MPGD technologies

Developments and perspectives

Florian M. Brunbauer (CERN GDD)

The 2020 International Workshop on the High Energy Circular Electron Positron Collider, October 26, 2020

MPGD technologies

State-of-the-art technologies and developments

- GEMs & THGEMs
- Micromegas
- μPIC and well-type MPGDs

Readout of MPGDs

- Electronic readout
- Optical readout
- Hybrid readout approaches

New perspectives

- Fast timing with gaseous detectors
- Additive manufacturing and novel materials

MPGD technologies

- Flushed/ sealed
- Radio purity
- **Amplification** High/low gain, single/multi stage
- **Gases** Mixture, quencher, electro-negative
- **Pressure** High pressure, low pressure, dual-phase
- **Conversion** Gas, photocathode, converter, emitter
- **Production** Photolithography, machining, printing
- **Rate** high rate / low rate
- **Drift** Electron / negative ion drift
- **Readout** Electronic, optical, hybrid
- **Shape** Planar, cylindrical, spherical
- **Readout geometry** Strips, pads, pixels, multiplexed
- Resistive / non-resistive
- Low material budget
- **Detection** MIPs, photons, neutrons, charged particles
- **Size** cm^2 to m^2
- **Conversion gap** Thin gap, thick gap, field shapers
- **Application** Tracking, calorimetry, reconstruction, imaging

MPGD technologies

Versatility

- Choice of **gas mixture** (He/Ar/Ne/Xe/… + quenchers)
- Operating **pressure** from mbar to several bar
- **Readout** approach (electronic/optical/hybrid)
- **Conversion**: gas ionisation / converter / photocathodes / secondary emitters
- Detector **geometries** and shape (planar / cylindrical / spherical)

Low energy threshold (≈ few keV)

Good spatial resolution (≈ tens of μm)

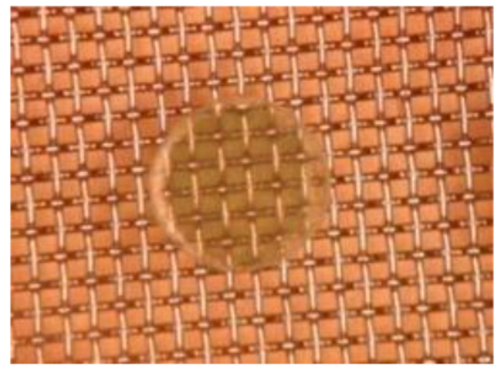
Low material budget (gas as active medium)

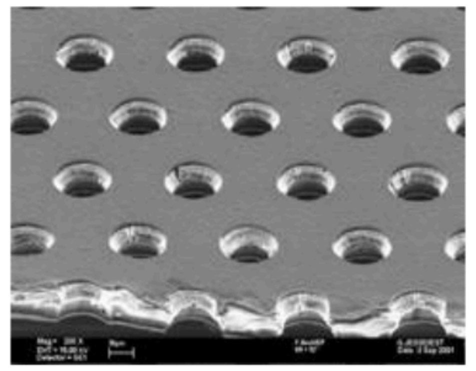
High-rate capability (up to MHz / mm^2)

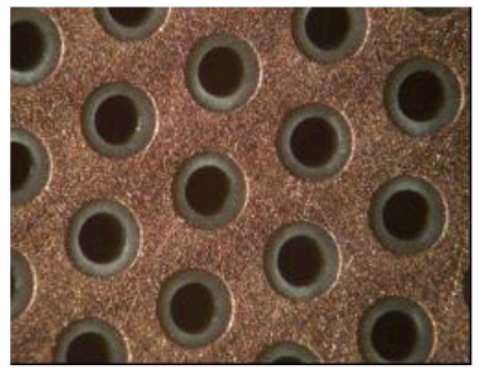
Large active area (up to hundreds of m^2)

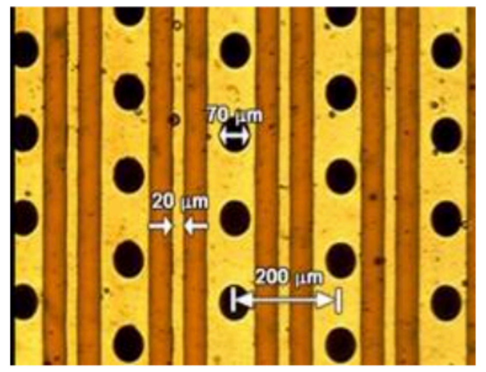
Radiation hardness

MPGD timeline

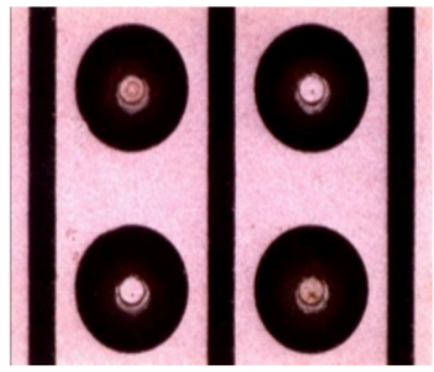

MicroMegas

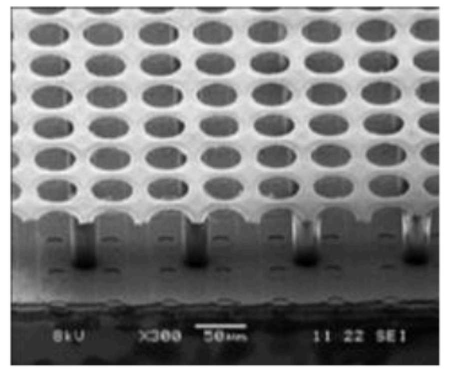

GEM

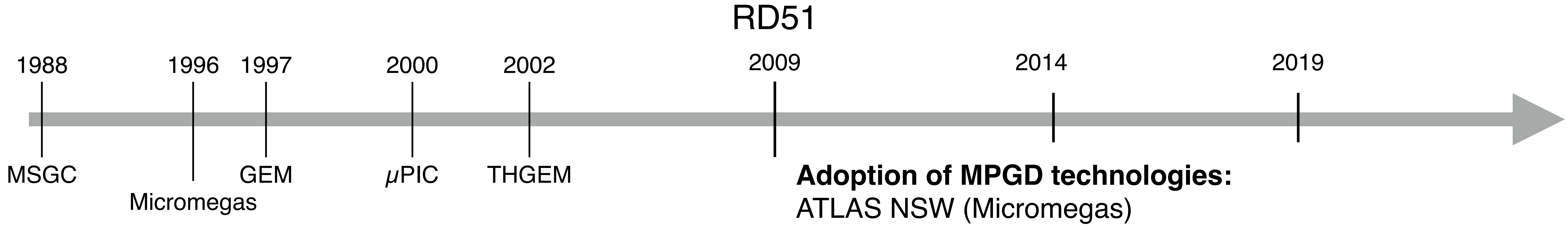

THGEM



MHSP

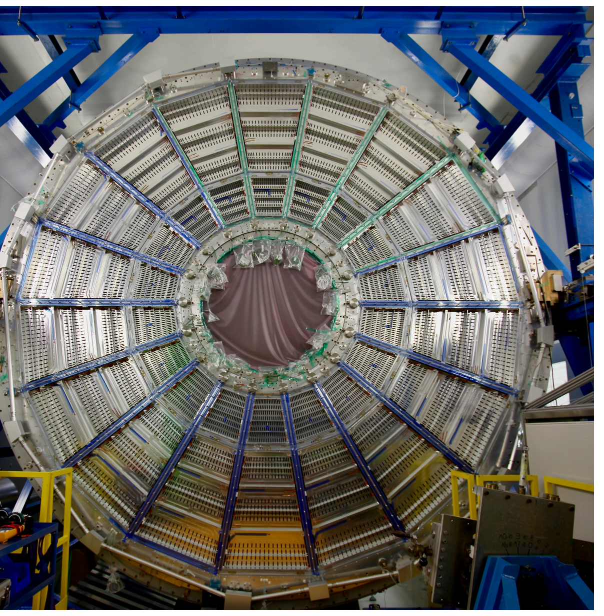

microPIC

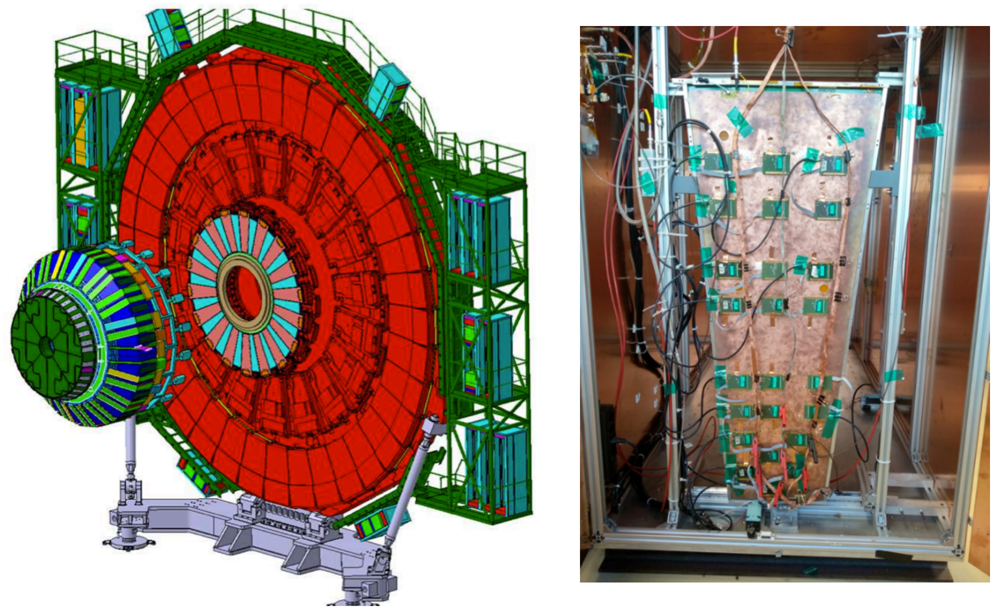

Ingrid

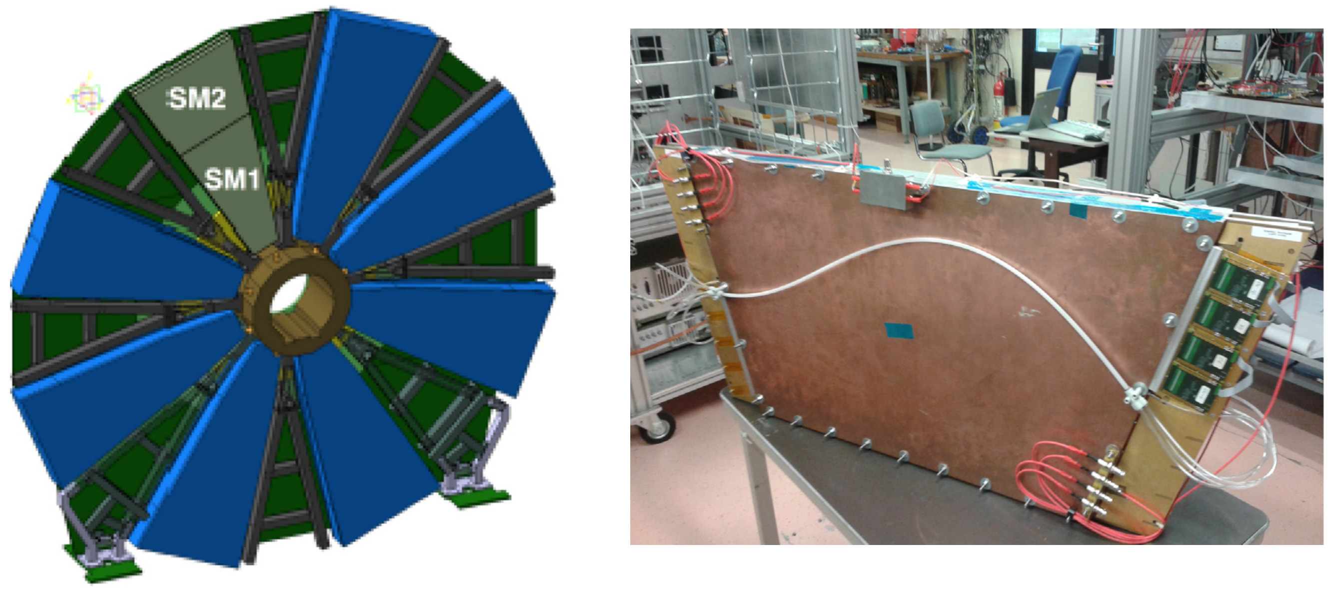


Adoption of MPGD technologies:

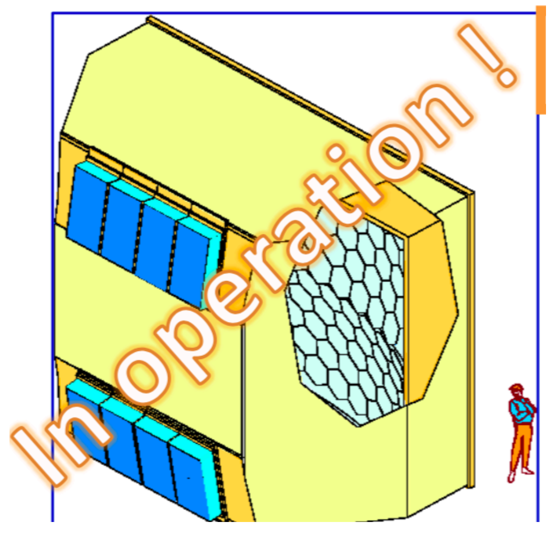
ATLAS NSW (Micromegas)
CMS forward tracking update (GEM)
COMPASS RICH upgrade (hybrid MPGD)
ALICE TPC upgrade (GEM)
KLOE2 & BESIII (GEM)
LBNO-DEMO (THGEM)
n-detection at ESS (GEM)
Muon radiography (Micromegas)
…


Alice GEM TPC

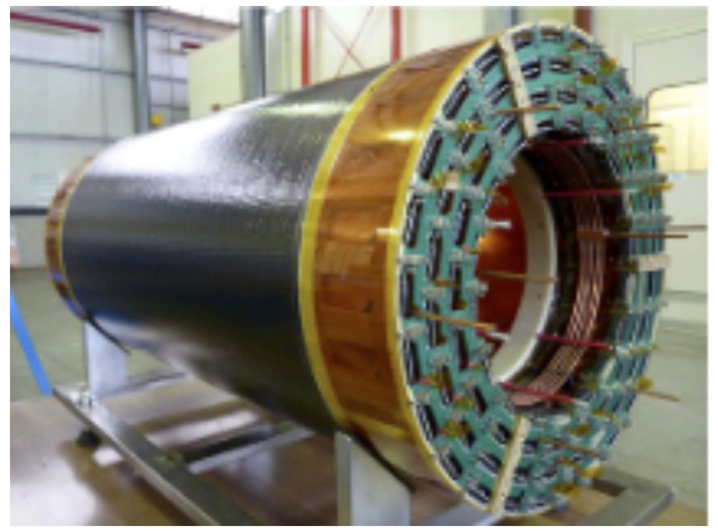

CMS Muon GEM upgrade



ATLAS NSW Micromegas upgrade



COMPASS RICH


KLOE-2 GEM tracker


Muography with Micromegas

RD51 collaboration

Development of Micro-Pattern Gas Detectors Technologies

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

Development

Exploit existing technologies
Large size single-mask GEMs
Resistive Micromegas

Develop novel technologies
µPIC, µR-WELL, GRIDPIX

Dissemination

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

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

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

Production techniques and industrialisation

Common infrastructures
(GDD lab, common test beam)

Electronics
(Scalable Readout System SRS, instrumentation)

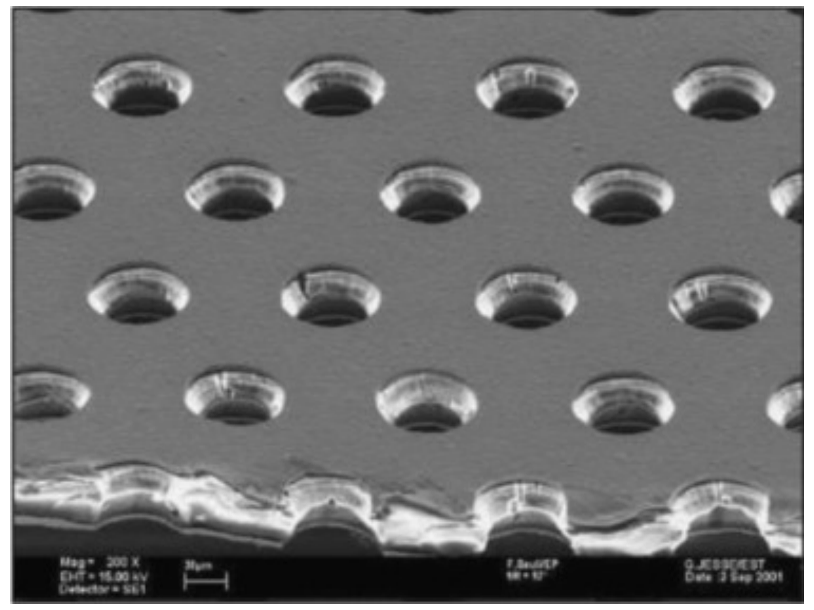
Simulation
(Garfield, Magboltz, Degrad, neBEM)

