Particle detector development in various fields of physics
Serge Duarte Pinto
Gaseous detectors
Ionization
Drift, multiplication
Induction
Gems
Large gems
Single mask technique
Splicing
Prototype
Spherical gems
Diffraction
Prototype
Tooling
Beam instrumentation
Robust triple gem

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PHOTONIS

4 July 2017

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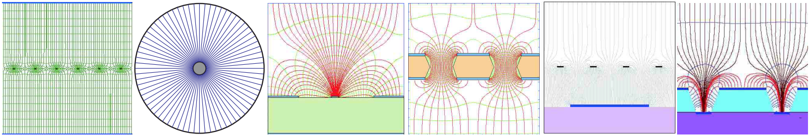
Gaseous detectors
Working principle

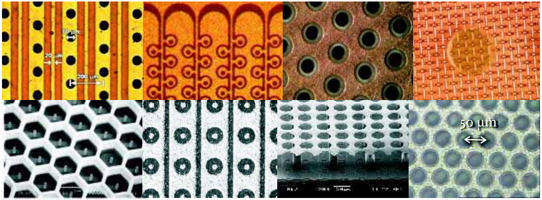


multiwire | single wire | strips | holes | parallel plate | grooves

Working principle of all gaseous detectors

1. Ionization
2. Drift
3. Multiplication
4. Charge collection/ signal induction

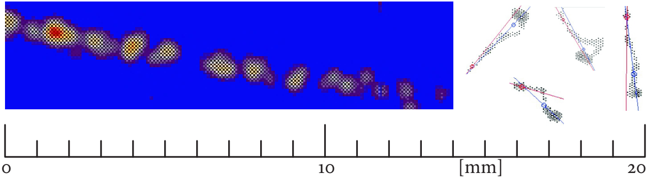
microhole & strip plate | Cobra | thickGEM | bulk Micromegas



micropin array | µ-PIC | InGrid on pixel chip | fine-pitch GEM

Ionisation

Charged and neutral particles



Ionization mechanisms

- Charged particles: tracks, clusters
  - Primary ionization
  - Secondary ionization
  - Penning transfer
- Neutral particles (photons, neutrons): conversion process
  - X-rays: heavy noble gases (Kr, Xe)
  - Neutrons: special isotopes (^{3}He, ^{10}B)

Isotopes used for thermal neutron detection

Isotope	σ(barn)	Reaction
^{3}He	$5.33 \cdot 10^3$	$^3\text{He} + \text{n} \rightarrow {}^3\text{H}(0.19\text{MeV}) + \text{p}(0.57\text{MeV})$
^{6}Li	$9.45 \cdot 10^2$	$^6\text{Li} + \text{n} \rightarrow {}^3\text{H}(2.74\text{MeV}) + \alpha(2.05\text{MeV})$
^{10}B	$4.01 \cdot 10^3$	$^{10}\text{B} + \text{n} \rightarrow {}^7\text{Li}(0.83\text{MeV}) + \alpha(1.47\text{MeV})$

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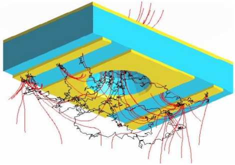
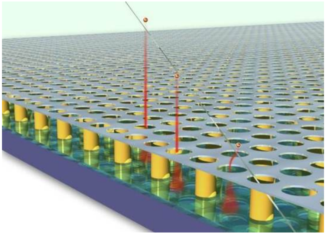
Drift

- Electrons: high drift velocity and strong diffusion:

$$\sigma_x = \sqrt{\frac{2DL}{\mu E}} \quad \text{(L is the drift length)}$$

- Ions: follow electric field lines, but $\sim 1000\times$ slower





Multiplication

- Strong electric fields, ~ 10 kV/cm and more
- Only electrons make ionizing collisions
- The avalanche develops exponentially:

$$\frac{N}{N_0} = \exp \int_a^b \alpha ds$$

(α is the *first Townsend coefficient*)

- Proportional mode (energy resolution)

Collection & induction

Signals induced by movement of charges

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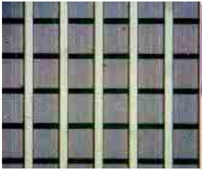
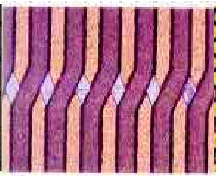
Induction

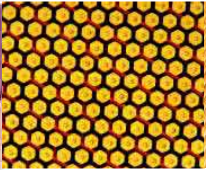
- All charges are absorbed by electrodes, or recombine.
- Only movement of charges causes signal induction.
  Ramo's theorem:
  $$I_n^{ind}(t) = -q\mathbf{E}_n\left[\mathbf{x}(t)\right]\cdot\mathbf{v}(t).$$
  $\mathbf{E}_n$ is the *weighting field*.
- Wire chamber signals are dominated by slow movement of ions (the so-called *ion tails*).
- The case of resistive readout electrodes is more complicated (the weighting field becomes time dependent).



