ECFA Detector R&D Roadmap Symposium of Task Force 1 Gaseous Detectors

Challenges and new developments

IBF, photocathode stability and alternatives

Fulvio Tessarotto (CERN and INFN – Trieste)

Ion backflow

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:

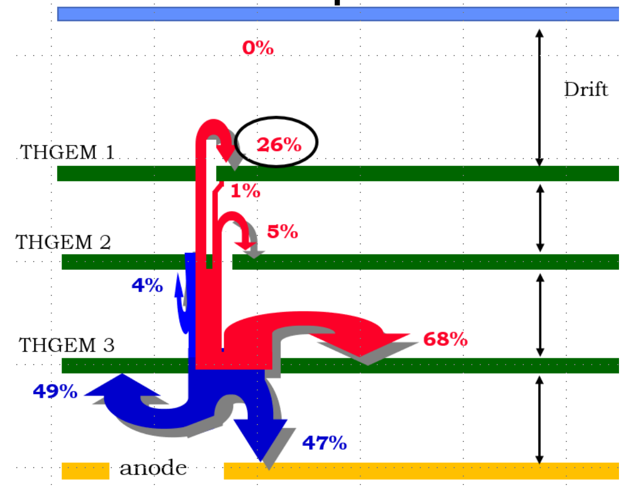
MWPC in continuous operation mode: IBF ~ 20%

TPC with pulsed gating grids: IBF ~10^{-5}

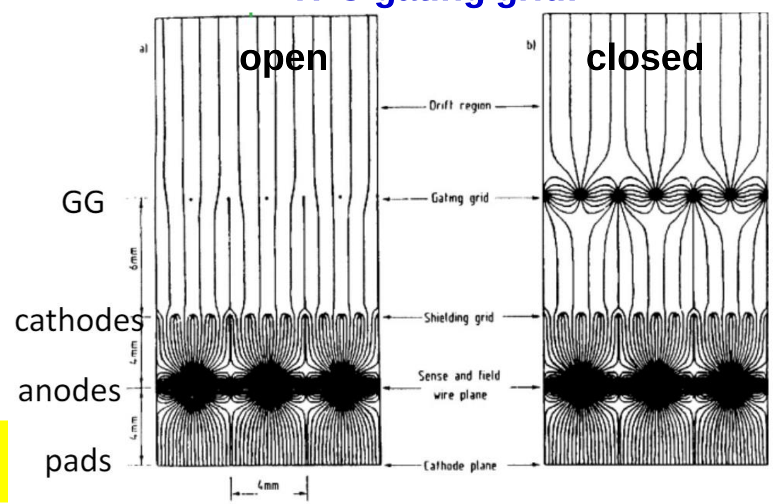
GG operation is rate limited: the gate must stay closed until the ions are collected (max rate: few kHz)

TPC requirements spelled out in the presentation of Piotr

where charges end in a standard triple THGEM PD:

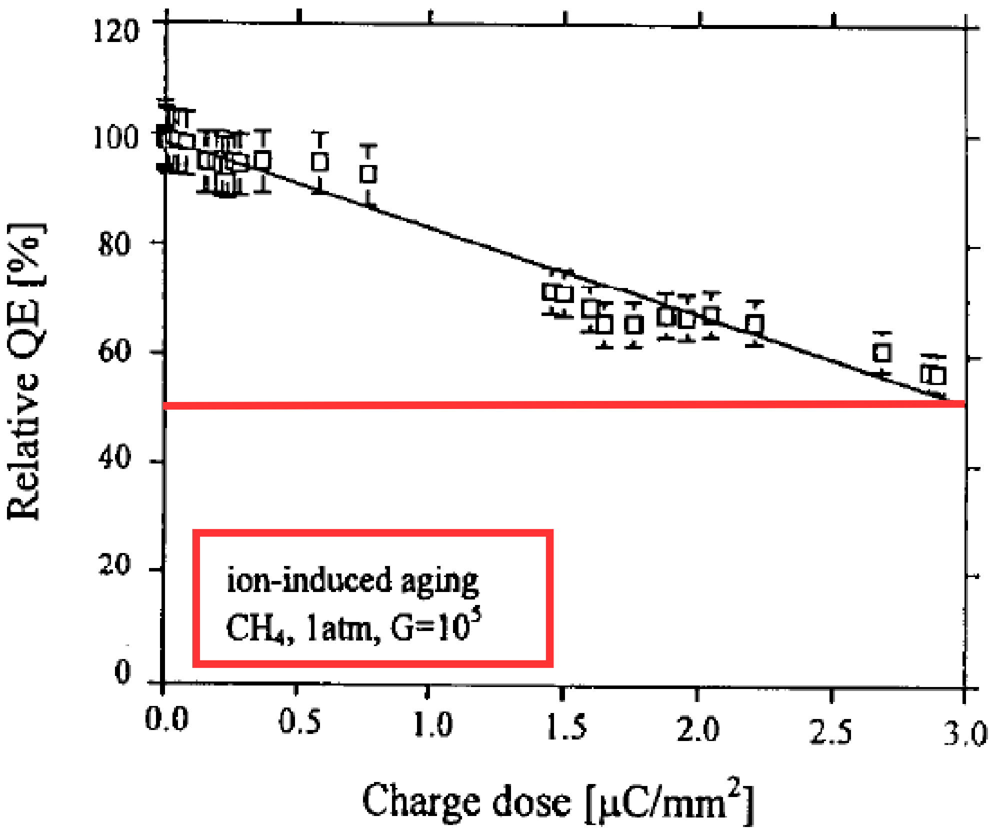


TPC gating grid:

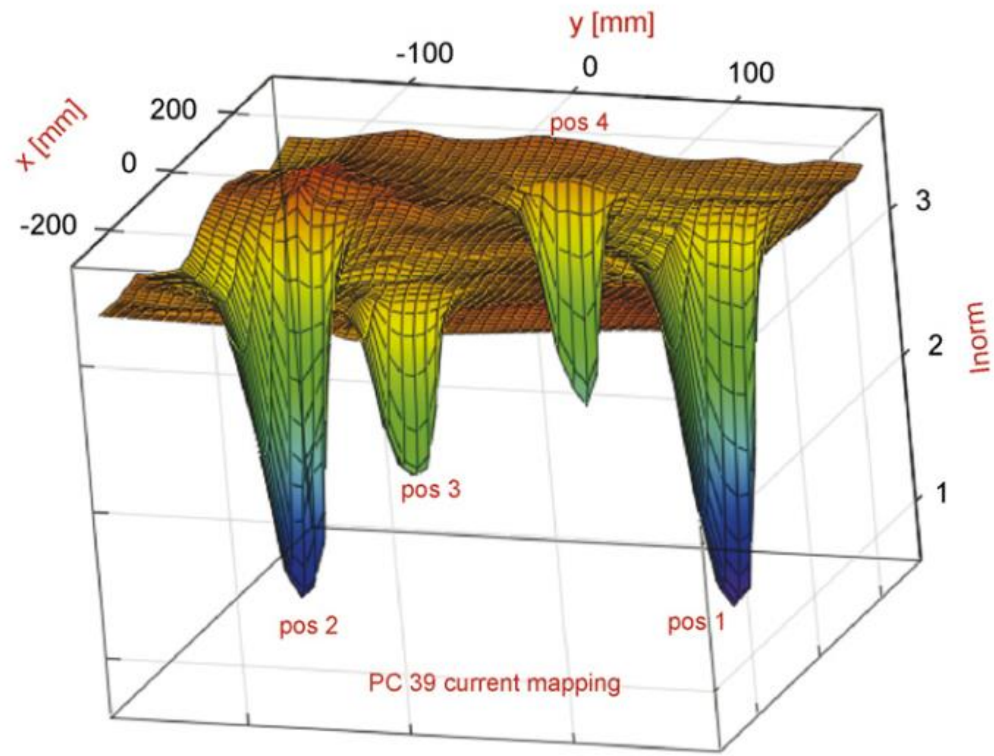


CsI QE degradation

Breskin et al., NIMA 371(1996)116



Hoedlmoser et al., NIMA 574(2007)28

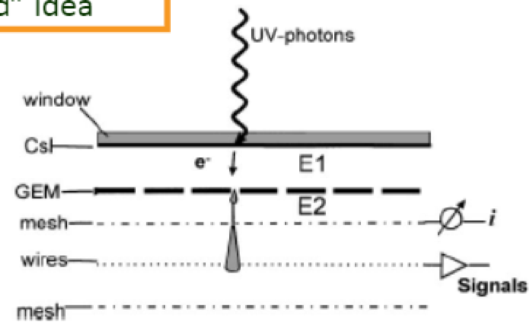


severe CsI QE degradation for accumulated charge ~ 0.2 mC/cm^2

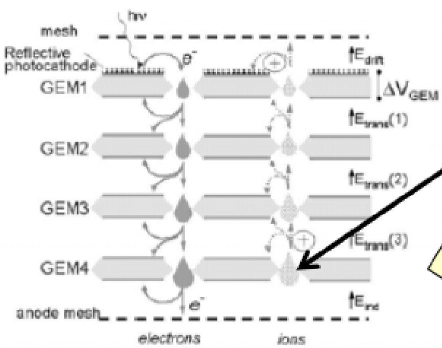
IBF in PDs with GEMs

GEMS used to reduce the ion backflow in PDs …

An “old” idea



R. Chechik et al., NIM A 419 (1998) 423



ion avalanche

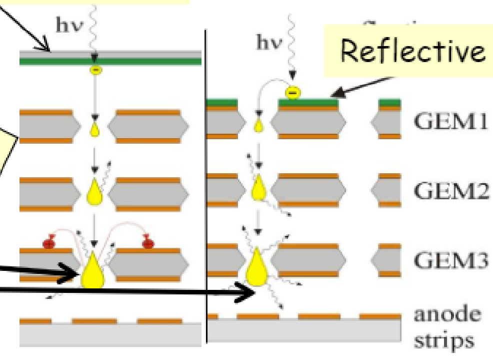
A. Breskin and R. Chechik, NIM A 595 (2008) 116

