LDRD-2614 (MPGD-nTOF) Kick-Off Meeting

November 5th, 2025

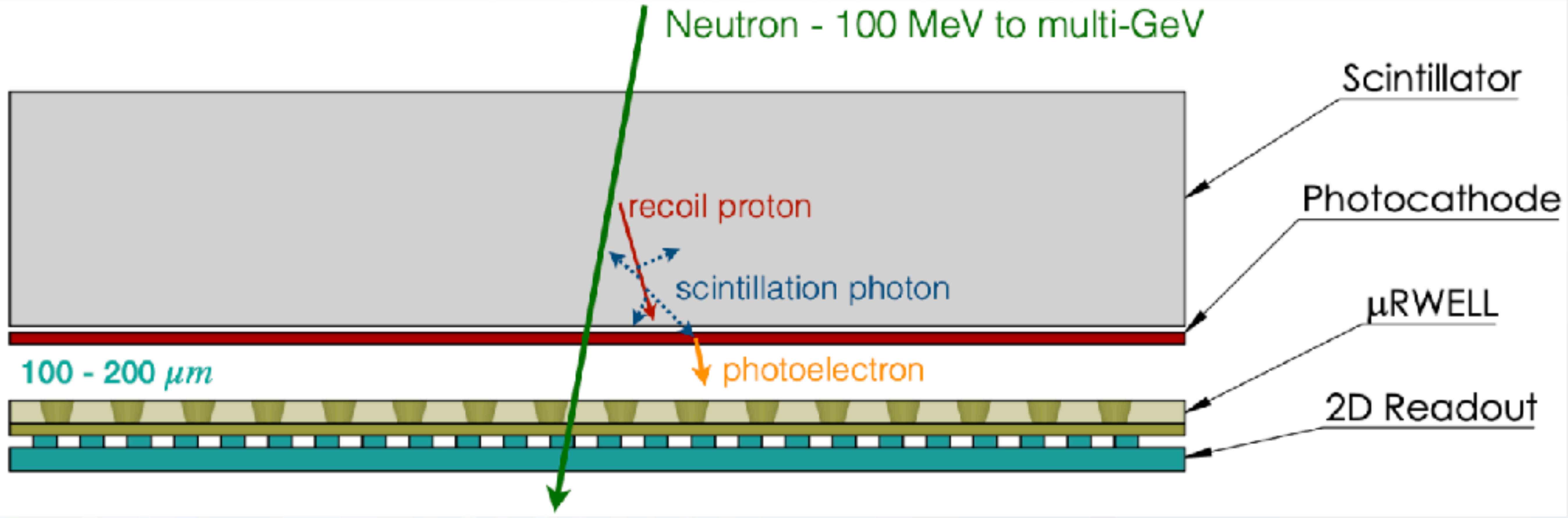
Project Objective – MPGD-nTOF

What we want to achieve?

- Fill the gap where no neutron TOF detector currently reach sub-100 ps timing resolution
- Develop and demonstrate a next-generation MPGD-nTOF detector by integrating MPGD technology, fast plastic scintillators, and UV/visible sensitive photocathode
- Advance photocathode for high-QE, long-term stable operation in gas environment
- Evaluate large area deployment and scalability for nuclear physics and medical applications

What we are proposing?

- Leverage MPGD detector R&D expertise and infrastructure currently available at JLab
- Make use of other DOE Office of Science user facilities for photocathode coating (graphene, DLC, etc)

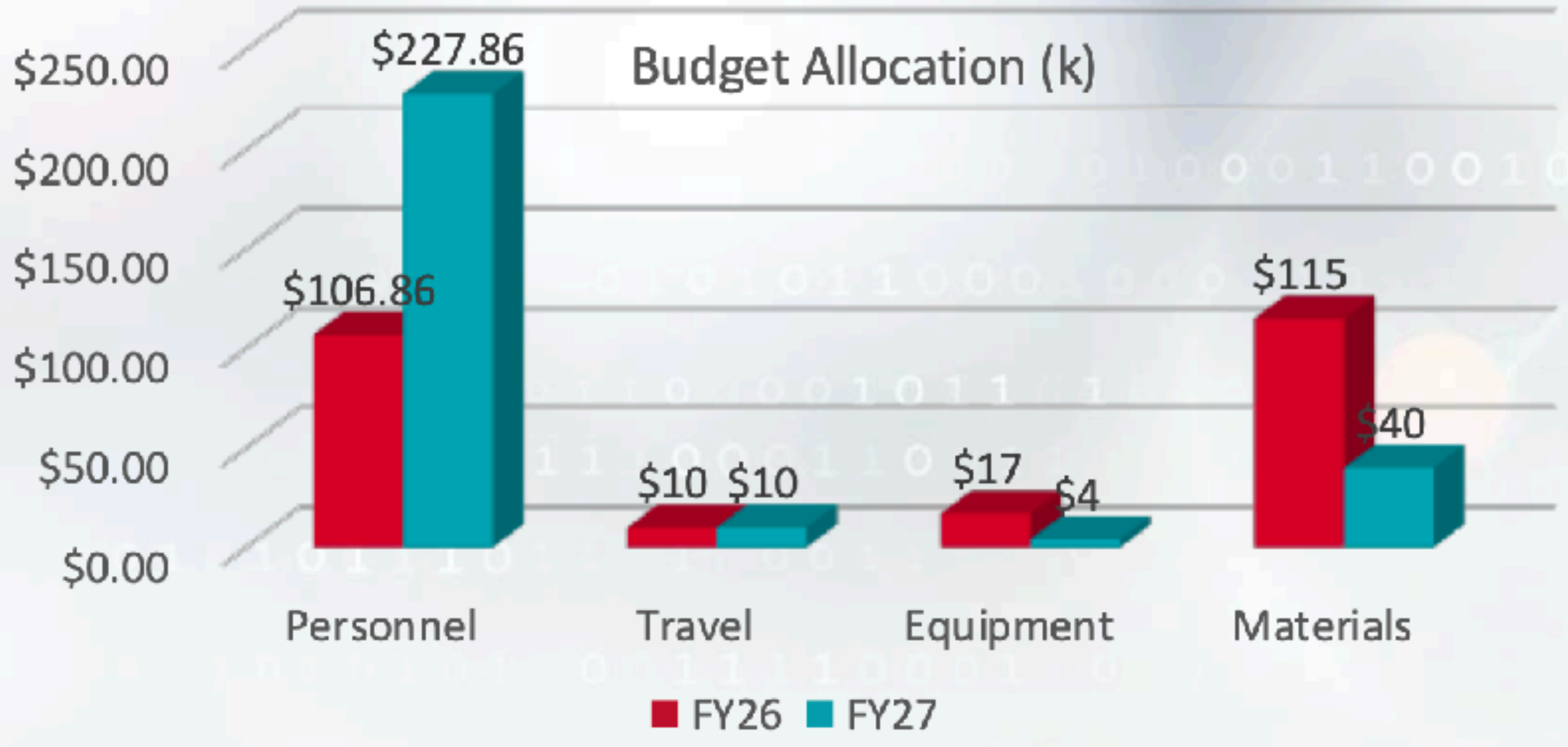


Cross sectional view of the MPGD-nTOF detector

Budget Justification

Budget: $516.72k for the total project

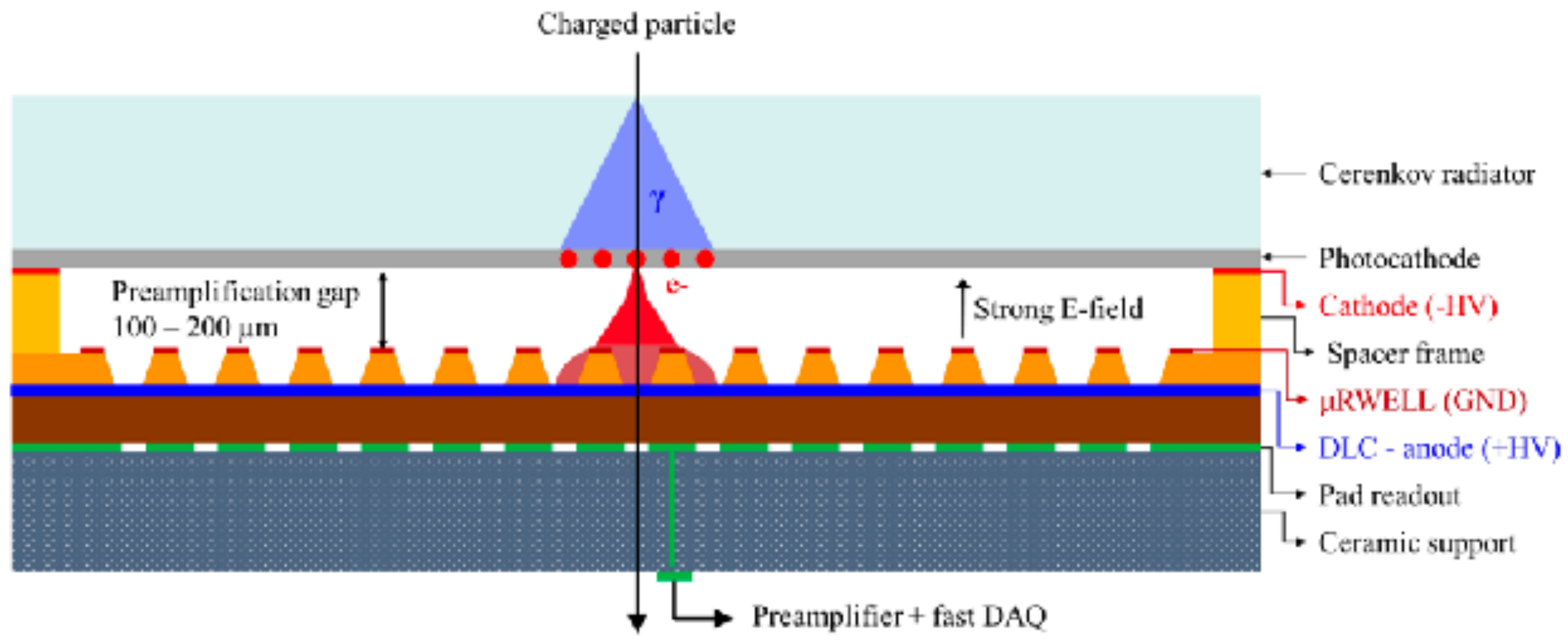
- FY26 – Total = $248.86k
  - Personnel: $106.86k
  - Travel: $10k for conferences, CERN beam tests
  - Equipment: $17k – picoTDC DAQ electronics
  - Materials: $115k
    - 80k – vacuum suitcase to provide a dry, ultra purity gas environment for transferring photocathode with coating, and for detector operation gas system (an integrated part of the detector assembly)
    - 35k – µRWELL PCB from CERN, plastic scintillator tiles, wrapping materials (Black Tedlar Film), photocathode raw materials, lab supplies
- FY27 – Total = $267.86k
  - Personnel: $227.86k (including 1 postdoc)
  - Travel: $10k for conferences, Argonne CNM Travel
  - Equipment: $4k for postdoc work computer
  - Materials: $26k
    - $10k – for µRWELL PCB from CERN
    - $16k – for photocathode raw materials, plastic scintillators, wrapping materials, lab supplies



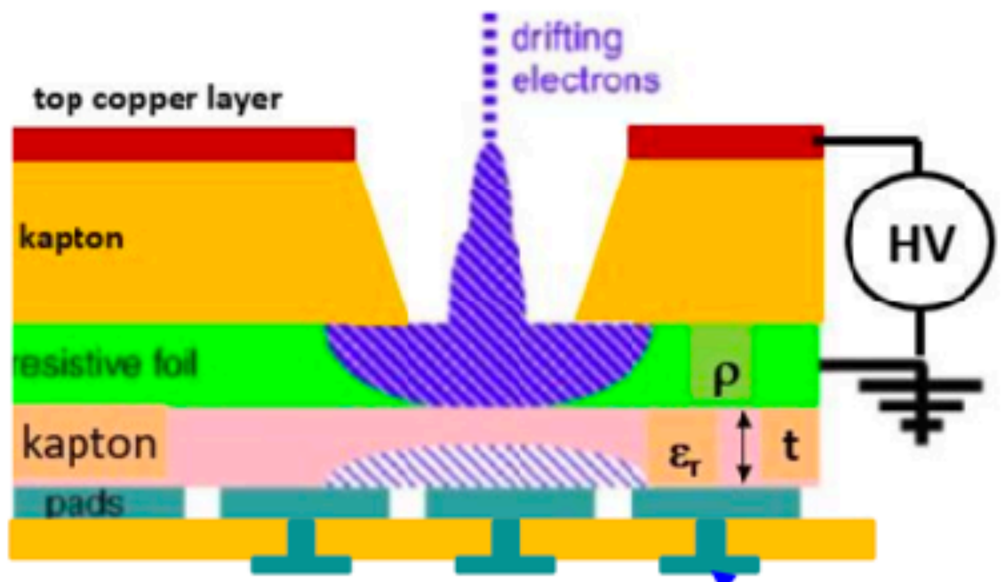
Current Technical Challenges

1. Photocathode
    - Bialkali photocathode is the only option — K_2CsSb
    - Operation in Gas environment, atmosphere pressure
    - Survive reasonable Ion Back Flow
2. Detector Design
    - Photocathode Integration
    - Vacuum assembly
    - Minimize Ion Back Flow
    - 5cm X 5 cm for prototype (Large area for future)
3. Electronics Design
    - PETIROC
    - SAMPIC Digitizer

