Ion Suppression Using Graphene Membranes

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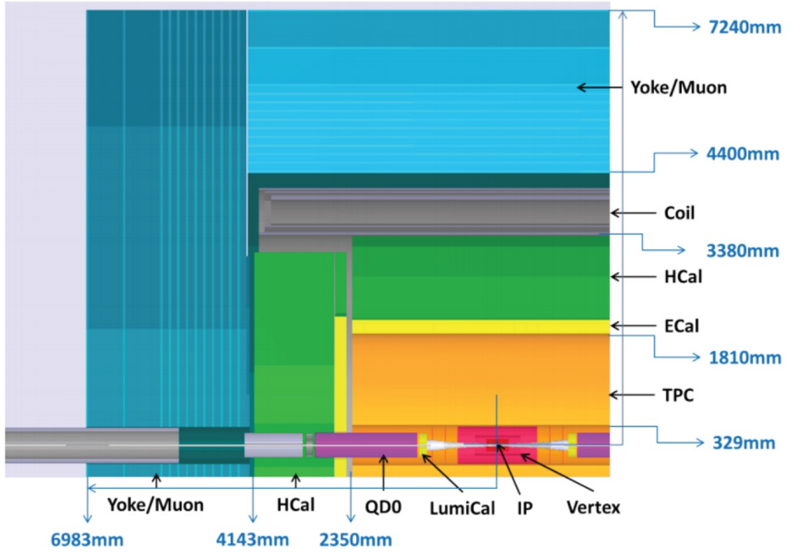
PART 01

Motivation

CEPC and TPC

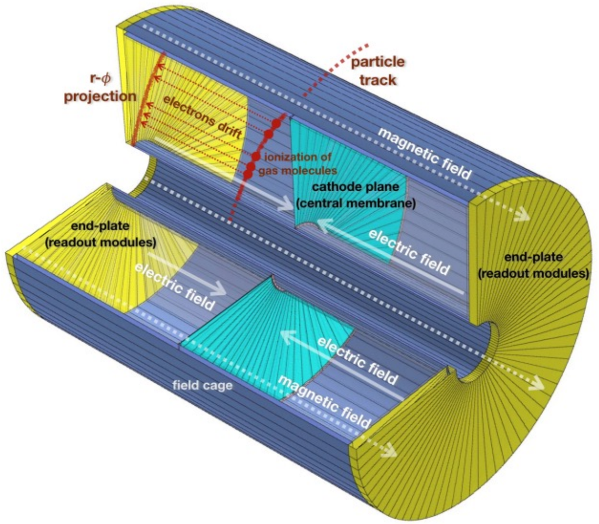
❖The CEPC experiment mainly aims to precisely measure the property of the Higgs boson.
❖ The high luminosity.
❖ Low background.



The CEPC baseline detector

● **Tracking Detector——TPC**

•simple structure and excellent momentum resolution
•wide usage ---- STAR，PANDA，ALICE......
•readout detector ---- MWPC(Multi-wire Proportion Chamber)、GEM(Gas Electron Multiplier) ......



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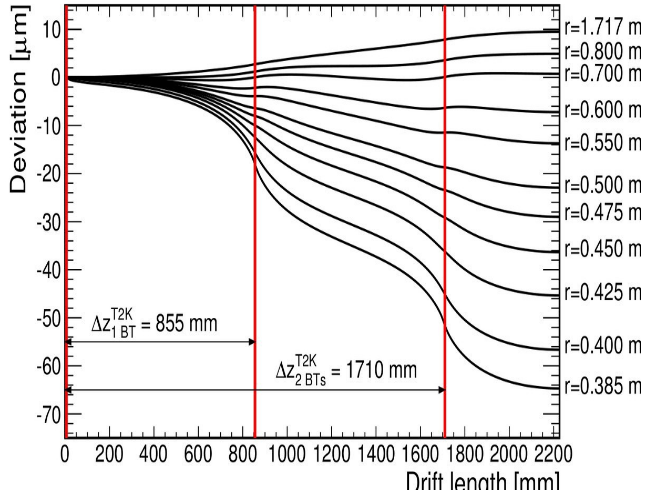
Sketch of TPC detector

Ions suppression and TPC module

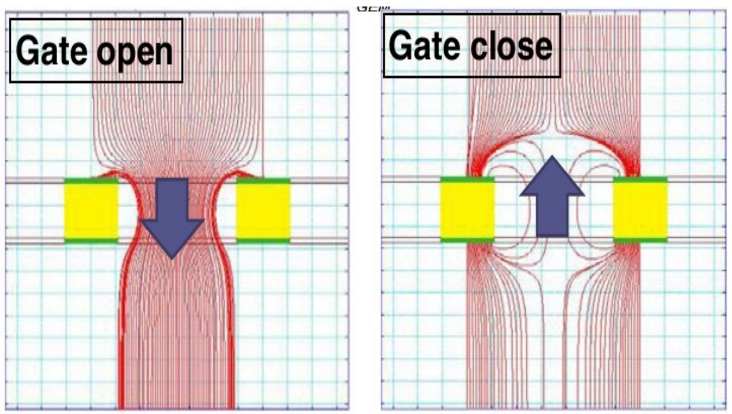
●Ion feedback in TPCs

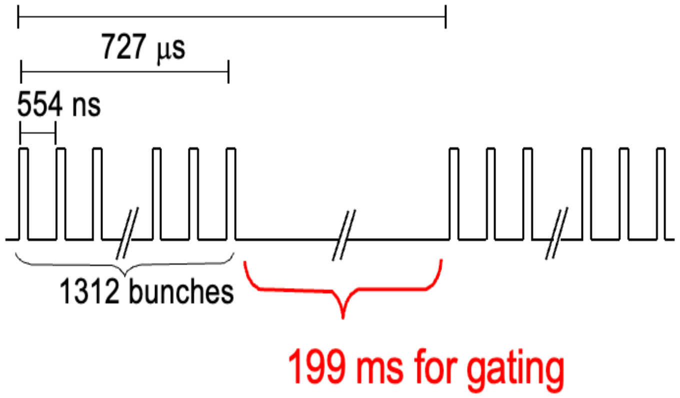
- decreased momentum resolution and introduce distortions in the reconstructed tracks
- Primary ions create distortions in the electric field which result in O(<1μm) track distortions including a safety margin of estimated BG at Higgs run.
- Track distortions are 20μm per disc without gating device, **if IBF is 1/gain**.

