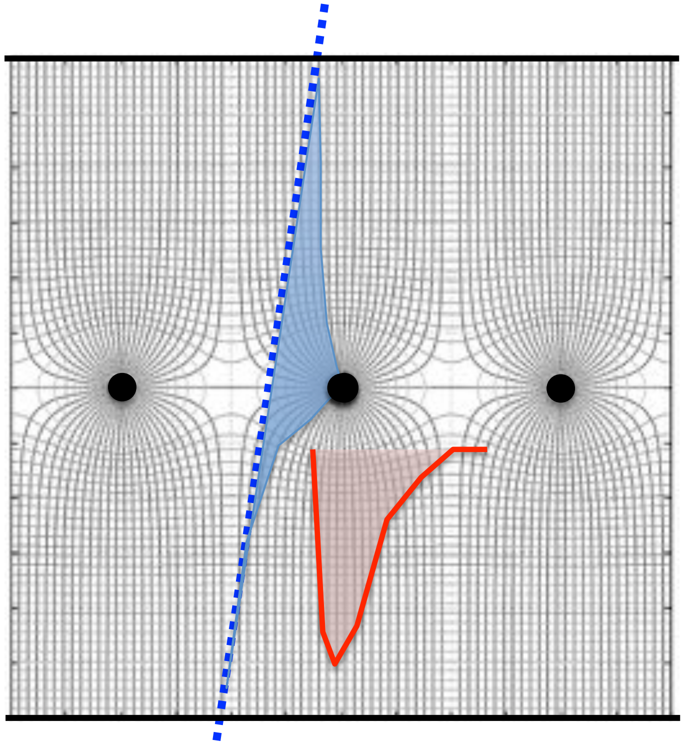
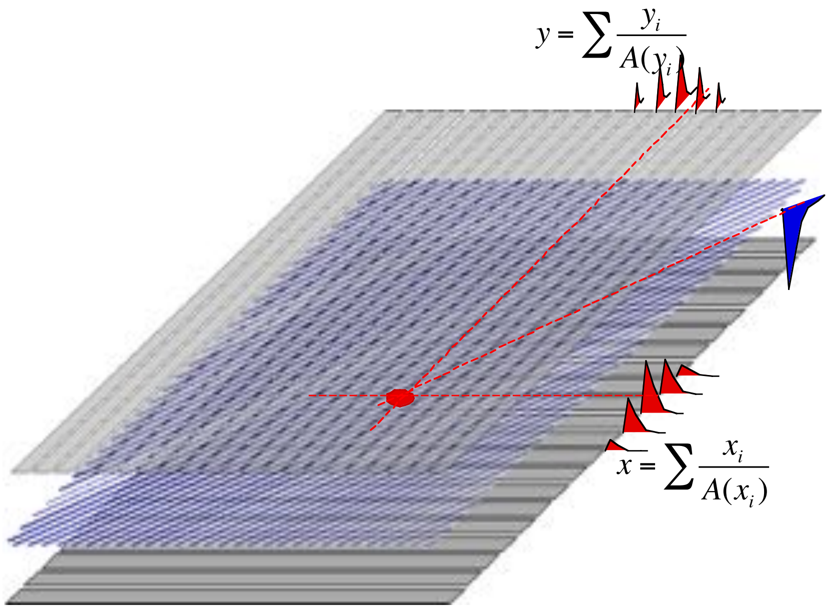

PART 2
PROBLEMS AND SOLUTIONS
WITH
GASEOUS COUNTERS
Fabio Sauli
TERA 20-29, 2Foundation and CERN
EDIT 2015 Laboratori Nazionali di Frascati, October 015

THIN ANODE WIRES BETWEEN TWO CATHODES:



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

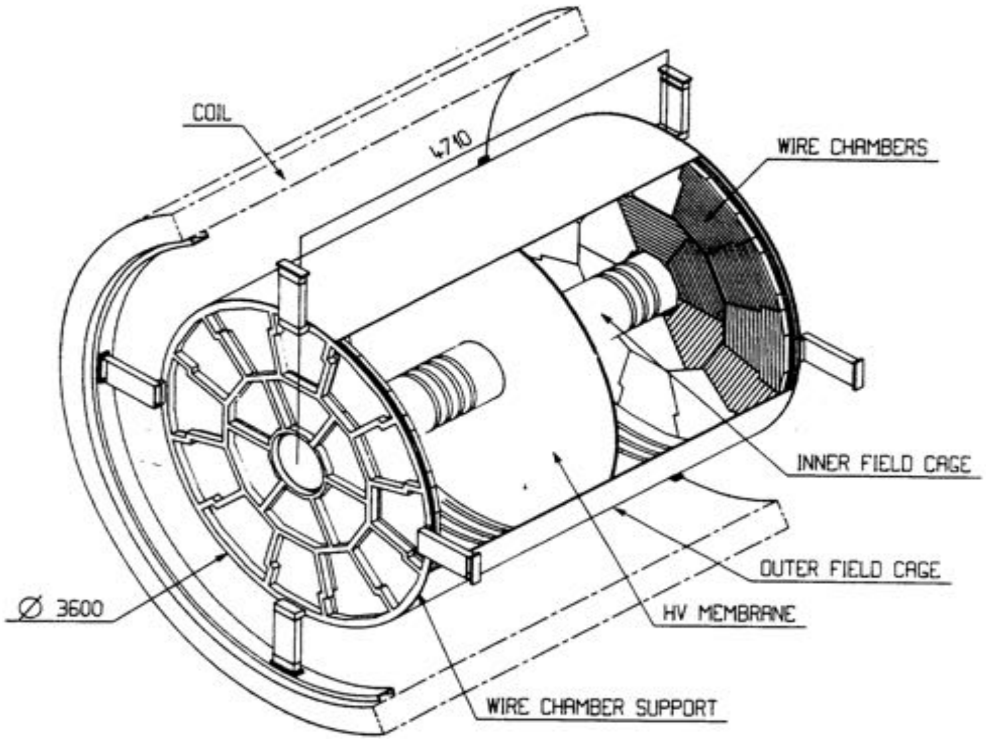
CHARGE INDUCTION ON CATHODE PLANES:
2-D LOCALIZATION

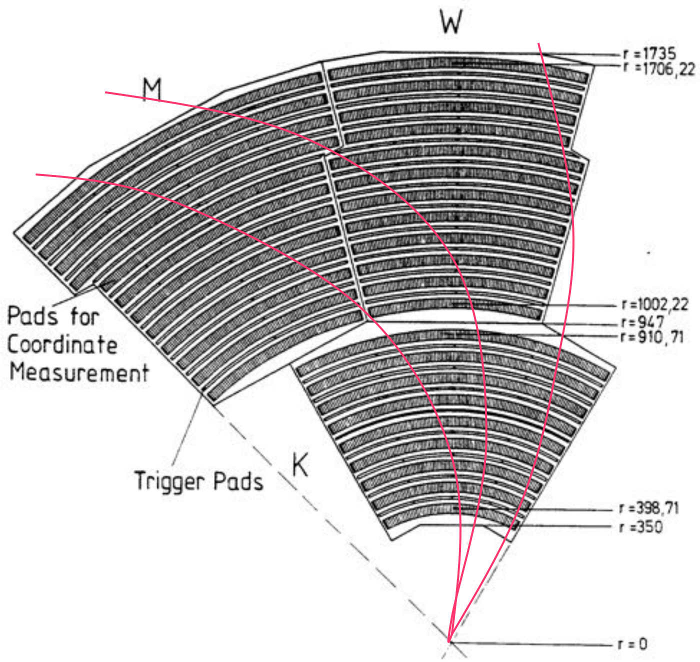


G. Charpak and F. Sauli
Nucl. Instr. and Meth. 113(1973)381

D.R. Nygren and J. N. Marx, Physics Today No.31 Vol. 10(1978)

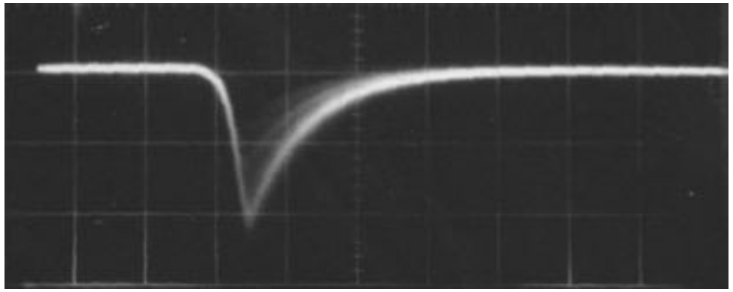
ALEPH TPC



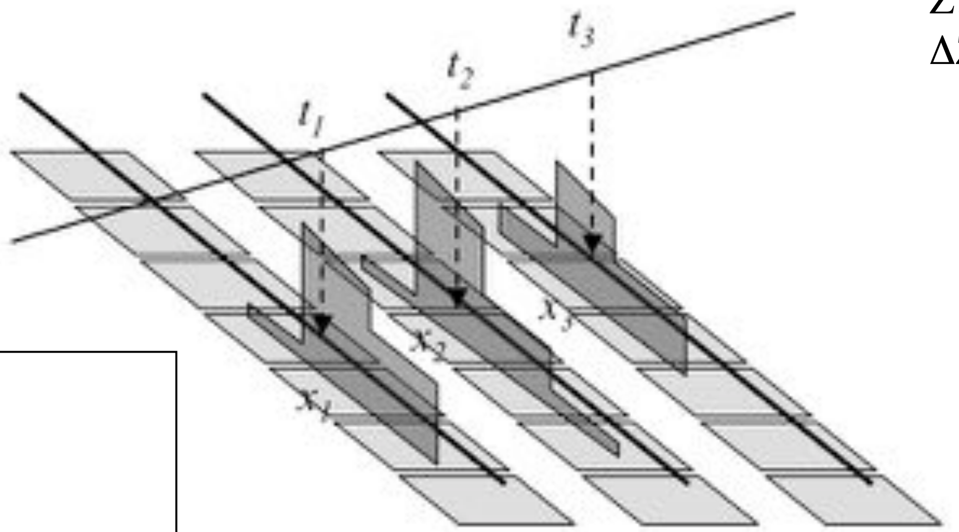


D. Decamp et al,Nucl. Instr. and Meth. A294(1990)125

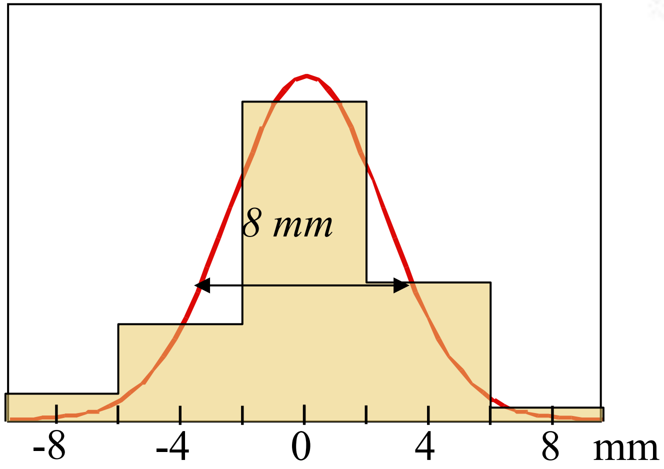
TPC: FULL 3-D LOCALIZATION



Z: DRIFT TIME
ΔZ ~ 10 mm (200 ns)



