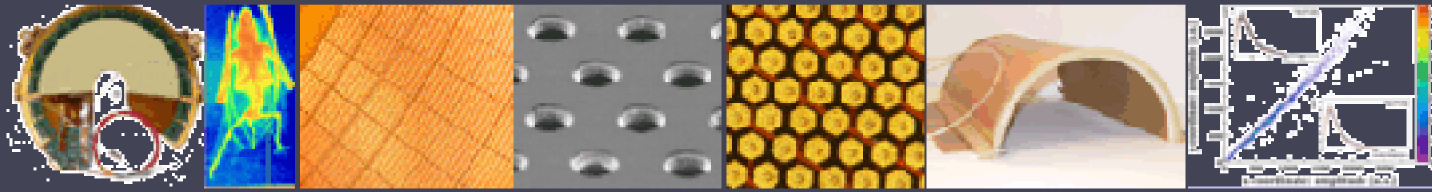


Progress on Large Area GEMs

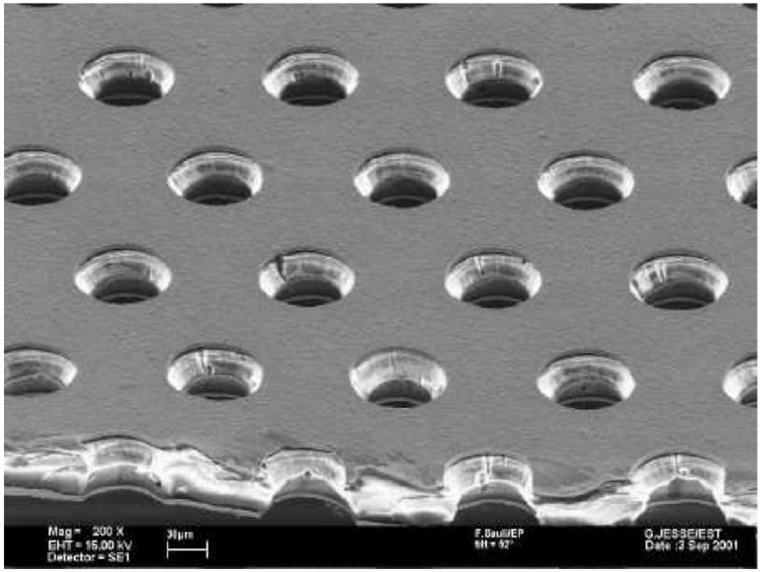
12th Vienna Conference on Instrumentation – VCI 2010
15 – 20 February 2010, Vienna

Marco Villa, Matteo Alfonsi, Ian Brock, Gabriele Croci, Eric David, Rui de Oliveira, Serge Duarte Pinto, Elena Rocco, Leszek Ropelewski, Hans Taureg, Miranda van Stenis

Outline

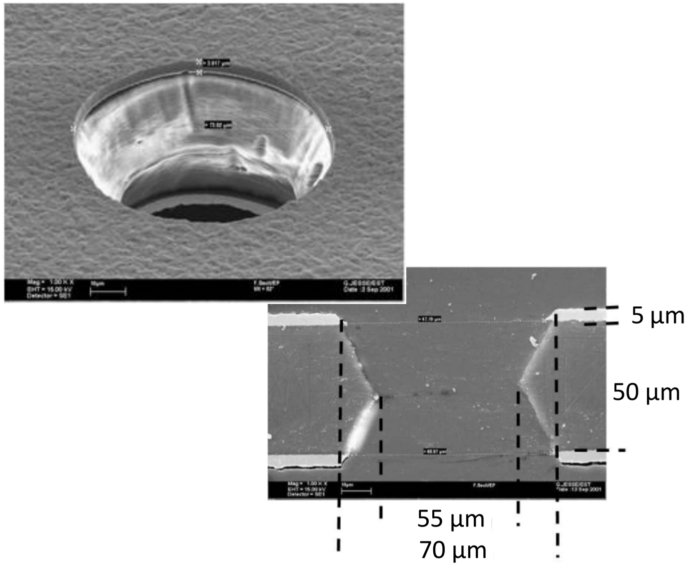
- Gas Electron Multipliers
- GEM applications
- Motivation for large area GEMs
- Single mask photolithography
  - Improving the polyimide etching
  - Improving the bottom copper etching
- Splicing GEMs
- Stretching large area GEMs
- Handling large area GEMs
- Simulating GEMs
  - Optimizing the hole geometry
- Conclusions & outlooks

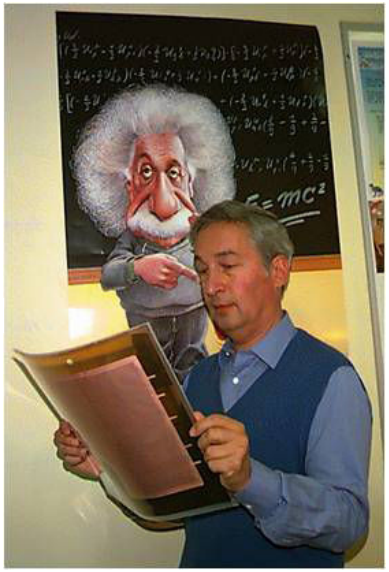
Gas Electron Multipliers

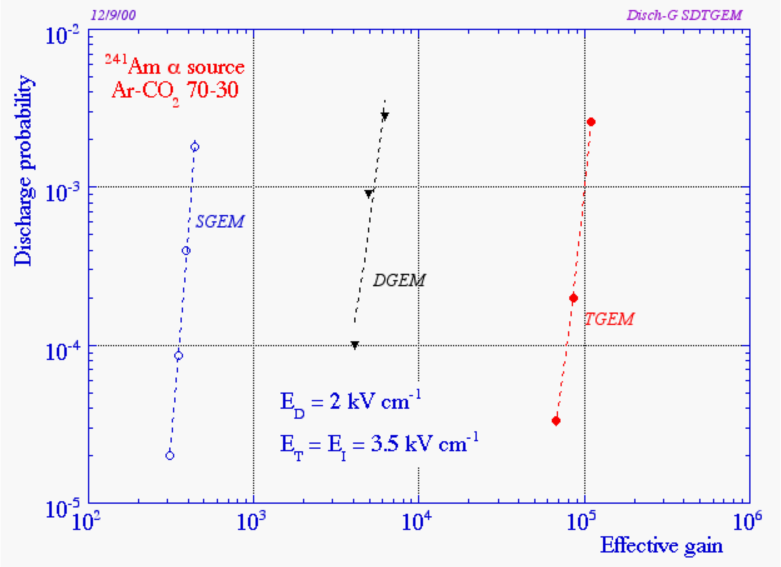


GEM properties:
- Fast electron signal, no ion tail
- Amplification structure independent from readout
- Flexible material allows non planar geometries
- Possibility to cascade
- Cascading GEMs reduces discharge probability

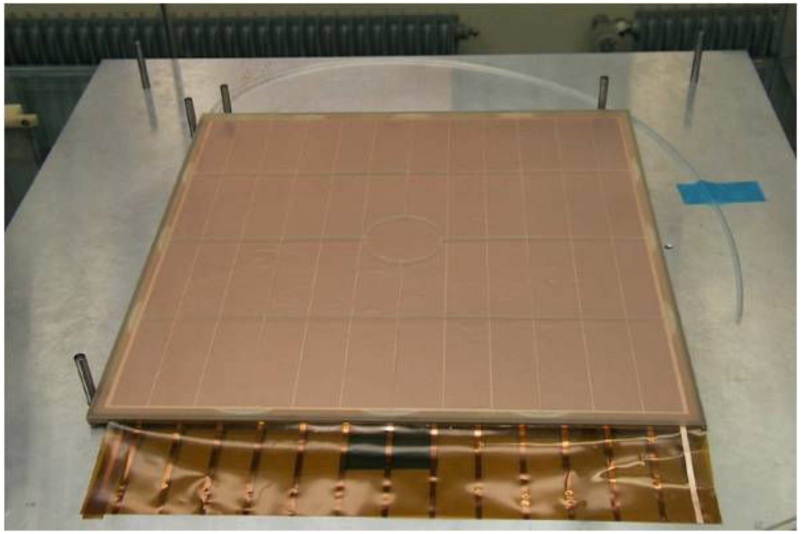
(F. Sauli NIM **A 386** (1997) **531**)





