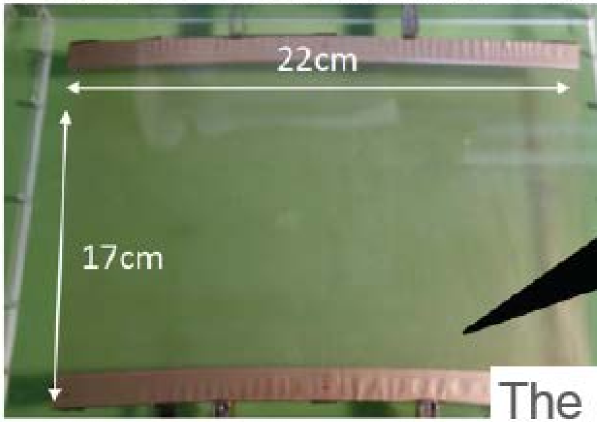


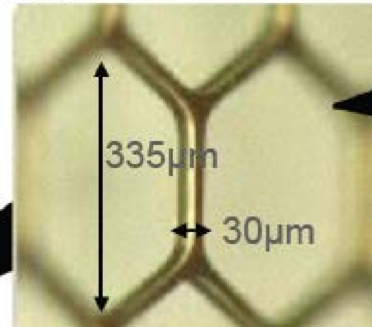
TPC detector concept

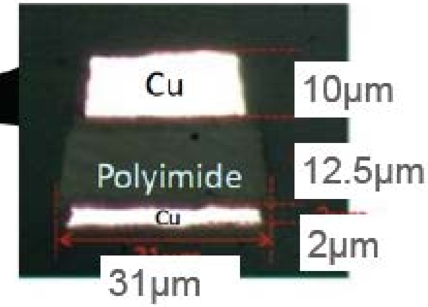
GEM gating in KEK@LCTPC

GEM as a gate ＝a large aperture GEM-like gating device (gating GEM)

The joint development with FUJIKURA



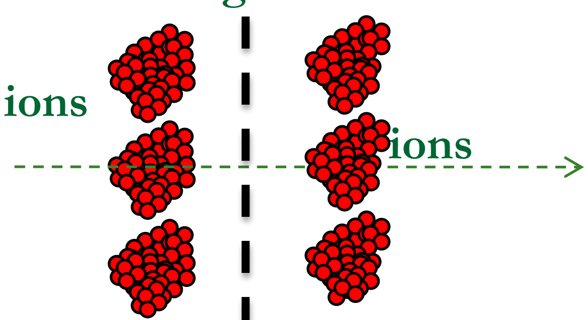


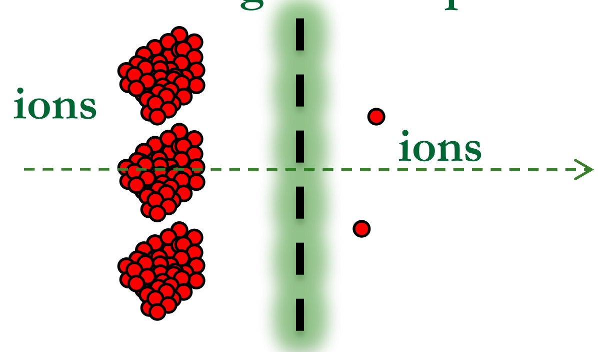


honeycomb structure

The optical transparency= 82 % 25 µm thick

Though gating GEM stop positive ions, should not stop electron too.→Electron transmission trate is important



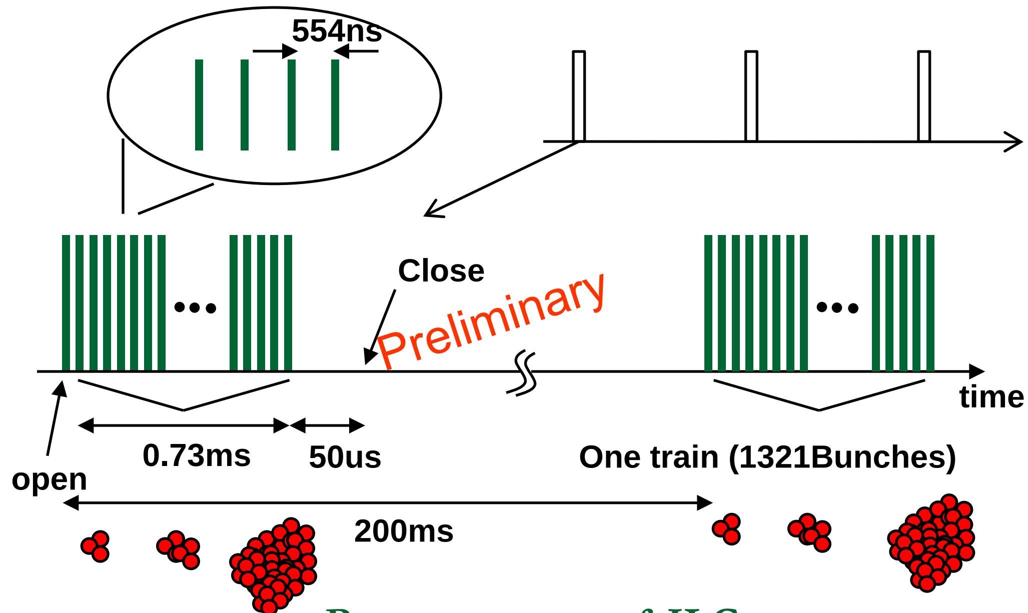


Open and close time of gating device for ions

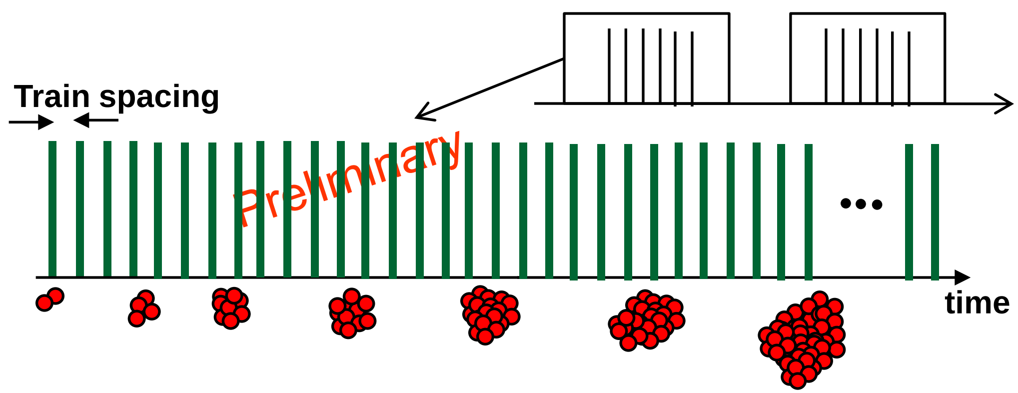
Compare with ILC beam structure

Haiyun, Yulian, Huirong

- 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 ~90μs) or partial double ring
  - No Gating device with open and close time
  - Continuous device for ions
  - Long working time



Beam structure of ILC



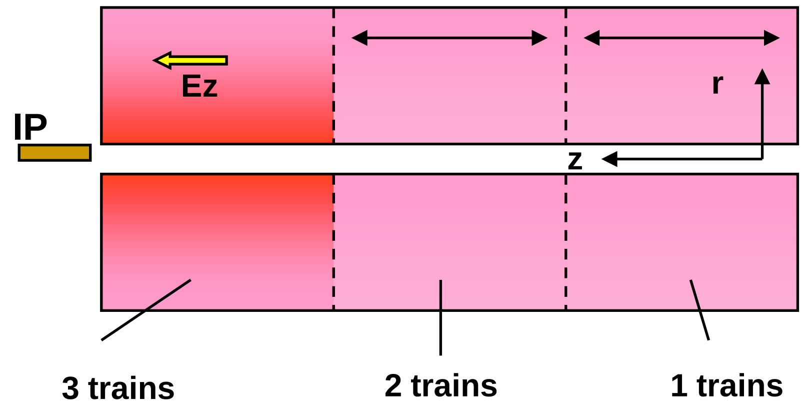
Beam structure of CEPC

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

Critical challenge: Ion Back Flow and Distortion

In the case of ILD-TPC

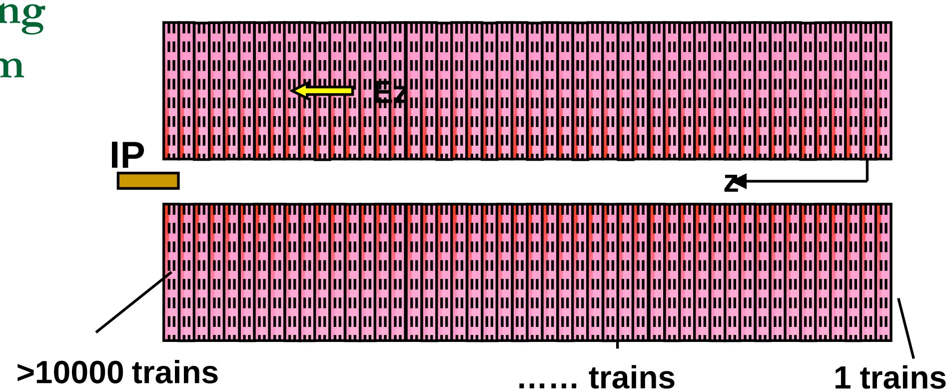
- Distortions by the primary ions at ILD are negligible
- Ions from the amplification will be concentrated in discs of about 1 cm thickness near the readout, and then drift back into the drift volume Shorter working time
- 3 discs co-exist and distorted the path of seed electron
- The ions have to be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

