DMM & TMM: the Double and Triple Micro-Mesh gaseous structures for high gain and low ion-backflow purposes

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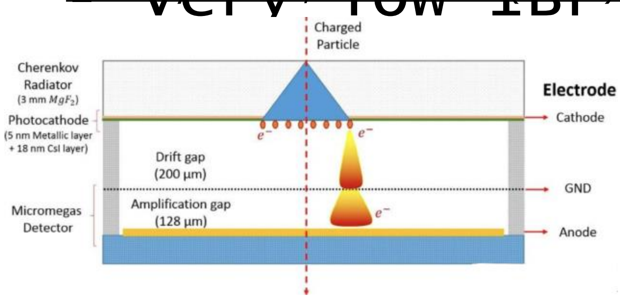
Outline

- Motivation
- Double Micro-Mesh gaseous structure
  - Design and Fabrication
  - Performance Characterization
  - Optimization for further IBF suppression
- Triple Micro-Mesh gaseous structure
  - Design and performance study
- Summary

Motivation : GPD

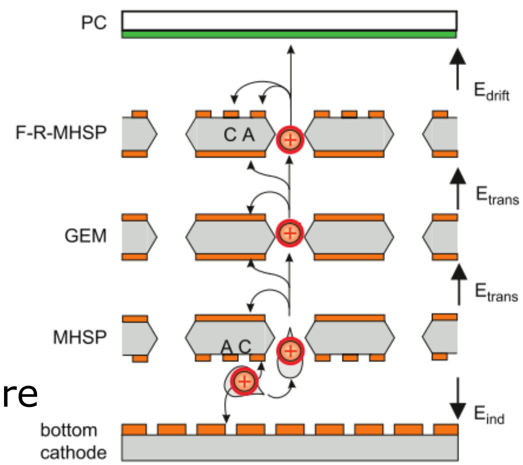
- Gaseous Photon Detectors (GPD) with MPGD
  - large area, high spatial and timing resolution, resistant to magnetic field, IBF suppression, low cost …
- Challenges
  - High gain: to be sensiti photons
    - UV light：CsI, ~mC/cm^2
    - Visible light：Bi-alkali, ~μC/cm^2
  - Very low IBF

J. Va'vra et al., NIM A 387 (1997) 154-162.
T. Moriya et al., NIM A 732 (2013) 269-272.



PIC-SEC

F-R-MHSP+GEM+MHSP



Gas-PMT

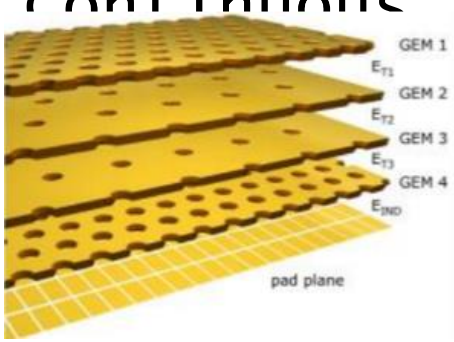
IBF: ~0.03%
Complex structure

A. Lyashenko et al. , NIM A 598(2009) 116-120

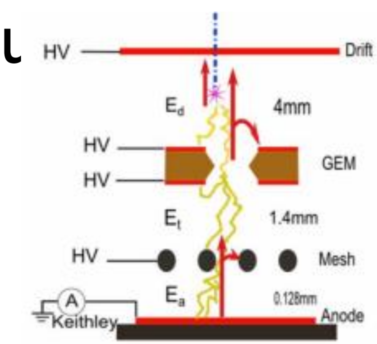
Motivation: TPC

- Application of TPC in high-rate environments: ALICE upgrade, ILD, CEPC …
  - Very low IBF is the key: to minimize drift field distortion caused by ion space charge
  - Continuous readou … rate

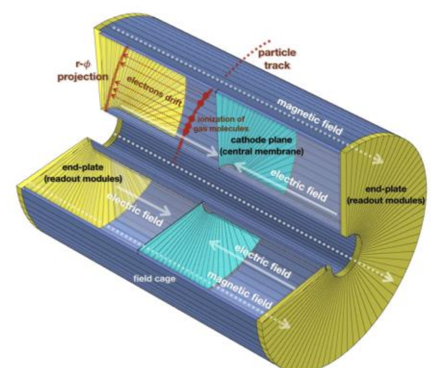
ALICE



Quadruple GEM, IBF < 1%



CEPC

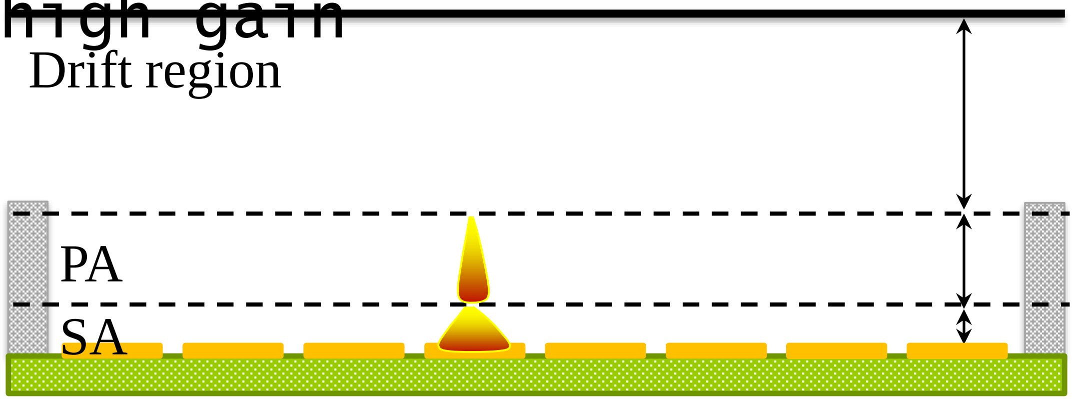


GEM+MM, Gain×IBF<~5
IBF <~ 0.1% required

MPGD is the only solution so far. The IBF still need to be further reduced.

DMM Design

- DMM: Double Micro-Mesh gaseous structure
  - Hole-type → mesh-type : to strongly reduce IBF
  - Double mesh: cascading avalanche for high gain

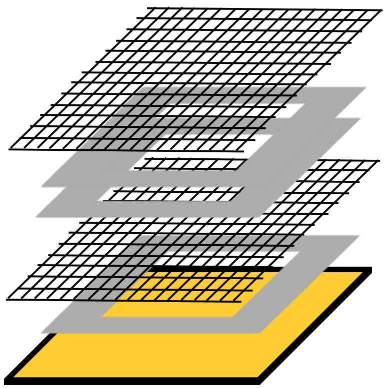


Stacked two meshes

- Gap between the stacked meshes: 200-300um, serving as pre-amplification (PA)
- Gap between the bottom mesh and anode: 50-100um as secondary amplification (SA)
- Allows to achieve very high gain, and yet significantly reduce ion back-flow.

DMM Fabrication

- DMM is fabricated with the thermal bonding method developed at USTC, which provides a concise and etching-free process for manufacturing Micromegas detectors



