Status and progress report from CEPC TPC tracker detector group

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Outline

- Physics requirements
  - rφ resolution
  - dE/dx
- Critical technology challenges
- Current R&D activities
  - Status of TPC module R&D
  - Status of TPC prototype R&D
  - Manpower
- Summary

Physics requirements

TPC requirements for collider concept

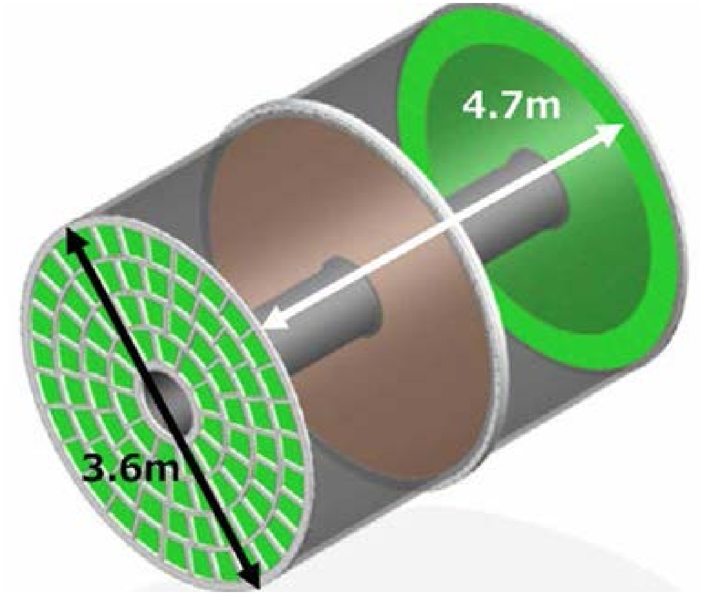
TPC could be as one tracker detector option for CEPC, 1M ZH events in 10yrs E_{cm} ≈250 GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, can also run at the Z-pole

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**

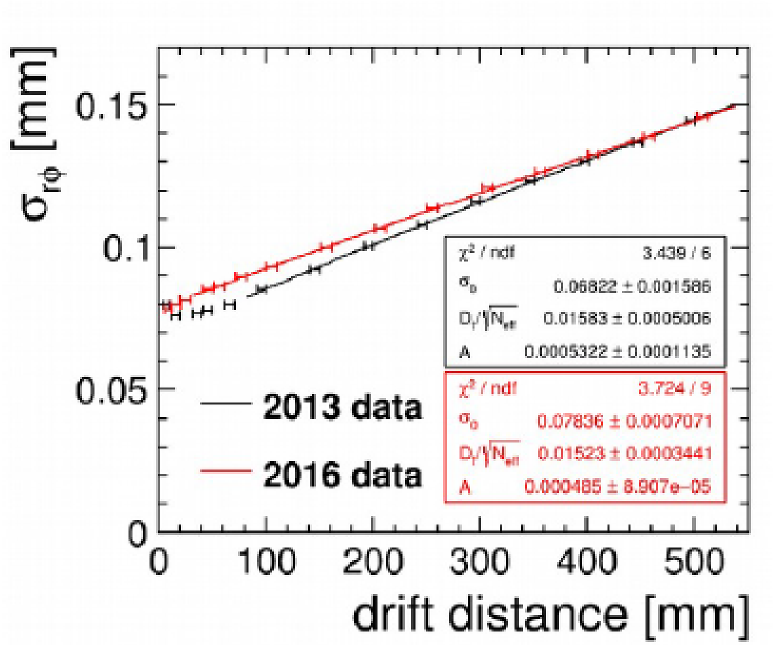


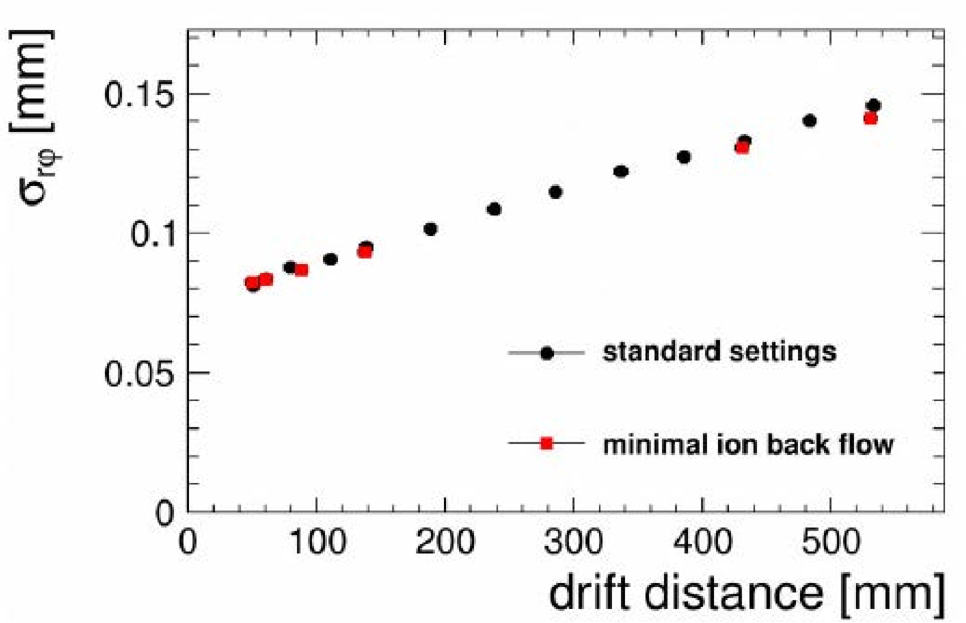
TPC detector concept

rφ Beam Tests Results/LC-TPC

Ralf Diener

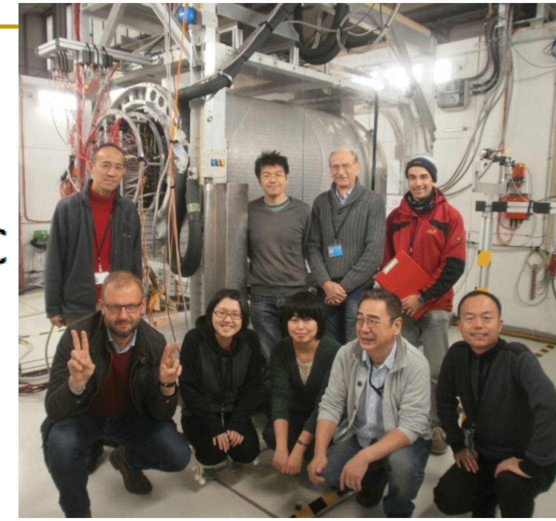
The rφ resolution of the prototype TPC was measured using the electron beam@5GeV in a magnet field@1.0T.





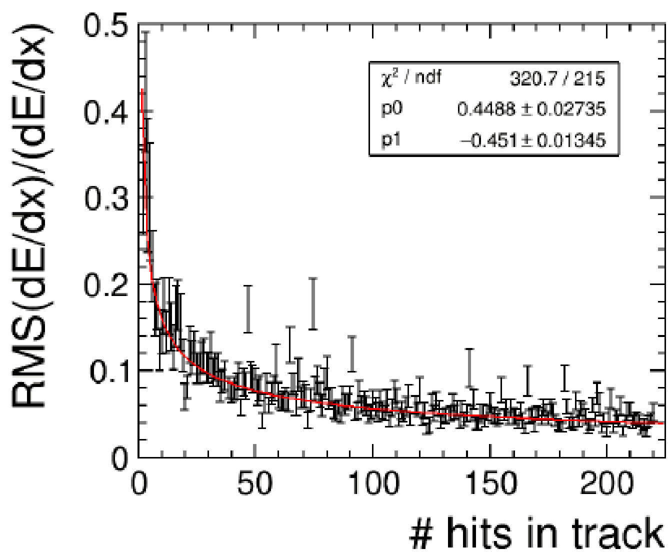
Slides from LCWS 2017 workshop in 23-27, October, 2017. Strasbourg, France

dE/dx Beam Tests Results/LC-TPC



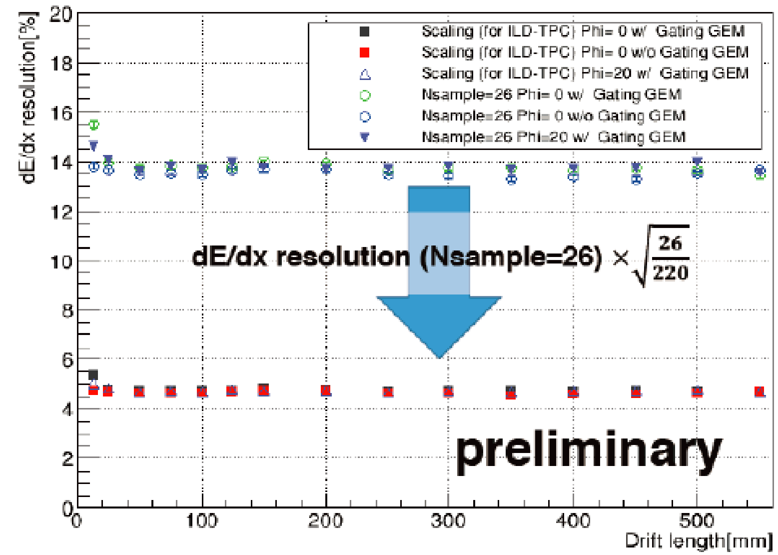
- Resolutions extrapolated to real 220-layer TPC
  - 4% : Triple CERN GEM w/o gate
  - 4.7% : Double Scienergy GEM w/ gate

Ralf Diener



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

Aiko Shoji



	Method① Sampling
w/ gating GEM, ϕ= 0°	4.66 ± 0.02%

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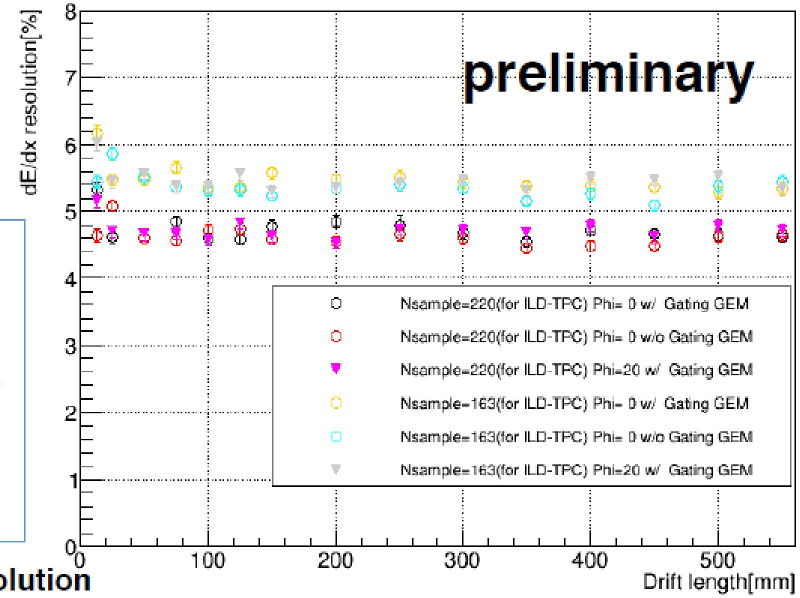
dE/dx Beam Tests Results/LC-TPC

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, $\phi = 0^\circ$	5.46 ± 0.02%	5.49 ± 0.01 %
w/o gating GEM, $\phi = 0^\circ$	5.35 ± 0.02%	5.40 ± 0.01%
w/ gating GEM, $\phi = 20^\circ$	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

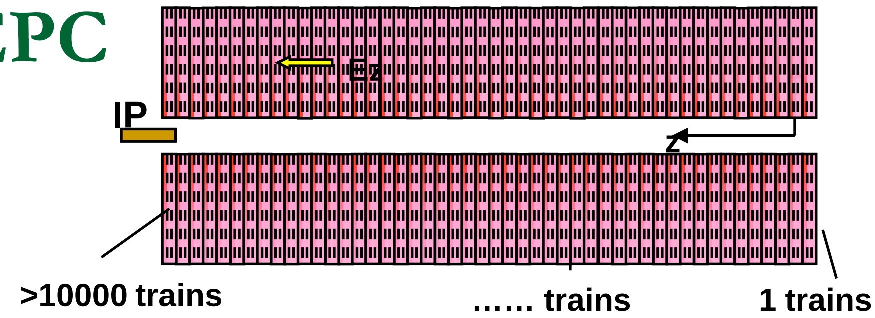
→ To reduce **IONS**
To reduce distortion

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

→ ~100um positron resolution with calibration

~2017, On-going activities for all

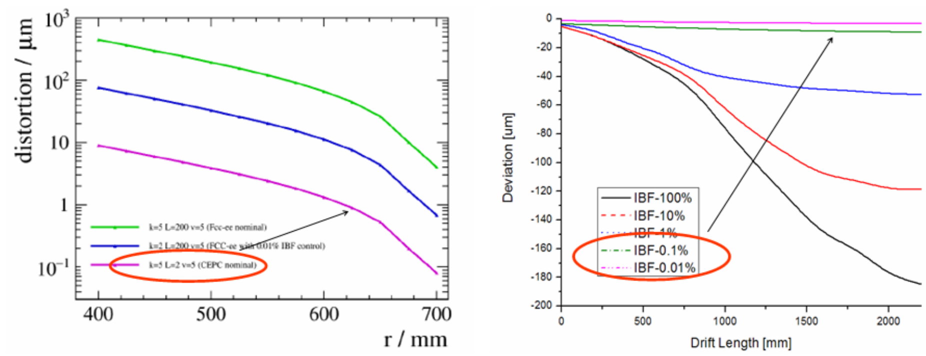
Technical challenges at CEPC



Amplification ions @CEPC

Ion Back Flow and Distortion :

