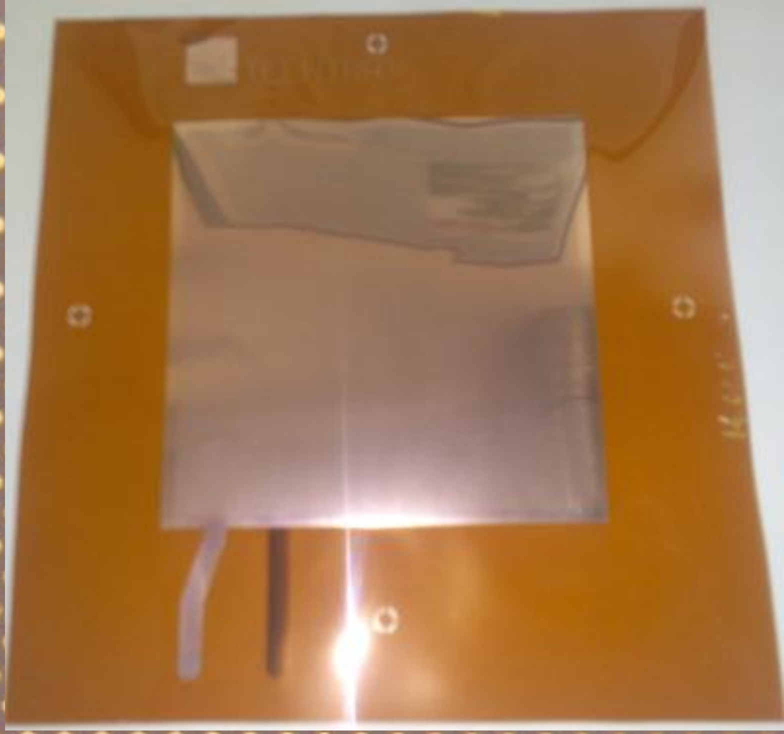


Technology of GEMs and their applications in detectors

P. Bielowka (Techtra)
J. Chorowski (University of Wroclaw)
K. Gut (Techtra)

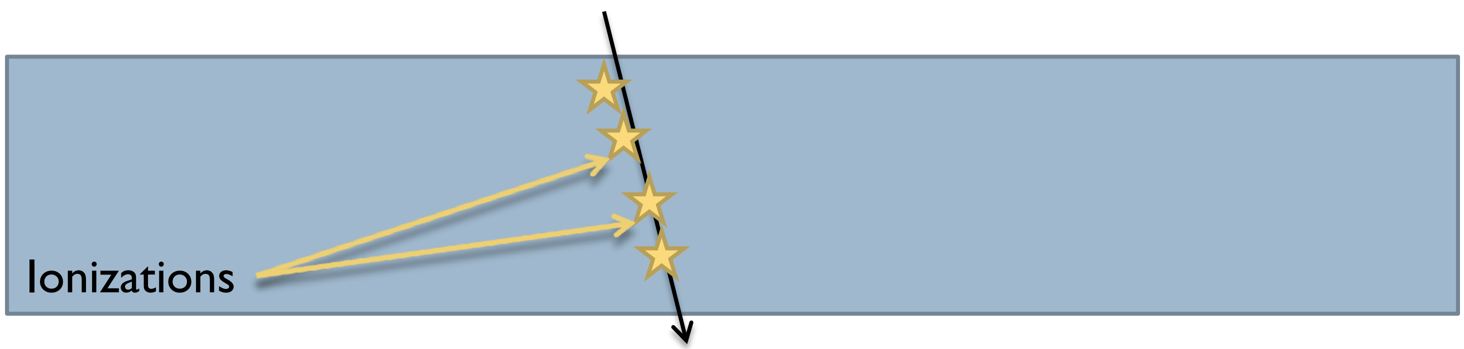
Wroclaw, 14.05.2014

Outline

- Gaseous radiation detectors and history of GEM development
- Principles of GEM detector operation
- GEM detector uses
- GEM production technology & limitations
- Research directions & unanswered questions

Single-wire proportional detector

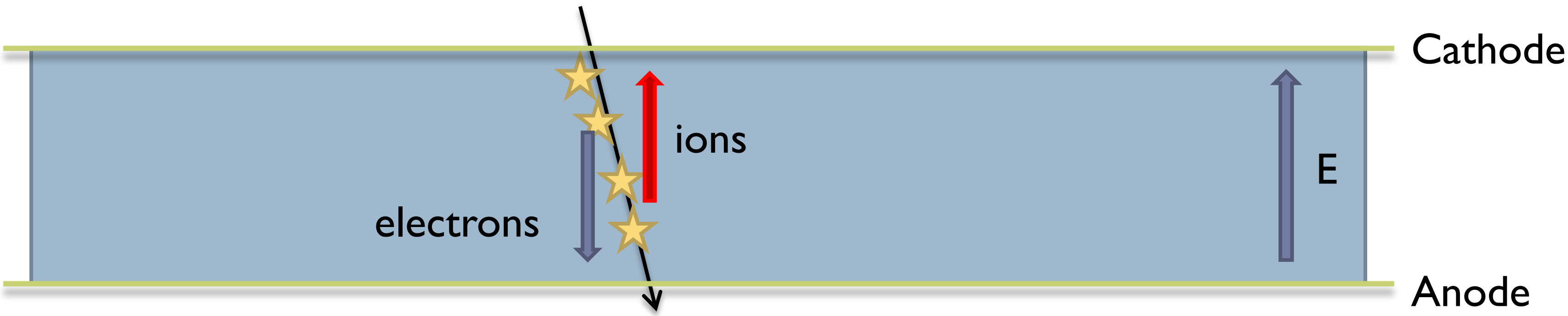
- Consider an ionizing particle travelling through gas (e.g. Ar)
- The amount of electron-ion pairs is proportional to the energy loss of the particle



F. Sauli, *Principles of Operation of Multiwire Proportional and Drift Chambers", CERN, Geneve 1977*

Single-wire proportional detector

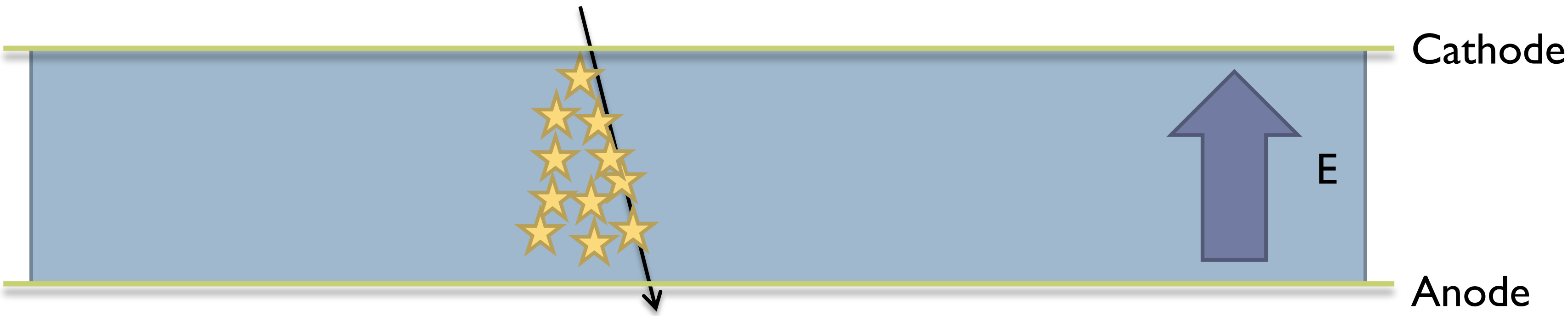
- If electrical field is applied to the gas, we can collect the electrons at the anode
- But the signal is extremely small (uV)



F. Sauli, *Principles of Operation of Multiwire Proportional and Drift Chambers", CERN, Geneve 1977*

Single-wire proportional detector

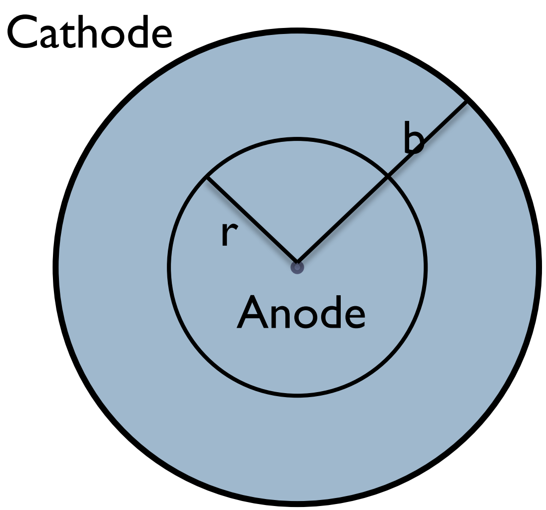
- Applying a large electric field allows us to create avalanche secondary ionization in the gas
- The signal is large, but we the magnitude depends on avalanche length – no proportionality to energy loss!