X: PAD ROWS
ΔX ~ 10 mm

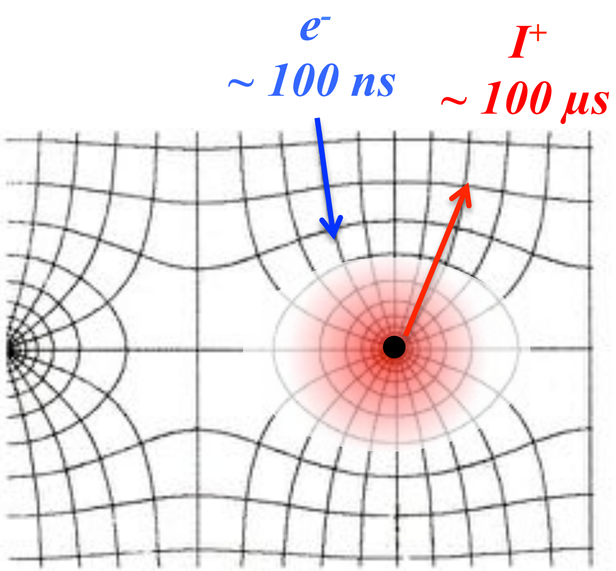


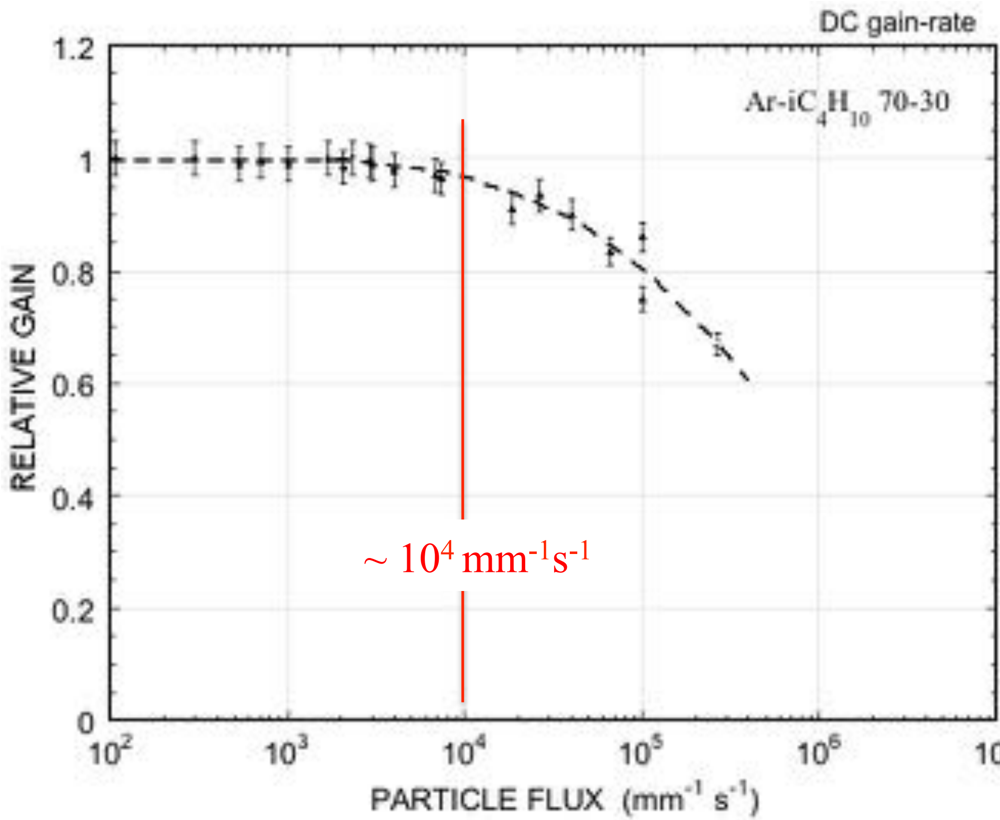
Y: ANODE WIRE
ΔY ~ 4 mm

Volume resolution
ΔV~ 50 mm^3

SPACE CHARGE NEAR THE ANODE:
BUILDUP OF SLOW POSITIVE IONS
MODIFIES THE ELECTRIC FIELD

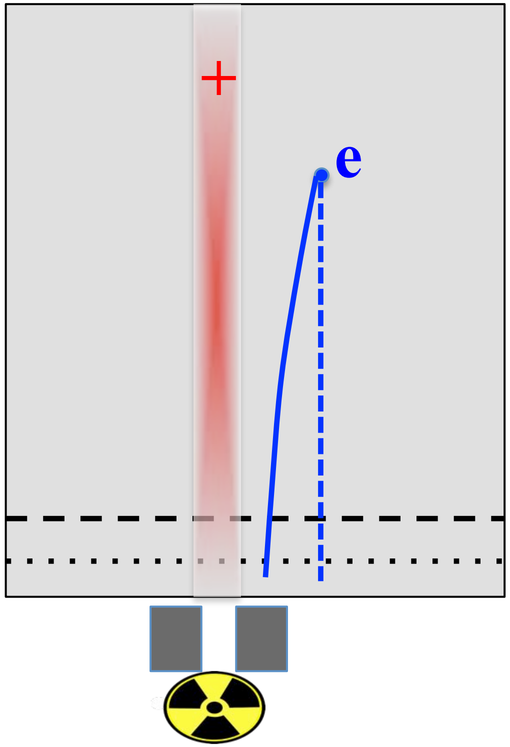
RELATIVE GAIN AS A FUNCTION OF RATE:



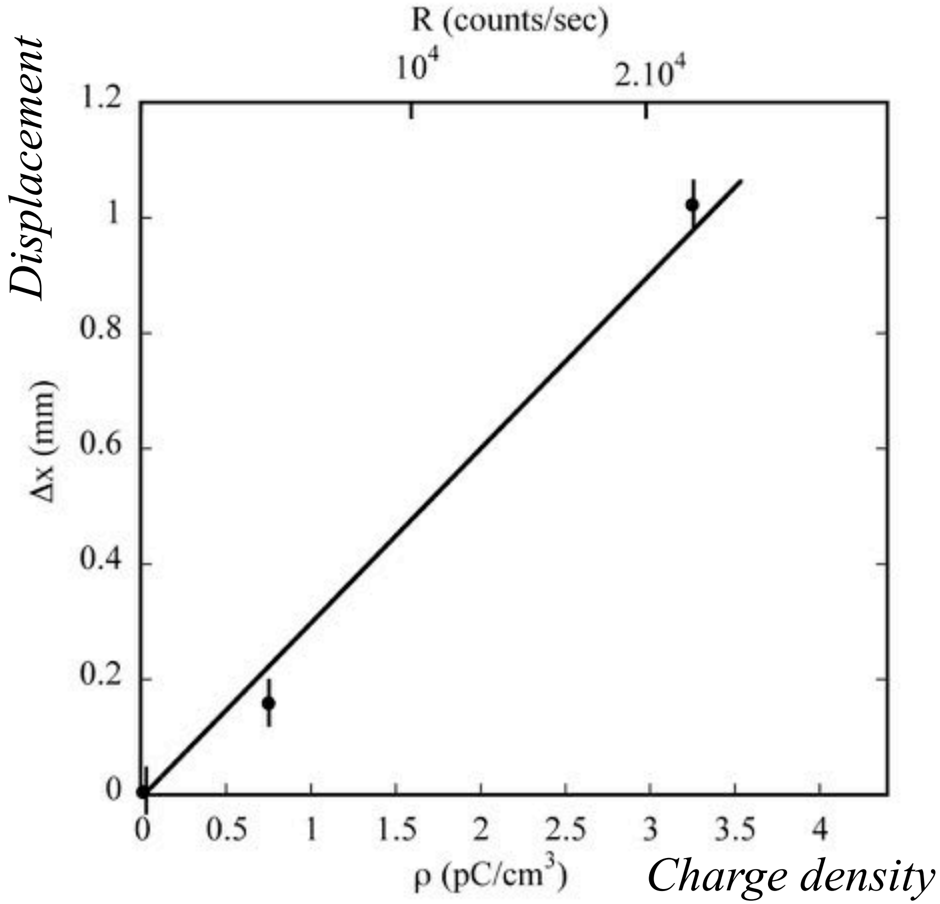


A. Breskin et al, Nucl. Instr. and Meth. 124(1974)189

LATERAL DISPLACEMENT OF ELECTRONS DRIFTING NEAR A POSITIVE IONS COLUMN

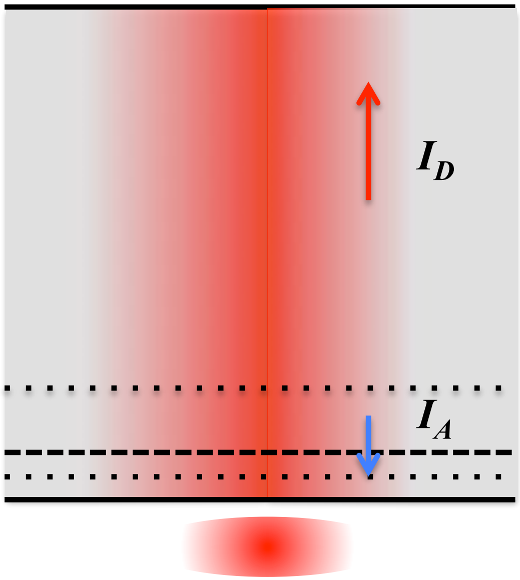


^{55}Fe SOURCE 1 cm FROM ION COLUMN , 10 cm DRIFT

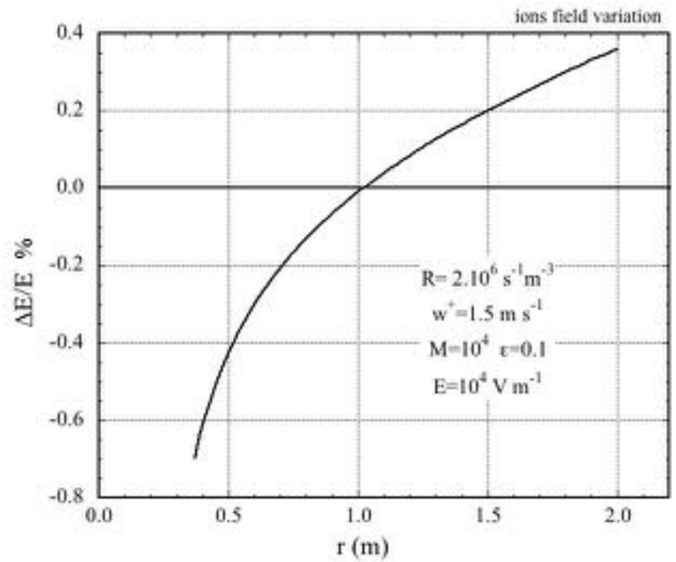


D. Friedrich, et al, Nucl. Instr. and Meth. 158(1979) 81

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

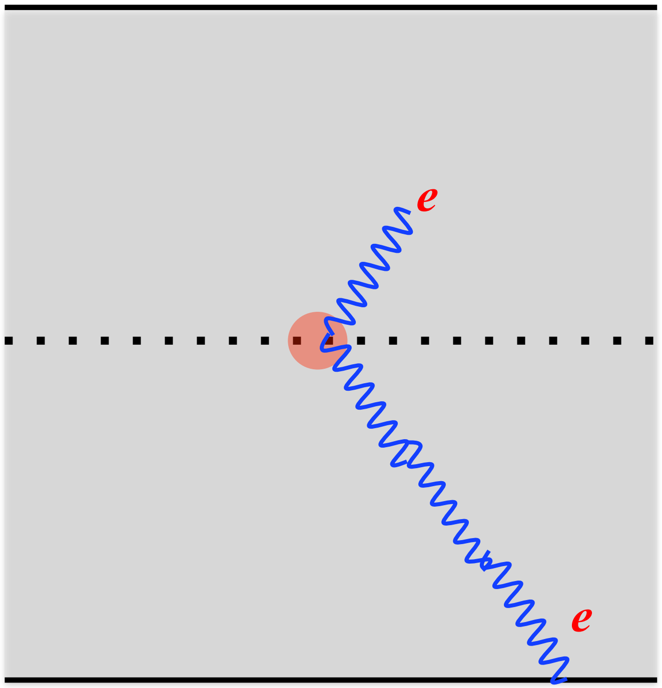
IONS BACKFLOW RATIO $IBF = \frac{I_{DRIFT}}{I_{ANODE}}$