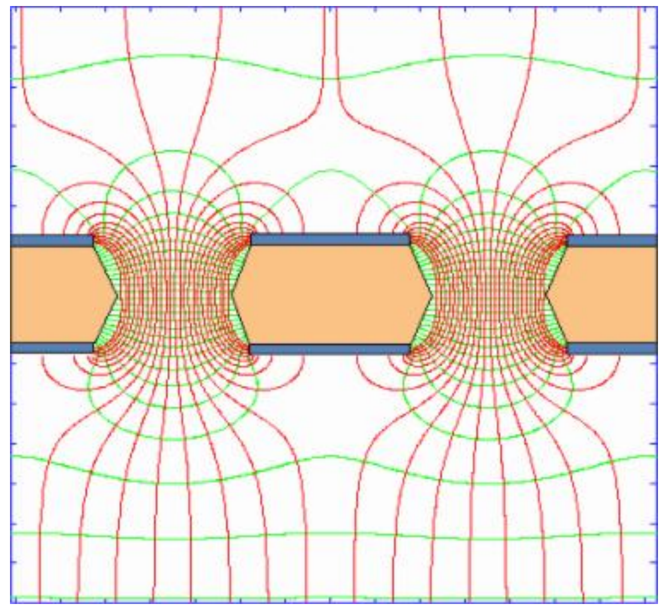
rd51-public.web.cern.ch

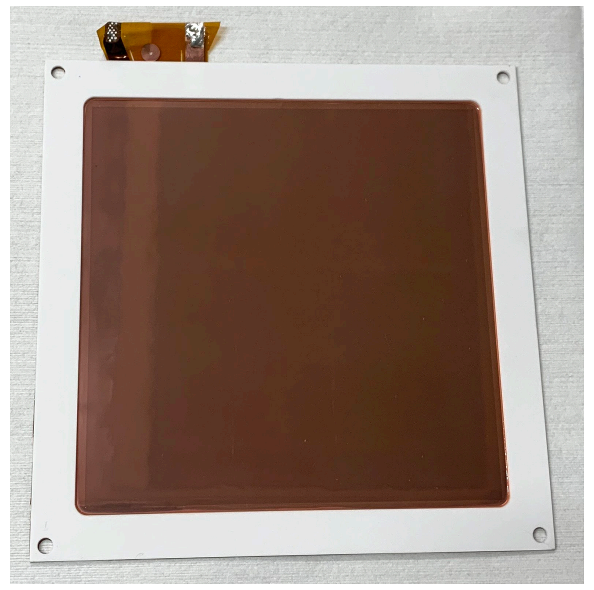
MPGD technologies and R&D

State-of-the-art MPGD technologies

Gaseous Electron Multipliers





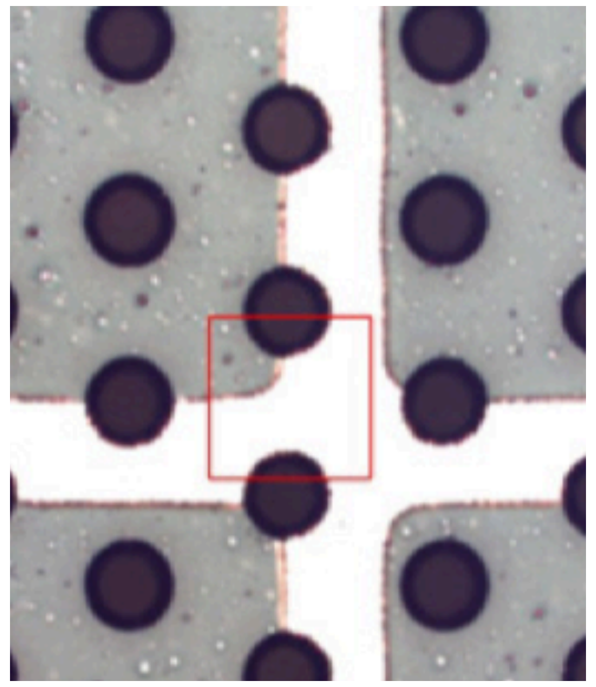


Fine-pitch holes in **conductor-insulator-conductor** structures
E.g. 70μm diameter holes at 140μm pitch in 50μm thick polyimide with Cu electrode on both sides

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

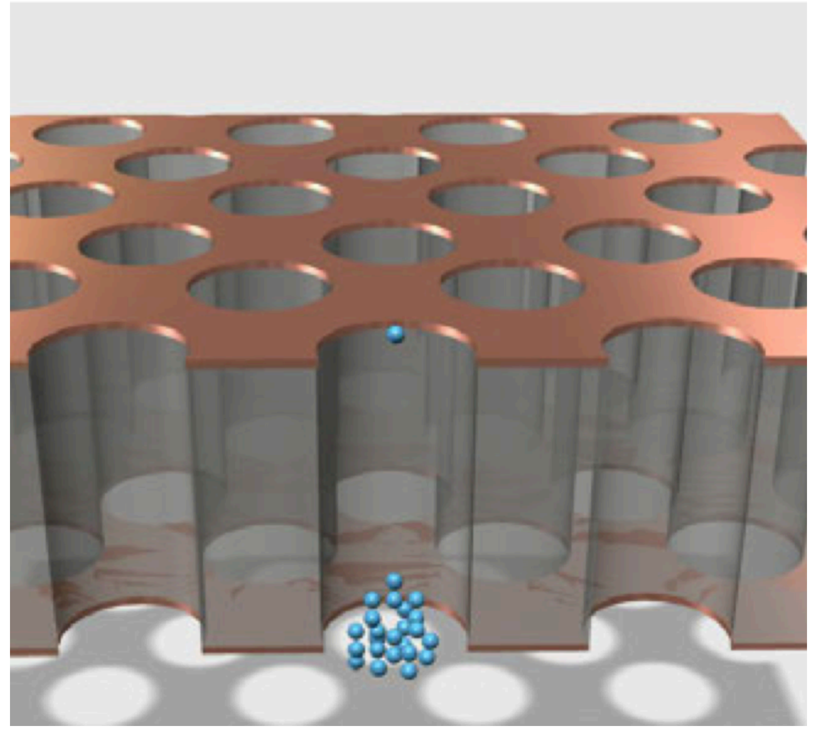
Varying geometries and materials for specific experimental requirements

Cr GEM



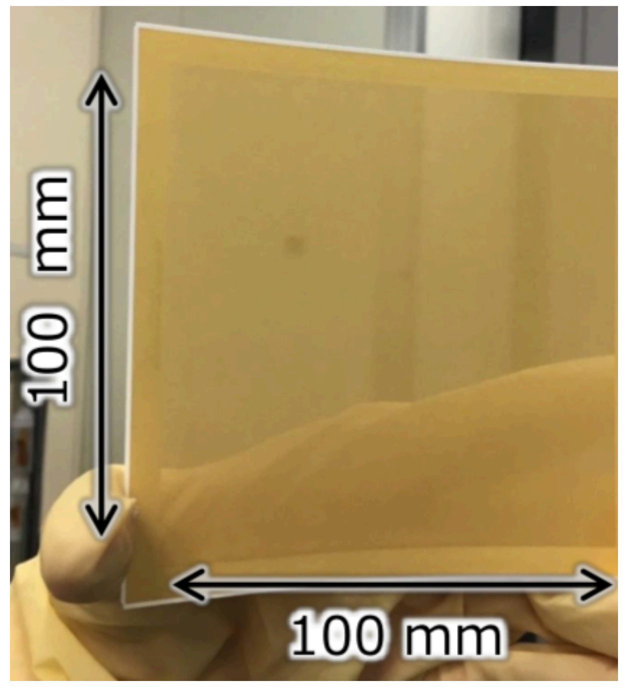
W. Dąbrowski et al 2016 JINST 11 C12025 doi: 10.1088/1748-0221/11/12/C12025

Glass GEM



T. Fujiwara, MPGD2017

LTCC GEM



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

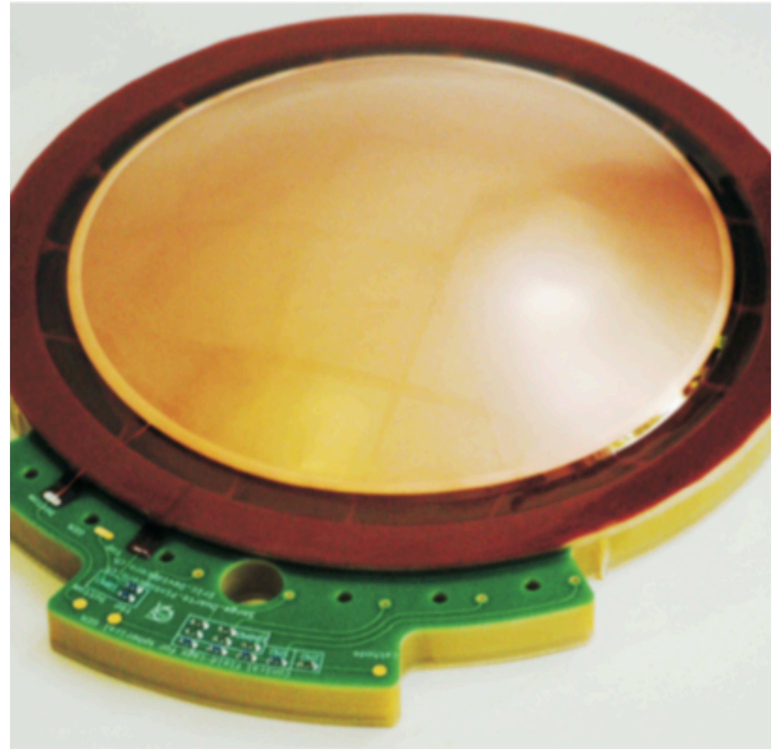
DLC GEM

M. Lisowska, RD51 CM May 2019

GEM tracker

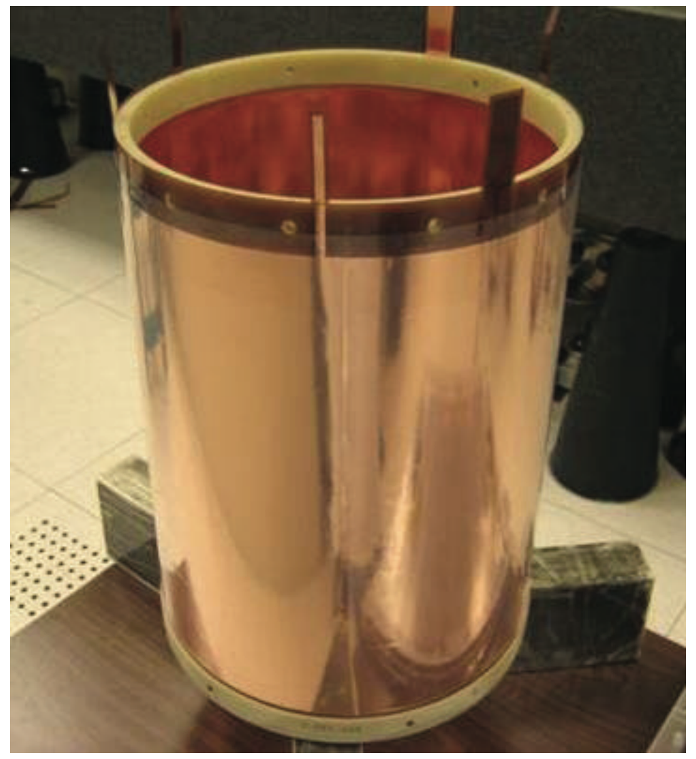
C. Altumbas et al, Nucl. Instr. and Meth. A490(2002)177

Spherical GEM



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

Cylindrical GEM

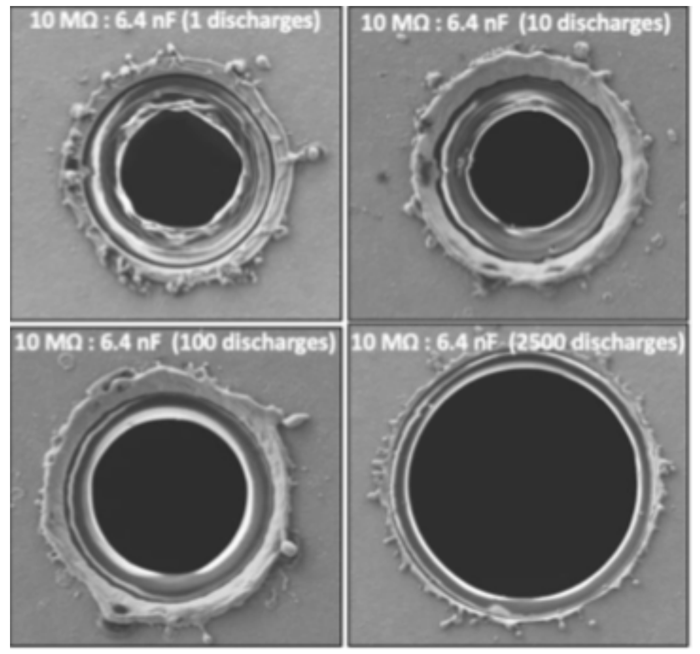


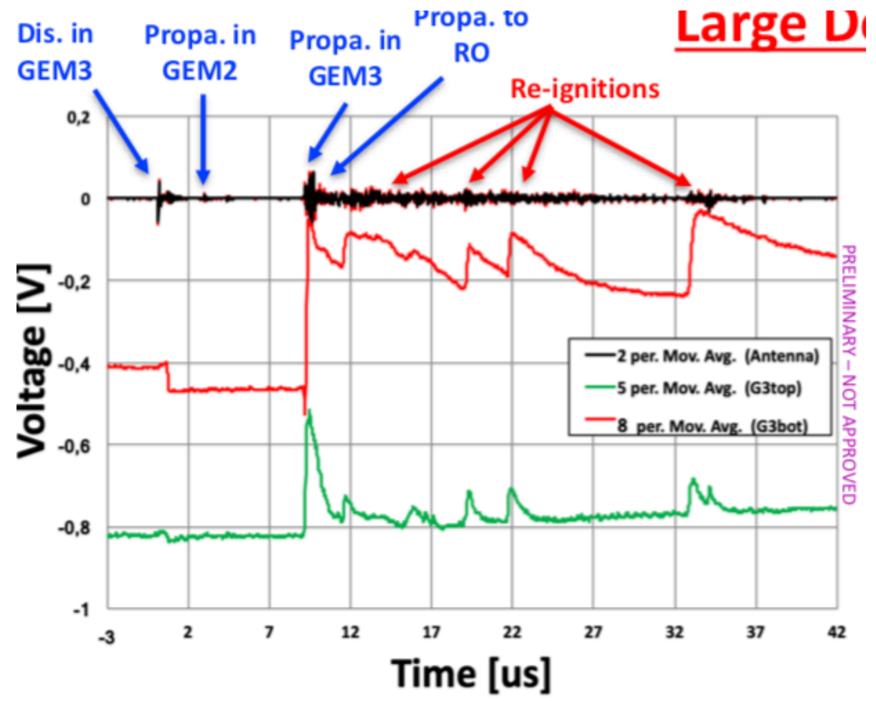
A. Balla et al., Physics Procedia 37 (2012) 522 – 529

Gaseous Electron Multipliers

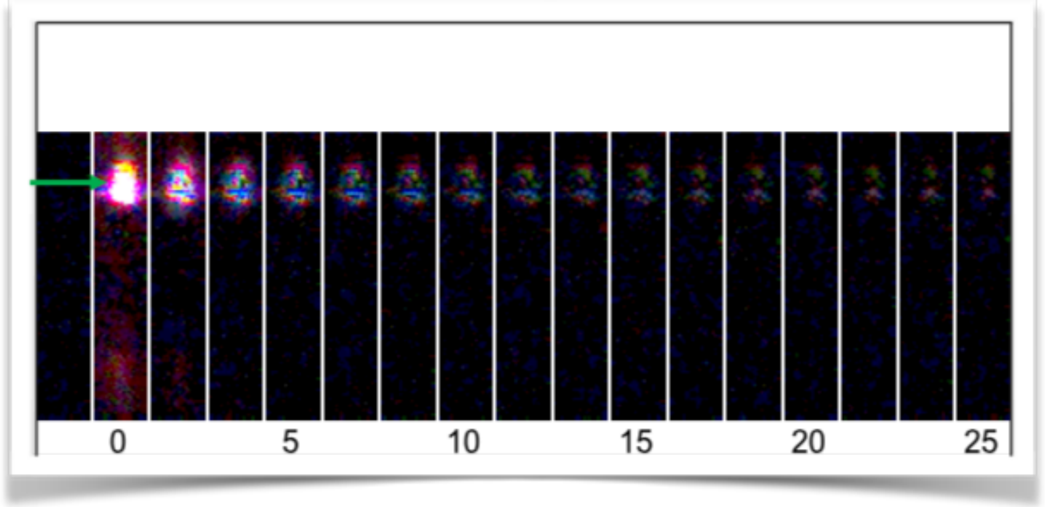
Discharge studies and mitigation

Understanding discharge formation and propagation and suppressing damaging processes





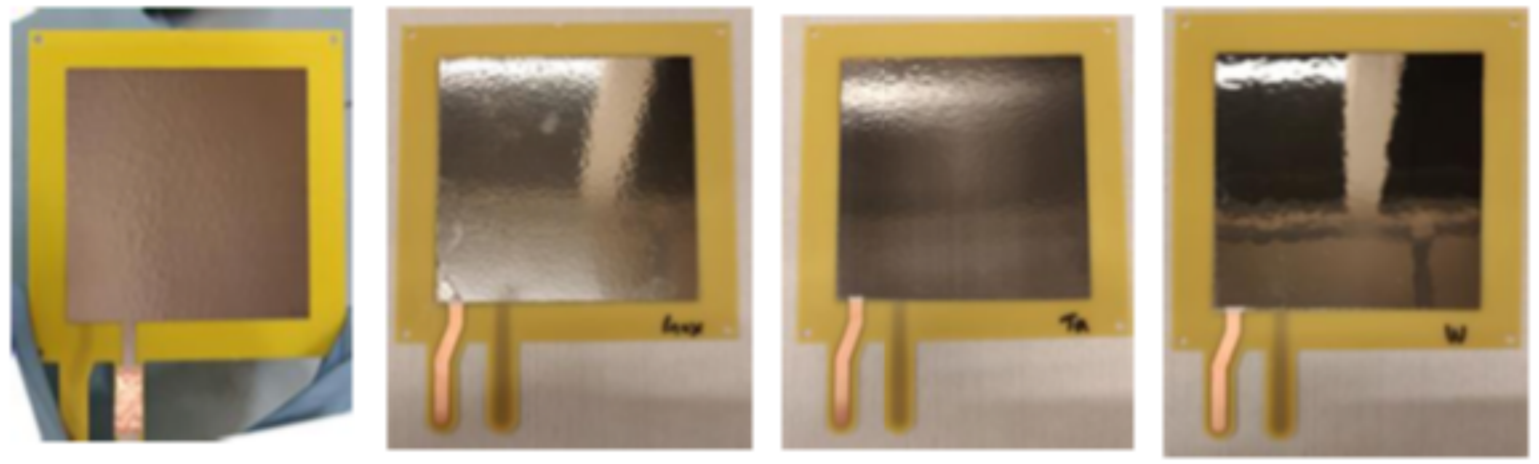
J. Merlin, IEEE-NSS, Sydney, 2018 & MPGD 2019



Antonija Utrobičić et al. MPGD 2019

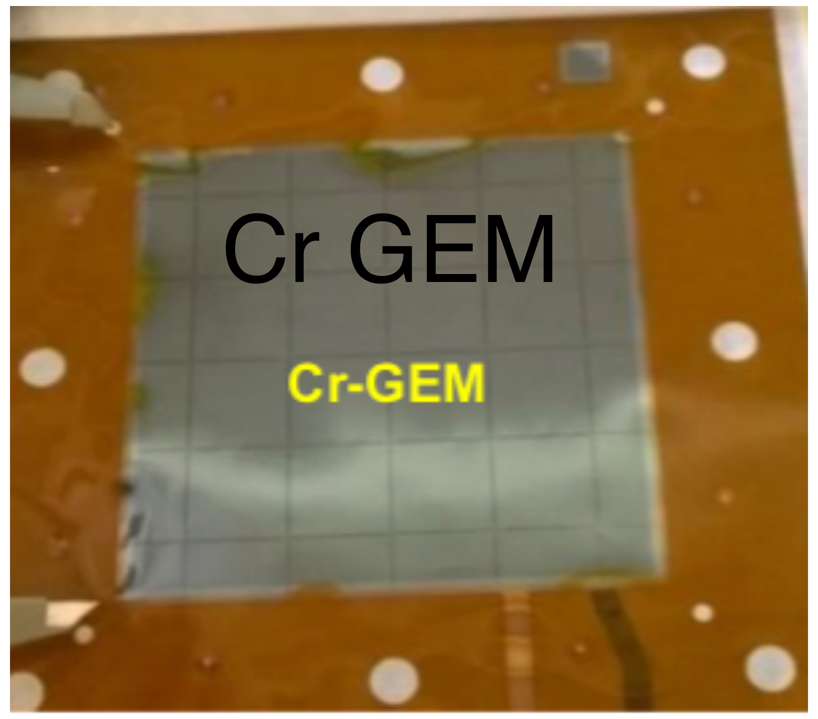
Alternative electrode materials

Lower material budget or increased spark resistance.



