Status and progress of TPC detector module and prototype for CEPC

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Outline

- Physics requirements
- Critical technology challenges
- Current R&D activities
  - Status of TPC module R&D
  - Status of TPC prototype R&D
  - Low power consumption ASIC
- Summary

Physics requirements

TPC requirements for collider concept

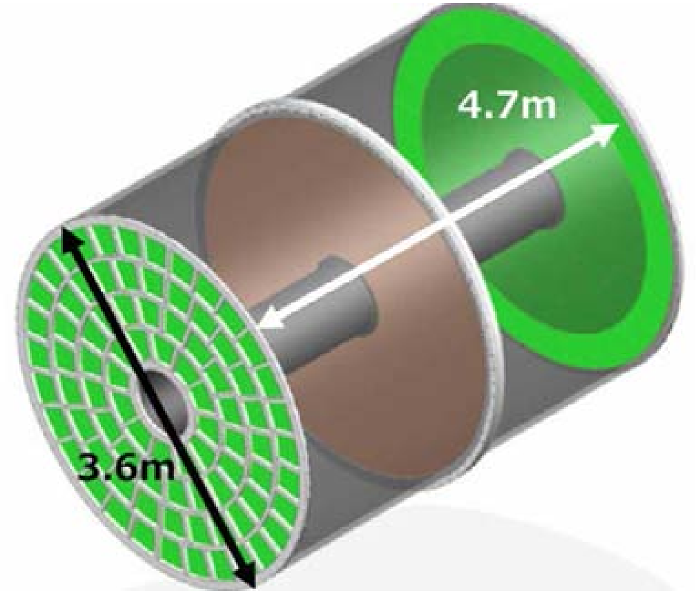
TPC could be as one tracker detector option for CEPC, 1M ZH events in 10yrs E_{cm} ≈250 GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, can also run at the Z-pole

The voxel occupancy takes its maximal value between 2×10^{-5} to 2×10^{-7}, which is safety for the Z pole operation. **Of course, it is well for Higgs run too.**

https://doi.org/10.1088/1748-0221/12/07/P07005

TPC 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**
- **dE/dx resolution: <5%**
- **Tracker efficiency: >97% for pT>1GeV**

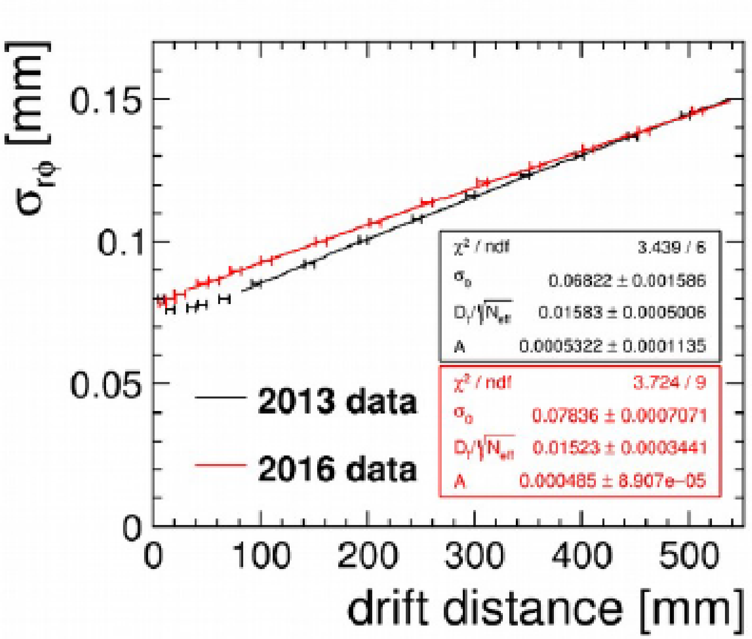


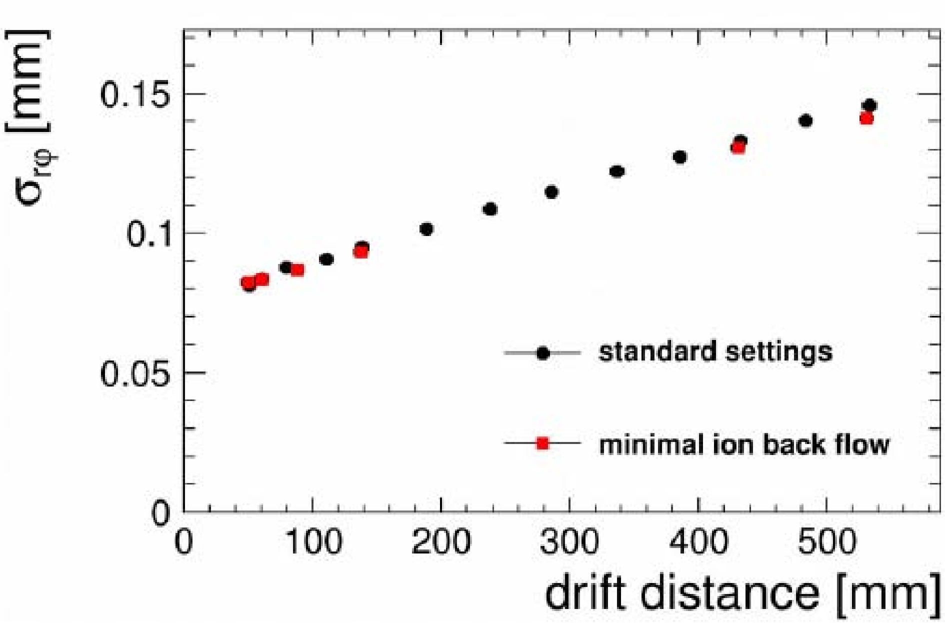
TPC detector concept

rφ Beam Tests Results/LC-TPC

Ralf Diener

The rφ resolution of the prototype TPC was measured using the electron beam@5GeV in a magnet field@1.0T.



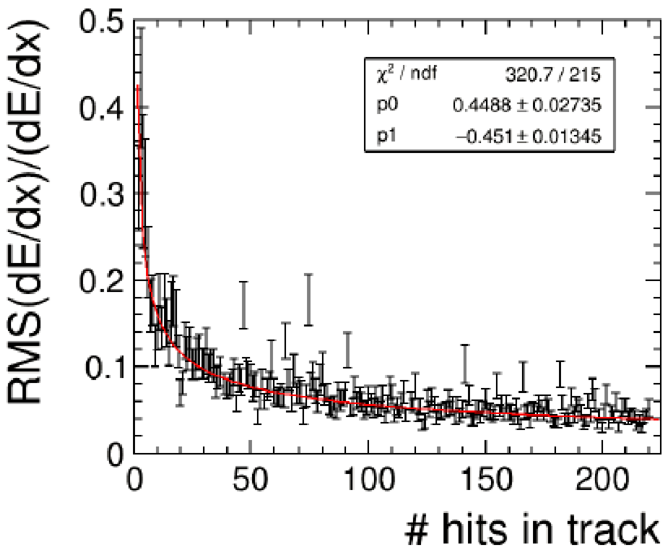


Slides from LCWS 2017 workshop in 23-27, October, 2017. Strasbourg, France

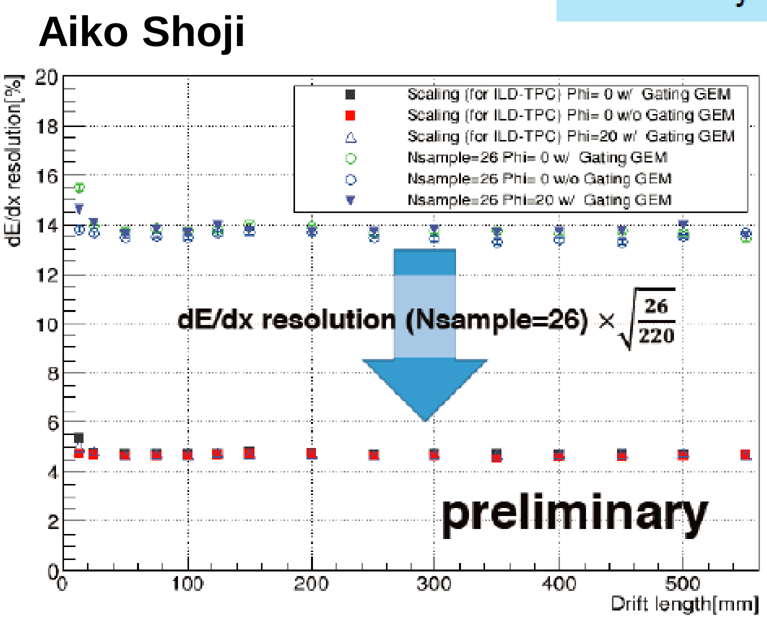
dE/dx Beam Tests Results/LC-TPC

- Resolutions extrapolated to real 220-layer TPC
  - 4% : Triple CERN GEM w/o gate
  - 4.7% : Double Scienergy GEM w/ gate

Ralf Diener



Aiko Shoji



- dE/dx resolution of 4 % reachable at ILD TPC (requirement: 5 %)

	Method① Sampling
w/ gating GEM, $\phi = 0^\circ$	4.66 ± 0.02%

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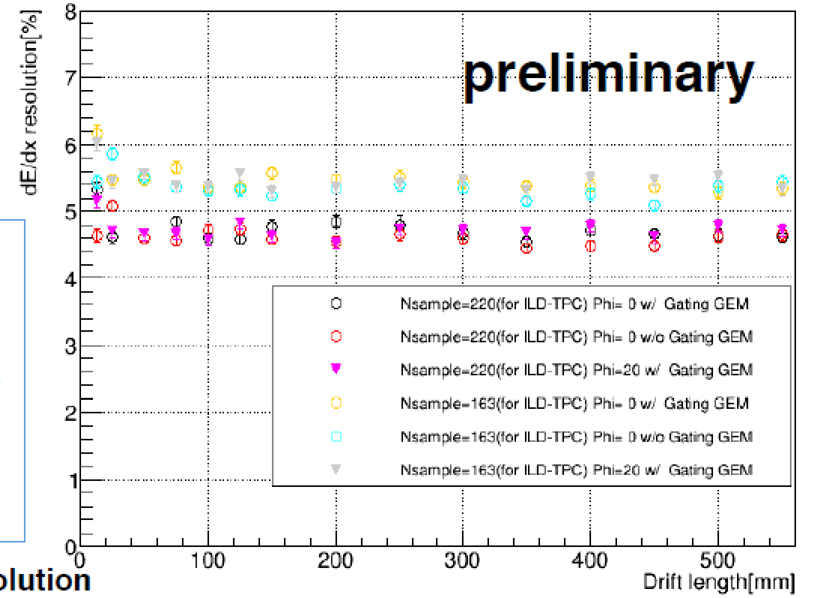
dE/dx Beam Tests Results/LC-TPC

Aiko Shoji

Also, the dE/dx resolution of ILD-TPC **(small, Pad rows: 163)** was estimated by Method① and ②.