THE WISH: $IBF \leq \frac{1}{GAIN} \approx 10^{-4}$

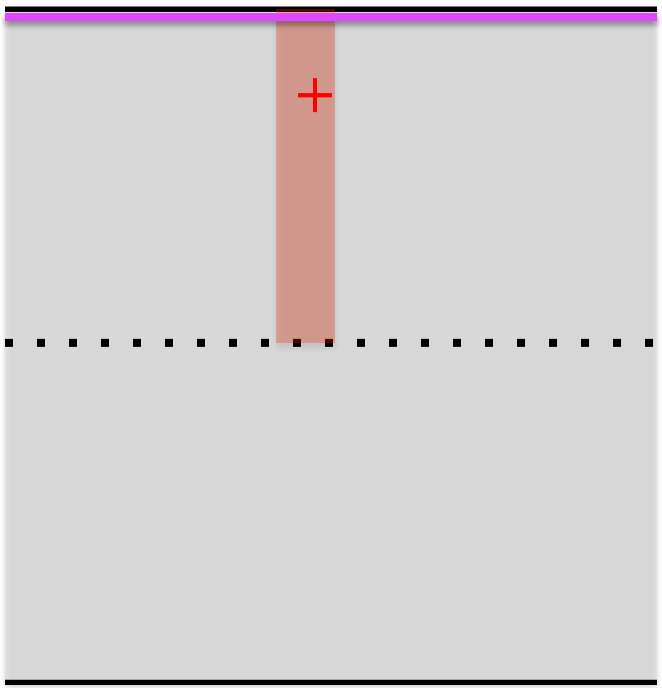
MWPC: IBF ~ 30%

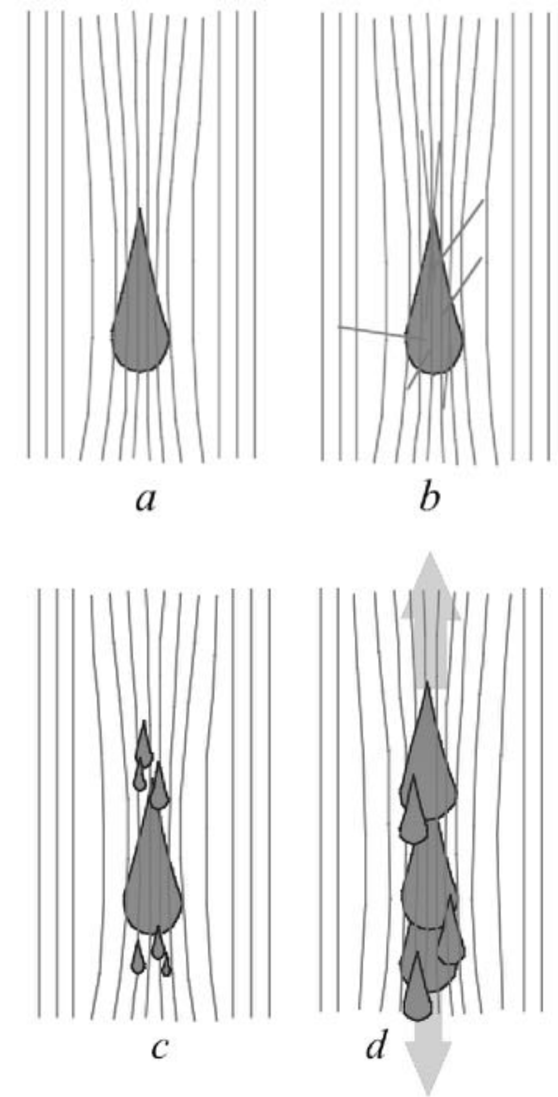
ONLY POSSIBLE AT SMALL RATES:
Maximum electron drift time
< Time between events

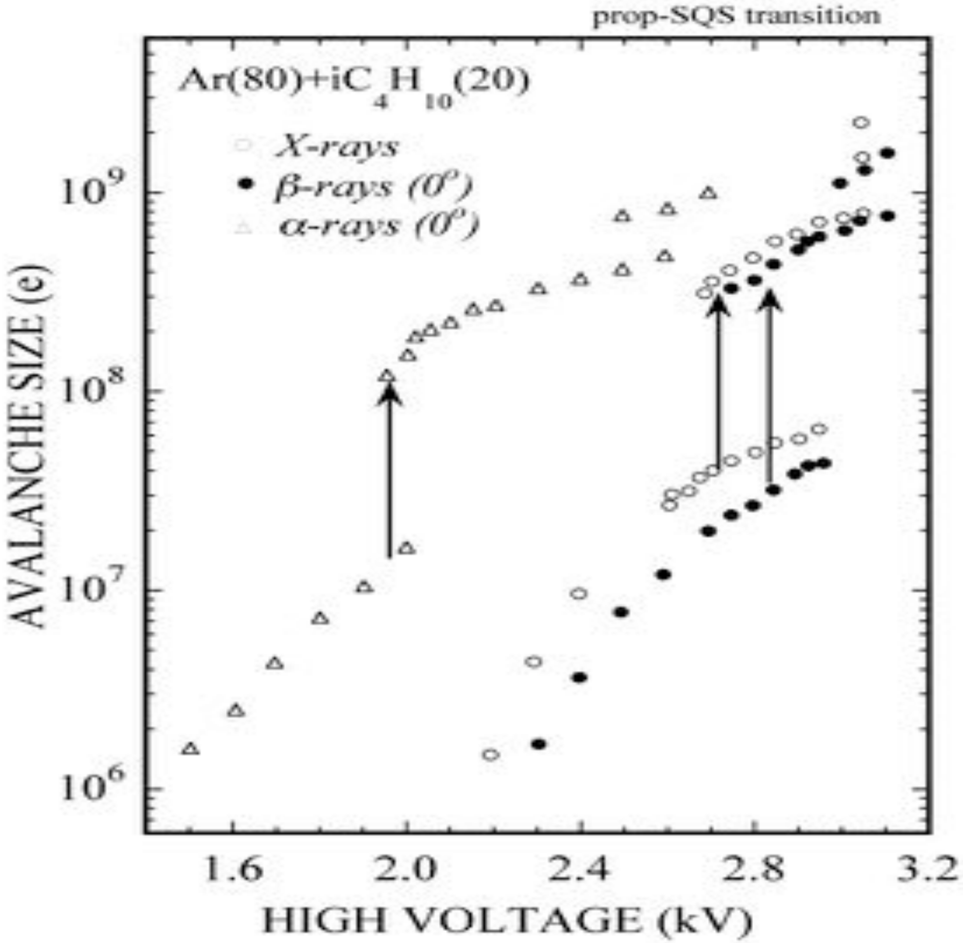
PHOTONS FEEDBACK:
AVALANCHE SPREAD



IONS FEEDBACK:
CATHODE DAMAGE, AGING, …..







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

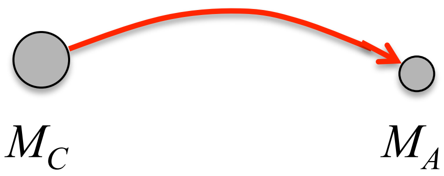
Maximum avalanche size before transition or breakdown:
Q_{MAX}=(Primary ionization)x(Gain) ~ 10^7 e

Typical proportional gain ~ 10^4

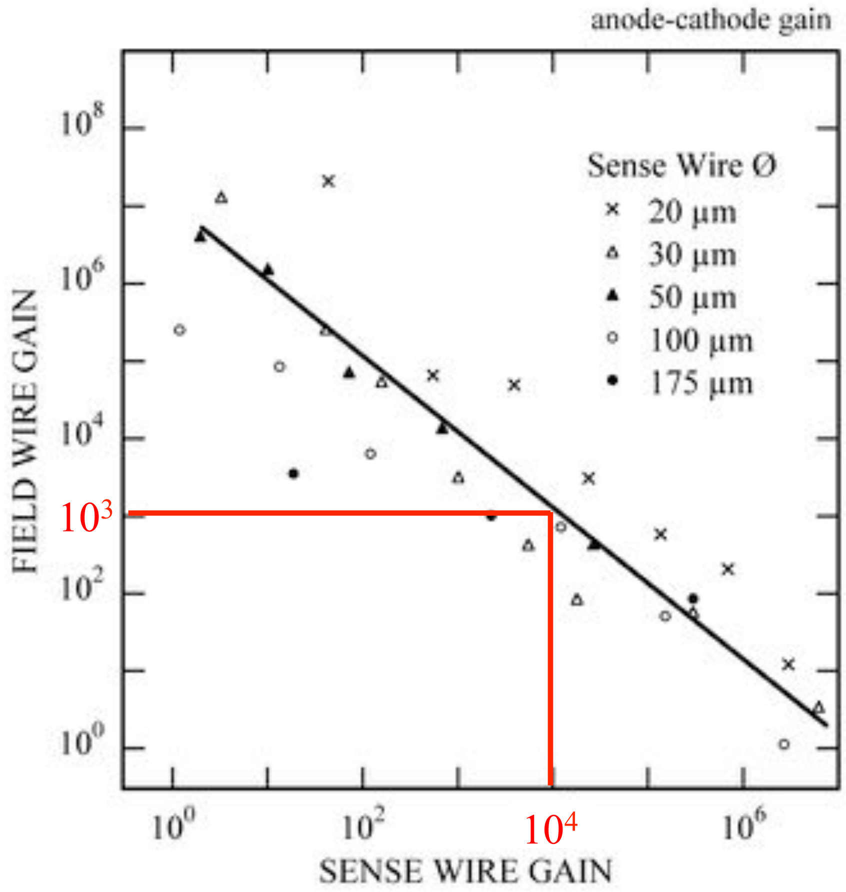
Fast particles ΔE ~ 2 keV:
$Q=(100)x(10^4)=10^6$

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

Multiwire structures:
Cathode pre-amplification of field emitted electrons

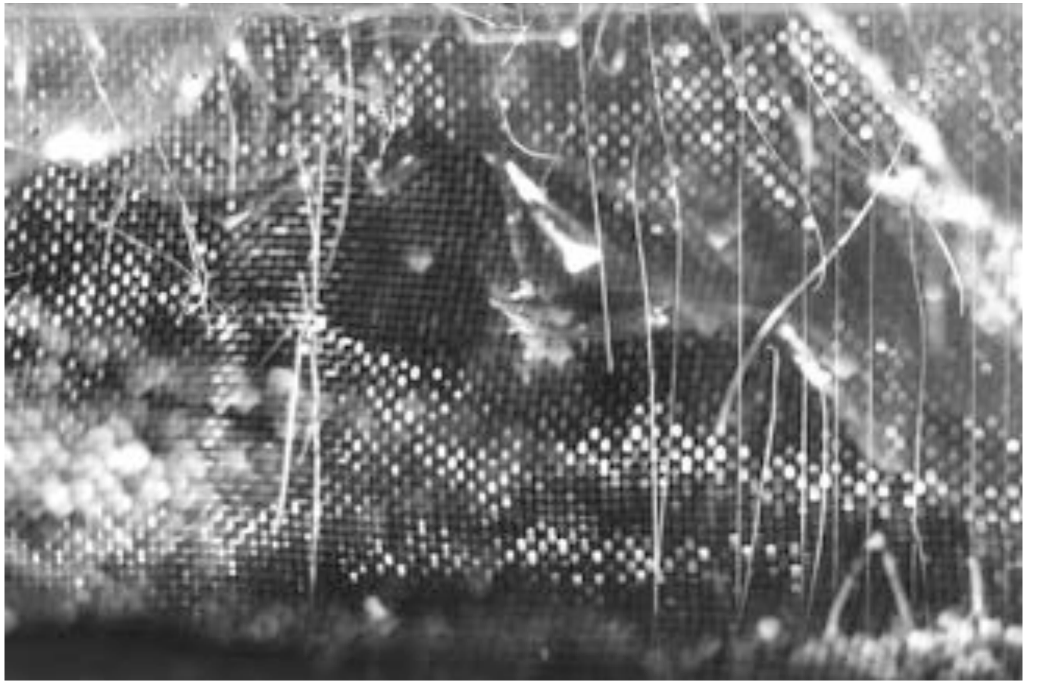


$M=M_C \times M_A$



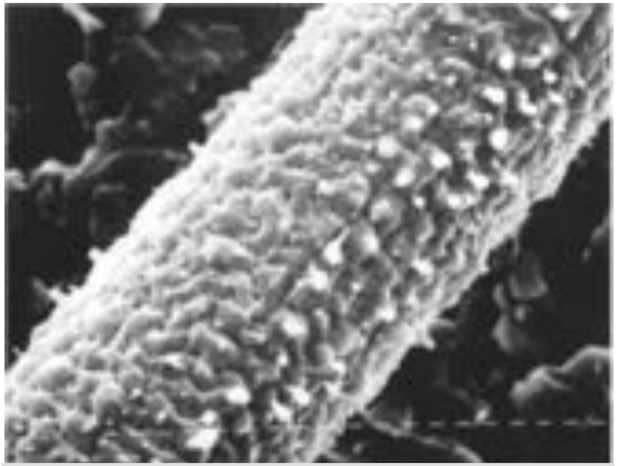
P. Giubellino et al, Nucl. Instr. and Meth. A245(1986)155

Spark damages in MWPCs:

