Status and progress of TPC module and prototype R&D for CEPC

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Outline

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

Physics requirements

TPC as one option

Motivation of TPC with MPGD

Critical technology challenges

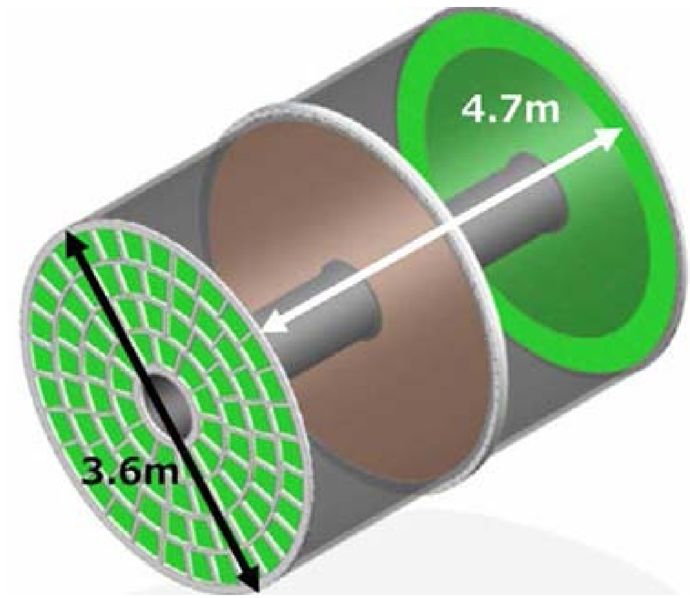
TPC requirements for collider concept

TPC could be as one tracker detector option for CEPC, 1M ZH events in 10yrs E_{cm} ≈240 GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, can also run at the Z-pole

TPC detector concept:

- Motivated by the H tagging and Z
- ~3 Tesla magnetic field
- ~100 μm position resolution in rφ
  - ~60μm for zero drift, <100μm overall
  - Systematics precision (<20μm internal
- Large number of 3D points(~220)
- Distortion by IBF issues
- dE/dx resolution: <5%
- Tracker efficiency: >97% for pT>1GeV
- 2-hit resolution in rφ : ~2mm
- Momentum resolution: ~10^{-4}/GeV/c
- TPC material budget
  - 0.05 X_0 including outer fieldcage in r
  - 0.25 X_0 for readout endcaps in z

from MoA document of LCTPC@2018



Overview of TPC detector concept

Motivation of TPC with MPGDs as readout

- Higher accuracy < 100mm(Overall along the drift)
- **Better two track resolution**
- Full 3-D track reconstruction
- Precise dE/dX
- **High magnetic field** (>3T)
- **Highly reduced $E \times B$ effect**
- Large detectors by industrial process
- **Easy assembled using the modules**
- **Minimal material budget**
- Much higher Ion feed back suppression
- Drift time gives the longitudinal coordinate

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;

Answer three key issue questions in CEPC CDR

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

Simulation → TPC as one option for CPEC 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

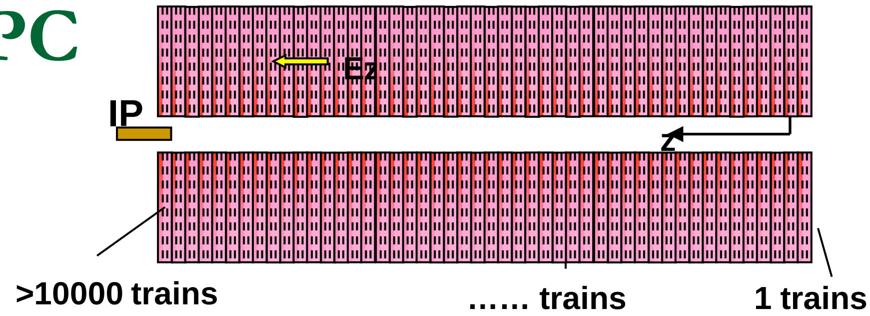
Simulation + R&D → To control IONS? To reduce distortion

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

Simulation + R&D → ~100um positron resolution with calibration?

Point resolution in rφ (~100 μm) and dE/dx (~4.2%) from LC-TPC collaboration in 2018

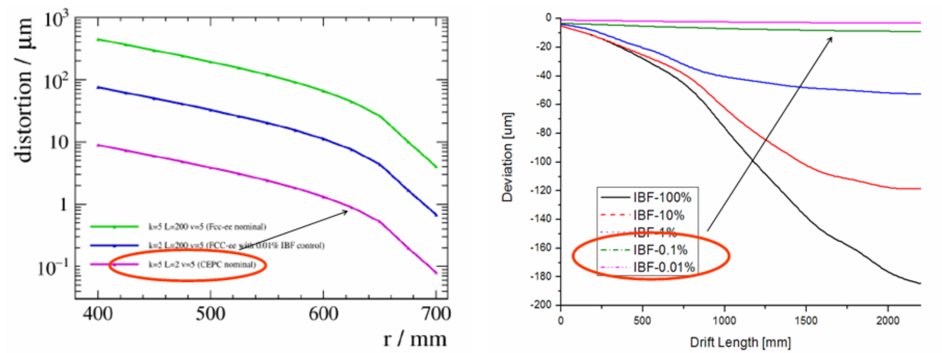
Technical challenges for TPC



Amplification ions @CEPC

Ion Back Flow and Distortion :

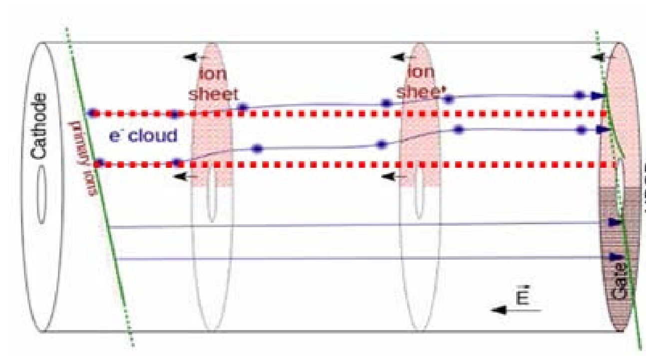
- ~100 μm position resolution in rφ
- Distortions by the primary ions at CEPC are negligible
- More than 10000 discs co-exist and distorted the path of the seed electrons
- The ions have to be cleared during the ~us period continuously
- Continuous device for the ions
- Long working time



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

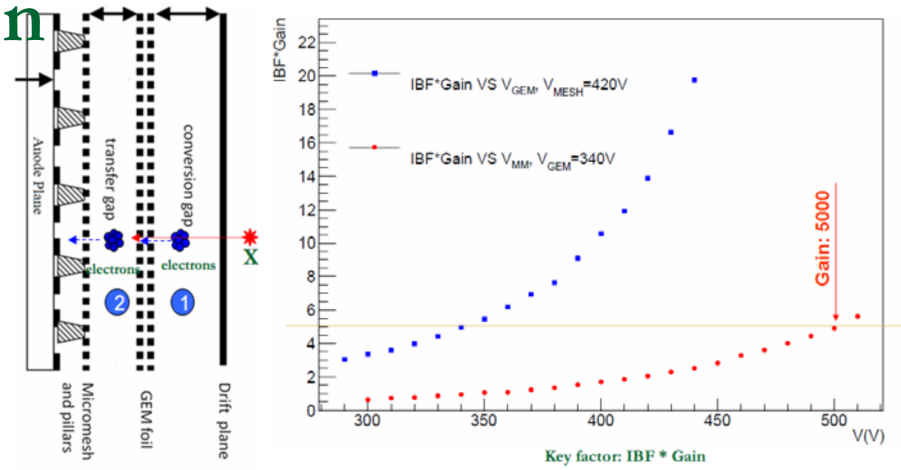


Ions backflow in drift volume for distortion

Options of technical solution

Continuous IBF module:

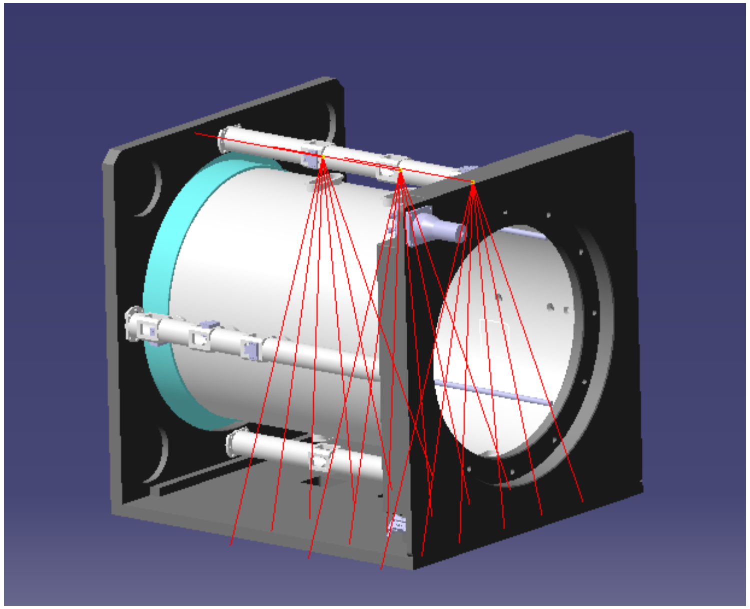
- Gating device may be used for Higgs run
- Open and close time of gating device for ions: ~ µs-ms
- No Gating device option for Z-pole run
- Continuous Ion Back Flow due to the continuous beam structure
- Low discharge and spark possibility



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



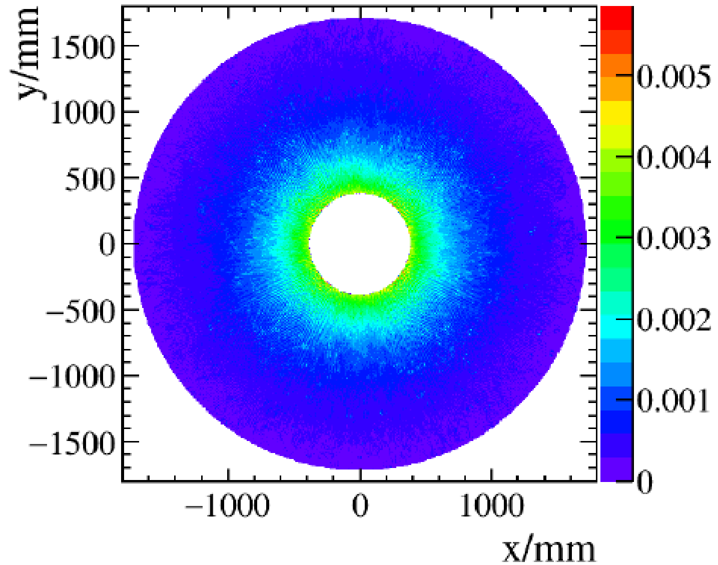
TPC prototype integrated with laser system

High rate at Z pole

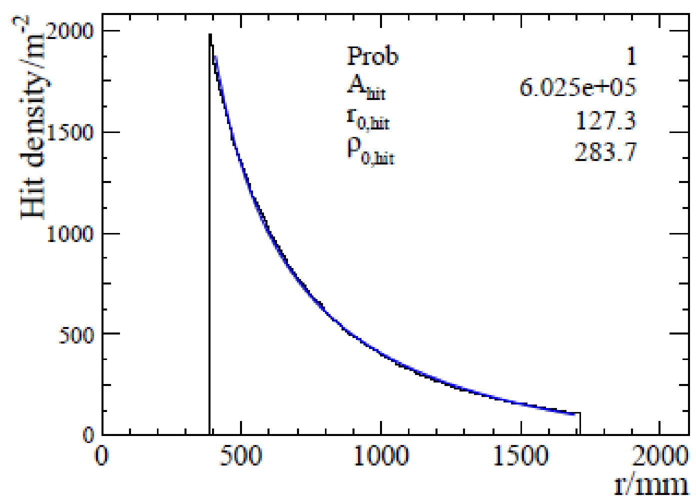
ArXiv: 1704.04401
Mingrui, Manqi, Huirong