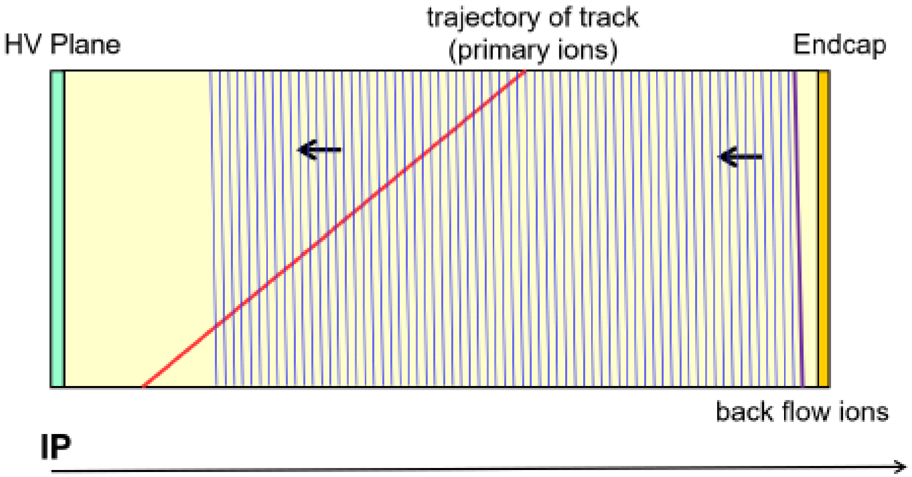


Amplification ions@CEPC

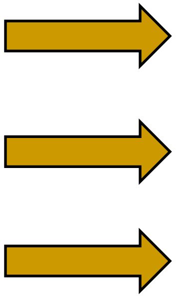
Simulation study of IBF for CEPC

Operation gas mixture

- Estimation in Z pole run:
  - Luminosity: ~2×10^{34} $cm^{-2}s^{-1}$
  - Z→*qq* in half length: ~300Hz per IP (Full simulation)
  - Velocity
    - Clearing time in drift length
  - Neutron absorption
    - Background in IP
    - Beam lost



Ions disk in the drift length

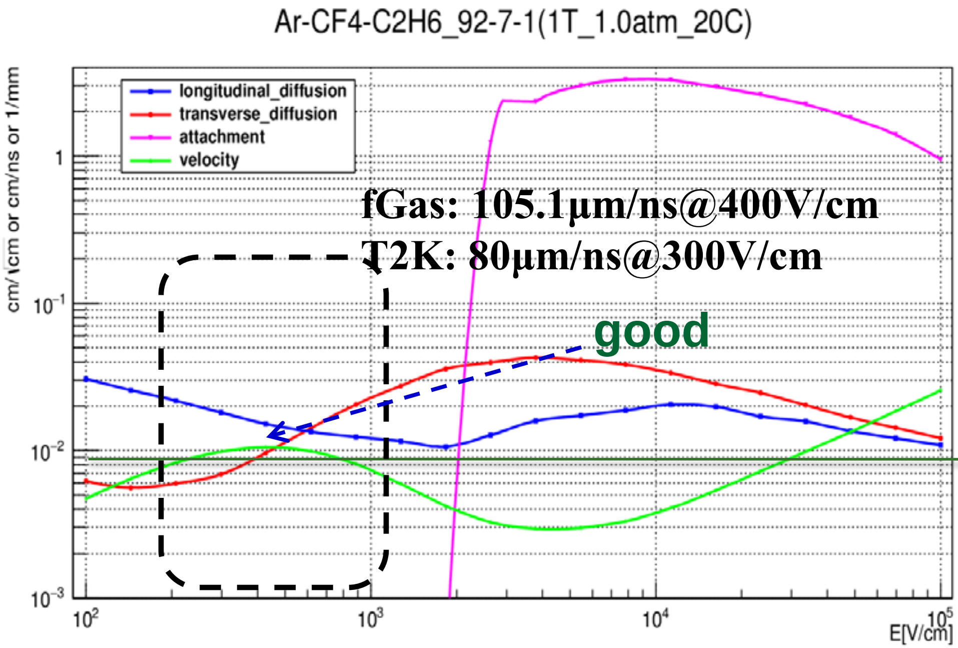


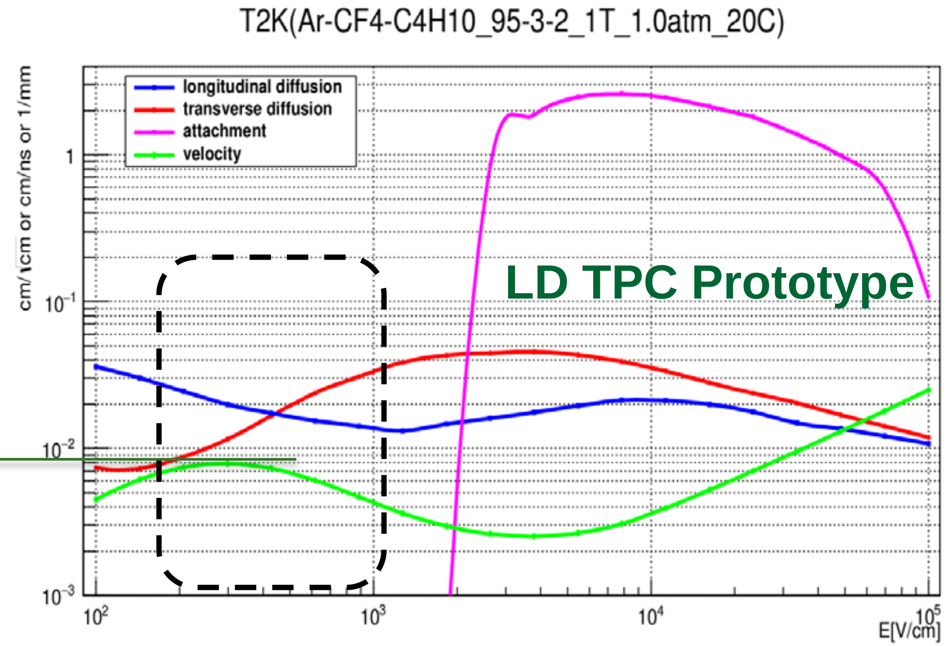
Fast velocity

Low diffusion

Low hydrogen content

Choosing a gas mixture – simulation





Ar-CF4-C2H6 gas **T2K gas**

fGas (Ar-CF4-C2H6=92:7:1) VS T2K(Ar-CF4-iC4H10=95:3:2)

------ fGas was seemed that a better working gas for the continuous beam structure

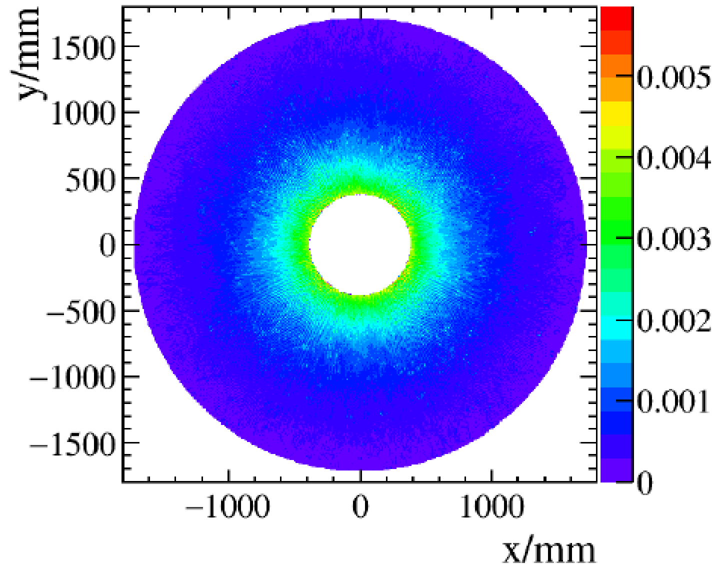
------ More works will be for the new mixture working gas

High rate at Z pole

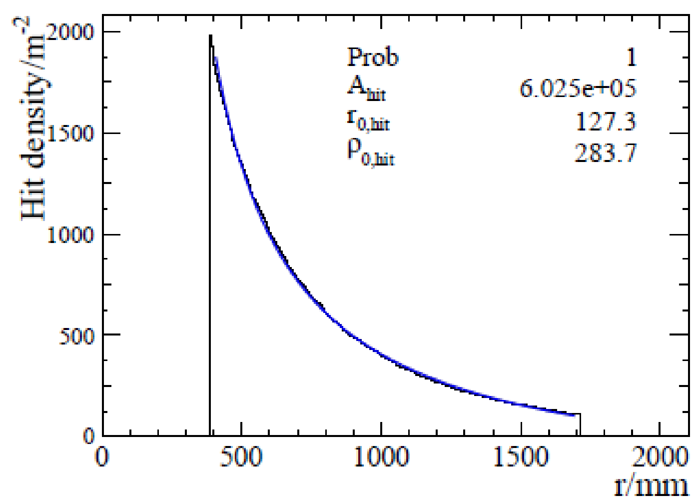
ArXiv: 1704.04401

- Voxel occupancy
  - The number of voxels /signal
  - 9 thousand Z to qq events
  - 60 million hits are generated in sample
  - 4000-6000 hits/(Z to qq) in TPC volume
  - Average hit density: 6 hits/mm^2
  - Peak value of hit density: 6 times
  - Voxel size: 1mm×6mm ×2mm
  - 1.33×10^{14} number of voxels/s @DAQ/40MHz
  - Average voxel occupancy: 1.33×10^{-8}
  - Voxel occupancy at TPC inner most layer: ~2×10^{-7}
  - Voxel occupancy at TPC inner inner most layer : ~2×10^{-5} @FCCee benchmark luminosity

The voxel occupancy takes its maximal value between 2×10^{-5} to 2×10^{-7}, which is safety for the Z pole operation.



