Gem Detectors
General Principles

Danilo Domenici – LNF

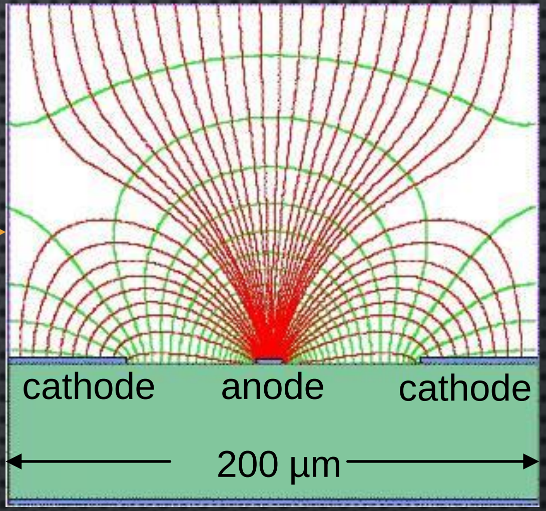
Frascati Detector School | LNF 21-23 March 2018

Micro-Pattern Gas Detectors

need to go beyond MWPC rate-capability limit

going from MILLI to MICRO electrode structure

first tentatives too fragile against discharges



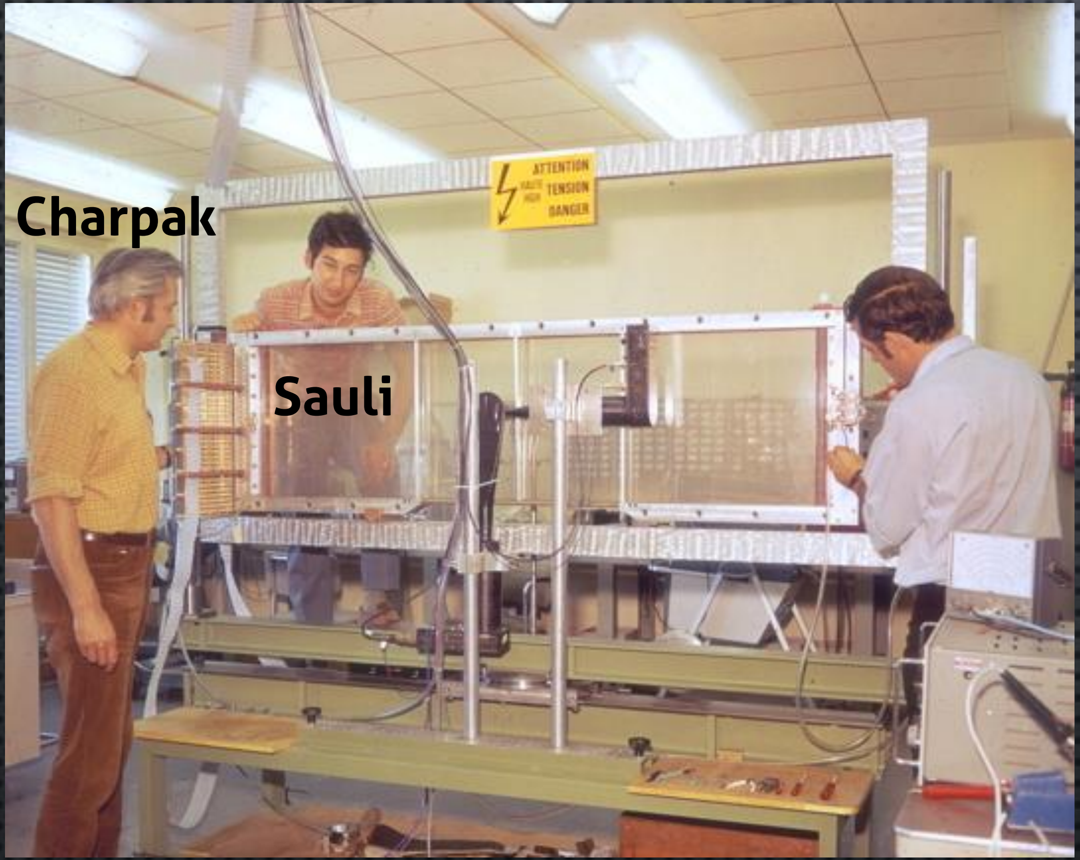
MSGC
Micro-Strip Gas Chamber
A. Oed, NIM A263(1988)351

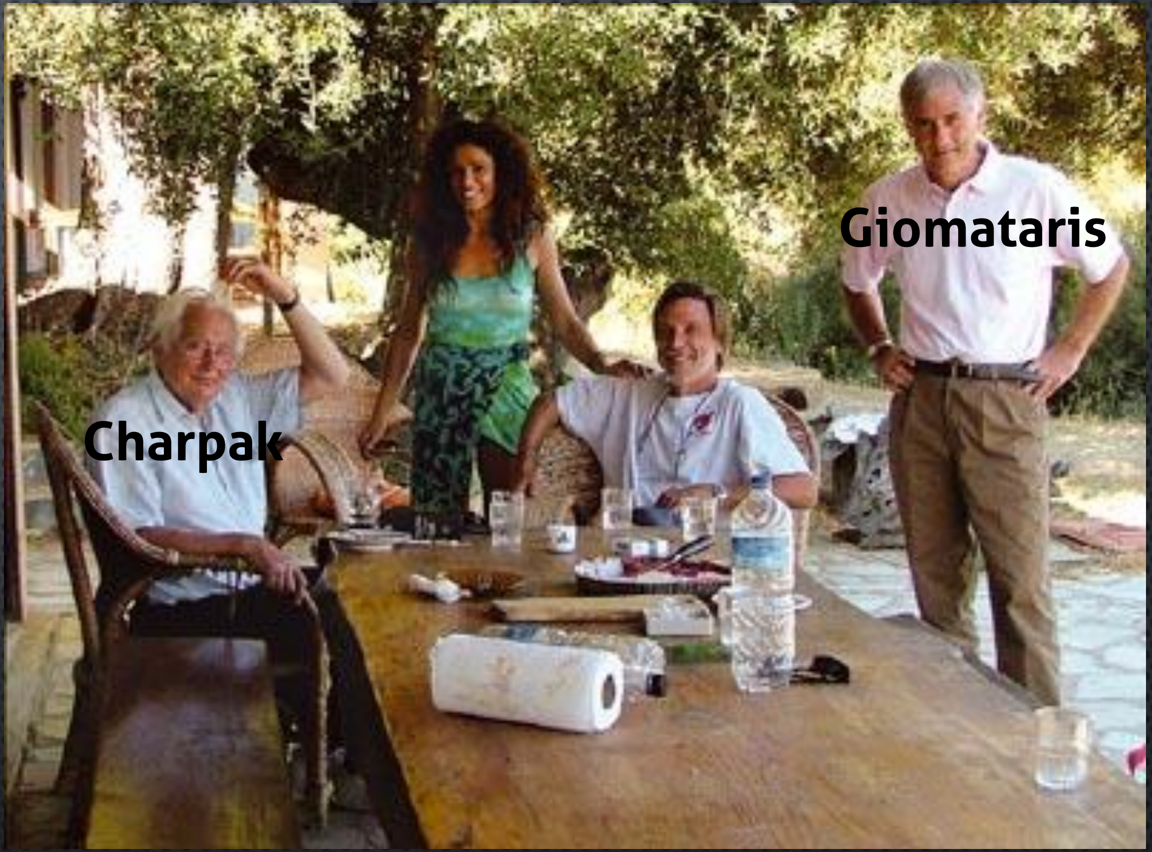
Micro-Pattern Gas Detectors
MPGD

Gas Electron Multiplier
GEM
F.Sauli, NIM A386(1997) 531

Micro-Mesh Gas detector
Micromegas
Y.Giomataris, NIM A376(1996) 26

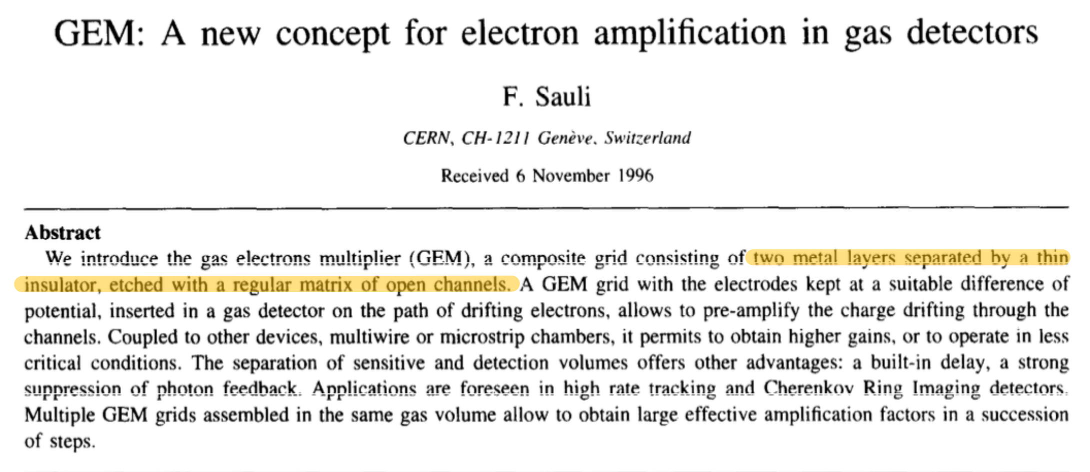
Georges Charpak's Legacy





Charpak (1924-2010) awarded with the Nobel Prize in 1992
for the developing of the Multi-Wire Proportional Chamber

GEM Electrode Structure



GEM: A new concept for electron amplification in gas detectors

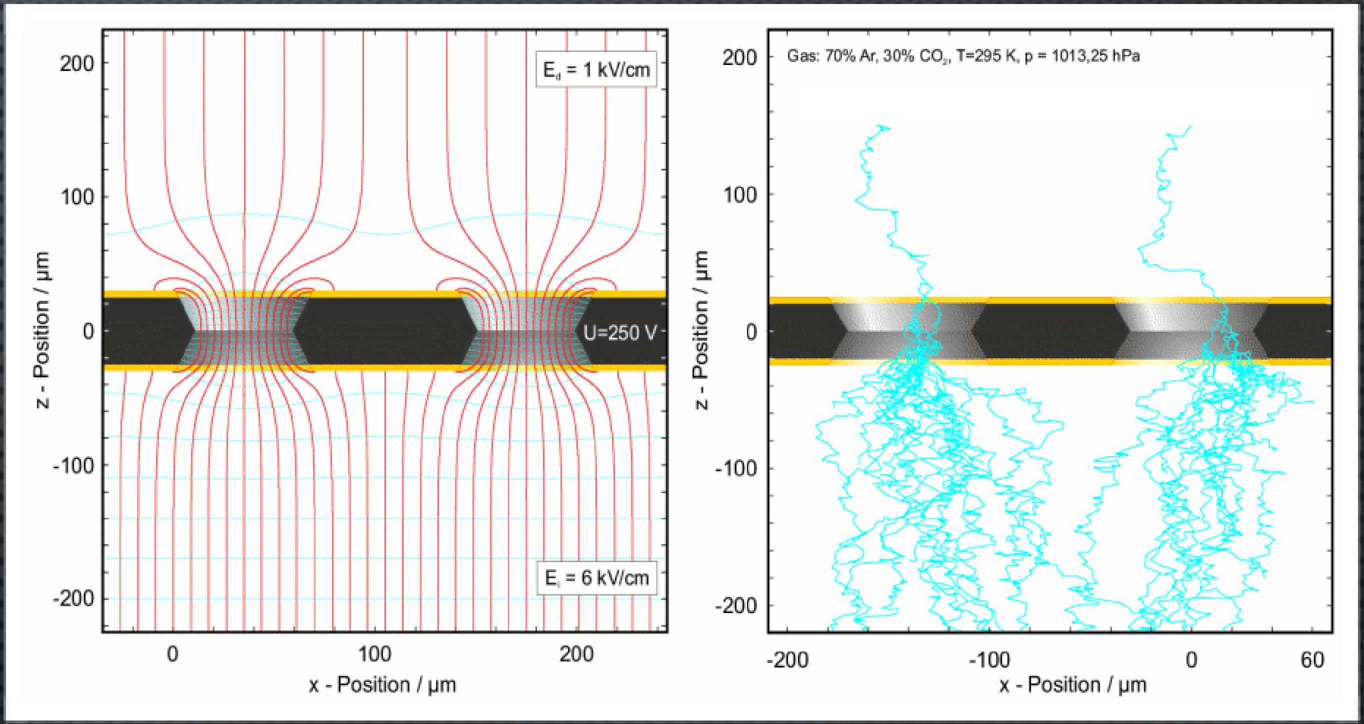
F. Sauli

CERN, CH-1211 Genève, Switzerland

Received 6 November 1996

Abstract

We introduce the gas electrons multiplier (GEM), a composite grid consisting of two metal layers separated by a thin insulator, etched with a regular matrix of open channels. A GEM grid with the electrodes kept at a suitable difference of potential, inserted in a gas detector on the path of drifting electrons, allows to pre-amplify the charge drifting through the channels. Coupled to other devices, multiwire or microstrip chambers, it permits to obtain higher gains, or to operate in less critical conditions. The separation of sensitive and detection volumes offers other advantages: a built-in delay, a strong suppression of photon feedback. Applications are foreseen in high rate tracking and Cherenkov Ring Imaging detectors. Multiple GEM grids assembled in the same gas volume allow to obtain large effective amplification factors in a succession of steps.



