3rd International Conference on DETECTOR STABILITY AND AGING PHENOMENA IN GASEOUS DETECTORS

Aging of Photocathodes and Exploration of Novel PC Materials

Shuddha Shankar Dasgupta

Center for Medical and Radiation Physics,

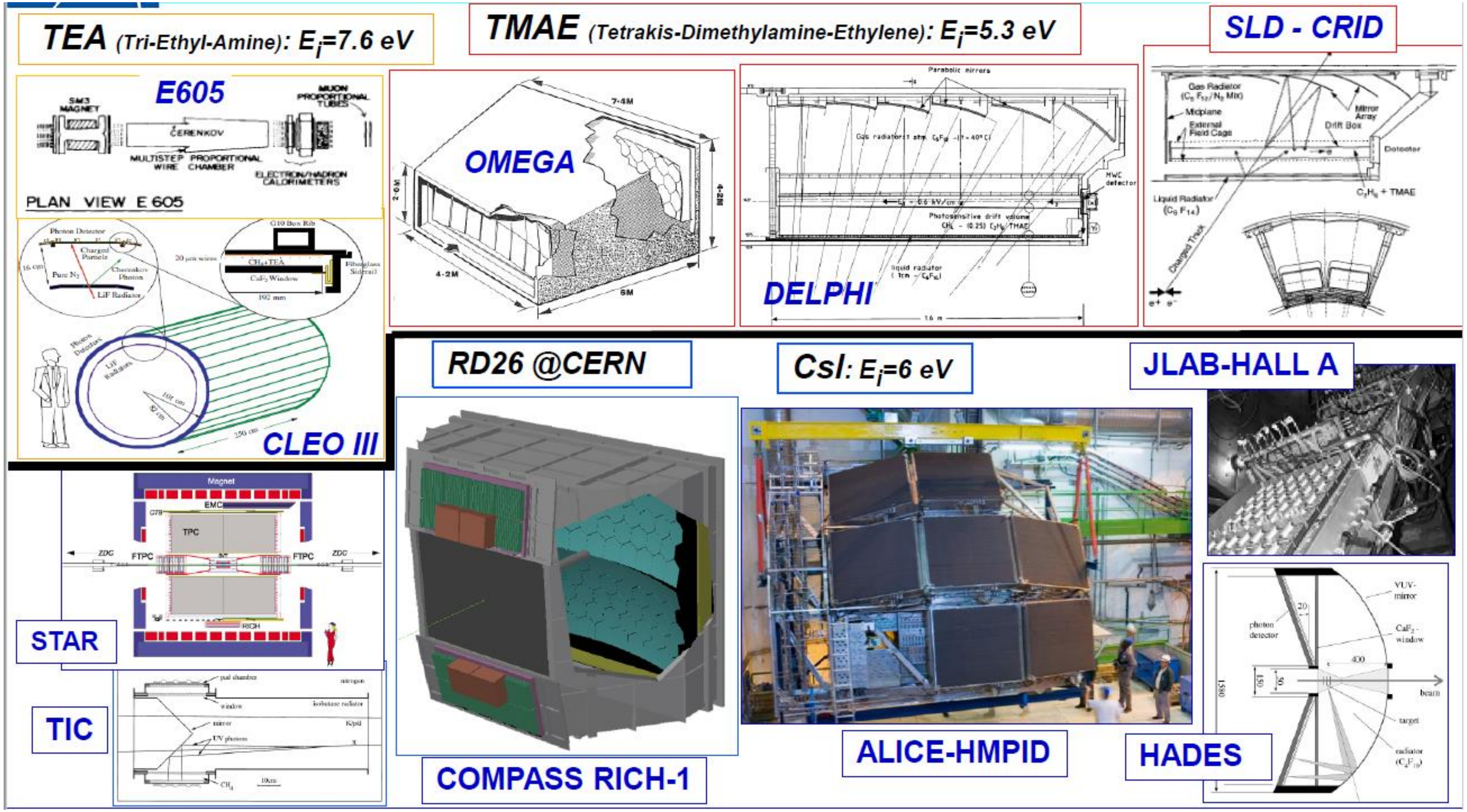
National Institute of Science Education and Research,

Bhubaneswar, India

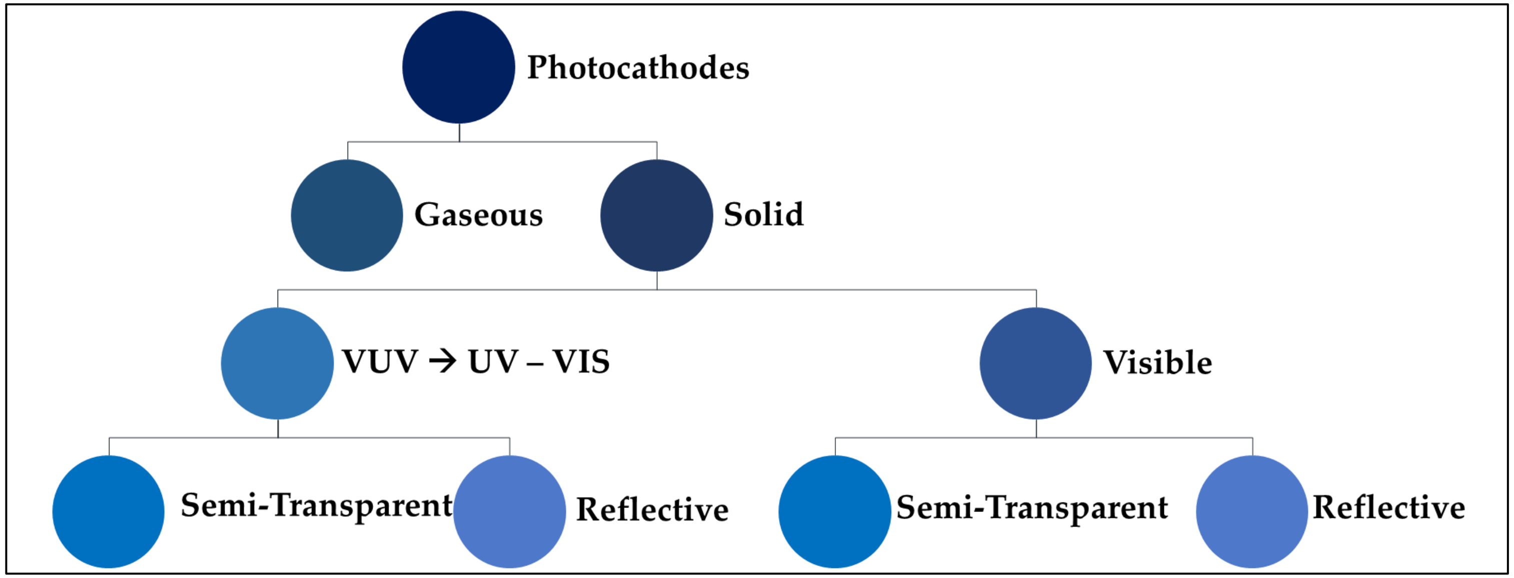
Outline

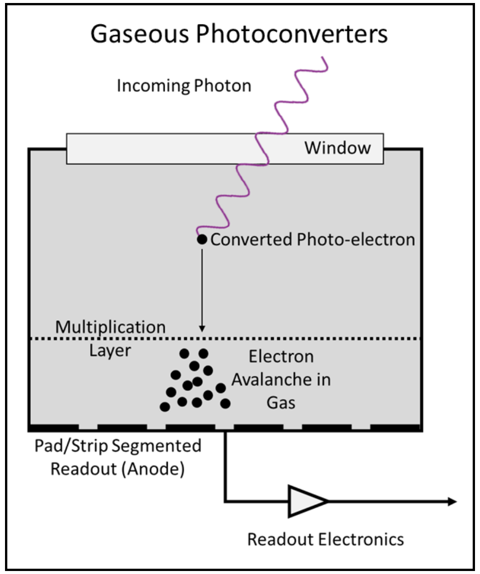
- Introduction
- Photocathodes
- Photon Detectors
- Aging Studies
- New Approaches
- Conclusions

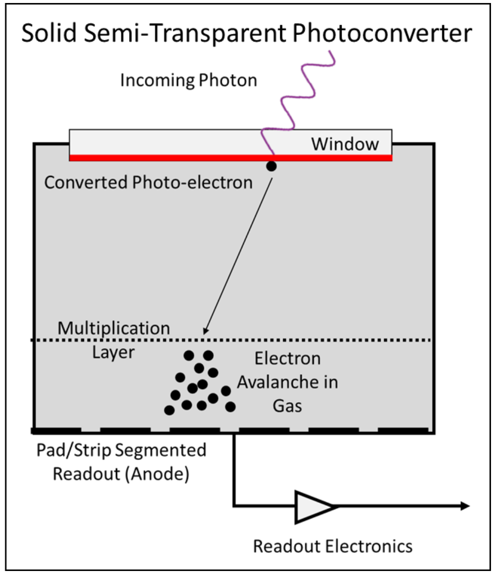
Gaseous Photon Detectors



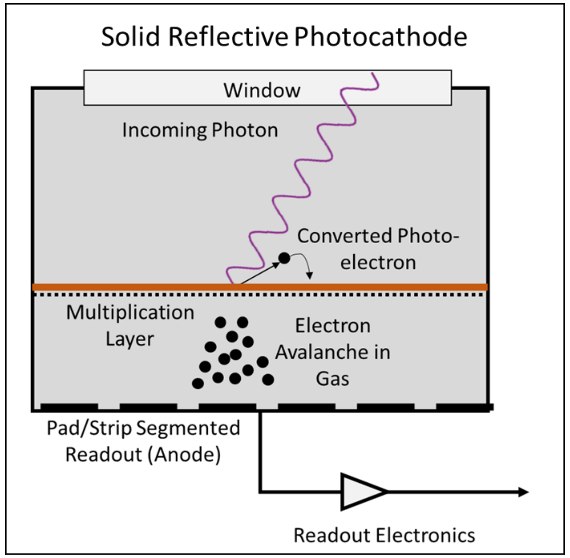
Type of Photocathodes and aging causes







- The main causes of PC aging are:
    1. Environmental Contaminations: e.g. O_2, H_2O, heat etc.
    2. Exposure of the PC to radiation due to particle flux.
    3. Ion back Flow (IBF) to the PC: mainly important for Gas avalanche detectors.
- In this presentation, we will discuss gaseous detectors → mainly the **Quantum Efficiency (QE) degradation** due to **IBF and radiation exposure** in terms of accumulated charge in units of **$mC.cm^{-2}$**.



CsI: Why and When

- Need for π-K identification from HEP Experiments
- Large momentum acceptance → Cherenkov angle measurement technique
- Large angular acceptance → large area of efficient single photon detection

- Gaseous detectors are:
  1. cheap,
  2. magnetic insensitive,
  3. low material budget

- **1956:**
- **CsI layer has large QE for photons with $h\nu > 6\ eV$ (Philipp and Taft)**

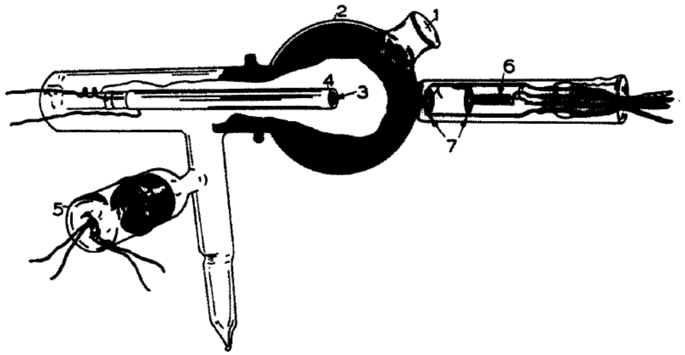


FIG. 1. Cutaway sketch of phototube; (1) 9741 glass bubble window, (2) graphite coated collector sphere 4 inches in diameter, (3) $\frac{3}{8}$ inch glass tube, platinum painted, (4) nickel sleeve insulated from tube by glass beads, (5) ion gauge, (6) evaporating cylinder and helical platinum heater, (7) collimating shields.

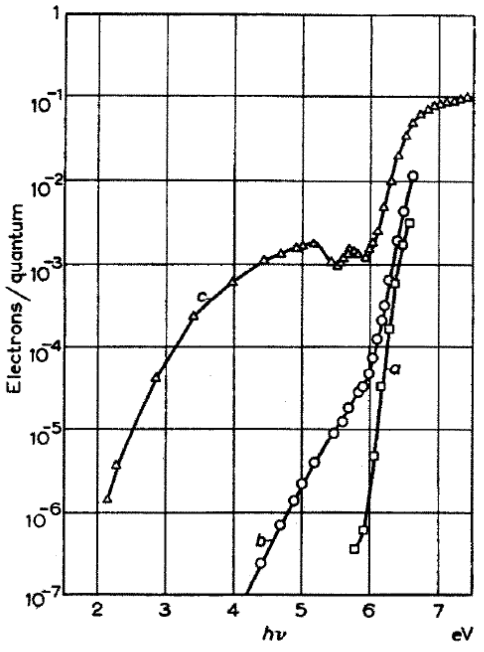


FIG. 2. Spectral distribution of the photoelectric yield for CsI surfaces: (a) thick film, (b) single crystal, (c) thin film evaporated in presence of excess Cs.

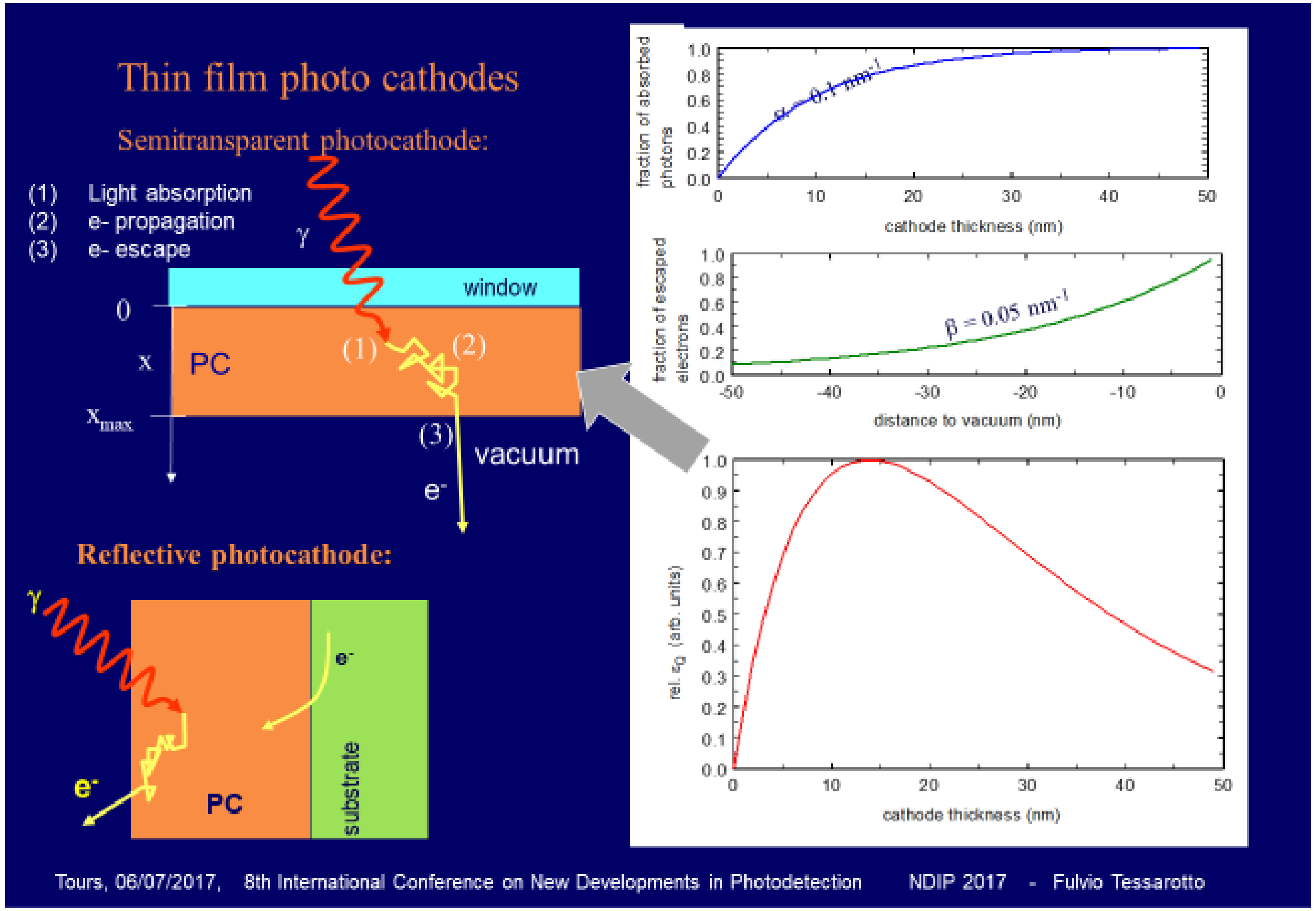
PHOTOELECTRIC EMISSION FROM THE VALENCE BAND OF CESIUM IODIDE

H. R. PHILIPP AND E. A. TAFT

General Electric Research Laboratory, Box 1088, Schenectady, New York

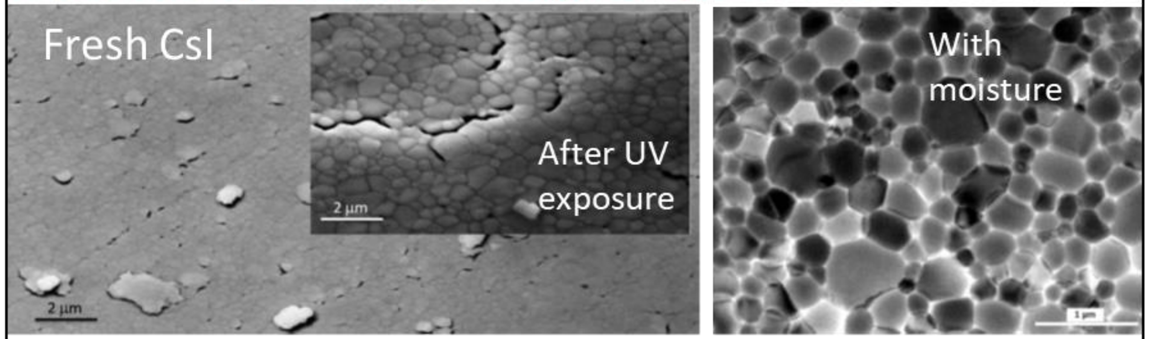
- **vacuum operated photocathodes were developed for space astronomy:**
- G.R.Carruthers,
  - Appl. Opt. 8 (1969) 633
  - Appl. Opt. 12 (1973) 2501
  - Appl. Opt. 14 (1975) 1667
- **The first position sensitive gas detectors with CsI photocathodes were developed at the end of the 80s:**
  - G.Charpak et al., Proceedings of Symposium on Particle Identification at
  - High Luminosity Hadron Colliders, Fermilab, Batavia, IL, 1989, p. 295.
  - J.Séguinot et al., Nucl. Instr. and Meth. A 297 (1990), p. 133