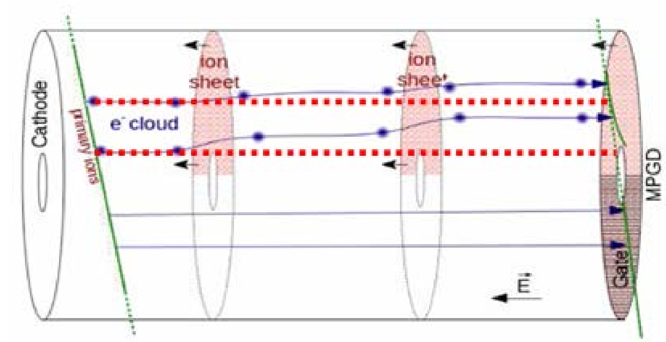
- ~100 μm position resolution in rφ
- Distortions by the primary ions at CEPC are negligible
- More than 10000 discs co-exist and distorted the path of the seed electrons
- The ions have to be cleared during the ~us period continuously
- Continuous device for the ions
- Long working time



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

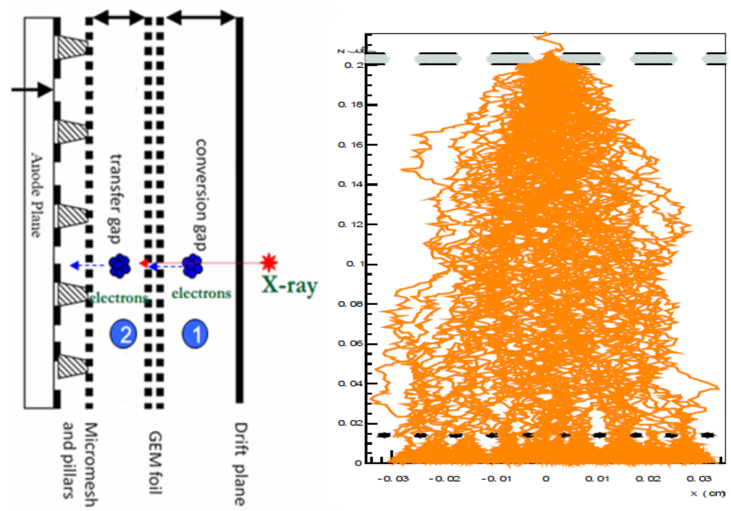
Options of technical solution

Continuous IBF module:

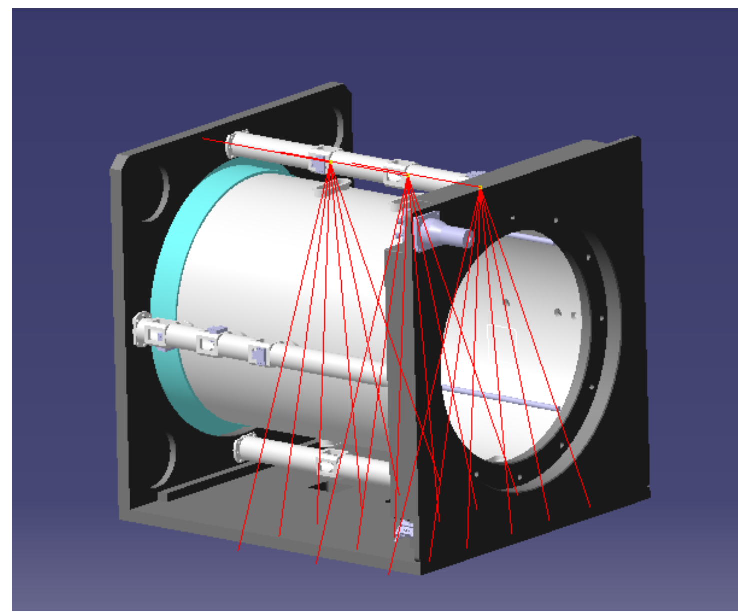
- Gating device may be used for Higgs run
- Open and close time of gating device for ions: ~ μs-ms
- No Gating device option for Z-pole run
- Continuous Ion Back Flow due to the continuous beam structure
- Low discharge and spark possibility

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 study of IBF for CEPC

Poster session: Mingrui

Feasibility study of TPC at CEPC at Z-pole operation

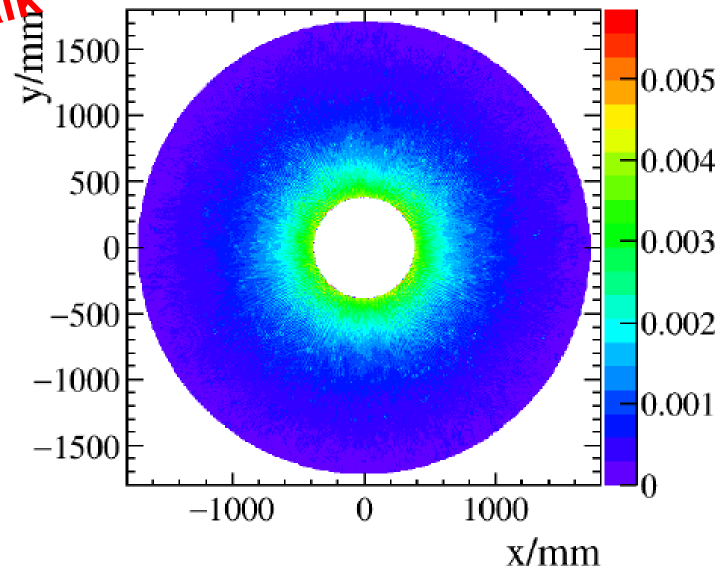
High rate at Z pole

ArXiv: 1704.04401

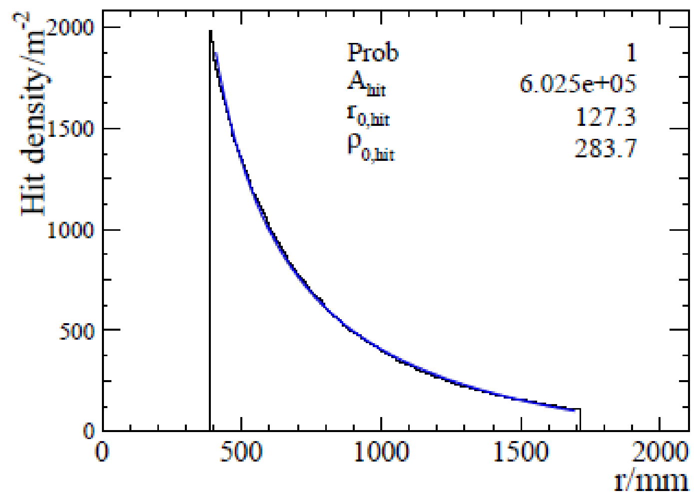
- Voxel occupancy
  - The number of voxels /signal
  - 9 thousand Z to qq events
  - 60 million hits are generated in sample
  - 4000-6000 hits/(Z to qq) in TPC volume
  - Average hit density: 6 hits/mm^2
  - Peak value of hit density: 6 times
  - Voxel size: 1mm × 6mm × 2mm
  - 1.33 × 10^{14} number 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

Manqi's talk

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

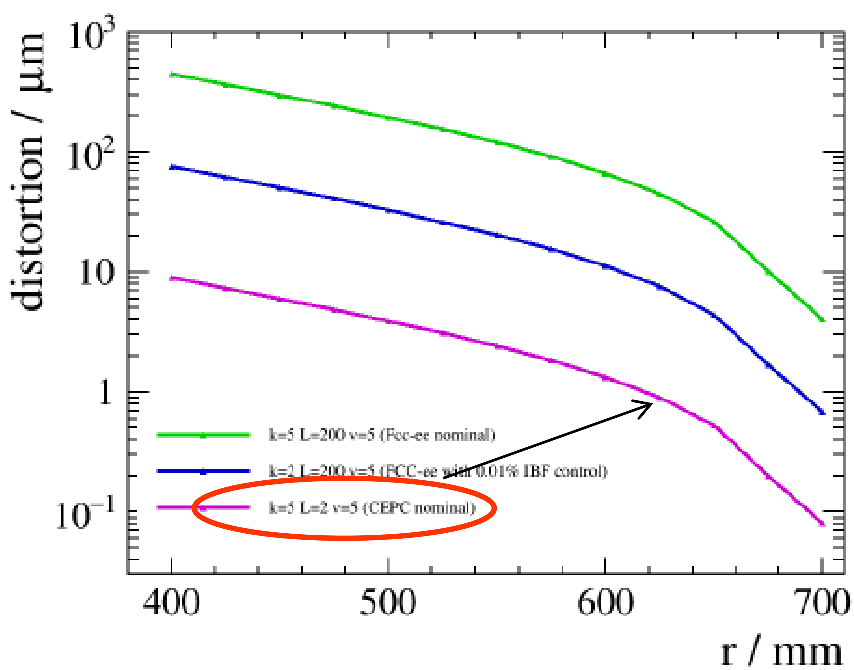
- Electron:
  - Drift velocity ~6-8cm/us@200V/cm
  - Mobility μ ~30-40000 $cm^2/(V.s)$
- Ion:
  - Mobility μ ~2 $cm^2/(V.s)$

  in a "classical mixture" (Ar/Iso)

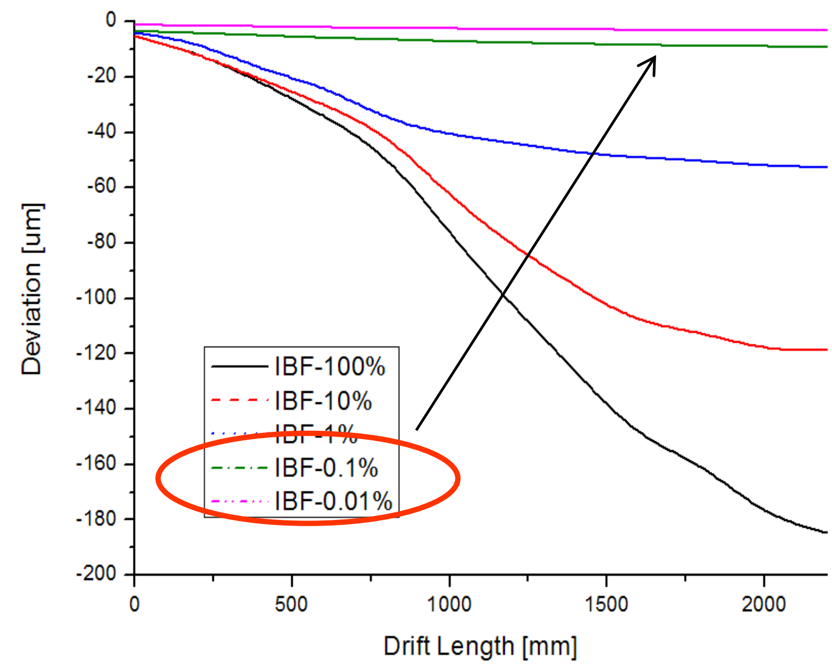
$$S_N = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 S_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 S_{x_2}^2 + \left(\frac{\partial f}{\partial x_3}\right)^2 S_{x_3}^2}$$

Standard error propagation function

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



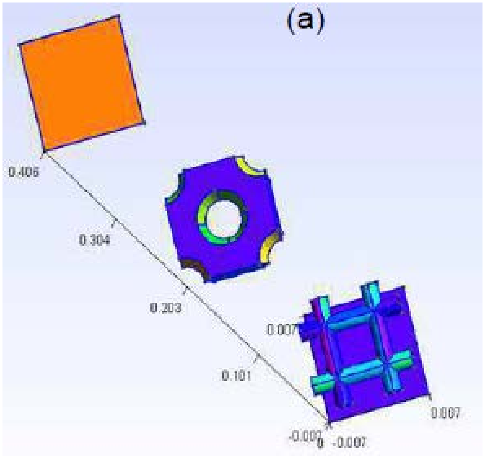
Distortion of as a function of electron initial r position



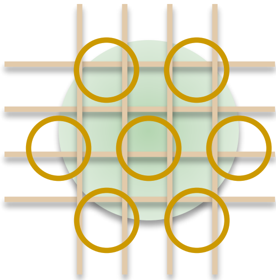
Evaluation of track distortions due to space charge effects of positive ions

