High gain, low ion backflow
Double and Triple Micro-Mesh (DMM/TMM) detectors
for High-rate TPC and gas photon detection

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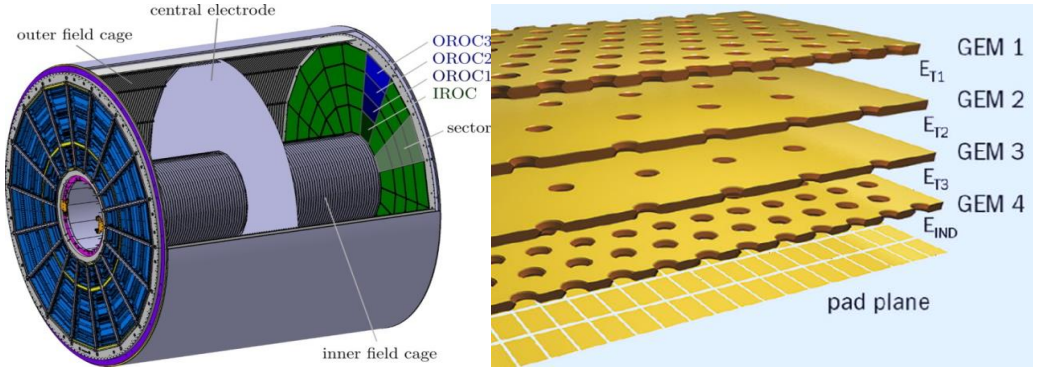
04 Gas photon detectors

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Motivation and requirements (High-rate TPCs)

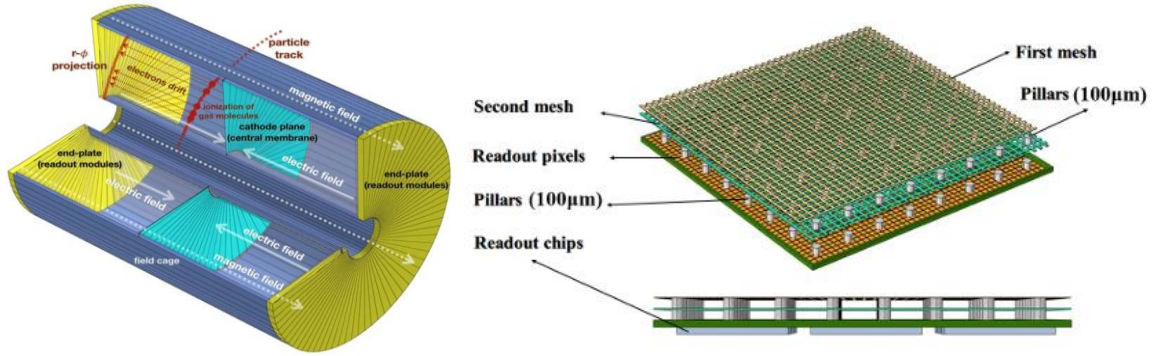
Inner tracker with high-rate TPC（ALICE、CEPC、FCC-ee)

- Very low IBF is the key to minimize drift field distortion caused by ion space charge



Quadruple-GEM scheme

ALICE-TPC： <1% IBF @2000 gain



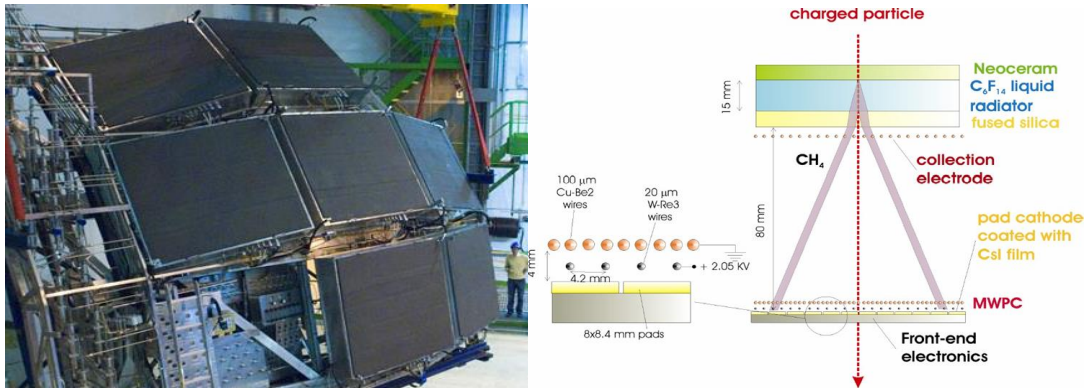
Micromegas/Double Mesh detectors

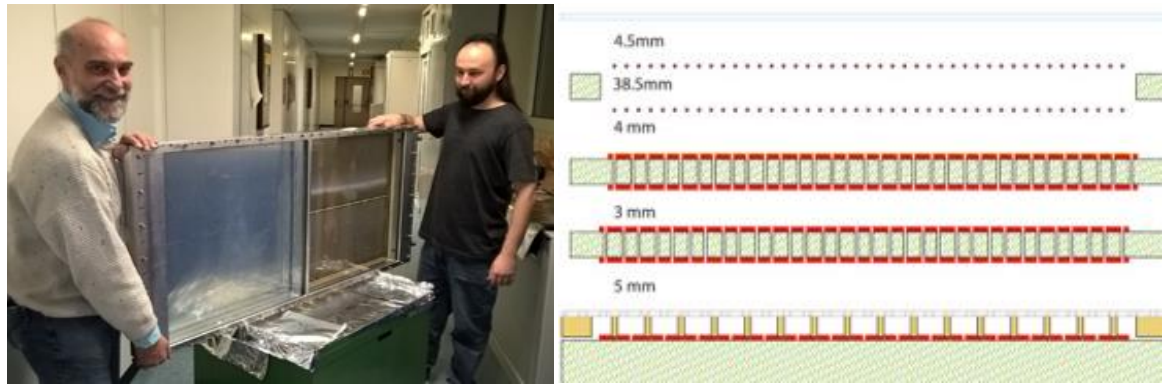
CEPC-TPC/FCC-ee： <0.1% IBF @2000 gain

Motivation and requirements (UV light detector)

Cherenkov lights readout（COMPASS-RICH、ALICE-RICH ）

- High gain: to be sensitive to single photons, **~10^5**
- Low IBF: to avoid damage of CsI， **~mC/cm^2**





MWPC with CsI cathode

ALICE –RICH: ~8 m^2 coverage area, counting rate was limited

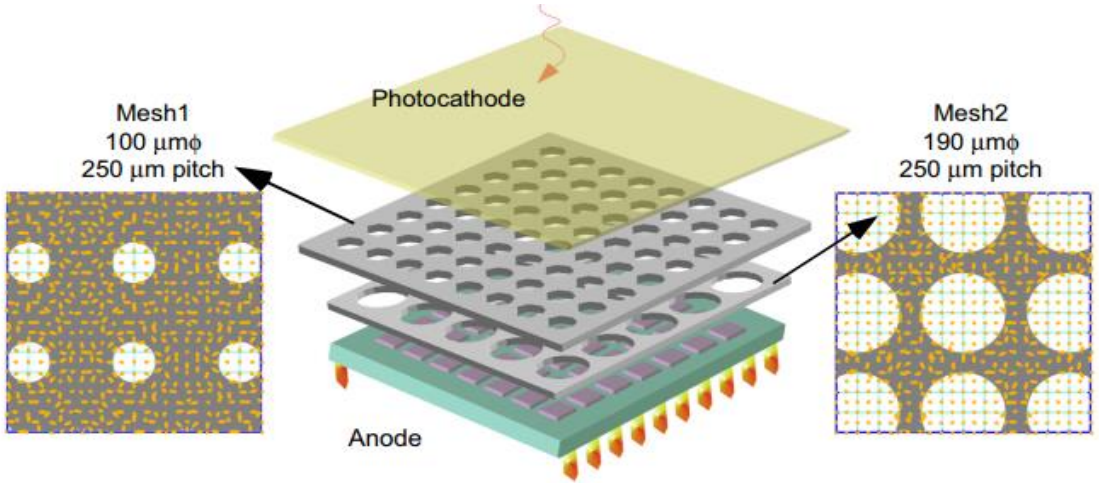
CsI coated THGEM +Micromegas

COMPASS –RICH: ~6 m^2 coverage area, ~10^4 gain

Motivation and requirements (visible light detector)