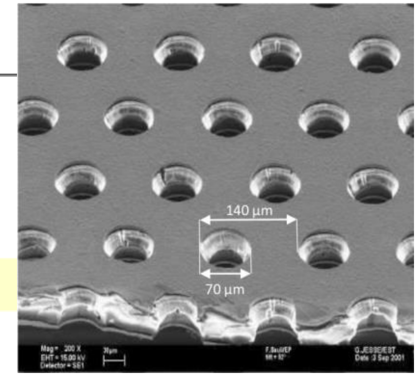
No photon feedback

Semi-transparent PC

Reflective PC

e^- avalanche





3% IBF @ 0.5 kV/cm
Gain ~ 10^5

- **triple gem with CsI pc**
- **semi-transparent vs reflective pc**
- **typical stable gains ~ 10^5**
- **large area > 1 m^2 can be produced**

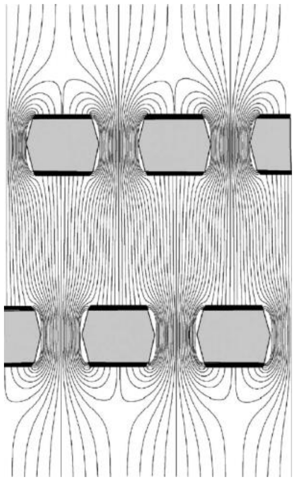
Bachman et al. NIMA 438(1999)376
Breskin et al. NIMA 478(2002)225
Bondar et al. NIMA 496(2003)325
Chechik and Breskin NIMA 595(2008) 116

PHENIX HBD:

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

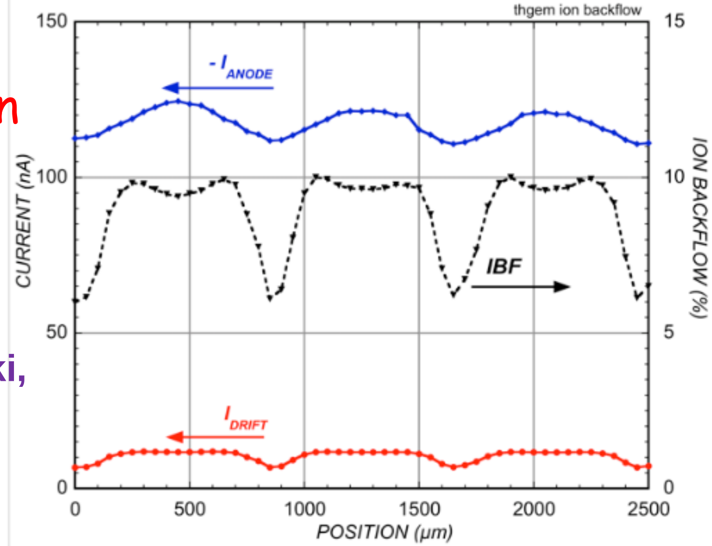
… not straightforward

IBF in TPCs with GEMs

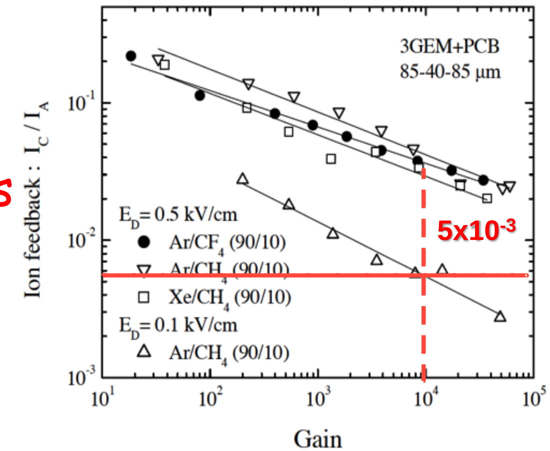


the HV optimization and holes alignment are crucial

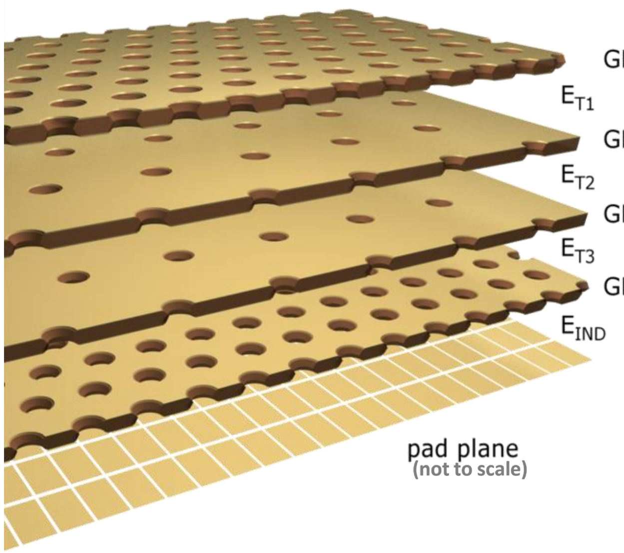
F. Sauli, L. Ropelewski, P. Everaerts, NIM A 560 (2006) 269.



and the gas choice too



A. Bondar *et al.*, NIM A 496 (2003) 325

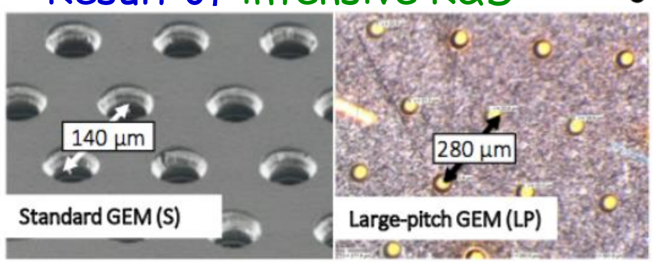


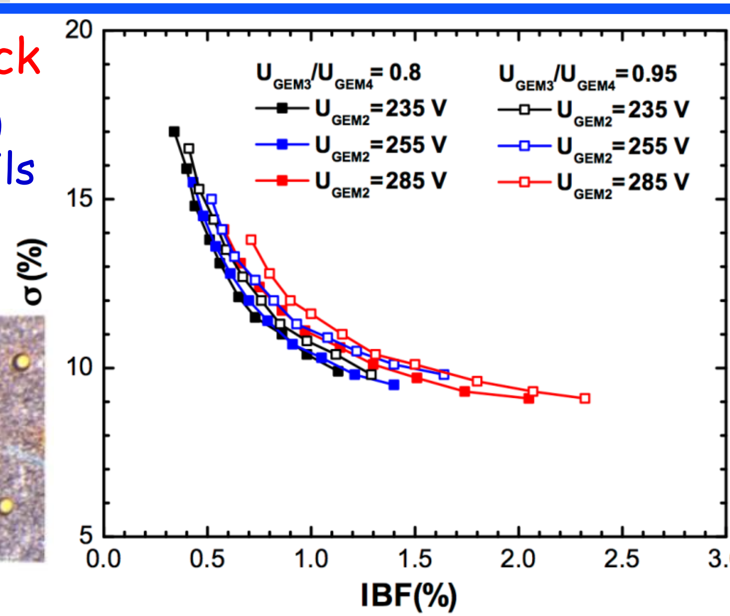
ALICE TPC: 4-GEM stack

Combination of standard (S) and large pitch (LP) GEM foils

Highly optimized HV

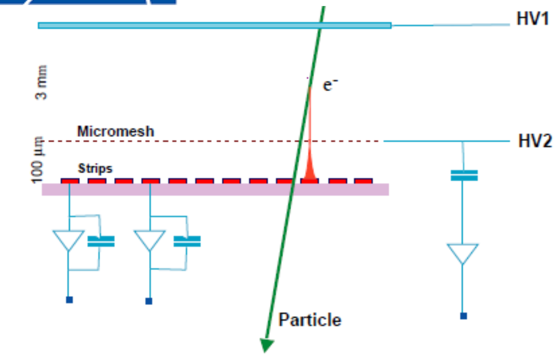
Result of intensive R&D

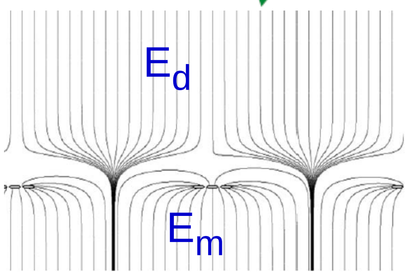


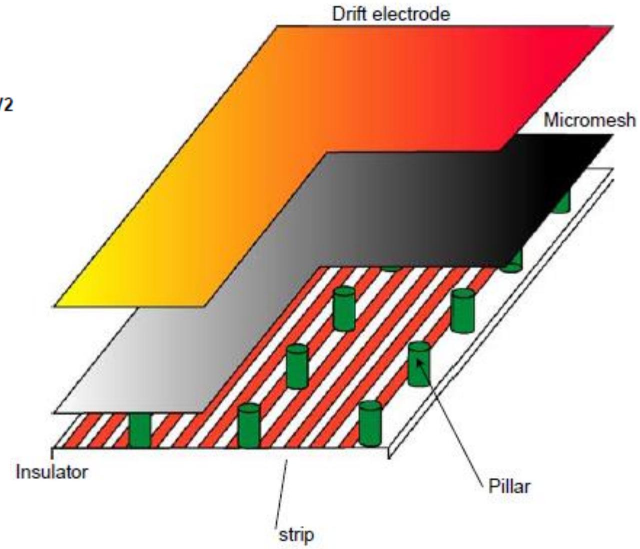


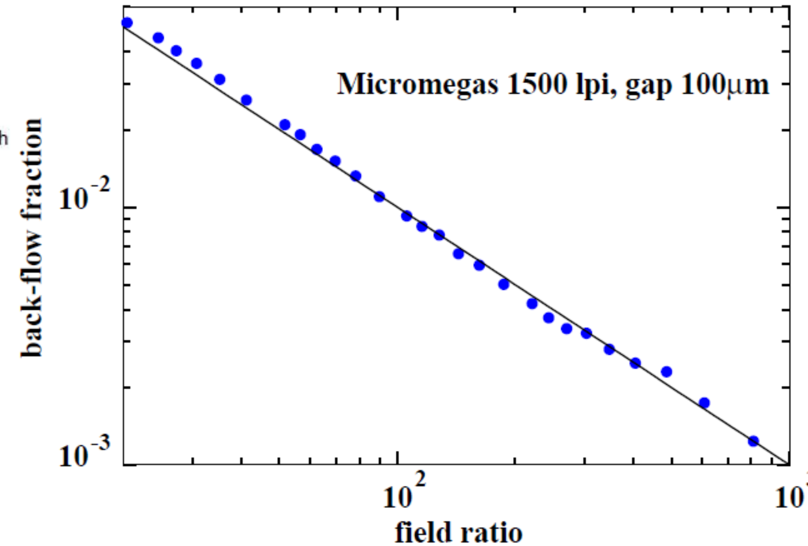
ALICE TPC Collaboration, JINST 16 (2021) P03022

