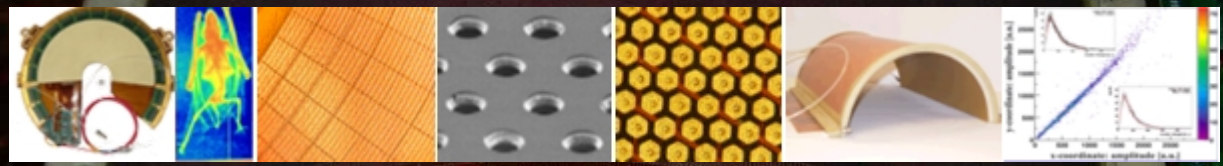
GEM at CERN

Leszek Ropelewski CERN PH-DT2-ST & TOTEM



Outline

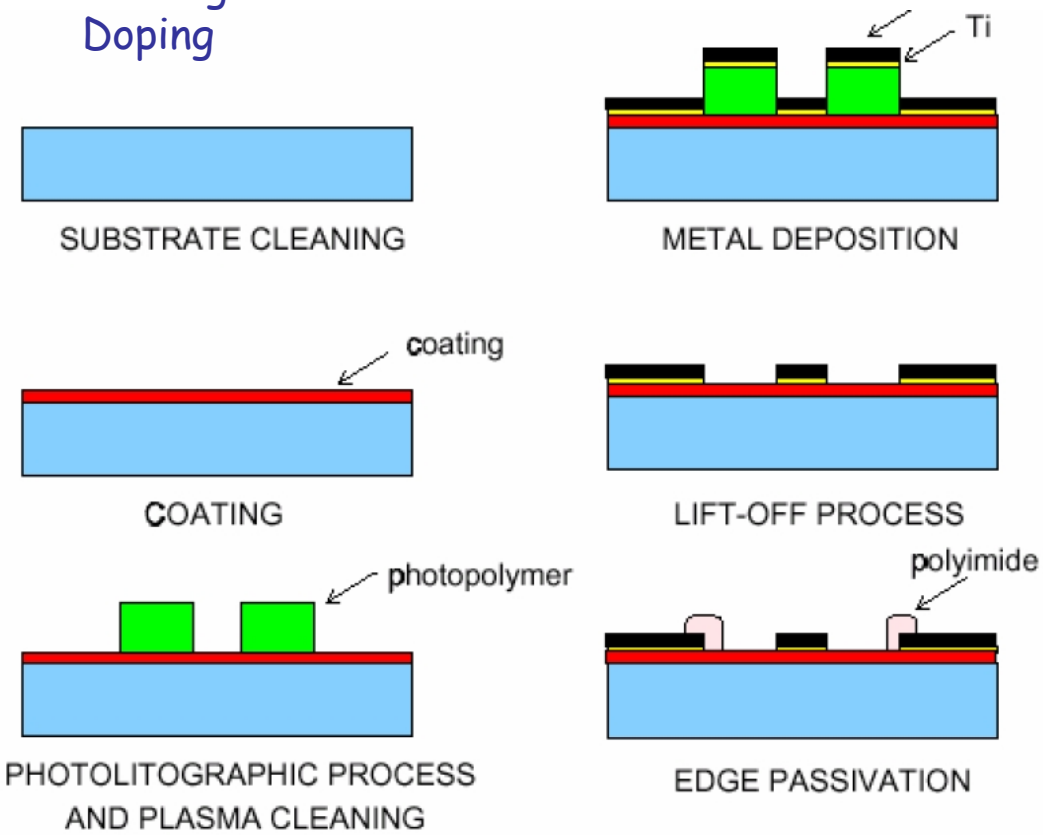
- Introduction to Gas Electron Amplifier
- Main Properties
- TOTEM
- Cylindrical GEM for NA-49 Future
- Other Applications and Perspectives
- Remarks about Future of GEM Technology at CERN

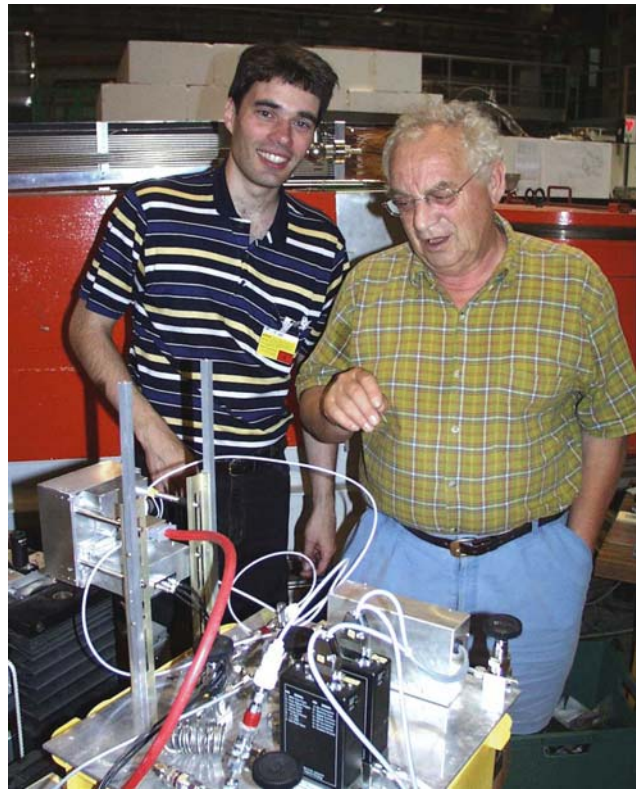
New and very old results
Limited to only GDD activities

MicroStrip Gas Chamber

Semiconductor industry technology:

Photolithography
Etching
Coating
Doping



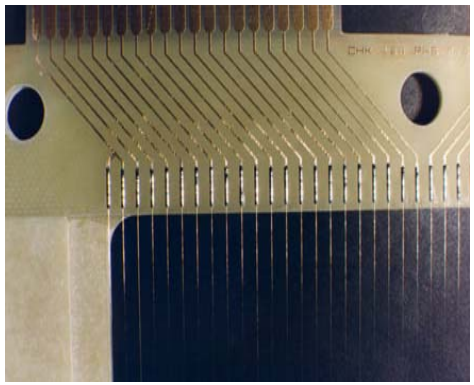


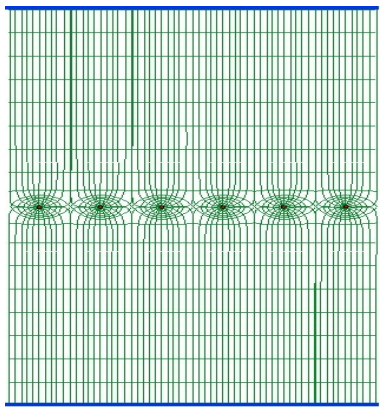
A. Oed
Nucl. Instr. and Meth. A263 (1988) 351.

Lift-off technique

MicroStrip Gas Chamber

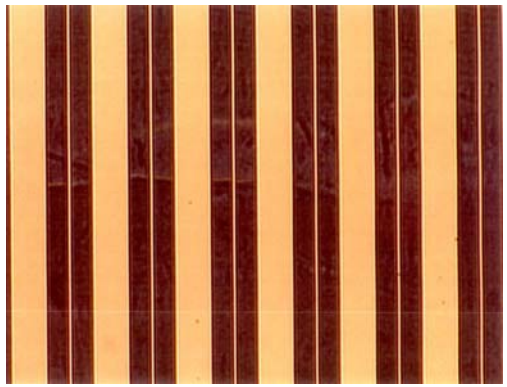
MWPC

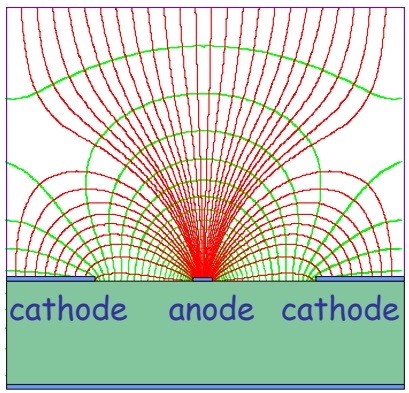




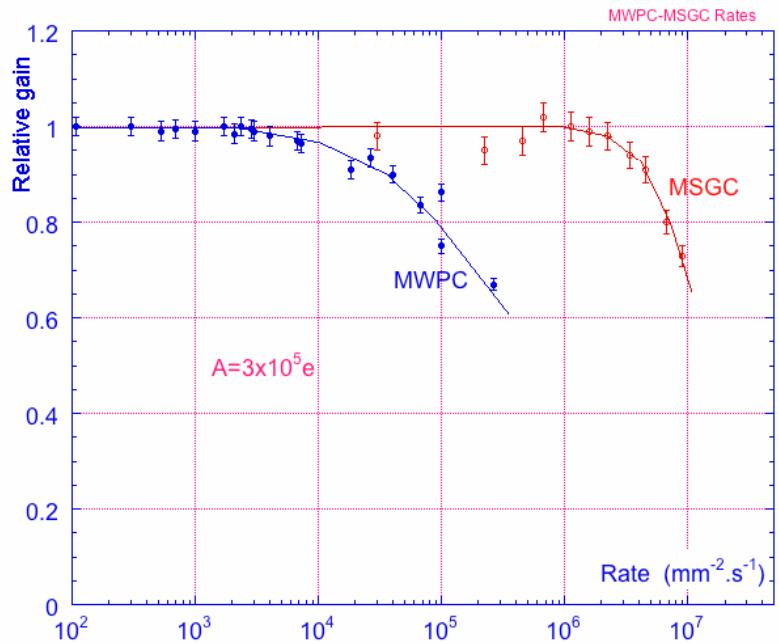
Typical distance between wires limited to 1 mm due to mechanical and electrostatic forces

MSGC





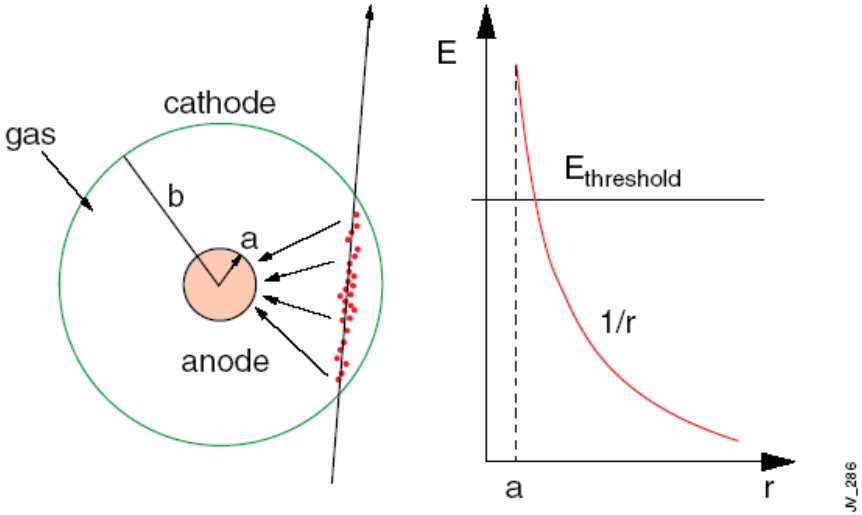
Typical distance between anodes 200 μm thanks to semiconductor etching technology



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

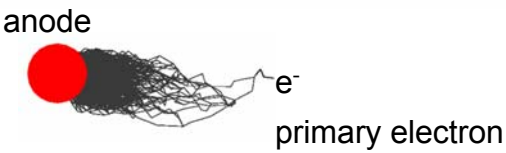
A. Oed
Nucl. Instr. and Meth. A263 (1988) 351.

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.

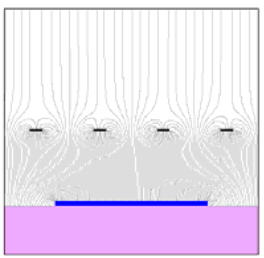


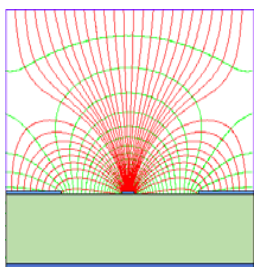
$$E(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \frac{1}{r}$$

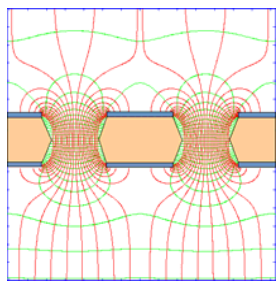
$$V(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \ln\frac{r}{a}$$

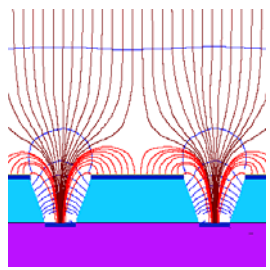
C – capacitance/unit length

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

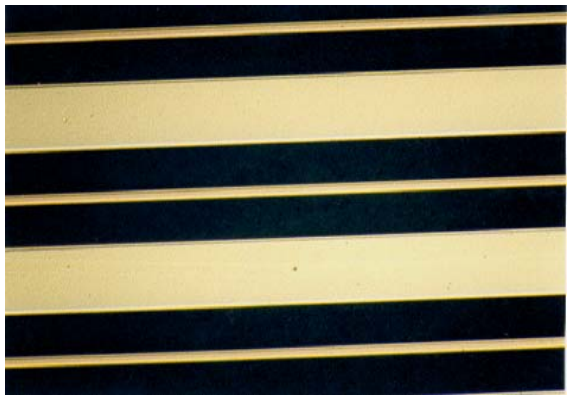

parallel plate

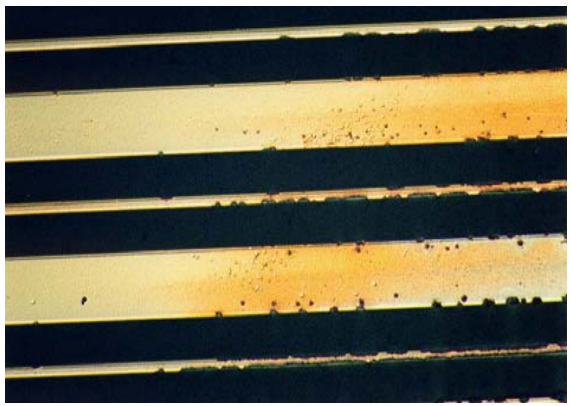

strip

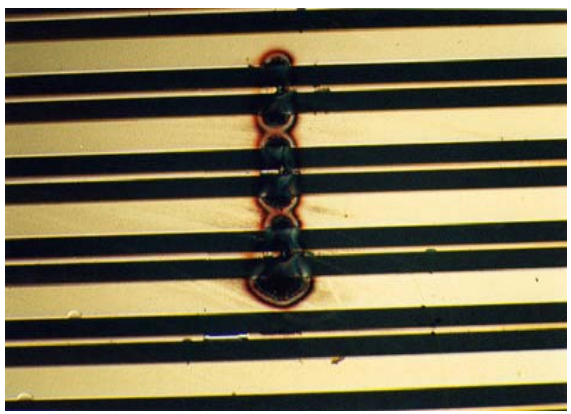

hole


groove

MicroStrip Gas Chamber







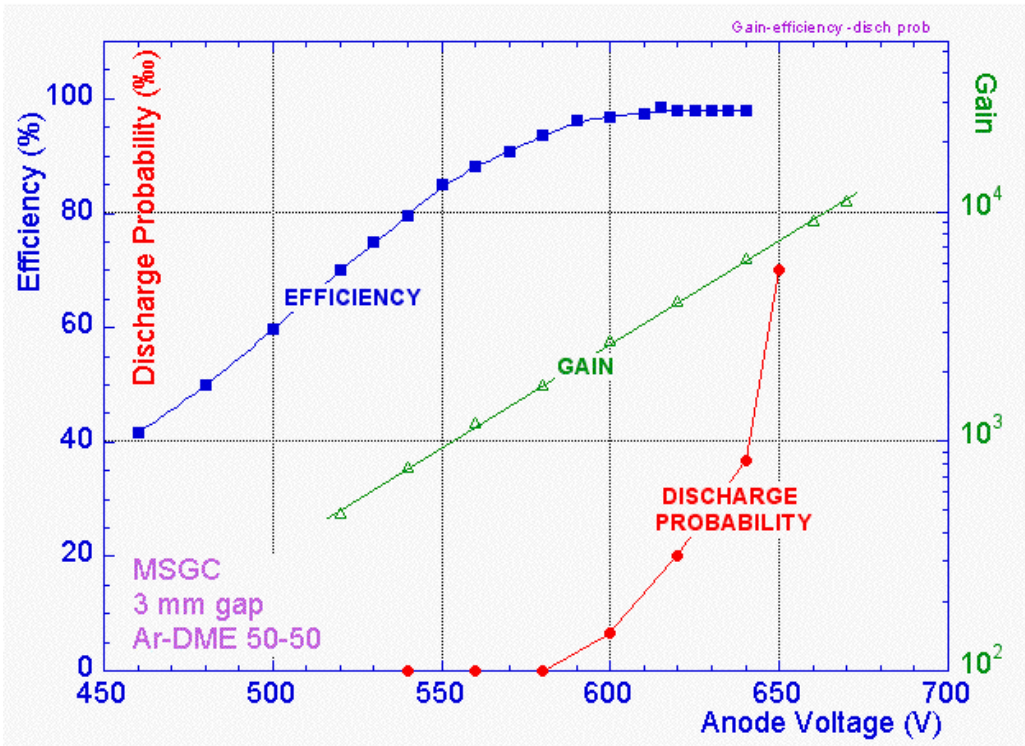
Surface charging

Bulk resistivity of the support material
Surface modification by doping or deposition

Ageing

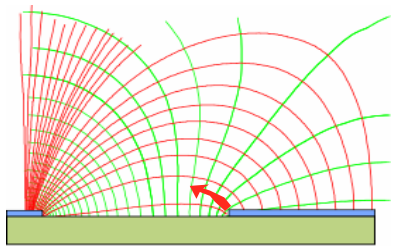
Gas, Gas system, MSGC support, Construction material

Discharges

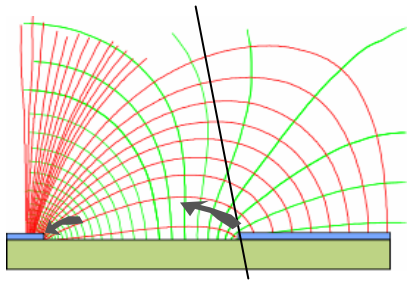


MicroStrip Gas Chamber

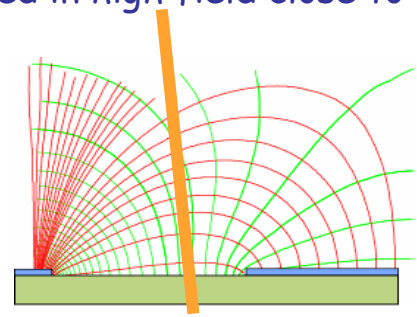
MSGC: Discharge mechanisms



Field emission from the cathode edge

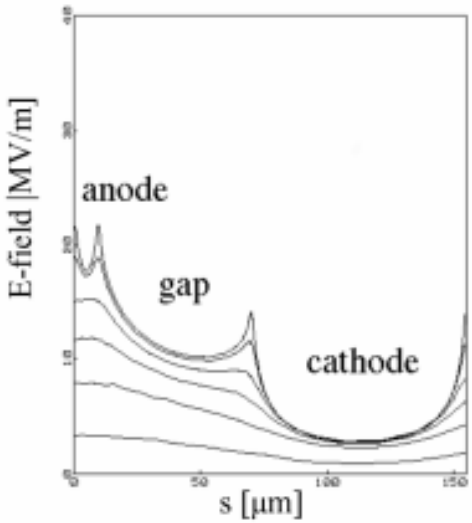


Charge pre-amplification for ionization released in high field close to cathode

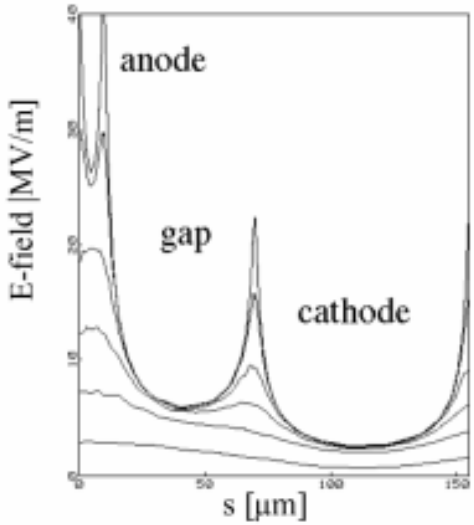


Very high ionization release:
avalanche size exceeds Reather's limit
$Q \sim 10^7$

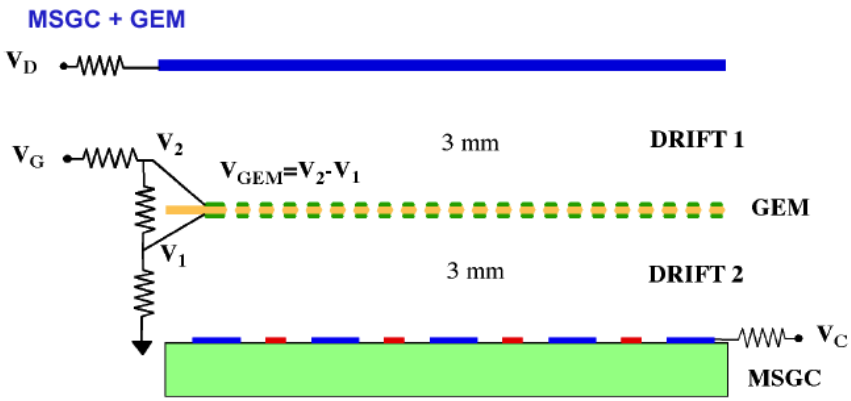
Electric field strength close to support plane in MSGC



Coated MSGC

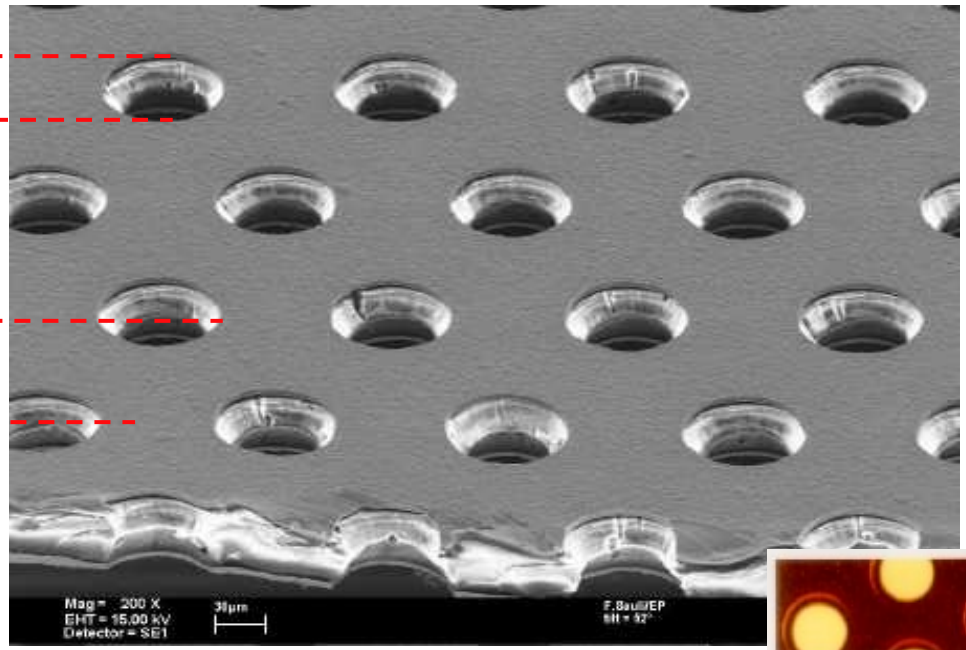


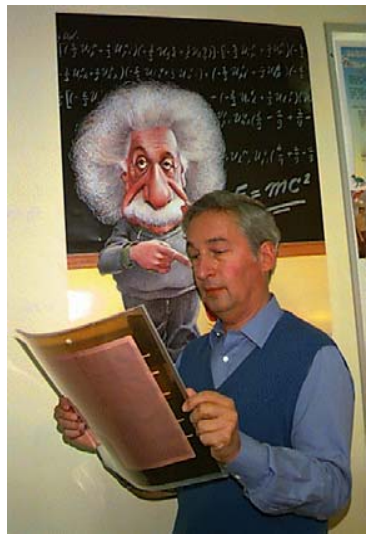
Uncoated MSGC



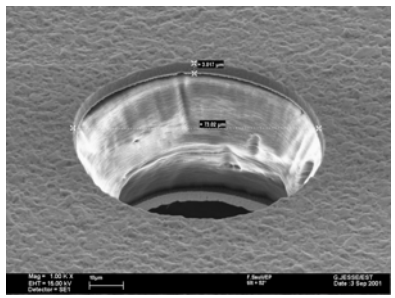
GEM: Gas Electron Multiplier

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

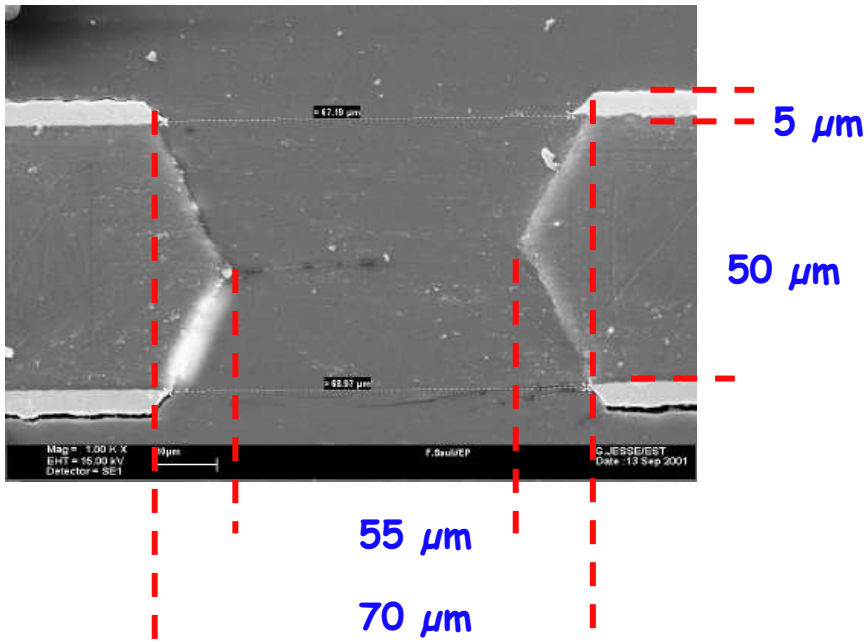




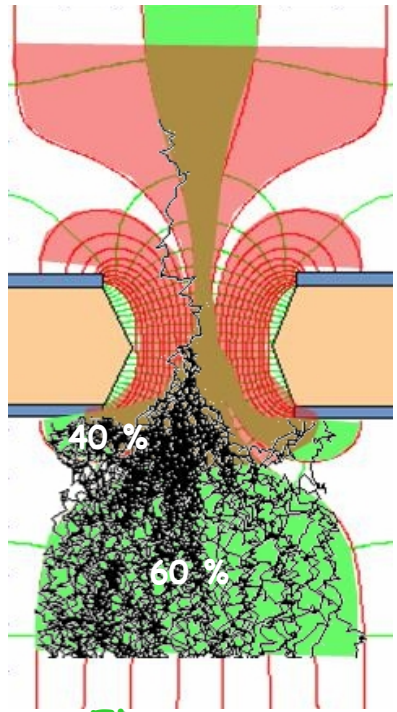
F. Sauli, Nucl. Instrum. Methods A386(1997)531



GEM Principle

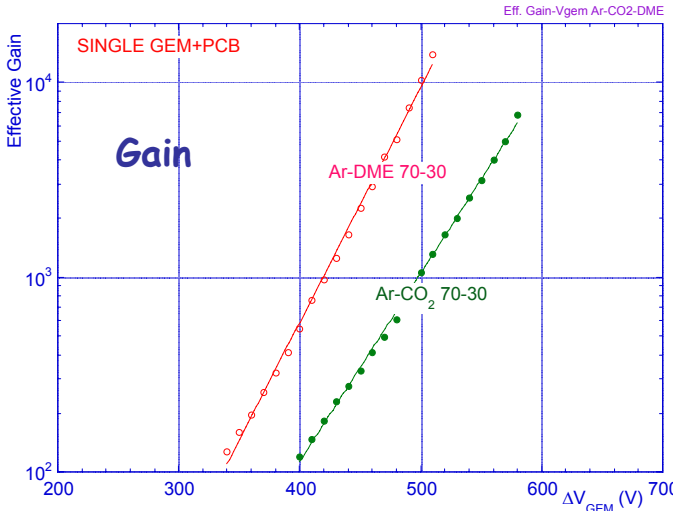


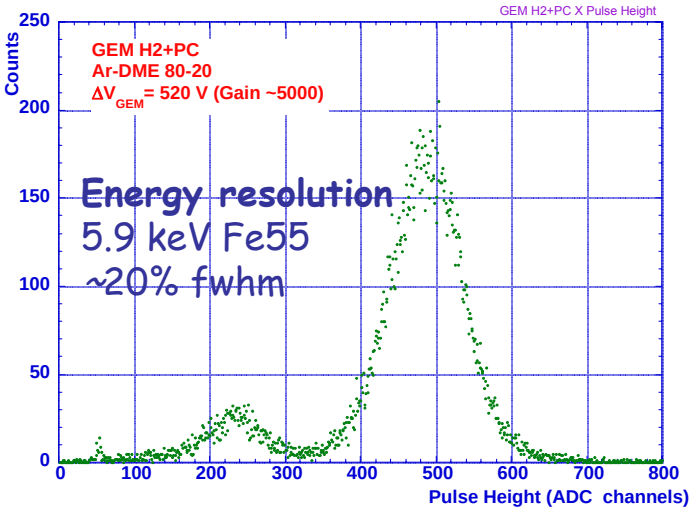
GEM hole cross section



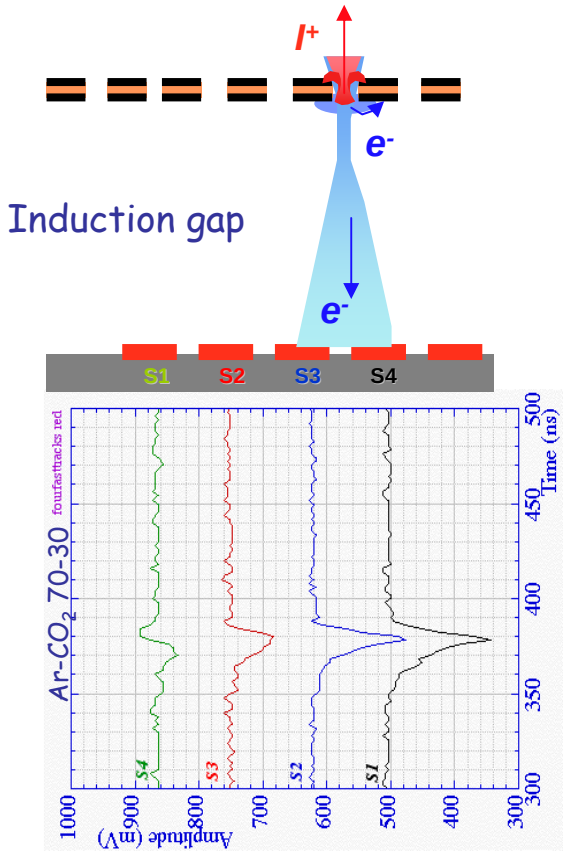
Avalanche simulation

Single GEM Performances





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

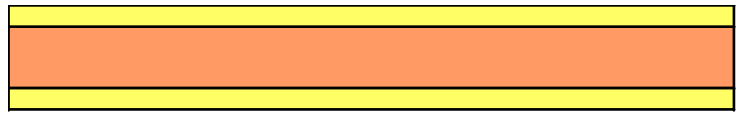


Electrons are collected on patterned readout board.
A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.
All readout electrodes are at ground potential.
Positive ions partially collected on the GEM electrodes.

