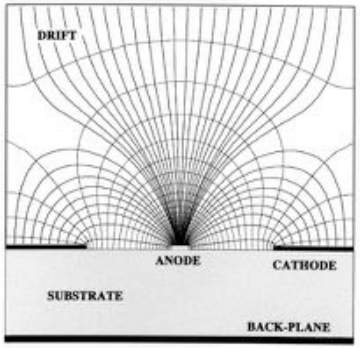
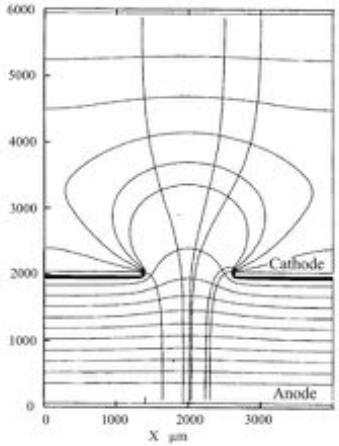
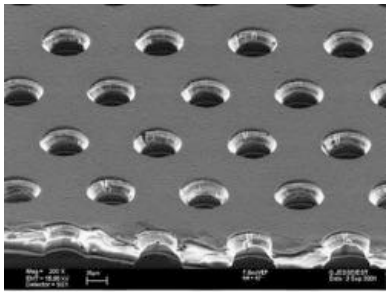
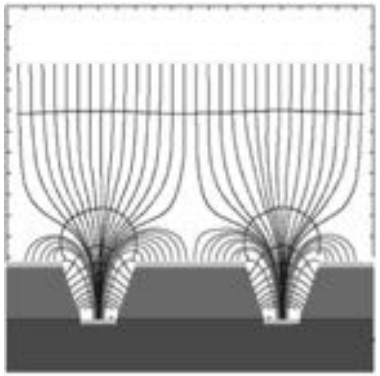
Micro-Pattern Gaseous Detectors

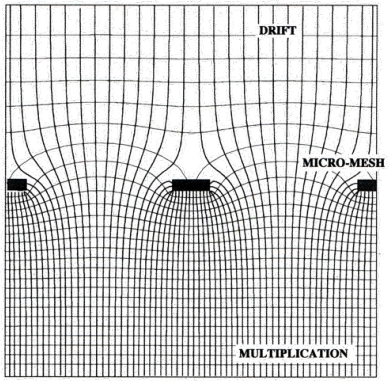
Fabio Sauli
TERA Foundation and CERN

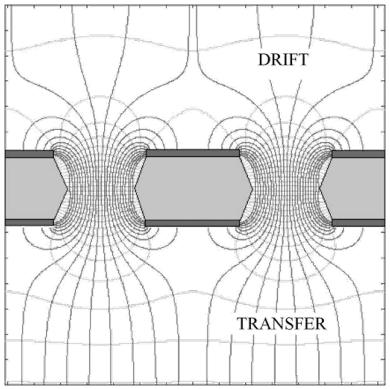


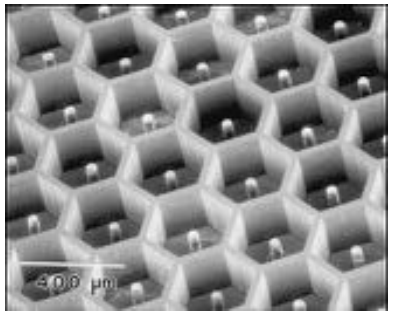








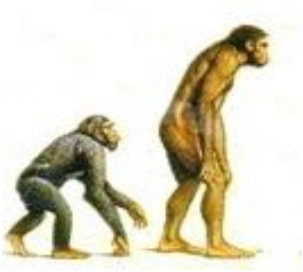




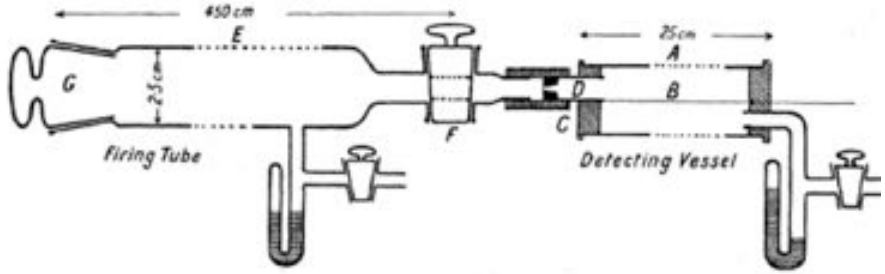
Bethe Forum on Particle Detectors
Bonn, March 31-April 11, 2014

PART 1

THE ANCESTORS

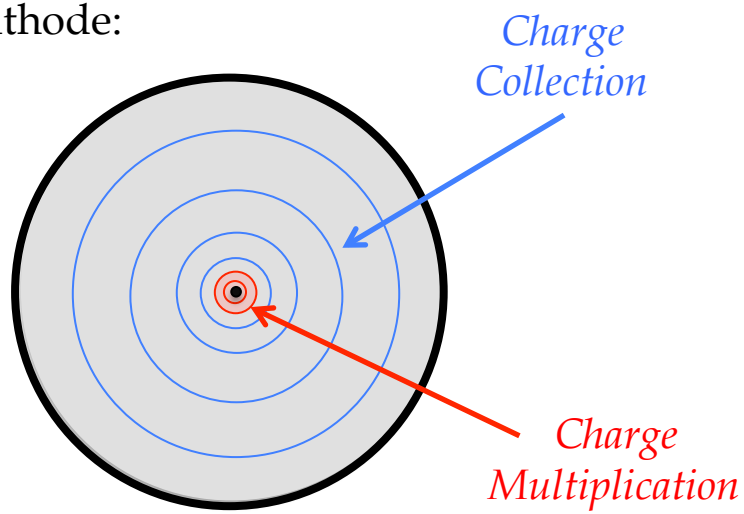


The first proportional counter:

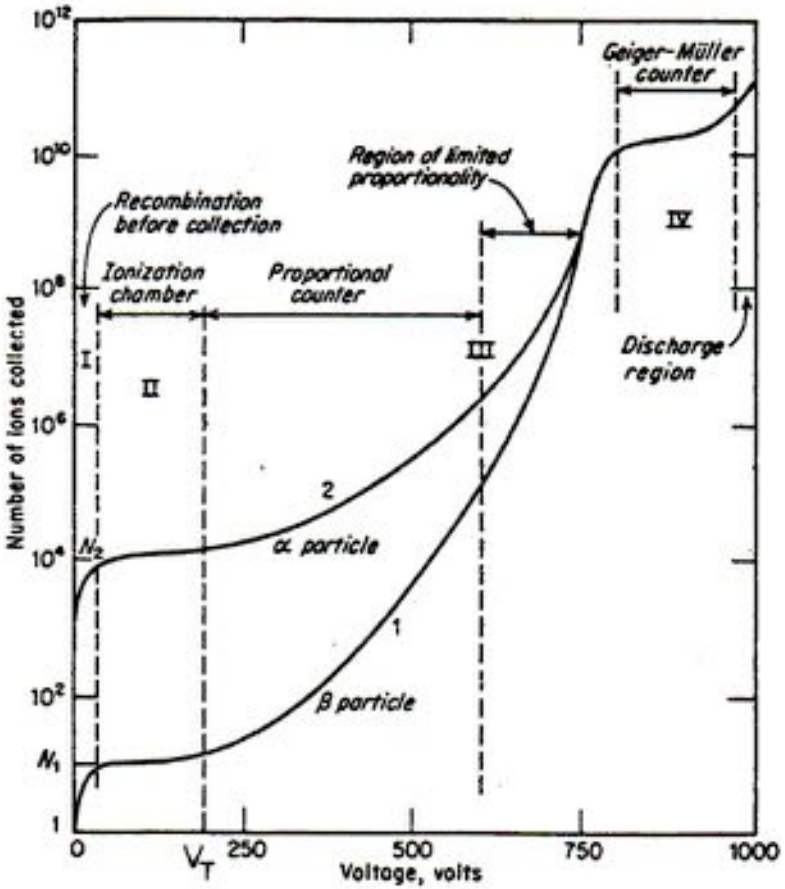


E. Rutherford and H. Geiger, Proc. Royal Soc. A81(1908)141

Thin anode wire centered in a cylindrical cathode:



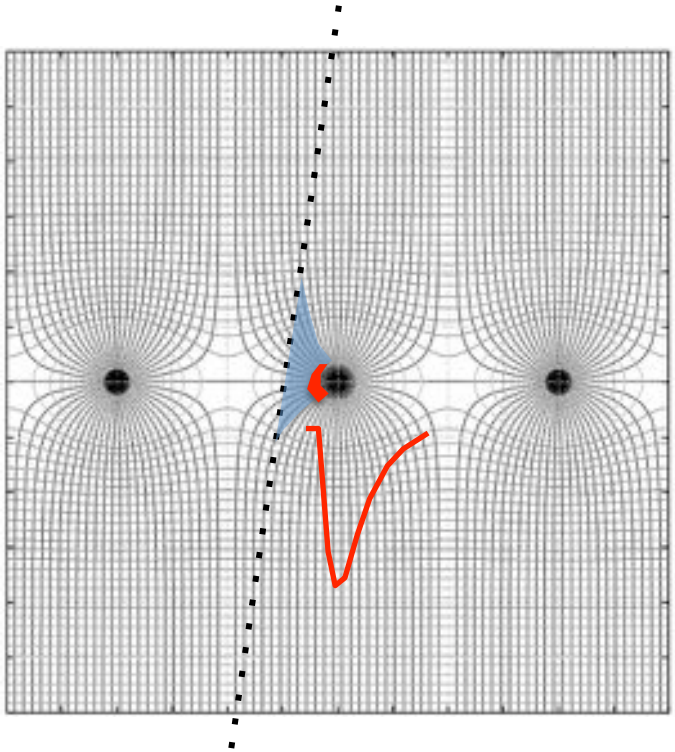
Charge-voltage characteristics:



G.C. Montgomery and D.D. Montgomery J. Franklin Inst. 231(1941)447

Georges Charpak (1968)

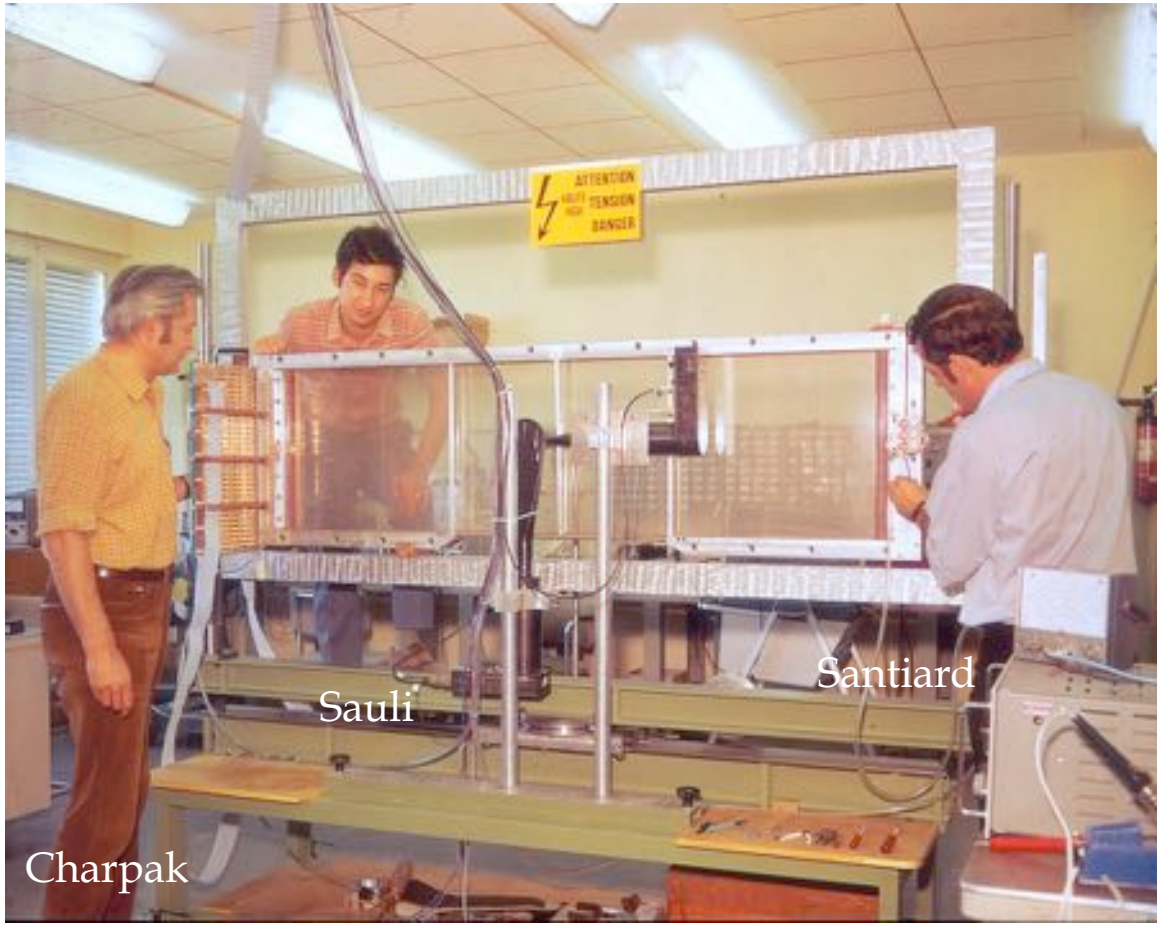
Grid of thin anode wires between two cathode planes:



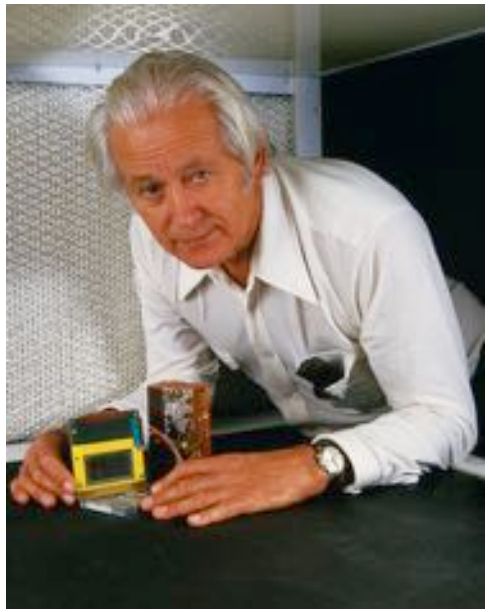
G. Charpak et al, Nucl. Instr. and Meth. 62(1968)262

The first MWPC (10x10 cm^2)

Prototype for the Split Field Magnet detector

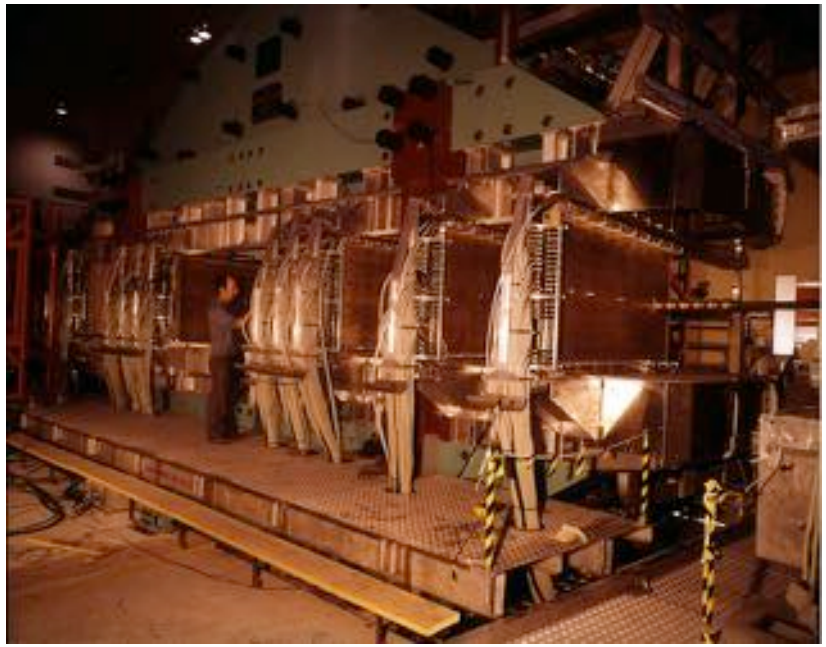


Georges Charpak
1992 Nobel Laureate for Physics



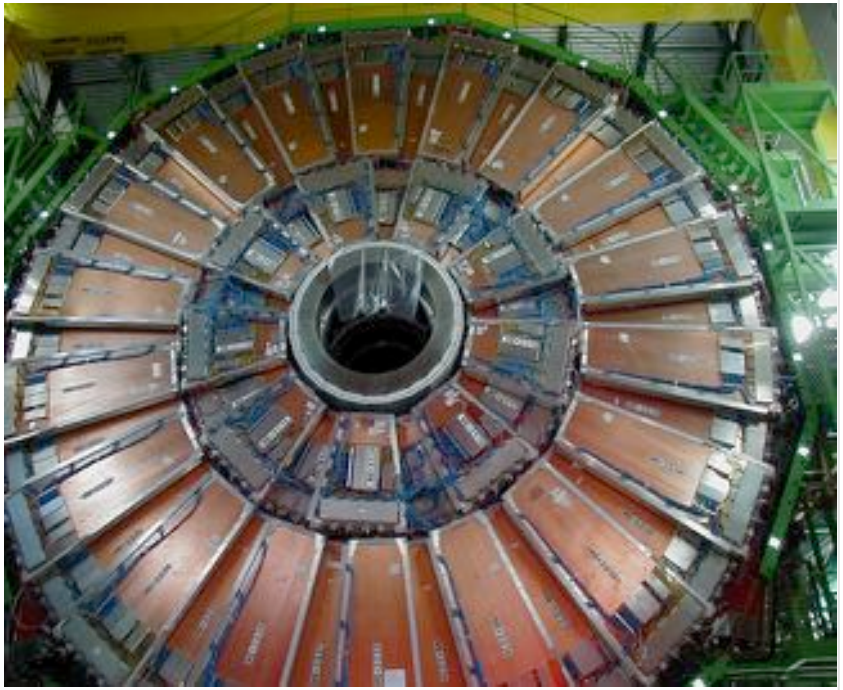
G. Charpak et al, Nucl. Instr. and Meth. 97(1971)377