F. Sauli, *Principles of Operation of Multiwire Proportional and Drift Chambers", CERN, Geneve 1977*

Single-wire proportional detector

- We need both a small-field proportional region to collect the primary-ionized electrons
- And a large field region of controlled geometry to form the amplifying secondary ionization avalanche
- Simplest case: an anode wire in a cylindrical cathode:

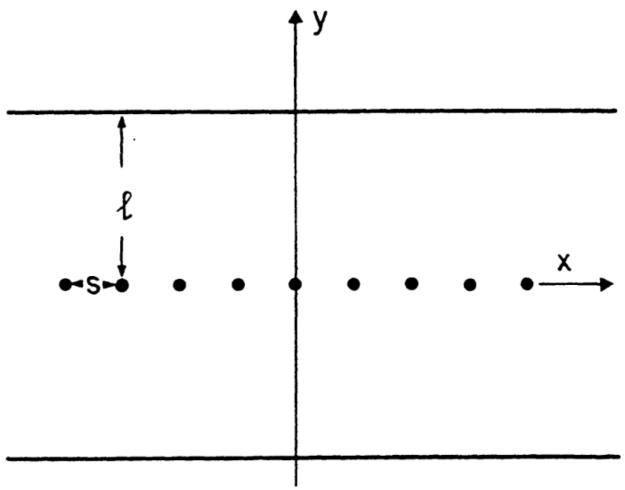


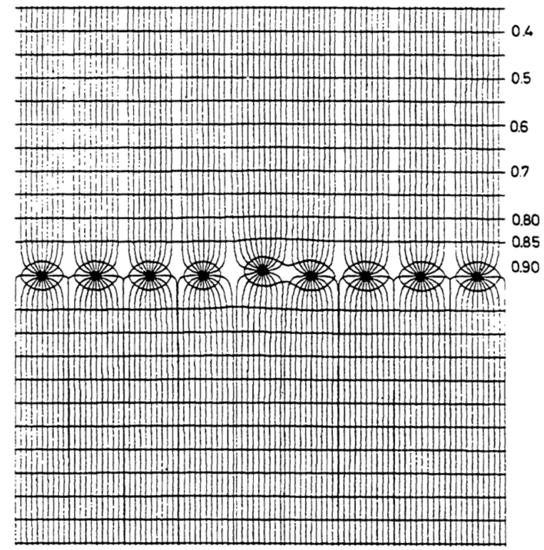
Since the electric field decreases as $1/x^2$ with the distance from the anode, the avalanche region will form under radius r.

F. Sauli, *Principles of Operation of Multiwire Proportional and Drift Chambers", CERN, Geneve 1977*

Multi-wire proportional chamber

- To record the position of the particle, we can use several parallel wires between two cathode planes:





- For a 2D localization we can use 2 wire planes at different orientations
- The development of MVPC in 1968 gave G. Charpak the Nobel prize in 1992!

F. Sauli, *Principles of Operation of Multiwire Proportional and Drift Chambers", CERN, Geneve 1977*

MWPC limitations

- MWPC for a long time was the work-horse of High Energy Physics (HEP) experiments.
- However, it has several limitations:
  - The spatial resolution is limited by wire spacing (few mm)
  - Moreover, the wires interact through electrostatic forces (they at the same potential).
  - Thus they will resonate when placed too closely.
  - At higher particle fluxes positive ions are not collected fast enough which leads to spatial charge build-up and gain drops.

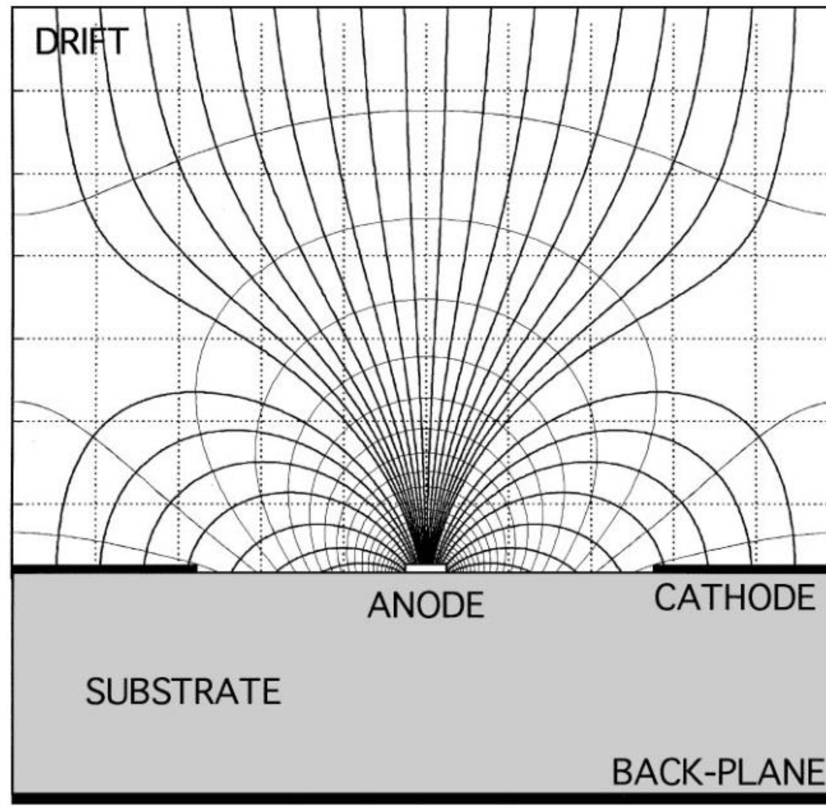
F. Sauli, A. Sharma, Microstrip Gaseous Detectors

Micro-pattern gaseous detectors

- Remember what is needed:
  - A large low electric-field *drift* region in which primary ionization will take place and electrons will drift towards readout.
  - A small and controlled large electric-field *amplification* region in which the collected char will be avalanche-multiplied.
- Micro-pattern gaseous detectors (MPGDs) are designs which utilize modern electronic manufacturing processes to shape the electrical field.

Multi-strip detector

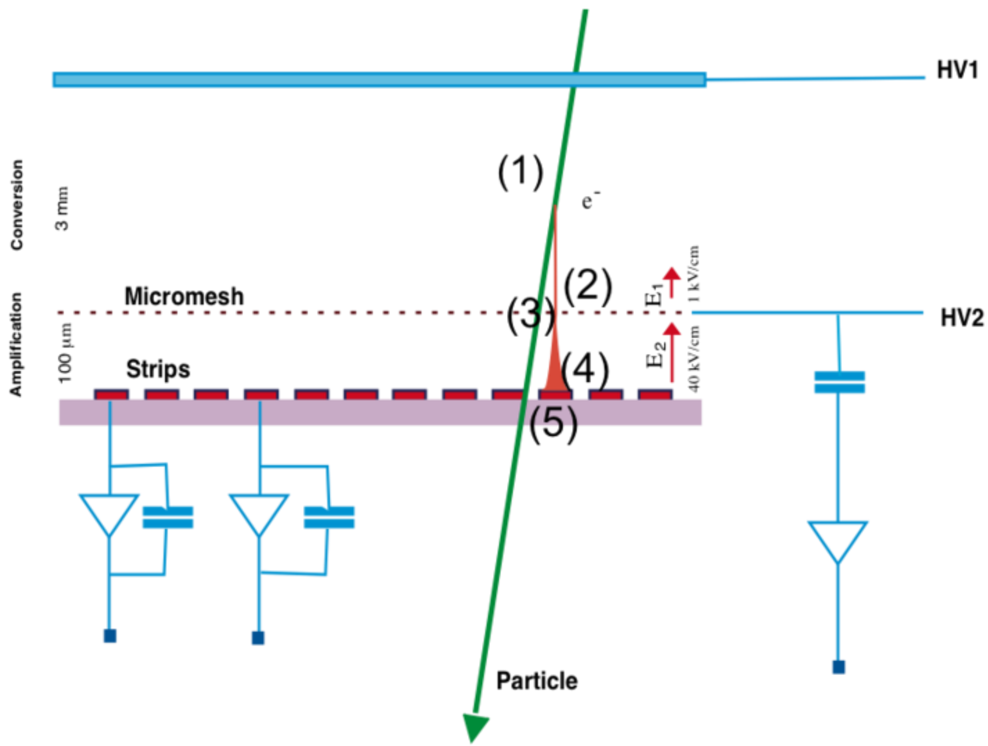
- In 1988 Oed et al. proposed to replace wires with thin PCB traces.
- Structure is rigid and can use fine stripes pitch.
- Positive ions are quickly collected by cathode strips.
- However sparks between neighboring anode and cathode stripes can destroy the device!



