Status and perspectives of micropattern gaseous photon detectors

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September 16, 2022 - RICH2022

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Gaseous photon detector applications
RICH detectors
Future developments
Beyond HEP

Novel structures and materials
MPGD geometry developments
Nanomaterials

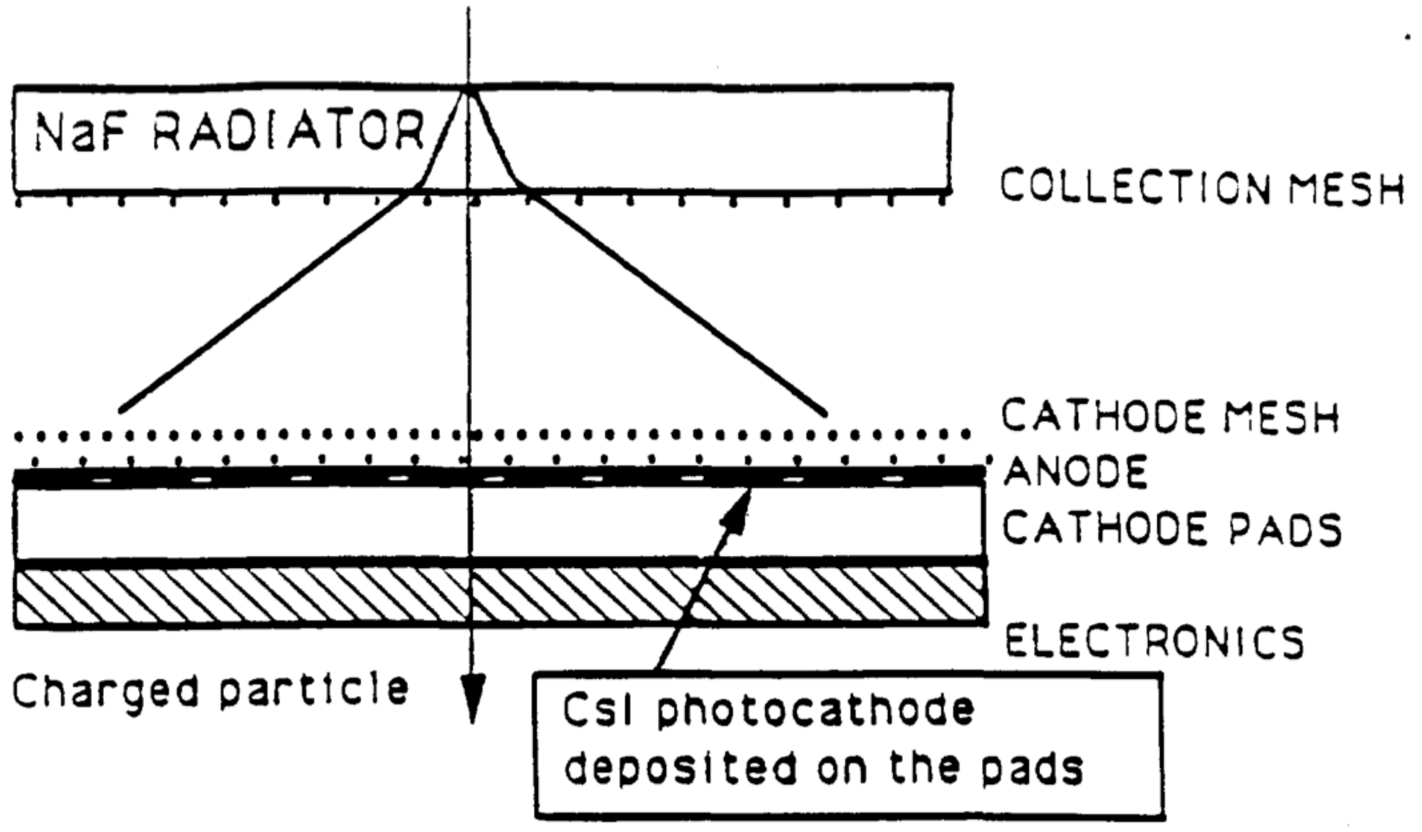
Gaseous photon detectors

Economic solution for instrumenting **large areas** (≈ multiple m2)

Compatible with operation in high **magnetic fields**

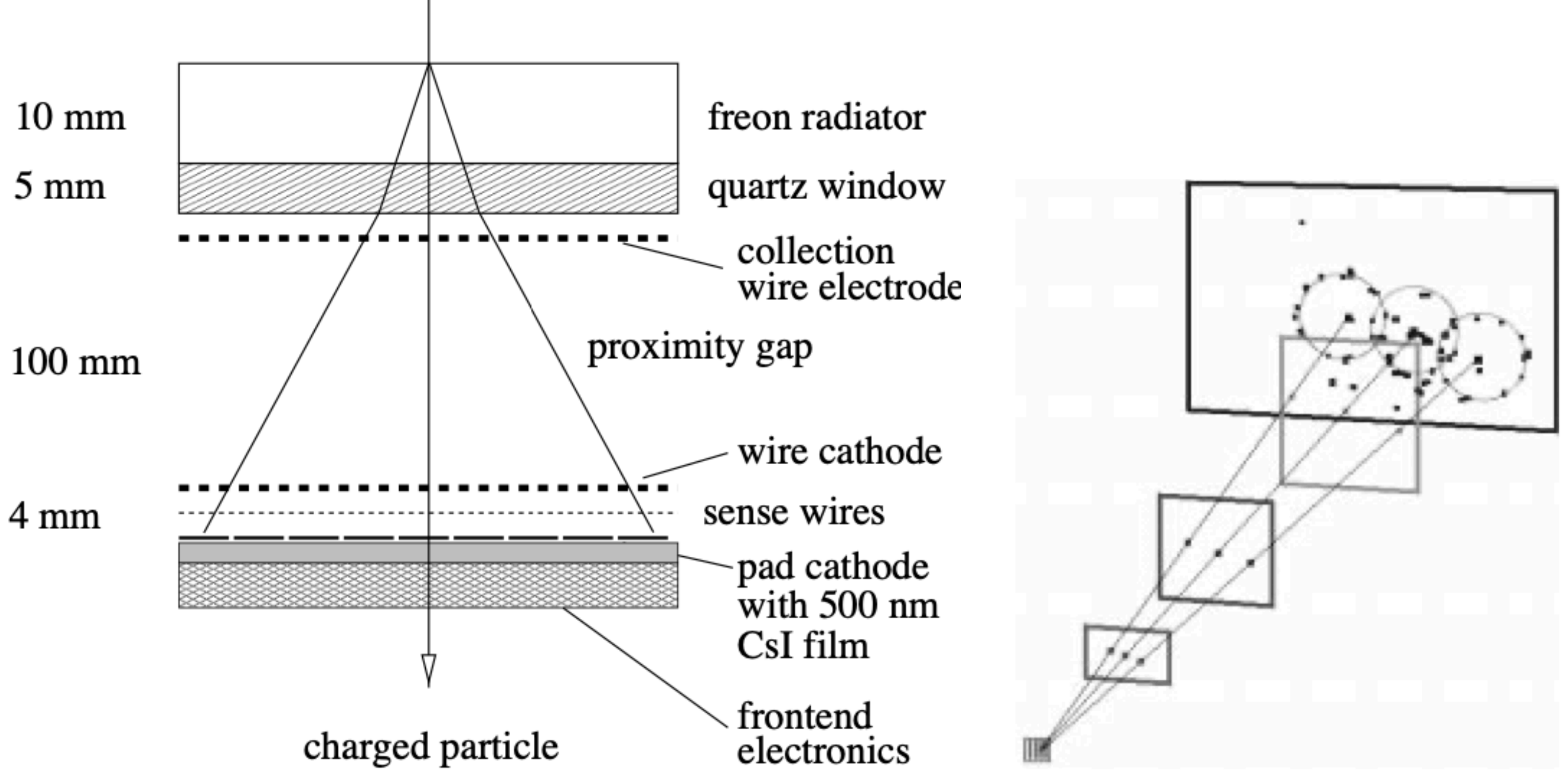
Possible to define **flat area** for acceptance and integration in compact spaces

Single-photon sensitivity due to **high gain** of gaseous detectors



RD26 collaboration http://cds.cern.ch/record/291164/files/

Fast ALICE CsI RICH

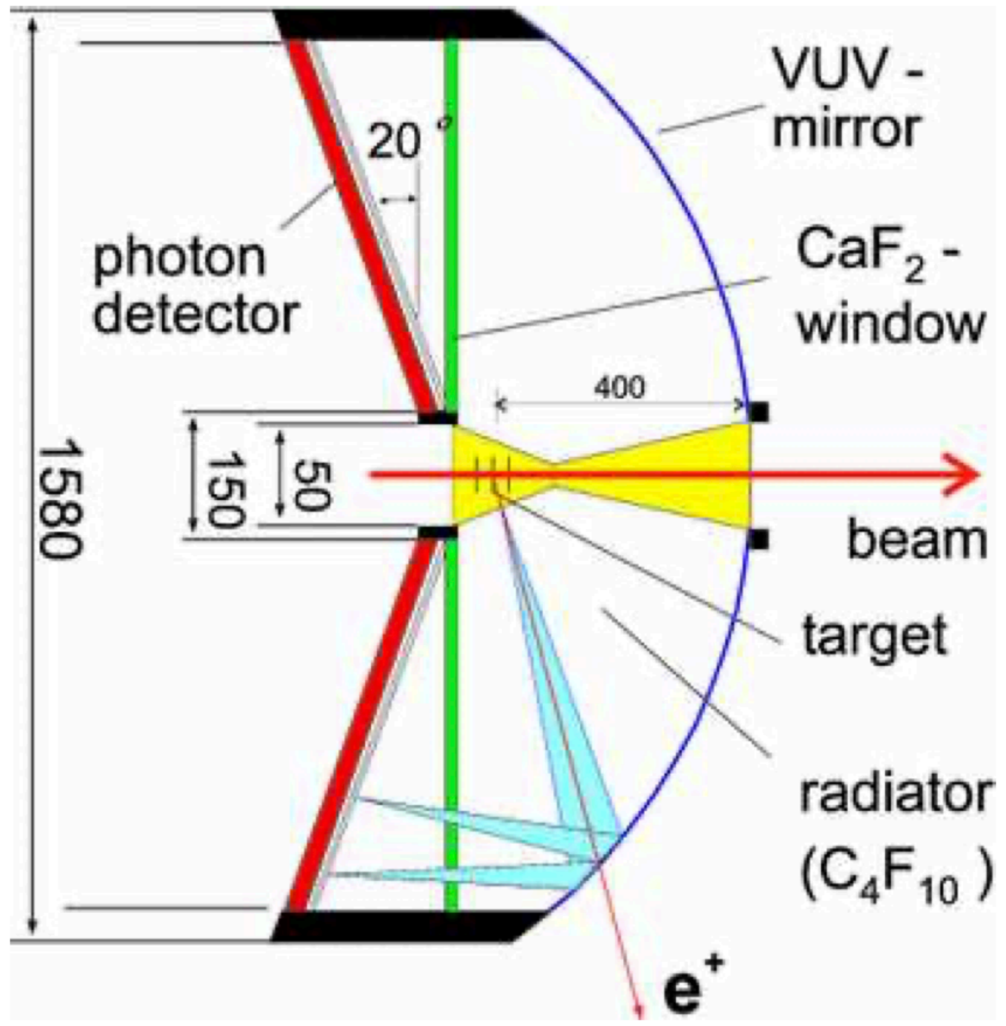


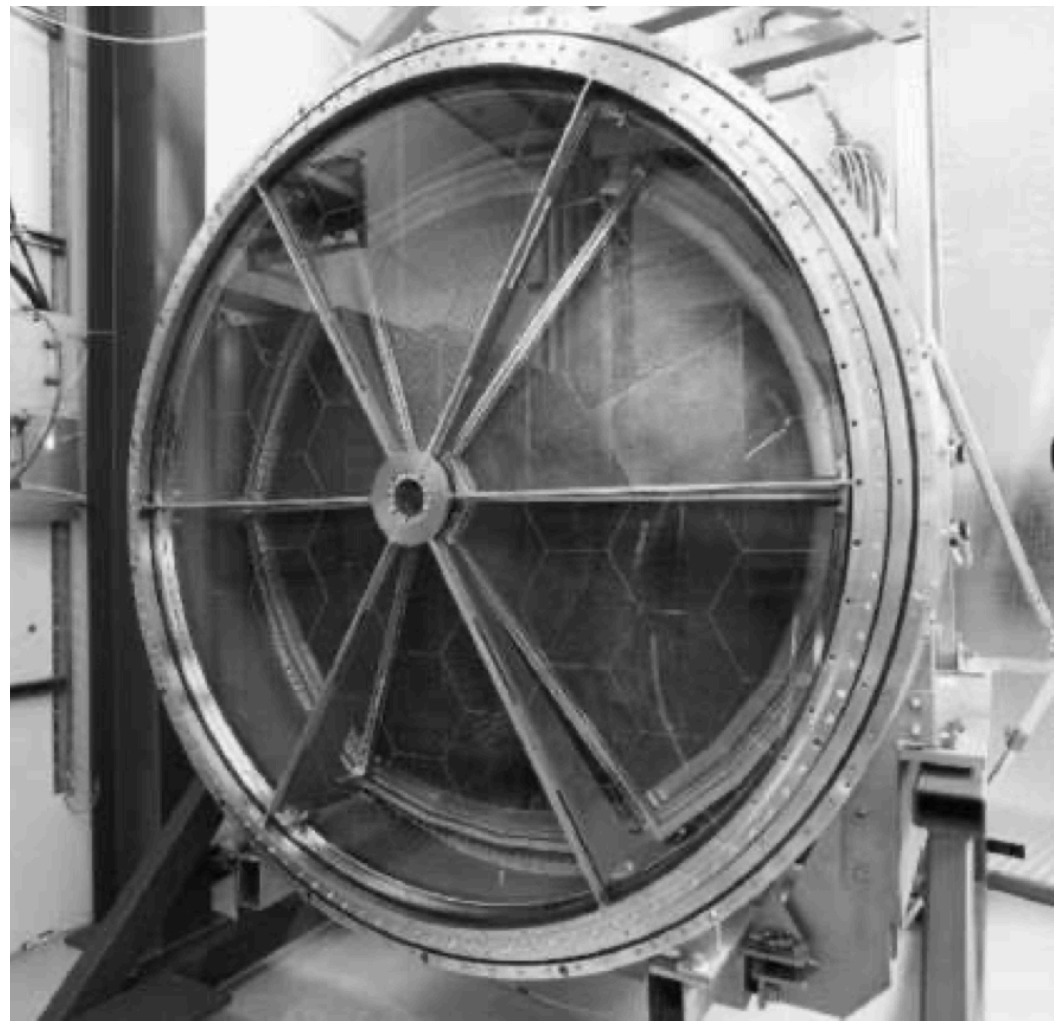
https://cds.cern.ch/record/426328/files/ali-98-016.pdf

Gaseous photon detectors

Gaseous photon detectors based on MWPCs have been widely used with both gaseous as well as solid-film photocathodes.

Their limitations include aging of wires, degradation of solid photocathodes due to significant ion back flow in “open geometry” of wire-based amplification and limited spatial and timing resolution. In addition, gain is limited by significant photon and ion induced feedback processes.

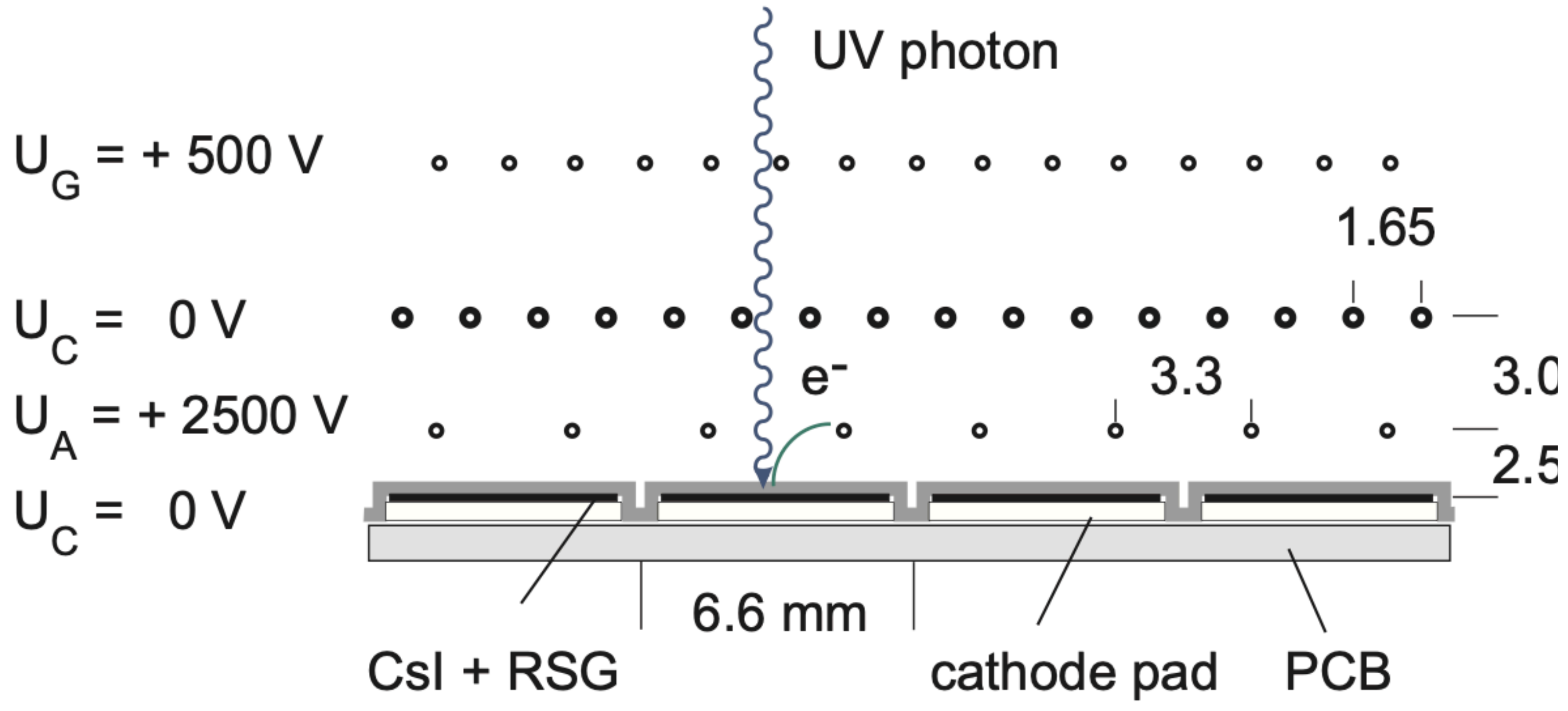


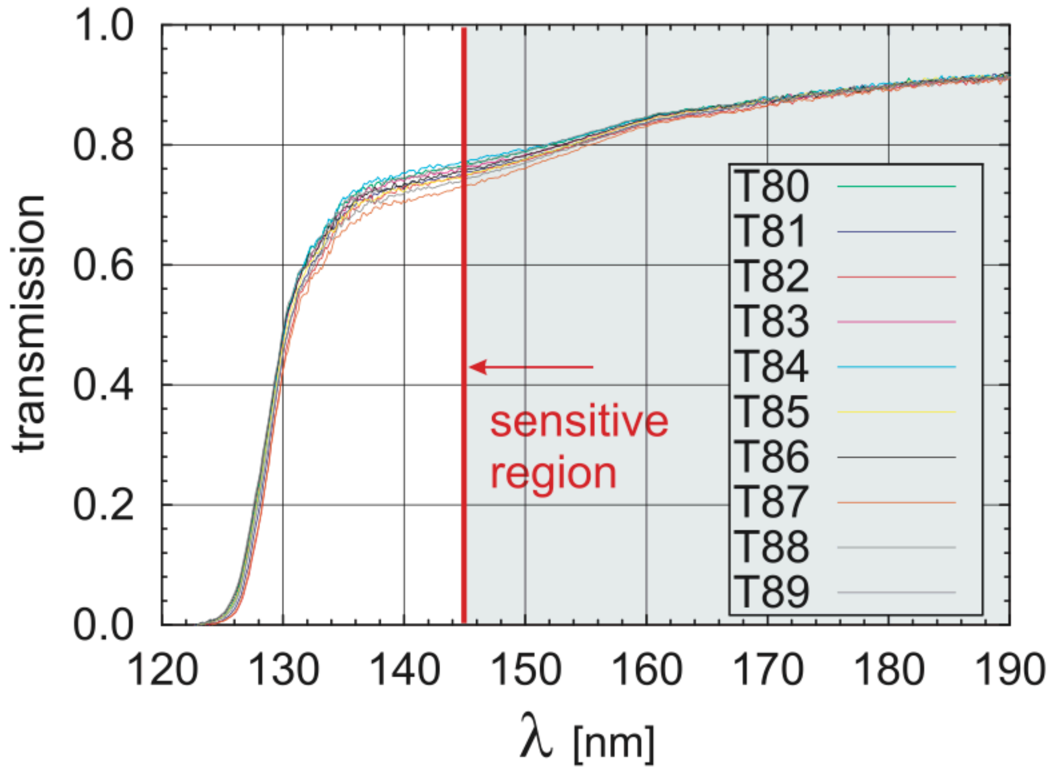


RICH of High-Acceptance Dielectron Spectrometer HADES at GSI

Successful operation of MWPCs with CsI deposited on cathode planes for applications including RICH systems for

- HADES at GSI
- ALICE and COMPASS at CERN
- Hall A at JLAB





https://arxiv.org/pdf/0902.3478.pdf

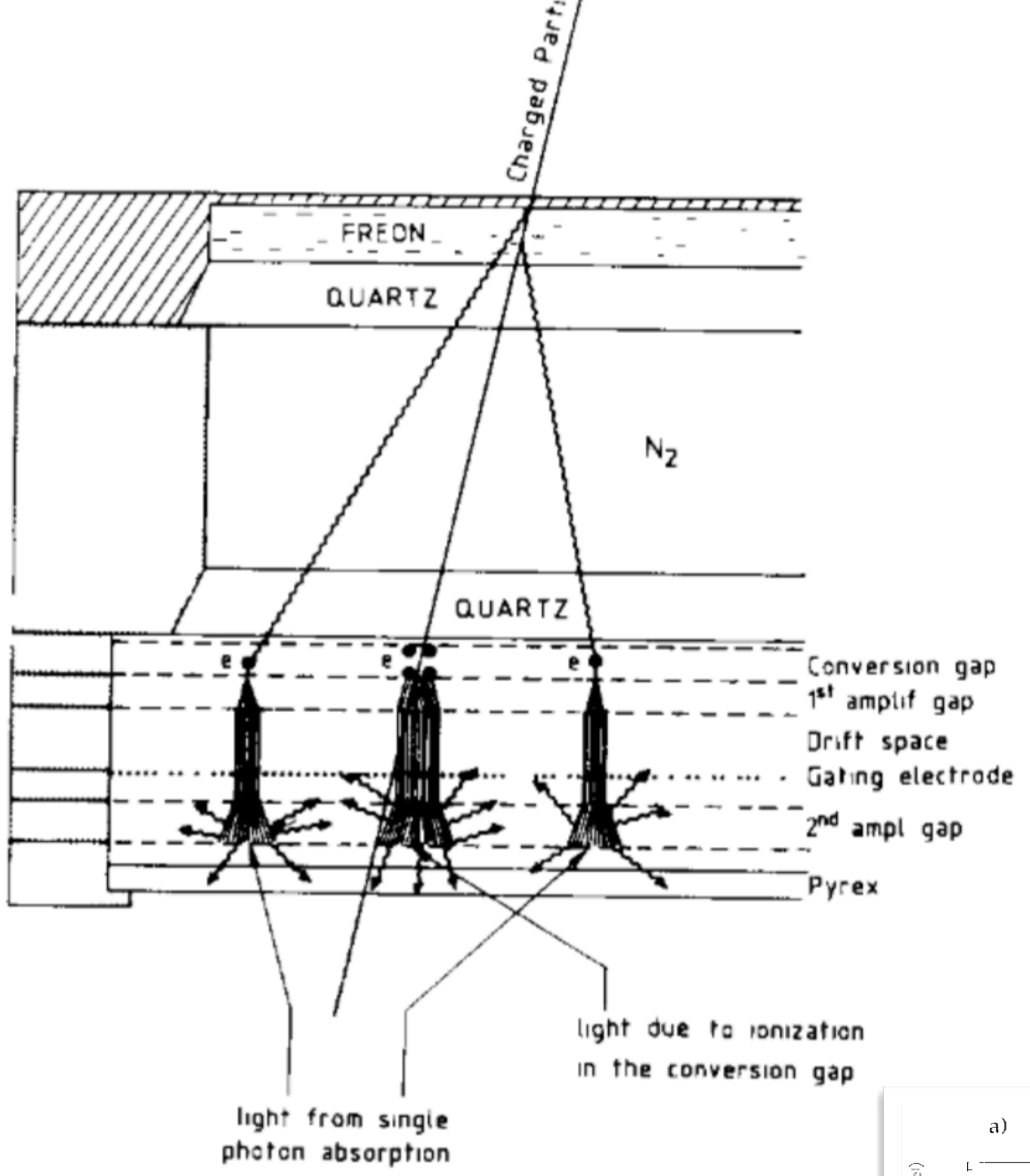
Optical RICH readout

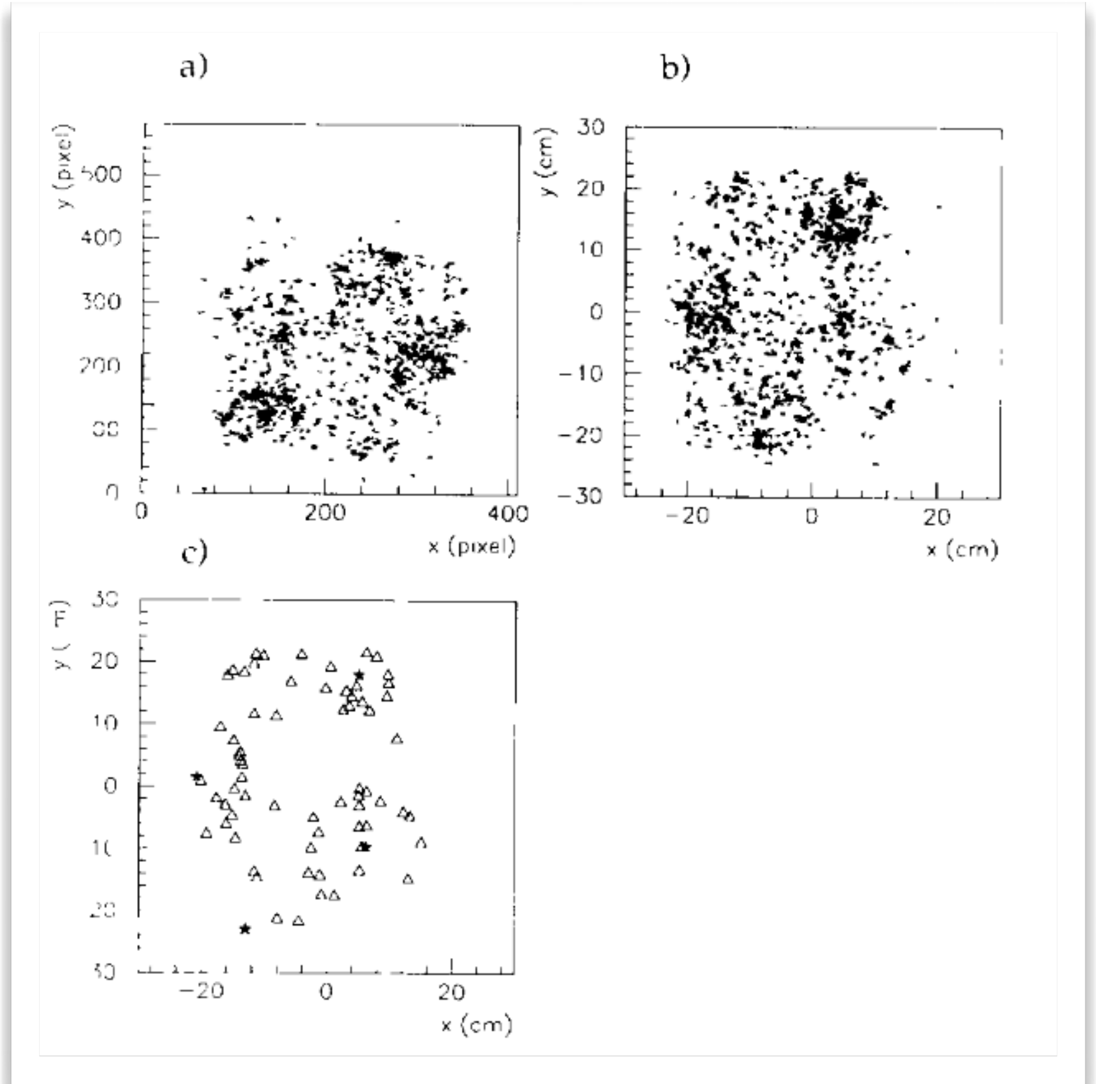
Demonstrate how **2D readout** with good spatial resolution and **high channel count** can be used to avoid ambiguities

50 x 50 cm 2 RICH detector prototype with optical readout using He/CH4 saturated with TMAE
MultiStep Avalanche Chamber (MSAC) as amplifying stage

Read out with **CCD camera** with image intensifier - requires operation at high gain and resulting in frequent sparking

Operated with a density of 20-25 charged particles per m2



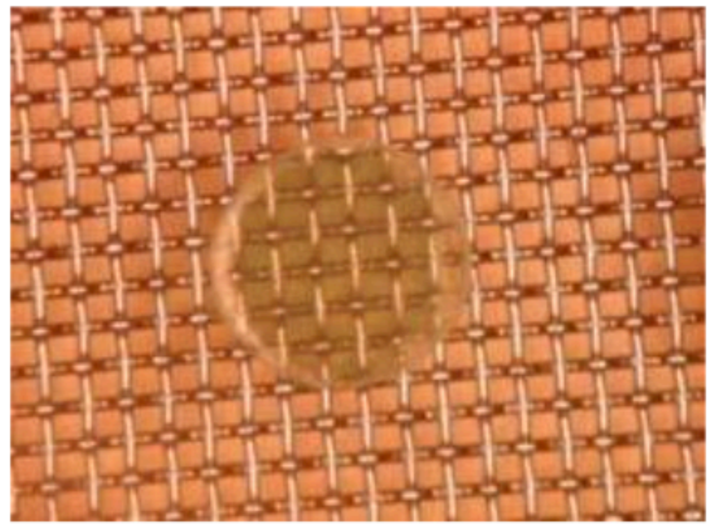


J. Baechler et al. /Nucl. Instr. and Meth. in Phys . Res. A 343 (1994) 213-217 https://doi.org/10.1016/0168-9002(94)90553-3

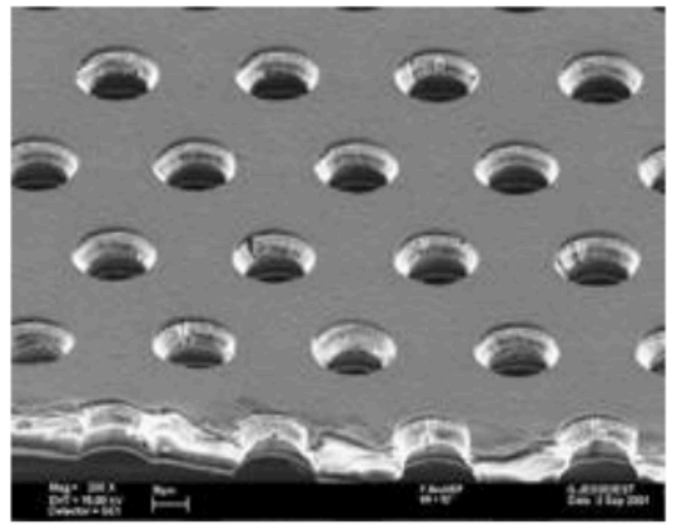
MicroPattern Gaseous Detectors

MicroPattern Gas Detectors exploit photolithographic structuring techniques to define precise, micrometer-scale structures on flat substrate as electron amplification devices

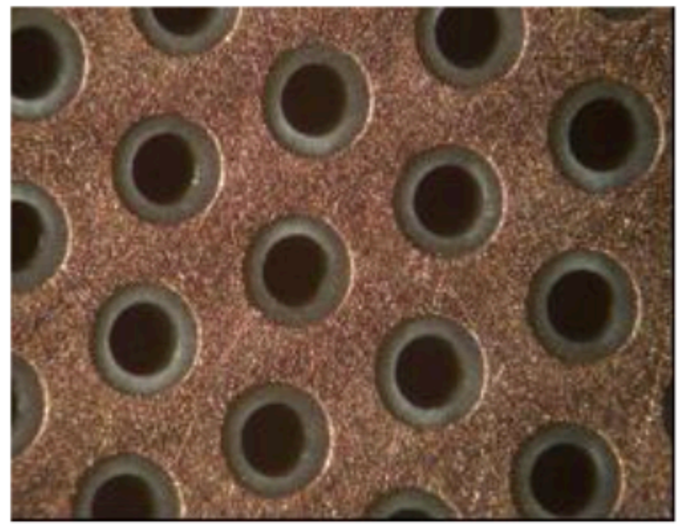
- High gain -> single photon sensitivity
- High granularity -> position resolution
- Suppressed ion back flow -> protection of photocathodes, possibility to use sensitive materials
- Fast signals -> higher time resolution
- High-rate operation (MHz/mm^2)



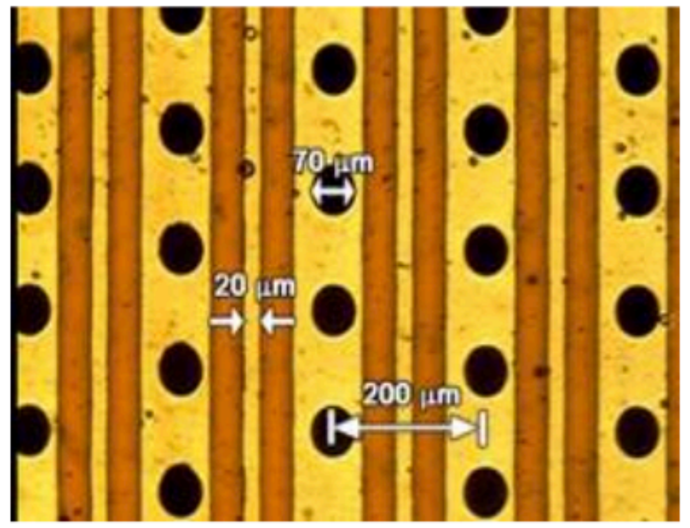
MicroMegas



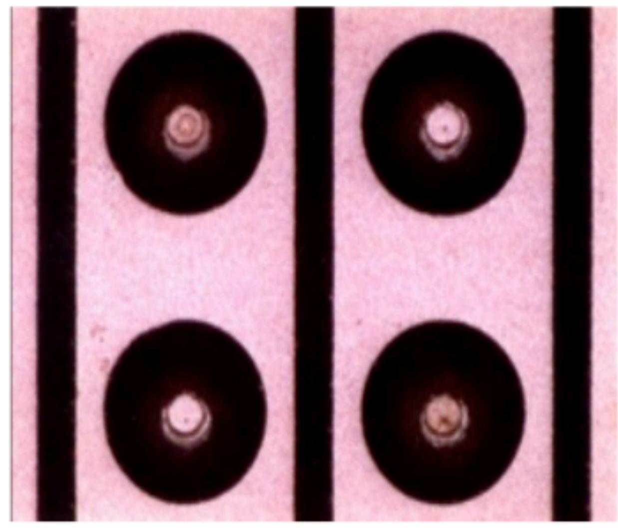
GEM



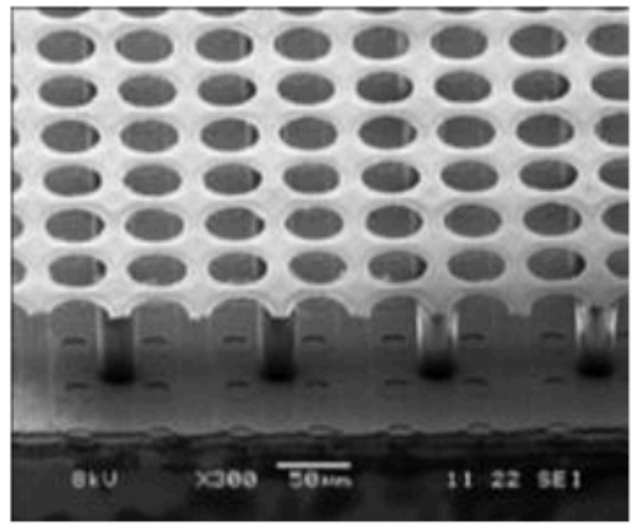
THGEM



MHSP



microPIC



Ingrid

RD51 collaboration

Development of Micro-Pattern Gas Detectors Technologies

Advance the technological development and application of MicroPattern Gas Detectors (MPGDs) and contribute to the dissemination of these technologies.

Development

Exploit existing technologies
Large size single-mask GEMs
Resistive Micromegas

Develop novel technologies
µPIC, µR-WELL, GRIDPIX

Dissemination

High-Energy Physics
ALICE, ATLAS, CMS, Compass, KLOE, BESIII

Fundamental research beyond HEP
LBNO-DEMO, active-target TPCs

Beyond fundamental research
Muon radiography, n-detection, X-ray radiographies

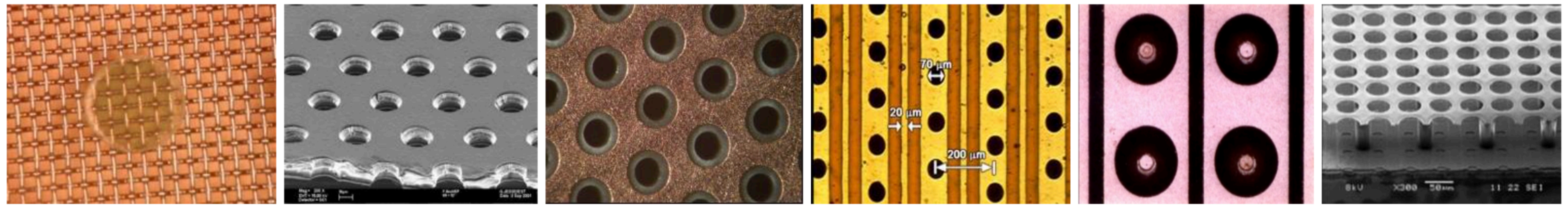
Production techniques and industrialisation

Common infrastructures
(GDD lab, common test beam)

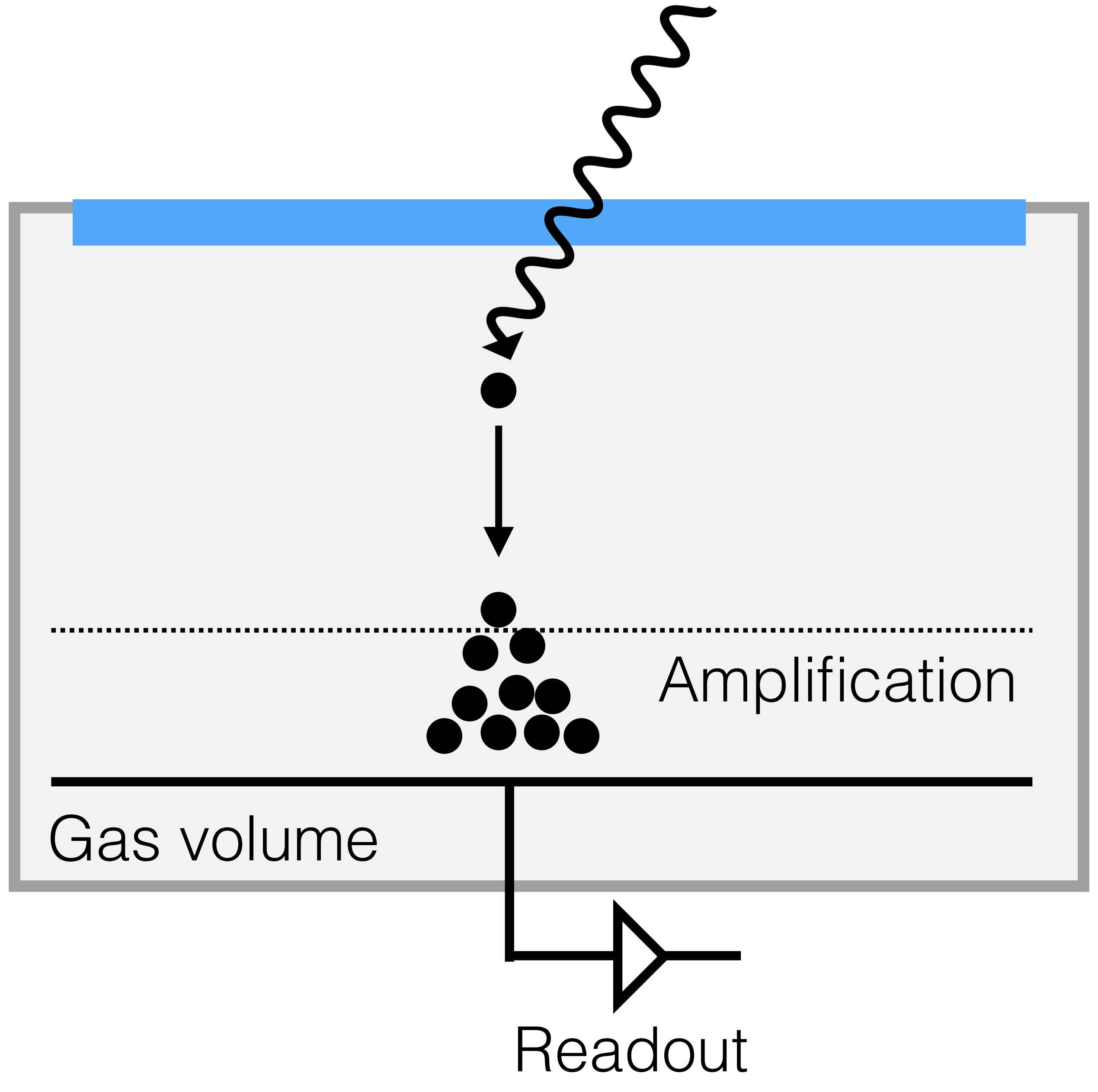
Electronics
(Scalable Readout System SRS, instrumentation)

Simulation
(Garfield, Magboltz, Degrad, neBEM)

rd51-public.web.cern.ch



Photon detection with gaseous detectors



Conversion of incident photons

- Gaseous photocathode
- Solid photocathodes

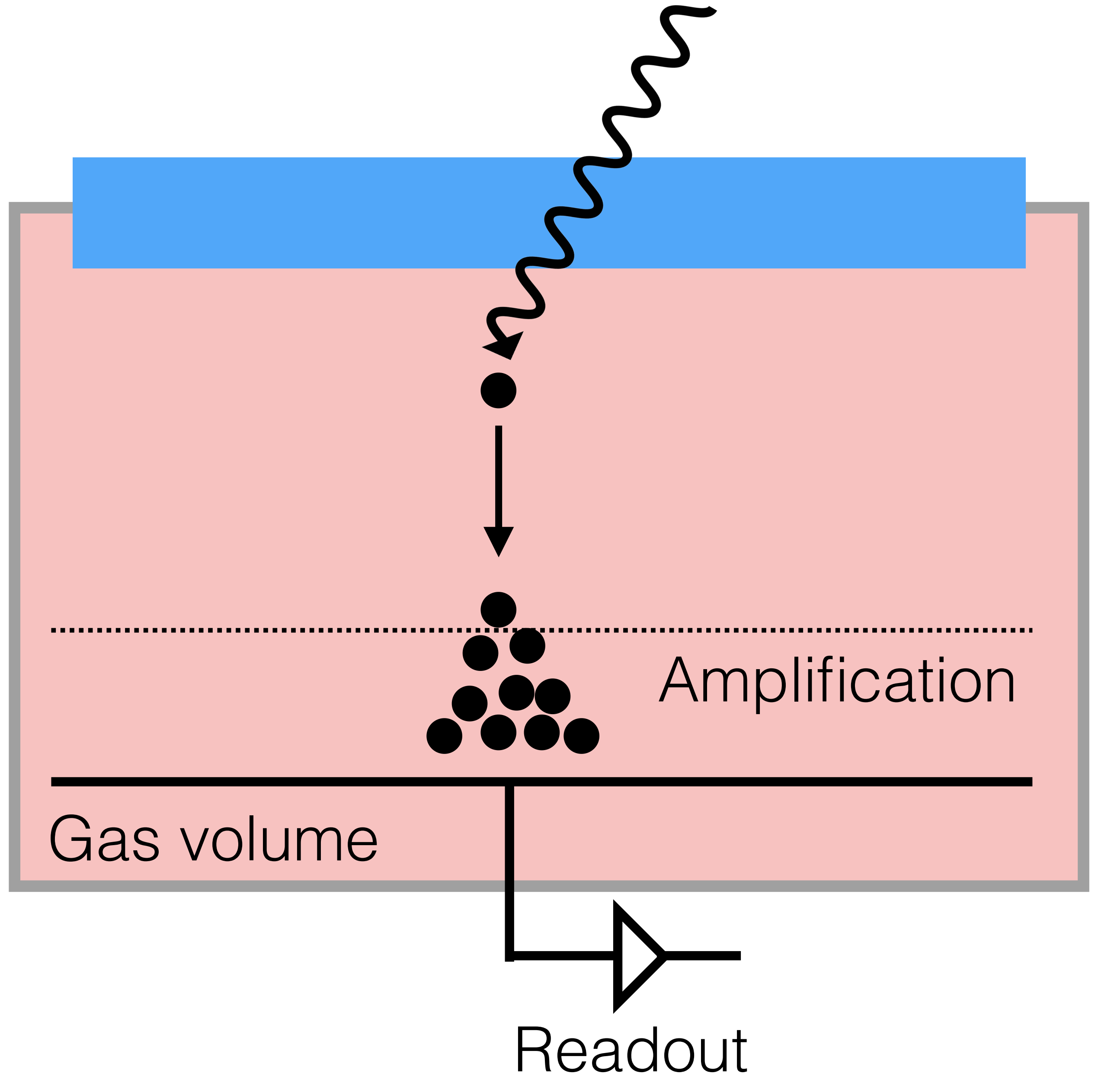
Signal amplification

- MWPC
- MPGDs
- …

Photocathodes

Photon detection with gaseous detectors

Photoconversion in gas



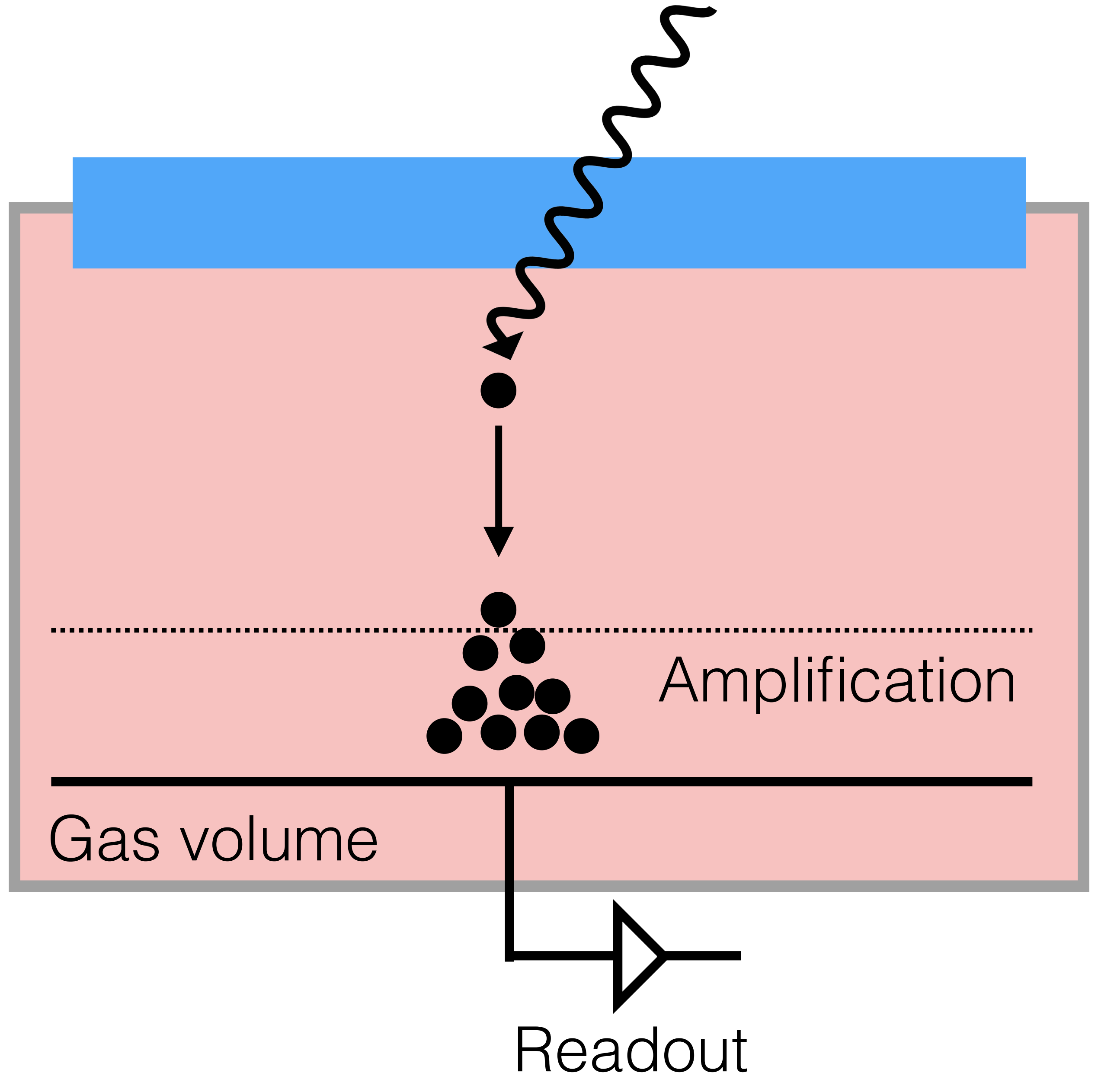
Gases (TEA, TMAE, …) can be used for direct photoconversion
Can be hard to handle (chemically aggressive, special choice of materials) and limit timing resolution due to time jitter resulting from initial interaction depth
Can be hundreds of ns -> improvements e.g. by operating at higher temperature

Gaseous photo converters:
lower photoionization threshold
5.3 eV for TMAE and 7.5 eV for TEA

