Progress on the TPC detector prototype with laser calibration and alignment

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Nov. 24, 2017, LCWS, Strasbourg

Outline

- Physics requirements
- Status of TPC module R&D
- Status of TPC prototype R&D
- Summary

Physics requirements

TPC requirements for collider concept

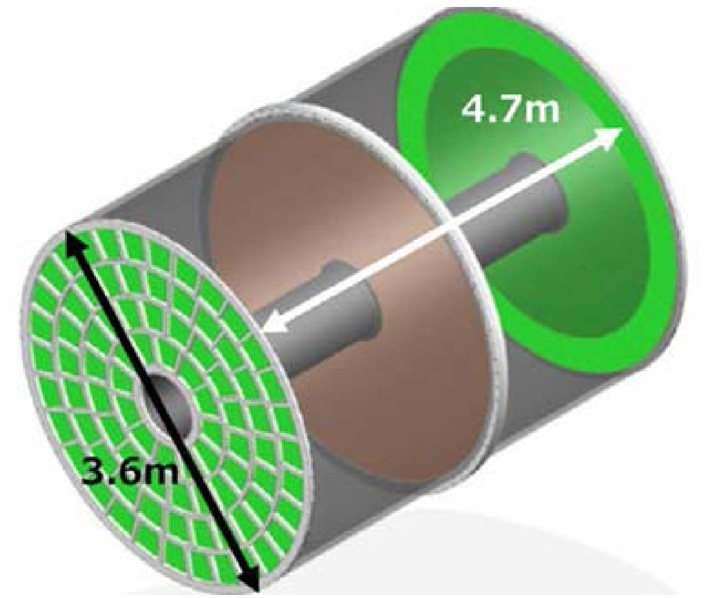
TPC could be as one tracker detector option for CEPC, 1M ZH events in 10yrs E_{cm} ≈250 GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, can also run at the Z-pole

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

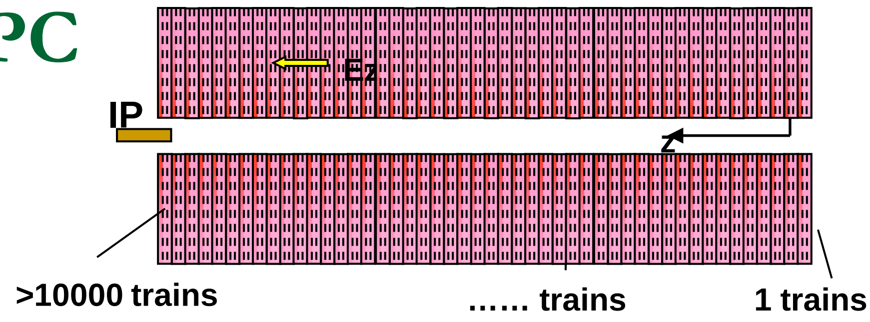
TPC detector concept:

- 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

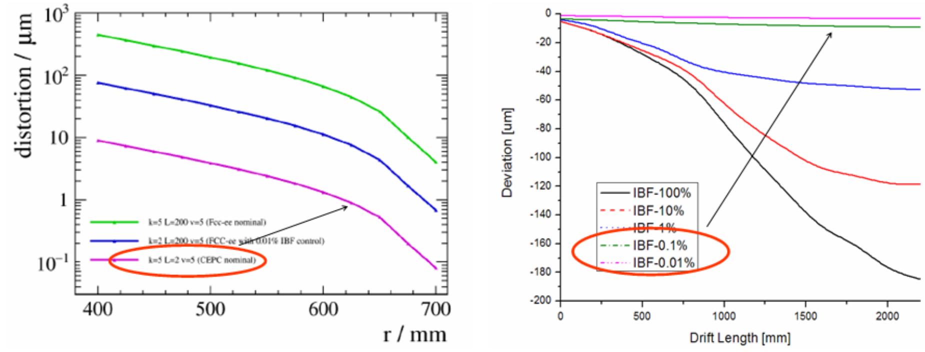
Technical challenges for TPC



Amplification ions @CEPC

Ion Back Flow and Distortion :

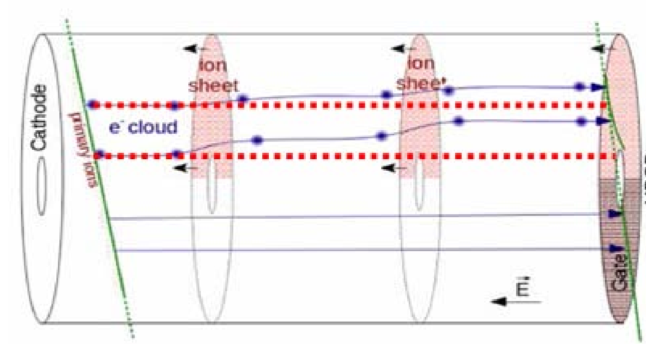
- ~100 μm position resolution in rφ
- Distortions by the primary ions at CEPC are negligible
- More than 10000 discs co-exist and distorted the path of the seed electrons
- The ions have to be cleared during the ~us period continuously
- Continuous device for the ions
- Long working time



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

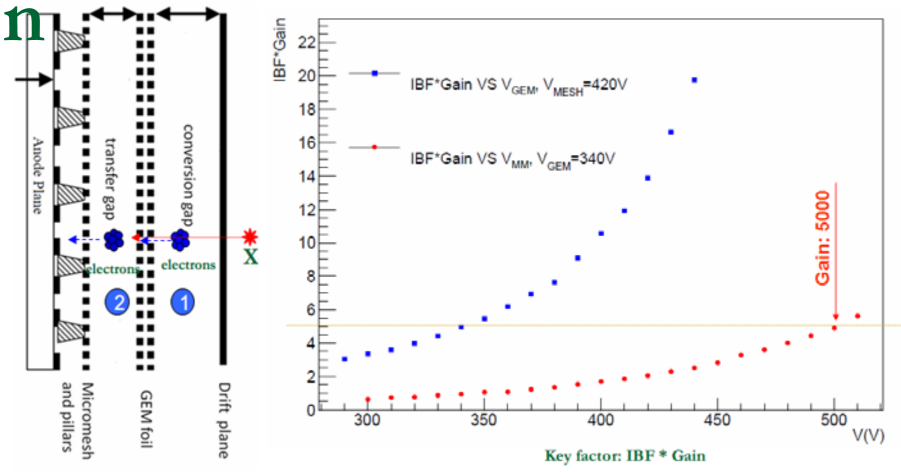


Ions backflow in drift volume for distortion

Options of technical solution

Continuous IBF module:

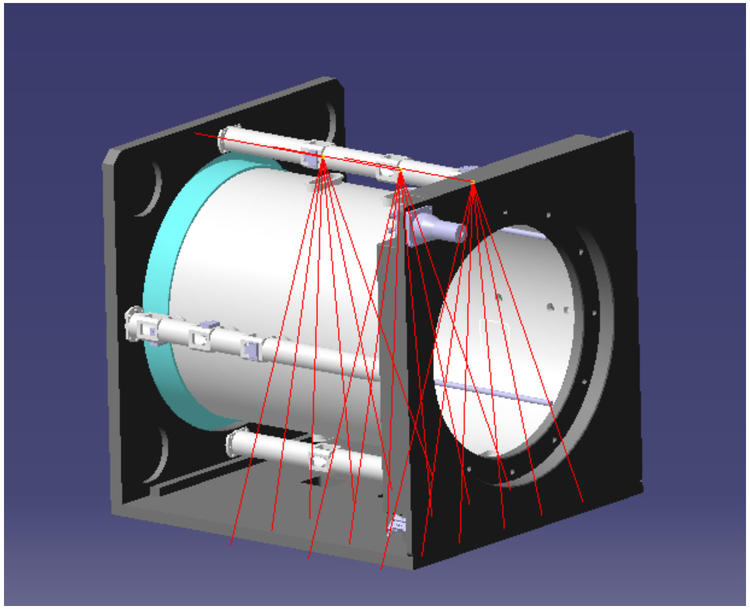
- Gating device may be used for Higgs run
- Open and close time of gating device for ions: ~ μs-ms
- No Gating device option for Z-pole run
- Continuous Ion Back Flow due to the continuous beam structure
- Low discharge and spark possibility



Continuous IBF prototype and IBF × Gain

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



TPC prototype integrated with laser system

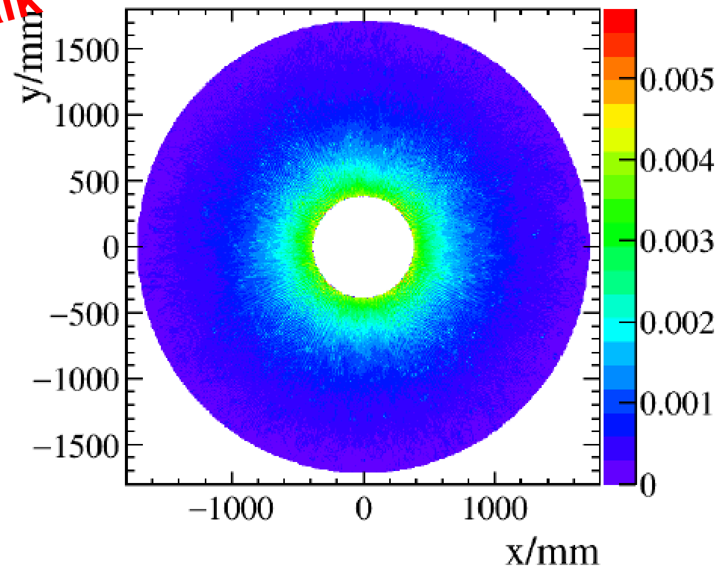
Simulation study of IBF for CEPC

High rate at Z pole

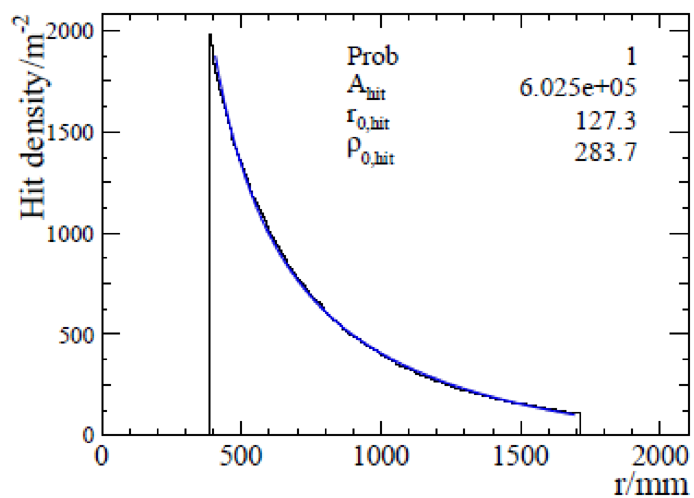
ArXiv: 1704.04401

- Voxel occupancy
  - The number of voxels /signal **Manqi's talk**
  - 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
  - 1.33×10^{14} number of voxels/s @DAQ/40MHz
  - Average voxel occupancy: 1.33×10^{-8}
  - Voxel occupancy at TPC inner most layer: $\sim2\times10^{-7}$
  - Voxel occupancy at TPC inner inner most layer : $\sim2\times10^{-5}$ @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

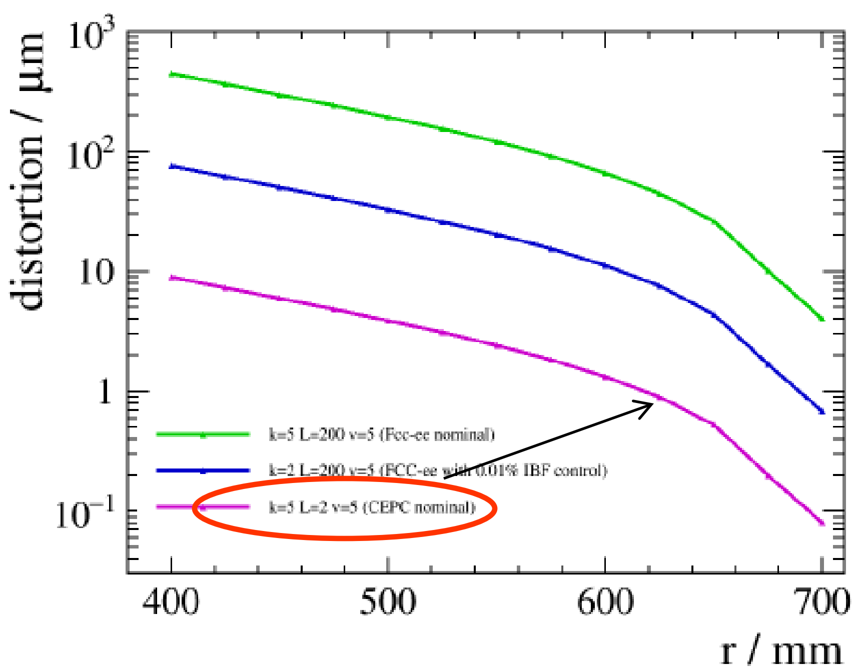
- Electron:
  - Drift velocity ~6-8cm/us@200V/cm
  - Mobility μ ~30-40000 cm²/(V.s)
- Ion:
  - Mobility μ ~2 cm²/(V.s)

  in a "classical mixture" (Ar/Iso)