Hit map on X-Y plan for Z to qq events



Hit density as a function of radius

Requirements of Ion Back Flow

Manqi, Mingrui, Huirong

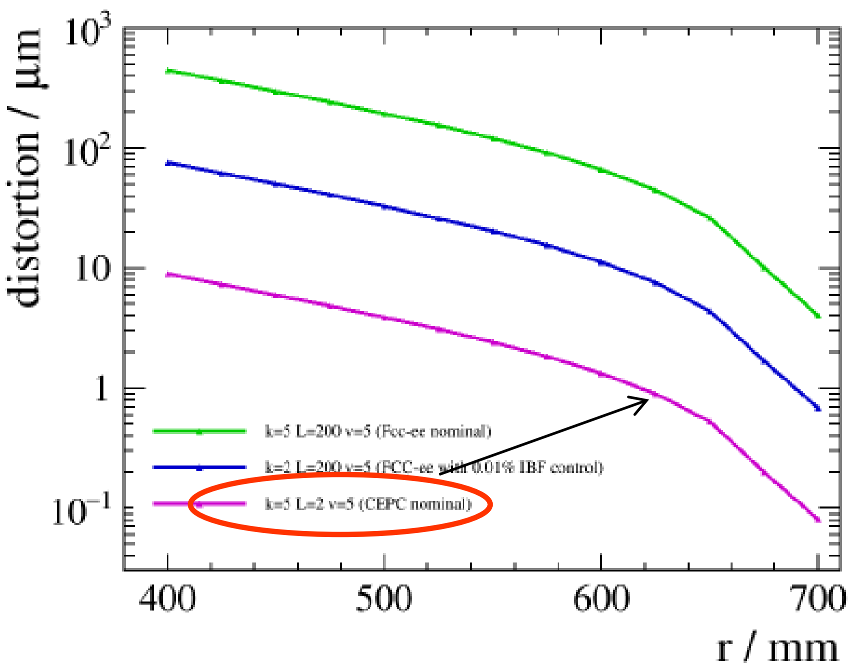
- Electron:
  - Drift velocity ~6-8cm/us@200V/cm
  - Mobility μ ~30-40000 $cm^2/(V.s)$
- Ion:
  - Mobility μ ~2 $cm^2/(V.s)$

  in a "classical mixture" (Ar/Iso)

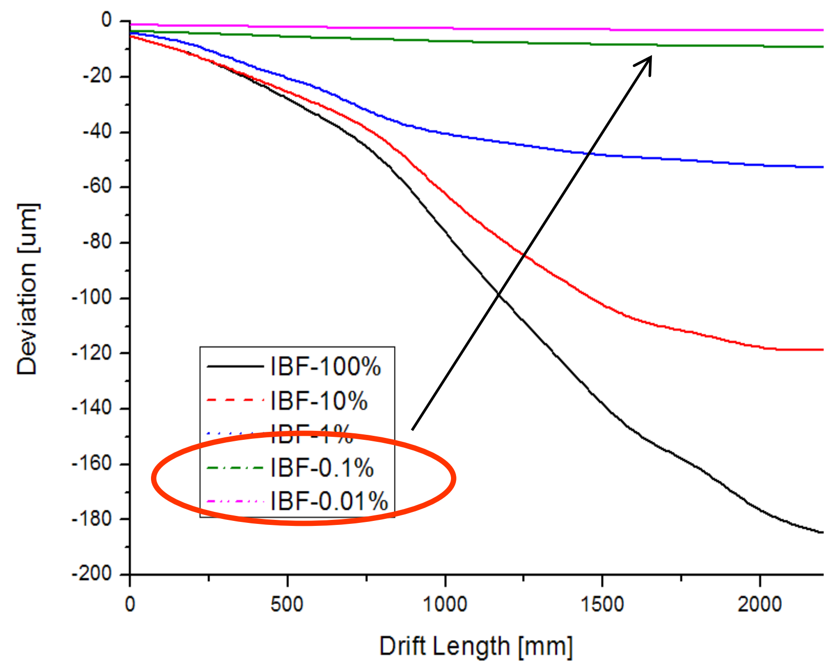
$$S_N = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 S_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 S_{x_2}^2 + \left(\frac{\partial f}{\partial x_3}\right)^2 S_{x_3}^2}$$

Standard error propagation function

Key prameters:
Neff=30/ Gain=5000 /T2K gas
Z pole run@10^{34}
r=400mm /k=IBF*Gain=5



Distortion of as a function of electron initial r position

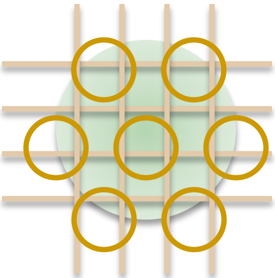


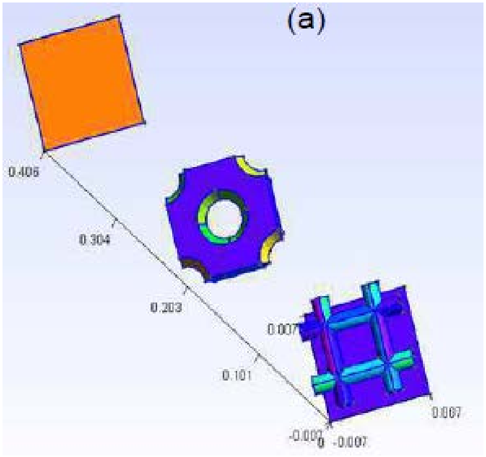
Evaluation of track distortions due to space charge effects of positive ions

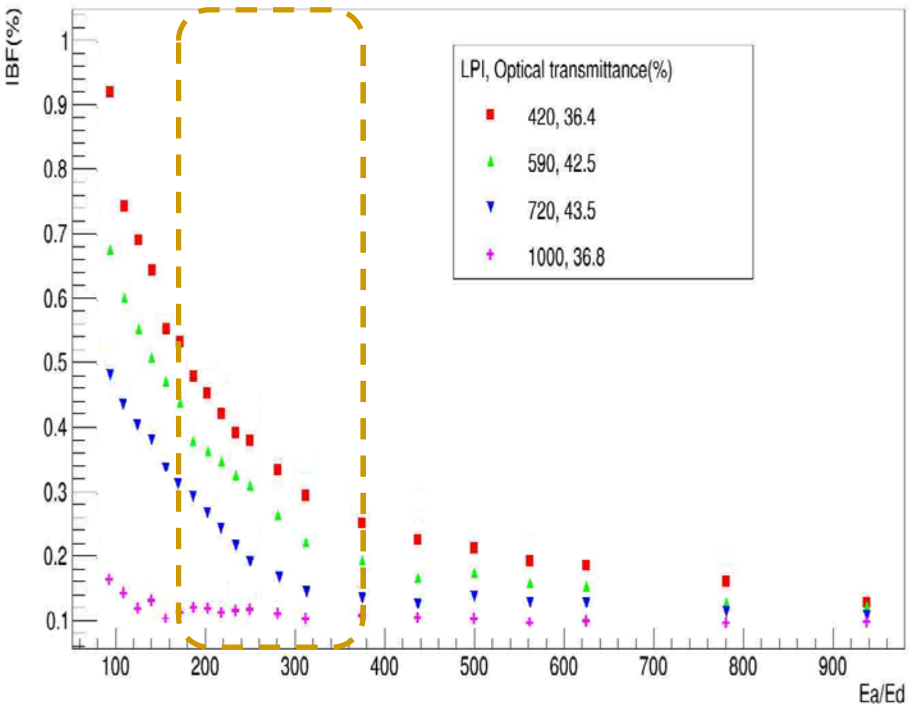
IBF simulation

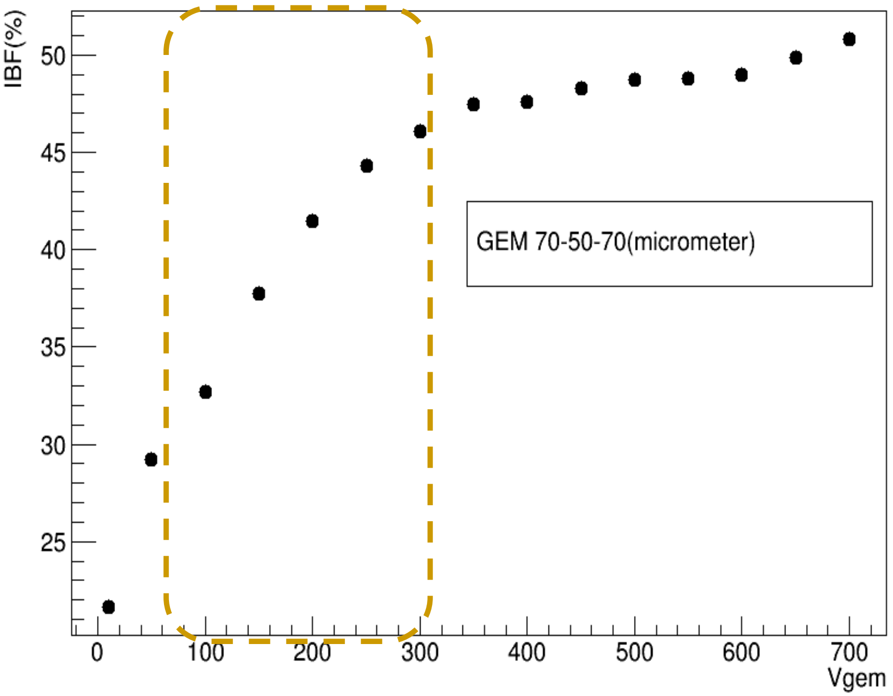
Yulian, Haiyun, Huirong

- Garfield++/ANSYS to simulate the ions back to drift
  - 420LPI/ 590LPI/ 720LPI/1000LPI
  - Ea is electric field of amplifier of Micromegas
  - Standard GEM module (70-50-70)