LDRD uRWELL-PICOSEC

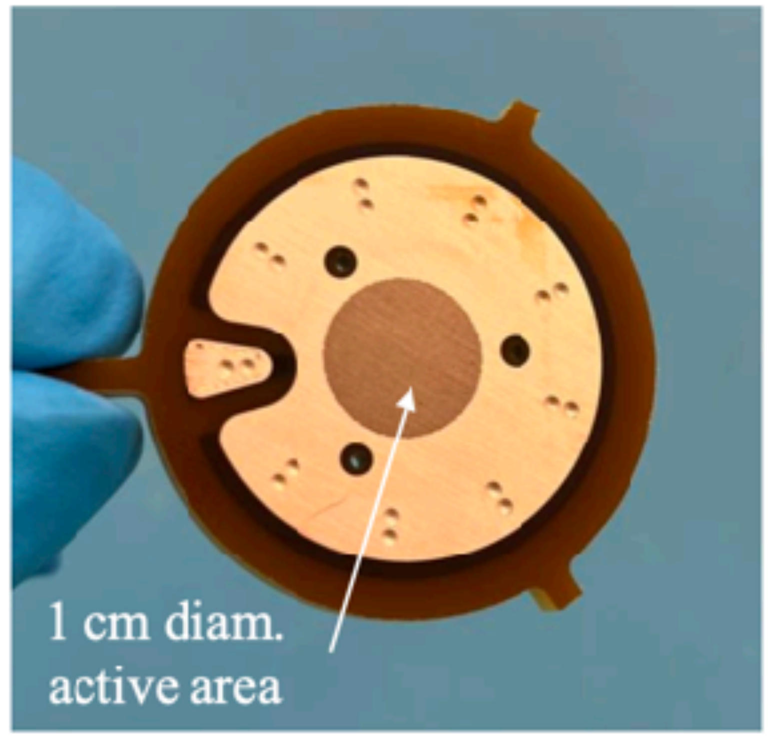


LDRD µRWELL-PICOSEC – Small prototype

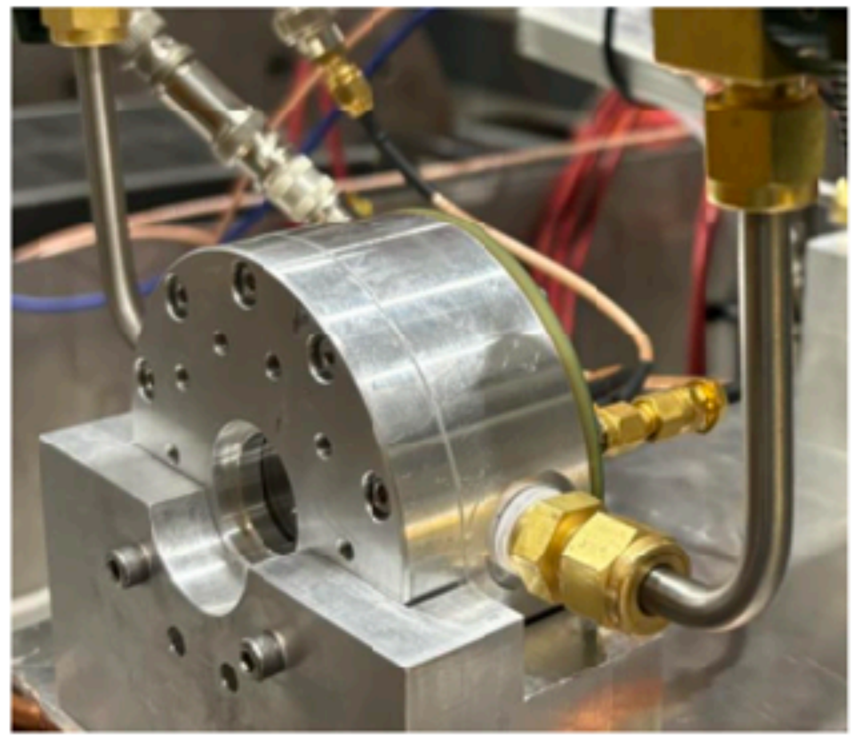


µRWELL PCB

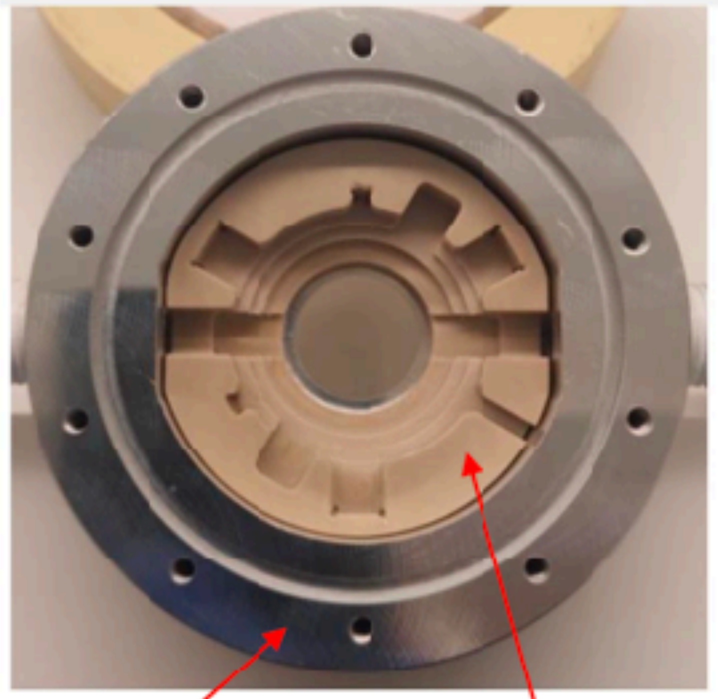
Readout pad contact



µRWELL PCB front side

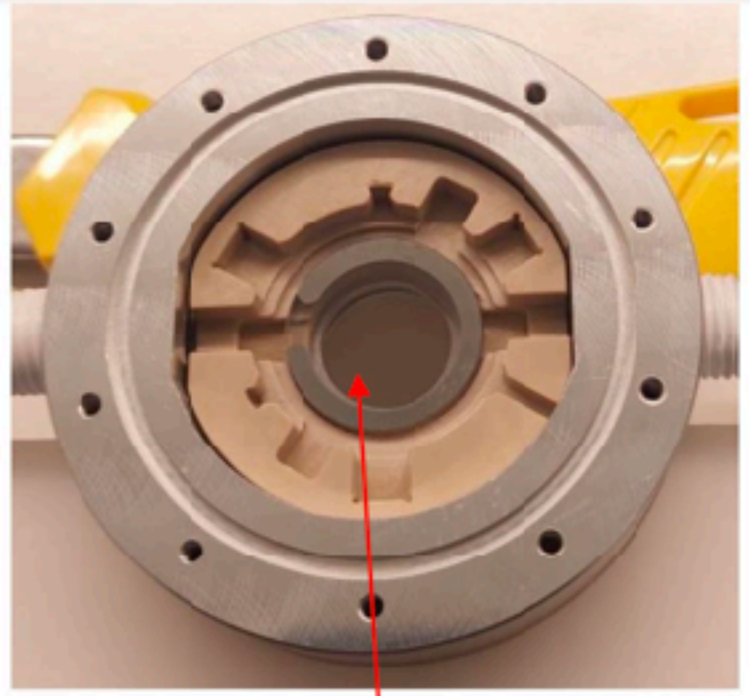


Prototype in Al chamber

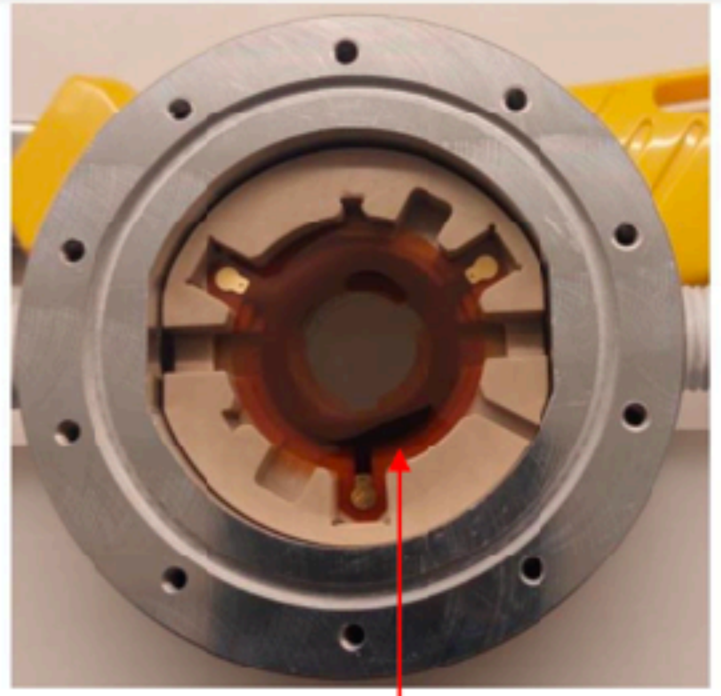


Al chamber

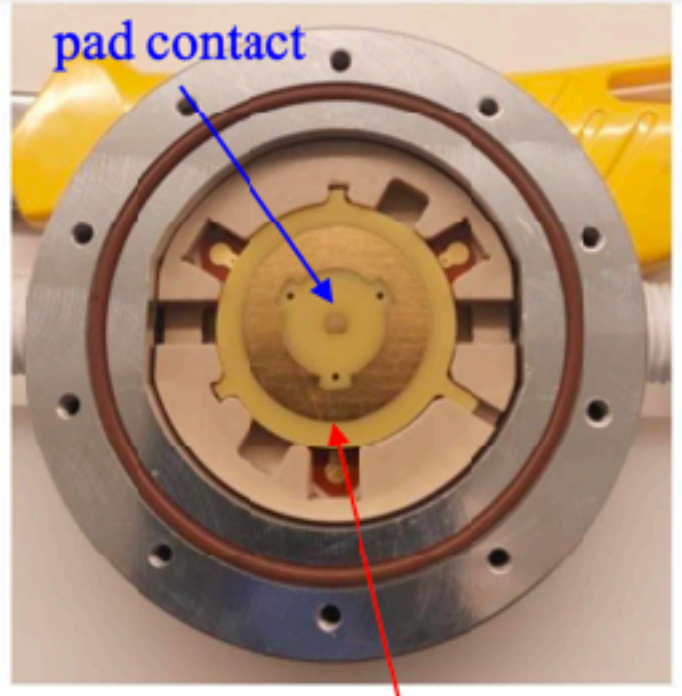
PEEK insert



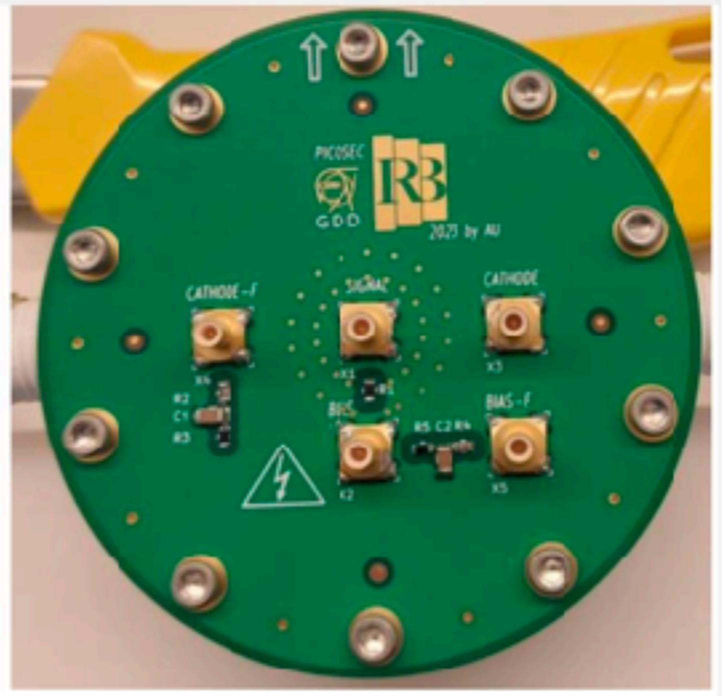
3mm MgF_2 crystal with 18nm CsI / 2nm DLC photocathode