The average of dE/dx resolution

	Method① Sampling	Method② Scaling
w/ gating GEM, ϕ= 0°	5.46 ± 0.02%	5.49 ± 0.01 %
w/o gating GEM, ϕ= 0°	5.35 ± 0.02%	5.40 ± 0.01%
w/ gating GEM, ϕ= 20°	5.42 ± 0.02%	5.49 ± 0.01%

① and ②: consistent

TPC radius: 1.8m

The dE/dx resolution of the ILD-TPC (large-model) with a gating GEM was estimated to be about 4.7 % for 5 GeV/c electrons on the Fermi plateau. In the small-model TPC, the dE/dx resolution was estimated to be about 5.5 %.

TPC radius: 1.6m

Slides from LCWS 2017 workshop in 23-27, October, 2017. Strasbourg, France

CEPC Detector for CDR

Manqi's talk

Feasibility & Optimized Parameters

√ Feasibility analysis: TPC and Passive Cooling Calorimeter is valid for CEPC

	CEPC_v1 (~ ILD)	Optimized (Preliminary)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	84 mm is optimized on Br(H->di photon) at 250 GeV;
ECAL Cell Size	5 mm	10 – 20 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	20 – 30	Depends on the Silicon Sensor thickness
HCAL Thickness	**1.3 m**	**1 m**	-
HCAL NLayer	**48**	**40**	Optimized on Higgs event at 250 GeV;

Critical technology challenges at CEPC

Critical challenges of CEPC TPC

- **Occupancy: at inner diameter**
  - Low occupancy
  - Overlapping tracks
  - Background at IP

TPC as one option for CPEC-TPC YES or NO

- **Ion Back Flow**
  - Continuous beam structure
  - Long working time with low discharge possibility
  - Necessary to fully suppress the space charge produced by ion back flow from the amplification gap

To reduce IONS
To reduce distortion

- **Calibration and alignment**
  - Complex MDI design
  - Laser calibration system

~100um positron resolution with calibration

~2017, On-going activities for all

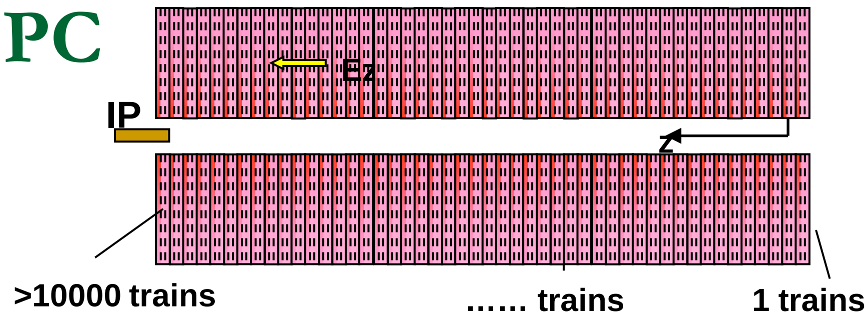
Technical challenges at CEPC

Ion Back Flow and Distortion :

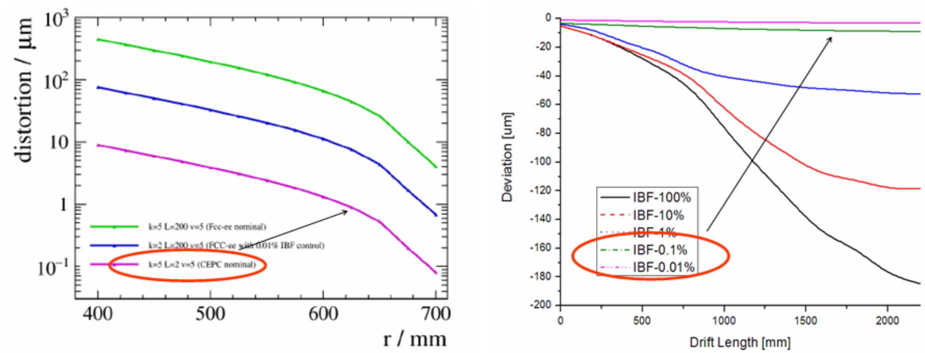
- ~100 μm position resolution in rφ
- Distortions by the primary ions at CEPC are negligible
- More than 10000 discs co-exist and distorted the path of the seed electrons
- The ions have to be cleared during the ~us period continuously
- Continuous device for the ions
- Long working time

Calibration and alignment:

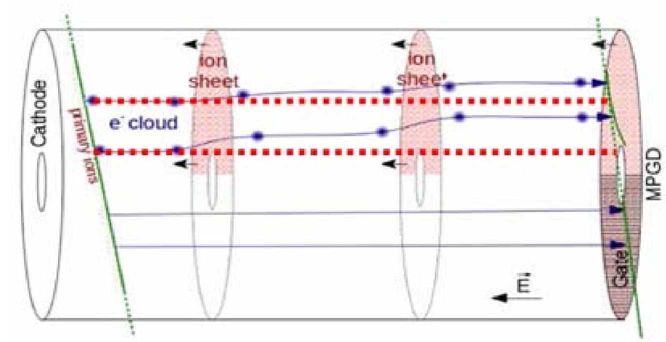
- Systematics precision (<20 μm internal)
- Geometry and mechanic of chamber
- Modules and readout pads
- Track distortions due to space charge effects of positive ions



Amplification ions @CEPC



Evaluation of track distortions



Ions backflow in drift volume for distortion

Simulation study of IBF for CEPC

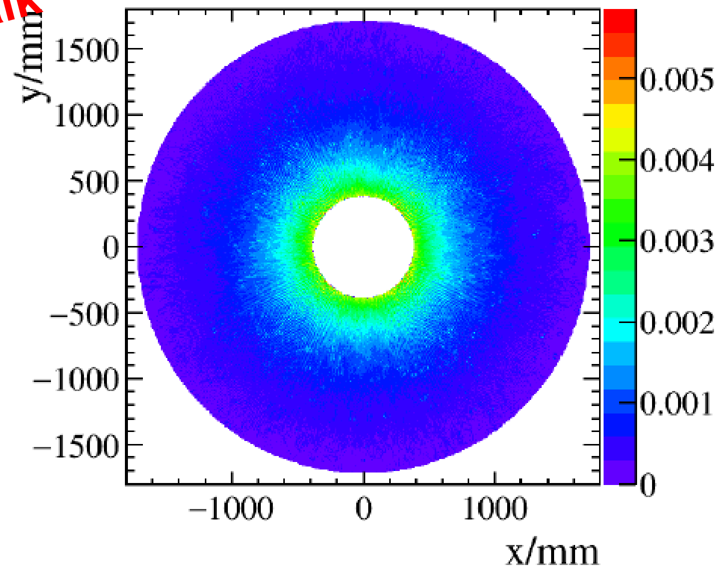
High rate at Z pole

ArXiv: 1704.04401

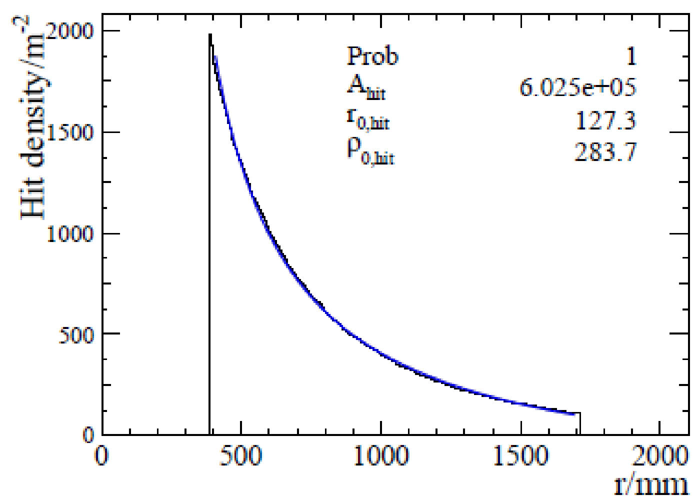
Manqi's talk

- 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$\times$6mm $\times$2mm
  - 1.33$\times 10^{14}$ number of voxels/s @DAQ/40MHz
  - Average voxel occupancy: 1.33$\times 10^{-8}$
  - Voxel occupancy at TPC inner most layer: ~2$\times 10^{-7}$
  - Voxel occupancy at TPC inner inner most layer : ~2$\times 10^{-5}$ @FCCee benchmark luminosity

The voxel occupancy takes its maximal value between 2$\times 10^{-5}$ to 2$\times 10^{-7}$, 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

