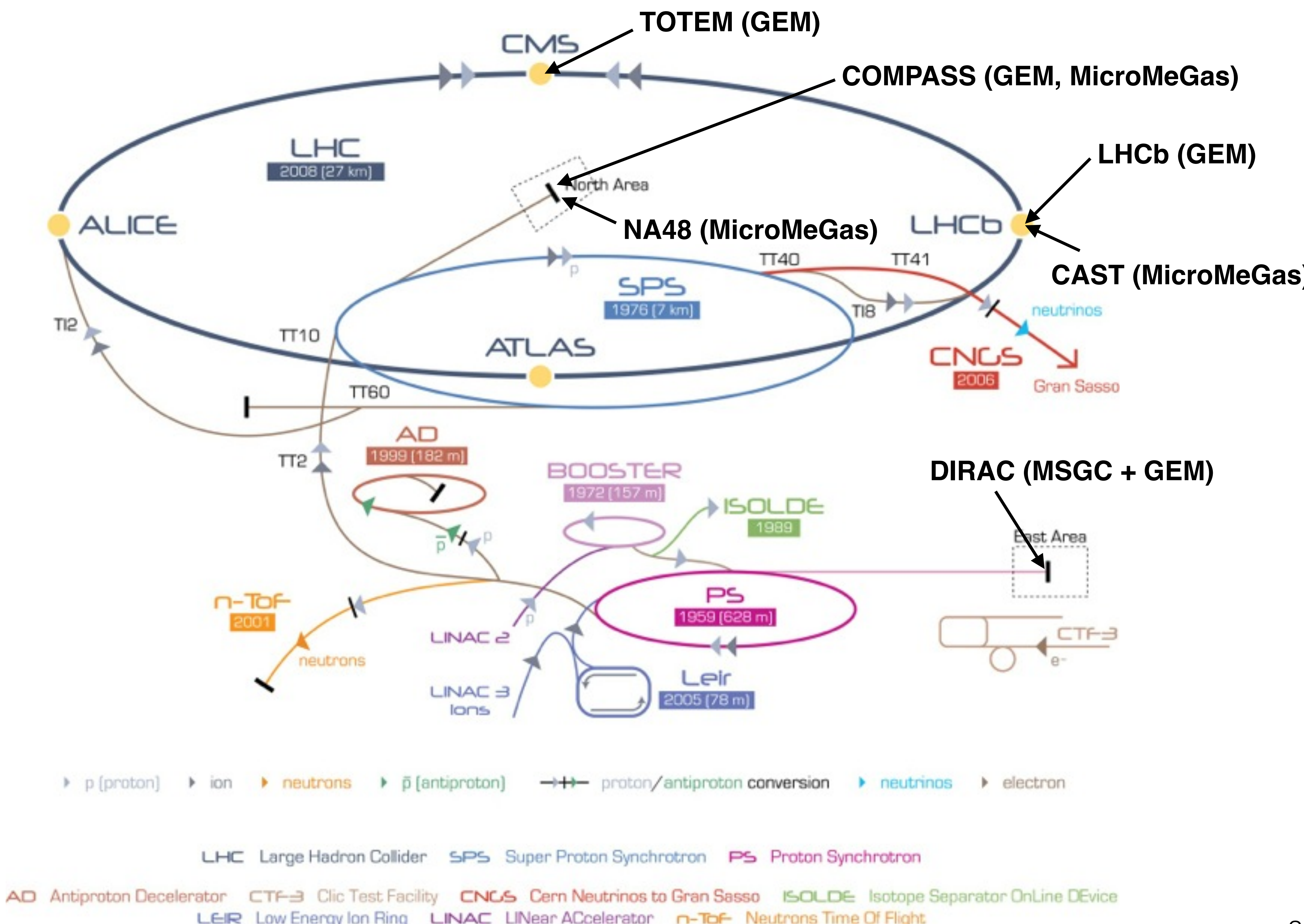
Review of Micro-Pattern Gaseous Detectors

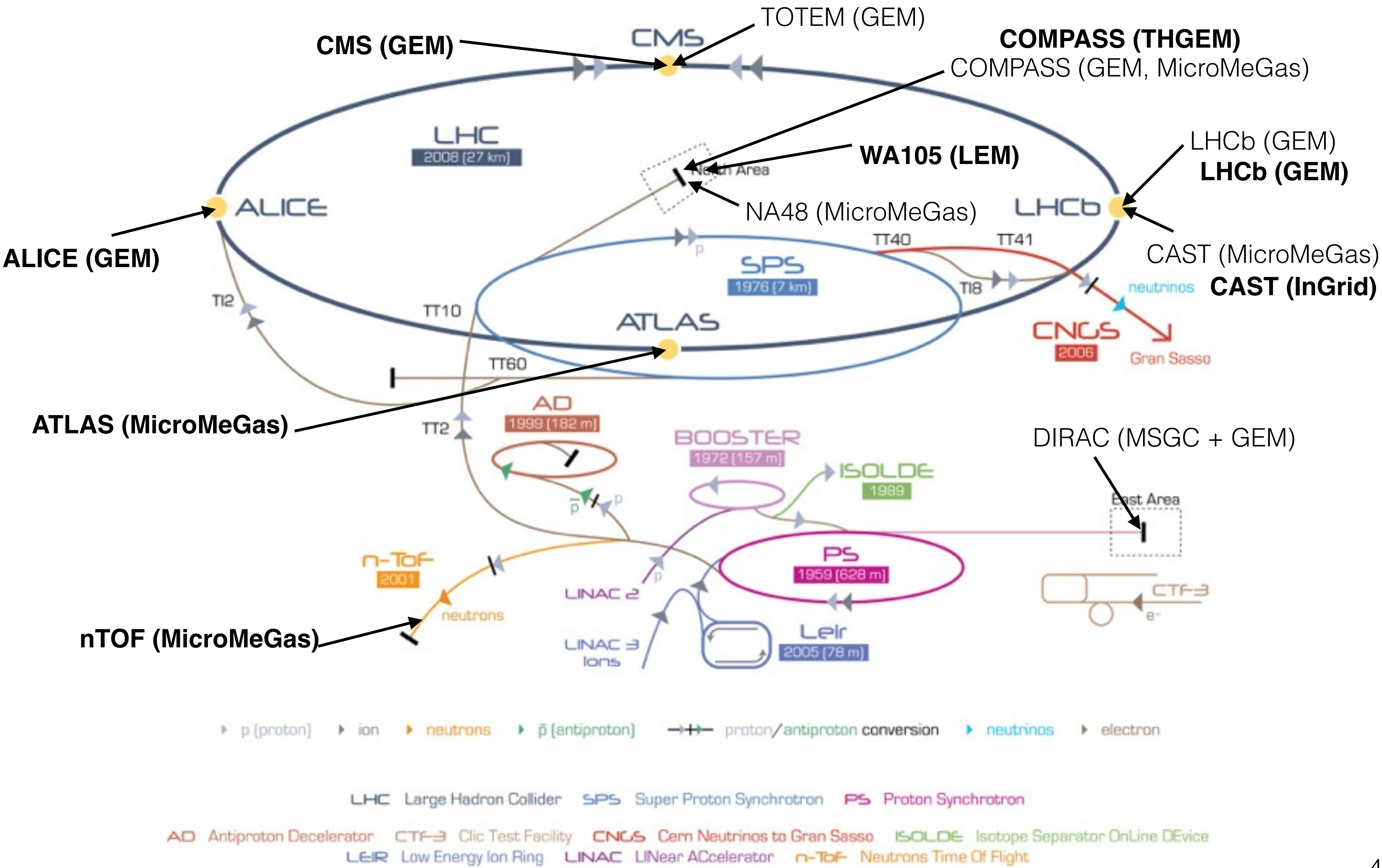
Filippo Resnati (CERN)

I’ll only mention the CGEM in this slide

An example


TOTEM (GEM)
COMPASS (GEM, MicroMeGas)
LHCb (GEM)
NA48 (MicroMeGas)
CAST (MicroMeGas)
DIRAC (MSGC + GEM)
CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT40
TT41
SPS
1976 (7 km)
TI8
neutrinos
TI2
TT10
ATLAS
CNGS
2006
Gran Sasso
TT60
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
PS
1959 (628 m)
n-ToF
2001
LINAC 2
CTF3
e-
neutrons
LINAC 3
Ions
LEIR
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
proton/antiproton conversion
neutrinos
electron
LHC Large Hadron Collider
SPS Super Proton Synchrotron
PS Proton Synchrotron
AD Antiproton Decelerator
CTF3 Clic Test Facility
CNGS Cern Neutrinos to Gran Sasso
ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring
LINAC LINear ACcelerator
n-ToF Neutrons Time Of Flight

In the future



MPGD highlights

- High flux capability
- High gain
- High space resolution
- Good time resolution
- Good energy resolution
- Excellent radiation hardness
- Good ageing properties
- Large size
- Low cost

MWPC Charpak, 1968

Few primary electron and ion pairs in gas
Charge amplification in gas via Townsend avalanche
High field region confined to preserve detector linearity

Small electrode curvature defines field drop with distance-> wires

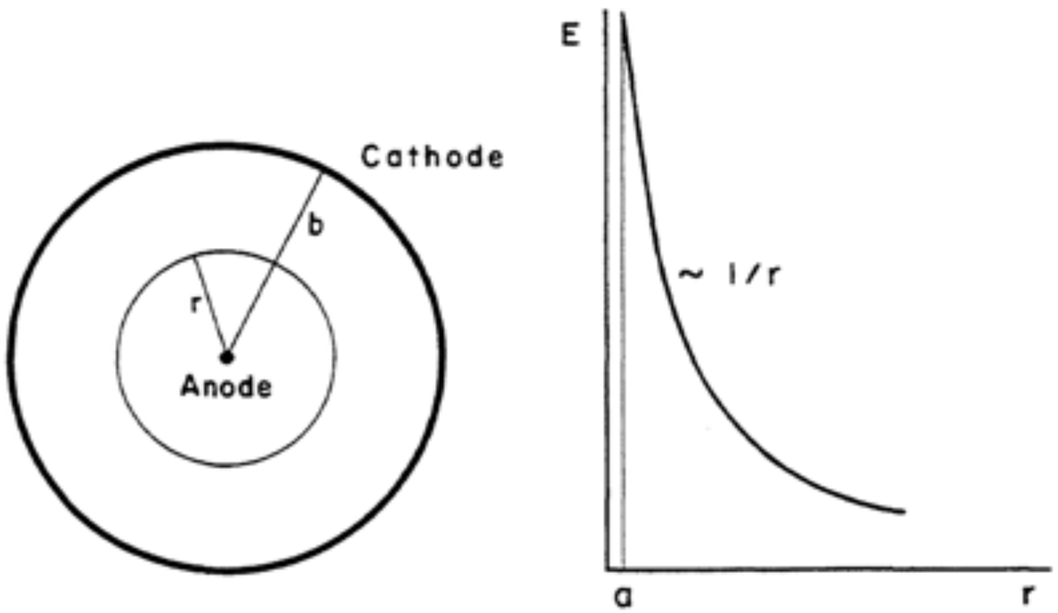


Fig. 48 The coaxial cylindrical proportional counter, and the shape of the electric field around the thin anode. Only very close to the anode the field grows high enough to allow avalanche multiplication.

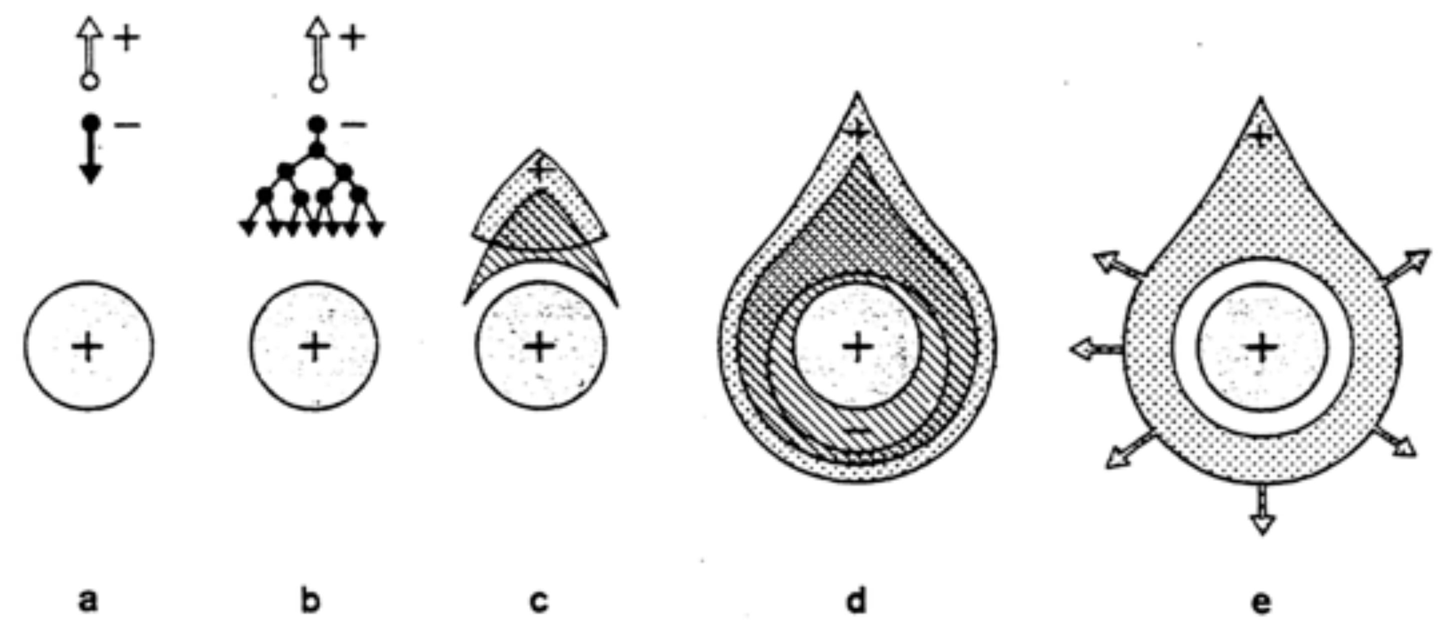


Fig. 49 Time development of an avalanche in a proportional counter[30]. A single primary electron proceeds towards the anode, in regions of increasingly high fields, experiencing ionizing collisions; due to the lateral diffusion, a drop-like avalanche, surrounding the wire, develops. Electrons are collected in a very short time (1 nsec or so) and a cloud of positive ions is left, slowly migrating towards the cathode.

F. Sauli, "Principles of Operation of Multiwire Proportional and Drift Chambers," CERN-77-09

Ions (slowly) drift back -> space charges -> field modifications -> rate capability
Electrostatics forces -> distance between wires -> position resolution
Organic molecules/pollutants -> modification of wire radius -> *classical* ageing

Change of paradigm (1)

In order to evacuate the ionic charge fast, the cathode electrodes are placed in the vicinity of the anode electrodes.

MSGC Oed, 1988

Electrodes on solid substrate -> smaller pitch -> higher resolution
Cathodes in the vicinity of the anode -> fast evacuations of ions -> high flux capability

Semiconductor industry technologies:
photolithography, etching,
lift-off, coating, …

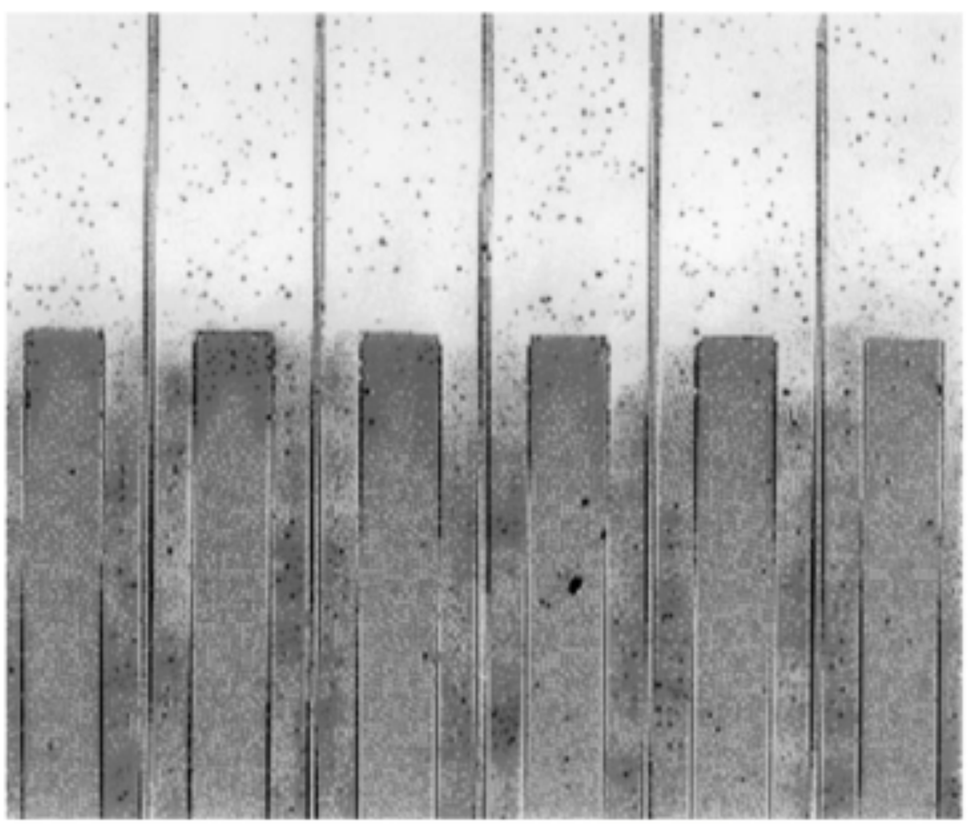


Figure 1 Close view of one of the first microstrip plates developed by Oed at the Institut Laue-Langevin. On an insulating substrate, thin metallic anode strips alternate with wider cathodes; the pitch is 200 μm.

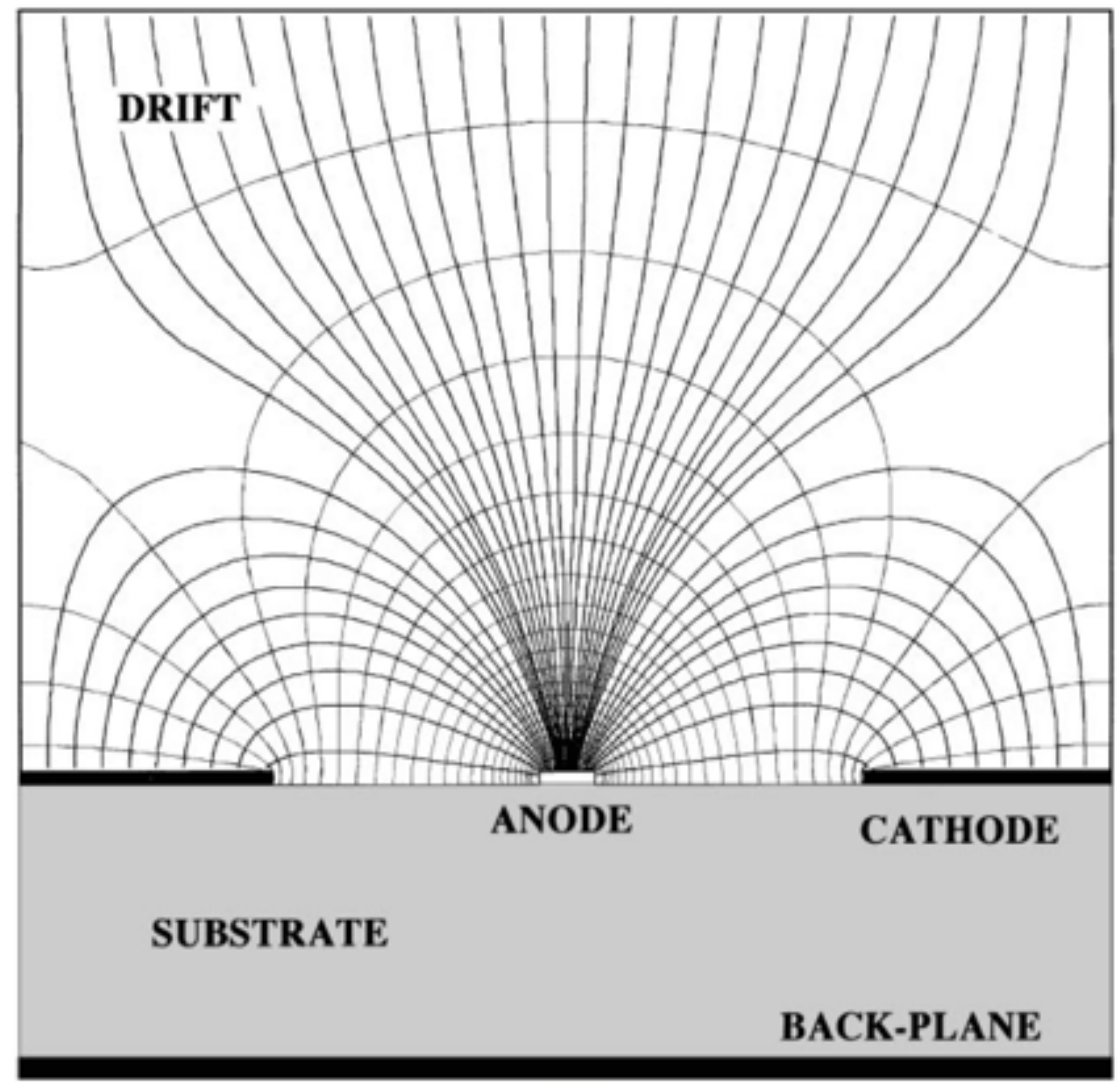


Figure 2 Equipotentials and field lines in the microstrip chamber, computed close to the substrate. The back-plane potential has been selected to prevent field lines entering the dielectric.

F. Sauli and A. Sharma, "Micropattern Gaseous Detectors," Annu. Rev. Nucl. Part. Sci. 49 (1999) 341

MSGC Oed, 1988

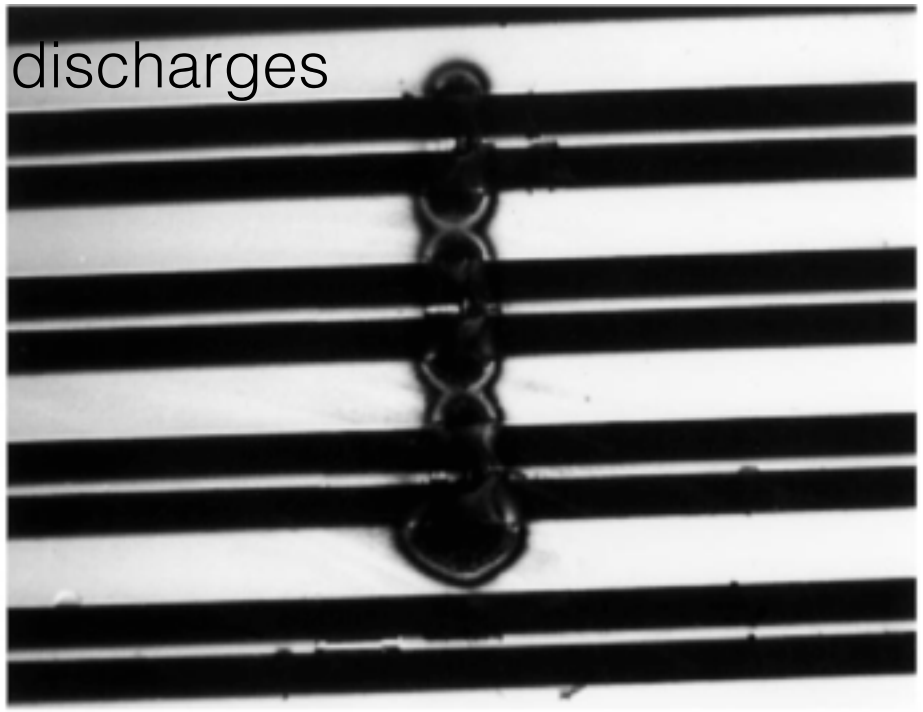


Figure 19 Close view of the strips on a plate in the region of a discharge. Note extensive damage to the strips.

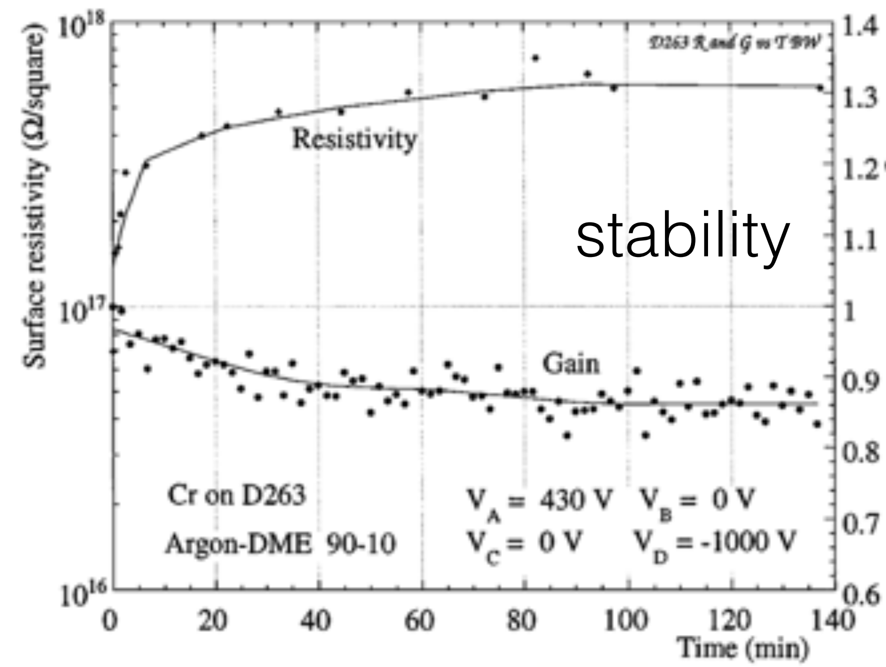


Figure 7 Initial gain variation of gain and resistivity as a function of time from the application of voltage for a plate made on insulating borosilicate glass substrate. V_A, V_B, V_C, and V_D are the anode, back-plane, cathode, and drift potentials, respectively.

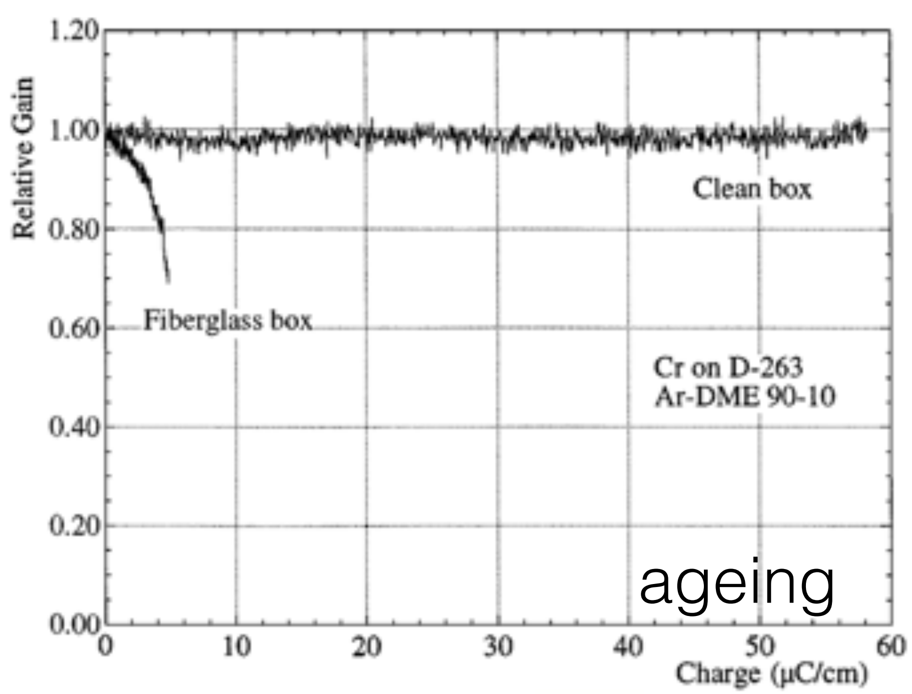


Figure 21 Comparison of aging rate under irradiation for identical plates, mounted either in a conventional fiberglass assembly or in a clean container.

