CEPC TPC 高精度径迹探测器关键技术及可行性方案研究进展

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Outline

- Critical technology challenges
  - Physics requirement
- Current R&D activities
  - Status of Occupancy
  - Status of TPC module IBF R&D
- Conclusions

Critical technology challenges at CEPC

TPC requirements for collider concept

TPC as one tracker detector option for CEPC:

E_{cm} = 240 GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, 1M ZH events in 10yrs at the Z-pole 91GeV, 10^{10} Z bosons/yr

The voxel occupancy takes its maximal value of $\mathcal{O}(10^{-6})$, which is safety for the Z pole operation. Of course, it is well for Higgs run too.

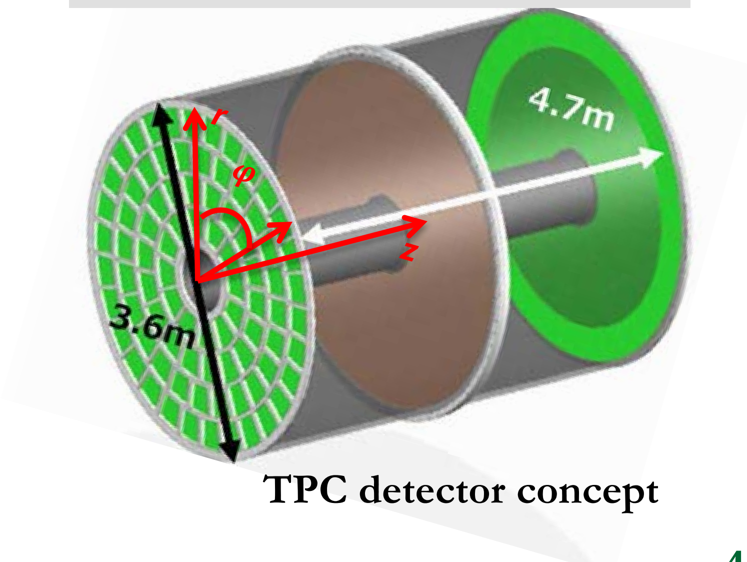
https://doi.org/10.1088/1748-0221/12/07/P07005

TPC detector concept:

- **Motivated by the H tagging and Z**
- **Main tracker detector with TPC**
- **B~3T magnetic field**
- **Large number of 3D points(N~220)**
- **~100 μm position resolution in rφ**
- **Distortion by IBF issues**
- **Systematics precision (<20 μm internal)**
- **dE/dx resolution: <5%**
- **Tracker efficiency: >97% for p_T>1GeV**

$$p_T(\mathrm{GeV/c}) = 0.3Br(T\cdot \mathrm{m})$$

$$\sigma\left(\frac{1}{p_T}\right) = \frac{\sigma(p_T)}{{p_T}^2} = \frac{\sigma_{r\varphi}}{0.3Bl^2}\sqrt{\frac{720}{(N+4)}}$$



TPC detector concept

Critical challenges of CEPC TPC

- **Occupancy: at inner diameter**
  - Low occupancy<1%
  - 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

→ ~100μm positron resolution with calibration

~2017, On-going activities for all

Occupancy

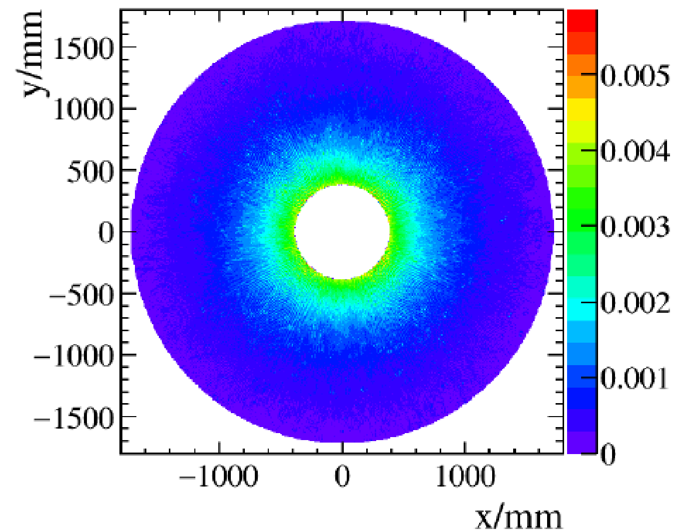
ArXiv: 1704.04401

Hit map

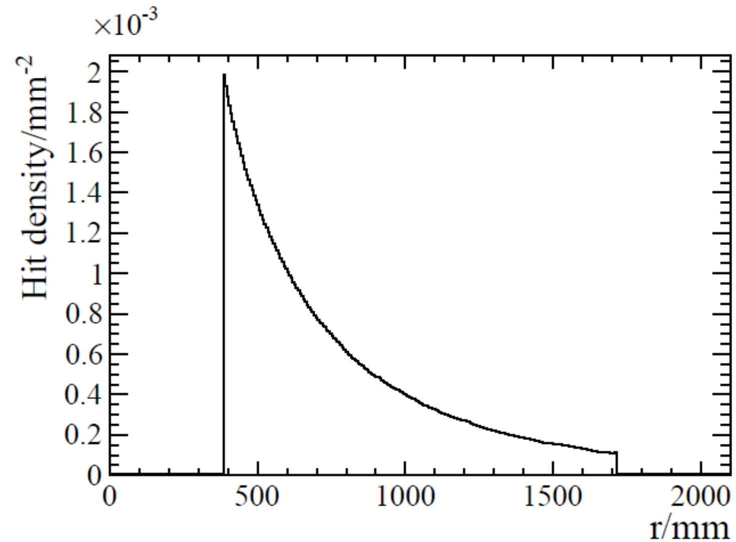
- Z to qqbar (rate 600 Hz), 9e3 events
- 60 million hits are generated in sample
- 4e3(mpv),6.9e3 (ava)hits/(Z to qqbar) in TPC volume
- Average hit density: 5e-4 hits/mm^2 normalized to one event
- Peak value of hit density: 4 times

