GEM & GATING

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ILC-TPC School , Jan. 7-11, 2008

Beijing, China

Contents

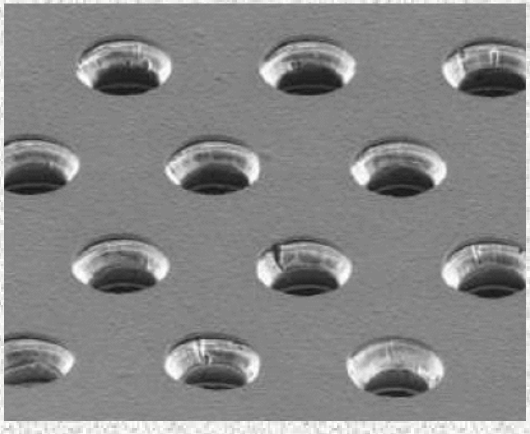
- GEM
  - Introduction
  - Working principle
  - Performance
  - Application
  - Mainly based on the talk Prof. Sauli gave in the MPGD workshop, CERN, 2006 (by courtesy of Prof. Fabio Sauli).
- Gating
  - Reason
  - GEM as gating structure
- Chinese students can discuss with me in Chinese.

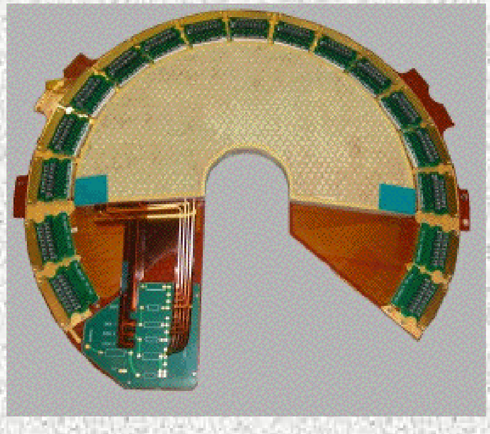
GEM

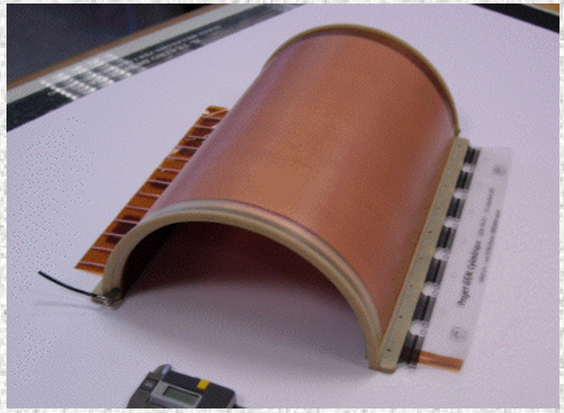
GAS ELECTRON MULTIPLIER DETECTORS: PERFORMANCES AND APPLICATIONS

Fabio SAULI

MPGD WORKSHOP
CERN, January 20, 2006

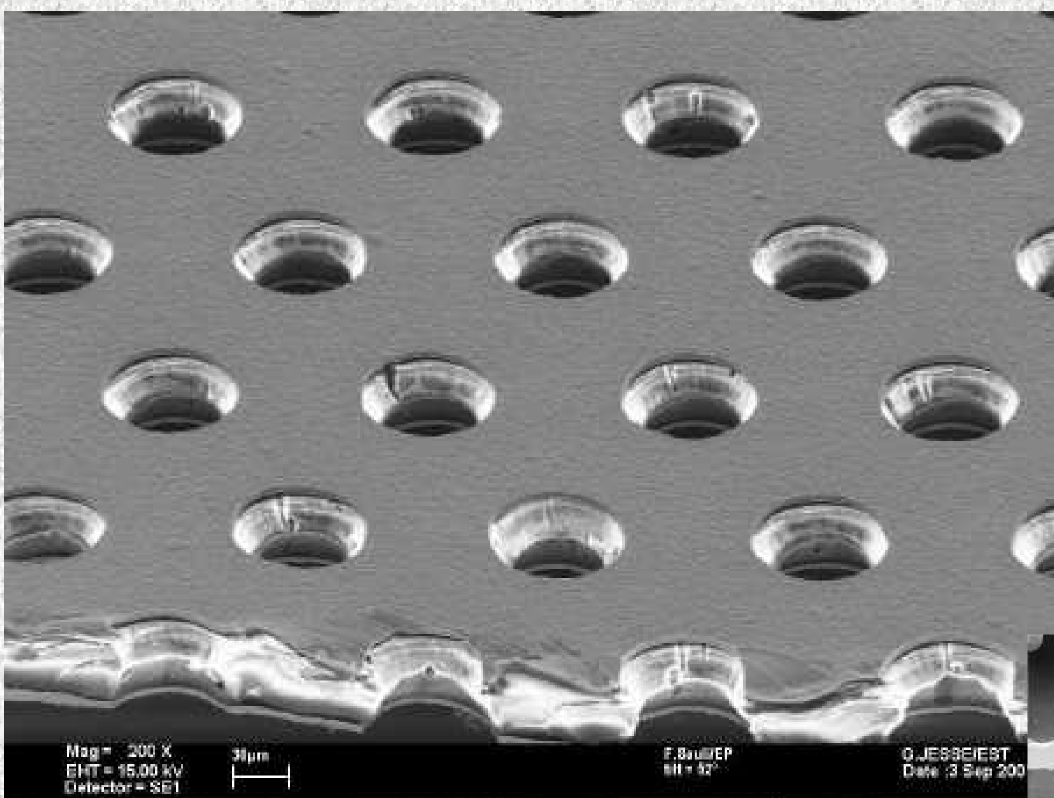




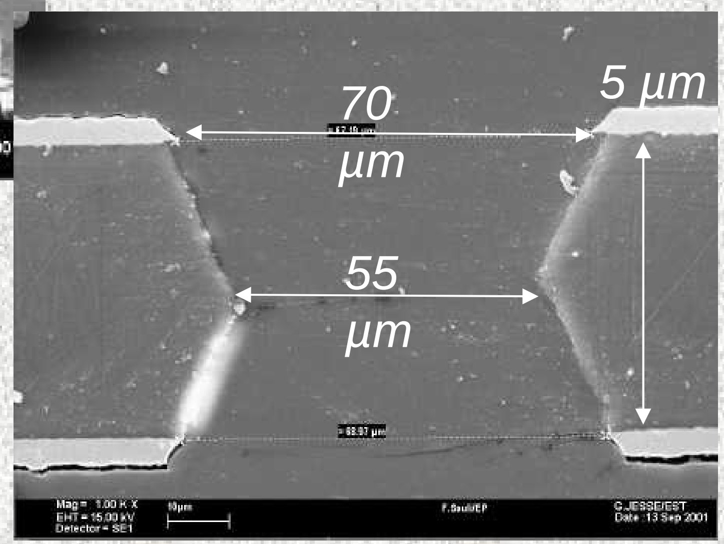


http://gdd.web.cern.ch/GDD/

THIN METAL-COATED POLYMER FOIL CHEMICALLY ETCHED WITH 5-100 HOLES mm^2



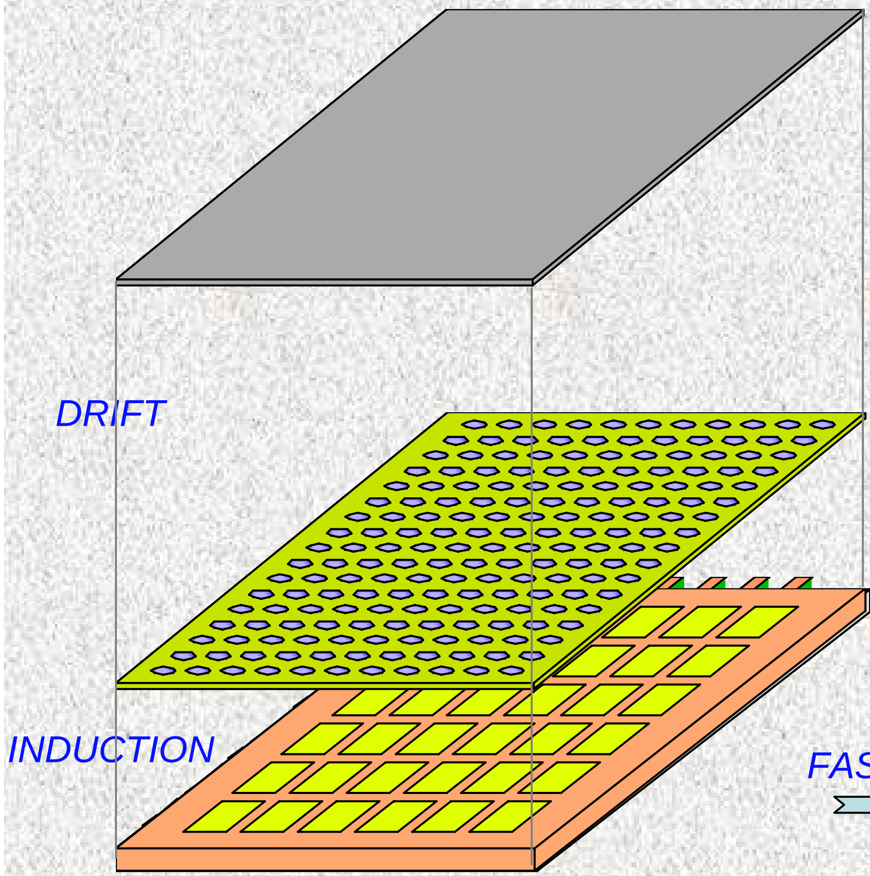
Typically:
50 µm Kapton
5 µm Copper
70 µm holes at 140 µm pitch

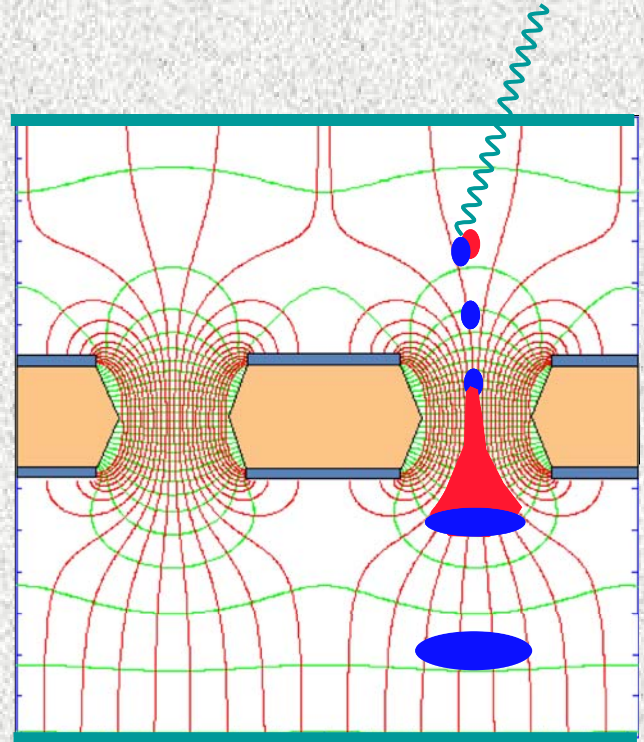


MANUFACTURED BY CERN-TS-DEM (Rui De Oliveira)

F. Sauli, NIMA 386(1997)531

AMPLIFICATION AND TRANSFER SINGLE GEM DETECTOR:





INDEPENDENT PROPORTIONAL COUNTERS (~ 50/mm^2) ⇒ HIGH RATE CAPABILITY

HIGH VOLTAGE ELECTRODE SEPARATED FROM READOUT ⇒ ROBUSTNESS

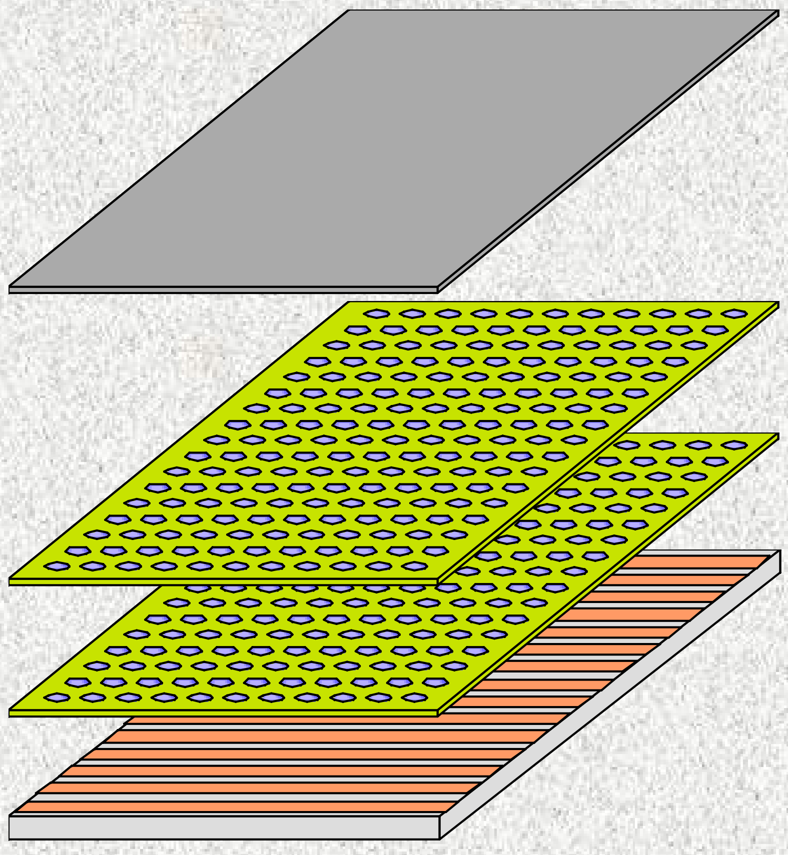
FAST ELECTRON SIGNAL ONLY ⇒ HIGH RATES, GOOD TWO-TRACK RESOLUTION

READOUT ELECTRODE: ARBITRARY PATTERN

MULTIPLE GEM DETECTORS:

HIGHER GAIN

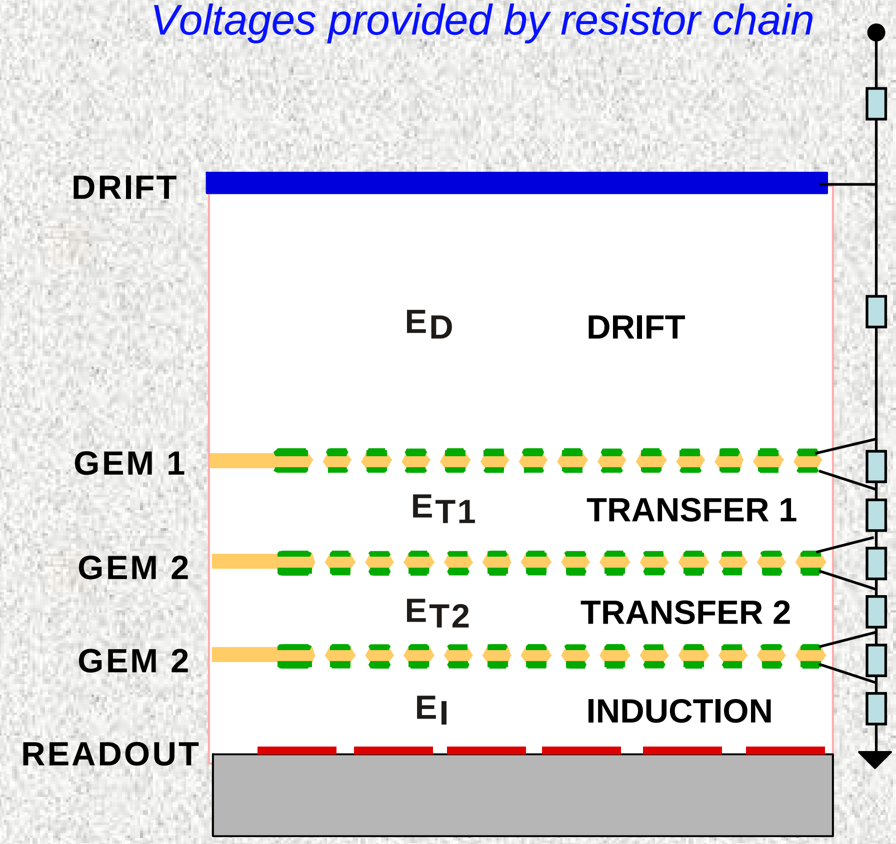
LOWER OPERATING VOLTAGE AND/OR SAFER OPERATION



UP TO 5 CASCADED GEMS TESTED

(for single photoelectron detection)

Voltages provided by resistor chain

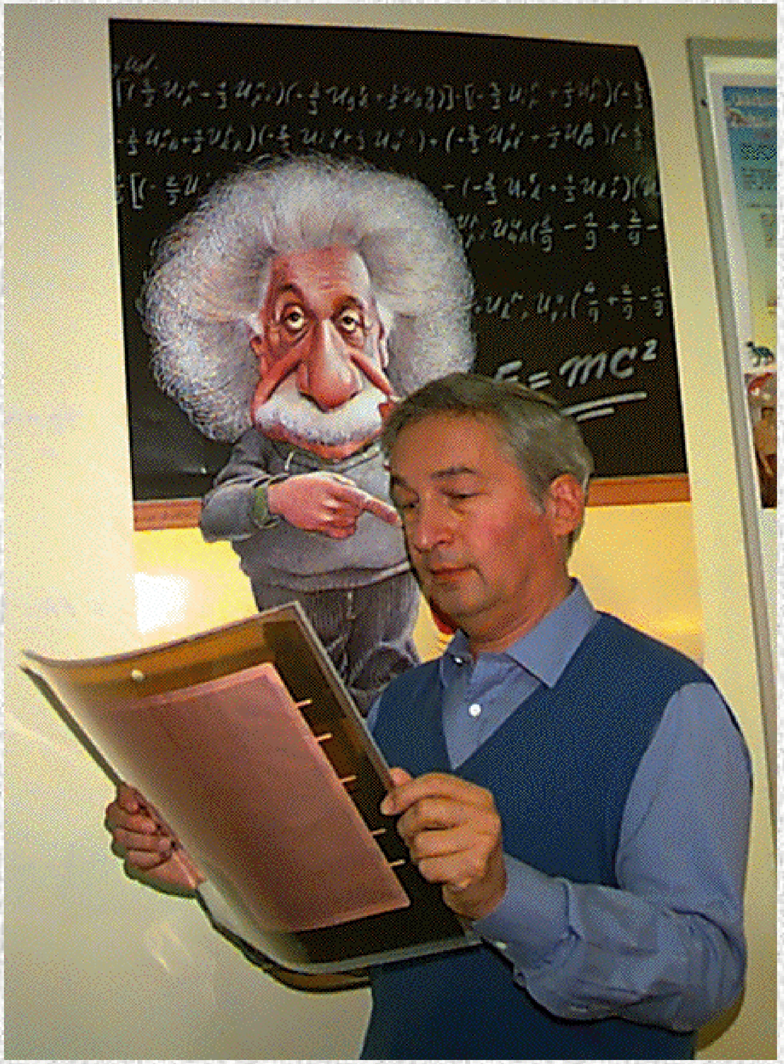


WIDE RANGE OF SHAPES AND SIZES

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

COMPASS GEM 31x31 cm^2

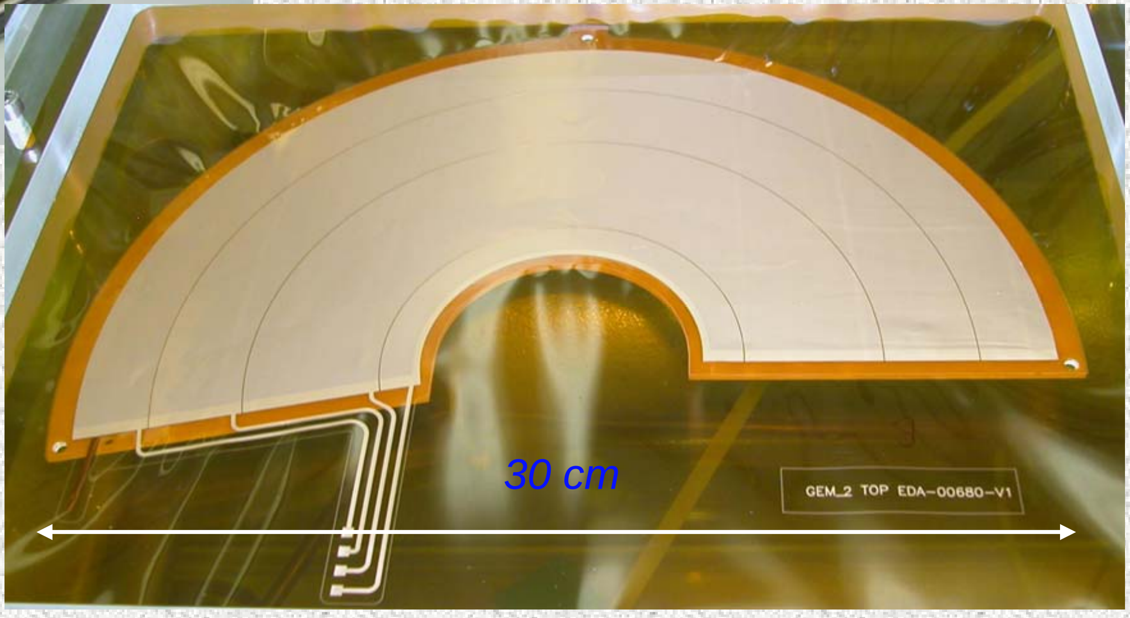
"Standard" GEM:
10x10 cm^2
(available in CERN stockroom)



Nuclear Magnetic Spectrometer (Osaka Univ.)

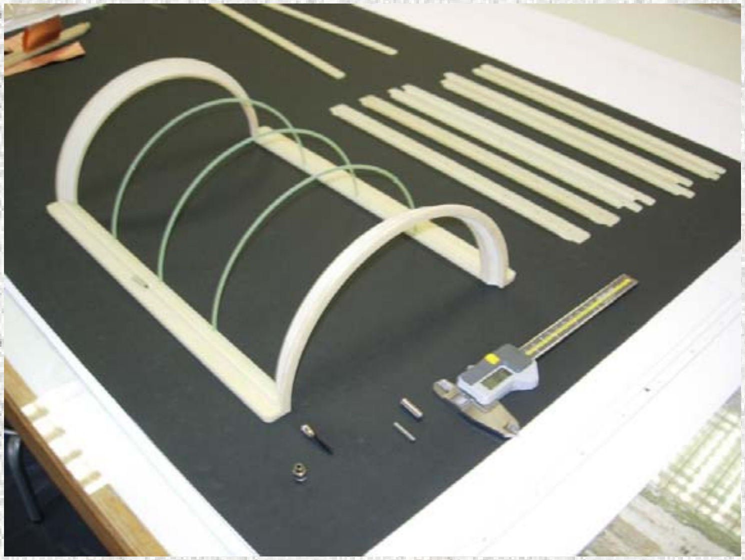
Round GEM (30 cm Ø)
ESA prototype

Half-Moon (TOTEM T2)



CYLINDRICAL GEM DETECTOR

CERN-PH-DT2 (NA49 UPGRADE?)



Eric David and Miranda Van Stenis

SPHERICAL GEM DETECTOR:

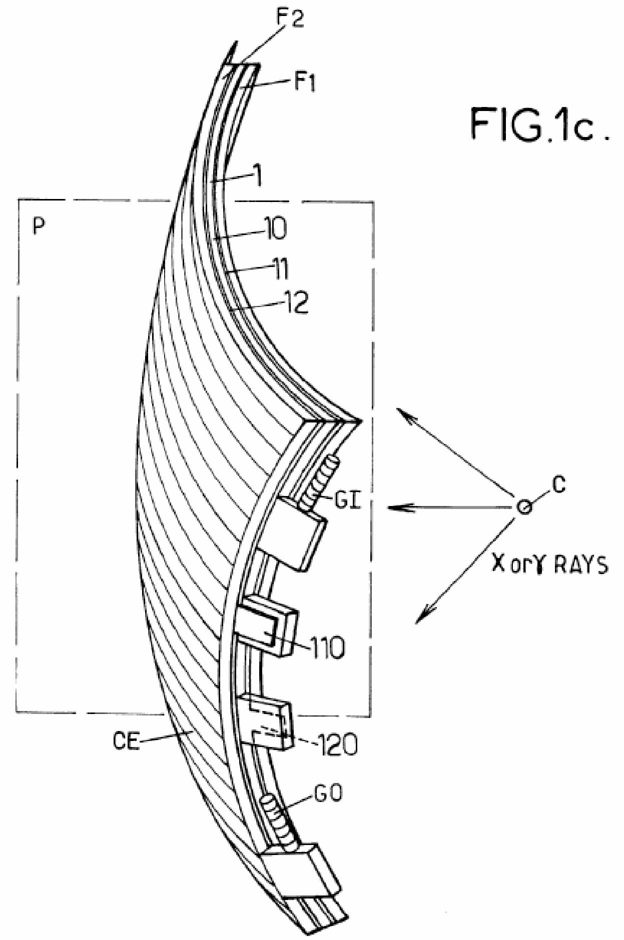
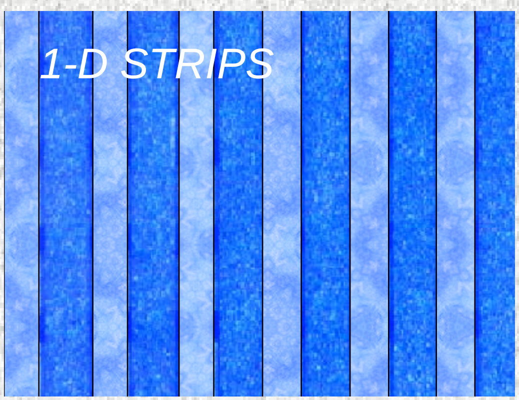
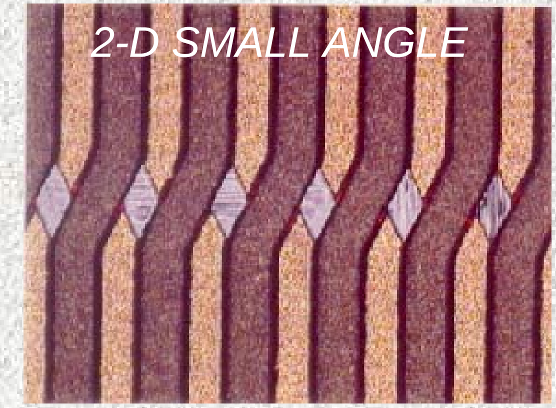


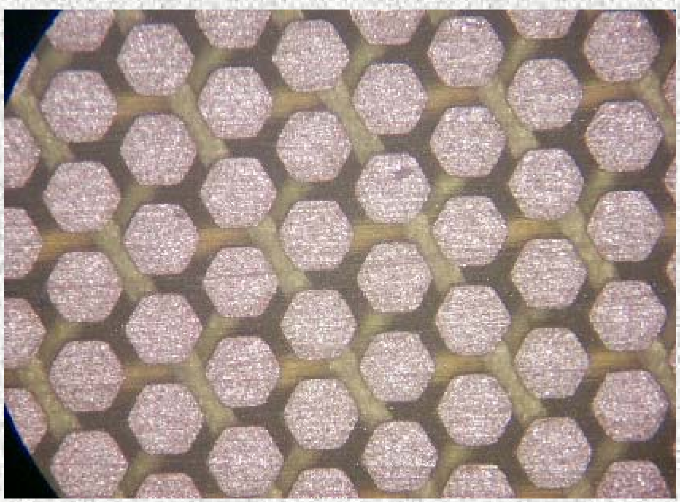
FIG.1c.

