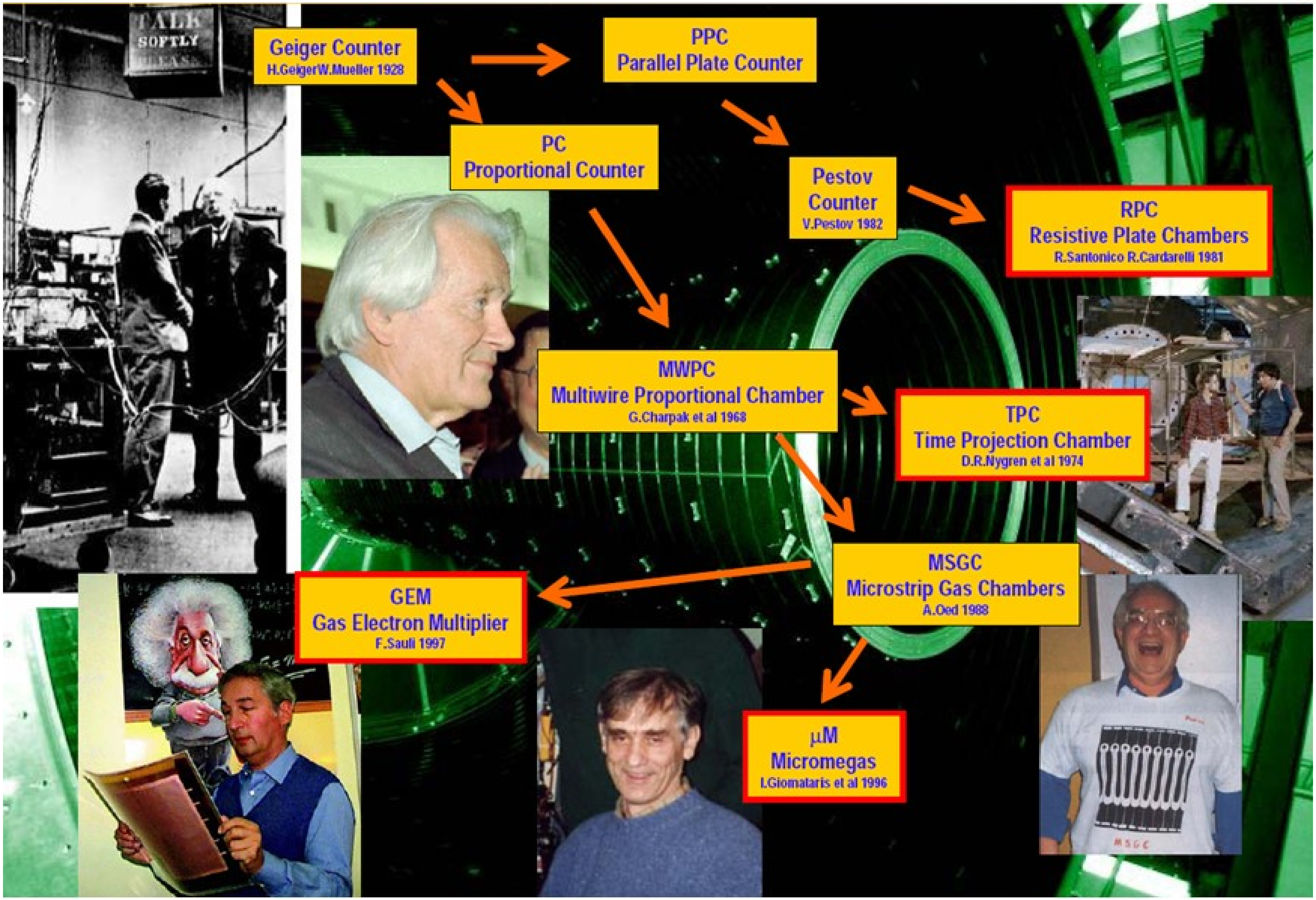
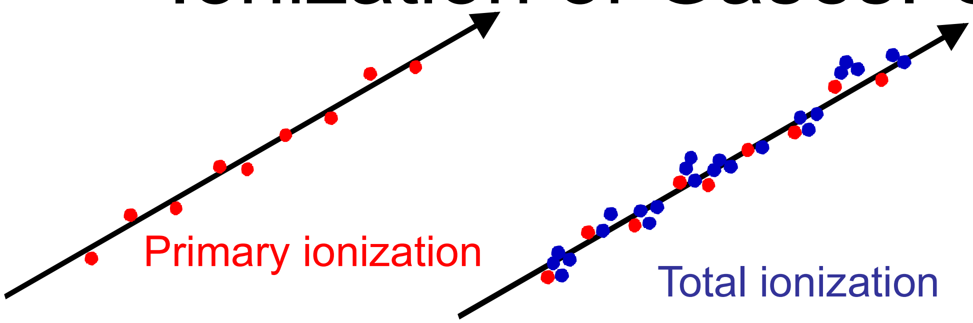
# Gaseous Detectors

# GAS DETECTOR DEVELOPMENT GROUP



# Ionization of Gases: Charged Particles




Lohse and Witzeling, Instrumentation In High Energy Physics, World Scientific,1992

Fast charged particles ionize atoms of gas.
Often resulting primary electron will have enough kinetic energy to ionize other atoms.

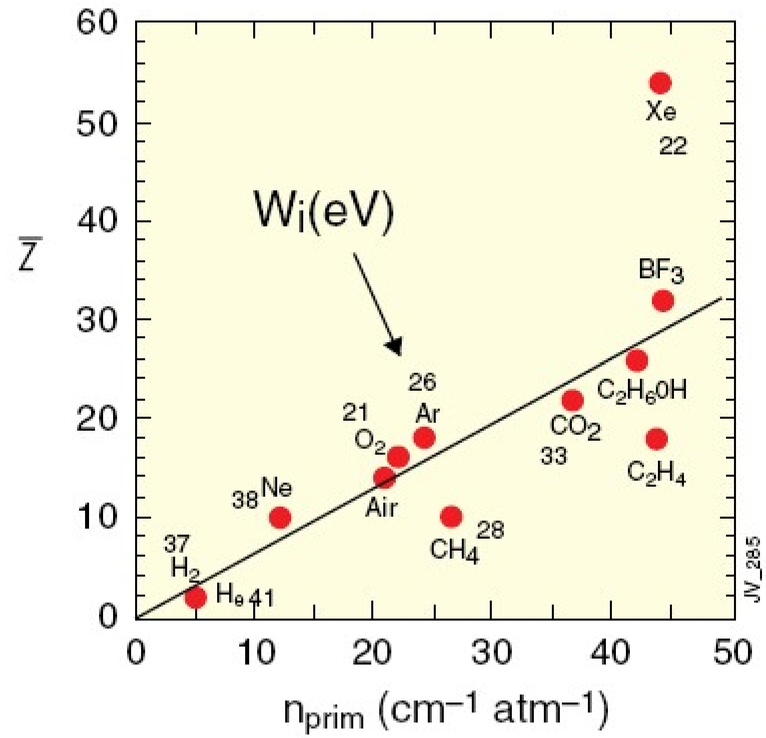
$$n_{total} = \frac{\Delta E}{W_i} = \frac{\frac{dE}{dx}\Delta x}{W_i}$$

$$n_{total} \approx 3 \ldots 4 \cdot n_{primary}$$

$n_{total}$ - number of created electron-ion pairs

$\Delta E$ = total energy loss

$W_i$ = effective <energy loss>/pair




Number of primary electron/ion pairs in frequently used gases.

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## Gaseous detectors – Operation Modes

High Voltage

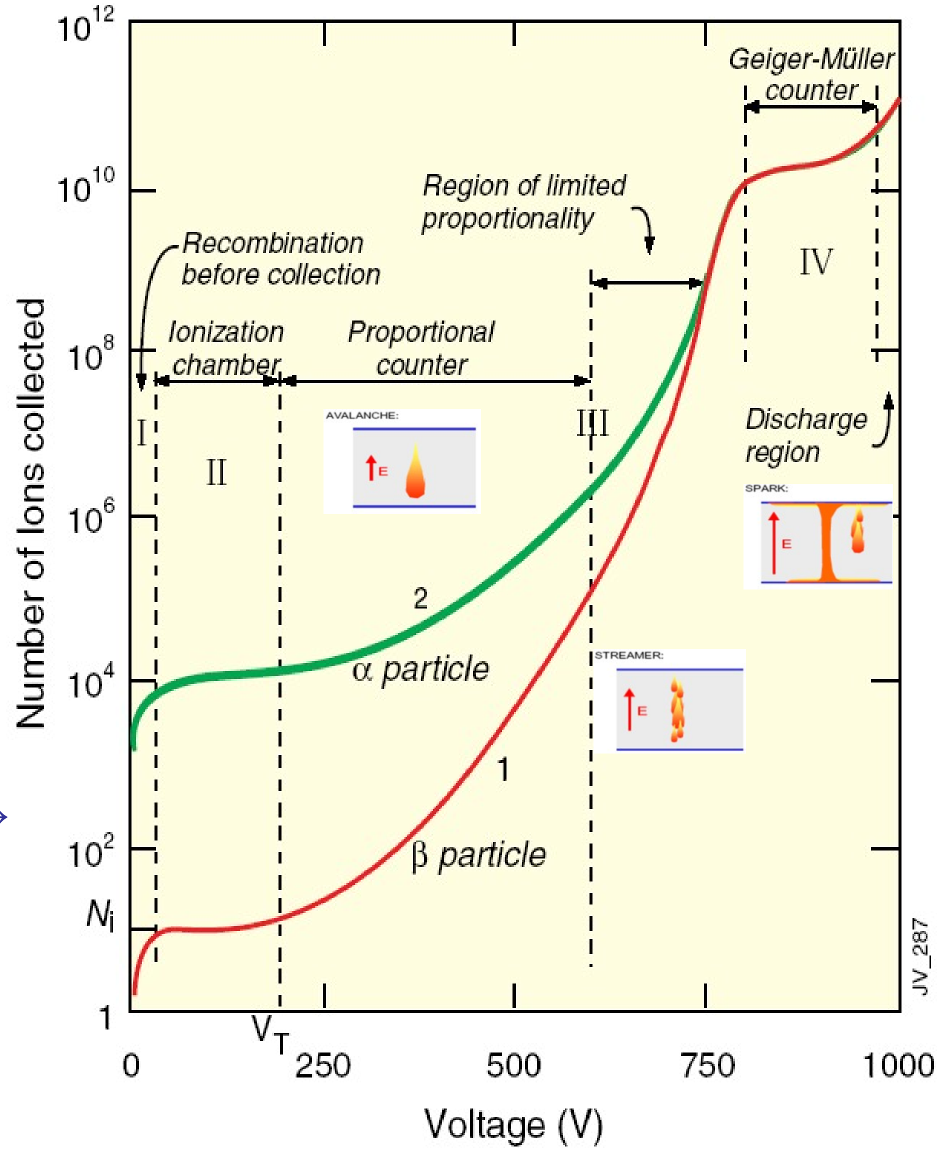
I. no collection – ions recombine before collection

II. ionization mode – full charge collection, but no charge multiplication; gain ~ 1

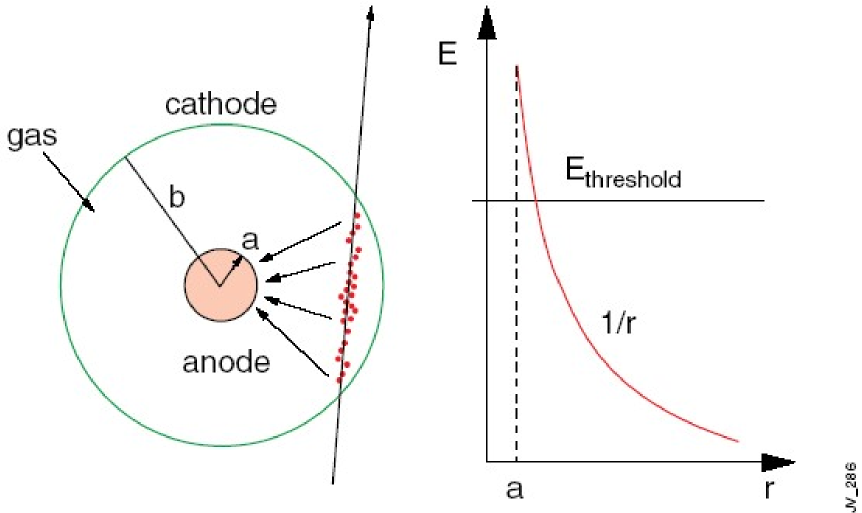
III. proportional mode – multiplication of ionization starts; detected signal proportional to original ionization → possible energy measurement (dE/dx); secondary avalanches have to be quenched; gain ~ $10^4 – 10^5$

limited proportional mode (saturated, streamer) –strong photoemission; secondary avalanches merging with original avalanche; requires strong quenchers or pulsed HV; large signals → simple electronics; gain ~ $10^{10}$

IV. Geiger mode – massive photoemission; full length of the anode wire affected; discharge stopped by HV cut; strong quenchers needed as well



# Single Wire Proportional Chamber




Electrons liberated by ionization drift towards the anode wire.

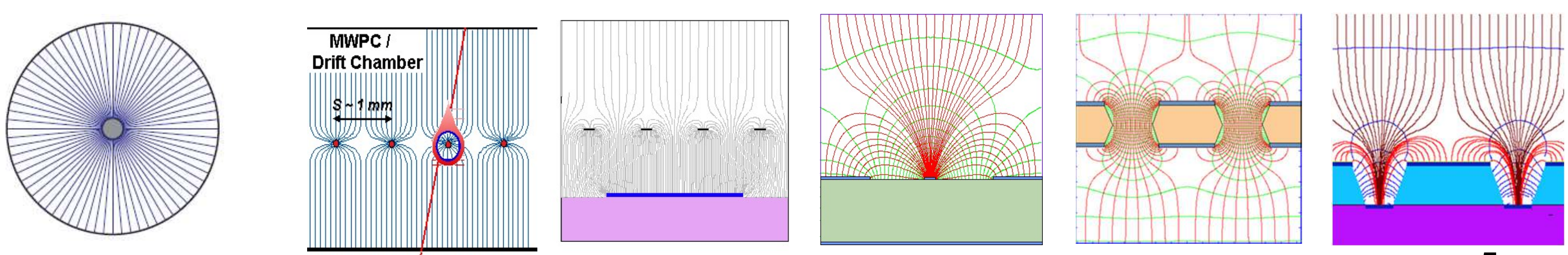
Electrical field close to the wire (typical wire Ø ~few tens of μm) is sufficiently high for electrons (above 10 kV/cm) to gain enough energy to ionize further → avalanche – exponential increase of number of electron ion pairs.


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

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

$C$ – capacitance/unit length

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



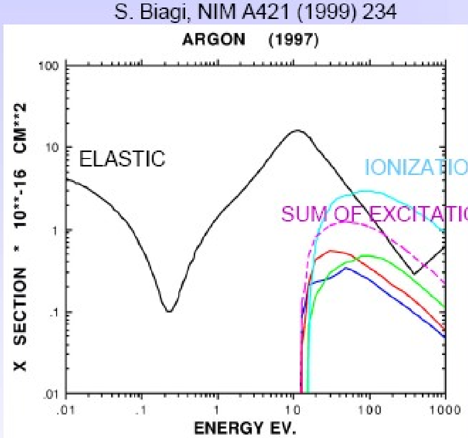

wire mwpc parallel plate strip hole groove/well

# SWPC – Choice of Gas



In the avalanche process molecules of the gas can be brought to excited states.

S. Biagi, NIM A421 (1999) 234

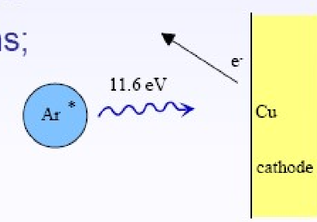



De-excitation of noble gases only via emission of photons;

e.g. 11.6 eV for Ar.

This is above ionization threshold of metals;

e.g. Cu 7.7 eV.



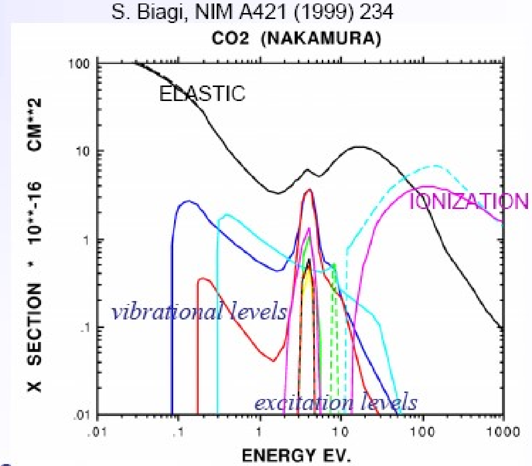

new avalanches → permanent discharges

Solution: addition of polyatomic gas as a quencher

Absorption of photons in a large energy range (many vibrational and rotational energy levels).

Energy dissipation by collisions or dissociation into smaller molecules.

