Status of the Continuous Ion Back Flow Module for TPC Detector

Huirong QI

Institute of High Energy Physics, CAS

August 25th, 2016, USTC, Heifei

Outline

- Motivation and goals
- Hybrid Gaseous Detector Module
- R&D Progress of the module
- Summary

Motivation and goals

Requirements of CEPC-TPC

- Critical Physics requirements for CEPC tracker Detector

$$\frac{\sigma_{P_T}}{P_T} \simeq \sqrt{\left(\frac{\alpha'\sigma_x}{BL^2}\right)^2 \left(\frac{720}{n+4}\right) {P_T}^2 + \left(\frac{\alpha' C}{BL}\right)^2 \left(\frac{10}{7}\left(\frac{X}{X_0}\right)\right)}$$

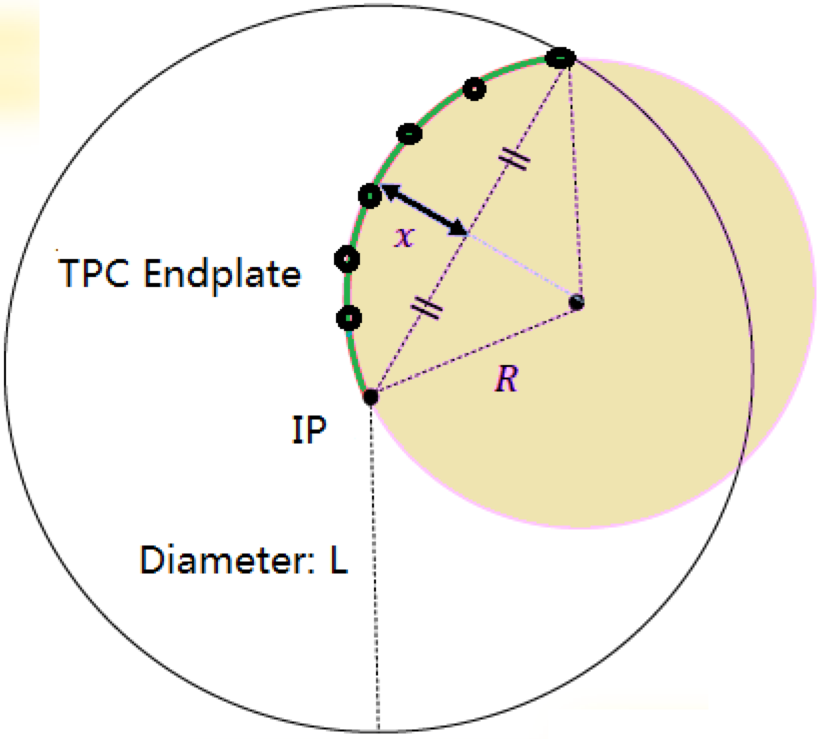
measurements multiple scattering

R.L. Gluckstern, NIM 24 (1963), 381

- Goal: momentum resolution

$$\sigma(1/p_T) = 10^{-4}\text{GeV}^{-1}$$

- Track number: ~200
- Position resolution: ~100μm
- Magnet field: 3T~5T
- PID
- …



Momentum resolution measurement

TPC segmentation and occupancy

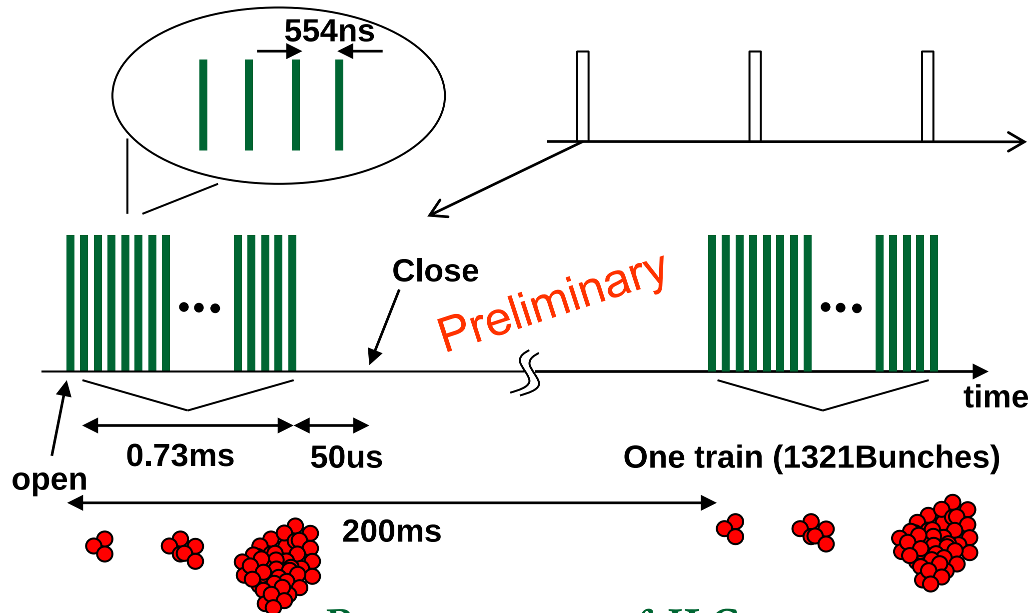
- r-Φ segmentation
  - Limited by the induction readout
  - Gas amplification due to an avalanche electron and ions
  - Induction signal on the Pad (W and H)
  - 2-track separation
- Z segmentation
  - Limited by the signal time width
  - Equal to height of the pad (typical)
- Occupancy: at inner diameter
  - Occupancy should be very smaller
  - Overlapping tracks
  - Background at IP

→

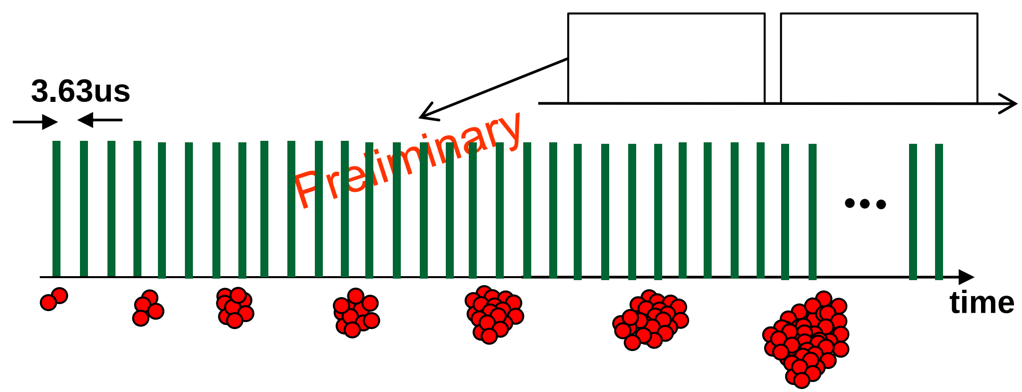
ILD design
CEPC Baseline design
Module design

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)
  - No Gating device with open and close time
  - Continuous device for ions
  - Long working time



Beam structure of ILC



Beam structure of CEPC

NO Gating device !