CsI: How to apply



1992, F. Piuz et al. Development of large area advanced fast-RICH detector for particle identification at LHC operated with heavy ions

CsI is highly reactive with moisture: it took many years to develop appropriate substrate preparation, deposition method, and handling technology for high QE gaseous PDs



B.K. Singh et al. NIMA 610 (2009) 350

Triloki et al. NIMA 695 (2012) 279–282

TO ACHIEVE HIGH CsI QE:

Substrate preparation:

Cu clad PCB coated by Ni (7 μm) and Au(0.5 μm), surface cleaning in ultrasonic bath, outgassing at 60 °C for 1 day

Slow deposition of 300 nm CsI film:

1 nm/s (by thermal evaporation or e⁻-gun) at a vacuum of ~ 10^{-7} mbar, monitoring of residual gas composition

Thermal treatment:

after deposition at 60 °C for 8 h

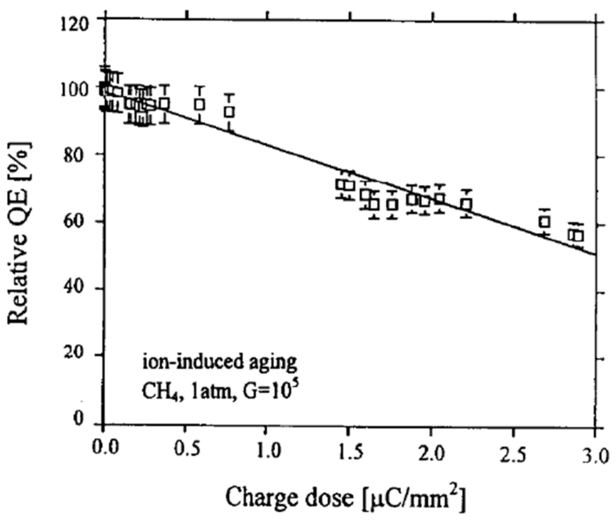
Careful Handling:

Measurement of PC response, encapsulation under dry Ar, mounting by glove-box.

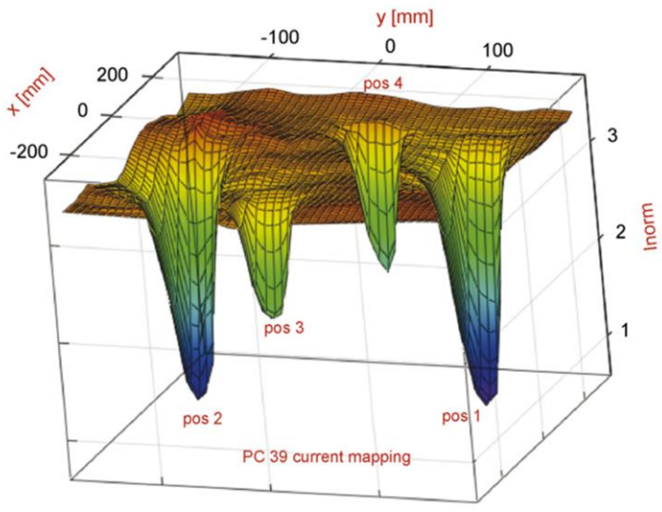
Aging of CsI Photocathodes

- Gaseous detectors → positive ions released out of the multiplication region
- Severe problems for high-rate / high-gain applications
- in Photon Detectors (PDs): photocathode ion bombardment
- in TPC: space charge → field distortion
- Before MPGDs:
- MWPC in continuous operation mode: IBF ~ 20%

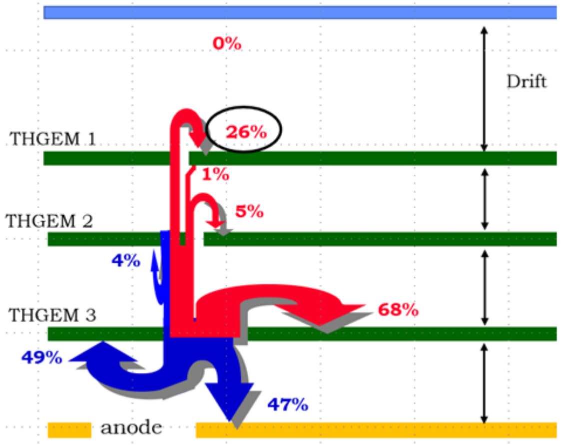
Breskin et al., NIMA 371(1996)116

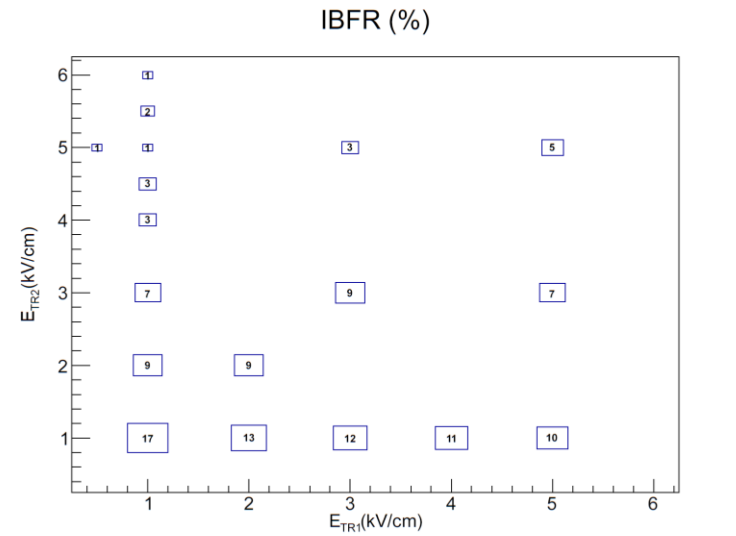


Hoedlmoser et al., NIMA 574(2007)28



Where charges end in a standard triple THGEM PD:





Severe CsI QE degradation for accumulated charge ~ 0.2 mC.cm^{-2}

- There are ways to reduce IBF to the photo-cathode:
  - Using multi-layer GEM/THGEM setups to reduce IBF to reflective PCs
  - Using the Micromegas (MM) Layer to trap ions in the MM layer.
- There are other innovative ideas like THCOBRA or MTHGEMs to reduce IBF.

ALICE HMPID

Ref: G. Volpe, RICH 2018 conference

HMPID detector description

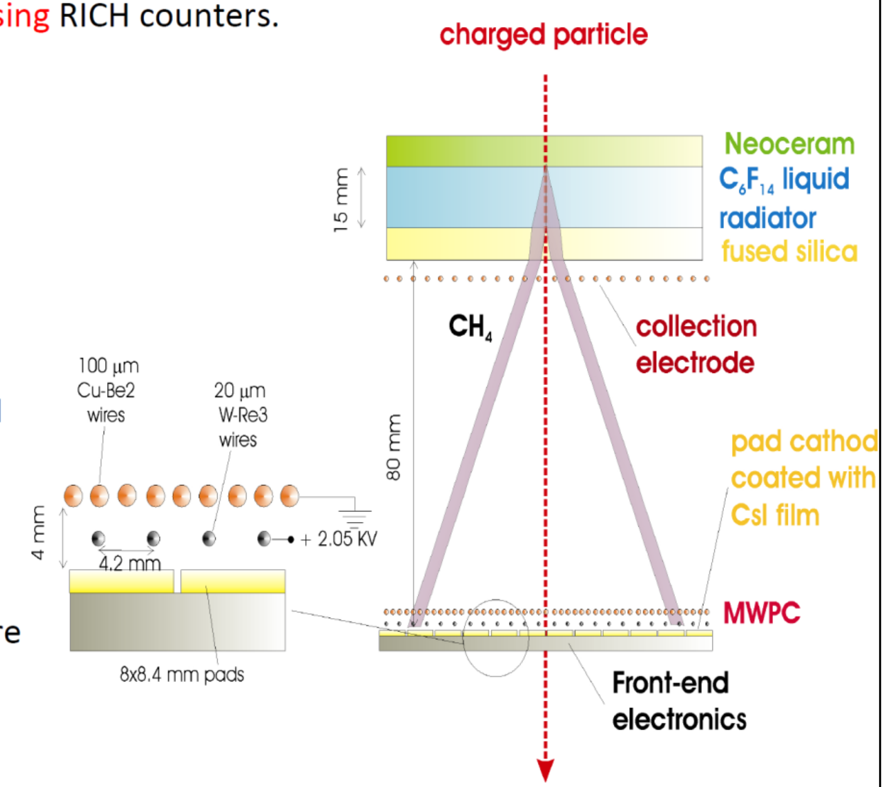
The ALICE-HMPID (**H**igh **M**omentum **P**article **Id**entification **D**etector) performs charged particle track-by-track identification by means of the measurement of the emission angle of Cherenkov radiation and of the momentum information provided by the tracking devices.

It consists of seven identical proximity focusing RICH counters.

RADIATOR
15 mm liquid C_6F_{14},
n ~ 1.2989 @ 175nm, β_{th} = 0.77

PHOTON CONVERTER
Reflective layer of CsI
QE ~ 25% @ 175 nm.
The largest scale (11 m^2) application of CsI photo-cathodes in HEP
≈ 5 % of TPC acceptance

PHOTOEL. DETECTOR
- MWPC with CH_4 at atmospheric pressure (4 mm gap) HV = 2050 V.
- Analogue pad readout

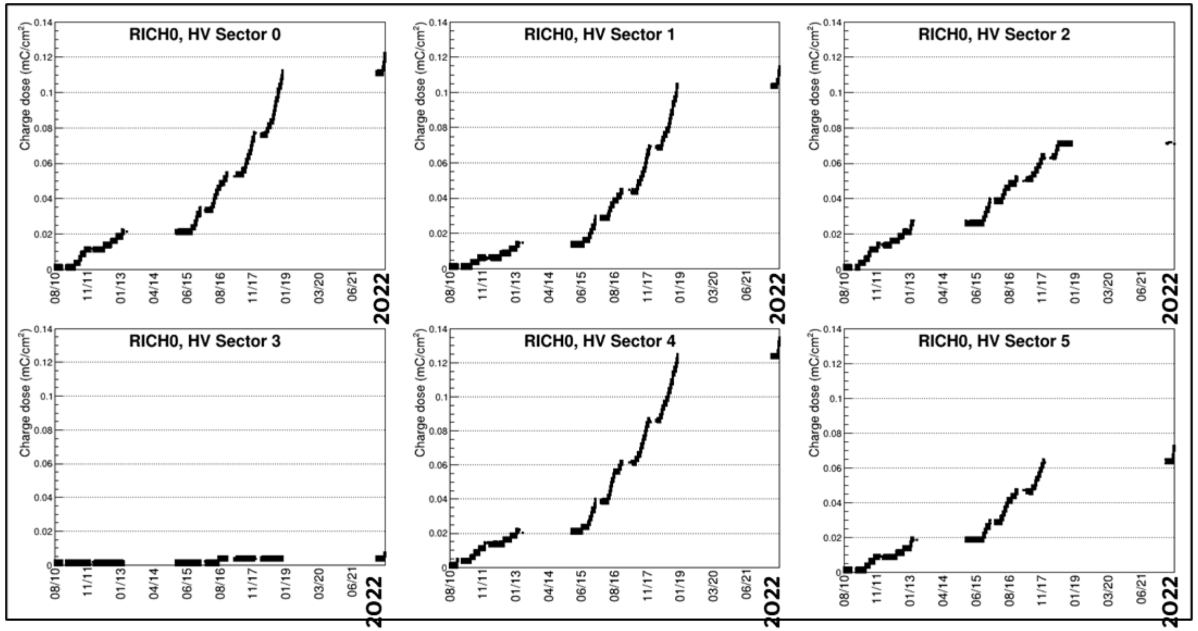


G. Volpe - RICH 2018 6

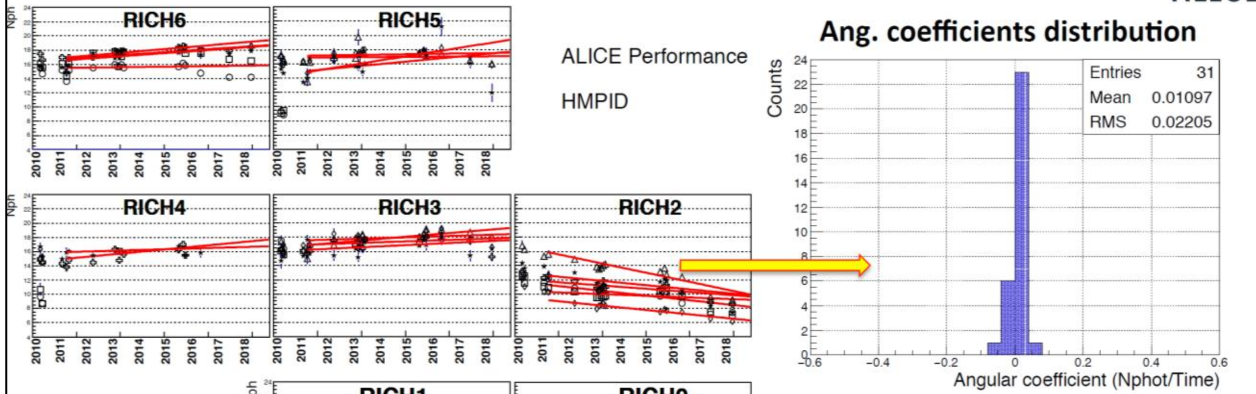
ALICE HMPID

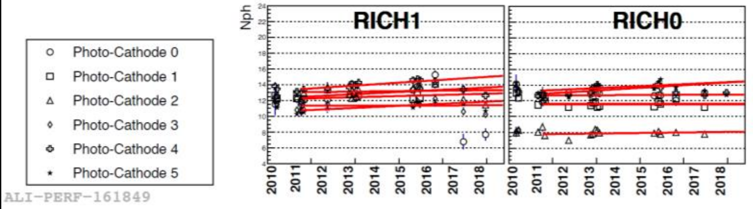
Ref: G. De Cataldo INFN Bari, It - CERN CH RICH 2022

Ref: G. Volpe, RICH 2018 conference



Detector stability: number of detected ph.e.





The distribution of the angular coefficients indicates no signs of ageing of the photocathodes!!

- Good N_{ph} stability infers a CsI QE stability;
- Except RICH2, where PC2 and PC3 show a drop of 30%. After cleaning, these PCs were re-evaporated during 2005, maybe procedure not optimised;
- Empty space between blobs represents LHC technical stops from 2010 up to 2015.

