Status and plans of TPC detector module for CEPC

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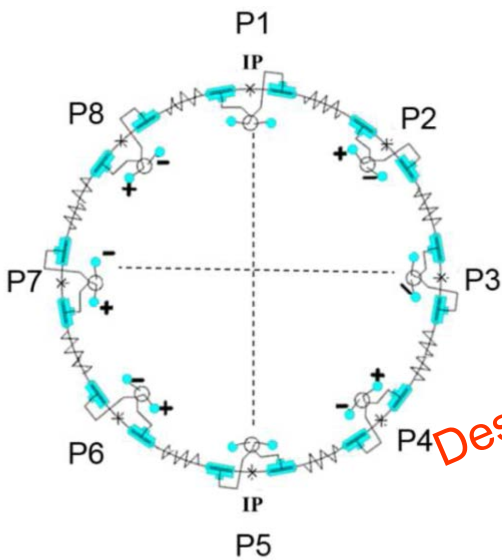
Outline

- Detector requirements
- Critical challenges of CEPC-TPC
- Some activities and progress
- Summary

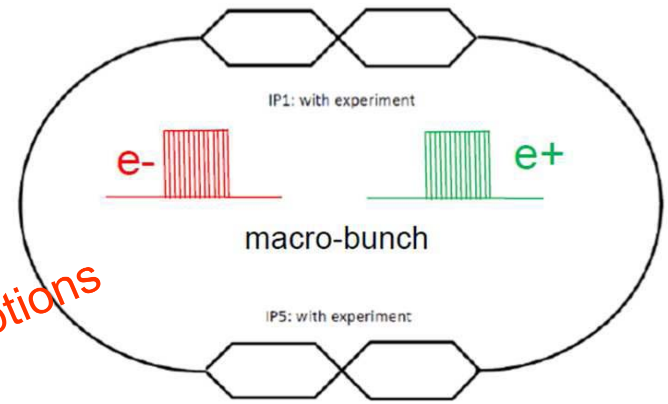
CEPC and its beam structure

Circular e^+e^- Higgs (Z) factory two detectors, 1M ZH events in 10yrs

E_{cm} ≈240 GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$, can also run at the Z-pole



Preliminary
Design of the options



Pretzel Scheme

- **Baseline design in pre-CDR**
- **48 bunches / beam**
- **Colliding every 3.6μs, continuously**

→Power pulsing not applicable

Partial Double-ring Scheme

- **Crab-waist collision to reduce beam and AC power**
- **Avoiding pretzel scheme to increase the flexibility and luminosity**
- **196ns bunch spacing**
- **48 bunches / train**
- **Duty cycle: 9.4μs/181μs**

Reference: CEPC/SppC with ILC (FCC), J. Gao, LCWS 2015, Nov. 2-6, 2015, Whistler, Canada

Detector requirements of TPC

- Physics requirements for CEPC tracker Detector

$$\frac{\sigma_{P_T}}{P_T} \simeq \sqrt{\left(\frac{\alpha'\sigma_x}{BL^2}\right)^2 \left(\frac{720}{n+4}\right) P_T{}^2 + \left(\frac{\alpha' C}{BL}\right)^2 \left(\frac{10}{7}\left(\frac{X}{X_0}\right)\right)}$$

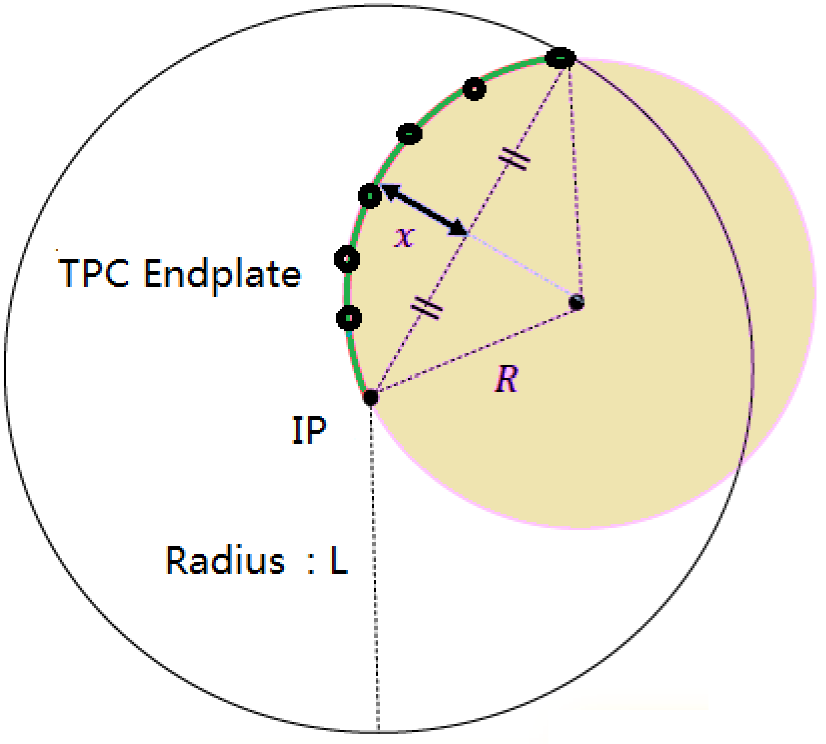
measurements multiple scattering

R.L. Gluckstern, NIM 24 (1963), 381

- Goal: momentum resolution

$$\sigma(1/p_T) = 10^{-4}\text{GeV}^{-1}$$

- Point number: ~200
- Position resolution: ~100μm
- Magnet field: 3T~5T
- PID
- …



Momentum resolution measurement

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

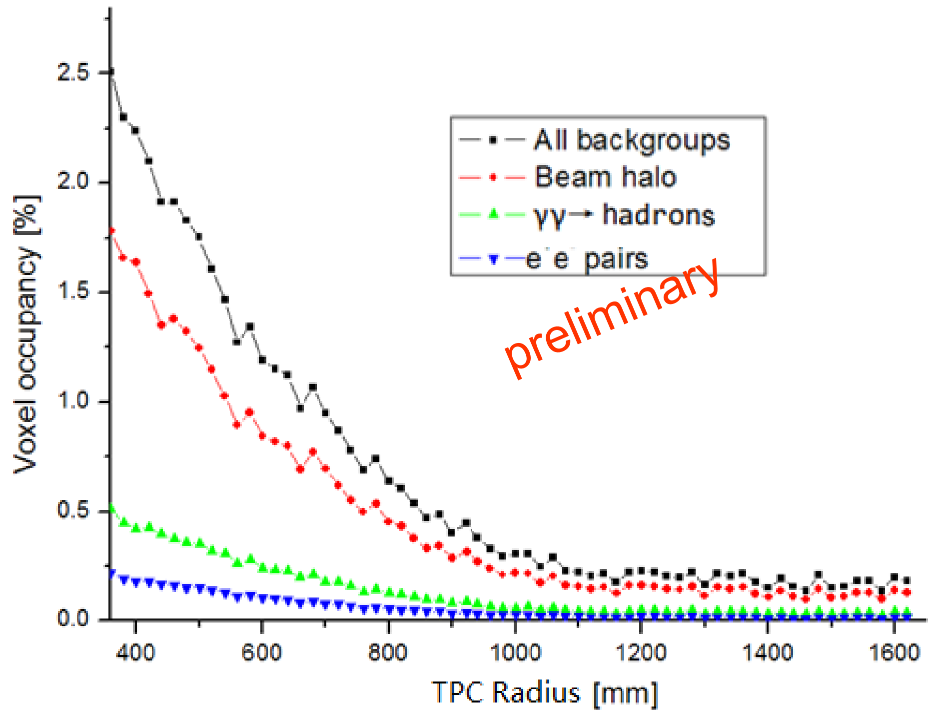
- **Calibration and alignment**
  - Complex MDI design
  - Laser calibration system

→ ~**100um** positron resolution with calibration

2015~2016, some activities for the critical challenges

Critical challenge: Occupancy

- Occupancy estimation
  - Beamstrahlung (e+e- pairs)
    - Pair production
    - Hadronic background
  - Lost Particles (Beam Halo)
  - Synchrotron Radiation
    - More than 100keV of Gamma
    - No damage for working gas
  - No consideration for the beam collimator, the value might larger