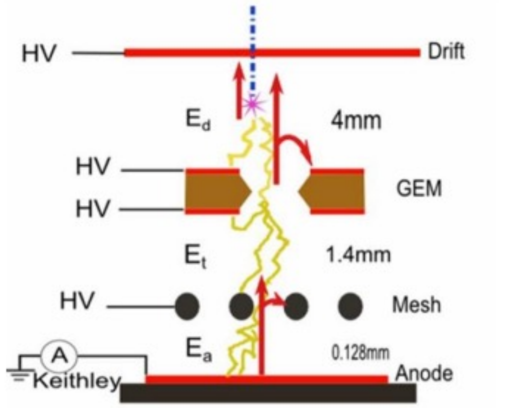


●Methods to suppress IBF

- Gating --- Gating GEM
- MPGD --- GEM + MicroMegas







Schematic diagram of the GEM-MM hybrid detector module.

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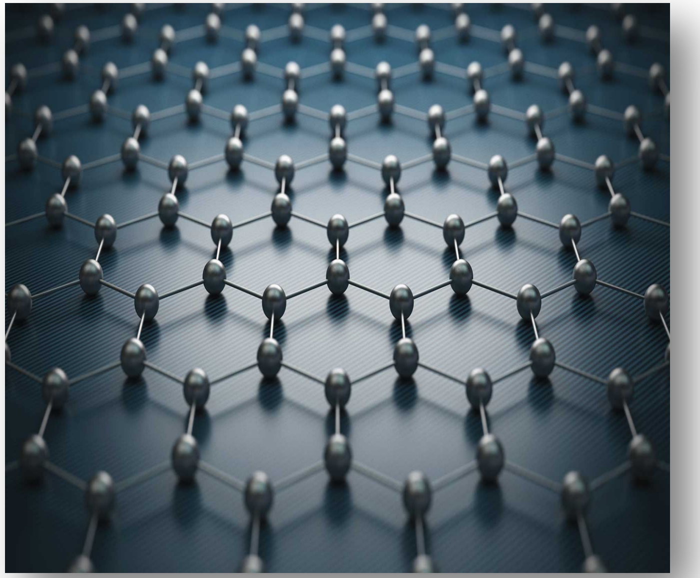
Graphene

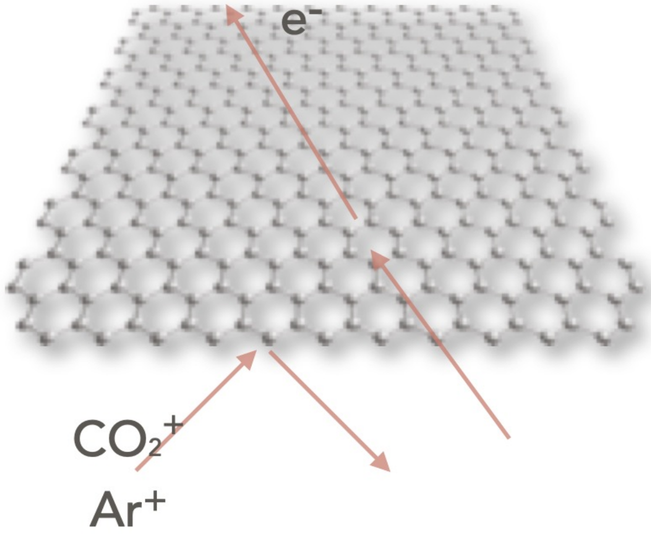
——a particularly attractive candidate for blocking the IBF in the TPC

● Nature of graphene

- Hexagonal atomic structure - Effective radius ~ 0.06 nm



- Allows electron passage, blocks large molecules:
  Effectively prevents positive ion feedback



- Excellent mechanical performance
  Capable of withstanding 10^{16}ions/cm2 @keV
  Can be suspended over micrometer-sized holes

- It requires sufficient transmission rate for drifting electrons in gas.

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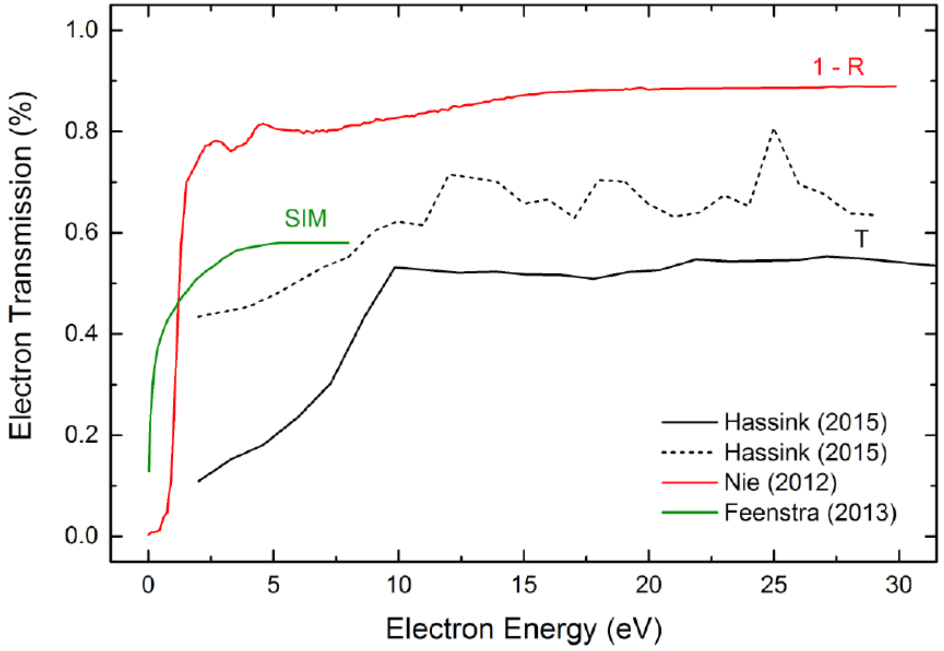
Graphene

——a particularly attractive candidate for blocking the IBF in the TPC

- **The transmission rate of electrons through graphene.**

  - High-energy electrons (above KeV) can pass through graphene membranes with high efficiency.
  - lower-energy electrons (below 1 KeV). the results from different experiments and theoretical calculations vary significantly.