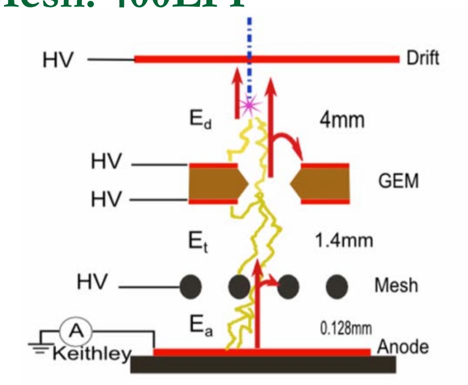


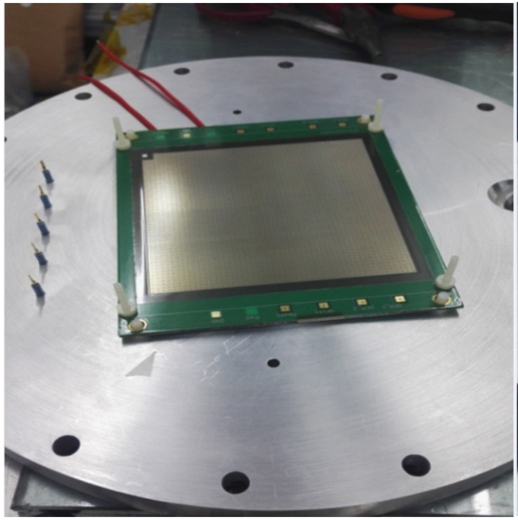
Electric field of amplifier VS Electric field of Drift and VGEM

Investigation of IBF study

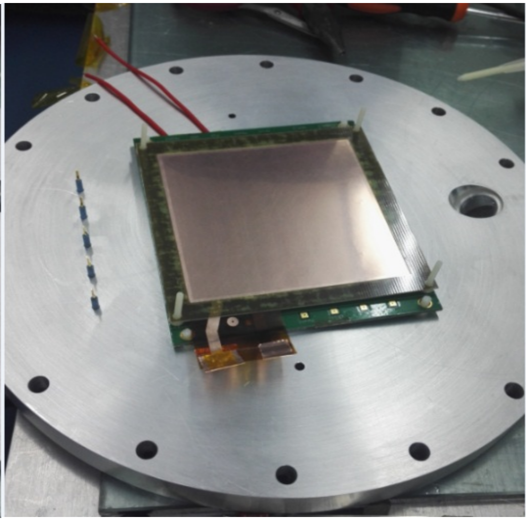
Test of the new module

- 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
  - Additional UV light device
  - Avalanche gap of MM:128μm
  - Transfer gap: 2mm
  - Drift length:2mm~200mm
  - Mesh: 400LPI

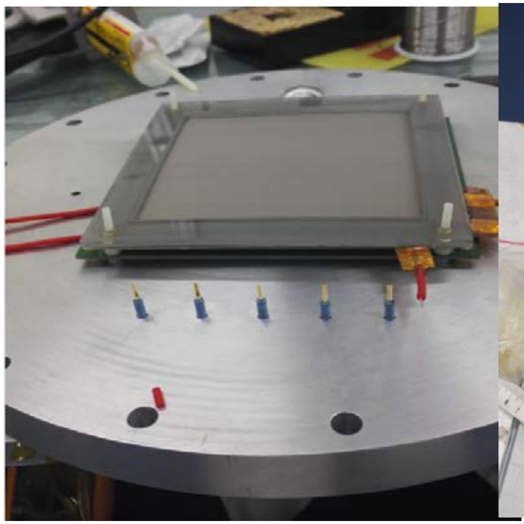




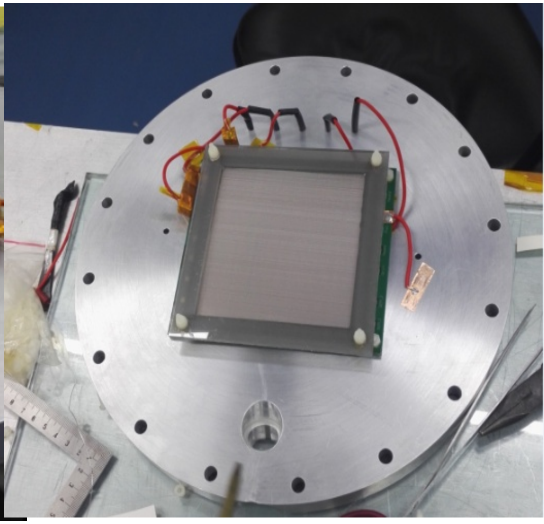
Micromegas(Saclay)



GEM(CERN)