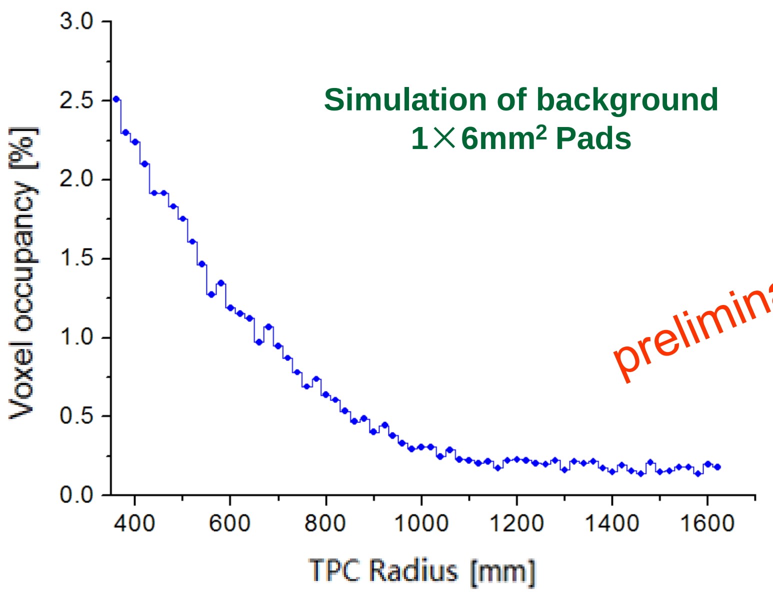


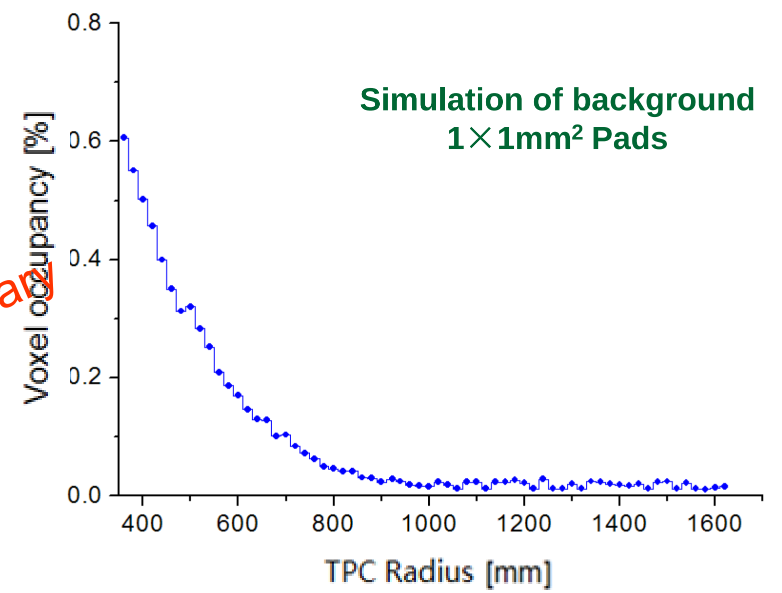
TPC voxel occupancy simulated in TPC radius

Simulation of occupancy

- Occupancy@250GeV
  - Very important parameter for TPC
  - Detector structure of the ILD-TPC like
  - ADC sampling 40MHz readout
  - Time structure of beam:·4us/Branch
  - Beam Induced Backgrounds at CEPC@250GeV(Beam halo muon/e+e- pairs)+γγ→hadrons with safe factors(×15)
  - Value of the occupancy inner radius smaller
  - Optimization for the pad size in rΦ

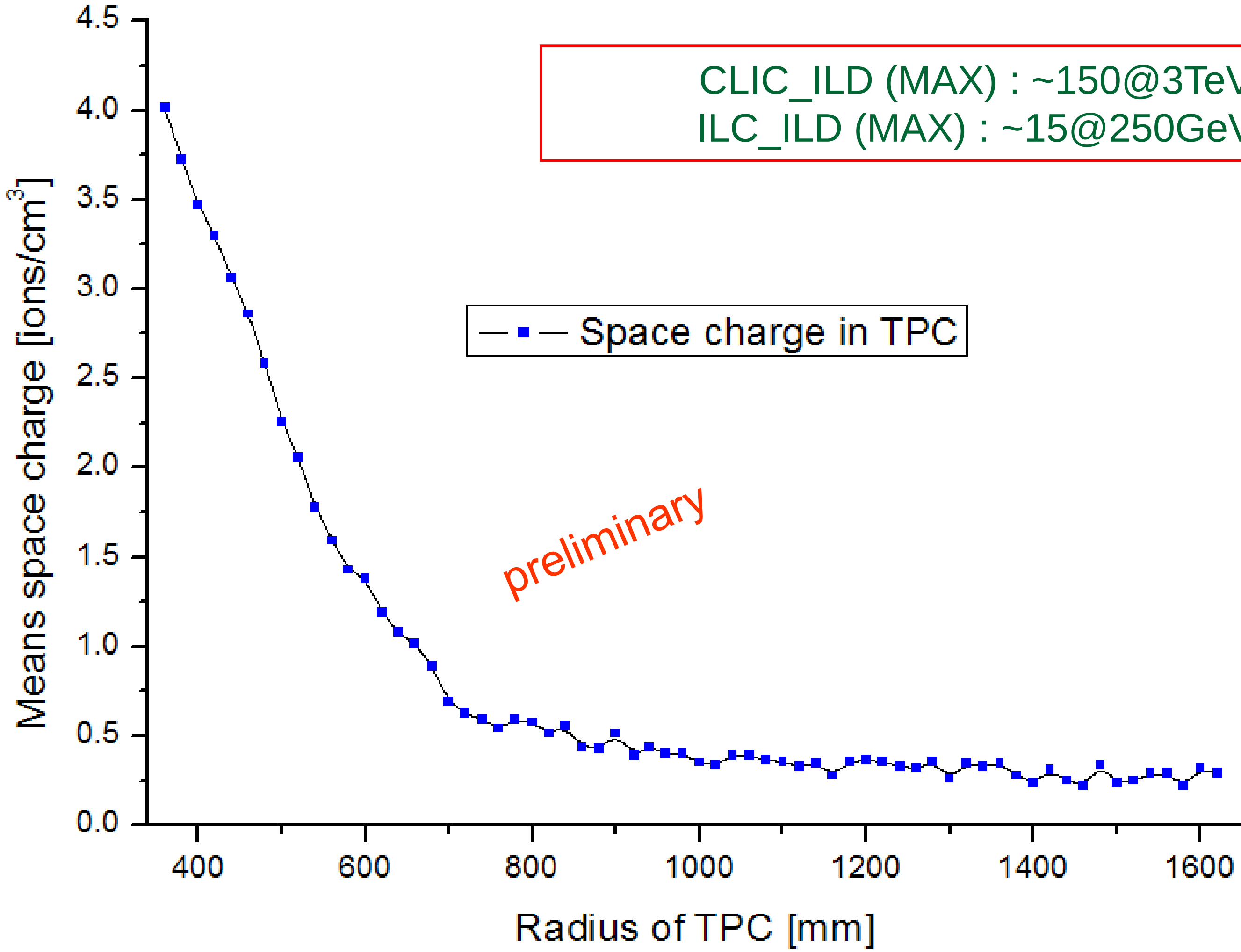
CLIC_ILD ~30%@3TeV
1×6mm² Pads
CLIC_ILD ~12%@3TeV
1×1mm² Pads
NO TPC Options!