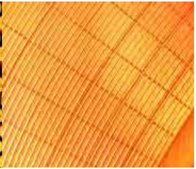
cartesian



small angle



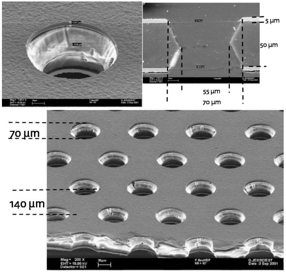
hexaboard



strips-on-pads

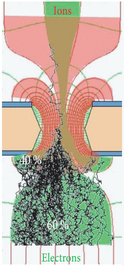
GEMs

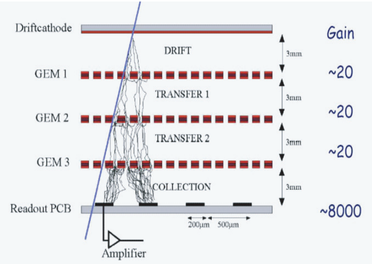
Gas Electron Multiplier

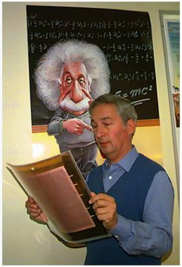


GEM properties

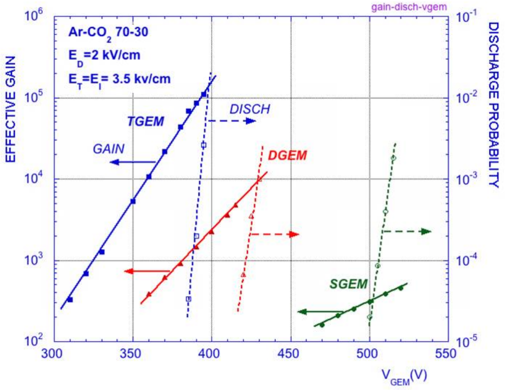
- Amplification structure independent from readout structure
- Fast electron signals, no ion tails
- Manufacturing based on industrial materials & procedures
- Possibility to cascade
- Flexible material, possible to change shape



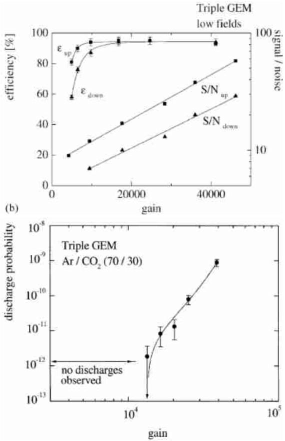




Cascading GEMS suppresses discharge probability



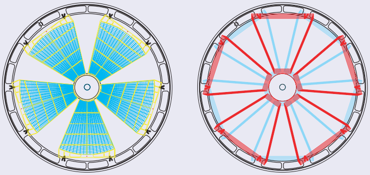
S. Bachmann et al Nucl. Instr. and Meth. A 479(2002)294

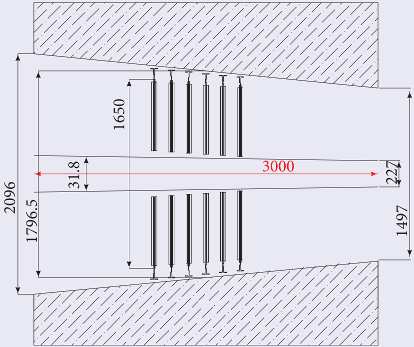


S. Bachmann et al, Nucl. Instr. and Meth. A 470 (2001)548

Ideas for a TOTEM T1 upgrade

- Large triple GEM chambers ($\sim 2000\ \text{cm}^2$)
- Discs of 2×5 chambers, back to back
- Overlap allows adjustable disc radius





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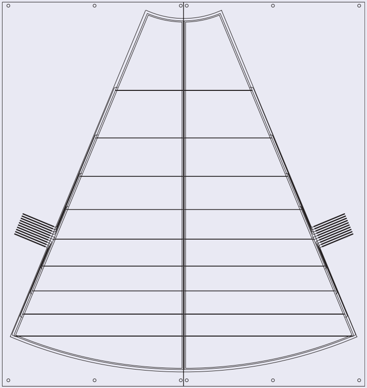
Technical hurdles for fabrication of large GEMs

- Double mask technique introduces alignment errors at such dimensions
- Base material is only 457 mm wide



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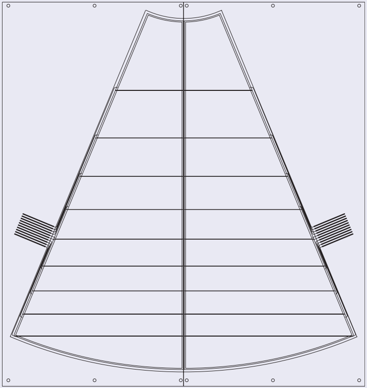
Technical hurdles for fabrication of large GEMs

- Double mask technique introduces alignment errors at such dimensions ⟶ *use single mask technique*
- Base material is only 457 mm wide



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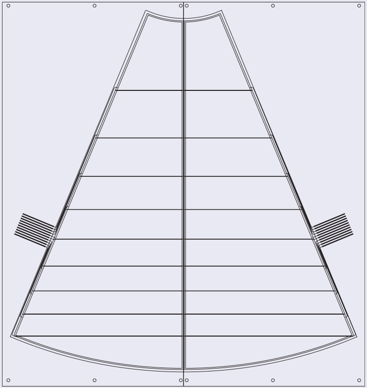
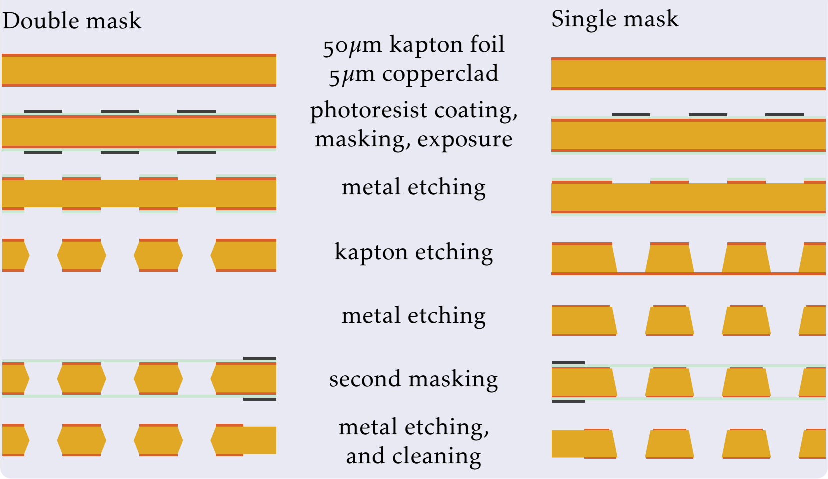
Technical hurdles for fabrication of large GEMS

- Double mask technique introduces alignment errors at such dimensions ⟶ *use single mask technique*
- Base material is only 457 mm wide ⟶ *splice foils together*