PA Mesh

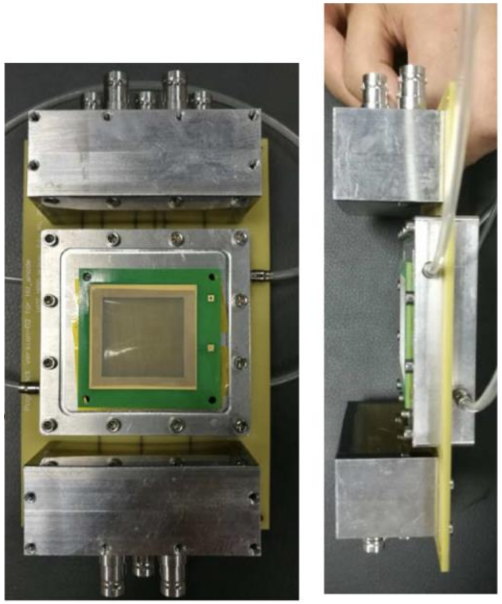
Thermal bonding film χ 2

SA Mesh

Thermal bonding film χ 1

Anode PCB

The schematic diagram of DMM fabrication

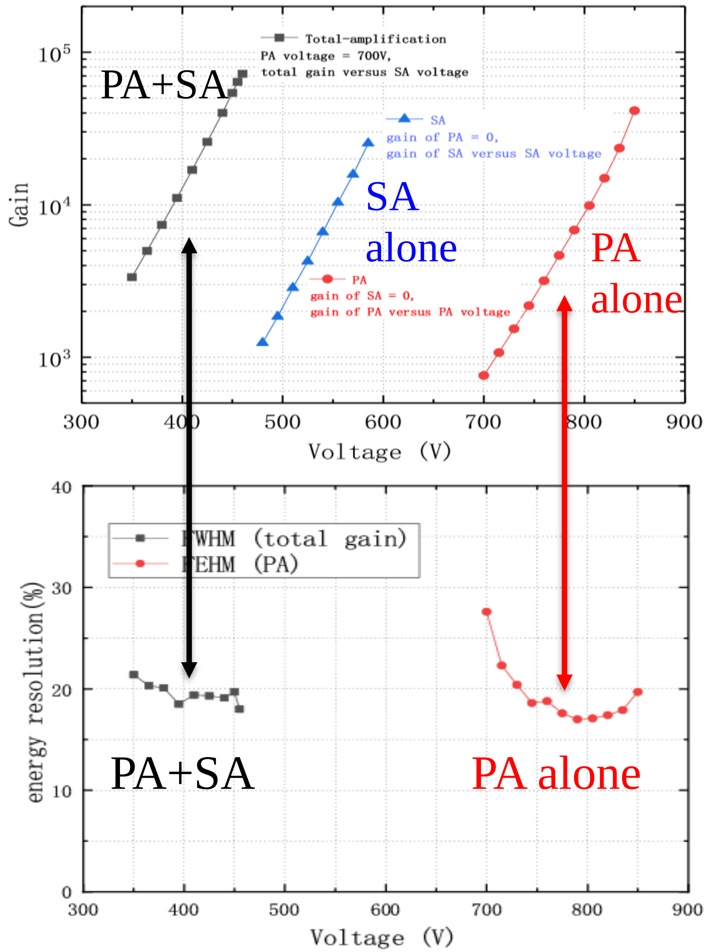


A 2.5cm×2.5cm DMM prototype

More details on thermal bonding method, see Jianxin's talk on 26/06 morning:
"Production and performance of Micromegas detectors using thermal bonding method"

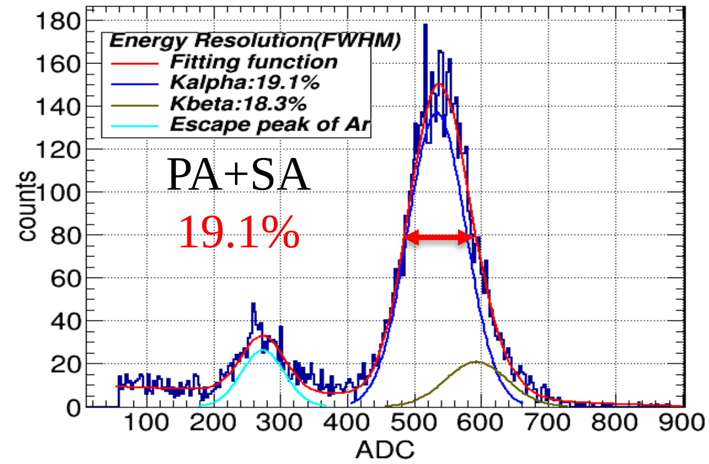
Gas Gain and Energy Resolution with ^{55}Fe

Gain: PA, SA and combined



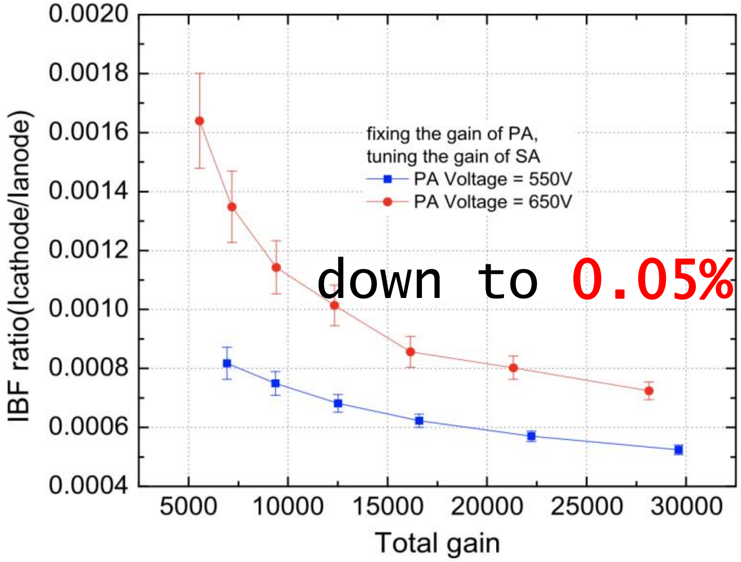
Resolution: PA and PA+SA combined

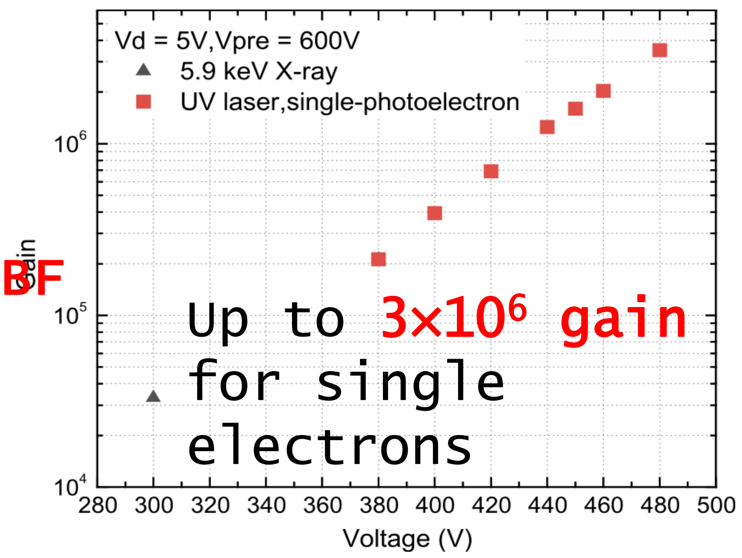
A typical ^{55}Fe energy spectrum



- Combined gain can reach up to 7×10^4 for 5.9 keV X-rays.
- Combined resolution remains almost constant and is close to PA-alone resolution, suggesting a close-to-full collection of primary electrons for the high-voltage configurations we used.

Previous results and validation





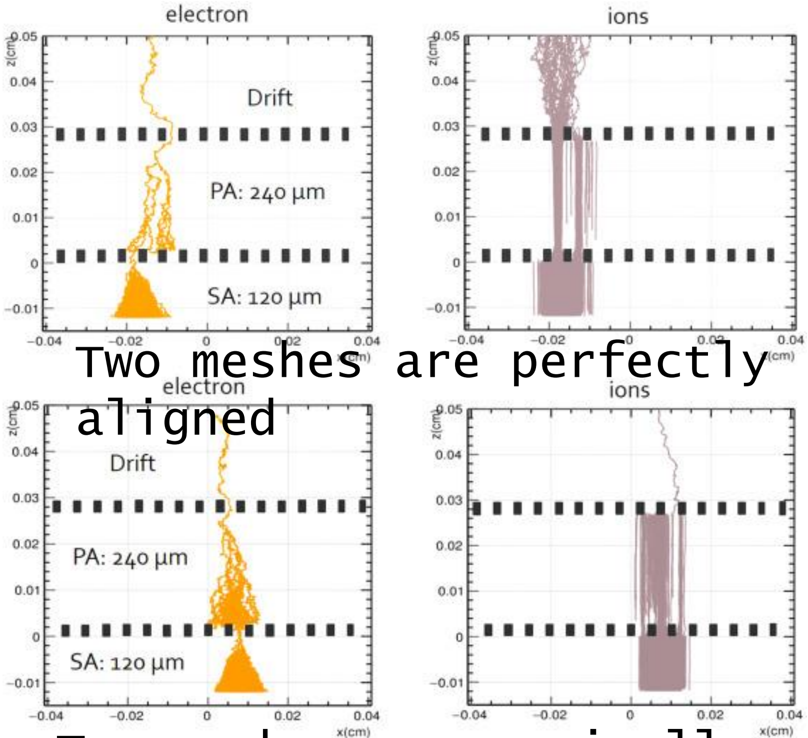
- Gain measured with X-ray energy spectrum ($Q_{full\text{-}energy\ peak}/Q_{Primary}$) is consistent with $I_{Anode}/I_{Primary}$.
- No ion space charge effect is confirmed in the DMM test.

More details:

- *A high-gain, low ion-backflow double micro-mesh gaseous structure for single electron detection， NIM-A , 889 (2018) 78–82.*
- *https://indico.cern.ch/event/757322/contributions/3387079/attachments/1840422/3017748/DMM-MPGD2019.pdf*
- *Also in backup slides*

Can we further lower the IBF?

