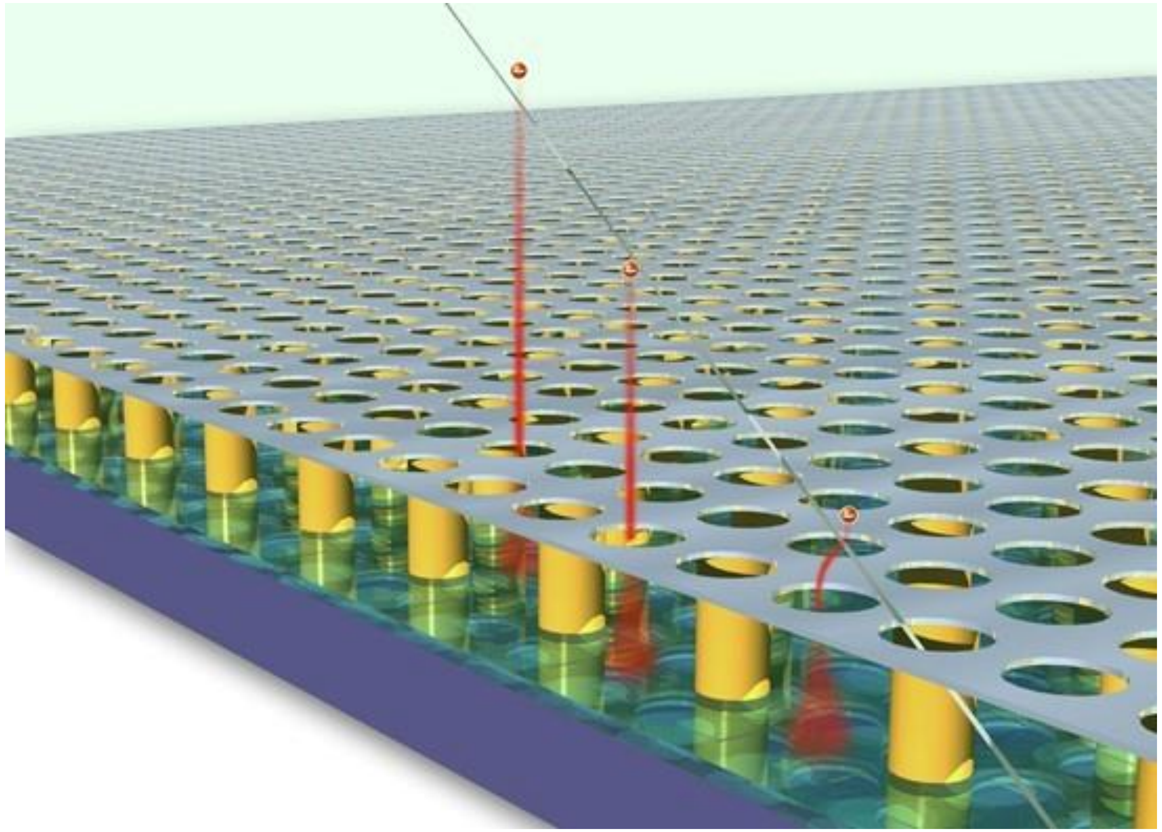
Overview of Micro Pattern Gaseous Detectors (MPGDs)

<u>Outline</u>

- ❖ Introduction to Micro Pattern Gaseous Detectors (MPGDs)
- ❖ MPGDs in High Energy (HEP) and Nuclear Physics (NP)
- ❖ Application of MPGDs outside NP & HEP field



Dr. Kondo Gnanvo

Radiation Detector & Imaging Group

Jefferson Lab, Newport News VA 23606

Introduction to Micro Pattern Gaseous Detectors (MPGDs)

Micro Pattern Gaseous Detectors (MPGDs):

- Goal is to overcome some of the limitation of MWPCs, DC …
- Reduce the ionization gap from O(cm) to O(mm) to allow fast evacuation of ions in the ionization volume
- Combine semiconductor technology with electron multiplication in gas
  - photolithography, etching, lift-off, coating, doping …
  - Micro structures O(100 μm) for the anode readout PCBs of MPGDs

Key features of MPGDs

- Rates capability: O(MHz / cm2)
- Spatial resolution: O(50 μm) are achievable
- Timing resolution: O(5 ns)
- Large area capabilities: O(m2)
- Low cost technologies compared to alternatives such as Silicon detectors
- Low material budget O(0.5% X0/X)
- Robustness: aging and radiation hardness

Micro Strip Gaseous Counter (MSGCs):

- First MPGD invented in 1988 (Oed) for high rate
- Cathode strips and anode strips on the same substrate
- pitch ~ 100 μm ⇨ Excellent spatial resolution
- But suffers high discharge rate and aging issues ⇨ challenging for use in real experiments
- Was used in a few experiments in the 1990s

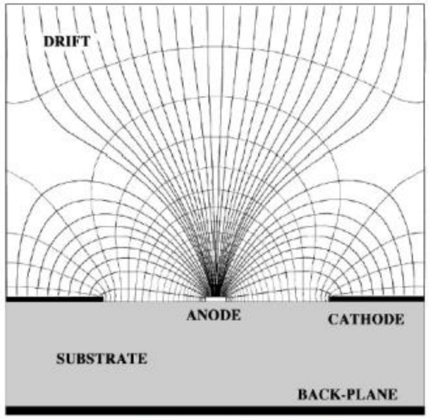
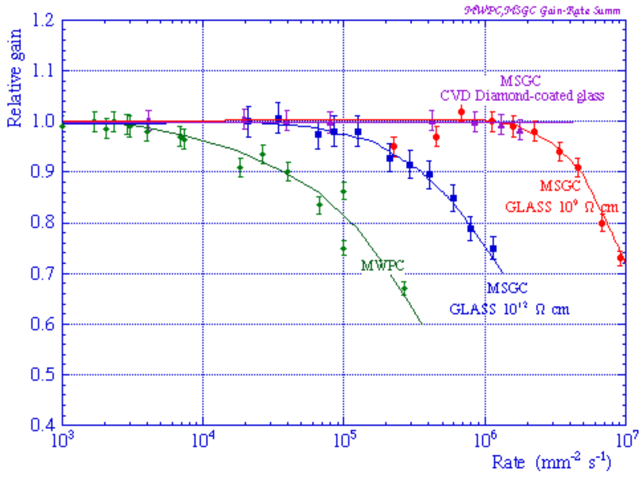
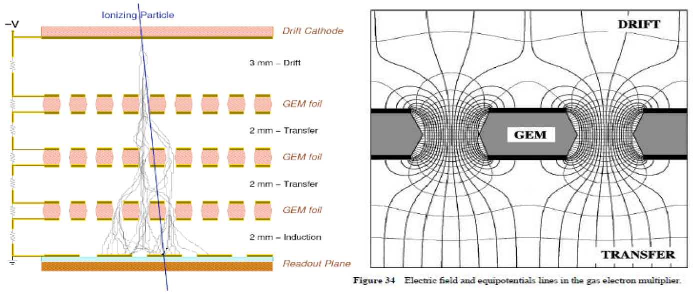


Figure 2 Equipotentials and field lines in the microstrip chamber, computed close to the substrate. The back-plane potential has been selected to prevent field lines entering the dielectric.



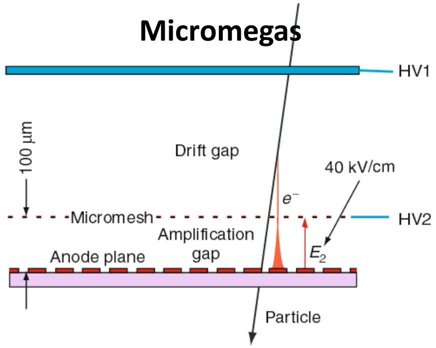
Overview of MPGDs over 25 years

Gas Electron Multipliers (GEMs)



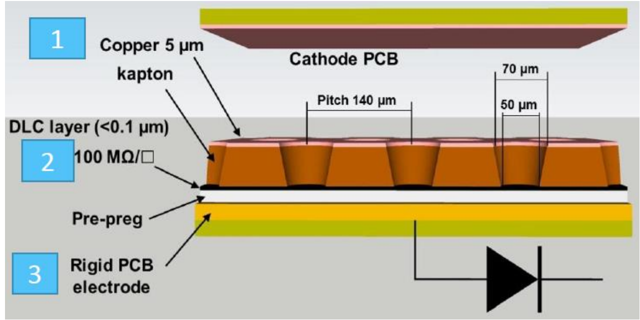
F. Sauli, Nucl. Instr. and Meth. A386(1997)531