F. Sauli, A. Sharma, Microstrip Gaseous Detectors

MicroMegas

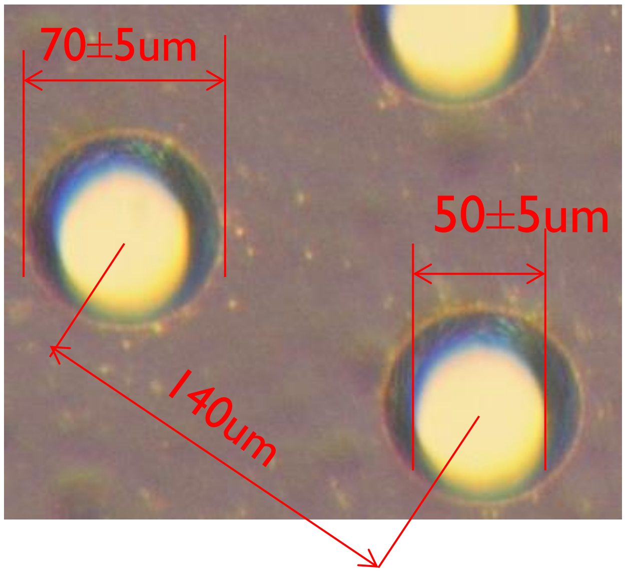
- MicroMegas (Micro-MEsh Gaseous Structure) were invented in 1992 by G. Charpak and I. Giomatrias.
- They consist of a micro-strip plane above which an conducting mesh is placed:

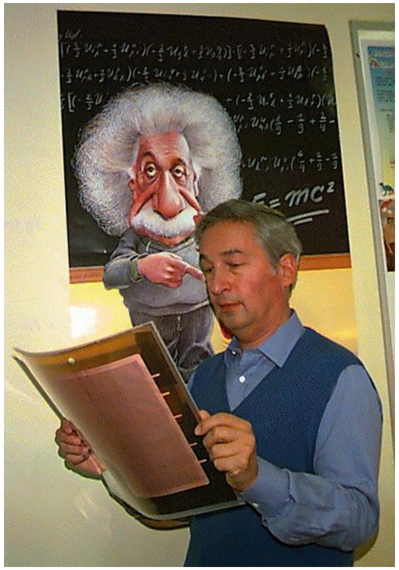


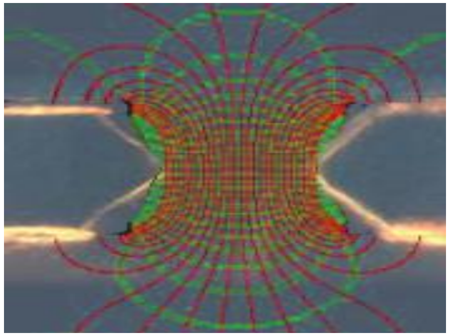
Y. Giomataris, Ph. Rebourgeard, J.P. Robert, G. Charpak, MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments, img. courtesy of Wikipedia

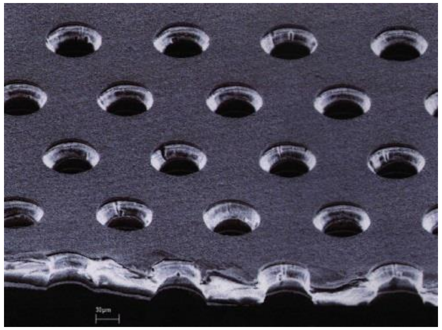
Gas Electron Multiplier (GEM)

- The GEM was introduced in 1997 by F. Sauli at CERN
- It is a thin (50um) parallel-plates capacitor with holes.
- Thus it creates locally high electric field!





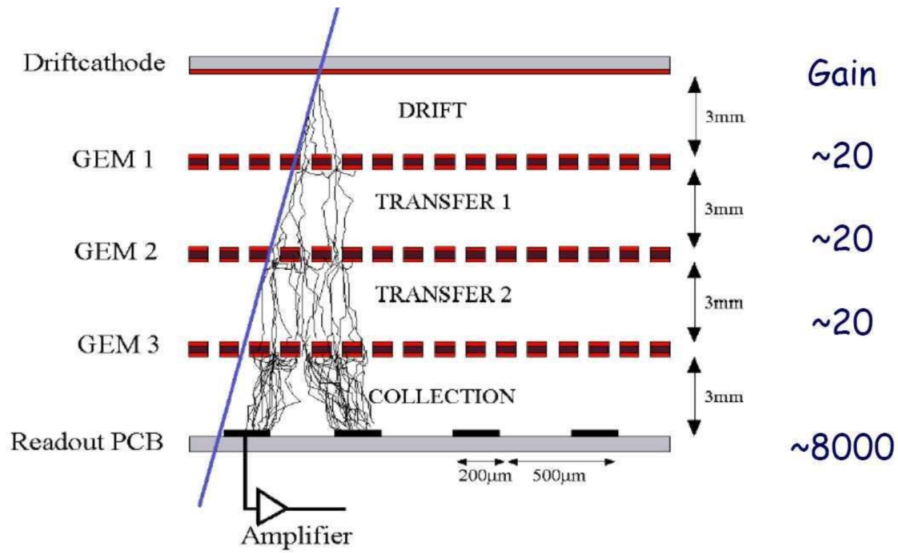




F. Sauli, GEM: A new concept for electron amplification in gas detectors. Img. Courtesy of CERN

Principles of GEM operation

- GEM detectors typically consist of a stack of foils, each operated at ca. 500V difference placed a drift cathode and a readout anode.

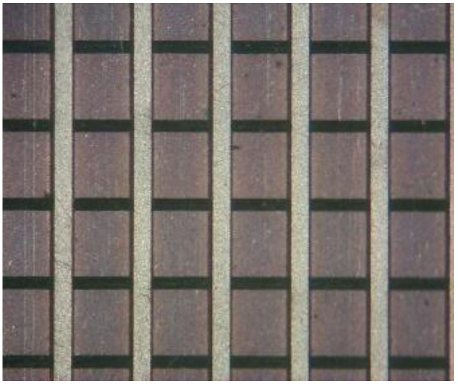


- GEM detectors offer excellent spatial, temporal and energy resolution at costs much lower than solid-state ones.
- GEM detectors tolerate extremely high radiation levels.

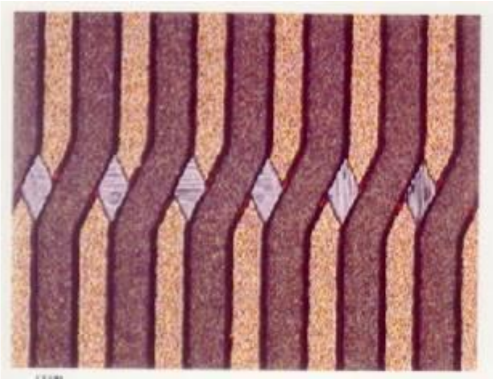
Img. courtesy L. Ropelewski, CERN

GEM & Micromegas Readout

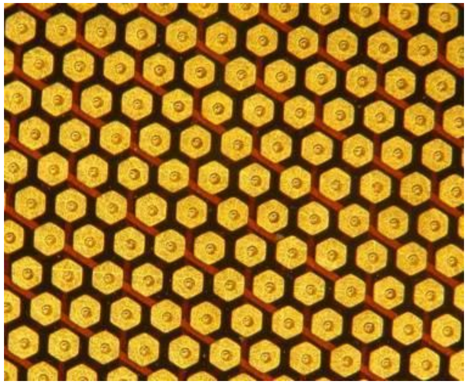
- GEMs and Micromegas decouple the readout geometry from charge collection and amplification.
- Thus readout is not limited to parallel strips/wires.