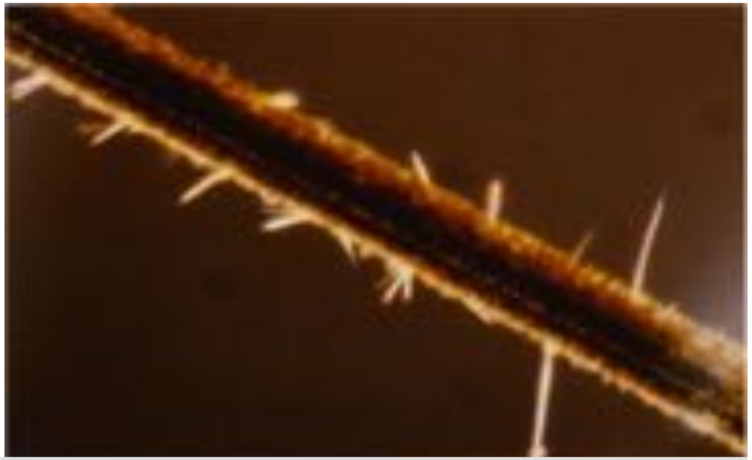


Fabio's Museum of Horrors

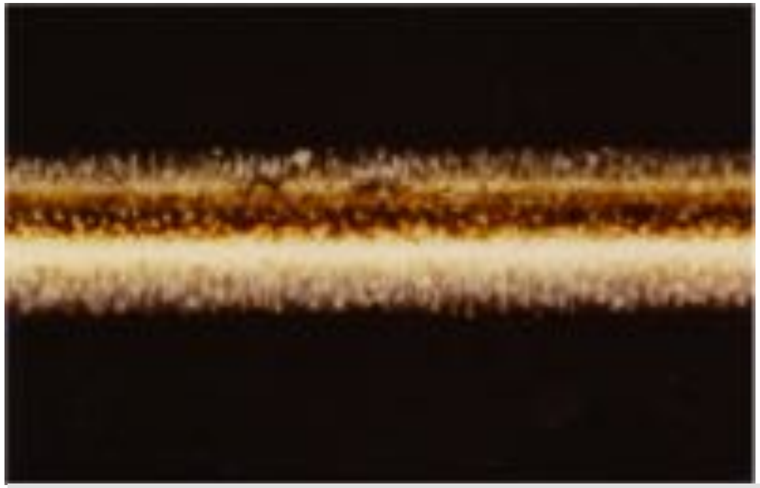
Polymerization of organic compounds with formation of deposits on thin wires:



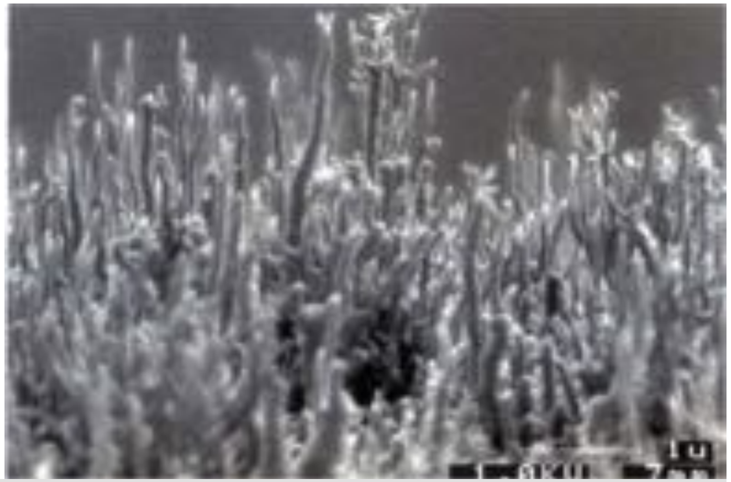
O. Ullaland, LBL-21170 (1986)107



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

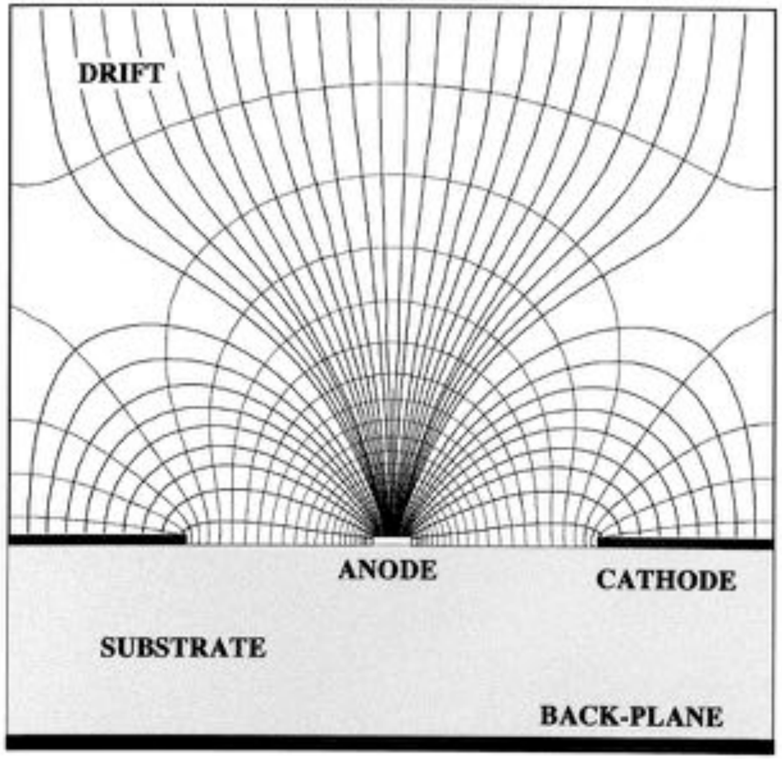


I. Juric and J. Kadyk, LBL-21170 (1986)141



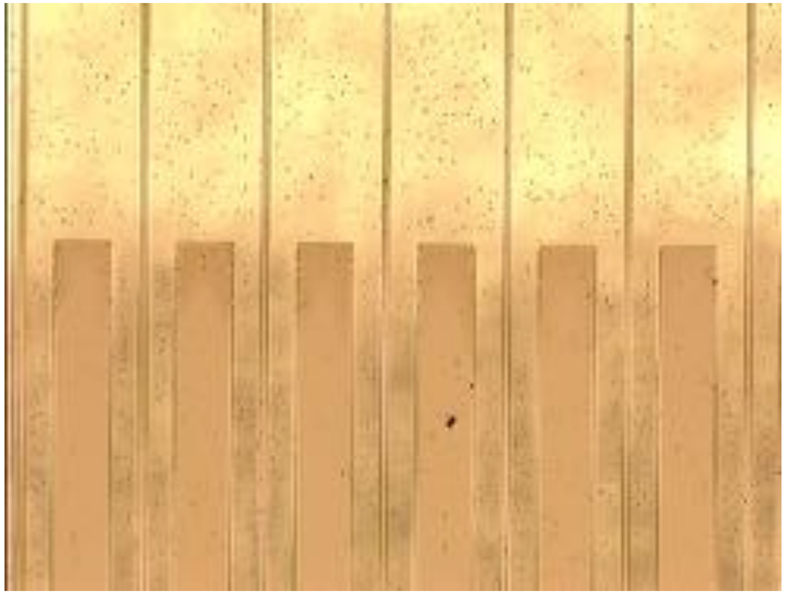
M. Binkley et al,
Nucl. Instr. and Meth. A515(2003)53

Anton Oed, 1988

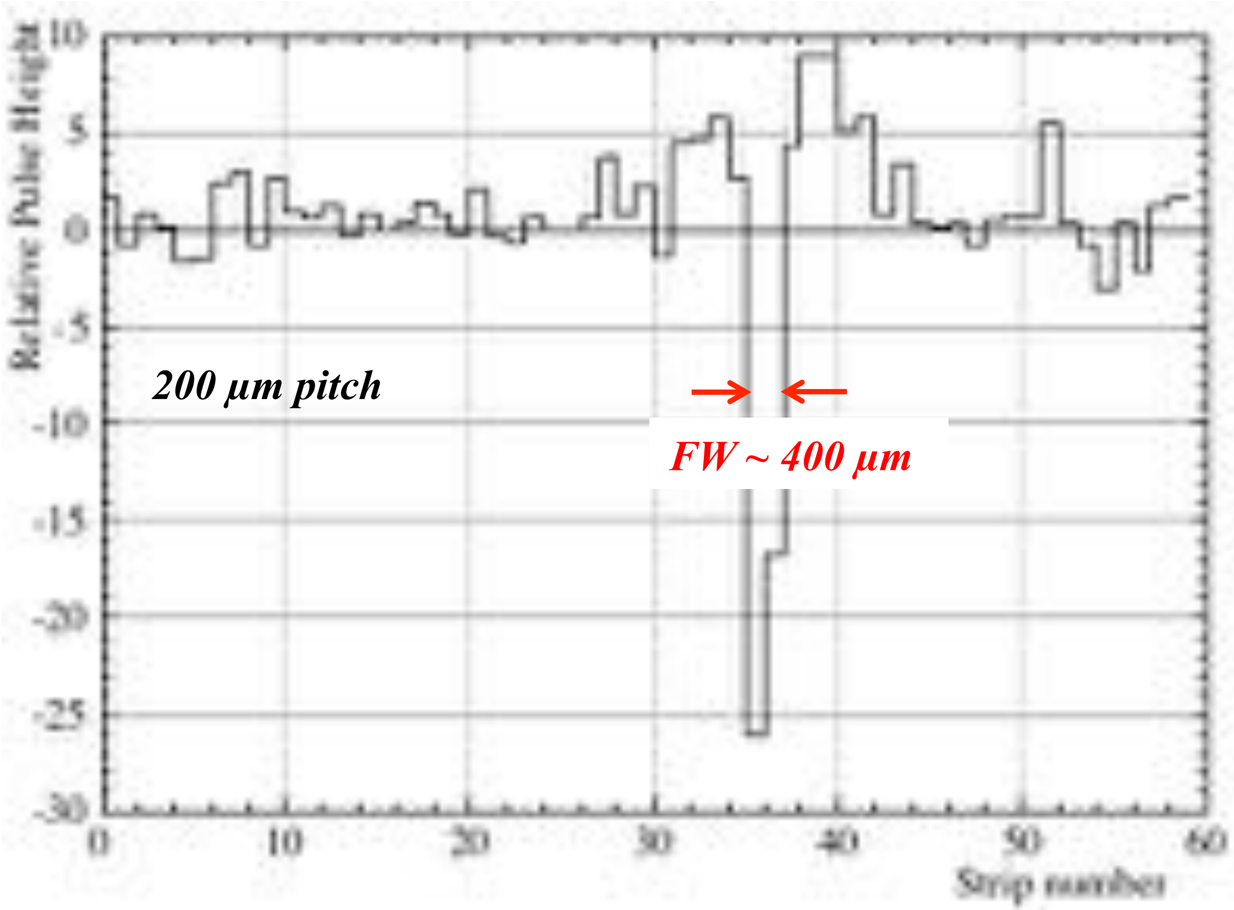


A. Oed, Nucl. Instr. and Meth. A263(1988)351

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

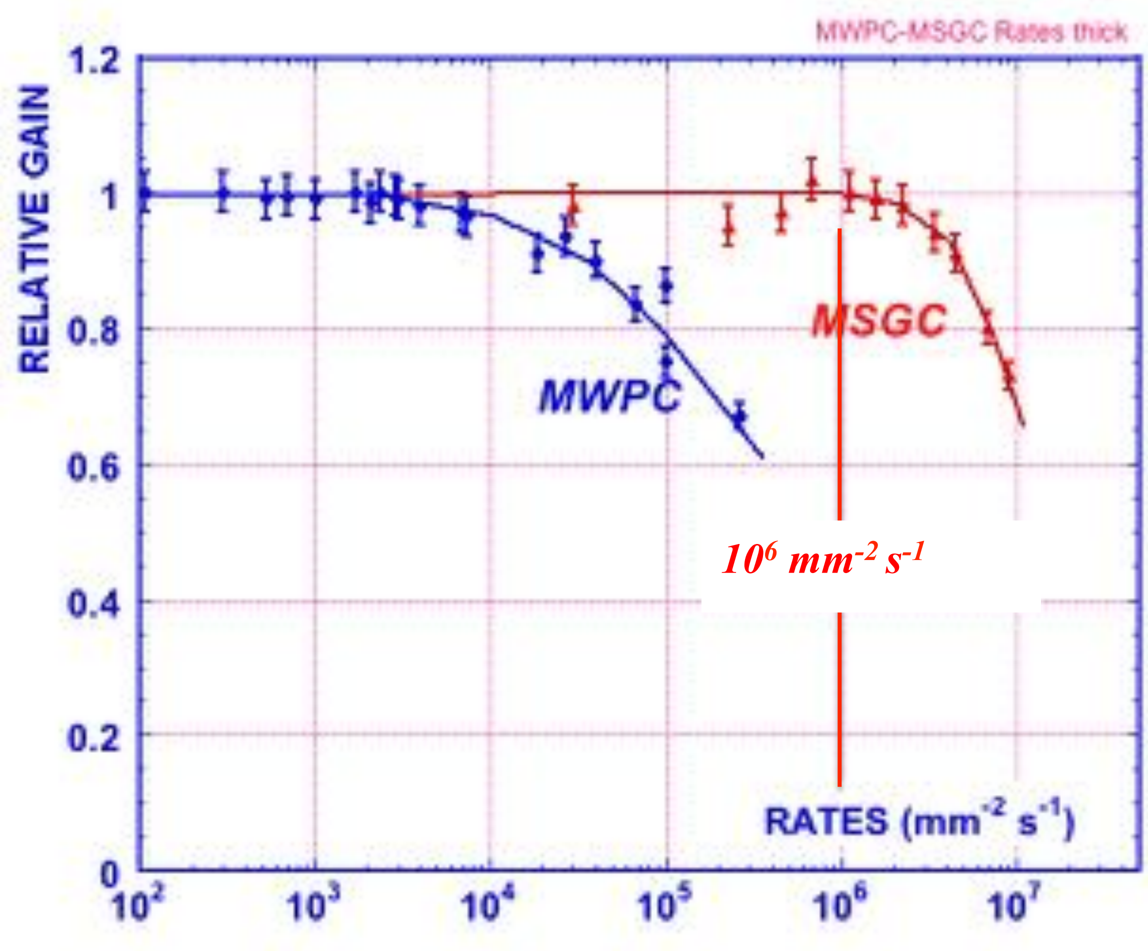


Single track signal width (two-track resolution):