Voxel occupancy

- Occupancy: voxels with sig/all voxels
- Voxel size: 6mm×1mm ×2mm
- 5.9e13 number of voxels/s @v_e 80km/s, DAQ 40MHz(half-length 2.35m)
- 600 events/s, 2e6 hits,~10 voxel/hit ava
- The number of voxels with sig: 2e7/s
- Average voxel occupancy Z to qqbar: 3.4e-7
- At TPC inner most layer: 1.4e-6
- Lum two orders of magnitude higher: 3.4e-5

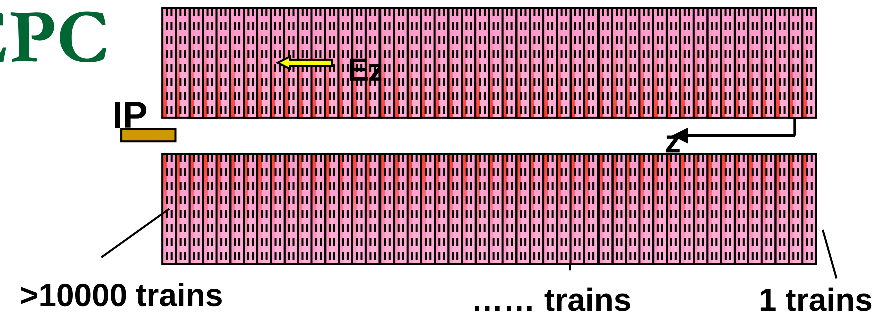


Hit map on X-Y plan for Z to qq events



Hit density as a function of radius

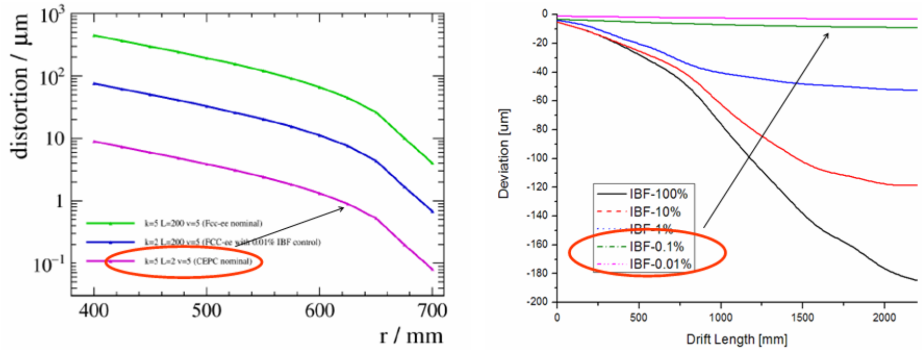
Technical challenges at CEPC



Amplification ions @CEPC

Ion Back Flow and Distortion :

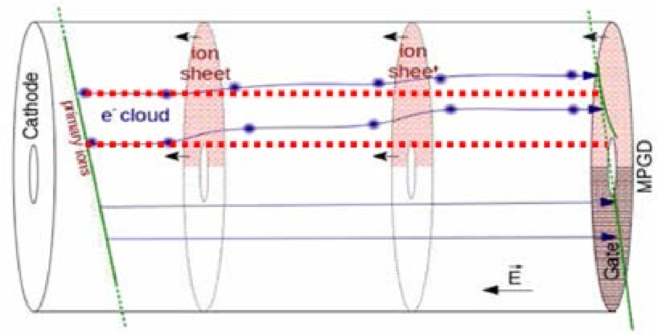
- ~100 μm position resolution in rφ
- Distortions by the primary ions at CEPC are negligible
- More than 10000 discs co-exist and distorted the path of the seed electrons
- Gating device may be used for Higgs run
- No Gating device option for Z-pole run
- The ions have to be cleared during the ~us period continuously
- Continuous device for the ion suppression
- Suppression level?



Evaluation of track distortions

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



Ions backflow in drift volume for distortion

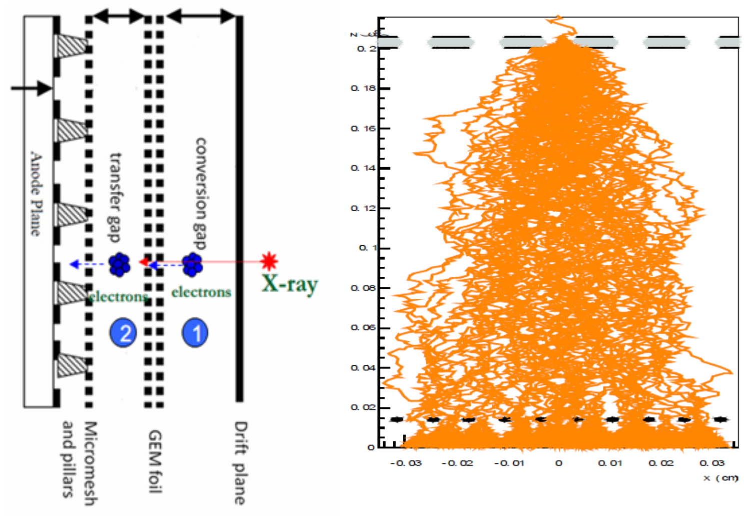
Options of technical solution

Continuous IBF module:

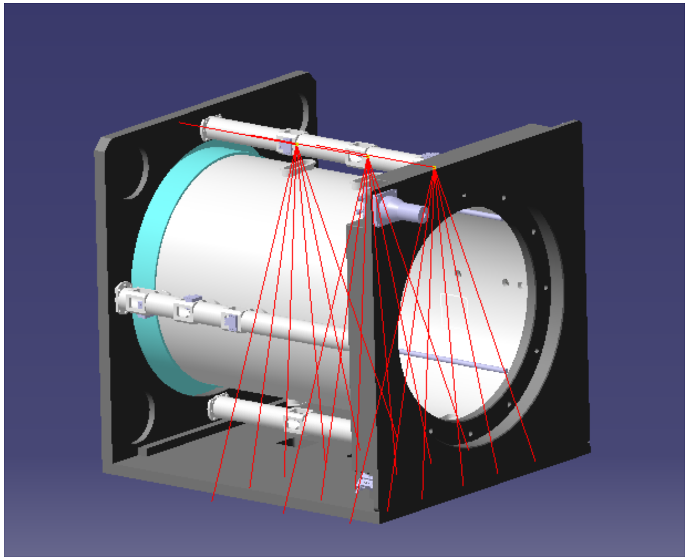
- Continuous Ion Back Flow due to the continuous beam structure
- Low discharge and spark possibility
- MPGD with intrinsic low suppression of the ion backflow
- Micromegas, GEM
- GEM-MM module

Laser calibration system:

- Laser calibration system for Z-pole run
- The ionization in the gas volume along the laser path occurs via two photon absorption by organic impurities
- Calibrated drift velocity, gain uniformity, ions back in chamber
- Calibration of the distortion
- Nd:YAG laser device@266nm



Continuous IBF module



TPC prototype integrated with laser system

Simulation on IBF for CEPC

Requirements of Ion Back Flow

Projective charge density and distortion:

- Z to qqbar events, hit density, charge density, space charge field, distortion on track
- Space charge density ∝ surface charge density & disk number density along z

$$(1+k)\frac{L}{V_{ion}} \times \rho \times R$$

  - Vion: 5–10ms^{-1}, R: 300 Hz
  - k: IBF*Gain 5–100

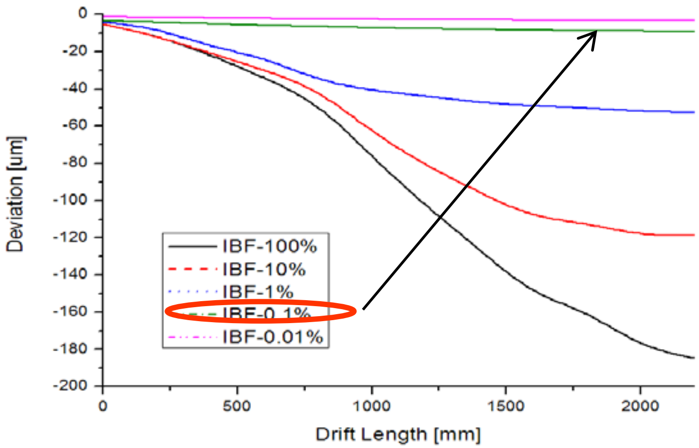
  depending on the control of back flow ions

- Distortion along φ

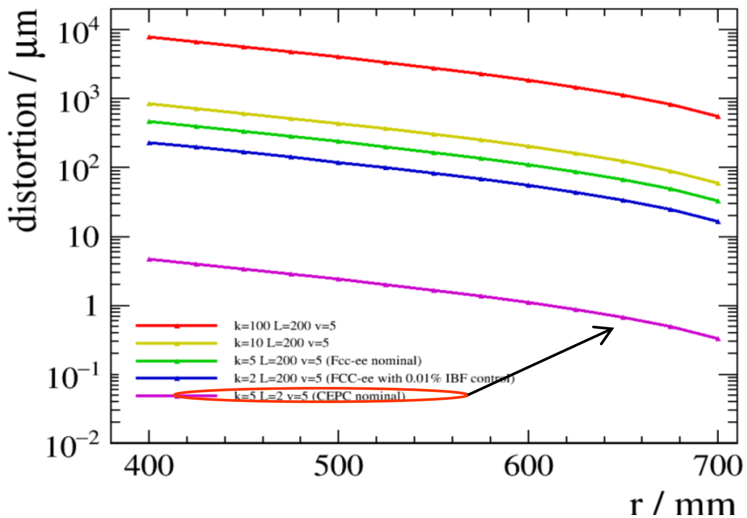
$$\Delta l = \frac{\omega\tau}{1+(\omega\tau)^2} \times \frac{E_r}{E_z} \Delta z$$

  space charge field is calculated using an analytical method

- The maximal distortion (L = 2, k = 5, Vion = 5ms^{-1})is less than 10 μm.



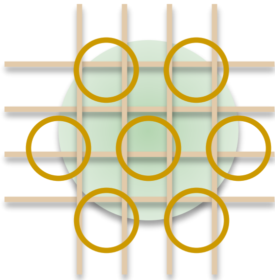
Evaluation of track distortions due to space charge effects of positive ions