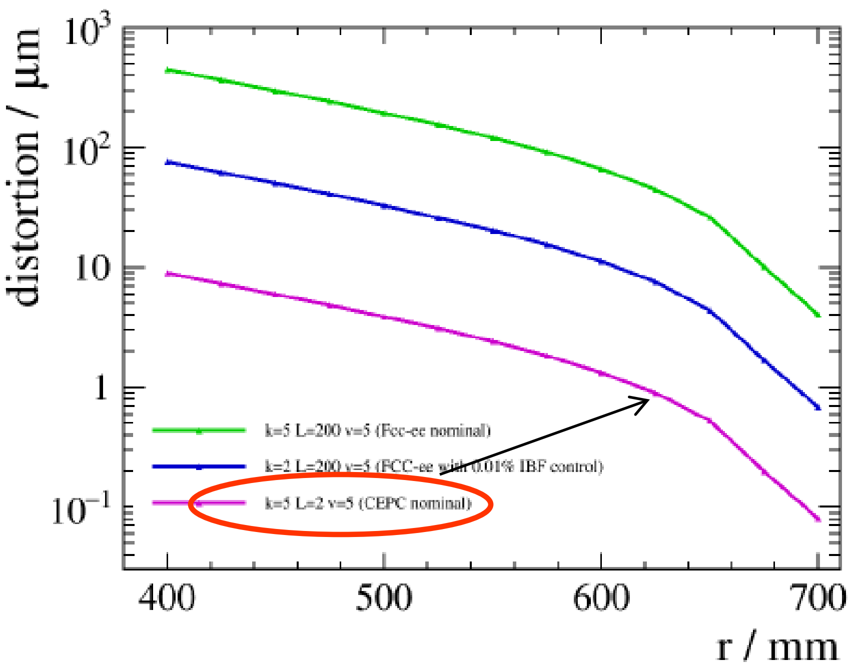
- Electron:
  - Drift velocity ~6-8cm/us@200V/cm
  - Mobility μ ~30-40000 cm^2/(V.s)
- Ion:
  - Mobility μ ~2 cm^2/(V.s)

  in a "classical mixture" (Ar/Iso)

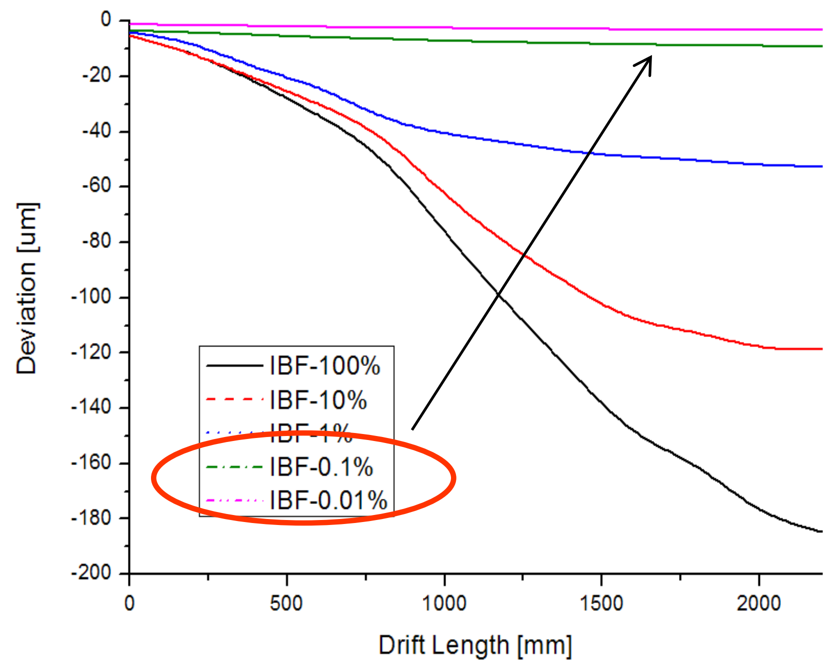
$$S_N = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 S_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 S_{x_2}^2 + \left(\frac{\partial f}{\partial x_3}\right)^2 S_{x_3}^2}$$

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

Simulation of GEM module

- Study with two size GEMs
  - 70-50-70@140um pitch
  - 90-70-90@140um pitch
  - Operation gas
    - $Ar/CO_2=90/10$
  - Set the ions disk
    - Under GEM/1.0mm
  - Drift length:
    - 4.0mm
  - Transfer length
    - 1.0mm
  - Operation high voltage
    - Setting and changing

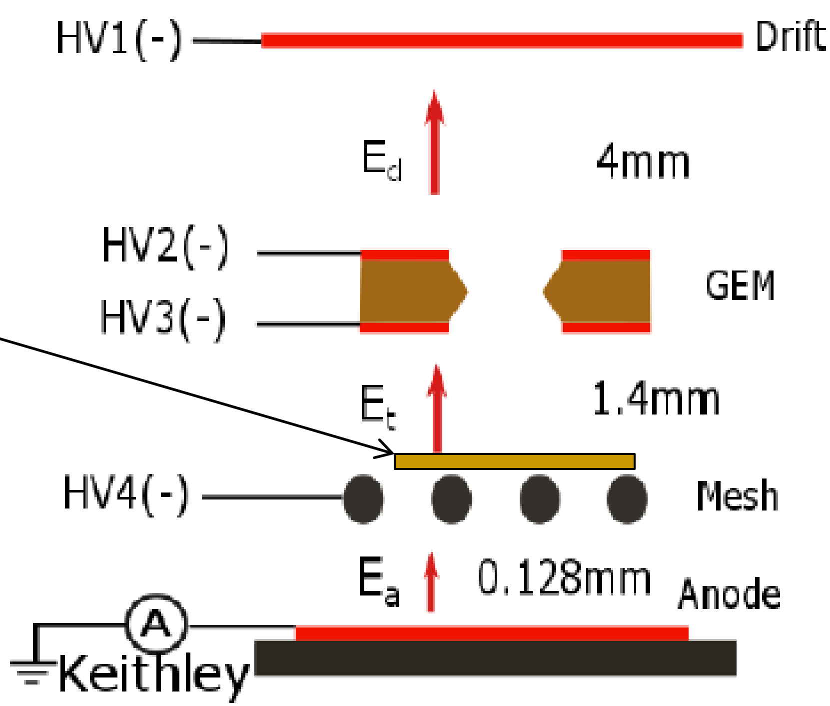
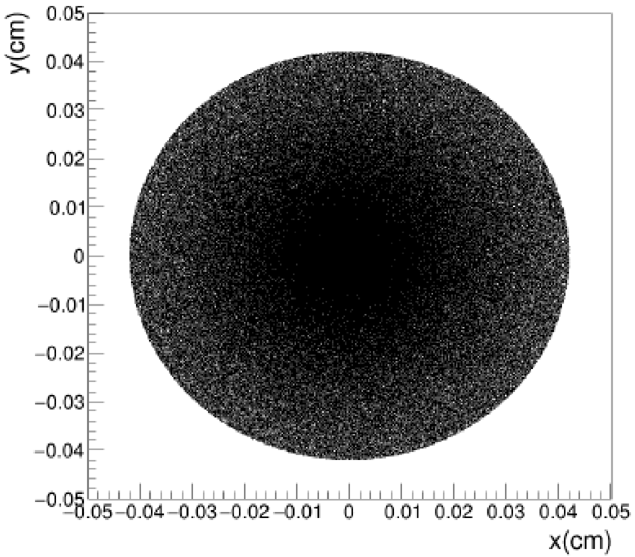
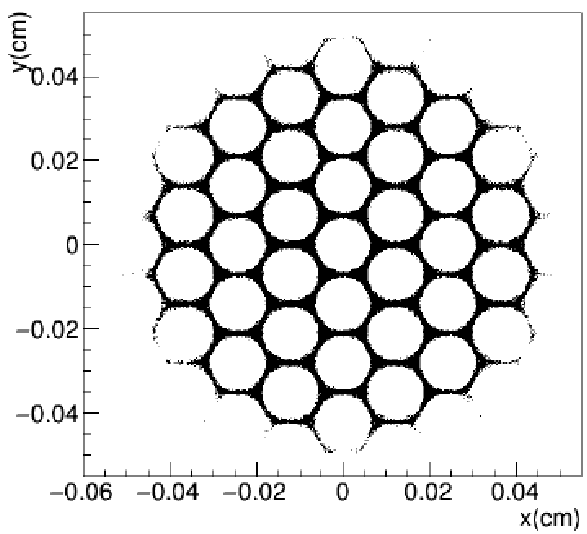