IBF in Micromegas

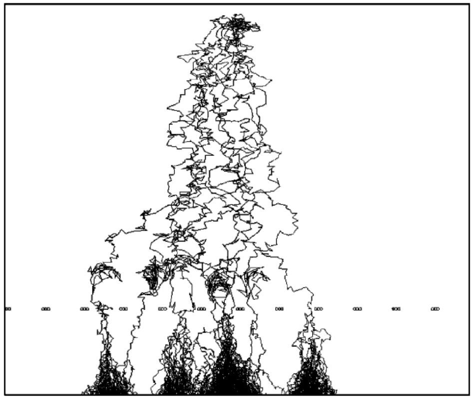




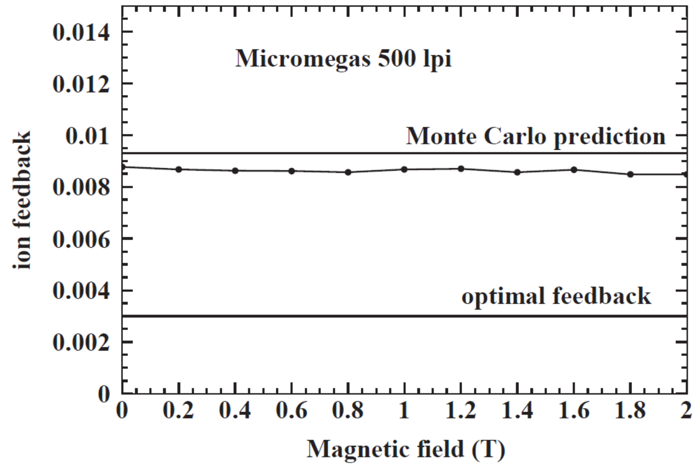




P. Colas et al. NIM A 535 (2004) 226



GARFIELD MC simulation



Micromegas:

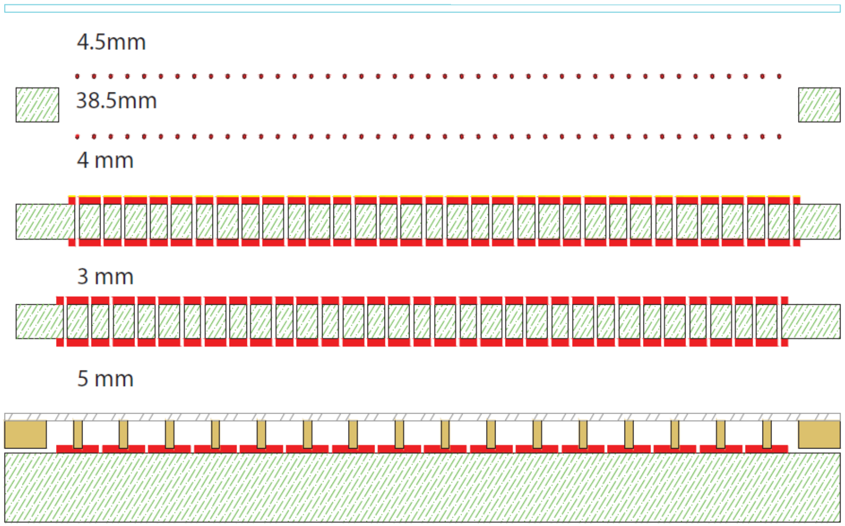
$IBF = E_d/E_m$

independent of B

in combination with GEMs or grids MM IBF is further reduced

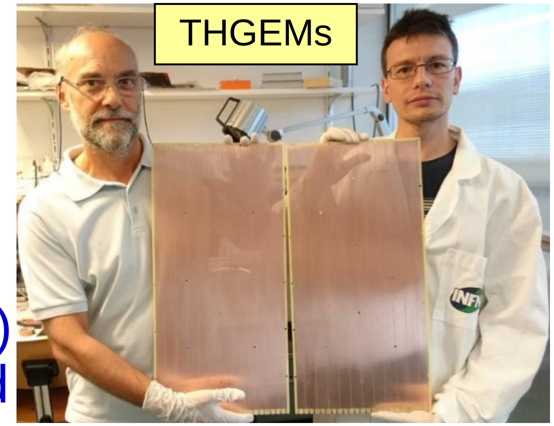
COMPASS Hybrid THGEM+MM PDs

Hybrid PD scheme

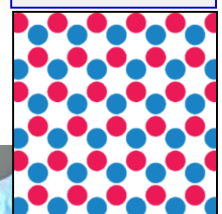


IBF = 3%

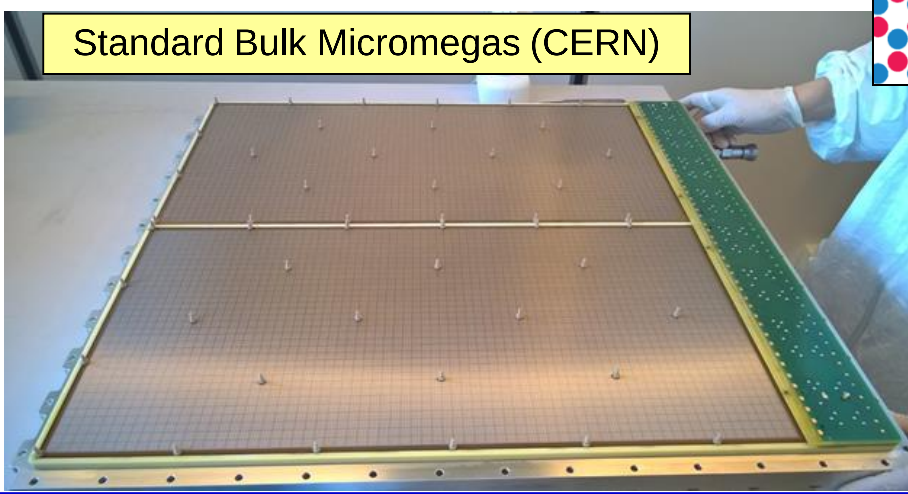
successfully implemented in 2016 on COMPASS RICH-1
active area = 1.4 m^2
eff. gain ~ 15000,
gain stability 5% (p/T corr.)
single γ ang. res. 1.8 mrad

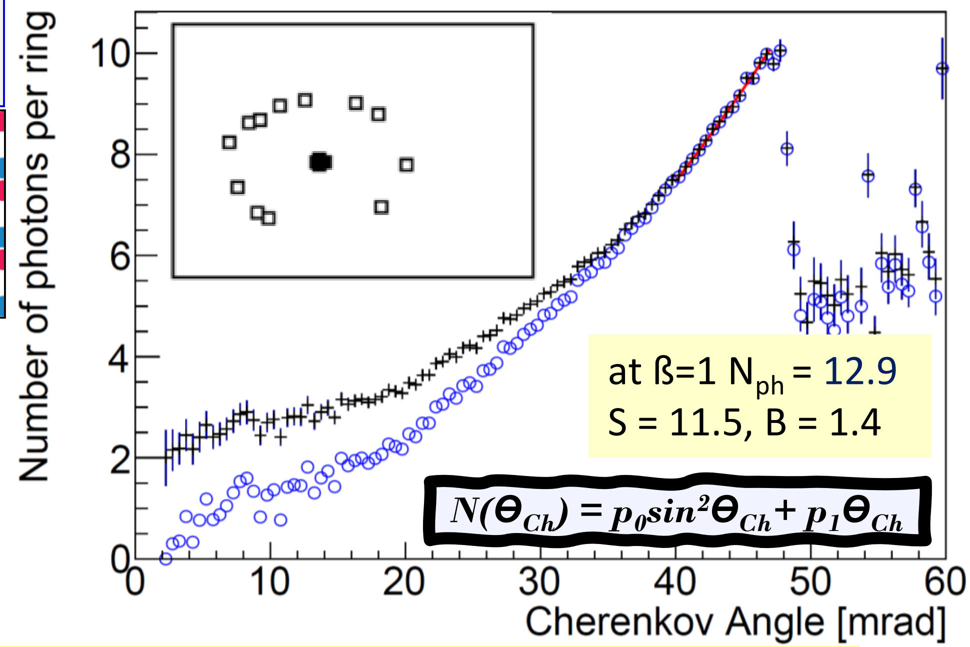


staggered THGEMs



Standard Bulk Micromegas (CERN)