SPLIT FIELD MAGNET (1973)
40 large MWPCs



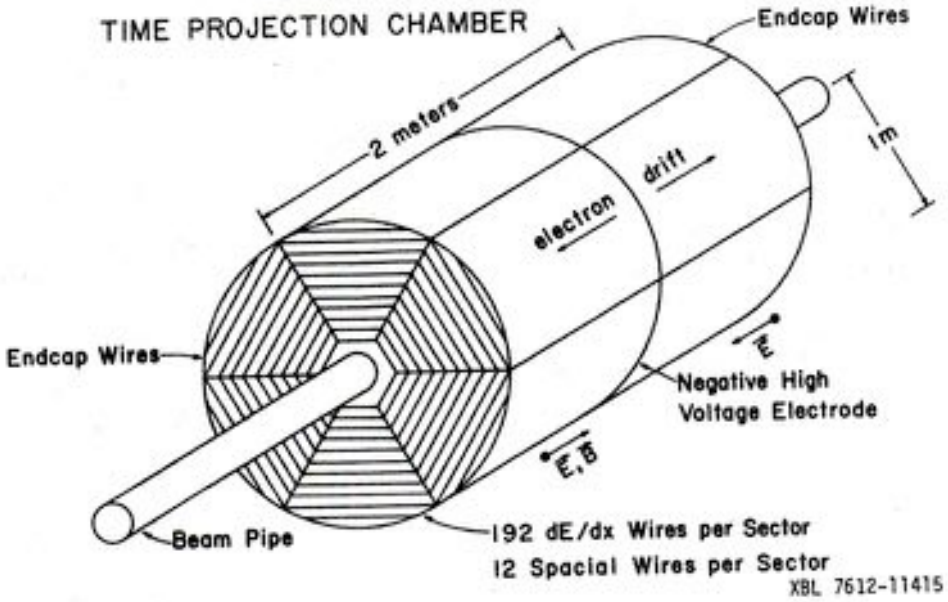
R. Bouclier et al,
Nucl. Instr. and Meth. 115 (1974)235

CMS muon end-cap detectors (2007)
~ 2000 Cathode Strip Chambers



D. Acosta et al,
Nucl. Instr. and Meth. 453(2000)182

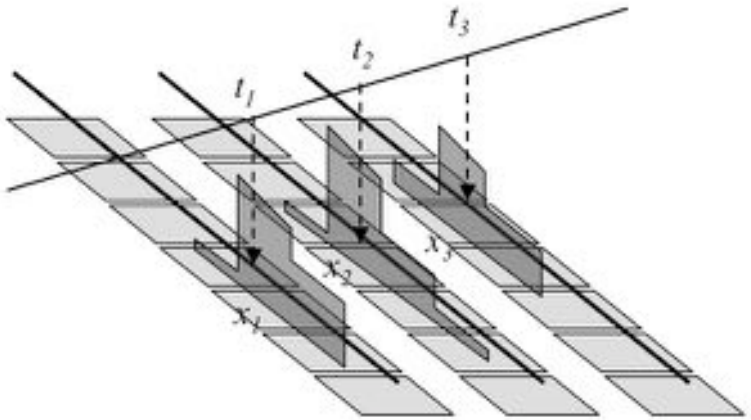
David Nygren, 1976



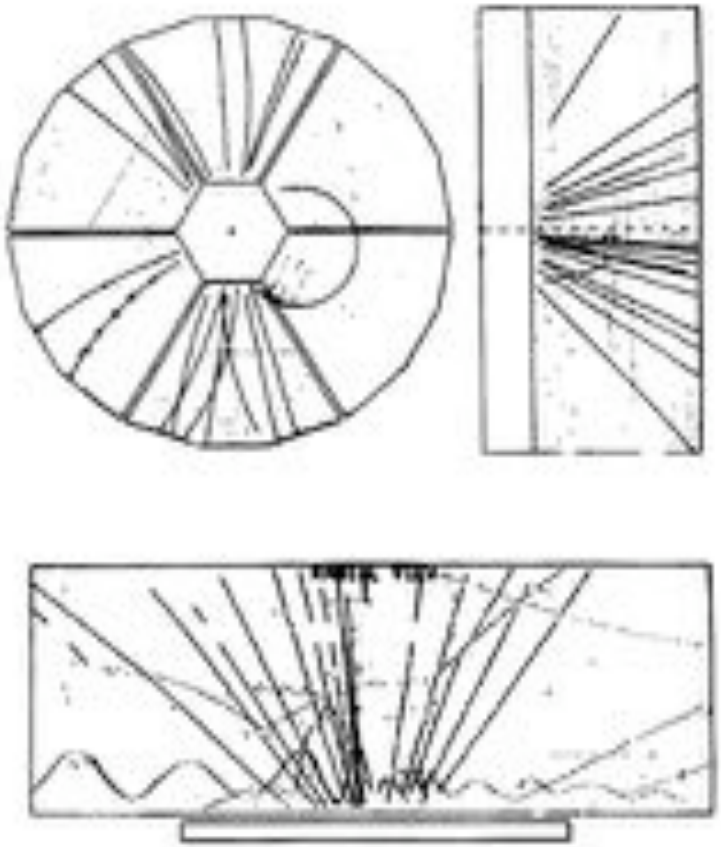
D. Nygren and J, Marx, Phys. Today 31 (1978) 46

Full 3-D localization:

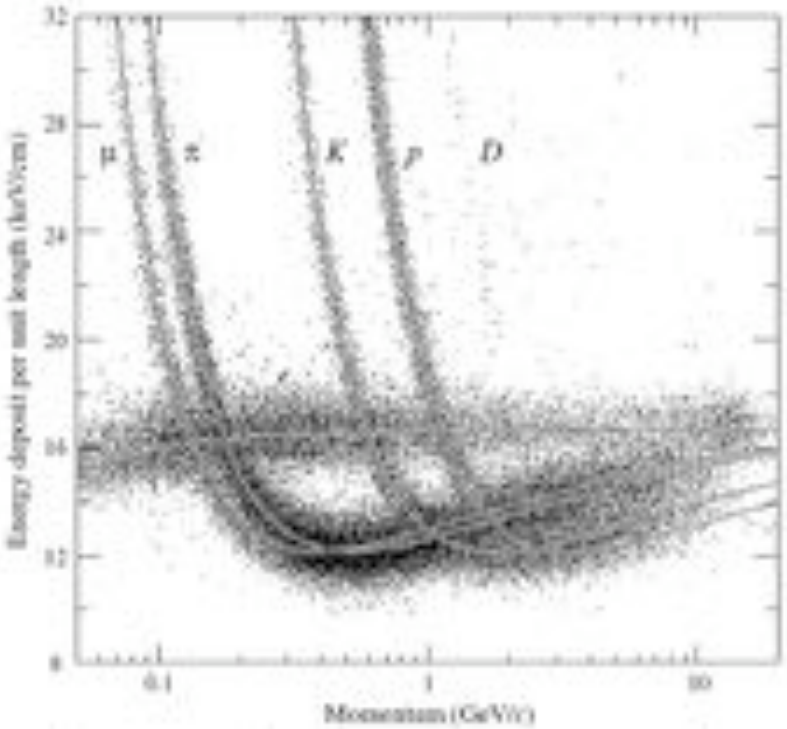
- x: Anode wire
- y: Center of Gravity (COG) on charge induced on Pad Rows
- z: Drift Time



3-D Tracking:



Particle Identification from dE/dx:

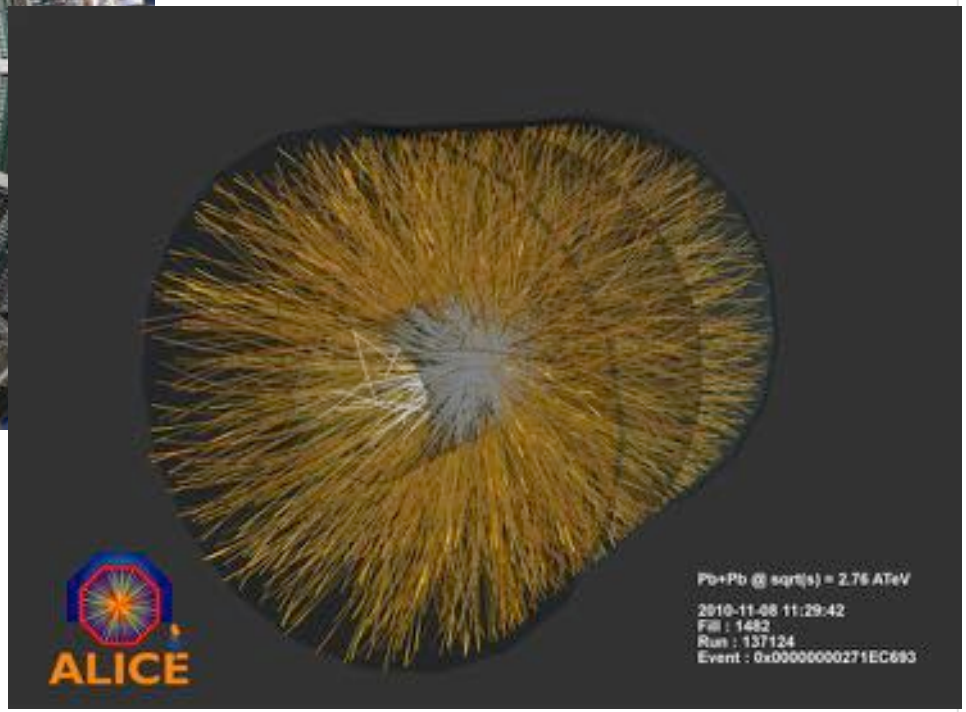


PEP4 TPC, D. Nygren personal communication

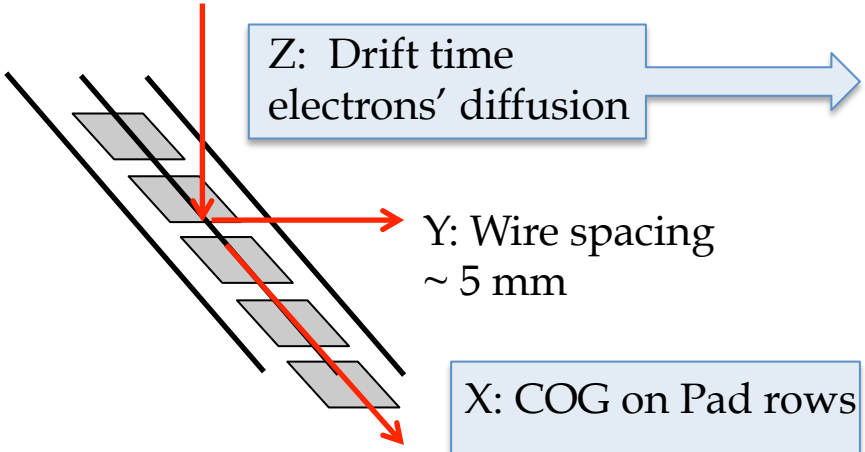
5 m Ø - ~ 100 m^3

J. Alme et al,
Nucl. Instr. and Meth. A622(2010)316

Pb-Pb interaction at 2.76 TeV:



WIRE CHAMBER LIMITATIONS

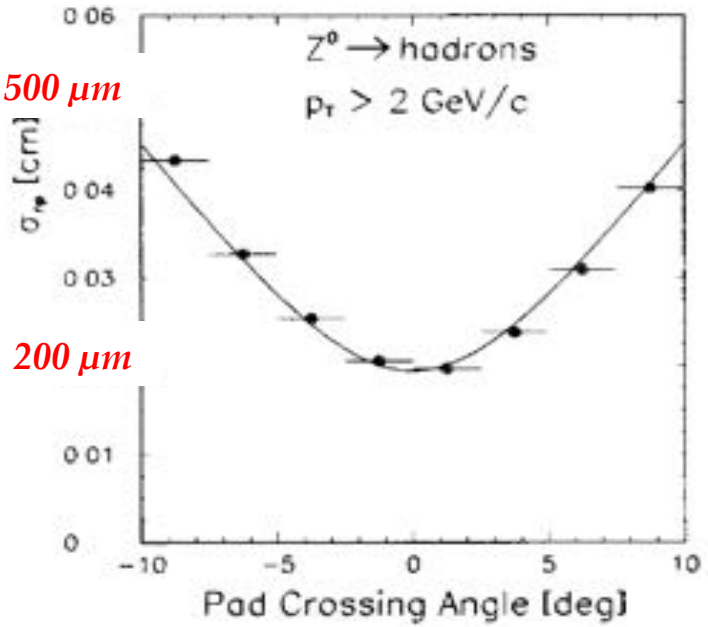


Z: Drift time
electrons' diffusion

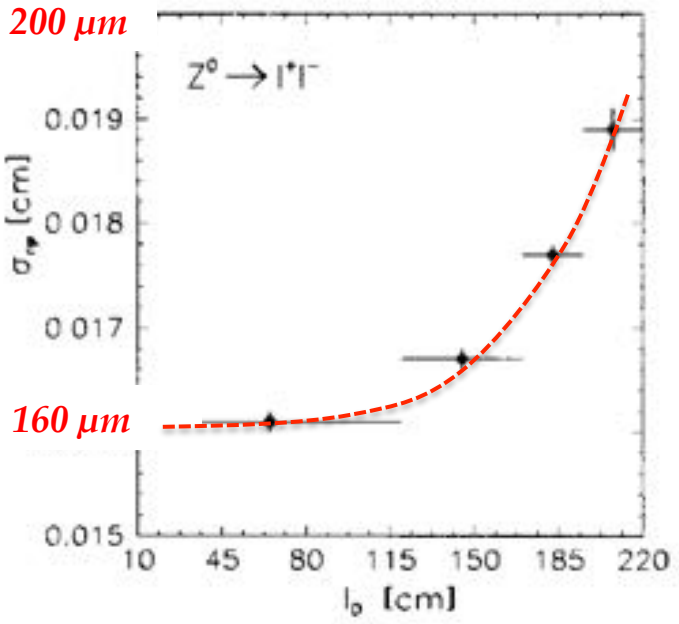
Y: Wire spacing
~ 5 mm

X: COG on Pad rows

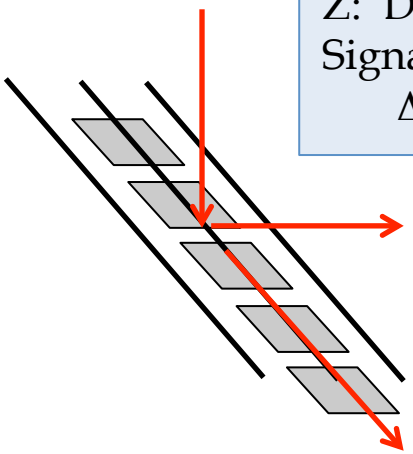
ACCURACY VS ANGLE



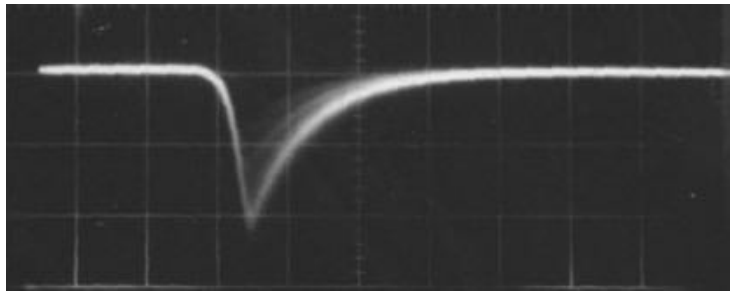
ACCURACY VS DRIFT LENGTH



W. Atwood et al,
Nucl. Instr. And Meth. A306(1991)446

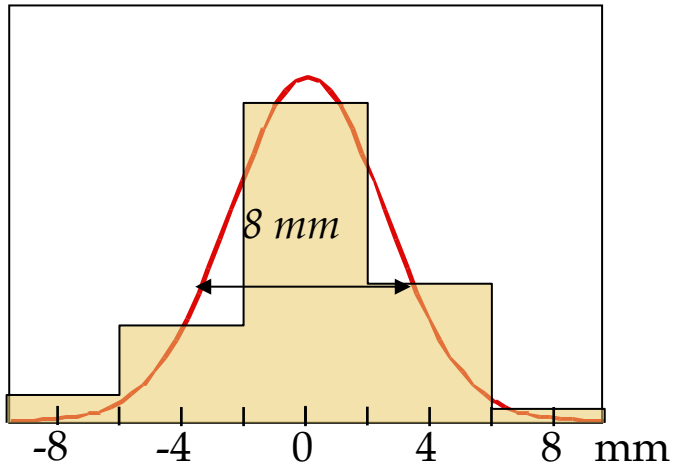


Z: Drift time
Signal width ~ 200 ns
ΔZ ~ 10 mm



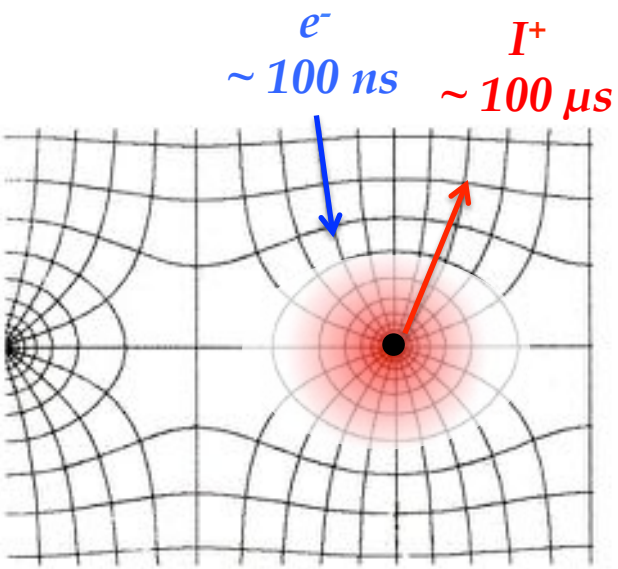
Y: Wire spacing
ΔY ~ 10 mm

X: Charge induction on pad rows:
ΔX ~ 10 mm

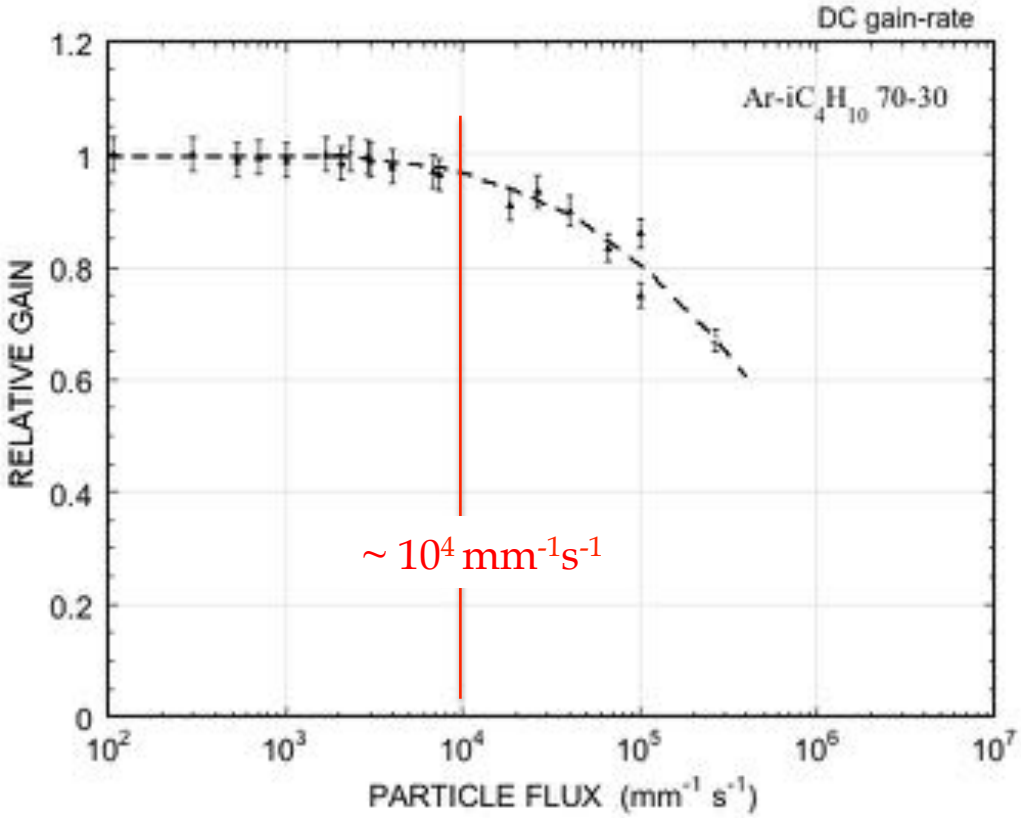


Volume resolution
ΔV~ 50 mm^3

Space charge near the anode:
Buildup of slow positive ions
modifies the electric field

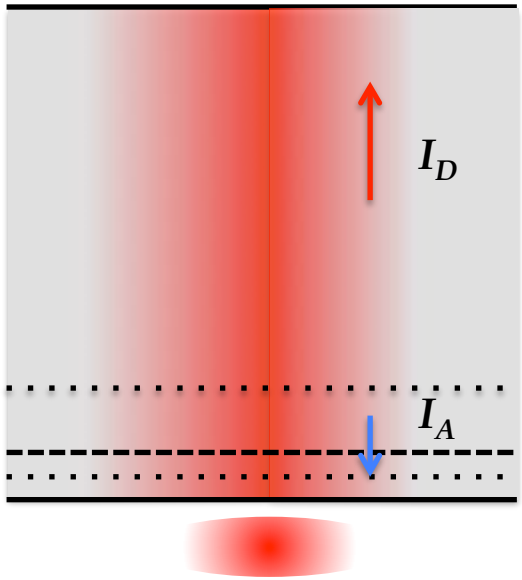


Relative gain as a function of rate:

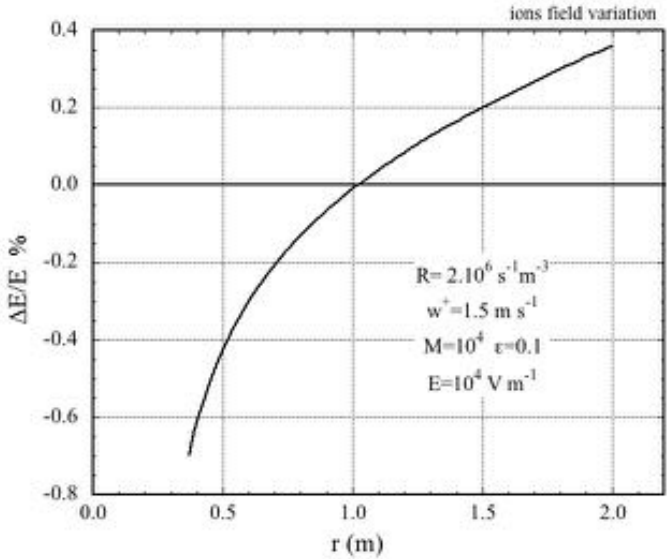


A. Breskin et al, Nucl. Instr. and Meth. 124(1974)189

SLOW POSITIVE IONS ACCUMULATE IN THE DRIFT VOLUME AND MODIFY THE FIELD RESULTING IN TRACKS DISTORTIONS:



PERCENTAGE DRIFT FIELD MODIFICATION (ALEPH MWPC-TPC)



GATING:
ADD A WIRE MESH WITH VOLTAGE-CONTROLLED TRANSPARENCY

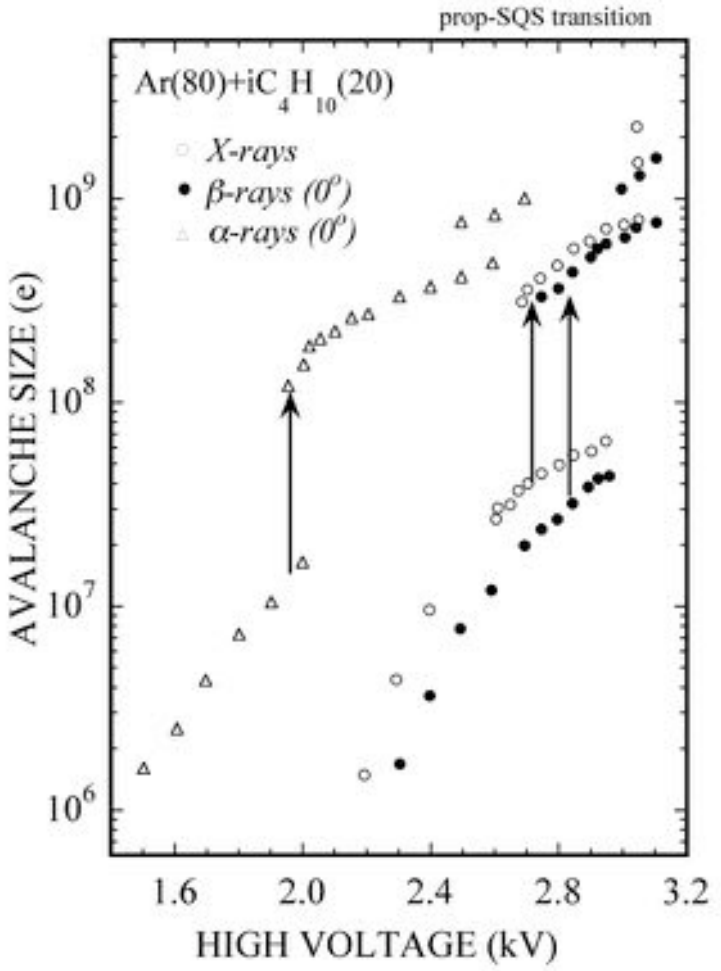
ION BACKFLOW FRACTION:
DRIFT CURRENT/ANODE CURRENT

$$IBF = \frac{I_{DRIFT}}{I_{ANODE}}$$

MWPC-TPC TYPICAL: IBF~30%

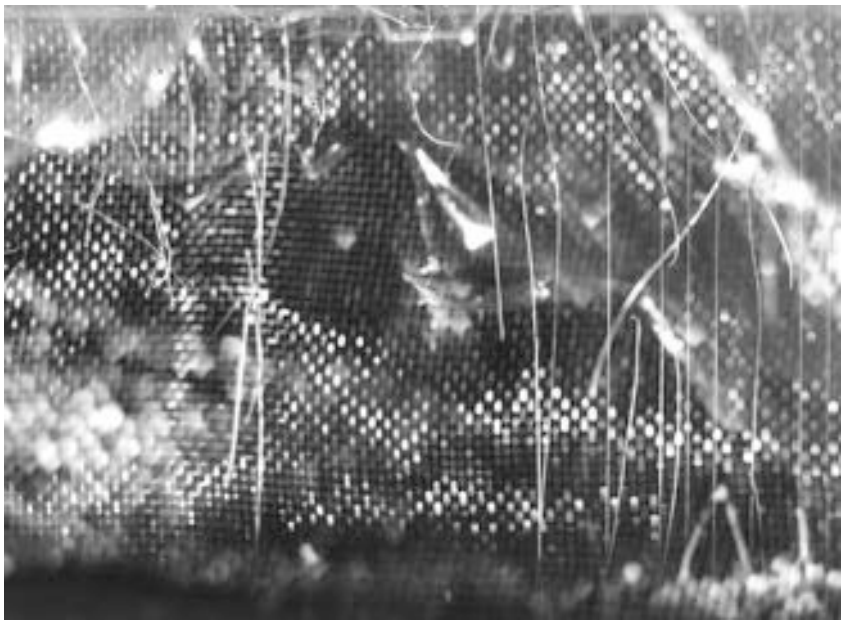
ONLY POSSIBLE AT SMALL RATES:
Maximum electron drift time
< Time between events

High gains: Transition from proportional amplification to streamer and/or breakdown



N. Koori et al, Jap. J. Appl. Phys. 25(1986)986

Spark damages in MWPCs:



Fabio's Museum of Horrors

Maximum avalanche size before transition or breakdown:
Q_{MAX}=(Primary ionization)x(Gain) ~ 10^7 e

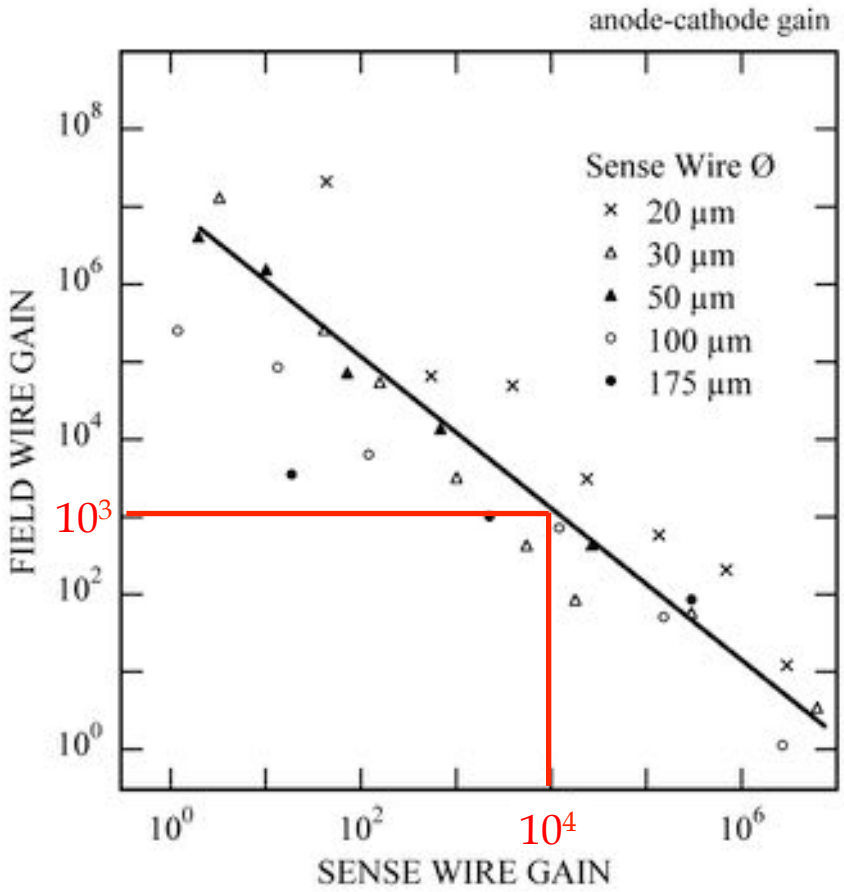
Typical proportional gain ~ 10^4

Fast particles ΔE ~ 2 keV:
Q=(100)x(10^4)=10^6

Neutrons ΔE ~ 2 MeV
Q=(10^5)x(10^4)=10^9

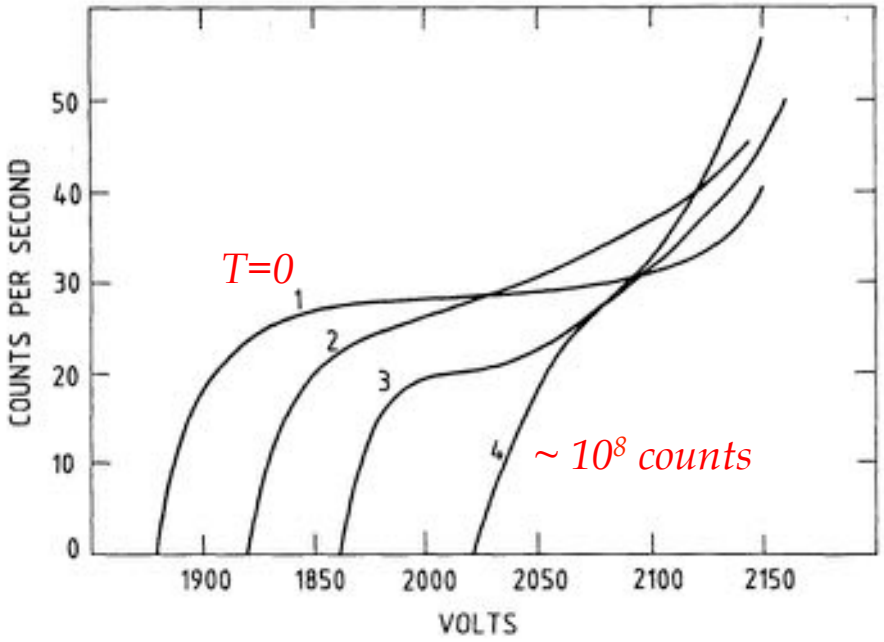
Multiwire structures:
Cathode pre-amplification of field emitted electrons

$M=M_C \, x \, M_A$

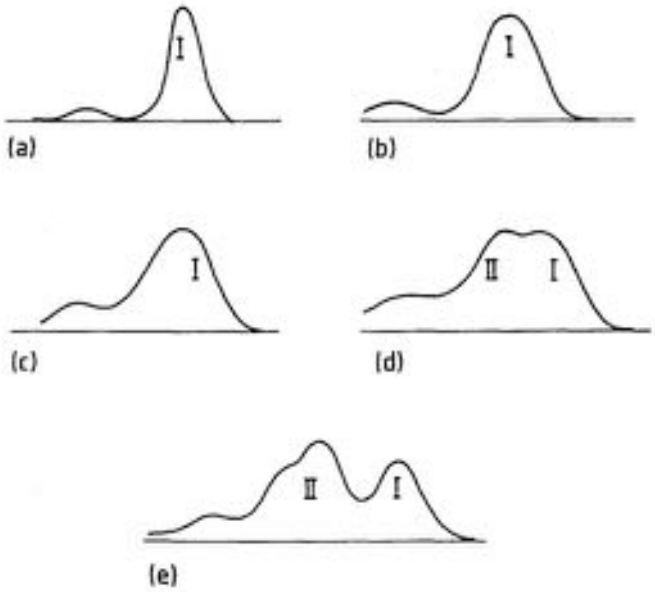


P. Giubellino et al, Nucl. Instr. and Meth. A245(1986)155

Counting rate plateau degradation after long term irradiation:

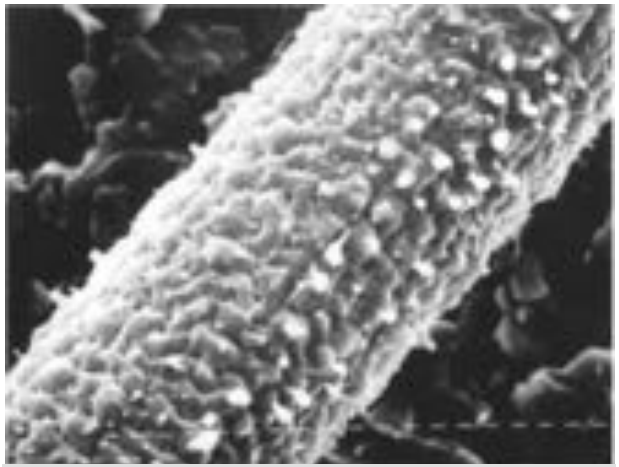


Gradual loss of the energy resolution:

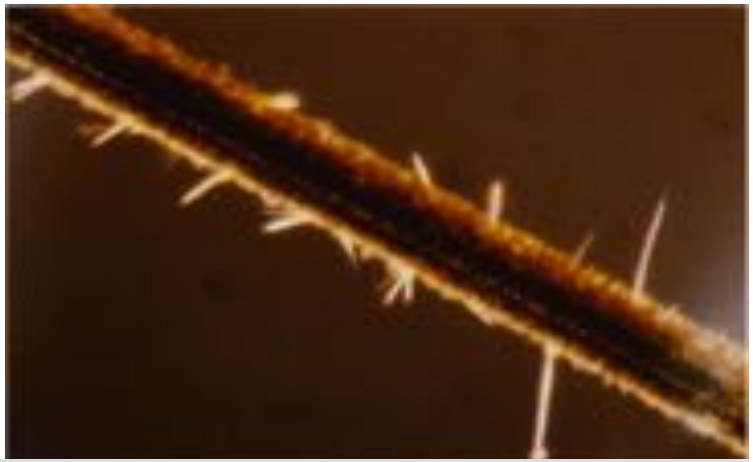


E. Farmer and S. Brown, Phys. Rev. 74(1948)902

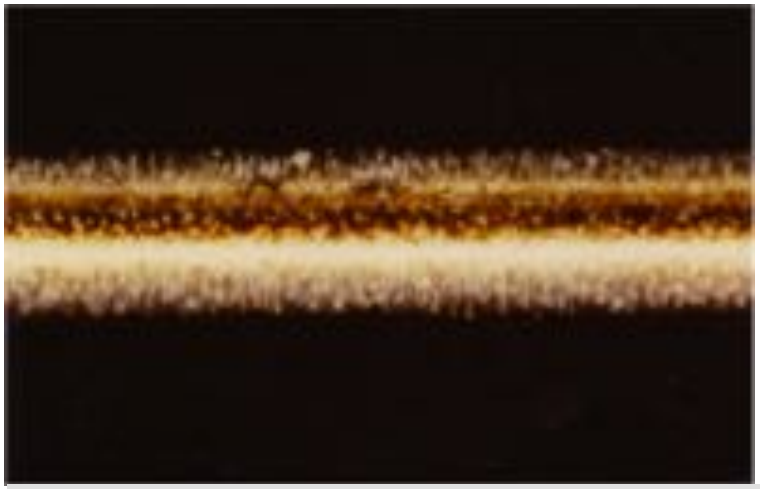
Polymerization of organic compounds with formation of deposits on thin wires:



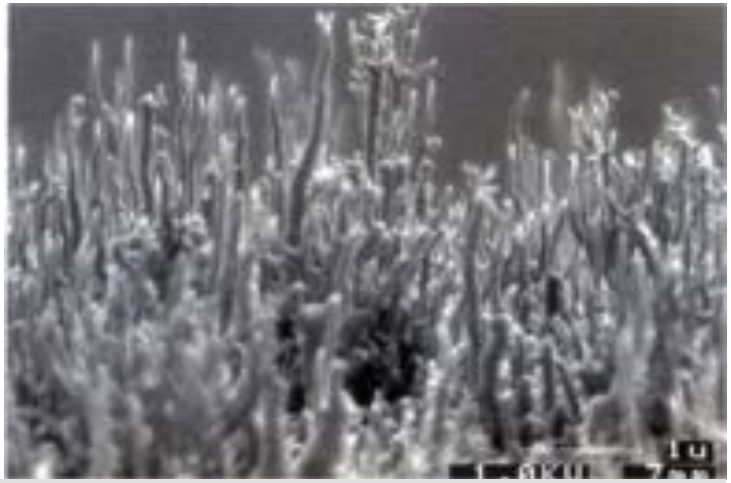
O. Ullaland, LBL-21170 (1986)107



I. Juric and J. Kadyk, LBL-21170 (1986)141



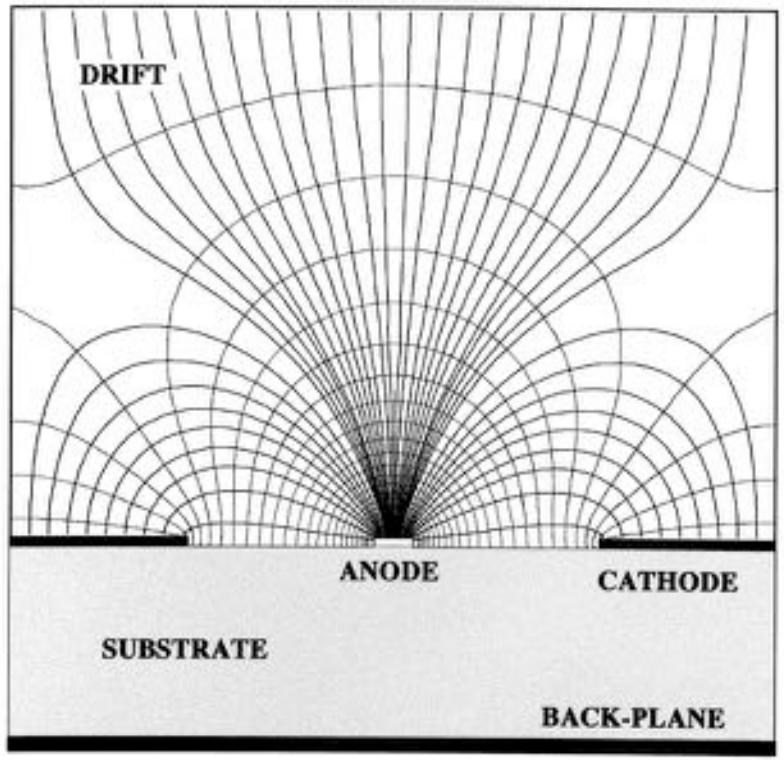
I. Juric and J. Kadyk, LBL-21170 (1986)141



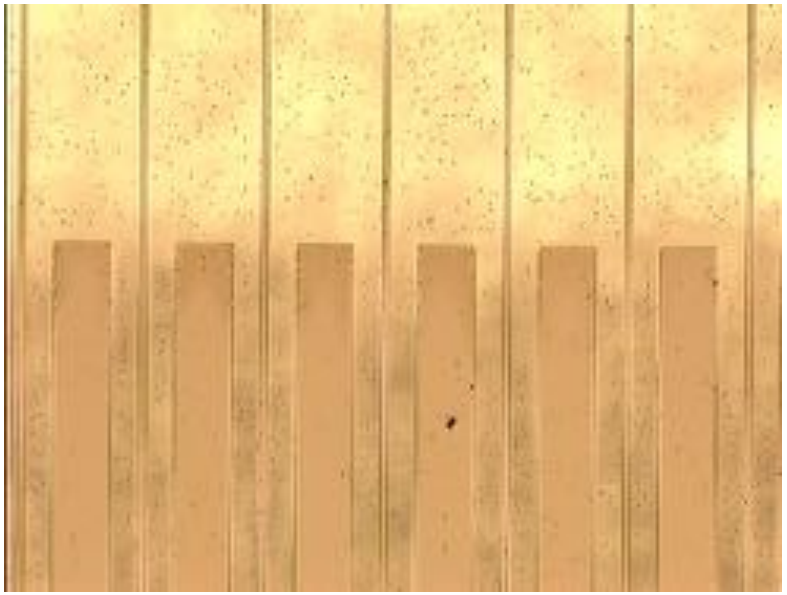
M. Binkley et al,
Nucl. Instr. and Meth. A515(2003)53

MICROPATTERN: THE NEW APPROACHES

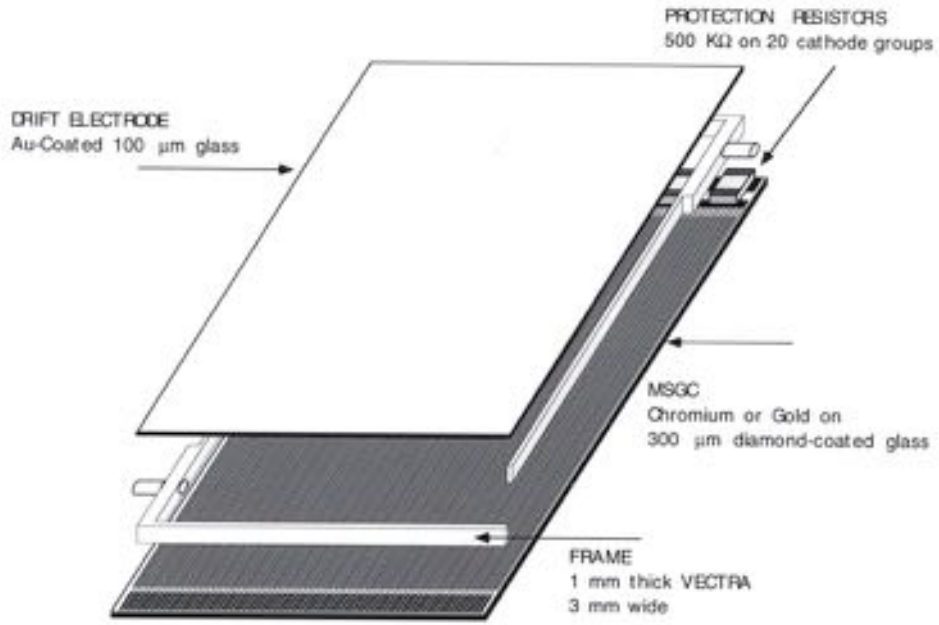
Anton Oed, 1988



10 μm wide anode strips, 50 μm cathode strips at 100 μm pitch on glass substrate:

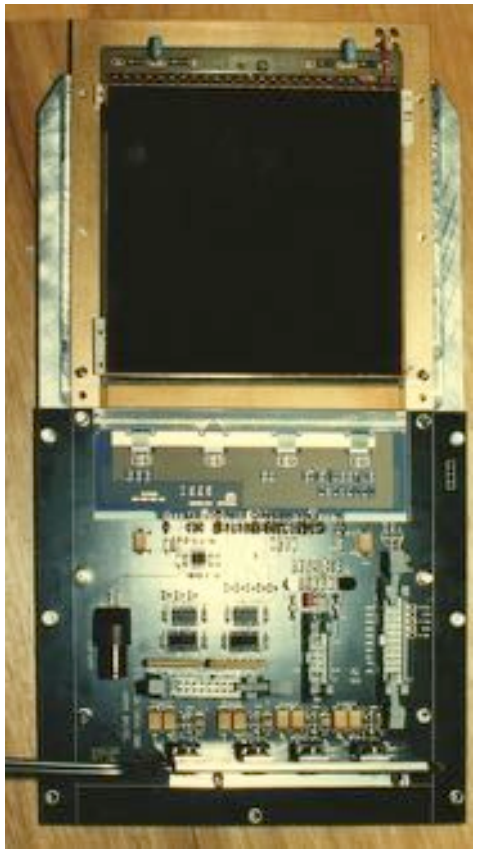


A. Oed, Nucl. Instr. and Meth. A263(1988)351



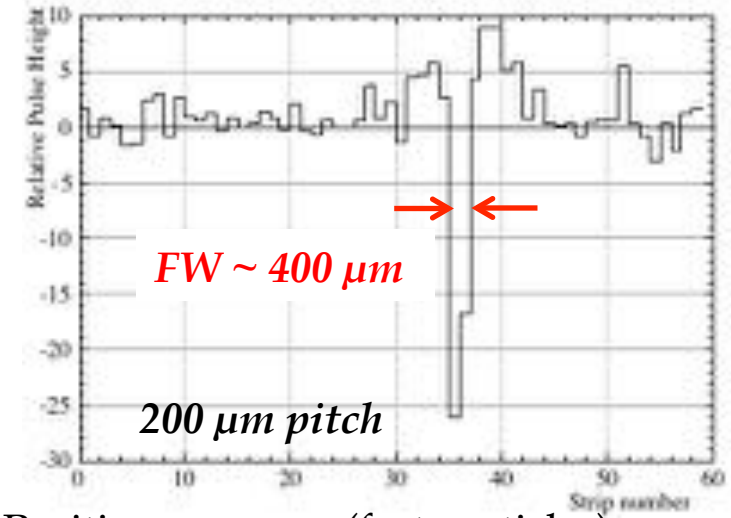
J. Bohm et al, Nucl. Instr. and Meth. A360(1995)34

MSGC prototype
400 anode strips at 200 μm pitch:

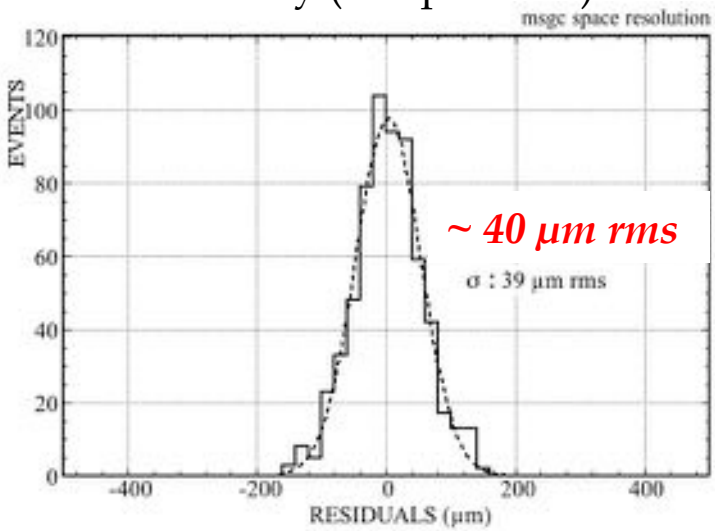


R. Bouclier et al,
Nucl. Instr. and Meth. A367(1995)163

Single track signal width (two-track resolution):

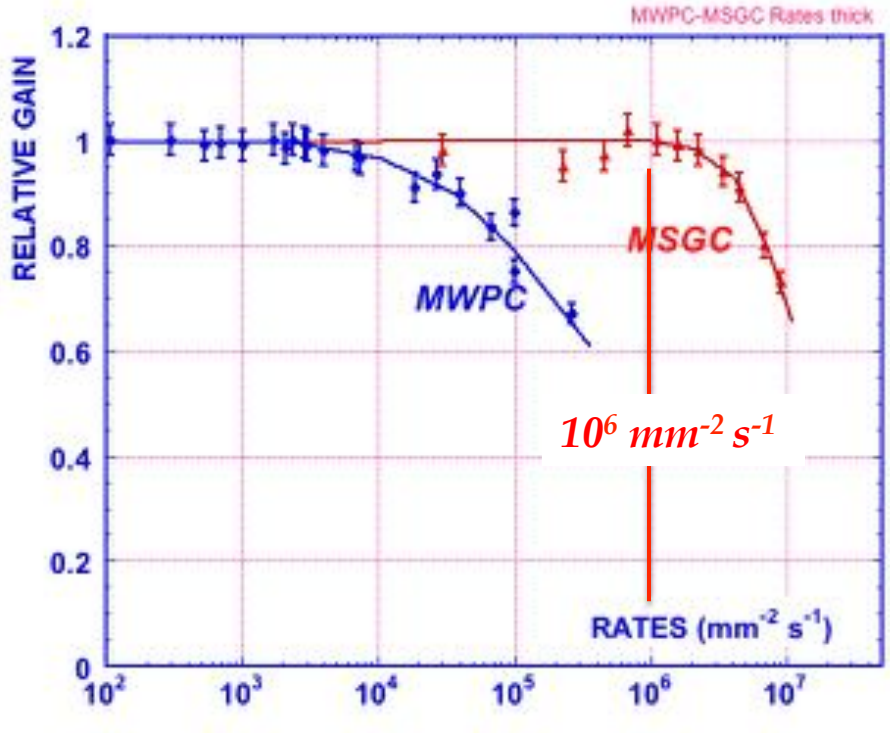


Position accuracy (fast particles):



R. Bouclier et al, Nucl. Instr. and Meth. A367(1995)163

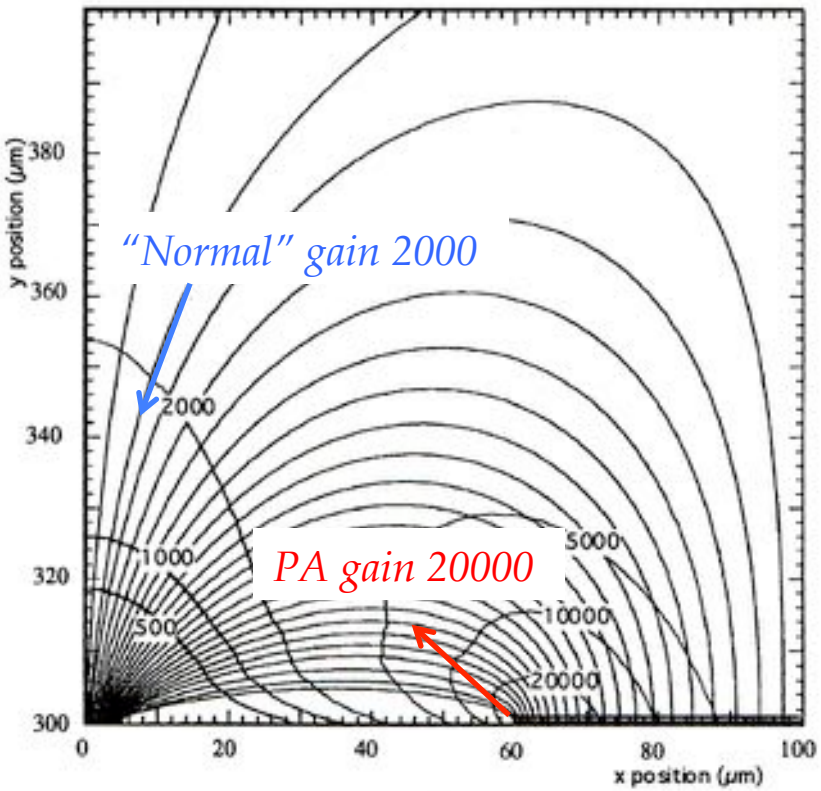
Rate capability: 1 MHz/mm^2



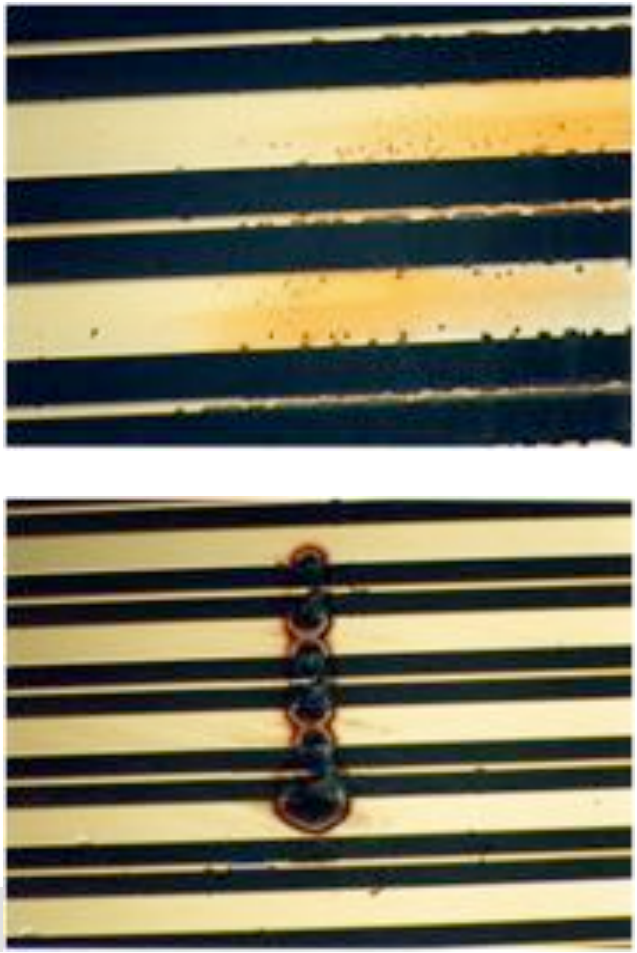
Fast signals ~ 30 ns (1.5 mm)