Large GEM manufacturing

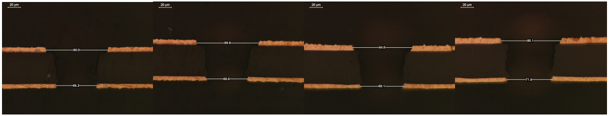
Double mask vs. single mask technique

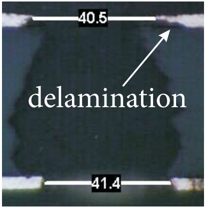


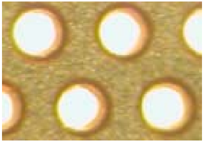
Single mask technique
Similar performance at lower cost

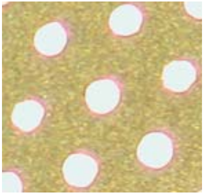
First results were not encouraging ⟶

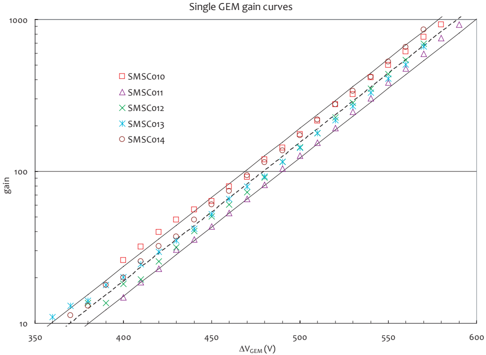
SMT now performs similar to standard GEM.



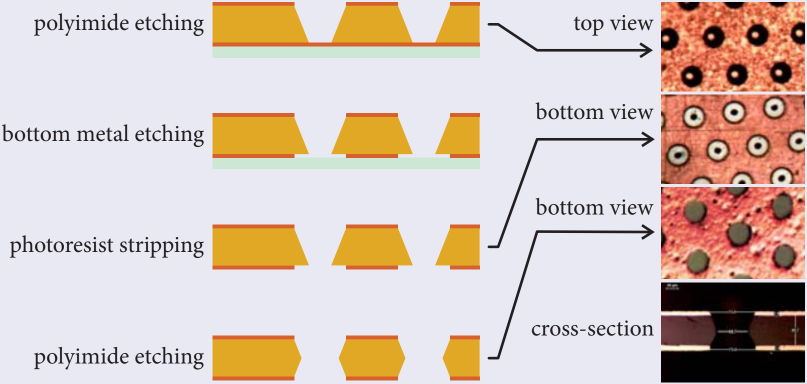








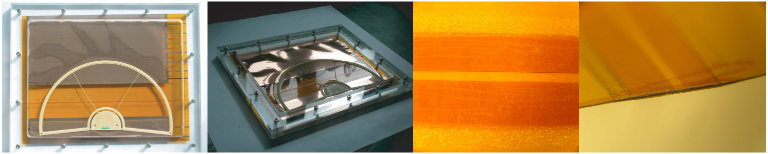
Evolution of single-mask technique results in biconical holes

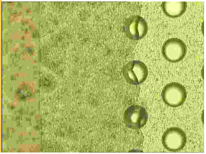


Both visually and in terms of performance these GEMs are almost indistinguishable from standard GEMs.

Splicing GEMs

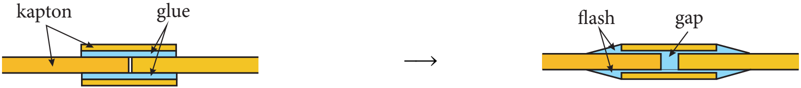
Glue foils with pyralux coverlay

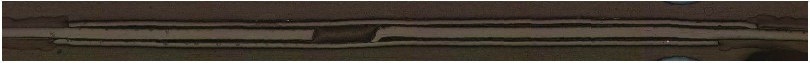




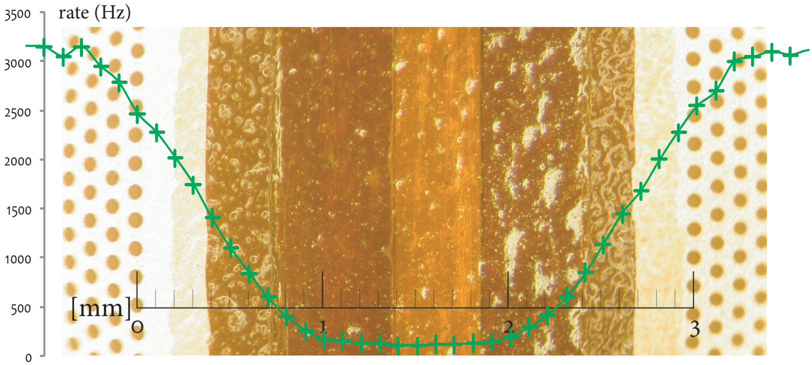
Coverlay to glue GEMs

Seam is flat, regular, mechanically and dielectrically strong, and only 2 mm wide.





- X-ray with ∅0.5 mm collimator
- Rate scan over the seam
- Behaves normally until at the seam
- Performance rest of GEM surface unaffected



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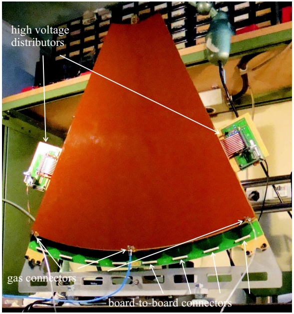
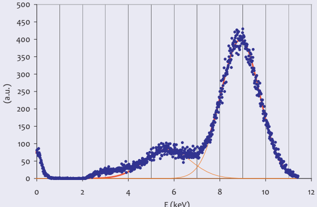


Energy resolution

$\frac{\sigma_E}{E} = 9.5\%$ at 8.05 keV (Cu x-rays)