*In gas detectors, the typical energy of electrons is lower than 10 eV.

* Graphene can allow electrons to pass through.

***It is necessary to accurately measure the transmission rate of electron experimentally, especially the low energy transmittance of graphene suspended over the hole under the influence of the hole edge, as the basis for the positive ion feedback inhibition in TPC.

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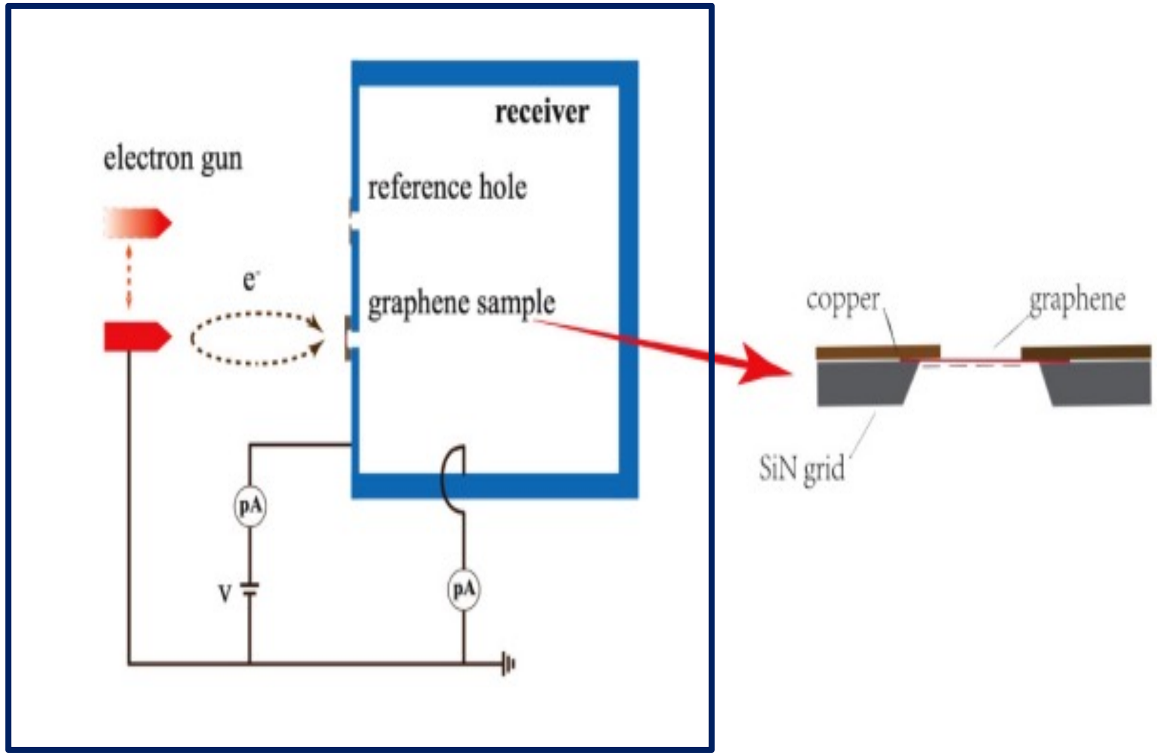
PART 02

Experimental setup

Schematic view of measurement system

- Lower-energy electron sources
- Graphene sample
- Electron receiver
- Pico-ampere meter
- vacuum chamber
  vacuum degree <$1e^{-5}Pa$



Schematic view of measurement system

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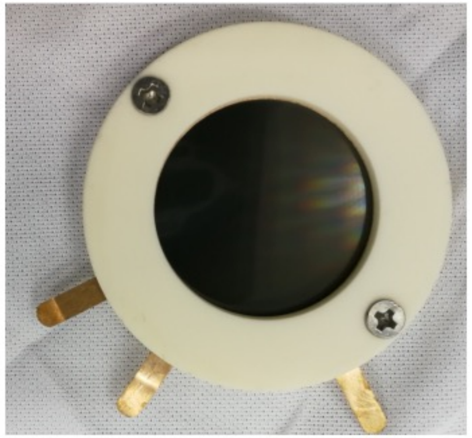
Low-energy electron sources



Option 1: MCP

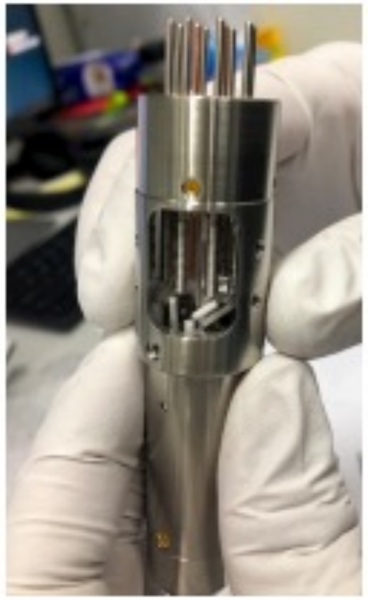
After testing, MCP is not suitable for low energy electron sources.