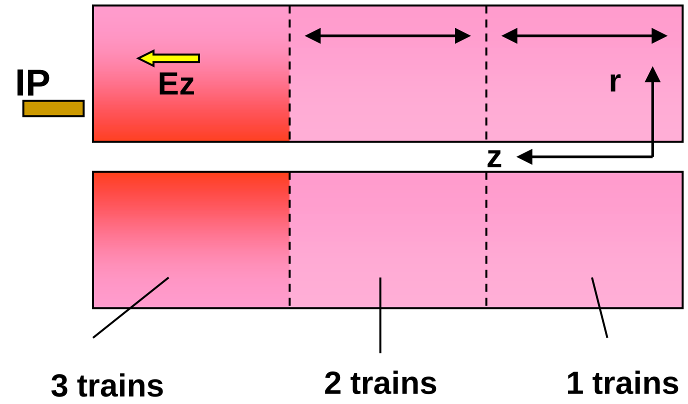
Critical challenge: Ion Back Flow and Distortion

In the case of ILD-TPC

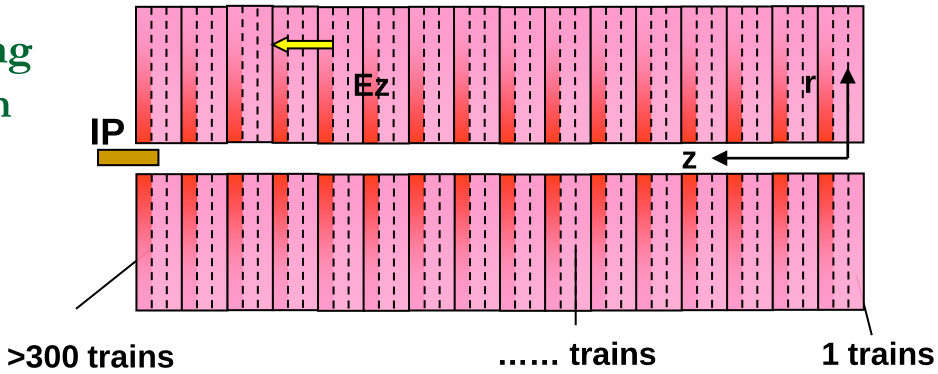
- Distortions by the primary ions at ILD are negligible
- Ions from the amplification will be concentrated in discs of about 1 cm thickness near the readout, and then drift back into the drift volume Shorter working time
- 3 discs co-exist and distorted the path of seed electron
- The ions have to be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

In the case of CEPC-TPC

- Distortions by the primary ions at CEPC are negligible too
- More than 300 discs co-exist and distorted the path of seed electron
- The ions have to be neutralized during the ~4us period continuously



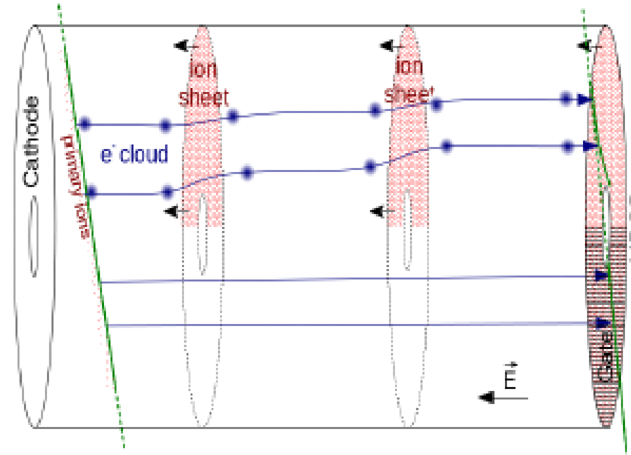
Amplification ions@ILC

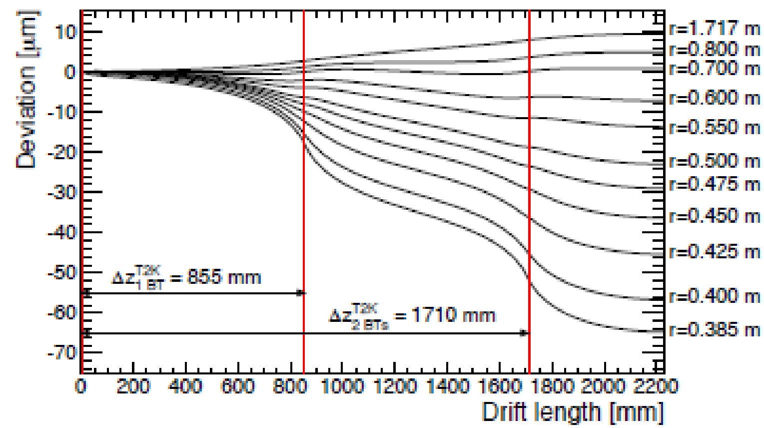


Amplification ions@CEPC

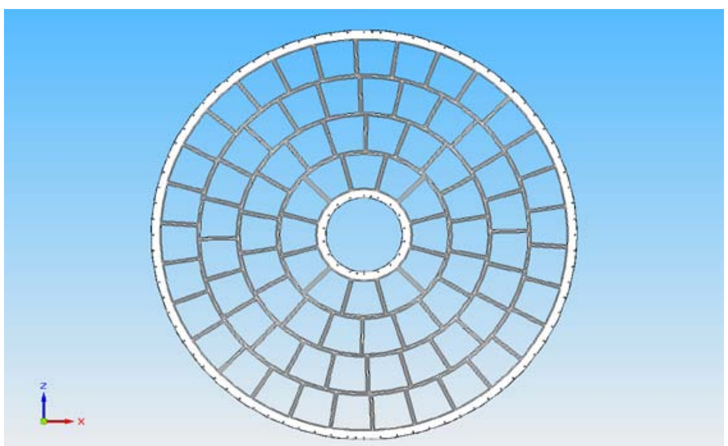
E_{drift} Distortion

- High performance requirements by the TPC relies strongly on the quality of the electric field in the drift volume
  - Ions drift back into the gas volume in CEPC TPC
  - Many such the discs in the chamber with ions
  - Ions could reduce the momentum resolution along the drift length
  - Ions should have to be neutralized