Preliminary of occupancy

Space charge from occupancy

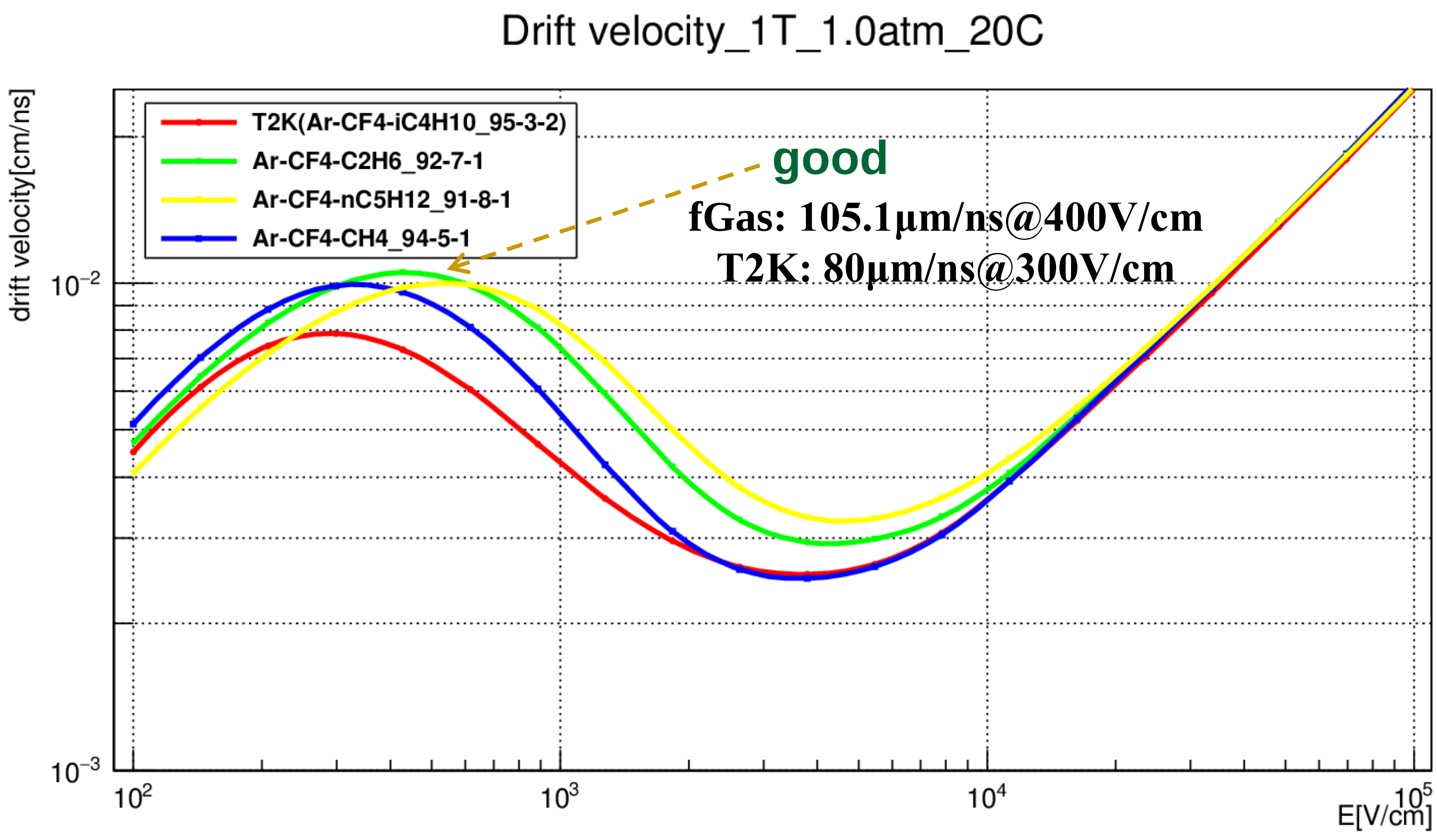


Space charge of ions based on the background

Choosing a gas mixture – simu.

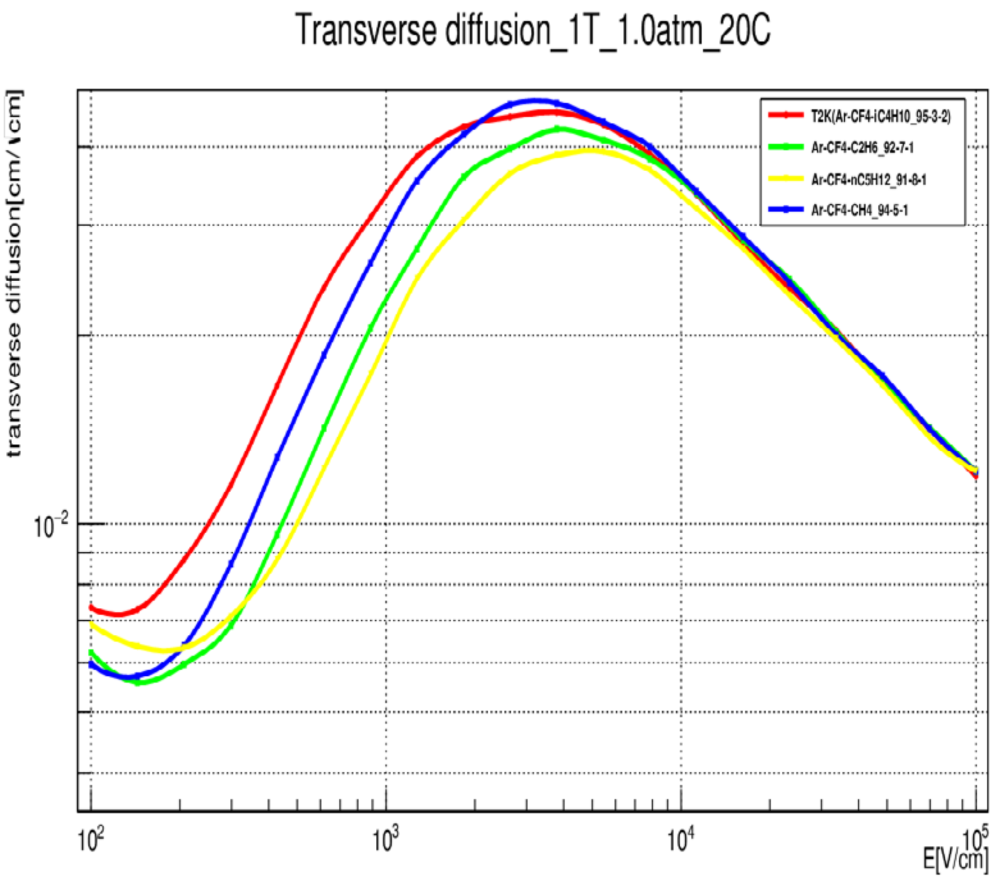
- Faster drift velocity @E_{drift}~300V/cm
  - Refer to T2K gas
  - Ar/CO2/CF4/iC4H10/nC5H12/C2H6

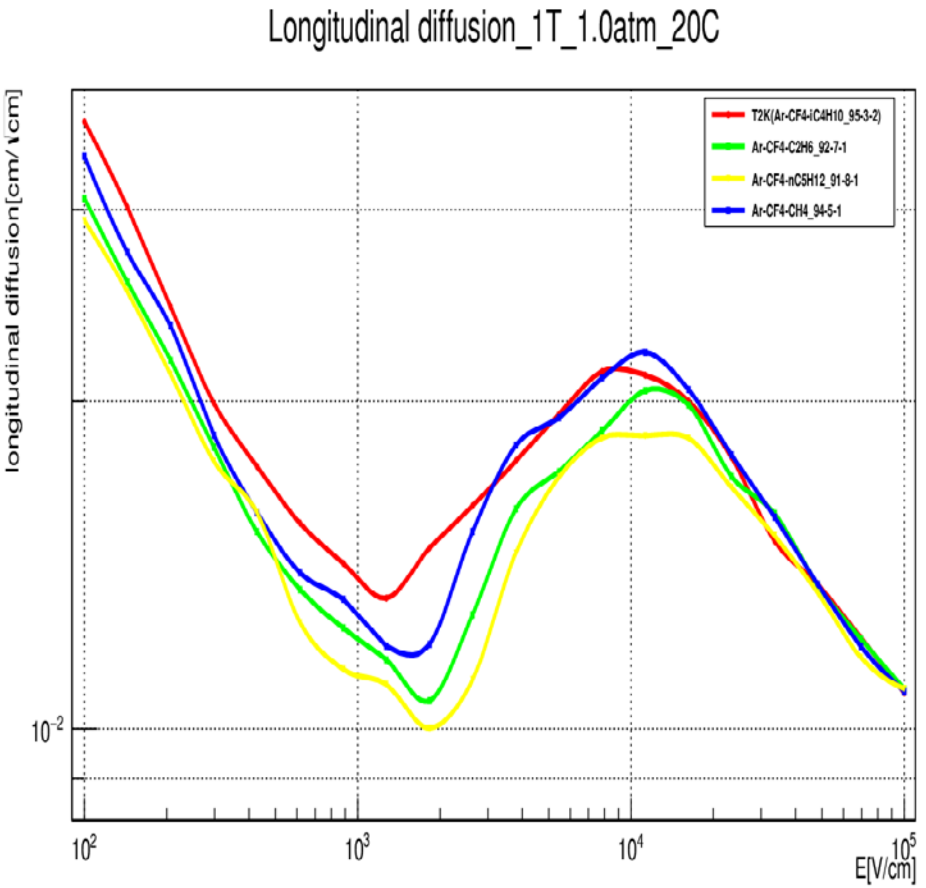
Defined:
fGas : Ar-CF4-C2H6=92:7:1



Drift velocity of some mixture working gases

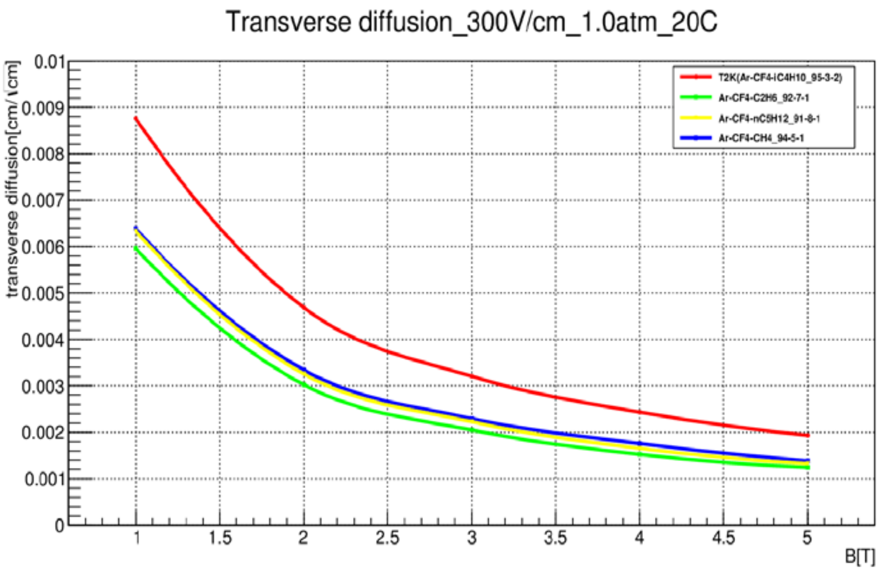
Choosing a gas mixture – simu.