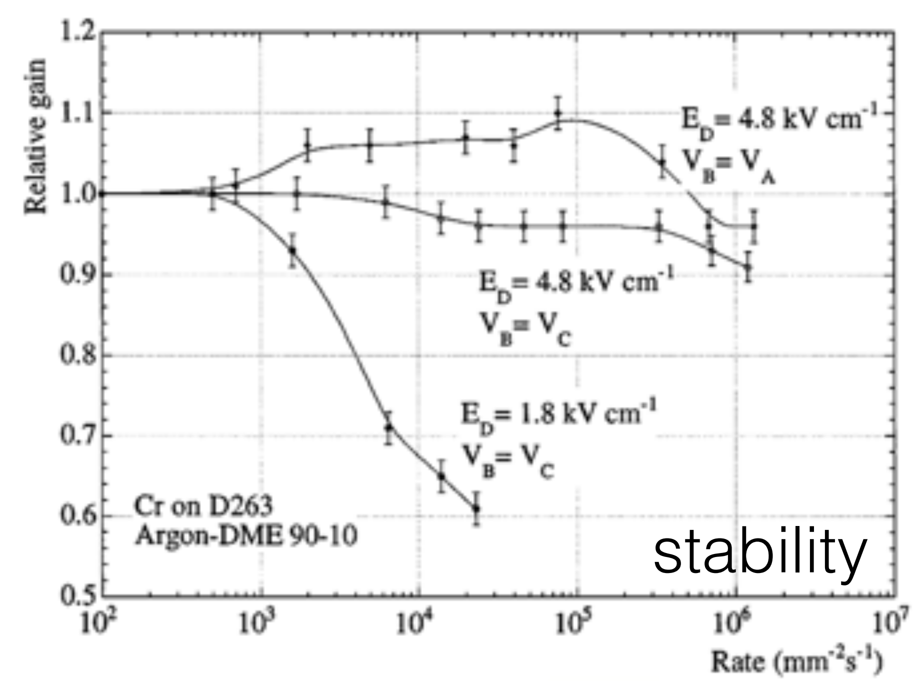


Figure 8 Relative gain as a function of irradiation rate, measured on a microstrip made on borosilicate glass. The performance depends strongly on the applied voltages. E_D is the drift field; V_B and V_C are the back-plane and cathode potentials.

Annu. Rev. Nucl. Part. Sci. 49 (1999) 341

F. Sauli,
"Development of High Rate MSGCs: Overview of Results From RD-28,"
Nucl. Phys. Proc. Suppl. 61B (1998) 236

Certainly some issues:

- Modification of the electric field by substrate polarisation
- Charging up of the insulator by electrons and ions produced in the avalanches
- Ion migration within the substrate
- Permanent deterioration (ageing) during sustained irradiation

Nevertheless

Use of a substrate with lower resistivity and electronic conductivity eliminates the polarisation and surface charging processes up to very high rates; it results also in more stable operation and reduced ageing rates.

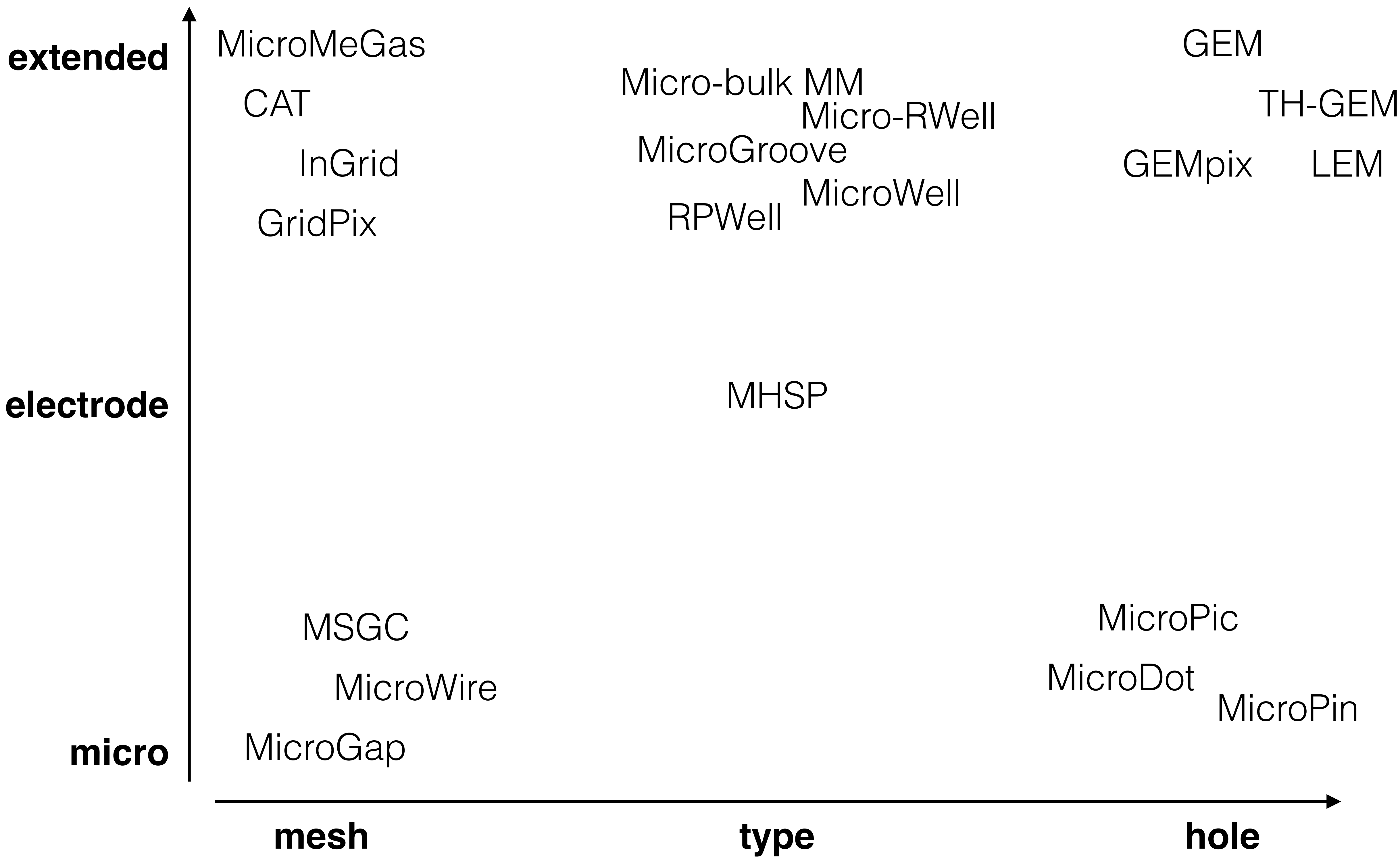
Topical session on resistive coating on 9th of December at RD51 Mini-Week

Change of paradigm (2)

In order to reduce the effects of the discharges and the *classical* ageing, the electric field responsible for the charge amplification is shaped by extended electrodes

MPGD: a rich variety

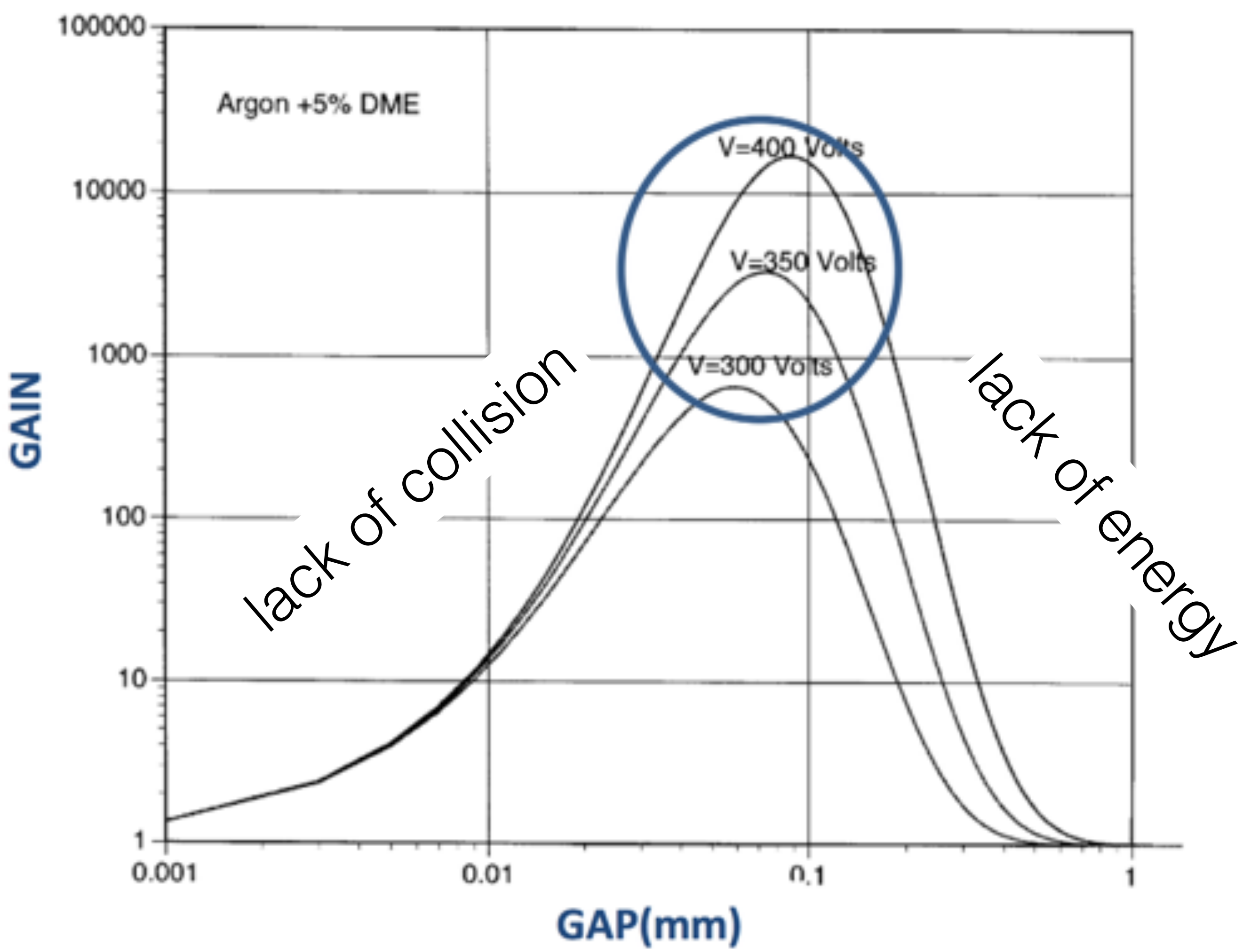
Non-exhaustive list



“Parallel plate”

In some circumstances, small dependance of the gain vs gap (pressure)
Better energy resolution… even on large surfaces

Gap on large surfaces controlled with dielectric material and spacers



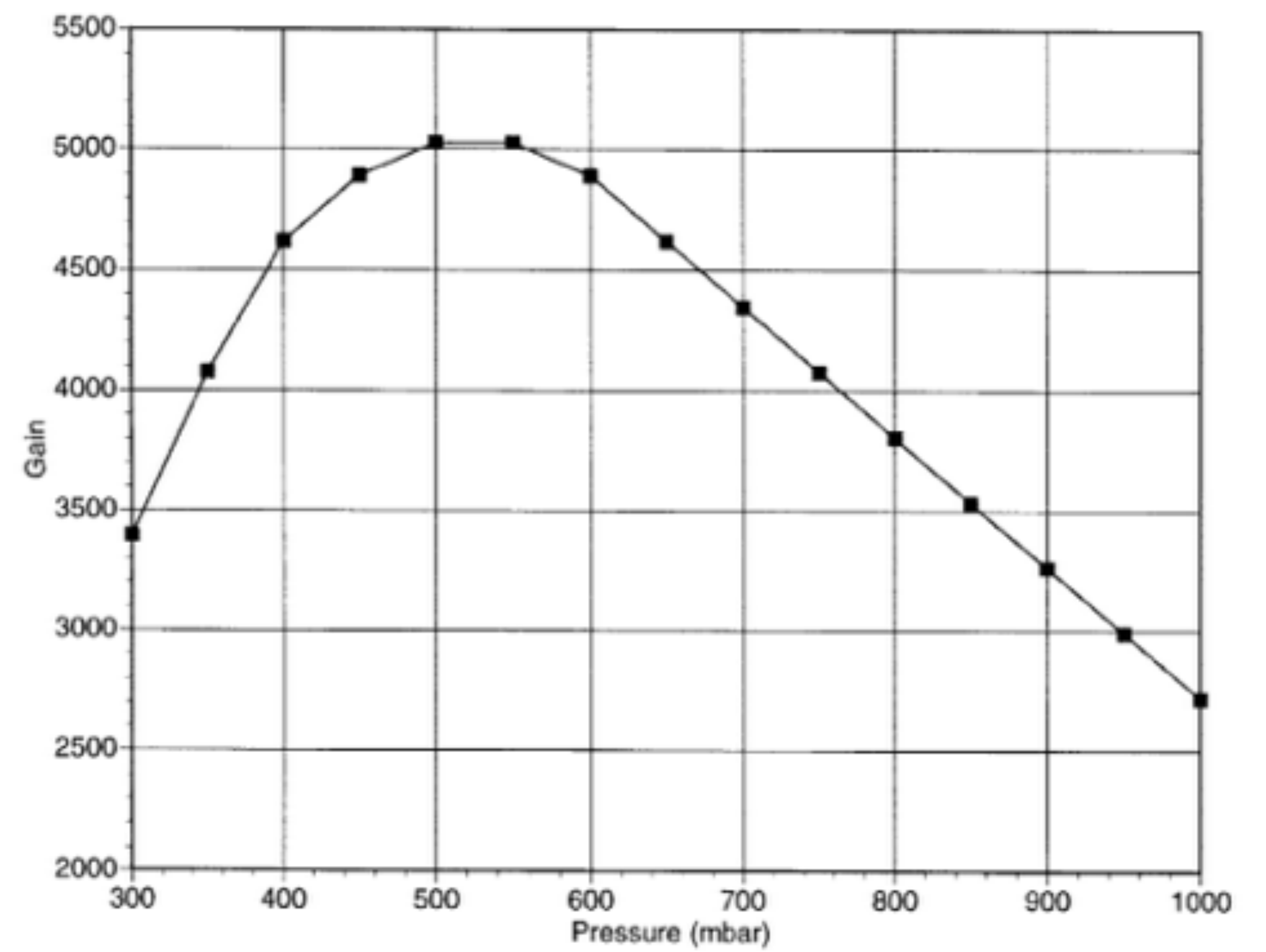


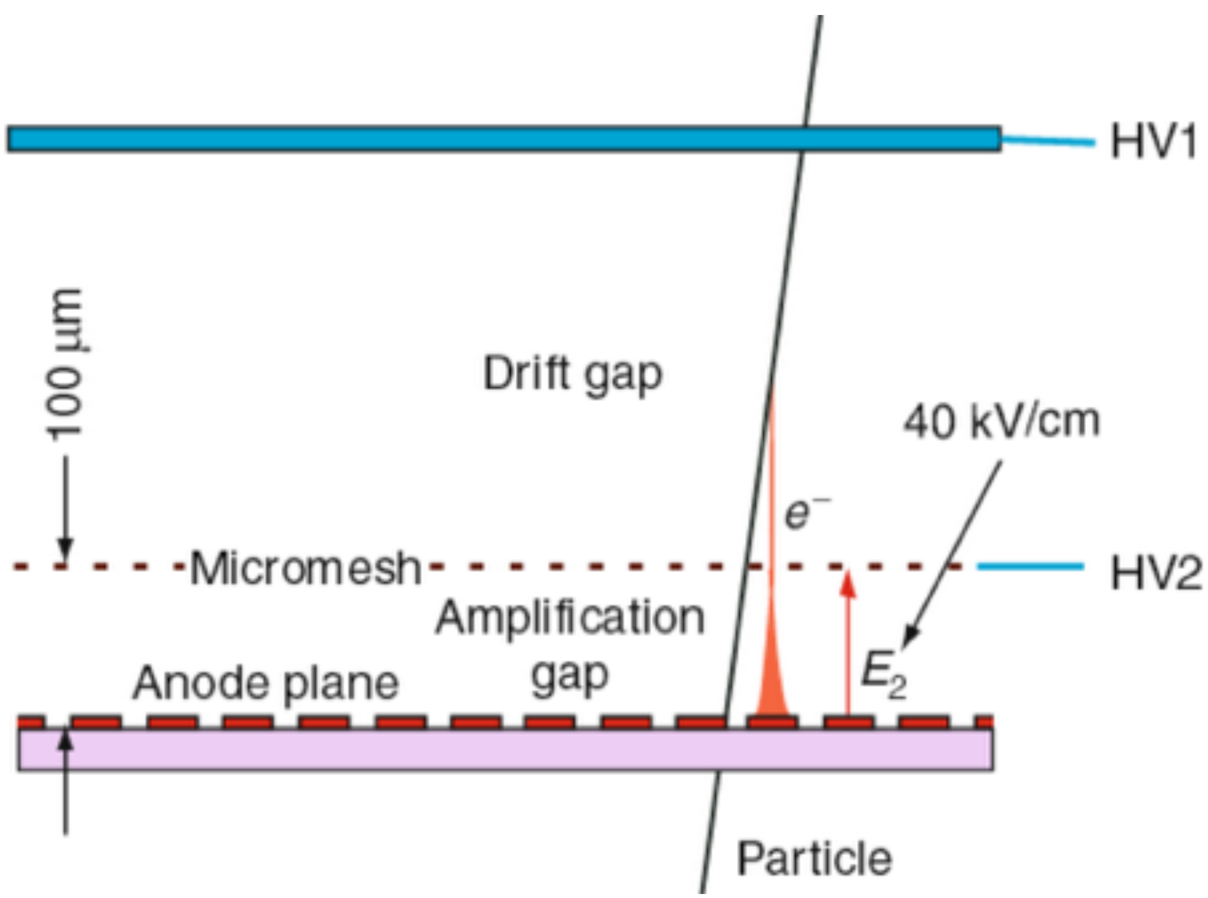
Fig. 3. Gain versus pressure for a gas mixture of Ar + 7% cyclohexane for a 50 μm amplification gap. The drift and the r
voltage was 1000 and 270 V, respectively.

Y. Giomataris, “Development and prospects of the new gaseous detector 'Micromegas',” NIM A419 (1998) 239

Meshes: MicroMeGas

Y. Giomataris *et al.* “MICROMEGAS: A High granularity position sensitive gaseous detector for high particle flux environments,” Nucl. Instr. and Meth. A 376 (1996) 29

Small gap, high field: fast movement of ions that are mostly collected on the mesh: small space-charge and very fast signals



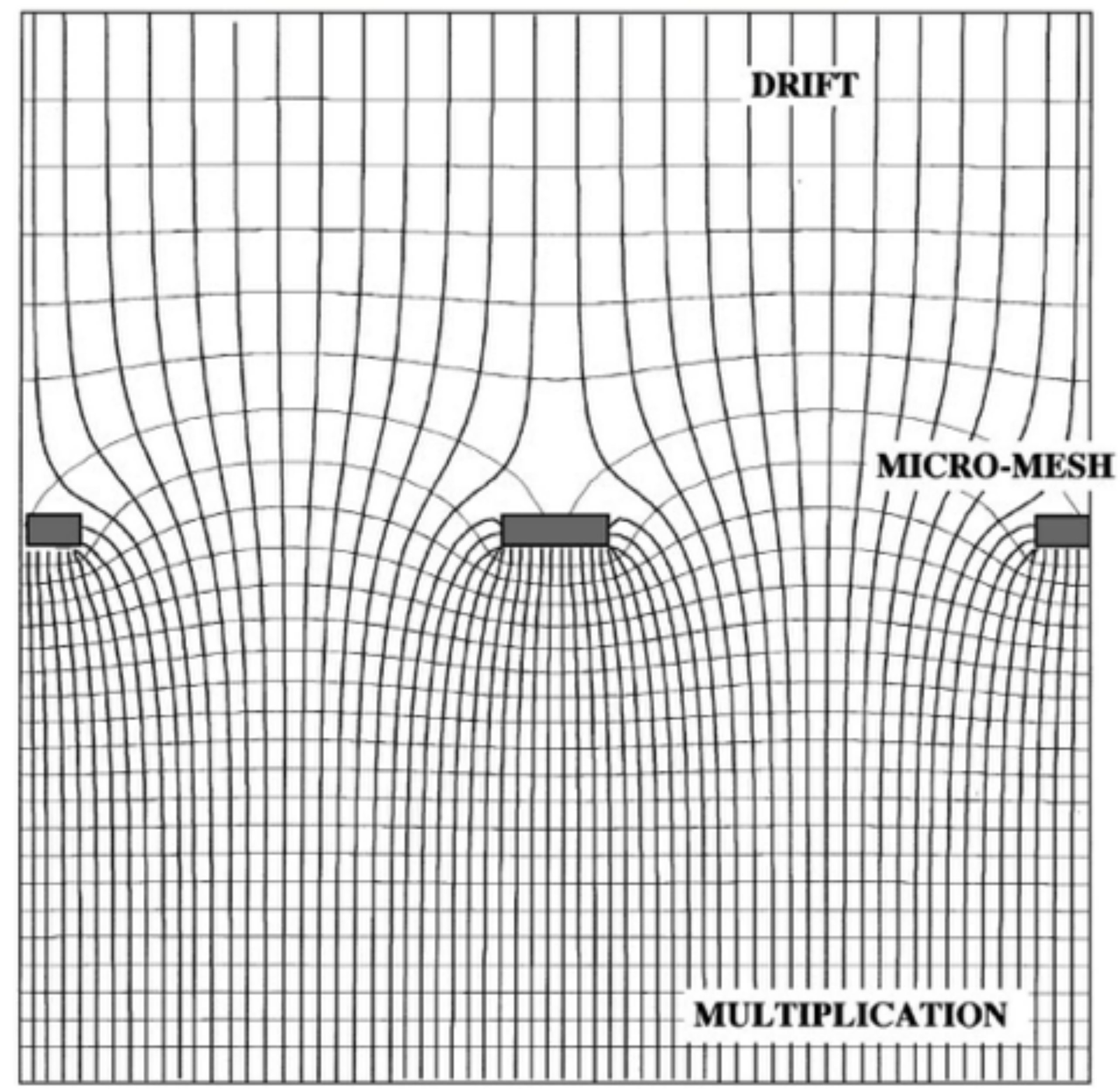
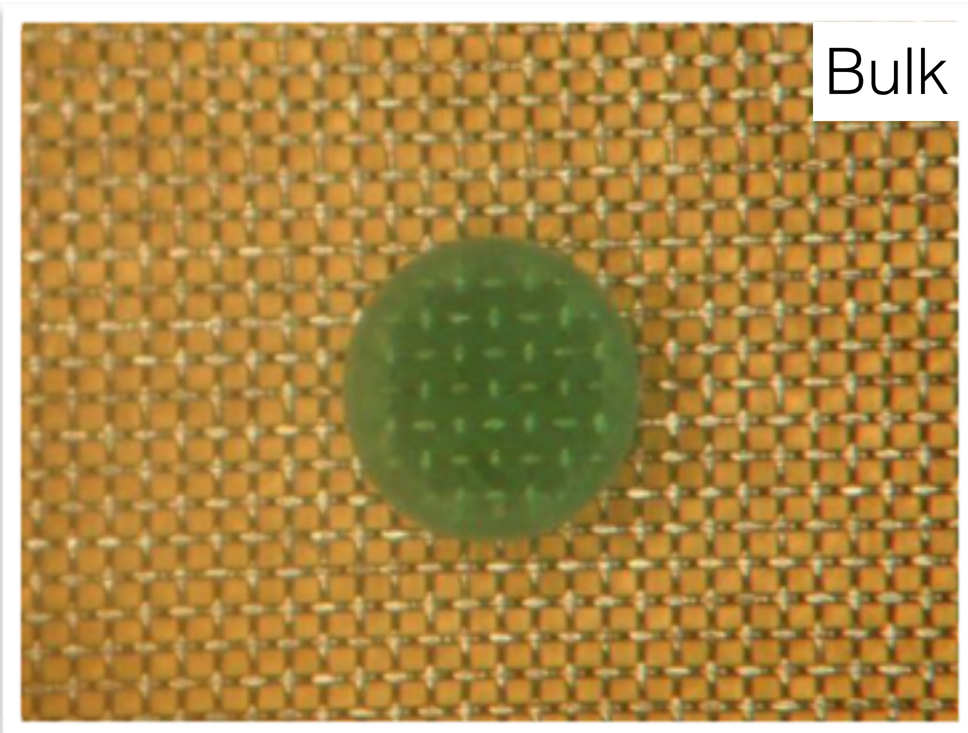
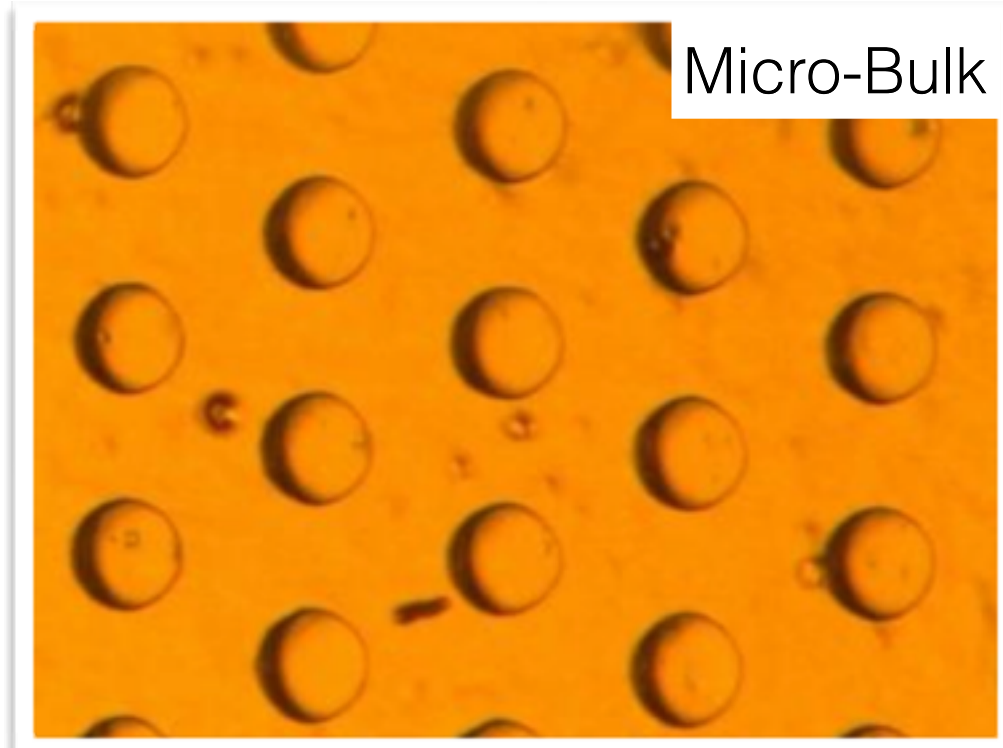


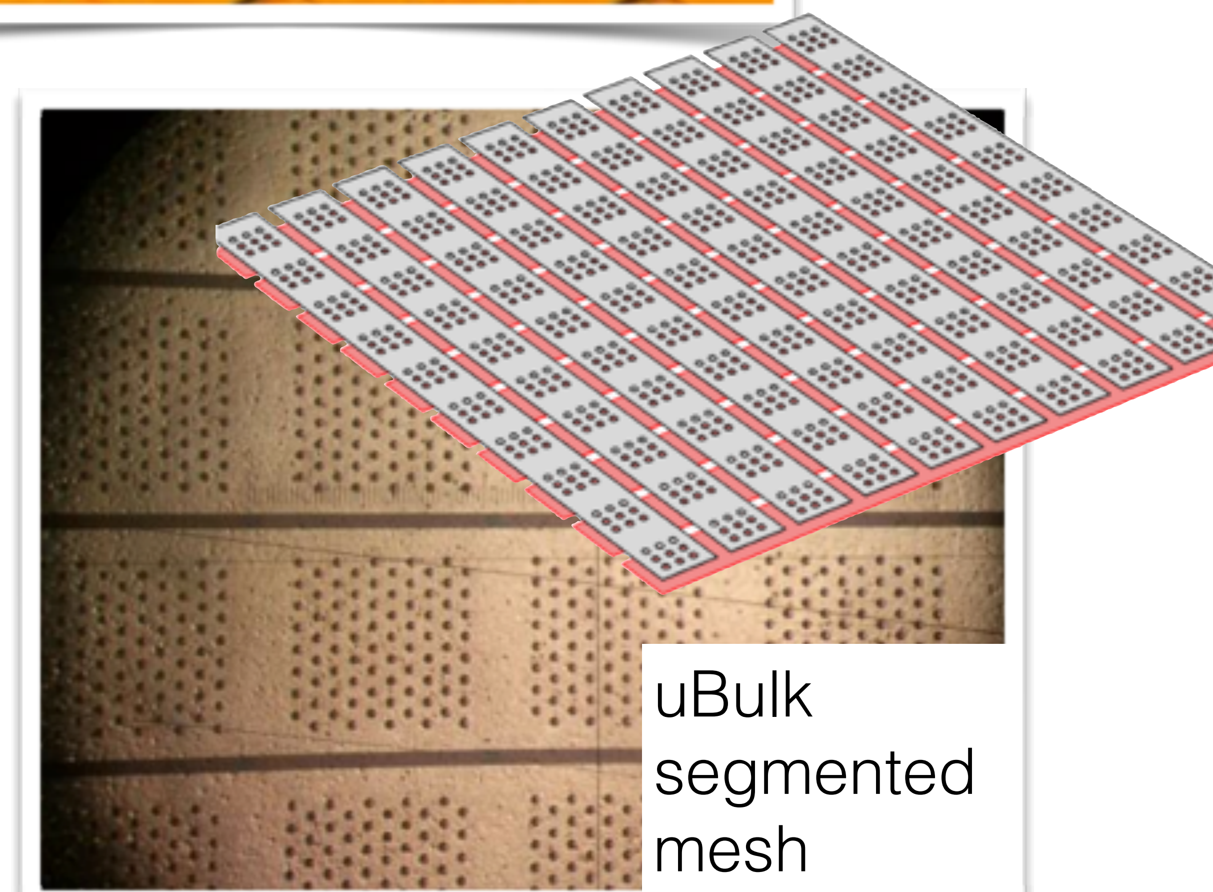
Figure 28 Schematics and electric field map in the micromegas. A metallic micromesh separates a low-field, or drift, region from the high-field multiplication region.