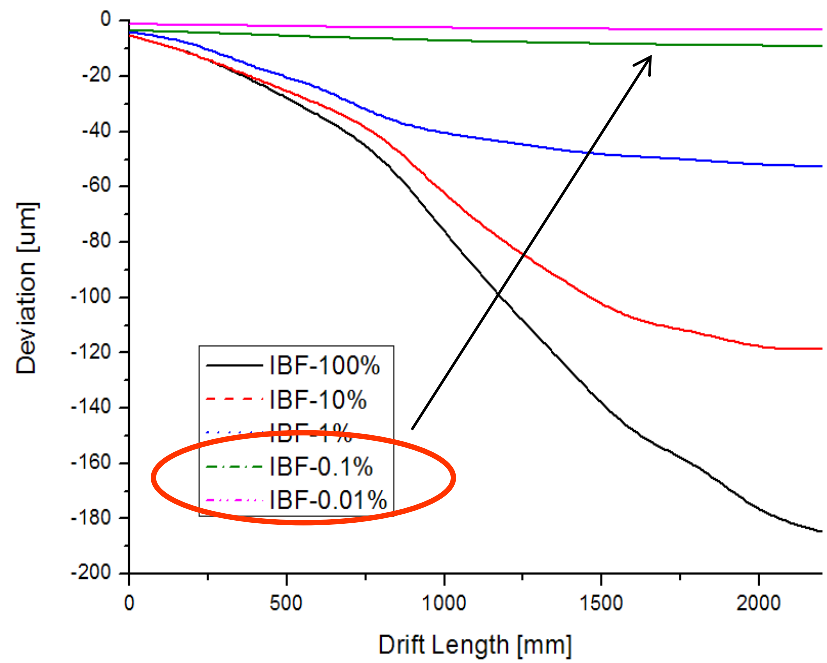
$$S_N = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 S_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 S_{x_2}^2 + \left(\frac{\partial f}{\partial x_3}\right)^2 S_{x_3}^2}$$

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

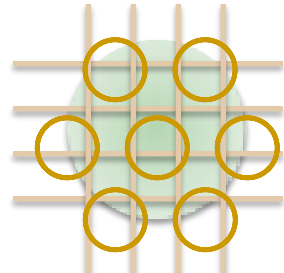


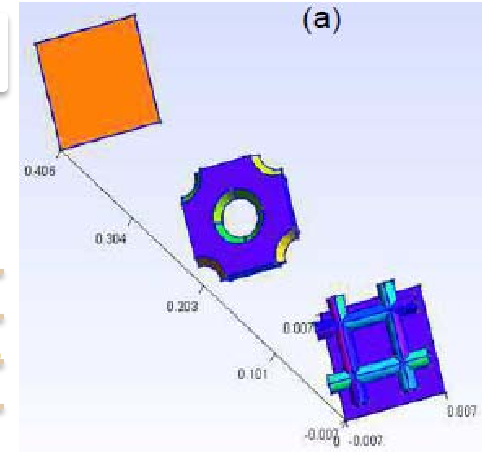
Evaluation of track distortions due to space charge effects of positive ions

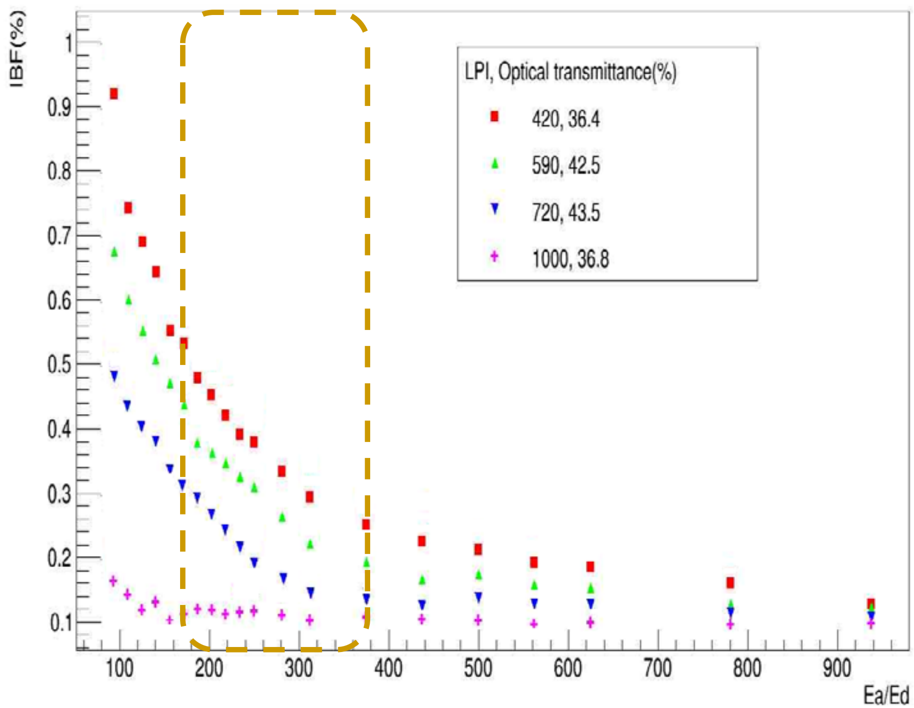
IBF simulation

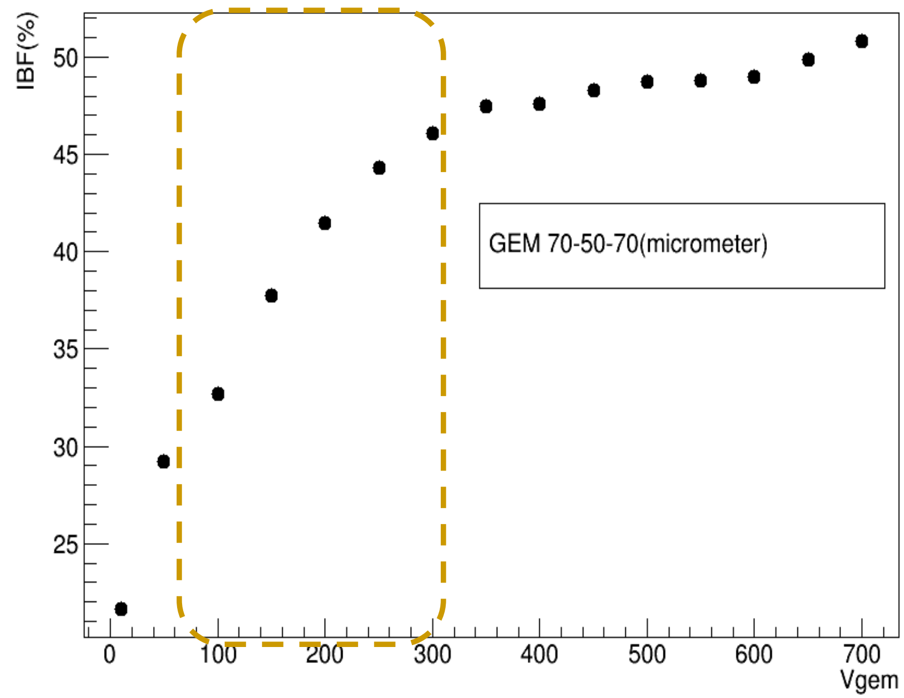
Yulian, Haiyun, Huirong

- 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)







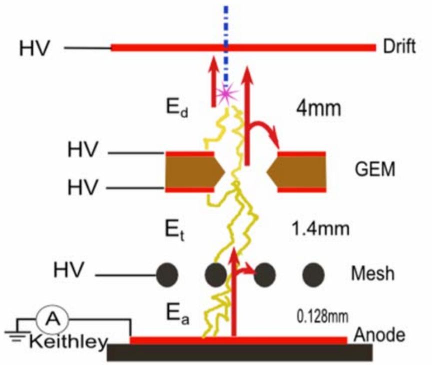


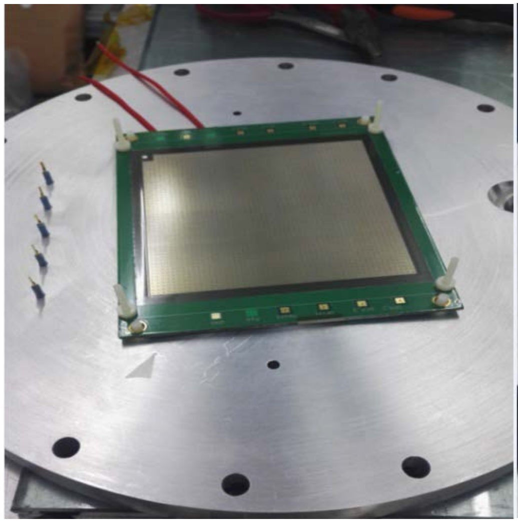
Electric field of amplifier VS Electric field of Drift and VGEM

Investigation of IBF study with module

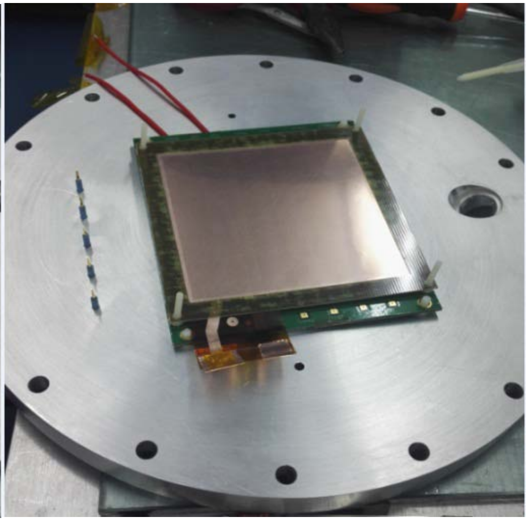
Test of the new module

- 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

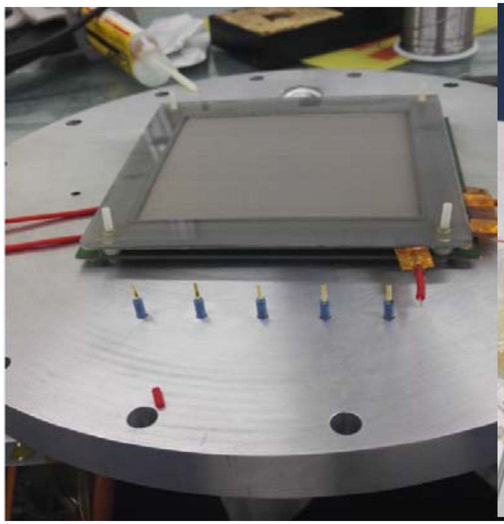




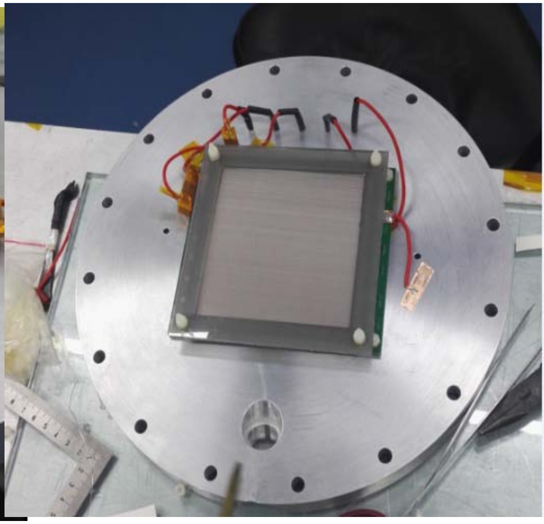
Micromegas(Saclay)



GEM(CERN)