Micromegas



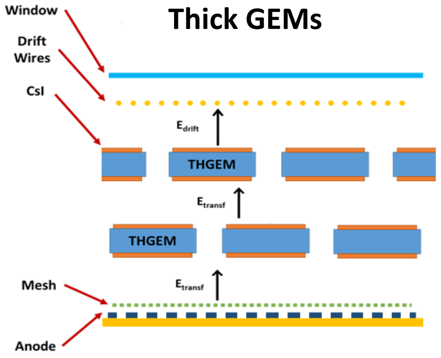
Y. Giomataris, NIMA 419 (1998) 239

Resistive Micro Well (μRWELL)



G. Bencivenni et al.; 2015_JINST_10_P02008

Thick GEMs



R. Chechik, A. Breskin, C. Shalem

MicroDot

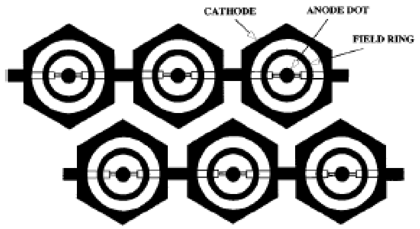
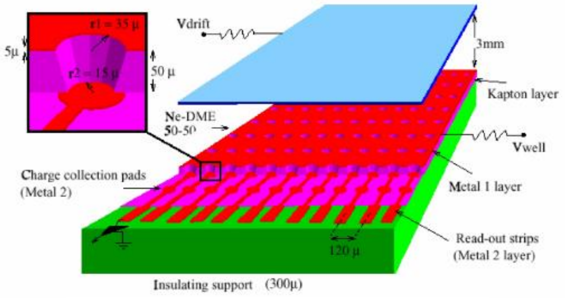


Figure 26 Schematics of the microdot chamber. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronics technology. Anodes are interconnected for readout.

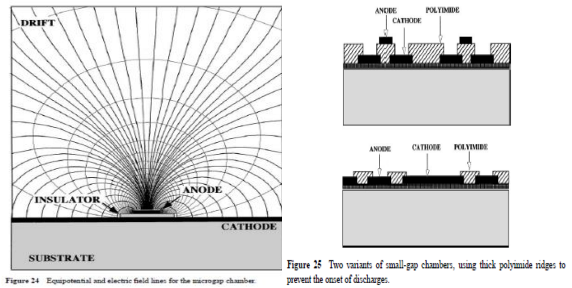
Biagi SF, Jones TJ. NIM A361:72 (1995)

MicroWELL



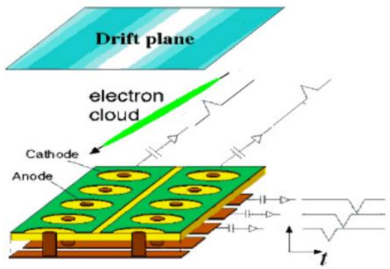
R. Bellazzini, NIMA 423 (1999) 125

Micro Gap Chambers



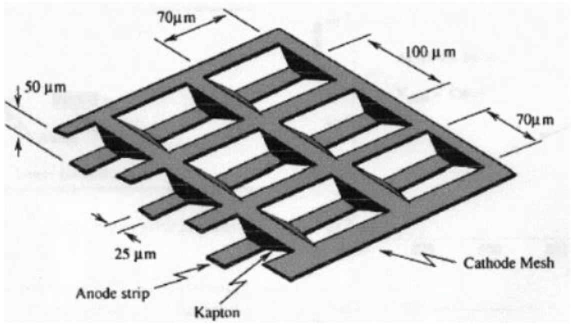
Angelini F., NIMA 335:69 (1993)

μ-PIC



Ochi et al NIMA 471 (2001) 264

Micro Wire Chamber



B. Adeva et al., NIMA 435 (1999) 402

Micro Gap Wire Chamber

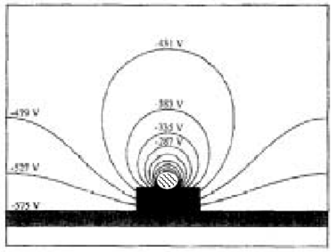
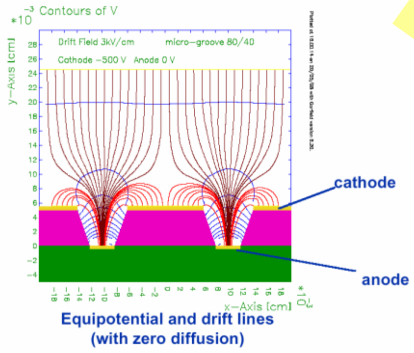


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997].

NIMA 398 (1997) 195

Micro Groove



R. Bellazzini , NIMA 424 (1999) 444

… and so many others

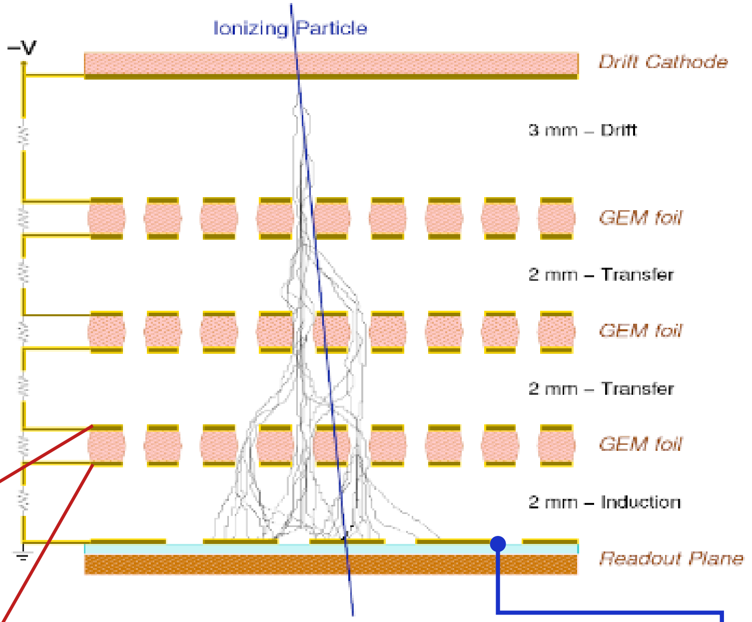
Gas Electron Multipliers (GEMs)

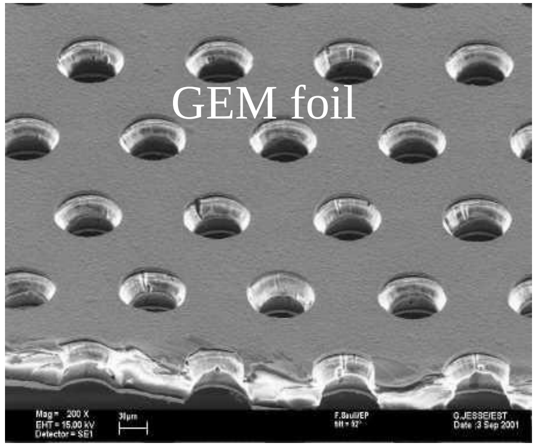
- ⇨ Thin, metal-clad polymer foil chemically perforated by a high density of holes (~100 /mm^2)
- ⇨ ~350 V across the Cu electrode creates a strong field in the hole leading to amplification
- ⇨ The ionization pattern is preserved by design with the E-field focusing the charges inside the holes

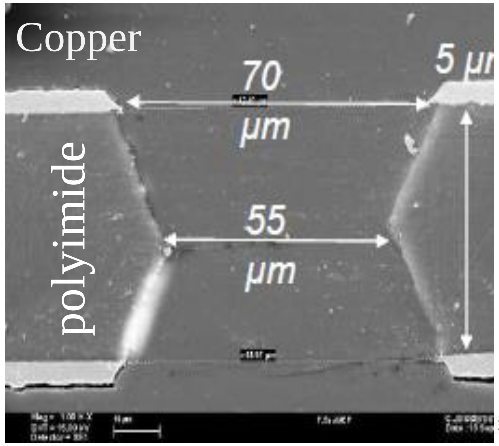
UNIQUE FEATURE

- ⇨ Charge amplification is decoupled from the charge collection ⇨ **Multi-stage amplification**
  - ❖ Default: Triple-GEM detector 3 GEM foils for amplification ➔ High gain / low spark rate
- ⇨ More flexibility on the readout strip / pad segmentation and features
  - ❖ Default: COMPASS X-Y strip readout, pitch = 400 um ➔ spatial resolution ~60 um