Diagram of the simulation

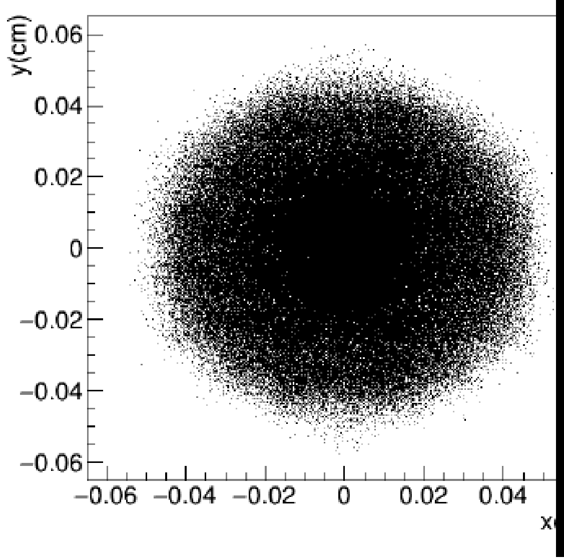
Recorded the stop ions



Initial ions disk



Ions recorded in GEM

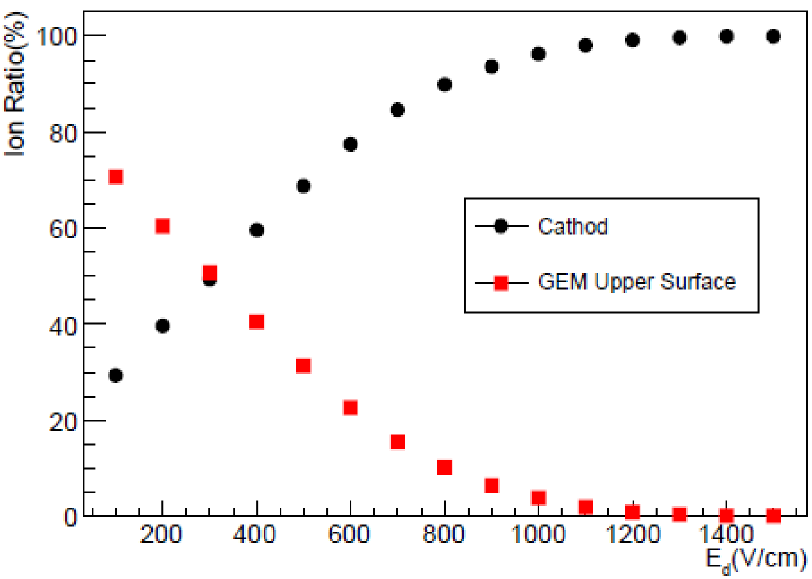


Ions recorded after GEM

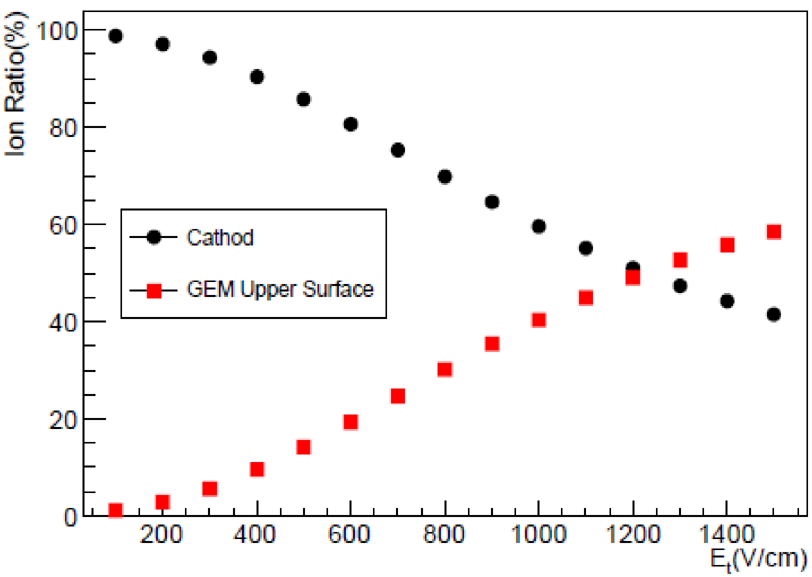
Recorded the stop ions

- Ions recorded in GEM and cathode
  - Ed @ VGEM=400V, Et=1000V/cm
  - VGEM @ Ed=250V/cm, Et= 1000V/cm
  - Et @ VGEM=250V, Ed=400V/cm

VGEM=250V
Et=1000V/cm
Ed=400V/cm



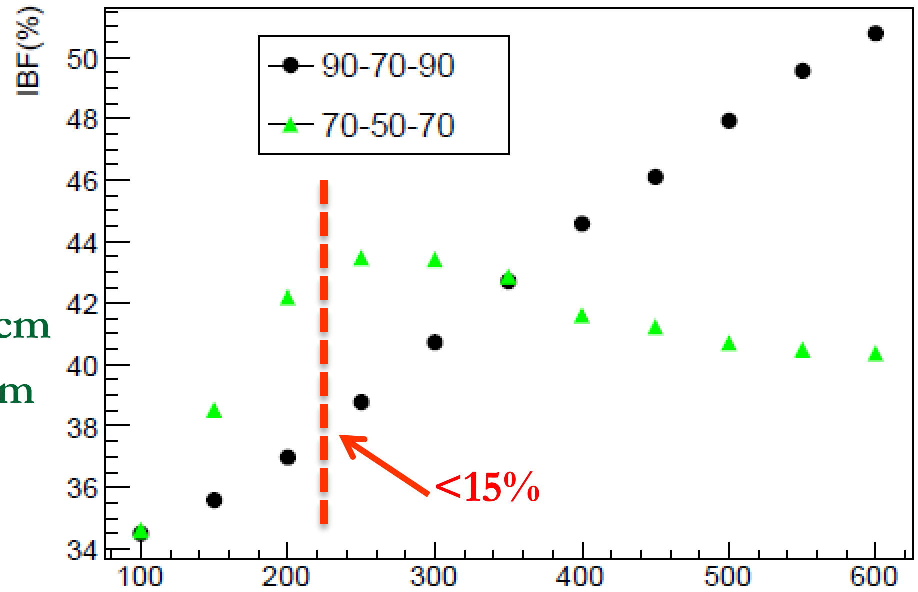
Ions recorded in GEM and cathode VS Ed



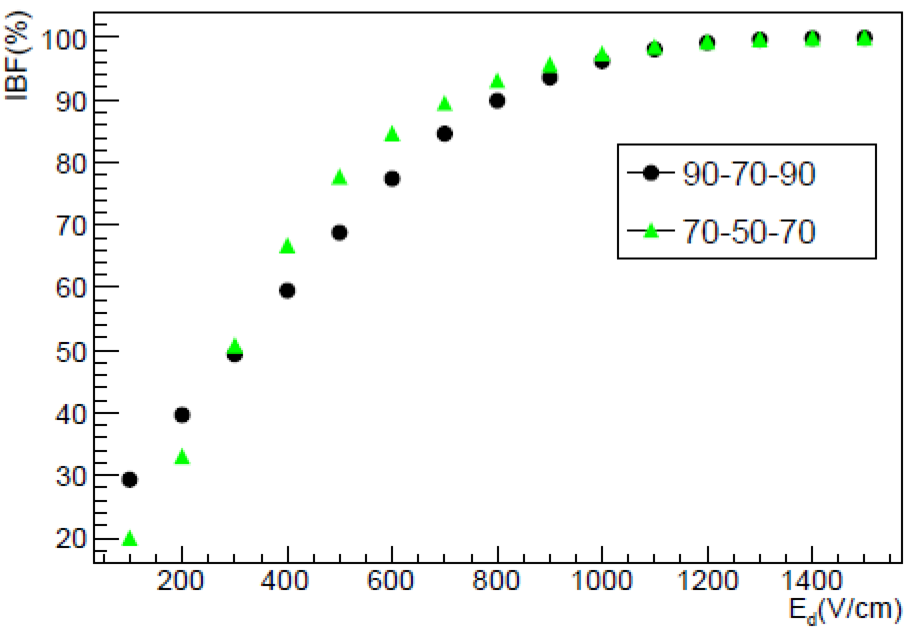
Ions recorded in GEM and cathode VS Et

IBF simulation

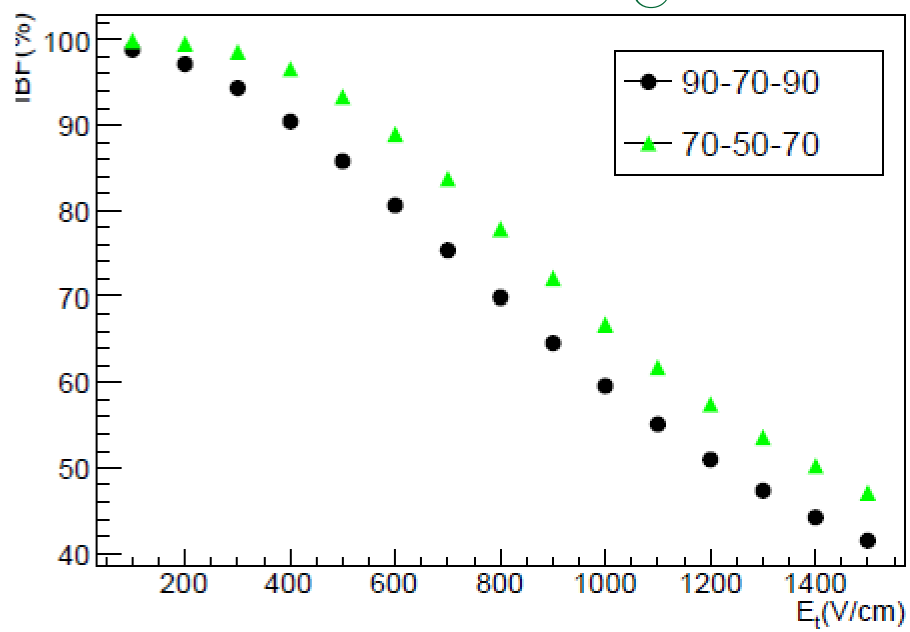
- IBF simulation with two size GEMs
  - Ed @ VGEM=400V, Et=1000V/cm
  - VGEM @Ed=250V/cm, Et=1000V/cm
  - Er @VGEM=250V/cm, Ed=400V/cm
  - Standard GEM
  - 90-70-90 could reduced the IBF than standard GEM (~15%)