Volume resolution
$\Delta V \sim 1 \times 1 \times 2 = 2$ mm^3

Pre-amplification of electrons emitted by cathode strip edges

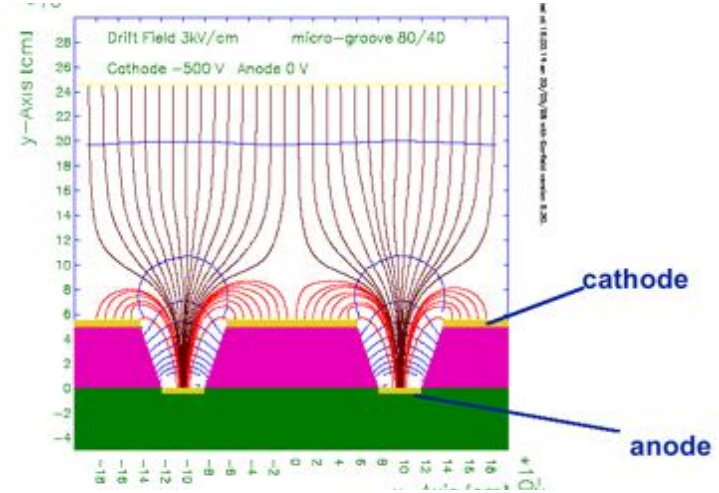


T. Beckers et al, Nucl. Instr. and Meth. A346(1994)95



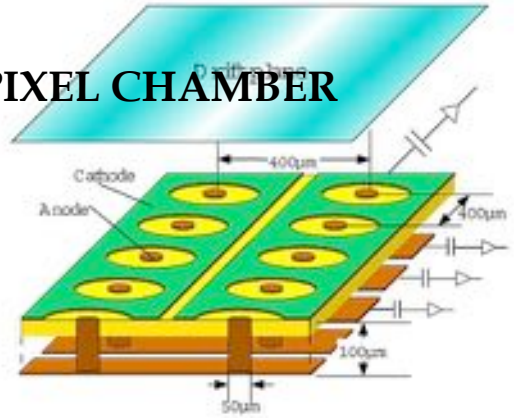
Fabio's Museum of Horrors

MICRO-GROOVE CHAMBER



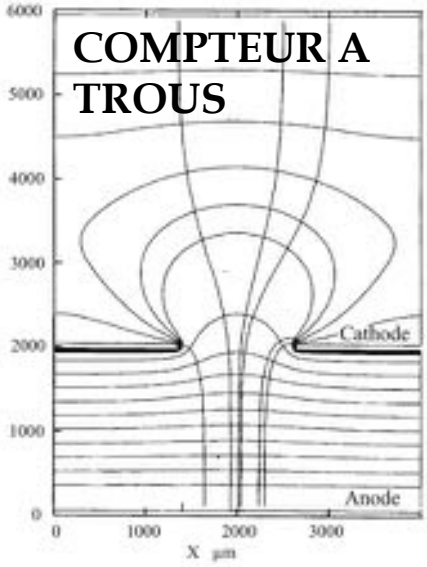
R. Bellazzini et al,
Nucl. Instr. Meth. A424(1998)444

MICRO-PIXEL CHAMBER



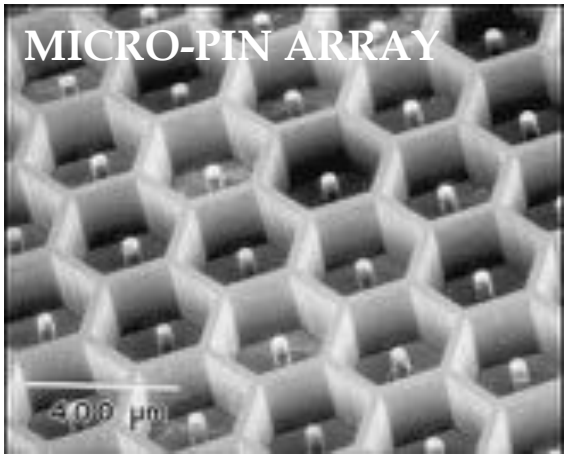
A. Ochi et al,
Nucl. Instr. and Meth. A478(2002)196

COMPTEUR A TROUS



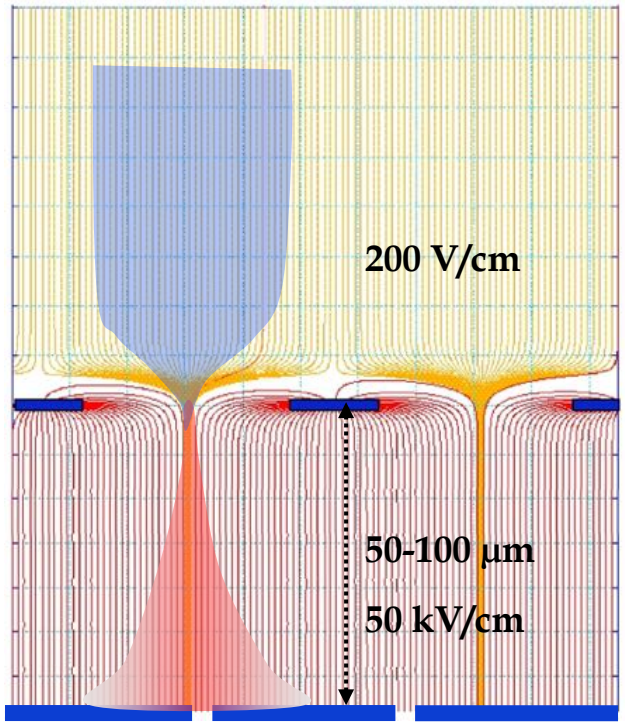
F. Bartol et al
J. Phys.III France 6(1996)337

MICRO-PIN ARRAY

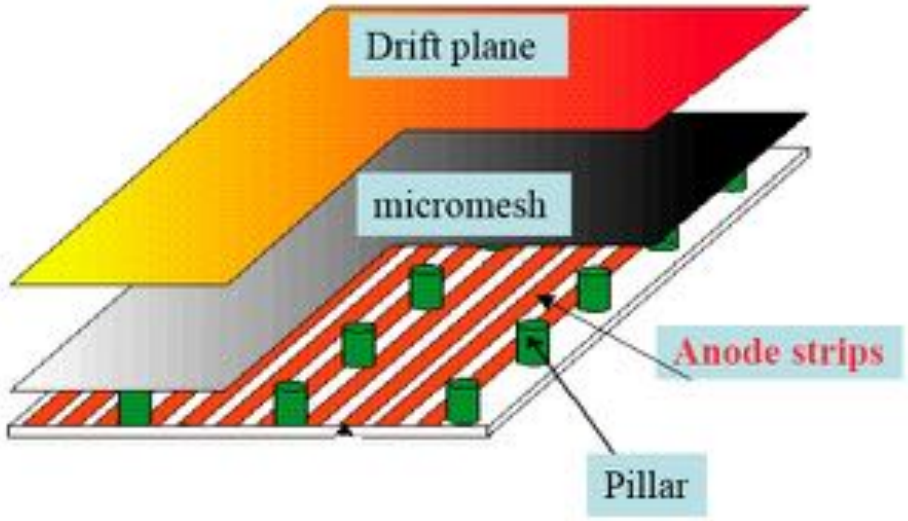


P. Rehak et al
IEEE TNS-47(2000)1426

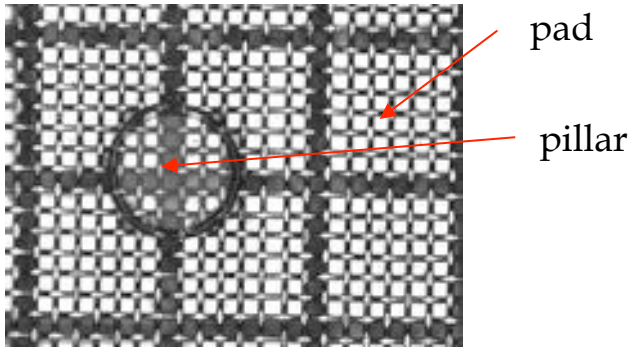
HIGH/LOW FIELD REGIONS SEPARATED BY A MESH

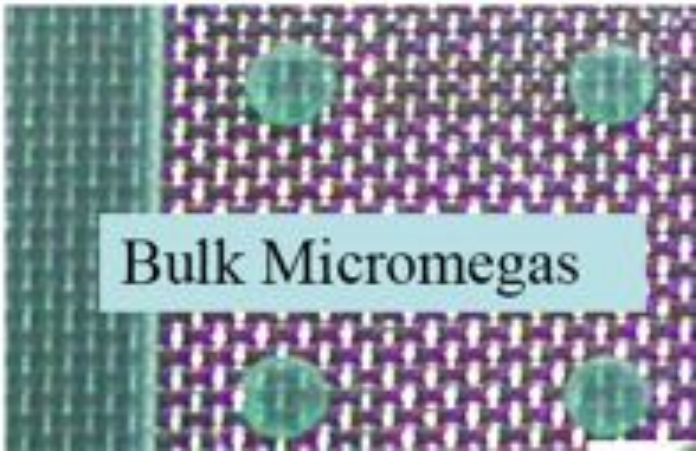


GAP UNIFORMITY:
SPACERS OR PILLARS



Y. Giomataris et al,
Nucl. Instr. and Meth. A 376(1996)29

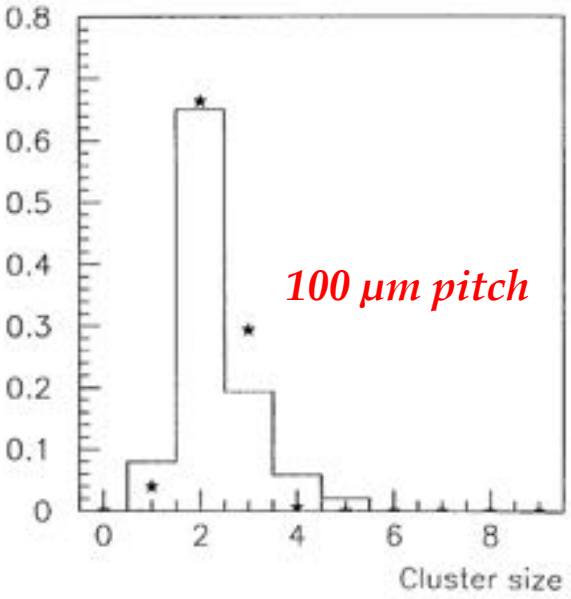




I. Giomataris et al,
Nucl. Instr. and Meth. A560(2006)405

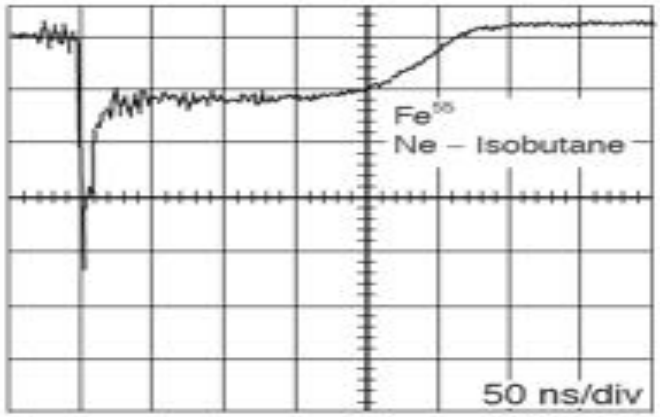
J. Bouchet et al,
Nucl. Instr. and Meth. A574(2007)425

Signal distribution: 200 μm fwhm

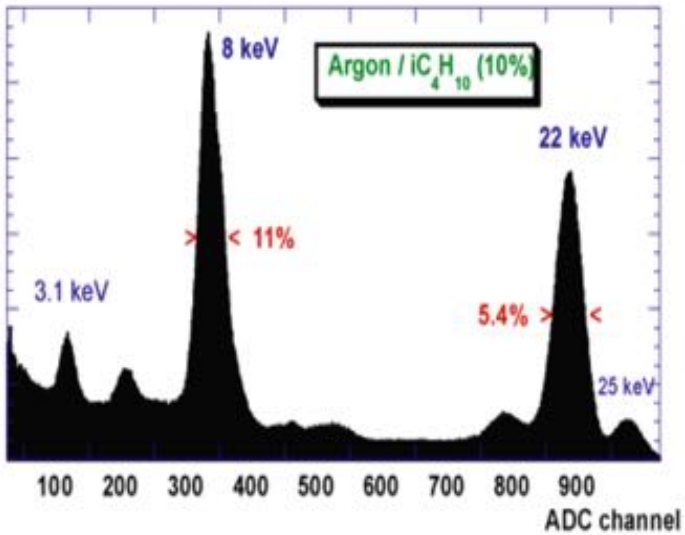


J. Derré et al,
Nucl. Instr. and Meth. A459(2001)523

Fast electron signal with slow ion tail:



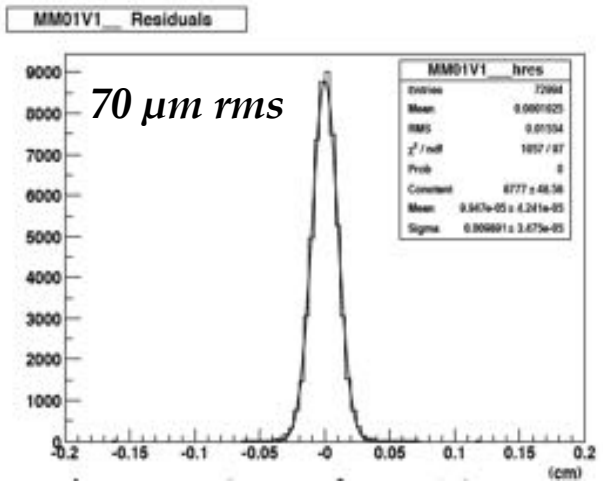
Energy resolution:



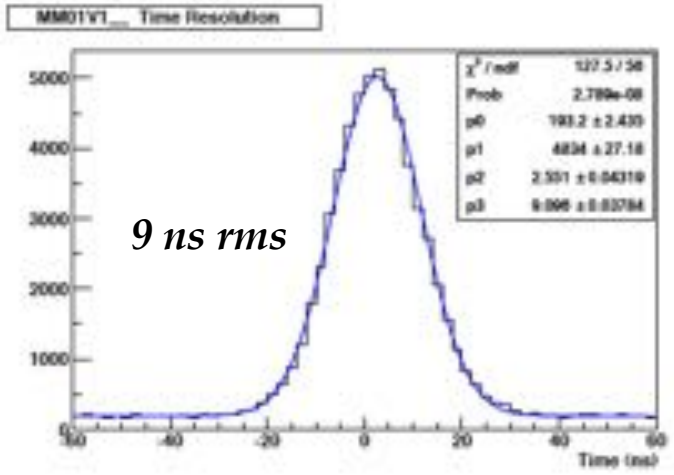
A. Delbart et al, Nucl. Instr. and Meth. A461(2001)84

12 planes in 3 stations X,Y, U, V
40x40 cm^2 active
350 μm strips with digital readout

SPACE RESOLUTION:

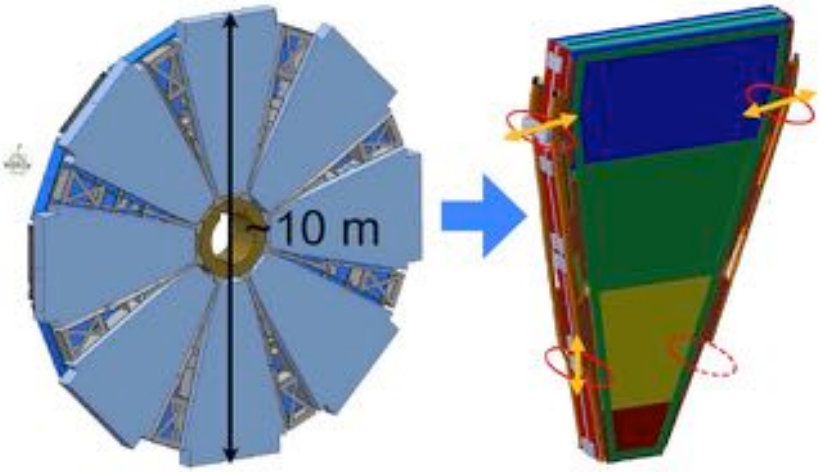


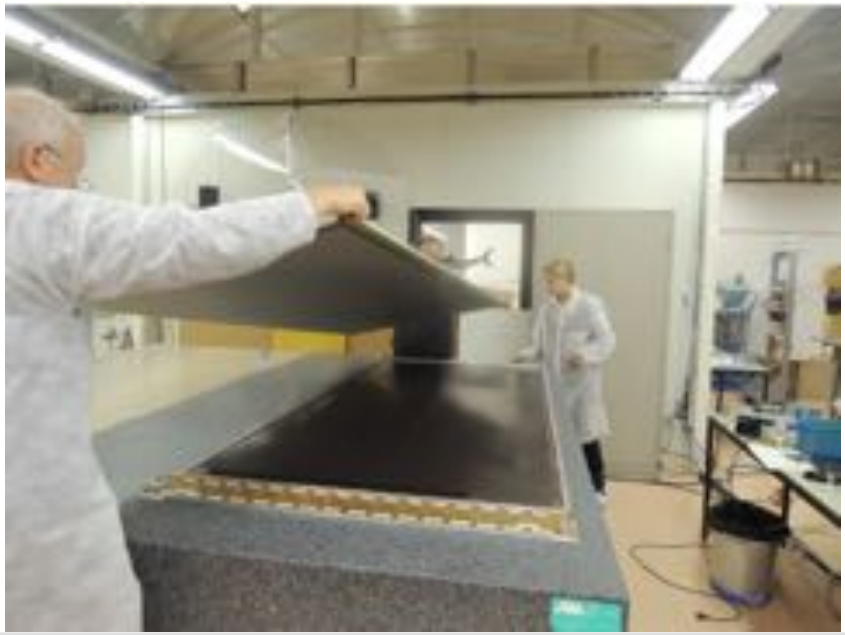
TIME RESOLUTION:

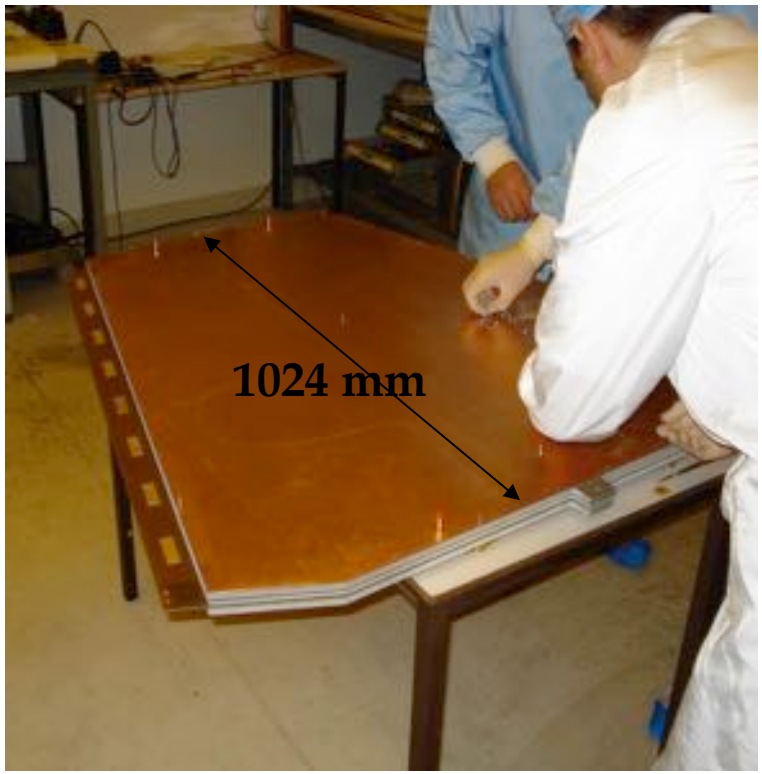


C. Bernet et al, Nucl. Instr. and Meth. A536(2005)61

ATLAS Forward muon upgrade:





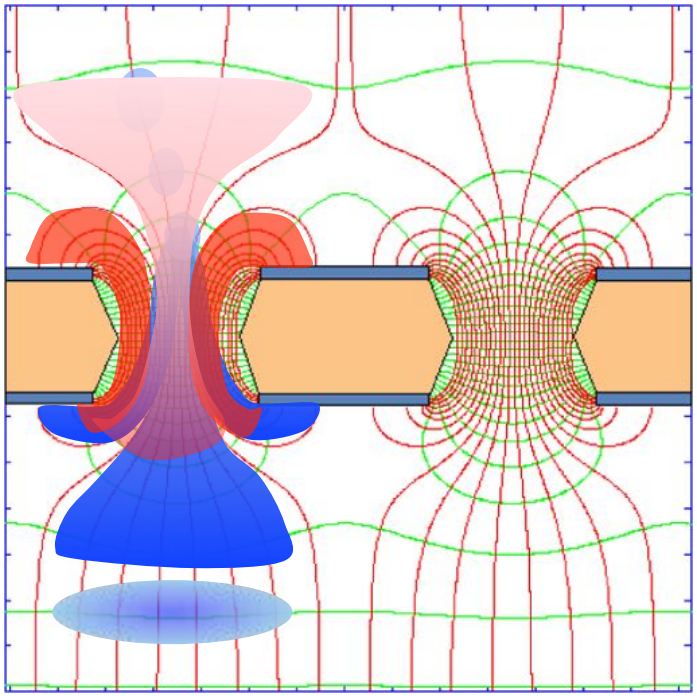


J. Wotschack, RD51 Meeting (CERN 2013)

J. Wotschack, JINST 7, C02021 (2012)

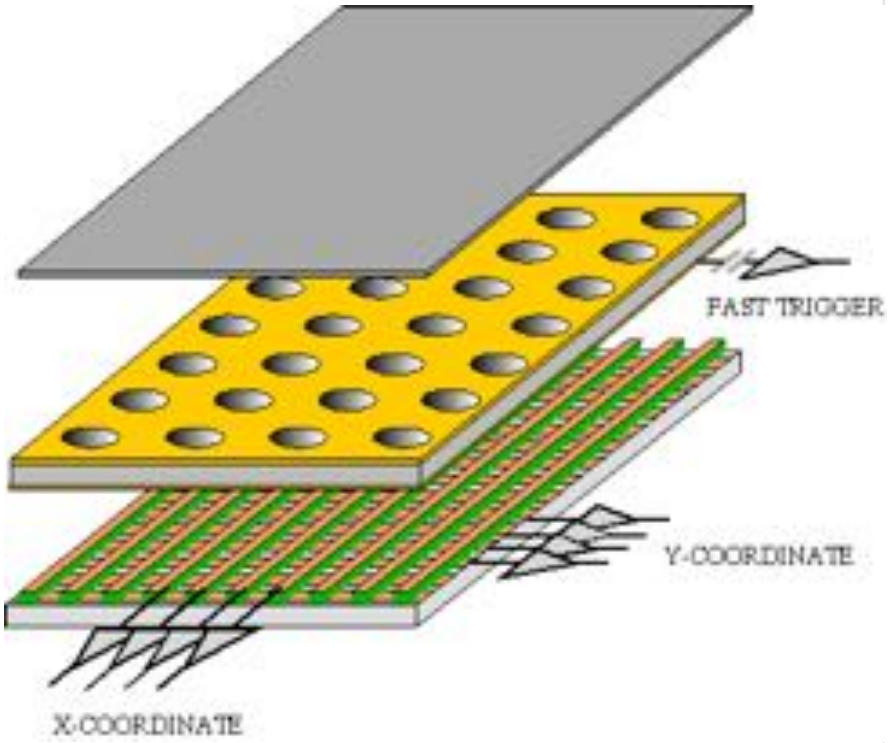
T. Alexopoulos et al,
Nucl. Instr. and Meth. A717(2010)161

Thin (50 μm) metal-coated polymer foil with high density of holes:



F. Sauli, Nucl. Instr. and Meth. A386(1997)531

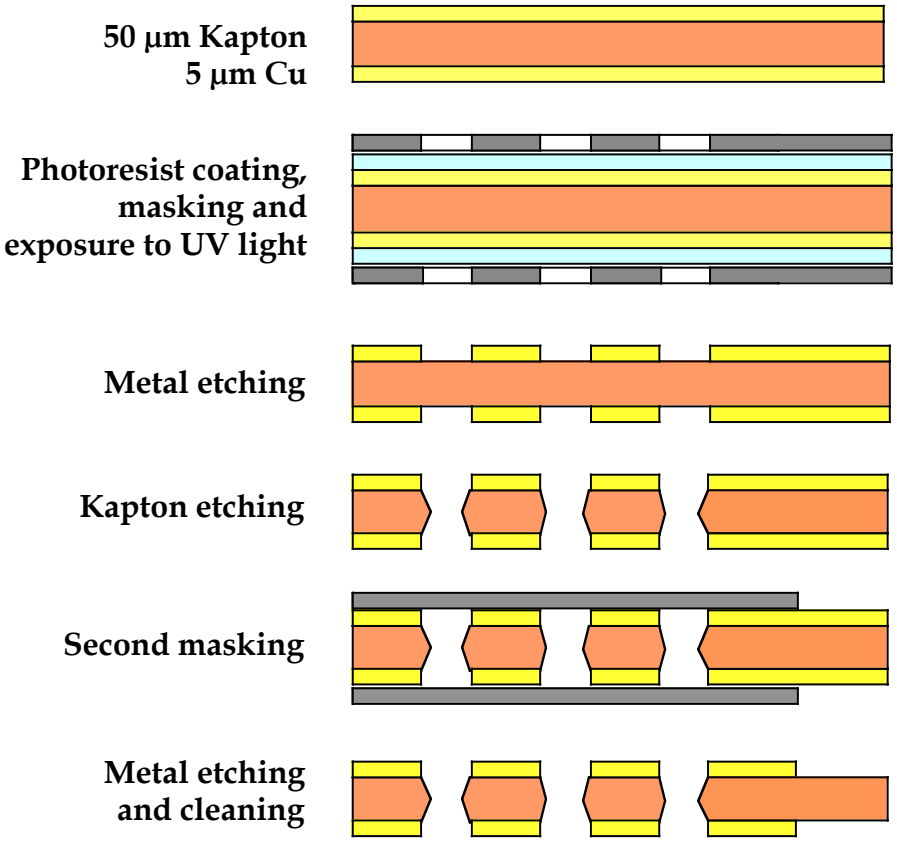
SINGLE GEM WITH 2-D READOUT BOARD

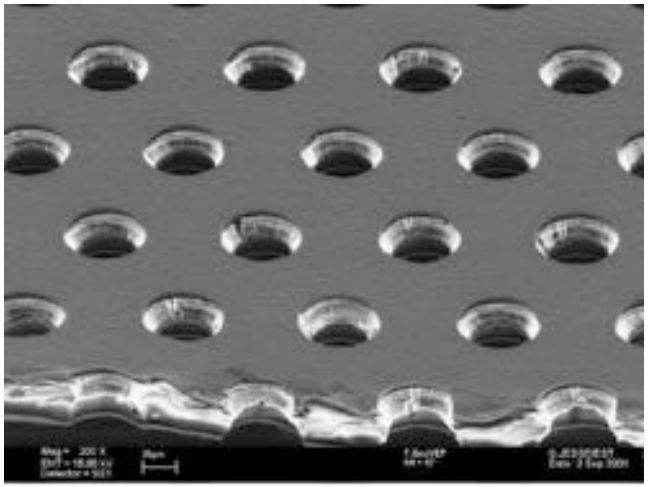


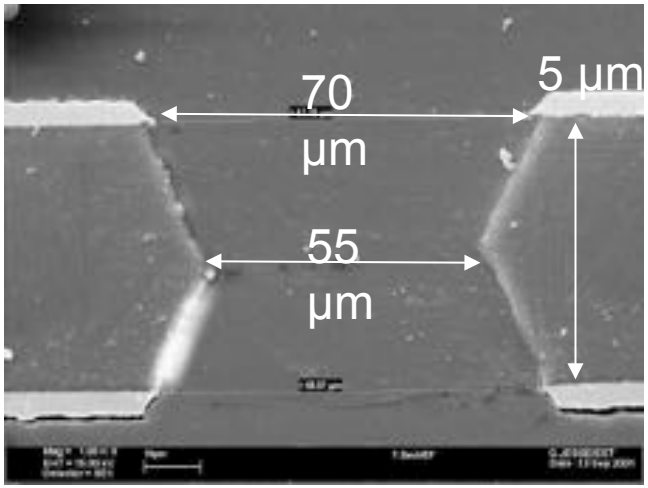
A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254

DOUBLE MASK PHOTOLITHOGRAPHY

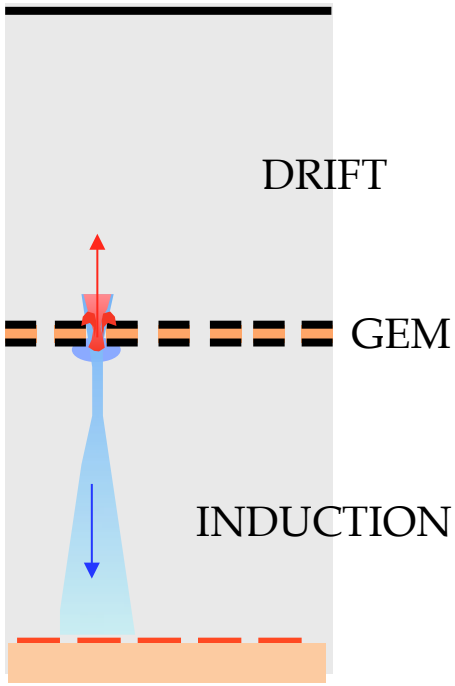
Standard GEM:70 µm Ø at 140 µm pitch







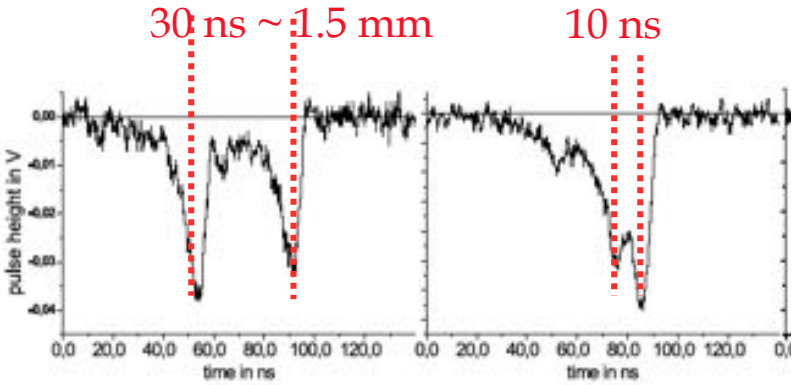
FAST ELECTRON SIGNAL ONLY
ON ANODE STRIPS



VOLUME RESOLUTION
~ 1 mm^3

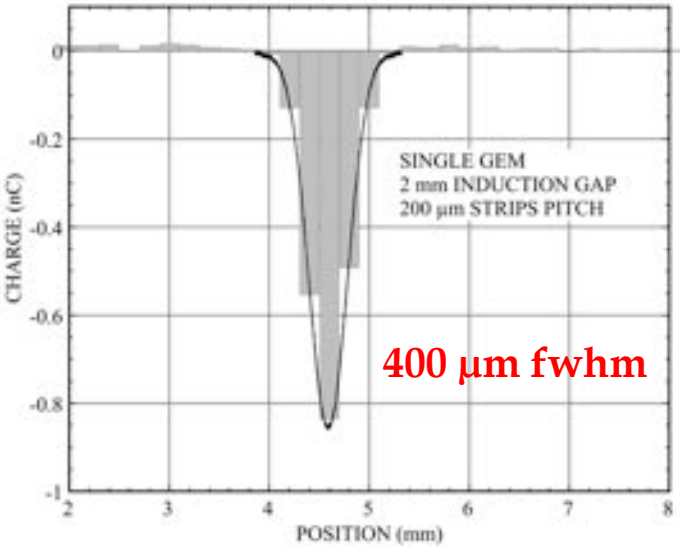
A. Bressan et al, Nucl. Instr. and Meth. A425(1999)262

TWO-TRACK RESOLUTION (DRIFT TIME):

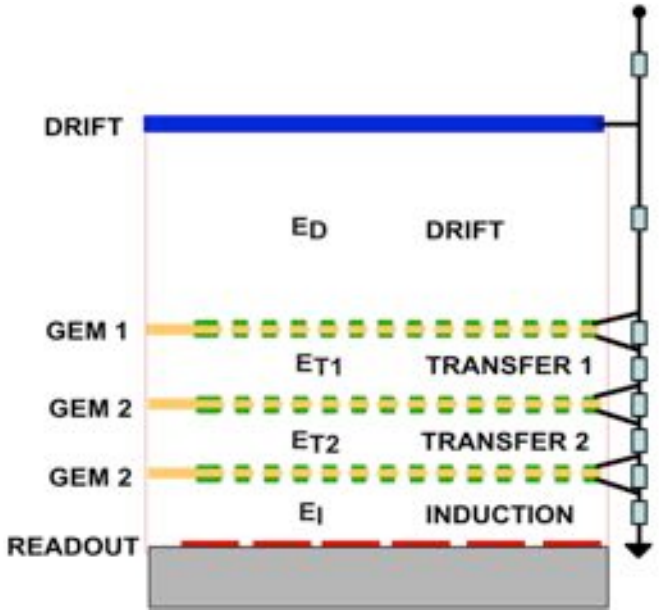


M. Ziegler, PhD Zürich Univ. (2002)

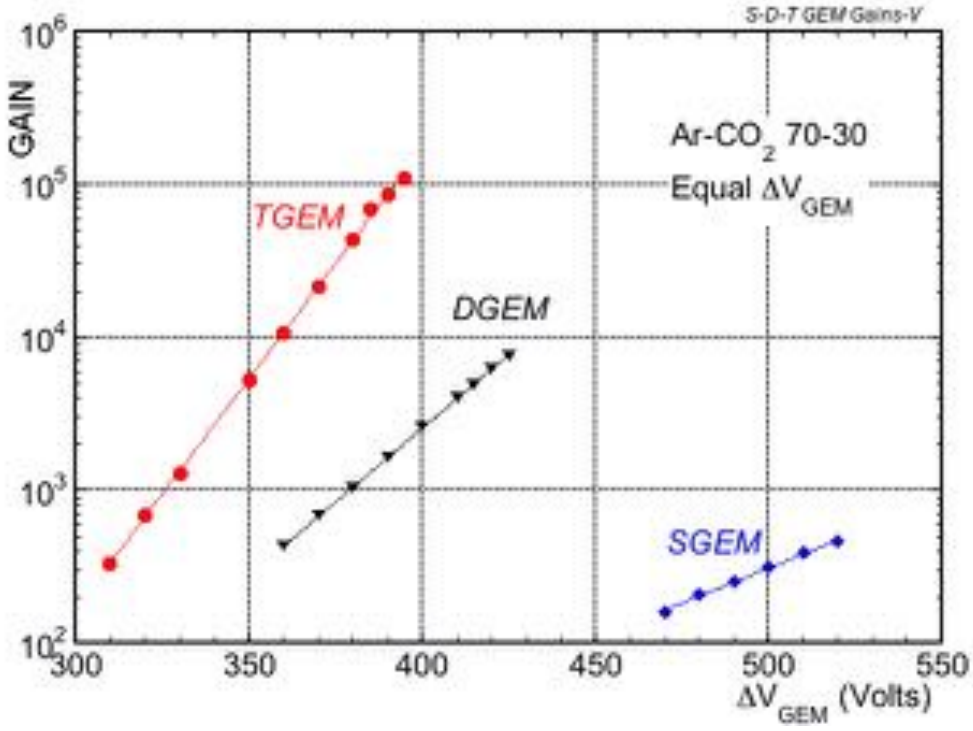
TWO-TRACK RESOLUTION (PROJECTION):



