



基于DMM的极低正离子反馈研究

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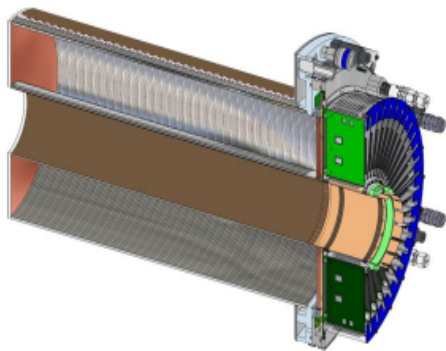
目录

- 为什么要低离子反馈 (IBF)
 - 高计数率TPC
 - 气体光电探测技术
- 双层微网探测器 (DMM)
 - 原理与性能
 - 极低IBF测量方法验证
 - 极低IBF的优化
- 小结与展望

为什么要低离子反馈

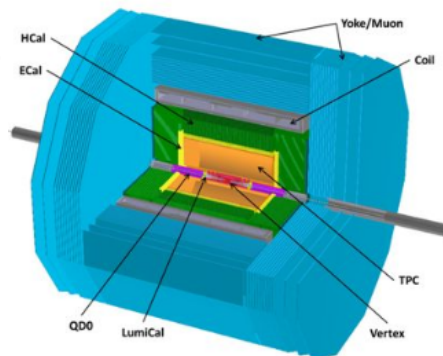
■ 高计数率TPC

- Space-charge引起漂移场畸变
- 传统gating方式, 引入死时间, 最高能到~kHz

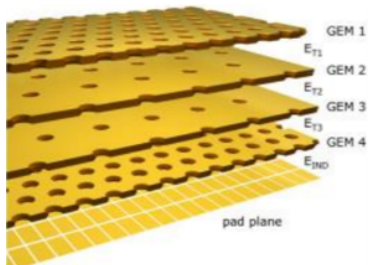


CEPC-TPC, also
~0.1%IBF

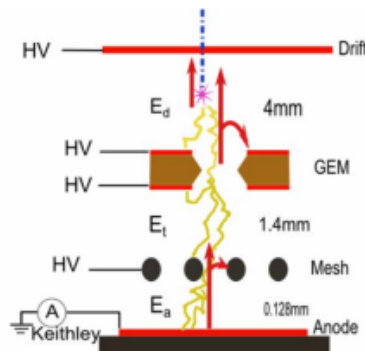
ILC-TPC: <0.1%IBF
required



□ 采用多层GEM或Hybrid结构



多层GEM
<0.3%IBF



GEM +Micromegas
<0.2%IBF

为什么要低离子反馈

■ 气体光电探测技术

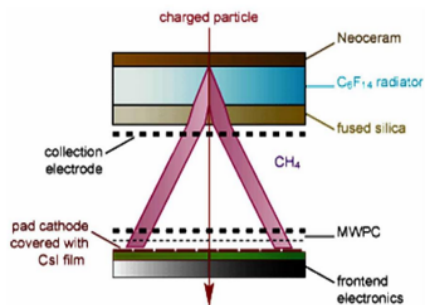
□ 优势与应用：大面积、强磁场环境、高计数率、位置灵敏、低成本…

◆ 科学研究:大型谱仪

◆ 医学诊断：正电子断层扫描（可与核磁共振成像同时）

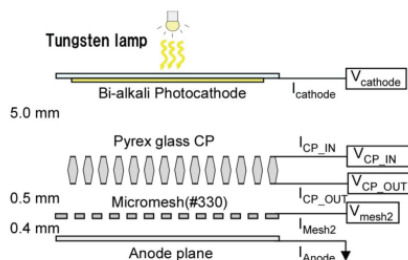
◆ 火灾监测：大规模铺设

□ 紫外光：CsI光阴极，耐IBF 轰击能力 $\sim \text{mC}/\text{cm}^2$

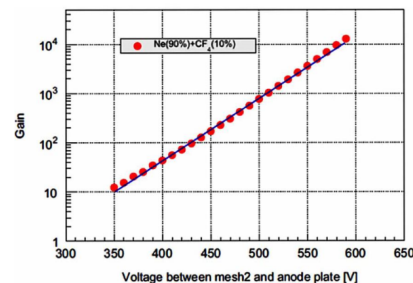


实验谱仪名称	CsI光阴极数（总面积/平米）	完成状态
ALICE	42 (10)	运行
COMPASS	16 (5.8)	运行
HADES	18 (1.5)	完成
HALL-A	3 (0.7)	完成
NA44	2 (0.4)	完成
STAR	4 (1)	完成

□ 可见光：碱基光阴极耐IBF 轰击能力 $\sim \mu\text{C}/\text{cm}^2$ ！



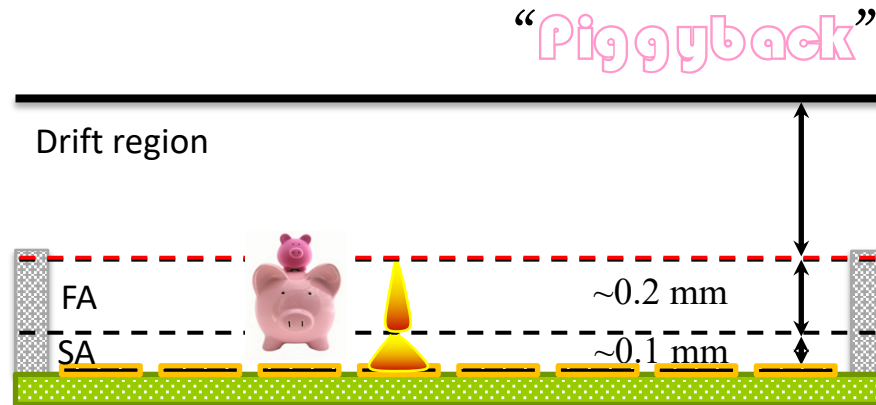
通过降低增益，降低IBF，但是 $<10^5$ 的低增益无法满足单光电子探测！



双层微网探测器 (DMM)

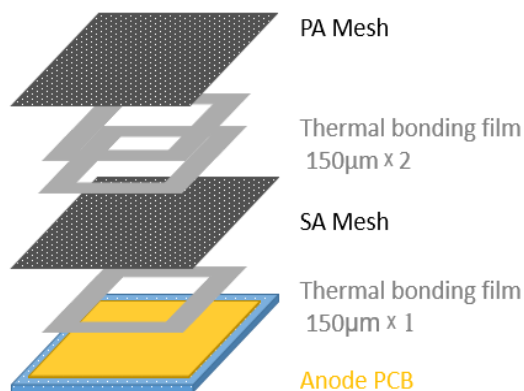
Double Micro-Meshes gaseous structure (DMM)