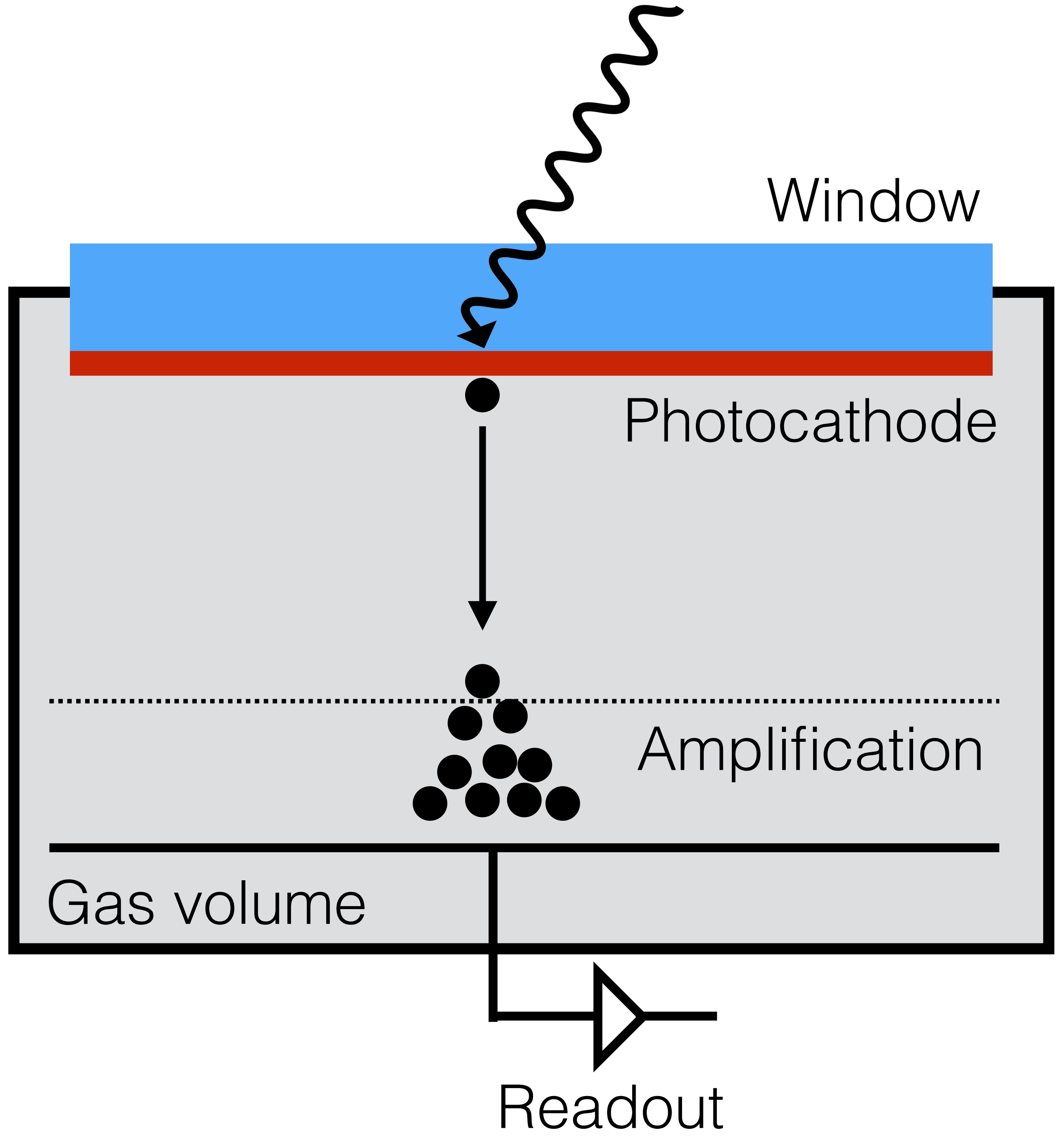
TMAE has lowest know photoionisation threshold and is thus compatible with wide range of Cherenkov radiators and window materials

Photon detection with gaseous detectors

Photoconversion in gas



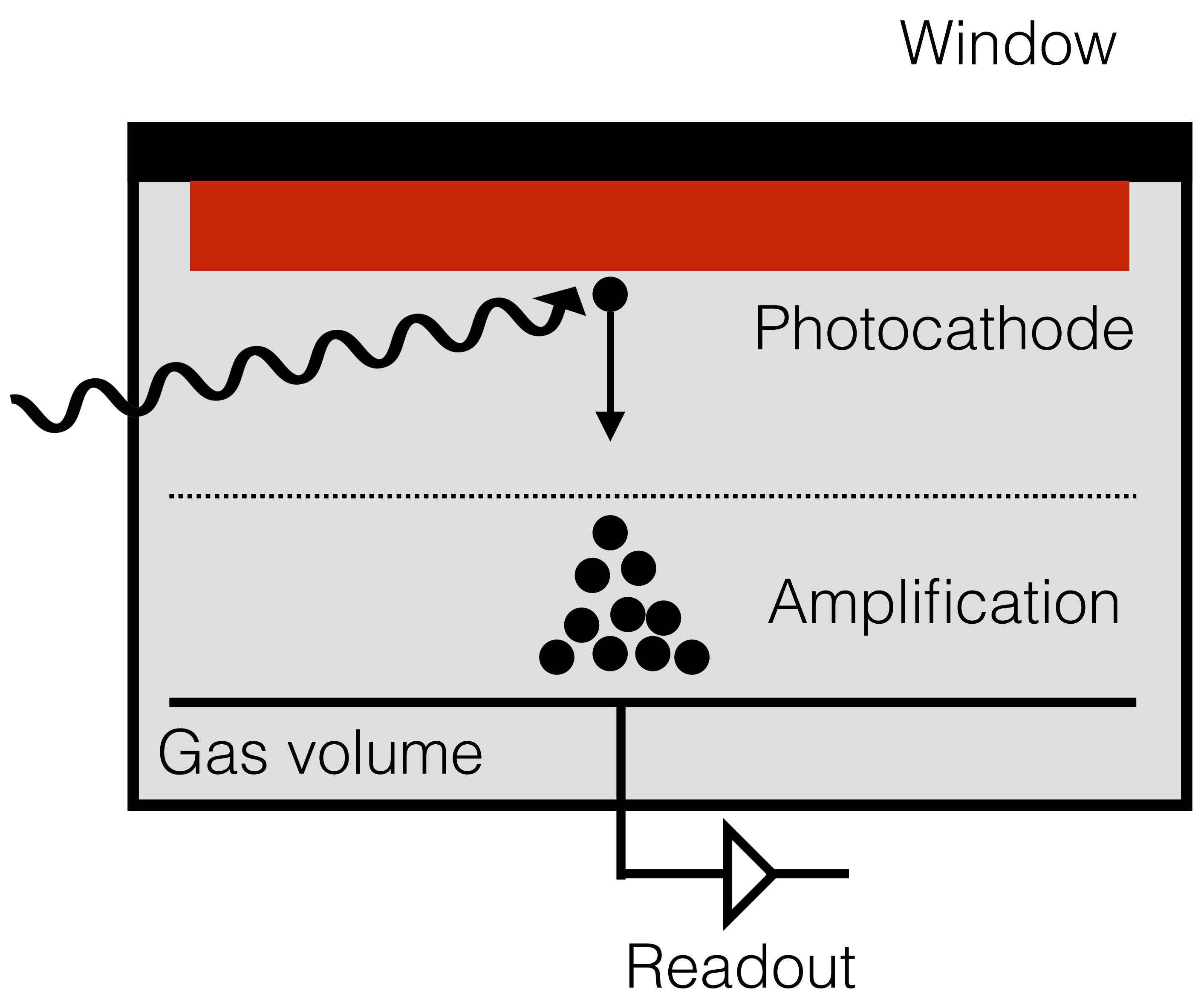
Solid photocathodes



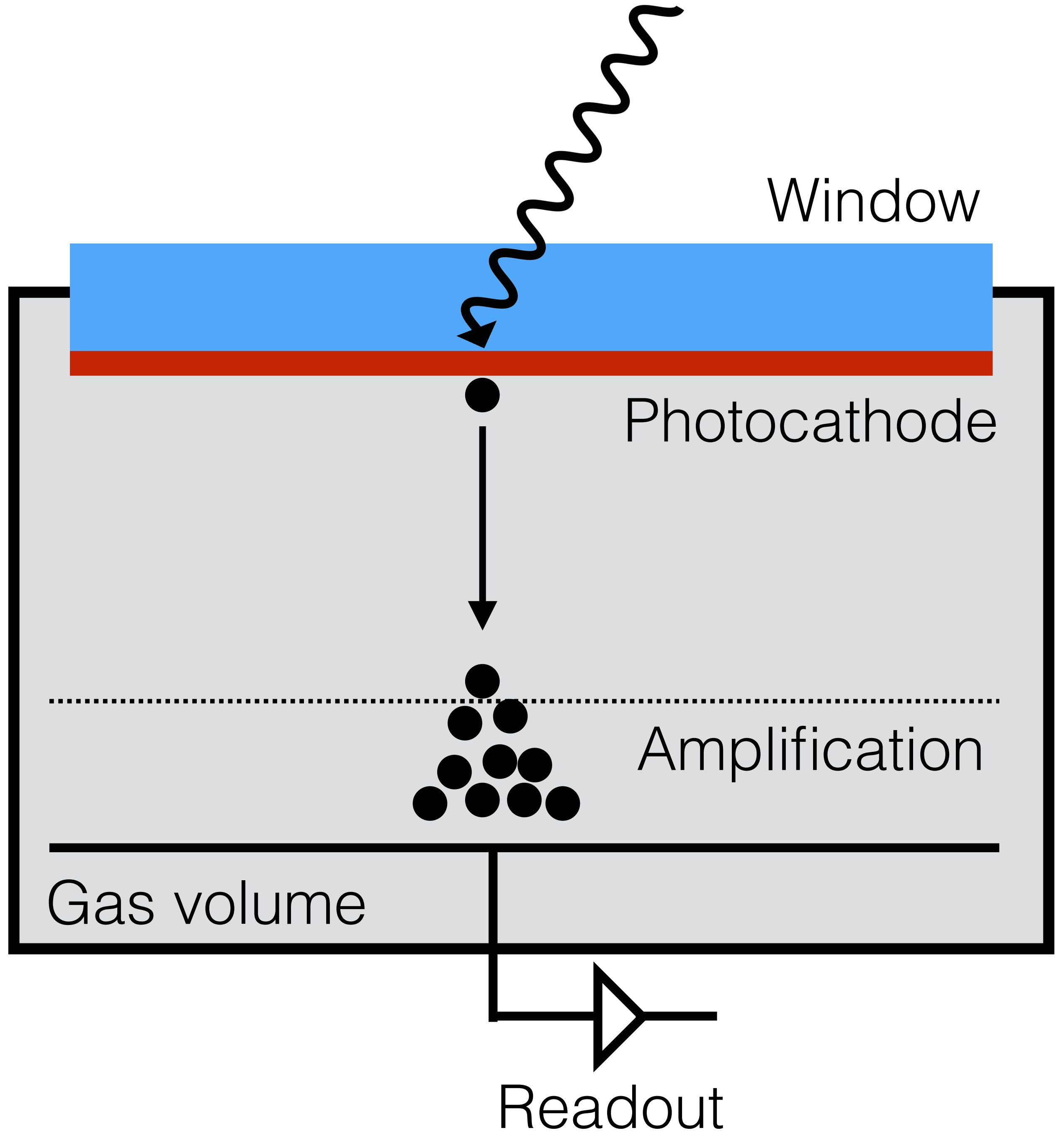
Solid photocathodes can be coated on windows or amplification structure
Provide parallax-free Cherenkov patterns

Photon detection with gaseous detectors

Reflective photocathodes



Semi-transparent photocathodes

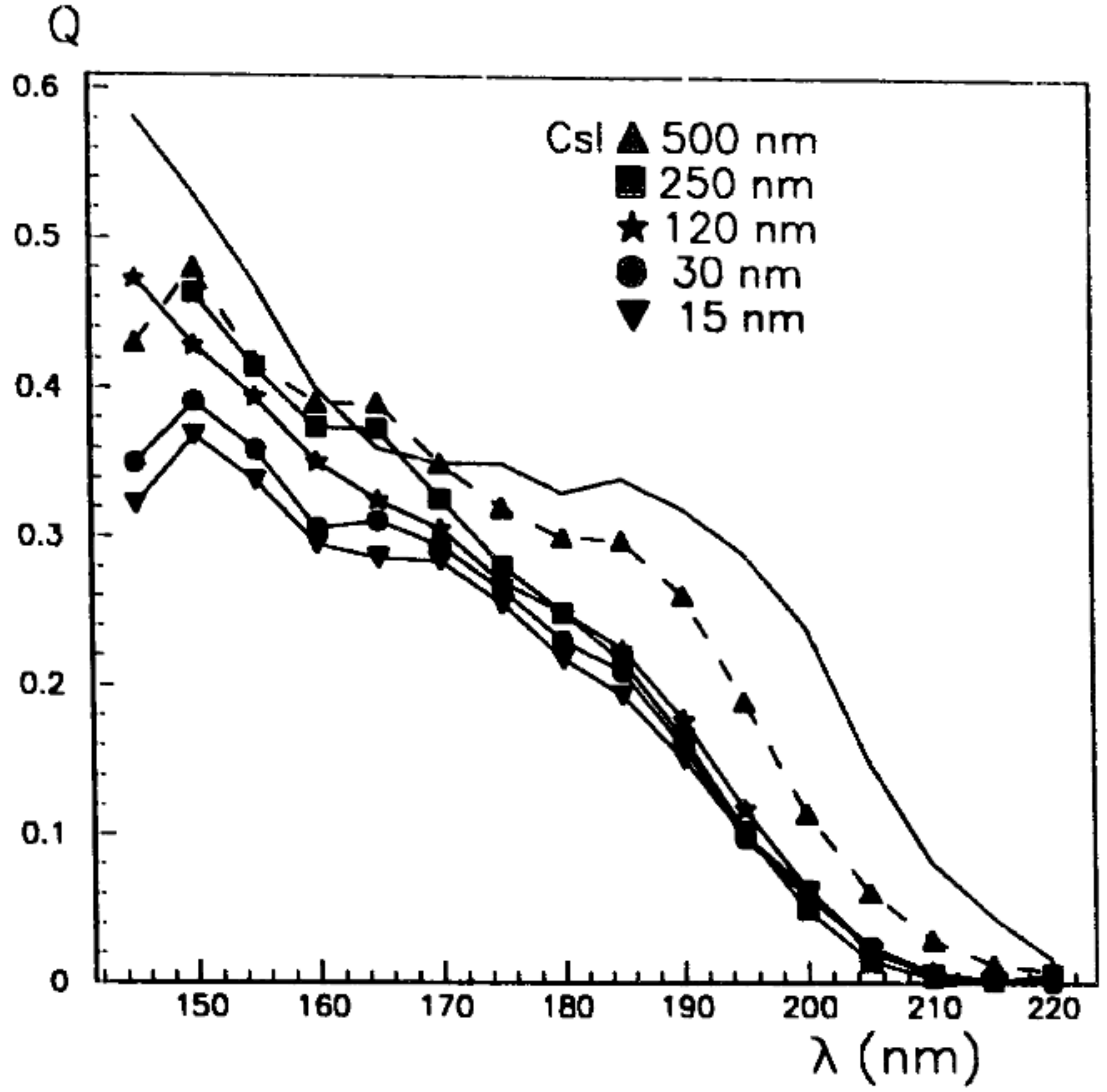


Solid photocathodes can be used in reflective or transmissive modes

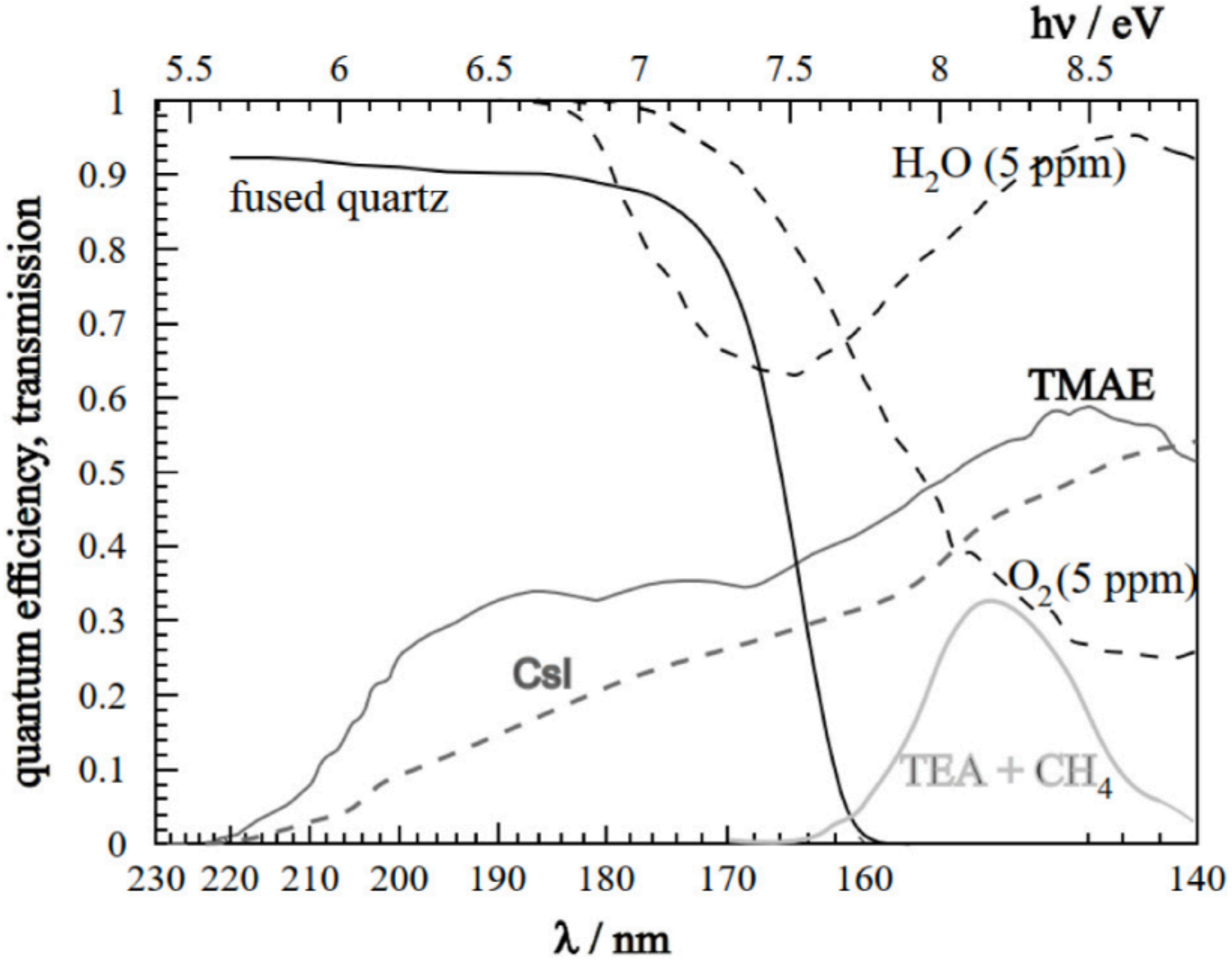
For reflective photocathodes, electron migration limits the thickness of active surface layer
For semi-transparent photocathodes, absorption of incident light and electron extraction from layer determine optimal photocathode thickness

Gaseous photon detectors

Detailed research into CsI as solid photocathode started following a paper by Jacques Séguinot demonstrating high extraction efficiency from CsI into gas comparable to extraction to vacuum.
CsI features the largest QE in vacuum of any other alkali halide and despite being sensitive to humidity can be deposited, handled and integrated relatively easily.



J. Séguinot et al. / Reflective UV photocathodes, NIM A A297 (1990) 133-147

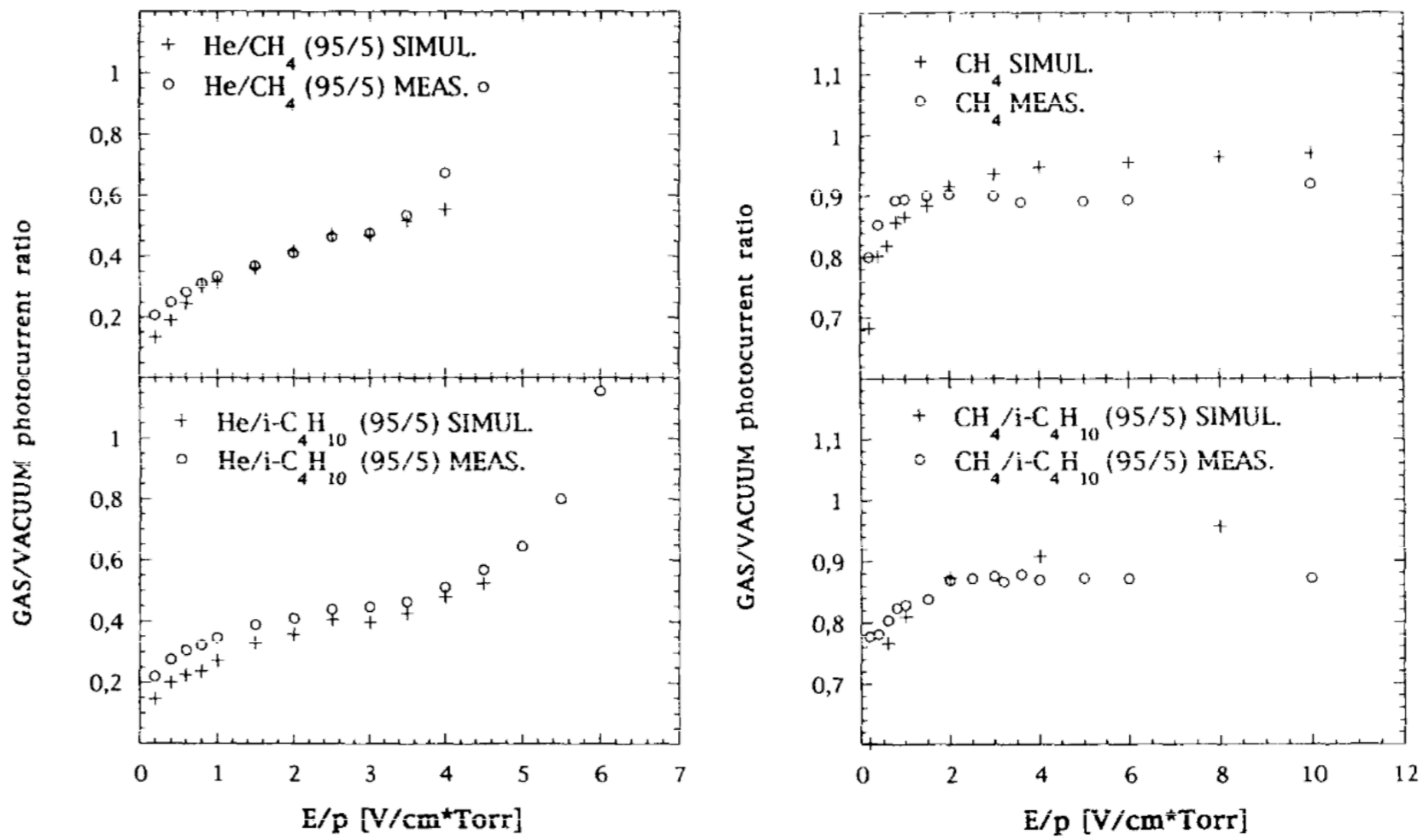


E. Nappi, J. Seguinot, La Riv. del Nuovo Cimento 28 (8/9) (2005)

Gaseous photon detectors

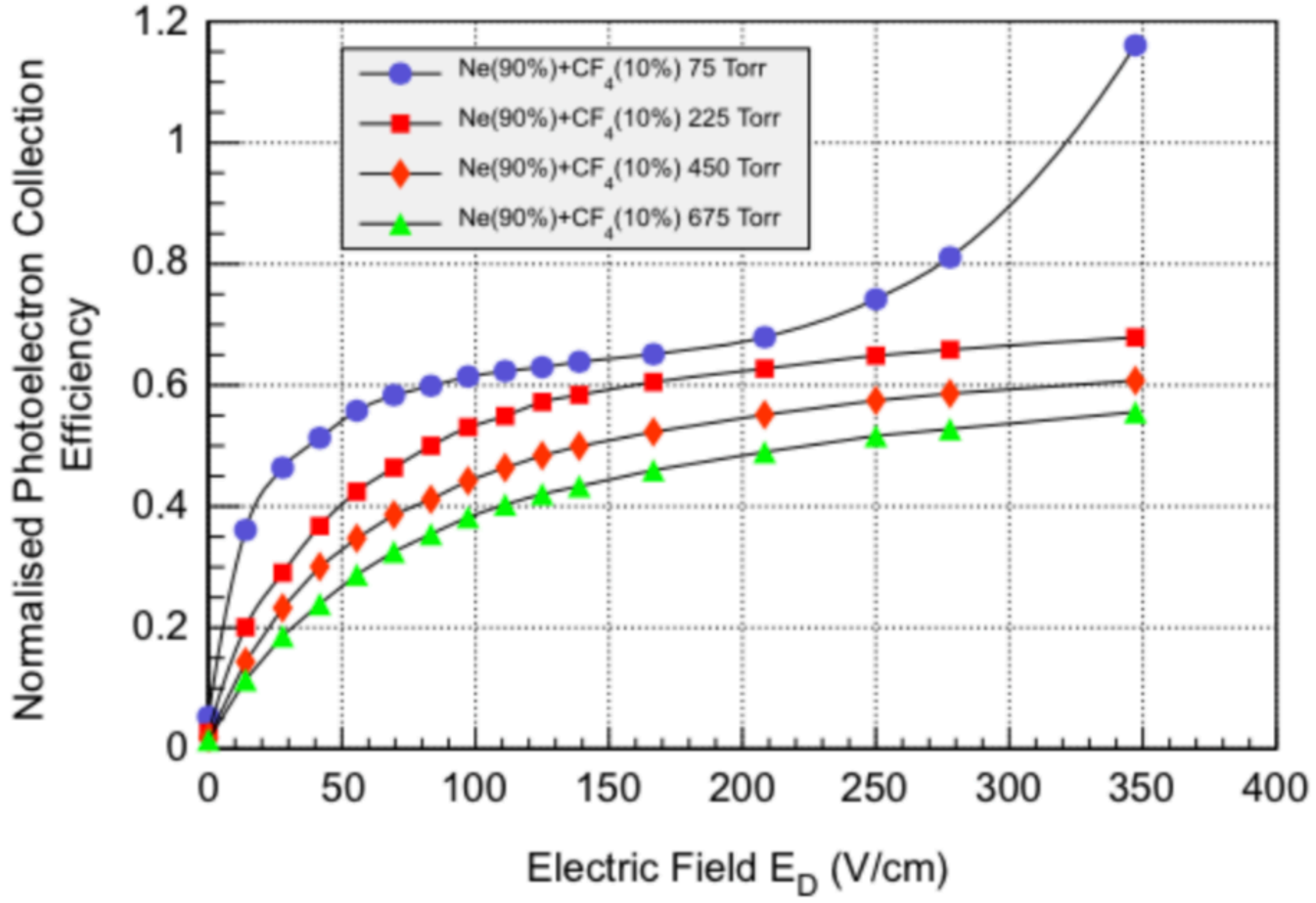
In gaseous media, **elastic backscattering** of electrons from solid photocathodes can significantly limit extraction efficiency. Especially for He mixtures, where there are no inelastic channels for electron-molecule interaction, this results in **suppressed photocurrent extraction** compared to vacuum emission. For high electric fields and when avalanche multiplication takes place, full collection comparable to vacuum can be achieved.

Photocurrent extraction into gas vs. vacuum from CsI



A. Di Mauro el al. I Nucl. Instr. and Meth. in Phys. Rex. A 371 (1996)

Photocurrent extraction from bialkali photocathode into Ne+CF4 at different pressures



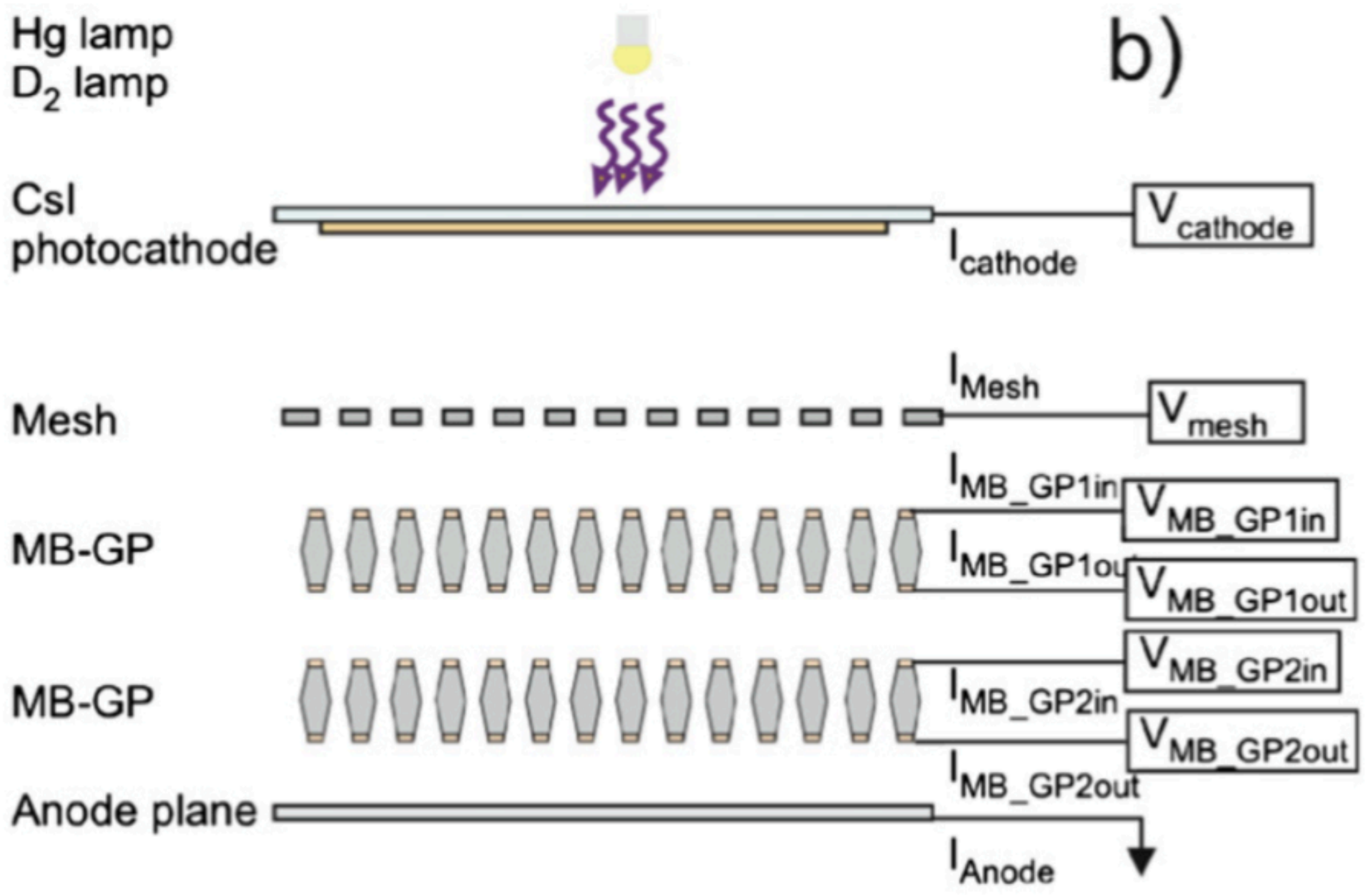
F. Tokanai et al. / Nuclear Instruments and Methods in Physics Research A 766 (2014) 176–179

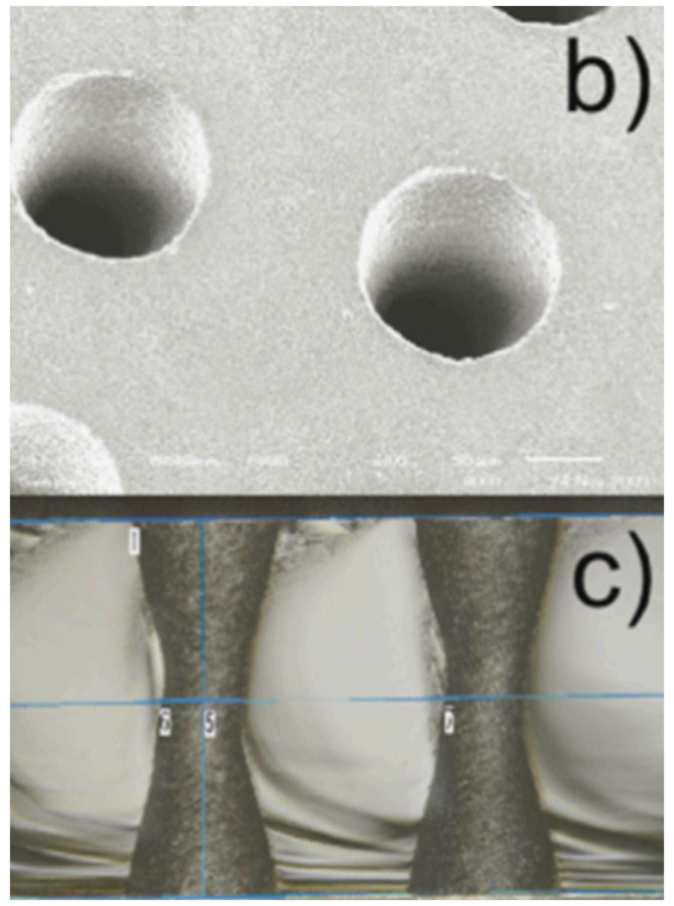
GPDs with CsI photocathodes

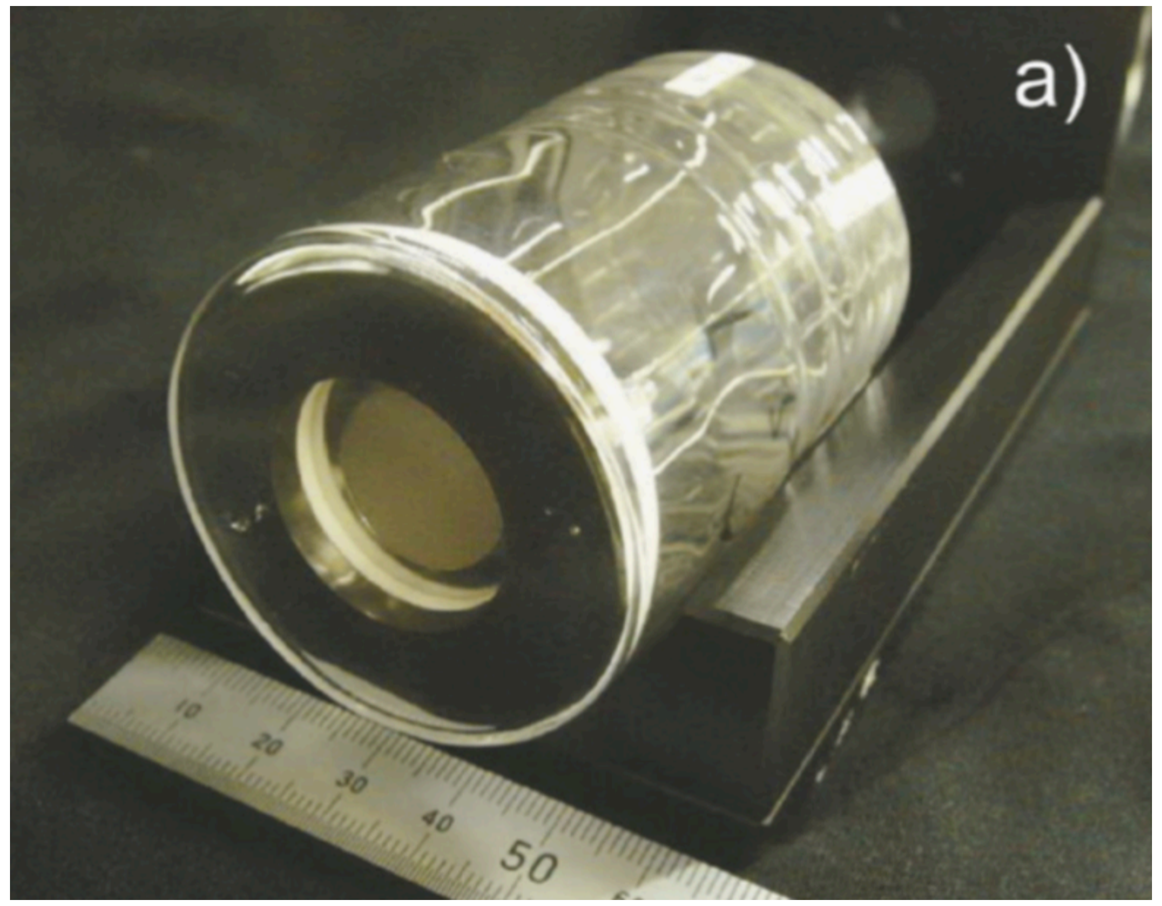
Sealed gaseous PMT with a CsI photocathode fabricated with quartz glass and a microblasted glass plate (MB-GP). Operated in gas mixtures of Ne+iC4H10 and Ne+CF4 and achieved gains of up to 10^5.

Achieved 0.5% QE but saw degradation of 16% after exposure to 25μC/mm2 on photocathode.

Gaseous photomultiplier tube based on micro channels in Pyrex glass







F. Tokanai et al. / Nuclear Instruments and Methods in Physics Research A 628 (2011) 190–193

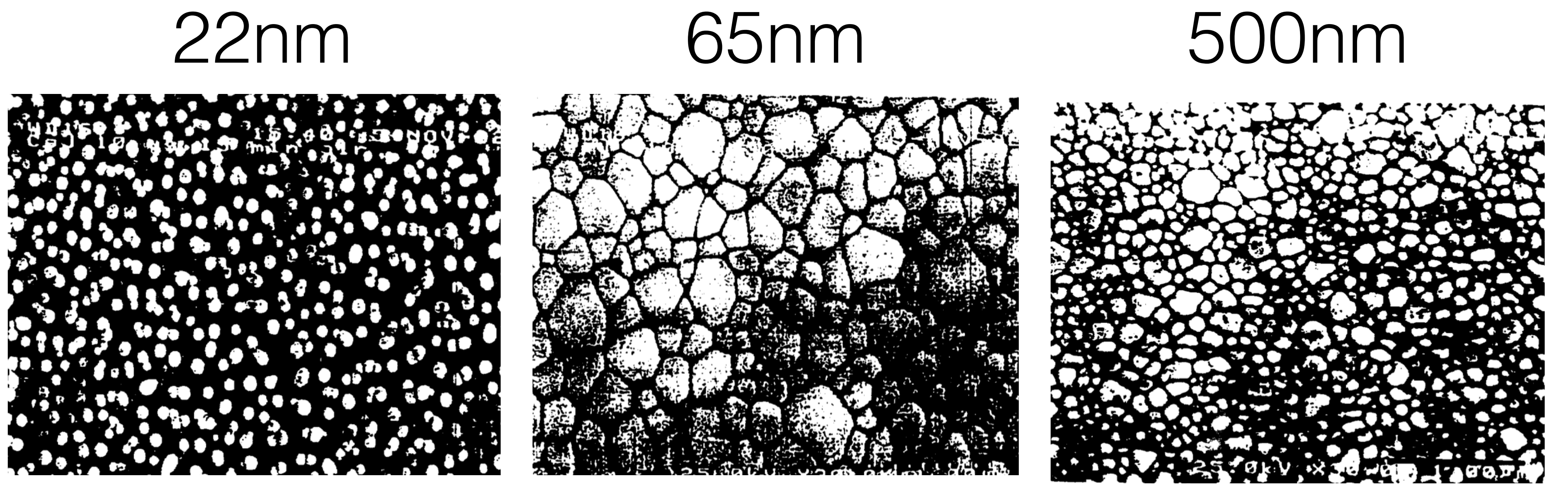
RD26 collaboration

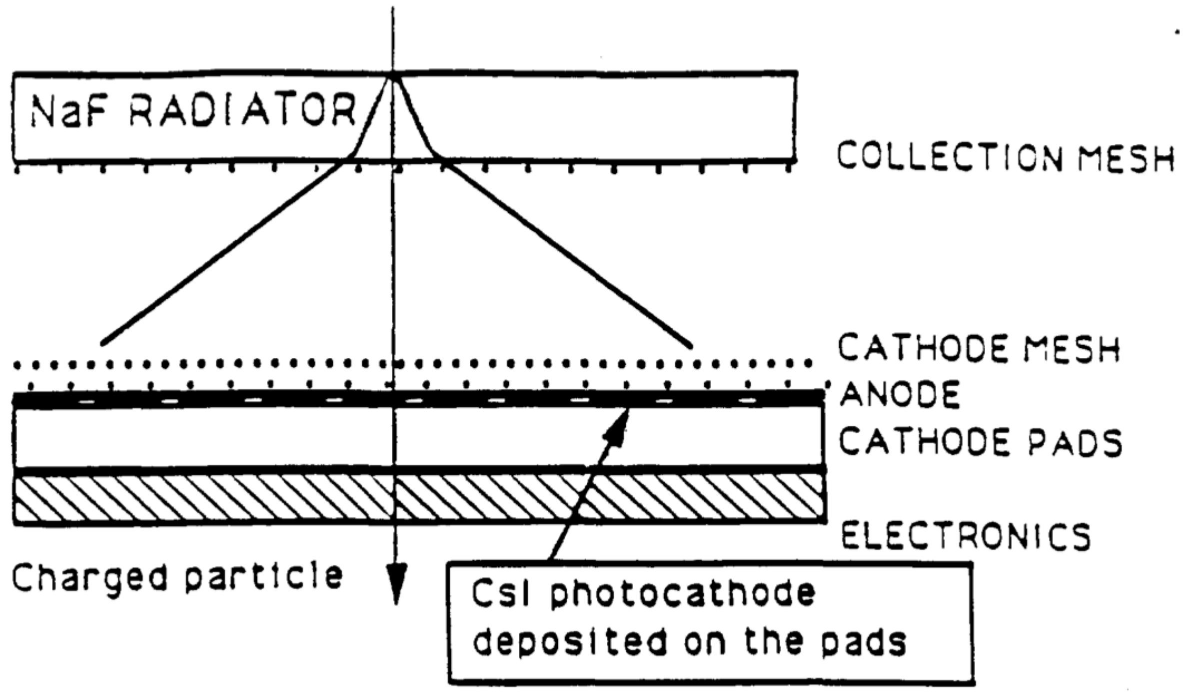
R&D for the development of a large area advanced fast rich detector for particle identification at the LHC operated with heavy ions

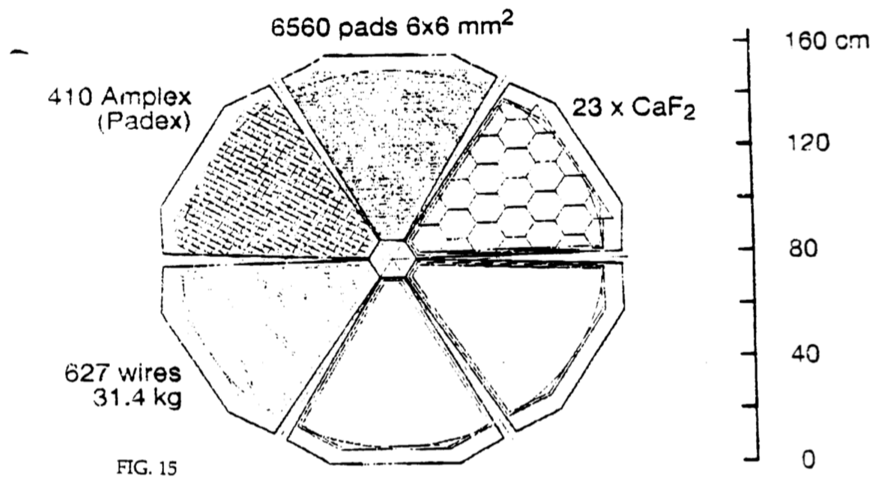
Significantly improved the **understanding of CsI photocathodes** and built up experience with integration of **large CsI photocathodes** for detectors

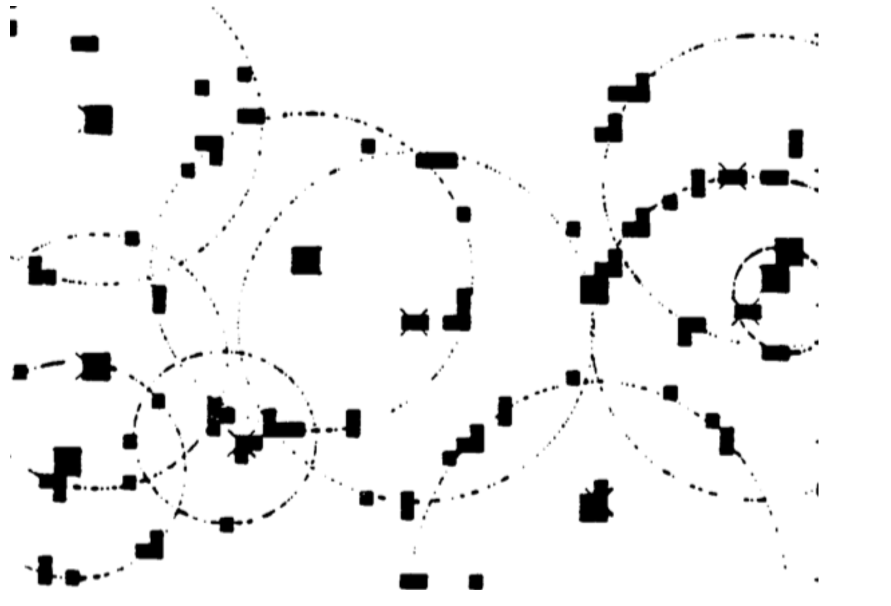
Building and commissioning a large evaporation station for the evaporation of cathodes of 50cm x 60cm

Characterization of the CsI surface in terms of **surface uniformity**; stoichiometry, and **photoemission qualities** using electron spectrometry









http://cds.cern.ch/record/291164/files/

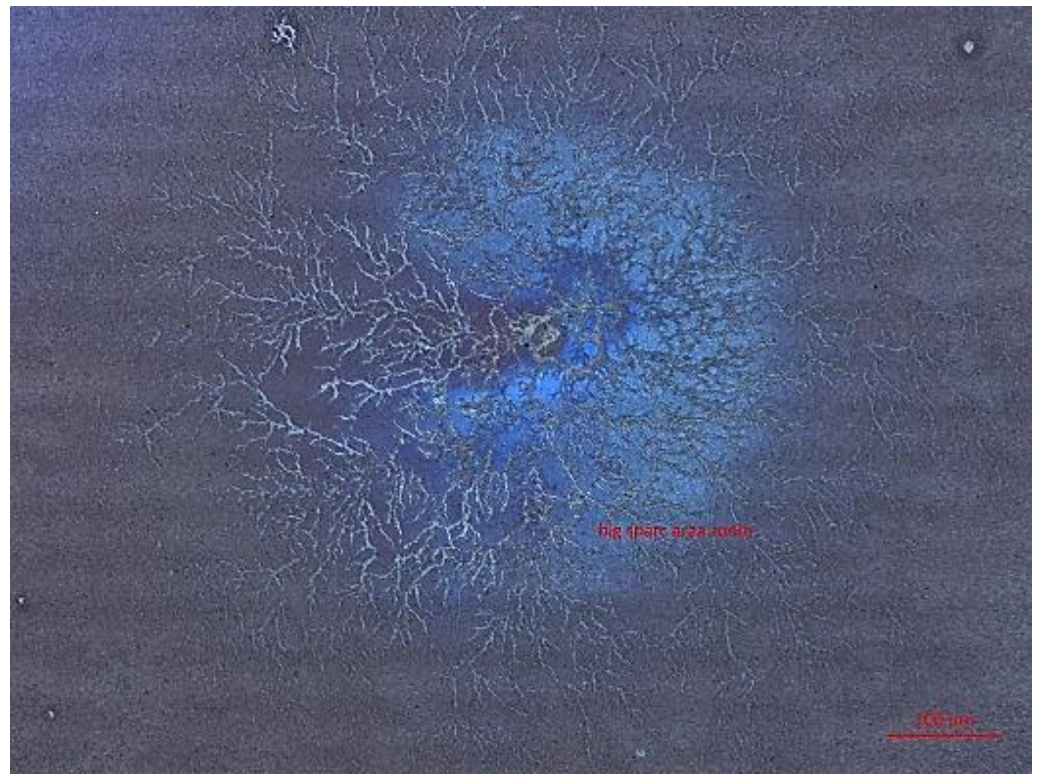
Limitations of CsI

Photocathode robustness

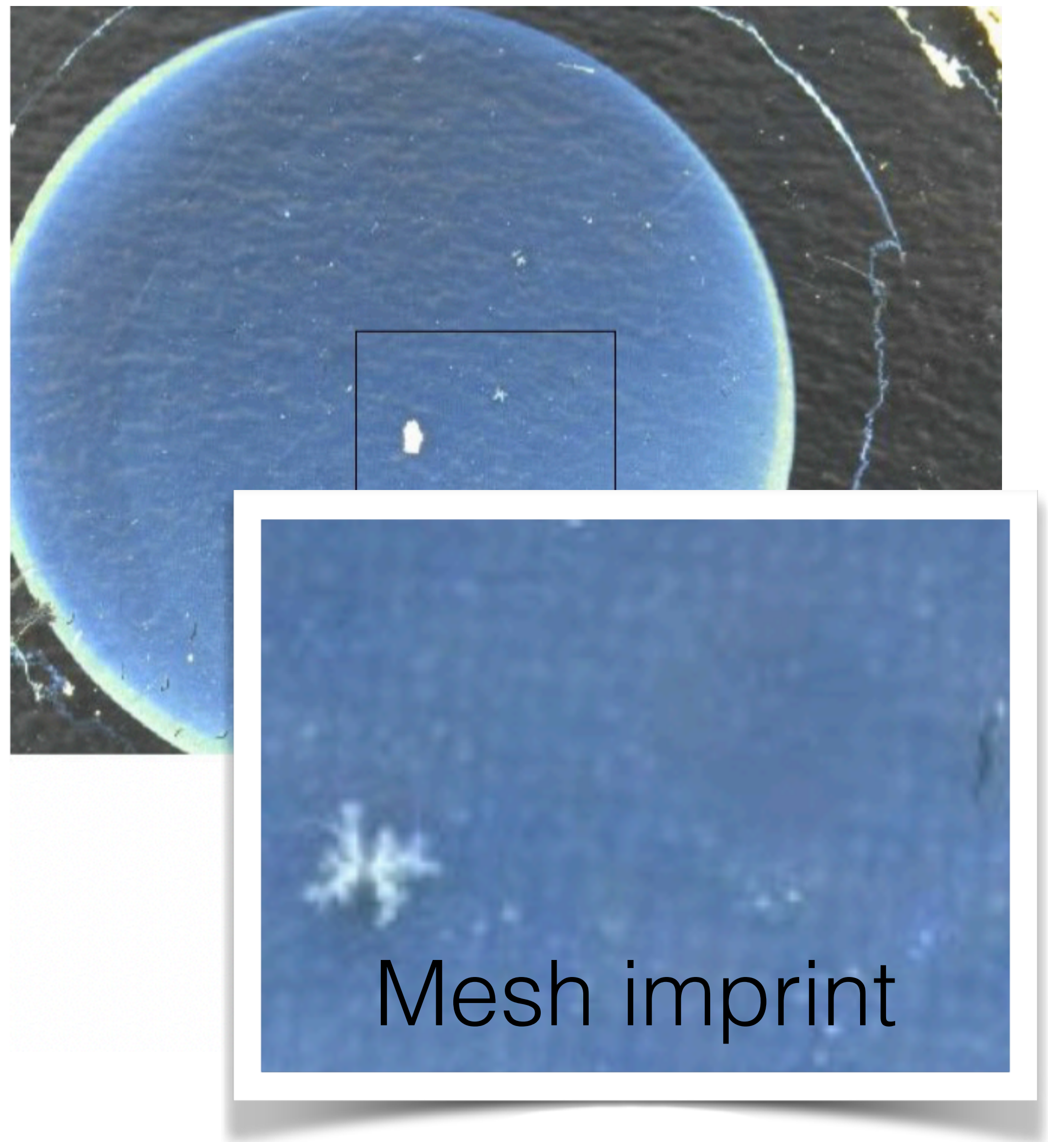
Widely used in MWPC and MPGD based detectors:
ALICE HMPID, COMPASS RICH, STAR, …

Limitations: environmental robustness (humidity), long-term degradation due to ion back flow, sensitivity to sparks, possibility for feedback processes limiting achievable gain