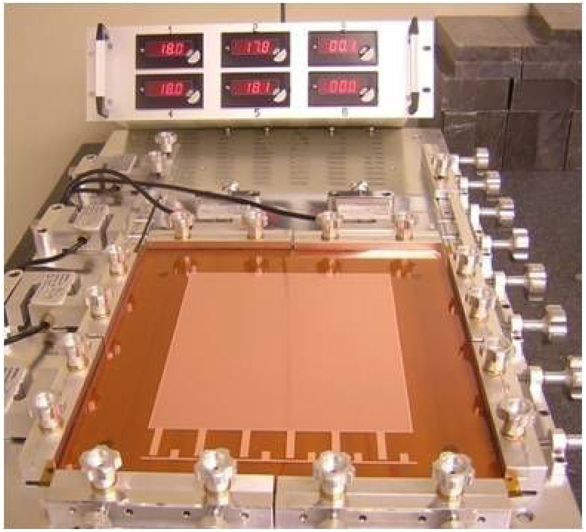


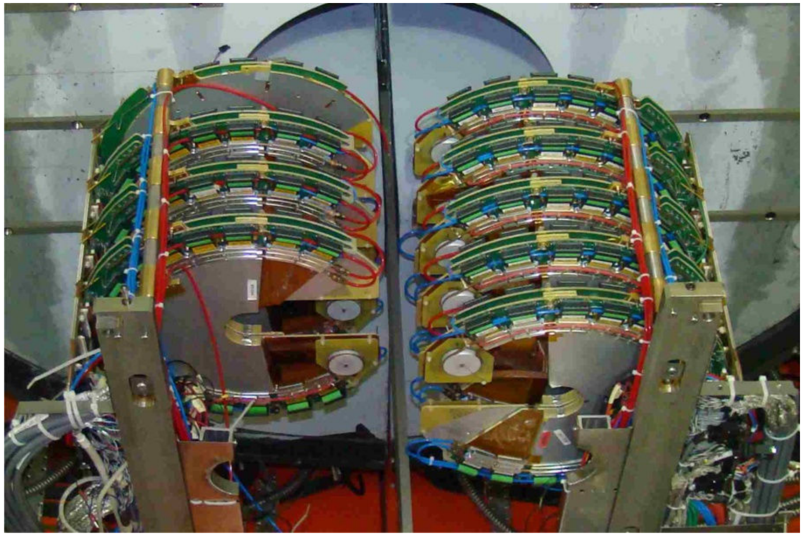
GEM applications (1)



COMPASS (NIM **A 577** (2007) **455**) – *tracking*:
- 31 x 31 cm^2 active area
- X–Y strip readout
- *Spatial resolution 46 μm*
- Required rate capability ~ 150 kHz/cm^2

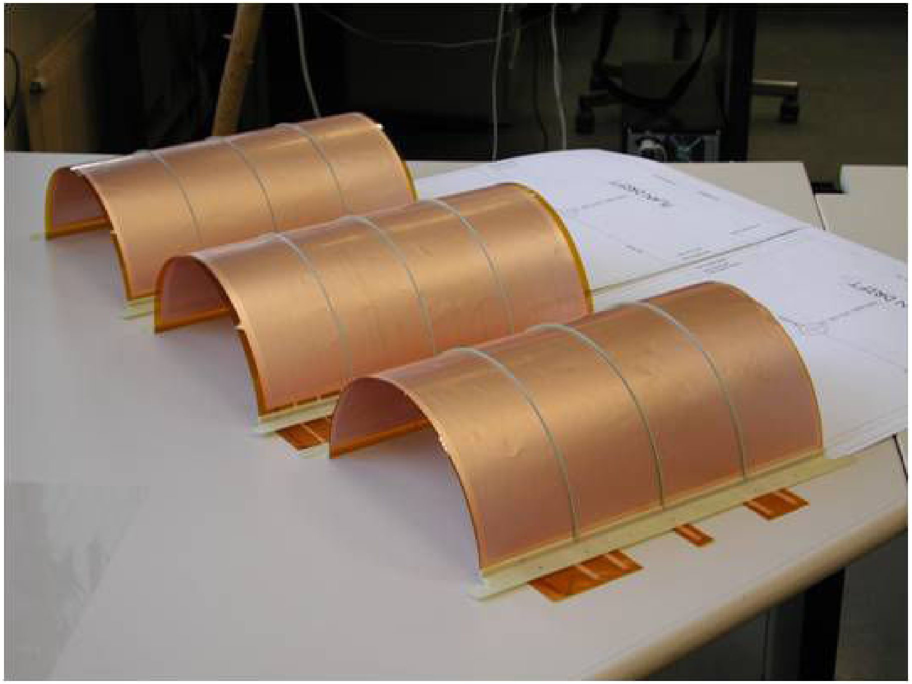
LHCb (2008 JINST 3 S08005) – *forward muon triggering*:
- 24 x 20 cm^2 area
- Pad readout
- *4.5 ns time res.*
- Required rate capability ~ 500 kHz/cm^2





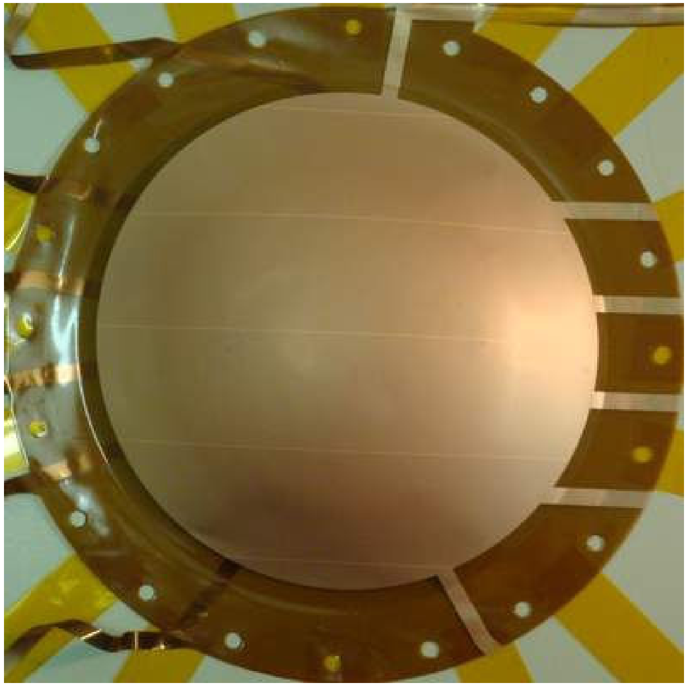
TOTEM (2008 JINST 3 S08007) – *forward tracking and triggering*:
- 30 cm diameter
- Combined strip and pad readout
- *Required rate capability ~ 1 MHz/cm^2*

GEM applications (2)

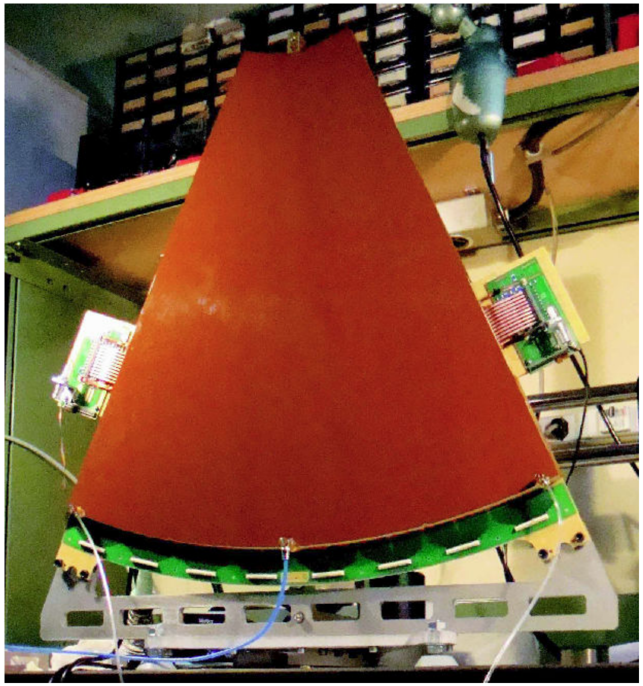


Cylindrical GEM feasibility study for Shine:
- Cylindrical triple GEM detector
- π coverage
- Based on 31 x 31 cm^2 COMPASS GEM foils
- 2D cartesian readout with 400 µm strip pitch
- APV25 readout electronics

