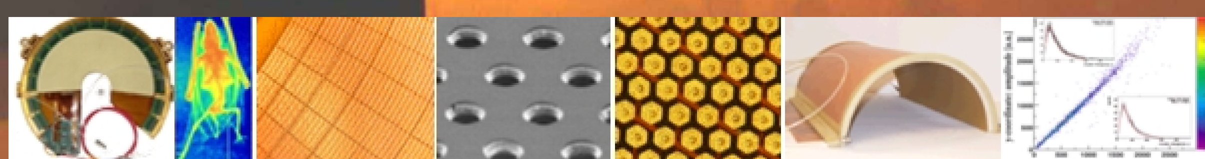
GEM at CERN

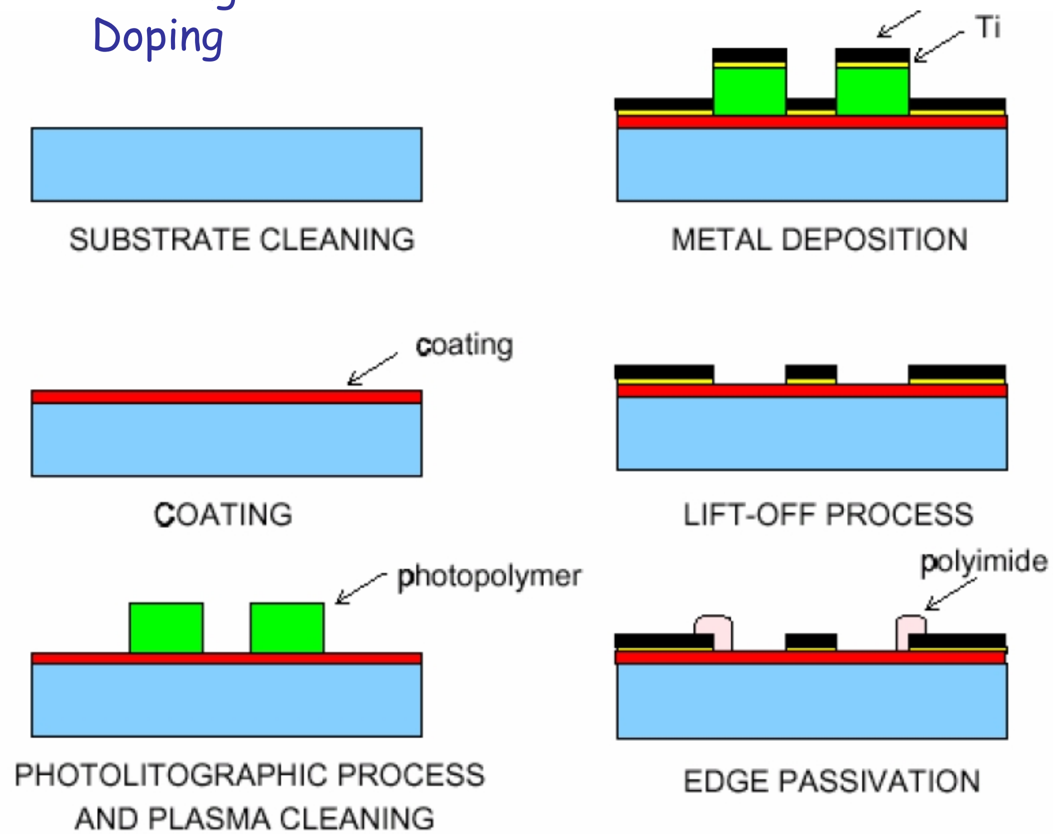
Leszek Ropelewski CERN PH-DT2-ST & TOTEM



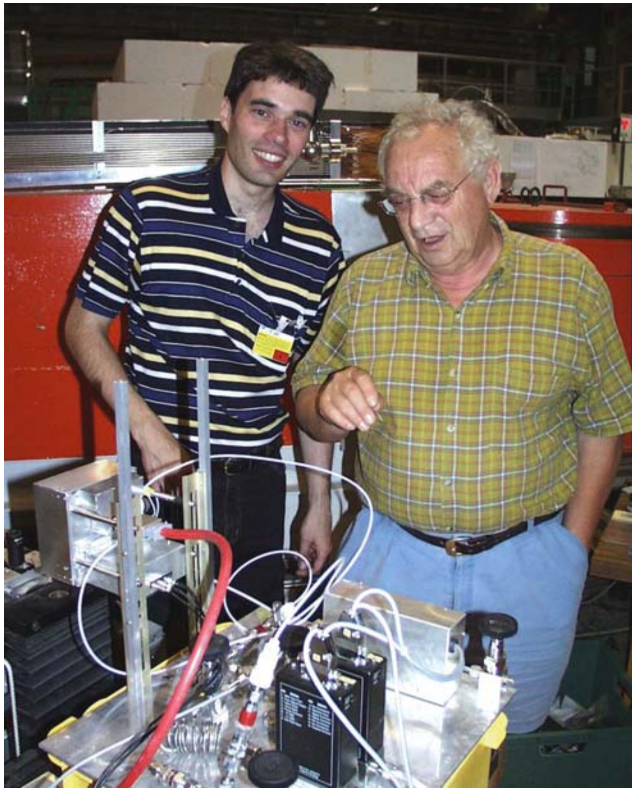
MicroStrip Gas Chamber

Semiconductor industry technology:

Photolithography
Etching
Coating
Doping



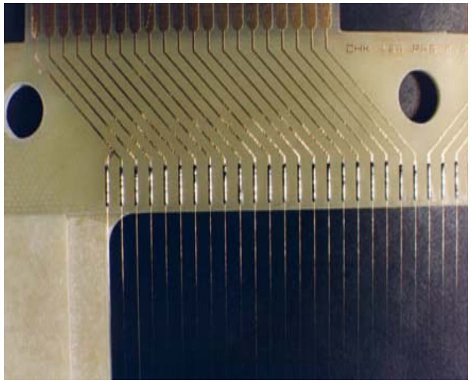
Lift-off technique

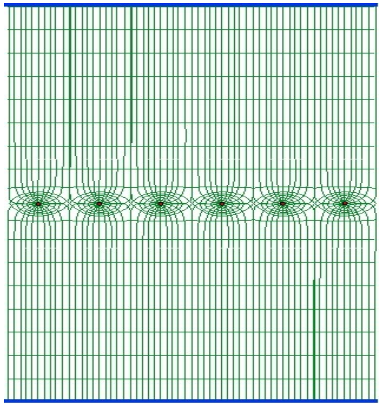


A. Oed
Nucl. Instr. and Meth. A263 (1988) 351.

MicroStrip Gas Chamber

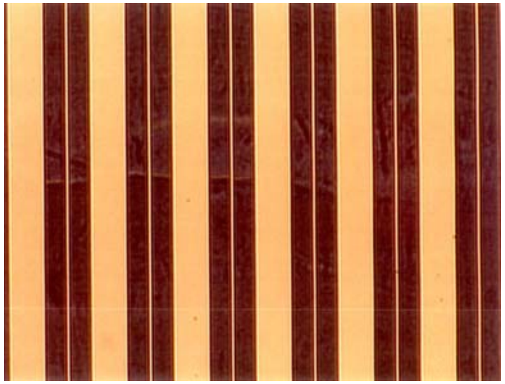
MWPC

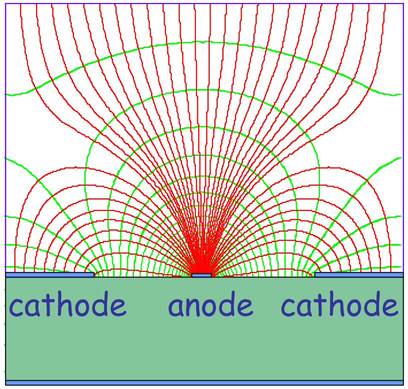




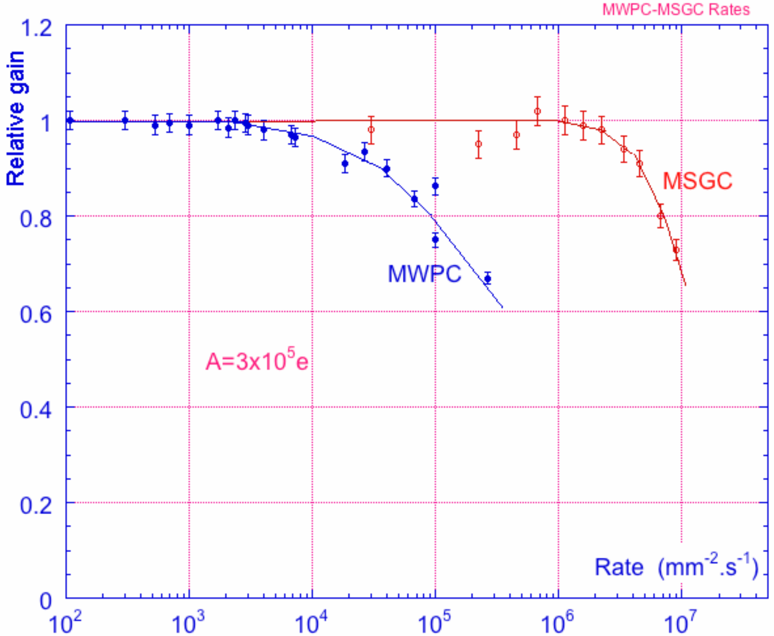
Typical distance between wires limited to 1 mm due to mechanical and electrostatic forces

MSGC





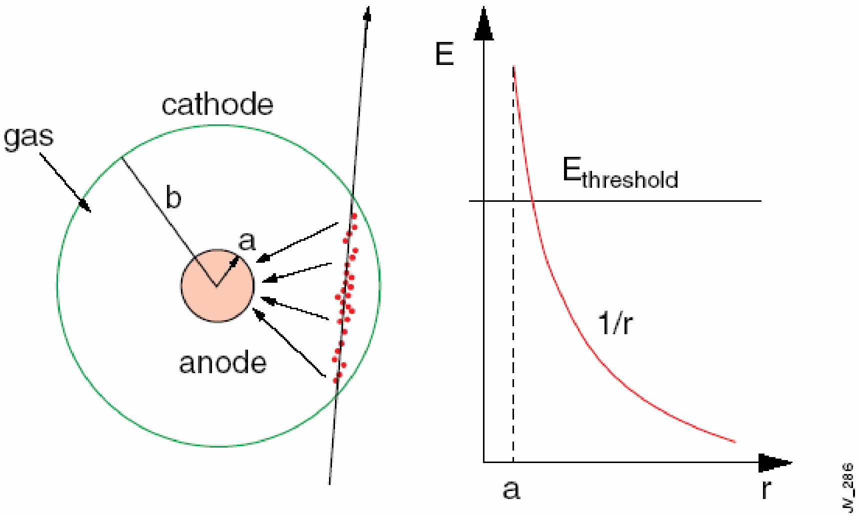
Typical distance between anodes 200 μm thanks to semiconductor etching technology



Rate capability limit due to space charge overcome by increased amplifying cell granularity

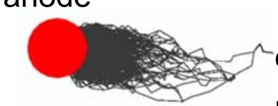
A. Oed
Nucl. Instr. and Meth. A263 (1988) 351.