Annu. Rev. Nucl. Part. Sci. 49 (1999) 341

Bulk, uBulk and no bulk

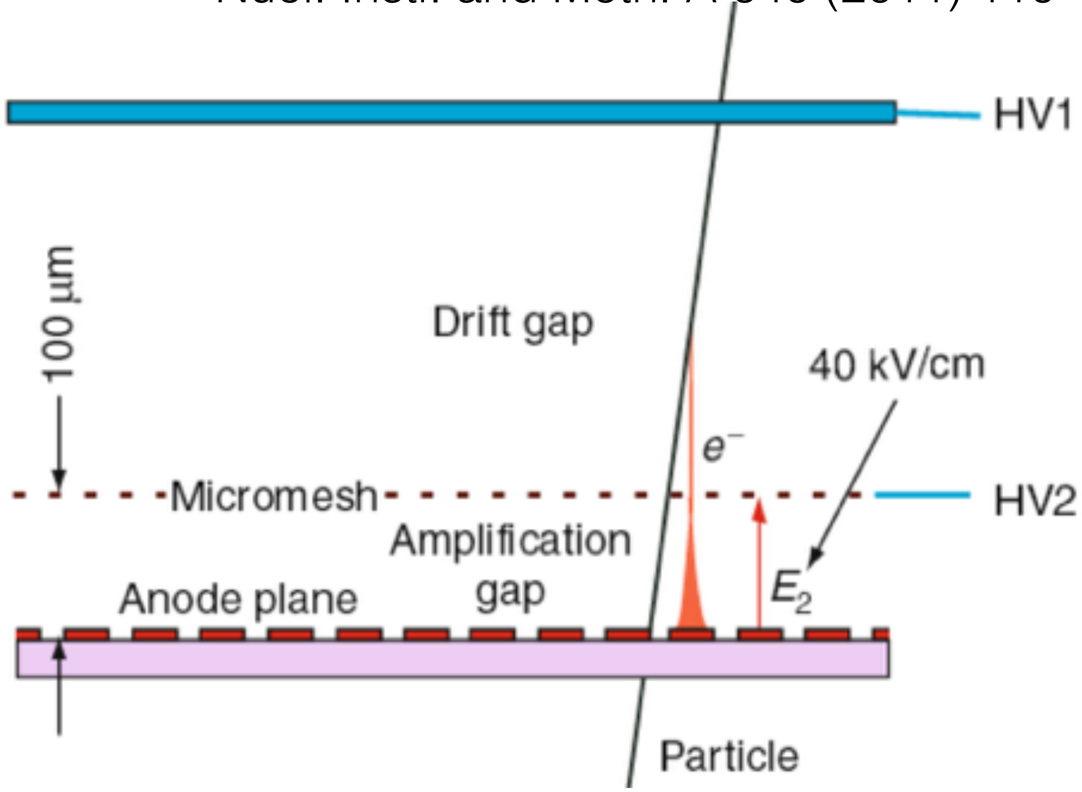


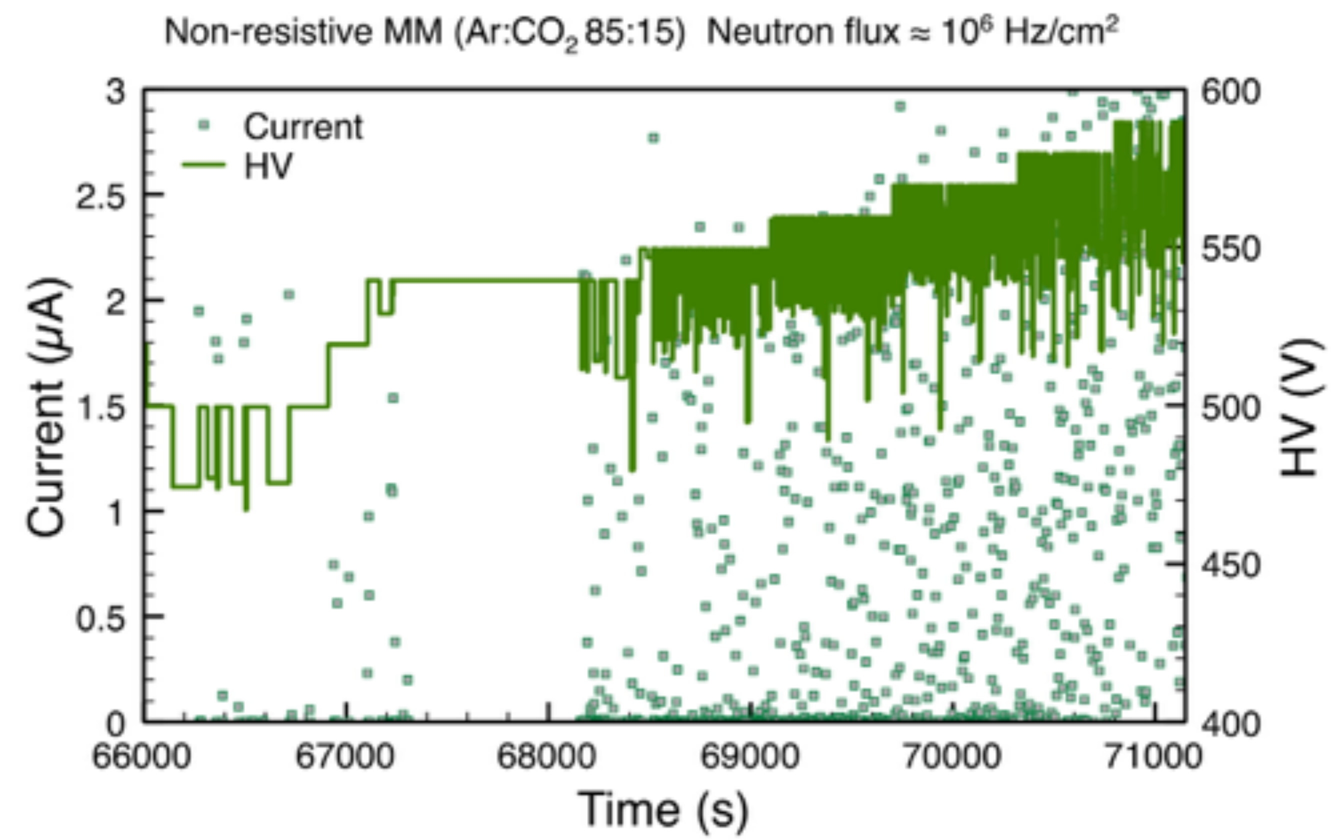


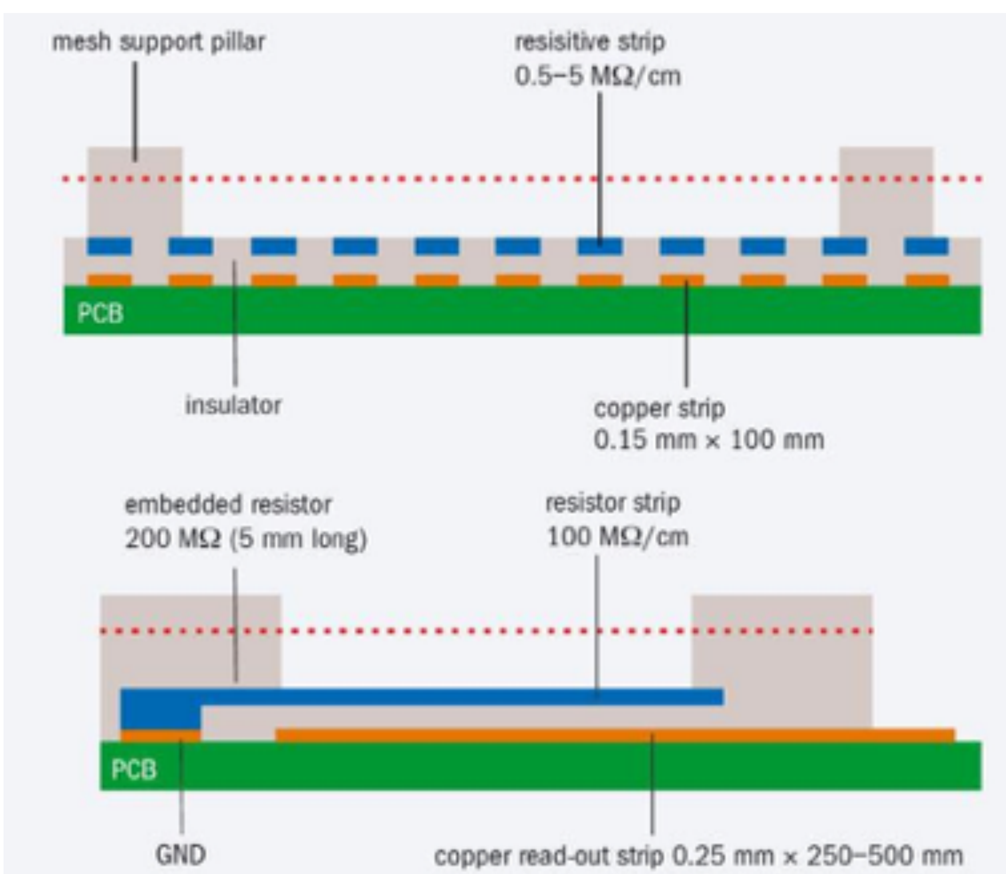


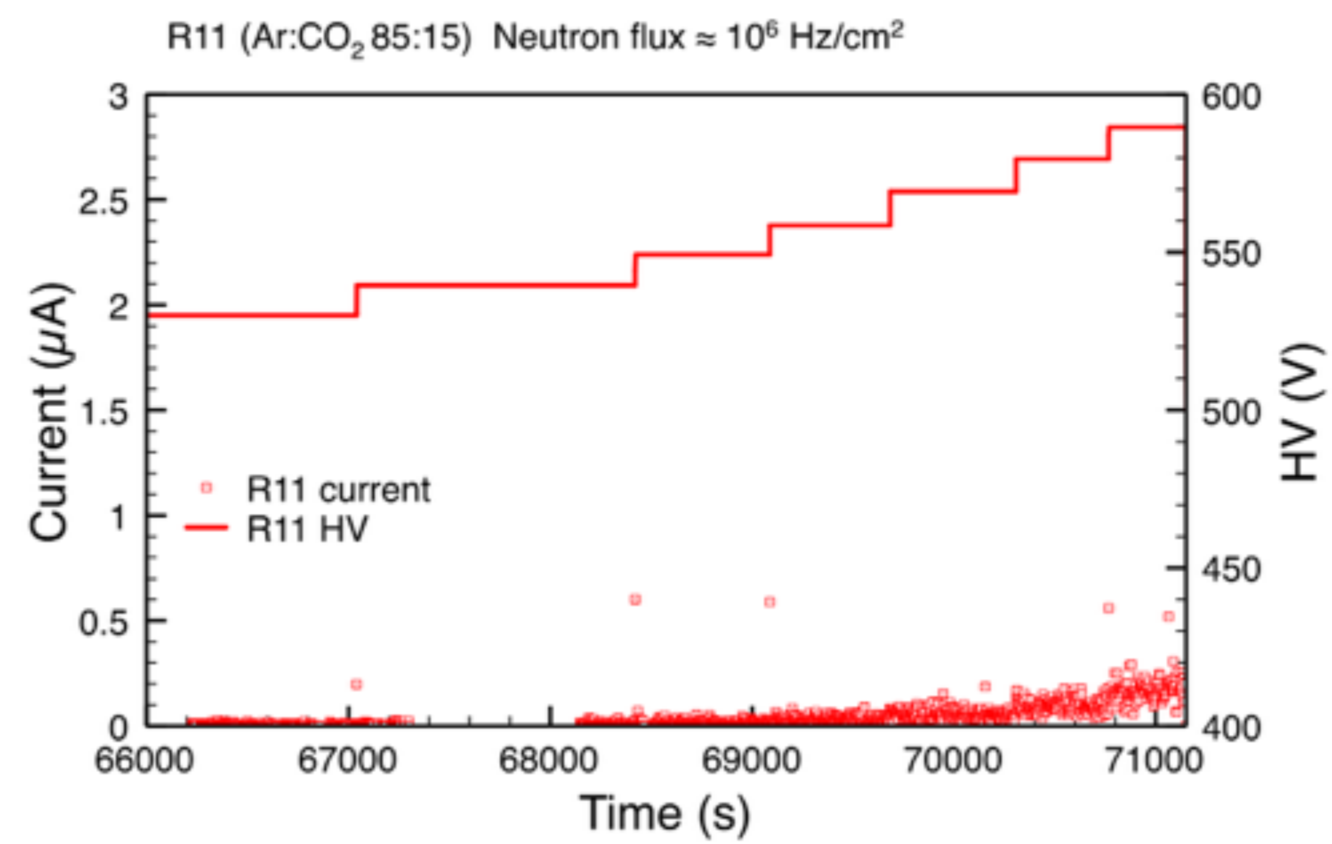
Resistive

T. Alexopoulos *et al.* “A spark-resistant bulk-micromegas chamber for high-rate applications,” Nucl. Instr. and Meth. A 640 (2011) 110



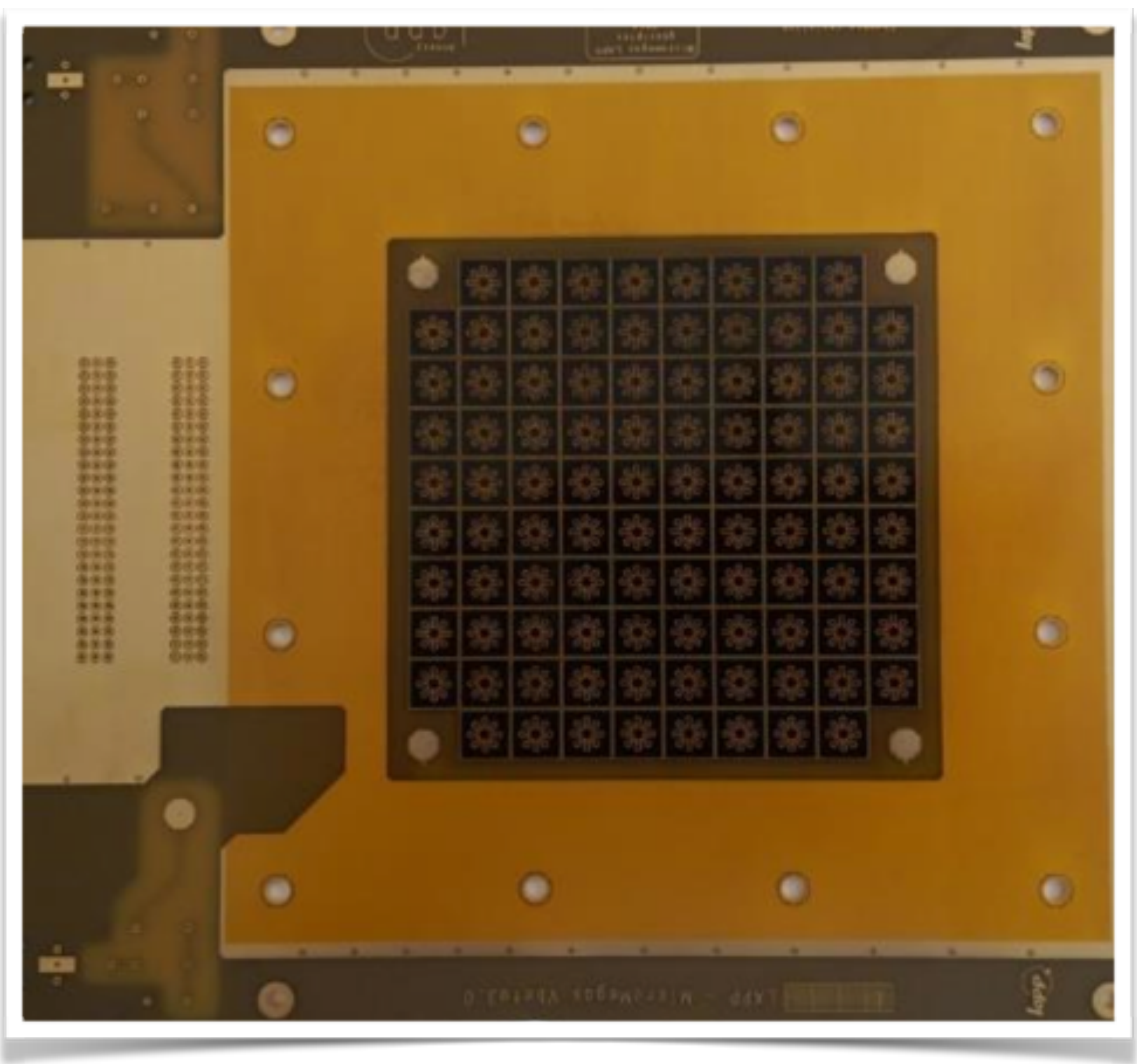


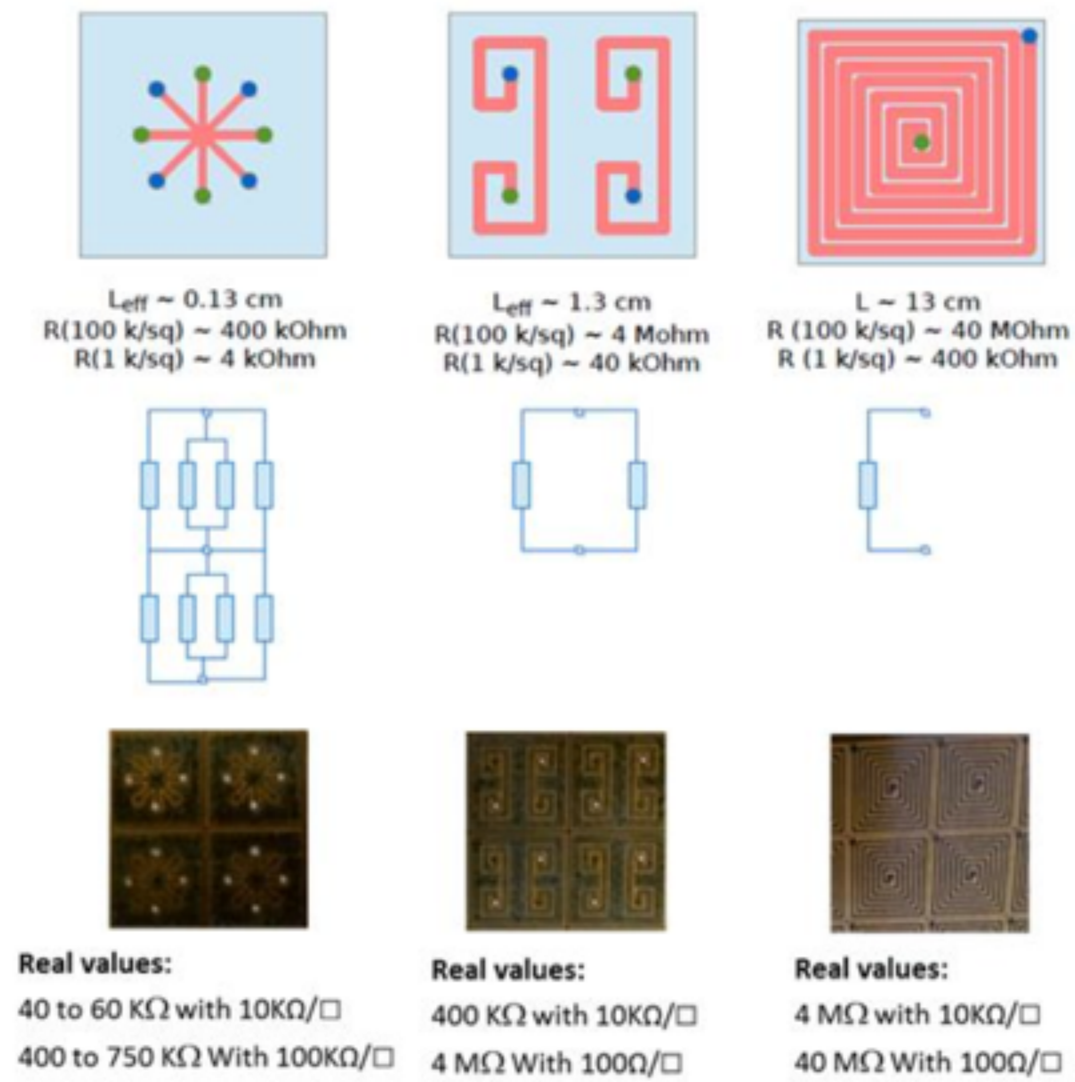




Discrete (buried) resistors

Charge evacuated *vertically*, not along the surface





Applied to calorimetry with MPGDs - M. Chefdeville *et al.*

Holes: GEM

F. Sauli, "GEM: A new concept for electron amplification in gas detectors," Nucl. Instr. and Meth. A 386 (1997) 531

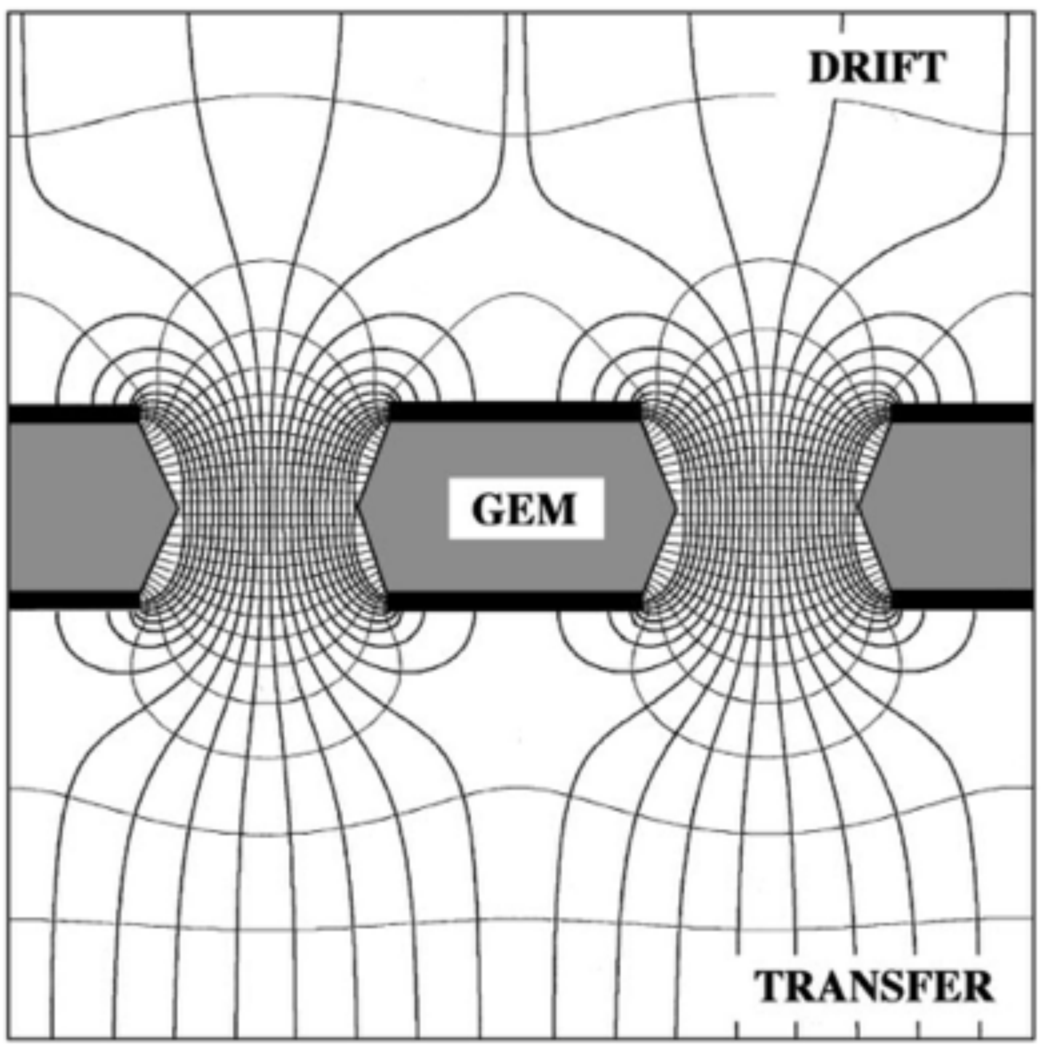
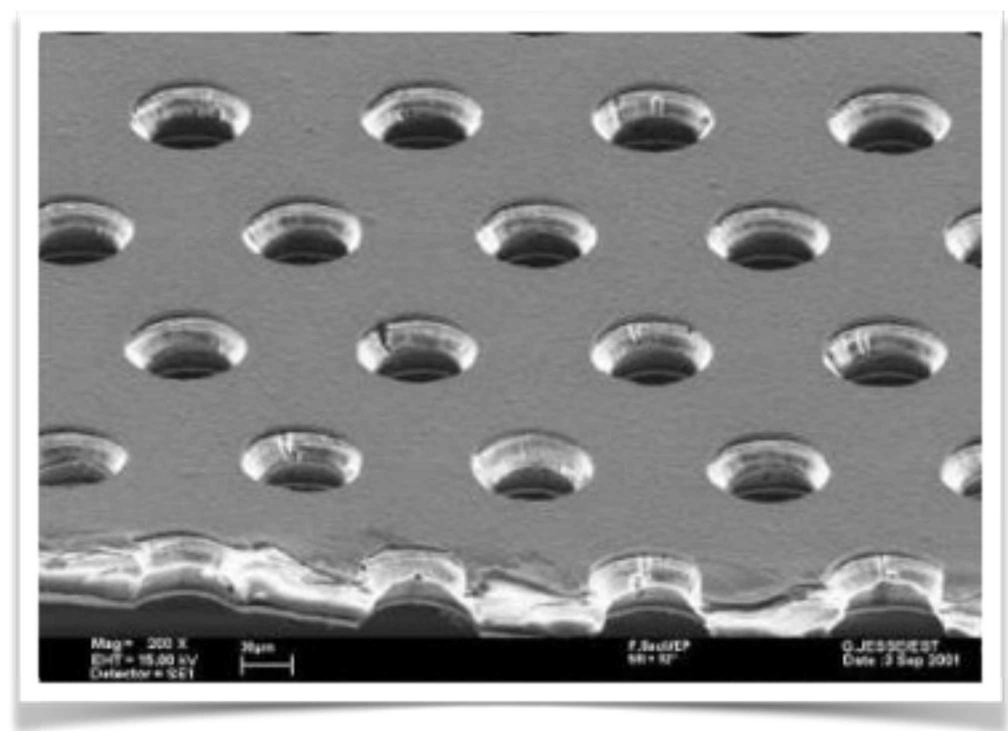