G. Volpe - RICH 2018 8

- No evidence for aging effects was seen for HMPID Photocathodes in RUN 1 and 2.
- Aging is expected for RUN3 with 4 times more accumulated charge in the photocathode

Specific CsI charge dose RUN 1-2

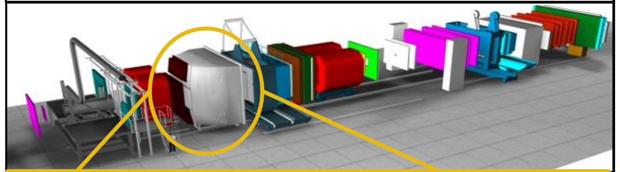
	Delivered Lumi	Measured <Specific Charge dose> mC/cm²	Measured <Tolal charge doose> mC/cm²	Expected CsI QE loss %
2010-2013 End of Run1	pp+Pb-Pb	0.002		0
2015 (Run2)	(pp) 7 pb^{-1} (Pb-Pb) 0.43 nb^{-1}	0.01 ~0.005	0.017	0
2016 (Run2)	(pp)13 pb^{-1} (p-Pb) 43 nb^{-1}	0.015 0.005	0.037	0
2017 (Run2)	(pp)18.9 pb^{-1} (Xe-Xe) 0.16 nb^{-1}	0.025 0.001	0.053	0
2018 (Run2)	(pp)27 pb^{-1} (Pb-Pb) 0.9 nb^{-1}	0.036 0.01	0.089 0.099	0
End Run2			**~0.1**	0

Expected CsI charge dose RUN 3

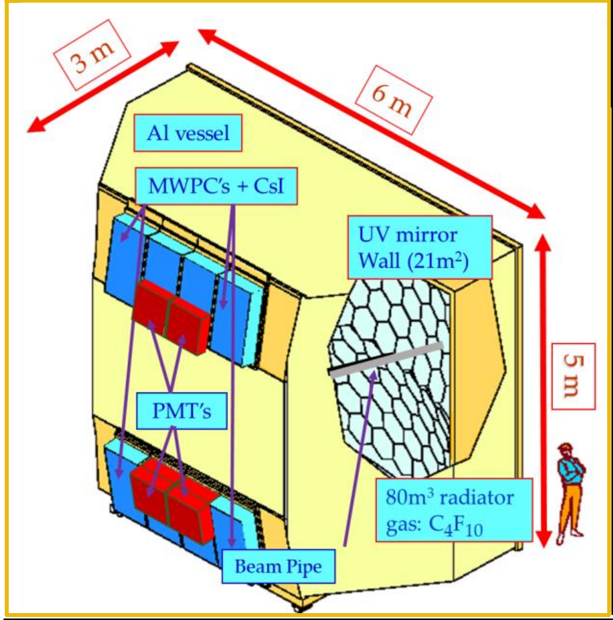
	Delivered Lumi	Measured <Specific Charge dose> mC/cm²	Measured <Tolal charge doose> mC/cm²	Expected CsI QE loss %
End Run2			0.1	0
2022 (Run 3)	(pp) 40 pb^{-1} (Pb-Pb) 3 nb^{-1}	0.054 0.034	0.188	
2023 (Run 3)	(pp)40 pb^{-1} (Pb-Pb ??) 3 nb^{-1}	0.054 0.034	0.276	5
2024 (Run 3)	(pp)40 pb^{-1} (Pb-Pb ?) 3 nb^{-1}	0.054 0.034	0.364	6
2025 (Run 3)	(pp)40 pb^{-1} (Pb-Pb) 3 nb^{-1}	0.054 0.034	0.452	8
End Run3			**~0.452**	

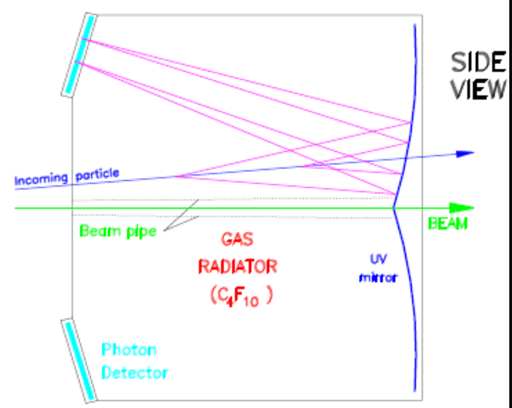
COMPASS Gaseous PDs: RICH1 Photosensors

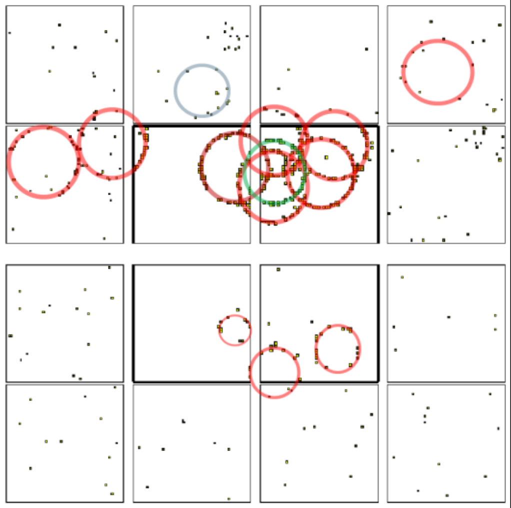
Compass Experimental Setup



Compass RICH1

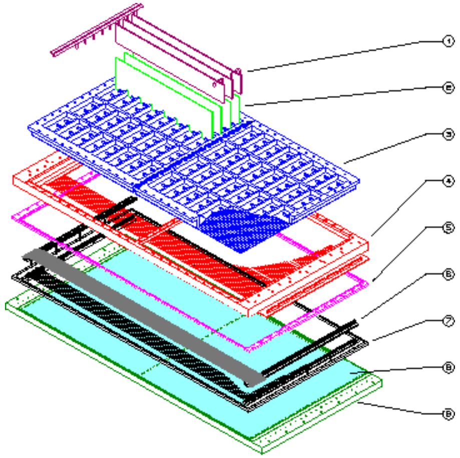


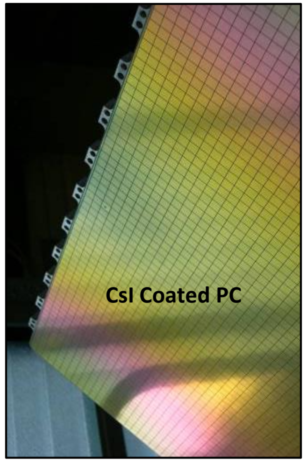


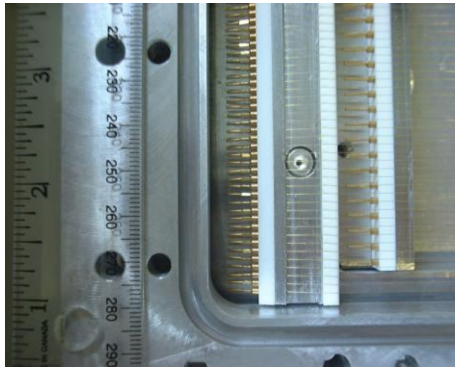


- hadron PID from 3 to 60 GeV/c
- acceptance: H: 500 mrad V: 400 mrad
- trigger rates: up to ~50 KHz
- beam rates up to ~10^8 Hz
- material in the beam region: 1.2% X_0
- material in the acceptance: 22% X_0

- detector designed in 1996
- In operation since 2002
- upgraded in 2006
- total investment: ~ 5 M €
- A NEW UPGRADE HAS BEEN DONE IN 2016



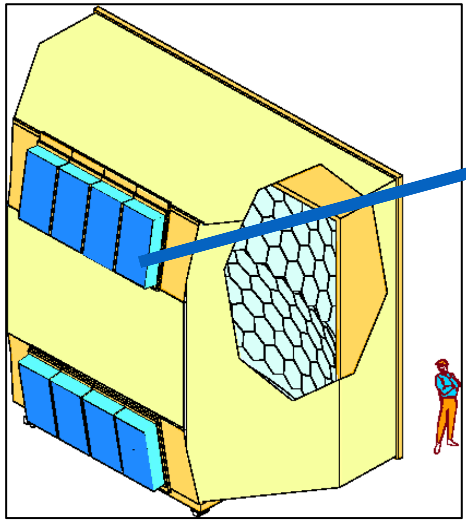


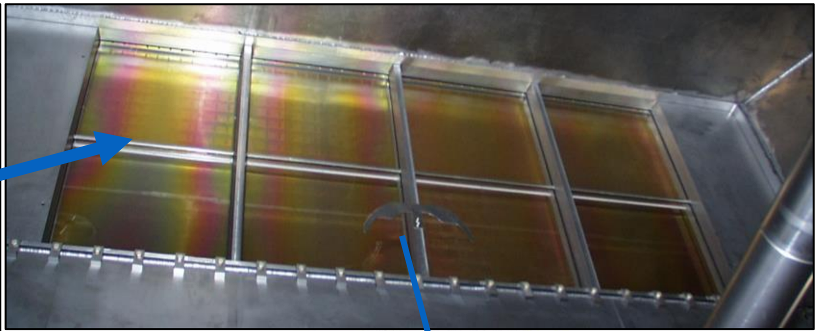


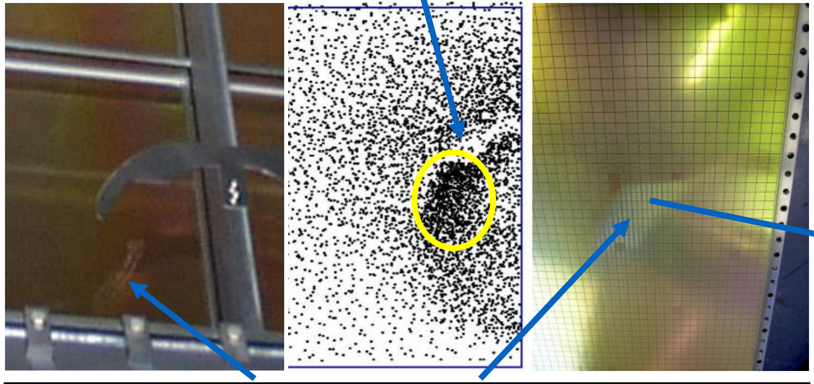
COMPASS RICH1 MWPCs with CsI:

- Minimal fiberglass material used.
- 0.3 mm cathode inter-pad.
- Anode wire only solder in PCB.
- Only metal and Ceramic components.
- All SS 305 gas connectors from Swagelok.

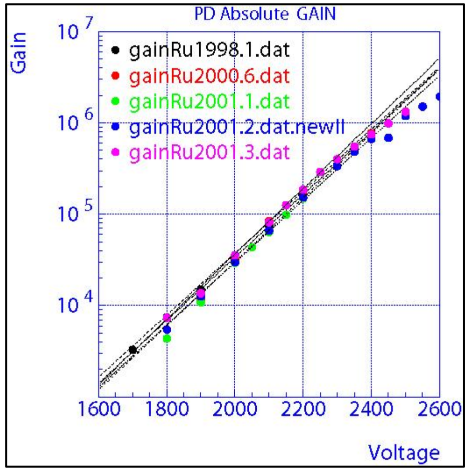
CsI Photocathode aging of COMPASS RICH1 MWPCs: CsI memory?



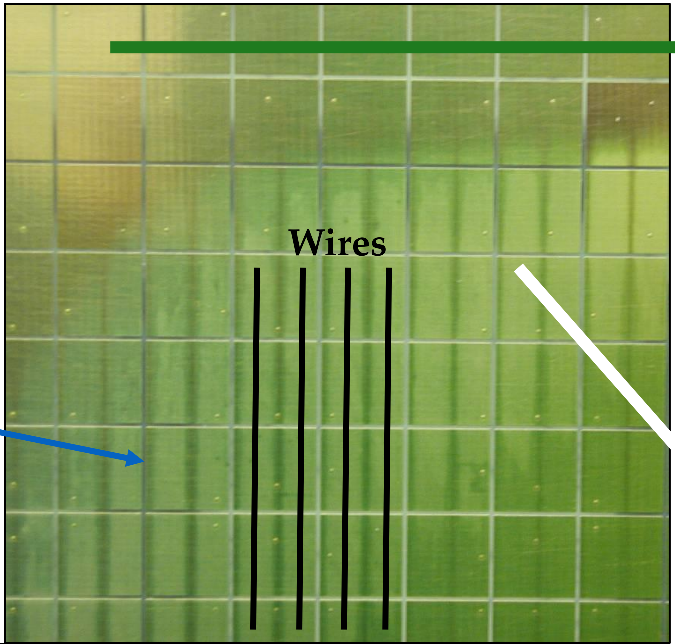


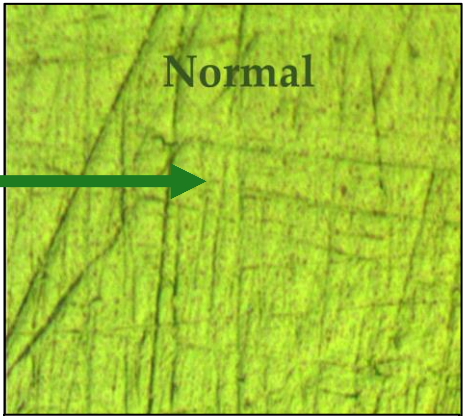


Highest photon flux region: Accumulated charge:~ 1 mC/pad

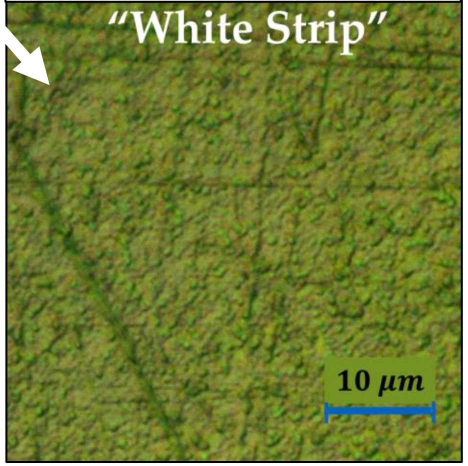


Accidental Exposure to the air of one CsI Photocathode





CsI surface at the microscope (x 1000)

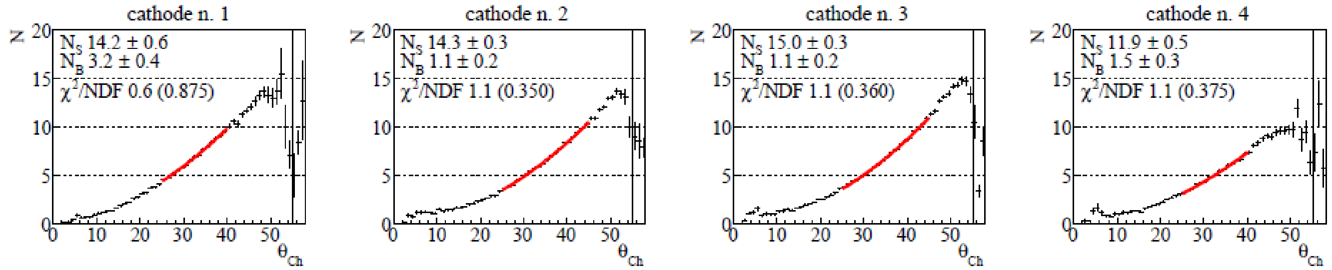


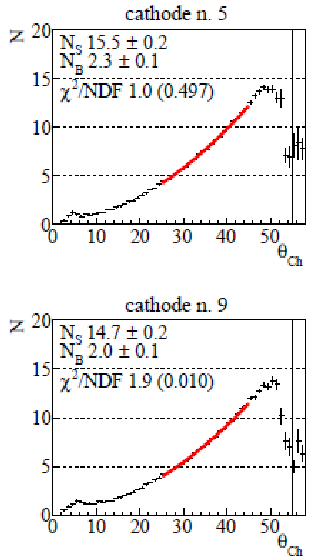
1) MWPCs with CsI photocathodes in COMPASS:
- Beam off: stable operation up to > 2300 V
- Beam on: stable operation only up to ~2000 V
- (in spill→ ph. flux: 0 - 50 kHz/cm^2 , mip flux: ~1 kHz/cm^2)
- Whenever a severe discharge happens, recovery takes ~1 day.

2) Photocathode aging:
- Our information from accidental contamination
- Very detailed study by Alice team

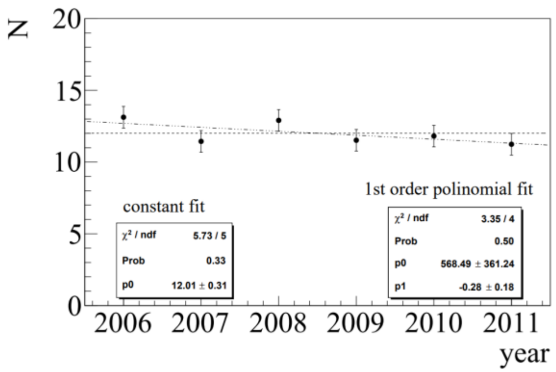
- **CsI has a memory of radiation exposure**: **Crystalline structure changes from nanocrystals to microcrystals**: **After accidental exposure to air one can see the area exposed to radiation becomes white**.