COMPASS Triple-GEM detector







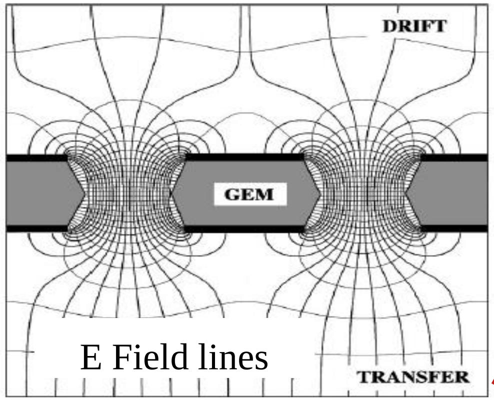
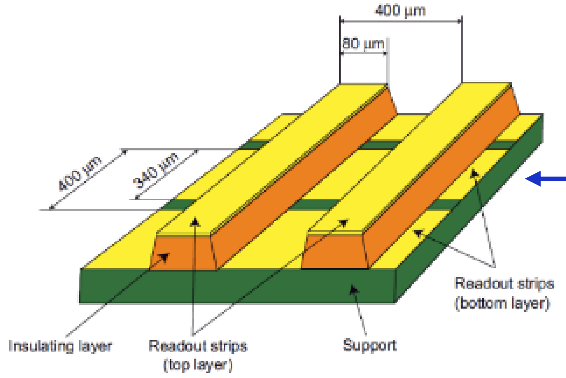


Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

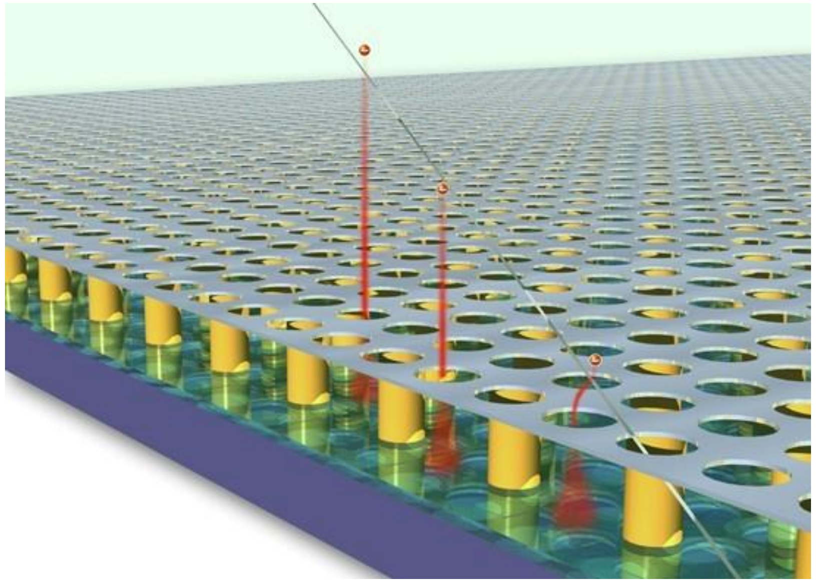
COMPASS X-Y strip readout



F. Sauli, Nucl. Instr. and Meth. A386 (1997)

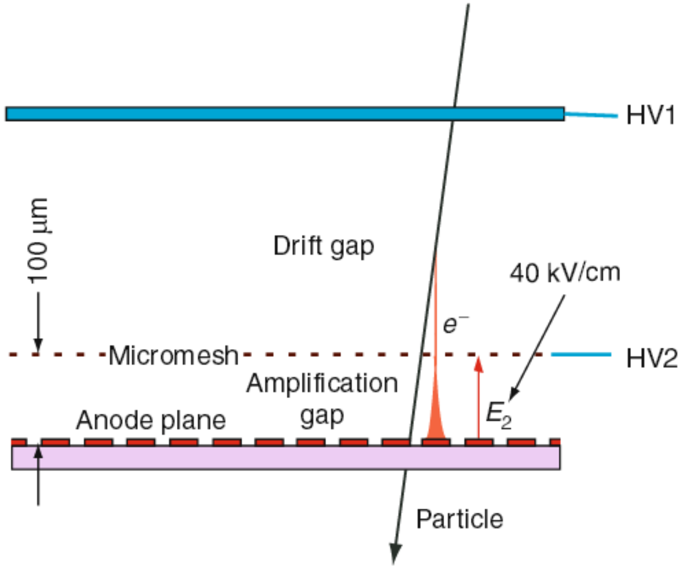
Micro-Mesh Gaseous Structures (Micromegas)

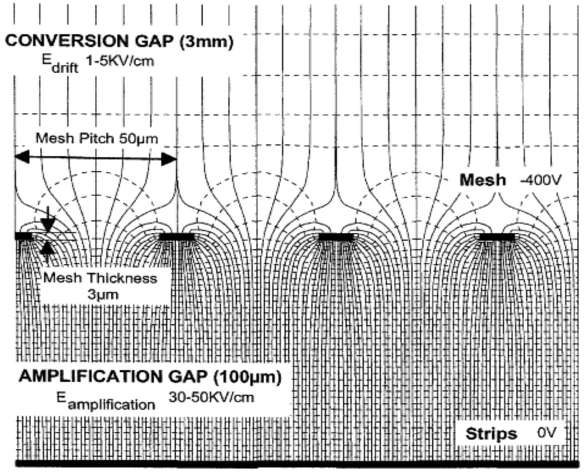
- ⇨ Two-stage parallel-plate avalanche chamber of small amplification gap
  - ❖ Fine structure metallic mesh as amplification device
  - ❖ Amplification in the (~100 µm) gap between the mesh and the anode



Small gap, high field:

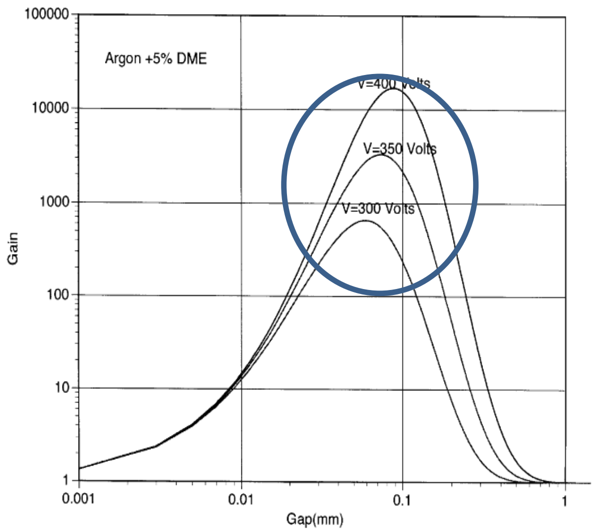
- ⇨ fast movement of positive ions that are mostly collected on the mesh
- ⇨ small space-charge accumulation and very fast signals
- ⇨ Resistive Micromegas to reduce sark rate and energy





Y. Giomataris, Nucl. Instr. and Meth. A419 (1998)

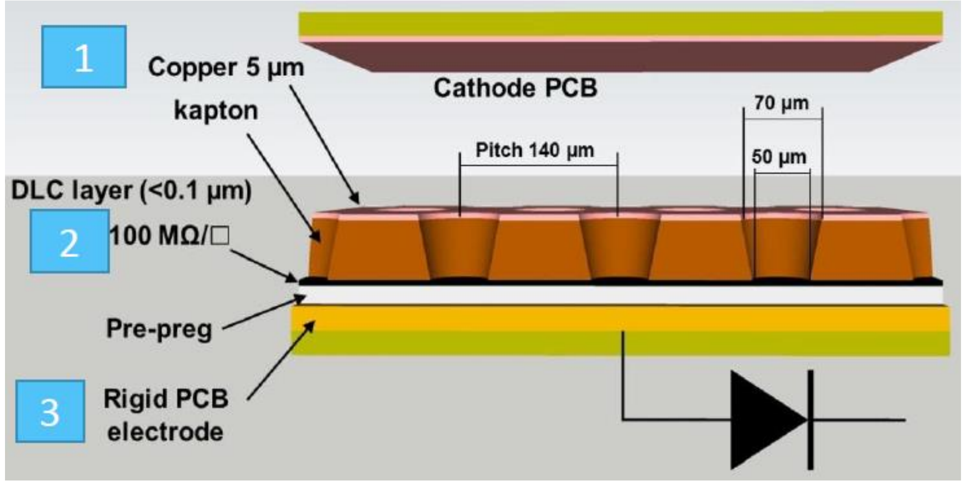
- ⇨ Gap around 100 µm: small gap variations compensated by an inverse variation of amplification factor
- ⇨ i.e. good uniformity and stabili of response over a large area.