Mo THGEM Inox THGEM Ta THGEM W THGEM

Berkin Ulukutlu et al. RD51 CM 2020



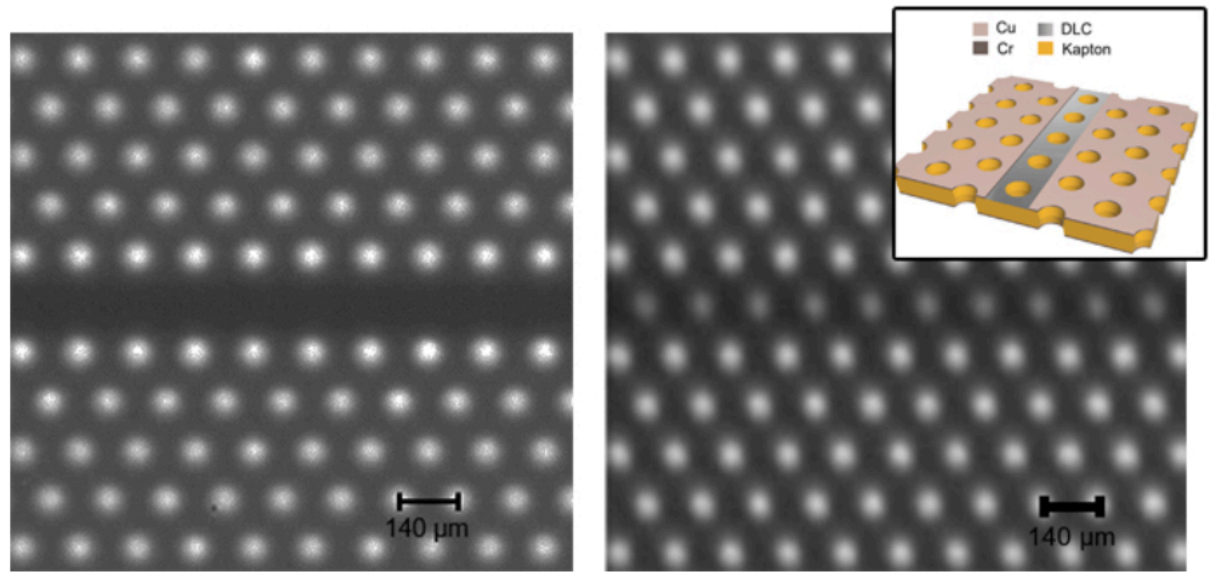
Kondo Gnanvo, RD51 Mini Week 2017

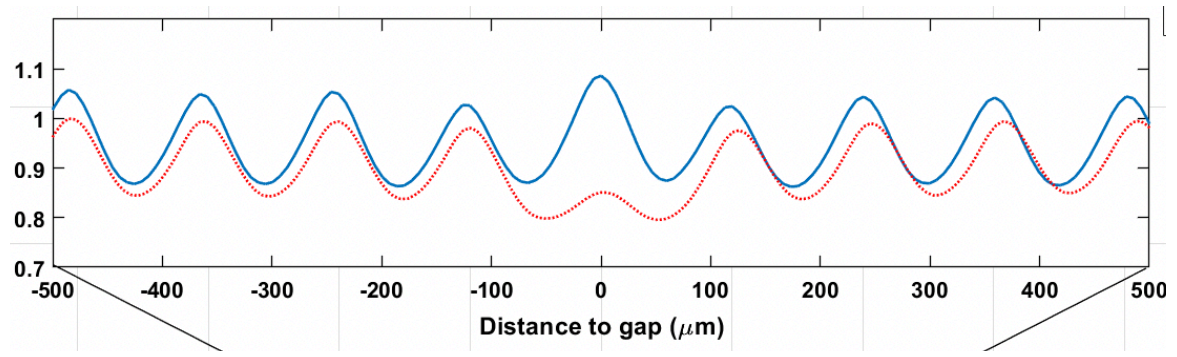
M. Lisowska, RD51 CM May 2019

Minimising distortions with DLC-based segmentation

Electrode segmentation limits capacitance for spark protection

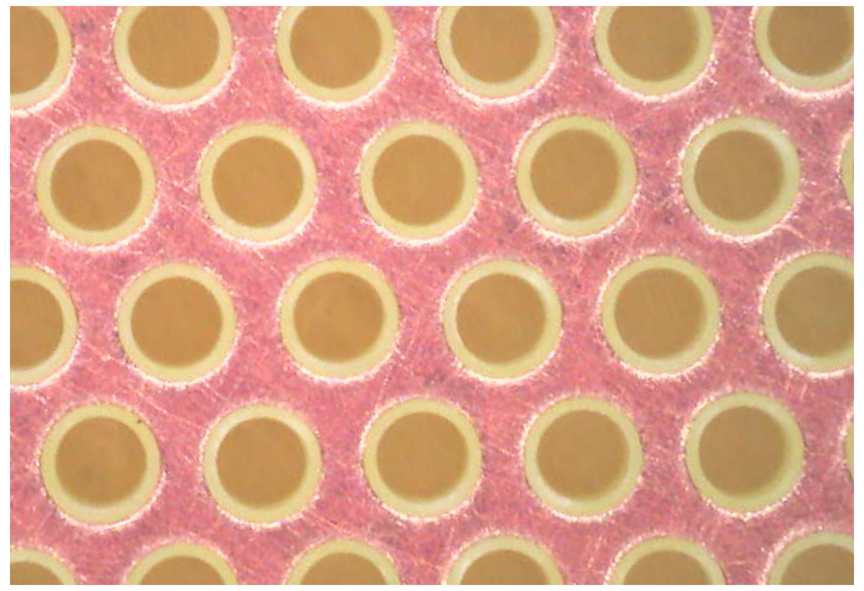
Holes in sector gaps can be used to minimise distortions

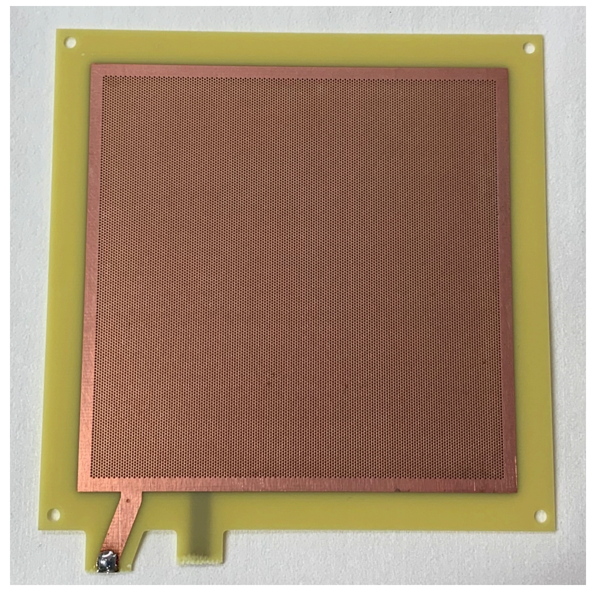




A.P. Marques et al. Minimizing distortions with sectored GEM electrodes, NIM A, 2020

THGEM



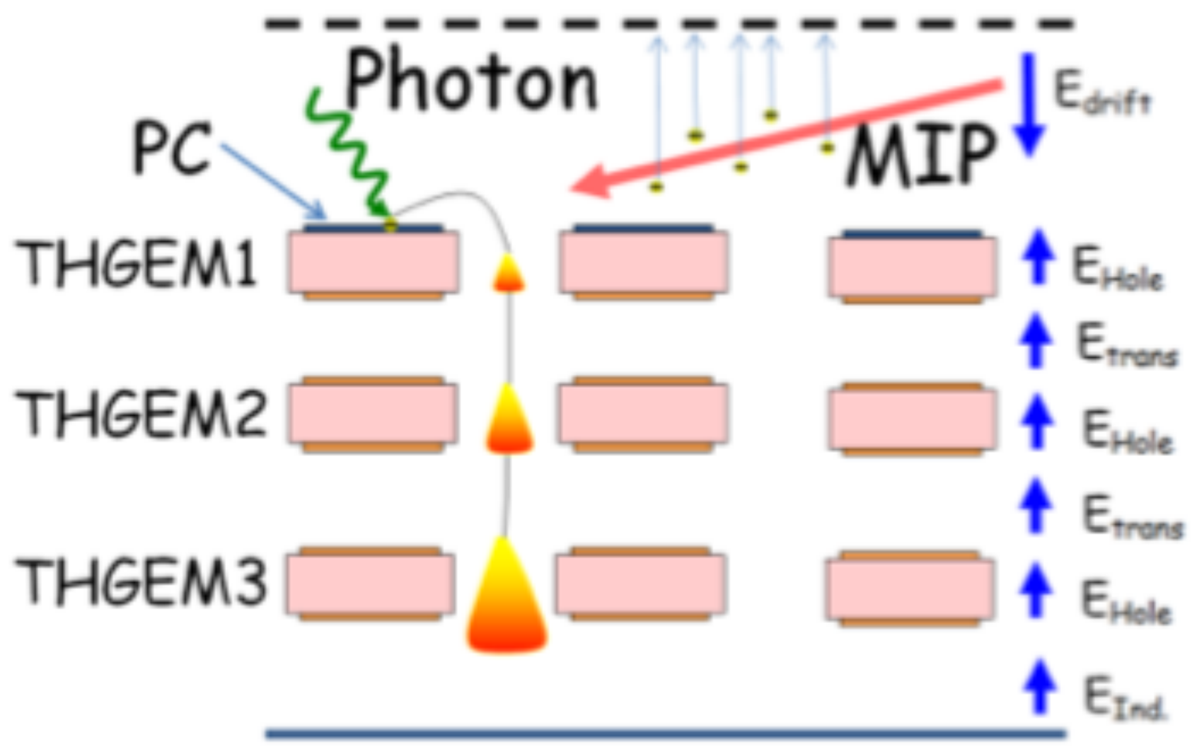


Mechanically drilled Cu-FR4-Cu structures with thickness ranging from hundreds of μm to millimetres

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

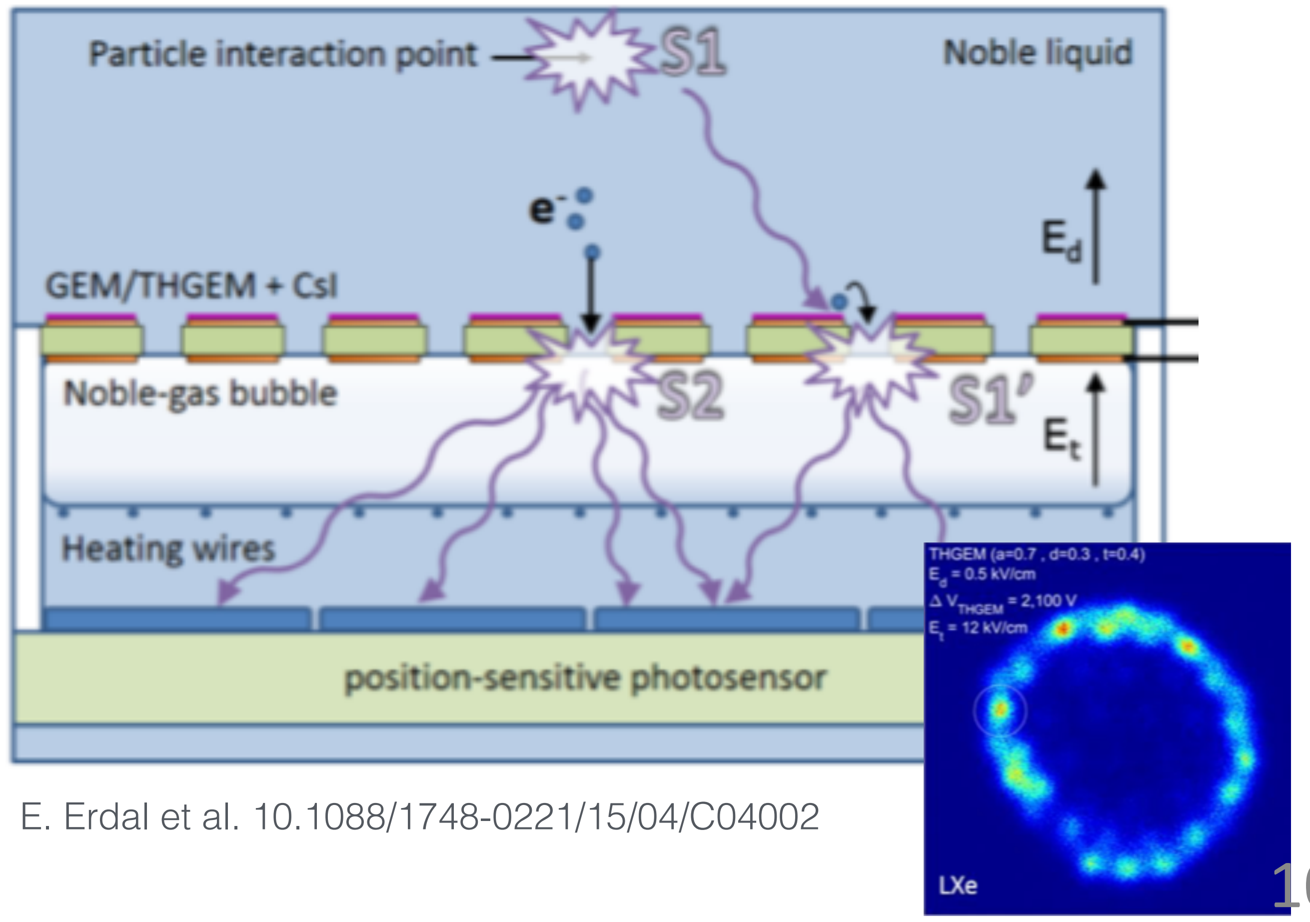
Long-amplification paths advantageous for low pressure operation

CsI-coated THGEM



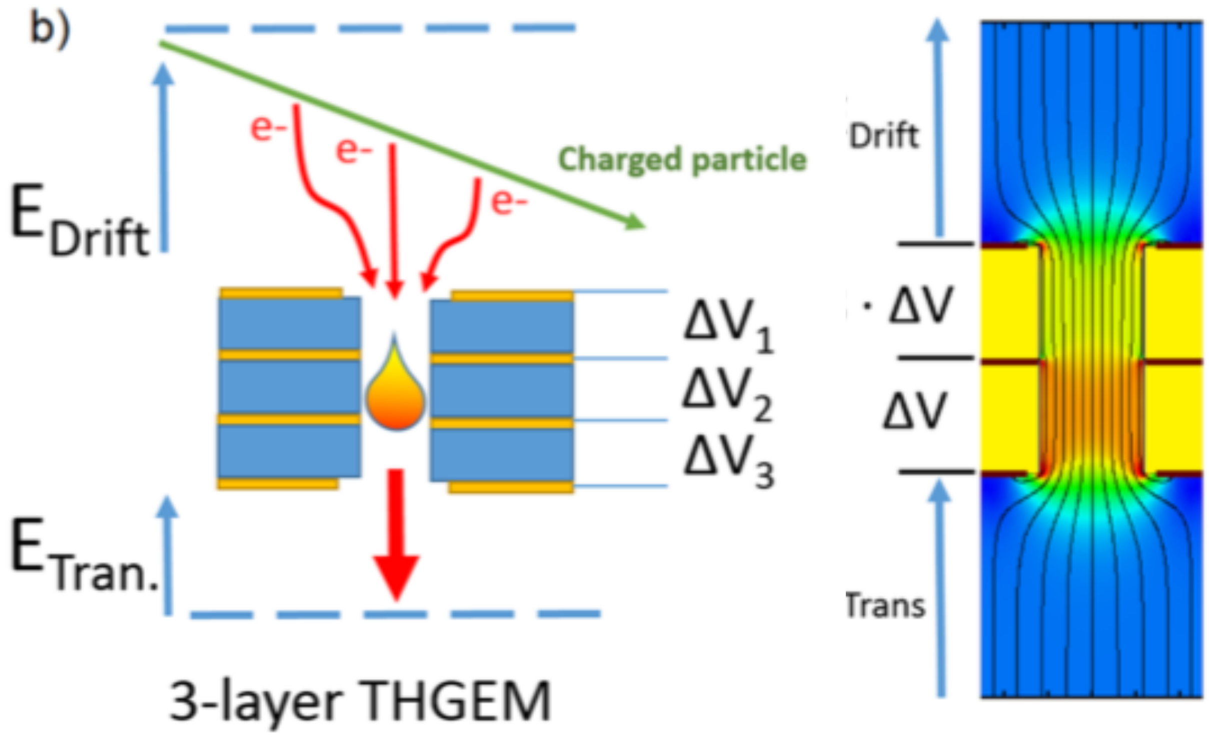
A. Breskin et al. 10.1016/j.nima.2010.10.034

Bubble-assisted Liquid Hole Multiplier



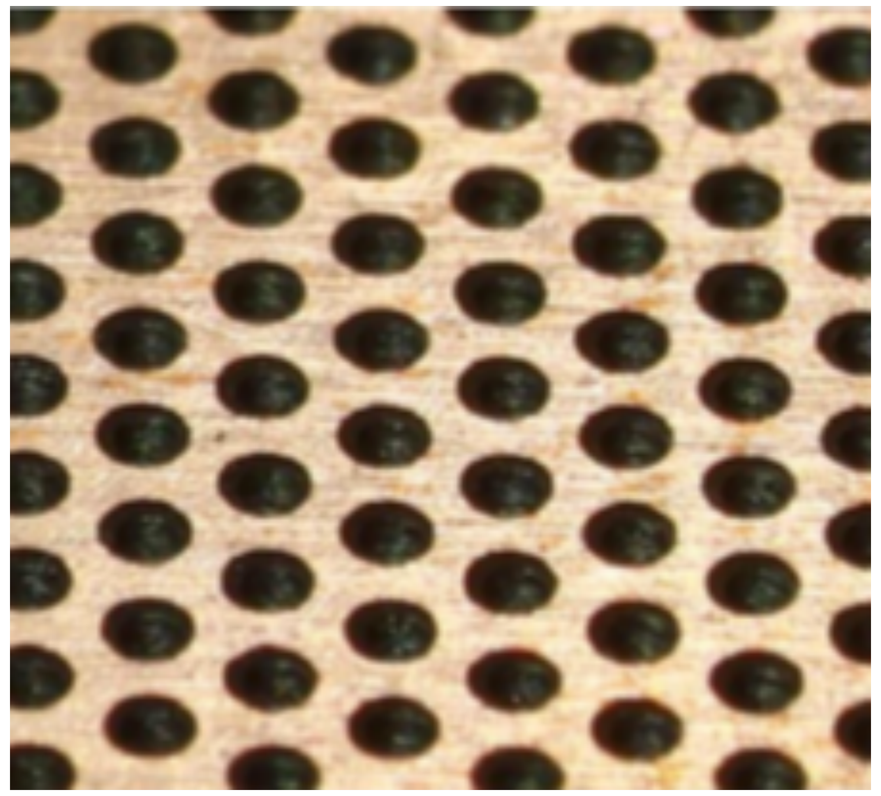
E. Erdal et al. 10.1088/1748-0221/15/04/C04002