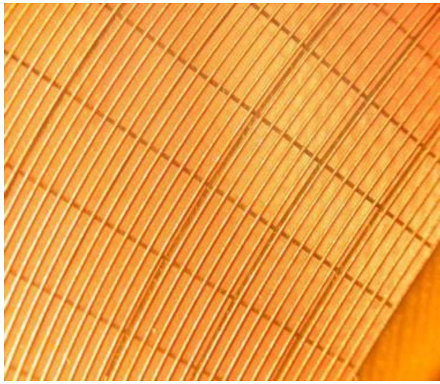
Cartesian, Compass, LHCb



Small Angle



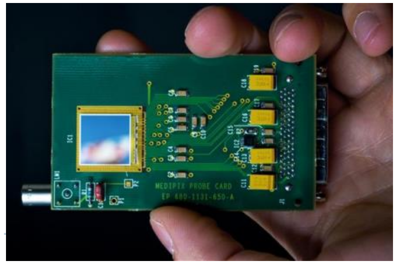
Haxagonal pads, MICE



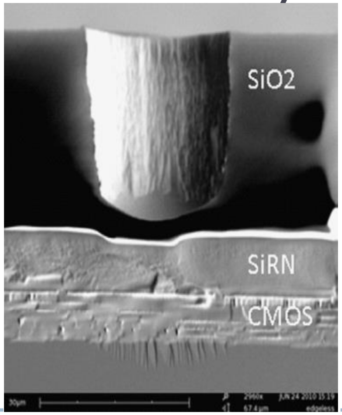
Mixed, TOTEM

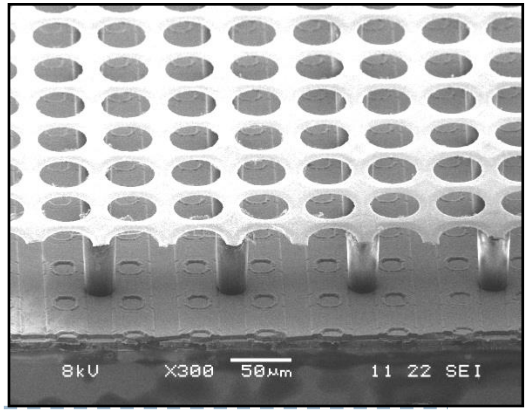
L. Ropelewski, GEM for ALICE TPC upgrade, CERN

Pixel Readout



- It is even possible to use dedicated CMOS pixel-readout chips with a GEM or MicroMega amplifier
- Medipix – a family of hybrid silicon pixel detectors developed by an international collaboration of institutes
- Used at the Large Hadron Collider
- Detectors in the family:
  - Medipix 1 – collaboration formed in early 90', 64x64 pixels
  - Medipix 2 – collaboration formed in late 90', 256×256 pixels
  - Timepix – a version of Medipix 2 with the functionality of time measurements
  - Medipix 3 – collaboration formed in 2006, determines energy levels of detected photons

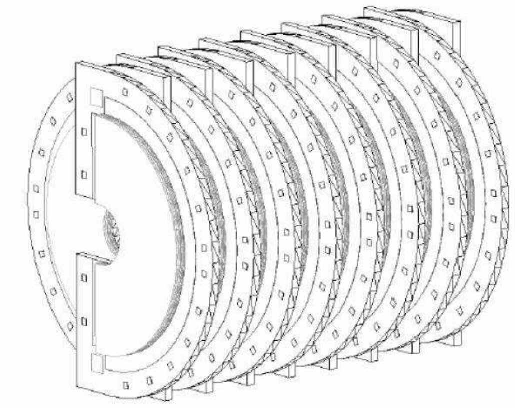




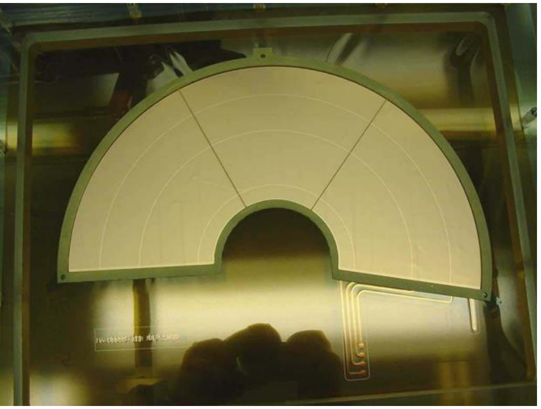
Images are courtesy of CERN and Medipix collaboration

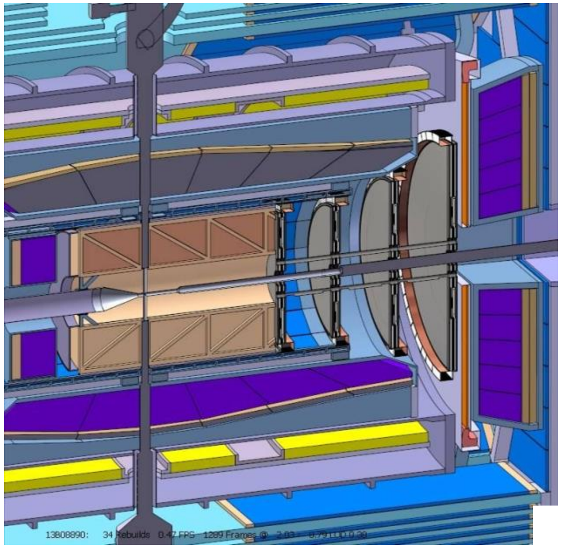
GEMs in HEP experiments

- Several HEP experiments use or will use GEM detectors, e.g.:

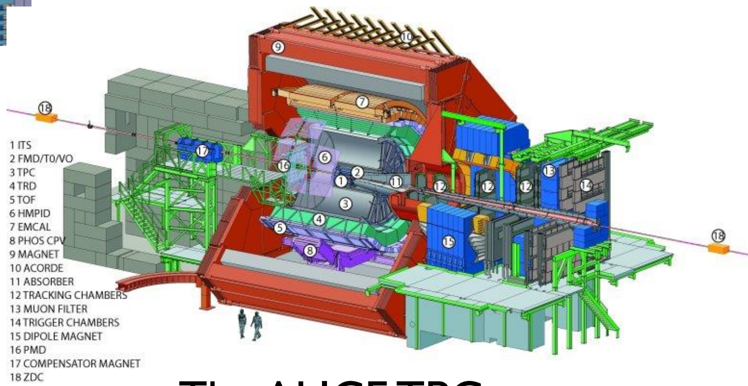


TOTEM T2 telescope





Target spectrometer
PANDA



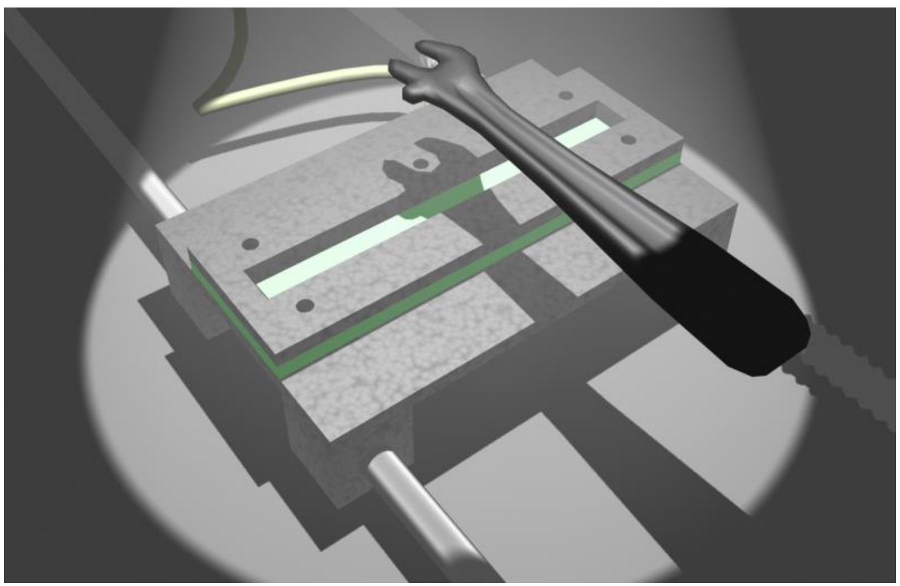
The ALICE TPC

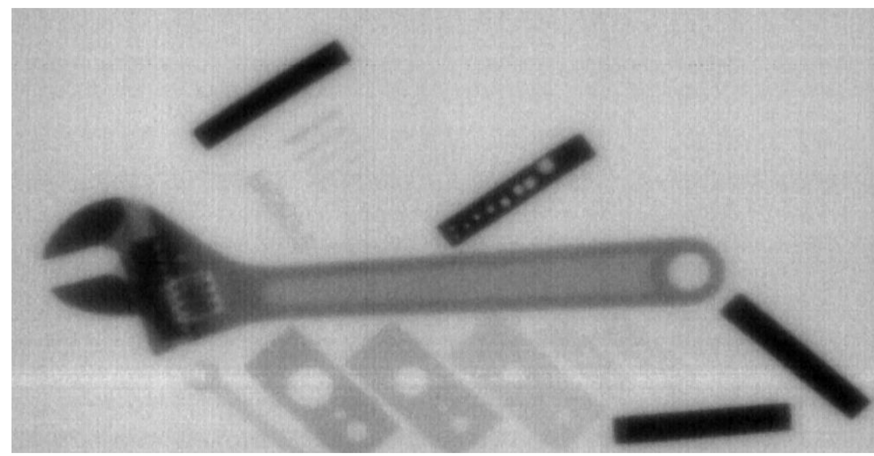
Techtra
a successful technology transfer from CERN

- Was established asa consulting company in 1998
- Has coordinated contacts between CERN and Polish industry
- Has partnered on R&D and technology transfer projects:
  - Silver-based High-Temperature Superconductors
  - CERN Micro-Chemical Vias for interconnections in flexible printed circuit boards
- Manufactures Gas Electron Multiplier (GEM) foils using technology licensed from CERN:
  - GEM licenses acquired in 2002, 2004, and 2012
  - In 2013 Techtra TTA was the only CERN-qualified supplier of small GEM foils that were delivered to CERN itself
  - Techtra is finishing the work on large-area GEM foil production
- Techtra builds GEM-based industrial detectors for NDT.