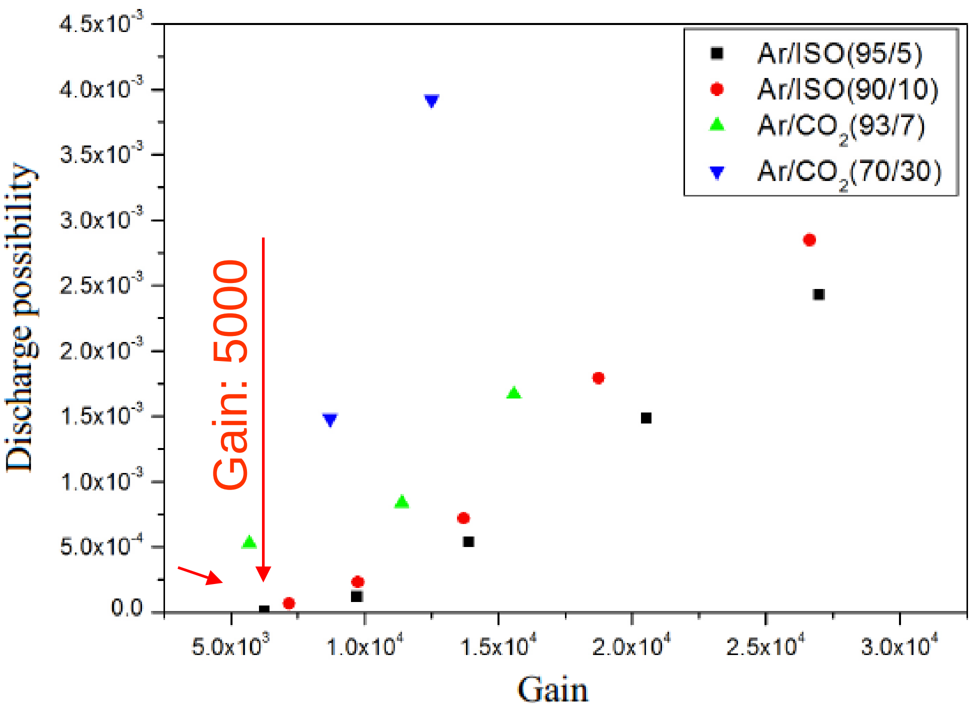


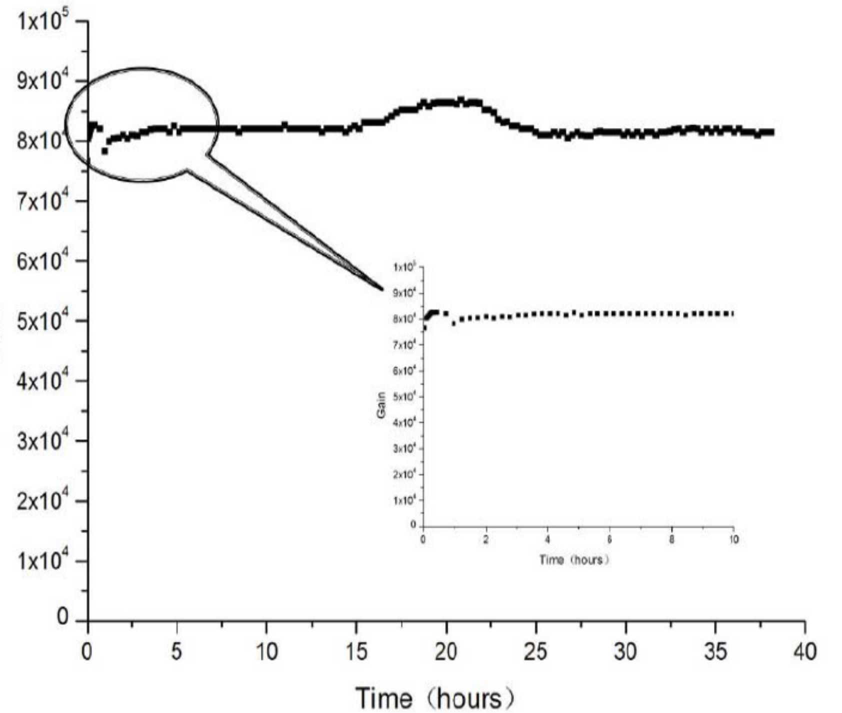
Cathode with mesh



GEM-MM Detector

Discharge and working time



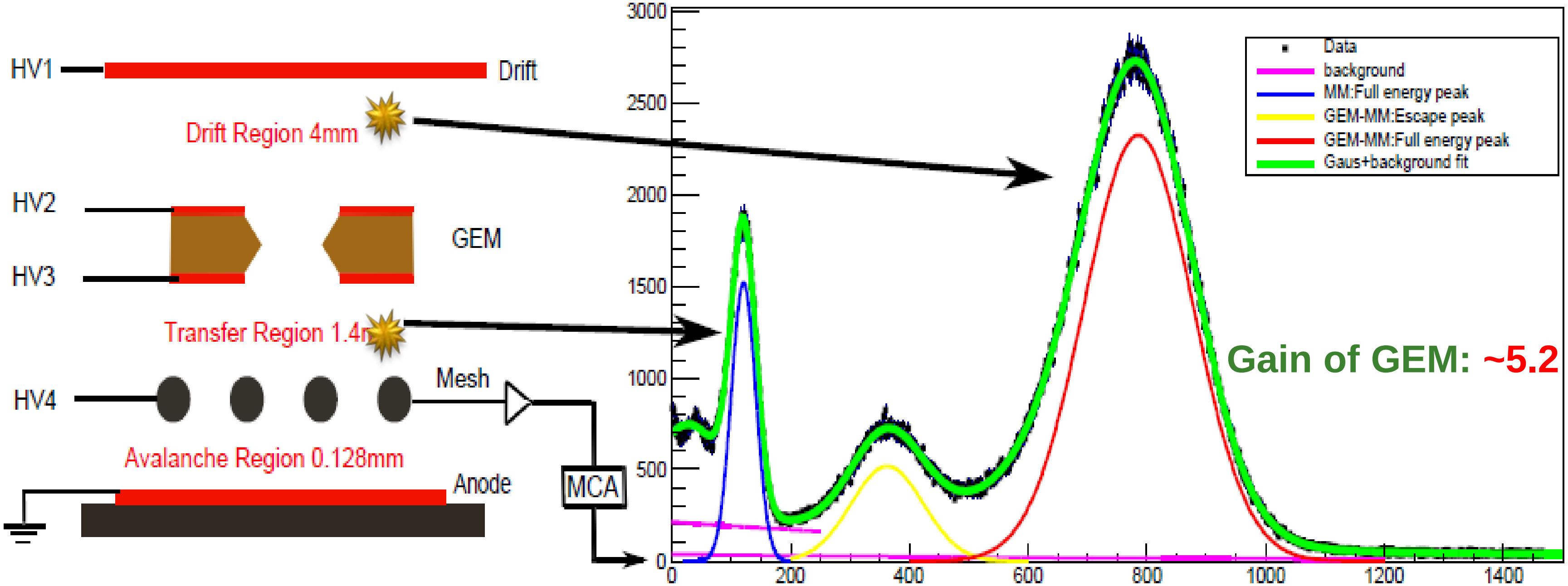


- Test with Fe-55 X-ray radiation source
  - Discharge possibility could be mostly reduced than the standard Bulk-Micromegas
  - Discharge possibility of hybrid detector could be used at Gain~10000
  - To reduce the discharge probability more obvious than standard Micromegas
  - At higher gain, the module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

Energy spectrum@^{55}Fe

Yulian, Haiyun, Huirong

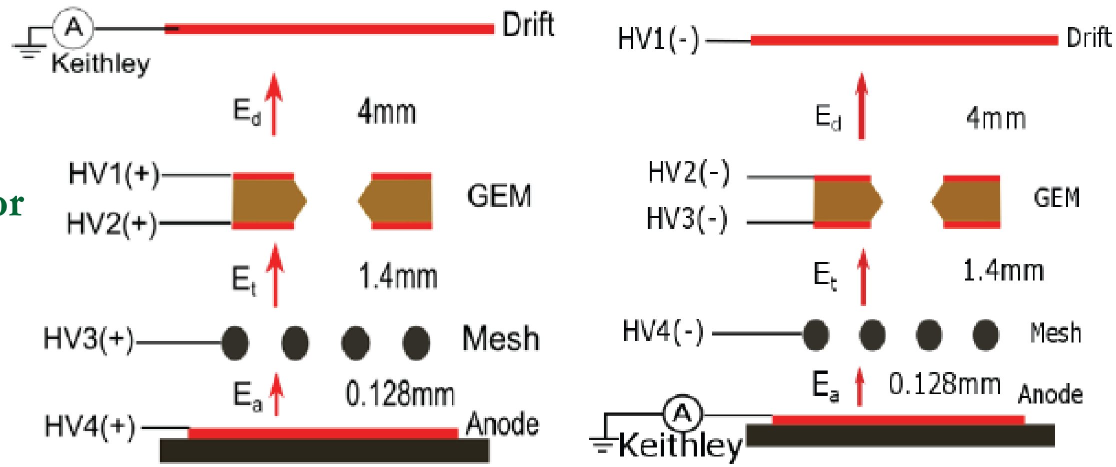
Source: ^{55}Fe, Gas mix: Ar(97) + iC_4H_{10}(3)



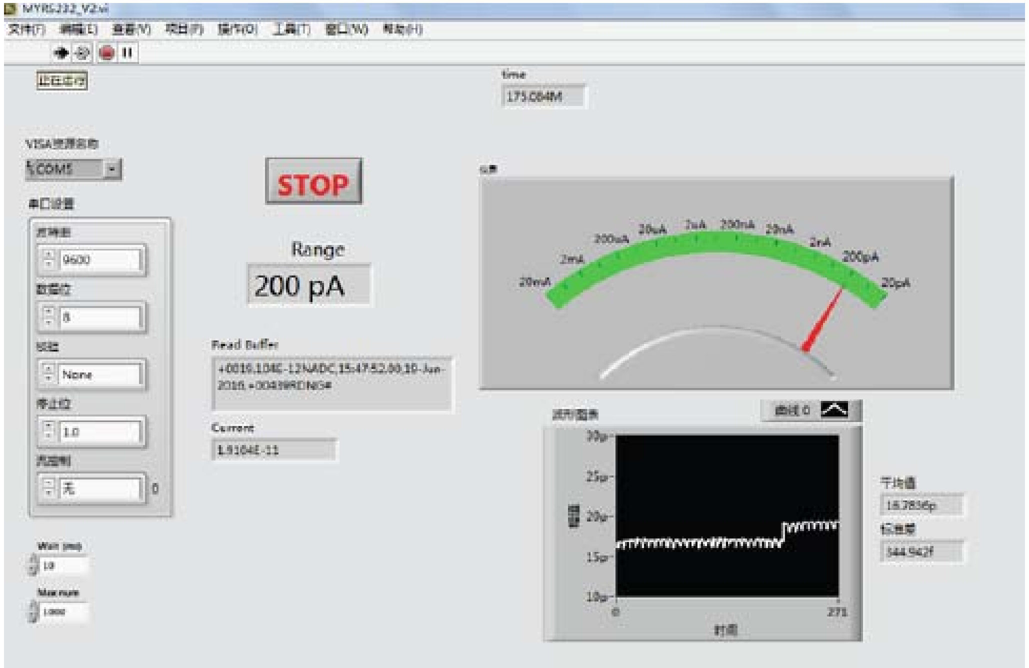
An example of the 55Fe spectra showing the correspondence between the location of an X-ray absorption and each peak.