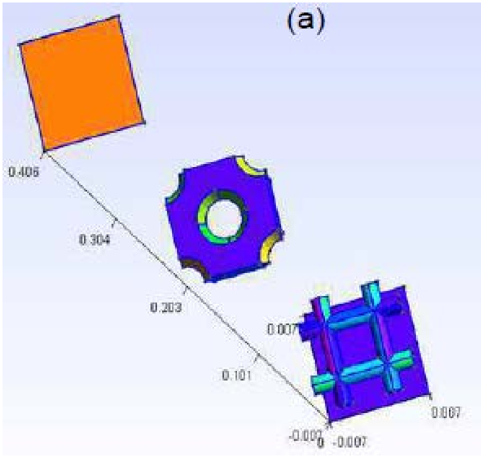


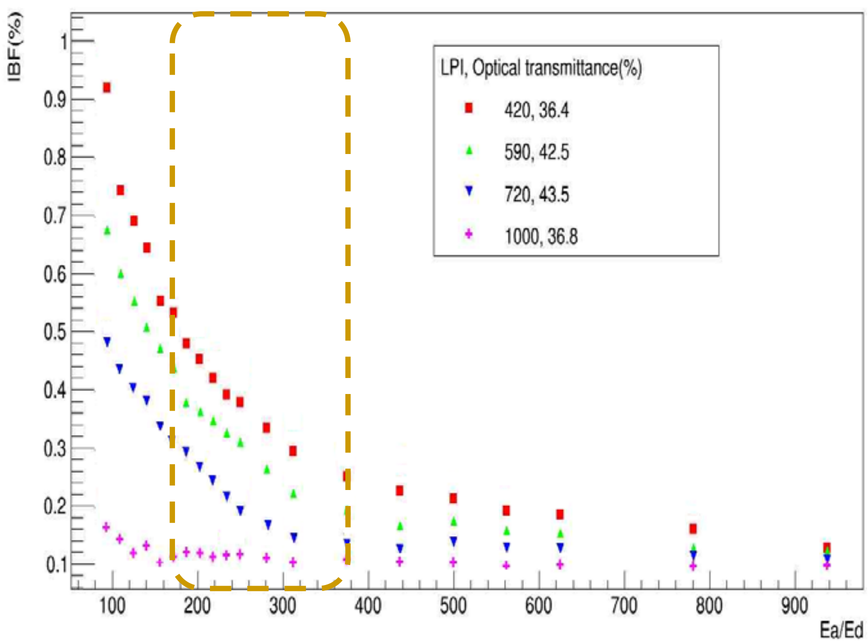
Distortion of as a function of electron initial r position @maximal drift length

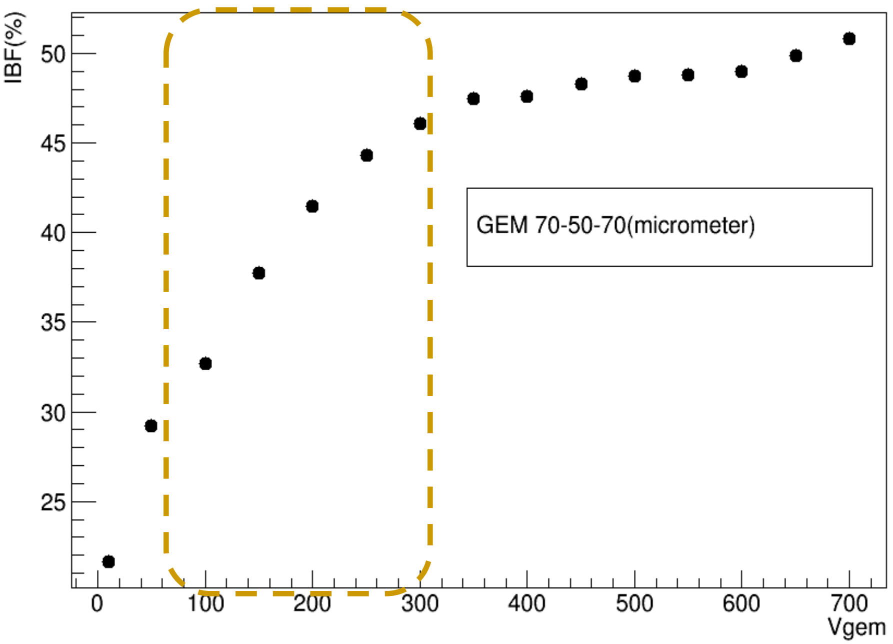
IBF simulation

- Garfield++/ANSYS to simulate the ions back to drift
  - 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







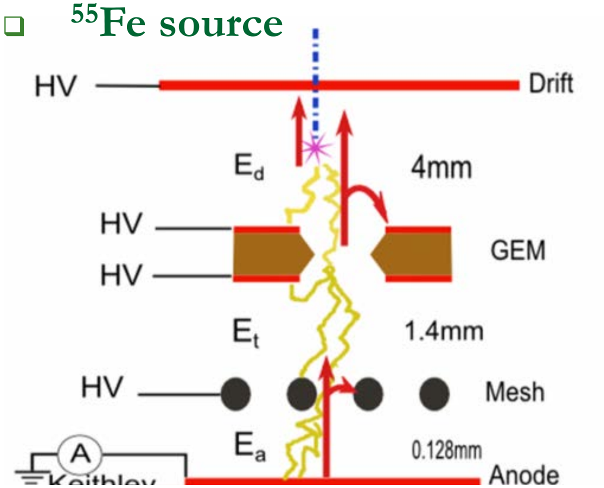


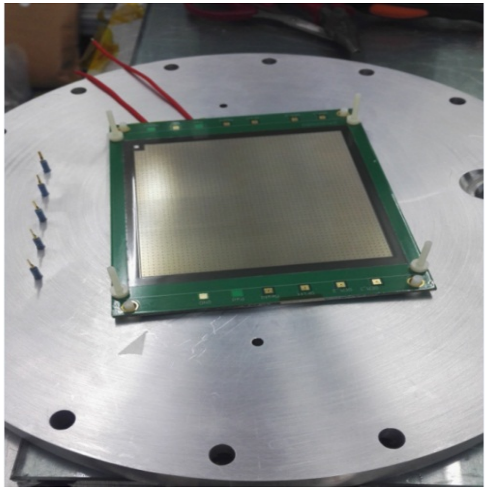
Electric field of amplifier VS Electric field of Drift and VGEM

