Title

NEW TRENDS IN GAS DETECTORS

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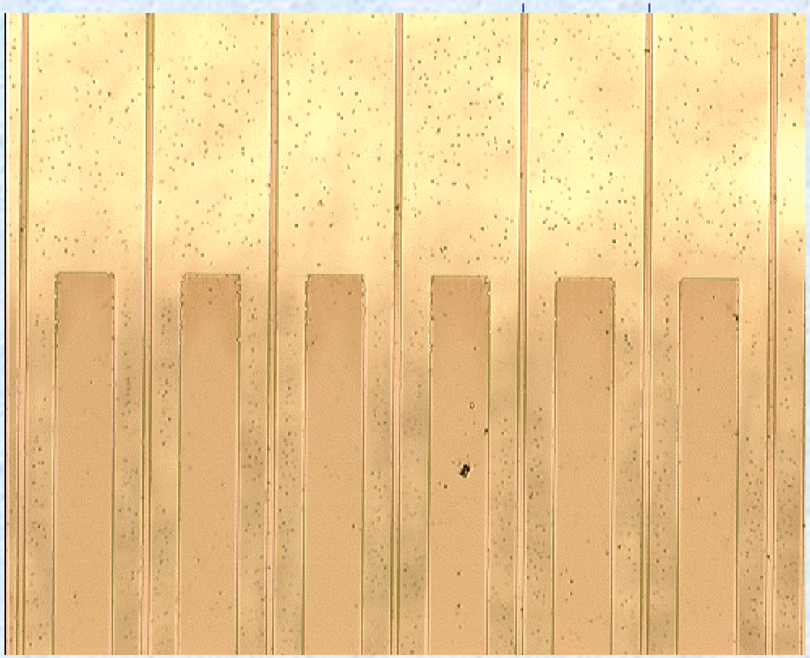
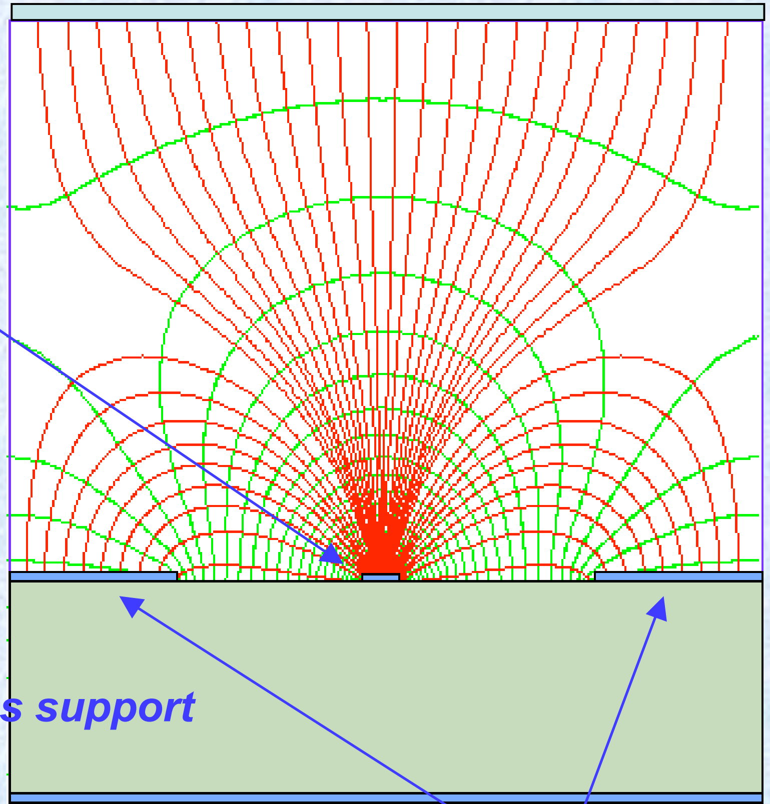
CERN, GENEVA, SWITZERLAND

INNOVATIVE DETECTORS FOR SUPERCOLLIDERS
ERICE, 28 September-4 October 2003

MICRO-STRIP GAS CHAMBER (MSGC)

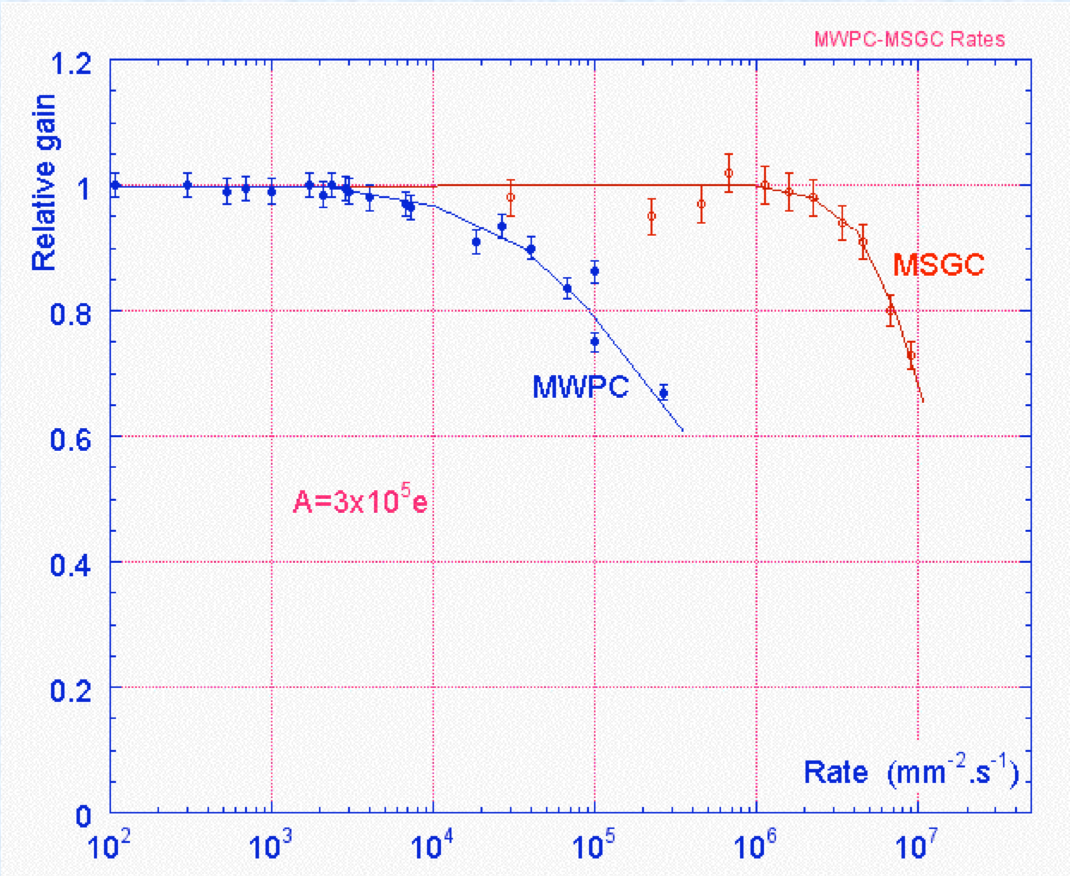
THIN ANODE AND CATHODE STRIPS
ON AN INSULATING SUPPORT



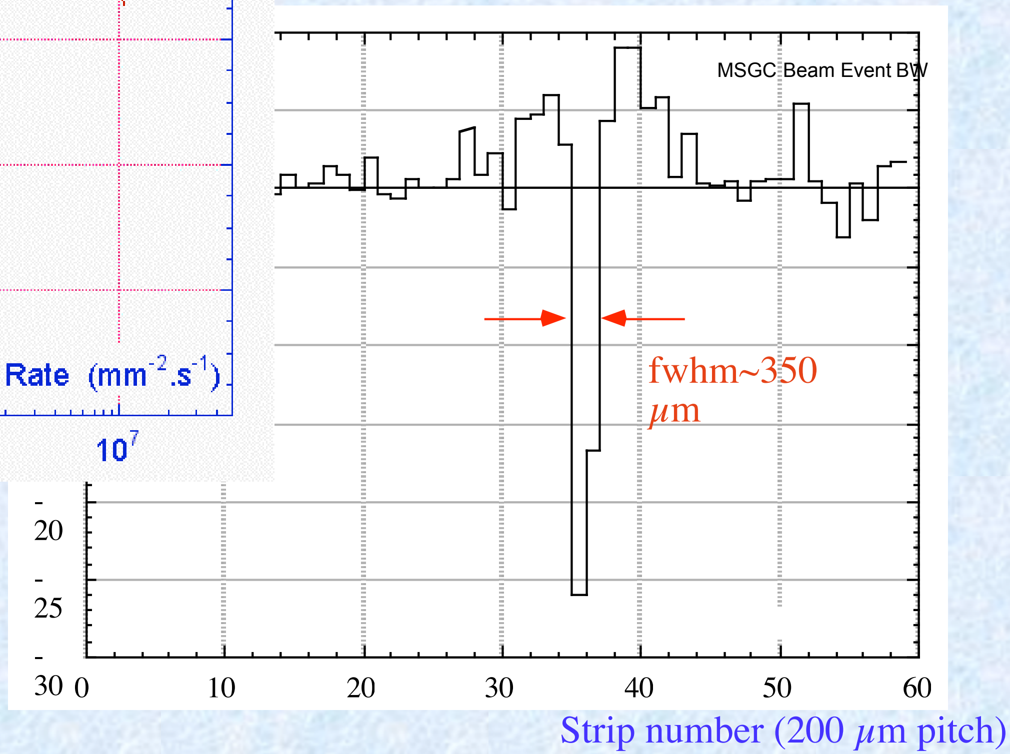


A. Oed
Nucl. Instr. and Meth. A263 (1988) 351.

MSGC Performances

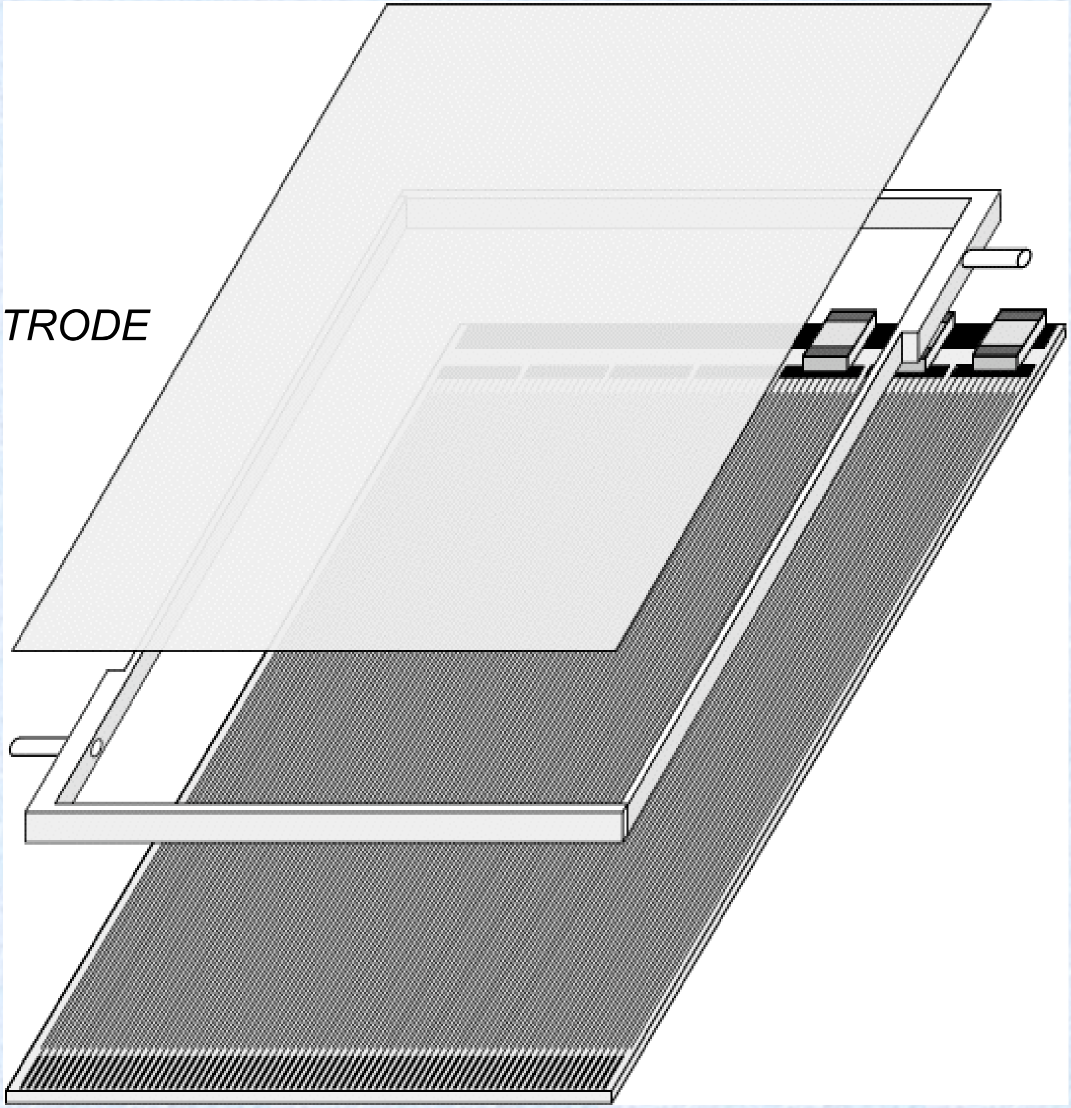


RATE CAPABILITY > 10^6/mm^2 s
SPACE ACCURACY ~ 40 μm rms
2-TRACK RESOLUTION ~ 400 μm



MSGC Assembly

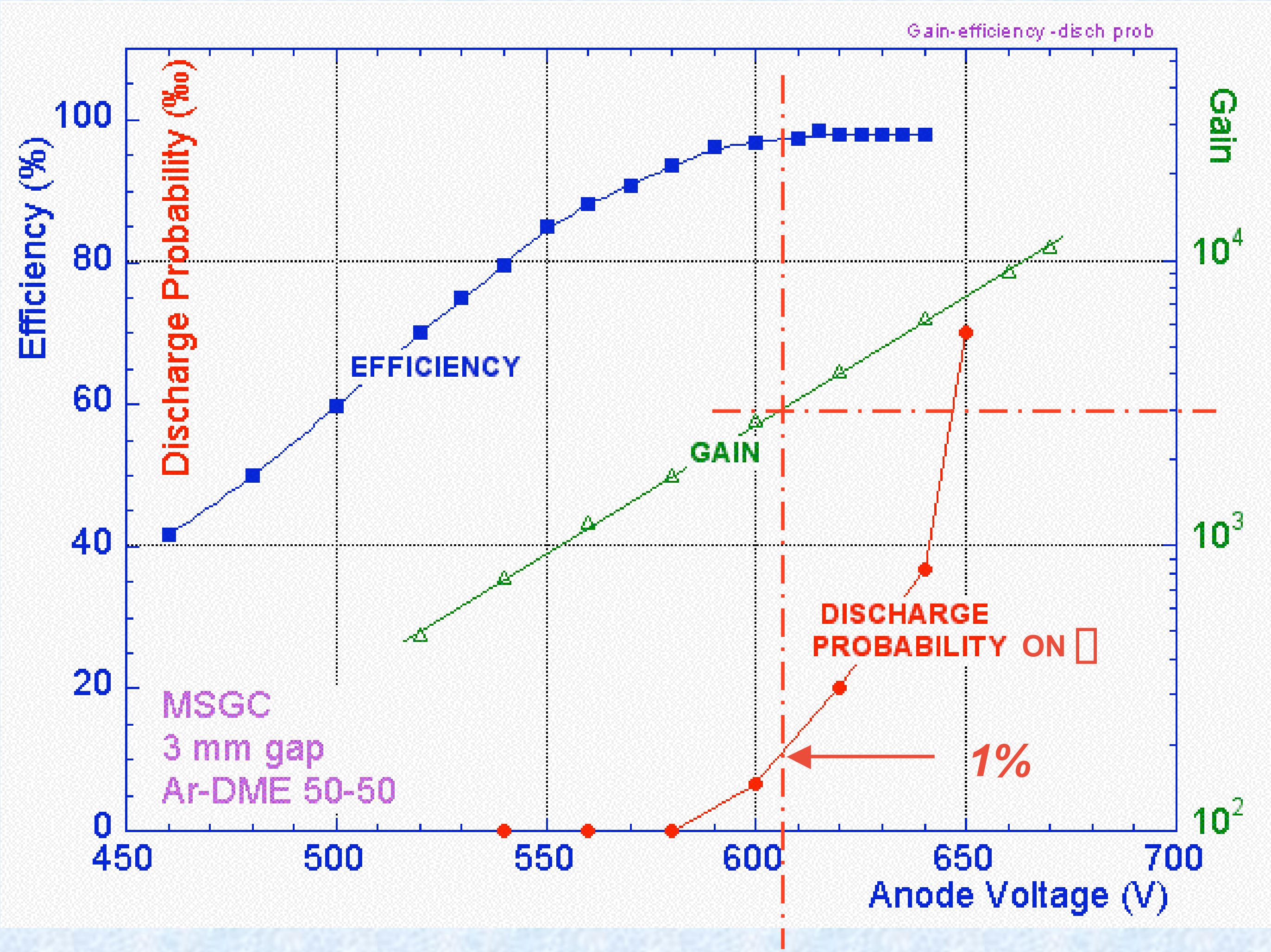
LIGHT AND SIMPLE CONSTRUCTION:



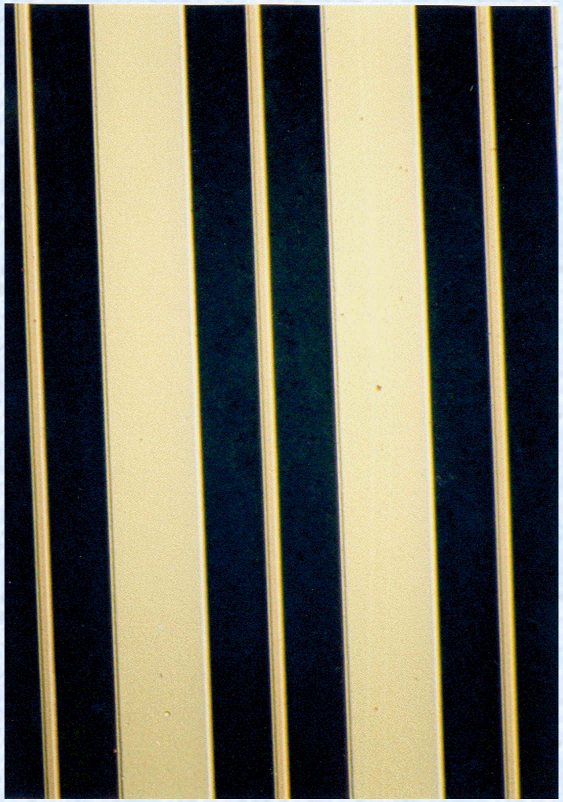
A. Barr et al, Nucl. Instrum. Methods A403(1998)31

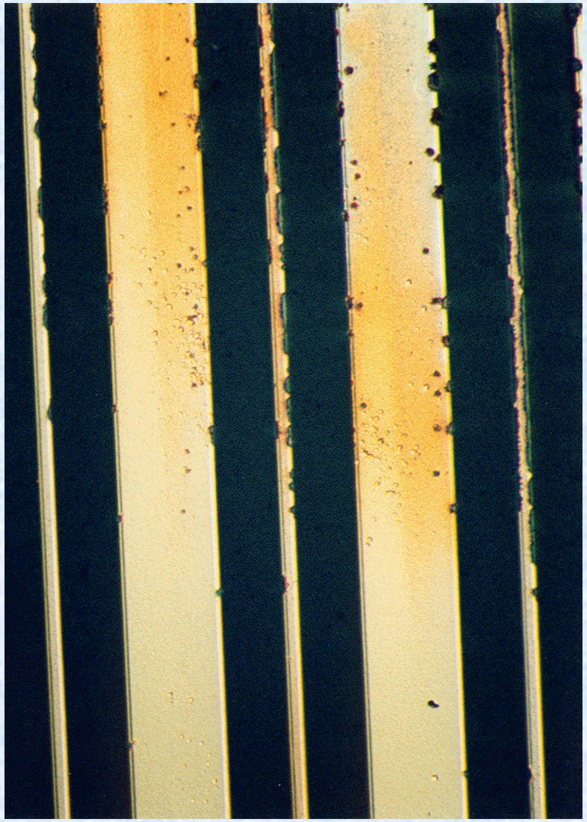
MSGC Discharges

A gain ~ 3000 is needed for detection of minimum ionizing tracks.
In presence of heavily ionizing particles background, the discharge probability is large:

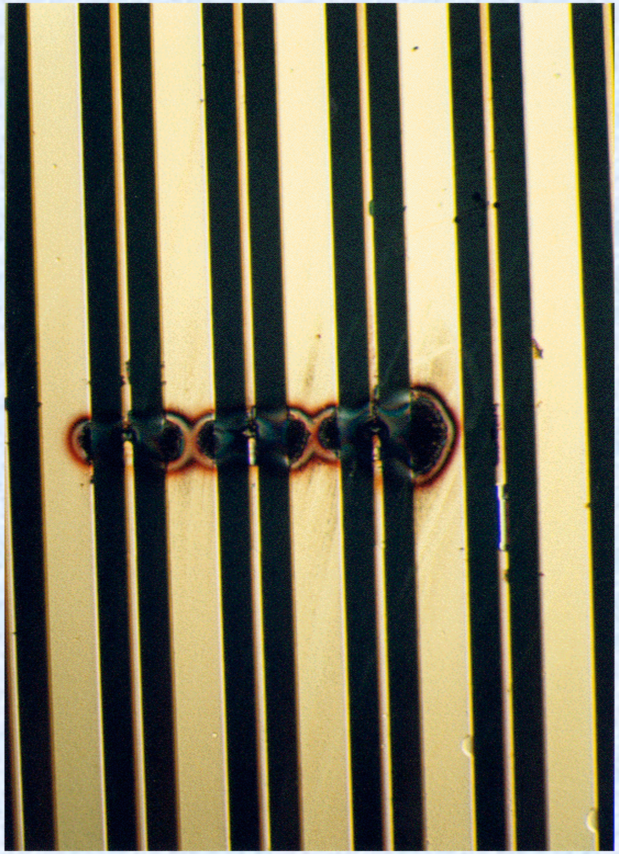


MSGC Discharges





MICRODISCHARGES

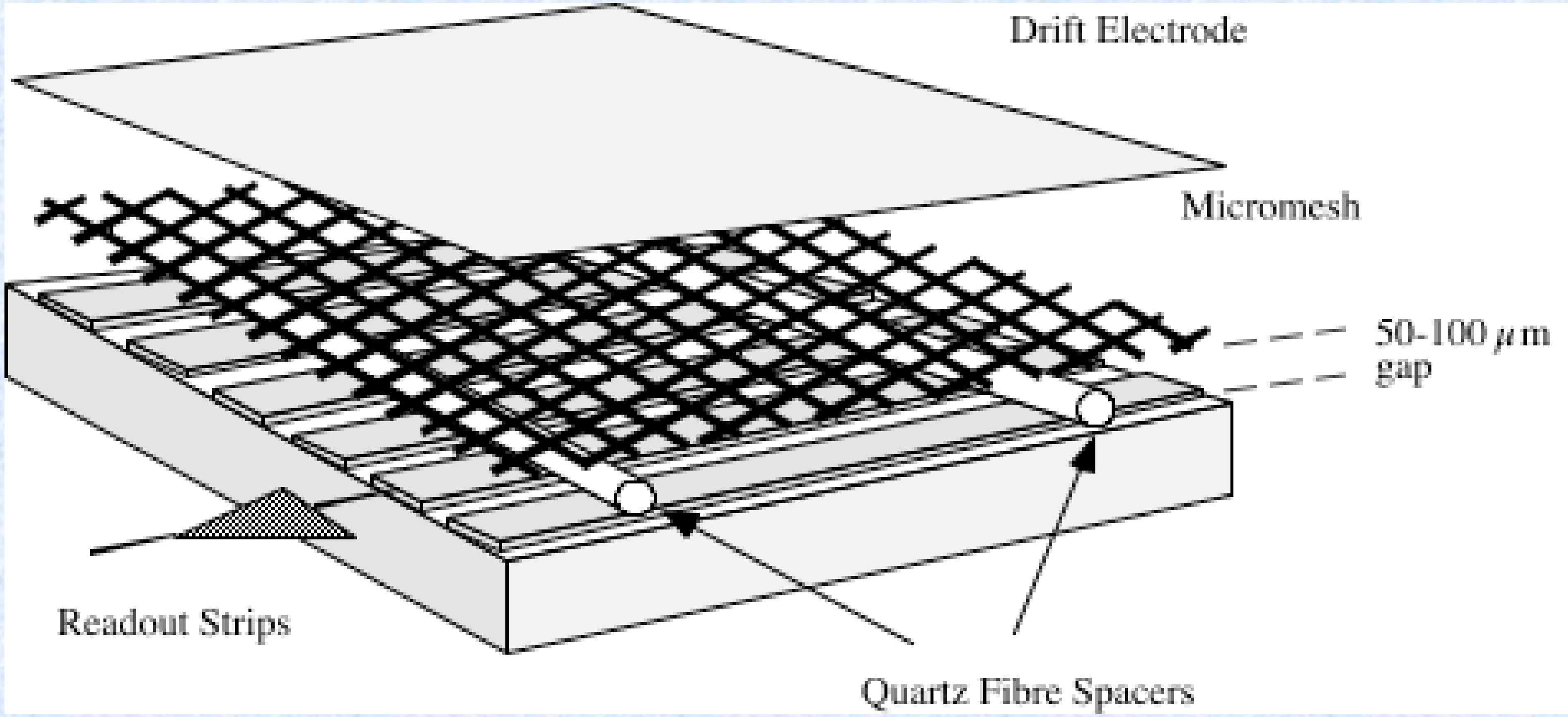


FULL BREAKDOWN

NEW Micropattern Detectors

MICROMEGAS:

THIN-GAP PARALLEL PLATE CHAMBER

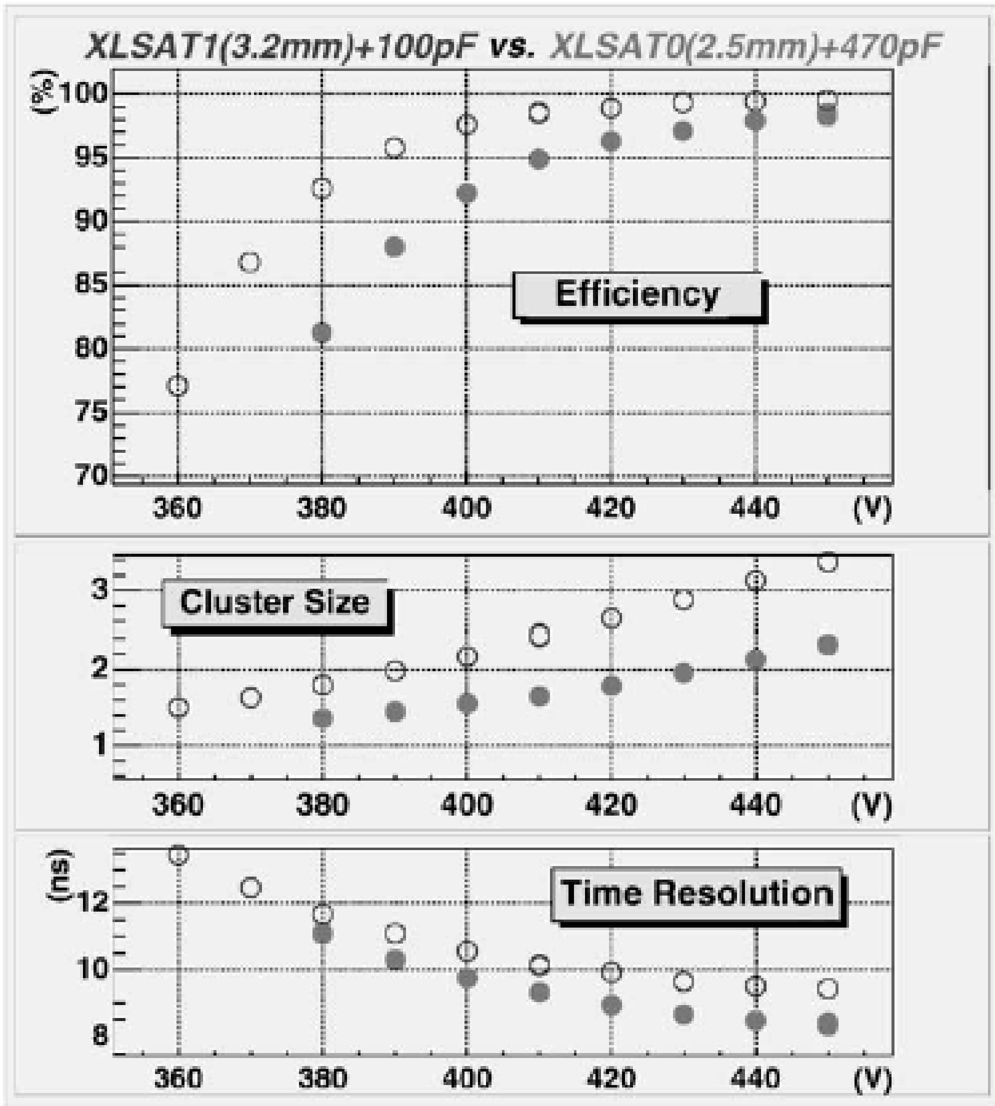


Y. Giomataris et al, Nucl. Instr. and Meth. A376(1996)29

MICROMEGAS for COMPASS

COMPASS:
FORWARD SPECTROMETER
PRIMARY BEAM ~10^8 μ/spill

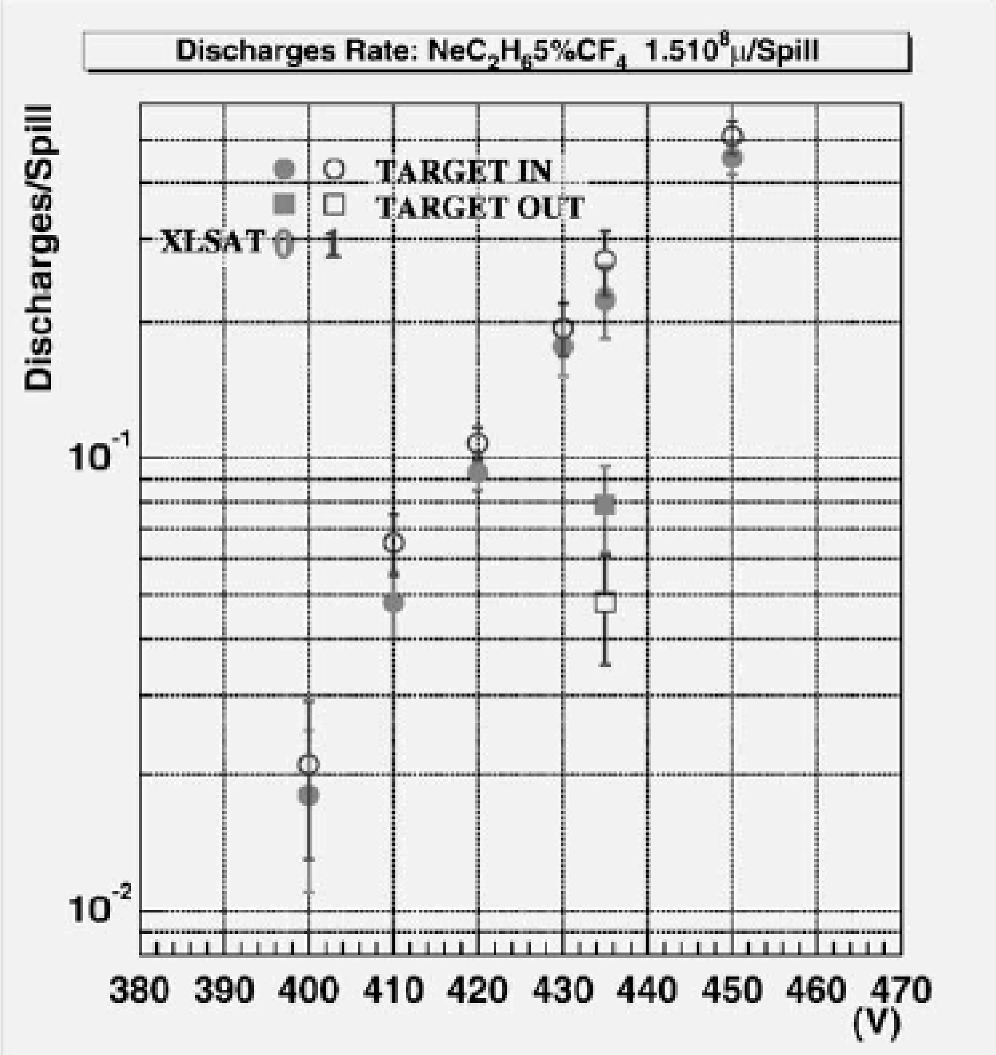
LARGE SIZE (40x40 cm^2) DETECTORS
5 cm Ø DEAD ZONE IN THE CENTER



A. Magnon et al, Nucl. Instrum. Meth. A478(2002)210

MICROMEGAS Discharges

DISCHARGE RATE PER SPILL:

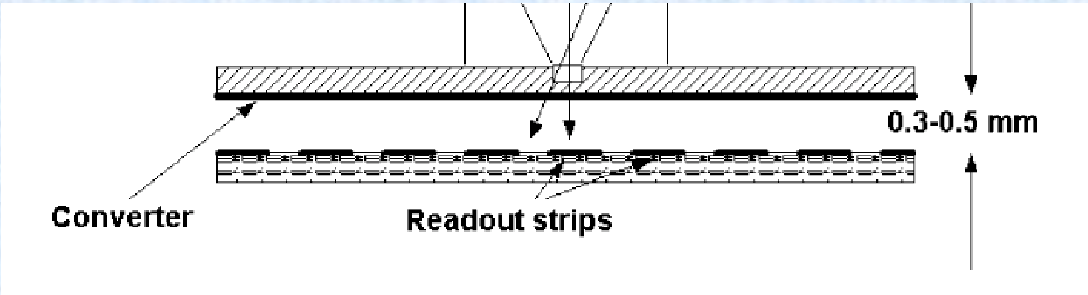


Detector and electronics designed to withstand discharges

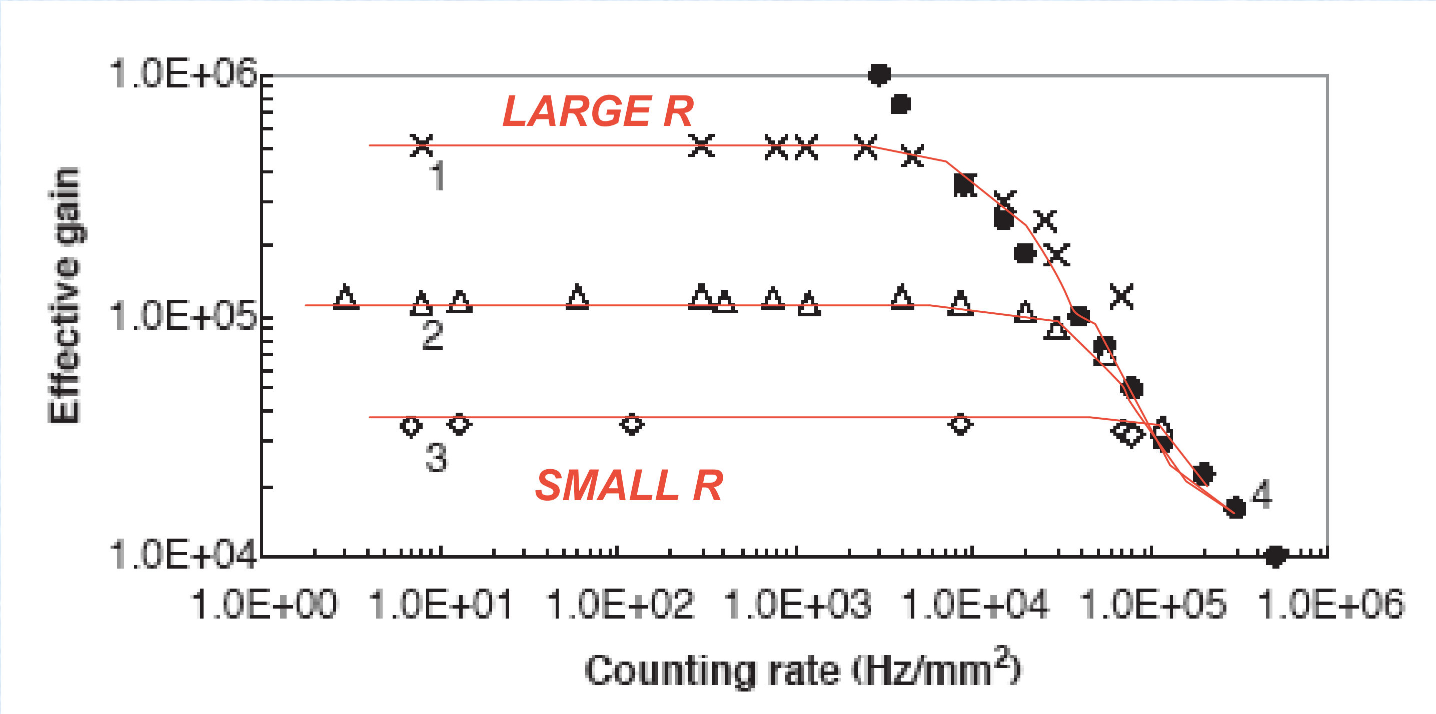
Dead time per discharge~ 10 ms

A. Magnon et al, Nucl. Instrum. Meth. A478(2002)210

PPAC, RPC



Parallel Plate Avalanche Chambers
Resistive Plate Chambers

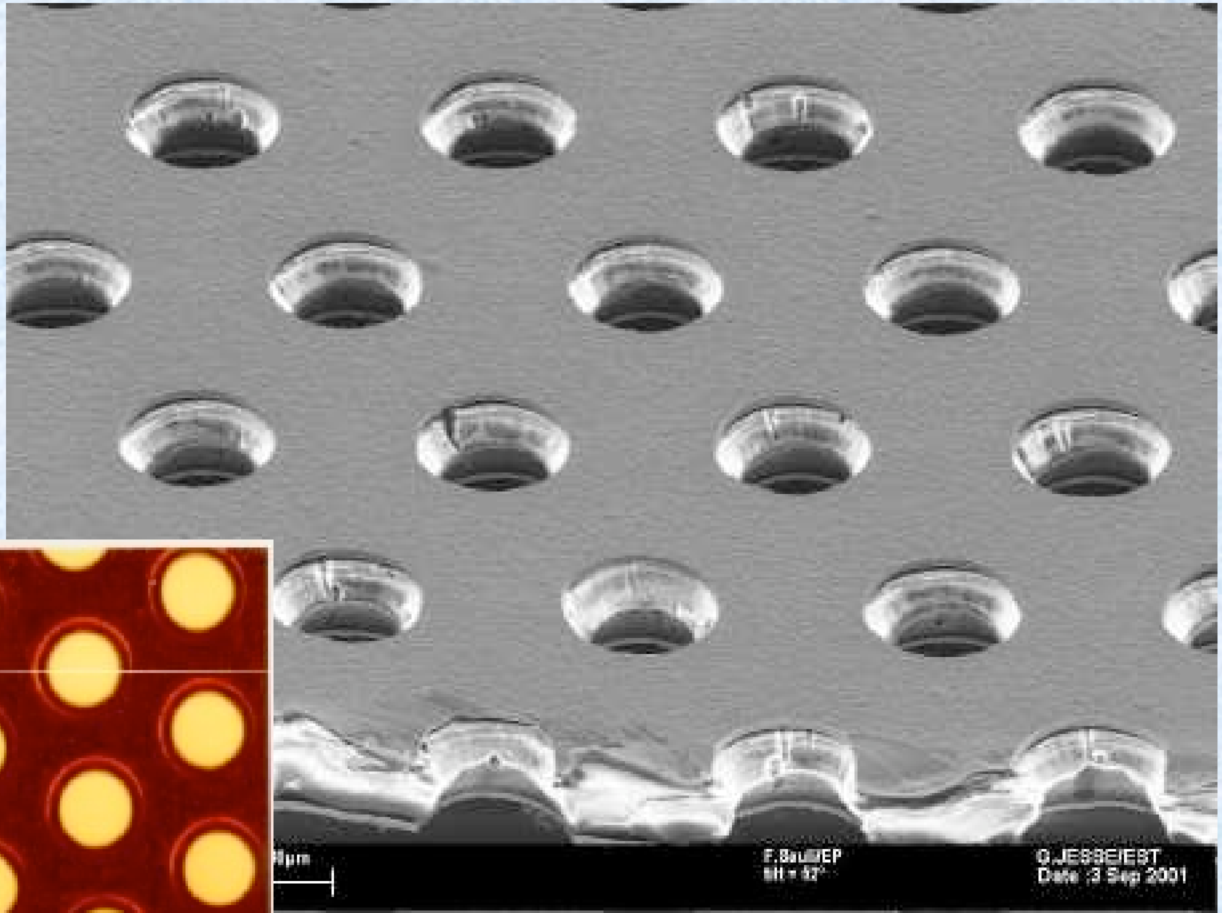


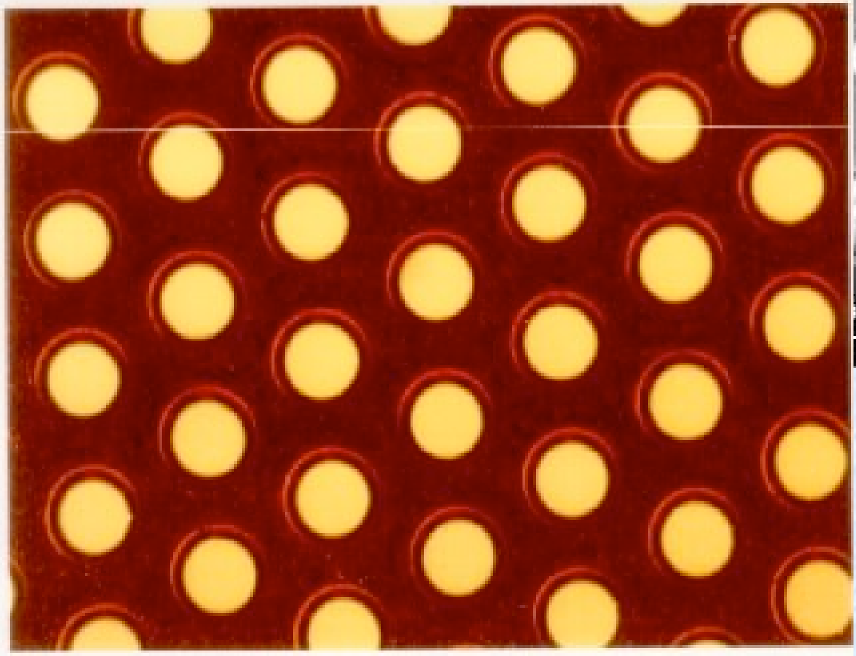
T. Francke et al Nucl. Instr. Meth. A508(2003)83