CsI photocathode after spark

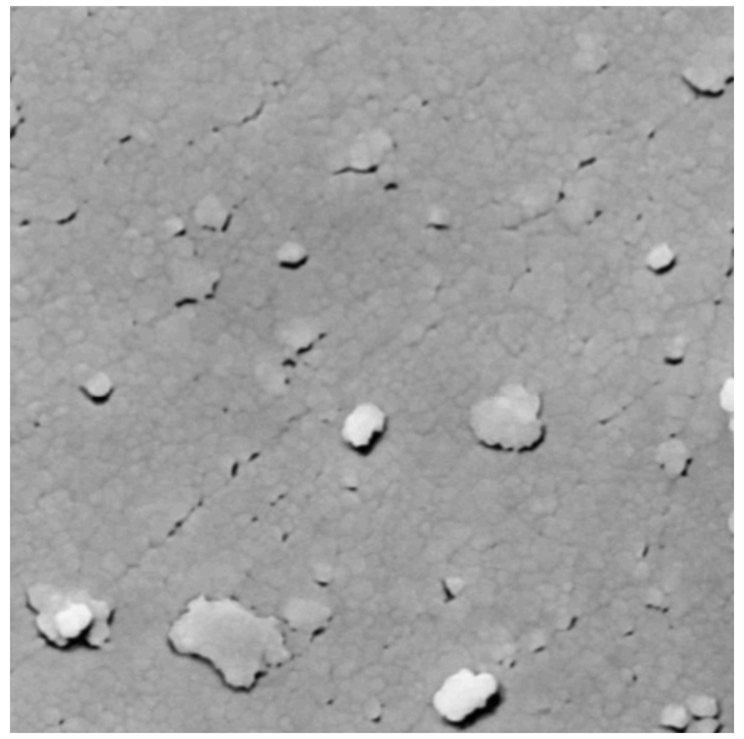


Ion backflow on CsI

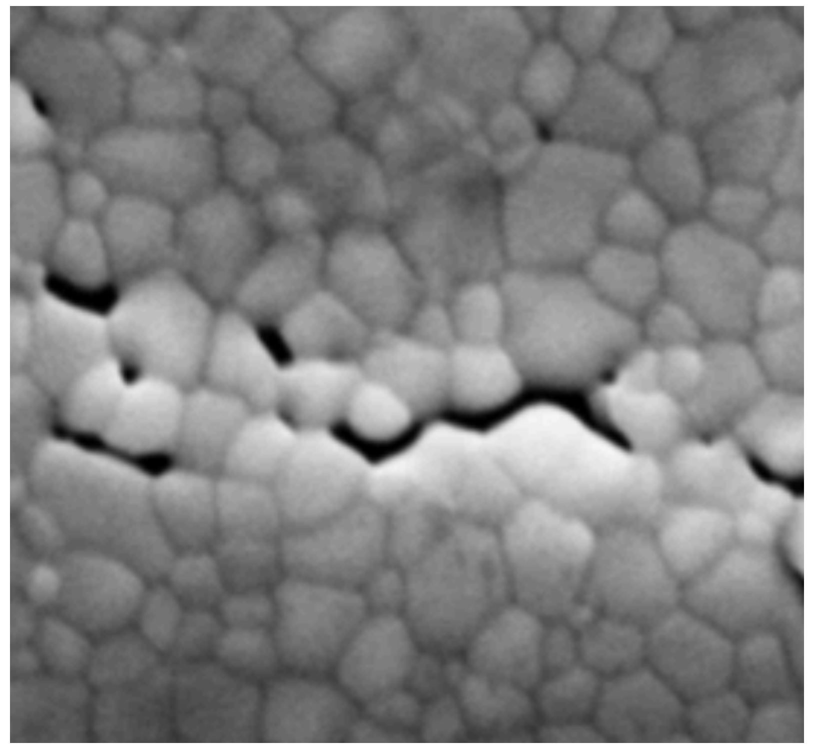


Scanning electron microscope images of CsI morphology

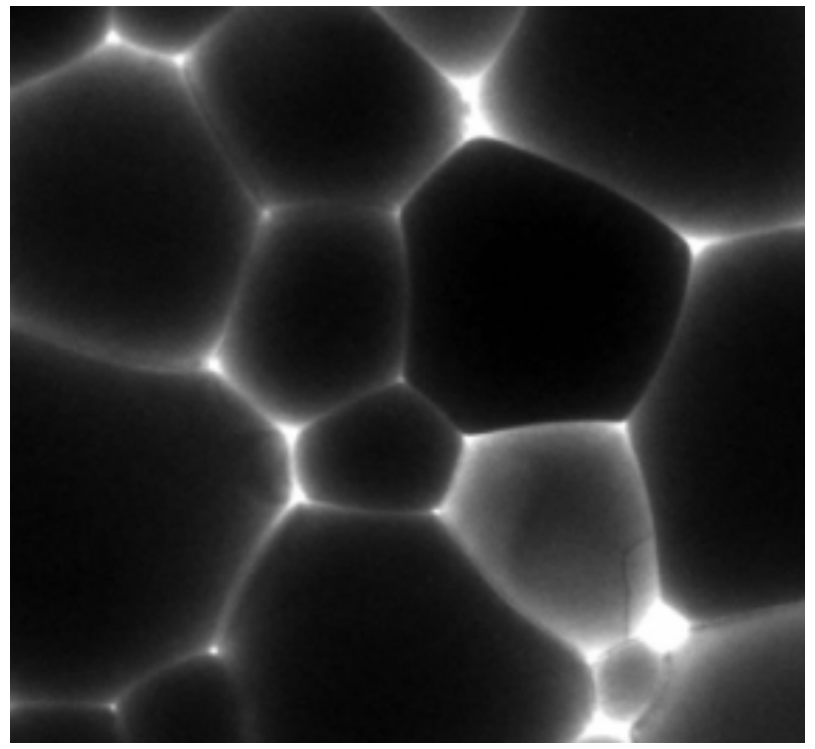
CsI: deposited



After VUV exposure



Humidity exposure



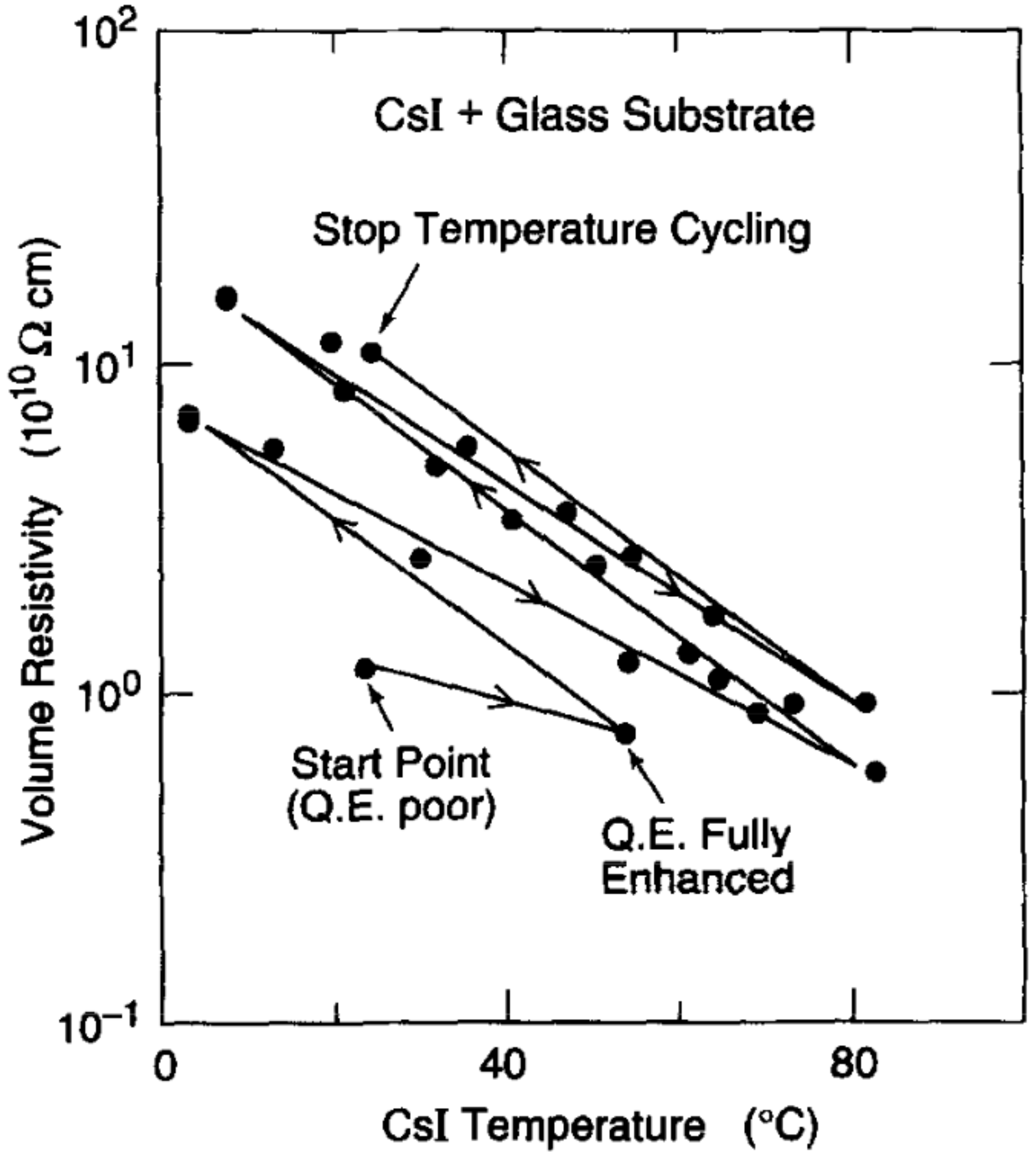
https://doi.org/10.1016/j.nima.2009.05.179

https://doi.org/10.1016/j.nima.2011.10.019

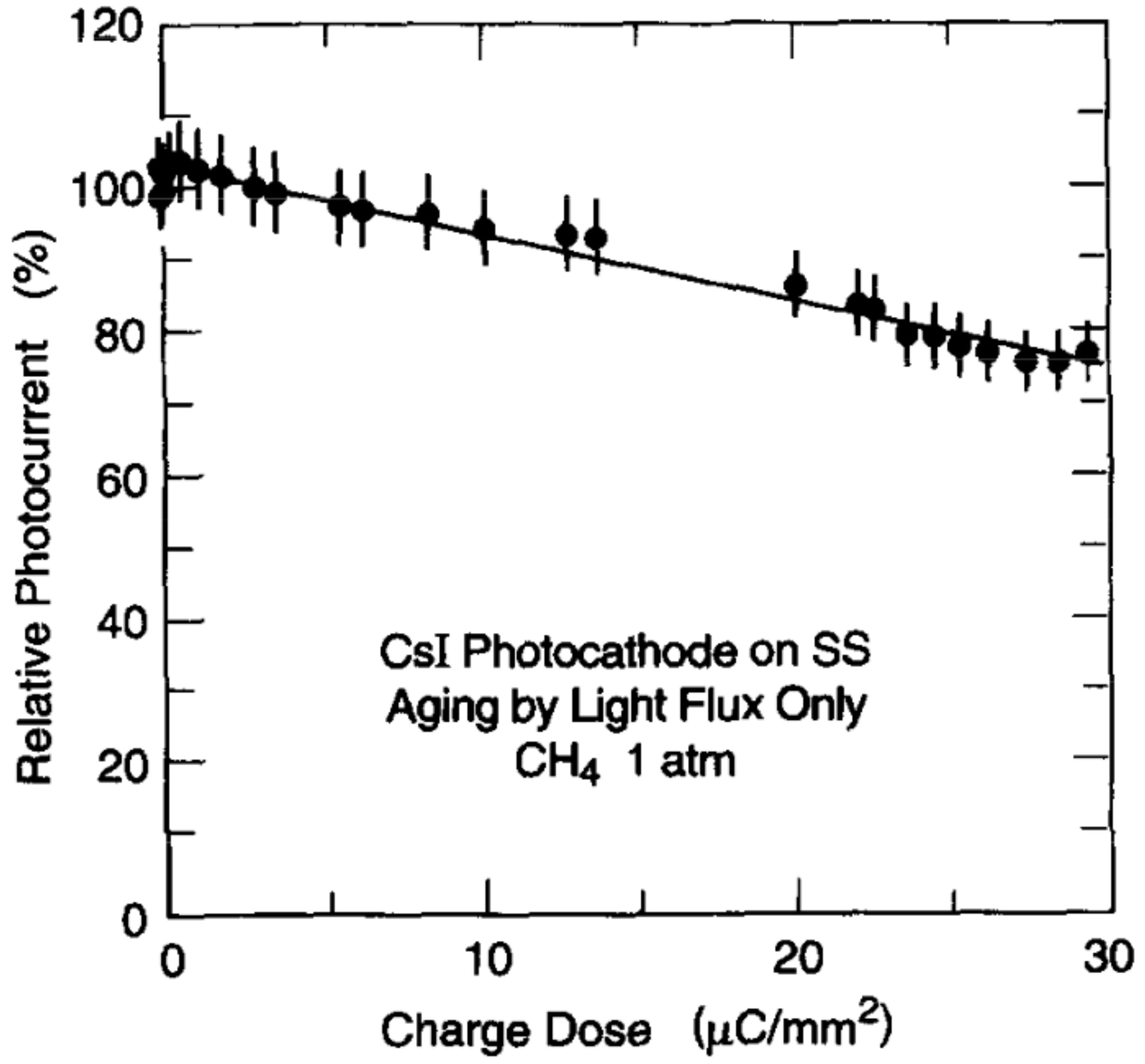
Limitations of CsI

Photocathode robustness

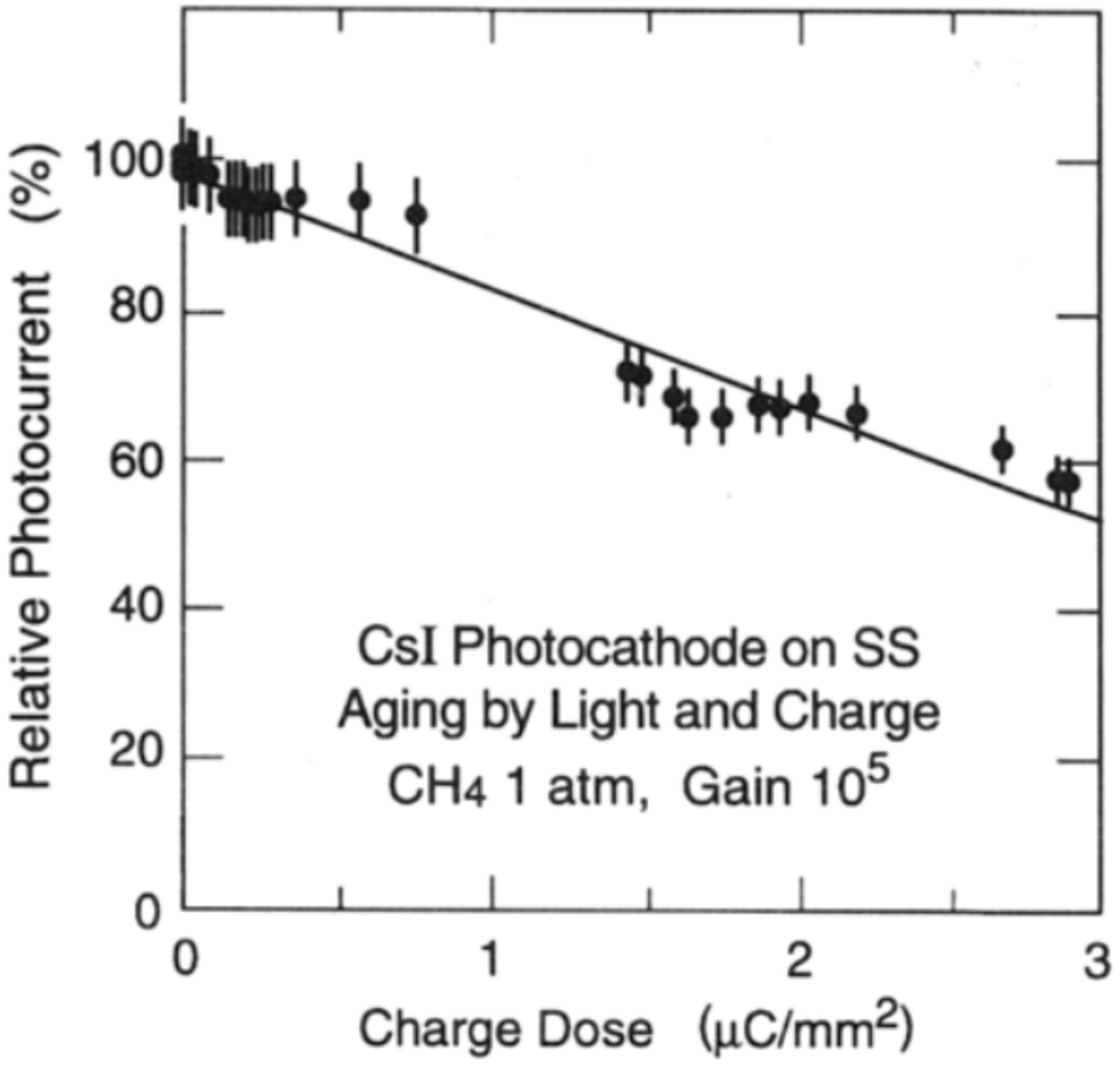
Low resistivity of CsI can limit rate capability and lead to charging up effects affecting electron extraction efficiency



Ageing due to light flux



Ageing due to light flux + charge accumulation



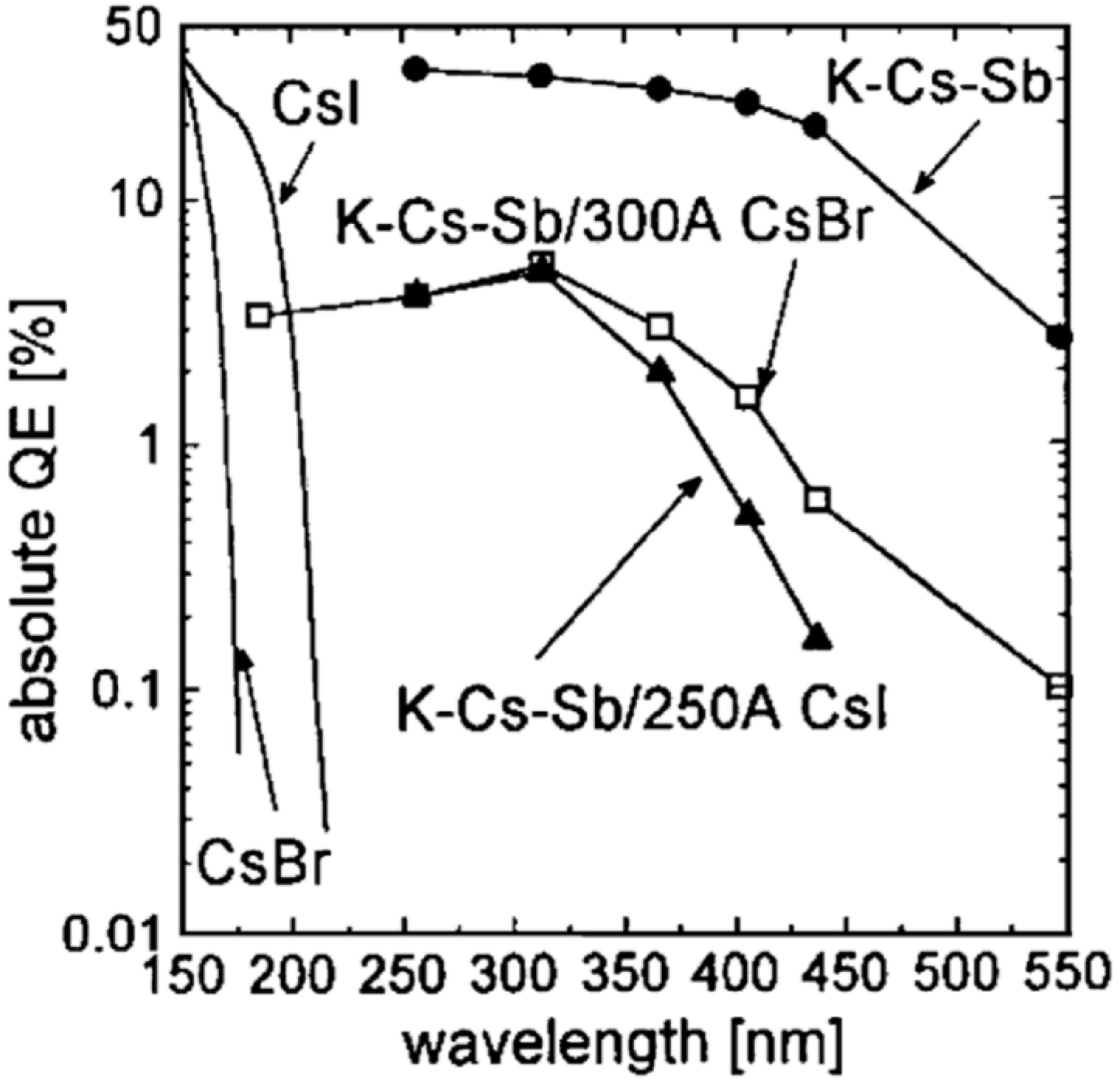
500nm CsI, CH4, gain 10^5

J. Va'vra et al. I Nucl. Instr. and Meth. in Phys. Rex. A 387 (1997) 154-162

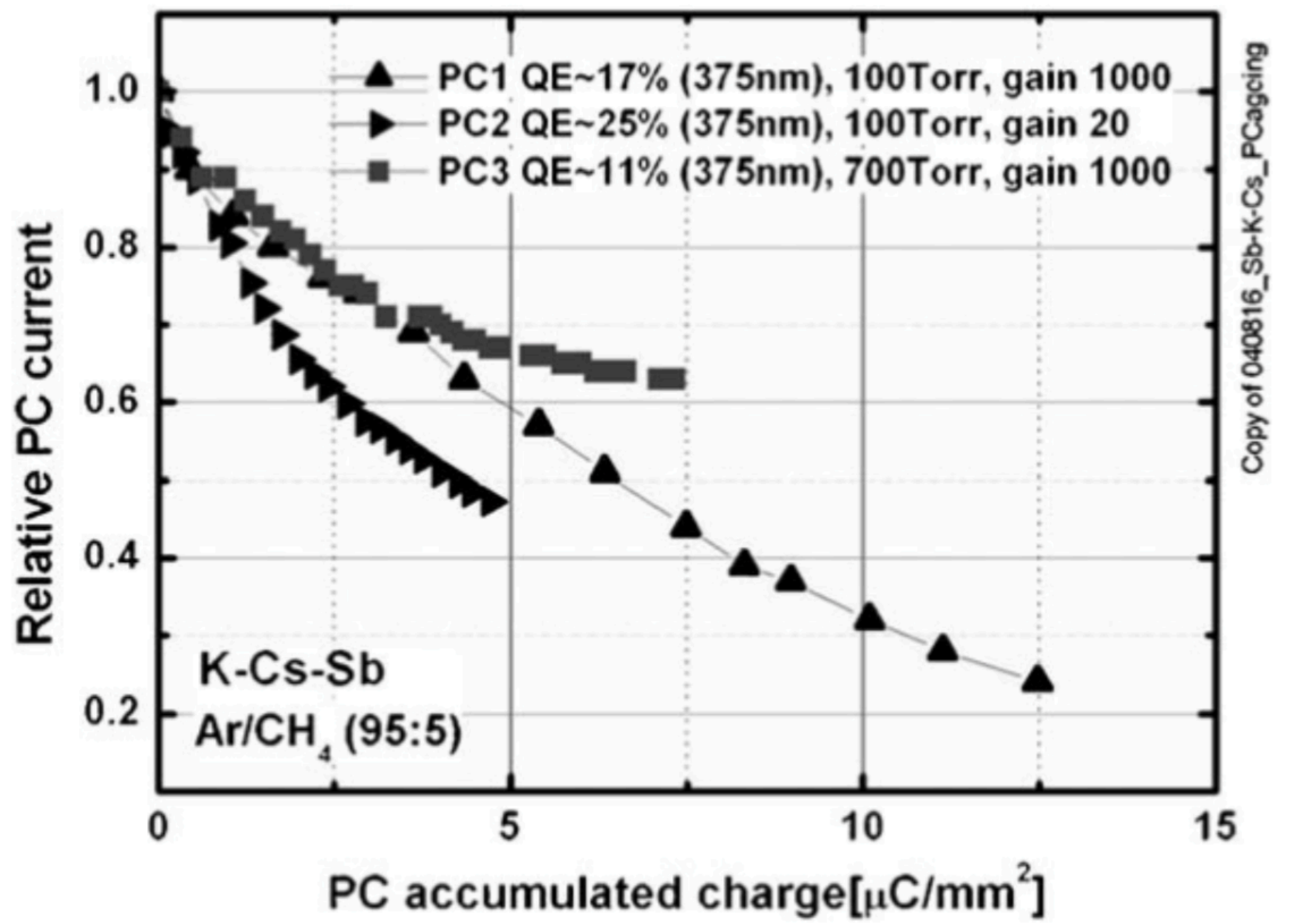
Visible photocathodes

The low electron emission threshold of visible photocathodes limits achievable factors due to probability of feedback processes leading to runaway conditions.

High chemical reactivity requires carful choice of construction materials compatible with minimal contamination on ppb level and operation in sealed mode.



E. Shefer, et al., Nucl. Instrum. Methods A 433 (1999) 502.



A. Lyashenko, et al., Aging studies of K–Cs–Sb photocathodes under gas avalanche.

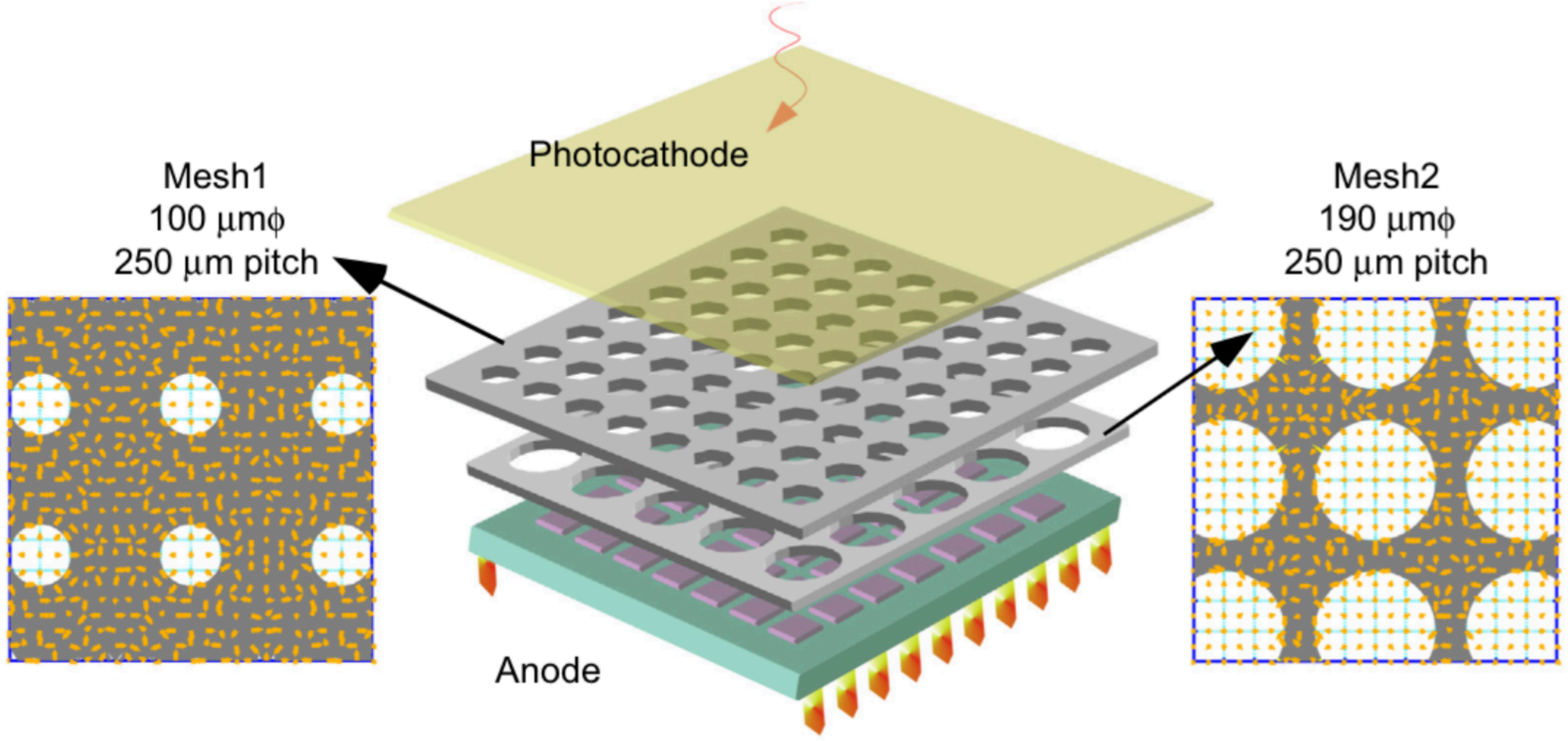
Low IBF values in % range are adequate for CsI-based photon detectors. For visible-sensitive photocathodes such as **K–Cs–Sb PCs**, significant secondary electron emission probability, around 0.05–0.5 electrons/ion in CH4 and Ar/CH4 mixtures **require IBF smaller than 10^4** for stable operation at high gain.

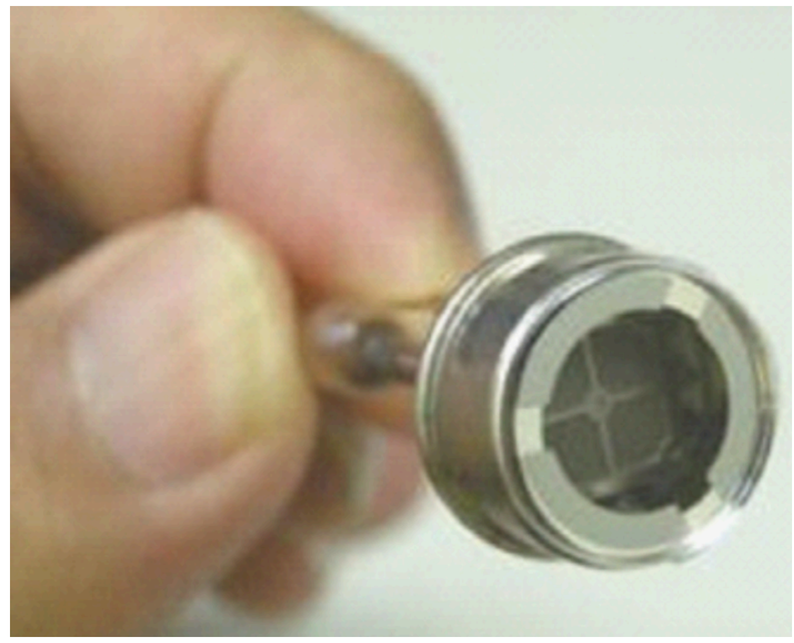
A. Breskin et al. / Nuclear Instruments and Methods in Physics Research A 553 (2005) 46–52

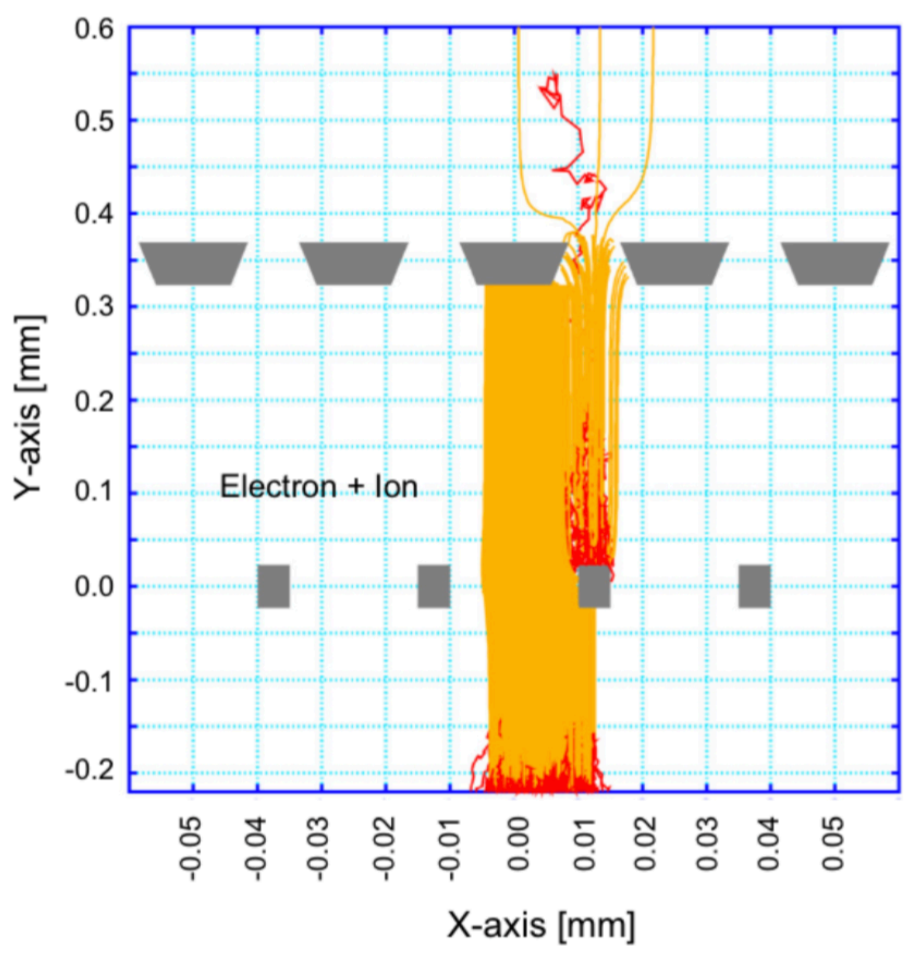
GPDs with visible photocathodes

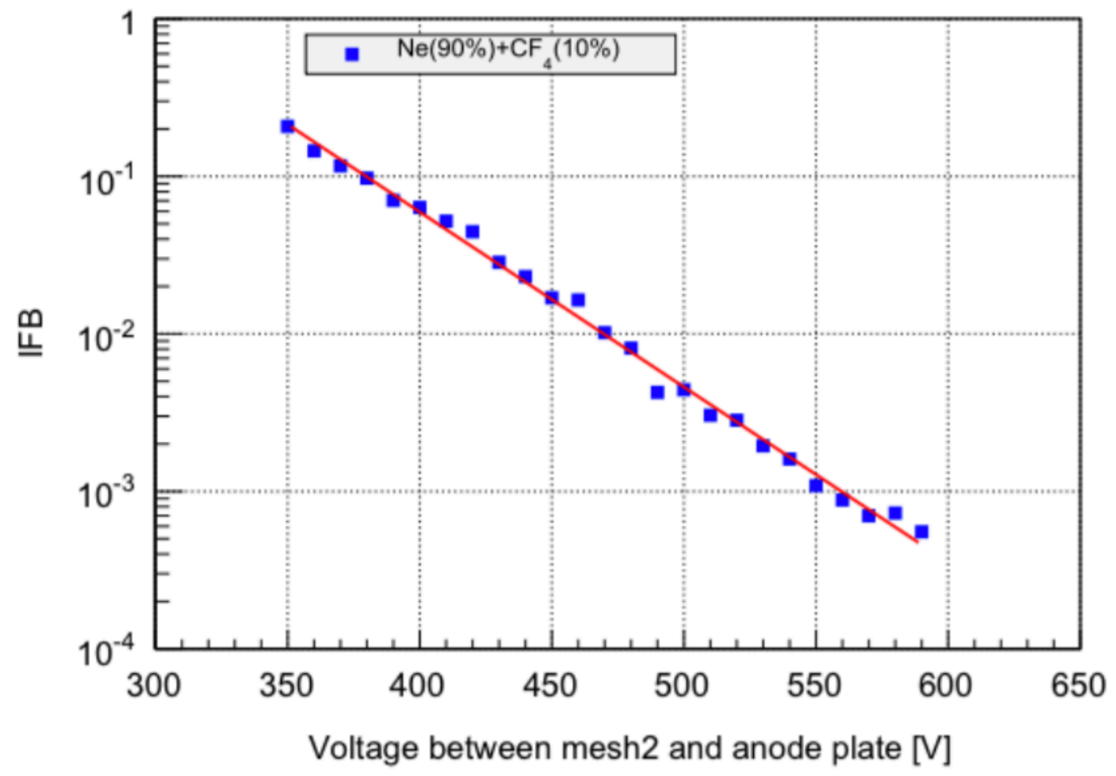
To be able to use bialkali photocathode for visible light sensitivity, a Micromegas-based photon detector was developed for reduced ion back flow fraction. Two micromeshes with different openings were used to minimise the ion back flow and IBF < 6x10^-4 was achieved.

Gaseous photomultiplier with Micromegas and bialkali photocathode









F. Tokanai et al. / Nuclear Instruments and Methods in Physics Research A 766 (2014) 176–179

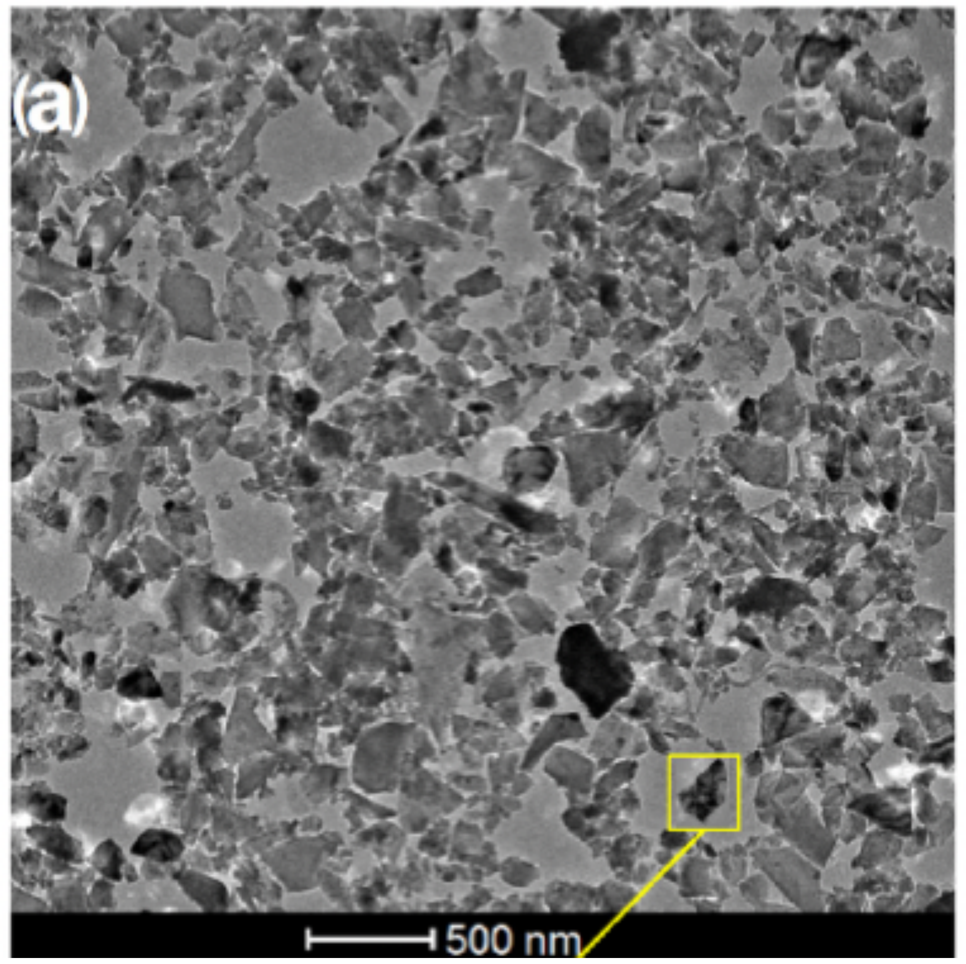
Nanodiamond photocathodes

Progress on coupling MPGD-based photon detectors with nanodiamond photocathodes
F. Tessarotto

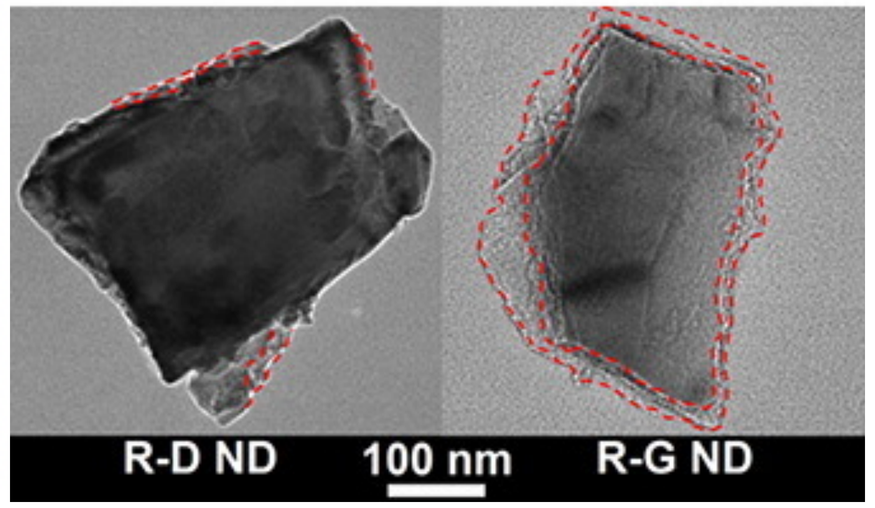
Based on ≈100nm diamonds particles deposited by spray technique, possibility for semi-transparent and reflective photocathodes

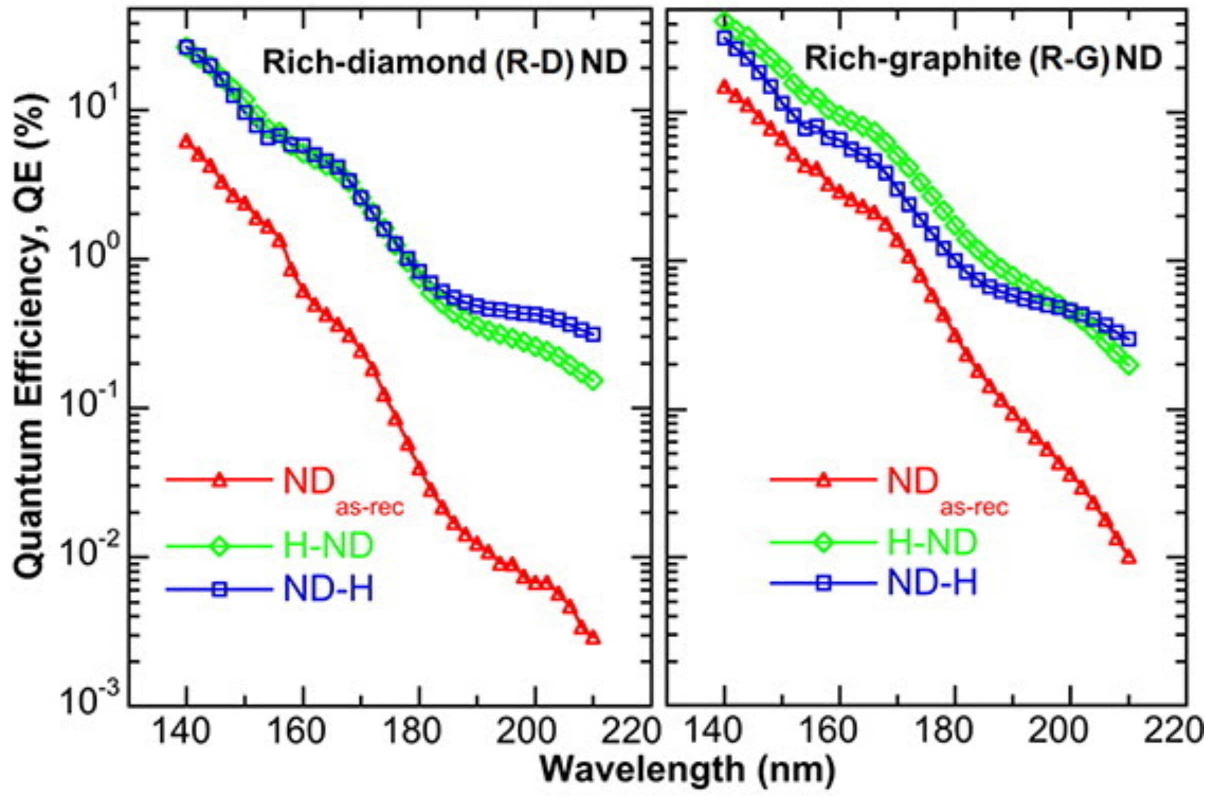
Promising performance >10% QE and environmental robustness
Hydrogenation can improve QE

Nanodiamond (ND) powder

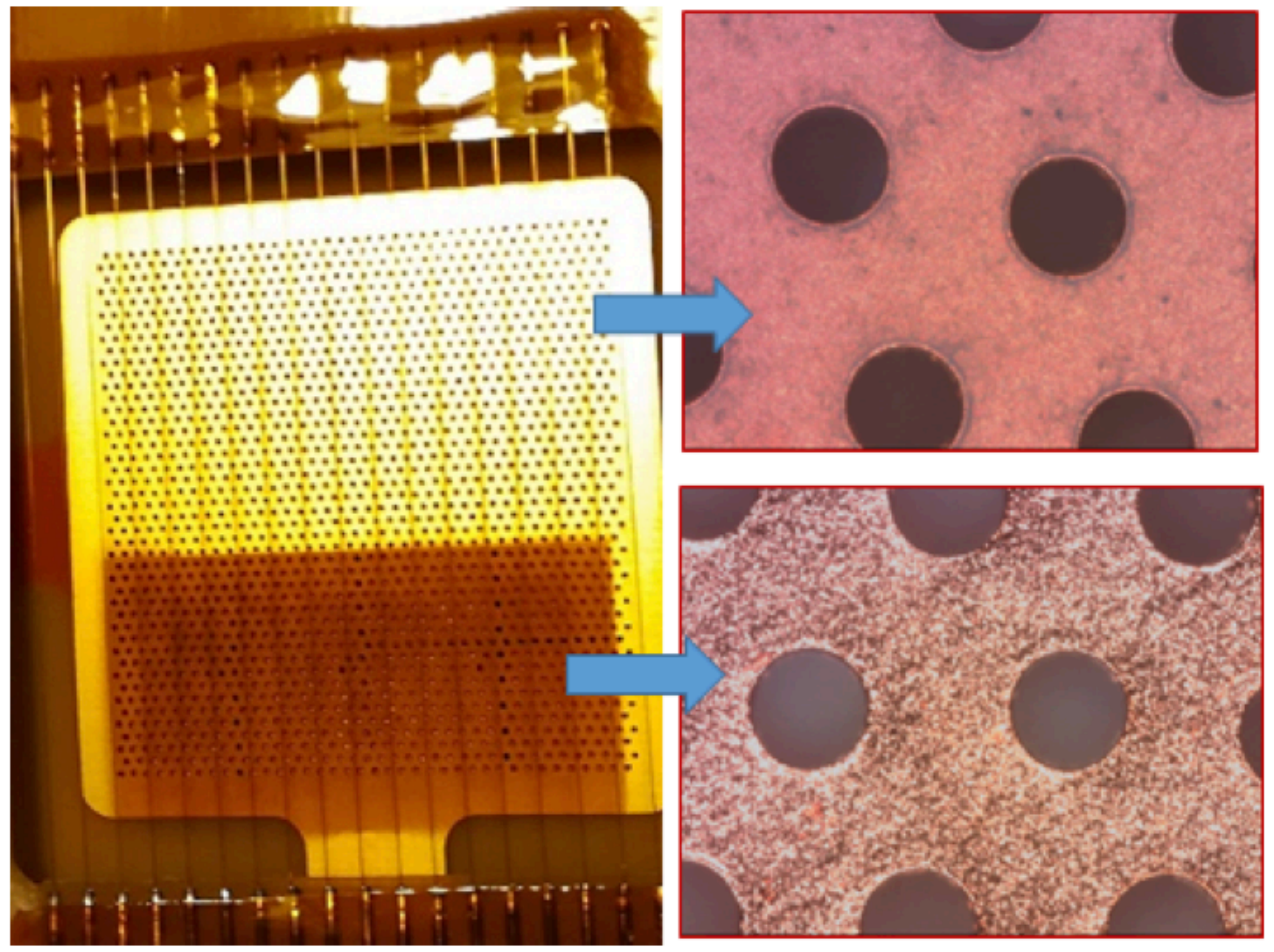


Highly efficient and stable ultraviolet photocathode based on nanodiamond particles L.Velardi,A.Valentini,and G.Cicala,Appl. Phys. Lett.108, 083503 (2016)





Velardi et al., https://doi.org/10.1016/j.diamond.2017.03.017
C. Chatterjee et al 2020 J. Phys.: Conf. Ser. 1498 012008
https://iopscience.iop.org/article/10.1088/1742-6596/1498/1/012008/pdf



Ion backflow suppression

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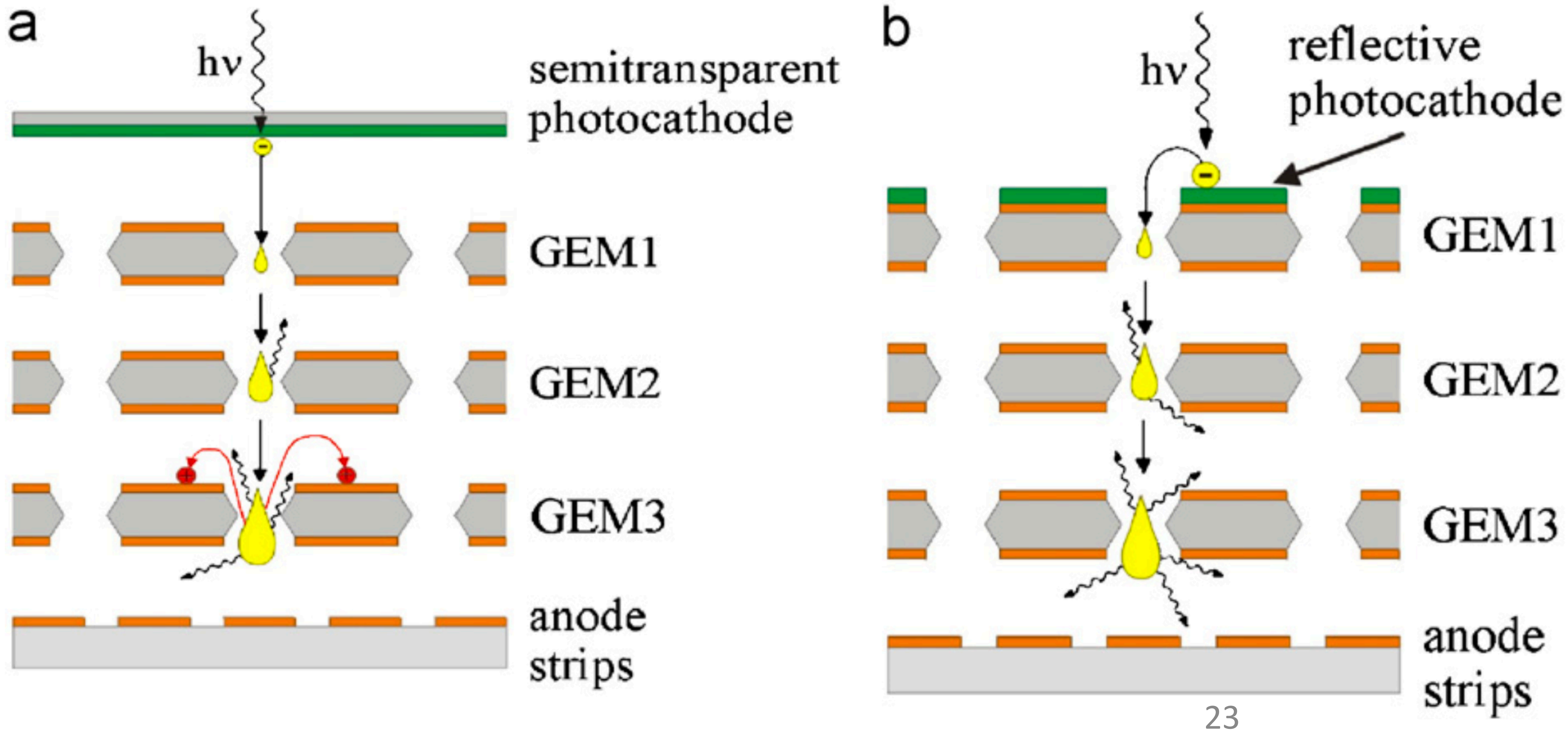
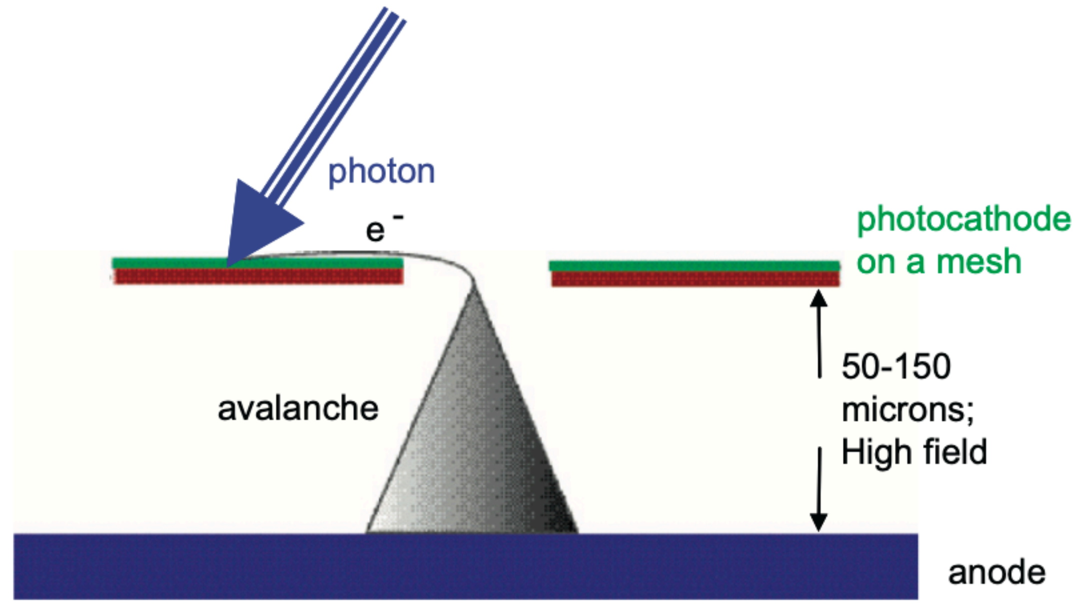
Their limitations include aging of wires, degradation of solid photocathodes due to significant ion back flow in “open geometry” of wire-based amplification and limited spatial and timing resolution. In addition, gain is limited by significant photon and ion induced feedback processes.