Typical GEM foil geometry

50 µm thick Kapton

5 µm thick Copper cladding on both faces

70 µm diameter holes at 140 µm pitch

Typical GEM operating parameters

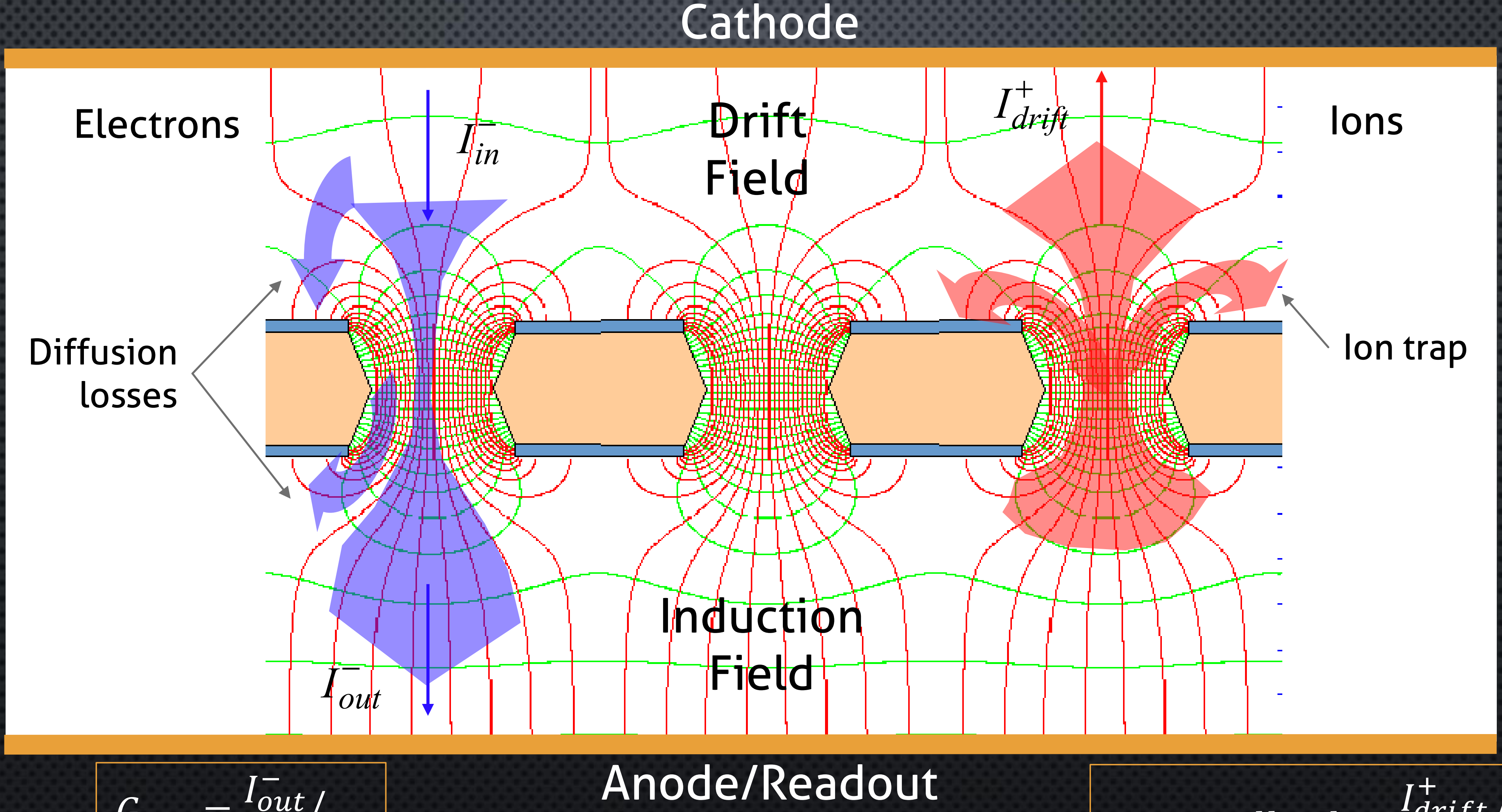
300 V bias between faces

80 kV/cm electric field in the hole

1000÷10000 gain

5000/cm^2 independent proportional counters

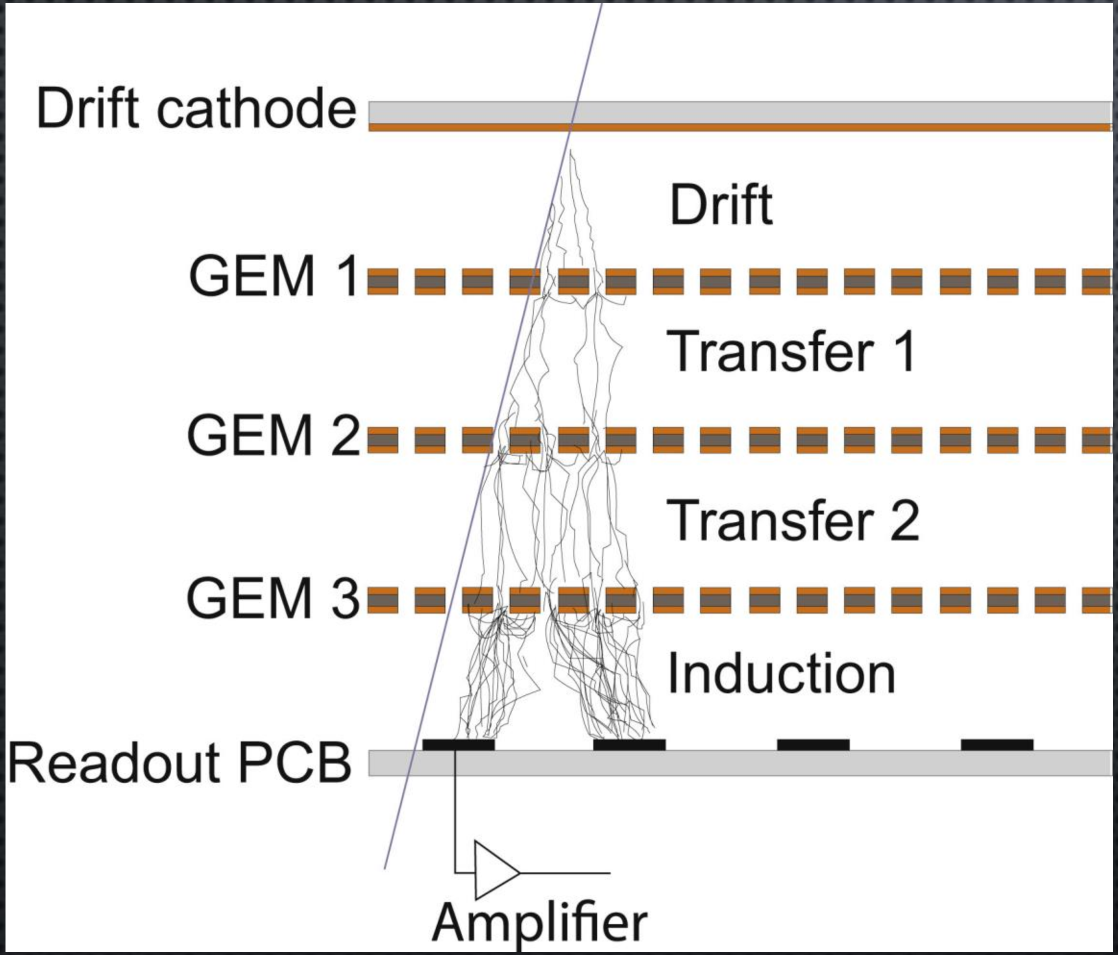
GEM Operation Principle



$$G_{eff} = I_{out}^{-} / I_{in}^{-}$$

$$Ion\ Feedback = I_{drift}^{+} / I_{out}^{-}$$

GEM Detector Scheme



triple-GEM emerged as most common scheme compromise between assembling complexity and discharge robustness

5 electrodes

- cathode
- 3 GEMs
- anode

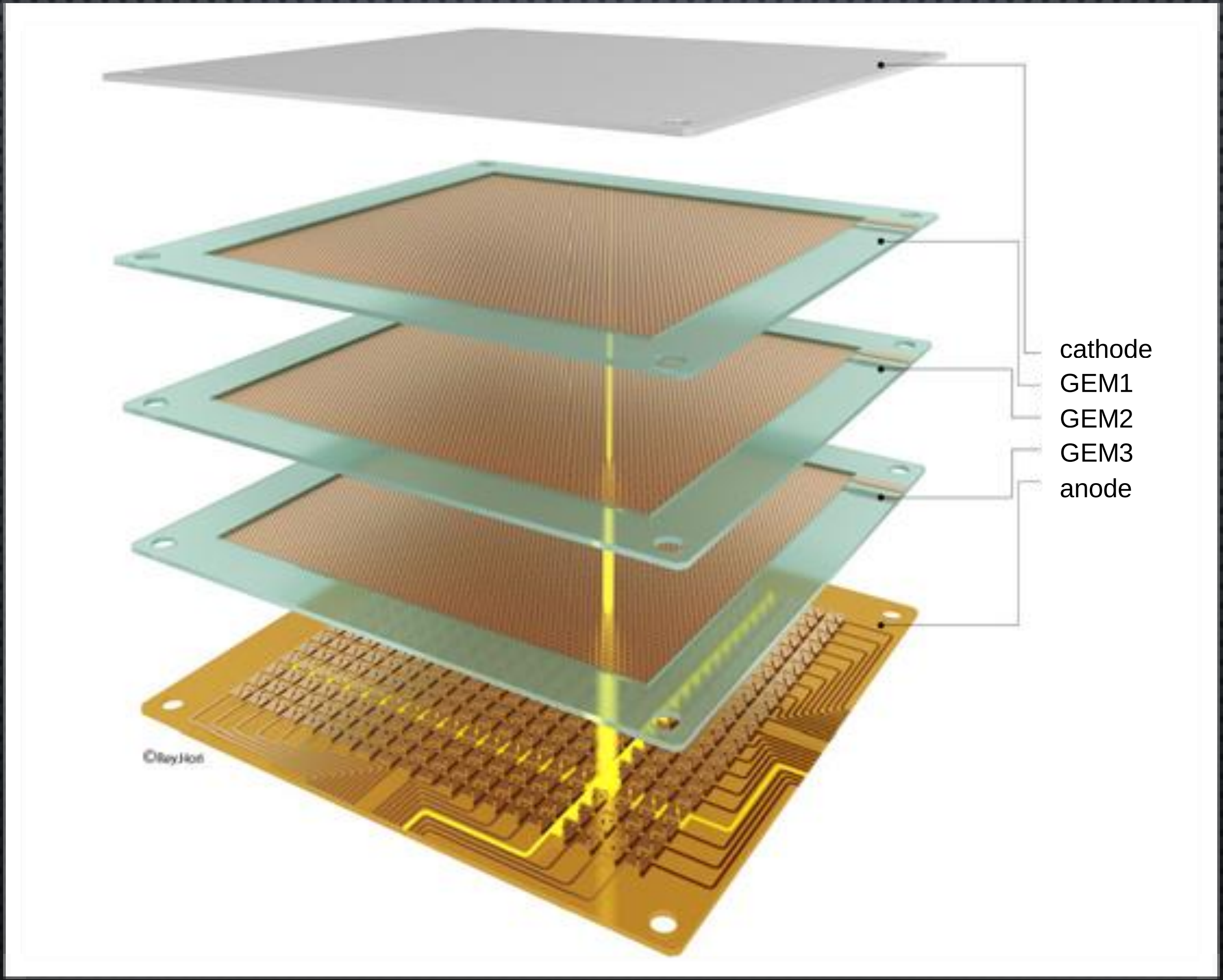
4 gaps/fields

- drift
- transfer1
- transfer2
- induction

each field must be set to optimize effective gain

$$\boxed{G_{eff} = \varepsilon_{drift} \times G_1 \times \varepsilon_{tr1} \times G_2 \times \varepsilon_{tr2} \times G_3 \times \varepsilon_{ind}}$$

Triple-GEM



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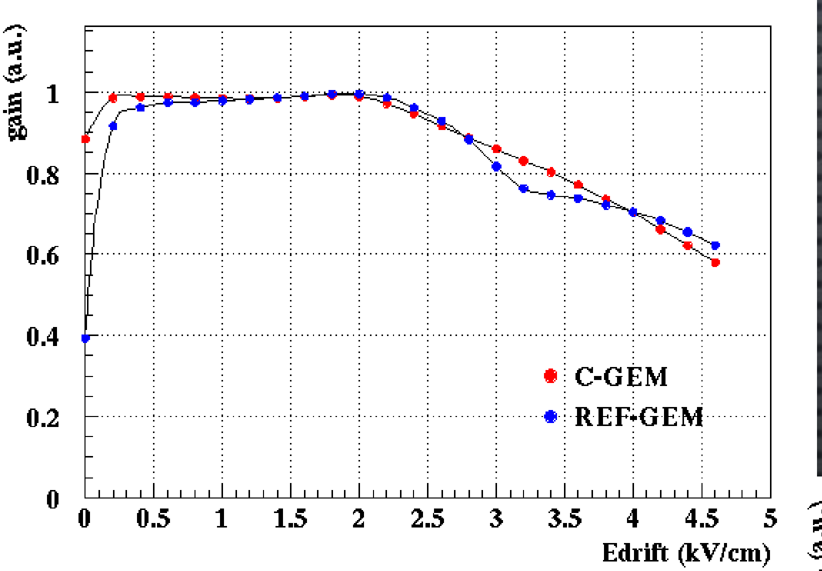
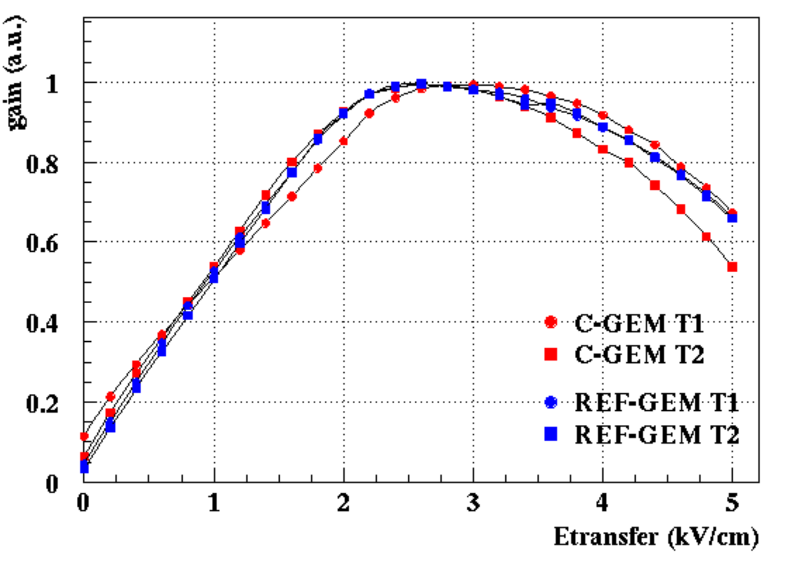
Transport Efficiency