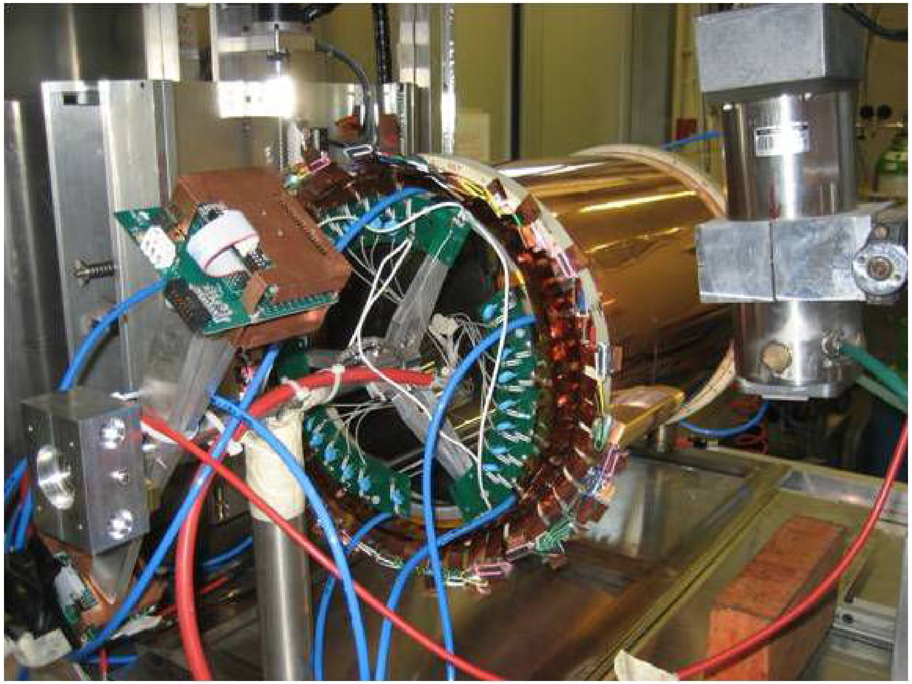
Truly spherical GEM for X–ray diffractometry:
- Spherical conversion gap gives zero parallax error
- GEM formed starting from a planar foil
- Forming on spherical mold with ~ 20 kg weight applied
- Temperature 350 °C for about 24 hours
- Conical field cage in the conversion gap
- Curved spacers to keep accurate spacing
- Planar or spherical readout



Motivation for large area GEMs (1)

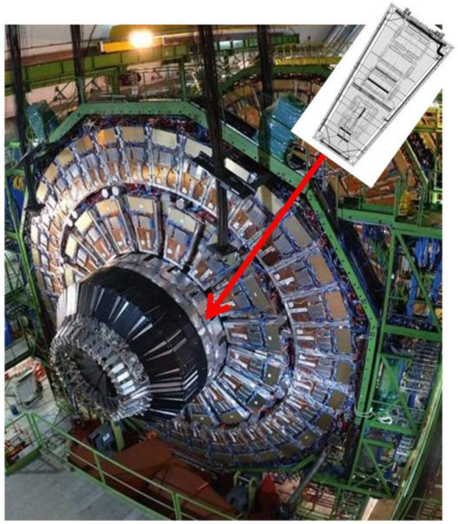


Upgrade of TOTEM T1:
- 2 telescopes constituted of back to back disks
- Each disk contains 5 chambers
- Chamber overlap allows adjustable disk radius
- Triple GEM chambers with ~ 2000 cm^2 active area
- Chambers based on GEM foils 66 x 66 cm^2
- Large area achieved splicing 2 GEMs together



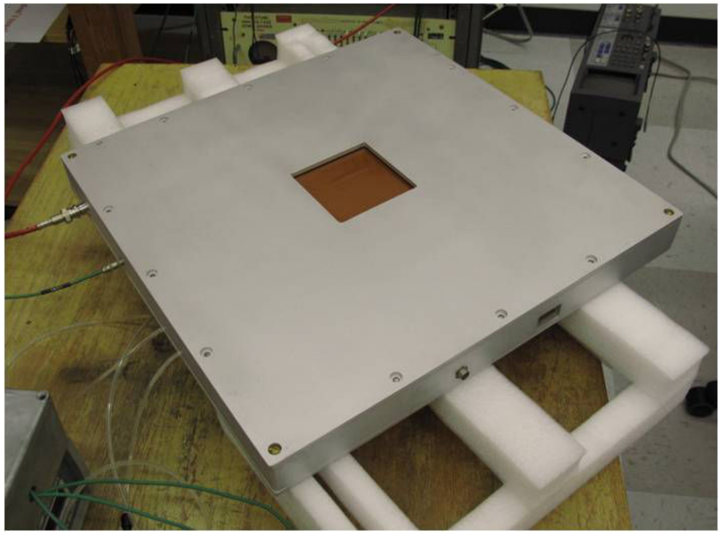
KLOE–2 inner tracker (See E. De Lucia talk):
- Cylindrical triple GEM detector
- GEMs 96 x 35.2 cm^2 active area
- Large area achieved splicing 3 GEMs together
- No spacers between GEM foils
- Cylindrical cathode with annular fiberglass support flanges

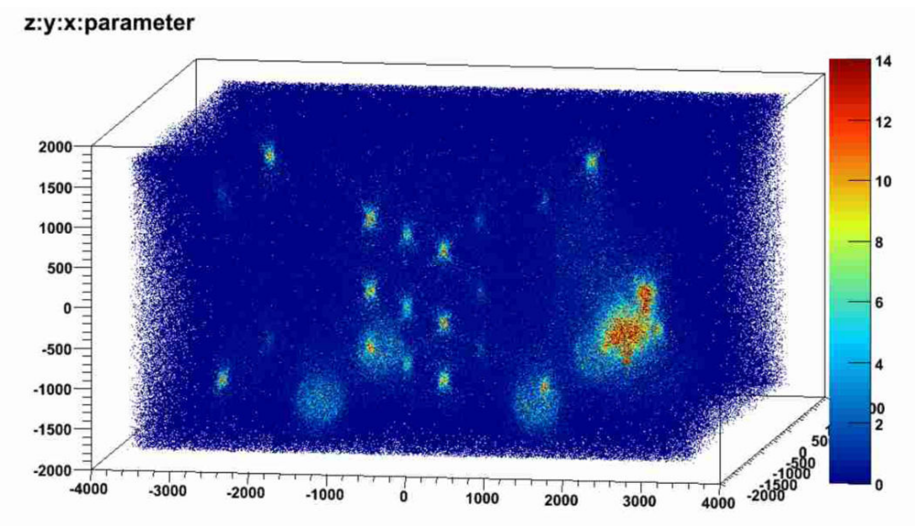
Motivation for large area GEMs (2)



CMS high η region feasibility study:
- In the 1.6 < η < 2.1 region the planned RPCs were never installed
- Studying the possibility of introducing large area MPGDs
- Triple GEM chambers with 97 x 42 cm^2 active area
- Rate capability sufficient for sLHC conditions

DHCal for ILC (A. White – MPGD 2009):
- Modules of 1 m^2 active area
- Double GEM, thin gaps to reduce total thickness



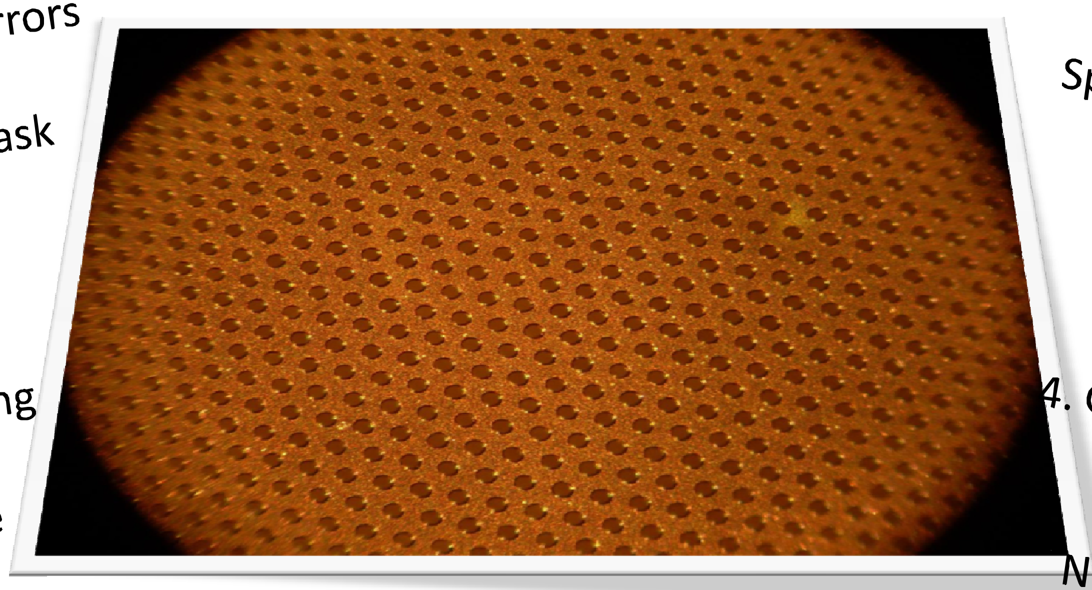


Muon tomography for homeland security (M. Hohlmann et al. – IEEE NSS 2009):
- Exploits multiple scattering of cosmic muons to locate high–Z materials in cargo
- Large area and many readout channels