Single Wire Proportional Chamber



Electrons liberated by ionization drift towards the anode wire.

Electrical field close to the wire (typical wire Ø ~few tens of μm) is sufficiently high for electrons (above 10 kV/cm) to gain enough energy to ionize further → avalanche – exponential increase of number of electron ion pairs.

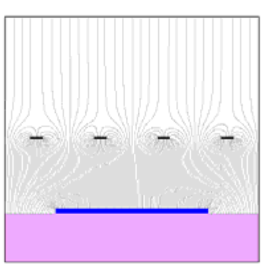


$$E(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \frac{1}{r}$$

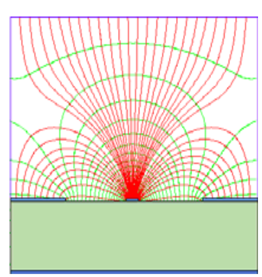
$$V(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \ln\frac{r}{a}$$

C – capacitance/unit length

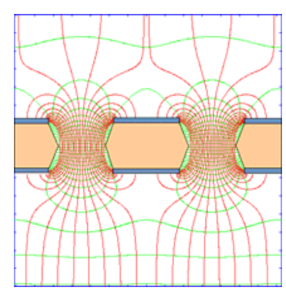
Cylindrical geometry is not the only one able to generate strong electric field:



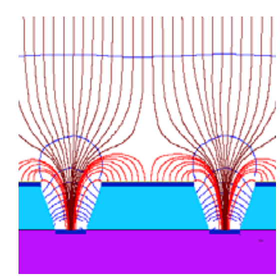
parallel plate



strip



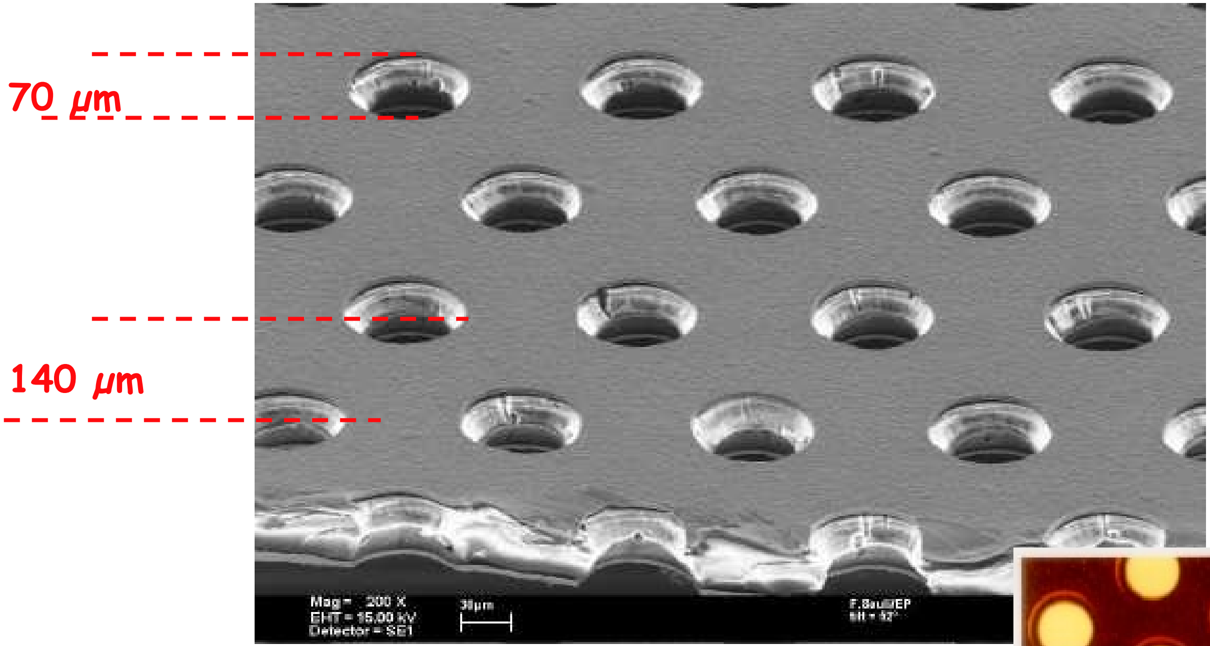
hole

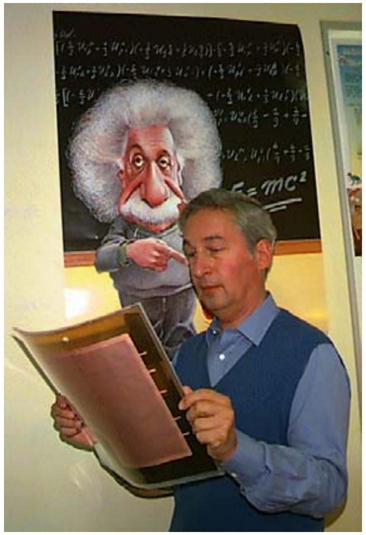


groove

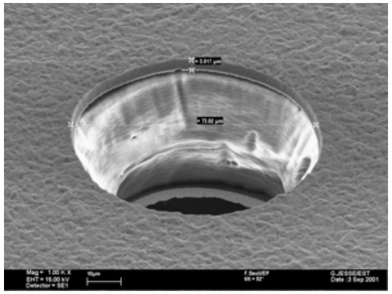
GEM: Gas Electron Multiplier

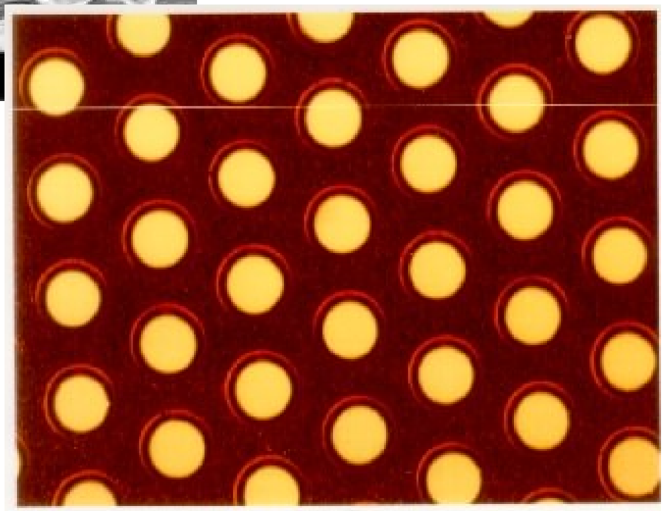
Thin metal-coated polymer foil pierced by a high density of holes (50-100/mm^2)
Typical geometry: 5 µm Cu on 50 µm Kapton, 70 µm holes at 140 µm pitch