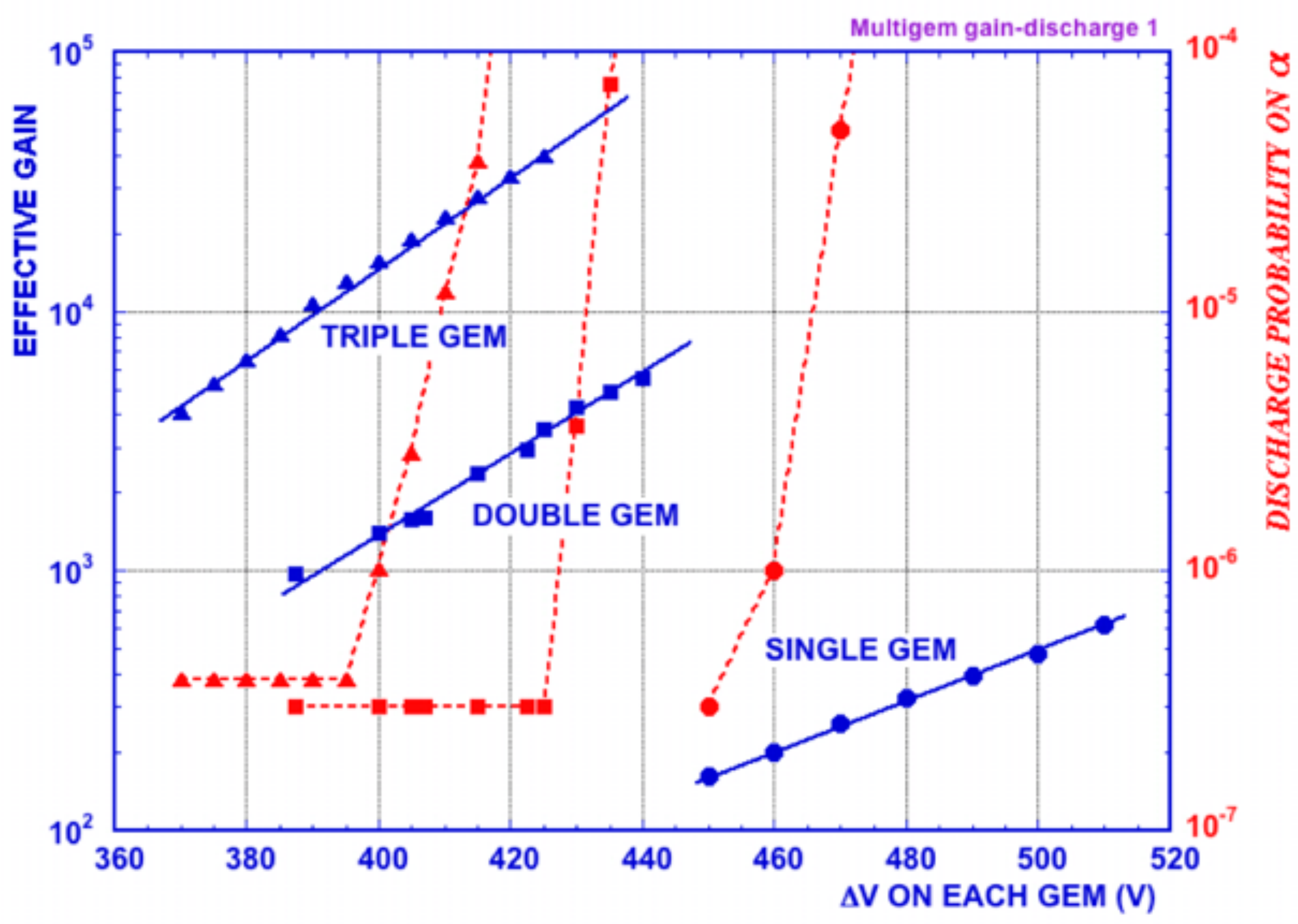
Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

Polyimide film metal cladded on both sides with holes chemically etched



Sharing the task

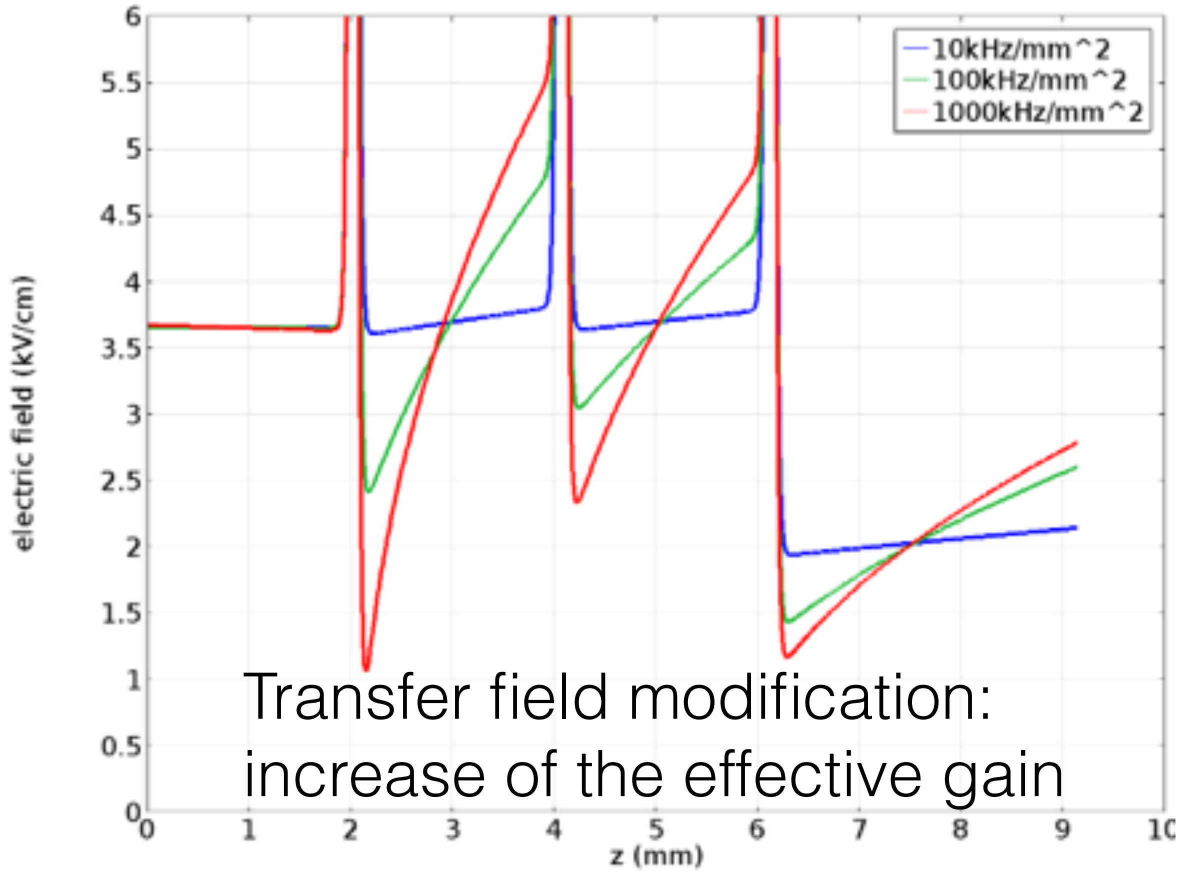
Unique feature of GEMs is charge transfer (electrons exit)
Share the gain between two or more GEM foils in cascade
to reduce the discharge probability and the discharge effects
Mixed/Hybrid detector (GEM + MM, …) also used



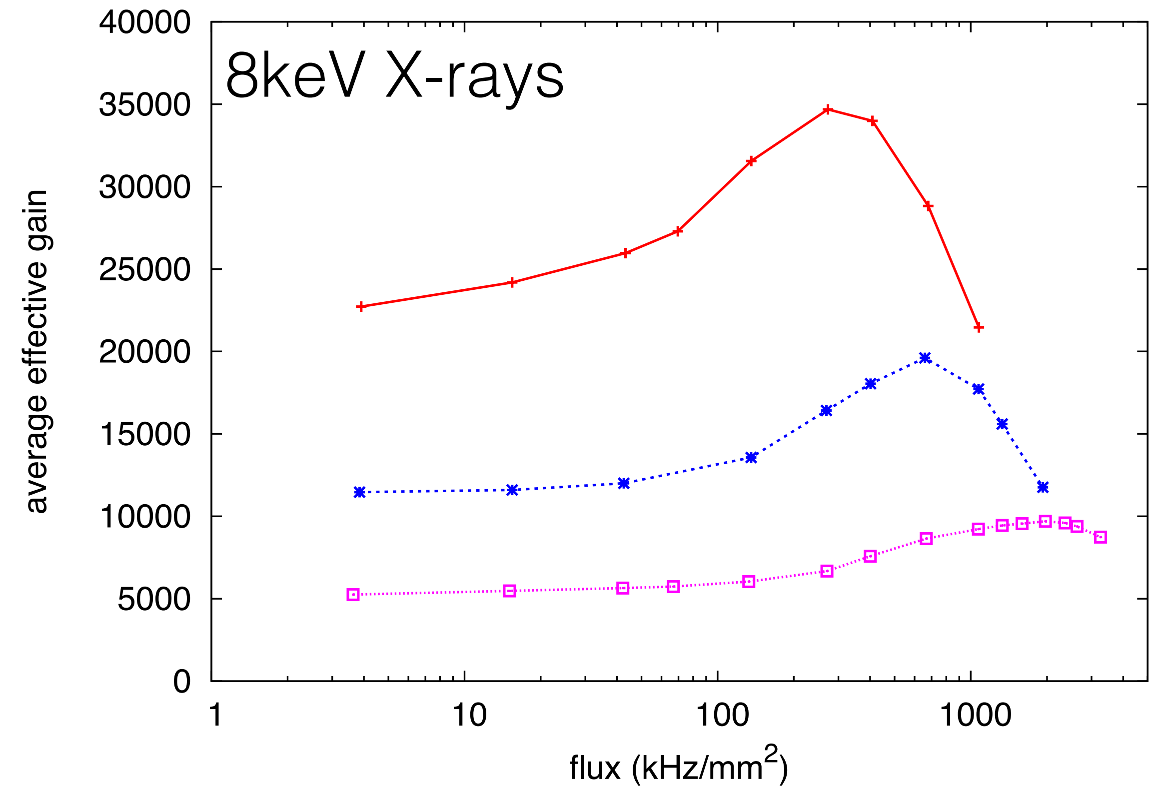
S. Bachmann et al, NIMA 479(2002)294

High flux capabilities

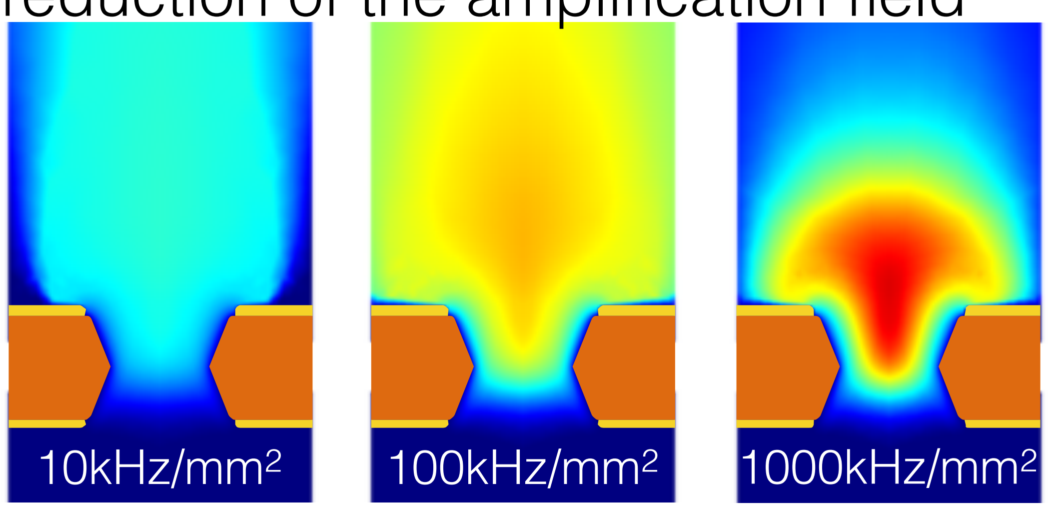
Ion charges instantaneously modify the electric fields

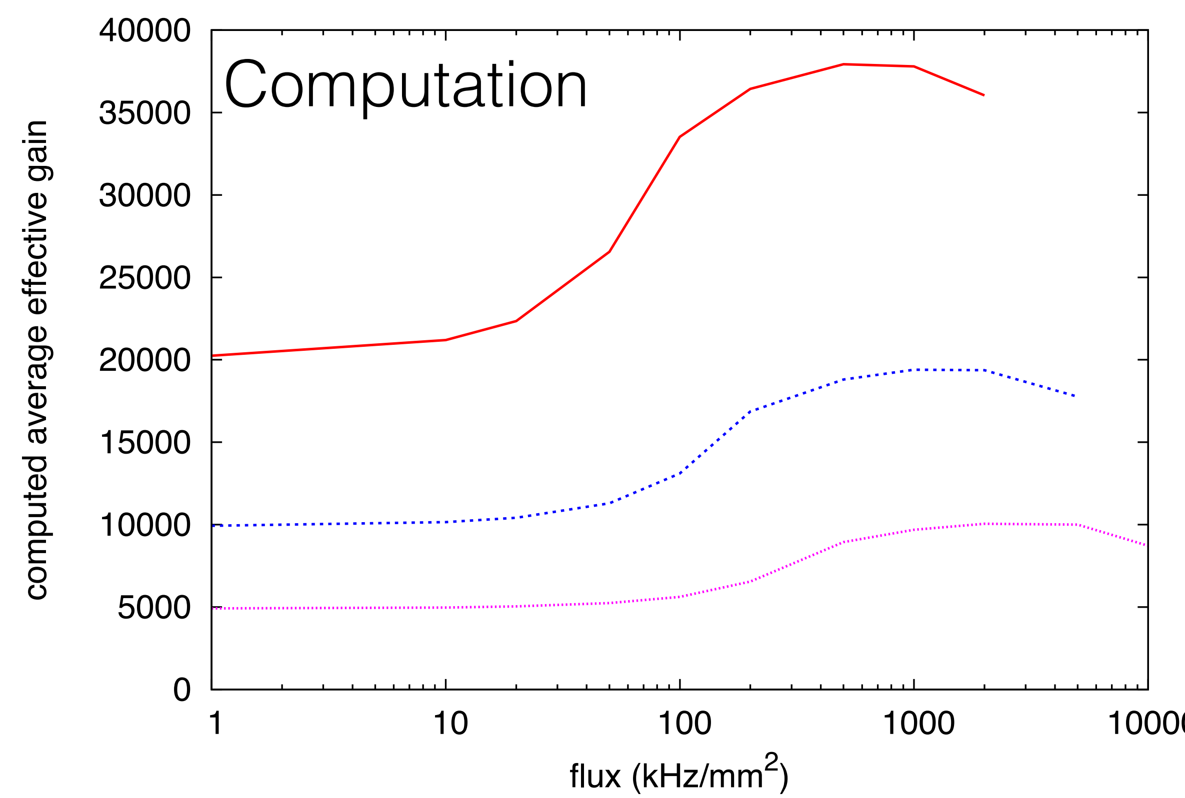


Transfer field modification:
increase of the effective gain



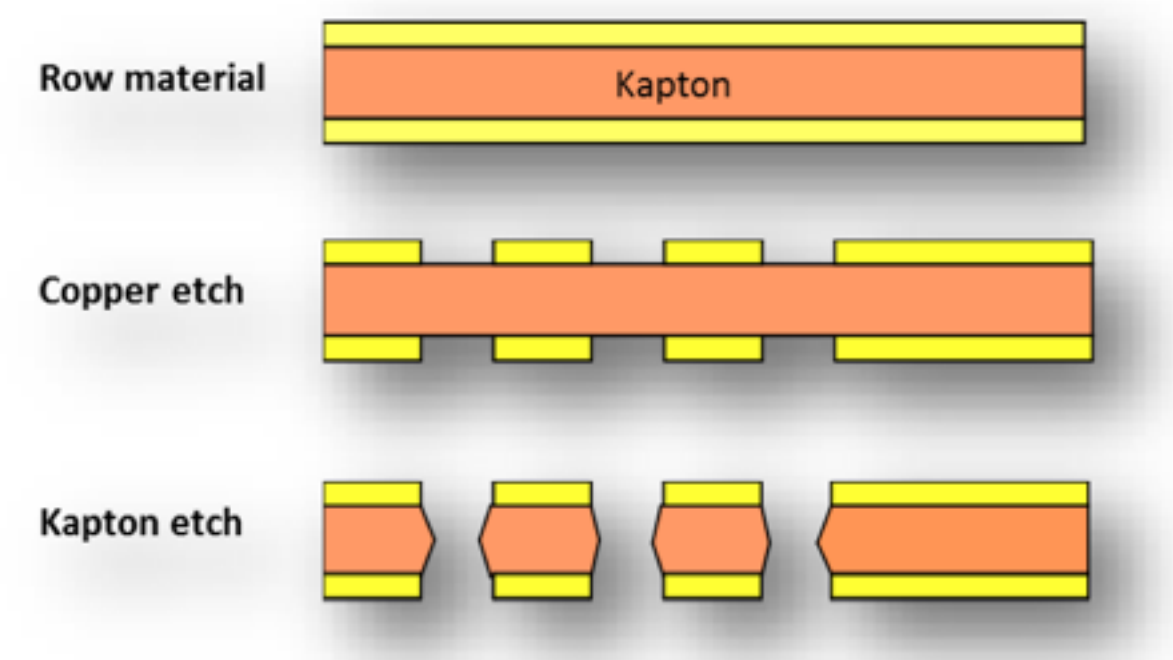
Ion distribution at the hole entrance:
reduction of the amplification field

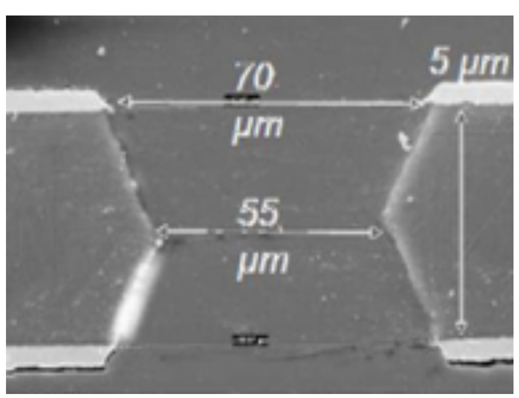




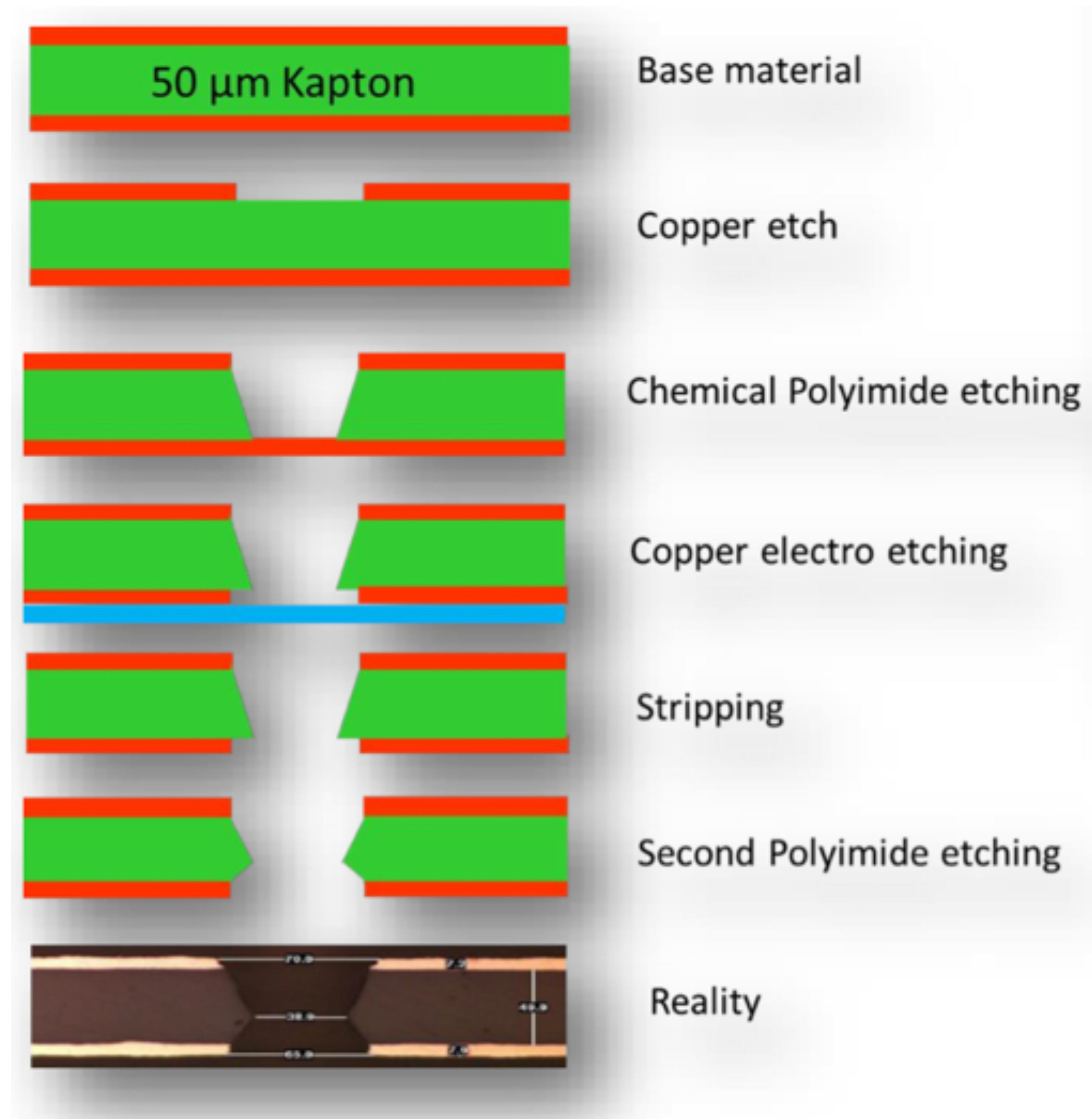
Production: two ways

The 'original'