Technological innovations

1. Double mask photolithography introduces alignment errors
↓
Use single mask

2. Raw material is only 457 (600) mm wide
↓
Splice GEM foils together

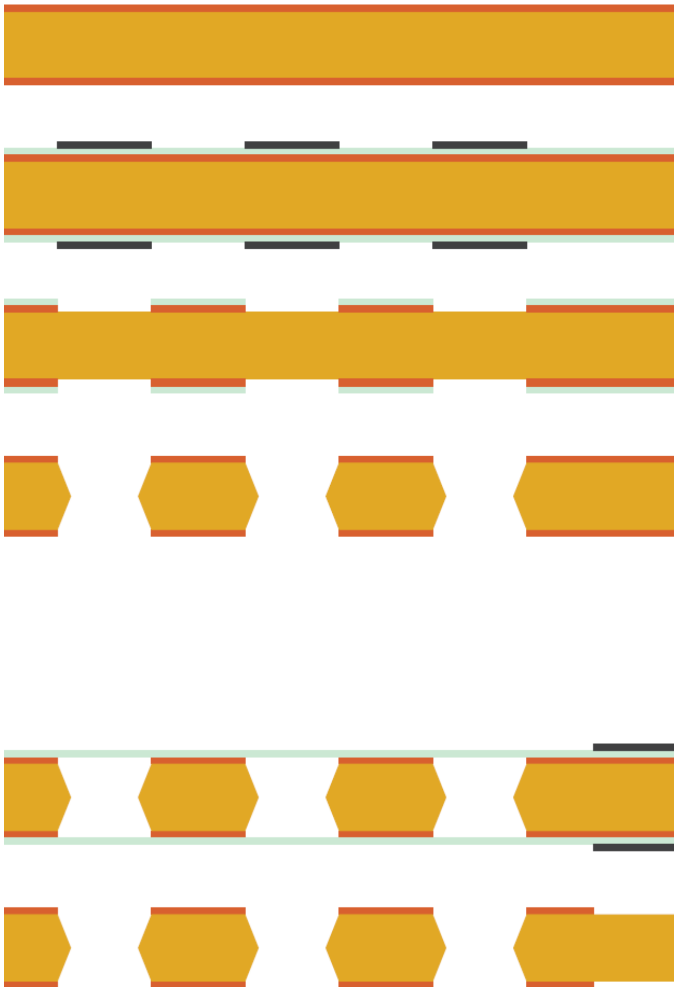


3. GEM stretching becomes troublesome
↓
Different approaches

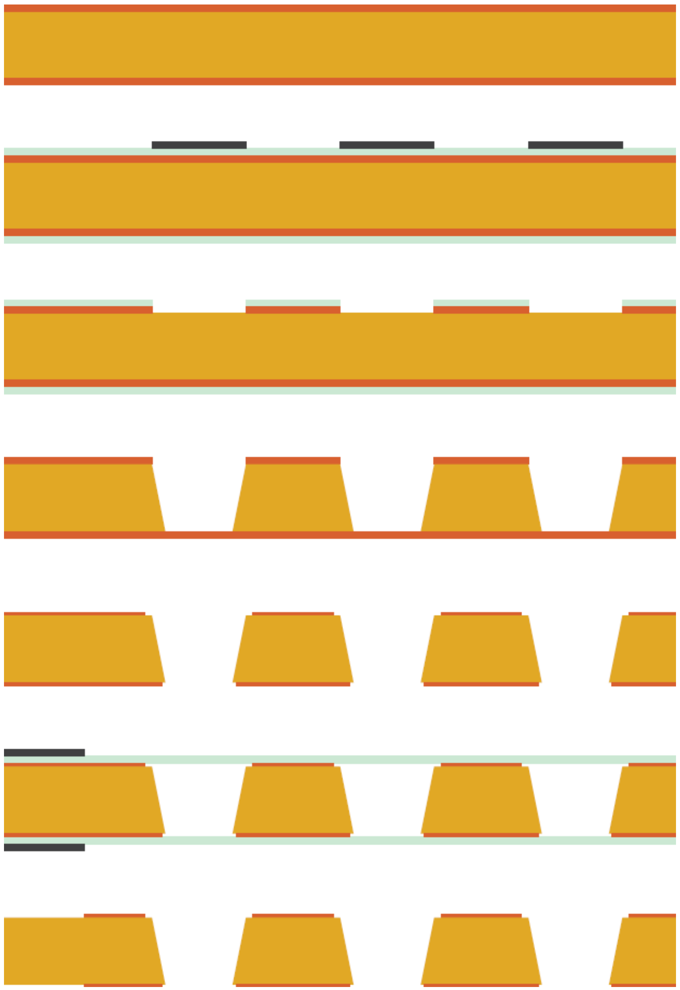
4. GEM handling gets difficult
↓
New tooling and machines

Double mask vs. single mask

Double mask photolithography



Single mask photolithography



50 µm kapton foil 5 µm copper clad on both sides

Photoresist coating, masking, exposure

Photoresist development, copper etching

Kapton etching

Metal etching

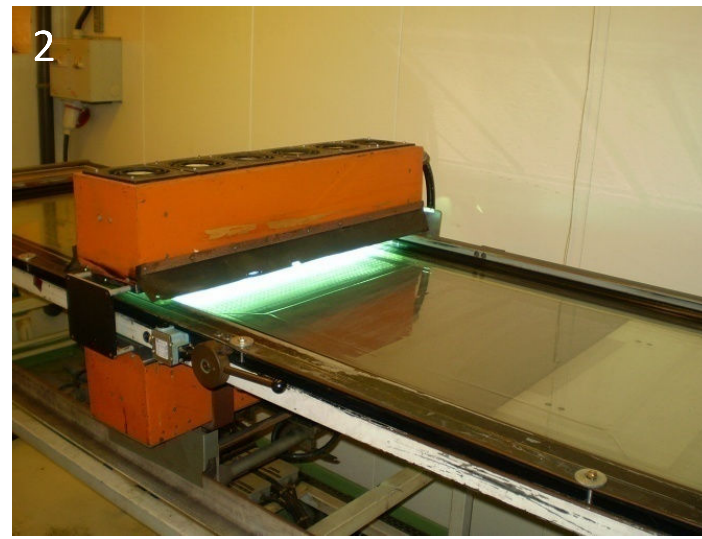
Second masking, exposure

Development, etching, final cleaning

Creating the GEM pattern

1 – **Photoresist lamination**:
- Base material delivered in 457 (600) mm x 100 m rolls
- Piece of base material gets laminated with photoresist
- Lamination performed under pressure at 100 – 110 °C
- It is important to prevent the formation of air bubbles

2 – **Exposition**:
- Mask kept in place by vacuum system
- UV light polymerizes unmasked photoresist
- Important to tune the amount of light

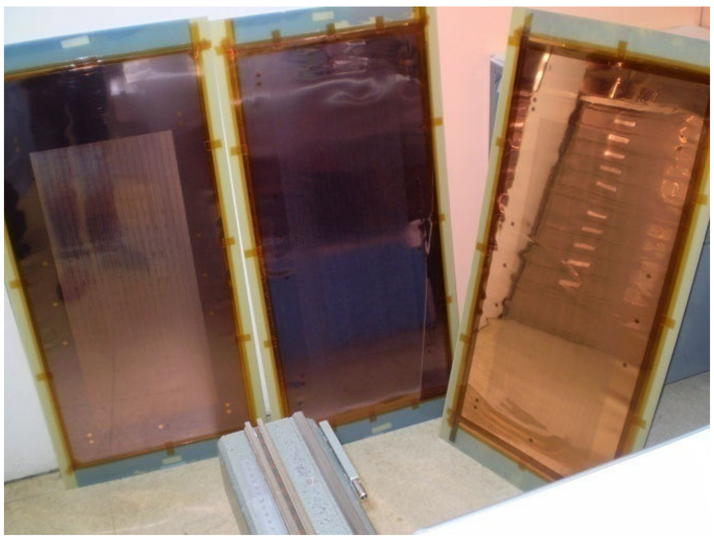


3 – **Photoresist development**:
- GEM placed in an oven at 100 °C for a few minutes
- Sodium carbonate rinsing removes non polymerized photoresist

Etching the holes in the GEM

Etching the top copper electrode:

- Ferric chloride and hydrochloric acid rinsing create the hole pattern on the top copper electrode
- Basic bath removes the chromium layer in the holes
- Neutralization necessary

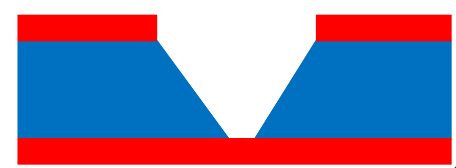


Photoresist removal:

- Ethanol used to remove the photoresist

Potassium hydroxide (KOH) → isotropic

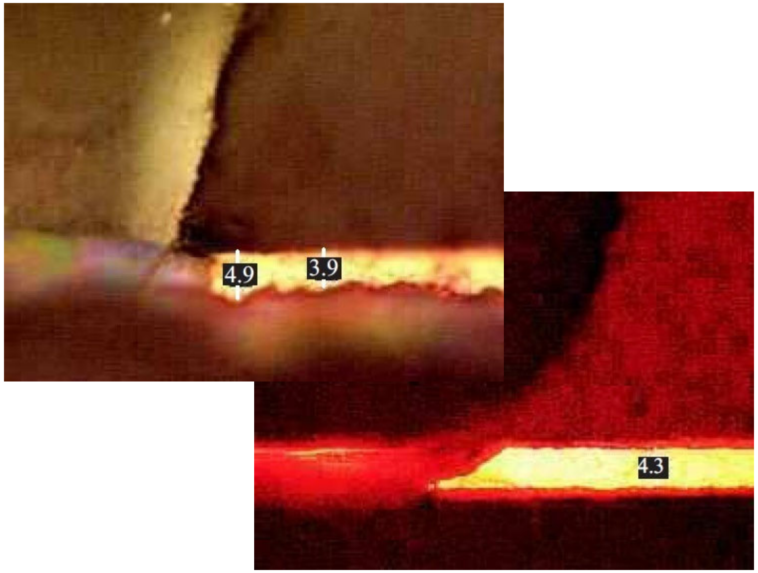
Ethylene diamine → anisotropic



Polyimide etching:

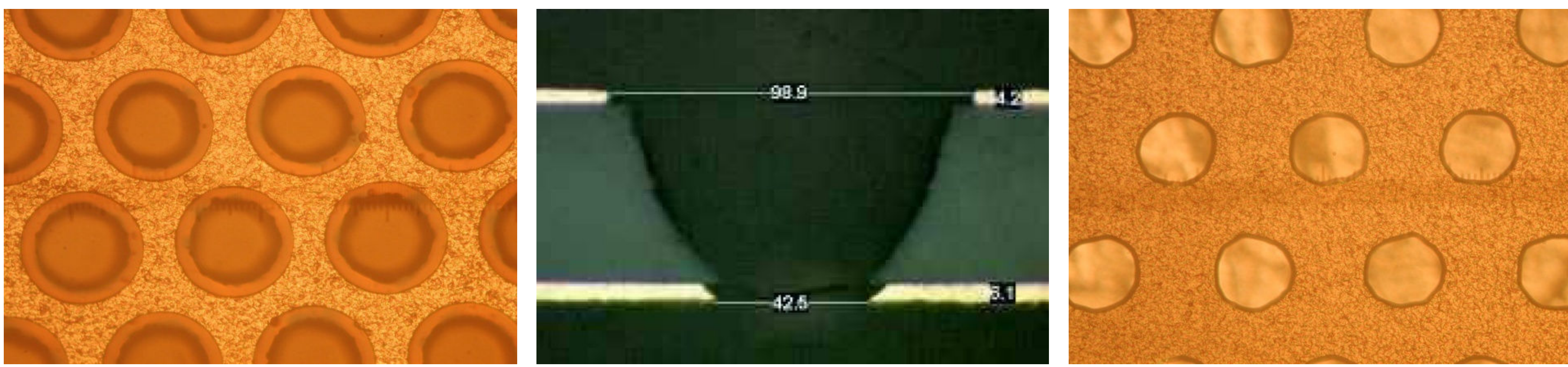
- Combining isotropic and anisotropic etching chemistries one can get steep holes
- Kapton holes form the mask for bottom copper etching
- Kapton profile will be finely tuned at a later stage

Etching the bottom copper layer



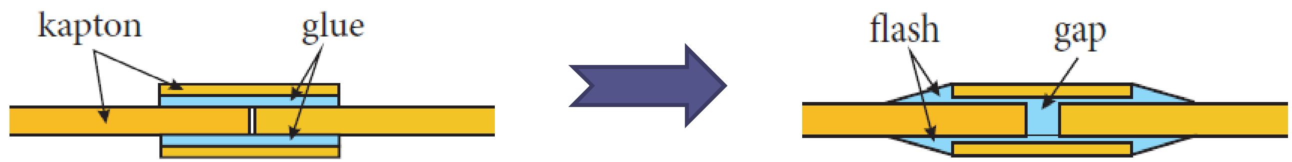
- Etching from the bottom
- Etching from the top, using the holes in the polyimide as mask

- Ammonium persulfate produces copper thickness variations over large areas → gain inhomogeneity
- Chromic acid produces more homogeneous etching
- GEM prototype for TOTEM T1 produced with this technique

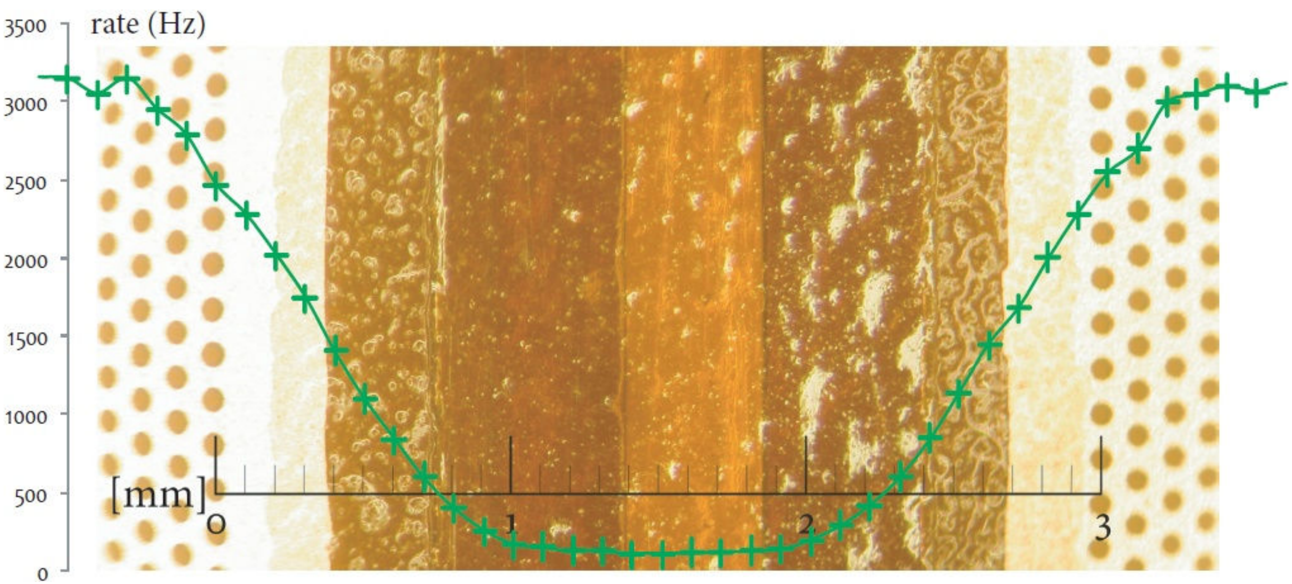


- Copper etching is isotropic → rim appears around the holes → gain stability deterioration
- Possible to reduce the rim by slimming down the copper thickness before etching the holes

Splicing GEMs

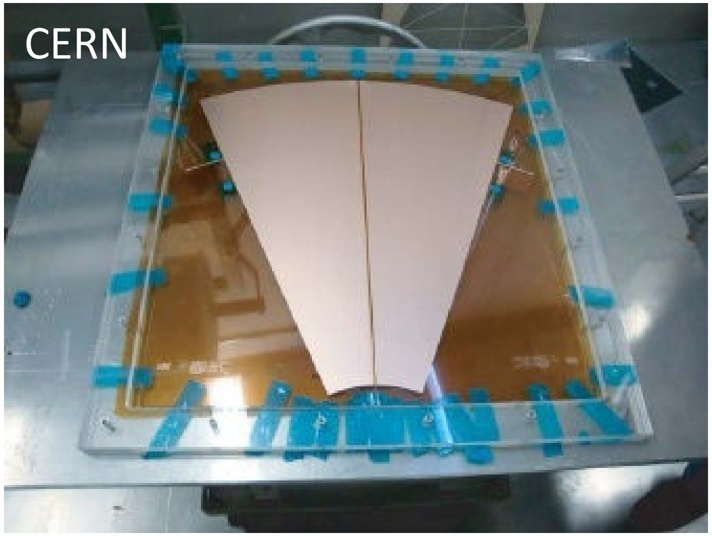


- The base material is only 457 (600) mm wide
- Possible to get larger width by splicing GEMs
- 2 mm width kapton coverlay on GEMs edges
- Pressed and heated up to 240 °C

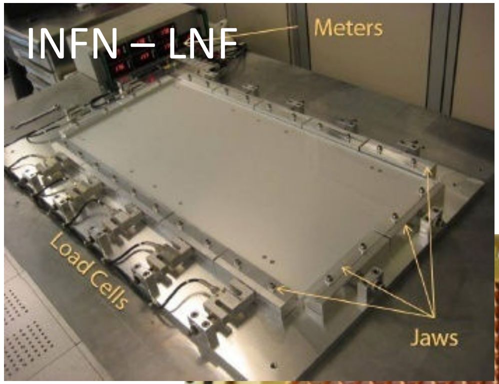


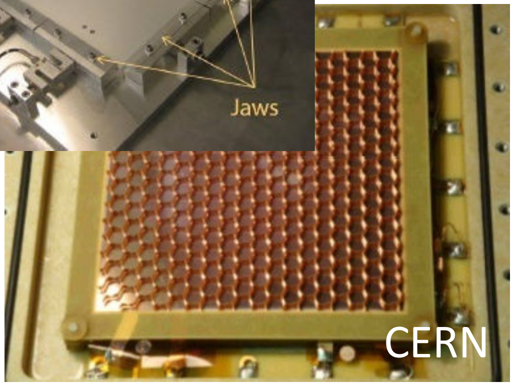
- Seam is flat, regular, mechanically and dielectrically strong
- Rate scan with ø 0.5 mm collimated X–ray beam
- Behaves normally until the seam
- Performance of the rest of the GEM is unaffected