Investigation of IBF study with module

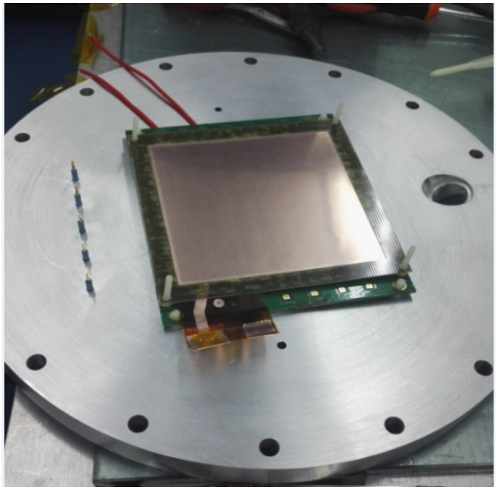
Test of the new module

- Test with GEM-MM module
  - New assembled module
  - Active area: 100mm×100mm
  - Bulk-Micromegas from Saclay
  - Standard GEM from CERN
  - Avalanche gap of MM:128μm
  - Transfer gap: 1.4mm
  - Drift length:4mm
  - Mesh: 590LPI
  - ^{55}Fe source

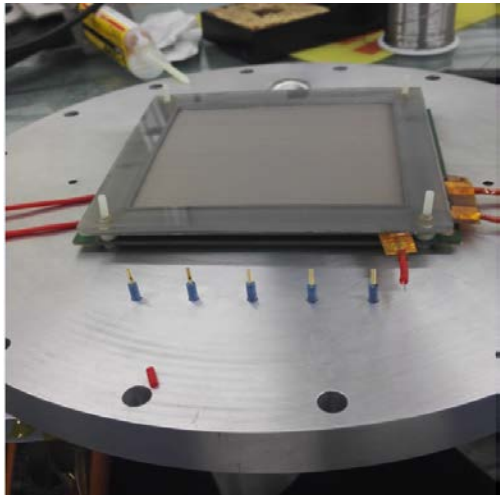




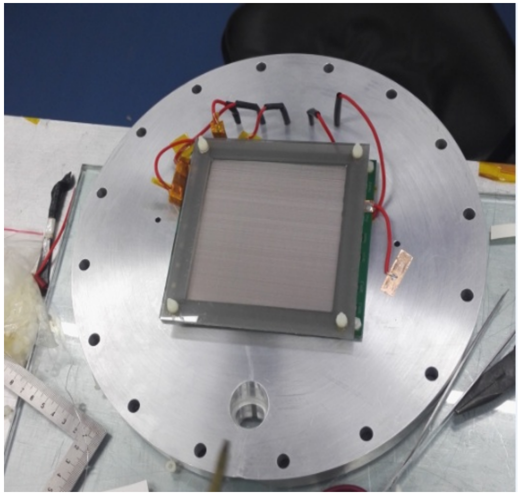
Micromegas(Saclay)



GEM(CERN)