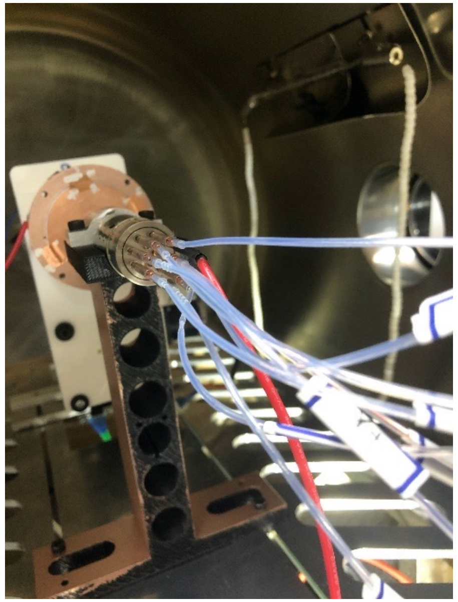
the influence of secondary electrons

the wide spectrum of electrons emitted by MCP

the wide distribution range of electrons…

Option 2: Kimball elg-2/egps-1022





•Energy range： 5 eV~2 KeV

•Energy stability（high energy）： ±0.01%

•Beam stability： Emission Current Control Mode ±0.1%/h

•At a distance of 20 mm, the electron gun beam can focus between 0.5mm and 5mm in diameter

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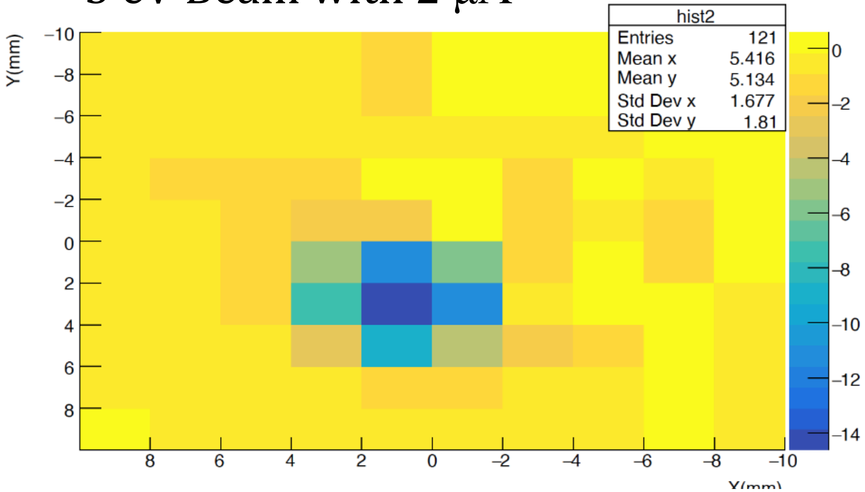
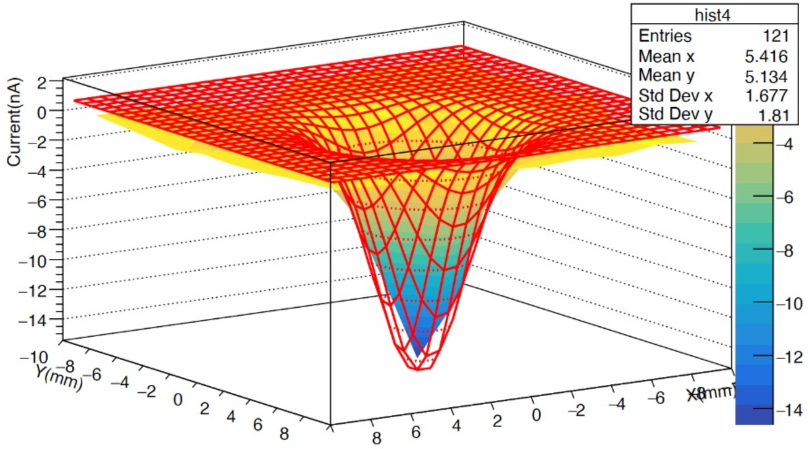
Calibration of Electron Gun

*Beam focusing test
< 10 eV electrons are best focused in the range of ~ 2 mm.

5 eV Beam with 2 μA   Focal distance ~3mm

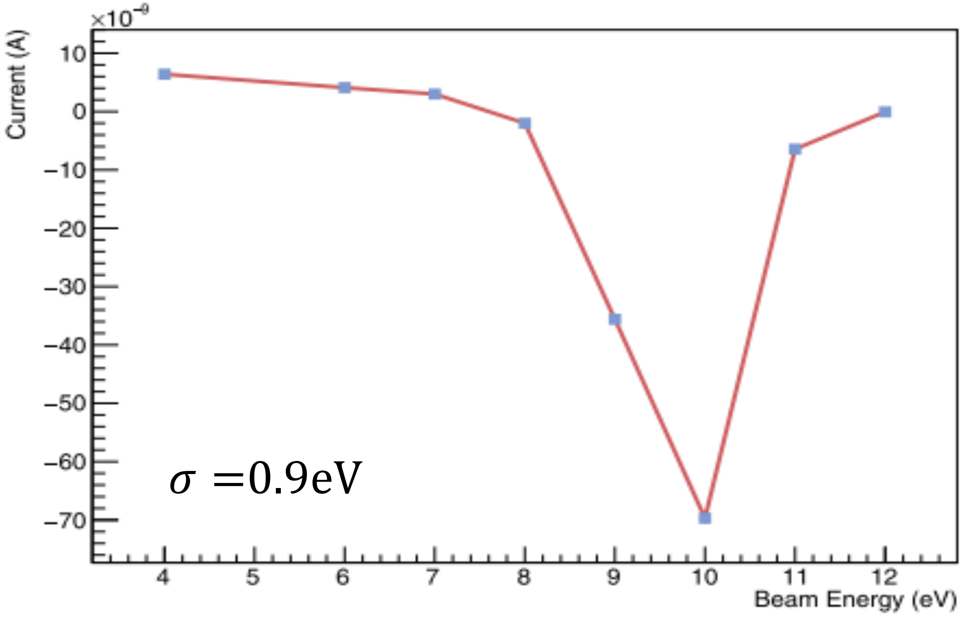




*Faraday Cup tests beam energy distribution

a beam of 0.3 μA with an energy of 10 eV

The current of the measuring device as a function of the electron energy with the gun nominal value tuned at 10 eV.