Towards the "GEM-View" detector

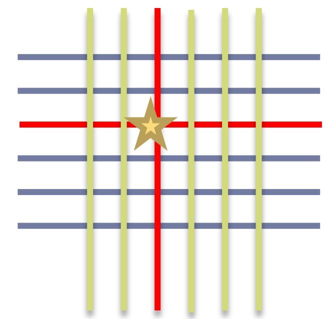
- The current market for GEM-based detectors is HEP experiments
- To bring the technology to a wider audience Techtra has collaborated with the Polish National Centre for Nuclear Research to build a detector for nondestructive testing.



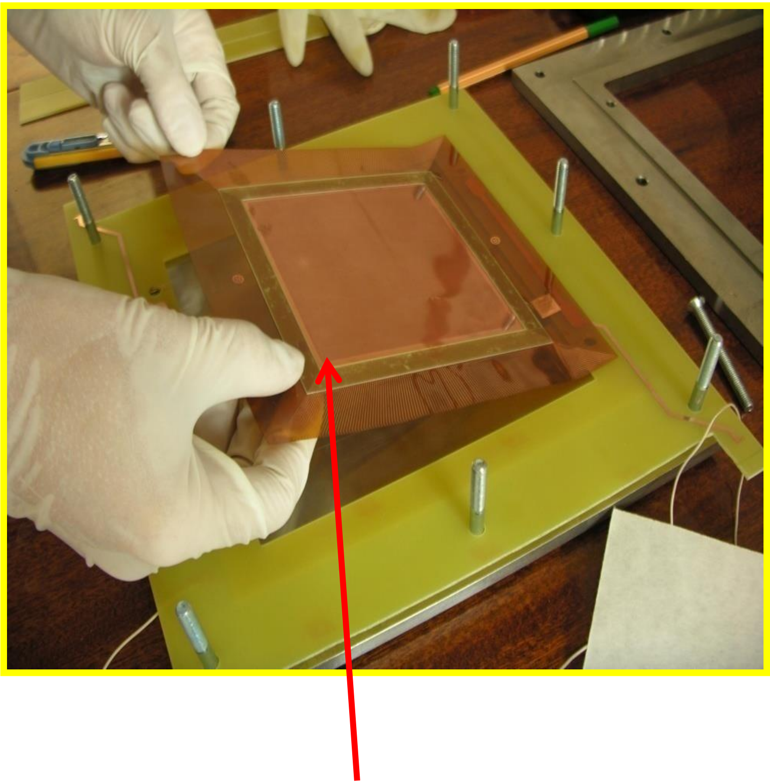


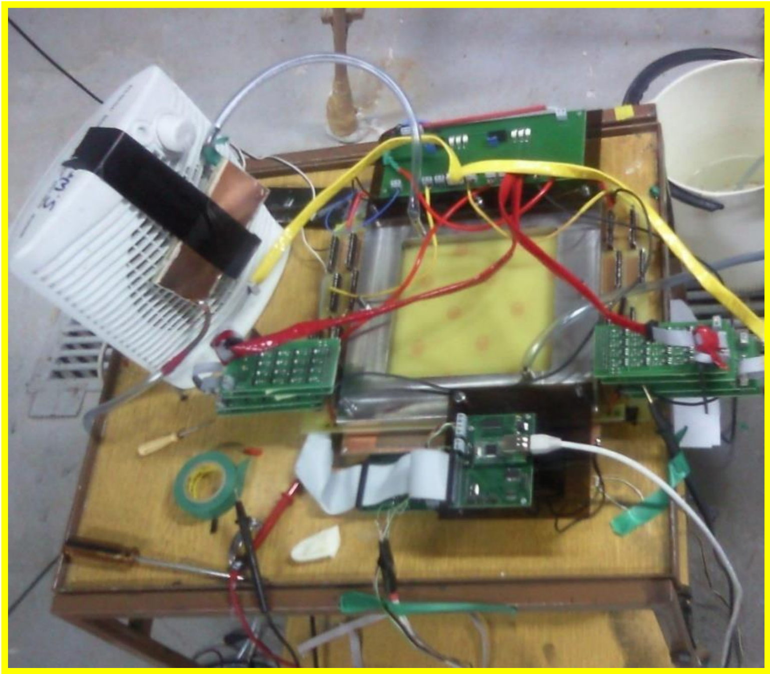
Techtra's & NCNR's NDT detector

- The main problem is readout – we can't afford a large area (~1x1 m^2) pixel readout.
- In HEP this is not a problem:
  - We assume that there is one event at a time
  - Thus we can get away without a large area pixel readout
  - But this limits the allowable particle flux!
- To work with larger particle fluxes we have built a scanner head



Some early prototypes





Our first try: multiple electrodes to scan without moving parts

Radiographs made with GEM-View

DIPLÔME

SALON INTERNATIONAL DES INVENTIONS

GENÈVE

Après examen, le Jury International a décidé

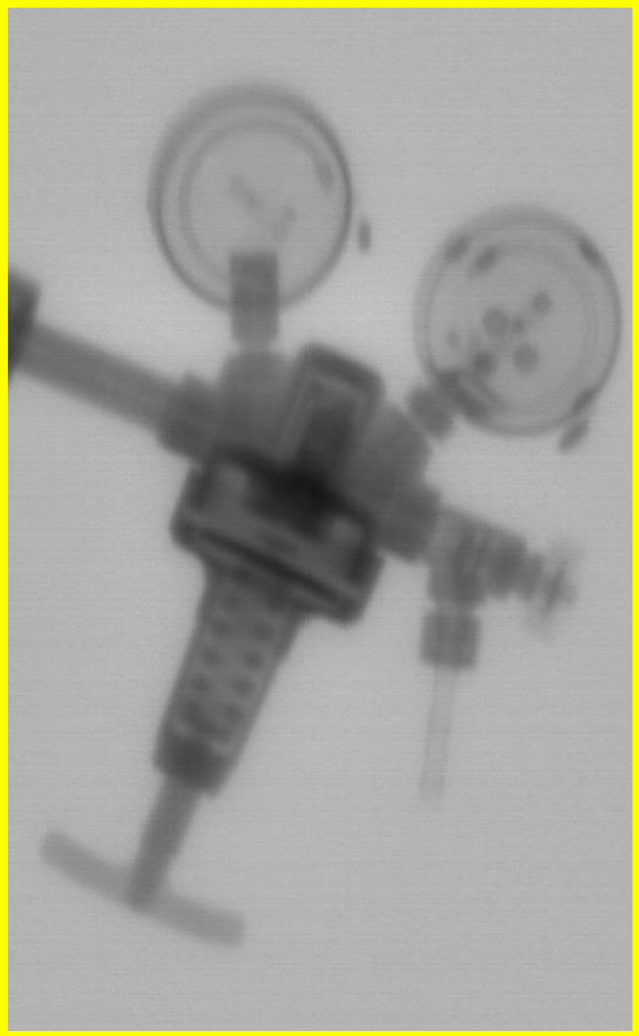
de remettre à: WROCLAW TECHNOLOGY PARK

pour l'invention: Moyen de démontrer la technologie des microvias chimiques

Genève, le 20 avril 2007

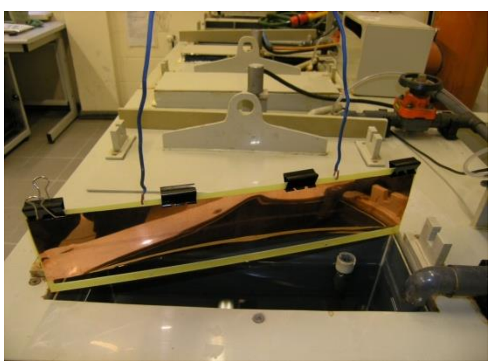
le Président du Jury

le Président du Salon



Our Production Facility

- We are located in the Wroclaw Technological Park
- We have support for flexible printed circuits manufacturing:
  - Dry resist lamination and development
  - Copper etching
- We have a wet Kapton etching line exclusively used for GEM foils
- We currently can manufacture GEM foils up to 300 x 300 mm^2
- We undergo an upgrade which will allow us to produce GEM foils up to 600 x 2000 mm^2