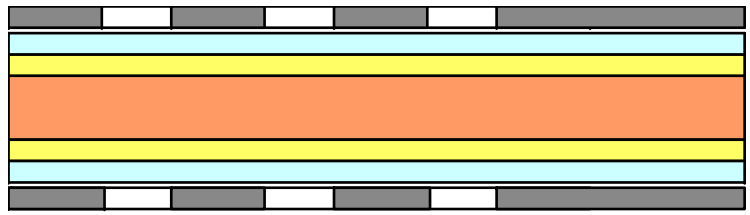
GEM Manufacturing

Rui De Oliveira
CERN-EST-DEM

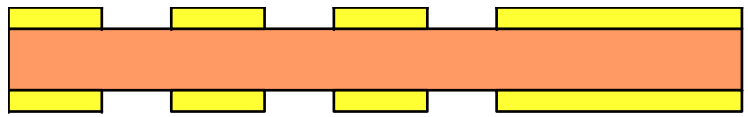
50 μm Kapton
5 μm Cu both sides



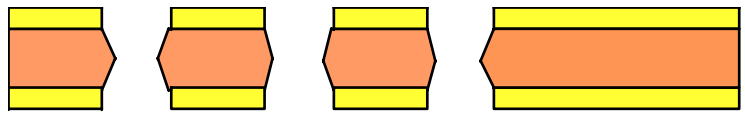
Photoresist coating,
masking and exposure
to UV light



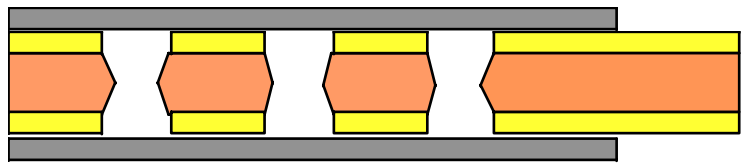
Metal etching



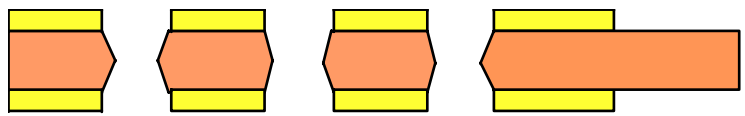
Kapton etching



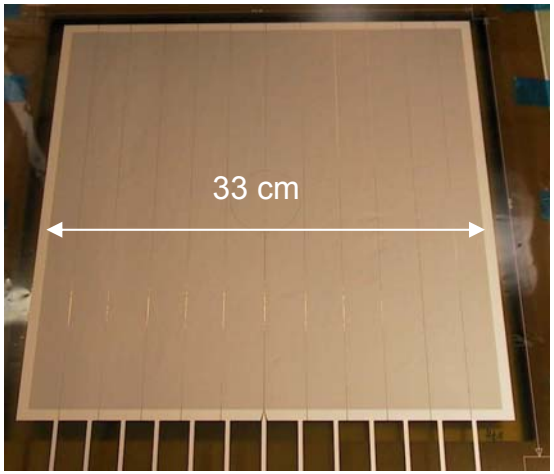
Second masking

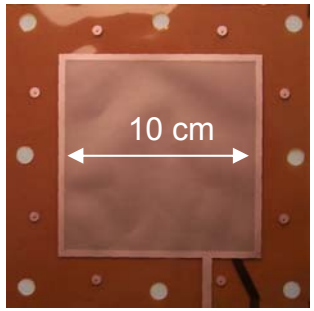


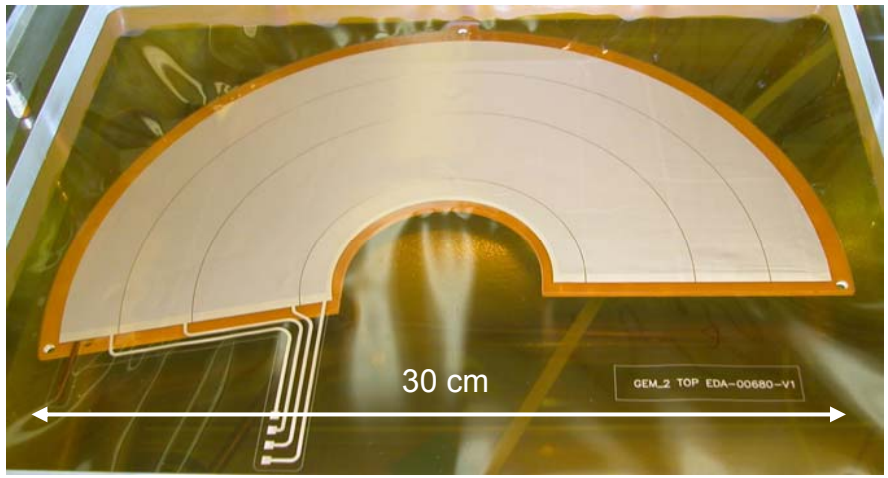
Metal etching
and cleaning

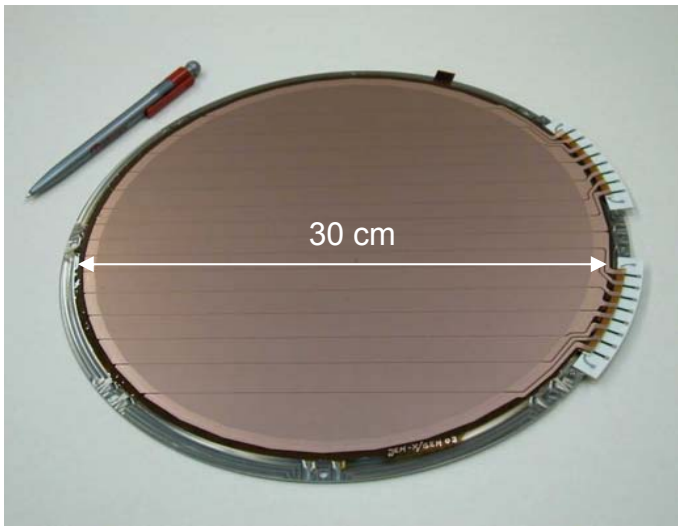


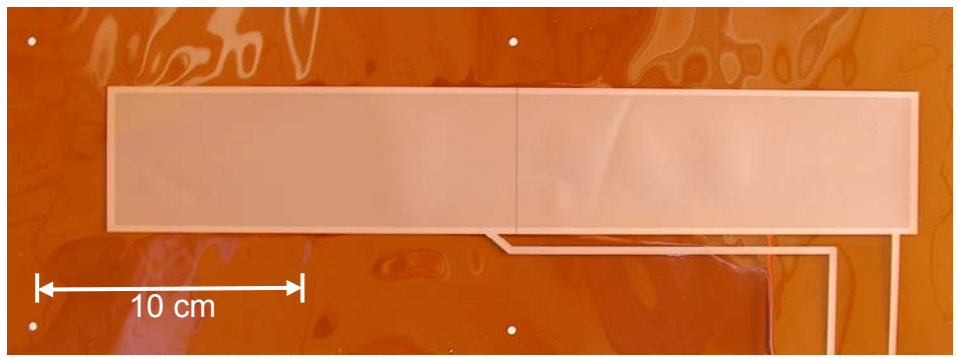
GEM Manufacturing







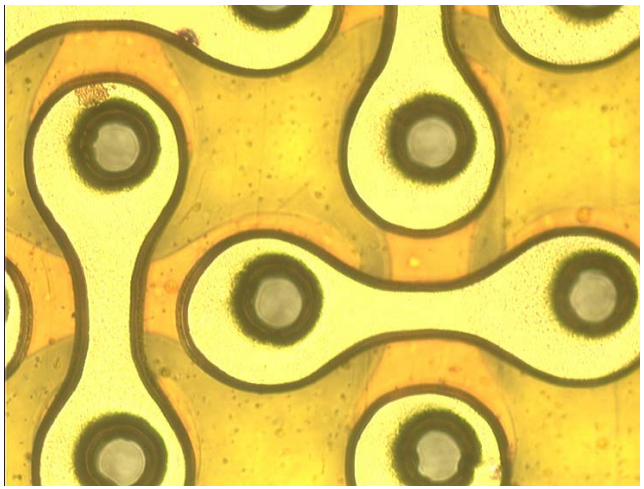


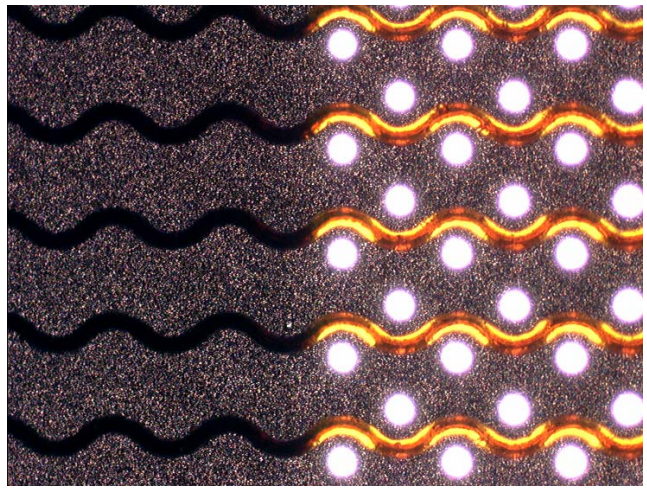


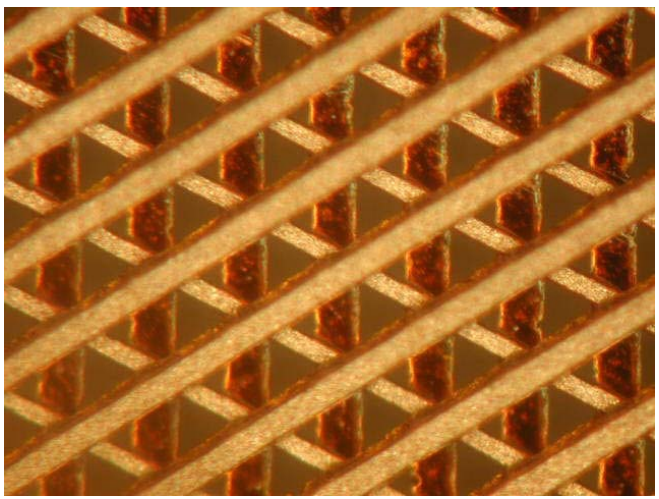
Wide rage of shapes and sizes

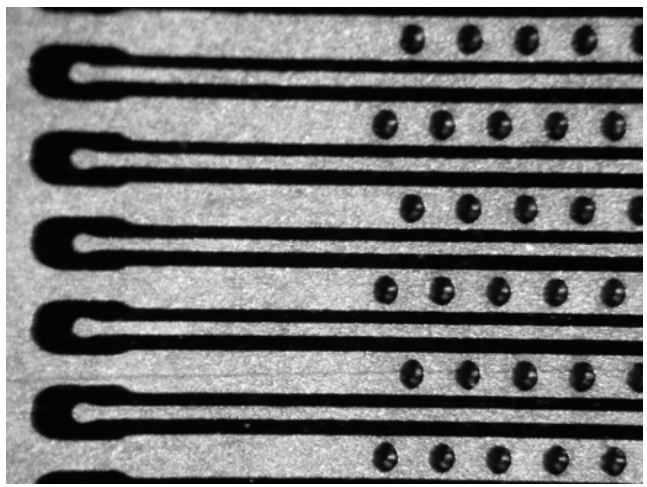
1500÷2000 foils manufactured at CERN
1 cm^2 to 1000 cm^2
30-200 μm holes, 50-300 μm pitch

Art of Kapton Etching

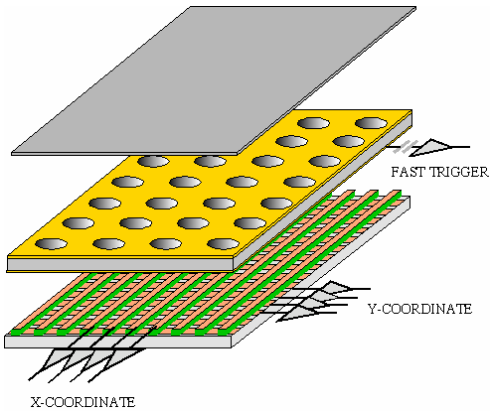








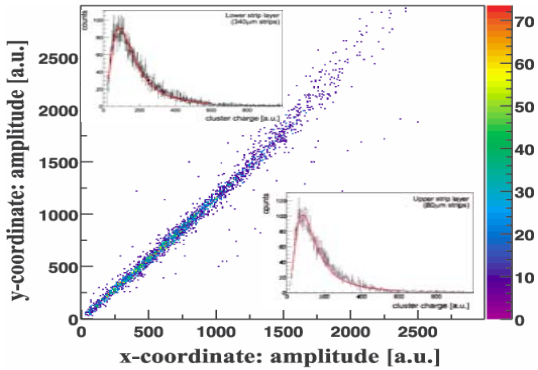
GEM – Gas Electron Multiplier



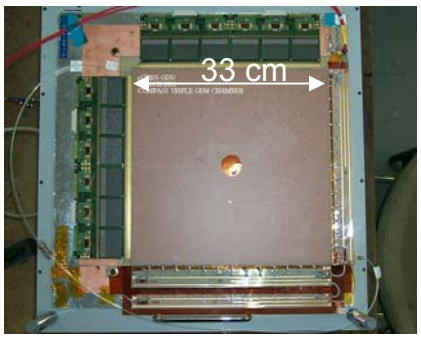
A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254

Full decoupling of the charge amplification structure from the charge collection and readout structure.

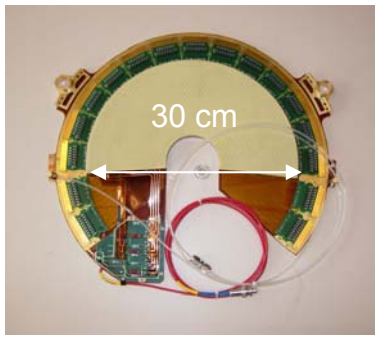
Both structures can be optimized independently !



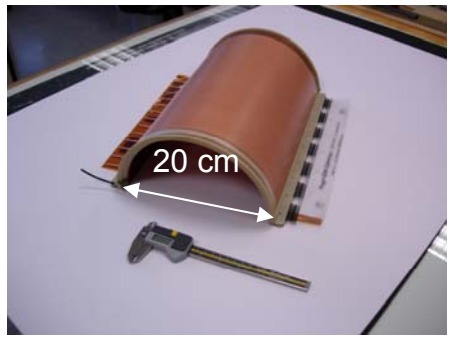
Charge correlation (Cartesian readout)



Compass

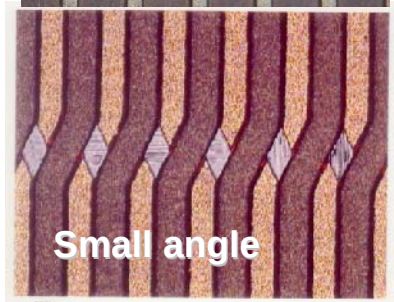


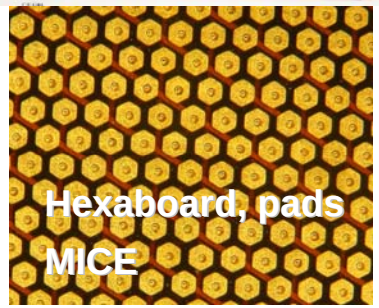
Totem



NA49-future

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

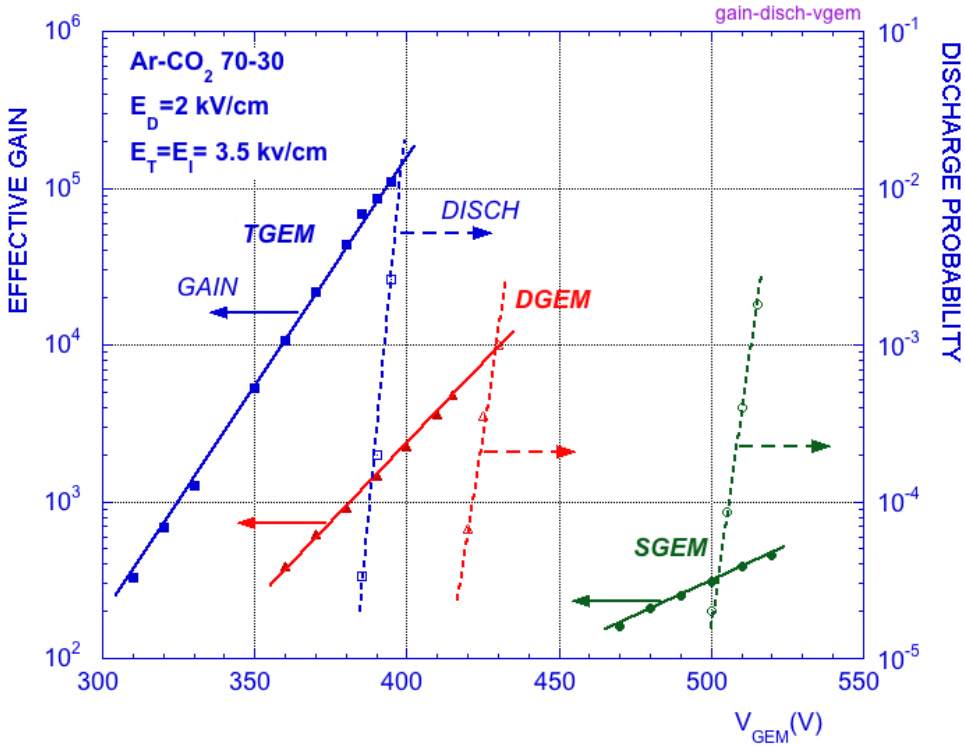




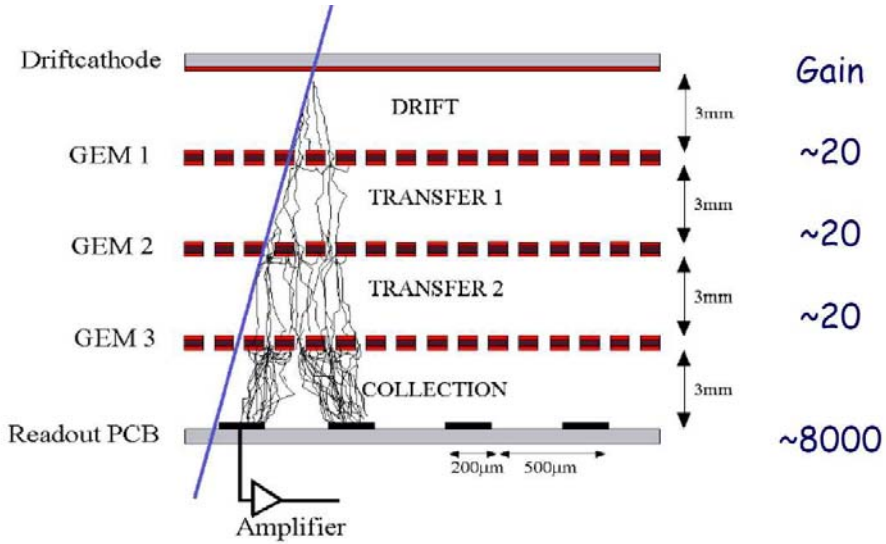
Multi-GEM Detectors

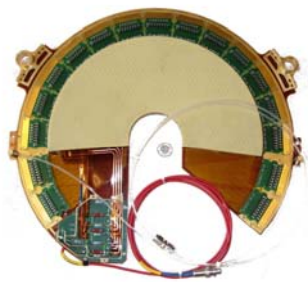
Discharge Probability on Exposure to 5 MeV Alphas

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



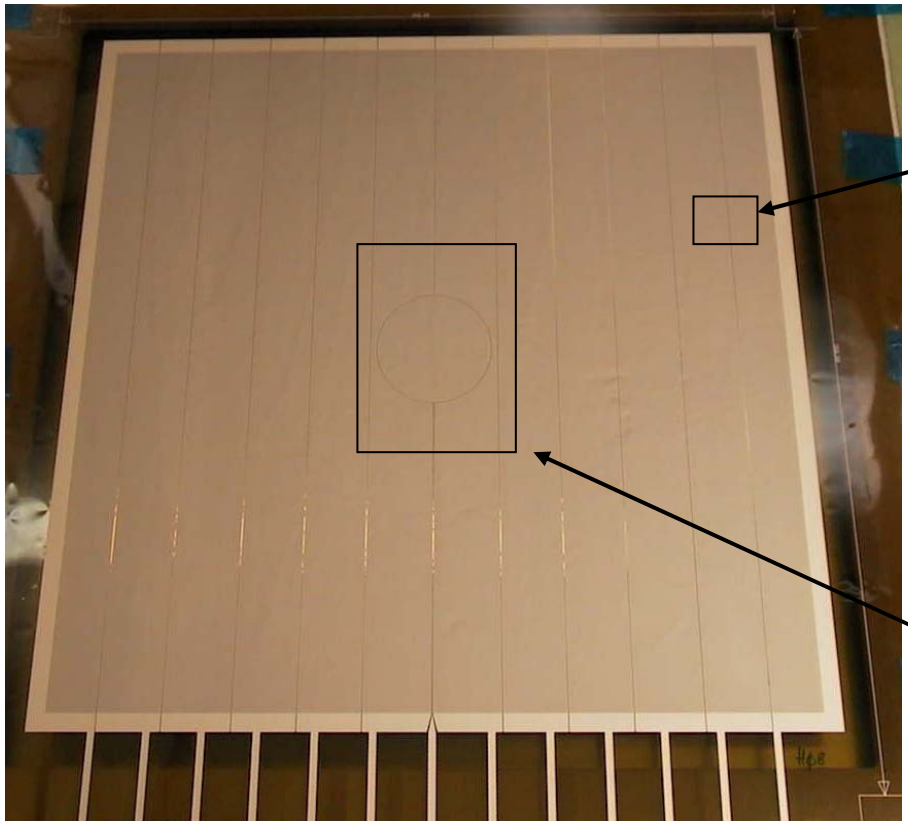
S. Bachmann et al Nucl. Instr. and Meth. A479(2002)294