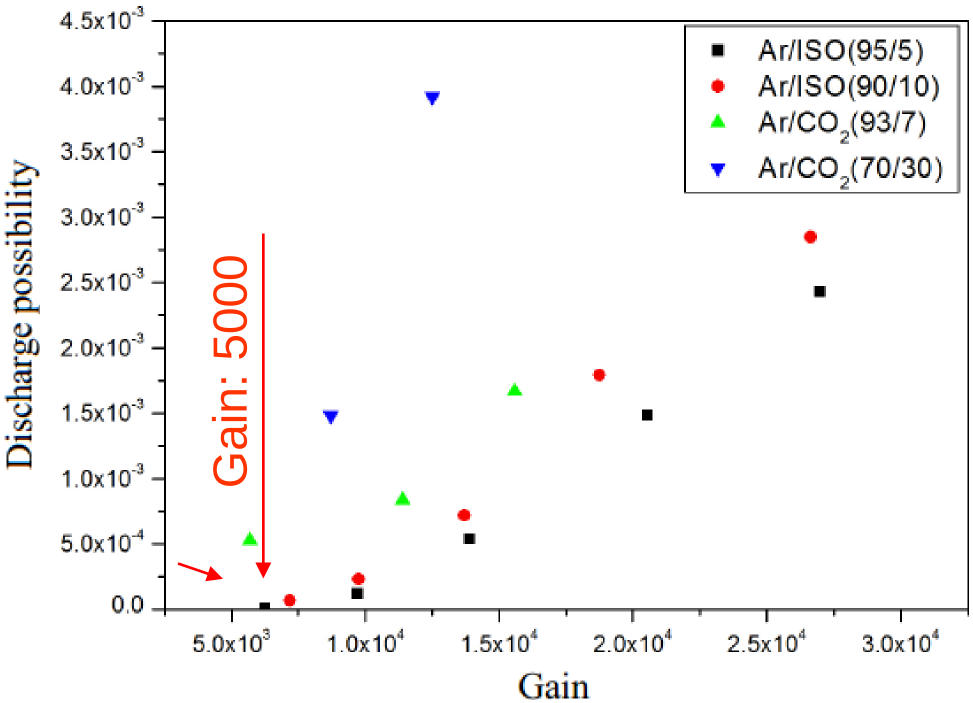


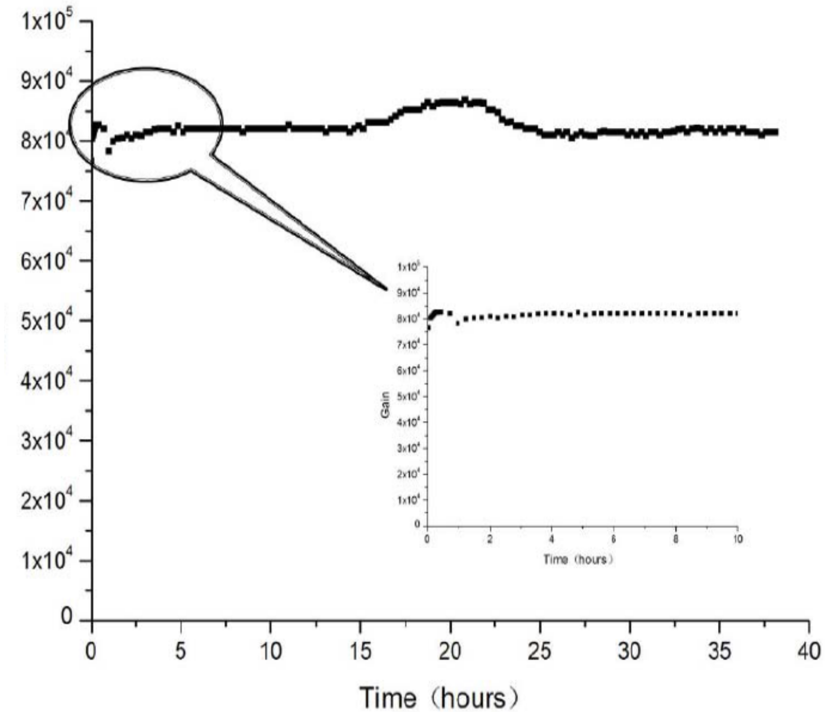
Cathode with mesh



GEM-MM Detector

Discharge and working time



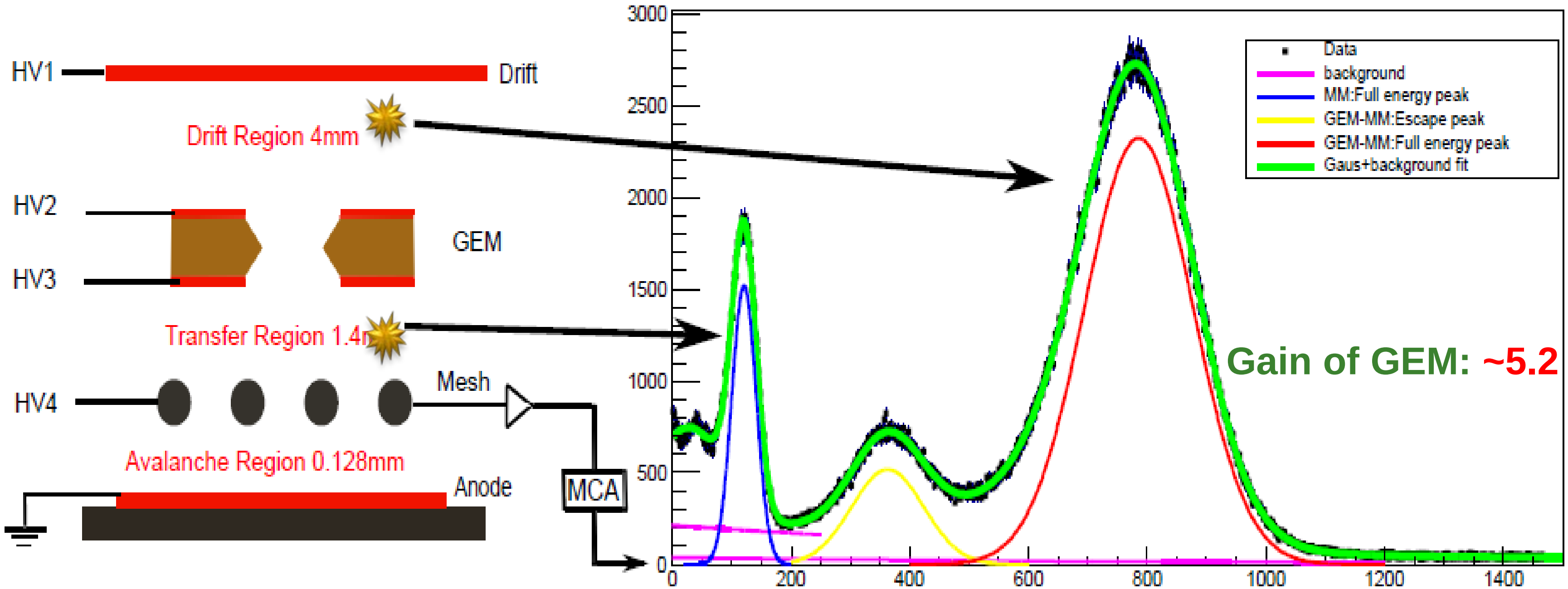


- Test with Fe-55 X-ray radiation source
  - Discharge possibility could be mostly reduced than the standard Bulk-Micromegas
  - Discharge possibility of hybrid detector could be used at Gain~10000
  - To reduce the discharge probability more obvious than standard Micromegas
  - At higher gain, the module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

Energy spectrum@^{55}Fe

Yulian, Haiyun, Huirong

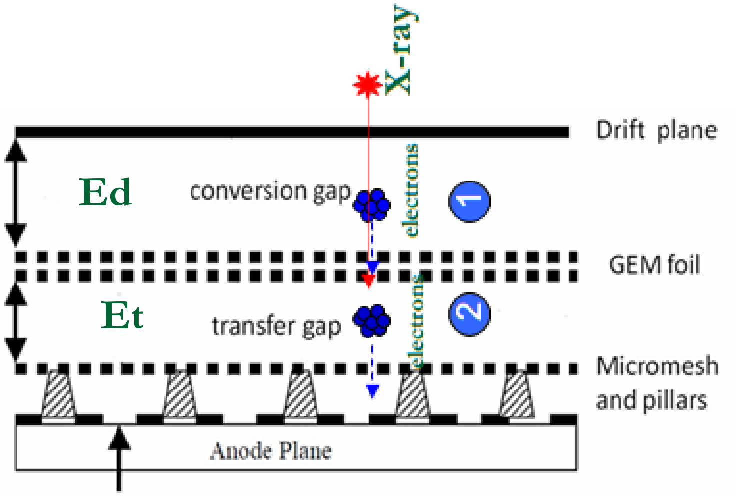
Source: ^{55}Fe, Gas mix: Ar(97) + iC_4H_{10}(3)



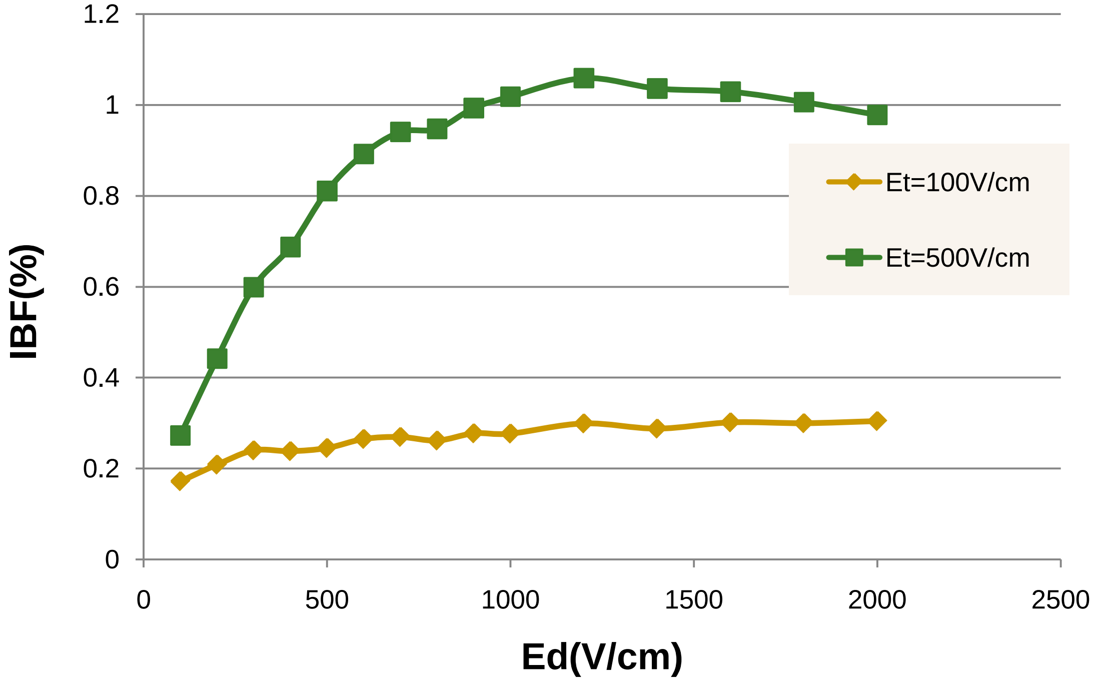
An example of the 55Fe spectra showing the correspondence between the location of an X-ray absorption and each peak.

IBF of GEM-MM module

- IBF of the GEM-MM
  - Electric field: 100V/cm and 500V/cm
  - IBF value comparion
  - Optimization of Et = 100V/cm
  - Ed/Et/Ed=2/1/5
  - V_{GEM}=340V and V_{mesh}=520V
  - Total gain: 3000~4000