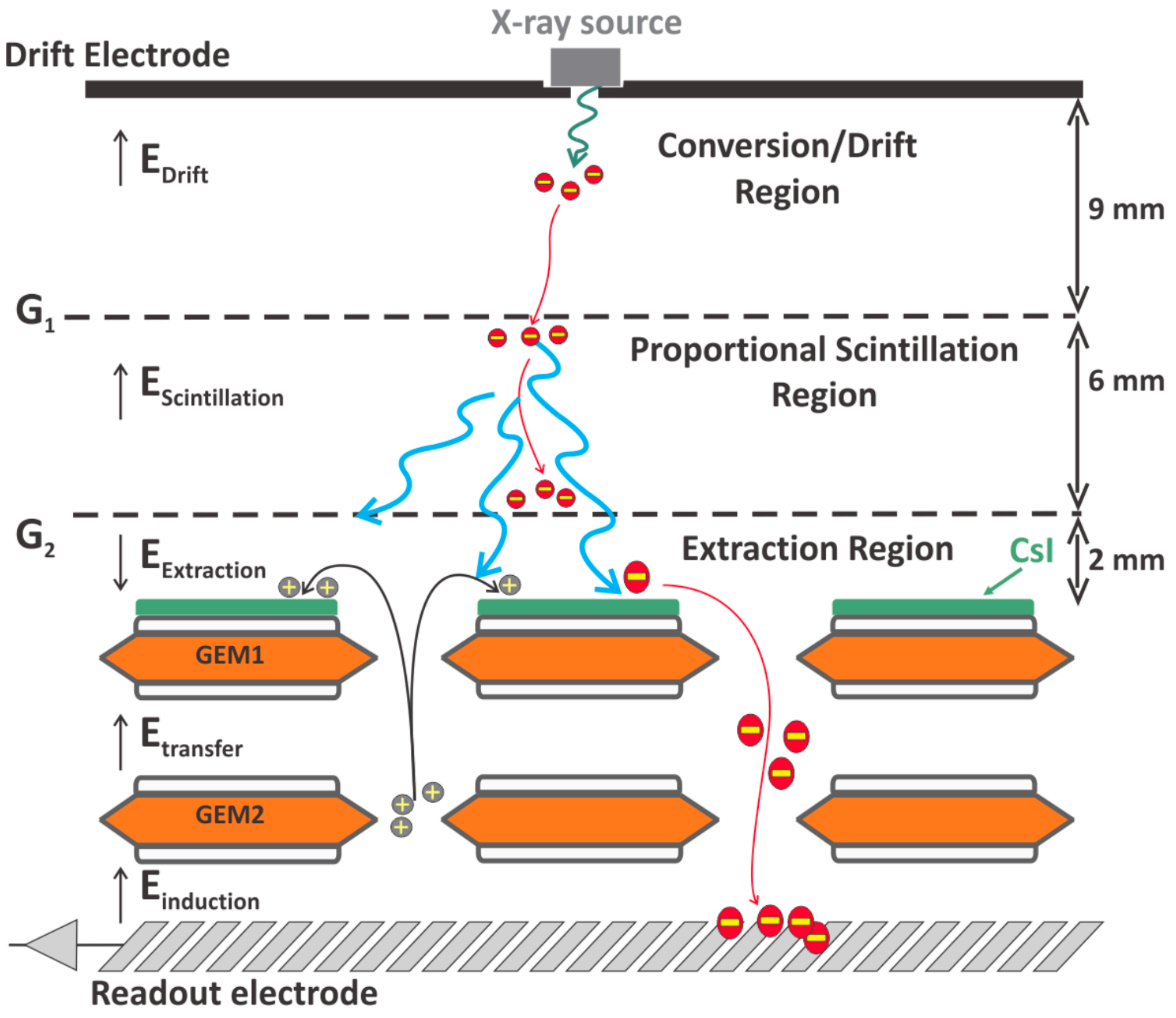


J. Darre, et al., Nucl. Instr. and Meth. A 449 (2000) 314.

R. Chechik, A. Breskin / Nuclear Instruments and Methods in Physics Research A 595 (2008) 116–127

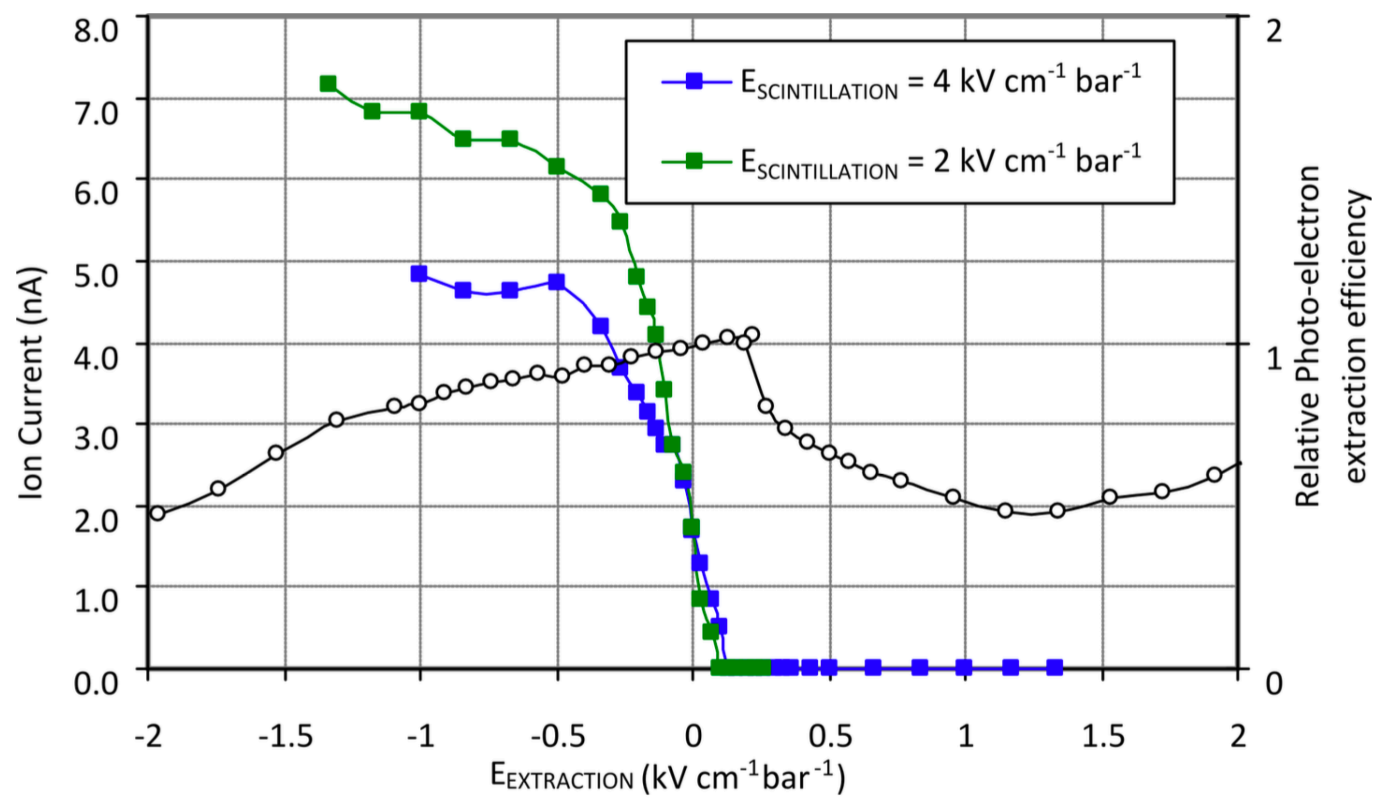
Gaseous photon detectors

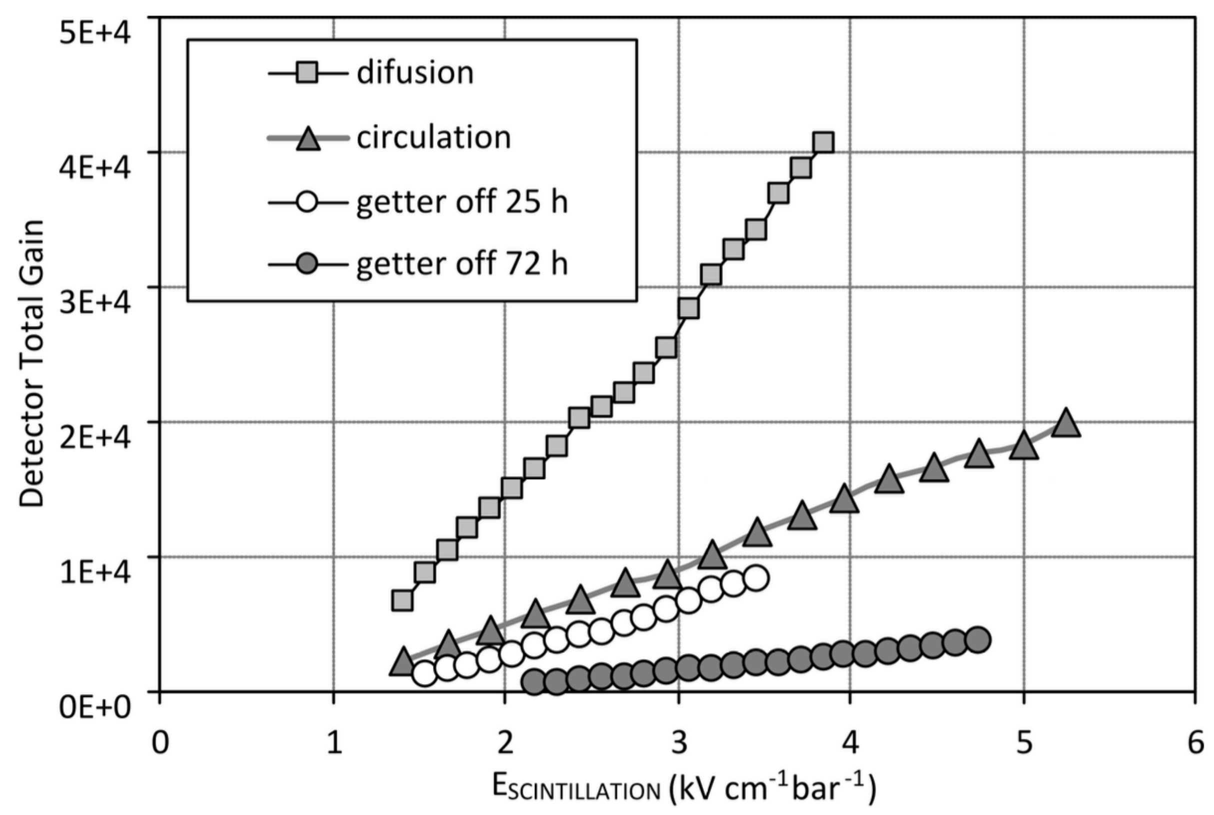
Coupling **proportional scintillation** between parallel meshes with a **gaseous photomultiplier** with CsI photocathode allows to **suppress ion back flow** to level of primary scintillation.



Primary electrons drift to proportional scintillation region. Light is produced between meshes and converted to electrons with photocathode coated on GEM electrode.

Inverted electric field between mesh and GEM result in all secondary ions being collected on mesh.





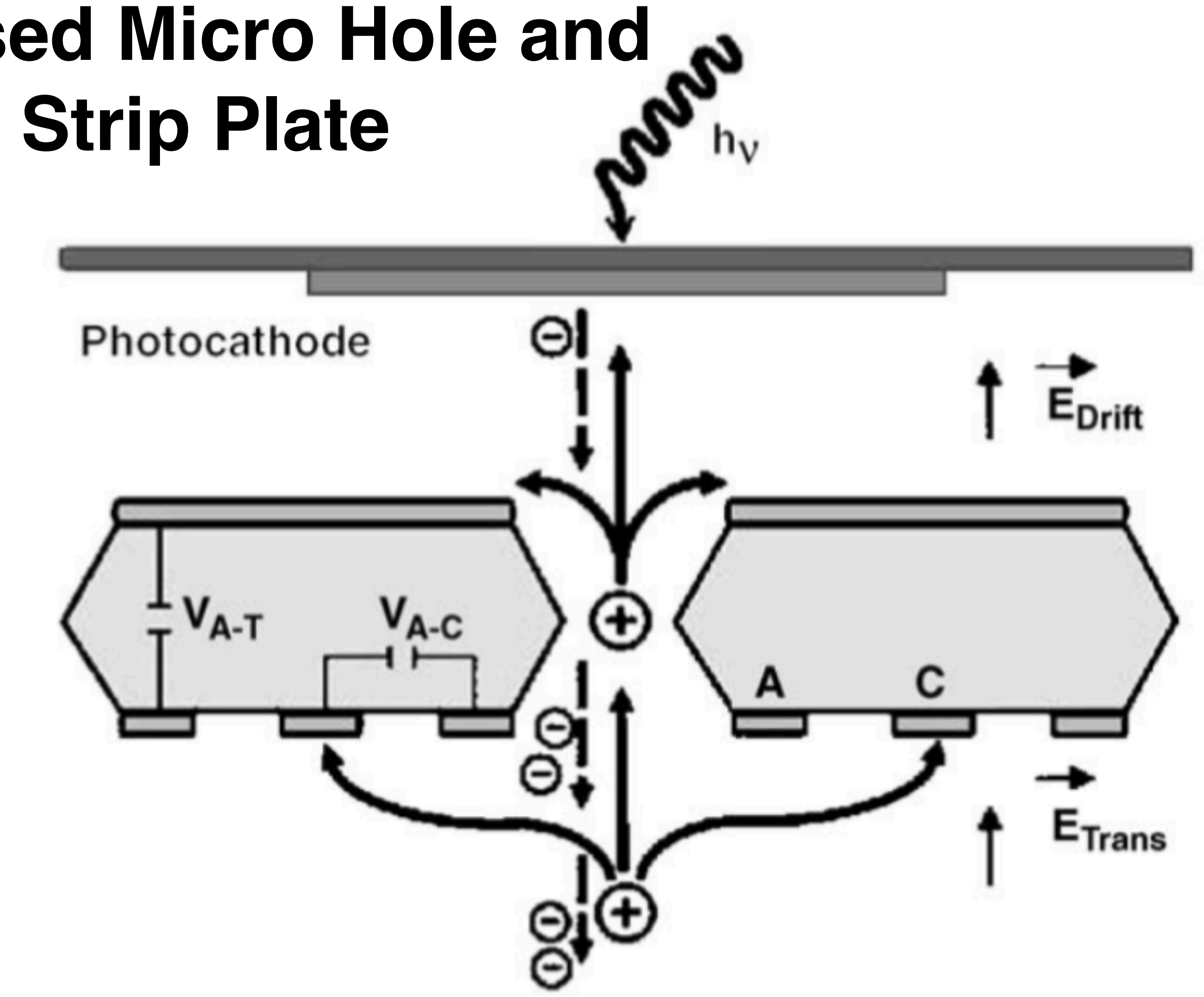
F.D. Amaro et al. / 2014 JINST 9 P02004

Gaseous photon detectors

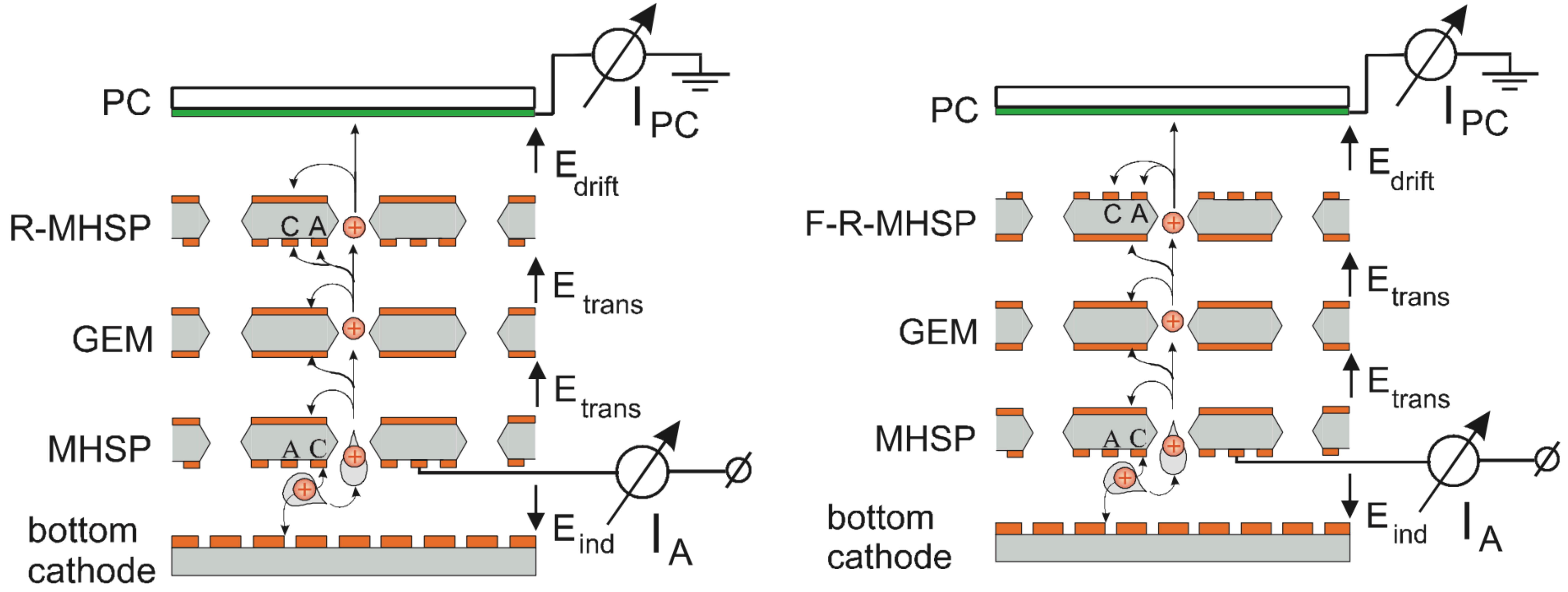
Patterned electrodes and configurations of using multiple patterned detectors in hole multiplier stacks can be used to suppress IBF.

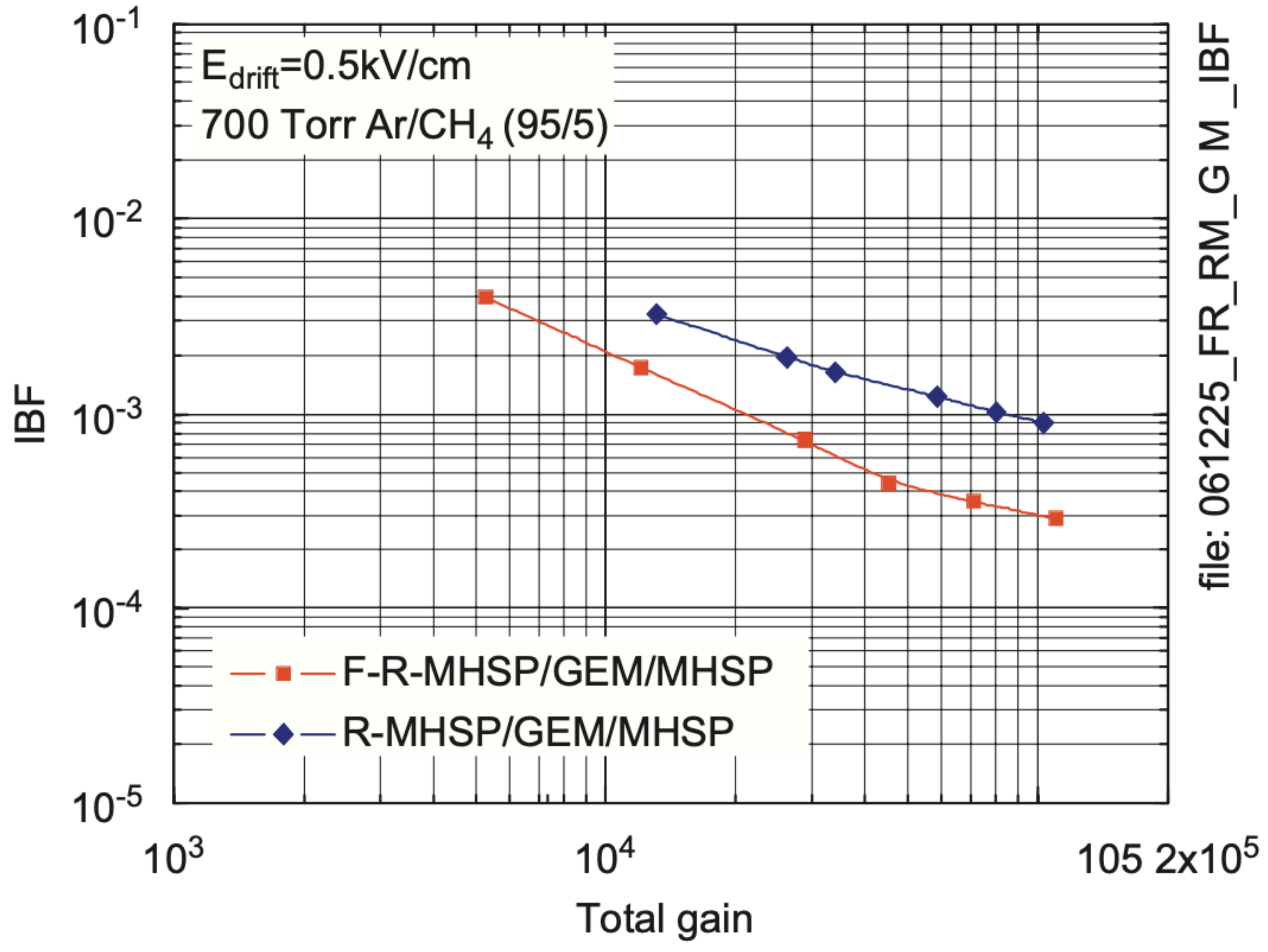
In addition to collecting ions produced in their own avalanche, MHSP or cobra detectors can **collect ions from successive amplification stages** and thus achieve IBF lower than cascades consisting only of GEMs.

Reversed Micro Hole and Strip Plate



A. Breskin et al. / Nuclear Instruments and Methods in Physics Research A 553 (2005) 46–52





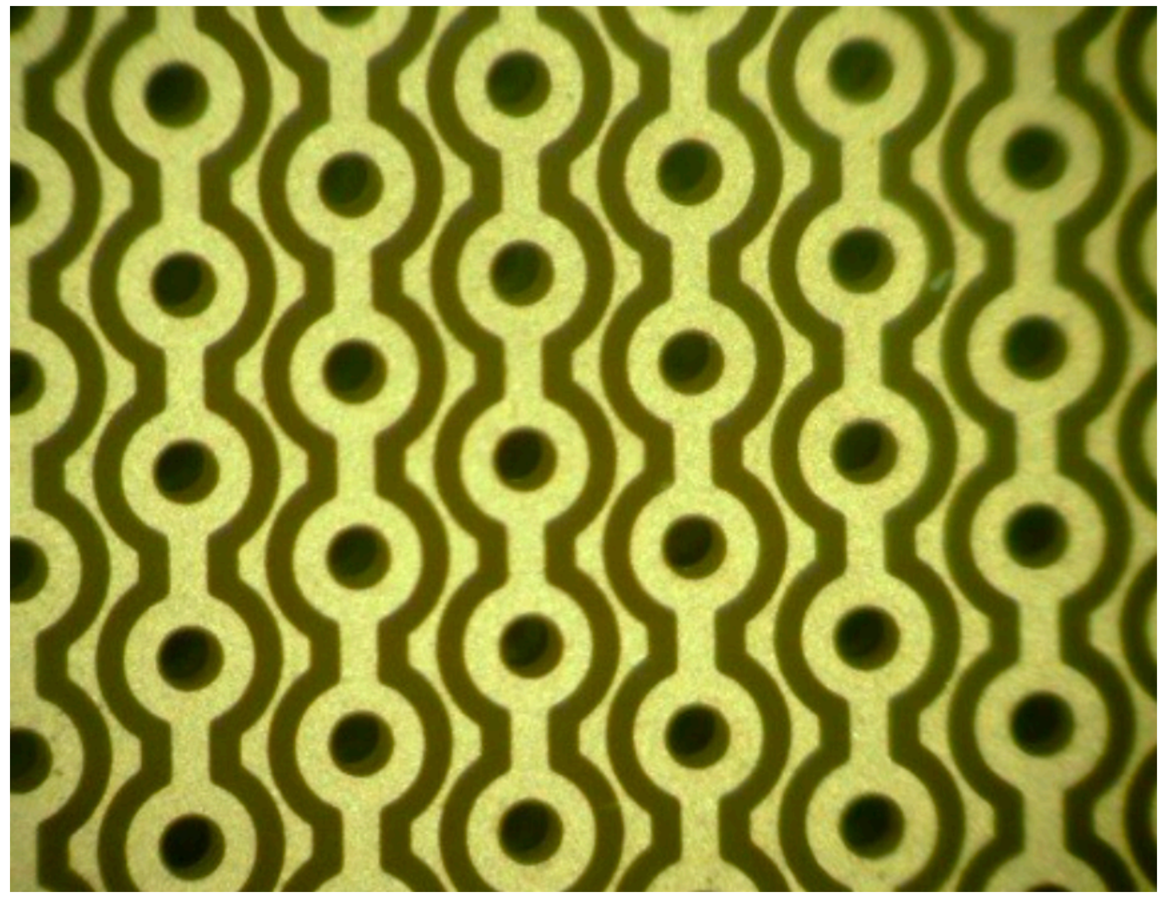
R. Chechik, A. Breskin / Nuclear Instruments and Methods in Physics Research A 595 (2008) 116–127

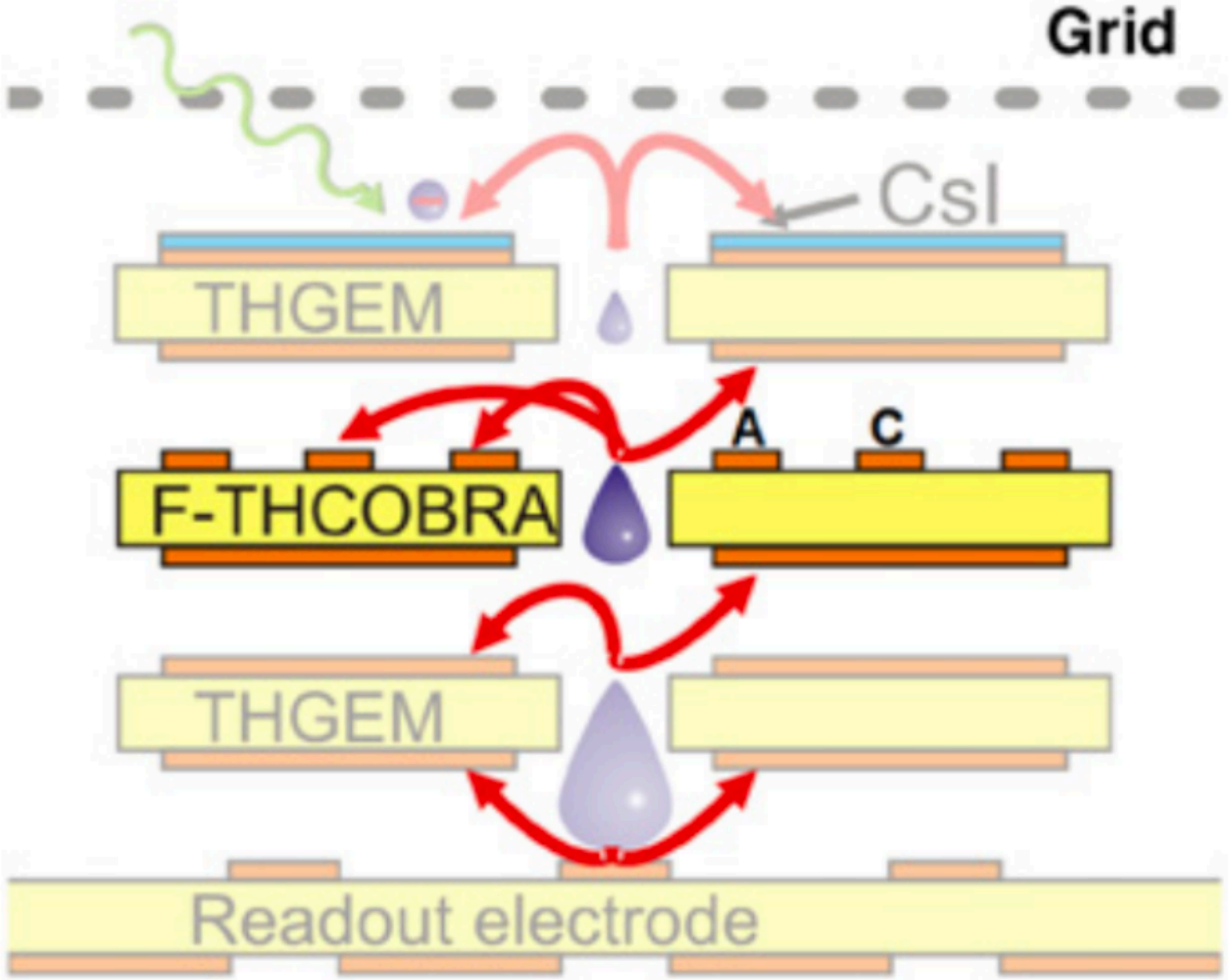
THCOBRA - patterned THGEM

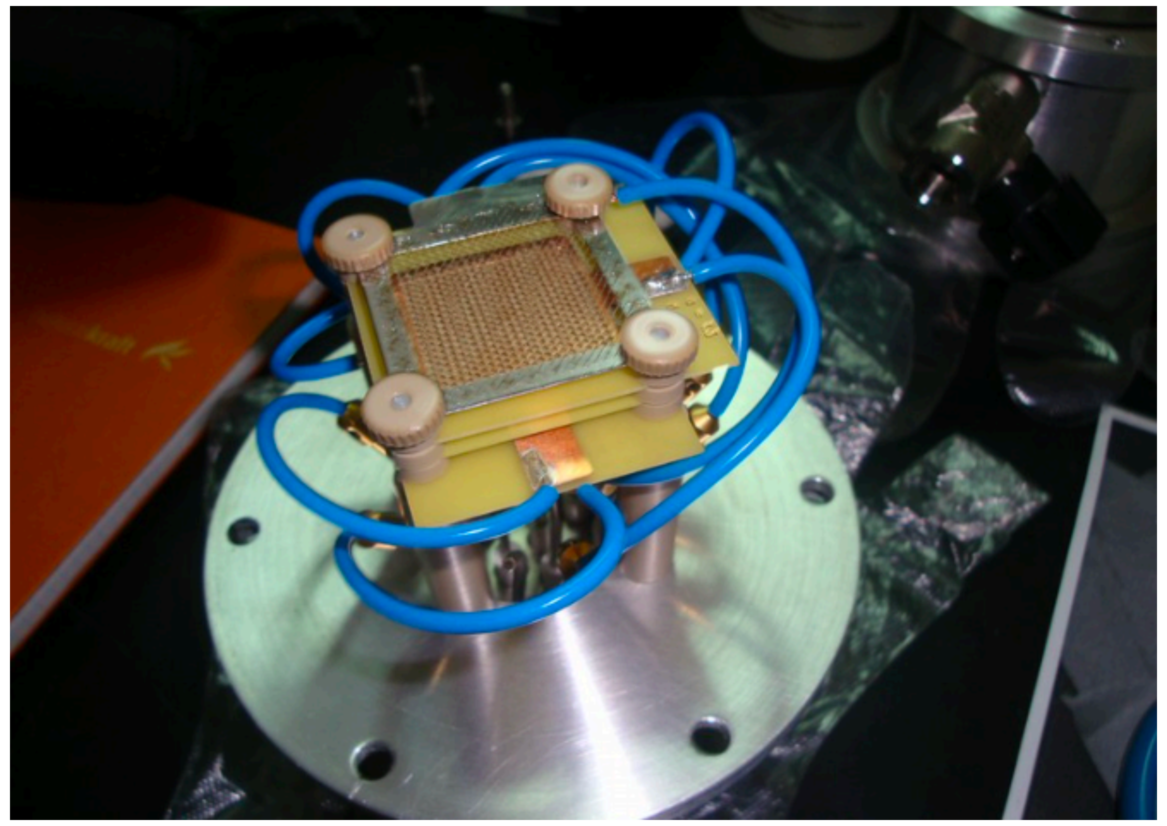
IBF suppression with pattered electrode to collect ions

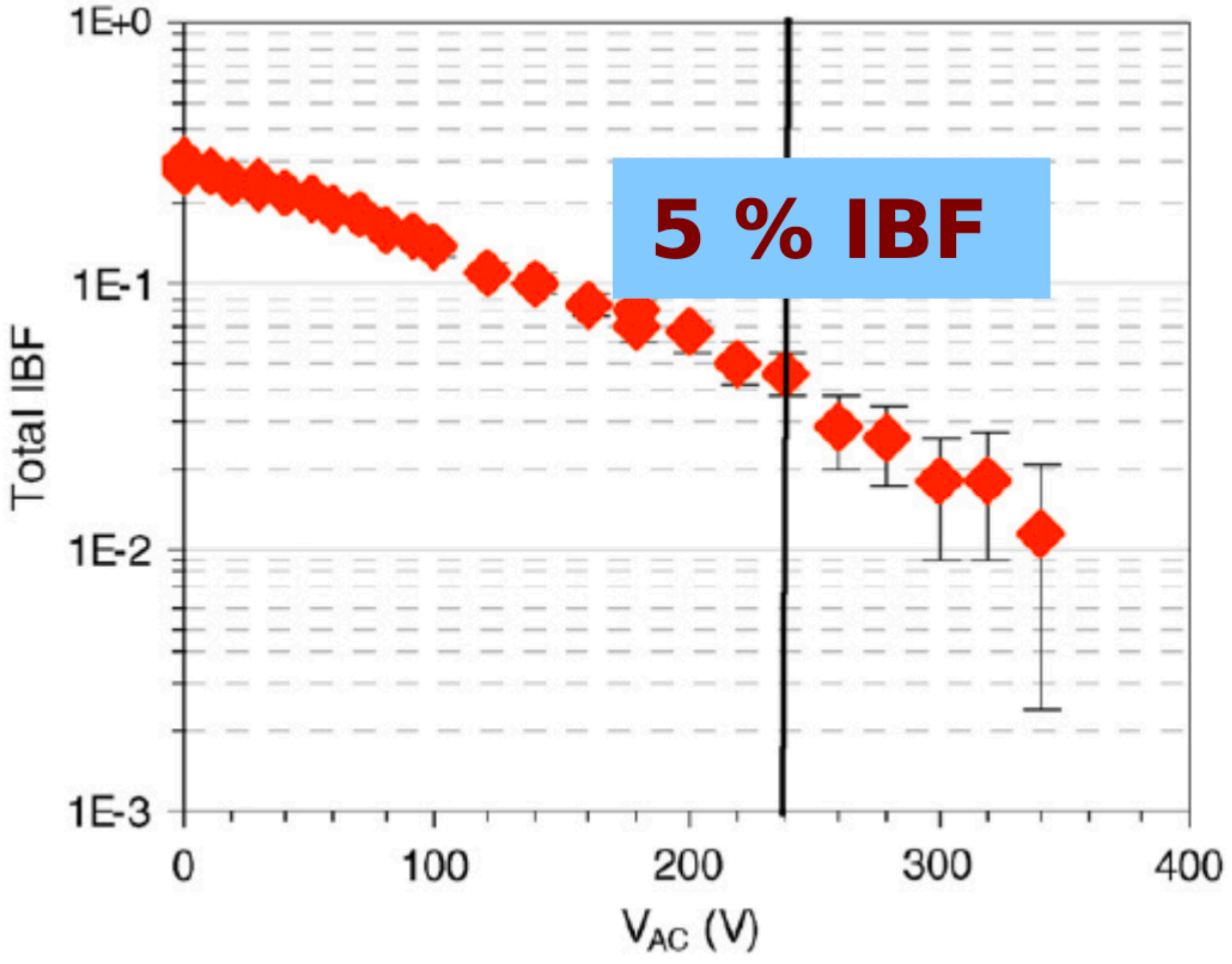
Anode and cathode strips on one surface of THGEM can be used to create electric field lines **trapping back flowing ions**

At full photoelectron detection efficiency, ion back flow is suppressed by about a factor of 6 compared to conventional THGEM cascade detectors.







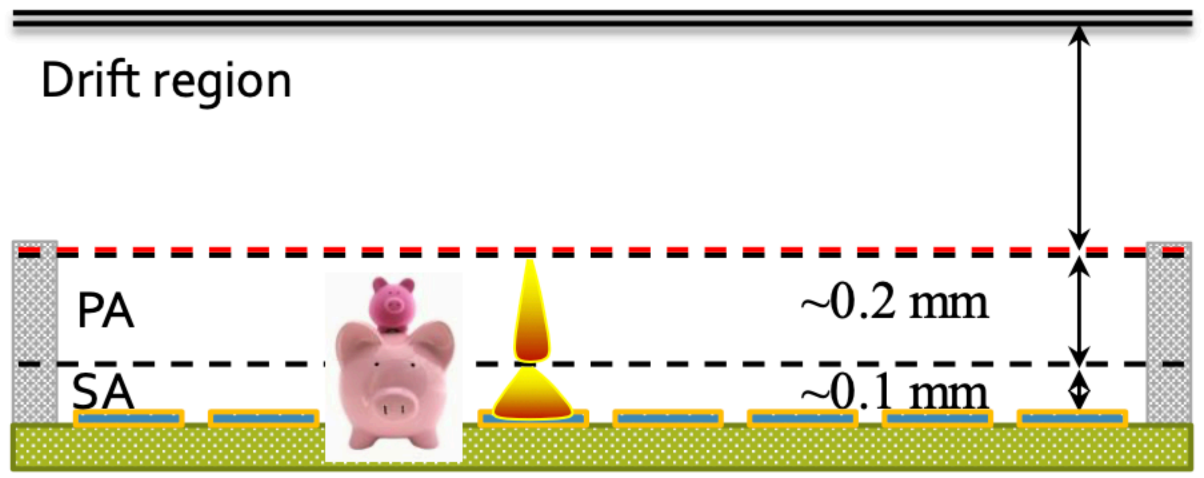


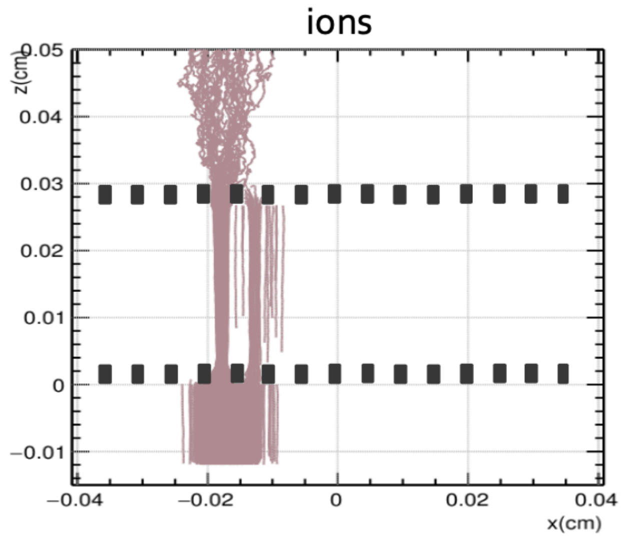
Veloso et al. NIMA 639(2011)134

Ion backflow suppression structures

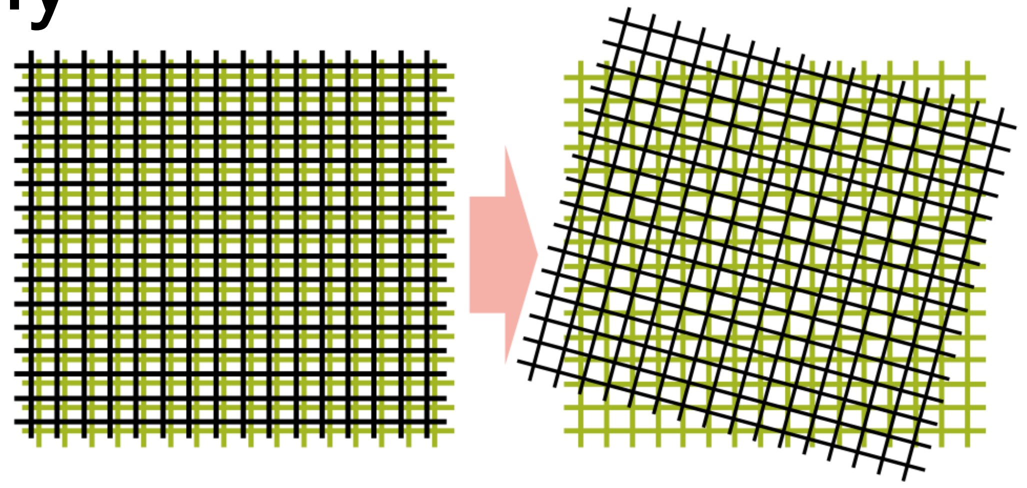
Double Mesh Micromeges
Stacking two meshes with thermal bonding technique

Achieving high gain of up to 10^6 for single primary electrons

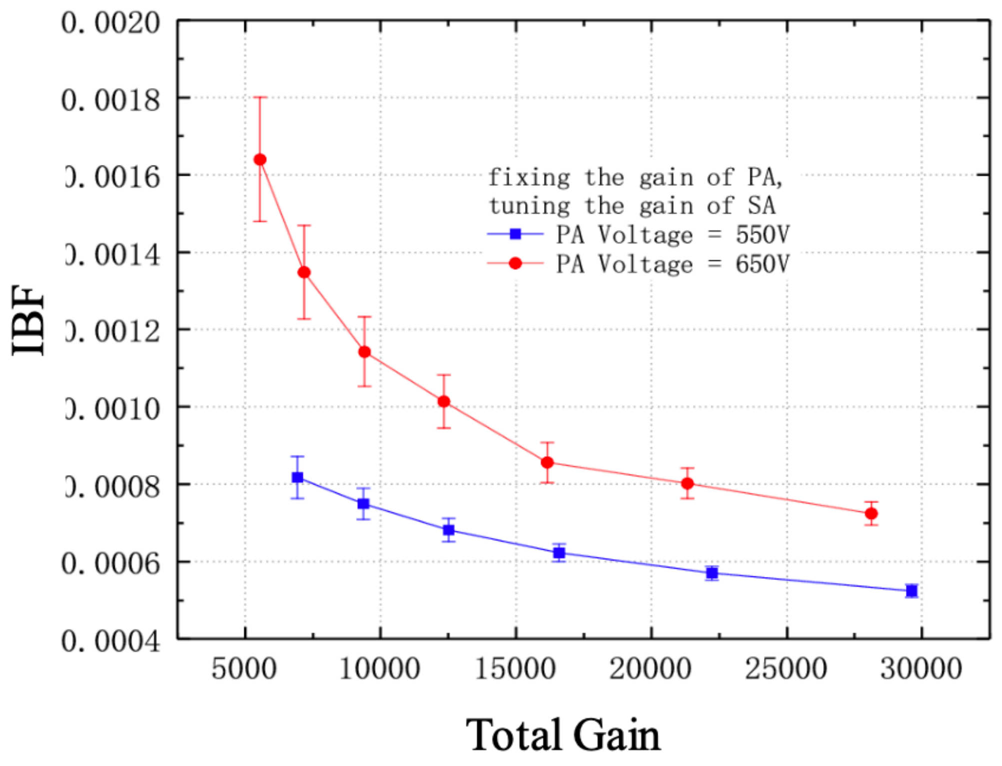


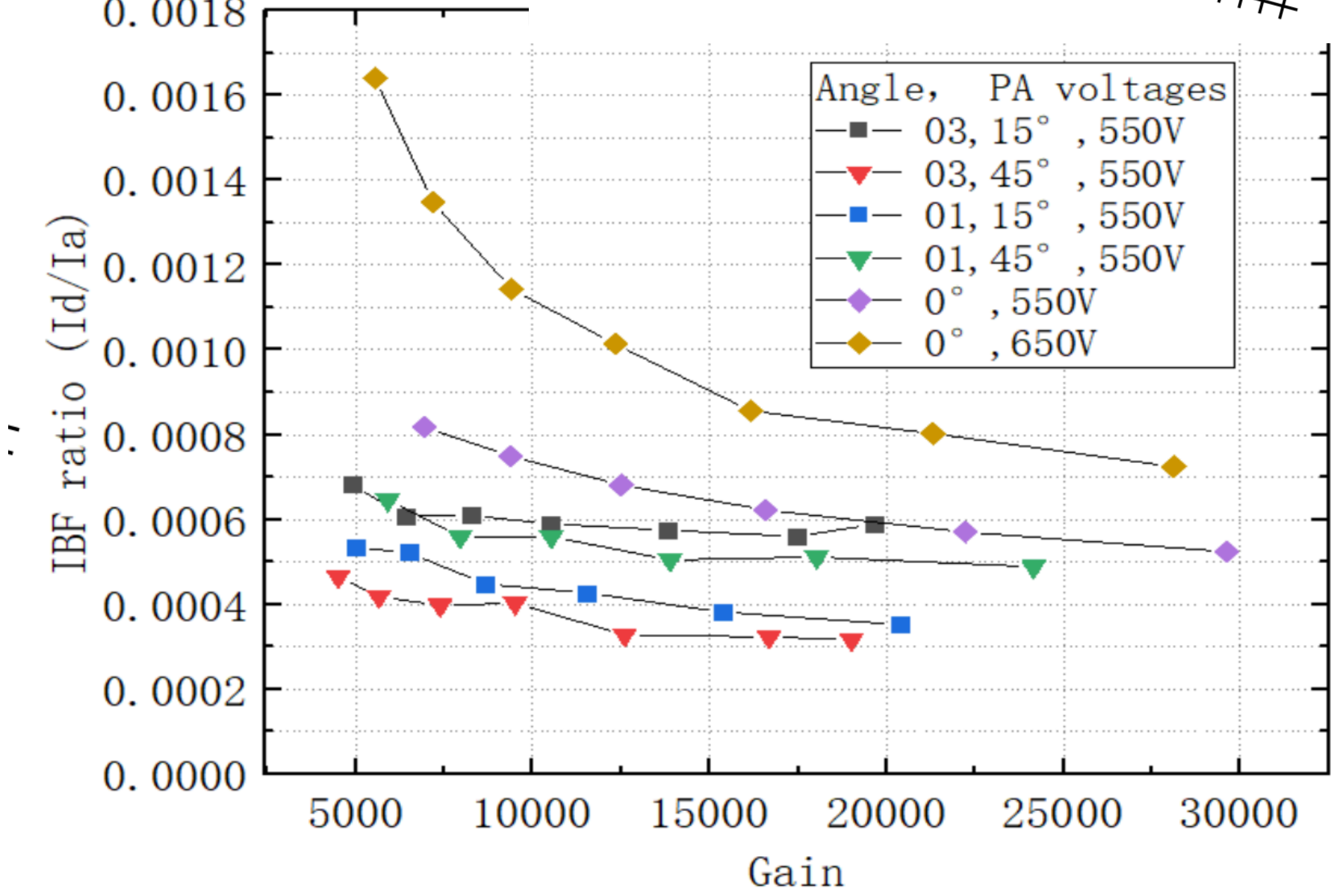


Tilting meshes relatively for improved IBF suppression



- Very low Ion-backflow ratio ~ 0.0004 obtained - high field ratio is helpful to suppress the IBF