Ions simulation @ILD TPC
From Fujii's slice



Layout of the endplate

Requirements of Ion Back Flow @CEPC

- 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

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

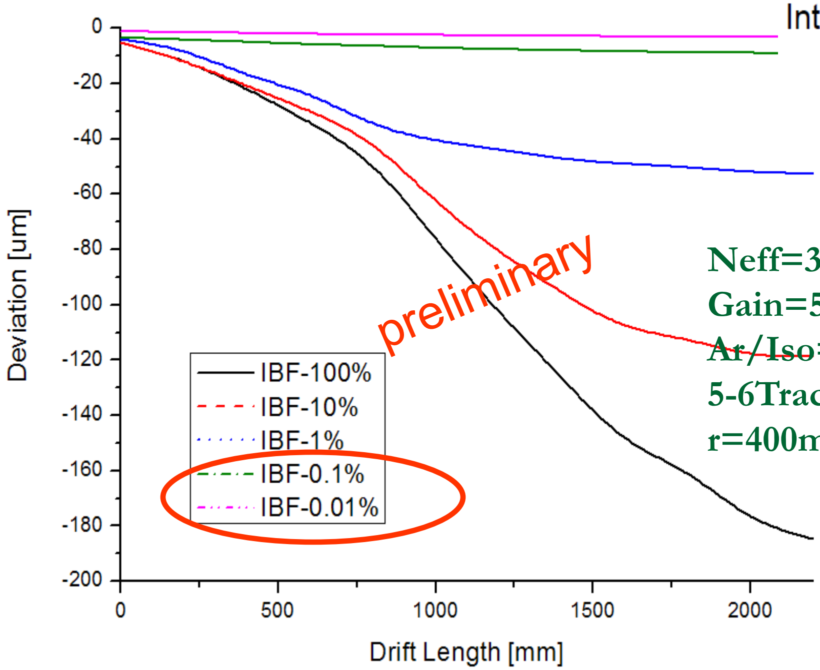
Transverse and

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

Effective number of primary signal electrons

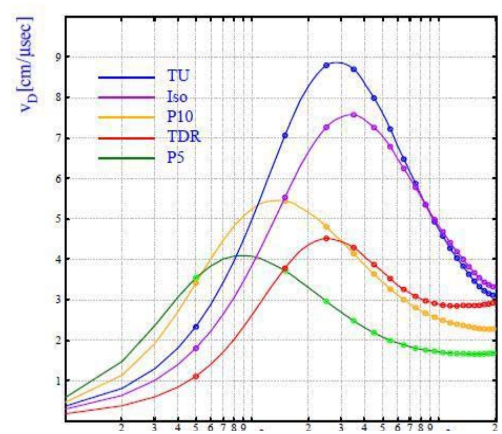
molecules during drift

Position resolution of the TPC function



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

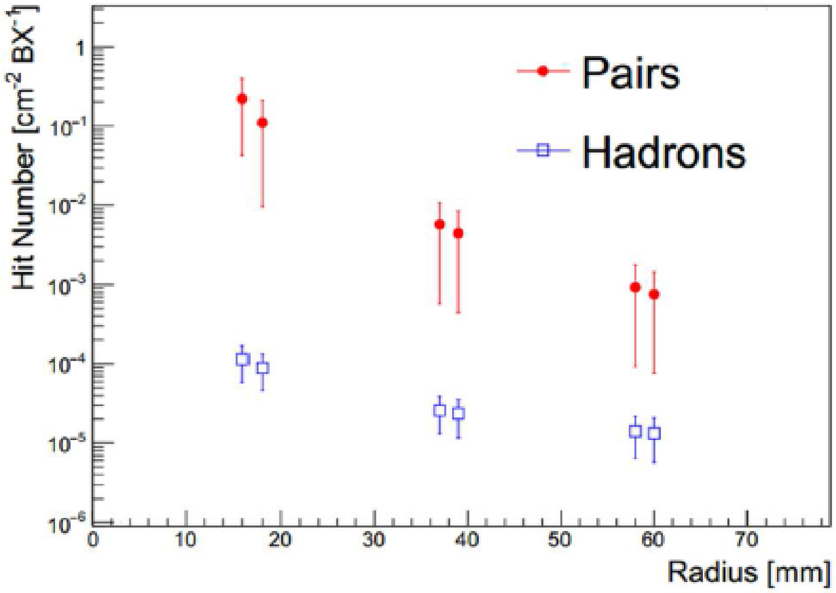
Evaluation of track distortions due to space charge effects of positive ions



Simulated the drift velocity in different gas mixture

Backgrounds @CEPC

- Beamstrahlung (e+e- pairs)
  - Pair production
  - Hadronic background
- Lost Particles (Beam Halo)
  - Radiative Bhabha
  - Beamstrahlung
  - Beam-Gas Scattering
  - …
- Synchrotron Radiation
  - More than 100keV of Gamma (No damage or effect for working gas)
  - Just consider at endcap (readout and modules for TPC)

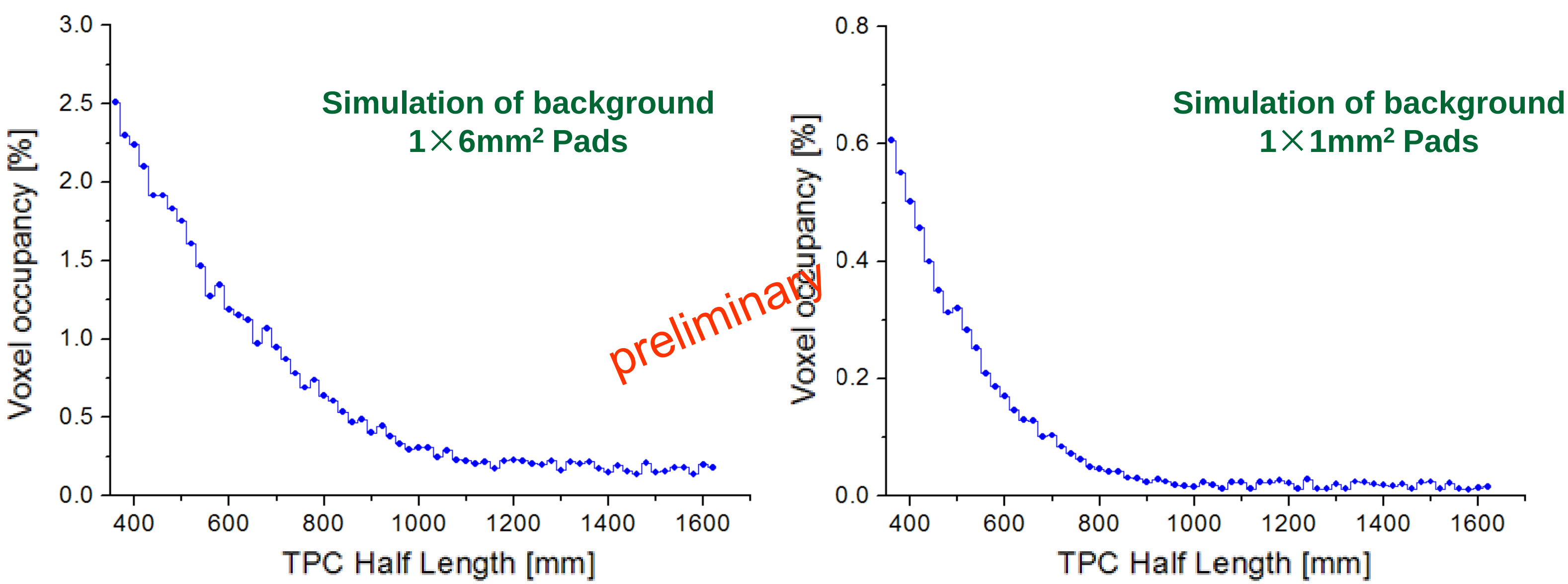


Hit density ~1 hits cm^{-2} BX^{-1}
(From Qing Lei's Simu.)

Simulation of occupancy

- **Occupancy@250GeV**
  - **Very important parameter for TPC**
  - **Detector structure of the ILD-TPC like**
  - **ADC sampling 40MHz readout**
  - **Time structure of beam:·4us/Branch**
  - **Beam Induced Backgrounds at CEPC@250GeV(Beam halo muon/e+e- pairs)+γγ→hadrons with safe factors(×15)**
  - **Value of the occupancy inner radius smaller**
  - **Optimization for the pad size in rΦ**

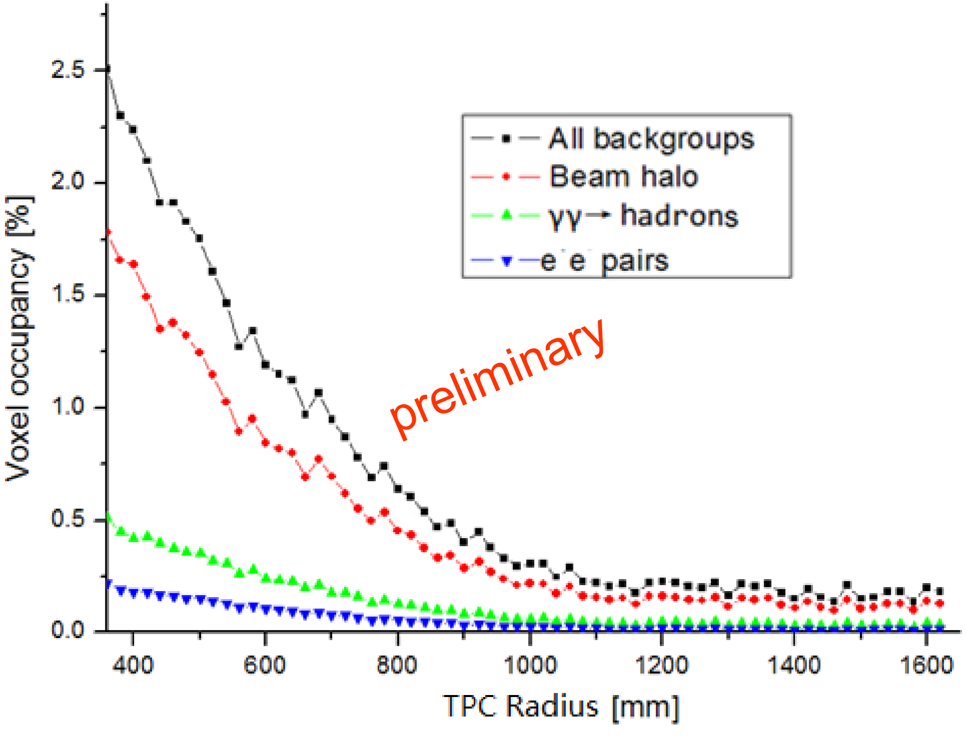
CLIC_ILD ~30%@3TeV
1×6mm^2 Pads
CLIC_ILD ~12%@3TeV
1×1mm^2 Pads
NO TPC Options!