Stretching and handling GEMs

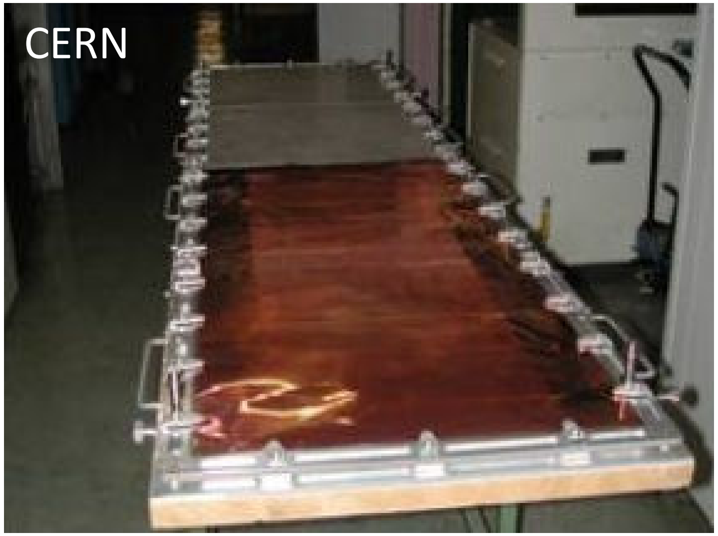


Stretching:
• Thermal expansion of a plexiglass frame can be exploited for foil stretching
• Stretching bench with load cells connected to meters
• Honeycomb spacers could avoid stretching GEMs at all

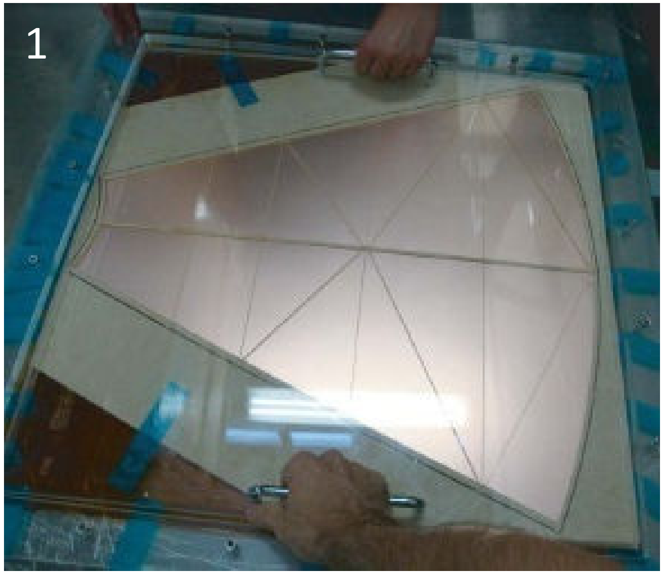




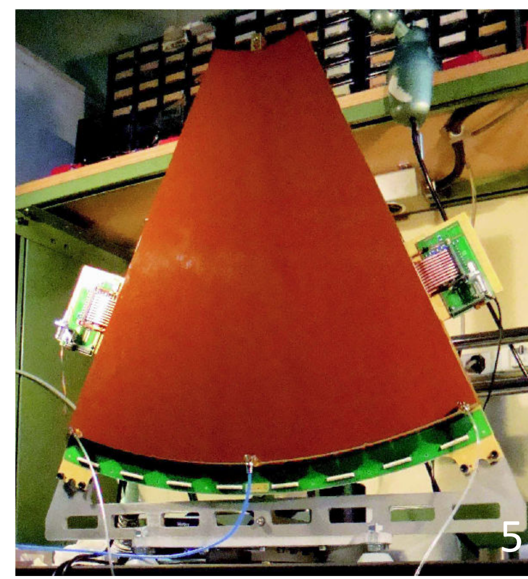
Handling:
• Some of the manufacturing steps take place in chemical baths of finite dimensions
• A foldable stainless steel portfolio allows handling GEM foils of up to 200 x 50 cm^2
• Single mask technology is suitable for mass production with roll–to–roll equipment



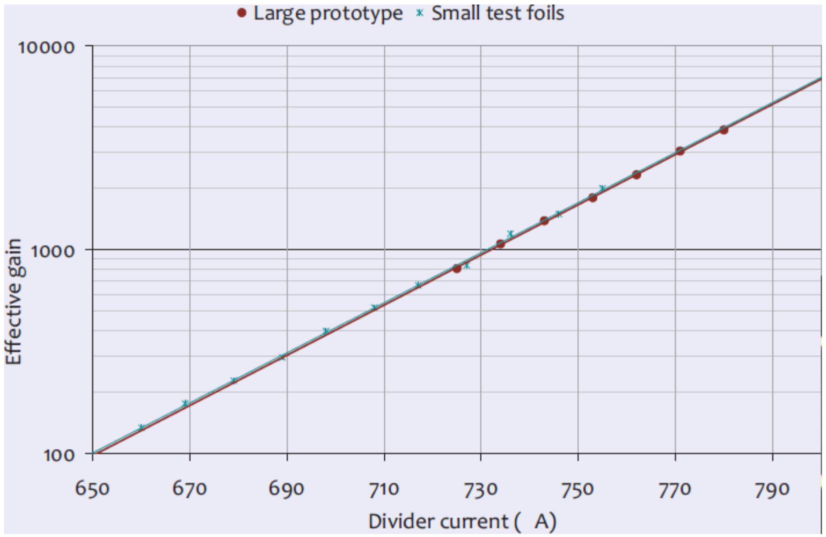
Producing the TOTEM T1 prototype



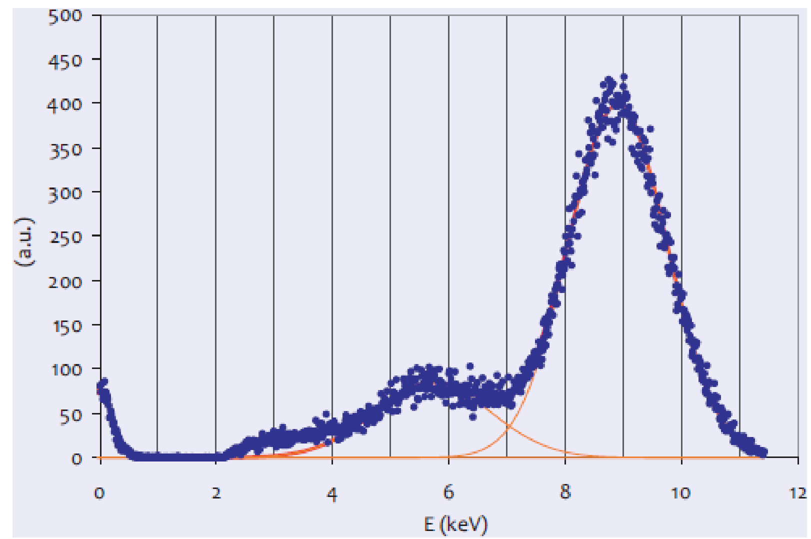
1 – Framing the sliced foils
2 – Making the honeycomb base plane and top cover
3 – Gluing the cathode to the honeycomb frame
4 – Final assembly of all frames
5 – Assembled prototype

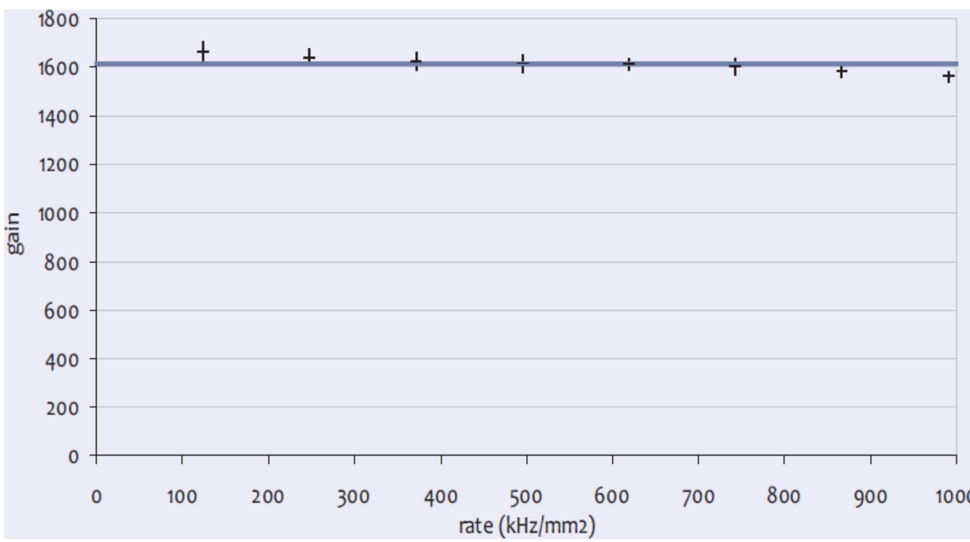


TOTEM T1 prototype performance



- Good gas tightness and high voltage stability
- Gain lower than standard (double mask) GEM, as expected from wider hole diameter
- Hole shape can be tuned by changing the composition of etching chemistry