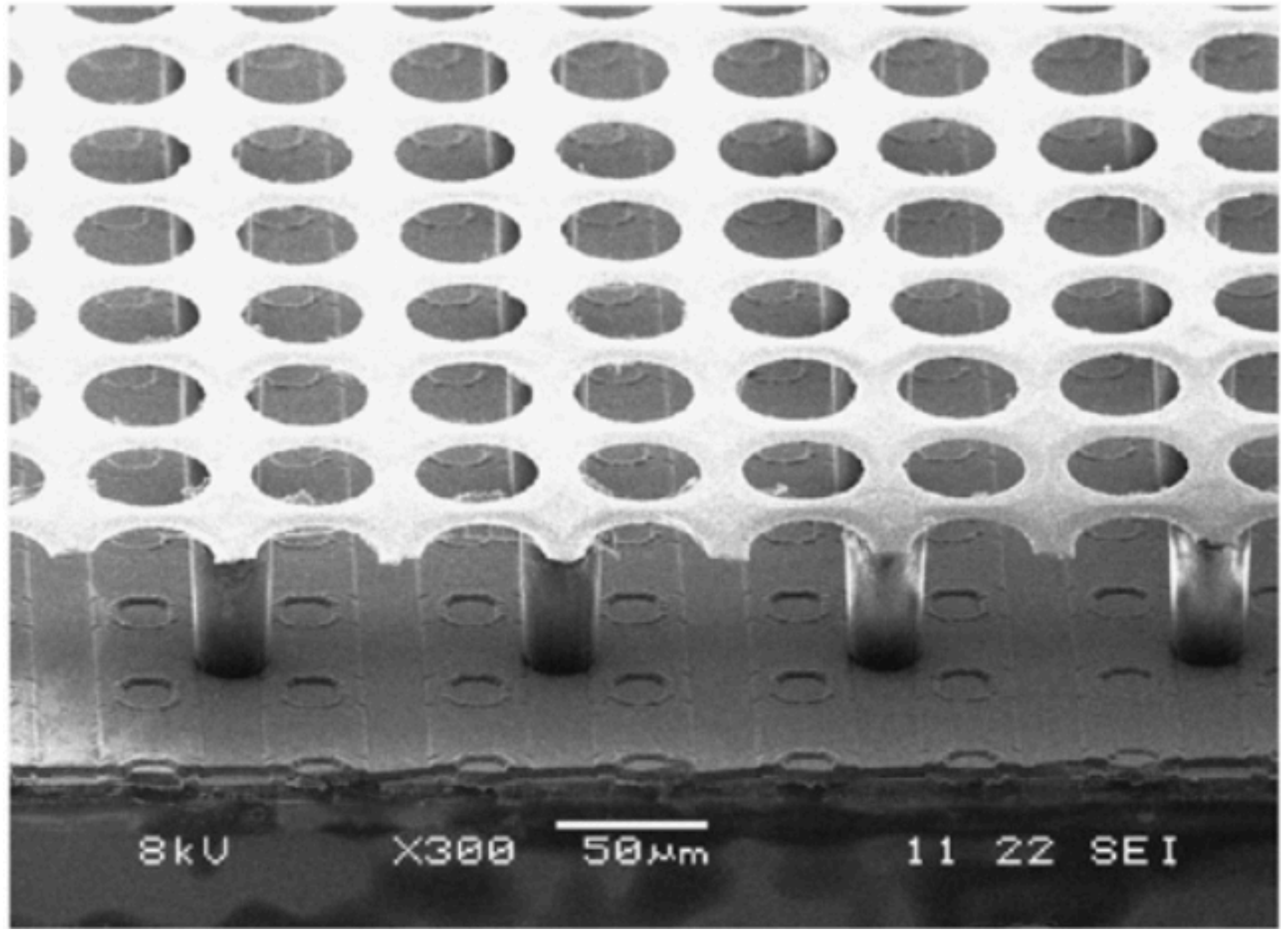


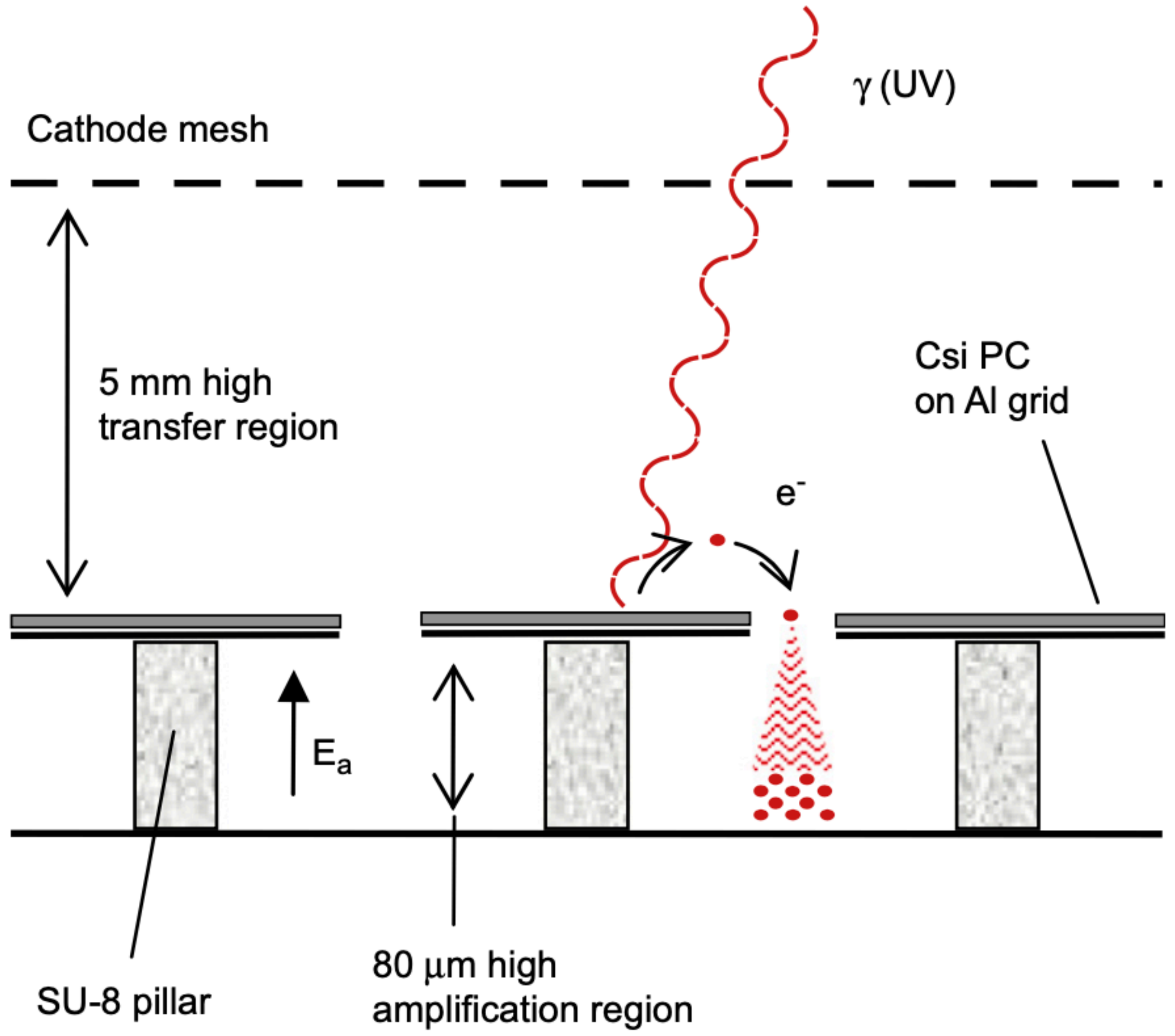
Ming SHAO et al. RICH2018

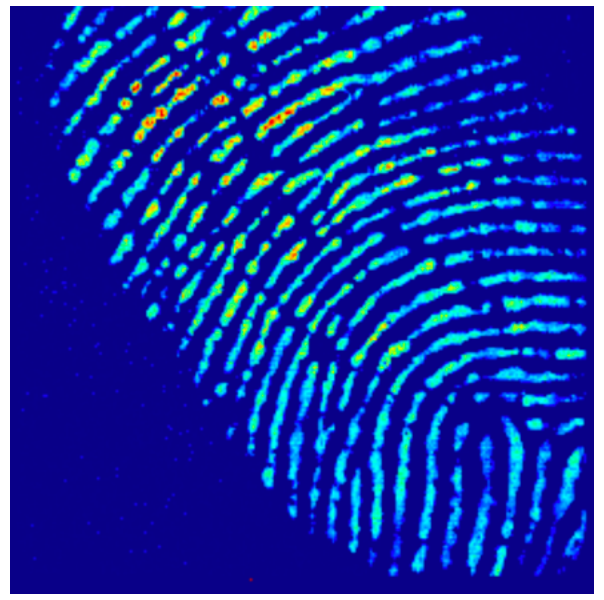
Micromegas/Ingrid photon detector

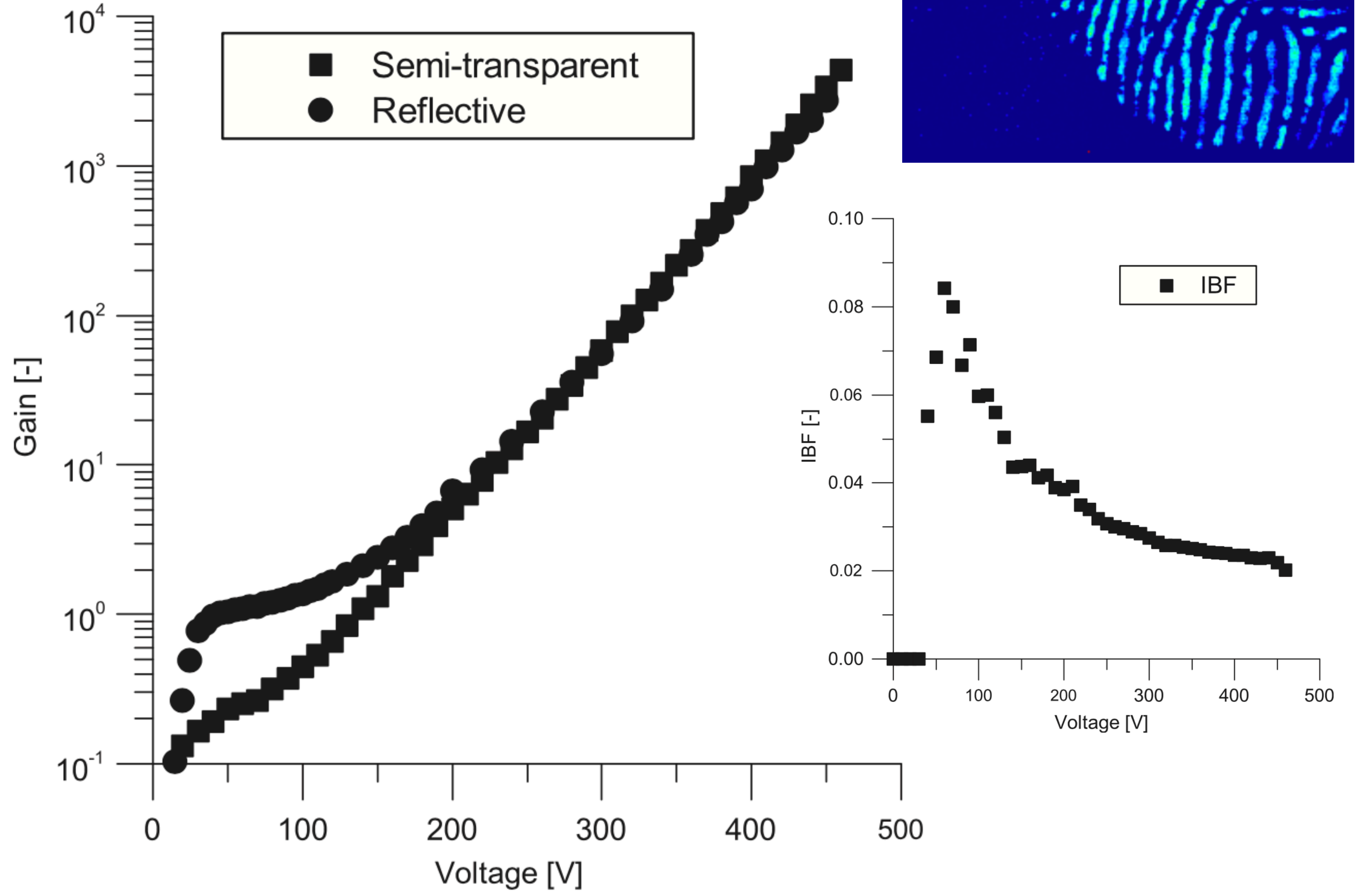
Micromegas amplifications stage directly integrated on **Timepix ASIC**
Added photosensitivity by either semi-transparent photocathode or reflective photocathode direction coated on Al grid

Very good position resolution (≈25μm) and good IBF suppression
Very well coupled to (integrated) readout electronics
Limited by size of pixels and integration procedure







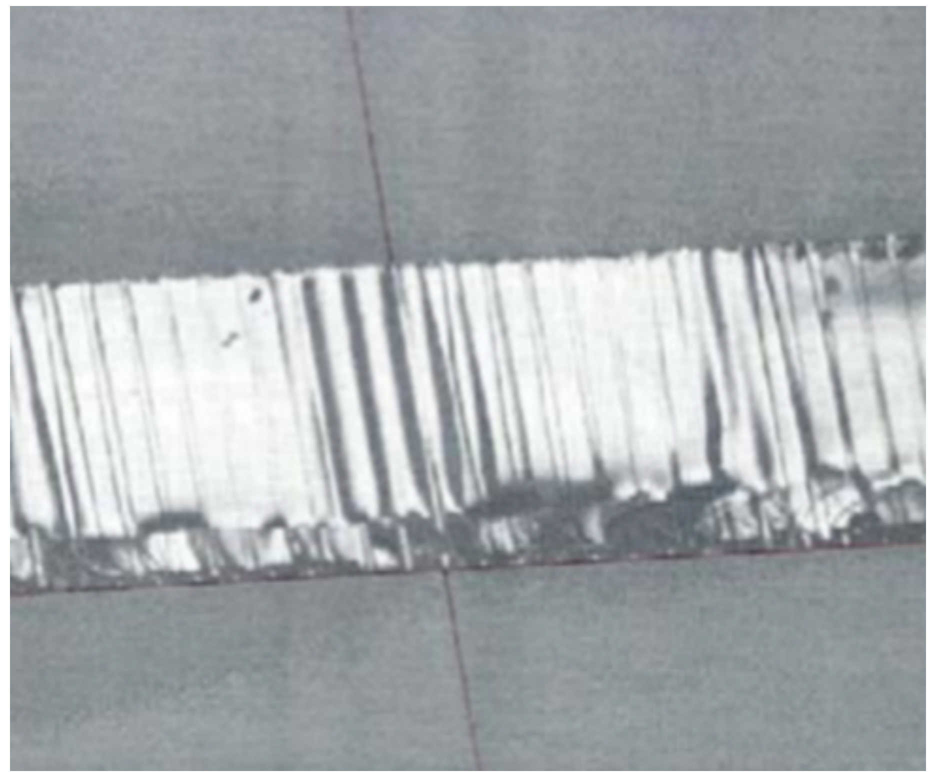


J. Melai et al. / Nuclear Instruments and Methods in Physics Research A 633 (2011) S194–S197

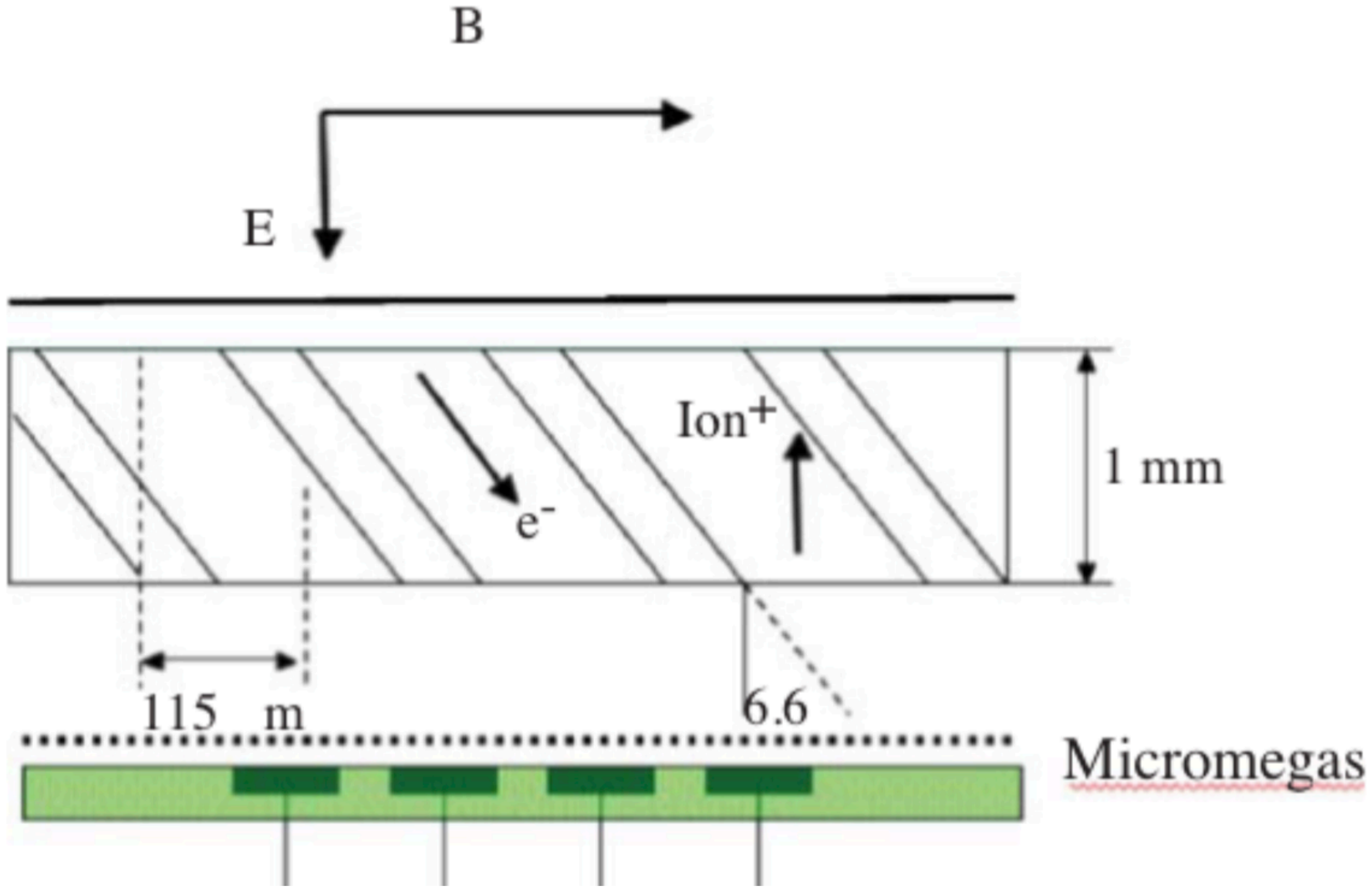
IBF suppression with inclined MCP holes

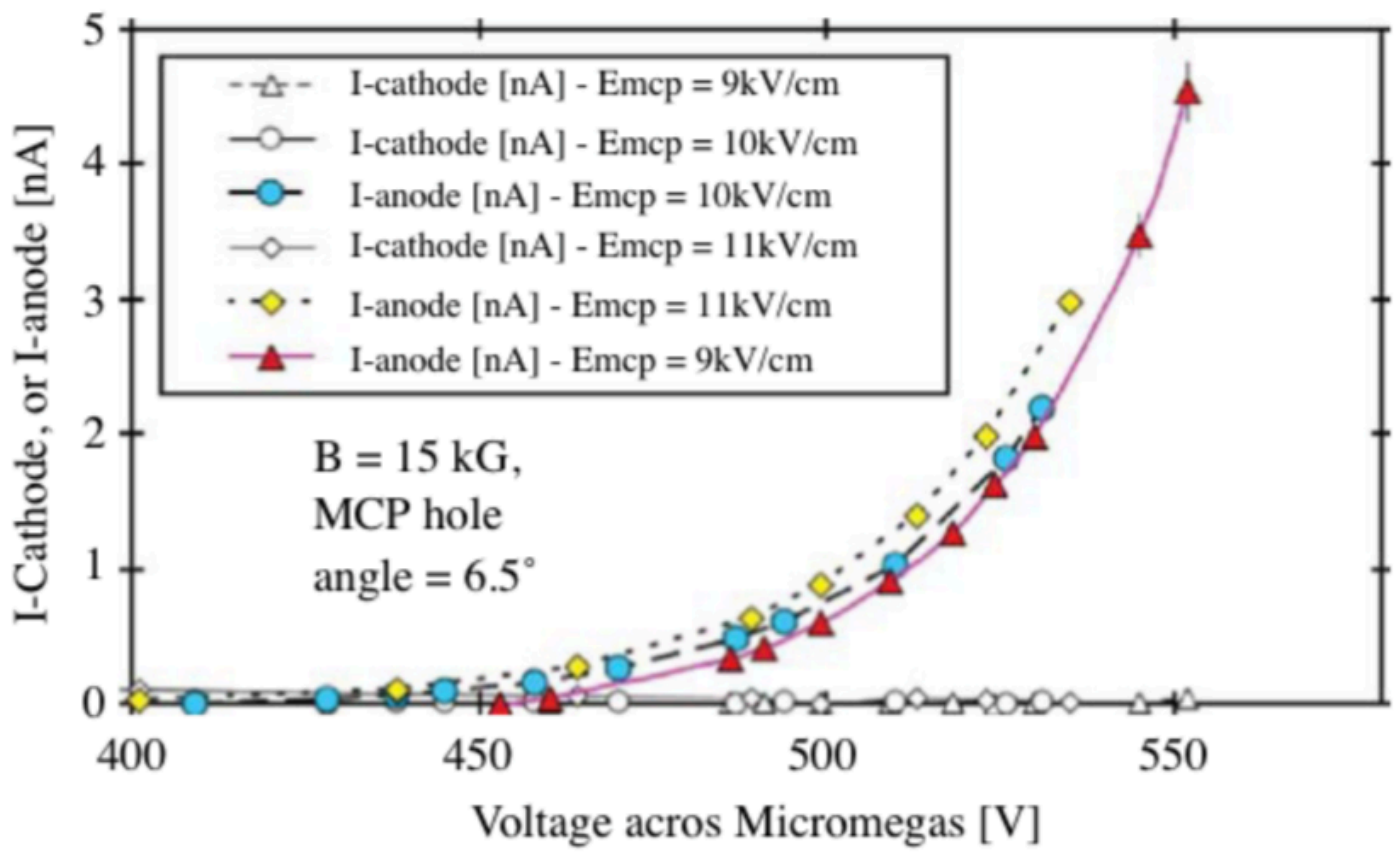
Inclined microchannels can be used to suppress ion back flow. MCP holes are aligned with **Lorentz angle** of electrons, while ions are blocked as they follow a different path.

Can be operated at low gain on top of amplification stage such as Micromegas. **Negligible ion back flow** current has been observed, no significant charging up measured.



Hamamatsu MCP with inclined holes





J. Va'vra, T. Sumiyoshi, Nucl. Instr. and Meth. A 553 (2005) 76

Gaseous photon detector applications

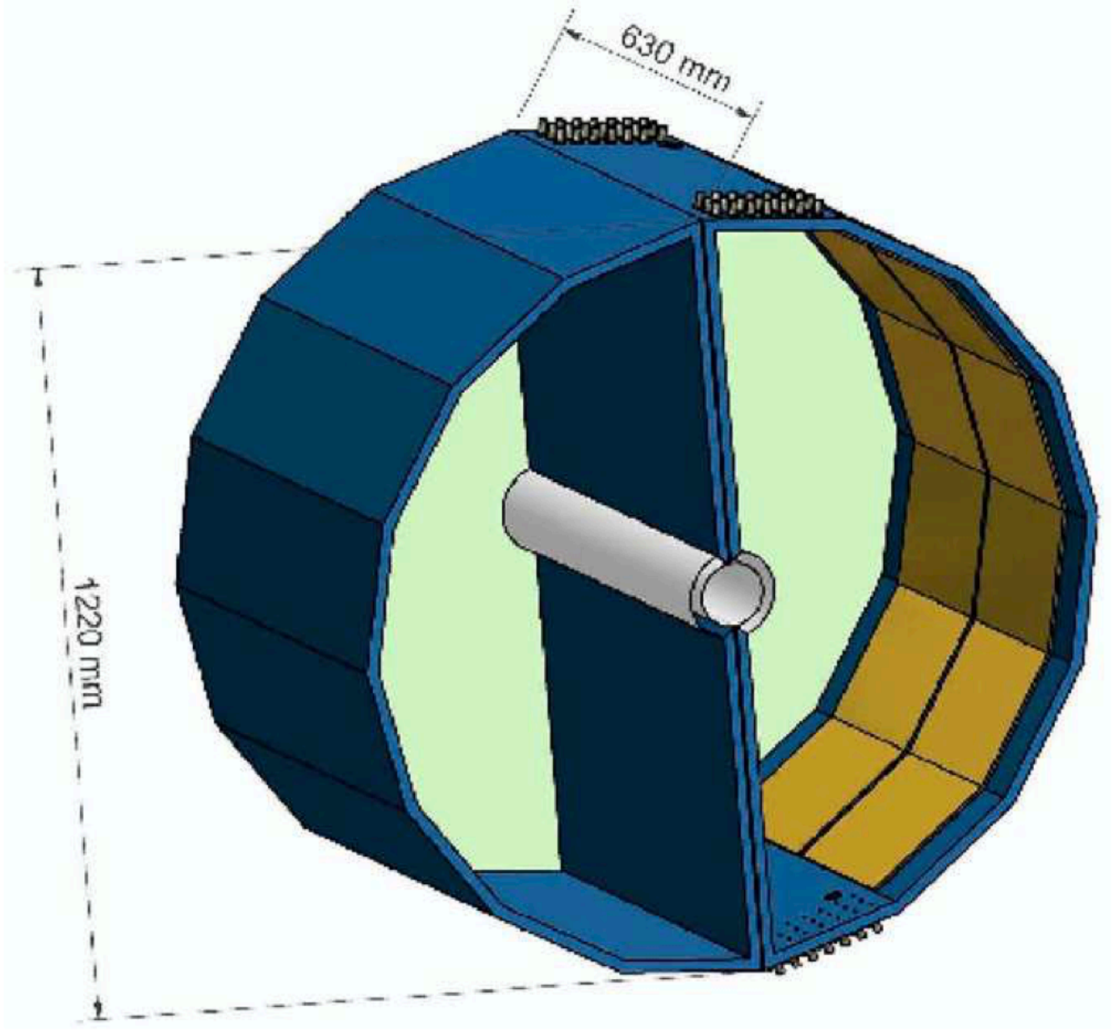
Gaseous photon detectors

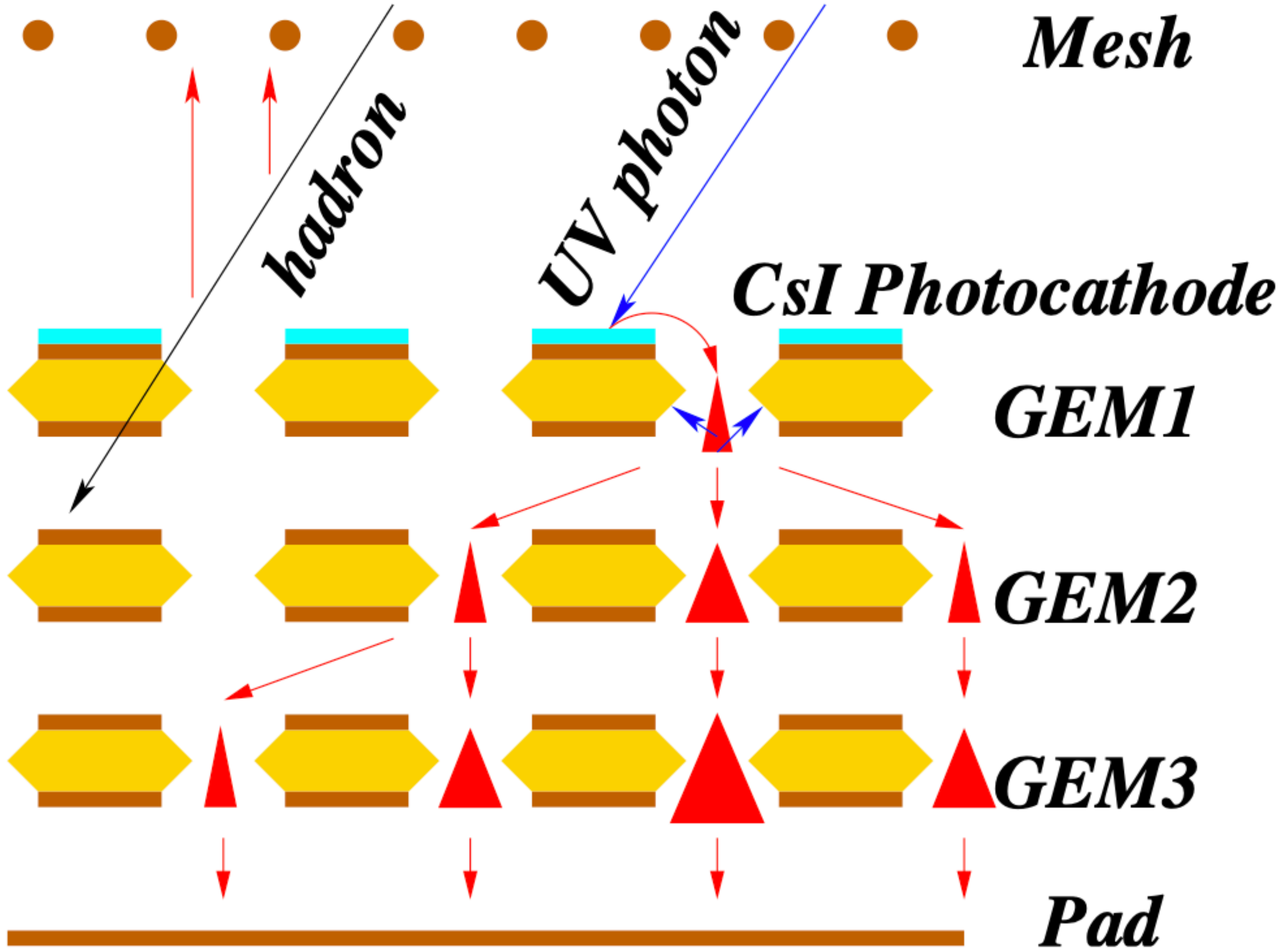
Hadron-Blind detector (HBD) at RHIC-PHENIX

Triple GEM multiplications stage to operate at gain ≈10^4

Insensitive to direct ionisation by hadrons due to reverse bias in drift region

UV photon detector with reflective CsI photocathode coated on top of first GEM





https://arxiv.org/pdf/nucl-ex/0609014.pdf
Anderson et al., NIMA 546 (2005) 466.

COMPASS RICH 1

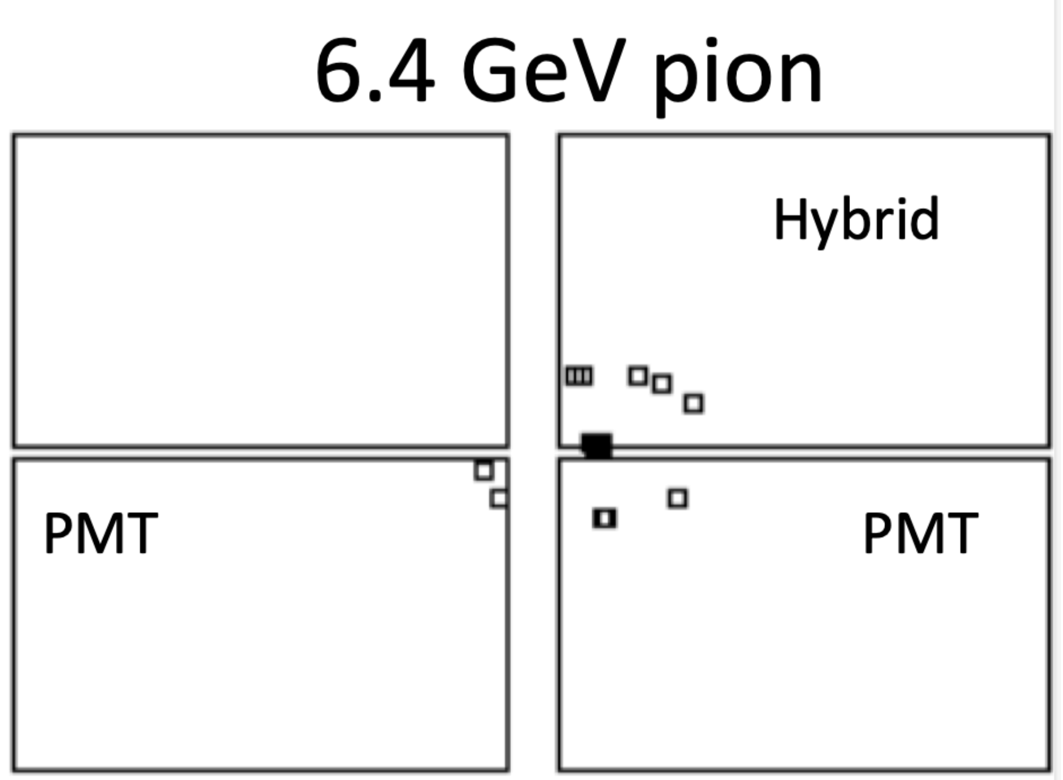
COMPASS RICH-1 requires efficient RICH for pbar cross-section, spectroscopy measurements - hadron PID from 3 to 60 GeV/c

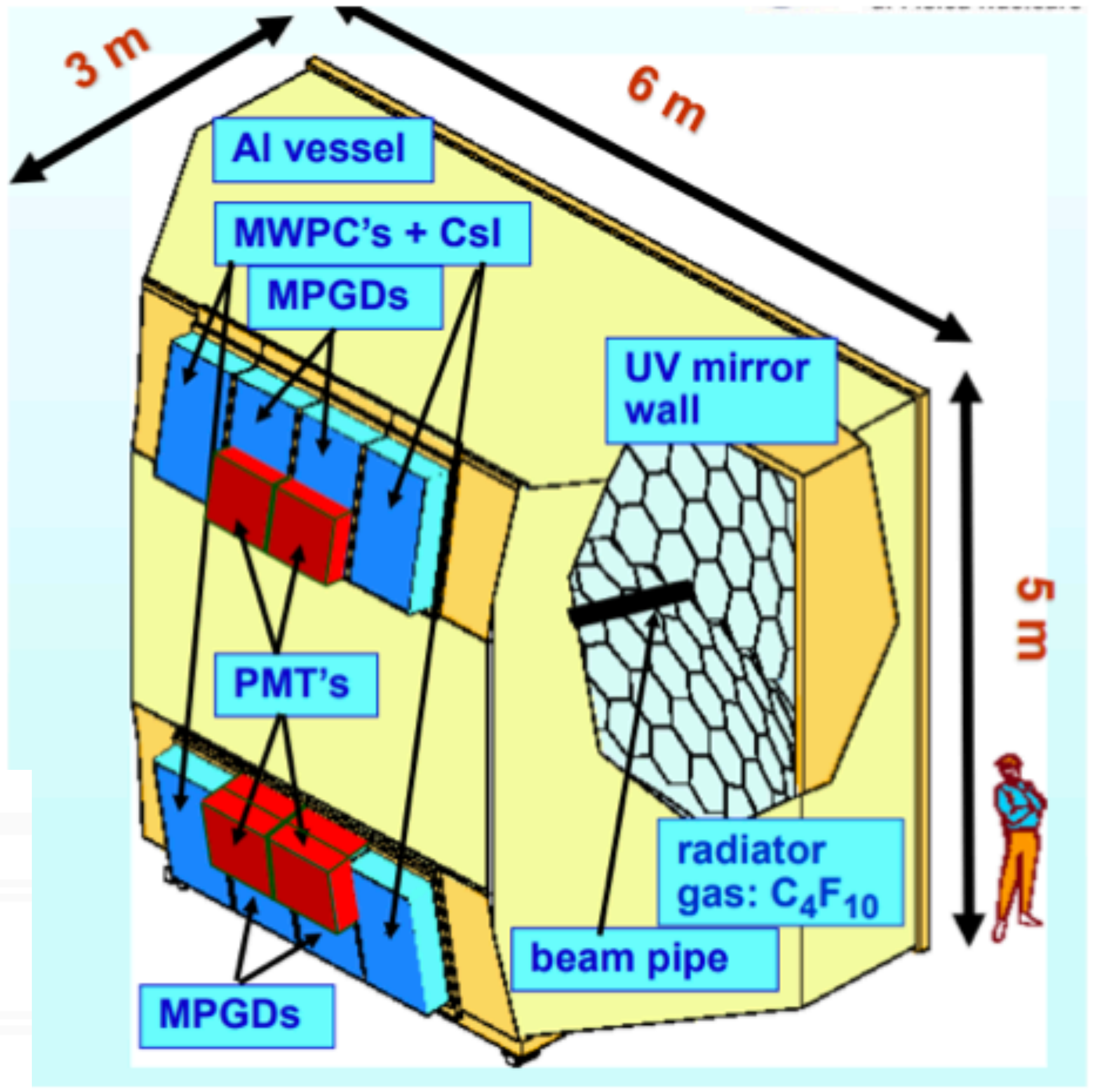
Long running RICH based on different (gaseous) photon detectors: MWPC, PMT, MPGD

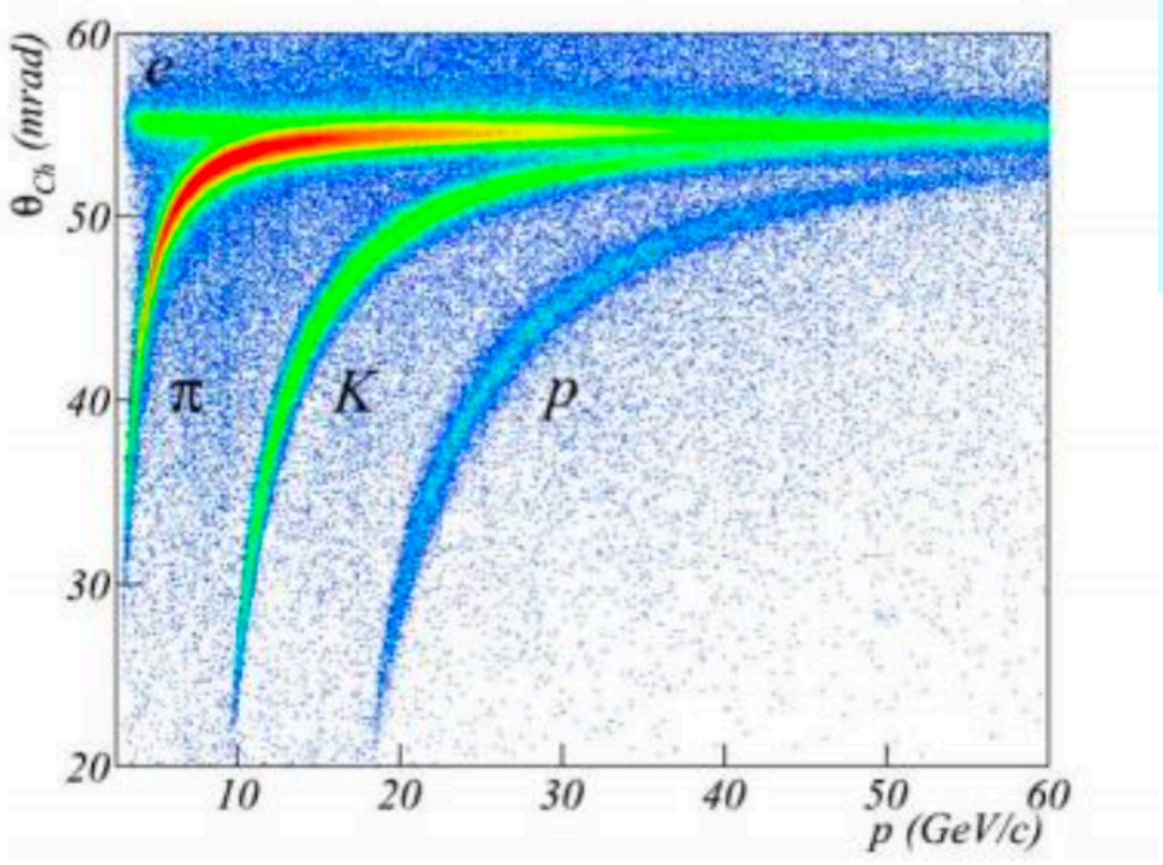
In operation since 2002, upgraded in 2006

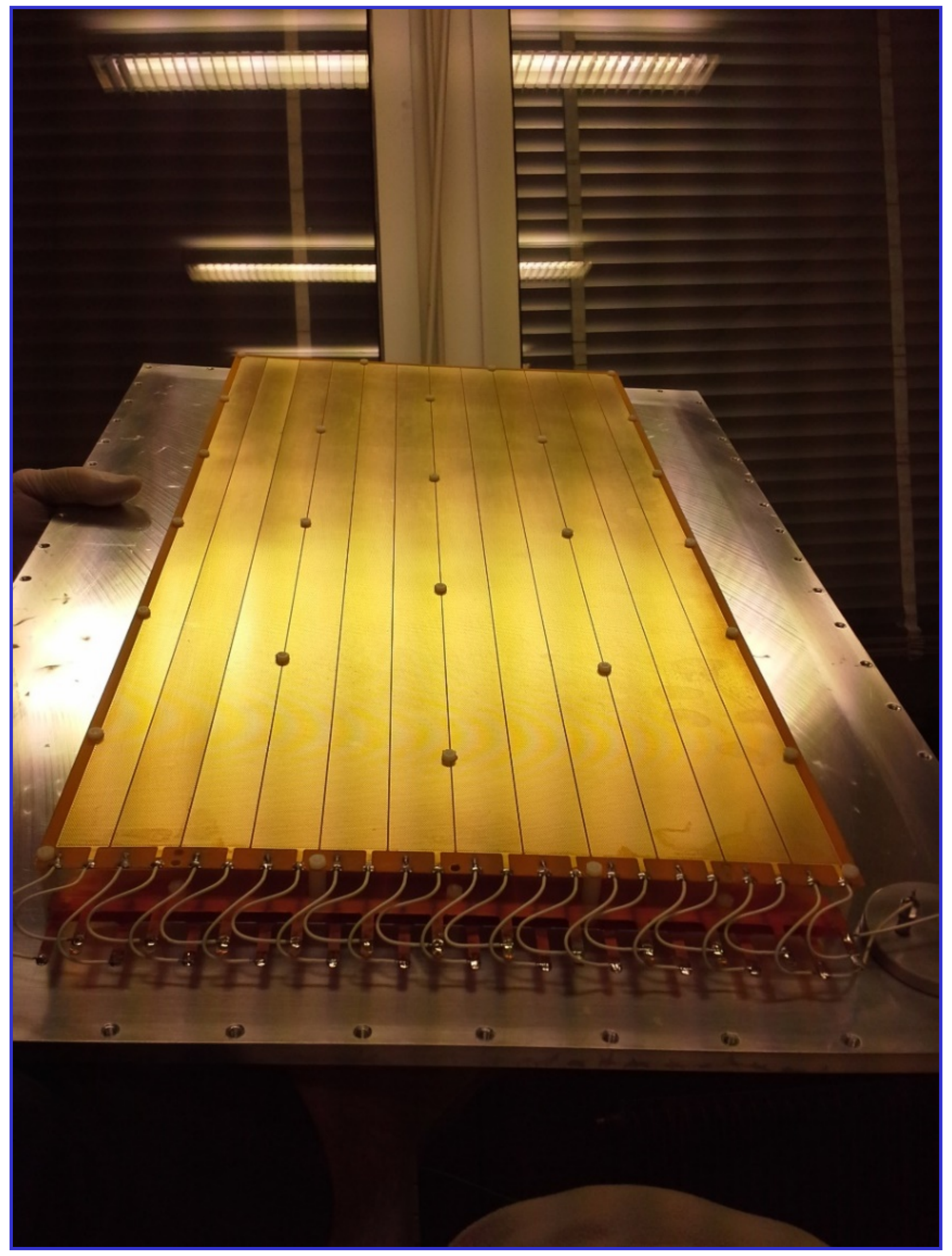
Hybrid PDs are working at an effective gain of 14k, with a level of 5% stability.
IBF < 3% is achieved by combining **MM and 2 THGEM** layers.

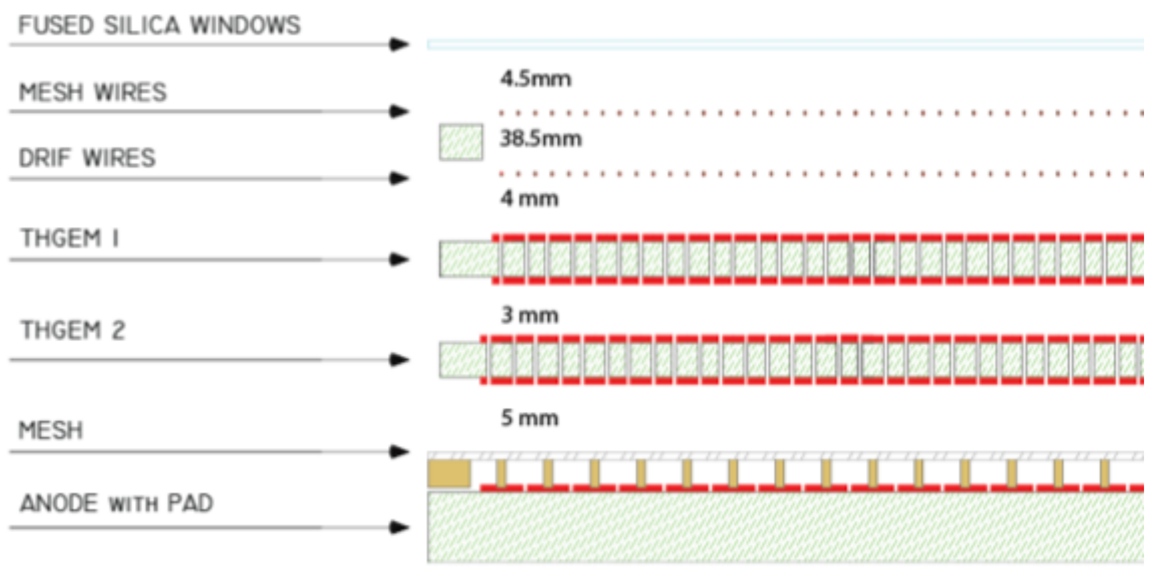
In best working condition the detector can detect up to ~11 signal photons per ring.
Trigger rates up to 50 kHz, 1.2% X0 in beam region







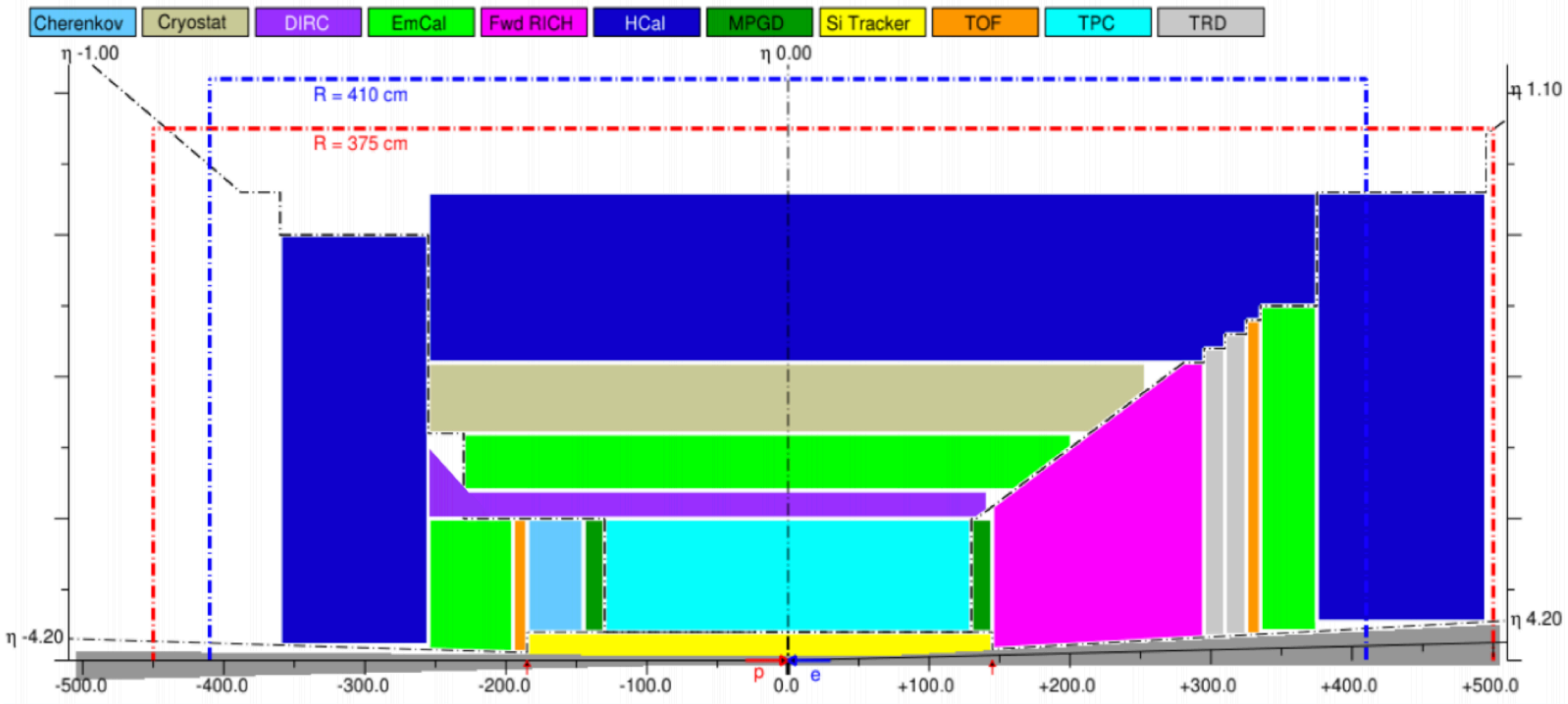




Chatterjee.C RD51 Workshop Gaseous Detector contributions to PID, https://indico.cern.ch/event/996326/contributions/4200958/attachments/2191009/3703183/RD51_PIDWS_16022021_Chatterjee.pdf

Windowless RICH for EIC

Future EIC requires **high momentum hadron identification**, which can be accomplished with optimised RICH counter with gas radiator which can operate in presence of **magnetic field**



A.Accardi et al., "Electron Ion Collider: The Next QCD Frontier," Eur. Phys. J., vol. A52, no. 9, p. 268, 2016.
National Academies of Sciences, Engineering, and Medicine, "An Assessment of U.S.- Based Electron-Ion Collider Science." The National Academies Press, Washington DC, 2018. https://doi.org/10.17226/25171.