Spacer / cathode contact



µRWELL PCB back side

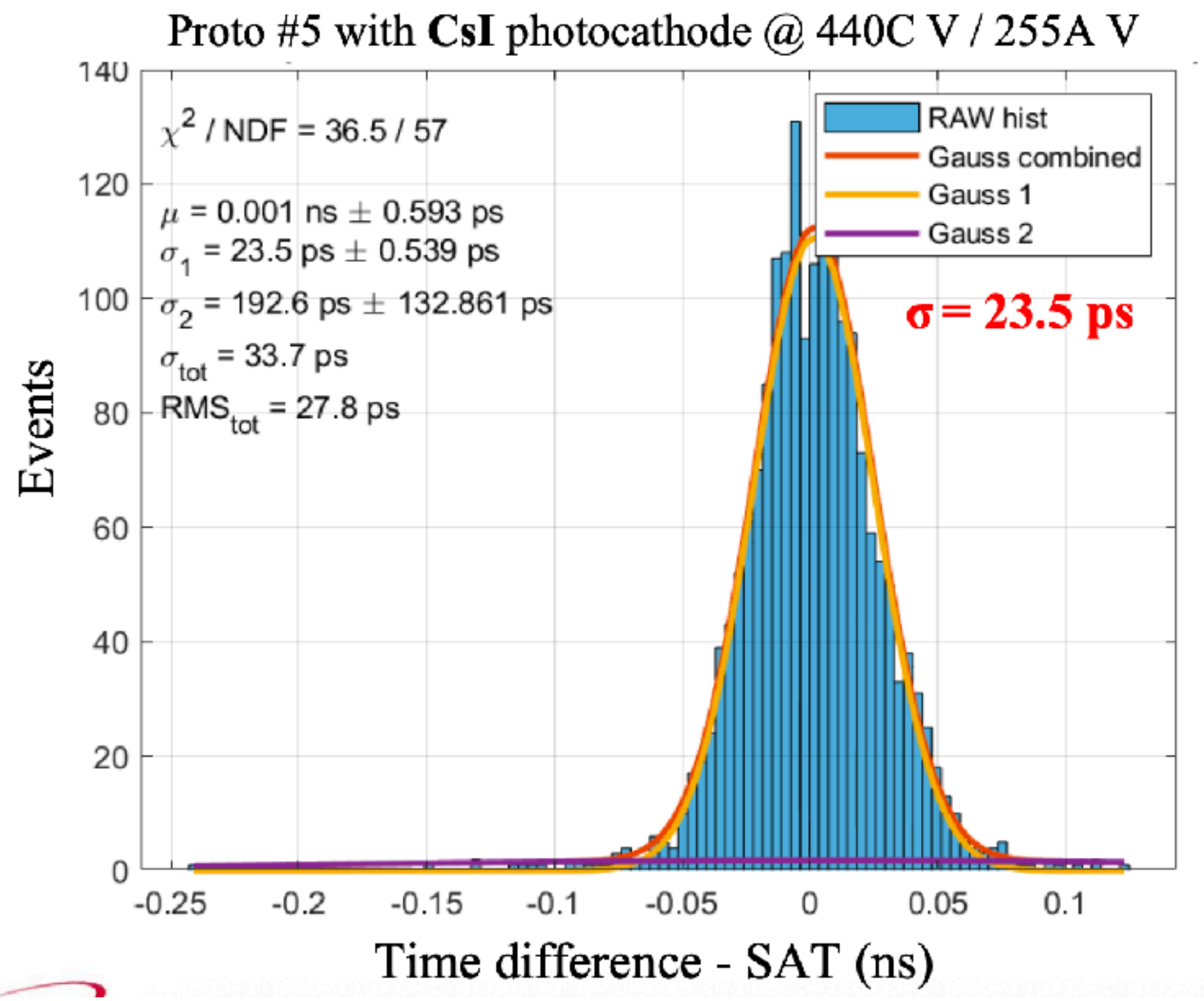


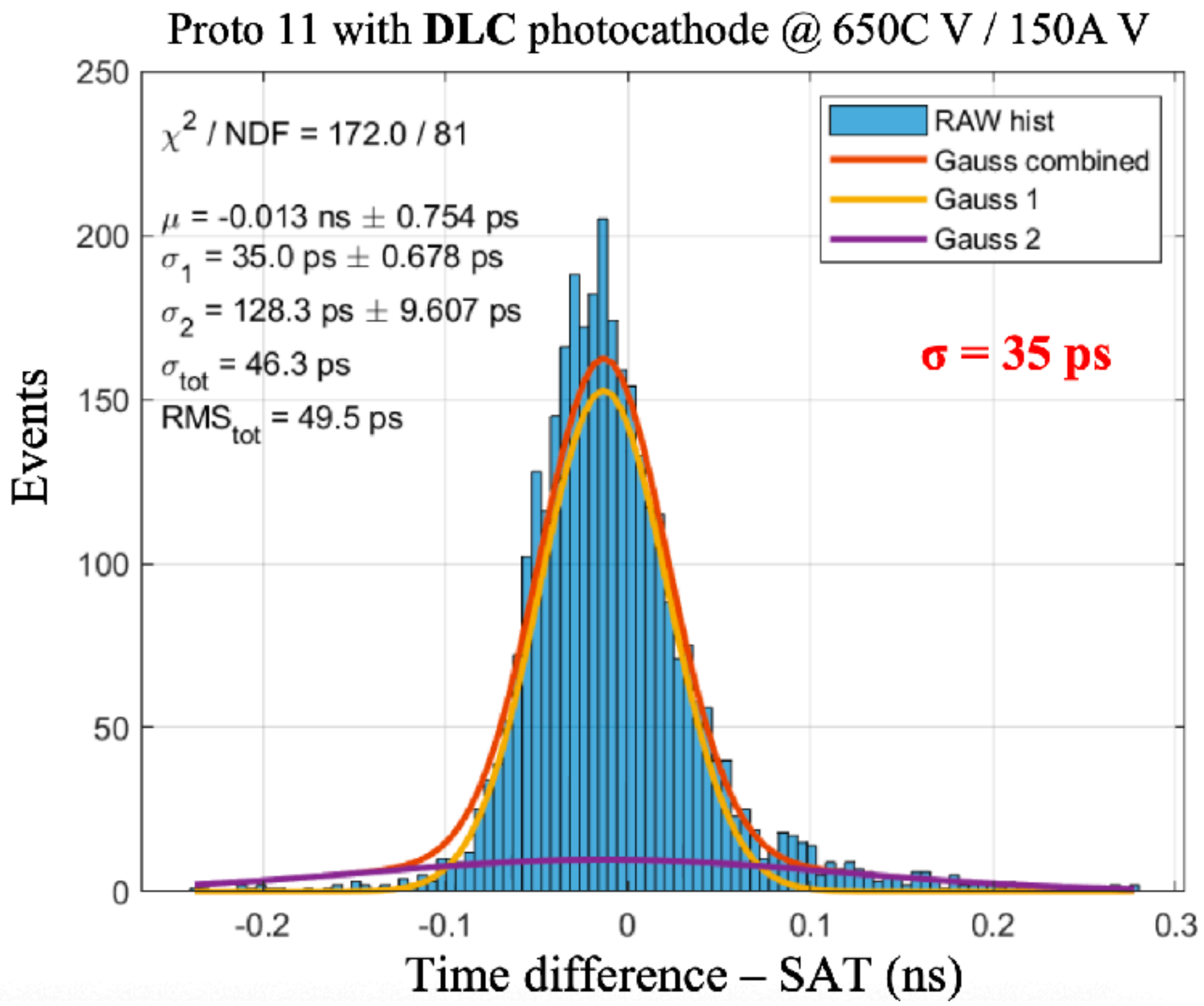
Outer board

LDRD uRWELL-PICOSEC

LDRD µRWELL-PICOSEC – Performance results

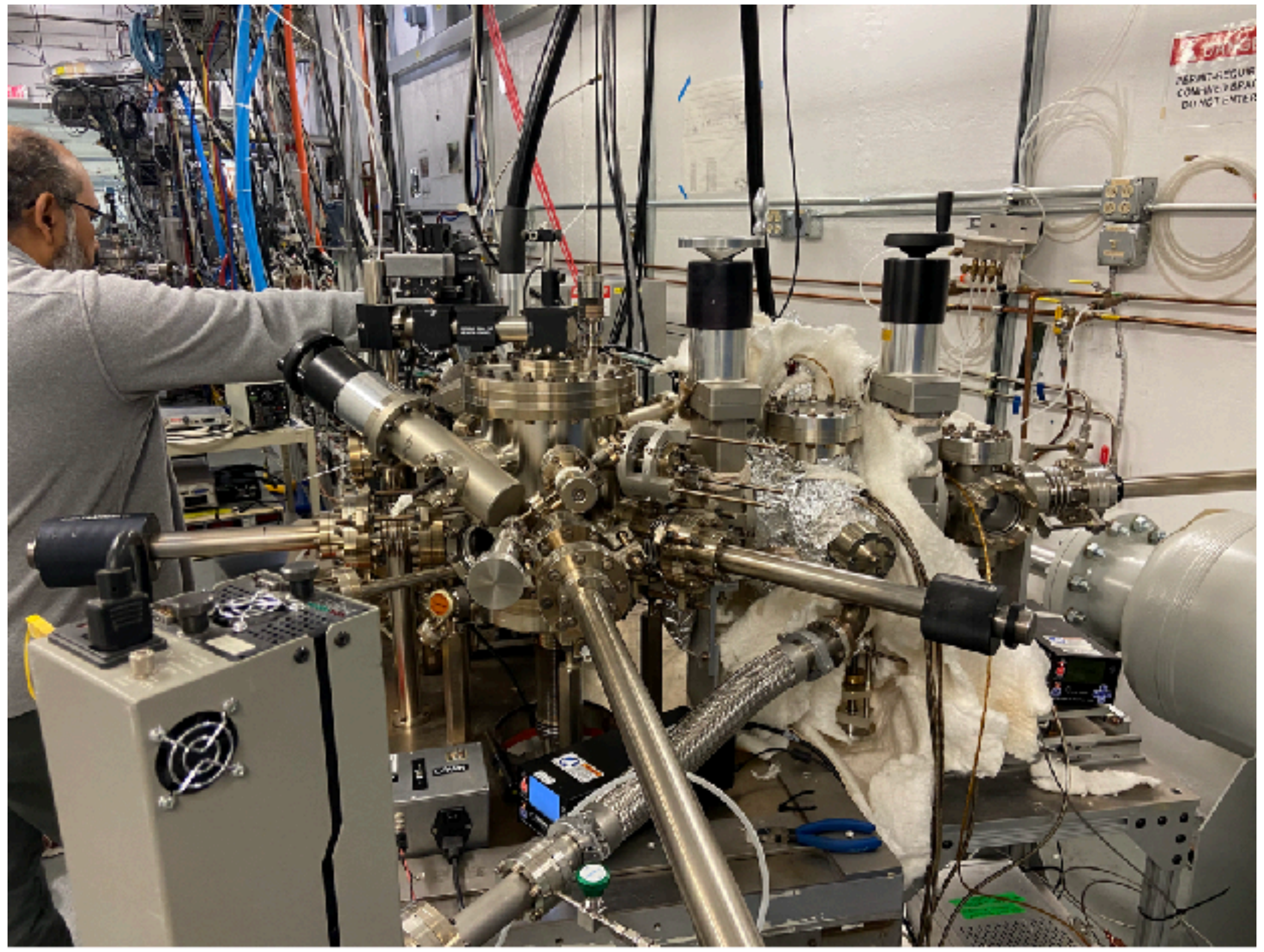
- 23.5 ps with **CsI** and 165 um drift gap ➔ < 20 ps possible at smaller gap and optimized µRWELL geometry
- 35 ps with **DLC** and 165 um drift gap ➔ < 25 ps possible at smaller gap and optimized µRWELL geometry



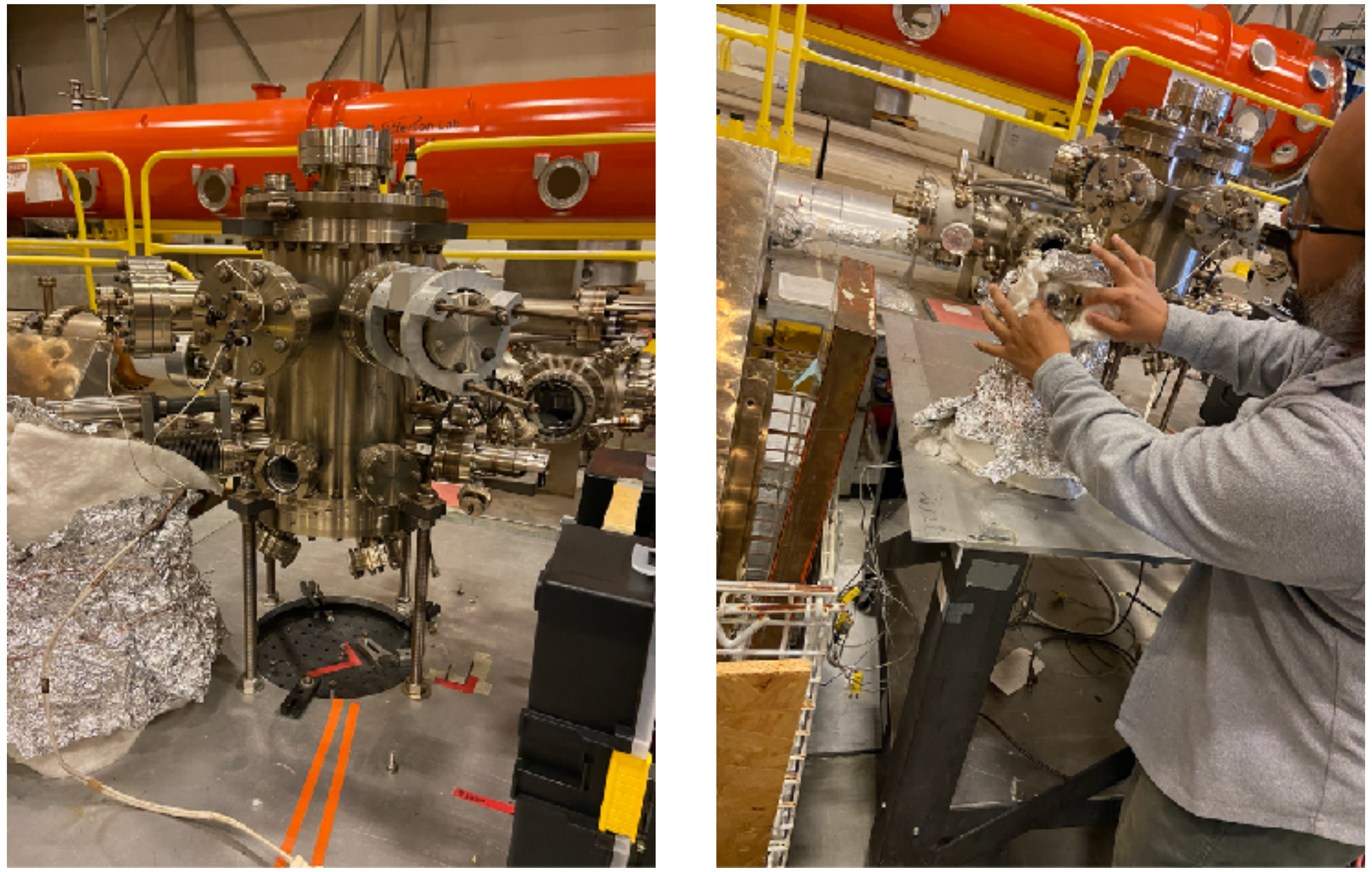


Infrastructure at JLab

- Vacuum deposition chambers at JLAB CIS group
- Used to manufacture K_2CsSb photocathode (decommissioned), needs a bit vacuum work to restore



Deposition Chamber in JLab UITF



Deposition Chamber in JLab Storage

Vacuum Suitcase

Transferring Photocathode to Detector

Removable organic protective coating for alkali-antimonide photocathodes

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[b] *Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia*

Received 14 January 1998

Abstract

We describe a technique for protecting alkali-antimonide visible light photocathodes against deterioration by exposure to impurities, during handling or storage in poor vacuum or gas. The photocathodes are coated with a ~ 1 μm vacuum-deposited hexatriacontane film, which can be subsequently removed by low-temperature sublimation. We show that Cs_3Sb coated photocathodes can be exposed for several minutes to considerable amounts of oxygen, without deterioration. Their initial photoemission properties are almost fully recovered after film removal.