- Hole-style → mesh-style to reduce the IBF
- Double or multi-avalanche for high gain

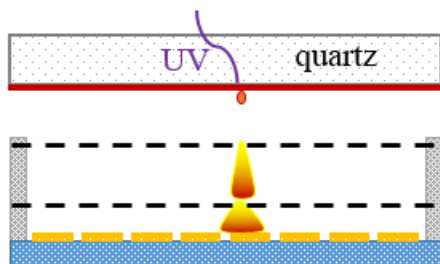


- 级联两层丝网
- 两层丝网间距离: 200-300um, 作为Pre-amplification (PA)
- 第二层丝网到阳极: 50-100um, 作为secondary amplification (SA)
- 这种结构利于实现非常高的增益, 同时有效的抑制正离子反馈!

DMM性能



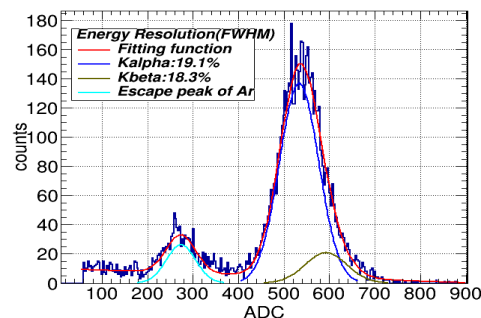
探测器组建



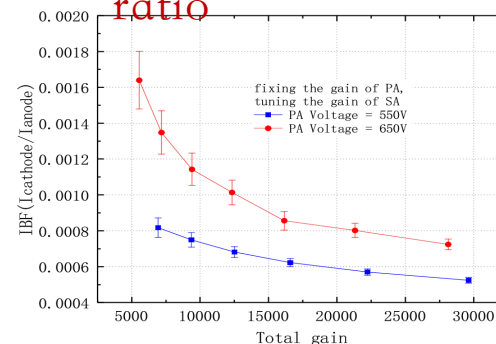
UV laser test

Published on NIM-A: A high-gain, low ion-backflow double micro-mesh gaseous structure for single electron detection, 889 (2018) 78 – 82.

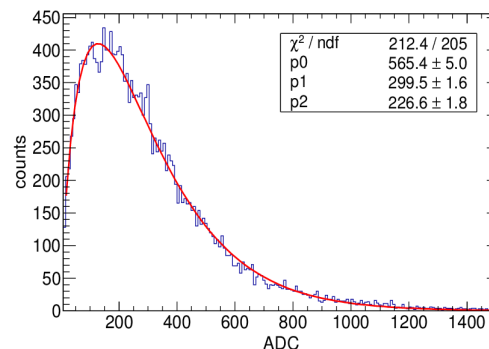
A 5.9keV x-ray spectrum



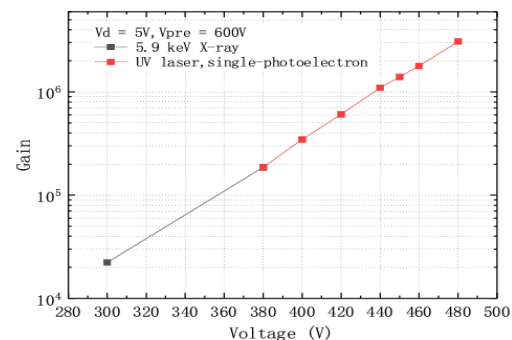
~0.0005 IBF ratio



Typical pulse height spectrum of single electron



3×10^6 high gain for single photoelectron



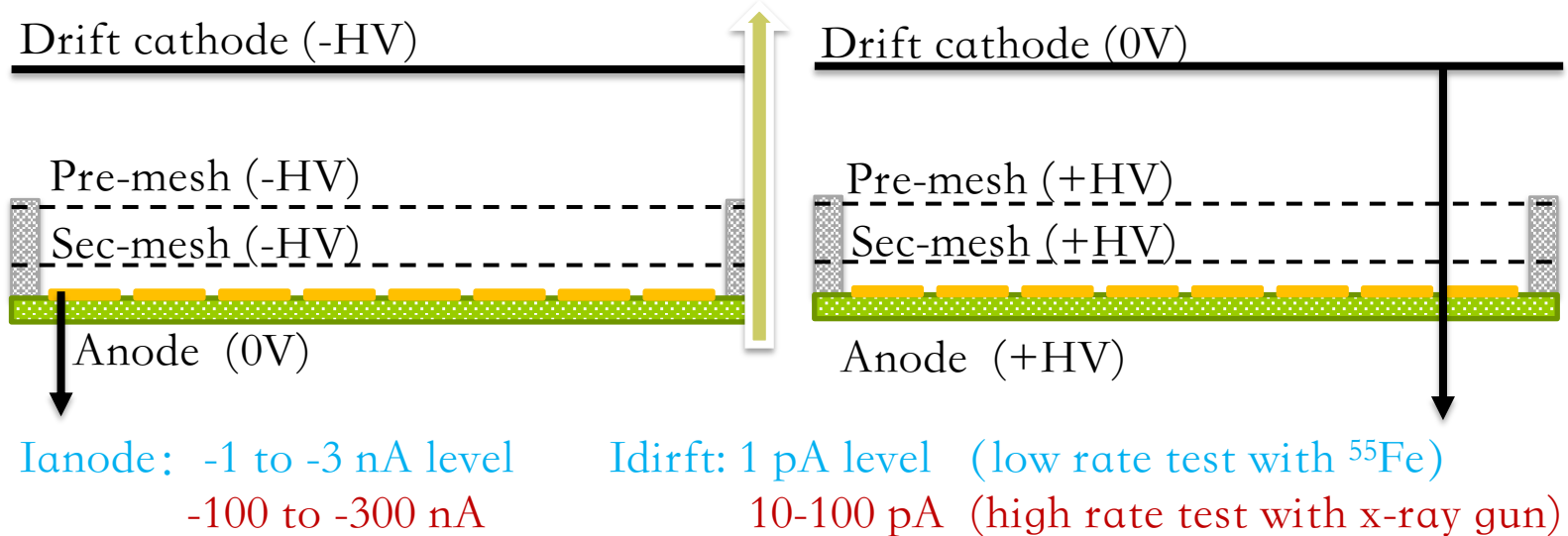
国内国际同行的疑问:

极低电流测量, Ion charge-up...