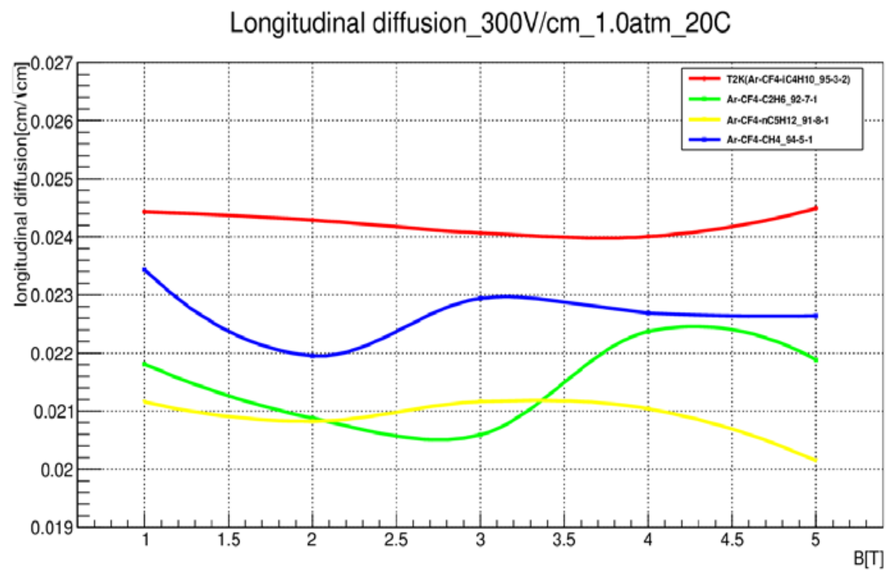




Diffusion in magnetic field of 1T

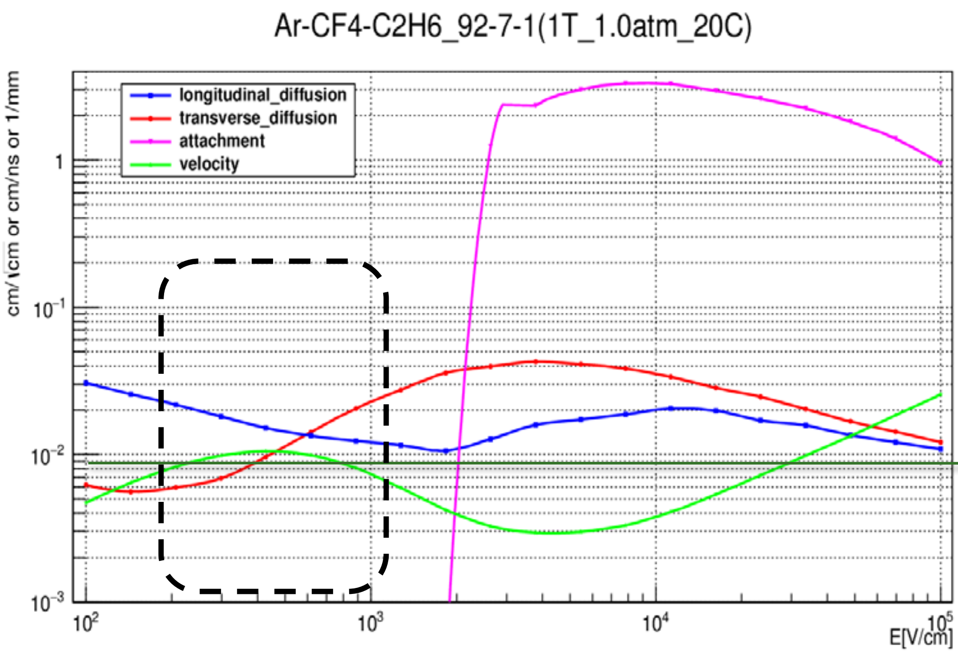
Choosing a gas mixture – simu.

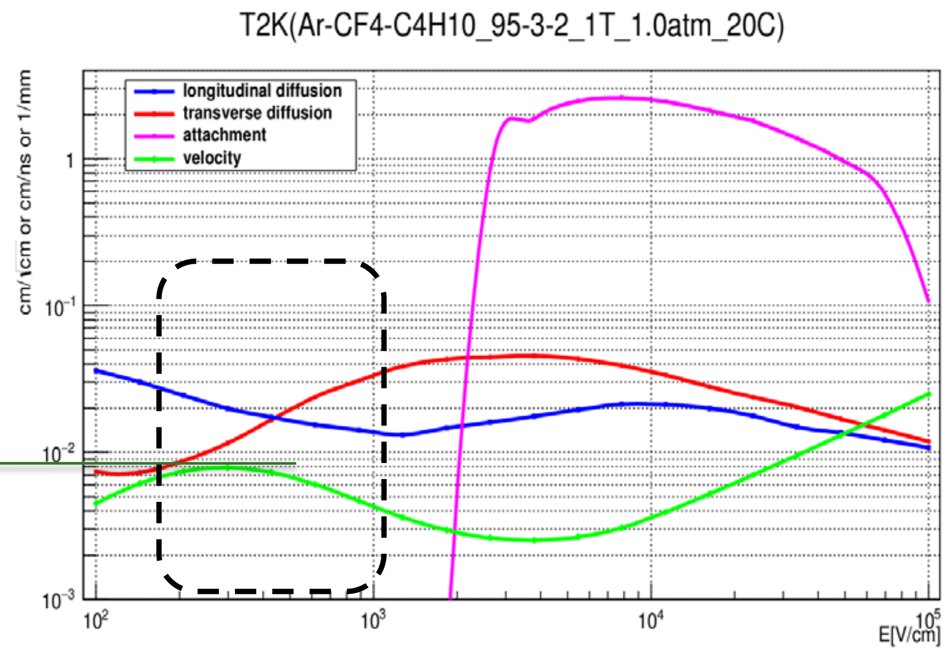




Diffusion @300V/cm in magnetic field from 1T to 5T

Choosing a gas mixture – simu.





Ar-CF4-C2H6 gas

T2K gas

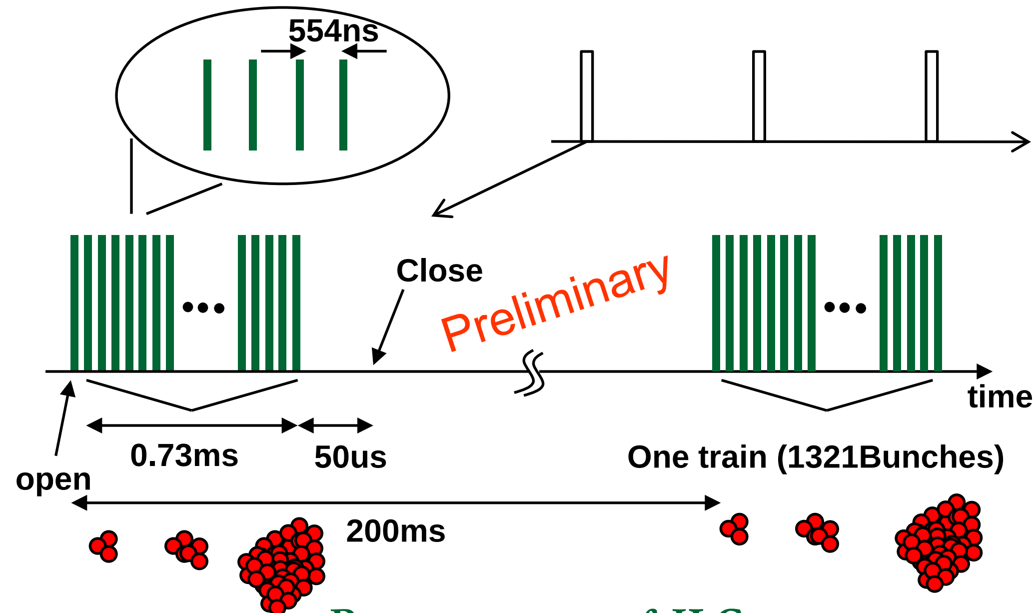
fGas (Ar-CF4-C2H6=92:7:1) VS T2K(Ar-CF4-iC4H10=95:3:2)

------ fGas was seemed that a better working gas for the continuous beam structure