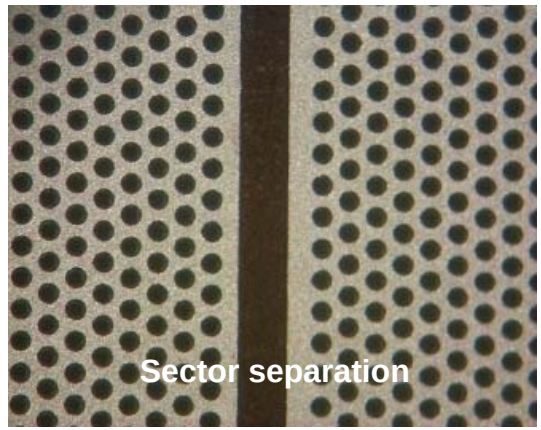


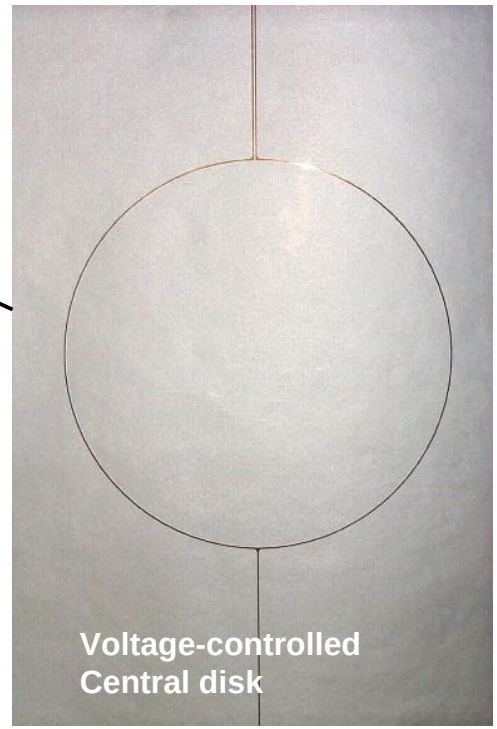


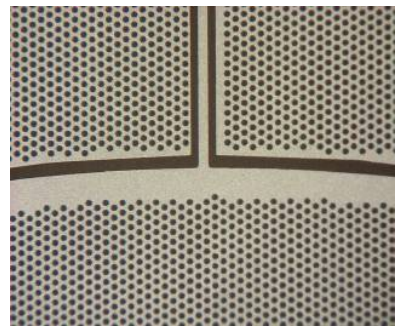
HV sectors

GEM foils for COMPASS (31x31 cm^2),
12-sectors + beam killer



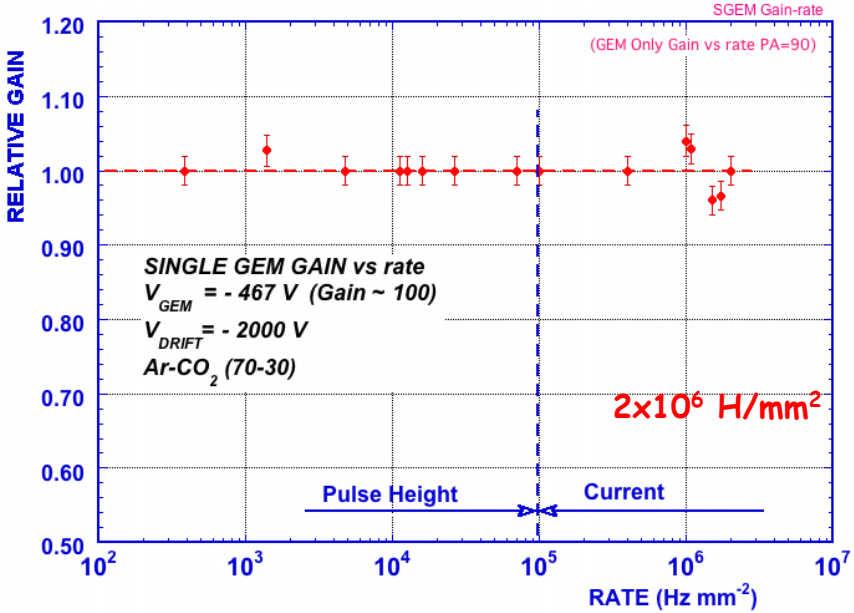




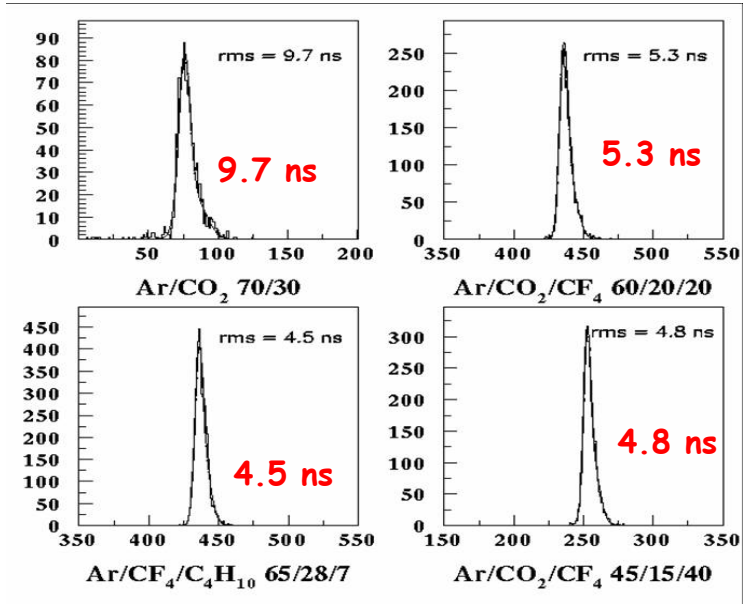


~ 100 foils produced
22 Triple-GEM detectors running

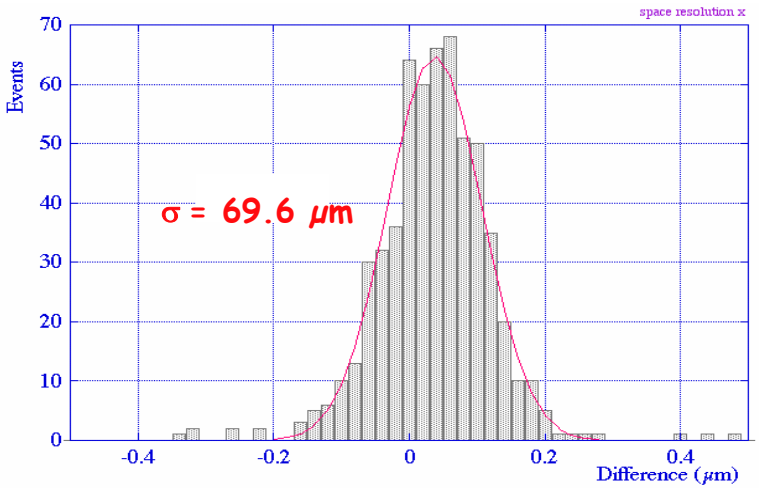
GEM – Gas Electron Multiplier



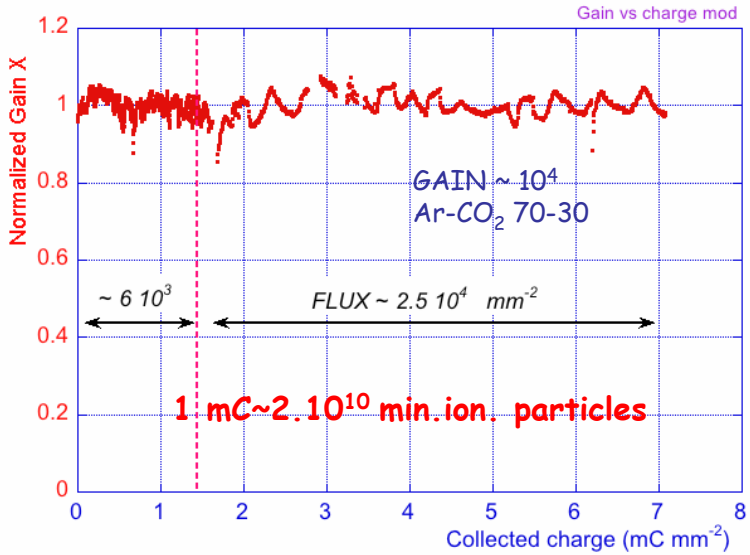
Rate capability



Time resolution

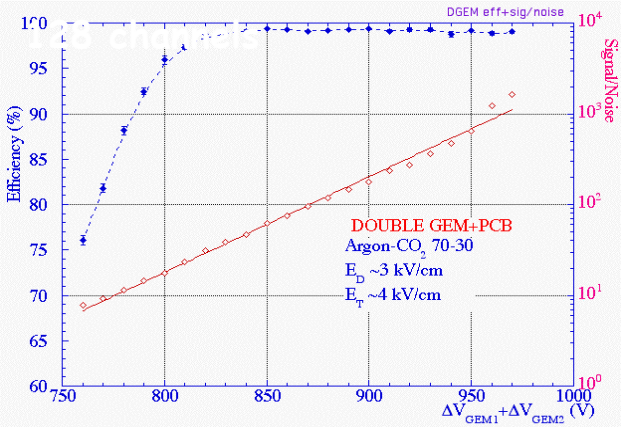


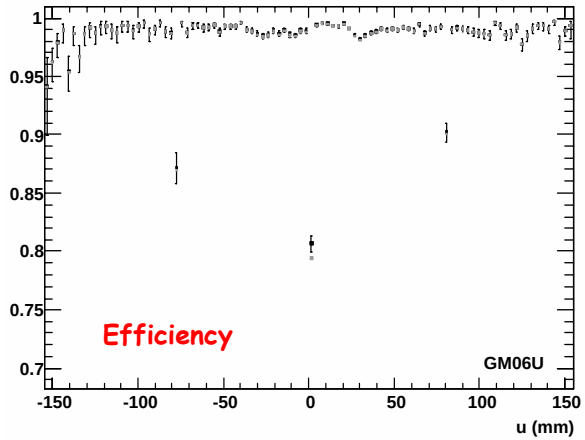
Space resolution

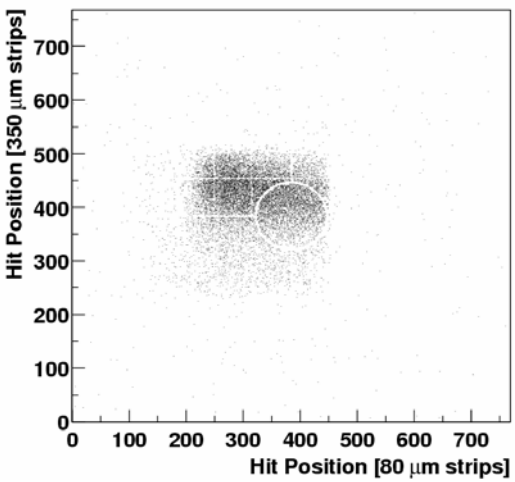


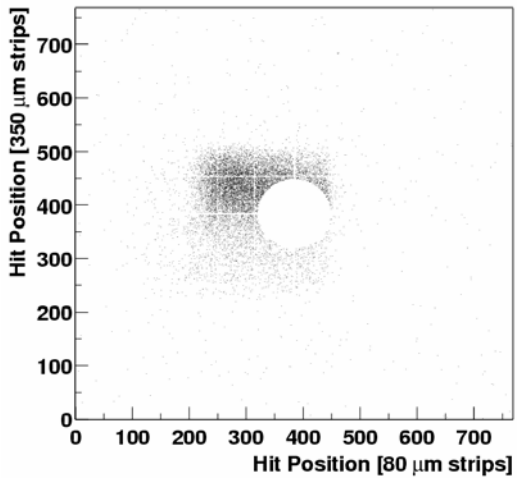
Ageing properties

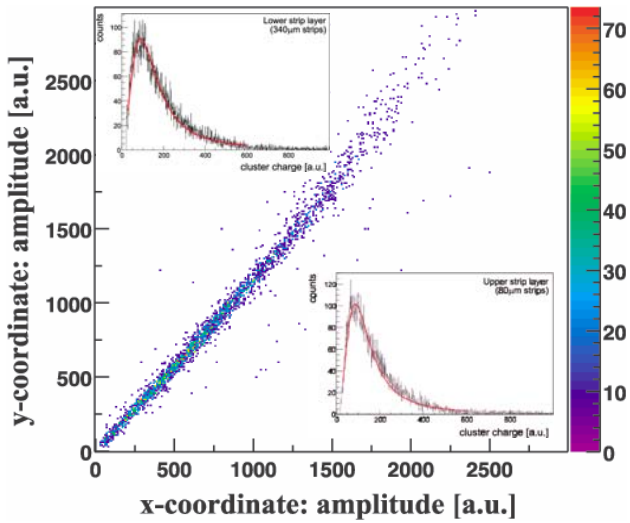
GEM - Gas Electron Multiplier





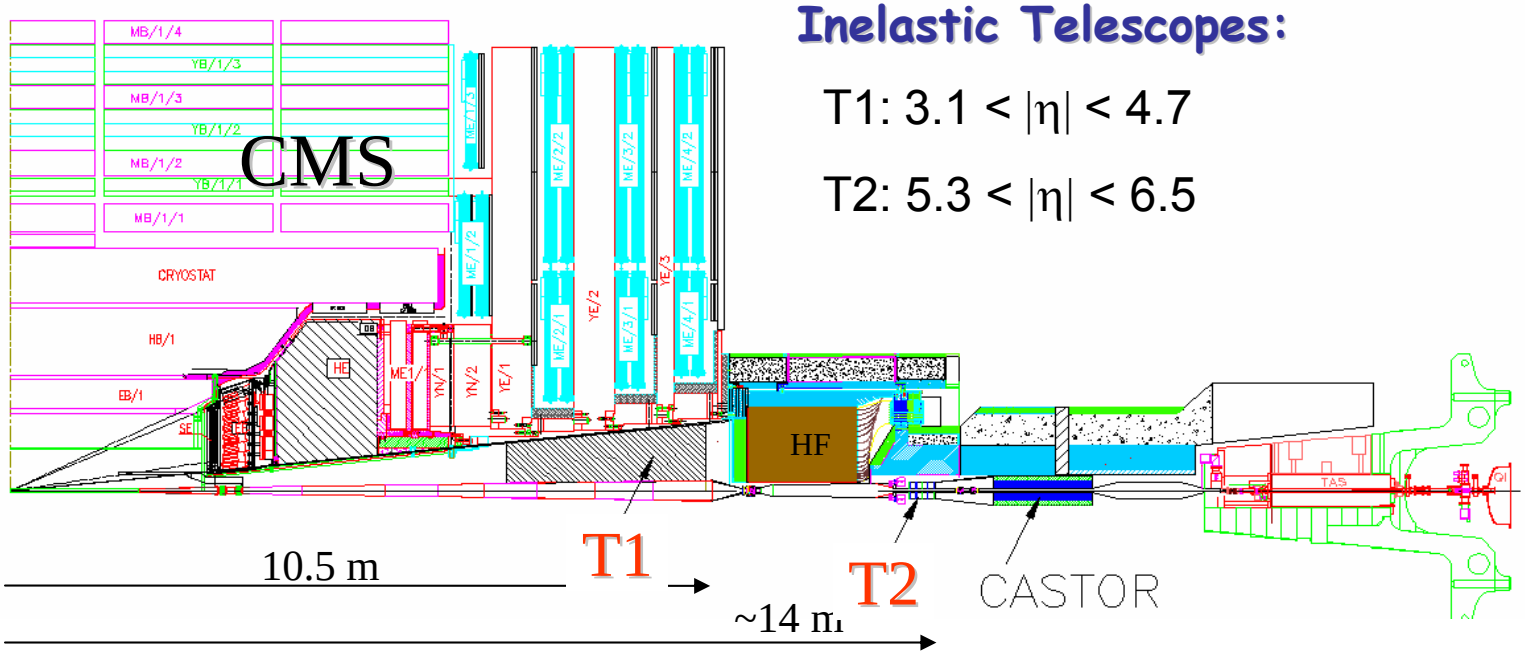






TOTEM Detectors

to measure total pp cross section and study elastic scattering and diffractive dissociation at the LHC

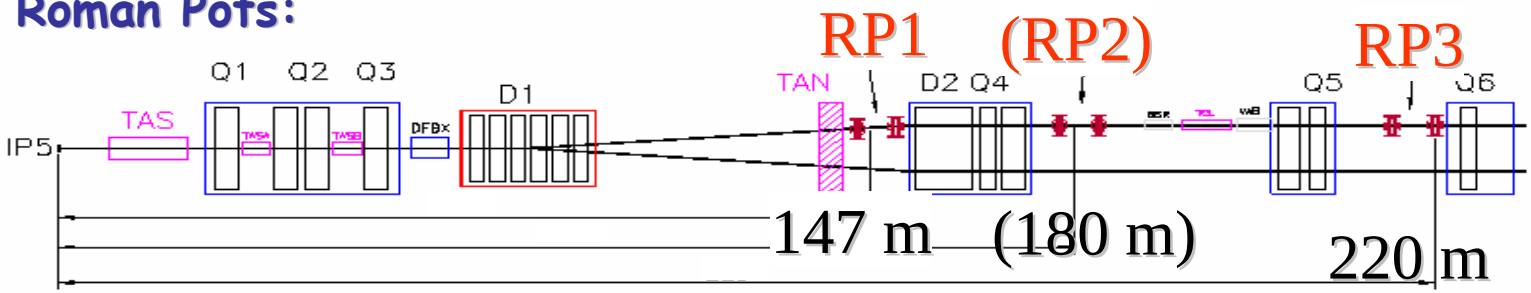


Inelastic Telescopes:

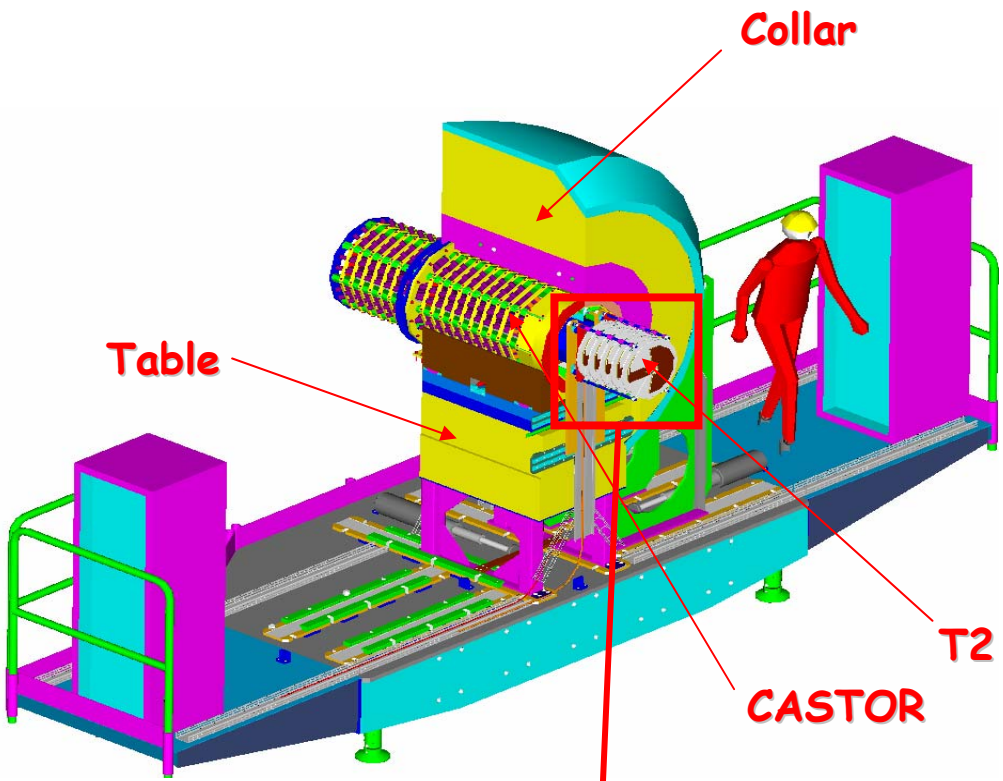
T1: $3.1 < |\eta| < 4.7$

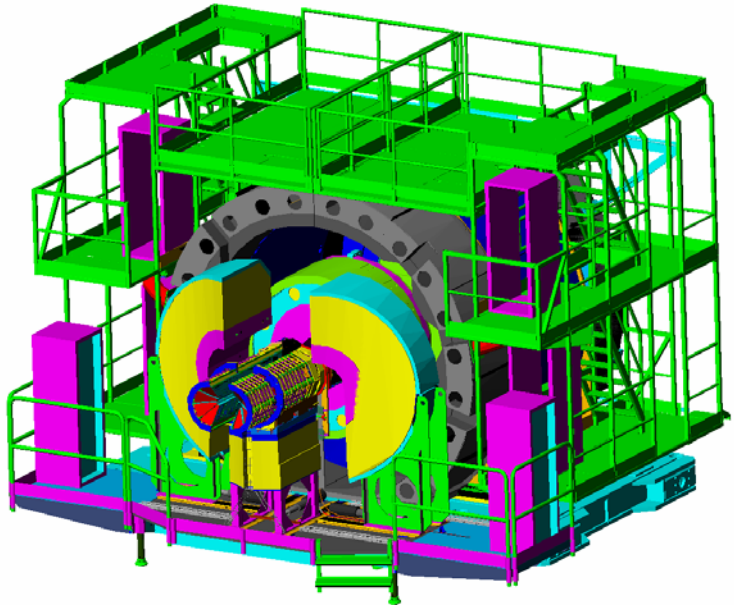
T2: $5.3 < |\eta| < 6.5$

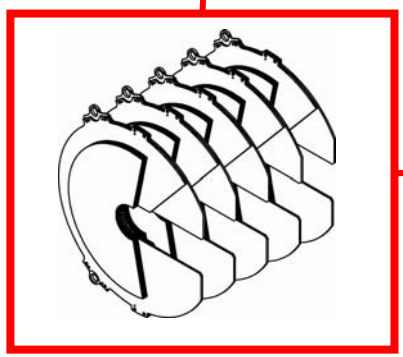
Roman Pots:

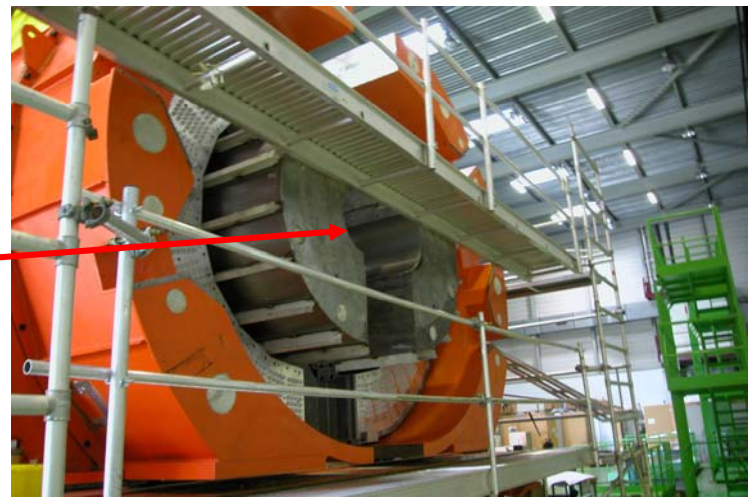


T2 Telescope







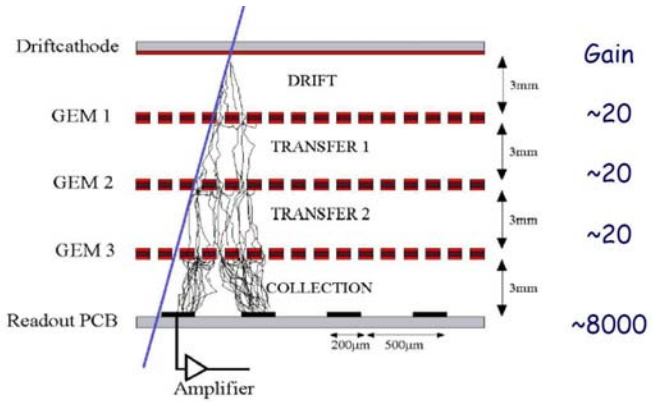


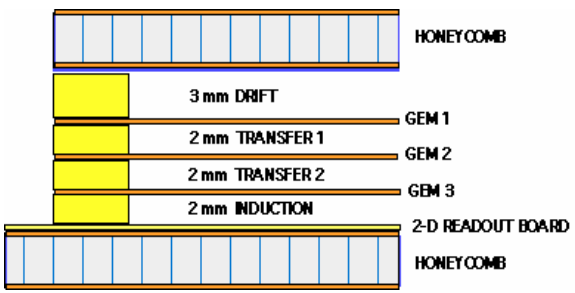
10 detector planes on each side of IP

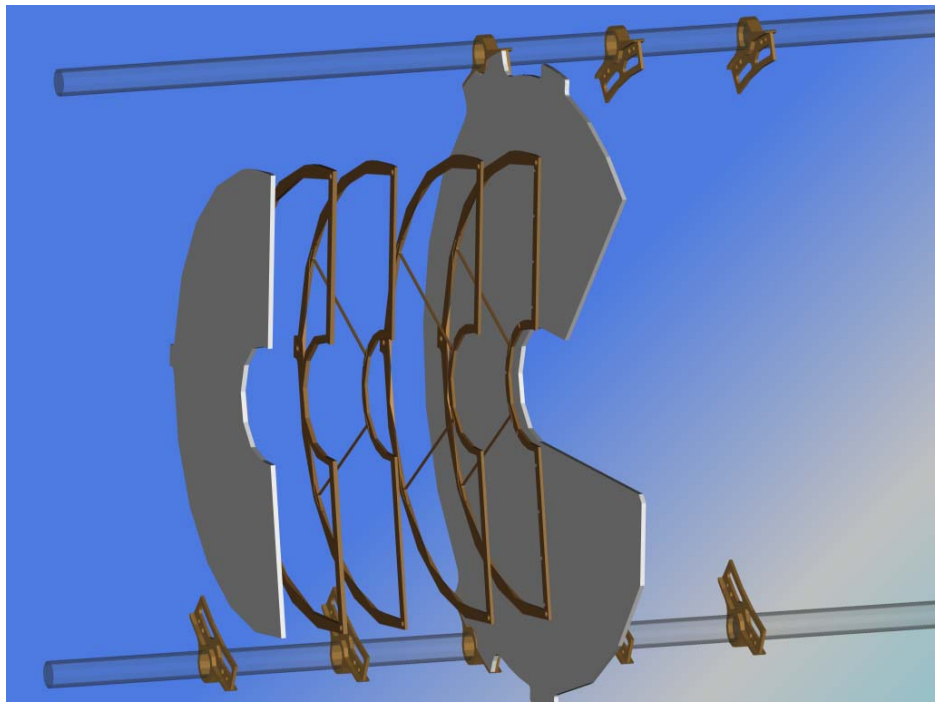
TOTEM GEM : Concept and Design

Detector requirements:

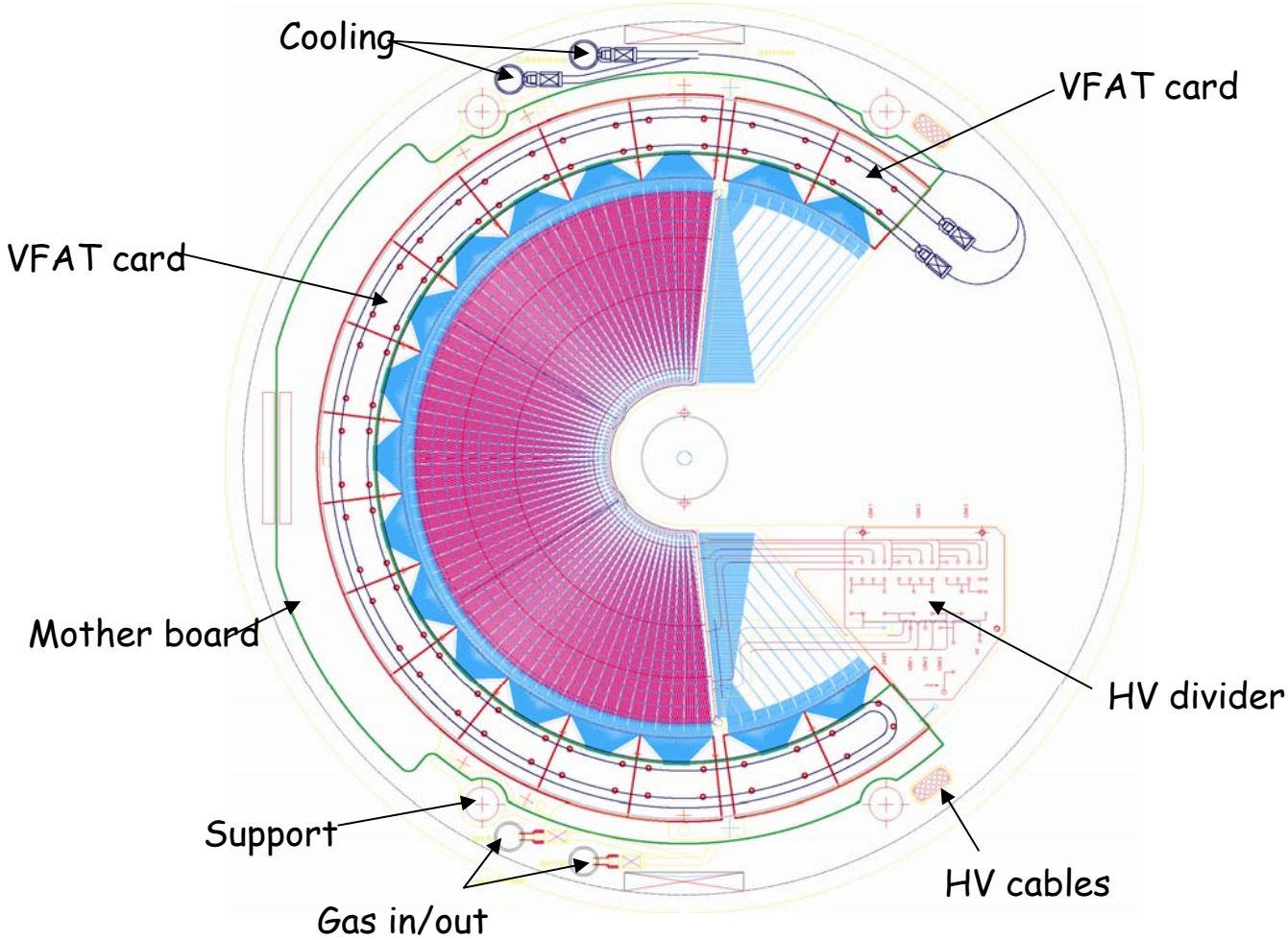
Rate Capability	- Charge particle rates 10^4 p mm^{-2}s^{-1} at $\mathcal{L}$ = 10^{33} cm^{-2}s^{-1}
Ageing	- 1 year of continuous operation 10^{11} p mm^{-2} -> 7 mC mm^{-2}
Discharges	- at probability of 10^{-12}/part. -> 10 disch. cm^{-2} year^{-1}
Time Resolution	- < 10 ns
Space Resolution	- < 100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