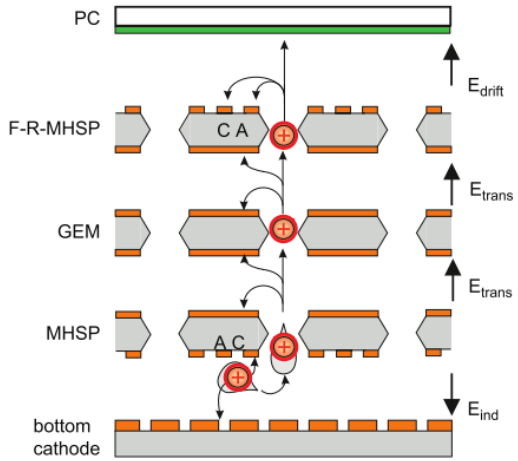
Visible lights detector (gas sealed PMT)

- High gain: to be sensitive to single photons, **~10^5**
- Extremely low IBF for Visible light: **Bi-alkali, ~μC/cm²** !



THGEM-like+MM: IBF~1%
double drilled boards: IBF~0.06%, G~10^4

F. Tokanai et al. , NIM A 766 (2014) 176–179



F-R-MHSP+GEM+MHSP:
IBF: ~0.03%
Complex structure

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

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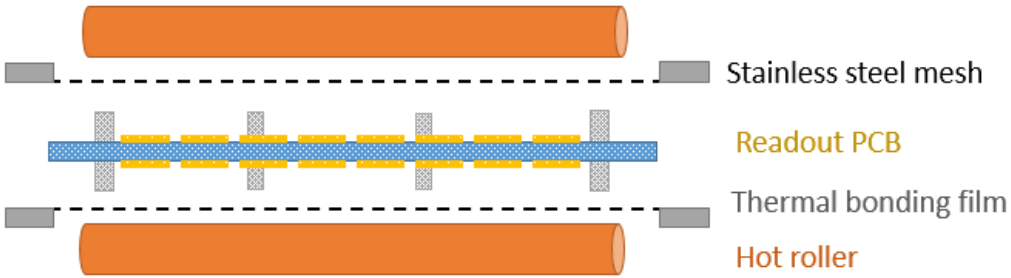
05 Summary

The thermal bonding method

The thermal bonding method provides a concise and etching-free mass-productive technology to fabricate Micromegas-like detector.

- ✓ Etching-free
- ✓ User-friendly for laboratory operations
- ✓ Low cost
- ✓ Suitable for large-area fabrication
- ✓ **Flexible selections on gaps、material、structures …**

Thermal bonding processing



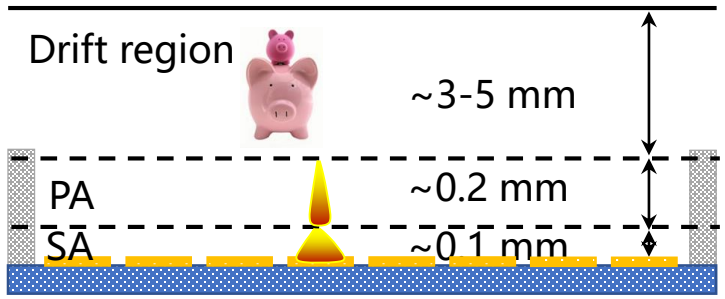
- The fabrication method made it possible to extend Micromegas from a single-stage detector to double and triple stage structures.

Jianxin Feng et al,. NIM-A 989 (2021) 164958.

DMM detectors for high-rate TPCs

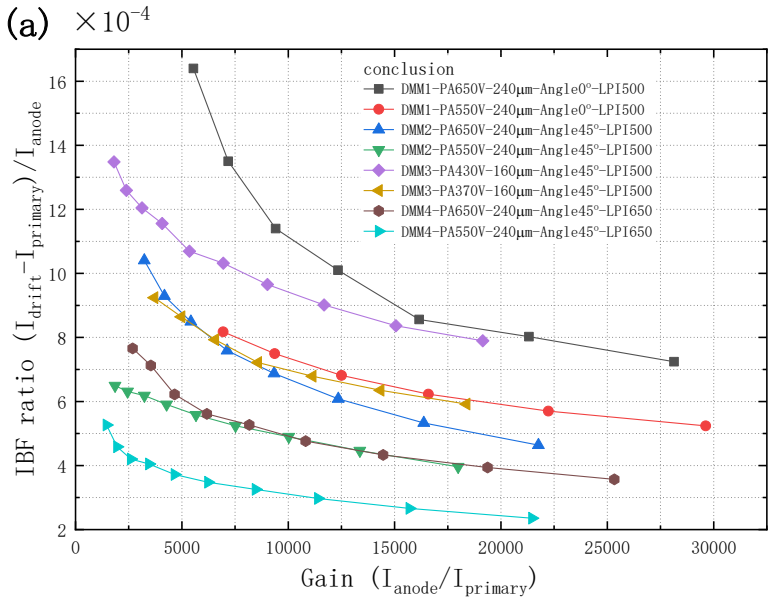
DMM: Double Micro-Mesh gaseous structure

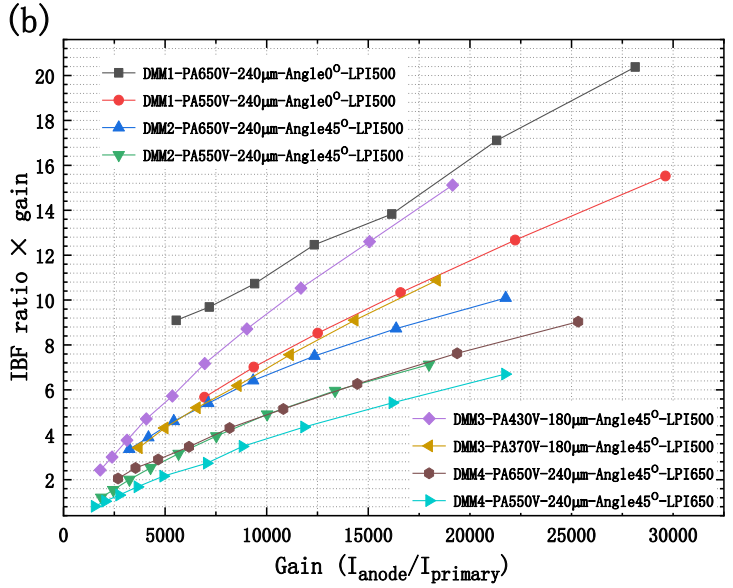
- Mesh-type to strongly suppress IBF
- Two stacked meshes for high gain



To achieve a low IBF level:

- Low PA electric field
- Large PA gap
- High mesh density
- Crossing mesh setting





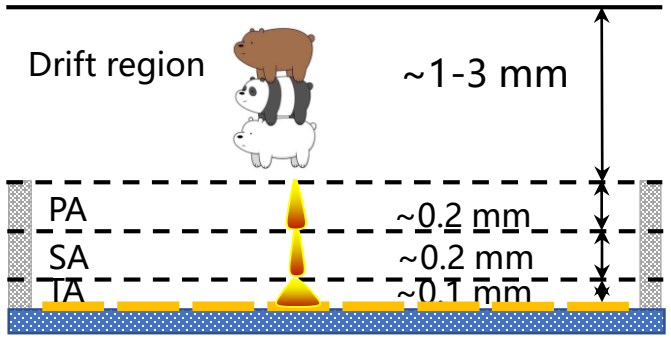
It is feasible to reduce the IBF × gain product to < 1, satisfying the requirements of most TPC experiments.