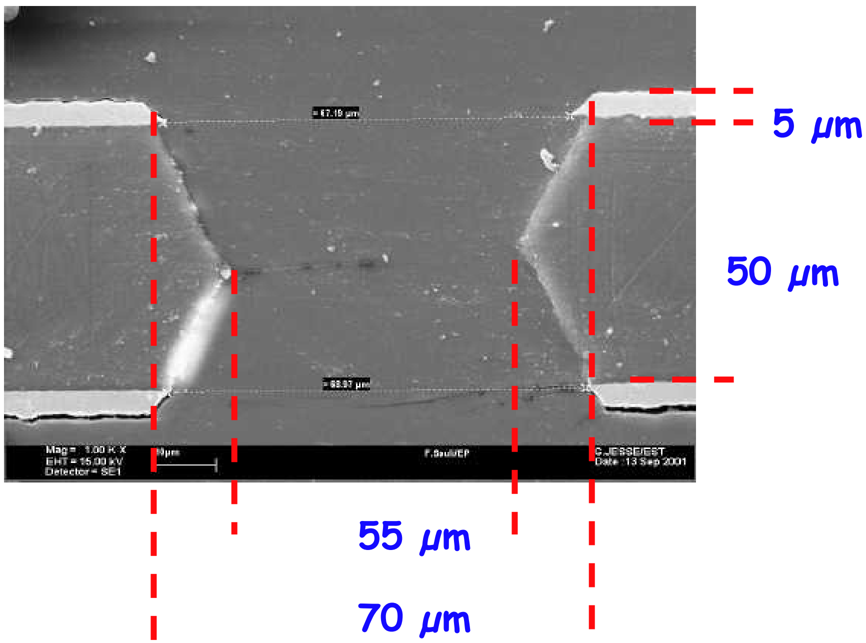


F. Sauli, Nucl. Instrum. Methods A386(1997)531

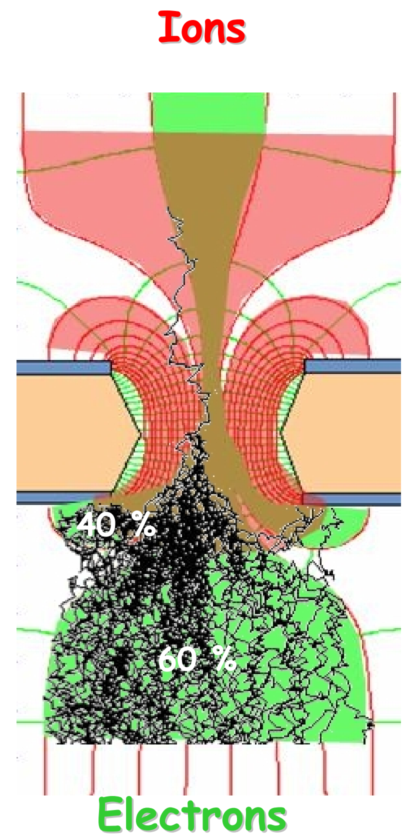




GEM Principle

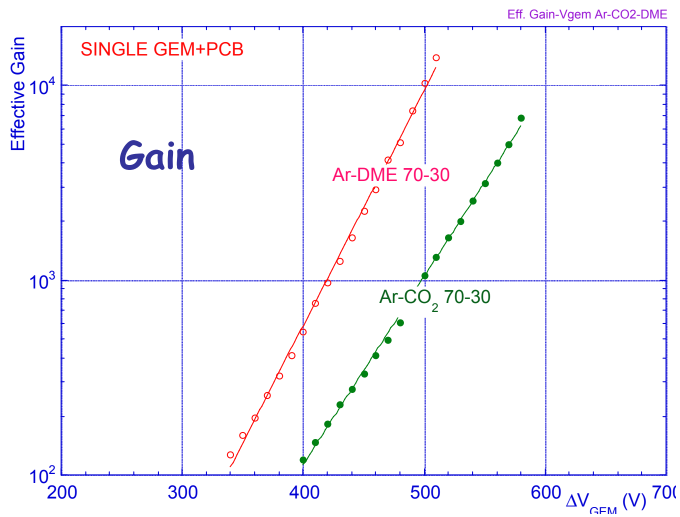


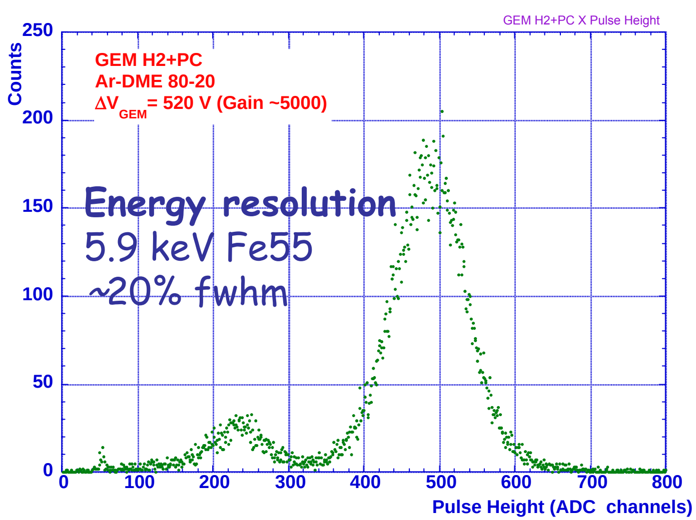
GEM hole cross section



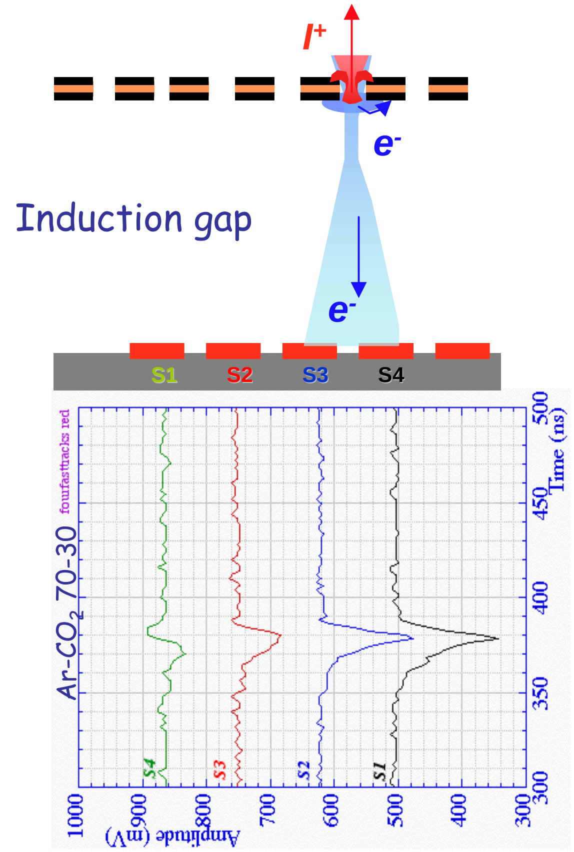
Avalanche simulation

Single GEM Performances





R. Bouclier et al NIM A 396 (1997) 50



Electrons are collected on patterned readout board.
A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.
All readout electrodes are at ground potential.
Positive ions partially collected on the GEM electrodes.

GEM Manufacturing

Rui De Oliveira
CERN-EST-DEM

50 μm Kapton
5 μm Cu both sides

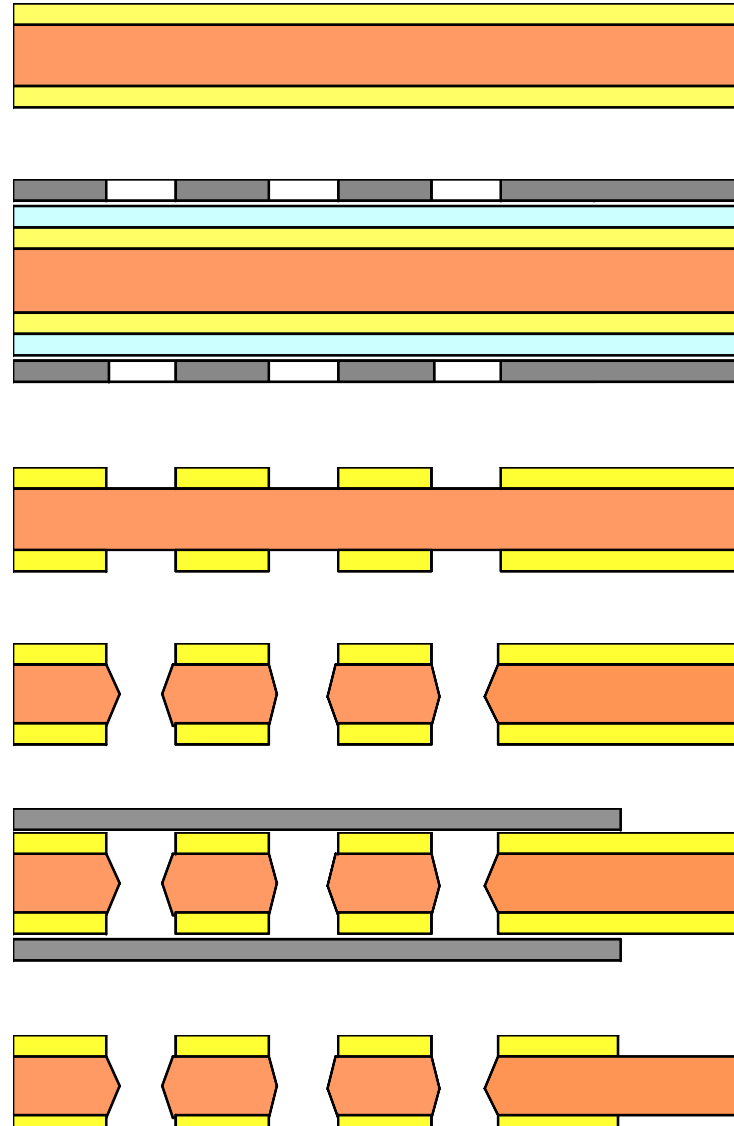
Photoresist coating,
masking and exposure
to UV light