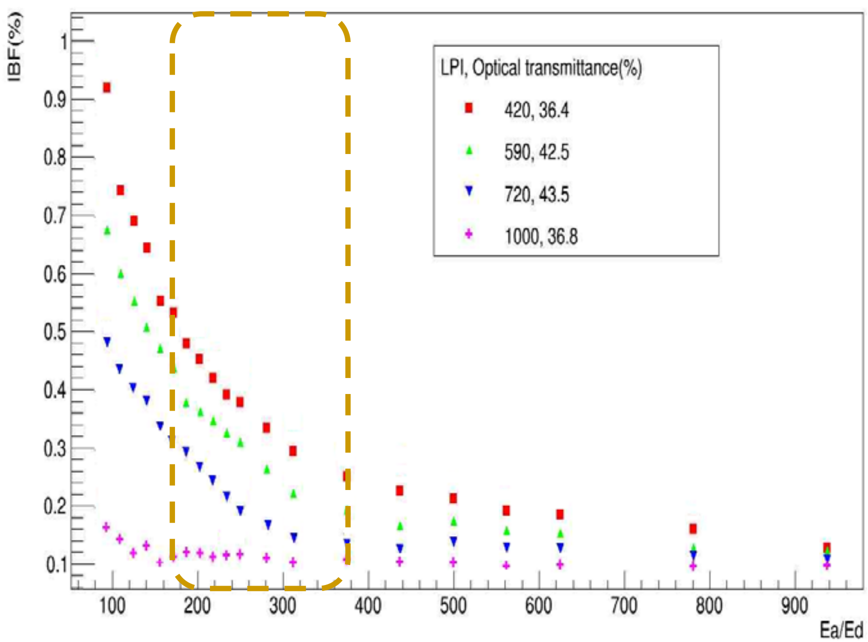
IBF simulation

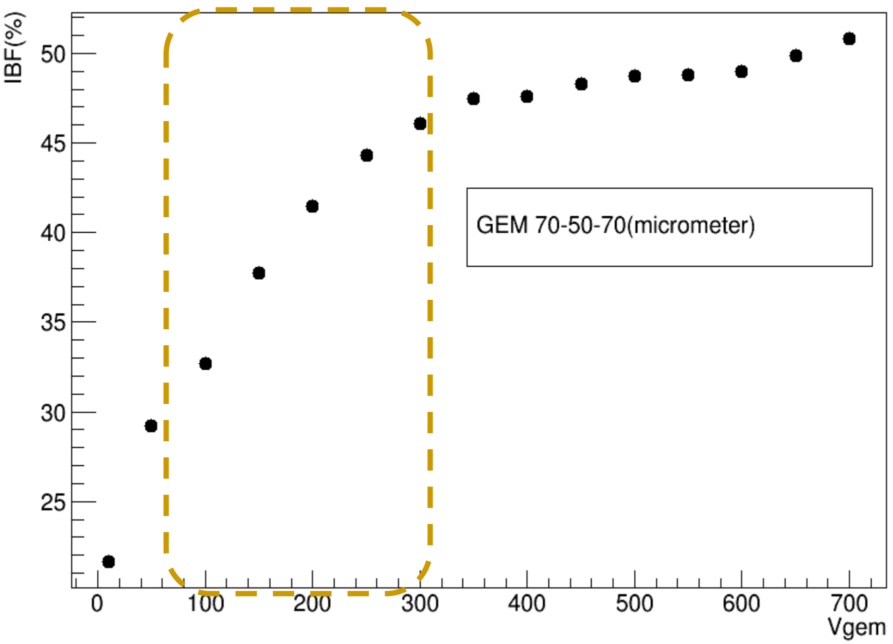
Yulian, Haiyun, Huirong



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

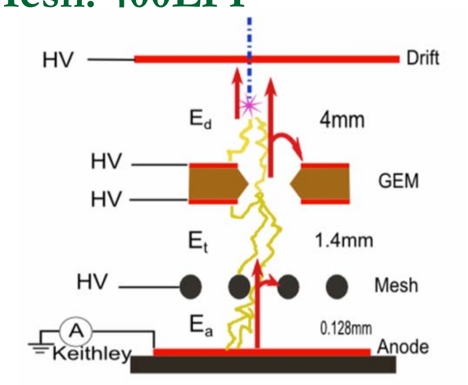
Investigation of IBF study with module

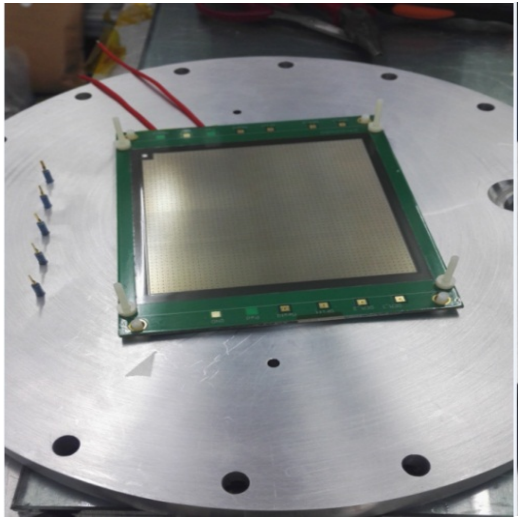
Poster session: Yulian

Continuous ion backflow suppression gaseous detector module for CEPC TPC

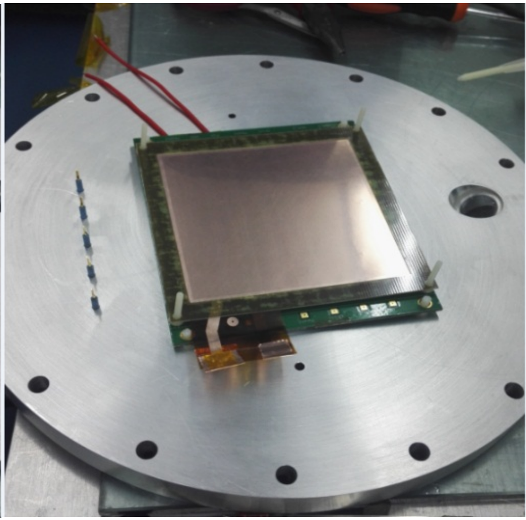
Test of the new module

- 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

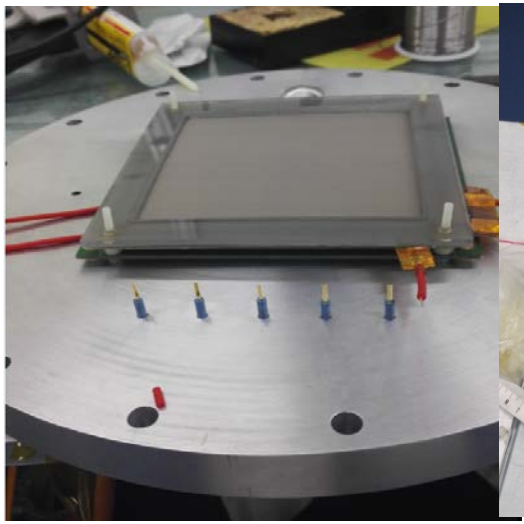




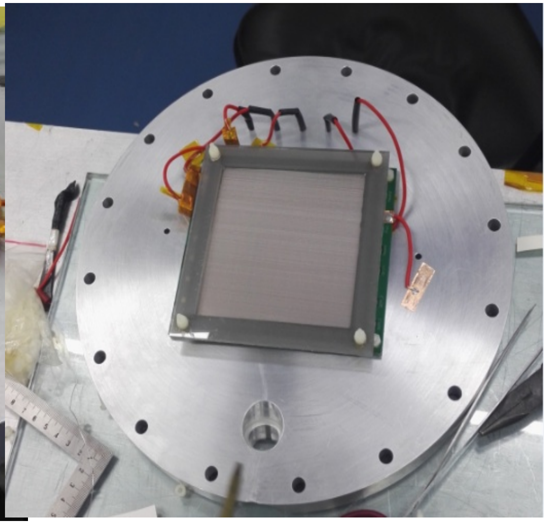
Micromegas(Saclay)



GEM(CERN)



Cathode with mesh

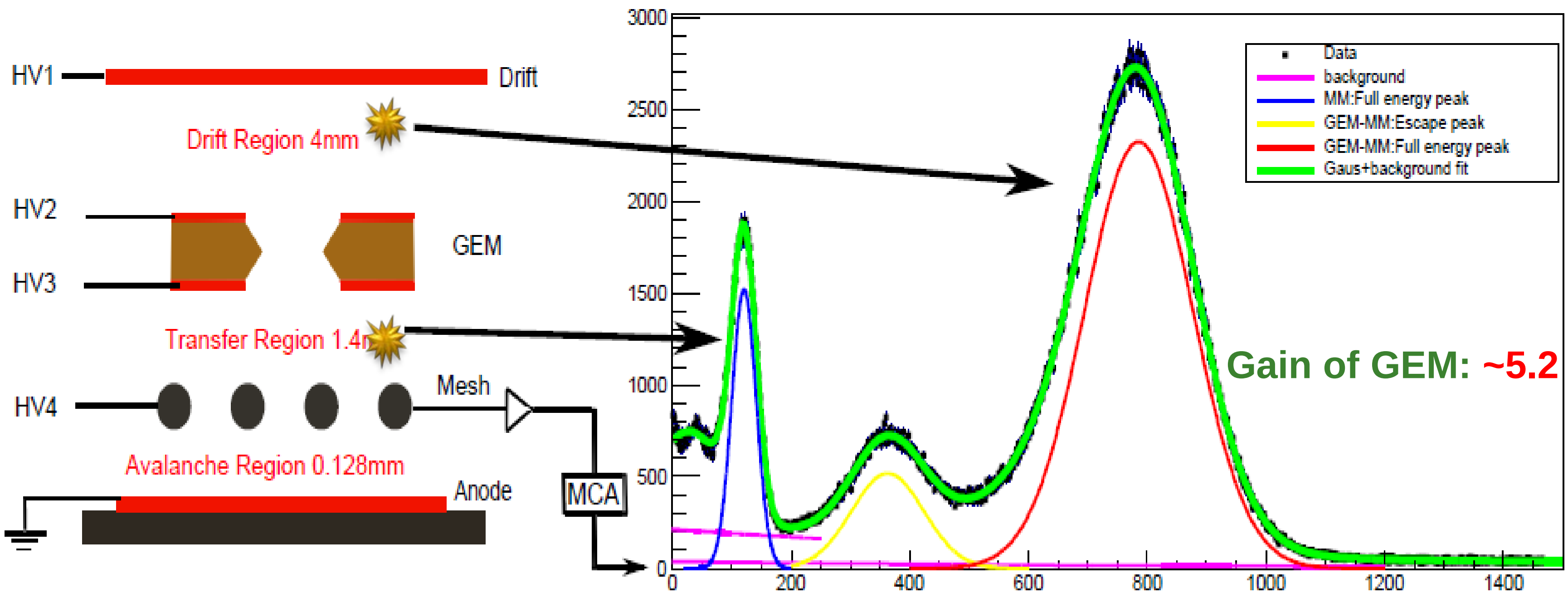


GEM-MM Detector

Energy spectrum@^{55}Fe

Yulian, Haiyun, Huirong

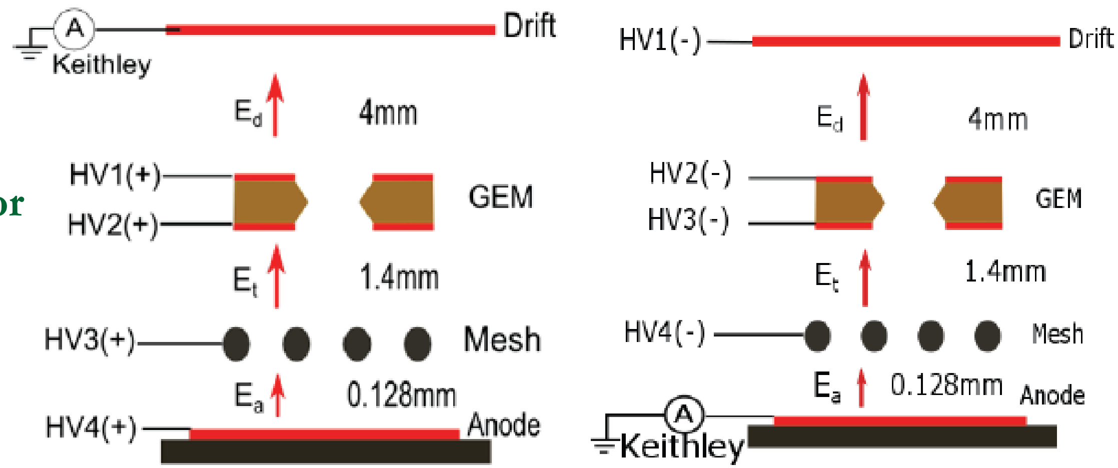
Source: ^{55}Fe, Gas mix: Ar(97) + iC_4H_{10}(3)



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

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

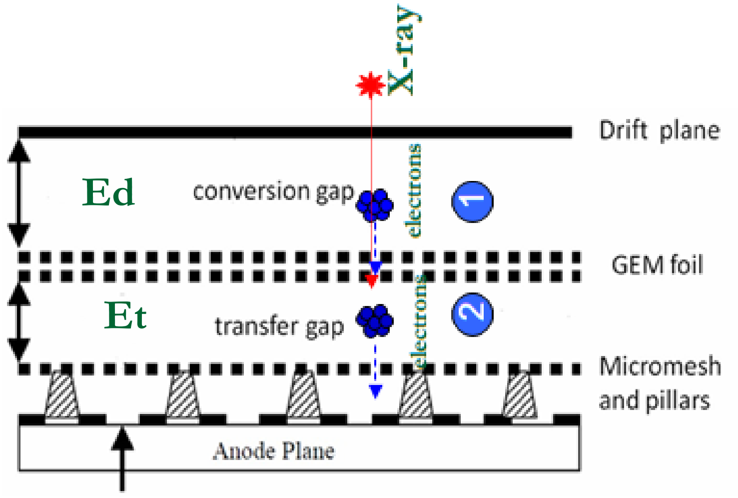


Measurement of the low current

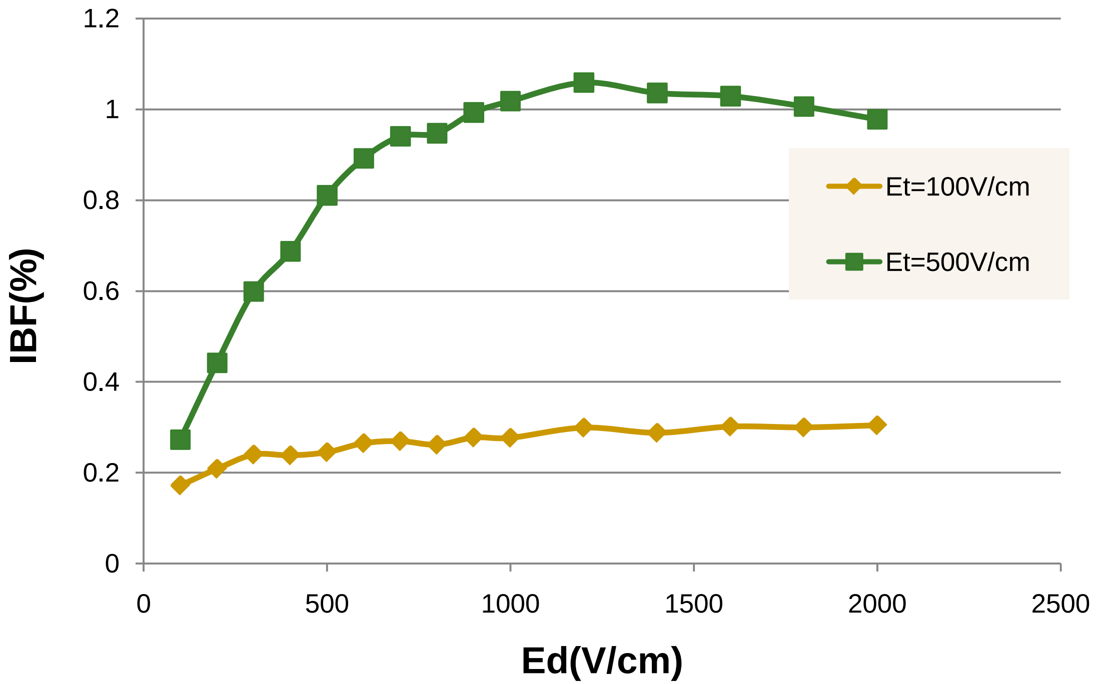
Labview interface of the current with Keithley