S. Biagi, NIM A421 (1999) 234



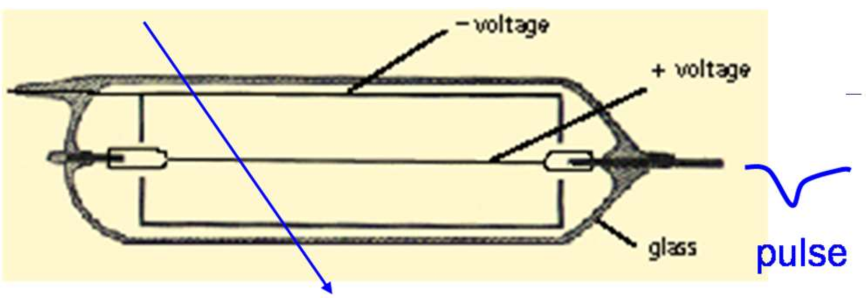

CERN Academic Training Programme 2004/2005

# Geiger Counter

- **The Geiger-Müller tube (1928 by Hans Geiger and Walther Müller)**
  - **Tube filled with inert gas (He, Ne, Ar) + organic vapour**
  - **Central thin wire (20 – 50 μm ∅) , high voltage (several 100 Volts) between wire and tube**


E. Rutherford 1909

H. Geiger 1927



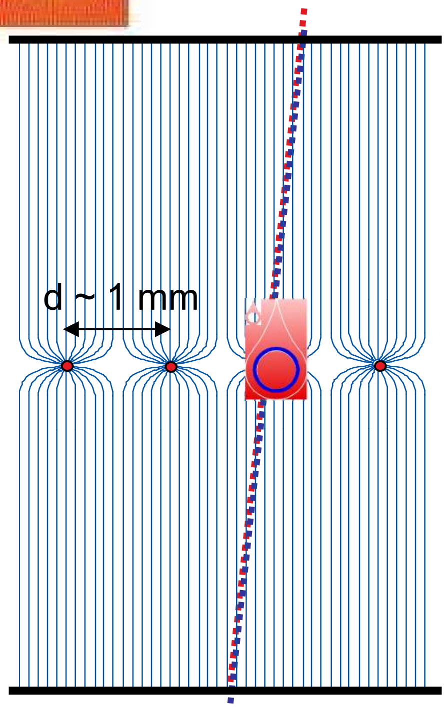

- Strong increase of E-field close to the wire
  - electron gains more and more energy
- above some threshold (>10 kV/cm)
  - electron energy high enough to ionize other gas molecules
  - newly created electrons also start ionizing
- avalanche effect: exponential increase of # electrons (and ions)
- measurable signal on wire
  - organic substances responsible for "quenching" (stopping) the discharge

E. Rutherford and H. Geiger, Proc. Royall Soc. A81 (1908) 141

H. Geiger and W. Müller, Phys. Zeits. 29 (1928) 839

First electrical signal from a particle

# Multiwire Proportional Chamber




- Simple idea to multiply SWPC cell : Nobel Prize 1992
- First electronic device allowing high statistics experiments !!

Georges Charpak

Typical geometry

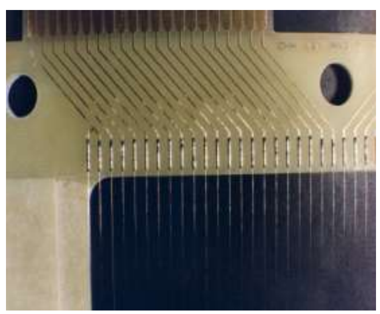
5mm, 1mm, 20 $\mu$m

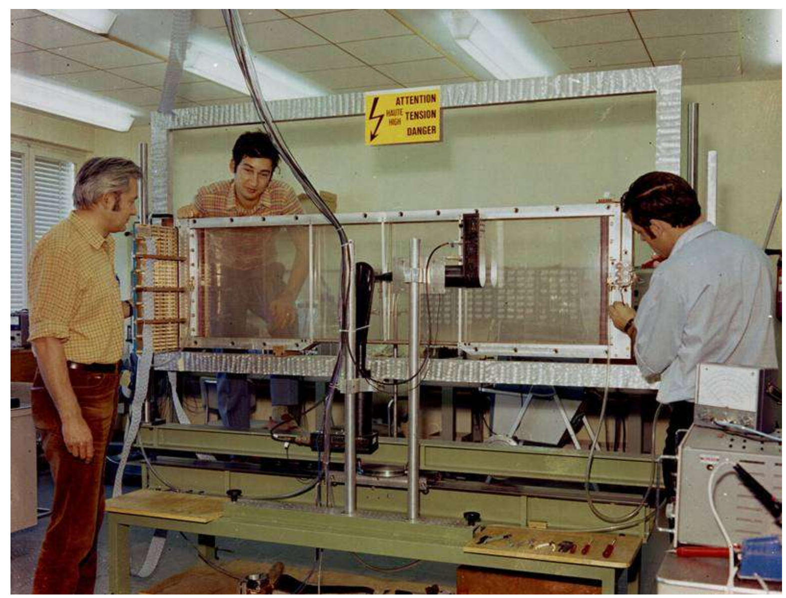
Normally digital readout :

spatial resolution limited to

$$\sigma_x \approx \frac{d}{\sqrt{12}}$$

for d = 1 mm $\sigma_x$ = 300 $\mu$m





G. Charpak, F. Sauli and J.C. Santiard

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# Multiwire Proportional Chamber: Drawbacks (1)

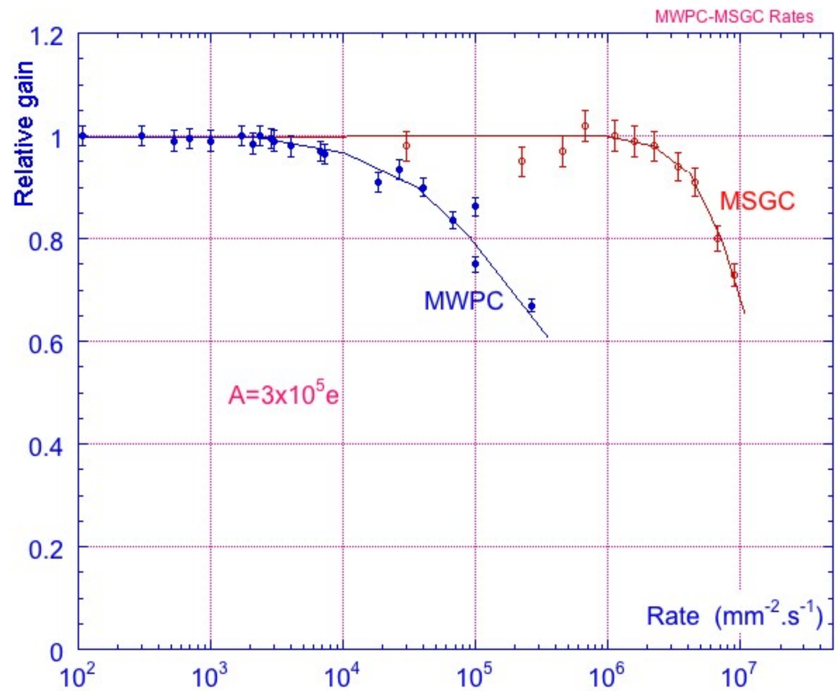
- Positive ions created during an avalanche slowly drift towards the cathode plates and cumulate in the gas volume.
- The presence of a large number of ions in the conversion gaps modifies the detector field configuration

The gain and the performance of the detector is affected

*Reduce ions back path to the cathode: introduction of closely spaced (0.5 mm) cathode wires (at ground potential) between anode wires*

*So closely spaced wires provoke mechanical instabilities, causing the detector to become very fragile.*

## Limited Rate Capability – Space charge effect



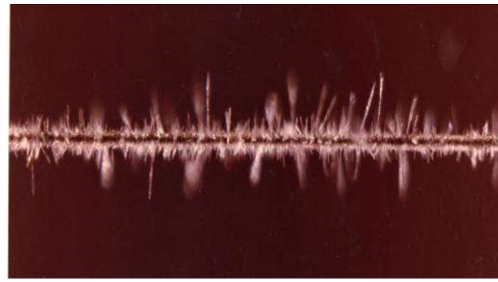

Introduction of Micro-Pattern Gaseous Detectors

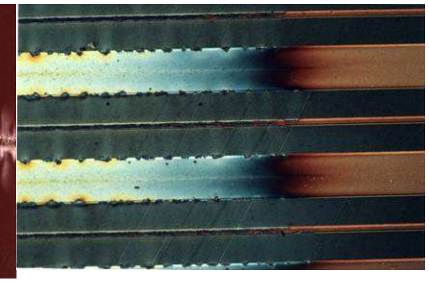
# Multiwire Proportional Chamber: Drawbacks (2)

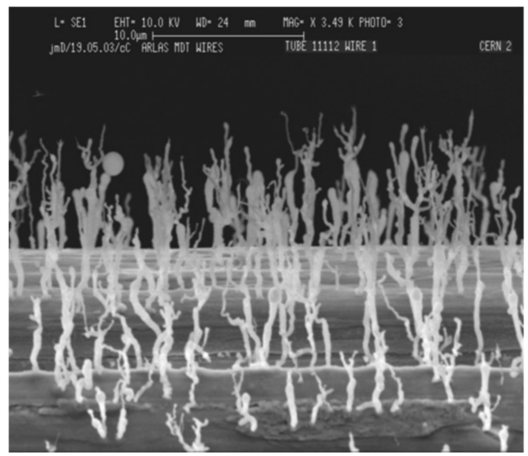
Avalanche region → plasma formation (complicated plasma chemistry)

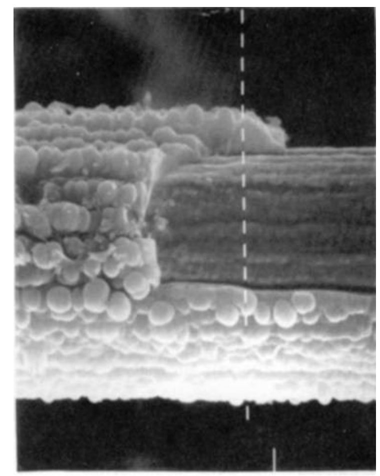
- Dissociation of detector gas and pollutants
- Highly active radicals formation
- Polymerization (organic quenchers)
- Insulating deposits on anodes and cathodes

## Ageing



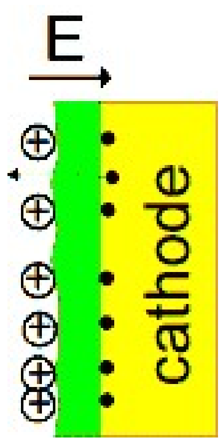






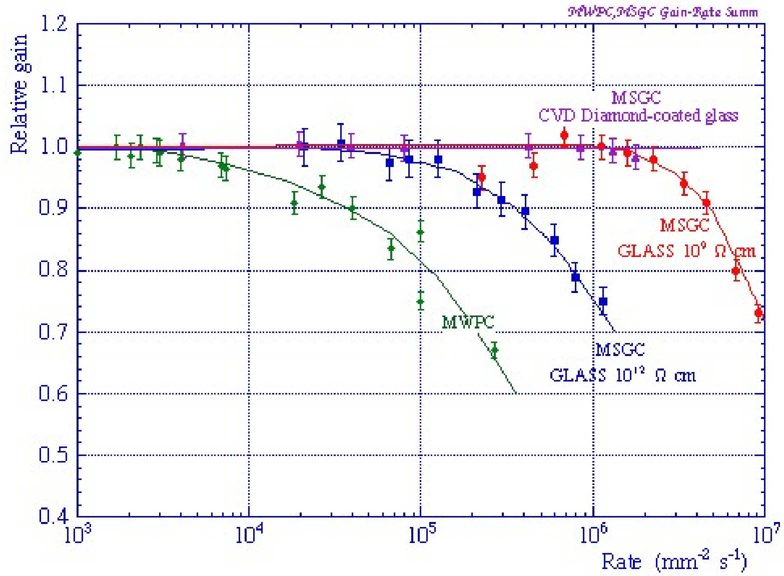

Anode: increase of the wire diameter, reduced and variable field, variable gain and energy resolution.

Cathode: formation of strong dipoles, field emmision and microdischarges (Malter effect).



# Micro-Pattern Gaseous Detectors (MPGDs)

# GAS DETECTOR DEVELOPMENT GROUP
## Micro-Pattern Gas Detectors




Advantages of gas detectors:

- low radiation length
- large areas at low price
- flexible geometry
- spatial, energy resolution …

Problem:

- rate capability limited by space charge defined by the time of evacuation of positive ions

Solution:

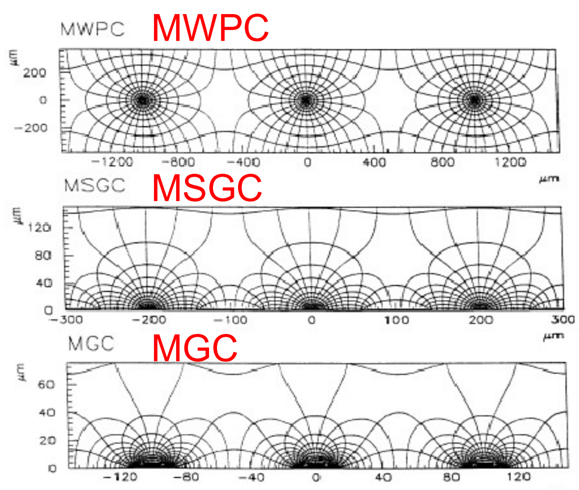
- reduction of the size of the detecting cell (limitation of the length of the ion path) using chemical etching techniques developed for microelectronics and keeping at same time similar field shape.

scale factor

1

5

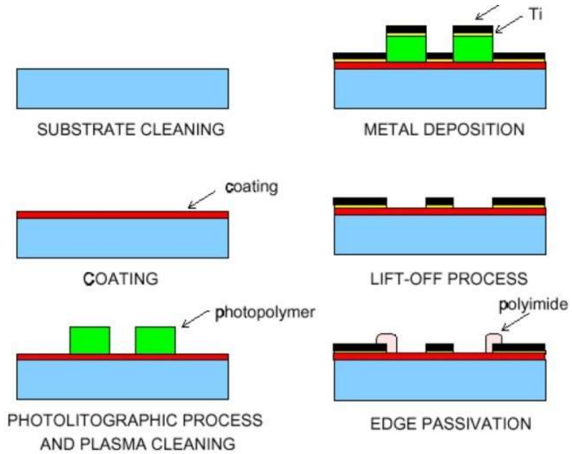
10




R. Bellazzini et al.

# MSGC – MicroStrip Gas Chamber

Anton Oed

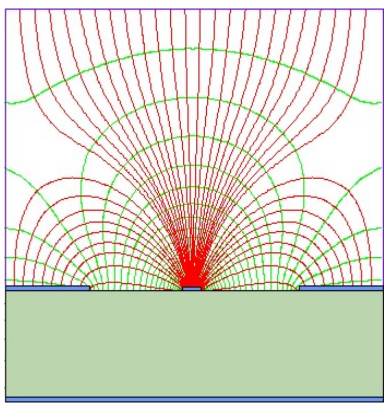


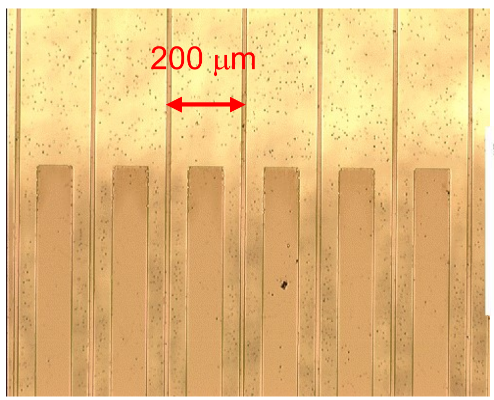

Thin metal anodes and cathodes on insulating support (glass, flexible polyimide ..)

Problems:

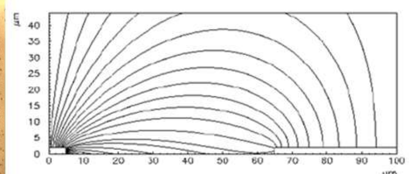
High discharge probability under exposure to highly ionizing particles caused by the regions of very high E field on the border between conductor and insulator.

Charging up of the insulator and modification of the E field → time evolution of the gain.