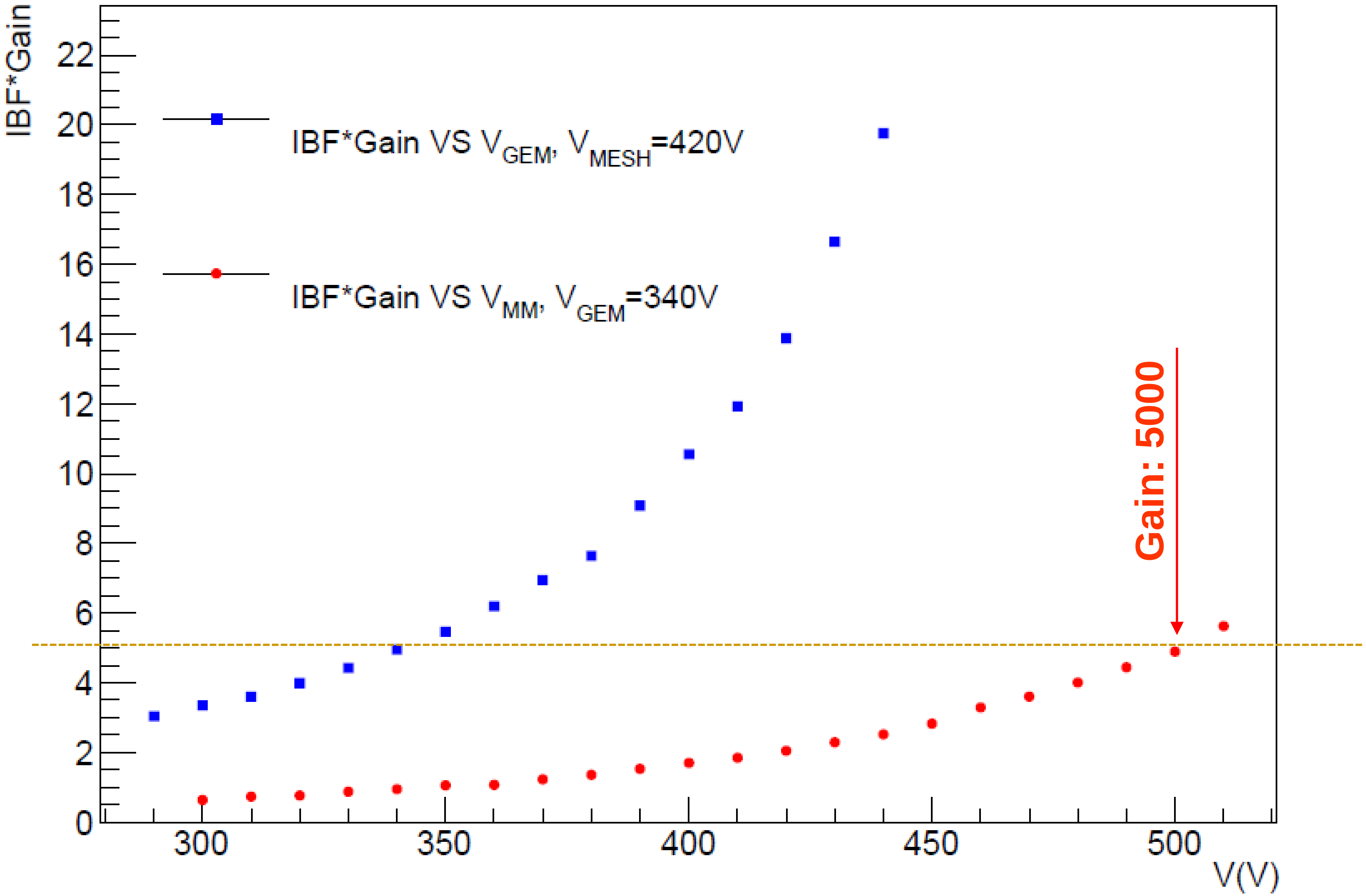
Schematic of the Gain with MM



IBF values with the Ed and Et in the GEM-MM detetctot

IBF test results

DOI: 10.1088/1674-1137/41/5/056003

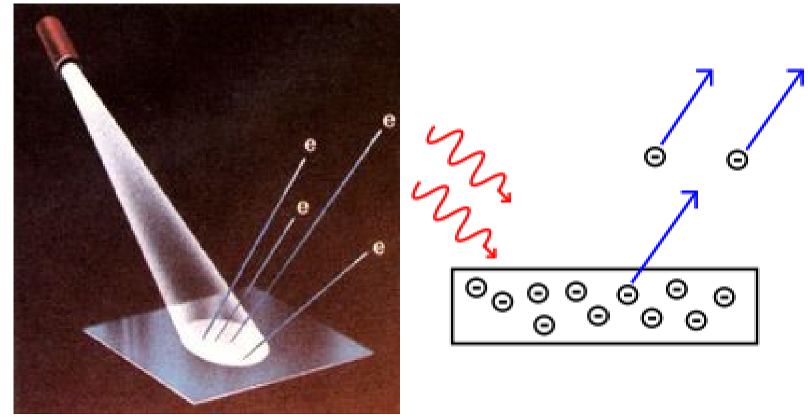


Key factor: IBF * Gain

	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 /One GEM as gating function	(0.4 –1.5)% Edrift = (0.1-0.4) kV/cm
<GA>	4000~5000	2000	2000
ϵ-parameter(=IBF*GA)	2~5	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)	$\sim 10^{-7}$ (S. Procureur report)
Possible main problem	Thin frame	More FEE channel	#
Goals	CEPC TPC	ALICE upgrade	#

Why UV light study

- IBF measurement methods
  - 55Fe radioactive source
  - X tube machine
  - Synchrotron radiation
  - UV light by the photoelectric effect



Photoelectric effect

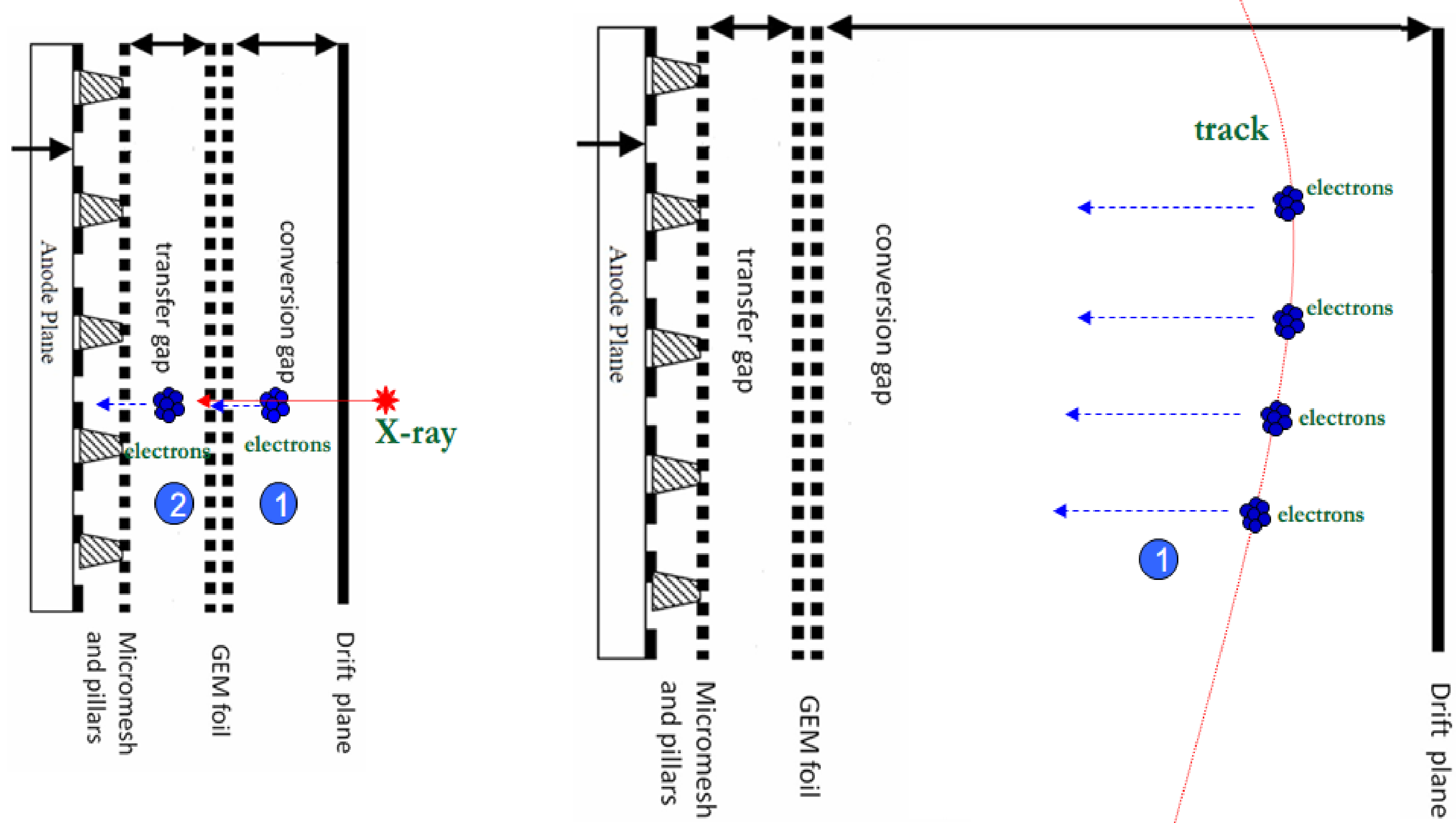


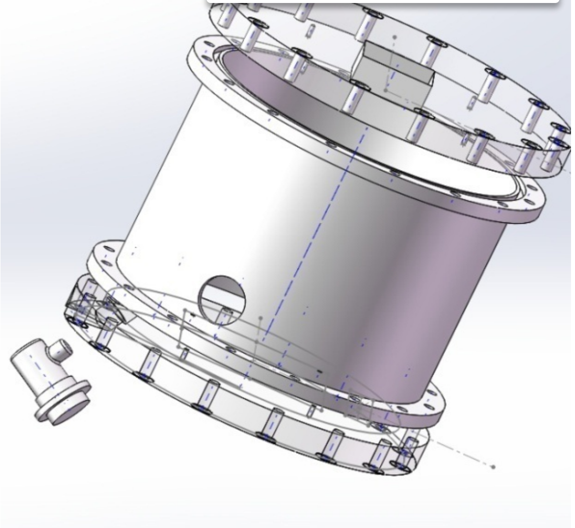
Diagram of the IBF test with the module

Yulian, Haiyun

UV test of the new module

- UV lamp measurement
  - New designed and assembled UV test chamber
  - Active area: 100mm╳100mm
  - Deuterium lamp and aluminum film
  - Principle of photoelectric effect
  - Wave length: 160nm~400nm
  - Fused silica: 99% light trans.@266nm
  - Improve the field cage in drift length