VARIOUS READOUT PATTERNS ON ANODE:

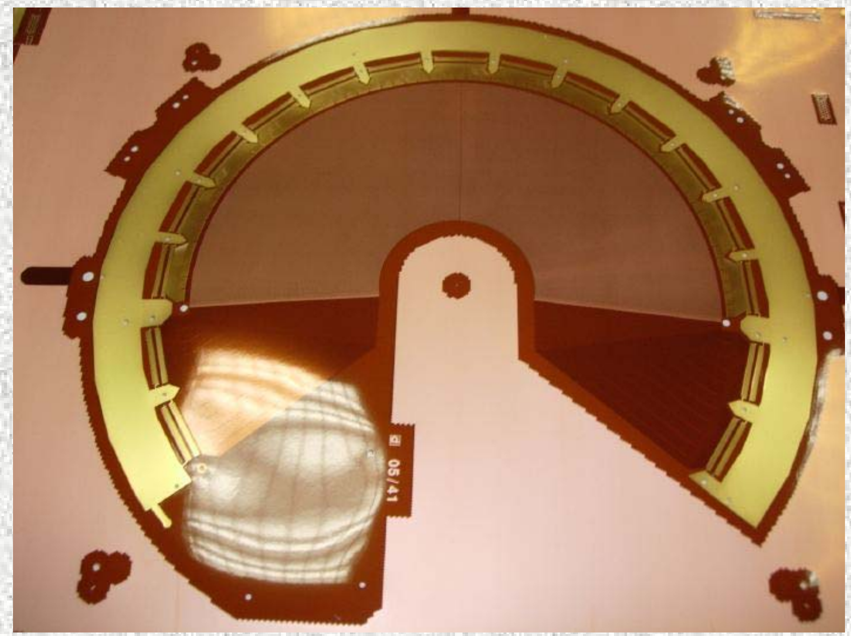




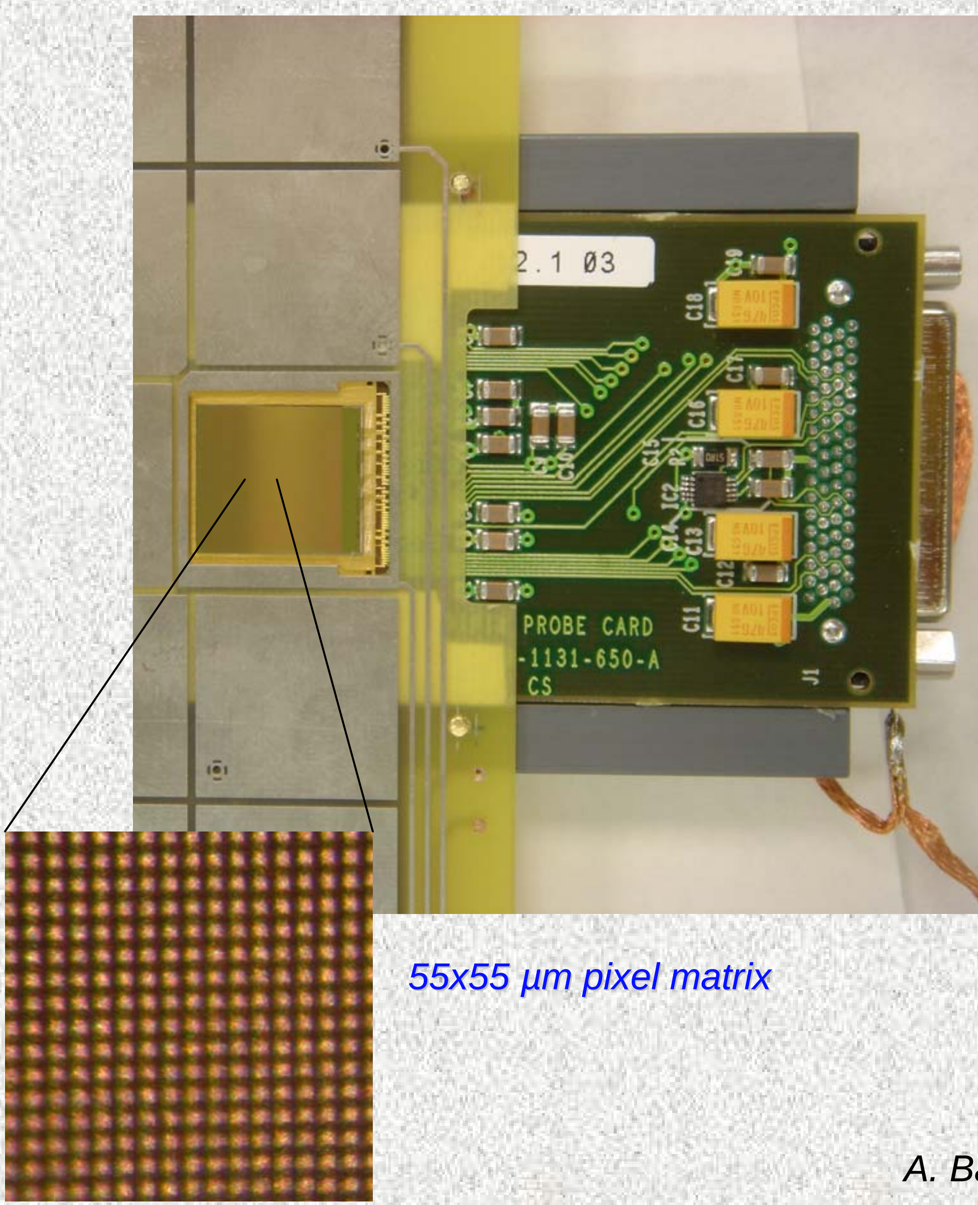
PADS



STIPS AND PADS (TOTEM):



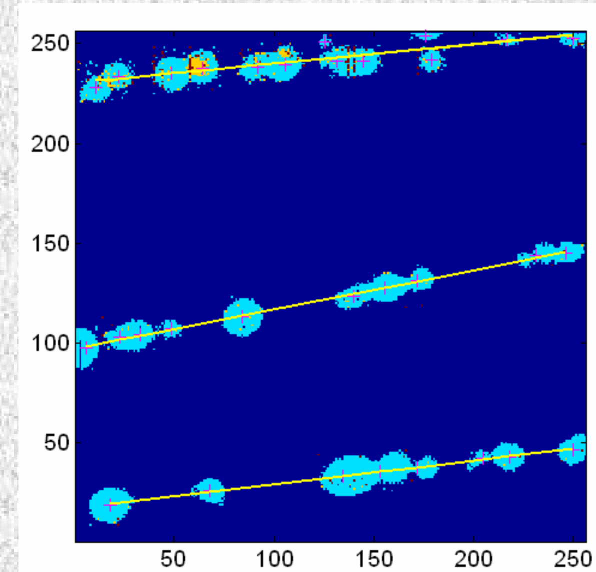
PIXEL READOUT OF GEM DETECTORS: MEDIPIX



55x55 µm pixel matrix

- Digital readout: preamp / discriminator
- Two DAC thresholds (low, high)
- Noise RMS ~ 150 e^-/channel

Triple GEM+MEDIPIX2
A-CO_2 70-30



ROBUST:
No damages to MEDIPIX in 10 months of running

A. Bamberger et al, IEEE NSS (Puerto Rico 2005)

GEM MANUFACTURING (CERN PROCESS)

DOUBLE-CONICAL STANDARD GEM:

50 µm Polymer +5 µm Cu both sides

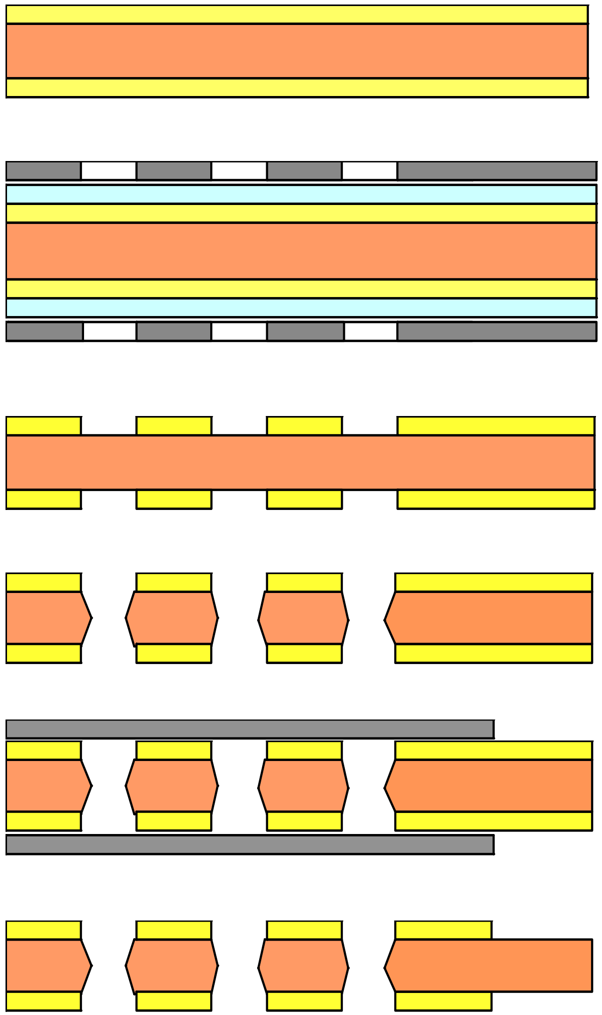
Photoresist coating, masking, exposure to UV light

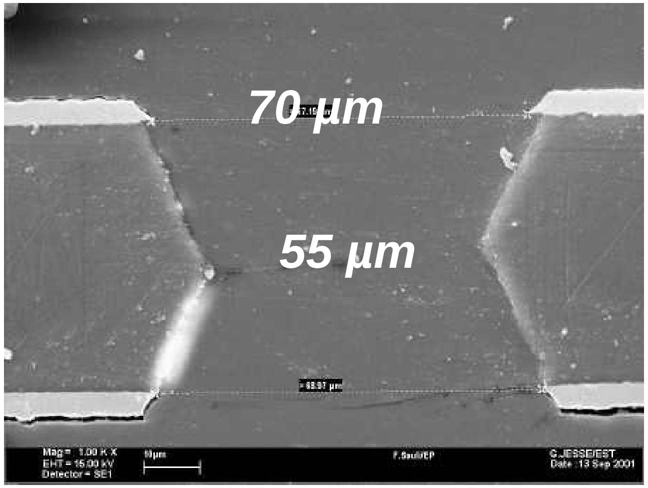
Metal etching

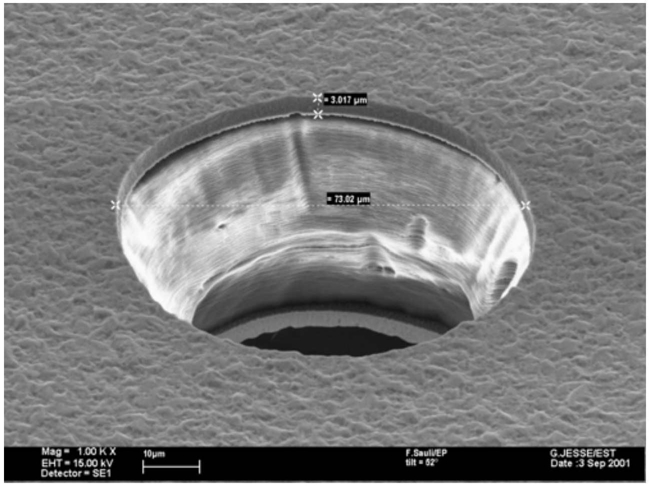
Polymer etching

Second masking

Edge metal etching and cleaning

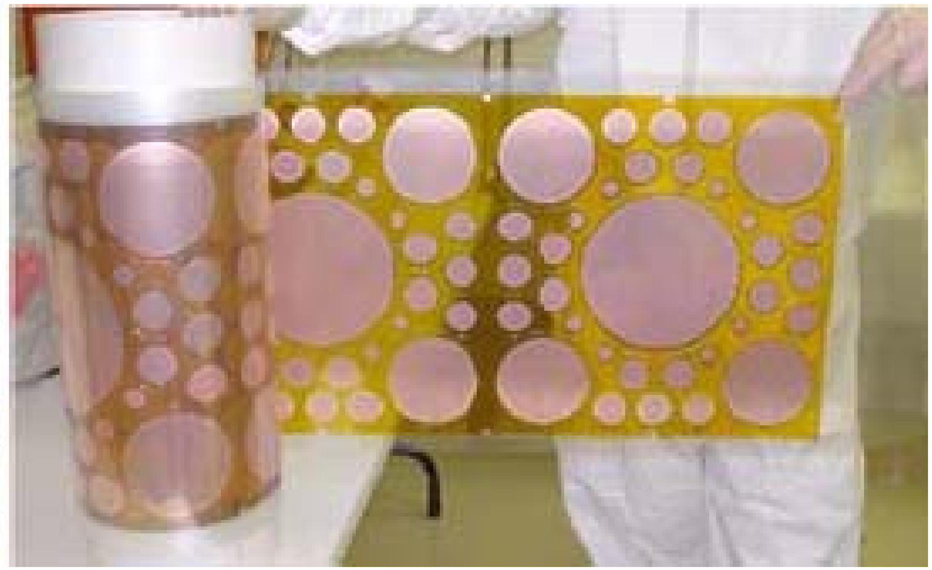






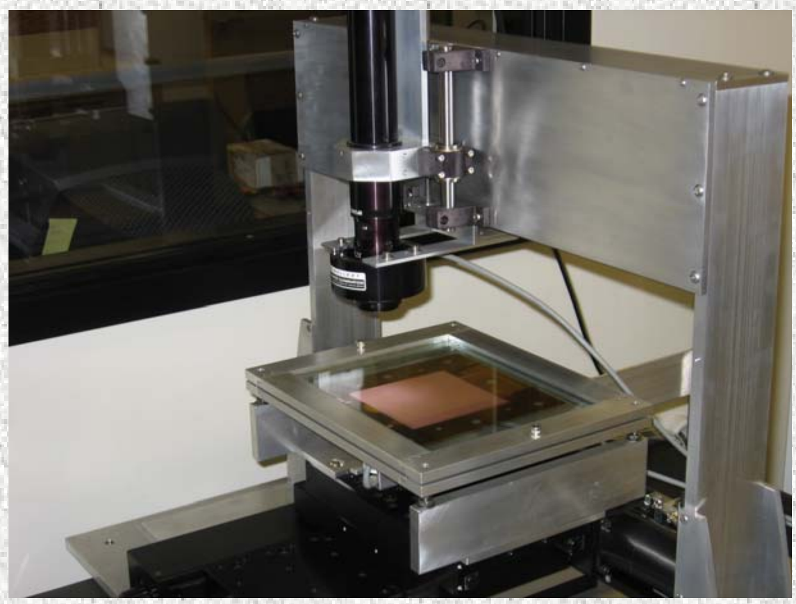
Other manufacturer

- 3M, USA: wet etching

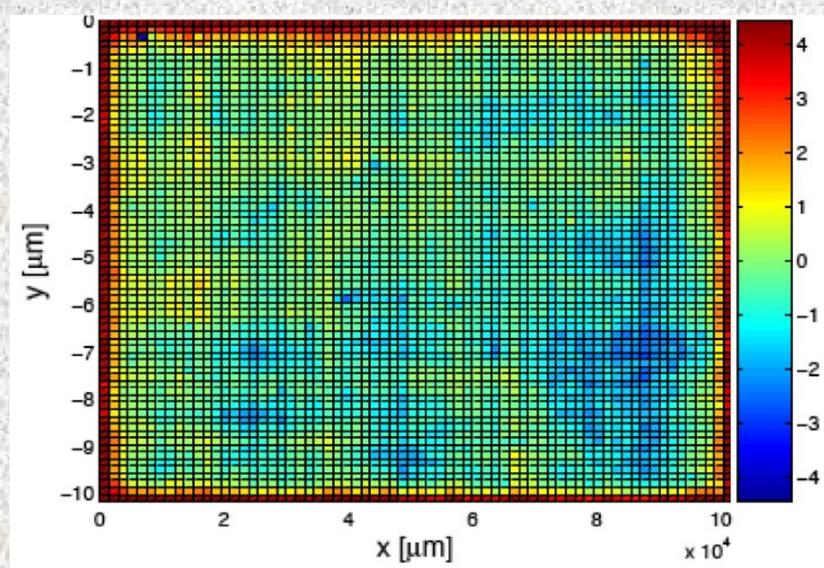


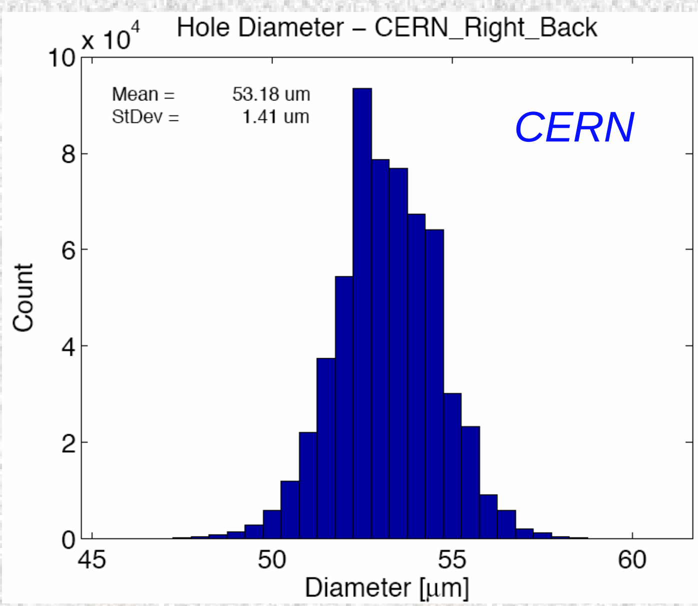
- TechEtch: wet etching
- Scienergy(Riken): Laser & Plasma Etching

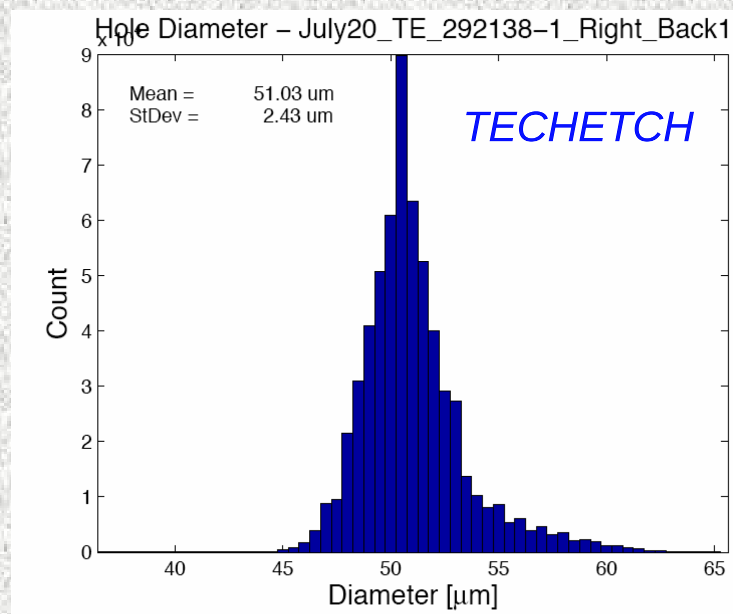
MIT OPTICAL SCANNER

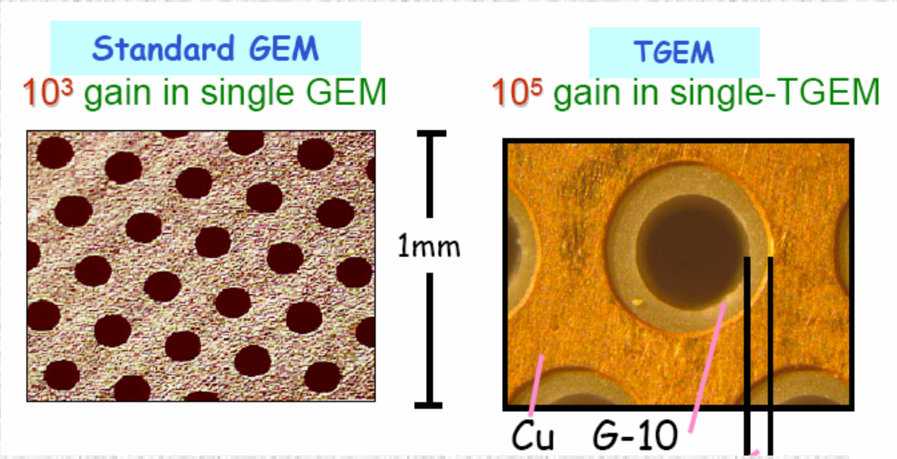


TechEtch GEMs Inner diameter distribution

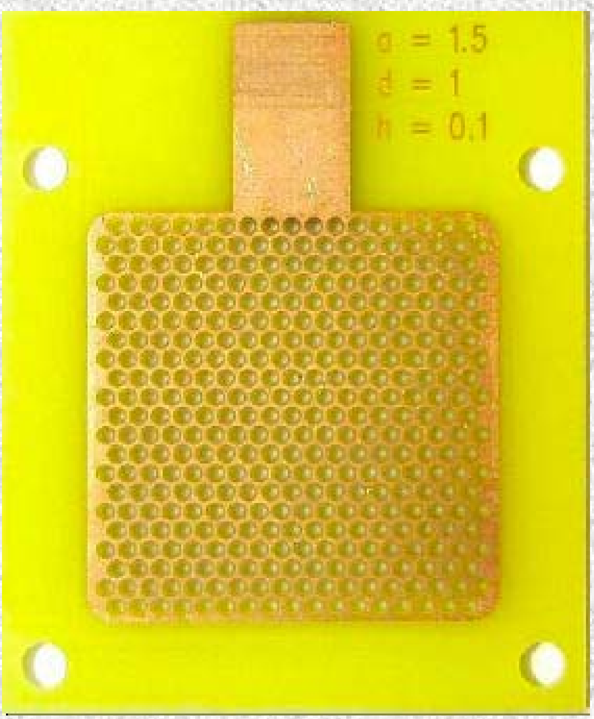


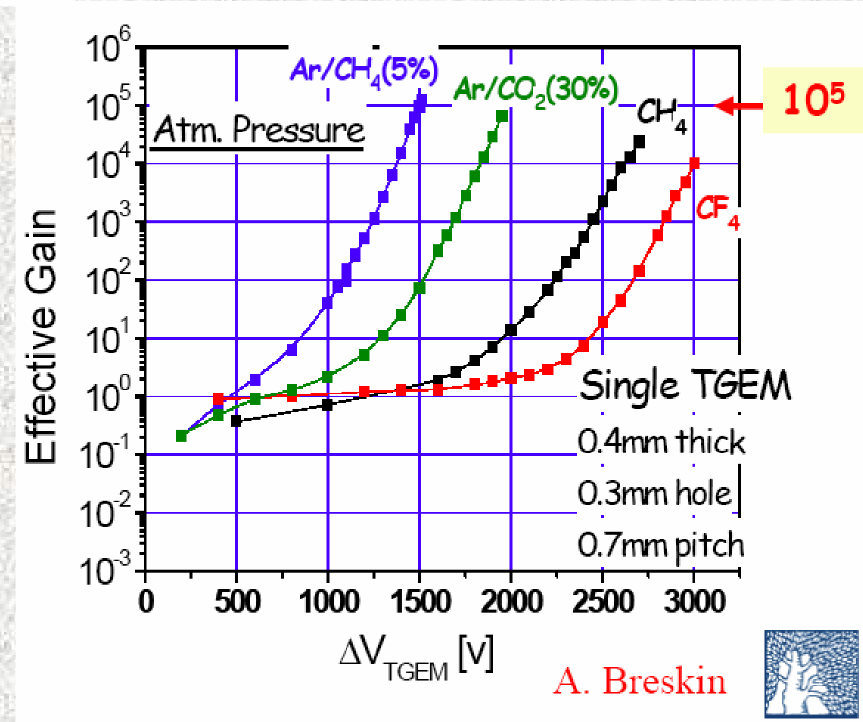






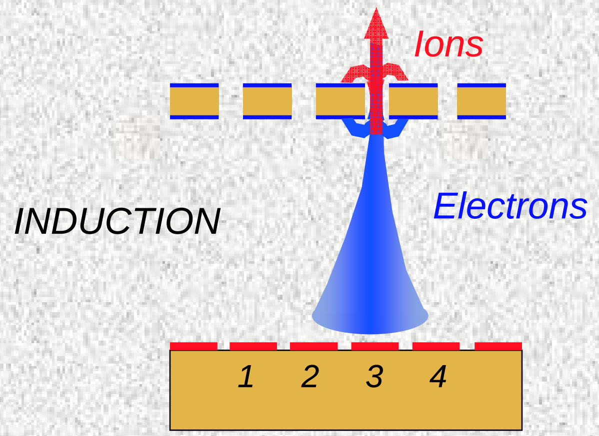
THICK GEM
(A. Breskin et al, WIS)



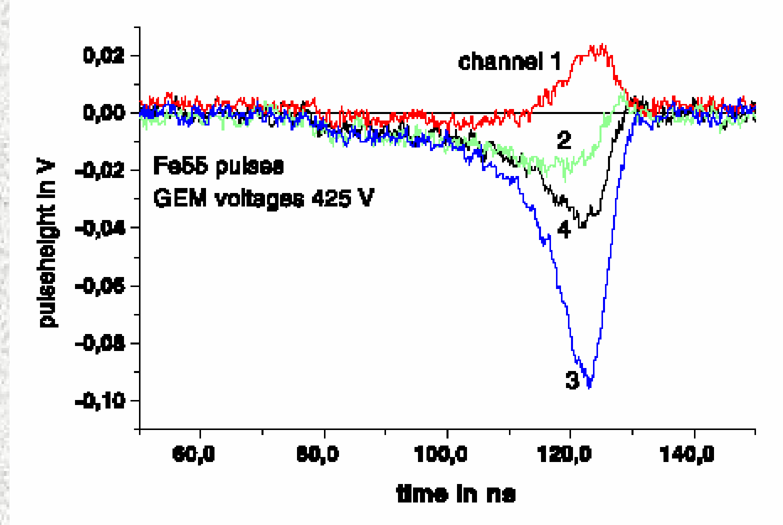


R. Chechick et al, NIMA 553(2005)35

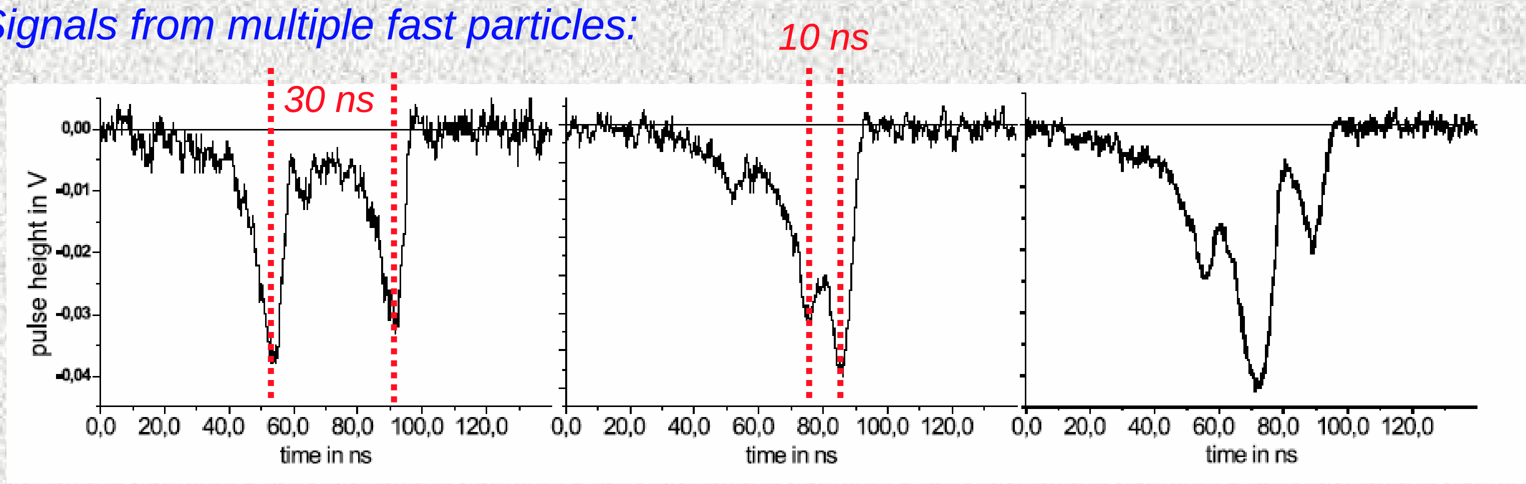
FAST ELECTRON SIGNAL ONLY
Excellent multi-track resolution!