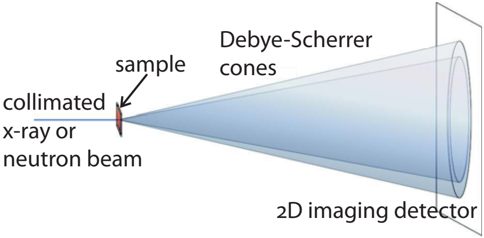


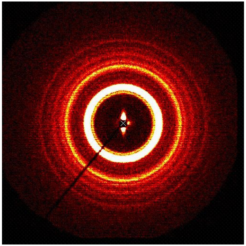
X-ray or neutron diffraction

Powder diffraction with 2D detector

Diffraction and detector requirements

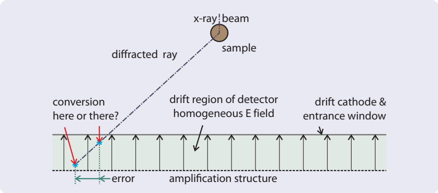
- Circular patterns if sample is powder of randomly oriented crystals.
- Need a large area detector (large for solid state standards)
- Gas detector seems natural solution, but introduces parallax error

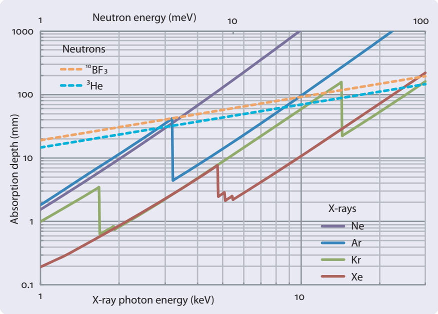




Diffraction with gas detectors

Parallax error & how it degrades resolution





Methods to suppress parallax error

- Efficient conversion gas reduces the probable conversion depth
- Increase in pressure has same effect, but necessitates thicker window
- Spherical entrance window helps a lot, and allows higher pressure
- Truly spherical conversion gap would be optimal (zero parallax error)

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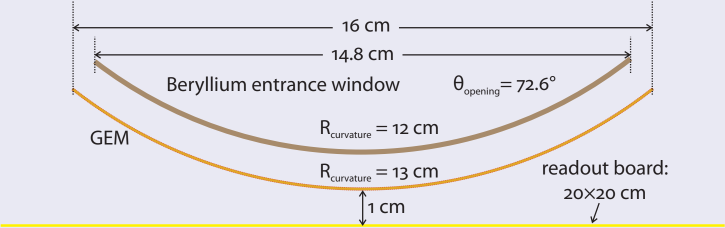
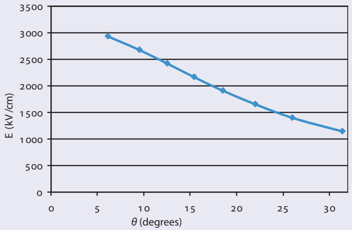
Enter a spherical GEM in an existing detector



Single spherical GEM

- Spherical Be entrance window
- Can work with 3 bar of Xe
- Spherical GEM creates radial drift field
- Charge transfer issues in induction region



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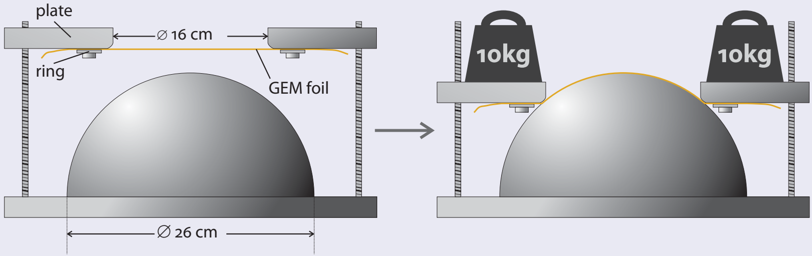
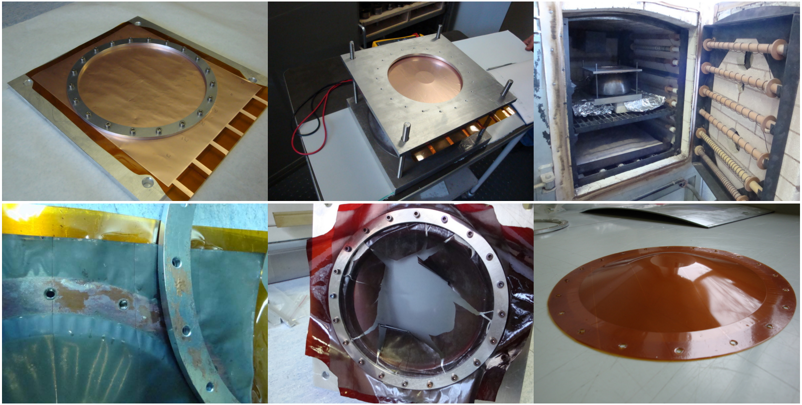


- Minimal amount of custom tooling
- The flat GEM is mounted on the plate without possibility to slip
- Opening diameters and radii of curvature can be individually tuned
- Temperature $\geq 350°$C for about 24 hours
- Weight of $\sim$ 20kg applied

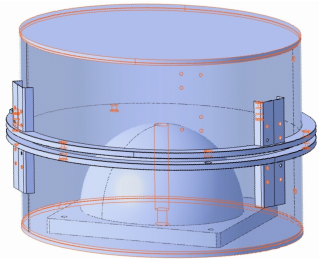
Forming spherical GEMs

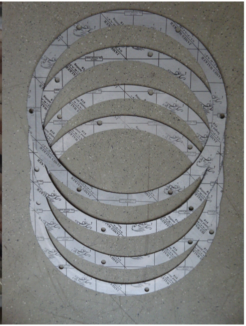
First tests: mapping a multi-parameter space



Forming spherical GEMs

Gas tight enclosure





- Stainless steel box encloses the setup completely
- Fits entirely in the oven, and can still be opened easily
- Upgraded later to work in a vacuum ($\sim 10^{-4}$ mbar)