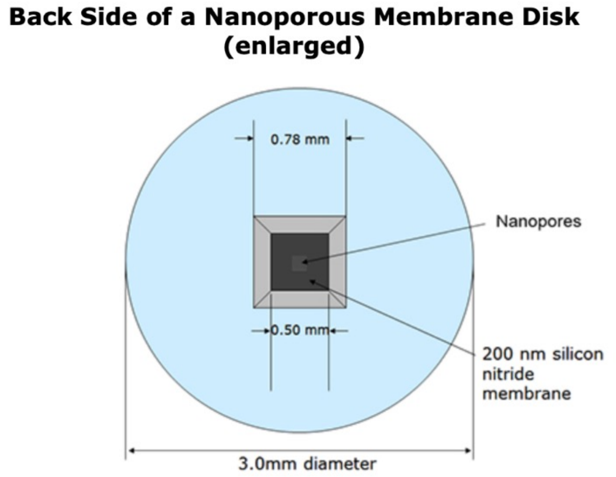


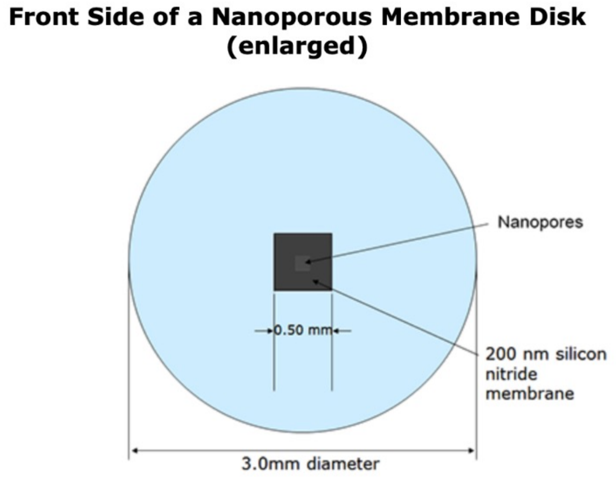
Graphene sample on SiN substrate

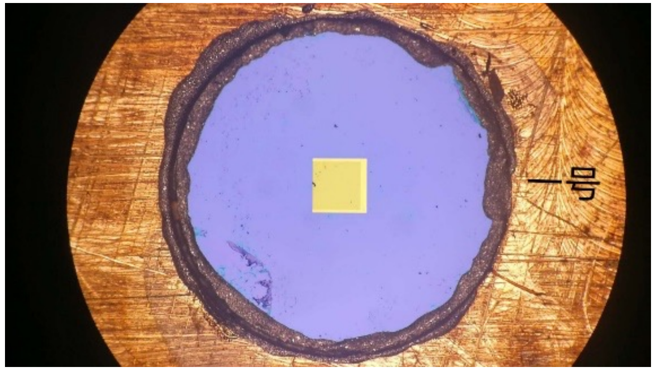
***Tedpella finished product:**
Silicon nitride covered with monolayer of graphene ~ 75% covered region.

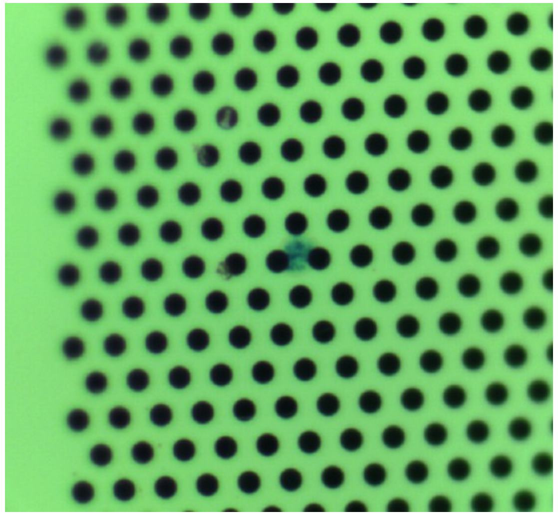
parameter	value
aperture	2.5 μm
pitch of hole	4.5 μm
thickness	200nm
mesh region	0.45*0.45mm

*Multiple-holes measurements with 360μm diameter region;
*Correct the hole proportion.