Limited number of photons due to **shorter radiator length** in compact design

Windowless RICH gaseous detector could be option to extend sensitive region to far UV range around 120 nm

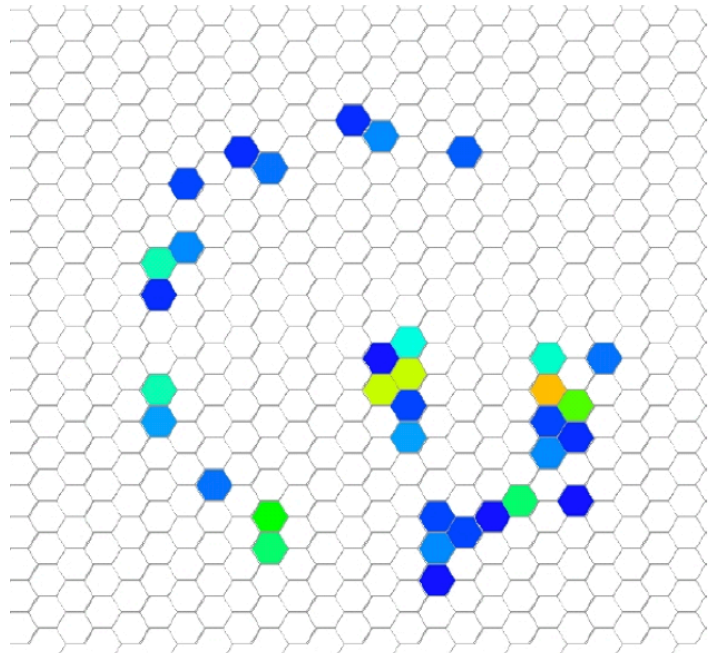
Requirement of efficient and robust VUV photocathodes

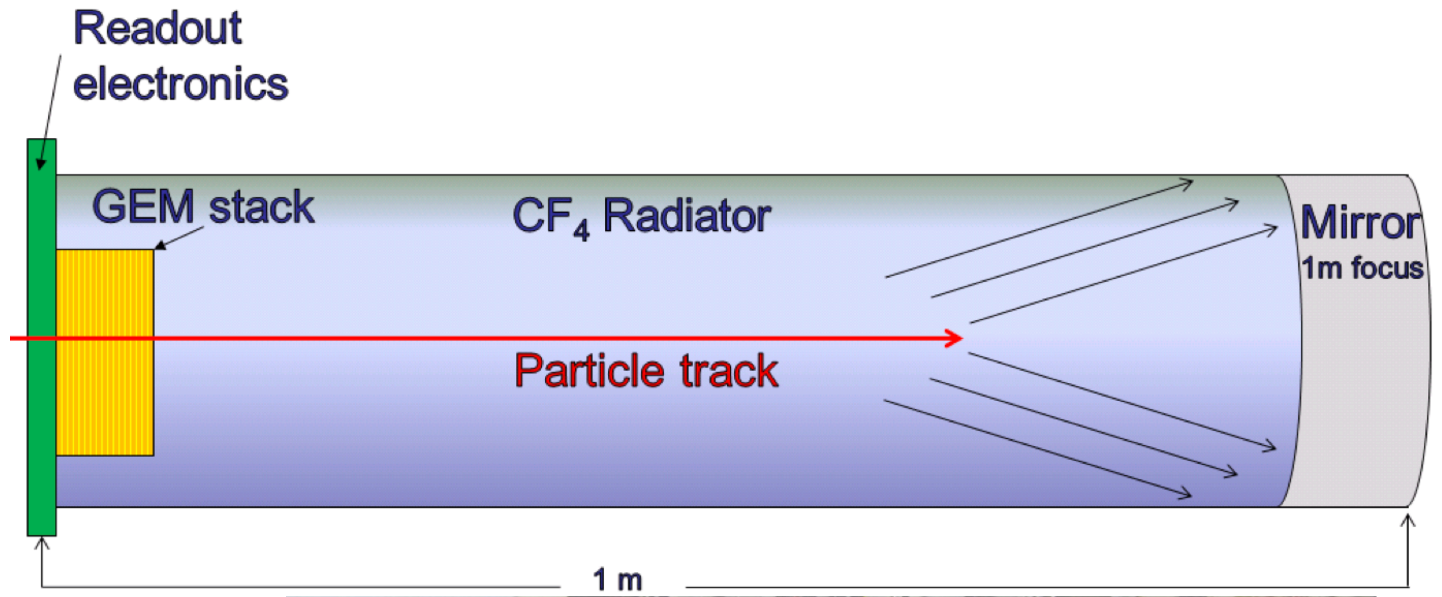
Windowless Quintuple-GEM Based RICH for EIC

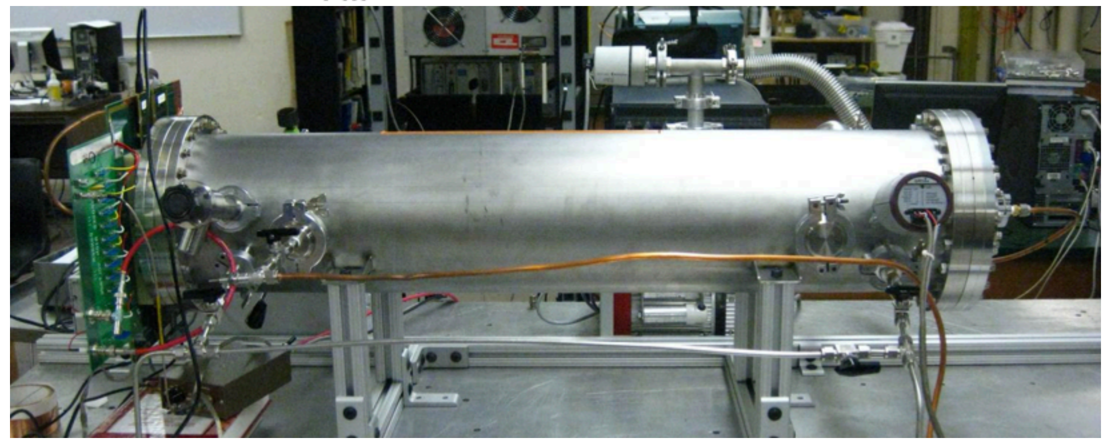
Both Cherenkov light yield is highest for low wavelengths and UV-sensitive materials typically have higher efficiency at low wavelengths -> pursue low wavelength sensitivity to maximise available photons

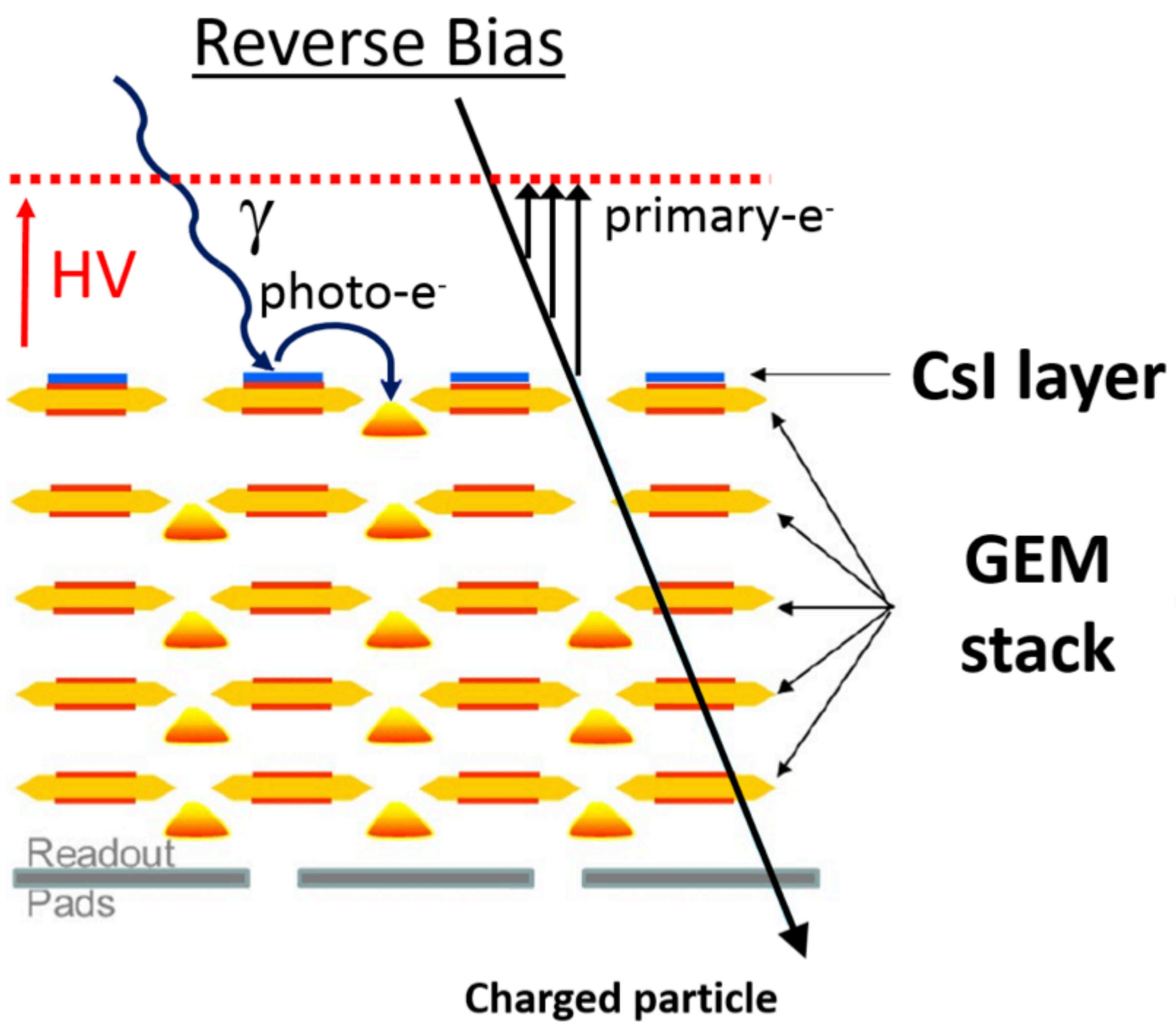
Implemented for maximised VUV photon sensitivity

- Windowless photocathode
- VUV high reflective mirror coating
- Quintuple GEM photo-detector



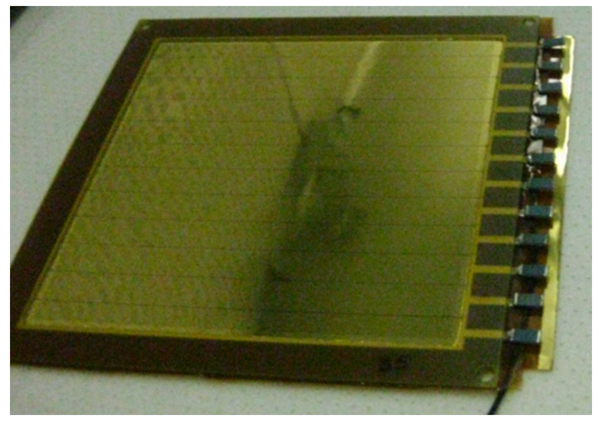




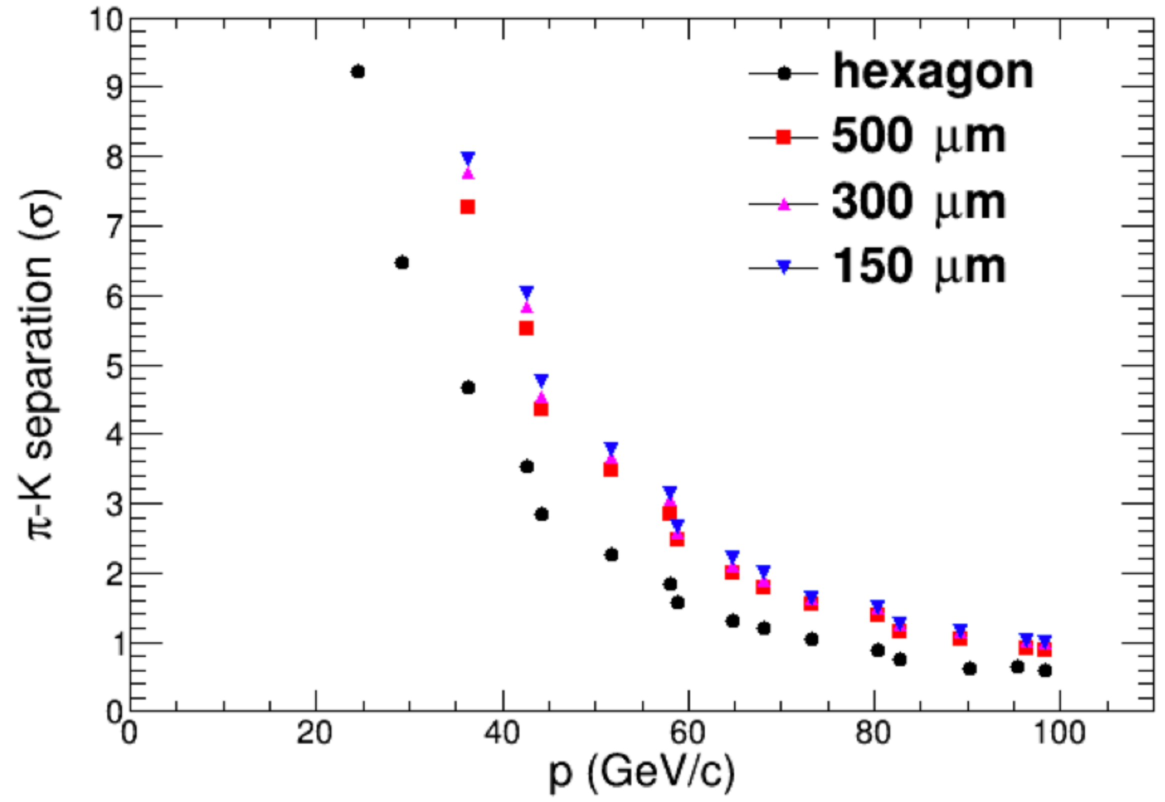


5 GEMs for possibility to operate **photosensitive GEM at gain ≈1** and still have 4 GEMs available to achieve high gain for single photon sensitivity

Also **shield photocathode** better from light emitted during avalanche and reflected on mirror



Improved separation power with increased readout granularity

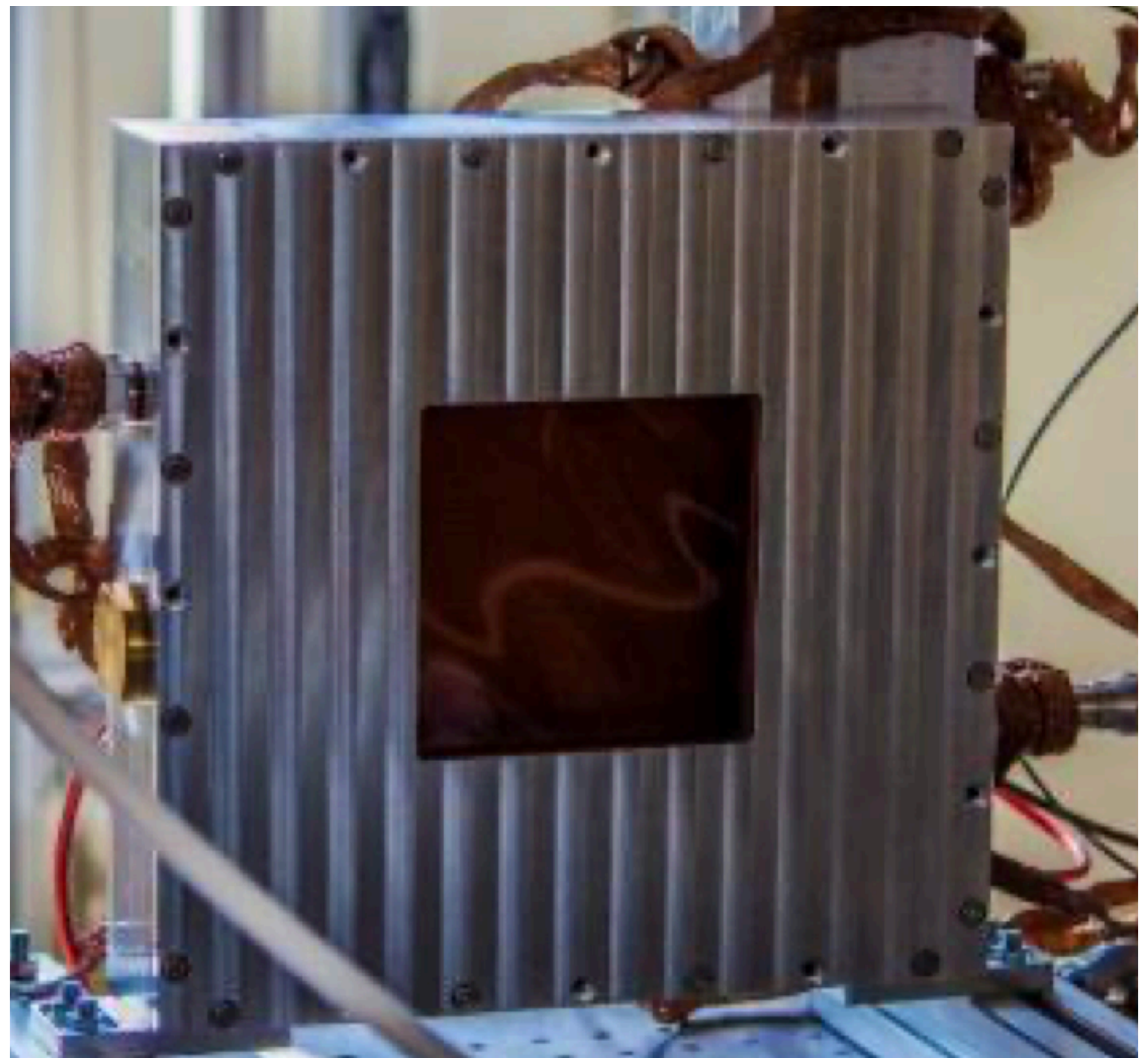


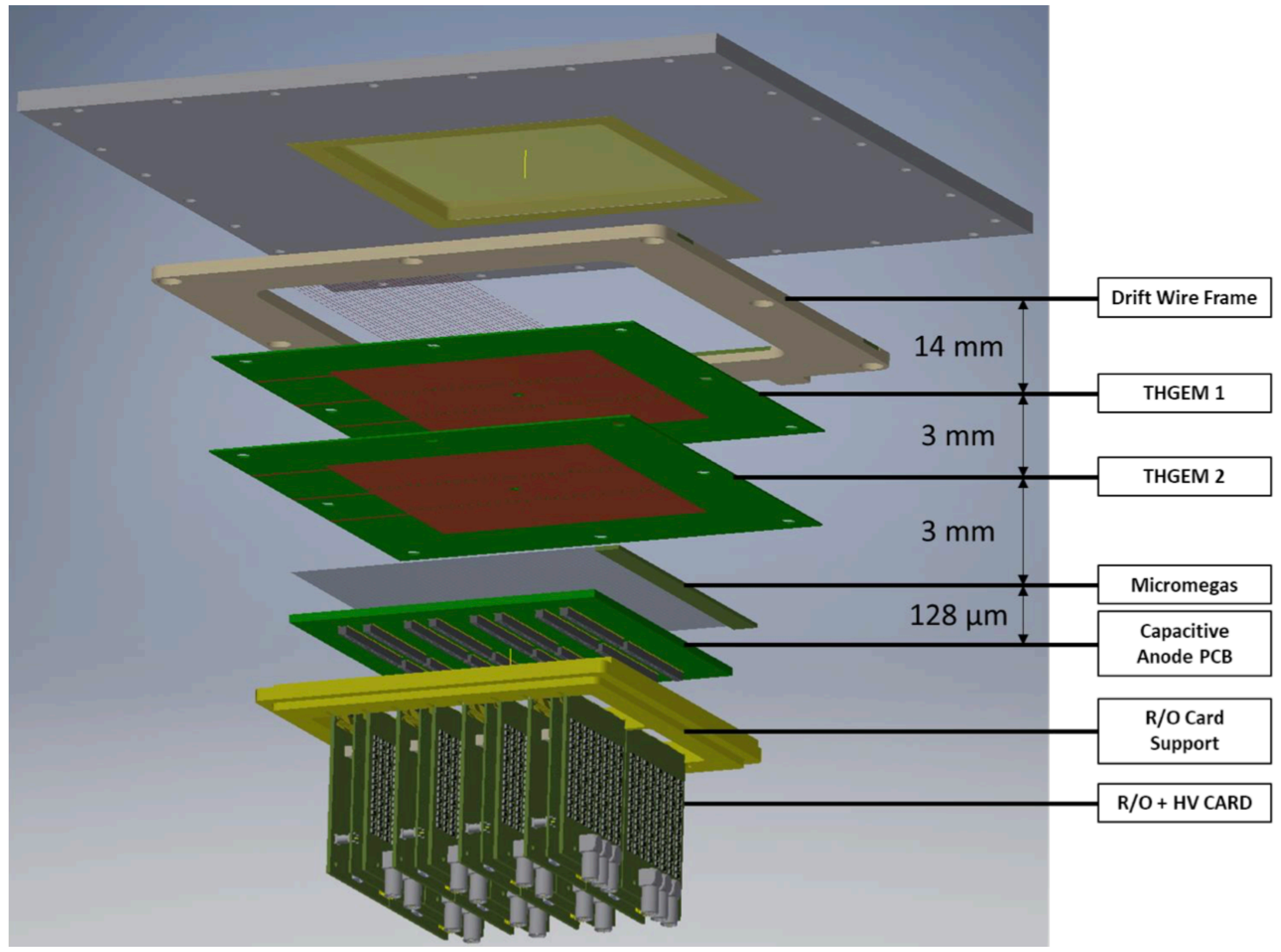
arXiv:1501.03530v3 [physics.ins-det] 27 Jun 2016
https://arxiv.org/pdf/1501.03530.pdf

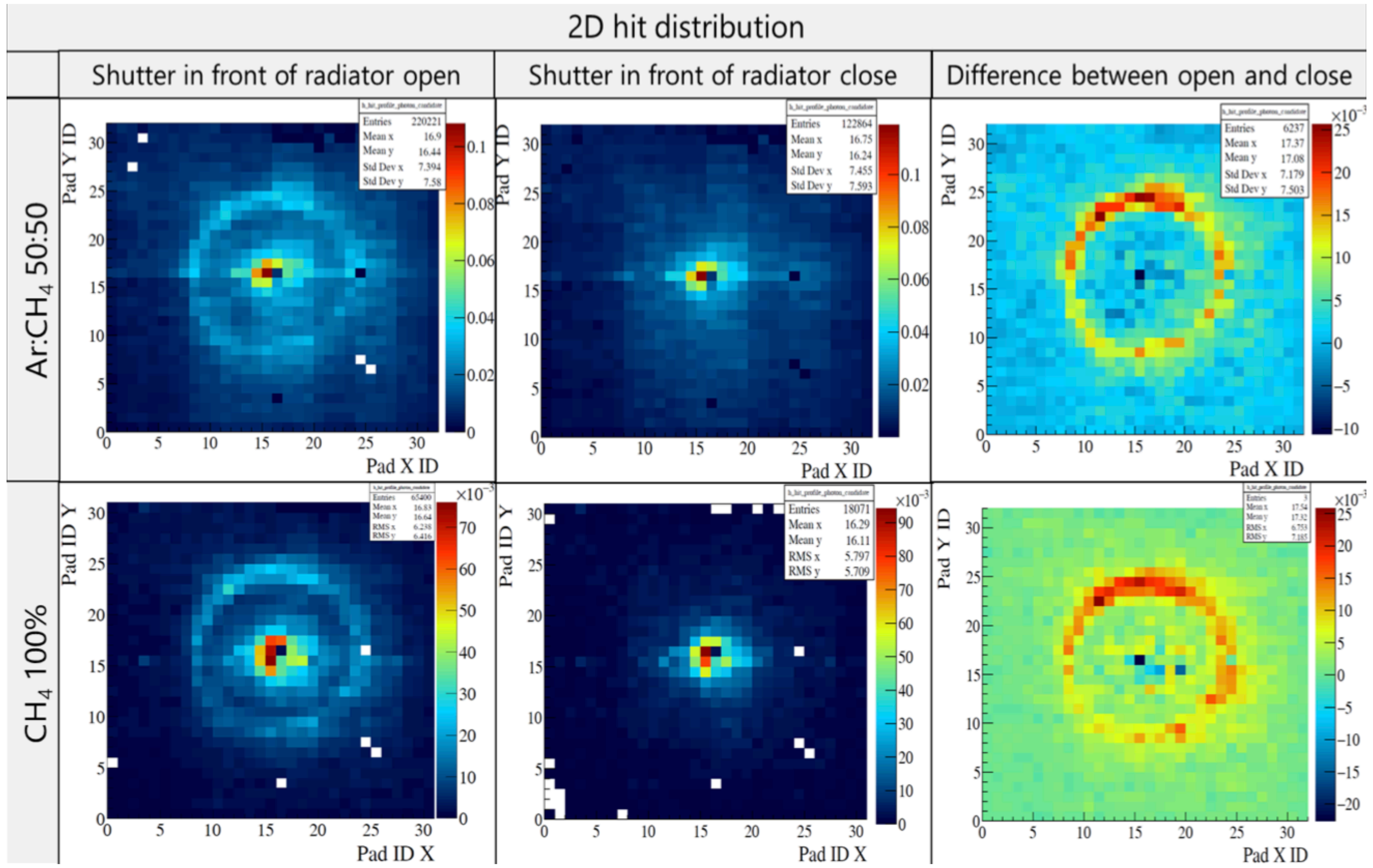
Minipad hybrid photon detector

2 THGEM + Micromegas hybrid detector with **3mm x 3mm minipad** for improved **spatial resolution**

Demonstrator built and operated in beam tests with RD51 SRS readout system in CH4 and Ar/CH4







Chatterjee.C RD51 Workshop Gaseous Detector contributions to PID, https://indico.cern.ch/event/996326/contributions/4200958/attachments/2191009/3703183/RD51_PIDWS_16022021_Chatterjee.pdf

RICH Design for High Intensity Electron Positron Accelerator (HIEPA)

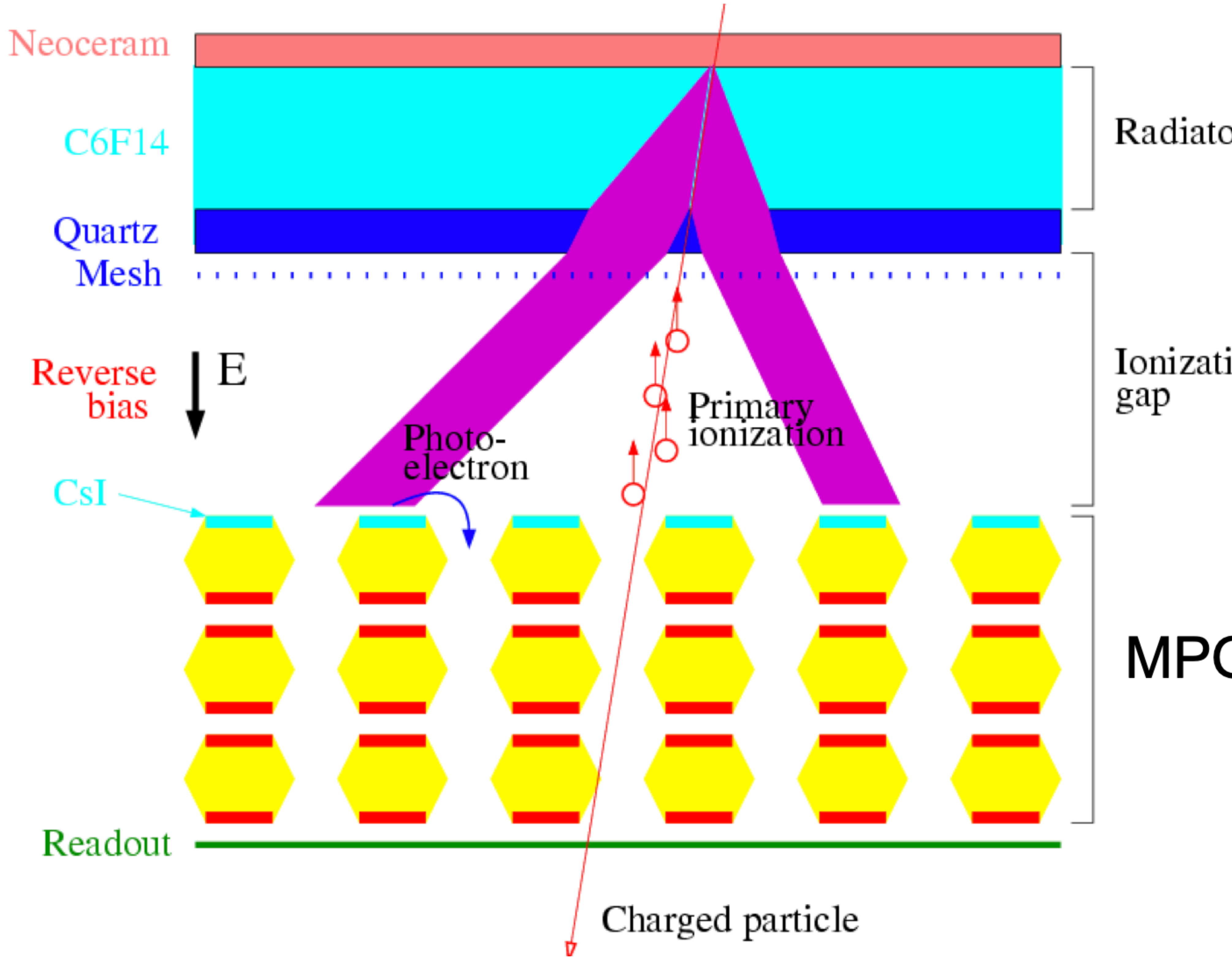
Proximity focusing RICH with CsI-coated MPGD as readout

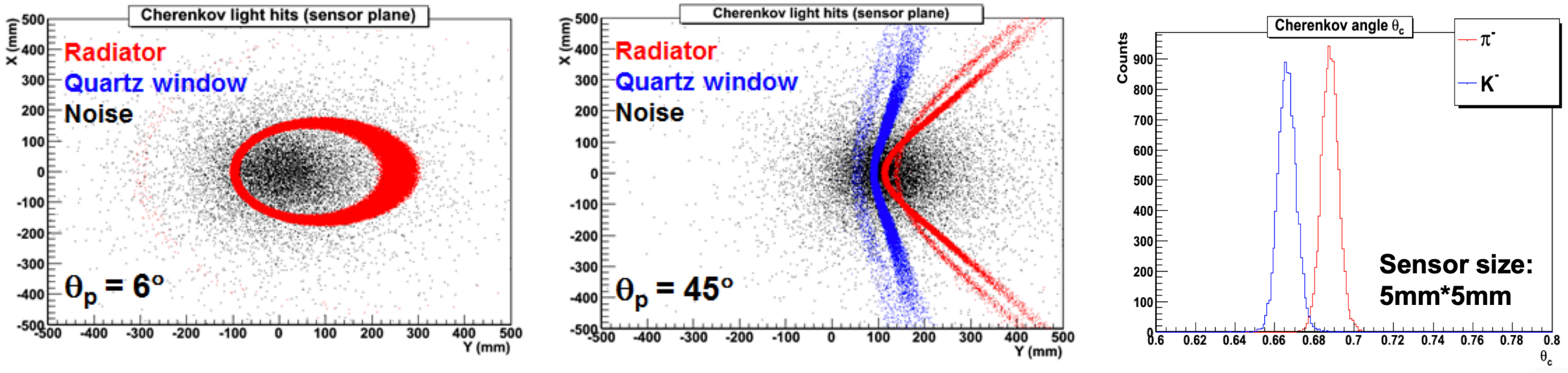
Proximity gap: ~10cm
Radiator: liquid C6F14, n~1.3, UV detection

MPGDs to cope with high-rate capability and radiation hardness requirement

Avoid ion back flow and feedback with multi-stage structure

Different MPGD geometries being studied including double-mesh Micromegas





http://cicpi.ustc.edu.cn/indico/getFile.py/access?contribId=42&sessionId=20&resId=1&materialId=slides&confId=1009

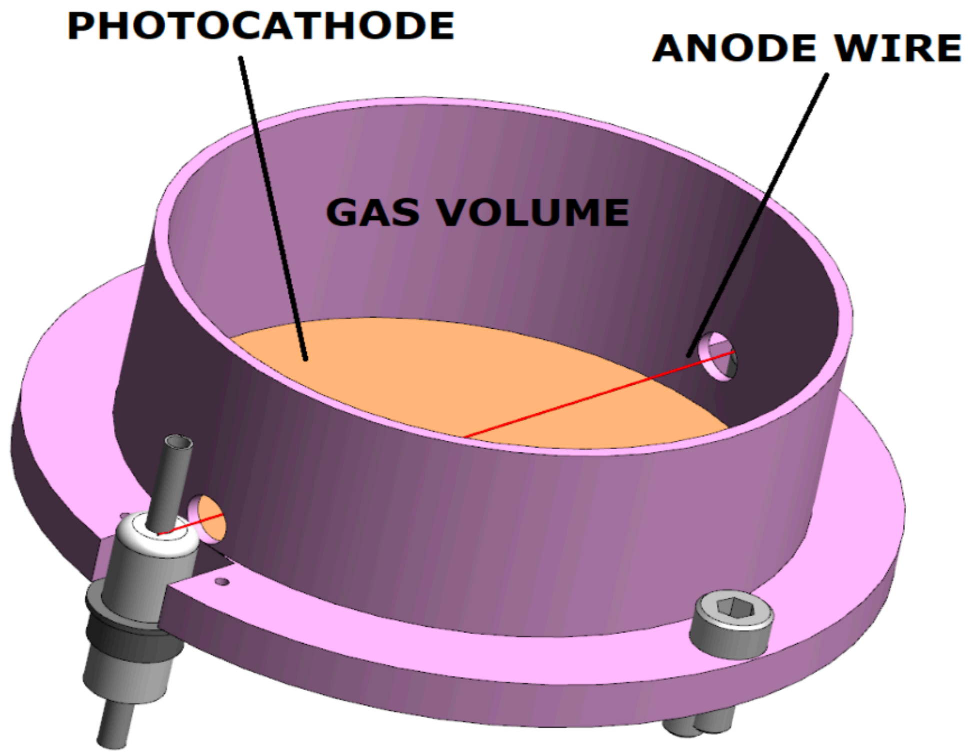
Solar blind flame detector

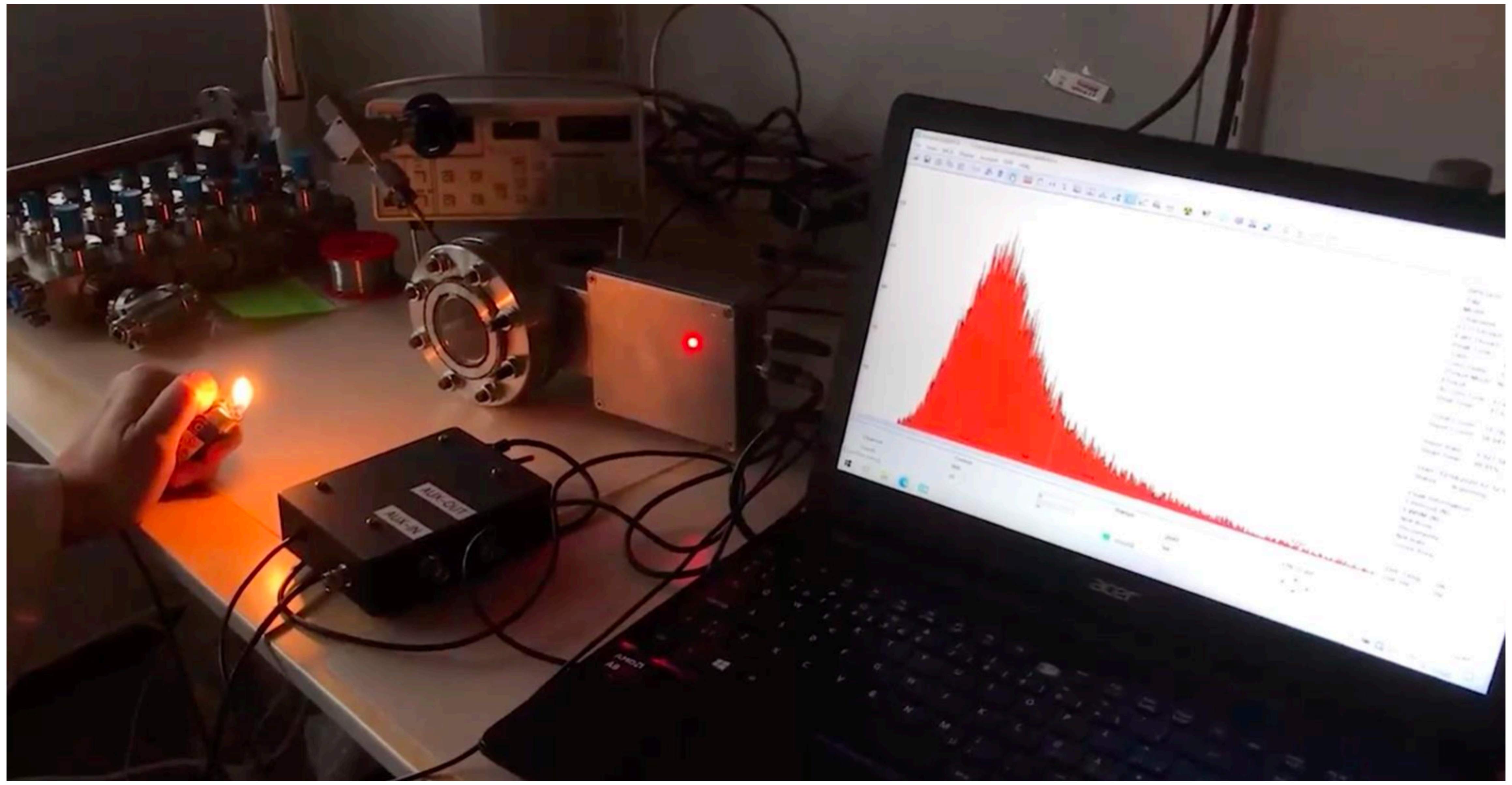
Flame sensor based on single-wire proportional counter with **solar blind photocathode**.

Large photodetector area for sensitivity up to 50m distance to small cancel flame

Started in context of ATTRACT phase 1 project and being pursed by Fenno-Aurum Oy Ltd

Studying applicability of **different photocathodes** incl. CsI, black silicon, DLC, metallic layers for solar blind sensitivity (only sensitive <280nm - UV-C band)





NIEMELA Arto et al, Flame Detector based on a Novel UV Sensor , NDIP Detector Conference 2022

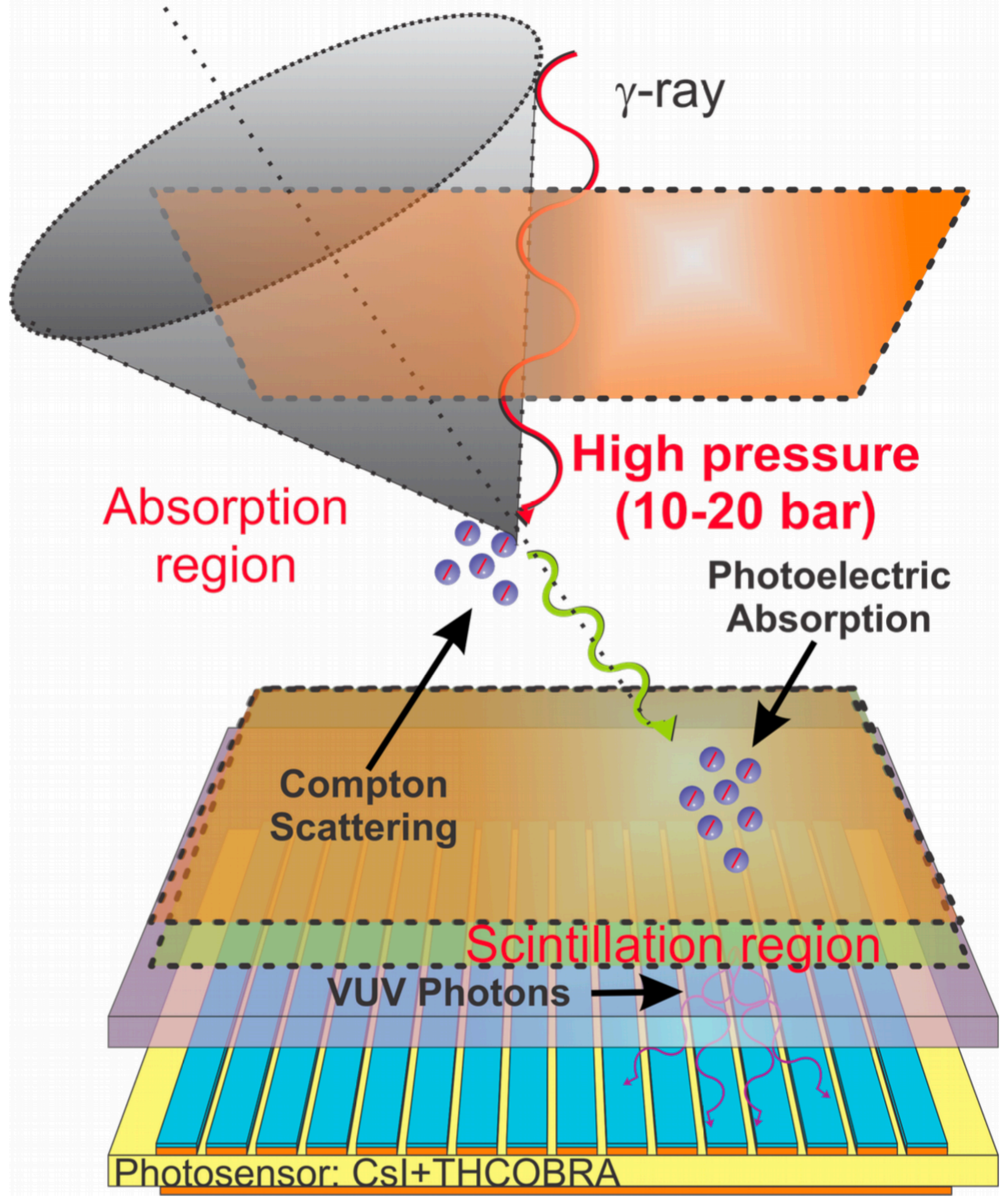
Compton camera based on GPM

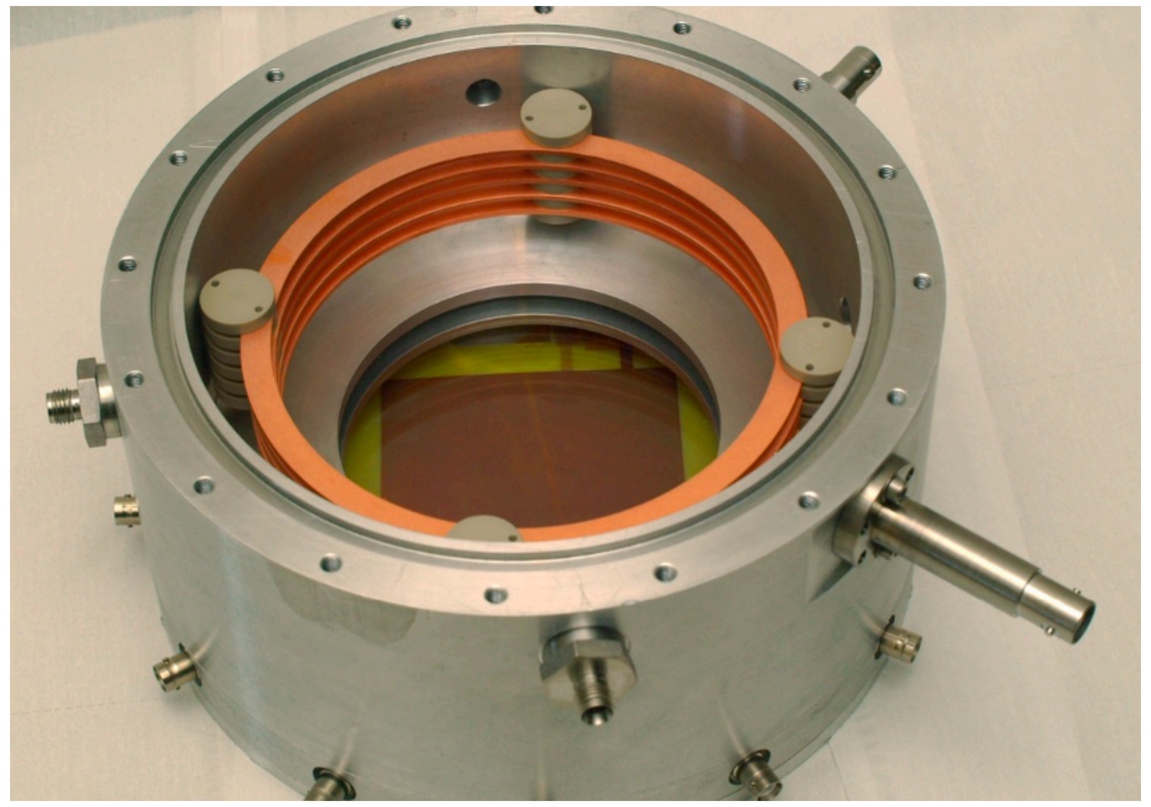
Compton Camera (CC) concept based on a **High Pressure Scintillation Chamber** coupled to a position-sensitive Gaseous PhotoMultiplier

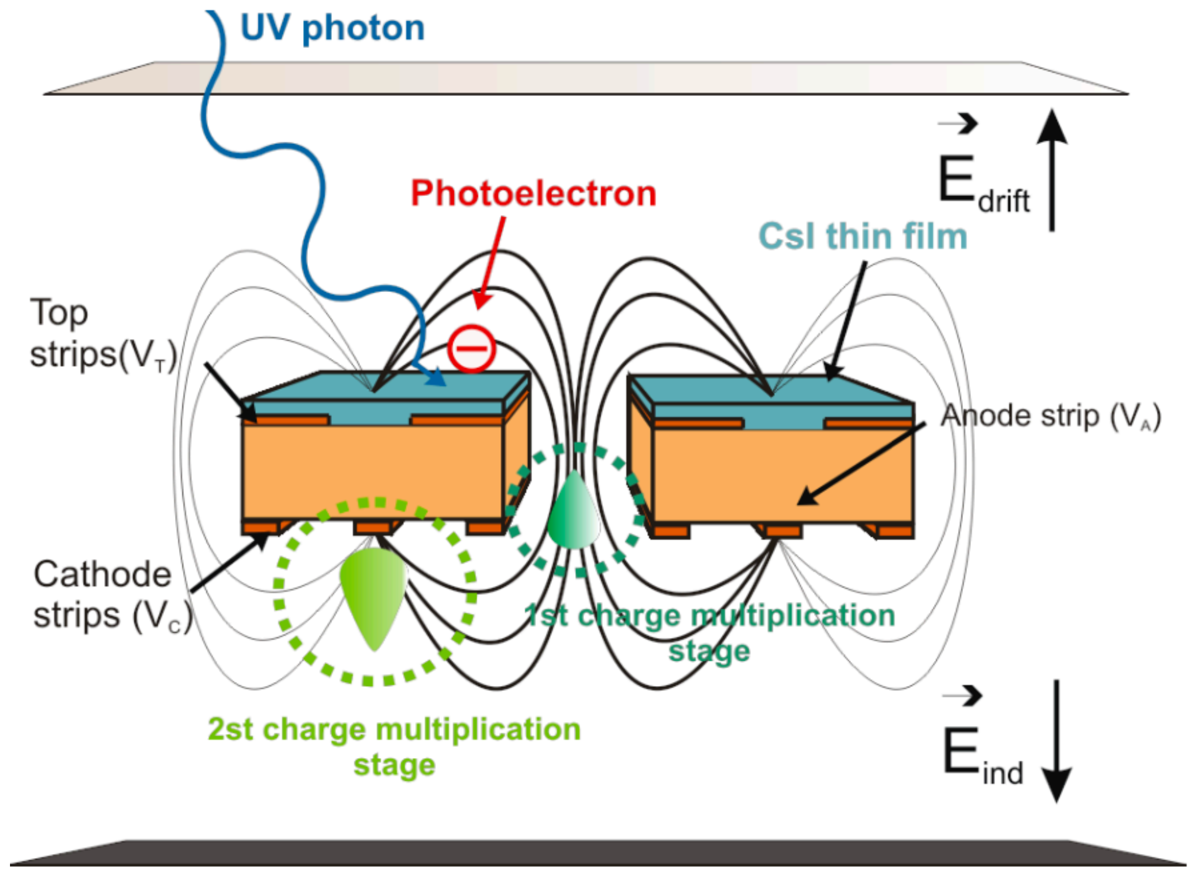
Amplification done with CsI coated **THCOBRA** detector

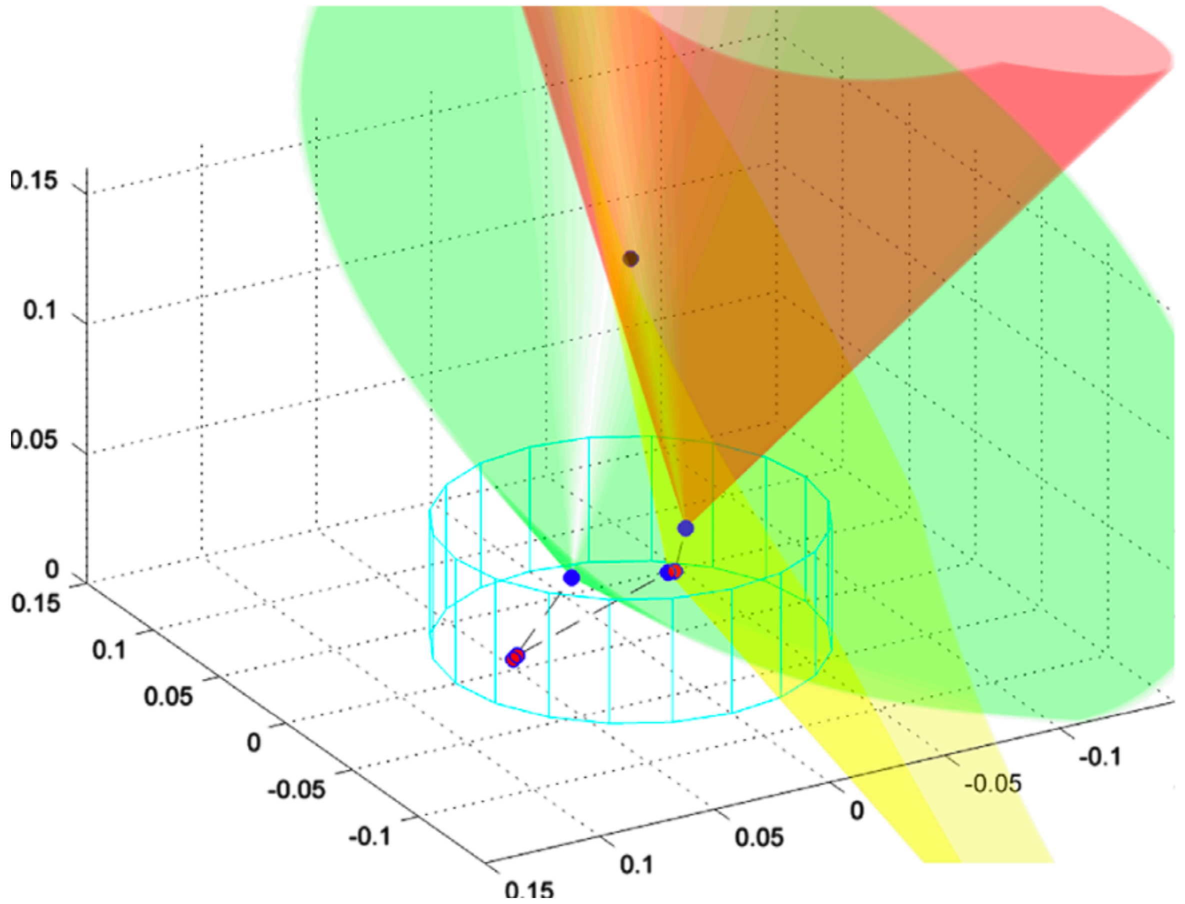
Proposed for Nuclear Medical Imaging applications and small animal imaging

Provides better position resolution than Anger camera as it records incoming photon direction









Azevedo et al., NIMA 732(2013) 551

https://doi.org/10.1016/j.nima.2013.05.116

Novel structures and materials

Gaseous Electron Multipliers

Fine-pitch holes in **conductor-insulator-conductor** structures
E.g. 70μm diameter holes at 140μm pitch in 50μm thick polyimide with Cu electrode on both sides