Preliminary of occupancy

Occupancy Simu.@250GeV CEPC

- Voxel occupancy
  - Very important parameter of TPC could determine to use or NOT as the tracker detector
  - No consideration for the beam collimator and synchrotron radiation, the value might larger



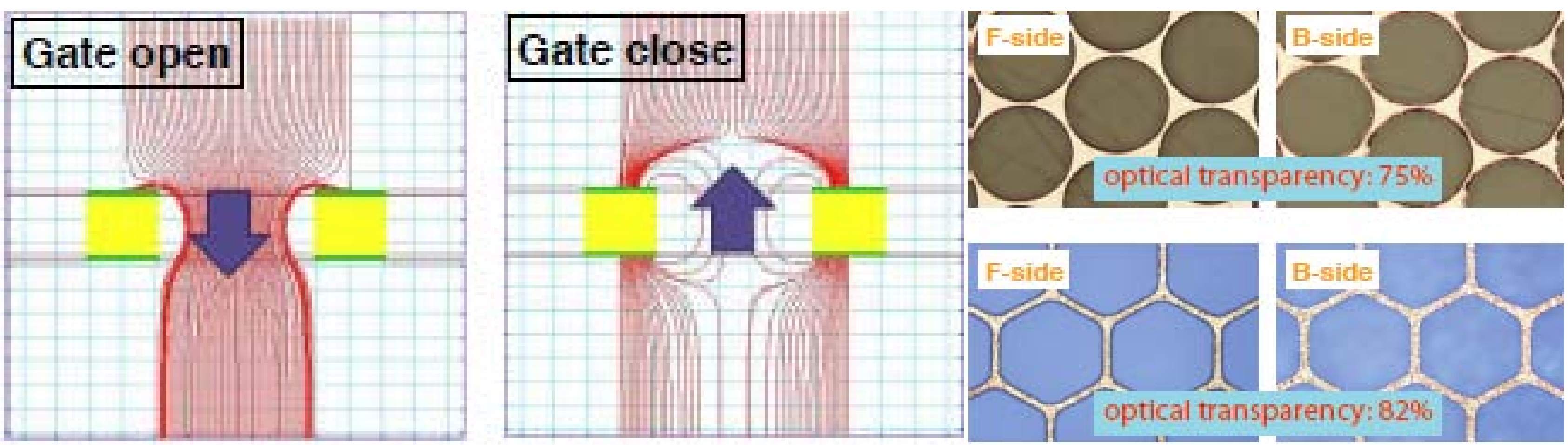
TPC voxel occupancy simulated in TPC radius

Hybrid Gaseous Detector Module

How to reduce the avalanche ions?

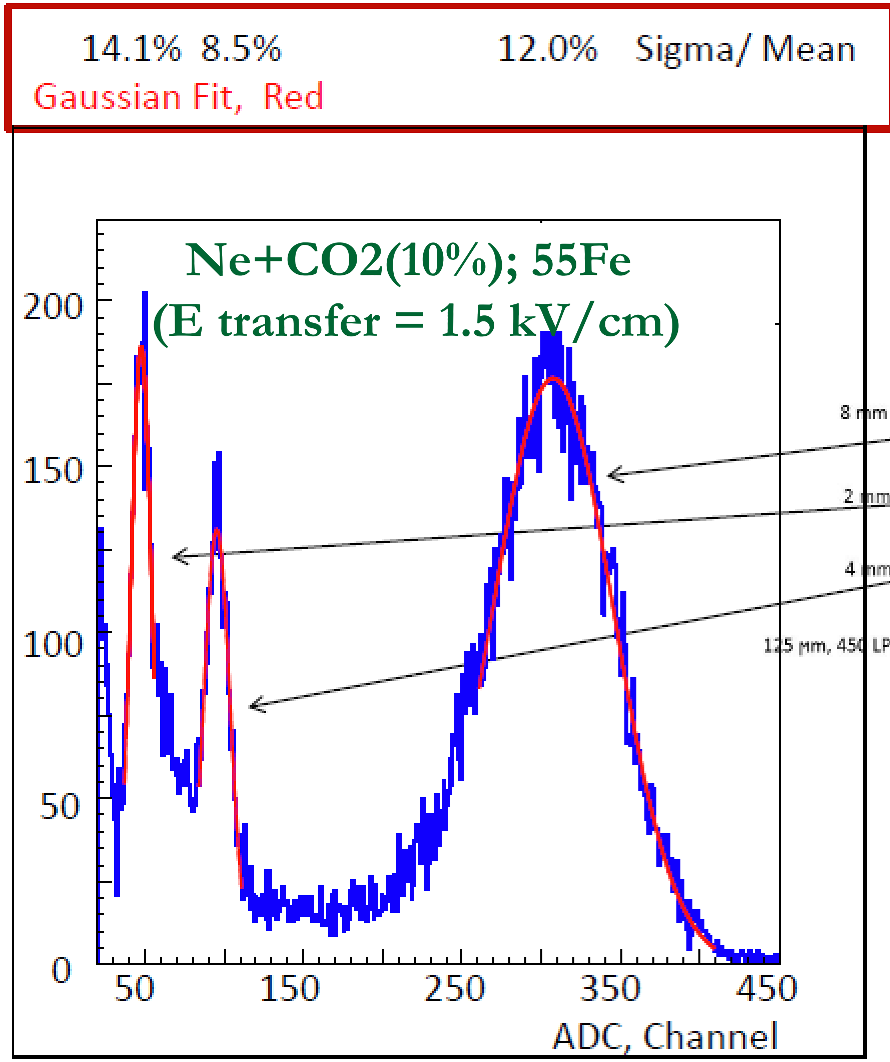
Requirement for Gate GEMs of ILD-TPC

- Goal: 80% electron transmission = corresponding the deterioration in the spatial resolution ~O(10%) for the ILD-TPC nominal electric field configuration
- Operated in a 3.5 T axial magnetic field
- High optical transparency of the gate is required to ensure its high transmission rate of the electrons in the open state



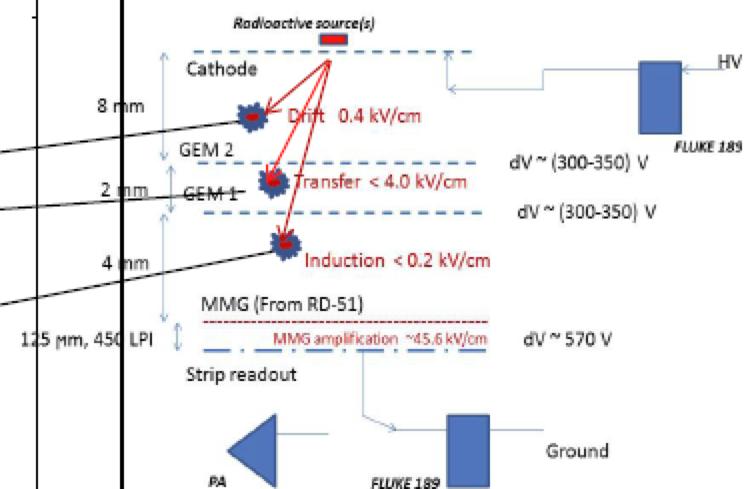
Gate device of the ILC-TPC@KEK

How to reduce the avalanche ions?