Triple-GEM (TGEM):
Cascaded GEM electrodes

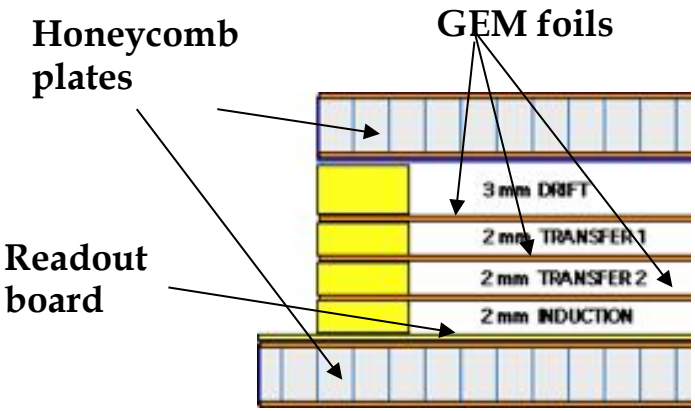


HIGHER GAIN, LOWER VOLTAGE
ON EACH GEM

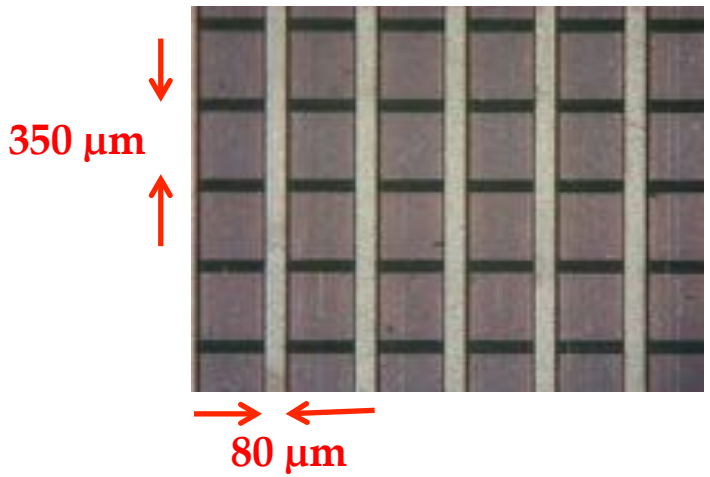


C. Büttner et al, Nucl. Instr. and Meth. A409(1998)79

31x31 cm^2 active 2-D strip readout
Total thickness in active area ~ 0.7% X_0

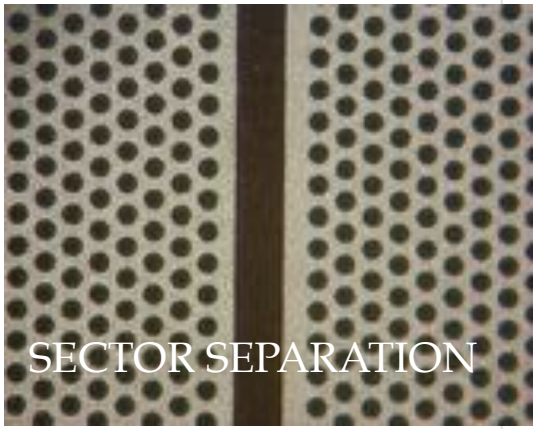


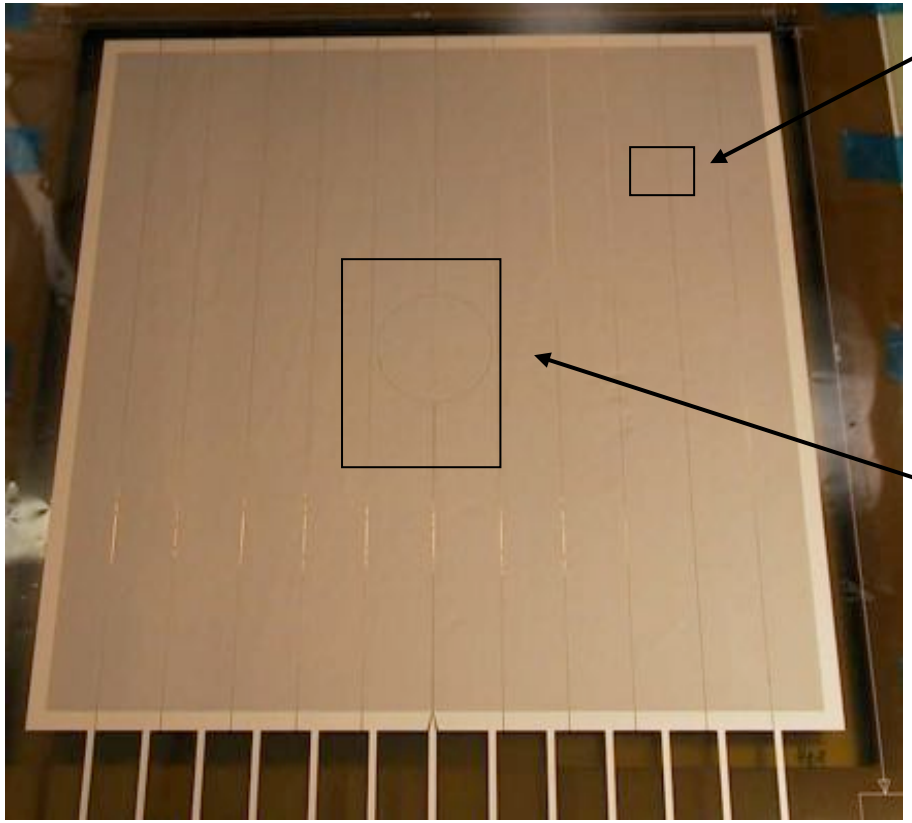
2-D readout board: 400 μm pitch strips

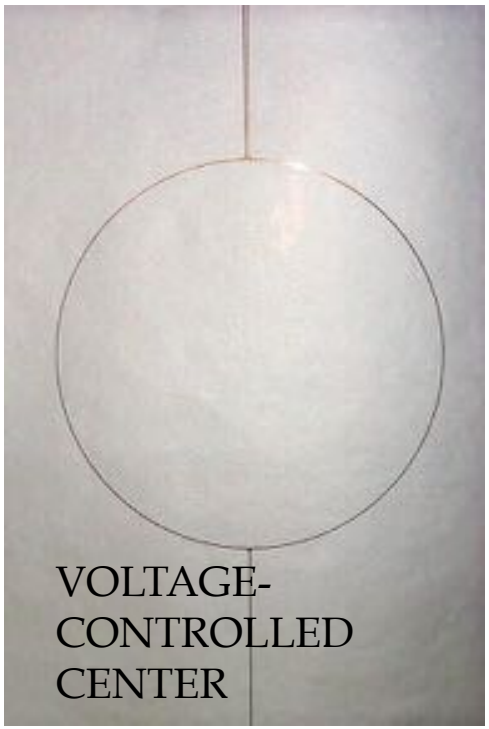


C. Altumbas et al,
Nucl. Instr. and Meth. A490(2002)177

COMPASS TRIPLE-GEM DETECTORS:
12 SECTORS WITH PROTECTION RESISTORS
CENTRAL BEAM KILLER

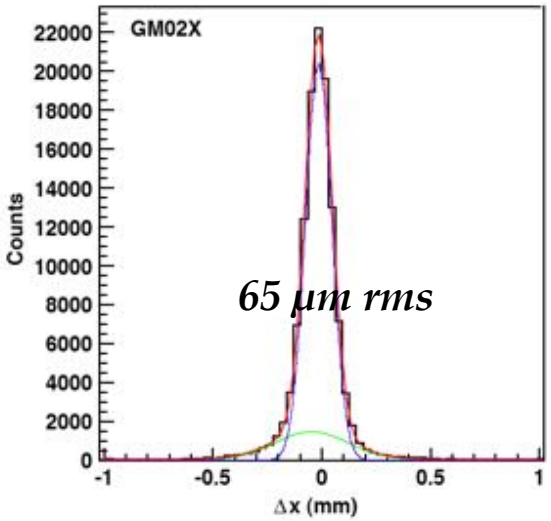




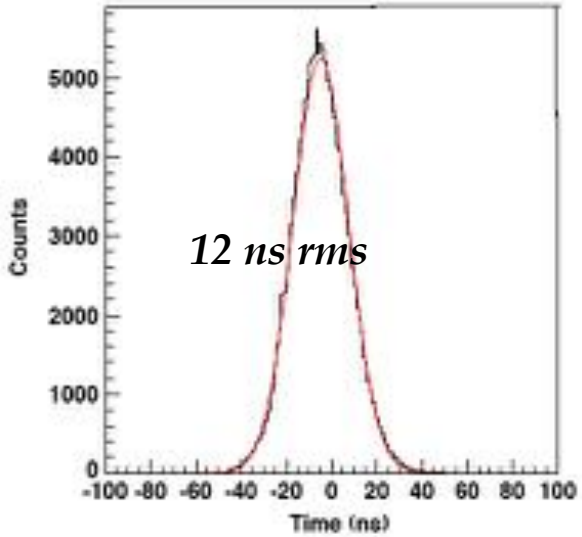


22 DETECTORS, OPERATIONAL 2002-2012

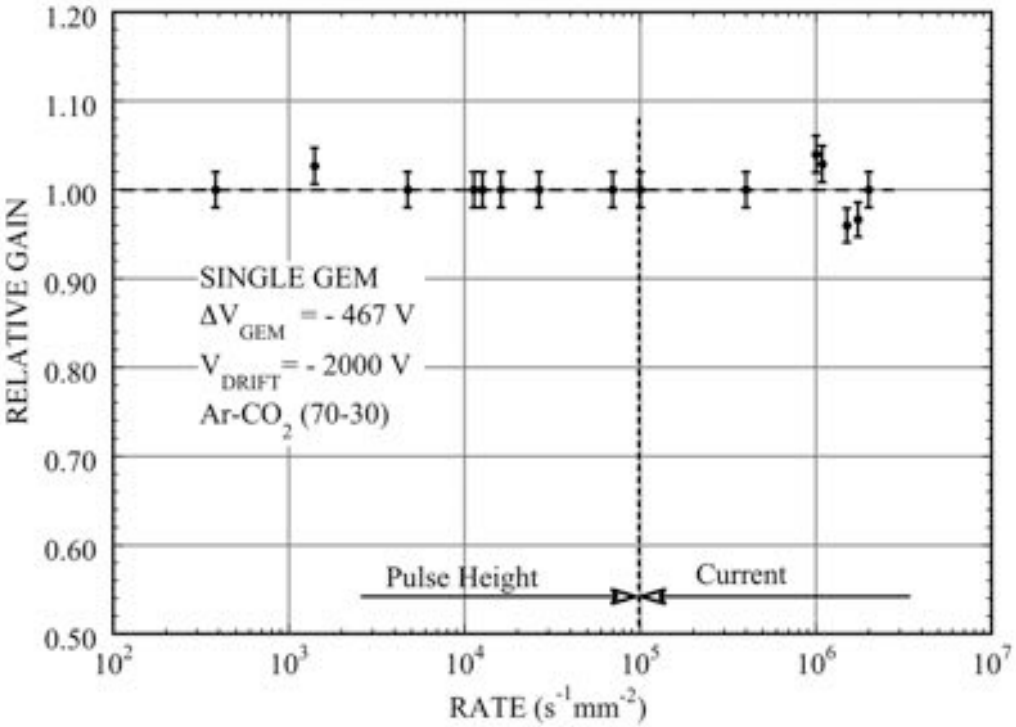
SPACE ACCURACY



TIME RESOLUTION



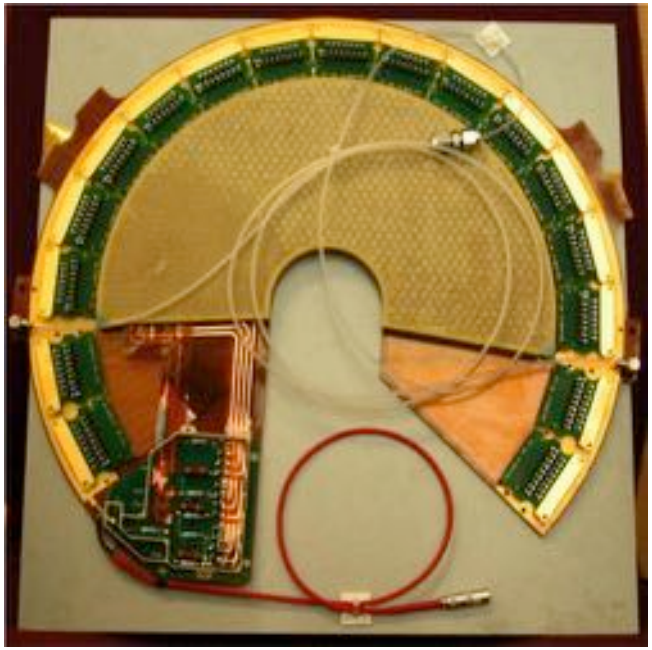
RATE CAPABILITY

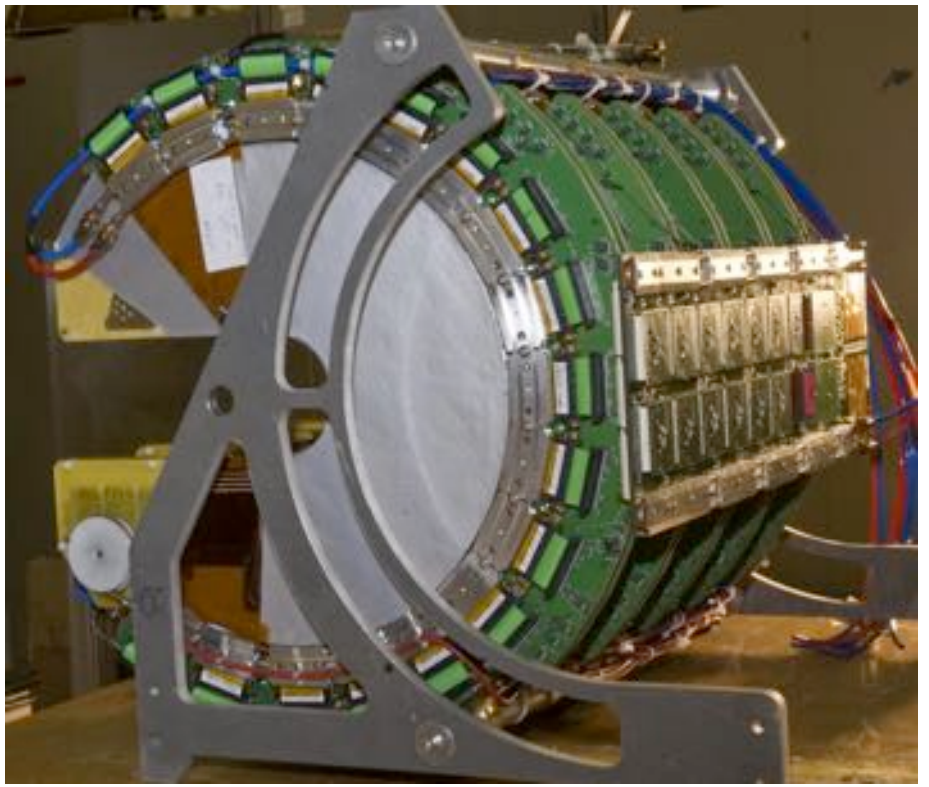


J. Benlloch et al, IEEE NS-45(1998)234

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

SEMI-CIRCULAR MODULES

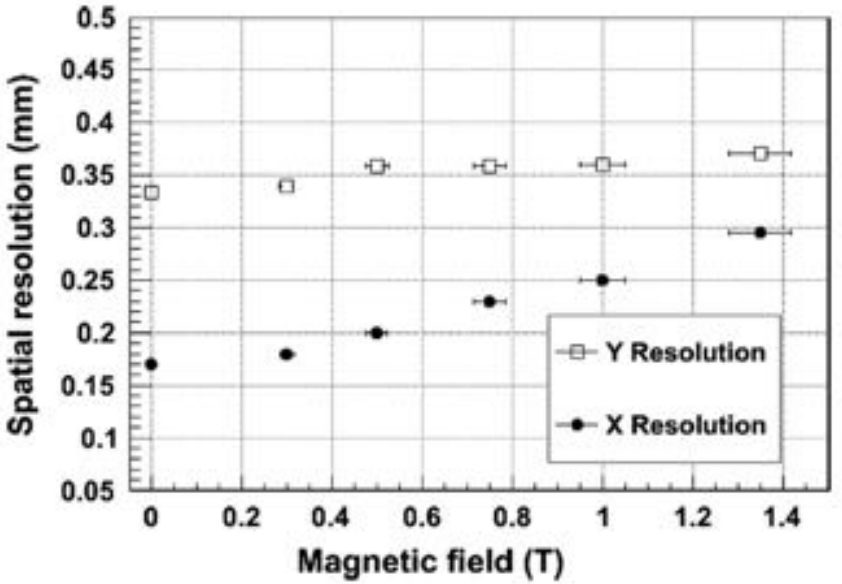




M.G. Bagliesi et al, Nucl. Instr. and Meth. A617(2010)134

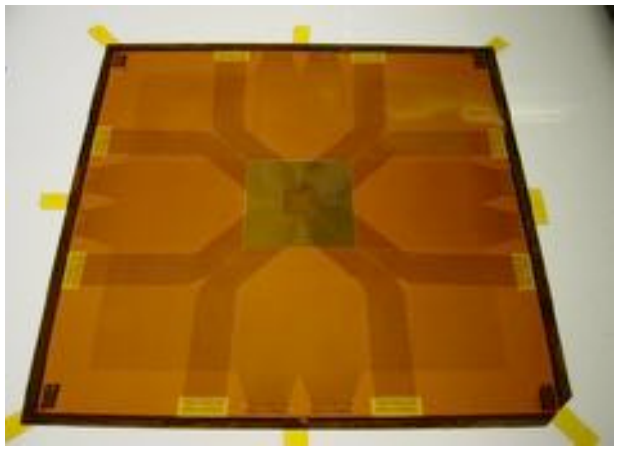
KLOE-2 Inner Tracker: Three layers of Triple-GEM detectors