IBF测量方法验证

◆ 利用X-ray tube替换 ^{55}Fe 增大反馈电流

$$\text{IBF ratio} = (I_{\text{drift}} - I_{\text{primary}}) / I_{\text{anode}}$$



Keithley (6482) 皮安表, 测量精度 ~ 10 fA at ± 20 nA

IBF测量方法验证

◆ 电流和增益测量

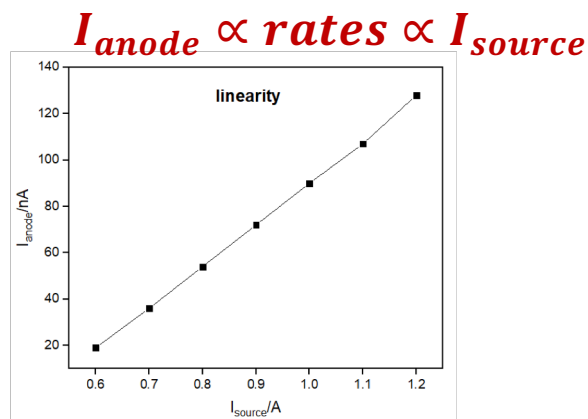
$$I_{\text{primary}} = Q_e \cdot N_e \cdot R = \sim 5.6 \text{ pA}$$

N_e 单个x-ray电离数;

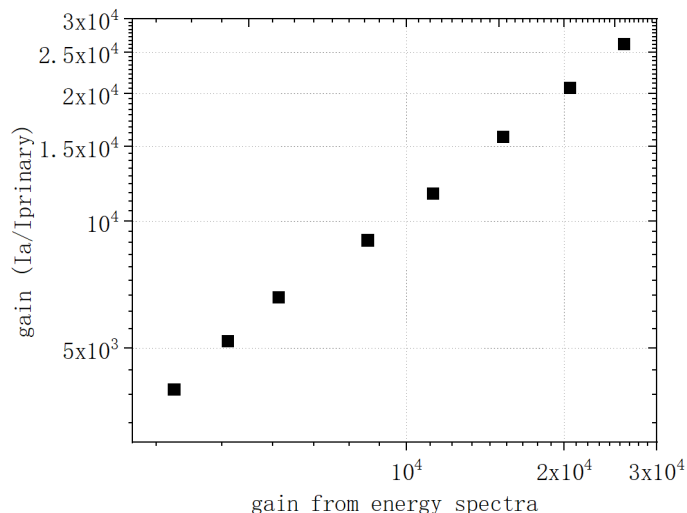
R 发生光电效应沉积能量的x-ray事例率;

皮安表直接测量: 6.5pA;

较小的偏差可能来自 N_e 和 R 的估计。



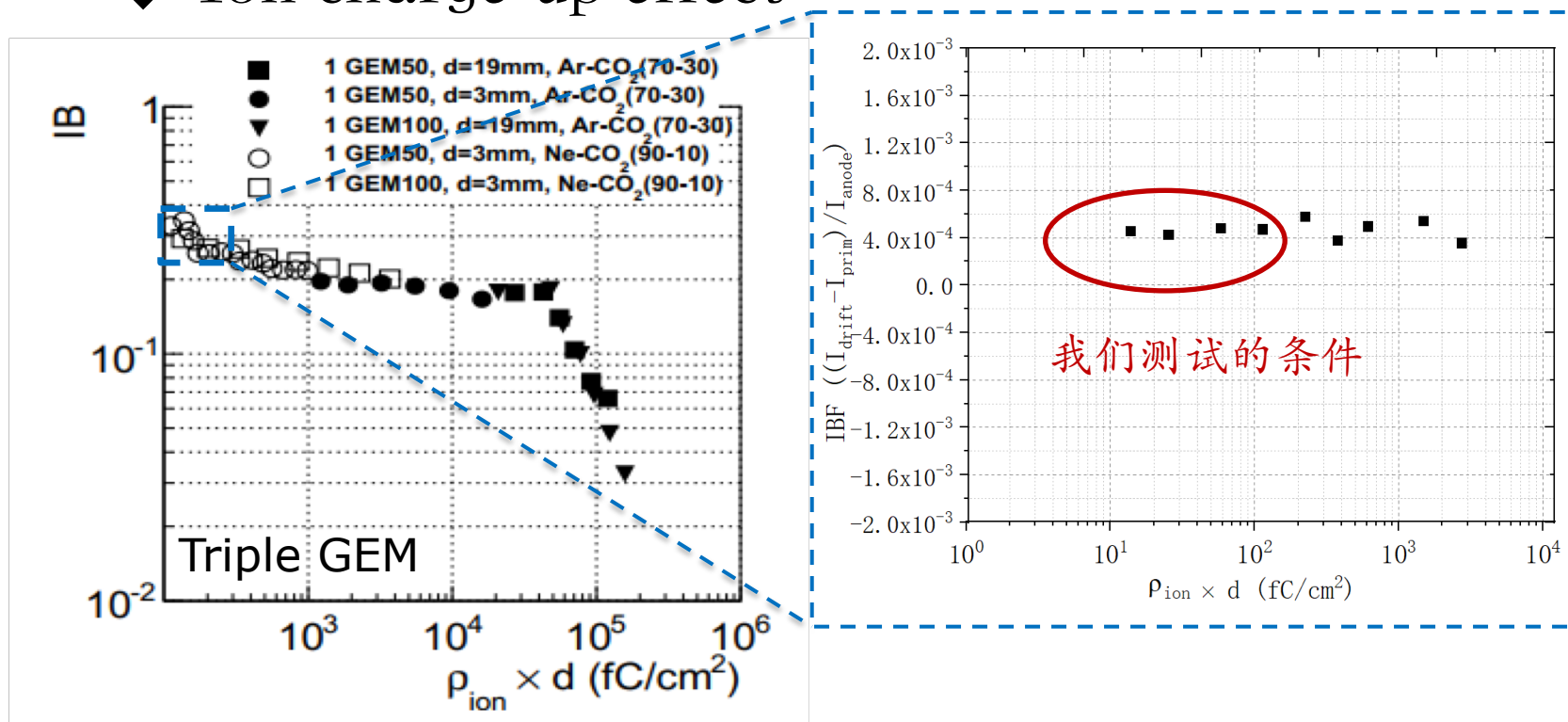
DMM阳极电流随X-ray tube电流变化表明在我们测量的辐照强度下, 探测器增益不受x-ray rate的影响。