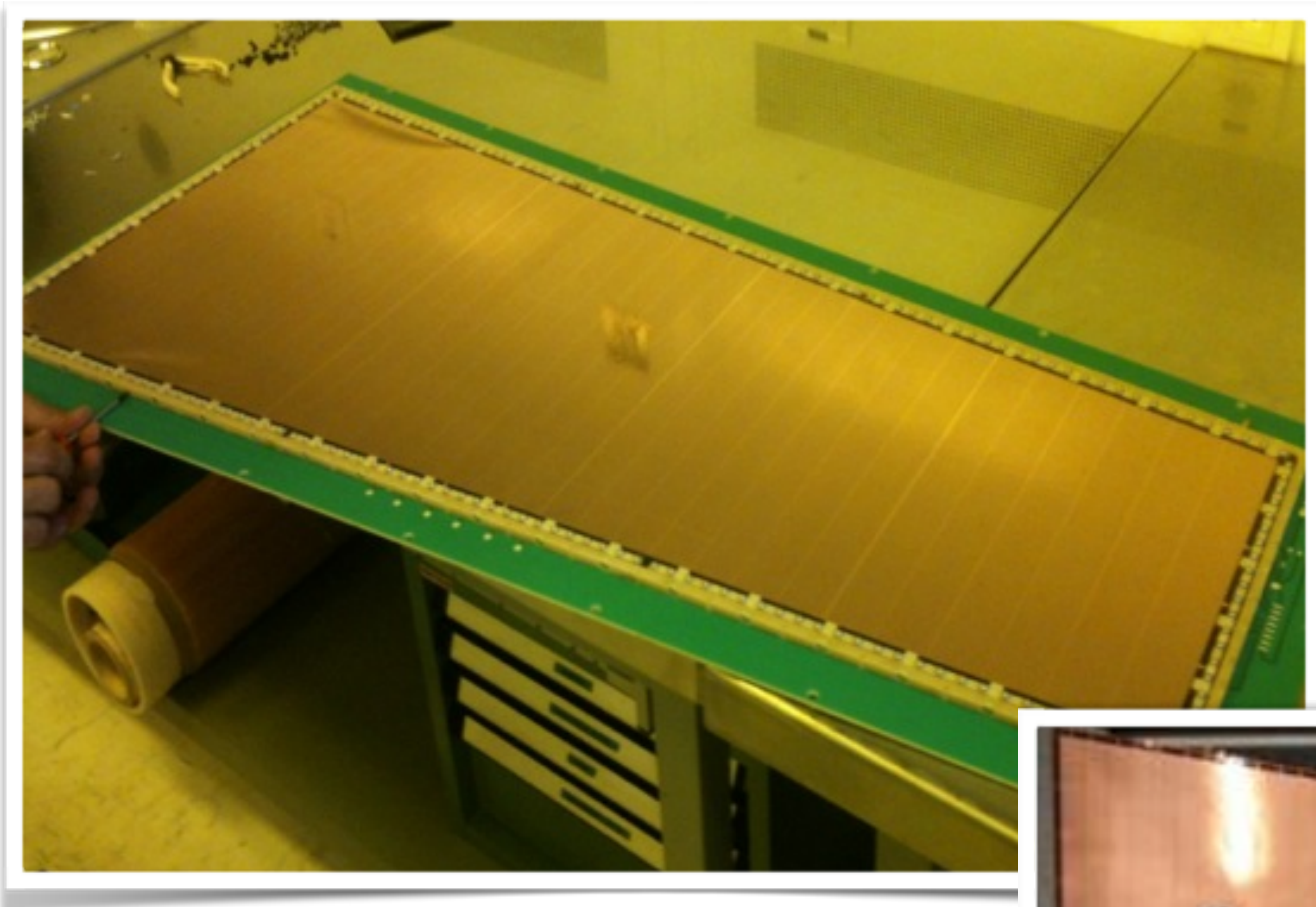


For big samples

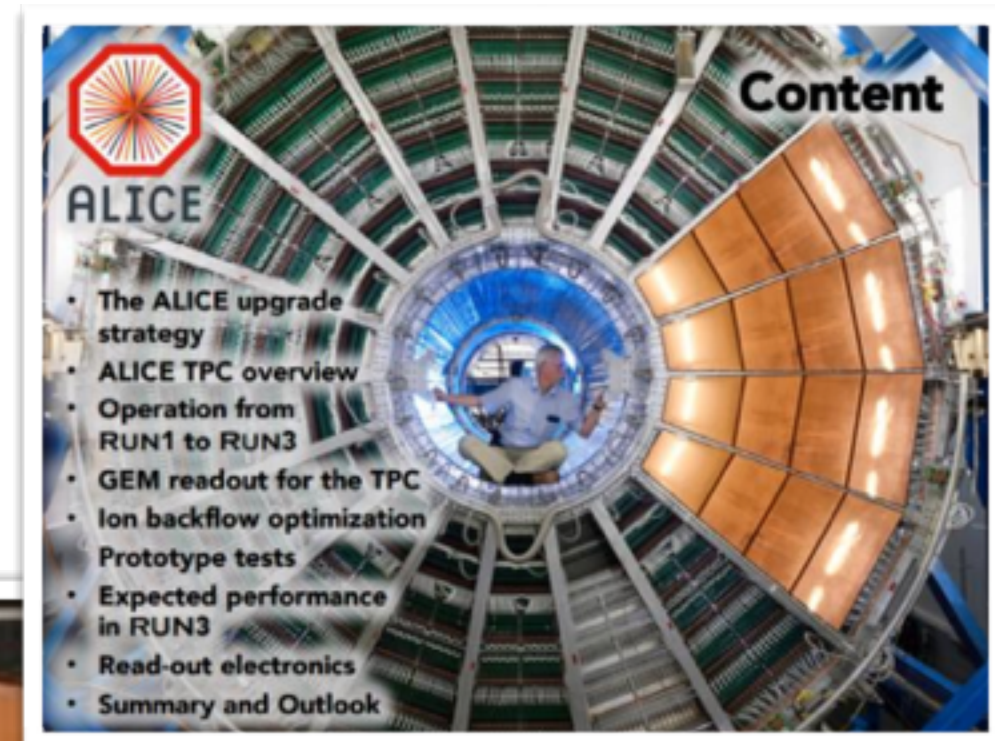


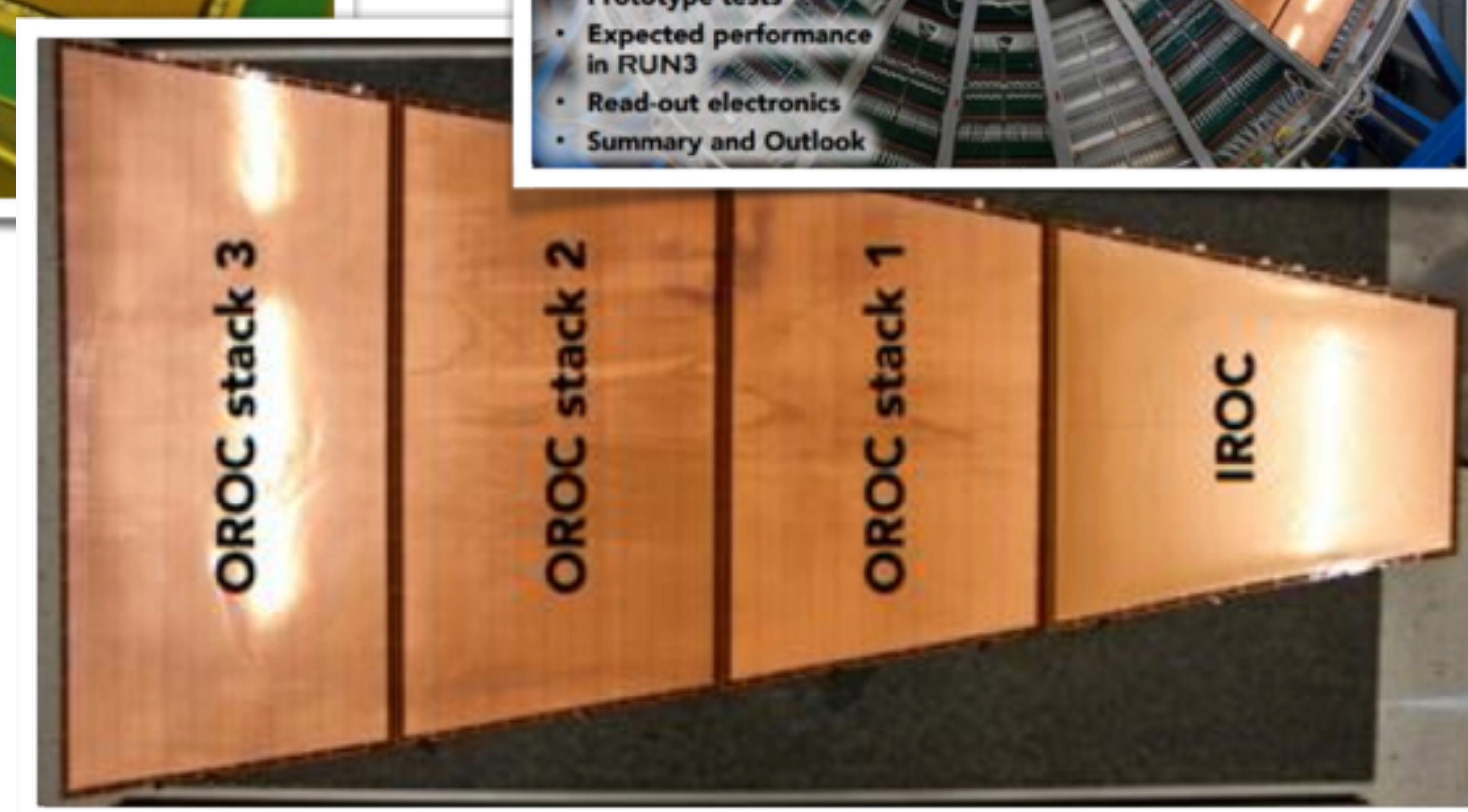
And are indeed big

CMS muon system upgrade with GEM



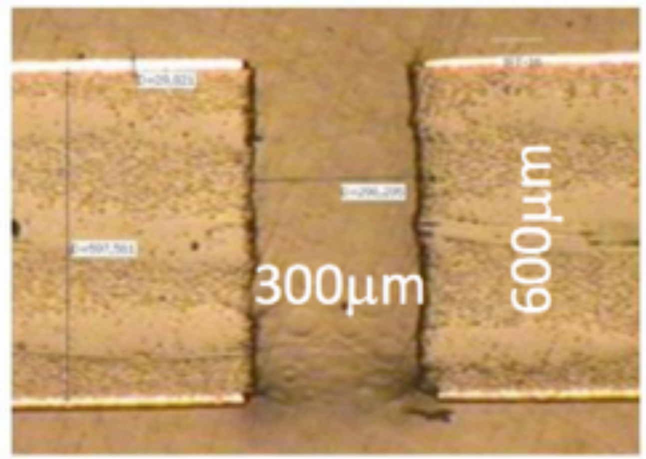
Alice TPC upgrade with GEM

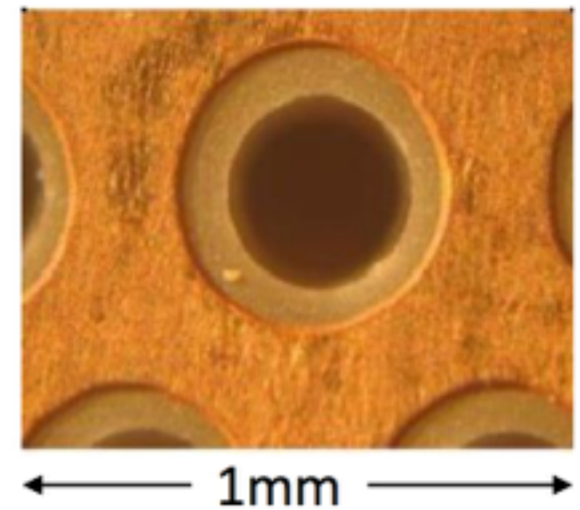


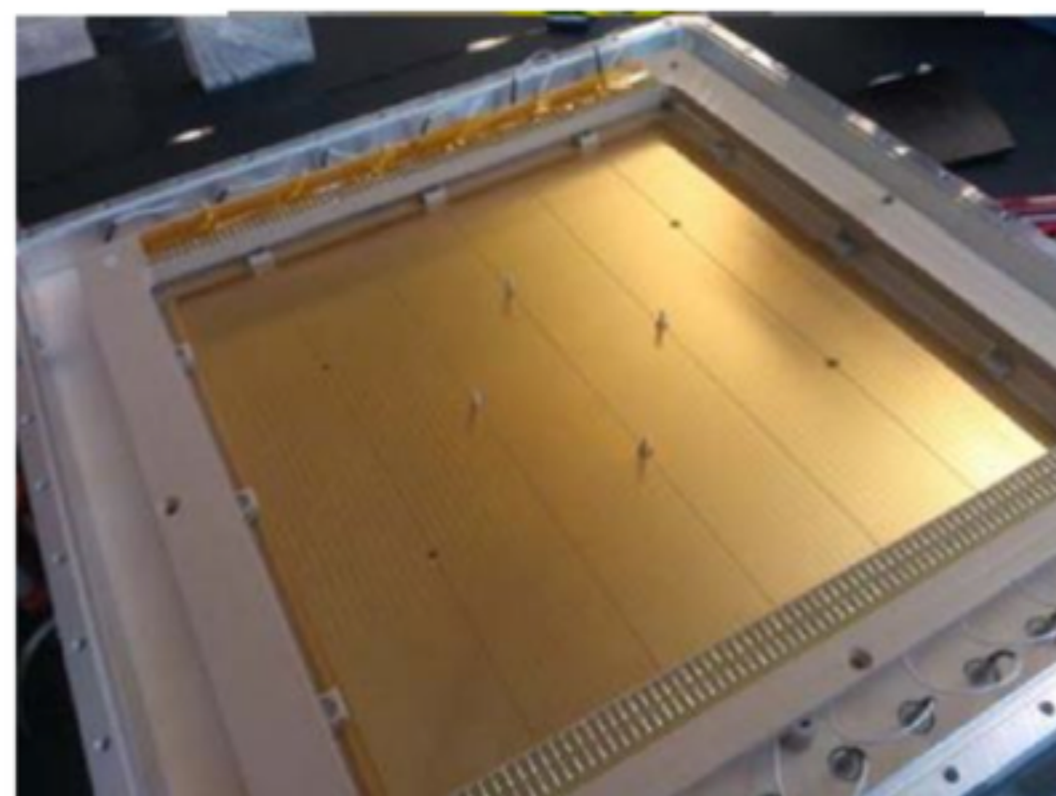


THGEM

10x thicker than GEMs
Typical mechanical drilled holes
Typically in Glass Epoxy
Robust and self-sustained



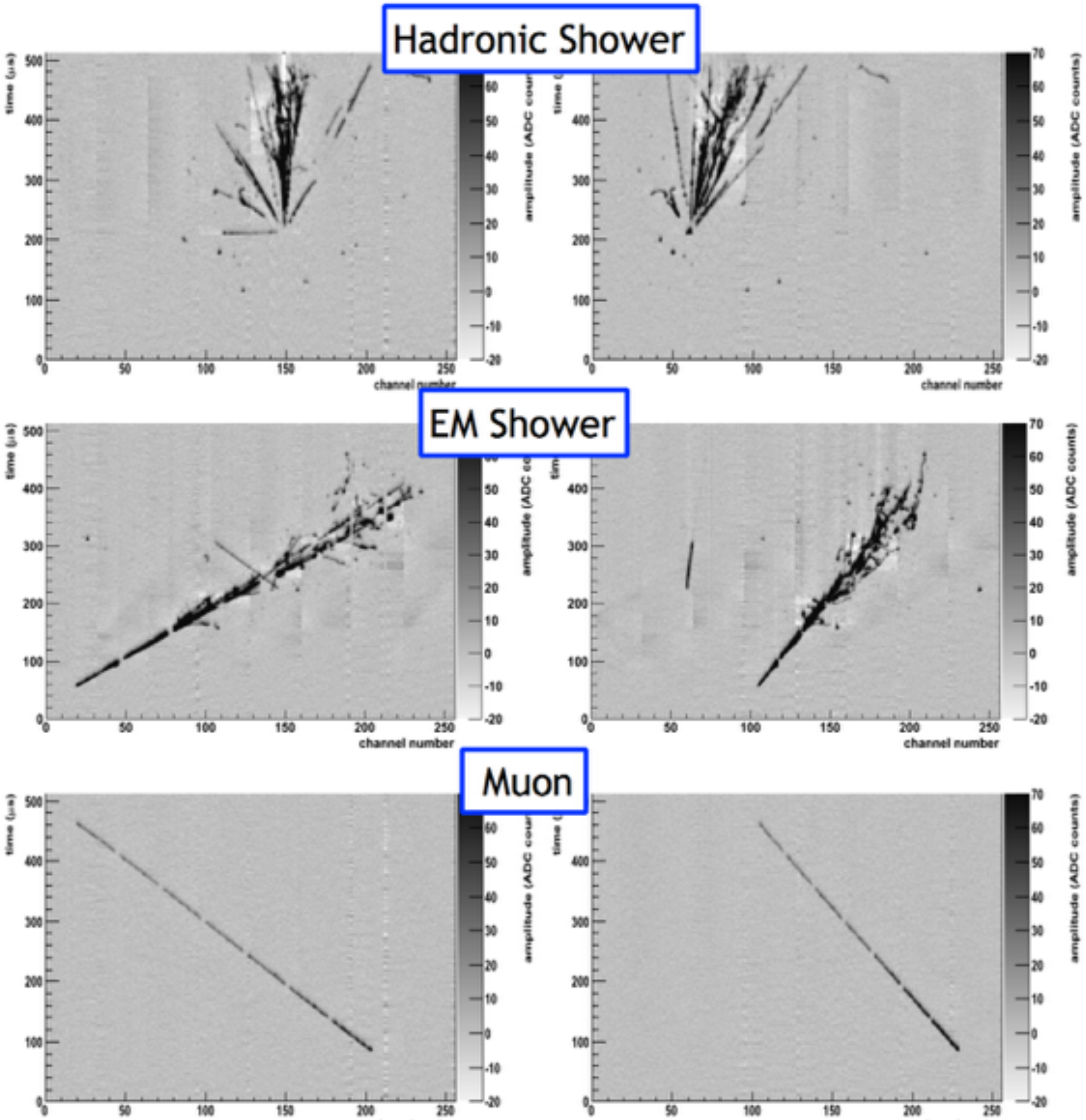




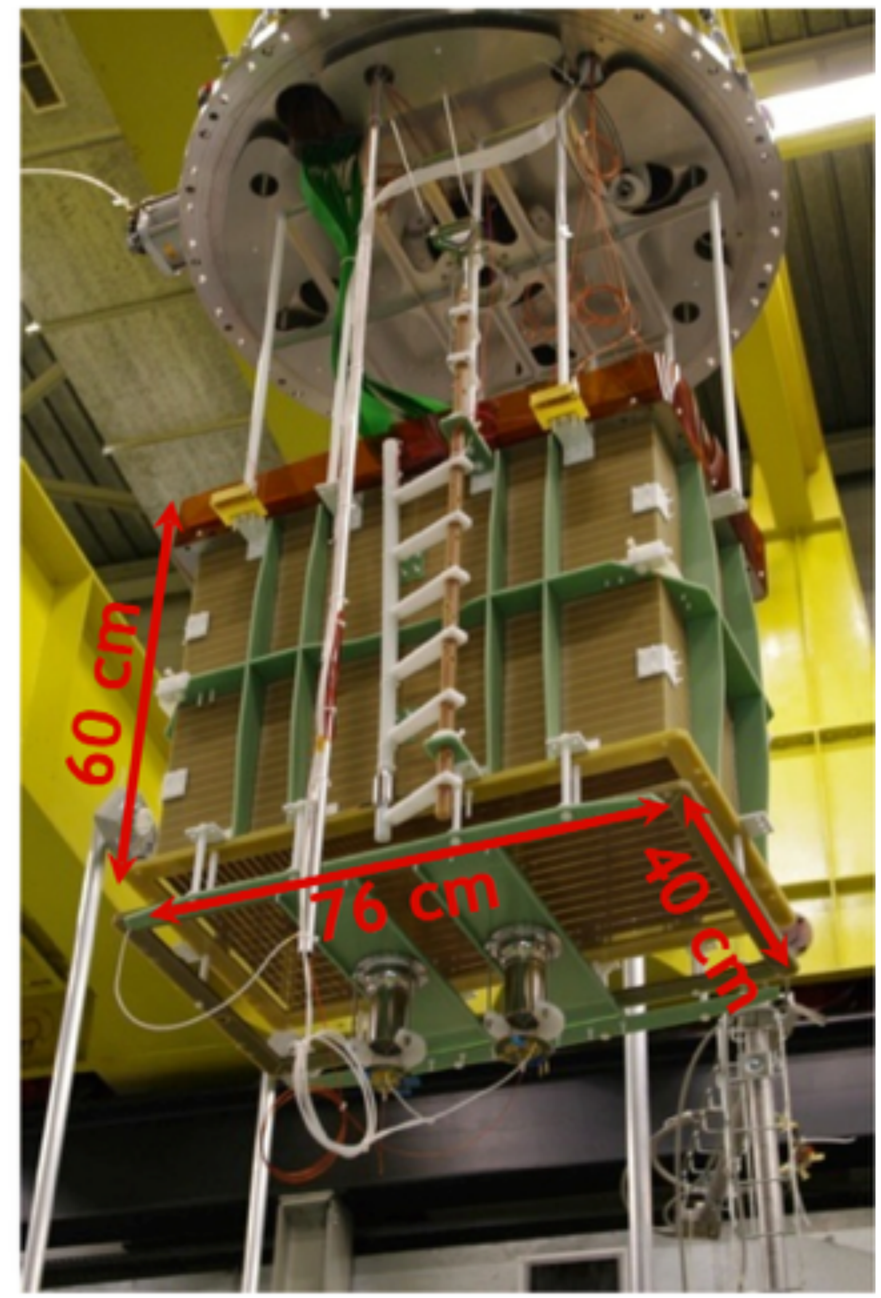
Compass RICH prototype

Also in cryogenic

S. Wu, “Recent results of double phase LAr LEM TPC R&D,” MPGD2015



40x76x60 cm³ LAr LEM TPC

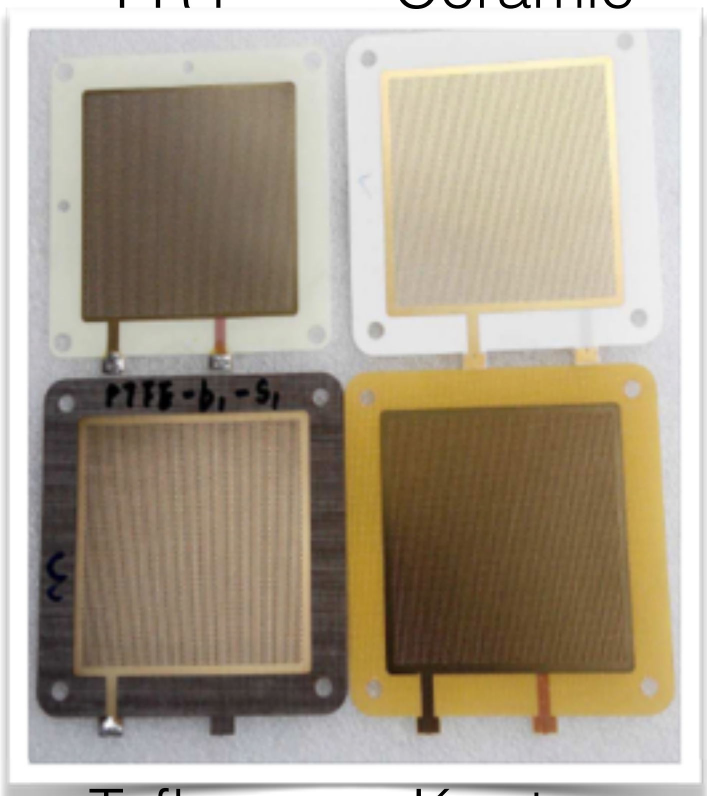


4

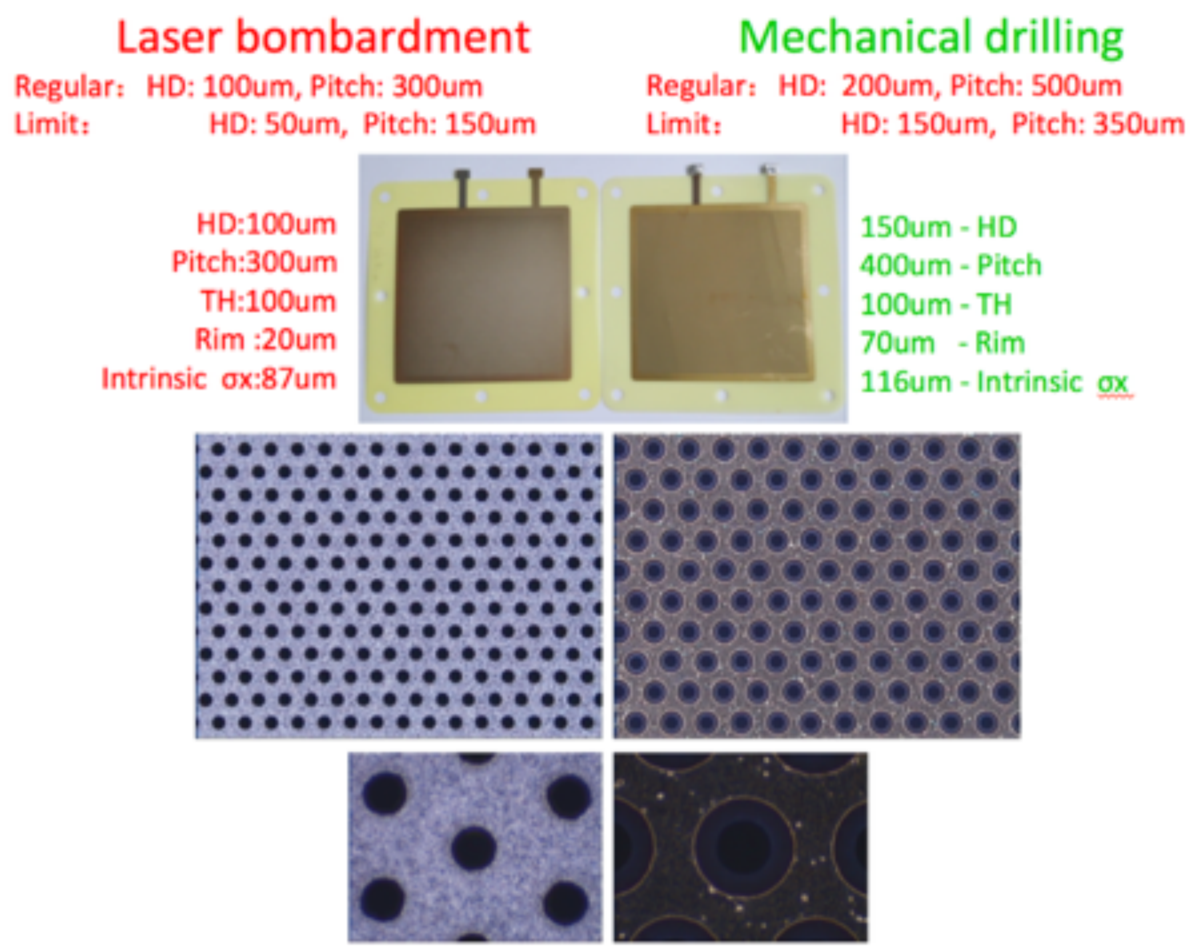
Also other materials

Y. Xie, “New substrate, high spatial resolution and big-area THGEMs: development and applications,” MPGD2015

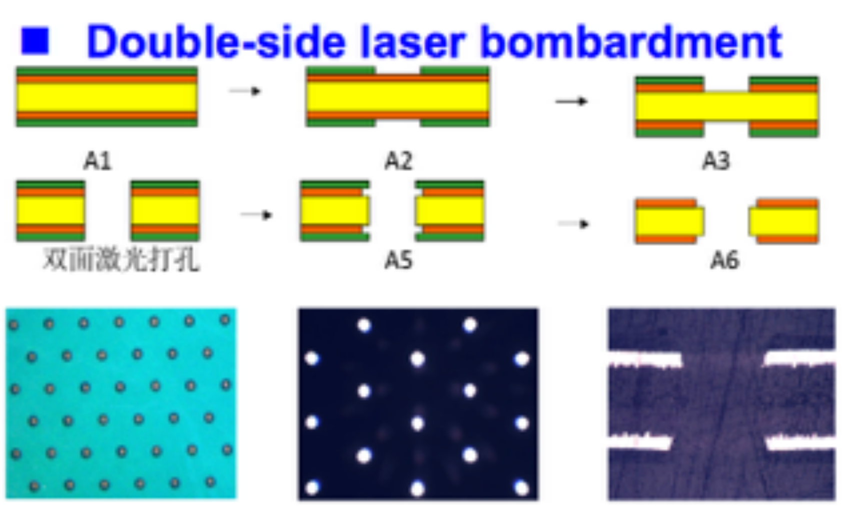
FR4 Ceramic



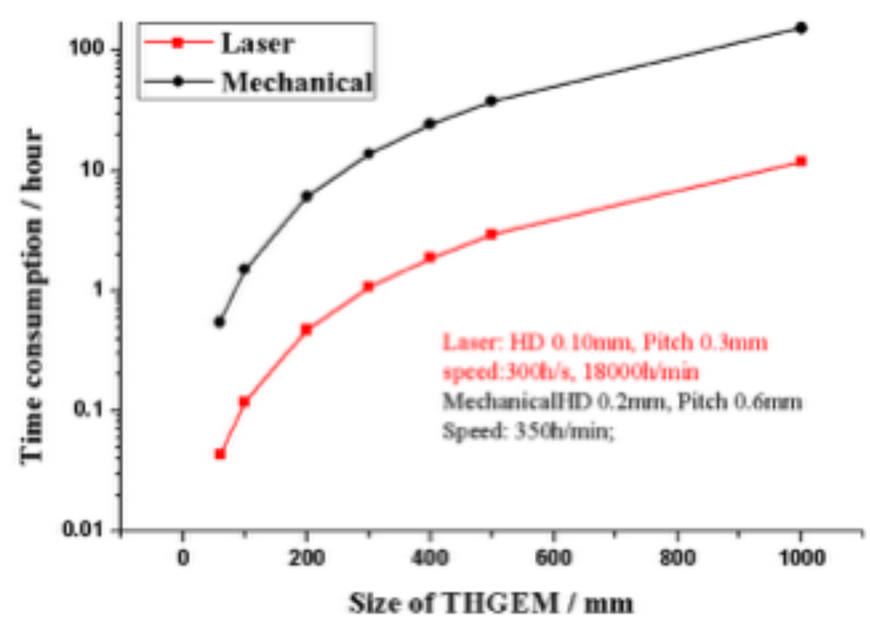
Teflon Kapton



And other methods:
Laser bombardment
faster and finer



Both FR-4 and Kapton is OK. Six main steps.
The key step is double-side bombardment