Metal etching

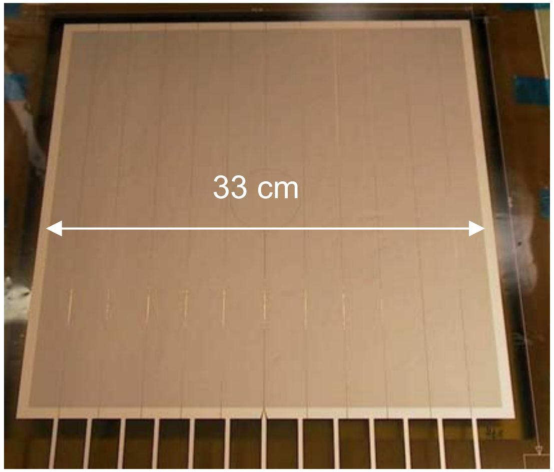
Kapton etching

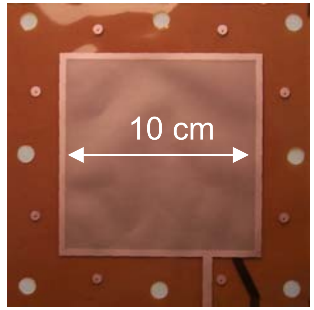
Second masking

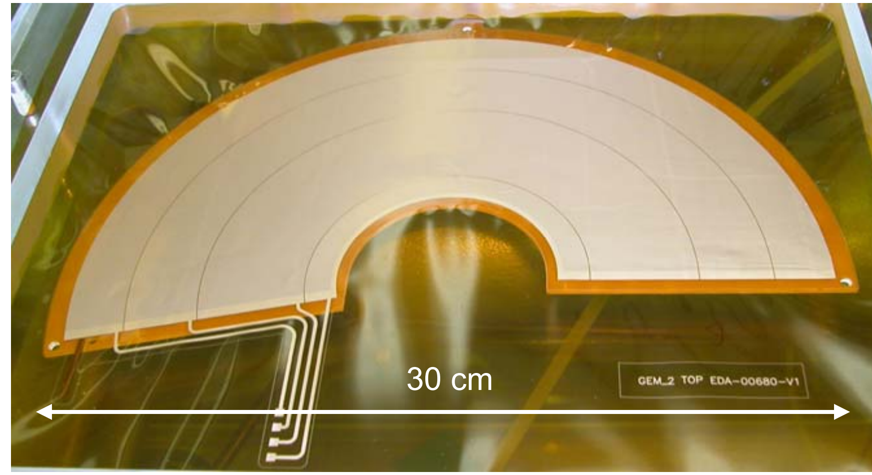
Metal etching
and cleaning

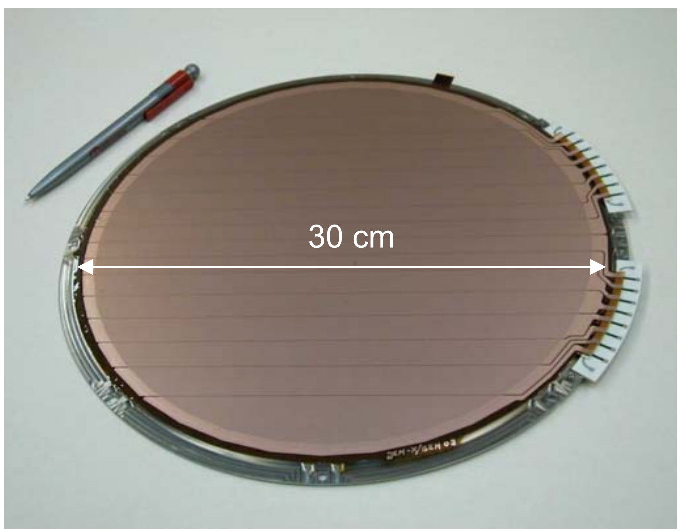


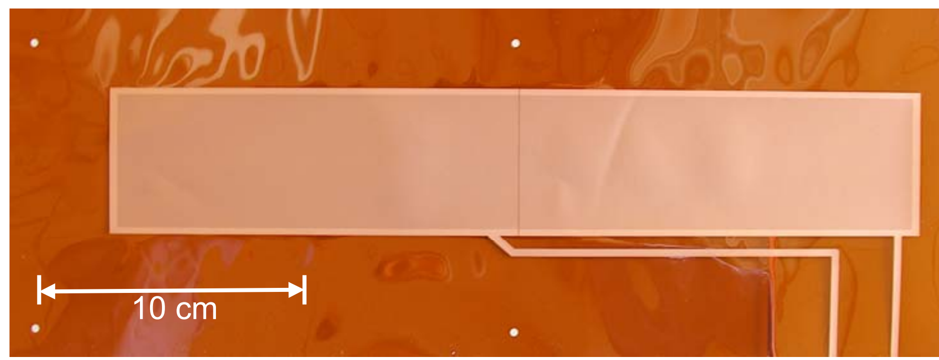
GEM Manufacturing







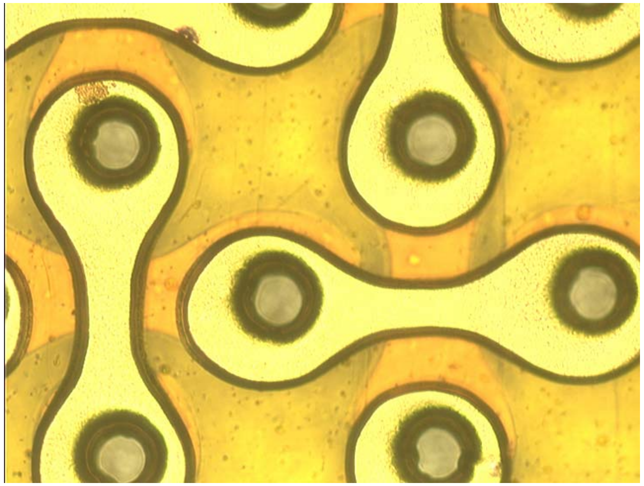


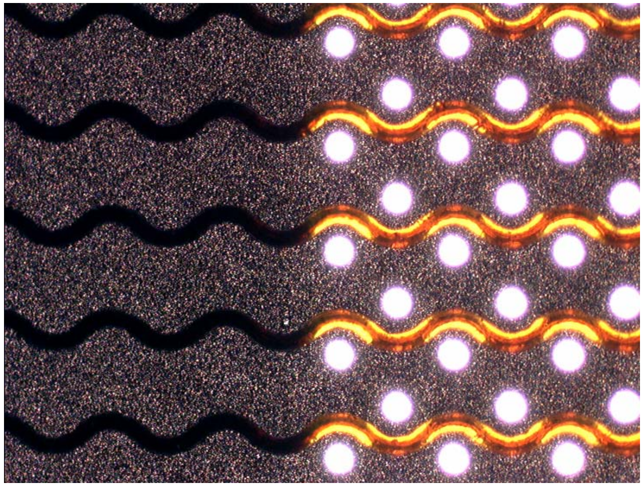


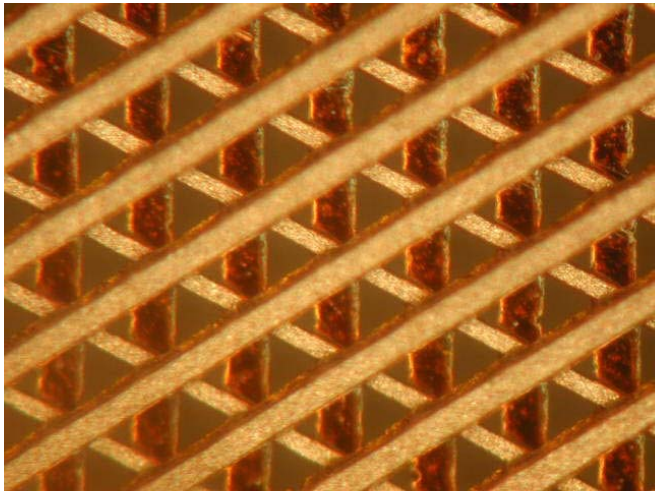
Wide rage of shapes and sizes

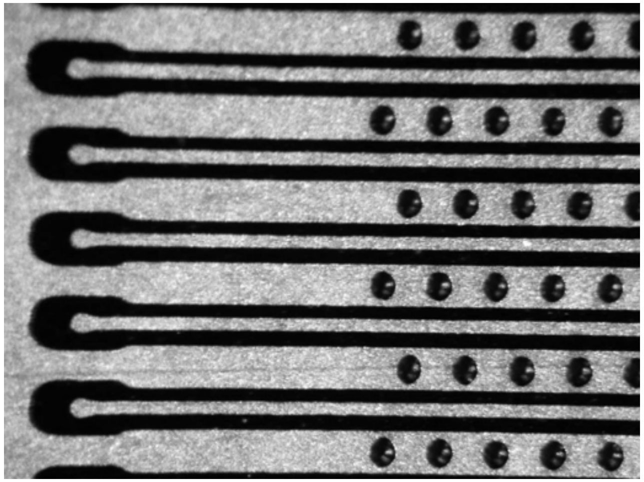
1500÷2000 foils manufactured at CERN
1 cm^2 to 1000 cm^2
30-200 μm holes, 50-300 μm pitch

Art of Kapton Etching



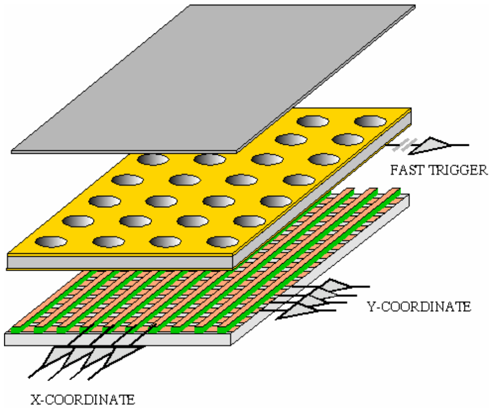




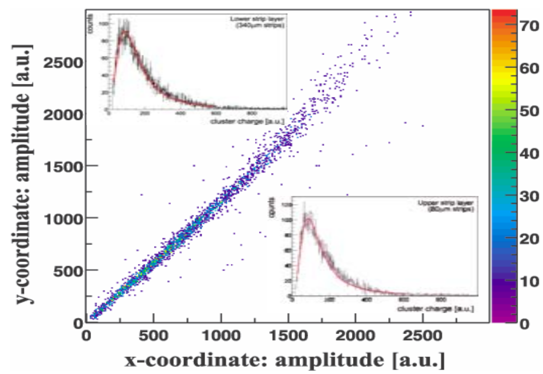


GEM – Gas Electron Multiplier

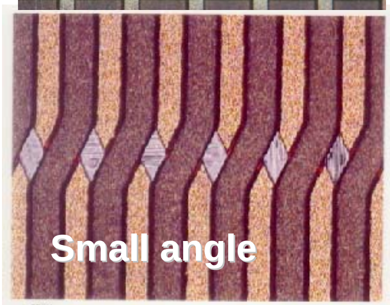
Full decoupling of the charge amplification structure from the charge collection and readout structure.
Both structures can be optimized independently !

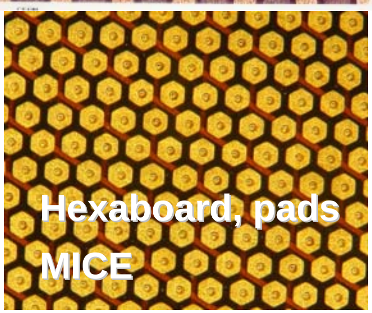


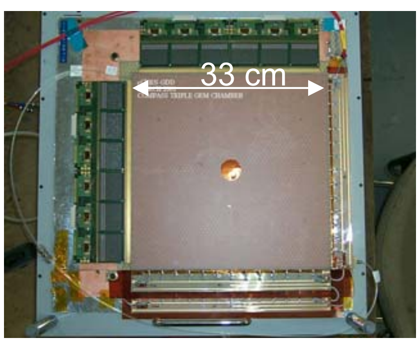
A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254



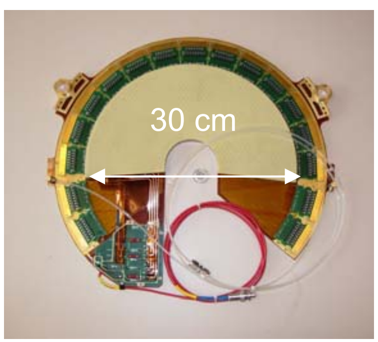
Charge correlation (Cartesian readout)



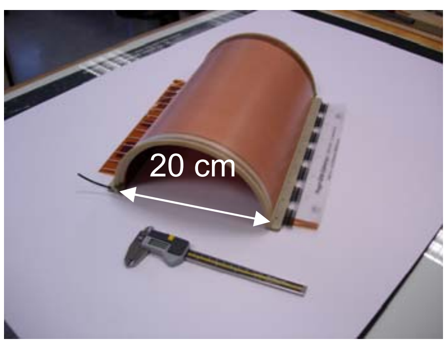




Compass



Totem



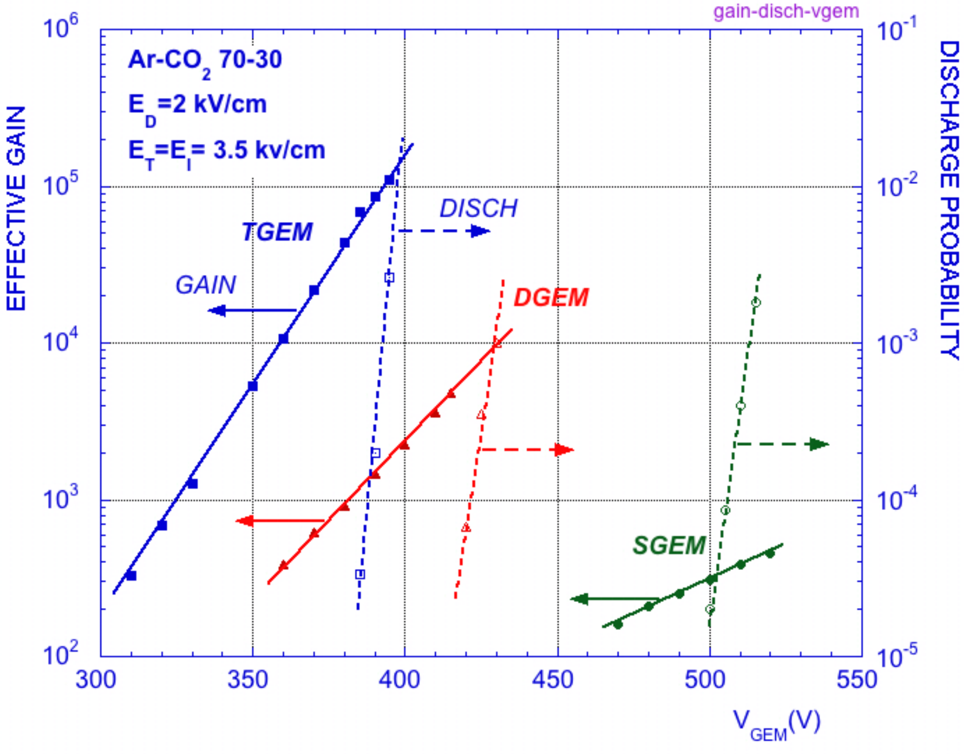
NA49-future

All detectors use three GEM foils in cascade for amplification to minimize discharge probability by reducing field strength.