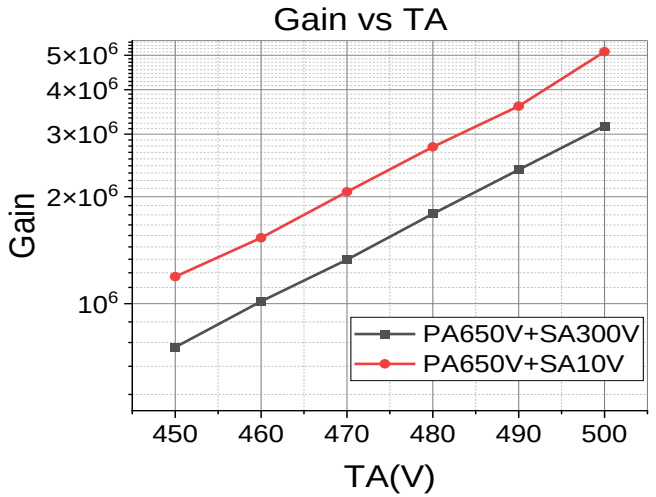
Zhiyong Zhang et al., NIM-A 889 (2018) 78–82
Binbin Qi et al., NIM-A 976 (2020) 164282

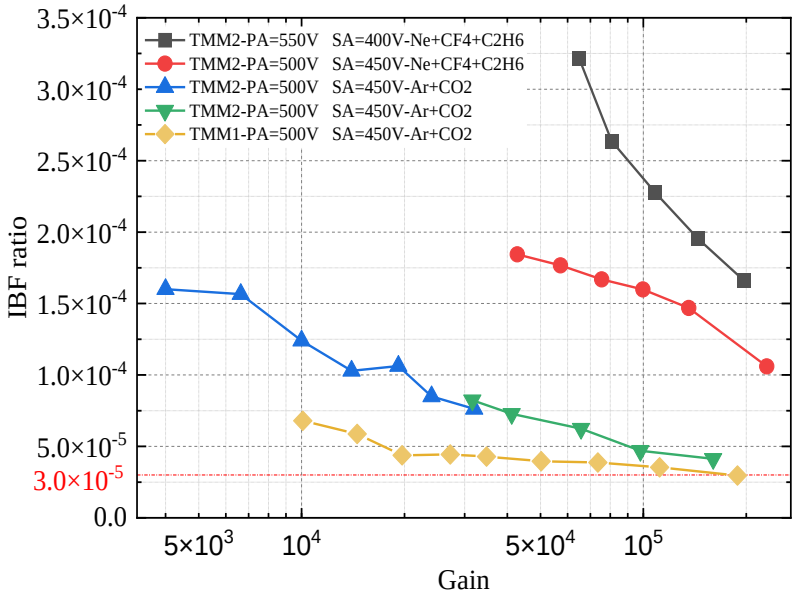
DMM detectors for ultra-low ion backflow

TMM: Triple Micro-Mesh gaseous structure

- One more mesh on the DMM
- More stable gain, lower IBF from second avalanche



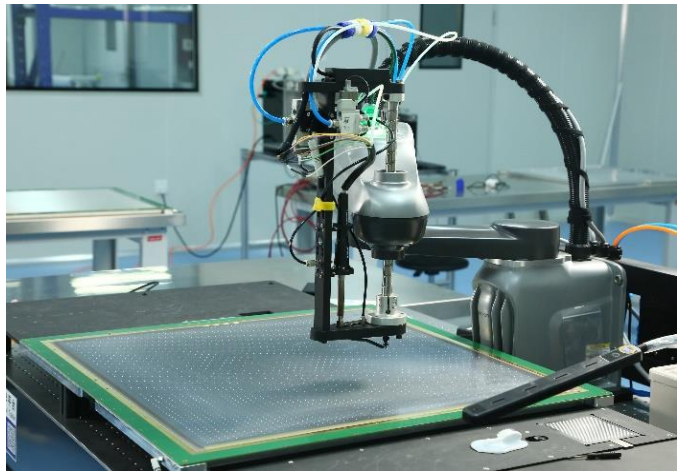




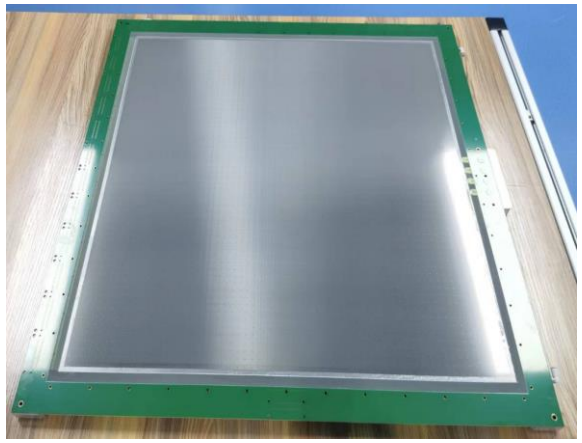
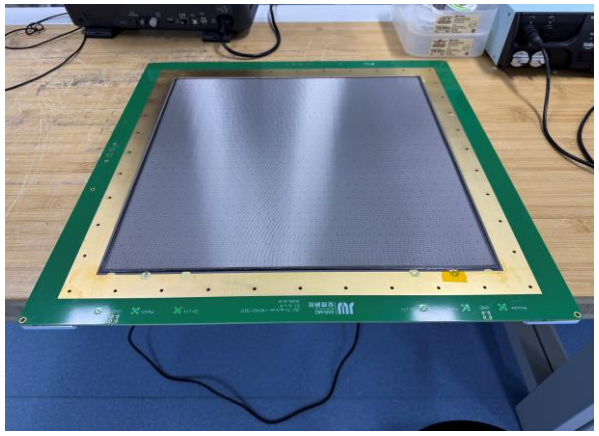
An unprecedented IBF ratio of 3×10^{-5} at gas gains exceeding 1×10^{5} was obtained, indicating a promising capability for **visible light detection**.

Kunyu Liang, Zhiyong Zhang, Jianbei Liu et al., NIM-A,1070 (2025) 170033.