Signals on adjacent strips (500 µm pitch)



Signals from multiple fast particles:

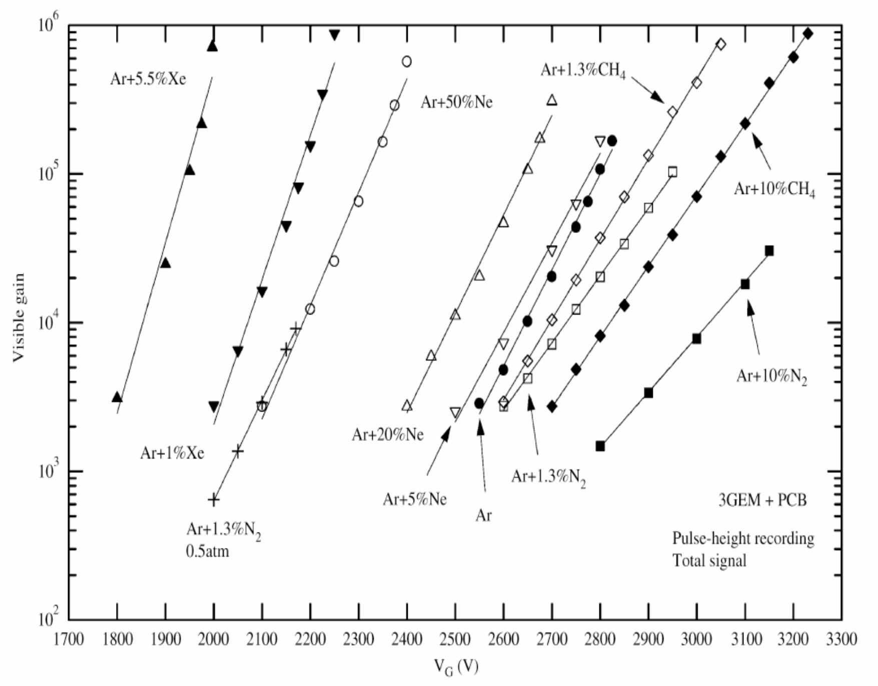


A-CO_2 70-30, 5kV cm^{-1} w = 7.5 cm μs^{-1}

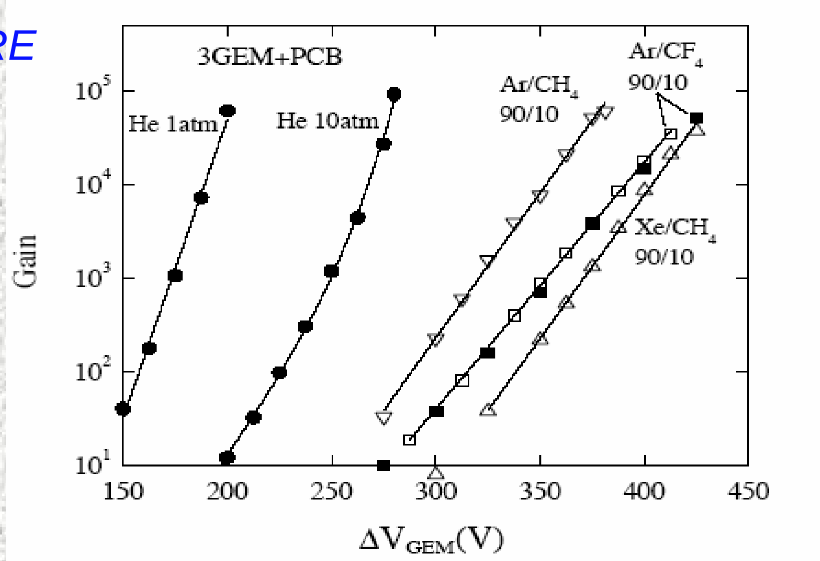
M. Ziegler, PhD dissertation (2002)

HIGH GAINS IN VIRTUALLY ANY GAS MIXTURE

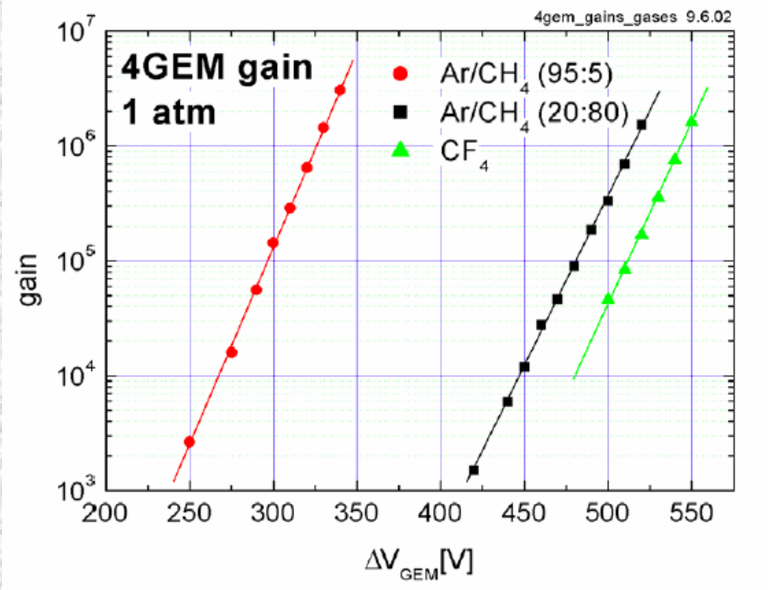
Noble Gases Mixtures
(Development of GEM photomultipliers)



A. Buzulutskov et al, NIMA 443(2000)164

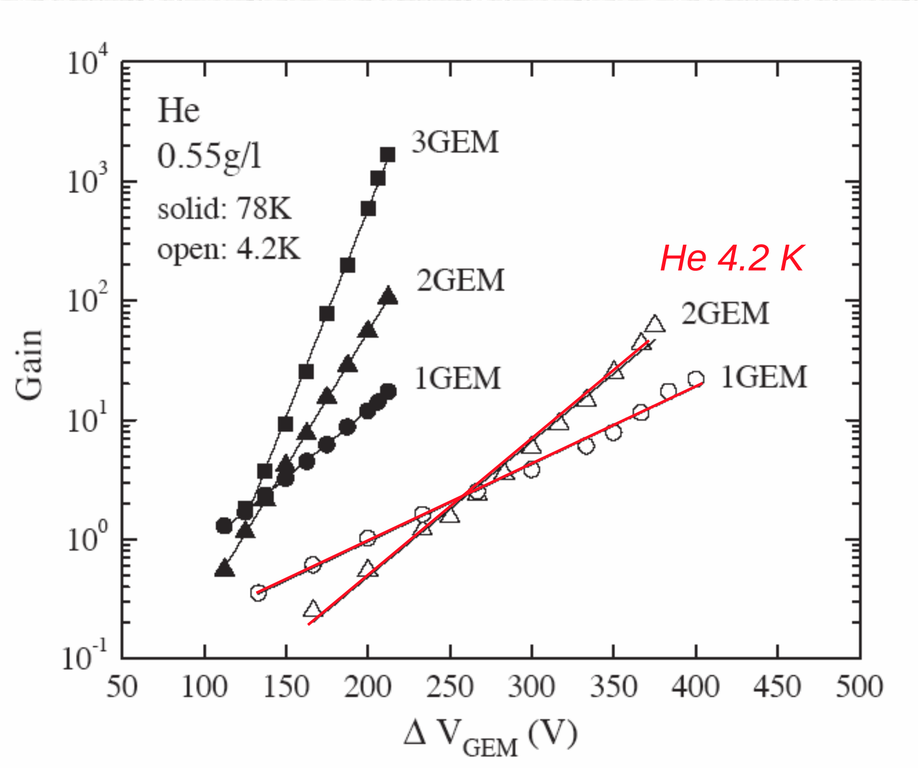


A.Bondar et al, NIMA 496(2003)325



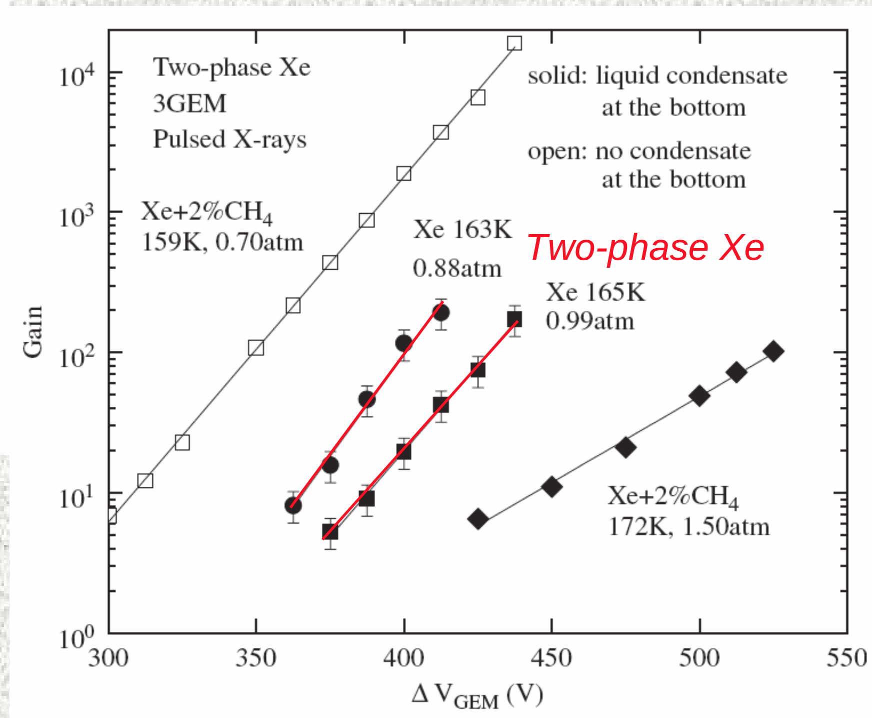
D. Mörmann et al, NIMA

LOW TEMPERATURE NOBLE GASES:



A. Buzulutskov et al, NIMA 548(2005)487

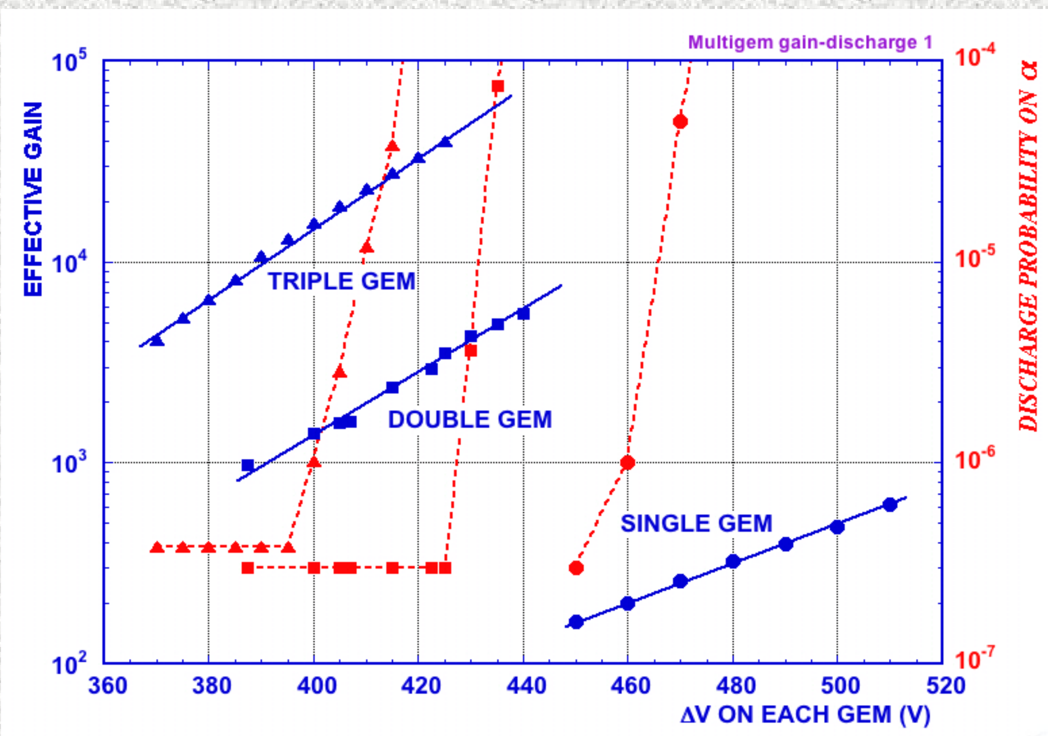
TWO-PHASES CRYOGENIC DETECTORS:



A. Bondar et al, NIMA 556(2006)273

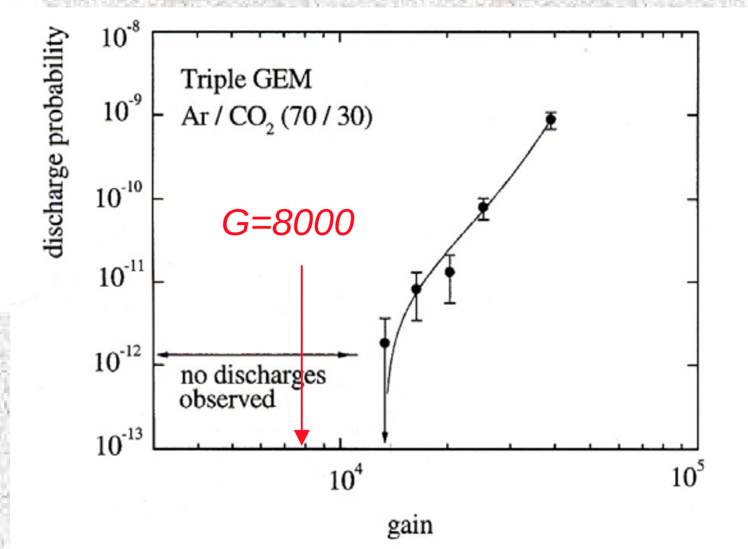
MULTIGEM: HIGH GAINS IN HOSTILE ENVIRONMENT

DISCHARGE PROBABILITY ON EXPOSURE TO 5 MeV α (from internal ^{220}Rn gas)



S. Bachmann et al, NIMA 479(2002)294

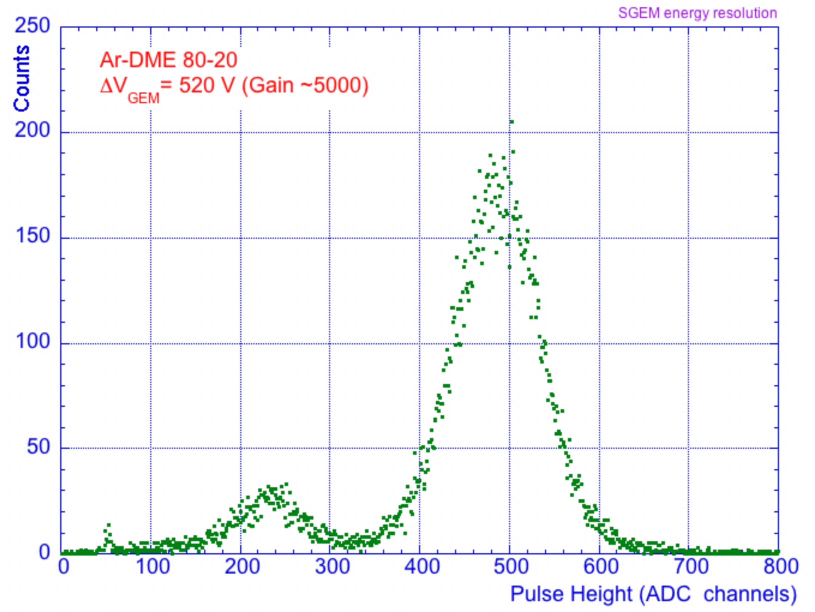
TEST AT PSI πM1 beam:
No discharges in 12 hrs of operation at gain 10^4
(and 4 years of operation in COMPASS!)



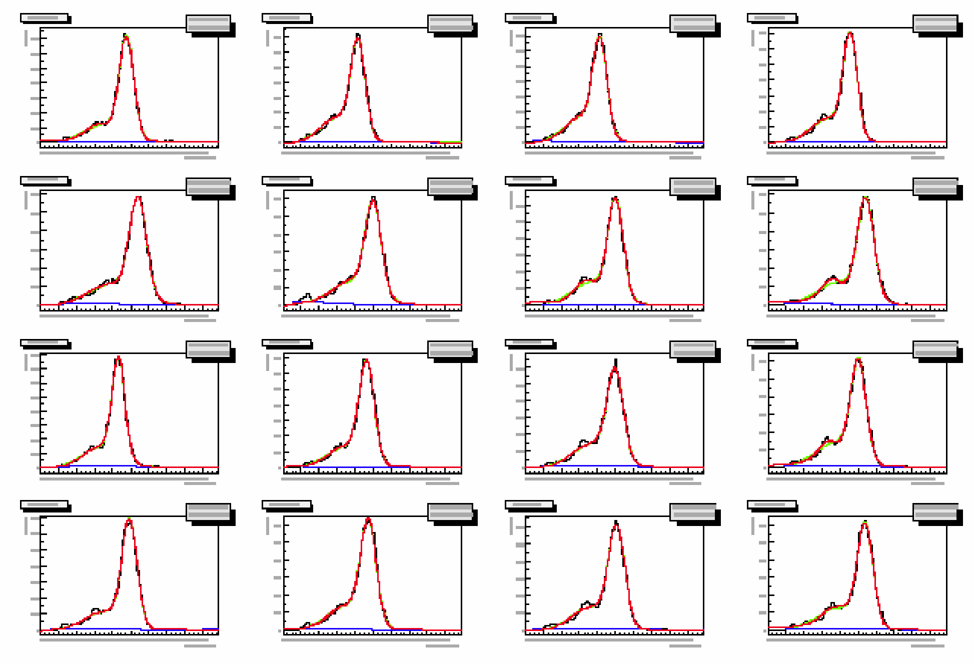
S. Bachmann et al, NIMA 470(2001)548

GEM DETECTORS PERFORMANCE: ENERGY RESOLUTION AND GAIN UNIFORMITY

5.9 keV ^{55}Fe : 20% FWHM

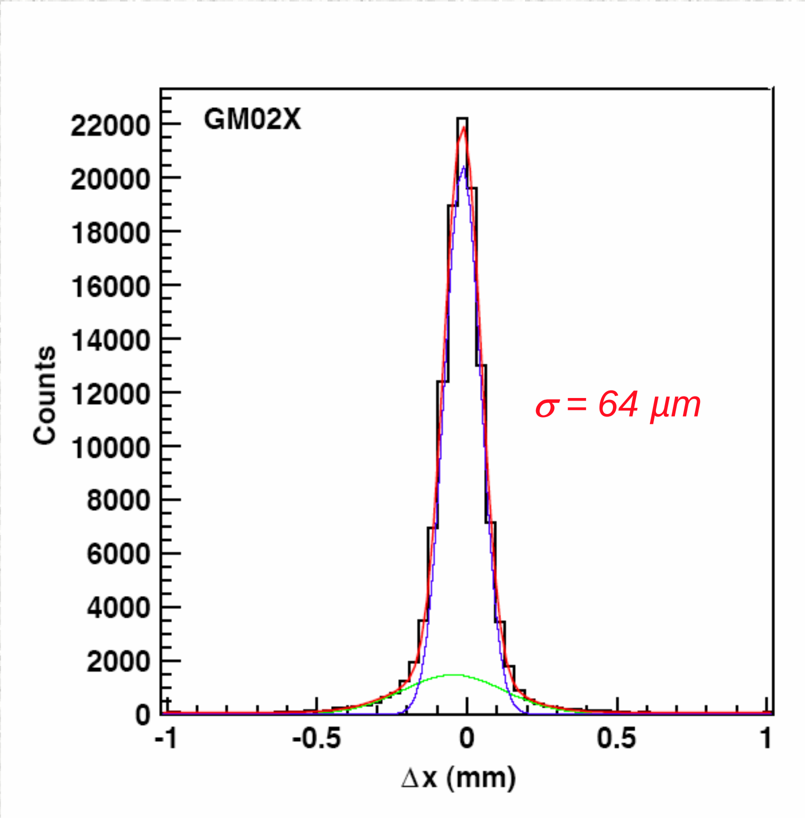


COMPASS CHAMBERS (31x31 cm^2)
PH spectra on 9 keV X-rays in 16 points
Maximum gain variation $\pm$ 15%



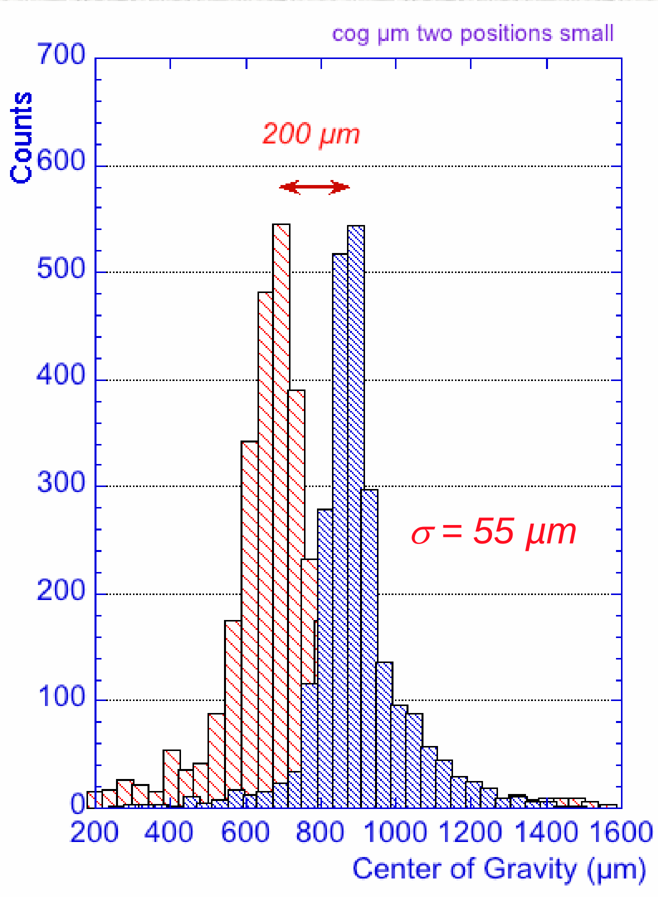
(Hole's diameter tolerance: $\pm$ 2.5 μm)

RESIDUALS FOR MINIMUM IONIZING PARTICLES (COMPASS TRACKER):



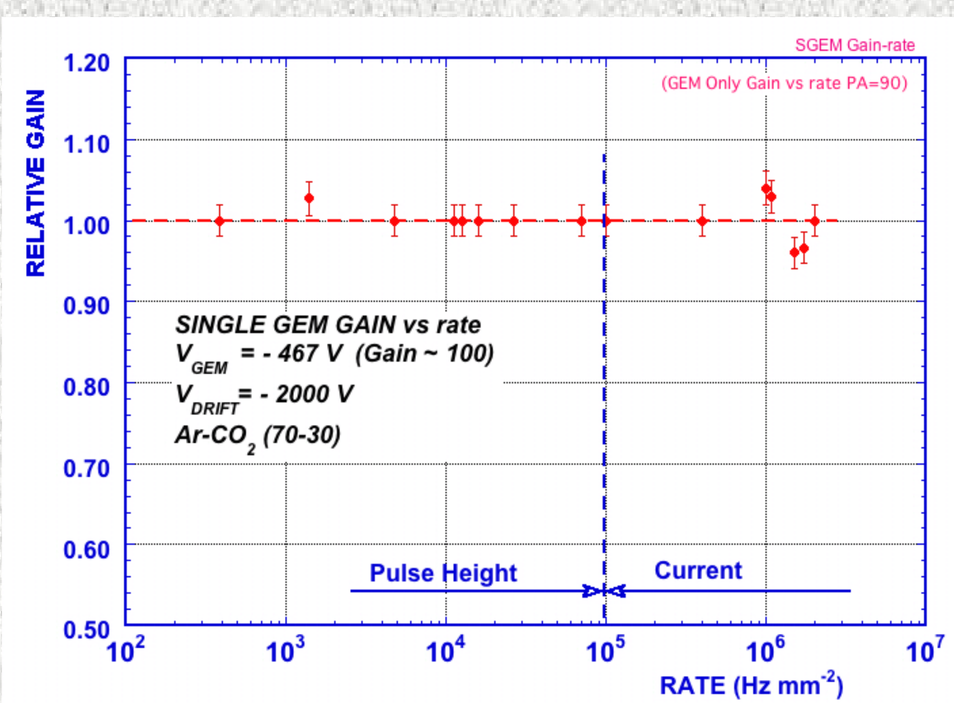
B. Ketzer et al, NIMA 535(2004)314

SINGLE PHOTOELECTRON (CsI-Coated T-GEM) Center of gravity distribution for two UV light beams, 200 µm apart:



T. Meinschad et al, NIMA 535(2004)324

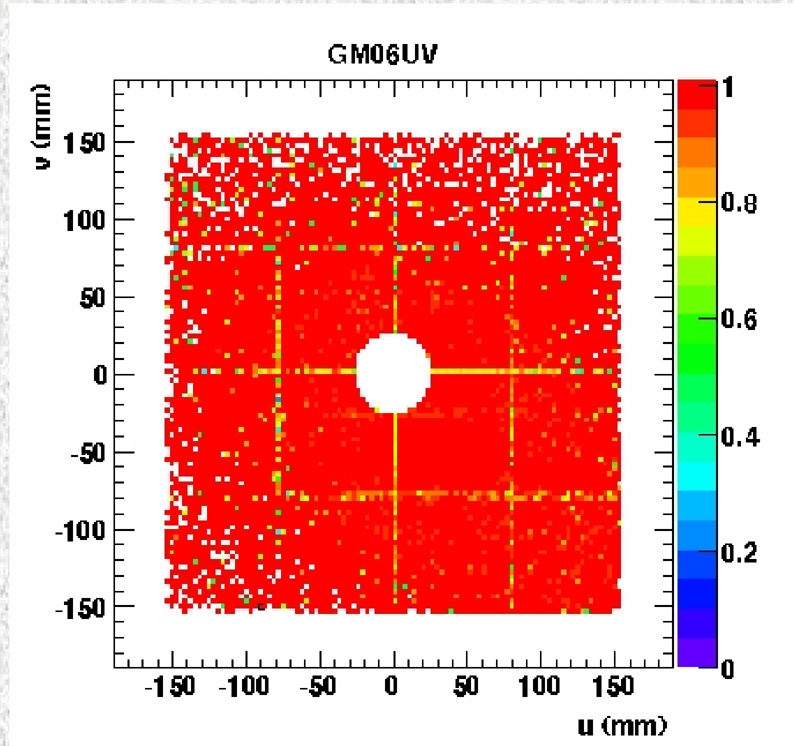
RATE CAPABILITY (5.9 keV X-rays): > 2.10^6 mm^{-2}



J. Benlloch et al, IEEE NS-45(1998)234

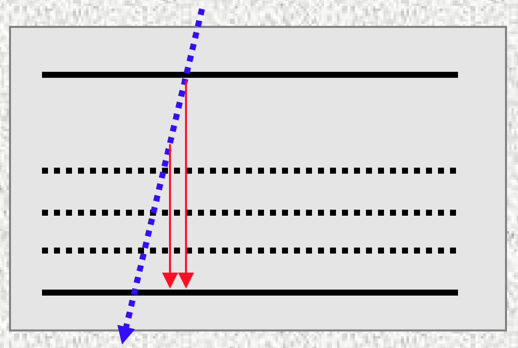
EFFICIENCY IN RUNNING CONDITIONS (COMPASS TGEM TRACKER) ~ 97.2 %

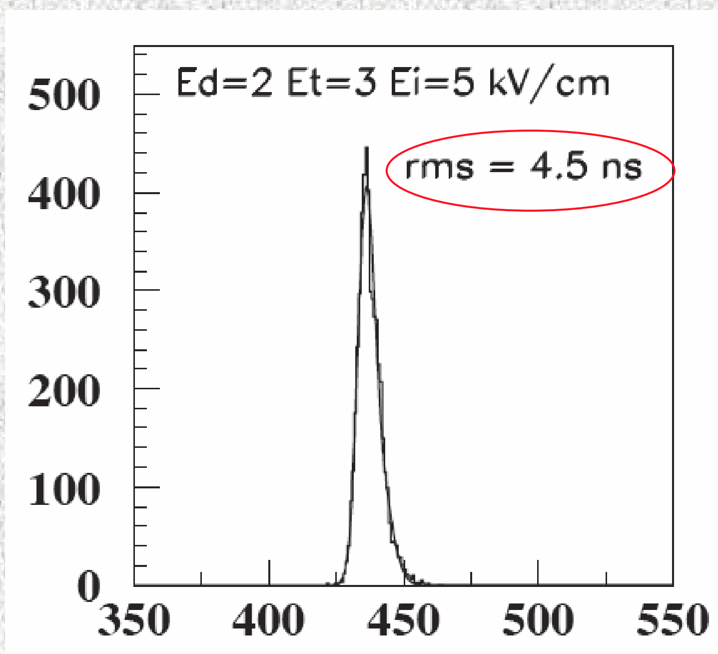
High intensity runs (25 kHz mm^{-2})



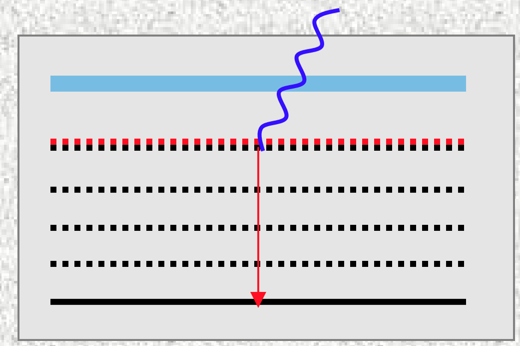
B. Ketzer et al, NIMA 535(2004)314

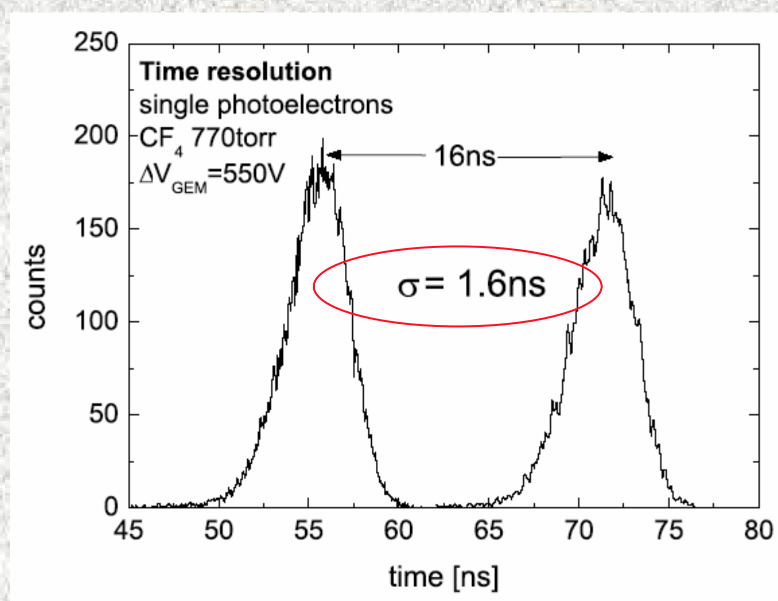
CHARGED PARTICLES
Using a fast gas (A-CO_2-CF_4)
LHCb muon trigger





INTRINSIC TIME RESOLUTION:
4-GEM with reflective photocathode
(isochronous electrons)

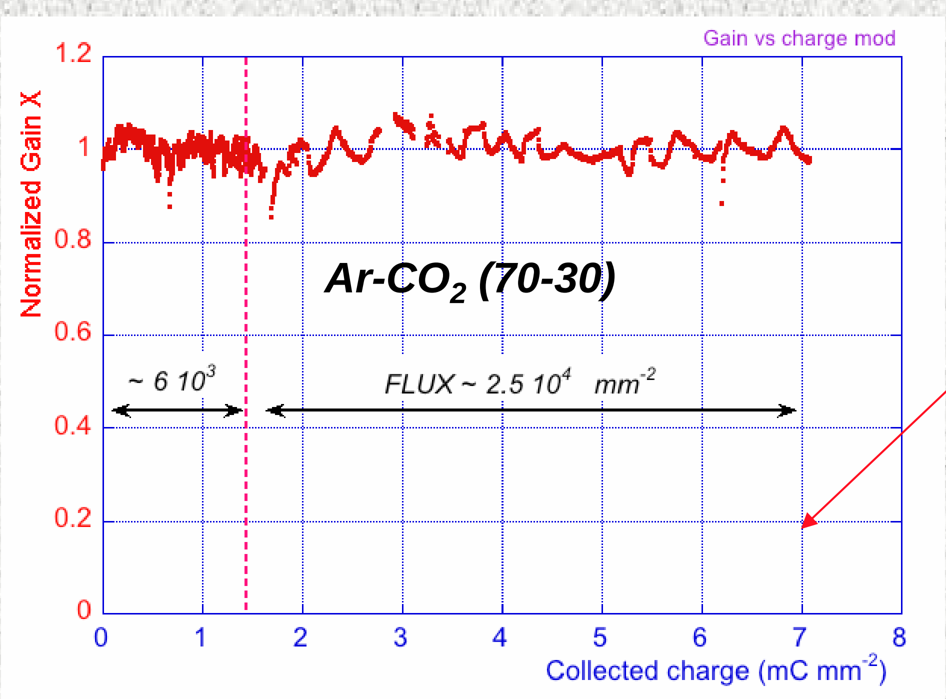




M. Alfonsi et al, NIMA A535(2004)319

D. Mormann et al, NIMA 504(2003)93

GAIN vs COLLECTED CHARGE (on continuous X-rays irradiation)



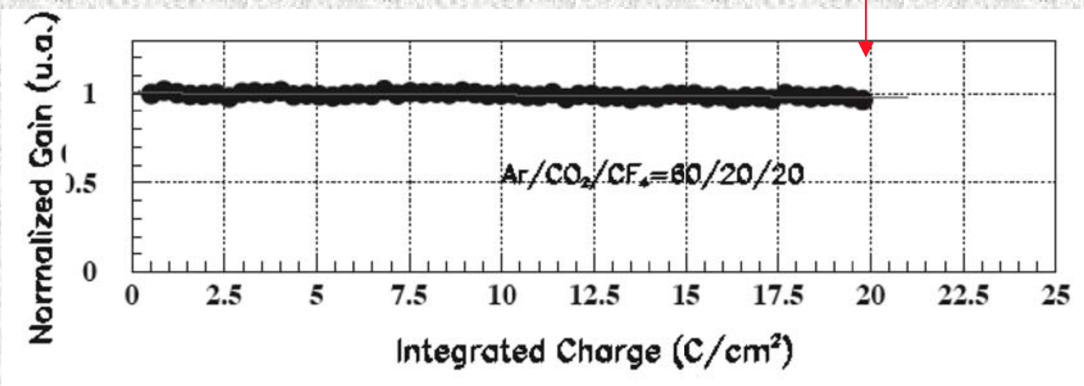
1 mC ~2 •10^{10} min.ion. particles (30 electrons/track, gain 10^4)

7 mC mm^{-2} ~ 10^{11} mips mm^{-2}

200 mC mm^{-2} ~ 4 •10^{12} mips mm^{-2}

C. Altunbas et al, NIMA 515(2003)249

Ar-CO_2-CF_4 (80-20-20)



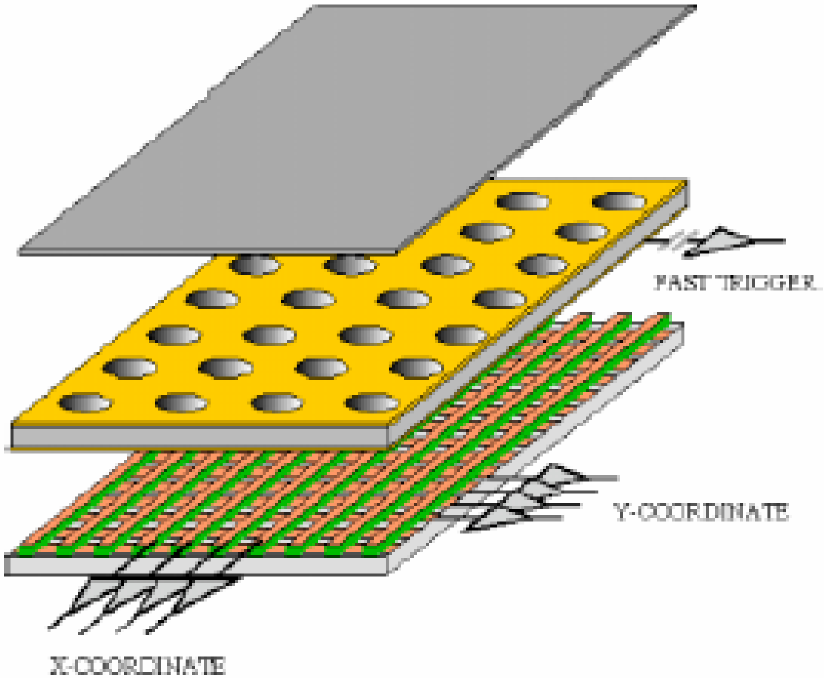
M. Alfonsi et al, NIMA 518(2004)106

GEM application

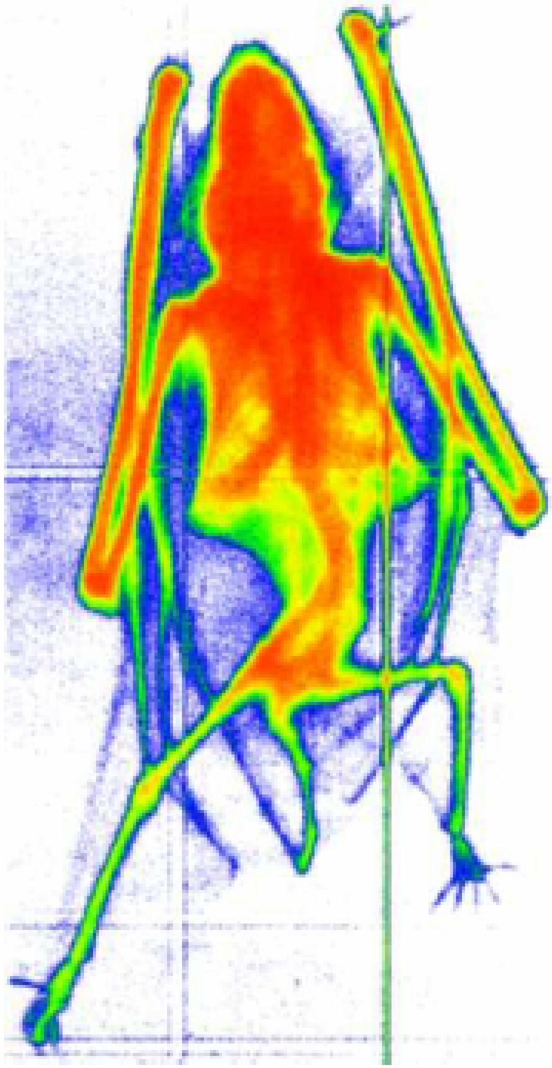
- Radiation imaging
  - X(γ)
  - Neutron
- High energy and particle physics
  - Tracker
  - Trigger
  - Photon detection
  - TPC readout
  - …

X-ray imaging

Using the lower GEM signal, the readout can be self-triggered with energy discrimination:



A. Bressan et al,
Nucl. Instr. and Meth. A 425(1999)254
F. Sauli,
Nucl. Instr. and Meth.A 461(2001)47

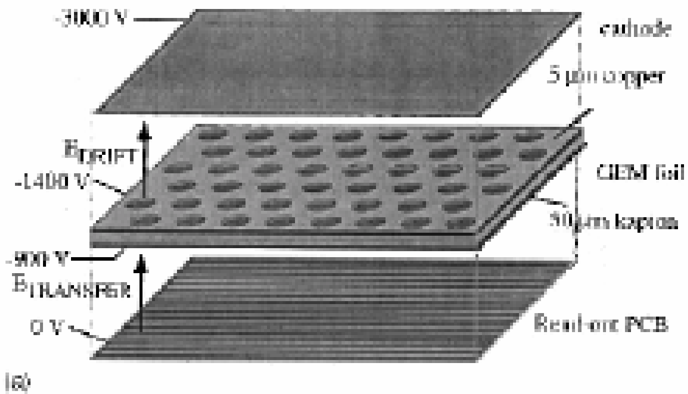


9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm^2)

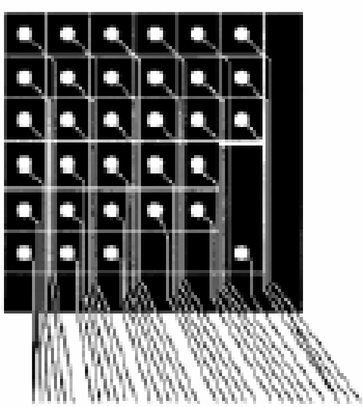
Ultrafast x-ray plasma diagnostics

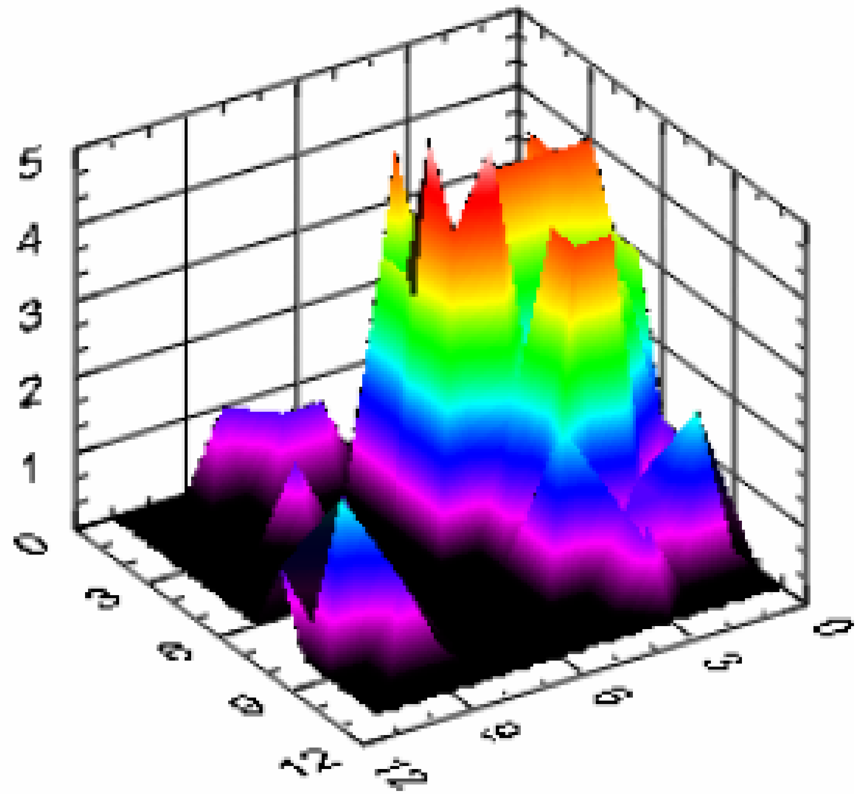
2-D mapping of soft X-ray activity of the plasma on a Tokamak fusion machine (EURATOM-ENEA Frascati, Italy)

Single GEM with fast pixel readout



Readout: 32 2 mm^2 pixels



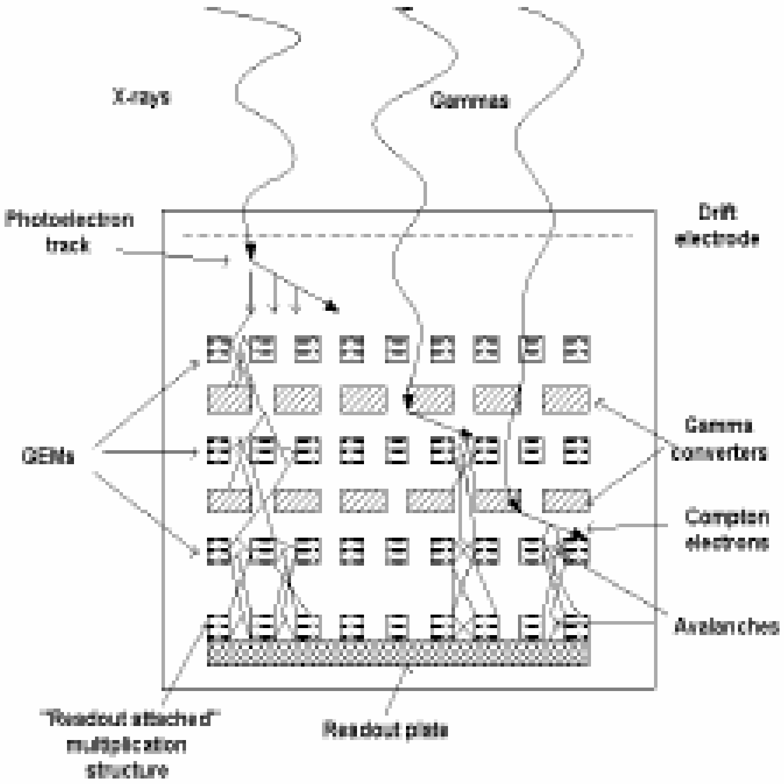


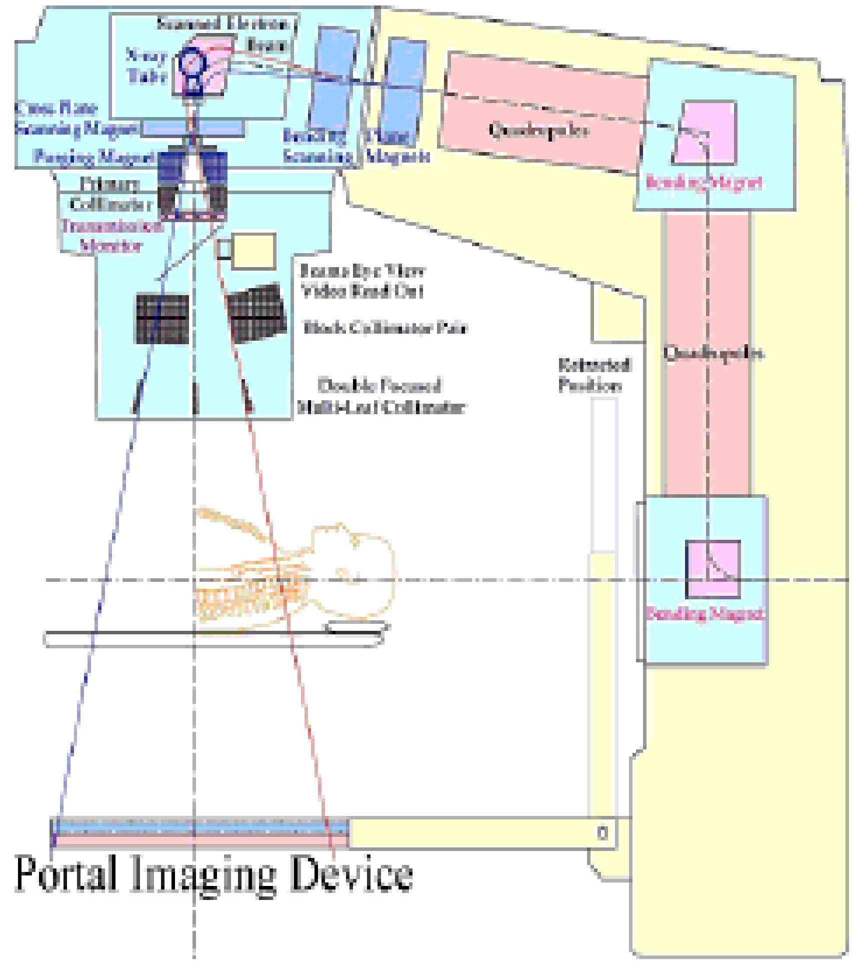
Counting rate vs position

D. Pacella et al, Rev. Scient. Instrum. 72 (2001) 1372

High Energy x(γ) imaging,

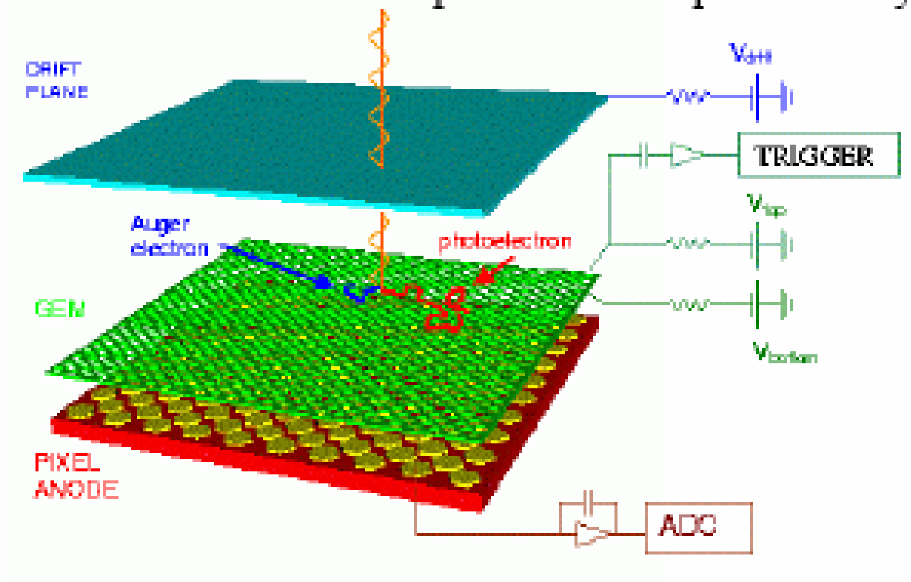
EPID: Electron Portal Imaging Device

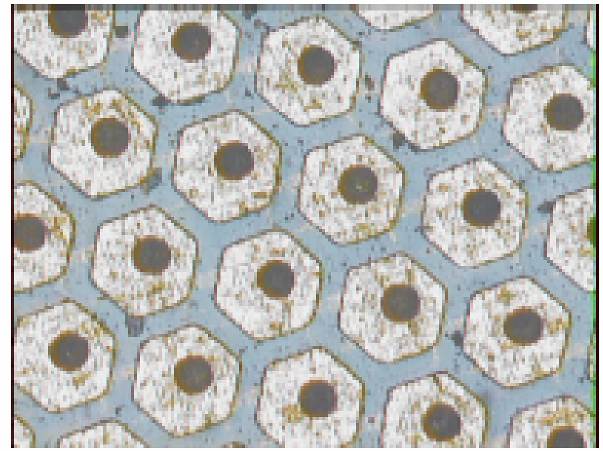




X-ray polarimeter

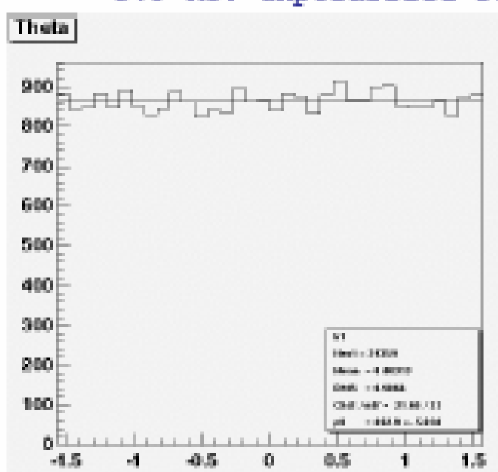
GEM chamber with pad readout to detect the direction of the photoelectron produced by X-rays