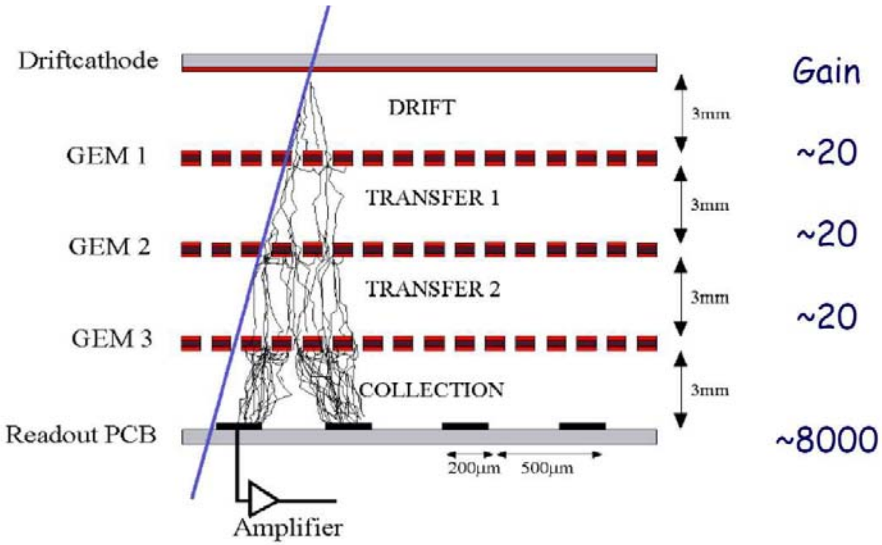
Multi-GEM Detectors

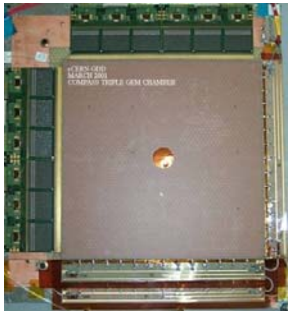
Discharge Probability on Exposure to 5 MeV Alphas

Multiple structures provide equal gain at lower voltage.
Discharge probability on exposure to α particles is strongly reduced.