Detector fabrication with the thermal bonding method





60cm×60cm Micromegas

40cm×40cm Double Micro-Mesh

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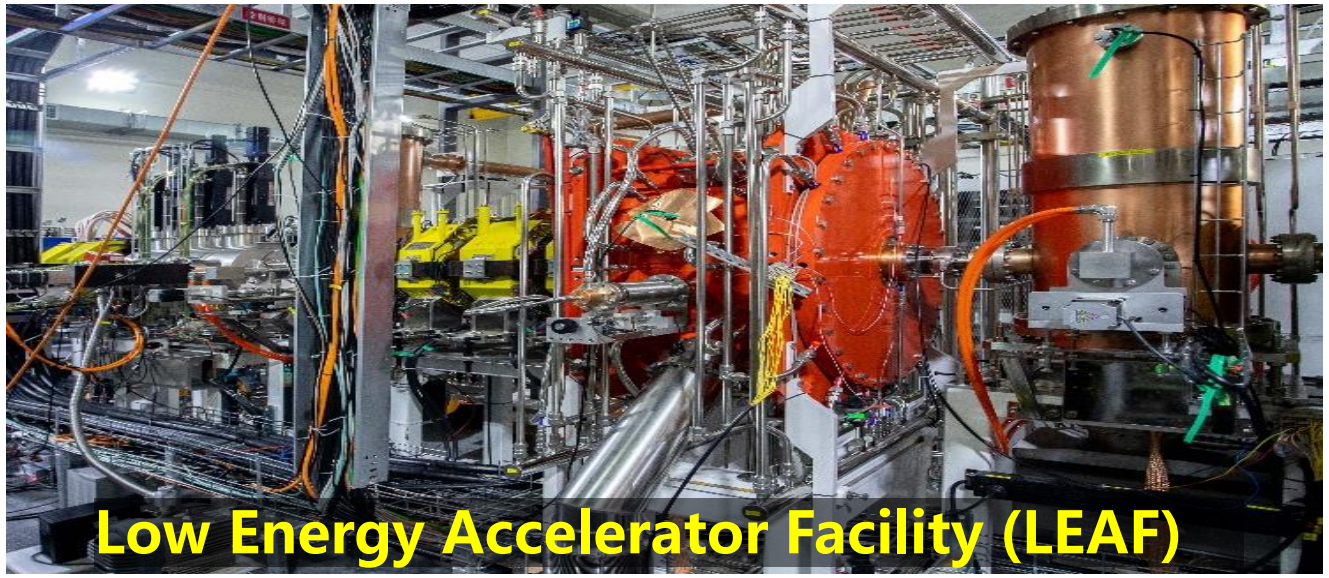
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High-rate TPC using DMM detectors

The $^{12}C+^{12}C$ fusion reaction is crucial in stellar evolution

- A large uncertainty in the reaction cross section at stellar energies (($E_{c.m.}$<3MeV)
- The main products of $^{12}C+^{12}C$ are n, p and α

- A TPC technique was developed to measure very low energy products
- LEAF has delivered 70puA, the highest beam intensity ever realized in the carbon fusion measurements





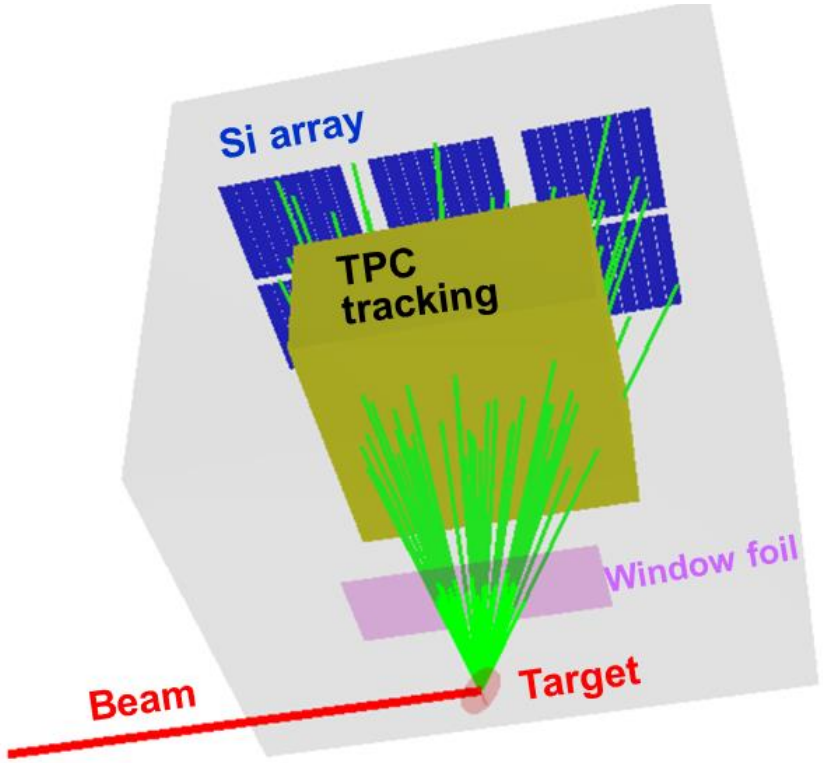
Courtesy of the nuclear astrophysics group (IMP)

The TPC and requirements

α stopped
A few MeV



TPC+ silicon ΔE-E system



Requirements for TPC:

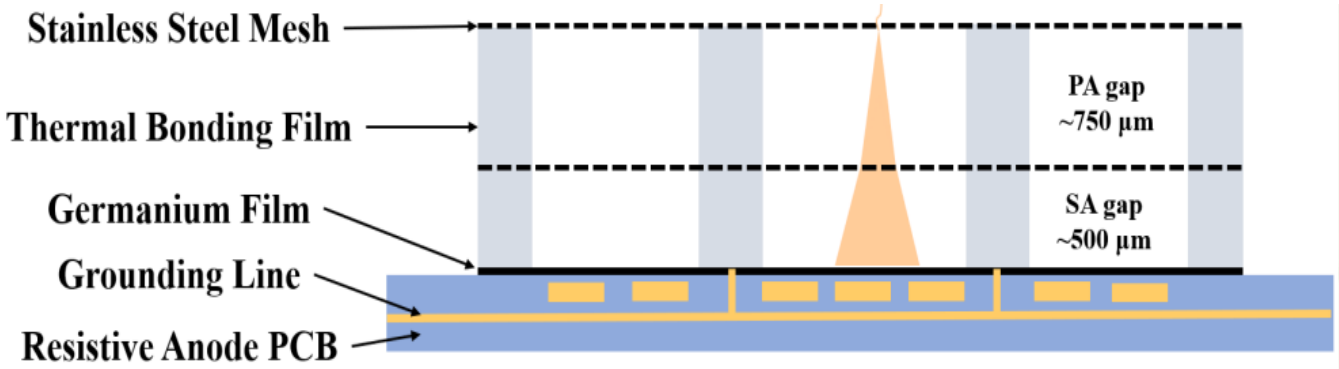
- 50-100 mbar He based gas
- High gain for proton measurements
- Low event-rate operation