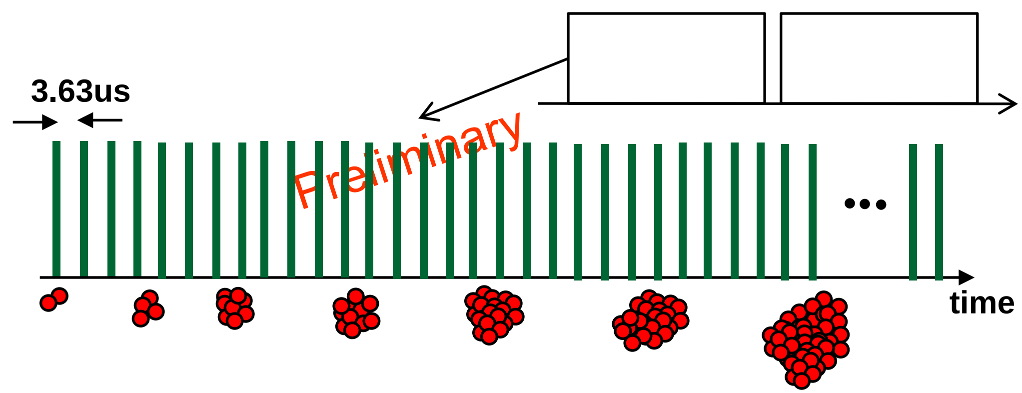
------ More works will be for the new mixture working gas

Compare with ILC beam structure

- In the case of ILD-TPC
  - Bunch-train structure of the ILC beam (one ~1ms train every 200 ms)
  - Bunches time ~554ns
  - Duration of train ~0.73ms
  - Used Gating device
  - Open to close time of Gating: 50μs+0.73ms
  - Shorter working time
- In the case of CEPC-TPC
  - Bunch-train structure of the CEPC beam (one bunch every 3.63μs) or partial double ring
  - No Gating device with open and close time
  - Continuous device for ions
  - Long working time



Beam structure of ILC



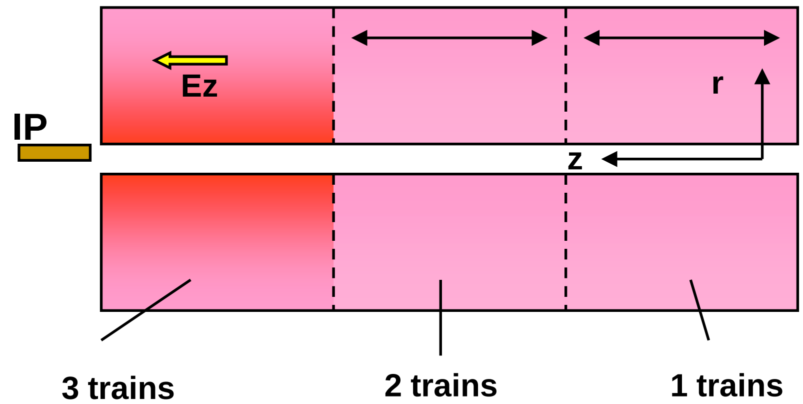
Beam structure of CEPC

NO Gating device !

Critical challenge: Ion Back Flow and Distortion

In the case of ILD-TPC

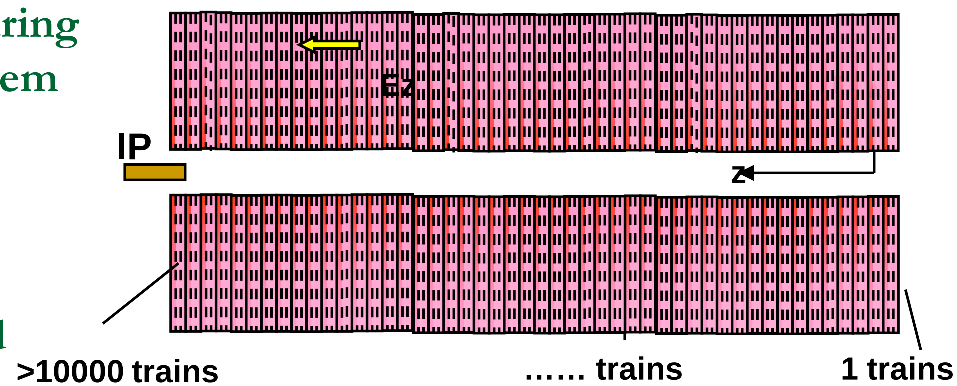
- Distortions by the primary ions at ILD are negligible
- Ions from the amplification will be concentrated in discs of about 1 cm thickness near the readout, and then drift back into the drift volume Shorter working time
- 3 discs co-exist and distorted the path of seed electron
- The ions have to be neutralized during the 200 ms period used gating system



Amplification ions@ILC

In the case of CEPC-TPC

- Distortions by the primary ions at CEPC are negligible too
- More than 10000 discs co-exist and distorted the path of seed electron
- The ions have to be neutralized during the ~4us period continuously



Amplification ions@CEPC

Requirements of Ion Back Flow @CEPC

- 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

$$\sigma_{r\varphi/z}(z) = \sqrt{\sigma_{0,r\varphi/z}^2 + \frac{D_{t/l}^2}{N_{\text{eff}} \cdot e^{-Az}} z}$$

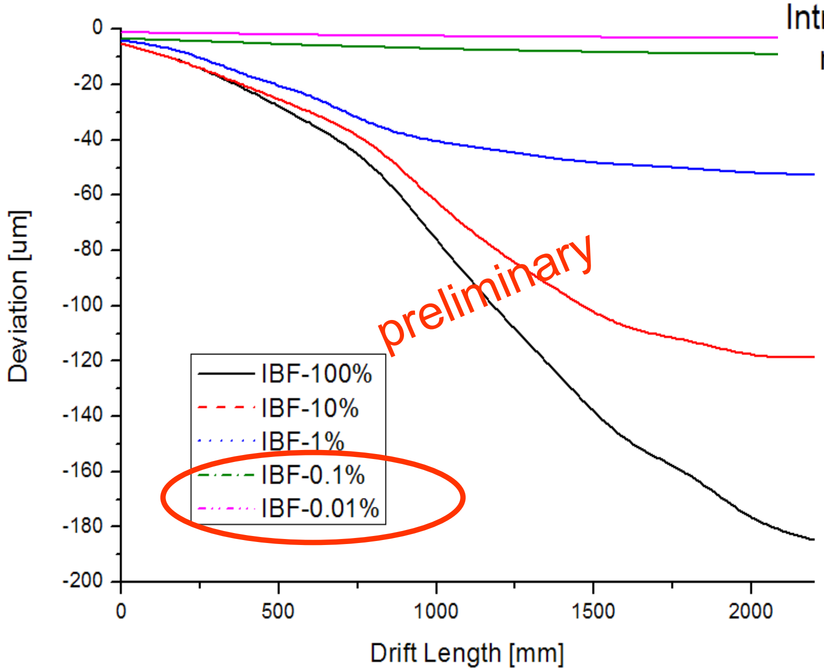
Transverse and

Intrinsic resolution of the readout at zero drift distance in rφ/z

Effective number of primary signal electrons

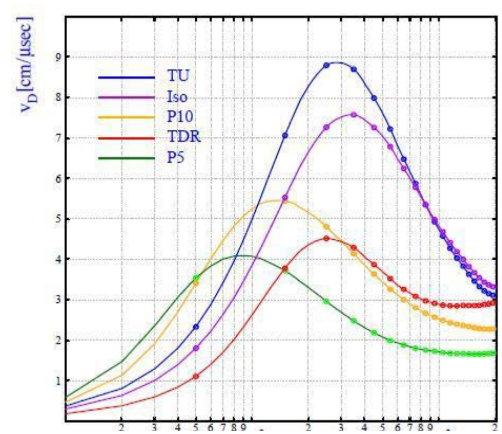
molecules during drift

Position resolution of the TPC function



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

Neff=33
Gain=5000
Ar/Iso=95/5
5-6Tracks/Branch
r=400mm

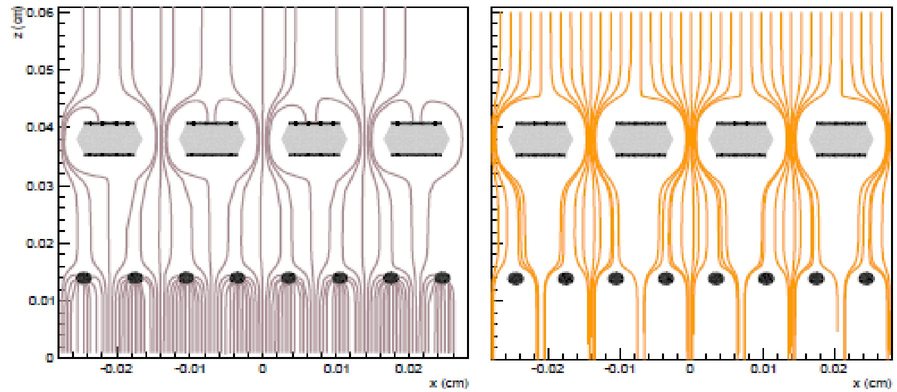


Simulated the drift velocity in different gas mixture

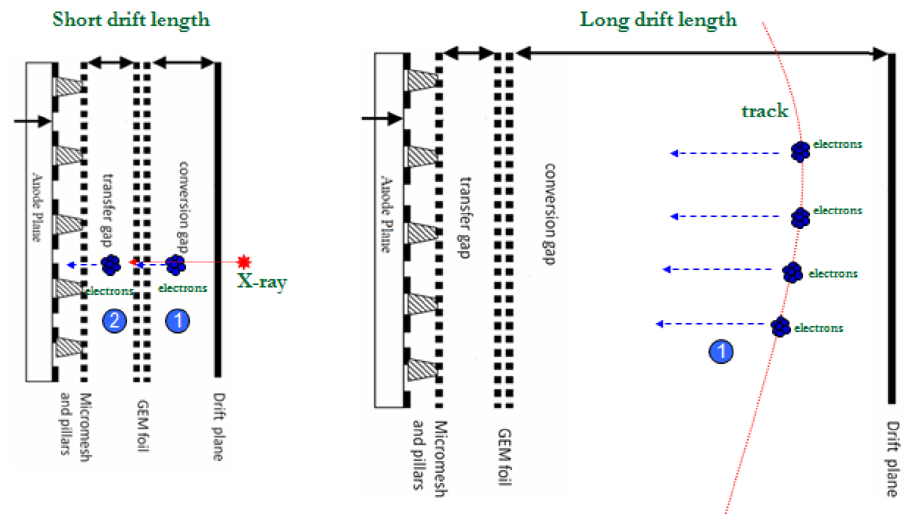
New ideas for the ions?