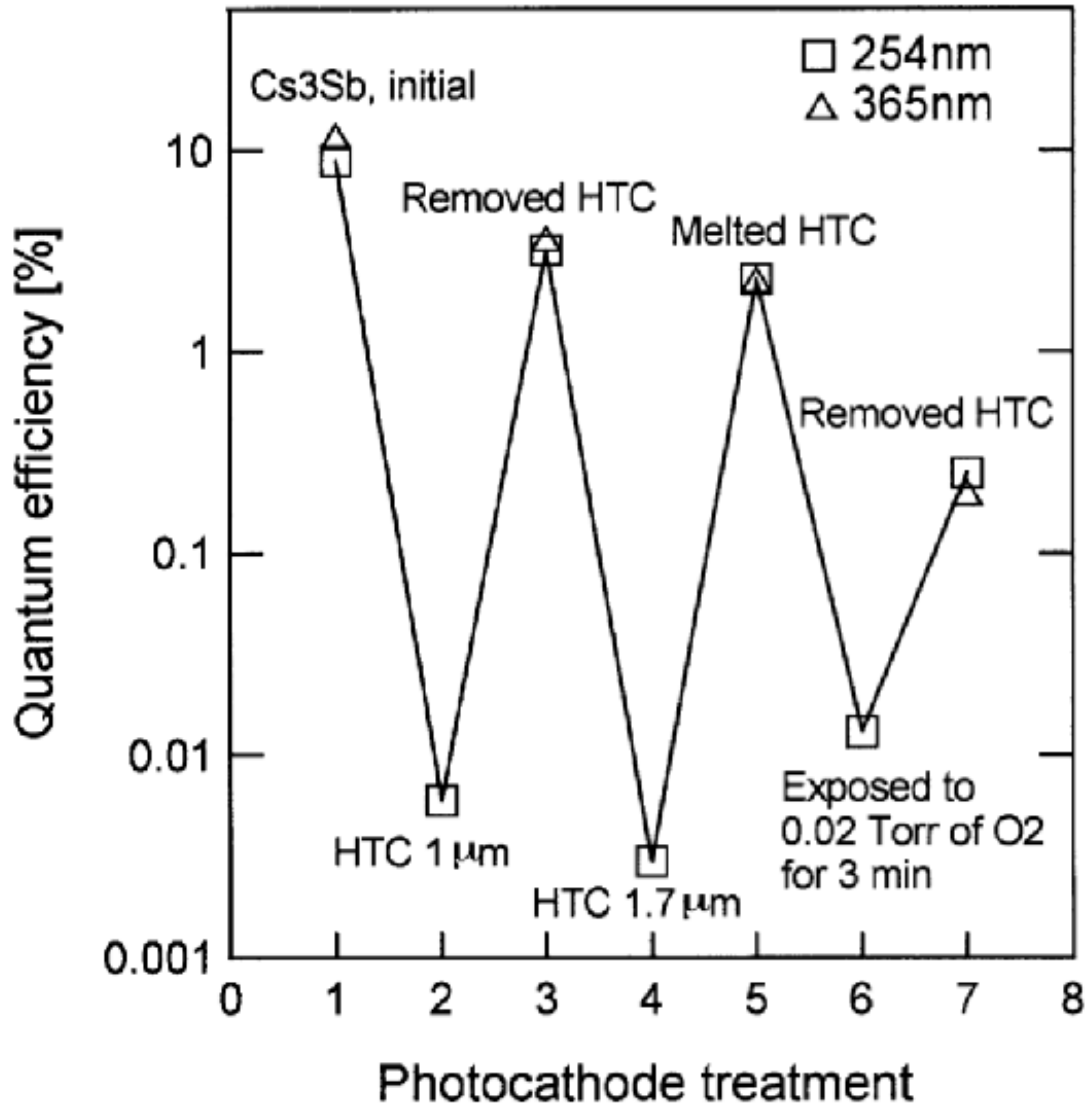
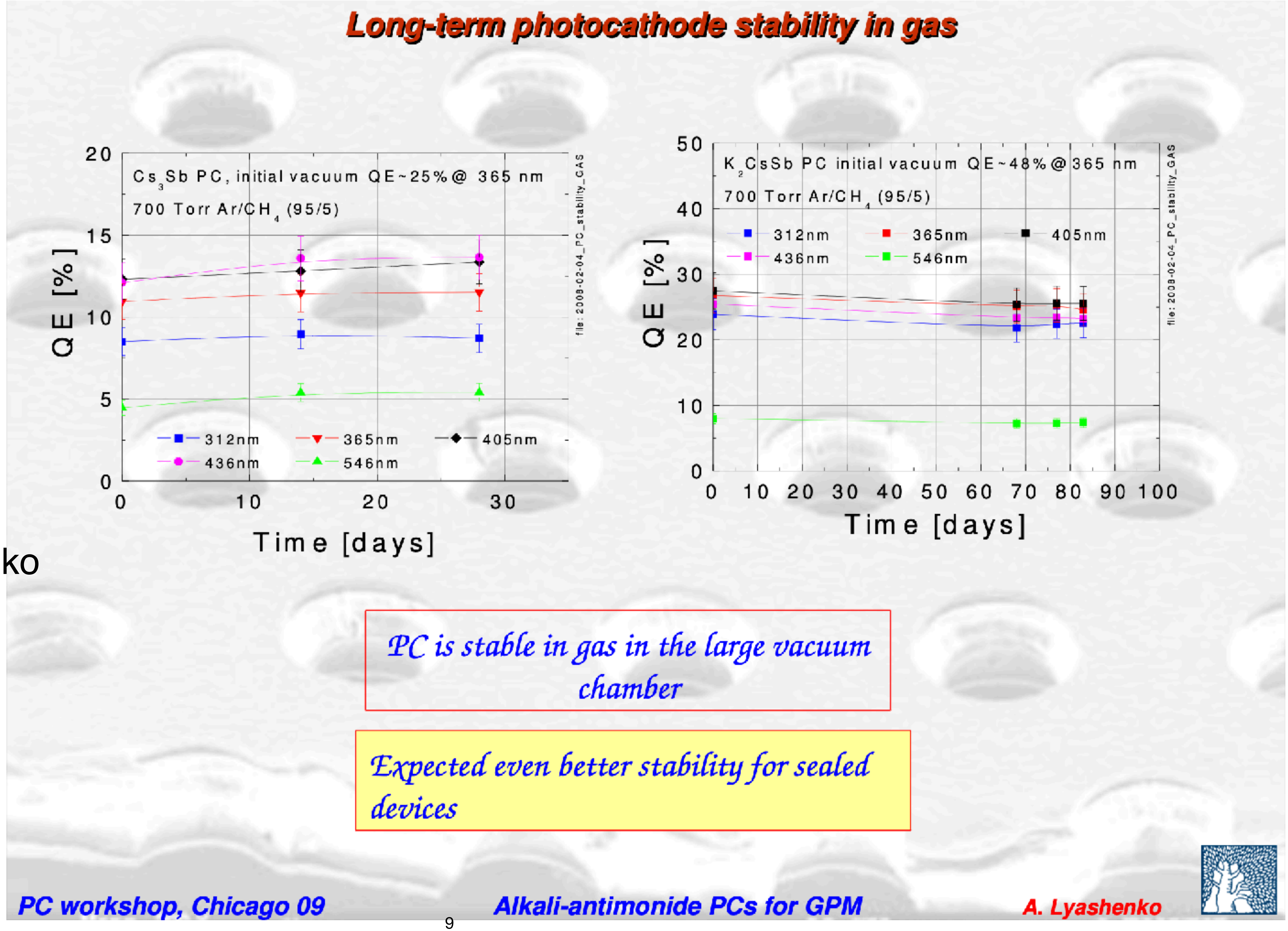


Fig. 5. Treatment of a Cs_3Sb photocathode with thick HTC films. The quantum efficiencies at 254 and 365 nm, measured after the following treatments: (1) initial Cs_3Sb deposition, (2) coating with 1 μm thick HTC, (3) HTC removal, (4) coating with 1.7 μm thick HTC, (5) HTC melting, (6) exposure to 0.02 Torr of oxygen for 3 min, (7) HTC removal, are shown.

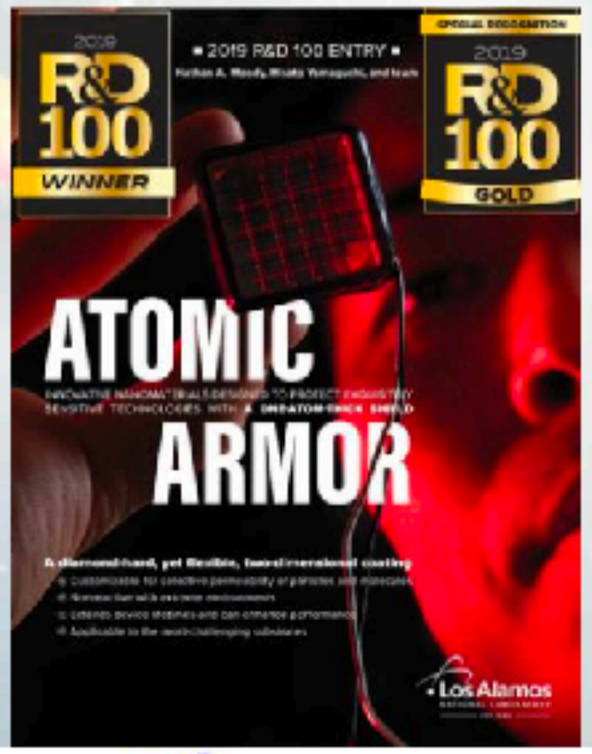
Photocathode Stability in Gas

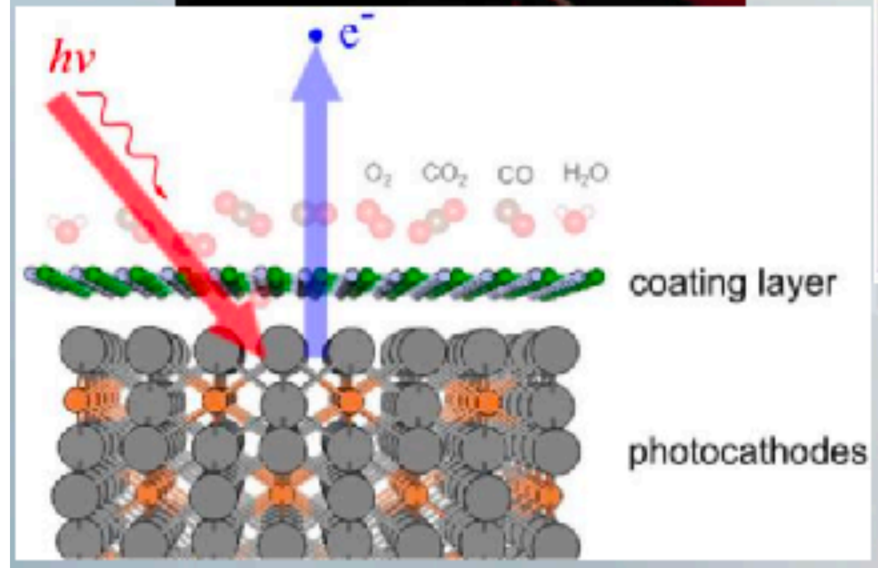


- Slide From A. Lyashenko (Weizmann Institute)
- With no Ion Back Flow

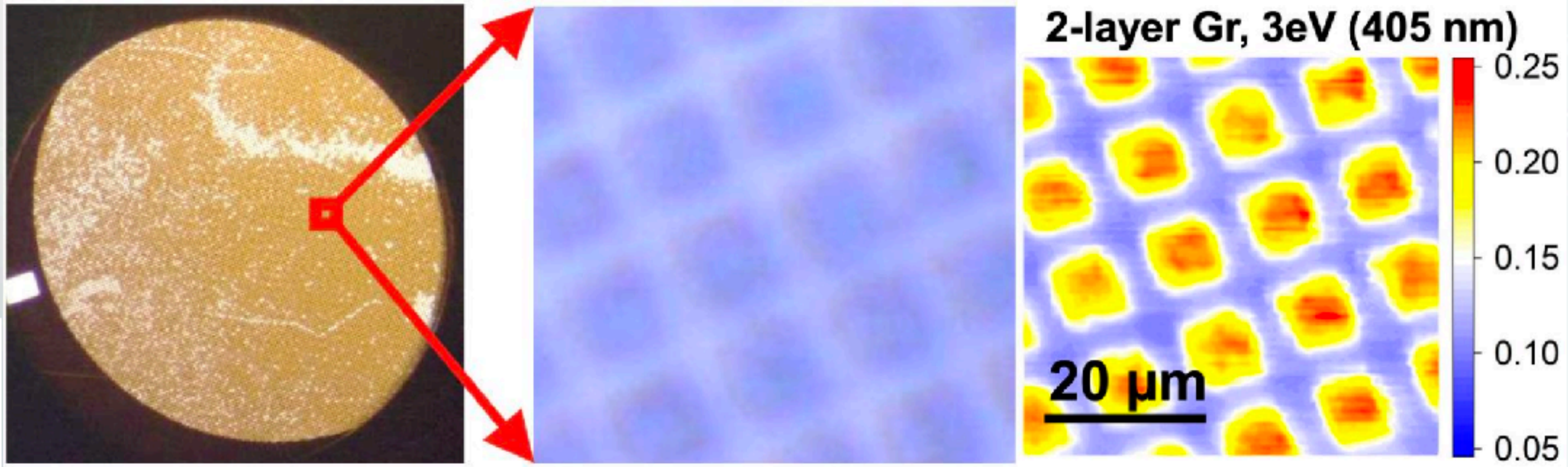
Strategies to Overcome Photocathode Challenge

- Develop protective photocathode coatings (coating material: graphene, DLC, thin metal films, etc)
  - Active on-going R&D for accelerator studies at BNL, LANL, SLAC, and others
  - Leverage external expertise through collaboration with researchers experienced in photocathode coating studies
- Detector structure improvement (Ion Trap)
  - Related work reduced Ion Feedback to below 4%