Deuterium lamp
X2D2 lamp



UV test geometry with GEM-MM

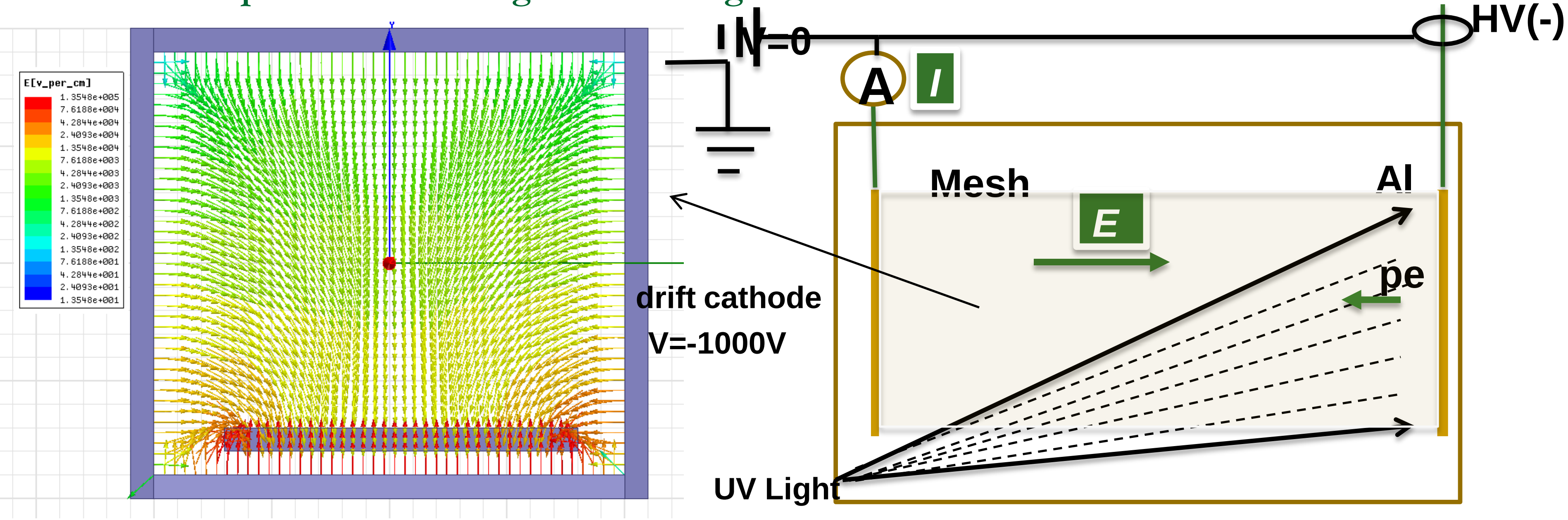


Diagram of the UV test with new module

Electrons produced by UV

- Re-mounted the UV light
  - Two mixture gases
  - High E test
  - Ar gas purity: 99.999%
  - iC4H10 gas purity: 99.99%
  - CO2 gas purity: 99.999%
  - CF4 gas purity: 99.99%

  - About 31000 electrons/s.mm^2
  - Electrons from Al
  - Electrons from drift length at 266nm UV light (~MIPs)

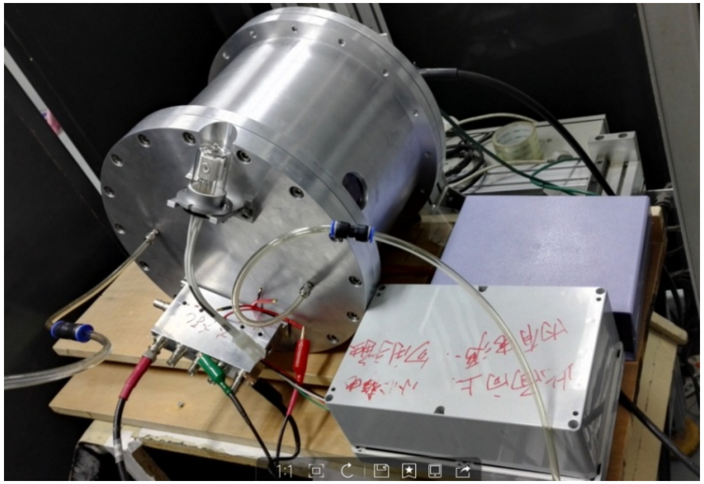
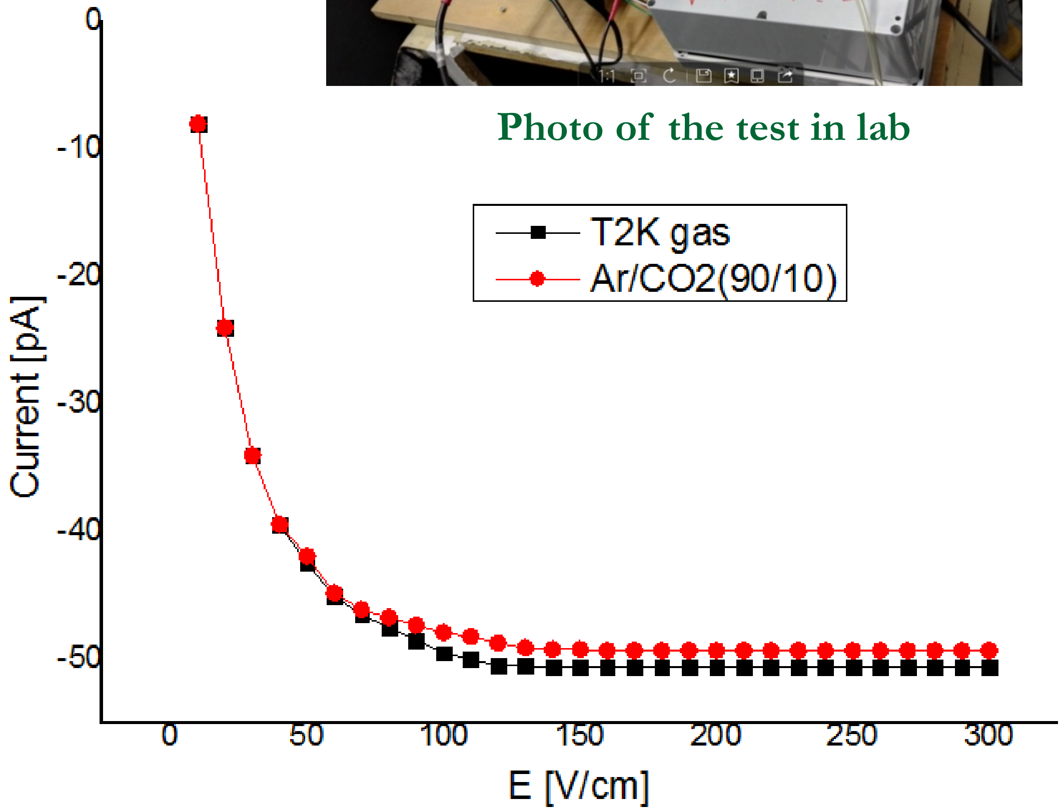
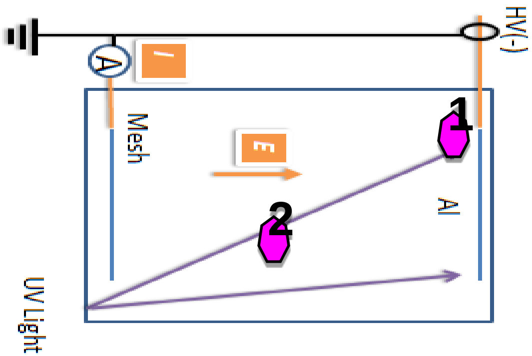