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



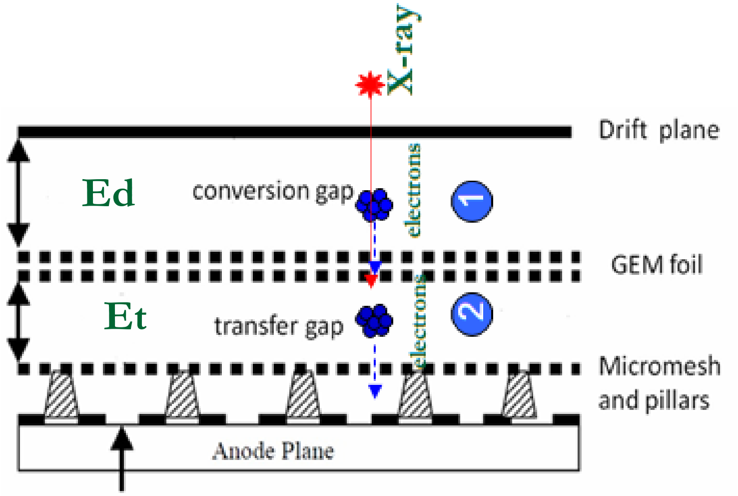
Measurement of the low current



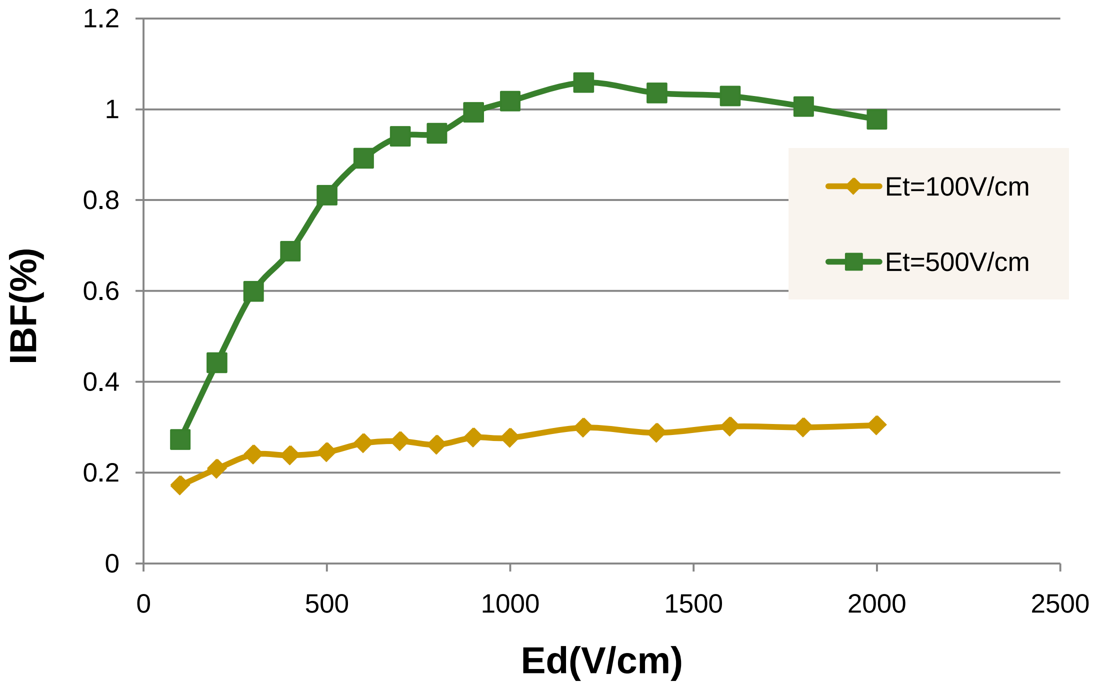
Labview interface of the current with Keithley

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



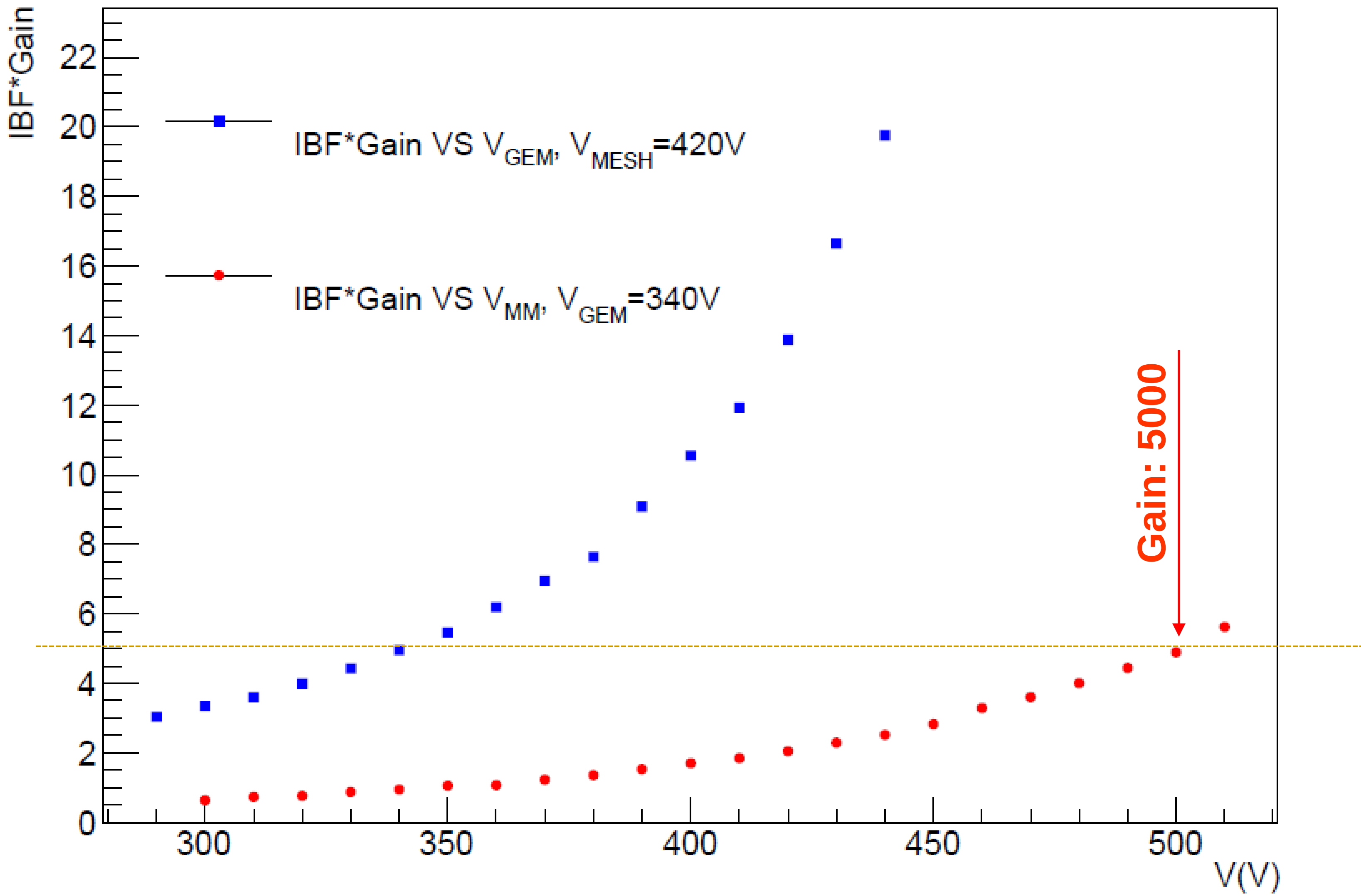
Schematic of the Gain with MM



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

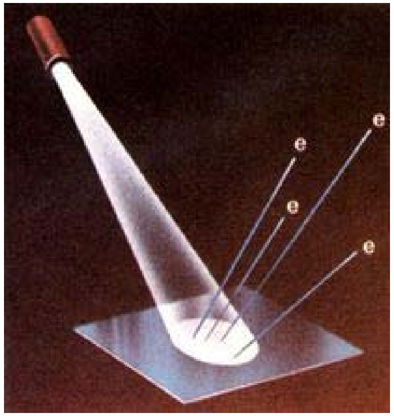
Parameters of the TPC prototype

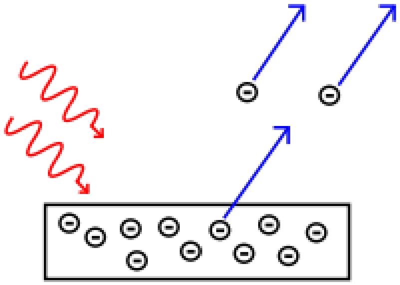
- To aim that the small TPC prototype for the estimation of the distortion due to the IBF, and the study of related physics parameters
- To mimic the bunch structure & the ions distortion with UV light and laser split beam