SEE Peskov Talk

GEM Gas Electron Multiplier

Thin metal-coated polymer foil chemically pierced by a high density of holes (technology developed at CERN)



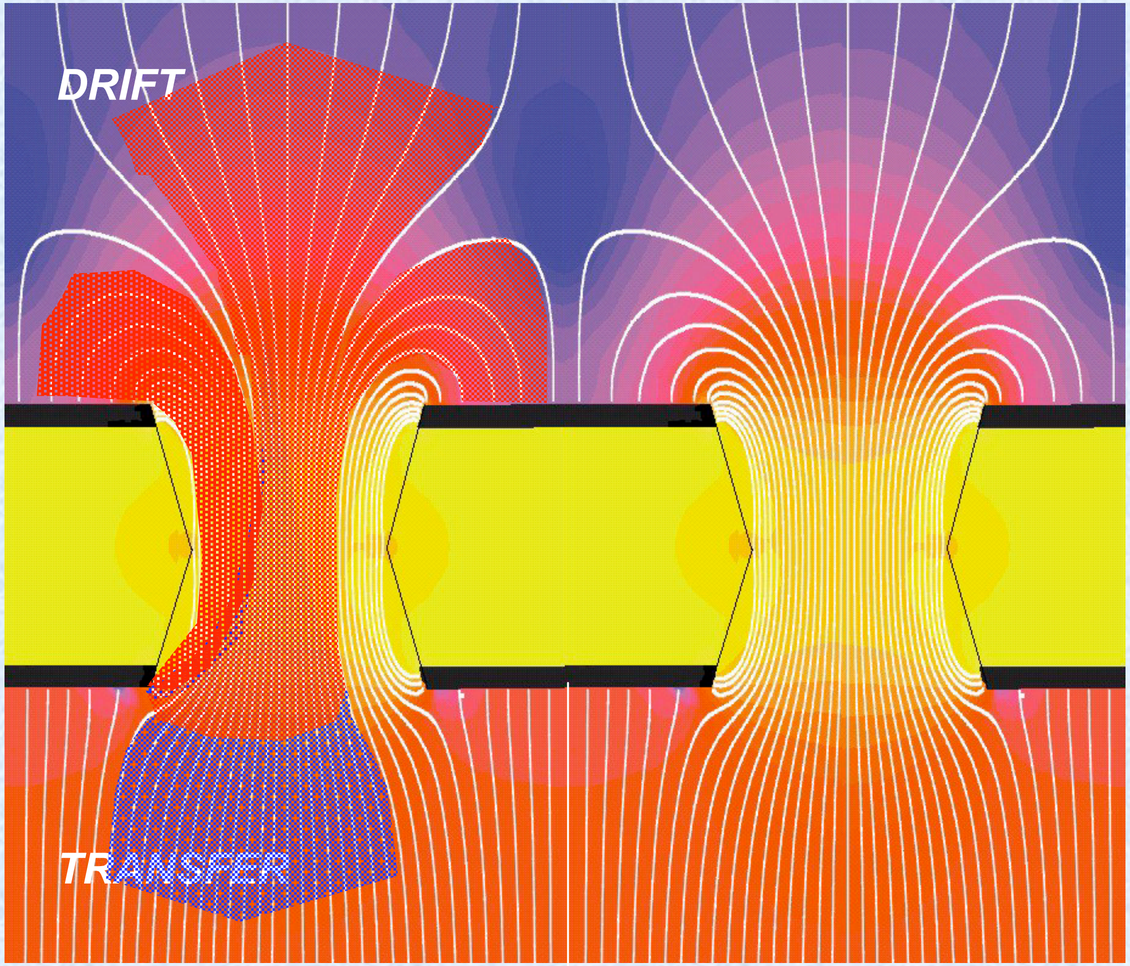


Typical geometry:
5 µm Cu on 50 µm Kapton
70 µm holes at 140 mm pitch

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

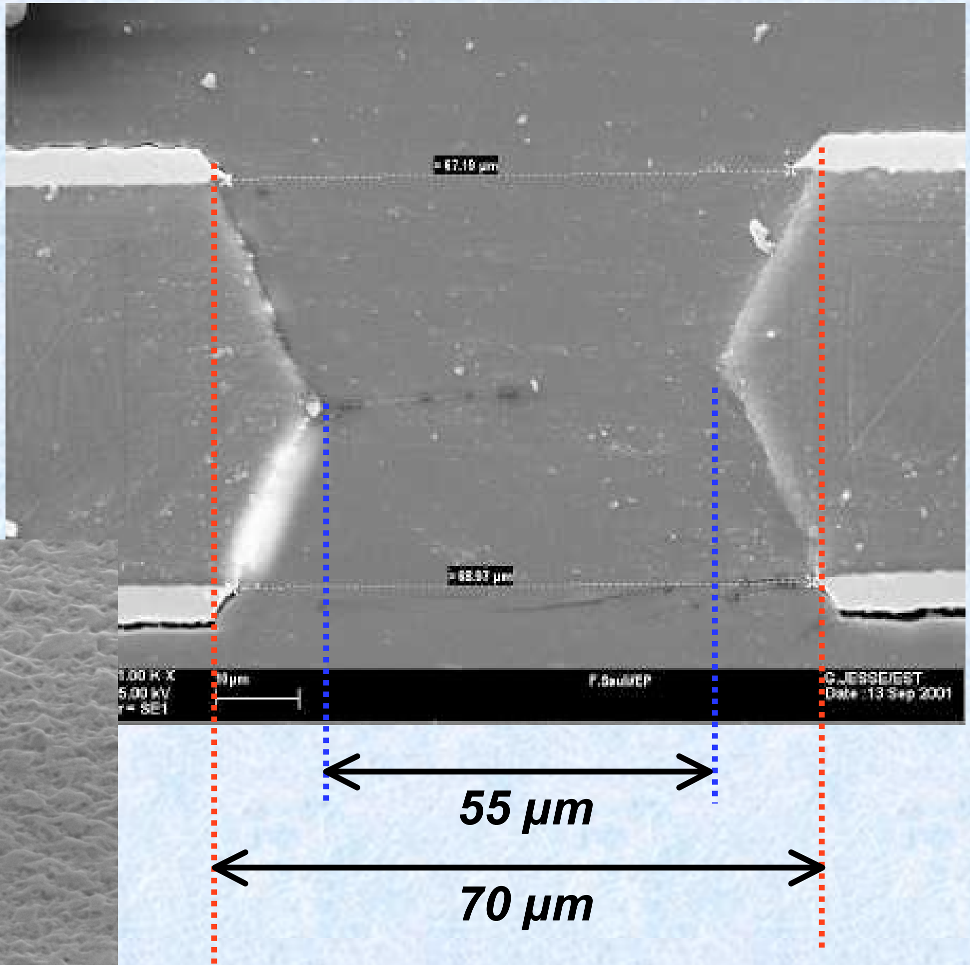
GEM Field

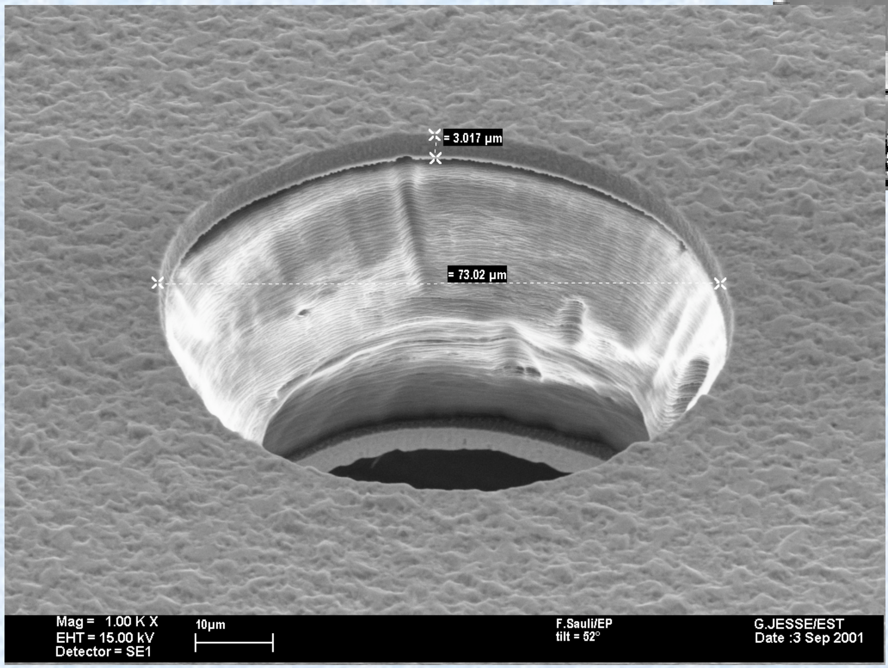
On application of a voltage gradient, electrons released on the drift side drift into the hole, multiply in avalanche and transfer the other side.



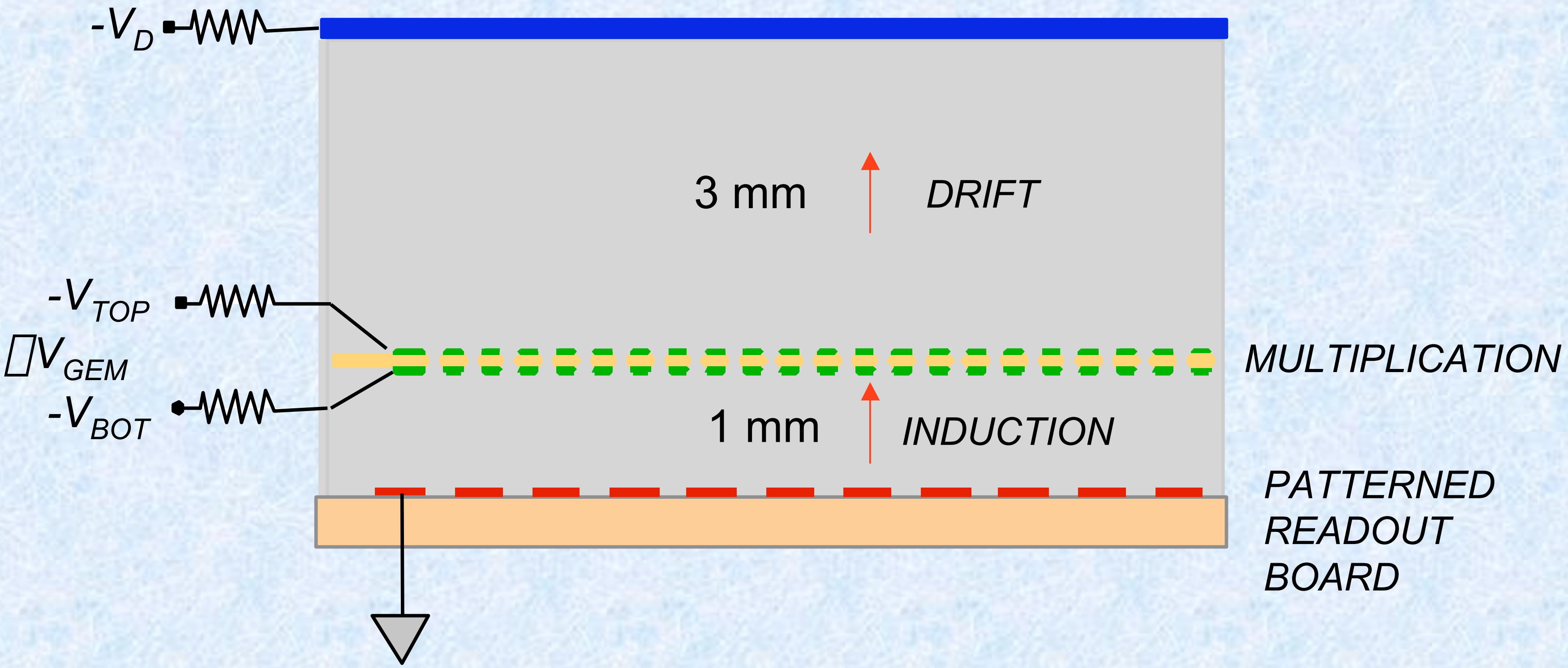
GEM Manufacturing

Double-conical
Standard GEM





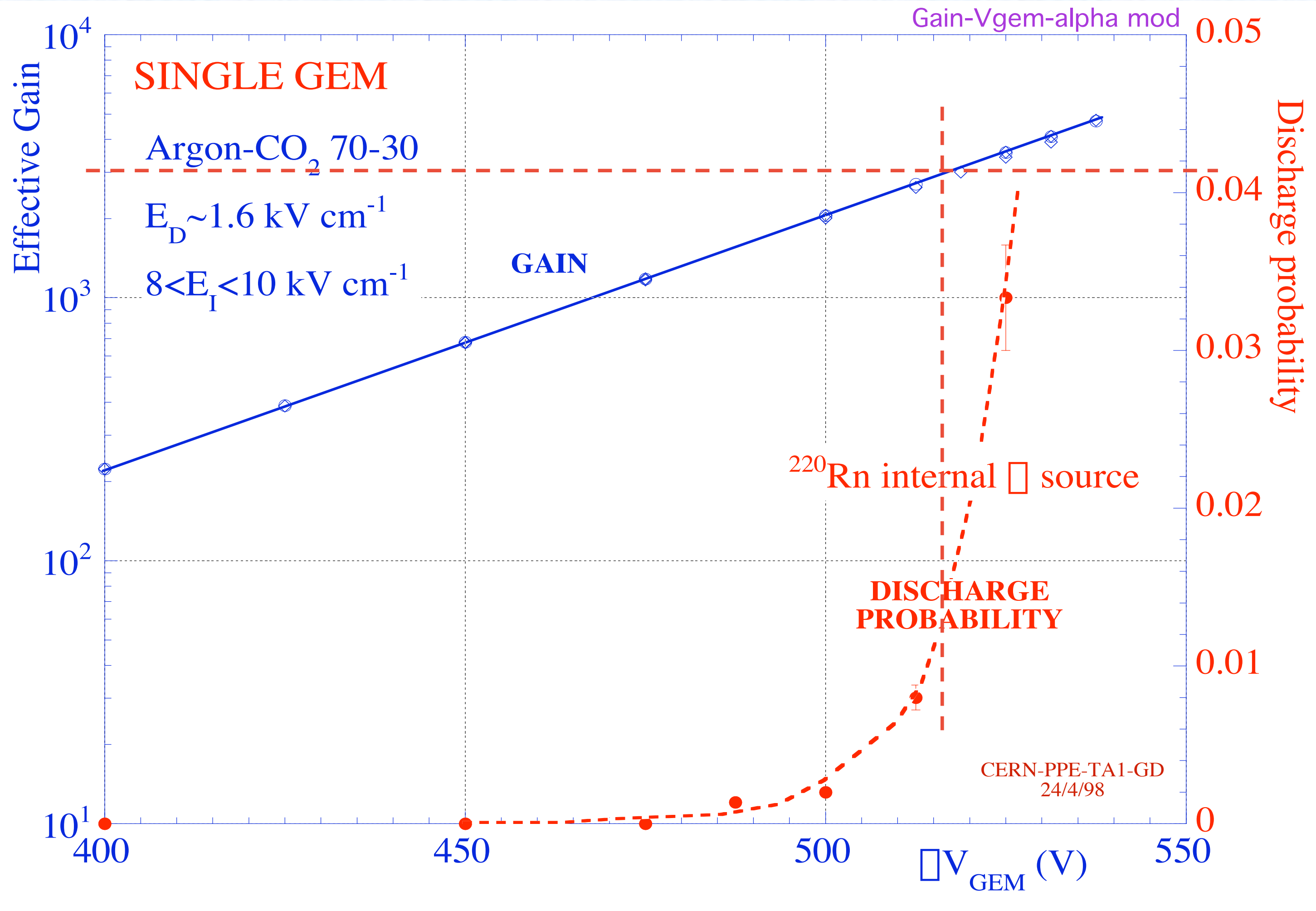
Single GEM detector



- Freedom in shape of the detector (including non-planar)
- Readout separated from multiplying electrodes
- Multiple cascaded structures possible (large gains, feedback suppression)
- Cheap and reliable

SGEM Discharges

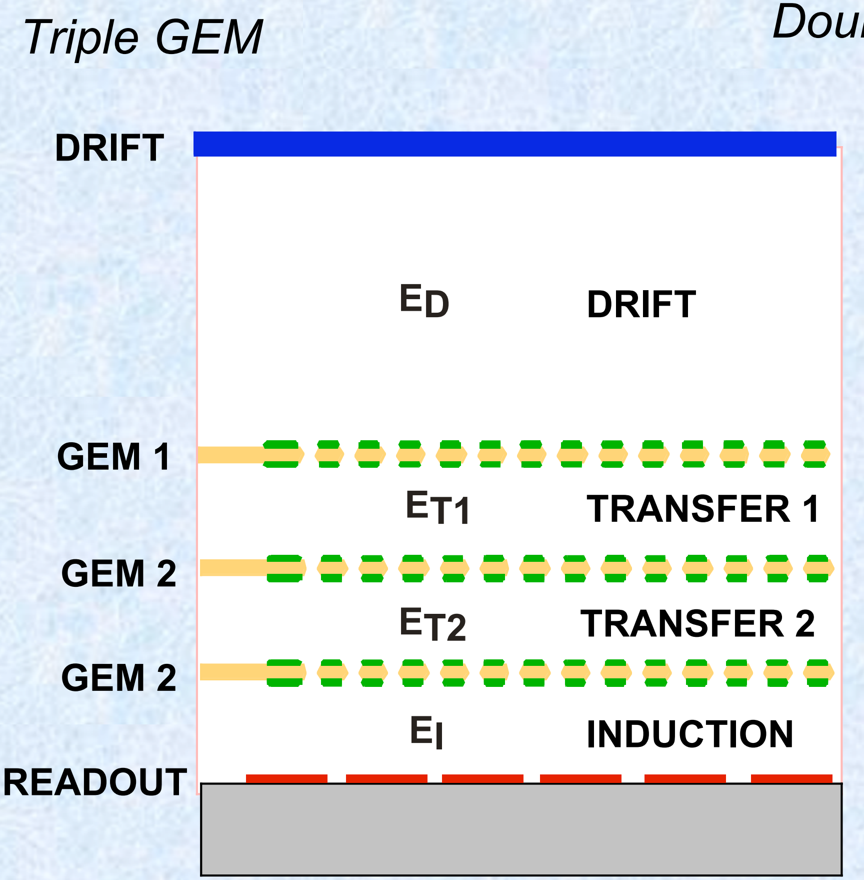
Gain: 5.9 keV X-rays
Discharge probability: 5 MeV particles

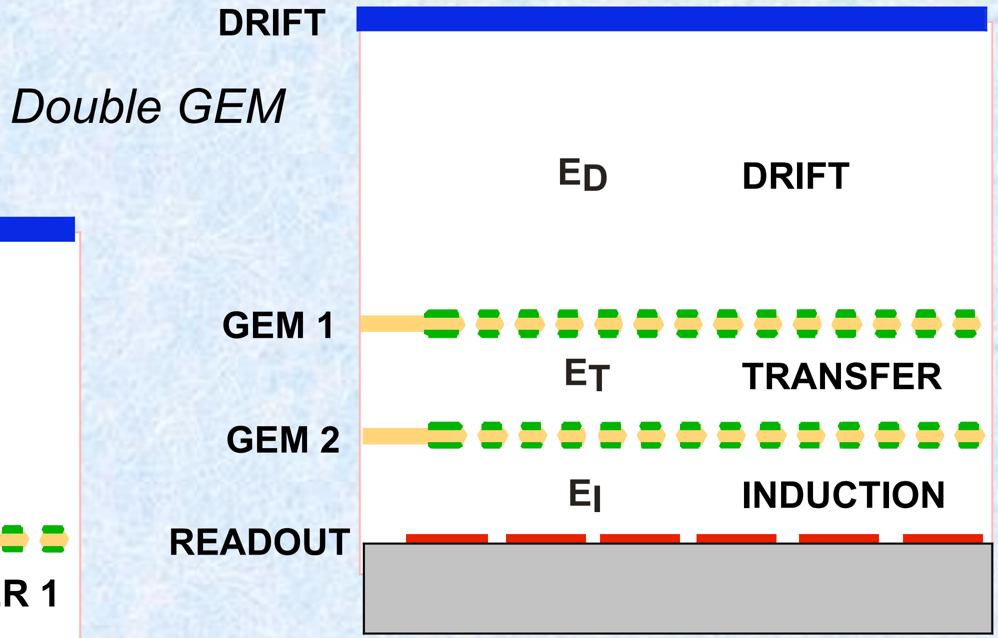


A. Bressan et al, Nucl. Instrum. Meth. A424(1999)321

Multiple GEM Structures

Cascaded GEMs achieve larger gains and safer operation in harsh environments

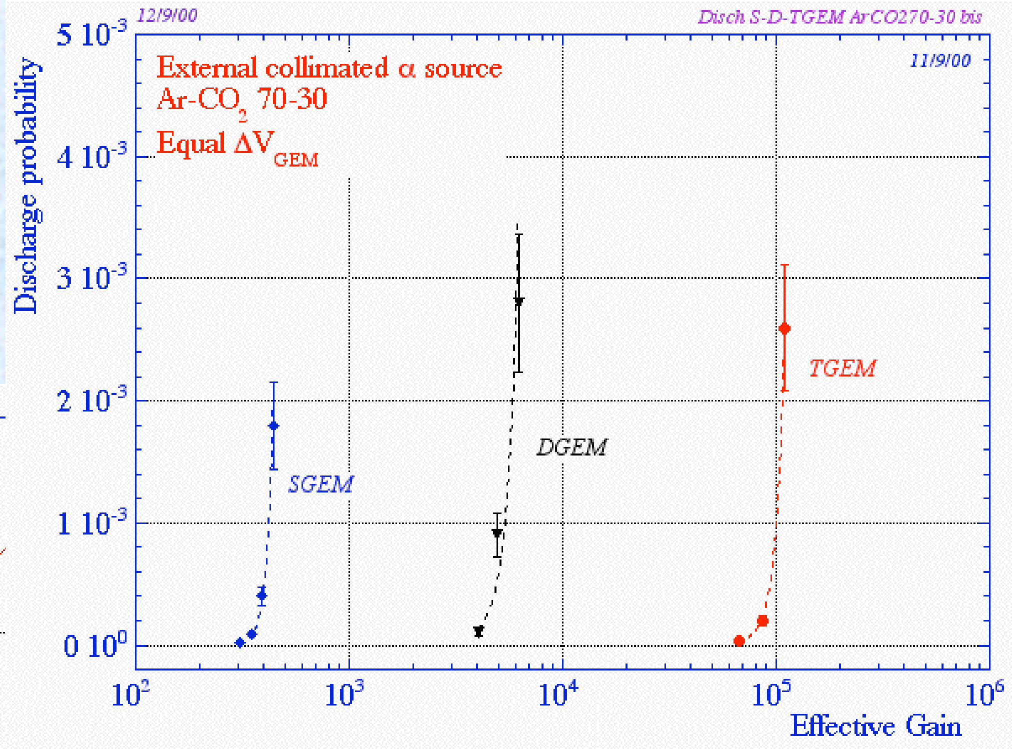


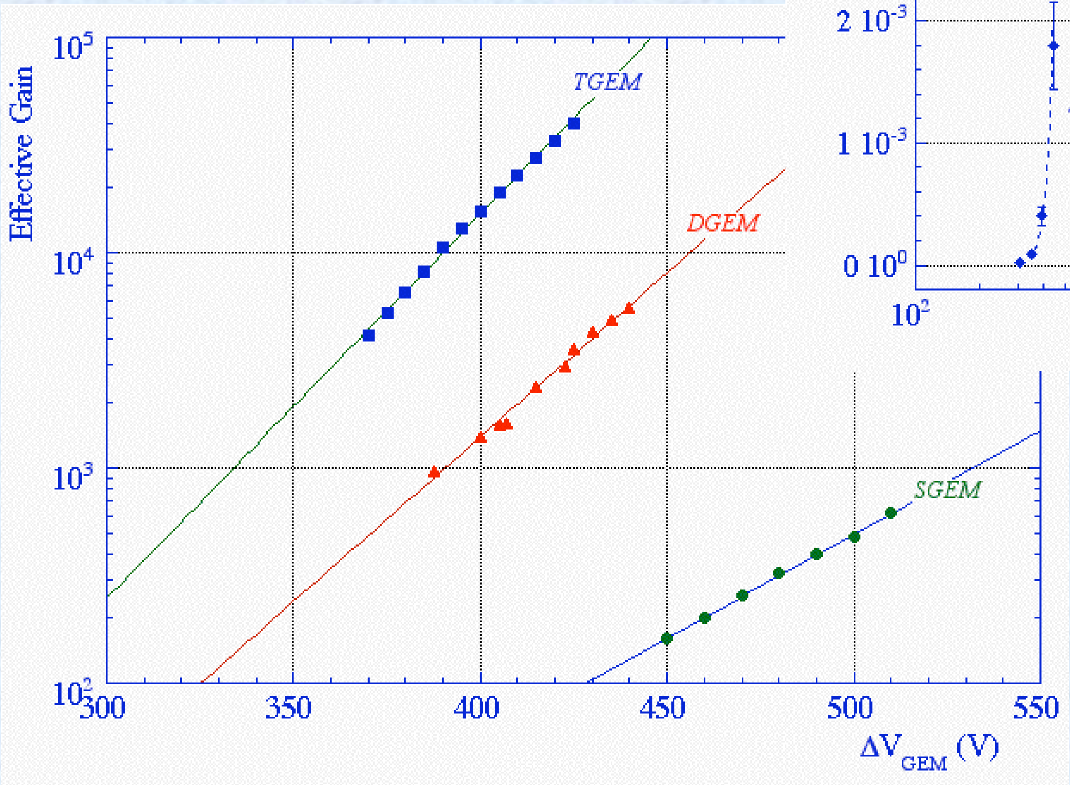


C. Buttner et al, Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464

MULTIGEM Gain and Discharges

Exposed to 5 MeV particles from ^{220}Rn





Multiple structures provide equal gain at lower voltage
The discharge probability on exposure to a particles is strongly reduced

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

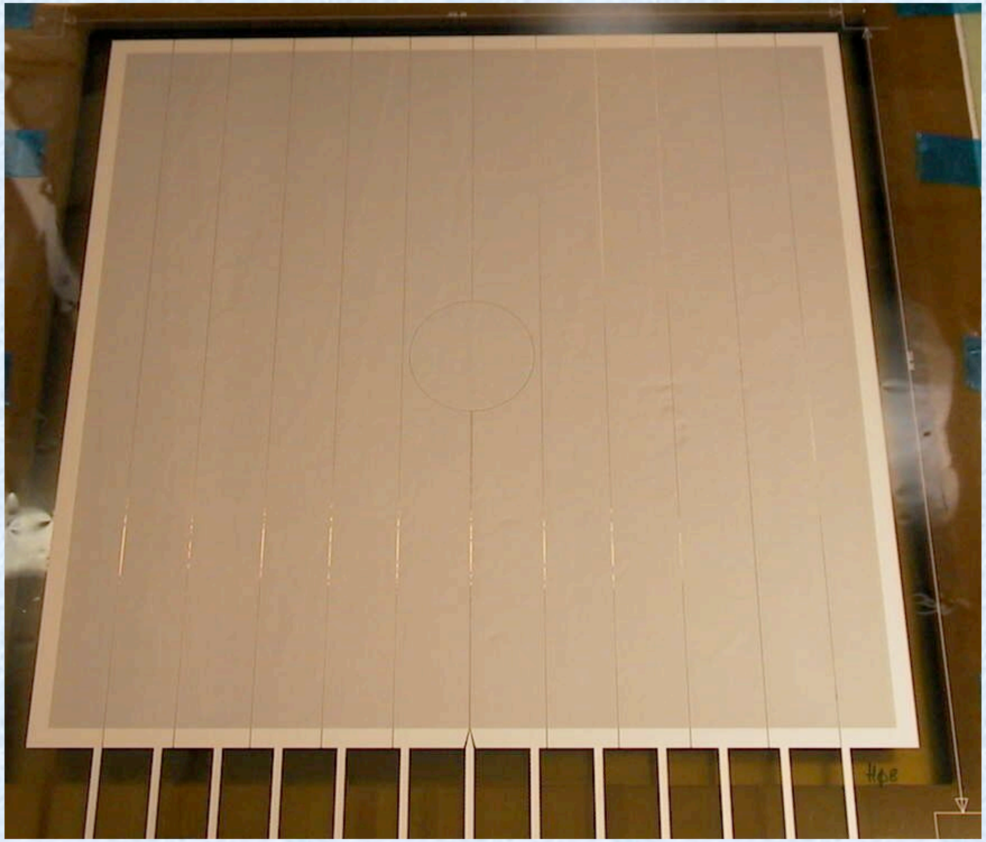
GEM: freedom of shapes

GEM for HERA-B (DESY)

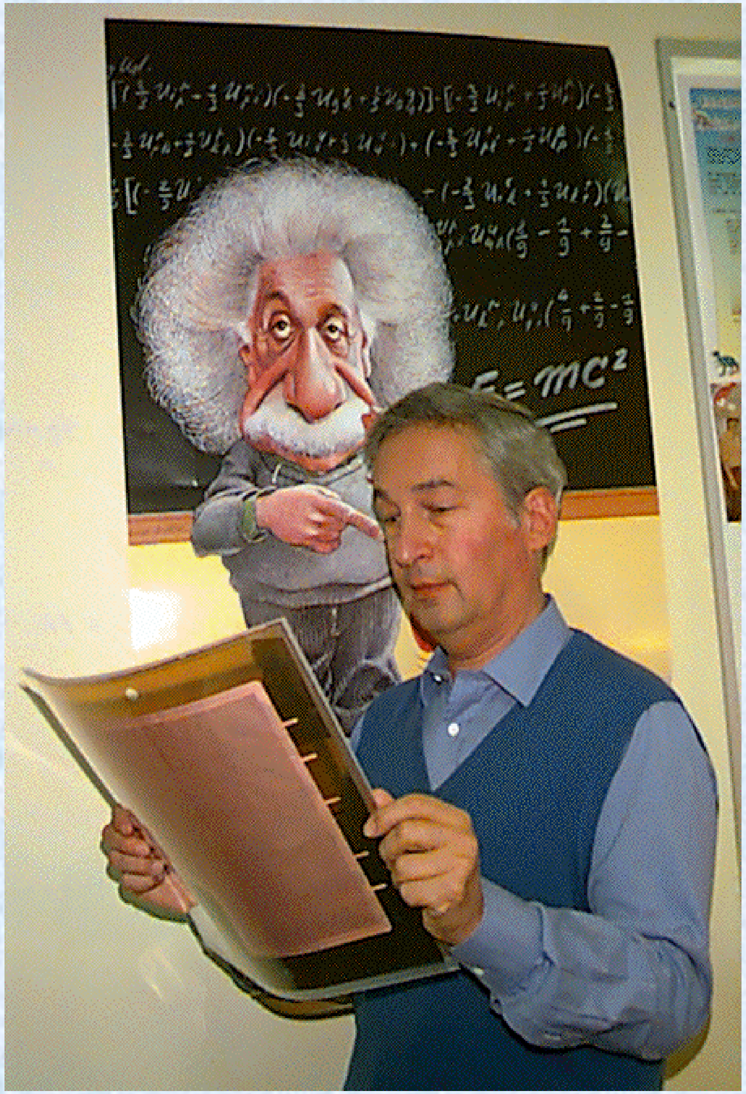
ESA-INTEGRAL Mission
Prototype GEM for JEM-X (25 cm Ø):