- Obviously, the IBF is depend on the geometry of the detector structure, in which the alignment, density, distance etc. of two meshes can be optimized.



Two meshes are perfectly aligned

Two meshes are maximally mis-aligned

This reference investigation suggests to increase the ion cloud size (σ) and decrease the mesh pitch (l)
➔can be achieved by enlarging the distance and the wire density of the two meshes

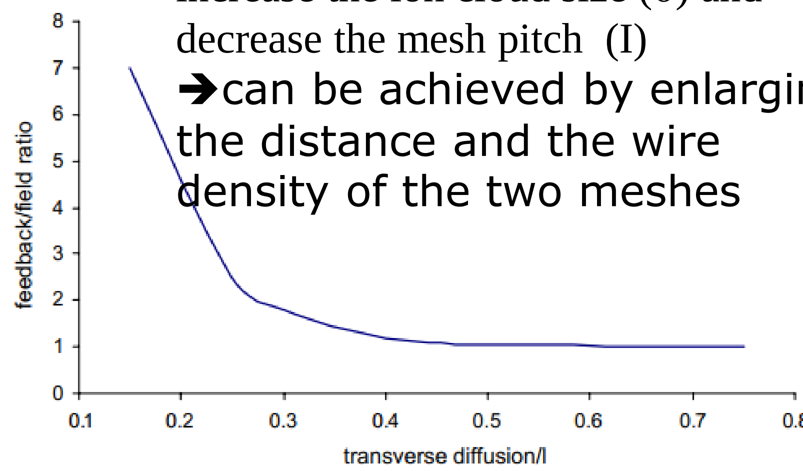
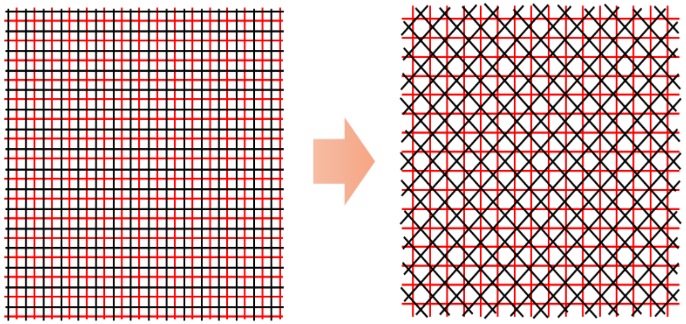


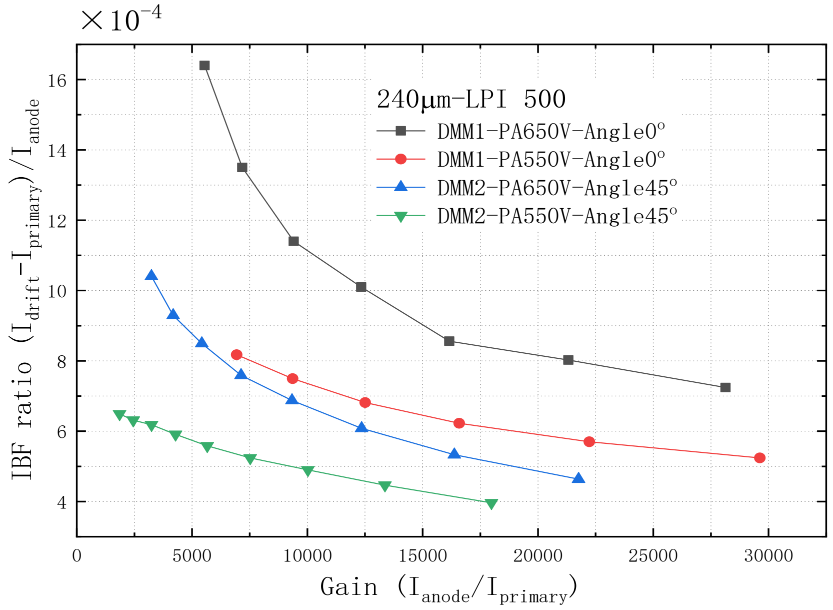
Fig. 4. Computed value of $\alpha\beta$ as a function of σ/l.

Colas P, Giomataris I, Lepeltier V. Ion backflow in the Micromegas TPC for the future linear collider, Nuclear Instruments and Methods in Physics Research Section A, 2004, 535(1-2): 226-230.

Optimization for Low IBF

Detectors	Cross Angle (°)	PA gaps (μm)	LPI
DMM1	0	240	500
DMM2	45	240	500
DMM3	45	180	500
DMM4	45	240	650

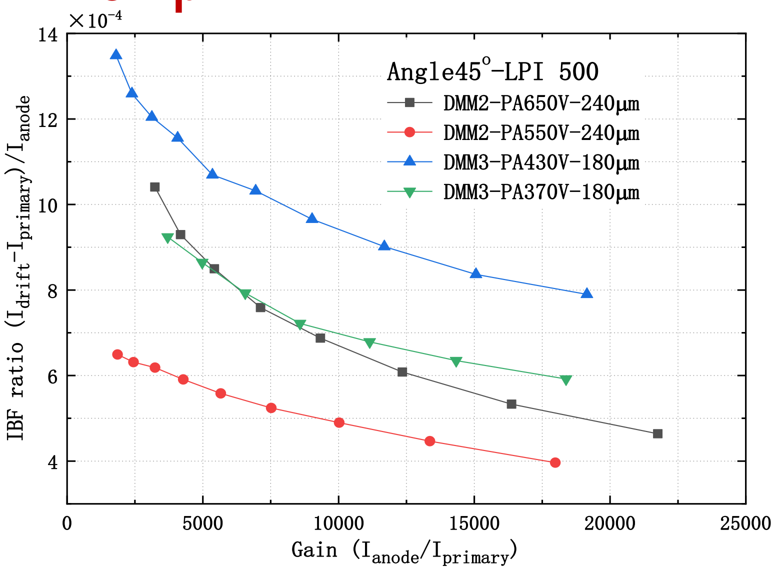


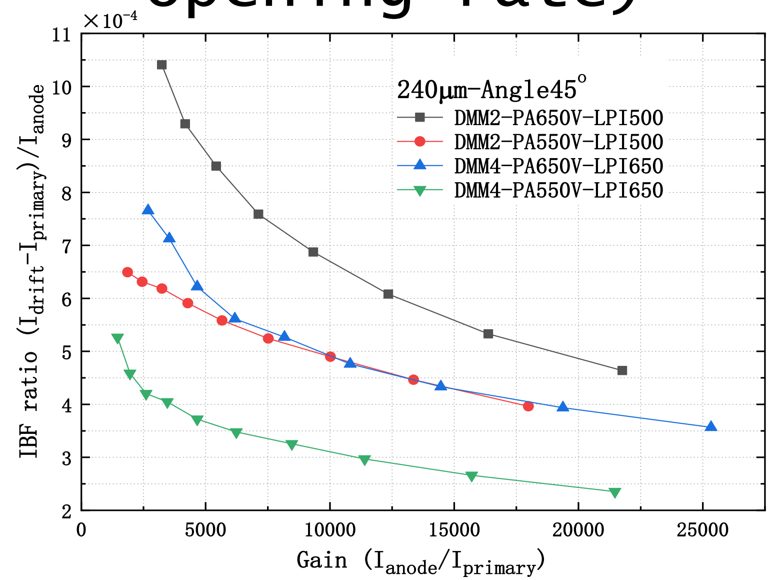


It's impractical to make any precise alignment of the two meshes. So setting the two meshes with a crossing angle is a practical way to ensure their mis-alignment.