- 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

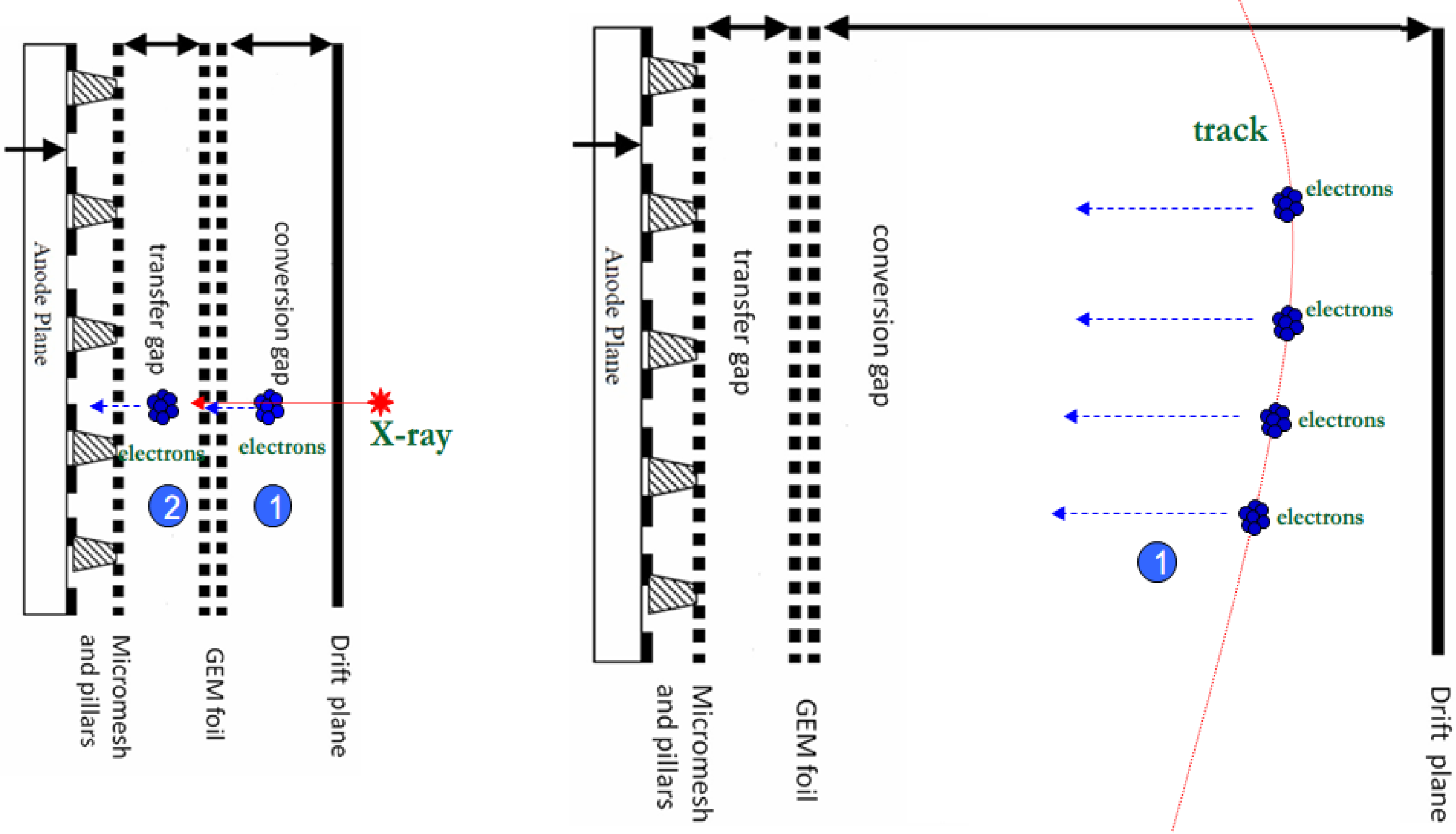


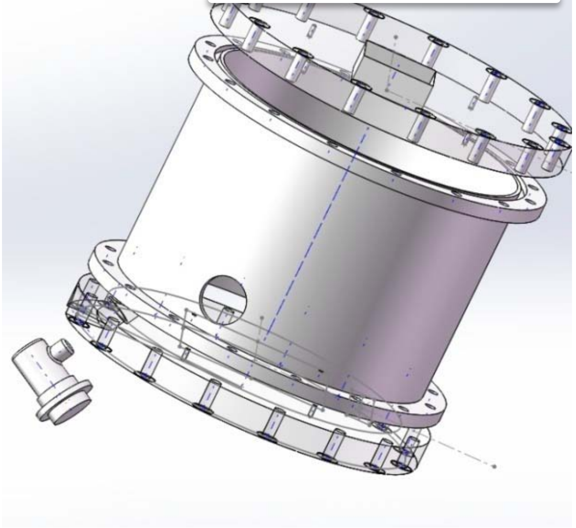
Diagram of the IBF test with the module

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

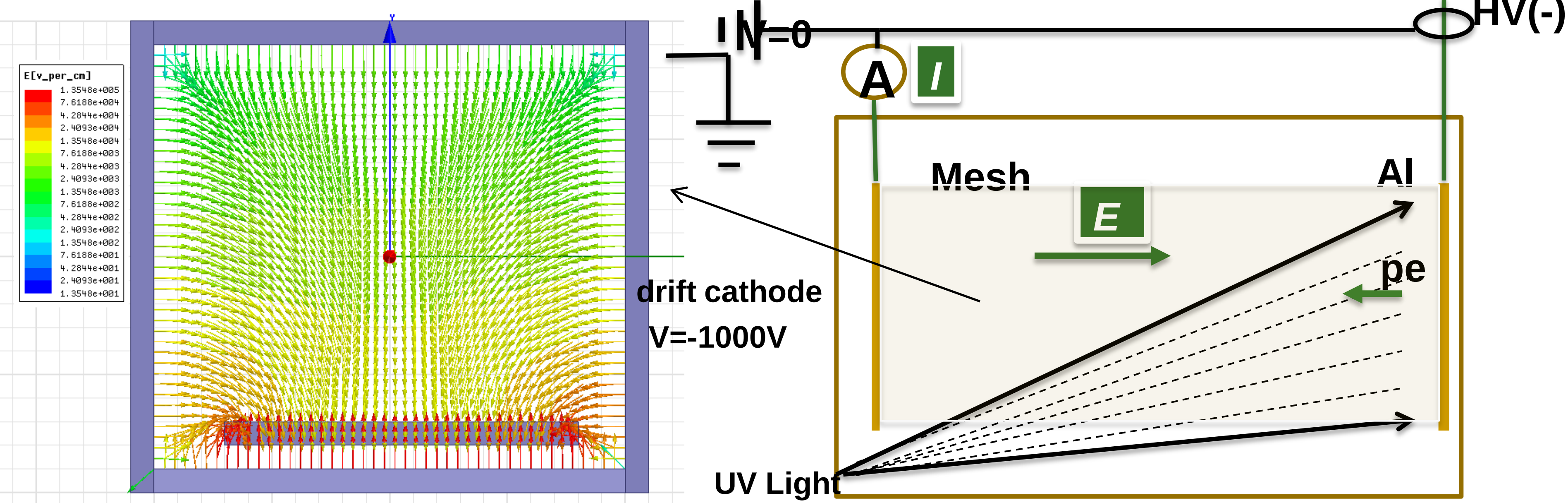


Diagram of the UV test with new module

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.mm^2
  - Electrons from Al
  - Electrons from drift length at 266nm UV light (~MIPs)

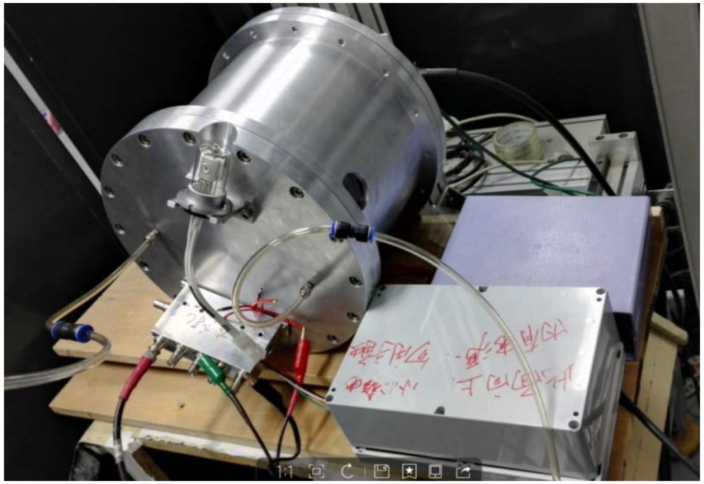
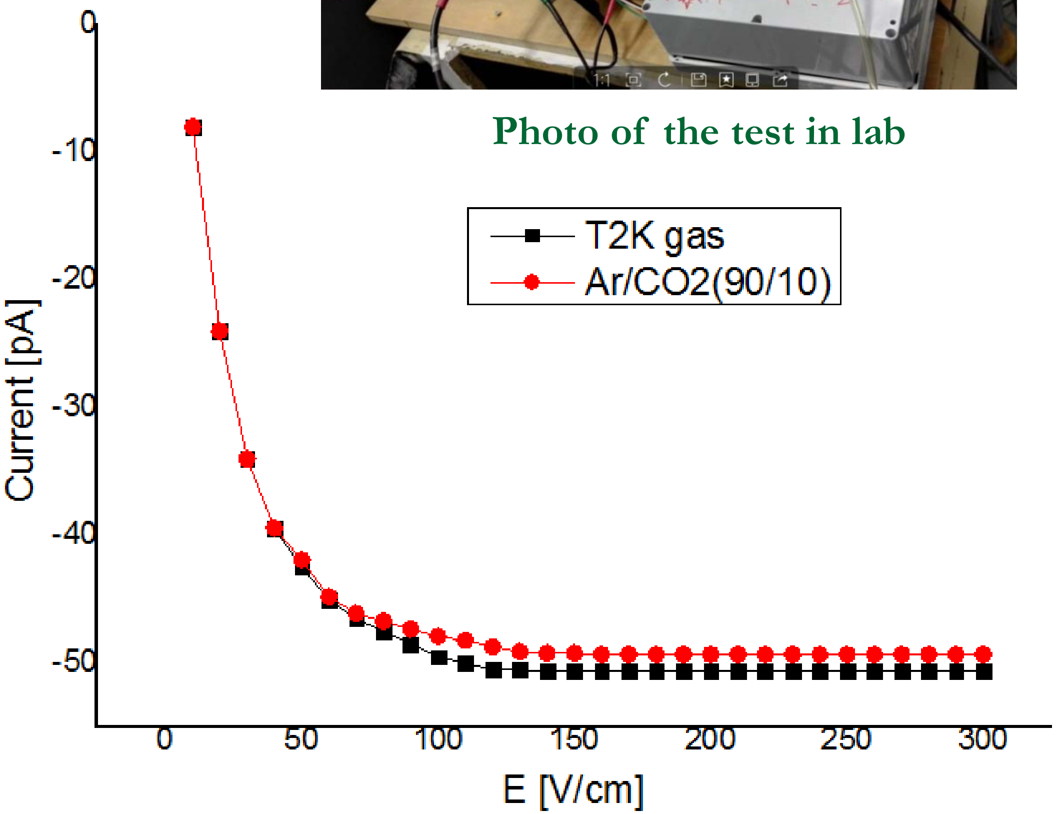
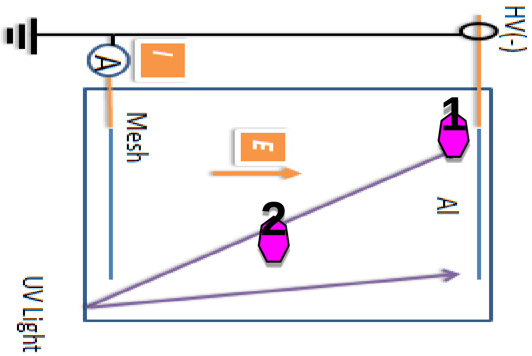


Photo of the test in lab



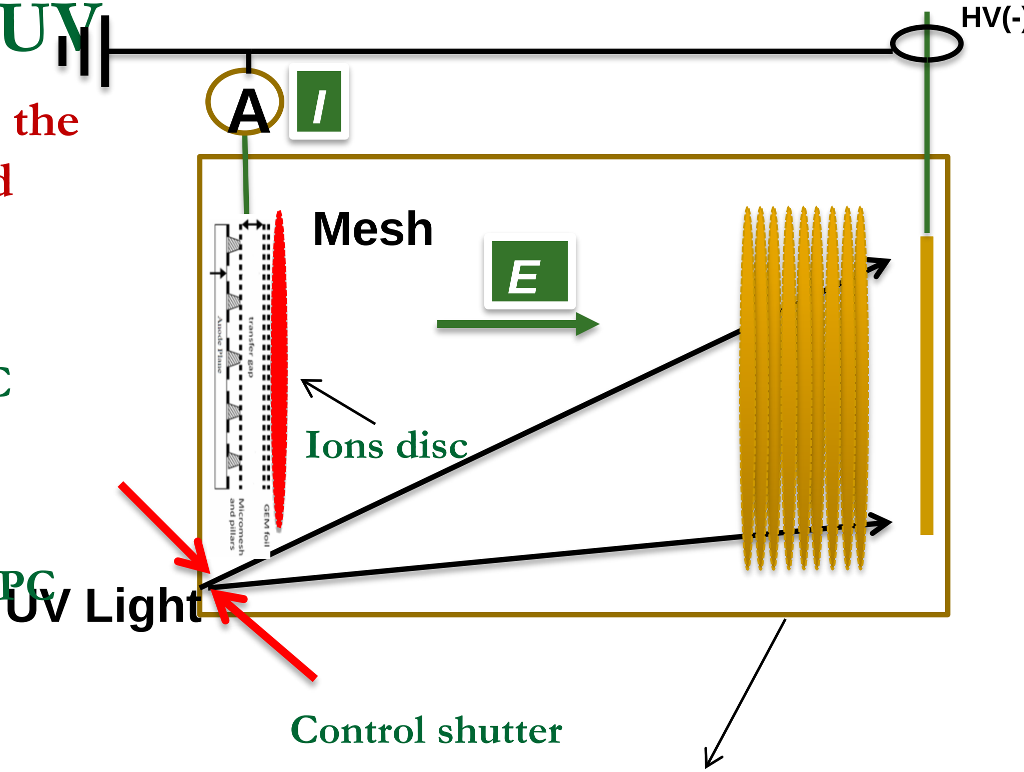
Current VS Electric field in drift length