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



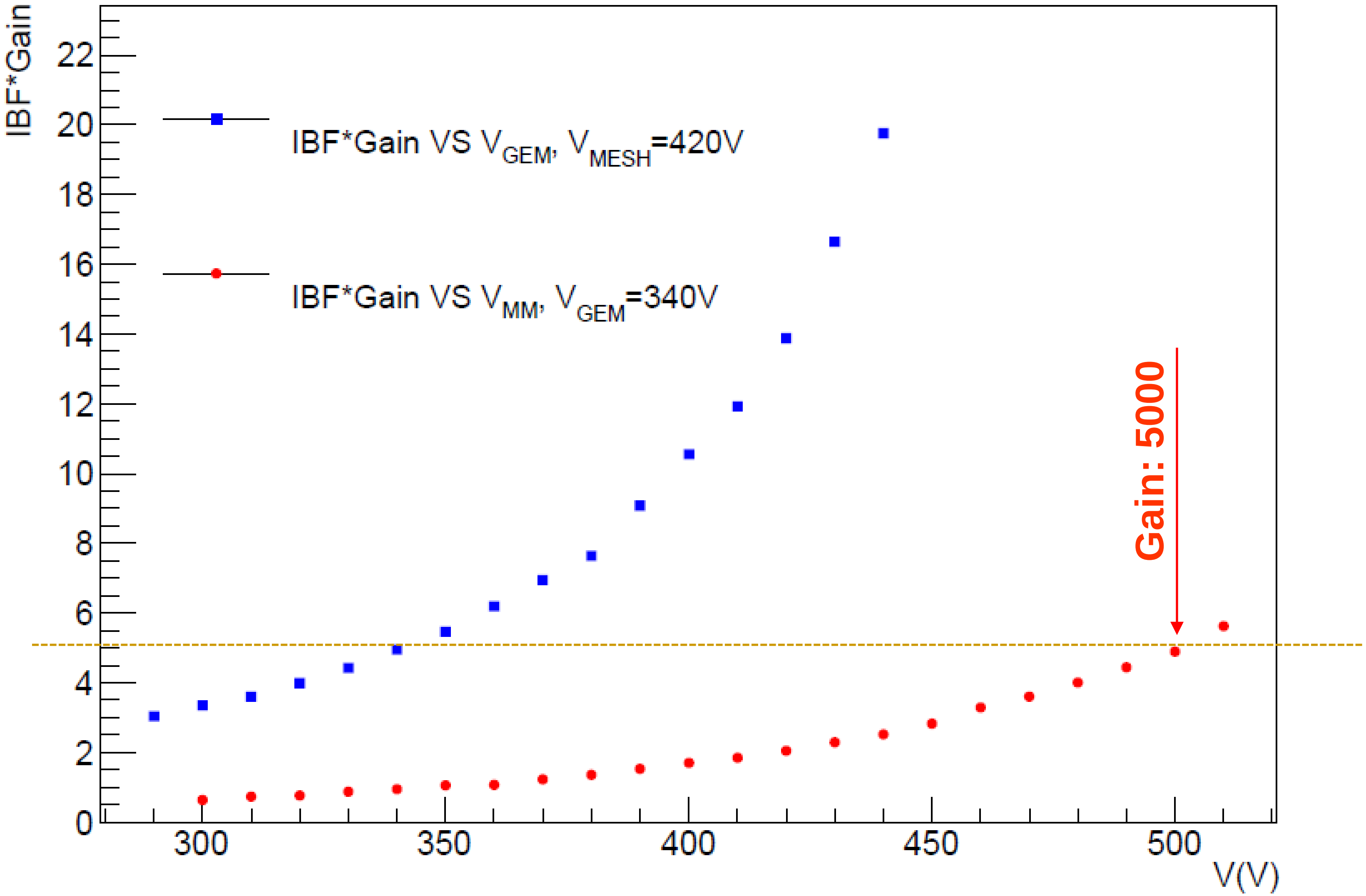
Schematic of the Gain with MM



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

Poster session: Haiyun

Status and progress of TPC prototype with 266nm laser calibration for CEPC TPC

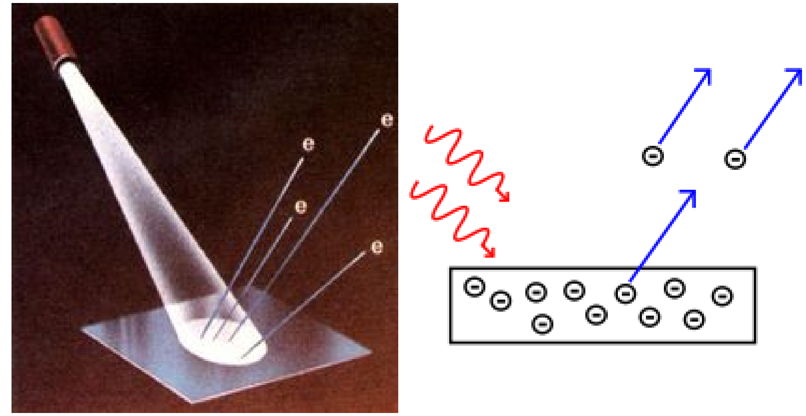
Parameters of the TPC prototype

- To aim that the small TPC prototype for the estimation of the distortion due to the IBF, and the study of related physics parameters
- To mimic the bunch structure & the ions distortion with UV light and laser split beam

- 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)

Why UV light study

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



Photoelectric effect

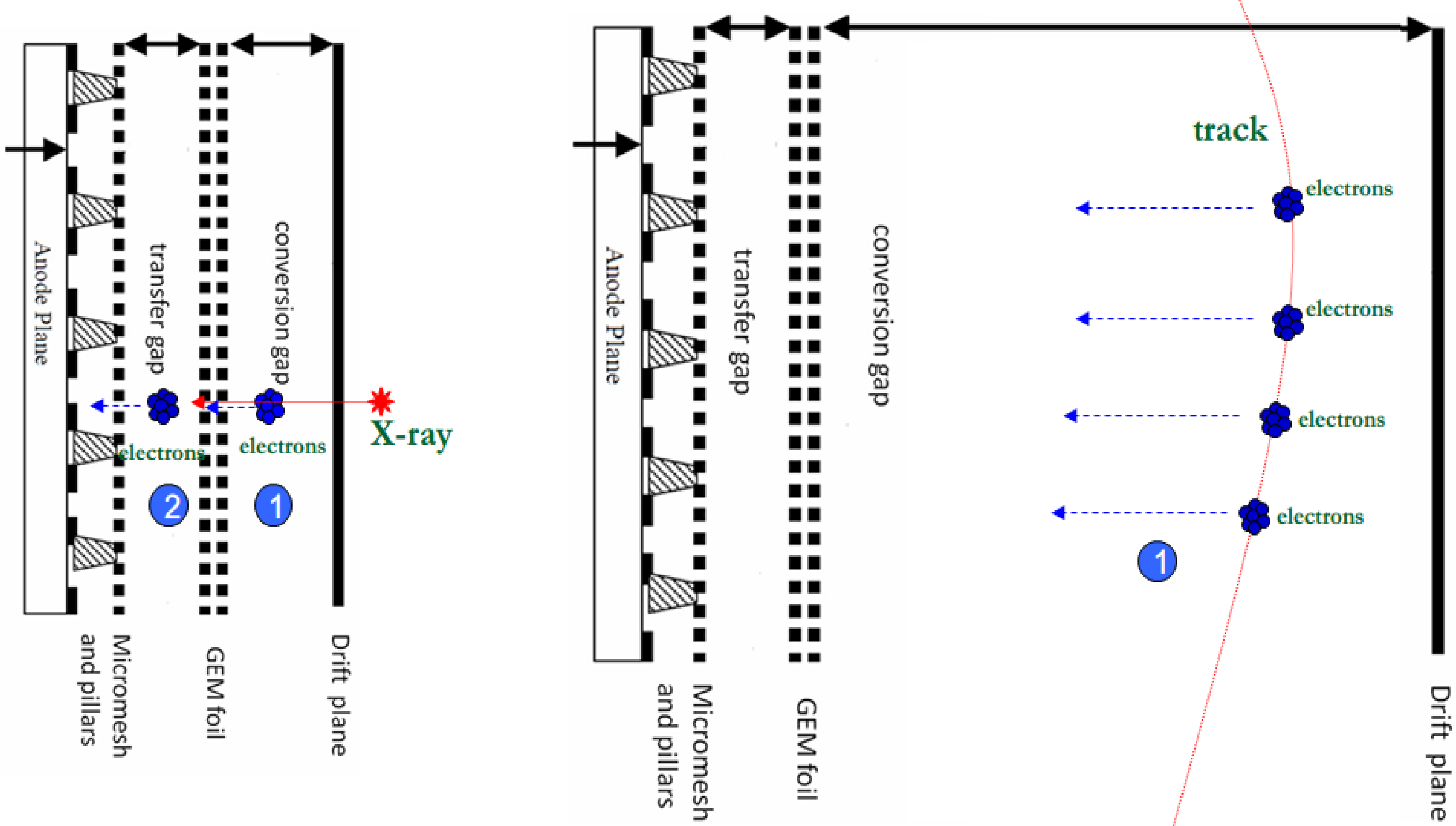


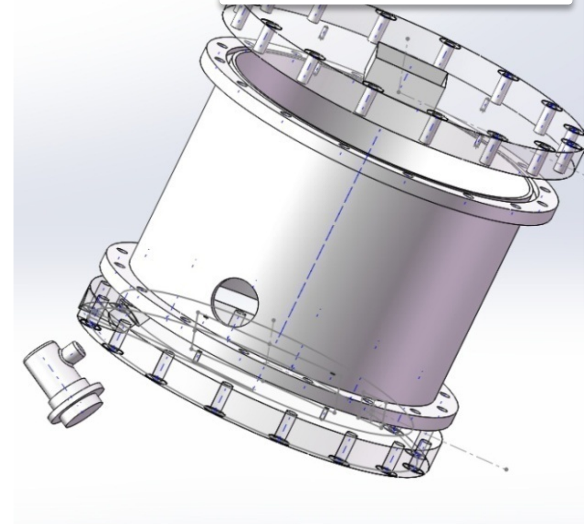
Diagram of the IBF test with the module

UV test of the new module

Yulian, Haiyun

- 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

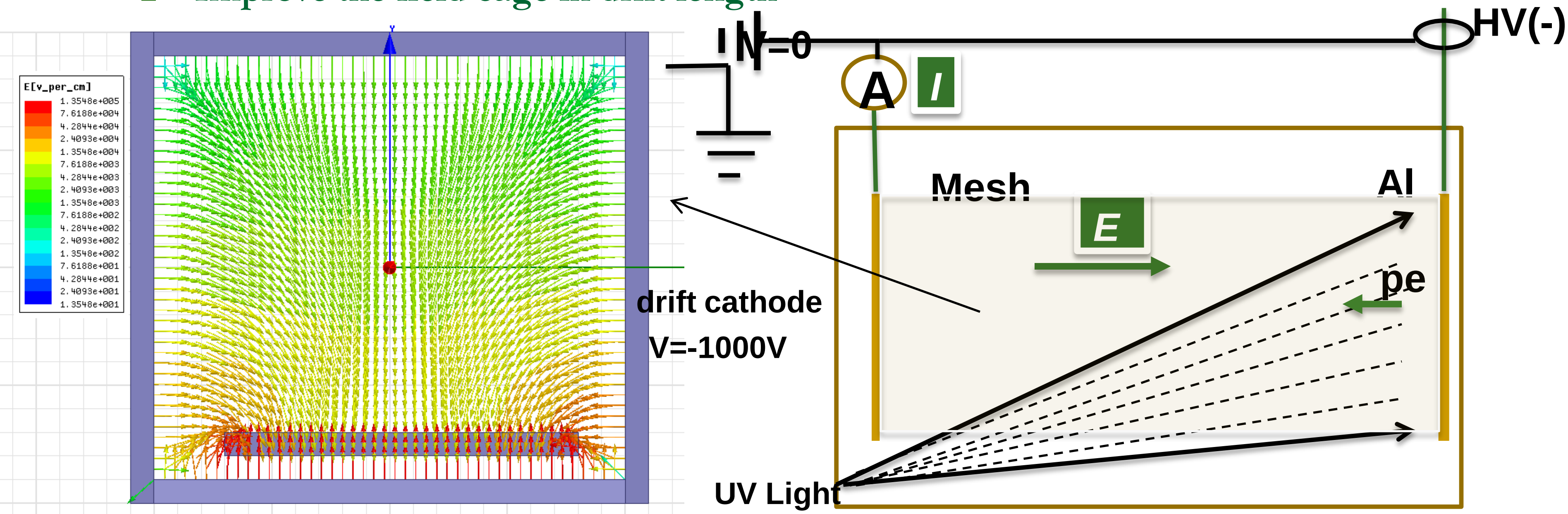


Diagram of the UV test with new module

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.mm²
- Electrons from Al
- Electrons from drift length at 266nm UV light (~MIPs)