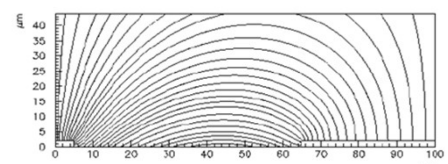





insulating support



slightly conductive support



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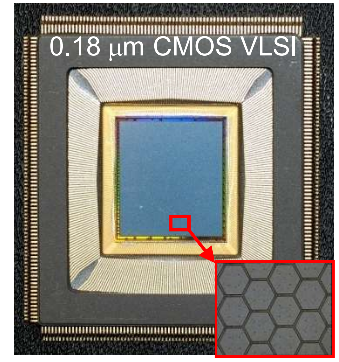
Solutions:

slightly conductive support

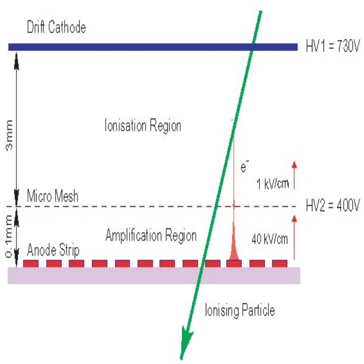
multistage amplification

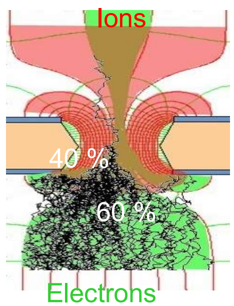
# Current Trends in Micro-Pattern Gas Detectors (Technologies)

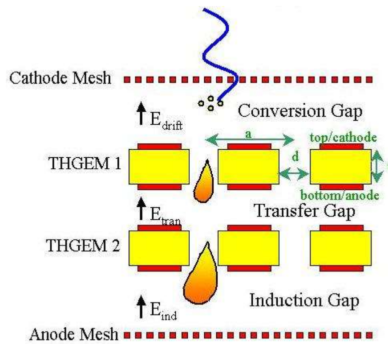
- MSGC
- **Micromegas**
- **GEM**
- Thick-GEM, Hole-Type Detectors and RETGEM
- MPDG with CMOS pixel ASICs
- Ingrid Technology

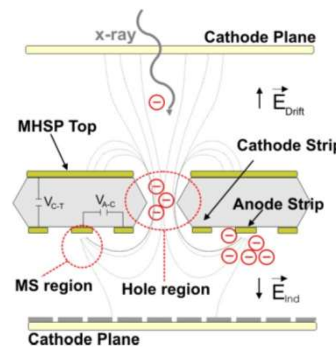


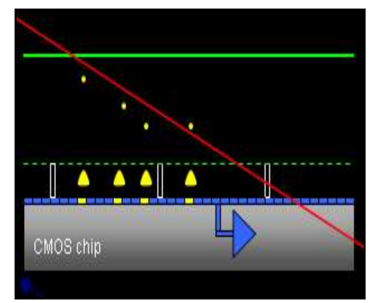

CMOS high density readout electronics

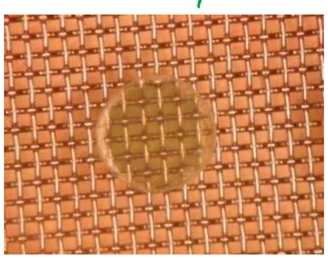


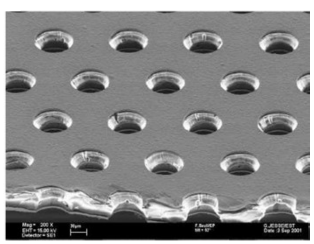



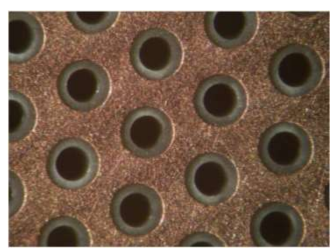



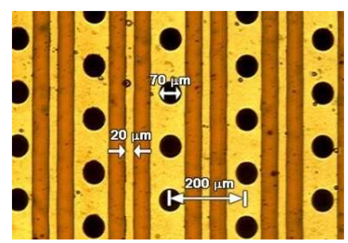
Micromegas



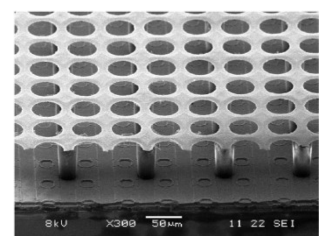
GEM



THGEM




MHSP

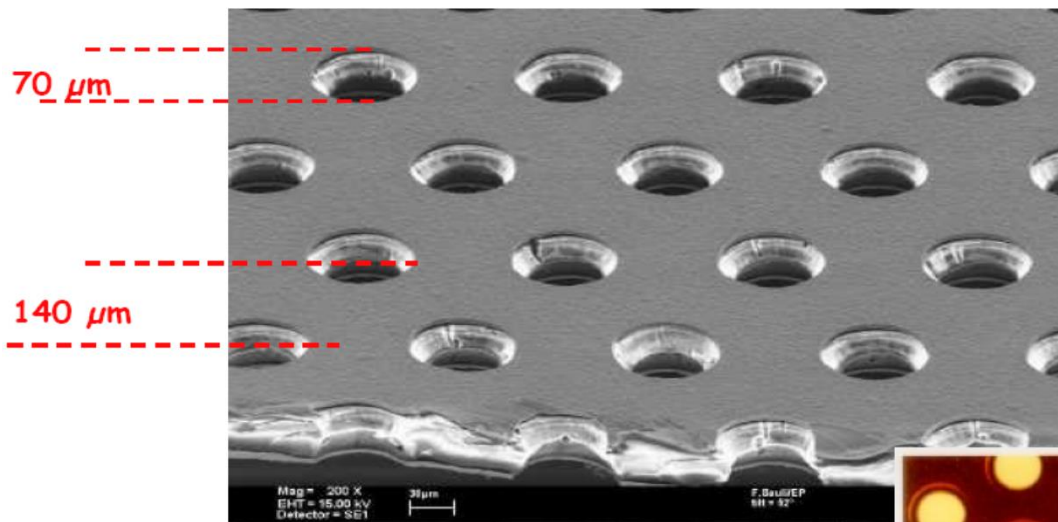


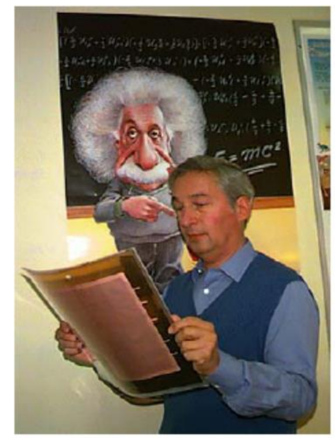
Ingrid

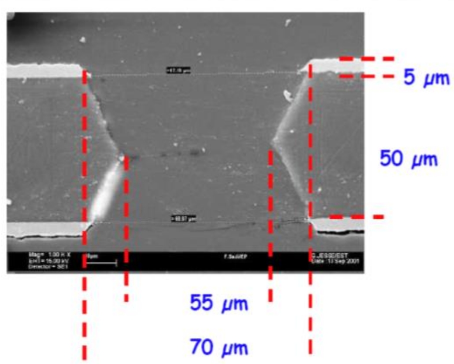
# *GEM detectors*

# *Gas Electron Multiplier*

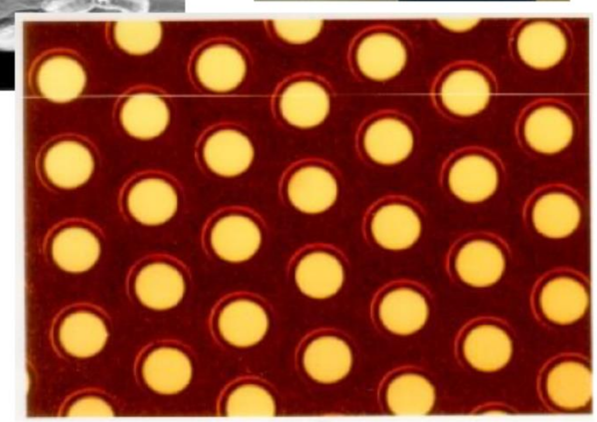
Thin metal-coated polymer foil pierced by a high density of holes (50-100/mm$^2$).
Typical geometry 5μm Cu on 50μm Kapton, 70μm holes at 140 μm pitch



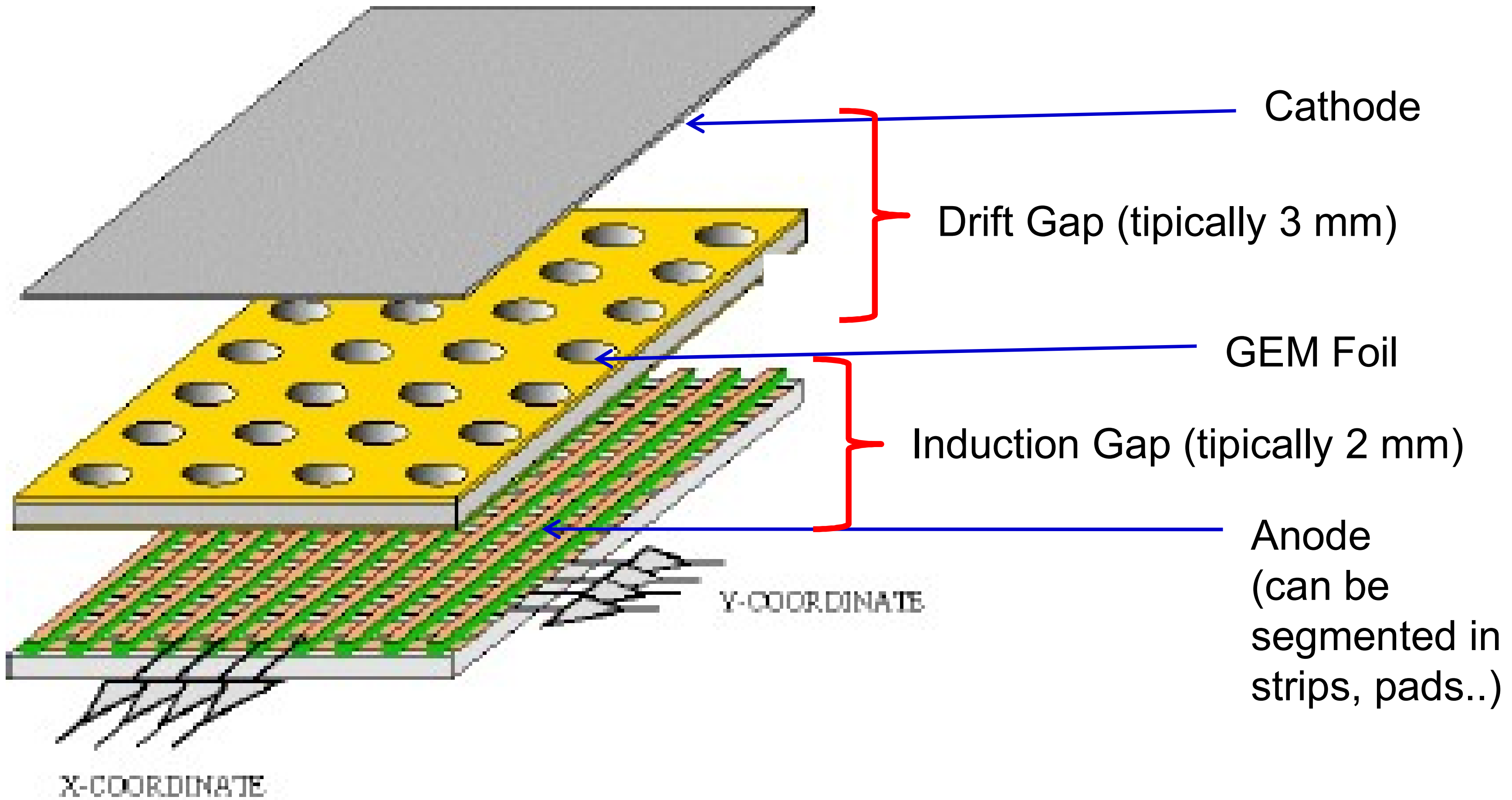






GEM hole cross section



# *Single GEM detector*



# GEM principle

CATHODE

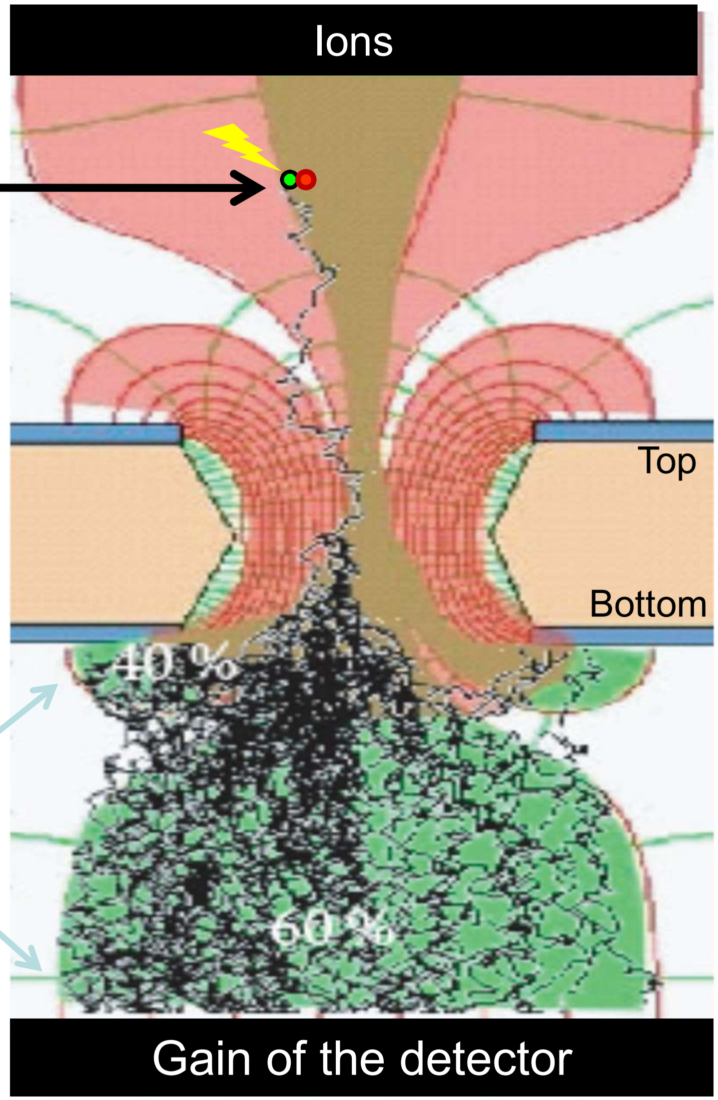
Electron-Ion pair

Drift field

GEM

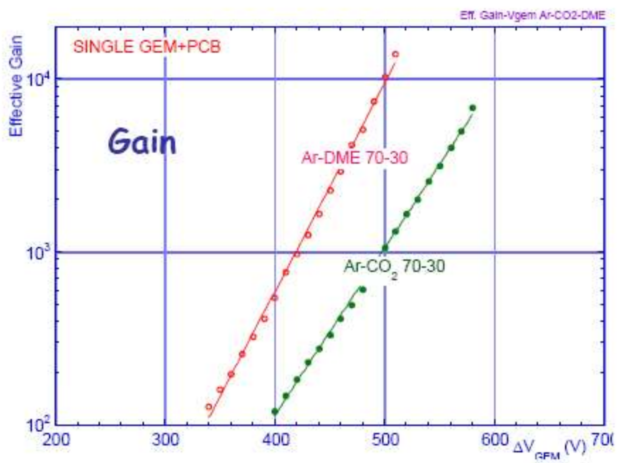
Electrons are shared between bottom GEM and anode

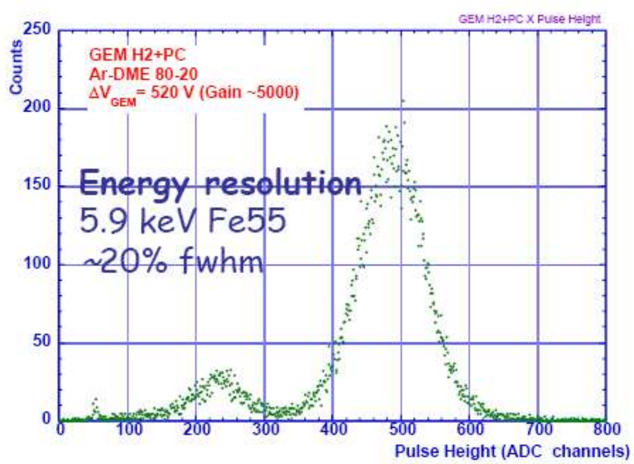
Induction field



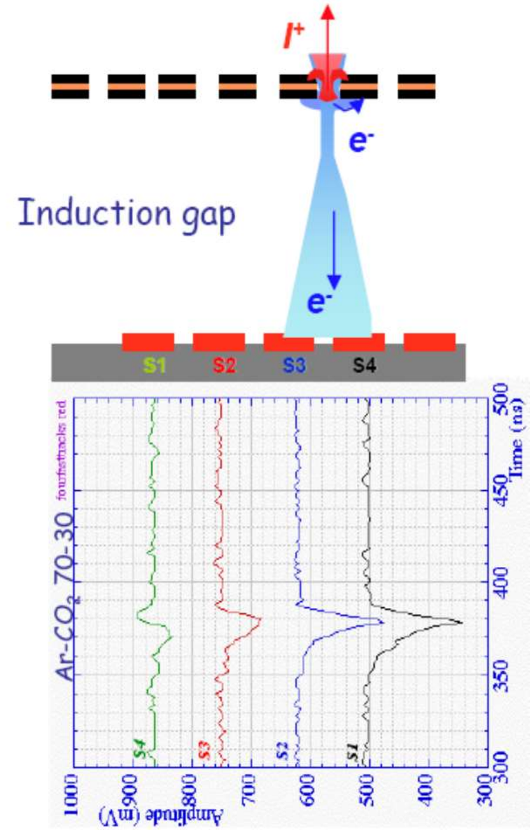

ANODE

# Single GEM performances




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




Electrons are collected on patterned readout board.
All readout electrodes are at ground potential.
Positive ions partially collected on the GEM electrodes