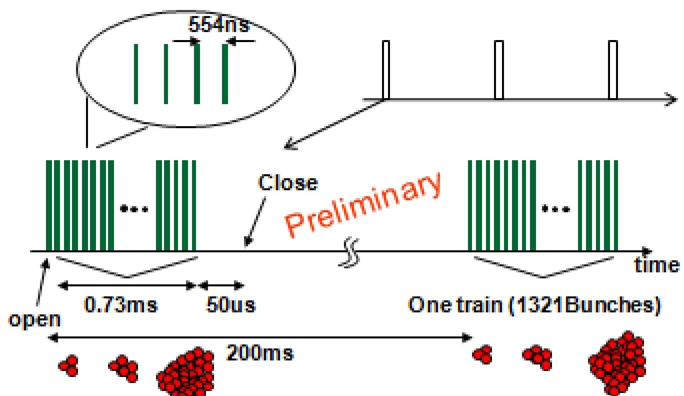


UV Shining diagram

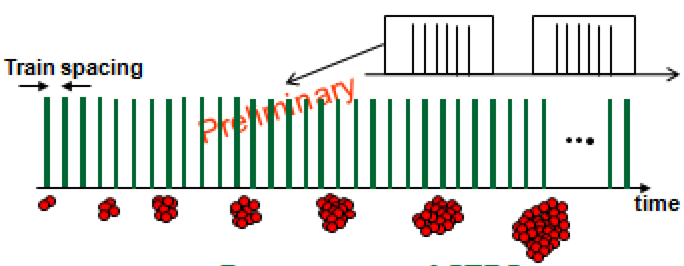
Electrons produced by UV

- 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

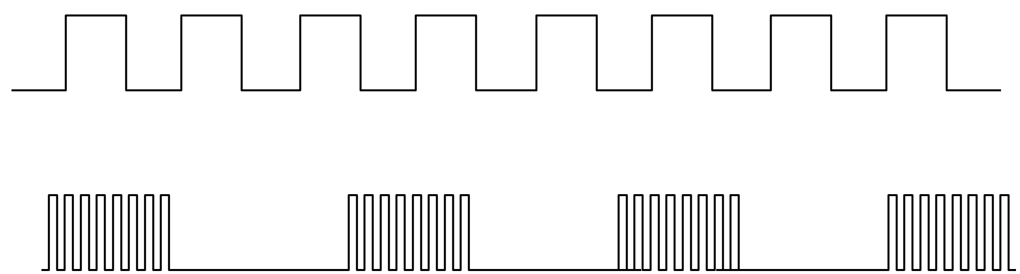




Beam structure of ILC

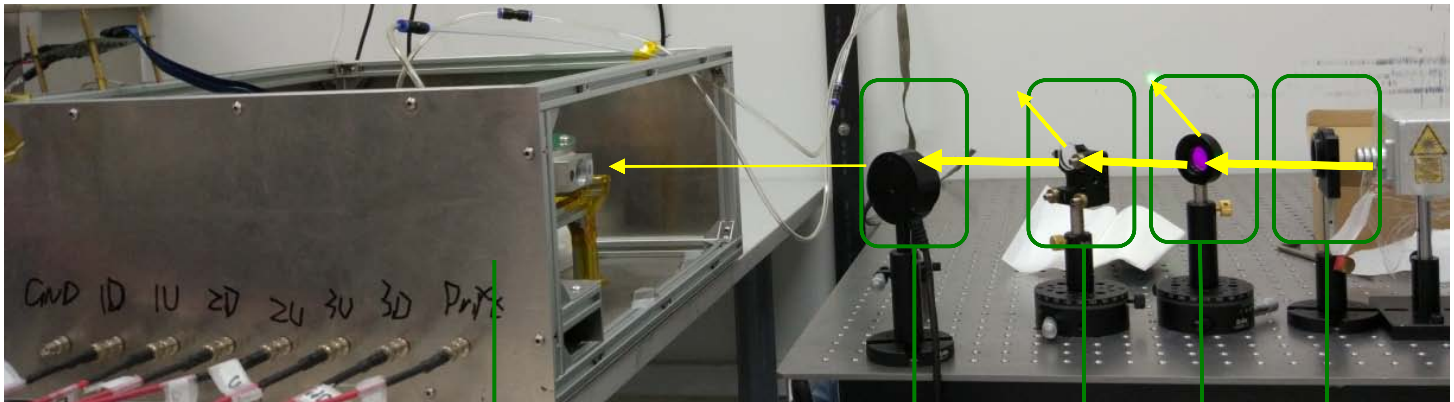


Beam structure of CEPC



Shutter time similar to ILC and CEPC beam structure

Signal of the laser with Φ1mm @266nm



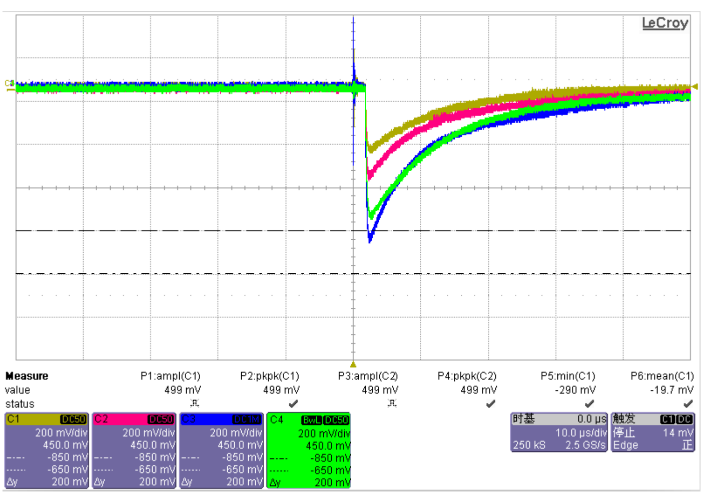
Triple GEMs detector

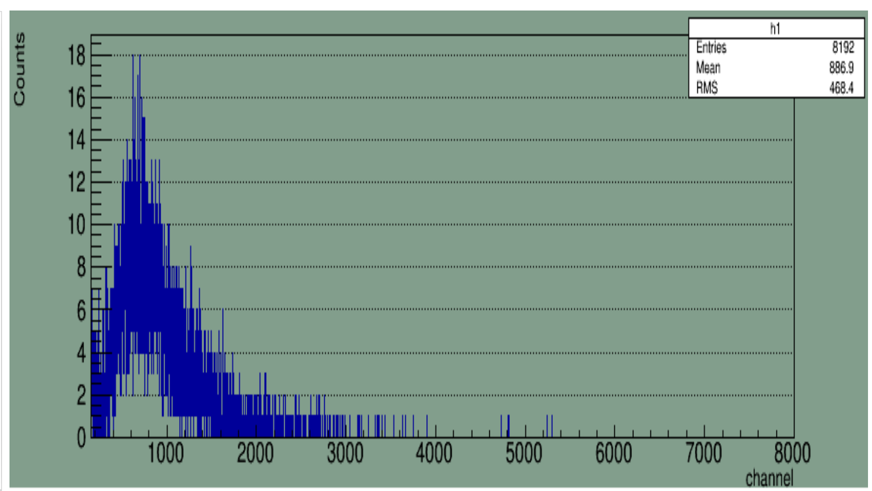
Hole collimator Φ1mm

Trans/refle. =1:99

Transmission mirror

Transmission mirror





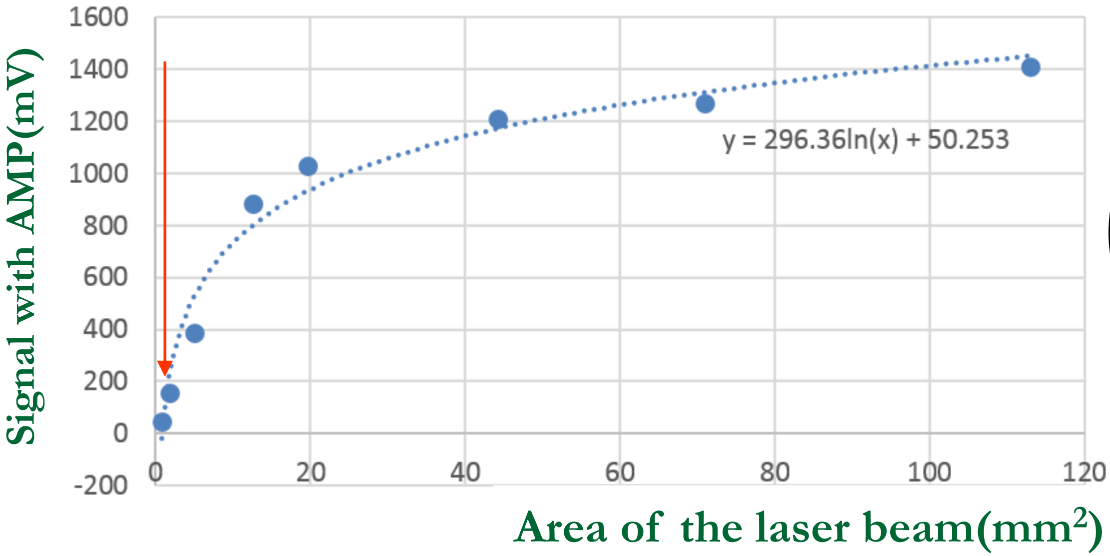
Signal of the laser with Φ1mm@Charge sensitive AMP/12mV/fC

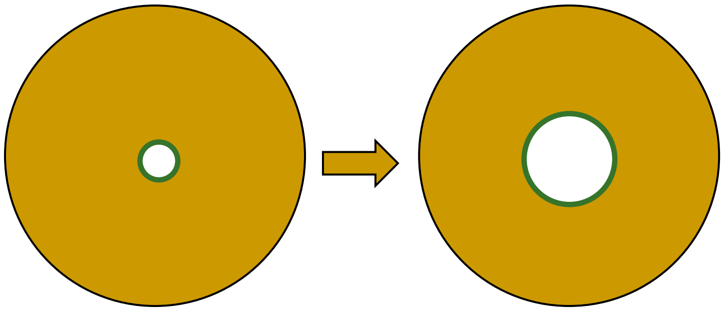
Collimator@Φ1~ Φ 12mm

- 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

入射光斑激光信号随面积变化关系



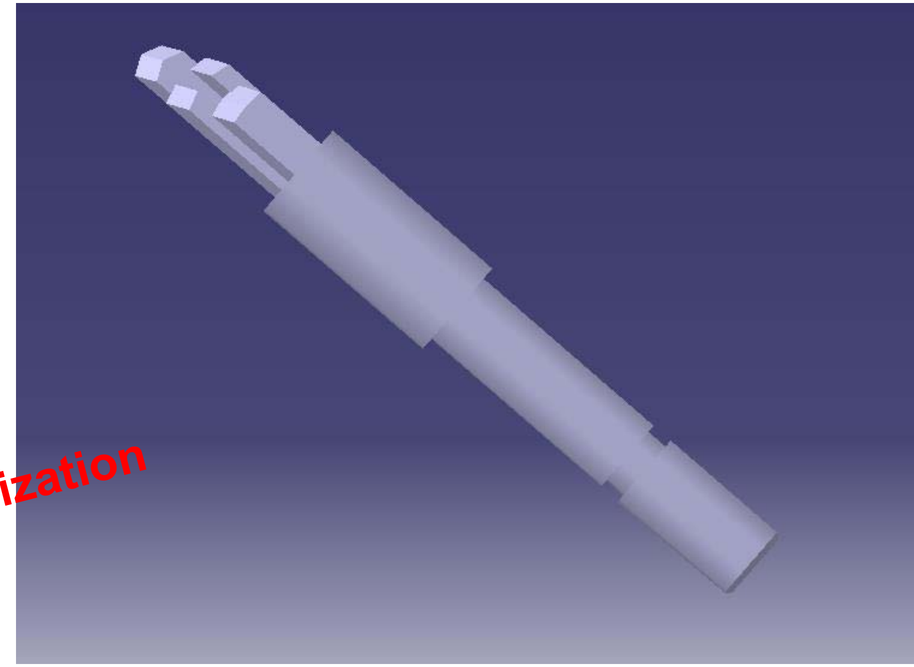


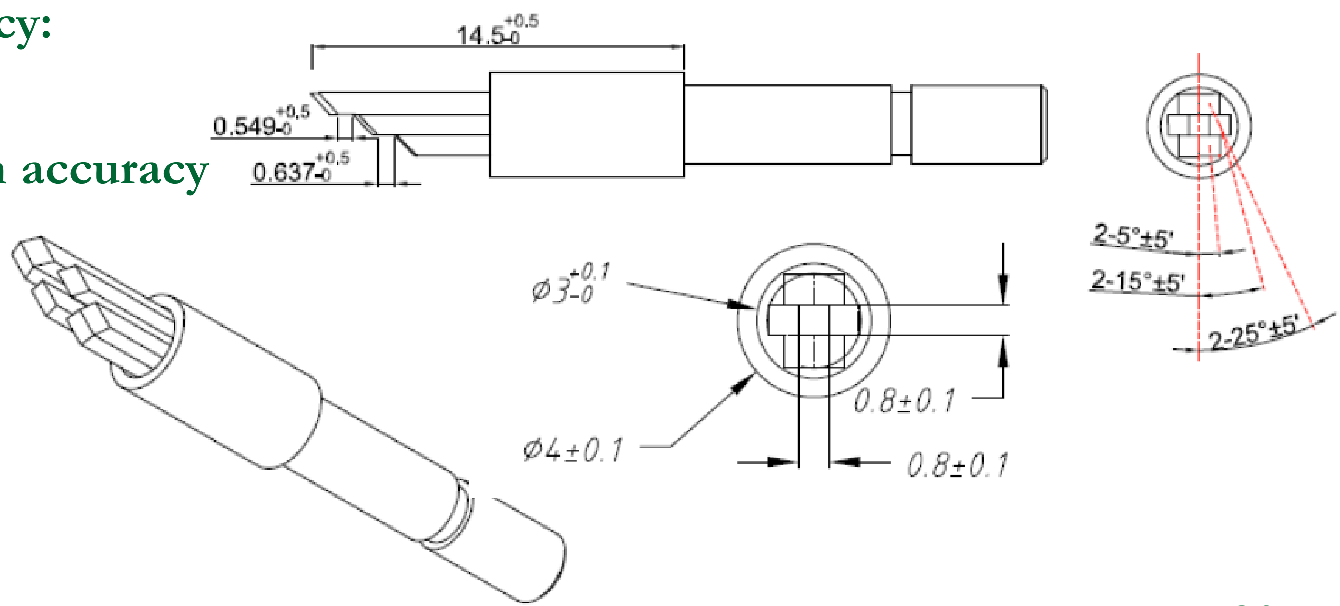
Area of laser beam in detector

Divide and reflection mirrors

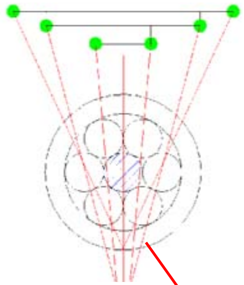
- Laser wave for the divide and reflection mirrors: 266nm
- Size: ~0.8mm×0.8mm
- Number of the divide trackers: 6
- Stainless steel support integrated the laser mirrors
- Reflection efficiency:
  >99%@266nm
- Reflection position accuracy
  1/30 degree