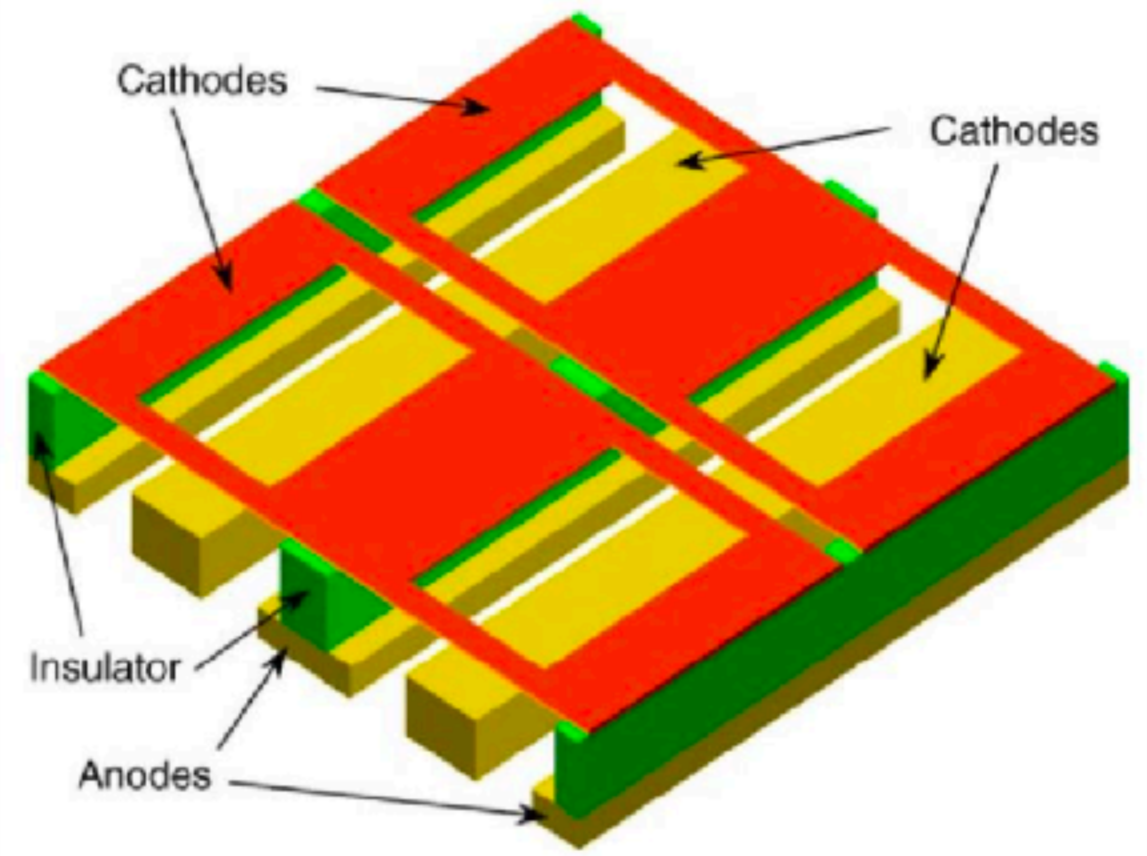




G.Wang and N.Moody et al.
NPJ. *2D Materials and Applications* 17 (2018)



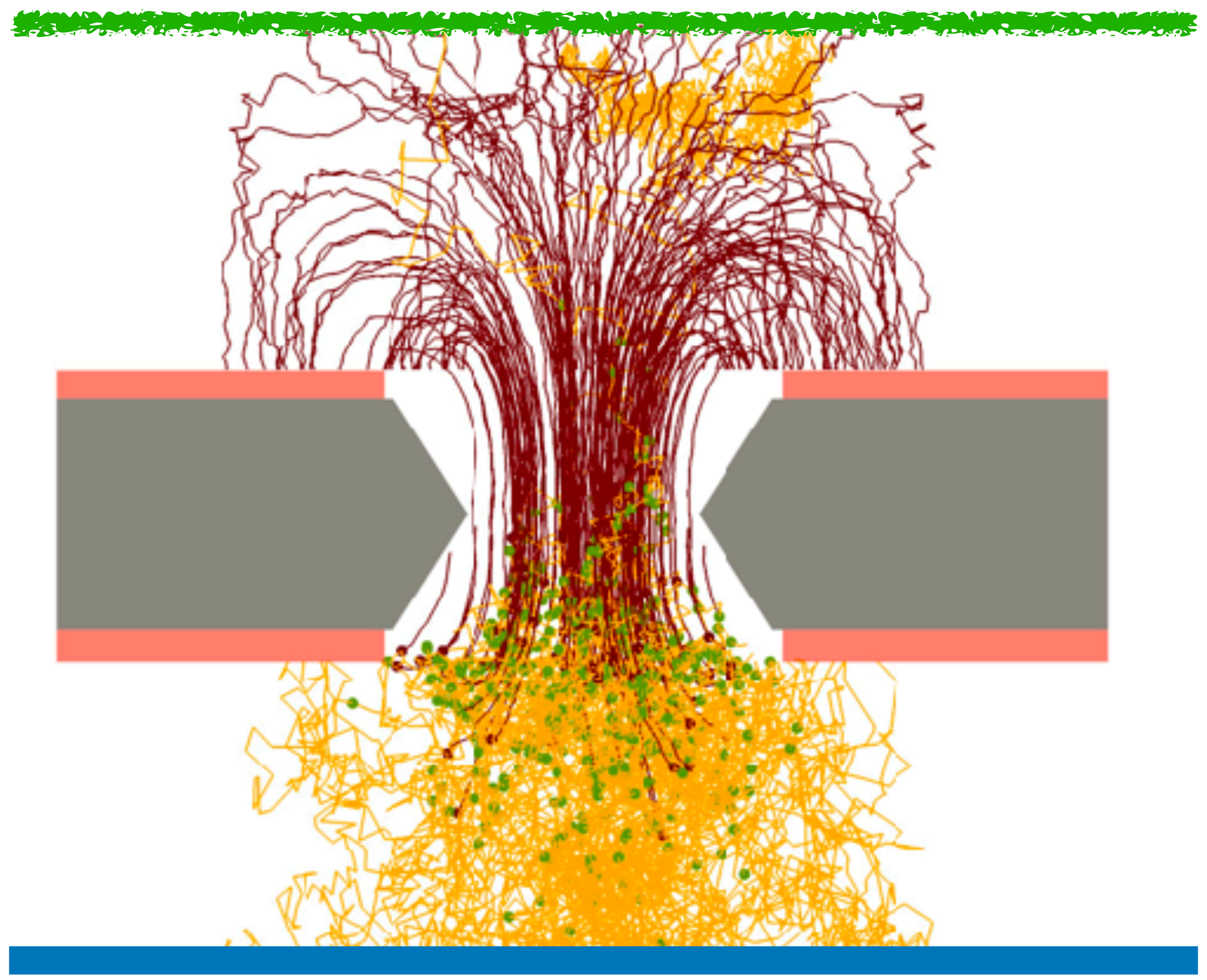
The Atomic Armor – Hisato Yamaguchi (LANL)



Ion Trap – Oleg Bouianov,
NIM-A 526 (2004) 413-419

Current Technical Challenges — Ion Back Flow

- Gas amplification process in GEM foil
- Normal ion back flow 60% per GEM foil
- Long term stable operation for Bialkali photocathode: IBF: **10^{-3} ~ 10^{-4}**
- Single electron detection requires gain ~ 10^4



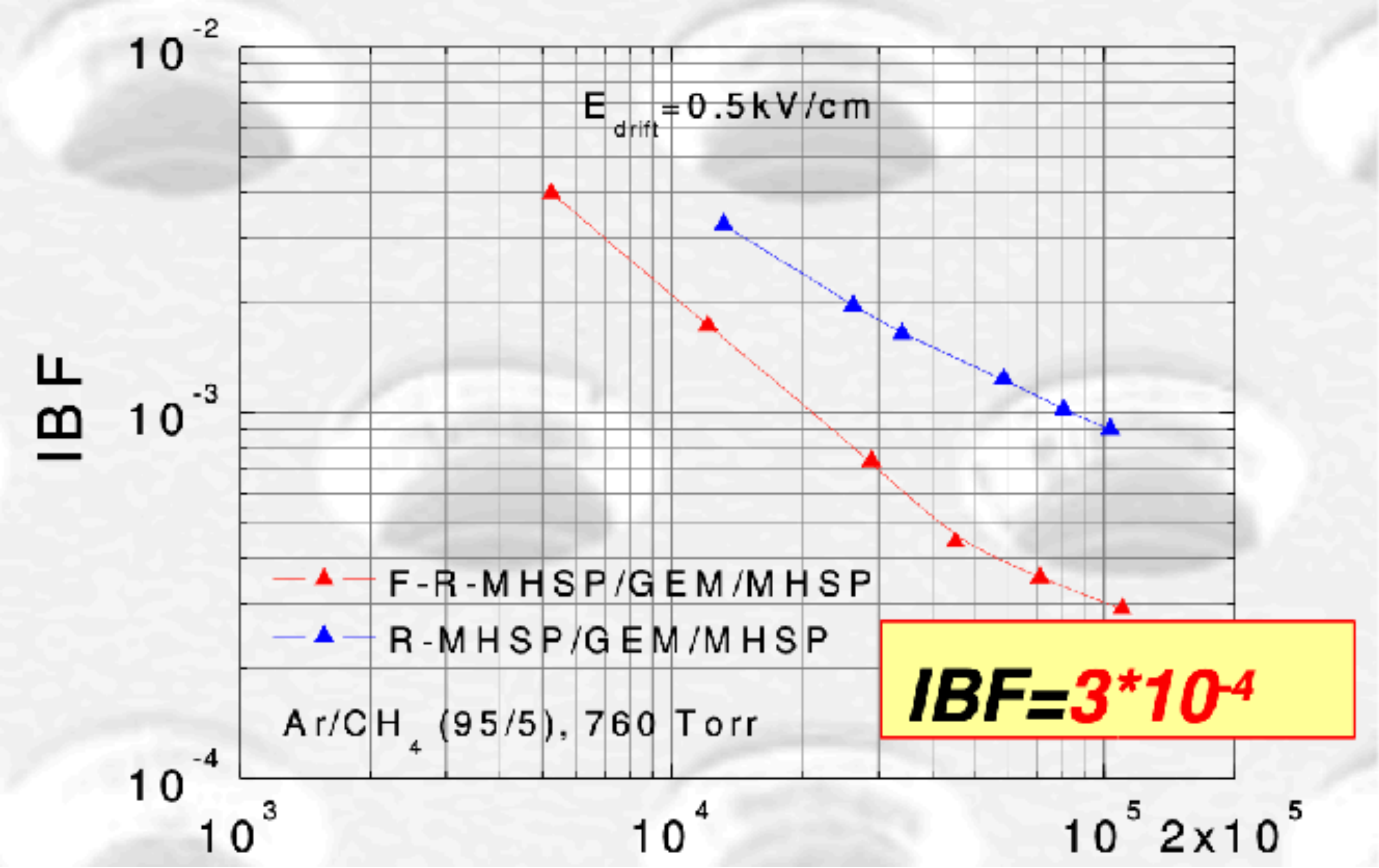
$$IB = \frac{I_{\text{cathode}}}{I_{\text{anode}}}$$

Ion Back Flow

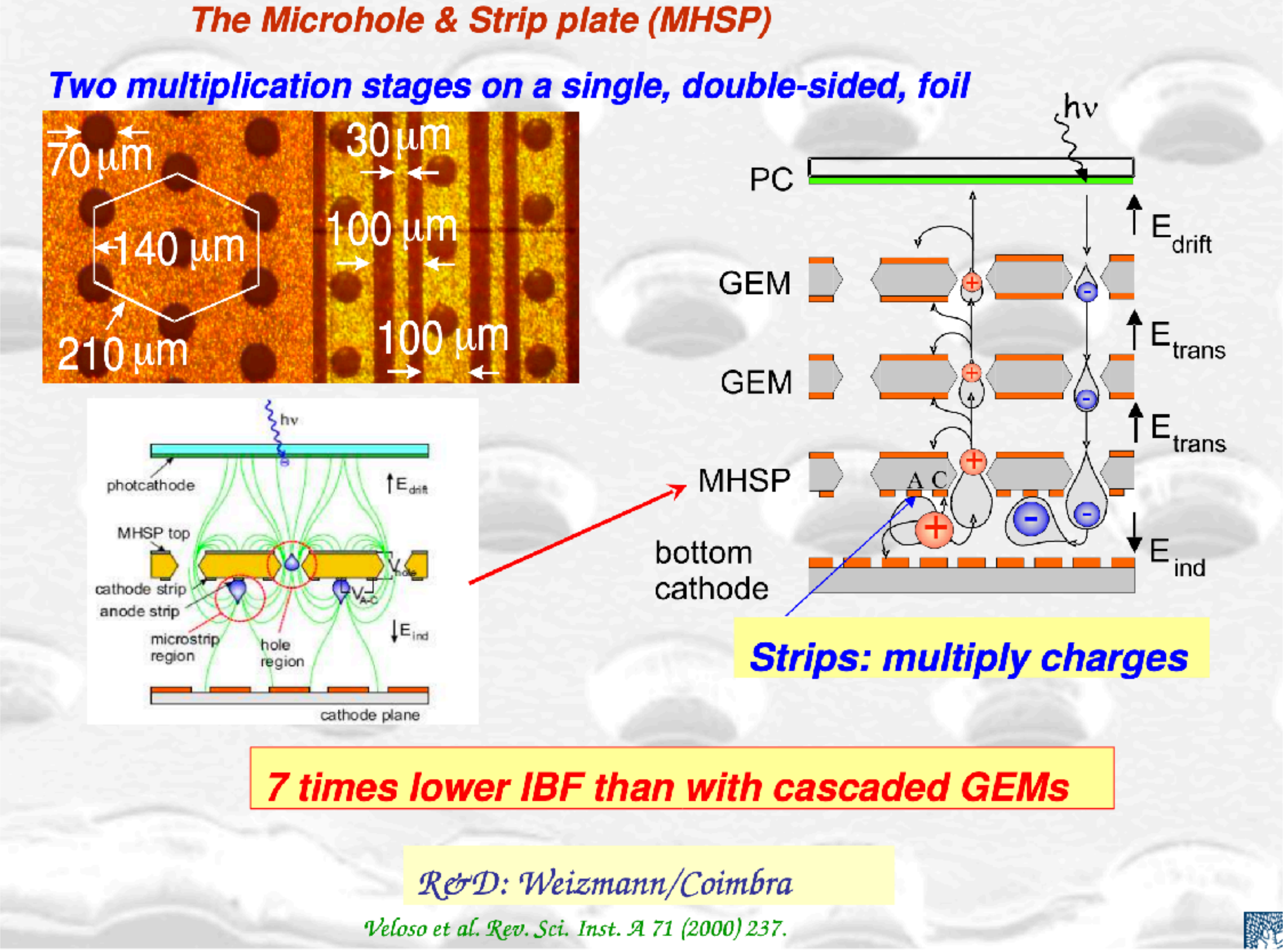
- Photocathode lifetime
- Low or Negative Electron Affinity photocathode
  - Back flowing ion cause secondary electron emission
  - Secondary photoelectron also has ion back flow
  - Cascade reaction — similar process like avalanche — discharge