- 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: $\sim2\times10^{-7}$
  - 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

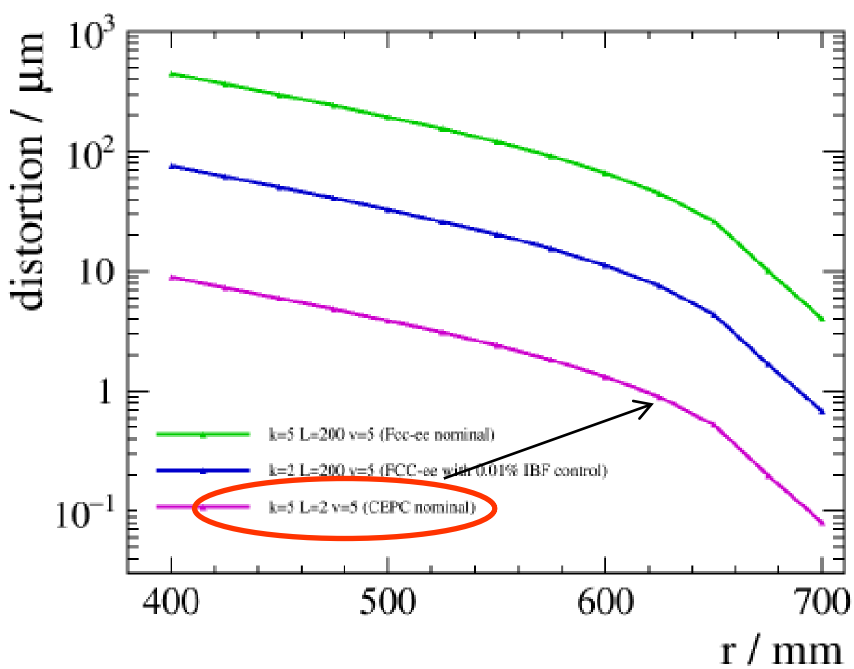
- Electron:
  - Drift velocity ~6-8cm/us@200V/cm
  - Mobility μ ~30-40000 $cm^2/(V.s)$
- Ion:
  - Mobility μ ~2 $cm^2/(V.s)$

  in a "classical mixture" (Ar/Iso)

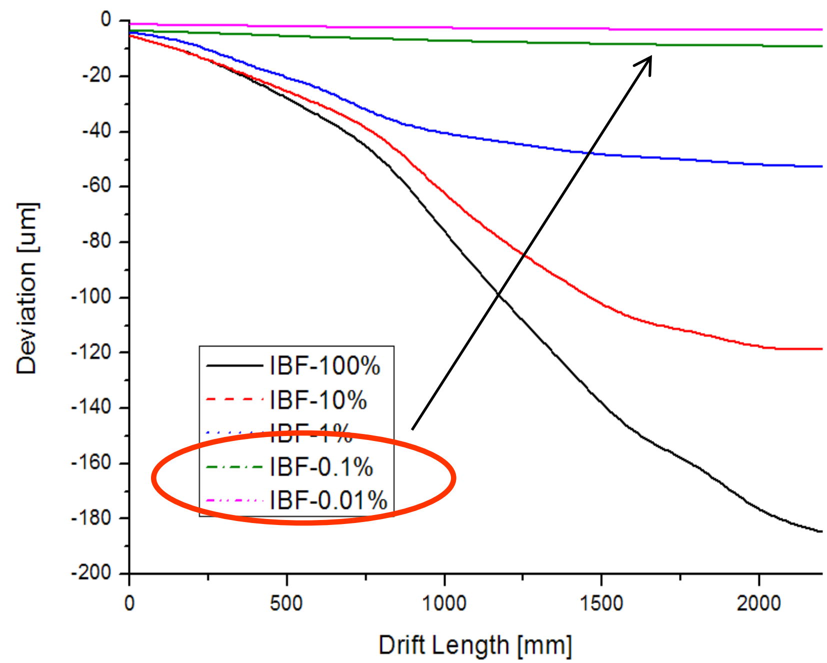
$$S_N = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 S_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 S_{x_2}^2 + \left(\frac{\partial f}{\partial x_3}\right)^2 S_{x_3}^2}$$

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

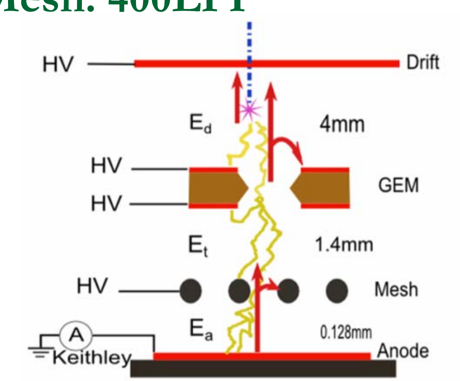
Investigation of IBF study with module

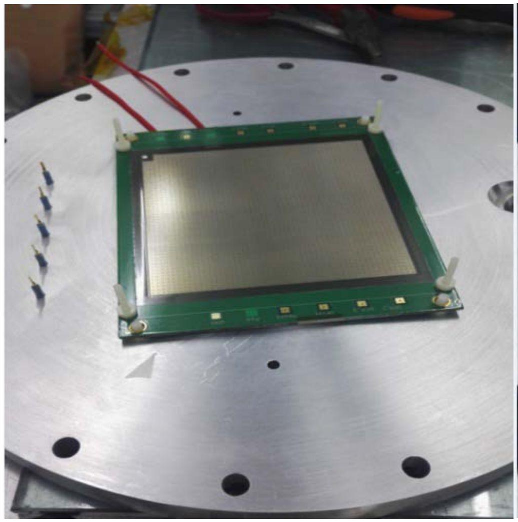
Combination detector

IBF control

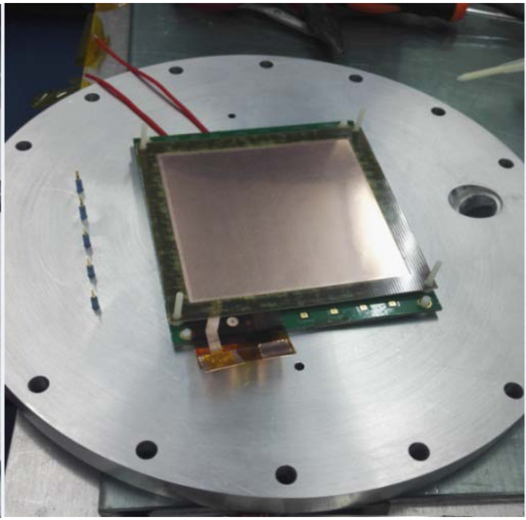
Test of the new module

- 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

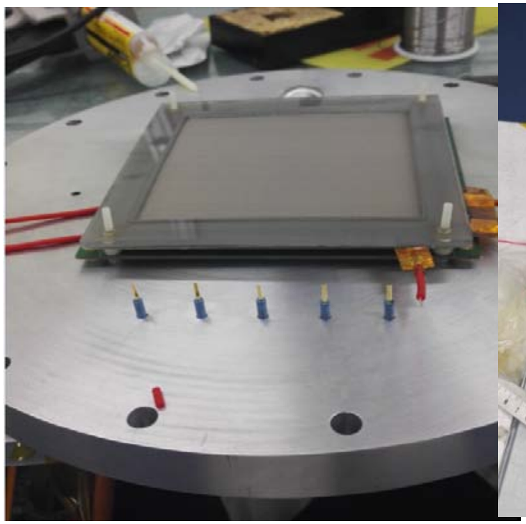




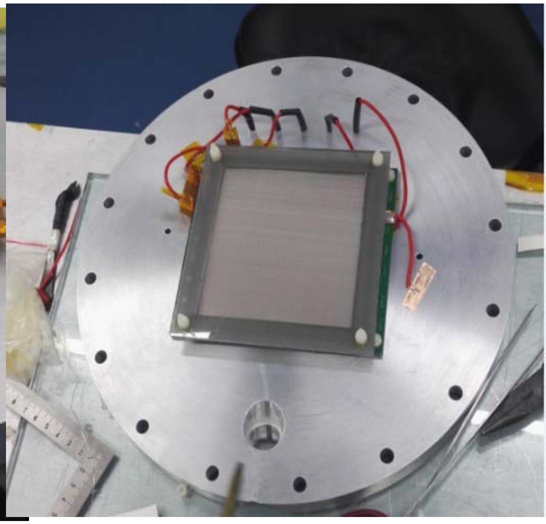
Micromegas(Saclay)



GEM(CERN)



Cathode with mesh



GEM-MM Detector

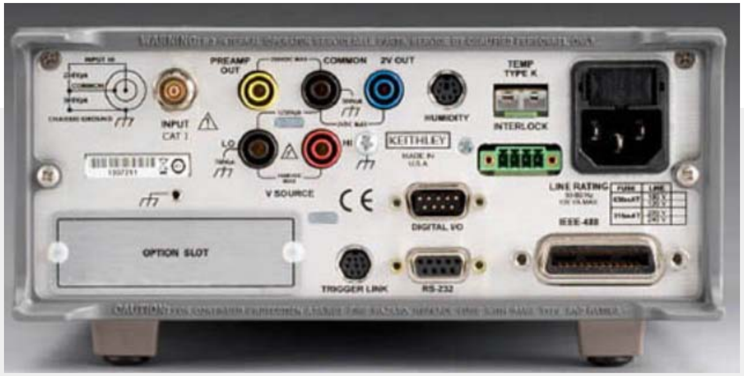
Electrometer/High Resistance Meter

Keithley 6517B

Electrometer/High Resistance Meter, 100aA - 20mA, 10µV - 200V, 100Ω - 10PΩ

Brand:	Keithley
Model No:	6517B

KEITHLEY
A Tektronix Company

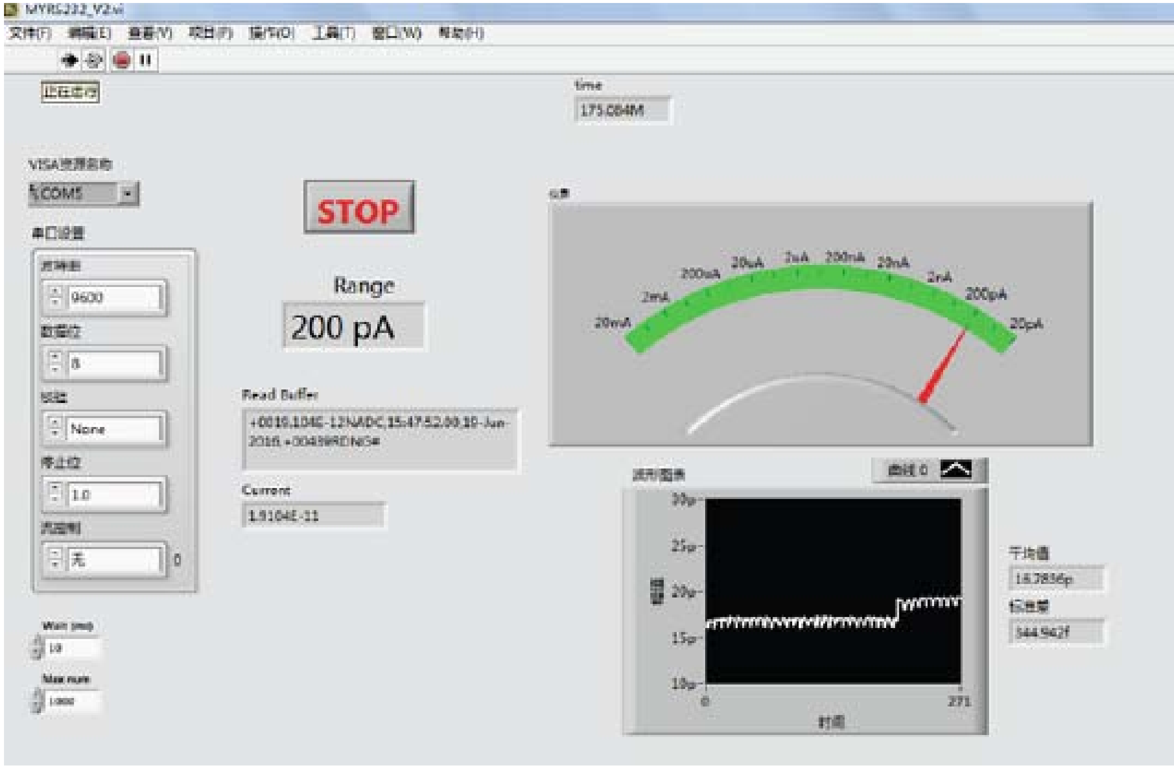


Product Features:

- Measures resistances up to 1018O
- 10aA (10×10-18A) current measurement resolution
- Less than 3fA input bias current
- 6 1/2-digit high accuracy measurement mode
- Less than 20µV burden voltage on the lowest current ranges
- Voltage measurements up to 200V with >200TO input impedance
- Built-in +/-1000V voltage source
- Unique alternating polarity voltage sourcing and measurement method for high resistance measurements
- Built-in test sequences for four different device characterization tests, surface and volume resistivity, surface insulation resistance, and voltage sweeping
- Optional plug-in scanner cards for testing up to 10 devices or material samples with one test setup

Measuremnt of GEM-MM module

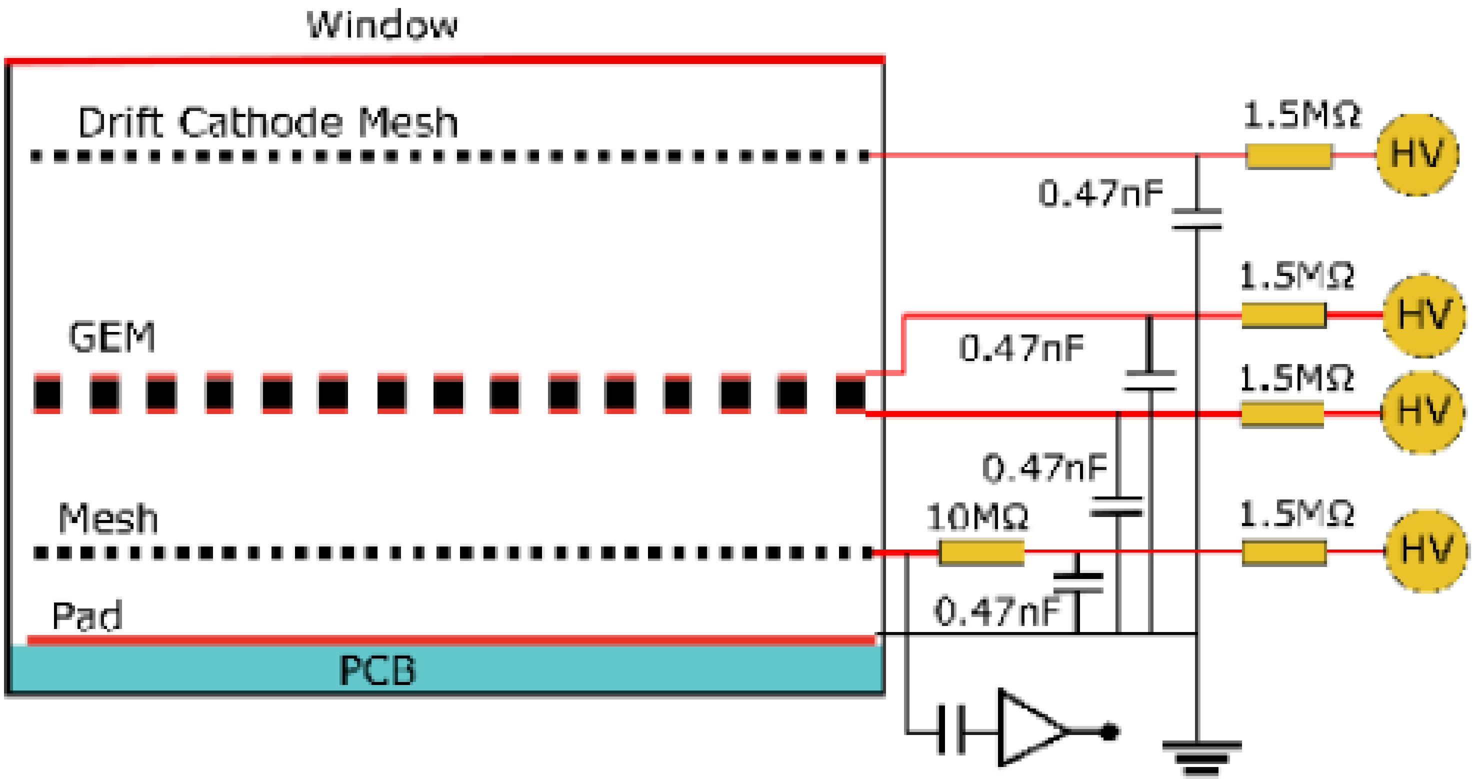
- Test with GEM-MM module
  - Keithley Electrometers for Ultra-Low Current Measurements: pA~mA
  - Keithley: 6517B
  - Test of cathode of the module
  - Test of readout anode of the module
  - Labview interface of the low current to make the record file automatically



Labview interface of the current with Keithley

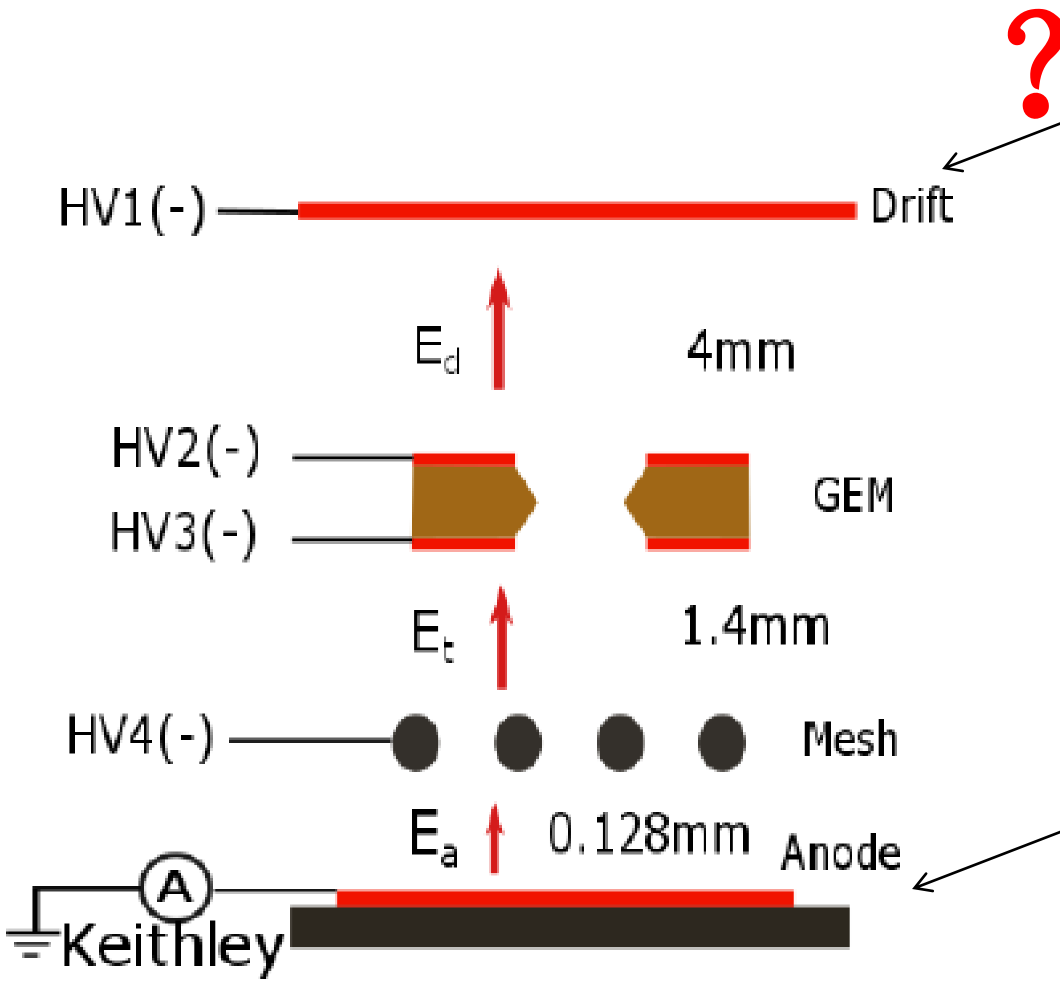
$$IBF = \frac{I_C - I_P}{I_A}$$

GEM-MM module



High voltage diagram of the detector module

pA current – How to measure?