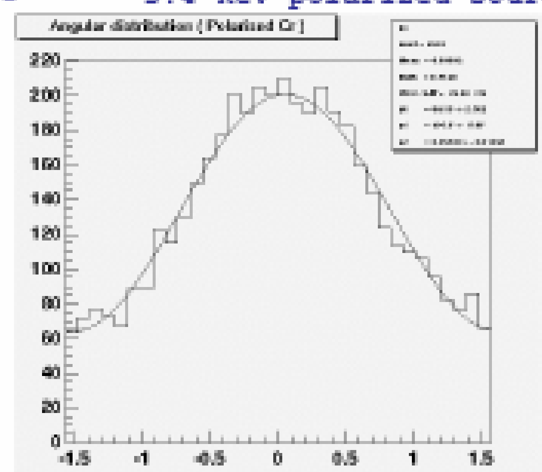


Charge asymmetry distributions for unpolarized and polarized 5.4 keV sources

5.9 KeV unpolarized source



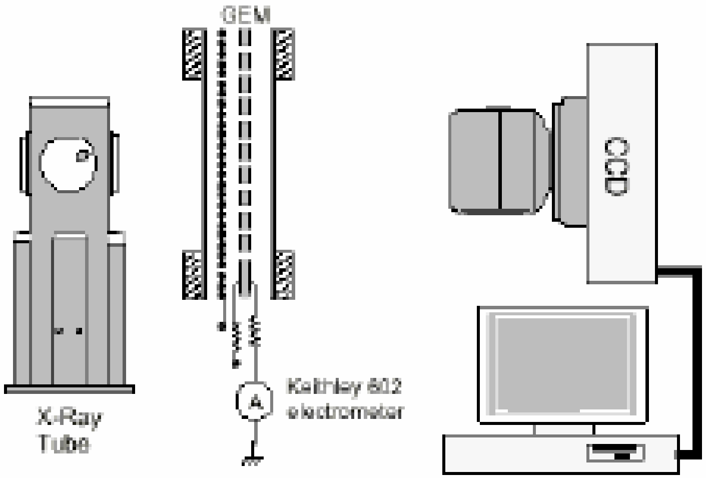
5.4 KeV polarized source



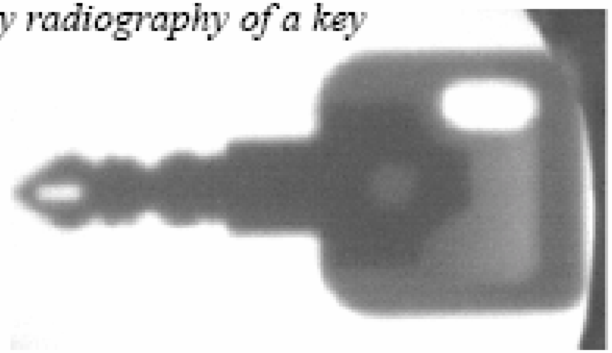
E. Costa et al, Nature 411(2001)662

GEM optical imager

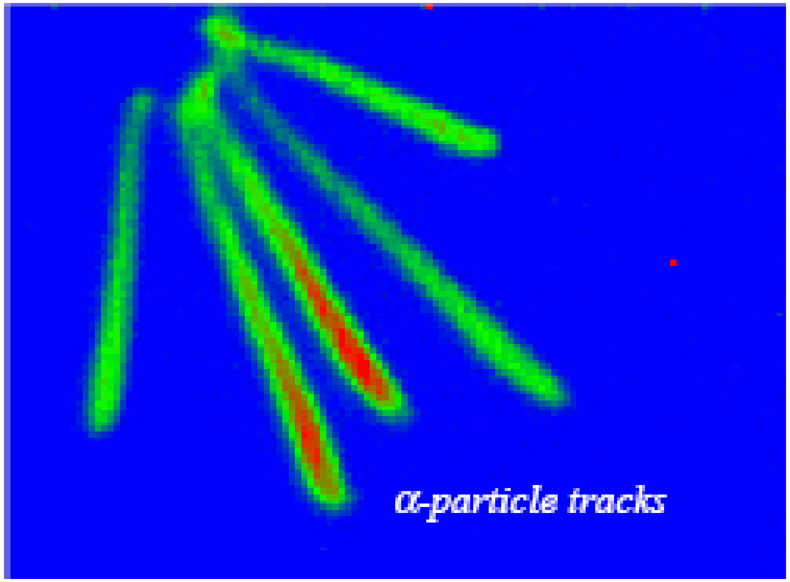
Scintillation light in a multiple GEM detector recorded by a CCD camera

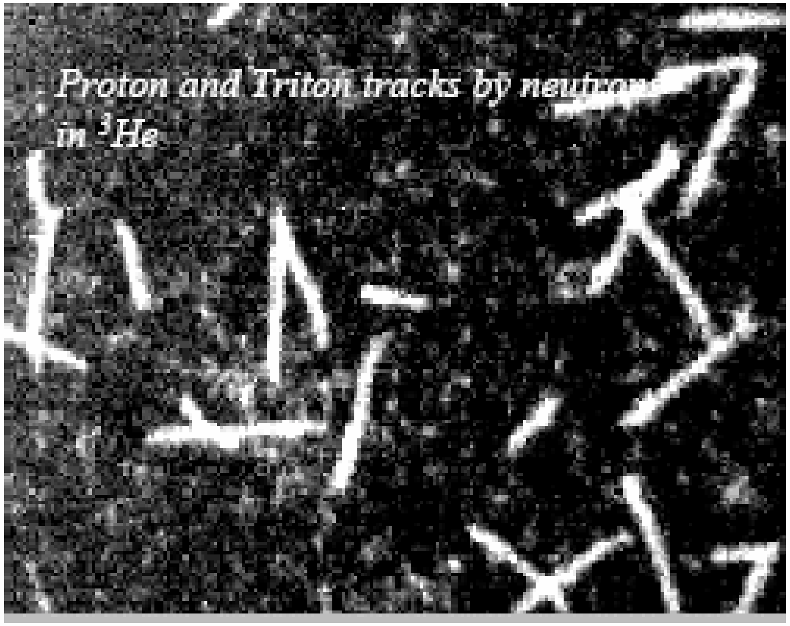


X-ray radiography of a key



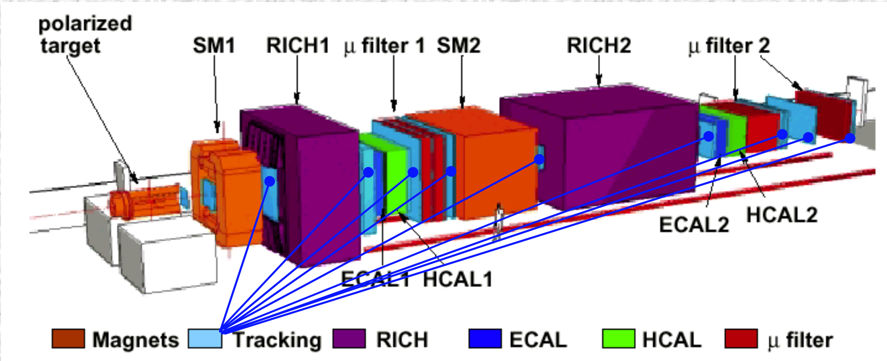
F.A.F. Fraga et al,
IEEE Nucl. Sci. Symp. NS-48 (2001)





TRIPLE GEM TRACKER FOR COMPASS (NA58)

High rate forward spectrometer:
~ 5.10[7] polarized 160 GeV μ^+/s on polarized [6]LiD target



22 Detectors, 31x31 cm^2 active area
2-D Analogue readout (APV25)

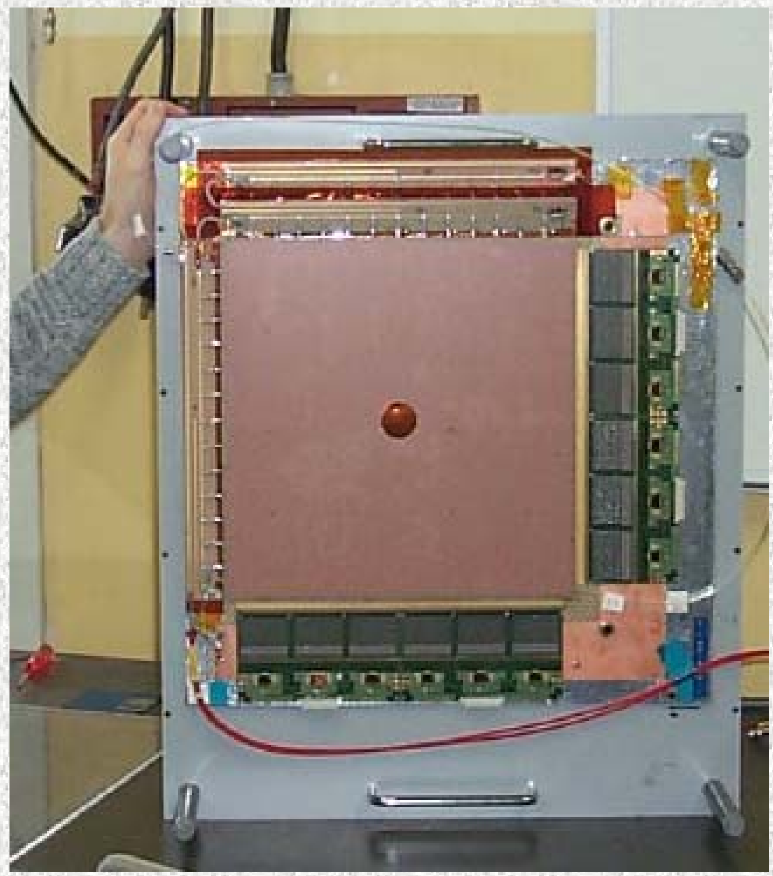
Data taking since 2001

http://wwwcompass.cern.ch/

COMPASS TRIPLE-GEM CHAMBERS

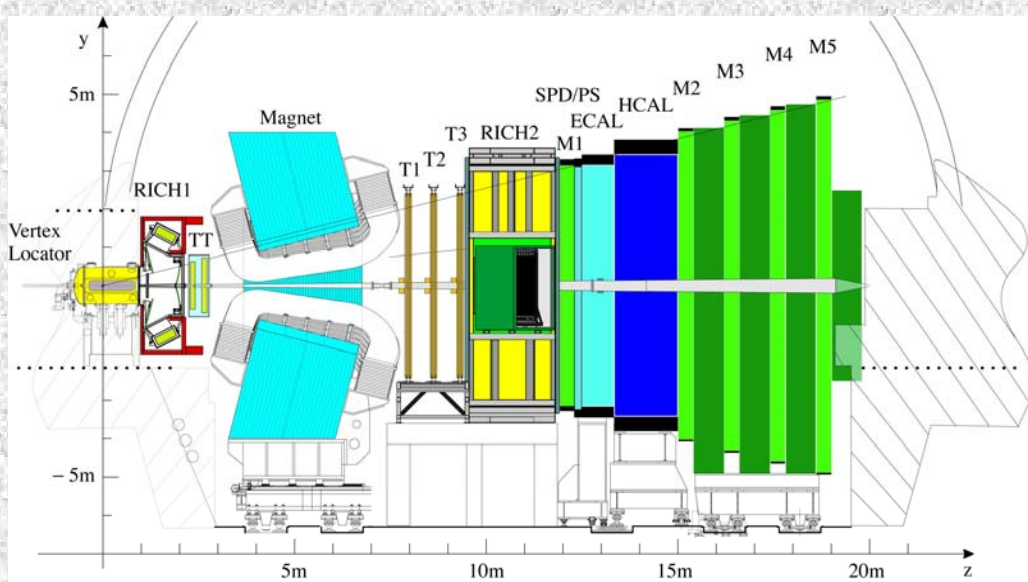
Light all-glued construction:
0.7% X_0 in active area

Bernhard Ketzer



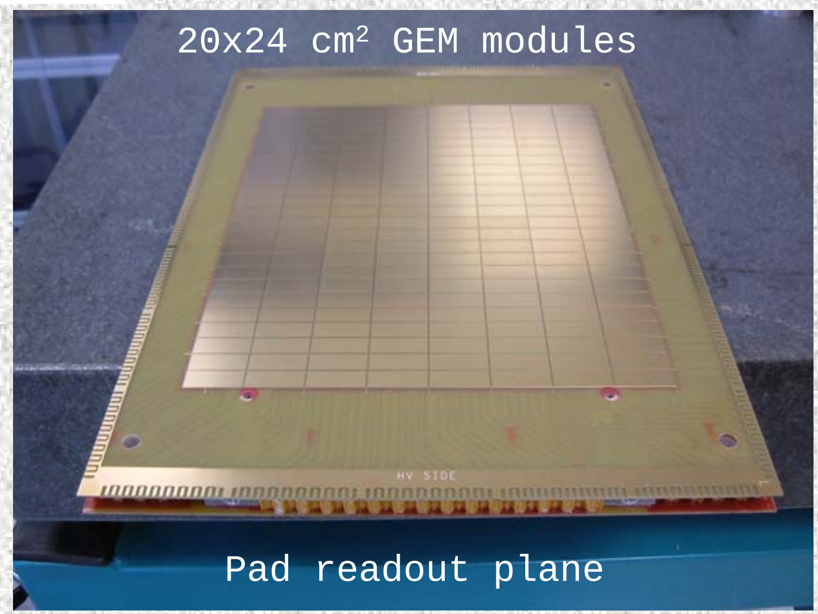
C. Altumbas et al, NIMA 490(2002)177

FAST MUON TRIGGER FOR LHCb



Rate - 5 kHz mm^{-2}
Time resolution 4.5 ns rms
No aging up to integrated charge of 20 mC mm^{-2} (15 LHCb years)

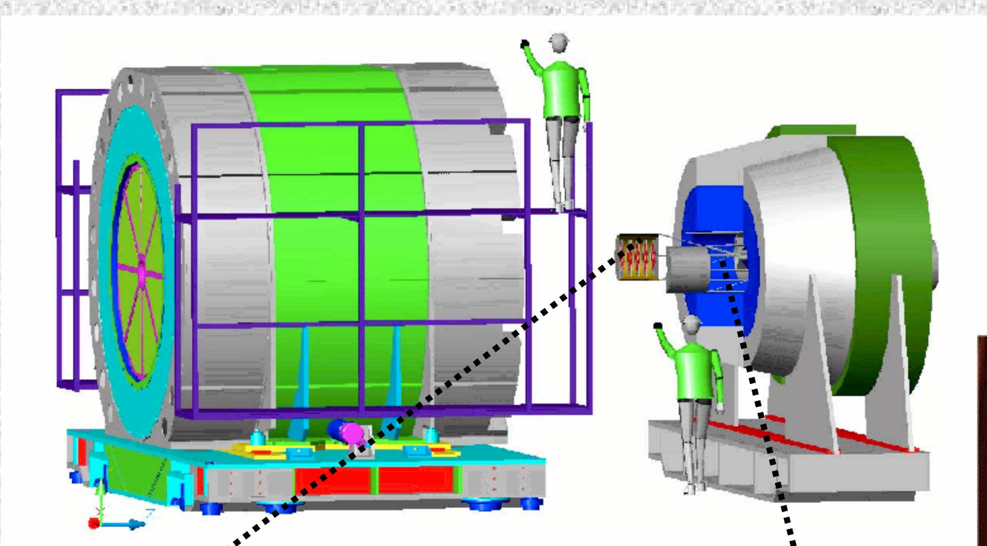
M. Alfonsi et al, NIMA 535(2004)319



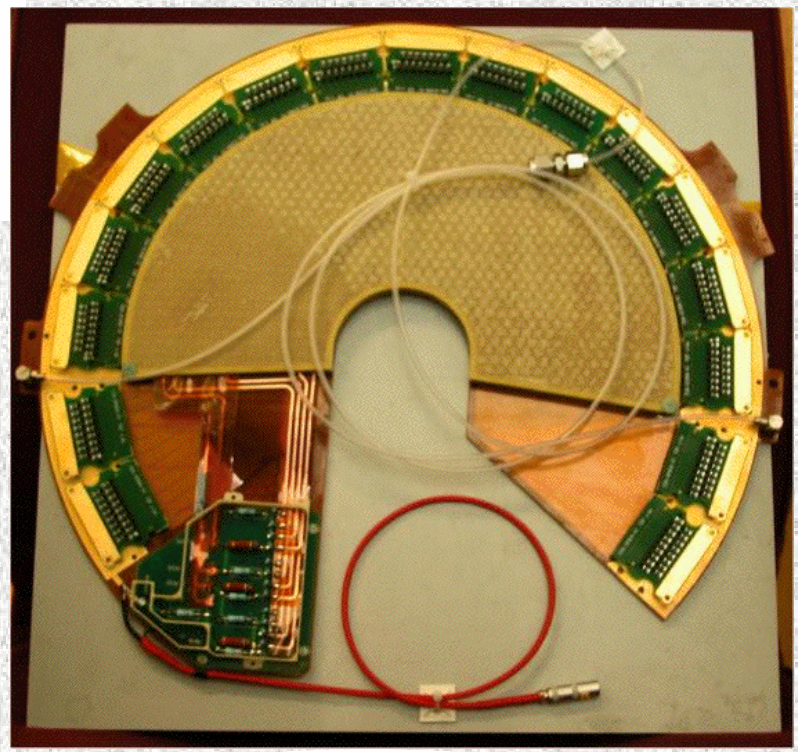
Alessandro Cardini

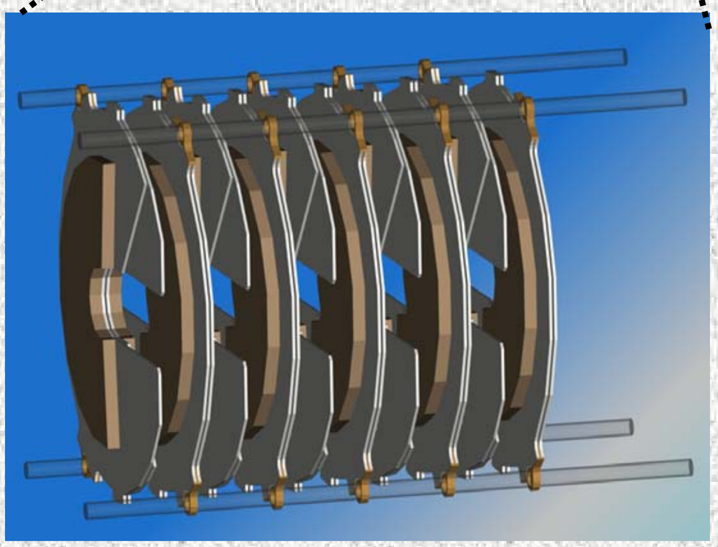
T2: TWO-ARMS FORWARD TRACKER IN CMS

TOTEM



Half-Moon Triple-GEM chambers
Inner Ø: 80 mm Outer Ø 300 mm
40 Detectors in construction
(Helsinki-CERN)





Leszek Ropelewski

GEM-TPC FOR LEGS (LASER ELECTRON GAMMA SOURCE) AT BNL

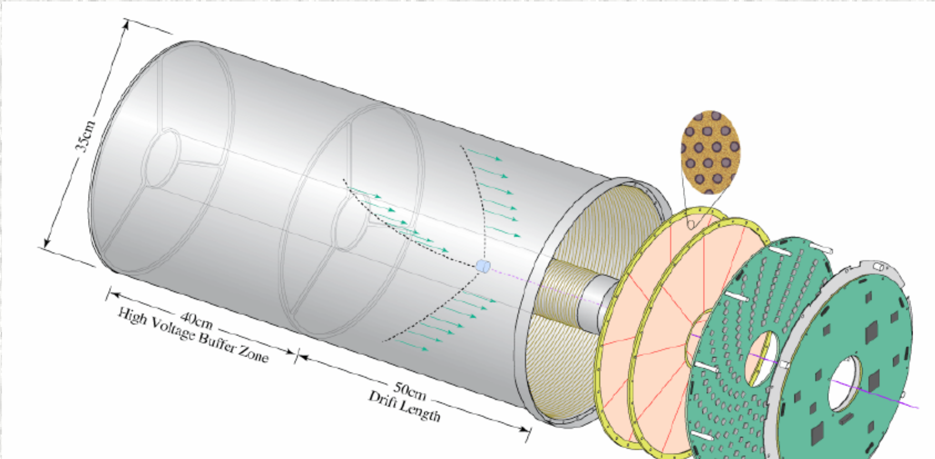
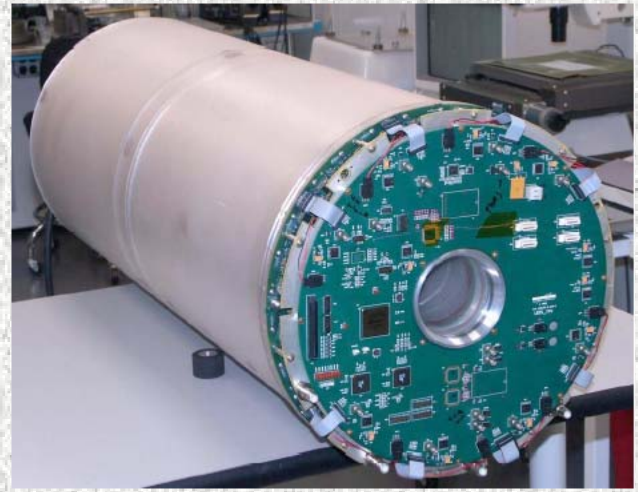
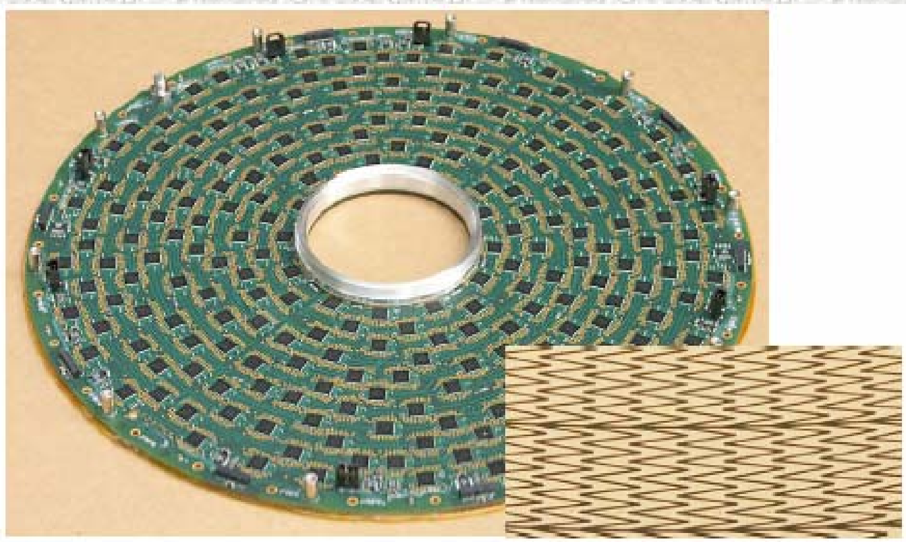


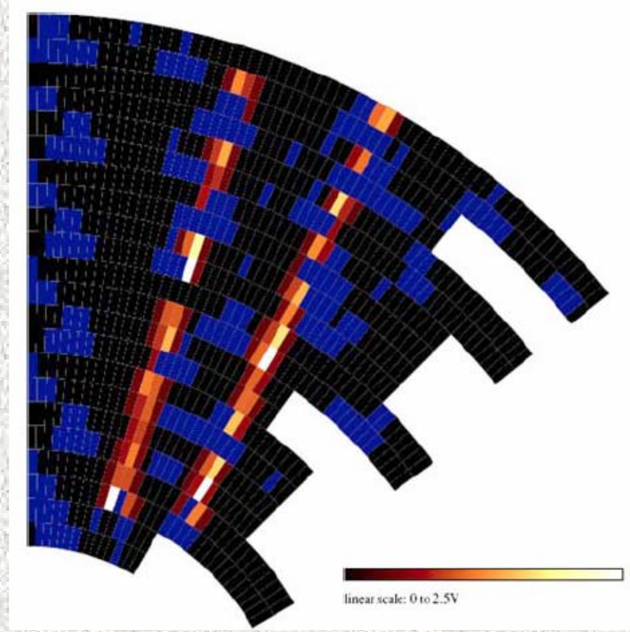
Fig. 1. A schematic illustration of the LEGS TPC.