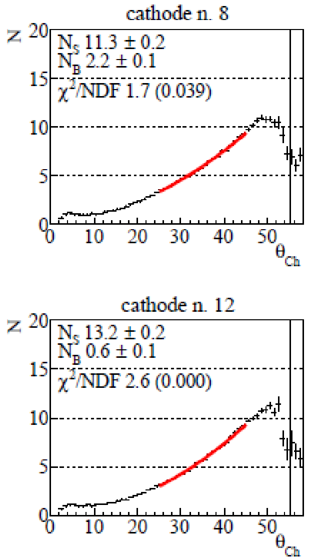
COMPASS RICH1

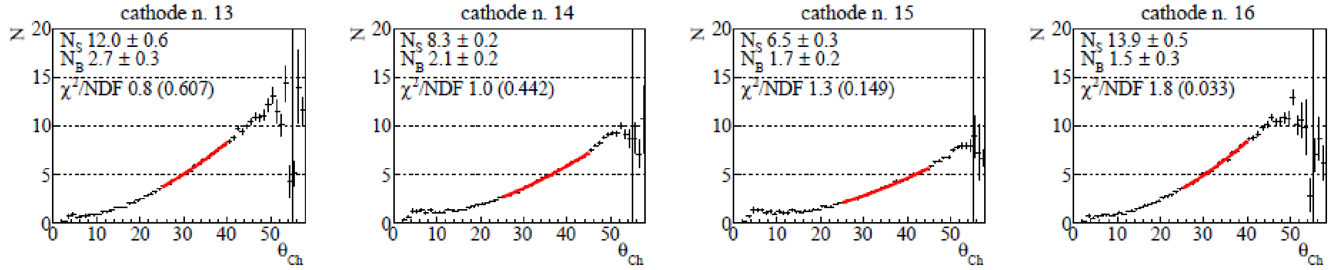


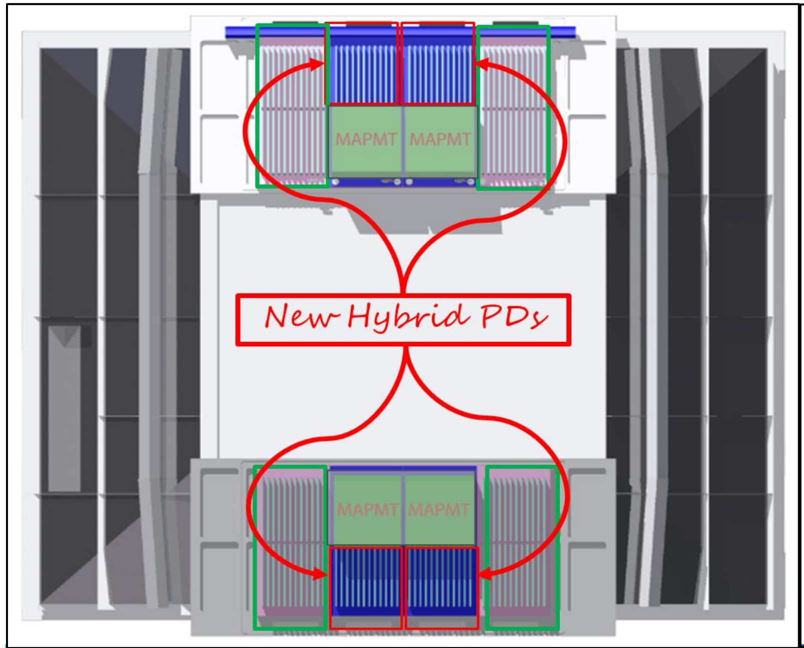


- No significant degradation of N_{ph} seen in the Detectors
- QE degradation ~ 2.5%





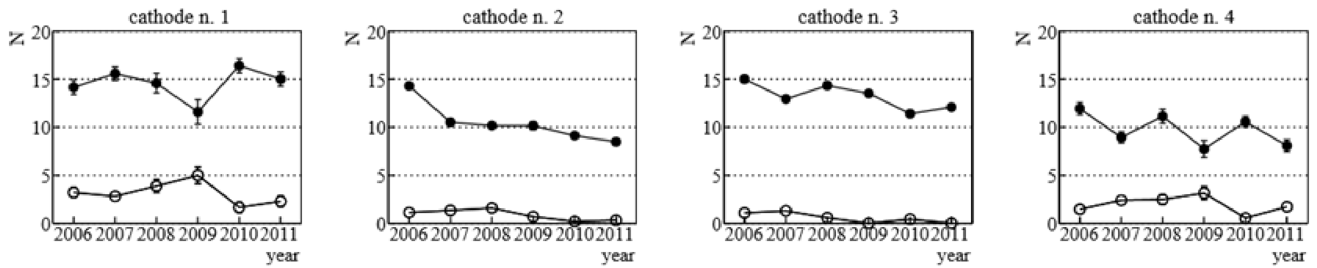


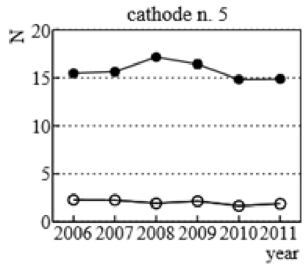


Photon View of the COMPASS RICH1

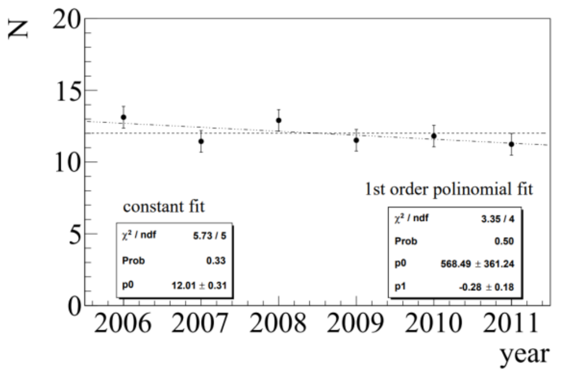
- In order to cope with the challenging requests posed by the future physics program of COMPASS a set of new generation, high performing photon detectors with an active area of 576X576 mm^2 will be installed. The characteristics of the new detectors are:
  1. A small time resolution ≤ 10 *ns*.
  2. A closed geometry to avoid photon feedback
  3. A large gain (≥ 10^5).
  4. A reduced Ion Back – Flow (IBF) to the CsI photocathode (≤ *few* %).

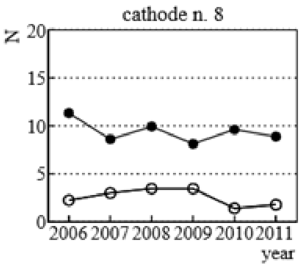
COMPASS RICH1

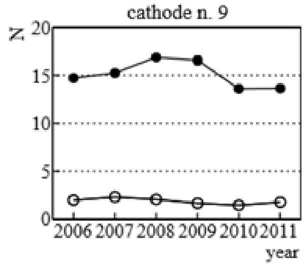


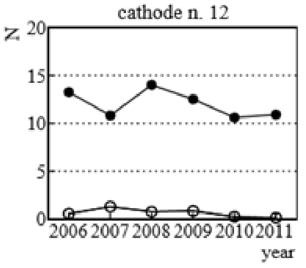


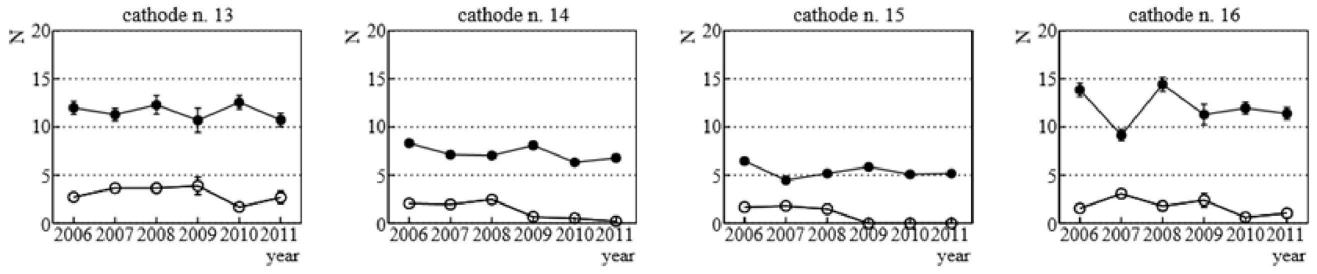
- No significant degradation of N_{ph} was seen in the Detectors
- QE degradation ~ 2.5%

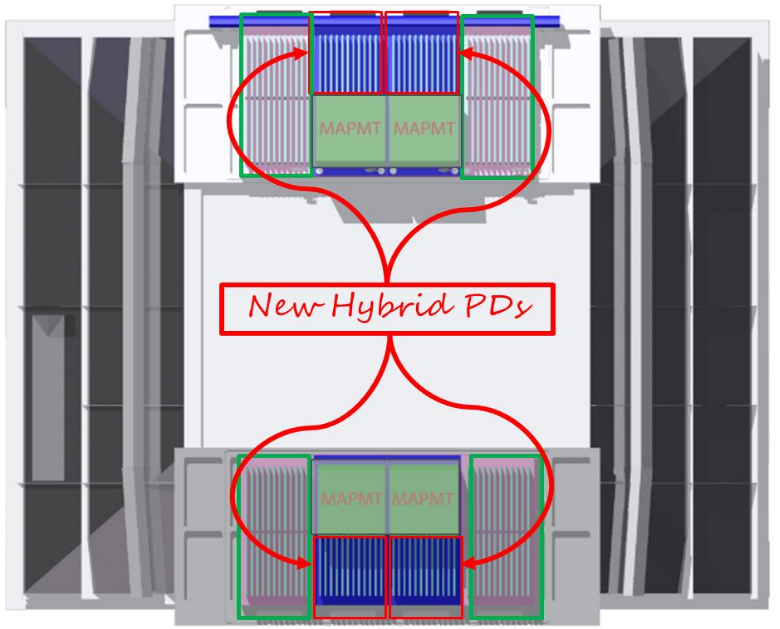










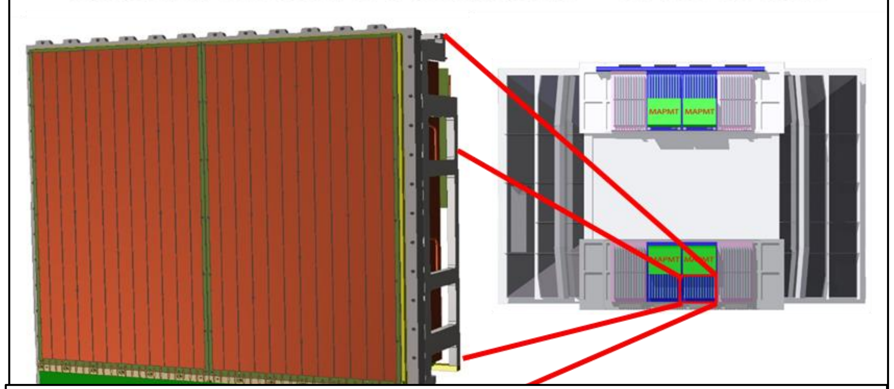


Photon View of the COMPASS RICH1

- In order to cope with the challenging requests posed by the future physics program of COMPASS a set of new generation, high performing photon detectors with an active area of 576X576 mm^2 will be installed. The characteristics of the new detectors are:
  1. A small time resolution $\leq 10\ ns$.
  2. A closed geometry to avoid photon feedback
  3. A large gain ($\geq 10^5$).
  4. A reduced Ion Back – Flow (IBF) to the CsI photocathode ($\leq few$ %).

Gaseous PDs using MPGDs

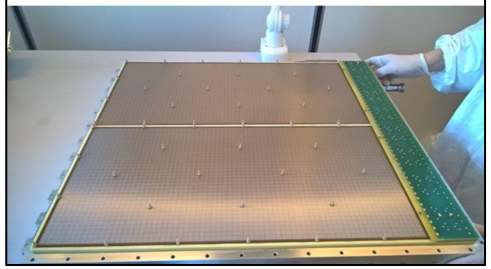
Modular structure: one module = 600x300 mm^2

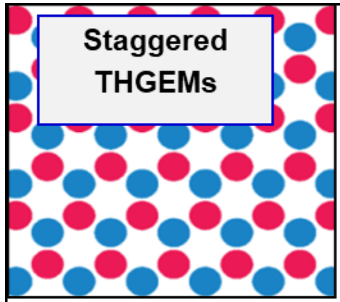


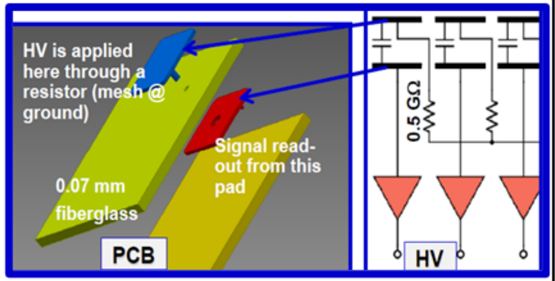
Ref: S. Dalla Torre, NIM A 970 (2020) 163768

Hybrid PD scheme

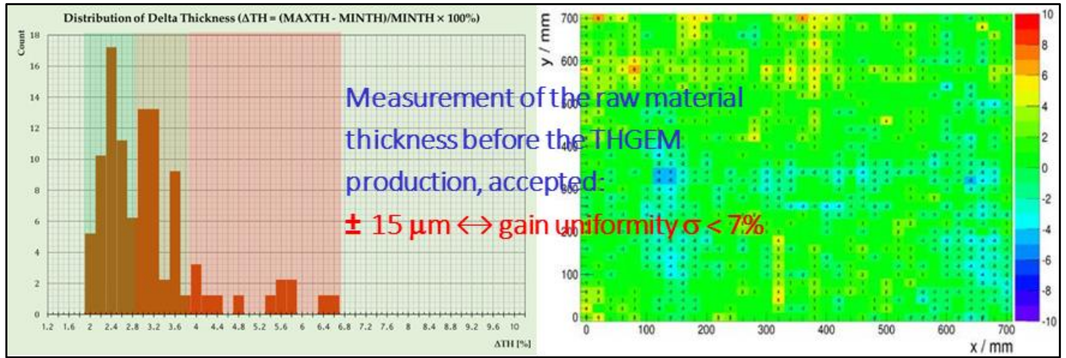
Standard Bulk Micromegas produced at CERN



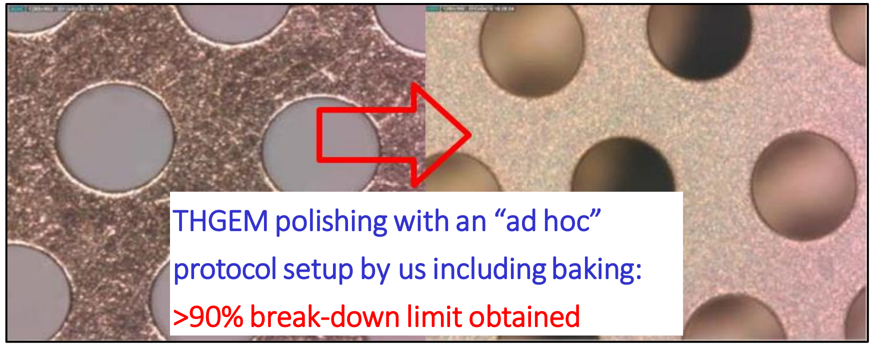




Thanks to staggering and MM → IBF reduced to < 4%

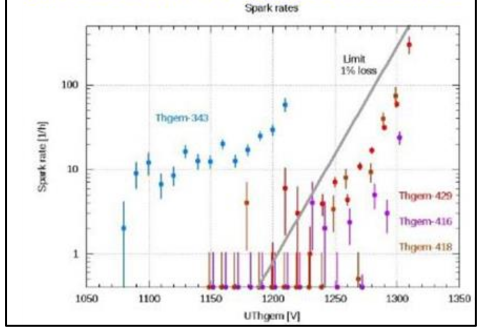


Measurement of the raw material thickness before the THGEM production, accepted:
± 15 μm ↔ gain uniformity σ < 7%

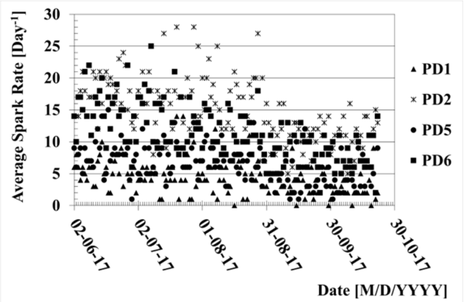


THGEM polishing with an "ad hoc" protocol setup by us including baking:
>90% break-down limit obtained

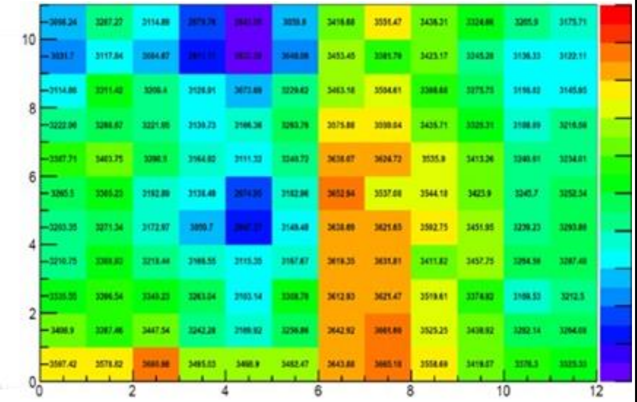
X-ray THGEM test to access gain uniformity (<7%) and spark behaviour