Forming spherical GEMs

Deposits

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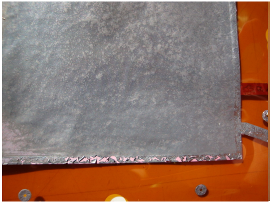
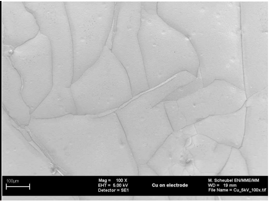
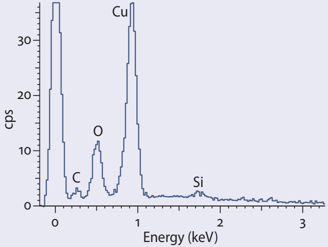




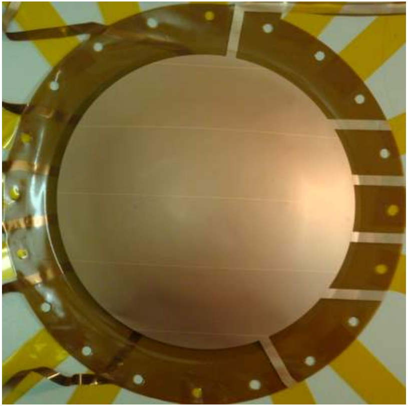


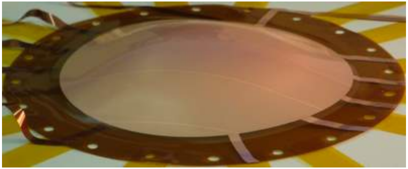
Thin film growth

- ↑ Apart from some oxidation, a thin film deposits on the electrodes
- ← Elemental analysis reveals this is also copper oxide
- . . . Working in a vacuum helps a lot to eliminate this phenomenon

Forming spherical GEMs

In a vacuum



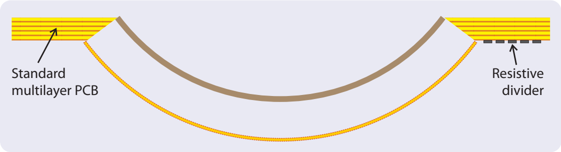


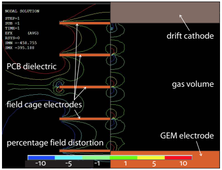
Great improvements

- Looks better than ever before
- Holds high voltage
- Still needs to be cleaned after forming, seems to be inevitable

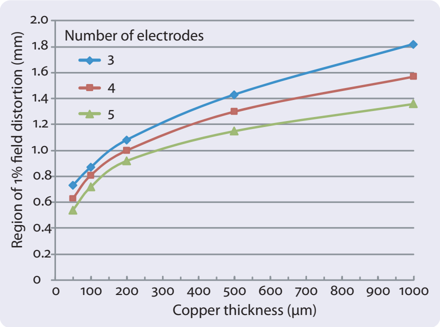
Conical field cage

For a well-defined field in the conversion region





- Lateral extension of fringe field between the spherical planes is proportional to width of conversion gap
- Radial field quality is critical for parallax-free property
- A field cage can be made of a standard multilayer PCB
- Resistive divider distributes voltages over layers
- The cage can be the mechanical fixture for the GEM

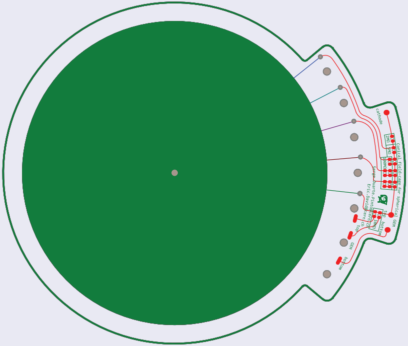


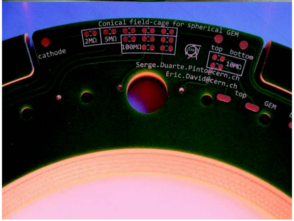
Conical field cage

Made from multilayer PCB

Design of conical field cage for first prototype

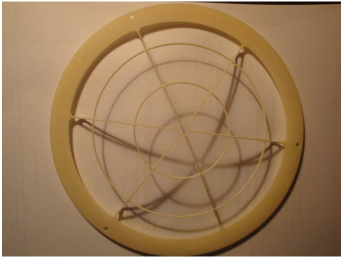
- 5 electrodes
- Also supplies GEM and fixes it mechanically
- Fabrication is fast and cheap