IBF with VGEM @ GEMs



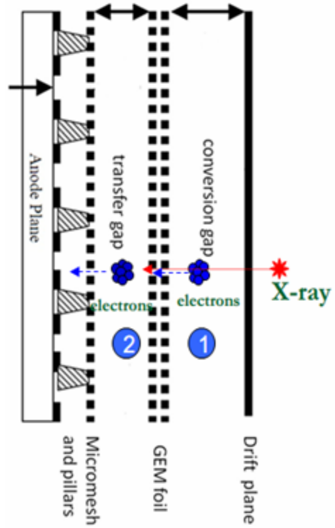
IBF with Ed @ GEMs

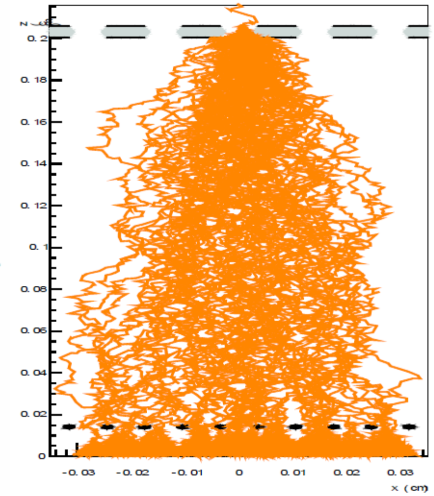


IBF with Et @ GEMs

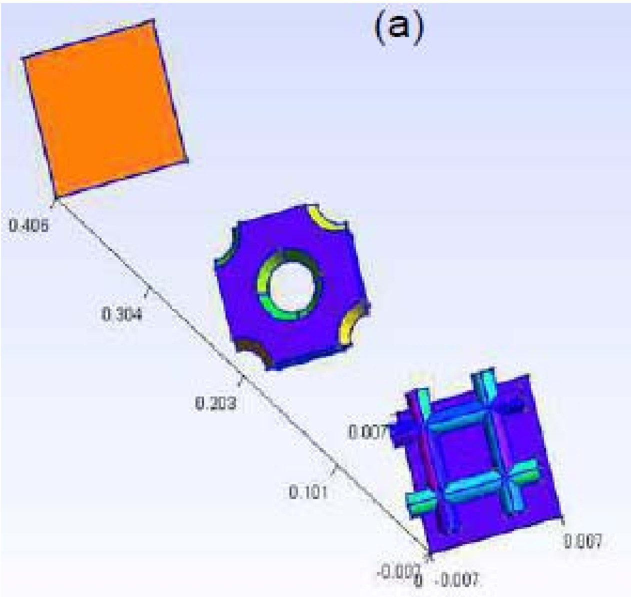
IBF simulation

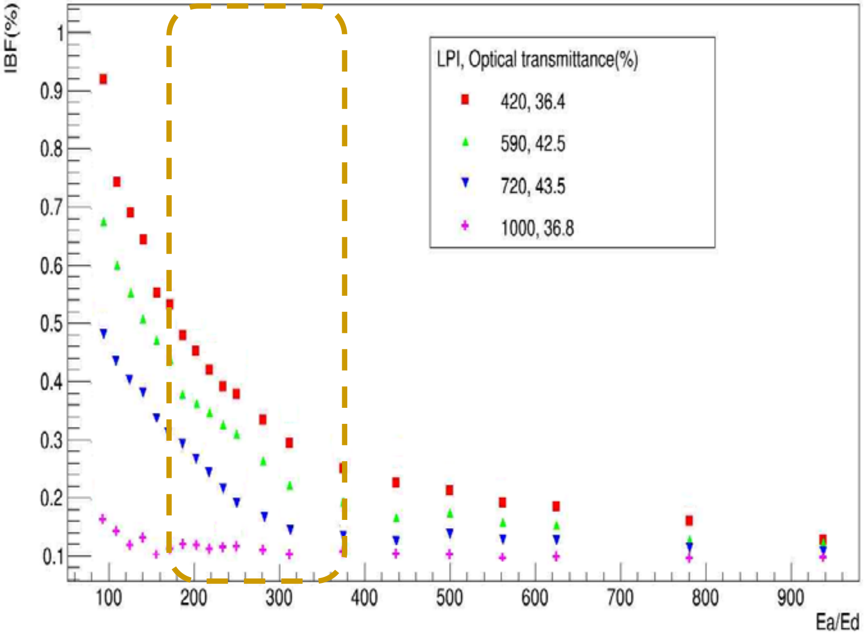
- Garfield++/ANSYS to simulate IBF
  - 420LPI/ 590LPI/ 720LPI/1000LPI
  - Ea is electric field of amplifier of Micromegas
  - Standard GEM foil (70-50-70)
  - Standard Bulk-Micromegas (420LPI)
  - GEM optimization: wider hole GEM/KEK
  - MM optimization: 590LPI mesh/Saclay





Combination detector simulation



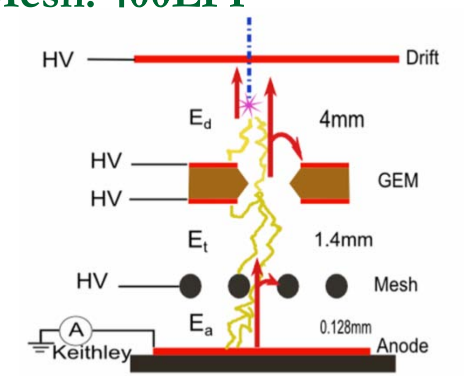


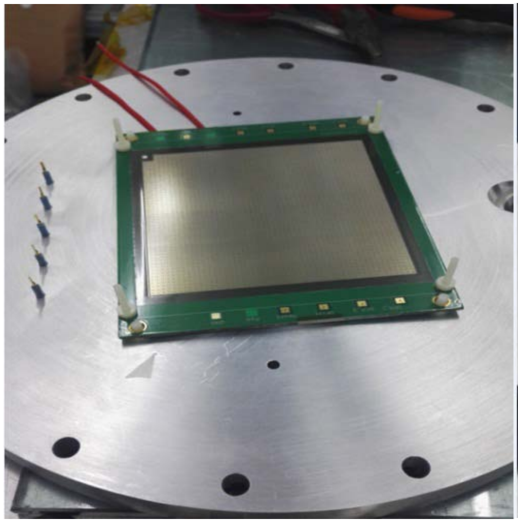
Electric field of amplifier VS Electric field of Drift

Investigation of IBF study with module

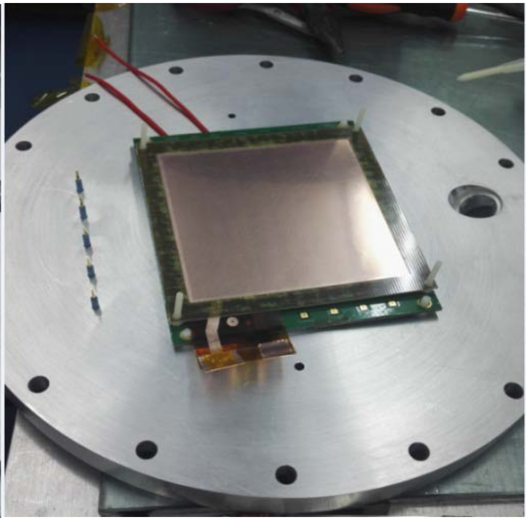
Test of the new module

- 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

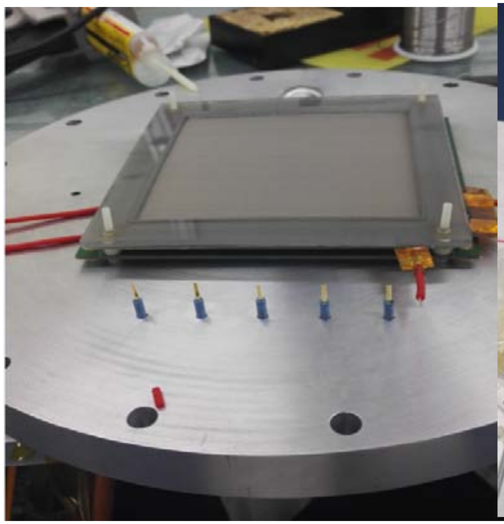




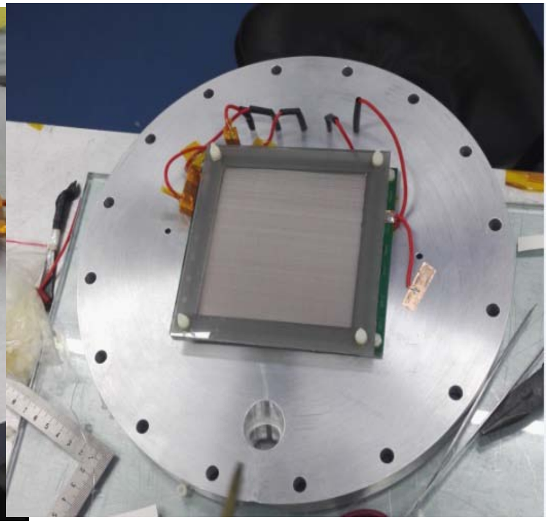
Micromegas(Saclay)



GEM(CERN)