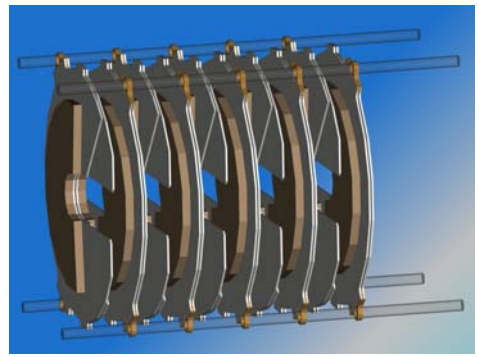


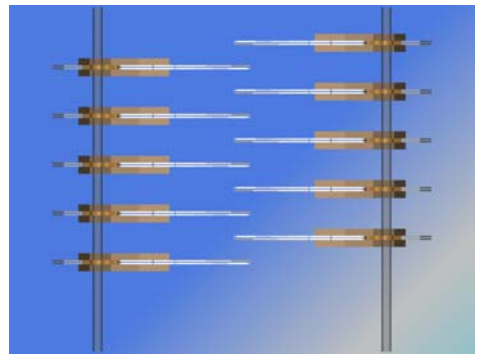


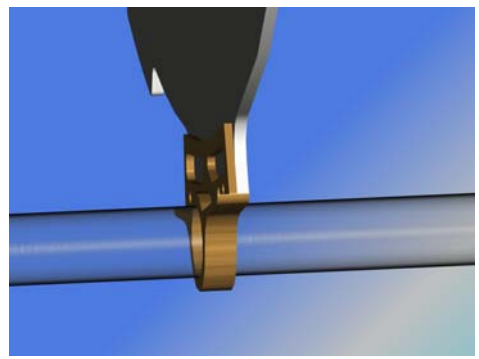


TOTEM GEM Final Detector Module

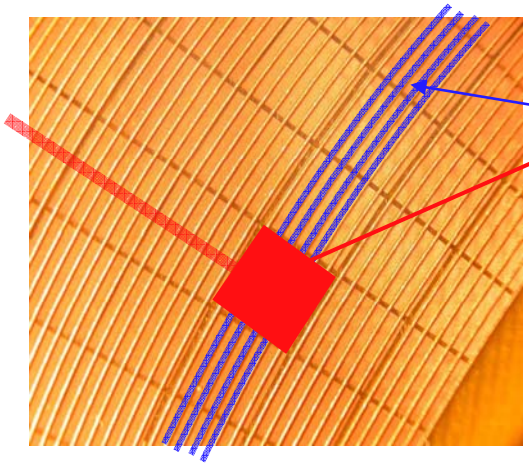




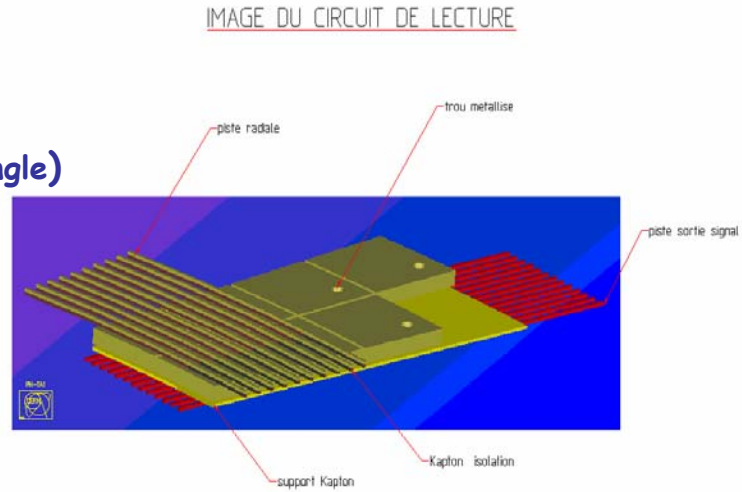


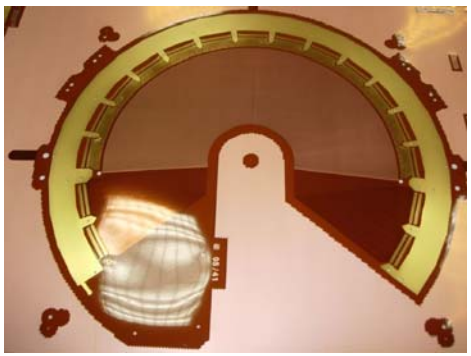


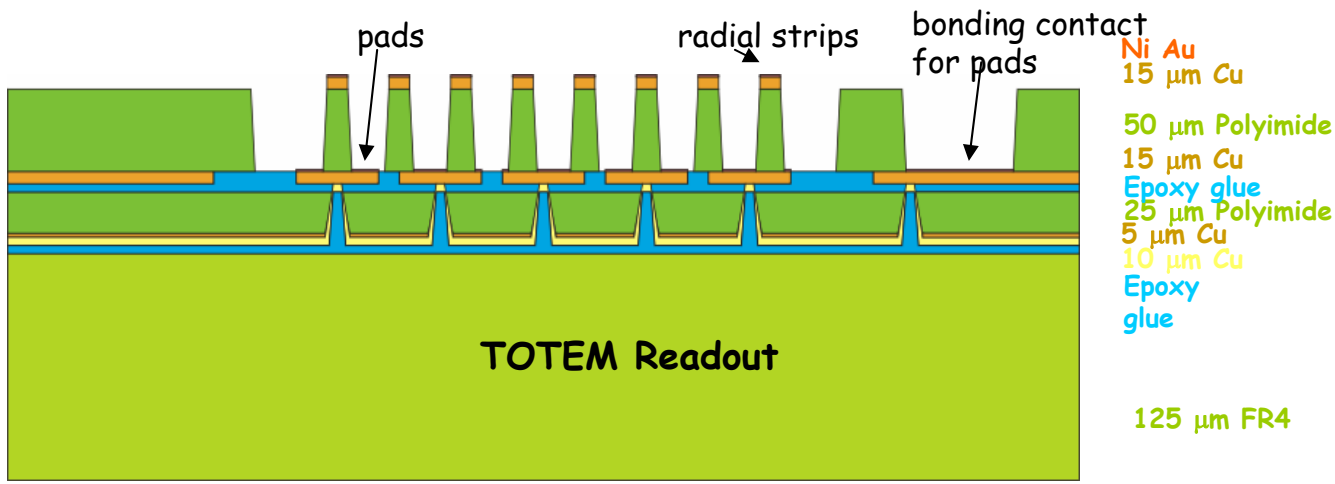
TOTEM GEM - Readout Board



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

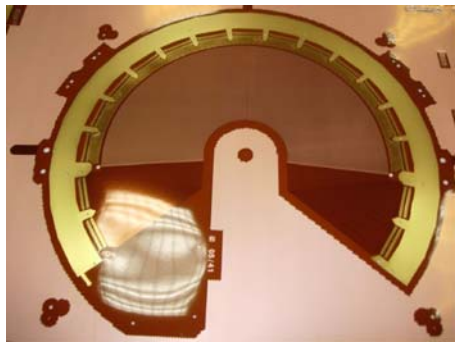


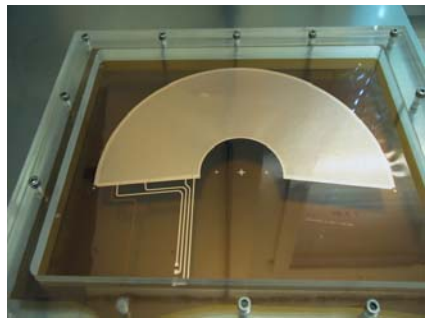




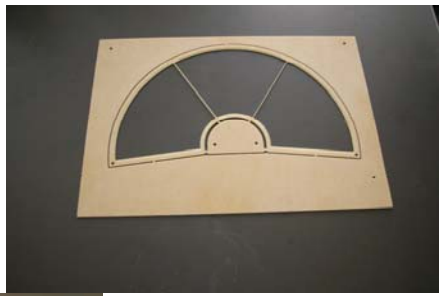
Detector Components

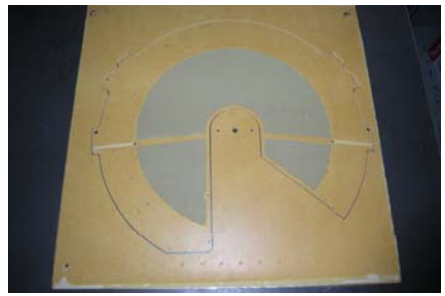
Readout board



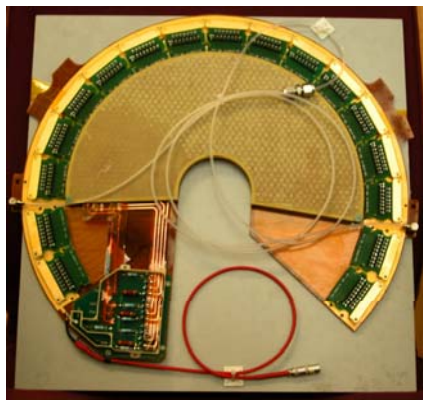


GEM foils



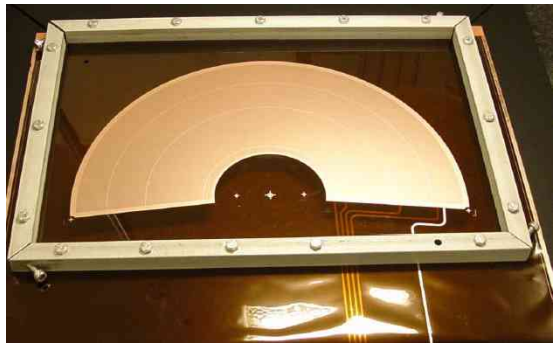


Frames, spacers and supports

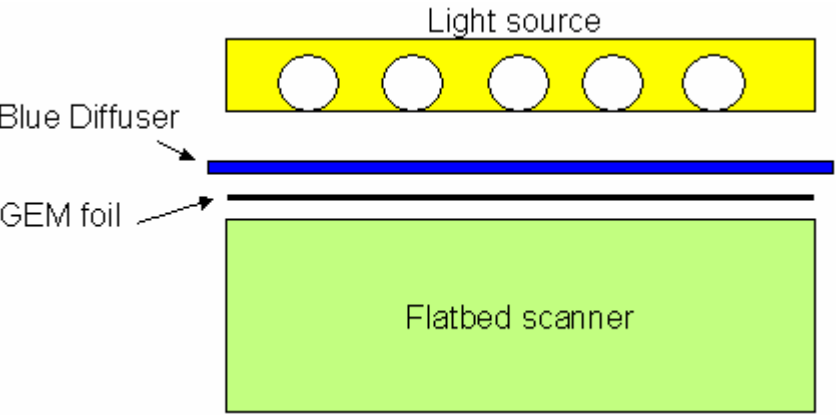


HV and electronics

GEM Detector Assembly



Optical Scanning of GEM Foils

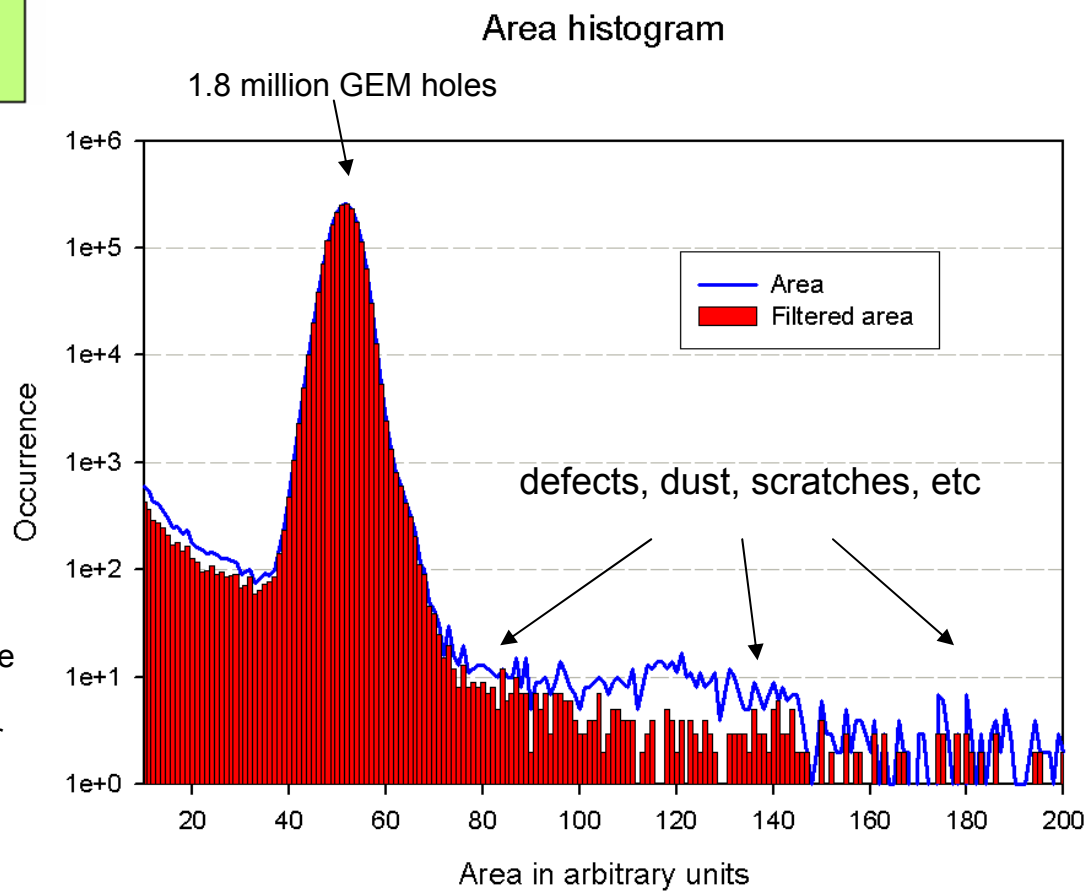


- scanning in mixed mode (transparent + reflective)
- blue diffuser produces a color contrast between the holes and copper surfaces

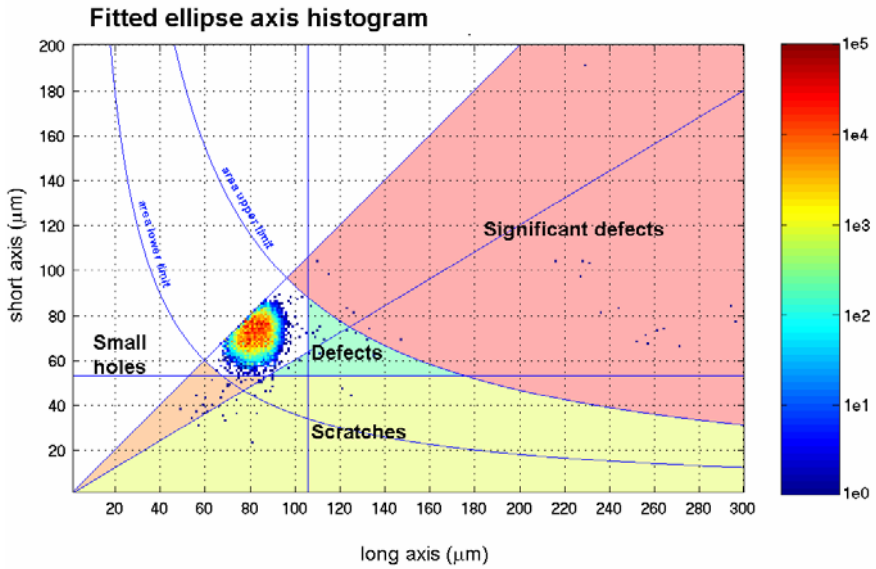
scanned pictures can be analyzed by using fitting algorithms to count anomalies and to register their coordinates

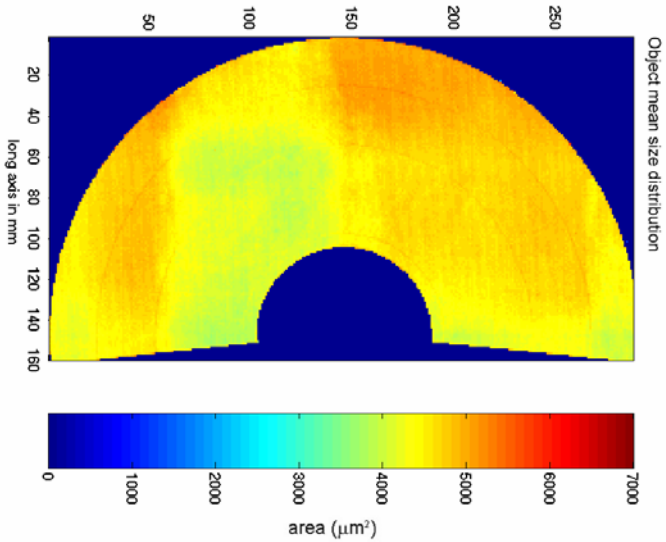
AIM:
a quantitative measure of the quality of GEM foils

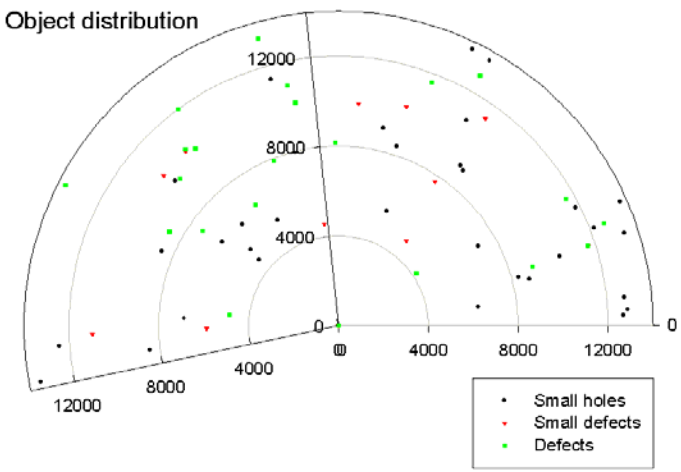
The worst foil so far: Blue curve shows all the seen objects; the red one only the "roughly round ones" (e.g. scratches are filtered out). The number of defects (red ones > 80) was 240, while only 40 were found under visual inspection (see previous slide).

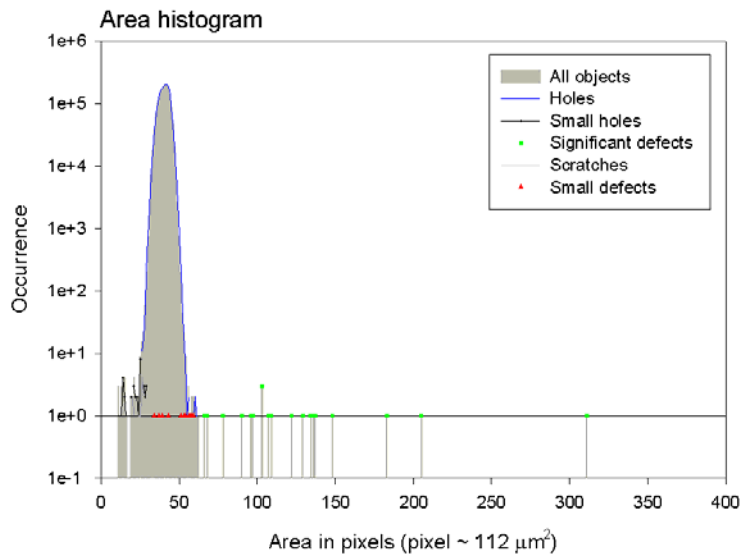


Analysis of defects and hole sizes

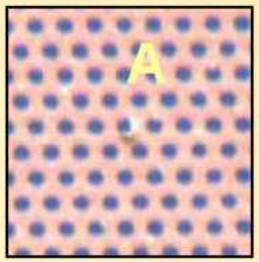


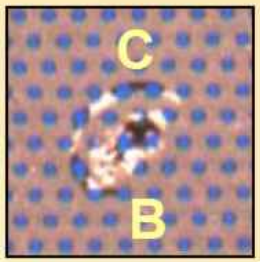


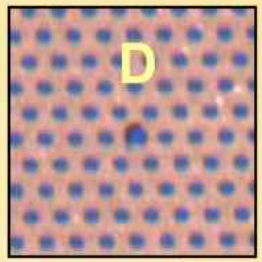


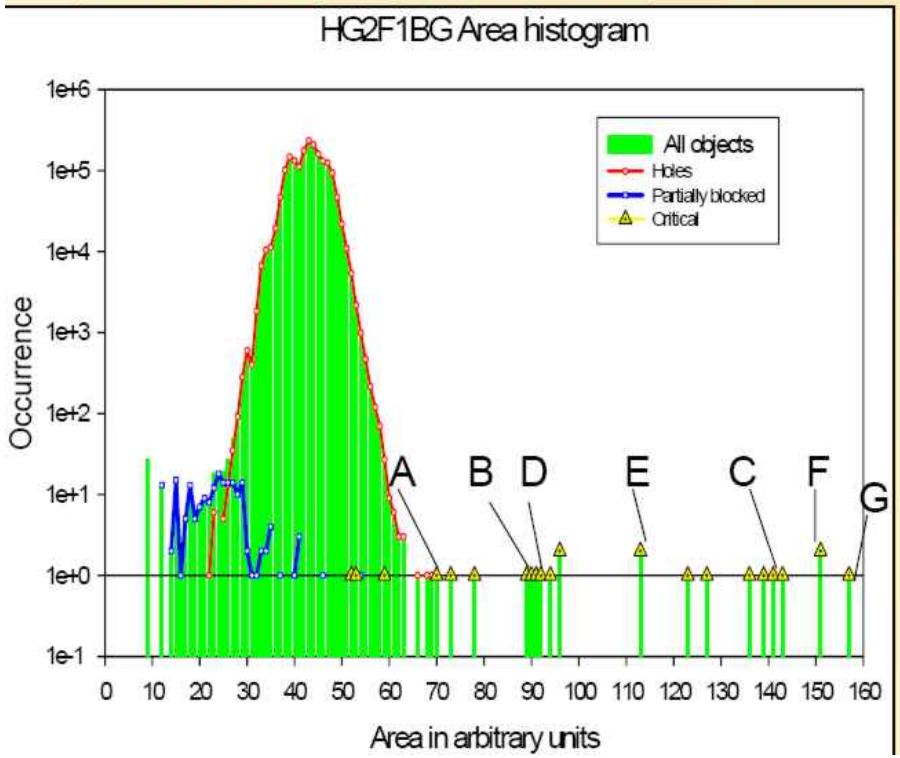


GEM Foil Defects



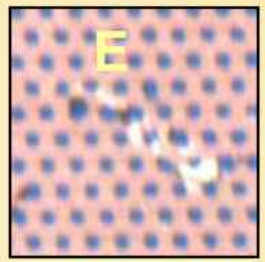


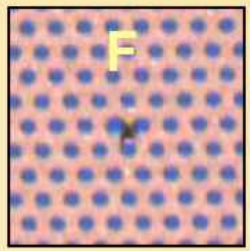


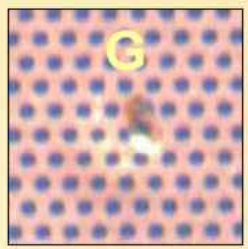


- all defects found in visual inspection are found

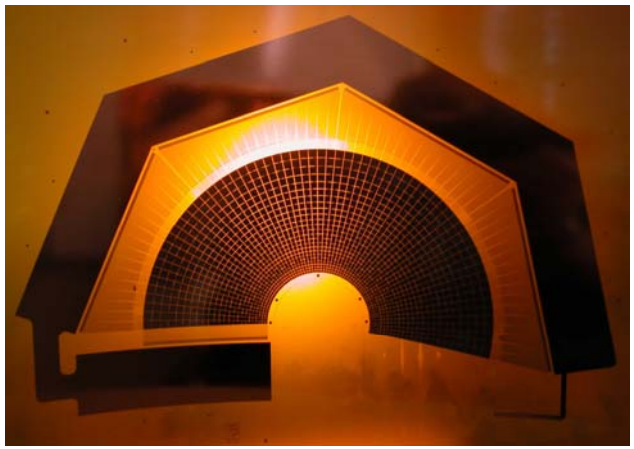
- found defects can be visually inspected if needed

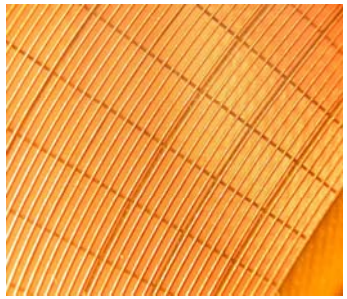


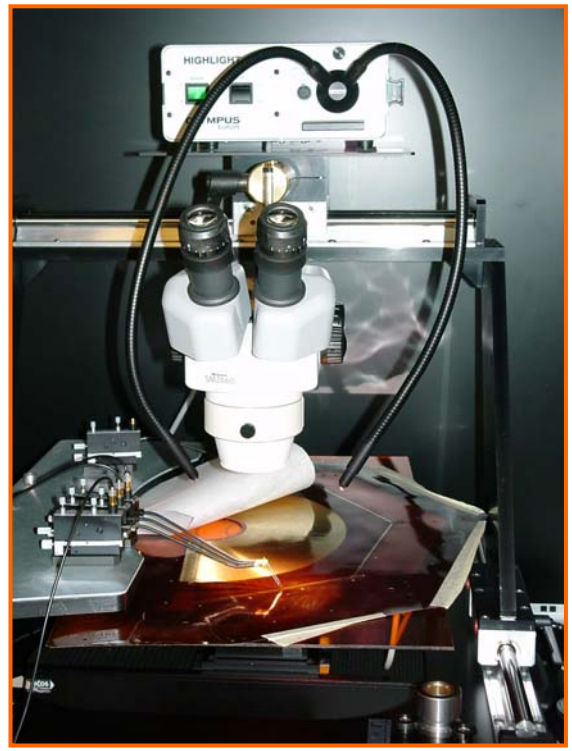


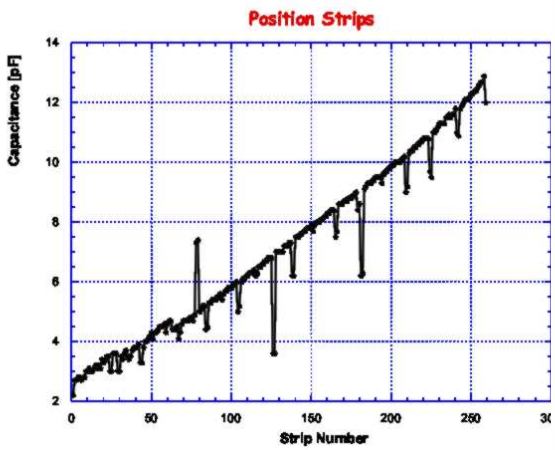


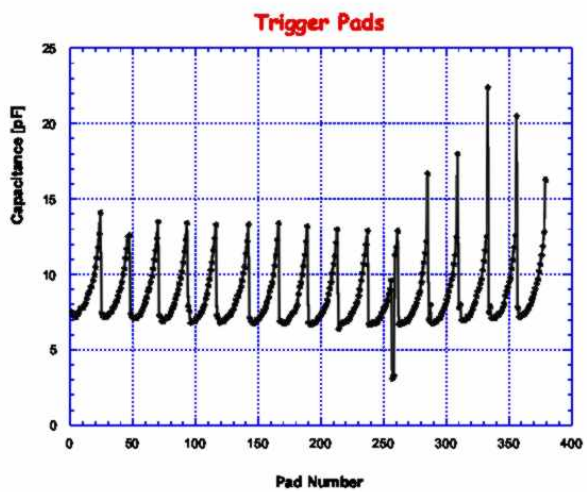
TOTEM GEM Readout Board Test





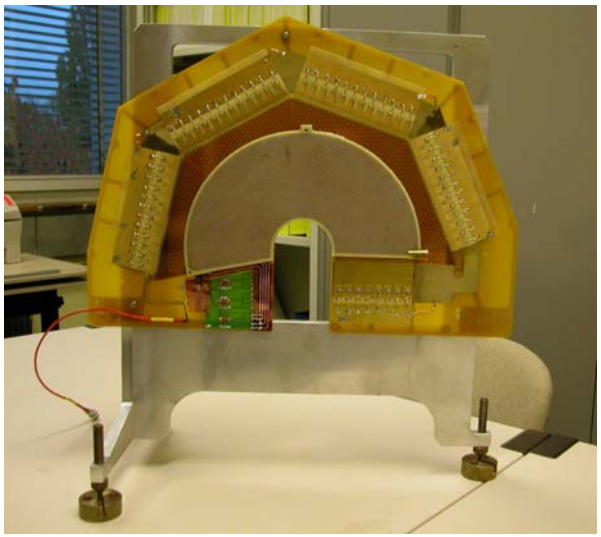


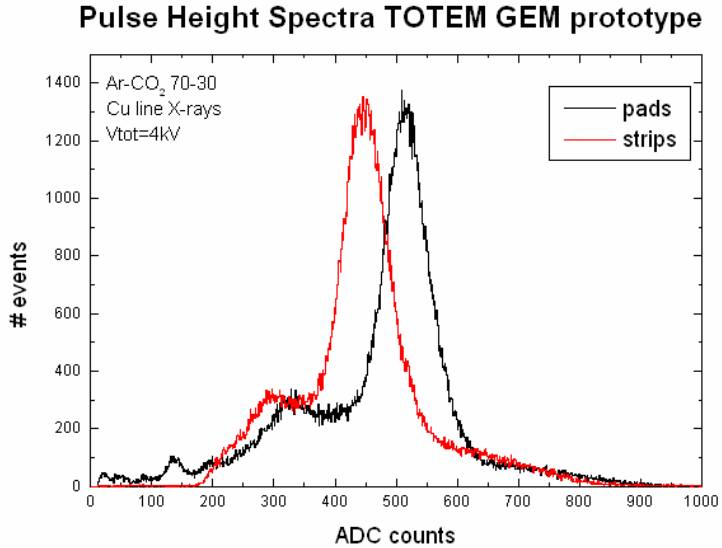


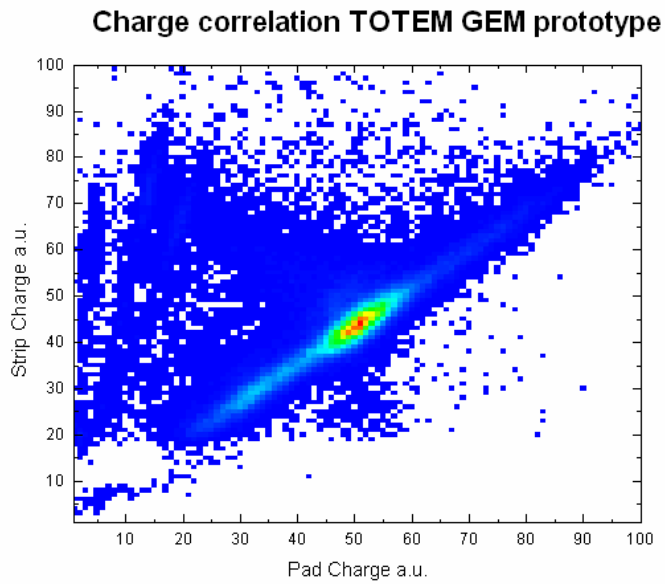


Quality test for continuity and shorts – Capacitance measurement between channels for strips and pads

Laboratory Tests







Lab performance as expected:

Gas gain 10^4

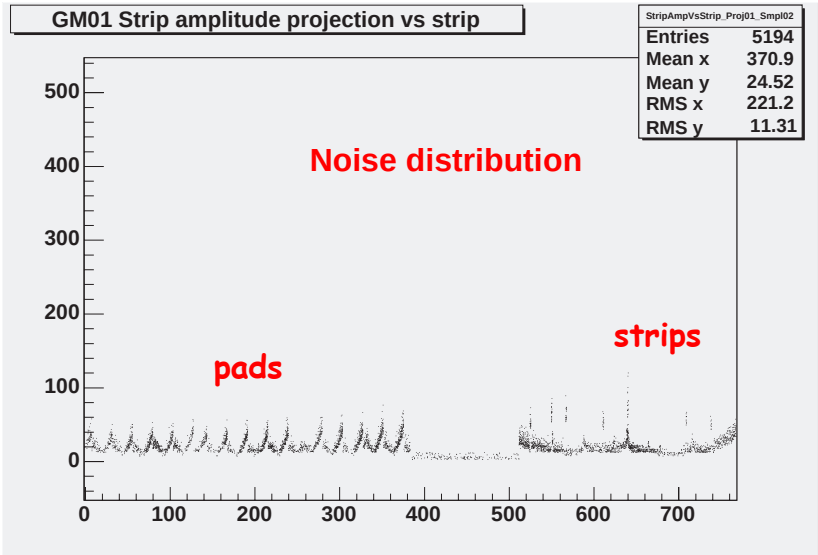
Charge sharing

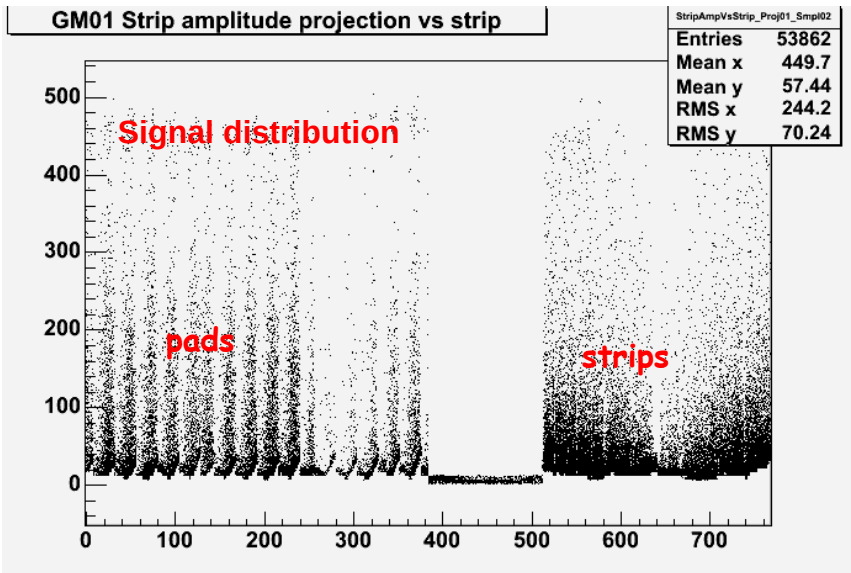
pad signal 10% higher – advantage
for higher S/N for trigger electronics

Good charge correlation

Good energy resolution

X5 - beam test





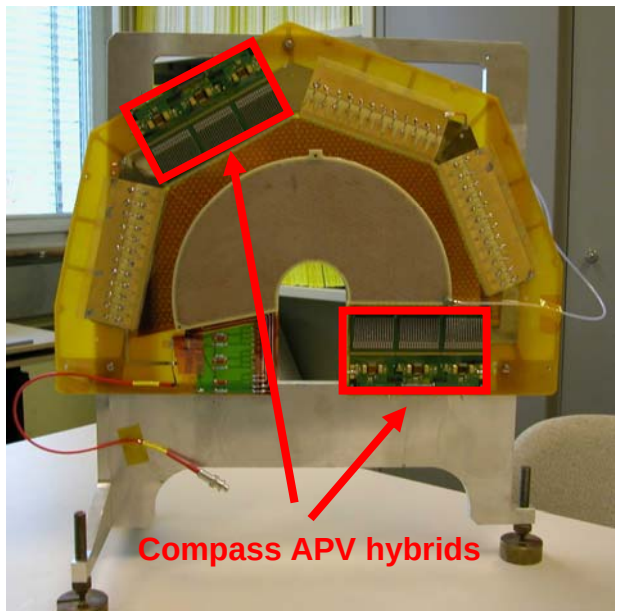
All strips and one (out of four) sectors of pads connected to COMPASS APV hybrids