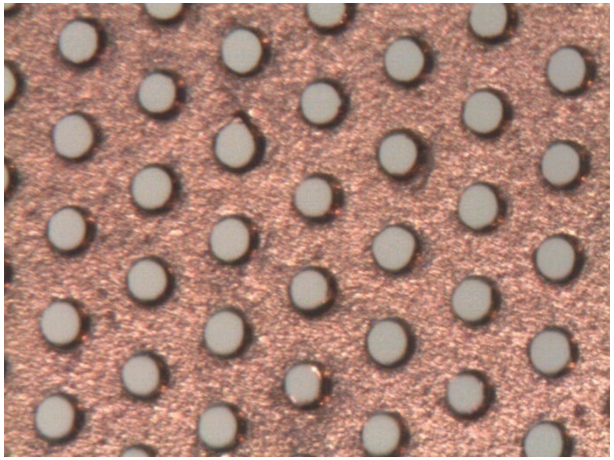


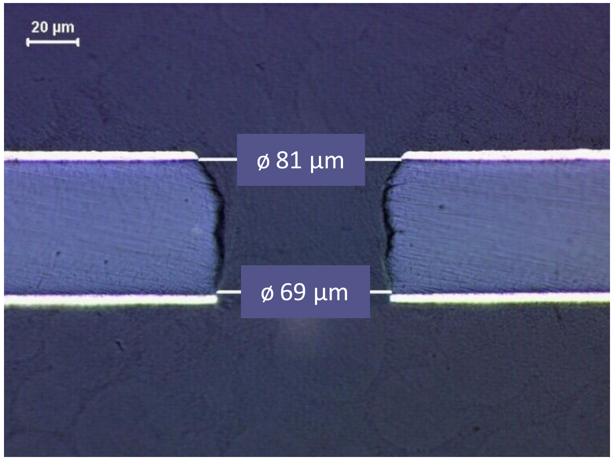


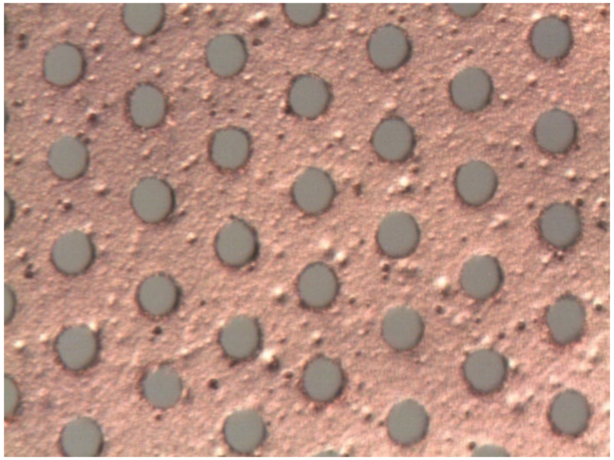
- Energy resolution 22.4 % FWHM/peak for Cu X-rays in Ar:CO_2 70:30

Improving the copper etching

In order not to create the rim at all:
- Laminate a photoresist layer on the bottom electrode
- Apply ~ – 3 V DC to the top electrode → copper becomes inert to etching solution
- Etch the bottom copper with chromic acid using the polyimide holes as mask
- Go back to polyimide etching for ~ 30 s to get almost cylindrical holes

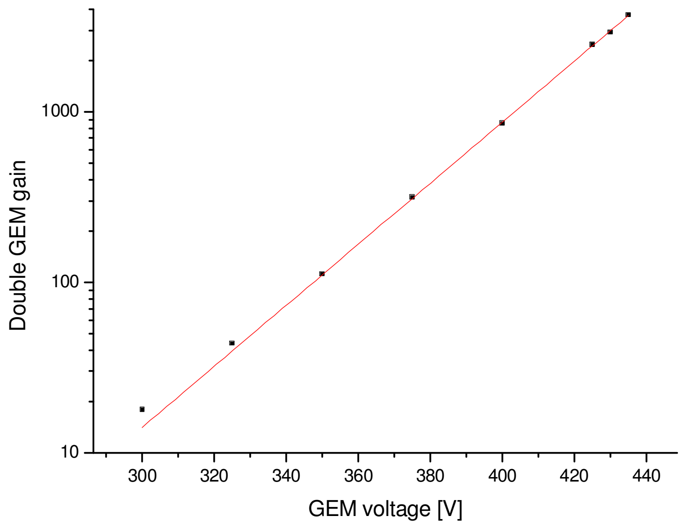




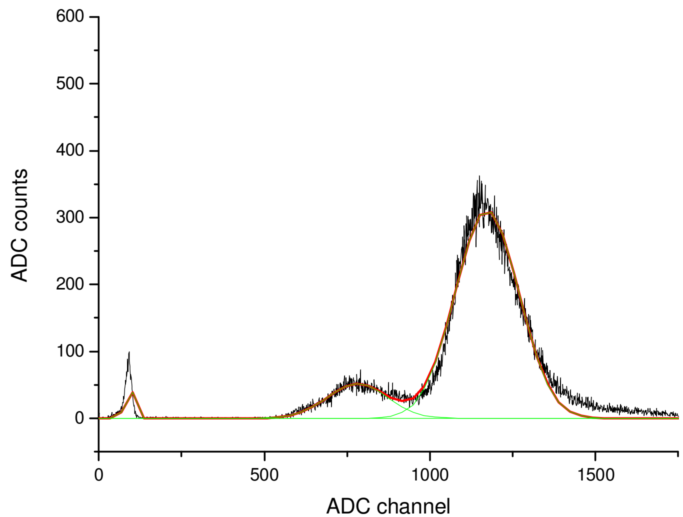


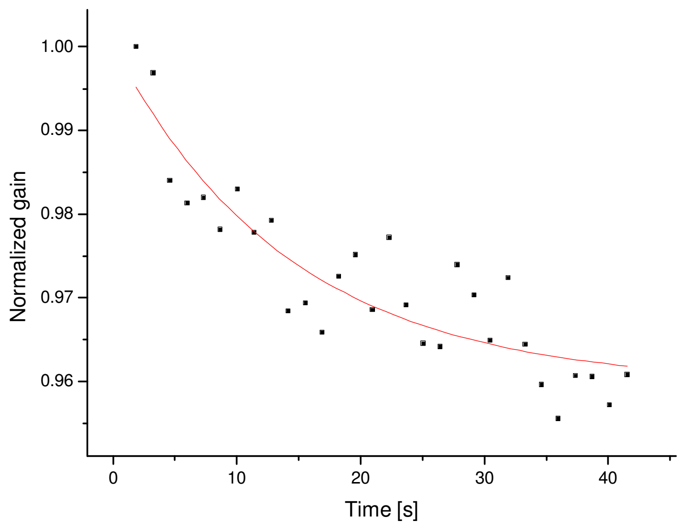
- Almost cylindrical hole profile in the polyimide
- Perfectly defined holes on both top and bottom electrodes
- Spark voltage in air (650 ± 40) V
- GEM cleaning assures good robustness against sparks

Single mask GEM performance



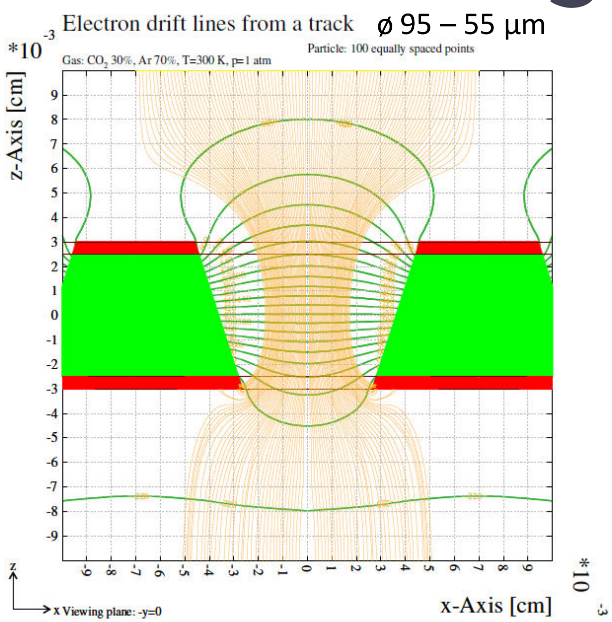
- Double GEM 10 x 10 cm^2 active area
- Gap_D 4.2 mm, gap_T = gap_I 2.2 mm
- $E_D = E_T$ 2 kV/cm, E_I 3 kV/cm
- Measurements performed in Ar:CO_2 70:30
- Cu X–ray tube (K_α 8.04 keV, K_β 8.9 keV)