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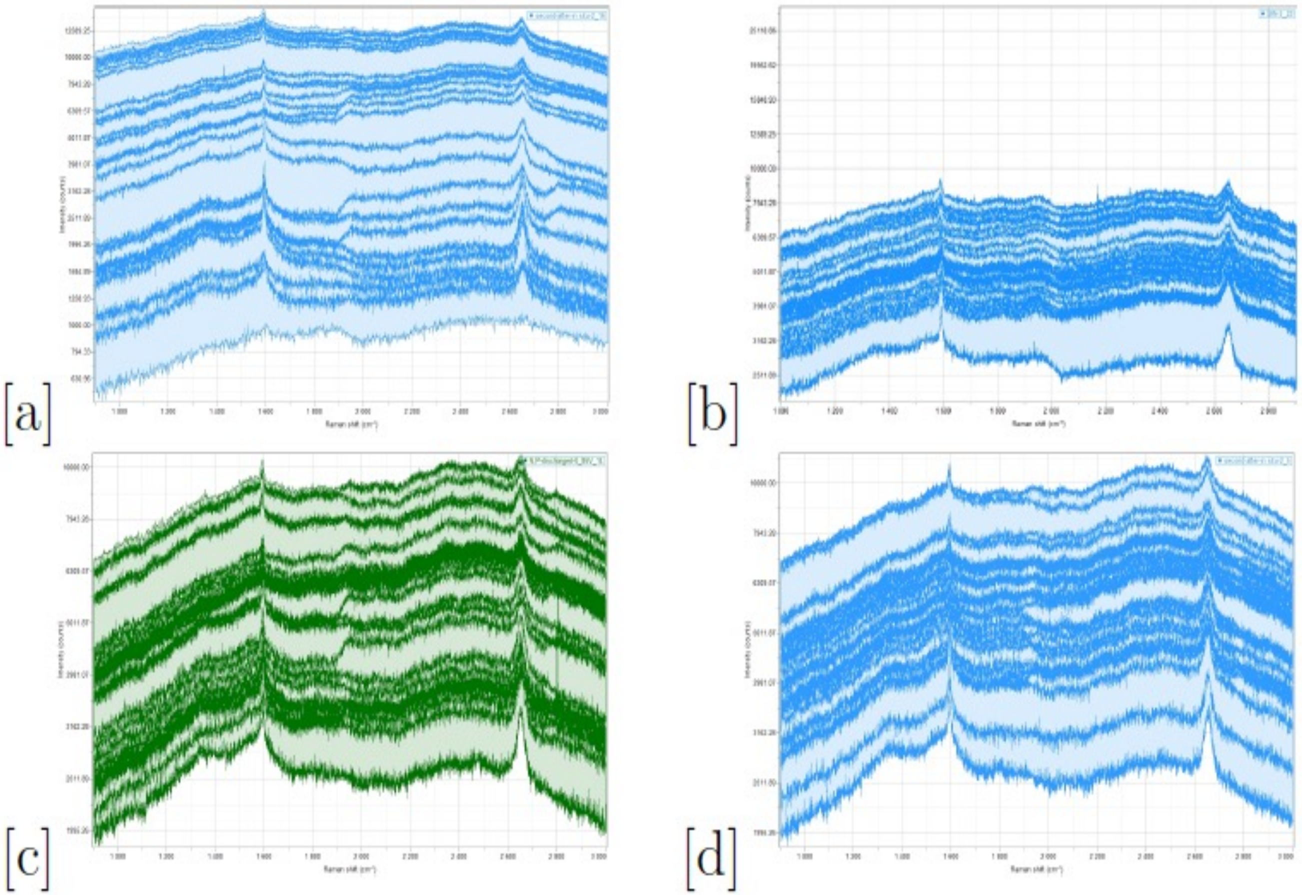
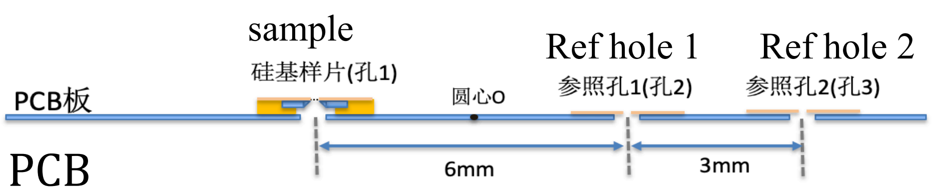
Raman spectrum of Graphene sample on SiN substrate

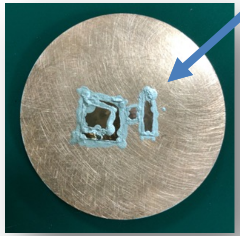
*The graphene on the test holes is intact.

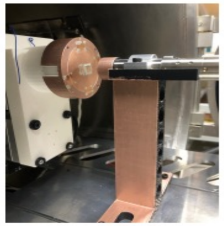
Raman spectrum test of 633nm laser with 4 samples.



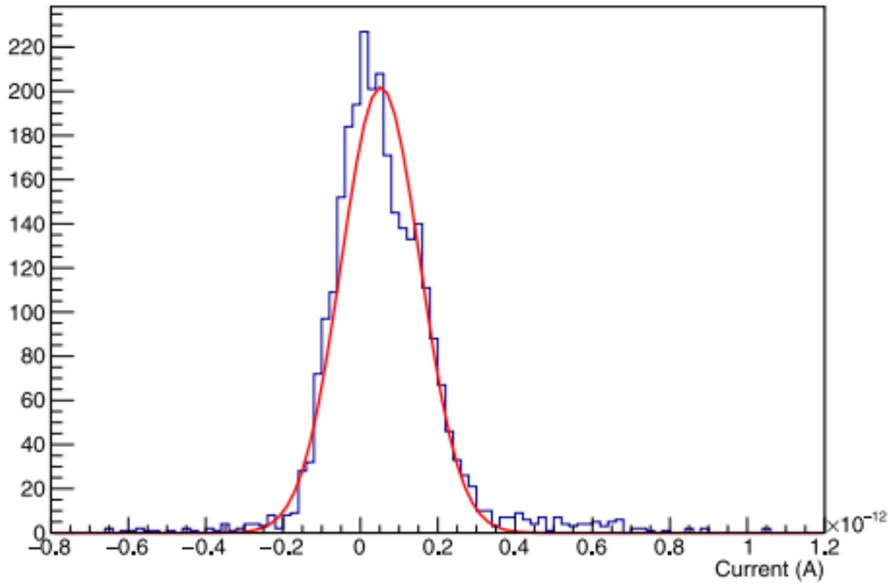
Assembly and calibration of the system







Test sample making → Receiver assembly → System alignment and collimation



Closing the electron gun, the fluctuation of the current from receiver is obtained.

The standard deviation of ~0.4 pA suggests the low noise of the system and the good resolution of the pico-ampere meter

PART 03

Measurements Method and Result

Measurement method

***The transmission coefficient is defined as:**

$$T = \frac{I_P - I_{ped}}{(I_T - I_{ped}) * M}$$

I_p:current passing through graphene sample
I_t: current passing through reference hole
I_{ped}:pedestal current in receiver
M: SiN mesh hole ratio

*According to the error transferring, the uncertainty of T is derived:

$$\sigma_T = \frac{1}{M} * \sqrt{\frac{\sigma_{I_P}^2}{(I_T - I_{ped})^2} + \frac{(I_P - I_{ped})^2\sigma_{I_T}^2 + (I_P - I_T)^2\sigma_{I_{ped}}^2}{(I_T - I_{ped})^4}}$$

Main systematic uncertainties:
1.The fluctuation of current measured by pico-ampere meter;
2.The difference between the size of reference hole and aperture in front of graphene sample ~4%;