And more materials

T. Fujiwara, “Development and application of Scintillating Glass-GEM detector,” MPGD2015

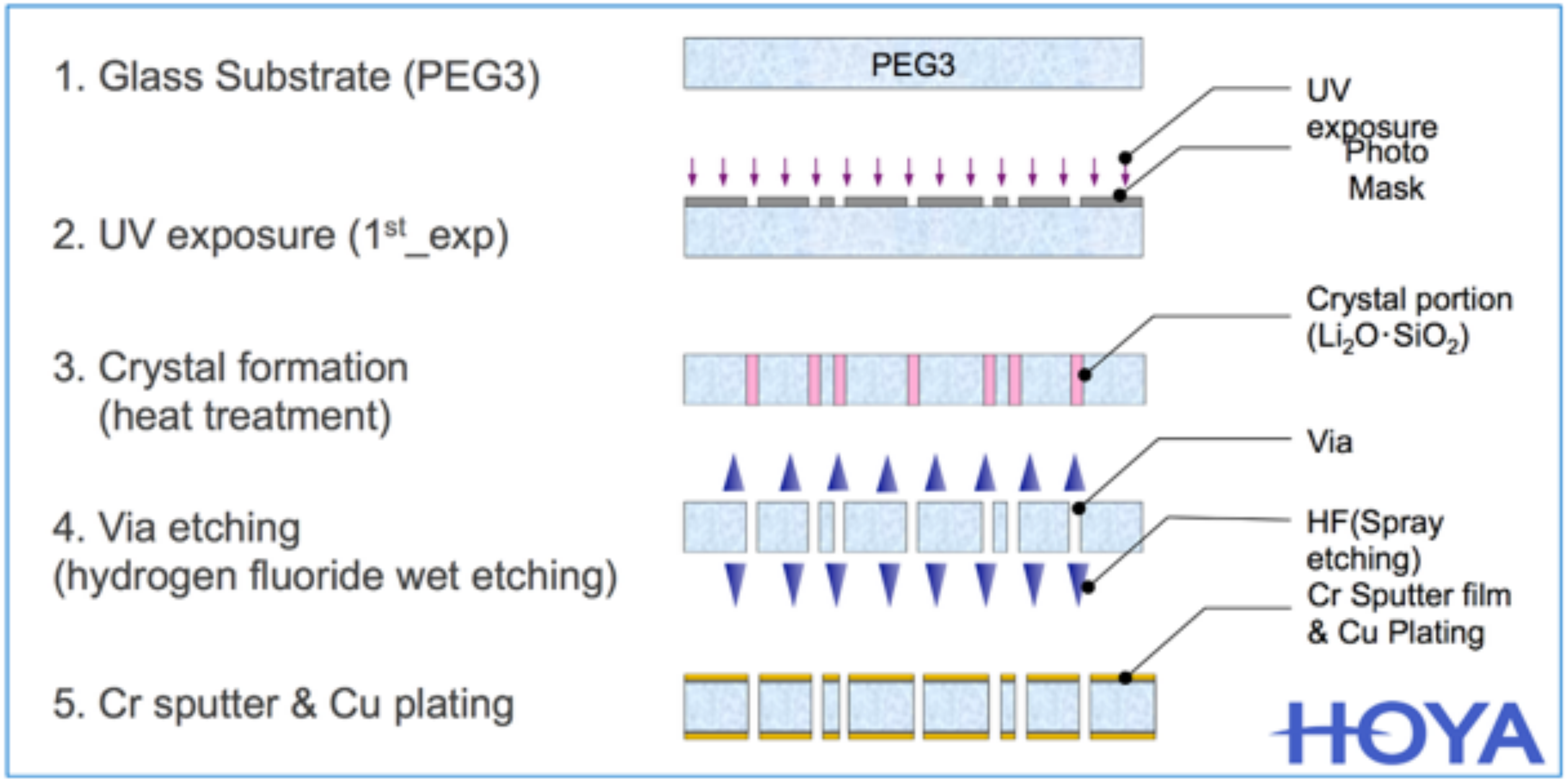
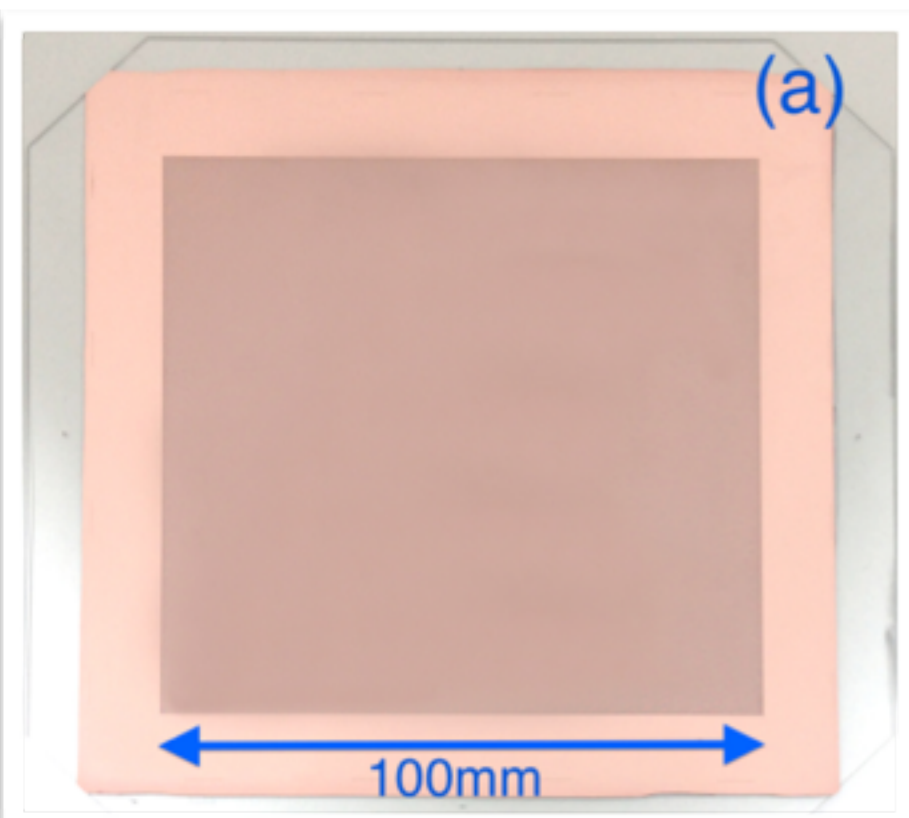
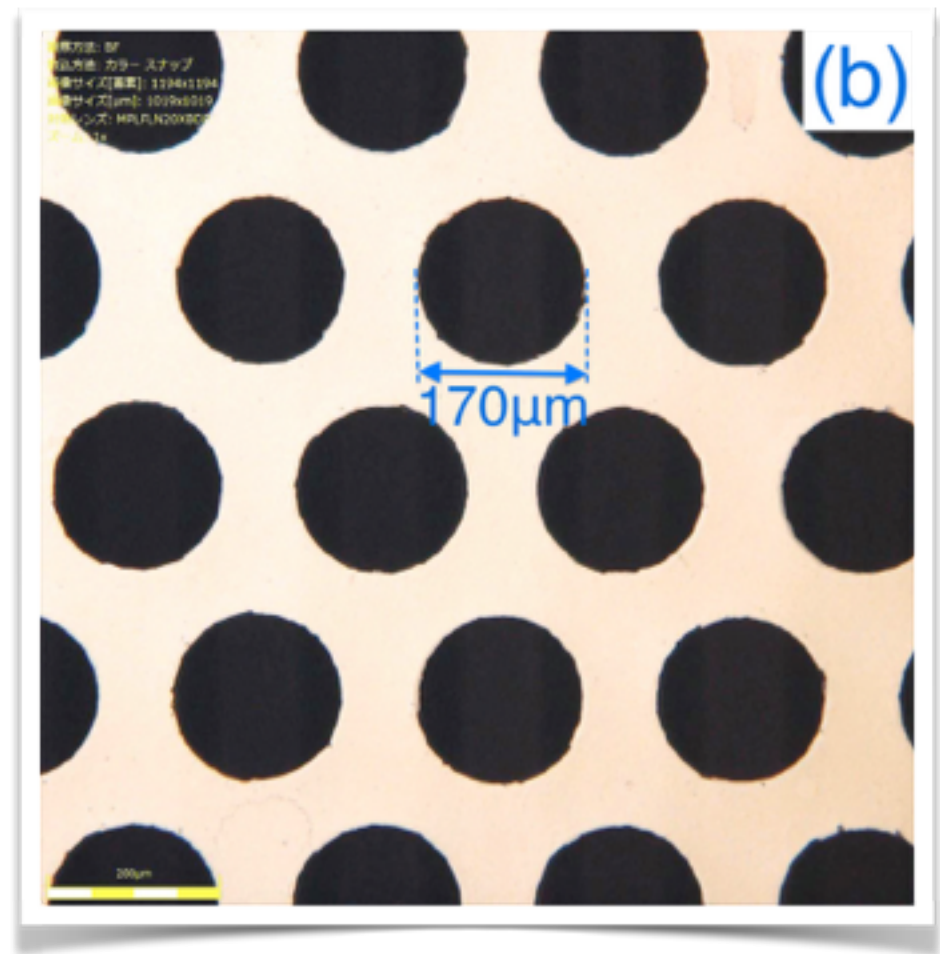


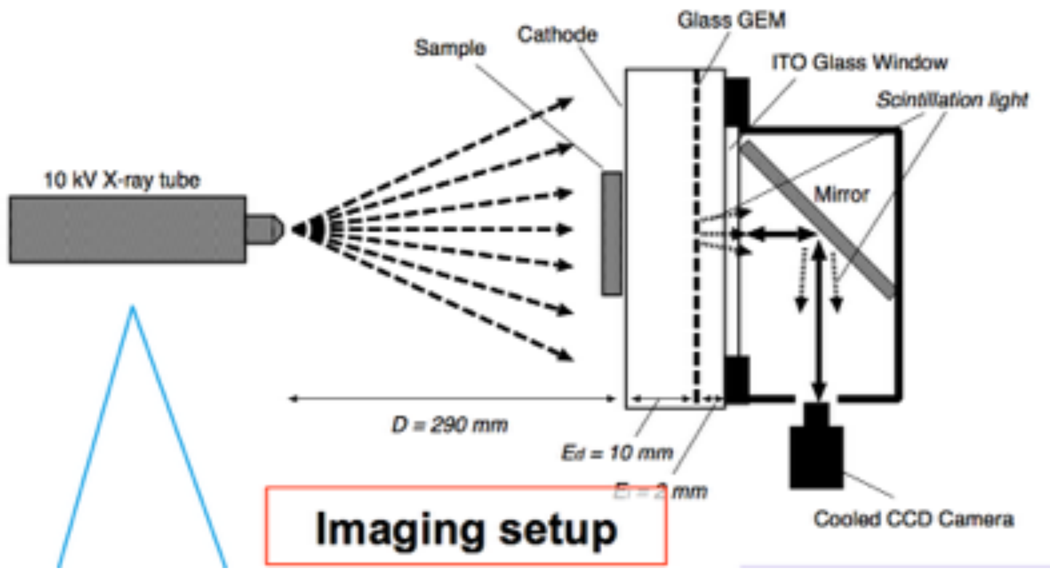
Photo Etchable Glass 3 (PEG3)
UV laser + wet etching

Glass can be very clean
Suitable for operation in sealed mode



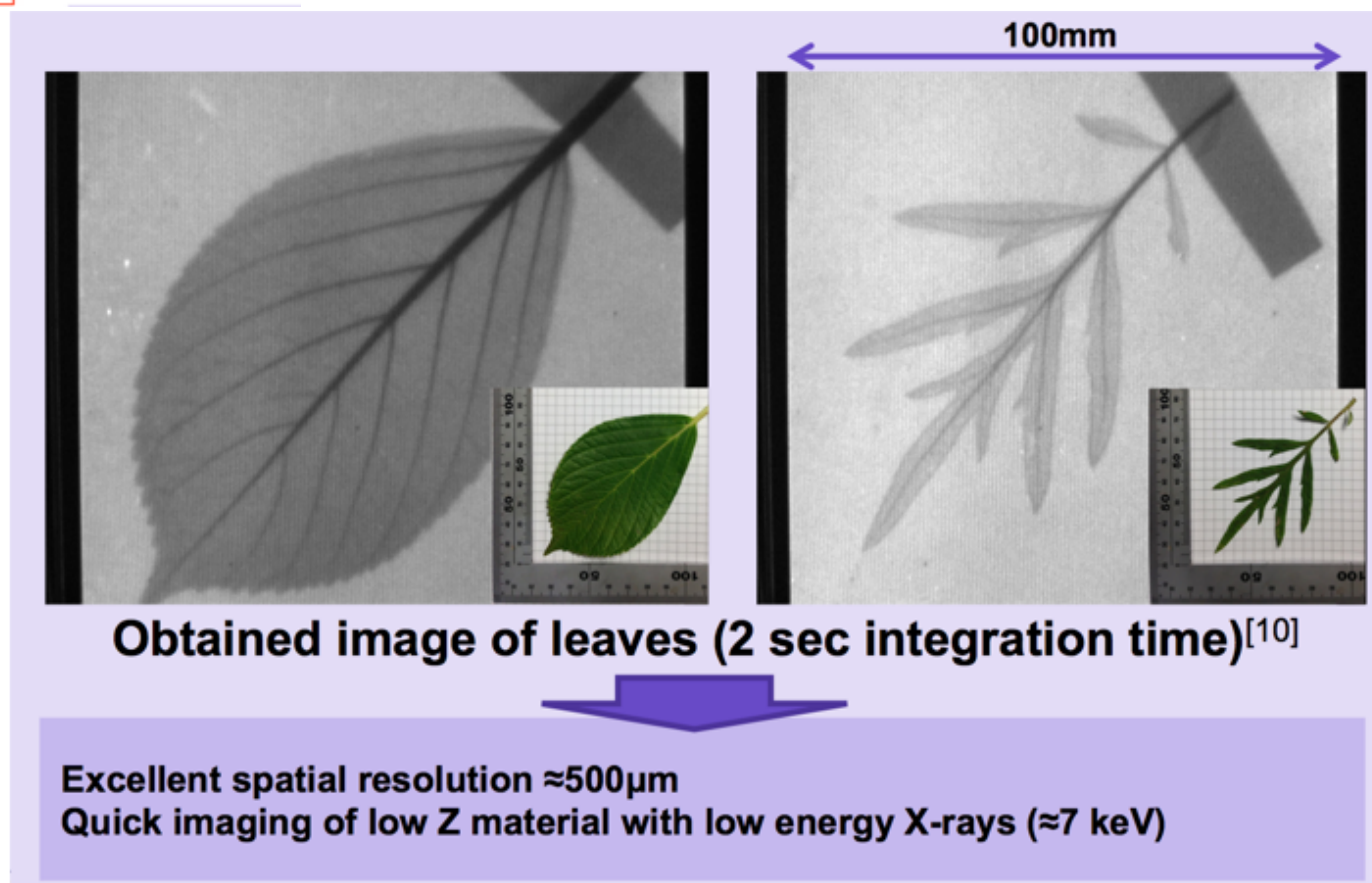


‘Scintillating GEM’



T. Fujiwara, “Development and application of Scintillating Glass-GEM detector,” MPGD2015

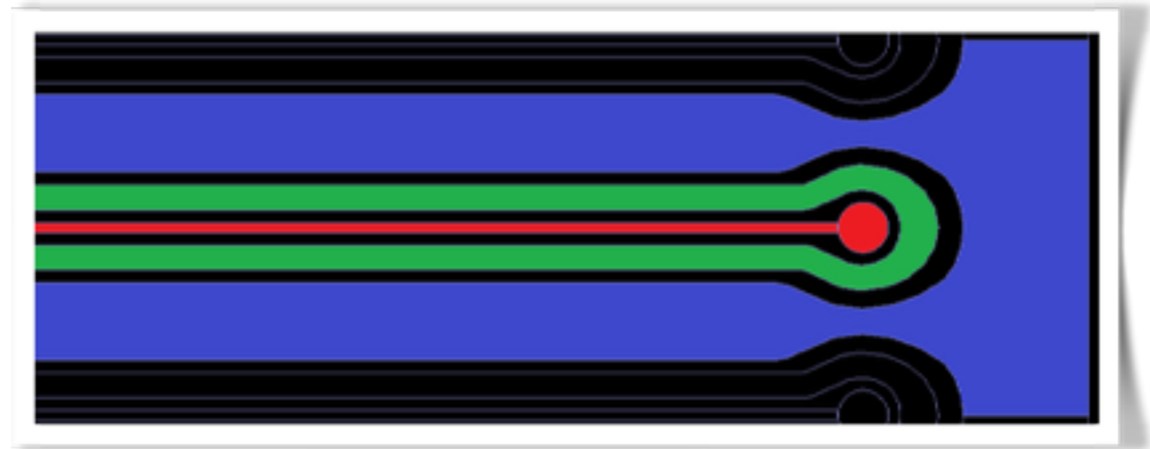
It’s the $ArCF_4$ that scintillates during the electron avalanche and it does it in the visible



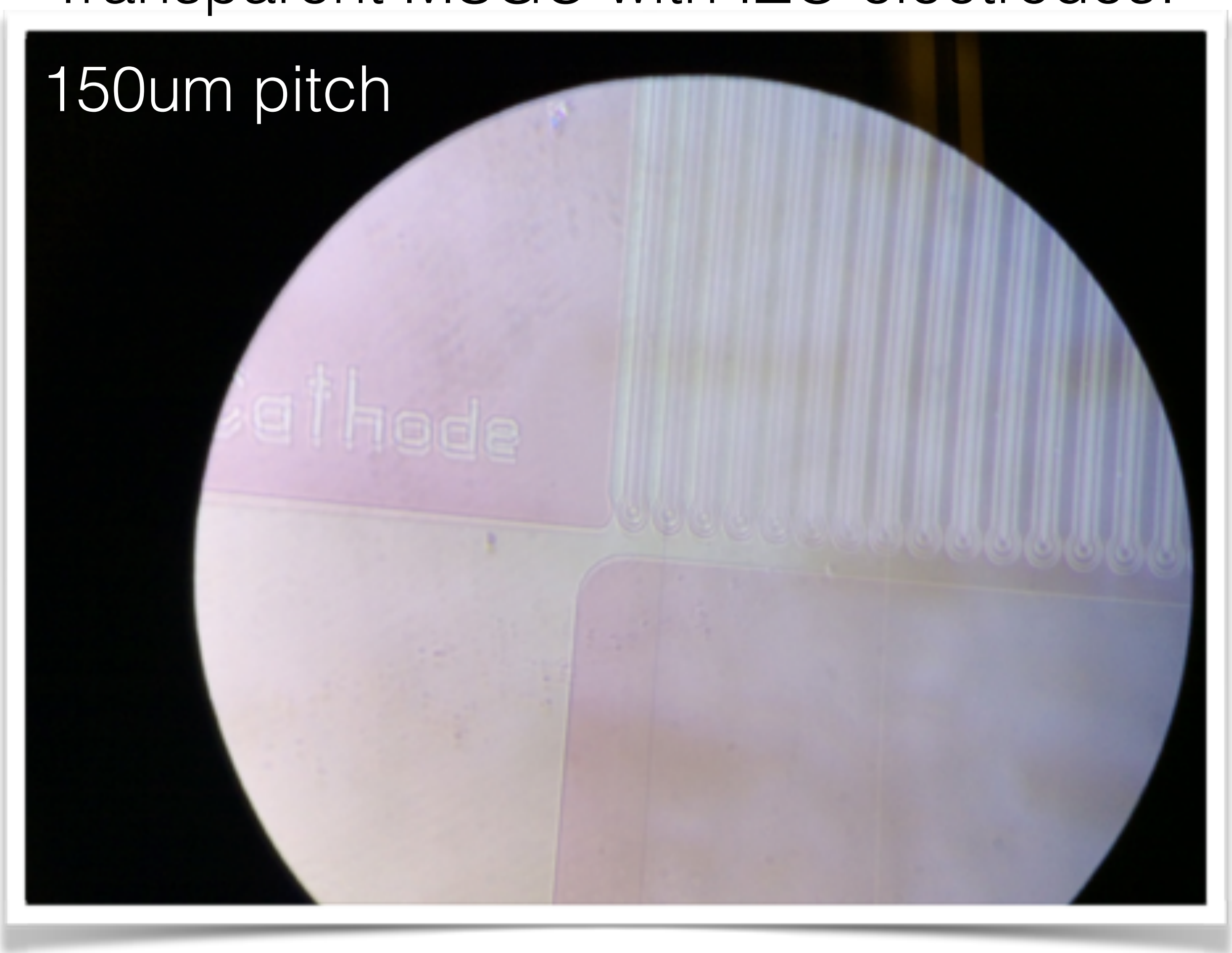
LCD technologies

H. Takahashi, “Development of a transparent Single-grid-type MSGC based on LCD technology,” MPGD2015

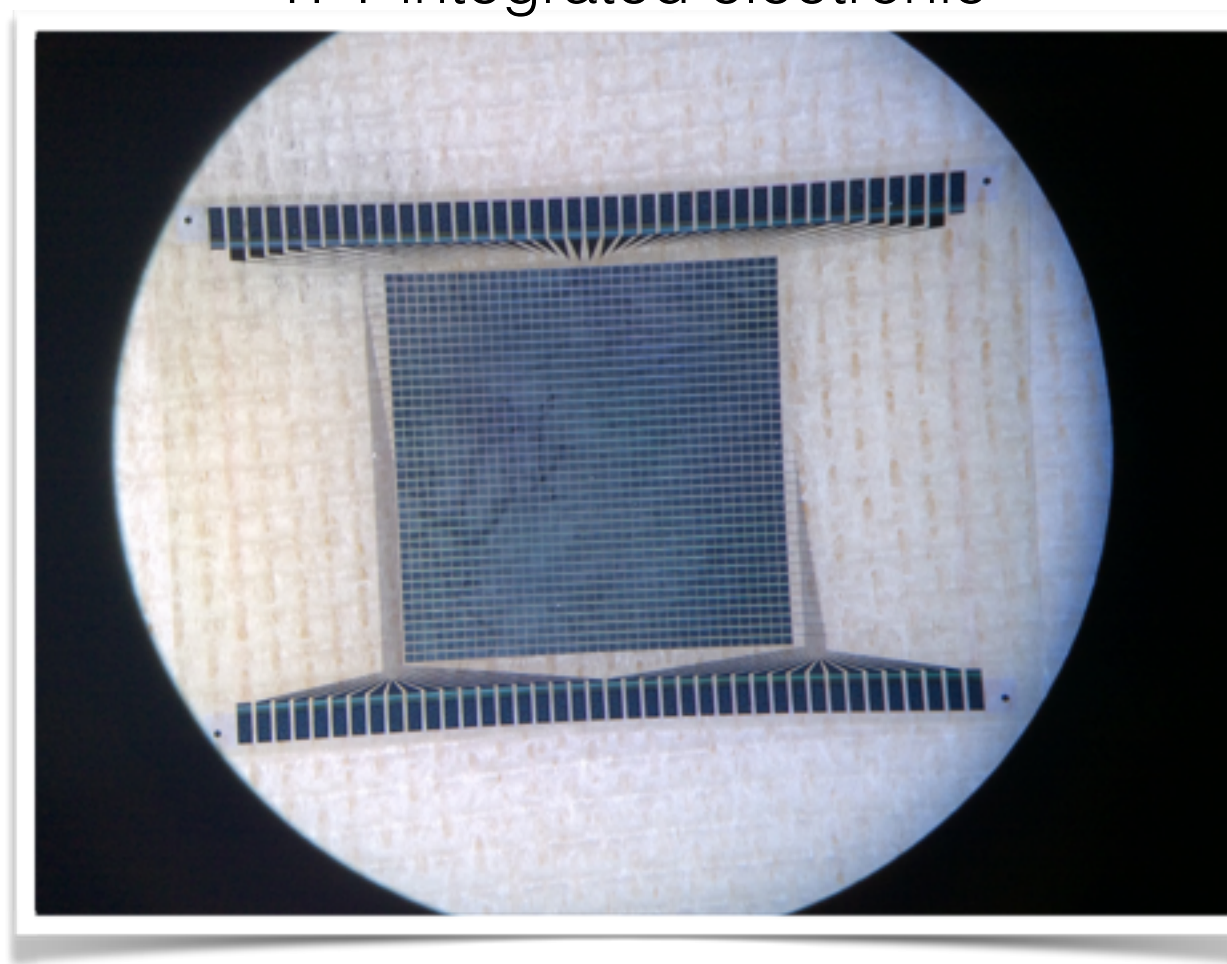
MSGC with ‘Grid’ electrode to control gain and reduce spark probability
By SHARP



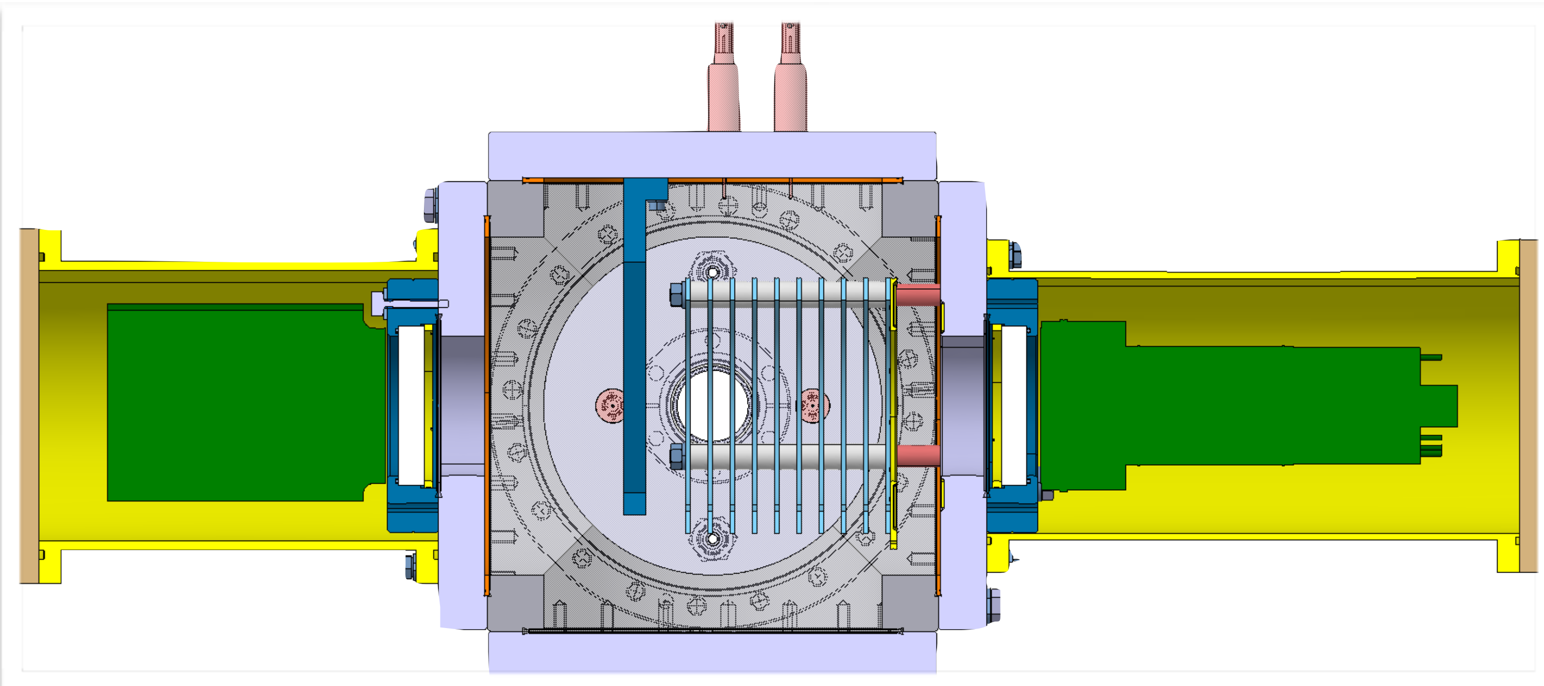
Transparent MSGC with IZO electrodes!