Requirement for ALICE

- Goal: ALICE has decided to upgrade TPC for continuous readout ; high rate 50kHz ; Pile-up: ~5 events overlapping



Gain GEM 2 (bot) ~= 0.52

Gain (GEM 2 & GEM 1) ~= 3.2

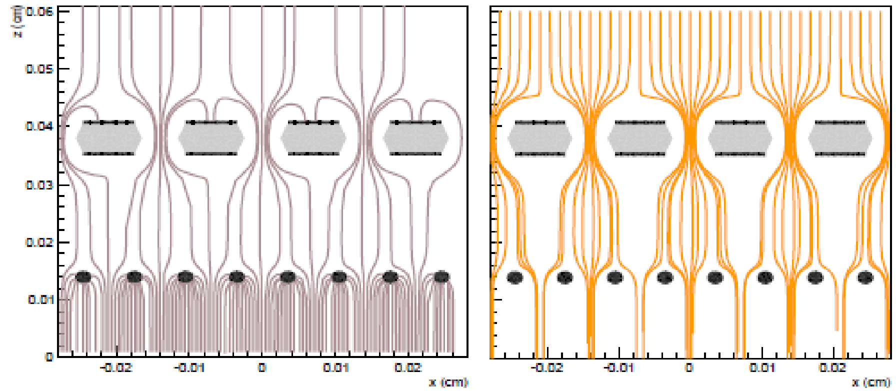
Gain GEM1 (top) ~= 6.15

One option of the ALICE TPC Upgrade

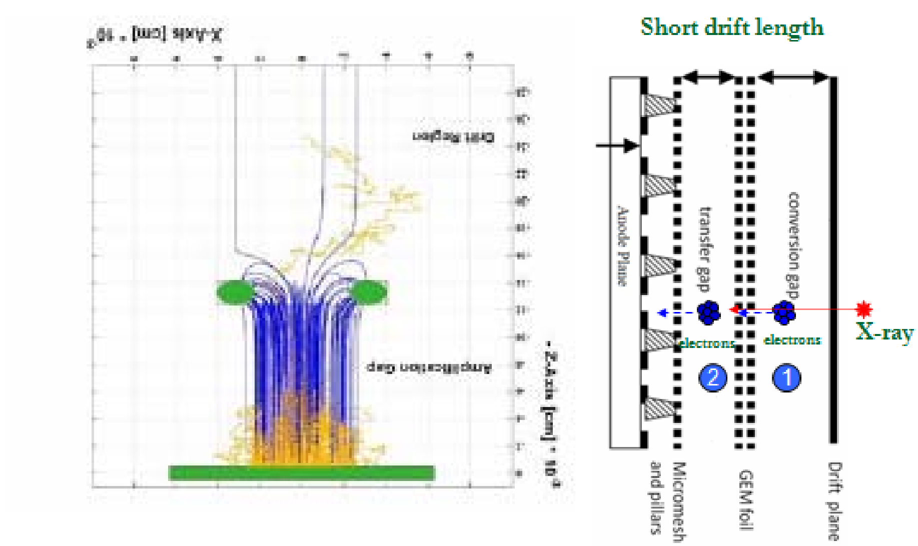
New ideas for the ions?

- 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)

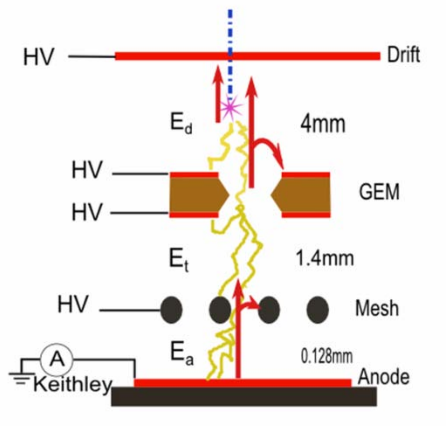


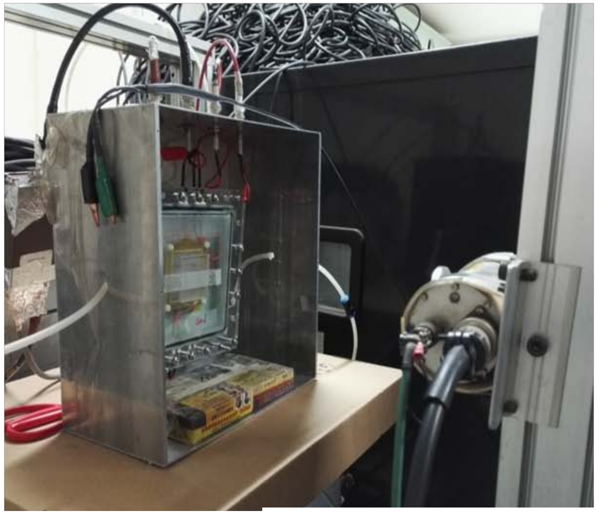
Simulation of the Mciromegas and Hybrid detector