Optimization for Extremely Low IBF

PA gap: from 180 to 240 µm	500 vs. 650 LPI (same opening rate)





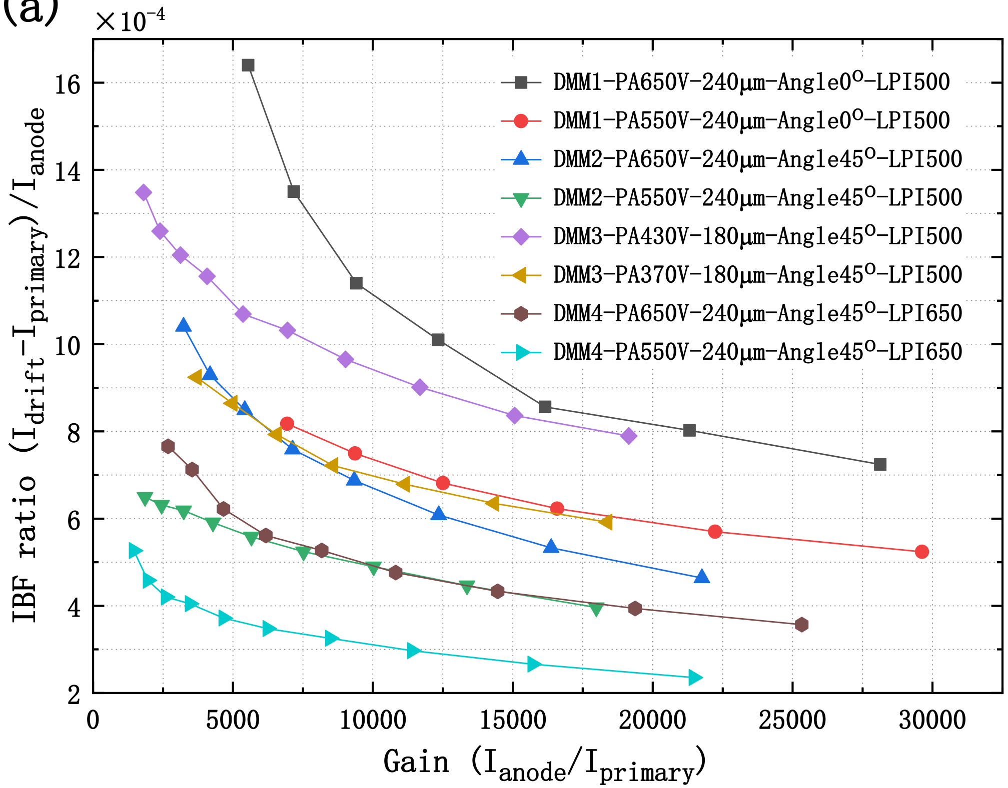
Larger gap increase the transverse diffusion of avalanche

Higher mesh density decrease the mesh pitch

Both of these increase the σ/l value, optimizing the IBF as a consequent.

Optimization Outcome For DMM

(a)

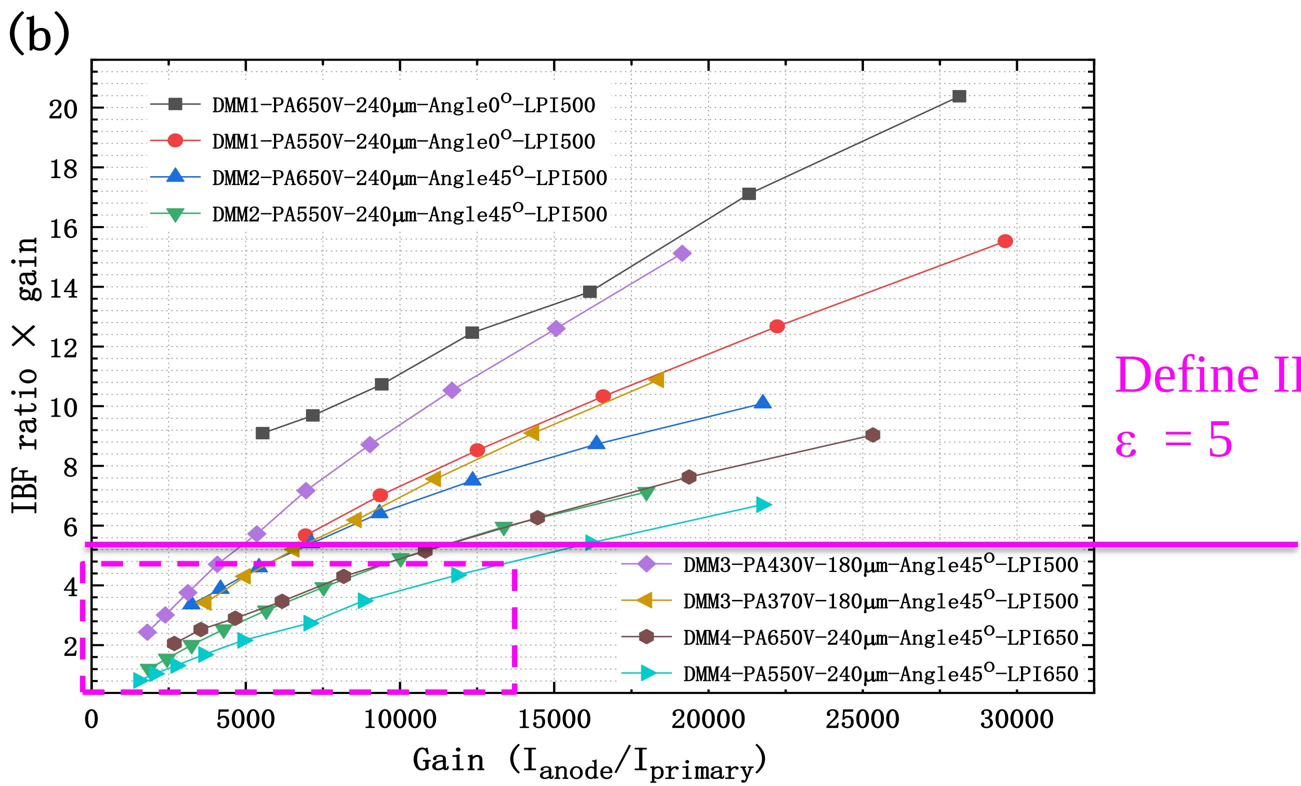


To push IBF down to an extremely low level:

- ✓ low PA electric field
- ✓ large PA gap
- ✓ high mesh density
- ✓ crossing mesh setting

A IBF ratio down to ~0.025%, which has been improved with a factor of 2 compared with that before optimization.

Optimization Outcome for DMM

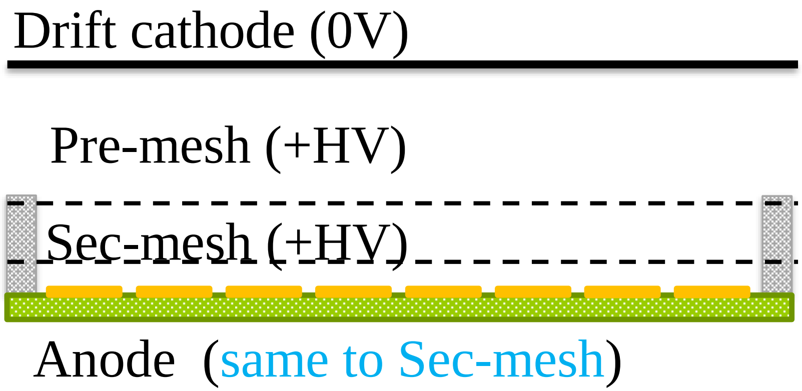


Define IBF ratio ×gain as ε:
ε = 5

This result fulfill the requirement of ε < 5 in some high rate TPC (CEPC-TPC), even operated in higher gain of >10000 is possible to improve the S/N.

Can the IBF be lower?

- For the case of DMM, when we set PA at 550V and switch off SA, the $I_{drift}/I_{primary}$ was measured at ~1.3



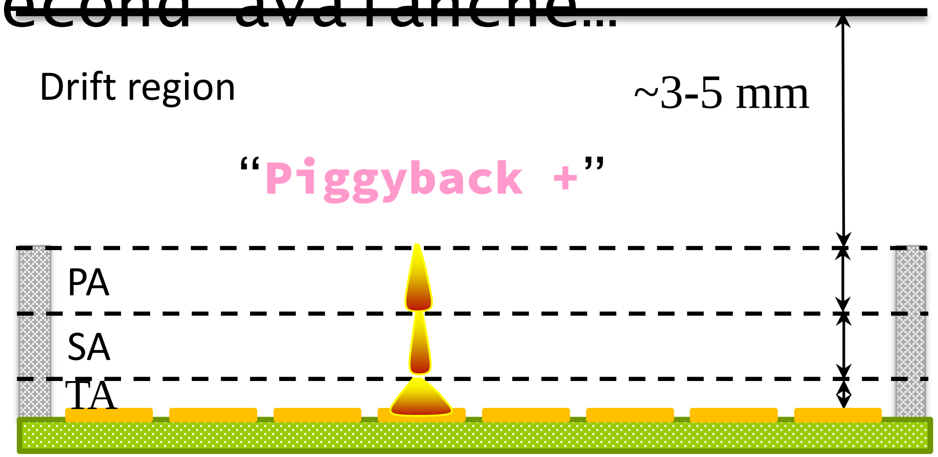
➔The PA only contributes ~0.3 for the ε factor, the SA dominates the total IBF

- So, adding another mesh on the DMM to suppress the SA ions is a easy option.