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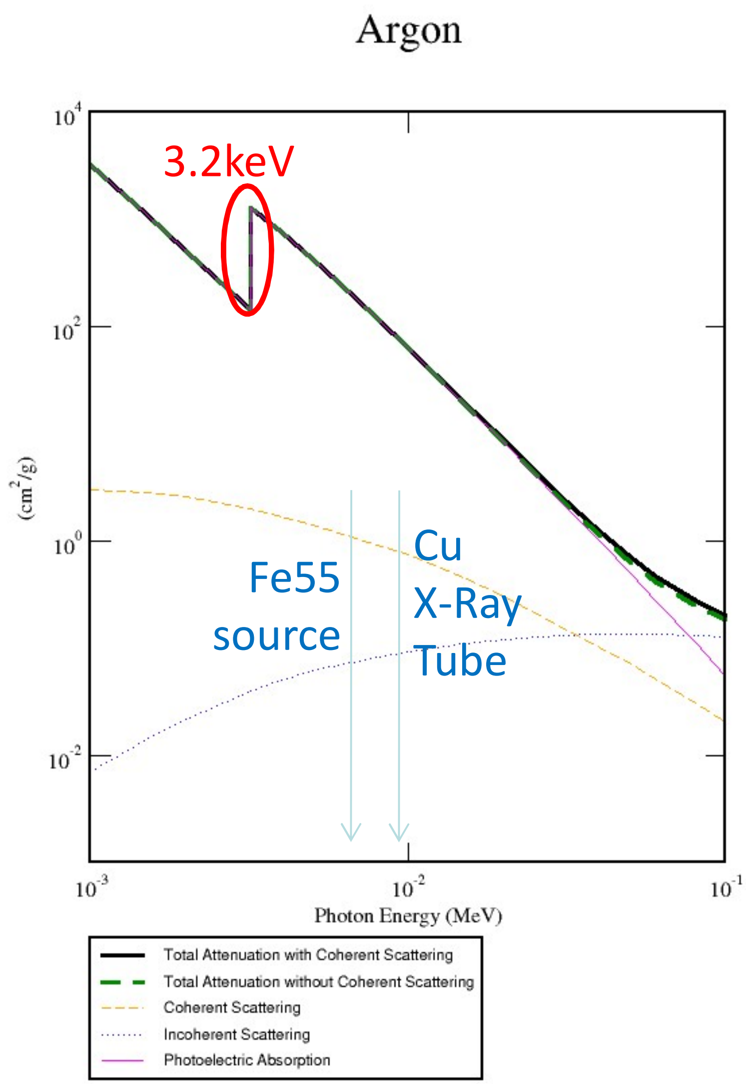
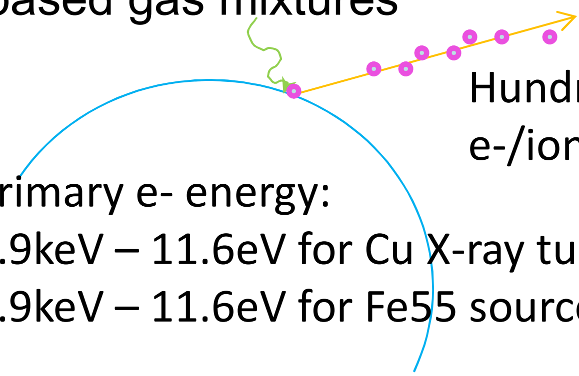
# Ionization of Gases: Neutral Particles

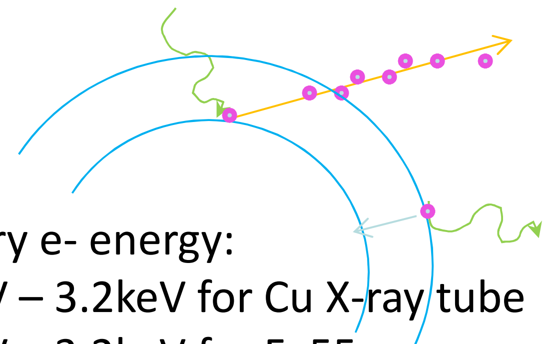
## X-Rays interaction with Ar-based gas mixtures



Hundreds of e-/ions pairs

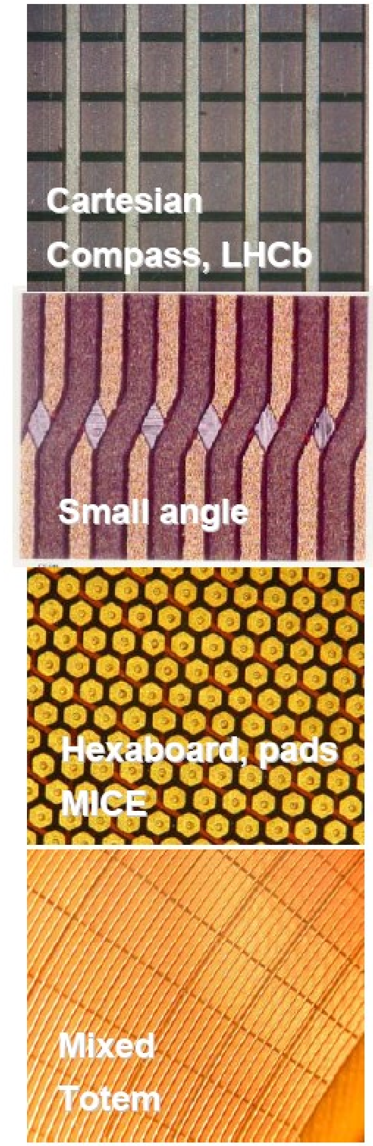
Primary e- energy:
8.9keV – 11.6eV for Cu X-ray tube
5.9keV – 11.6eV for Fe55 source



Primary e- energy:
8.9keV – 3.2keV for Cu X-ray tube
5.9keV – 3.2keV for Fe55 source

If the 3.2keV photon emitted during de-excitation escapes the detector volume, the energy is lost!!!

# Advantages

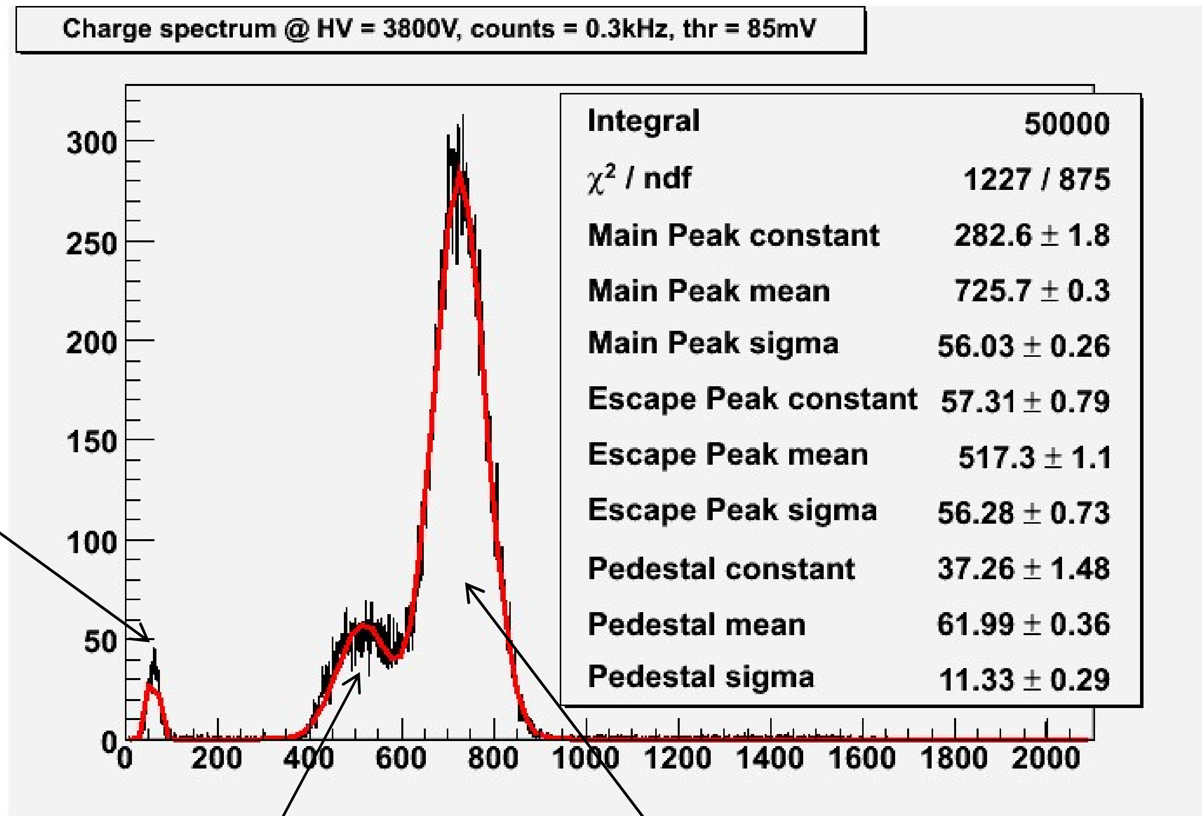



- Full decoupling of the charge amplification structure from the charge collection and readout structure. Both structures can be optimized independently

- Purely electronic signal → Fast signal without ion tails

- Possibility to use more GEM foils in cascade

# Pulse Height Spectrum




Pedestal (artificially produced)

Inner shell electrons signal with energy loss due to de-excitation photon escape

Outest shell electrons signal OR inner shell electrons but de-excitation photon did not escape

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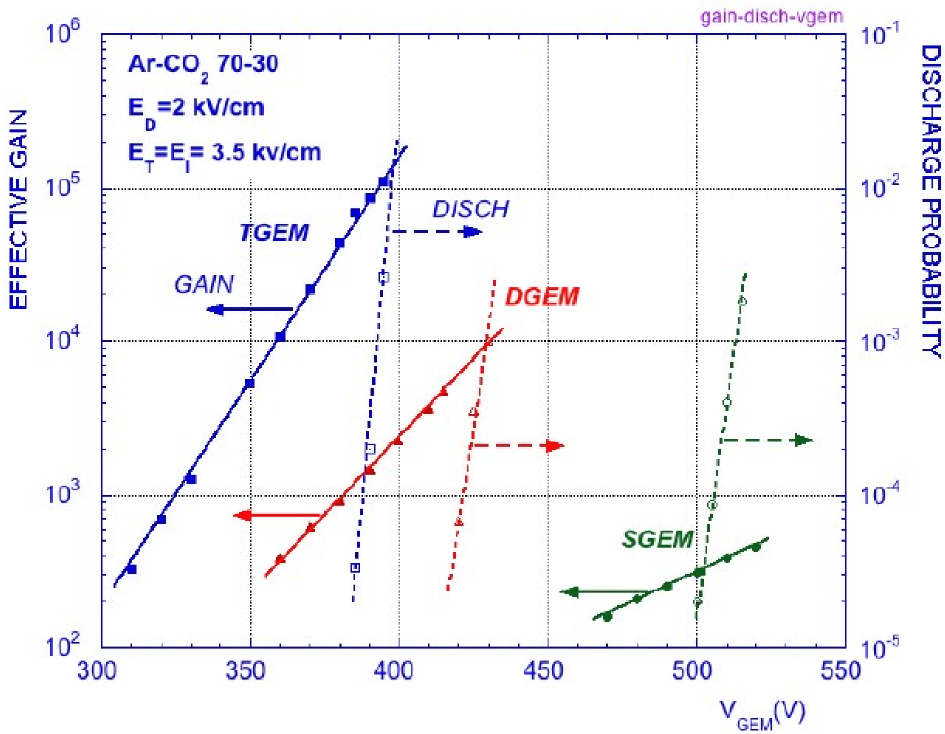
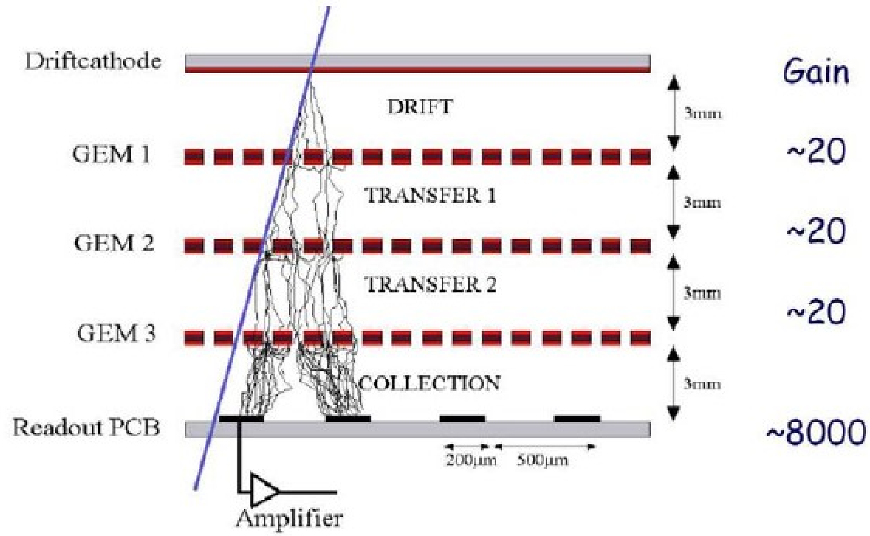
# Multi-GEM Detectors



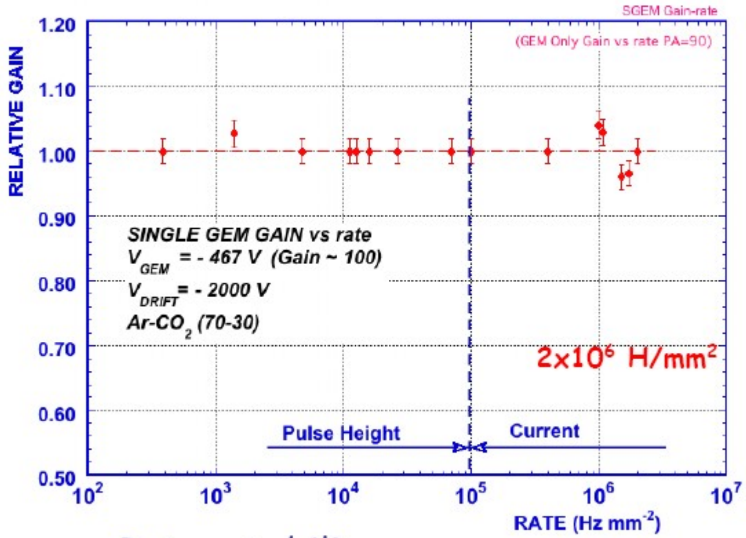

S. Bachmann et al Nucl. Instr. and Meth. A479(2002)294



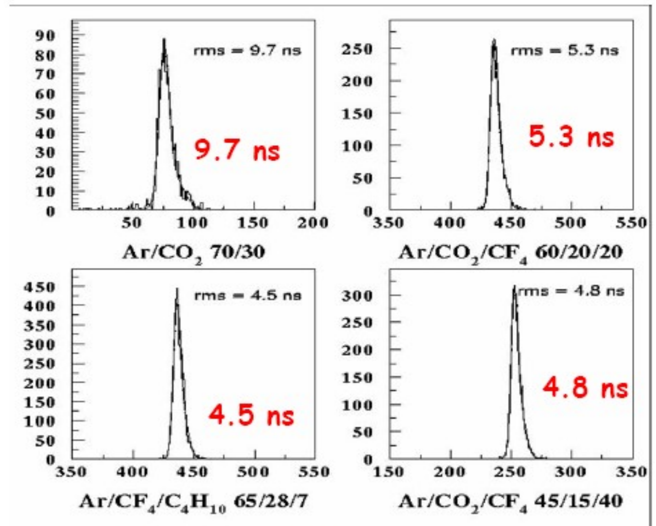

Multiple structures provide equal gain at lower voltage.

Discharge probability on exposure to α particles is strongly reduced

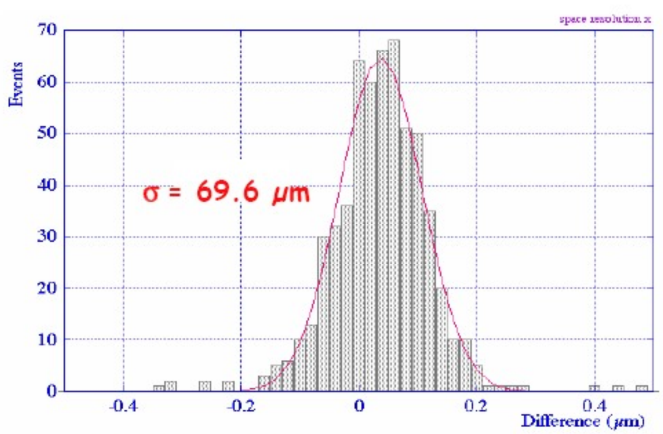
# GEM Performances



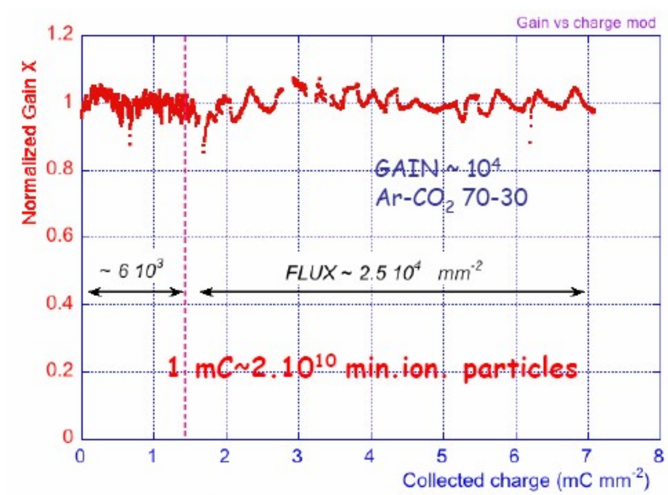

Rate capability




Time resolution




Space resolution




Ageing properties

# GEM Manufacturing

Rui De Oliveira
CERN-EST-DEM


50 μm Kapton
5 μm Cu both sides

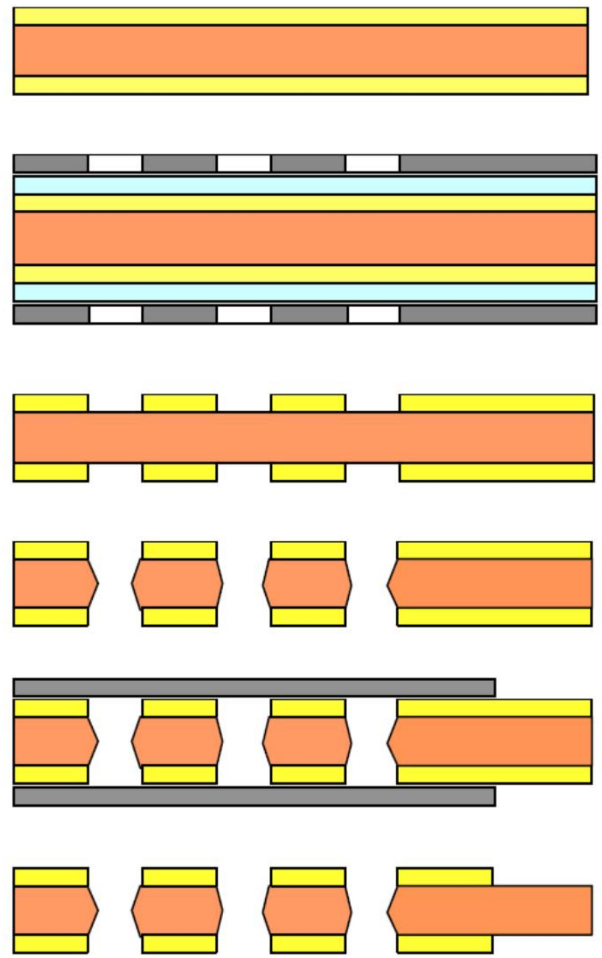
Photoresist coating,
masking and exposure
to UV light