Multi-layer THGEM



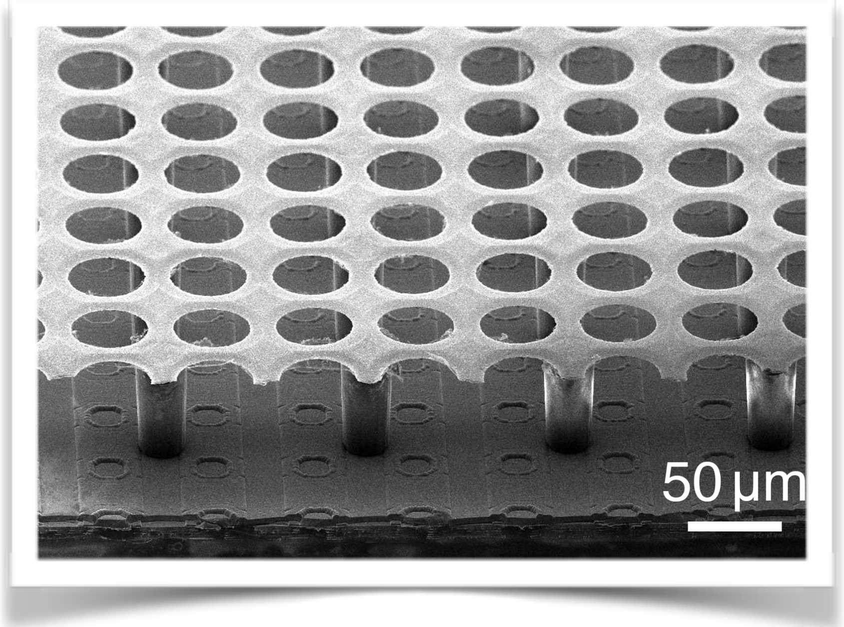
M. Cortesi et al. Rev. Sci. Instrum. 88, 013303 (2017); https://doi.org/10.1063/1.4974333

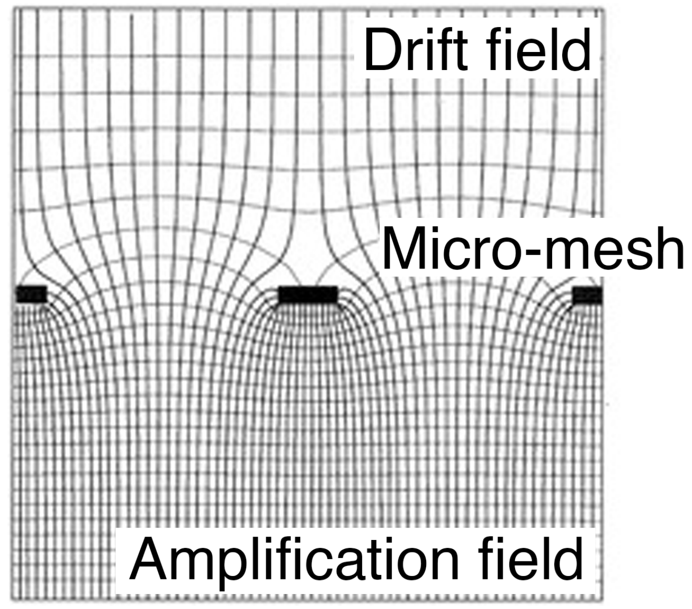
DLC-coated THGEM



Guofeng Song et al. /10.1016/j.nima.2020.163868

Micromegas



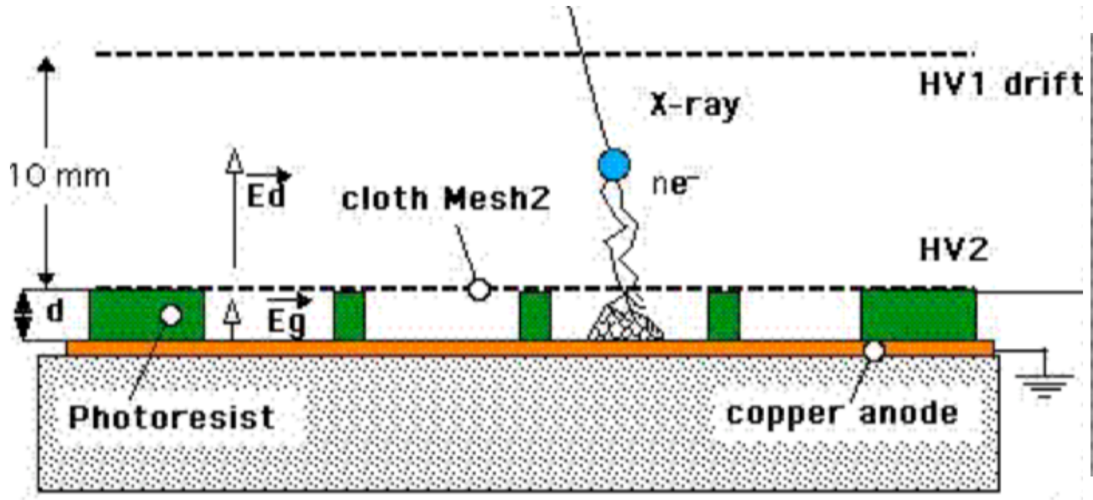


InGrid Micromegas

Micro-mesh suspended by pillars above anode.
Single-stage amplification with high gain and energy resolution realised in bulk or microbulk varieties.

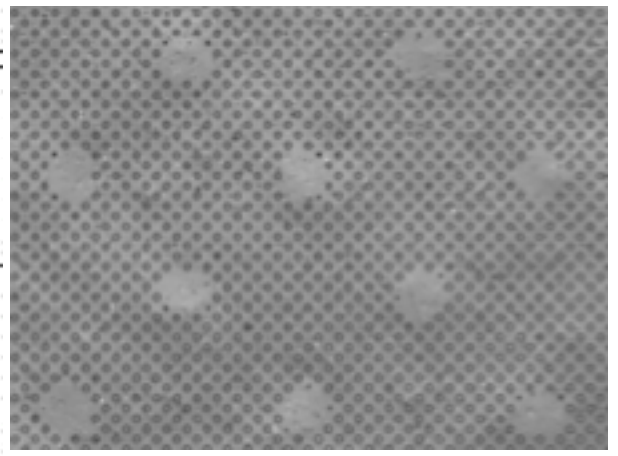
Resistive anode for spark protection and signal spreading

Bulk Micromegas



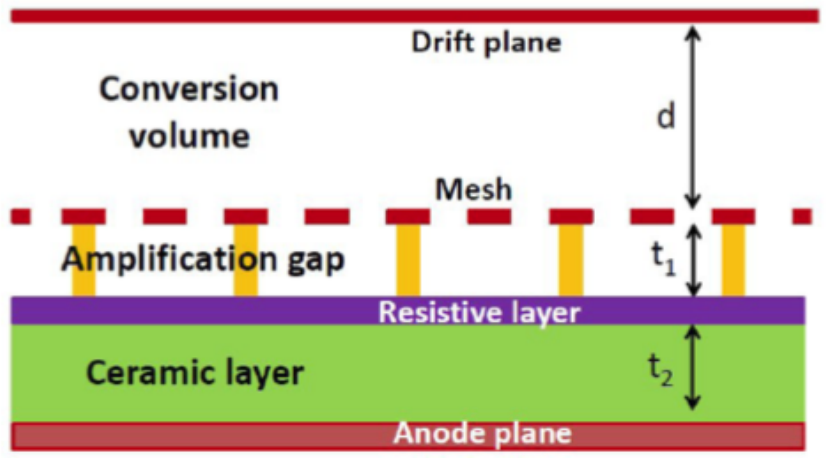
I. Giomataris et al. https://doi.org/10.1016/j.nima.2005.12.222

Microbulk MM



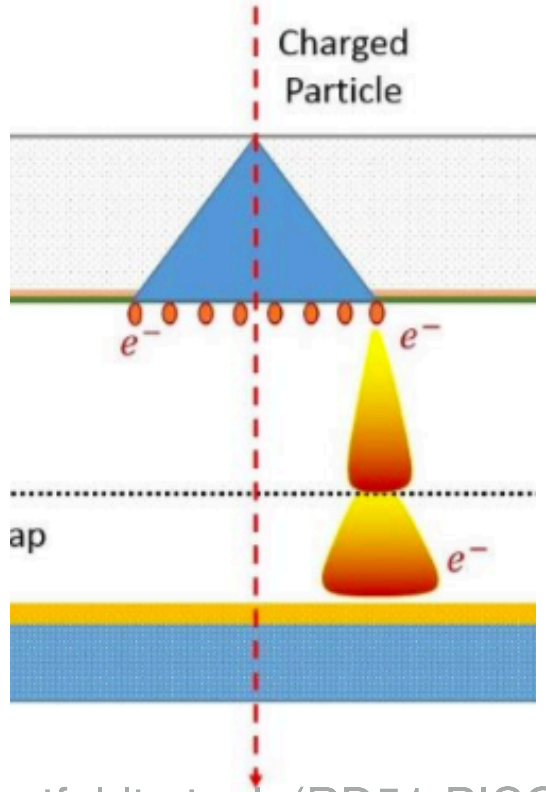
S Andriamonje et al 2010 JINST 5 P02001

Piggyback resistive Micromegas



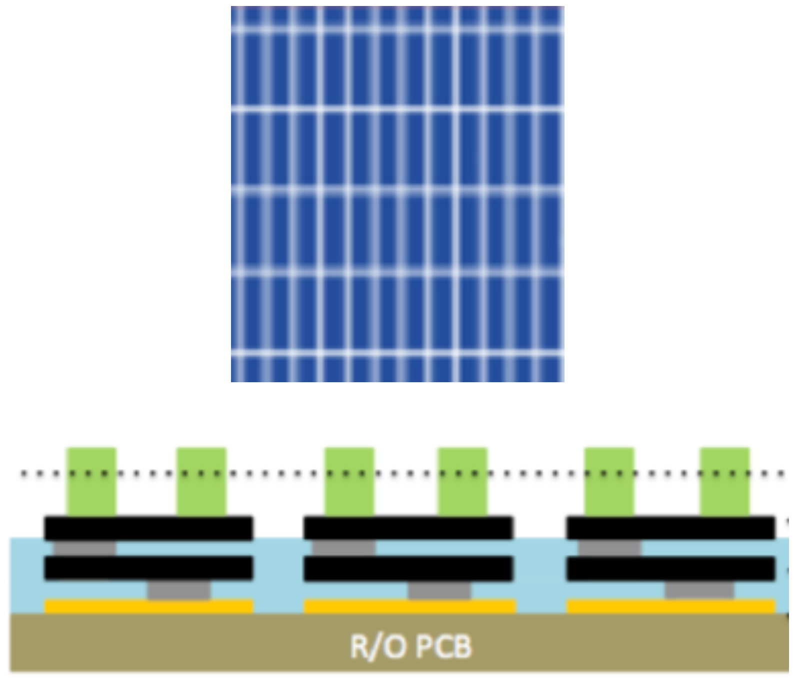
D. Attié et al. 10.1088/1748-0221/8/05/P05019,

Precise-timing Micromegas



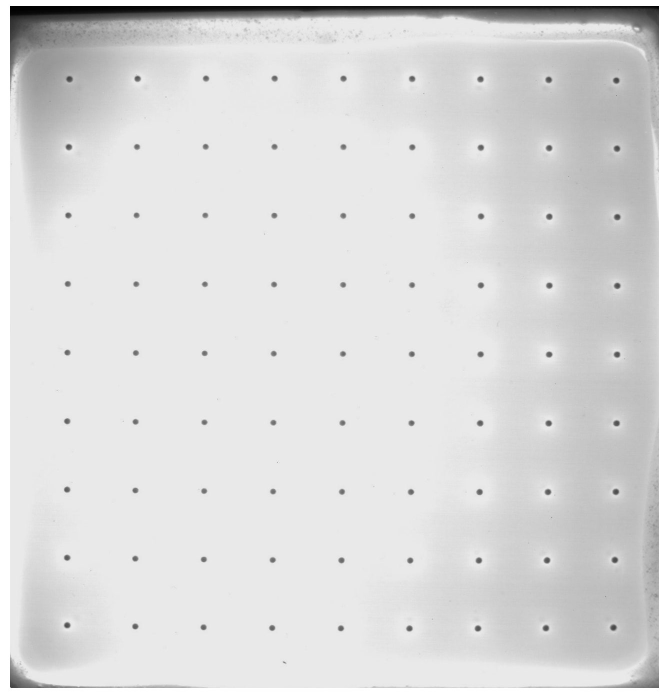
J. Bortfeldt et. al. (RD51-PICOSEC collaboration), Nuclear. Inst. & Methods A 903 (2018) 317-325

Small Pad Micromegas



Mauro Iodice et al. MPGD 2019

Glass Micromegas



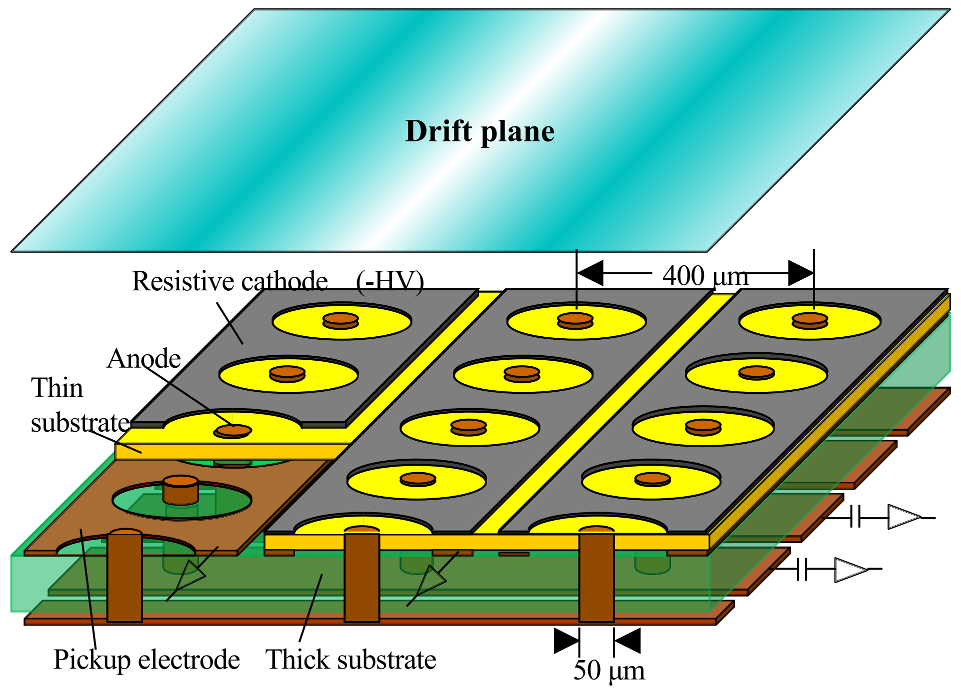
F. Brunbauer et al. https://doi.org/10.1016/j.nima.2019.163320

μPIC & well-type MPGDs

Single-stage amplification devices with resistive anodes for spark protection

Micro Pixel Chamber *μ*PIC

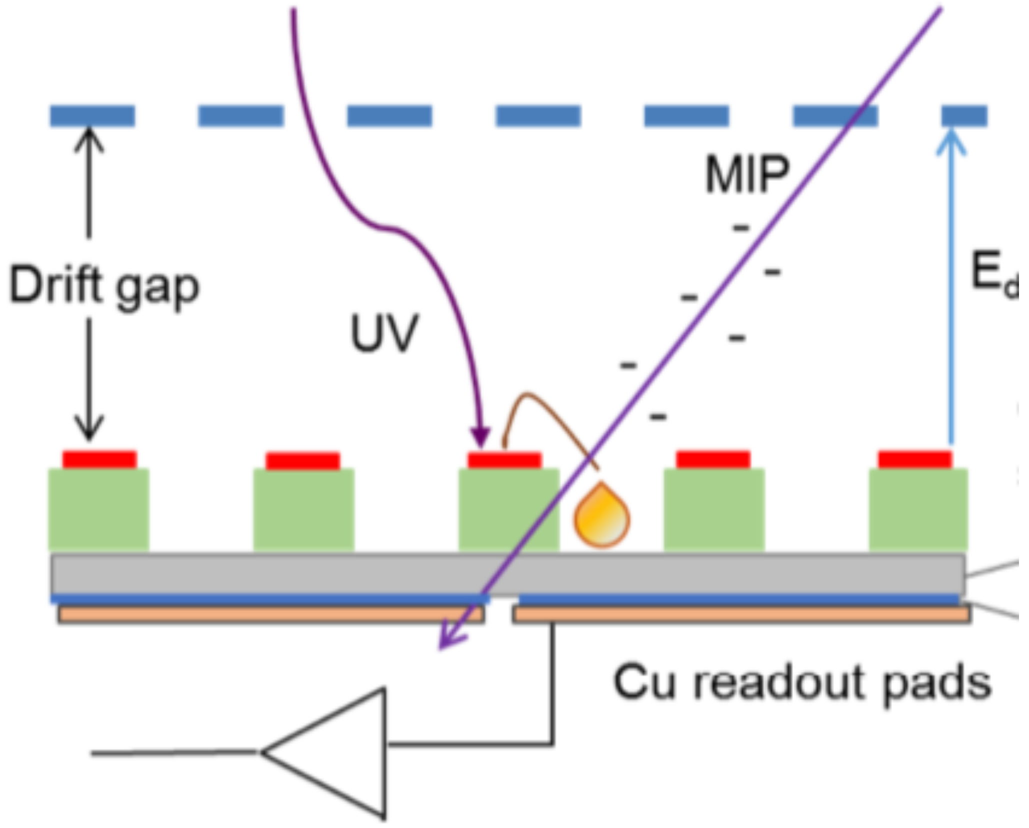
Pixellated anode structure for robustness, capable of high-rate operation and good spatial resolution