➔Let's go to TMM

TMM Design

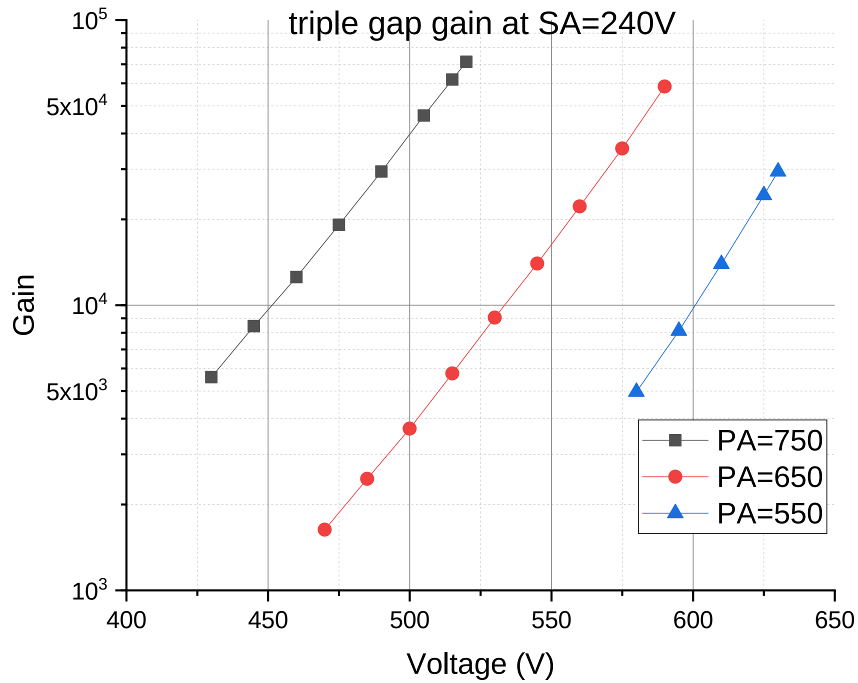
- TMM: Triple Micro-Mesh gaseous structure
  - One more mesh on the DMM
  - More stable gain, lower IBF from second avalanche…

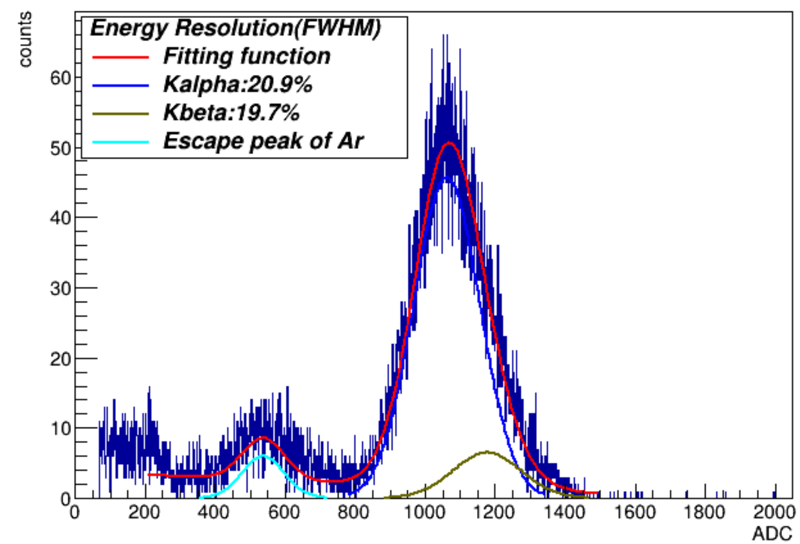


Stacked three meshes

- Gap between the 1st and 2nd meshes: 200-300um, serving as pre-amplification (PA)
- Gap between the 2nd and 3rd meshes : 200-300um as secondary amplification (SA)
- Gap between the bottom mesh and anode: 50-100um as secondary amplification (TA)

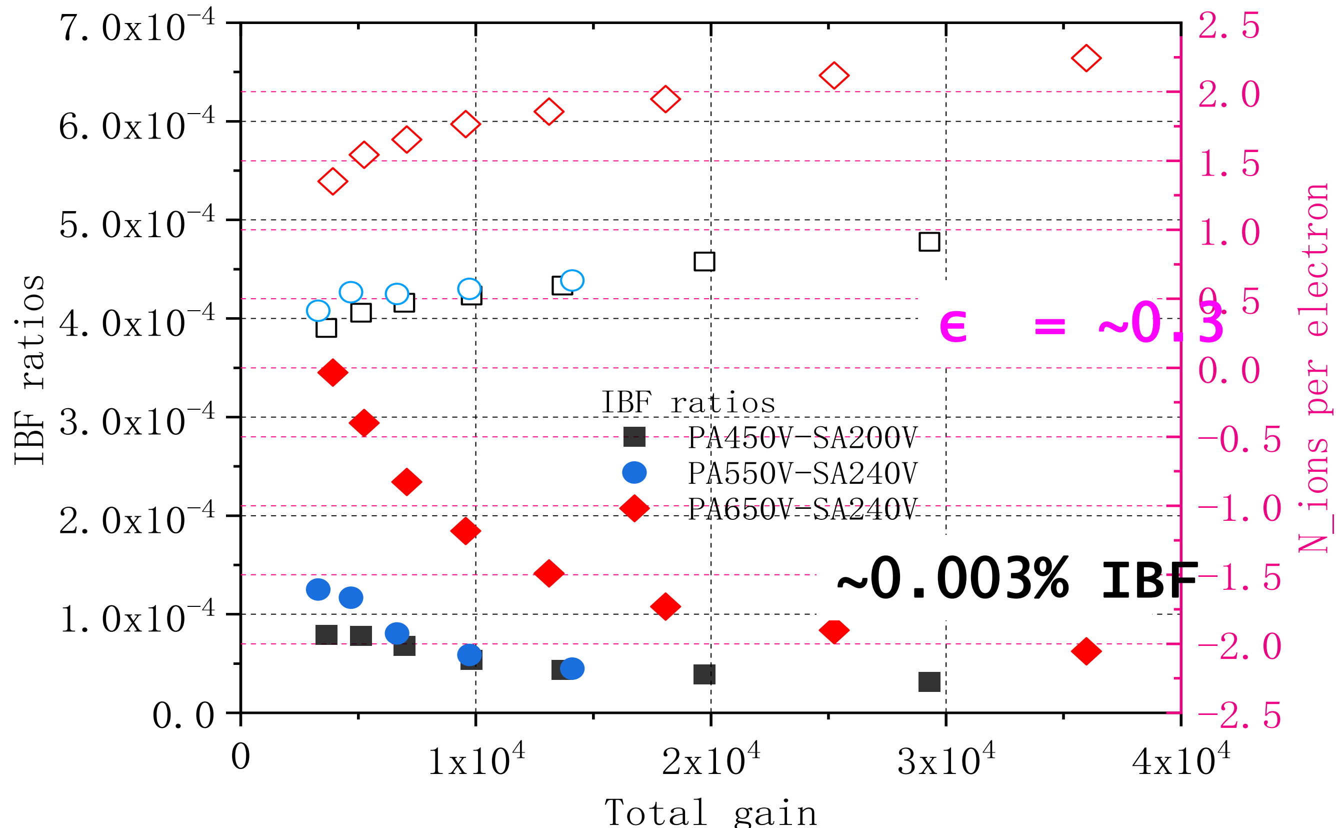
Gain and energy resolution





- Gas gain reaches up to 7×10^4 for 5.9 keV X-rays
- Energy resolution at ~21% (FWHM) indicates a high collection efficiency of the primary electrons