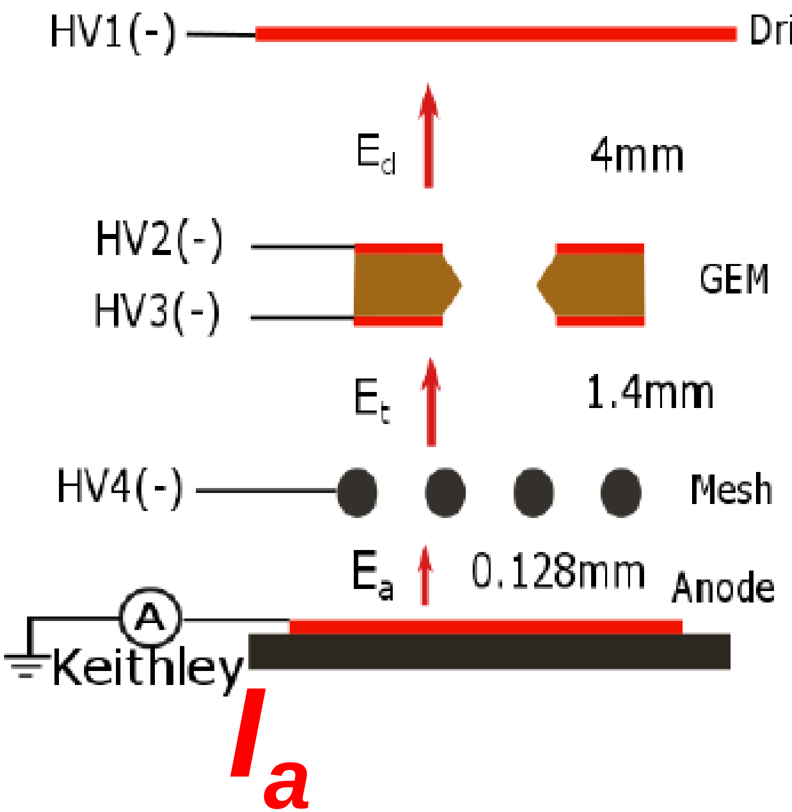
To -2600V high voltage

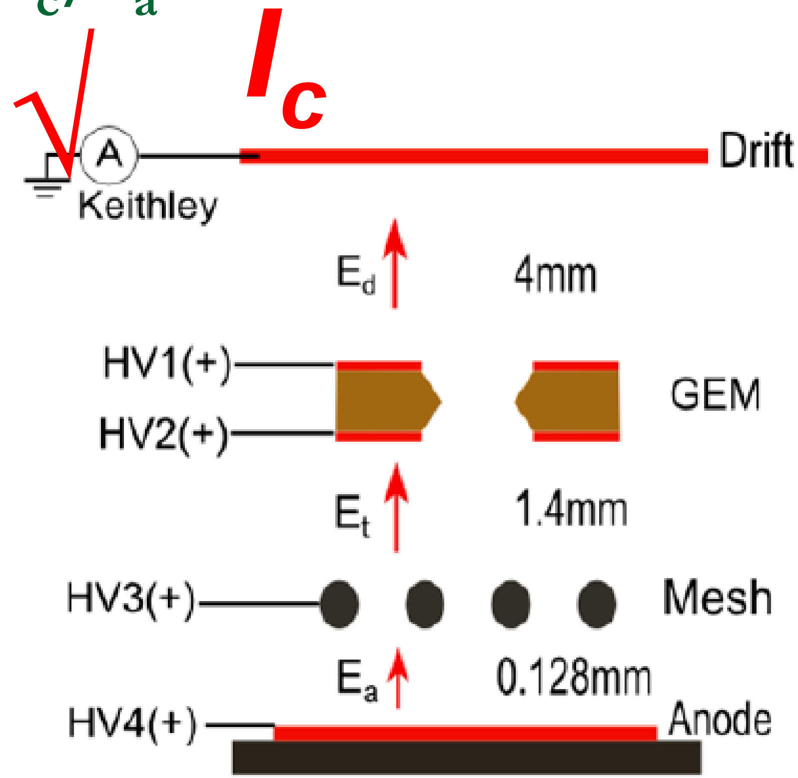
Can not connect with Keithley meter

To ground with Keithley meter

Rang: ~nA

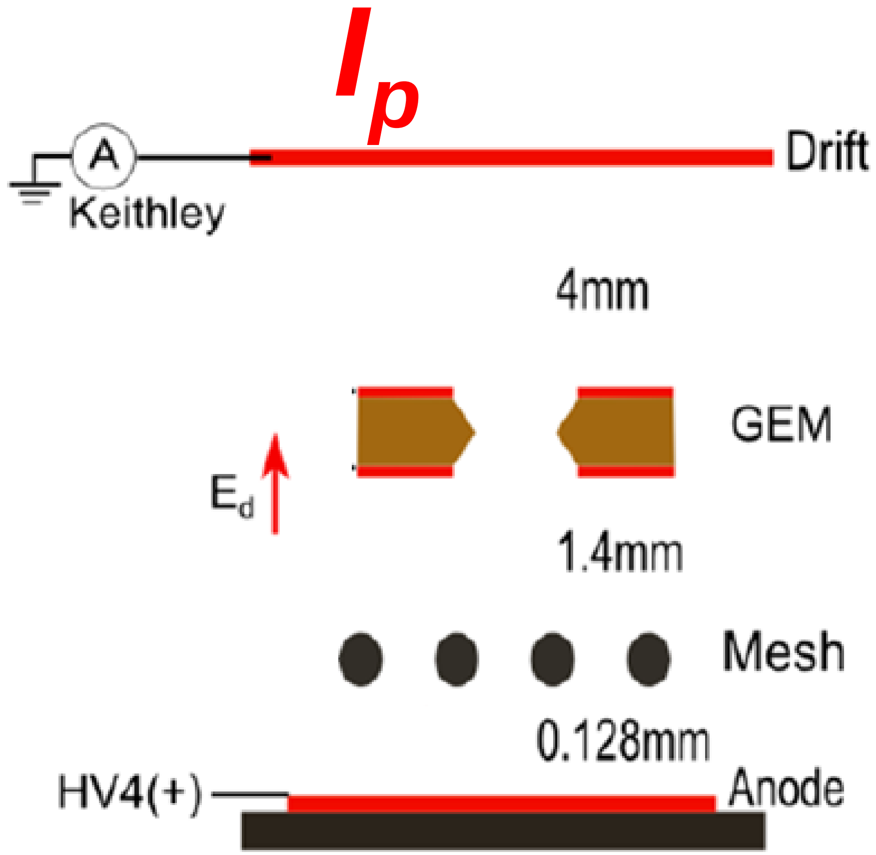
pA current measurement – I_c/I_a





- Different polarity
- Same electric filed
  - Ed=Ed; Et=Et; Ea=Ea

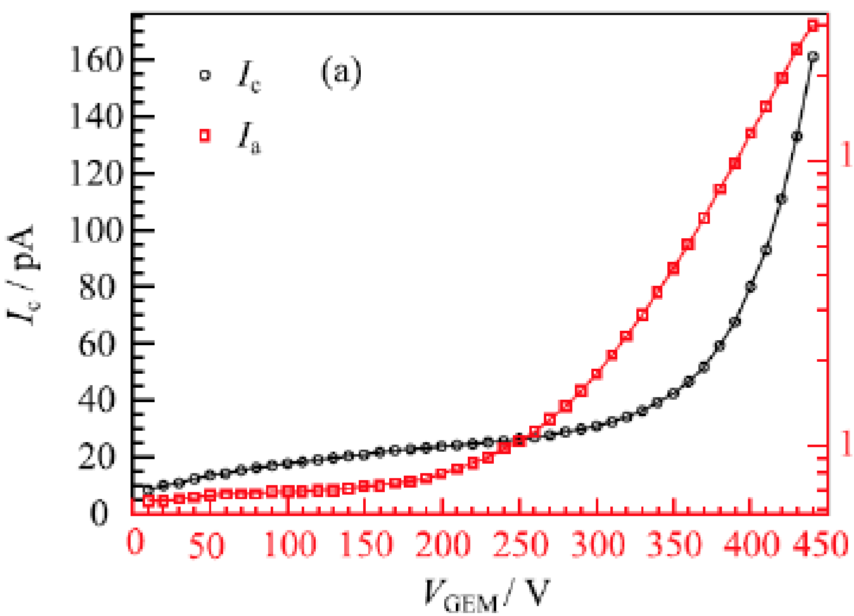
Primary electrons current - I_p

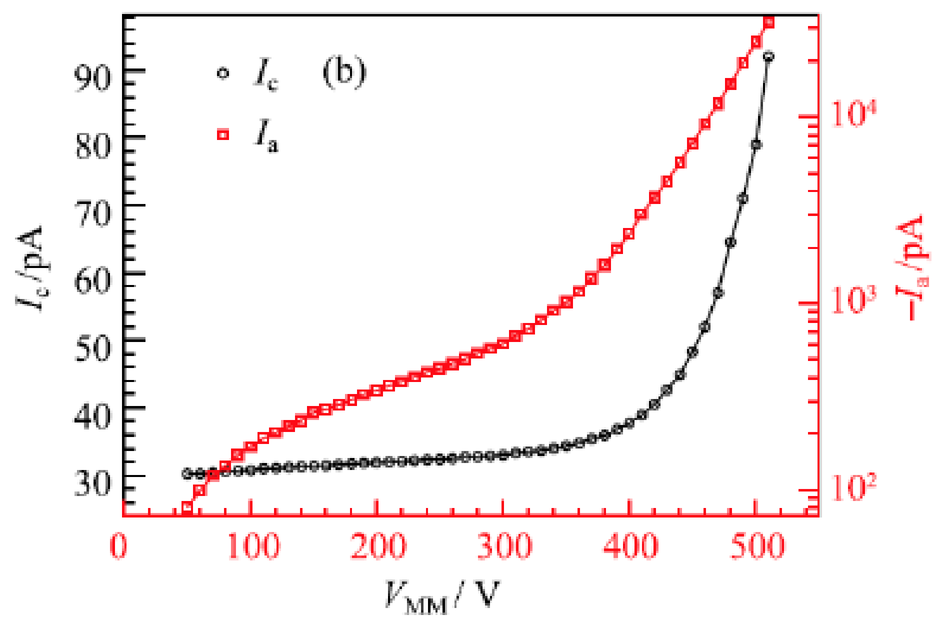


- No operation voltage of the GEM-MM detector
- Just test current of the primary electrons (~pA)

Ic and Ia

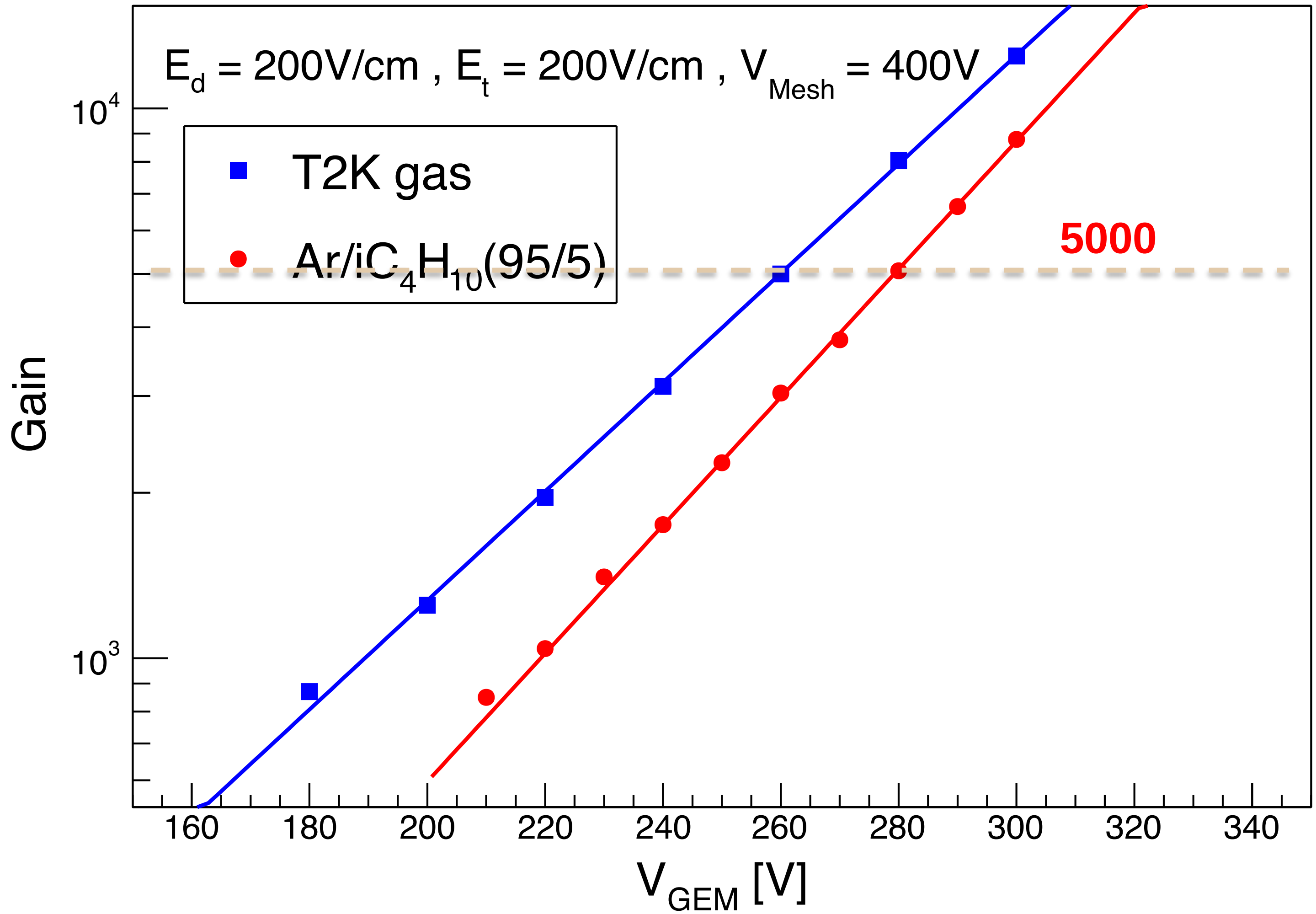
- V_MM set to 400V
- V_GEM set to from 150V to 350V
- Gain of the hybrid structure detector (GEM-MM) set to 4000-6000