增益通过能谱测量和电流 $I_{\text{anode}}/I_{\text{primary}}$ (^{55}Fe , 5.9keV 和 x-ray gun, 8keV); 测试结果显示很好的一致性。

IBF测量方法验证

◆ Ion charge-up effect

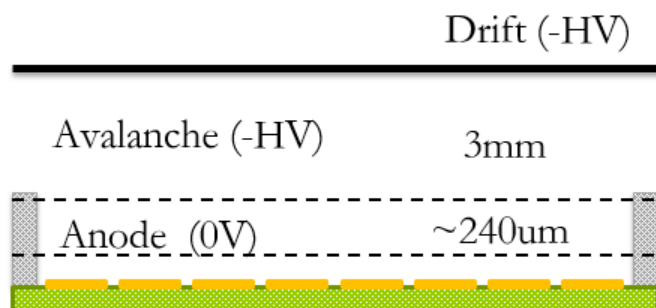


DMM的测试条件下，漂移区的空间电荷密度很低！

We operated the DMM in the safe area, which is far from the breakdown threshold.

IBF测量方法验证

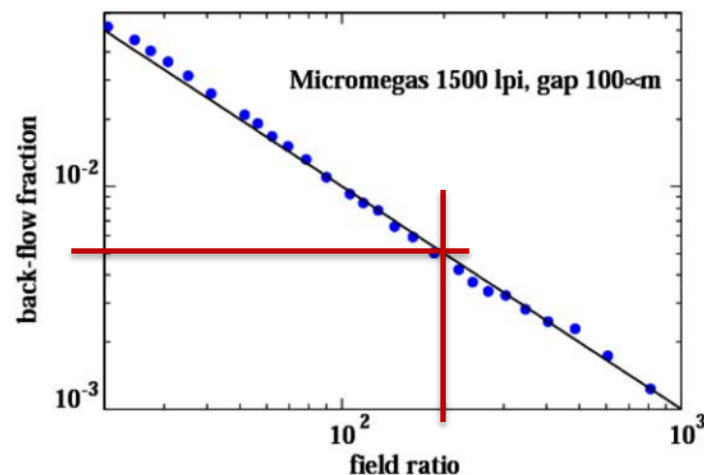
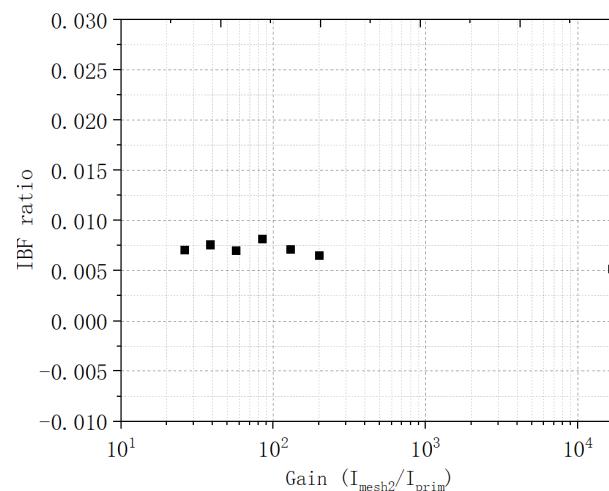
◆ 单层放大模式



仅测试第一级放大情况标准的
(Micromegas) :