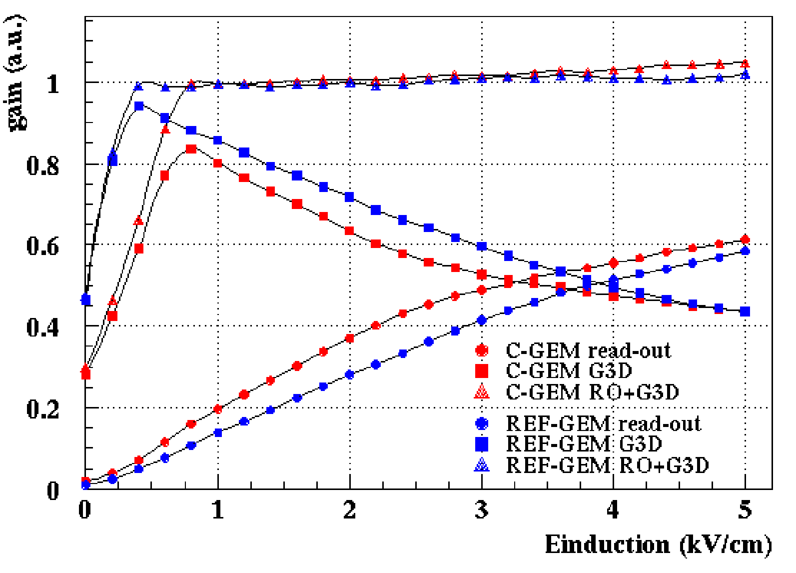
Drift Efficiency



Transfer Efficiency



Induction Efficiency and Charge Sharing

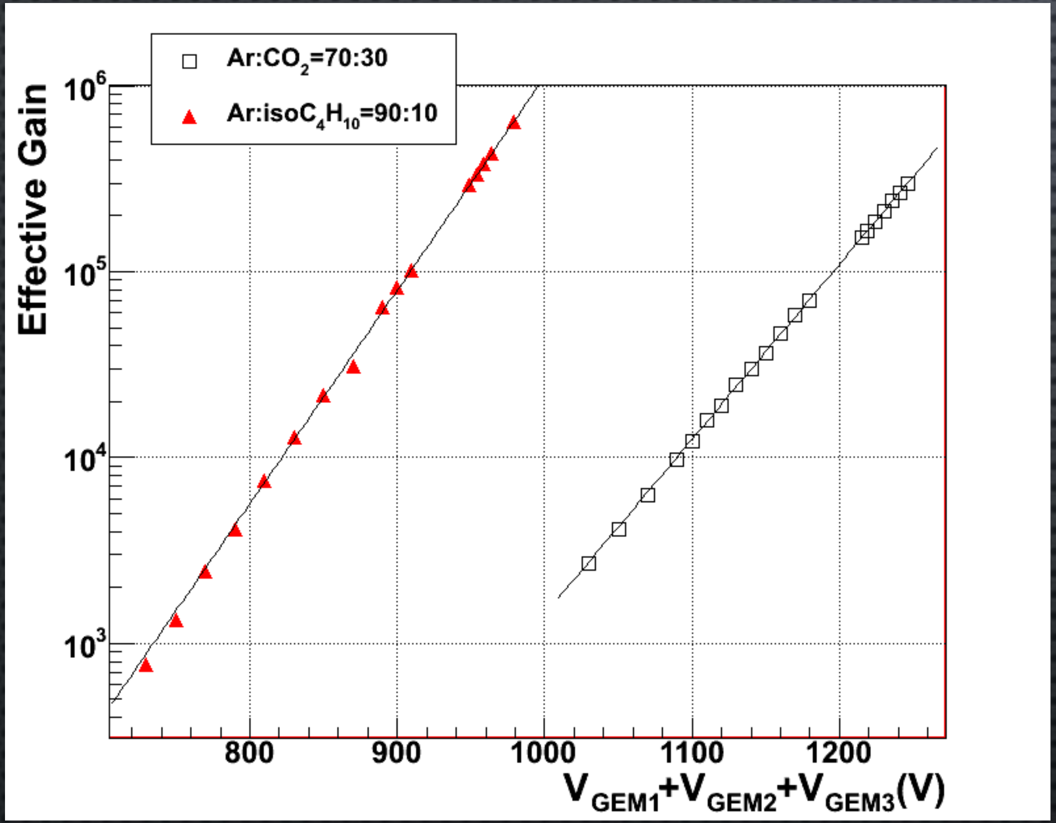


Optical transparency of a GEM is 22%

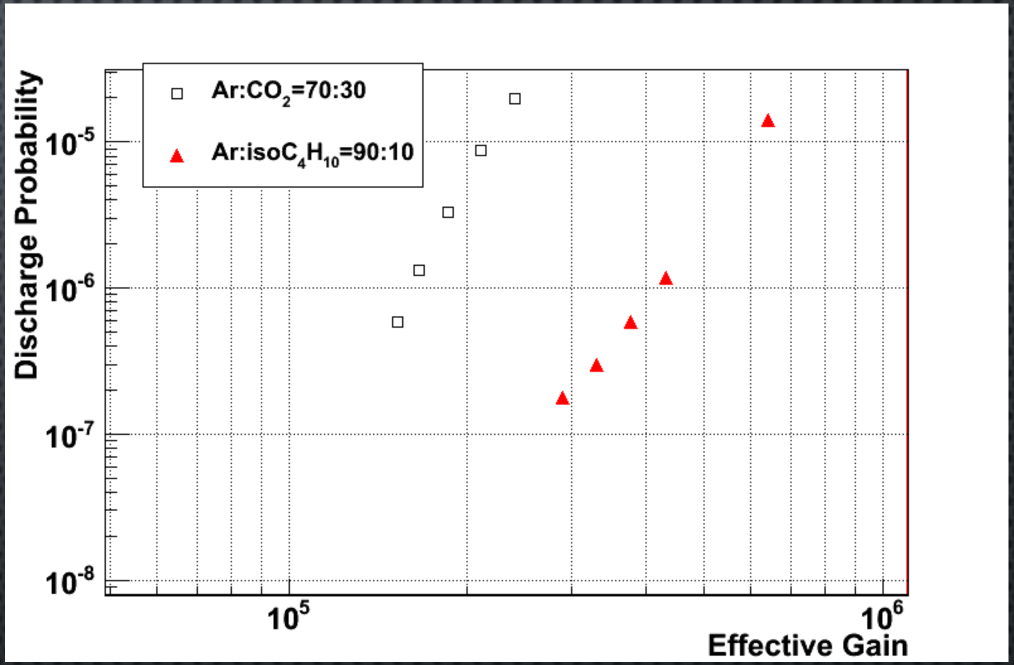
Electron trasparency can be as high as 90%

Gas Gain and Discharges

example of gas gain for a triple-GEM

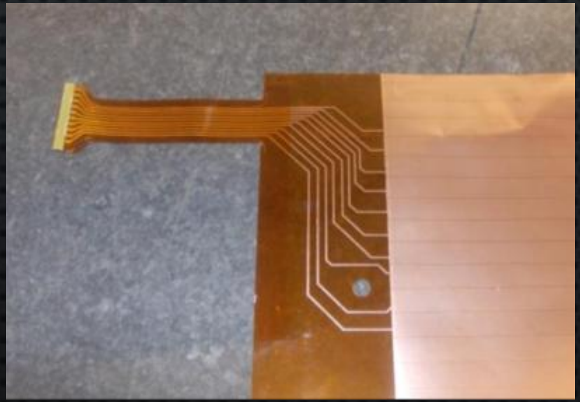


discharge probability for the same gas mixtures as a funcion of the gain

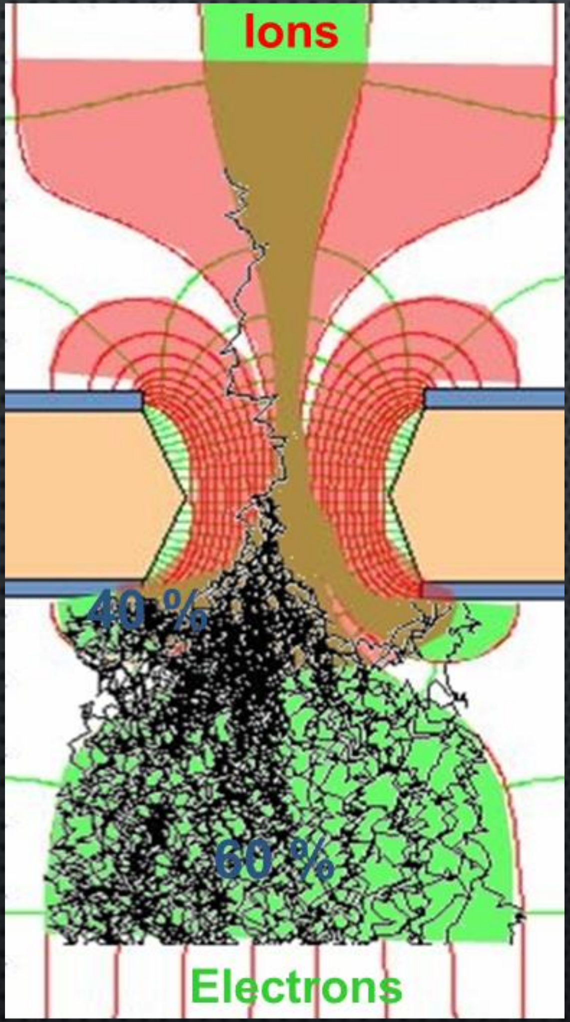


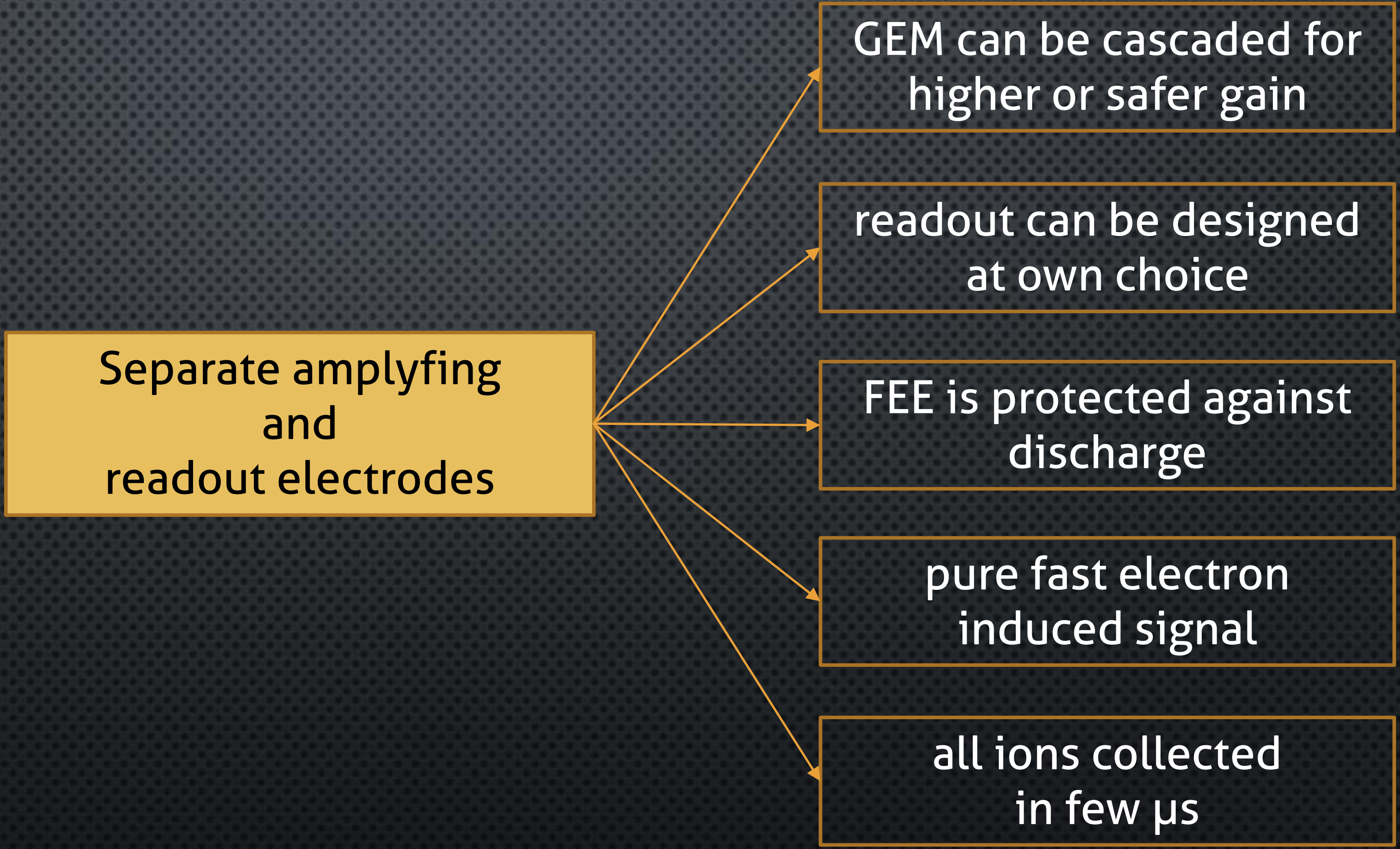
gain mostly depends on the sum of the 3 GEM bias

GEM surface is divided in separately supplied sectors to limit the damage in case of discharge
thumb rule: 100 cm^2



Unique GEM Characteristics





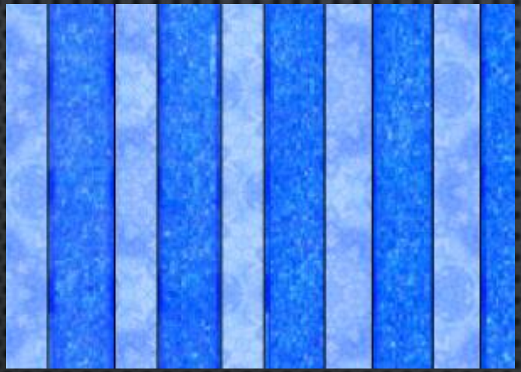
Separate amplyfing and readout electrodes

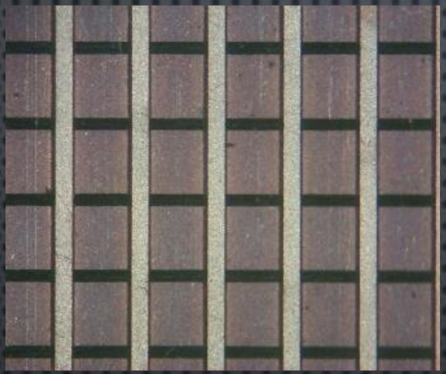
- GEM can be cascaded for higher or safer gain
- readout can be designed at own choice
- FEE is protected against discharge
- pure fast electron induced signal
- all ions collected in few μs

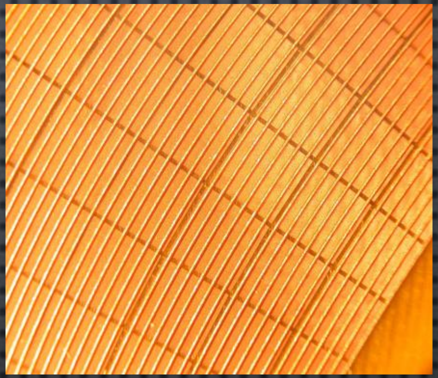
READOUT CIRCUITS

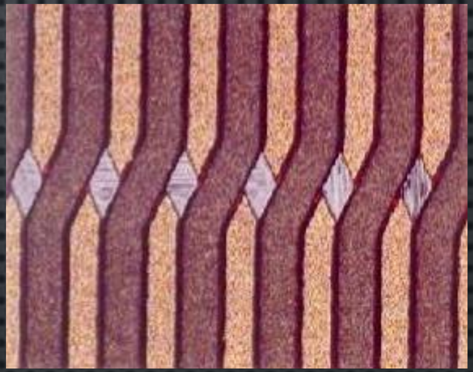
Full decoupling of the charge amplification structure from the charge collection and readout structure allows both to be optimized independently