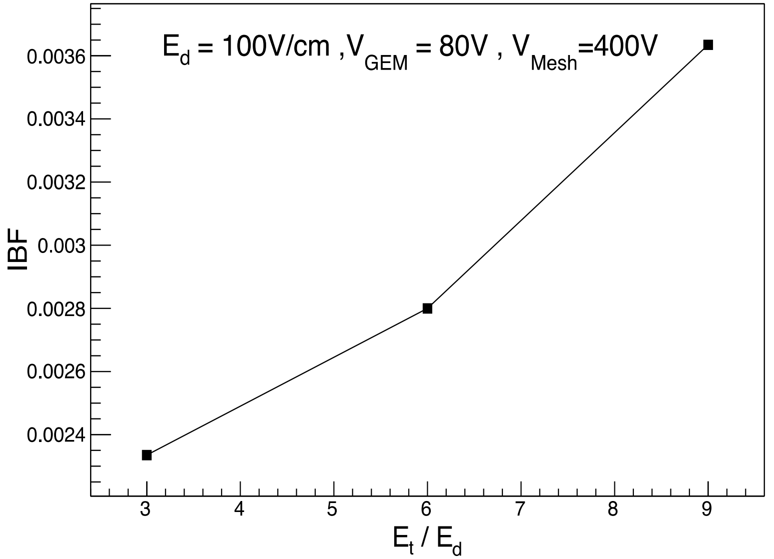
- GEM with operation voltage
- MM with operation voltage

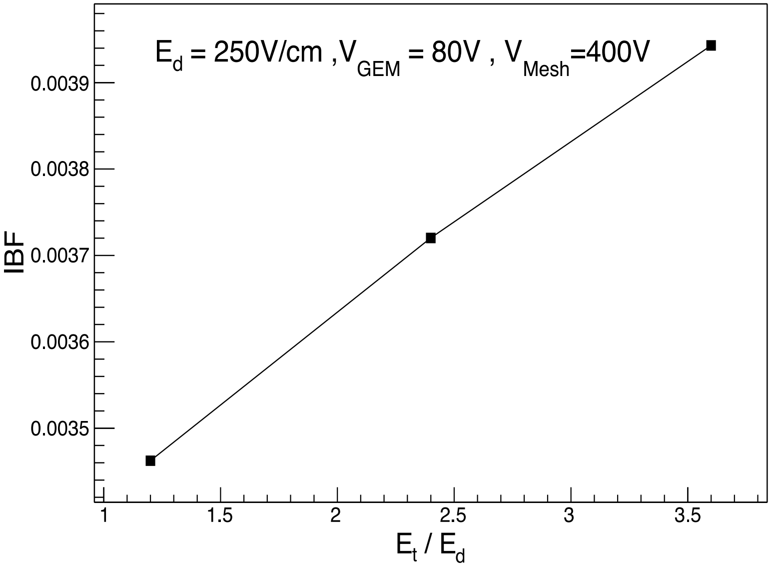
Gain of the hybrid structure detector

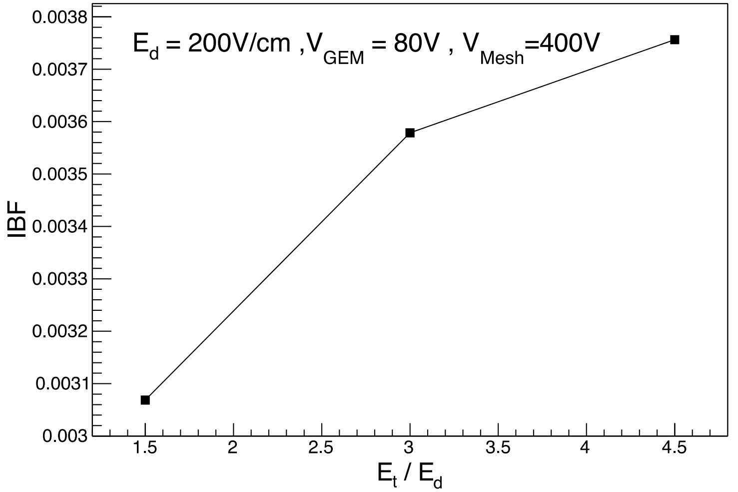


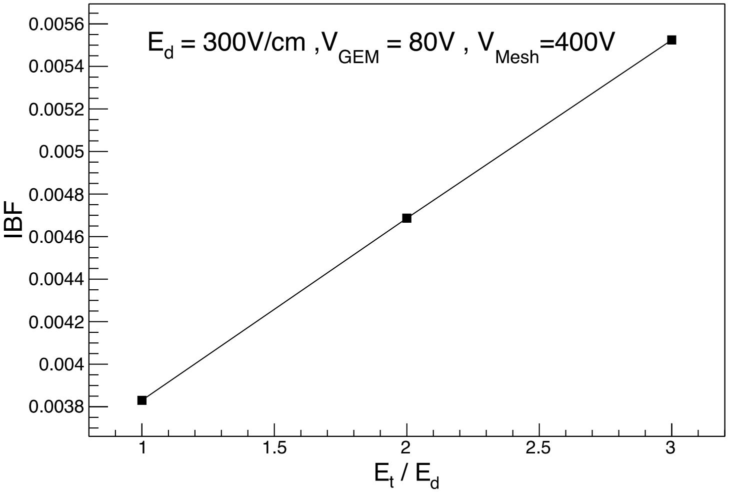
Optimization of Et/Ed

- Et/Ed set to 1-1.5 to control the IBF
- Ed=200V/cm for T2K at the saturation velocity