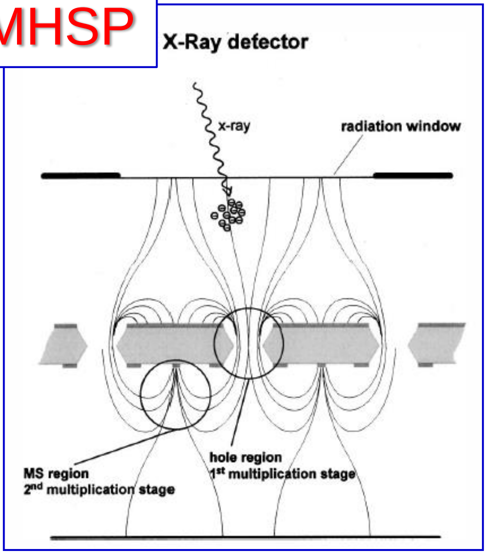
S. Dalla Torre, NIM A 970 (2020) 163768

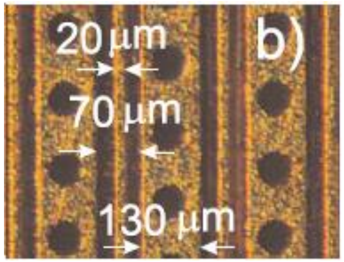
low IBF with COBRAS

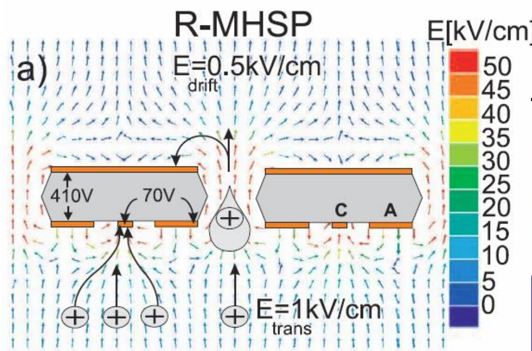
More complex geometries with extra electrodes to trap the ions:

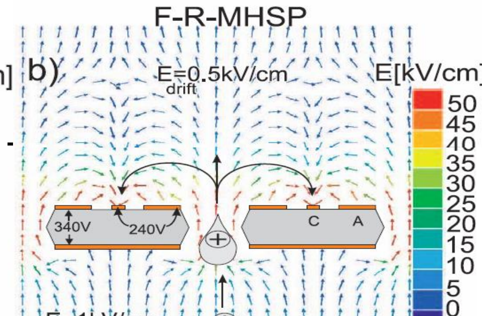
Micro-Hole & Strip Plate (MHSP), COBRA

MHSP



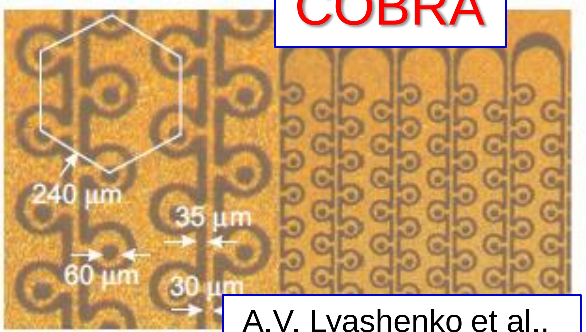




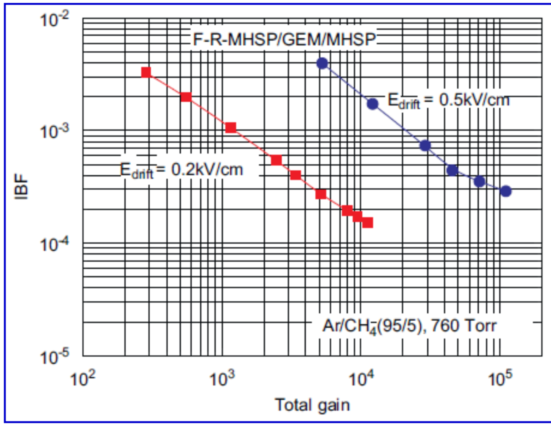


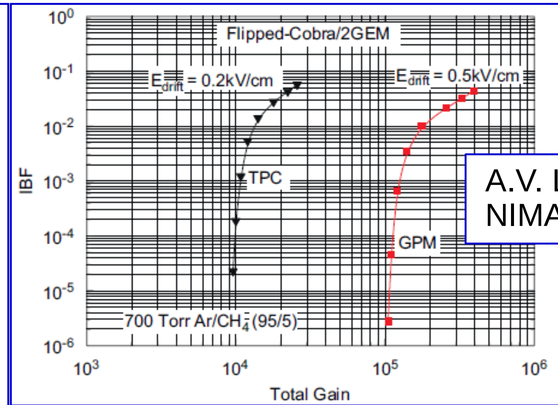
A.V. Lyashenko et al., JINST 2 (2007) P08004

COBRA



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





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

THCOBRAs used in small area applications

Reducing IBF with grids

Measurement of the ion backflow suppression by the passive bi-polar grid

E. Shulga*, V. Zakharov§, P. Garg§, T. Hemmick§, and A. Milov*
*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
§Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY, USA

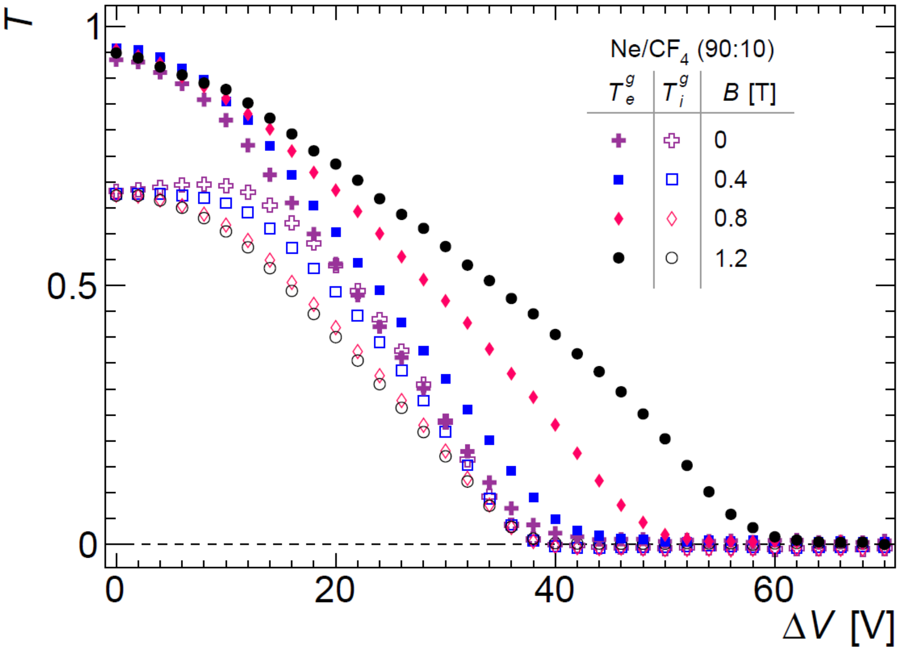
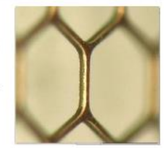


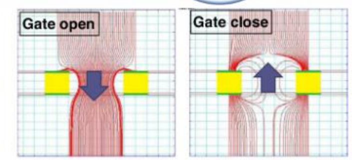
Fig. 5. BPG transparency in Ne/CF_4 (90:10) gas mixture at different magnetic field setting. $E_d = 320$ V/cm, $E_t = 480$ V/cm.

demonstrate that passive bipolar grid operated in a magnetic field above 1 T can be used as an effective instrument to suppress the ion backflow in TPCs.

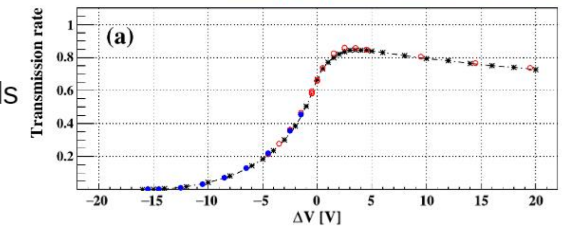
Gating GEM

The gating GEM is a favorite, which has large holes (Ø 300 µm) and thin strips inbetween (30 µm).





The electron transparency has been determined with different measurements and corresponds to 82 % as expected from simulations.



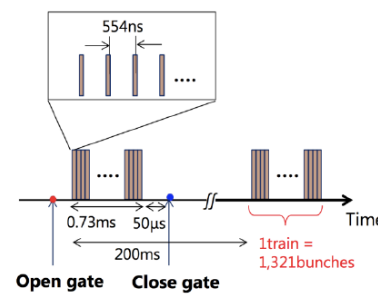
The ion blocking power still has to be determined and quantified.
First measurements have been initiated for this, but no results yet.
Also a fast HV switching circuit has to be developed.
The gate should also be tested in B = 3.5-4 T.