Metal etching

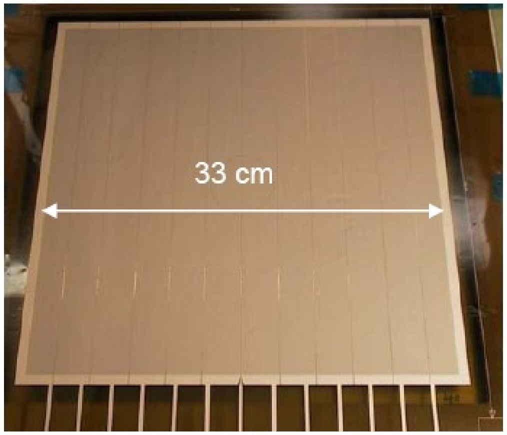
Kapton etching

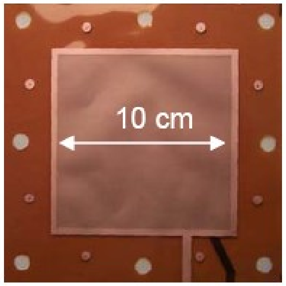
Second masking

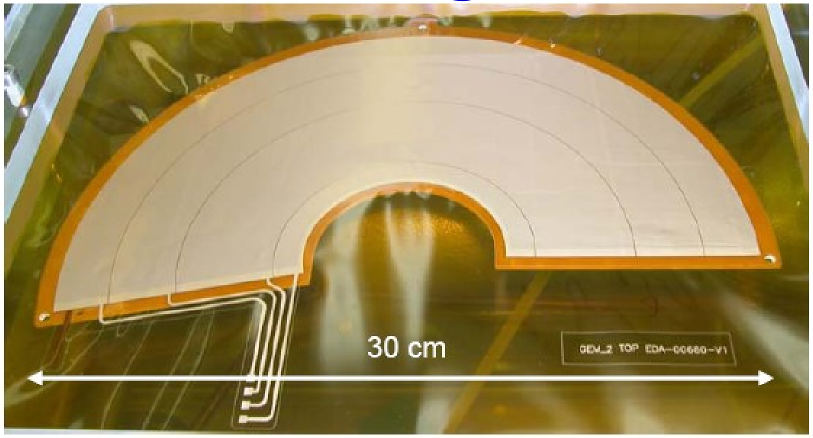
Metal etching
and cleaning

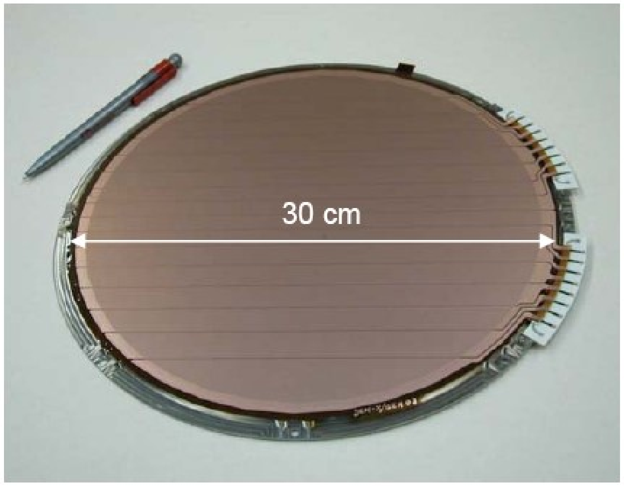


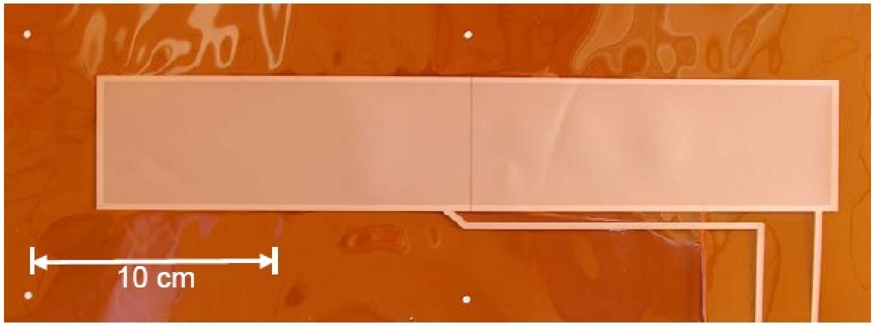
# GEM Manufacturing



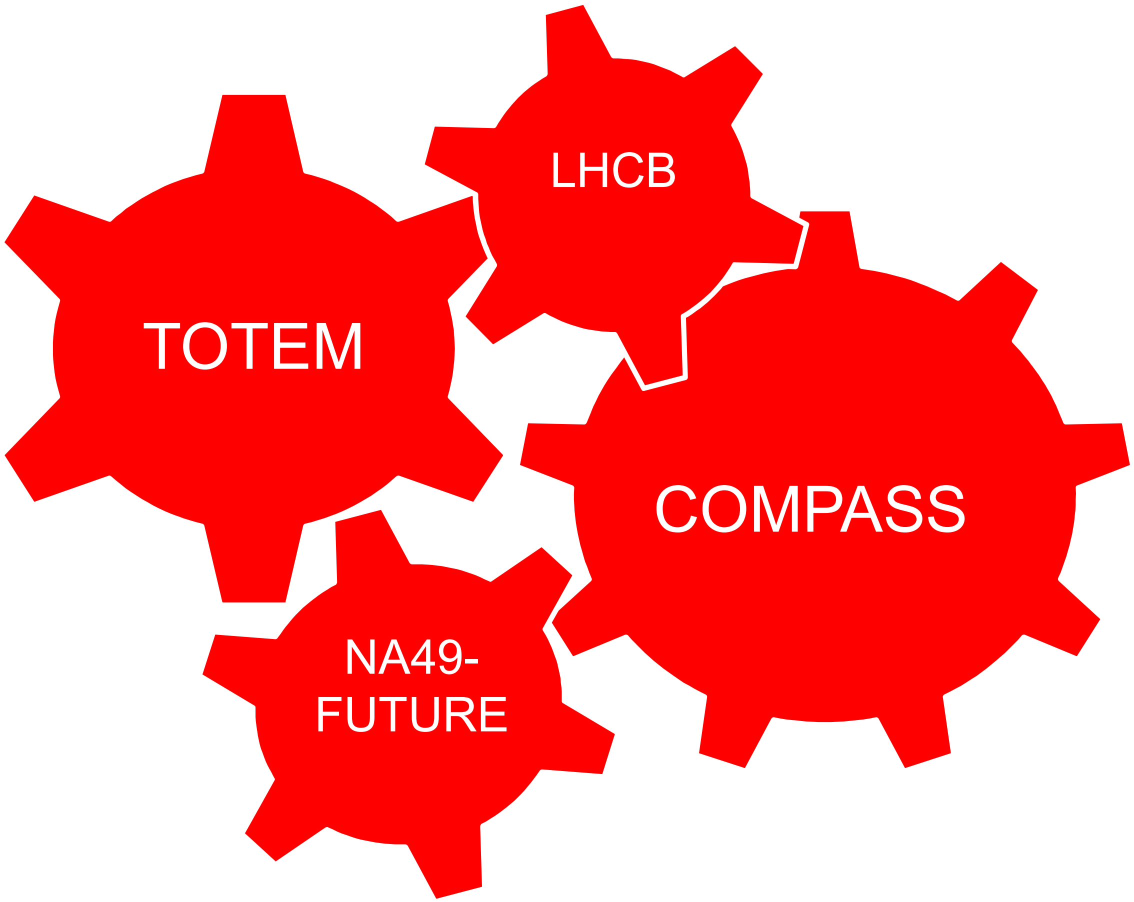




**Wide rage of shapes and sizes**

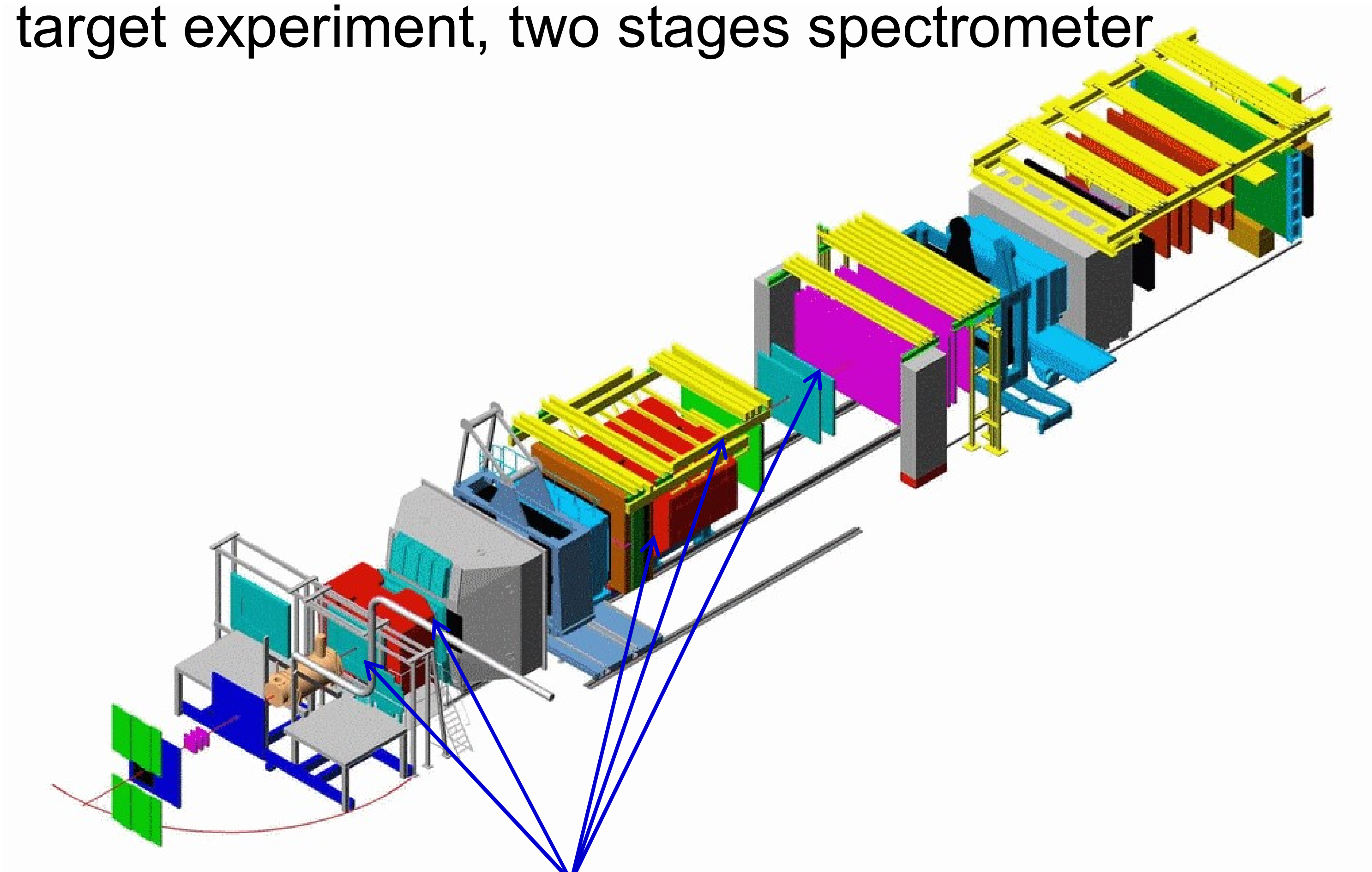
1500÷2000 foils manufactured at CERN
1 cm$^2$ to 1000 cm$^2$
30-200 $\mu$m holes, 50-300 $\mu$m pitch

# *Different HEP Applications*



# Compass Detector

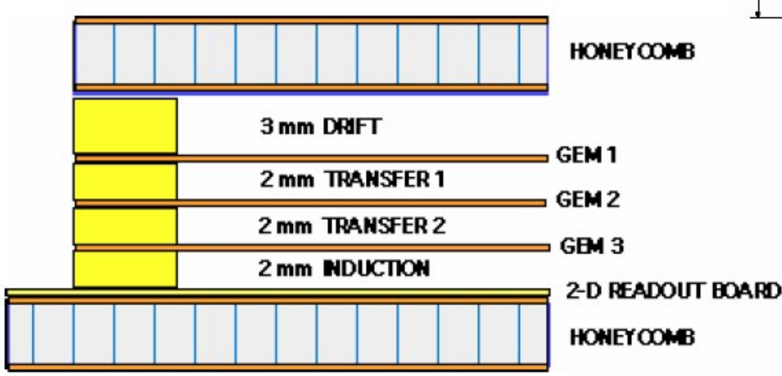
Fixed target experiment, two stages spectrometer

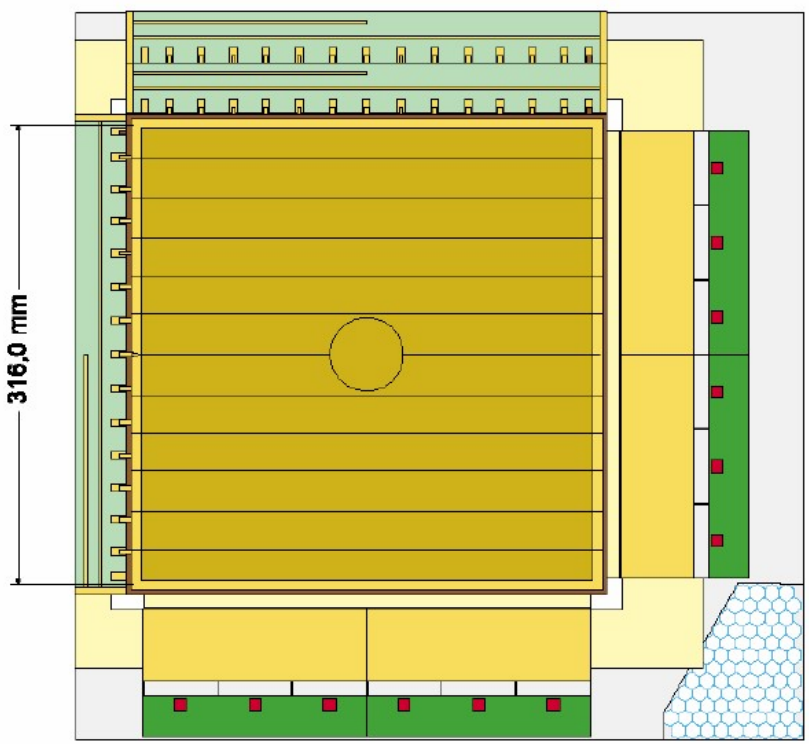


**22 Triple-GEM detectors**, mounted in pairs on 11 stations
Data taking since 2001

# COMPASS Triple GEM

- Active Area 30.7 x 30.7 $cm^2$
- 2-Dimensional Read-out with 2 x 768 Strips @ 400 $\mu m$ pitch
- 12+1 sectors GEM foils
- Central Beam Killer 5 cm Ø (remotely controlled)
- Total Thickness: 15 mm
- Honeycomb support plates
- Thickness in active area 0.7% $X_0$