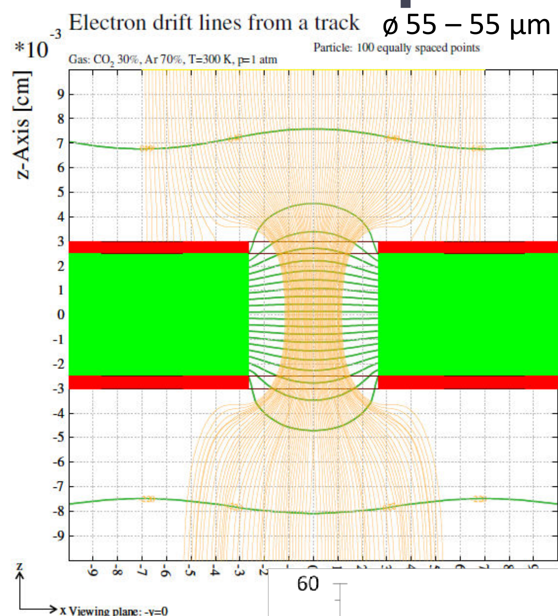


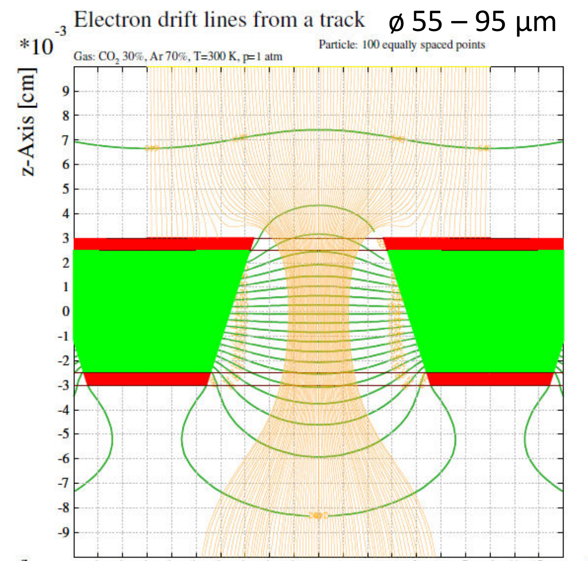


- Max. gain ~ 3700 @ ΔV_{GEM} 435 V [few 10^4 std GEM]
- Energy res. 20.8 % FWHM/peak [~ 20 % std GEM]
- Good time stability τ (14 ± 4) s [~ 30 min std GEM]
- Small gain variation 4 % [~ 10% std GEM]
- Robustness against sparks compatible with std GEMs

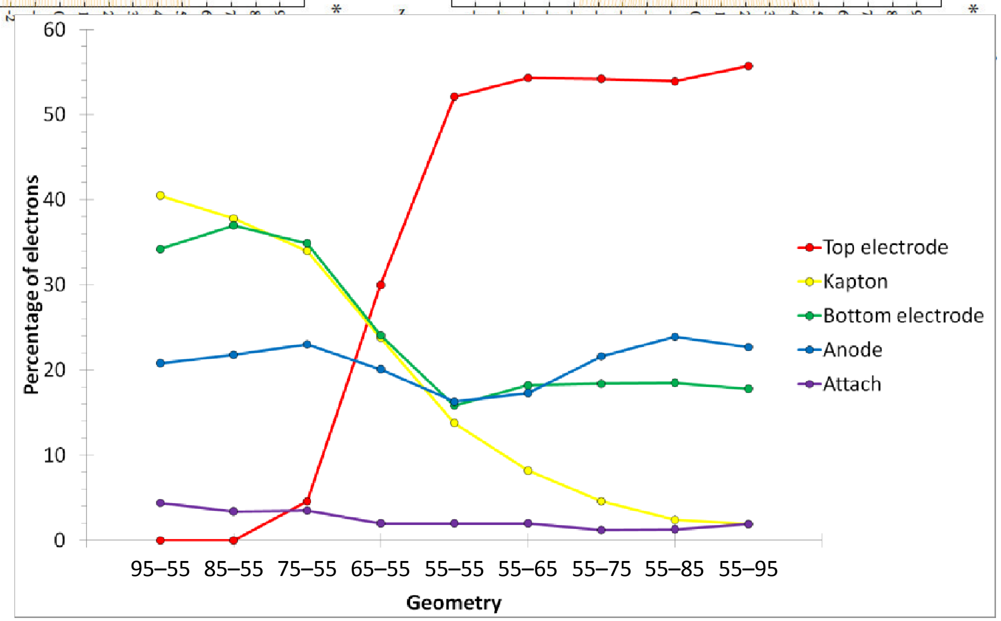
Simulating hole shape effects







- Hole shape can be tuned by changing the composition of etching chemistry
- Possibility of choosing the optimal shape according to application
- Simulation of electric field lines for different geometries (Garfield)
- Simulation of electron end point as a function of the geometry (Garfield)



Conclusions & outlooks

- The single mask technique has proven to be a valid manufacturing technology for GEMs
- Hole parameters are under study and the optimization process is ongoing
- Using this technology it was possible to build a large size triple GEM of ~ 2000 cm^2 active area which has successfully been tested
- Recent refinements of the production method give better control over the hole shape
- The technique offers attractive advantages for large area and large scale production
- Very well suited for industrial processing with roll–to–roll equipment
- A roll–to–roll compatible copper micro–etching machine and polyamide etching machine are foreseen for installation in the CERN workshop by the end of 2010
- Cost reduction from optimizing large scale production in collaboration with industry

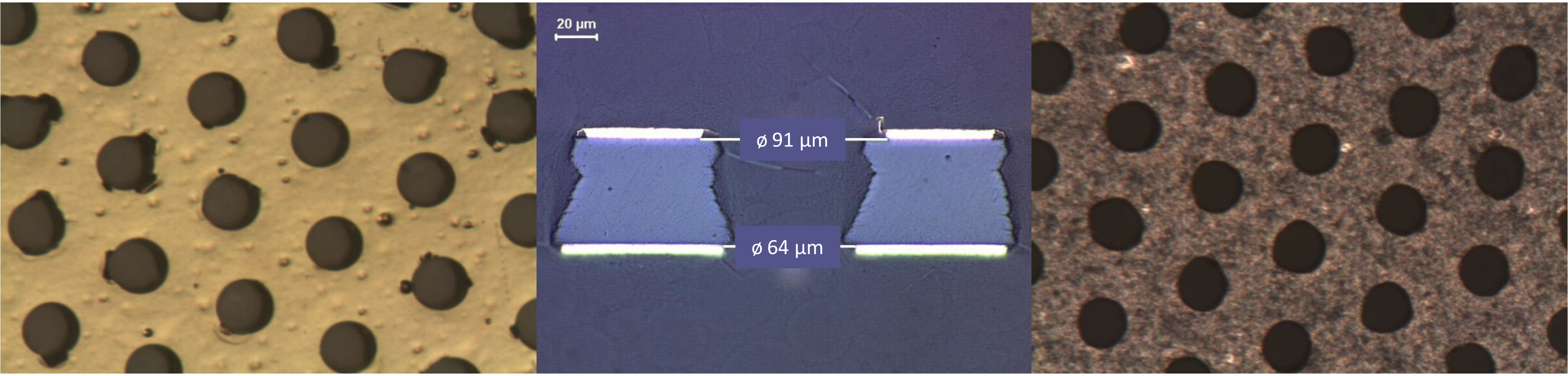
Backup slides

CERN workshop capabilities

Detector technology	Currently produced	Future requirements
	cm * cm	cm * cm
GEM	40 * 40	50 * 50
GEM, single mask	70 * 40	200 * 50
THGEM	70 * 50	200 * 100
RTHGEM, serial graphics	20 * 10	100 * 50
Micromegas, bulk	150 * 50	200 * 100
Micromegas, microbulk	10 * 10	30 * 30
MHSP (Micro-Hole and Strip Plate)	3 * 3	10 * 10

Improving the copper etching

In order not to create the rim at all:
- Laminate a photoresist layer on the bottom electrode
- Cover the top electrode with gold or tin by galvanic deposition
- Etch the bottom copper with chromic acid using the polyimide holes as mask
- Strip the photoresist layer, leave the top protection layer



- The holes on the bottom appear to be very well defined
- Difficult to obtain good hermeticity of the top protective layer
- The slightest delamination between copper and kapton leads to copper underetching
- Gold remains above underetched copper increase spark probability

Simulating the gain stability

- Deposition of electric charges on the polyimide plays an important role in GEMs behavior
- Successful simulation of electron charging up in a standard GEM with no gain
- Electrons created randomly above the GEM
- Electrons drifted and end point recorded
- Generation of new field map with deposited charges