CHEVRON PAD READOUT

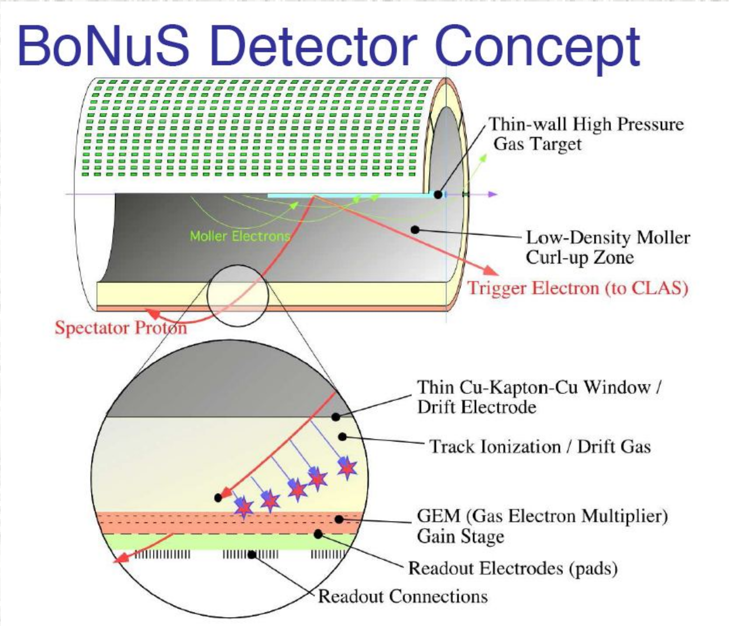


Double cosmic track in prototype:



B. Yu et al, IEEE Nucl. Sci. Symp. (Puerto Rico 2005)

RADIAL TPC FOR BoNuS (Barely Off-Shell Nucleon Structure, CLAS Collaboration, JLAB)

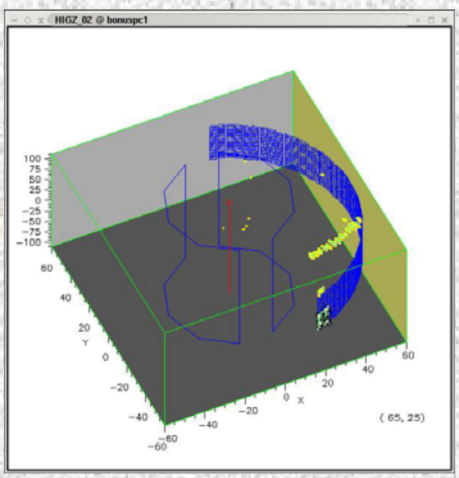


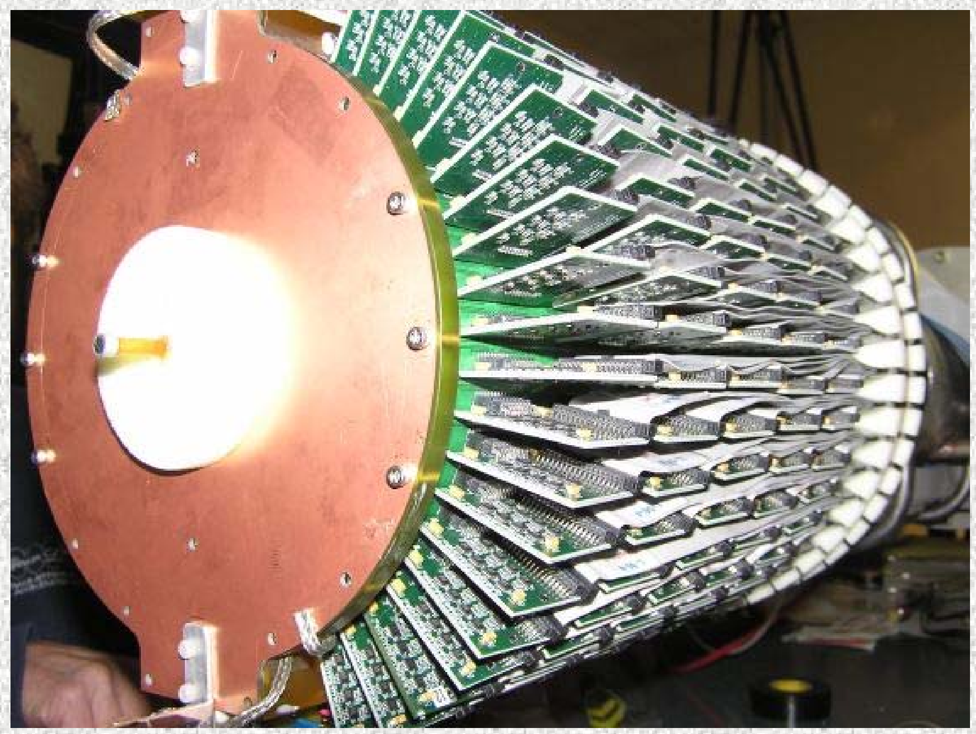
$e^- d \longrightarrow e^- n\ p$ Low energy proton spectator

—> low density, large acceptance detector

Radial GEM TPC with pixel readout
3200 pixels, ALICE ALTRO ADC

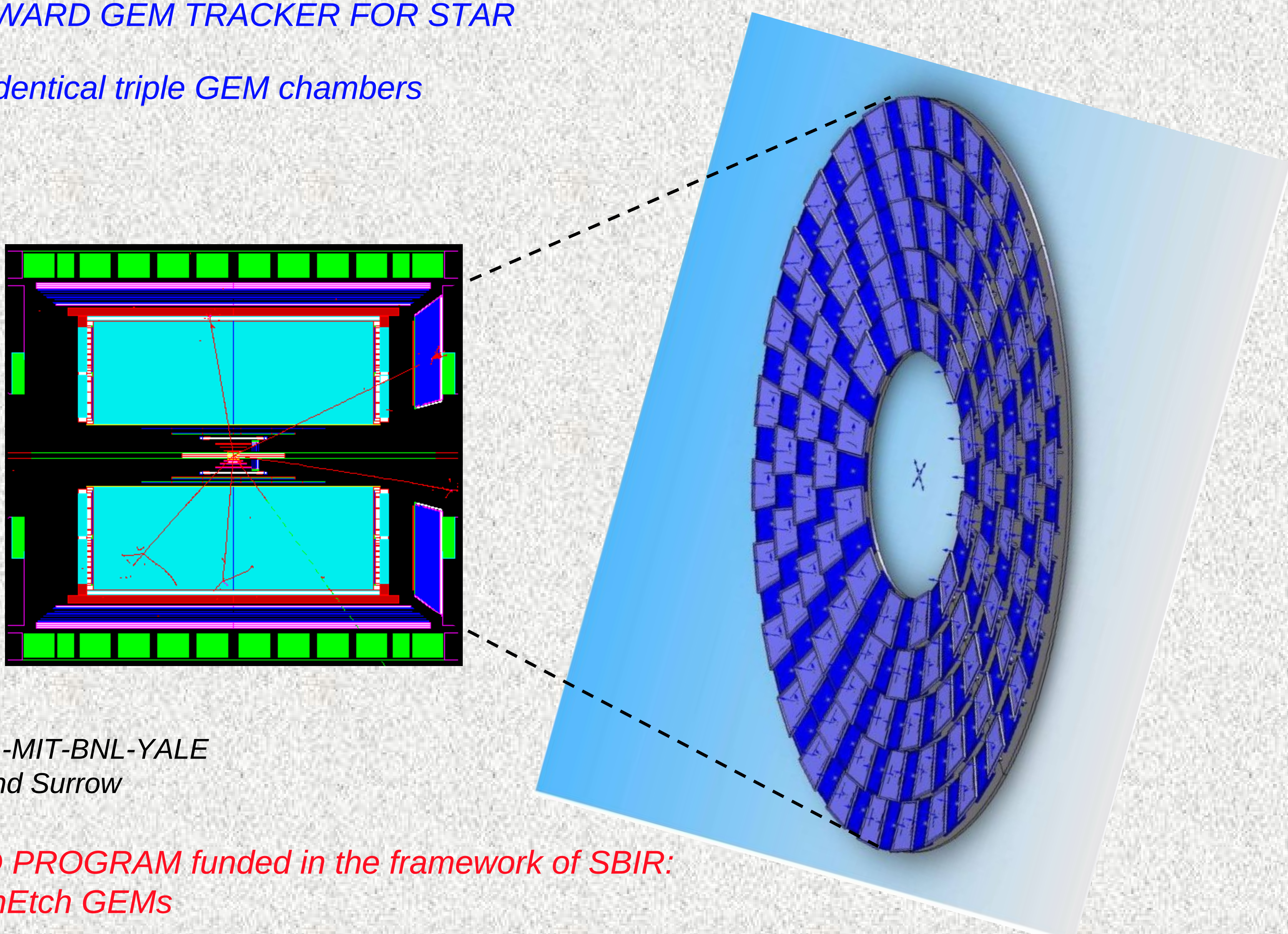
GEMS from TechEtch





FORWARD GEM TRACKER FOR STAR

180 identical triple GEM chambers

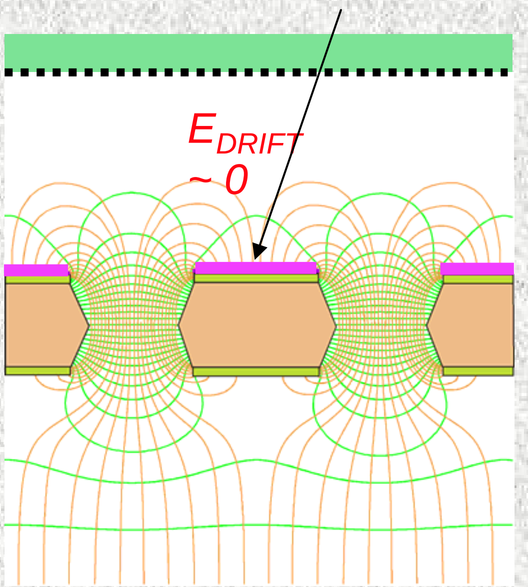


ANL-MIT-BNL-YALE
Bernd Surrow

R&D PROGRAM funded in the framework of SBIR:
TechEtch GEMs

PHOTON DETECTION WITH GEM

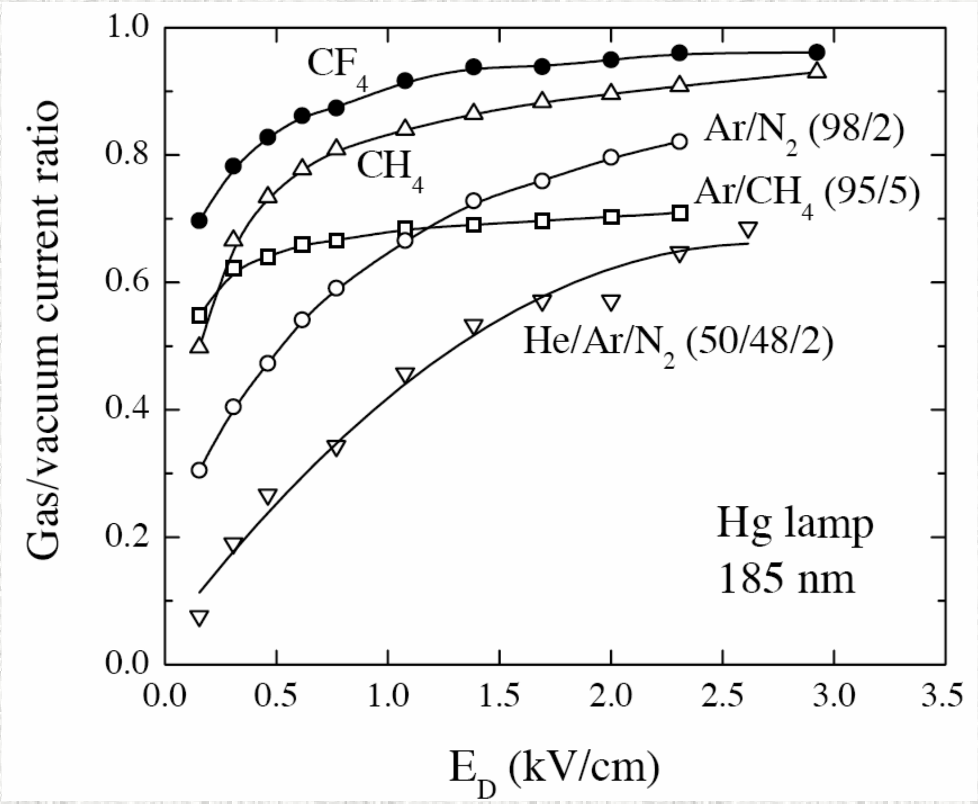
Reflective Photocathode deposited on upper GEM face



R. Bouclier et al, IEEE Trans. Nucl. Science NS-44(1997)646

CsI photocathode in gas detectors

Efficiency relative to vacuum (at 185 nm):

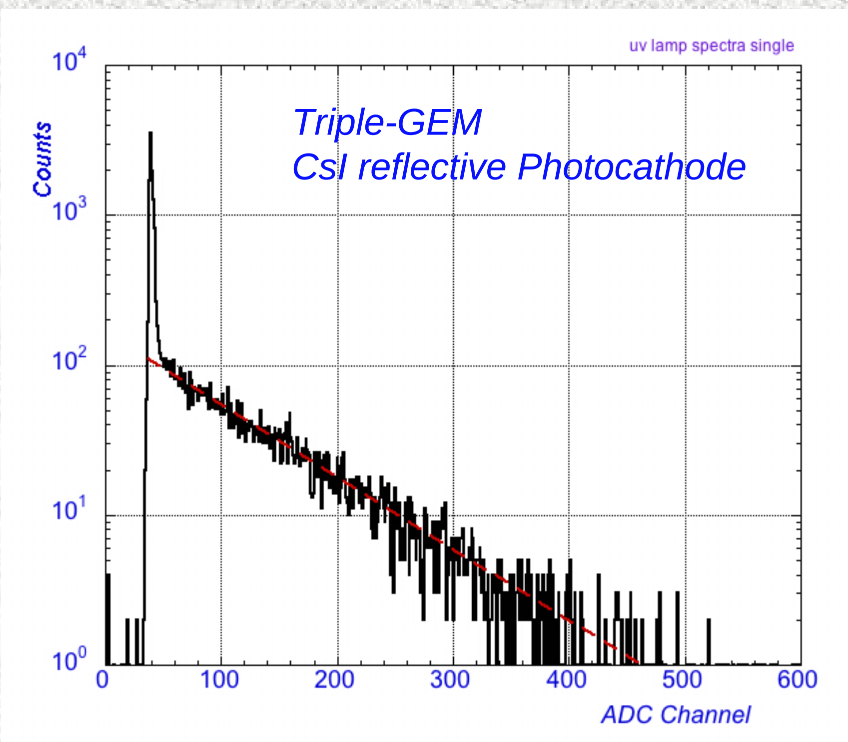


A. Breskin et al, Nucl. Instrum. Methods A483(2001)670

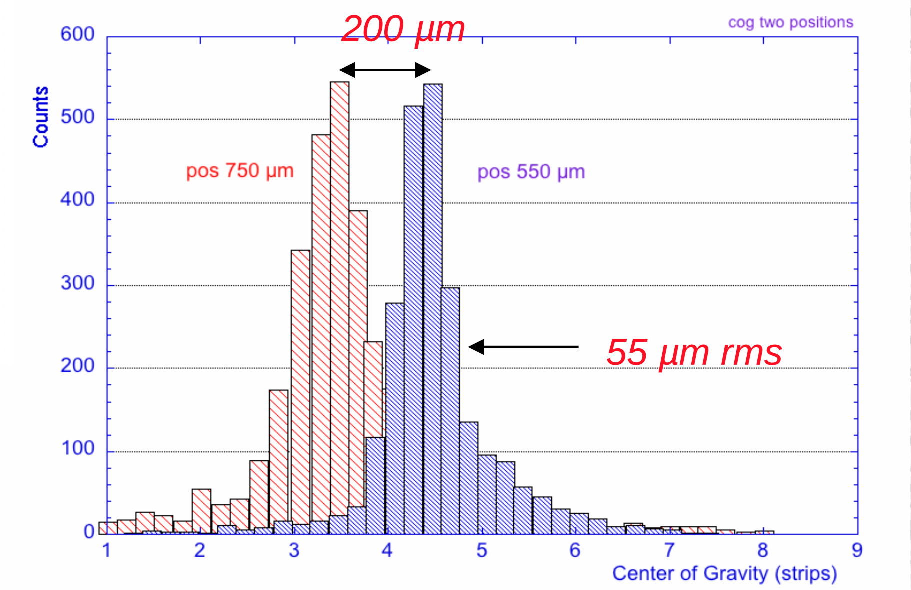
D. Mormann et al, Nucl. Instr. and Meth. A478(2002)230

TRIPLE-GEM WITH CsI PHOTOCATHODE

Single photoelectron PH spectrum:



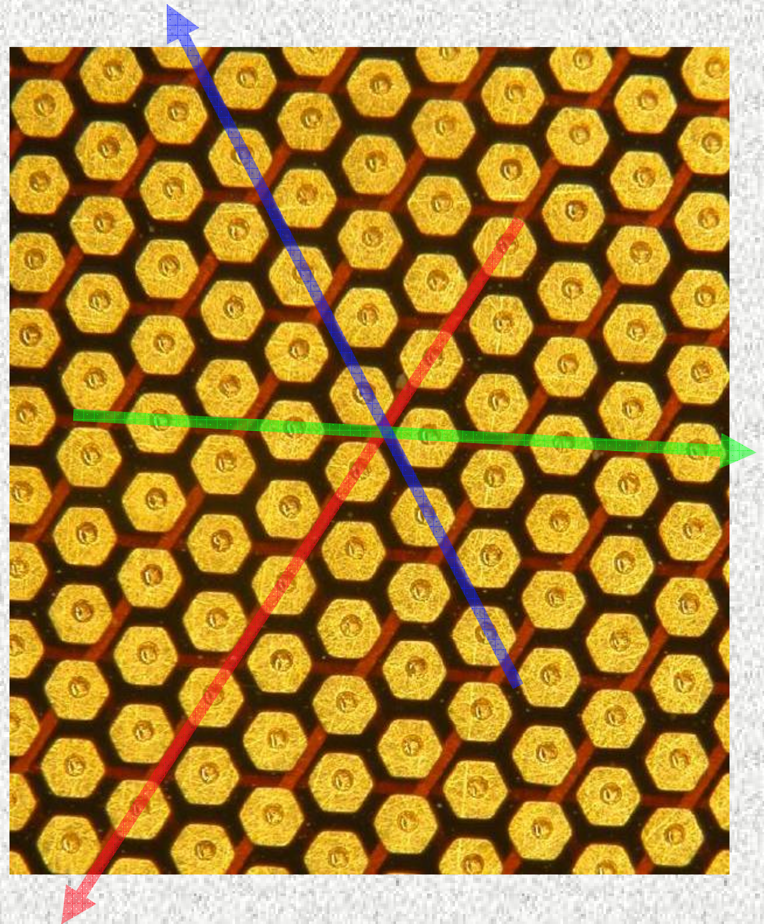
Single photoelectron space accuracy
Center-of-gravity distribution for two collimated UV beam positions, 200 µm apart:



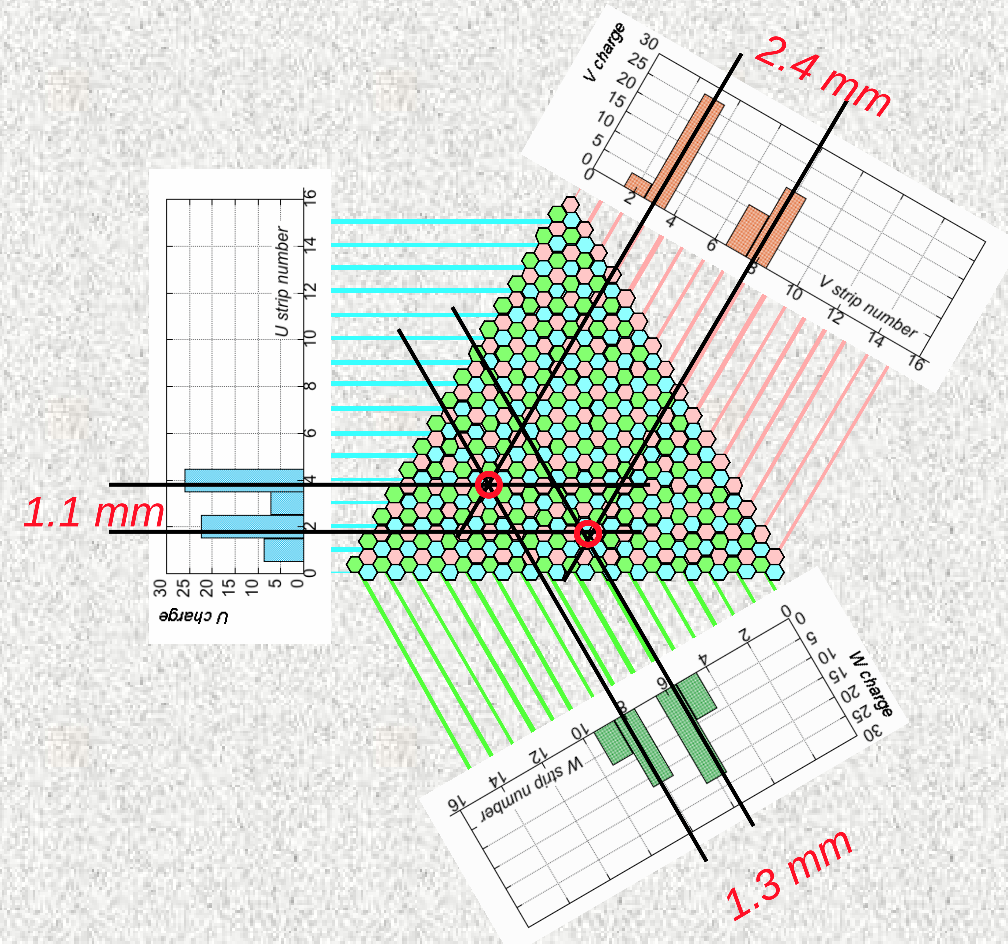
T. Meinschad, L. Ropelewski and F. Sauli, NIMA 535(2004)324

HEXABOARD READOUT

Hexagonal pad rows, 500 µm Ø
Interconnected along three directions:



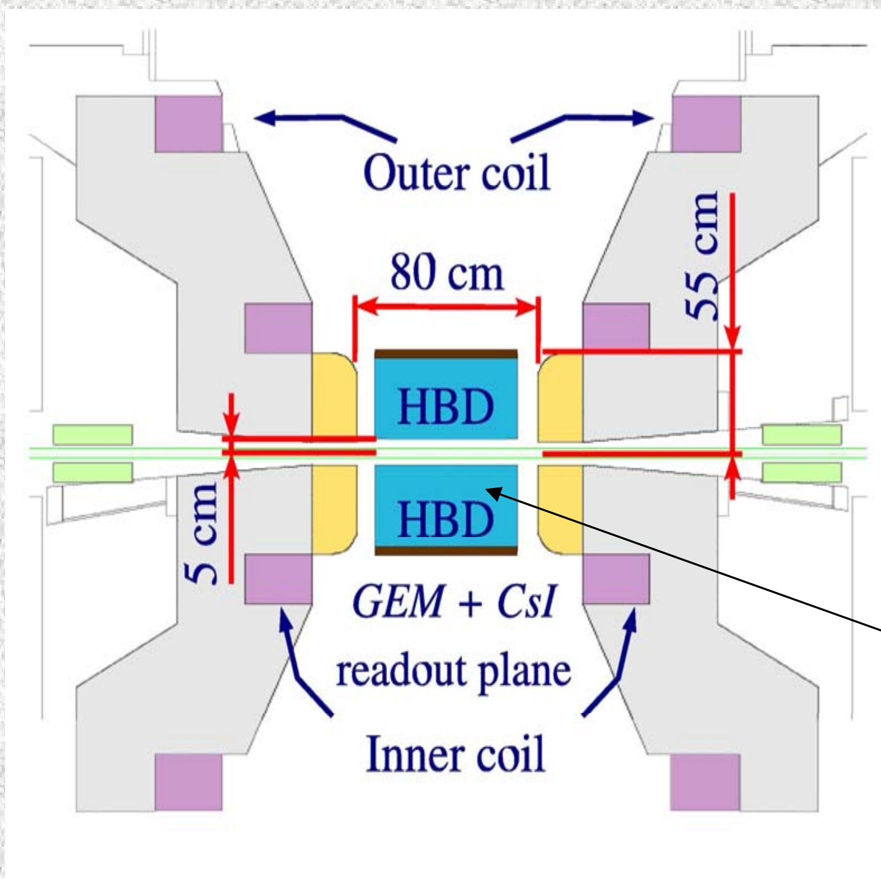
DOUBLE PHOTON EVENT:



S. Bachman et al, NIMA 478(2002)104
F. Sauli, NIMA 553(2005)18

FAST RICH (<2 ns resolution)

PHENIX UPGRADE - HADRON BLIND DETECTOR

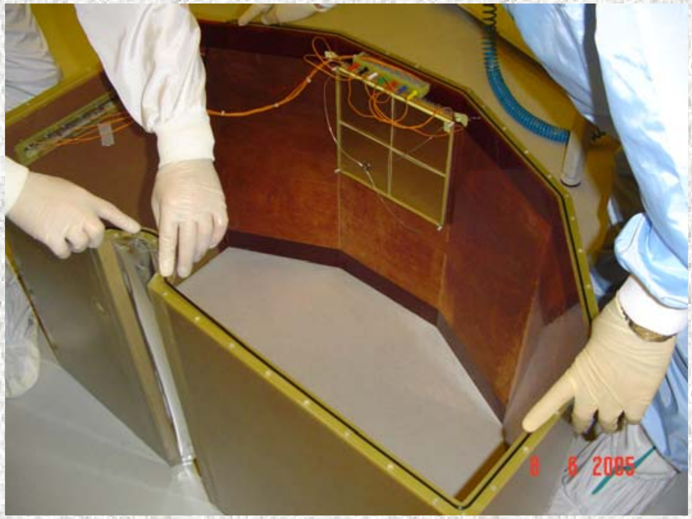


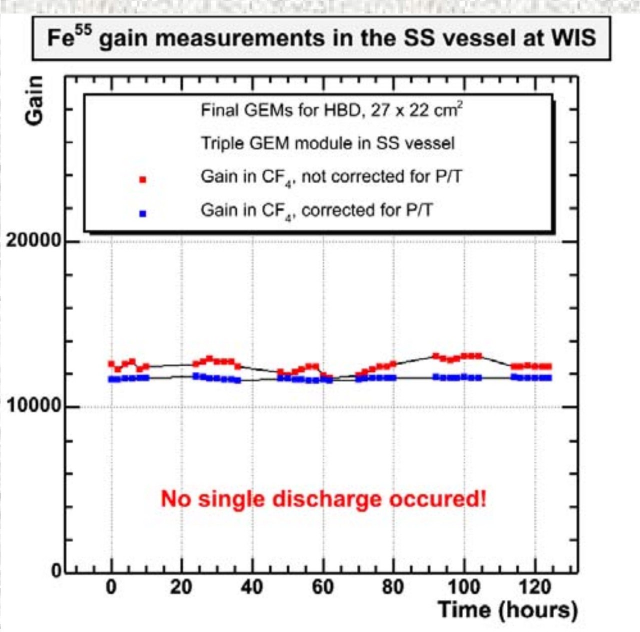
AIMS:
IMPROVE HADRON REJECTION
REDUCE COMBINATORIAL BACKGROUND

WINDOWLESS RICH DETECTOR WITH CF_4 GAS RADIATOR

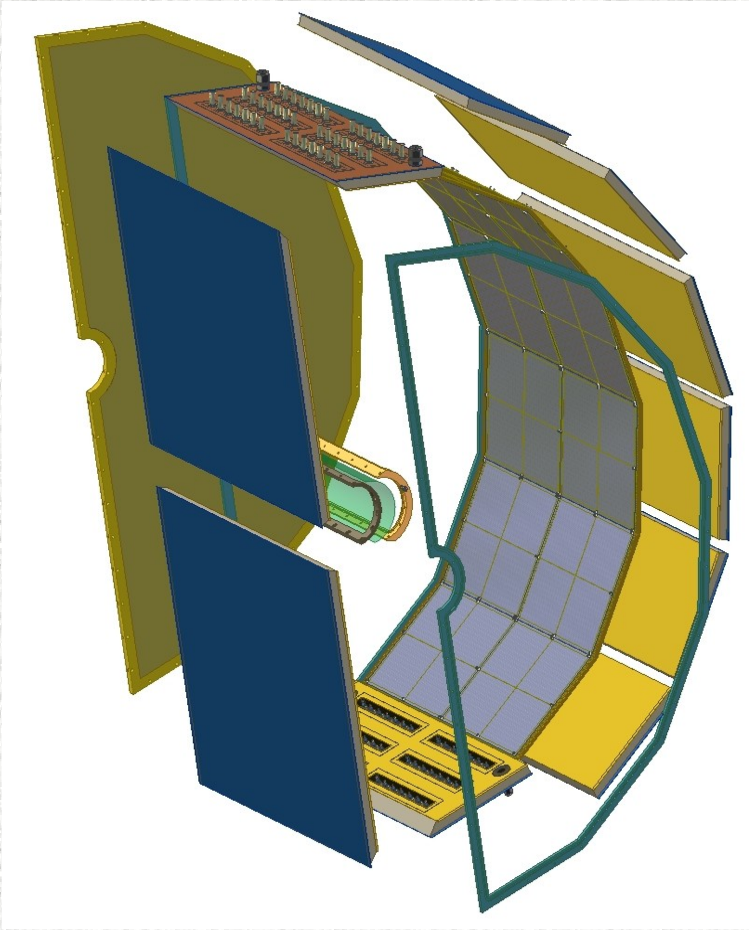
WIS-BNL-Stony Brook-NEVIS-Florida IT-RIKEN-Un. Illinois