- Our group was asked to "think" on an alternative option for CEPC TPC concept design
- And we did our best …
- We proposed and investigated the performance of a novel configuration for TPC gas amplification: GEM plus a Micromegas (GEM+Micromegas)
- Hybrid micro-pattern gaseous detector module

- GEM+Micromegas detector module
  - GEM as the preamplifier device
  - GEM as the device to reduce the ion back flow continuously
  - Stable operation in long time
  - Low material budget of the module



ANSYS-Garfield++ simulation
(0T, Left: ions; Right: electrons)

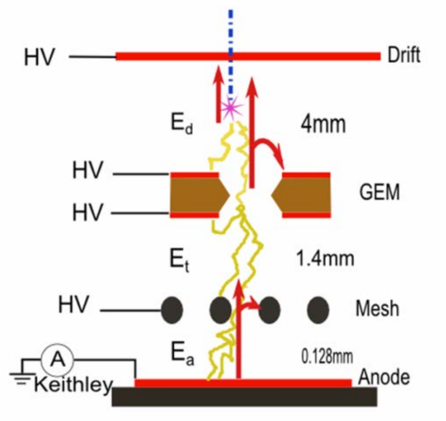


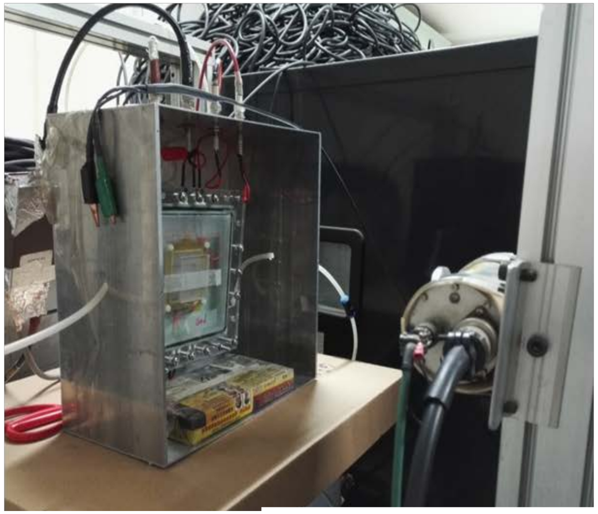
Hybrid detector

Test of the new module

Supported by 高能所创新基金

- Test of GEM+Micromegas module
  - Assembled with the GEM and Bulk-Micromegas
  - Active area: 50mm×50mm
  - X-tube ray and X-ray radiation source
  - Simulation using the Garfield
  - Ion back flow with the higher X-ray: from 1% to 3%
  - Stable operation time: more than 48 hours
  - Separated GEM gain: 1~10





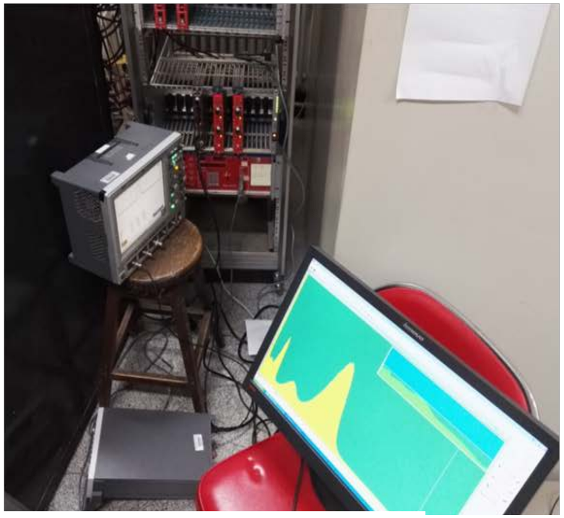
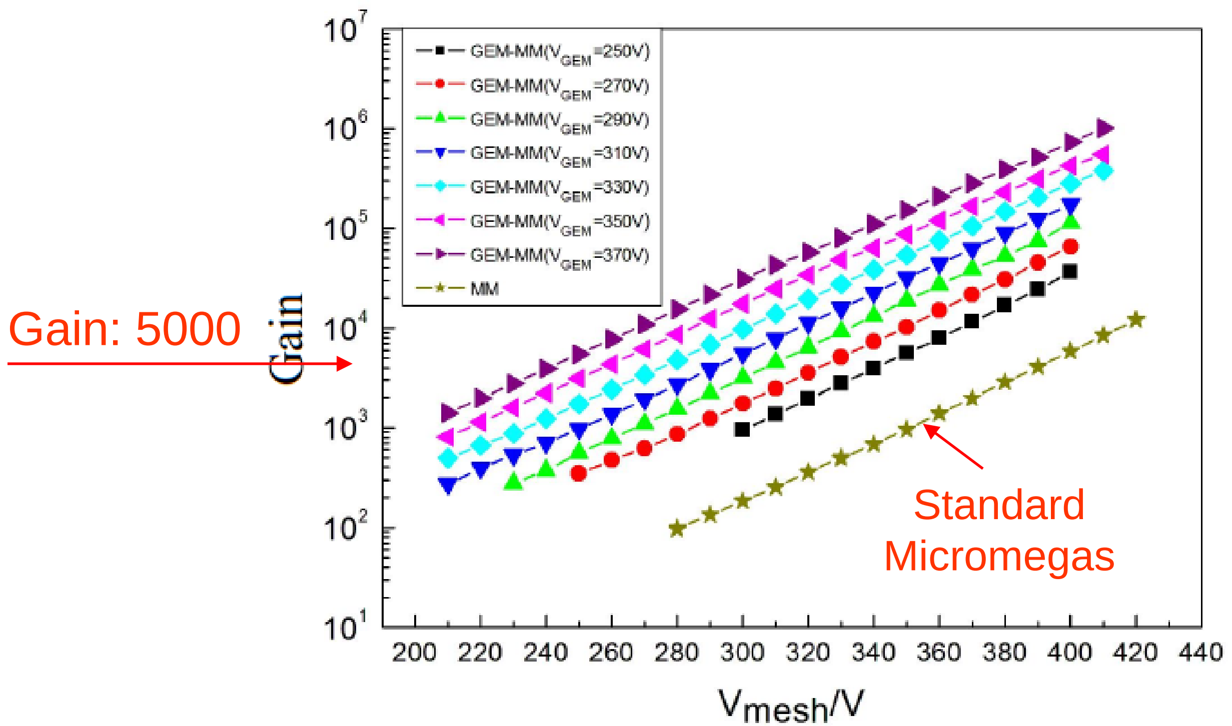


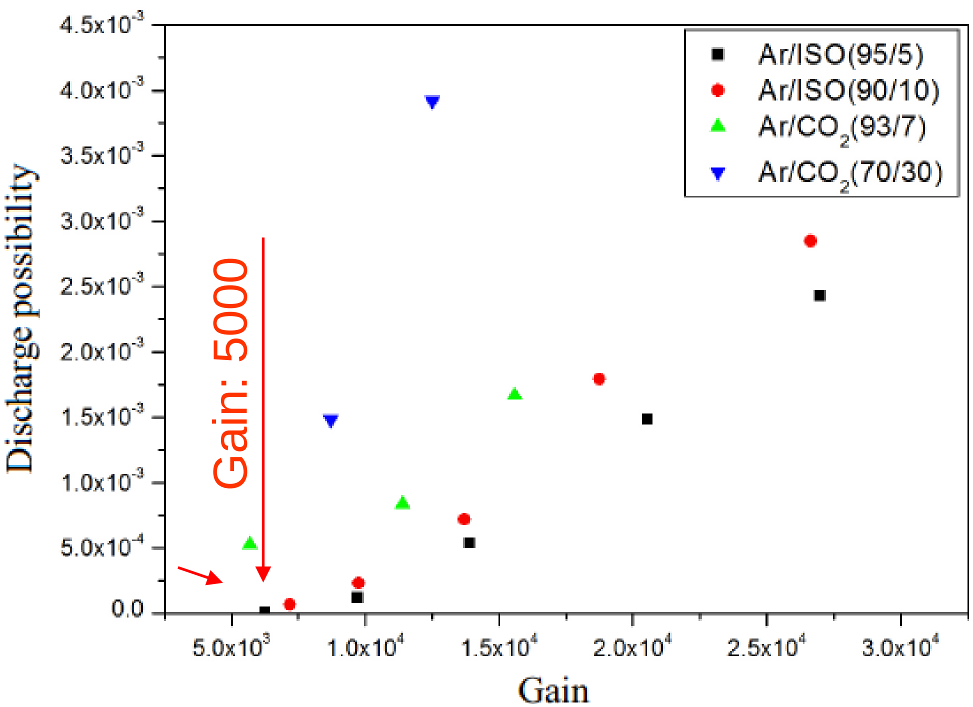
Photo of the GEM+Micromegas Module with X-ray