固定 $E_{\text{avalanche}}/E_{\text{drift}}=200$, 测试IBF随
探测器增益的变化。

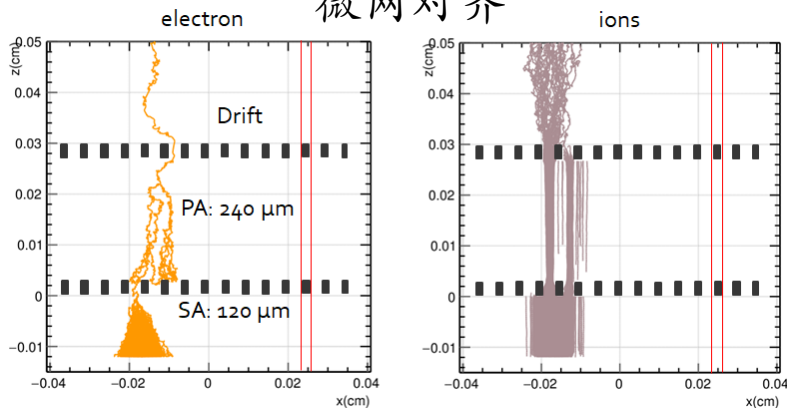
至此，测试结果的正确性
得以验证！



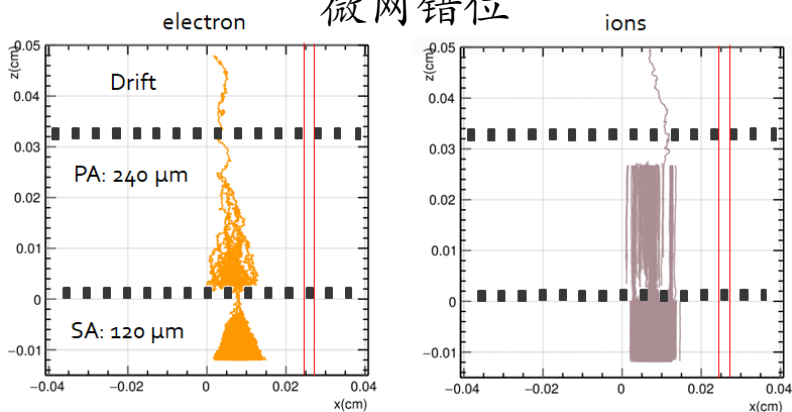
IBF优化

◆ 网孔错位

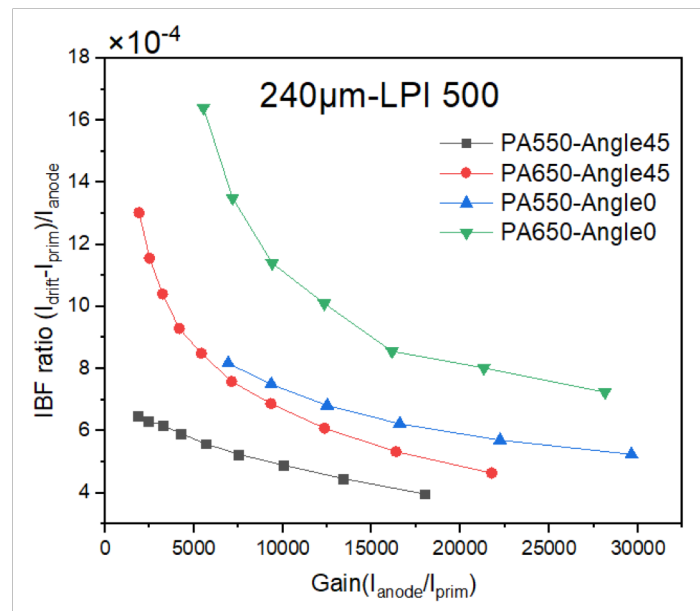
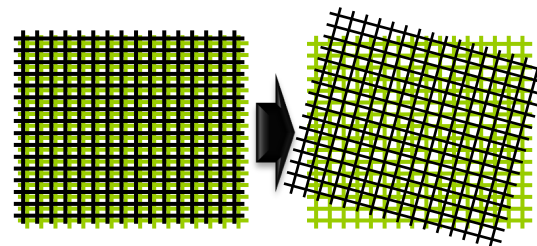
微网对齐