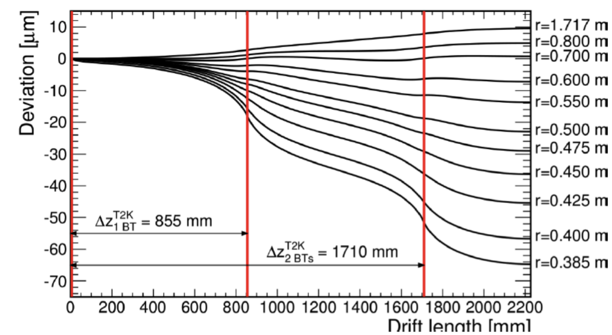
UNIVERSITÄT BONN

J. Kaminski
CPAD 2021

NIM A918 (2019) 41-53

15

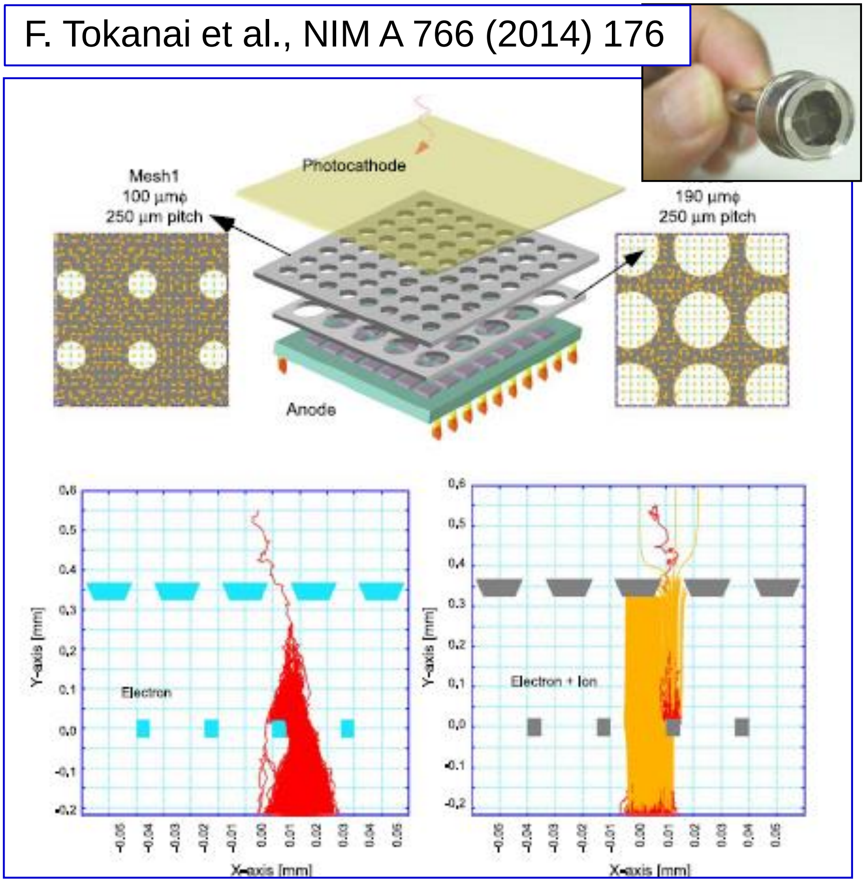




TPC IBF suppression: room for further improvement

IBF in Double Micro Mesh (DMM)

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



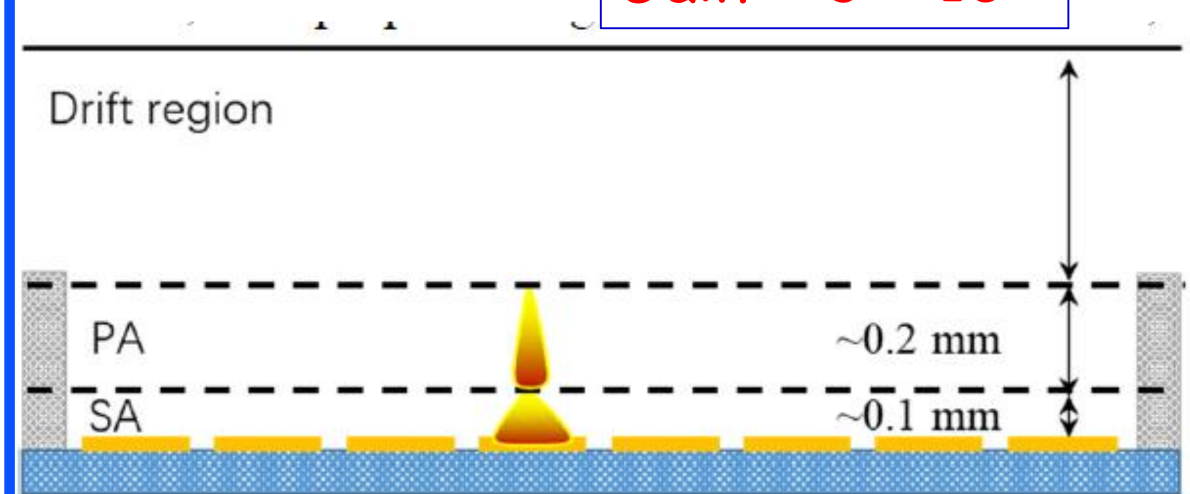
R&D on gaseous PD for visible light (collaboration with Hamamatsu)

IBF : 6 $\times 10^{-4}$
Gain : 10^4

B. Qi et al., NIM A 976 (2020) 164282

DMM:

IBF : 2.5 $\times 10^{-4}$
Gain : 3 $\times 10^6$



Z. Zhang et al., NIM A 952 (2020) 161978

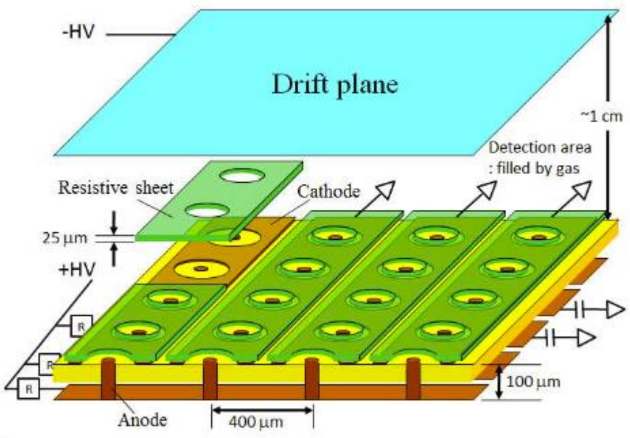
A high-gain, low ion-backflow double micro-mesh gaseous structure

Zhiyong Zhang*(zhzhy@ustc.edu.cn), Jianbei Liu, Ming Shao, Yi Zhou
State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China

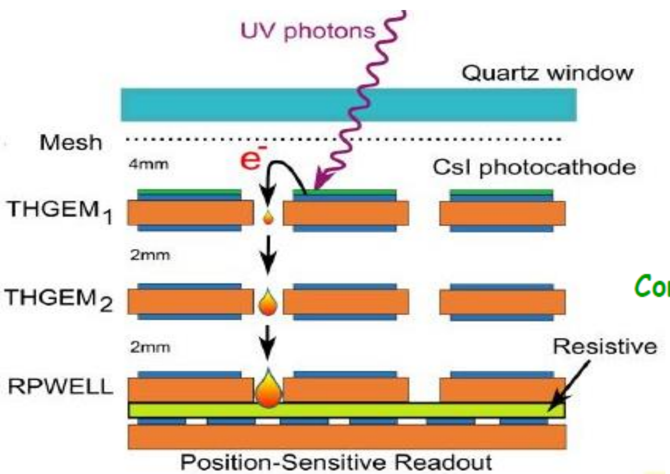
TMM IBF: 3 $\times 10^{-5}$

one of the most effective approach to IBF suppression

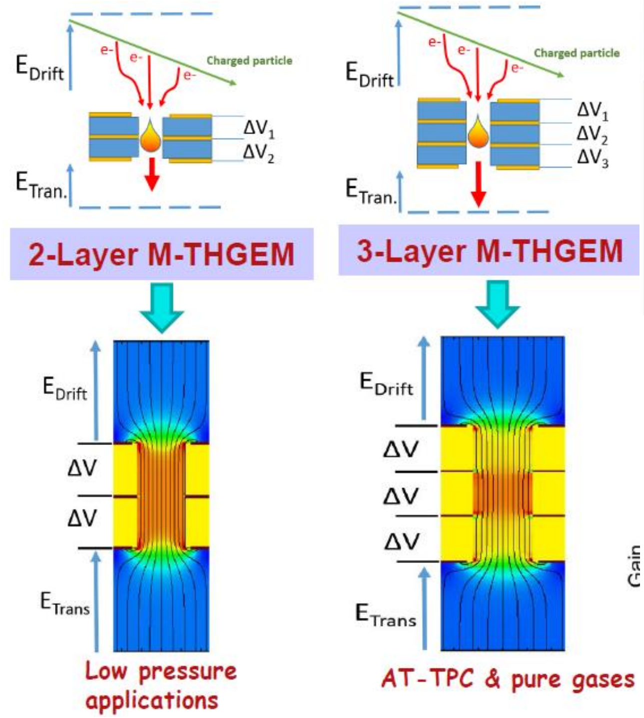
other MPGD detector architectures



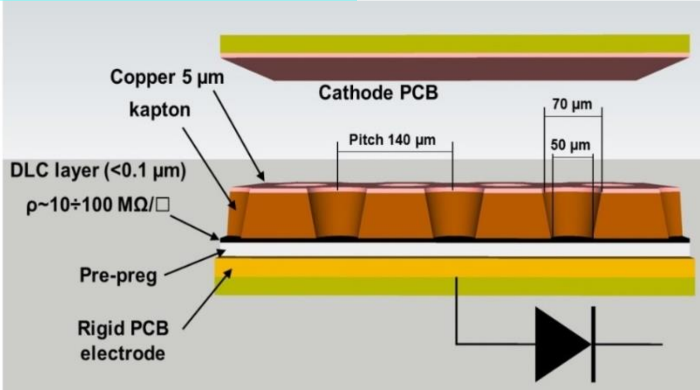
A. Ochi et al. JINST 7 (2012) C05005



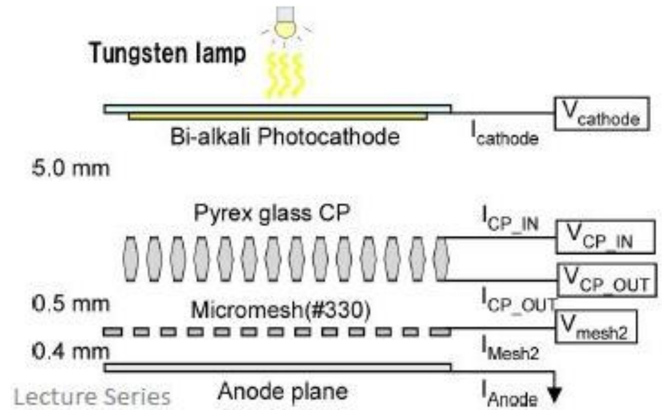
L. Arazi et al. 2012 JINST 7 C05011



Cortesi et al., Rev. Sci. Ins. 88, 013303 (2017)