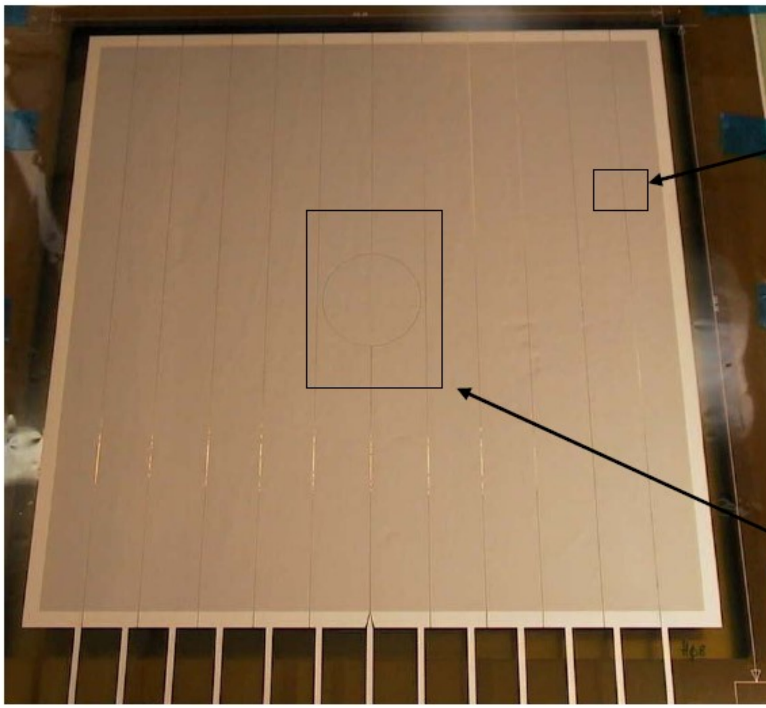


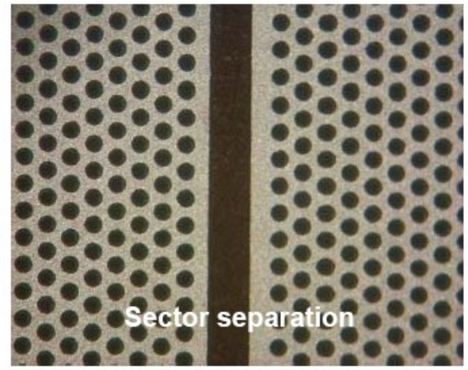



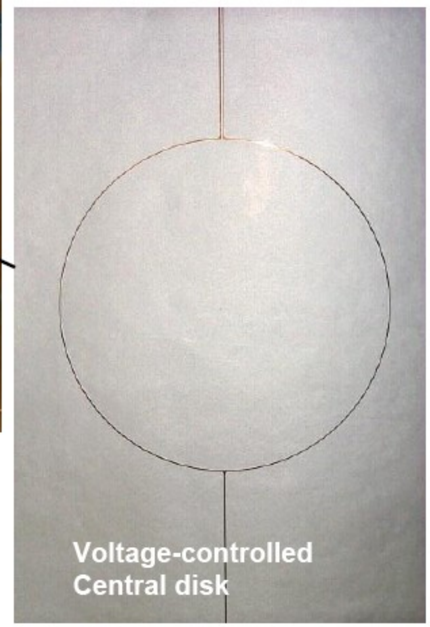

B. Ketzer et al, IEEE Trans. Nucl. Sci. NS-48(2001)1065
C. Altumbas et al, NIM A490(2002)177

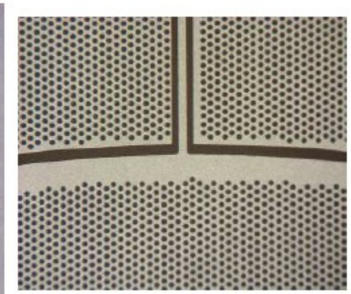
# COMPASS GEMs

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



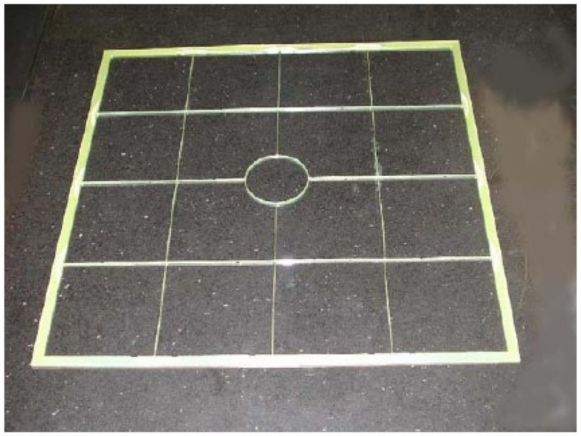


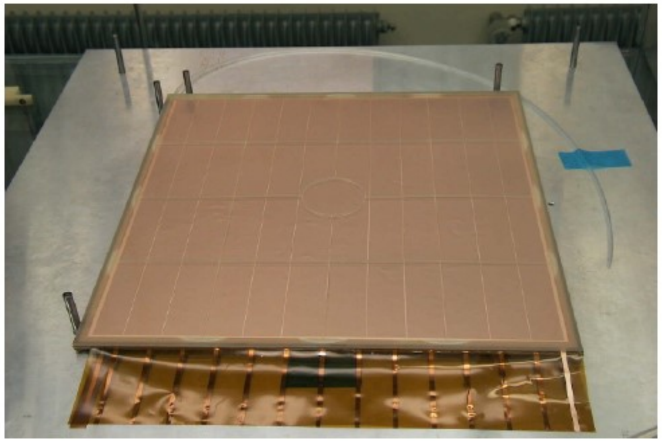



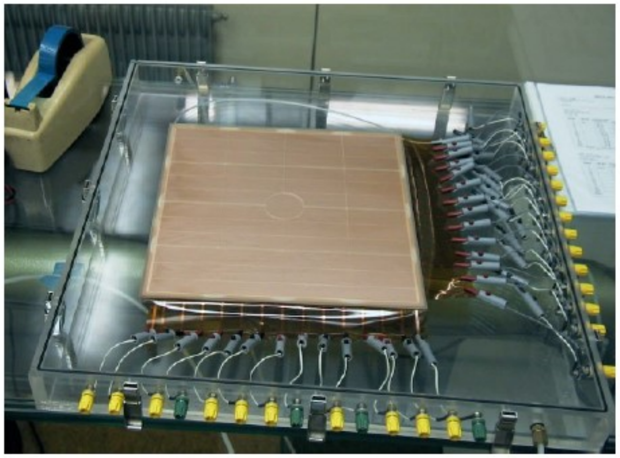
~ 100 foils produced
22 Triple-GEM detectors running

# COMPASS Triple GEM assembly

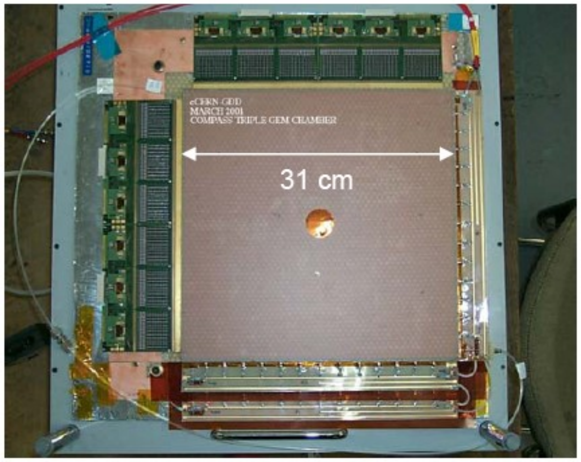


Spacer Grid: 2 mm thick fibreglass plate
with thin (~300 μm) gap-restoring strips





HV test of the foil after every step

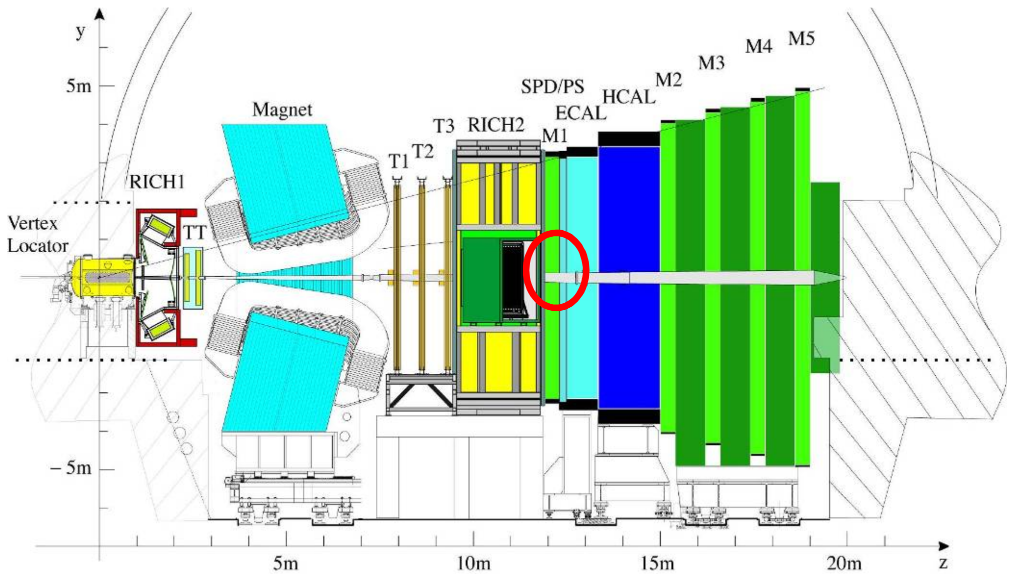



Final detector module

# *The LHCb GEM detector in M1R1*

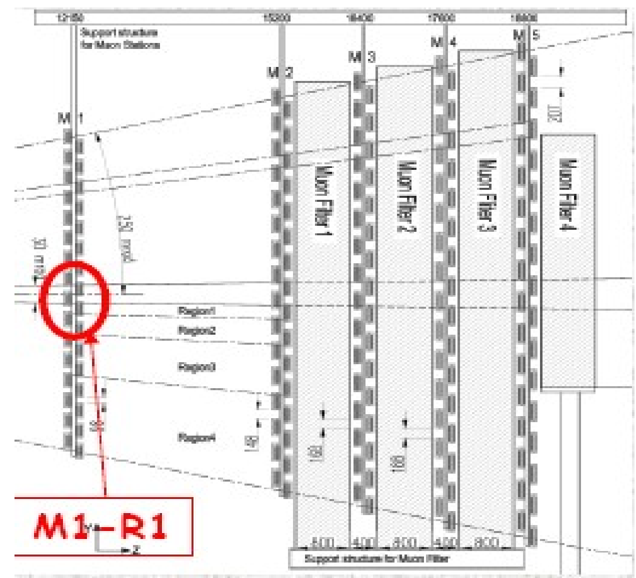
LHCb apparatus

~~CP~~ in B-meson system $B^0_d \rightarrow J/\Psi + K^0_S$ $B^0_S \rightarrow \mu^+\mu^-$




Muon detector:

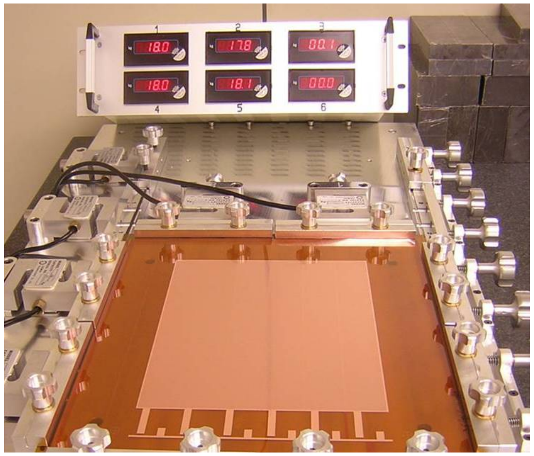
L0 high $p_T$ trigger + offline muon ID

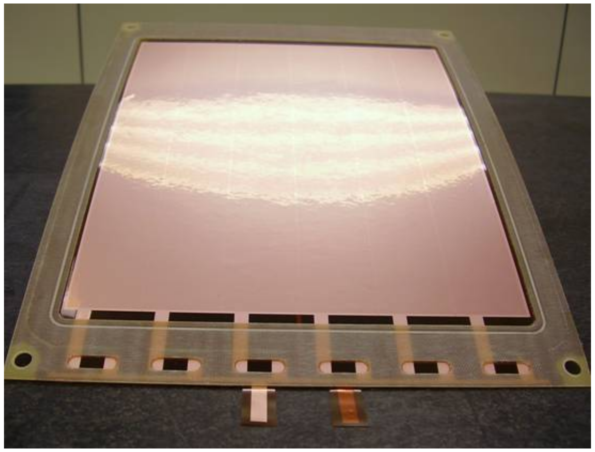



All stations are equipped with small gap MWPCs with the exception of M1R1 station (area ~ 1 $m^2$), that will be instrumented with triple-GEM detectors. About 20% of triggered muons will come from M1R1.

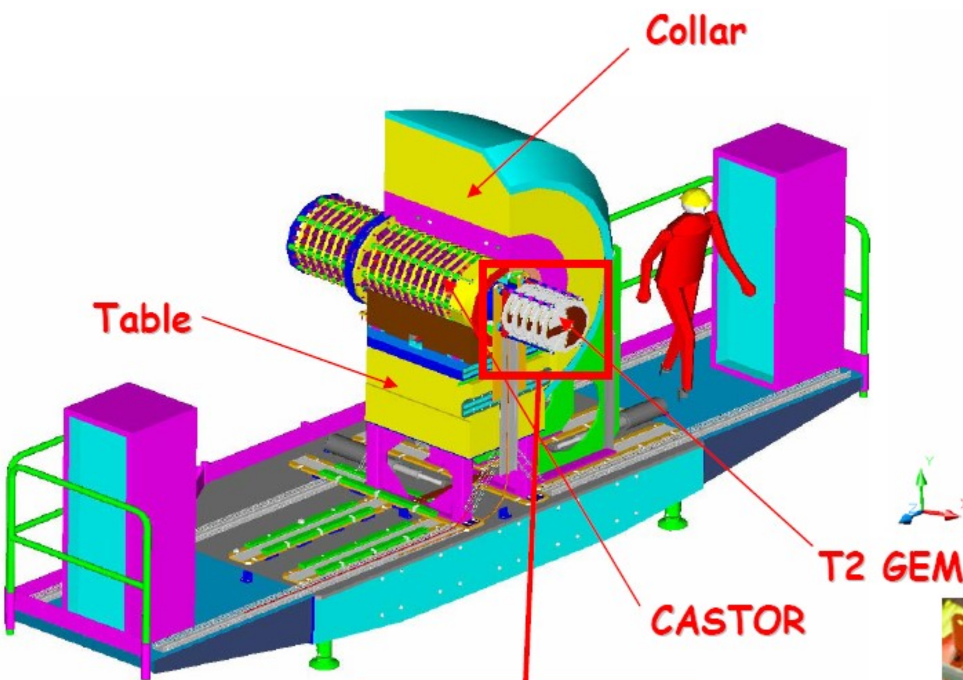
The M1R1 station is placed in front of the calorimeters and very close to the beam pipe, so that low material budget, high rate capability, radiation tolerant and high time performance detectors are required.