A. Ochi, RCGD2019@Bari

RPWELL

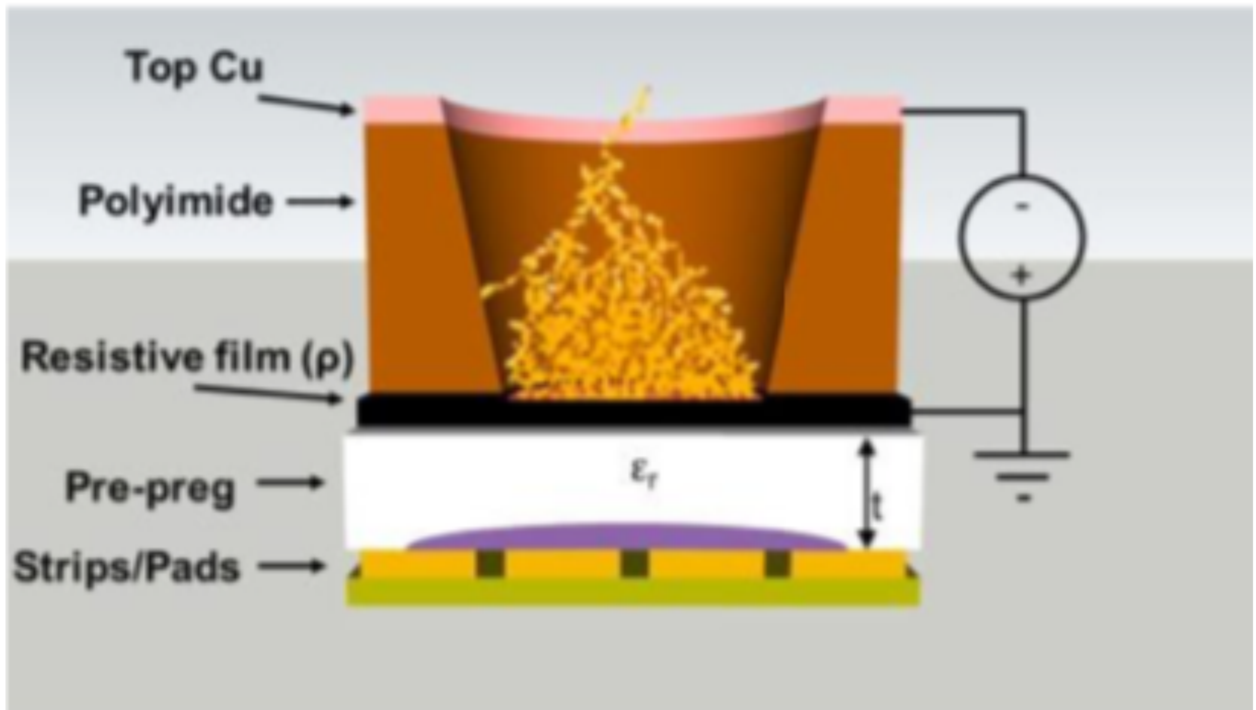
Single-sided Thick Gaseous Electron Multiplier coupled to resistive anode

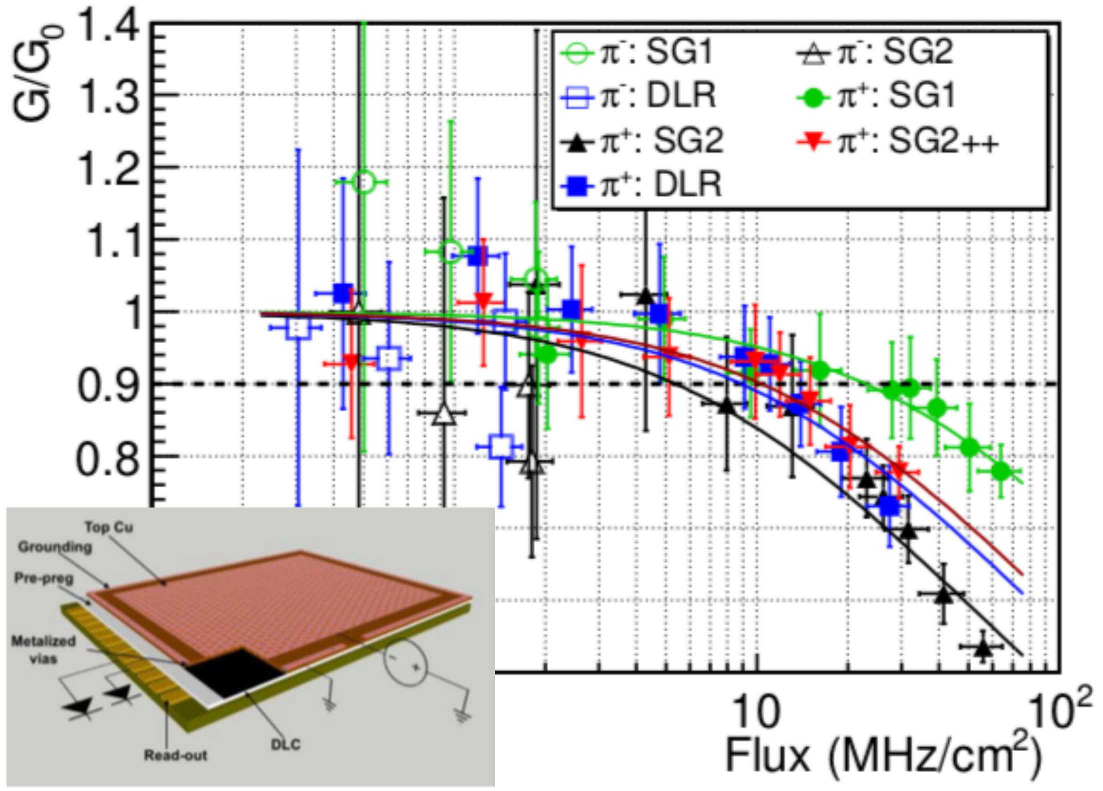


A. Roy et al 2019 JINST 14 P10014

*μ*RWELL

DLC based resistive layers with charge evacuation schemes compatible with high-rate operation



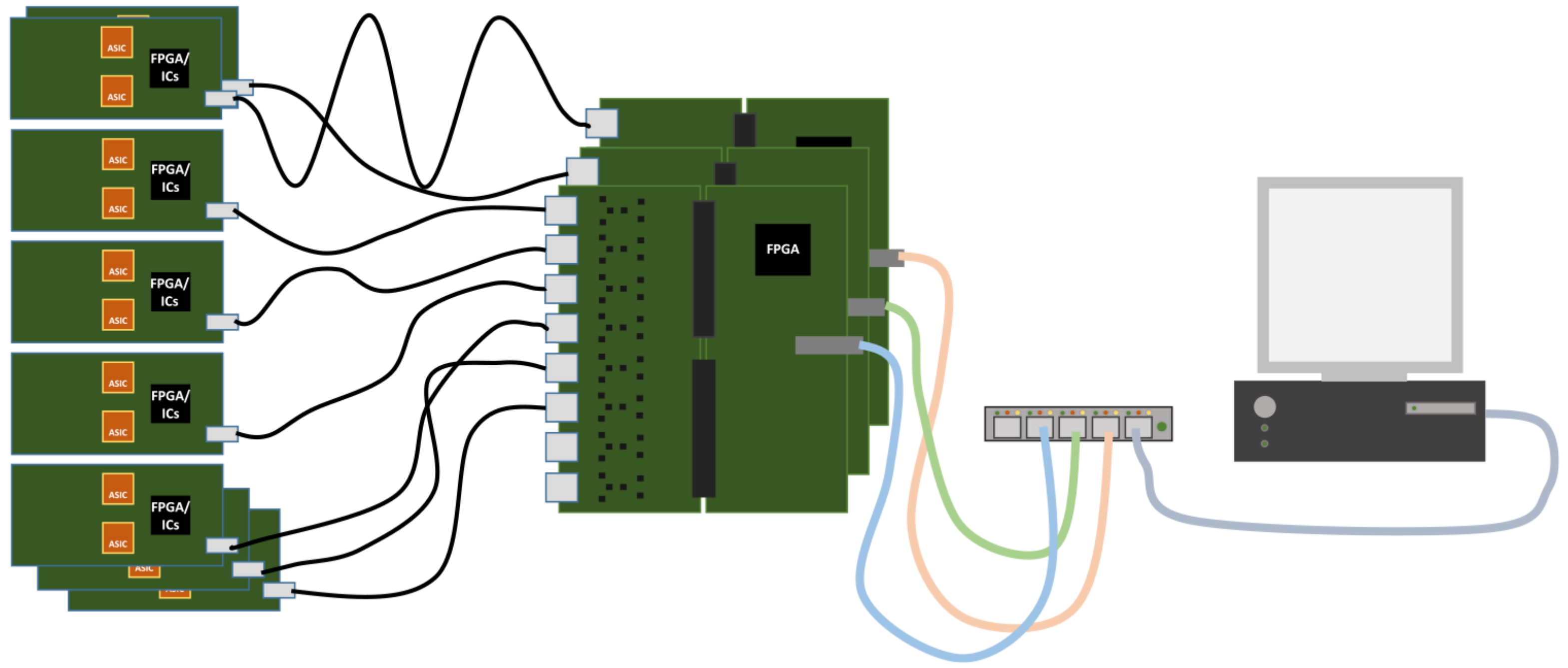


G. Bencivenni et al 2019 JINST 14 P05014

Readout of MPGDs

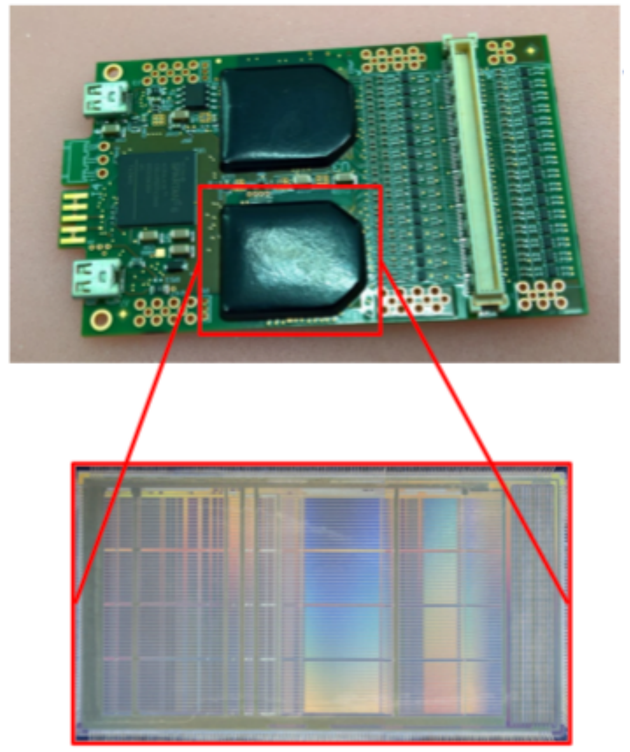
Electronic readout

RD51 Scalable Readout System (SRS) with different front-end chips for small prototypes to operational experiments.



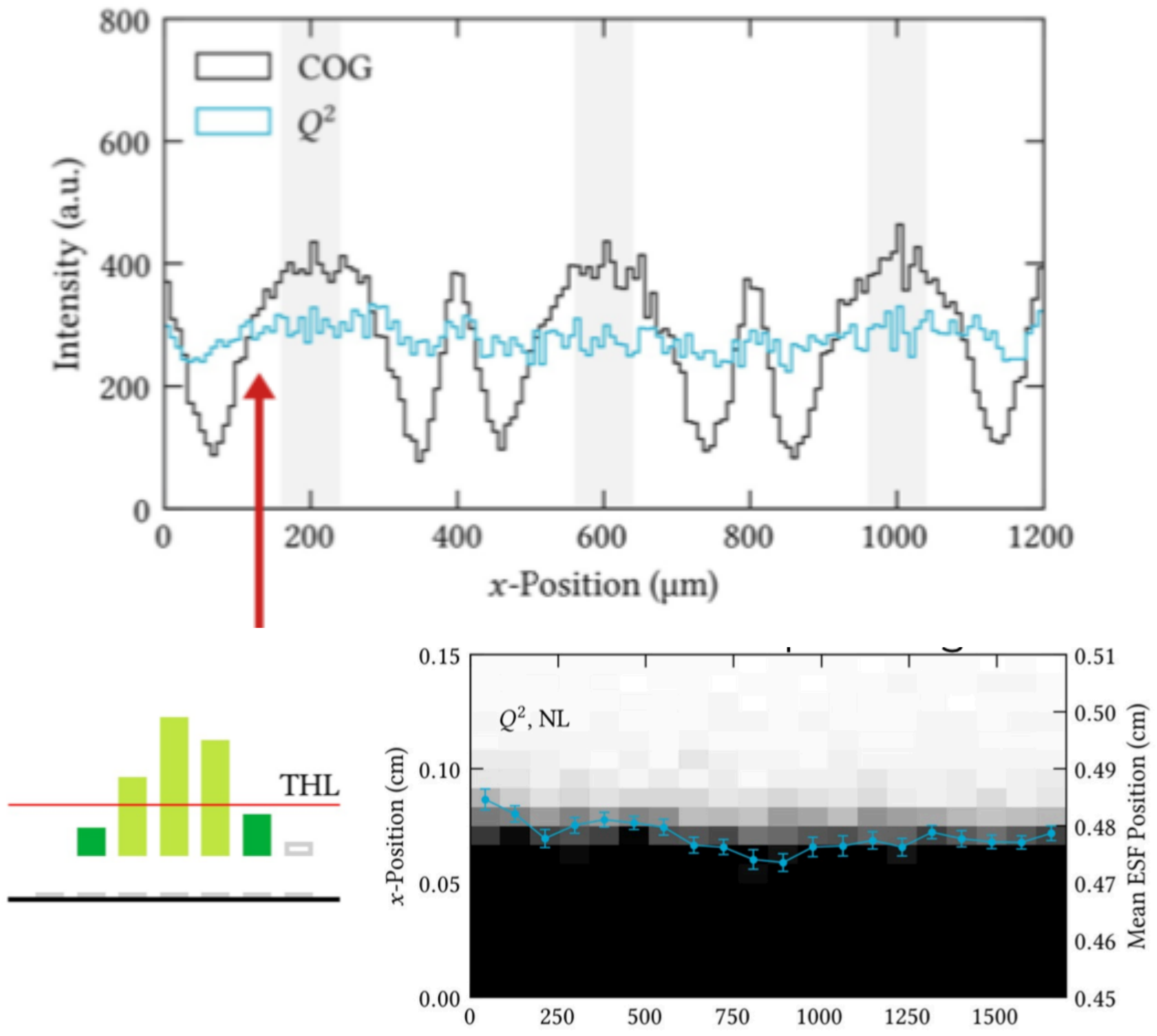
https://doi.org/10.1016/j.nima.2018.06.046

H. Müller, Development of multi-channel readout system optimised for gaseous detectors
https://indico.desy.de/indico/event/7435/material/1/4.pdf



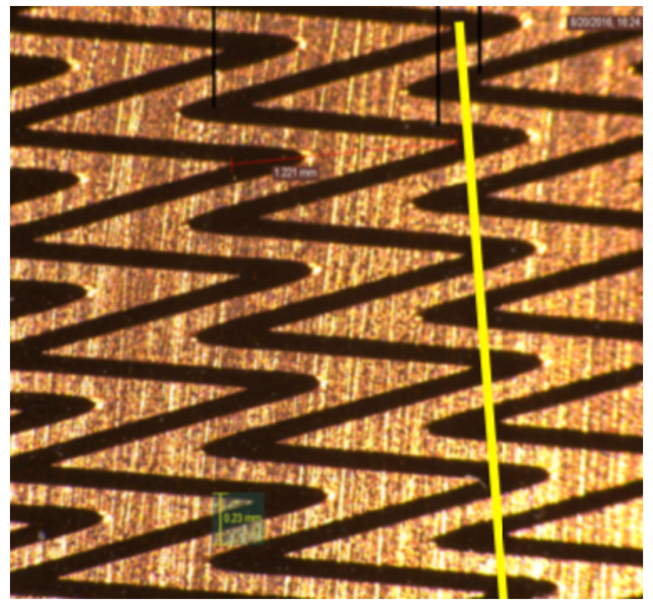
Different front end ASICs for varying experimental needs: APV25, VMM, Timepix, …

Decreasing readout modulation with **VMM3a** hardware features and Q^2-weighted reconstruction



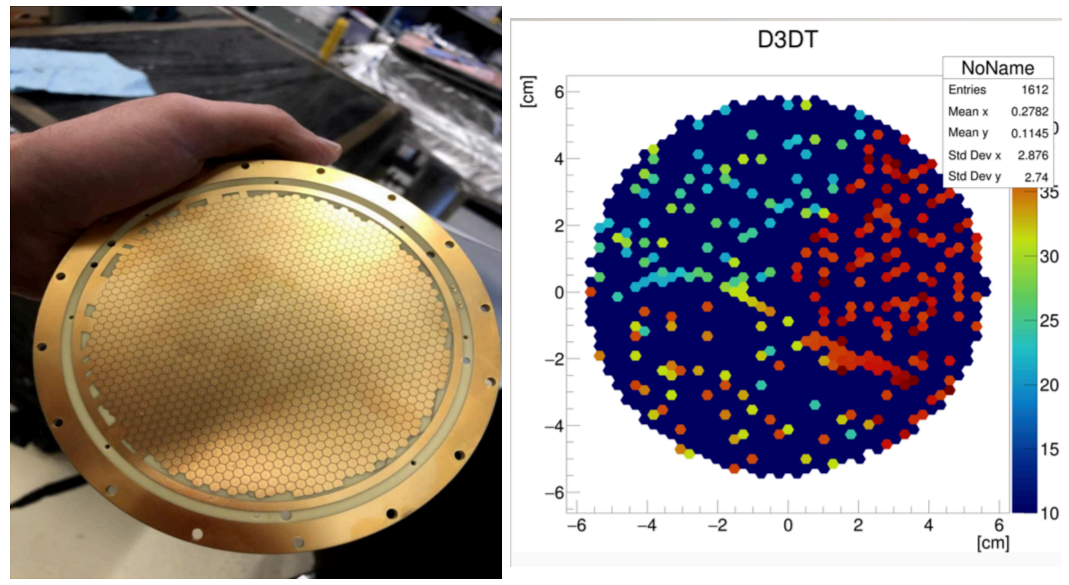
L. Scharenberg @ RD51 Collaboration Meeting 2020

Zigzag readout to minimise number of strips and maintain spatial resolution



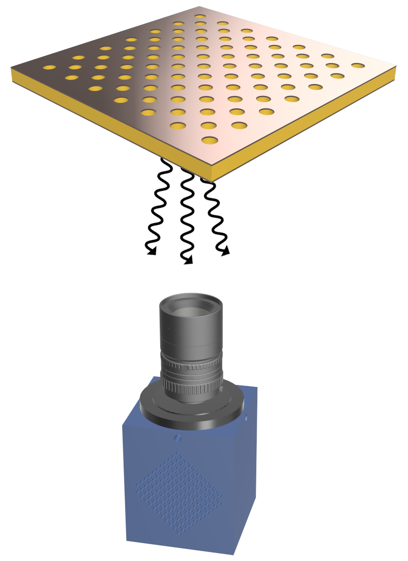
M. Hohlmann, et al. MPGD 2017

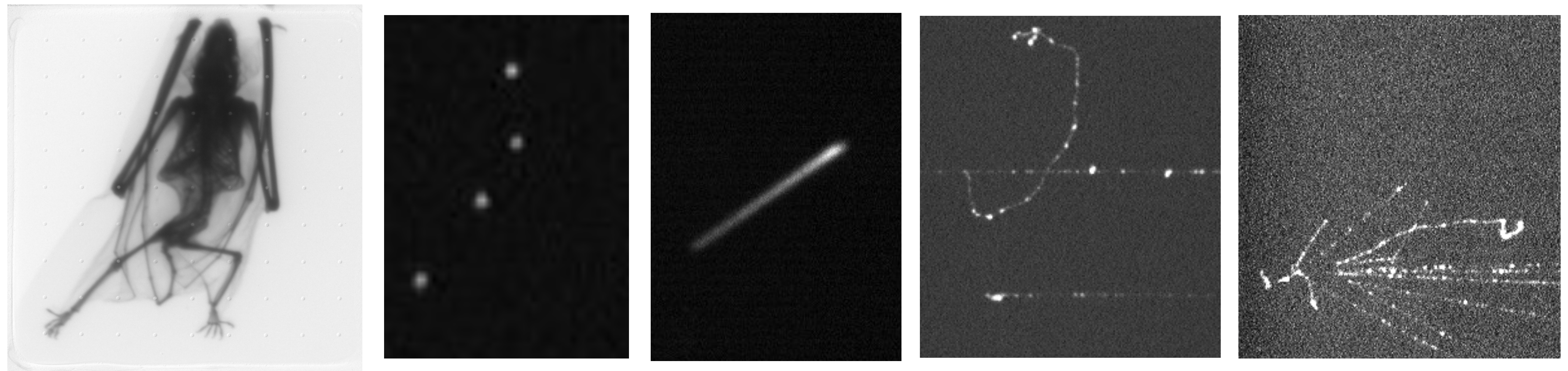
Multiplexed readouts for lower readout channel count