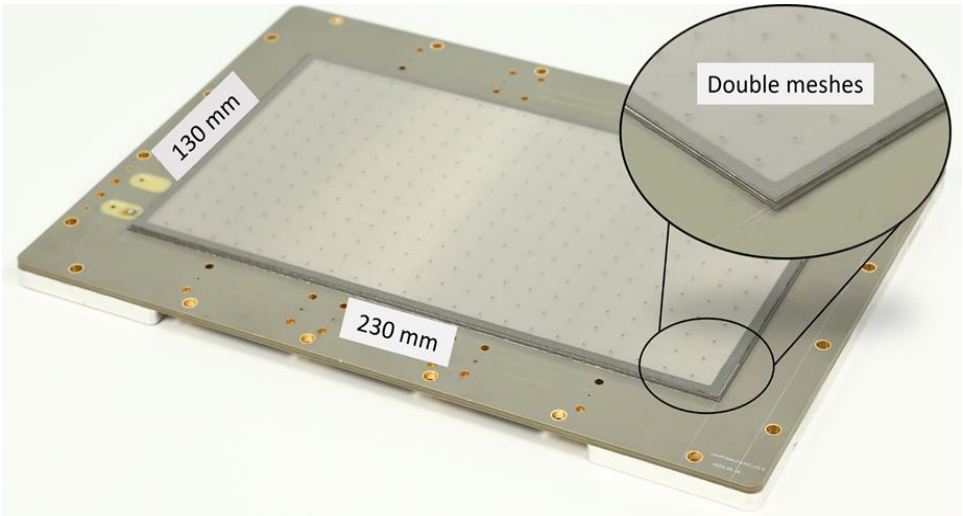
  ➔long-term stability
- High x-ray radiation background

  ➔high rate capability, low IBF to mitigate the space charge effects

DMM design and fabrication

Simulation to optimize the design for low pressure

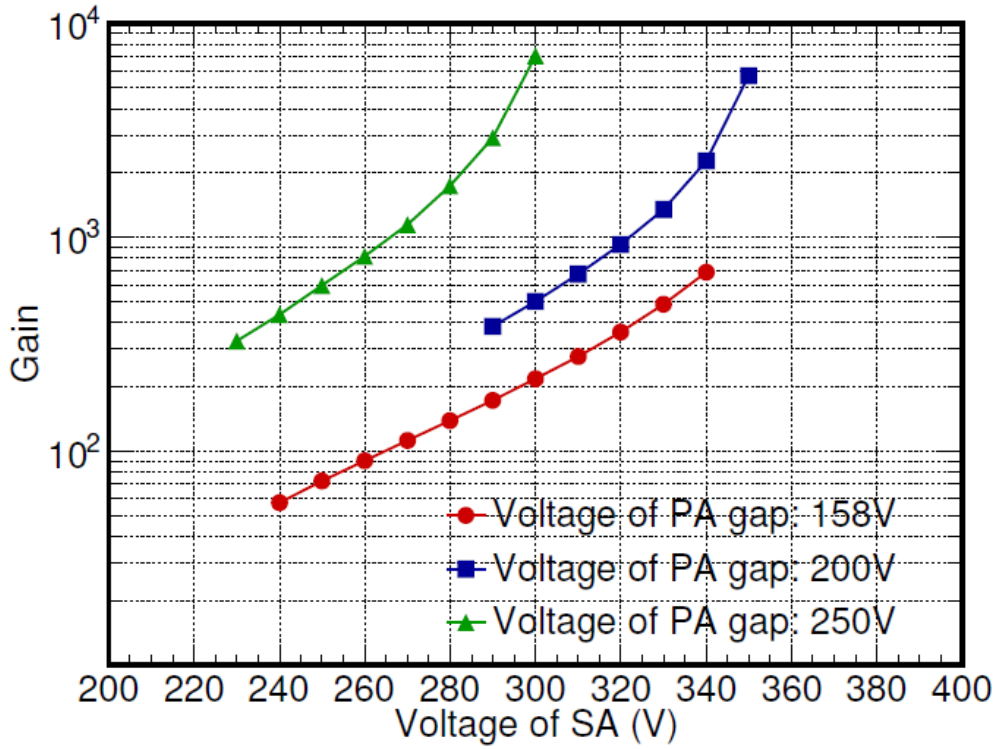




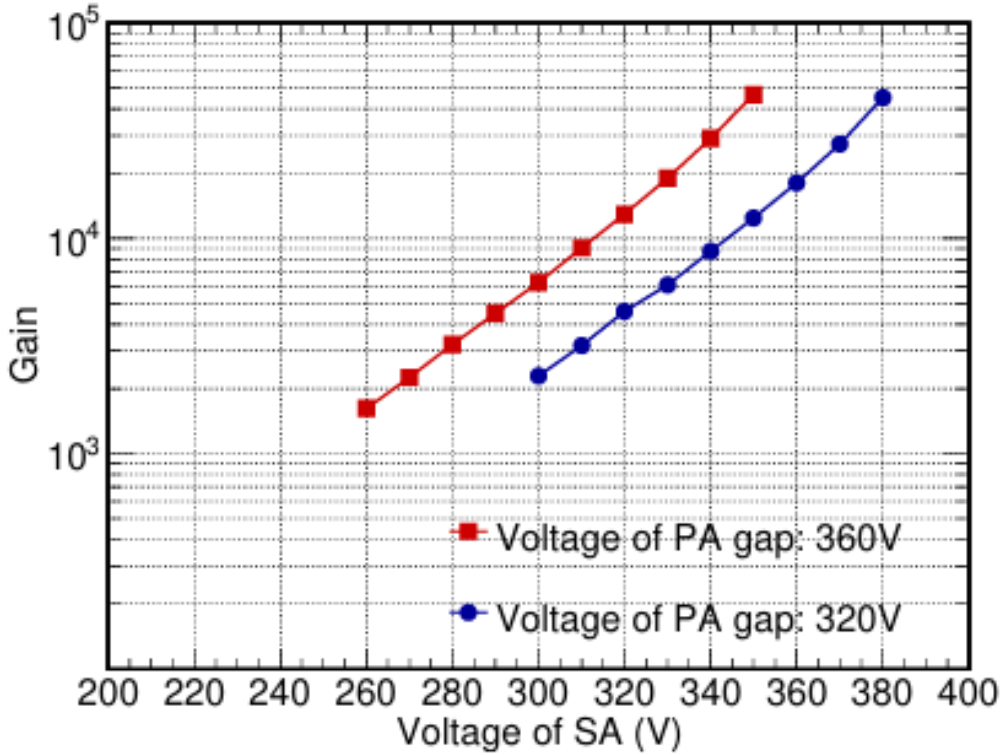
- large avalanche gap for low pressure
- High optical transparency mesh (~63%) for electron collection
- Ge coated anode for high gain and long term stability
- Fast grounding to deal with high X-ray background