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Result of Graphene sample on SiN substrate

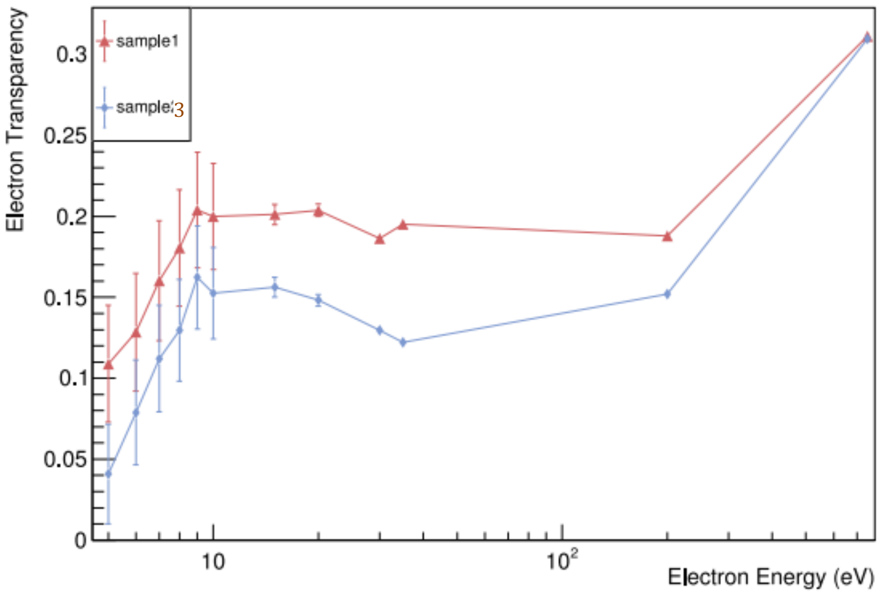


Table 1
Measurement result.

Beam energy (eV)	Pedestal current (nA)	Transmission current			Transmission coefficient	
		Reference hole (nA)	Sample 1 (nA)	Sample 2 (nA)	Sample 1	Sample 2
5	-0.029 ± 0.003	-0.554 ± 0.011	-0.045 ± 0.005	-0.035 ± 0.004	$(11 \pm 4)\%$	$(4.1 \pm 3)\%$
6	-0.032 ± 0.003	-0.64 ± 0.013	-0.054 ± 0.005	-0.046 ± 0.004	$(13 \pm 4)\%$	$(7.9 \pm 3)\%$
7	-0.032 ± 0.003	-0.702 ± 0.014	-0.062 ± 0.006	-0.053 ± 0.005	$(16 \pm 4)\%$	$(11.2 \pm 3)\%$
8	-0.032 ± 0.003	-0.804 ± 0.016	-0.071 ± 0.007	-0.06 ± 0.006	$(18 \pm 4)\%$	$(13.0 \pm 3)\%$
9	-0.031 ± 0.003	-0.89 ± 0.018	-0.08 ± 0.008	-0.07 ± 0.007	$(20 \pm 4)\%$	$(16.2 \pm 3)\%$
10	-0.031 ± 0.003	-1.05 ± 0.021	-0.088 ± 0.009	-0.0745 ± 0.007	$(20 \pm 3)\%$	$(15.3 \pm 3)\%$
15	-0.033 ± 0.003	-2.023 ± 0.004	-0.145 ± 0.001	-0.12 ± 0.001	$(20.1 \pm 0.6)\%$	$(15.6 \pm 0.6)\%$
20	-0.033 ± 0.003	-3.7 ± 0.007	-0.242 ± 0.002	-0.185 ± 0.002	$(20.4 \pm 0.4)\%$	$(14.8 \pm 0.4)\%$
30	-0.036 ± 0.004	-8.97 ± 0.018	-0.502 ± 0.004	-0.36 ± 0.004	$(18.64 \pm 0.2)\%$	$(12.96 \pm 0.2)\%$
200	-0.016 ± 0.002	-21.4 ± 0.043	-1.14 ± 0.008	-0.926 ± 0.009	$(18.79 \pm 0.1)\%$	$(15.21 \pm 0.2)\%$
750	-0.016 ± 0.002	-10.45 ± 0.021	-0.926 ± 0.006	-0.921 ± 0.009	$(31.31 \pm 0.2)\%$	$(31.09 \pm 0.3)\%$

*Raman spectroscopy confirmed the integrity of the graphene on each sample.

*The transmission rate of samples 1 and 3 has the same trend with the increase of electron energy.

*The graphene samples have a certain proportion of folds, layers and contamination.

*The differences between different samples are due to the different quality of the graphene samples.

Effective aperture correction

*The transmittance of samples 1 and 3 at 750 eV is the same
*Repeat the experiment, same results

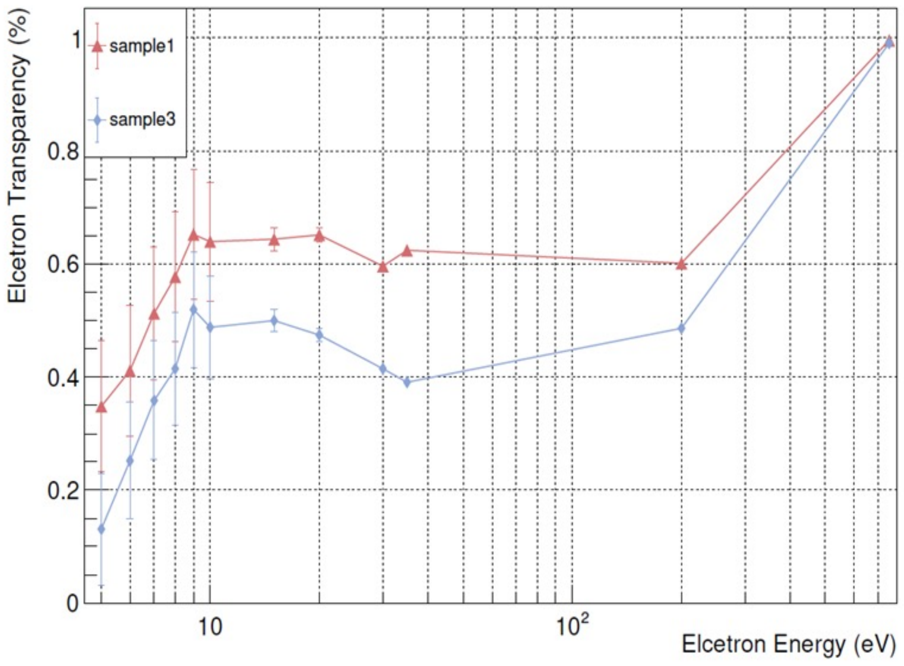
*Assuming that the electron transmission rate of a single layer of graphene is f_E , with each additional layer of graphene, the electron penetration coefficient is reduced to f_E times the original [5]