M. VANDENBROUCKE, TPC workshop, RD51 October 2020

Optical readout



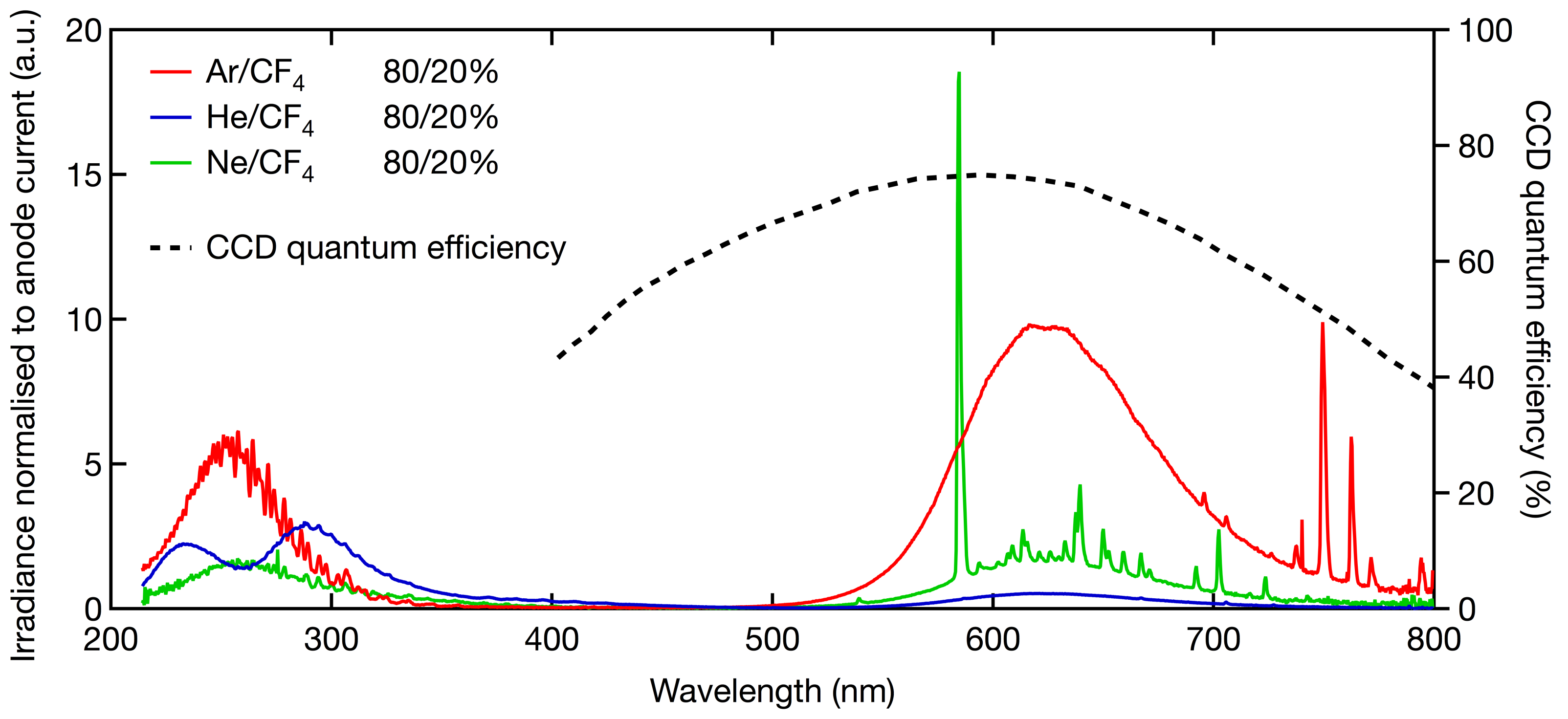


X-ray radiography | X-ray photons | Alpha track | Muon tracks with δ-ray | Hadronic shower

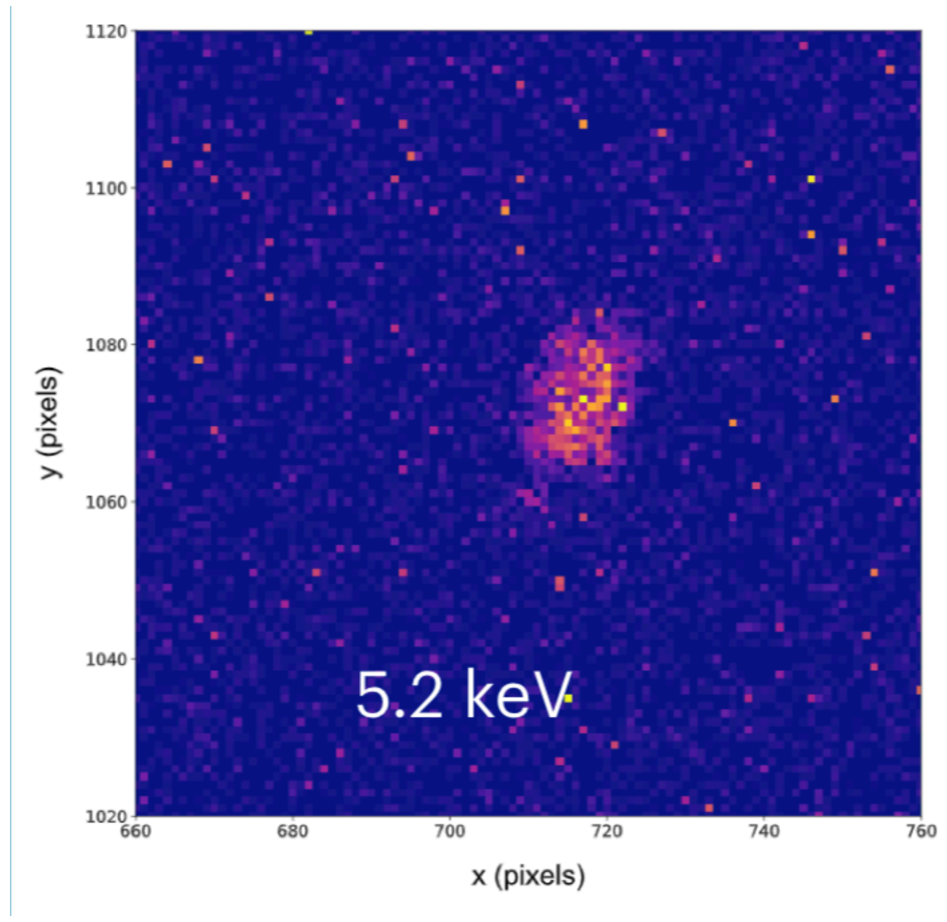
Readout of scintillation light emitted during avalanche multiplication by high granularity CCD or CMOS imaging sensors

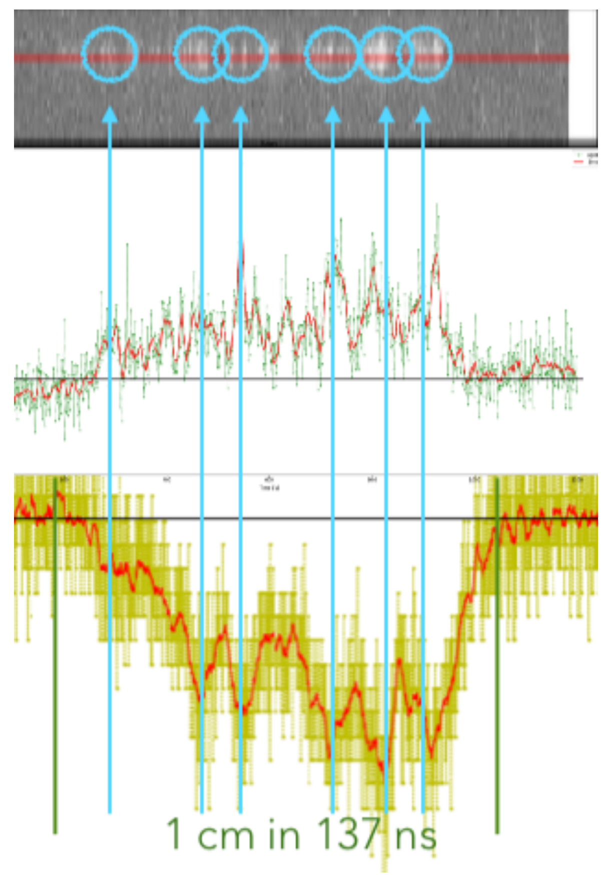
Requires gas mixtures with visible light emission (CF_4) or wavelength shifters

Used for high granularity track reconstruction for e.g. rare event searches



High-granularity track reconstruction

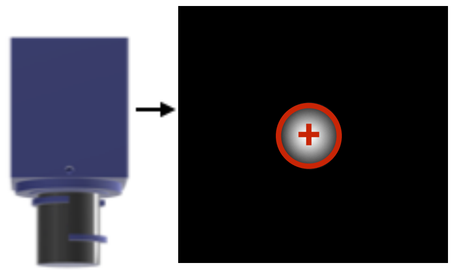


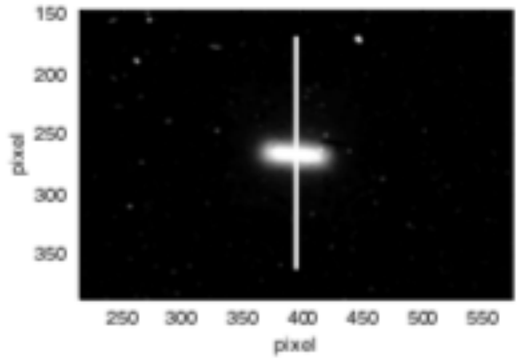


D. Pinci - INFN Roma - RD51 Coll. Meeting June 2020 & MiniWeek 2019

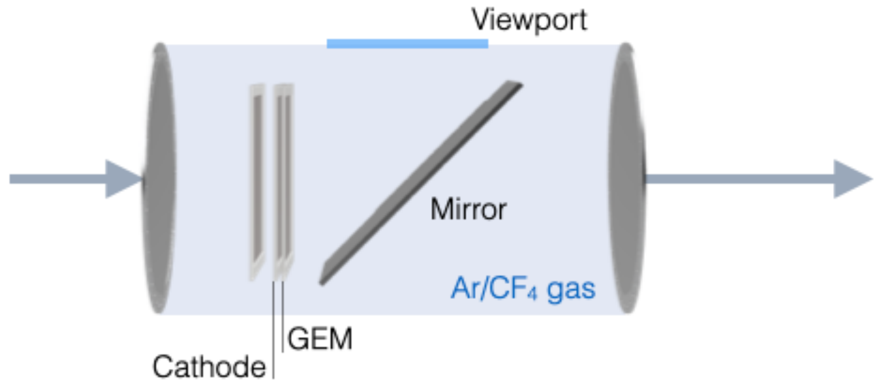
Beam monitoring

Proton beam tracking and monitoring, 2D dosimetry





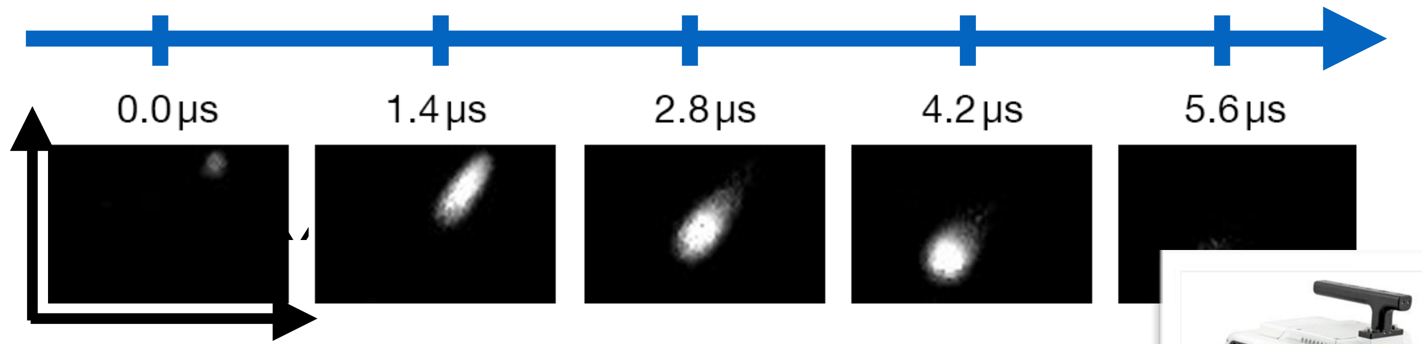
E Seravalli et al 2009 Phys. Med. Biol. 54 3755



F. Brunbauer, MPGD2019

Ultra-fast cameras

Up to 1 million frames per second for rapid imaging, X-ray fluorescence, beam monitoring and 3D track reconstruction