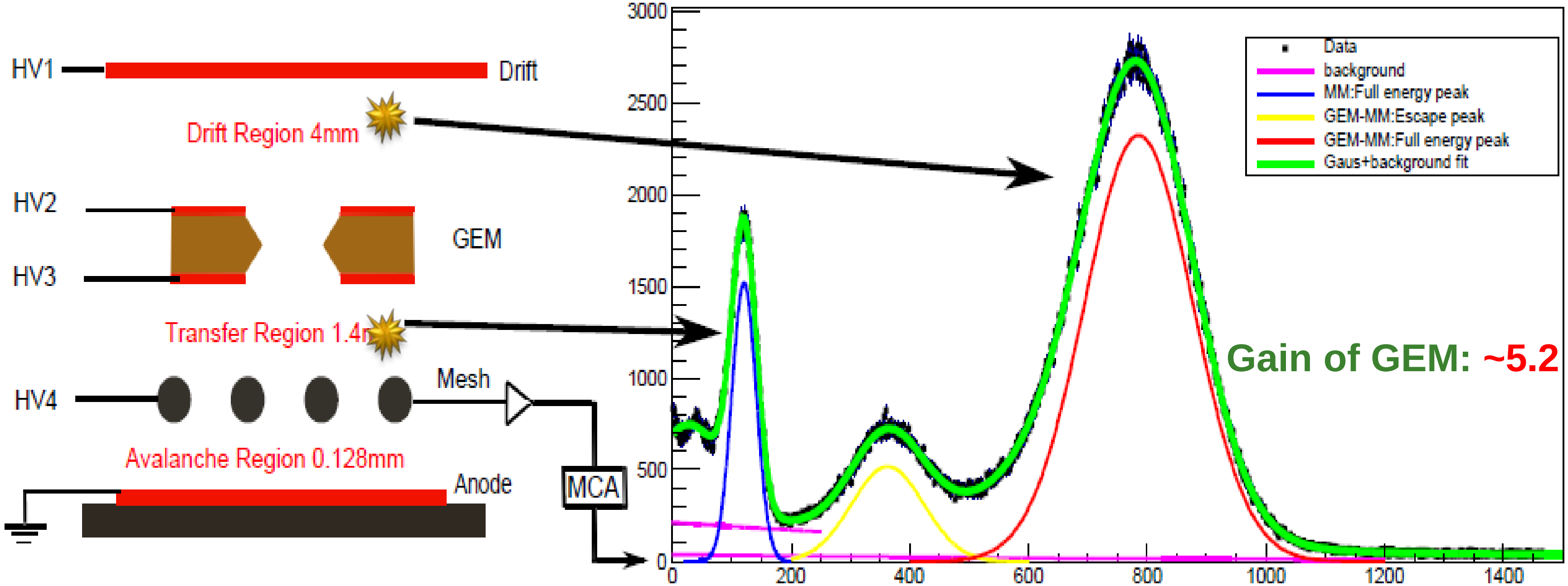
Cathode with mesh



GEM-MM Detector

Energy spectrum@^{55}Fe

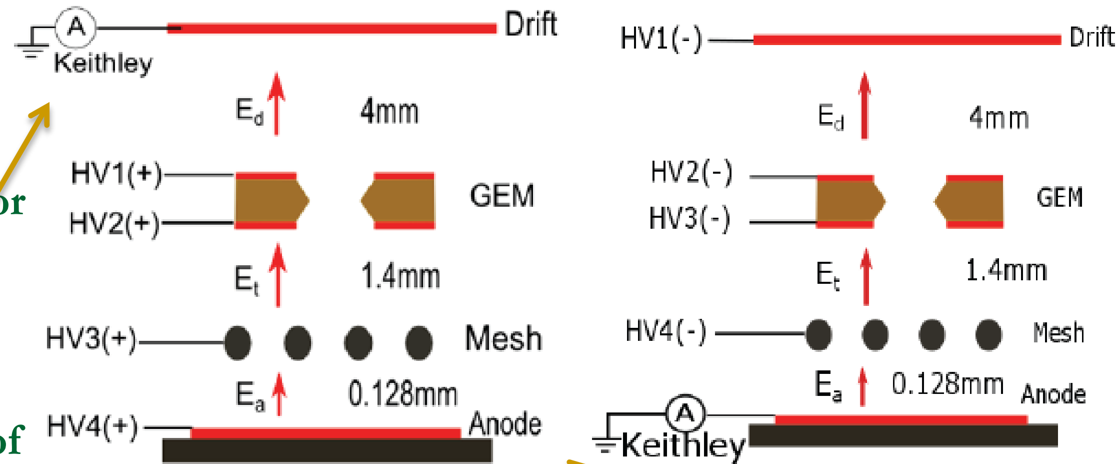
Source: ^{55}Fe, Gas mix: Ar(97) + iC_4H_{10}(3)



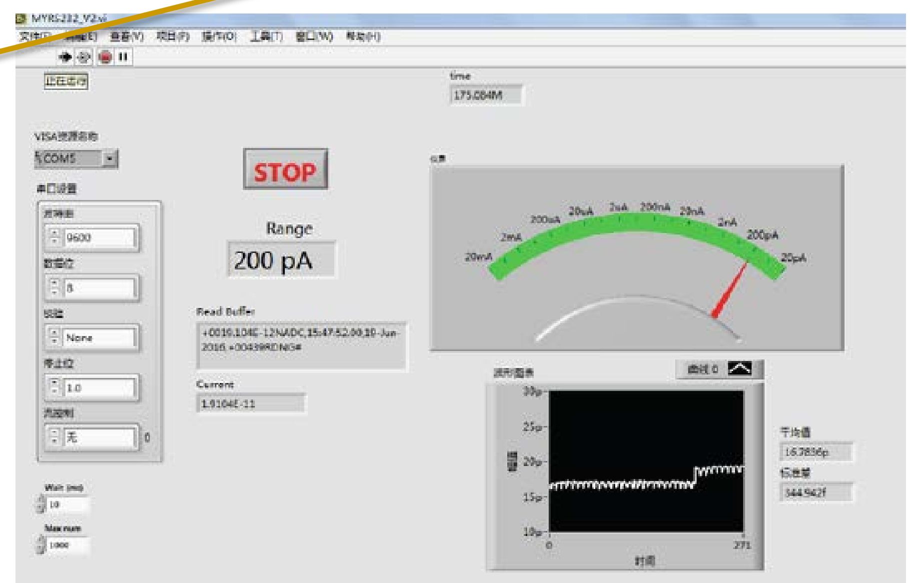
An example of the ^{55}Fe spectra showing the correspondence between the location of an X-ray absorption and each peak.

Measuremnt of GEM-MM module

- Test with GEM-MM module
  - Keithley Electrometers for Ultra-Low Current Measurements: pA~μA
  - Keithley: 6517B
  - Test of cathode current of the module, I_C
  - Test of readout anode current of the module, I_A
  - $IBF=(I_C-I_{prim})/I_A$
  - Iprim: Current on the cathode without amplification
  - Labview interface of the low current to make the record file automatically