Optimization



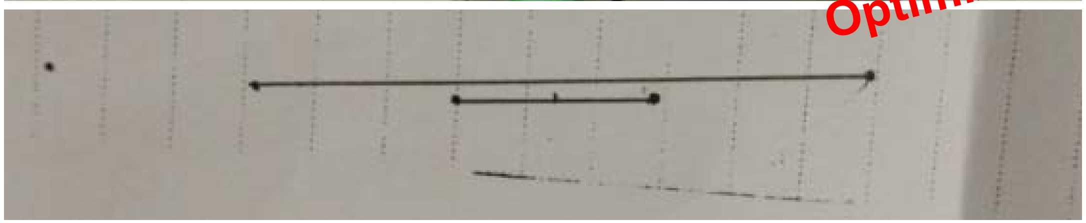


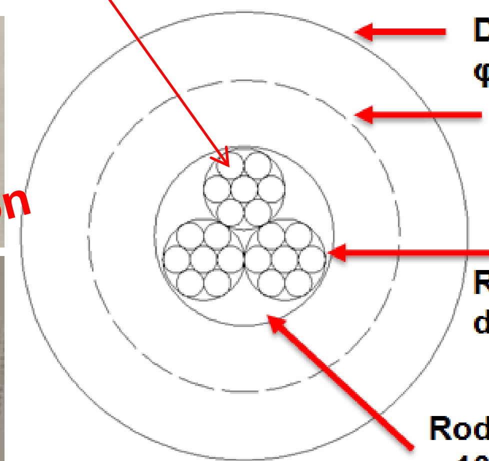
Mirrors test with 266nm



Test:

Optimization





Diameter of outline φ15mm

1st collimator φ12mm

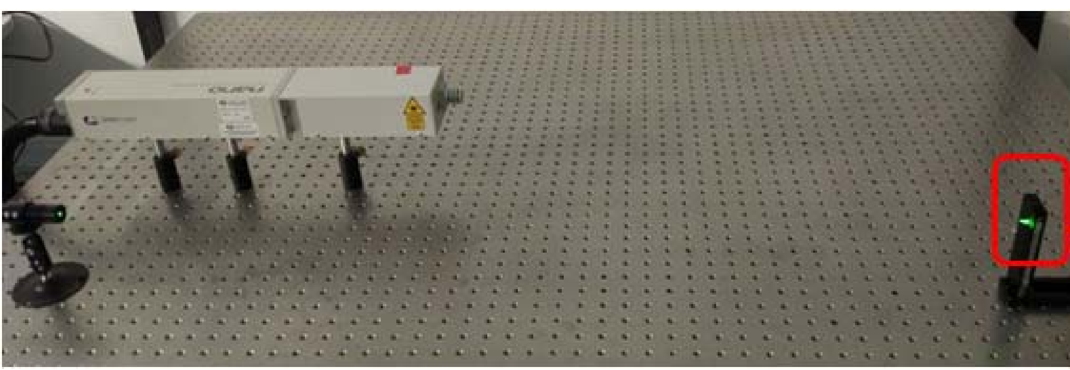
Reflection mirror diameter φ1mm

Rod outline φ10mm

Report of the mirrors:

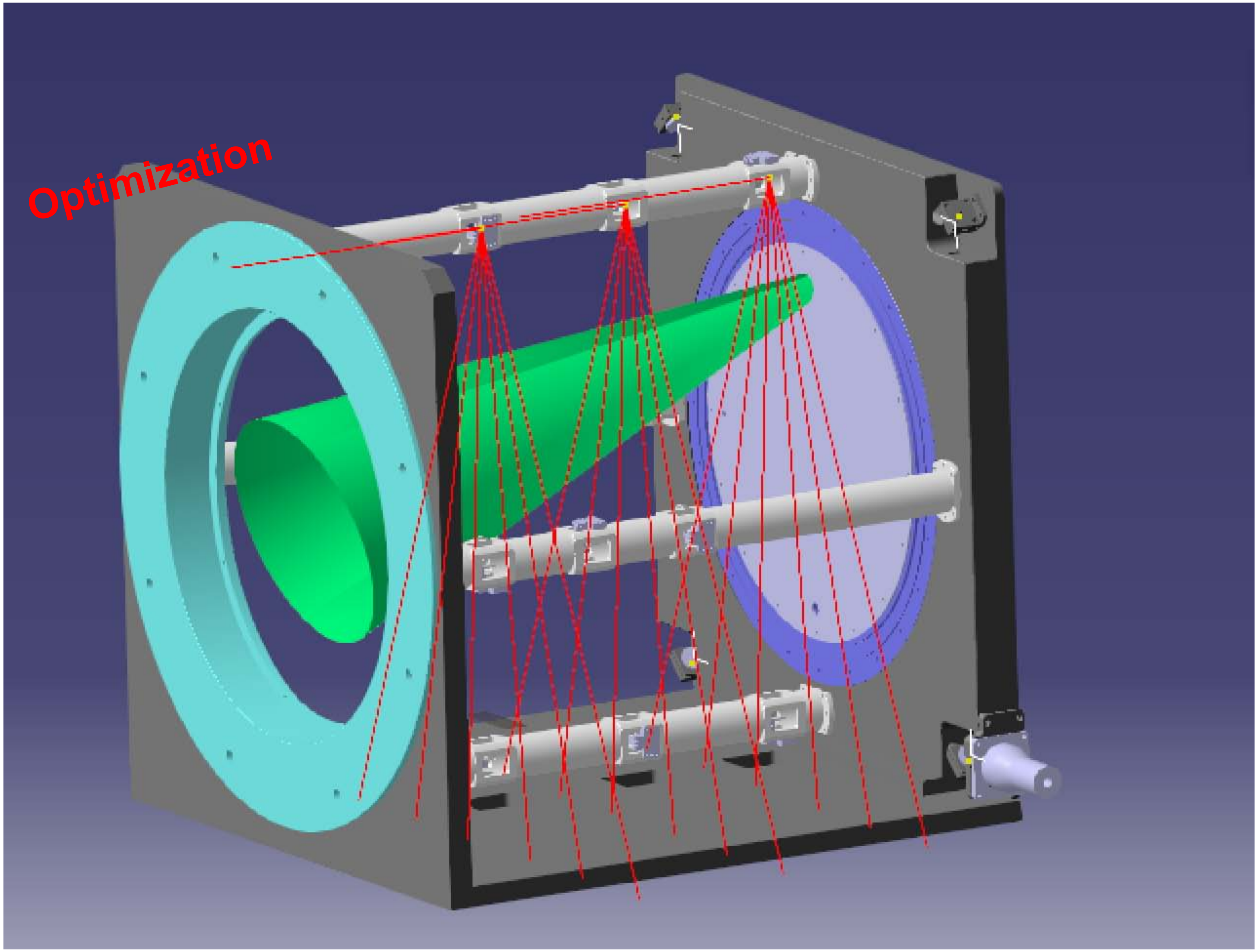
夹角公差 Reflection mirror

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

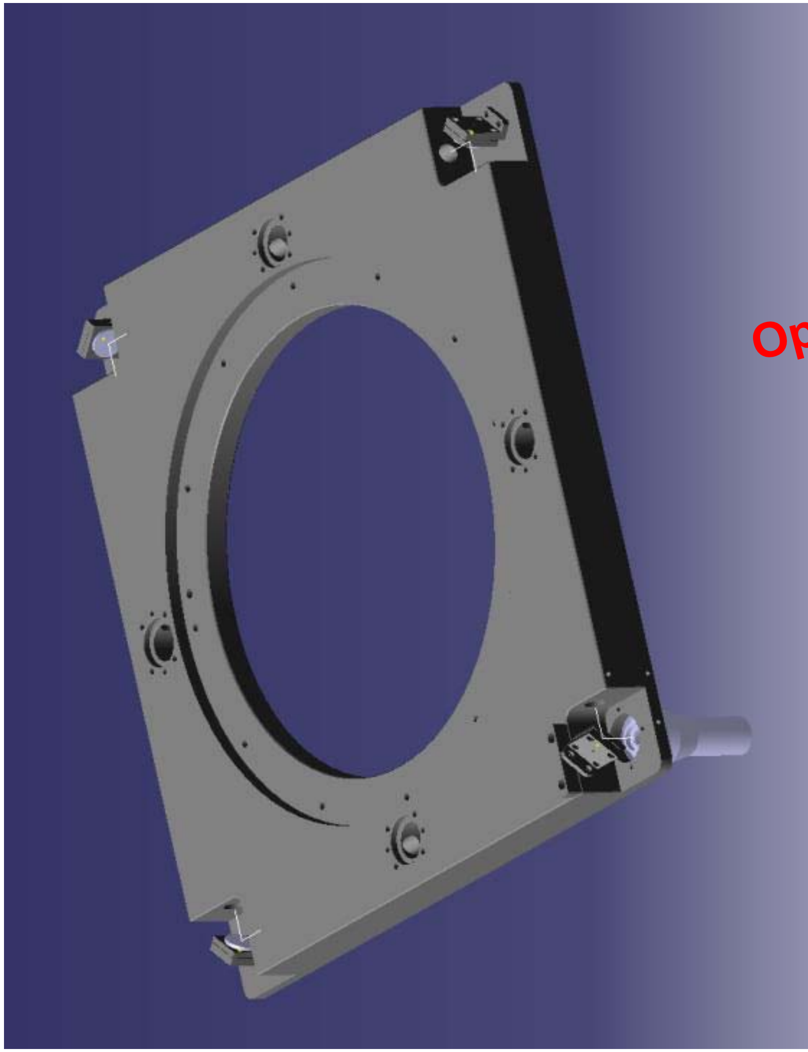
Design of the prototype with laser and UV



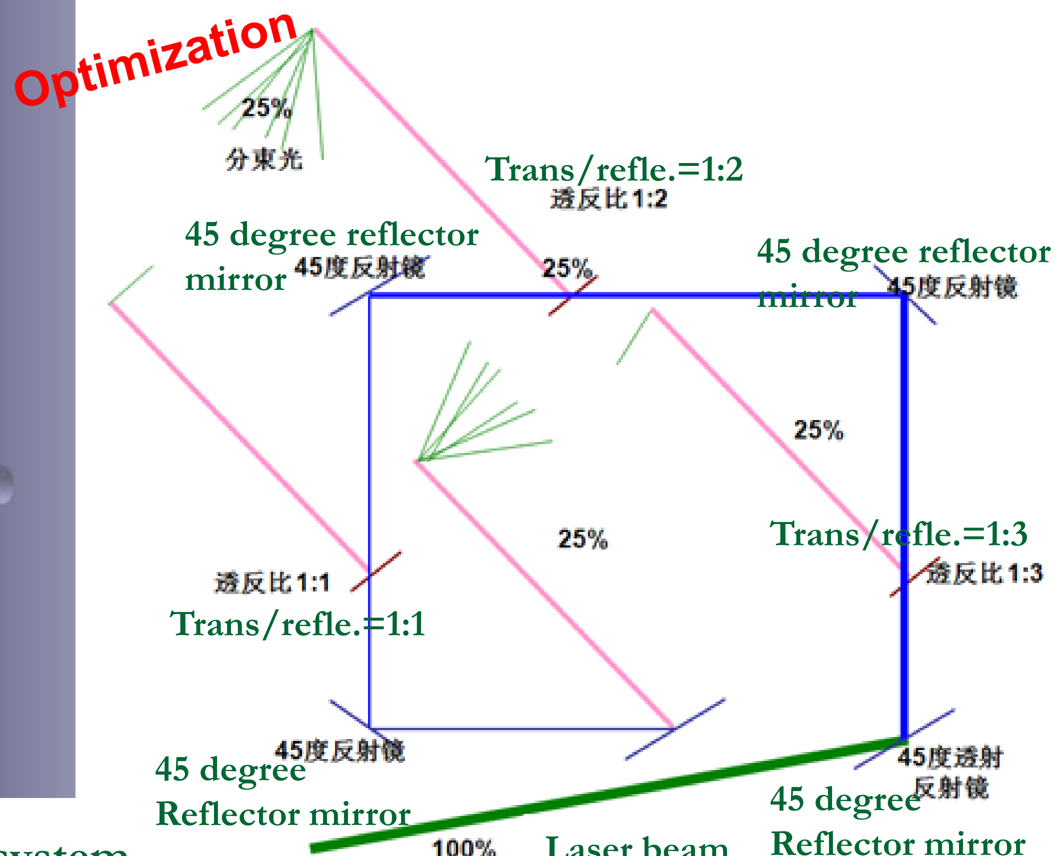
The laser and UV lamp structure without the TPC barrel