PROTOTYPE CONSTRUCTION





FINAL HDB DESIGN

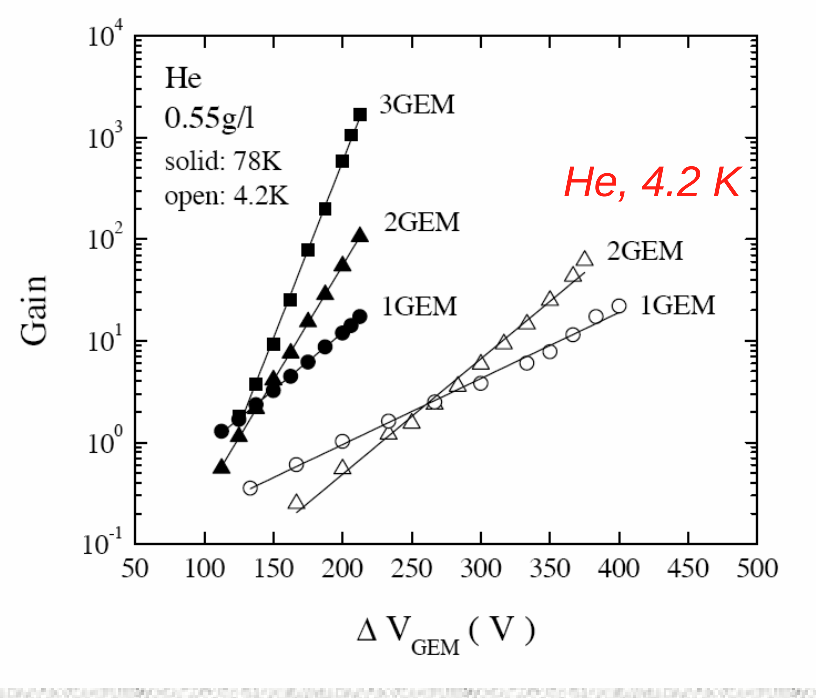


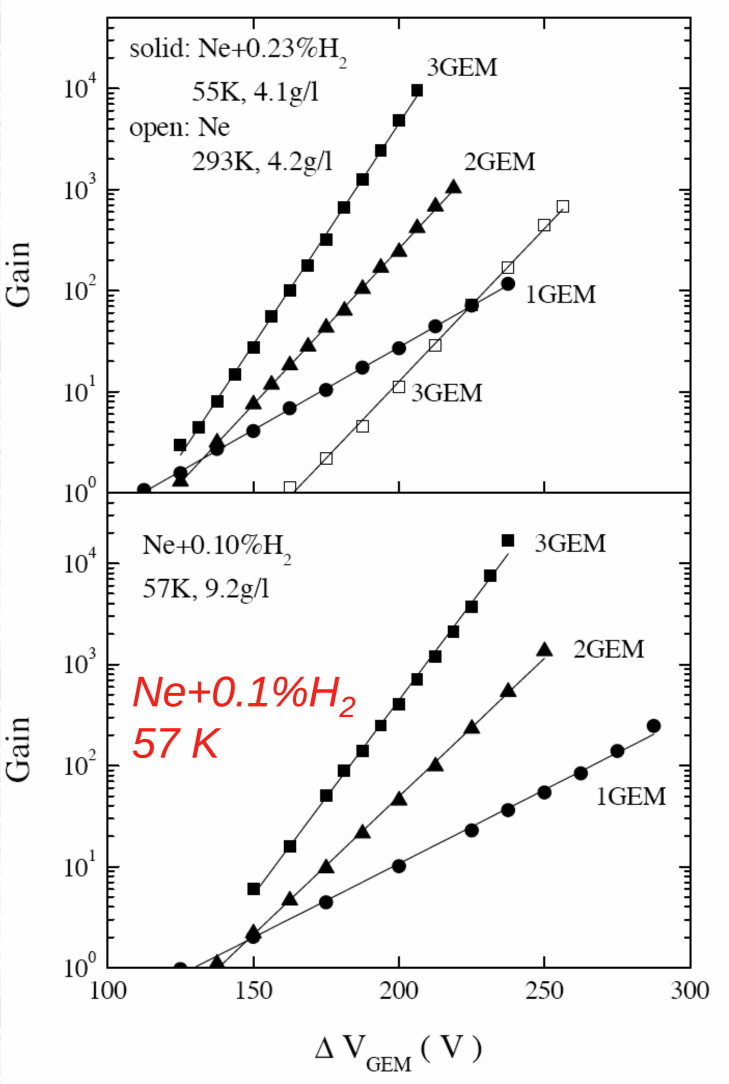
24 TGEM DETECTORS WITH PAD READOUT
(IN PRODUCTION AT CERN-EST-DM)

I. Ravinovich, QM 2005

GEM operation in low temperature He and Ne
NEVIS, BNL, BINP Novosibirsk

e-bubble chamber for solar neutrino detection (Bill Willis)





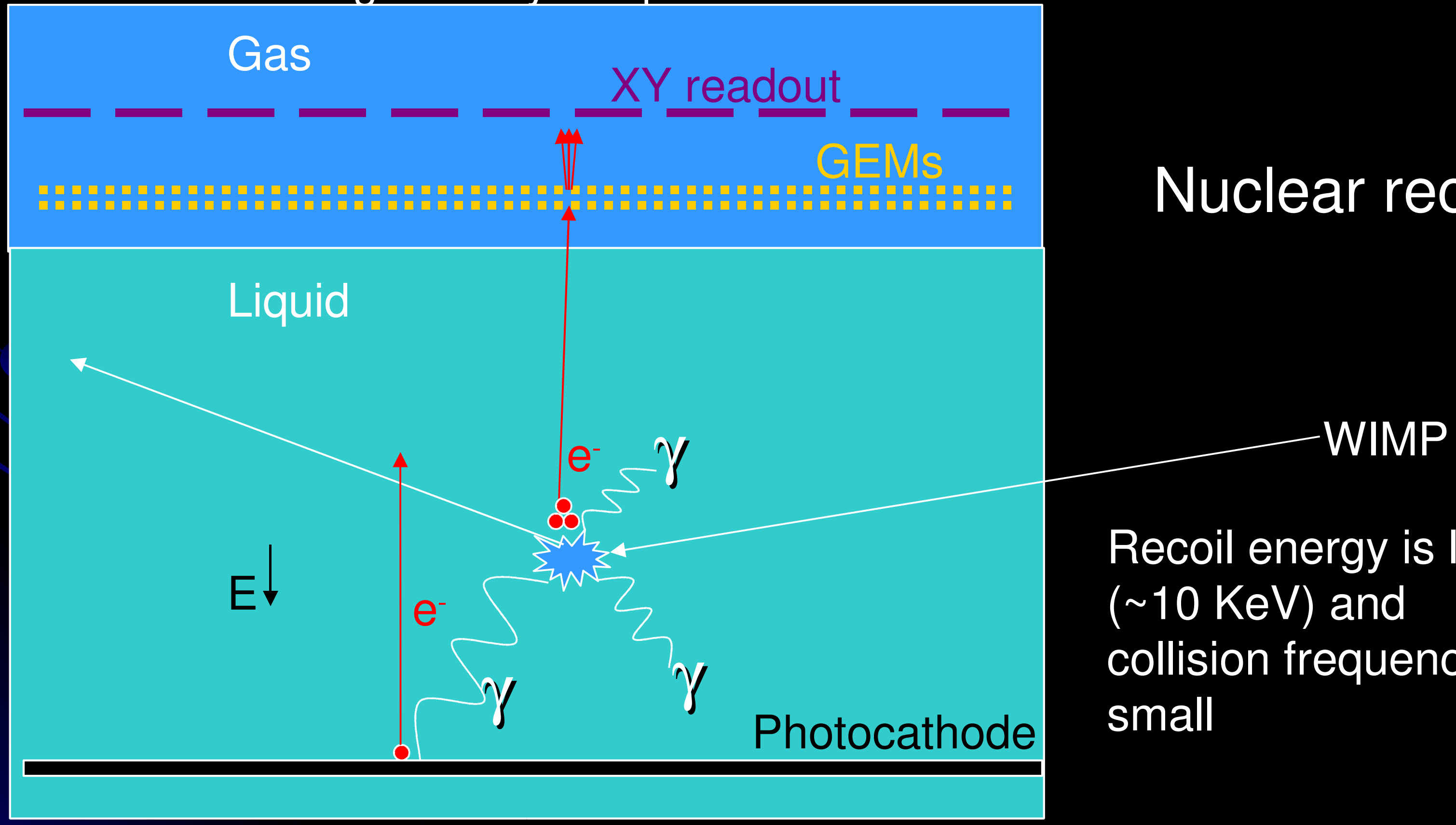
A. Buzulutskov et al, NIMA 548(2005)487

Dark matter detection

•Background radioactivity from PMT glass is a limiting factor in future dark matter searches. PMT glass yields an ample amount of gamma rays and ~2 neutrons per day in the XENON experiment.

- •Cirlex GEMs have a low U-Th content

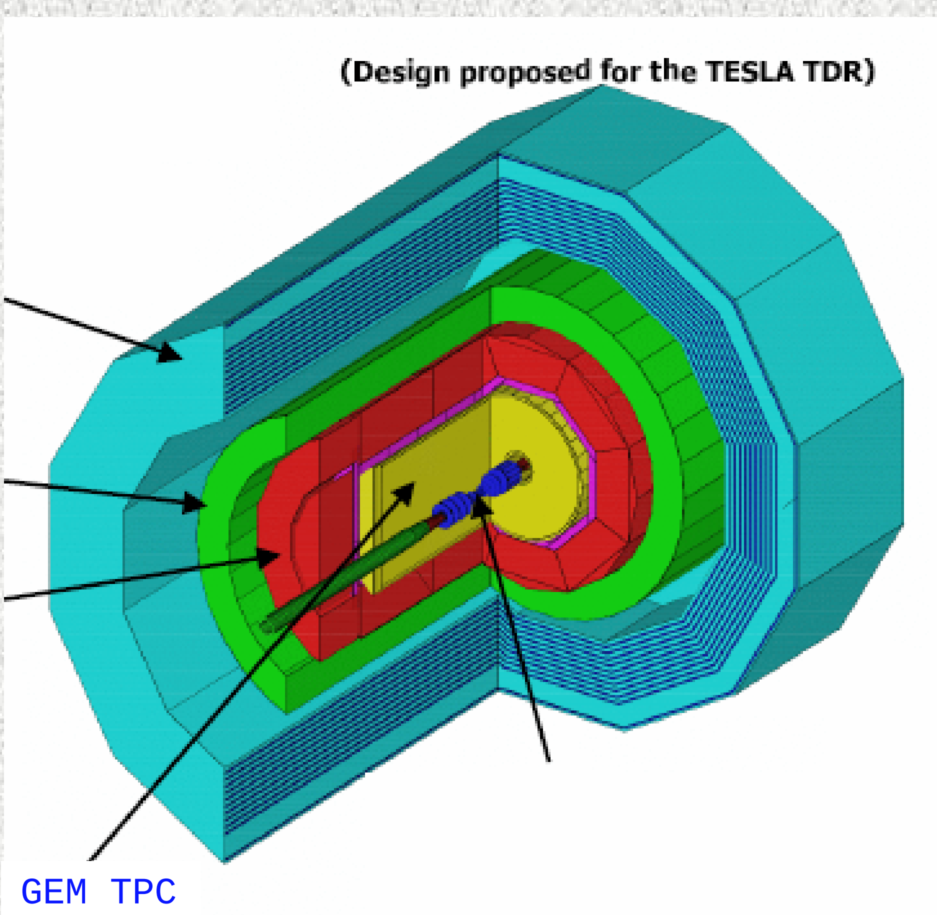
•Note that GEMs are placed in the gas phase of the detector because the ionization avalanche does not occur significantly in liquid.



Nuclear recoil

Recoil energy is low (~10 KeV) and collision frequency is small

GEM TPC FOR THE INTERNATIONAL LINEAR COLLIDER



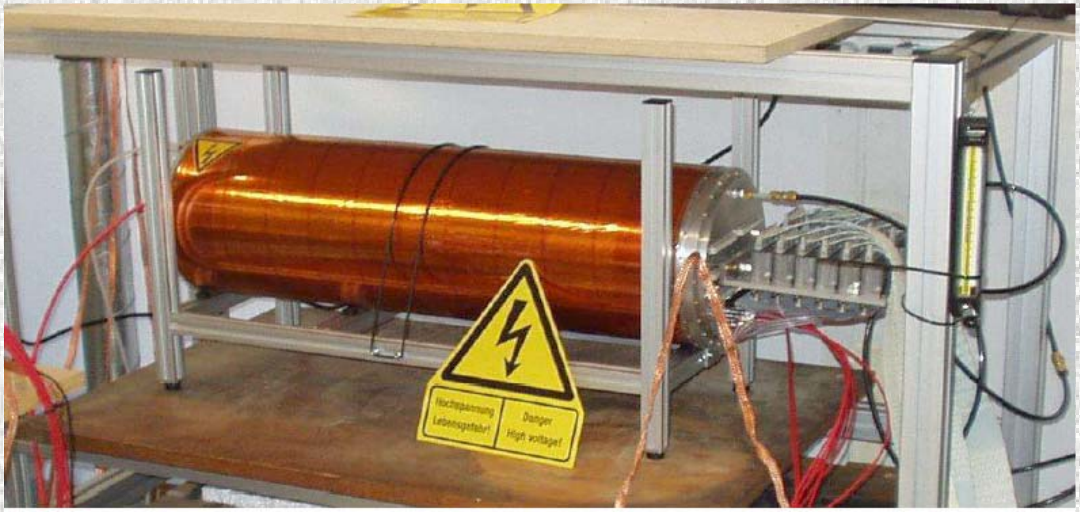
ADVANTAGES OF GEM READOUT:

- Fast signals (no ion tail): ΔT~20 ns
- Narrow pad response function: Δs ~ 1 mm
- Very good multi-track resolution: ΔV ~ 1 mm^3 (Standard MWPC TPC ~ 1 cm^3)
- Ion feedback suppression: I^+/I^- < 0.1%
- No ExB distortions
- Freedom in end-cap shapes
- Robust, radiation resistant

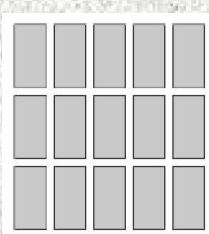
ILC TPC R&D GROUPS (~ 40):
DESY, Aachen, Karlsruhe, LBL, Saclay, Orsay, Vancouver, Carleton, KEK,…..

TPC: 250 cm long, 140 cm radius
~ 40 m^3
4 T operation

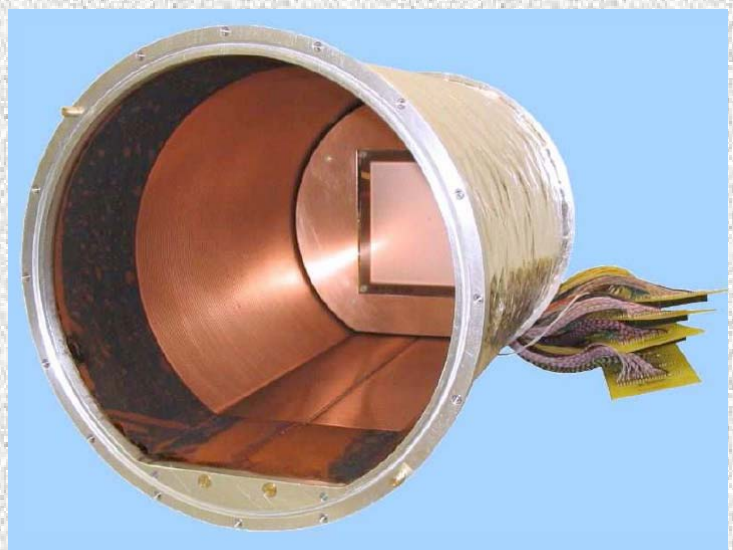
DESY GEM-TPC: 80 cm drift



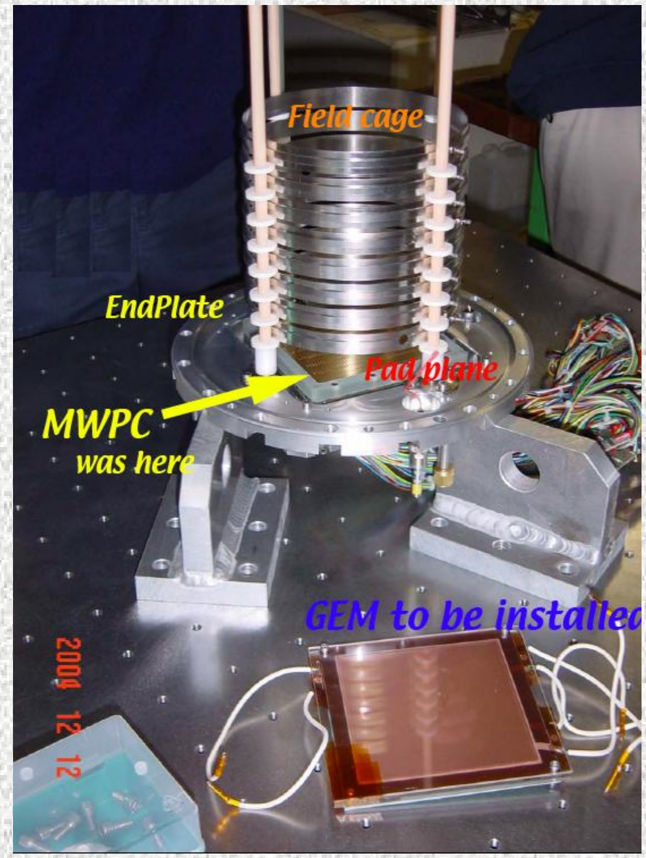
2.2x6.2 mm^2
pads readout



AACHEN GEM-TPC:

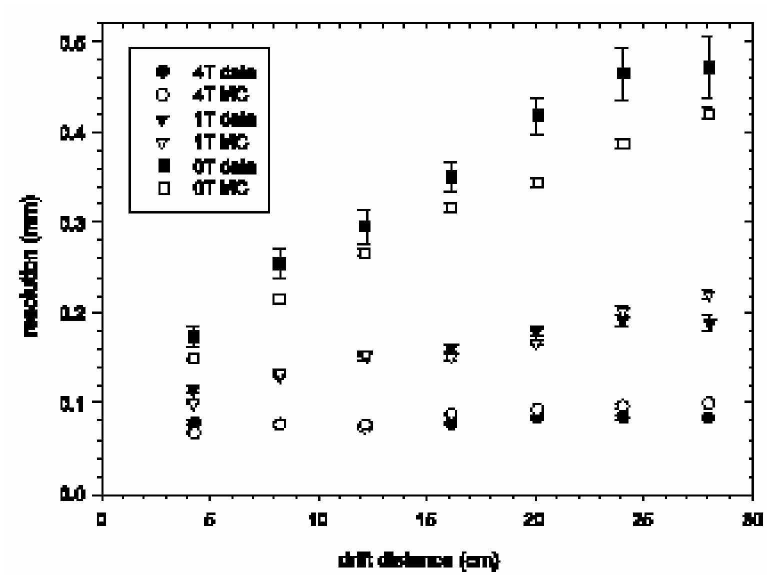


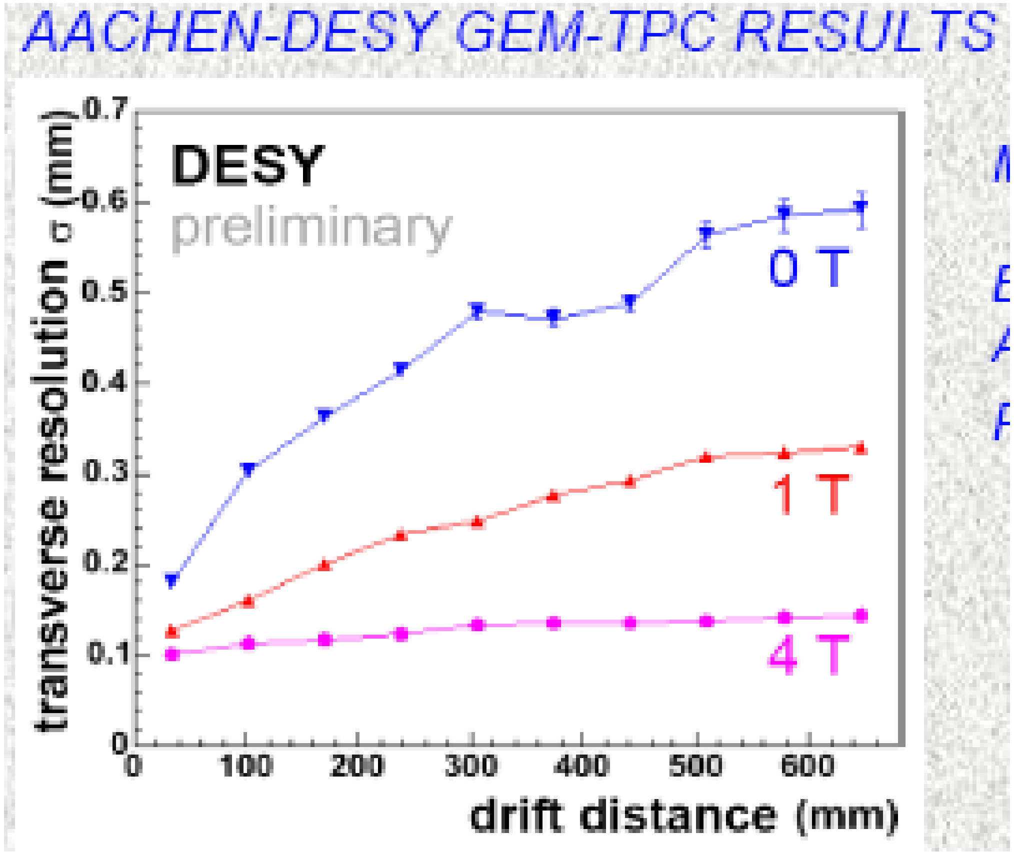
Asian GEM TPC:



Tsinghua TU-TPC: 50 cm drift length

GEM-TPC for ILC is feasible

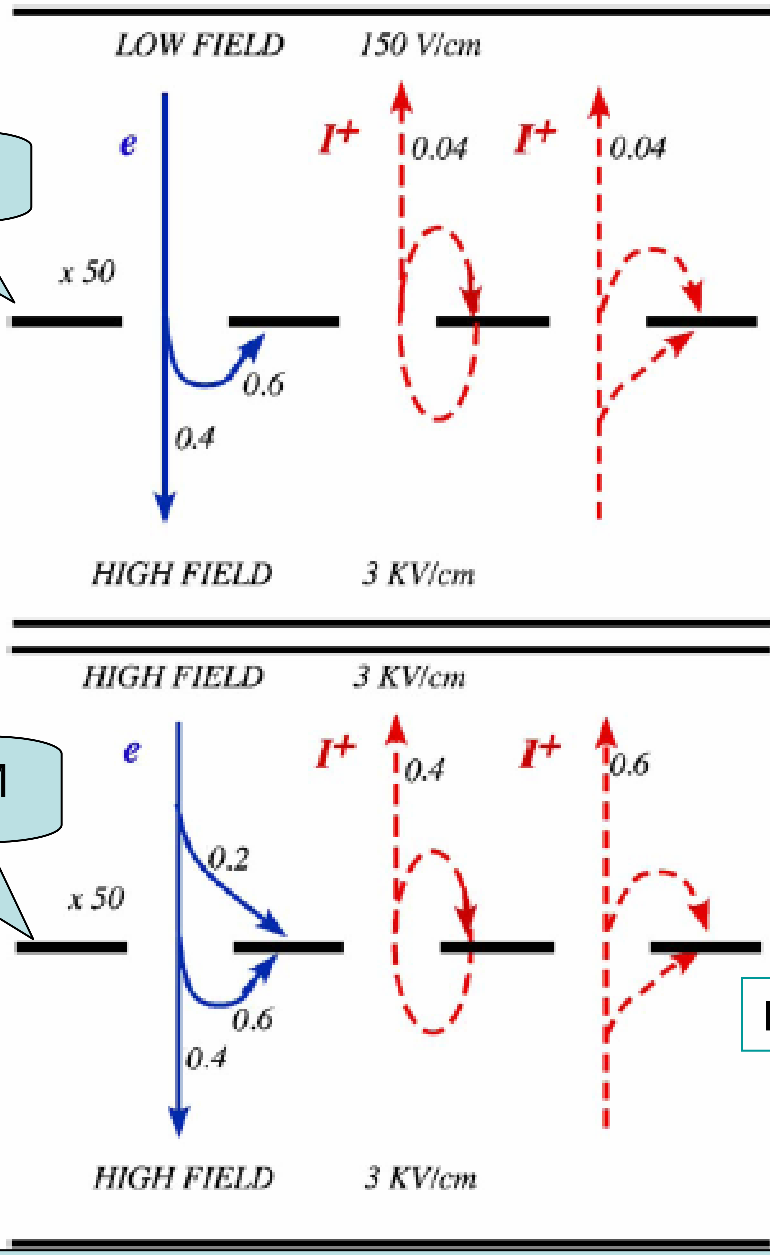




- **Local position resolution: 100 μm**
- **Open issue:**
  Ion feedback and gating

1st GEM

2nd or 3rd GEM



Triple GEM，
G_{eff}=20 × 16 × 16= ~ 5000

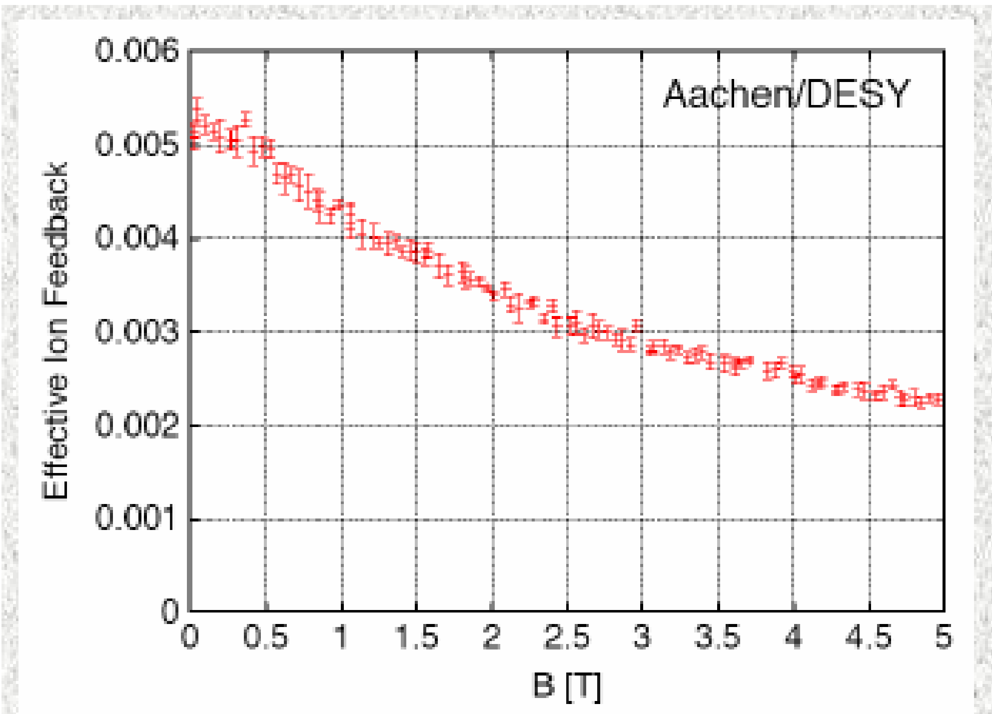
Fractional Ion Feedback:

$$FIF = \frac{\text{Ion current into drift volume}}{\text{Electron current on anode}}$$

FIF = （2 + 12 + 110）/5000 =2.5%

GEM charge transmission properties

- Magnetic field can reduce FIF
- FIF can be minimised by the variation of electrical fields within the GEM structure.