$f_{750eV} = {f_{750eV}}^{n}$, that is , f_{750eV}=100%

*The transmission rate corrected according to the effective pore proportion is:

$$X_E = \frac{T_E}{31\%}$$

The measured transmittance of 750eV is 31%



The electron transparency after effective aperture correction

***We propose the reason is that the charge effect of the edge of SiN hole reduces the effective aperture to 31%.**

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Data Fitting

* Assuming that the proportion of graphene monolayer on the sample is a, the overall graphene transmittance is

$$T_E = f_E \times a + f_E^n \times (1 - a)$$

- n (quality factor) is the combined effect of multiple layers of graphene and pollution.

* Taking the electron penetration rate f_E of monolayer graphene at different energies, the proportion a of monolayer graphene on the sample and the quality coefficient n as parameters, the chi square function was constructed:

$$\chi^2 = \sum_{i=1}^{num} \frac{(f_E \times a + f_E^n \times (1 - a) - T_E)^2}{\sigma_T^2 + \sigma_h^2}$$

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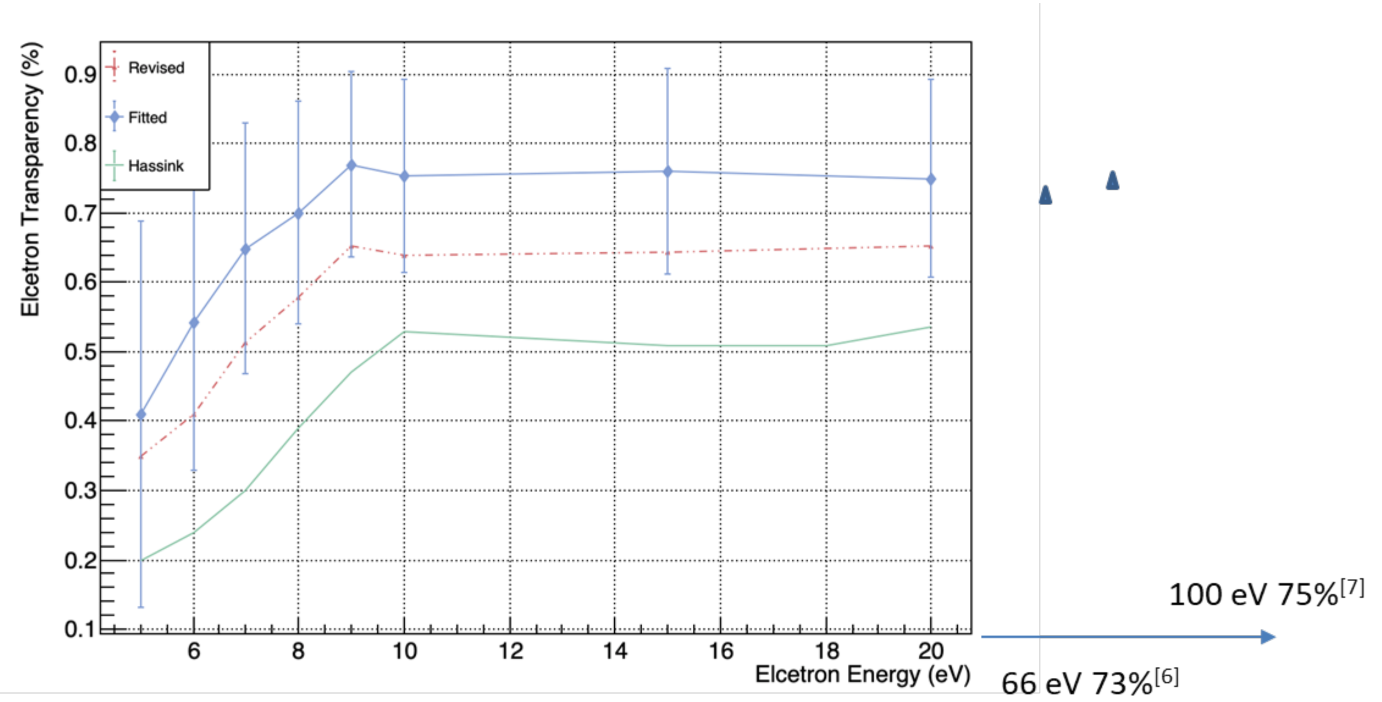
Fitted Result of Monolayer Graphene on SiN substrate



1.The transmittance increases with the increase of energy between 5 and 10 eV.
2. The transmittance remains stable between 10 and 20 eV.
3.Monolayer graphene has a transmittance of about 40% near 5 eV.

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PART 04

Summary

Summary

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* We have experimentally measured the transmittance of graphene to EV-scale electrons.

*The electron energies under 10 eV, the transmission coefficient increases with the electron energy, and the electron energies between 10 eV and 200 eV, the transmission coefficient remains stable at ~70%.

The transmission coefficient of 5 eV electrons to monolayer graphene is about 40%~50%.

*It provides the basis for its application of the IBF suppression in the TPC.

In the future, we should pay attention to big problem:

Large area graphene preparation with mesh-structure and application into TPC.

Thank you for listening

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