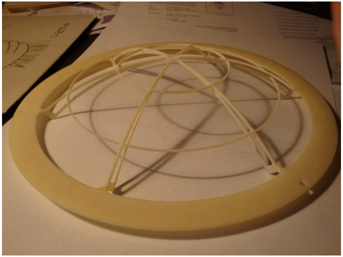




Spacers

Curved structure to keep accurate spacing

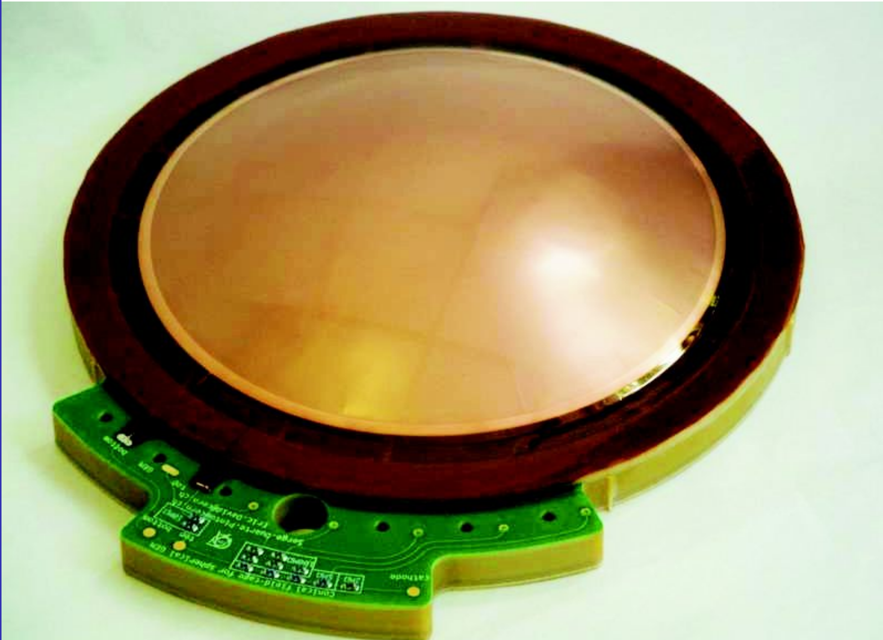




Curved spacer in drift gap

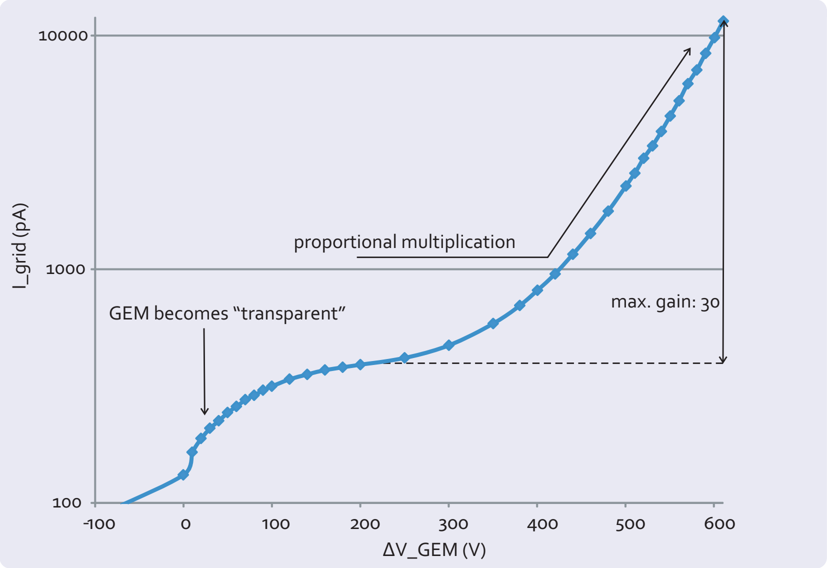
- Not certain if it is needed, spherical GEMs seem rather self-supporting
- Fabrication less straightforward than flat spacers
- Stereolithography is accurate, fast, and affordable
- Improved design solves minor flaws

Final assembly
Before integration in detector



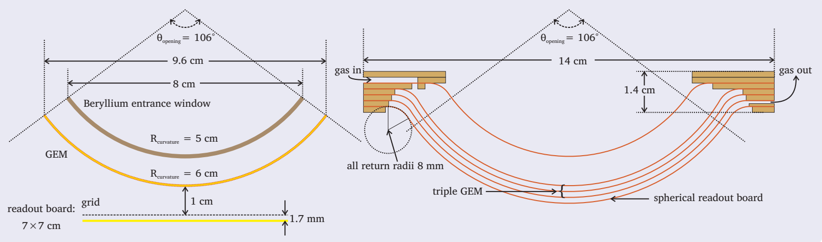
First results

At 2 bar pressure



Spherical multiple GEM

Solves transfer issues



Multiple GEM with spherical readout

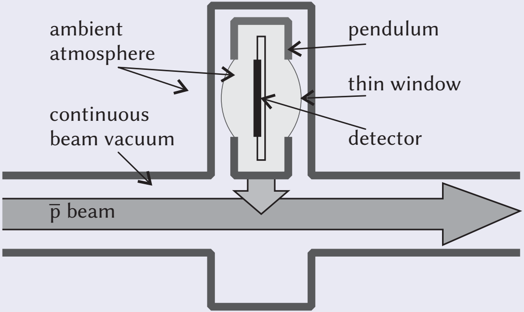
- We can recycle some tooling and films from existing design
- With 2D readout one can avoid effective gain variations with θ
- For mechanical tolerance, we may need to increase inter-GEM spacing
- Spherical readout board will be highly non-trivial

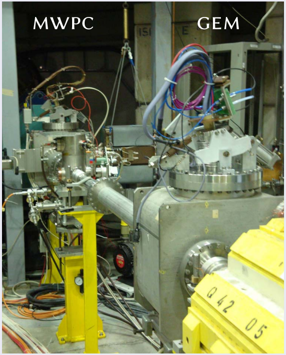
Antiproton decelerator

Beam profile measurements

Movable detector that absorbs beam

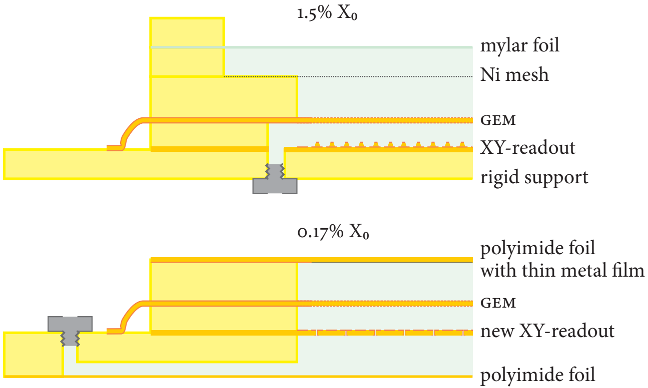
- Due to low energy (5.3 MeV) beam profile measurements are necessarily destructive.
- Detector installed in a pendulum that can be moved in & out the beam.
- The inside of the pendulum is in contact with ambient air.
- Window of 25 μm (ss) causes energy loss and multiple scattering.