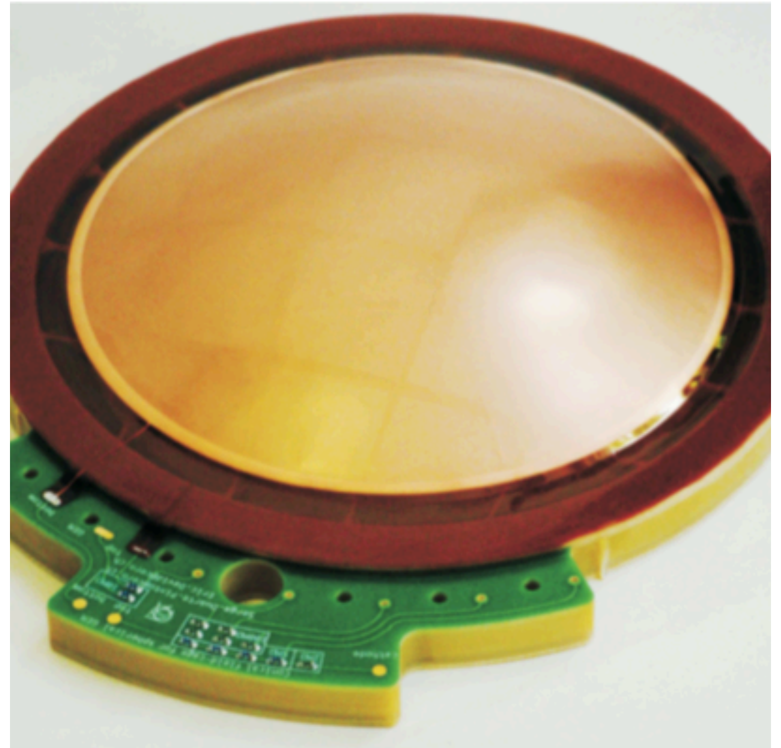
Open structure allowing for **multi-stage amplification** multi-GEM stacks

Varying geometries and materials for specific experimental requirements

GEM tracker

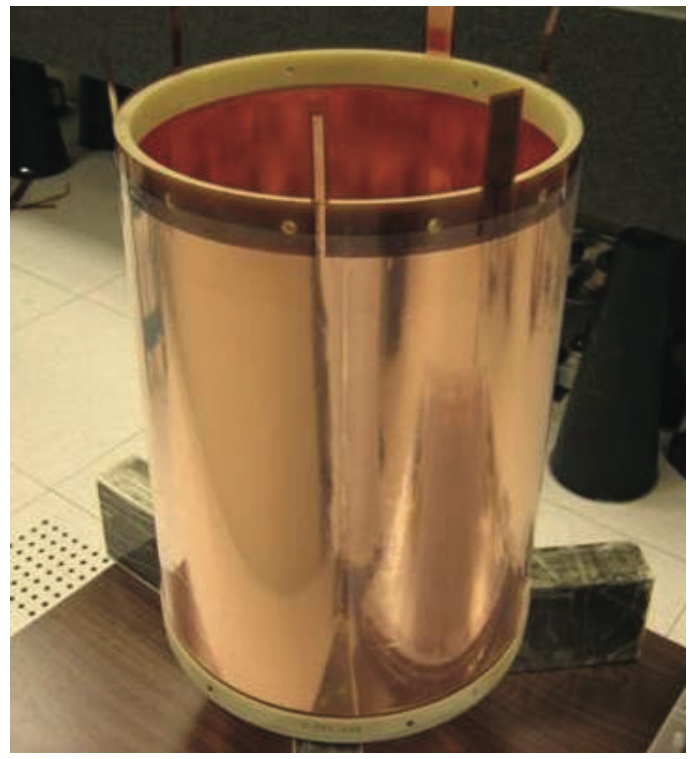
C. Altumbas et al, Nucl. Instr. and Meth. A490(2002)177

Spherical GEM



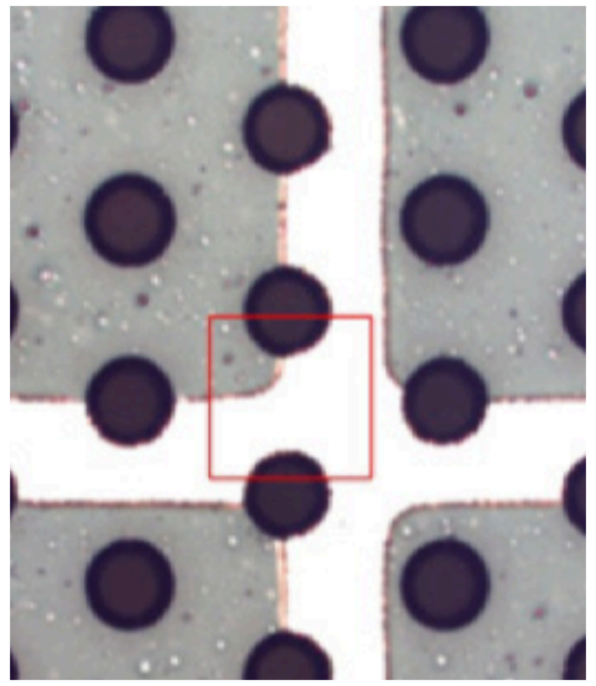
S. Duarte Pinto et al., 10.1109/NSSMIC.2010.5874100

Cylindrical GEM



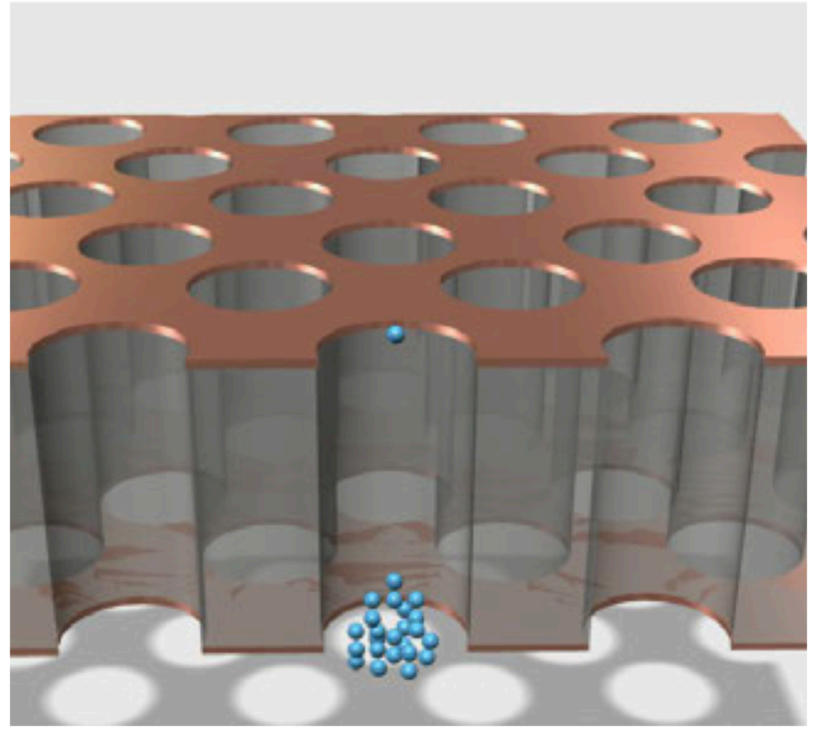
A. Balla et al., Physics Procedia 37 (2012) 522 – 529

Cr GEM



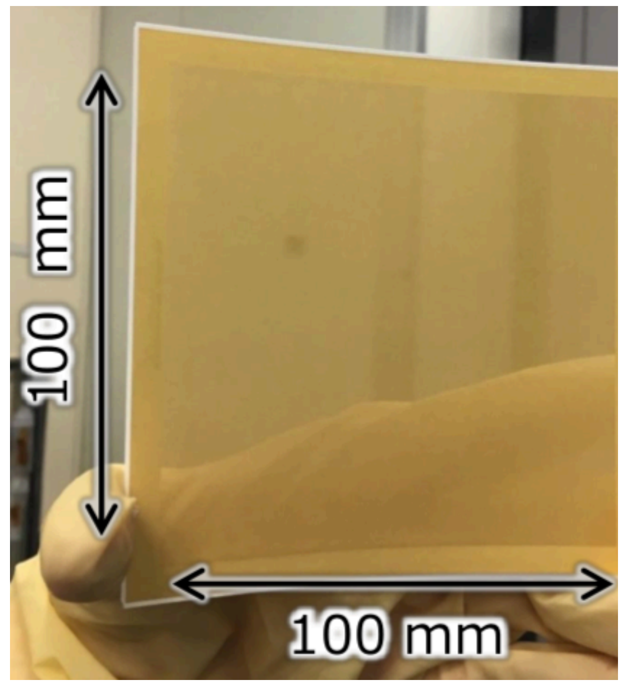
W. Dąbrowski et al 2016 JINST 11 C12025 doi:10.1088/1748-0221/11/12/C12025

Glass GEM



T. Fujiwara, MPGD2017

LTCC GEM



Y. Takeuchi et al 2020 J. Phys.: Conf. Ser. 1498 012011

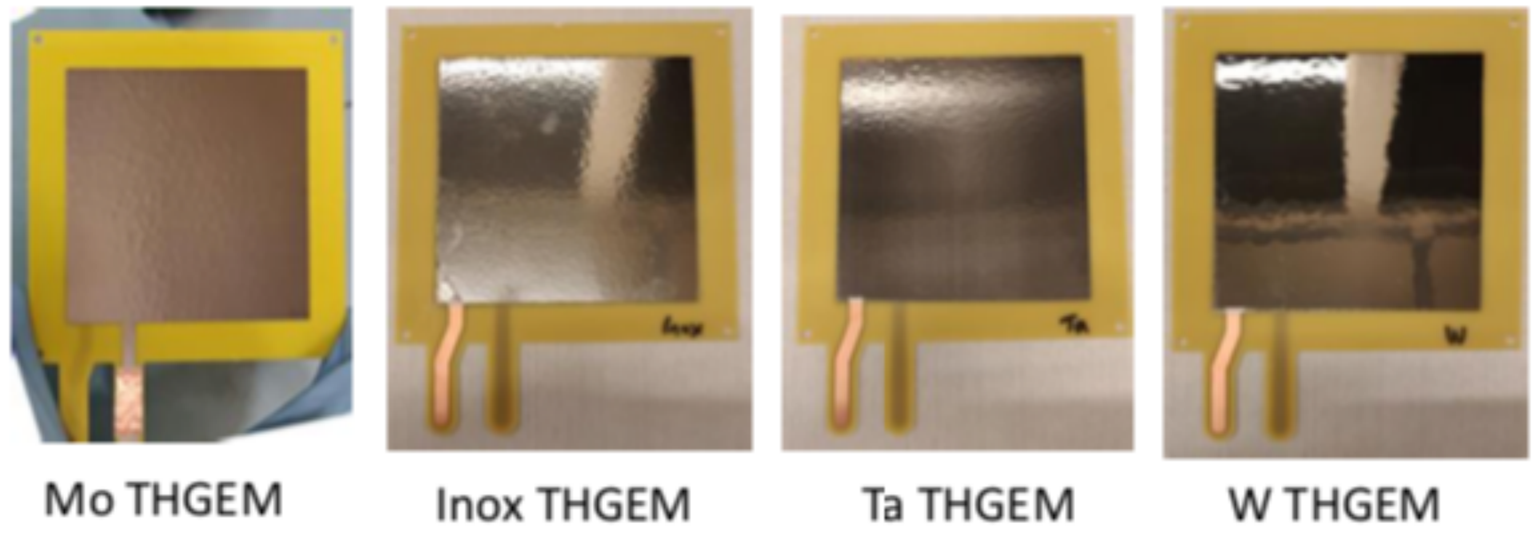
DLC GEM

M. Lisowska, RD51 CM May 2019

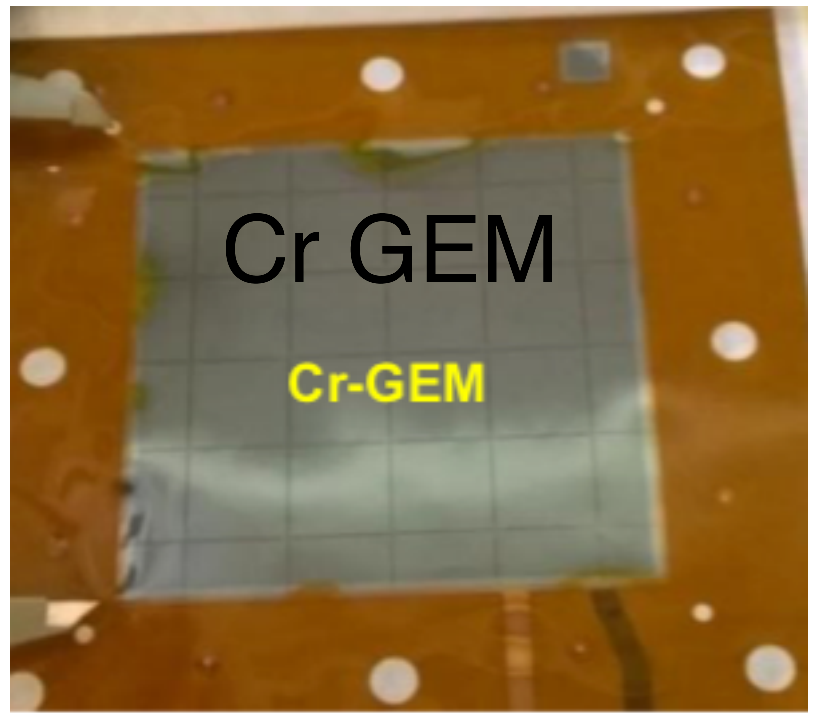
Gaseous Electron Multipliers

Alternative electrode materials

Lower material budget or increased spark resistance.



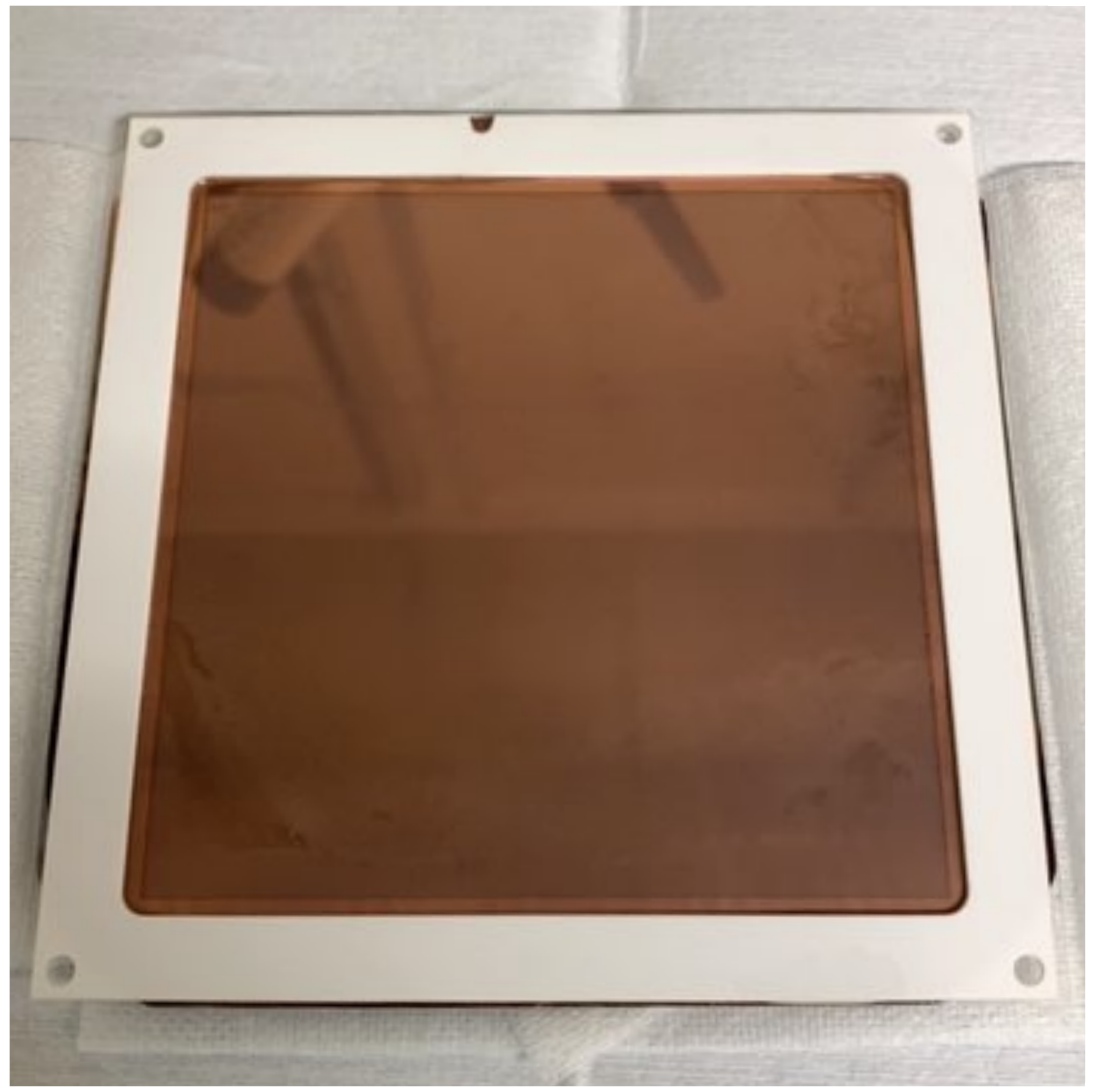
Berkin Ulukutlu et al. RD51 CM 2020

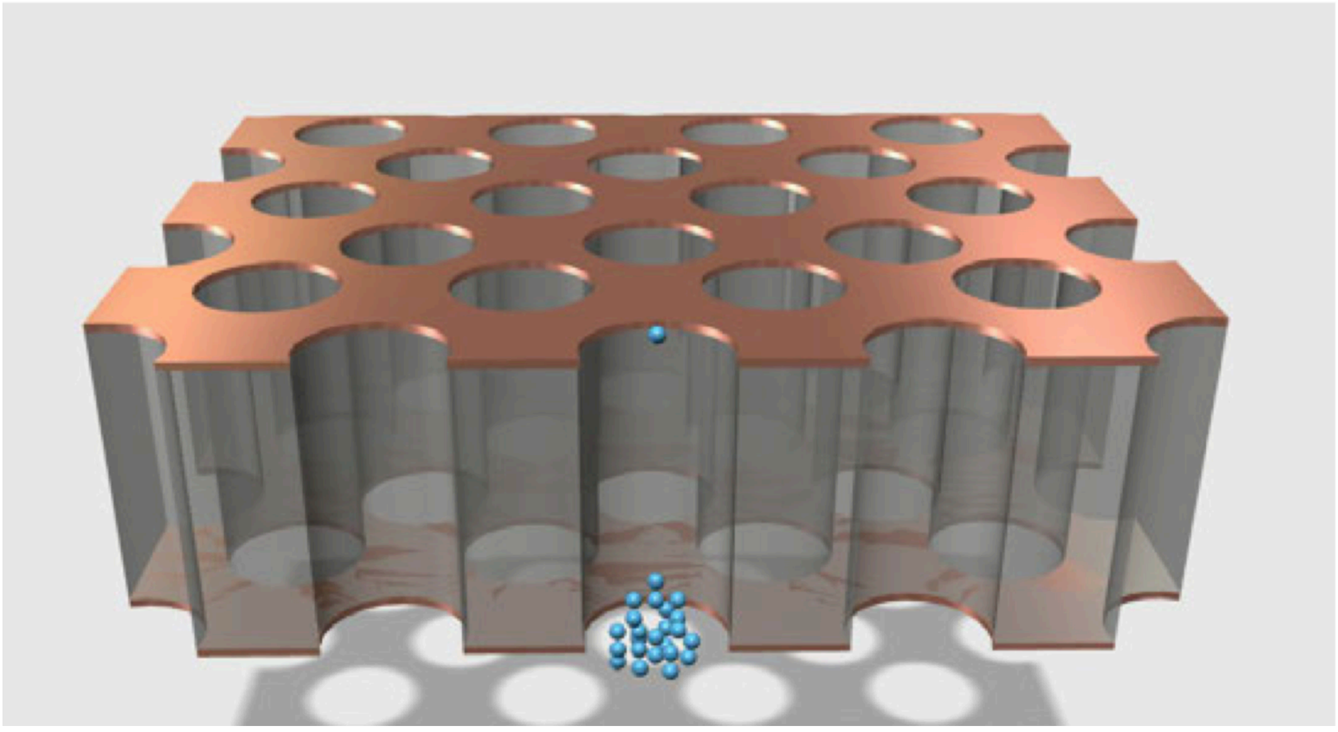


Kondo Gnanvo, RD51 Mini Week 2017

M. Lisowska, RD51 CM May 2019

Glass GEM





T. Fujiwara, MPGD2017

Glass GEMs are high aspect ratio THGEMs with

Substrate: 570μm photo-etchable glass
Electrodes: 2μm Cu

Hole pitch: 280μm
Hole diameter: 160-180μm
No rim

Interesting for low pressure applications, high gain factors reachable in low pressure TPCs

Disadvantage: leakage current through glass substrate

Limited material and geometry choice

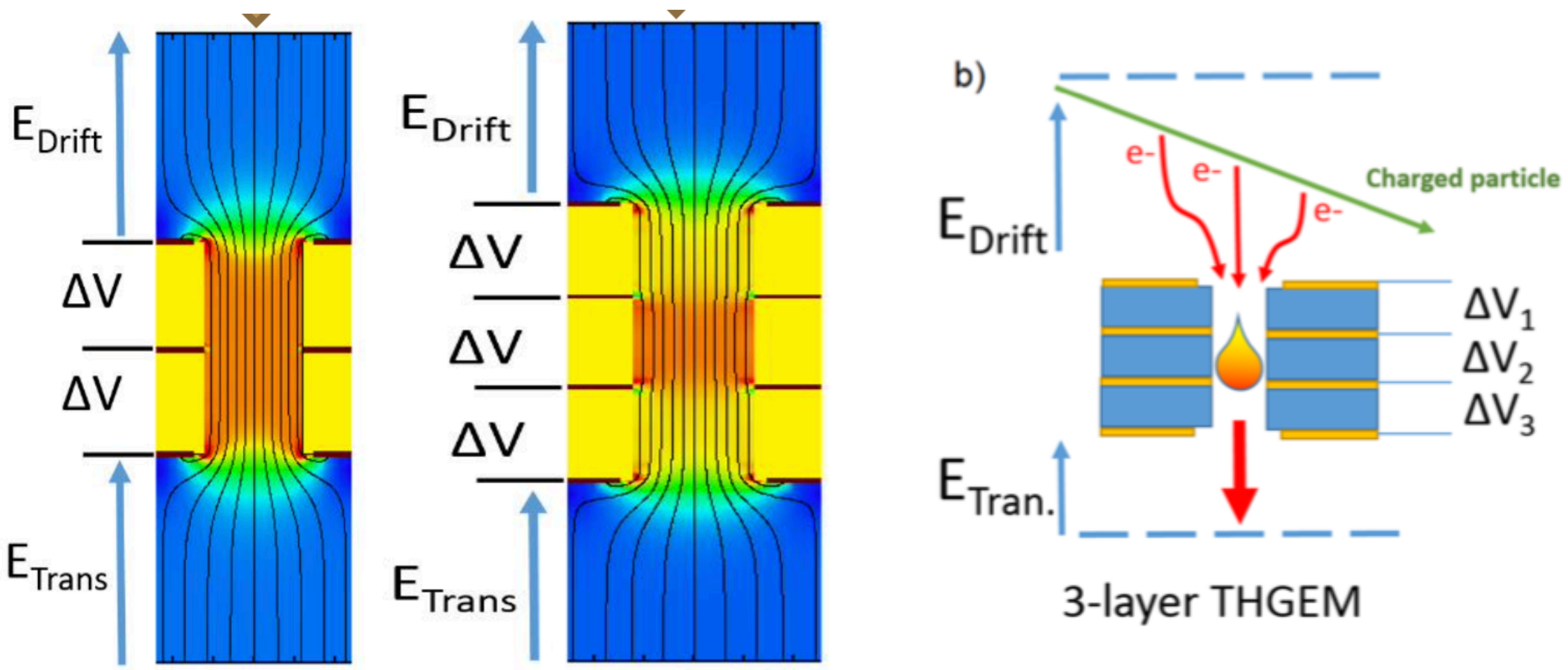
Multi-layer THGEMs and MM-THGEMs

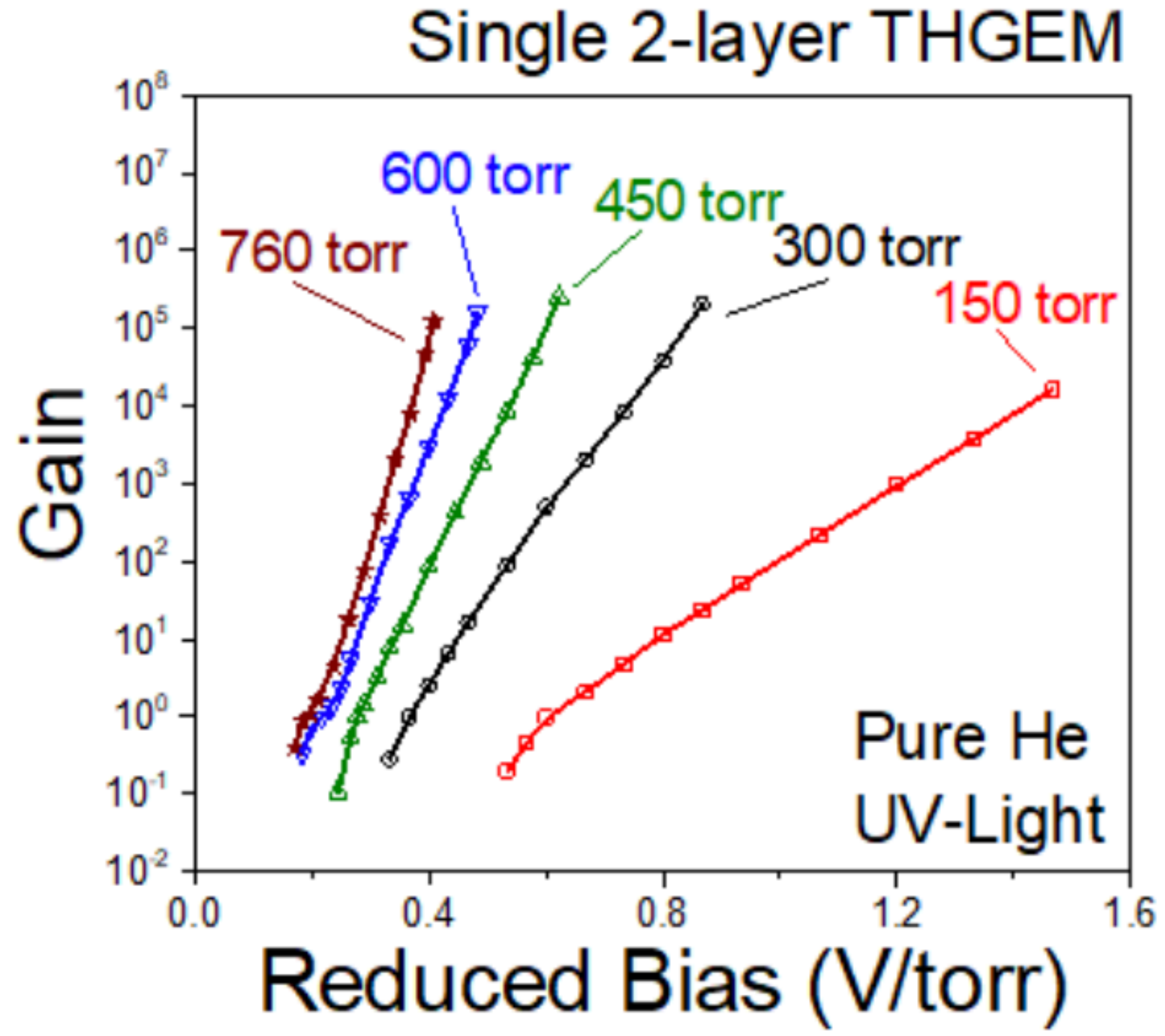
Multi-layer THGEMs with long amplification channels and embedded electrodes can be used to confine gain region within thick substrate for improved feedback properties.

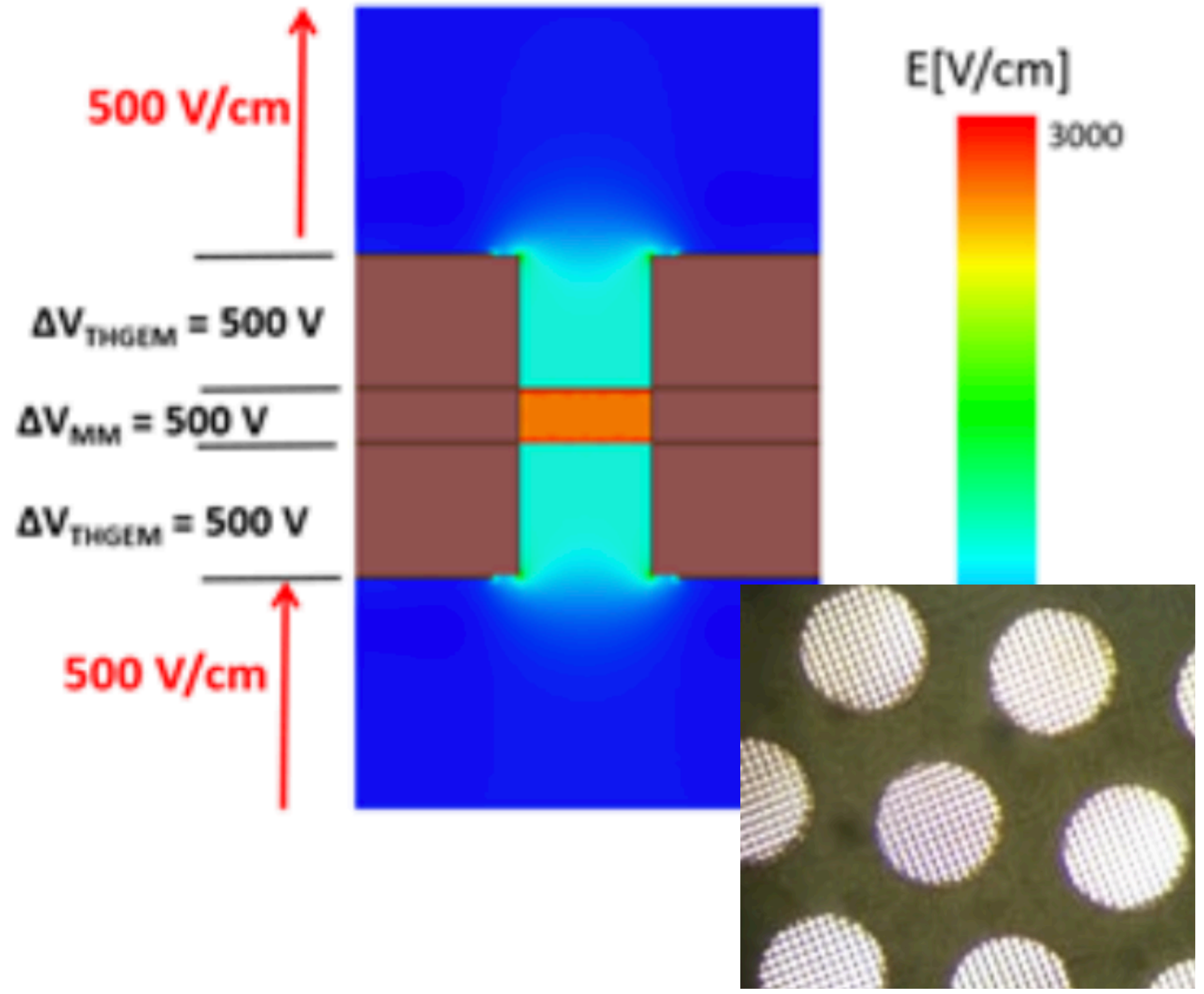
Maintain high gain in low pressure conditions, where typically feedback would be limiting factor.

Combination of THGEM with embedded micromeshes used to create uniform field region within holes for improved photon feedback and suppressed ion back flow.

Multi-layer THGEM







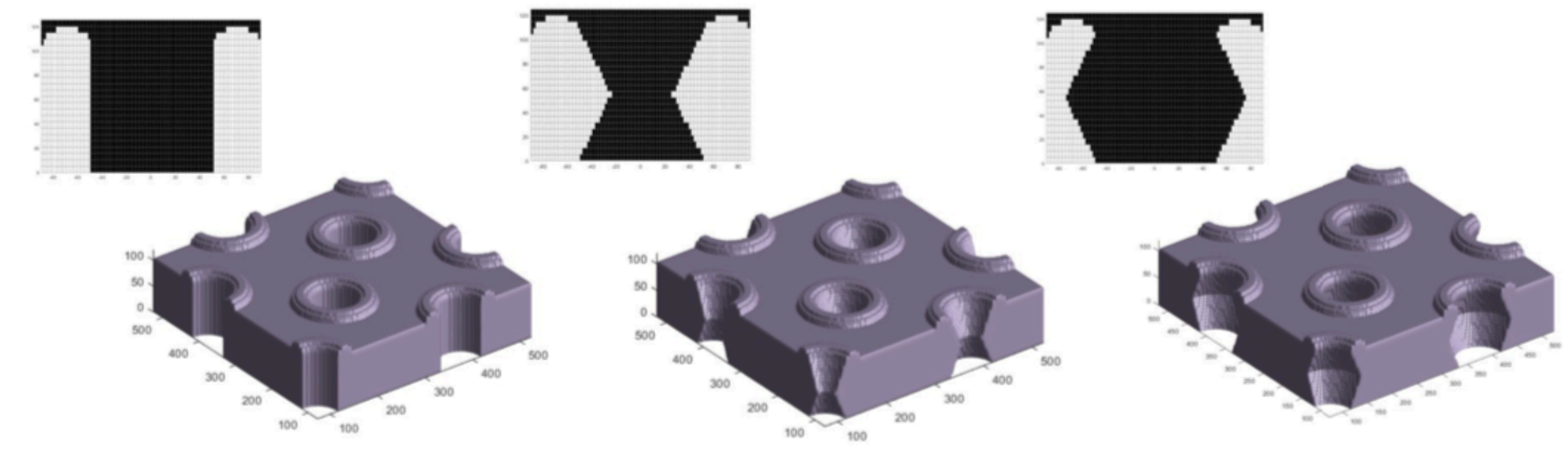
M. Cortesi et al. Rev. Sci. Instrum. 88, 013303 (2017); https://doi.org/10.1063/1.4974333
https://indico.cern.ch/event/1071632/contributions/4610166/attachments/2346345/4001114/Cortesi_MTHGEM.pdf

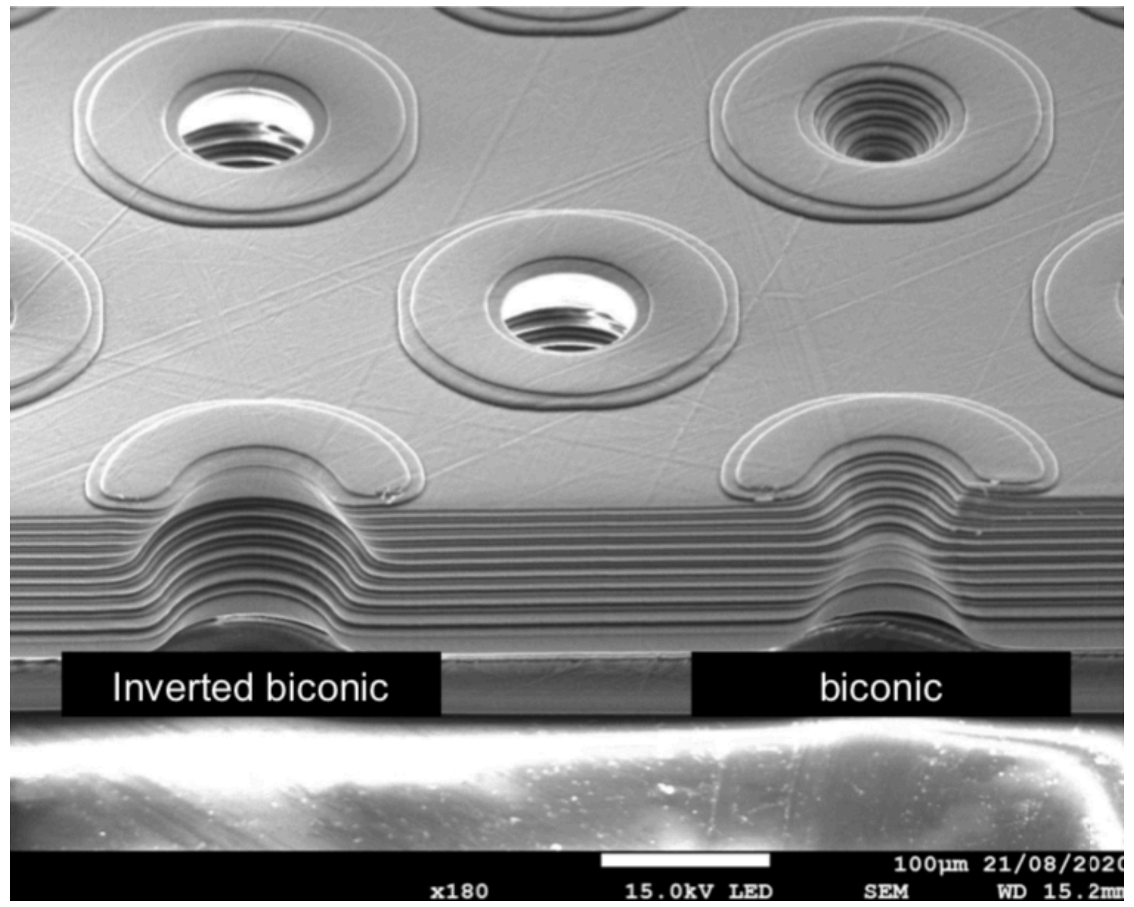
GEM optimisation by additive manufacturing

Optimized GEMs with micro-additive fabrication technique

“Decorations” on GEM electrodes to minimise charging up and charge transport characteristics

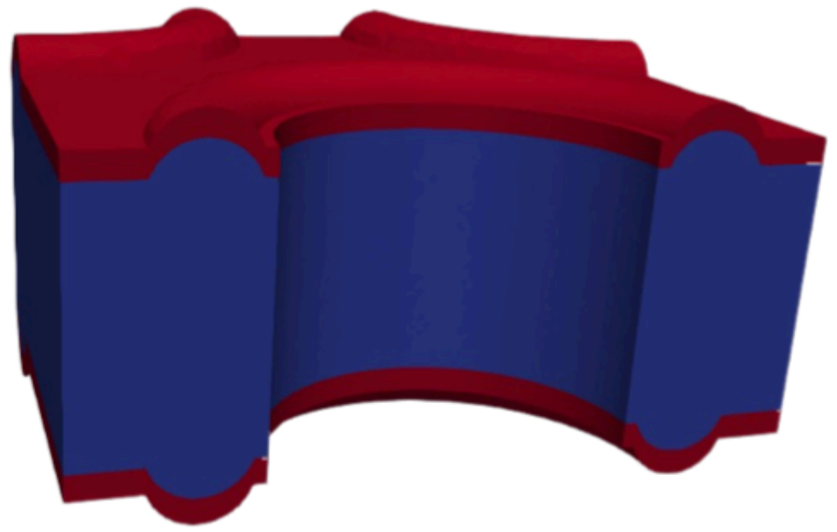
50μm diameter printed holes in HDDA based polymer

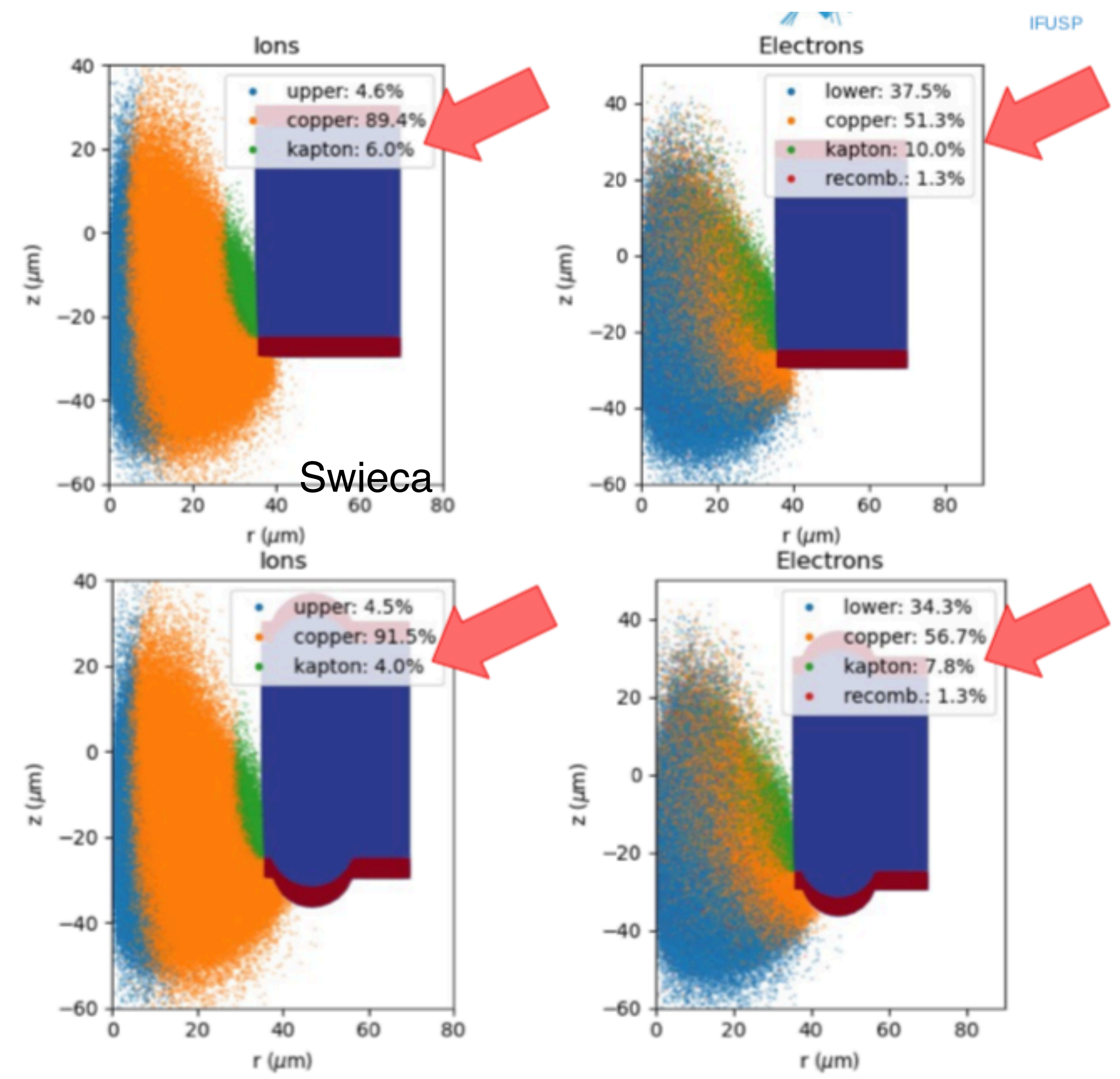




https://indico.cern.ch/event/889369/contributions/4032682/attachments/2116131/3560697/RD51_TFS_public.pdf

Simulation of micro-structures for GEM optimization





https://indico.cern.ch/event/889369/contributions/4041558/attachments/2115142/3558763/RD51_TBS.pdf

Precise timing with Micromegas

PICOSEC MM detection concept

To mitigate pile-up and separate particles coming from different vertices:

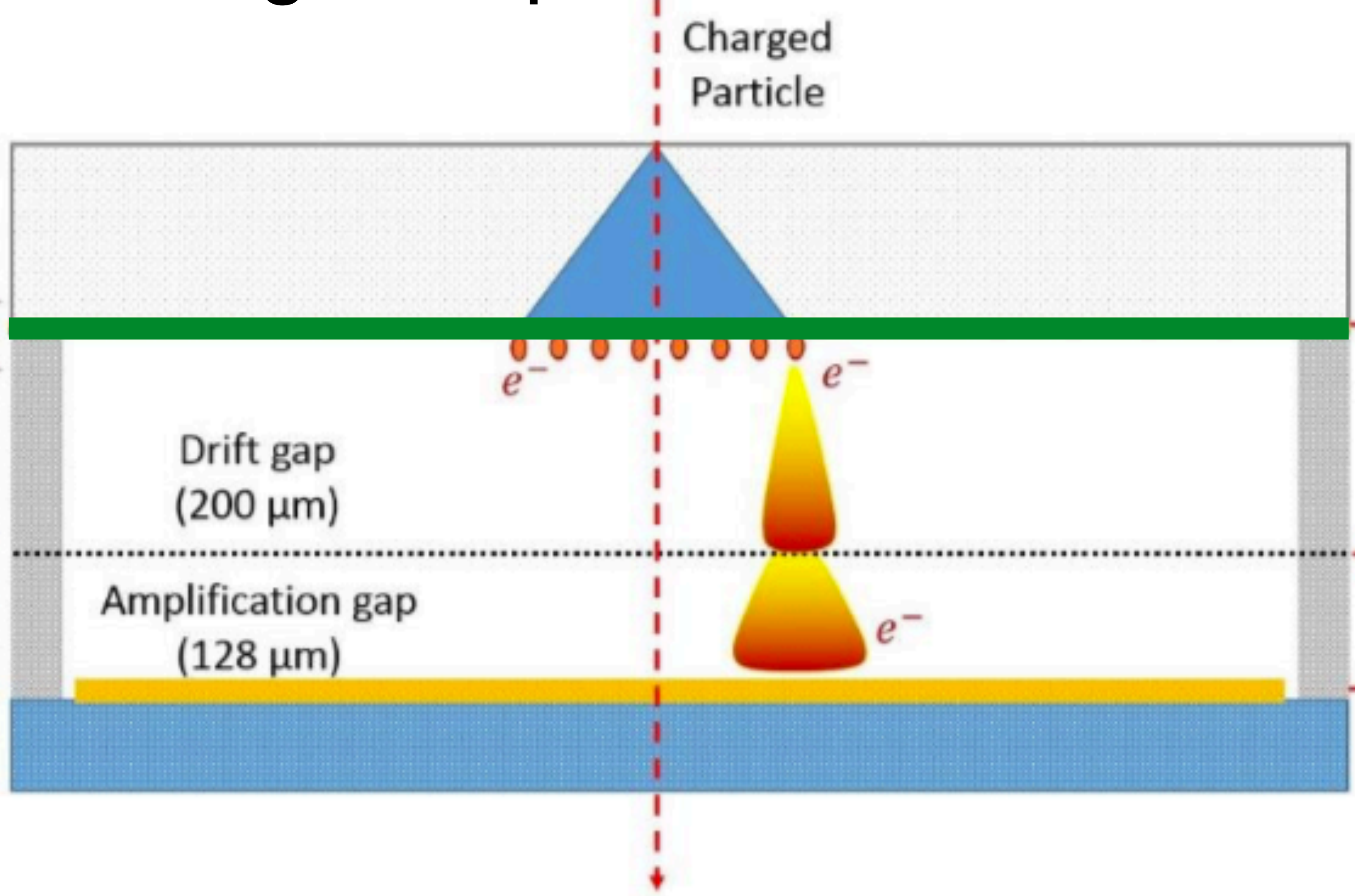
- Exploit precise timing to separate tracks

Cherenkov radiator
(3 mm MgF_2)

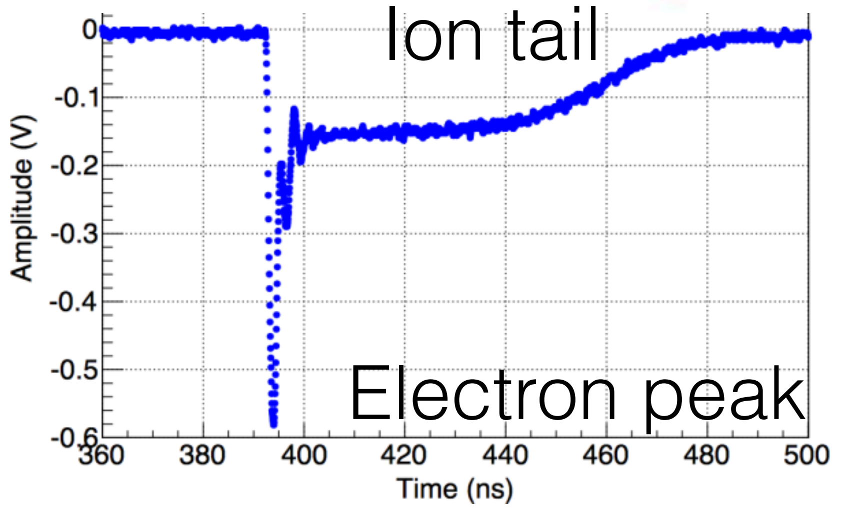
Photocathode
(3 nm Cr + 18 nm CsI)

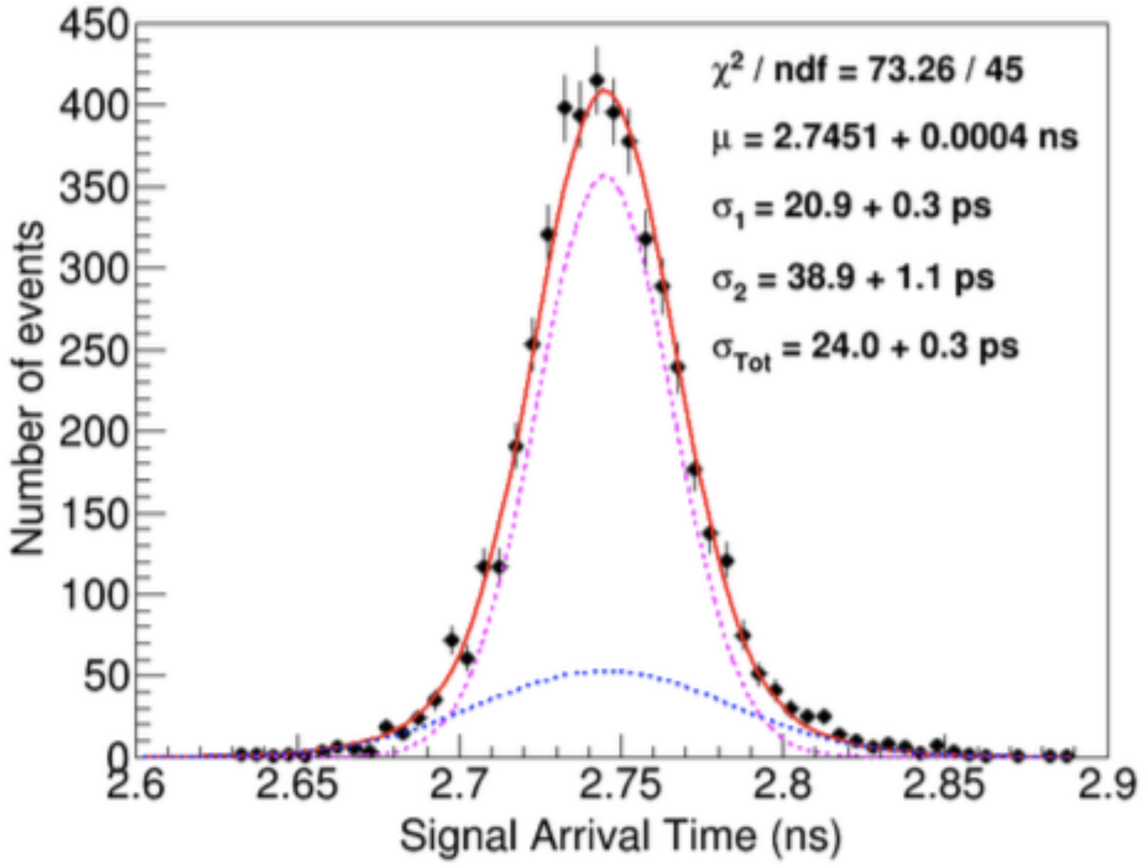
Drift gap
(Pre-amplification)