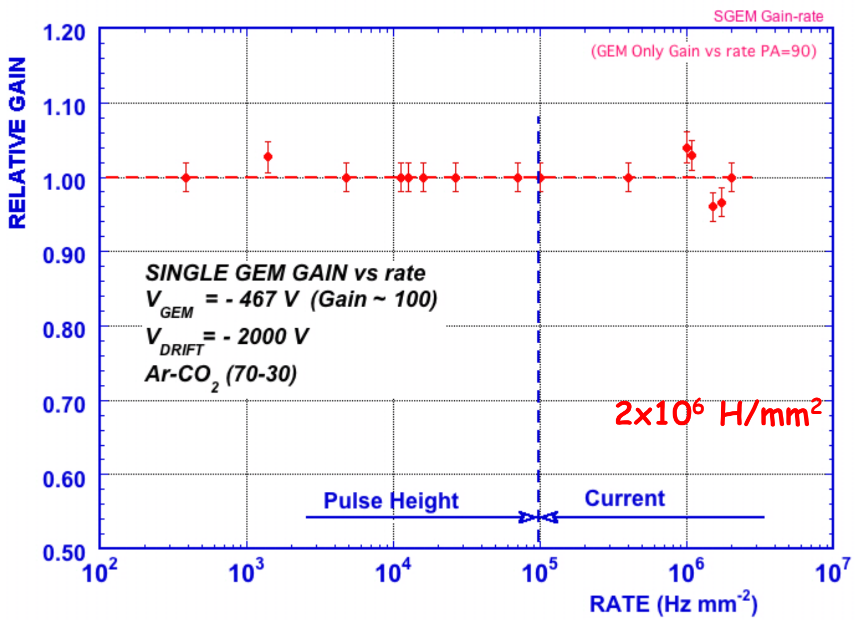


S. Bachmann et al Nucl. Instr. and Meth. A479(2002)294

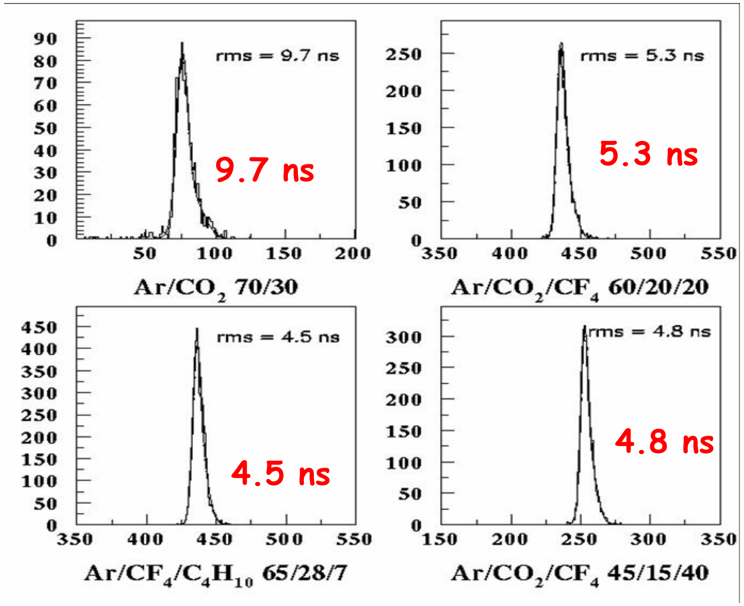




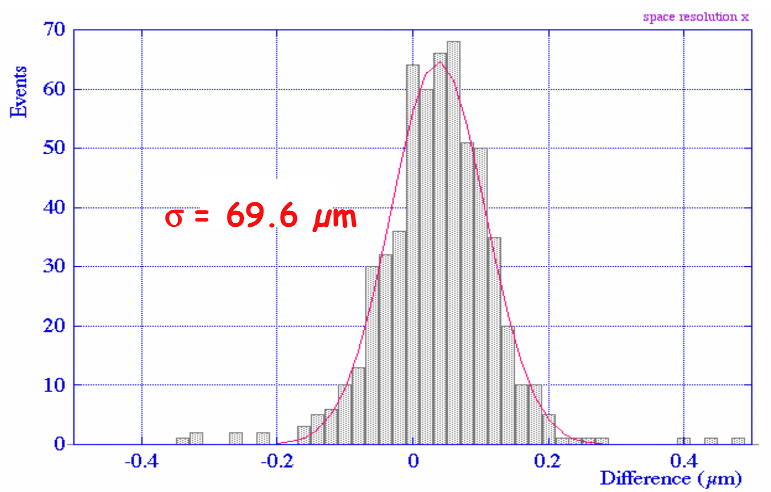
GEM – Gas Electron Multiplier



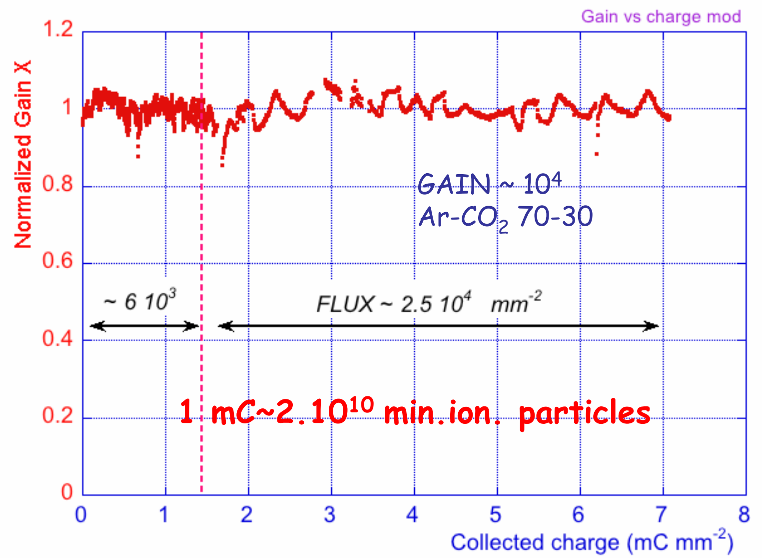
Rate capability



Time resolution



Space resolution

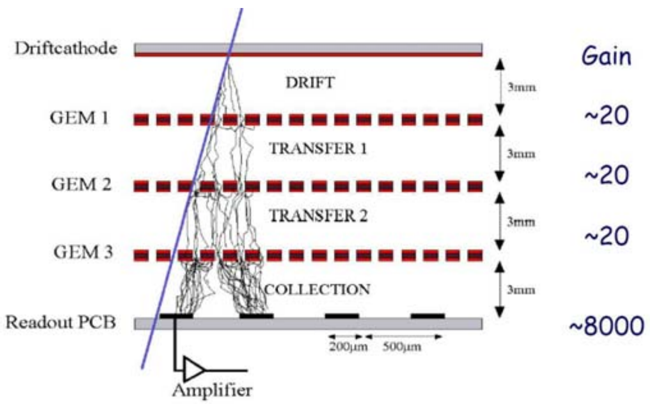


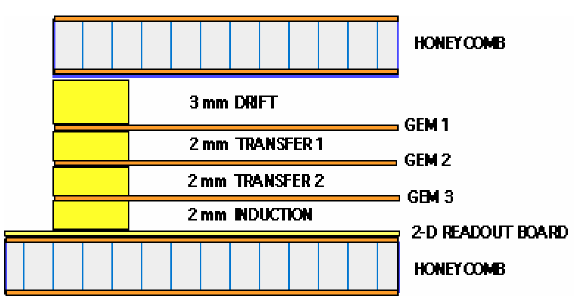
Ageing properties

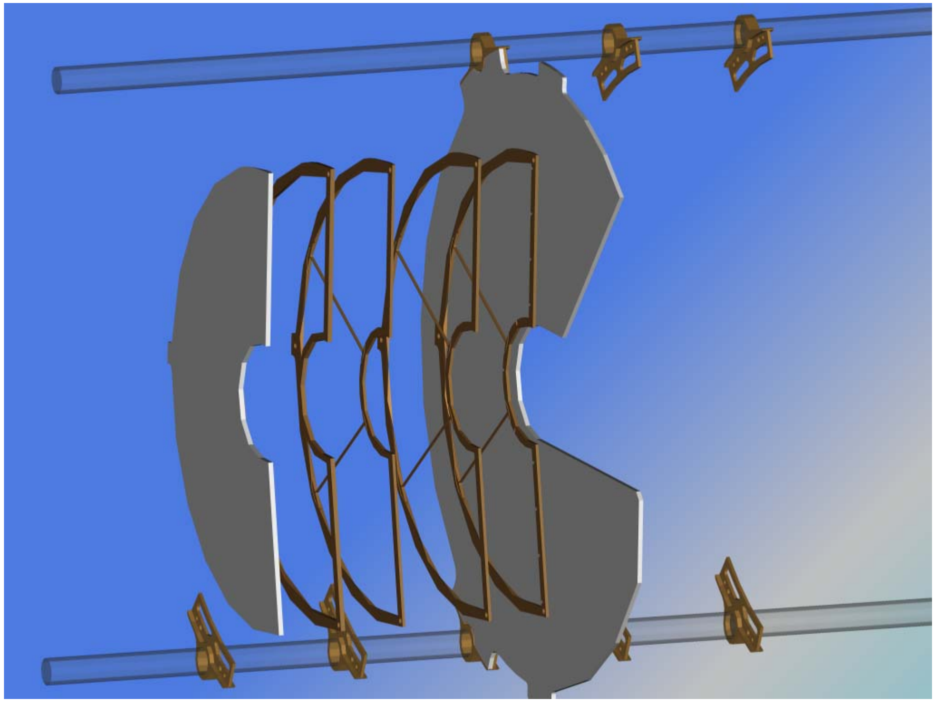
TOTEM GEM : Concept and Design

Detector requirements:

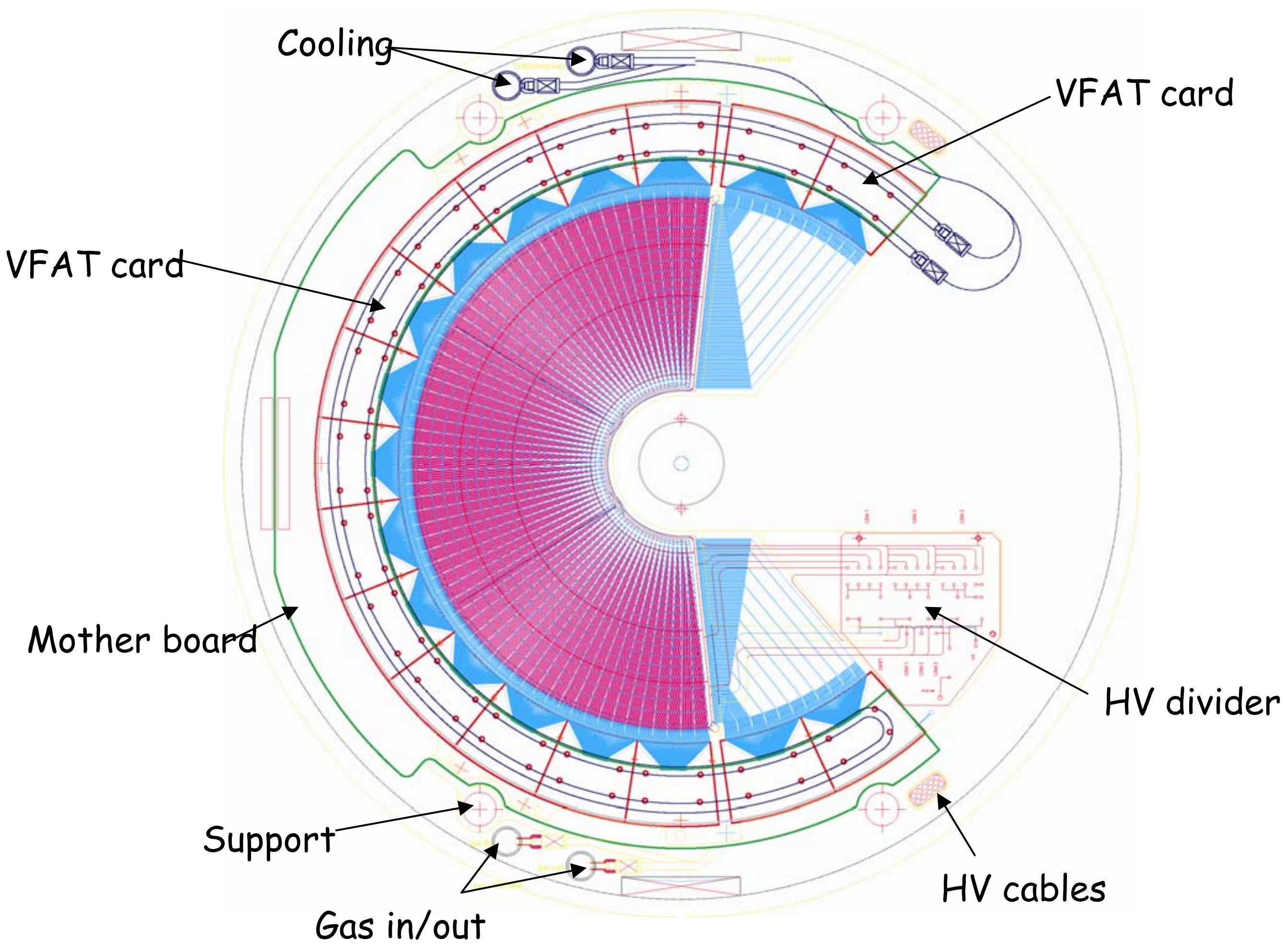
Rate Capability	- Charge particle rates 10^{4} p mm^{-2}s^{-1} at $\mathcal{L} = 10^{33}$ cm^{-2}s^{-1}
Ageing	- 1 year of continuous operation 10^{11} p mm^{-2} -> 7 mC mm^{-2}
Discharges	- at probability of 10^{-12}/part. -> 10 disch. cm^{-2} year^{-1}
Time Resolution	- $<$ 10 ns
Space Resolution	- $<$ 100 μm
Efficiency	- $>$ 97 %