Detailed Spark Rate analysis over 5 months of Data Taking had been performed

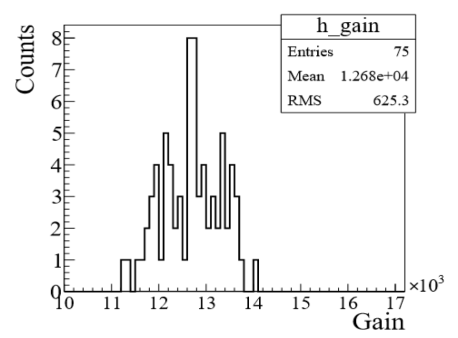


188	202	185	198	206	207
196	207	196	198	199	207
192		193	198	204	204
192		188	199	202	205
199	199	191	195	195	
199	196	199	205	195	199
192	190	194	197	195	194
198	190	195	209	195	199
198	199	195	208	197	201
198	199	195	199	200	199
190	186	185	199	190	199

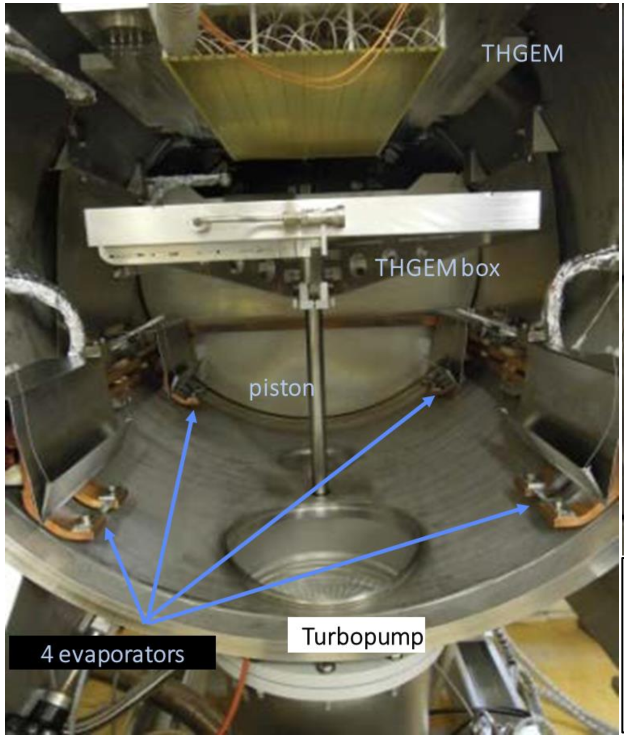


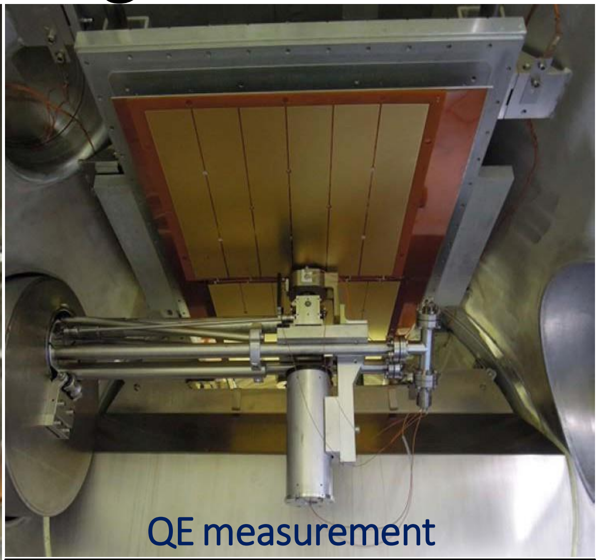
- THGEM Eff. GAIN uniformity ~ 5%
- MM Eff. GAIN Uniformity < 10%
- Only THGEM Having less sparks chosen.

- Eff. Gain stability over 75 sectors ~5%
- Daily 1 sparks/Sector/day



THGEM CsI coating at CERN



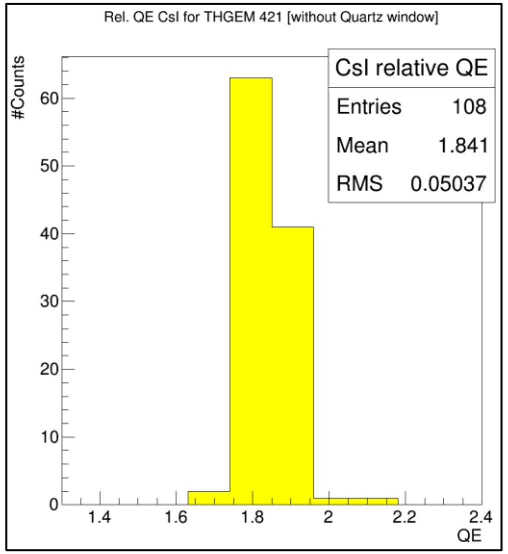


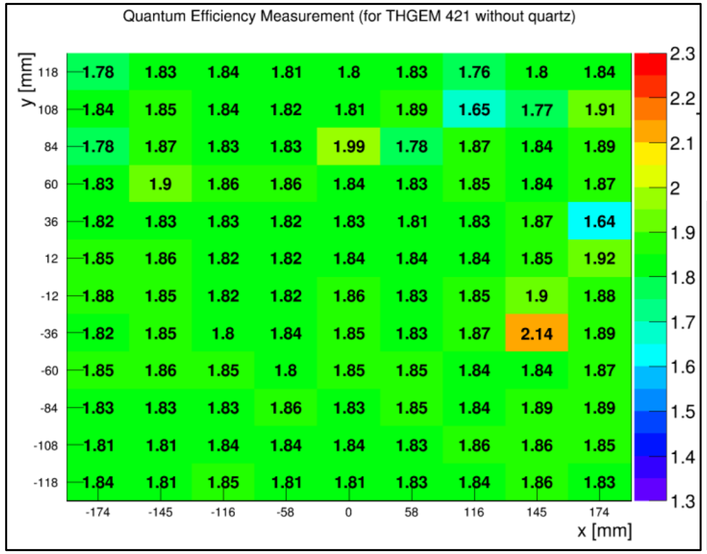
QE uniformity
- ✓ 3 % r.m.s. within a photocathode
- ✓ 10 % r.m.s. among photocathodes
- ✓ mean value: 93% of reference

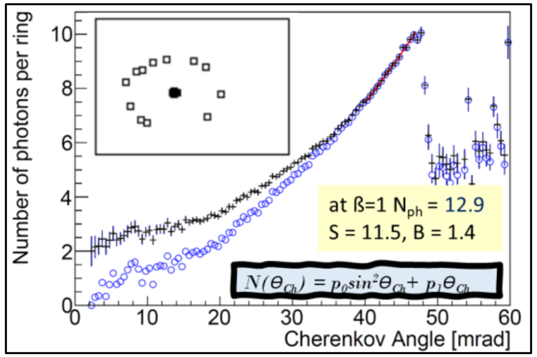
REL QE	Jura		Saleve	
Top	3	3.14	2.83	2.74
Bot	2.47	2.44	2.47	2.98

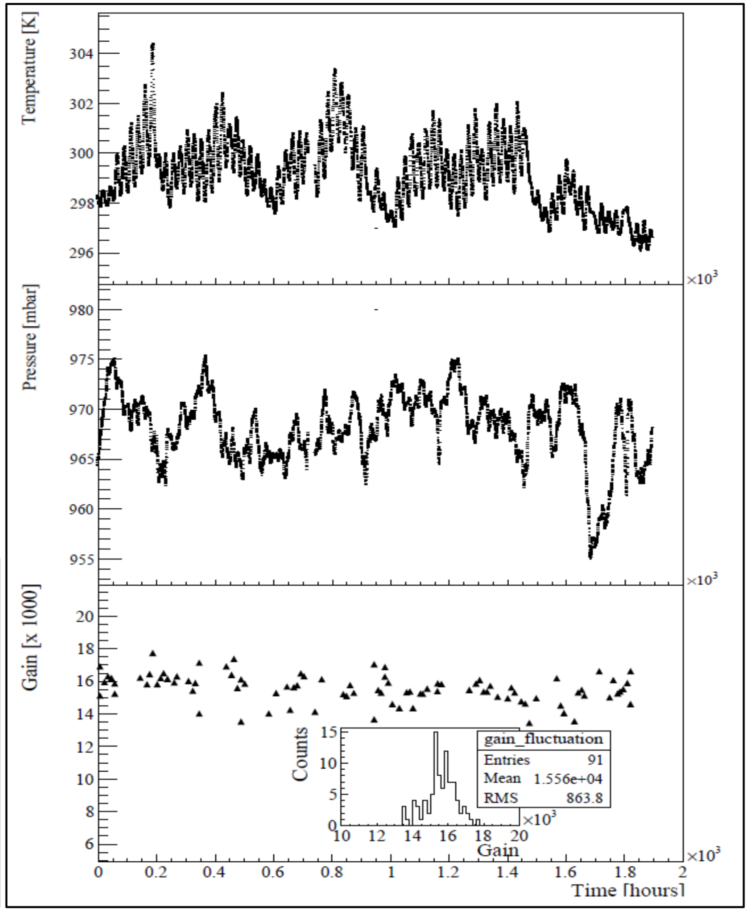
PD6				PD5				Total
S3	S2	S1	S0	S3	S2	S1	S0	All Sectors
2	3	0	9	0	3	Crazy	1	18
PD2				**PD1**				**Total**
S3	S2	S1	S0	S3	S2	S1	S0	All Sectors
0	0	4	3	2	0	0	2	11

- The Sparks created shorts in the MM but didn't affected the CsI QE
- The detector shows a gain stability ~ 5% for Effective Gain of ~ 16k with 1.8 mbar angular resolution over 1.4 m^2 Detection area.
- Thanks to the Micromegas layer that reduces IBF < 5%







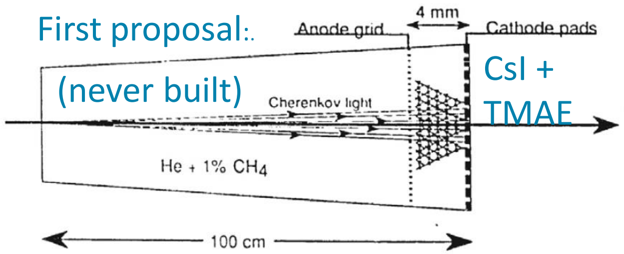


GEMs + CsI photocathodes for "HBDs"

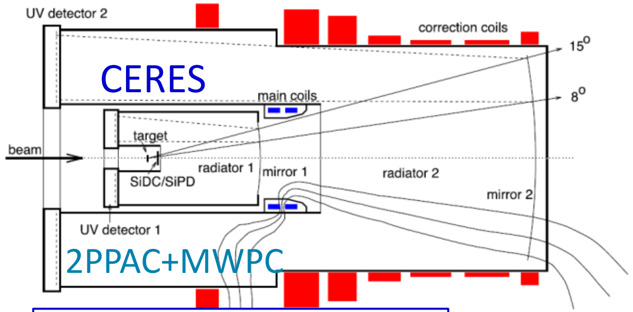
Review: I.Tserruya et al. NIM A 970 (2020) 163765

First proposal:

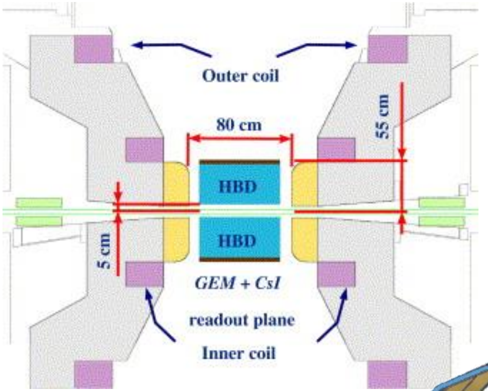
(never built)



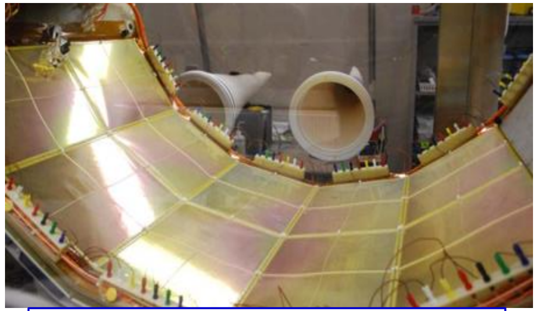
Y. Giomataris et al. NIM A 310 (1991) 589



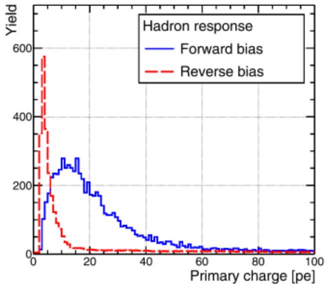
R. Baur et al. NIM A 343 (1994) 60



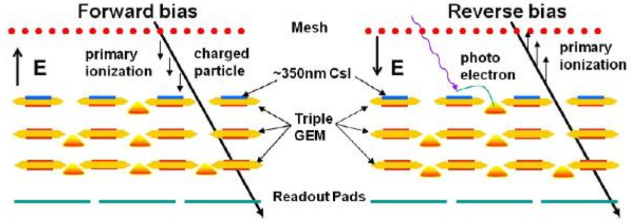
PHENIX

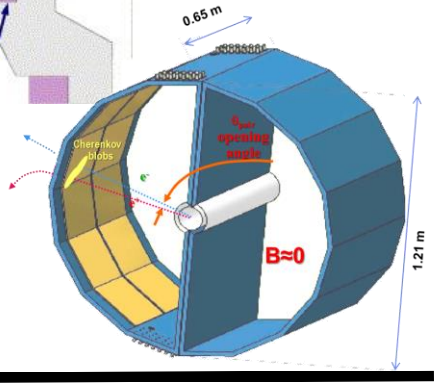


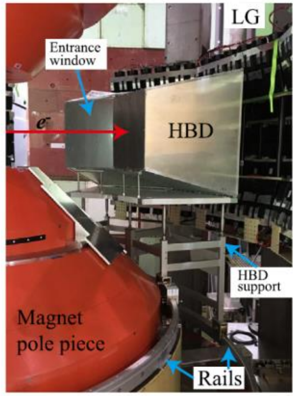
W. Anderson et al. NIM A 646 (2011) 35



Triple GEM windowless

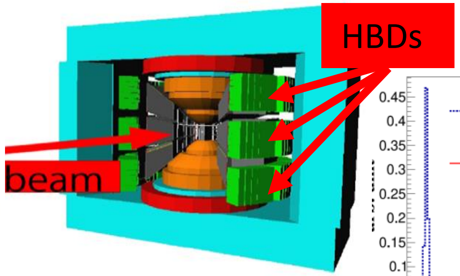






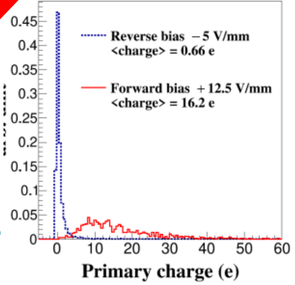
J-PARC E16

Triple GEM

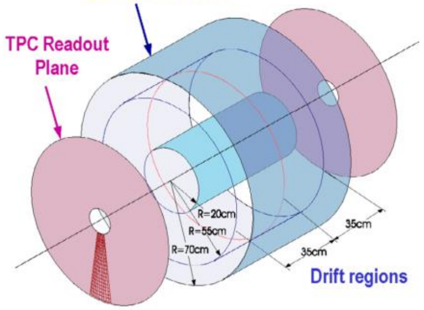


hexagonal pads,10 mm side

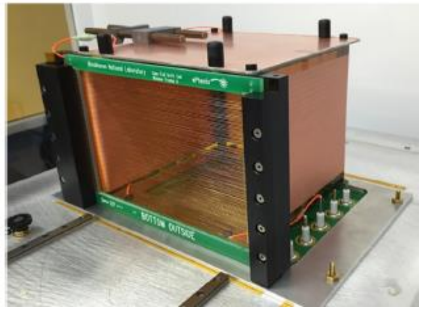
→ cluster size analysis



TPC Cherenkov Detector



Quadruple GEM



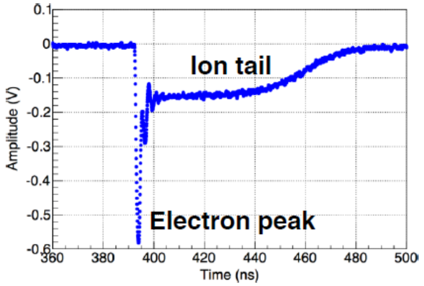
B. Azmoun et al. IEEE TNS 66 (2019) 1984

“PICOSEC” timing with gaseous PD

PICOSEC detection concept

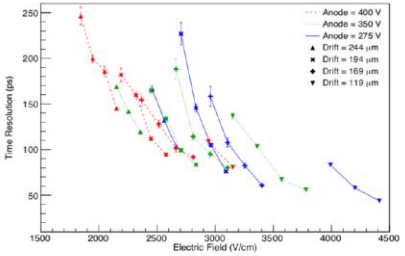
Precise timing with Micromegas

PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector
J. Bortfeldt et. al. (RD51-PICOSEC collaboration), Nuclear. Inst. & Methods A 903 (2018) 317-325