The readout board

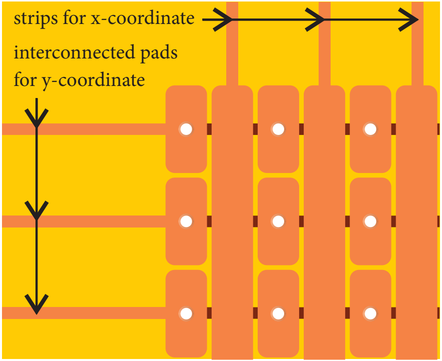
Light version



Design changes

- Change of readout board and drift electrode leads to 89% reduction in material budget
- Gas distribution through the vias

Particle detector development in various fields of physics
Serge Duarte Pinto
Gaseous detectors
Ionization
Drift, multiplication
Induction
GEMs
Large GEMs
Single mask technique
Splicing
Prototype
Spherical GEMs
Diffraction
Prototype
Tooling
Beam instrumentation
Robust triple GEM



Readout optimized for the purpose

- Lower pitch allows space for vias
- Much cheaper and more robust structure
- Equal charge sharing by geometry, no surface charging involved
- Same design works on rigid board or flex

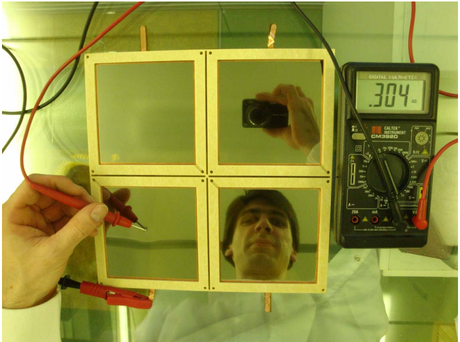
A flex readout board allows a significant reduction of material budget …

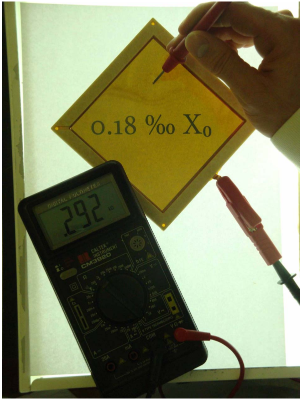
The cathode

Thin metal layer deposited on Kapton

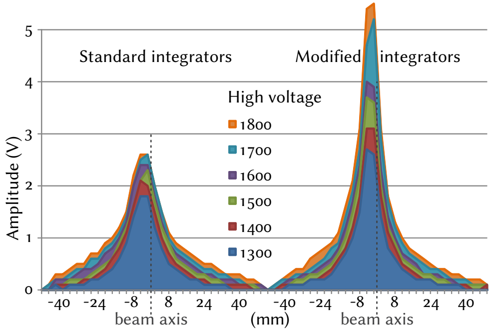
Cathode & window

- Made from the base material of CERN GEMs.
- In the active area all copper is removed, but not the submicron tie-coat of chrome.
- The resistivity is reproducible from foil to foil, and does not change after stretching.
- Any surface impact must be avoided.

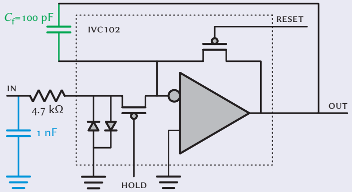




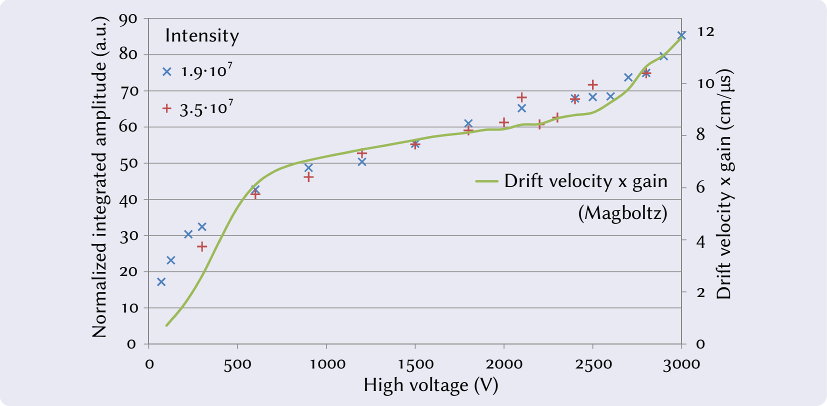
Light single GEM
For the antiproton decelerator



- Single GEM to accommodate also 126 MeV beam
- Modifications of local electronics were needed to cope with fast spill structure
- Now installed throughout the AD



Profiles
Without the GEM

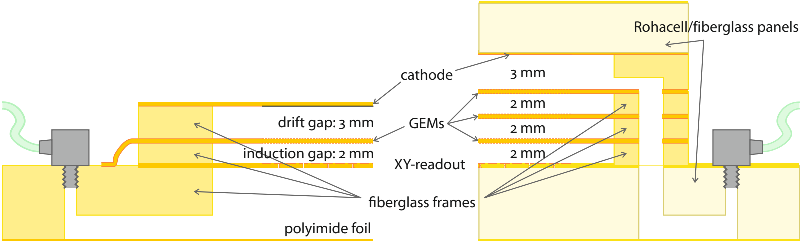


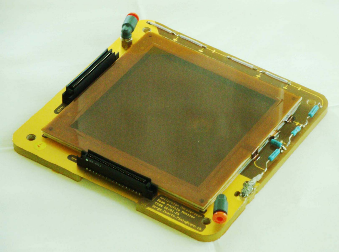
Micropattern ionization chamber (100 pF)

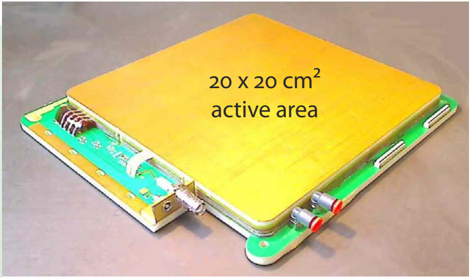
- Works fine, no distortion, proportional with beam intensity.
- Amplitude largely defined by recombination.
- Ionization density in center of the beam of order 10^{12} cm^{-3}!