Micromegas
(Amplification)

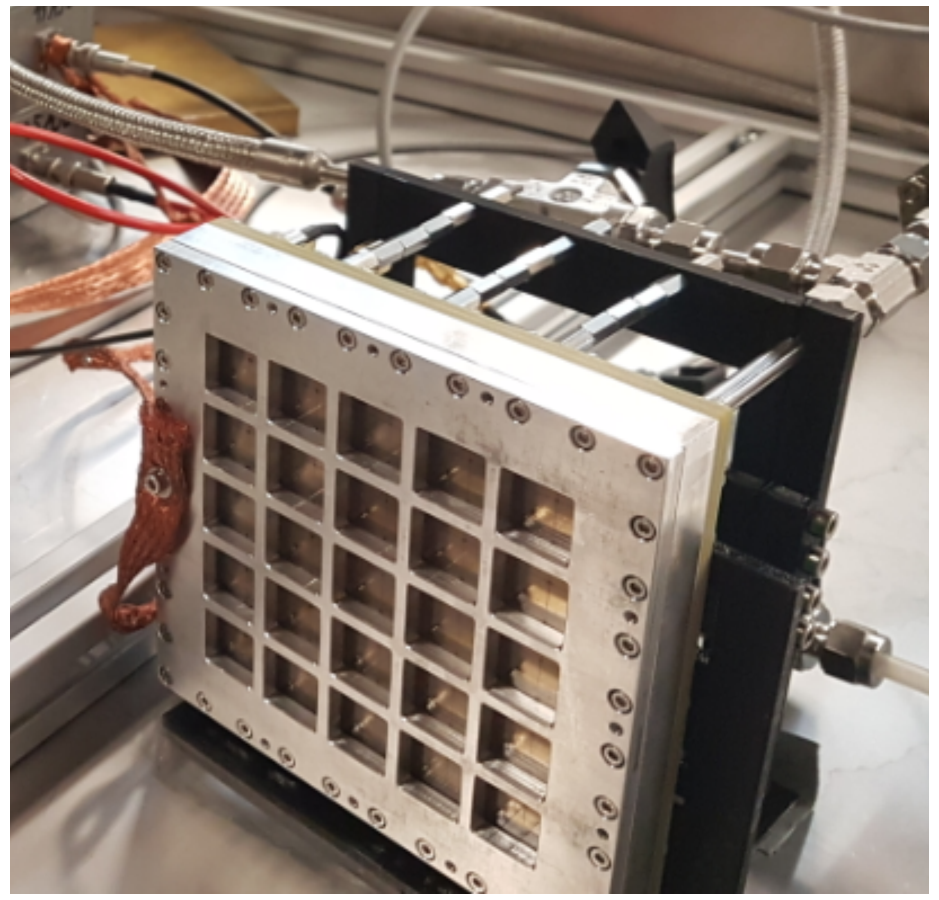


Typical signal shape





24 ps MIP timing resolution

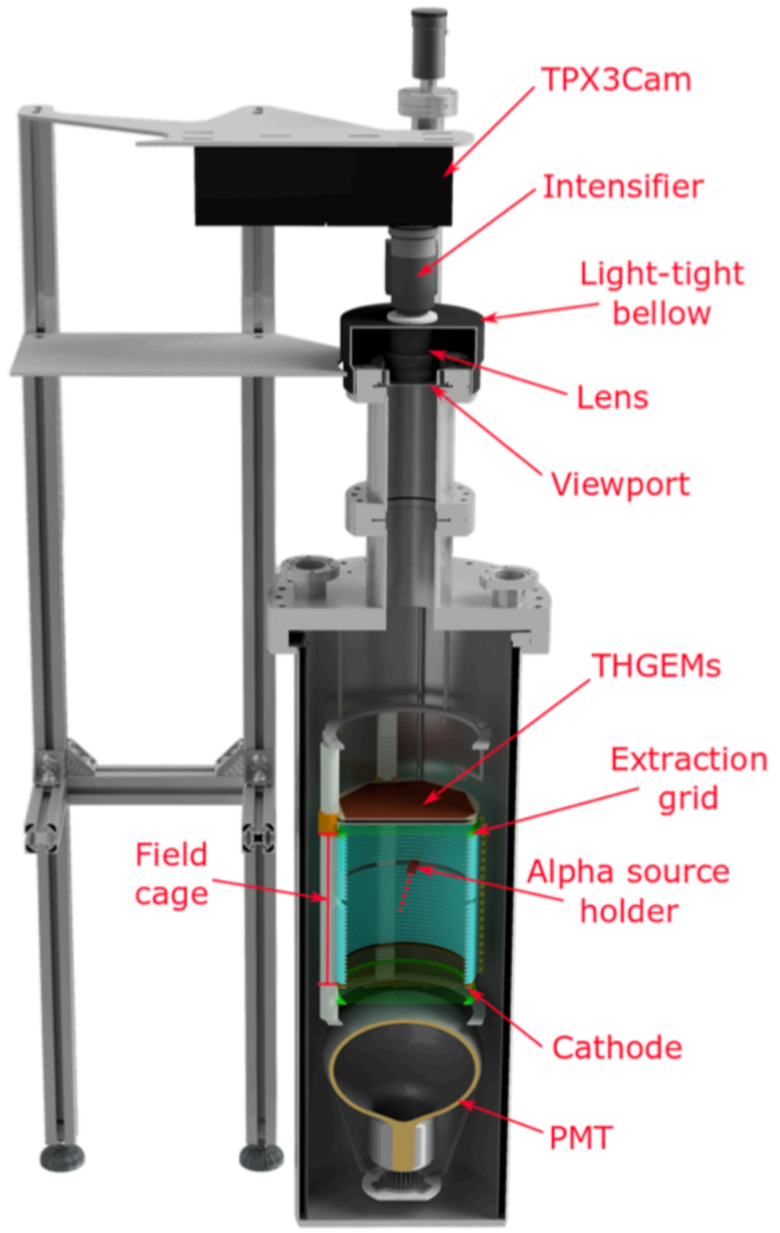


10x10 module
□ 1 cm

Can be applied for precise time tagging of particles and as photon detector with high time resolution

J. Bortfeldt et. al. (RD51-PICOSEC collaboration), Nuclear. Inst. & Methods A 903 (2018) 317-325

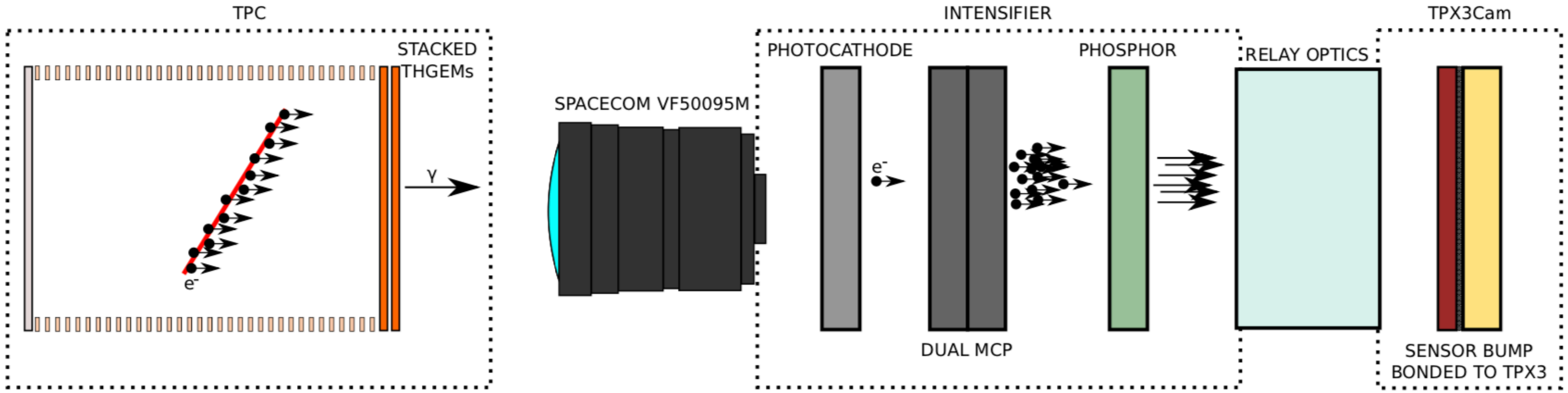
3D track reconstruction
Intensified TPX3Cam

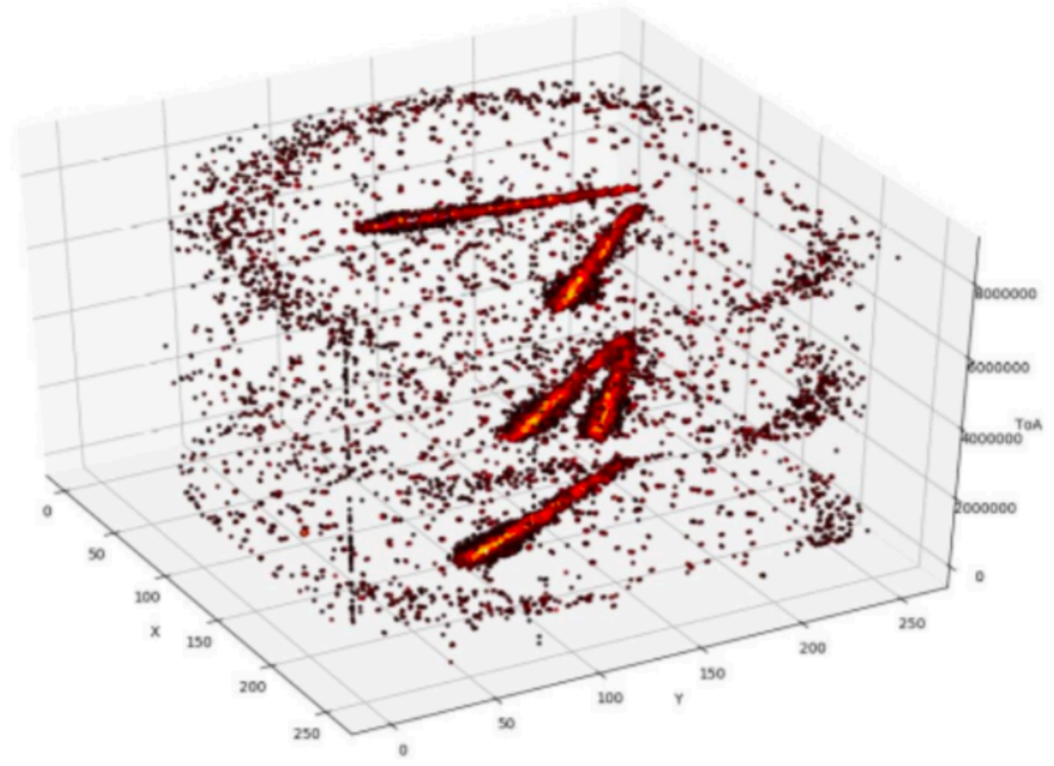


Readout of S2 scintillation in **dual phase TPC**

Light production with THGEM / GlassGEM in avalanche mode, operated at low amplification due to inherent signal amplification in image intensifier of readout system

TPB wavelength shifter and VIS **photocathode** or **direct VUV imaging** with UV photocathode on intensifier

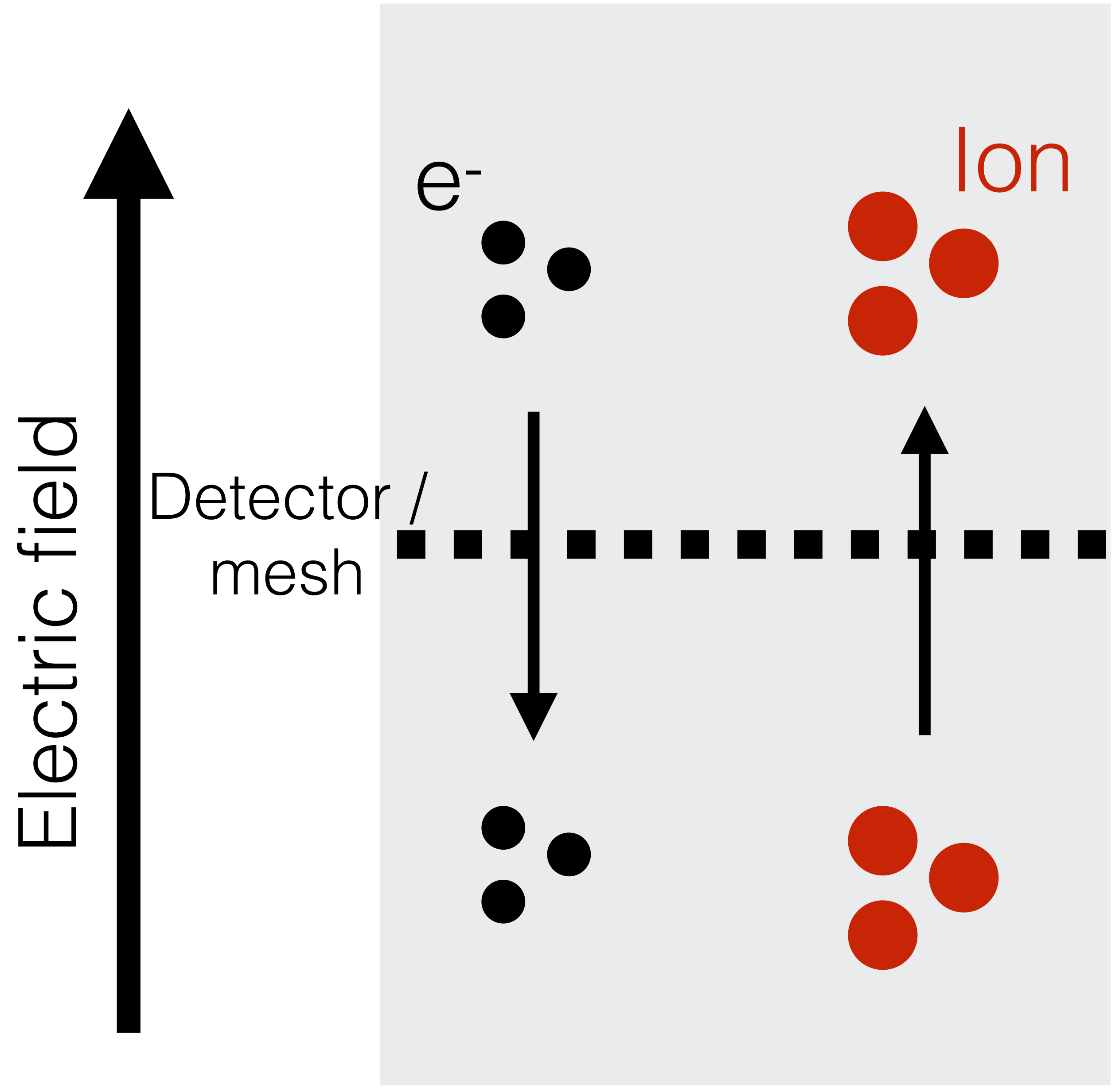




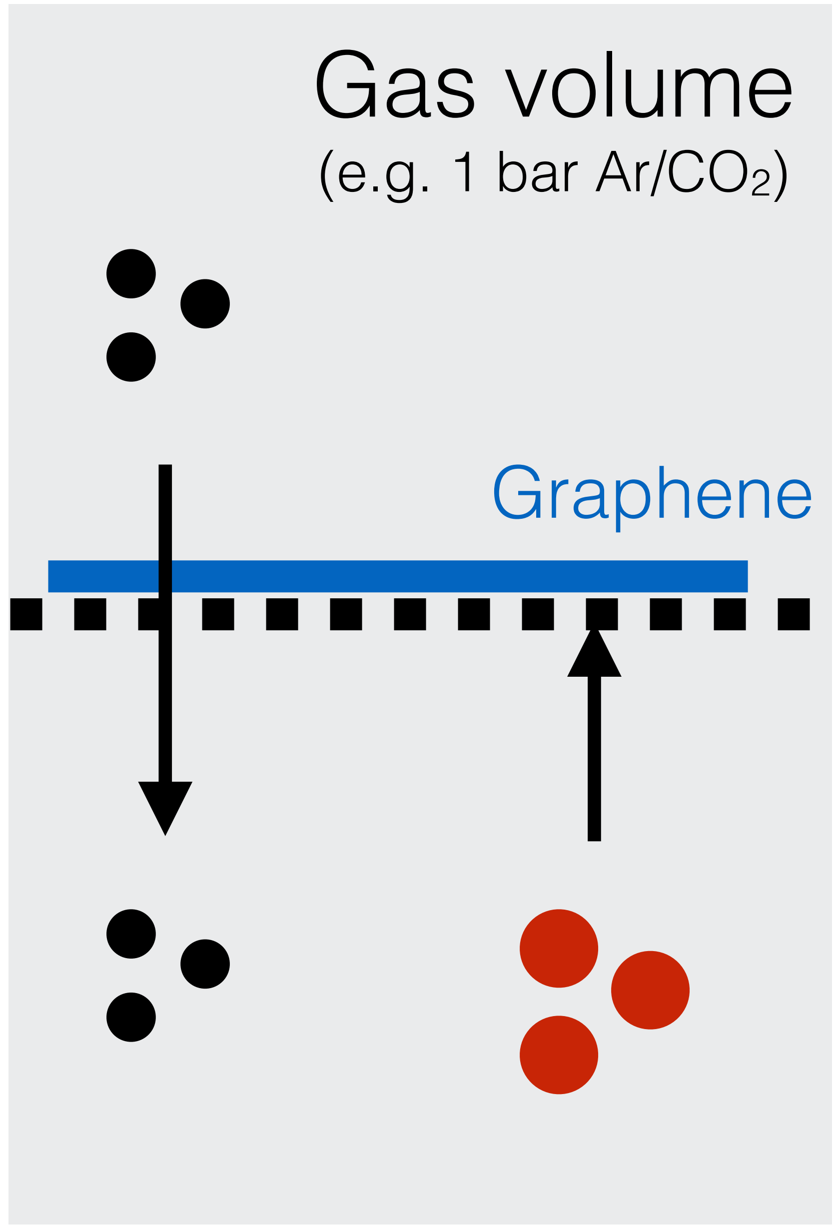
A. Roberts, ARIADNE, arXiv:1810.09955v3
https://indico.cern.ch/event/989298/contributions/4217751/attachments/2190565/3702236/RD51%20Optical%20readout.pdf

Suspended graphene for ion back-flow suppression

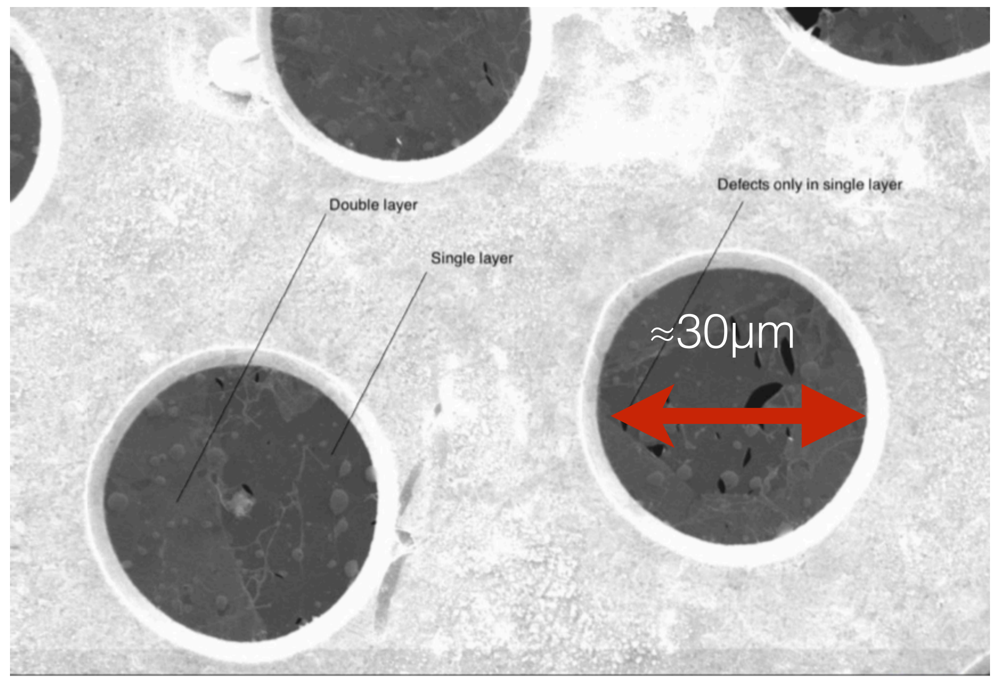
- Layers with transparency for electrons and opacity for ions / gas molecules
- Can be used to suppress ion back-flow and separate volumes with different gases
- Suspended graphene layers on perforated foils or meshes

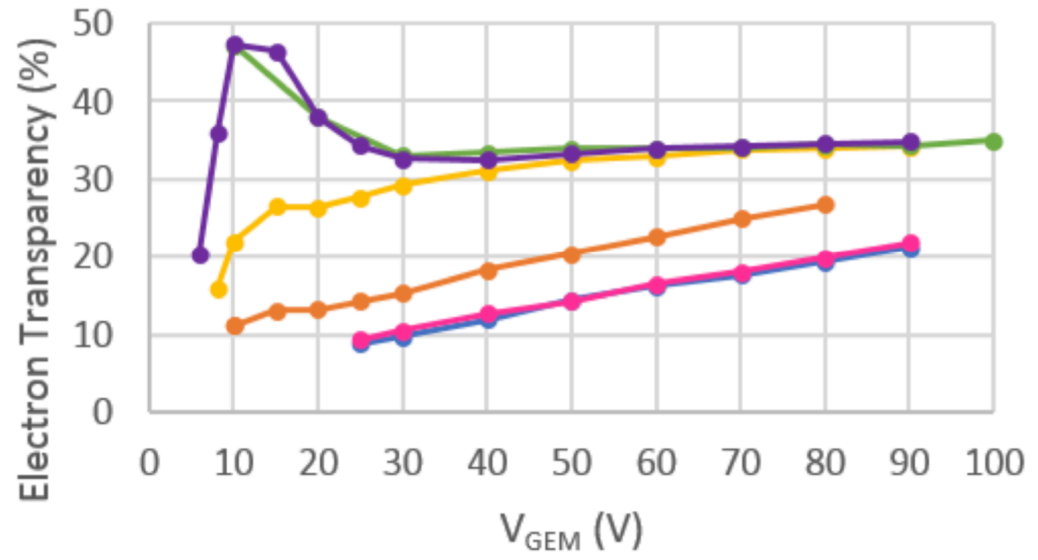


Electrons and ions are transmitted through detector/mesh



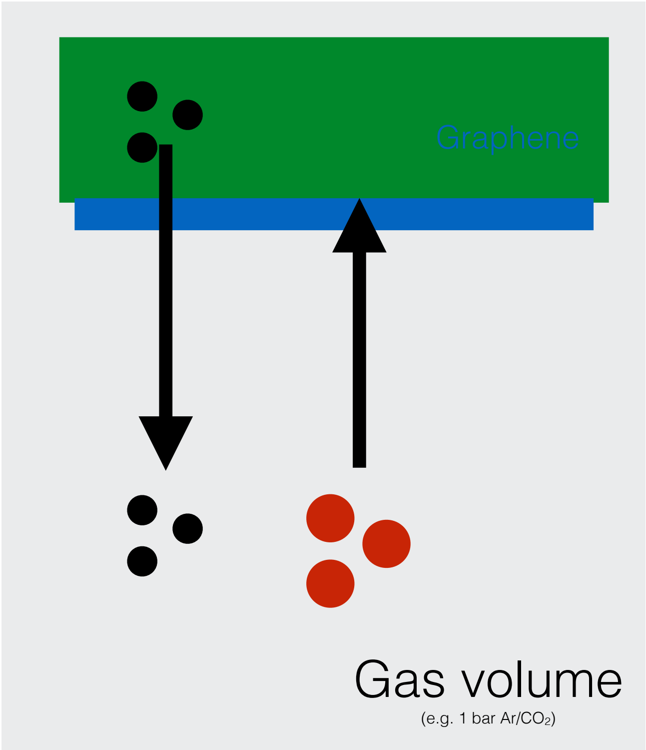
Electrons can pass and ions are blocked





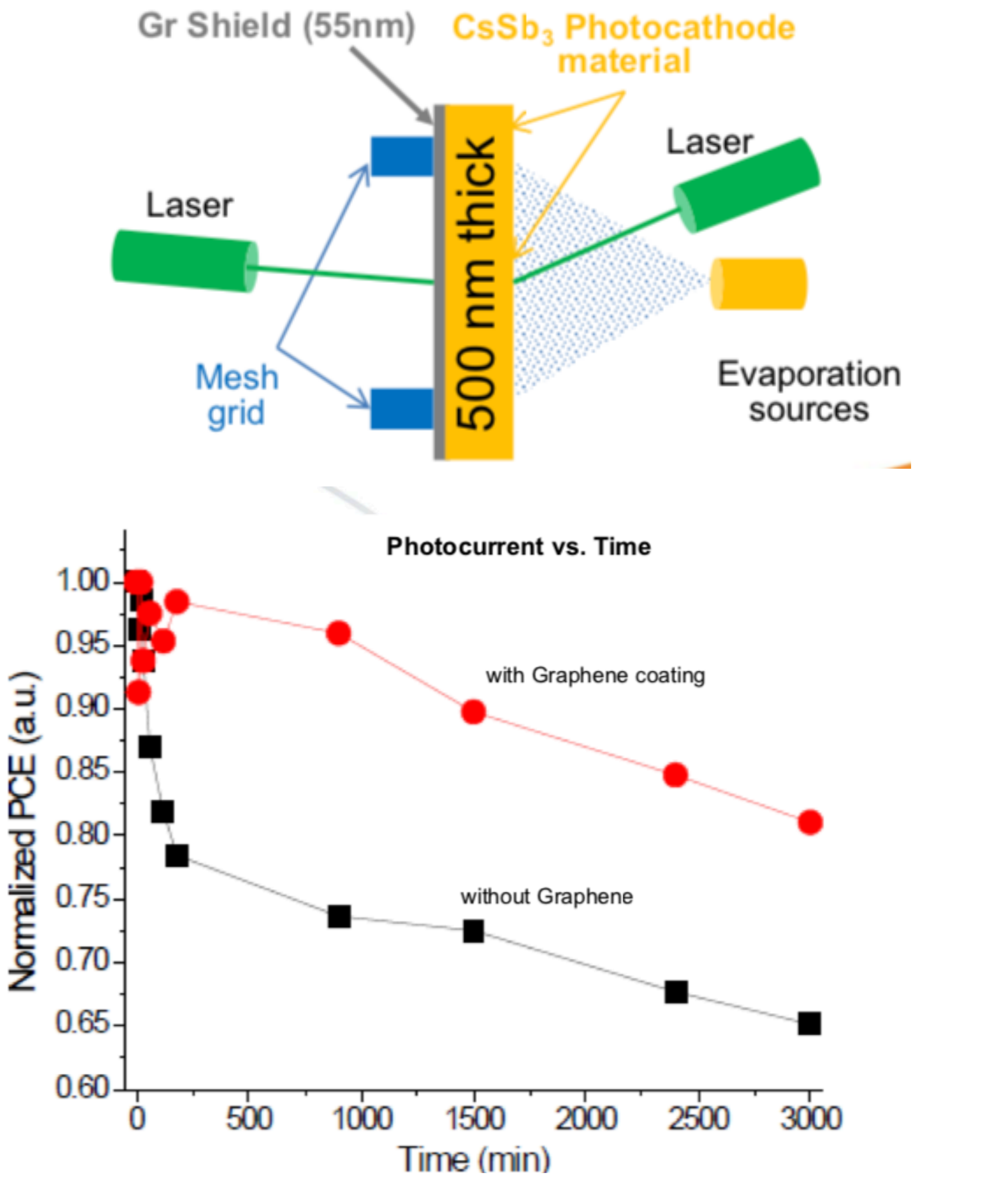
QUANTUM TECHNOLOGY INITIATIVE

Protection of photocathodes with graphene layers



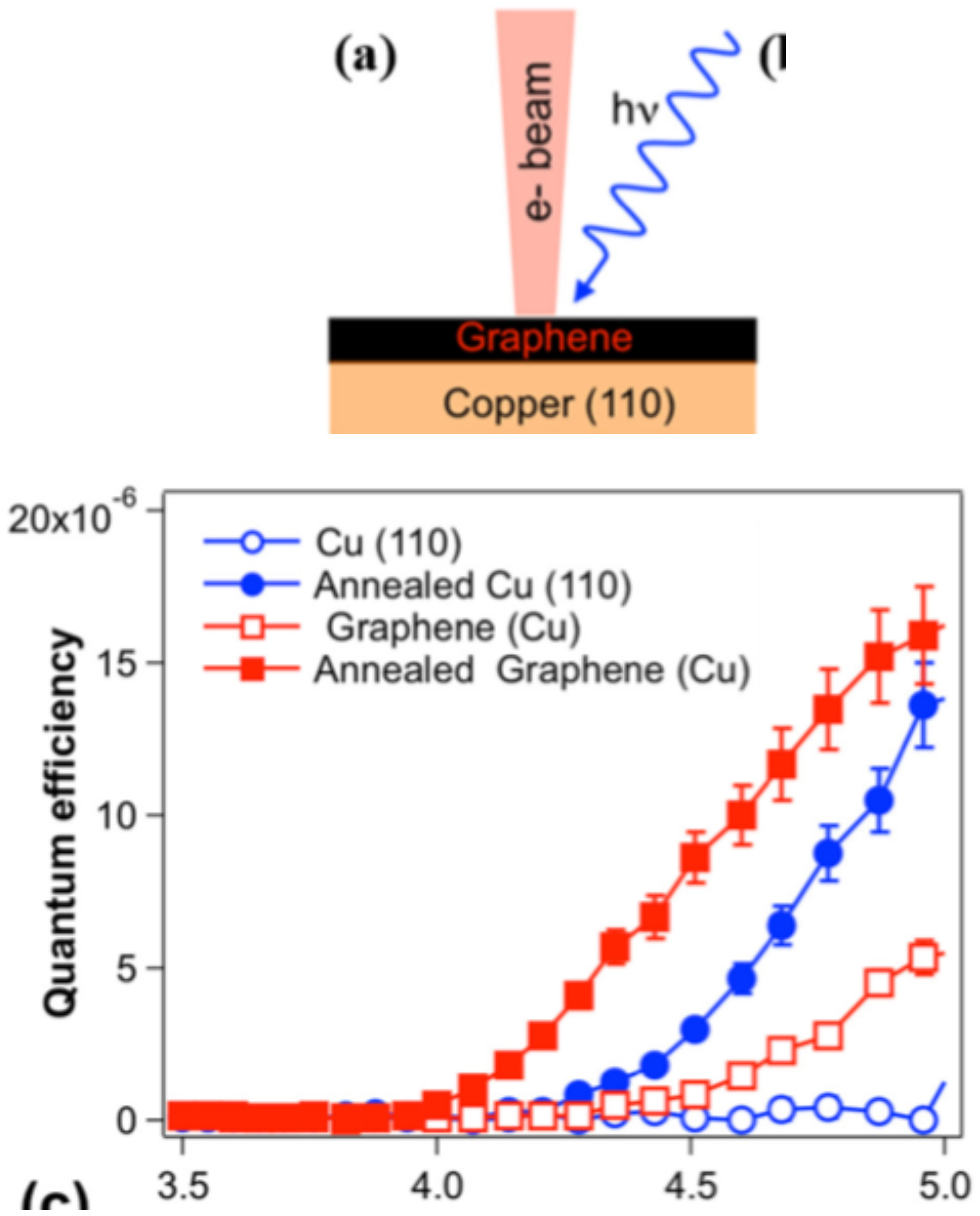
Passivation with graphene has been demonstrated for photocathodes

- Lifetime enhancement for chemically reactive surfaces
- Photoemission from UV through graphene layer



https://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-14-28720

Single layer graphene protective gas barrier for copper photocathodes



Liu et al. Appl. Phys. Lett. 110, 041607 (2017)

In addition to passivation, change of work function by graphene coating may be exploited

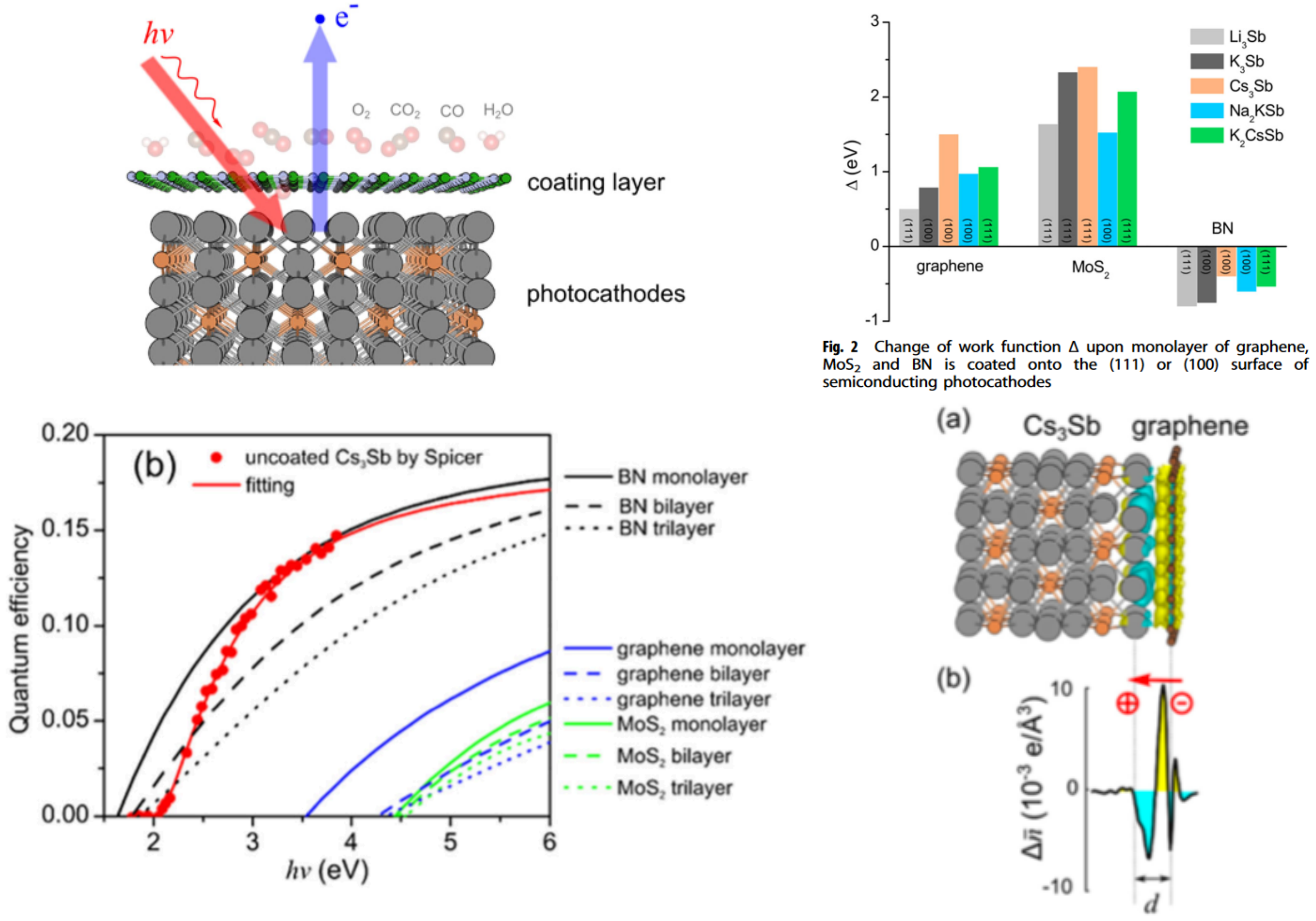
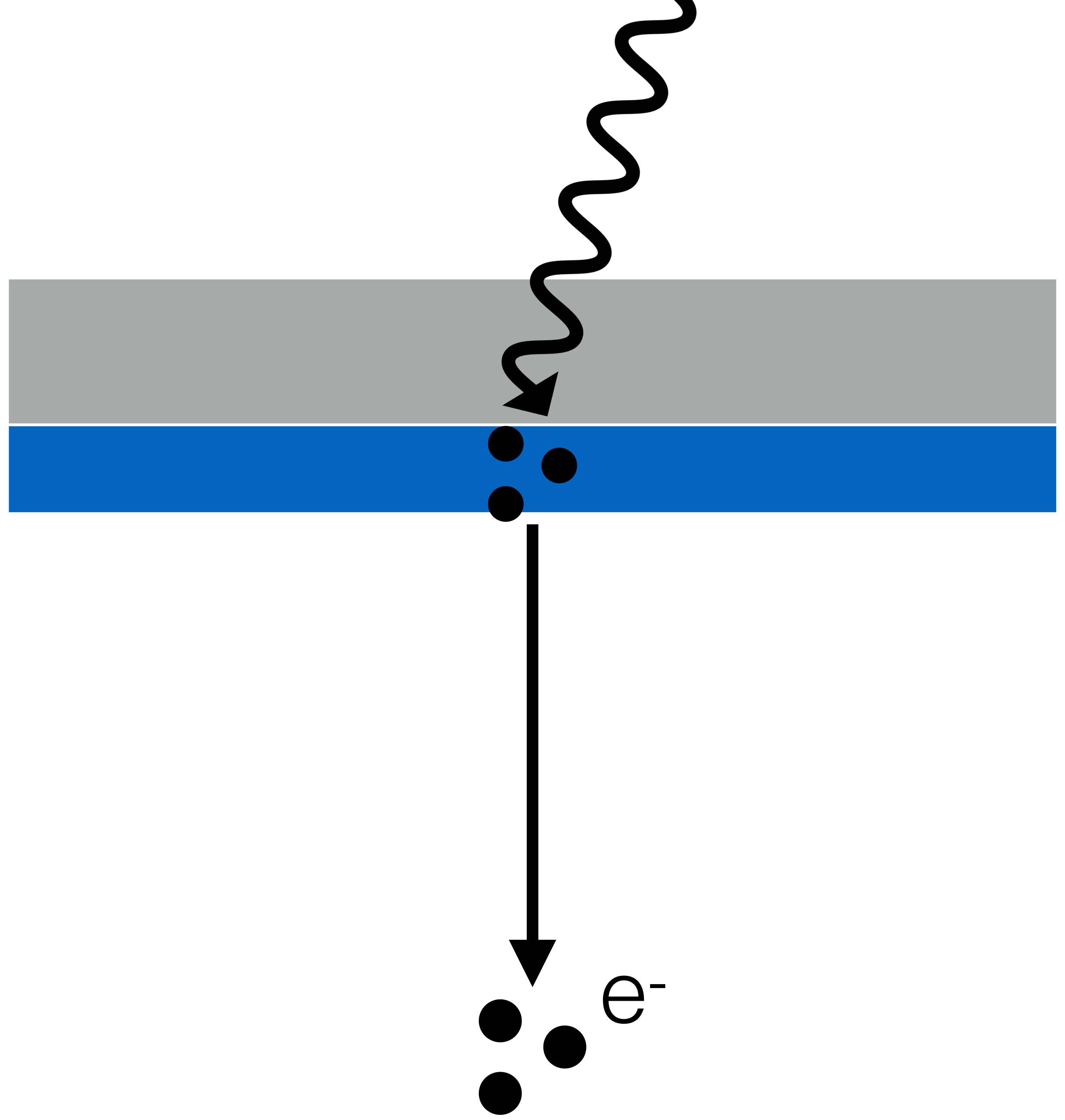


Fig. 2 Change of work function Δ upon monolayer of graphene, MoS_2 and BN is coated onto the (111) or (100) surface of semiconducting photocathodes

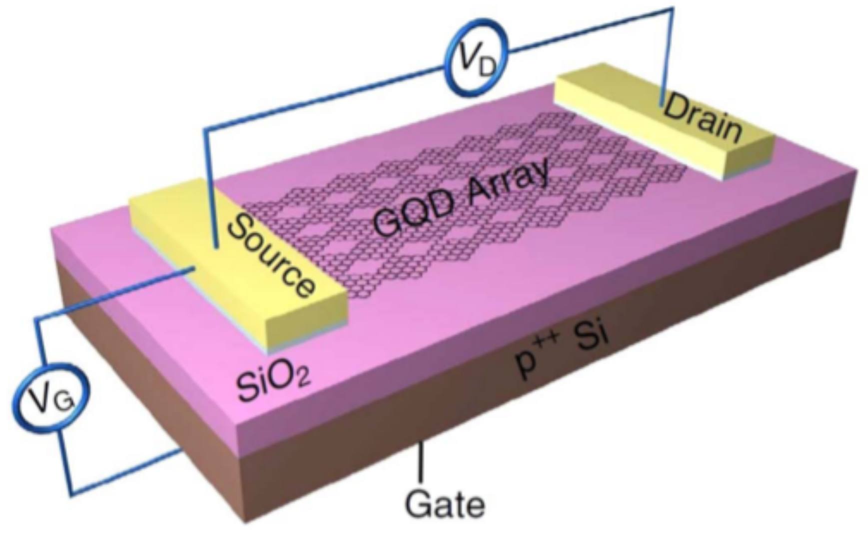
https://www.nature.com/articles/s41699-018-0062-6

Graphene and nanostructures as solid converter



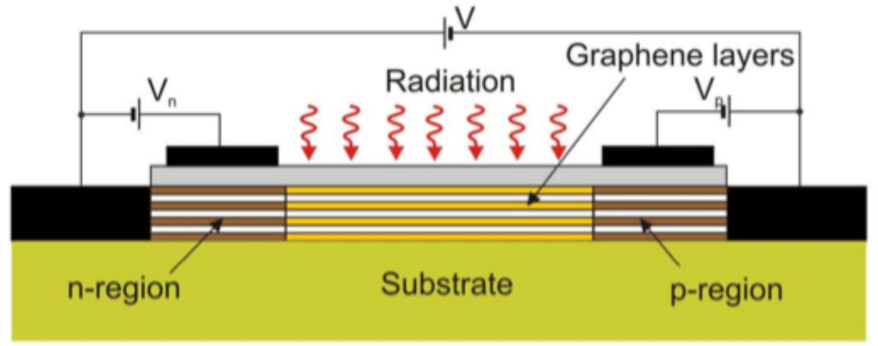
- Photodetectors using graphene and GQDs have been demonstrated in solid-state devices
- Can electrons be extracted into gas to use these layers/structures as photocathodes / converters for gaseous detectors?

Broadband (532nm, 1.47μm, 10μm) GQC array photodetector



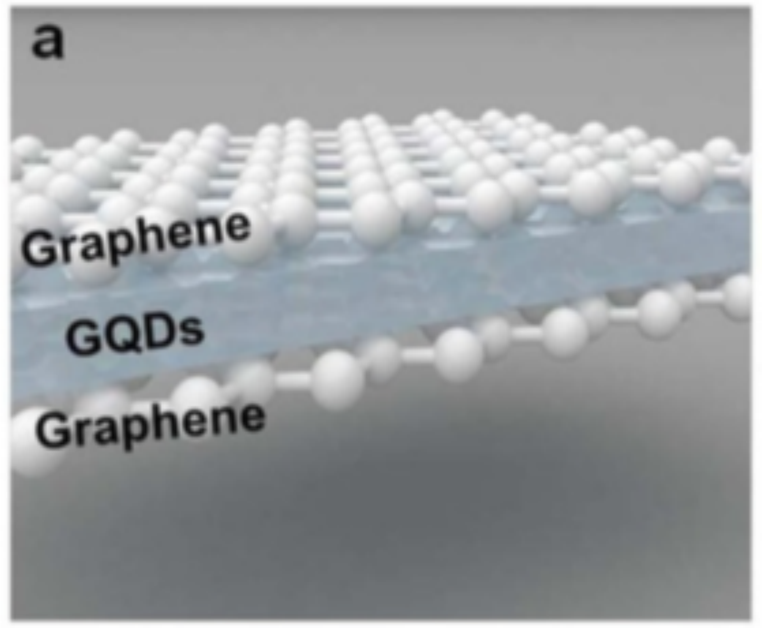
Zhang et al., Nat. Commun. 4, 1811 (2013) [55]

THz detector based on multiple graphene layers



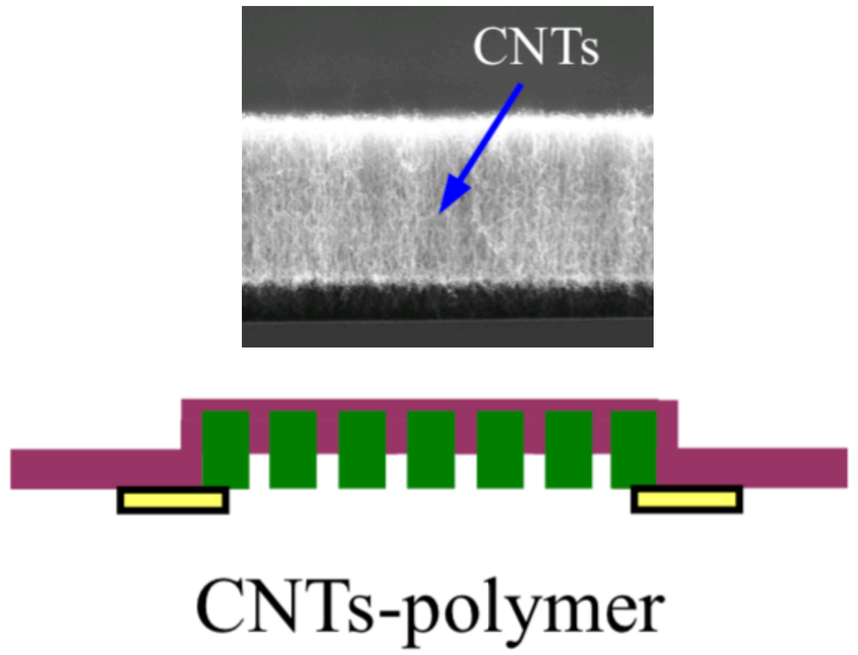
https://doi.org/10.1063/1.3327441

UV-to-NIR response of GQDs between graphene layers



https://www.nature.com/articles/srep05603.pdf

Broadband photodetector based on vertical CNTs



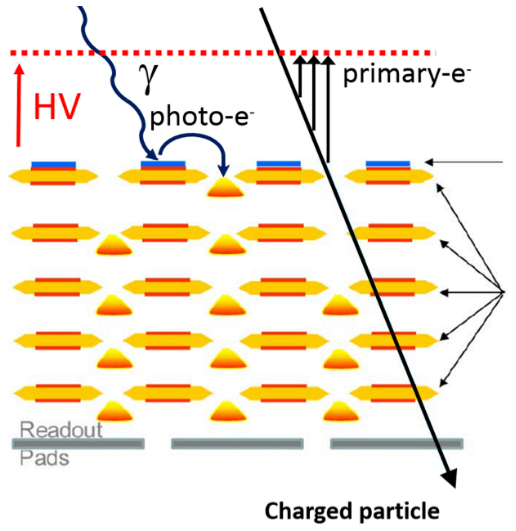
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5442534

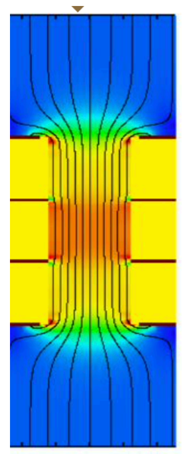
Summary

Gaseous photon detectors

Gaseous photon detectors provide economic solution for instrumenting large areas with high-sensitivity photon detectors. They provide high-gain and are compatible with high-rate operation and operation in magnetic fields. Flat detector structures are well suited for integration in compact spaces.

COMPASS RICH-1

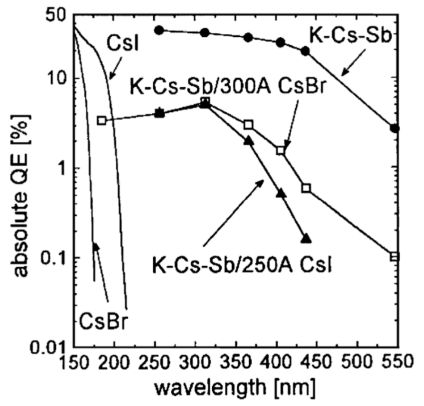


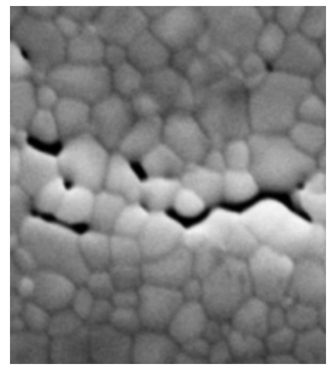


M-THGEM

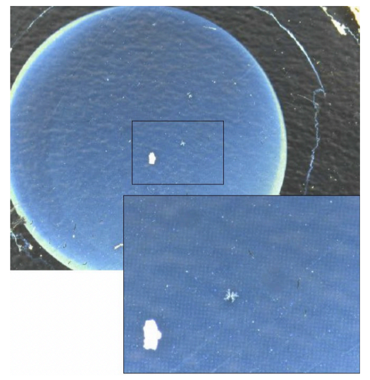
Photocathodes

Solid photocathodes replace vapour photocathodes in gaseous detectors due to ease of handling and improved spatial and timing information. CsI remains most widely used VUV photocathodes. Ion back flow suppression (by detector geometry optimisation) is pursued in view of using visible light photocathodes with low electron emission threshold



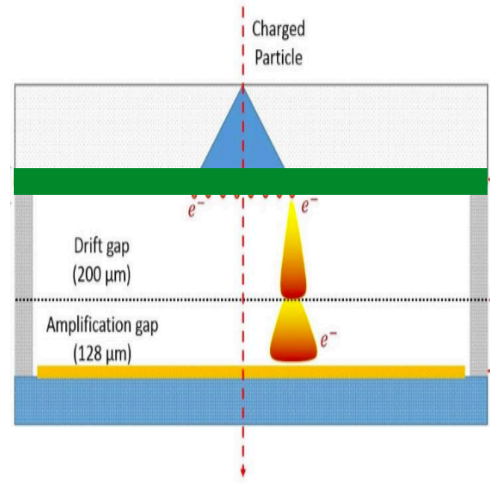


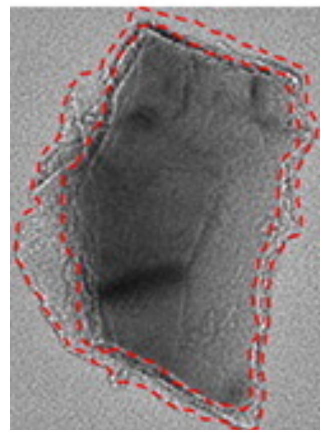
https://doi.org/10.1016/j.nima.2009.05.179



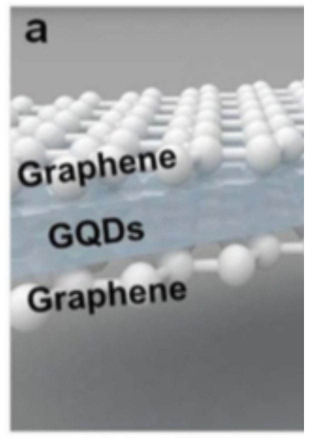
New detector structures and materials

Optimised detector structures for lower ion back flow are developed - hybrid MPGDs, additive manufacturing of detailed electrode structures and multi-stage amplification. Nanomaterials such as graphene may be used to protect photocathodes against ion bombardment and may also be used as novel photocathodes with wideband sensitivity.





L.Velardi,A.Valentini,and G.Cicala, Appl. Phys. Lett.108, 083503 (2016)



https://www.nature.com/articles/srep05603.pdf