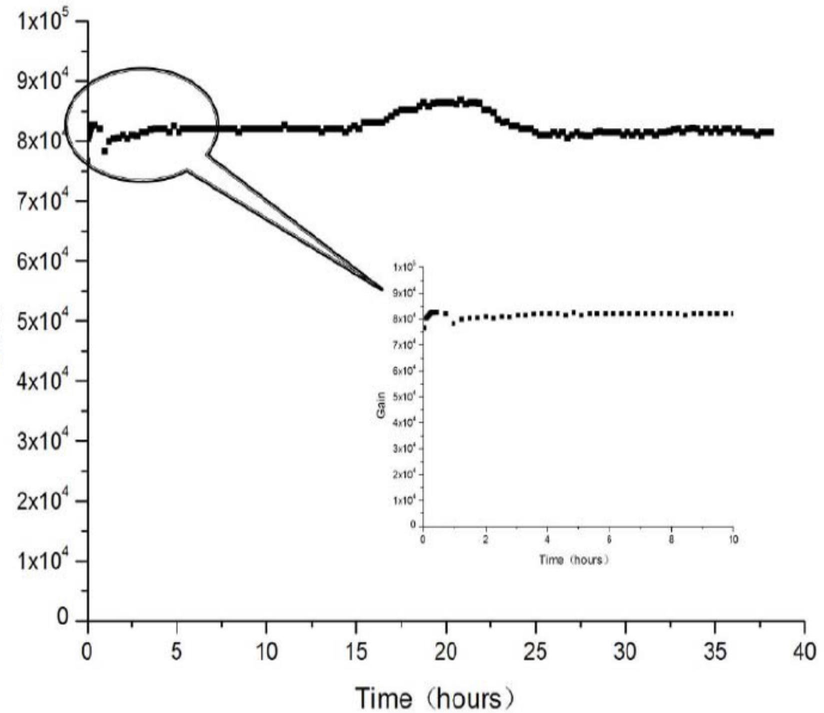
Gain of GEM + MM



- Test with Fe-55 X-ray radiation source
  - Reach to the higher gain than standard Micromegas with the pre-amplification GEM detector
  - Similar Energy resolution as the standard Micromegas
  - Increase the operating voltage of GEM detector to enlarge the whole gain

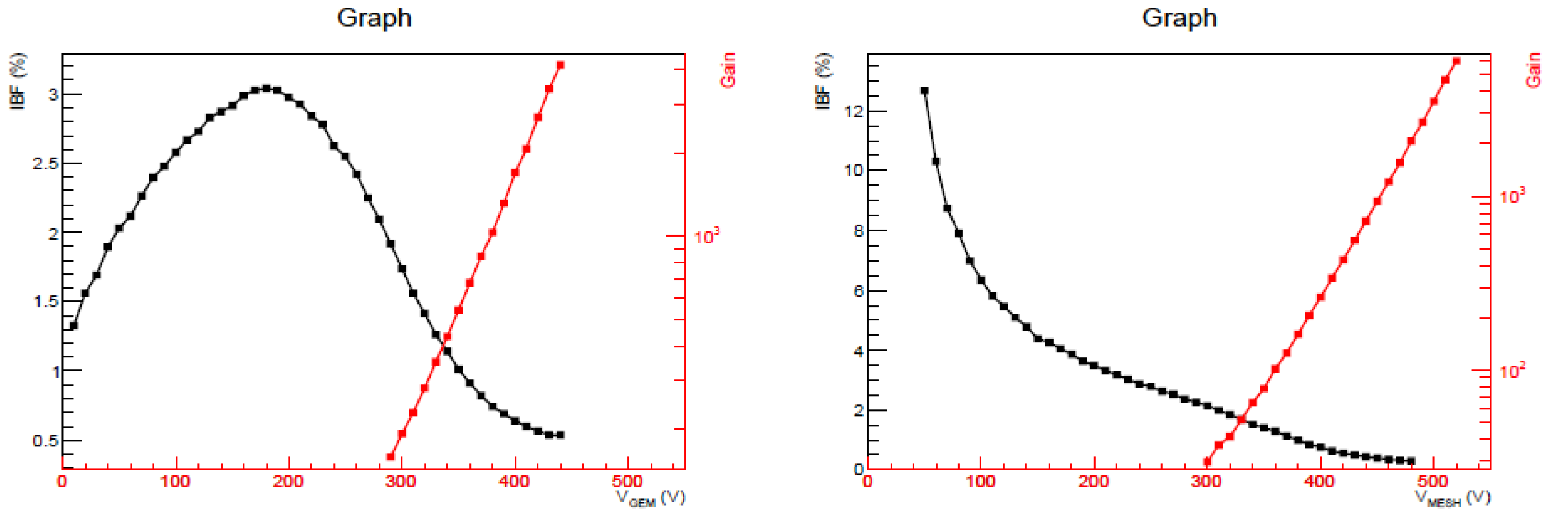
Discharge and working time





- 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

IBF preliminary result



(a) (b)

Gas gain and IBF versus (a): GEM voltage, micromesh $V_{mesh} = 420V$ and (b): micromesh voltage, $V_{GEM} = 340V$. $E_d = 250V/cm$, $E_t = 500V/cm$

- Test with X-tube@21kV~25kV using the Hybrid module
  - Charge sensitive preamplifier ORTEC 142IH
  - Amplifier ORTEC 572 A
  - MCA of ORTEC ASPEC 927
  - Mesh Readout
  - Gas: Ar-iC4H10(95-5)
  - Gain: ~6000

Contribution of the ions from the drift region to be γ, calculation of IBF, η:

$$I_{mesh} = G\gamma$$

$$I_c = \gamma + G\gamma\eta = \gamma + \eta\, I_{mesh}$$

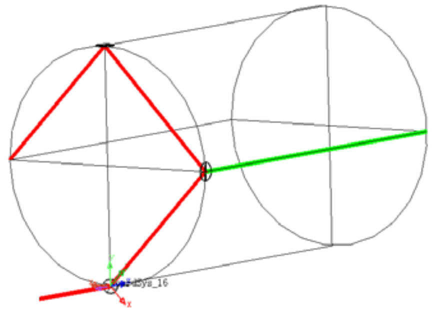
G is the gas gain of the detector.

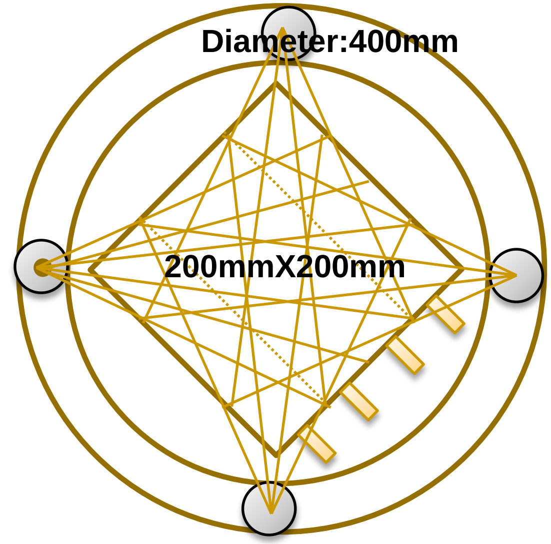
	GEM+MMG 420LPI (IHEP)	2GEMs + MMG 450 LPI (Yale University)	Micromegas only 450 LPI (Yale University)
Ion Back Flow	~0.1% Edrift = 0.25 kV/cm	(0.3 –0.4)% Edrift = 0.4 kV/cm	(0.4 –1.5)% Edrift= (0.1-0.4) kV/cm
<GA>	4000~5000	2000	2000
ϵ-parameter(=IBF*GA)	4~5	6~8	8~30
E –resolution	~16%	<12%	<= 8%
Gas Mixture (2-3 components)	Ar + iC4H10	Ne+CO2+N2, Ne+CO2,Ne+CF4, Ne+CO2+CH4	X + iC4H10 (Ar+CF4+iC4H10)
Sparking (^{241}Am)	<10^{-8}	< 3.*10^{-7}(Ne+CO2) (N.Smirnov report)	~ 10^{-7} (S. Procureur report)
Possible main problem	Thin frame	More FEE channel	#
Goals	CEPC TPC	ALICE upgrade	#