Resistive Micro Well Detectors (µRWELL)

The µRWELL PCB is realized by coupling:

1. "Suitable WELL patterned Kapton foil as "amplification stage"
2. "Resistive stage" for discharge suppression & current evacuation:
   - i. "Low rate" (LR) << 100 kHz/cm^2: single resistive layer (~100 MΩ/□)
   - ii. "High rate" (HR) >> 100 kHz/cm^2: more sophisticated resistive scheme
3. a standard readout PCB with strip or pad readout



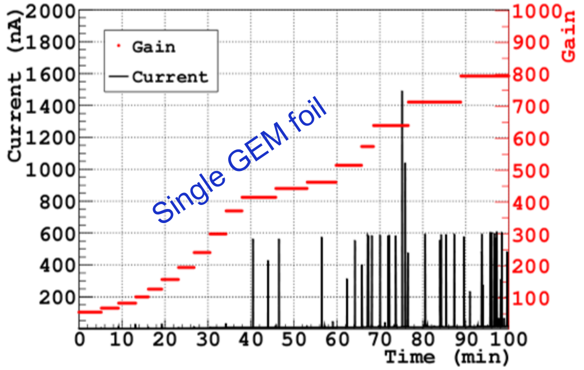


Figure 9. Monitoring of the current drawn (in black) by the single-GEM detector for different gas gain (in red). Discharge amplitudes as high as 1µA are recorded at higher gains.

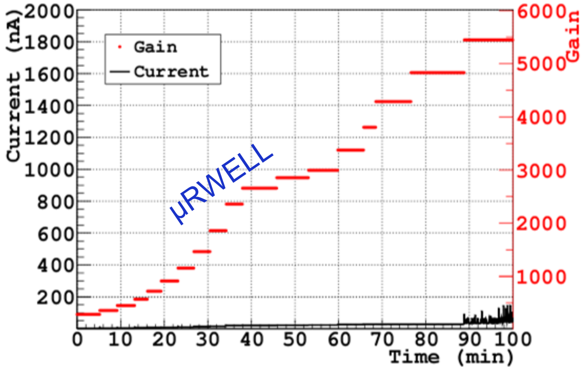
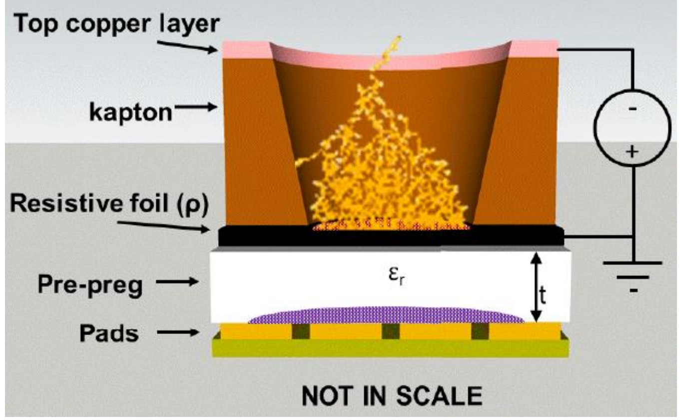


Figure 10. Monitoring of the current drawn (in black) by the µ-RWELL detector for different gas gain (in red). Discharges are quenched down to few tens of nA even at high gains.



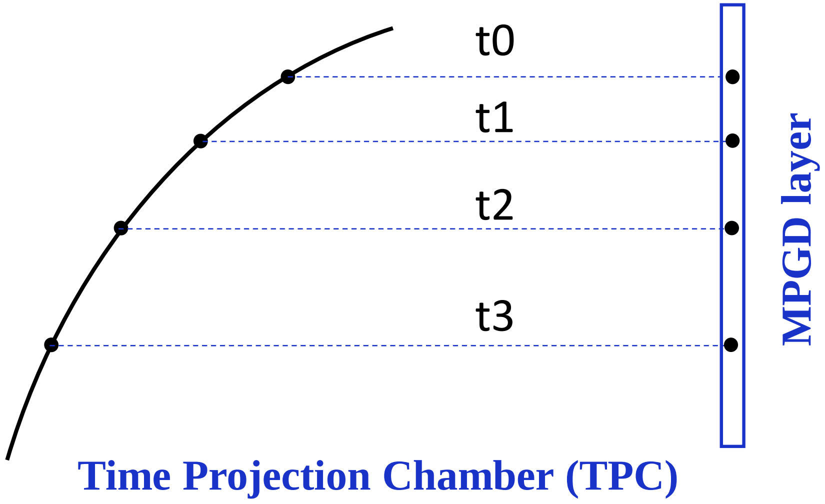
G. Bencivenni et al.; 2015_JINST_10_P02008

- ❖ **Like Micromegas ⇨ Single amplification stage, no stretch**
- ❖ **Like GEM ⇨ Same amplification device structure**

Tracking in NP and HEP experiments

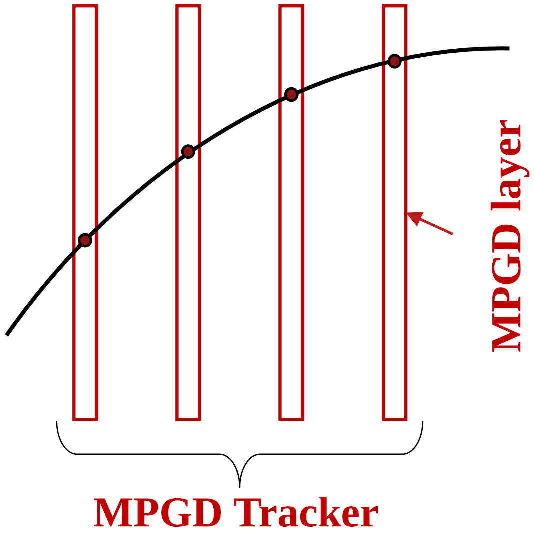
Role of tracking detectors in NP and HEP experiments:

- Measure the trajectory of high energy charged particles
- Measure the momentum of the particle in a magnetic field
- Various tracking detector technologies
  - Silicon trackers
  - Gaseous trackers
  - Scintillator fiber trackers …



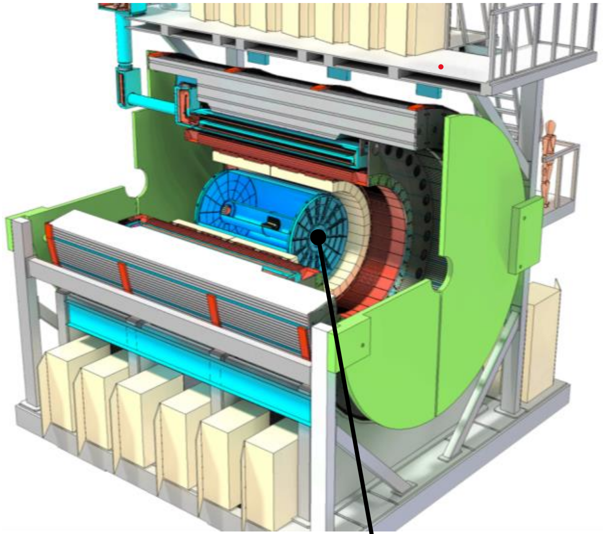
Gaseous Trackers:

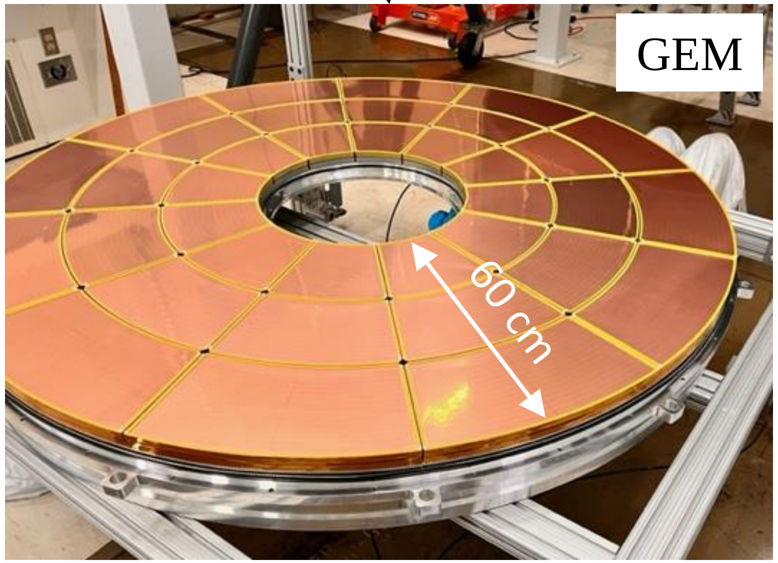
- Multi Wire Proportional Chambers (MWPCs)
- Drift Chambers (DCs)
- **Micro Pattern Gaseous Detectors (MPGDs)**
- **Time Projection Chambers (TPCs)**