Technical Design Report for the Upgrade of the ALICE Time Projection Chamber, CERN-LHCC-2013-020, February 19, 2014

Current Technical Challenges — Ion Back Flow

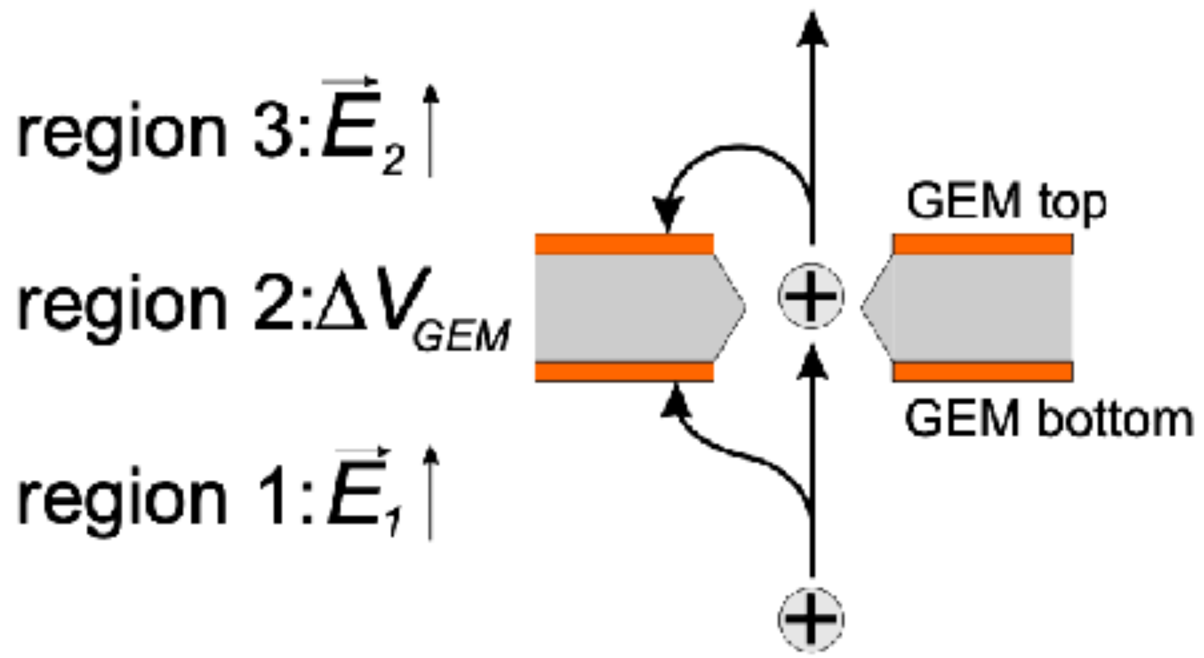


Slide From A. Lyashenko (Weizmann Institute)



Optimize E Field to Minimize IBF — Multiple Layer of Amplification

$$\epsilon_{bf} = \frac{I_{pc}}{I_A}$$



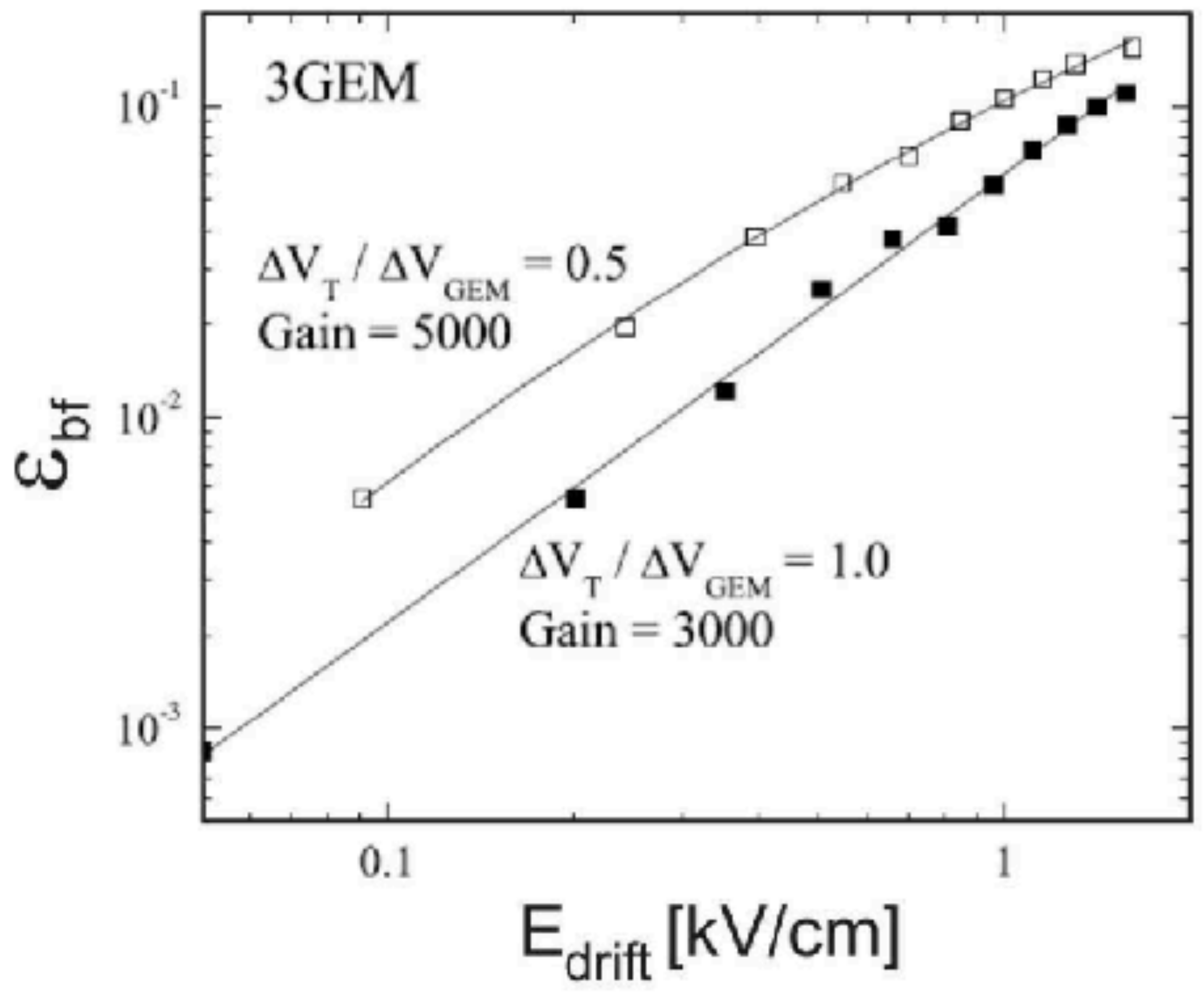
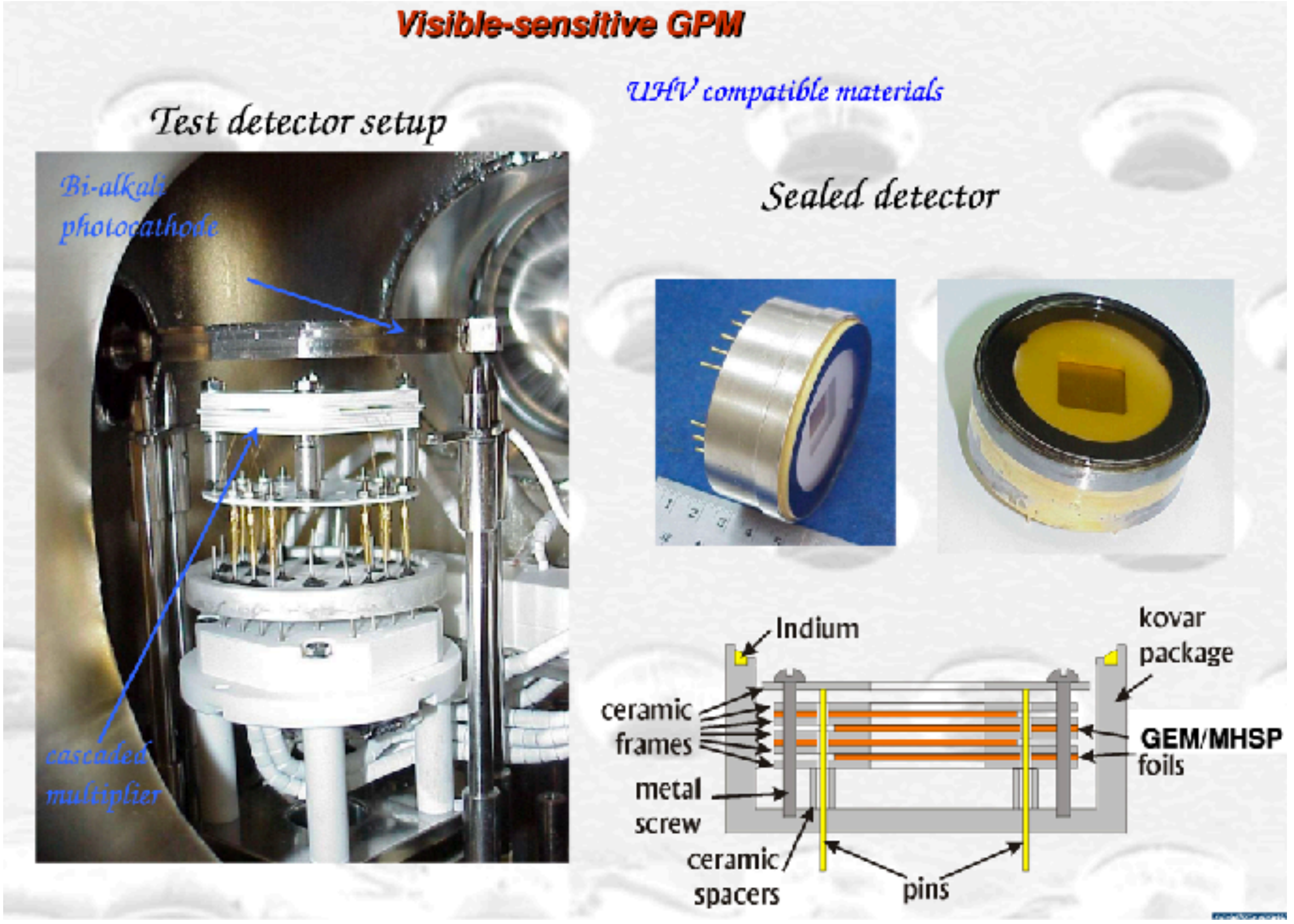


Fig. 6.2: Influence of the drift field (taken from [67]).



IBF Minimization — DMM

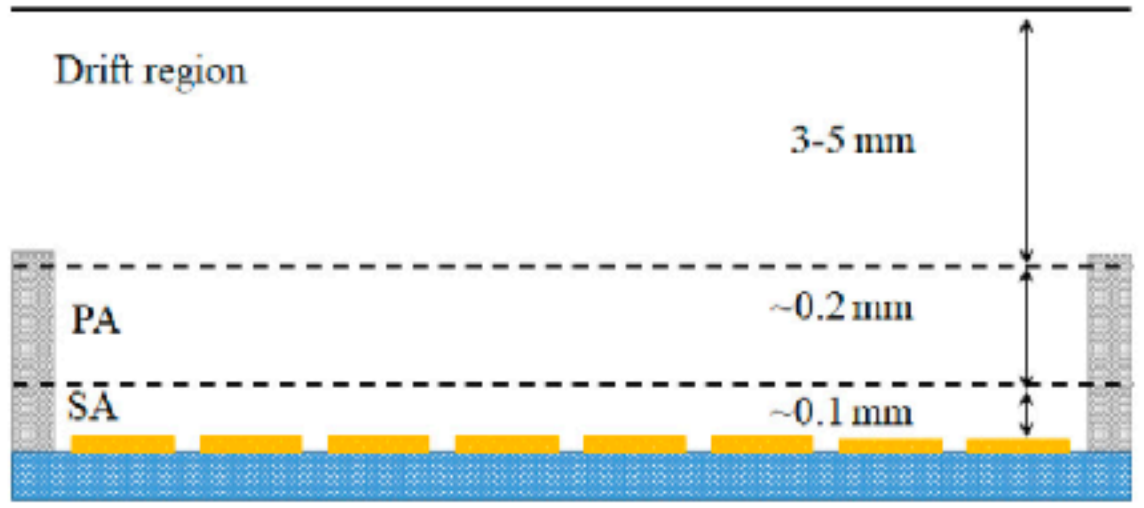


Fig. 1. Schematic of the DMM.

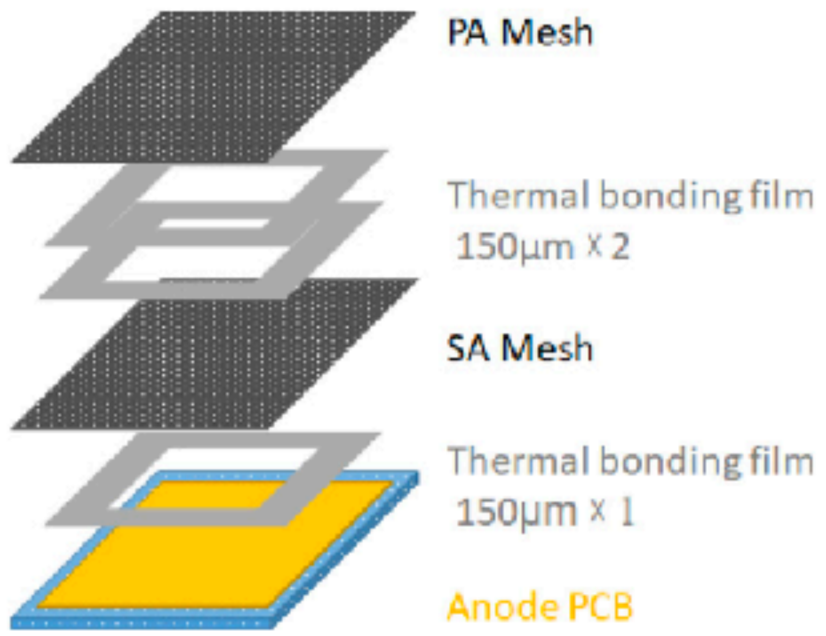


Fig. 2. Design diagram for the fabrication of prototype.