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

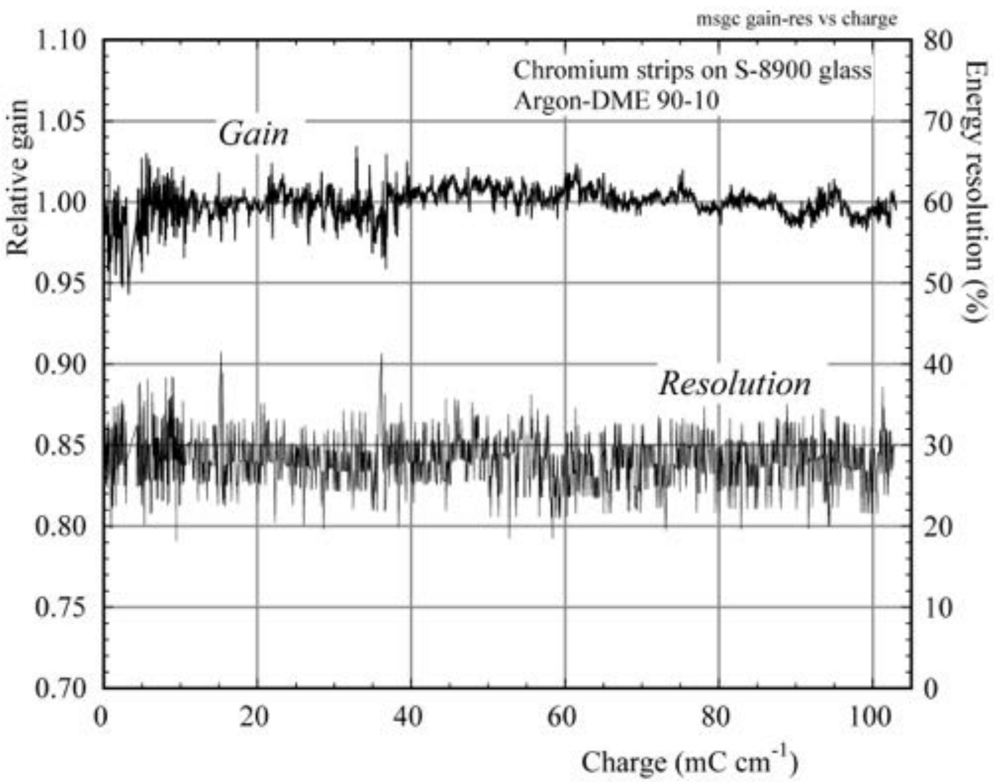
Rate capability: 1 MHz/mm^2



Fast signals ~ 30 ns (1.5 mm)

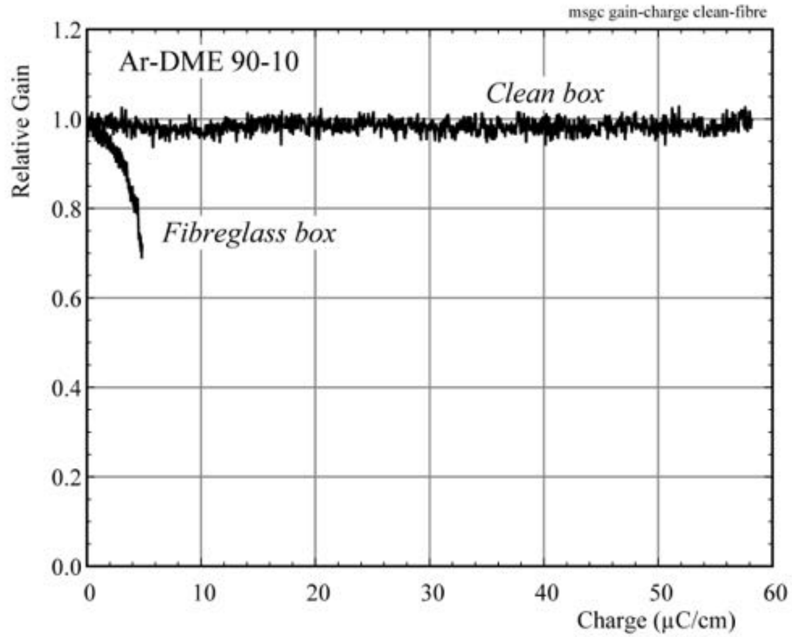
Volume resolution
$\Delta V \sim 1 \times 1 \times 2 = 2\ mm^3$

MSGC GAIN vs COLLECTED CHARGE



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

EXTREME SENSITIVITY TO CONTAMINATIONS

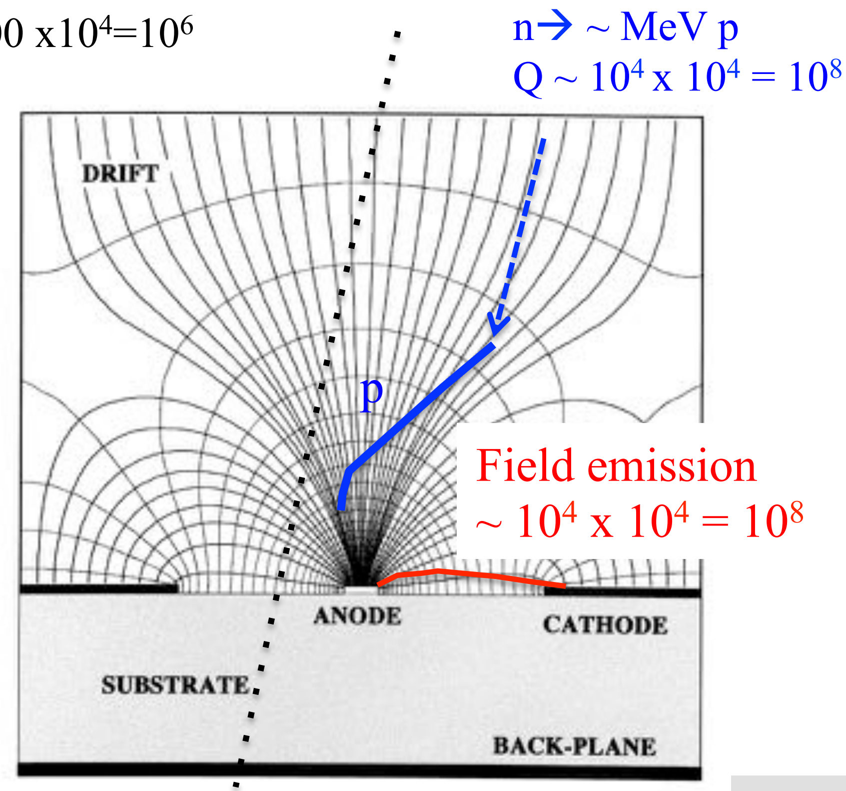


R. Boucler et al, Nucl. Instr. and Meth. A348(1994)109

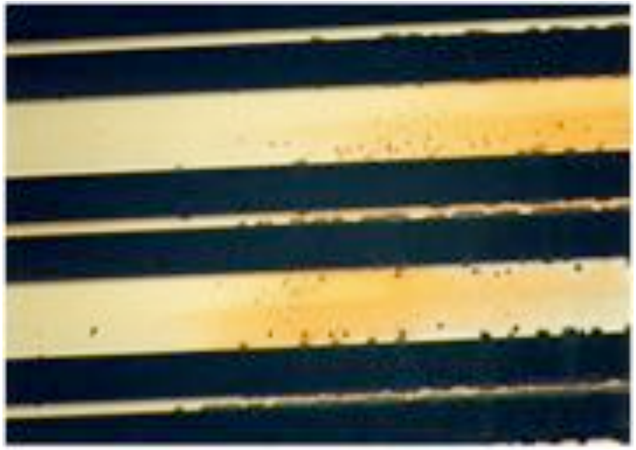
DISCHARGES IN MICROSTRIP CHAMBERS

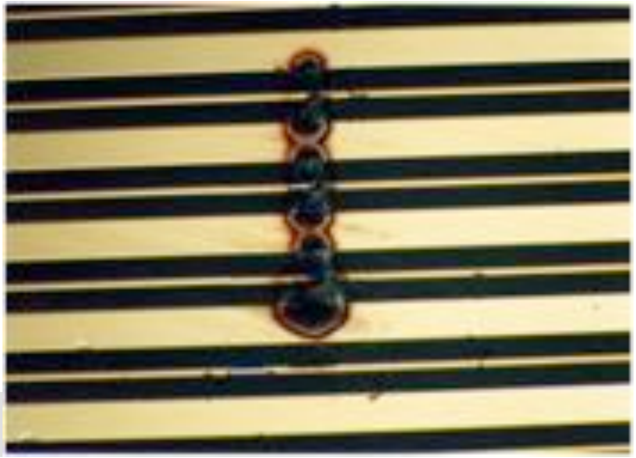
Pre-amplification of electrons emitted by cathode strip edges

MINIMUM IONIZING PARTICLES
$Q = 100 \times 10^4 = 10^6$



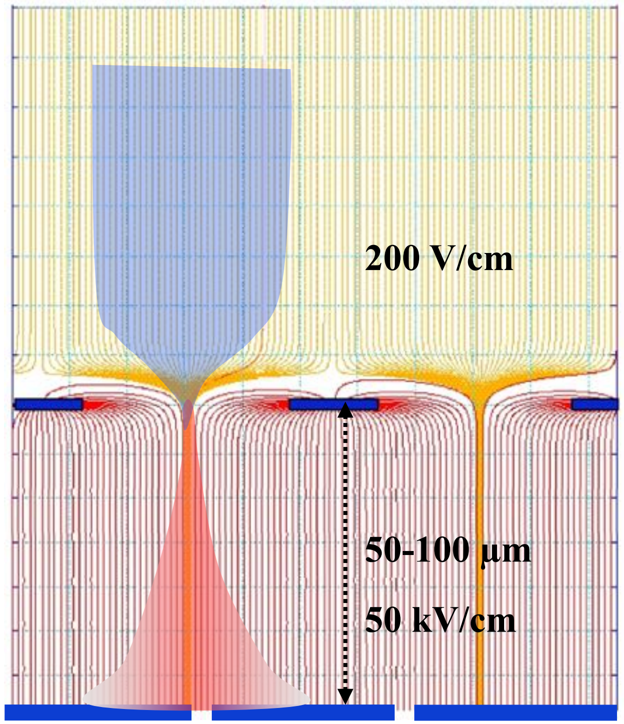
T. Beckers et al, Nucl. Instr. and Meth. A346(1994)95