Performance study of the DMMs

Gas gain tests with ^{55}Fe x-ray source at low pressure



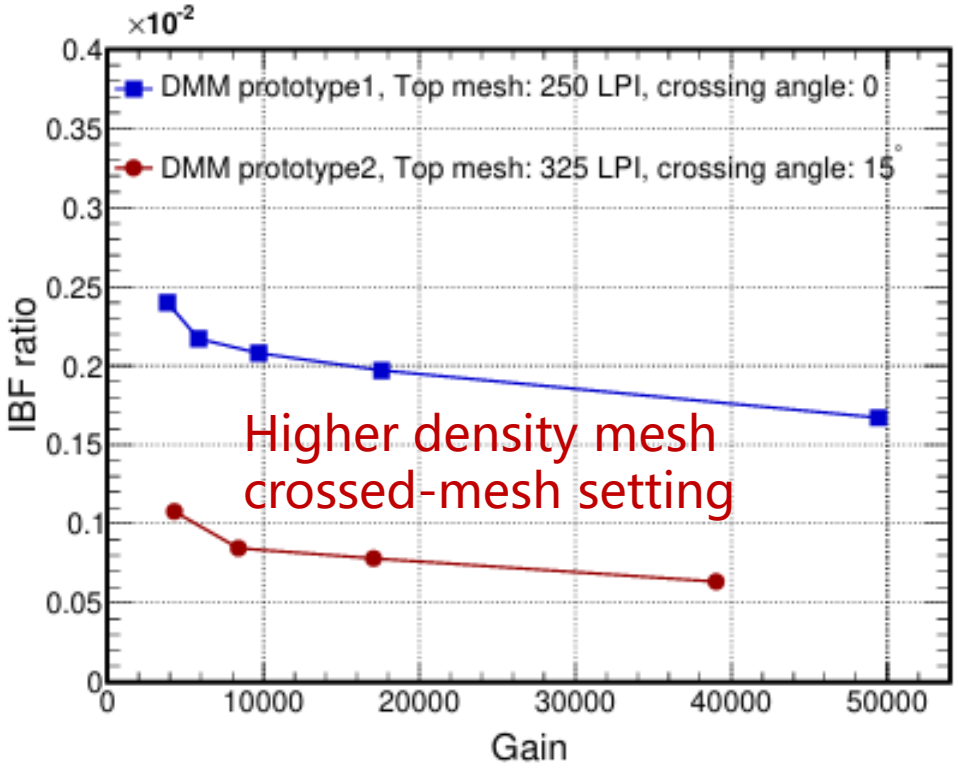
90%He + 5%CO_2 + 5%Ar at 110 mbar

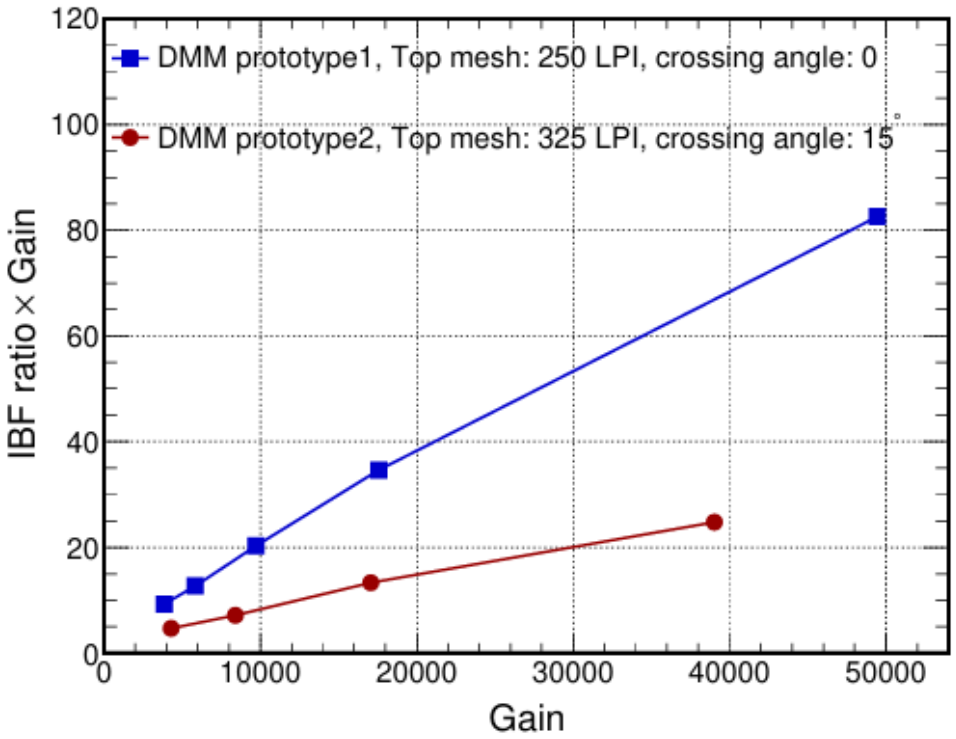


50%Kr + 15%CO_2 + 35%Ar at 90 mbar

Performance study of the DMMs

IBF ratio and product of IBF ratio and gain





50%Kr + 15%CO_2 + 35%Ar at 90 mbar

The minimal achieved IBF ratio is **around 0.06%.** The minimal IBF-gain product is **below 5** at a gas gain of approximately 4000.

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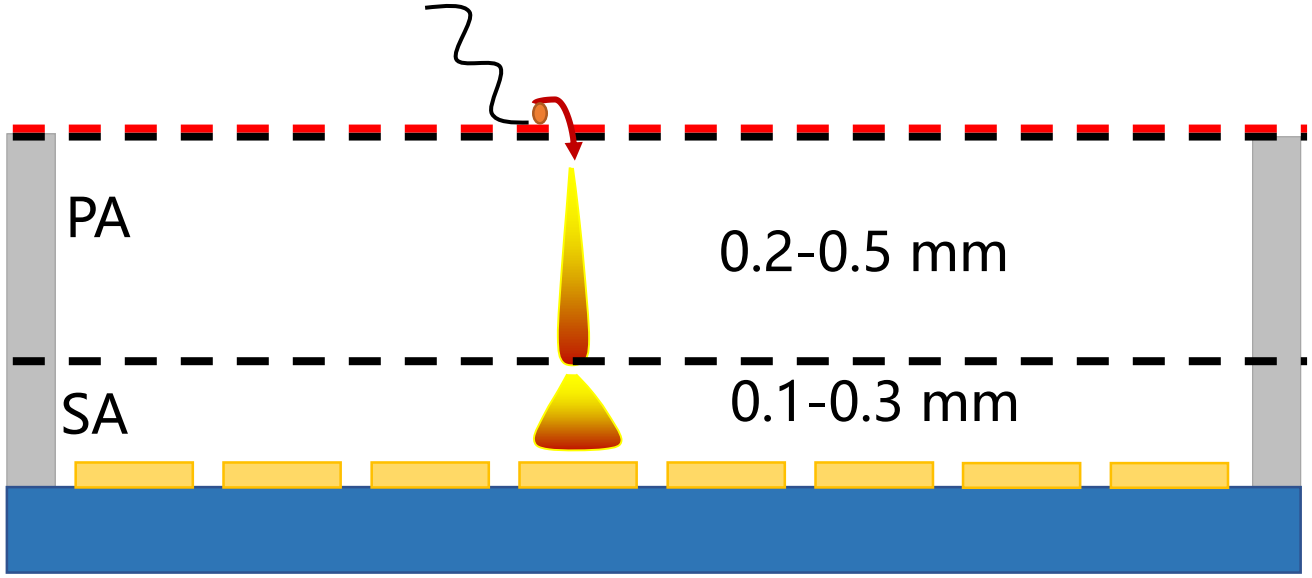
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Gas photon detectors (UV light detection)

Photon detector with DMM



Conceptual design

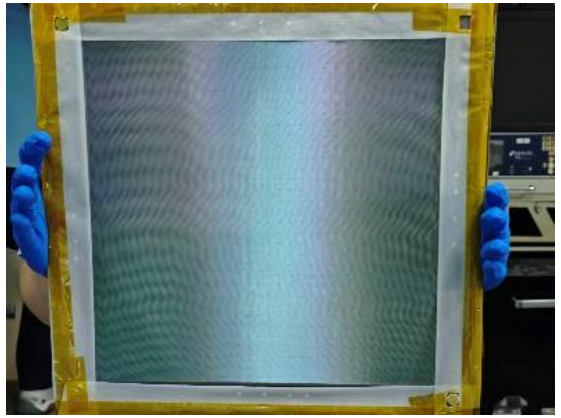
CsI coated on the top mesh as a reflective photocathode