Laser calibration for TPC prototype

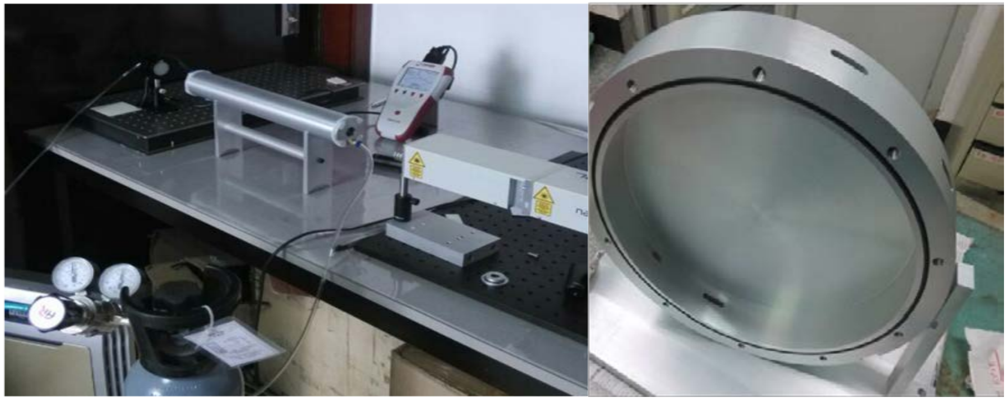
Supported by 国家基金委重点基金

- Goals of laser for TPC detector
  - The ionization in the gas volume along the laser path occurs via two photon absorption by organic impurities
  - Drift velocity, gain uniformity
- To reduce the distortion effect
  - E×B effect study
  - Drift Velocity measurement
  - Good resolution in space and tin
    - No production of σ-rays
    - No multiple scattering
- Baseline design **(DONE)**
  - Nd:YAG laser device
  - λ = 266 nm or E = hν = 4.66 eV
  - Energy: ~100 uJ/pulse
  - Duration of pulse: 5 ns
  - Active area:200mm×200mm
  - Drift length: 500mm
  - Outer diameter:~400mm
  - GEM readout





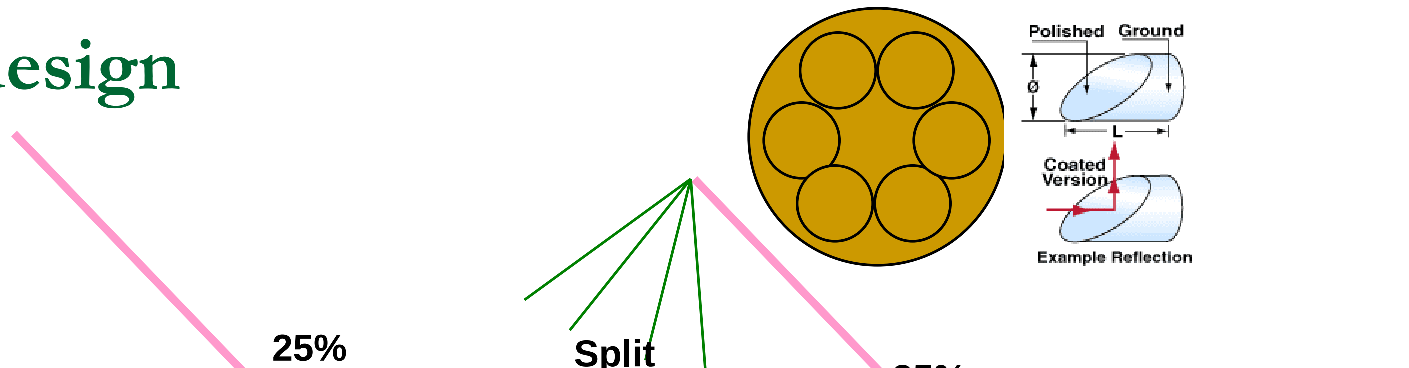
Laser calibration baseline design

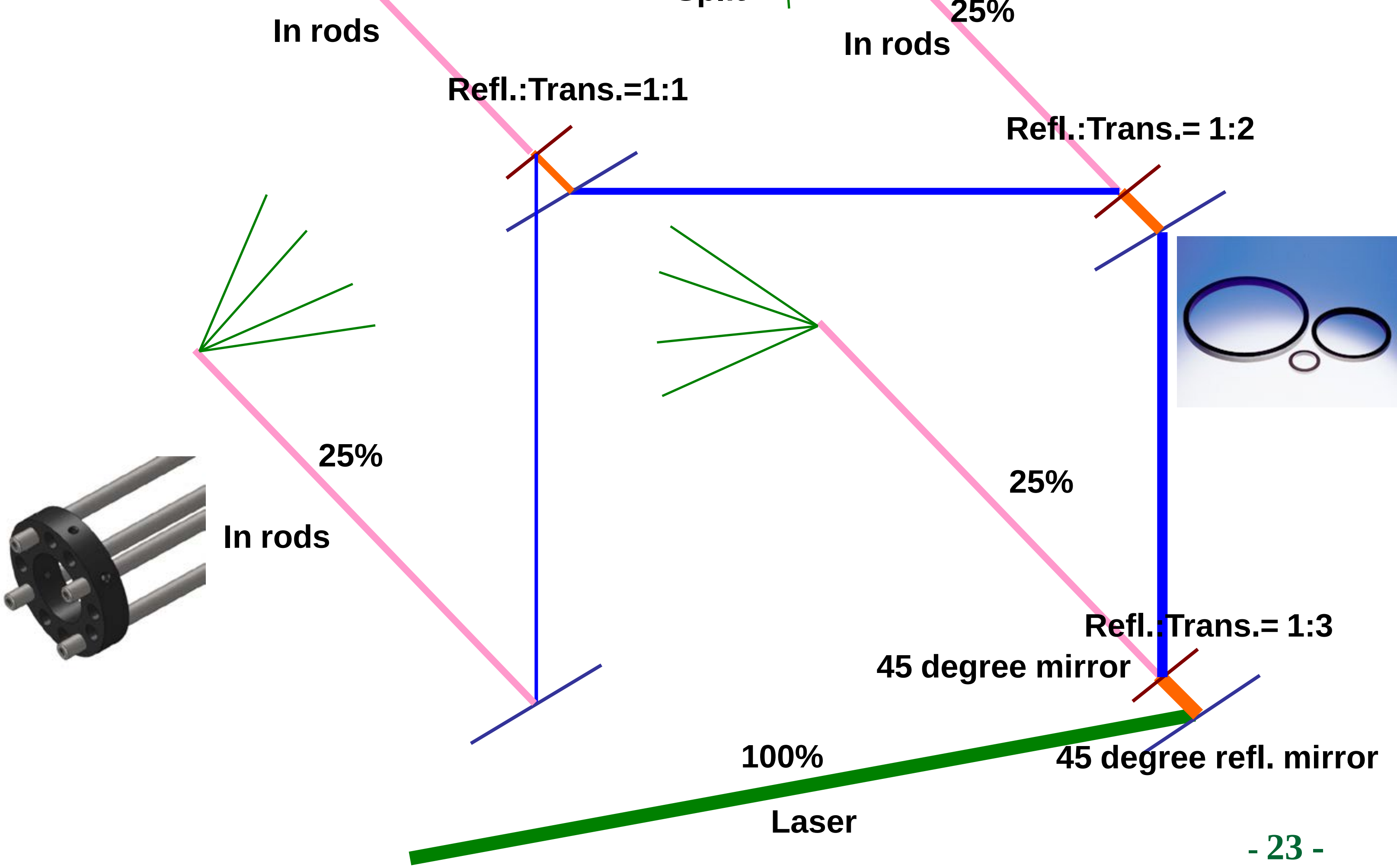


The assembled module test with 266nm laser

Tsinghua and IHEP Cooperation

Laser map design





R/Micromegas detector cooperation with Saclay

- This year (next months)
  - Designed three readout PCB boards with the active area of 200mm×200mm
  - Designed three readout PCB boards with the active area of 100mm×100mm
  - Delivered them to Saclay to assemble the Micromegas or resistive layer
  - To send one person to Scalay one weeks in Nov.(Doctoral students: Yulian Zhang or Haiyun Wang)

- Next year
  - Micromegas+GEM detector tested with UV light fot IBF
  - fGas tested with the detector module
  - Mini-workshops
  - Personnel exchanges for detector module
  - …

Summary

- **Critical requirements for CEPC TPC modules**
  - Beam structure
  - Obvious distortion
  - Continuous Ion Back Flow

- **Some activities for the module**
  - Simulation of the occupancy of the detector, the hybrid structure gaseous detector's IBF
  - TPC gas amplification setup GEM+MM investigated as a high rate TPC option without the standard gating grid or others gating device
  - Some preliminary IBF results
  - Some common effort R&D to participate in the collaboration

Thanks very much for your attention !