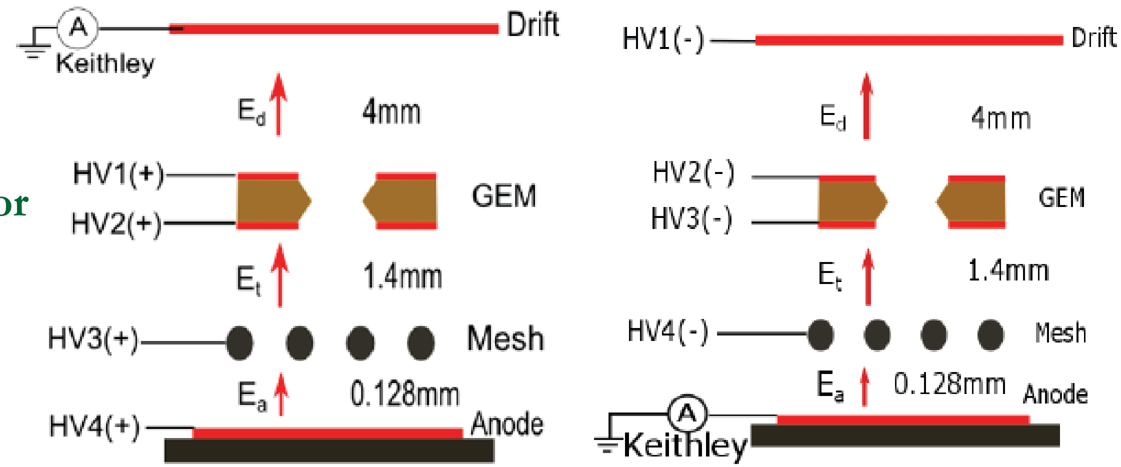
Cathode with mesh



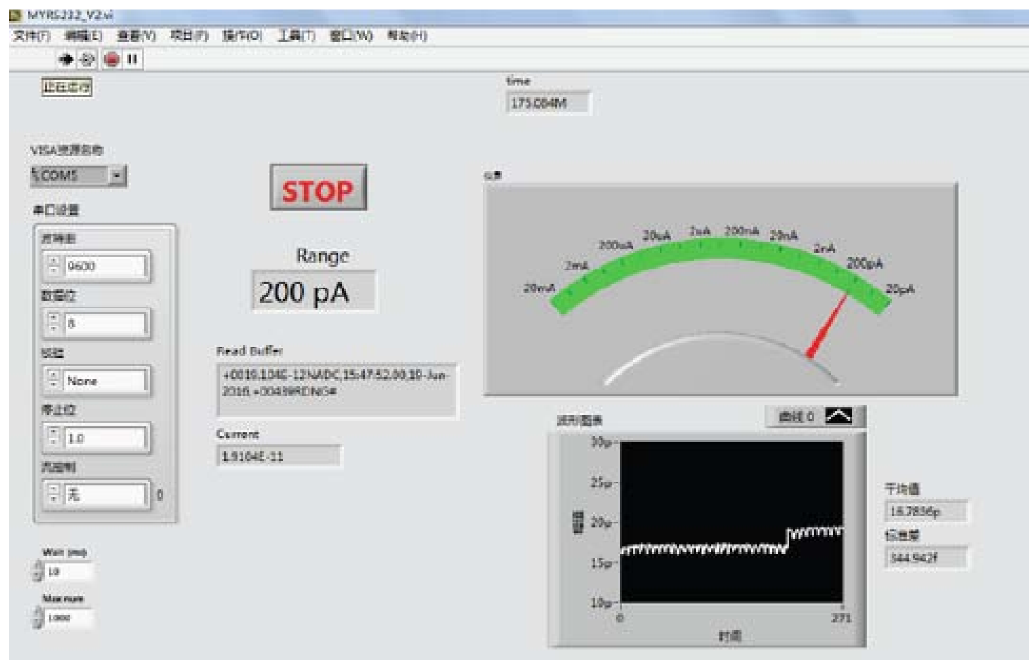
GEM-MM Detector

Measuremnt 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



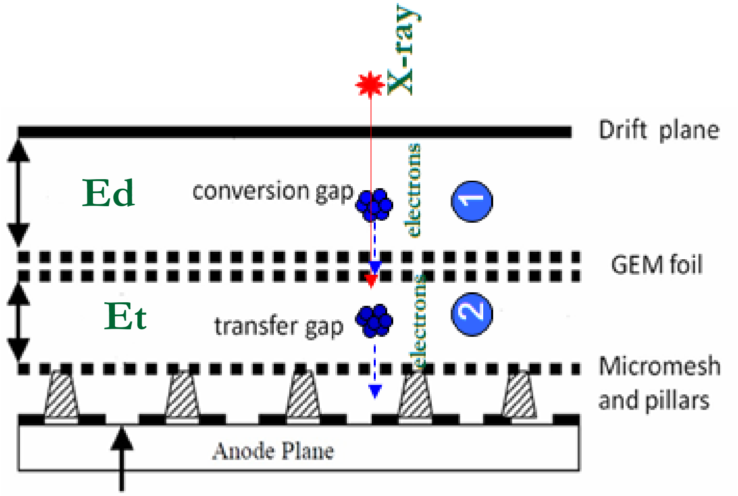
Measurement of the low current



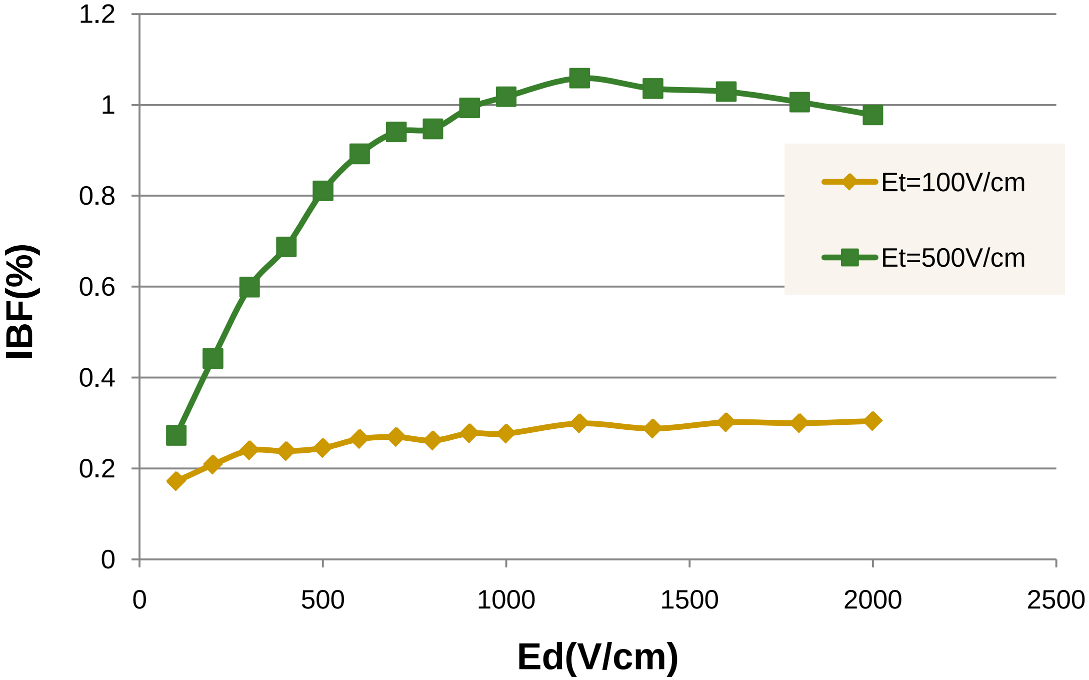
Labview interface of the current with Keithley

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



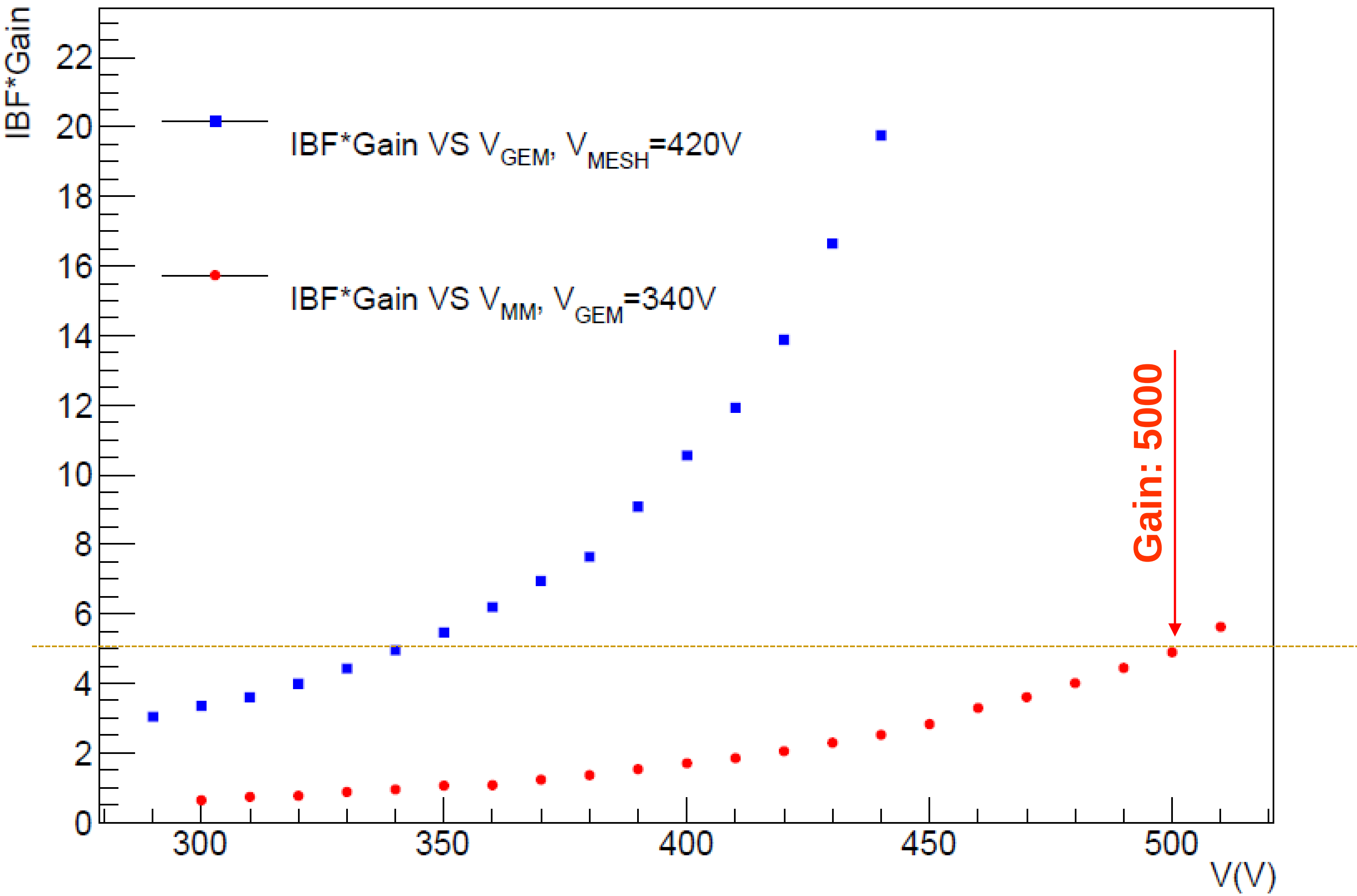
Schematic of the Gain with MM



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

Status of TPC prototype R&D

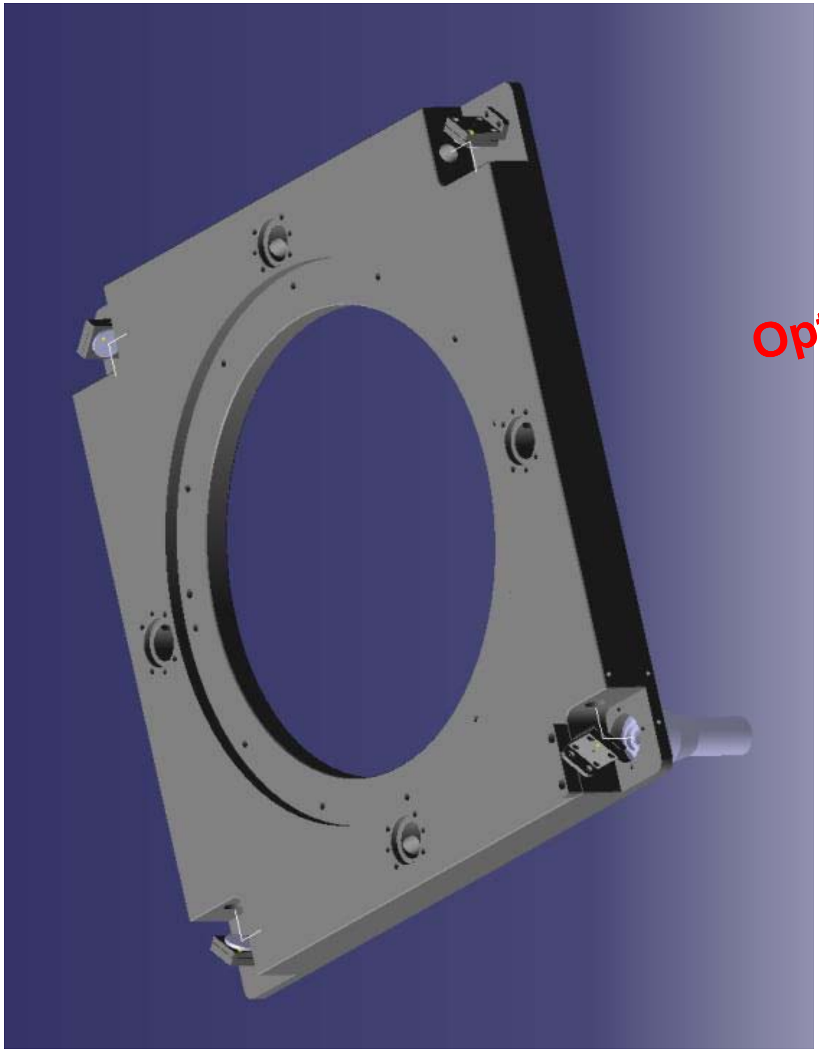
Parameters of the TPC prototype

- To aim that the small TPC prototype for the estimation of the distortion due to the IBF, and the study of related physics parameters
- Drift velocity, gain uniformity, T/P stability