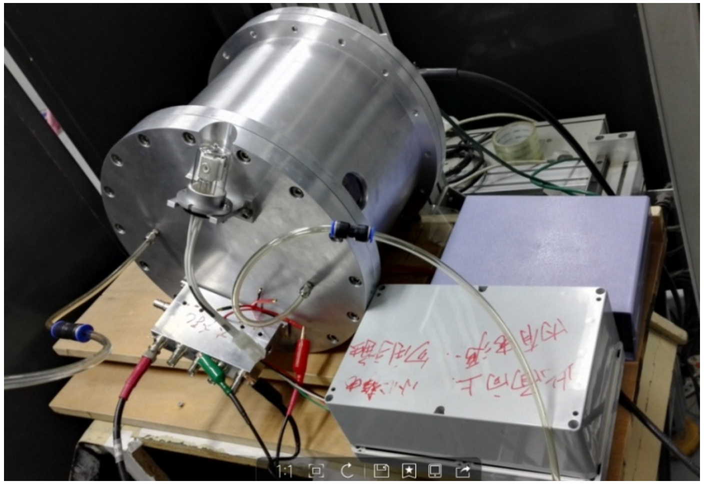
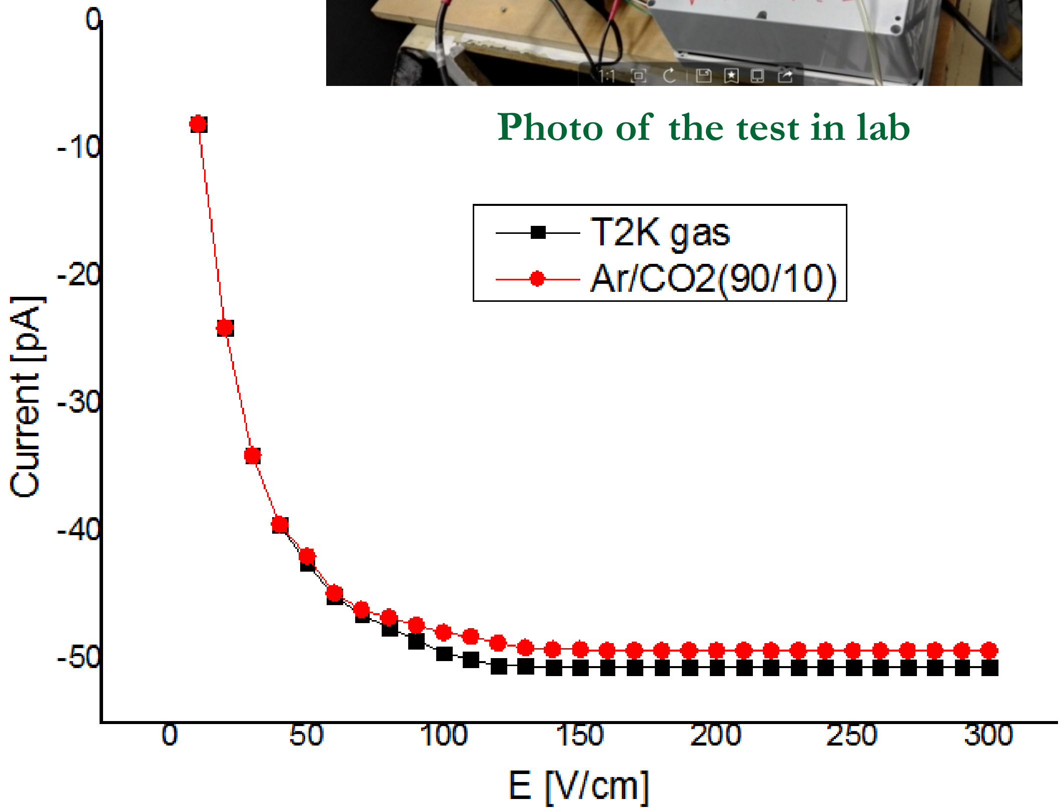
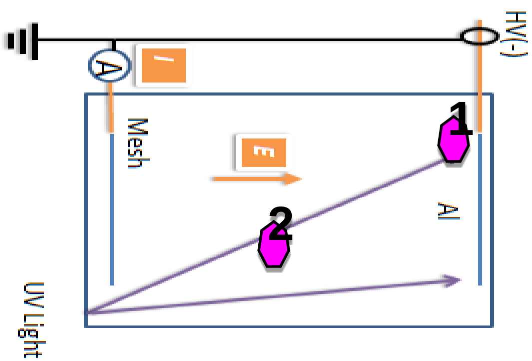


Photo of the test in lab



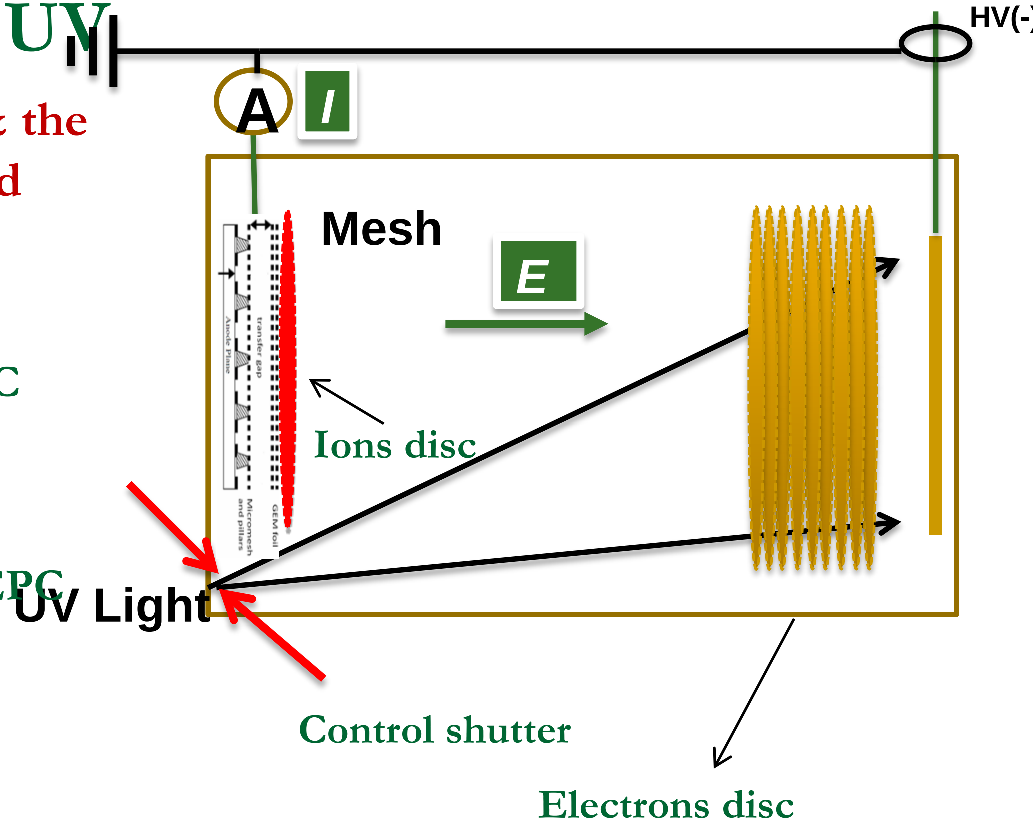
Current VS Electric field in drift length