微网错位

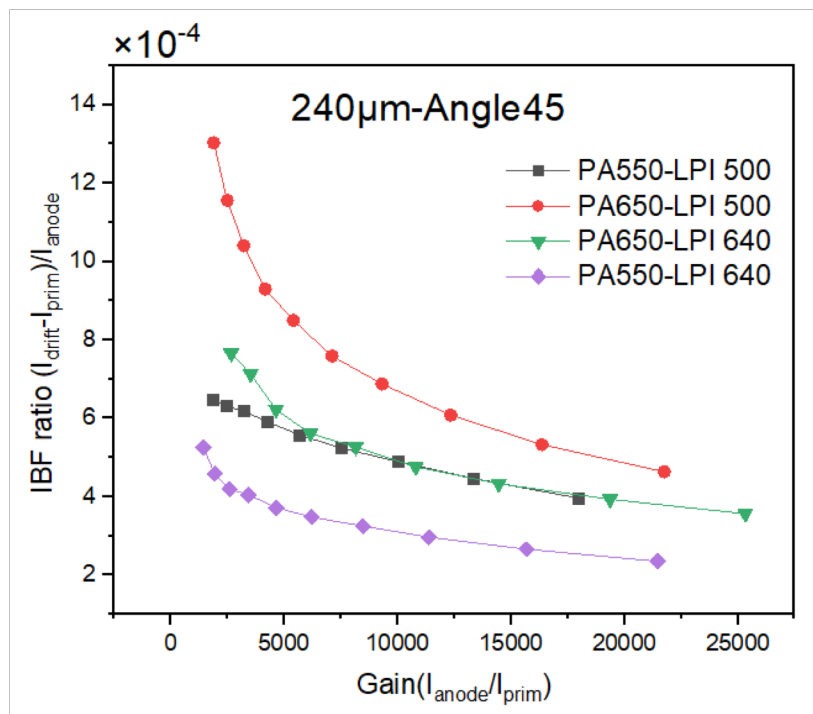


但是微网的不均匀性，
无法严格的对齐和错位，错开角
度是种折中的方案。

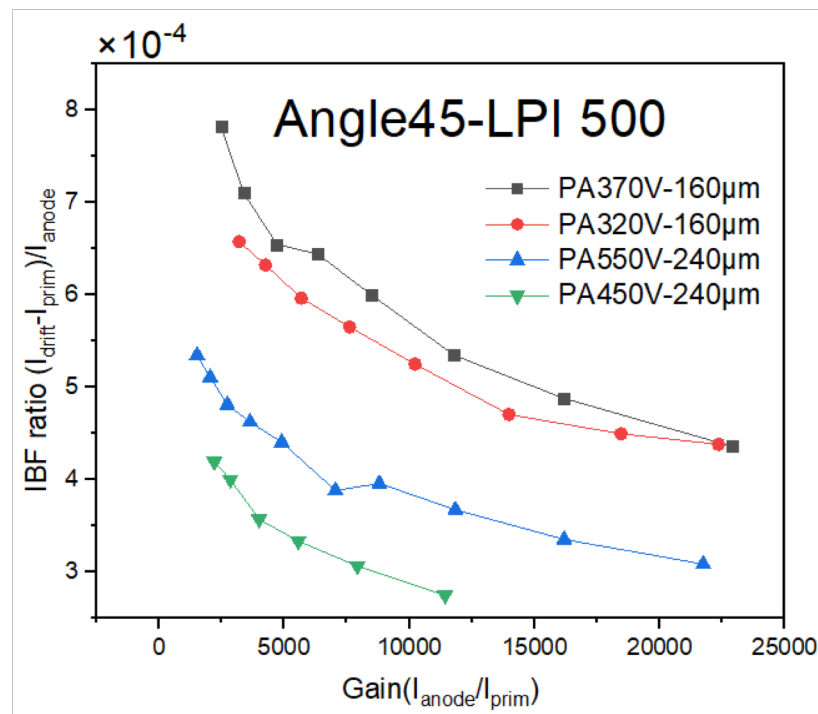


IBF优化

◆ 网孔密度及预防大间隙



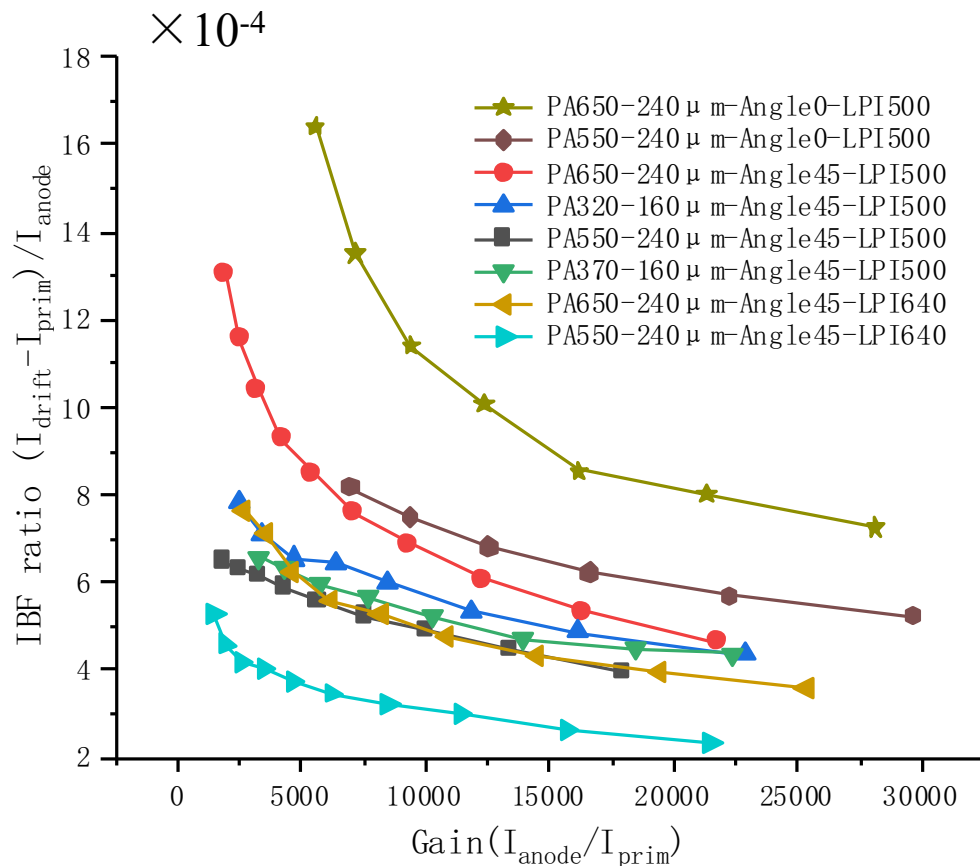
固定网开窗率，选择不同密度的网型：500 vs 640 LPI



采用不同PA间距：
160 vs 240 μm

IBF优化

Put all together

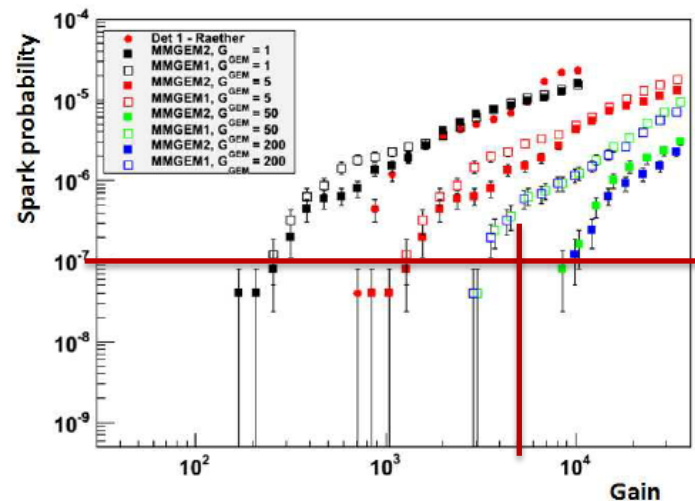
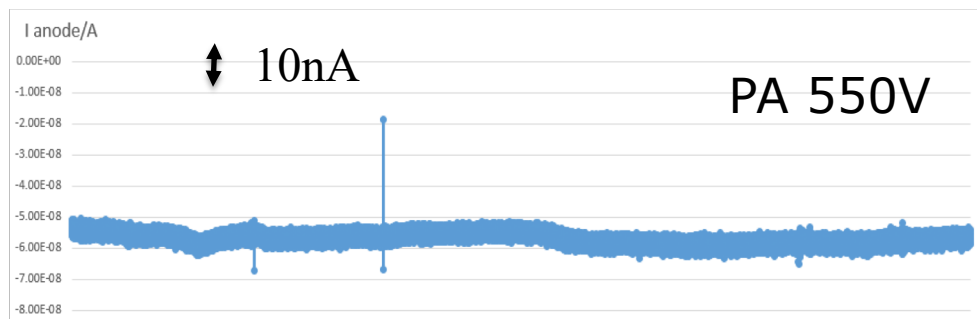
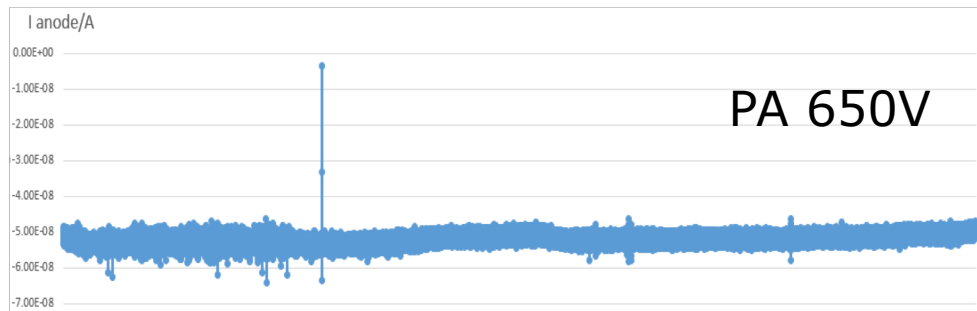


Best IBF suppression
<0.03% obtained at

- ✓ low PA electric field
- ✓ high mesh density
- ✓ with crossing angle

DMM长期稳定性

增益~5000, 测试~24 hours
240 μ m-Angel45-LPI 640



2012 JINST 7 C06009

总计数: $\sim 2 \times 10^{10}$

Spark probability: $< 10^{-9}$

主要成果

文章发表:

A high-gain, low ion-backflow double micro-mesh gaseous structure for single electron detection, **NIM A**, 889 (2018) 78 – 82.

会议文集:

Study on the double micro-mesh gaseous structure (DMM) as a photon detector, **NIM A**, <https://doi.org/10.1016/j.nima.2019.03.033>. 2019

已受理专利申请:

用于大面积 Micromegas 探测器制作的热熔胶膜热压接方法 中国 申请号: 201810274814.2 2018-03-28 ;

一种基于镀锗薄膜的微结构气体探测器阻性电极的制作方法 中国, 申请号: 201811331007.6 2018-11-09 ;

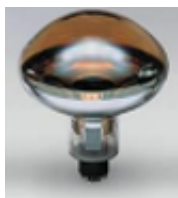
小结和展望

小结:

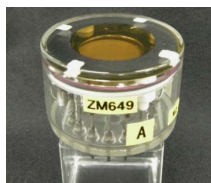
- DMM新结构可以实现 $>10^6$ 高增益和 $\sim 0.05\%$ 低正离子反馈率。
- 多项验证试验, 确保了低离子反馈测量的准确性!
- 网孔错位、改变目数和间距等, 进一步优化IBF到 $<0.03\%$ 。
- ➔ 满足高计数率TPC需求;
- ➔ 用作CEPC, STCF-RICH光电读出探测器。

展望:

- 发展气体可见光探测技术, 要求进一步降低IBF到 $<0.01\%$!
- ➔ 网孔精准错位方法, 发展多层微网结构, 目前初步测试显示好于 0.01% !