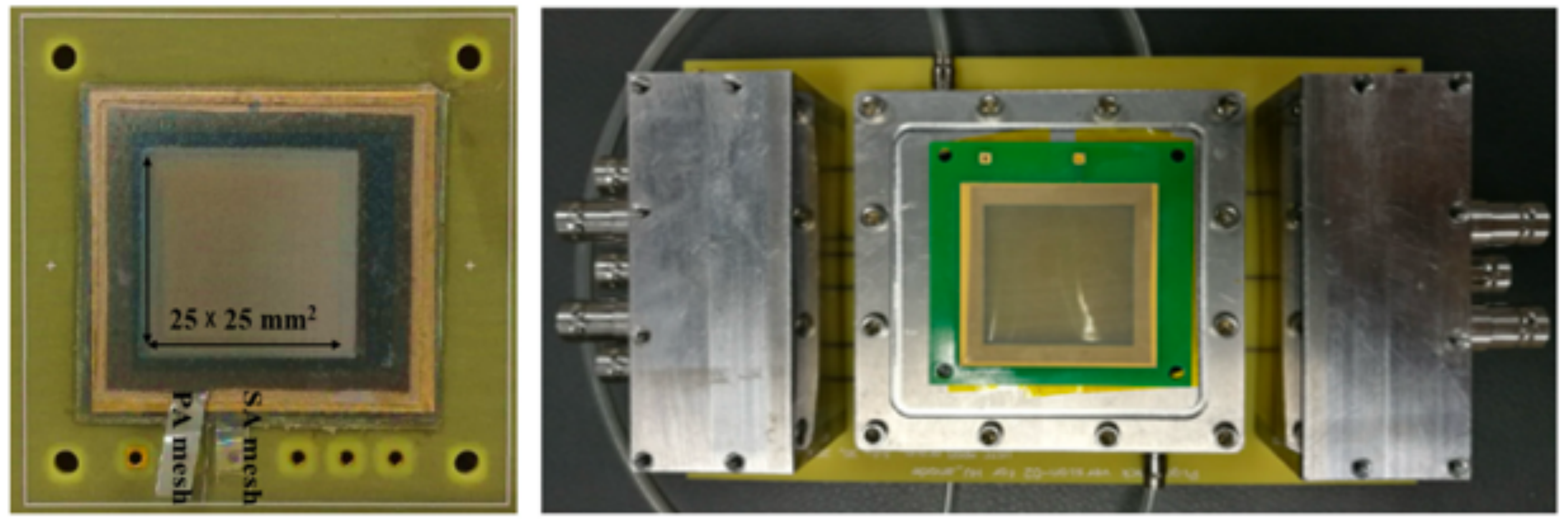


Fig. 3. DMM prototype (left) and the detector chamber after assembly (right).

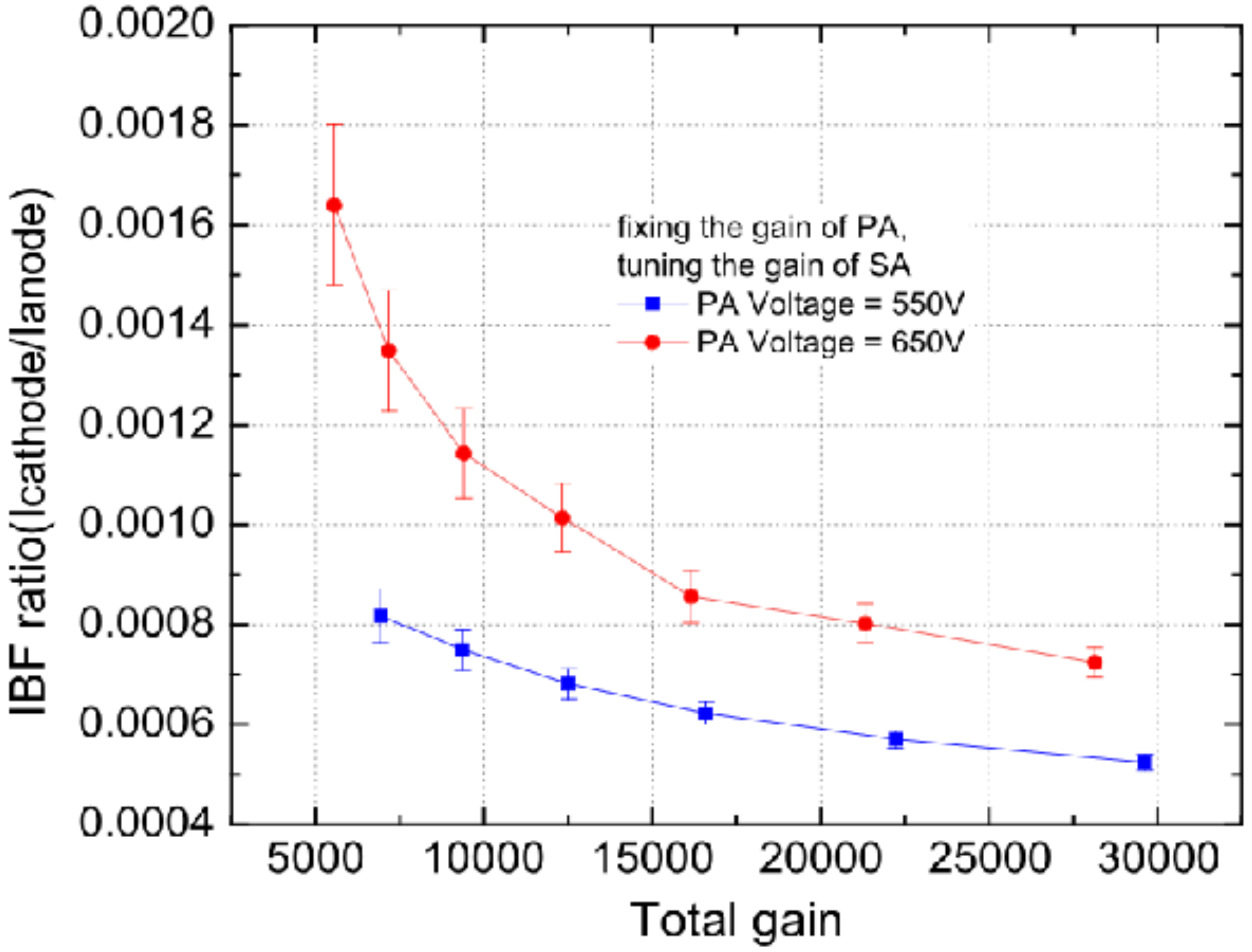


Fig. 7. IBF ratios at different total gas gains with a fixed PA voltage.

Zhiyong Zhang, et al, A high-gain, low ion-backflow double micro-mesh gaseous structure for single electron detection, Nuclear Inst. and Methods in Physics Research, A 889 (2018) 78–82

IBF Minimization — COBRA GEM Foil (ALICE TPC)

- IBF reduced to 10^{-4}

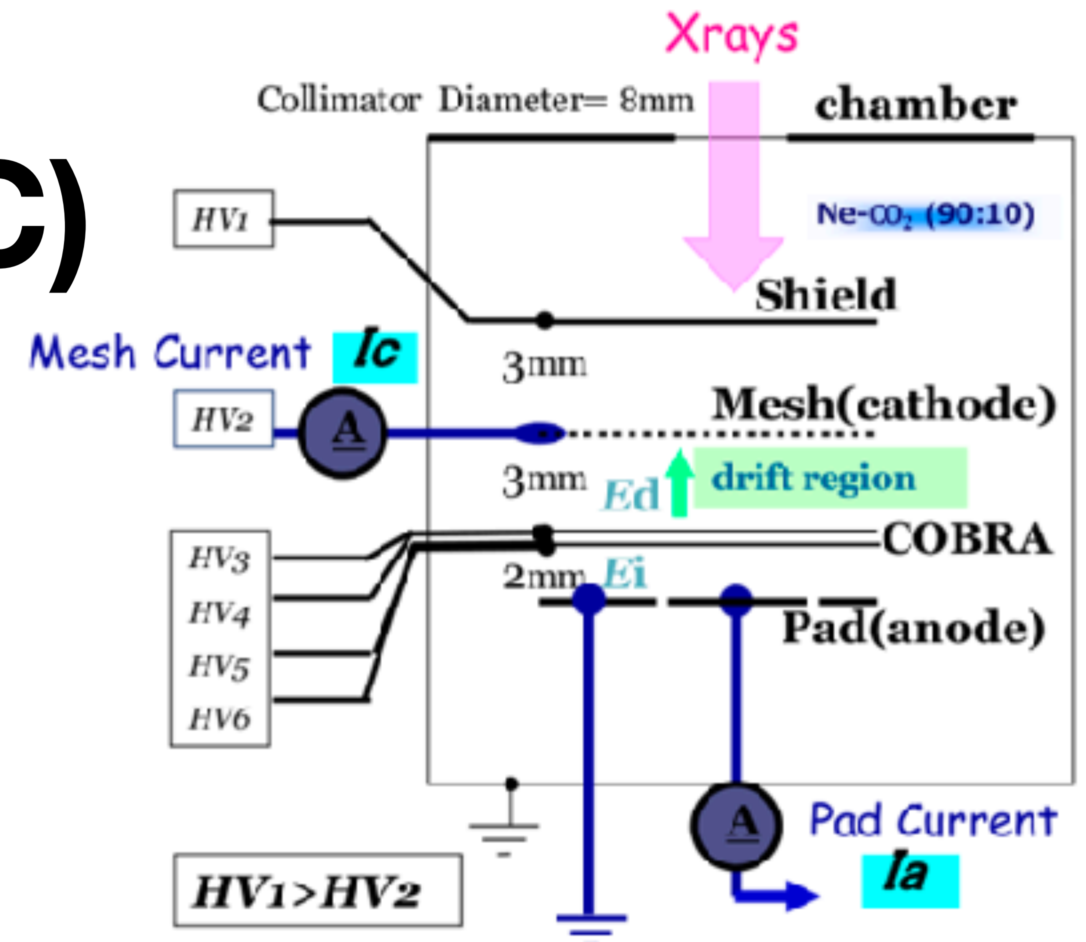


Figure 9.3: Schematic setup for the measurement of gas gain and ion backflow with an X-ray source.

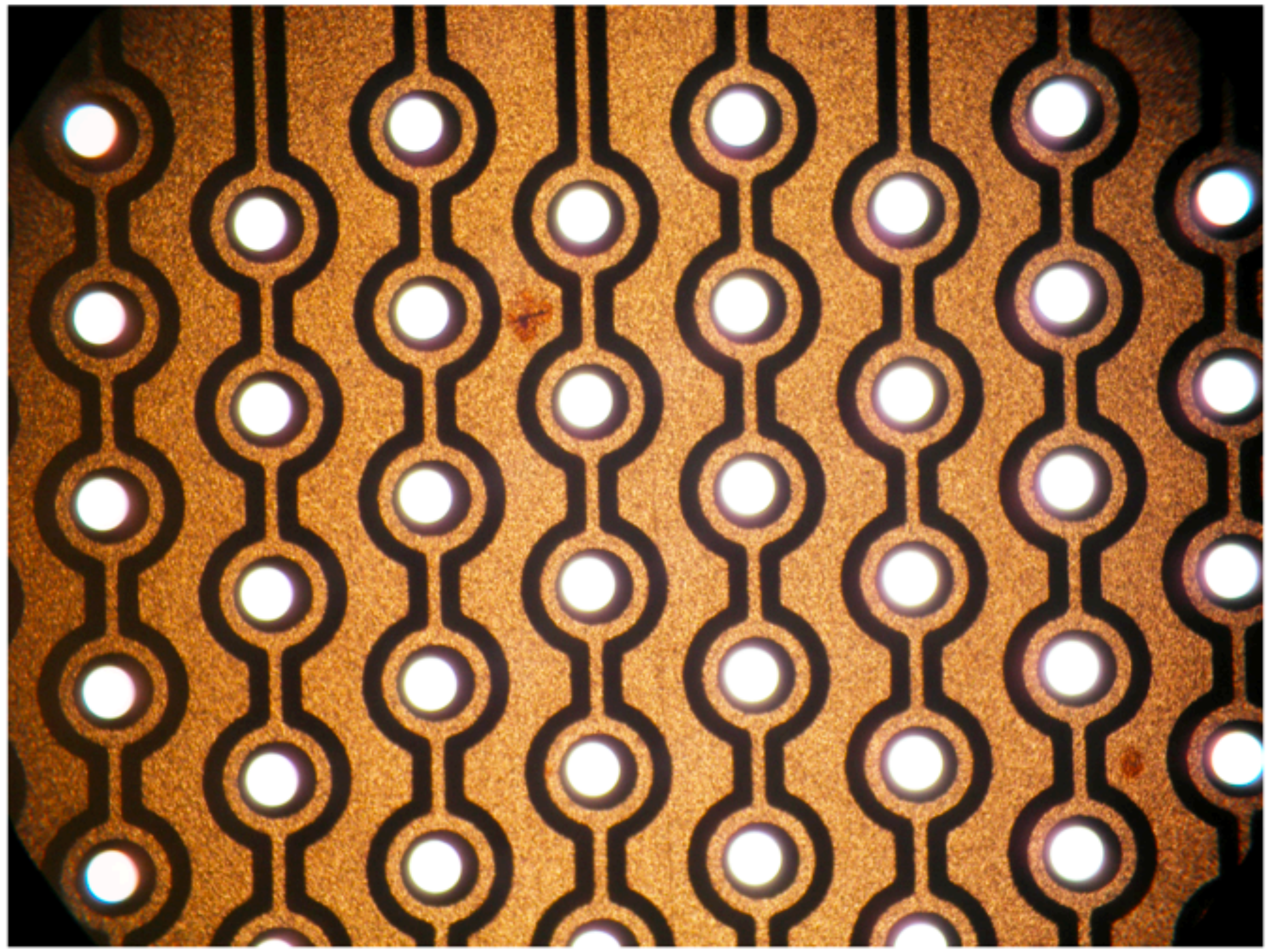


Figure 9.1: Photograph of COBRA 1.