Readout chain from COMPASS

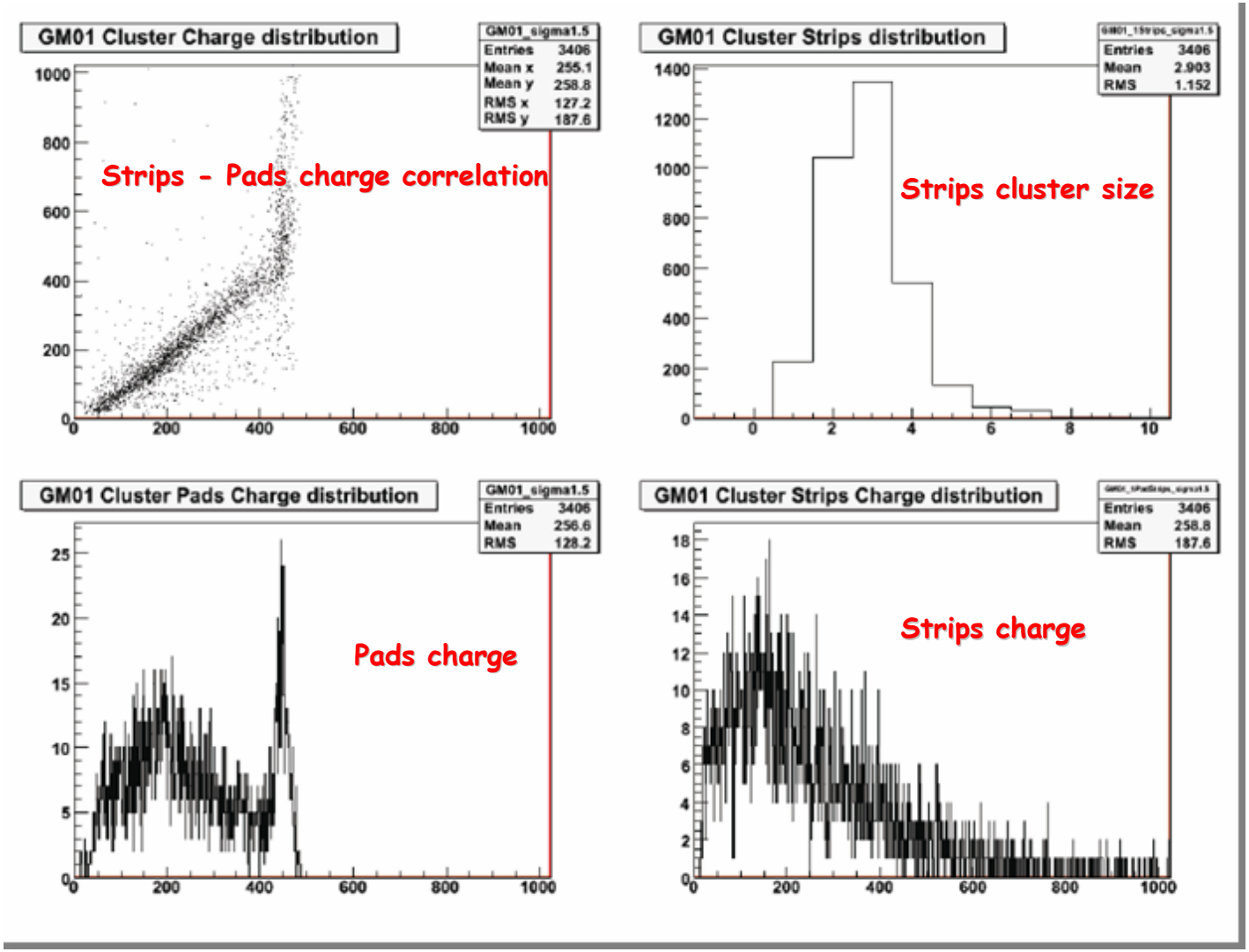
All channels readout

Latency and HV scan

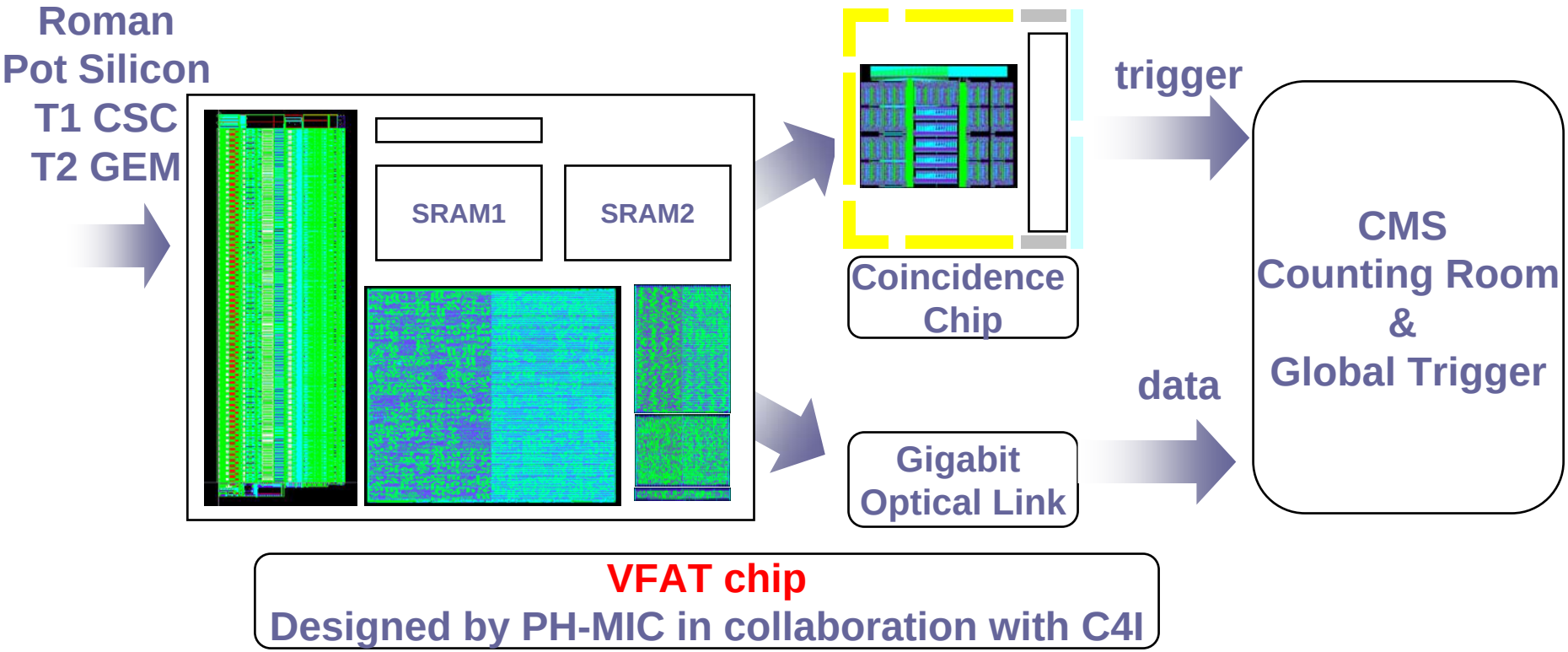
Good noise-signal peak separation



X5 – beam test with APV electronics



Electronics

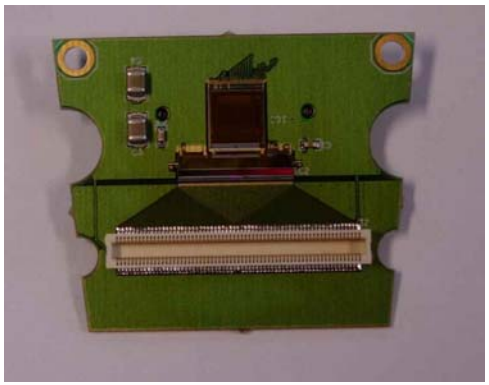


- VFAT chip 128 channels with front end and comparator with adjustable threshold
- VFAT/CC design team: **P. Aspell, G. Anelli, J. Kaplon, K. Kloukinas, W. Snoeys, H. Mugnier, P. Chalmet (CERN-C4i)**

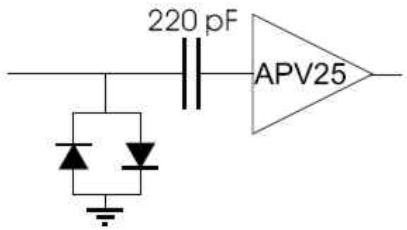
VFAT Front End Specs

- **Pulse Gain** at discriminator input; 53mV/fC (simulated for maximum charge collection time)
- **Integral nonlinearity error**:
- <1% for input charge 0 to 12fC
- <3% for input charge 0 to 16fC
- **Peaking time**; 22.5ns (simulated for 3.5fC input charge and maximum charge collection time)
- **Power consumption** for nominal bias condition; 1.9mW/channel (250mW for whole front end)
- **Noise** performance for nominal bias condition;
- <1000 e- rms for Cinput = 10pF
- <1400 e- rms for Cinput = 20pF
- **Maximum load of the analogue test outputs**; <5pF

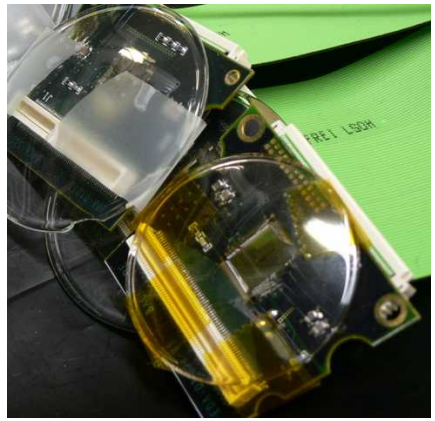
Discharge Protection Circuit



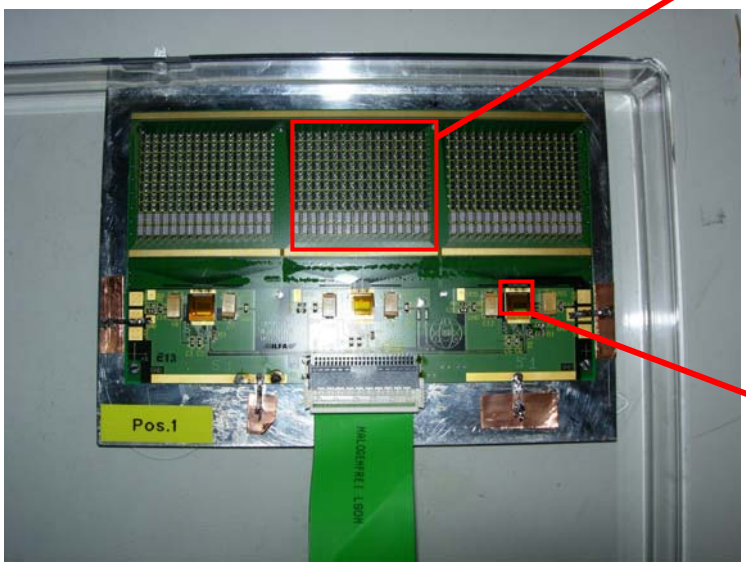
APV



Protection Circuit

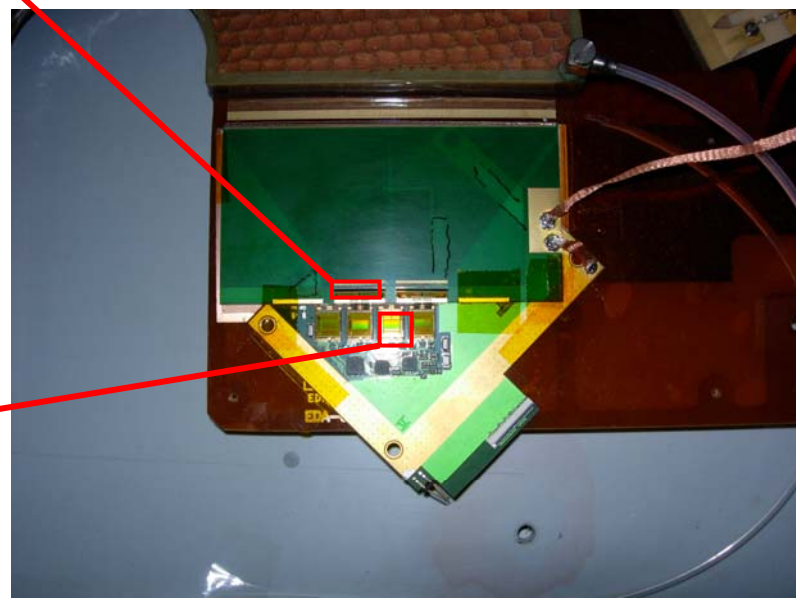


VFAT



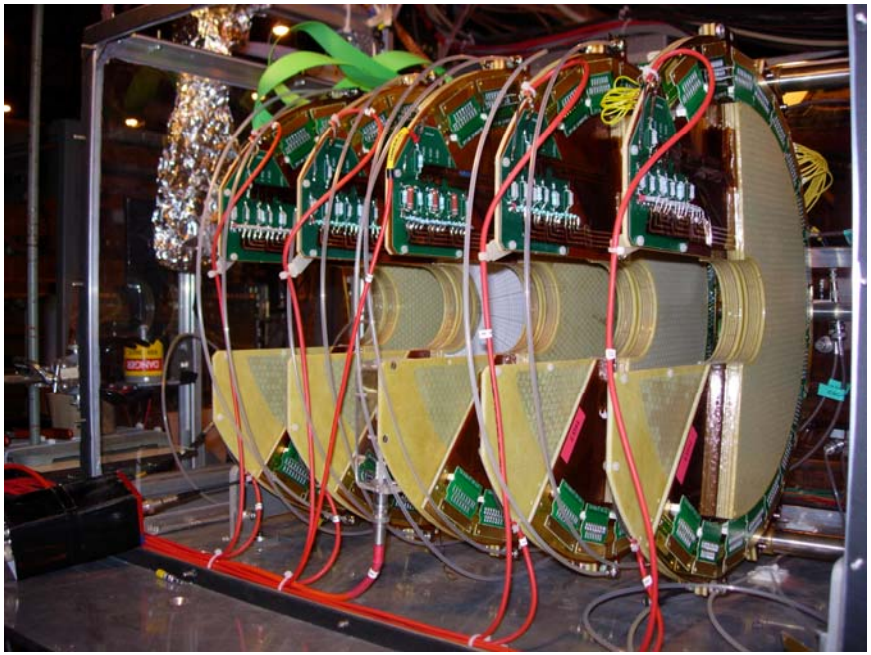
COMPASS

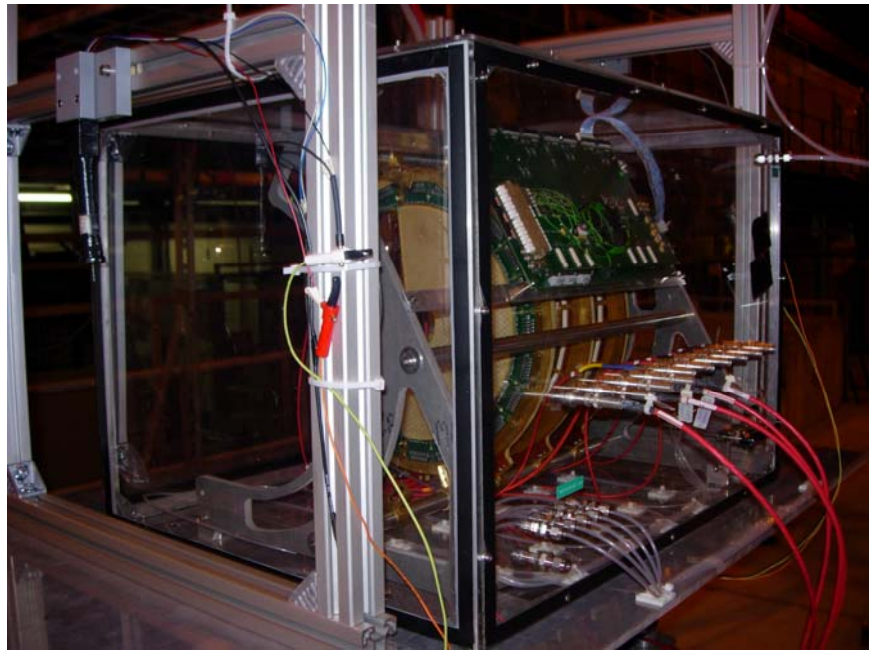
APV chip



TOTEM

Totemino @ SPS H8

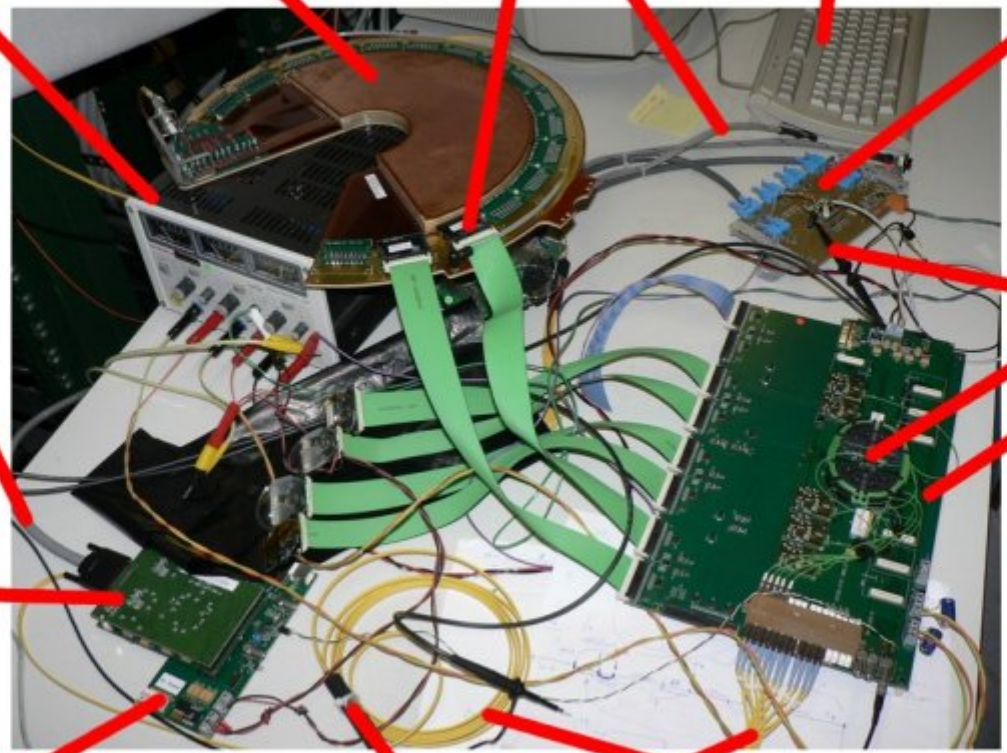




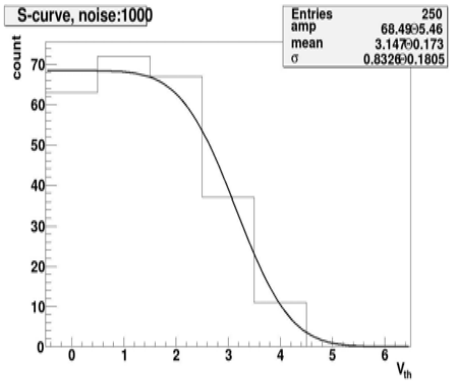
10 detectors in 5 pairs back to back
8 assembled in Helsinki
1 G&A
1 CERN

Electronics capable to read 16 VFAT hybrids
2 hybrids/detector connected to pads & strips

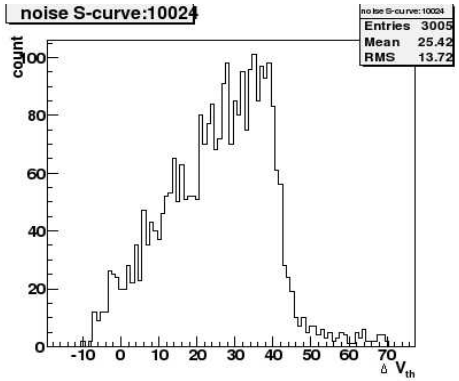
Totemino Electronics



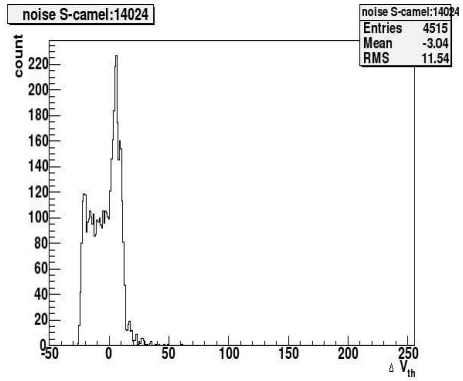
VFAT & GEM



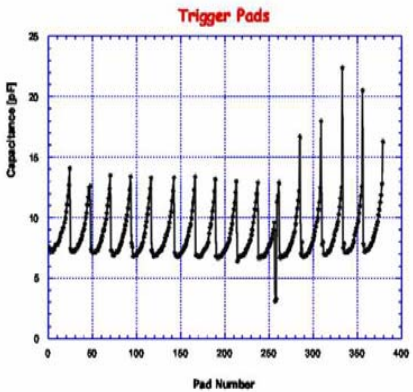
S-curve VFAT only



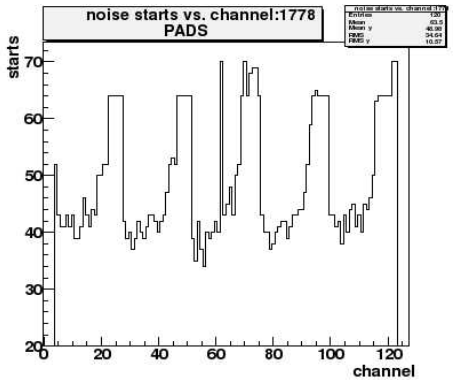
S-curve GEM pad noisy



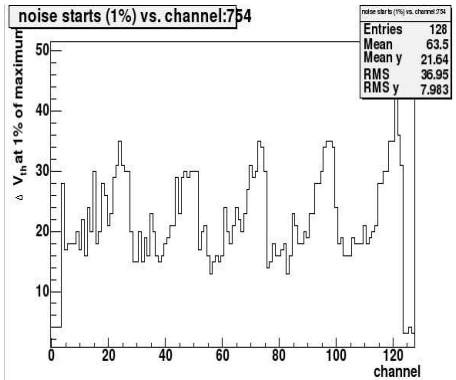
S-curve GEM pad



Pads capacitance

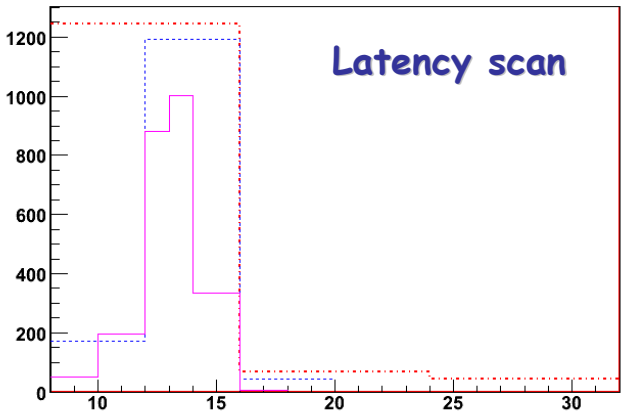


Pads thresholds noisy

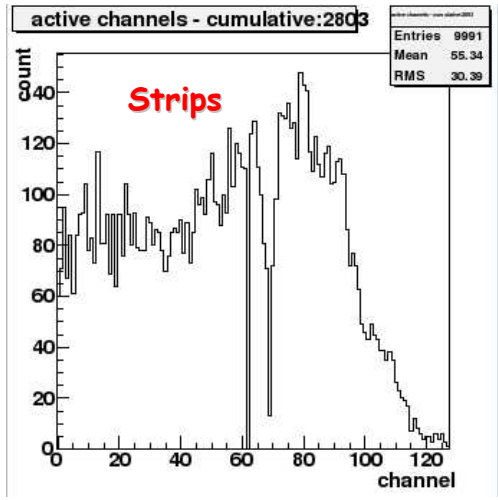


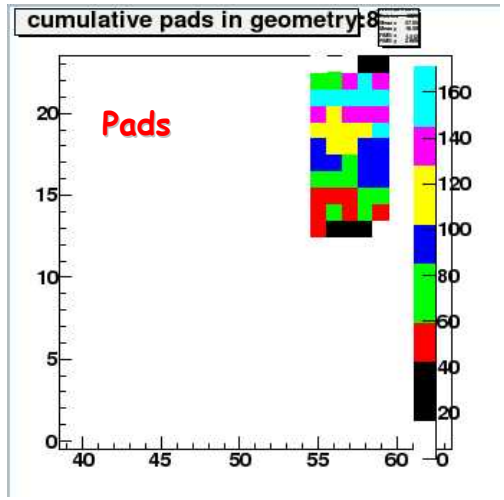
Pads thresholds

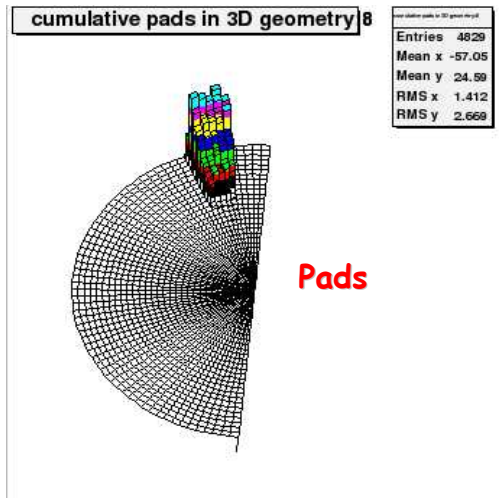
Totemino – first beam profiles

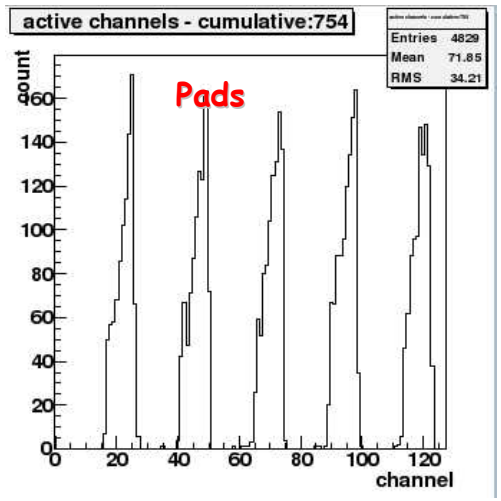


Time Slots 25 ns

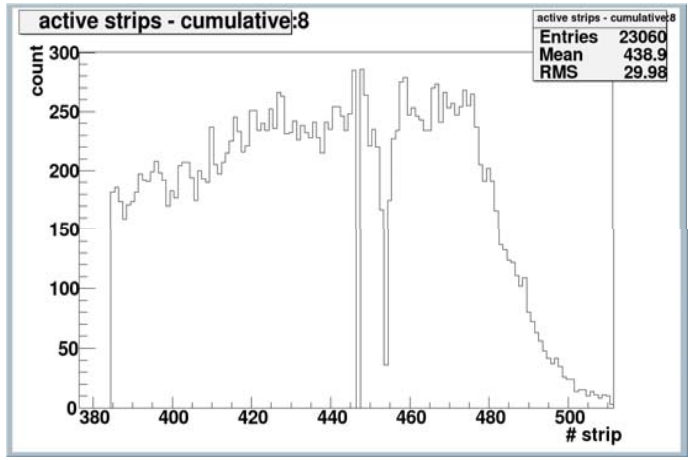


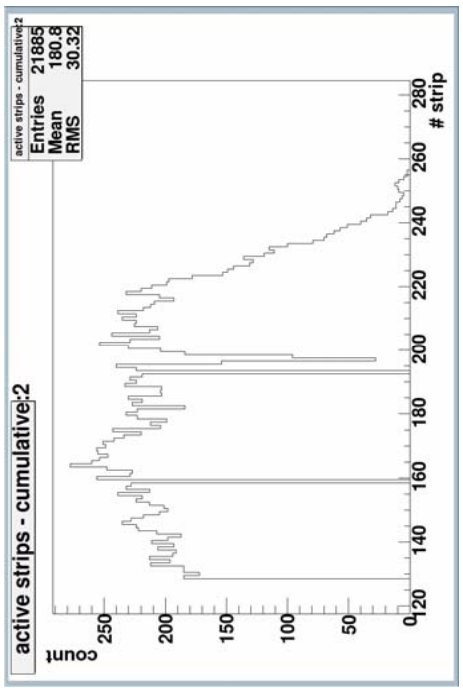


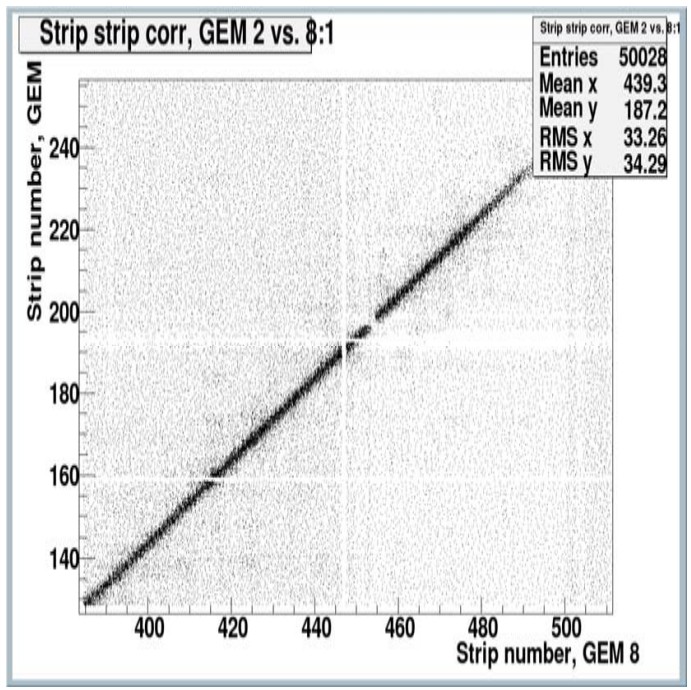




Totemino - first tracks







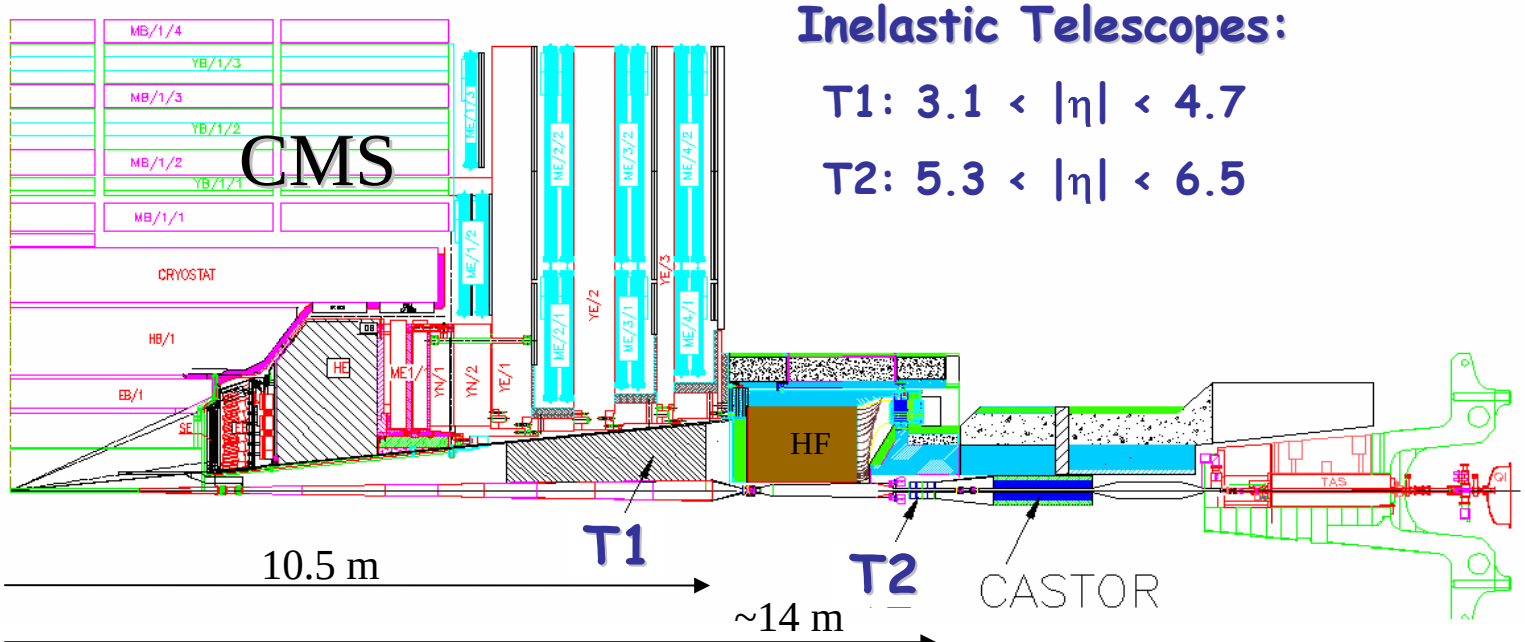
2 different detectors
hit correlation on strips