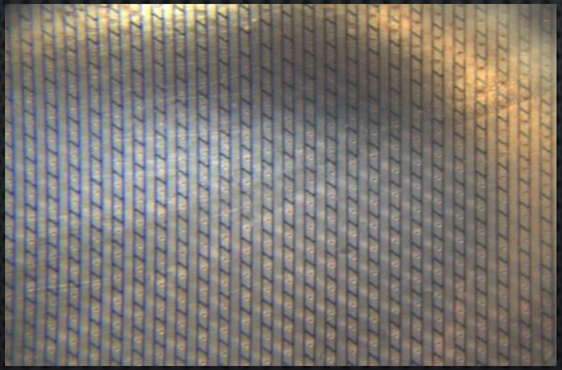
Most of these structure can be obtained with the same etching procedure used to make GEM foils

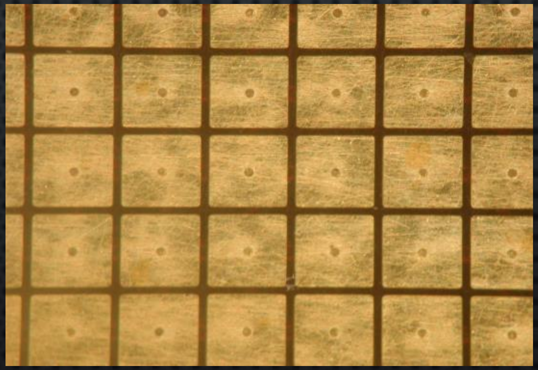

1D strips

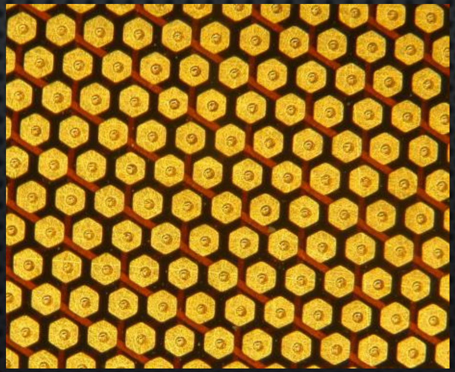

2D cartesian

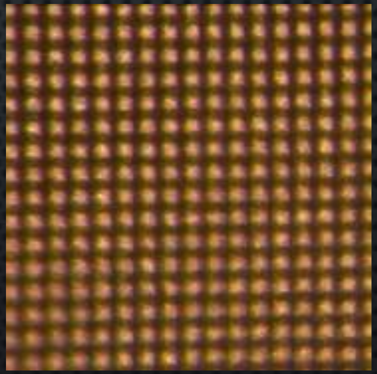

2D polar


2D small angle

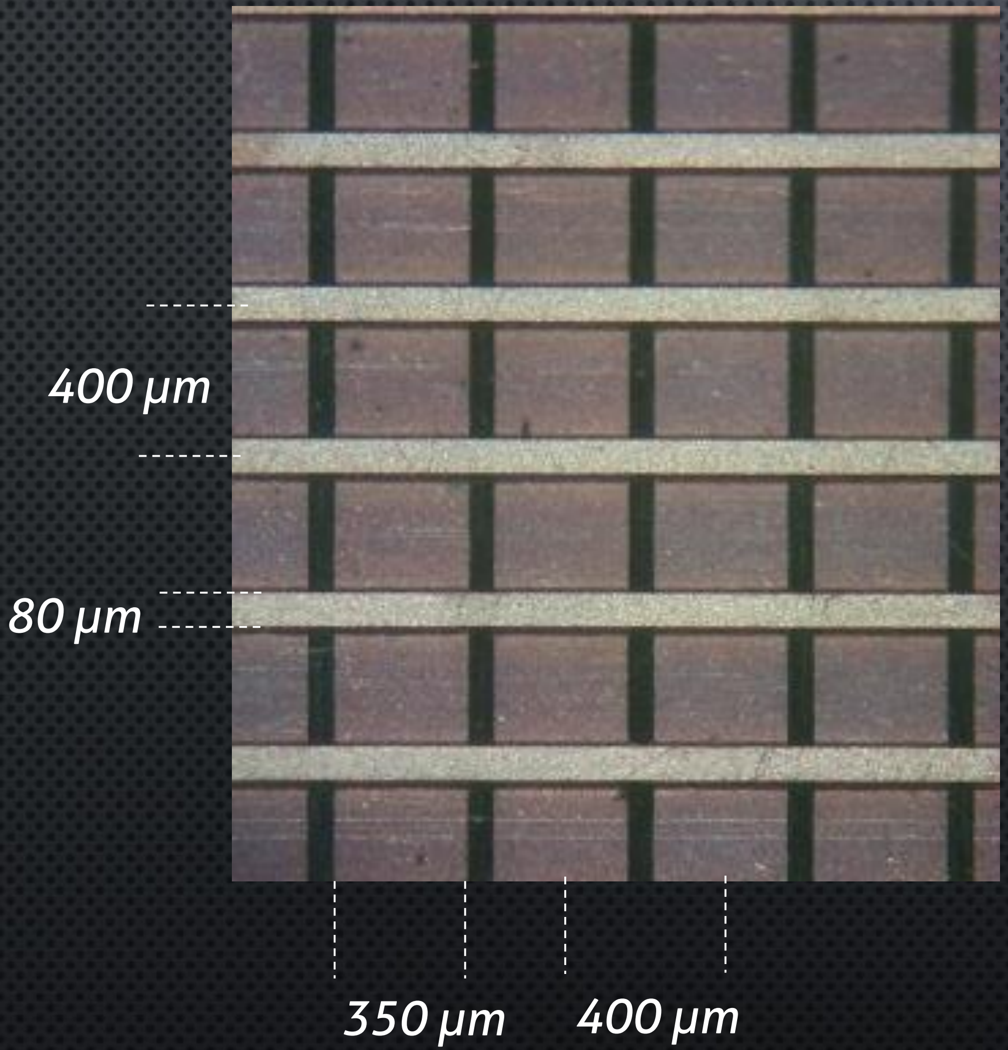

pads and strips


pads


hexagonal pads

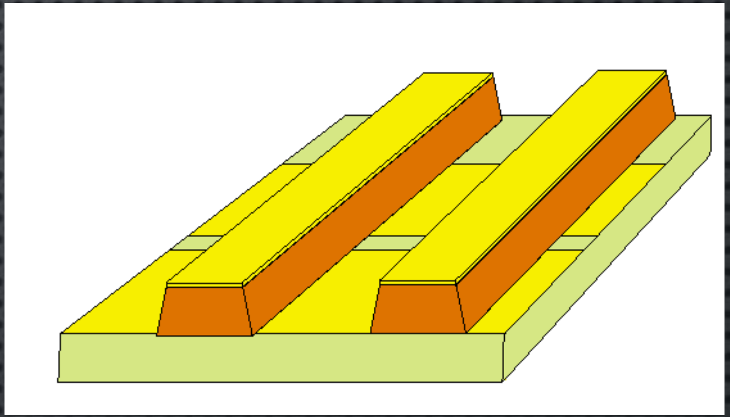

pixels

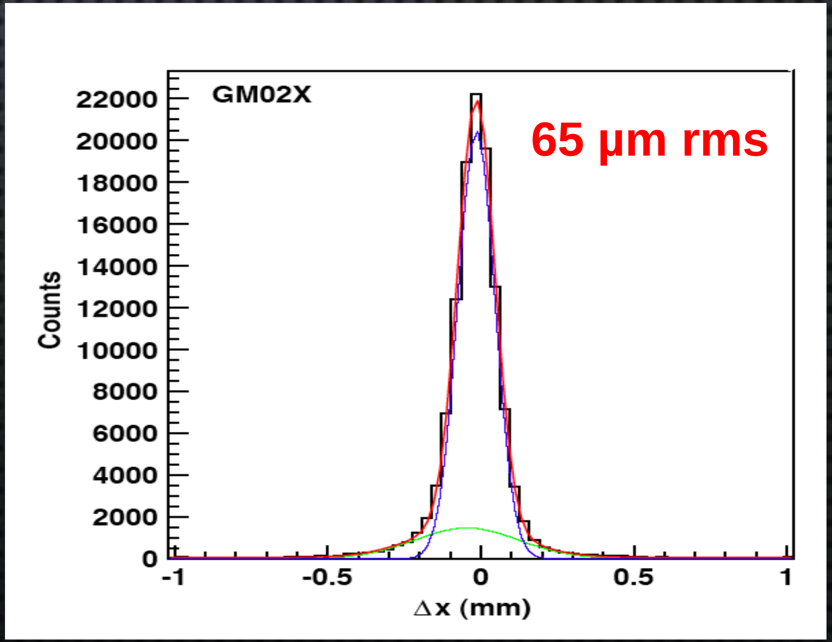
Spatial Resolution



COMPASS
Experiment

Two orthogonal sets of strips at 400 µm pitch engraved on 50 µm Kapton, 80 µm wide on upper side 350 µm wide on lower side (for equal charge sharing)



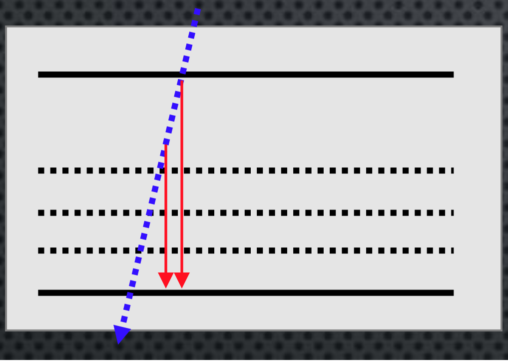


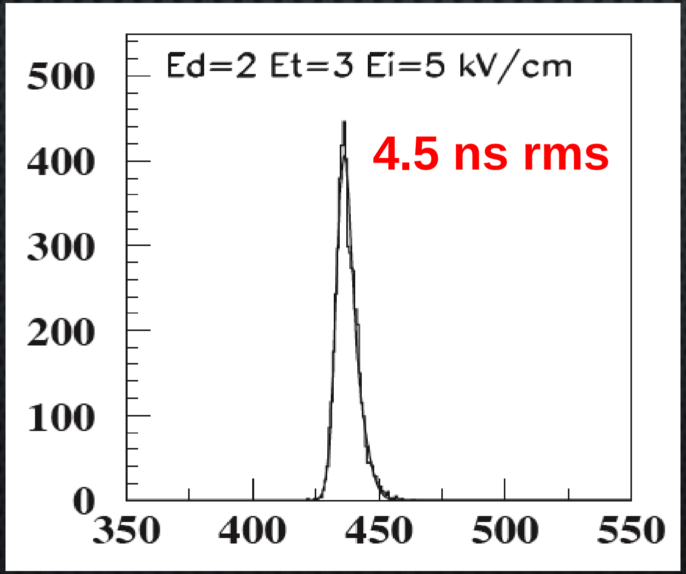
B. Ketzer et al, NIMA535(2004)314

Time Resolution

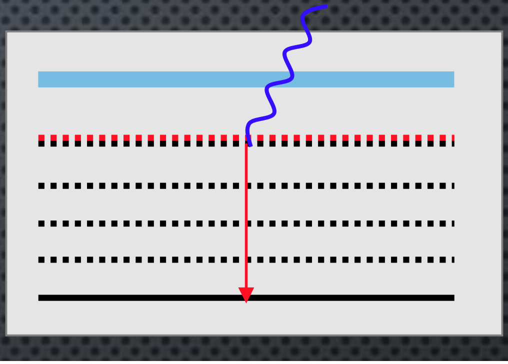
LHCb muon trigger
with fast gas mixture
Ar-CO_2-CF_4 (45-15-40)

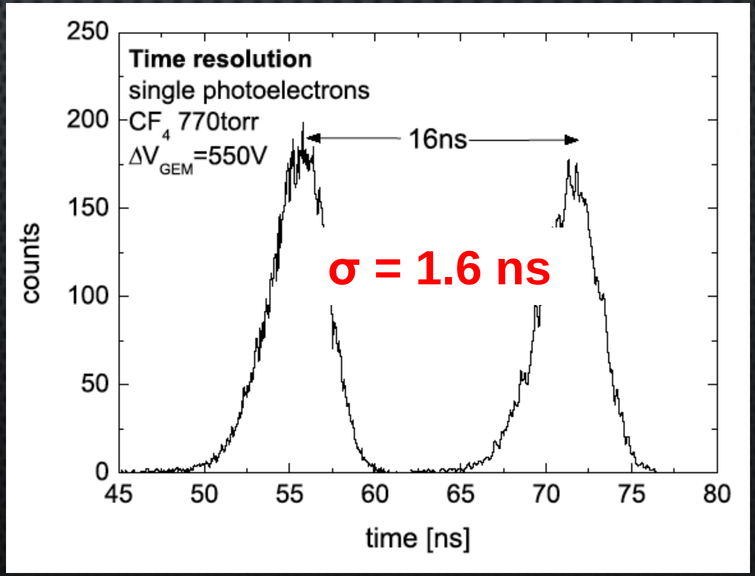
intrinsic time resolution
4-GEM with reflective
photocathode