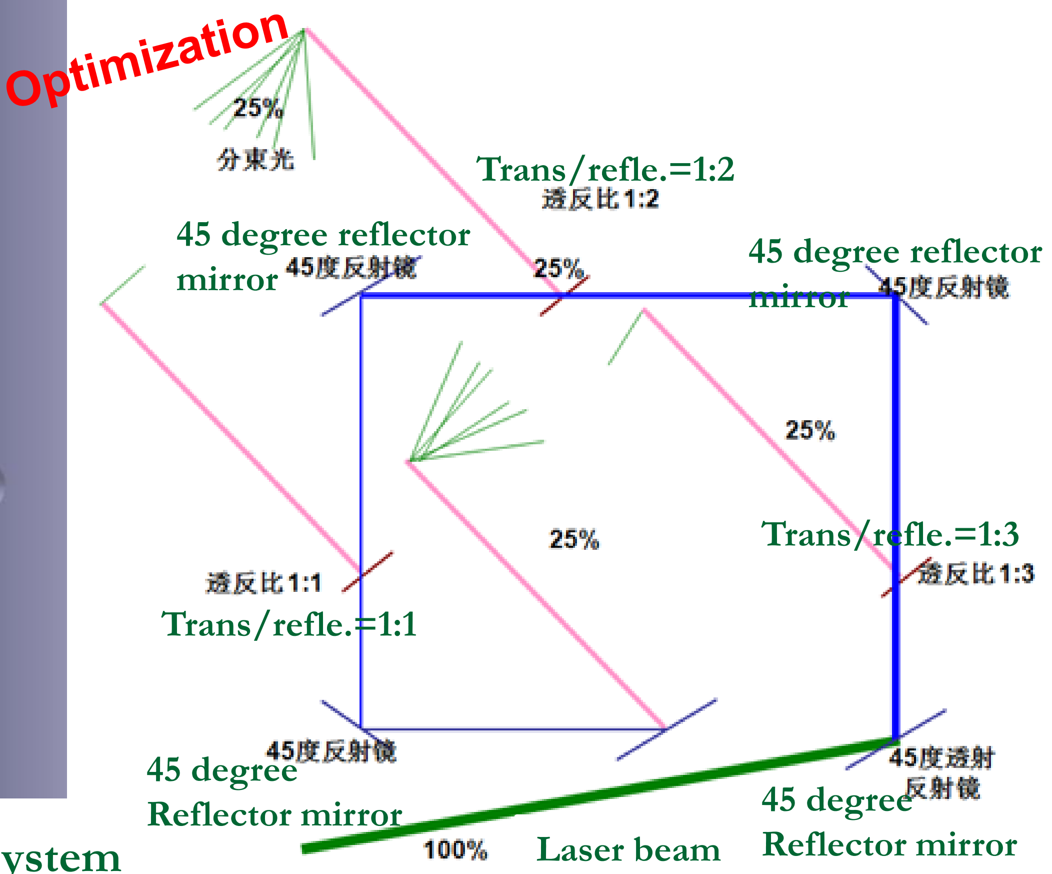
- Main parameters
  - Drift length: 510mm
  - Readout active area: 200mm×200mm
  - Integrated the laser and UV lamp device
  - Wavelength of laser: 266nm
  - GEMs/Micromegas as the readout
  - Materials: Non-magnetic material (Stainless steel, Aluminum)

Laser map in drift length

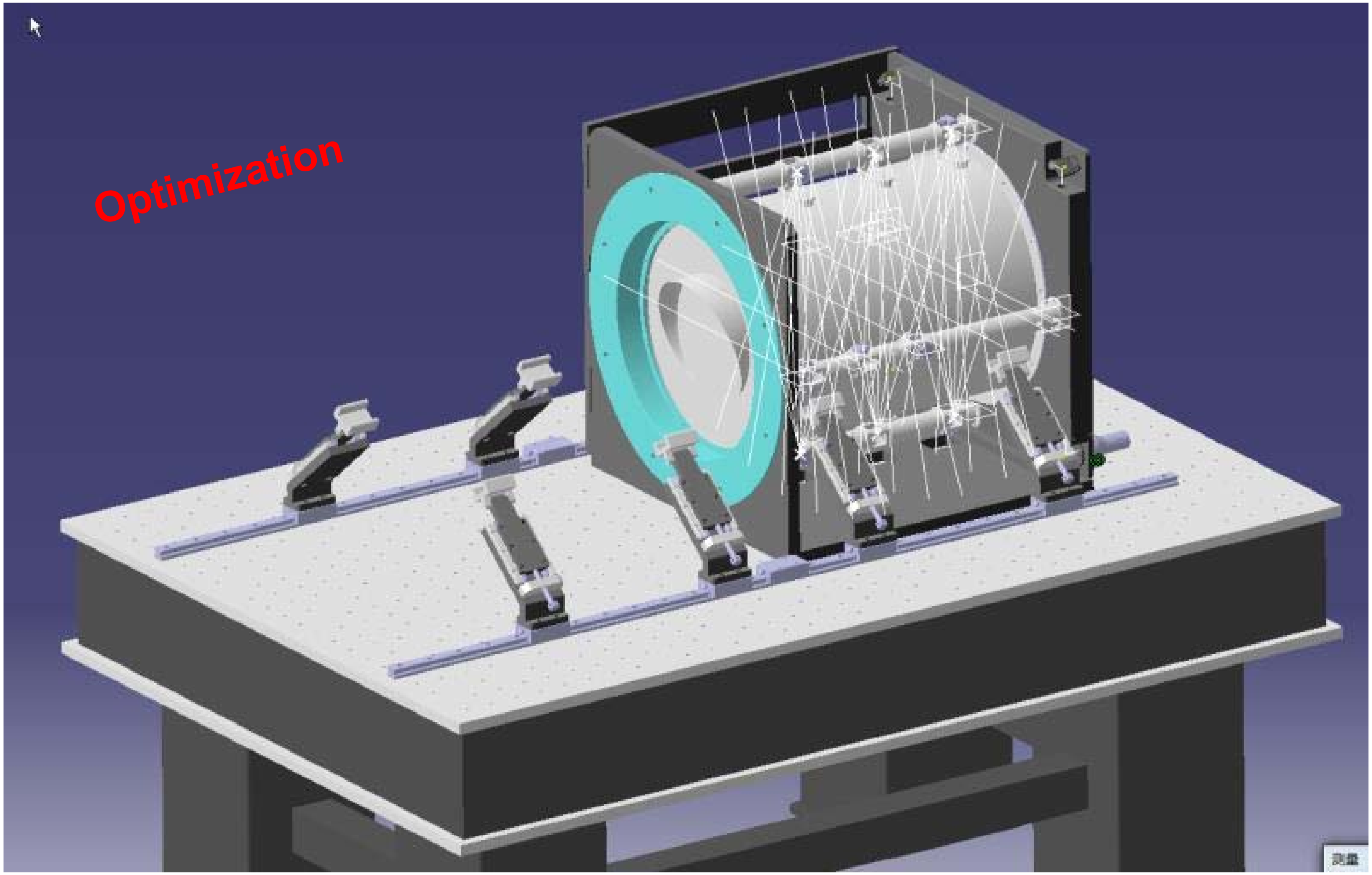
- Laser wave: 266nm
- Size: ~1mm×1mm
- Transmission and reflection mirrors
- Aluminum board integrated the laser device and supports



Aluminum board integrated the laser system



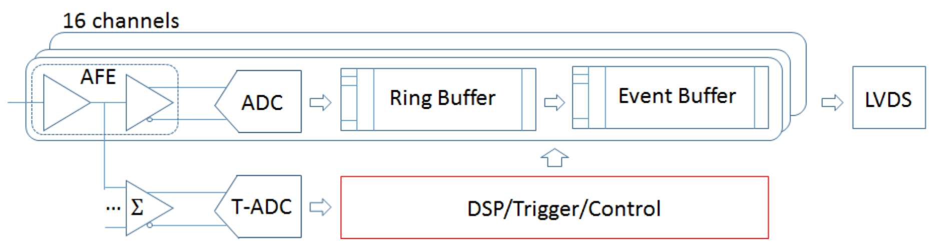
Design of the prototype with laser (Final version)



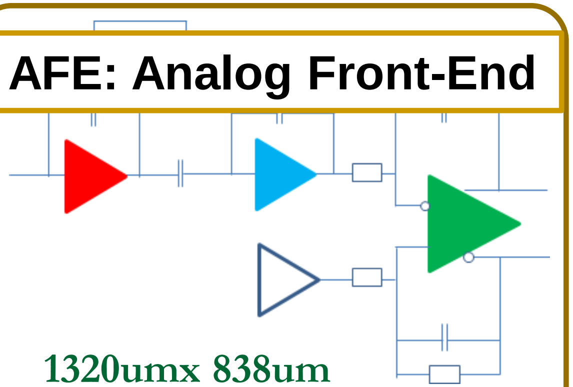
- Support platform: 1200mm×1500mm (all size as the actual geometry)
- TPC barrel mount and re-mount with the support brackets
- Design is done and hardware would be assembled the end of this year.