G. Bencivenni et al. e-Print: 2007.03223 [physics.ins-det]

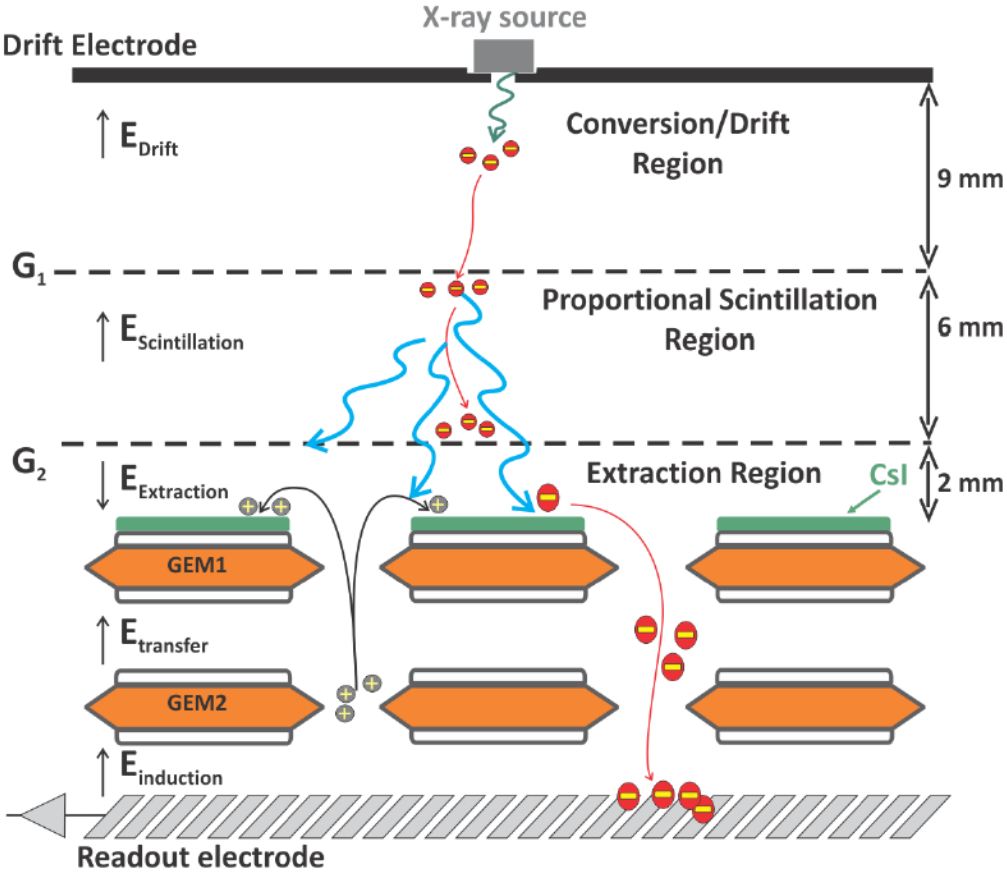


H. Sugiyama et al., NIMA (2016)

need careful study of their IBF suppression potential

Zero IBF electron multiplier

F.D. Amaro et al. JINST 9 (2014) P02004



Primary ionization electrons end in the proportional scintillation region and produce photons

Scintillation photons reach a photocathode and are converted in photoelectrons

Photoelectrons are multiplied in avalanches

Avalache ions remain local

Avalanche ions totally blocked by the electric screening region,

IBF = 0 independent of the gain

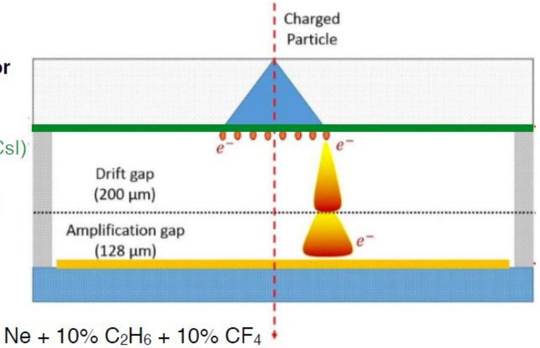
One example of a wide innovative exploration field

PICOSEC needs new photoconverter

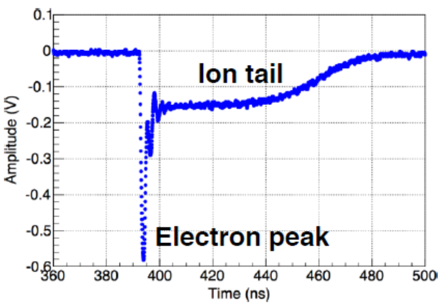
PICOSEC detection concept

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

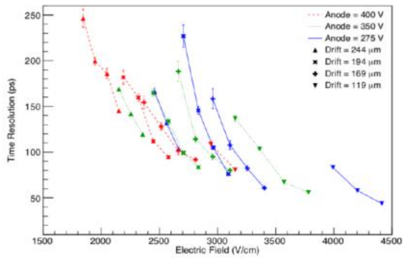


Gas mixture: 80% Ne + 10% C_2H_6 + 10% CF_4
(COMPASS gas)



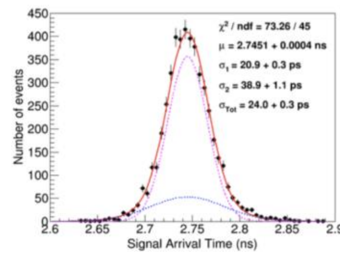
- **Signal with two distinct components:**
  Electron peak: fast (≈0.5 ns)
- Ion tail: slow (≈100 ns)

Single photoelectron studies



<50 ps single photoelectron timing resolution

MIP test beam measurements

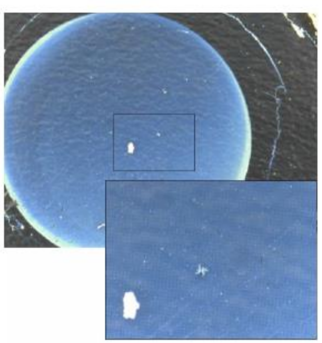


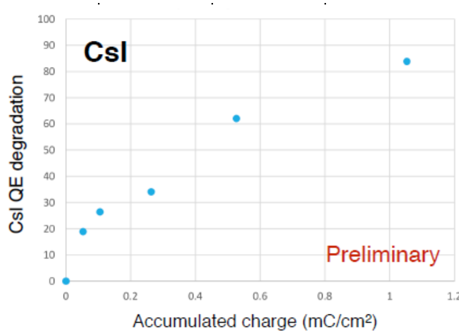
24 ps MIP timing resolution

challenges:
large area coverage,
robust photocathode,
…

Standard PICOSEC photocathode: 18 nm CsI + 3 nm Cr

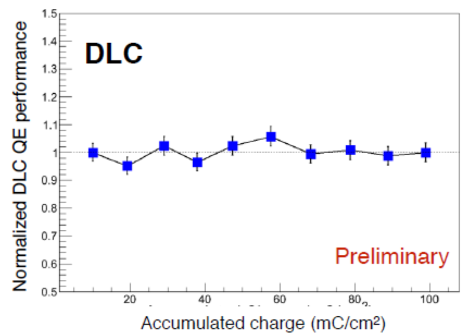
Ion backflow on CsI



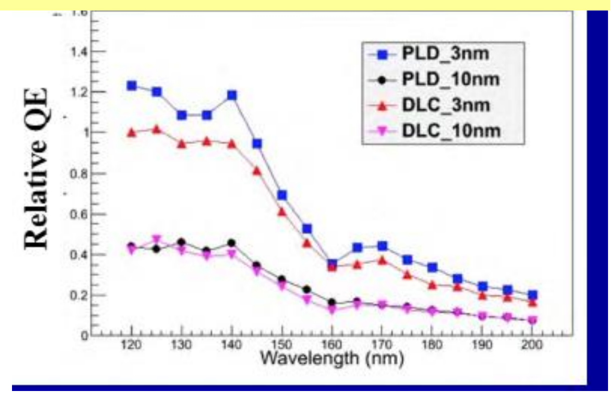


M. Lisowska, ASSET - Photocathode characterisation device, RD51 Mini-Week February 2020, https://indico.cern.ch/event/872501/contributions/3726017

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 graphite protection layer on CsI also attempted