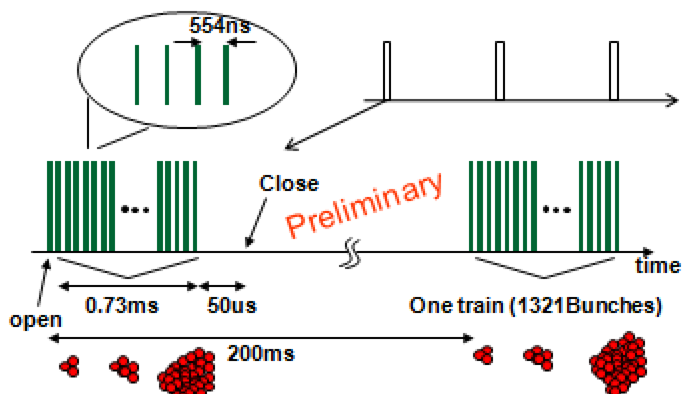


UV Shining diagram

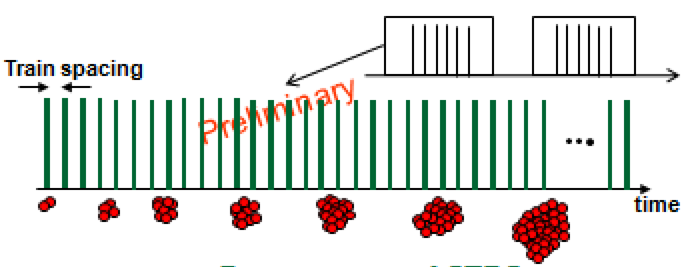
Electrons produced by UV

- 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

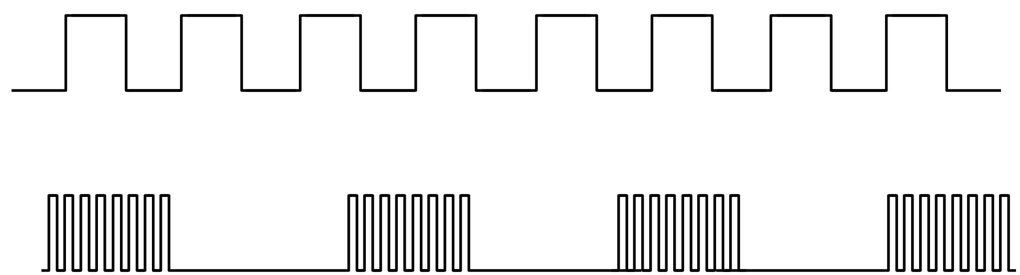




Beam structure of ILC

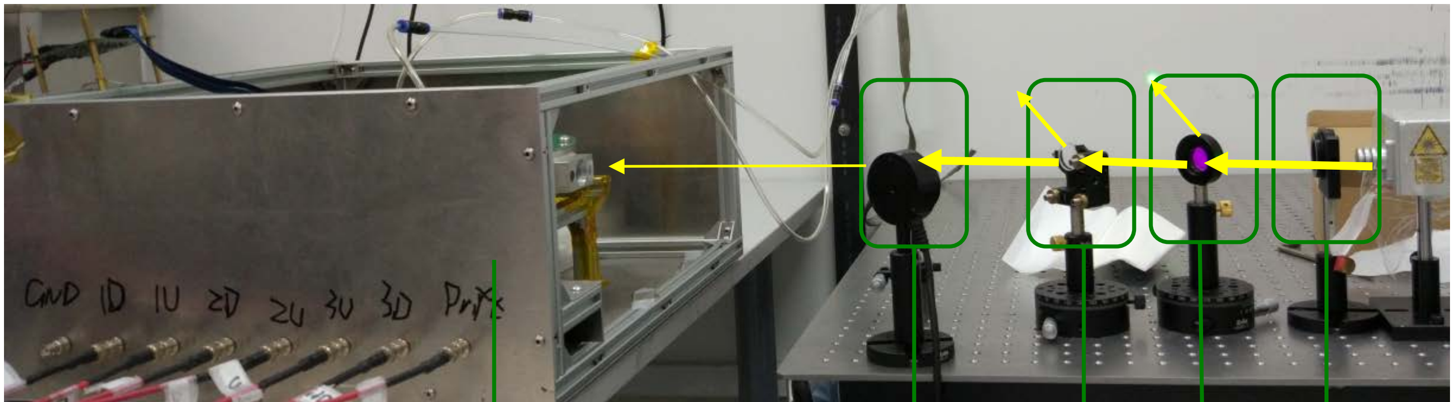


Beam structure of CEPC



Shutter time similar to ILC and CEPC beam structure

Signal of the laser with Φ1mm @266nm



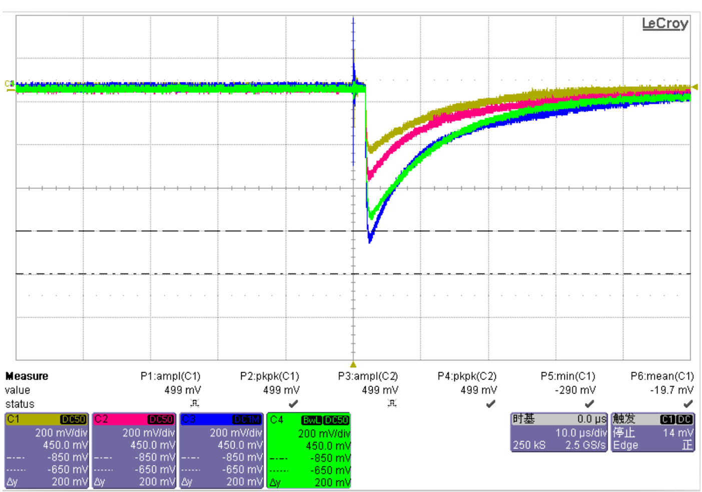
Triple GEMs detector

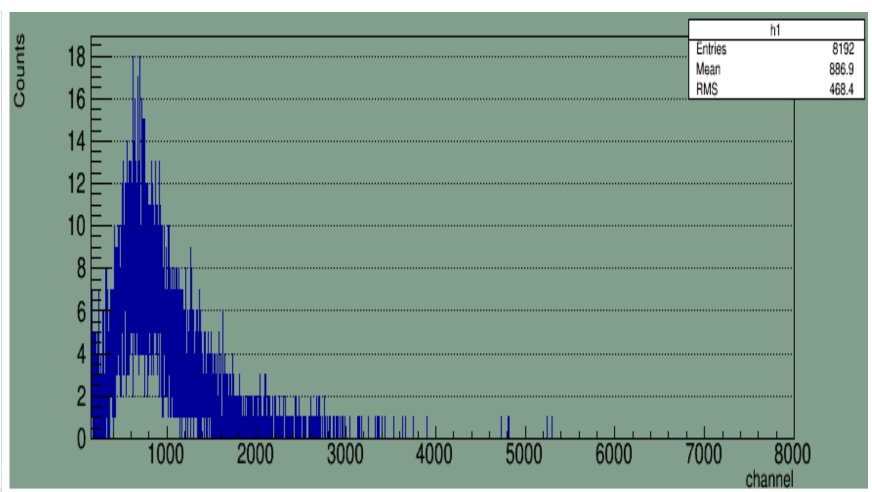
Hole collimator Φ1mm

Trans/refle. =1:99

Transmission mirror

Transmission mirror

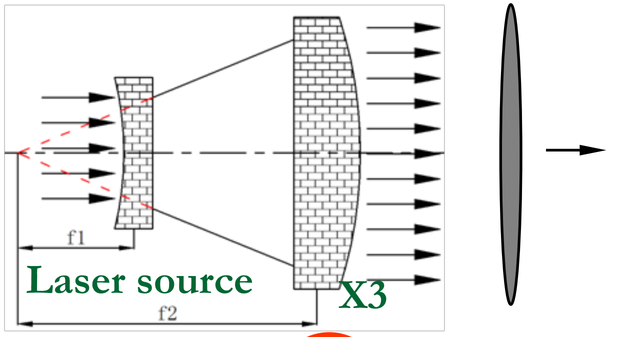




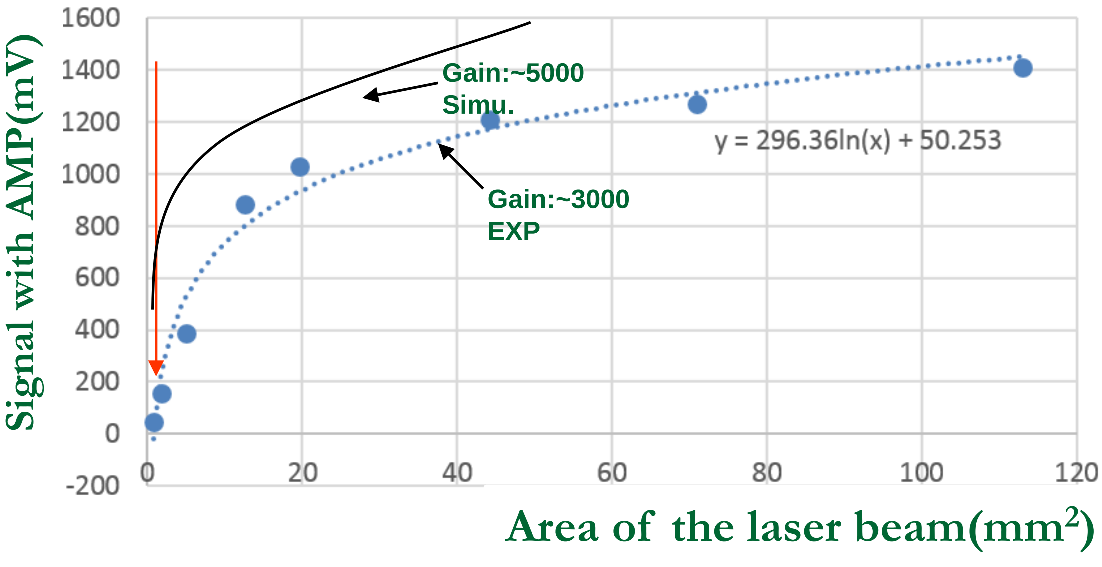
Signal of the laser with Φ1mm@Charge sensitive AMP/12mV/fC

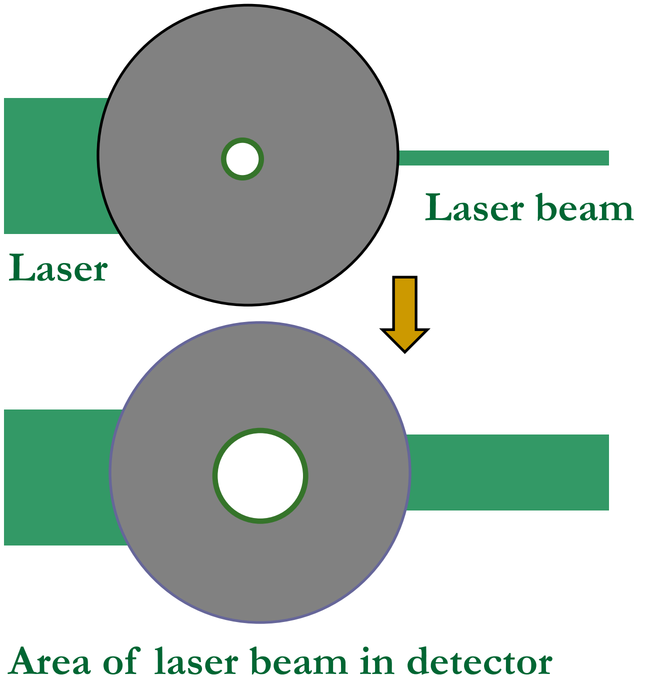
Collimator@Φ1~ Φ 12mm

- Laser beam with expander mirror: 5mm×3
- Primary laser power: 170uJ
- Gain:~3000



直径/mm	12	9.5	7.5	5	4	2.5	1.5	1
面积/mm2	113.1	70.882	44.179	19.635	12.566	4.9087	1.7671	0.785
道数	6648	5990	5717	4856	4177	1853	779	267
幅度/mV	1411.5	1270.6	1212.2	1027.8	882.47	384.9	154.96	45.34

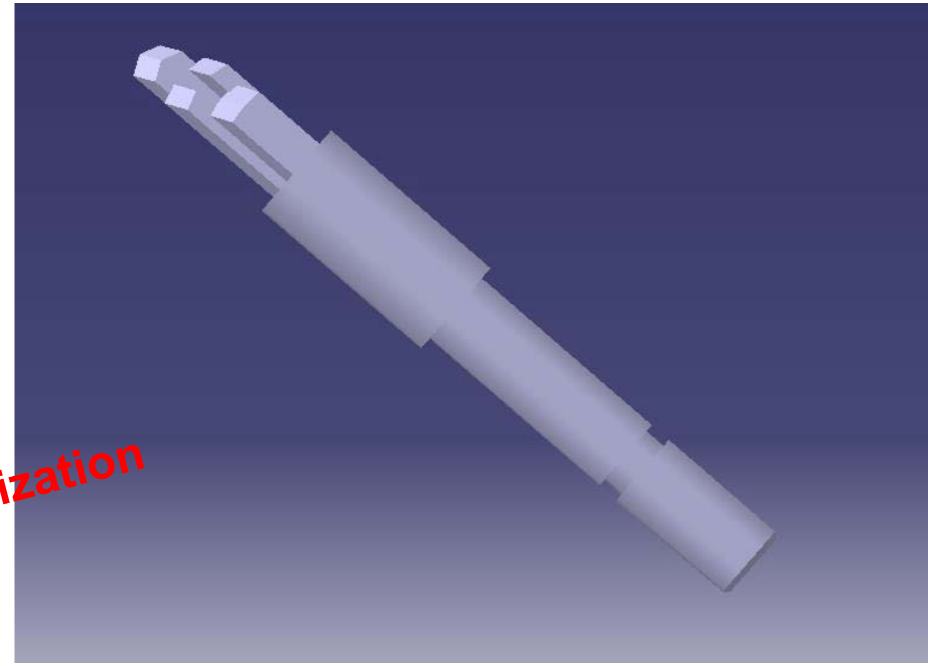


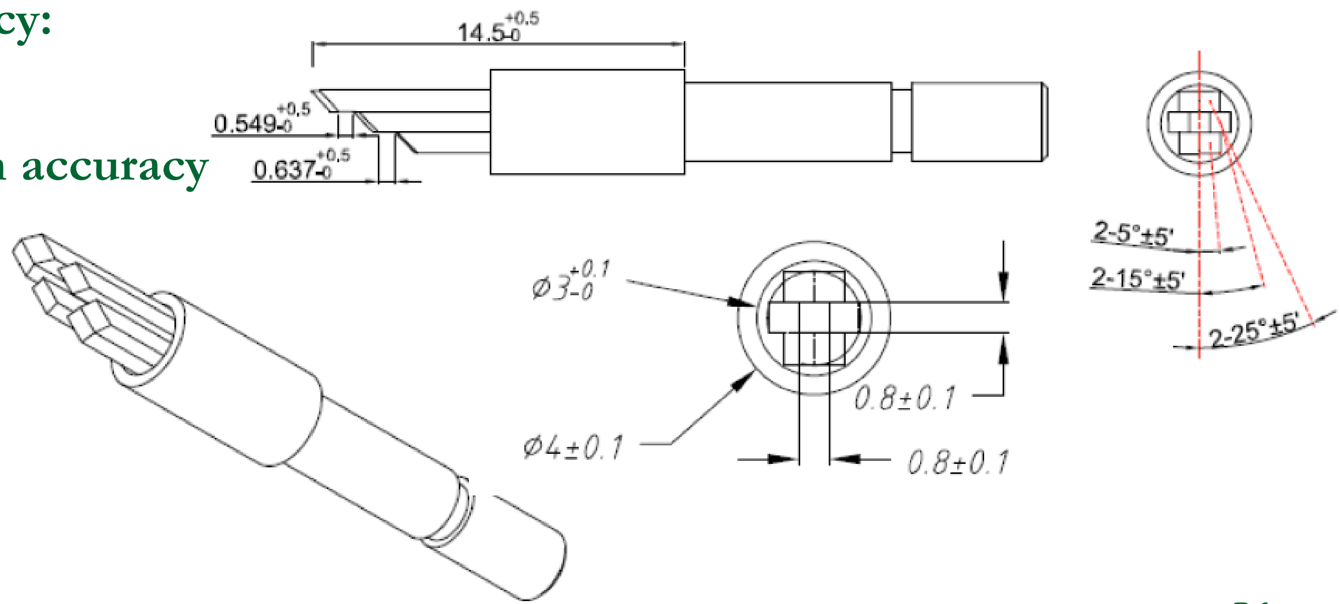


Divide and reflection mirrors

- Laser wave for the divide and reflection mirrors: 266nm
- Size: ~0.8mm×0.8mm
- Number of the divide trackers: 6
- Stainless steel support integrated the laser mirrors
- Reflection efficiency:
  >99%@266nm
- Reflection position accuracy
  1/30 degree