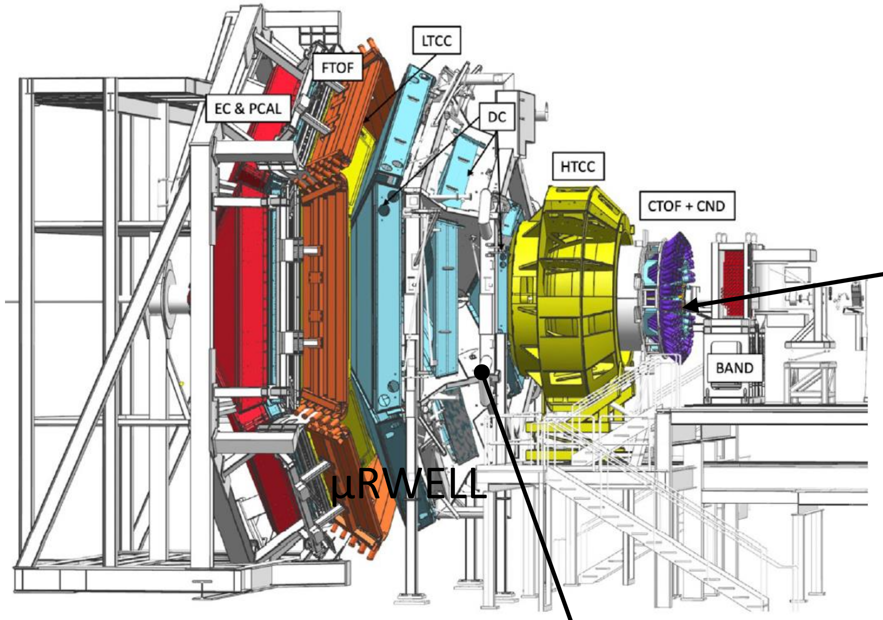
MPGD Trackers in NP experiments

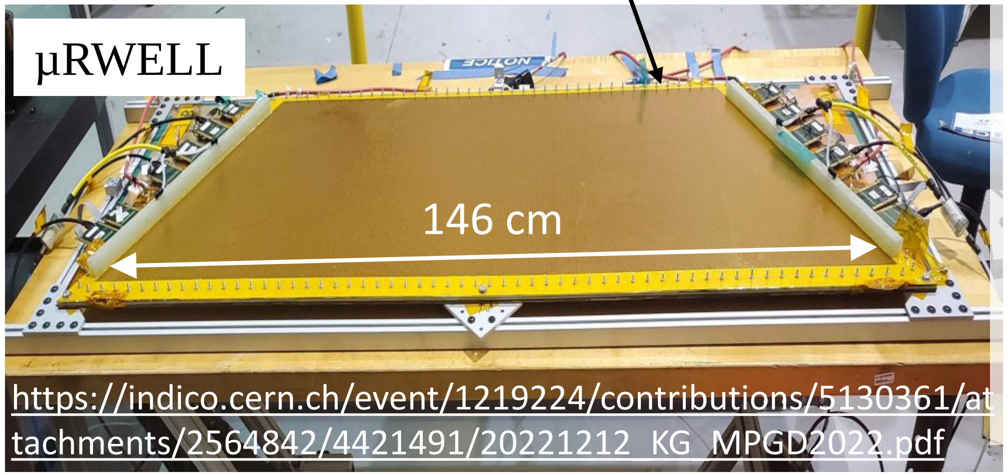
sPHENIX TPC end cap GEM readout (BNL)



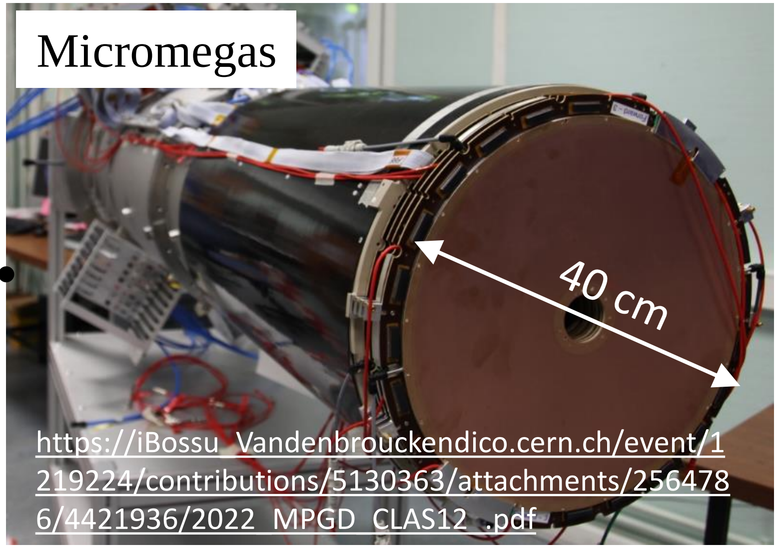


CLAS12 μRWELL Forward Tracker (JLab)





CLAS12 Micromegas Vertex Trackers (JLab)



But also:

- **JLab:** SBS GEMs, BoNuS radial radial TPC, SoLID Moller GEMs
- **BNL:** STAR Forward GEM Trackers, PHENIX HBD, sPHENIX TPOT …
- **FRIB:** Multi-layer thick GEMs
- **EIC:** Micromegas & μRWELL barrel trackers

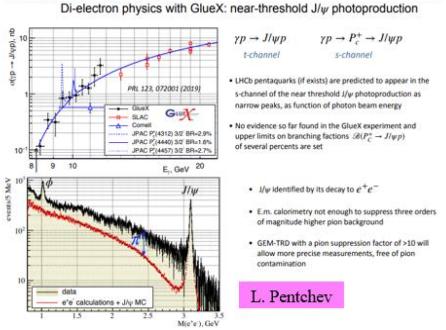
Applications in NP and HEP beyond tracking

MPGDs are also used in NP & HEP for non-tracking applications such as:

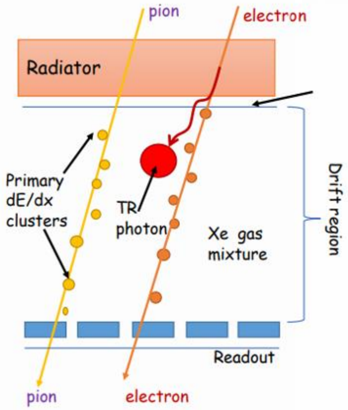
- single photon photosensor for Ring Imaging Cherenkov (RICH)
- Amplification device for Transition Radiation Detectors (TRDs)
- Fast timing device for Time of Flight (TOF) detectors
- Position sensitive detectors for Digital Calorimeters
- And many more …

eID: GEM-based Transition Radiation Detector (EIC R&D)