TOTEM Inelastic Telescopes

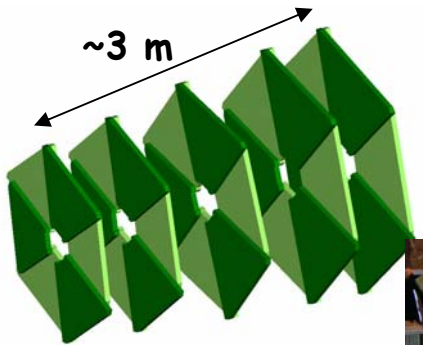
Inelastic Telescopes:

T1: 3.1 < |η| < 4.7

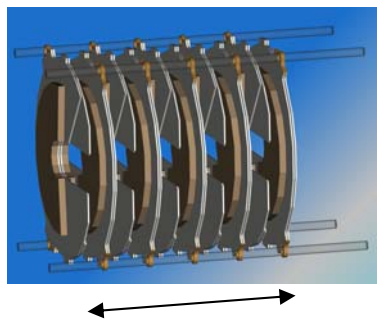
T2: 5.3 < |η| < 6.5

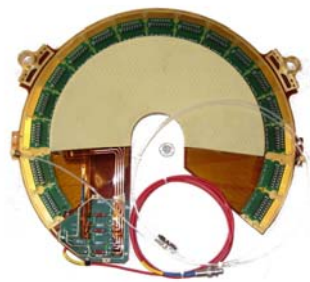


T1: Cathode Strip Chambers



T2: GEMs



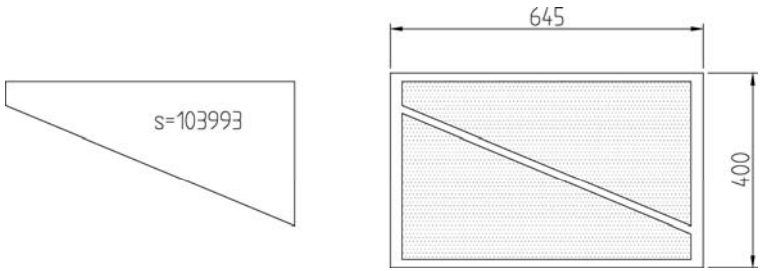


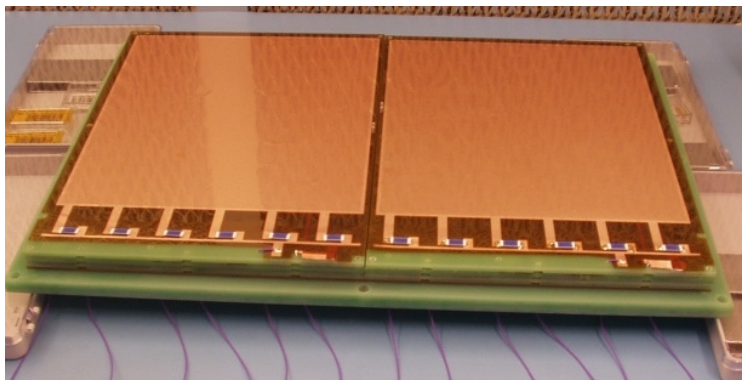
T1 Upgrade - Large GEM Detectors

GEM foil size is limited by :

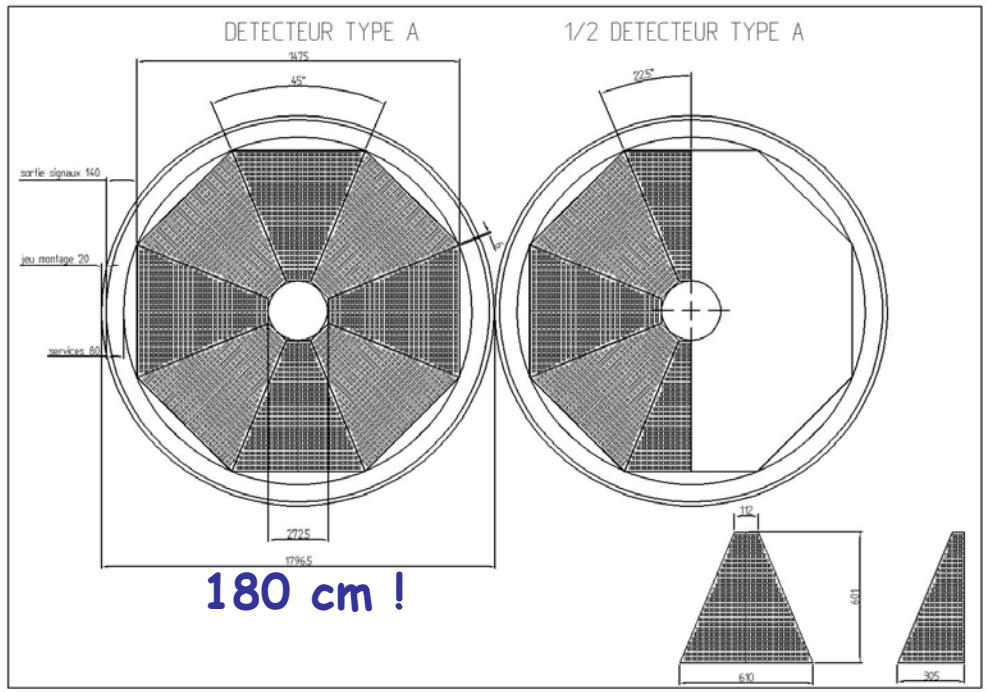
Starting raw material dimensions

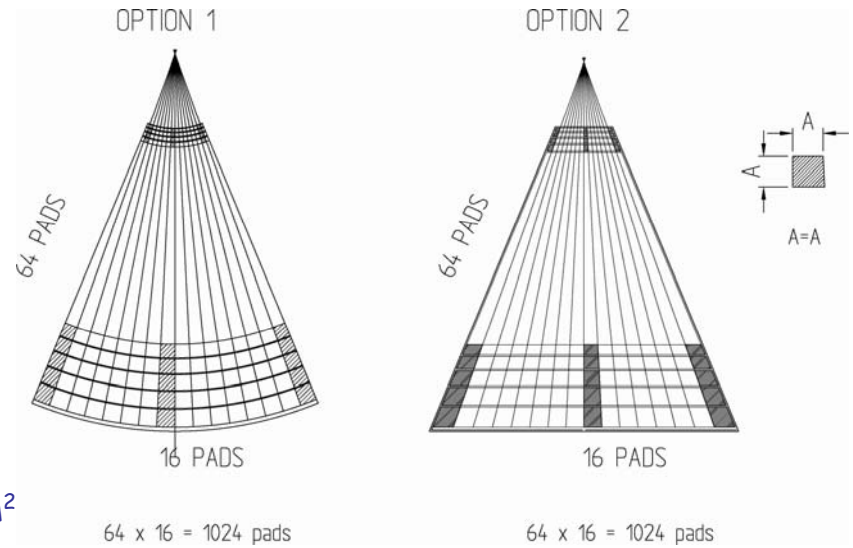
Precision of 2 masks alignment





Emilio Radicioni et al.

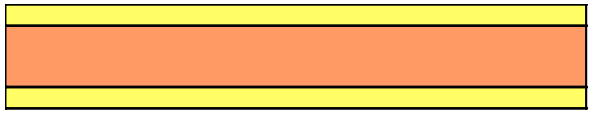




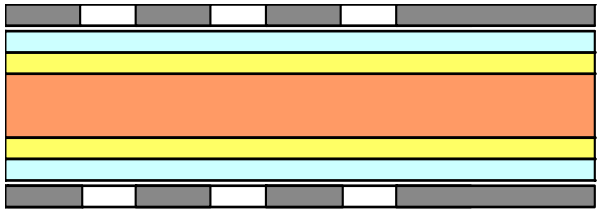
mean pad size ~ 2 cm^2
16x64 7x7 mm^2 —> 38x38 mm^2

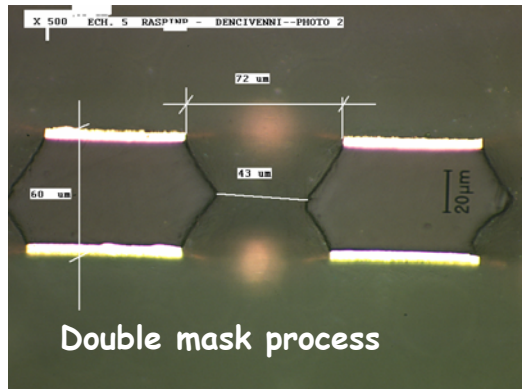
GEM Manufacturing

50 μm Kapton
5 μm Cu both sides



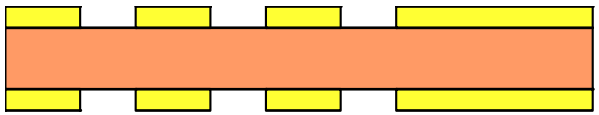
Photoresist coating,
masking and exposure
to UV light



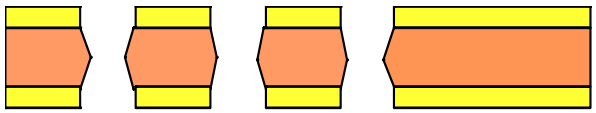


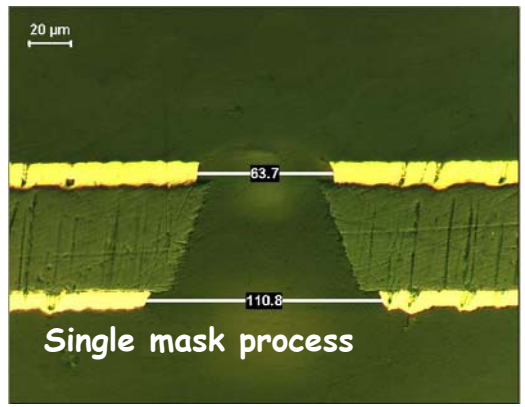
Double mask process

Metal etching



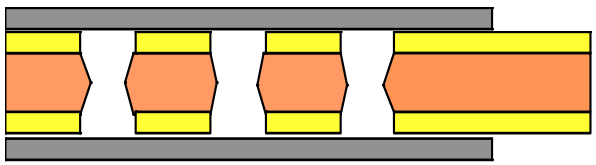
Kapton etching



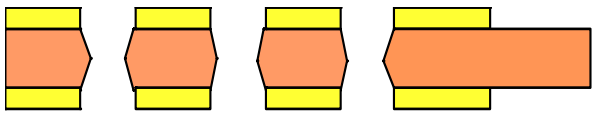


Single mask process

Second masking



Metal etching
and cleaning

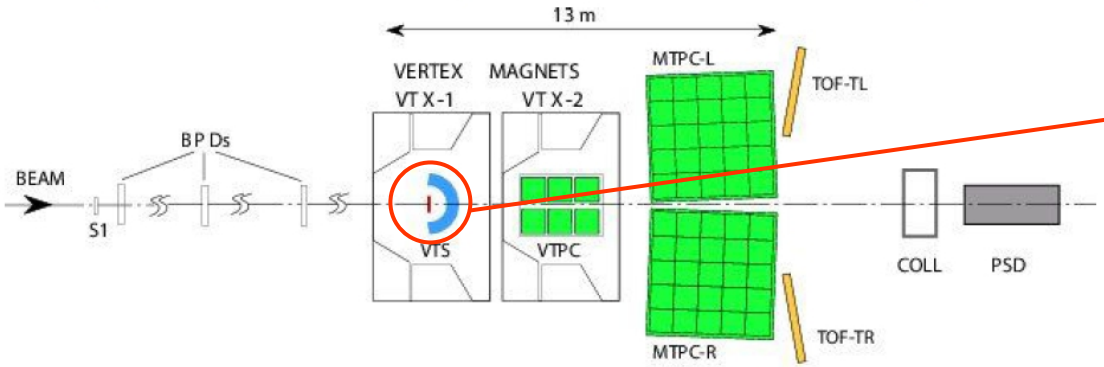


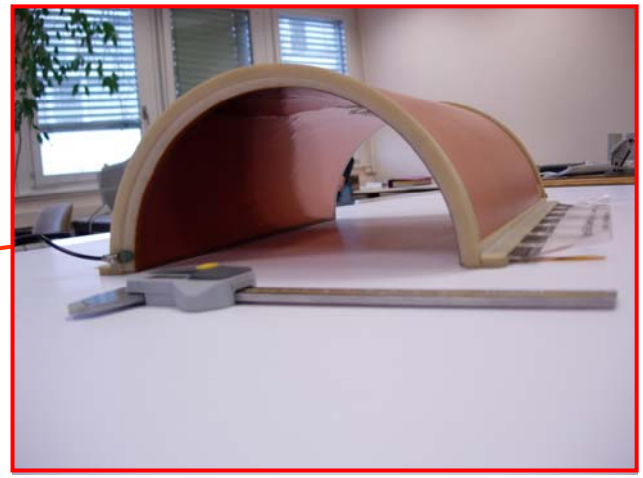
Positively tested for:

Gas gain
Charging up process (asymmetry)
Maximum gain in presence of HIPs

Cylindrical GEM for NA49-Future

A possible "critical" experiment at the CERN SPS



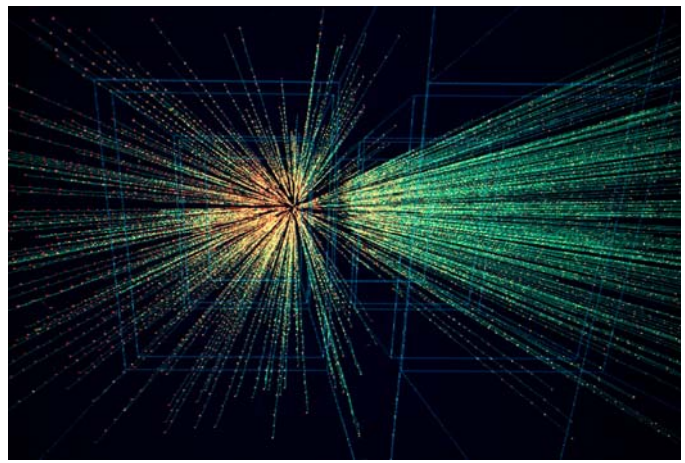


-a precise determination of an event centrality (**PSD**)

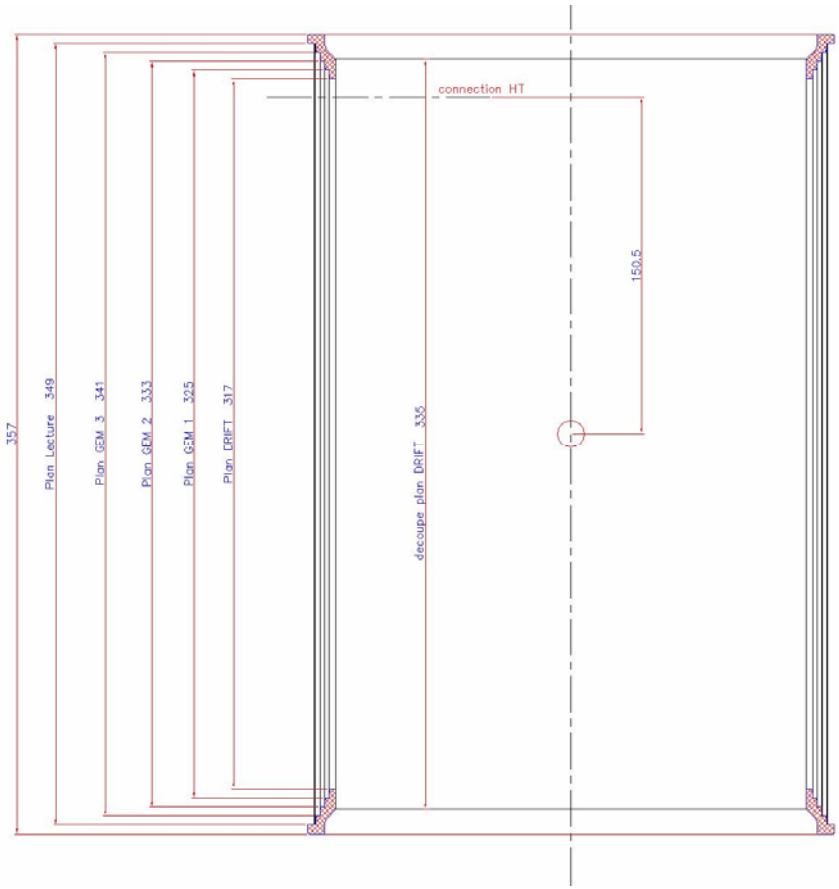
-full acceptance for charged hadrons (**VTS**)
and limited for identified hadrons (**TPCs**)

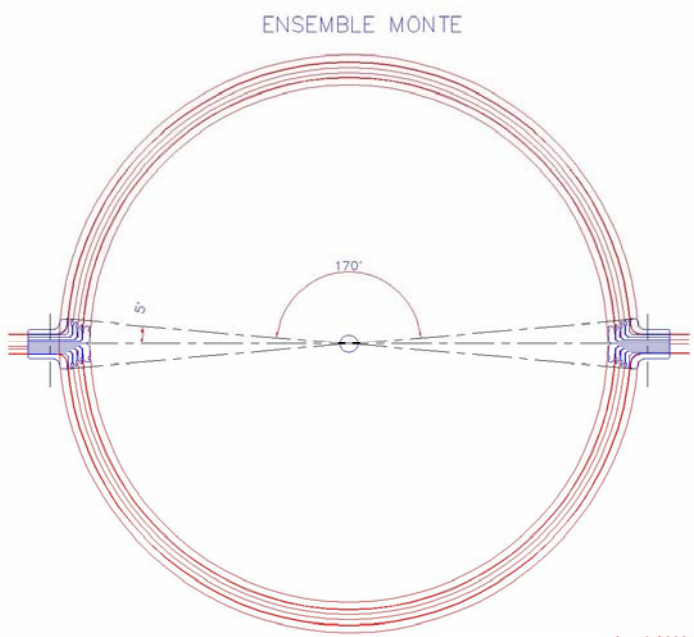
-a high event rate (**DAQ**)

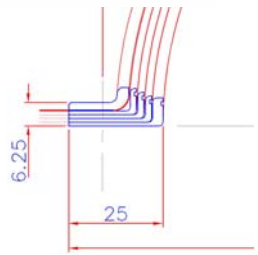
-high precision measurements of inclusive spectra
of identified hadrons (**TPCs+TOF**)