Large GEMs for COMPASS

31x31 cm^2 active
12 sectors+ central beam killer
~ 100 manufactured at CERN

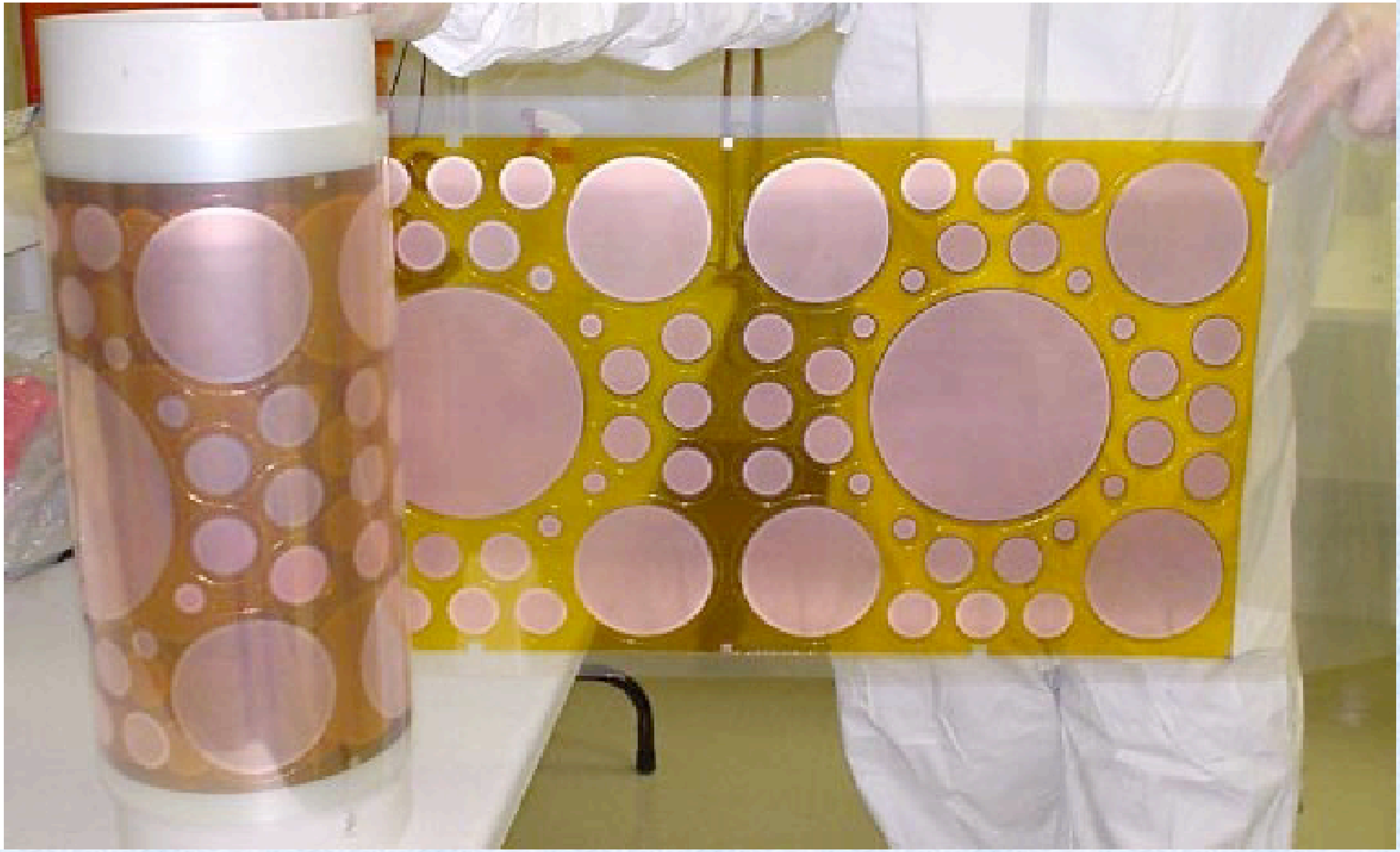


C. Altumbas et al, Nucl. Instr. Meth. A490(2002)177



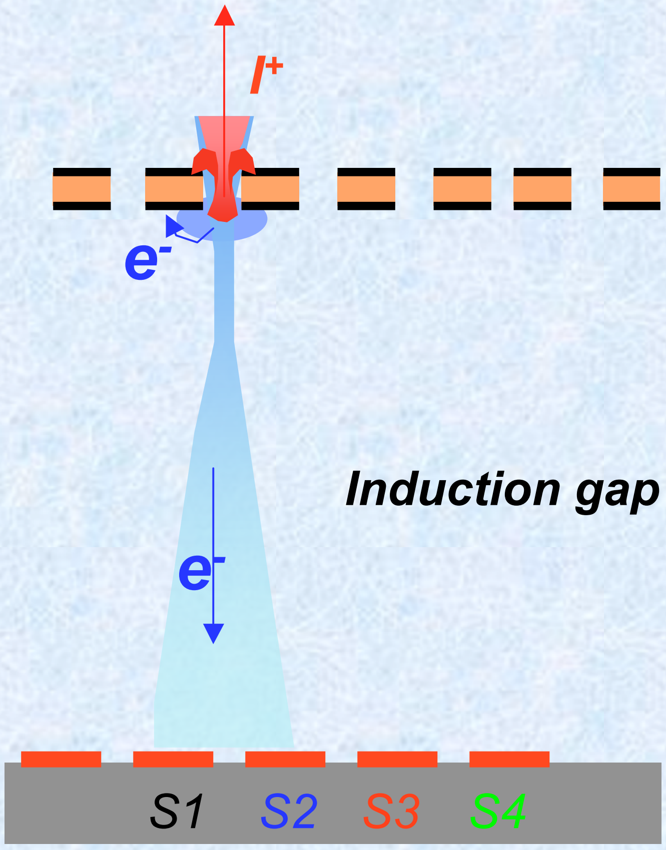
3-M GEM mass production

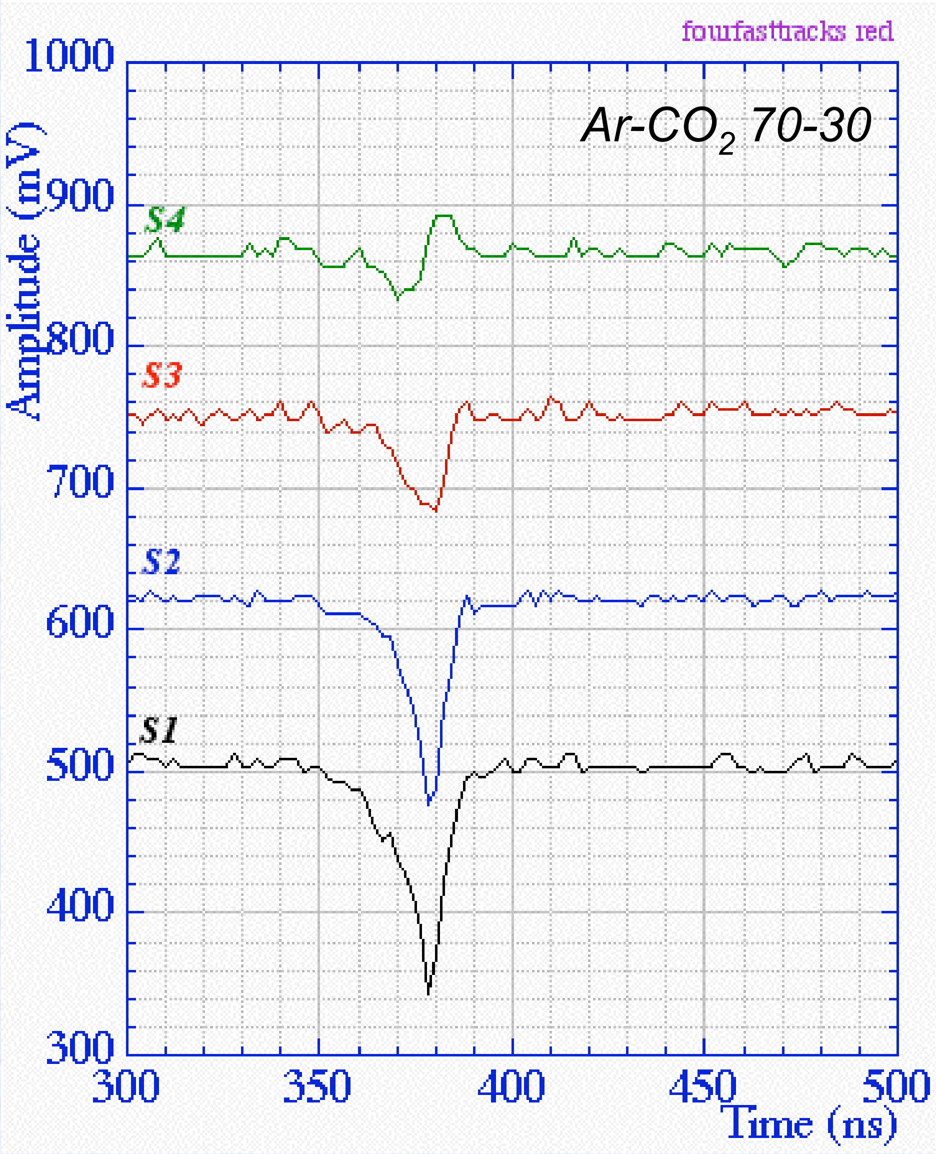
Thousand delivered



P. S. Barbeau et al, Subm. NIMA (2003)

GEM signal formation

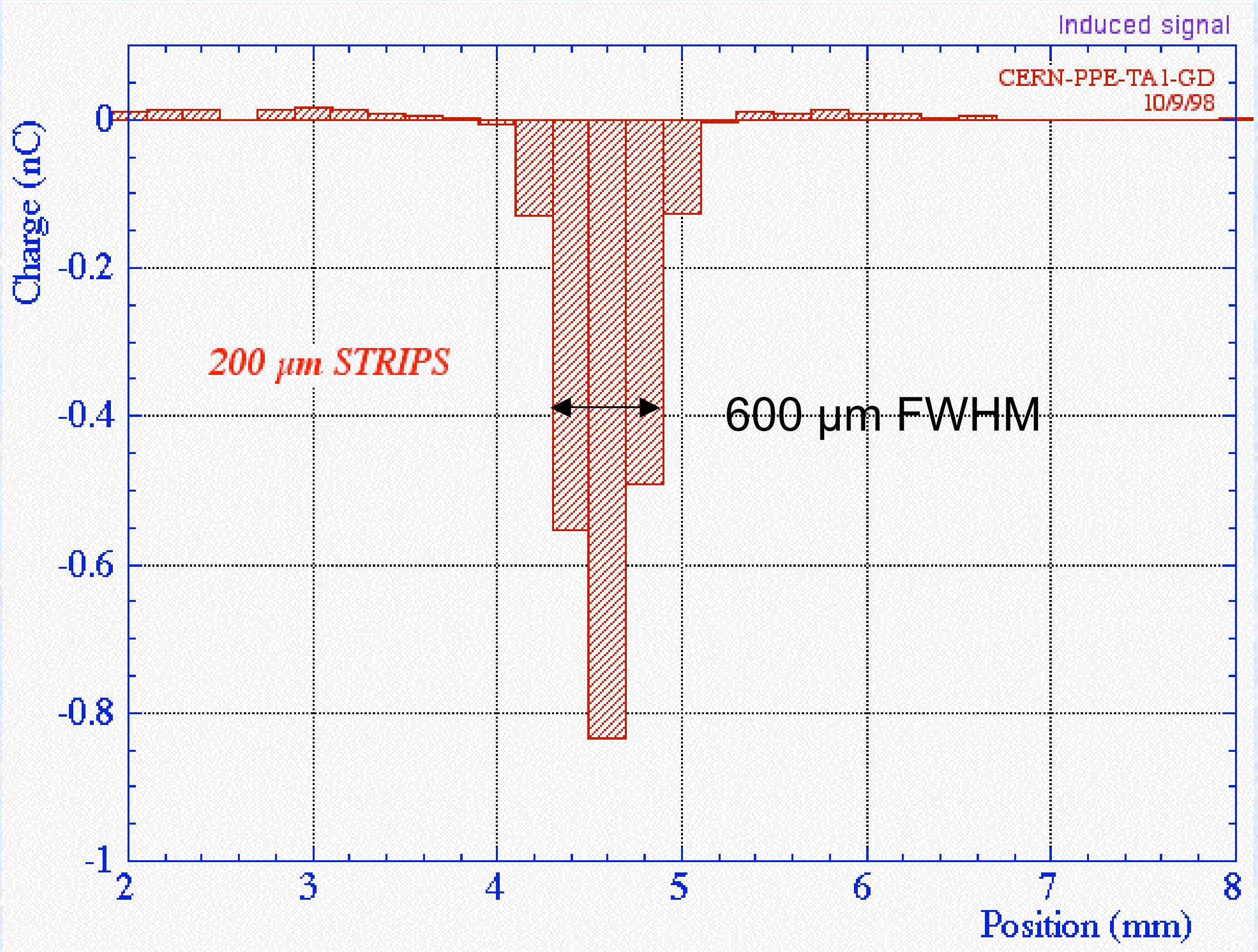




Fast electron signal only

No positive ion tail ⟶ very good multi-track time resolution

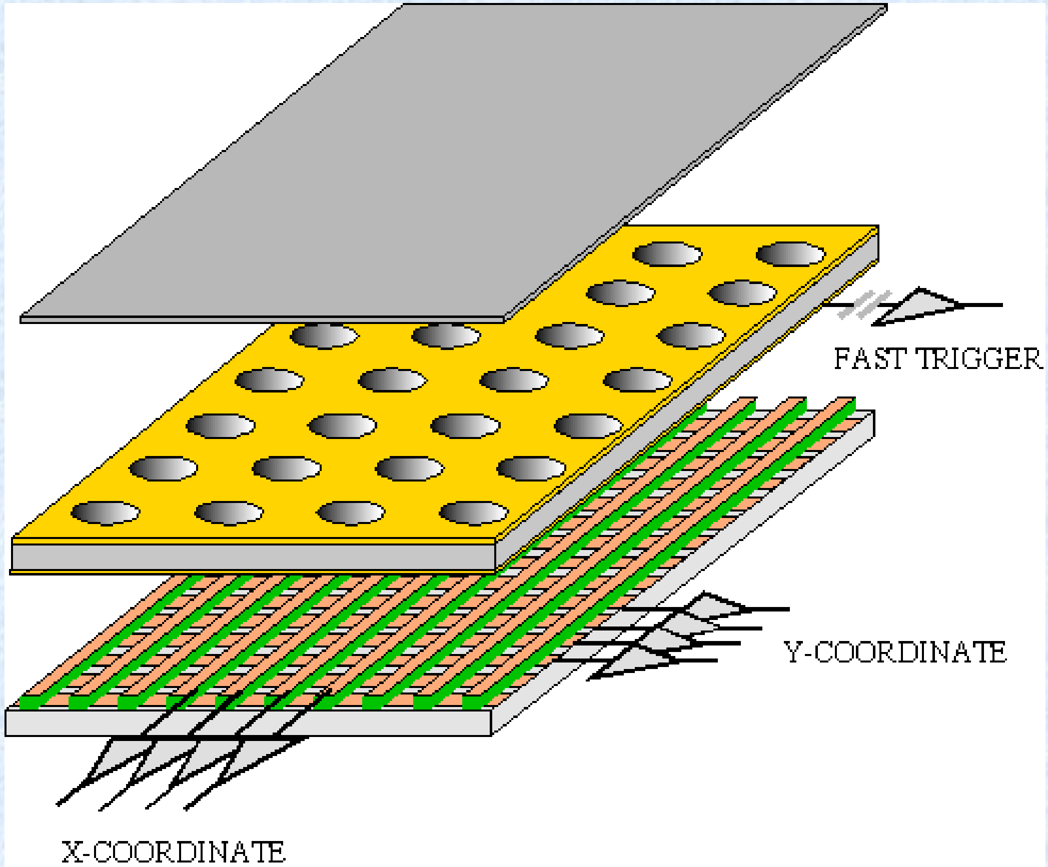
Narrow collected charge profile



- (+) Very good multi-track resolution
- (−) Requires high density of readout channels

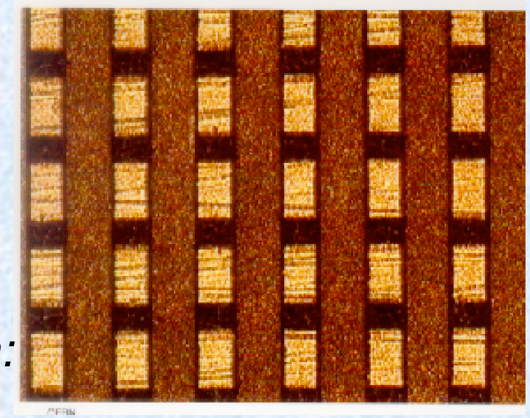
2-Dimensional Readout

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

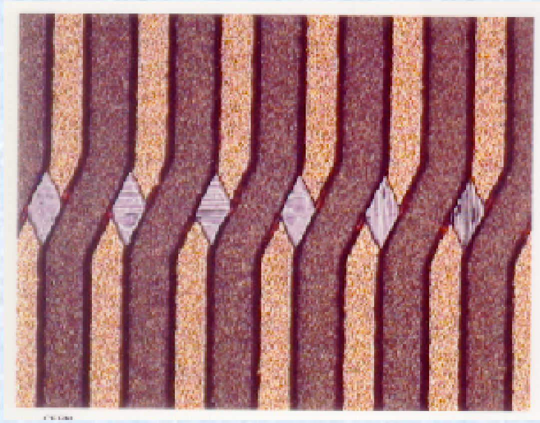


A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254

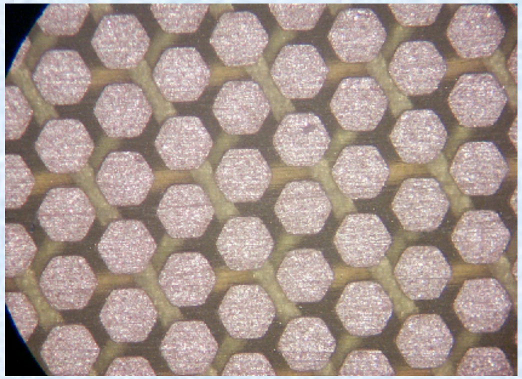
Cartesian:



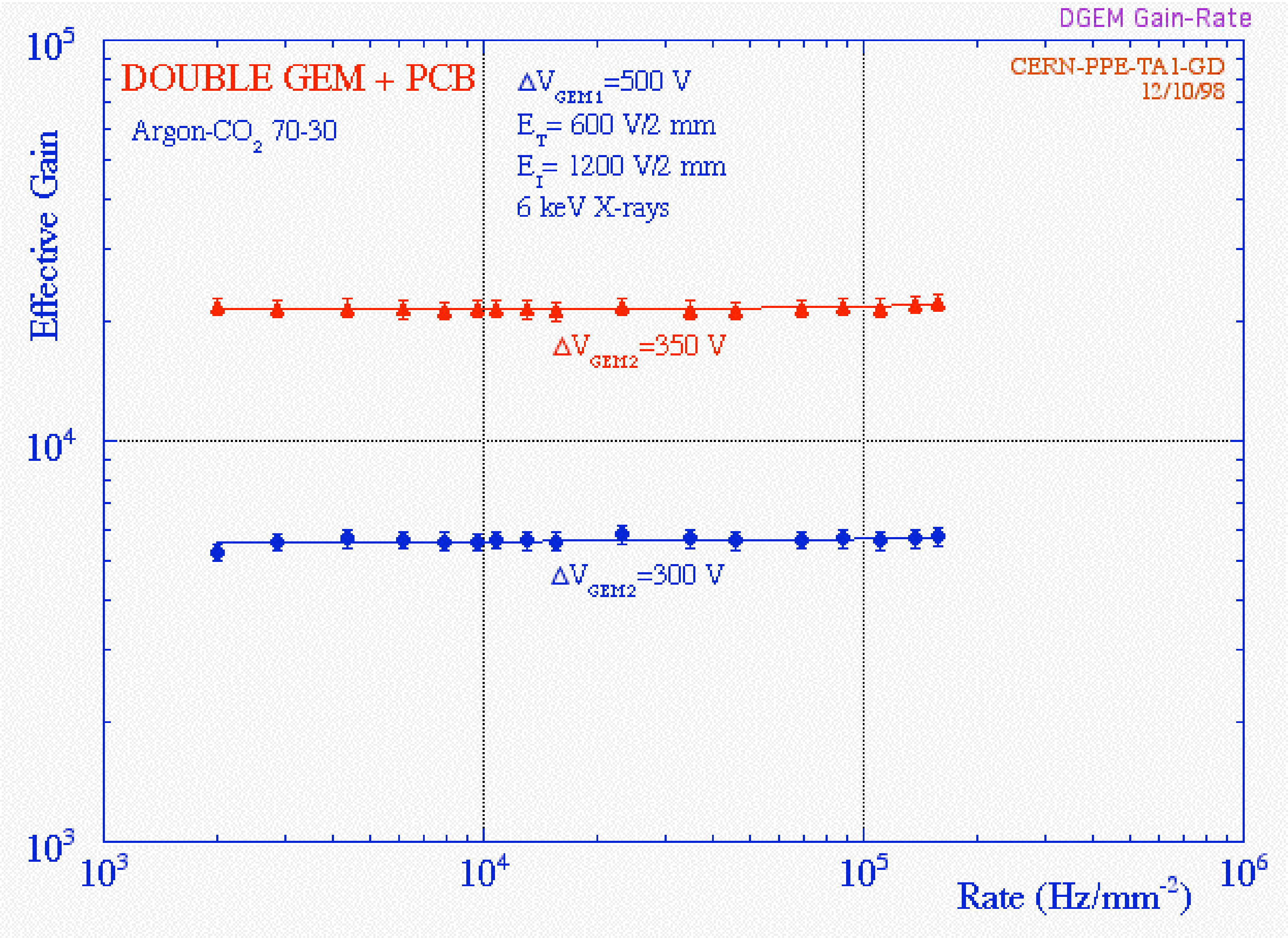
Small angle:



Pads:



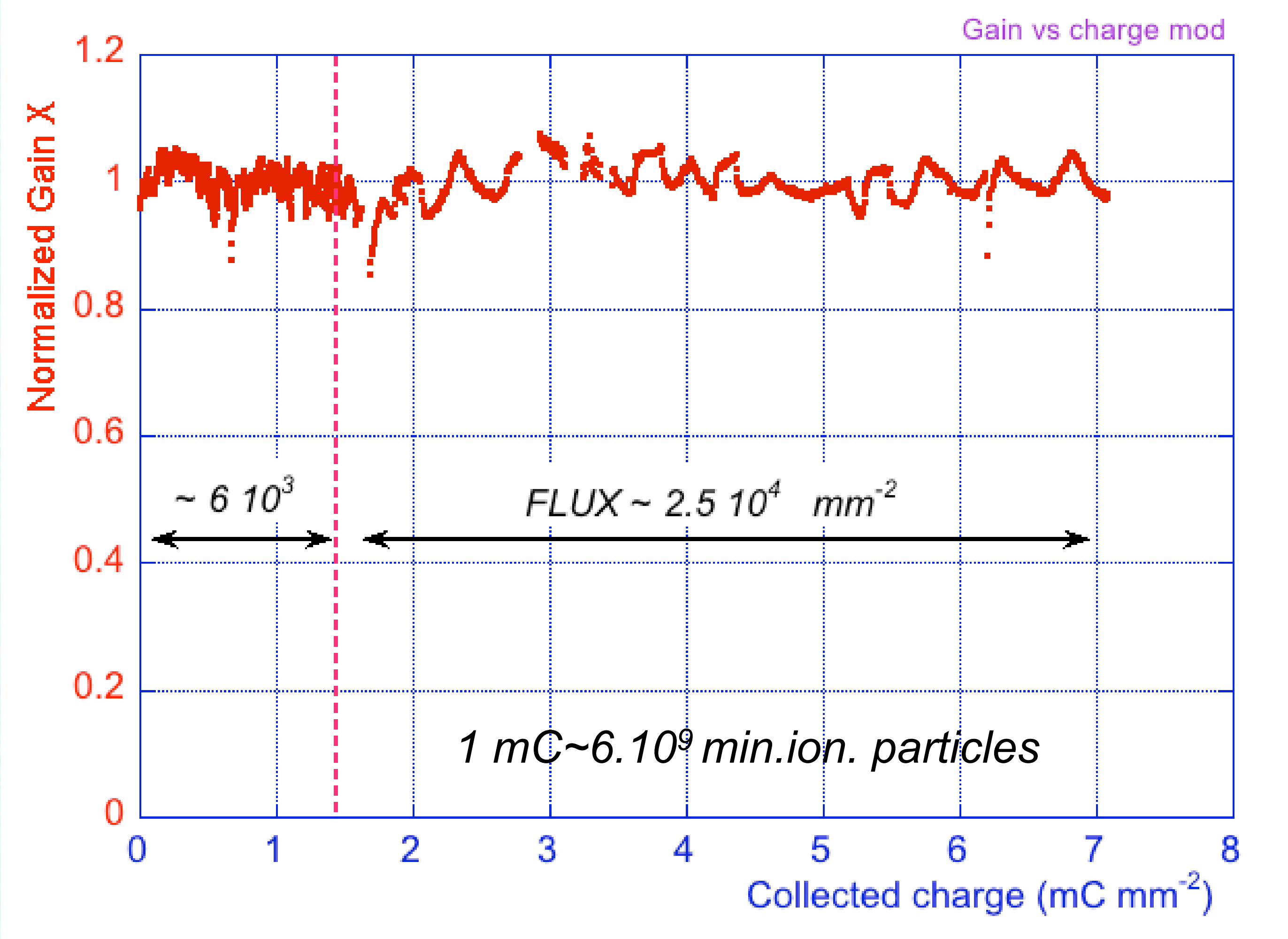
Rate capability > 10^5 Hz mm^{-2}



Radiation Tolerance

GEM detectors are rather insensitive to aging under sustained irradiation

Gain as a function of collected charge, measured on a production TGEM COMPASS chamber

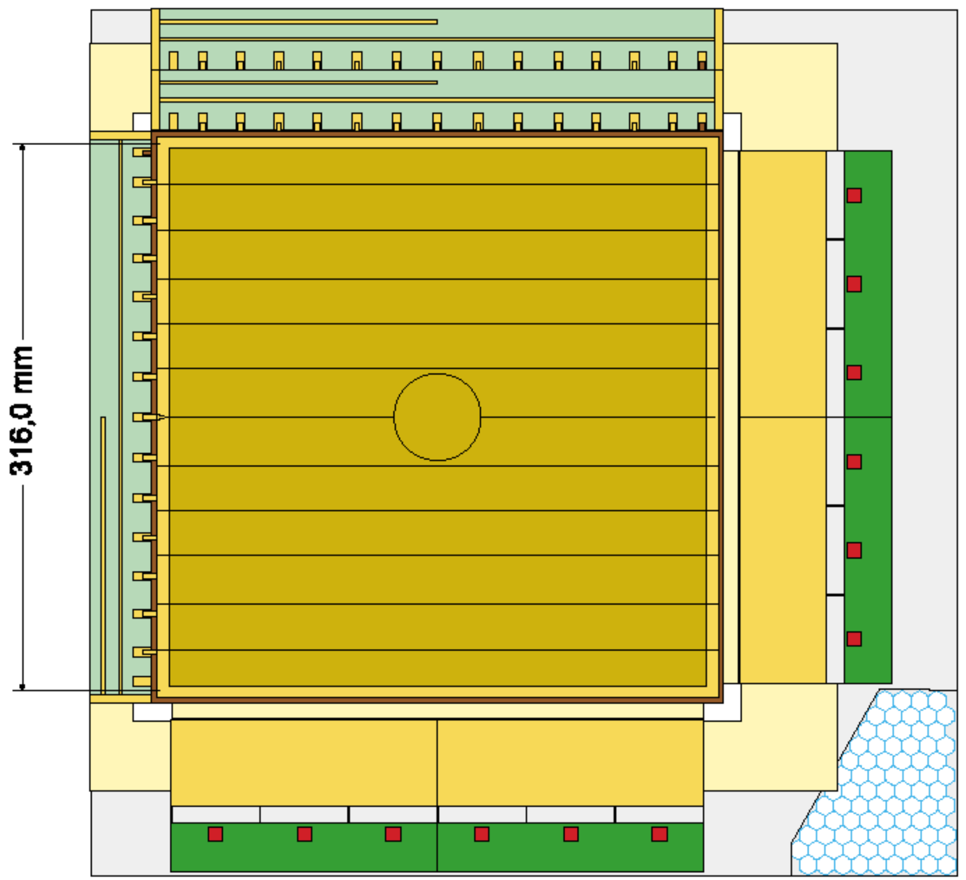


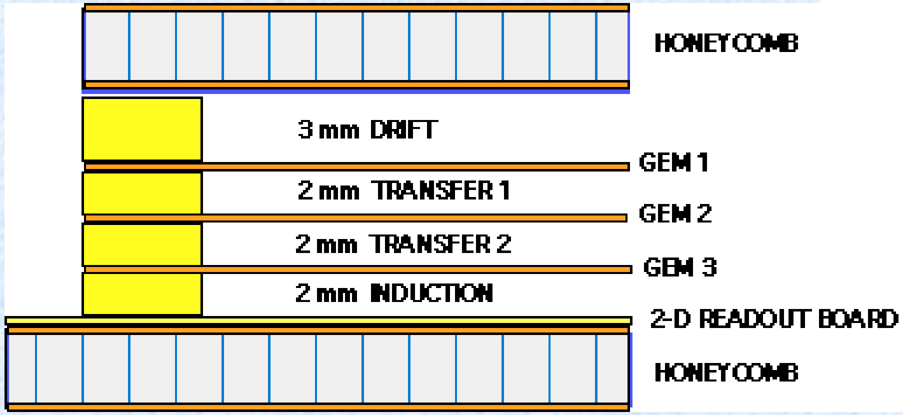
Ar-CO_2 70-30
GAIN ~ 10^4

C. Altunbas et al, DESY Aging Workshop (Nov. 2001) Nucl. Instr. and Meth. A

COMPASS Triple-GEM Detector

- Active Area 30.7 x 30.7 cm^2
- 2-Dimensional Read-out with 2 x 768 Strips @ 400 μm pitch
- 12+1 sectors GEM foils (to reduce discharge energy)
- Central Beam Killer 5 cm Ø (remotely controlled)
- Total Thickness: 15 mm
- Honeycomb support plates (Low Mass)



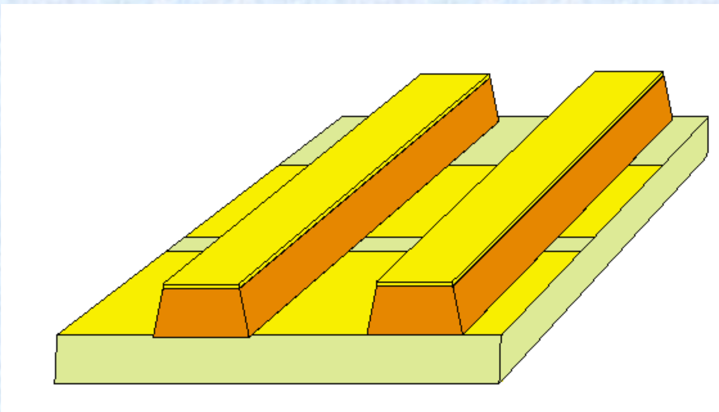


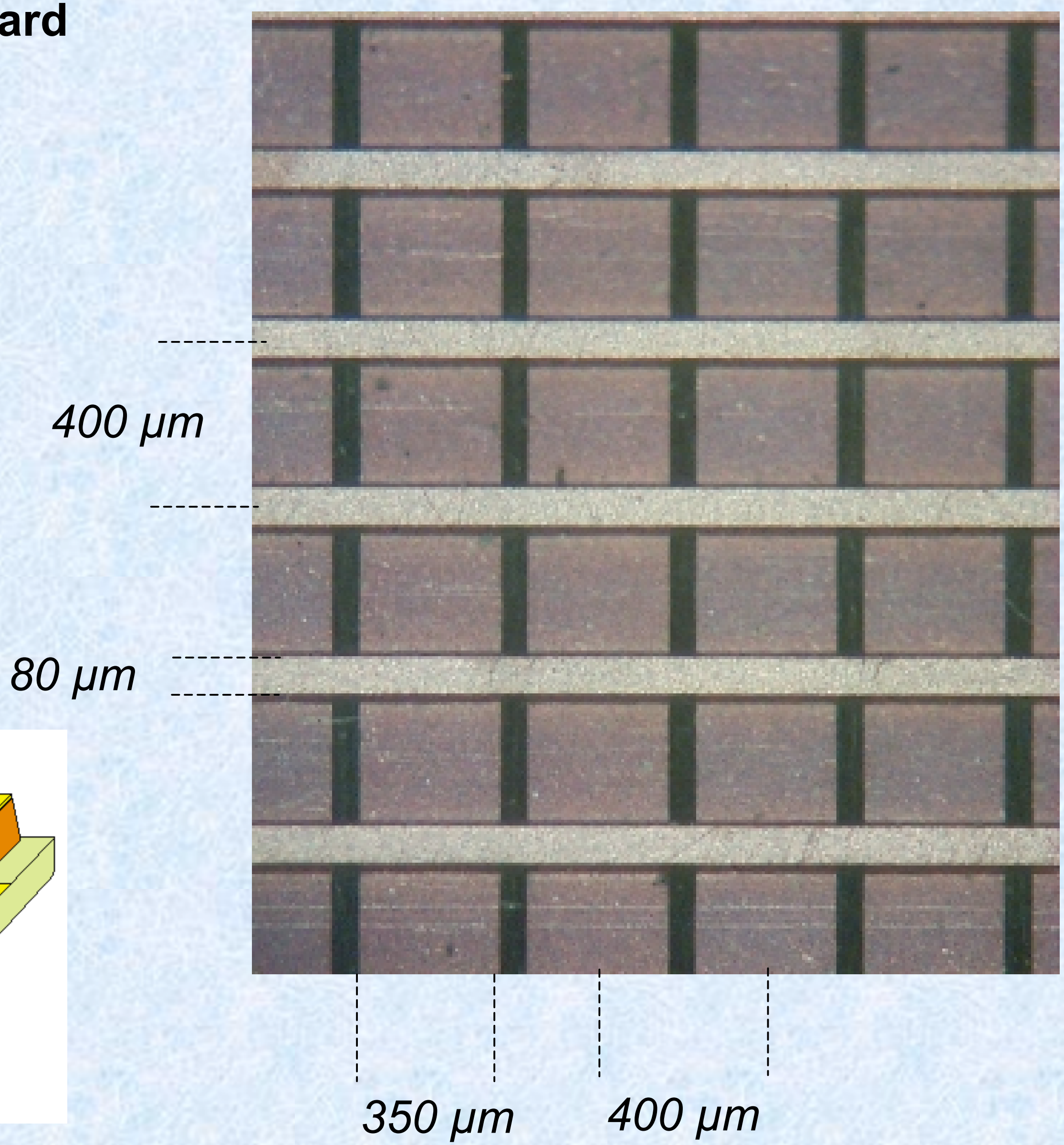
A succession of thin frames holding GEMs is glued on light honeycomb supporting plates

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

2-Dimensional Read-out Board

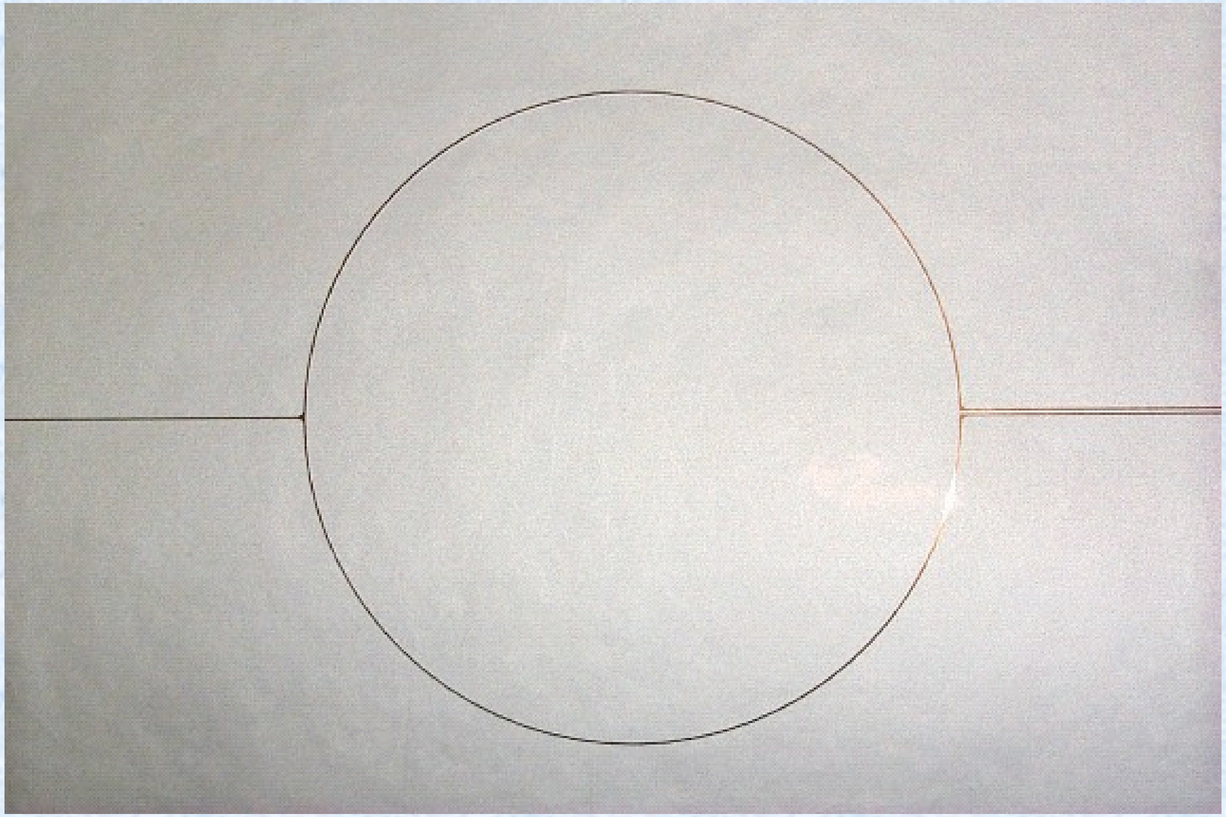
Two orthogonal sets of
parallel strips at 400 μm pitch
engraved on 50 μm Kapton
80 μm wide on upper side,
350 μm wide on lower side
(for equal charge sharing)





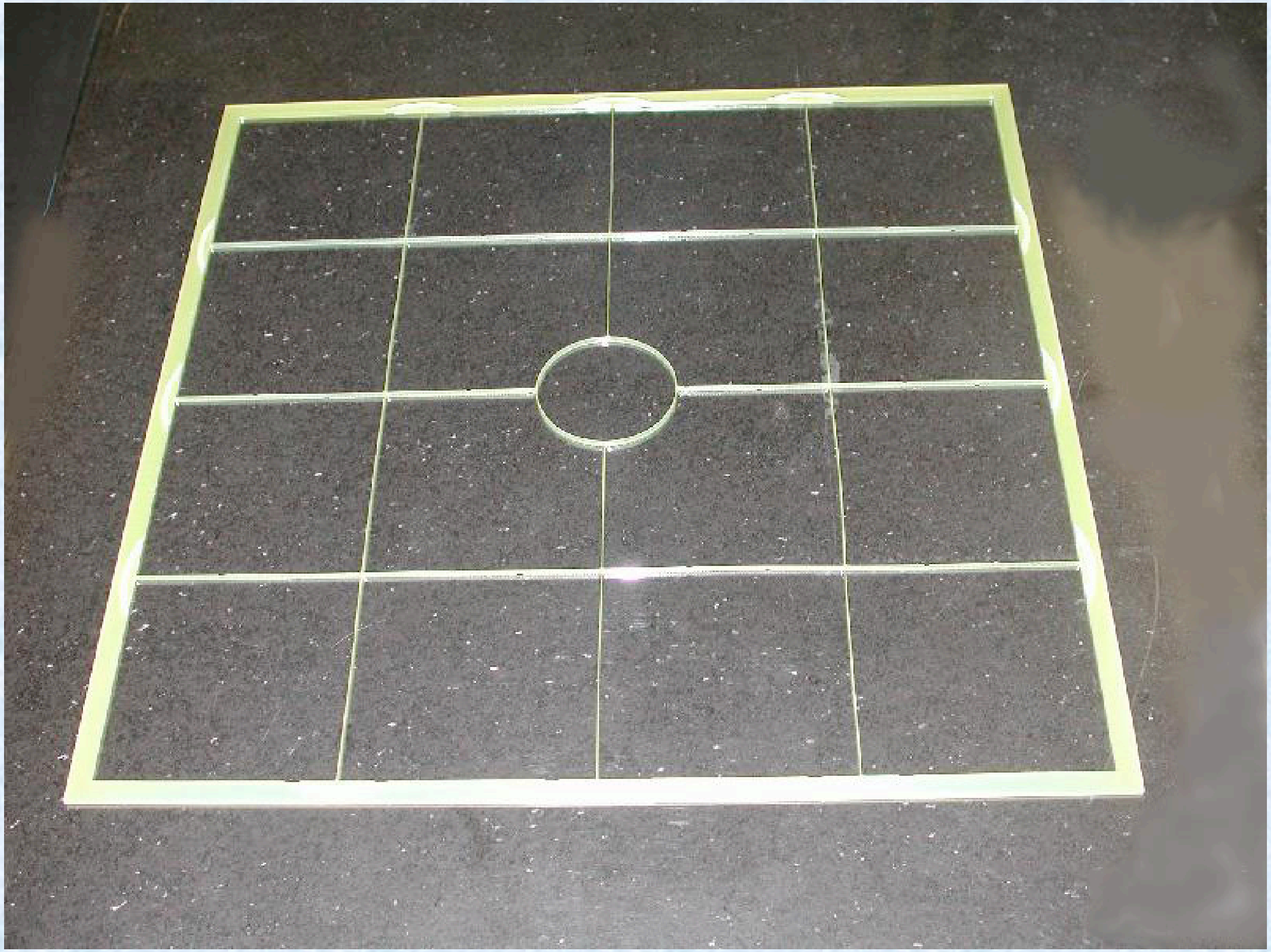
Beam killer

A central sector on each GEM, 5 cm in diameter, is independently powered. Application of a ~ 200 V lower potential on the sector completely kills detection of the main beam.