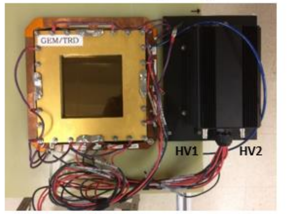
Physics motivation



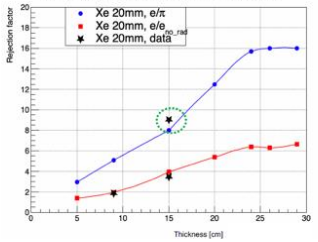
GEM-TRD/T principle



GEM-TRD/T prototype



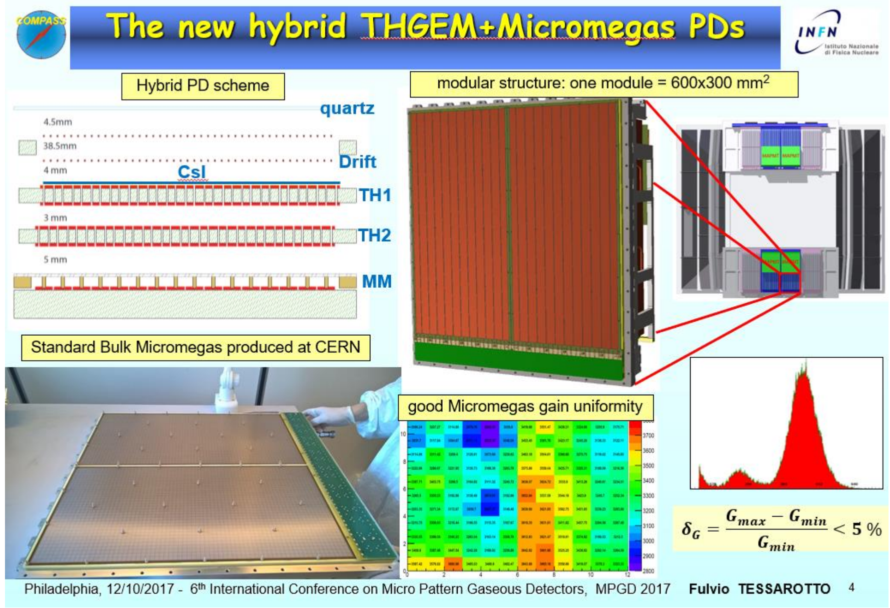
e/π separation from one layer



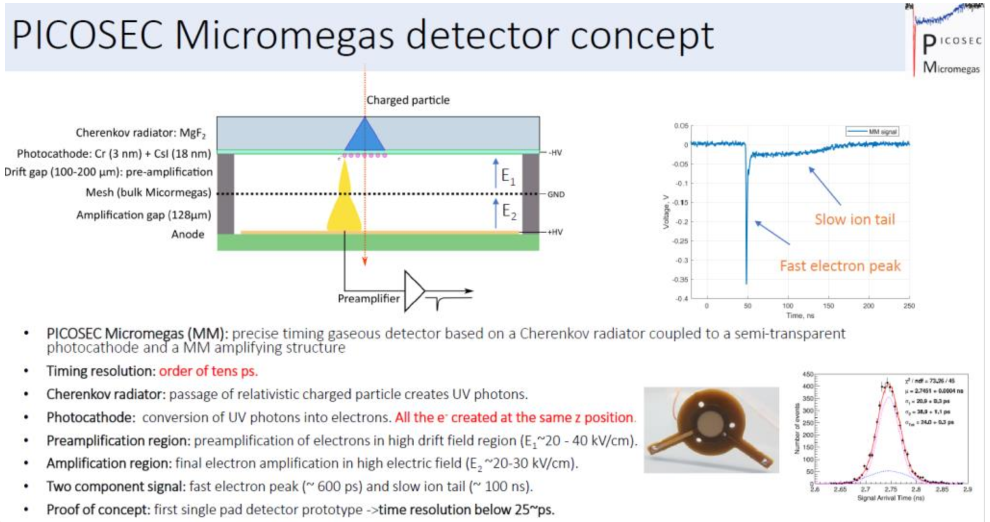
Converting standard GEM tracker into GEM-TRD

- Drift gap increases from 3 mm to 20 - 30 mm (photon yield)
- Argon based gas mixture (ArCO2) replaced by Xenon based (XeCO2)
- Add radiator at the entrance window / drift cathode foil of the detector

Single photon detector (COMPASS RICH @ CERN)



Fast timing for charged particles (MM-PICOSEC Coll.)



and so many others…

Applications beyond NP and HEP field

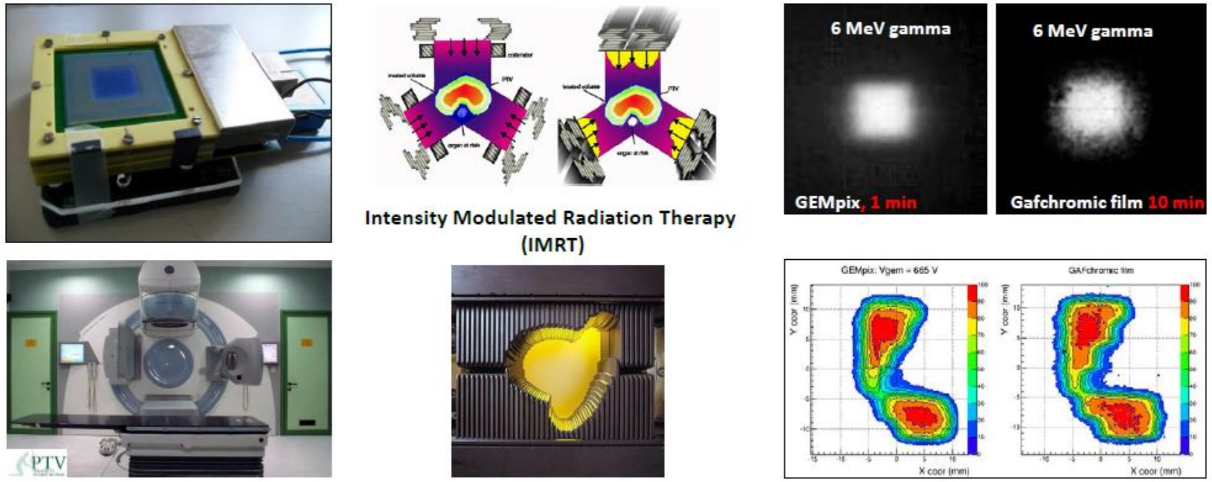
Muography with Micromegas: Scanning pyramids

- 4 2D readout Micromegas
  - Organized in 2 doublets to optimize the angular resolution and the acceptance
- Electronics box
  - PC + readout + HV
- In gas and ambient T,P sensors
- Switching power supply between 220V and battery
- Premix T2K gas bottle

https://indico.cern.ch/event/581417/contributions/2556694/attachments/1464839/2265943/MPGD_2017_SB.pdf

GEMPix detector for Hadrontherapy application

GEMPix detector (8cm^2 GEM detector read by 55x55µm pixels, 262 000 channels)
- 2D measurements of energy released in IMRT (Policlinico Tor Vergata Roma)



F. Murtas , G. Claps, D. Falco
CERN, INFN, PTV

An optimal agreement between GEMPix and gafchromic film is obtained
Real-time measurements with GEMPix allows fast Quality Assurance procedure

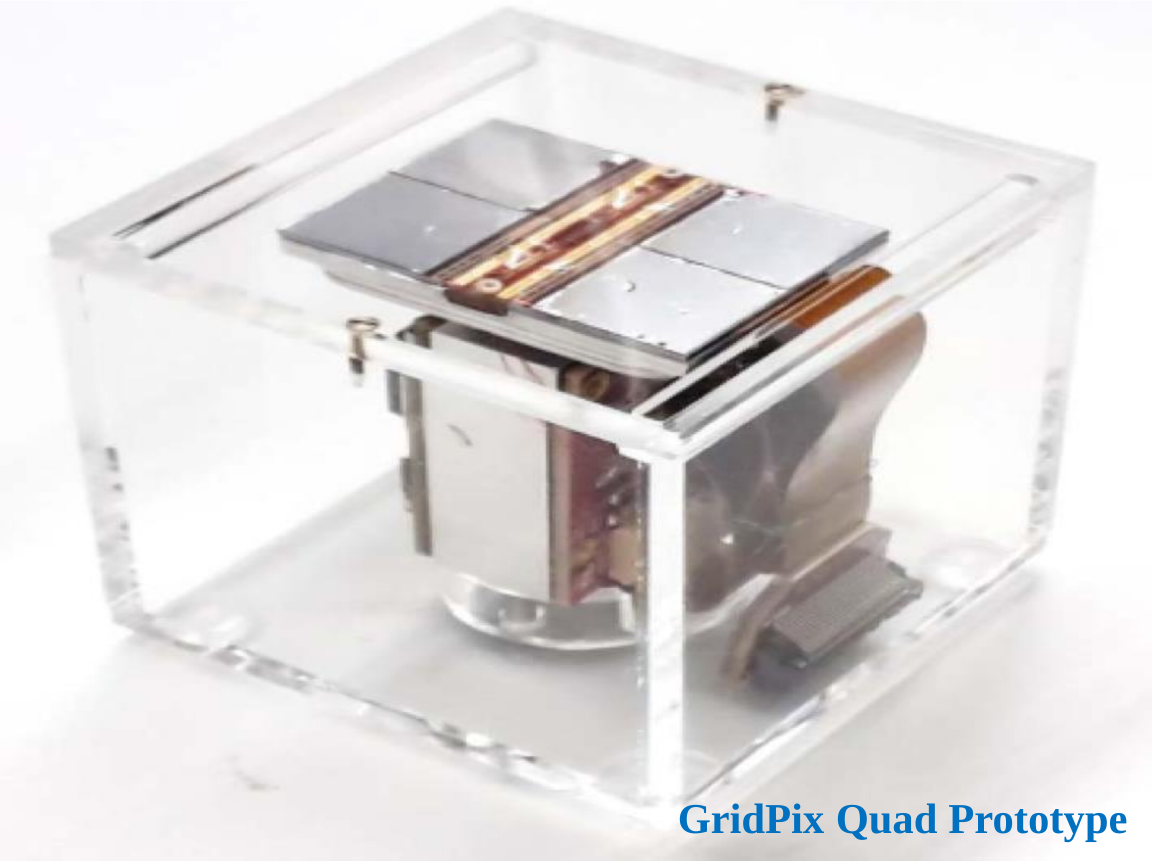
https://indico.cern.ch/event/392209/contributions/1828216/attachments/1291499/1923737/4_Fabrizio_Murtas.pdf

Summary

- ❖ MPGDs are mature detector technologies for applications in NP and HEP experiments
- ❖ Provide high rate, excellent spatial and timing resolution, large area and low cost capabilities
- ❖ Aging and radiation hardness and operation stability remain the focus of intense R&D effort
- ❖ Exploration for applications outside particle physics and specially in medical instrumentation

Questions?