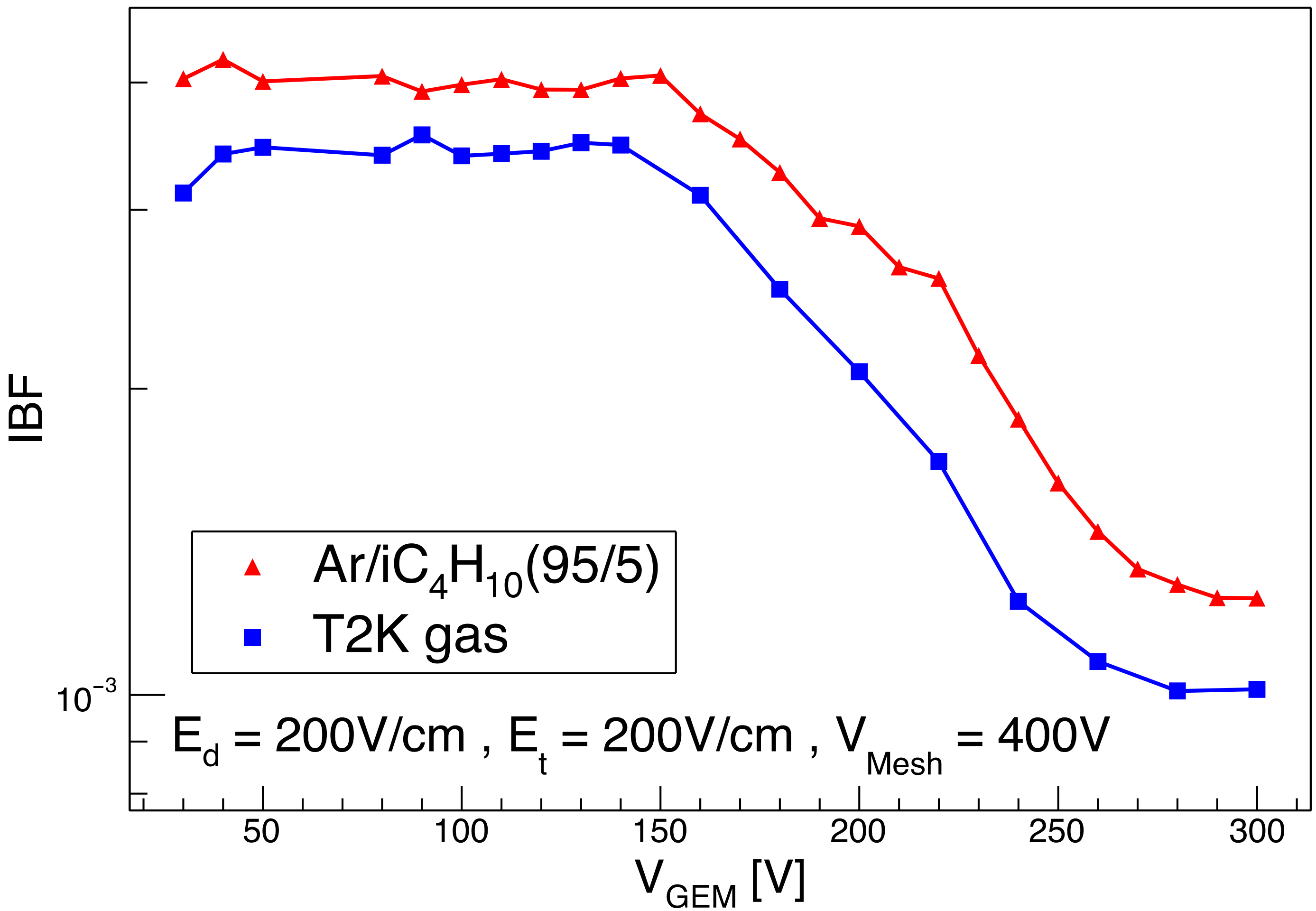






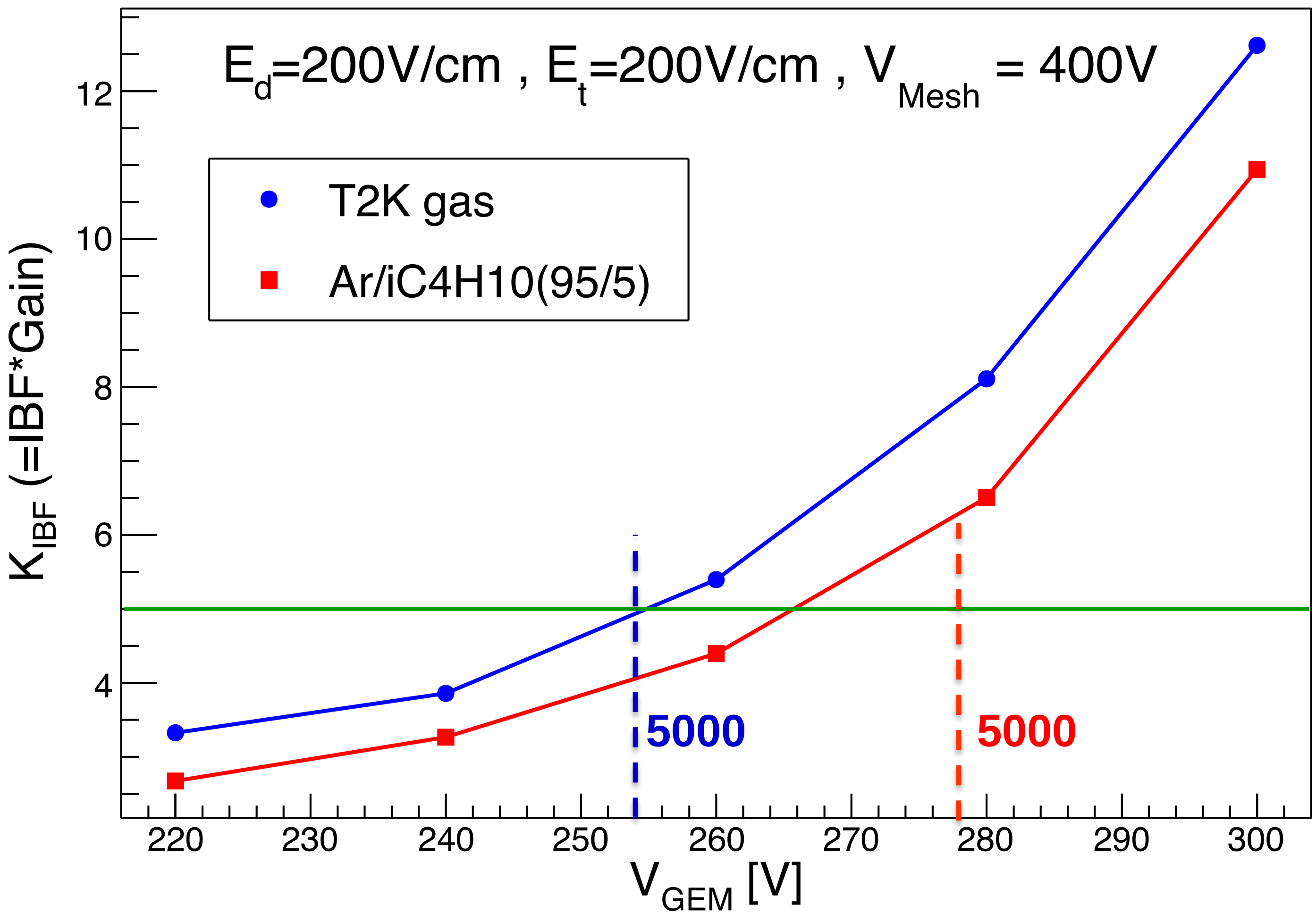


Optimization with V_{GEM}



- T2K gas@VGEM=260V/Vmesh=400V@Et/Ed=1
- IBF reaches 1.07‰

Key IBF factor: IBF × Gain



Status of TPC prototype R&D

Drift velocity @Gas/P/T/Operation

Uniformity

Online calibration

Distortion

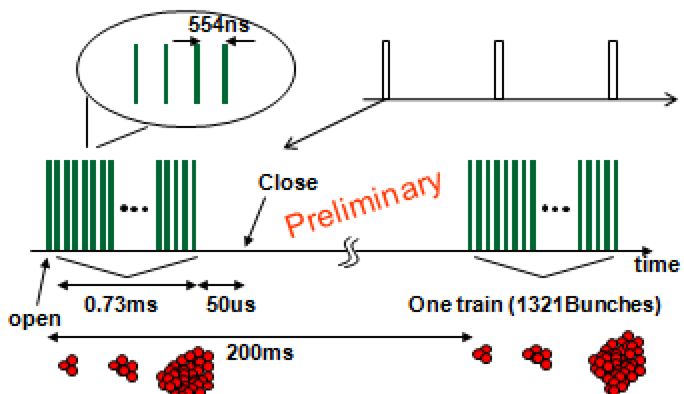
Parameters of the TPC prototype

- 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

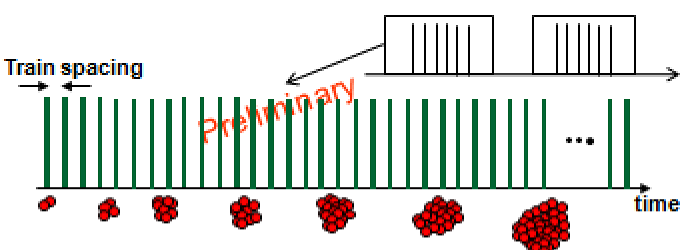
- Main parameters
  - Drift length: 510mm
  - Readout active area: 200mm×200mm
  - Integrated the laser and UV lamp device
  - Wavelength of laser: 266nm
  - GEMs/Micromegas as the readout
  - Materials: Non-magnetic material (Stainless steel, Aluminum)

Distortion by UV+Laser

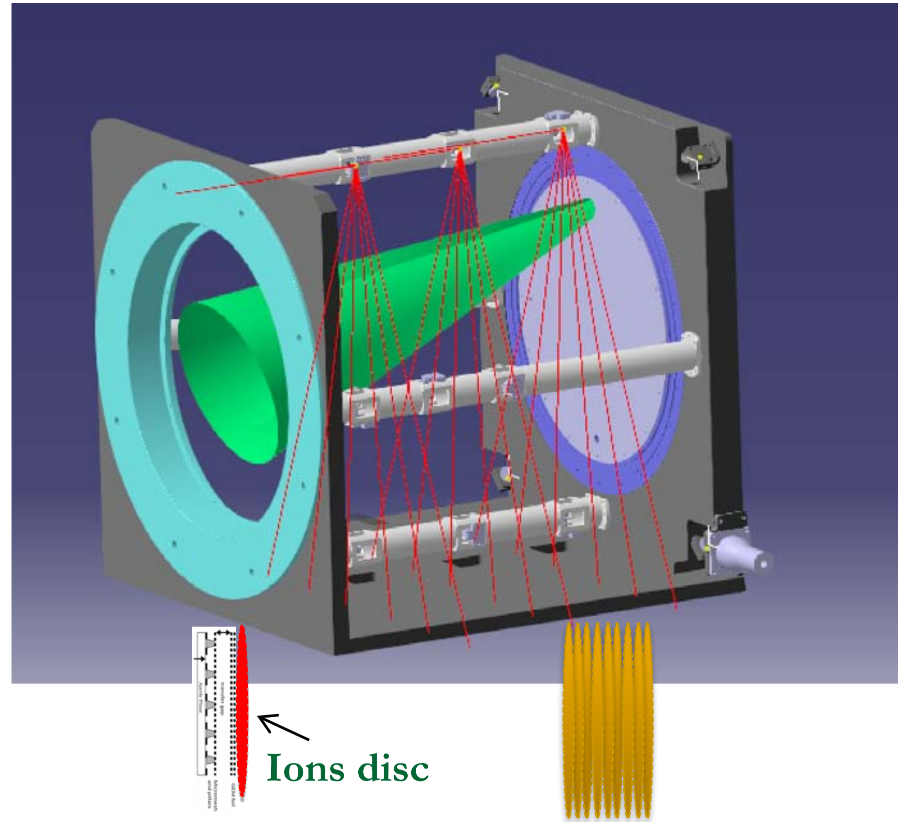
- To mimic the bunch structure & the ions distortion with UV light and laser split beam
- In the case of ILD-TPC
  - Bunch-train structure of the ILC
  - Power pulsing mode
- In the case of CEPC-TPC
  - Bunch-train structure of the CEPC

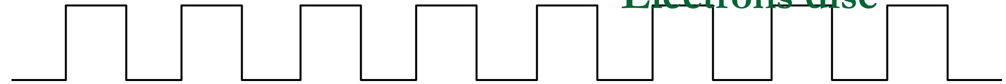


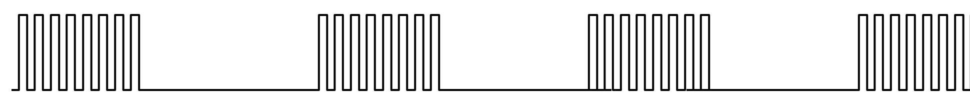
Beam structure of ILC



Beam structure of CEPC





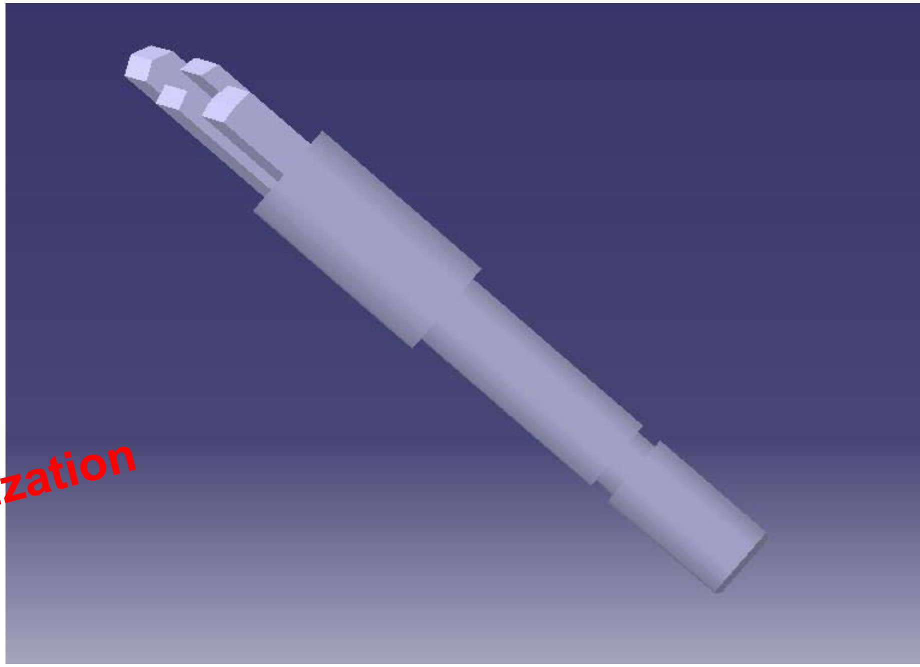


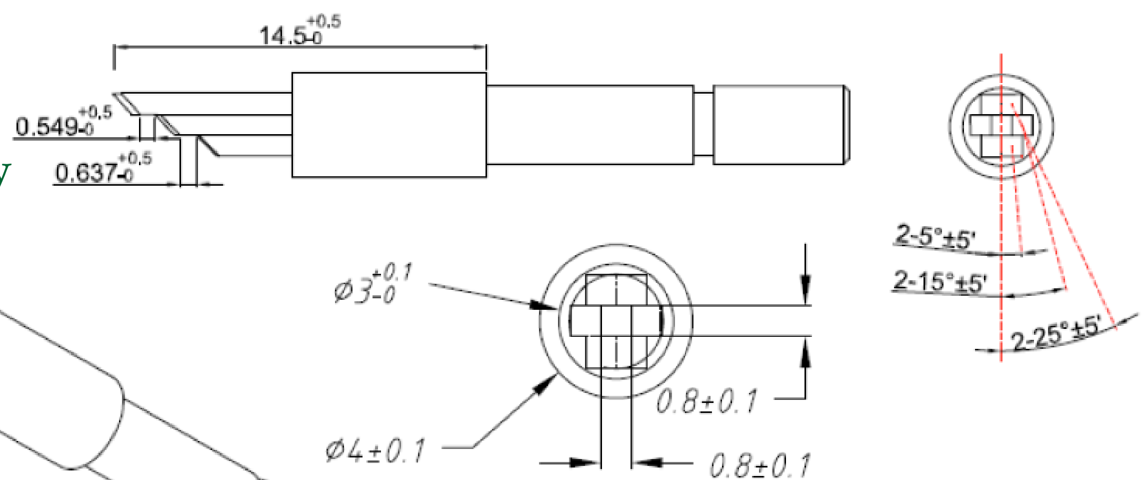
Shutter time similar to ILC and CEPC beam structure