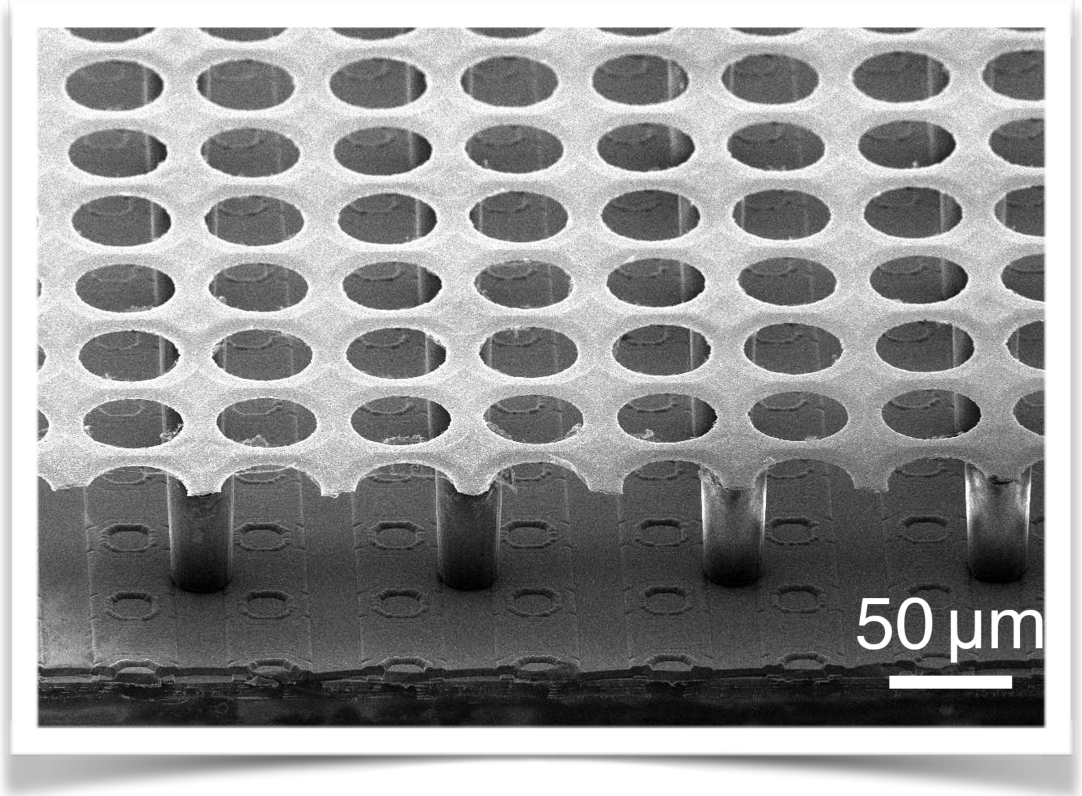


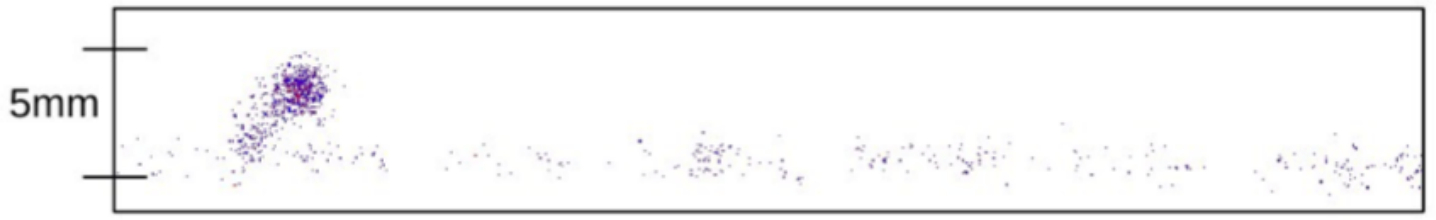
F. Brunbauer, MPGD2019

Hybrid readout approaches

Ingrid: MM + Timepix

Amplification below micromesh and direct readout by Timepix ASIC

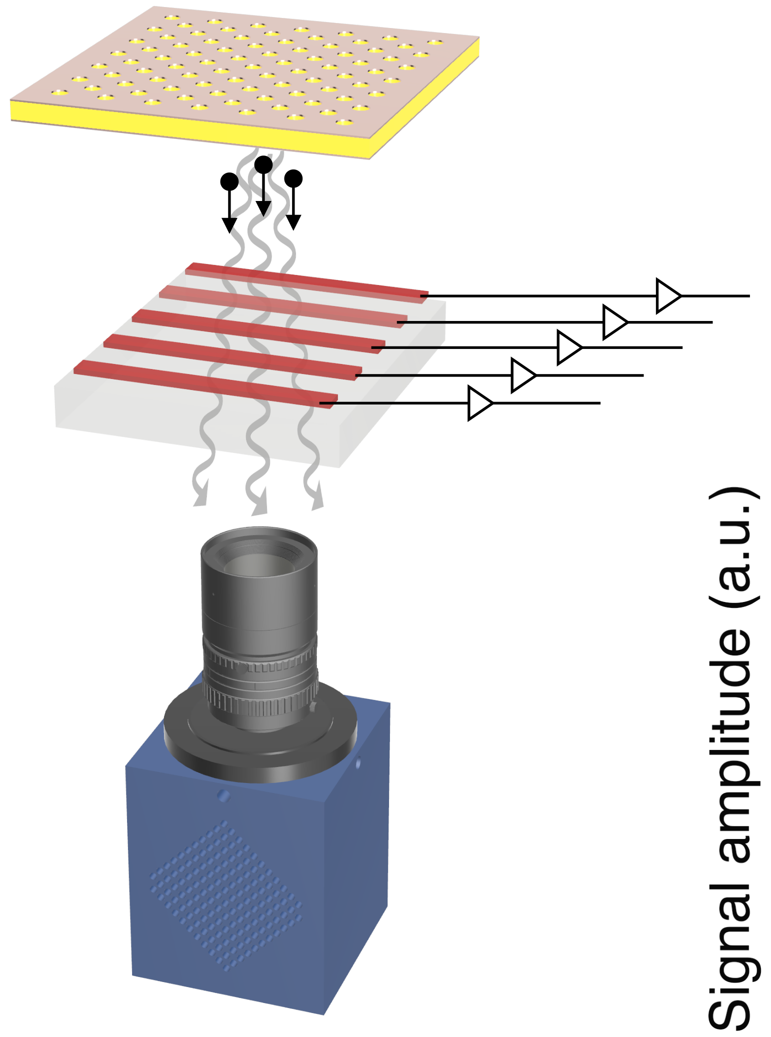


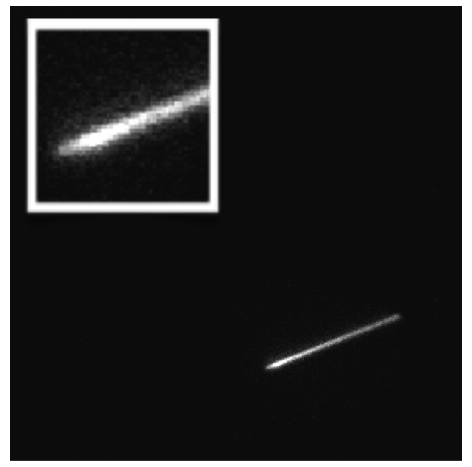


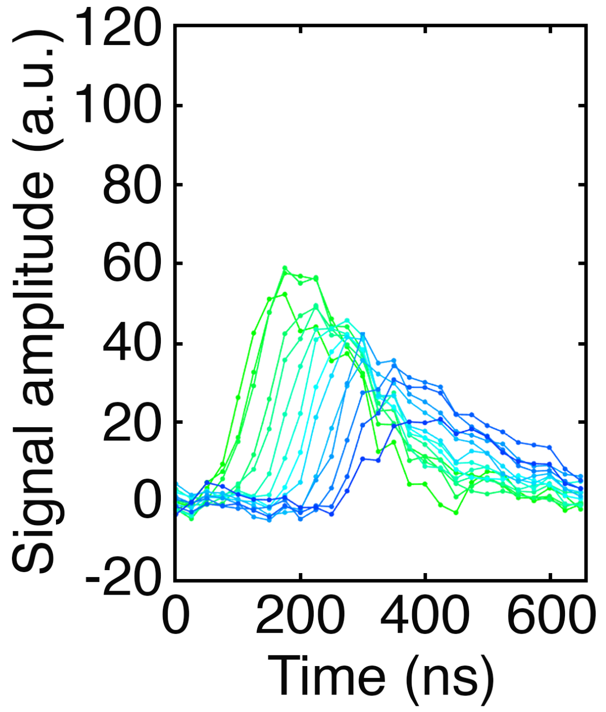
M Lupberger et al. https://doi.org/10.22323/1.213.0225

Optical + electronic

Transparent electronic readout and scintillation light recording in OTPCs



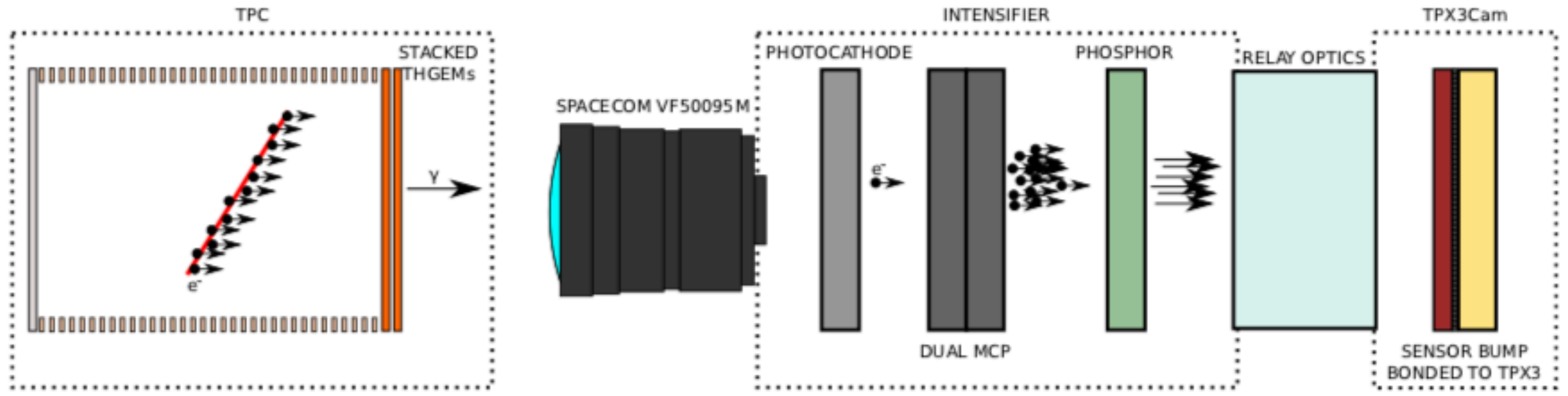


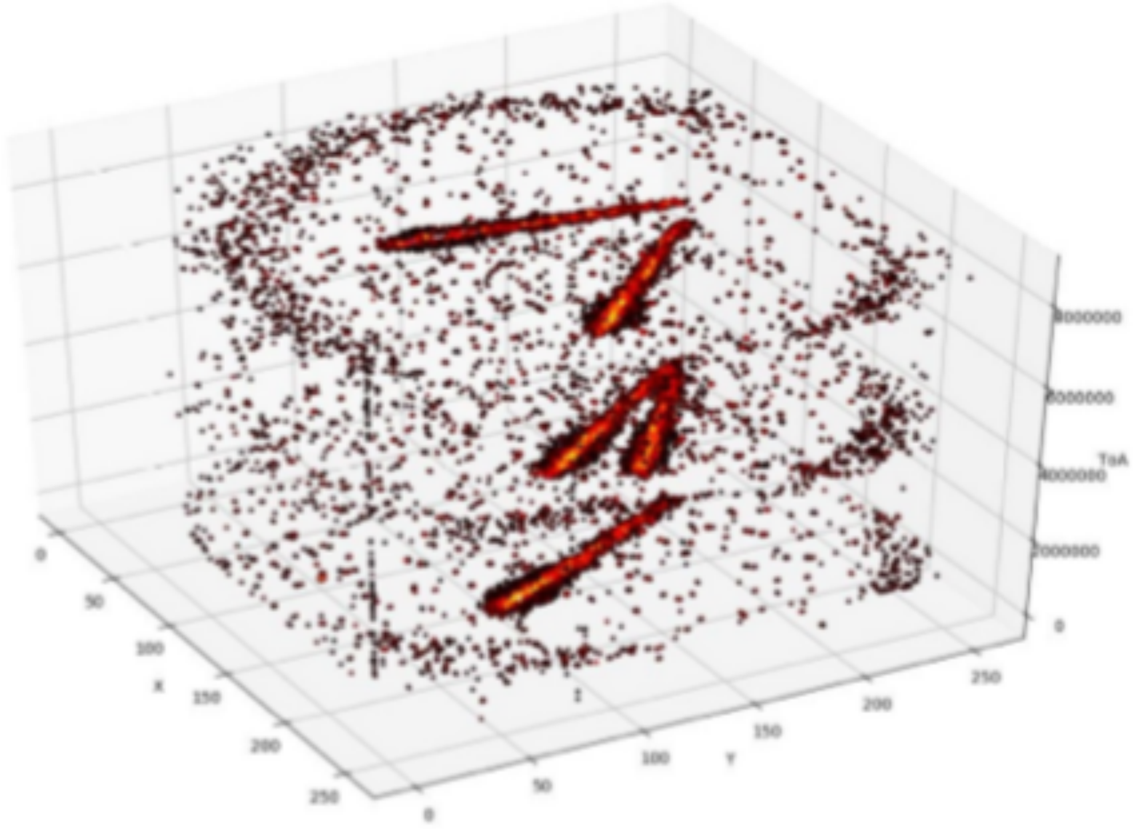


F. Brunbauer et al. IEEE TNS, VOL. 65, NO. 3, 2018

Optical converter/ intensifier + Timepix

Timepix cameras with optical sensitivity and image intensifier





A. Roberts et al. arXiv:1810.09955v3 [physics.ins-det] 25 May 2019

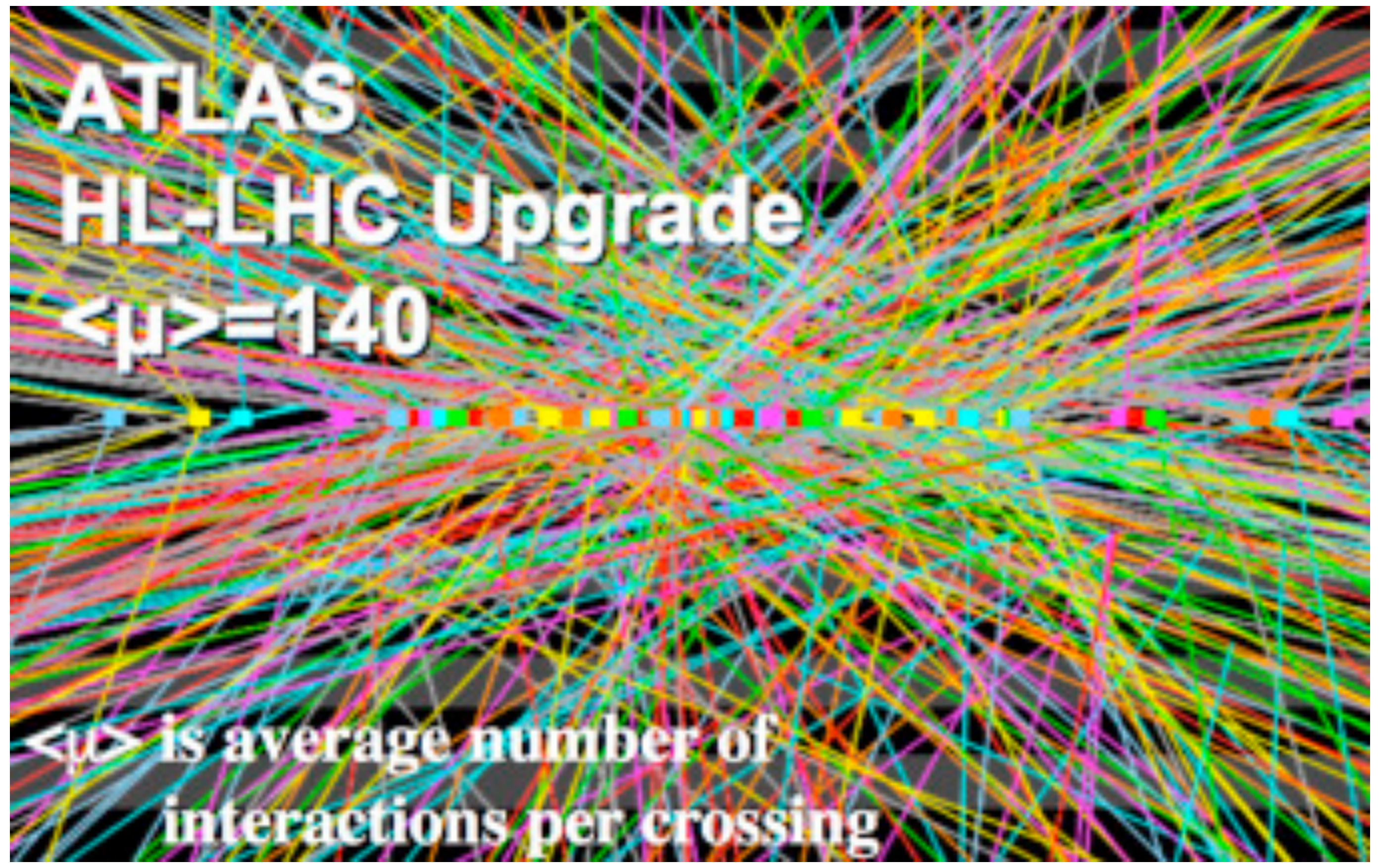
New perspectives

Precise timing with Micromegas
PICOSEC detection concept

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

- Exploit precise timing to separate tracks

Tens of ps timing + tracking info required



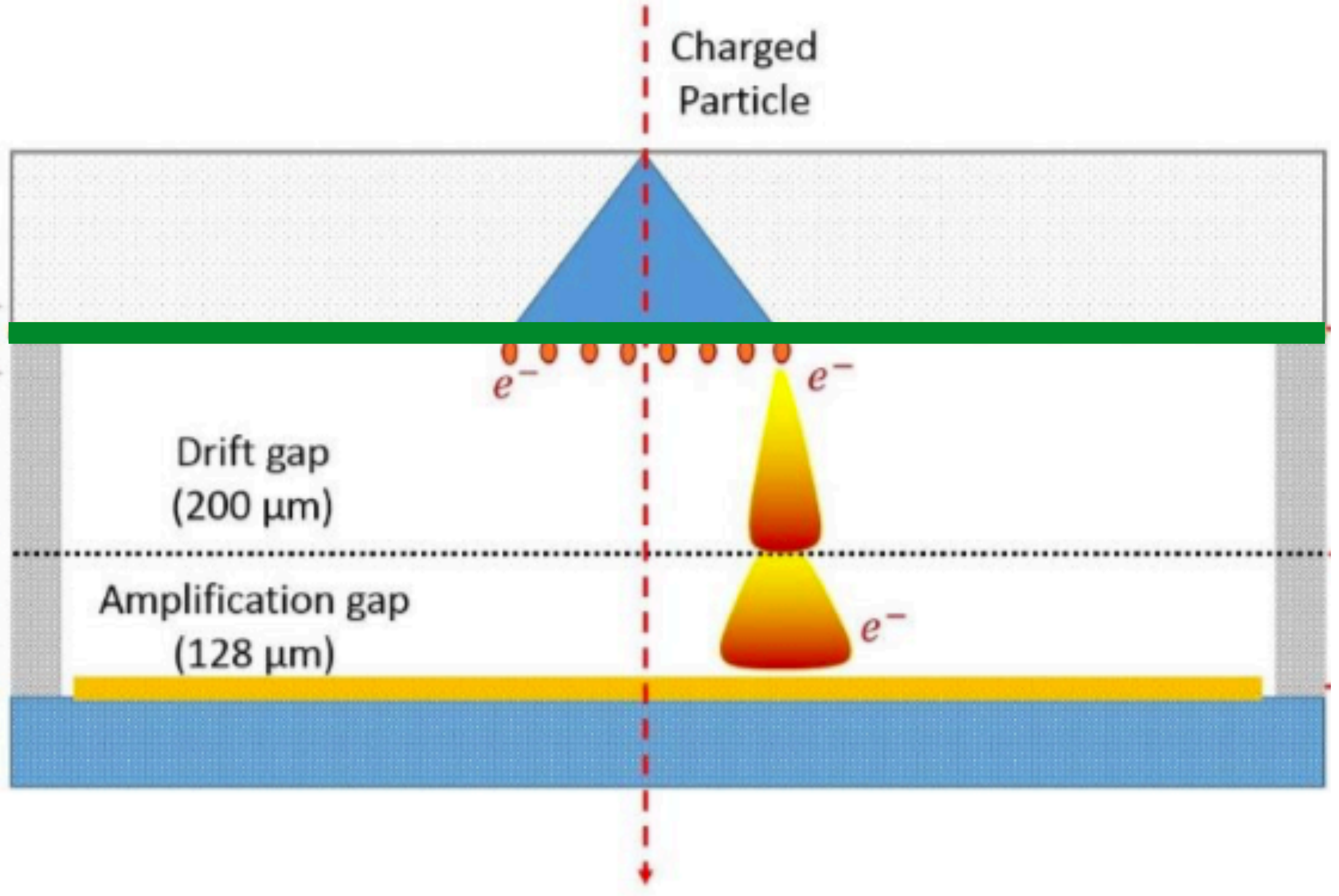
PID techniques: Alternatives to RICH methods, J. Va'vra, NIMA **876** (2017) 185-193, https://dx.doi.org/10.1016/j.nima.2017.02.075

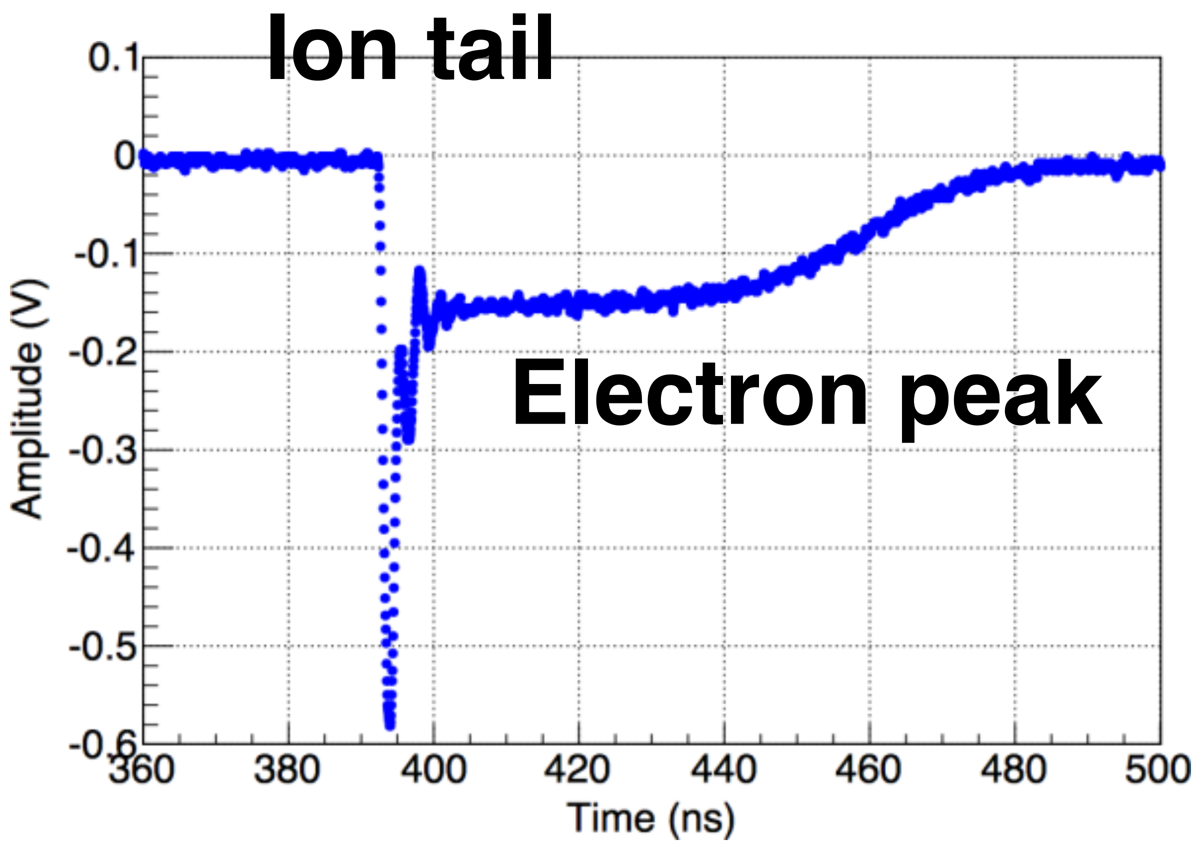
Cherenkov radiator
(3 mm MgF_2)