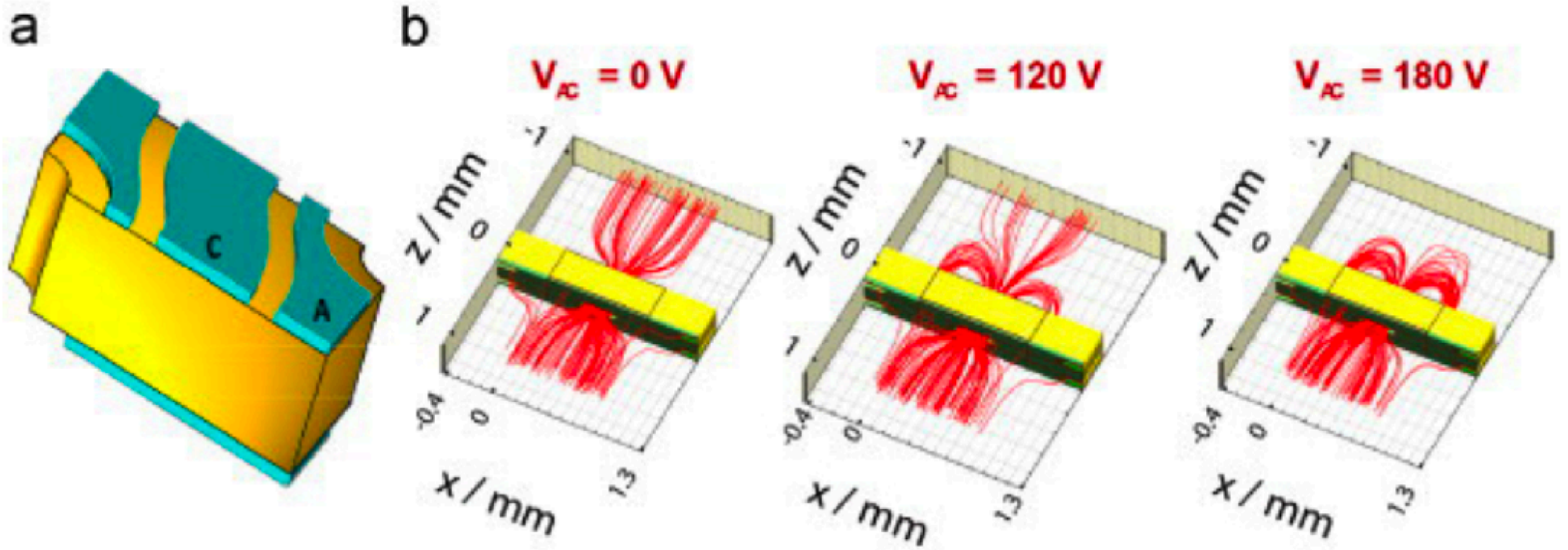
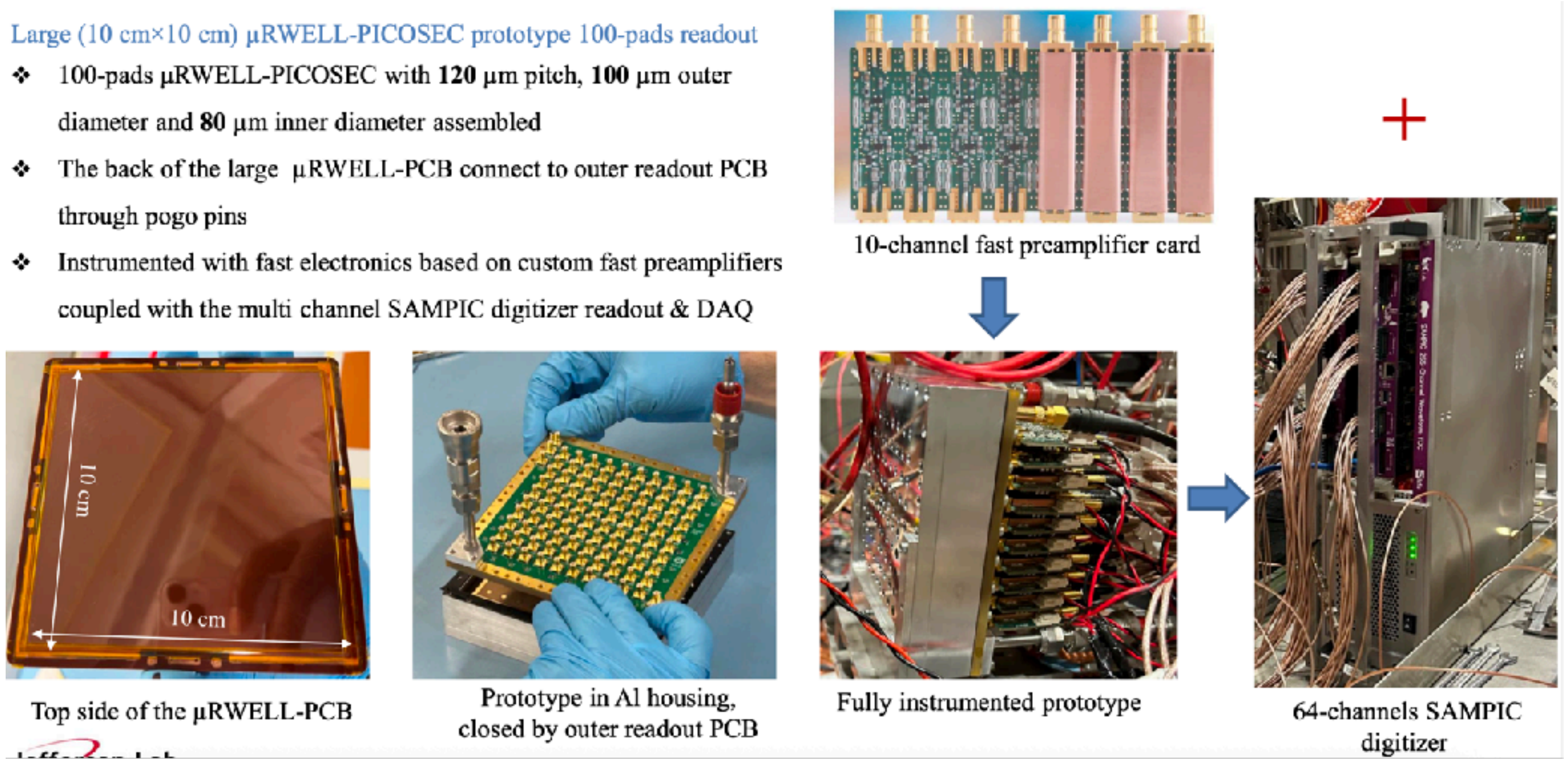


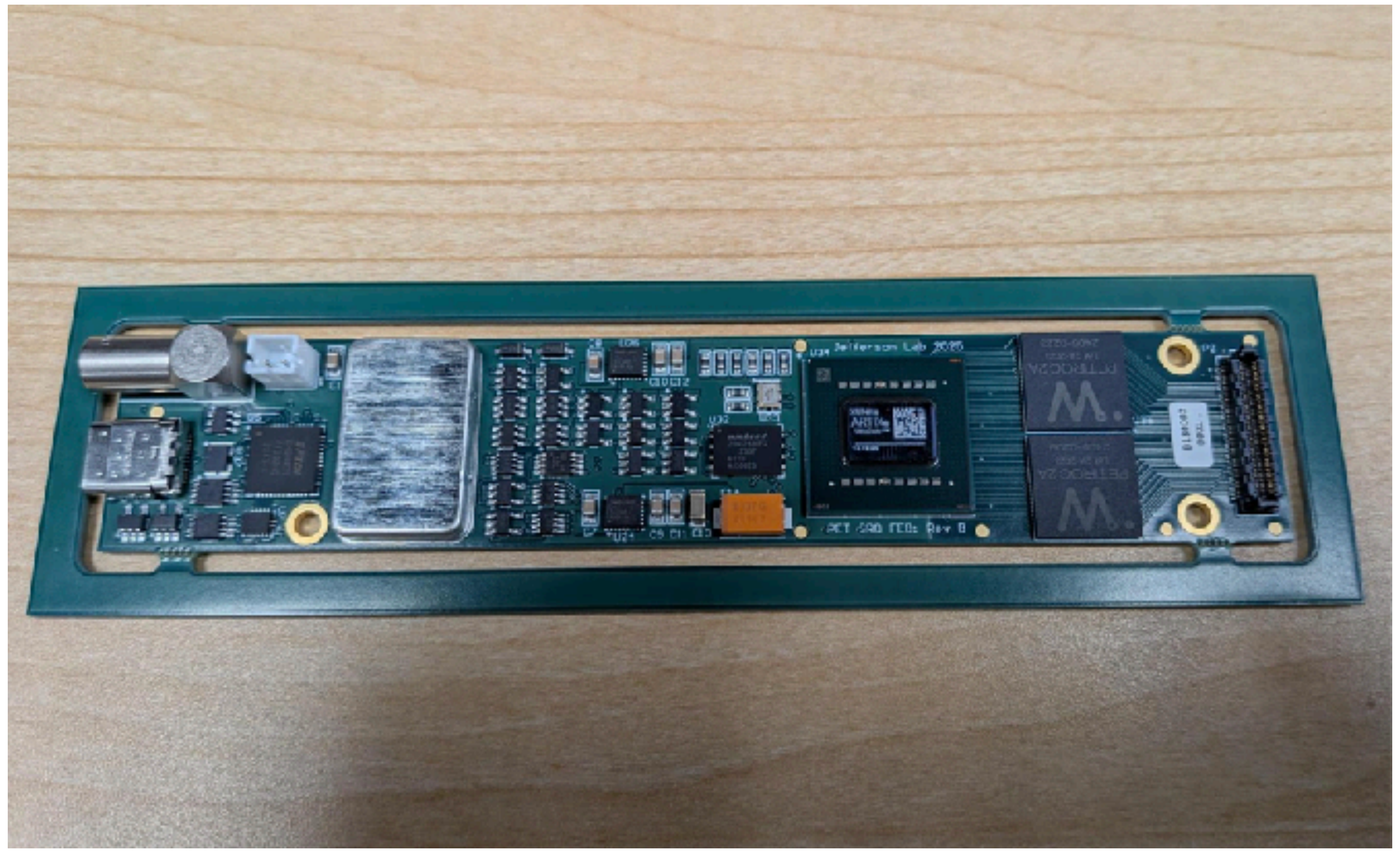
Figure 9.2: (a) COBRA GEM unit cell built in the simulat ion program ANSYS (b) ion drift lines in a COBRA GEM with a potential difference ΔU_{AC} between GEM electrode (A) and COBRA electrode (C). Image is taken from [1].

Technical Design Report for the Upgrade of the ALICE Time Projection Chamber, CERN-LHCC-2013-020, February 19, 2014

Electronics Integration — DAQ



SAMPIC



PETIROC

Path Moving Forward in First Year

- In first year, we use **proton** to characterize the detector — neutron is only a matter of detection efficiency

- Need to go parallel in first year with 4 different configurations:

  1. Bare K_2CsSb with amplification layer directly beneath it — 200 um away (Do it at JLab)

  2. Bare K_2CsSb with an ion trap (mesh or GEM foil) between photocathode and amplification layer (Do it at JLab)

  3. Coating K_2CsSb with MgF_2, Al_2O_3, carbon flash coatings, try sub-1 nm thickness (BNL? JLab?)

  4. Coating K2CsSb with graphene — probably the only solution (BNL? LBNL?)

Project Team and Responsibilities

1. Detector design. 2. Photocathode. 3. Electronics Integration (DAQ)

Role	Person	Capacity	Scope	FTE FY 26	FTE FY 27
PI:	**Xinzhan Bai**	RD&I scientist	1, 2, 3	25%	25%
Co-I:	**Kondo Gnanvo**	RD&I scientist	1, 2, 3	8%	8%
Engineering Support:	**Seung Joon Lee**	Biomedical engineer	1, 3	5%	5%
DAQ, Simulation Support:	**Cameron Clarke**	BRIC scientist	1, 3	5%	5%
Electronics Developer:	**Jack McKission**	Electronics engineer	3	5%	5%
Beam Test, Data Analysis:	**TBD**	Postdoc	2, 3	0%	100%
Contributor – Photocathode:	**Mengjia Gaowei**	BNL physicist	Contributor/Advisor	-	-
Advisor – Photocathode:	**John Smedley**	SLAC/Stanford	Advisor	-	-
Advisor – Detector Physics:	**Bogdan Wojtsekhowski**	Hall A physicist	Advisor	-	-
Advisor – Project Supervision:	**Drew Weisenberger**	RD&I Group Leader	Advisor	-	-

Summary

- Lots of on-going efforts in this field
- This is a right project at the right timing for LDRD

Alkali-antimonide PCs for GPMs

High (>40%) QE values reached

Stability in gas verified

Probability of IISEE evaluated → Required IBF estimated

MHSP/GEM-based CASCADED MULTIPLIERS

- *100 times lower IBF than with cascaded GEMs* **with full efficiency for collecting primary electrons!**
- *Gain ~10^5 reached with visible-sensitive K-Cs-Sb PC*
- *Demonstrated stable GPM operation at a gain 10^5*
- *Atmospheric pressure operation → Many potential applications in large-area photon detectors: Particle Physics, Medical Imaging, Astroparticle, Military, Bio*

Slide From A. Lyashenko (Weizmann Institute)

Backup Slides

Coating K_2CsSb with CsI

Another option to prevent ion feedback might be surface-coating of the K–Cs–Sb photocathodes with higher band-gap materials (e.g. CsI), similar to the approach proposed for protecting them from gas impurities [25]. Indeed in this work [25], a gas gain of 10^4 was reached in atmospheric methane in a parallel plate gas amplification mode with a K–Cs–Sb photocathode coated with 300 Å of CsBr. Though in this configuration all avalanche ions hit the photocathode, the authors did not observe any ion feedback. A feedback probability of $\gamma_+ \leq 10^{-4}$ can therefore be inferred, albeit at the cost of a considerable loss in QE by a factor ~7–10 for the 300 Å coating film. Since the thickness of 300 Å was chosen to provide sufficient protection from oxygen, it may not be the optimal for providing protection form Auger ion neutralization. Therefore, it remains to be investigated if thinner coating films, yielding higher residual QE values, will show a similar effect on γ_+. In photocathodes with a spectral sensitivity further extended to the red, e.g. NEA photocathodes, ion feedback effects are expected to be even more severe.