M. Alfonsi et al,
NIM A535(2004)319

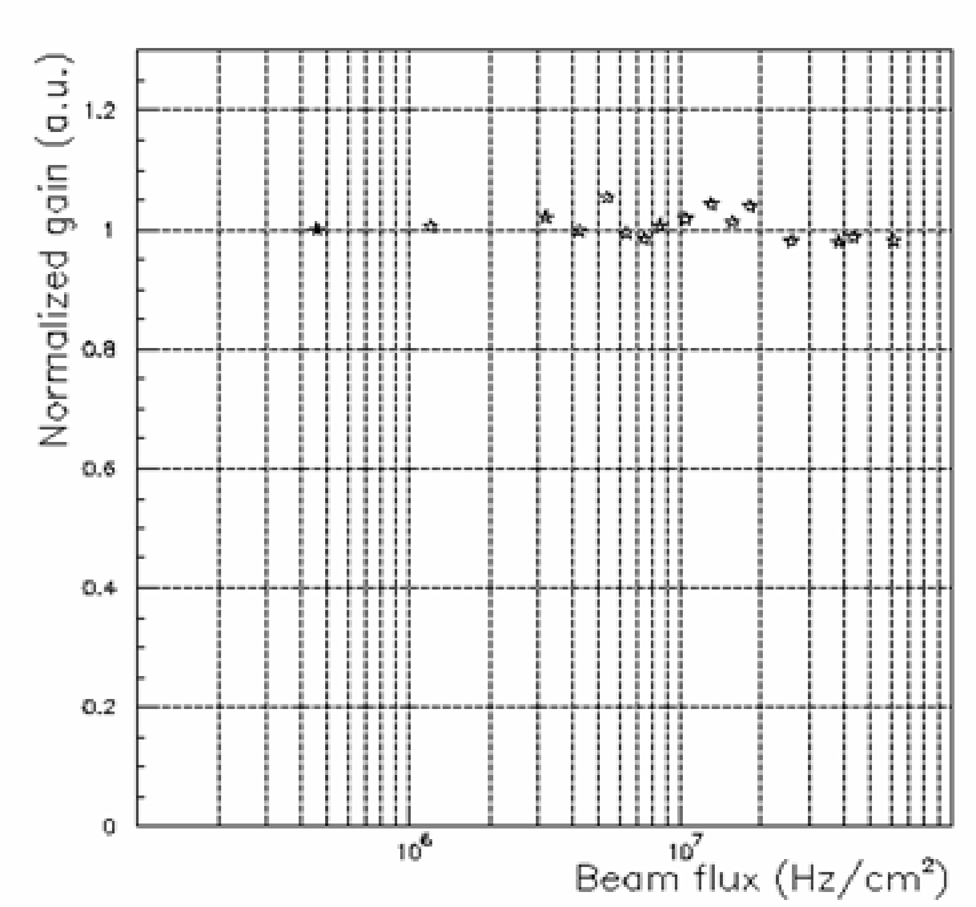




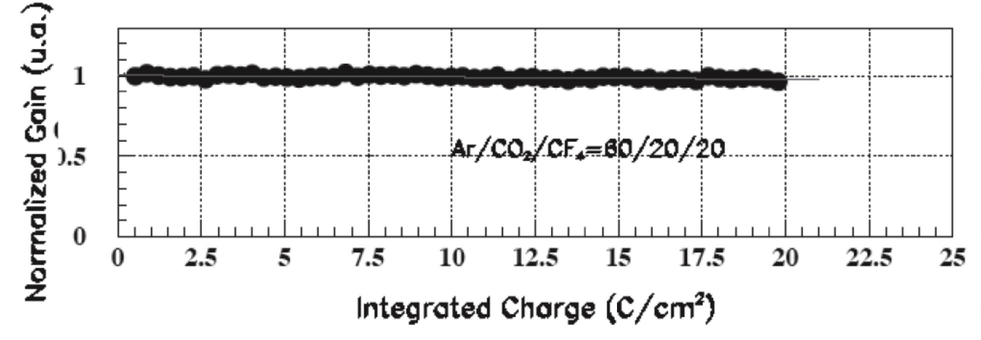
D. Normann et al,
NIM A504(2003)93

Rate Capability and Radiation Hardness

no gain loss up to
60 MHz/cm² of MIP rate



no gain loss up to
20 C/cm² of integrated charge
corresponding to
4×10^{12} MIPs/mm²



M. Alfonsi et al, NIM A518(2004)106

HIGH VOLTAGE SUPPLY

Triple-GEM needs electrodes to be supplied with 7 different voltages

Typical
GEM bias and Field values

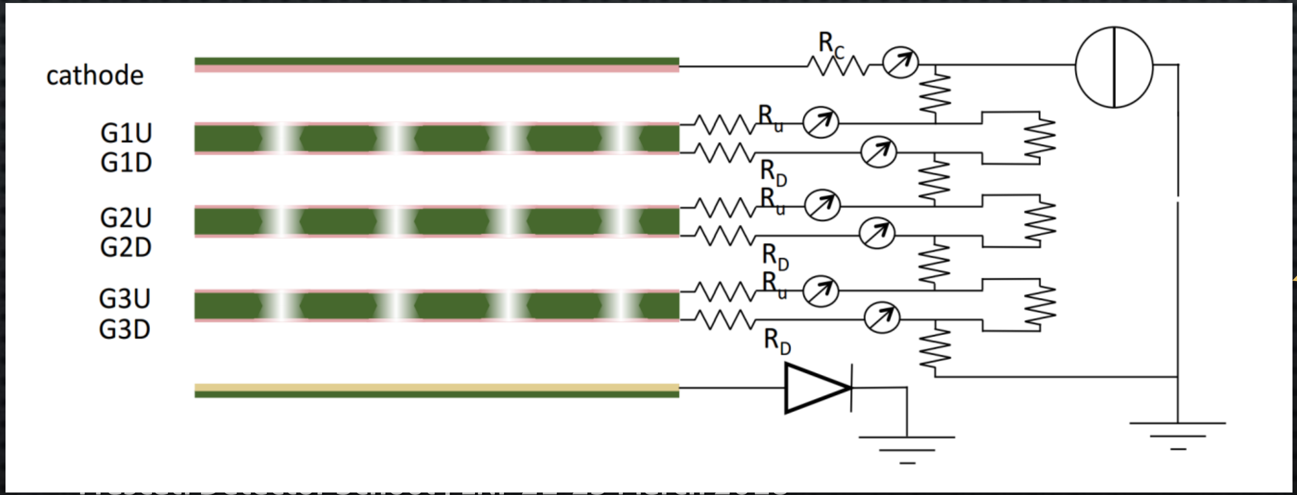
Drift Field: 1.5 kV/cm^2
GEM1: 300 V
Transfer1 Field: 3.5 kV/cm^2
GEM2: 290 V
Transfer2 Field: 3.5 kV/cm^2
GEM3: 280 V
Induction Field: 6 kV/cm^2

Voltages with
3/2/2/2 mm gaps

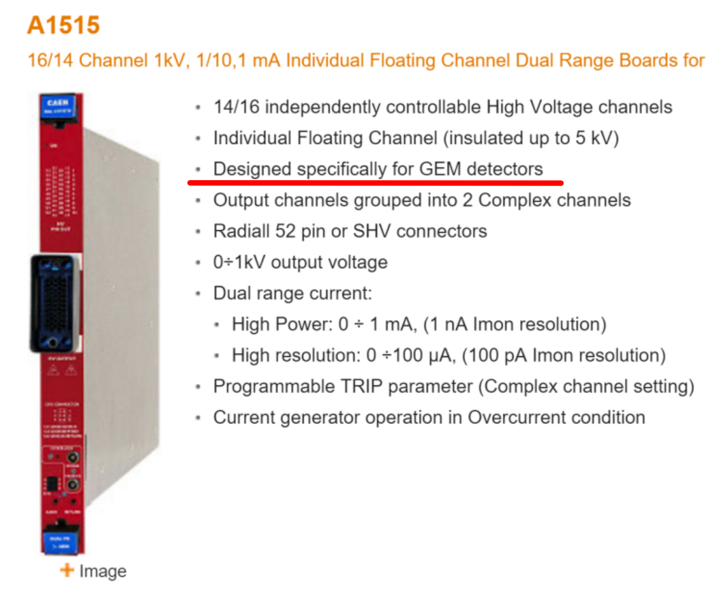
Cathode: 3920 V
GEM1 Top: 3470 V
GEM1 Bot: 3170 V
GEM2 Top: 2470 V
GEM2 Bot: 2180 V
GEM3 Top: 1480 V
GEM3 Bot: 1200 V
Anode: GND

Simpler and safer way is a
resistive voltage divider
1 HV channel
Voltage ratios fixed

Using 7 independent HV channel
is not recommended in high
radiation environment



Valuable solution: CAEN A1515



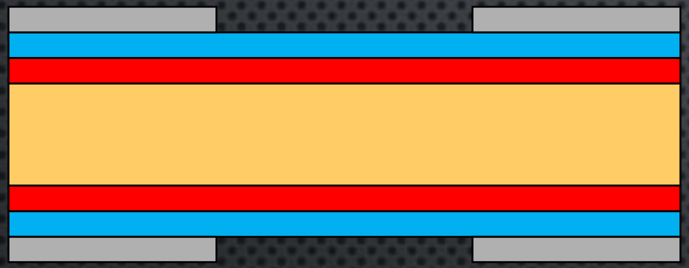
A1515

16/14 Channel 1kV, 1/10,1 mA Individual Floating Channel Dual Range Boards for

- 14/16 independently controllable High Voltage channels
- Individual Floating Channel (insulated up to 5 kV)
- Designed specifically for GEM detectors
- Output channels grouped into 2 Complex channels
- Radiall 52 pin or SHV connectors
- 0÷1kV output voltage
- Dual range current:
  - High Power: 0 ÷ 1 mA, (1 nA Imon resolution)
  - High resolution: 0 ÷100 µA, (100 pA Imon resolution)
- Programmable TRIP parameter (Complex channel setting)
- Current generator operation in Overcurrent condition

GEM Manufacturing Process at CERN

start from raw material
5+50+5 μm Cu+Kapton+Cu glueless
(Kaneka, Sheldahl)

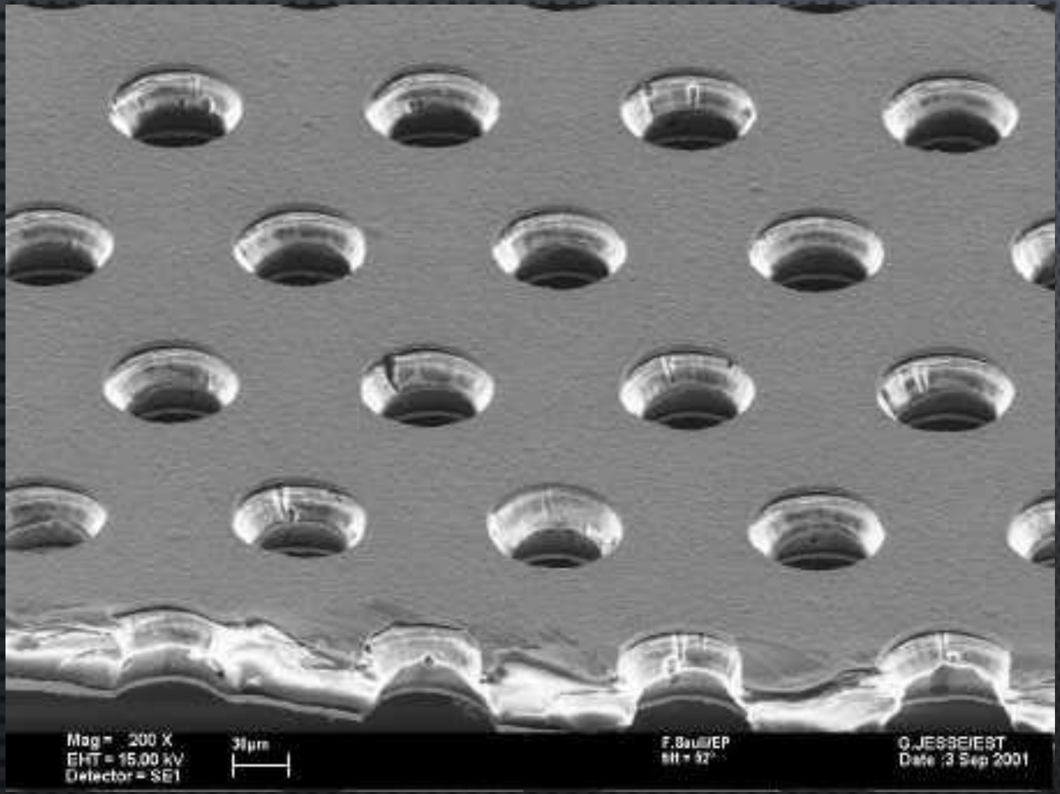


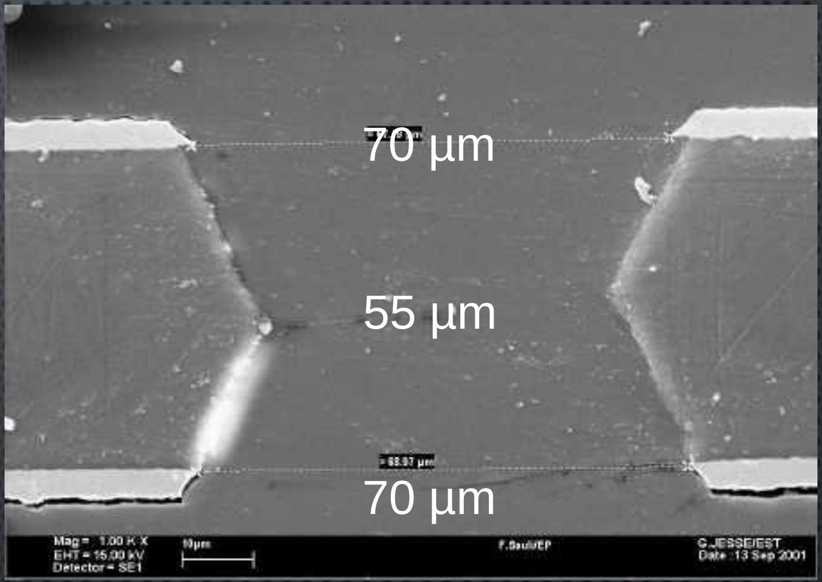
photoresist coating
CAD masks with hole pattern
UV exposure

chemical etching of metal

chemical etching of Kapton
(typical double-conic hole)

GEM Foil at Microscope

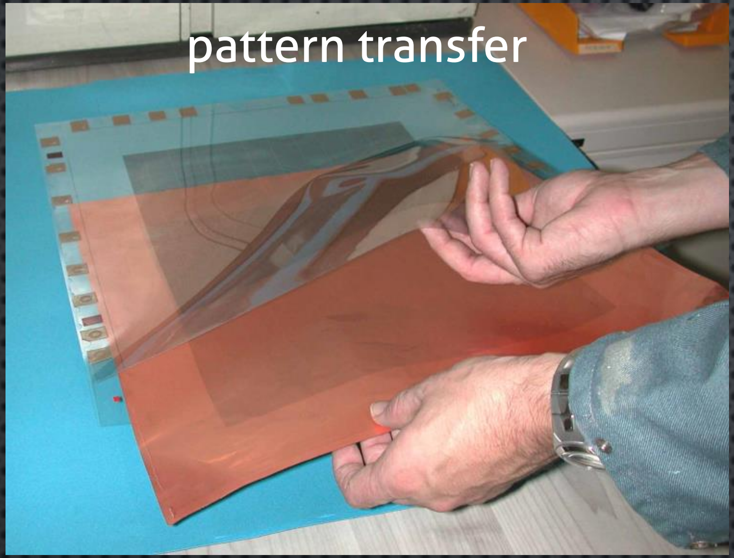




bi-conical hole shape has 2 advantages:

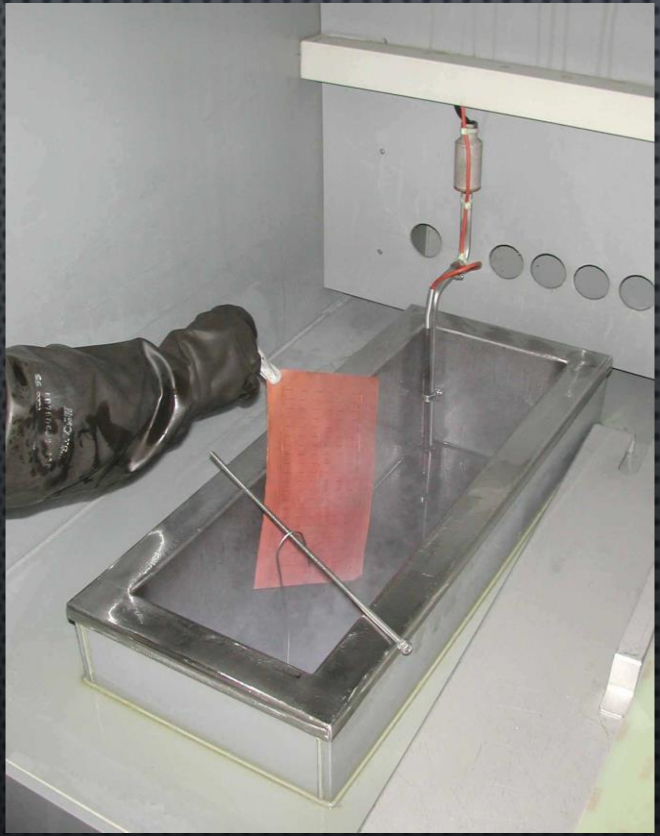
shield electrodes protecting from discharge
increase charging-up enhancing the gain

Manufacturing Process


pattern transfer

Copper chemical etching bath

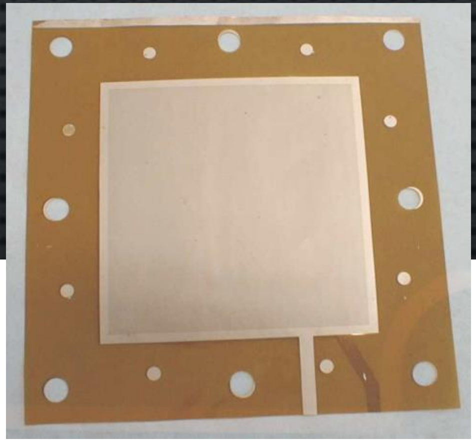
Kapton chemical etching bath



electrical test

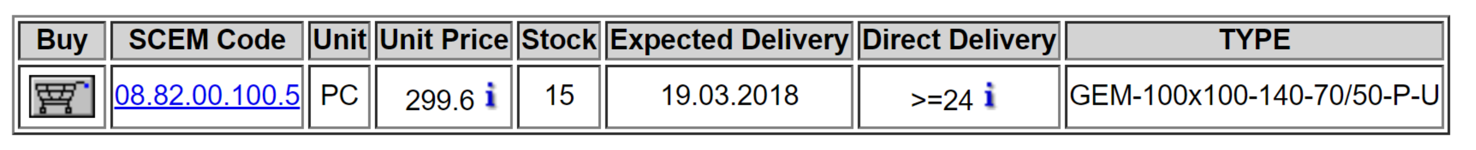
Application Driven Layouts

wide range of shapes and sizes
active areas from 1 to 5000 cm^2
custom connection paths
10×10 cm^2 available at CERN store



08.82.00.100.5 - GEM-100x100-140-70/50-P-U

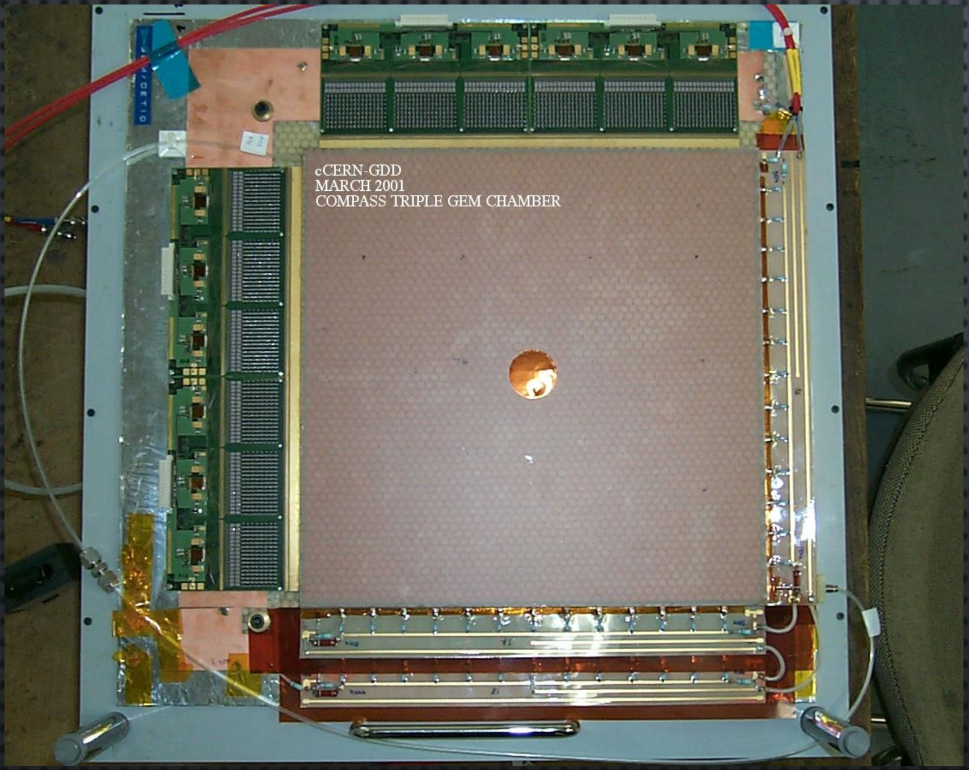
Unit Price: 299.6 CHF / PIECE(S)
Unit of distribution: 1 PACKET(S) of 5 PIECE(S)



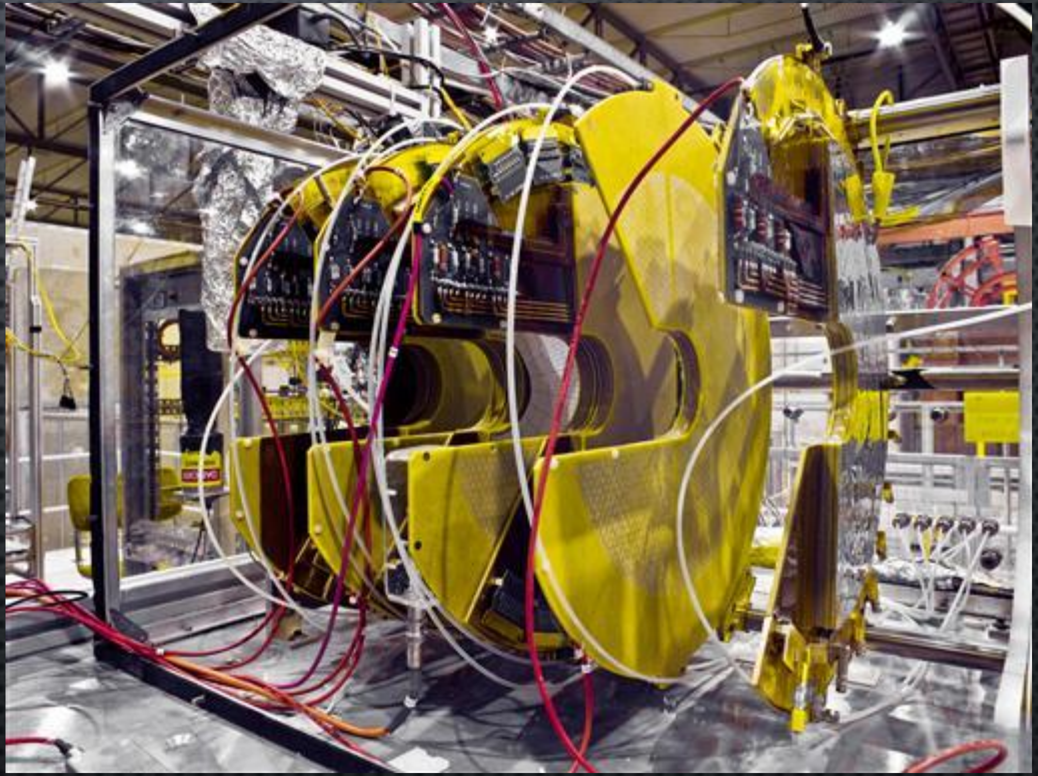
Buy	SCEM Code	Unit	Unit Price	Stock	Expected Delivery	Direct Delivery	TYPE
🛒	08.82.00.100.5	PC	299.6 ℹ	15	19.03.2018	>=24 ℹ	GEM-100x100-140-70/50-P-U

Pioneering GEM Experiments

COMPASS at CERN-SPS
first experiment using GEM



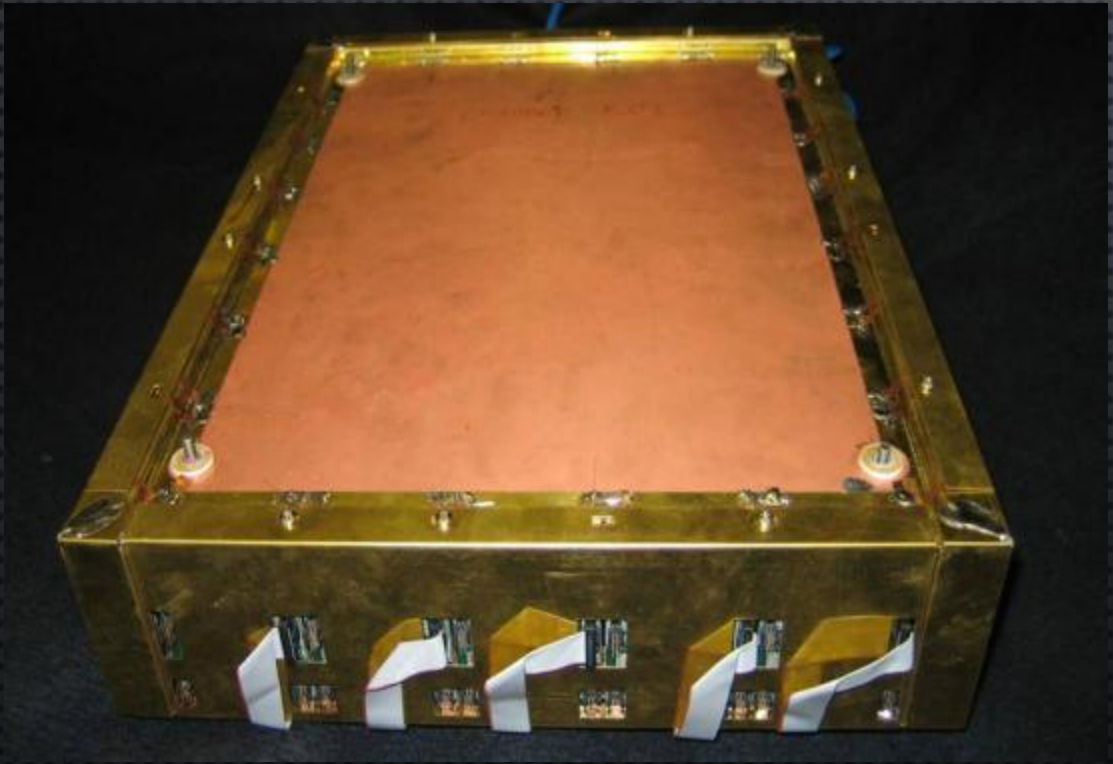
TOTEM at CERN-LHC
second experiment using GEM



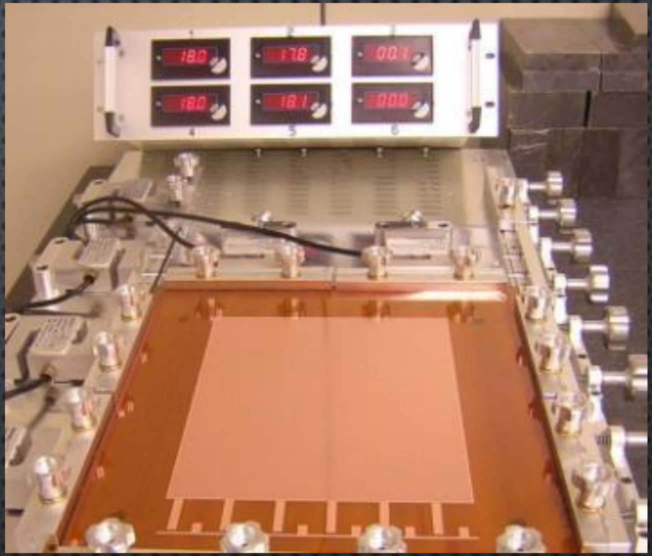
Tracker-GEM
high granularity + analog readout = high space resolution (50 ÷ 100 μm)

GEM arrive at LHC

LHCb at CERN-LHC
first experiment using GEM at LHC
Trigger-GEM
fast gas + digital readout =
high time resolution (5 ns)

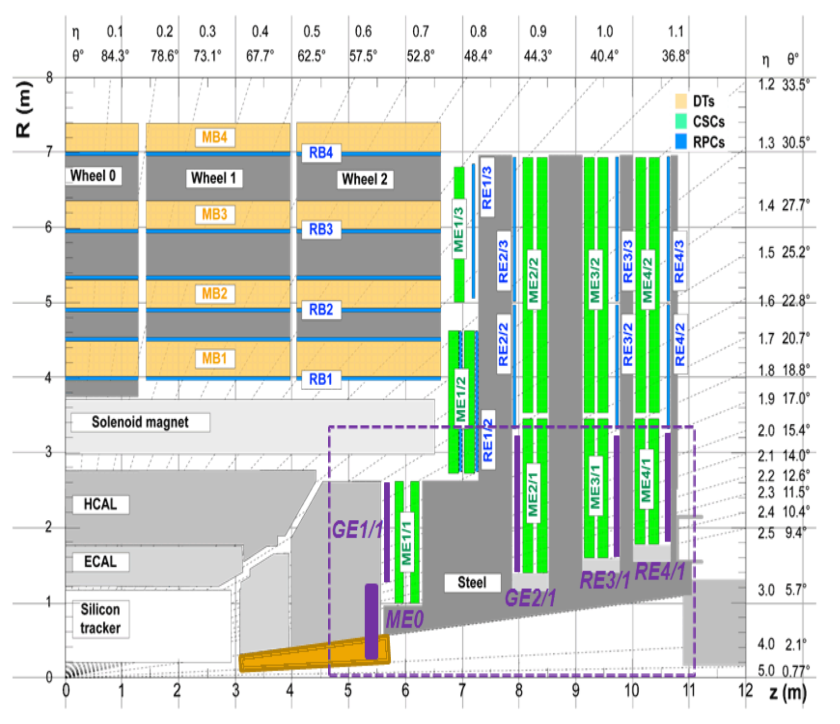


first GEM detectors designed and realized outside CERN (INFN-LNF and INFN-CA)