Spacer frame

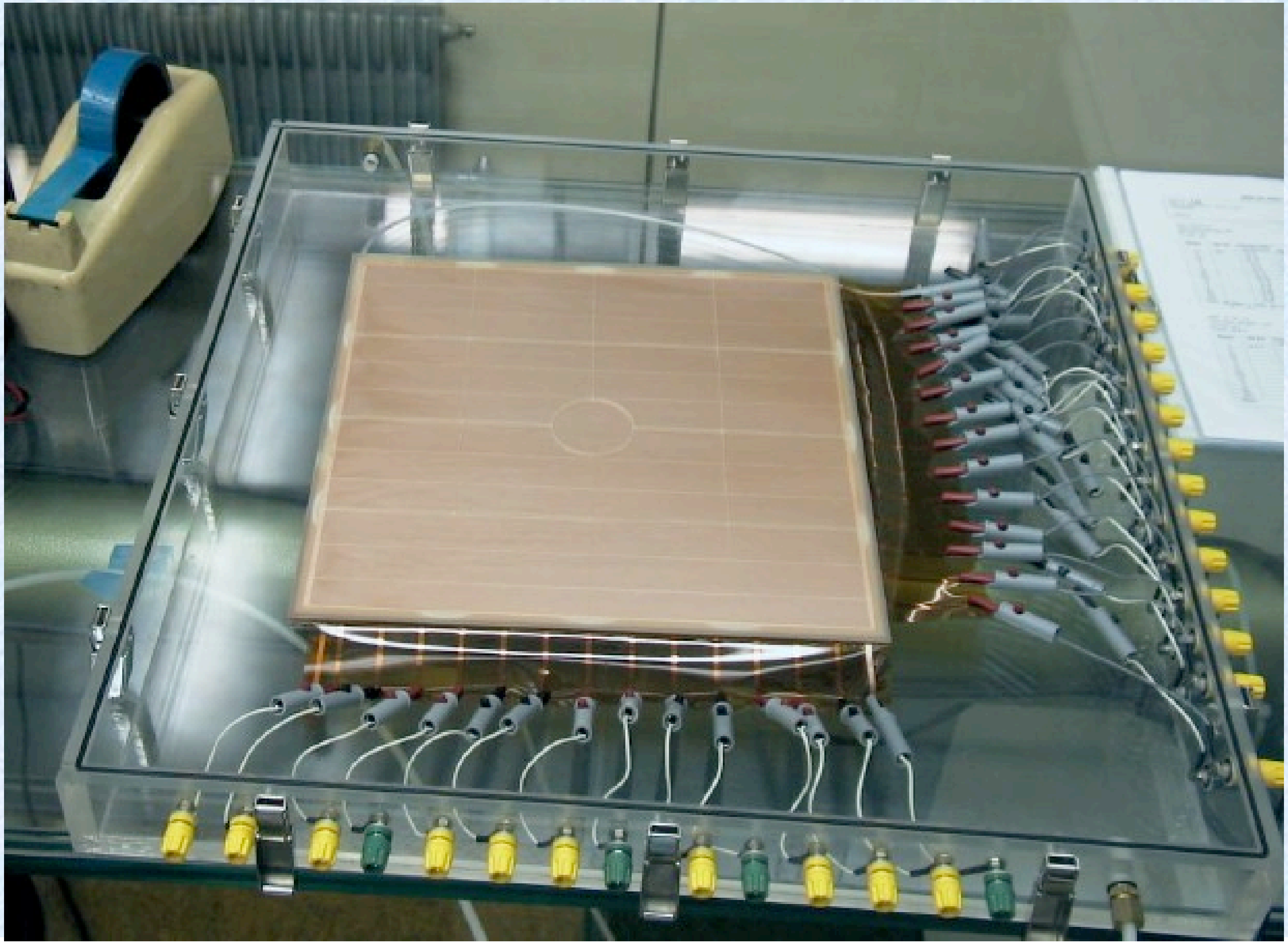
Machined fibreglass frame with thin (~300 μm) spacer strips, 2 mm wide



GEM Chamber Manufacturing

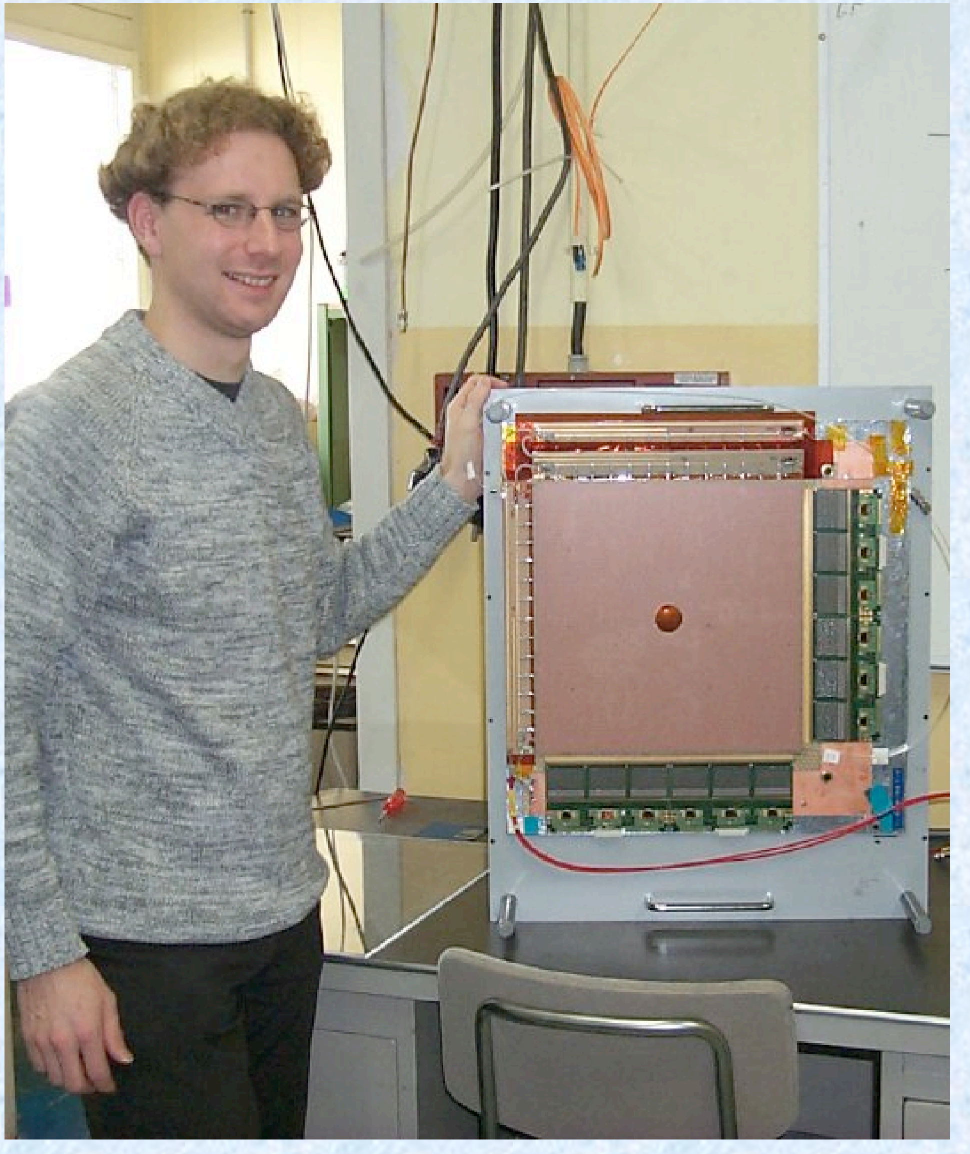
Before mounting, and at each assembly step, GEM foils are HV tested in a N_2 gas box (requirement: < 5 nA at 550 V on each sector)

(The normal operating voltage is ~ 370 V)



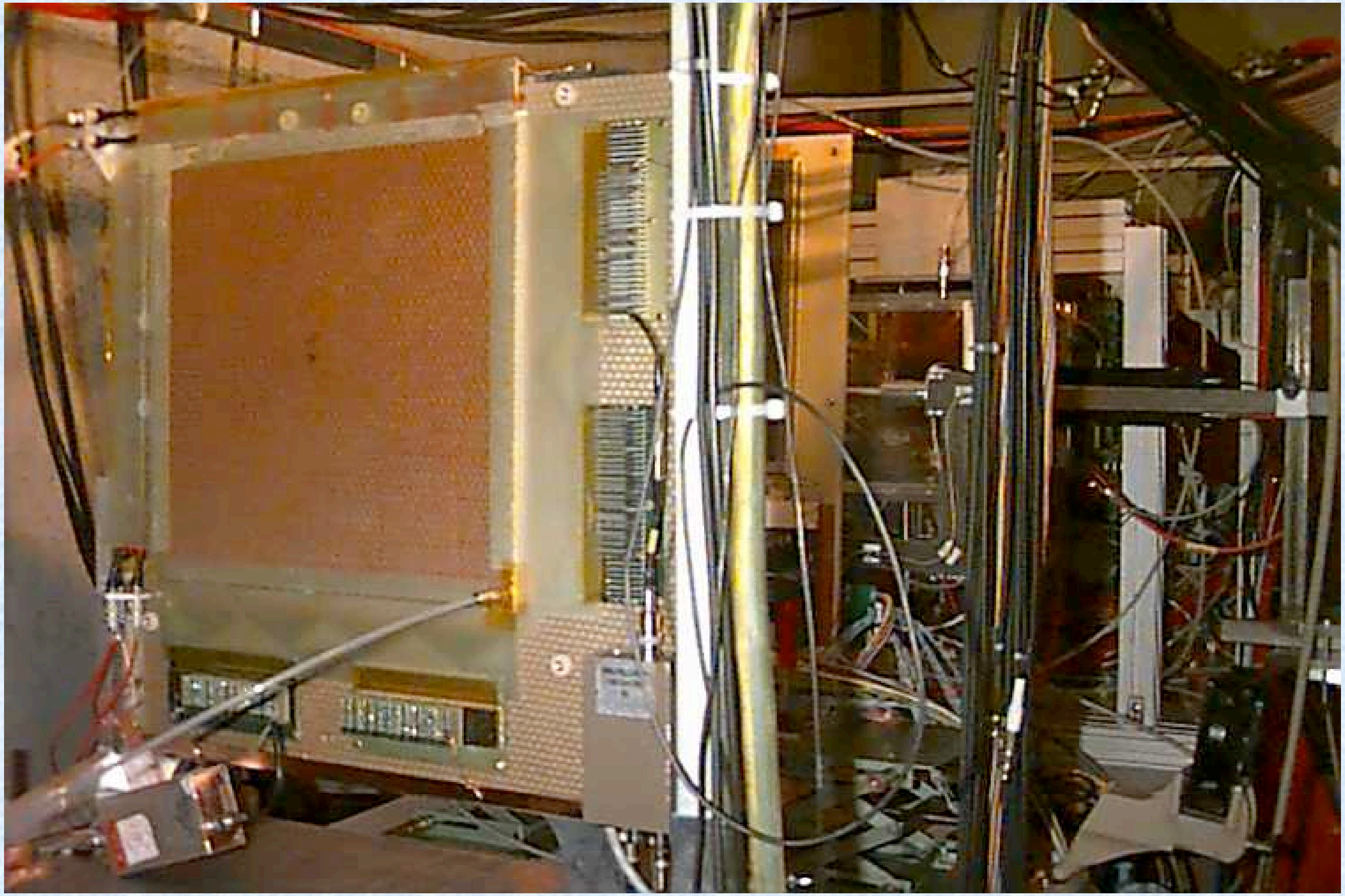
COMPASS Triple GEM chambers

31x31 cm² active, 2-D readout



COMPASS experiment: 20 Triple-GEM detectors

Forward spectrometer, primary beam ~10^7 Particles/second
~ 10 Tracks/event, 50 µm accuracy, 10 ns time resolution

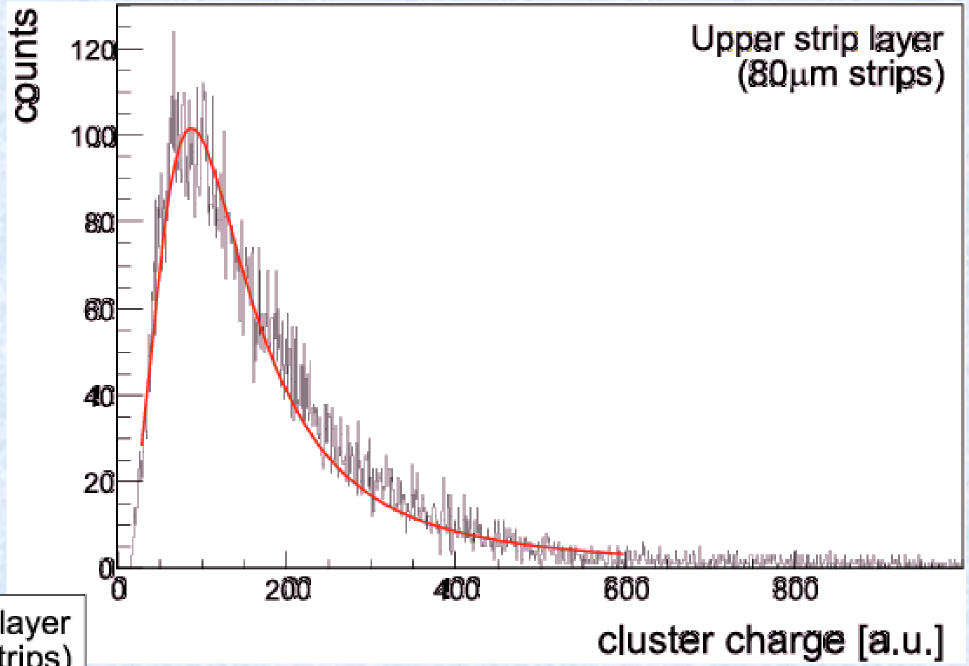


Pulse height spectra

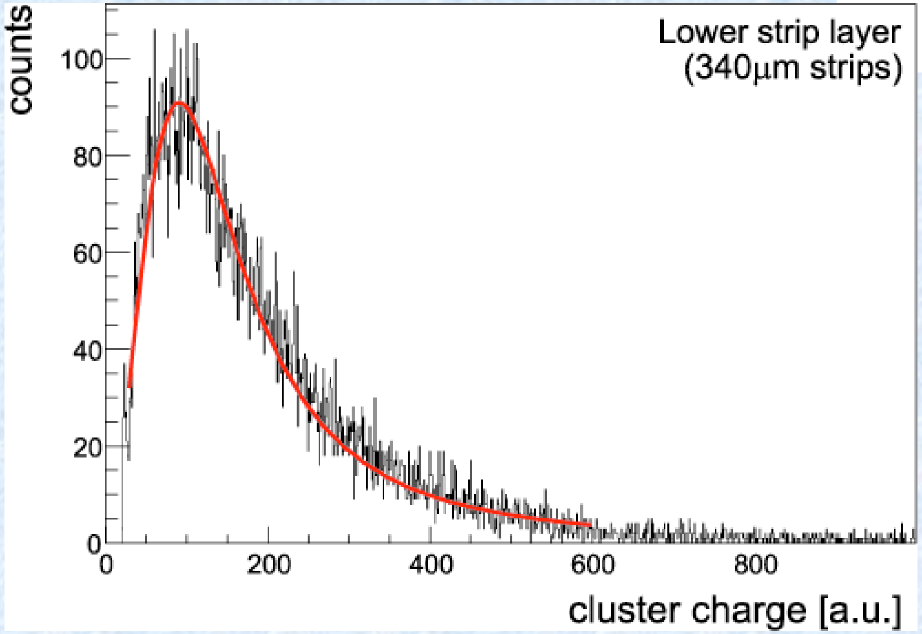
Minimum ionizing particles
3 mm drift gap
Ar-CO_2 70-30

Gain 8000

Y-coordinate:

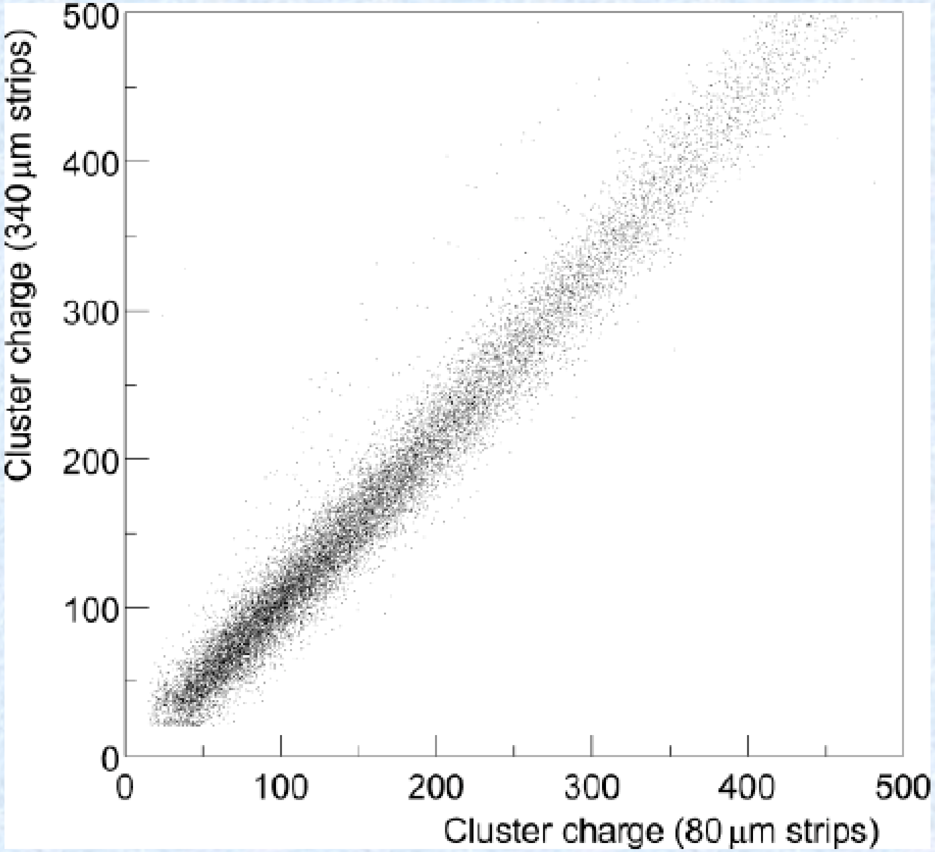


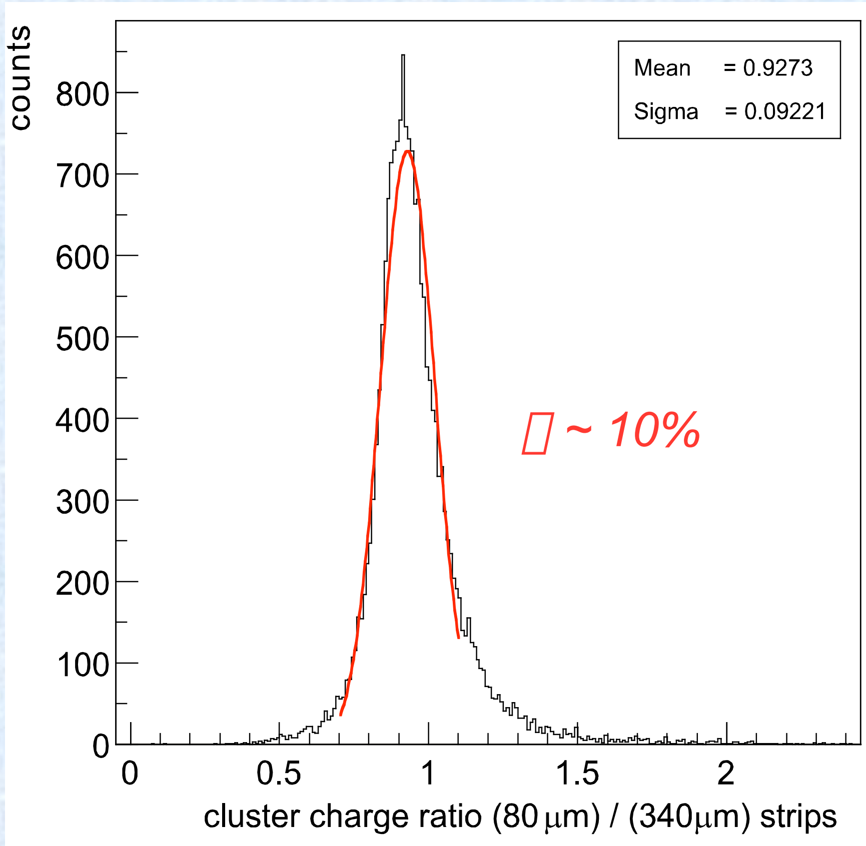
X-coordinate:



Cluster charge

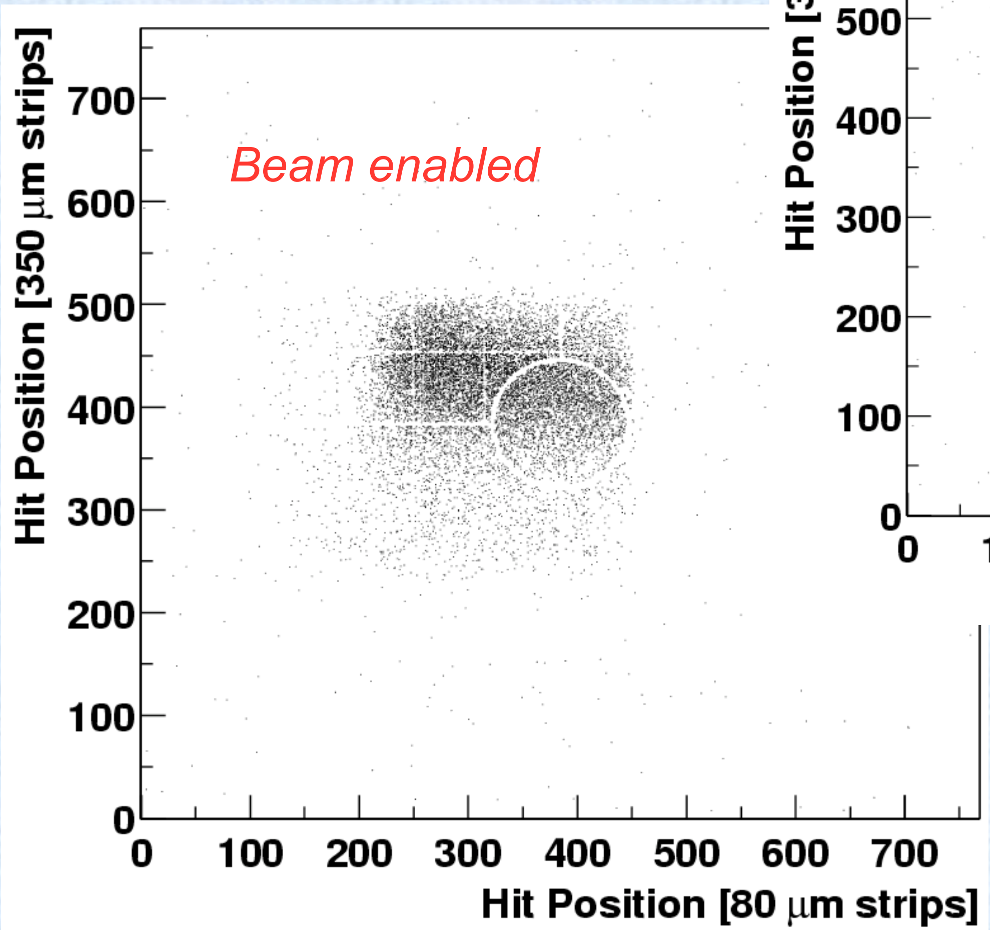
Very good X-Y charge correlation, exploited for multi-track ambiguity resolution:

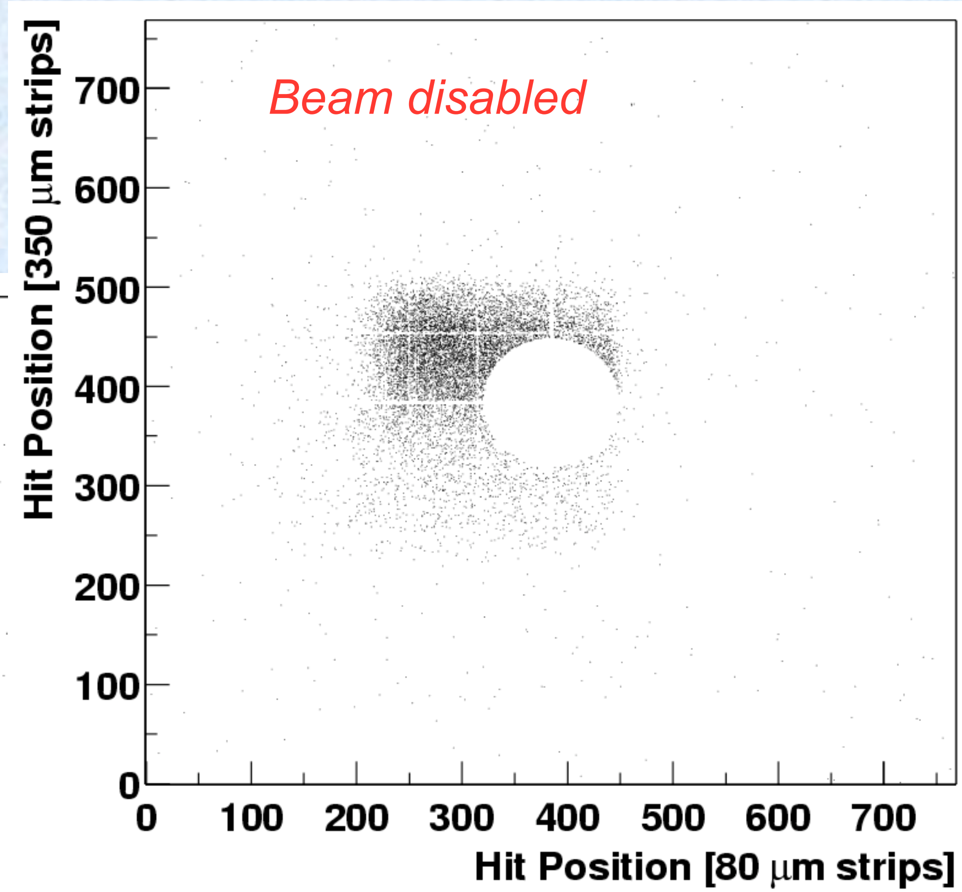




Beam killer

The central beam area can be remotely activated for calibrations and alignments, and disabled during high intensity runs.



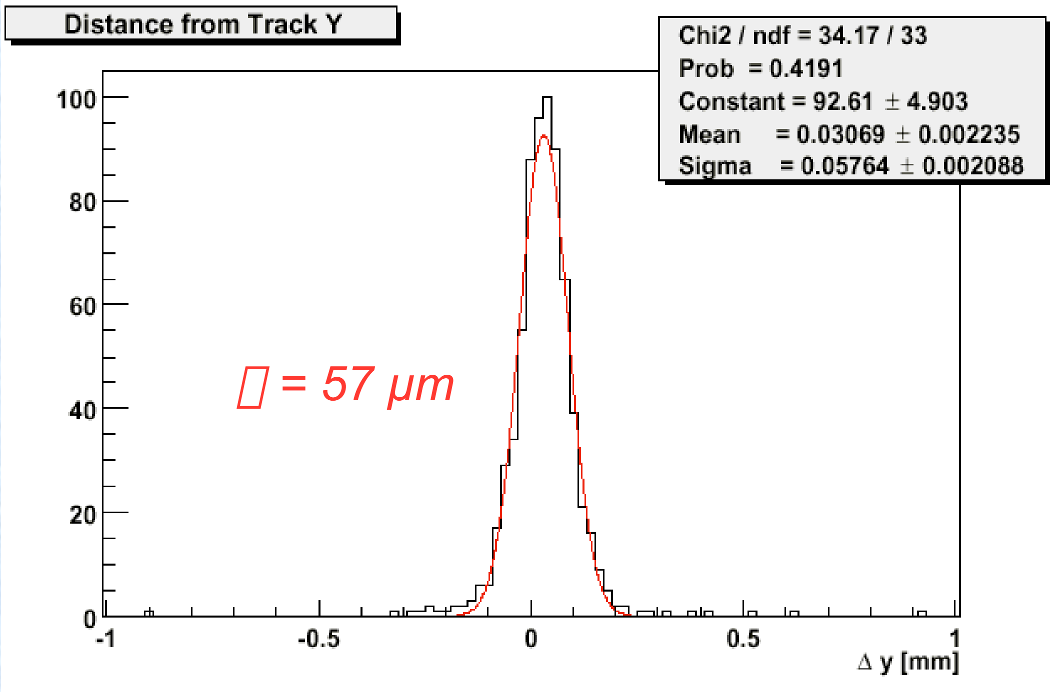


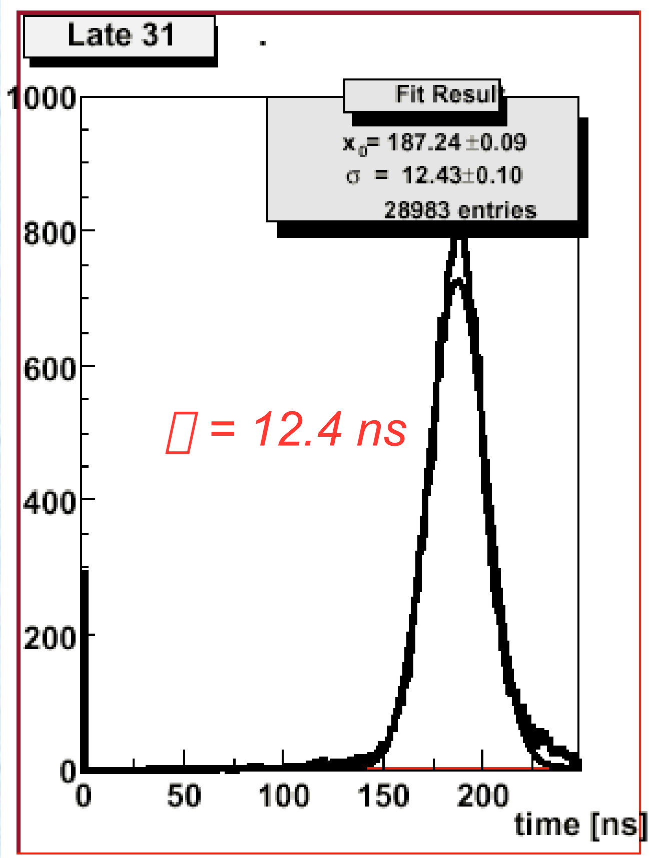
Space and time resolution

Traks fit with two TGEM and one silicon microstrip
After deconvolution ~ 46 μm

Time resolution: computed from charge in three consecutive samples (at 25 ns intervals):

Space resolution:

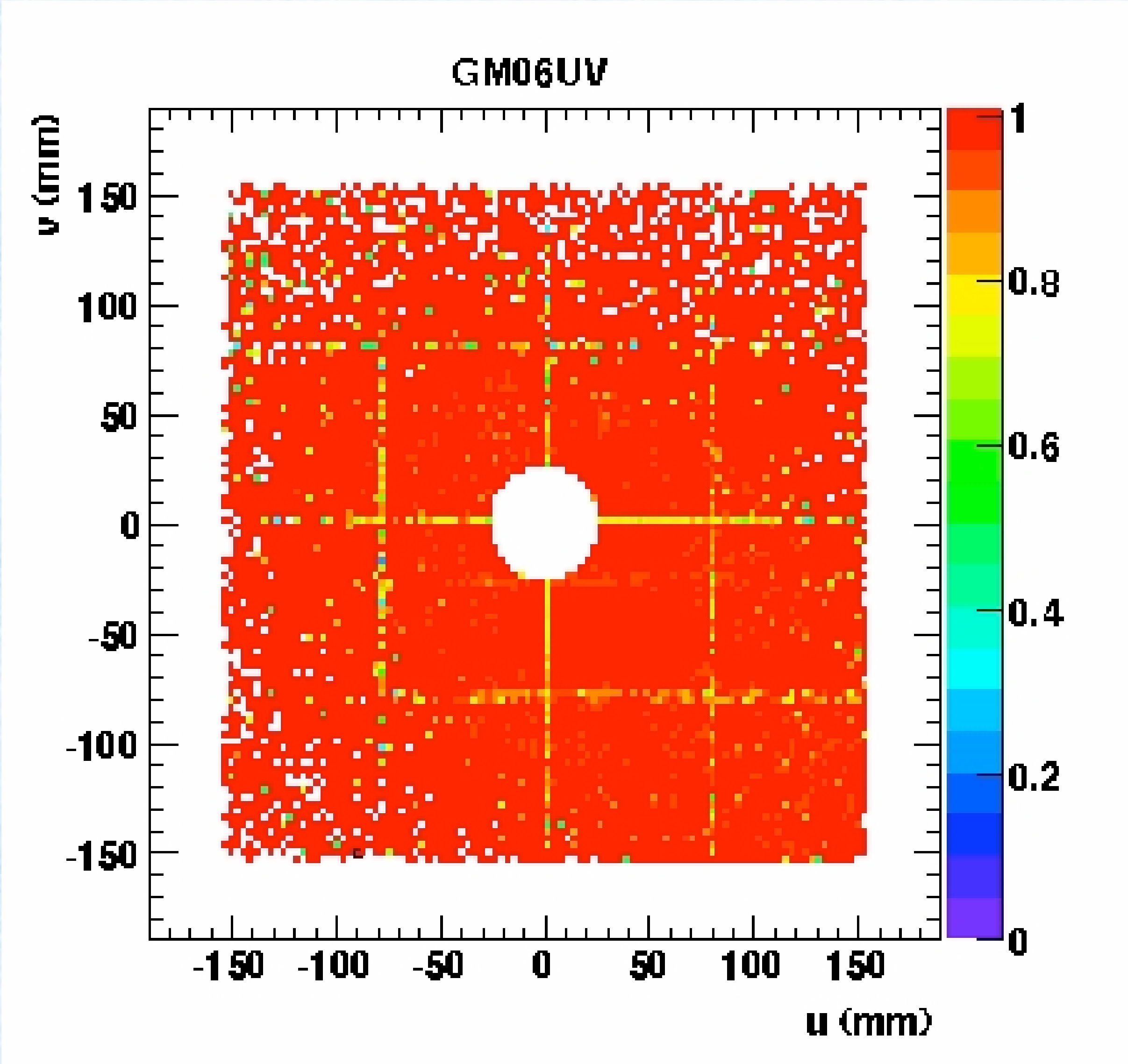




High Rate operation

COMPASS high rate beam ~ 10^7 muons/s

U-V distribution of reconstructed tracks:



B. Ketzer and Q. Weitzel (COMPASS)

High rate-efficiency

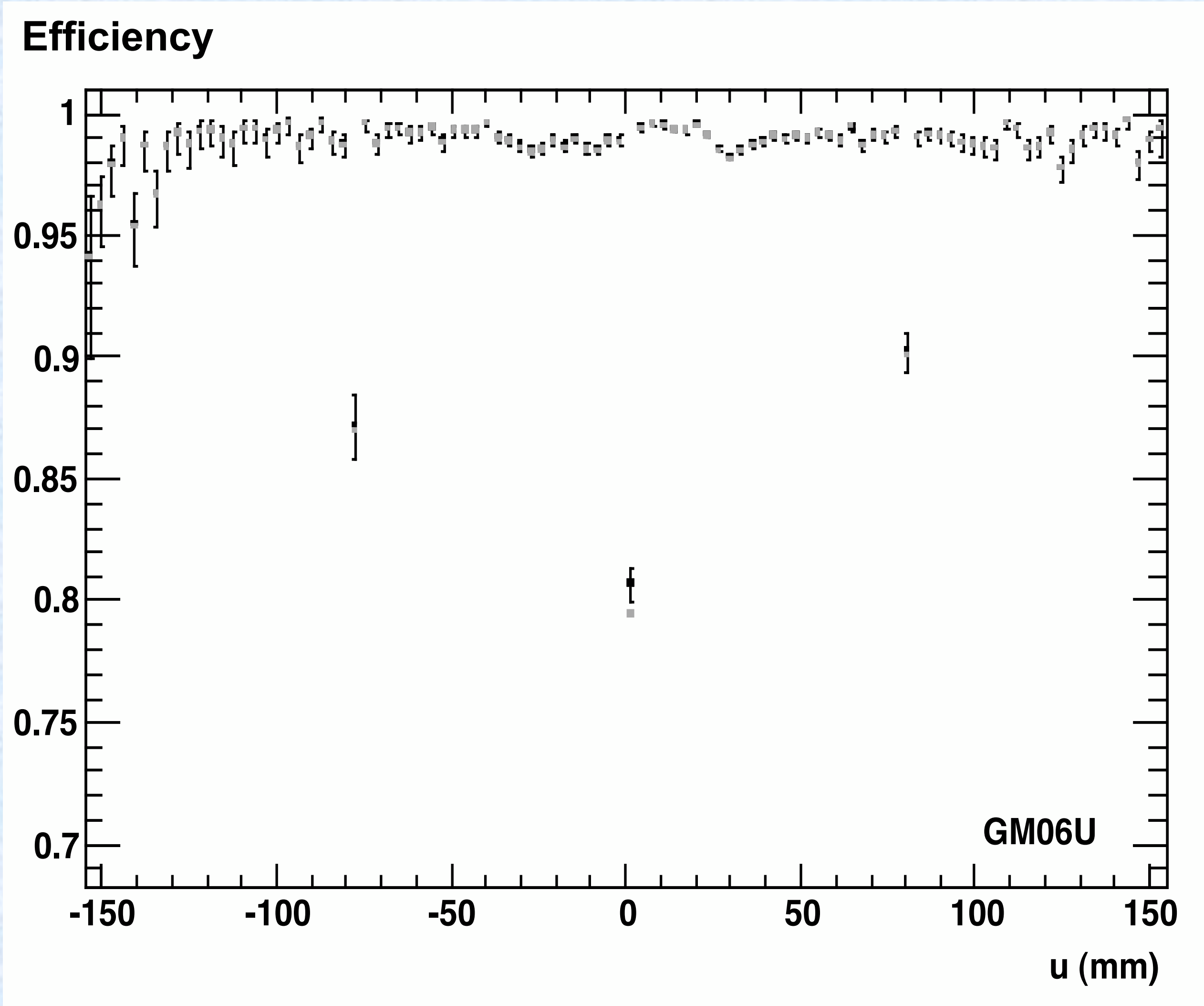
Efficiency vs position

Average, all tracks:

□=97.5 %

Average, spacers removed:

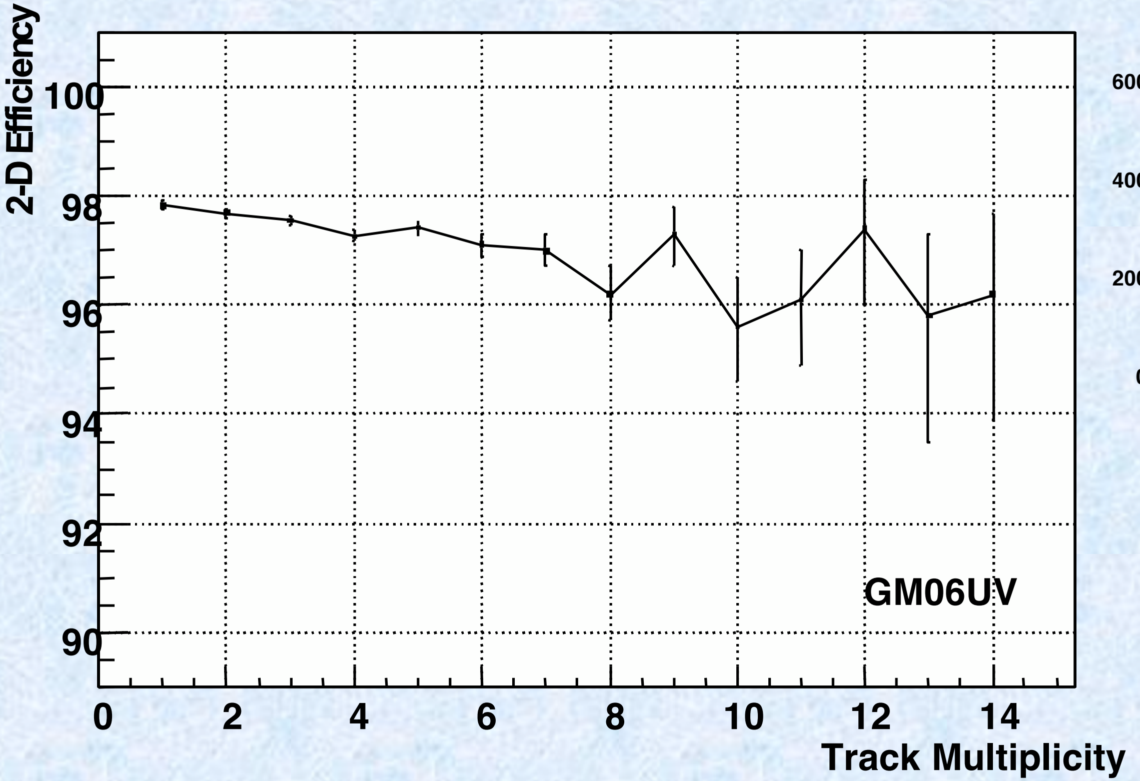
□=98.7 %



B. Ketzer and Q. Weitzel (COMPASS)

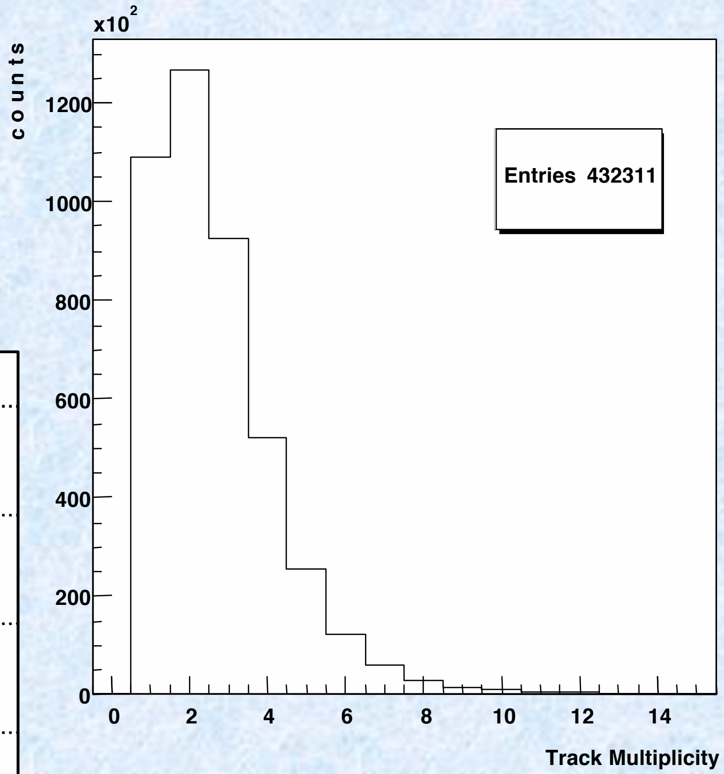
High rate-multiplicity

Reconstruction efficiency as a function of track multiplicity:



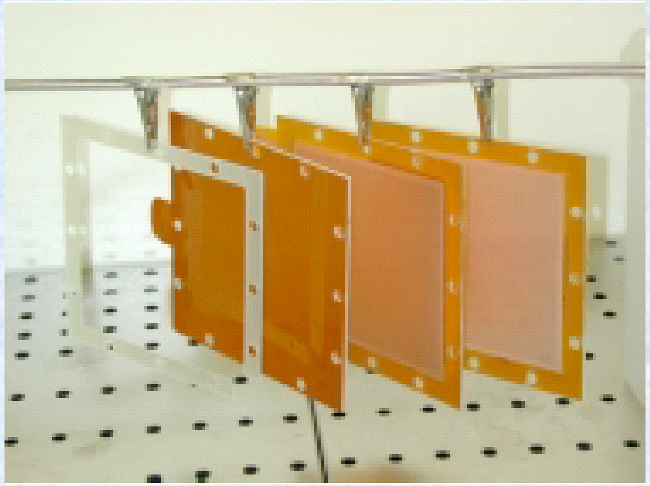
B. Ketzer and Q. Weitzel (COMPASS)

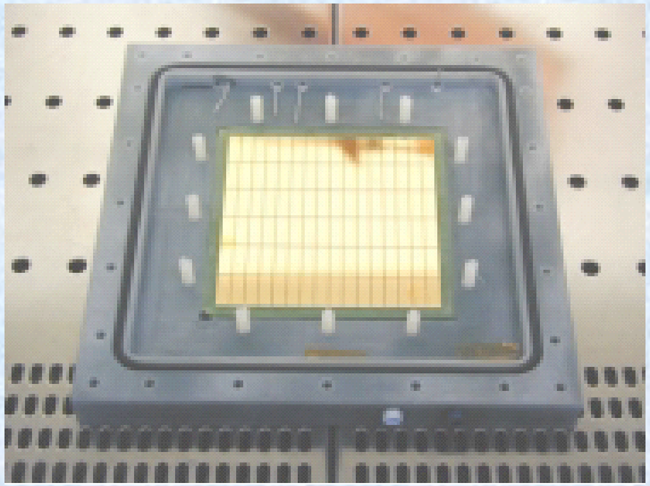
Track multiplicity:

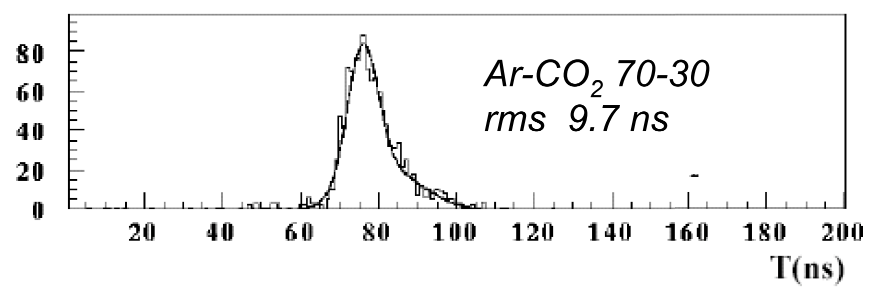


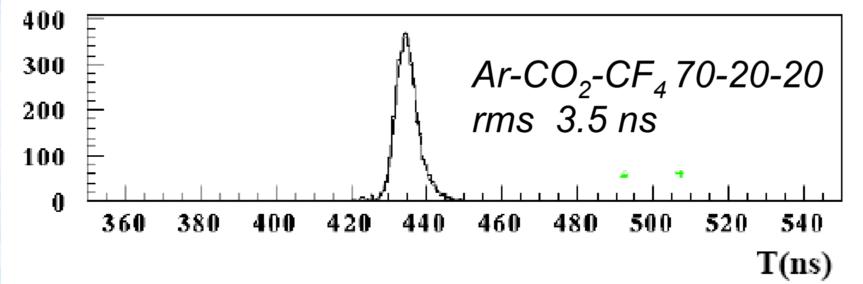
Intrinsic time resolution

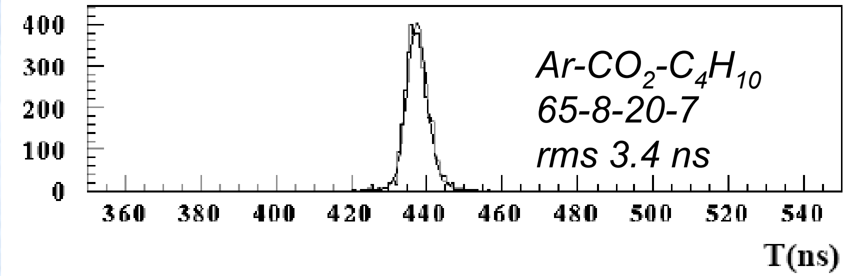
Triple GEM for LHCb muon detector:

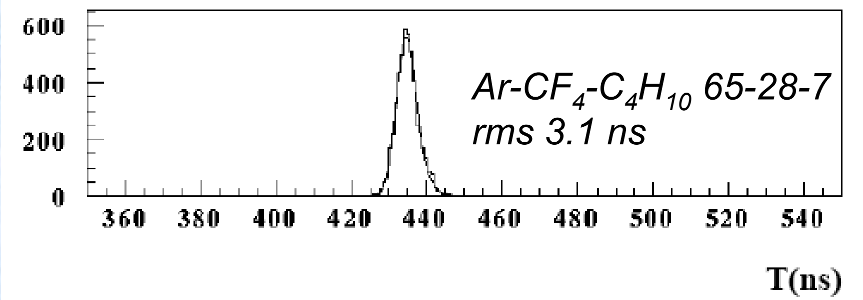






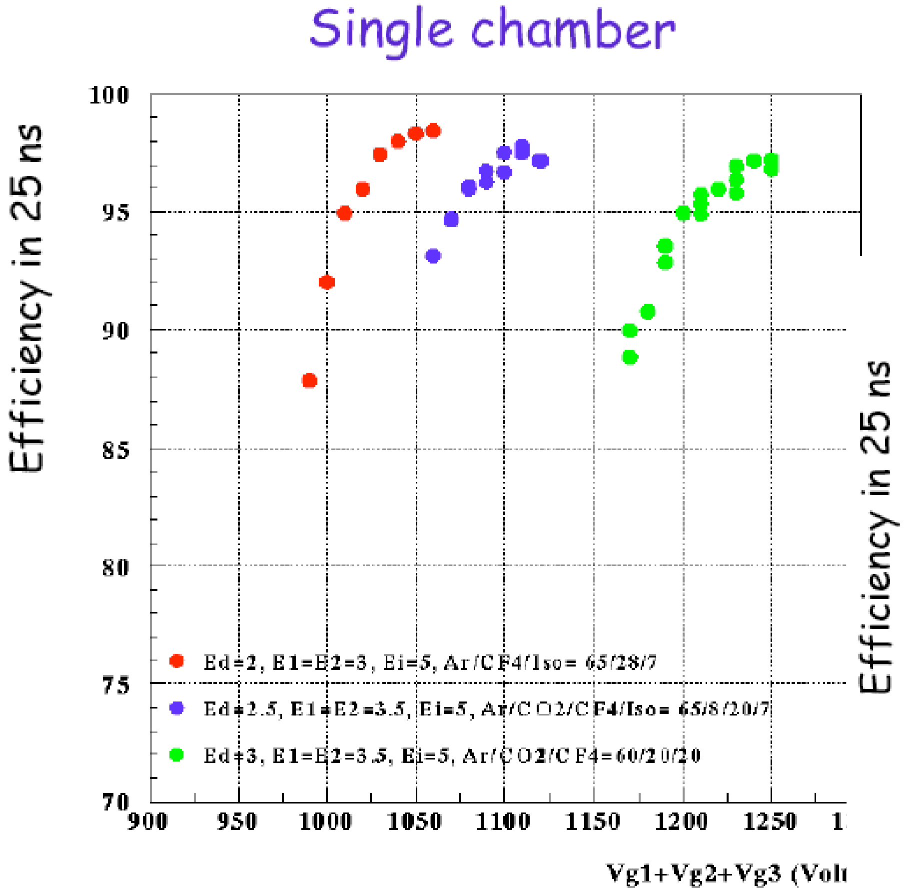


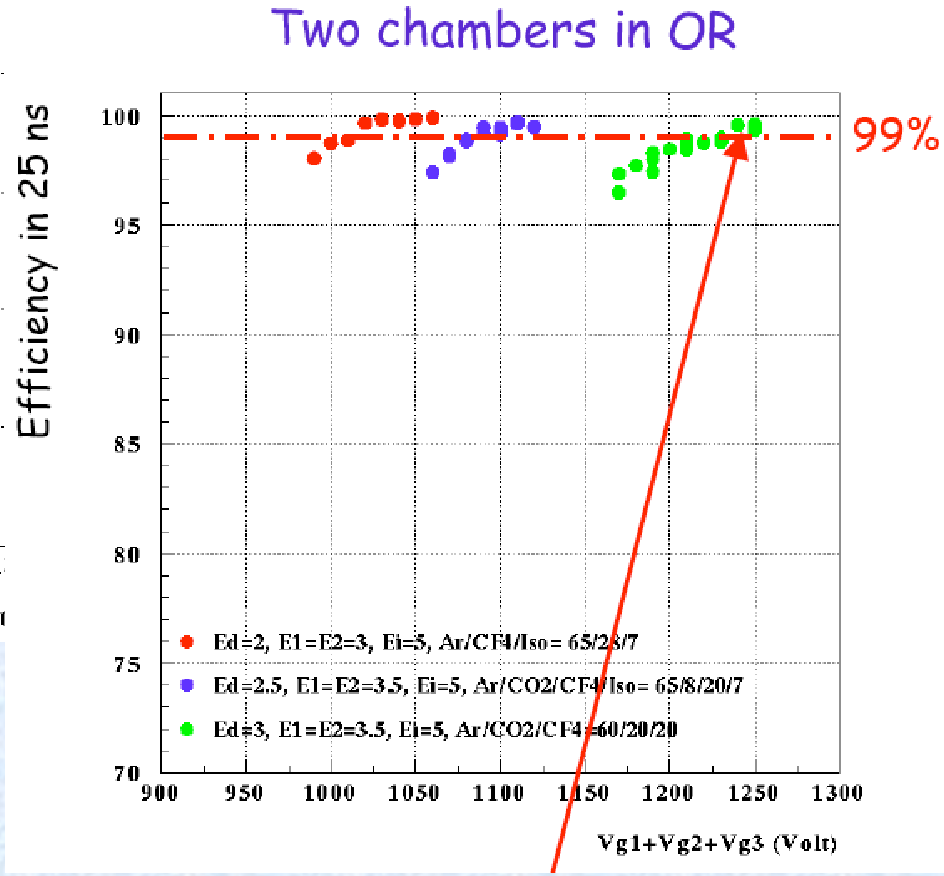




G. Bencivenni et al, NIM A 488(2002)493

Time resolution





G. Bencivenni et al, NIM A 488(2002)493

GEM TPC

Narrow pad response function: ***$\sigma_s \sim 1$ mm***

Fast signals (no ion tail): ***$\Delta T \sim 20$ ns***

Very good multi-track resolution: ***$\Delta V \sim 1$ mm^3***
(Standard MWPC TPC ~ 1 cm^3)

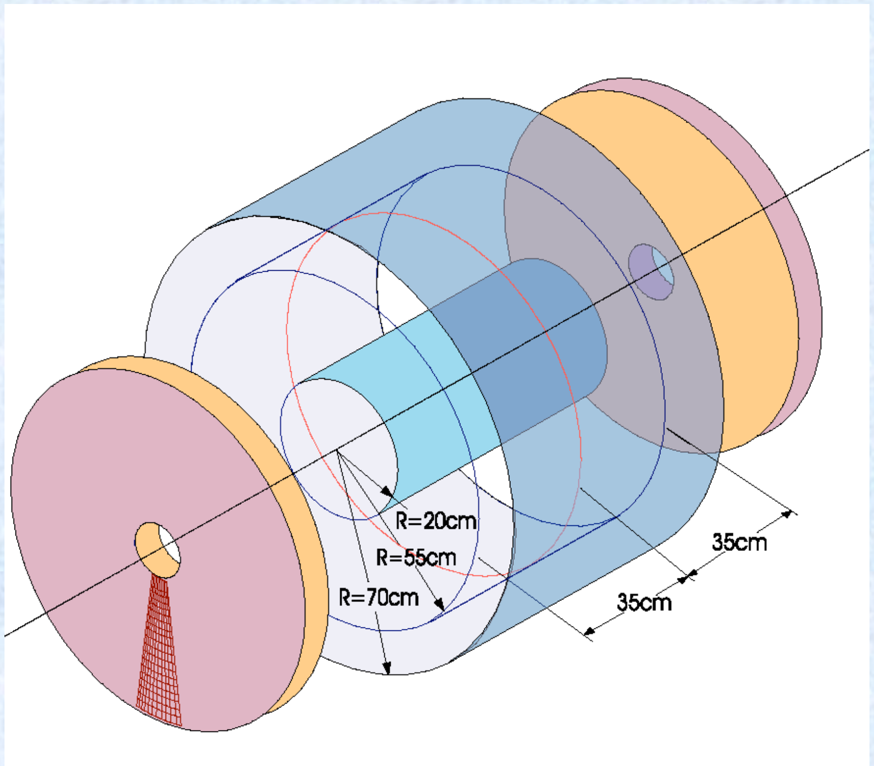
Ion feedback suppression: $\frac{I^+}{I^-} \sim 2\%$

No ExB distortions

Freedom in end-cap shapes

Robustness

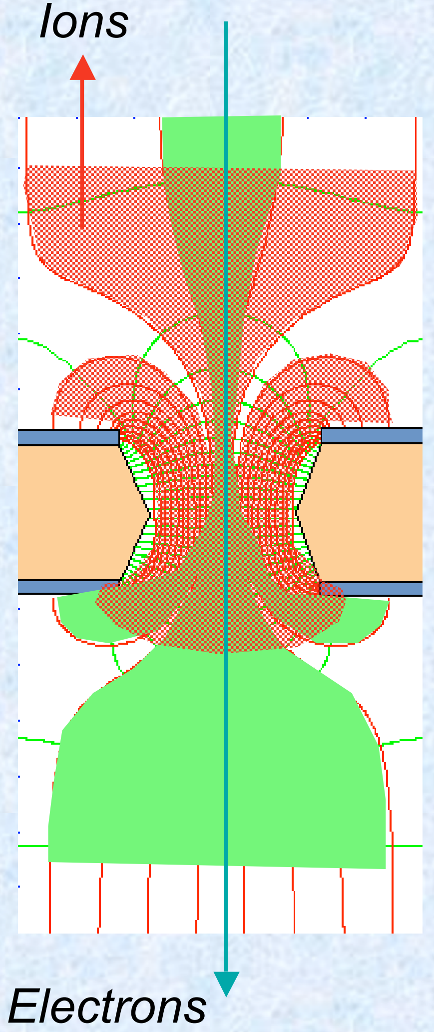
INVESTIGATED FOR:
- TESLA LINEAR COLLIDER
- PHENIX UPGRADE
- MICE (muon cooling)
- CLAS (JLAB)
- Astrophysics

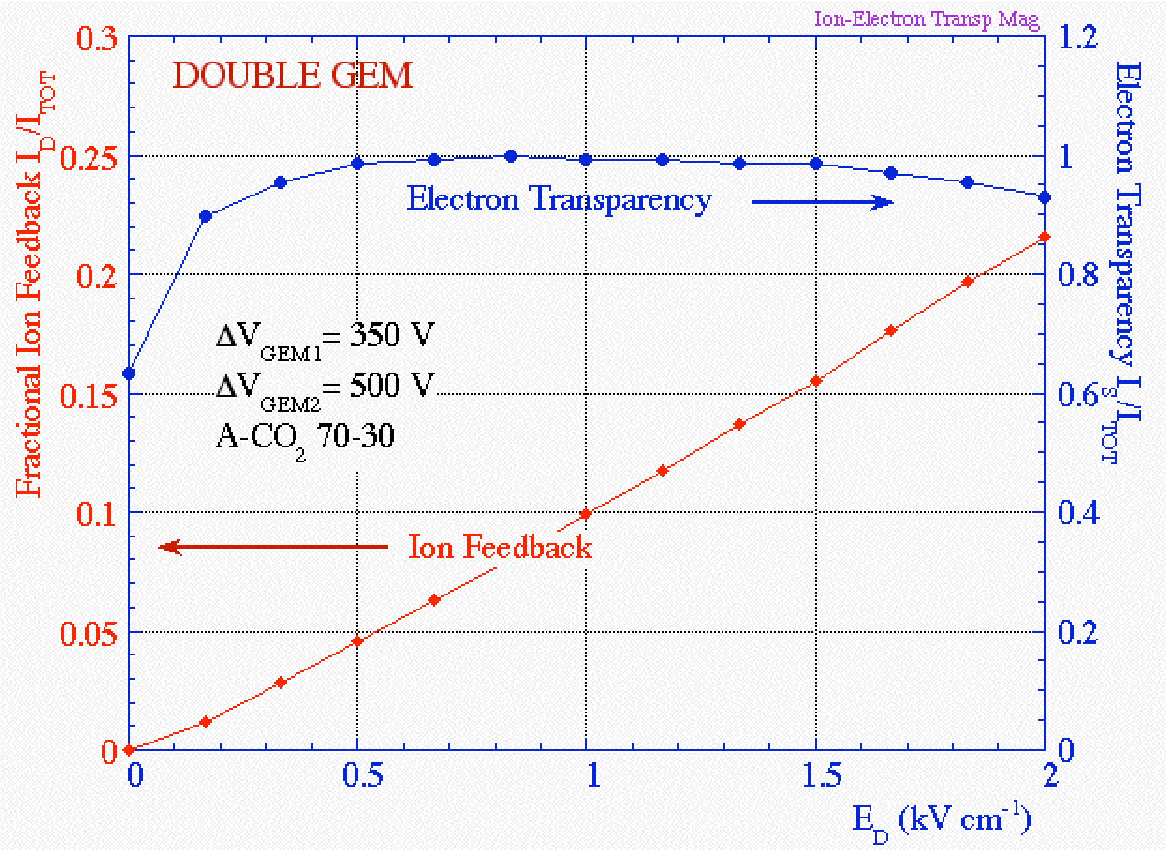


I. Tserruya, Phenix upgrade

Ion Feedback suppression

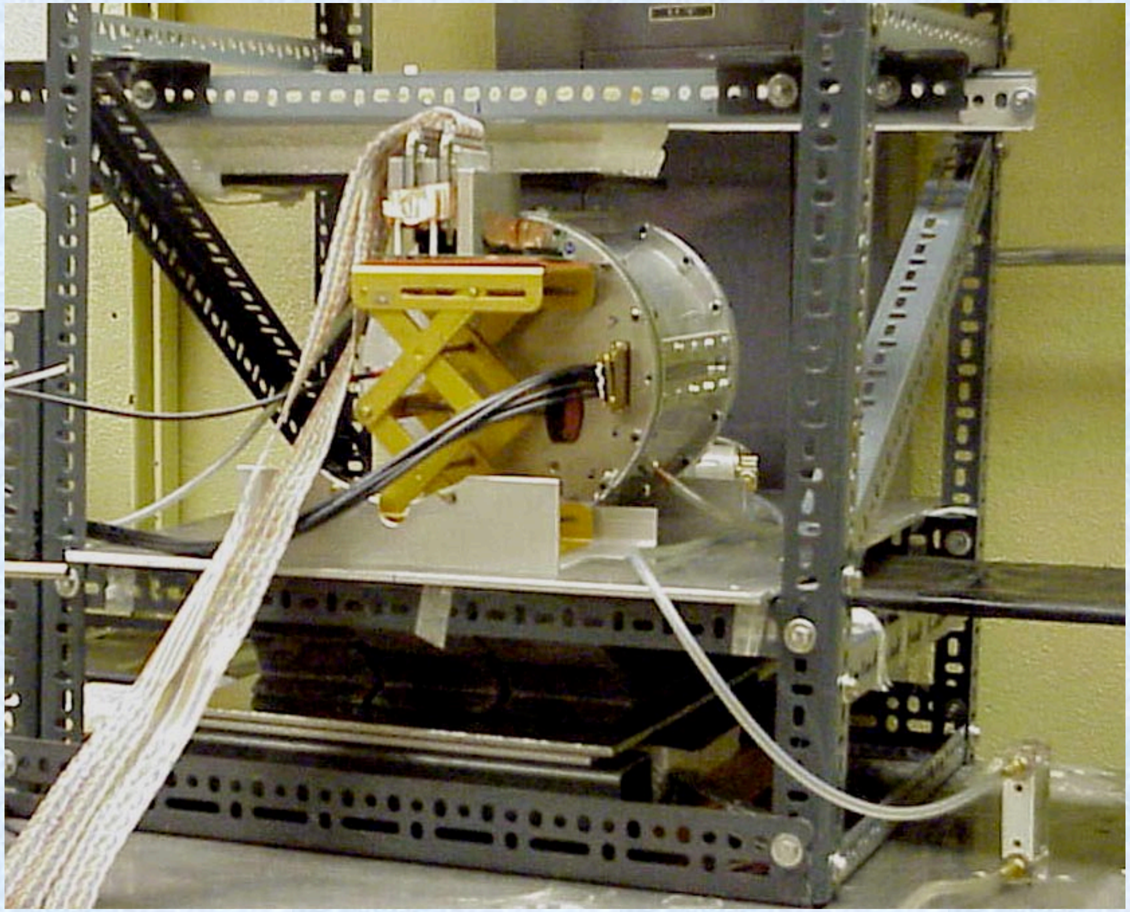
In a Double GEM, in normal operating conditions (E_{DRIFT}=200 V/cm), the Ion feedback is ~ 1.5%





S. Bachmann et al, Nucl. Instr. and Meth. A 438(1999)376

GEM-TPC studies for the Linear Collider



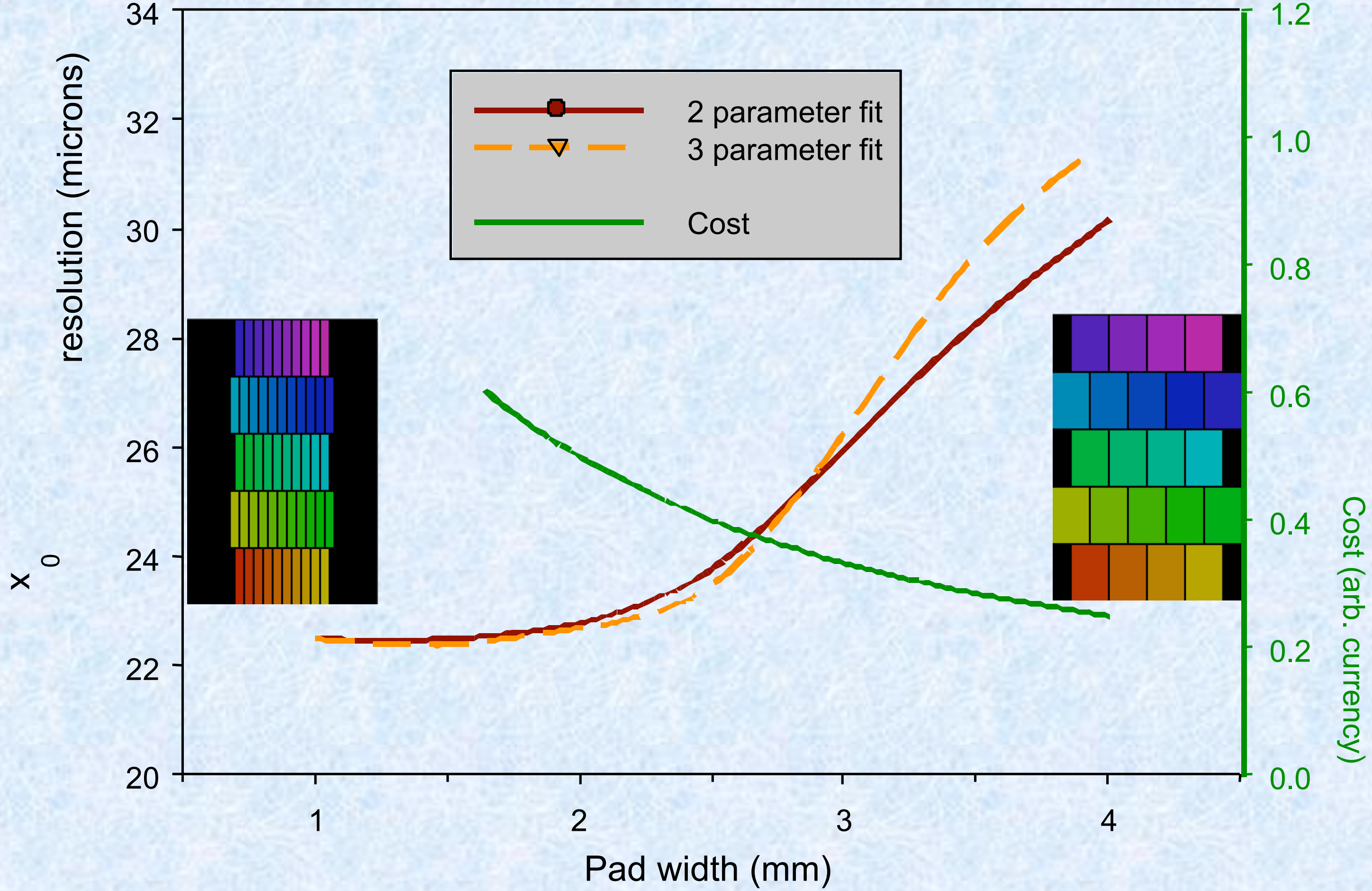
LC TPC Group:

- Aachen
- Berkeley
- Carleton/Montreal/Victoria
- DESY/Hamburg
- Karlsruhe
- Cracow
- MIT
- MPI-Munich
- NIKHEF
- Novosibirsk
- Orsay/Saclay
- Rostock
- St. Petersburg

GEM-TPC prototype
Carleton-Montreal-Victoria-TRIUMF

GEM TPC: pad width optimization

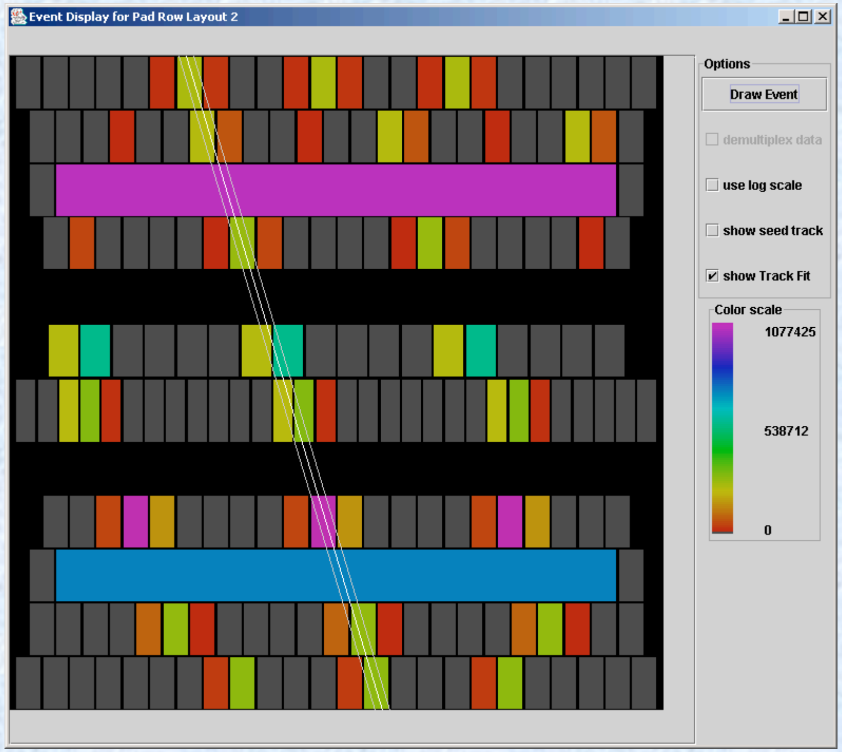
Resolution and cost vs pad width:

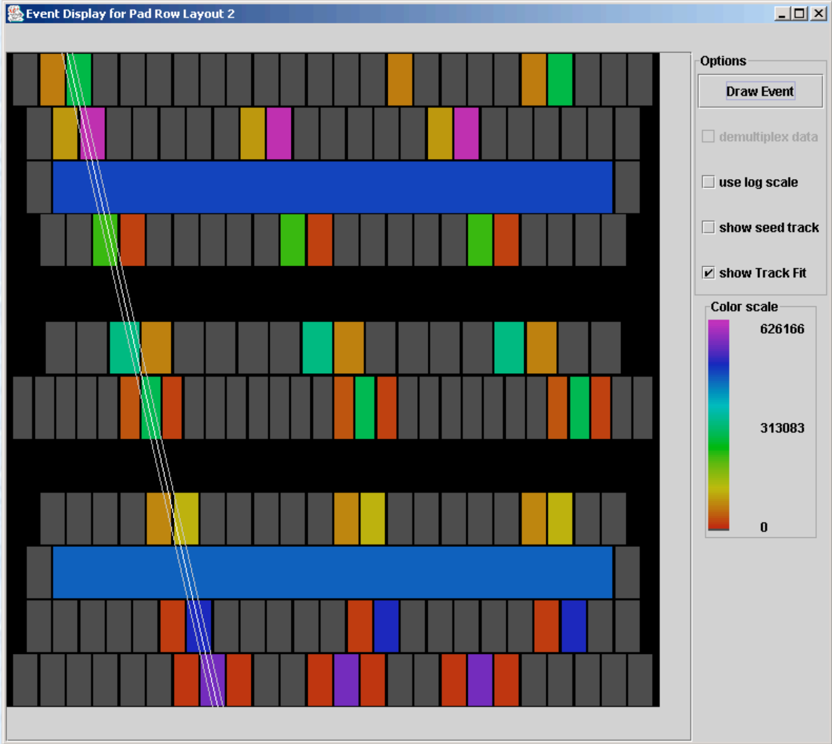


Carleton-Montreal-Victoria-TRIUMF
D Karlen- Prague Nov. 2002

GEM-TPC for Linear Collider

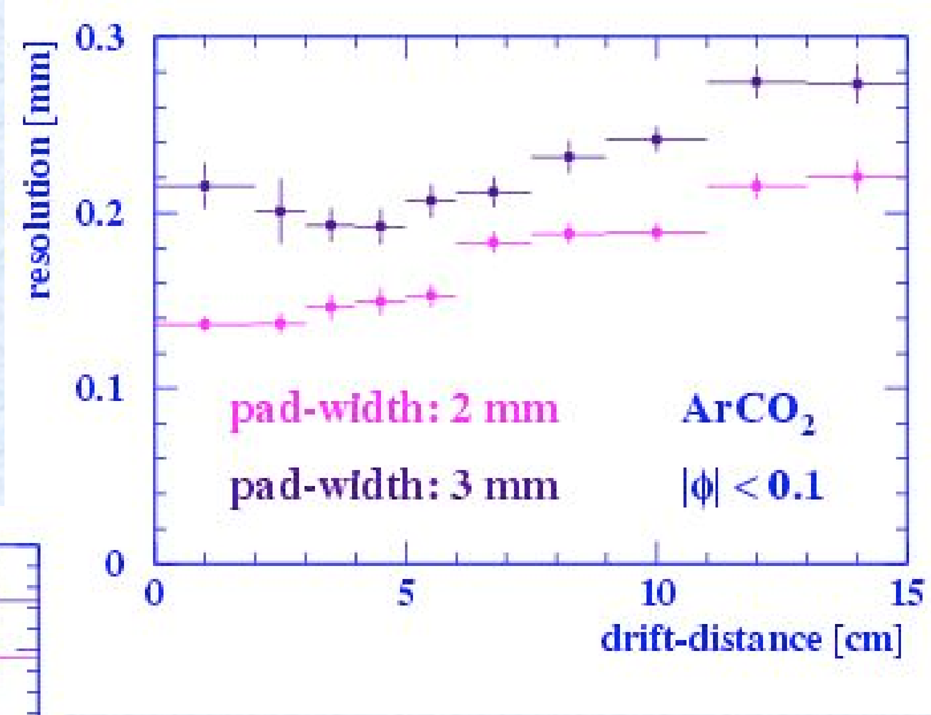
Resolution studies with 2x6 mm and 3x5 mm pad rows:



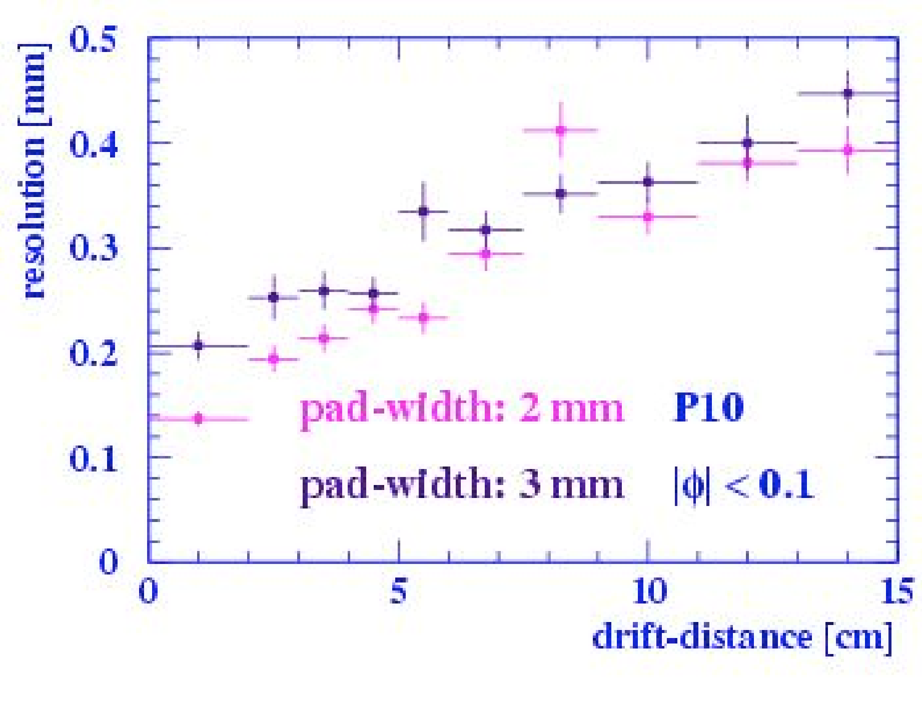


Carleton-Montreal-Victoria-TRIUMF
D Karlen- Prague Nov. 2002

GEM TPC studies

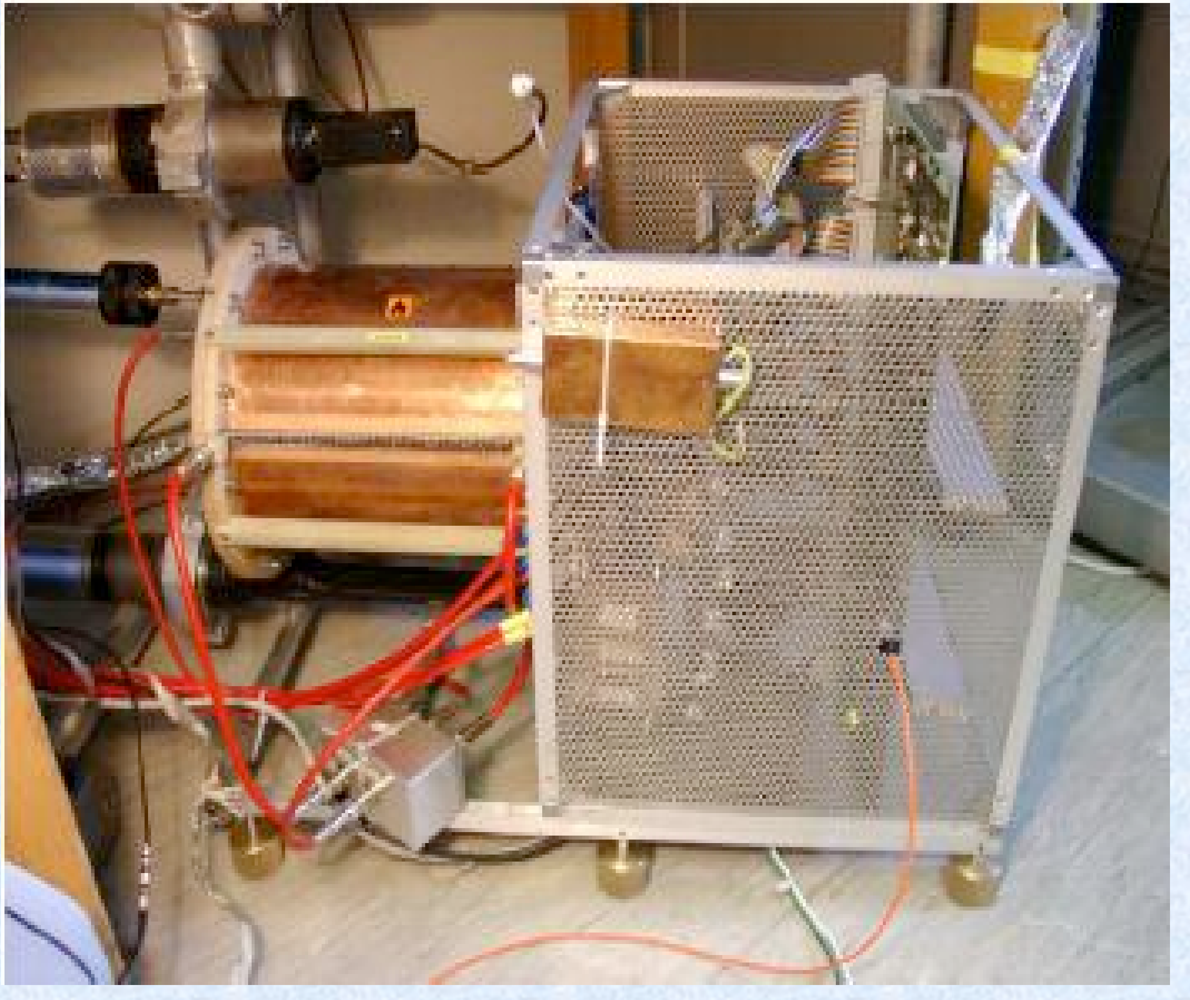


Single-point track resolution for two gases and different pad widths:



Carleton-Montreal-Victoria-TRIUMF
M. Dixit - Prague Nov. 2002

GEM-TPC Studies

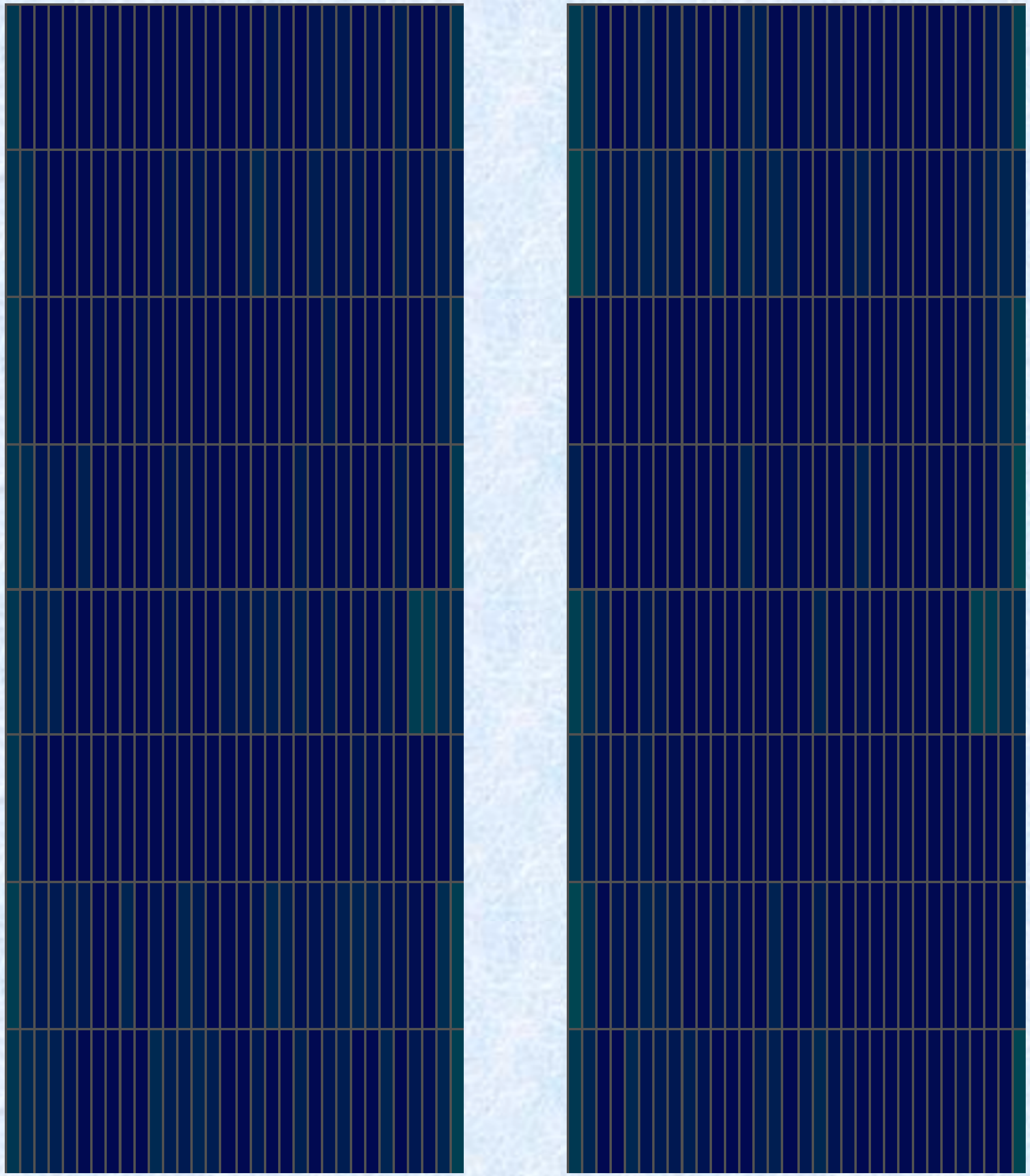


LBNL - Karlsruhe - CERN

GEM-TPC studies

Two events, recorded in the CERN test beam run (August 03)

8 pad rows equipped



LBNL- Karlsruhe - CERN

Simplified readout schemes: Chevron

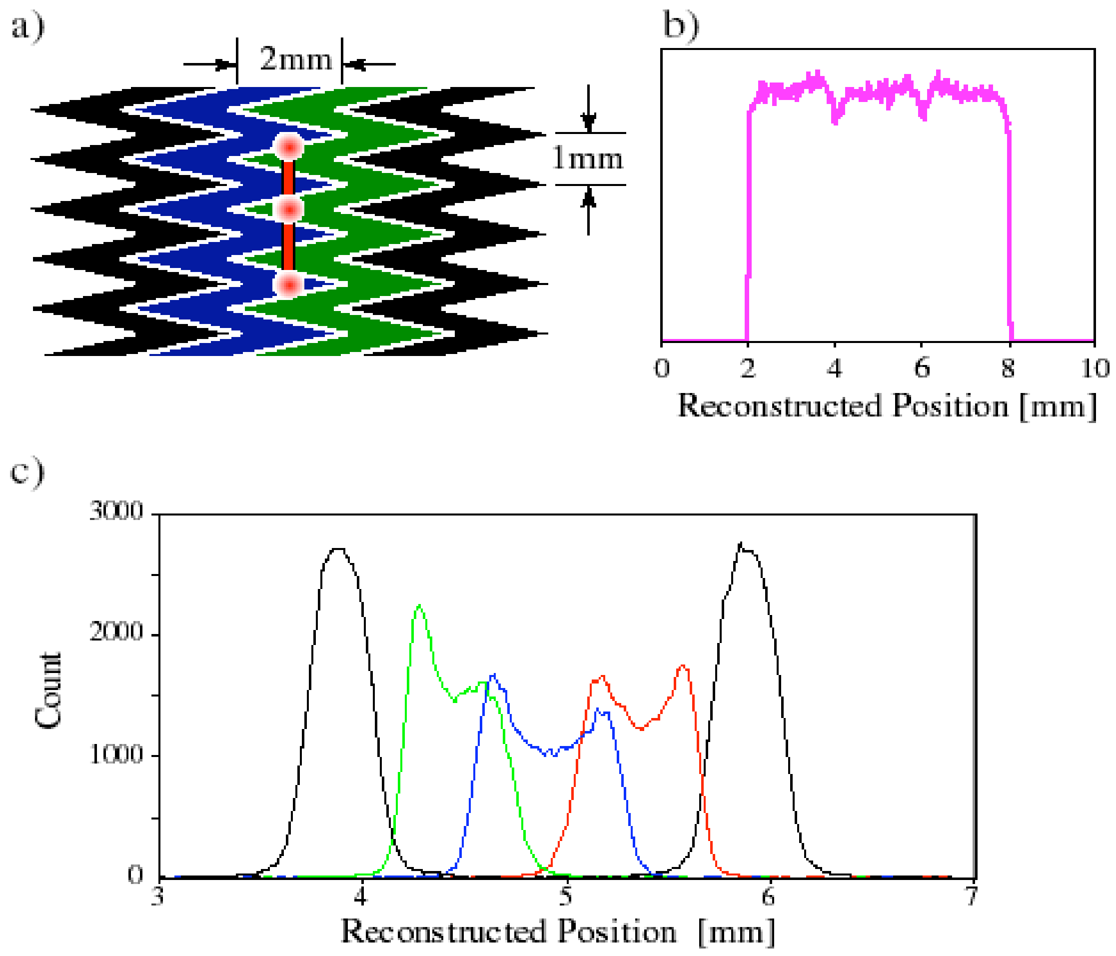
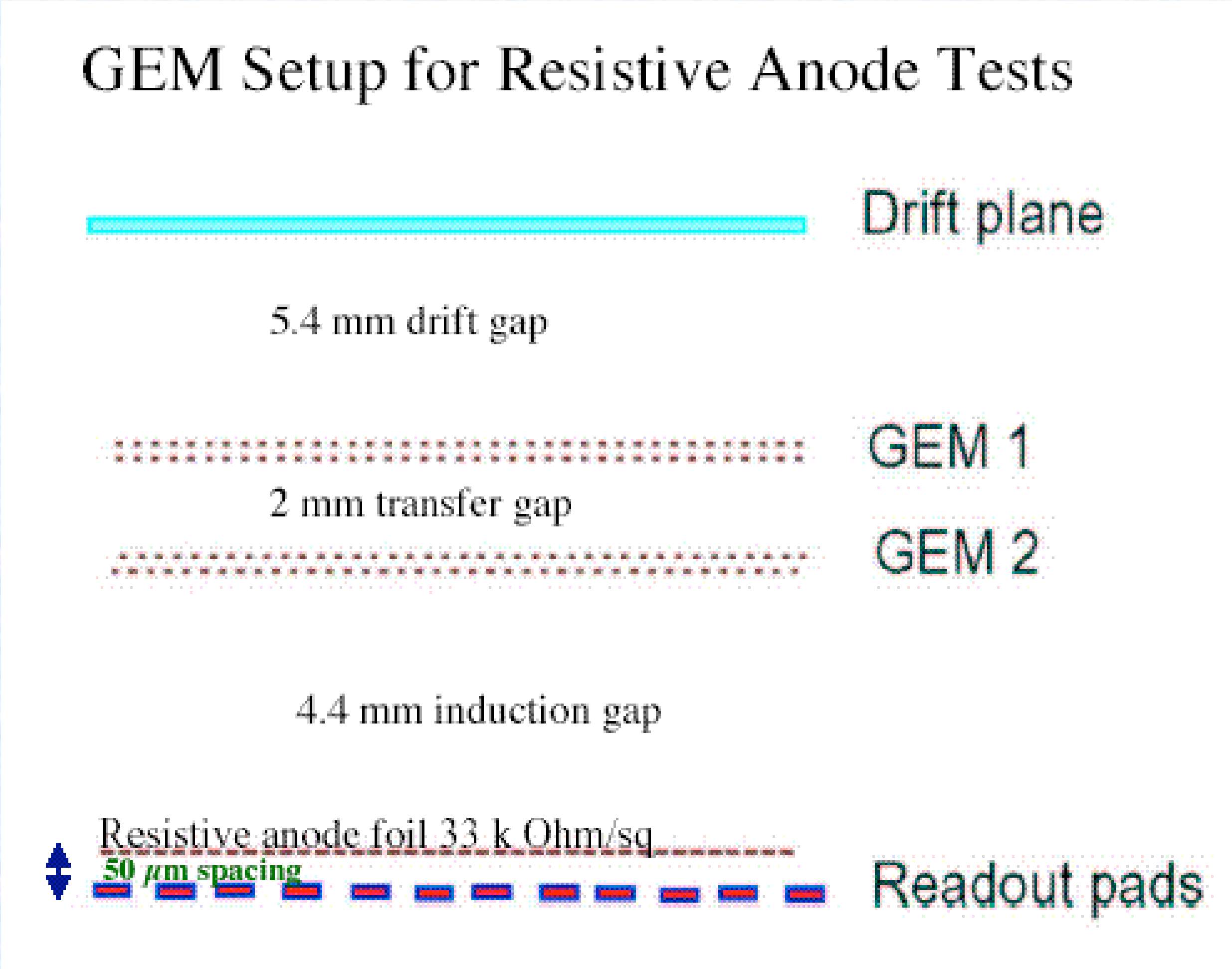


Fig. 6. a) Coarse zigzag pattern, b) its uniform irradiation response, and c) position responses of a line beam.

B. Yu et al, Trans. Nucl. Sci. NS50(2003)836

Resistive anode readout

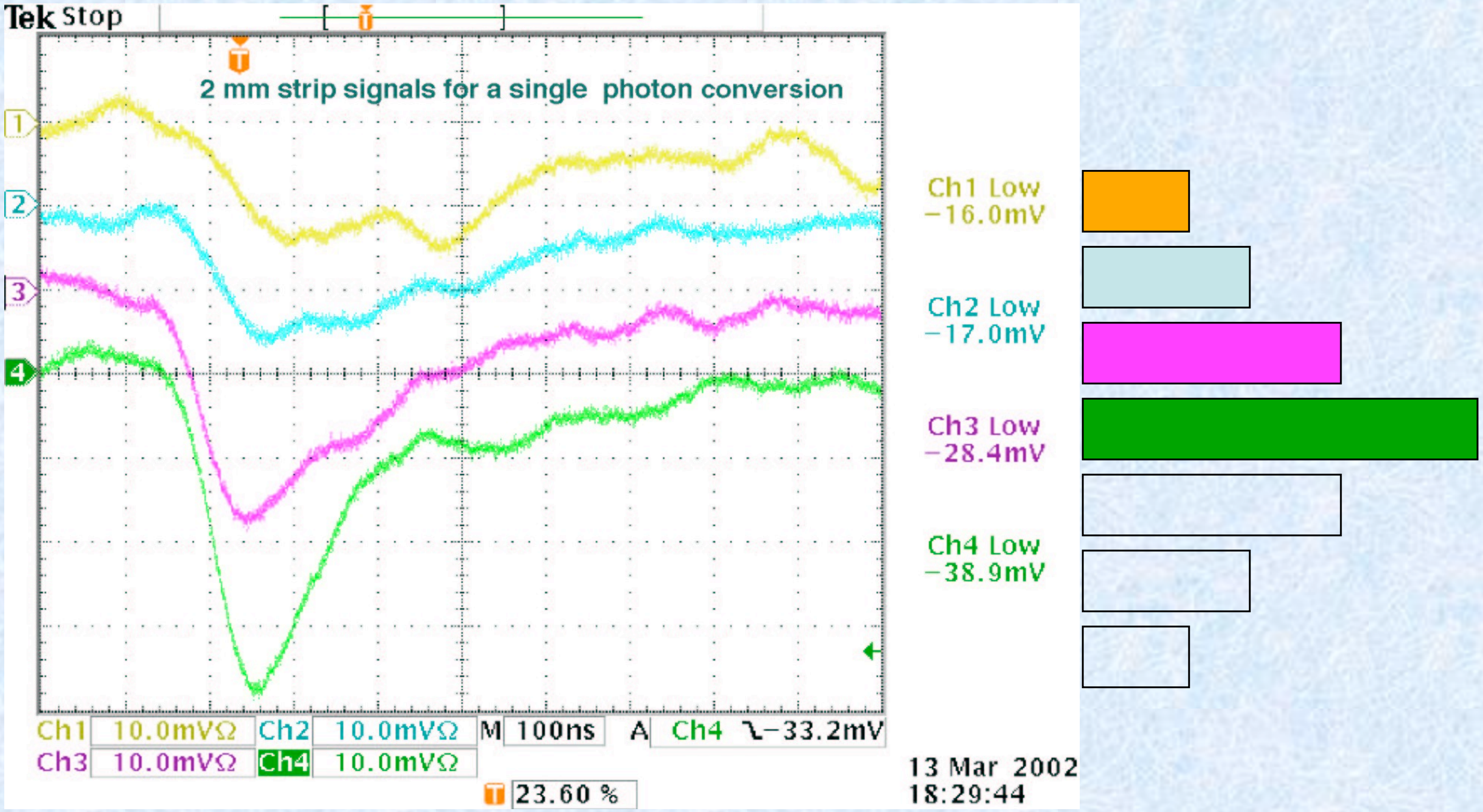
Signals are read out by induction through a resistive foil anode:



Carleton-Montreal-Victoria

Resistive anode readout

Charge cluster size ~ 1 mm ; signal detected by ~7 anodes (2 mm width)

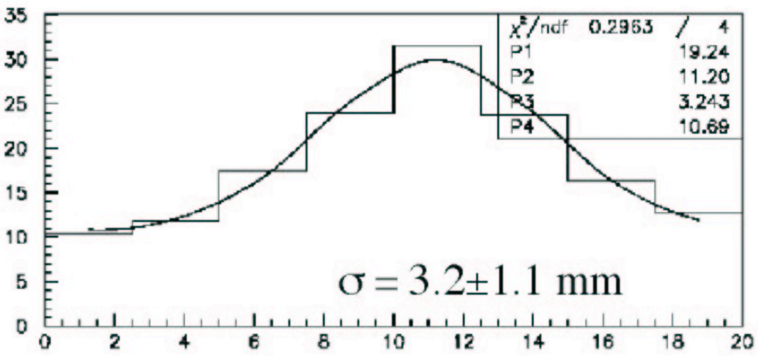


Carleton-Montreal-Victoria

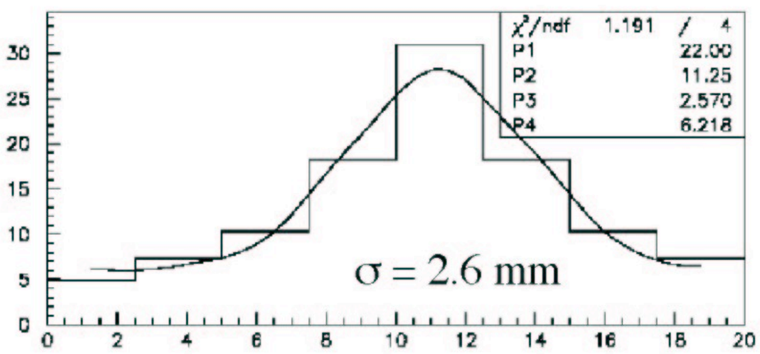
M. S. Dixit et al, Subm. Nucl. Instr. Methods A (2003)

Resistive anode readout

Pad response function through resistive foil:



Measured pad response function

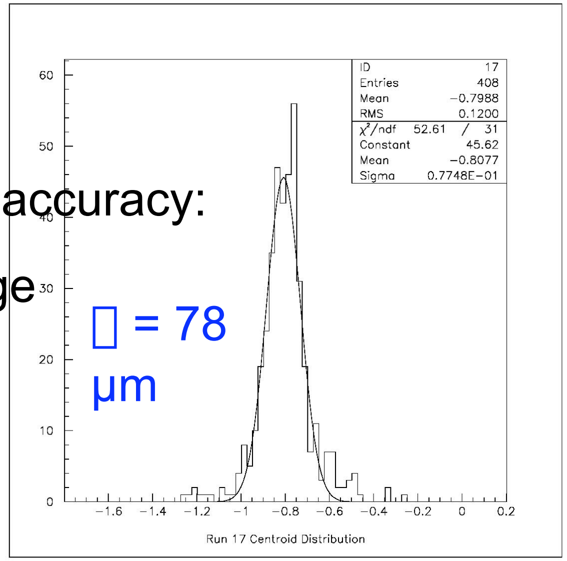


Simulated Pad Response Function

Position accuracy:

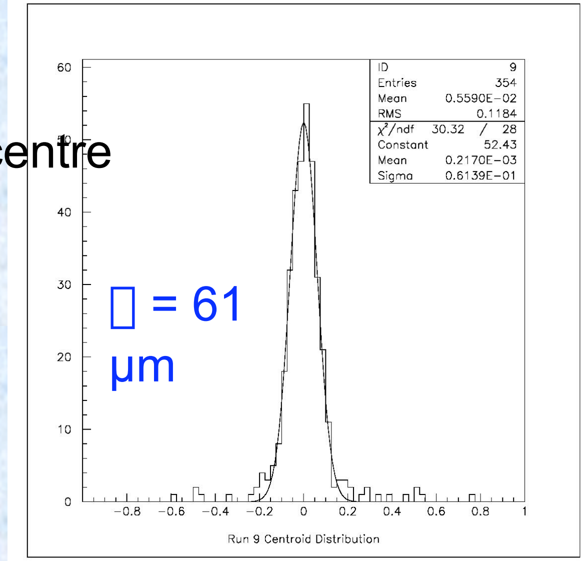
Strip edge

σ = 78 µm



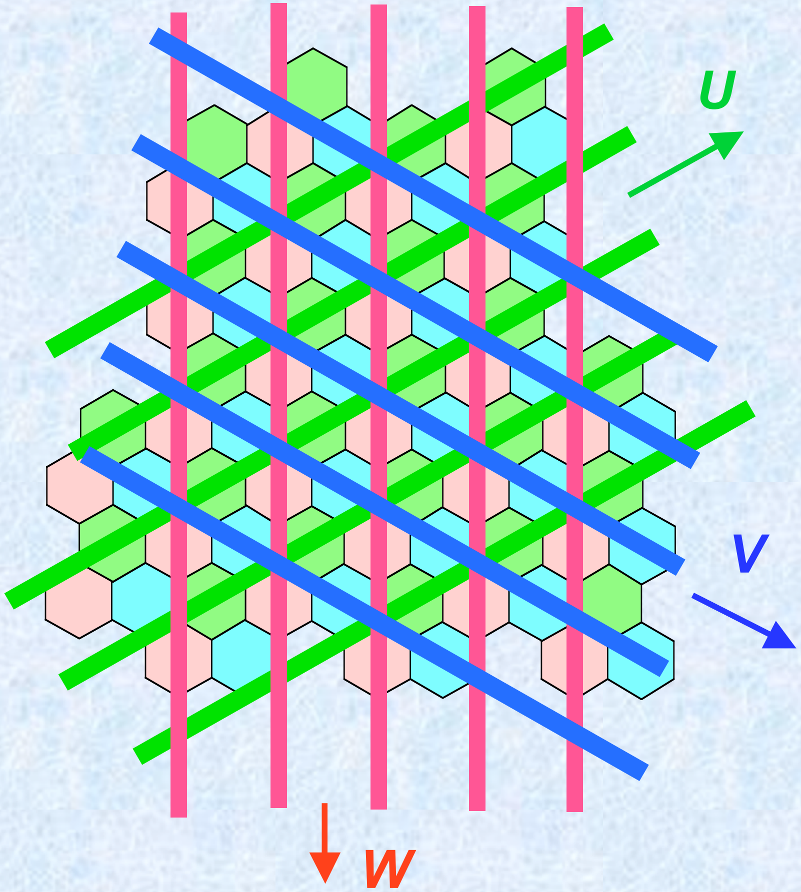
Strip centre

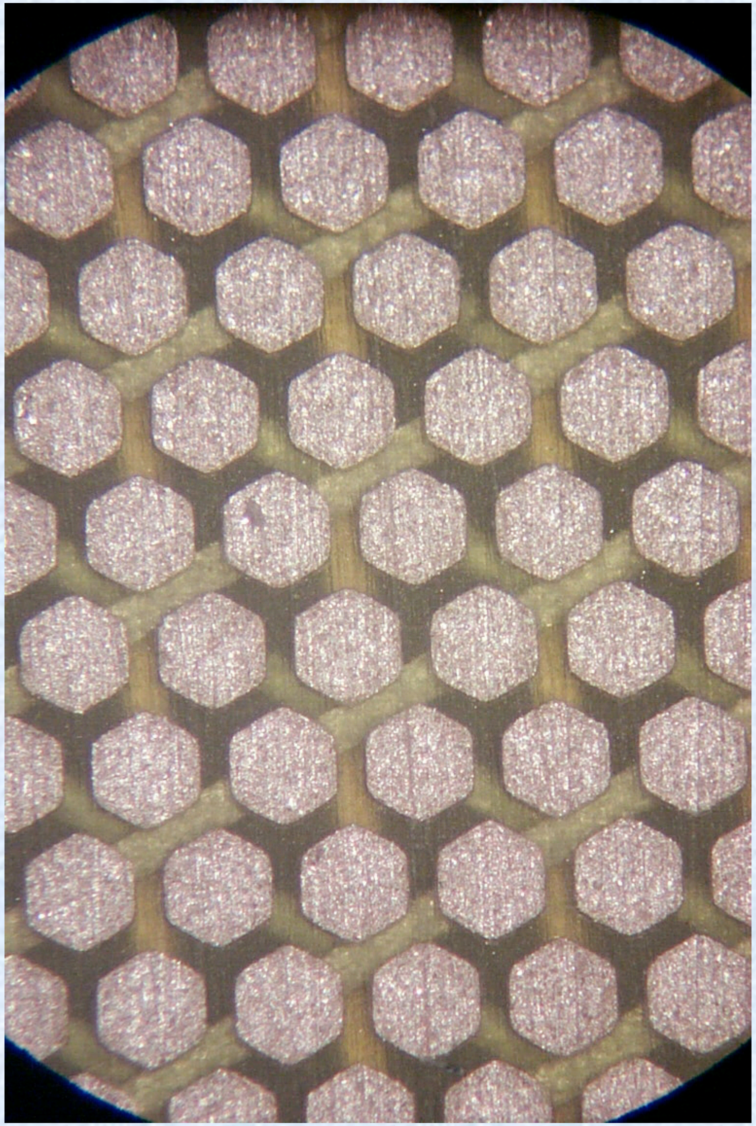
σ = 61 µm



http://www.physics.carleton.ca/~gmd/

GEM-TPC readout: Hexaboard



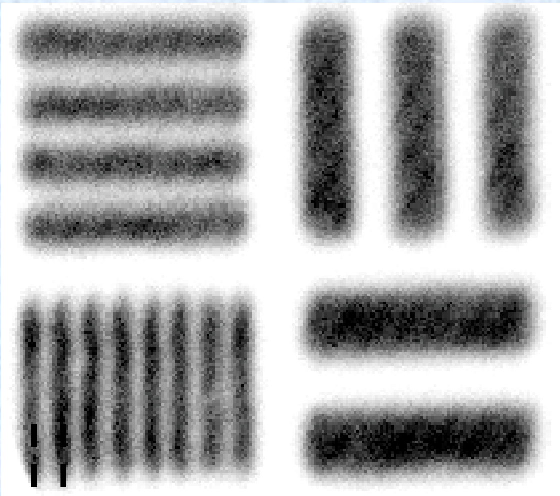


S. Bachman et al, NIM A 478(2002)104

Imaging with the Hexaboard *8 keV X-rays*

X-ray Absorption mask pattern:

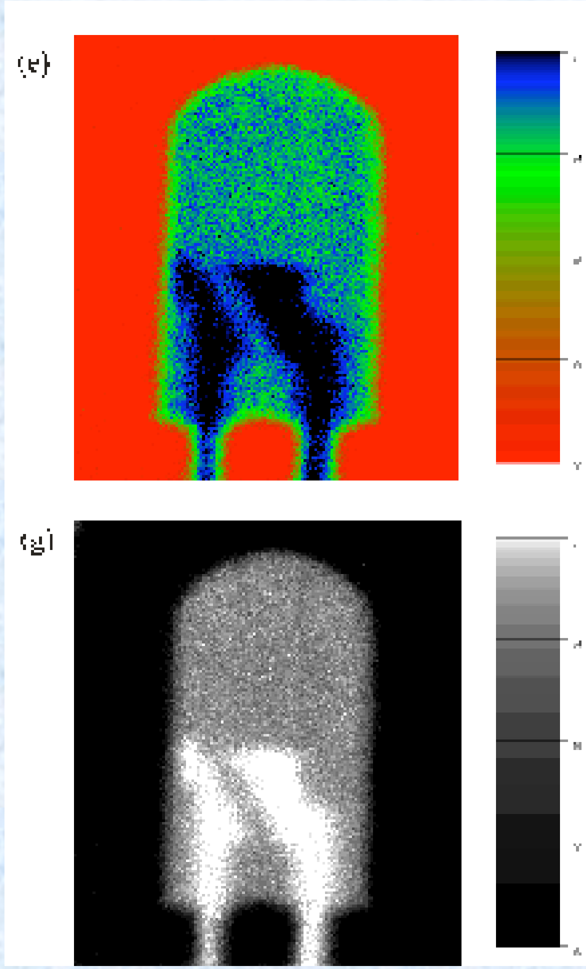
10 mm



10 mm

500 μm

LED Absorption Radiography:

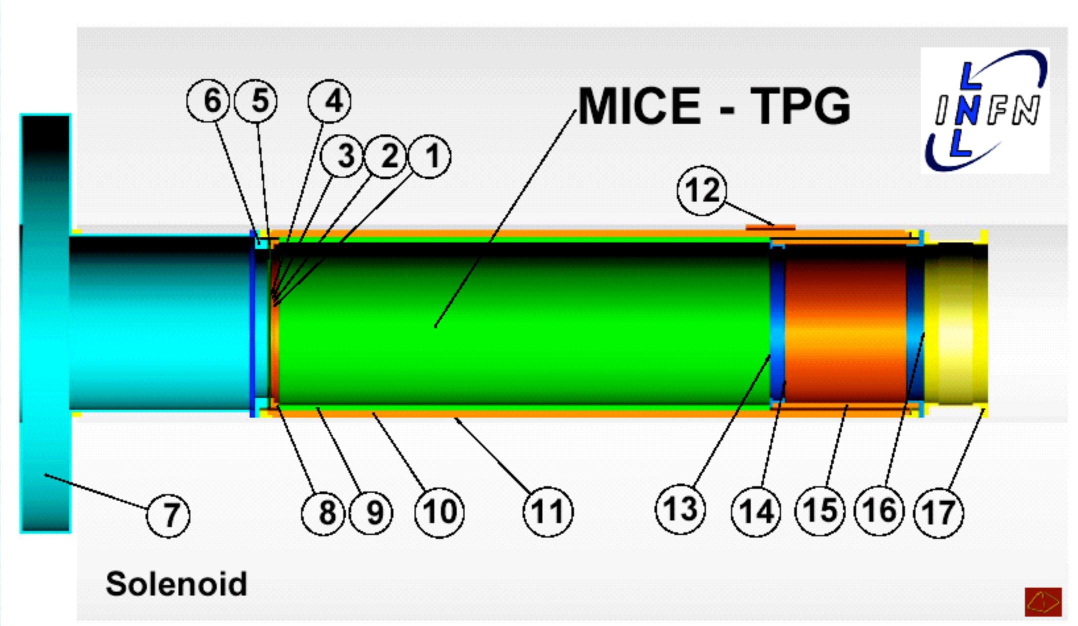


2 mm

S. Kappler, Applications of Multi-GEM Detectors in X-ray imaging (Diploma work at Karlsruhe Univ.)

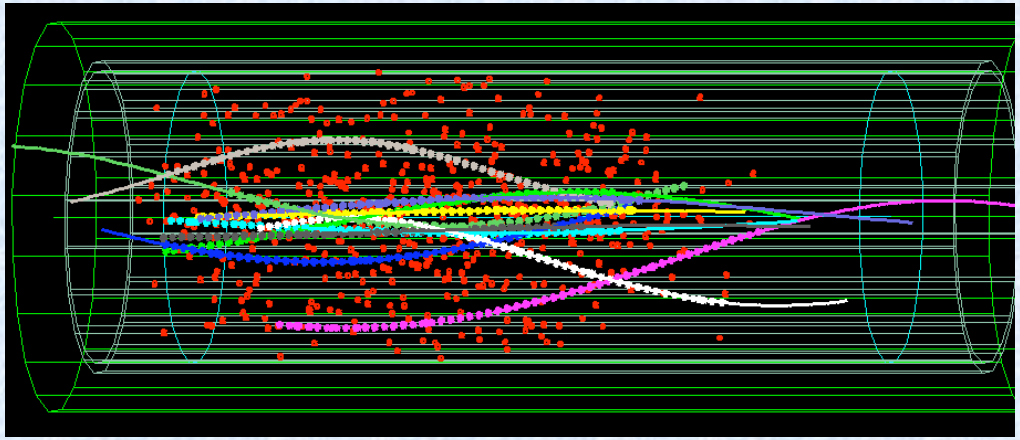
TPG: Time Projection GEM for MICE

Muon **I**onization **C**ooling **E**xperiment



Triple-GEM TPC with Hexaboard read-out

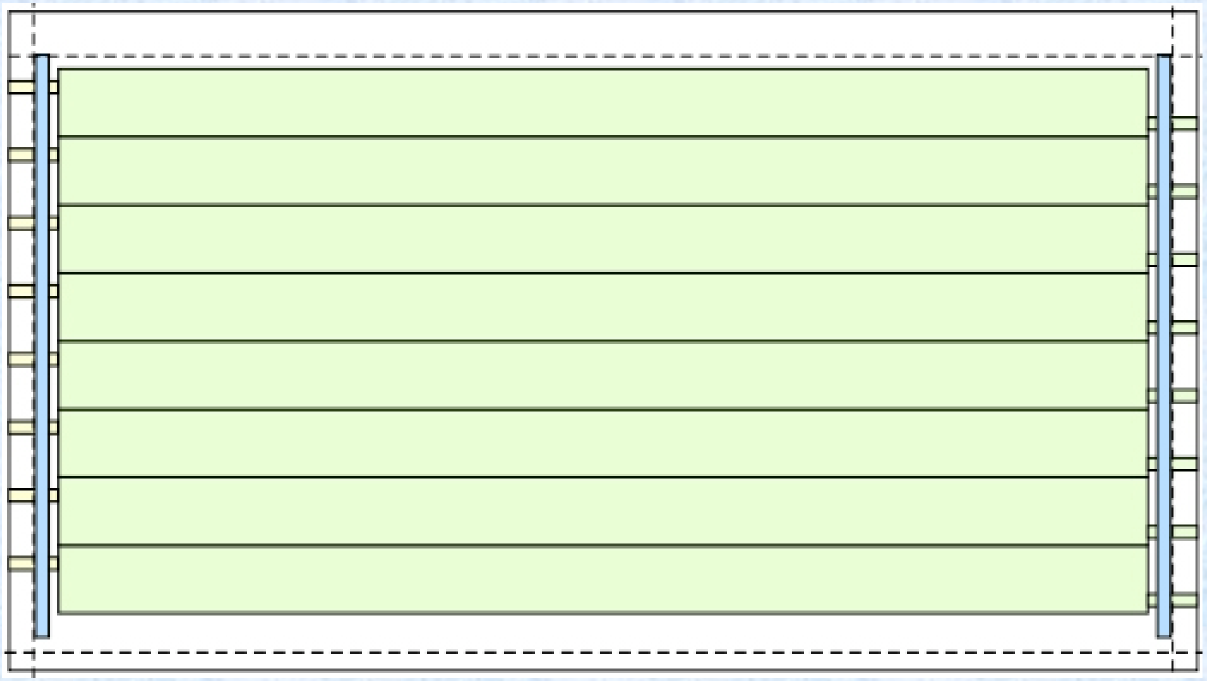
Simulated tracks:

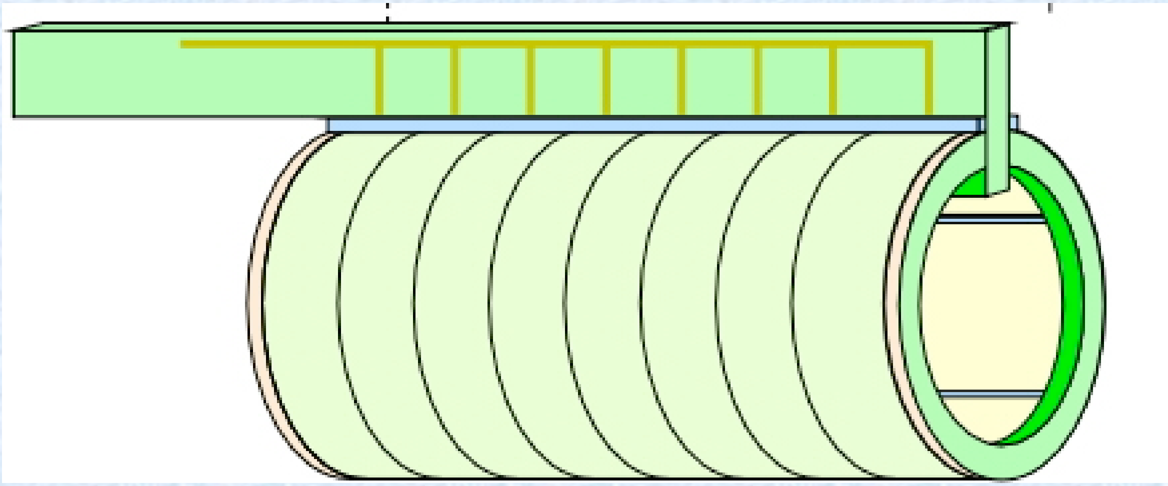


Geneva, CERN, RAL, Legnaro, …..