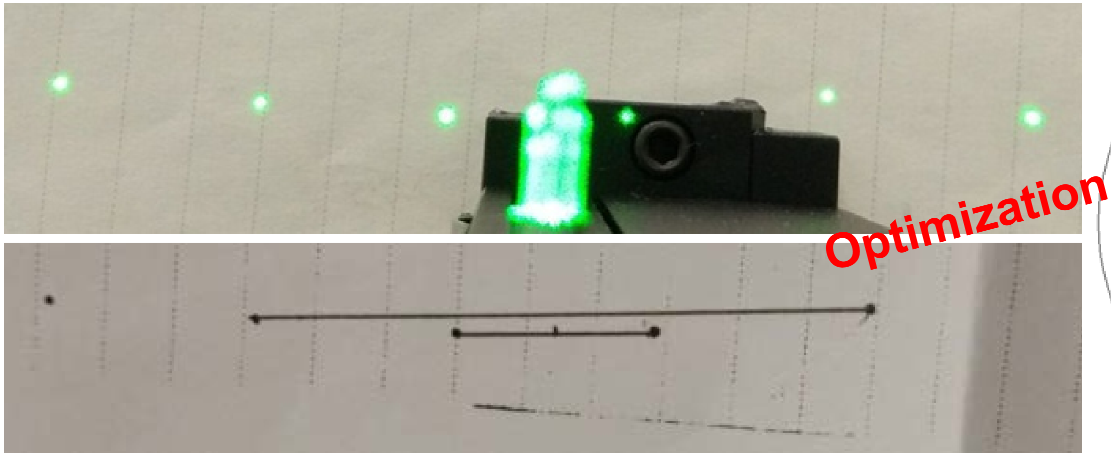
Optimization

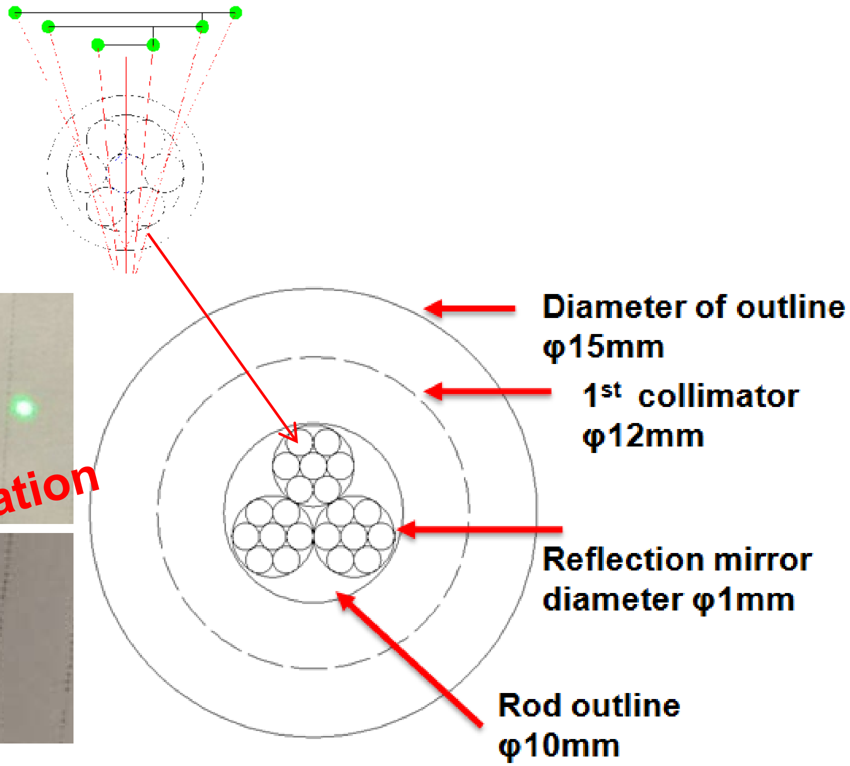




Mirrors test with 266nm

Test:

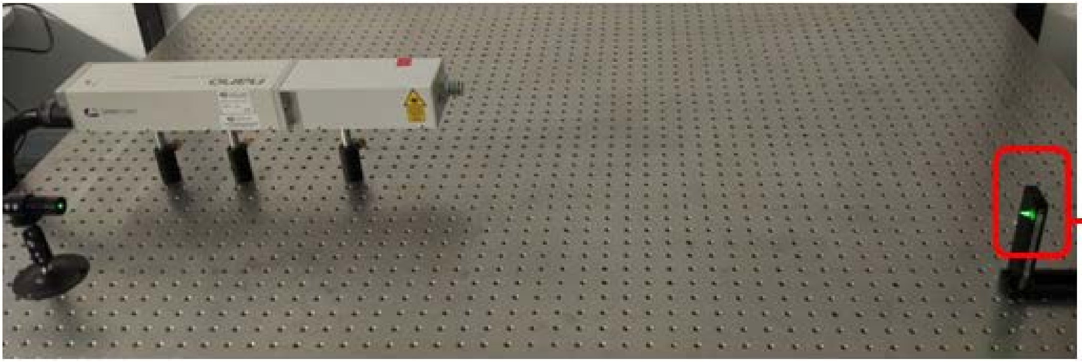




Report of the mirrors:

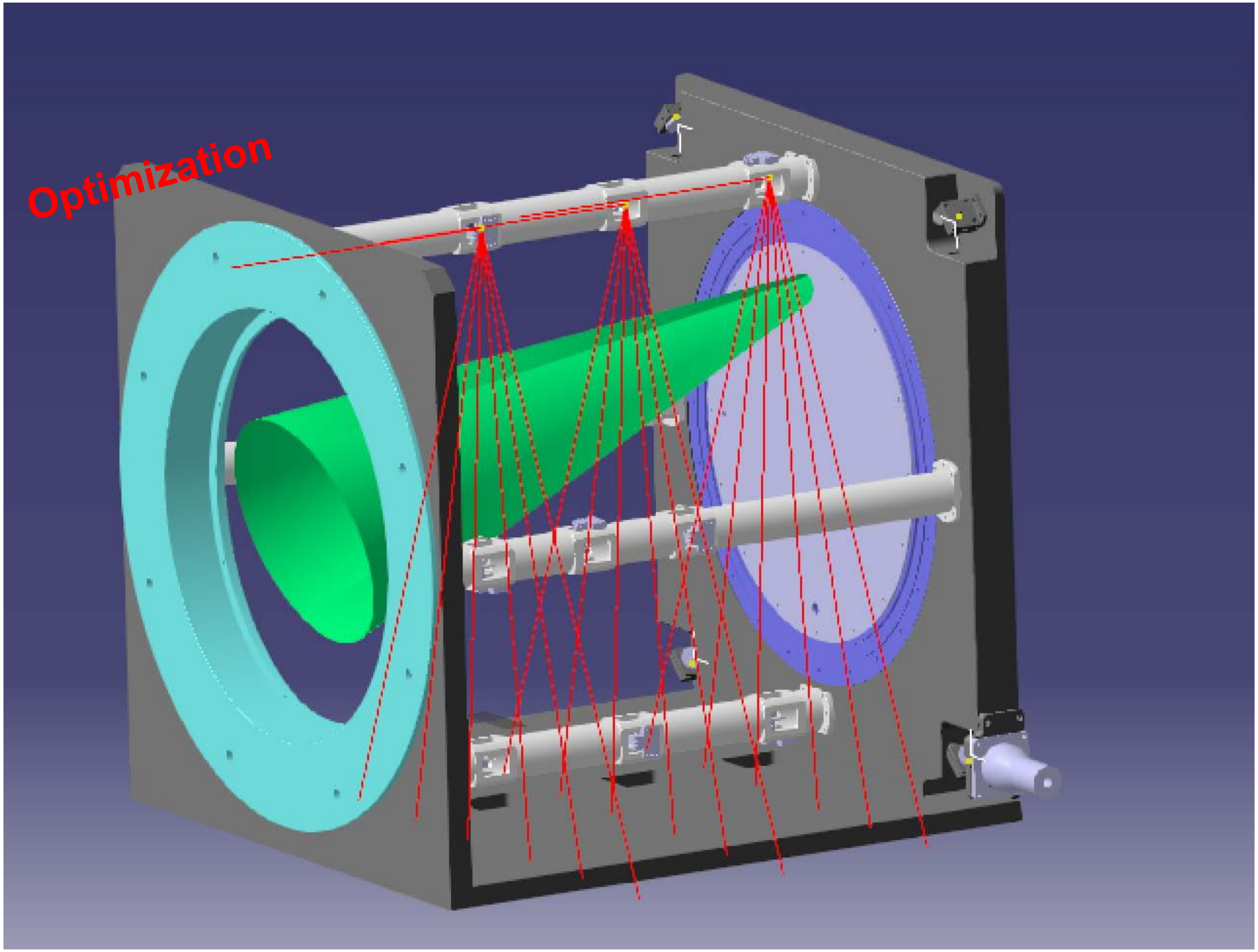
Reflection mirror

5°角	<5′	合格
15°角	<5′	合格
25°角	<5′	合格



1 号	<5′	合格
2 号	<5′	合格
3 号	<1°	需优化
4 号	<10′	需优化
5 号	<5′	合格
6 号	<5′	合格

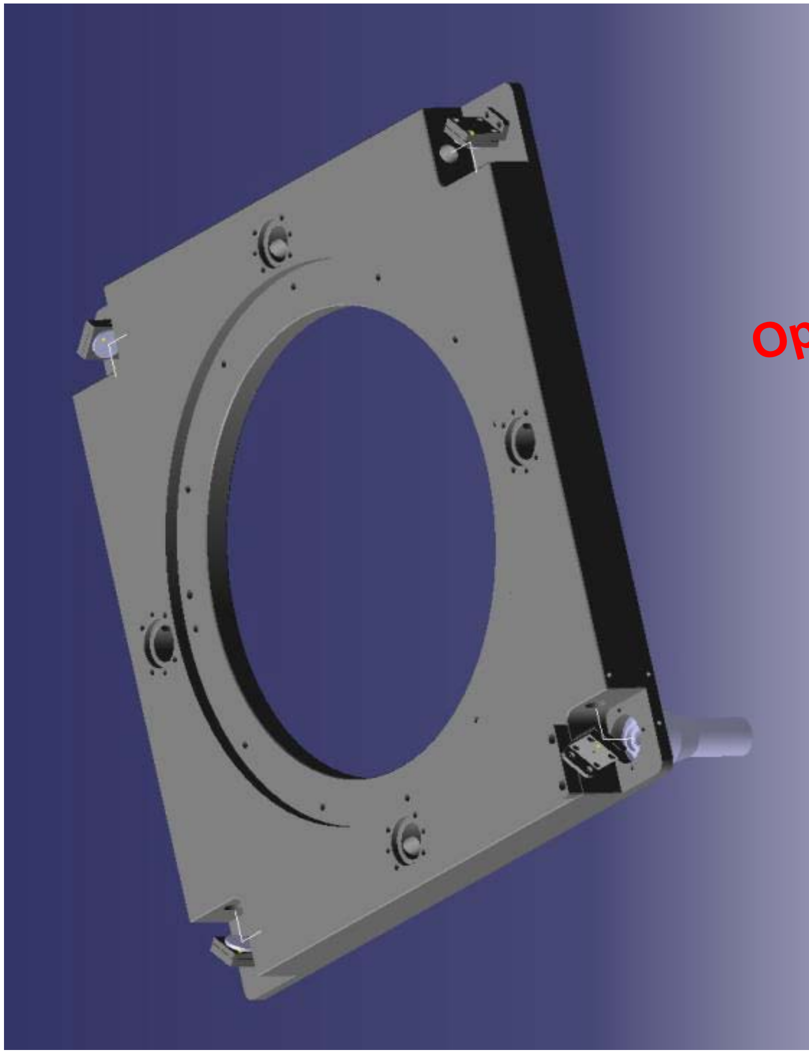
Design of the prototype with laser and UV



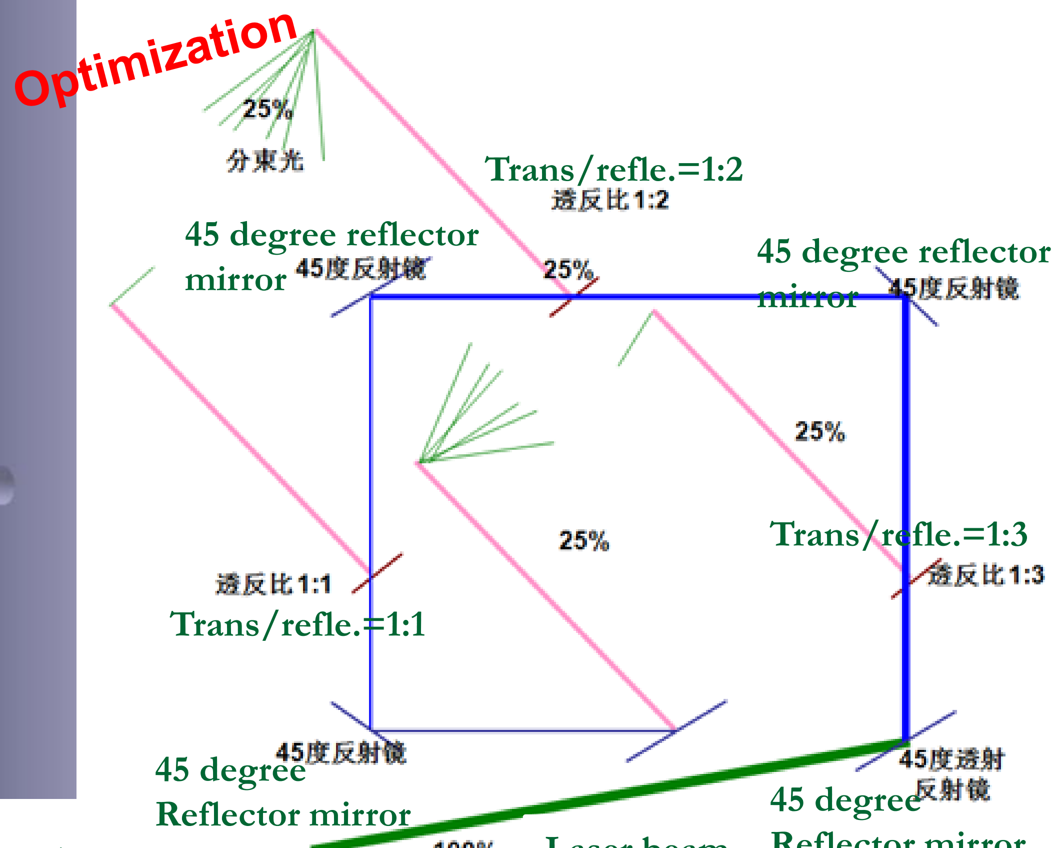
The laser and UV lamp structure without the TPC barrel