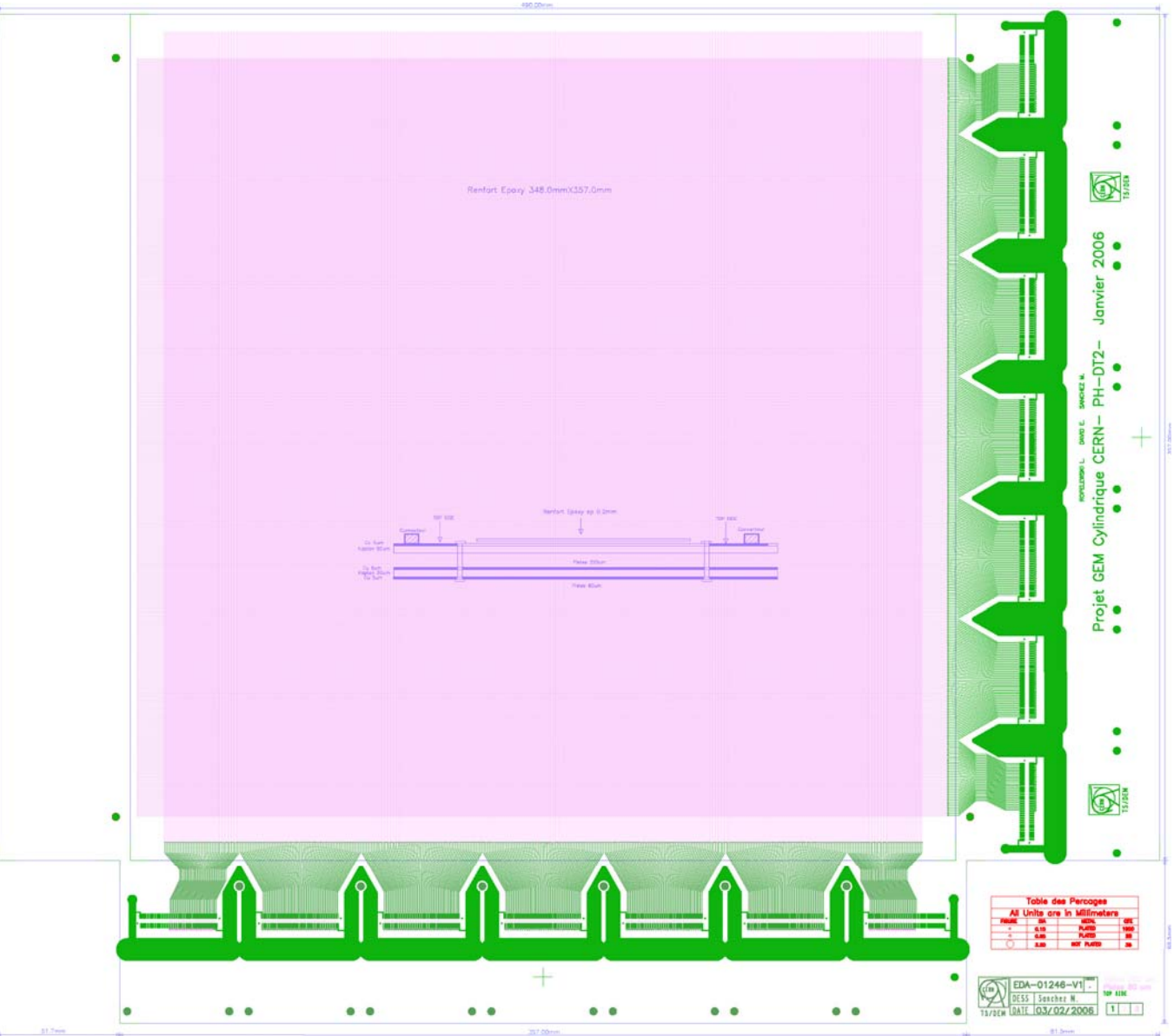
Cylindrical GEM Design

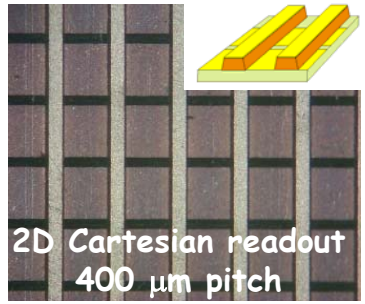


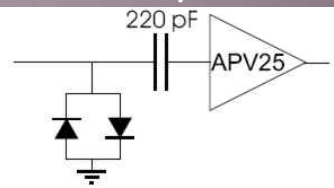




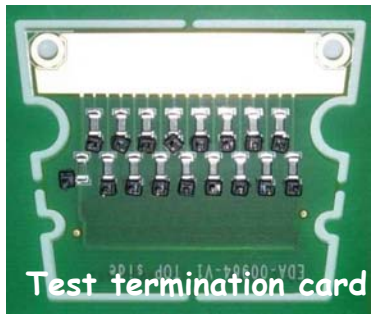
Cylindrical GEM Readout Board Design



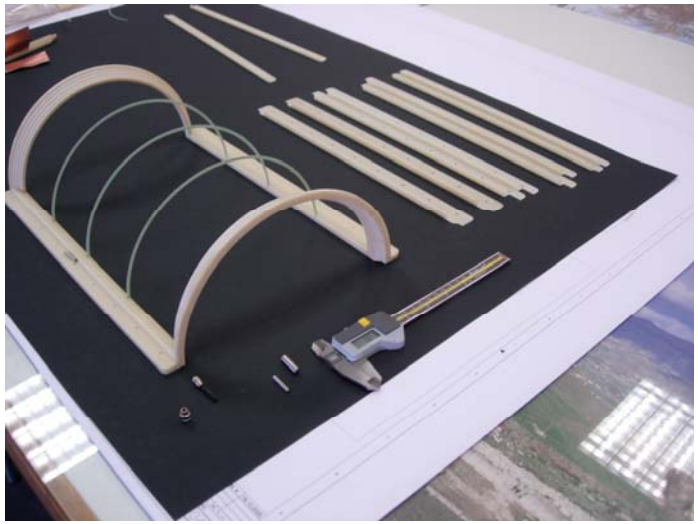


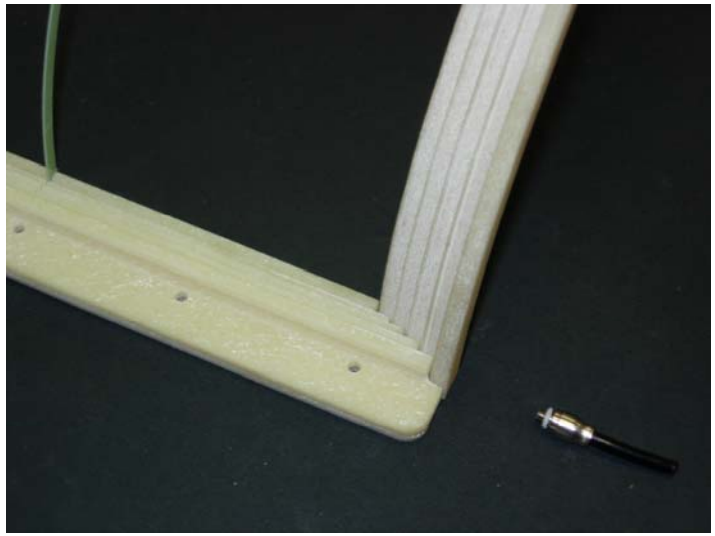


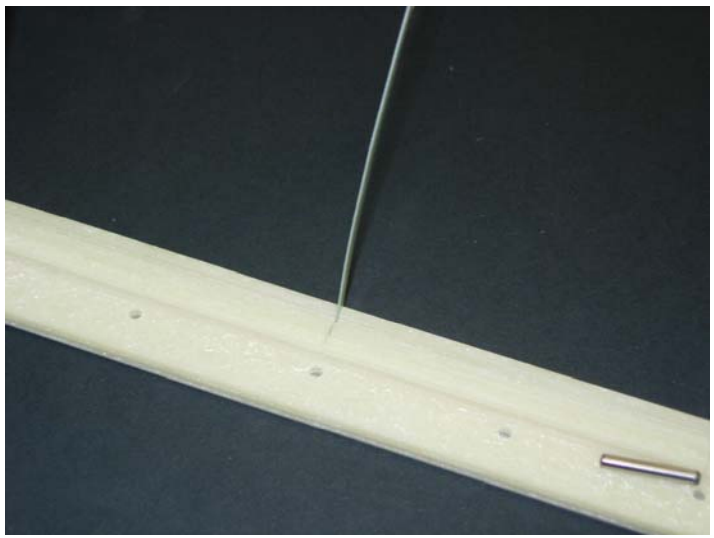
Protection Circuit



Cylindrical GEM Mechanical Parts and Tools

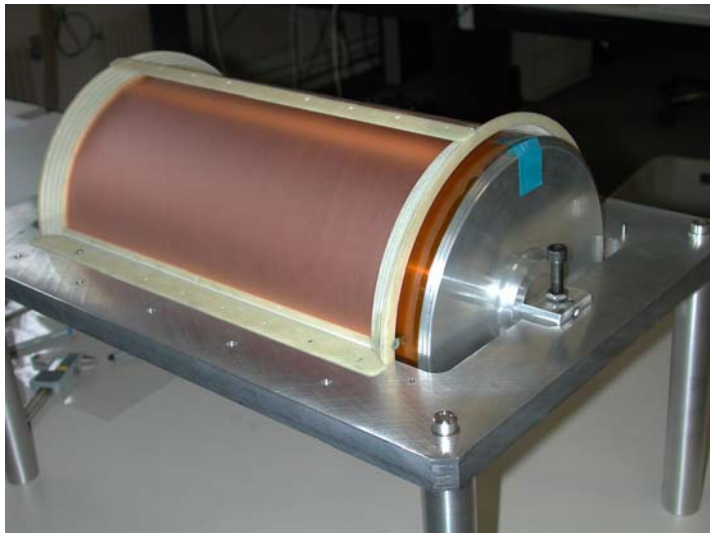


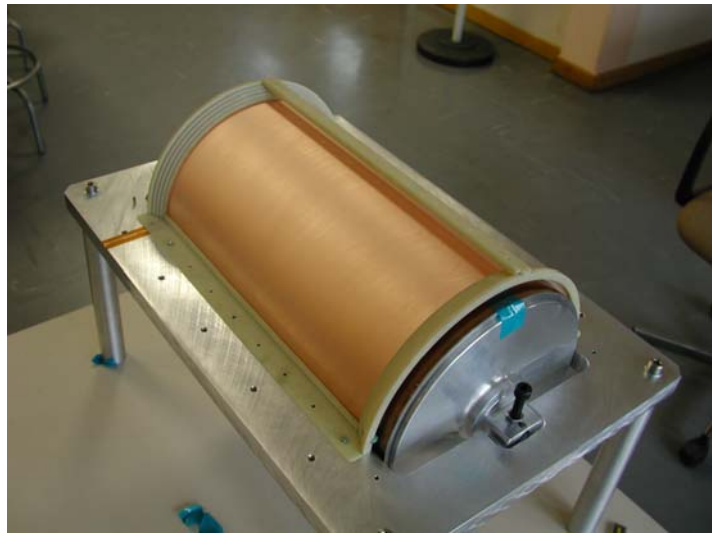


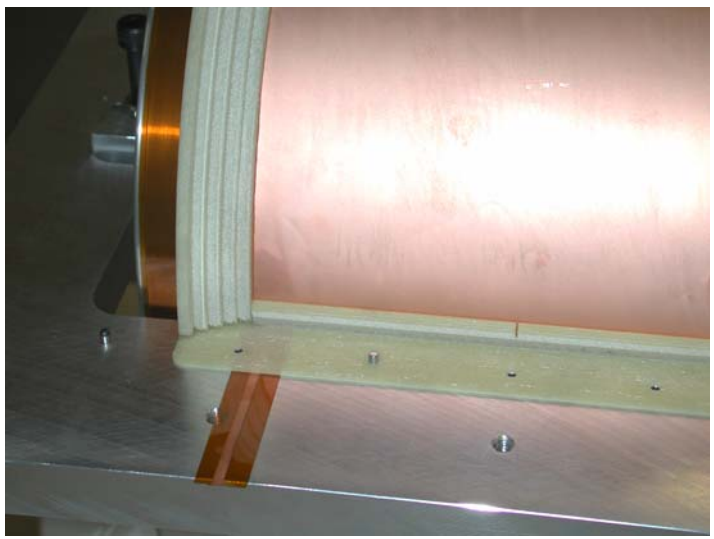


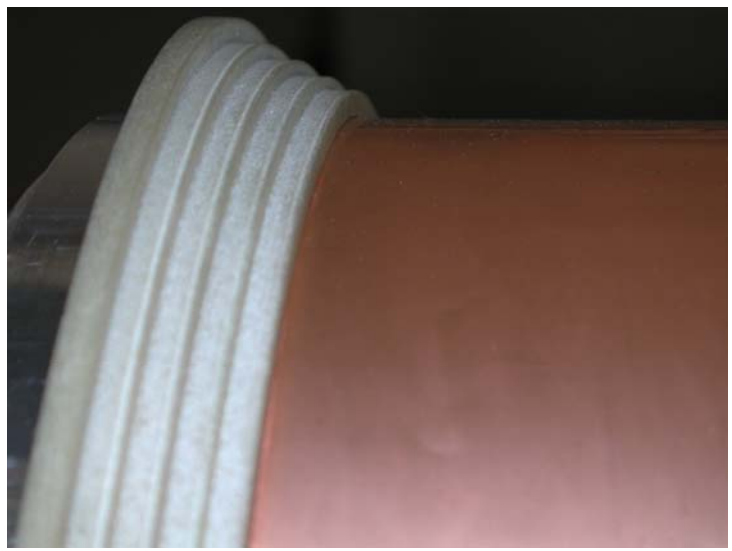
Cylindrical GEM Assembly 1

Drift Electrode



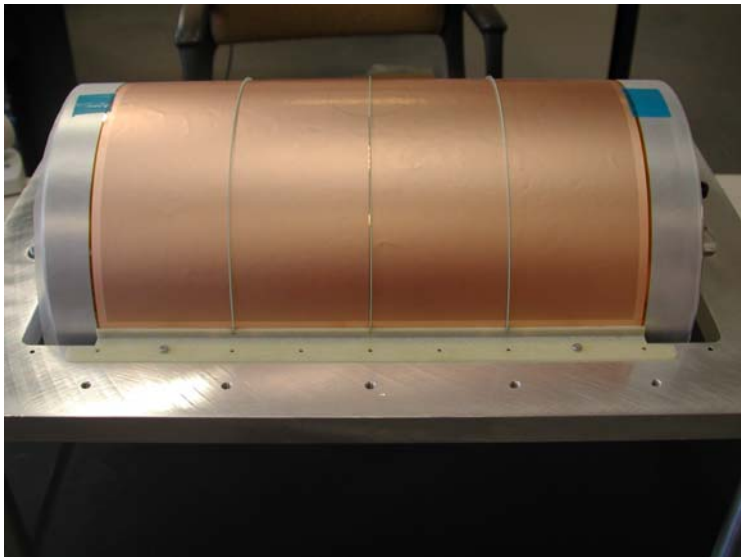


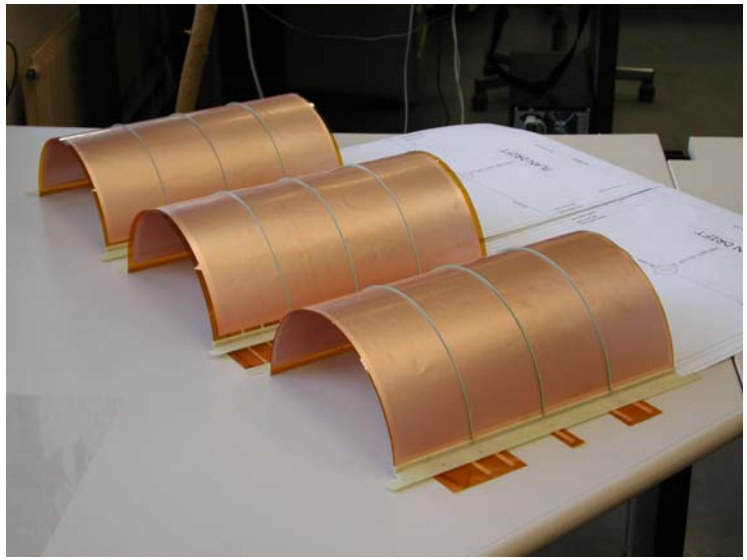


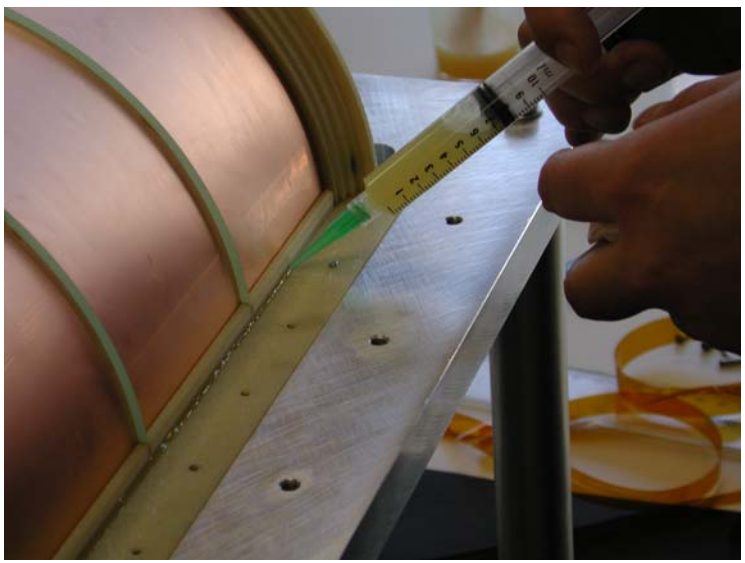


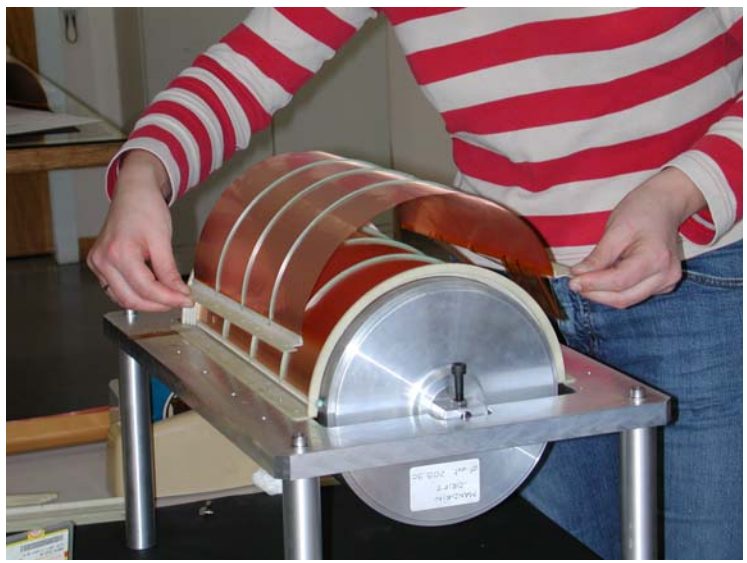
Cylindrical GEM Assembly 2

GEM foils

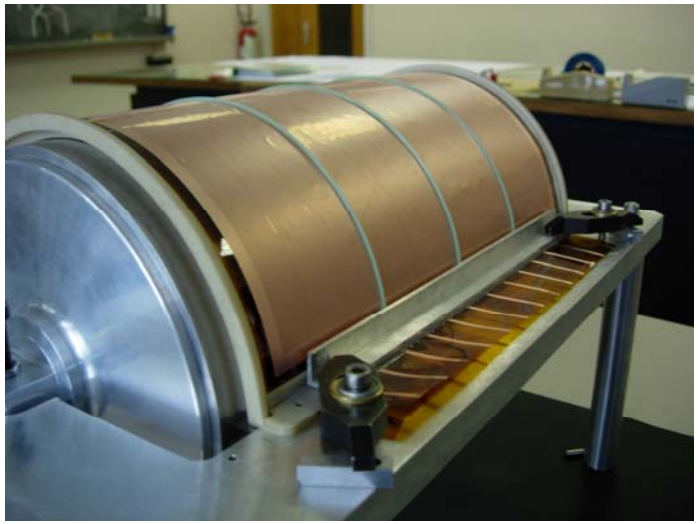


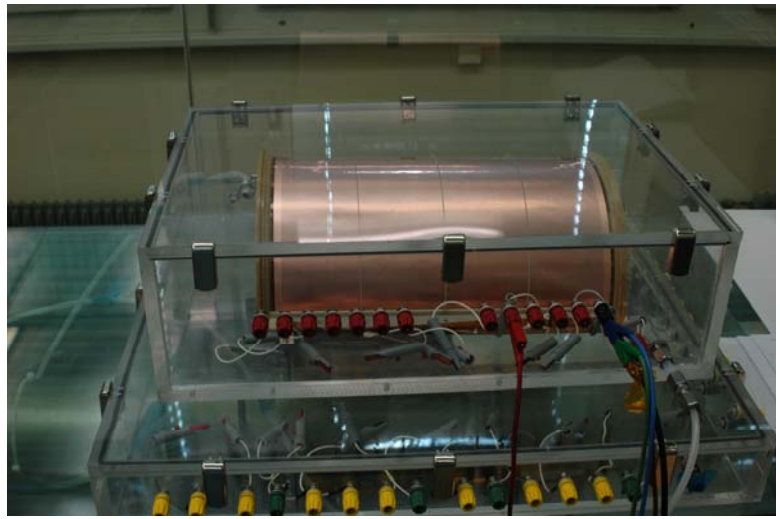


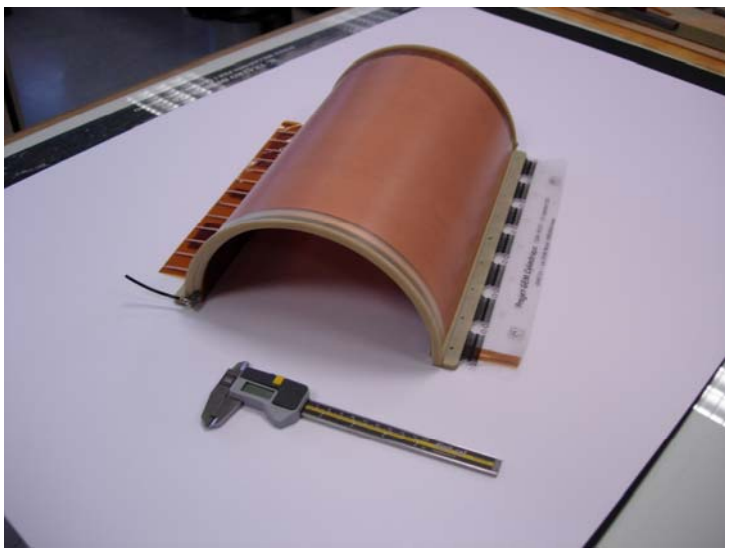




Cylindrical GEM Assembly 3







Mechanical Prototype was tested for:

Mechanical stability
Gas tightness

Final detector finalized:

Completed at the end of June.

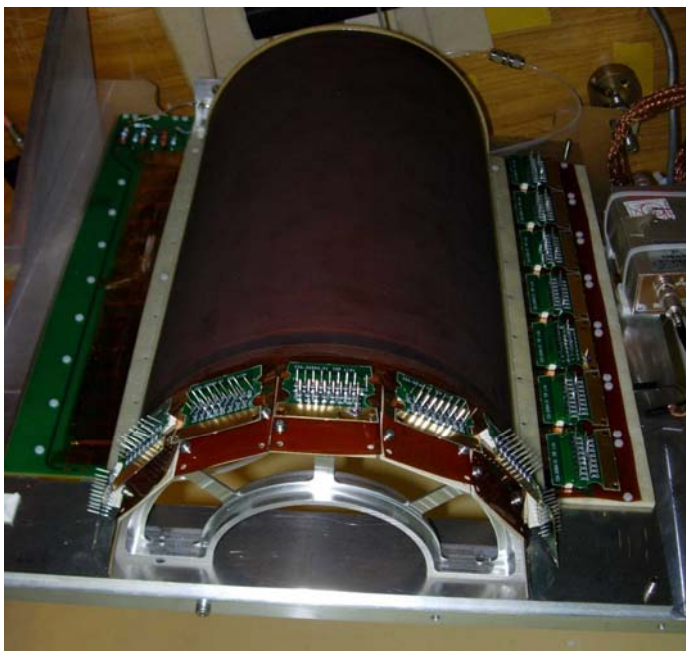
Cylindrical GEM Preparation

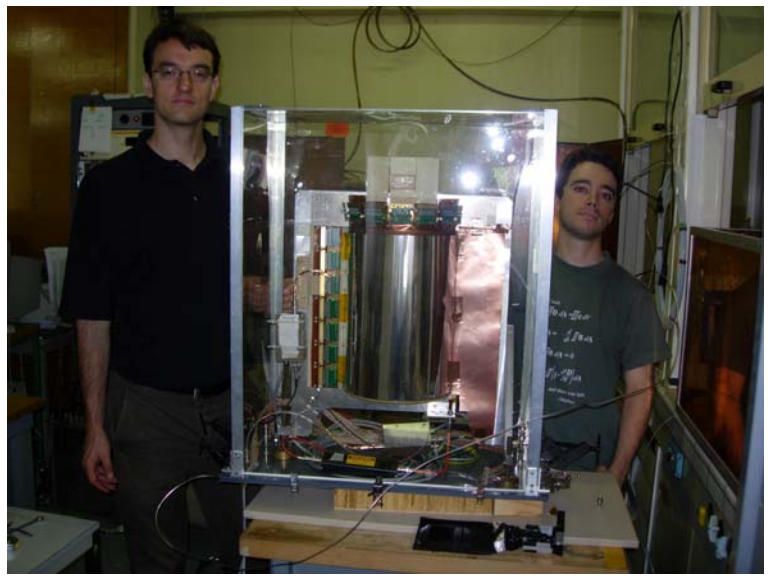
Lab work:

HV board

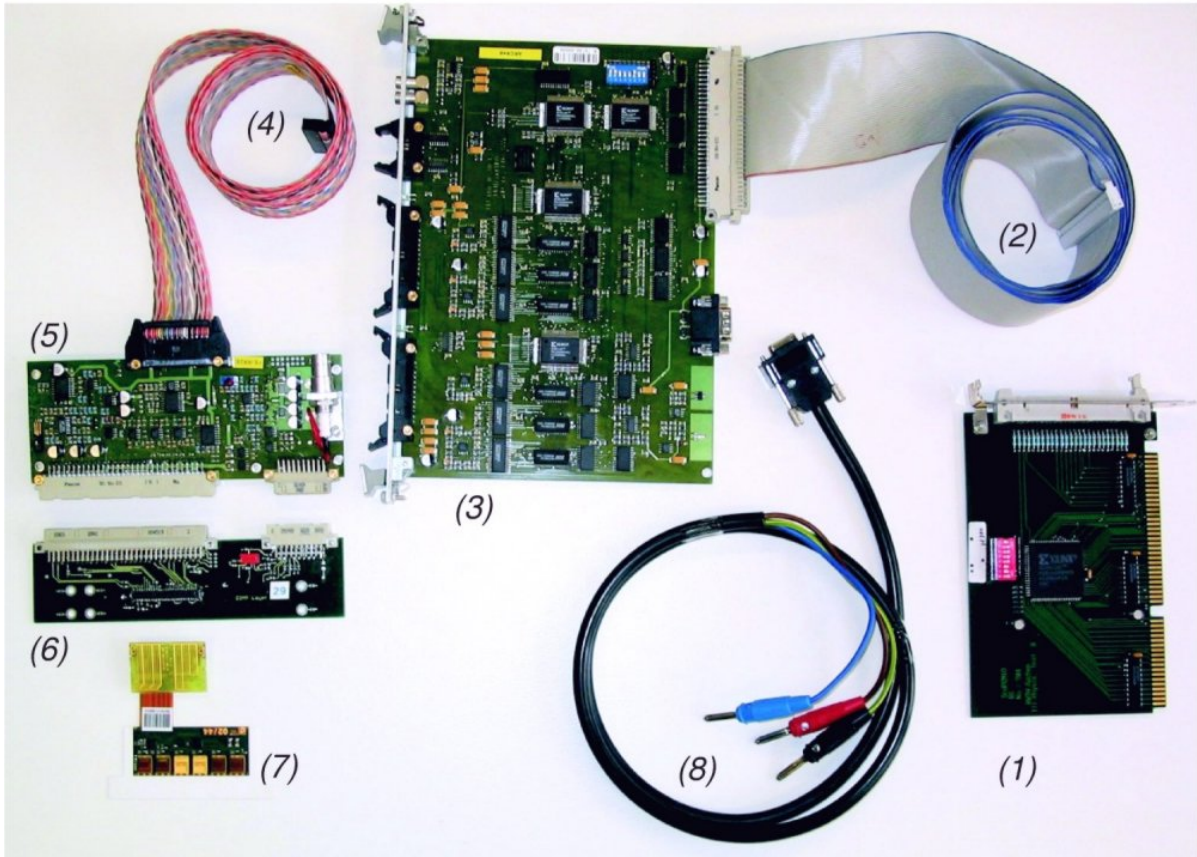
Electronic noise reduction

Nitrogen hut (r. humidity ~90%)
(h.v. board and/or relatively thin window)





The ARC System

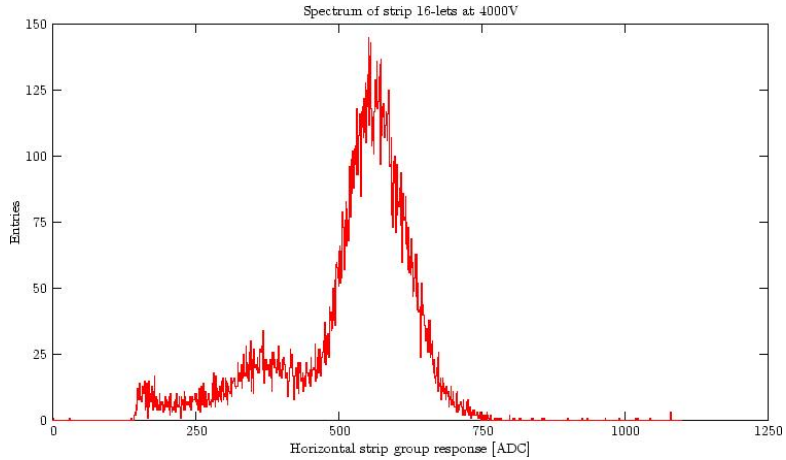


Photograph of a complete ARC setup: (1) PCMIO Interface, to be plugged into an ISA slot of the PC motherboard, (2) 50 pin flat cable, (3) ARC board, (4) 26 pin twisted pair flat cable, (5) ARC front-end adapter, (6) Hybrid-to-VUTRI adapter card, (7) front-end hybrid, (8) power supply cable for the ARC board.

1-2 128 channels APV hybrids

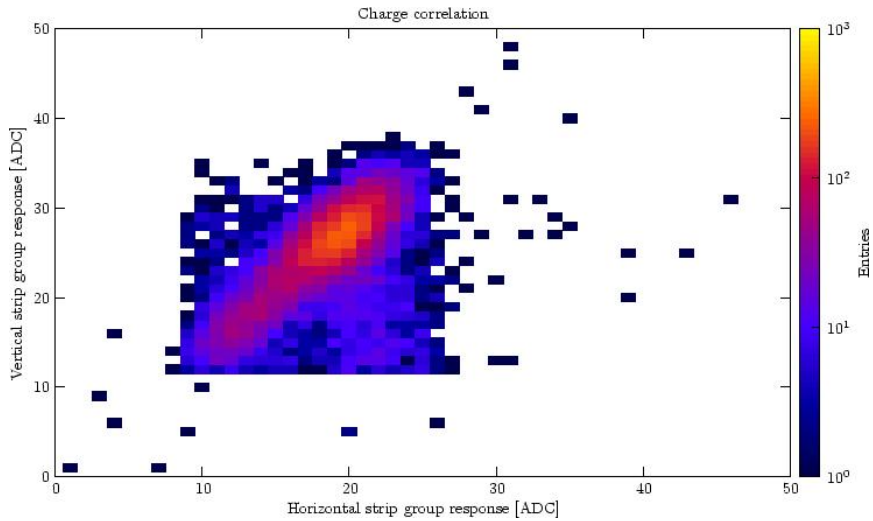
Shortcomings: Old fast PC, small distance to detector

Cylindrical GEM Lab Test



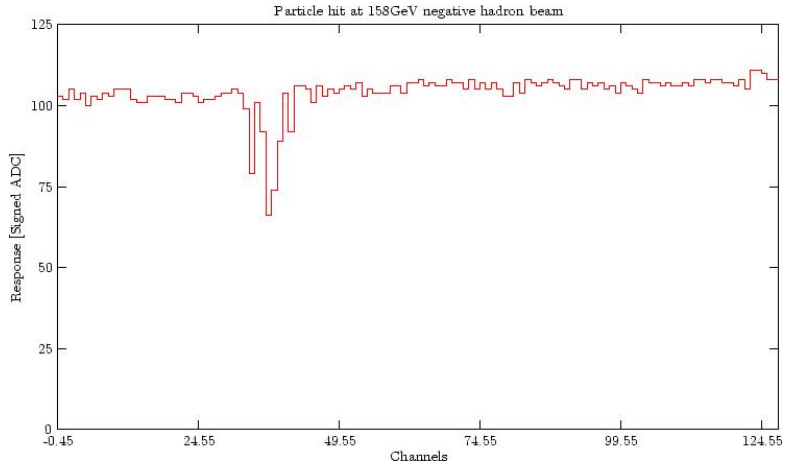
Lab performance as planar detector:

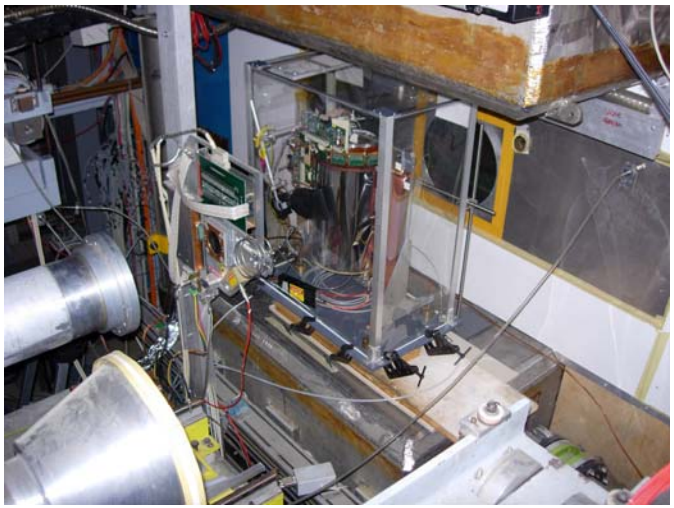
- Gas gain
- Charge sharing
- Charge correlation
- Energy resolution
- Mechanical and electrical stability

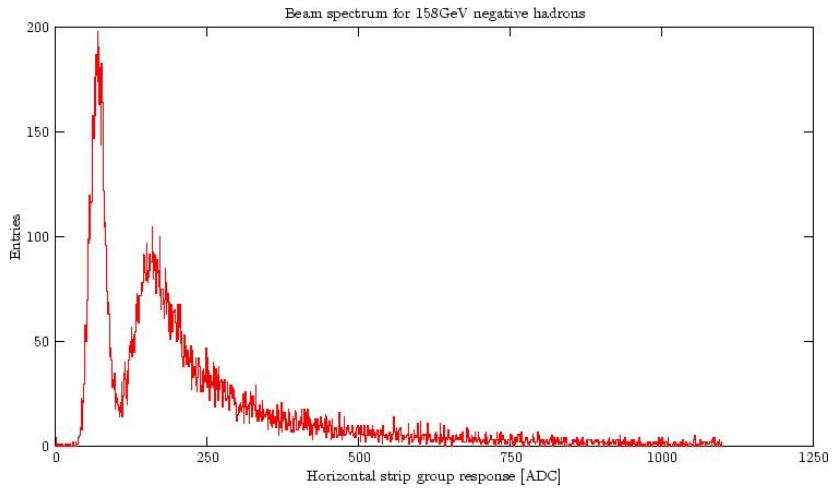


Cylindrical GEM Beam Test @ SPS H2

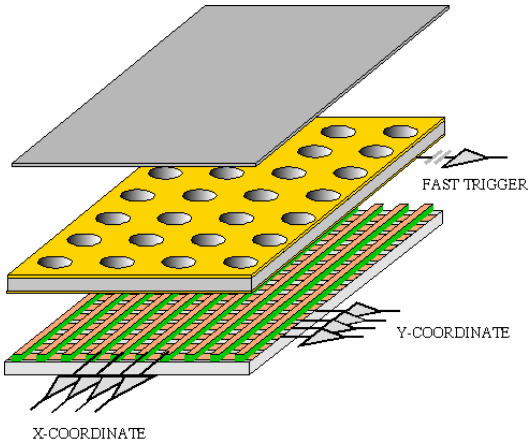
Hadron beam at 3 10^6 p/spill

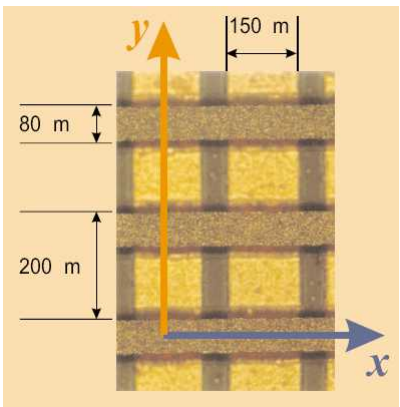


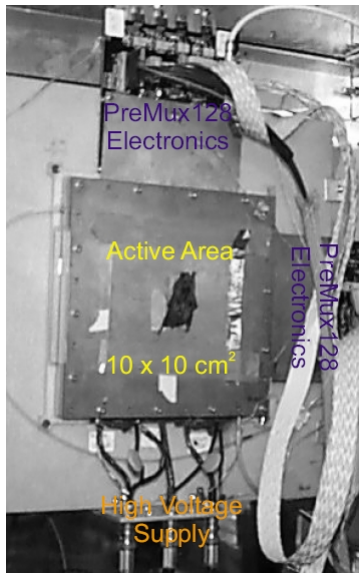


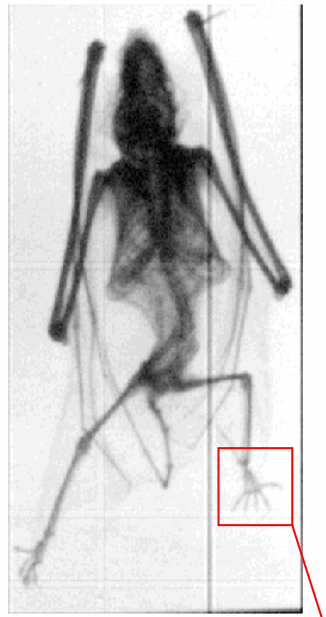


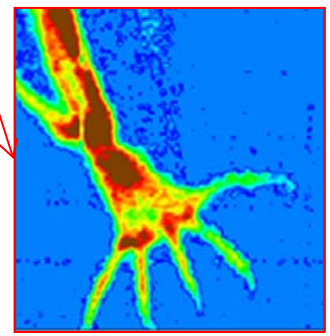
Absorption radiography with GEM (8 keV X-rays)

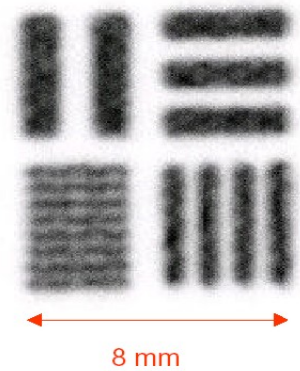








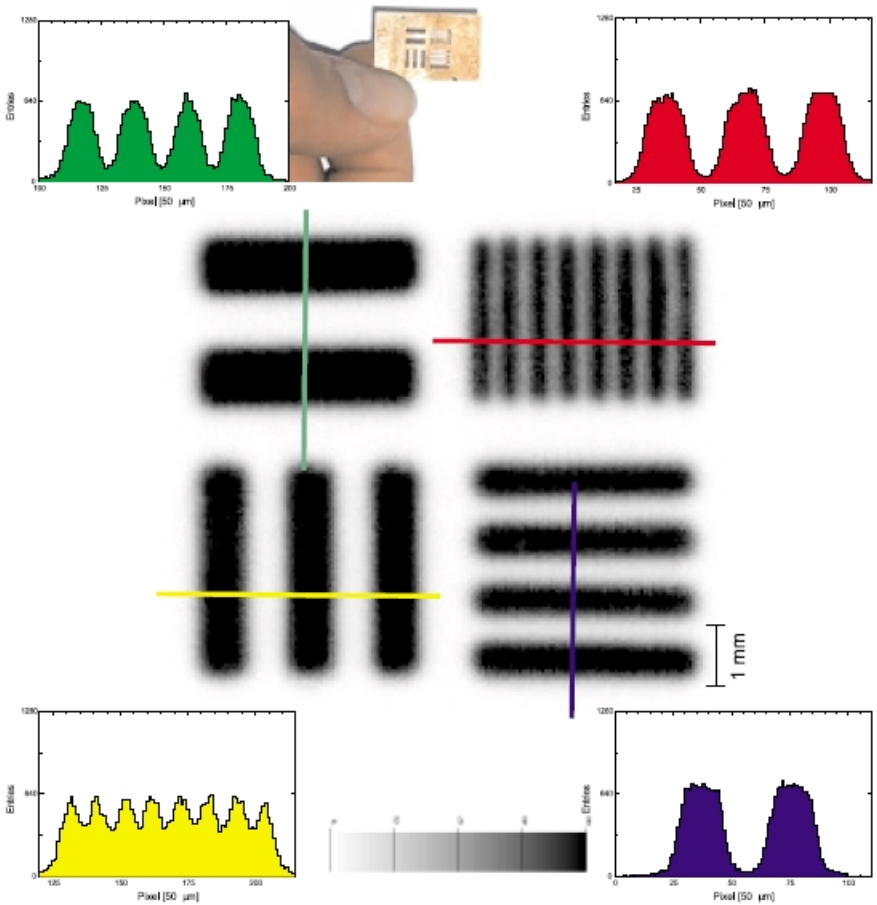


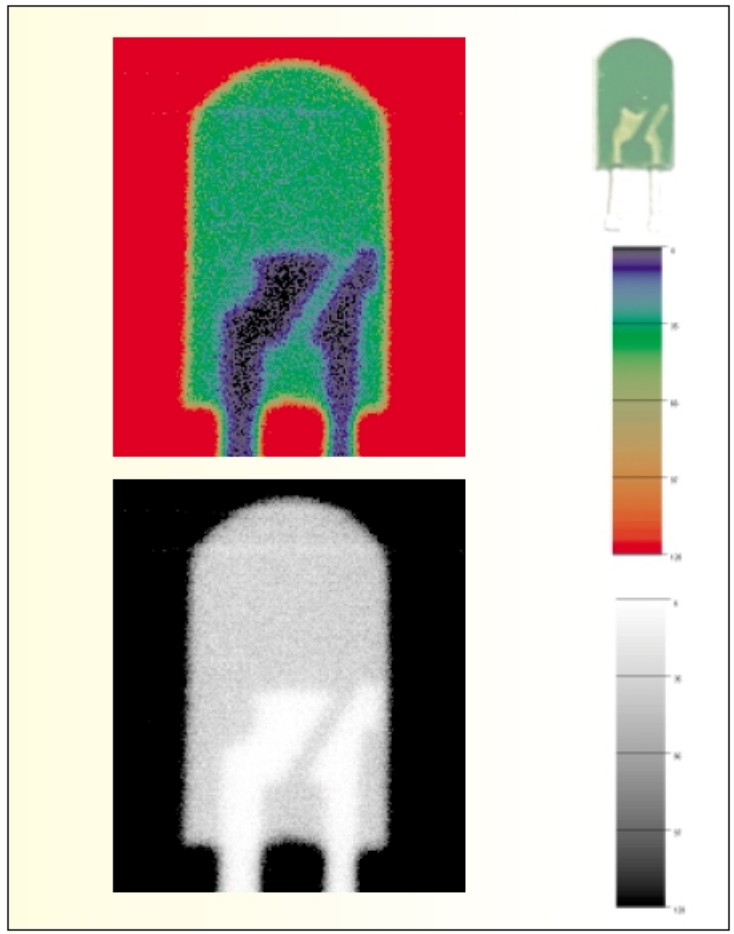


Trigger from the bottom electrode of GEM.