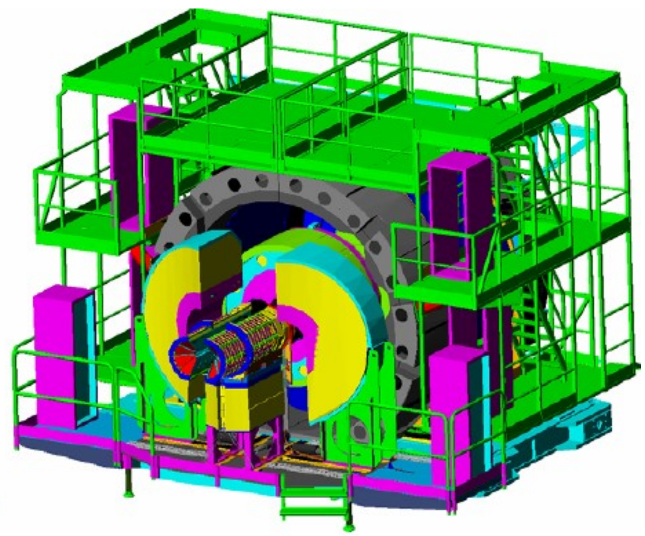
# *LHCb GEMs*

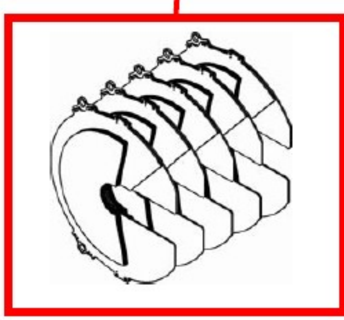


# Totem T2 Telescope

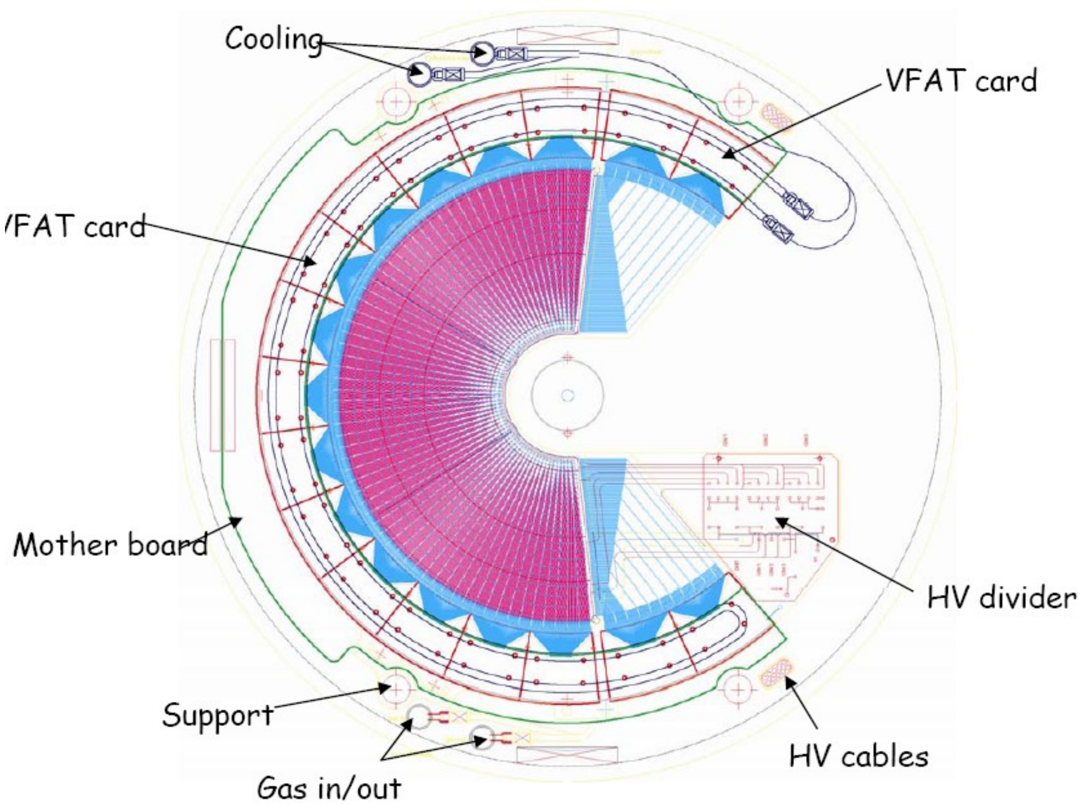


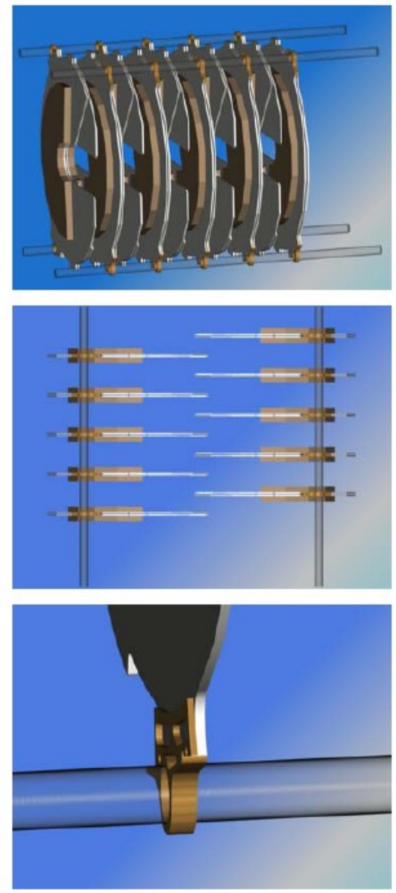





10 detector planes on each side of IP

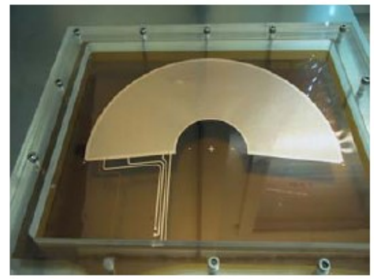
# TOTEM GEM Final Detector Module



# Totem GEM Detectors Components

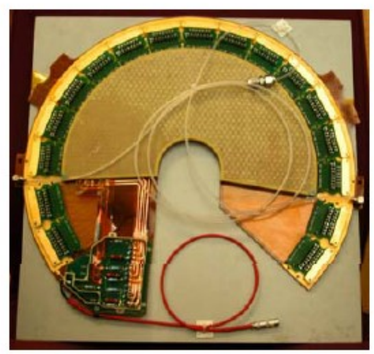
Readout board



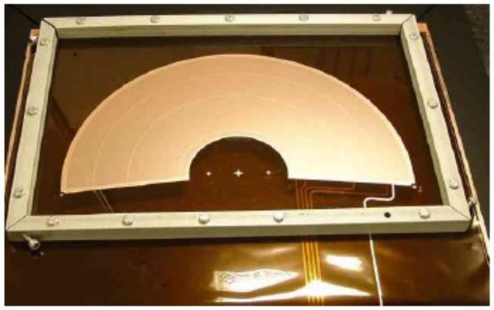
GEM foils

Frames, spacers and supports

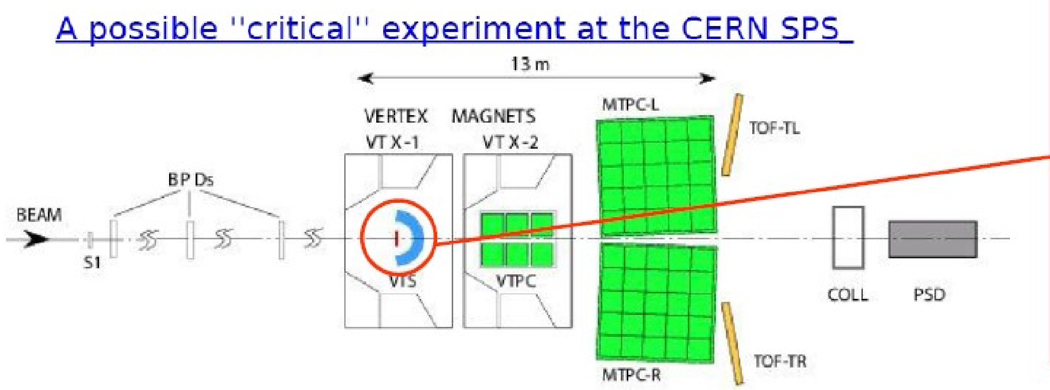
HV and electronics



# TOTEM GEM detector assembly



# Cylindrical GEM for NA49-Future

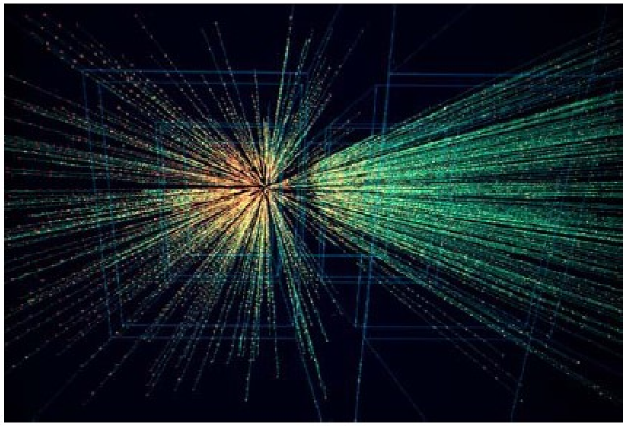



-a precise determination of an event centrality (**PSD**)

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

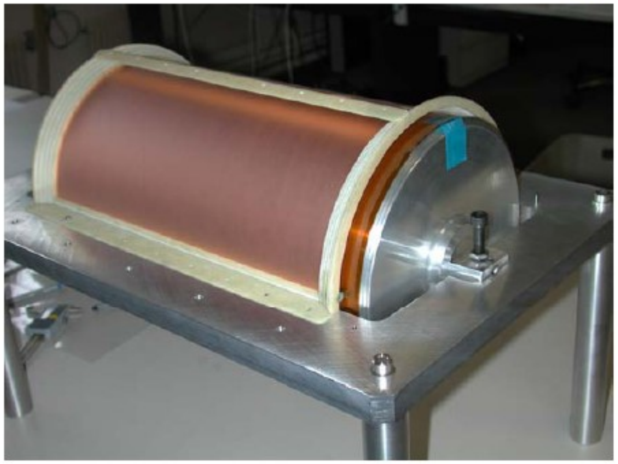
-a high event rate (**DAQ**)

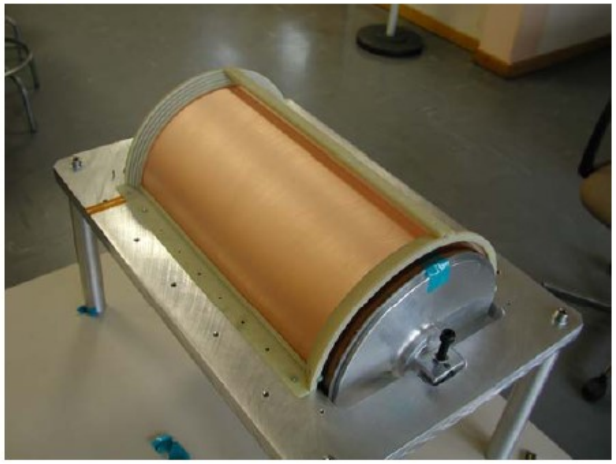
-high precision measurements of inclusive spectra
of identified hadrons (**TPCs+TOF**)

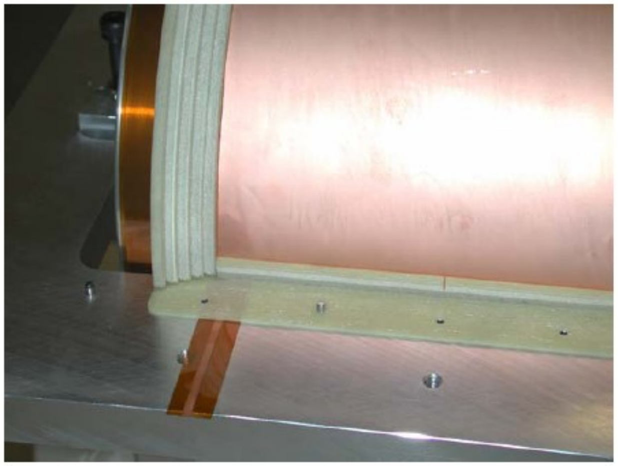


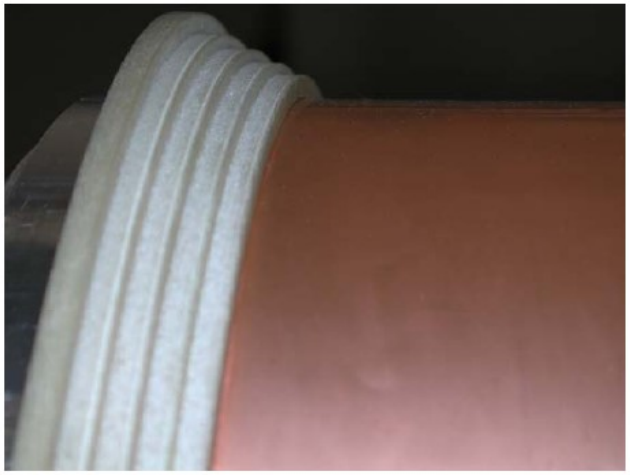
# Cylindrical GEM assembly

Drift Electrode



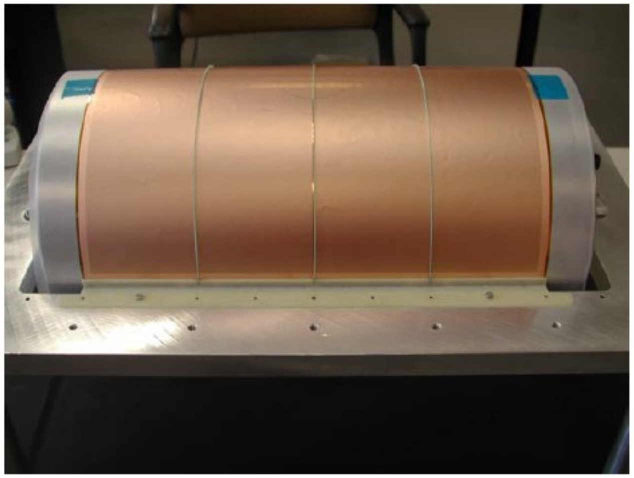


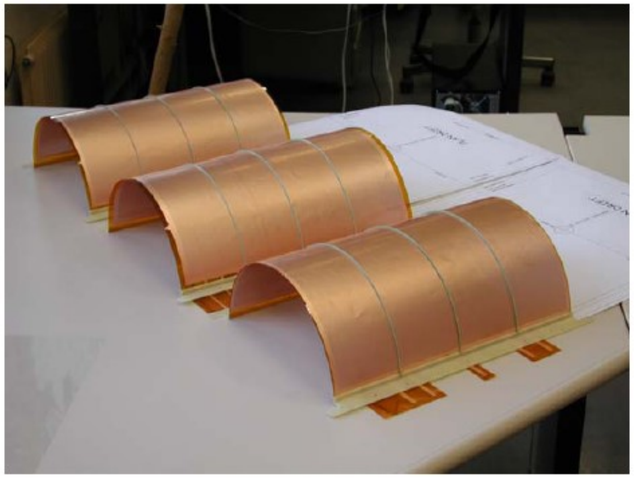


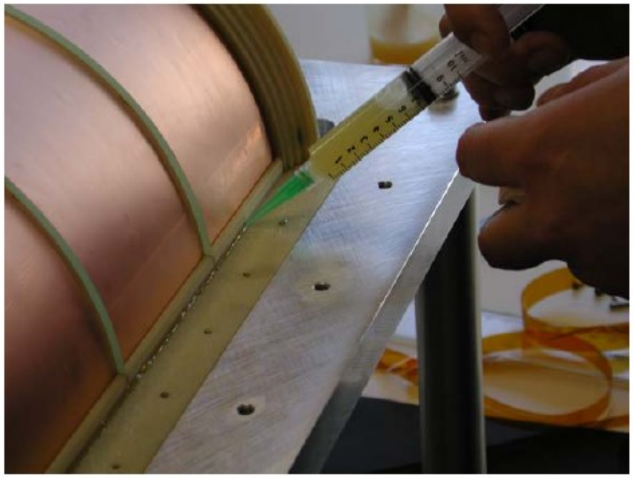


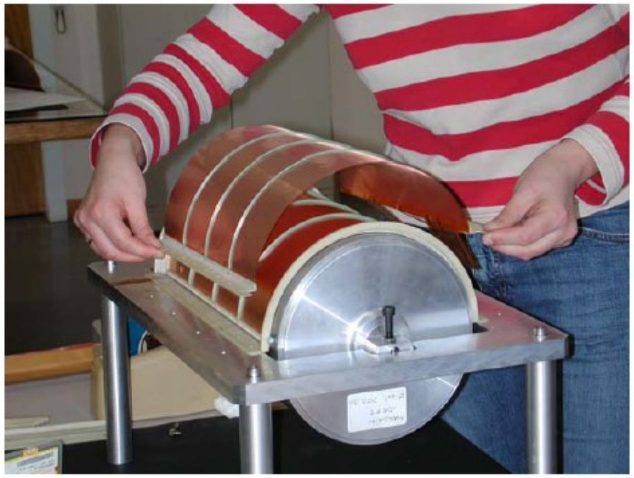
# Cylindrical GEM assembly

GEM foils



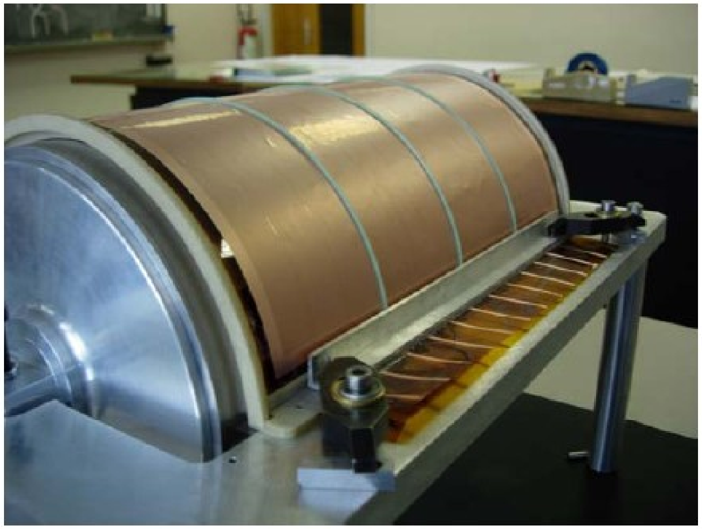


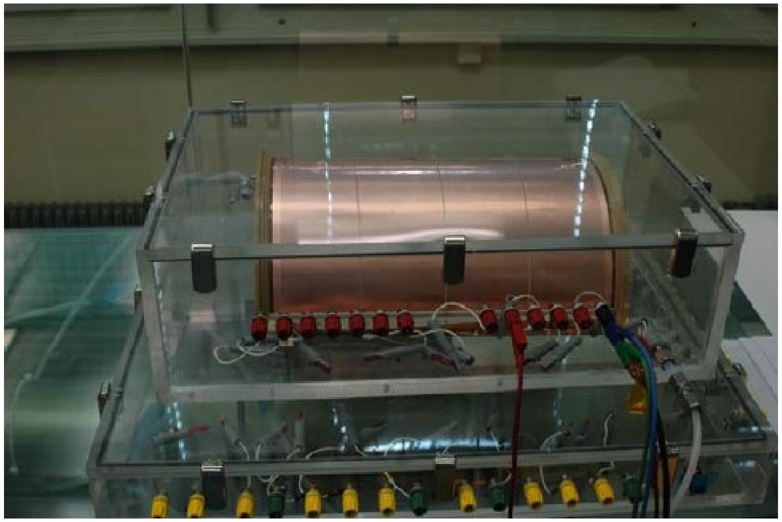


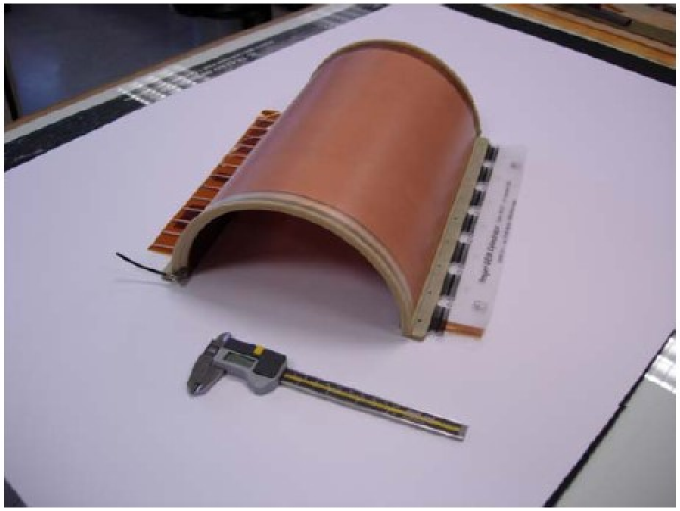


GAS DETECTOR DEVELOPMENT GROUP

# Cylindrical GEM assembly



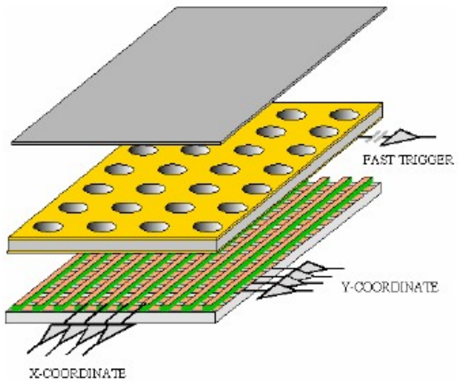


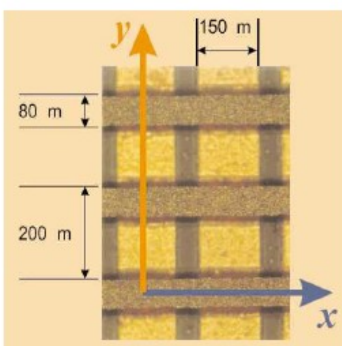


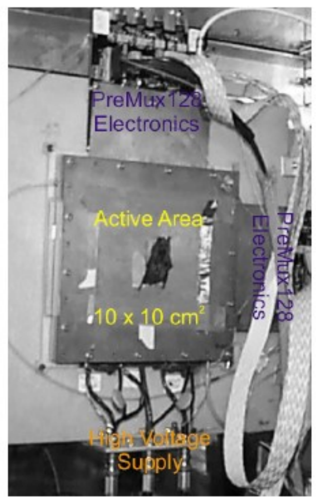
GAS DETECTOR DEVELOPMENT GROUP

# Others Applications

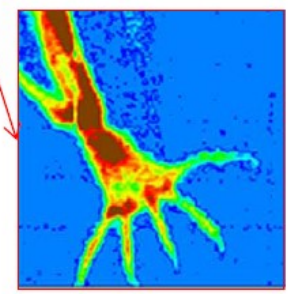
## Absorption radiography with GEM (8 keV X-rays)