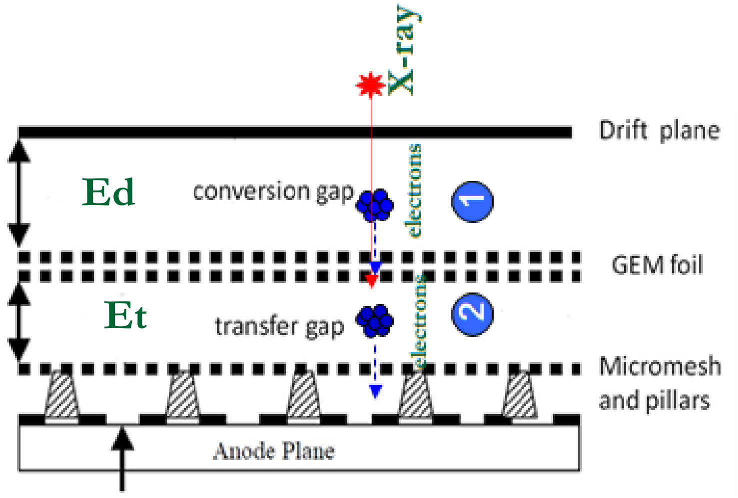
Measurement of the low current



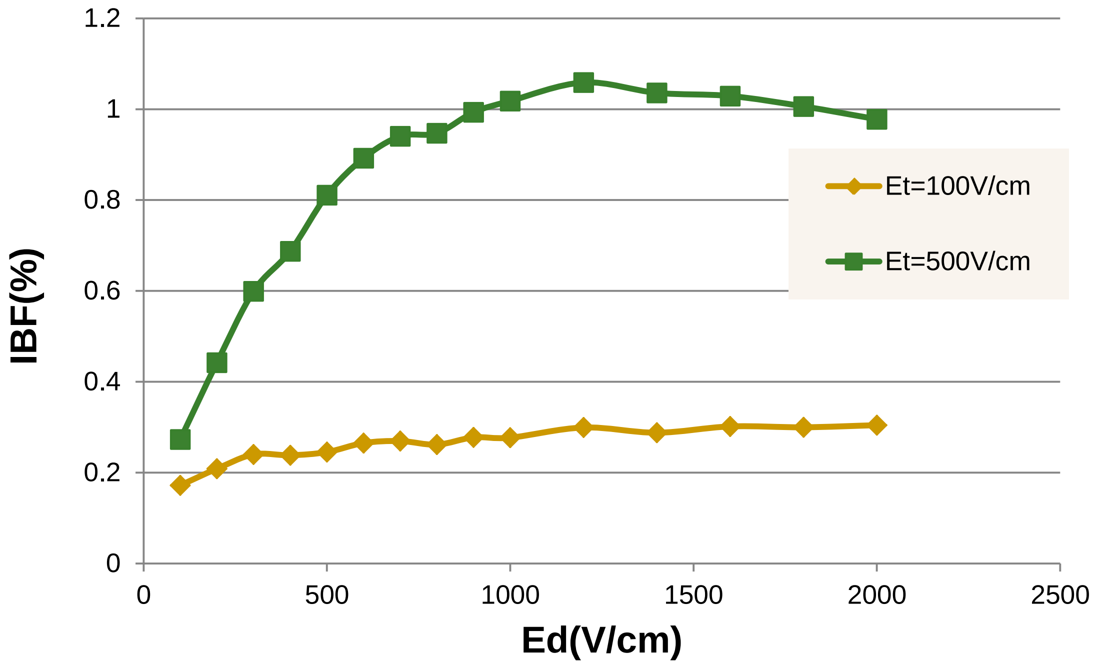
Labview interface of the current with Keithley

IBF of GEM-MM module

- IBF of the GEM-MM
  - Electric field: 100V/cm and 500V/cm
  - IBF value comparison
  - Optimization of Et = 100V/cm
  - Ed/Et/Ed=2/1/5
  - V_{GEM}=340V and V_{mesh}=520V
  - Total gain: 2000 and 4000