TFT integrated electronic

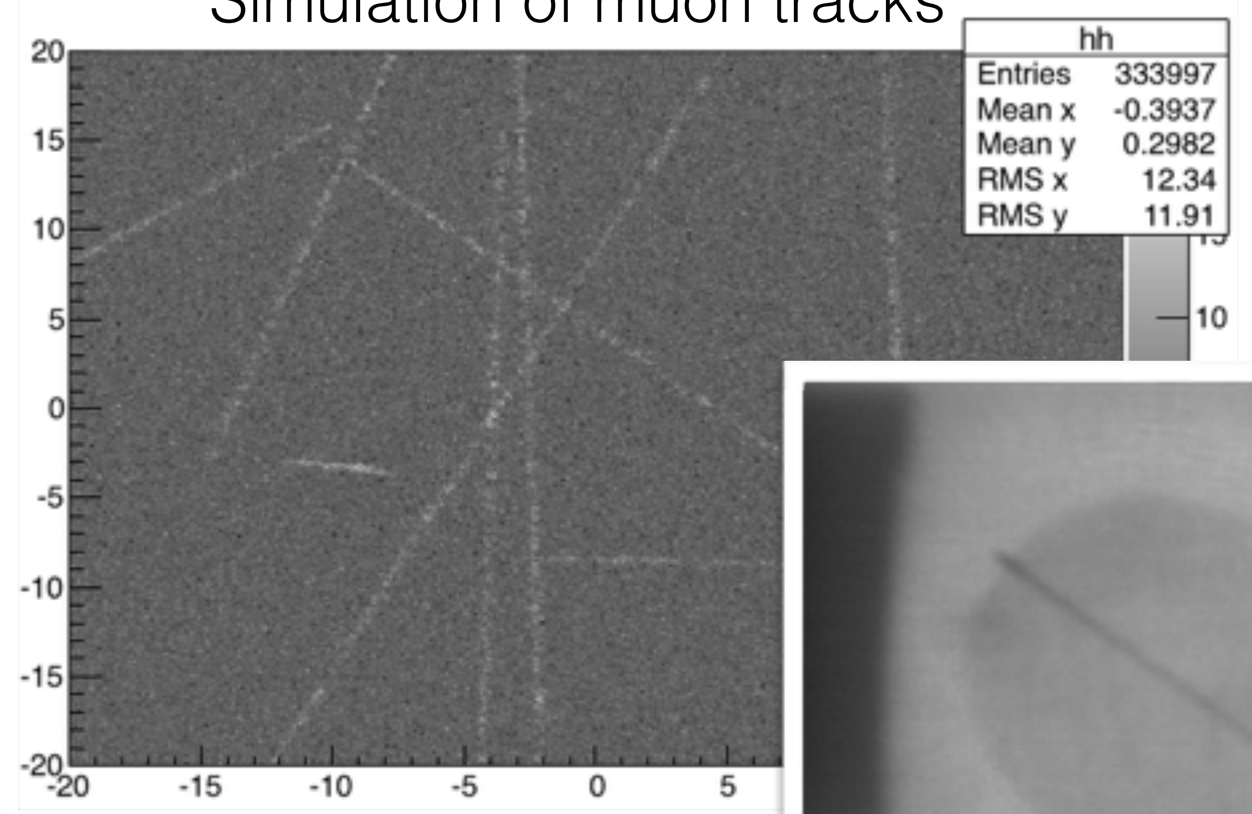


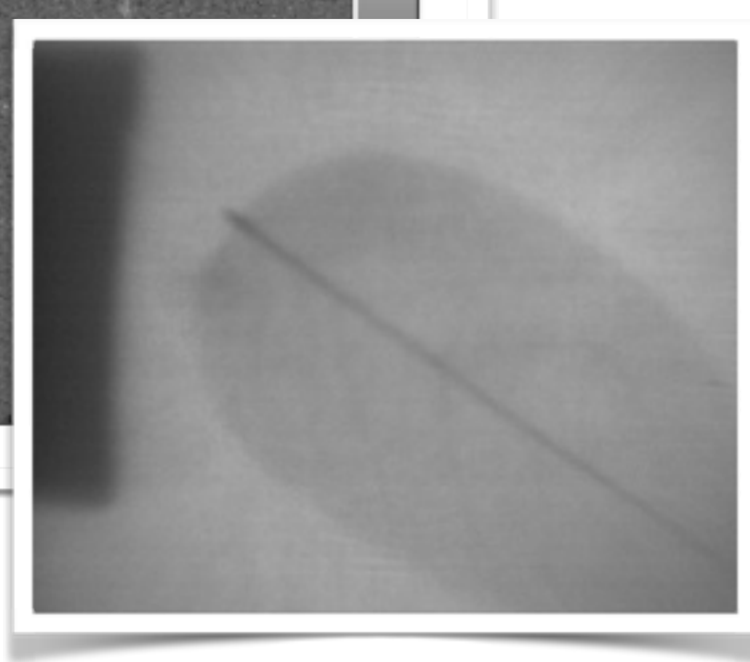
TPC with optical readout



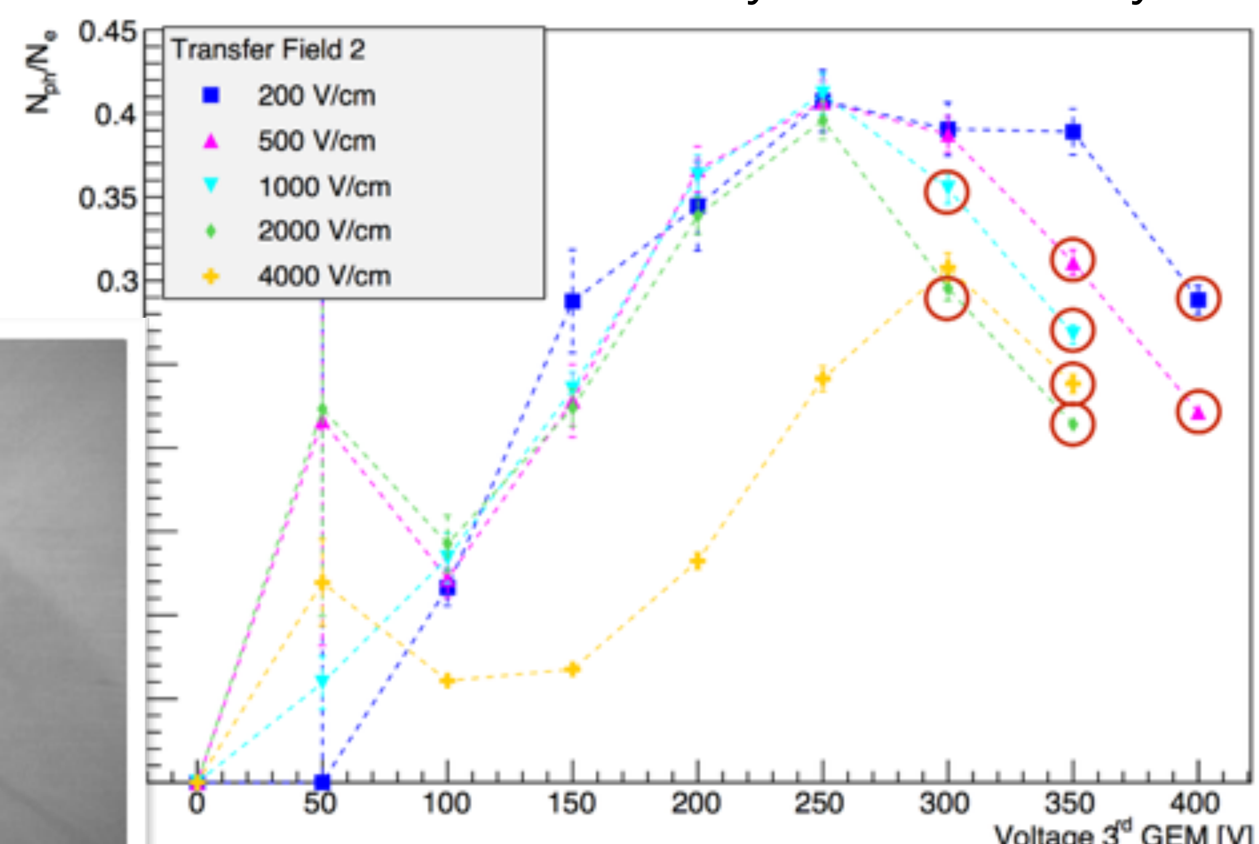
With triple GEM amplifier
Study:
- Visible (near UV and near IR) scintillation of gasses
- Event topology study
- Imaging
- …

Simulation of muon tracks





Ar/CF_4 80/20 secondary scintillation yield



Micro RWELL

G. Bencivenni *et al.*, “The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD,” 2015 JINST 10 P02008

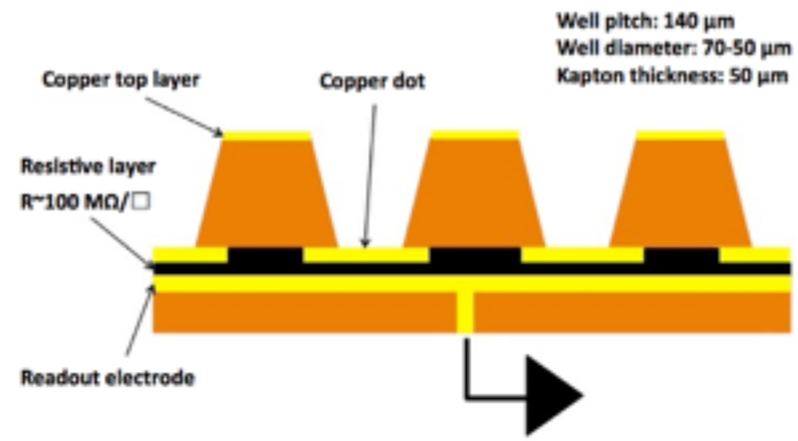


Figure 1. Schematic drawing of the μ-RWELL PCB.

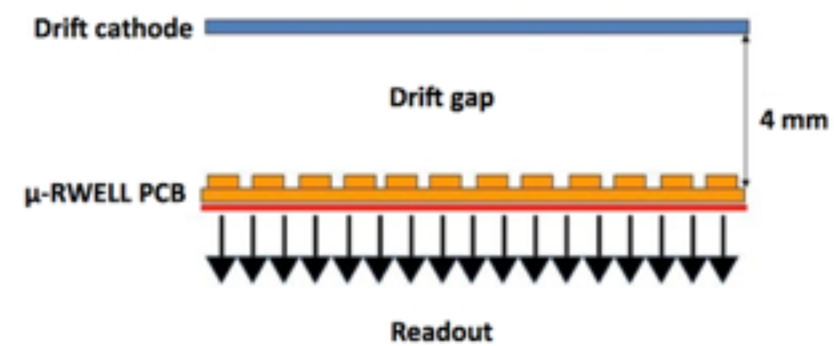


Figure 2. Schematic drawing of the μ-RWELL detector.

See Lener’s talk

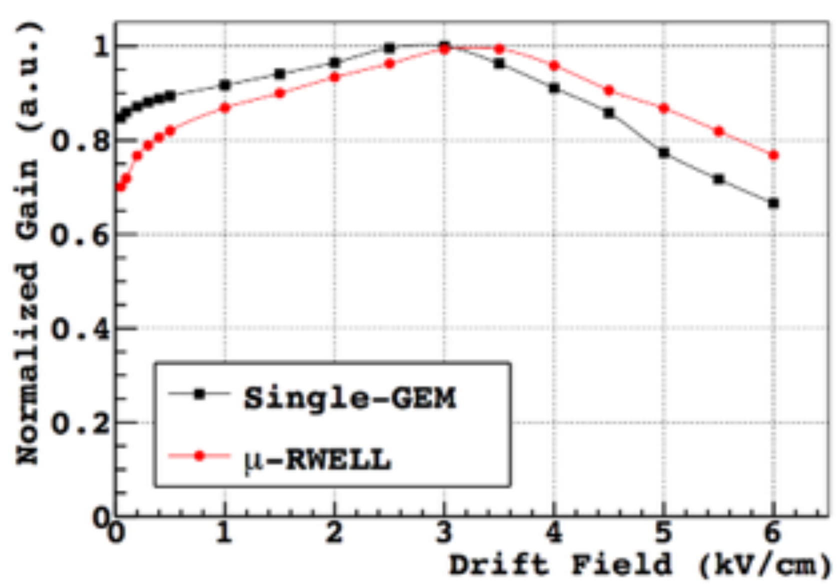


Figure 7. Relative charge collection efficiency as a function of the drift field with a gain of 2000 in Ar:CO_2 70:30.

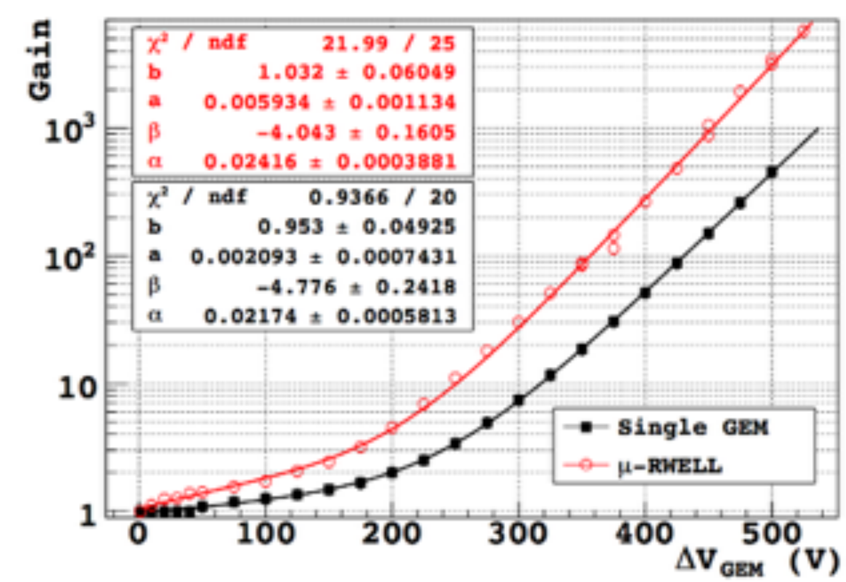
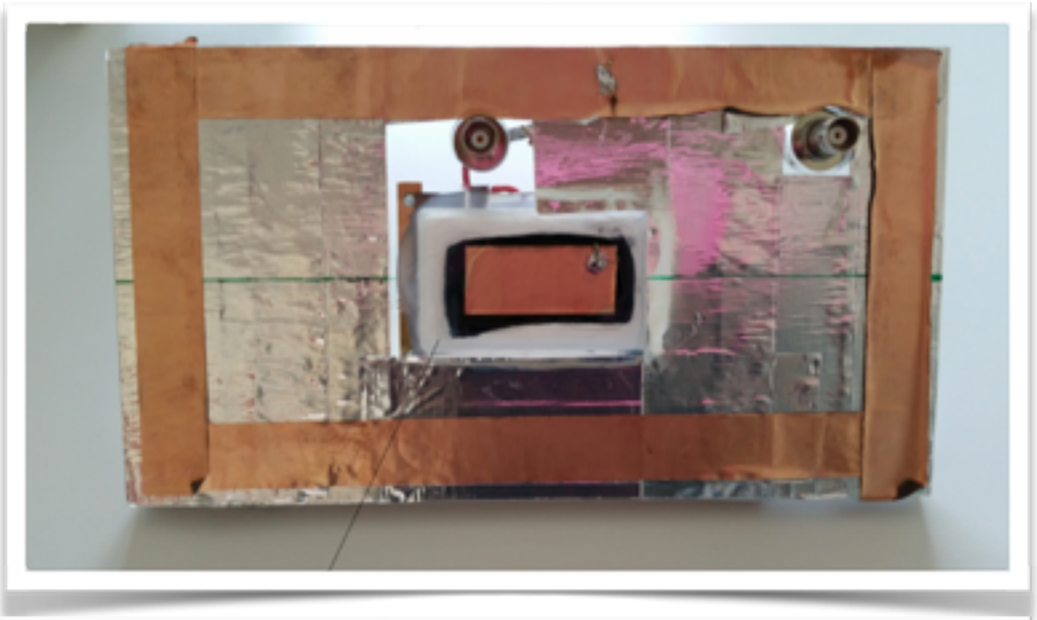


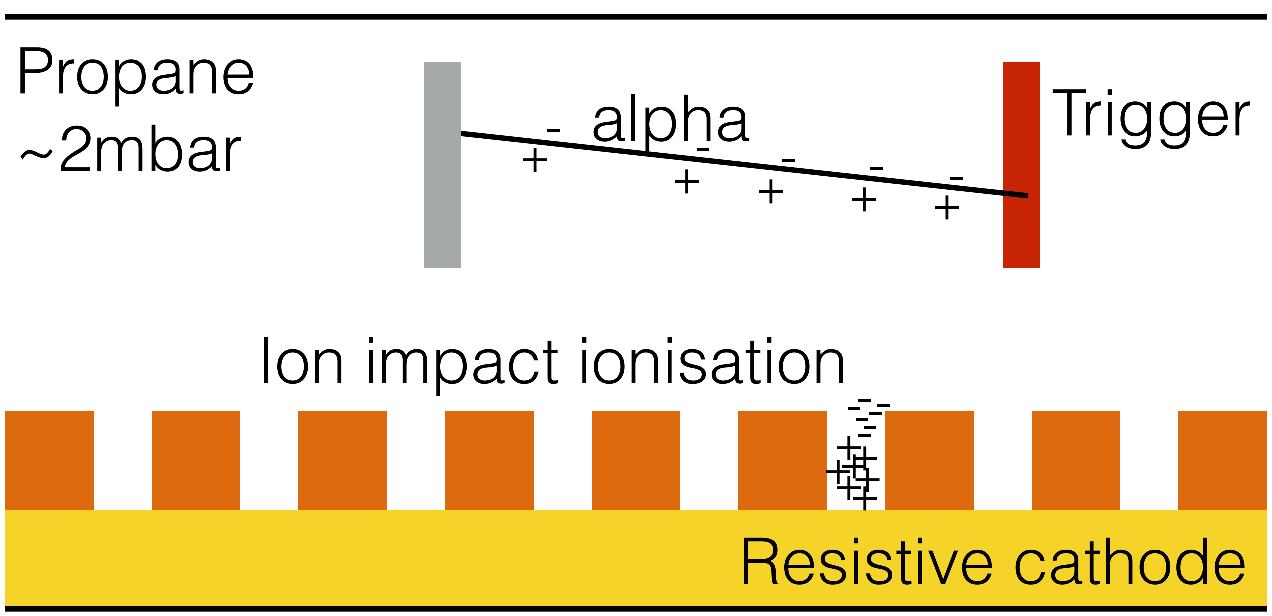
Figure 8. Gas gain for the μ-RWELL (red points) and the single-GEM (black points) in Ar:CO_2 70:30.

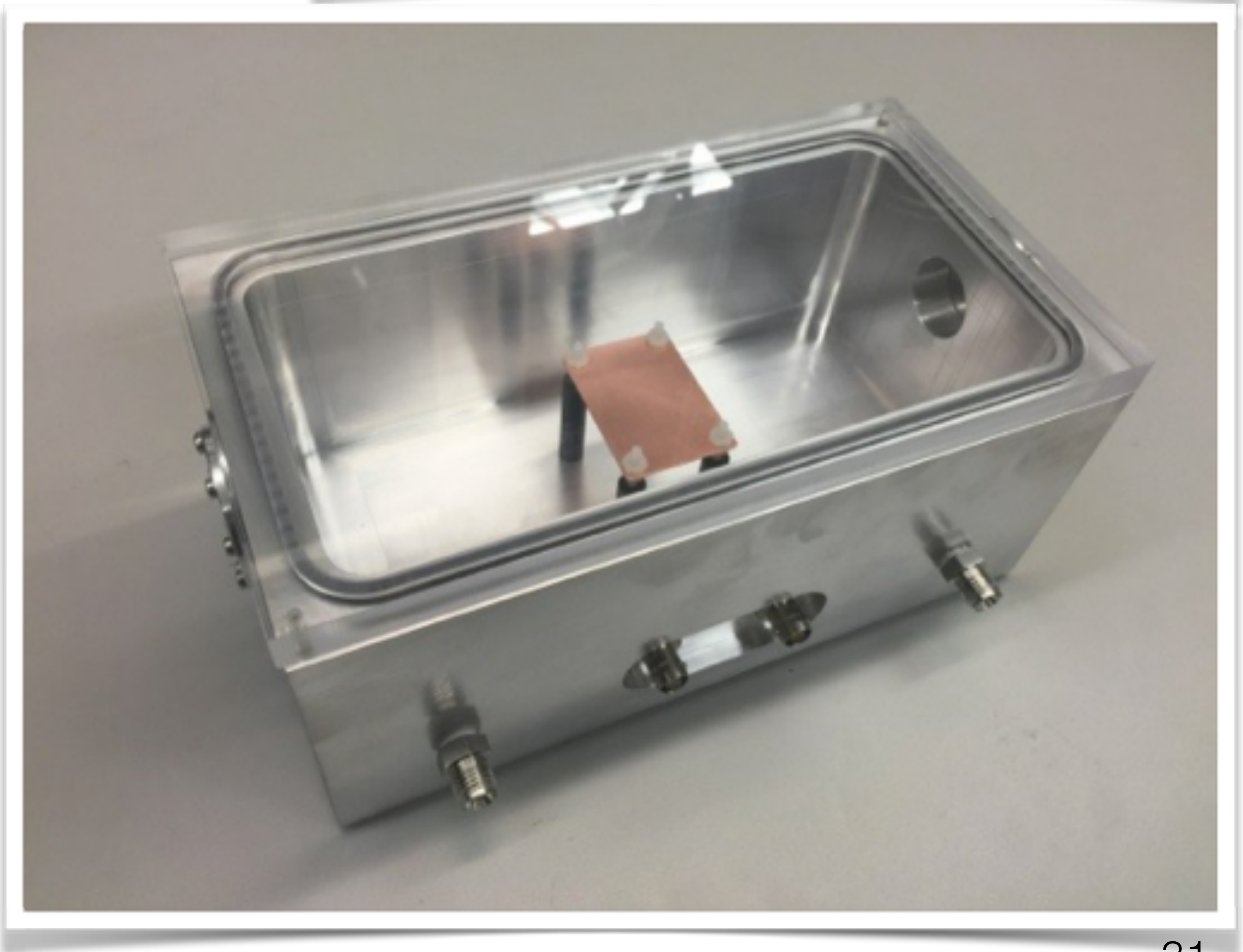
Nanodosimetry

Margherita Casiraghi *et al.*

Positive ion TPC in low pressure propane:
Rarefied atoms -> distance -> zoom effect
Ionisation density at the scale of the DNA size
Ions: low diffusion preserve time and spatial information
THGEM based amplification