M. Killenberg et al, NIMA 530(2004)251

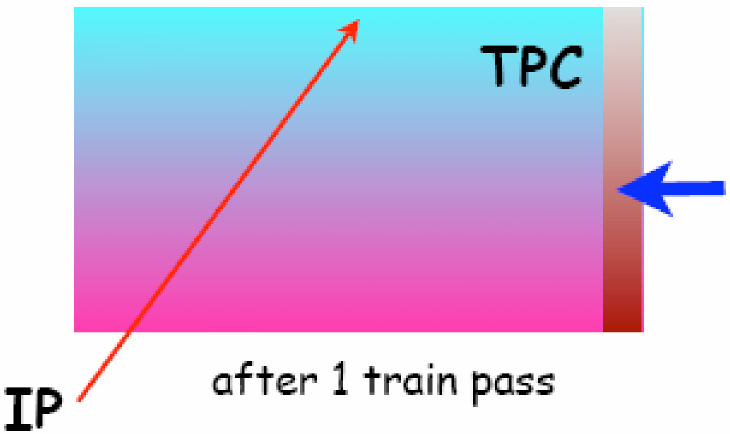
- $V_{GEM-1,2}$=310V
- $V_{GEM-1,2}$=350V
- E_{t1}= 6 kV/cm
- E_{t2}= 60 V/cm
- E_i= 8 kV/cm

- Not good enough
- If the gain is 10^4, FIF$\leqslant 10^{-4}$

Why do we need Gate for ions ?

Ions are produced at the Drift region as primary ionization
at MPGD region from gas multiplications (1000 times larger)

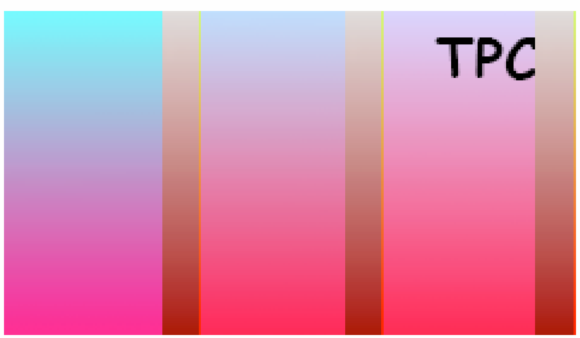
Ions @ drift may be accumulate for a few trains
as ions drift is slow



Ions produced at gas multiplications

after 1 train pass

Ions @ MPGD will form like a ion-dense disc
which travel in drift region slowly
if we don't have any gate mechanism to block ions



after several trains

this disc may deteriorate drifting electron by E,
ExB ...
and these effects are not stable as ions are moving.

Ions produced at gas multiplications
must be shut off by GATE

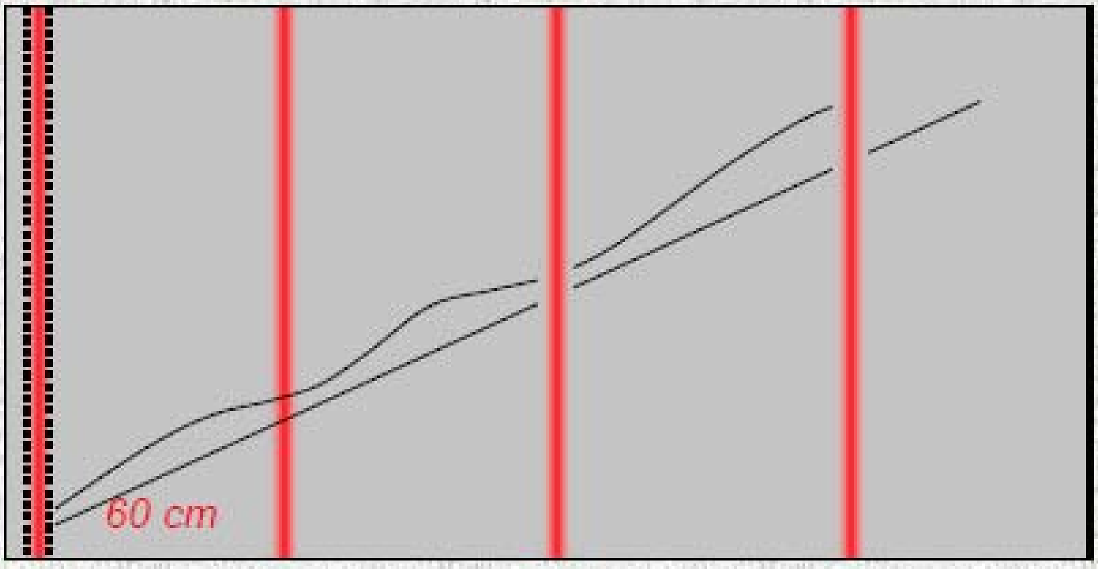
SPILL STRUCTURE AT ILC:

In A-CH_4 90-10:

E_{DRIFT} = 150 V cm^{-1} w^- (electrons): 6 cm μs^{-1} $w^+(CH_4^+)$: 2.9 μm μs^{-1}

TPC, 2 m long:

Total collection time: electrons ~ 40 μs ; ions ~ 0.7 s



Gating for back-drift ions

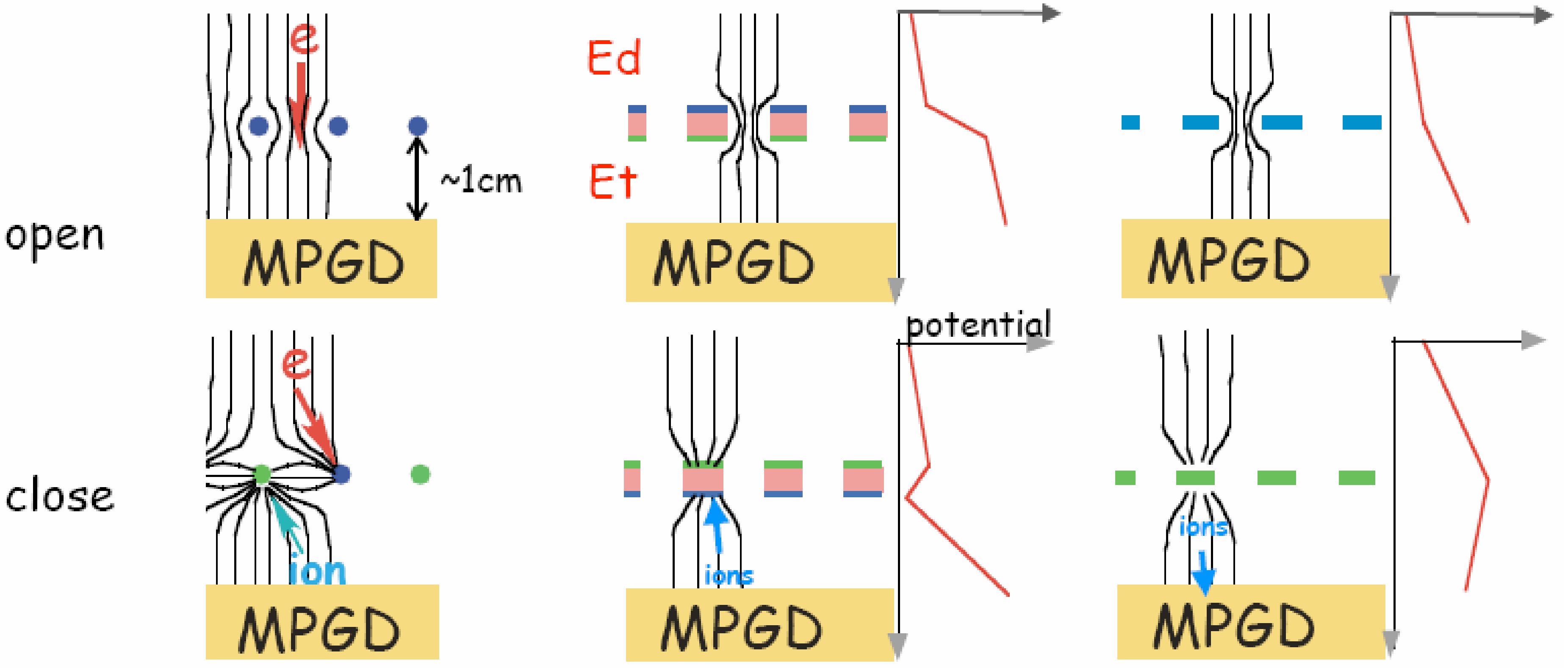
ILC case : ions feedback must be smaller than 10^{-3}(ie. no ions from MPGD)

Gate can be open for 1 msec and be closed following 199 msec.

ion can dirft < 1cm

Gate: wire GEM micromesh

3 candidates

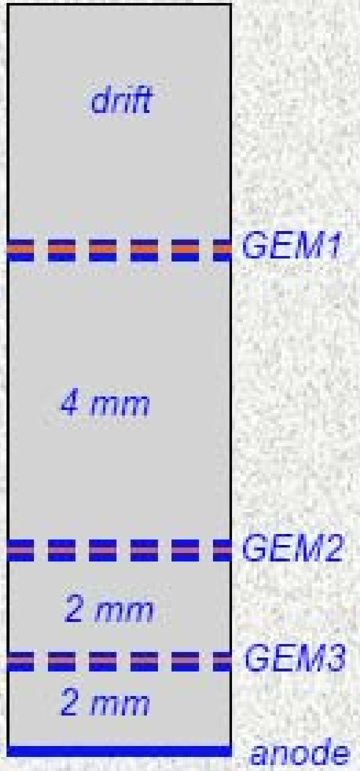


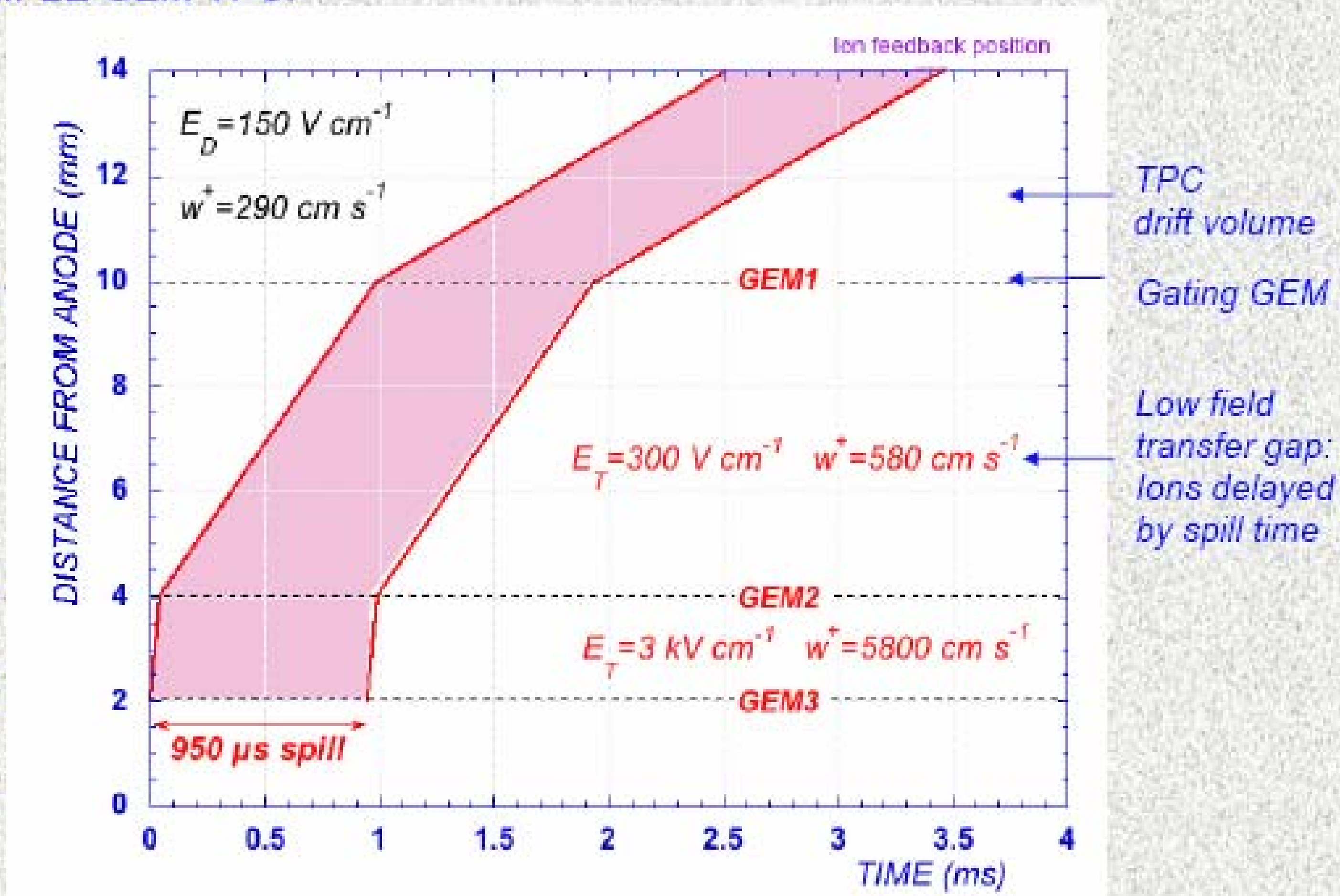
local change of E — wire tension, ExB

local change of E — electron transmission

change of drift E — electron transmission

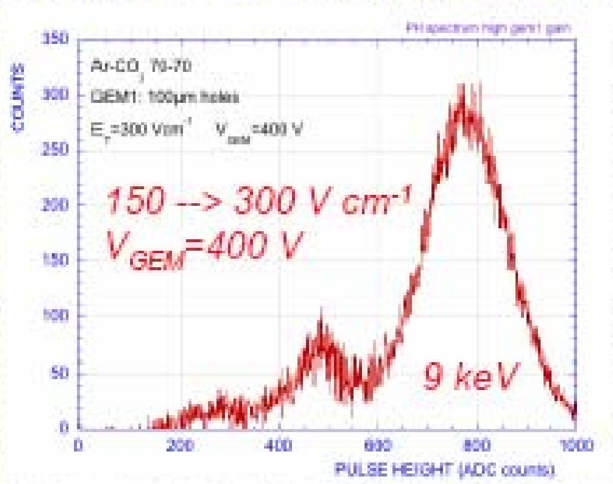
ION FLOW IN A TRIPLE GEM TPC:



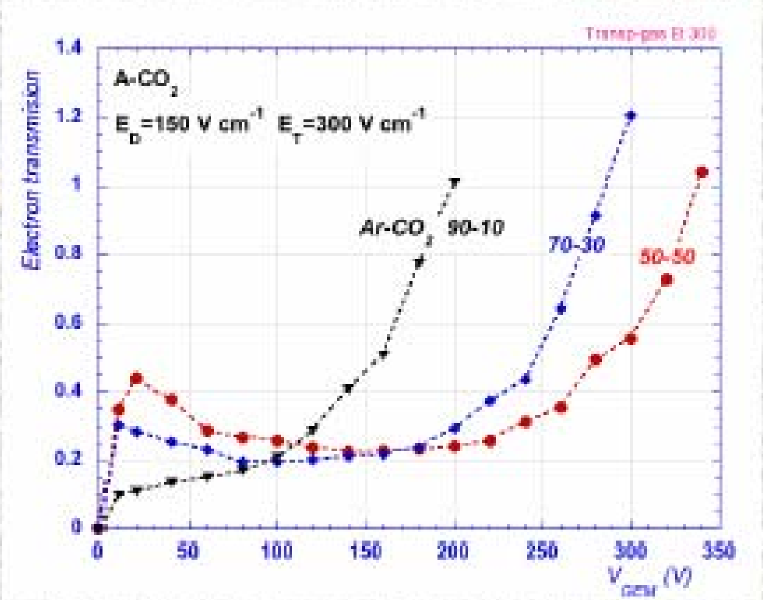


? GEM CHARGE TRANSMISSION INTO LOW FIELDS

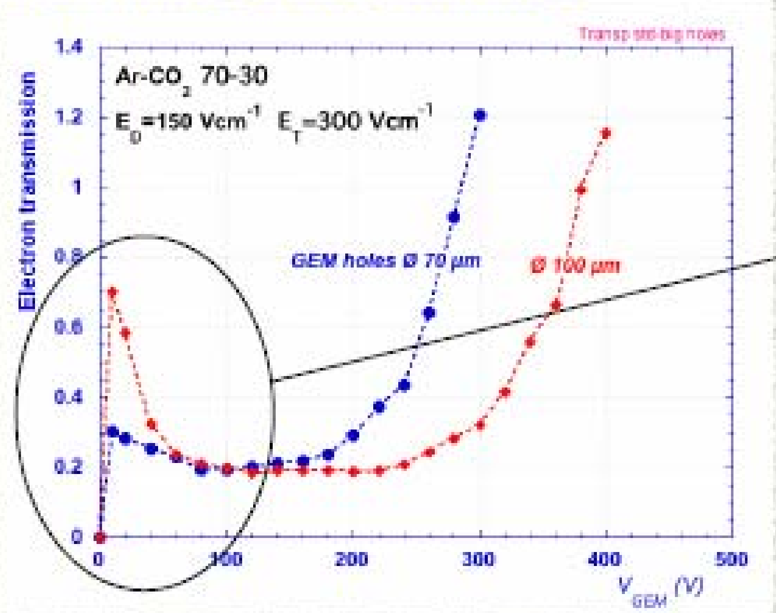
GEM LOW FIELD TRANSMISSION:



GAS DEPENDENCE (Transverse diffusion):



HOLE DIAMETER DEPENDENCE:



- **Low voltage operation may give good electron transmission, where no gas amplification happen**
- **GATING WITH 10V**

F. Sauli, L. Ropelewski, P. Everaerts, NIMA in press (Jan. 2006)

Simulation study (Saga Univ.)

- Simulation results match with measurements
- Optimization of GEM Gating for LC-TPC

High Magnetic Field (3 ~ 4 Tesla)
High ωτ gas

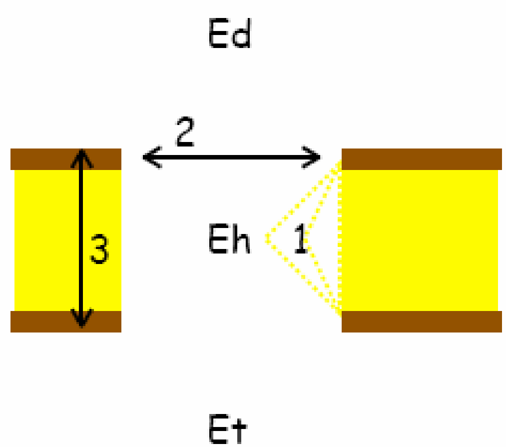
Ar:CF4 is the first candidate for this (w/ iso-C4H10)

Optimization of GEM itself

1. Hole shape
2. Hole Size/pitch
3. thickness

Optimization of operation condition

1. Drift E field : Ed
2. Hole E field (V_{GEM}) : Eh
3. transfer E field : Et



Summary of simulation study

If GEM would be used for GATE, it must be

- Aperture must be large (larger hole size)
- Thinner GEM is better for Gating
  - Field shaping around hole
  - Eh need to be kept low (diffuion)
- Ed must be low (50V/cm)
- Et must be high (300V/cm) (but just below diffusion rise)

We may be able to achieve 70% transmission @25um thick GEM in simulation.
(10% error may exist)

Do you accept this number ??

Confirmation is necessary ! especially under High B field

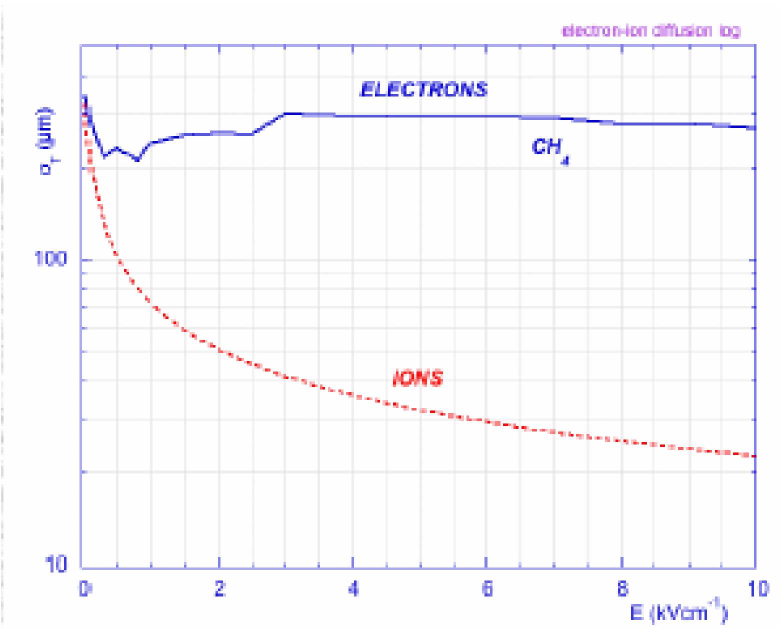
Need to establish how to measure.

25um thick GEM is available (though hole diameter is 90 um)

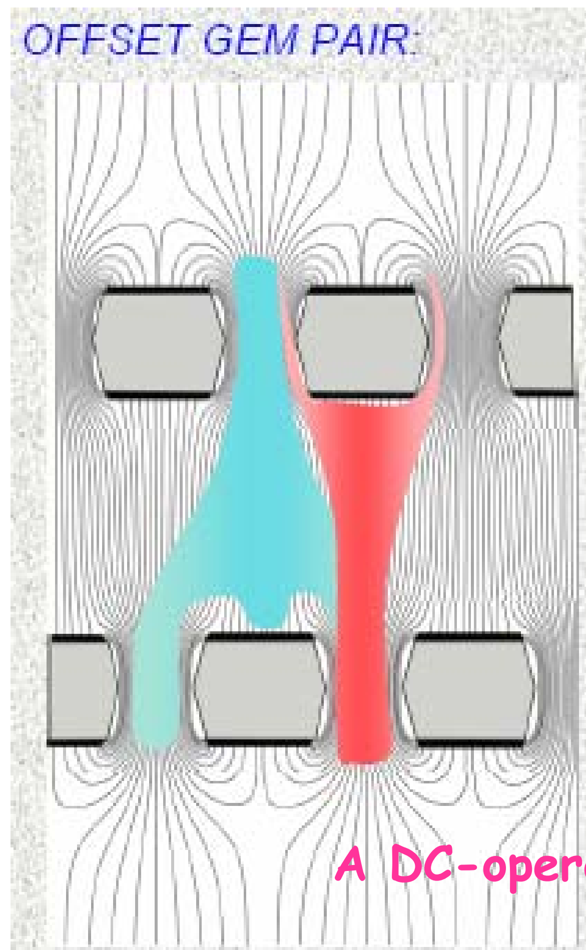
Do we try 12.5um for 10% improvement ?

DESY 5T magnet is necessary for this

ELECTRON AND ION DIFFUSION



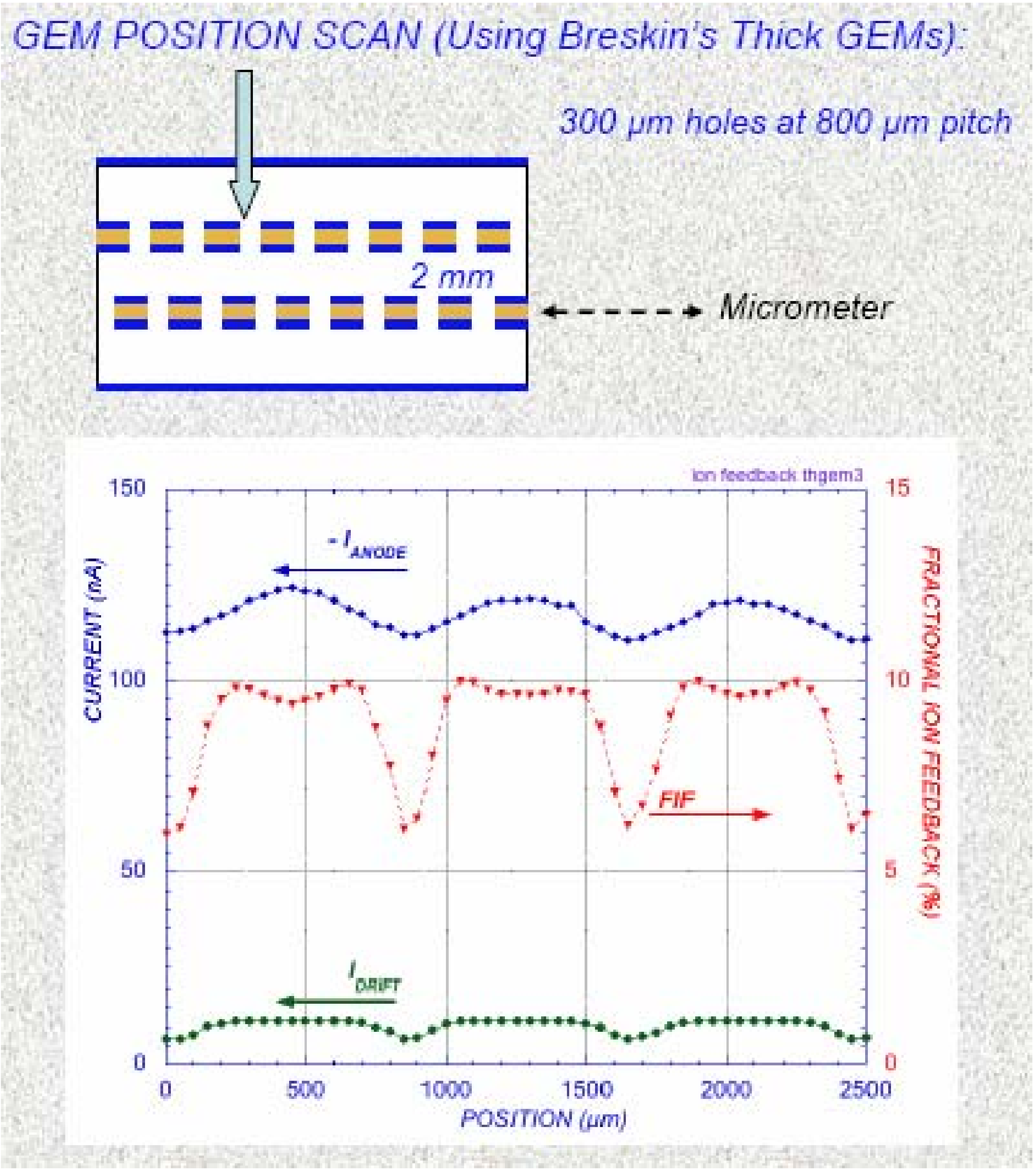
At the common value of field, the electron cloud emerging from a hole spread almost an order of magnitude more than ion.



- Distance: ~pitch
- Offset: ½ pitch

- A good fraction of electron will still make their way through the structure
- Ions would be mostly collected by the facing electrode.

A DC-operated ion filter



- The gap comparable to the hole's pitch
- Thick-GEM is needed

- The gap comparable to the hole's pitch
- Thick-GEM is needed

- **FIF decreases from 10% to 6%**
- **Too small to be useful in practical.**

Summary

- GEM is a novel MPGD detector with a lot of advantages;
- GEM has found a lot of application in the field of radiation imaging and particle physics;
- TPC based on GEM for ILC is feasible;
- It is possible to use GEM for ILC TPC gating, but more study is needed.

The end !!

Thanks to

Prof. Sauli, Prof. Murtas, Prof. Sugiyama

whom I borrowed slides from !!

Thanks for your attention !!

Any Question is Welcomed !!