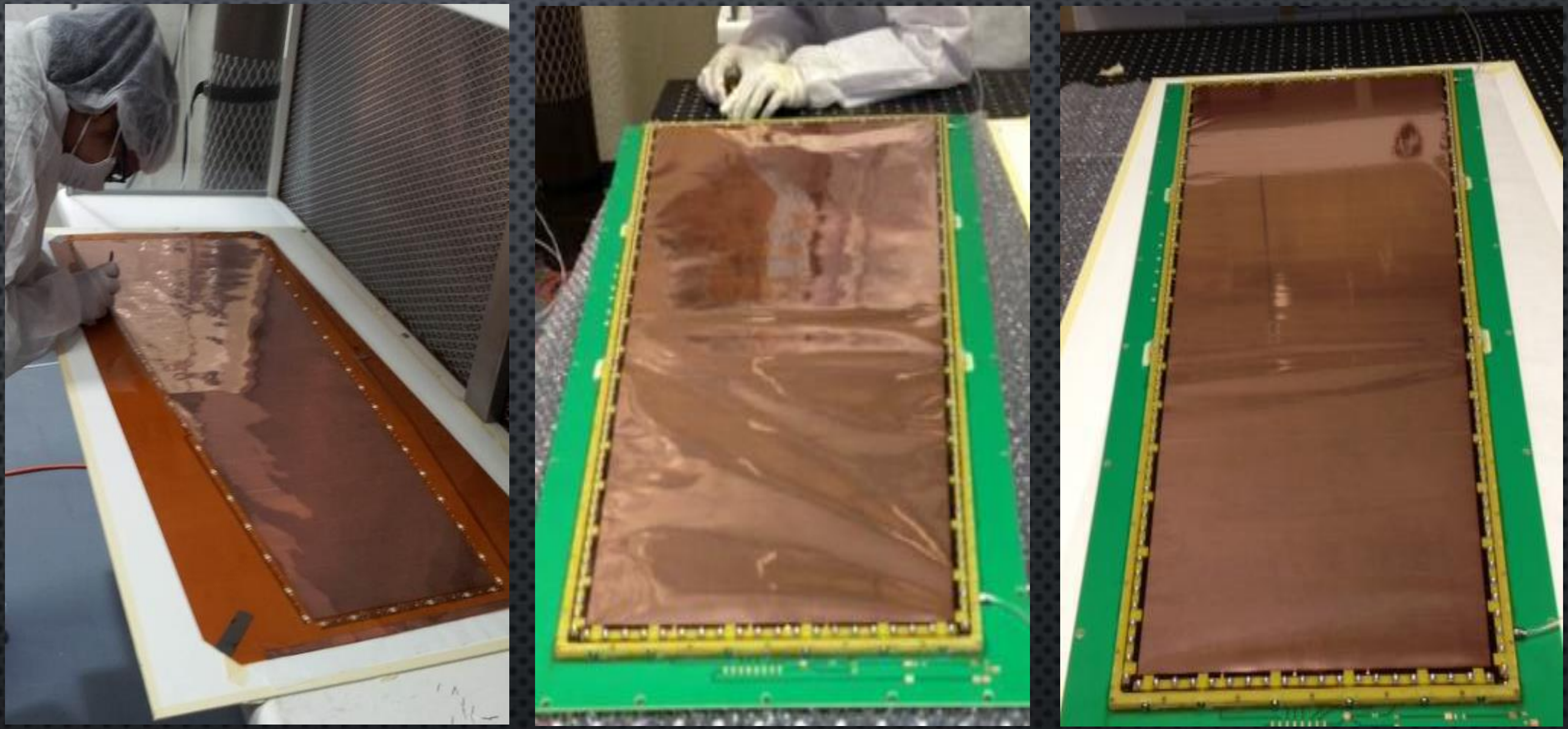


introduction of foil stretching

CMS Upgrade with GEM



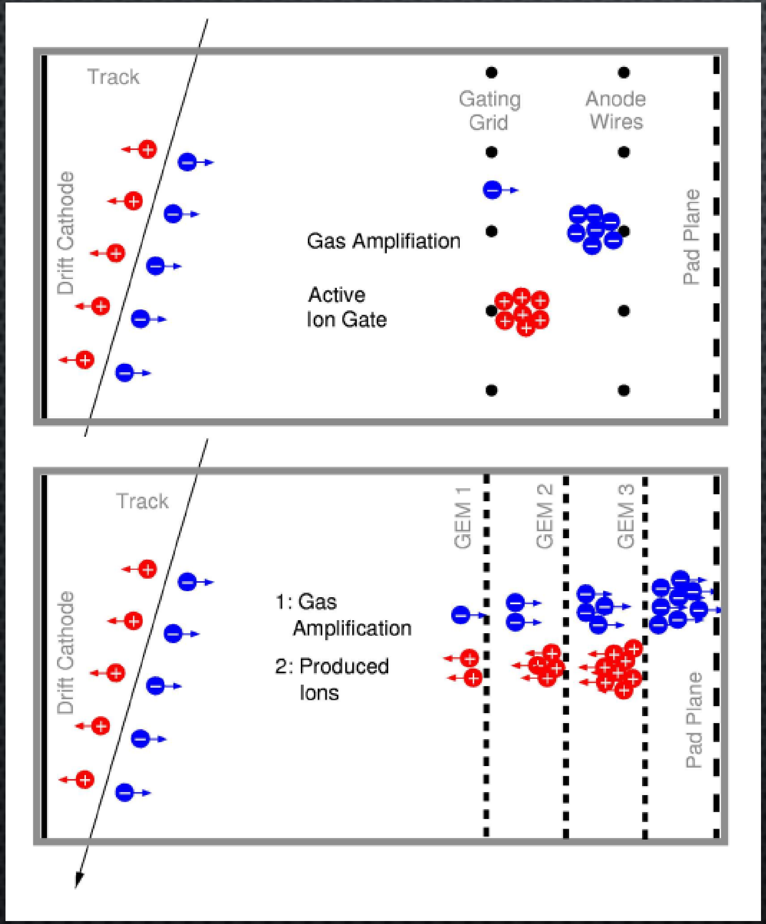
In LHC Phase II upgrade large area GEM detectors will be installed in the forward muon regions



Self-stretching technique to avoid glue and save time
Stretching frames are part of the detector
Can be open after test to change one foil

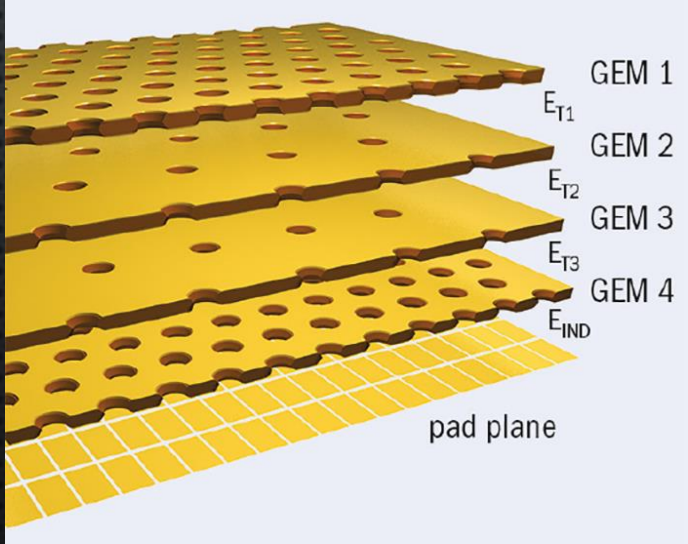
TPC – Time Projection GEM

natural ion-feedback suppression make GEM very suitable for TPC avoiding gating



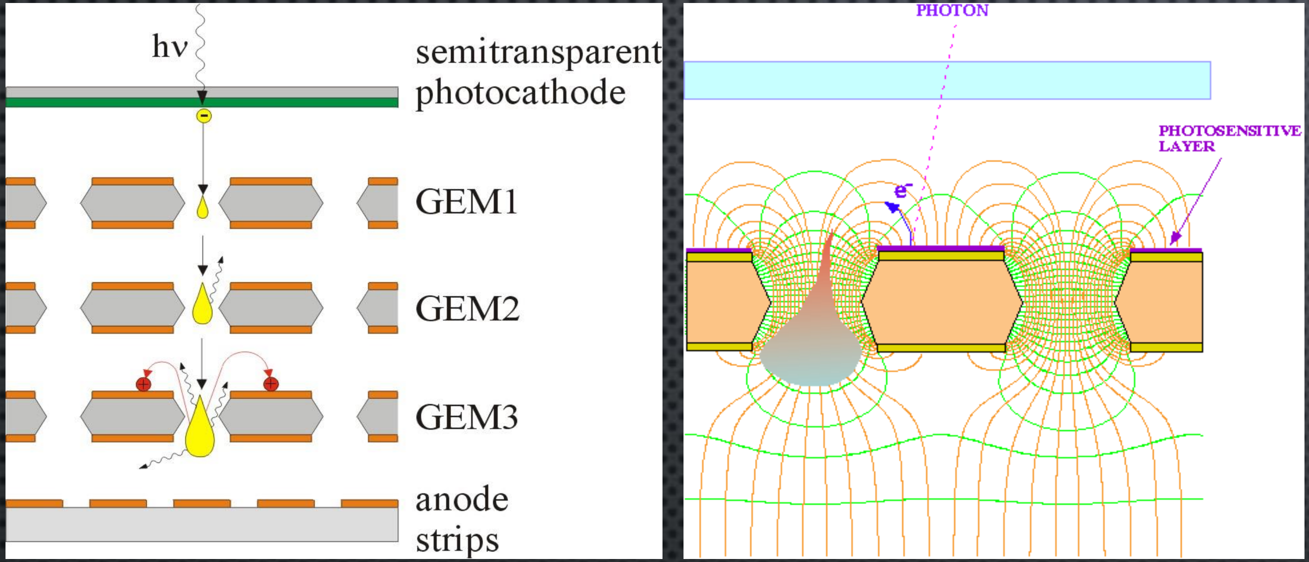
first TPG prototype for ILC

ALICE TPC will be upgraded with 4-GEM modules for readout

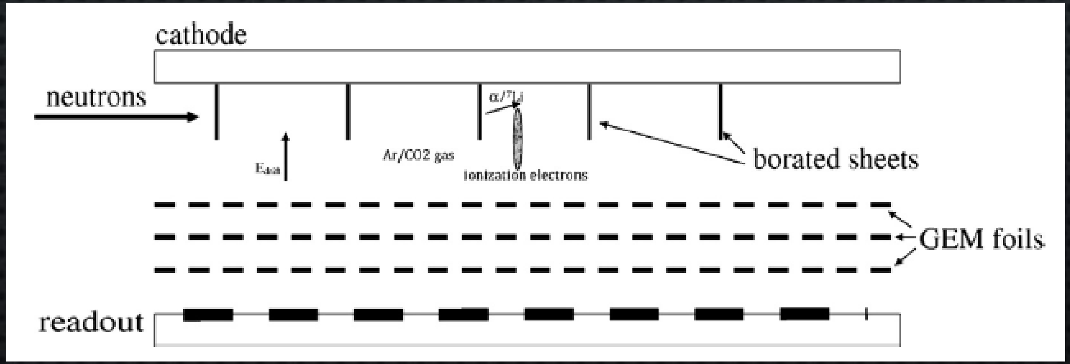


GEM Detector for Light and Neutrons

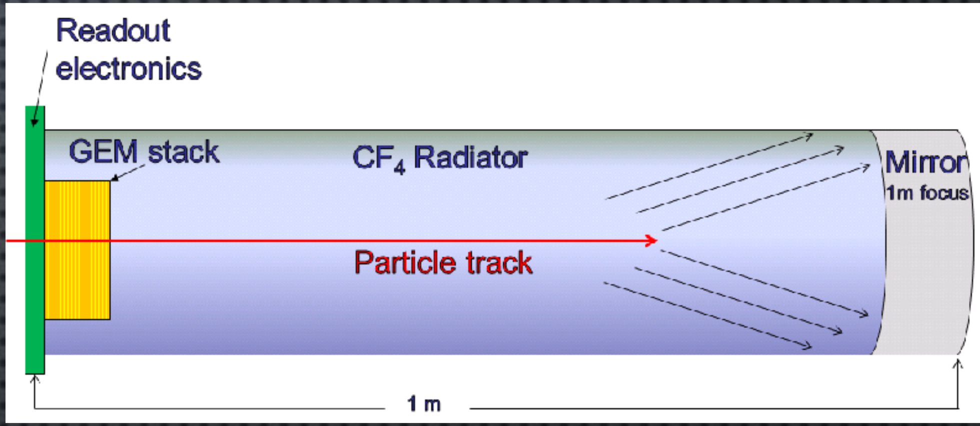
photocathode or top GEM face can be coated
with photosensitive layer to detect light