Rich-graphite Nano-Diamond film

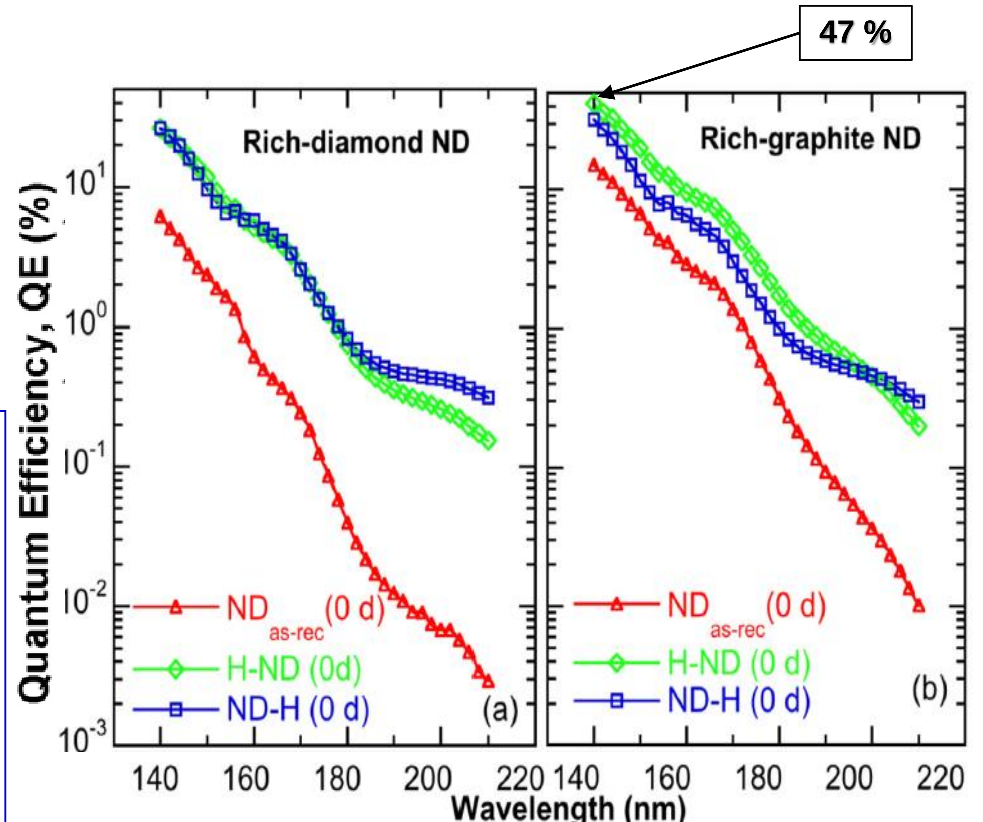
CsI bandgap: 6.2 eV; electron affinity: 0.1 eV; hygroscopic; ages by ion bombardment (~mC/cm^2)

Diamond bandgap: 5.5 eV; chemically inert and robust; if hydrogenated: electron affinity -1.27 eV

Hydrogenated chemical vapor deposited diamond films (4-6 µm) known to have QE ~15% @ 140 nm.

Heterogranular-structured diamond-gold nanohybrids proposed as stable field emission cathode material

Nano-Diamond grains (size: ~250 nm), with variable sp^2 (graphite phase) and sp^3 (diamond phase) hybridized carbon contents treated in H2 microwave plasma show large QE: ~50% @ 140 nm

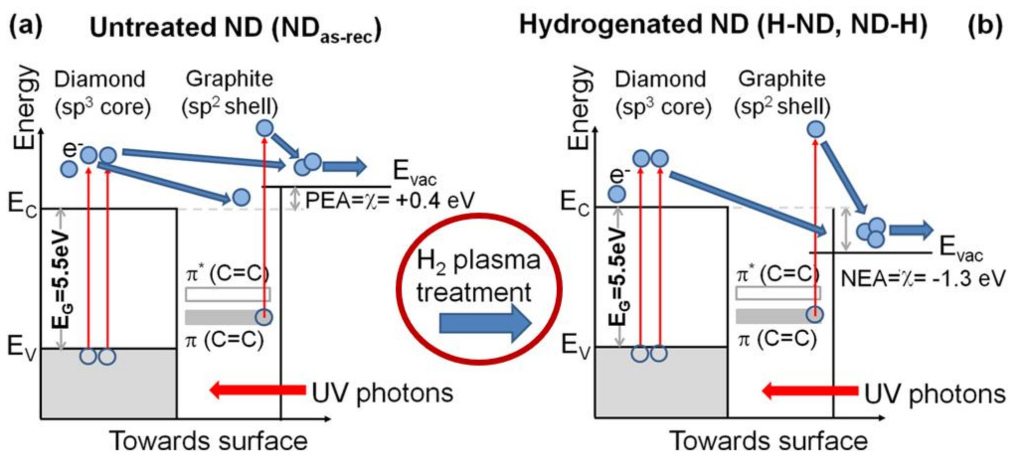


L.Velardi, A.Valentini, G.Cicala, Diamond & Related Materials 76 (2017) 1

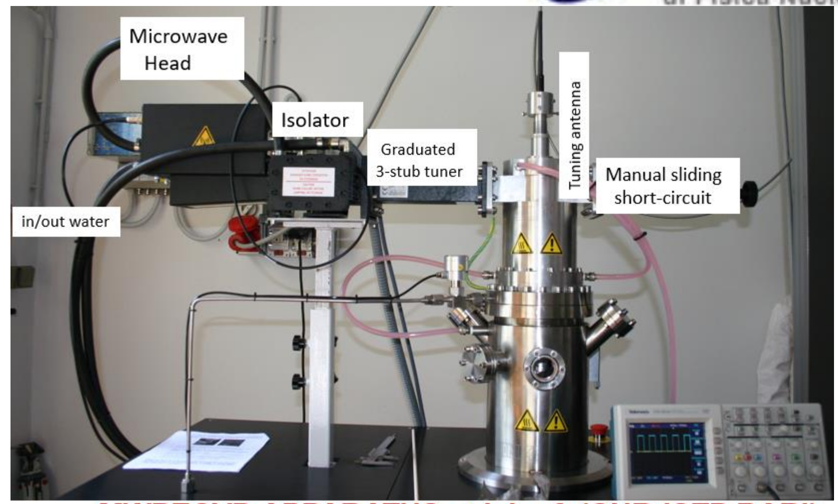
Photocatodes: diamond film obtained with Spray Technique

Spray technique: T ~ 120° (instead of ~800° as in standard techniques)

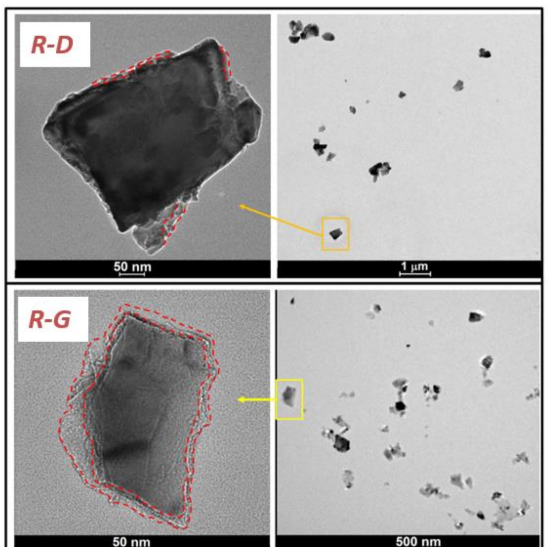
Hydrogenated Nano-Diamond



Schematic representation of the process of photoemission components sp^3 e sp^2 for **PEA** (a) and for **NEA** (b)

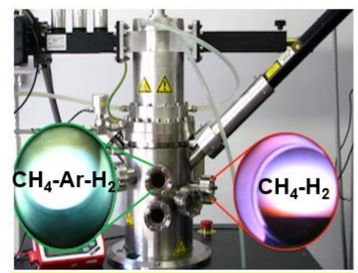


MWPECVD APPARATUS at lab of (CNR-ISTP BARI)

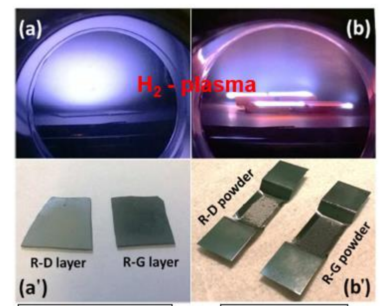


Properties	Diamond	CsI
Density (g/cm^3)	3.51	4.51
E_G (eV)	5.5	6.2
Electron Affinity χ (eV)	<1 eV (or negative)	0.1
Resistivity (Ω cm)	10^8-10^{12} !?	10^{10}-10^{11}
Optical transparency	From UV to far IR	From UV to far IR

CH_4-H_2 and CH_4-Ar-H_2 plasmas for deposition of PCD and NCD films, and H_2 plasma for treatment of sprayed ND layer and ND particles



CNR-ISTP *Sezione di Bari*



Sprayed ND Layer on Si

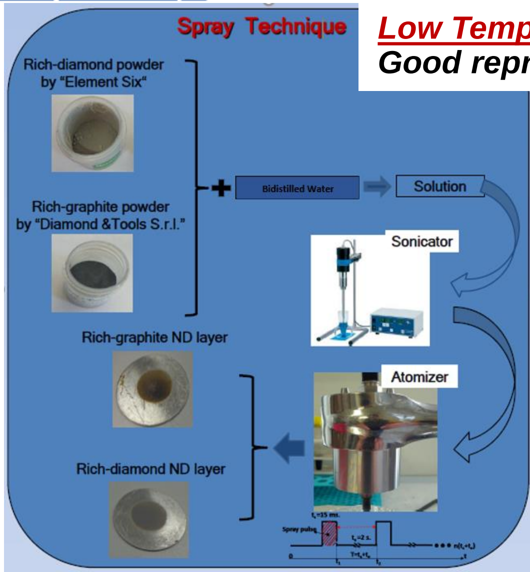
ND particles

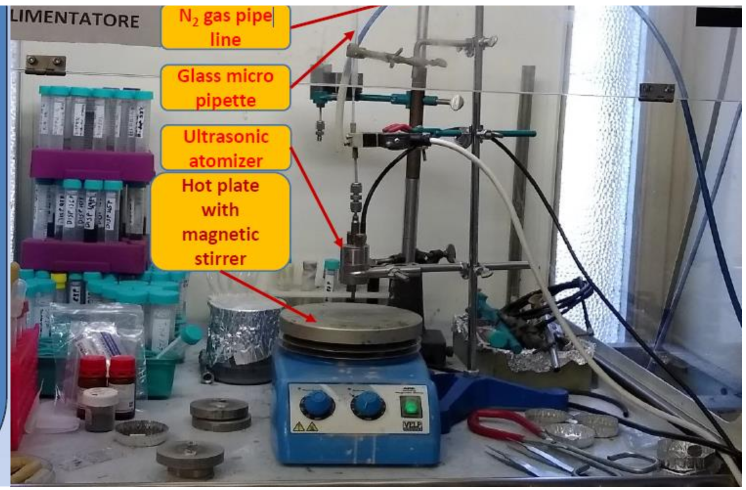
L. Velardi, A. Valentini, G. Cicala Diamond & Related Materials 76 (2017) 1–8