Laser map in drift length

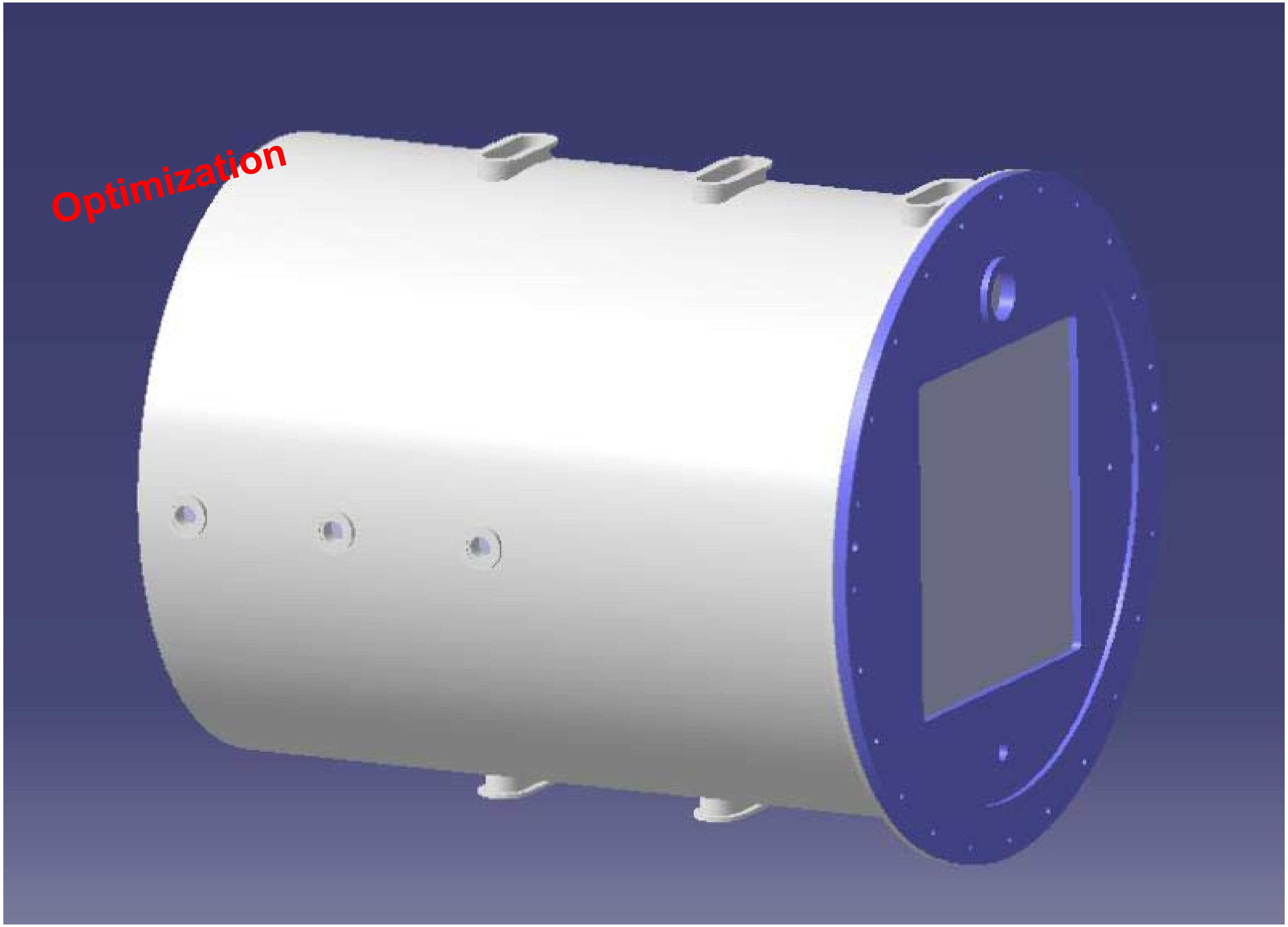
- Laser wave: 266nm
- Size: ~1mm╳1mm
- Transmission and reflection mirrors
- Aluminum board integrated the laser device and supports



Aluminum board integrated the laser system

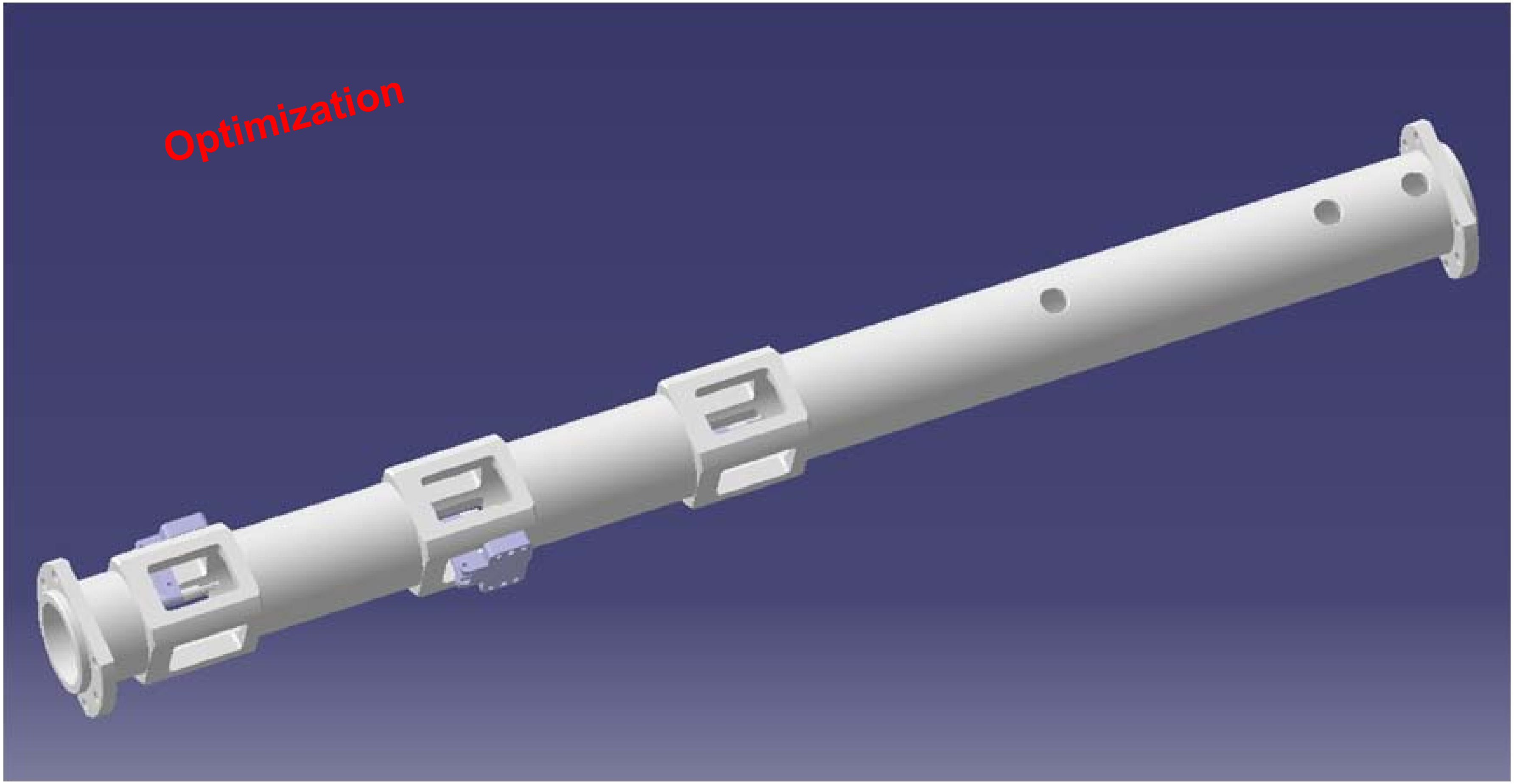


TPC barrel

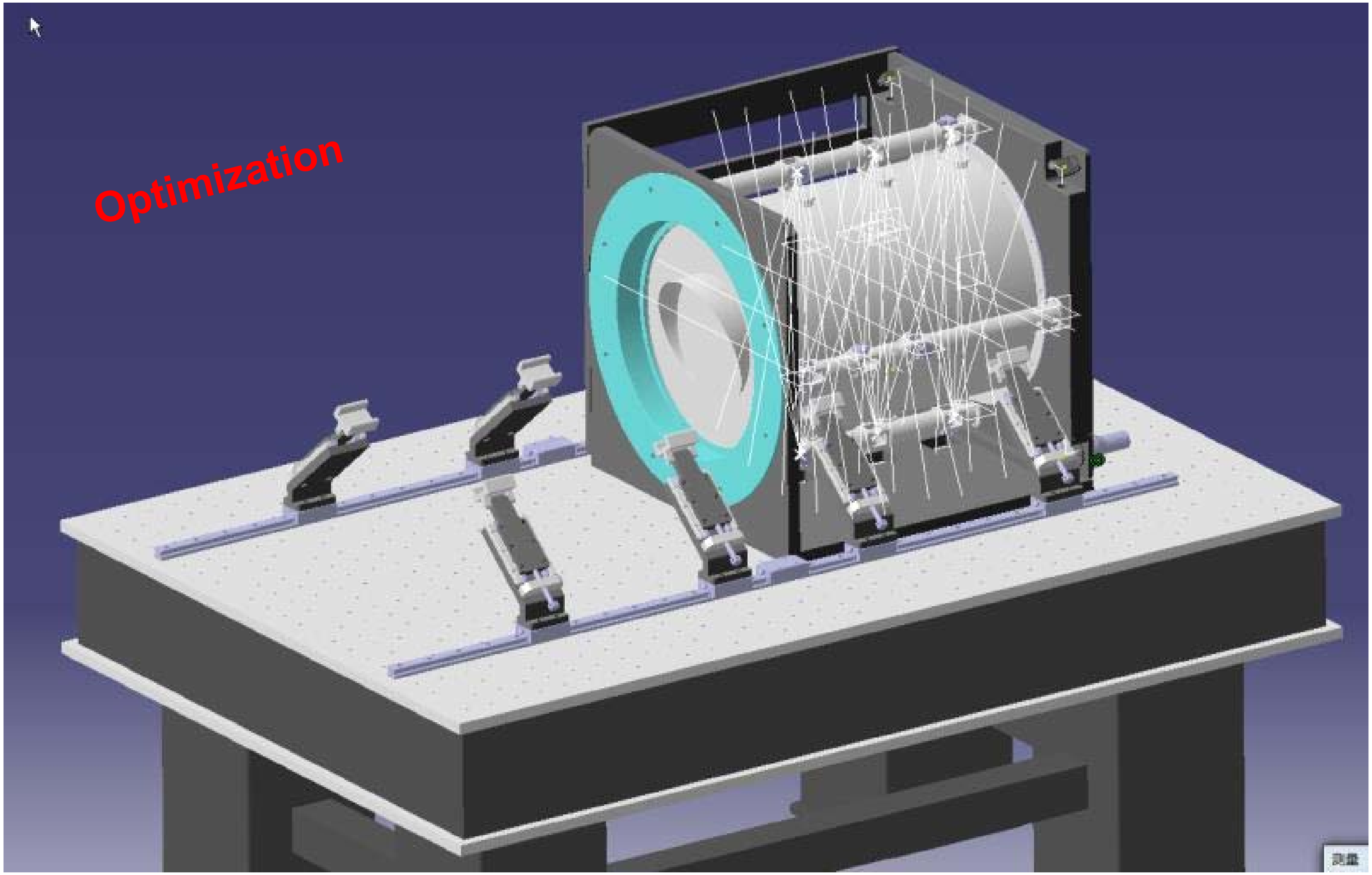


The TPC barrel with the 266nm laser windows

Rod for the mirrors



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.

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 and prototype**
  - 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 design of the prototype integrated with UV and 266nm laser has been done and assembled.
- **R&D work within some collaboration(LC-TPC/CEPC)**

Thanks for your attention!