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





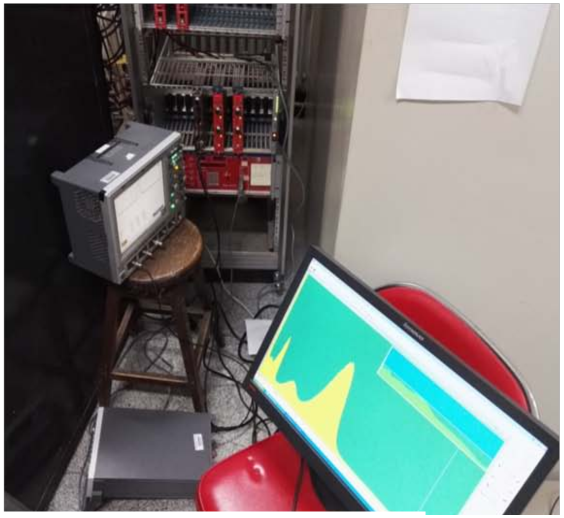


Photo of the GEM+Micromegas Module with X-ray

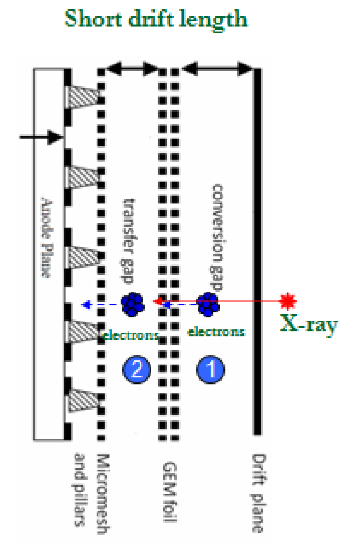
Current test

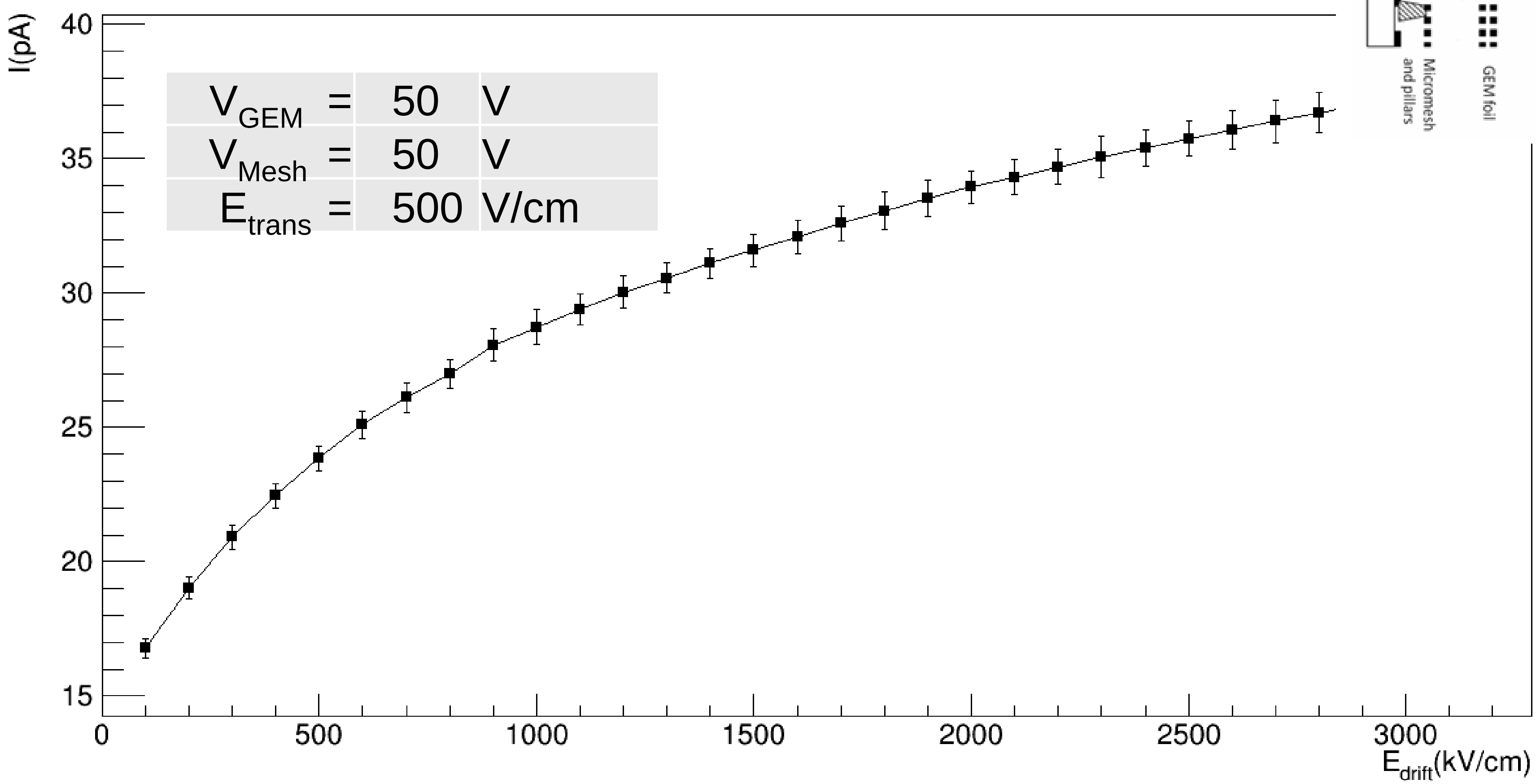
- Keithley pA current meter as the monitor
  - Continuous readout with Labview interface
  - Very tiny current in the cathode and anode

Layout of Labview in the test

Current test of the primary ionization

- Primary ionization test using monitor
  - Primary ions from 1/Drift and 2/Transfer
  - Current data with the standard error bar
  - Ions transmission efficiency with electric field of drift

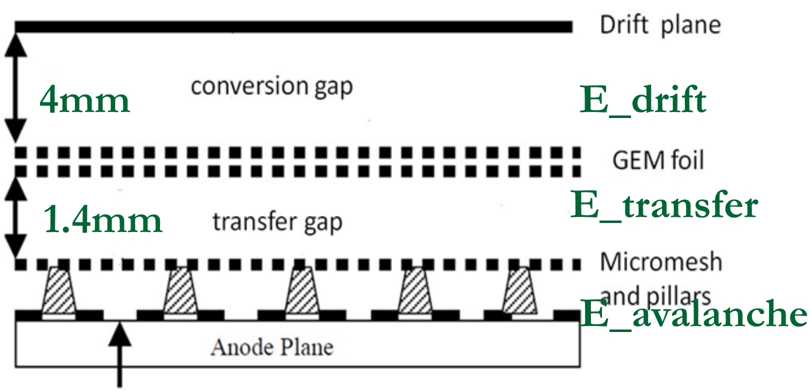


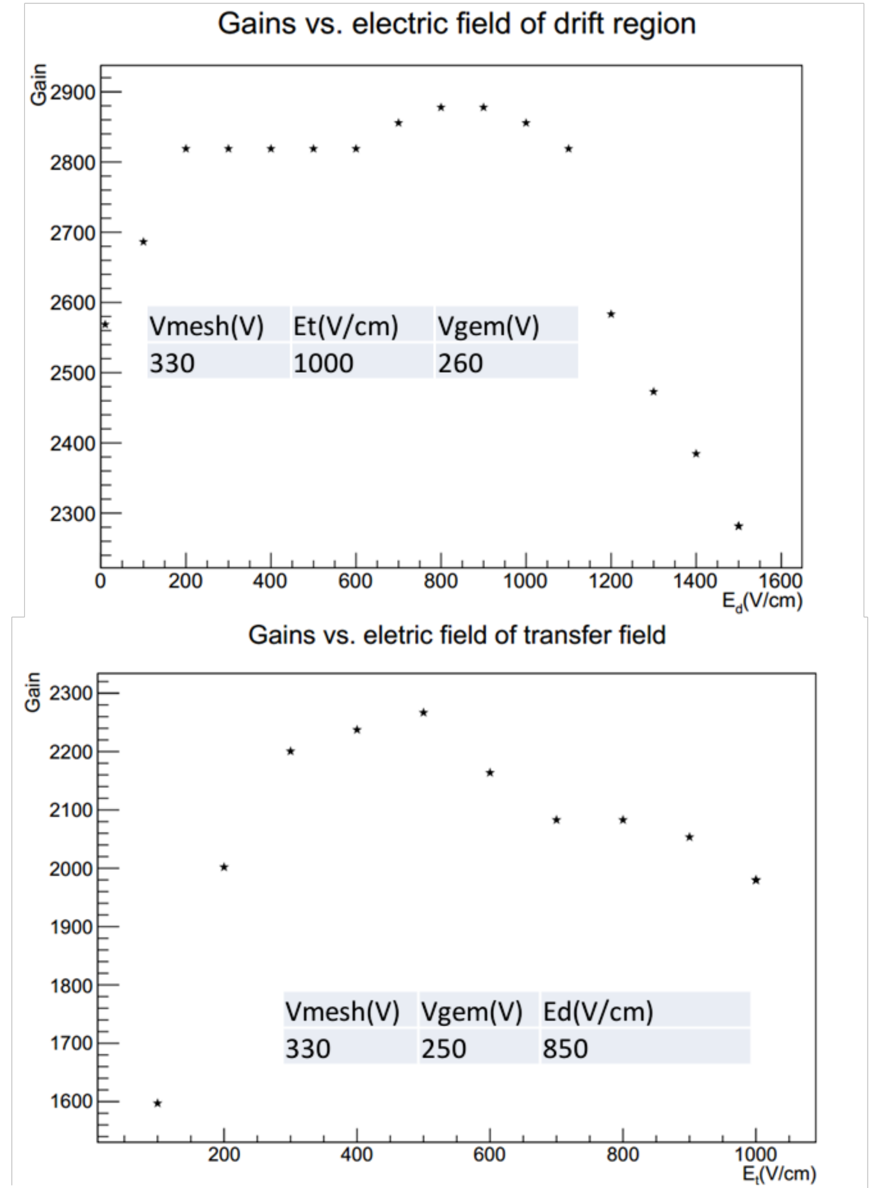


Current test of primary ionization

Electron transmission

- Optimized operating voltage
  - To achieve the higher electron transmission in the hybrid structure module
  - The ratio of E_avalanche and E_transfer of Micromegas detector is 216.8
  - The ratio of E_transfer and E_drift of GEM detector is 67.08