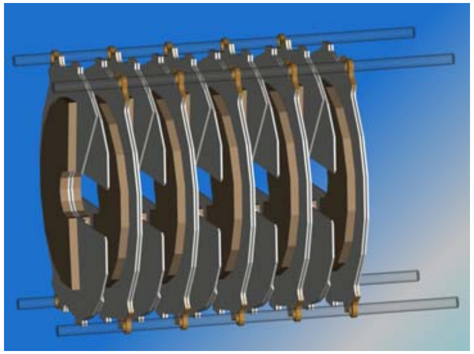


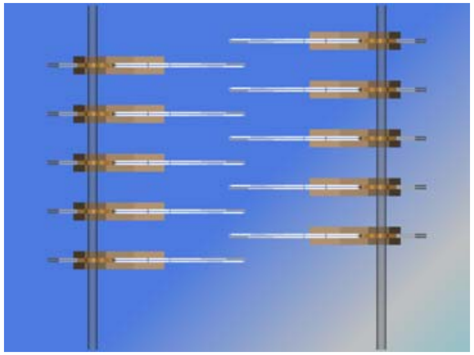


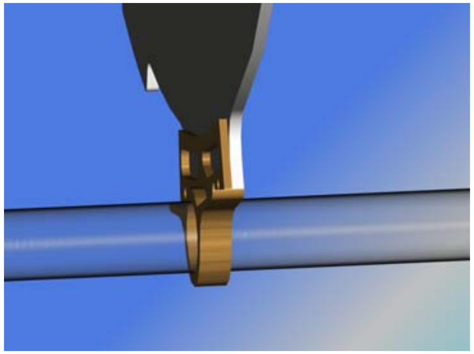


TOTEM GEM Final Detector Module

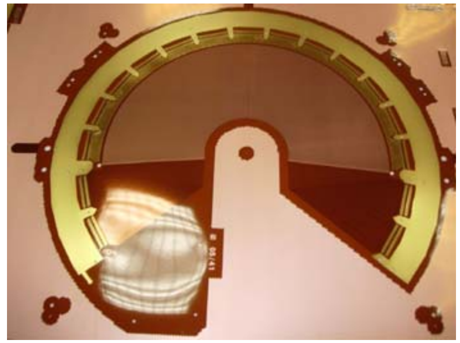




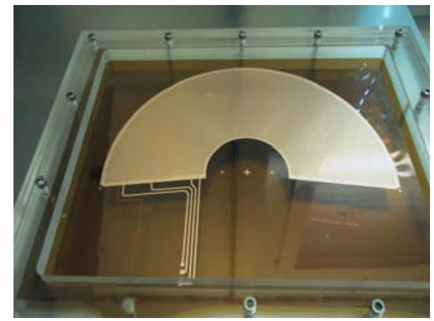




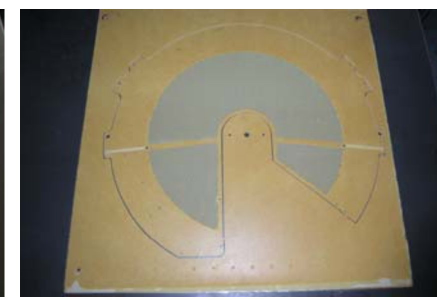
Detector Components



Readout board

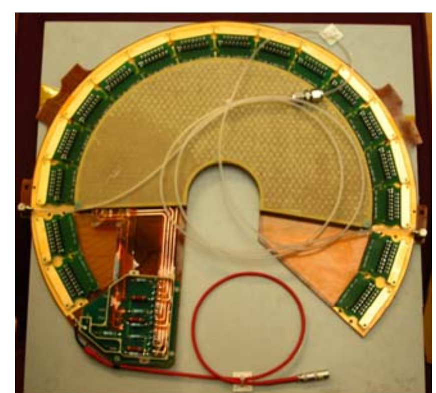


GEM foils

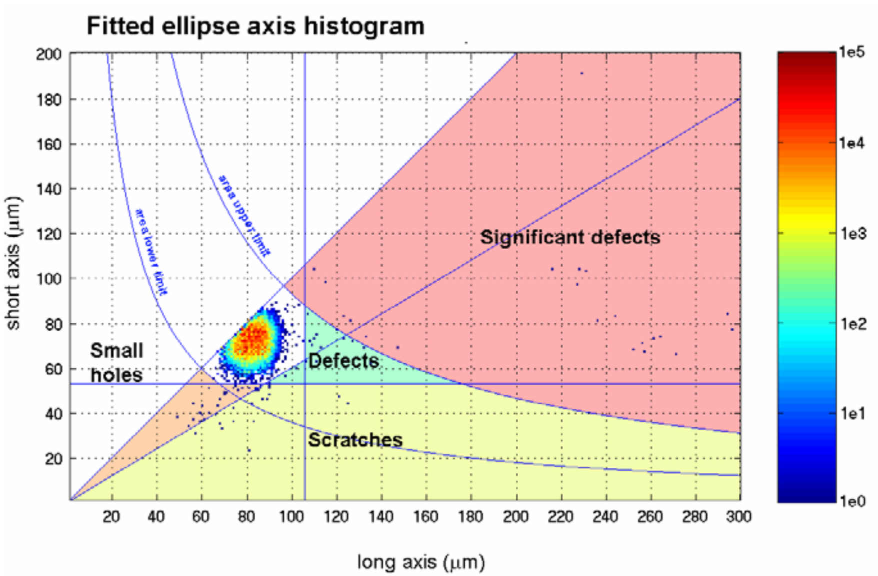


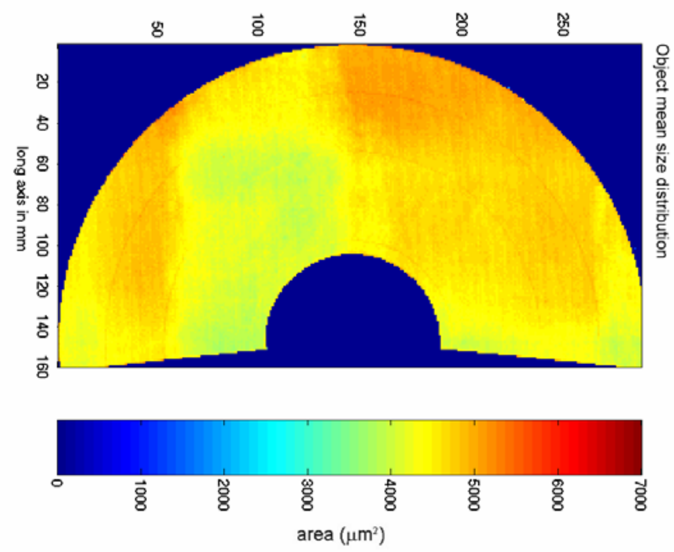
Frames, spacers and supports

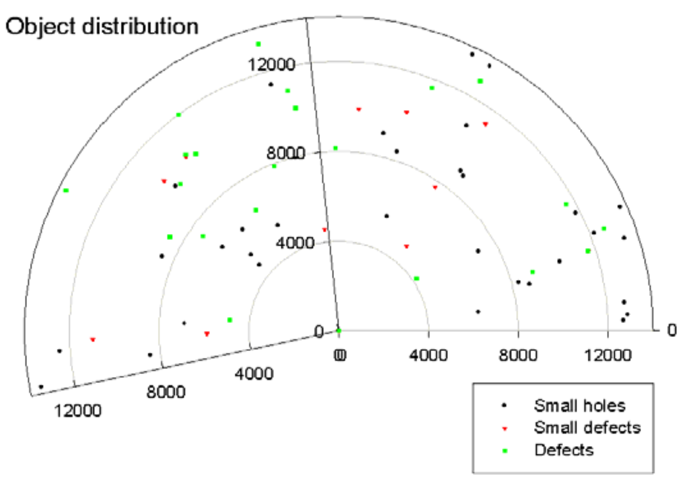
HV and electronics

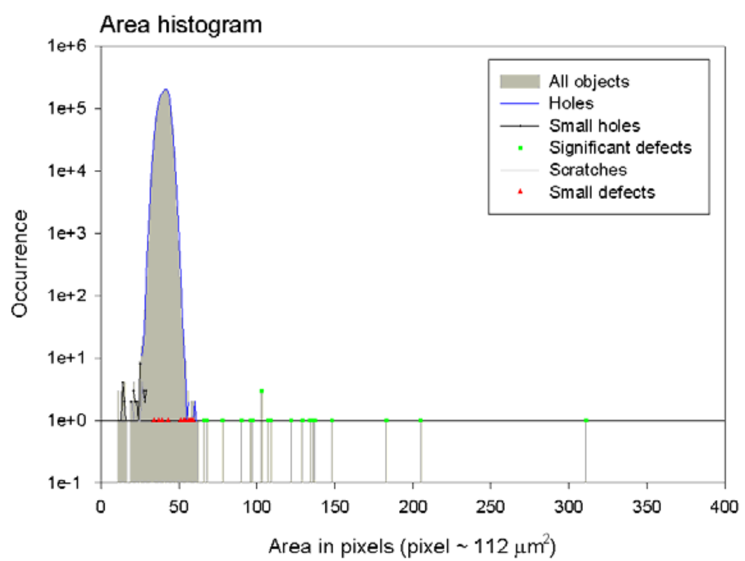


Analysis of defects and hole sizes

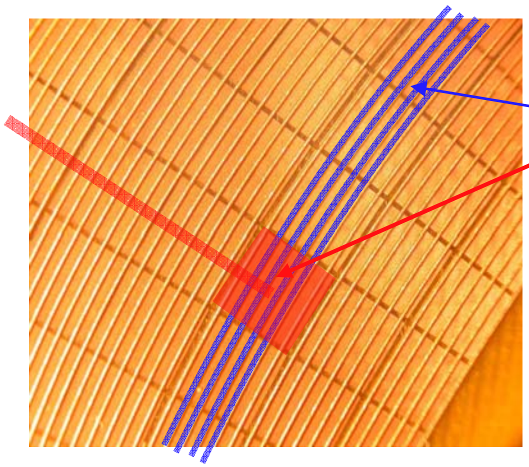




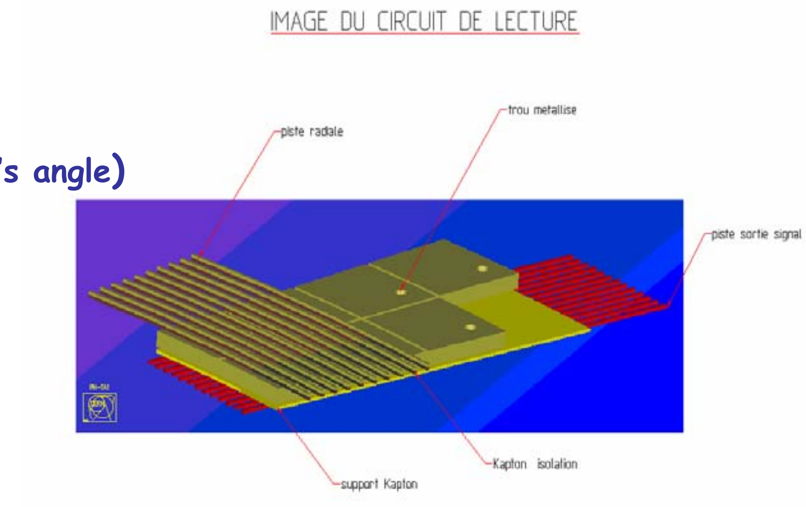


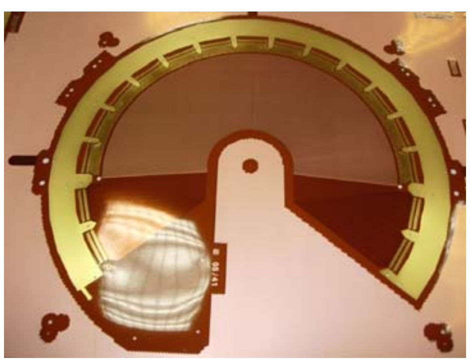


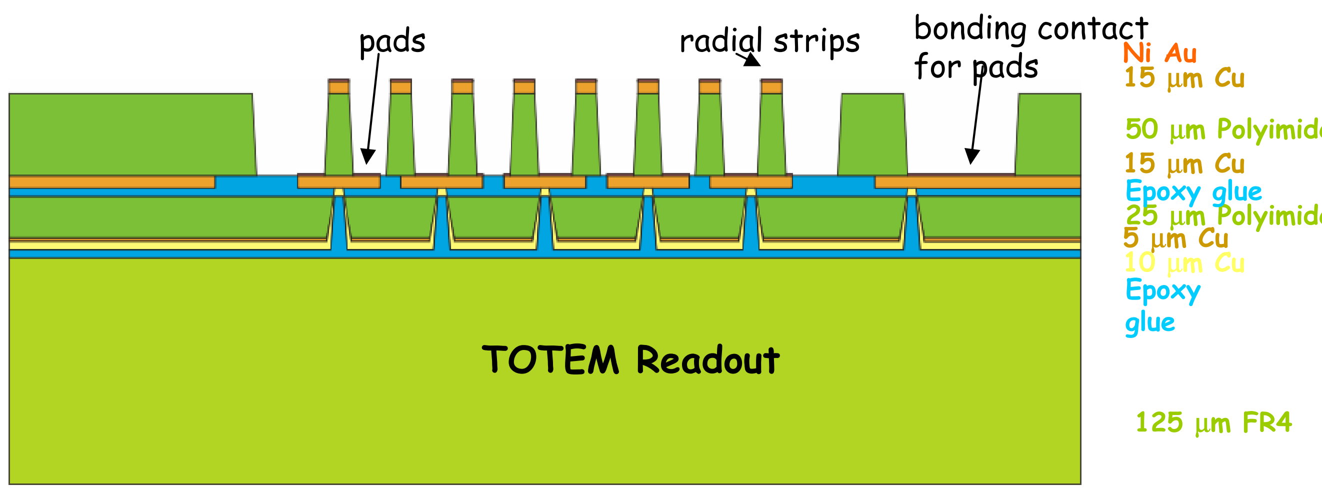
TOTEM GEM - Readout Board



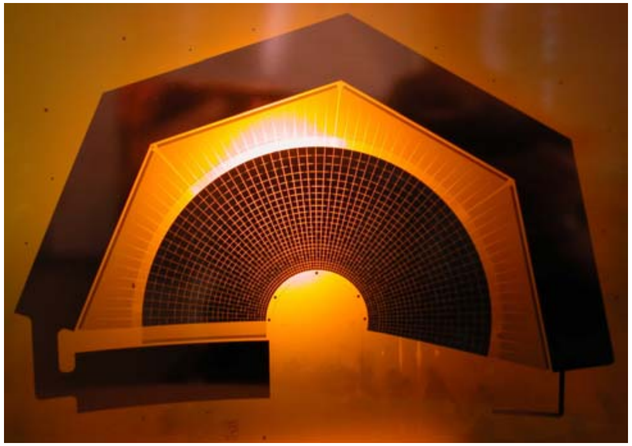
TOTEM READOUT BOARD:
Radial strips (accurate track's angle)
Pad matrix (fast trigger)