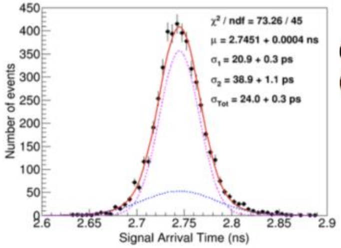
- **Signal with two distinct components:**
  Electron peak: fast (≈0.5 ns)
- Ion tail: slow (≈100 ns)

Single photoelectron studies



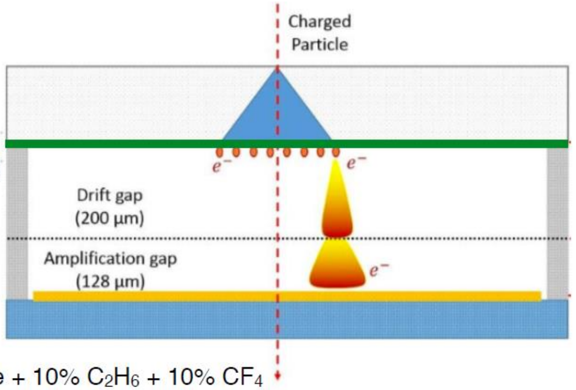
<50 ps single photoelectron timing resolution

MIP test beam measurements



24 ps MIP timing resolution

Cherenkov radiator
(3 mm MgF_2)
Photocathode
(3 nm Cr + 18 nm CsI)
Drift gap
(Pre-amplification)
Micromegas
(Amplification)

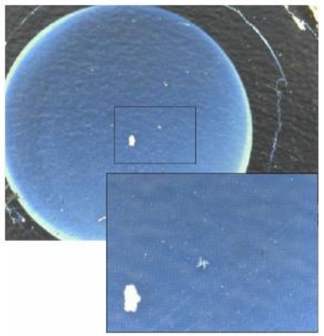


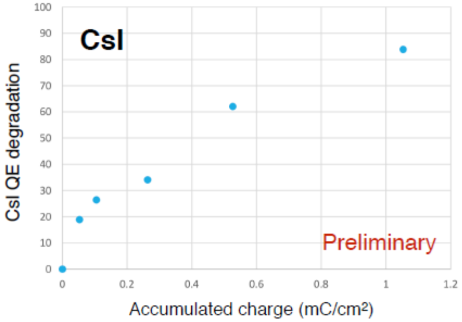
Gas mixture: 80% Ne + 10% C_2H_6 + 10% CF_4
(COMPASS gas)

challenges:
large area coverage,
robust photocathode, …

Standard PICOSEC photocathode: 18 nm CsI + 3 nm Cr

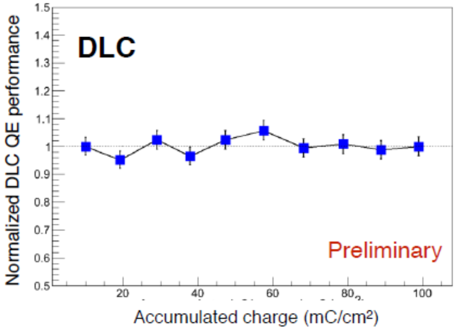
Ion backflow on CsI



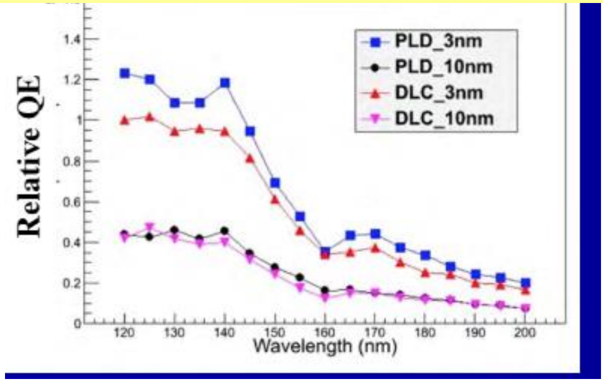


M. Lisowska, ASSET - Photocathode characterisation device, RD51 Mini-Week February 2020, https://indico.cern.ch/event/872501/contributions/3726017

alternative to CsI: Diamond-Like Carbon tested

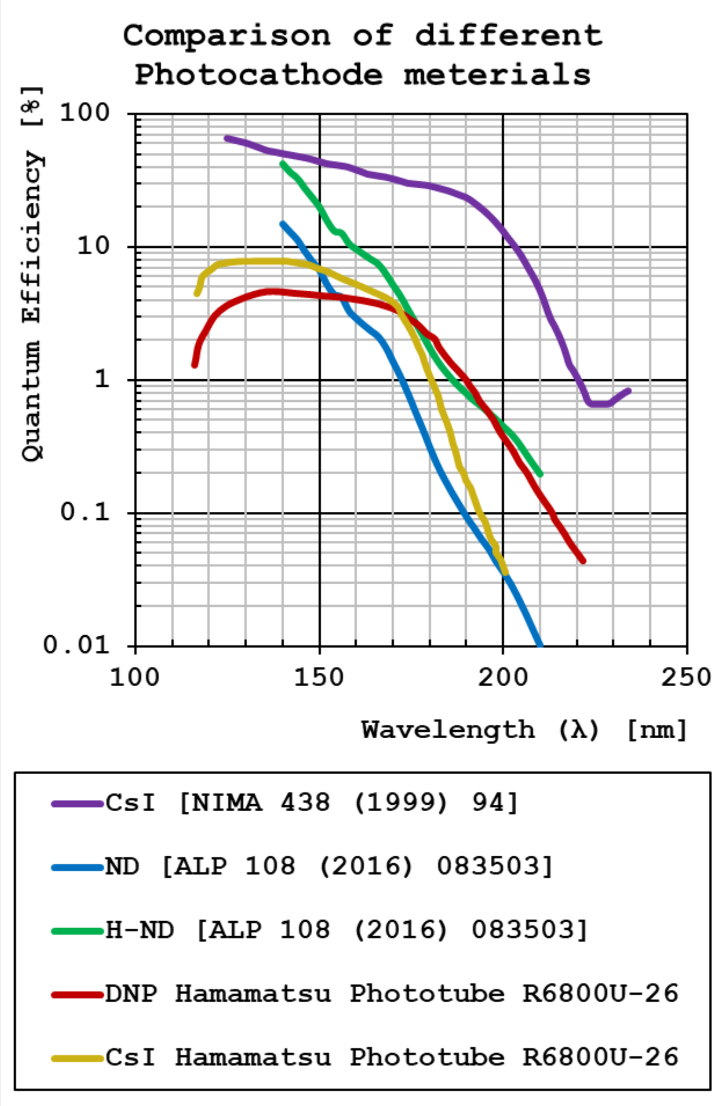


X. Wang, Recent photocathode and sensor developments for the PICOSEC Micromegas detector, MPGD 2019 https://indico.cern.ch/event/757322/contributions/3387110

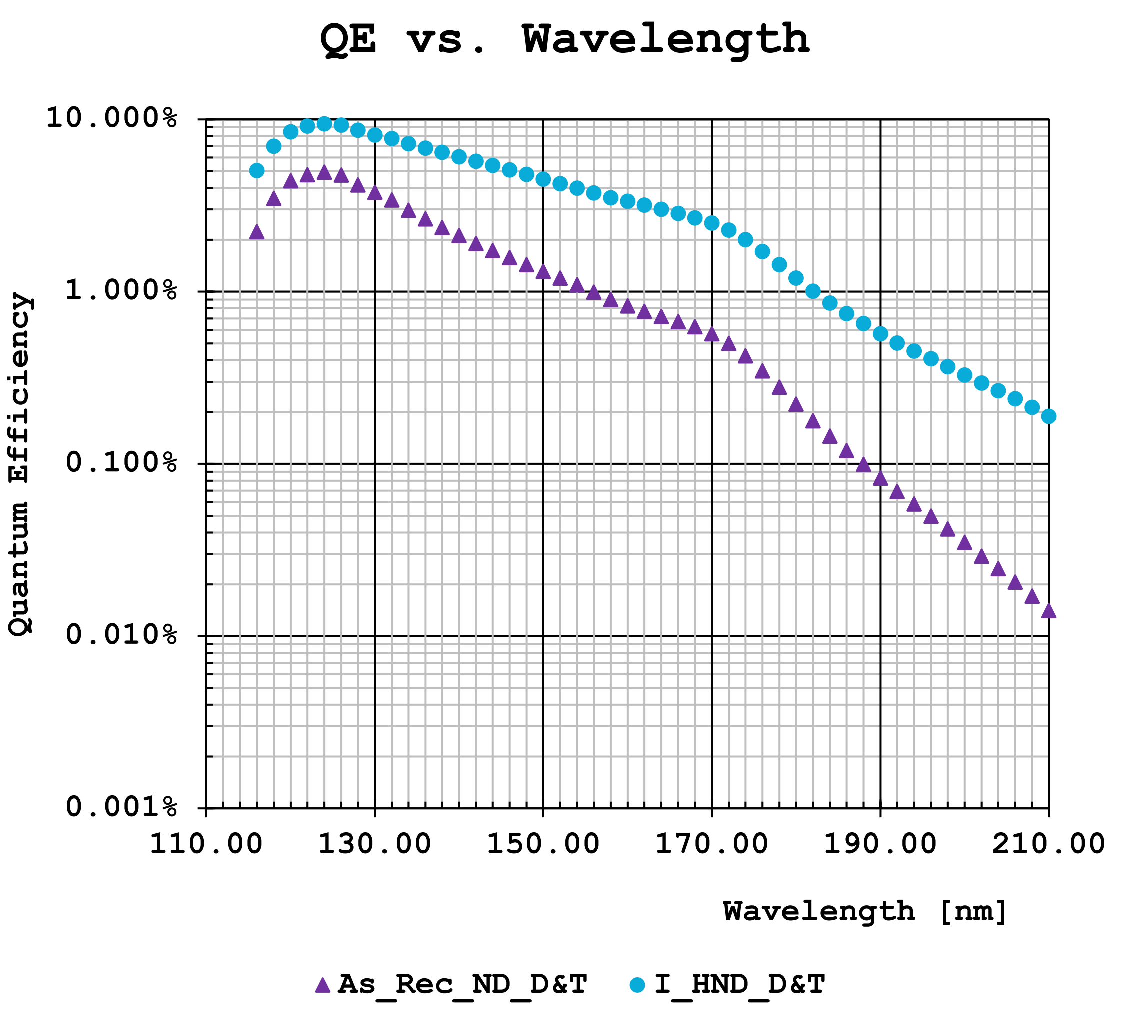


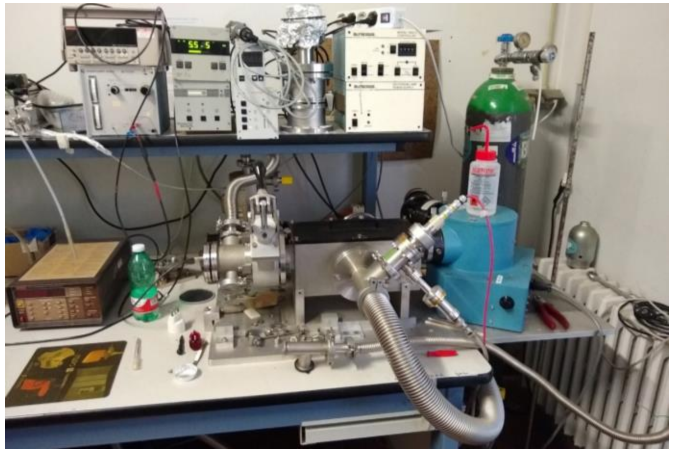
MgF_2 or graphene protection layer on CsI

Quest for new PC materials: Nano Diamond



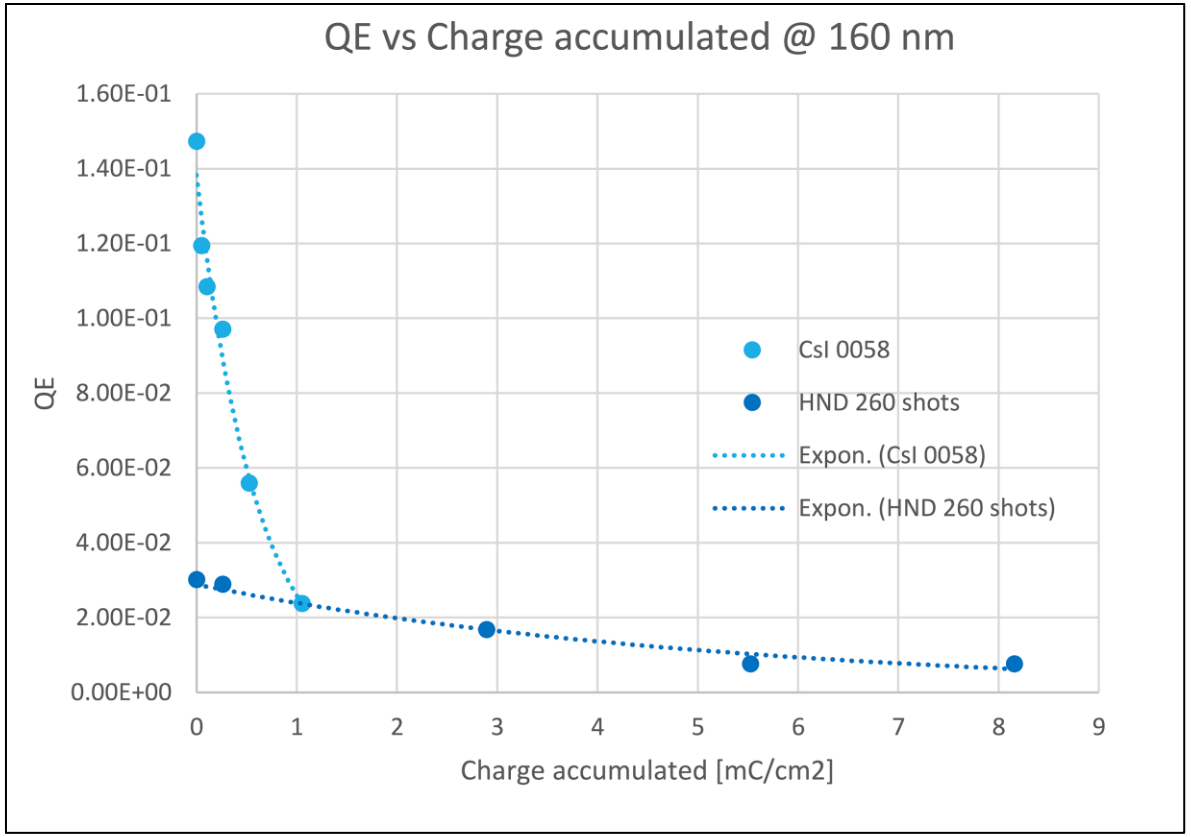
Triloki, *et. Al.*, NIMA **1048** (2023) 168014