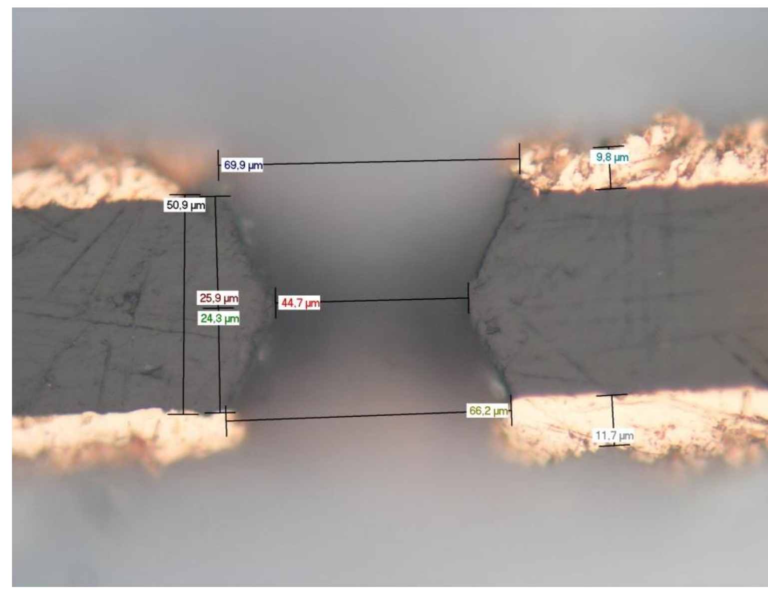


R&D Kapton etch line

WISE Chemstar equipment:
Industrial grade Cu and Kapton etch line for large GEMs

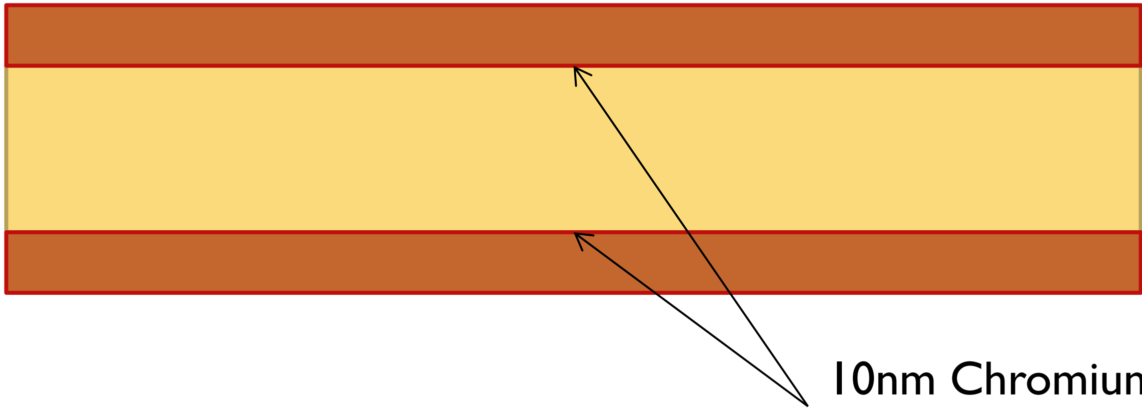
GEM production technology & limitations

- The GEM is typically made of a copper polyimide foil in which the holes are patterned using photolitography and chemical etching.
- The special process is a polyimide etching bath developed by Rui De Oliveira at CERN.
- Other processes are typical, but the tolerances on dimensions and overall pattern uniformity however much stricter.
- Thus the production uses typical processes, but at their most precise limits.



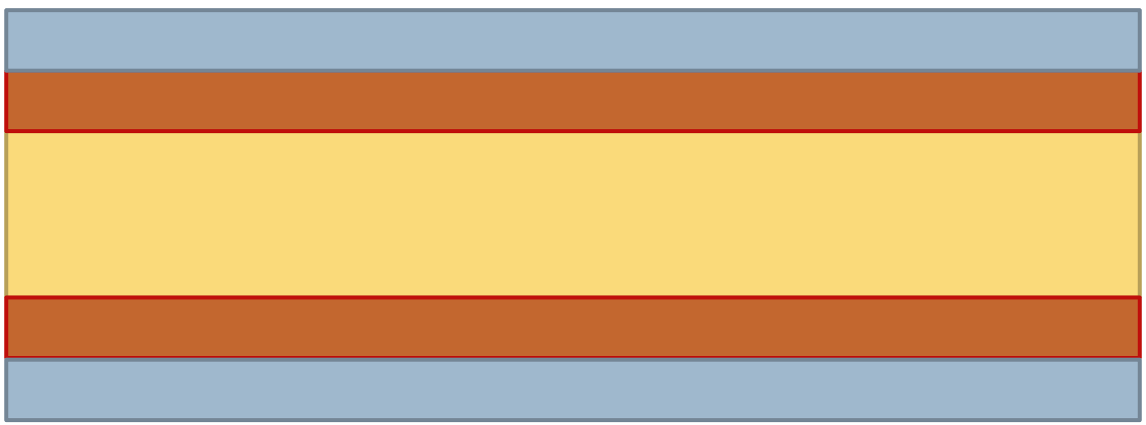
Typical process

- Originally, the GEMs were manufactured by applying photolithography to both sides.
- Base material is 50um adhesiveless copperclad polyimide.