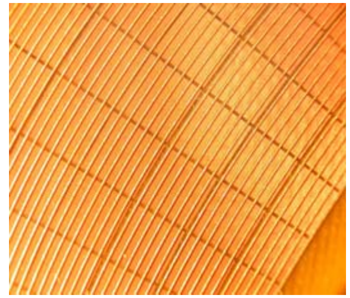


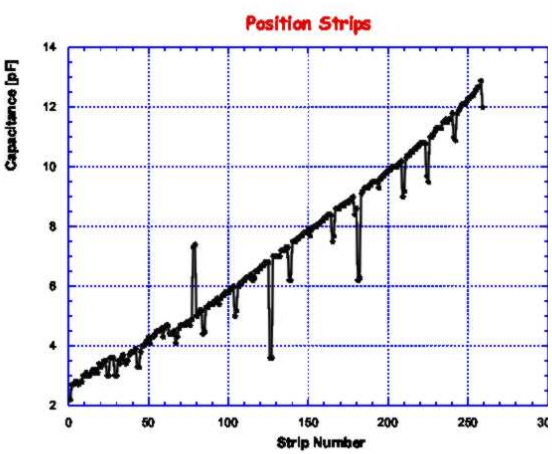


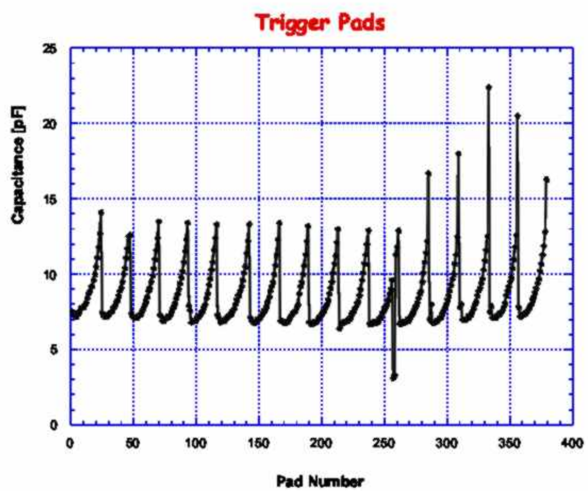


TOTEM GEM Readout Board Test







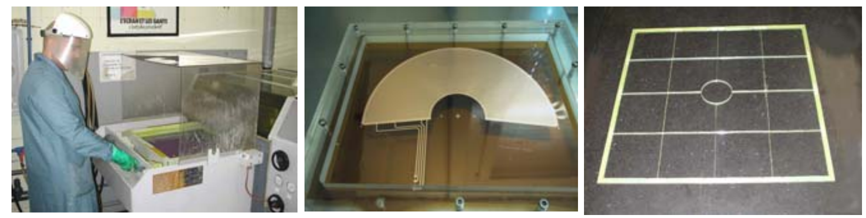


Quality test for continuity and shorts – Capacitance measurement between channels for strips and pads

GEM Detectors Production at CERN

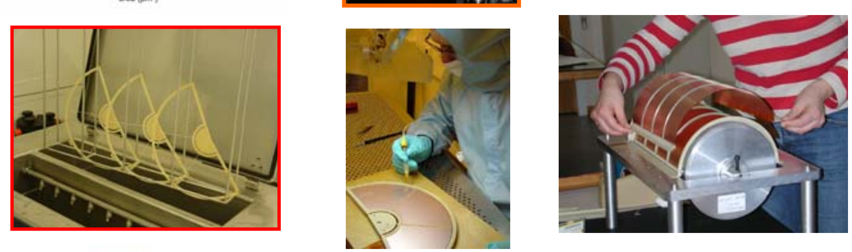
Detector Design

Component Production

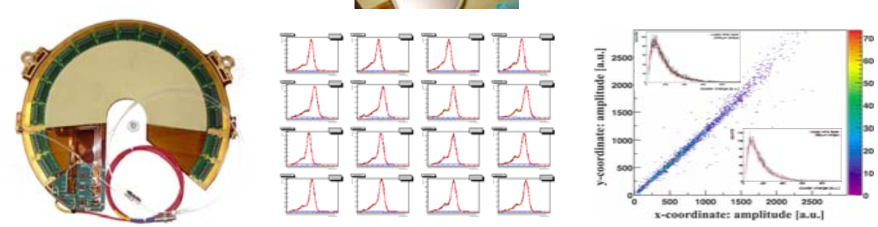


Component Quality Control

Detector Assembly

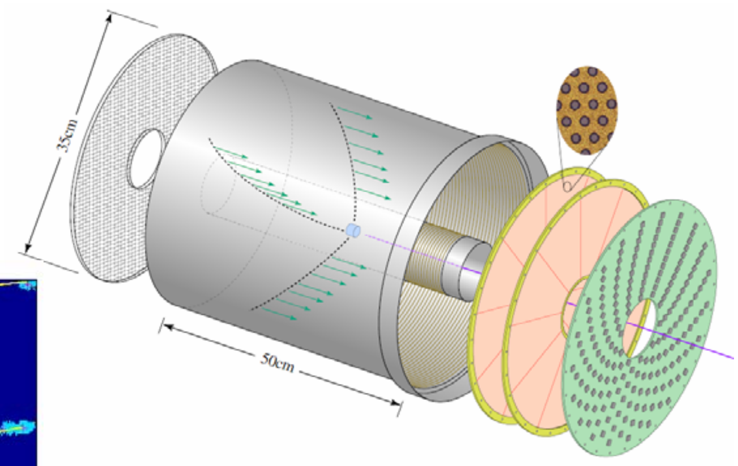


Detector Test

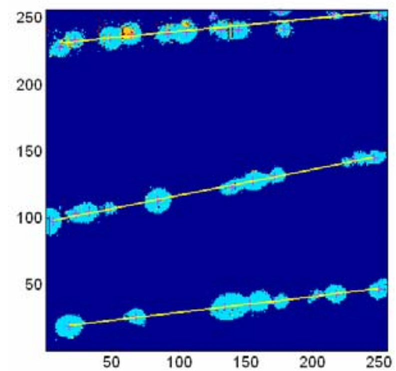


Staff Training

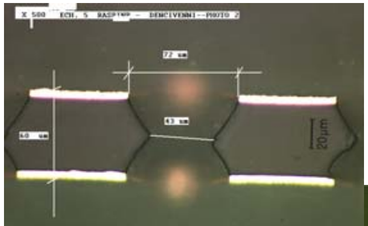
Perspectives

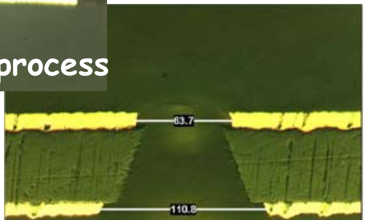


Tracking and triggering (LHCb & TOTEM)
TPC end cap readout (ion feedback reduction)
X-ray radiography
UV light detection
Parallax error free detector
Hadron blind
Neutron detection
Optical GEM
Cryogenic detectors
Two-phase detectors
High resolution detectors integrated with pixel CMOS chips



Non planar large acceptance detectors
Light detectors – mass reduction
New readout structures adopted to experimental needs
Large size detectors
Industrialization of the mass production

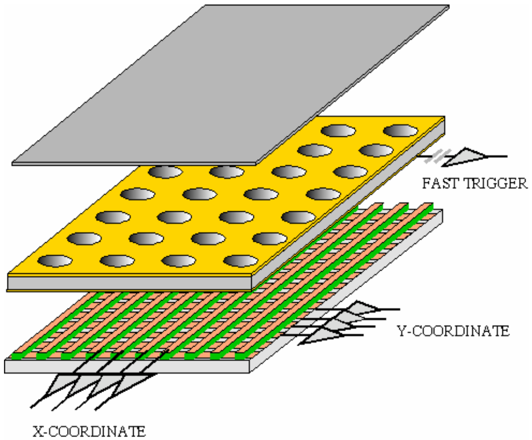

Double mask process

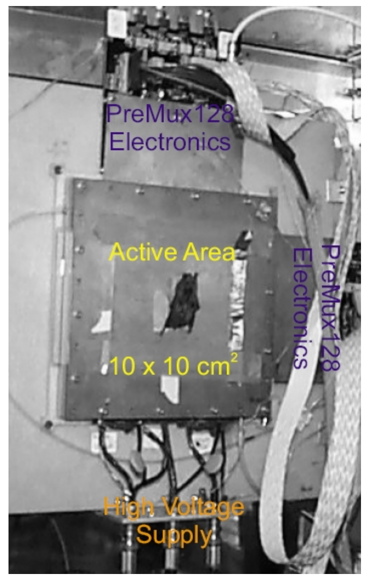


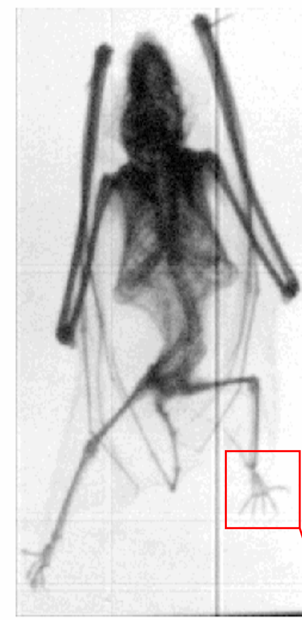
Single mask process

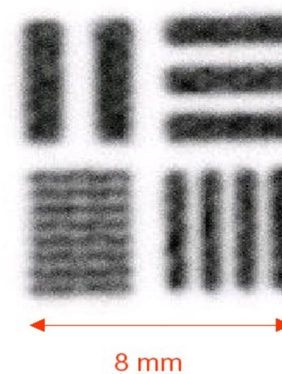
http://gdd.web.cern.ch/GDD/

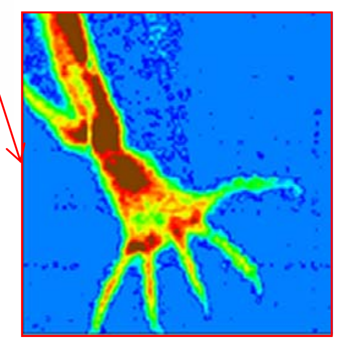
Absorption radiography with GEM (8 keV X-rays)

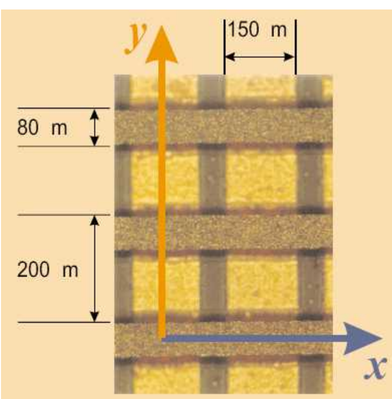












Trigger from the bottom electrode of GEM.

S. Bachmann et al, Nucl. Instr. and Meth. A471(2001)115

Absorption radiography with GEM (8 keV X-rays)