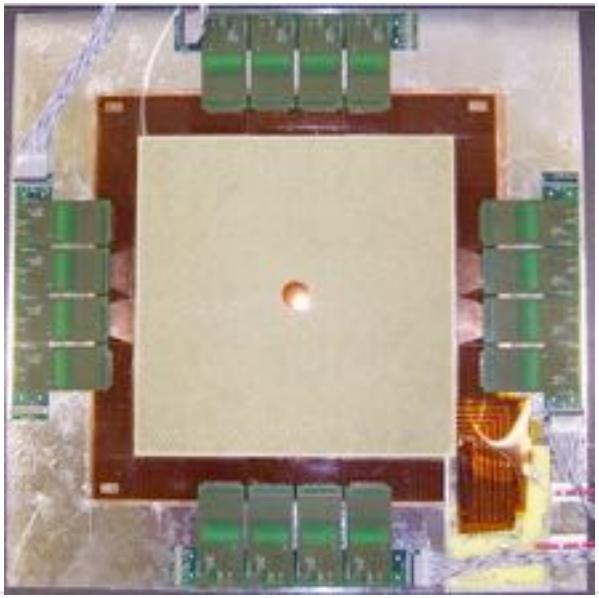
SPATIAL RESOLUTION
(X: Bending Plane):



A. Balla et al, Nucl. Instr. and Meth. A732(2013)221

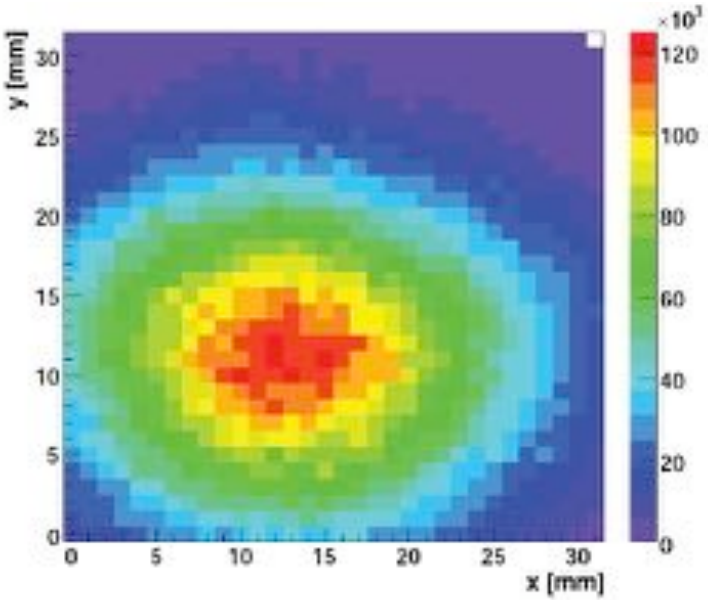
CENTER: 32x32 PIXELS, 1 mm^2 SIDES: 512x512 STRIPS, 400 μm pitch





MEASURED FLUX IN HADRON BEAM:

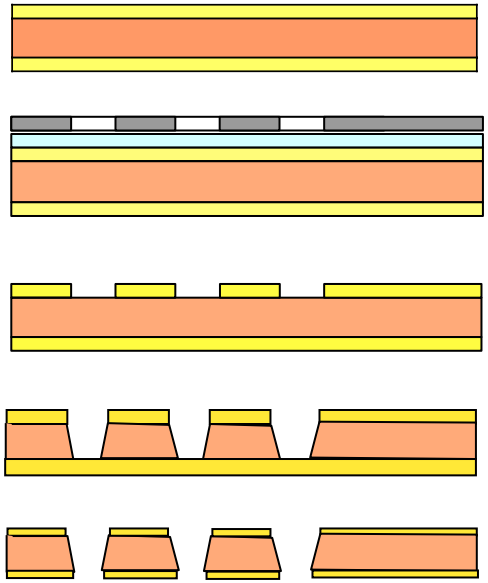
1.2 10^5 Hz/mm^2

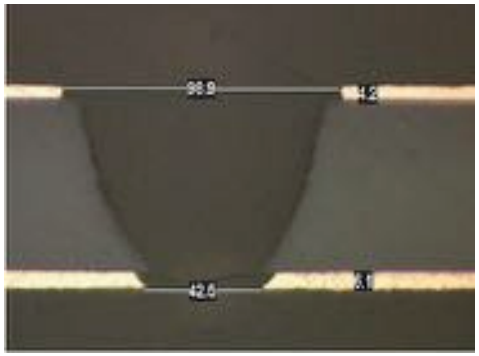


B. Ketzer et al, 2007 IEEE Nucl. Sci. Symp. Conf. Rec.

M. Krämer et al, 2008 IEEE Nucl. Sci. Symp. Conf. Rec.

SINGLE MASK PROCESS

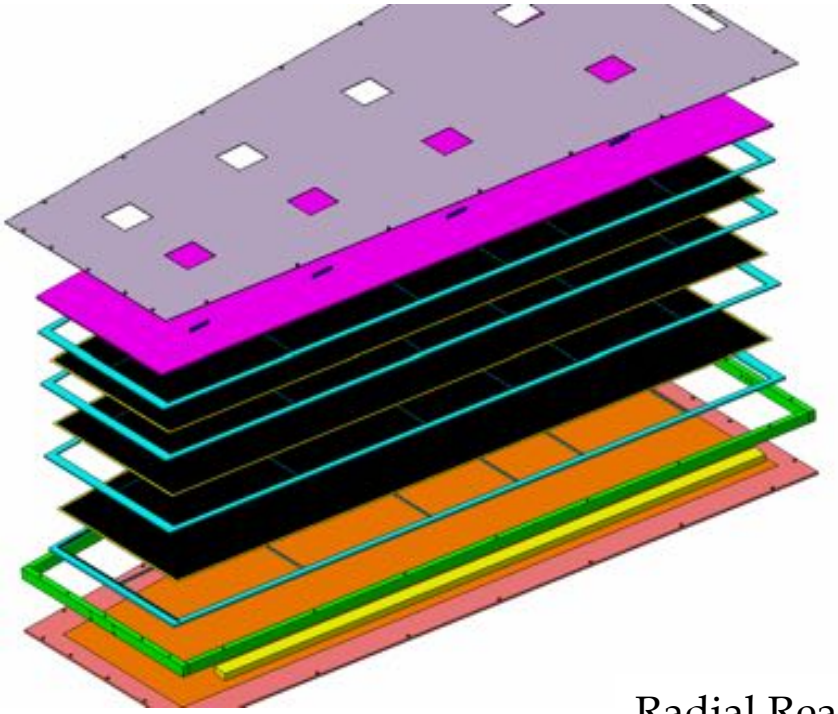




M. Alfonsi et al, Nucl. Instr. and Meth. A617(2010)151

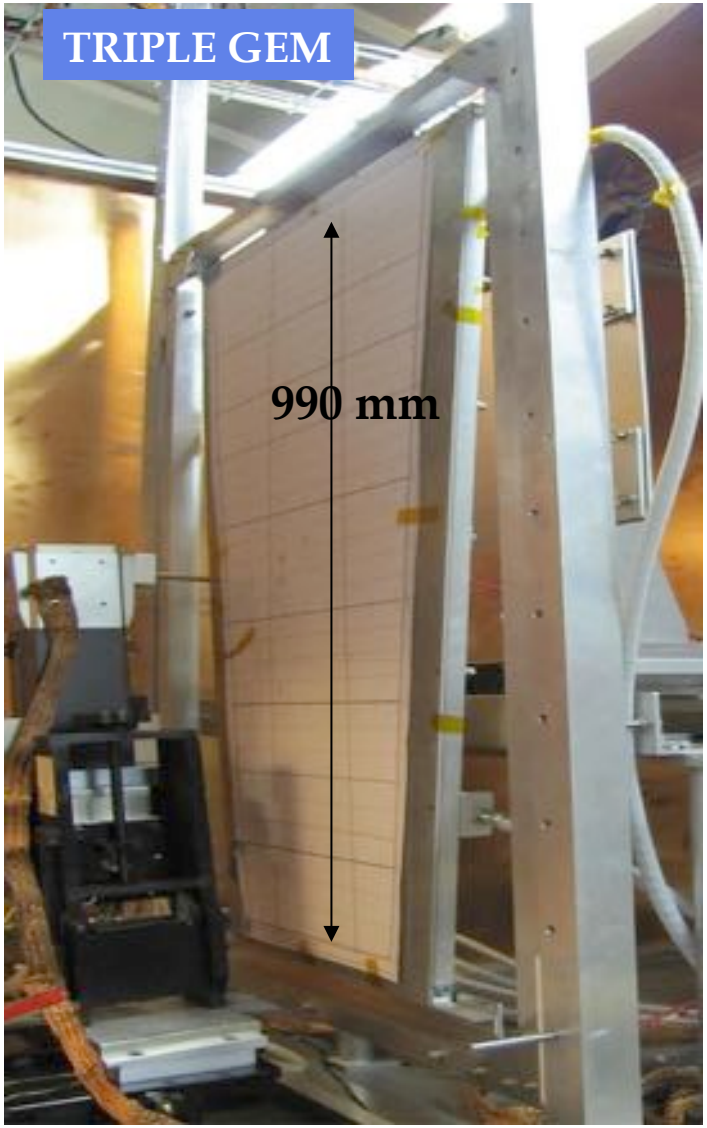
CMS Muon Detector Upgrade

990 x (220-455)mm^2

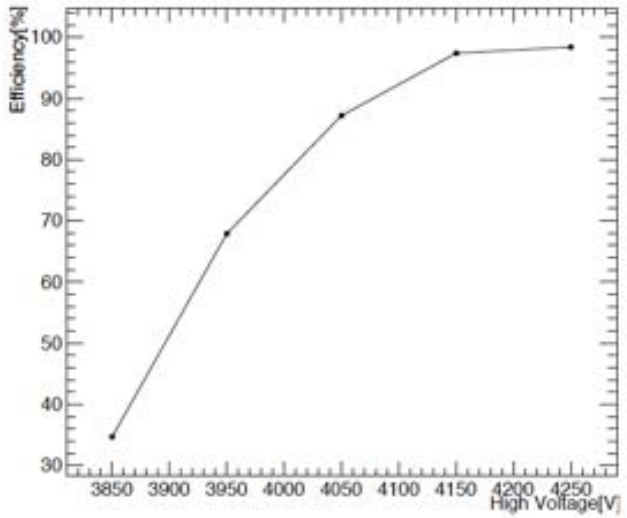


Radial Readout Strips
0.6 to 1.2 mm pitch

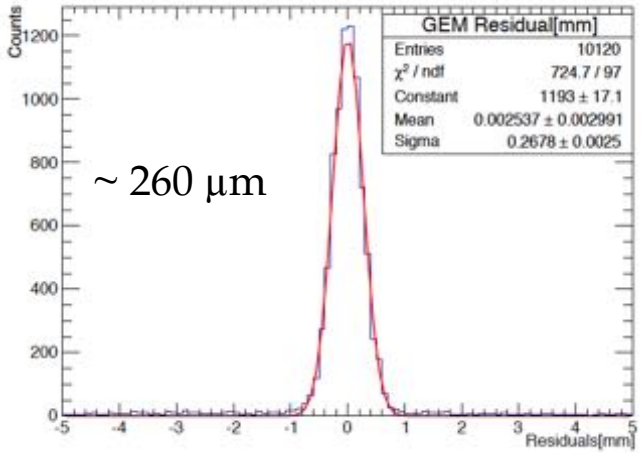
M. Tytgat, MPGD 2013



EFFICIENCY



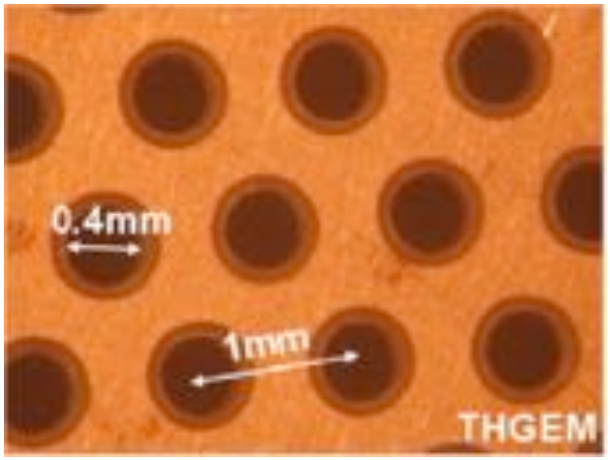
POSITION ACCURACY



D. Abbaneo et al, JINST 9(2014)C01053

MECHANICAL DRILLING OF METAL-CLAD PC BOARD:

- SELF-SUPPORTING
- HIGH GAIN



R.Chechik et al,
Nucl. Instr. and Meth. A535(2004)303

A. Breskin et al,
B. Nucl. Instr. And Meth. A623(2010)132

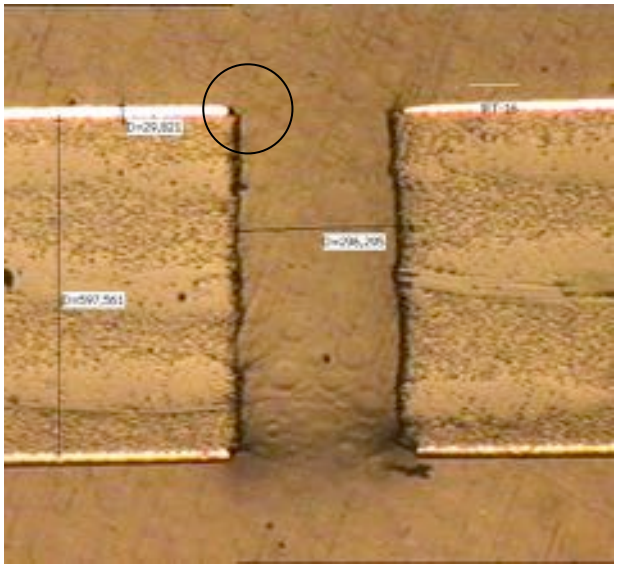
ALSO NAMED LARGE ELECTRON MULTIPLIER (LEM)

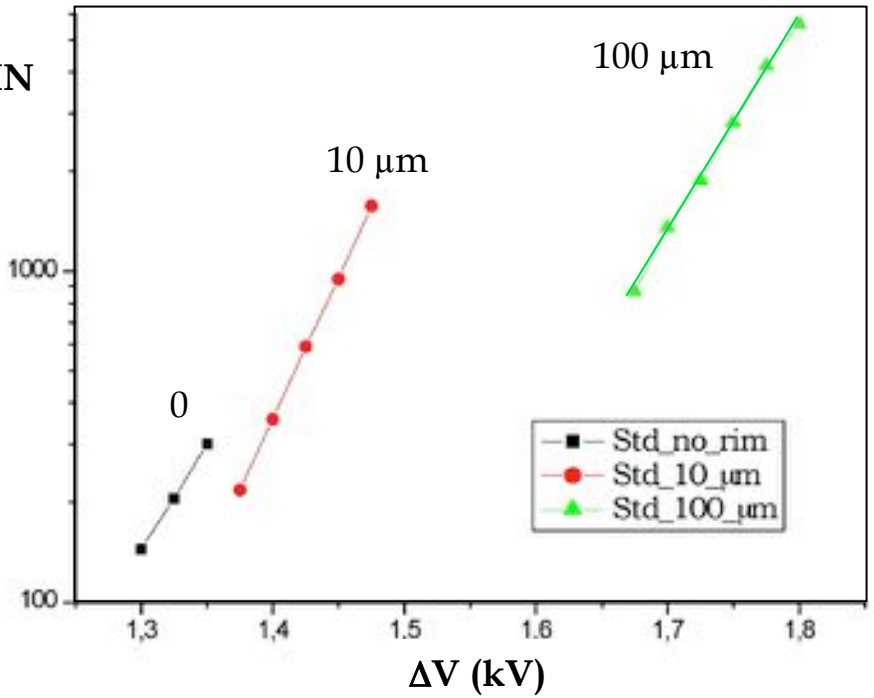
P. Janneret, Thesis at Neuchatel University (2001)

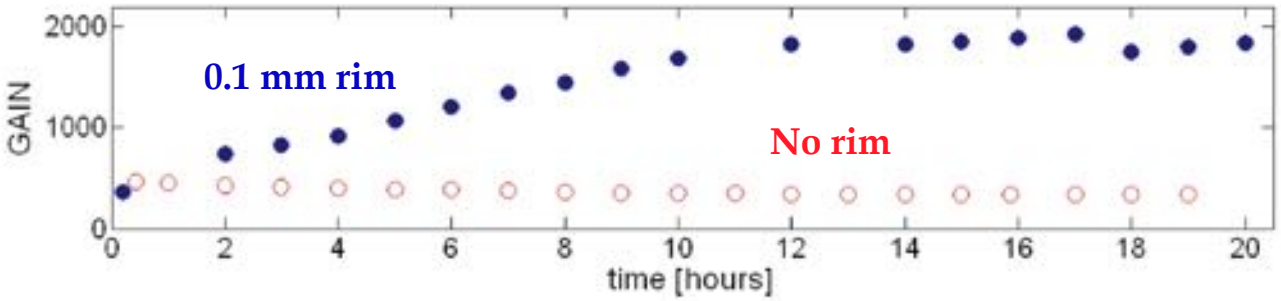
A. Badertscher et al, Nucl. Instr. And Meth. A617(2010)188

LARGE RIM:
- HIGH GAIN
- CHARGING UP

RIMLESS:
- LOW GAIN
- STABLE







M. Alexeev et al, Nucl. Instr. and Meth. A695(2012)159