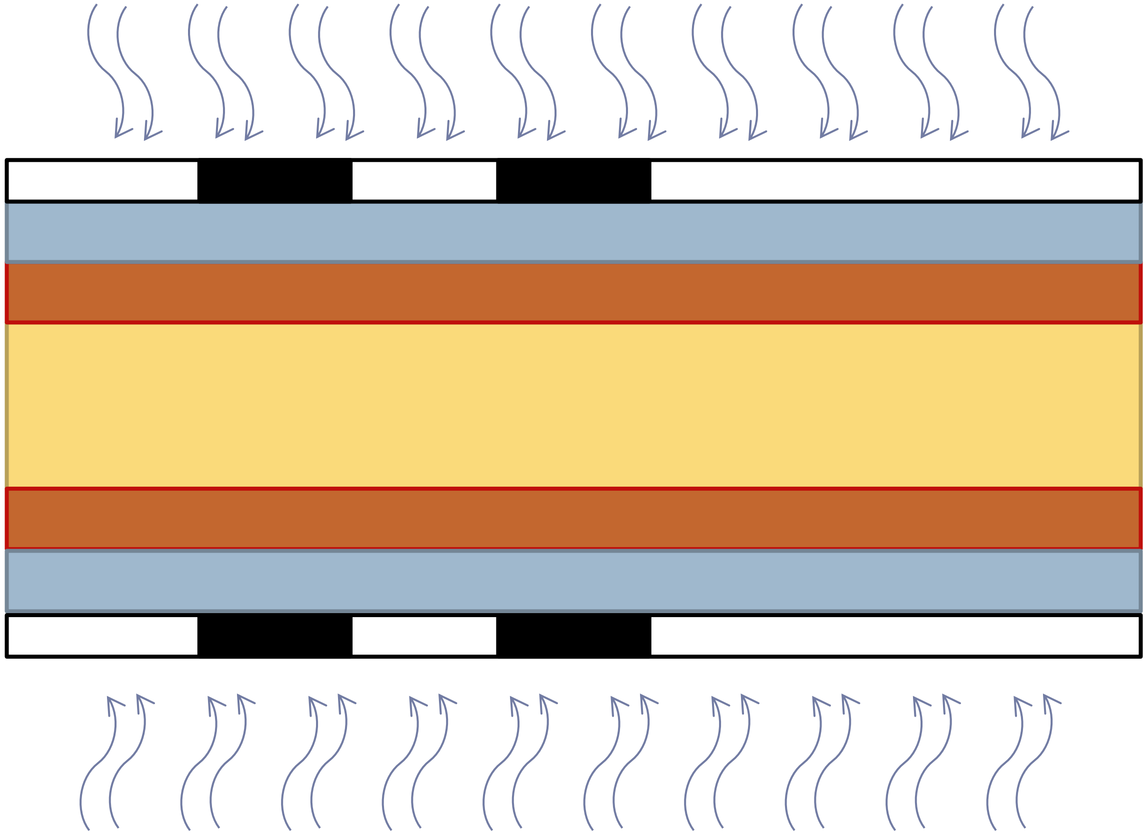
Typical process

- Application of dry-film photoresist



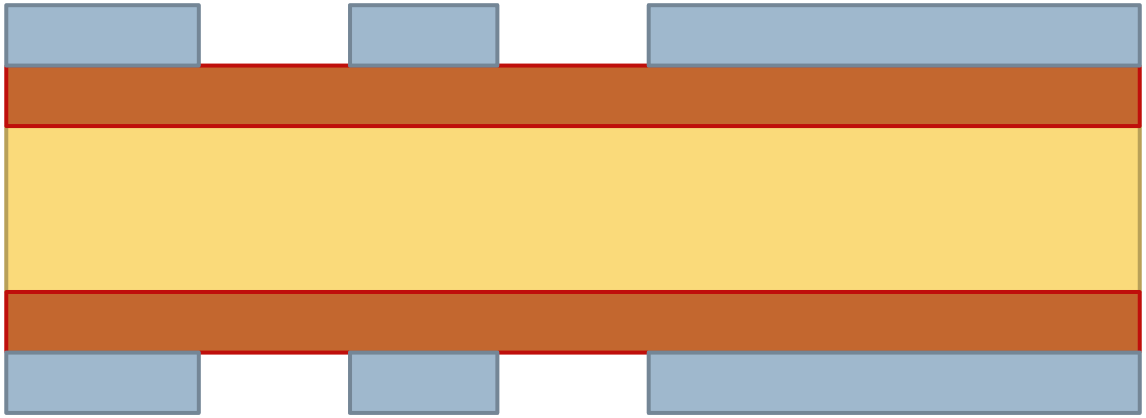
Typical process

- UV pattern exposure



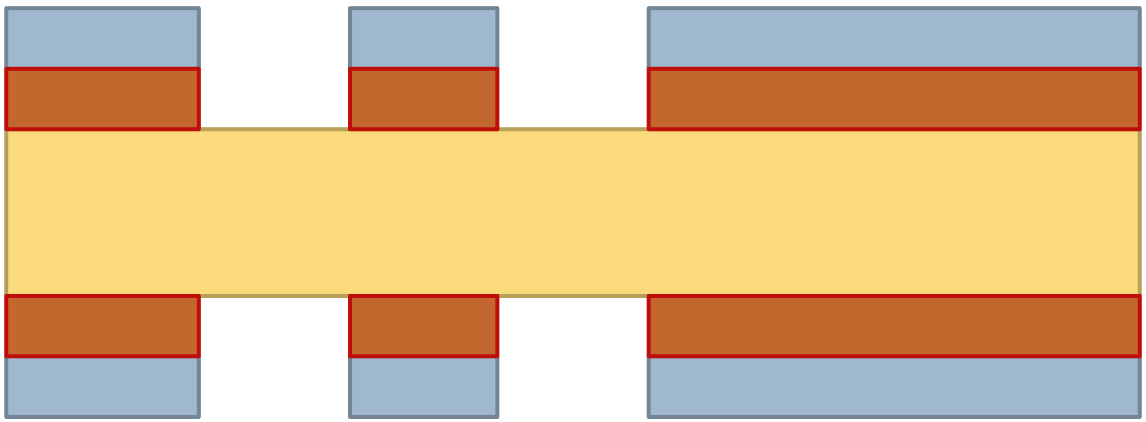
Typical process

- Develop unexposed resist



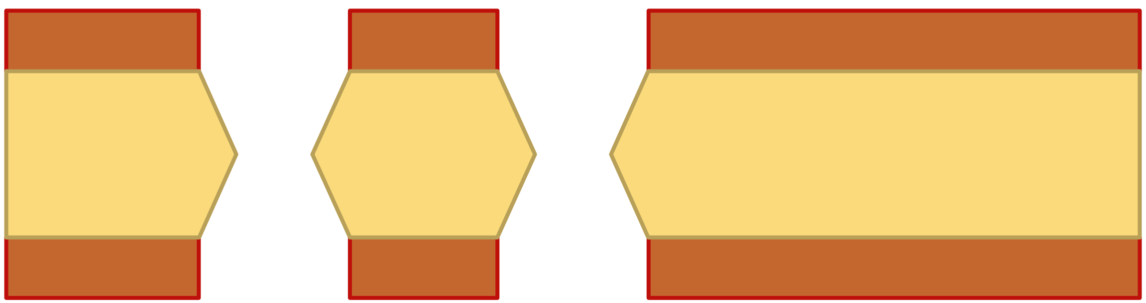
Typical process

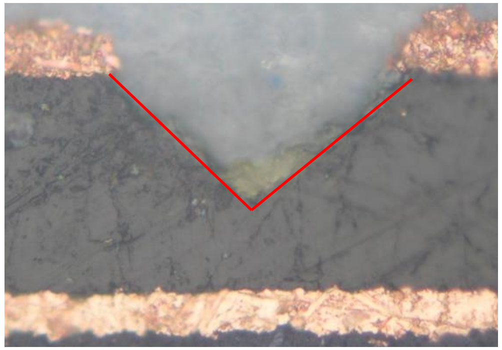
- Etch Copper & strip resist

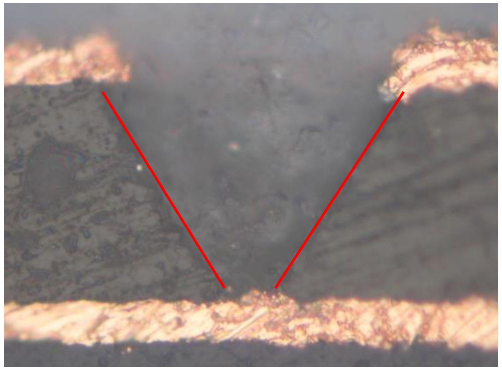


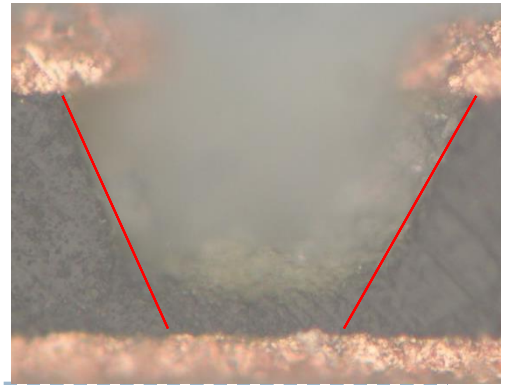
Typical process

- CERN patented polyimide etch
  - Anisotropic!
  - Very little undercut
  - Can tune the angle



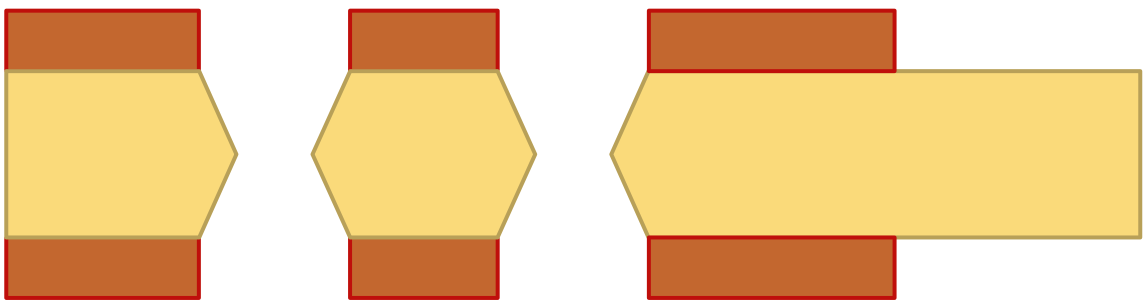


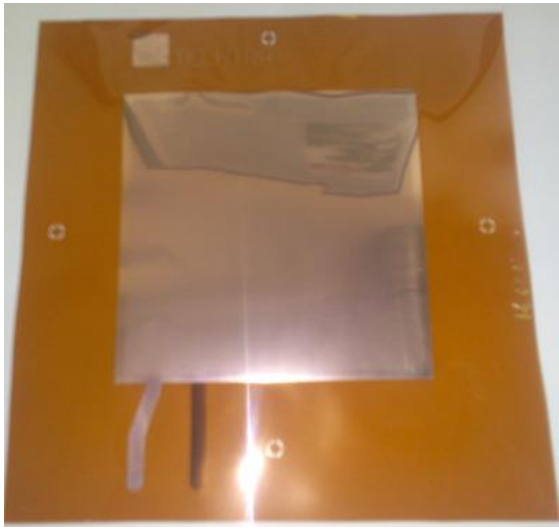




Typical process

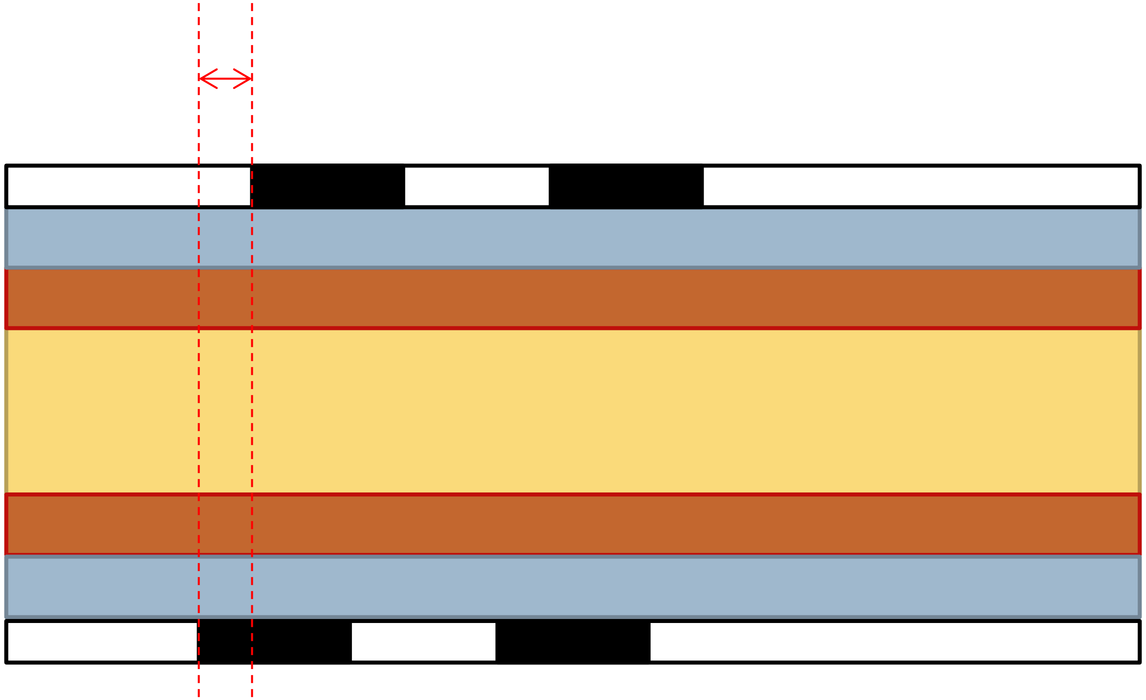
- Finally run another photolitography to pattern the elctrodes
- Apply copper passivation in an acid bath