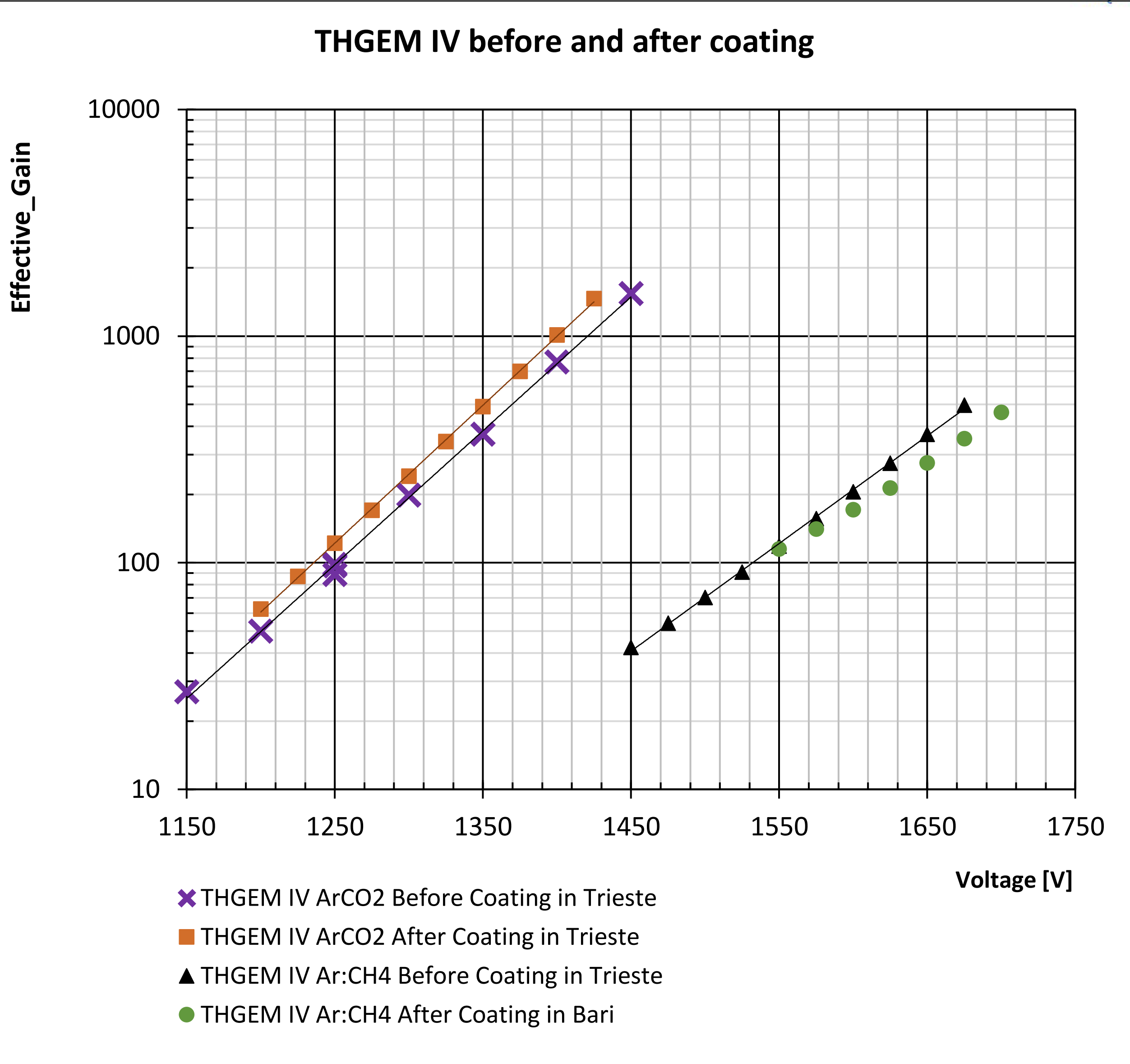




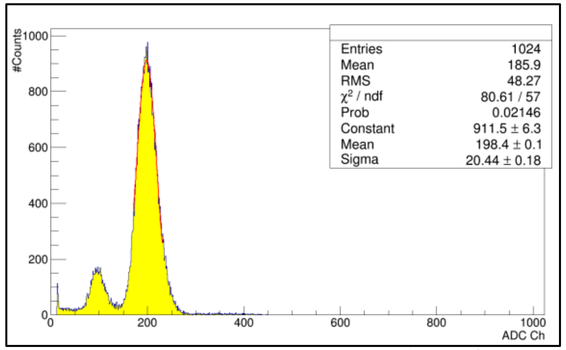
- Nano Diamond powder shows ~ 8 – 10% QE values @ 140 nm.
- Hydrogenation of the ND powder shows even higher values of QE for the same wavelength.
- A detailed measurement of the response is ongoing.

Aging of ND and application to detectors



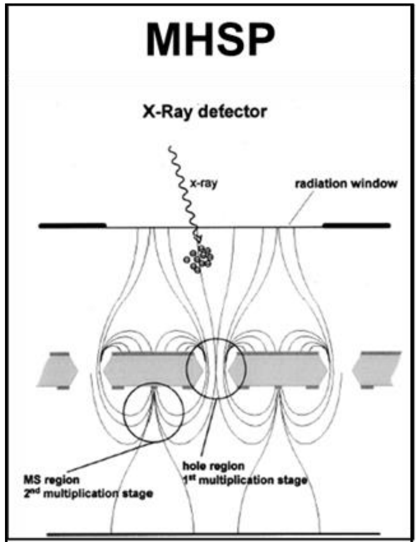


- Nano Diamond based PCs are showing promising results.
- R&D ongoing → Richa Rai's Talk

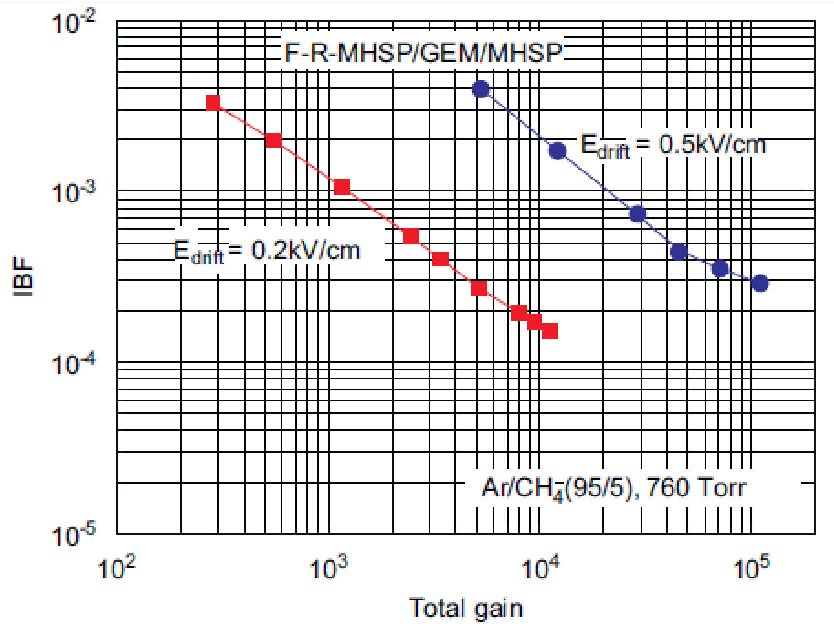


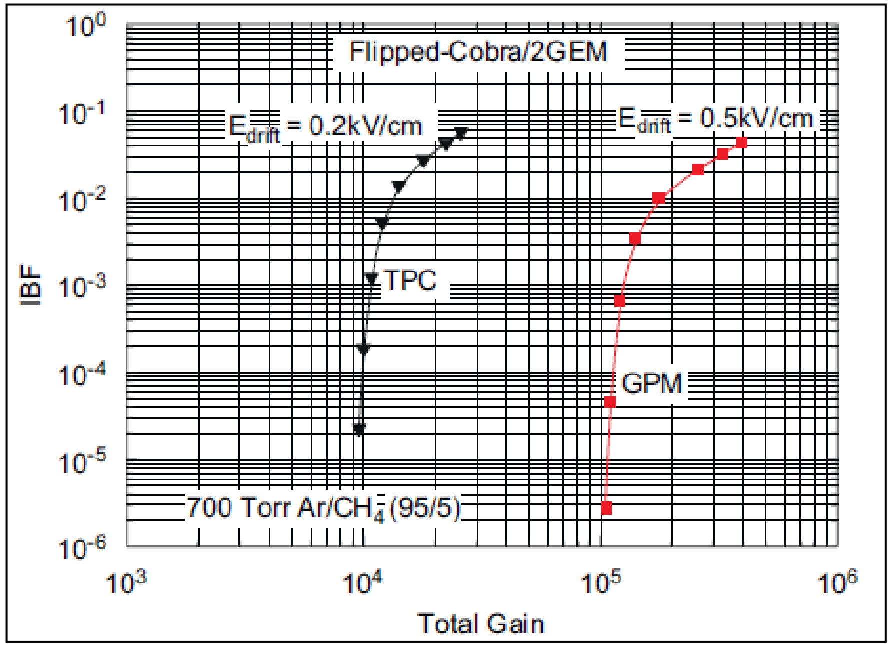
Ideas to reduce IBF: MHSPs COBRAs → IBF ~< 10^{-4}

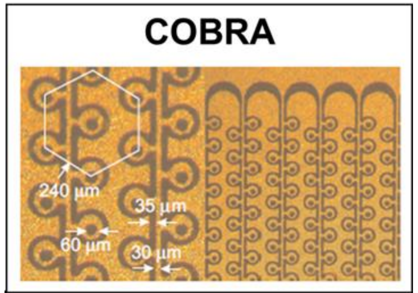
More complex geometries with extra electrodes to trap the ions: Micro-Hole & Strip Plate (MHSP), COBRA



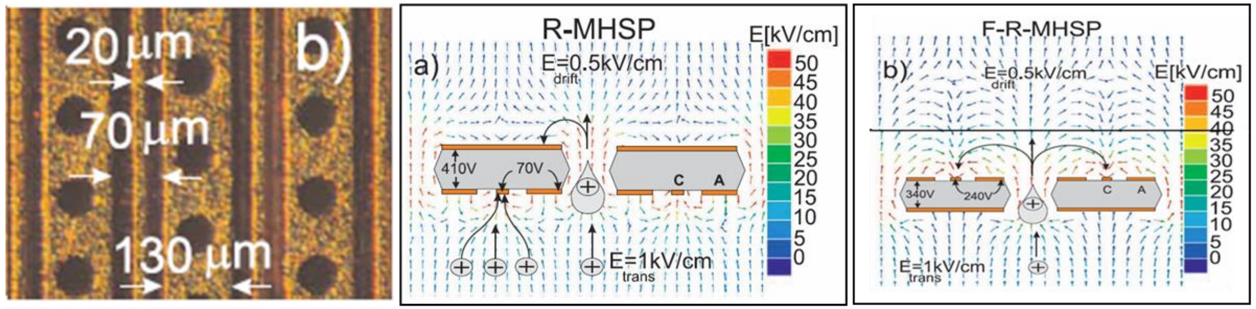
J. F. C. A. Veloso et al., Rev. Sci. Inst. A71 (2000) 2371







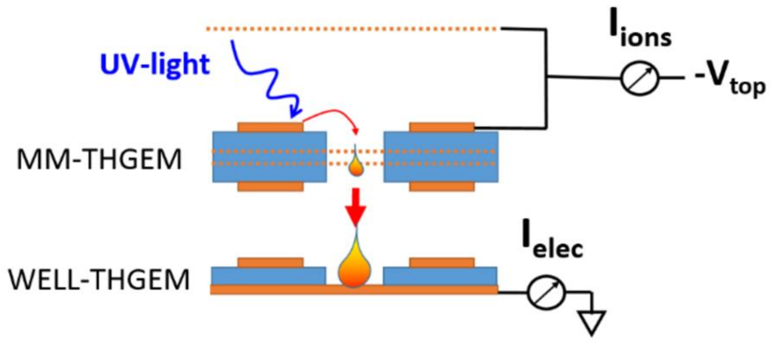
A.V. Lyashenko et al., NIMA 598 (2009) 116

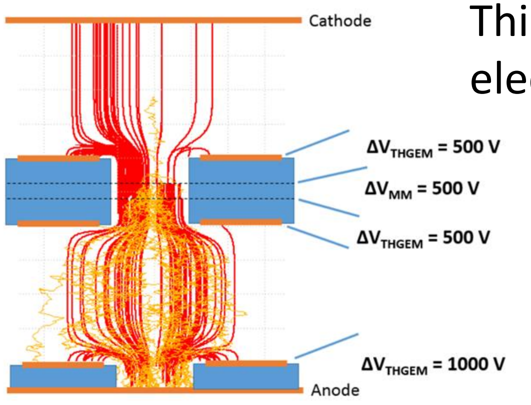


A.V. Lyashenko et al., JINST 2 (2007) P08004

THCOBRAs used in small-area applications

MM-THGEM/WELL-THGEM detector





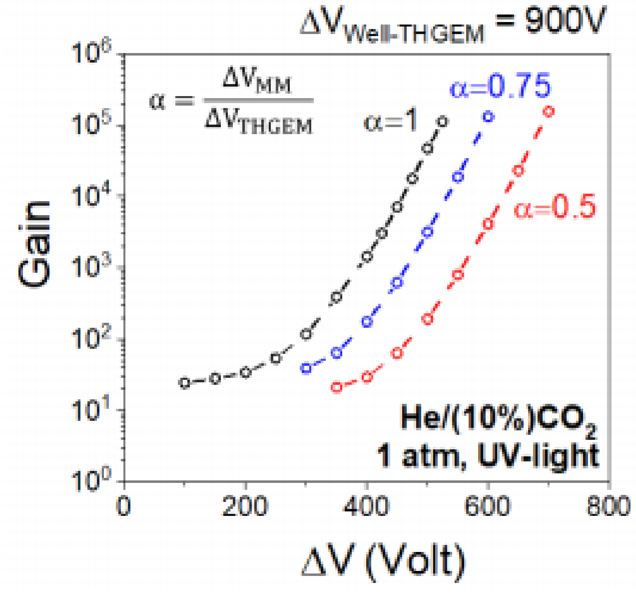
First performance evaluation of a Multi-layer Thick Gaseous Electron Multiplier with in-built electrode meshes—MM-THGEM

- Gain ~10^6
- Fair IBF for CsI pcs

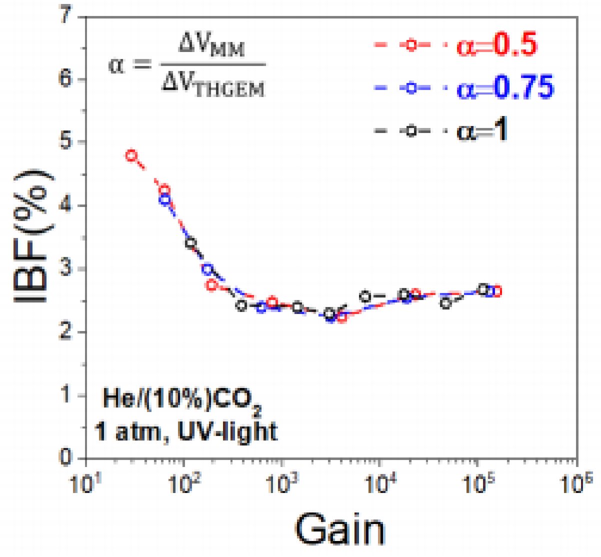
IBF ~2-3%

Ref: Stefano Levorato | 16 February 2021 | RD51 Workshop on Gaseous Detector Contributions to PID

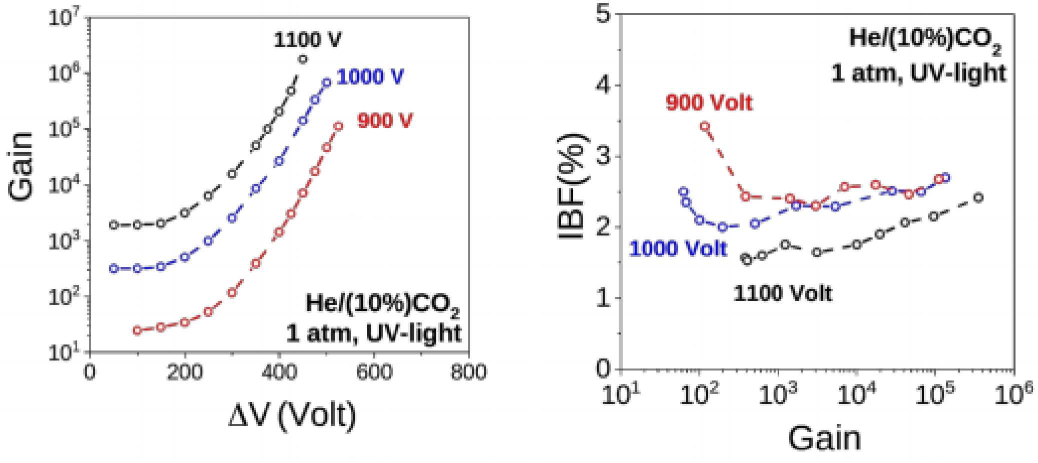
THGEM electrode contribution to the total gain is high



(a)



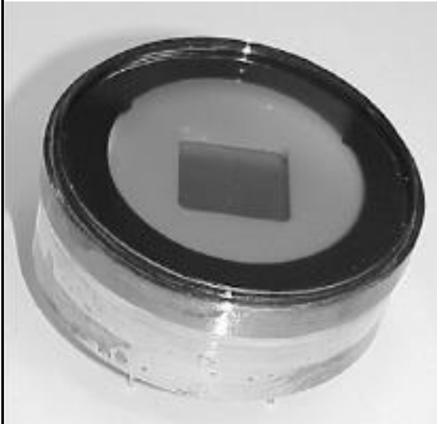
(b)