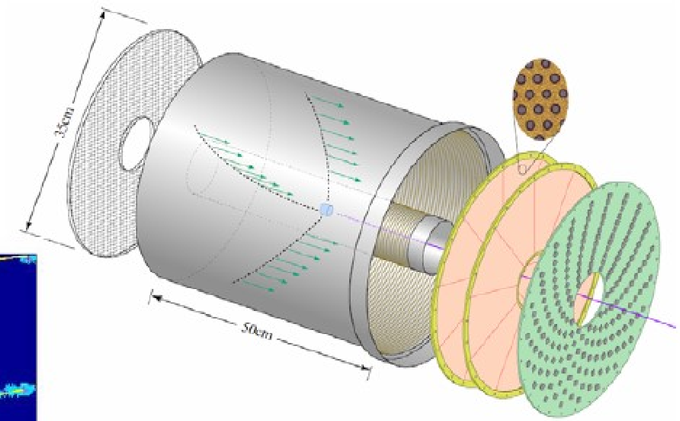




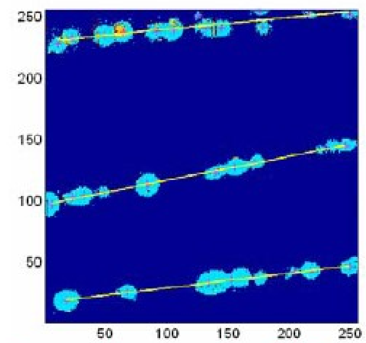
Trigger from the bottom electrode of GEM.

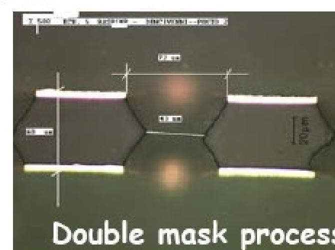
S. Bachmann et al, Nucl. Instr. and Meth. A471(2001)115

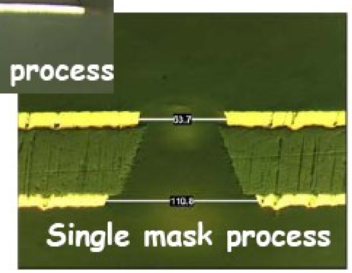
# Perspectives




- 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

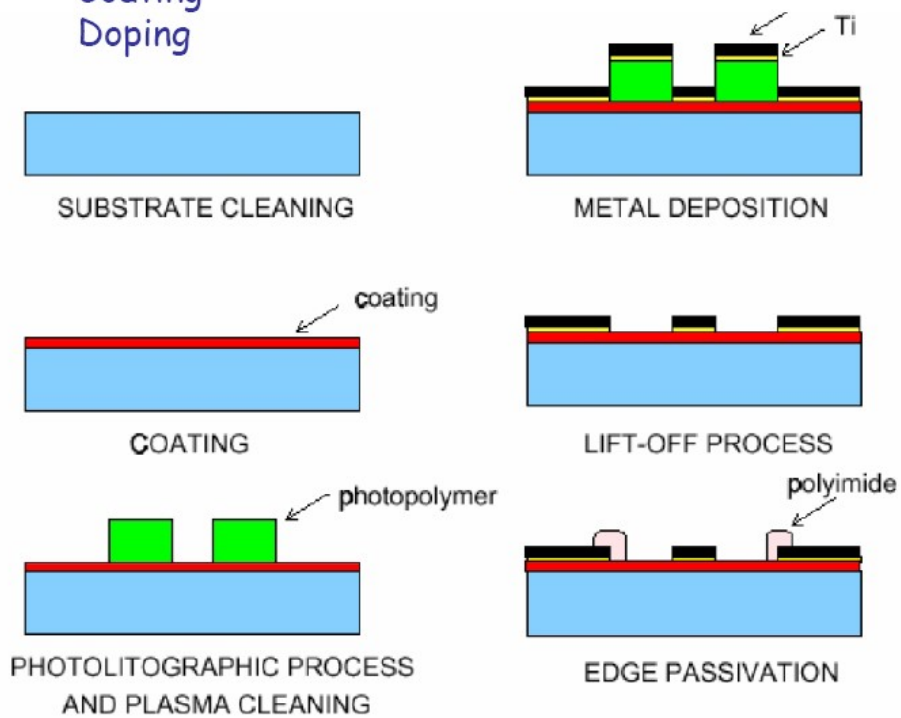

http://gdd.web.cern.ch/GDD/

# Spare Slides

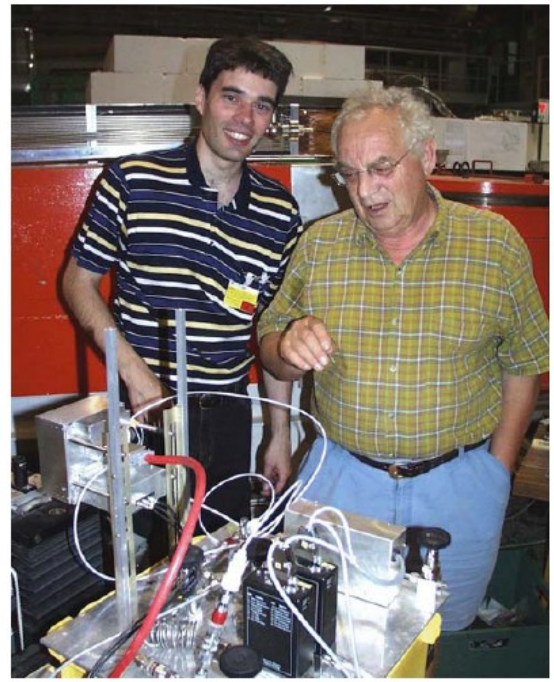
# MicroStrip Gas Chamber

**Semiconductor industry technology:**

Photolithography
Etching
Coating
Doping



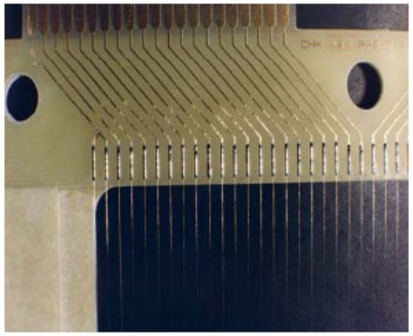

**Lift-off technique**

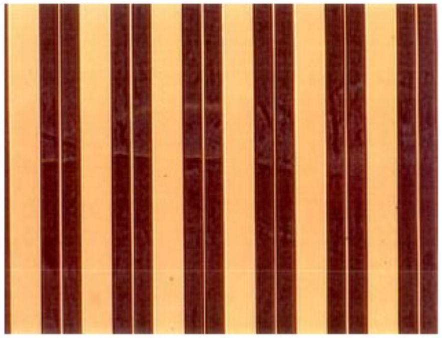


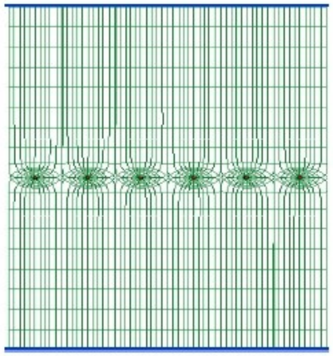
A. Oed
Nucl. Instr. and Meth. A263 (1988) 351.

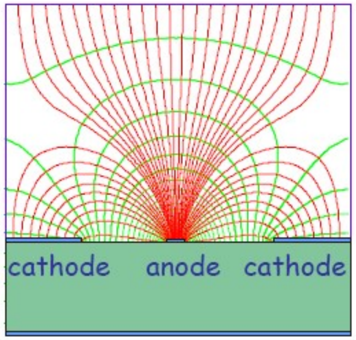
# MicroStrip Gas Chamber

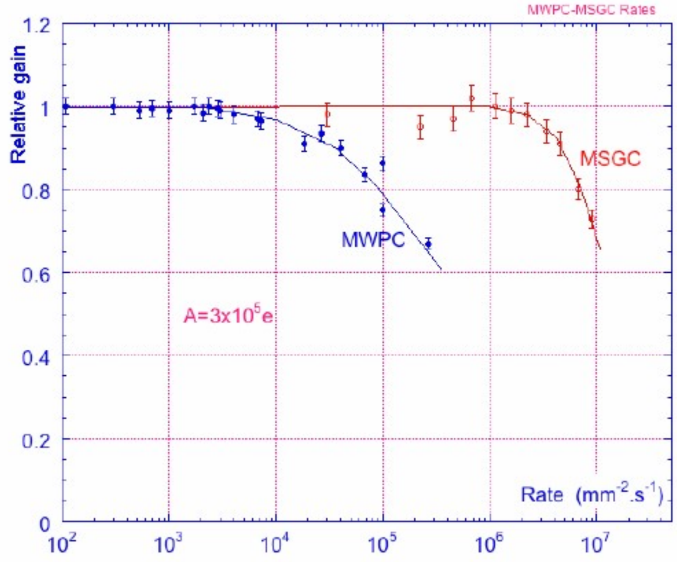
**MWPC** **MSGC**










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

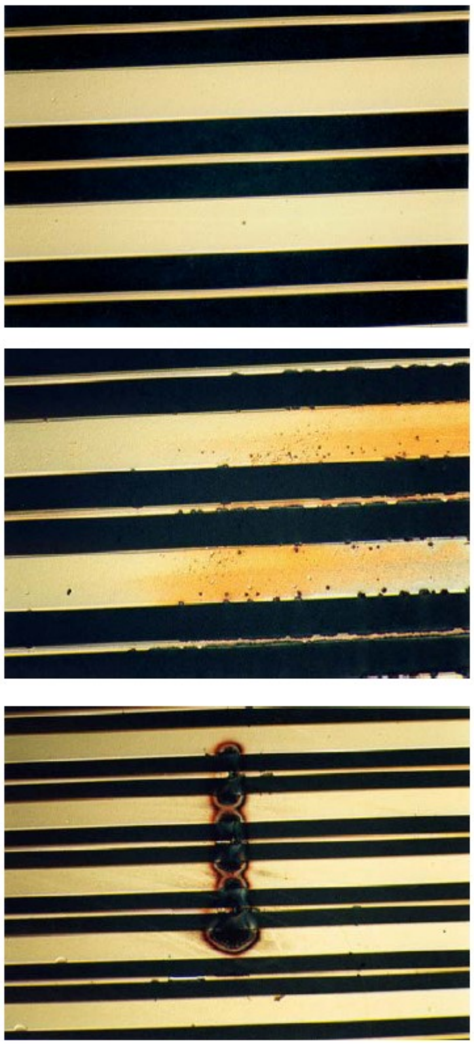
Typical distance between anodes 200 μm thanks to semiconductor etching technology

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

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

GAS DETECTOR DEVELOPMENT GROUP

# MicroStrip Gas Chamber



**Surface charging**

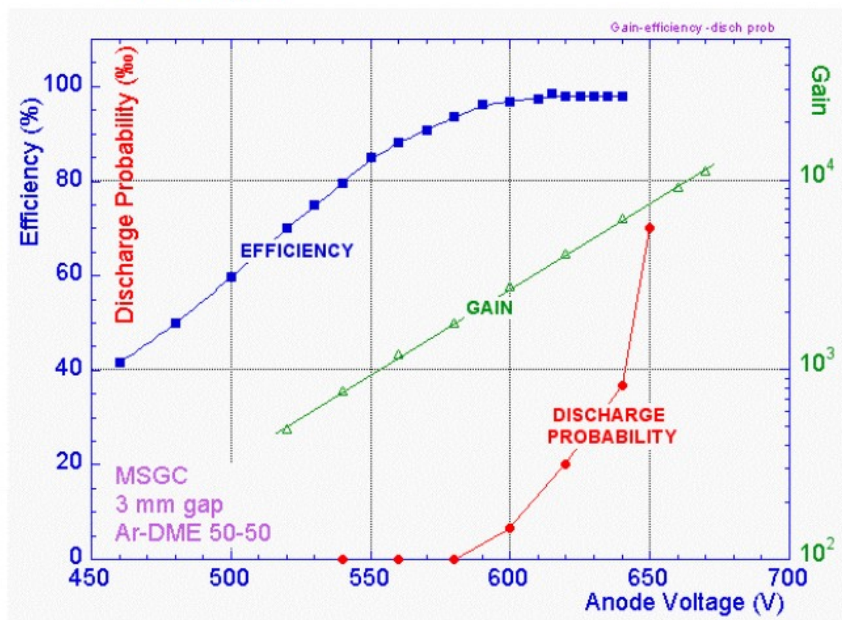
Bulk resistivity of the support material

Surface modification by doping or deposition

**Ageing**

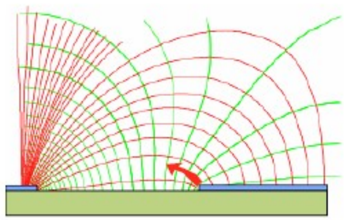
Gas, Gas system, MSGC support, Construction material

**Discharges**

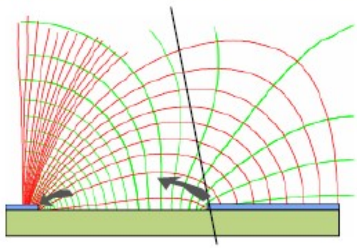


# *MicroStrip Gas Chamber*

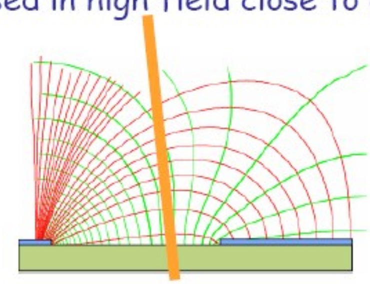
## MSGC: Discharge mechanisms



Field emission from the cathode edge

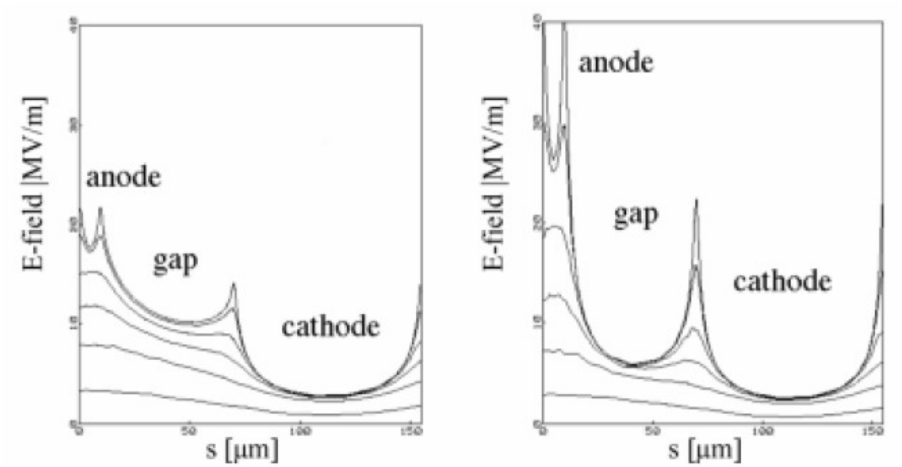


Charge pre-amplification for ionization released in high field close to cathode



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