Laser map in drift length

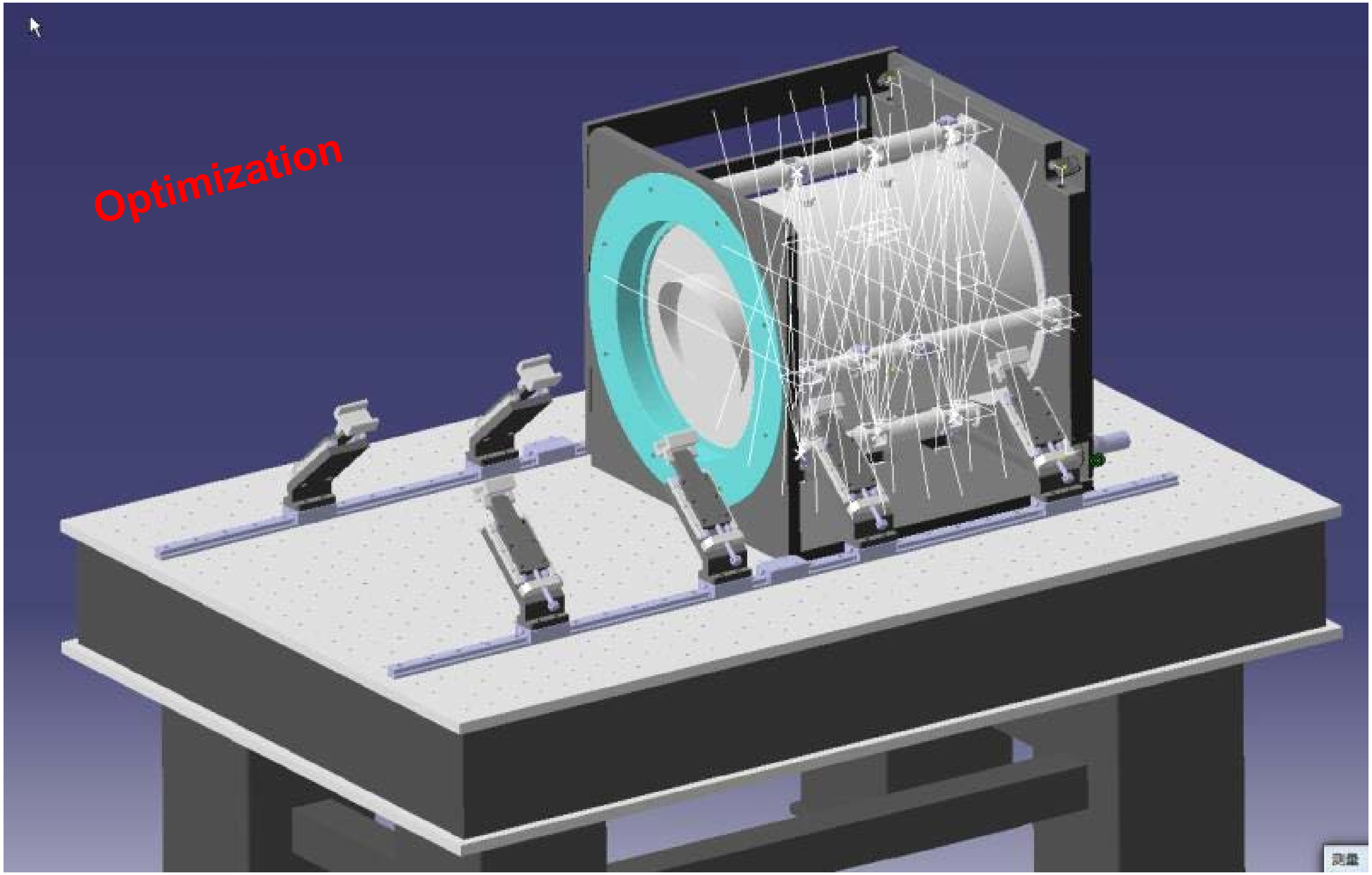
- Laser wave: 266nm
- Size: ~1mm×1mm
- Transmission and reflection mirrors
- Aluminum board integrated the laser device and supports



Aluminum board integrated the laser system



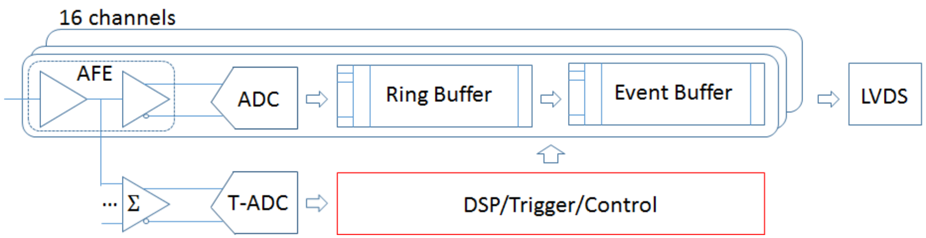
Design of the prototype with laser (Final version)

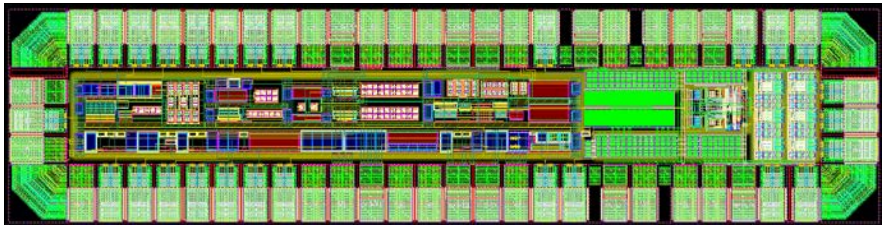


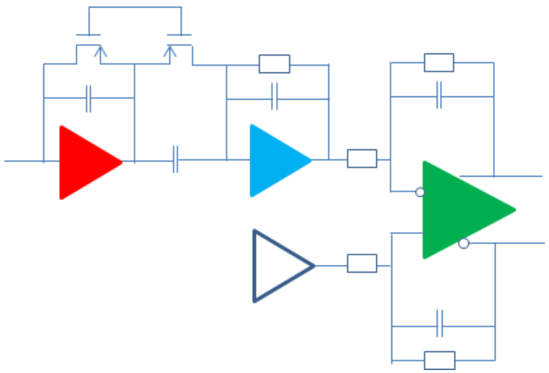
- Support platform: 1200mm×1500mm (all size as the actual geometry)
- TPC barrel mount and re-mount with the Auxiliary brackets
- Design is done and hardware would be assembled the end of this year.

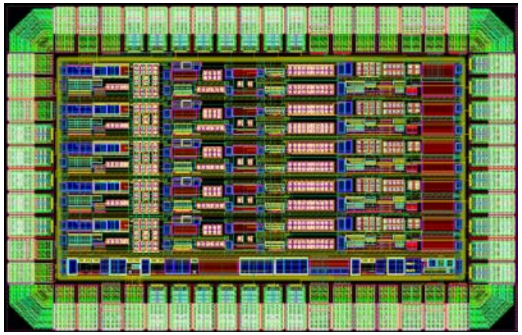
Low Power TPC Readout ASIC in 65nm

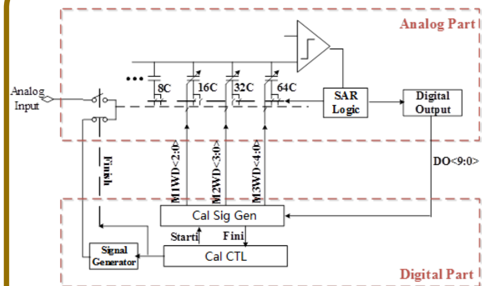
Deng Zhi, Tsinghua

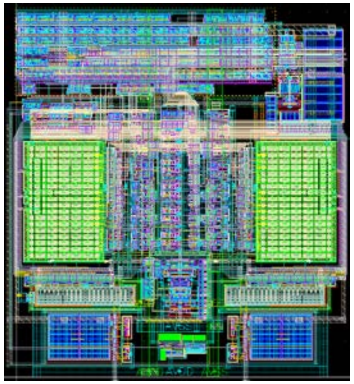


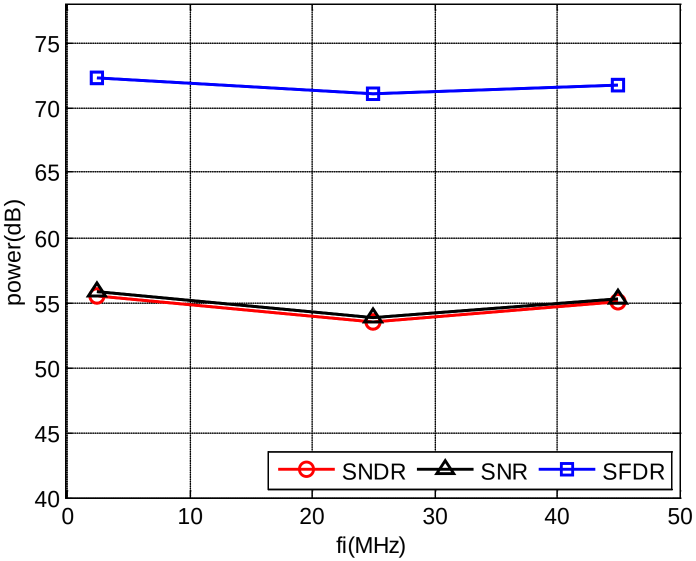












0.7mW @ 100MSPS,
ENOB=8.8bit

International cooperation

- CEA-Saclay IRFU group (FCPPL)
  - Three vidyo meetings with Prof. Aleksan Roy/ Prof. Yuanning/ Manqi and some related persons (2016~2017)
  - Exchange PhD students: Haiyun Wang participates Saclay's R&D six months in 2017~2018
  - Bulk-Micromegas detector assembled and IBF test
  - IBF test using the new Micromegas module with more 590 LPI
- LCTPC collaboration group (LCTPC)
  - Singed MOA and joined in LC-TPC collaboration @Dec. 14,2016
  - As coordinator in ions test and the new module design work package
  - Regular meeting bi-weeks
  - Plan to beam test in DESY with our hybrid detector module in 2018

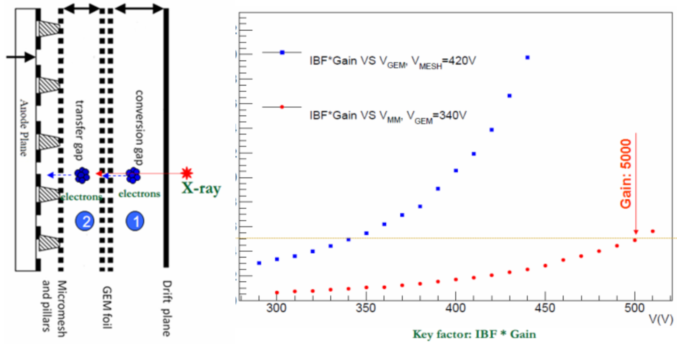
Manpower and activities

- TPC detector R&D @IHEP (2016~2020)
  - Huirong Qi,
  - Yulian Zhang (PhD,IHEP), Haiyun Wang(PhD,IHEP), Zhiwen Wen(PhD,IHEP)
  - Prof. Jin Li
  - Funding from MOST and NSFC(~3.5 Million RMB)
- Electronics R&D &Tsinghua (2016~2020)
  - Zhi Deng
  - Yiming Cai(PhD,THU), Zhao Mingrui (Master, THU) and three PhDs in electronics lab
  - Prof. Yuanning Gao, Prof. Yulan Li
  - Funding from NSFC (~2.0 Million RMB)
- Inhabitation of IBF using graphene @Shandong Univ. (2016~2019)
  - Zhu Chengguang
  - Zhao xiao (PhD,SDU)

Highlights and summary

Continuous IBF module for CEPC:

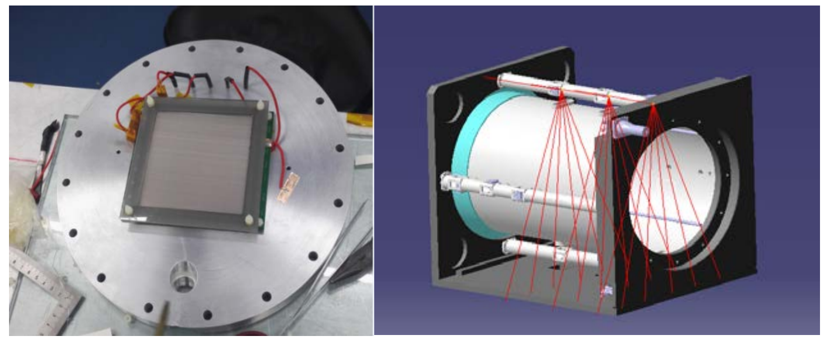
- No Gating device options used for Higgs/Z pole run
- Continuous Ion Back Flow due to the continuous beam structure (Developed in IHEP)
- ~100 μm position resolution in rφ
- Key factor: IBF×Gain=5 and leas than (R&D)
- Low discharge and spark possibility



Continuous IBF prototype and IBF×Gain

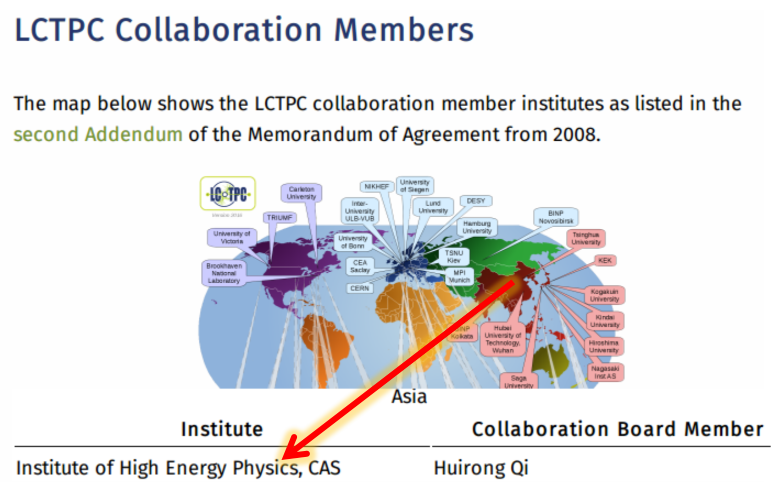
Prototype with laser calibration for CEPC :

- 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!