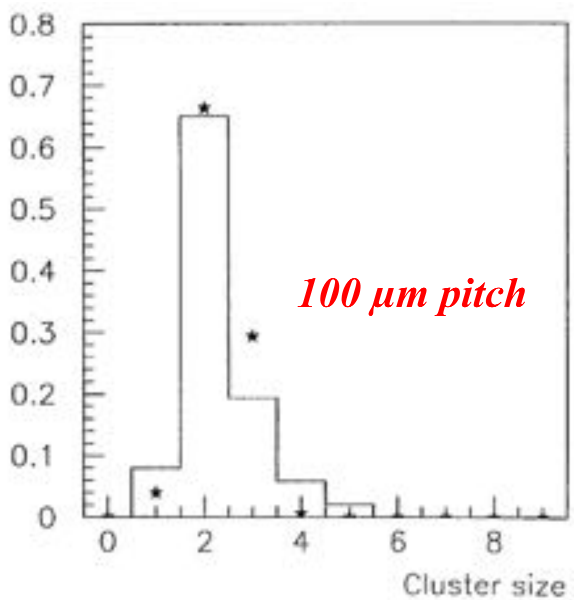


Fabio's Museum of Horrors

HIGH/LOW FIELD REGIONS SEPARATED BY A MESH



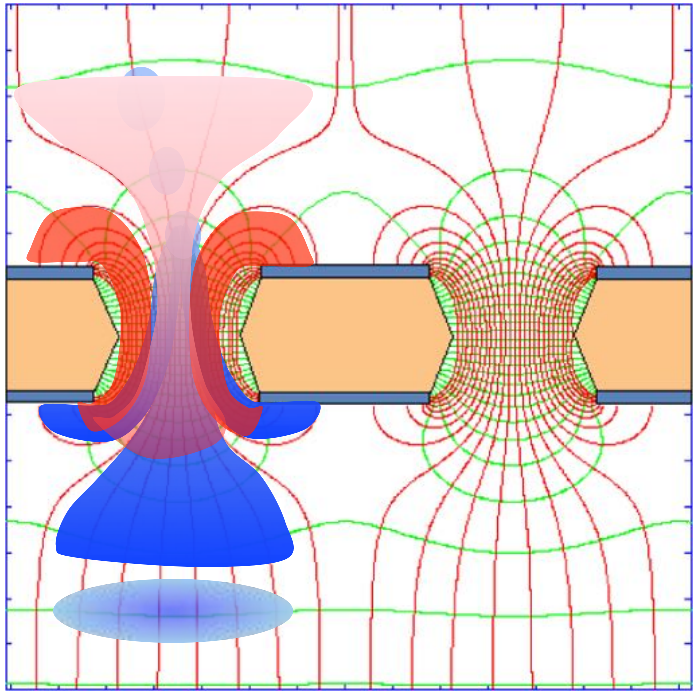
Signal distribution: 200 µm fwhm



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

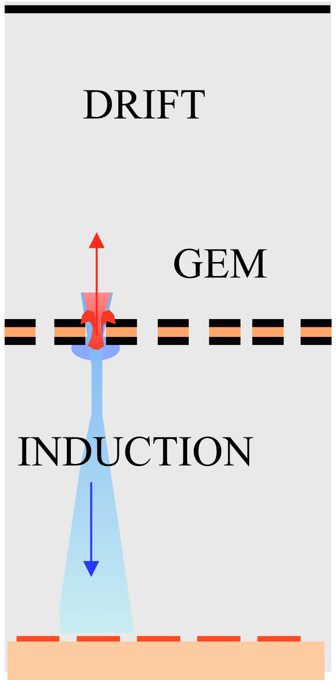
J. Derré et al,
Nucl. Instr. and Meth. A459(2001)523

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

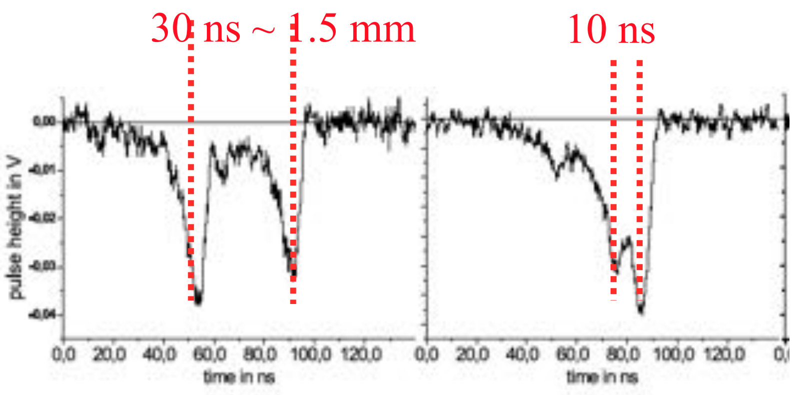


F. Sauli, Nucl. Instr. and Meth. A386(1997)531

FAST ELECTRON SIGNAL ONLY ON ANODE STRIPS



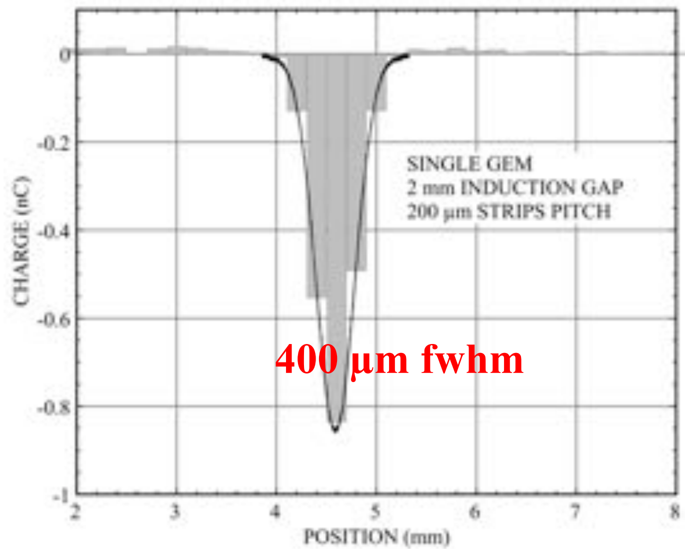
TWO-TRACK RESOLUTION
(DRIFT TIME):



M. Ziegler, PhD Zürich Univ. (2002)

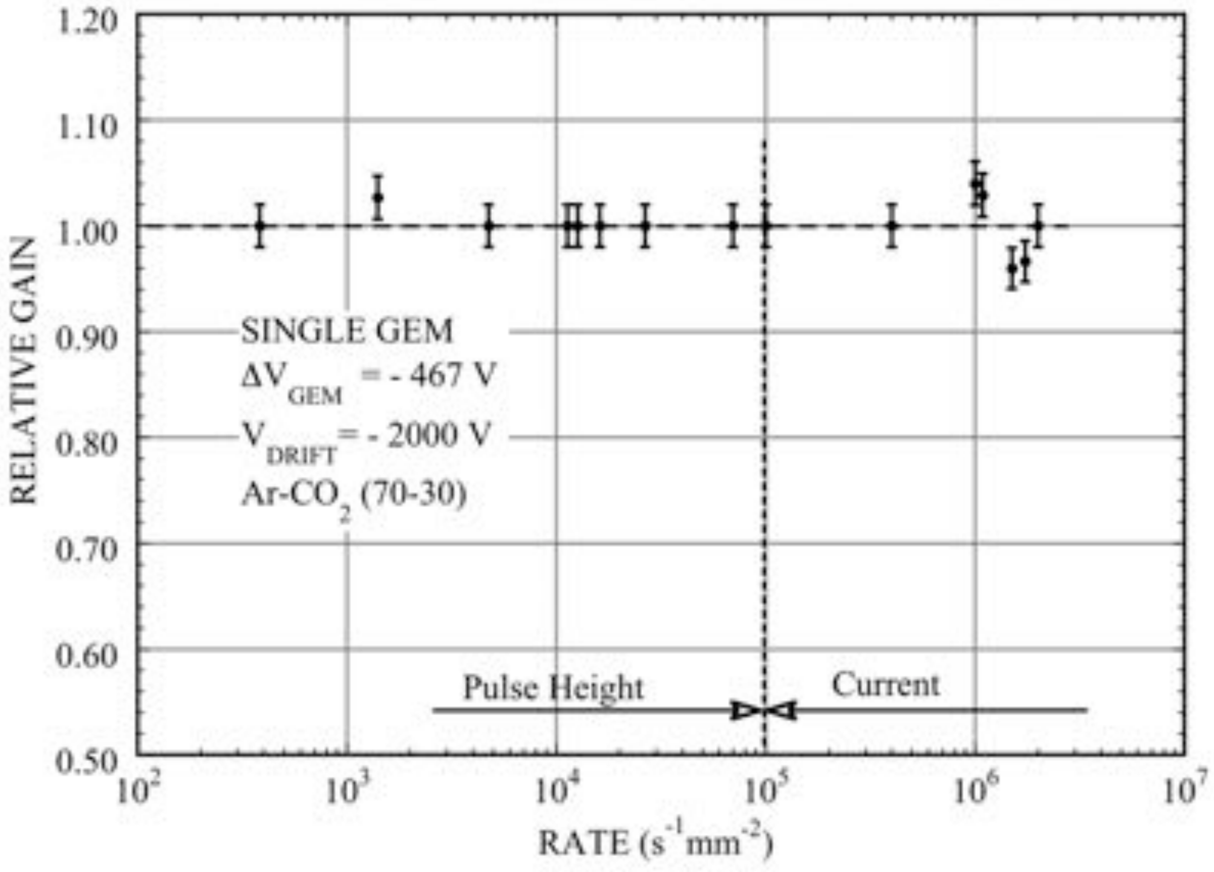
VOLUME RESOLUTION
~ 1 mm^3

TWO-TRACK RESOLUTION
(PROJECTION):



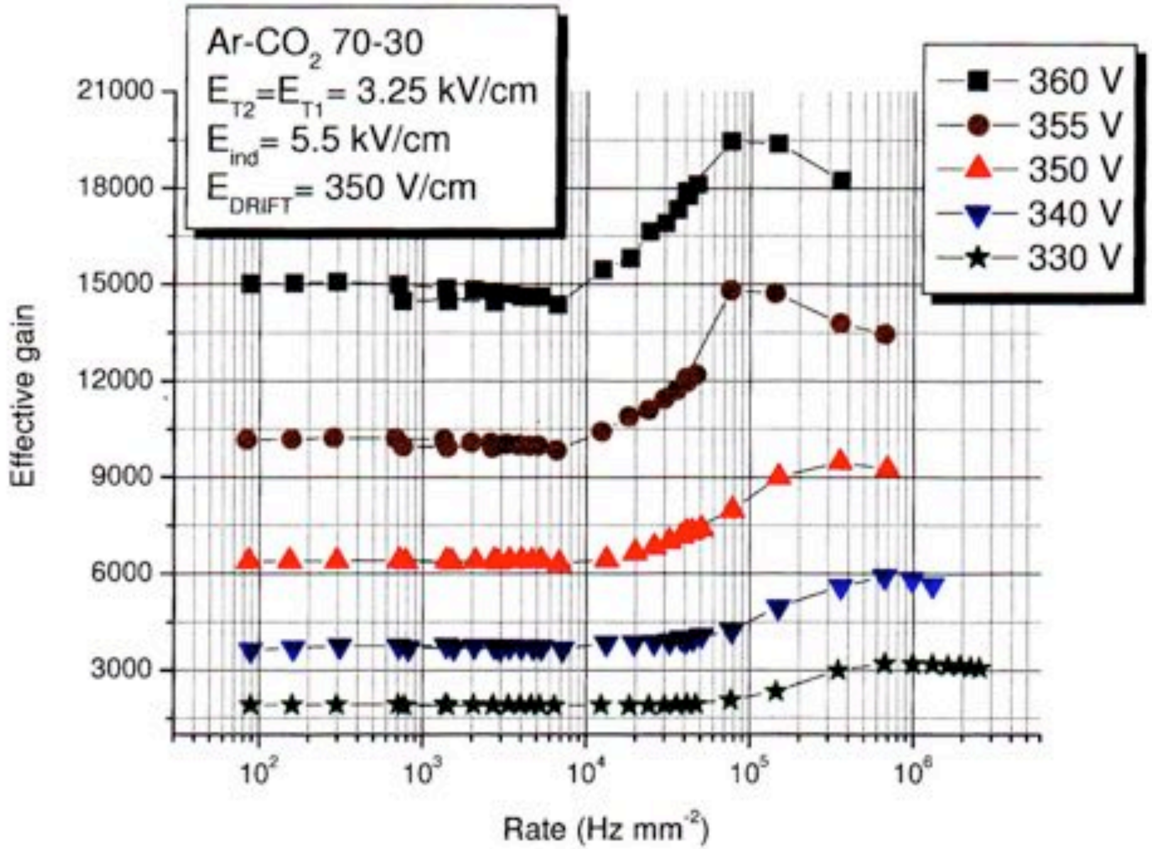
A. Bressan et al, Nucl. Instr. and Meth. A425(1999)262

GEM GAIN vs RATE (SOFT X-Rays)