Towards to gas PMT

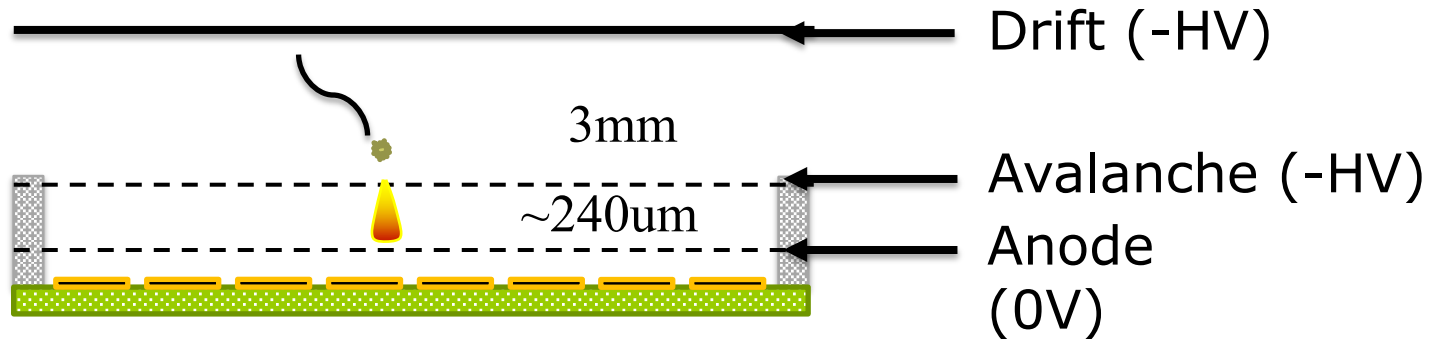


非常感谢国家重点实验室多年的经费支持!

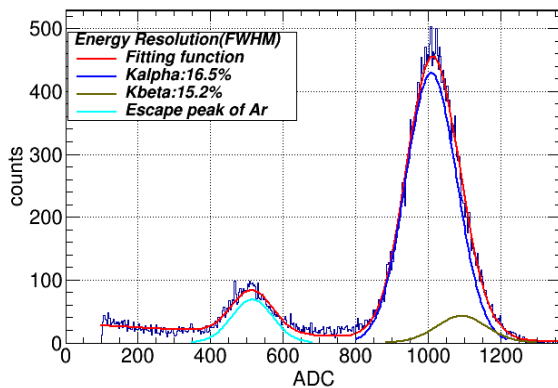
Back-up slides

Pre-amplification (PA)

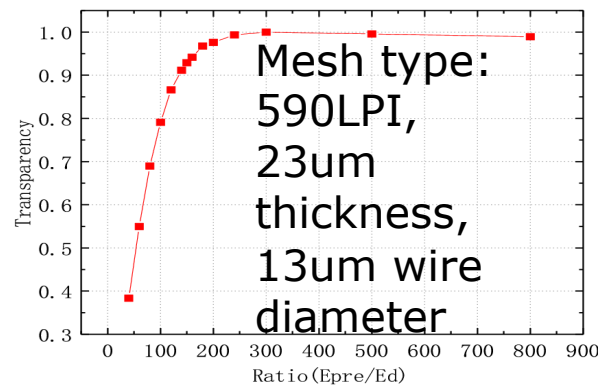
Operating as a typical Micromegas detector individually for PA and SA regions.



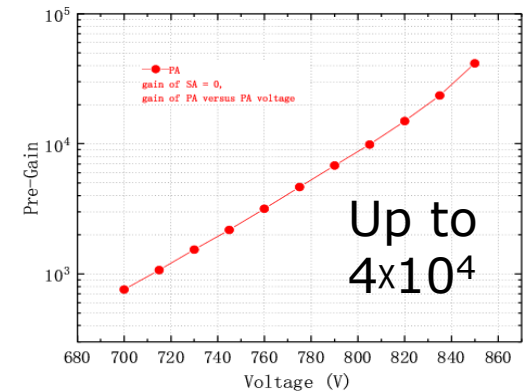
Energy spectrum of ^{55}Fe x-rays



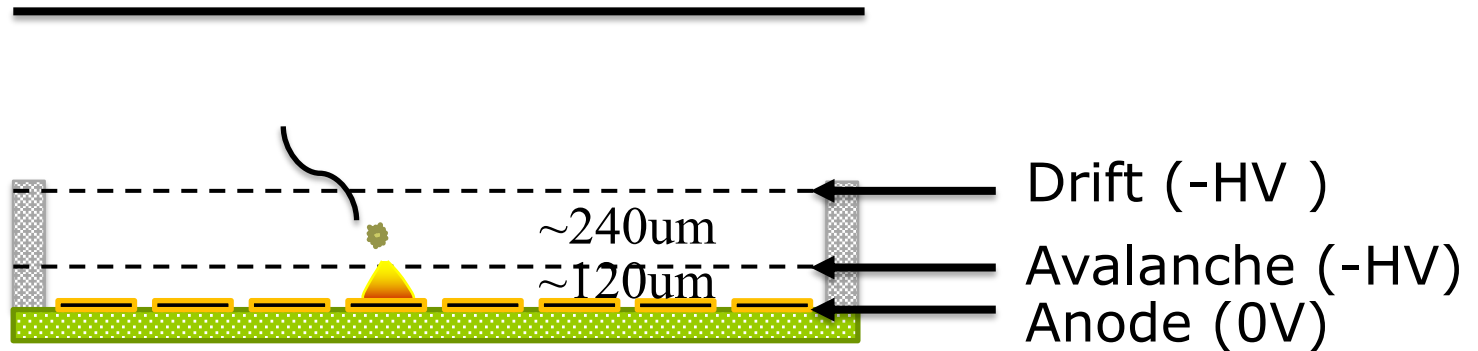
Transparency versus Eratio



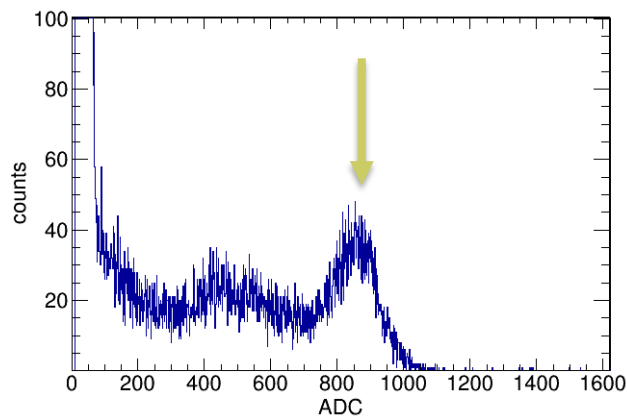
Gain VS avalanche voltages



Sec-amplification (SA)