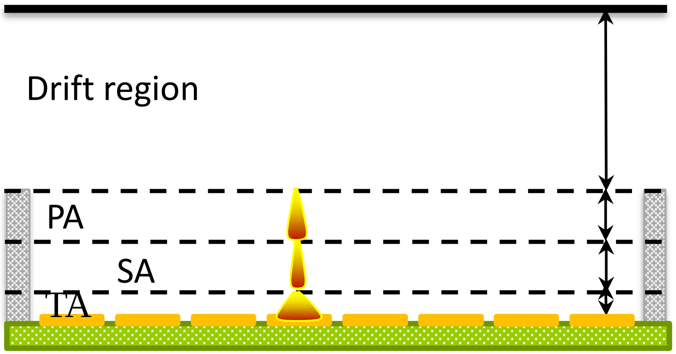
IBF measurement for TMM

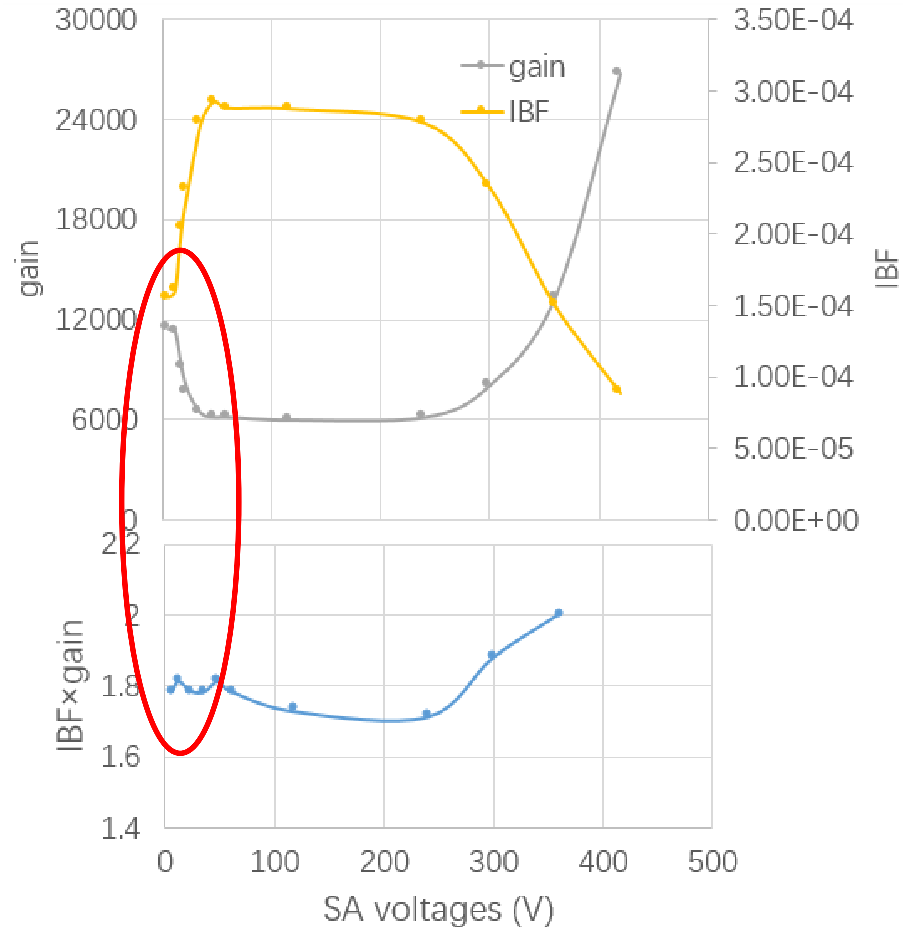


The back-flow ions (at **ε = ~0.3)** is mainly from PA, concluding that the IBF can not be further reduced by adding more meshes, the TMM reaches the lowest IBF level for the mesh-type structure.

To optimize

Combined gain = PA gain × SA trans × SA gain × TA trans × TA gain





PA and TA voltages are fixed at 650V and 530V, this plot shows the combined gain, IBF and their product change with the variation of SA voltages

Summary

- Developed the DMM &TMM featuring high gain and low IBF
- Demonstrated the performance of DMM &TMM with small-size prototypes:
  - Gain: 7×10^4 for 5.9 keV X-rays and 3×10^6 for single electrons.
  - IBF ratio: down to ~ 0.03% for DMM, ~ 0.003% for TMM
- Potential applications
  - Gaseous photon detectors
  - High-rate TPC readout
  - Many others…

Summary

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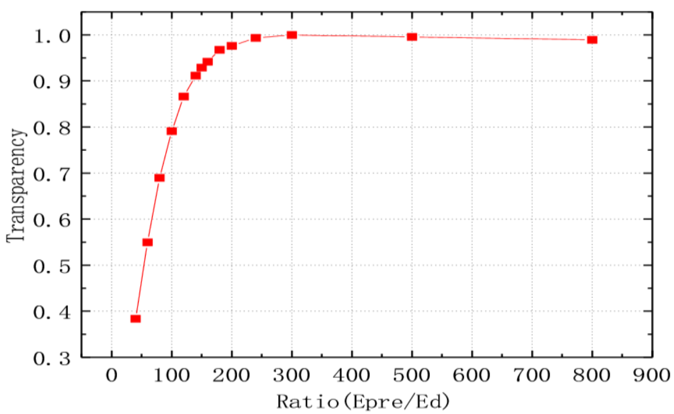
Thank you!

Back-up

Electron Transparency

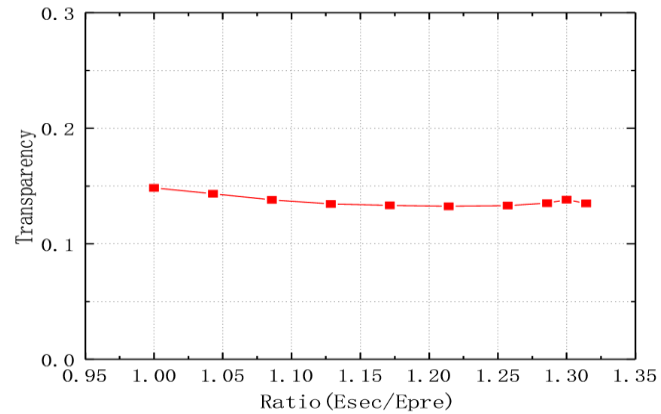
- Transparencies for electrons passing through PA and SA meshes are extracted by measuring PA, SA and total (PA and SA combined, DMM) gas gains
  - Combined gain = PA gain × SA trans ×

PA relative transparency



E_{PA}/E_{drift} is set to 200 to maximize transparency most of the time.