SPRAYED H-ND TECHNIQUE

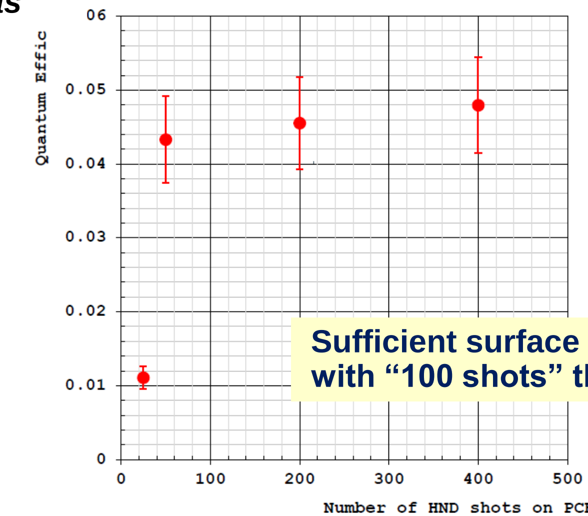
Low Temperature Deposition (≤ 120 °C)

Good reproducibility technique, Scalable to cover large areas





Quantum Efficiency Vs. H-ND Shots @ 160 nm @ 2 kV/cm



Sufficient surface coverage with "100 shots" thickness

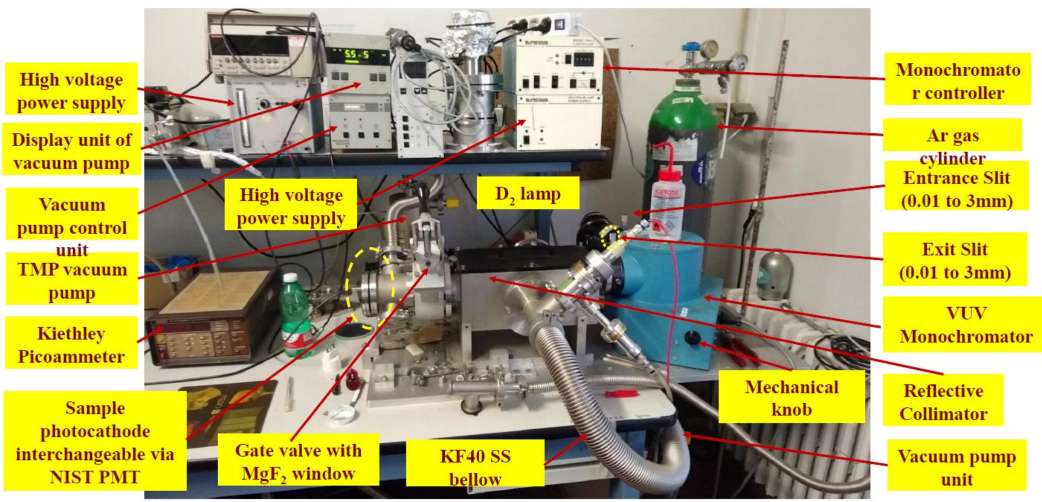
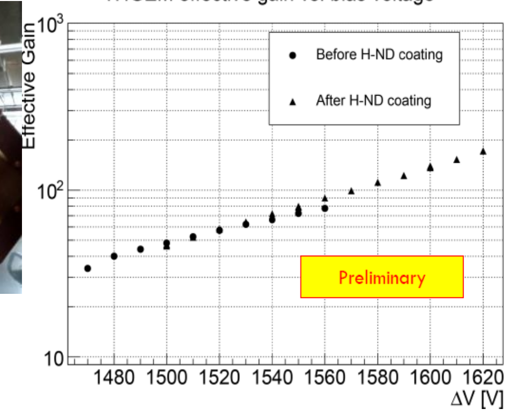


Figure : McPherson VUV monochromator for the photocurrent measurement at INFN Bari, Italy

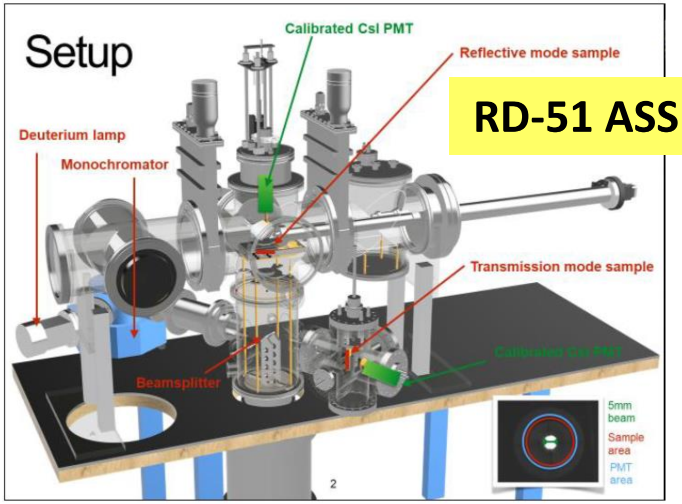
A SET OF SMALL THGEMS PREPARED AND CHARACTERIZED FOR SYSTEMATIC H-ND STUDIES

THGEM effective gain vs. bias voltage

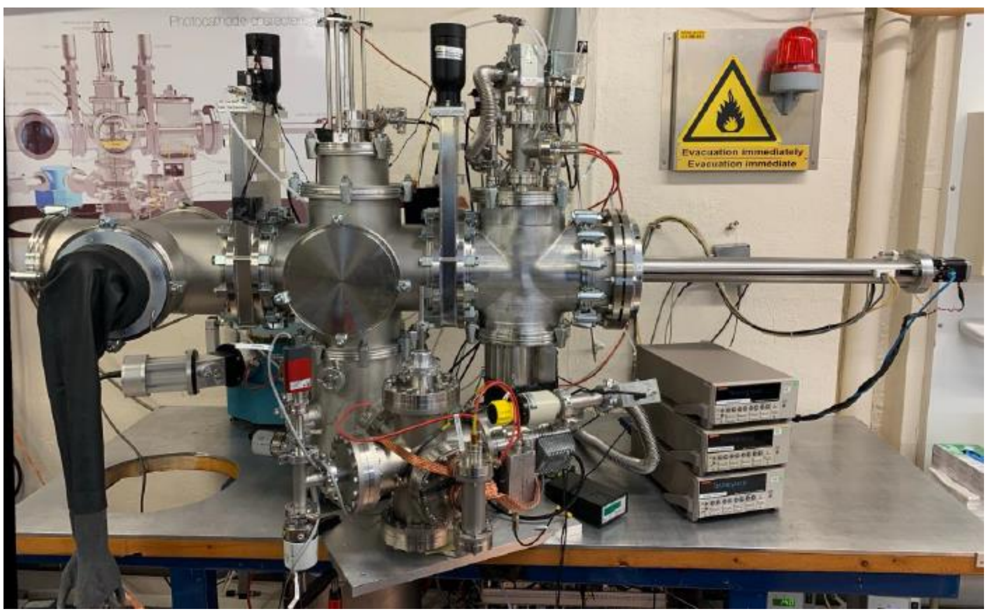


H-ND coated THGEMS operate nicely as electron multipliers

Exploratory H-ND aging study



RD-51 ASSET at CERN



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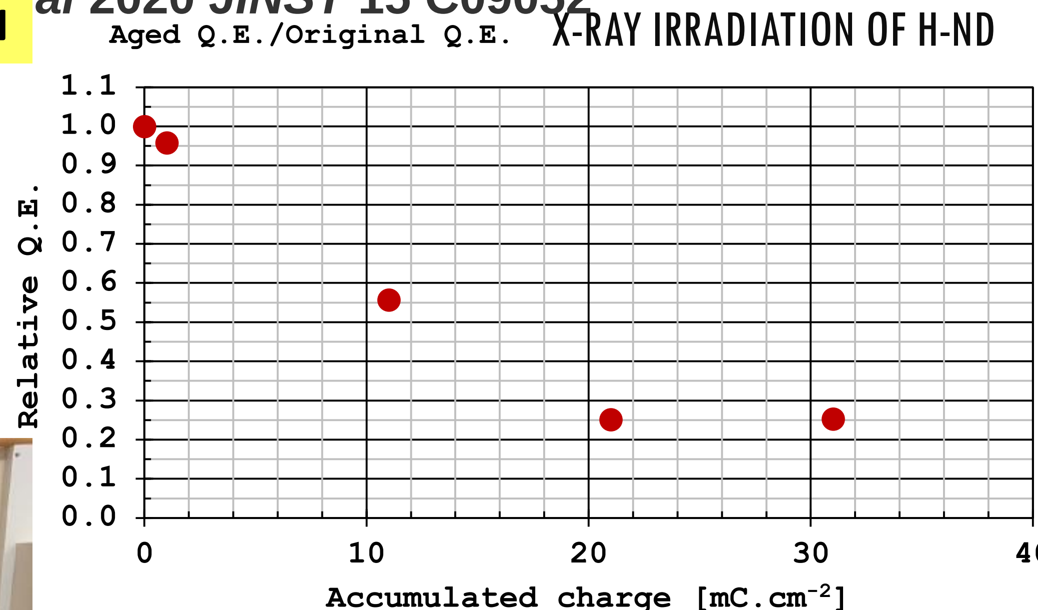

preliminary indication: H-ND is at least ten times more robust than CsI