Thank you



GridPix Quad Prototype

Back up

Introduction to Micro Pattern Gaseous Detectors (MPGDs)

Multi Wire Proportional Chambers (MWPCs), Drift Chambers (DCs)

- Used for tracking of charged particles in Nuclear Physics (NP) and High Energy Physics (HEP): Excellent spatial resolution
- But limited timing performance, counting rate capabilities, Aging and operation stability issues

Micro Pattern Gaseous Detectors (MPGDs):

- Goal is to overcome some of the limitation of MWPCs, DC …
- Basic idea: Allow fast evacuation of the ions
  - Reduce the ionization volume gap from O(cm) to O(mm)
- MPGD technology combine:
  - Semiconductor industry technology i.e. photolithography, etching, lift-off, coating, doping)
  - with electron multiplication in gaseous media
- Micro structures anode readout with micro-structure PCB patterns

Micro Strip Gaseous Counter (MSGCs):

- First MPGD invented in 1988 (Oed) for high rate
- Cathode strips and anode strips on the same substrate
- pitch ~ 100 µm ⇨ Excellent spatial resolution
- But suffers high discharge rate and aging issues ⇨ challenging for use in real experiments
- Was used in a few experiments in the 1990s

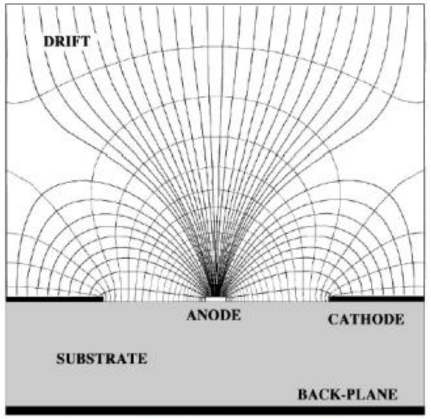
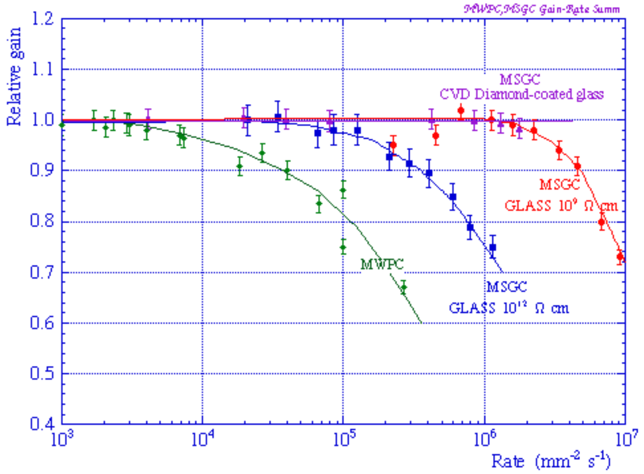
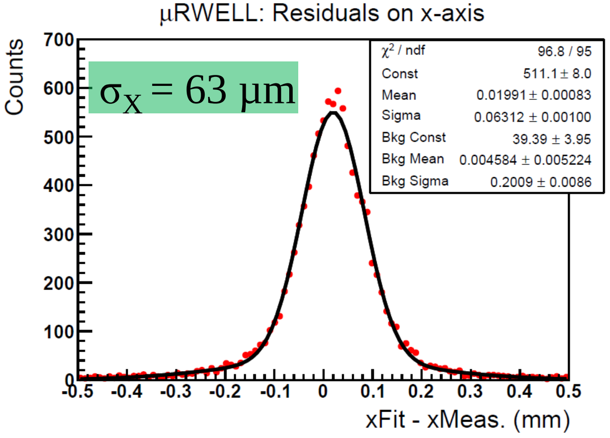


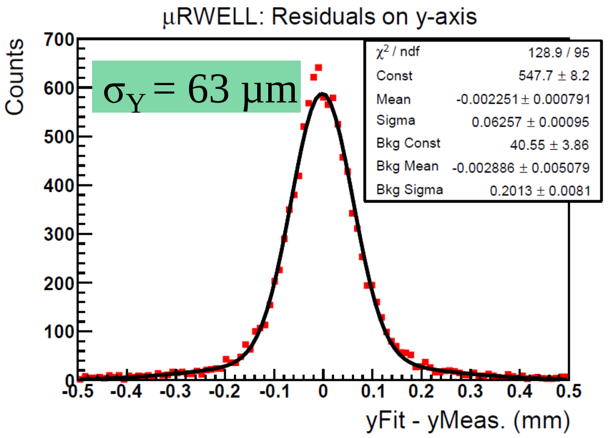
Figure 2 Equipotentials and field lines in the microstrip chamber, computed close to the substrate. The back-plane potential has been selected to prevent field lines entering the dielectric.

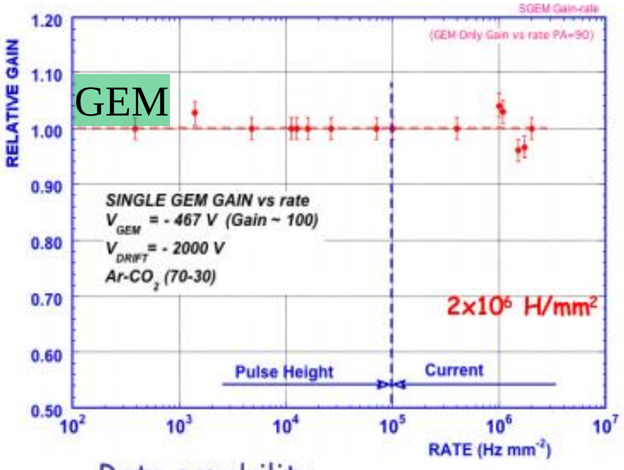


Properties of MPGDs

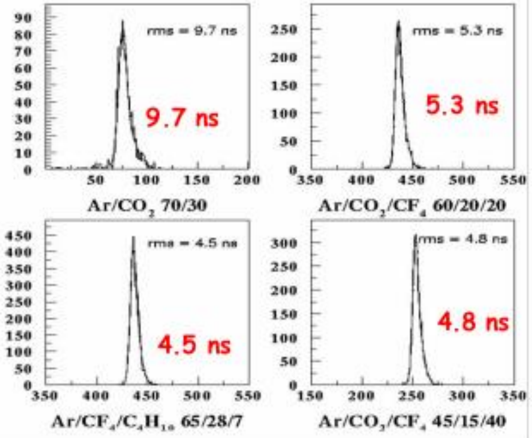
- Rates capability: O(MHz / cm^2)
- Spatial resolution: O(50 μm) are achievable
- Timing resolution: O(5 ns)
- Large area capabilities: O(m^2)
- Low cost technologies compared to alternatives
- Low material budget O(0.5% X_0/X)
- Robustness: aging and radiation hardness