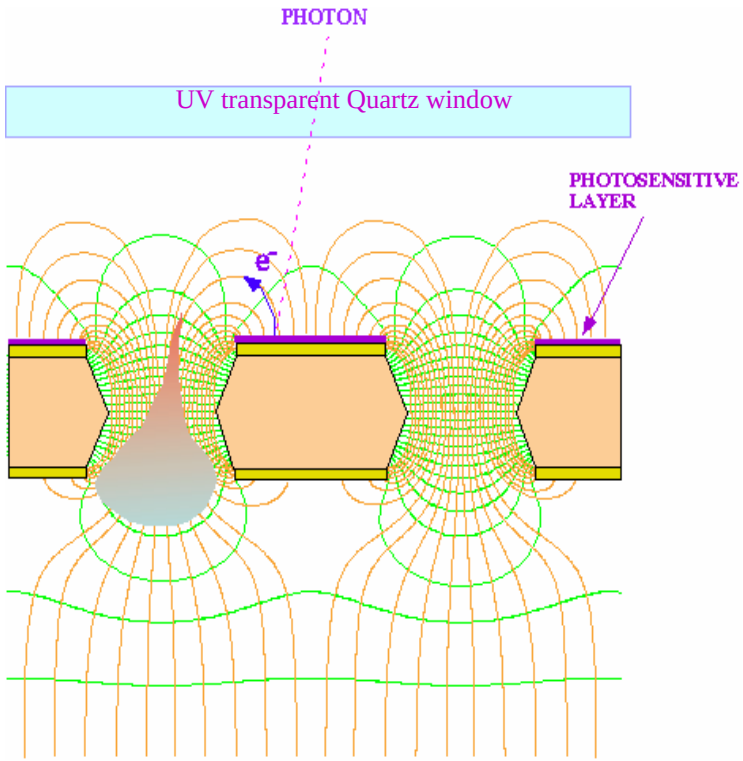
S. Bachmann et al, Nucl. Instr. and Meth. A471(2001)115

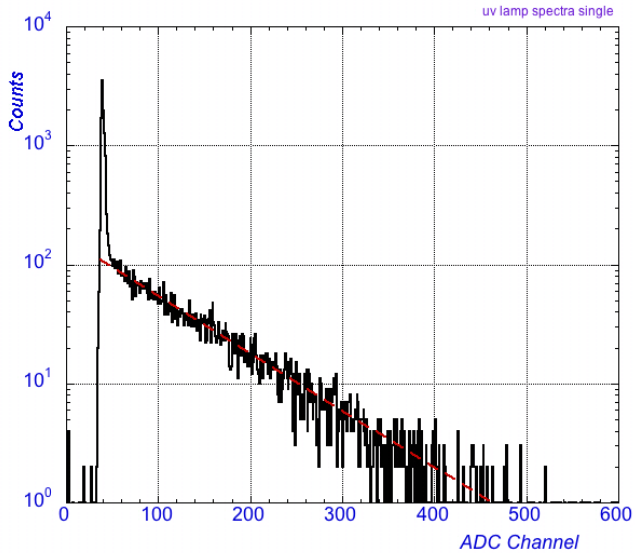
Absorption radiography with GEM (8 keV X-rays)



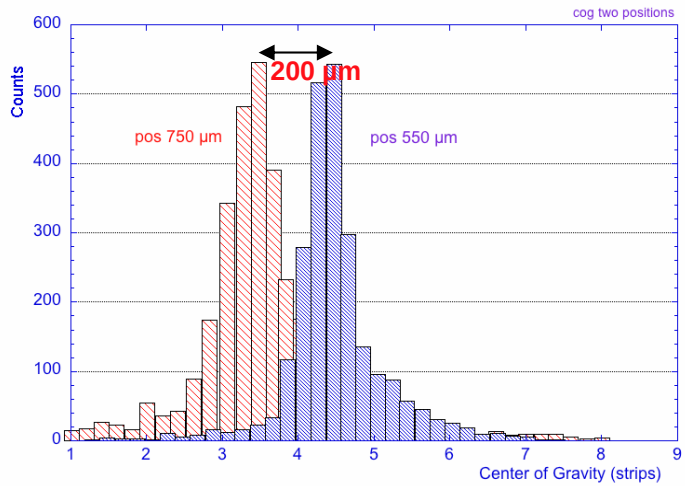


UV Light Detection (RICH)





Single photoelectron p.h. spectrum



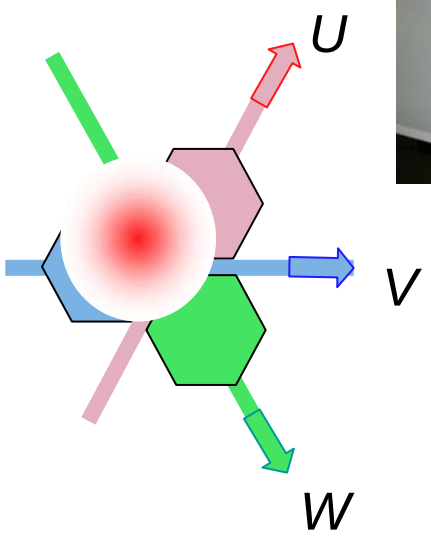
D. Mormann et al, Nucl. Instr. and Meth. A478(2002)230

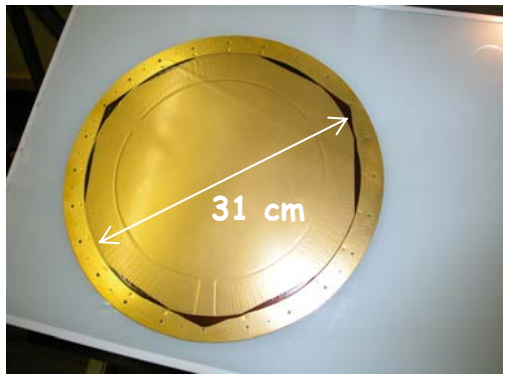
T. Meinschad, L. Ropelewski and F. Sauli, Nucl. Instr. and Meth. A535(2004)324

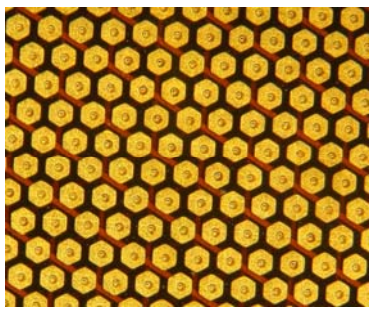
Hexaboard Readout

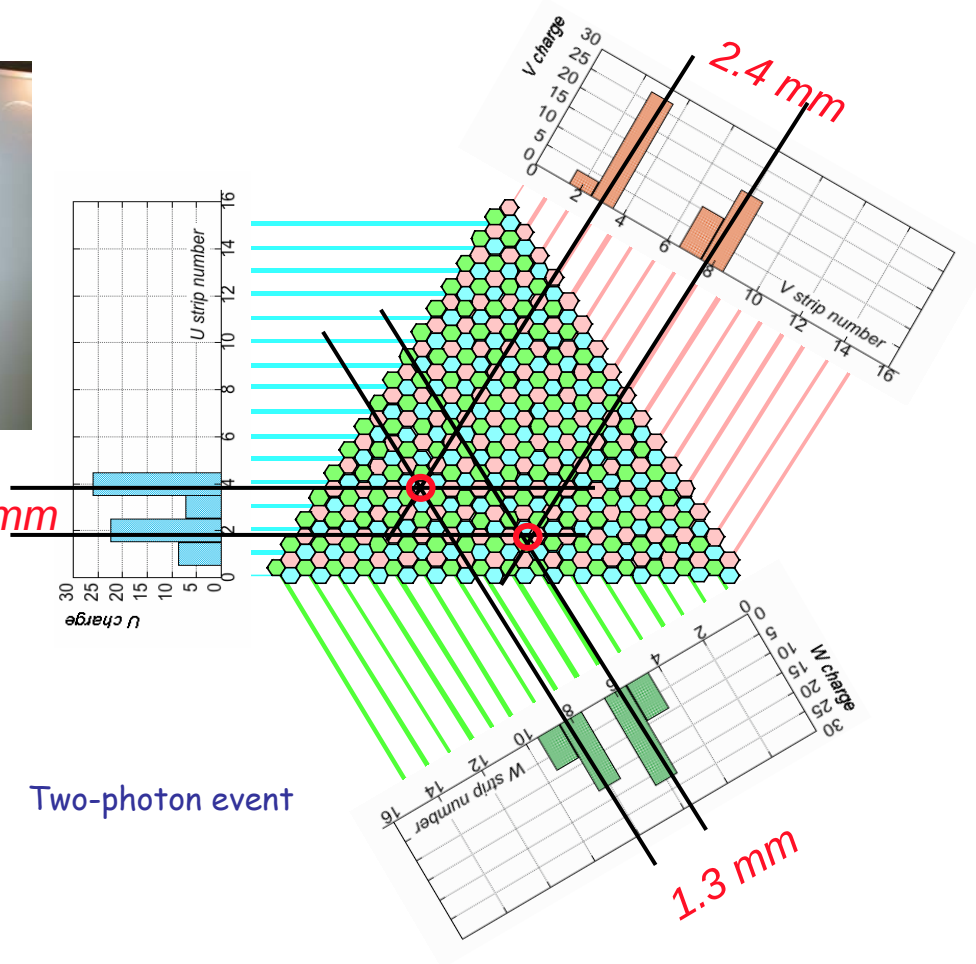
Hexaboard readout:

matrix of hexagonal pads interconnected along three projections at 120°









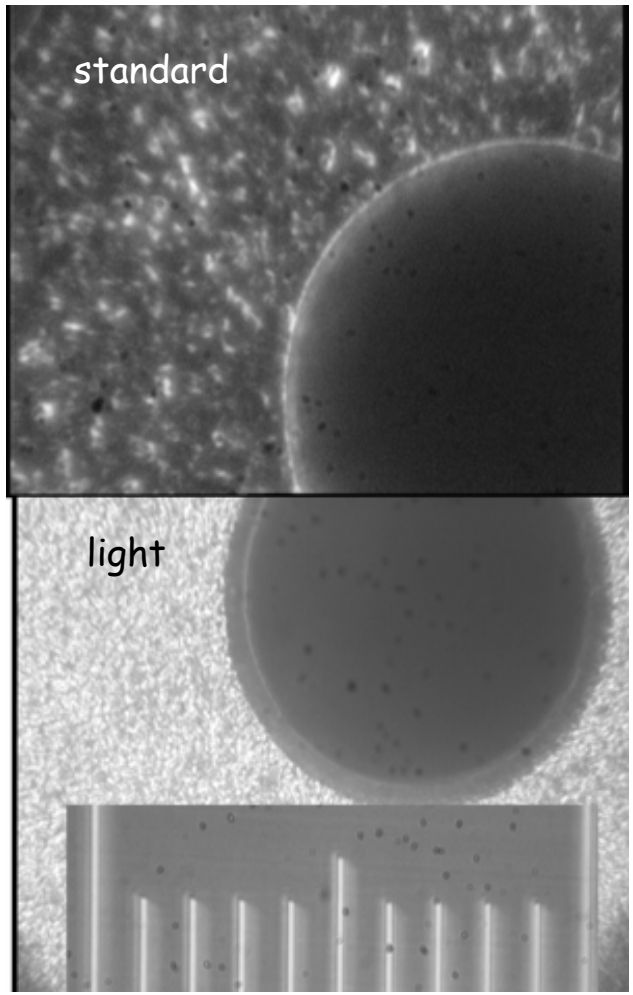
Two-photon event

S. Bachmann et al Nucl. Instr. and Meth. A 478 (2002) 104
F. Sauli, RICH04 (Playa del Carmen, Nov. 30-Dec. 5, 2004 Subm. Nucl. Instr. And Meth.

GEM Foil Material Budget Reduction

By reducing Cu layer thickness 5 μm —> 1 μm

Detector element (material)	Rad. length [cm]	x/X0
Si 300 μm	9.4	$3.2\ 10^{-3}$
Cu 5 μm	1.44	$3.5\ 10^{-4}$
Kapton 50 μm	8.57	$1.8\ 10^{-4}$
Argon 1 cm	11762	$0.85\ 10^{-4}$
Triple **GEM standard**: 5 x Kapton 50 μm 7 x Cu **5 μm** Argon 7 mm		$3.4\ 10^{-3}$
Triple **GEM light**: 5 x Kapton 50 μm 7 x Cu **1 μm** Argon 7 mm		$1.5\ 10^{-3}$



GEM TPC

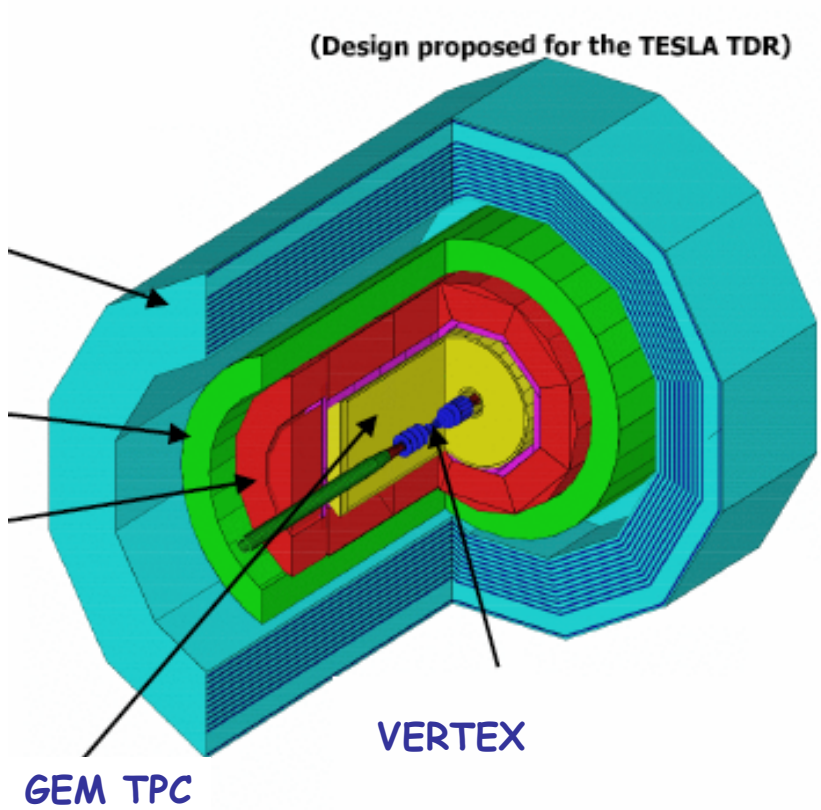
GEM readout for the Time Projection Chamber (GEM-TPC)

Narrow pad response function: $\Delta s \sim 1$ mm
Fast signals (no ion tail): $\Delta T \sim 20$ ns
Very good multi-track resolution: $\Delta V \sim 1\ mm^3$
(Standard MWPC TPC ~ 1 cm^3)
Strong ion feedback suppression
No ExB distortions
Freedom in end-cap shapes
Robustness

ILC TPC R&D groups (~ 40)

http://alephwww.mppmu.mpg.de/~settles/tpc/welcome3.html

International Linear Collider Detector



GEM TPC

Small charge spread:

Optimization of pad geometry

Resistive anode

Small pads & high density integrated pixel electronics

Ion feedback reduction:

Gas composition

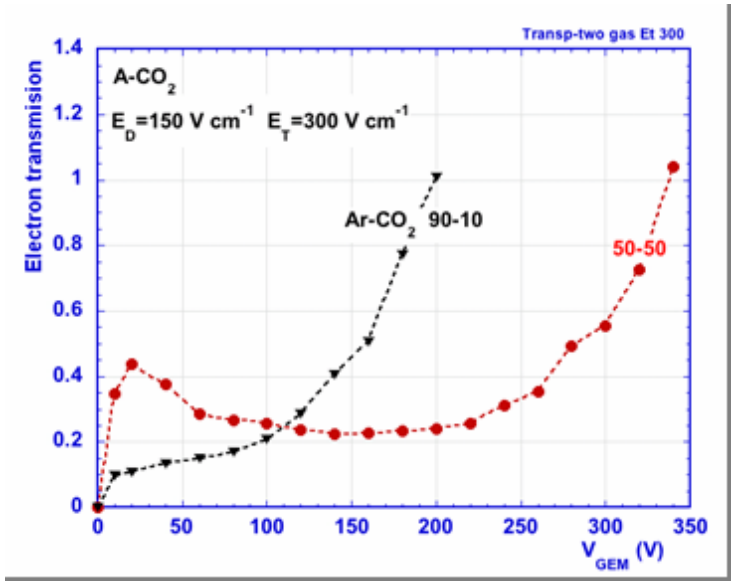
Spill structure

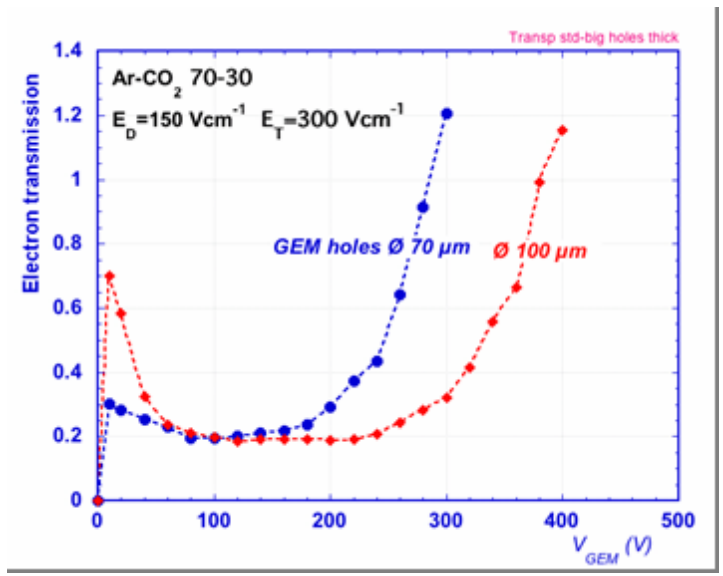
Geometry

New amplifier structures

Mesh gating

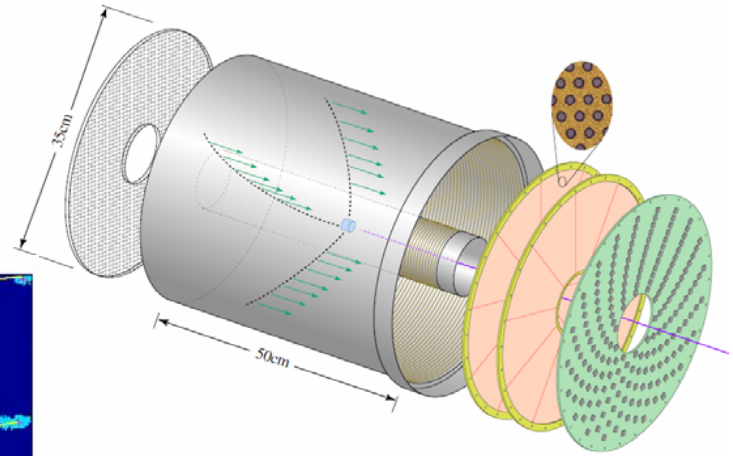
Low voltage Gem gating ->



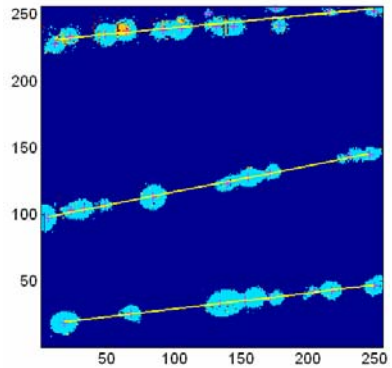


Low voltage GEM electron transmission

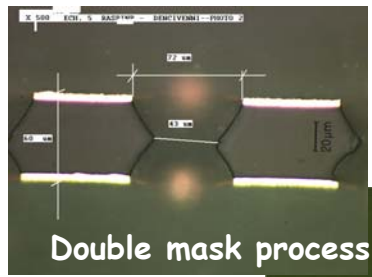
Perspectives

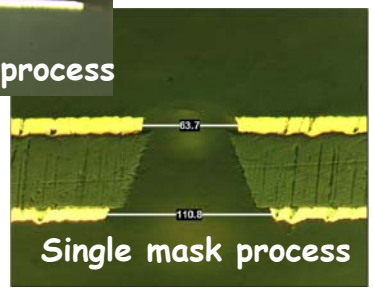


Tracking and triggering (LHCb & TOTEM)
TPC end cap readout
X-ray radiography
UV light detection
Parallax error free detector
Hadron blind
Neutron detection
Optical GEM
Cryogenic detectors
Two-phase detectors



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
Radiation hardness of assembly materials
Industrialization of the mass production
Medical applications

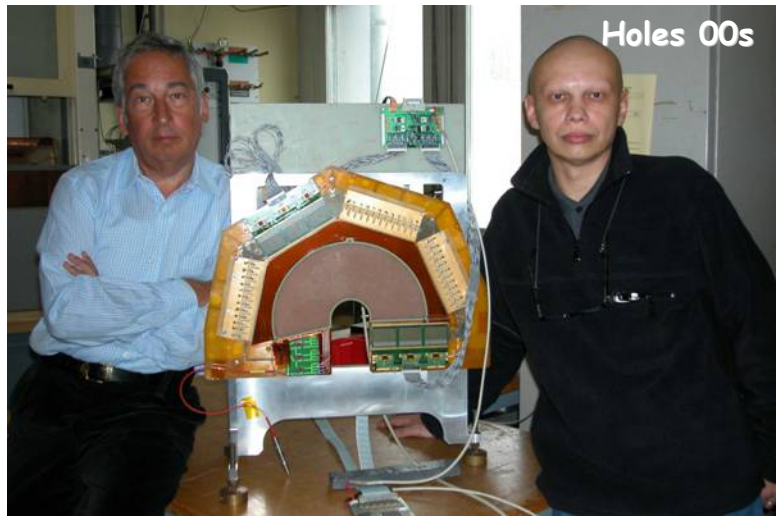

Double mask process



Single mask process

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

GDD population evolution

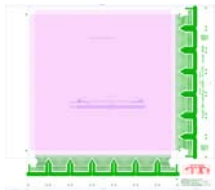


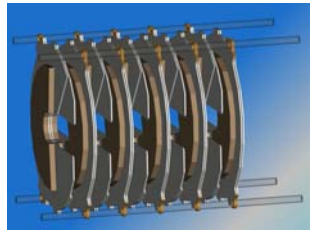
Positives:

Budget
New gas detector lab
Student(s)

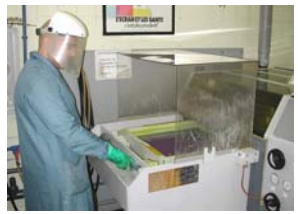
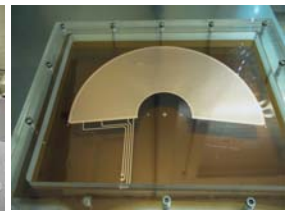
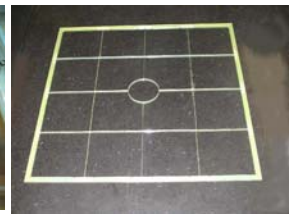
GEM Detectors at CERN

Detector Design
DT2

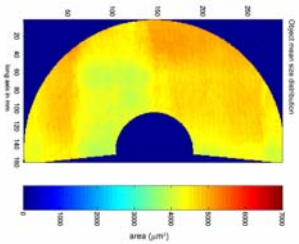




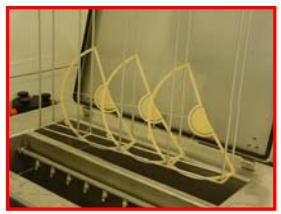
Component Production
TS-DEM -> industry

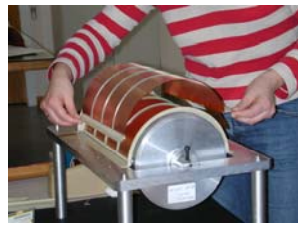




Component Quality Control
DT2 & institutes -> TS-DEM -> industry

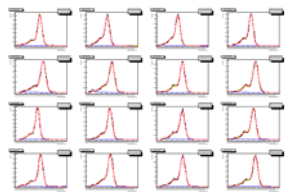
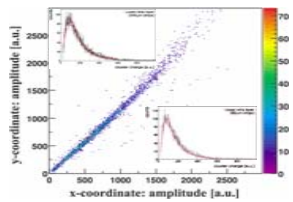


Detector Assembly
DT2 -> institutes -> industry



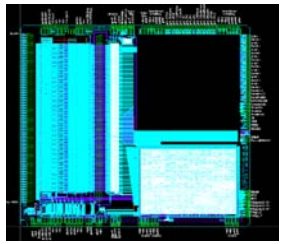


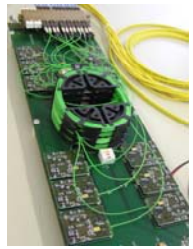
Detector Test
DT2 -> institutes

GEM Detectors at CERN

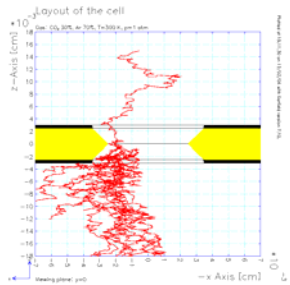
Electronics
MIC

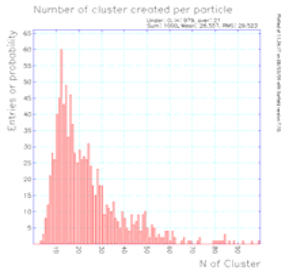


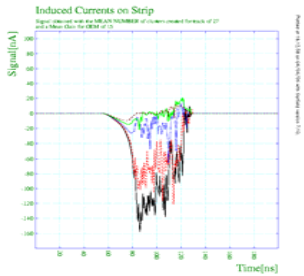


APV
VFAT
GP5
ALTRO

Detector Simulations
DT2 -> SFT

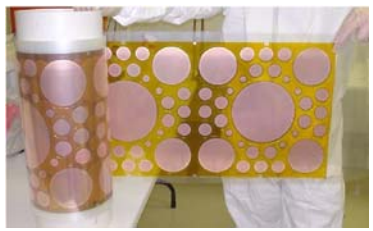


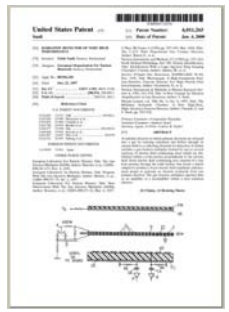




Garfield
Maxwell
Magboltz
Imonte
Heed

Technology Dissemination
DT2 -> DSU-TT





PANalytical
3M
TechEtch
Techtra
G&A

In 2 weeks meeting of all players to define roles and objectives of better cooperation and use of available resources – perhaps come with the proposal of wider collaboration on Micropattern Gas Detectors.