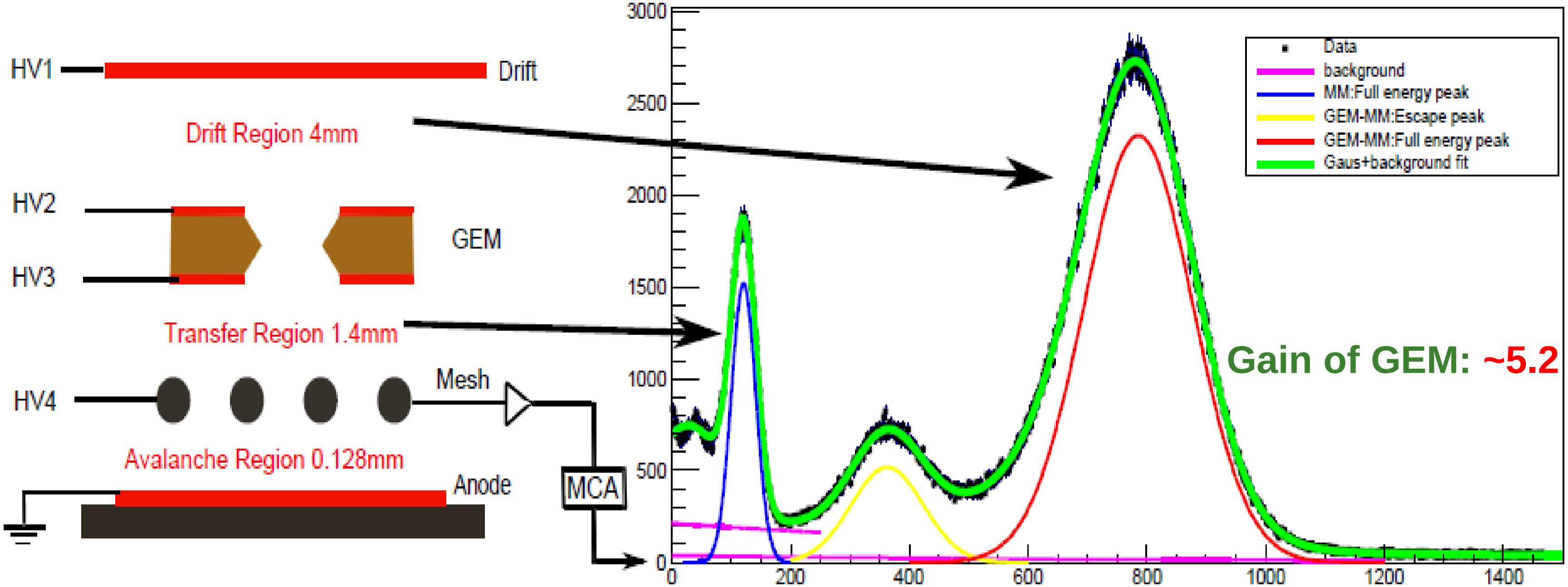




Electron transmission in GEM and Micromegas

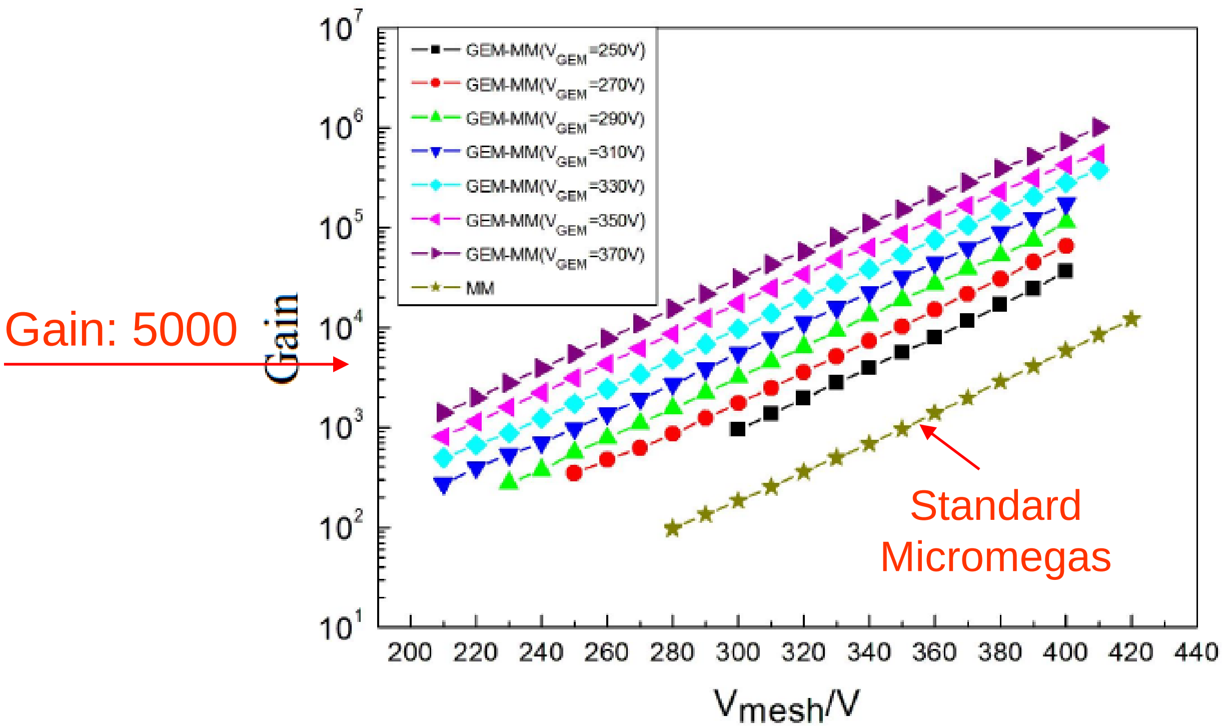
Energy spectrum@^{55}Fe

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



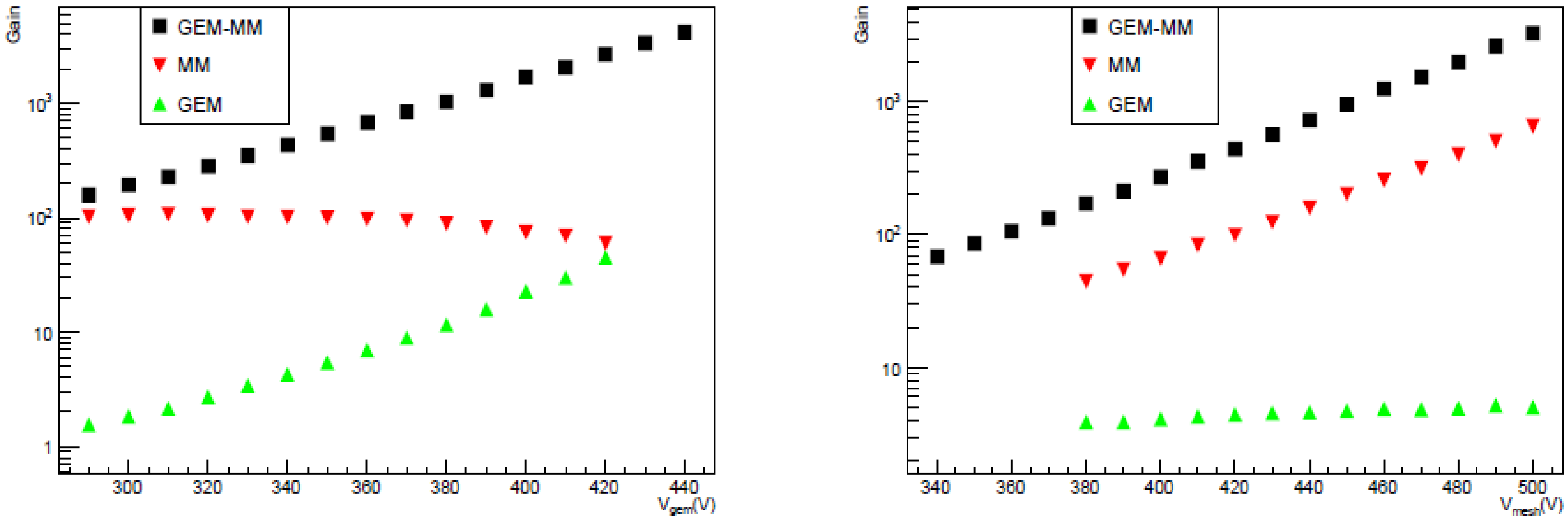
An example of the 55Fe spectra showing the correspondence between the location of an X-ray absorption and each peak.