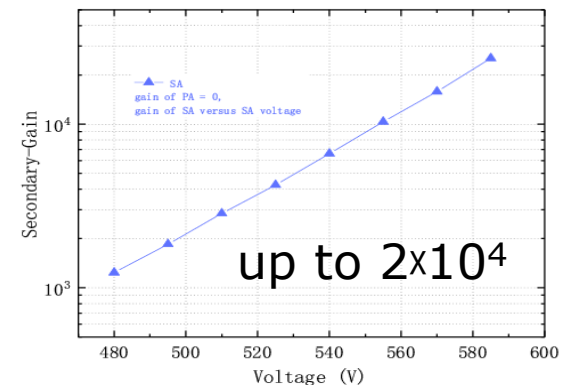


Full energy peak due to the lateral angle
photoelectrons and Auger electrons



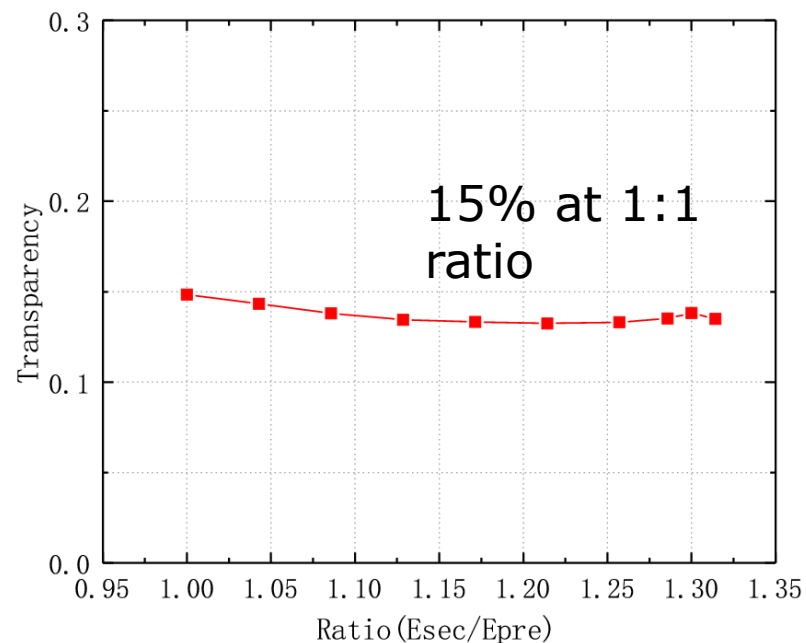
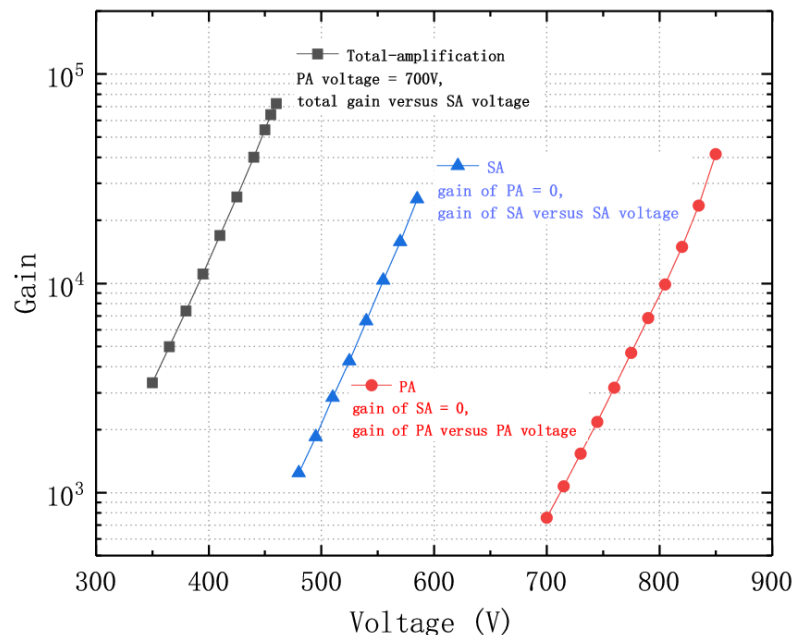
The transparency should be similar to PA's, since they have the same mesh type.

Gain VS avalanche voltages



Electron transparency from PA to SA

Simply estimate by: Total gain = PA gain*Trans*SA gain



气体光电探测器的优势

ALICE RICH each module
 $40 \times 60 \text{ cm}^2$

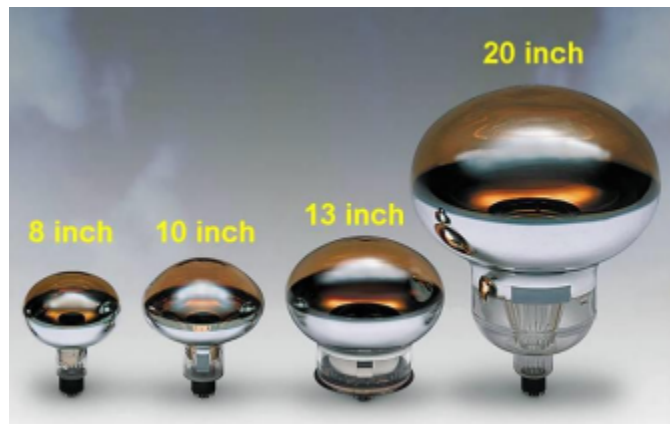


优势:

大面积、位置灵敏、低成本

难点:

光阴极老化、离子反馈、气体泄漏



Vacuum PMT

Vacuum MCP