CLAS Gem

Non-planar GEM deetctors are under study:

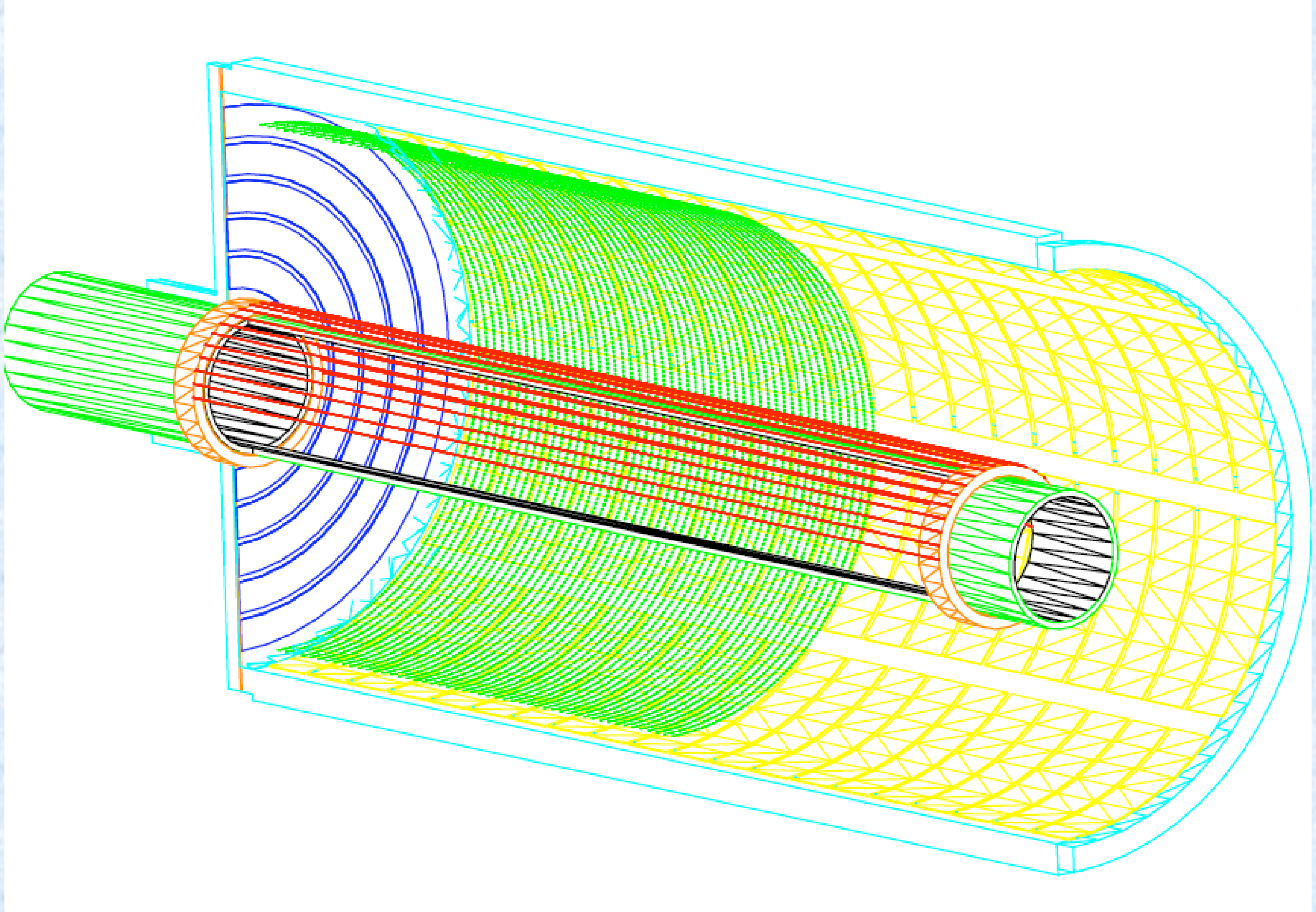




TACTIC at TRIUMF

Study of $^{8}Li(\alpha,n)^{11}B$ reaction for astrophysics

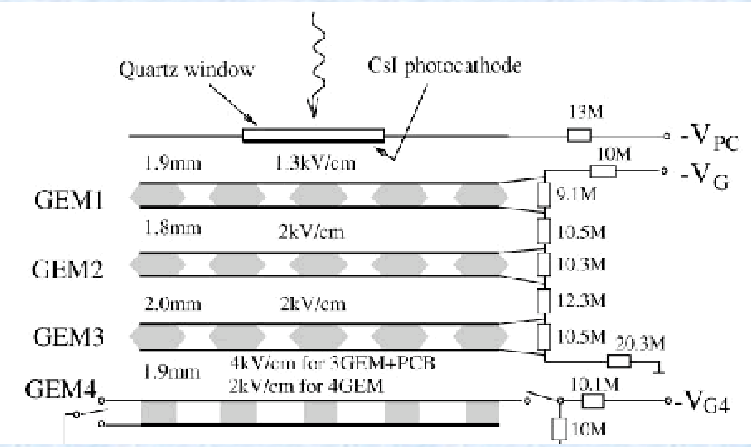
Radial He-filled TPC with cylindrical GEM readout:

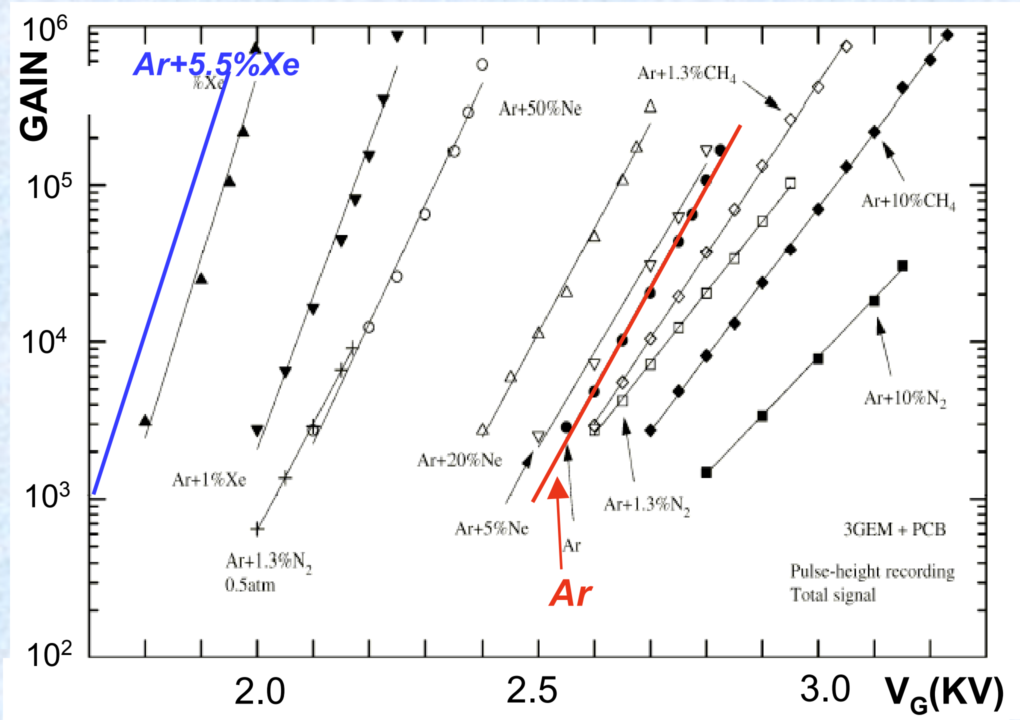


P-A. Amaudruz, private communication (TRIUMF, 2003)

Multi-GEM for photon detection

Multiple GEM detectors permit to achieve very large gains (10^6) in photocathode-friendly pure noble gases or poorly quenched mixtures.
Reduced transparency strongly suppresses photon and ion feedback

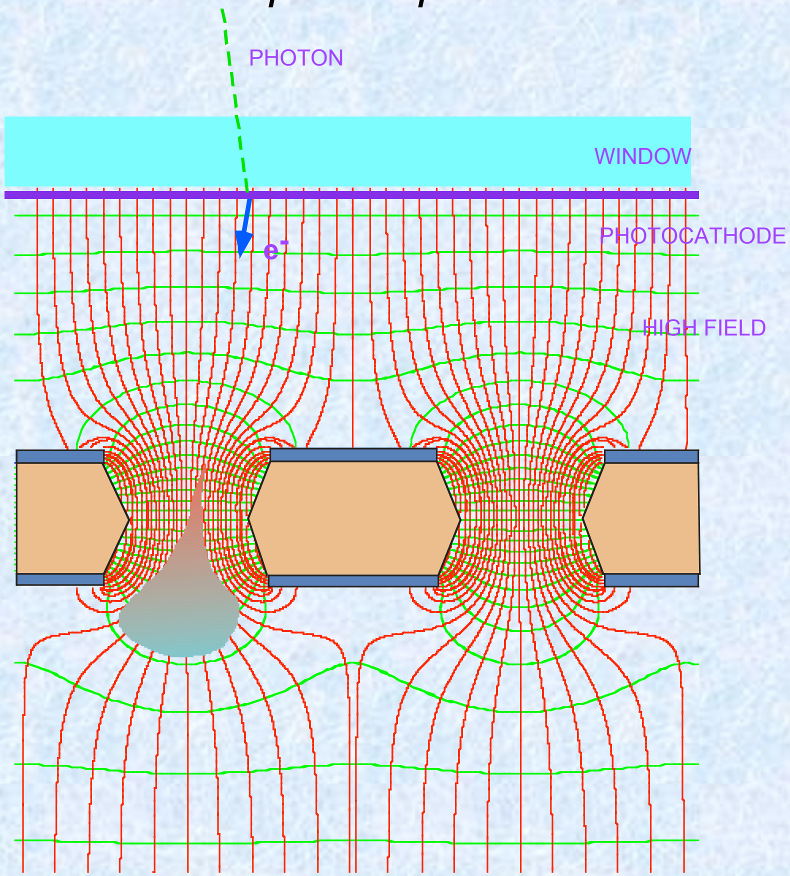




A. Buzulutskov et al, Nucl. Instrum. Methods A443(2000)164

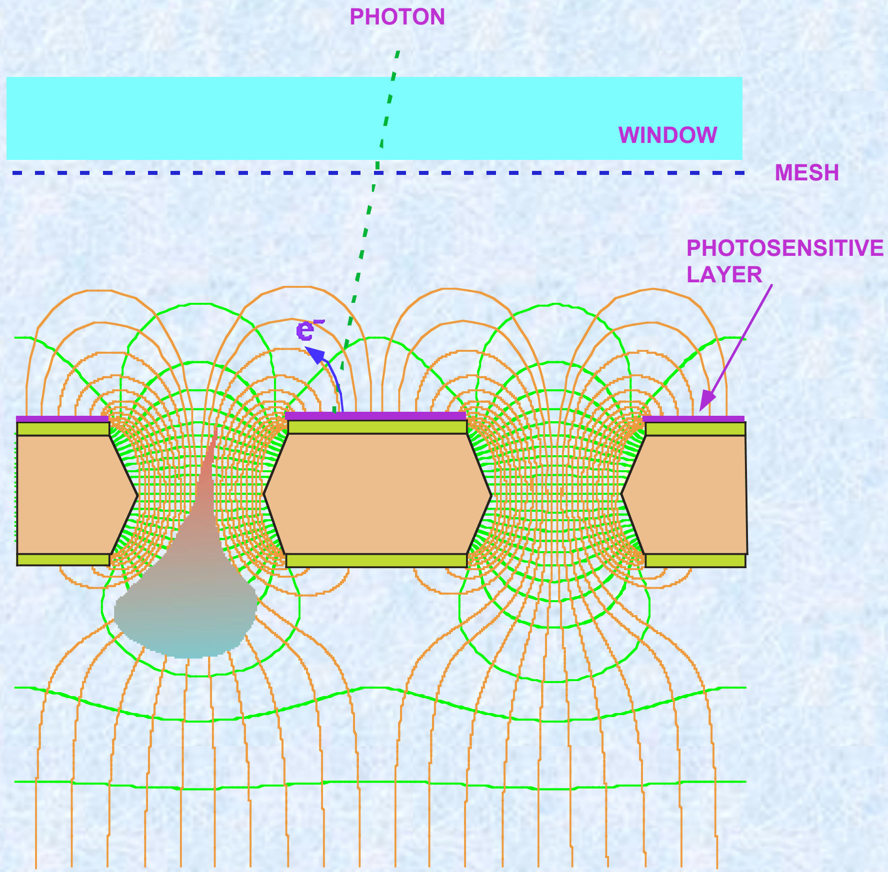
UV Photon detection

Semi-transparent photocathode:



Higher surface
Lower quantum efficiency

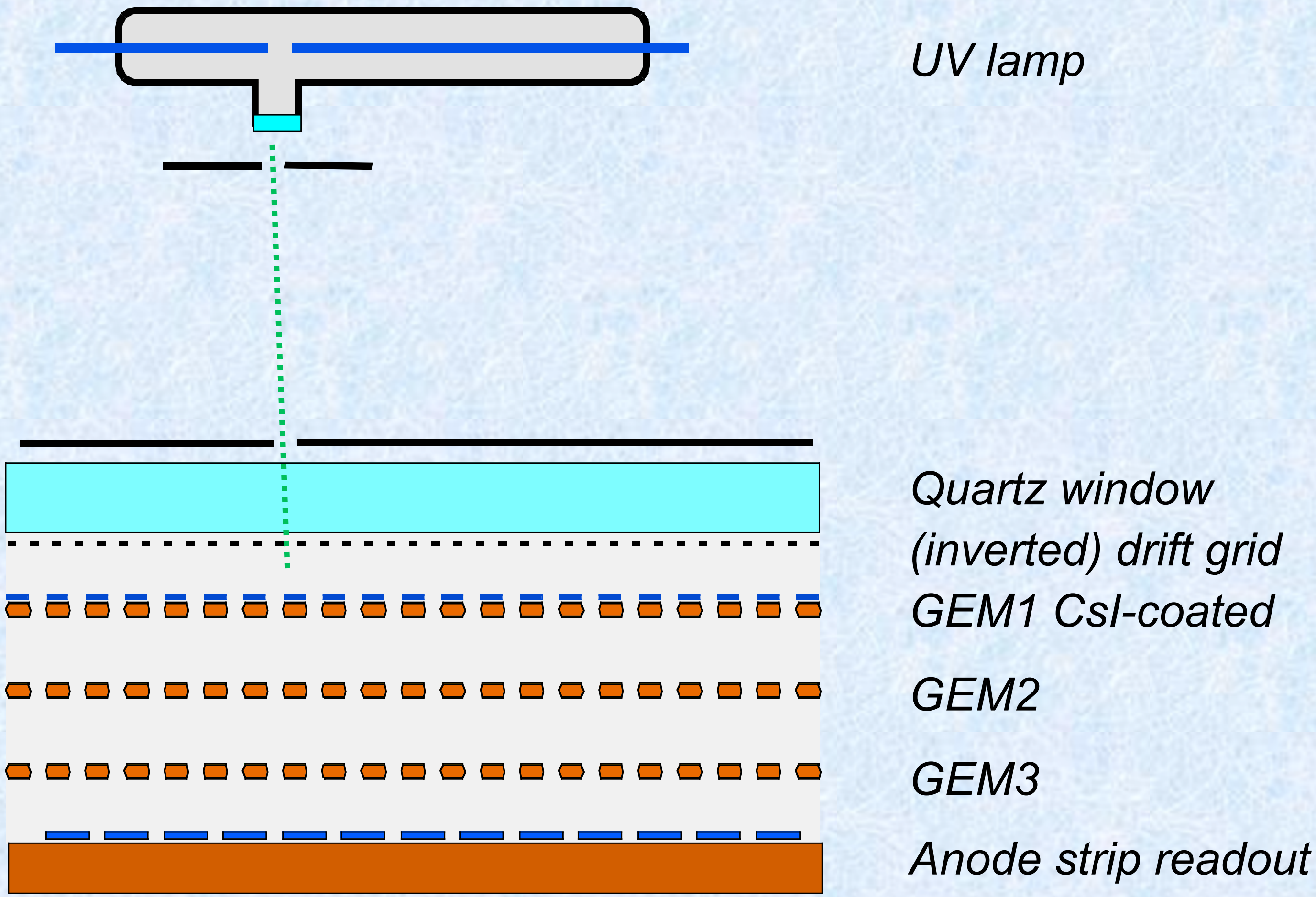
Reflective photocathode:



Lower surface
Higher quantum efficiency

GEM-RICH development

Triple GEM with CsI coating of upper GEM side

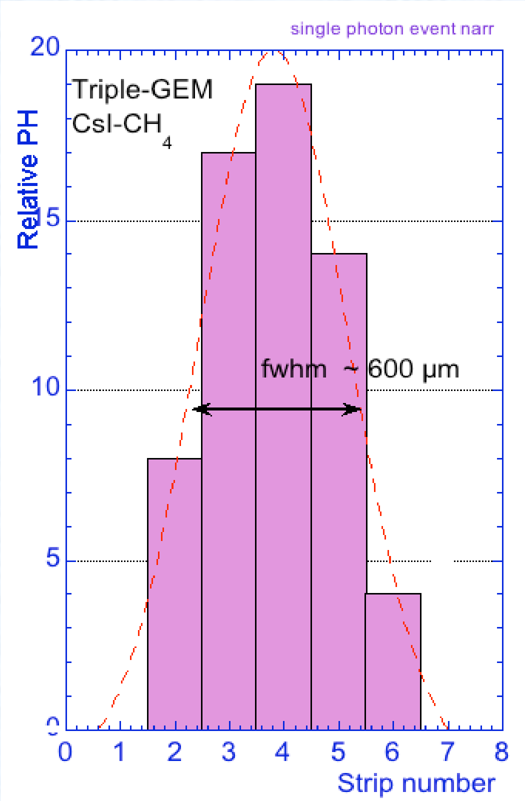


T. Meinschad, L. Ropelewski , F. Sauli -CERN-GDD

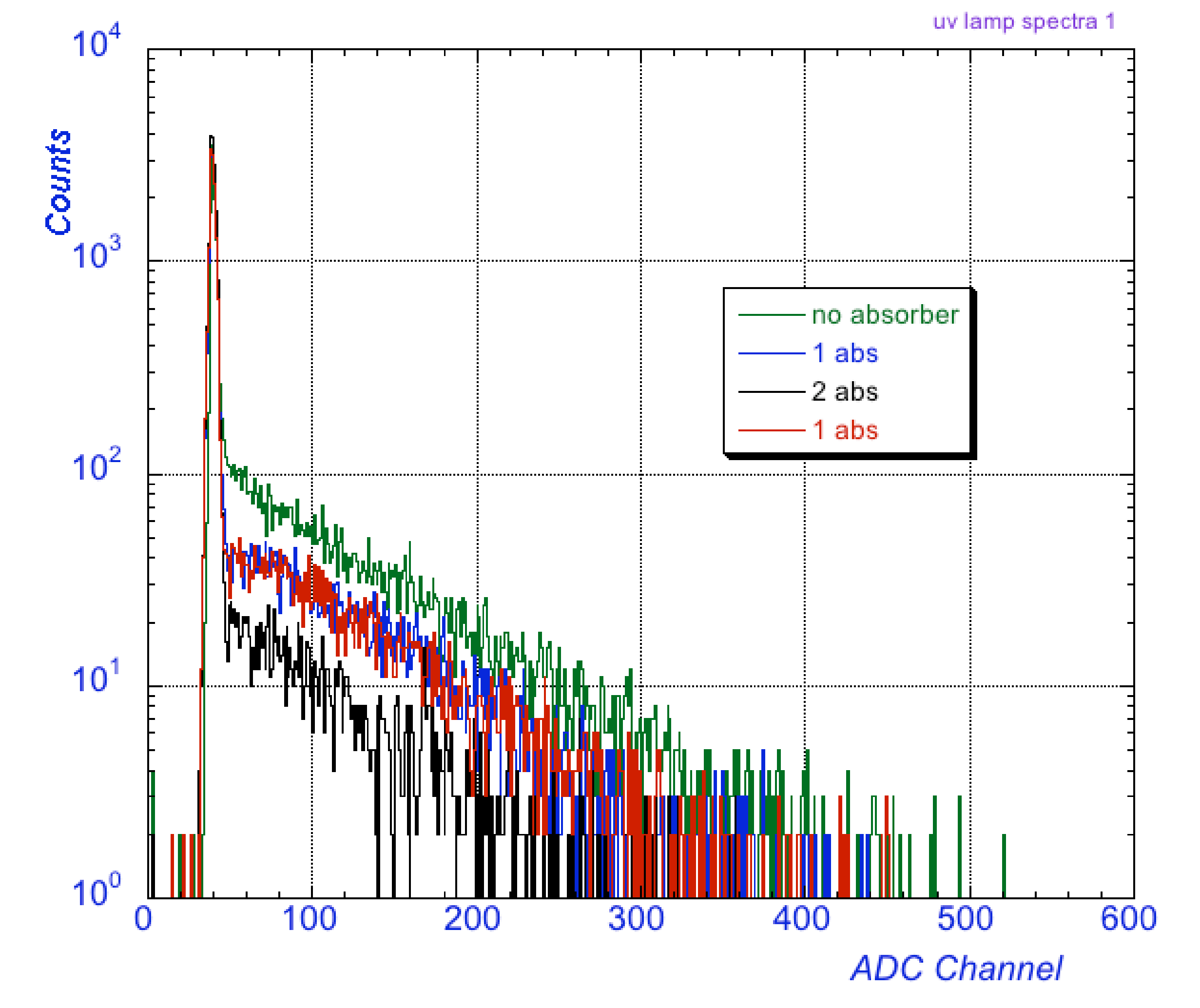
GEM-RICH

Triple-GEM
CsI reflective-CH_4 fill

Single photoelectron event:



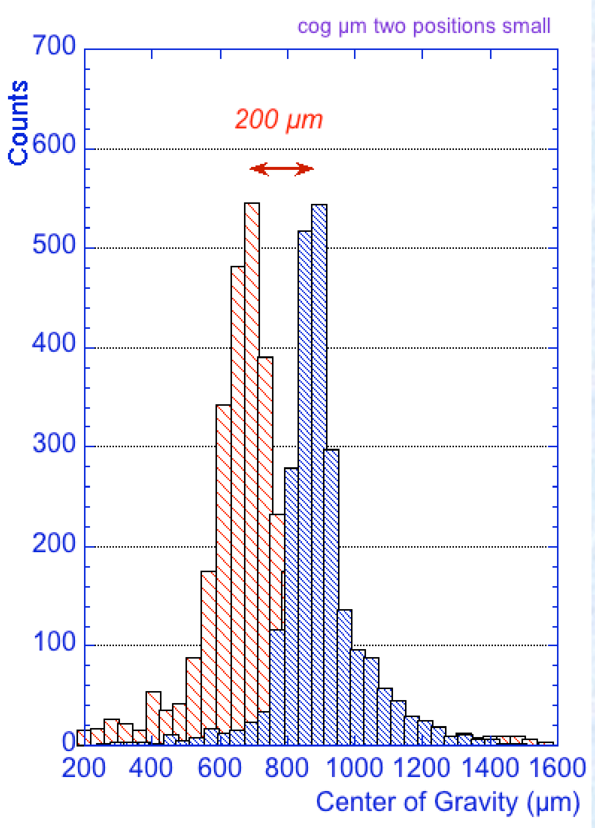
PH distributions for increasing UV light attenuation:



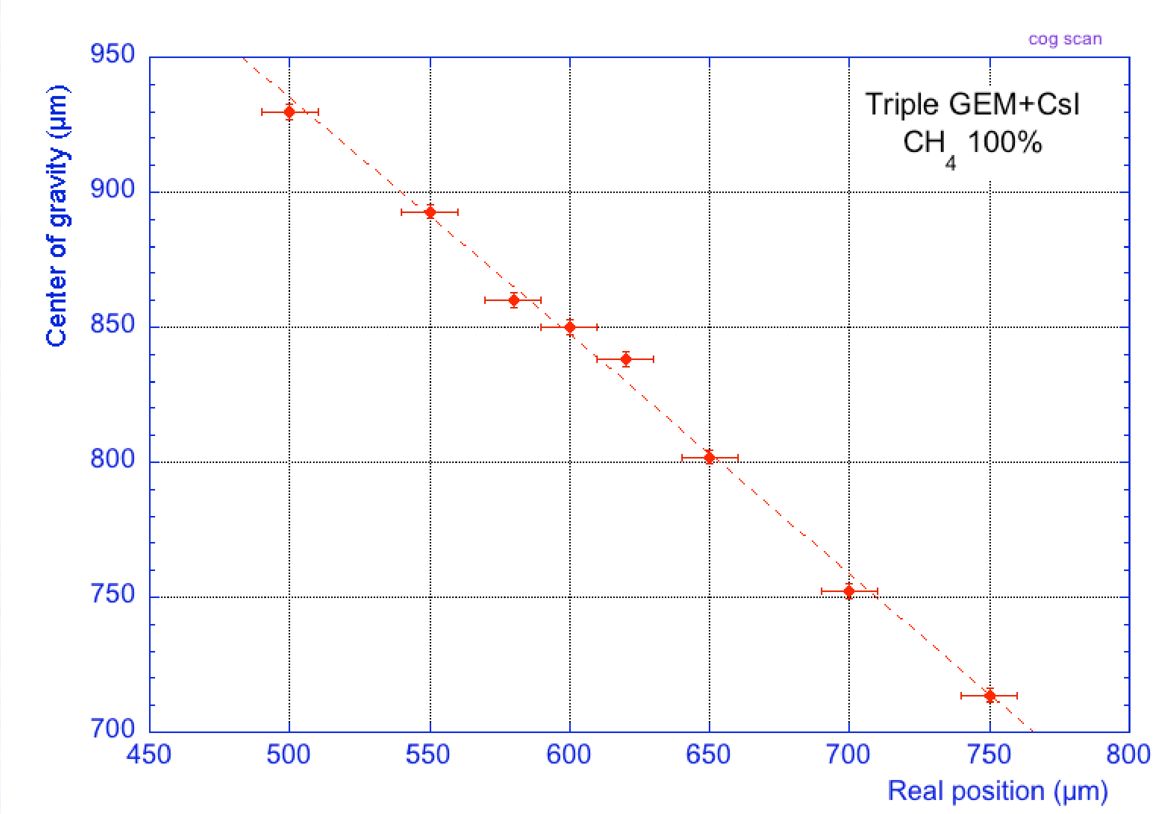
T. Meinschad, L. Ropelewski , F. Sauli -CERN-GDD

GEM-RICH Collimated UV source
Position scan on 8 adjacent strips (200 μm pitch)

Two positions 200 μm apart:
fwhm ~ 150 μm
(including source collimation!)



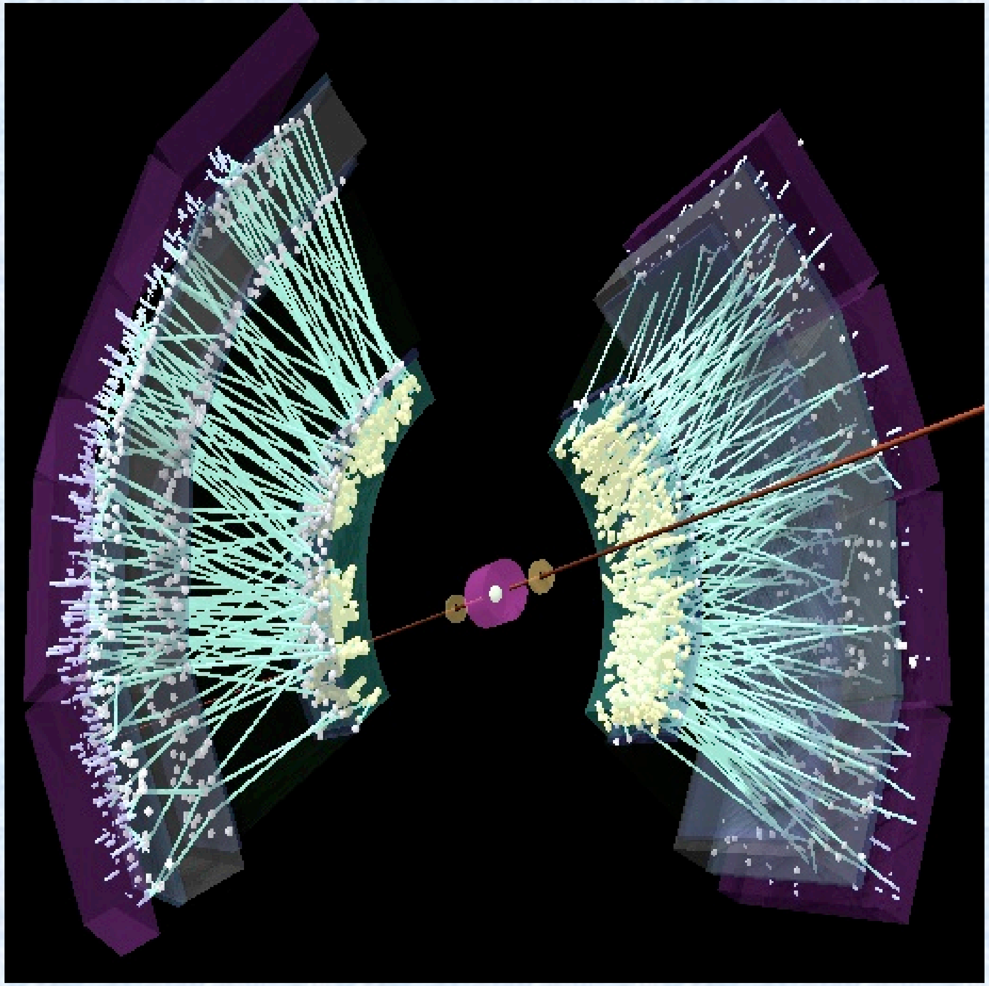
Computed vs real position:



T. Meinschad, L. Ropelewski , F. Sauli -CERN-GDD

PHENIX Upgrade

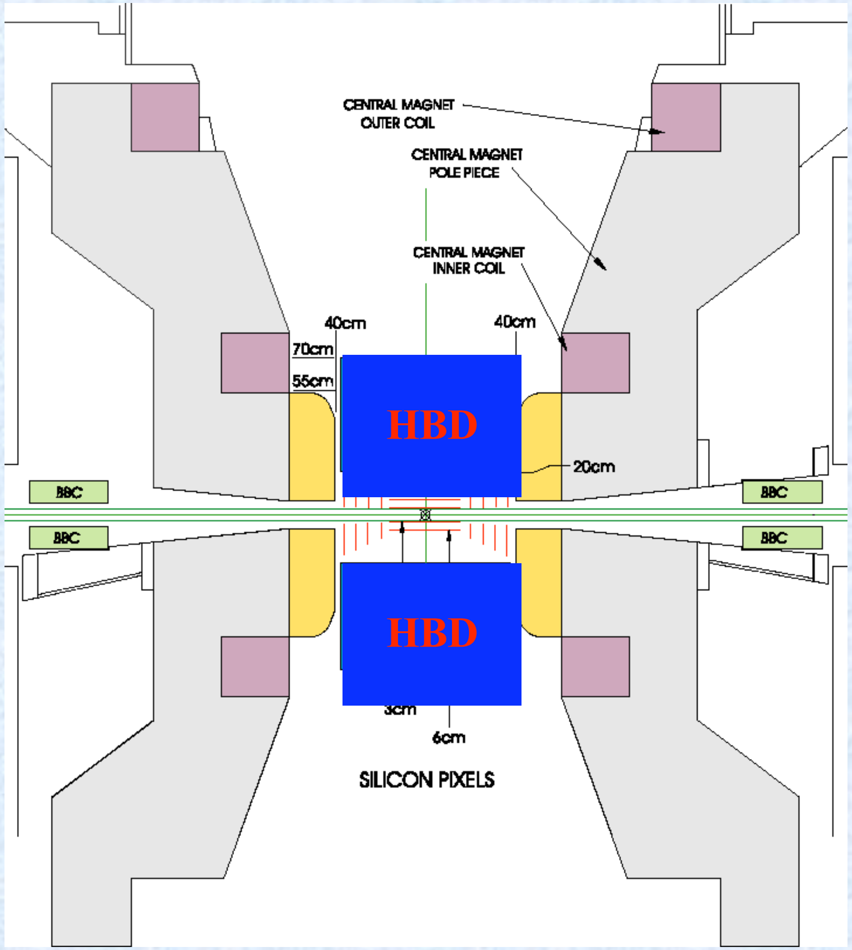
PHENIX: Search for Quark-Gluon Plasma at RHIC
Au-Au collision at 200 GeV:



PHENIX UPGRADE:
Detect low-mass e^+e^- pairs from decay of light vector mesons □, □, □

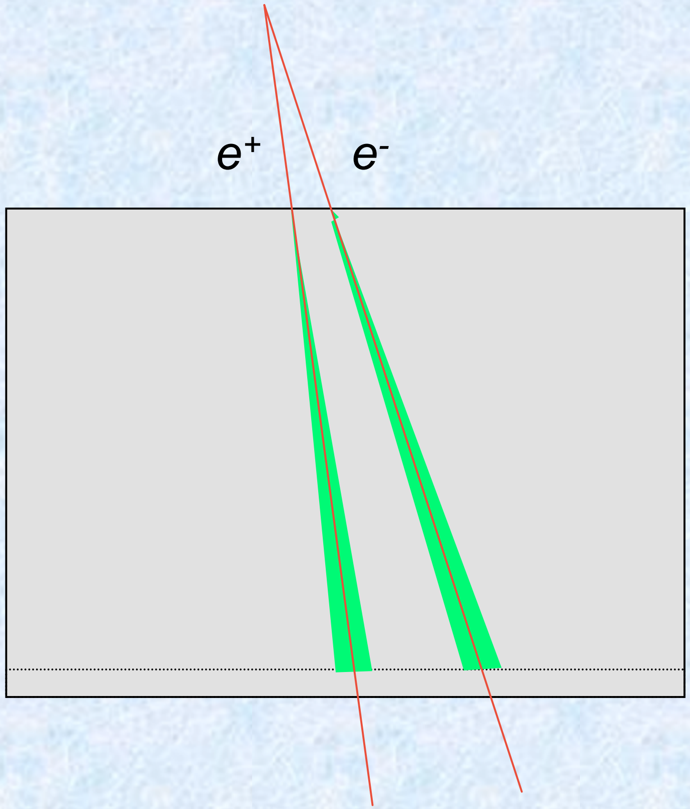
HADRON BLIND DETECTOR:
Identify electrons with > 90% efficiency
Pion rejection ~200

PHENIX Hadron Blind



Electron pair identification from Cherenkov light cone

Windowless proximity focusing detector:



PHENIX Upgrade

Radiator: CF_4 gas
Photocathode; CsI

- wide bandwith (6 to 11.5 eV)

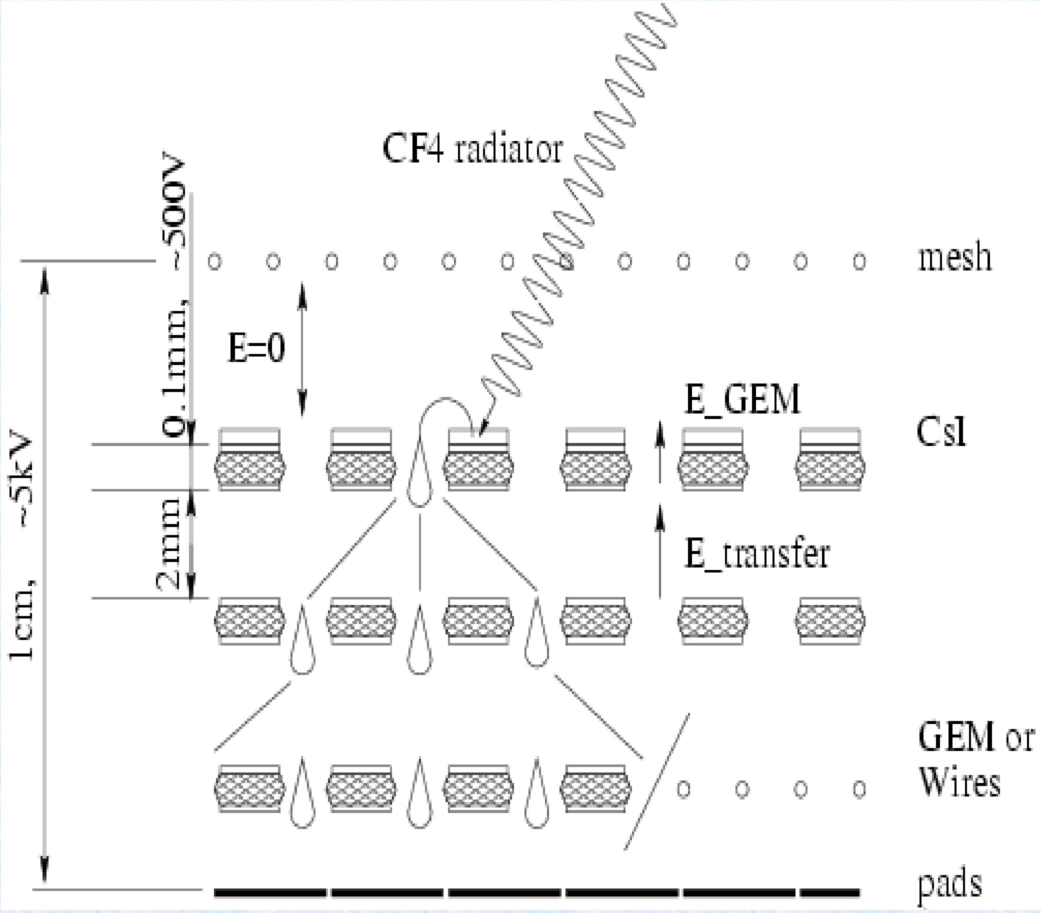
N_0 ~ 900

Detector: Triple GEM with reflective photocathode on first GEM

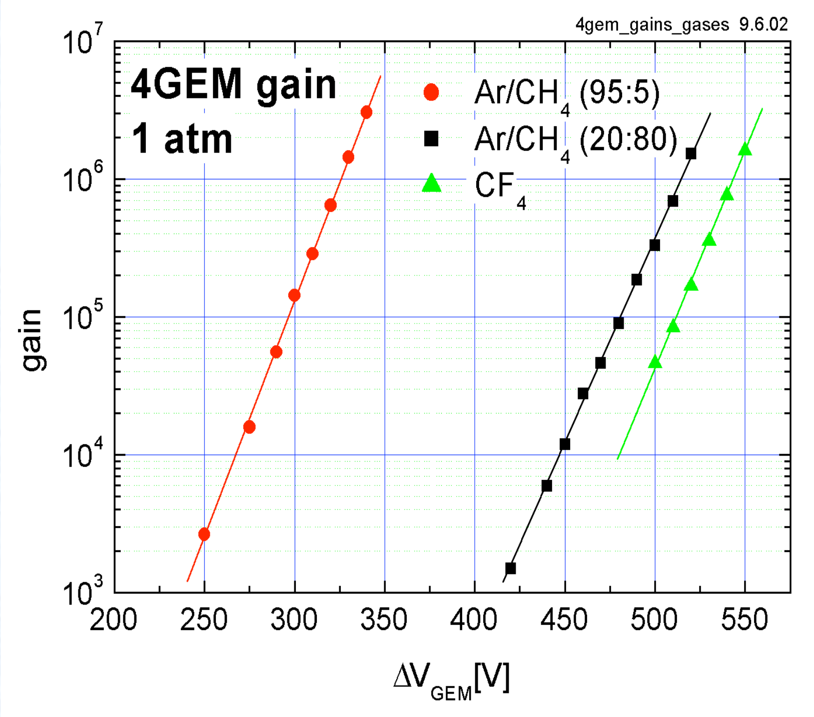
- large gains in CF4

- no photon feedback from avalanches

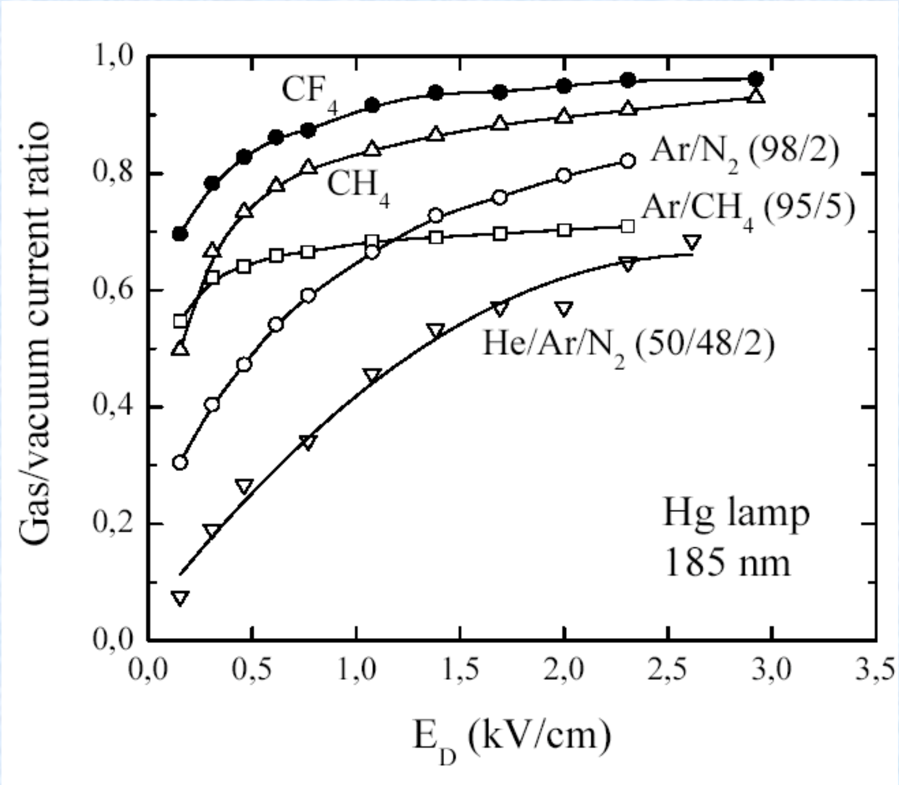
~ 40 detected photoelectrons/electron



GEM operation in CF4



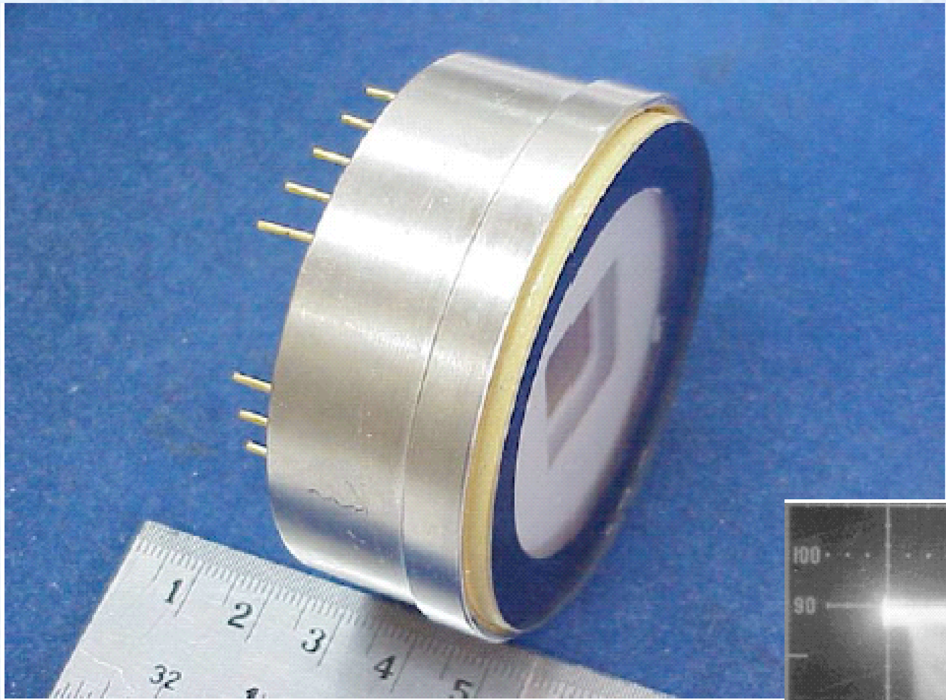
Photoelectron extraction from CsI: gas/vacuum