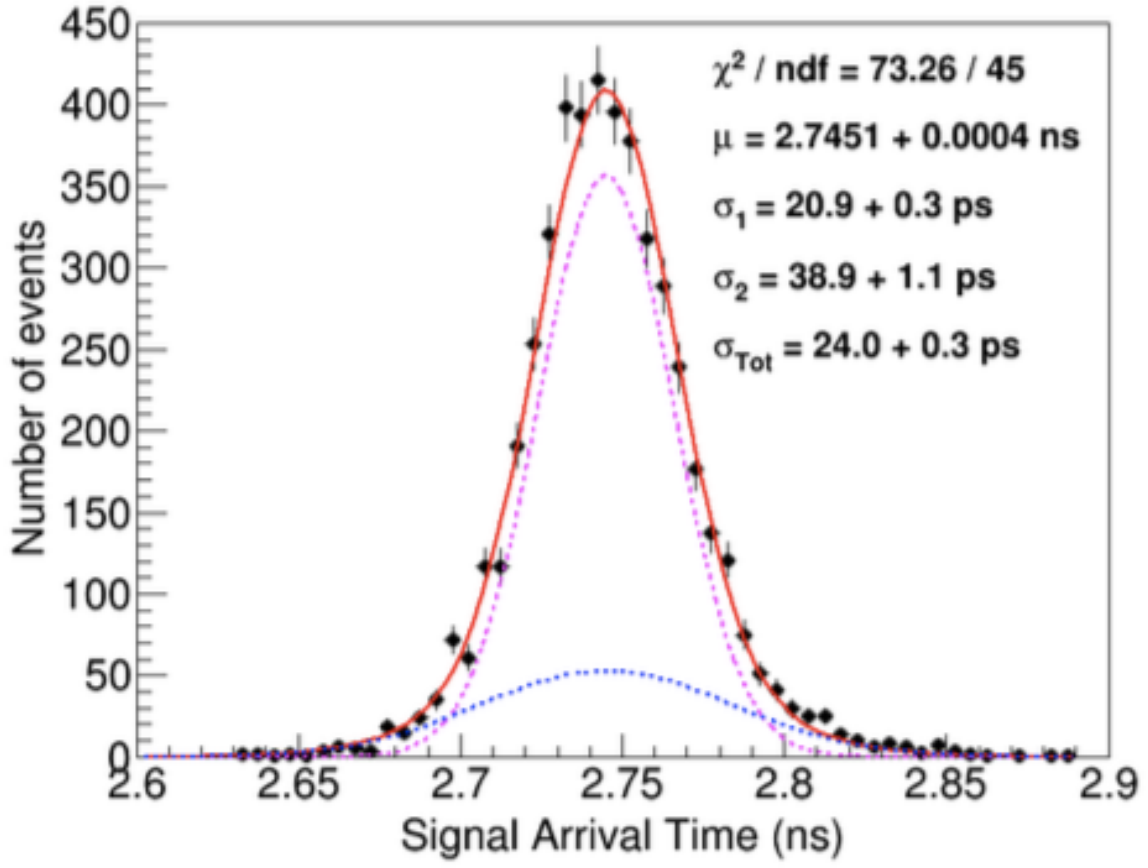
Photocathode
(3 nm Cr + 18 nm CsI)

Drift gap
(Pre-amplification)

Micromegas
(Amplification)







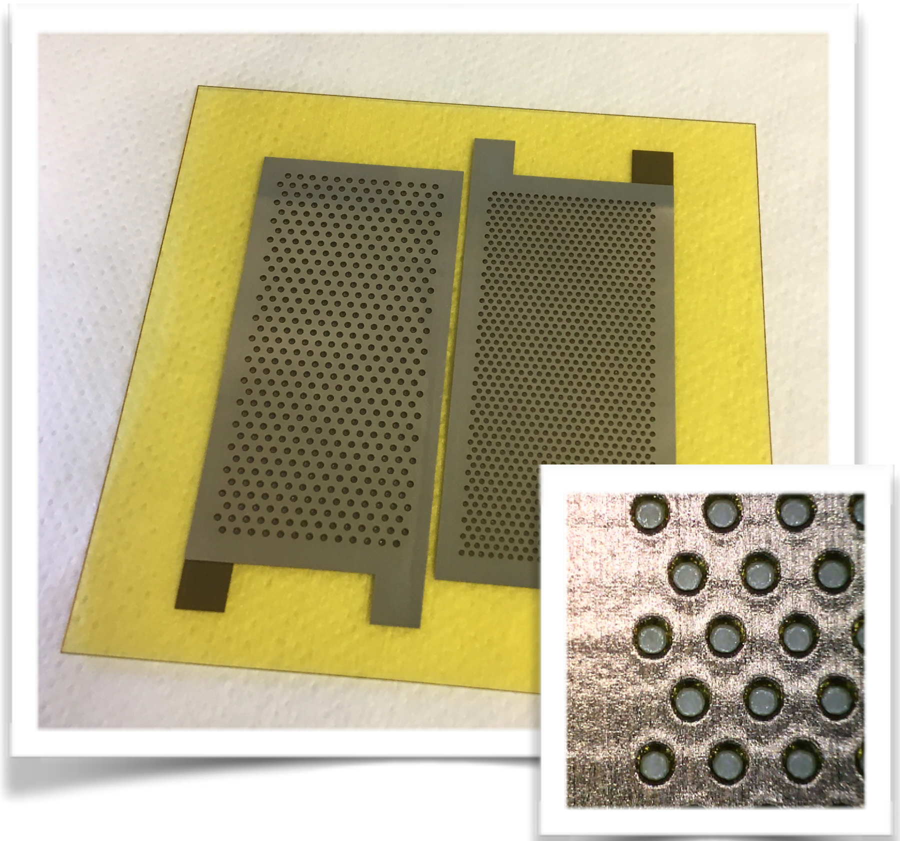
24 ps MIP timing resolution

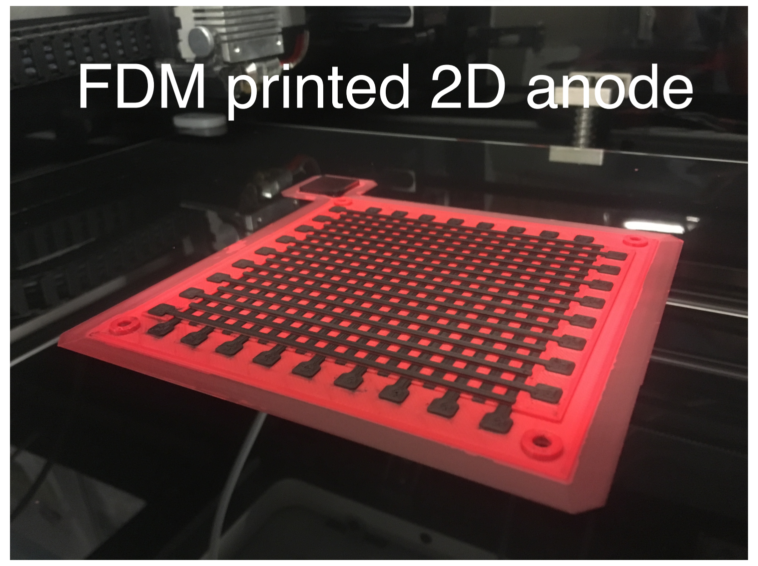
J. Bortfeldt et. al. (RD51-PICOSEC collaboration), Nuclear. Inst. & Methods A 903 (2018) 317-325

Additive manufacturing and novel materials

3D printing of amplication structures for fast, results-driven prototyping

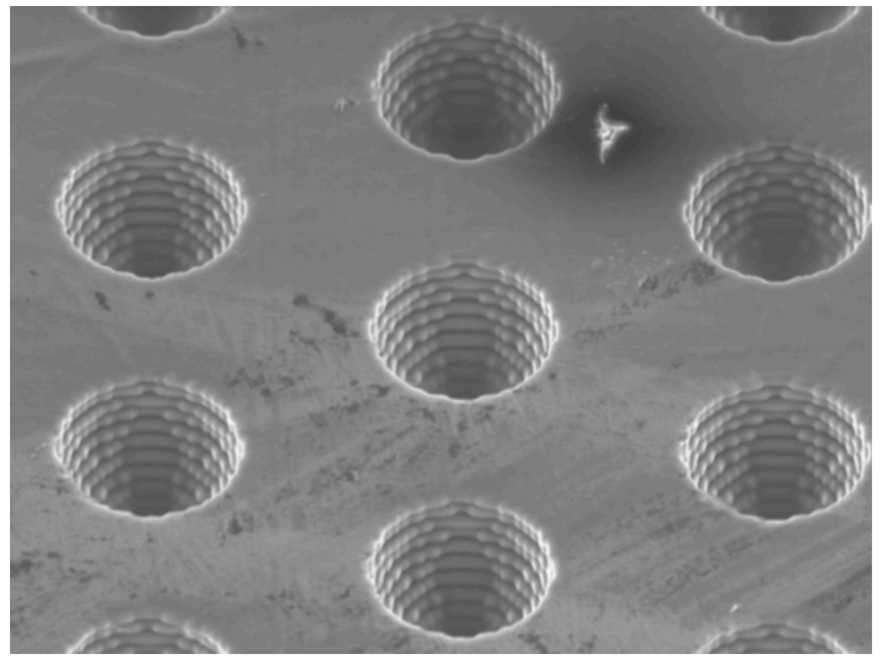
Dual-material inkjet printed THGEM

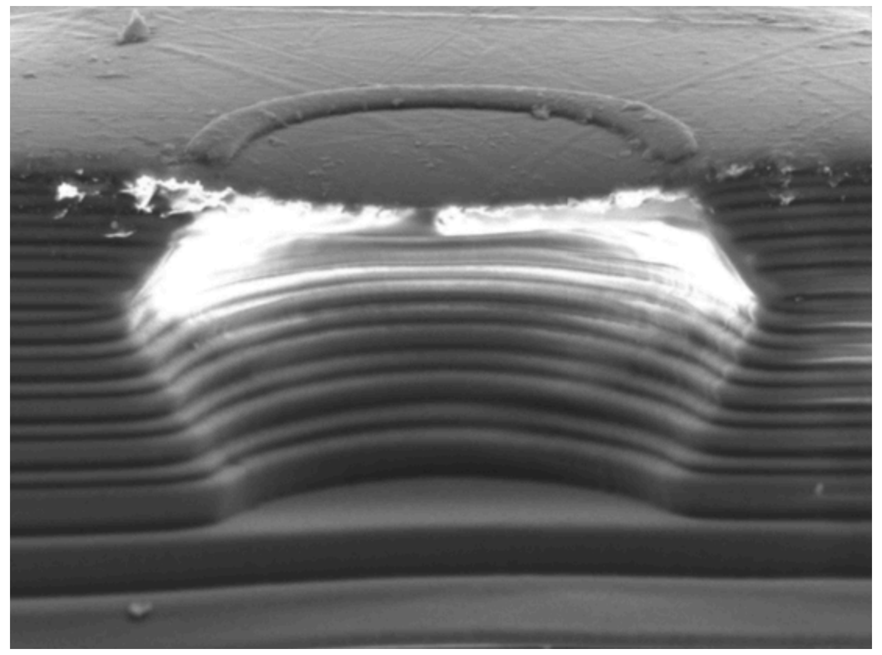




F.M. Brunbauer et al 2019 JINST 14 P12005

50μm diameter pµSLA printed holes

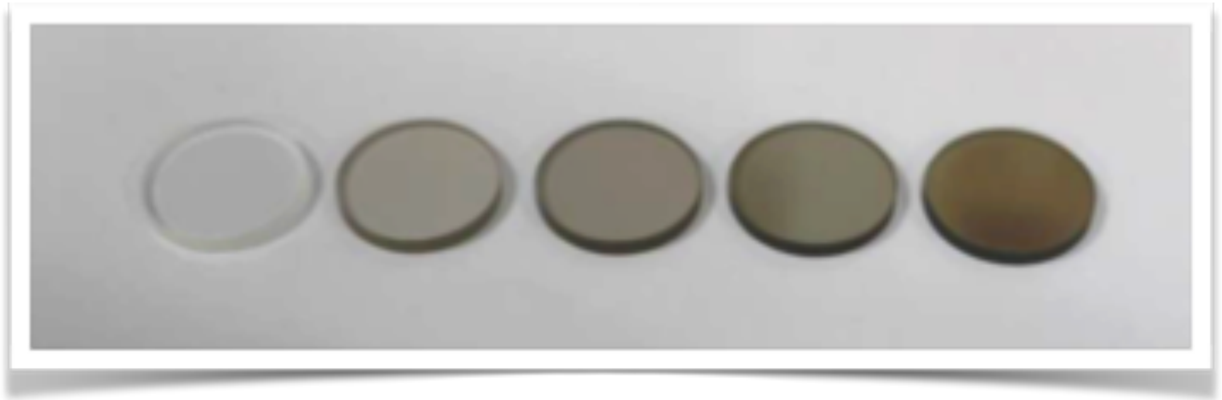




Tiago F. Silva et al., RD51 CM 2020

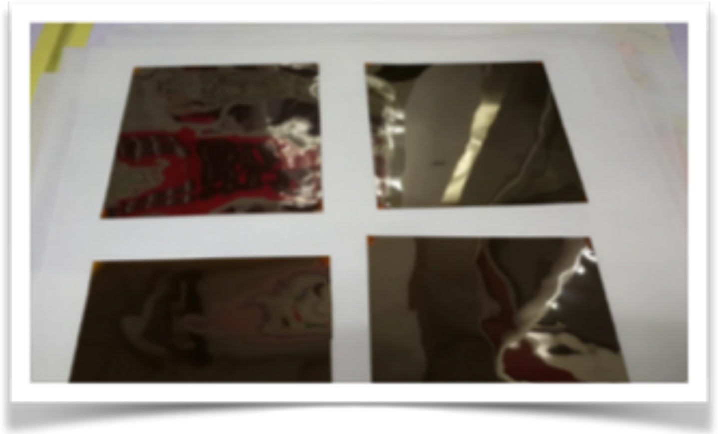
Novel materials as photocathodes, converters or secondary emitters for efficient primary charge production, charge sharing, detector stability, …

DLC photocathode 2.4 p.e. / muon



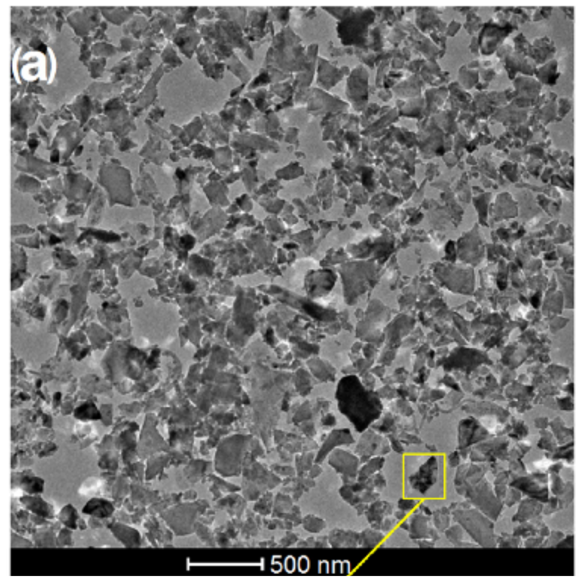
Yi Zhou et al., RD51 collaboration meeting, 2018

DLC + Cu coating



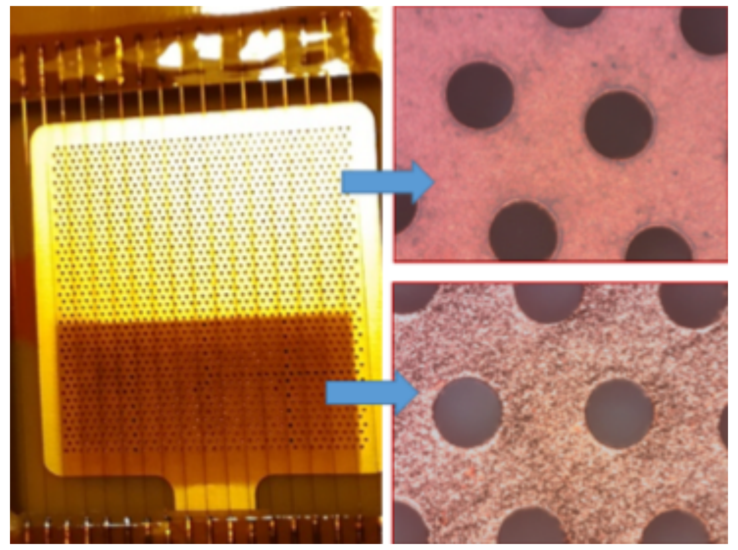
Yi Zhou et al., RD51 collaboration meeting, 2018

Nano diamond powder



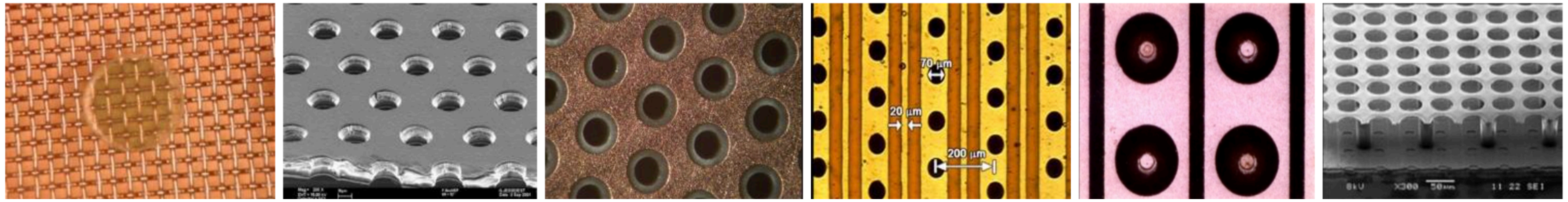
L. Velardi, A. Valentini, and G. Cicala, Appl. Phys. Lett.108, 083503 (2016)

ND-coated THGEM



C. Chatterjee et al. arXiv:1908.05058v1 [physics.ins-det] 14 Aug 2019

Summary



MPGDs are a **highly versatile** and **mature technology** for a wide range of experimental requirements ranging from high-energy physics to applications beyond fundmental research.

A global community driven by the **RD51 collaboration** is focused on increasing the understanding of detector physics to optimise existing structures and exploit technological advances to introduce **novel detector geometries.**

The requirement for **precise timing**, advances in **additive manufacturing** and **new materials** can lead to next-generation MPGD technologies and detectors for future experimental needs.