Photo of the test in lab



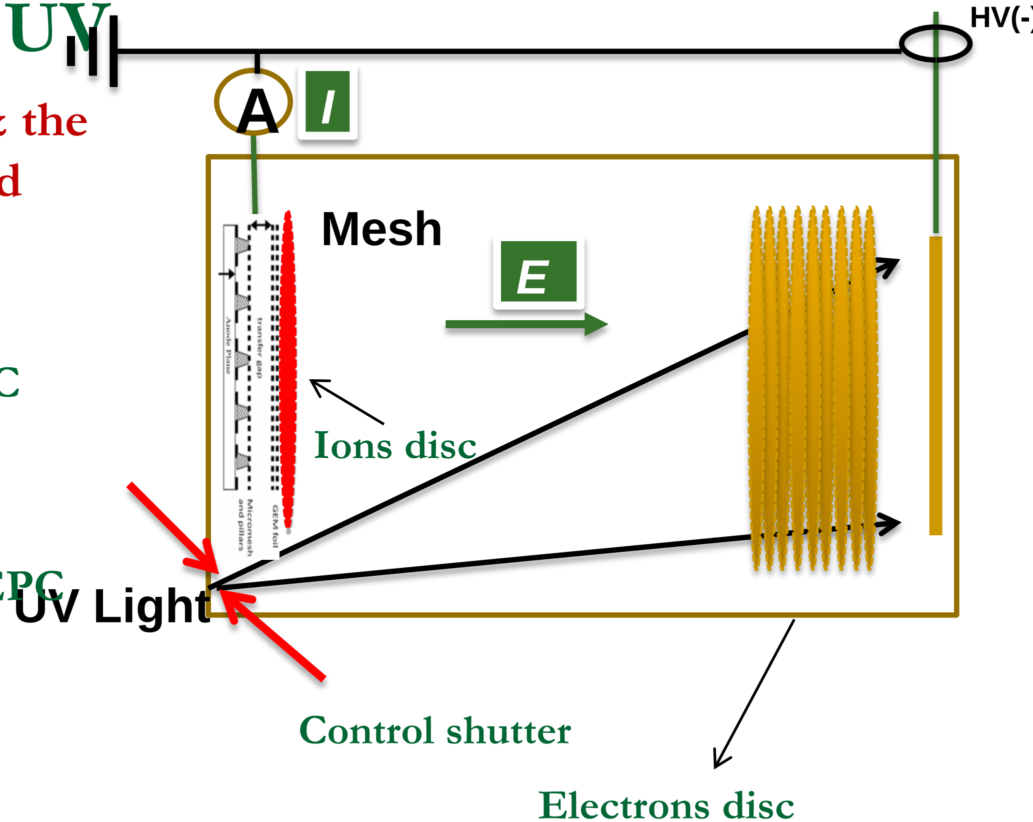
Current VS Electric field in drift length

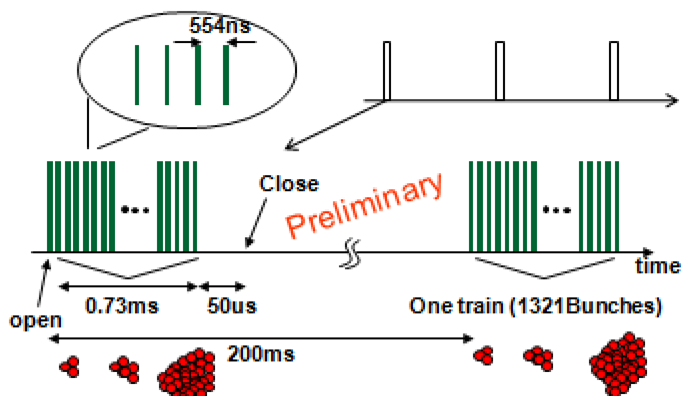


UV Shining diagram

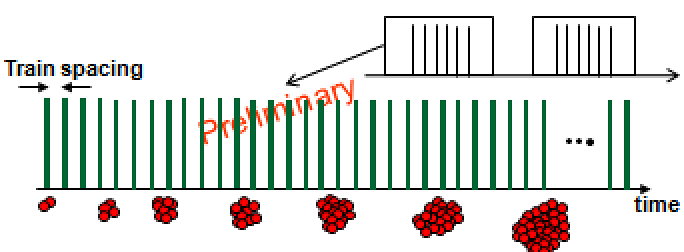
Electrons produced by UV

- To mimic the bunch structure & the ions distortion with UV light and laser split beam
- In the case of ILD-TPC
  - Bunch-train structure of the ILC
  - Power pulsing mode
- In the case of CEPC-TPC
  - Bunch-train structure of the CEPC

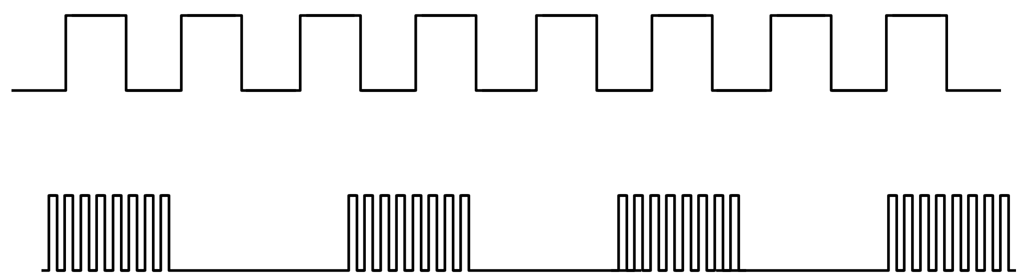




Beam structure of ILC



Beam structure of CEPC



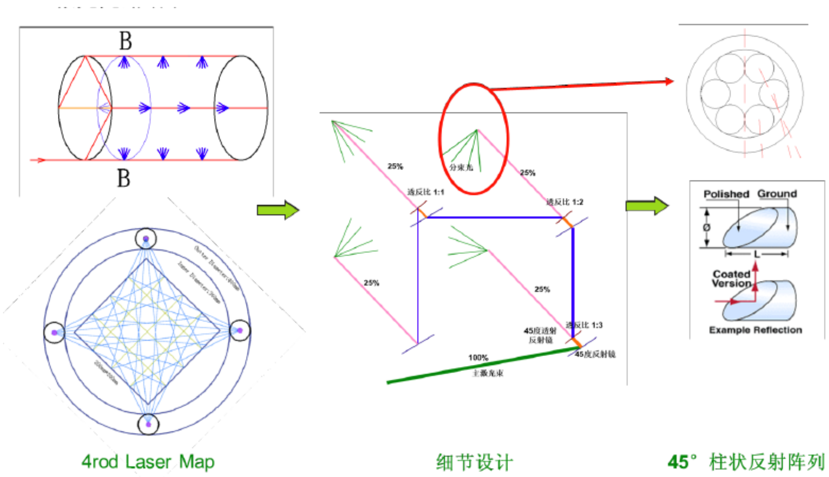
Shutter time similar to ILC and CEPC beam structure

Plans and timeline

Module design and beam test plan

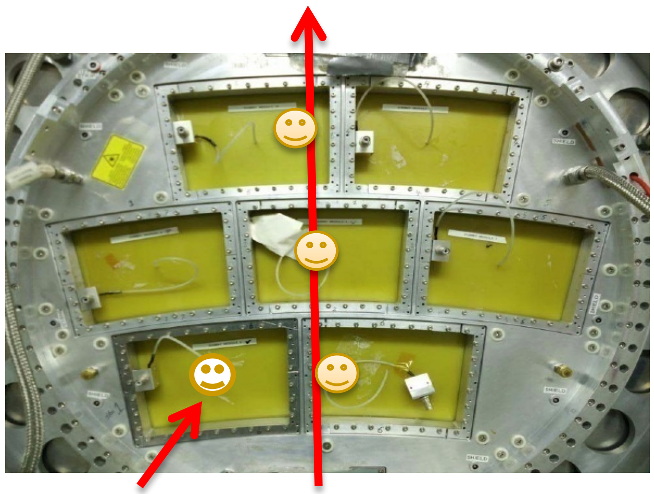
Yulian, Haiyun,Yiming,Zhi wen, Huirong…

- UV light and laser integrated
  - The ionization in the gas volume along the laser path occurs via two photon absorption by organic impurities
  - Drift velocity, gain uniformity
  - Distortion of the laser tracker
    - Nd:YAG laser device
    - λ = 266 nm or E = hν = 4.66 eV
    - Active area:200mm×200mm
    - Drift length: 500mm



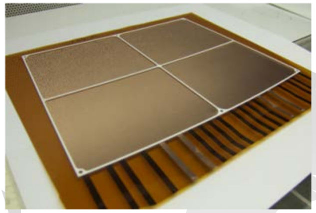
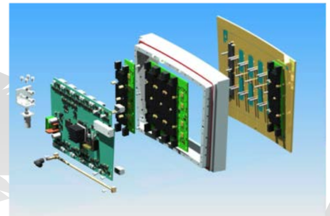
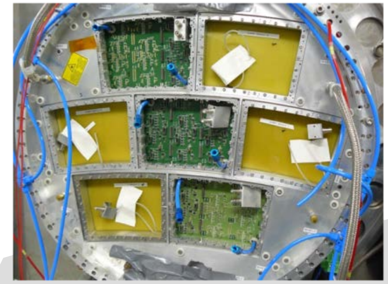
UV light and laser integrated system

- Plan of the module IBF test
  - April ~ November /2017
    - Designed and assembled
    - Test of the modules
  - January ~ April /2018
    - Optimized the modules
    - Application of the beam
  - 2018 (first option)
    - Beam test in two weeks in DESY



Hybrid module IBF beam test

Timelines

Concept study | Smaller prototype | Large prototype | Common module

2006~2010 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

TUTPC prototype
GEM-TPC prototype
Micromega-TPC

MPGDs suffer less from ExB effects than MWPCs
They require less heavy mechanics

GEM prototype
Micromemgas protype
Ingrid prototype
Hybrid prototype

Common module
Laser calibration
Cooling
Electronics

Tsinghua starting for prototype
PCB readout design
Dr. Li bo
Prof. Yulan Li

IHEP starting for prototype
Hybrid concept for IBF
Dr. Huirong Qi
Prof. Yuanning Gao

We are in here
Hybrid prototype starting
Calibration using laser
CDR for CEPC

Summary

- **Physics requirements for the TPC modules**
  - Continuous Ion Back Flow due to the continuous beam structure
  - Gating device could NOT be used due to the limit time
  - Ion back flow is the most critical issue for the TPC module at circular colliders
- **Some activities for the module**
  - IBF simulation of the detector have been started and further simulated.
  - 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.
- **R&D work within the some collaboration is starting.**

Thanks for your attention!