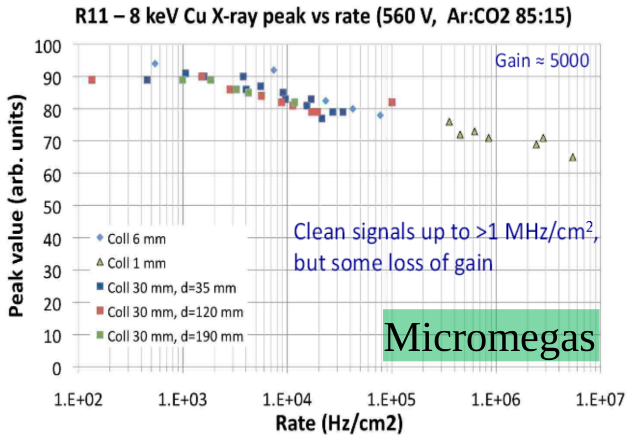


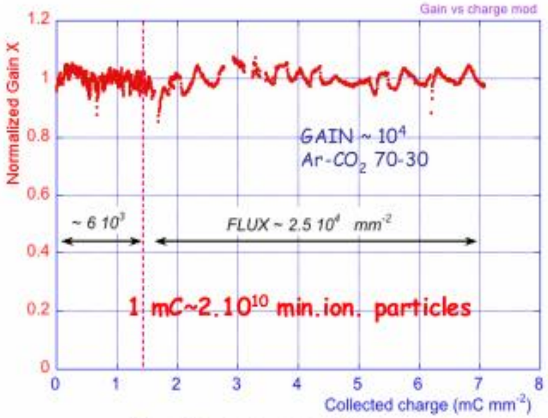


Rate capability



Time resolution

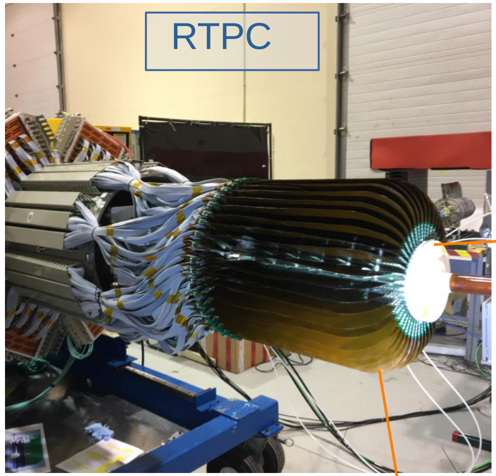


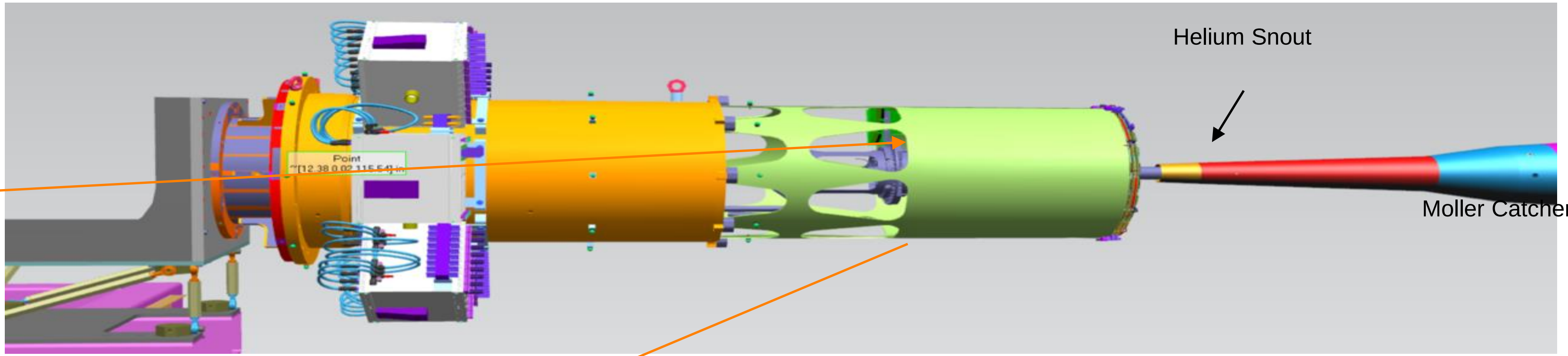


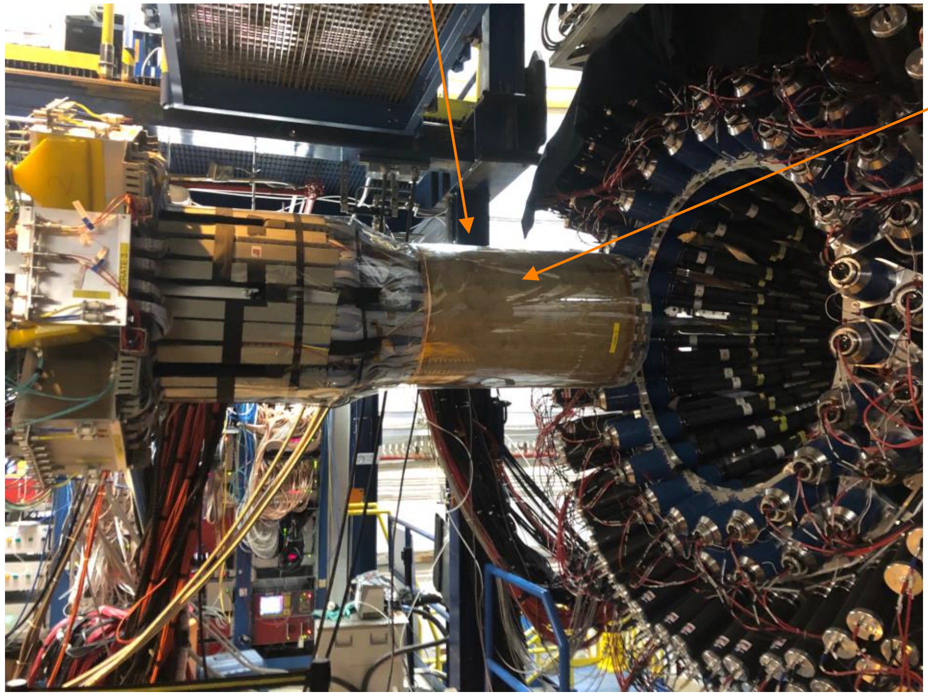
Ageing properties

Jefferson Lab

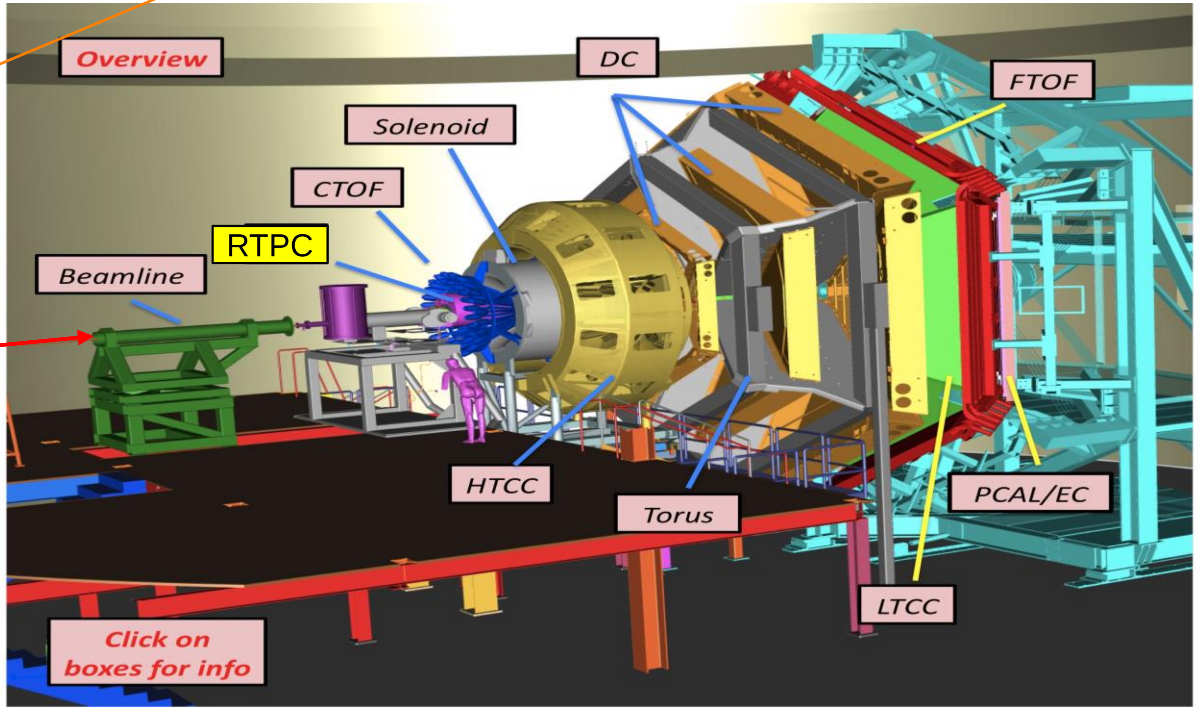
Integration of BoNuS in CLAS12 detector







beam



BoNuS rTPC track reconstruction