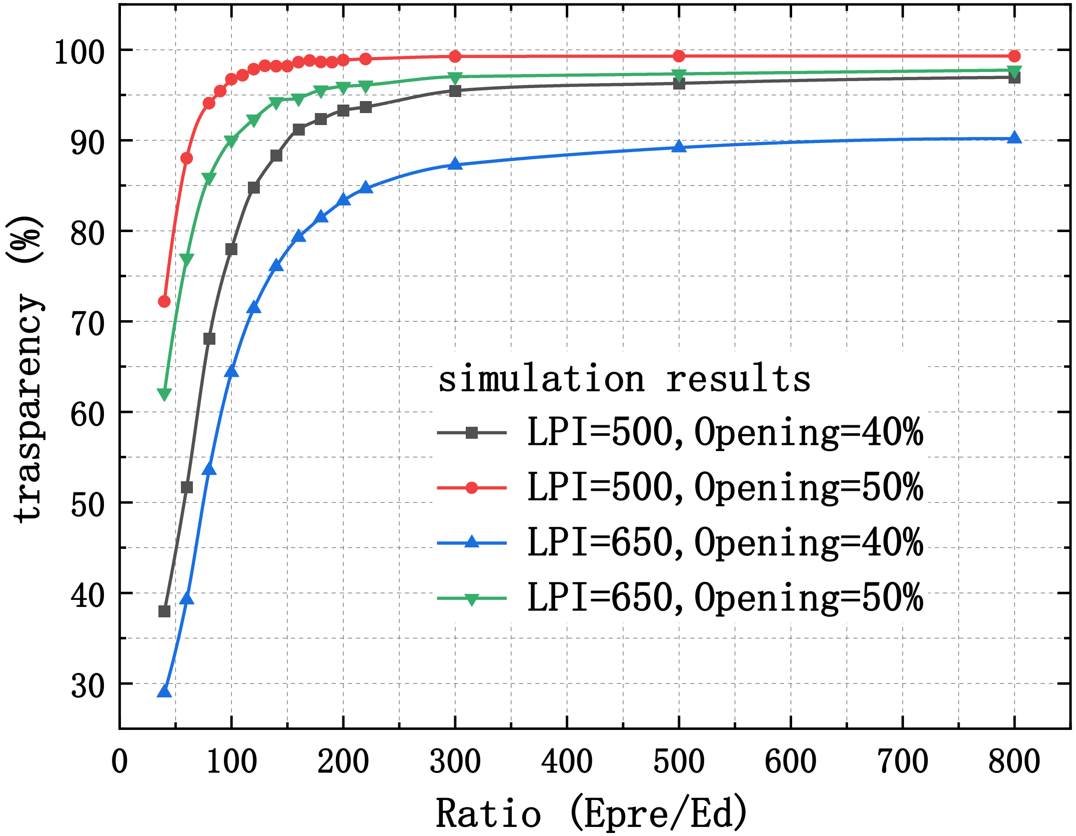
SA transparency



SA trans ~ 15% @ E_{SA}/E_{PA} ~ 1

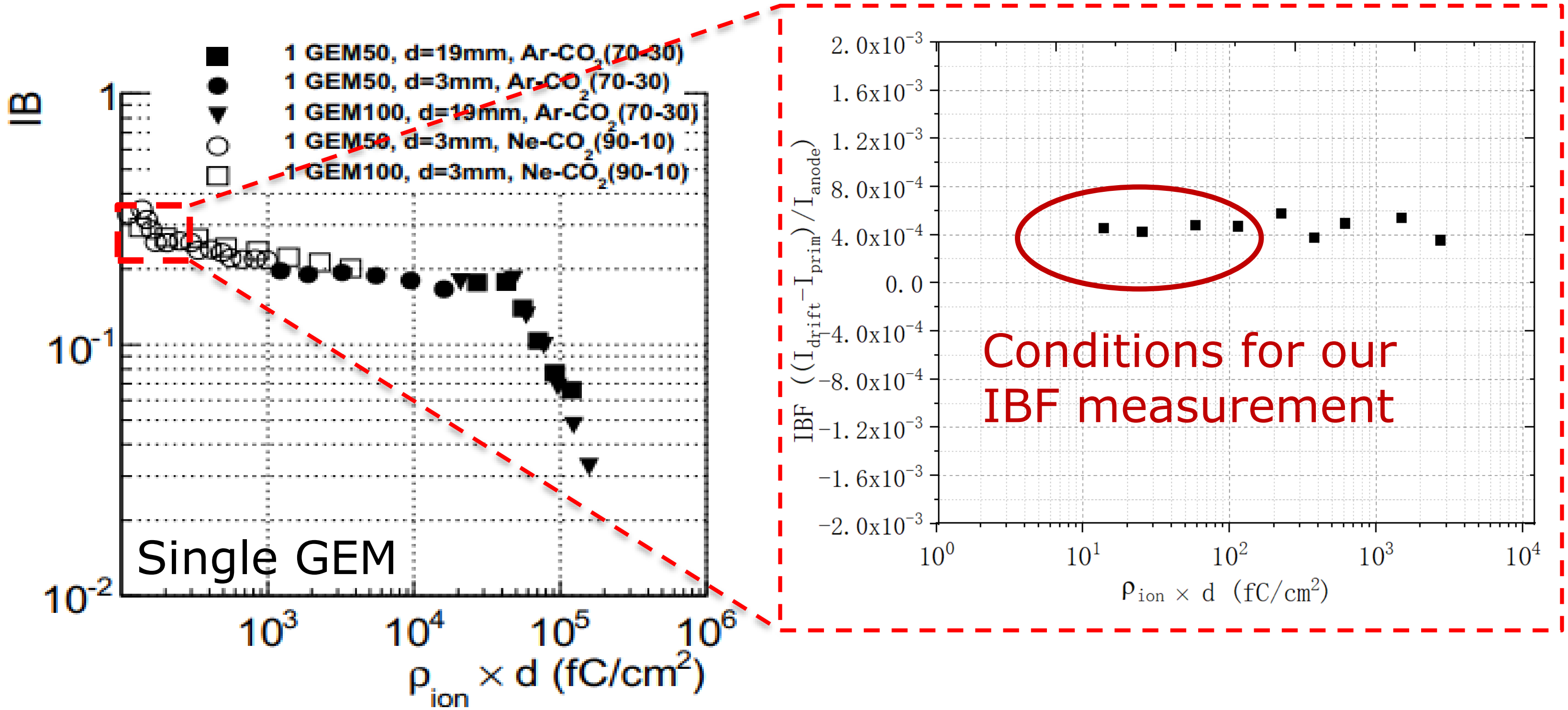
Electron Transparency

Simulation study on Electron transparency with different mesh density



Ion Space-Charge Effect

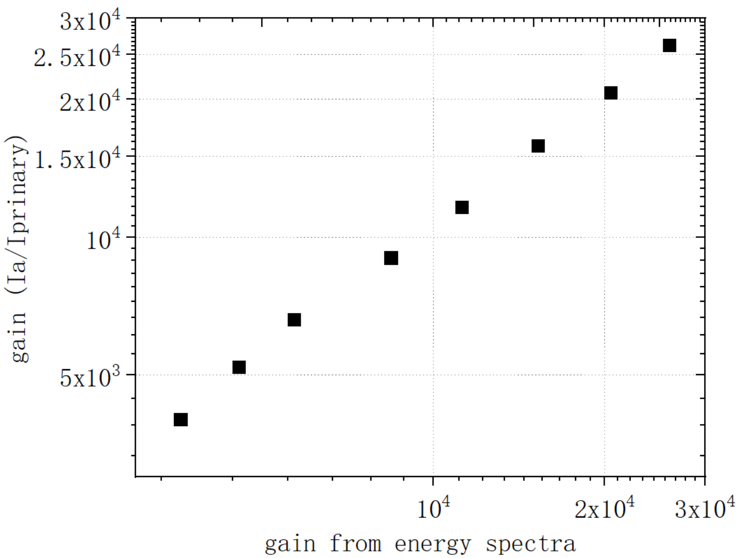
M Ball *et al* 2014 *JINST* 9 C04025



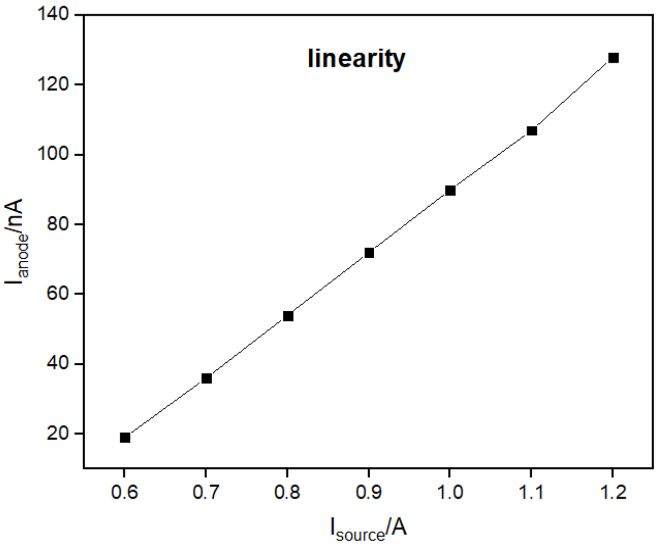
- Our IBF measurements are reliable in terms of ion space-charge effect (impact is negligible).

Validation of IBF Measurement

$Q_{full\text{-}energy\ peak}/Q_{Primary} = I_{Anode}/I_{Primay}$



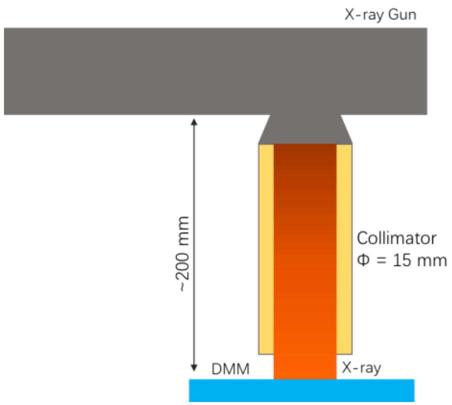
no gas gain saturation



- Gain measured with X-ray energy spectrum ($Q_{full\text{-}energy\ peak}/Q_{Primary}$) consistent with I_{Anode}/I_{Primay}
- I_{Anode} stays proportional to X-ray intensity in a rather wide range, suggesting no gas gain saturation in the IBF measurement.