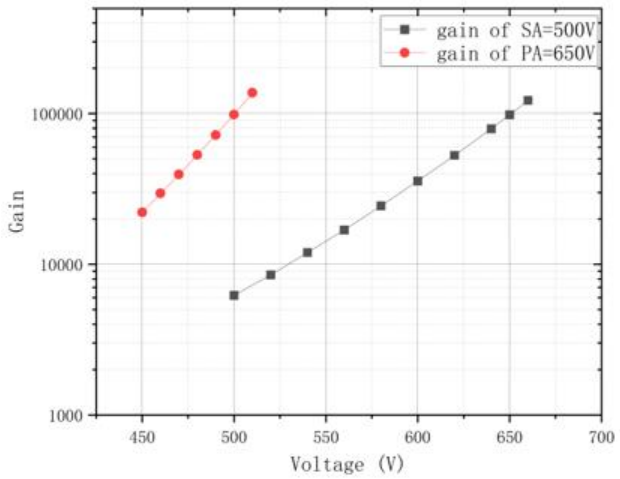
Compared with the THGEM+MM ones:

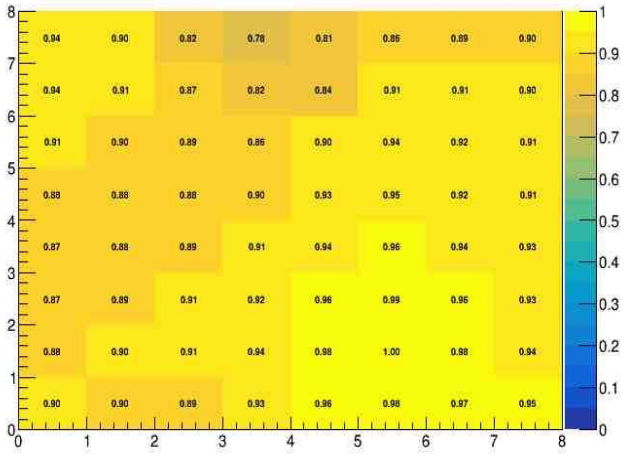
- ✓ Stable high gain > 10^5
- ✓ Very **compact structure**
- ✓ Low outgas without PCB holes
- ✓ Vey low IBF of ~1% level
- ✓ High timing resolution of **~300ps** for single photoelectron

Gas photon detectors (UV light detection)

Photon detector with DMM: detector fabrication

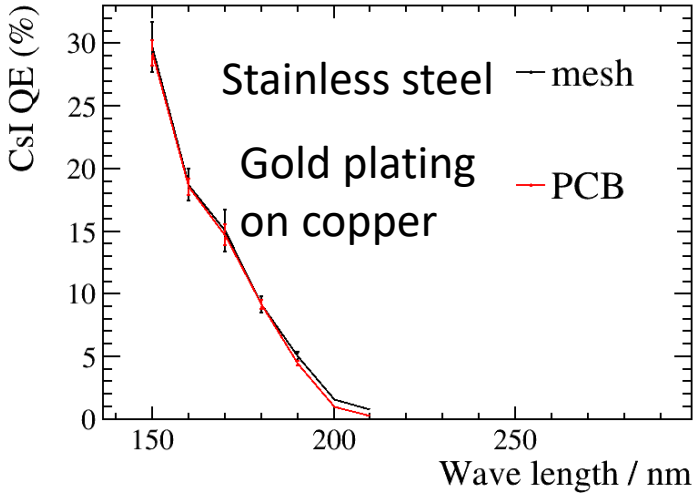






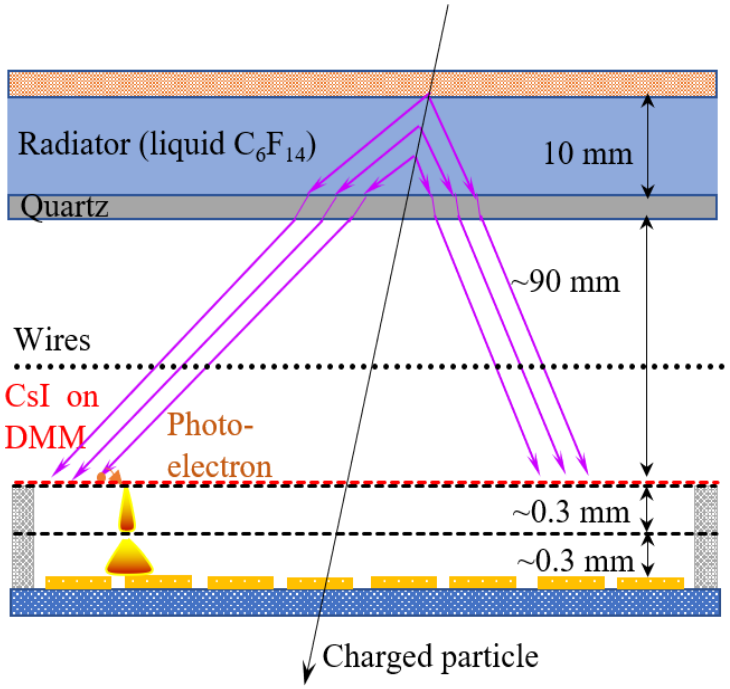
CsI coated DMM detectors

- ✓ Active area: 320mm × 320mm
- ✓ Gap sizes: 300μm (PA) and 300μm (SA)Gain: >10^5
- ✓ Gain non-uniformity: ~5% (RMS/MEAM)
- ✓ Photocathode: ~500 nm CsI

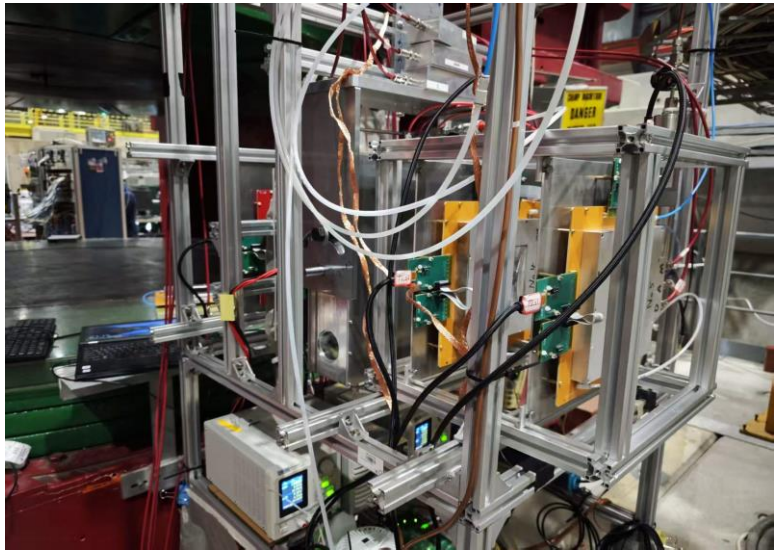


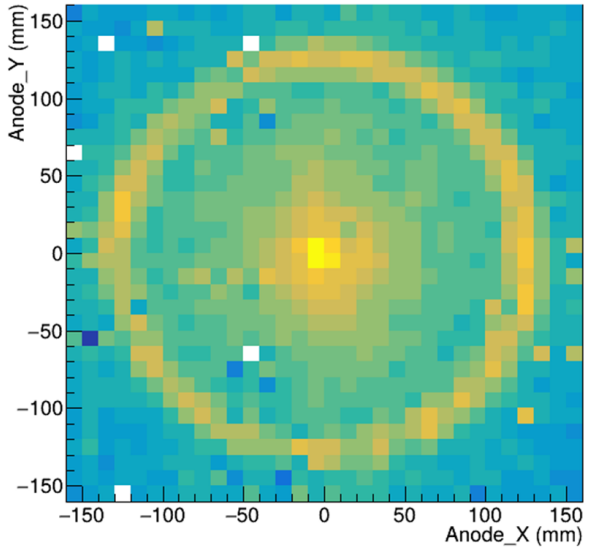
Gas photon detectors (UV light detection)