Gain



- 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

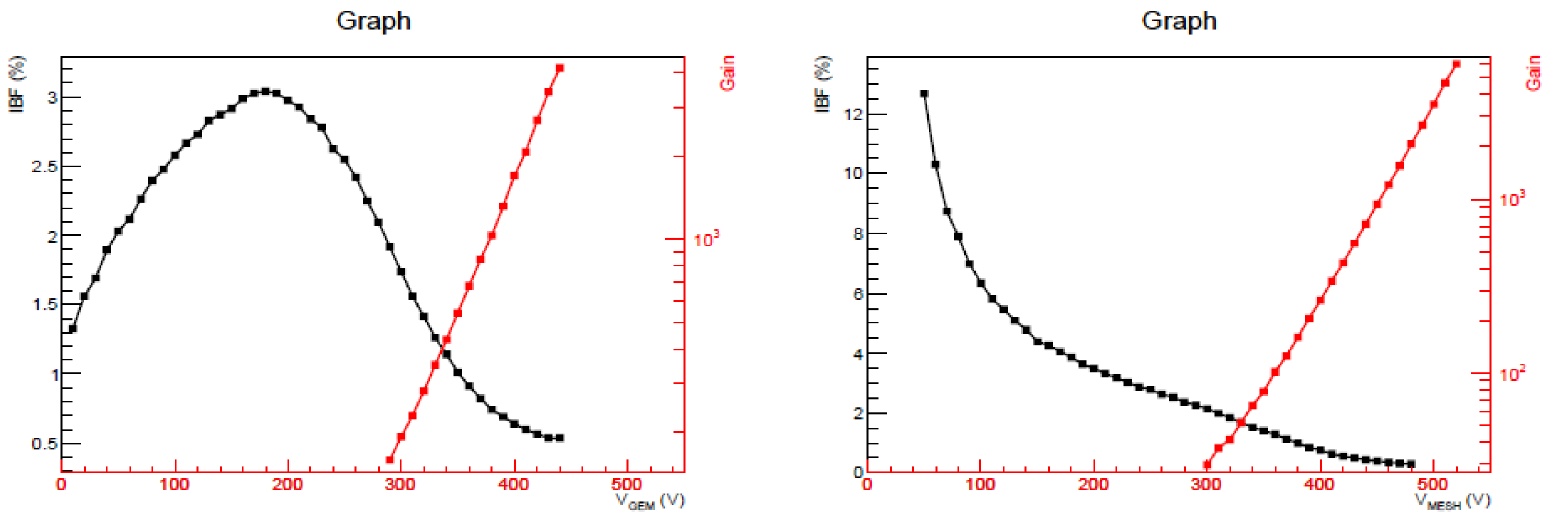
Gain of GEM and MM



(a) (b)

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

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:

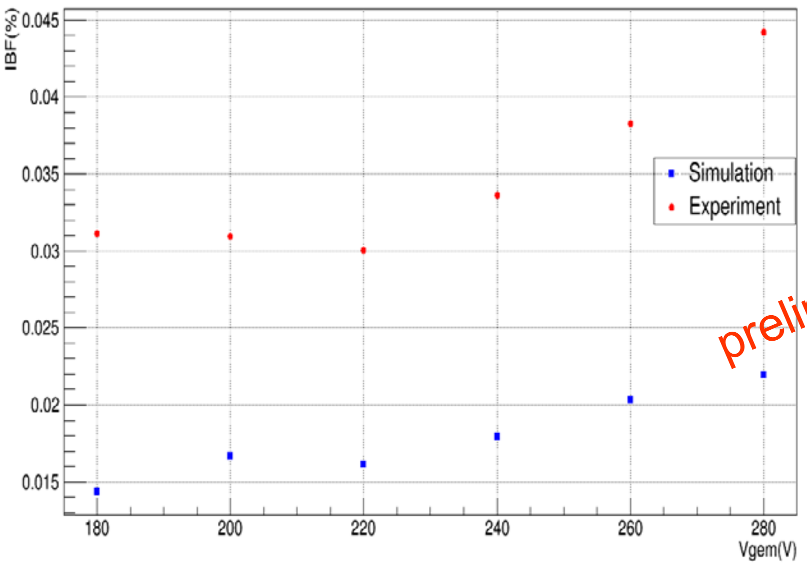
$$I_{mesh} = G\gamma$$

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

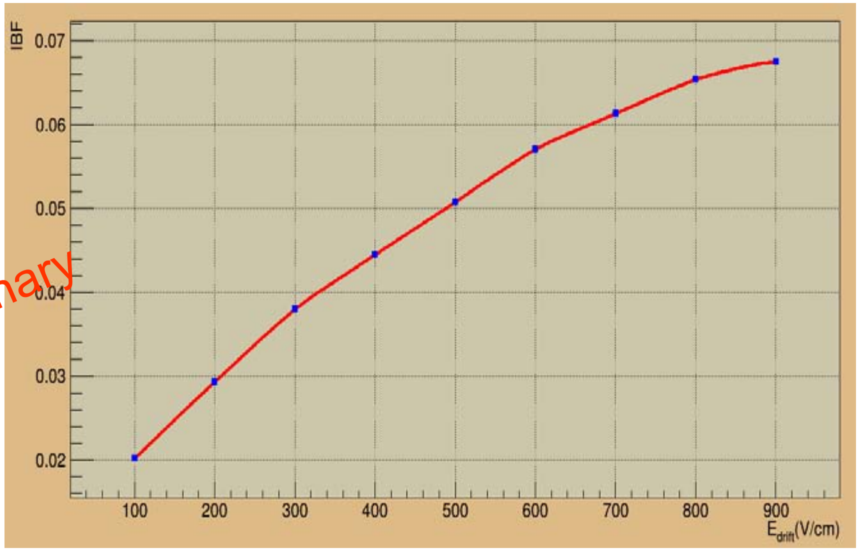
G is the gas gain of the detector.

IBF VS E/V

IBF vs. Voltage across GEM foil



IBF vs. Drift Field



- Expt. value higher that the simulation data. Contribution to the drift current from the ions from primary ionization(in the Drift region).
- With the increase of drift field:
  a) current on drift cathode increases,
  b) current on the top electrode of GEM decreases,
  c) sum of the above two remains about the same,
  d) current on mesh keeps stable.

	GEM+MMG 420LPI (IHEP)	2GEMs + MMG 450 LPI (Yale University)	Micromegas only 450 LPI (Yale University)
Ion Back Flow	~0.1% 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)	15~20	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	#

Summary

- Critical requirements for CEPC TPC modules
  - Beam structure
  - Obvious distortion
  - Continuous Ion Back Flow
- Some activities and simulations
  - Simulation of the occupancy of the detector, the hybrid structure gaseous detector's IBF
  - TPC gas amplification setup GEM+MM investigated as a high rate TPC option without the standard gating grid or others gating device
  - Some preliminary IBF results

Thanks very much for your attention !