Robust triple GEM

Stiff Rohacell front and back panels







Particle detector development in various fields of physics

Serge Duarte Pinto

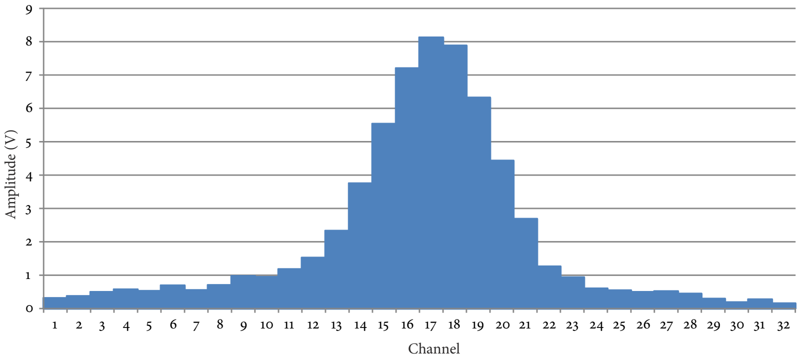
Gaseous detectors
- Ionization
- Drift, multiplication
- Induction

GEMs

Large GEMs
- Single mask technique
- Splicing
- Prototype

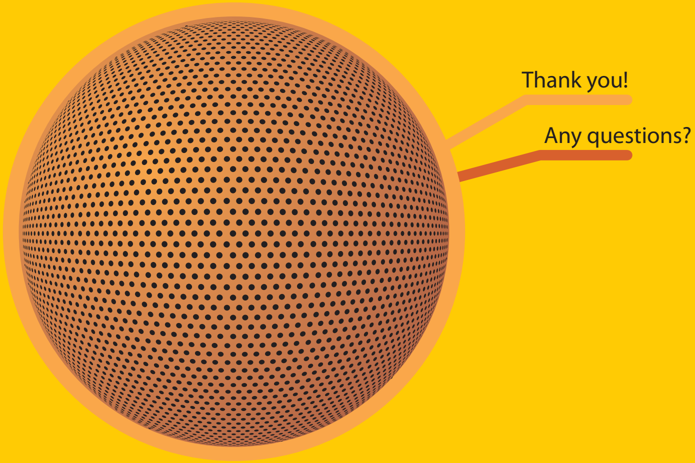
Spherical GEMs
- Diffraction
- Prototype
- Tooling

Beam instrumentation
- Robust triple GEM



- Successfully tested in SPS
- Design modification to prevent gas leakage through Rohacell foam
- Material budget of 0.85% X_0 too large for many applications of 10×10 cm² detectors

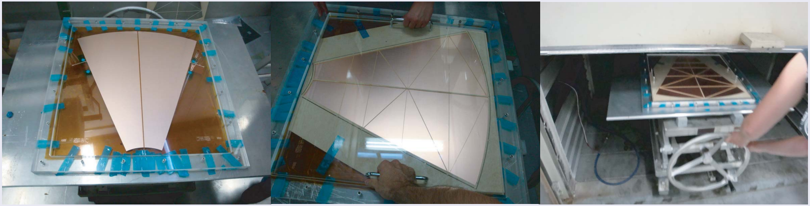
Thanks



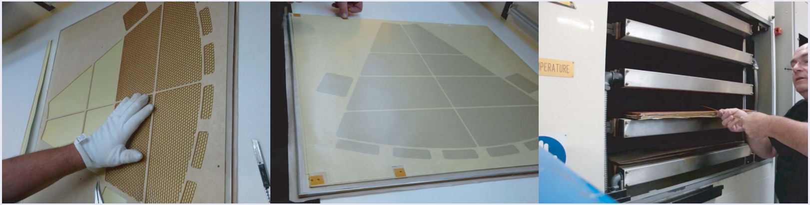
Assembly

From the design to a prototype

Stretching and framing the spliced single mask GEM foils



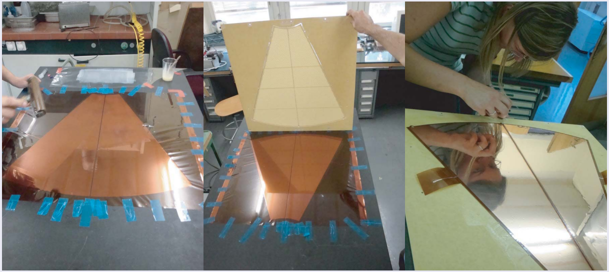
Making the honeycomb base plane and top cover



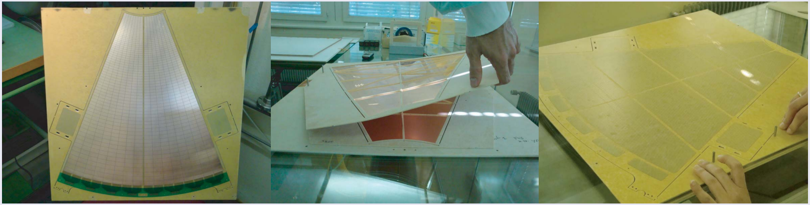
Assembly

From the design to a prototype

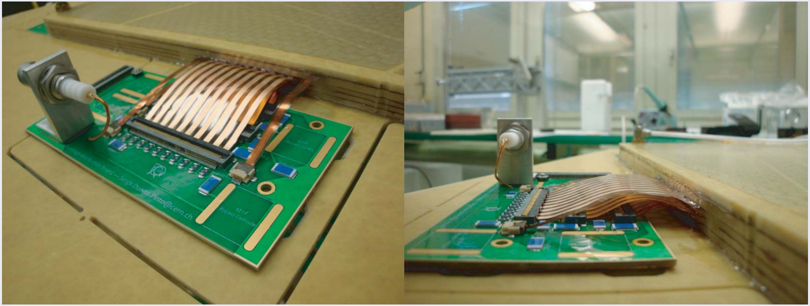
Gluing the cathode to the honeycomb frame



Final assembly of all frames



Compact high voltage divider board



- Based on only SMD components
- Using ZIF sockets to connect to GEM terminals
- Traces that lead to GEM sectors are embedded in frame
- Easy to make, and to replace or debug