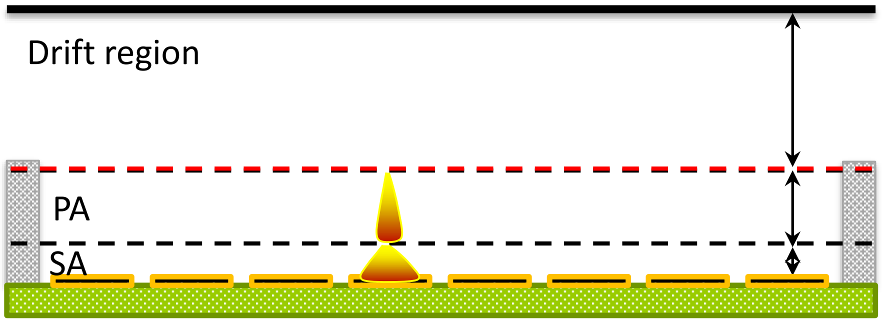
- IBF ratios measured with 55Fe and X-ray tube are consistent

Performance Characterization

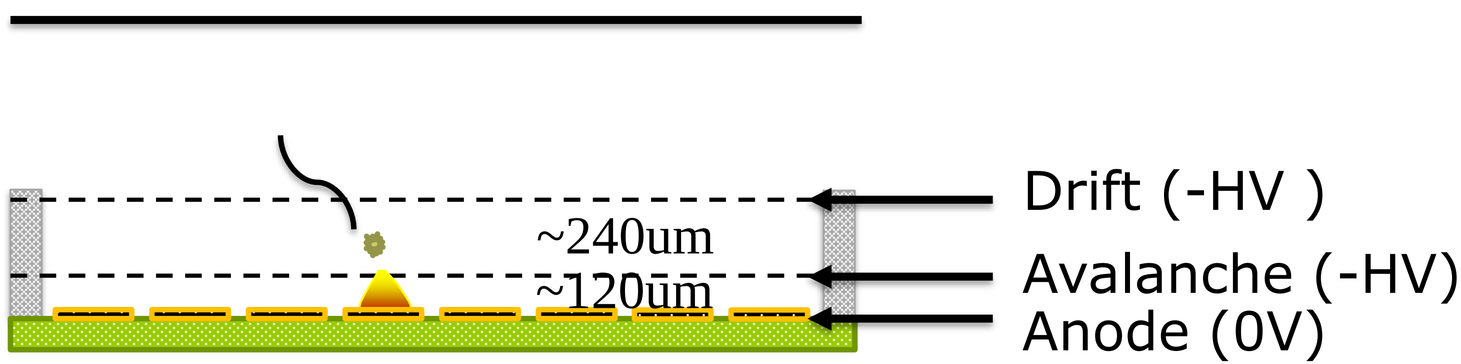


IBF measurement setting

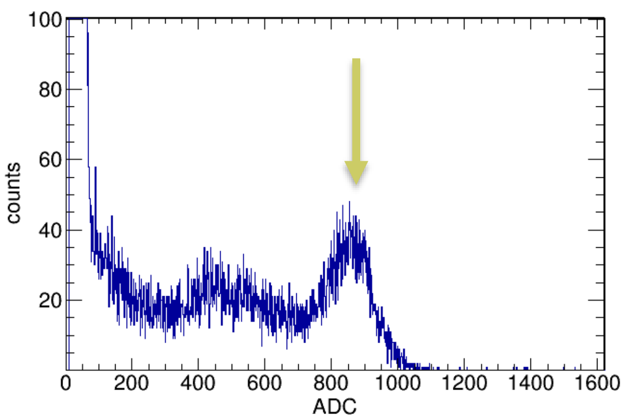
- DMM with Ar (93%) + CO_2 (7%)
  - Electron transparency
  - Energy resolution and gas gain
  - Ion back-flow ratio
- DMM with Ne (80%) + CF_4 (10%) + C_2H_6 (10%)
  - Single photon electron response



Sec-amplification (SA)

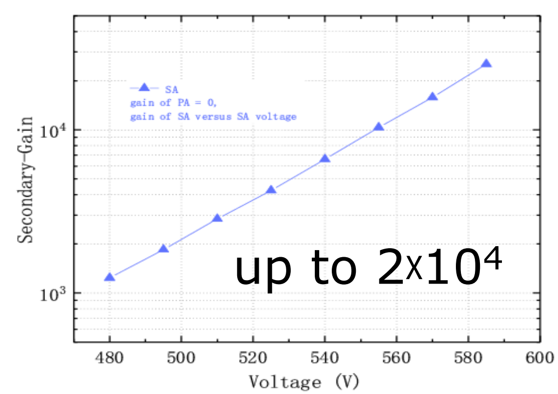


Full energy peak due to the lateral angle
photoelectrons and Auger electrons



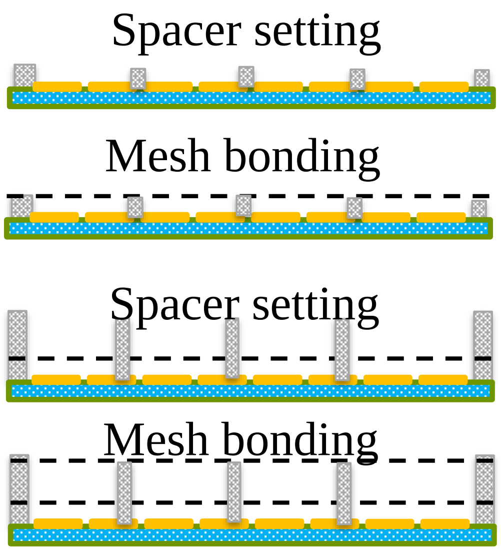
The transparency should be similar to PA's, since their have the same mesh type.

Gain VS avalanche voltages

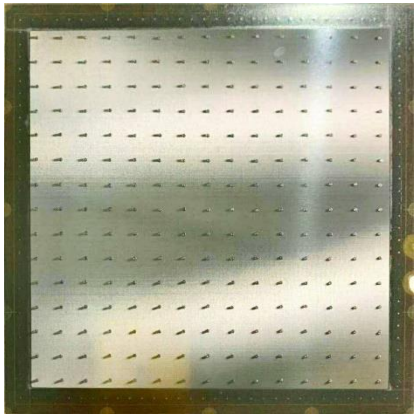


Towards large area

- It is a crucial issue for the DMM (TMM) is to make a large area for real experiments
- Thermal bonding method open the door to make this complex fabrication



Thermal bonding

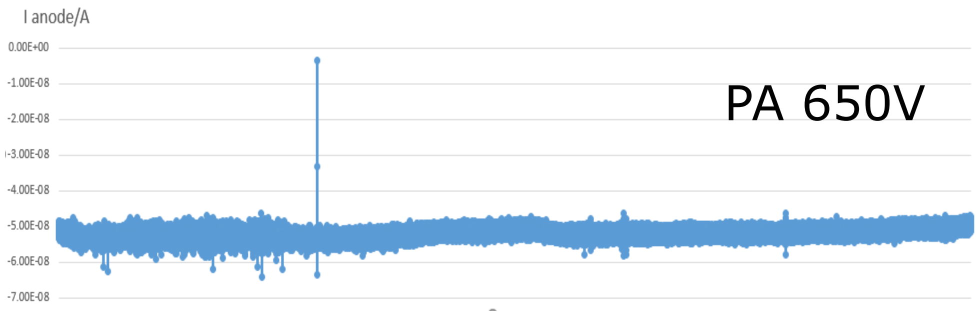


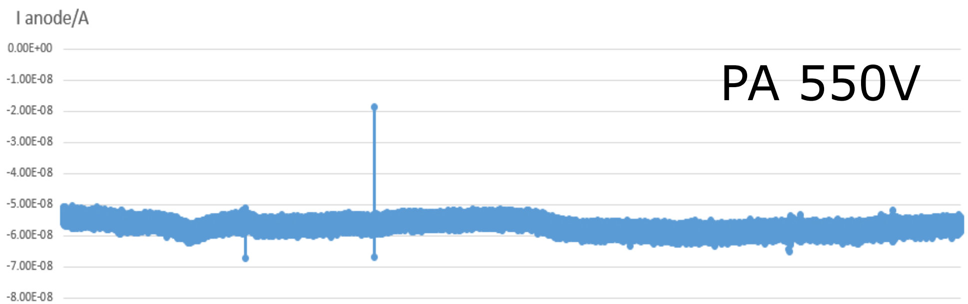
A 150mm ×150mm DMM prototype

Long-Term Stability

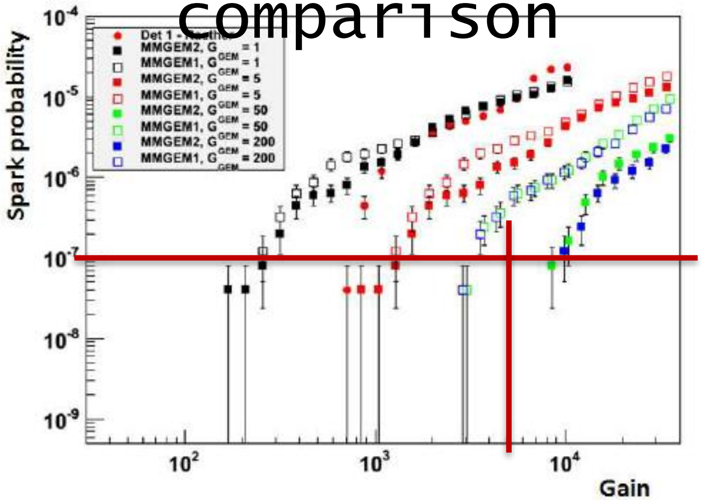
DMM: 240μm- 45^0 - LPI650

~24 hours of X-ray





Reference for comparison



2012 JINST 7 C06009

Spark probability < 10^{-9}