A. Breskin, A. Buzulutskov, R. Chechik Nucl. Instr. and Meth. A 483(2002)658

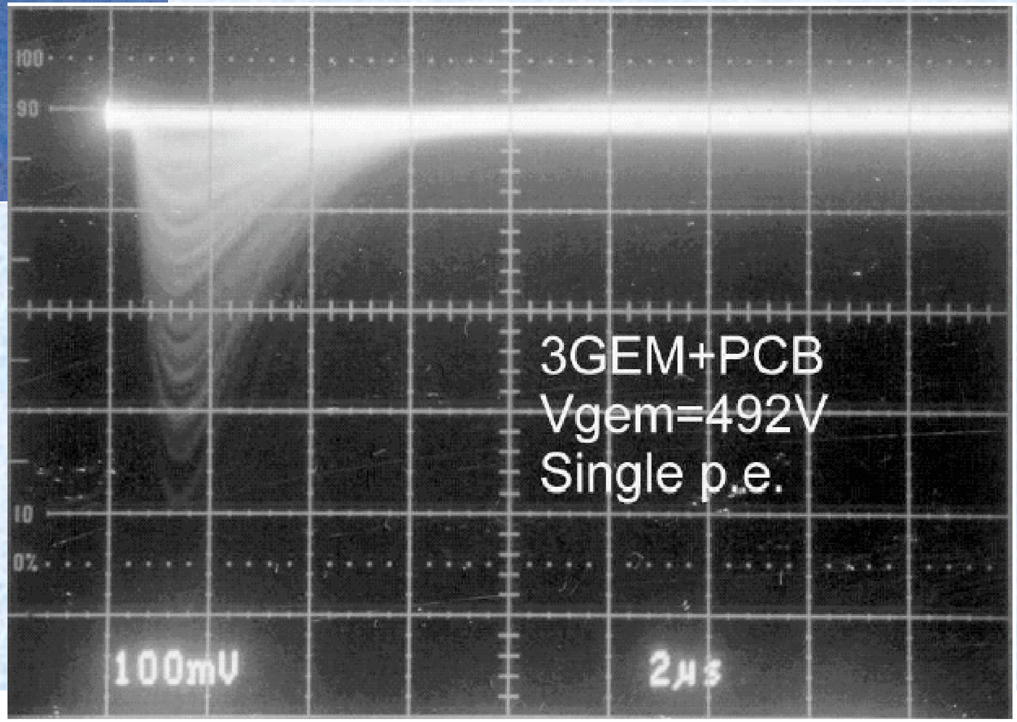
D. Mörmann et al, NIM A504(2003)93

Sealed GEM Photomultiplier



Semi-transparent CsI photocathode: towards large area, position-sensitive photomultipliers

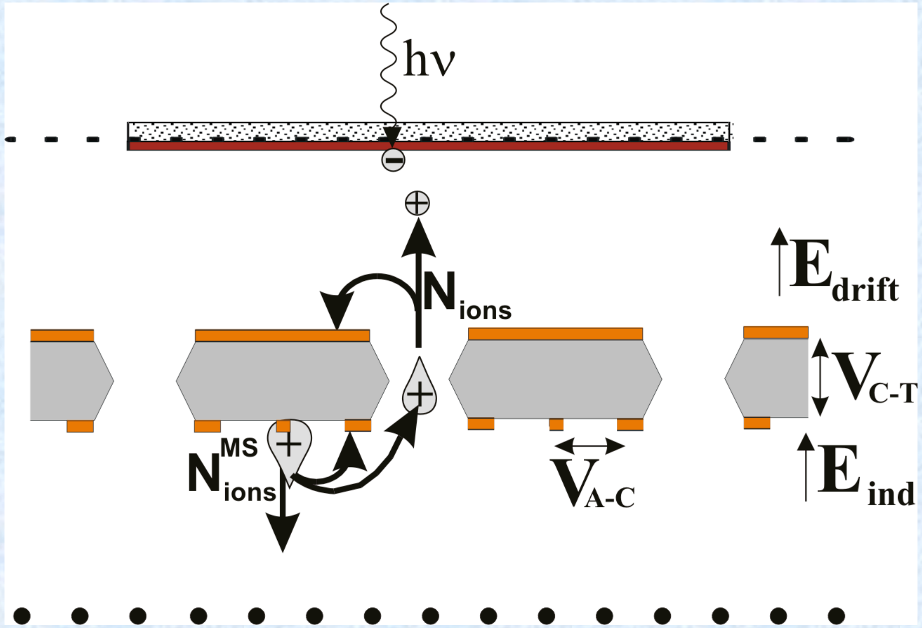
Single photo-electron signals:

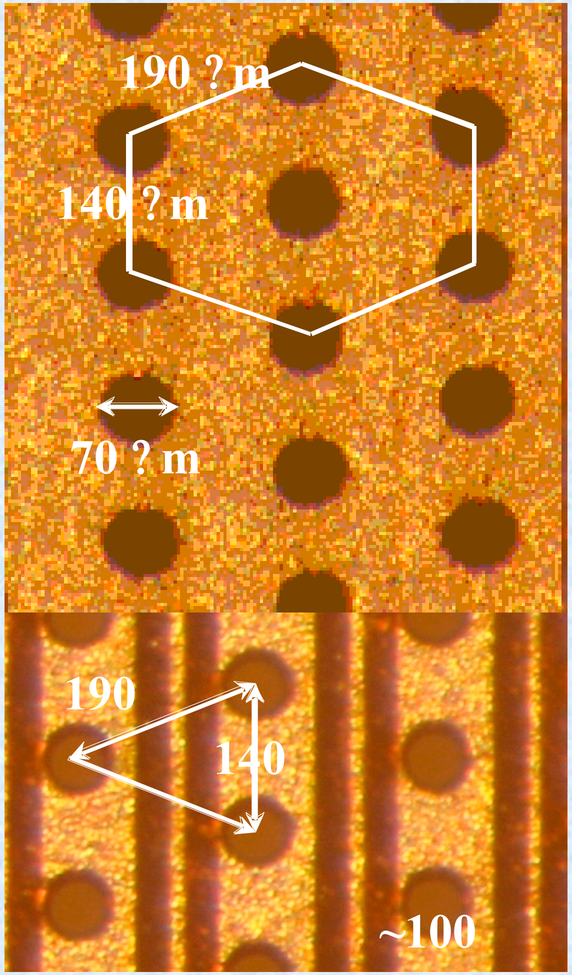


A. Breskin et al,
Nucl. Instr. and Meth. A478(2002)225

Micro-Hole and Strip GEM

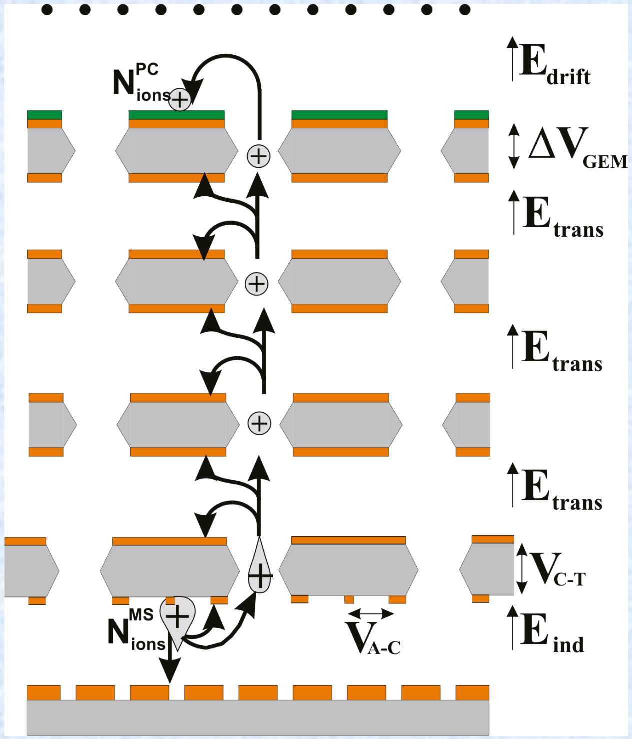
Ion feedback reduction:

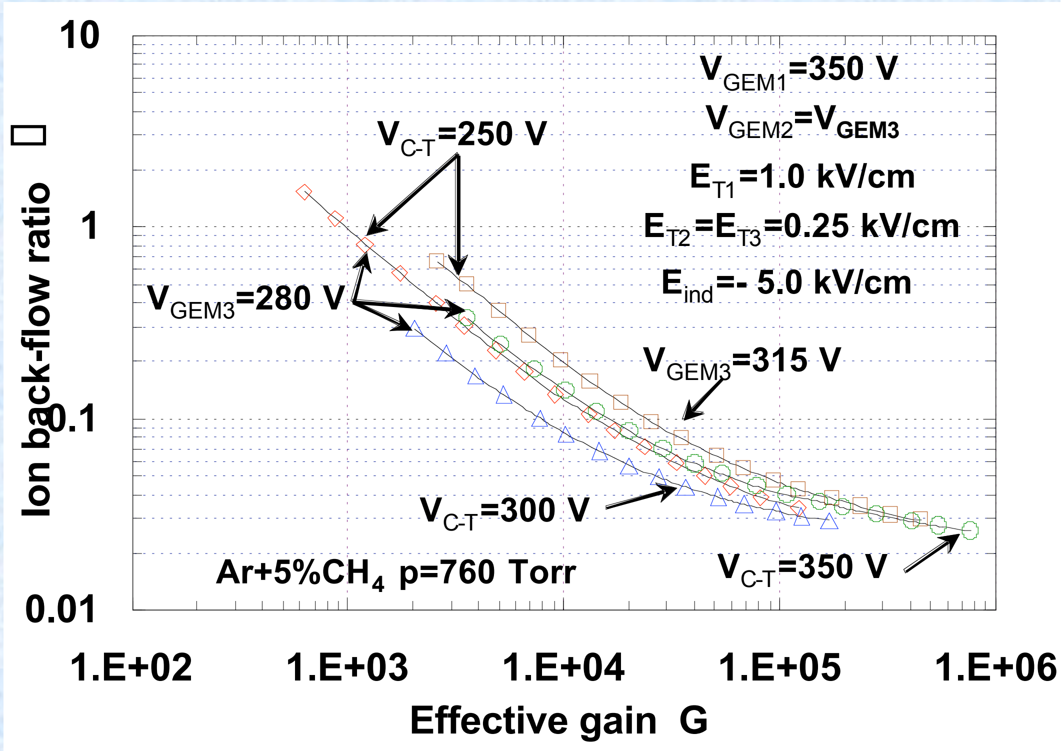




J.M.Maia et al. IEEE NS49 (2002)
J.M.Maia et al. NIM A203(2003)364

Micro-Hole and Strip GEM



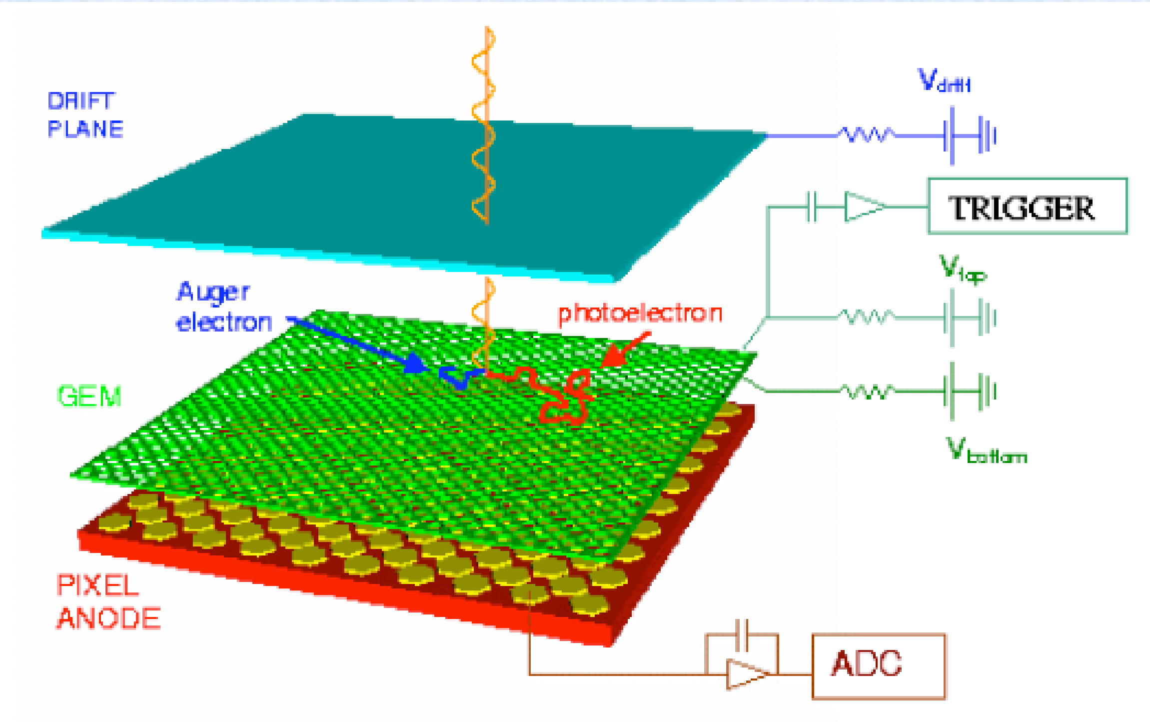


J.M.Maia et al. NIM A203(2003)364

X-Ray Polarimeter

Photoelectrons from soft X-rays are emitted preferentially in the direction of polarization

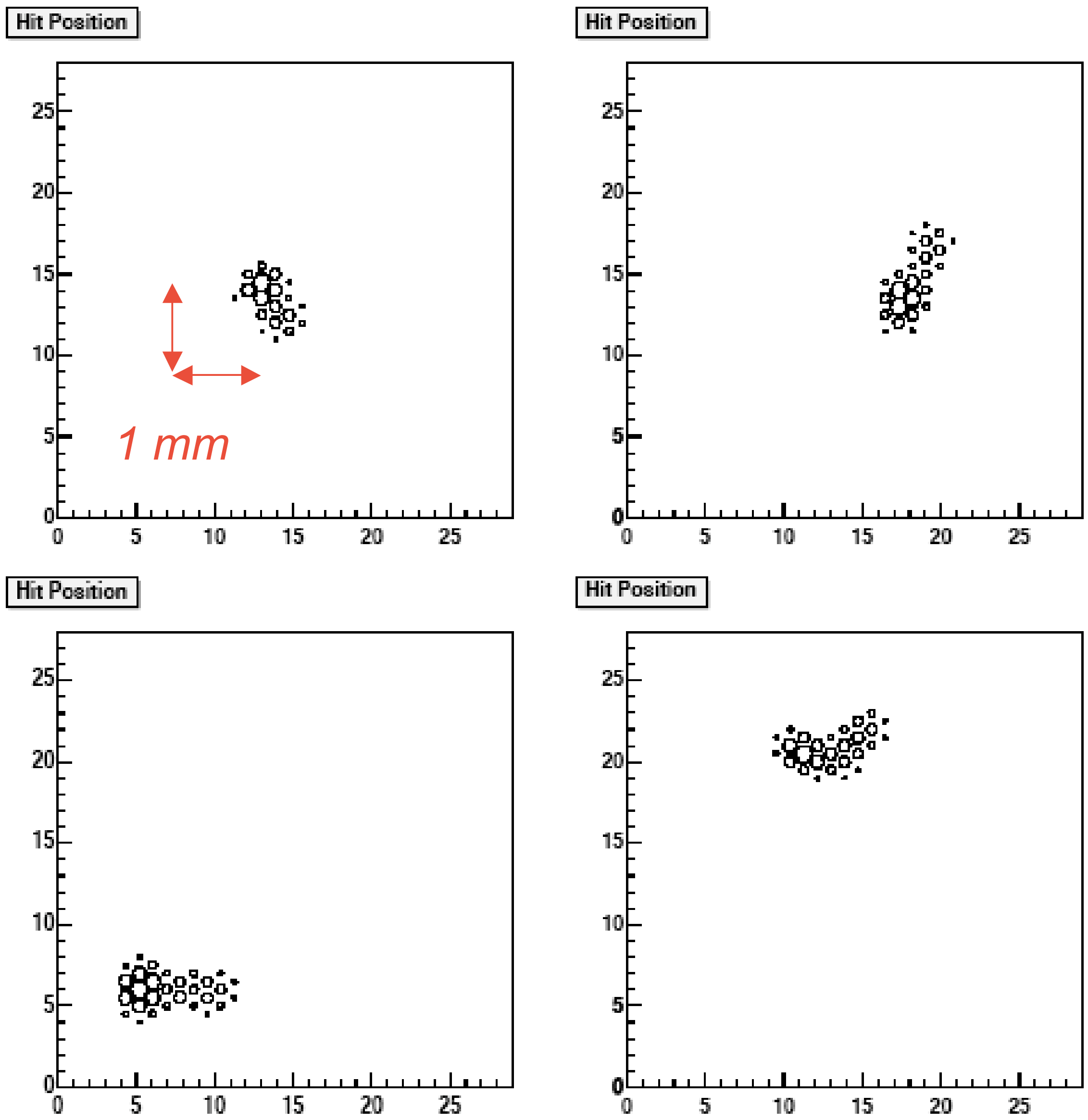
Single GEM detector with 200 μm pitch pixel readout:



E. Costa et al, Nature 411(2001)662
R. Bellazzini et al Nucl. Instr. and Meth. A478(2002)13

X-Ray Polarimeter

Single events (5.9 keV photoelectrons):

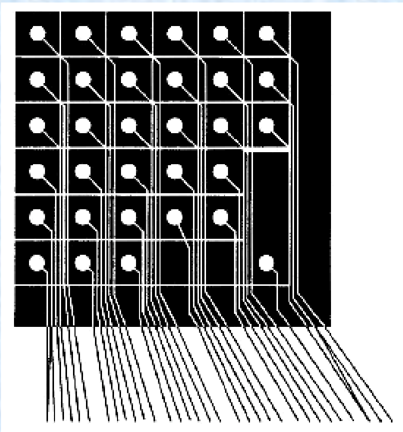


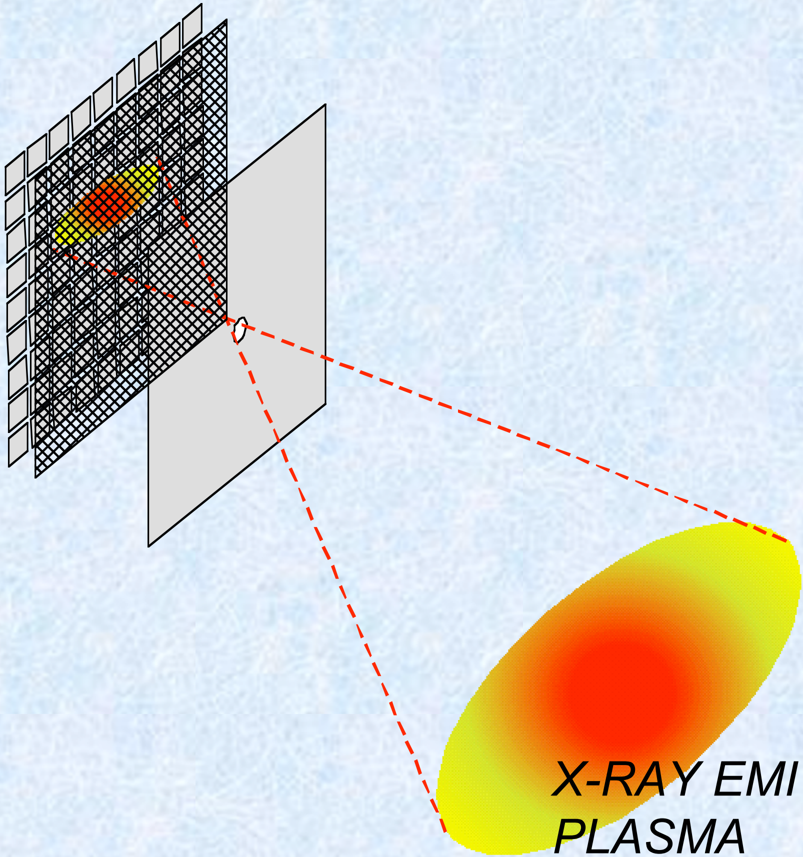
R. Bellazzini et al, NIMA in press (2003)

X-ray plasma diagnostics

Single GEM pinhole camera with fast pixel readout

Readout:
32 pixels, 2 mm^2 each

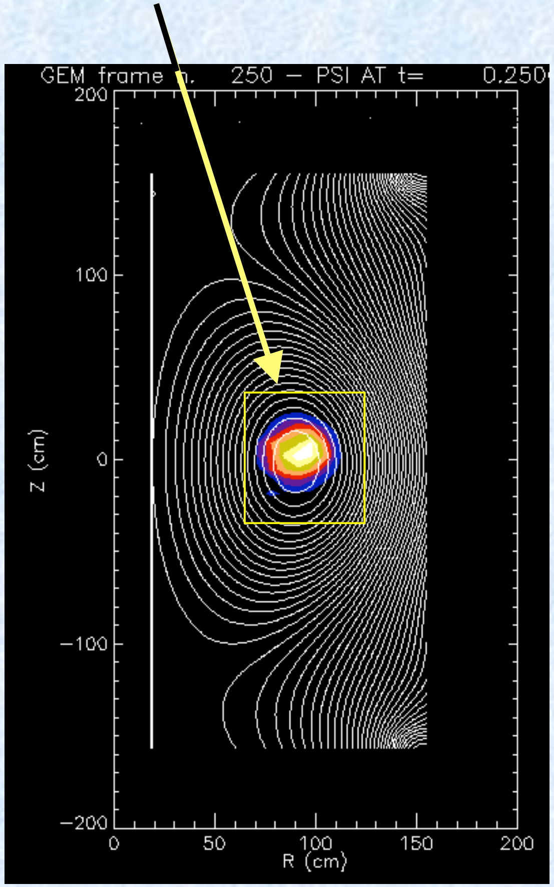




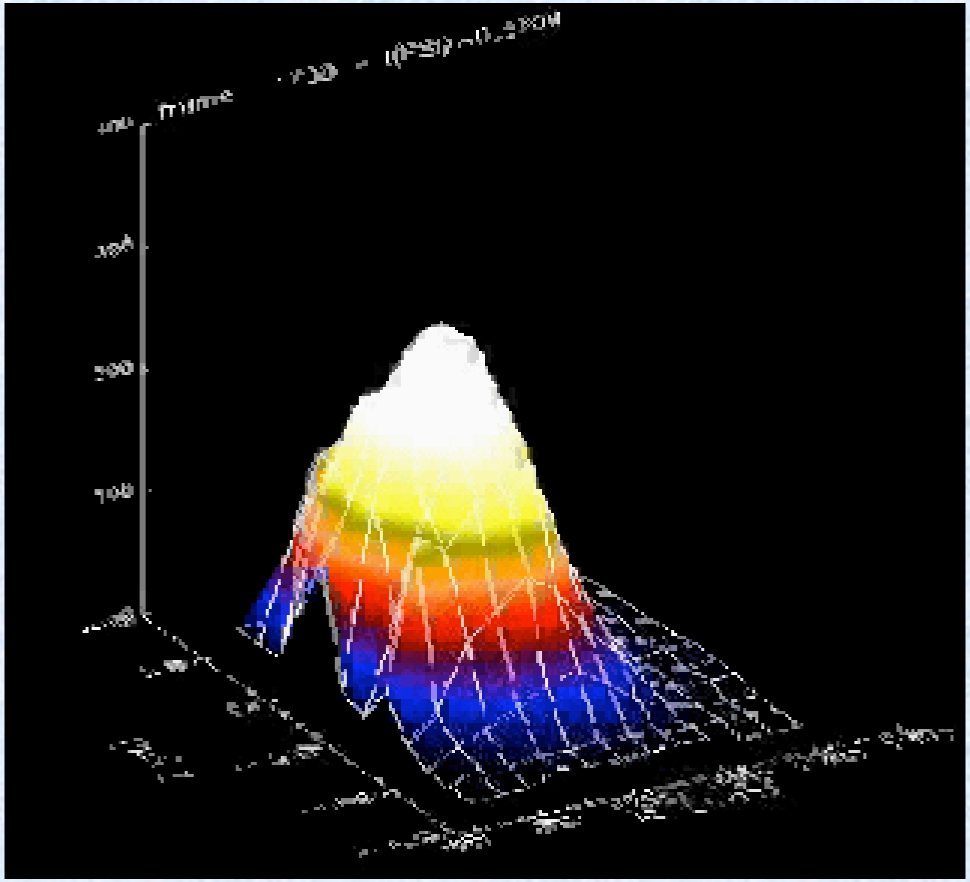
D. Pacella et al, Rev. Scient. Instrum. 72 (2001) 1372
R. Bellazzini et al, Nucl. Instr. and Meth. A478(2002)13

X-Ray plasma diagnostics

Image size 80x80 cm^2



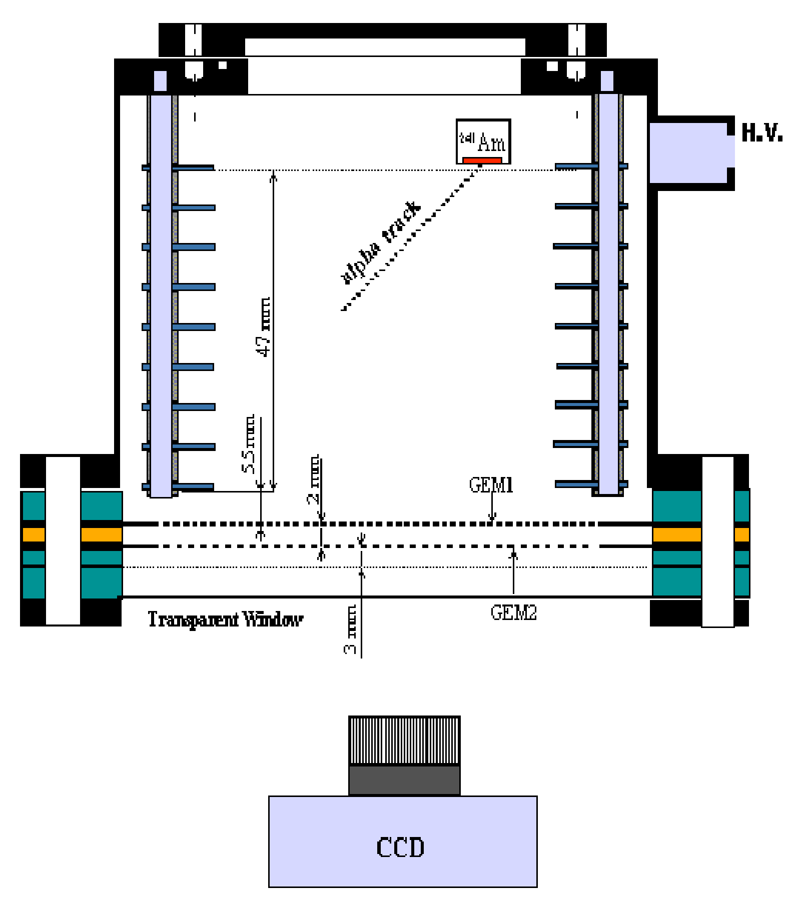
Plasma emission (at ~ 1.5 keV) sampled at 10 kHz: first observation of plasma rotation



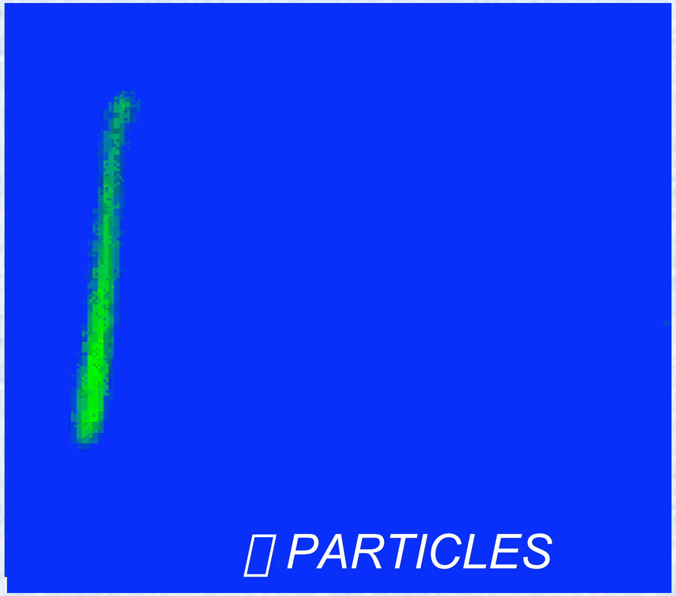
D. Pacella, Princeton Plasma Physics Laboratory

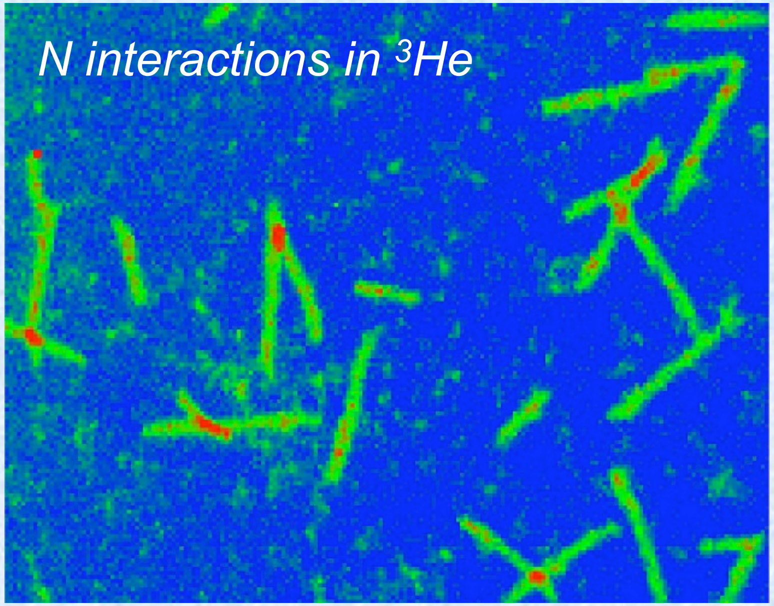
GEM optical imager

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



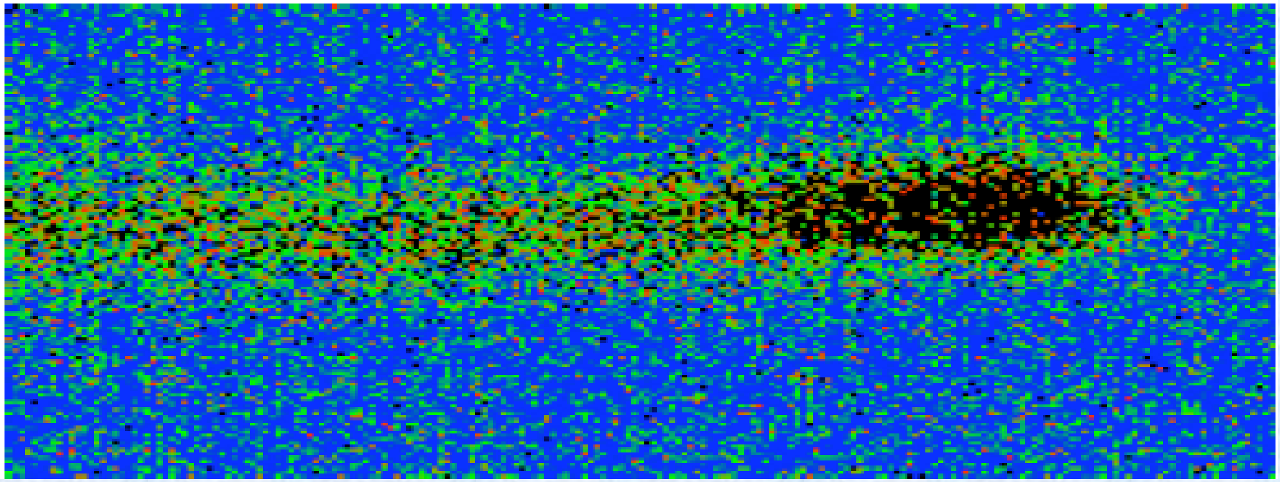
F.A.F. Fraga et al, NIM A478 (2002) 357

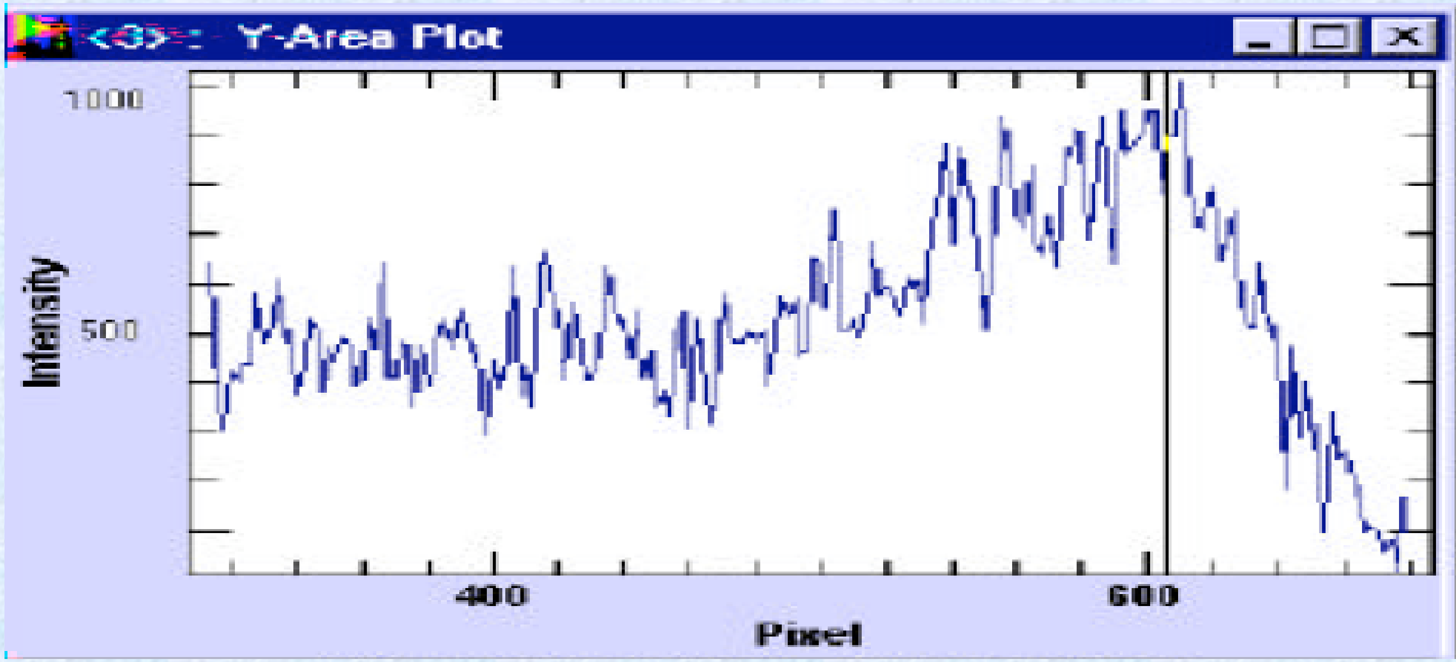




Imaging GEM

Bragg peak for alpha particles:





F.A.F. Fraga et al, IEEE TNS 49(2002)281

The End

THE END