Oliveira and Cortesi., JINST 13 (2018) P06019

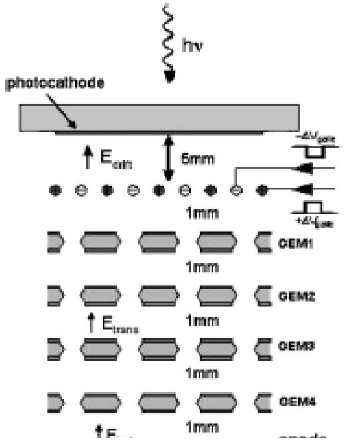
Gaseous PDs for visible light: MPGDs

Multiple GEM sealed



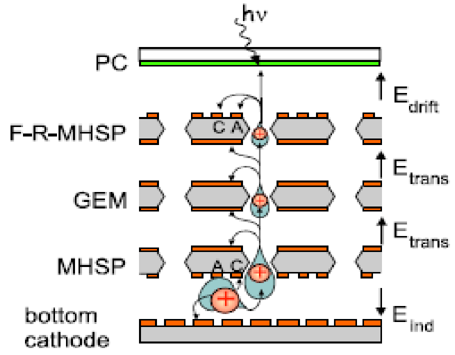
R. Chechik et al.,
NIM A 502 (2003) 195

Pulsed ion gating



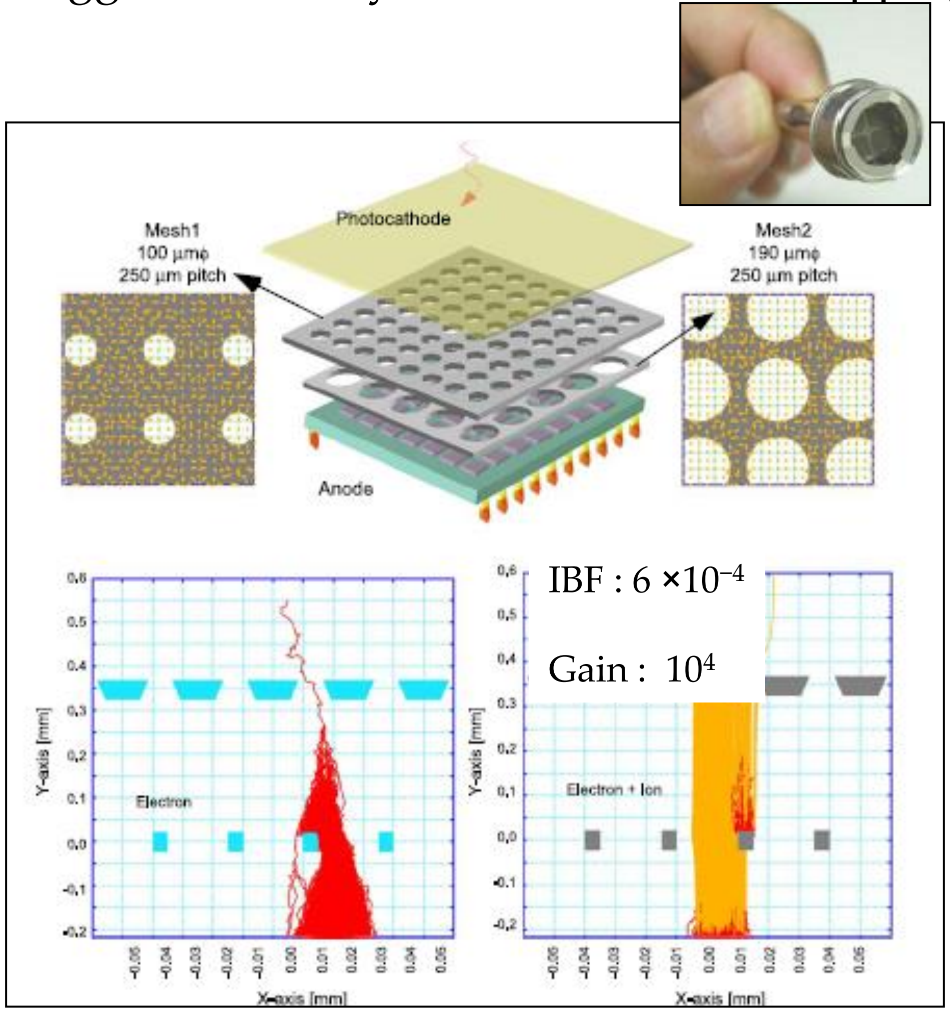
A. Breskin et al.,
NIM A 553 (2005) 46

K-Cs-Sb - Continuous mode, not a sealed PD



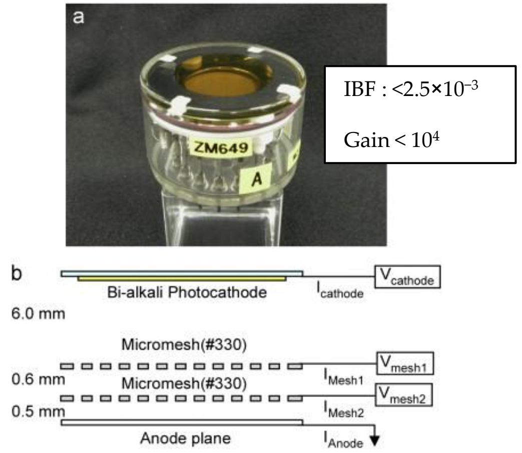
A.V.Lyashenko et al.,
2009 JINST 4 P07005

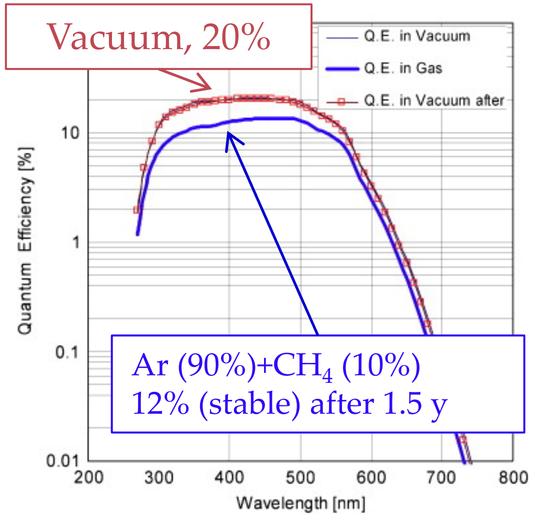
2 staggered MM layers to enhance ion trapping



F. Tokanai et al., NIMA 766 (2014) 176

K-Cs-Sb, Double MM, Ni mesh
In collaboration with HAMAMATSU



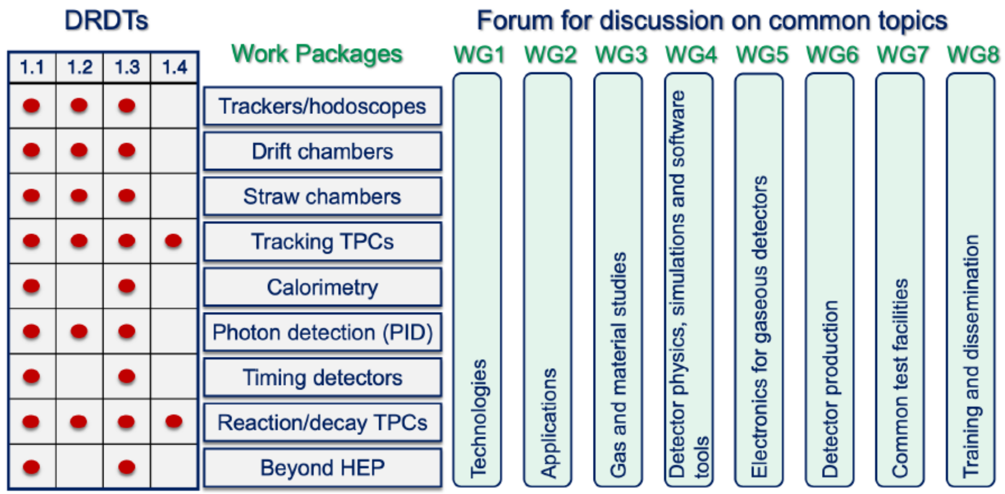


F. Tokanai et al., NIMA 610 (2009) 164

The Gaseous Detectors R&D Collaboration: DRD1

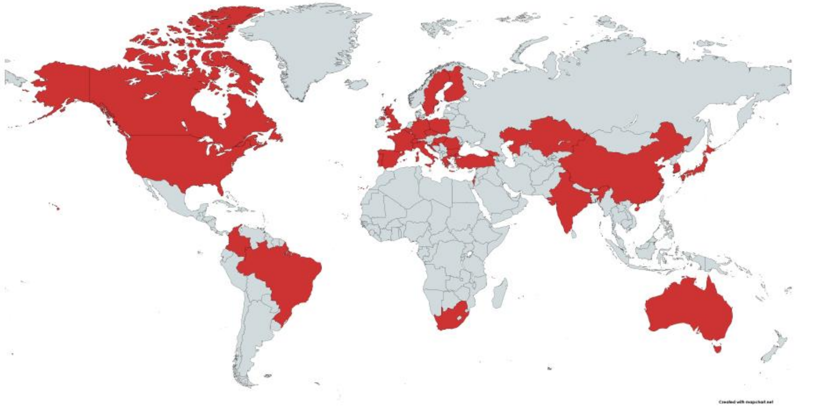
- DRD1 will be CERN based Collaboration for Gaseous Detectors R&D.
- There are 9 Work Packages and 8 Working Groups in DRD1 Scientific Organization.
- There are more than 100 institutes are participating in DRD1 → 11 Institutes so far in WP6 → The Work Package for R&D and Development of Gaseous Photon Detectors.

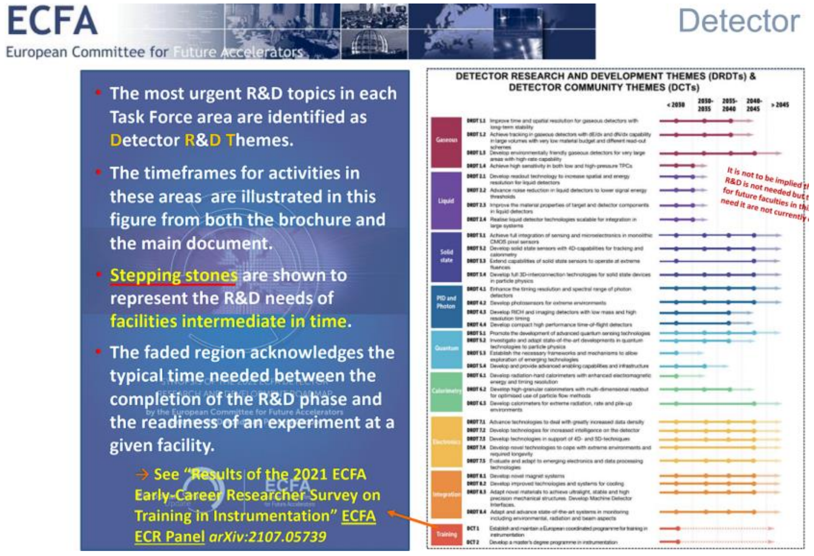
DRD1 Scientific Organization



WP6: Gaseous Photon Detector Participating Institutes.

1. Aristotle University of Thessaloniki (AUTh), Thessaloniki, Greece
2. University of Science and Technology of China (USTC), Hefei, China
3. National Institute of Science, Education and Research (NISER), Bhubaneshwar, India
4. European Organisation for Nuclear Research (CERN), Geneva, Switzerland
5. Weizmann Institute of Science (WIS), Rehovot, Israel
6. Università degli studi di Padova e Istituto Nazionale di Fisica Nucleare, Sezione di Padova (INFN-PD)
7. Istituto Nazionale di Fisica Nucleare, Sezione di Trieste (INFN-TS)
8. Helsinki Institute of Physics (HIP), Helsinki, Finland
9. Universidade de Aveiro (Aveiro), Aveiro, Portugal
10. Facility for Rare Isotope Beams (FRIB), Michigan State University, Michigan, USA
11. Technical University of Munich (TUM), Munich, Germany

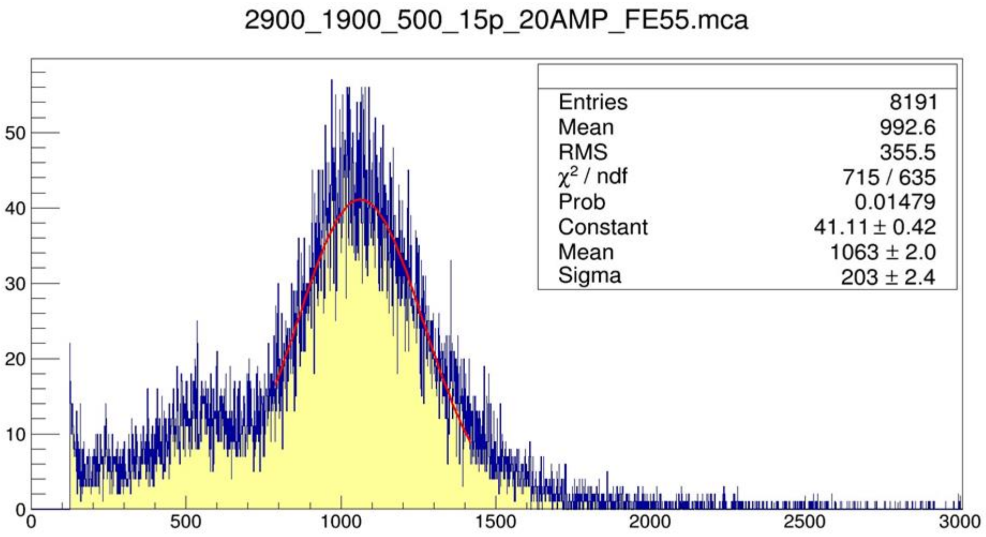


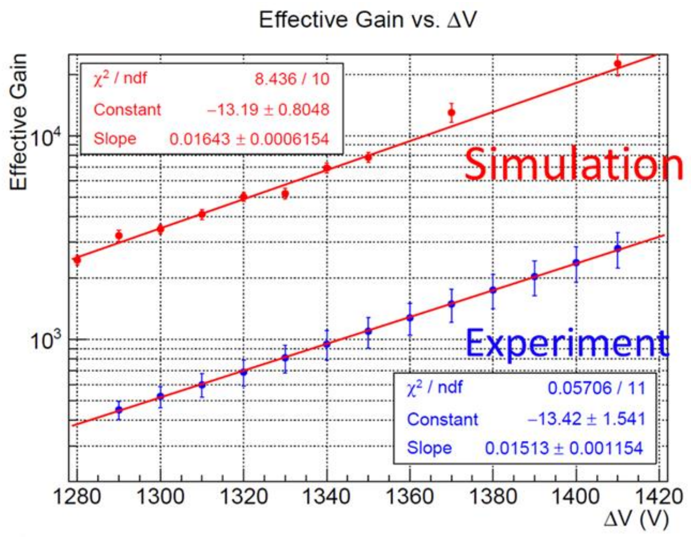


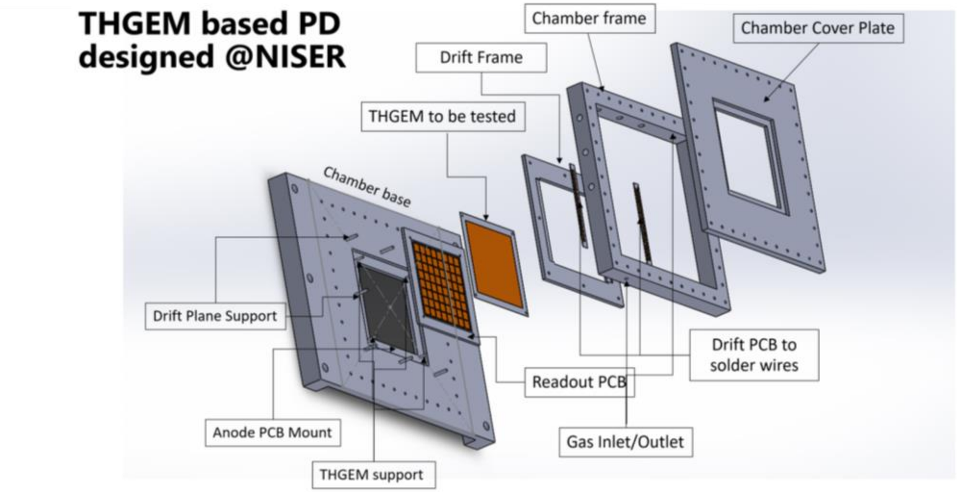
Conclusions

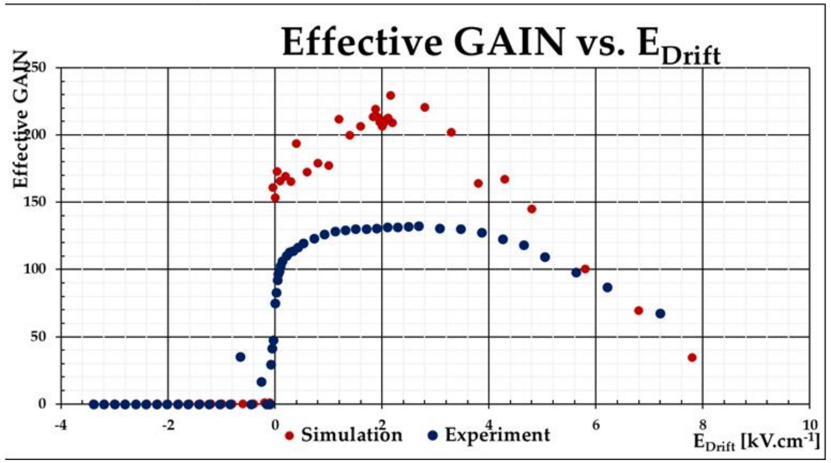
- MWPC and MPGD based gaseous Photon Detectors using CsI have been very successful.
- Overcoming CsI limitations is necessary for future applications.
- H – ND is a promising candidate for its robustness.
- The quest for visible sensitive photocathodes in gaseous detectors motivates a long term R&D program.

THANK YOU









Some preliminary activities on Gaseous PD R&D at CMRP, NISER

THANK YOU