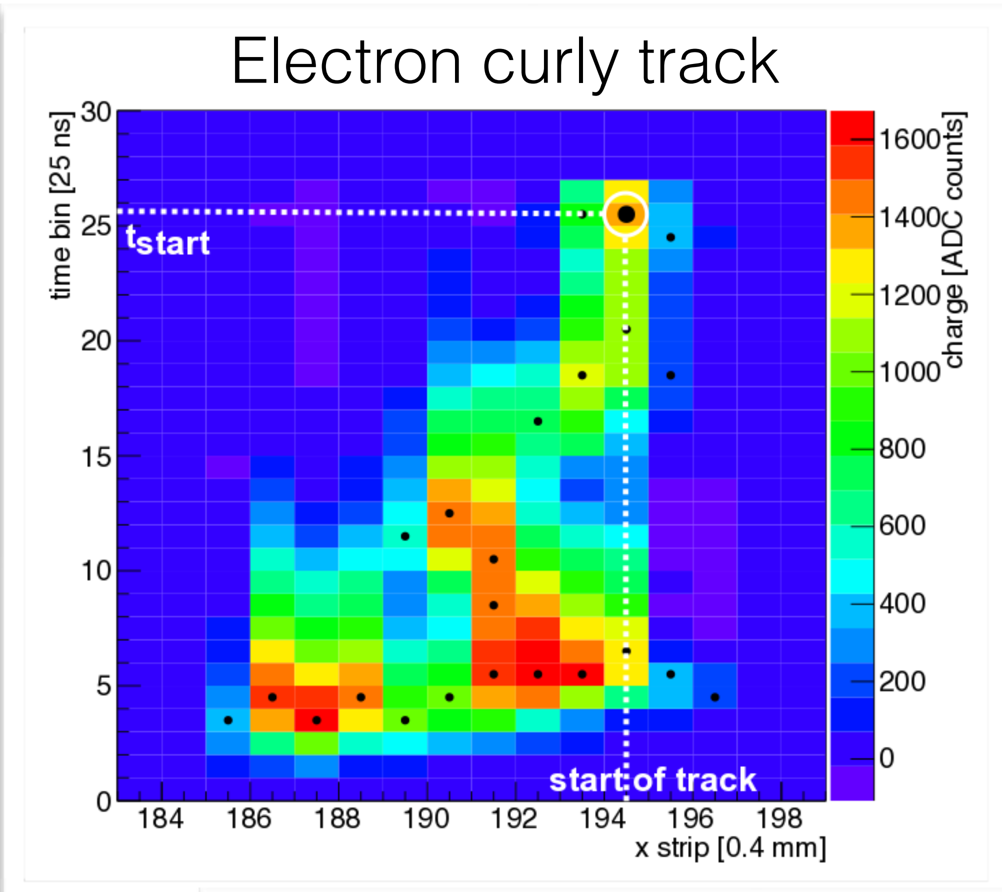


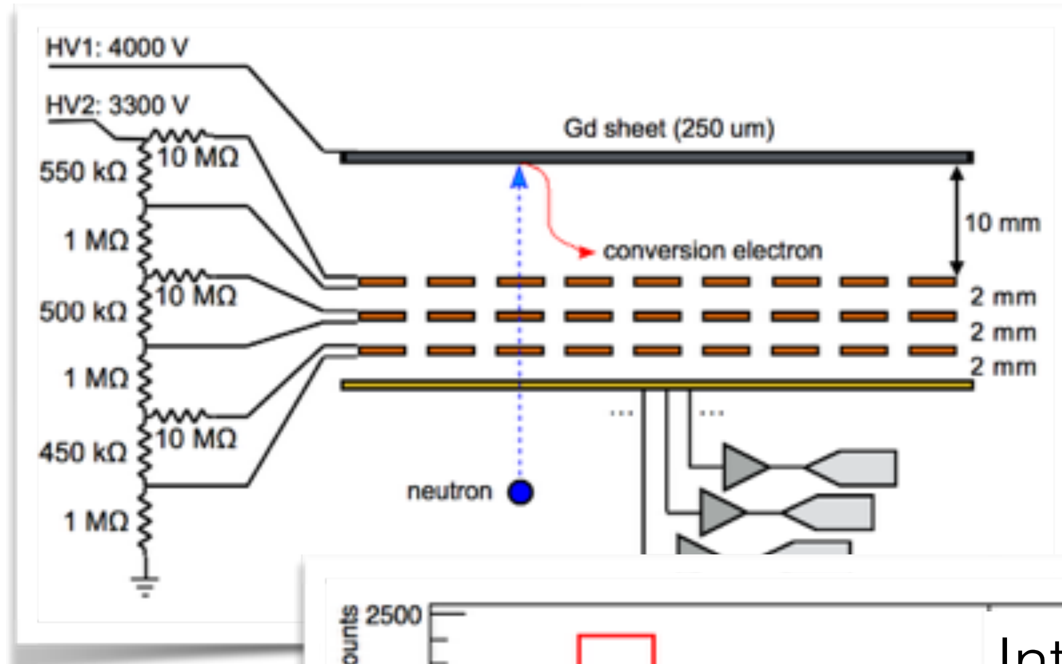


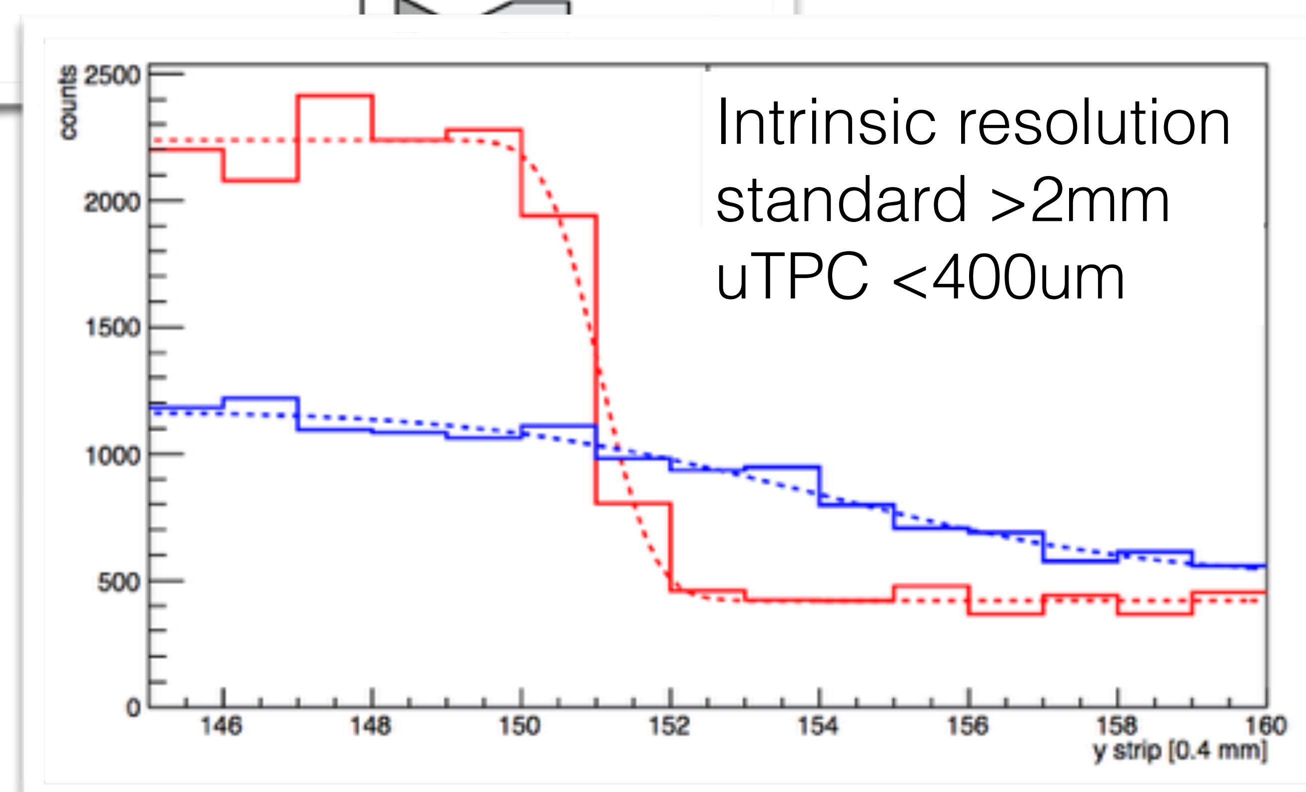


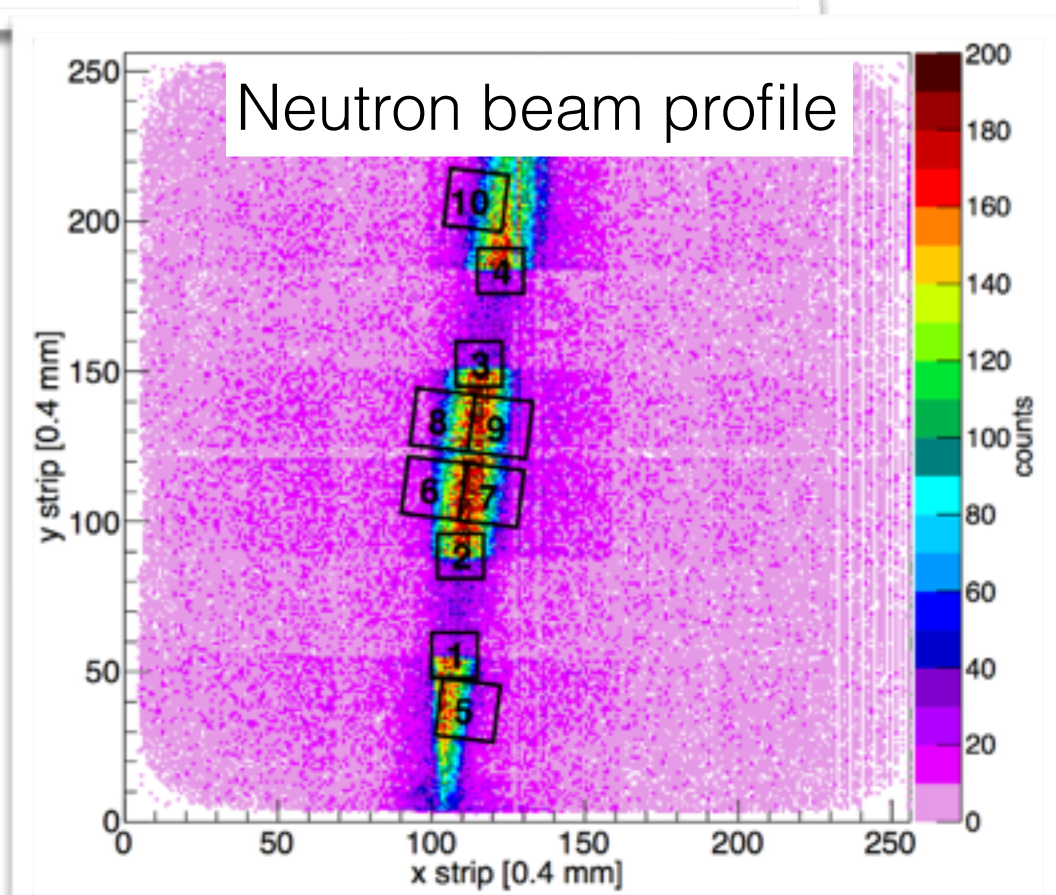
Neutron detectors

D. Pfeiffer *et al.*, *"The µTPC method: improving the position resolution neutron detectors based on MPGDs,"* JINST 10 (2015) 04, P04004









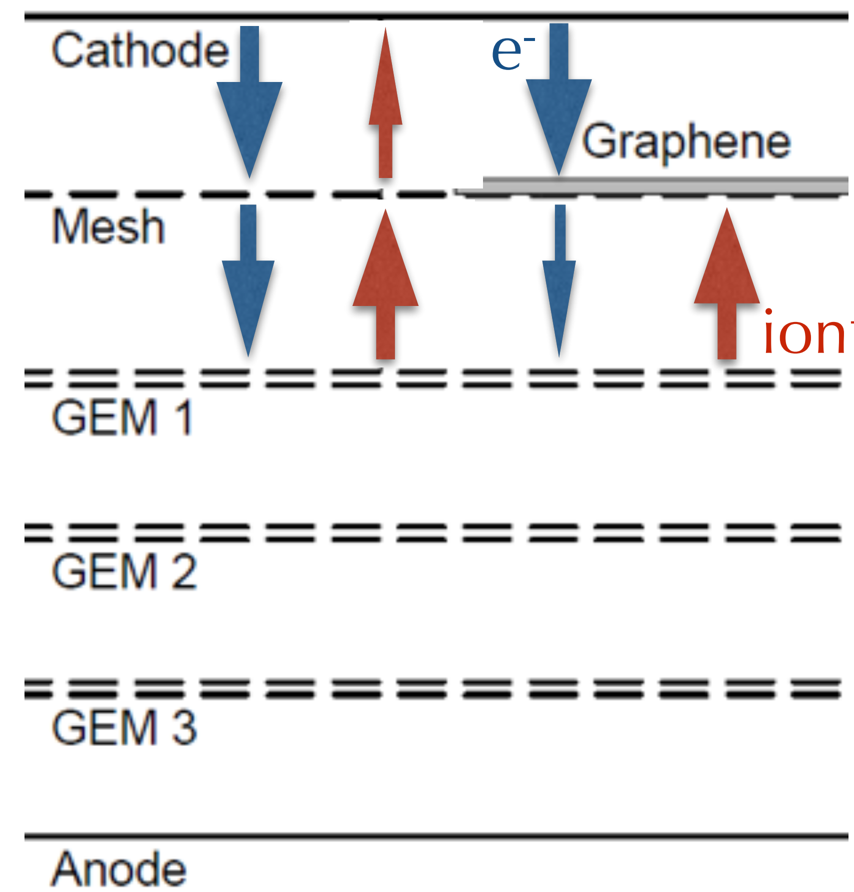
NMX instrument at ESS:

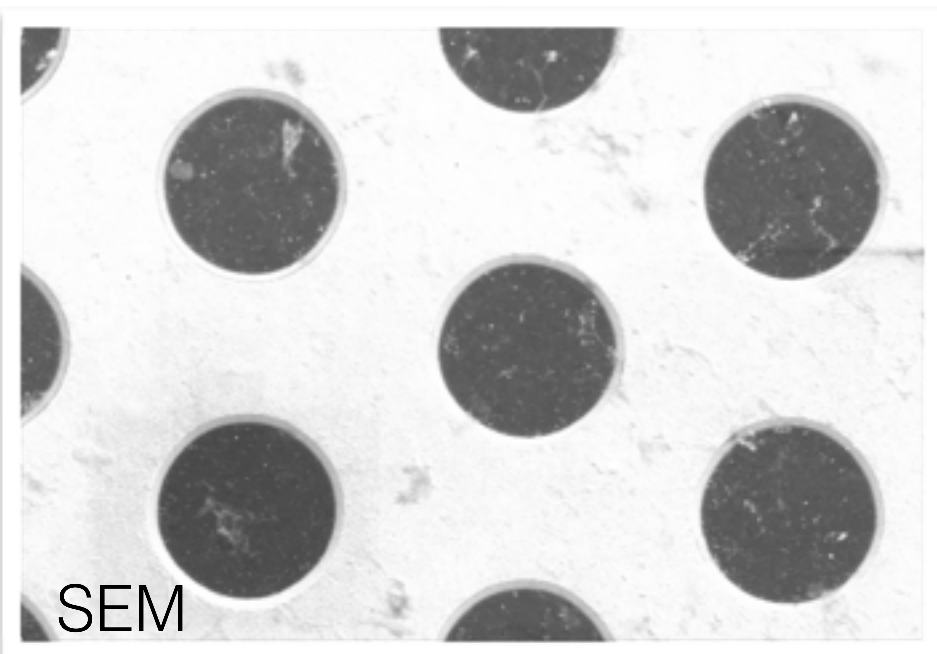
- Gd converter (high efficiency)
- Triple GEM (high flux capability)
- TPC analysis (improved resolution)

Graphene

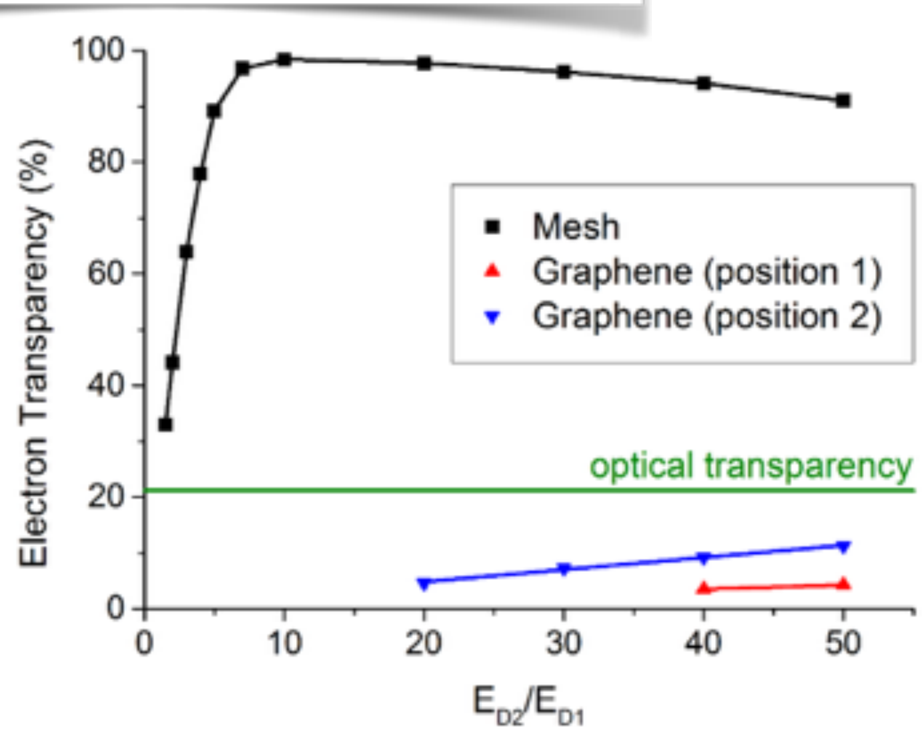
P. Thuiner, "Charge Transfer Properties Through Graphene Layers in Gas Detectors,"

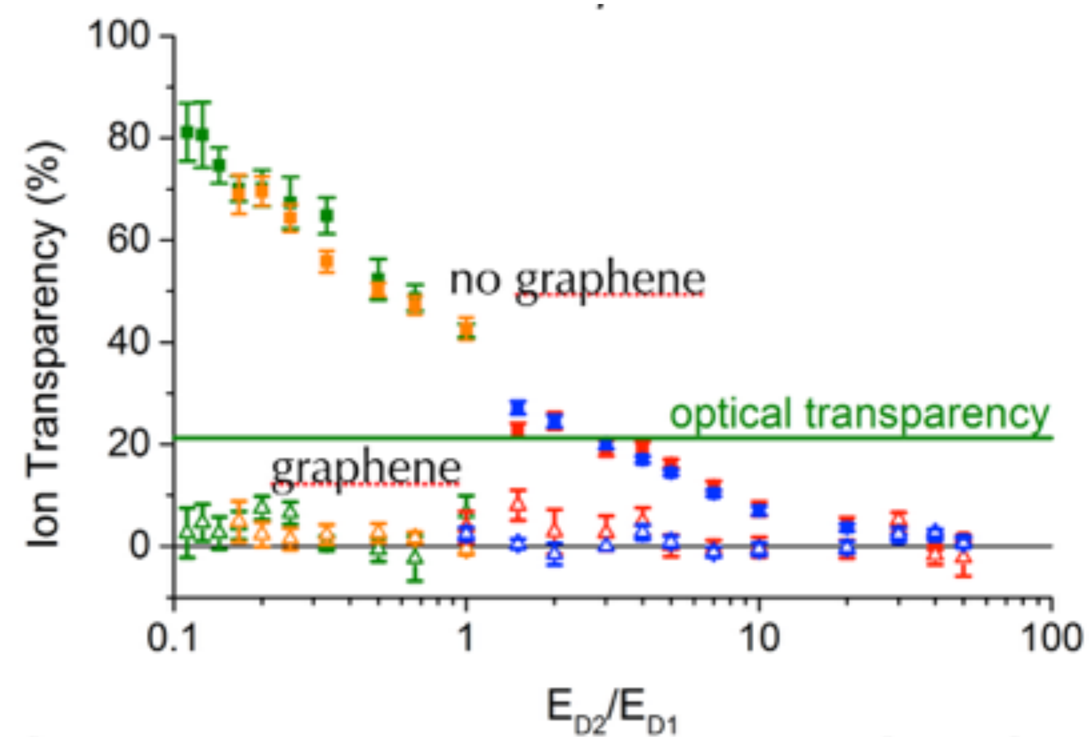
Membrane opaque to ions and transparent to electrons
- solution of the ion back-flow in gaseous detectors
- protective layer on photocathodes
- enhancement of electron emission





~99% (suspended) graphene tri-layer coverage

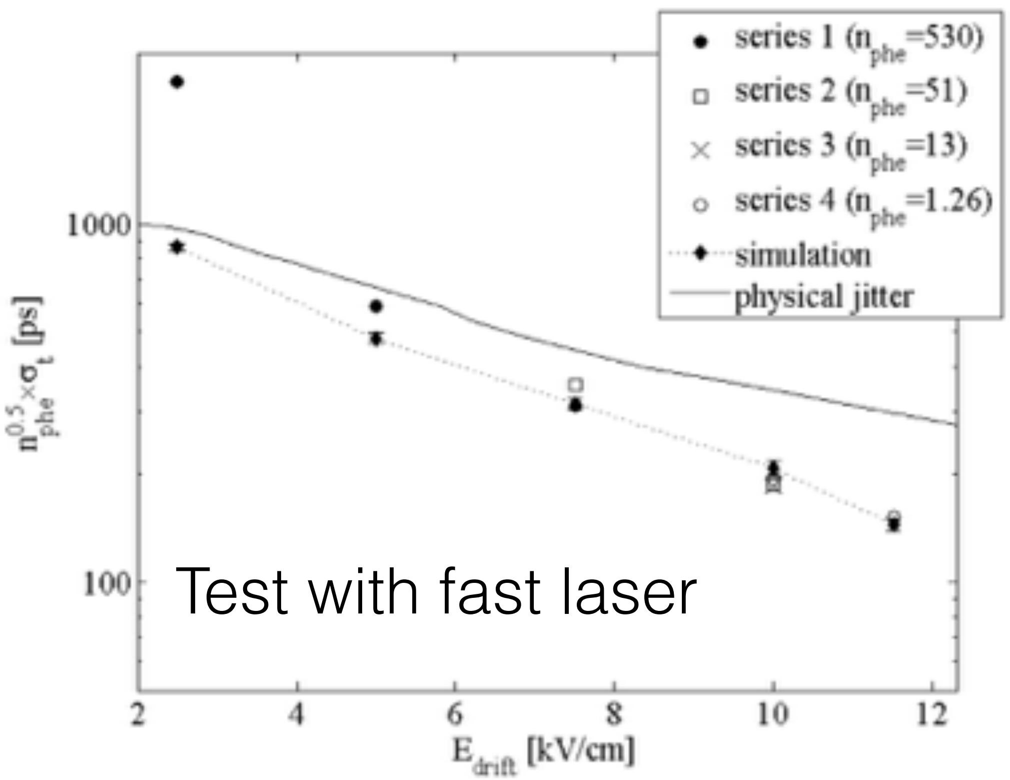


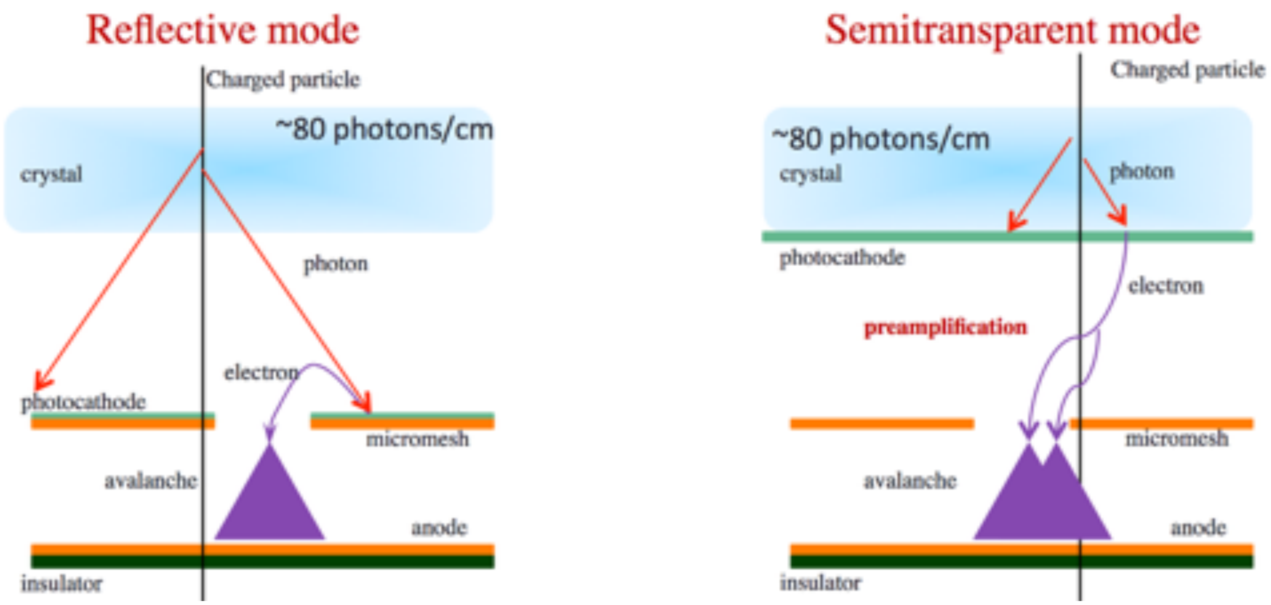


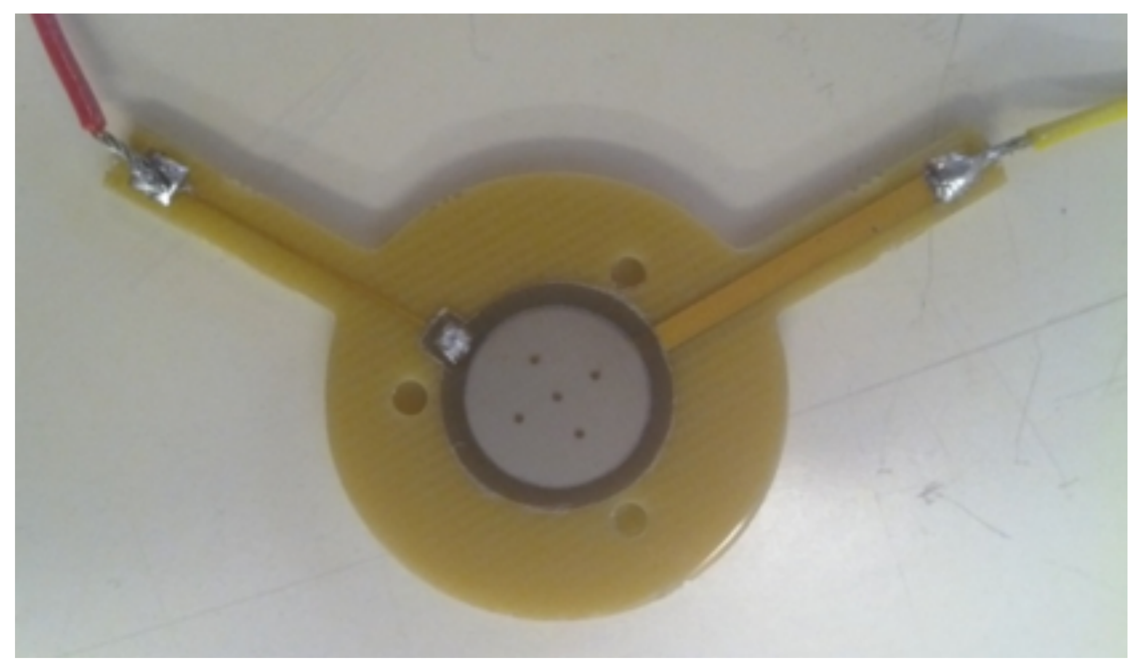
Time resolution challenge

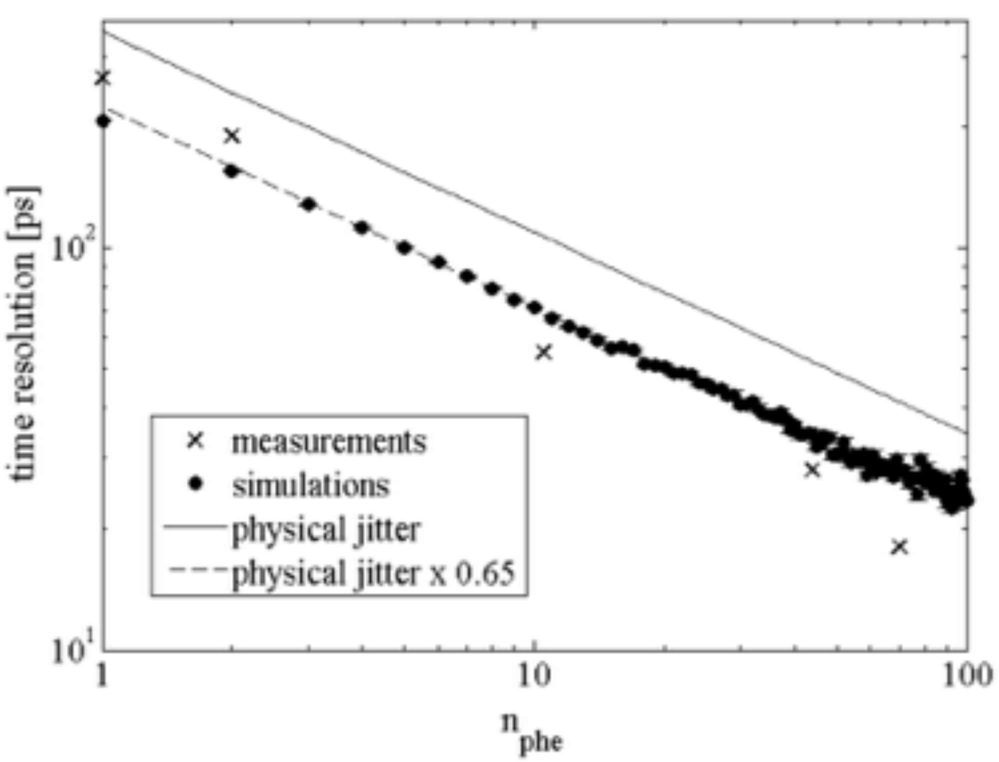
In gaseous detector the time resolution is limited by the fluctuation in the position of the 'last' primary ionisation cluster. Typically few ns…

Small drift gap (no gas ionisation and small diffusion) primaries all generated at the cathode









T. Papaevangelou, "Fast Timing for High-Rate Environments with Micromegas," MPGD2015

Conclusions

Very rich variety of technologies in evolution

Very active community of ‘developers’ and ‘users’

Typically R&D campaign is needed for specific applications users are developers

Extended anode types MPGDs are the most common nowadays, but not the only ones

Several applications, and growing interest outside high energy physics

Large and above all collaborative community behind