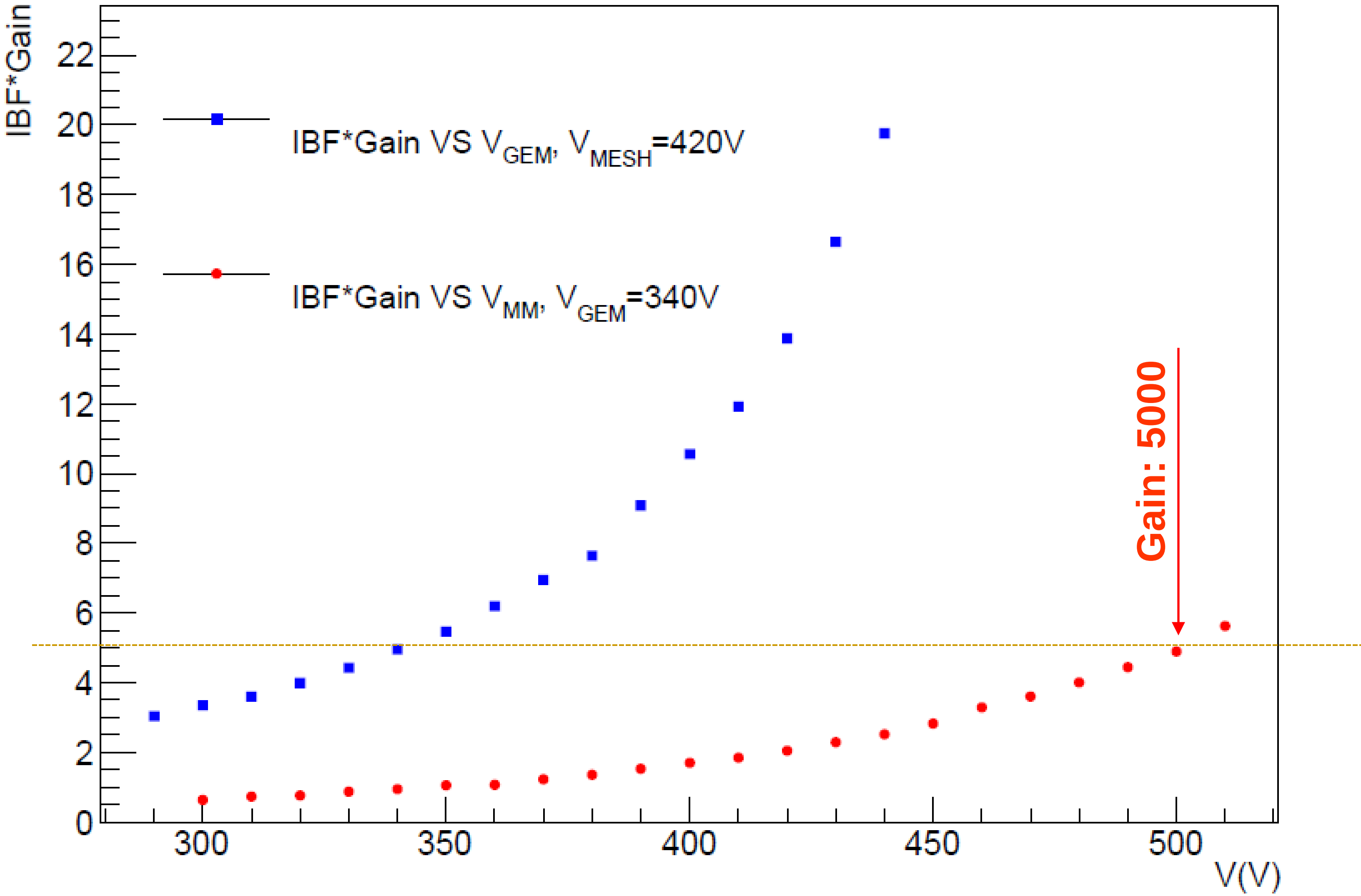
Schematic of the Gain with MM



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

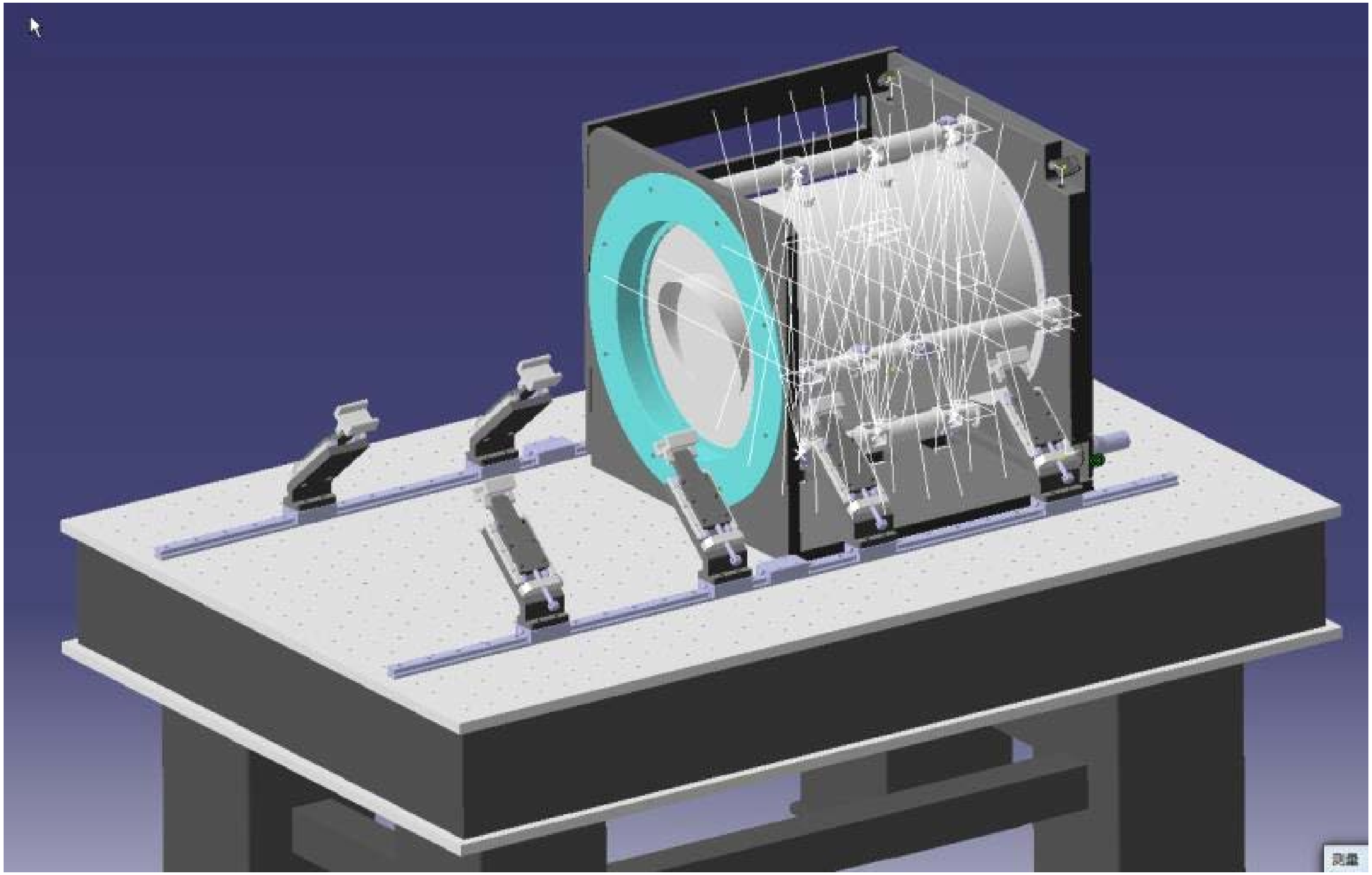
IBF test results

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



Key factor: IBF * Gain

Design of the prototype with laser



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

Conclusions

TPC option at CEPC:

- Key issue: Occupancy and Ion backflow
- Using a sample of 9 thousand fully simulated Z to qqbar events at center of mass energy of 91 GeV
- Voxel occupancy is extremely low: 3.4e-7 ava, 1.4e-6 inner most layer
- Occupancy poses no pressure for the TPC usage at CEPC running at Z pole
- Track distortion, k<5, maximal distortion is less than $10\ \mu m$,necessary for $10\ \mu m$ resolution
- Continuous device for the ion suppression

GEM-MM module for TPC readout:

- Module fabrication
- IBF measured: k=5 reached at a gain of 5000

Prototype with laser undergoing

Supported by State Key Laboratory of Particle Detection and Electronics

Thanks for your attention!