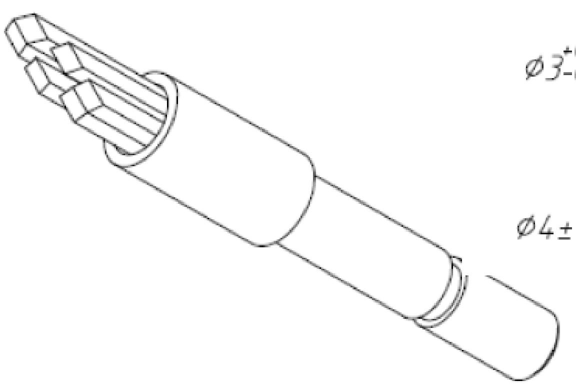
Divide and reflection mirrors

- 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

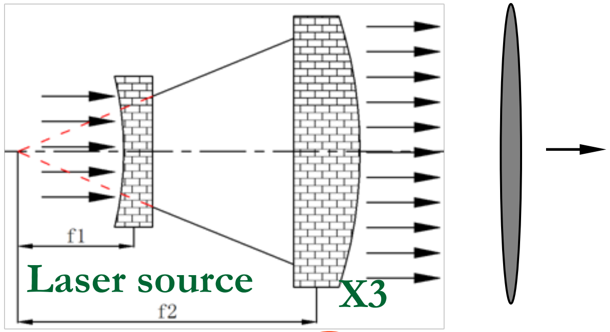




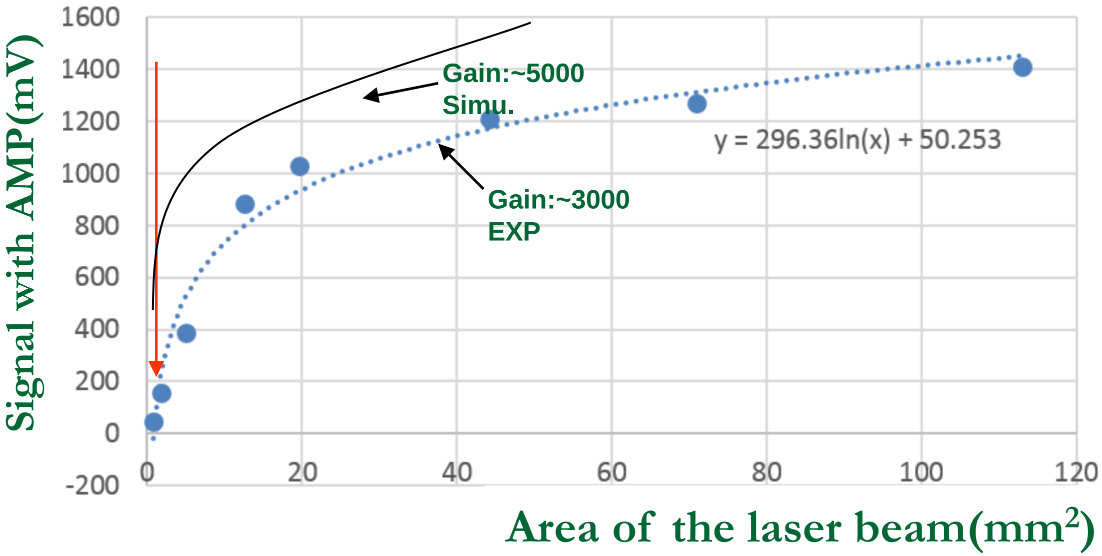


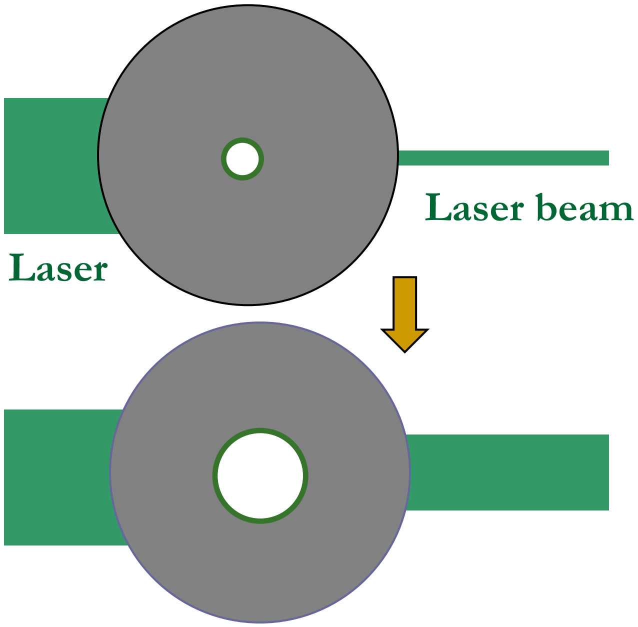
Collimator@Φ1~ Φ 12mm

- 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

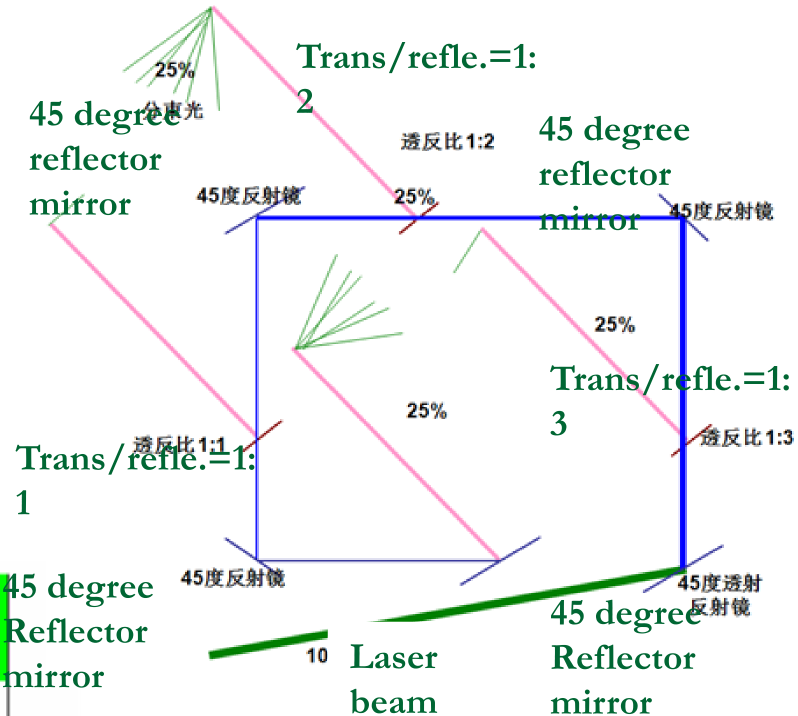


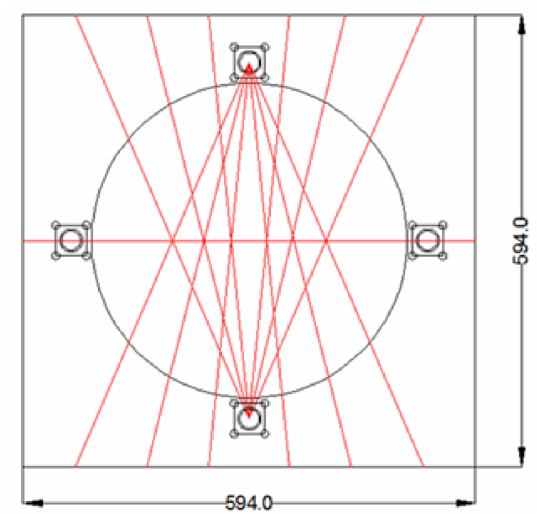


Area of laser beam in detector

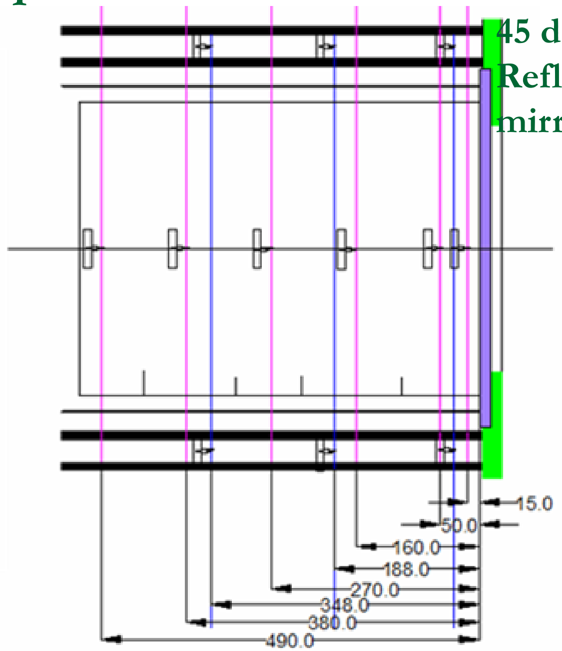
Laser map in drift length

- Size: ~0.85mm╳0.85mm
- Transmission and reflection mirrors
- Aluminum board integrated the laser device and supports
- Drift velocity in Z
- Uniformity in X-Y plane