Low power TPC Readout ASIC in 65nm

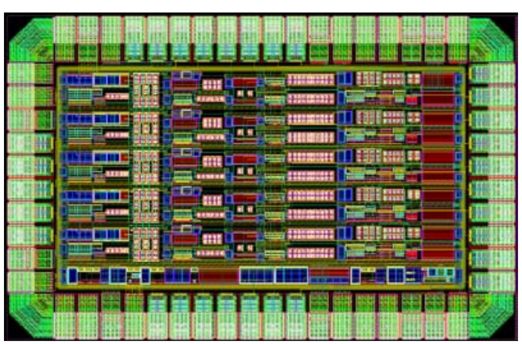
Deng Zhi, Tsinghua



AFE: Analog Front-End

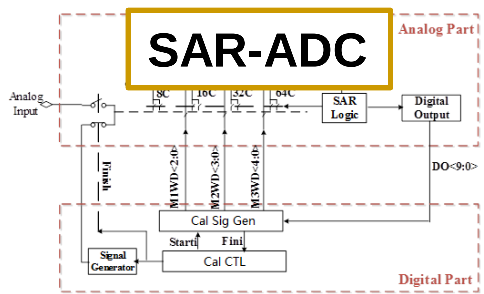


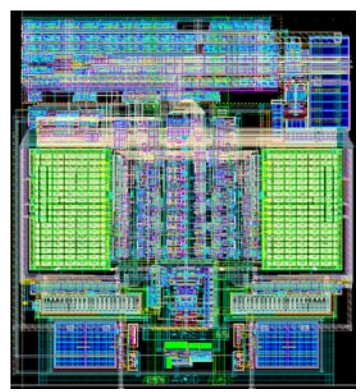
1320umx 838um



1.93mW/ch (Simulation)

SAR-ADC





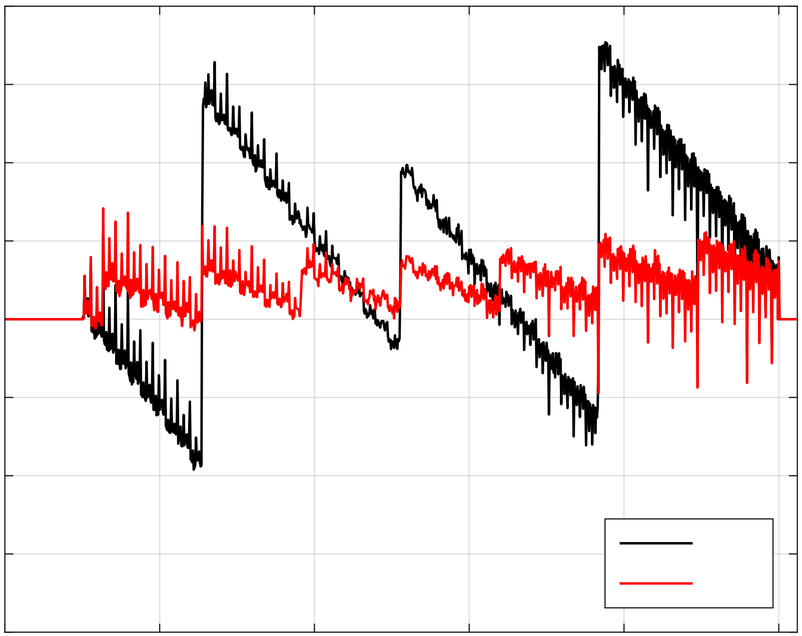
0.55 mW/ch(Simulation)

AFE	
Signal Polarity	Negative
Detector Capacitance	5-20 pF
Shaper	CR-RC
Shaping Time	160 ns
ENC (Equivalent Noise Charge)	<500 e @ 10 pF
Dynamic Range	120 fC
Gain	10 mV/fC
INL (Integrated Non-Linearity)	<1%
Crosstalk	<0.3%
Power Consumption (AFE)	<2.5 mW/ch

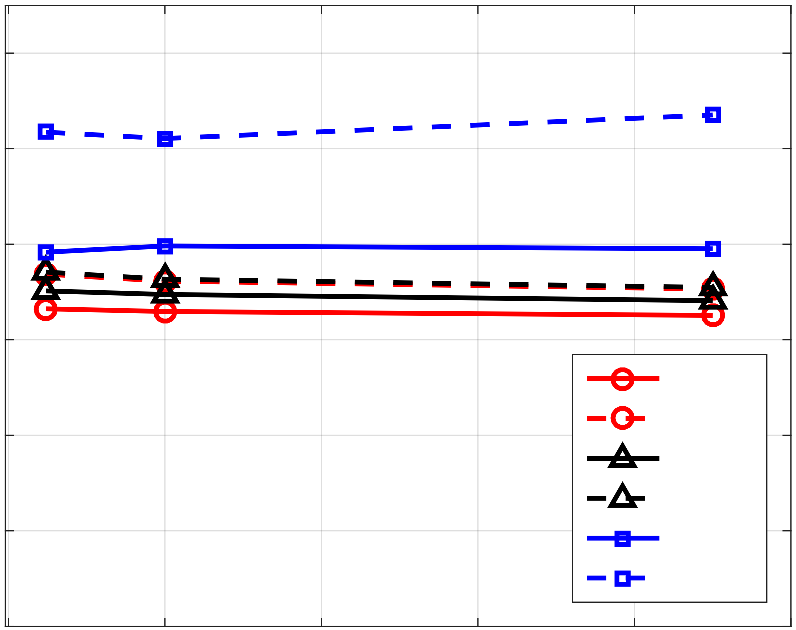
ADC	
Input Range	-0.6V~0.6V diff.
Resolution	10 bit
Sampling Rate	20 MSPS
DNL	<0.65 LSB
INL	<0.6 LSB
SFDR @ 2MHz, 40MSPS	68 dBc
SINAD	57 dB
ENOB	>9.2 bit @ 2MHz
Power Consumption (ADC)	<2.5 mW/ch

ADC Test Results @ 50 MS/s

INL: <0.6LSB



Dynamic Performance: ENOB~9.17bit



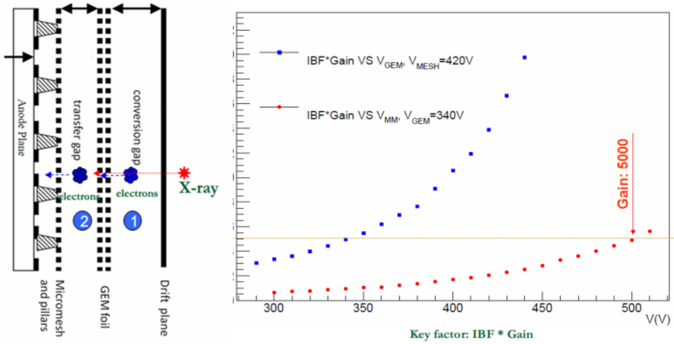
Circuit Module	Power consumption (mW)
Reference buffer	0.25
SAR ADC Core	1.0
Others(CLK gen.)	2.75
Total	4.0

FOM=21.3fJ/conv.

Highlights and summary

Continuous IBF module for CEPC:

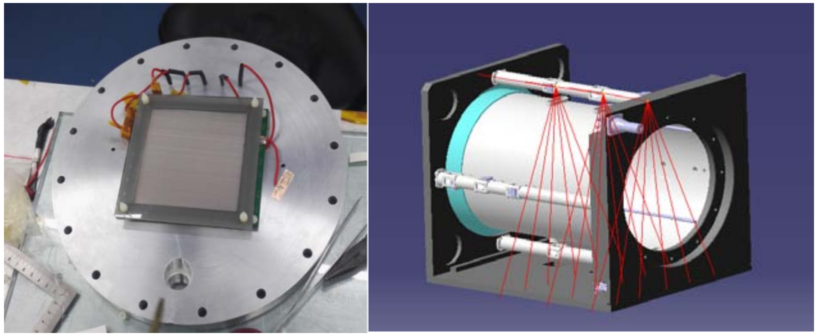
- No Gating device options used for Higgs/Z pole run
- Continuous Ion Back Flow due to the continuous beam structure (Developed in IHEP)
- ~100 μm position resolution in rφ
- Key factor: IBF×Gain=5 and leas than (R&D)
- Low discharge and spark possibility



Continuous IBF prototype and IBF×Gain

Prototype with laser calibration for CEPC :

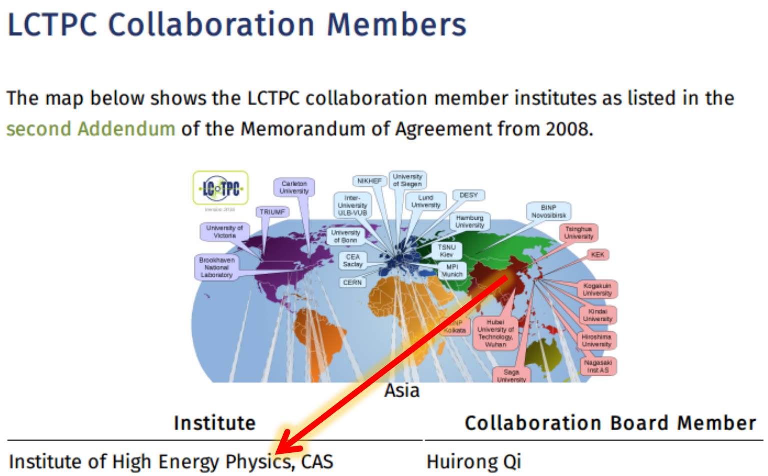
- Laser calibration system integrated UV lamp
- Calibrated drift velocity, gain uniformity, ions back in chamber
- Prototype has been designed with laser (Developed in IHEP and Tsinghua)_
- Nd:YAG laser device@266nm, 42 separated laser beam along 510mm drift length



TPC prototype integrated with laser system

Collaboration:

- Signed MOA with LCTPC international collaboration on 14, Dec., 2016
- New design detector collaborated with KEK and CEA-Saclay



Joint LCTPC international collaboration

Thanks for your attention!