DMM-RICH prototype assembly and test



Schematic design for RICH and test setup with a tracking system



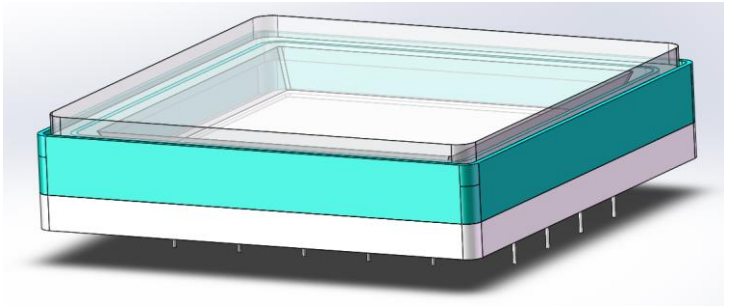


Very preliminary imaging results of the Cherenkov ring with a muon beam

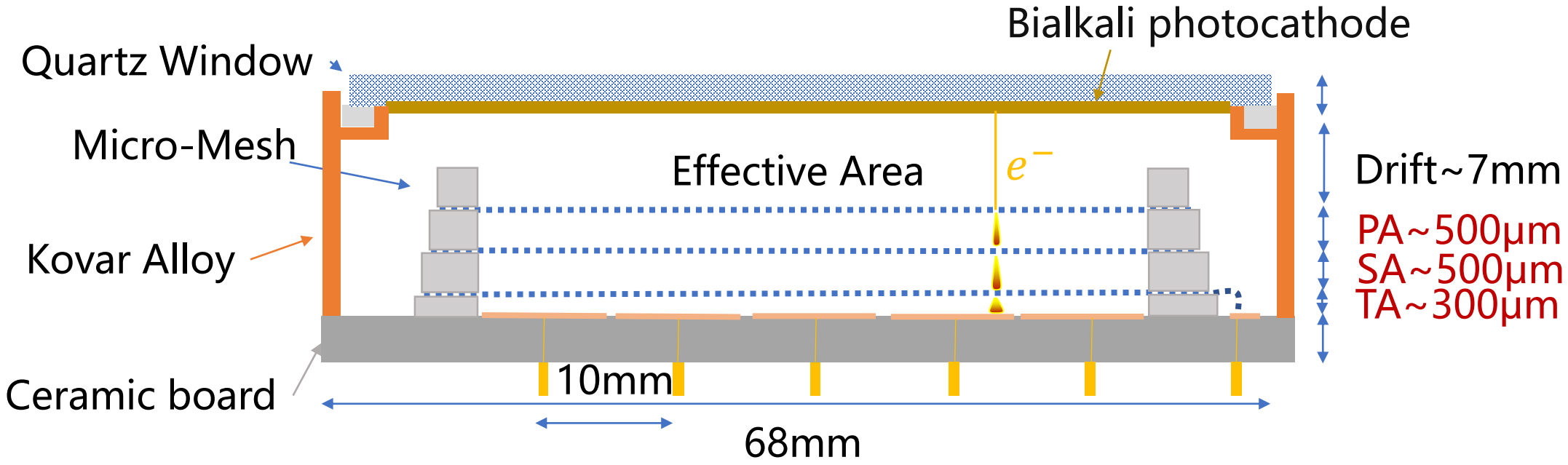
More details: see Xu Wang' s talk on MPGD2026 , "Development of a large area DMM-based photodetector for the RICH detector in STCF"

Gas photon detectors (visible light)

Gas PMT sensitive to visible lights



- **Window and photocathode:** Quartz with in-situ deposited Bi-alkali.
- **Anode Base:** Ceramic board with 10mm pitch readout pads.
- **Envelope:** Kovar alloy flange with Indium sealing groove.
- **Working Gas:** $90\%\mathrm{Ne} + 10\%\mathrm{CF_4}$, 1 atm



First Gas-PMT with TMM detector (visible light)

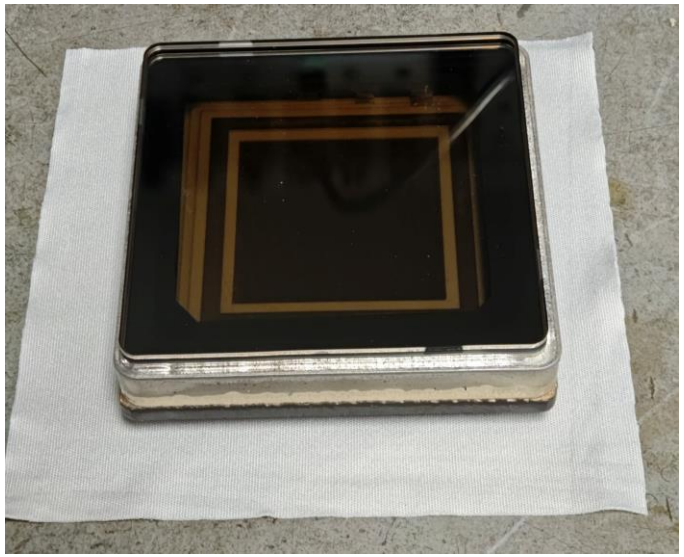
Gas PMT sensitive to visible lights



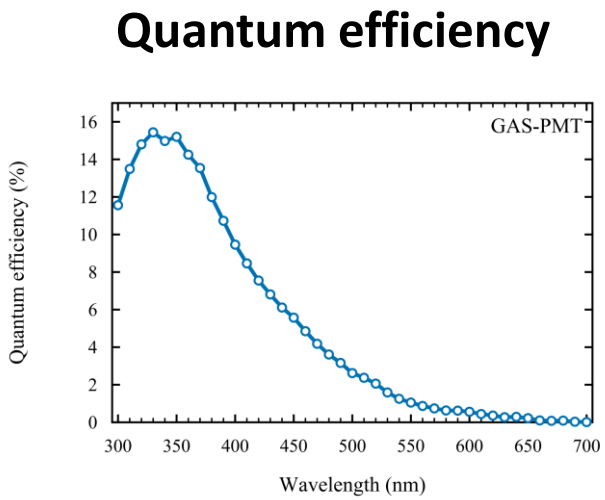
Readout ceramic Board



Brazed TMM structure



A visible-light Gas-PMT prototype



- ✓ Gas gain: $\sim 3 \times 10^5$
- ✓ **The largest size** that have ever achieved for visible light sensitive gas-PMT
- ✓ **Peak QE ~15%** @340nm

More details: see Kunyu Liang' s talk on MPGD2026 , "Visible Light Gas-PMT Based on Triple MicroMegas"

Summary

Double and Triple Micro-Mesh detectors had been proposed and manufactured at USTC for high-rate TPC and gas photon detection

The DMM-TPC in $^{12}C+^{12}C$ fusion measurements

- **IBF ratio <0.1%;** Gain: > **2000 at 50 mbar**; long-term operation over more than **6 months,** achieving an exciting physics measurement.

Gas photon detectors

- DMM with CsI provided a competitive solution **for large-area UV light detector**
- A gas-PMT **sensitive to visible** light was achieved with TMM and Bi-alkali

Thank you for your attention!