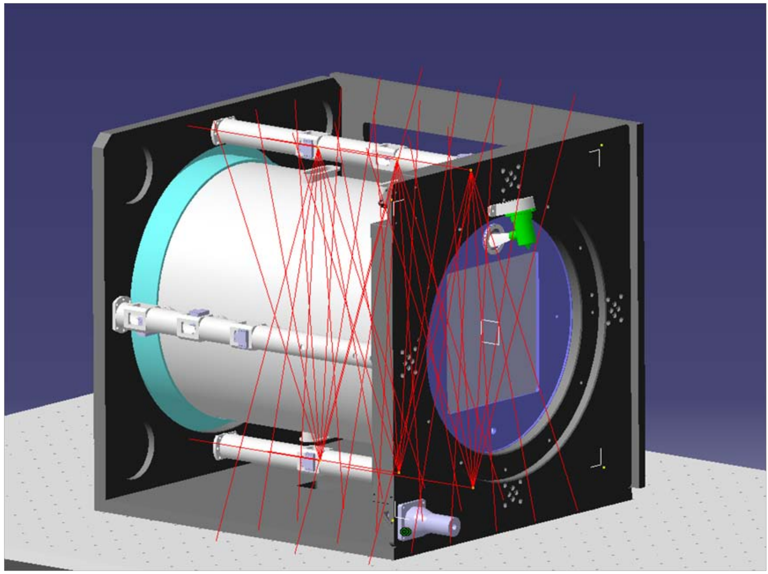




Laser map in X-Y plane

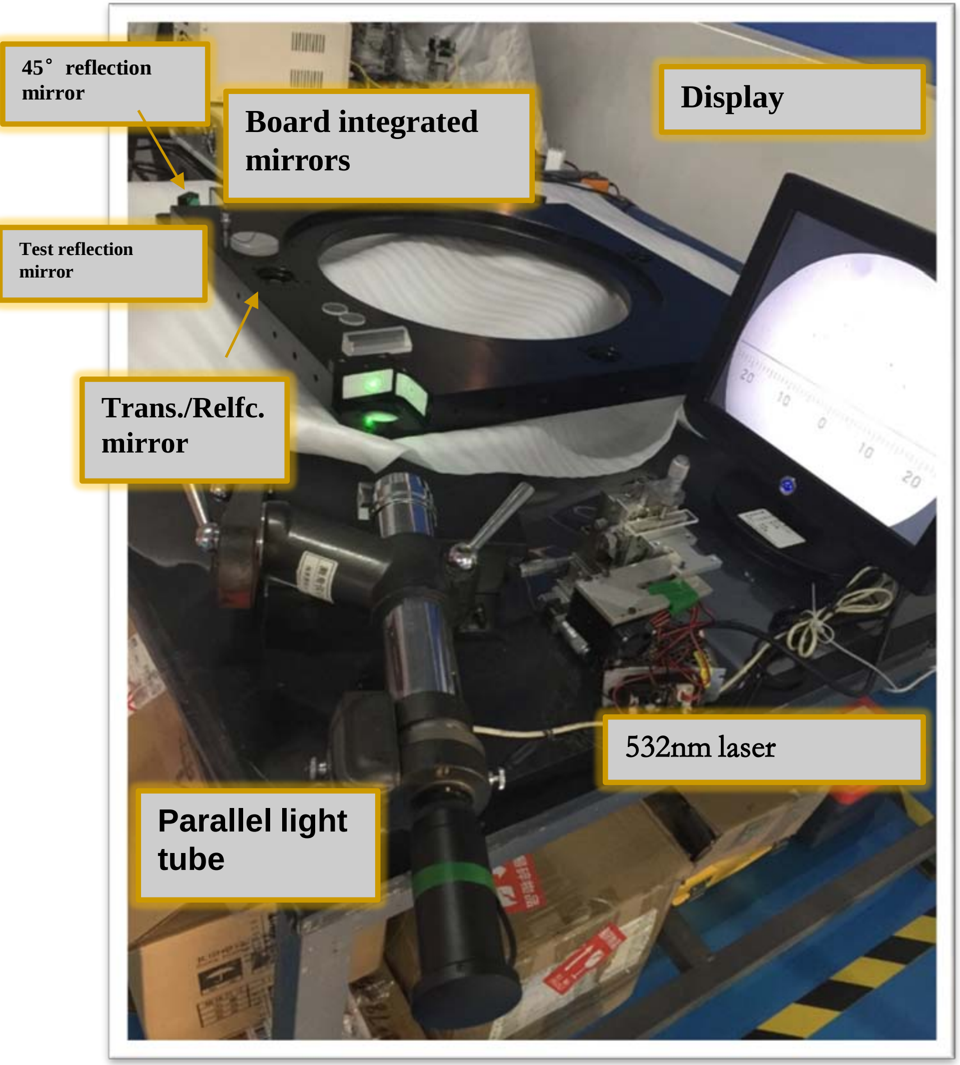


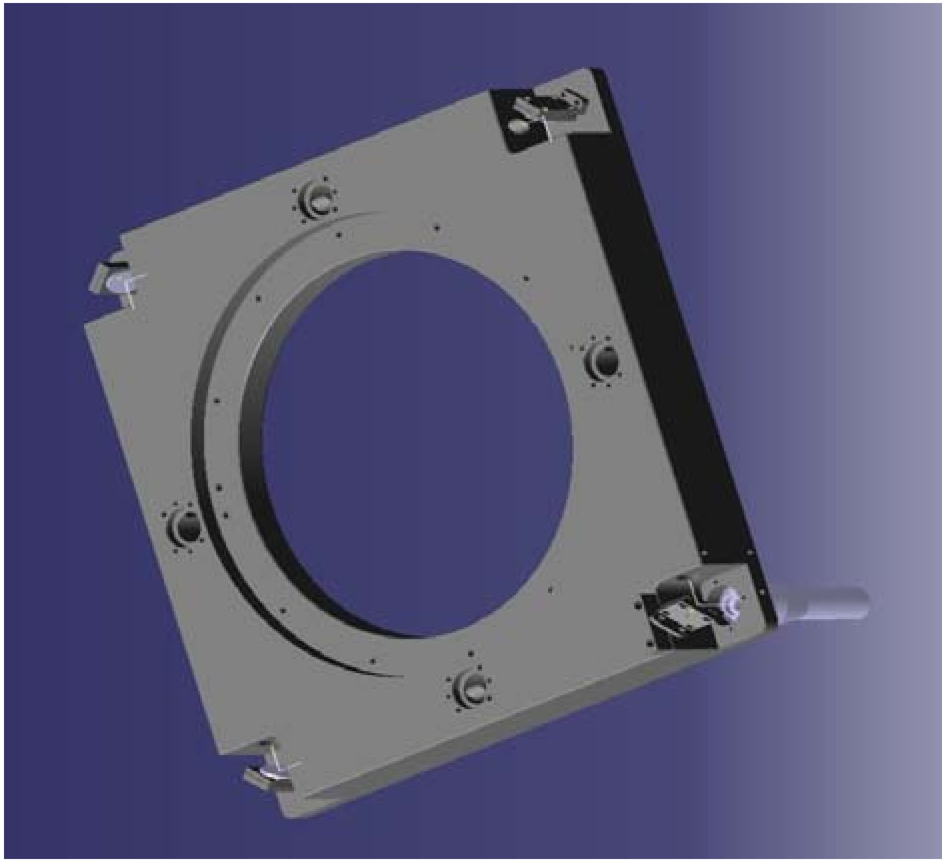
Laser map along Z



Detector with the laser system

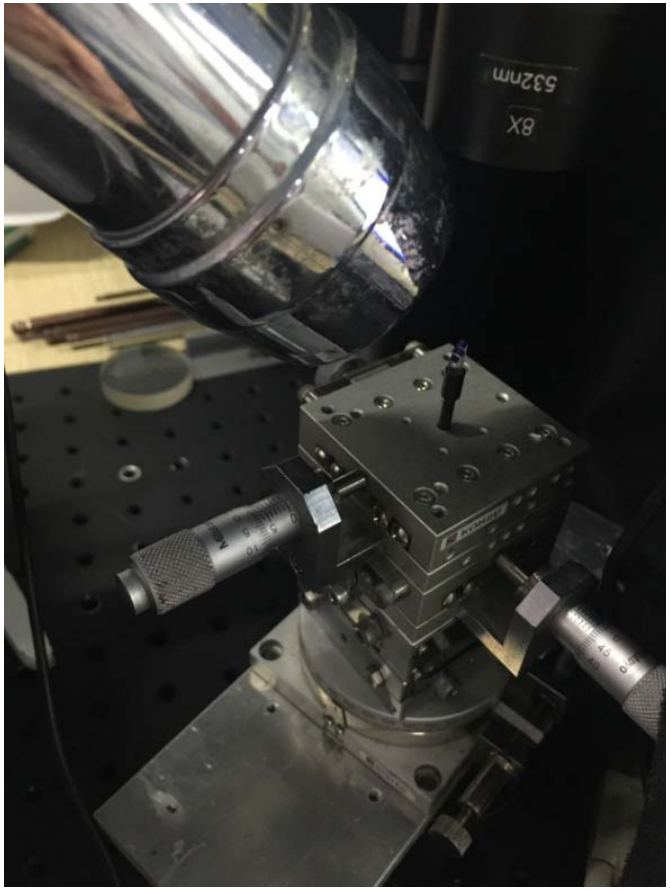
Test of mounted board integrated mirrors





Laser splitting mirrors

Angle accuracy: ~1/60 degree
1 minnte



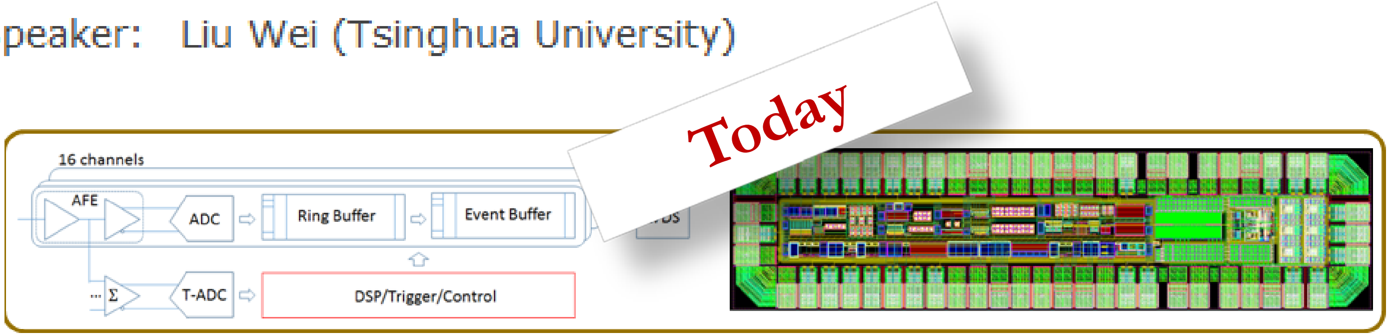
Design of the prototype with laser

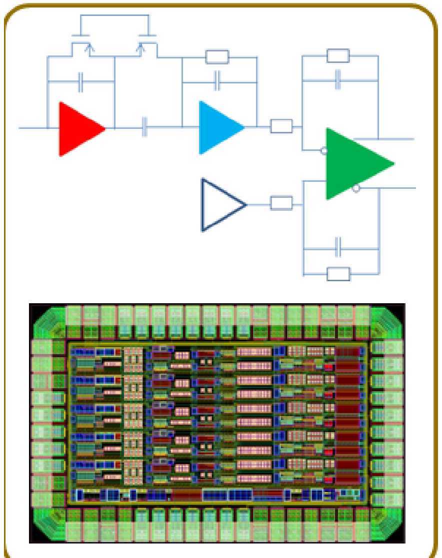
- Support platform: 1200mm×1500mm (all size as the actual geometry)
- TPC barrel mount and re-mount with the Auxiliary brackets
- Readout board (Done), Laser mirror (Done), PCB board (Done)

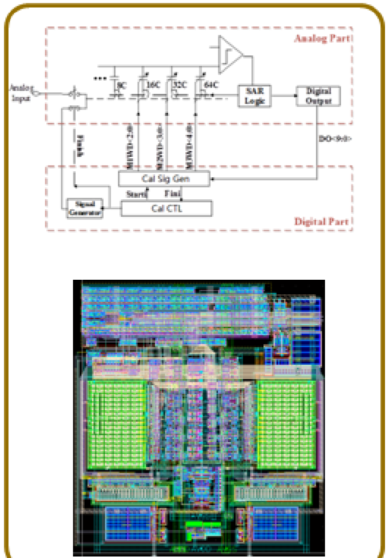
R&D of the low power ASIC@65nm

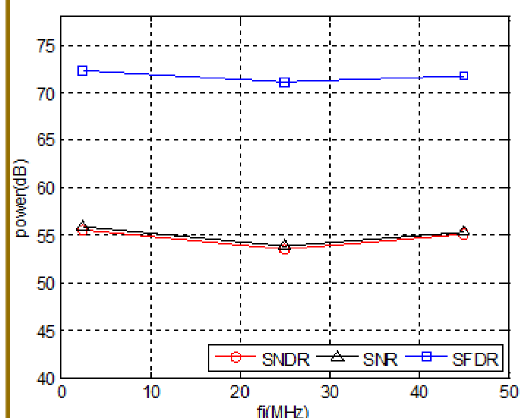
12:30 **Progress on the low power readout ASIC for TPC with 65nm CMOS** *30'*

Speaker: Liu Wei (Tsinghua University)









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
  - CSC funding: PhD Haiyun jiont CEA-Scalay TPC group(6 months)
  - Plan to beam test in DESY with our hybrid detector module in 2019

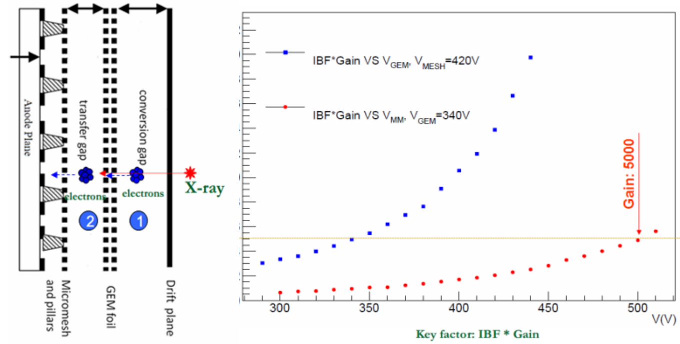
Manpower and activities

- 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)

Further R&D

Continuous IBF module for CEPC:

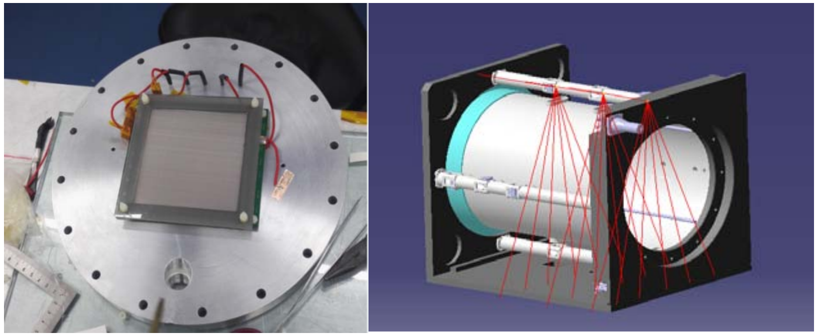
- No Gating device options used for Higgs/Z pole run
- Continuous Ion Back Flow due to the continuous beam structure (Developed in IHEP)
- ~100 μm position resolution in rφ
- Key factor: IBF×Gain=5 and leas than (R&D)
- Low discharge and spark possibility



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



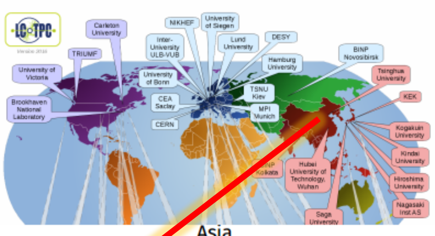
TPC prototype integrated with laser system

Collaboration:

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

LCTPC Collaboration Members

The map below shows the LCTPC collaboration member institutes as listed in the second Addendum of the Memorandum of Agreement from 2008.



Institute	Collaboration Board Member
Institute of High Energy Physics, CAS	Huirong Qi

Joint LCTPC international collaboration

Thanks.