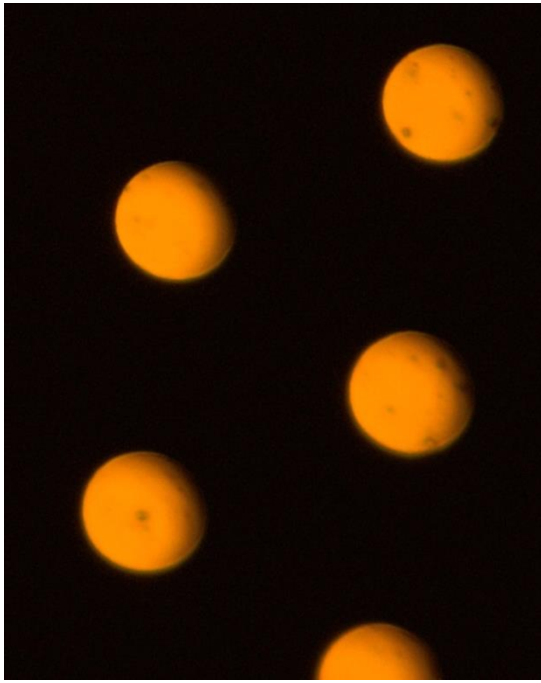




The main problem is misalignment

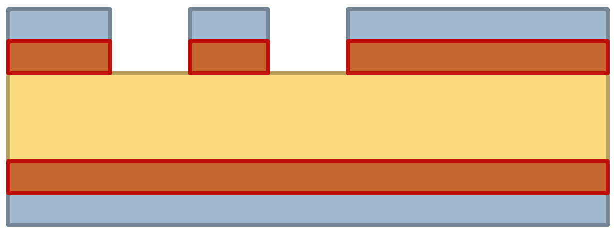
- For a large area GEM (>= 30x30 cm^2) it is nearly impossible to reliably align the masks to within 2um

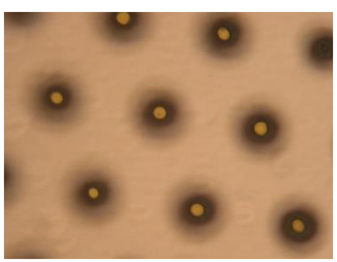


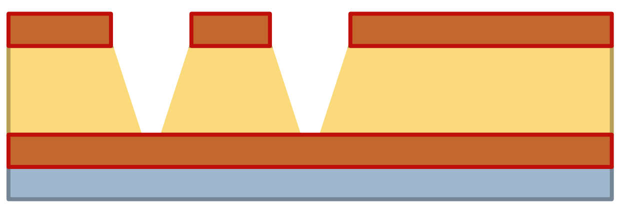


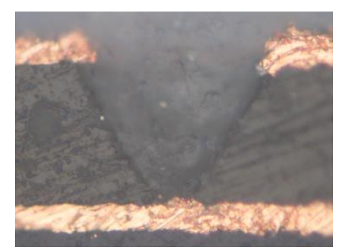
Single-mask technique

- The solution is not to try to align
- But work from one side only!
- You first pattern the holes and etch polyimide from one side.



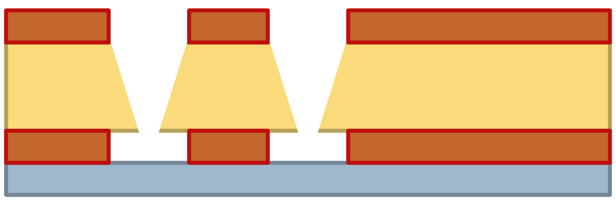


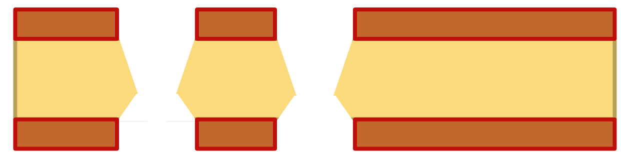


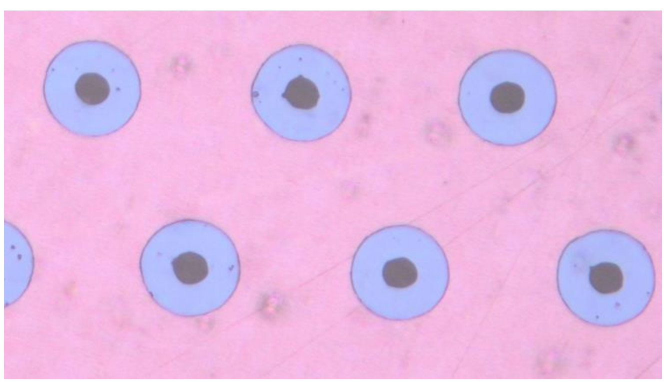


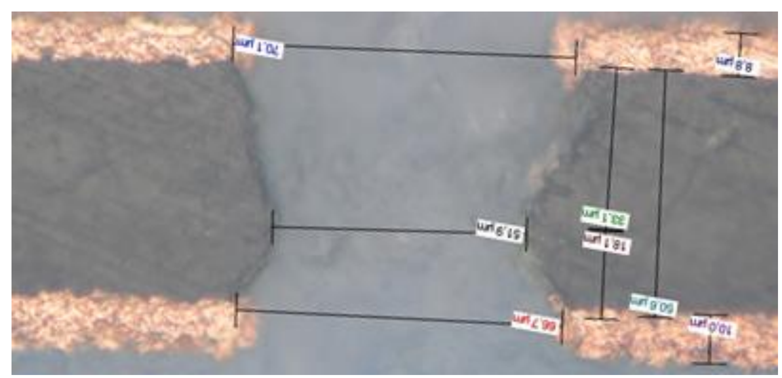
Single-mask technique

- R. De oliveira has show how to use electrical corrosion protection to etch the bottom copper, while keepint the unexposed top one intact.
- Finally, a second polyimide etch forms the cones.



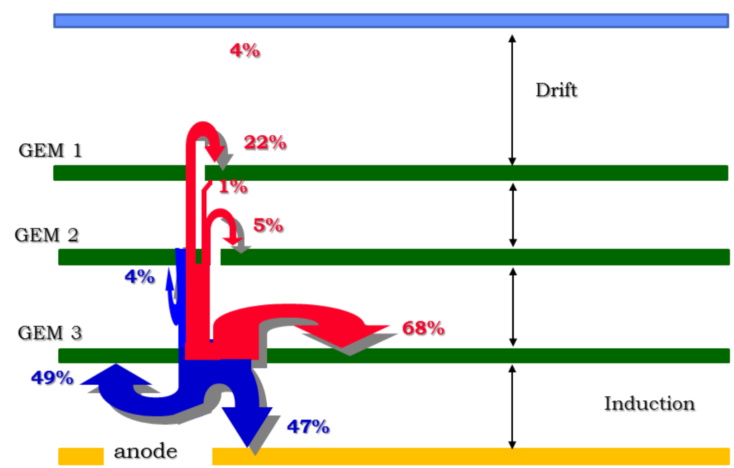






GEM research directions & unknowns

- Other materials:
  - Polyimide is hygroscopic, possible to replace with a les moisture adsorbing material?
  - Is it possible to manufacture resistive electrodes?
  - Lower-Z materials
  - Use of normal fiberglass laminate (Thick GEM)
- Operating stability:
  - Limiting ion backflow.
  - Intentional stack miaslignment.
    - Many new GEM geometries



- How radiation-resistant a GEM really is?

Img L. Ropelewski, GEM for ALICE TPC upgrade, CERN 2012