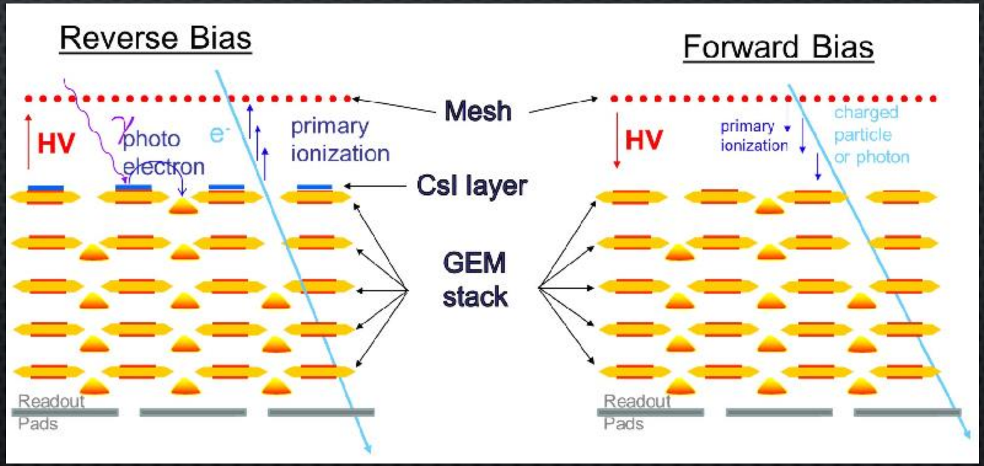


neutrons can be detected using suitable Boron converter



PHENIX at RHIC-BNL
Hadron-blind Cerenkov detector



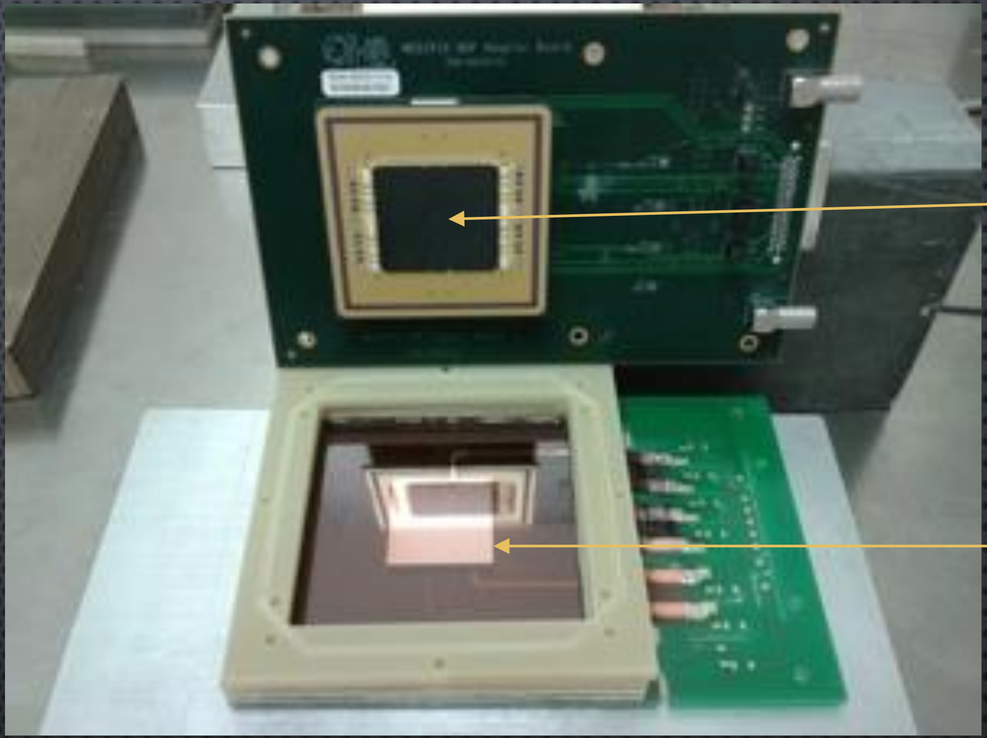


GEMPIX = GEM + MEDIPIX

CERN - Medipix Collaboration
Development of large CMOS sensors for Medical Imaging, Space Dosimetry and High-Energy Physics

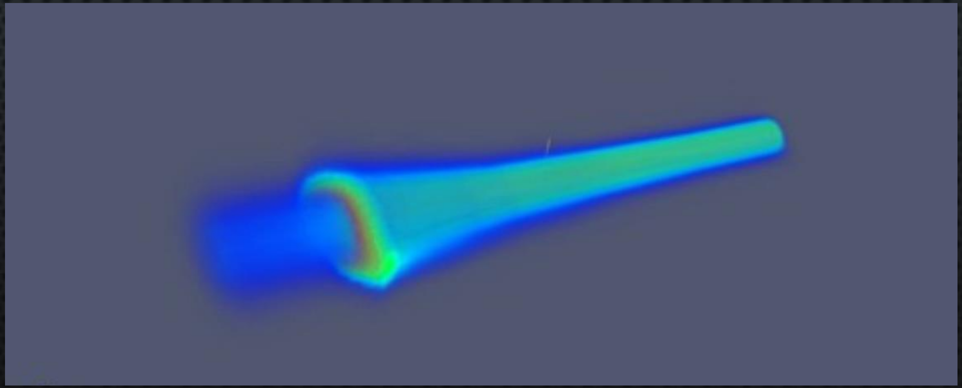
GEMPIX
Coupling of Medipix chip to a Triple-GEM stack

Applications
Hadrontherapy monitor – CNAO
Radioactive waste – CERN
X-ray monitor at Tokamak – Korea
Directional Dark Matter search



2×2 Medipix
512 × 512
55μm × 55μm
pixels

28 × 28 mm^2
Triple-GEM

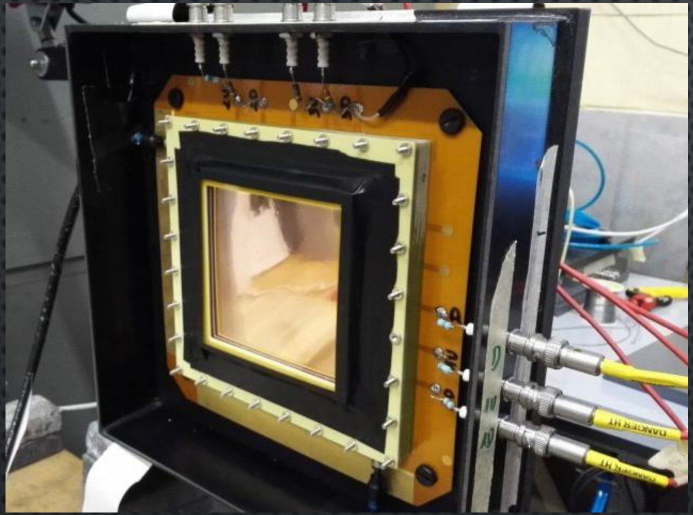


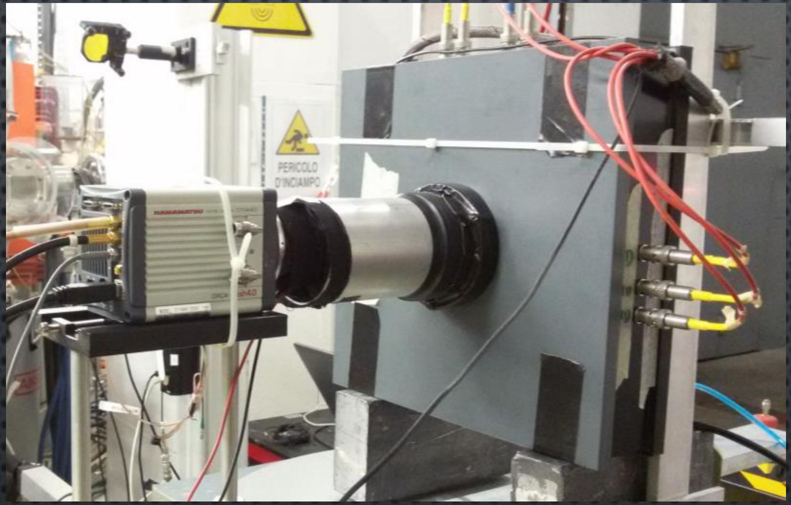
3D reconstruction of proton beam energy deposition in phantom at CNAO

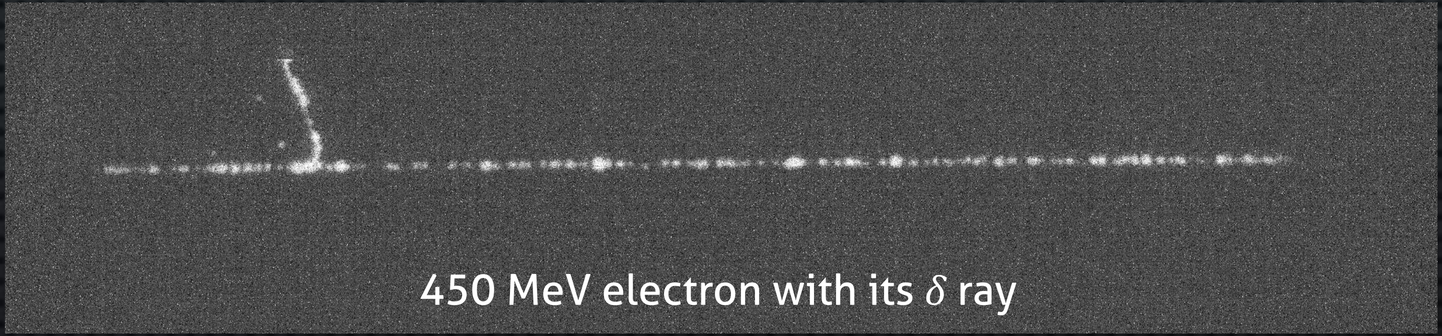
TPC with Optical Readout

light produced along with electrons during the multiplication process by de-excitation of gas molecules is readout with a commercial high-sensitivity/low-noise CMOS camera

Cygnus-RD Project by INFN-Roma & INFN-LNF

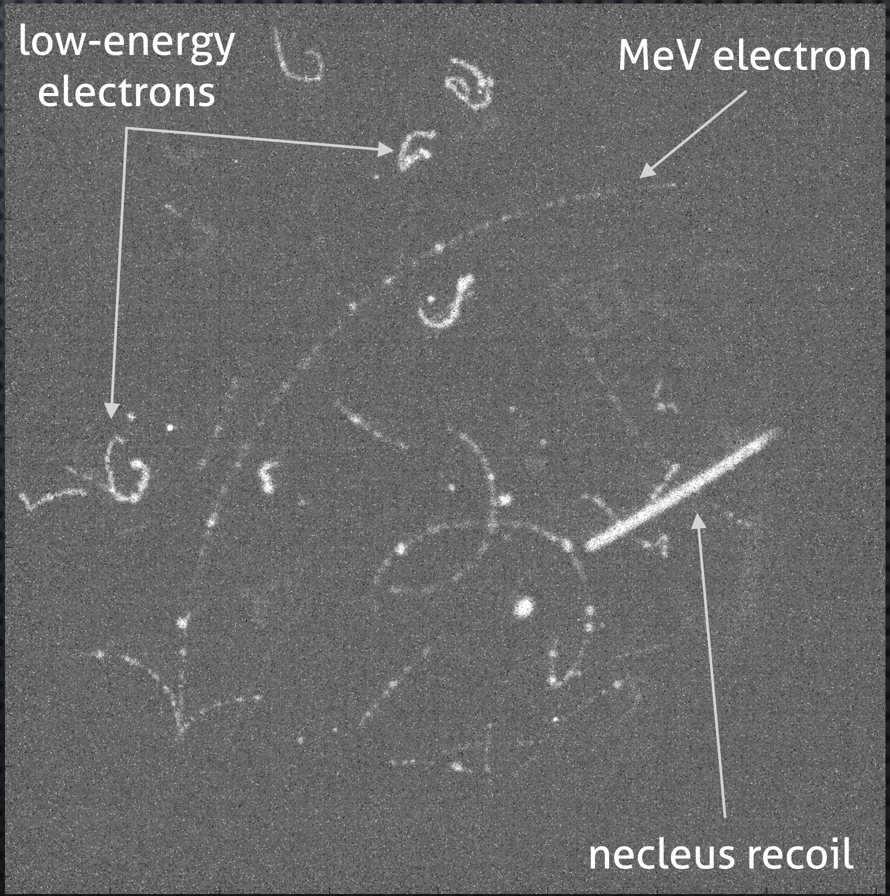






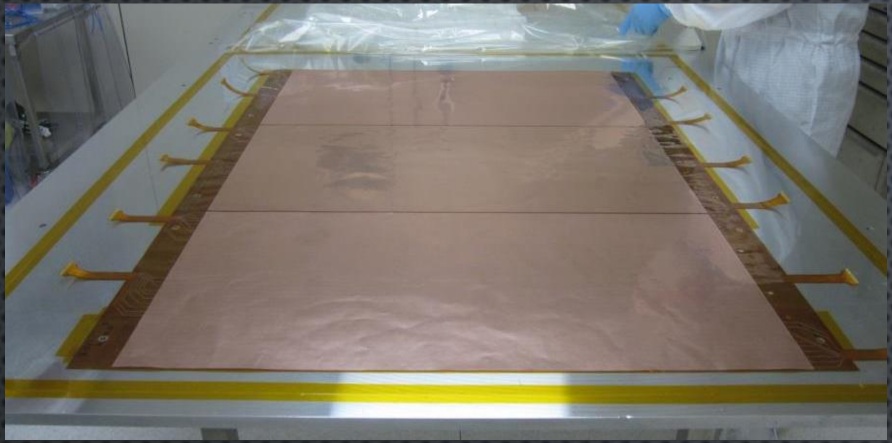
450 MeV electron with its δ ray

Am-Be source in 0.2 T field



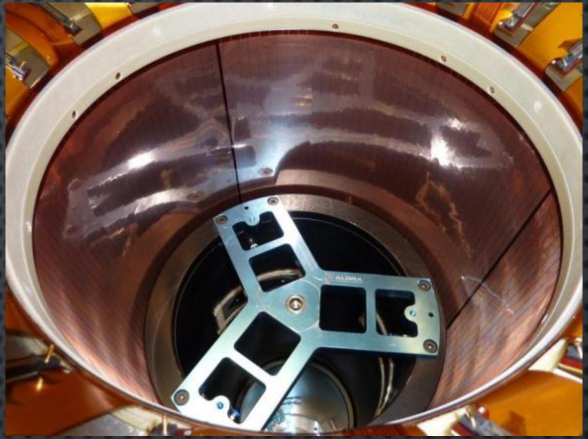
Cylindrical GEM at KLOE

the largest GEM electrode ever is built splicing 3 single foil



rolled over a mould to obtain cylindrical electrode

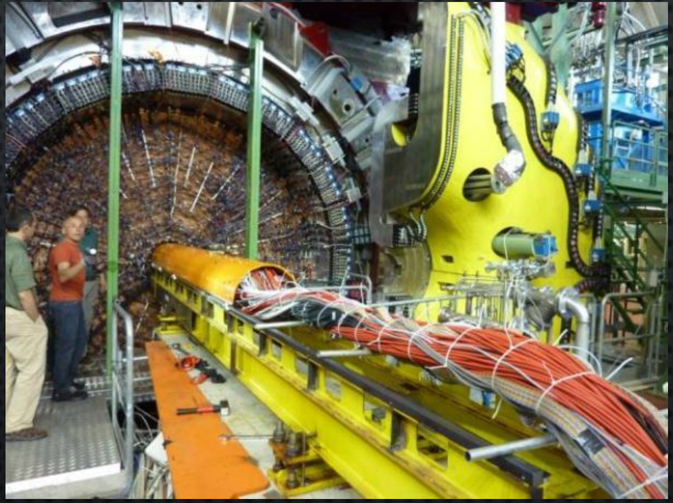
repeat for the 5 electrodes and insert one into the other for a Triple-GEM



build 4 Triple-GEM with increasing diameter

assembly the complete tracker

insert into KLOE detector



Summary

20 years ago Micro-Pattern Gas Detectors have been developed to overcome the limitation of Wire Chambers.
Nowadays they represent the most valuable option for gaseous detectors

Among MPGD GEM have the unique feature of having separate amplifying and readout electrodes.
This allows to customize geometry and layout at own needs

Several experiments and R&D are using GEM in diverse fields:
High-Energy Physics (tracking, triggering, photodetection)
Monitoring Applications (fusion facilities, hadronterapy, radioactivity)
Astrophysics (X-ray polarimetry)
Nuclear Medicine (PET detector)