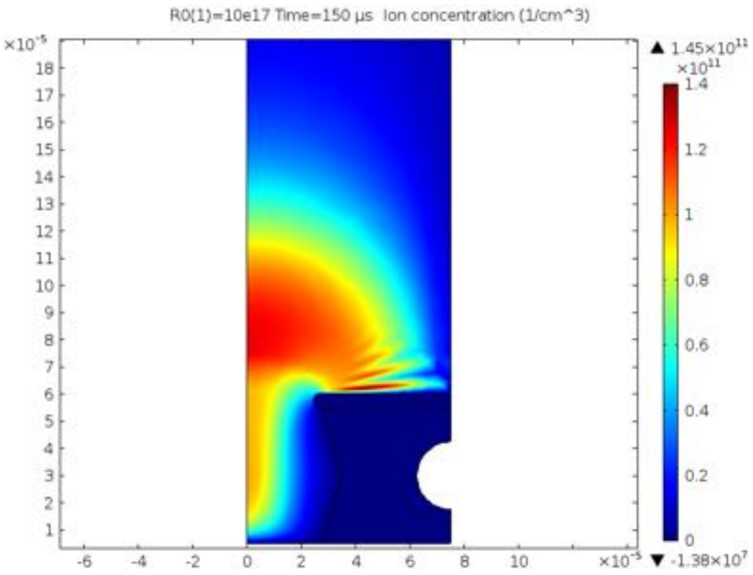
J. Benlloch et al, IEEE NS-45(1998)234

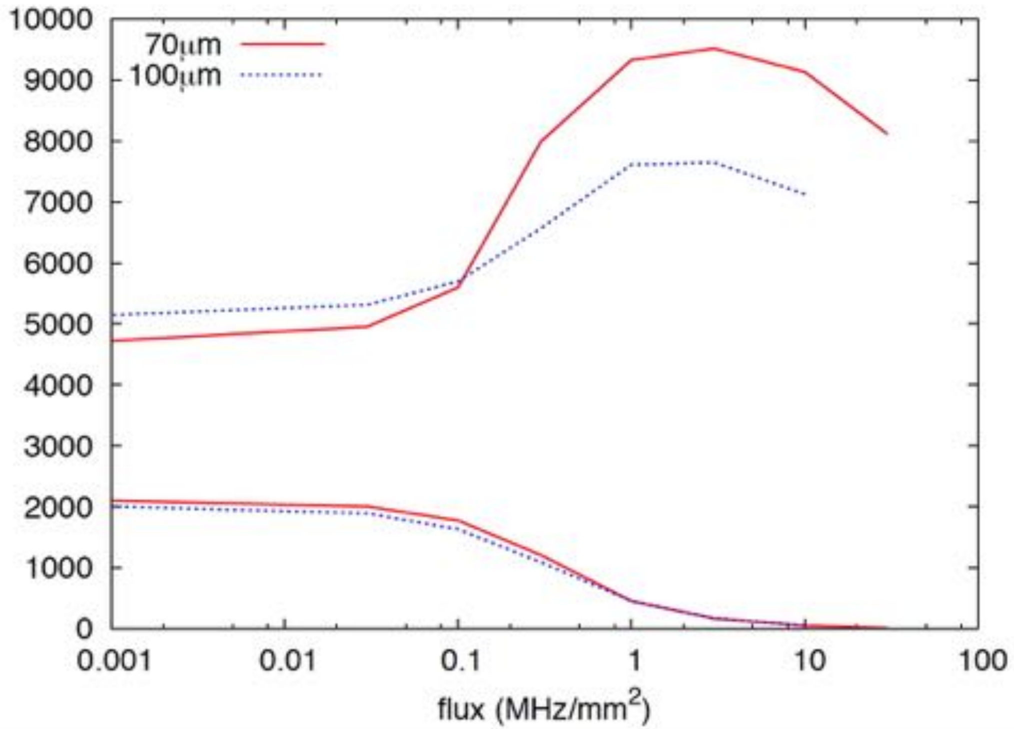
A STRANGE OBSERVATION: GAIN INCREASE AT VERY HIGH RATES (2006, UNPUBLISHED)



Peter Everaerts, PhD Gent University (2006)

A RECENT SIMULATION



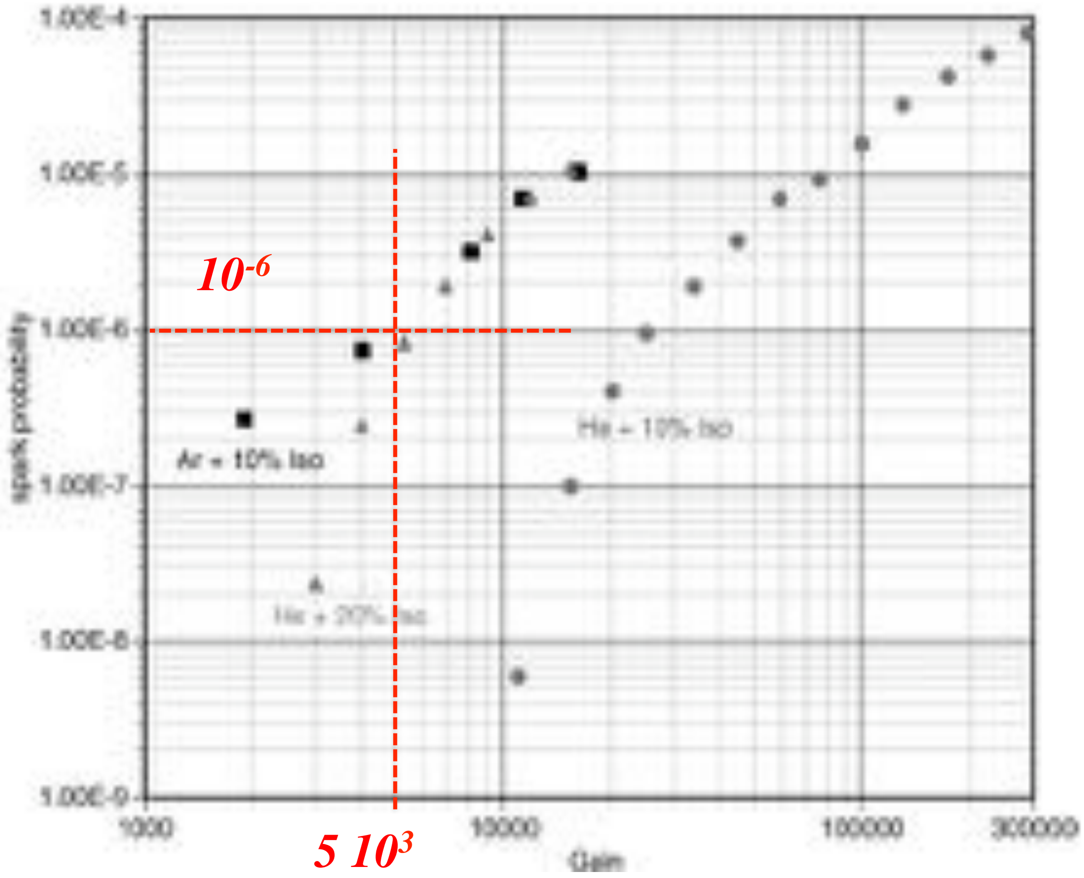


COMSOL Finite Element Analysis
GARFIELD

S. Franchino et al, Subm. IEEE Nucl. Sci. Symposium (San Diego, Oct. 31, 2015)

MICROMEGAS: SPARK PROBABILITY IN HADRON BEAM

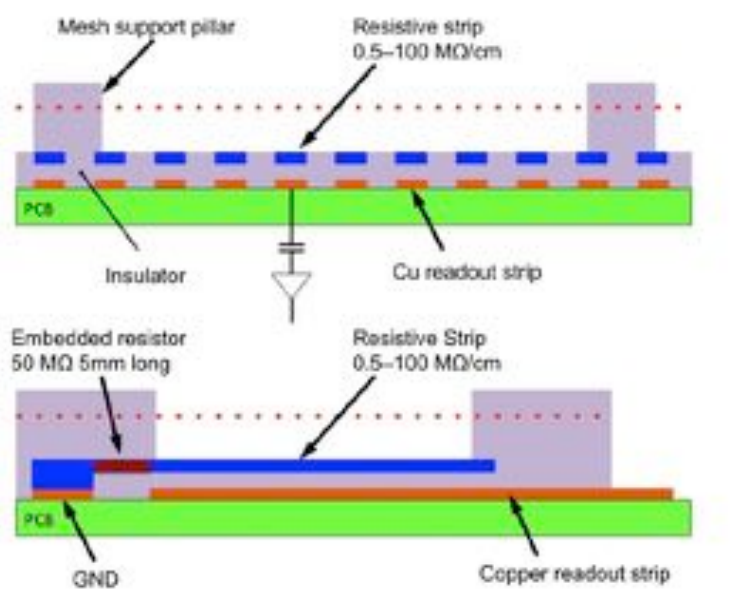
FOR A GAIN OF 5.10^3 , 10^6 PARTICLES s^{-1}:
~ ONE DISCHARGE / SECOND

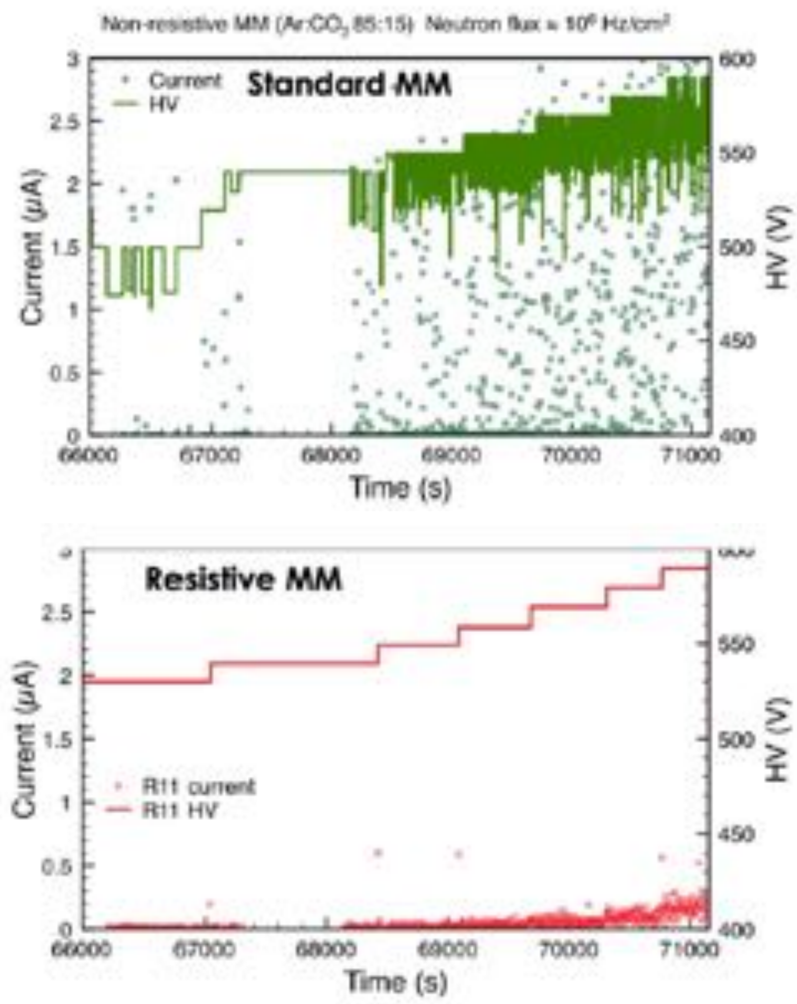


A. Delbart et al, Nucl. Instr. and Meth. A478(2002)205

SPARK RATES IN NEUTRON BEAM EXPOSURE:

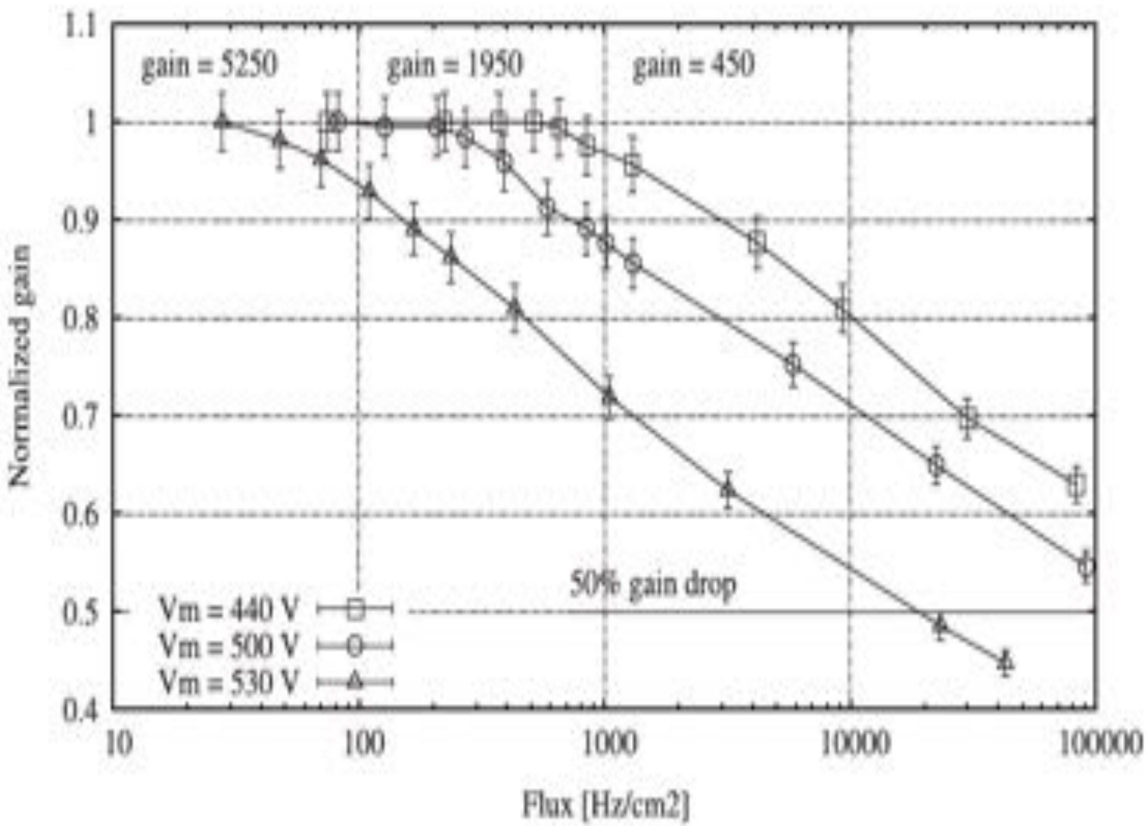
BUILT ON A HIGH-RESISTIVITY POLYMER





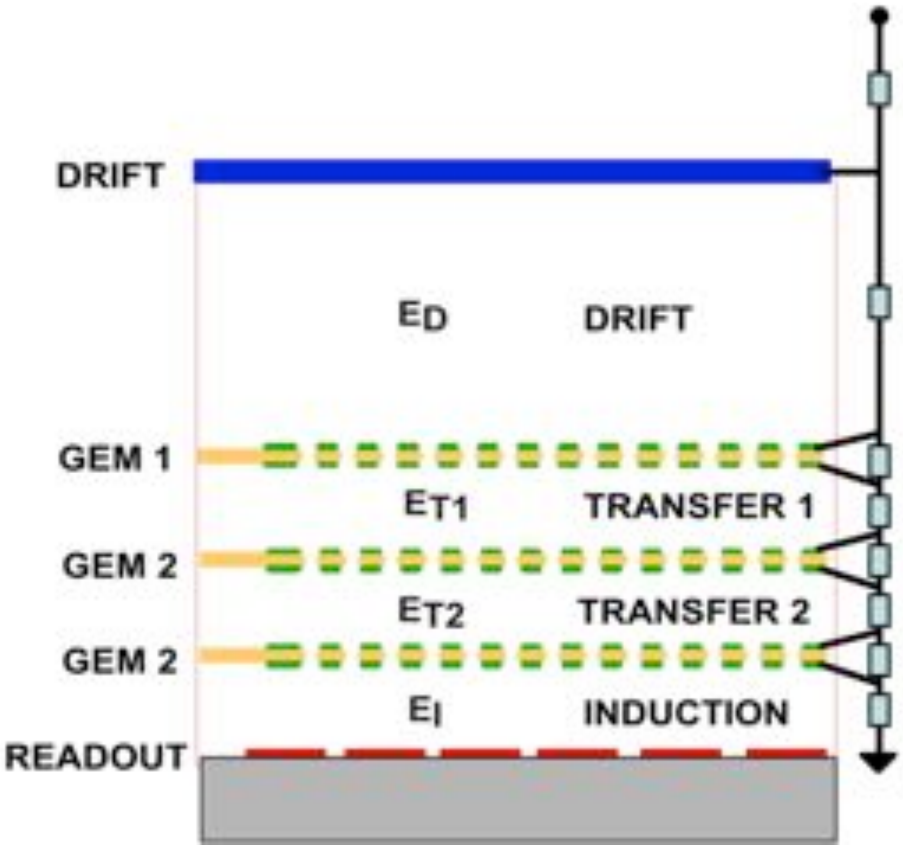
T. Alexopolous et al, Nucl. Instr. and Meth. A640(2011)110

GAIN REDUCTION AS A FUNCTION OF RATES:



J. Galán et al, Nucl. Instr. and Meth. A732(2013)229

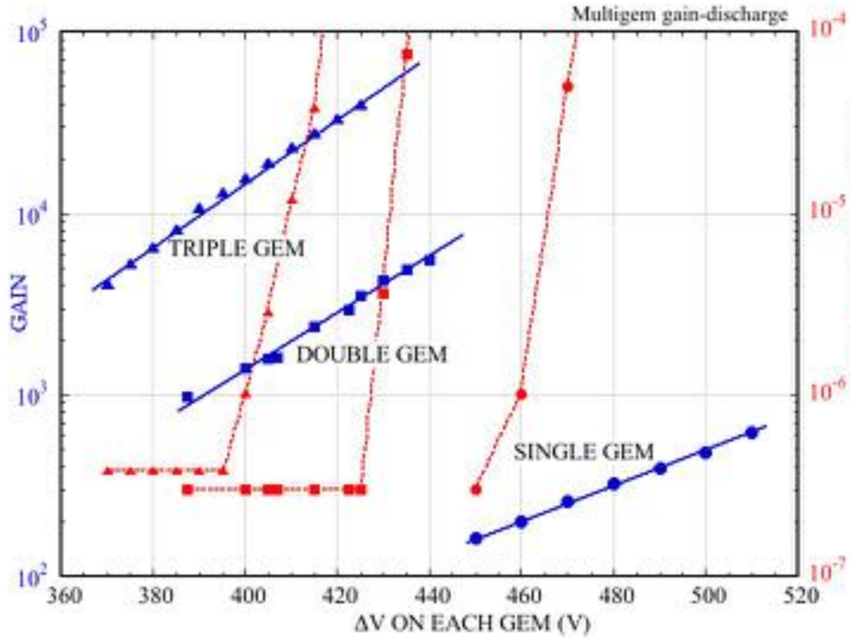
TRIPLE-GEM (TGEM): CASCADED GEM ELECTRODES



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

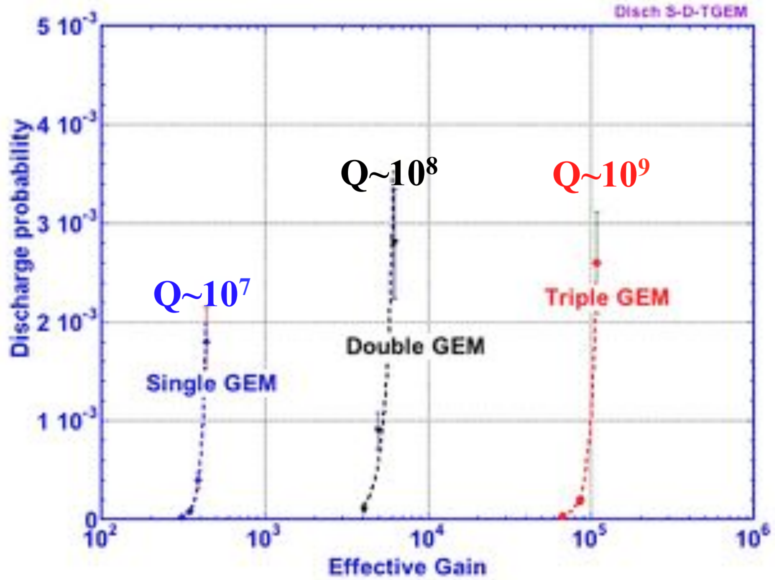
GAIN VS VOLTAGE – 5.9 keV

DISCHARGE RATE ON ~ 5 MeV α



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

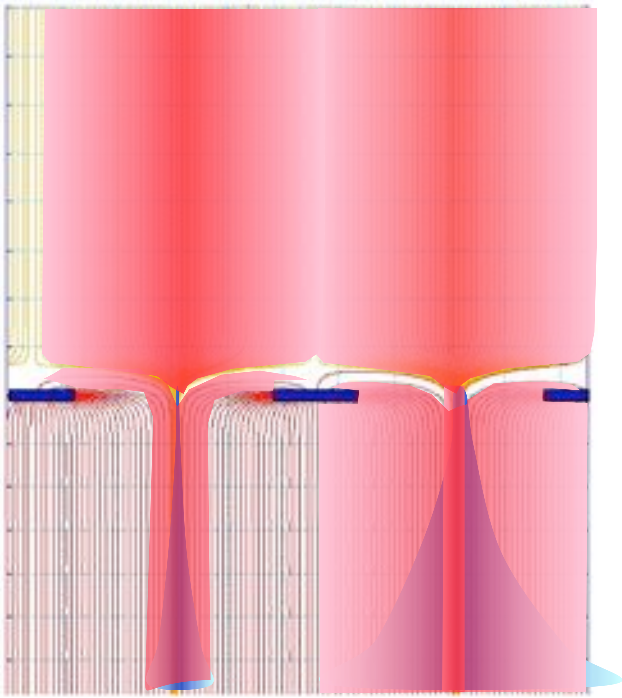
DISCHARGE PROBABILITY VS GAIN:

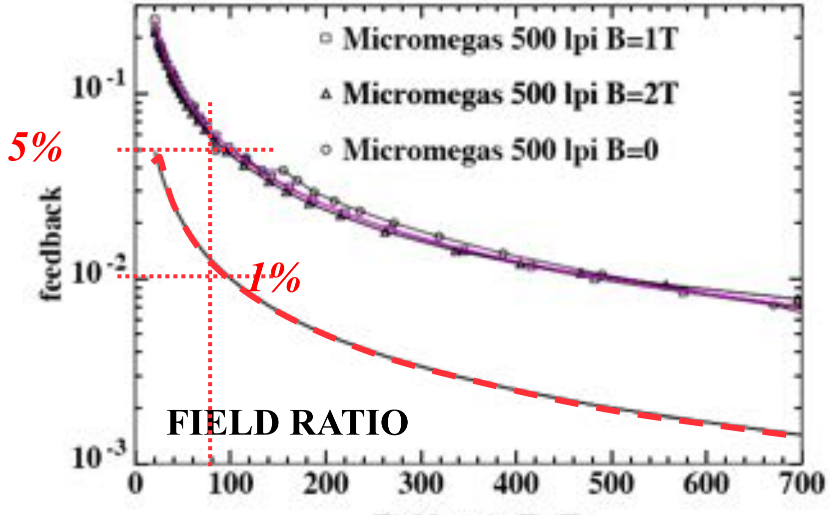


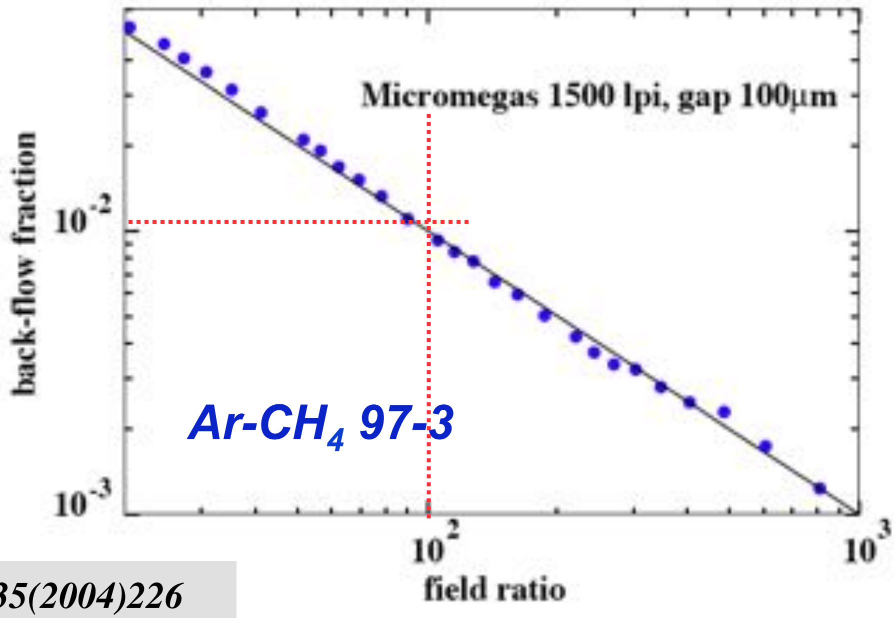
WHAT ABOUT THE RAETHER LIMIT?

IN MULTI-GEMS, THE CHARGE SPREADS OVER MANY INDEPENDENT HOLES!

THE IONS BACKFLOW DEPENDS ON AVALANCHE SPREAD, BUT CANNOT BE SMALLER THAN THE FIELD RATIO:

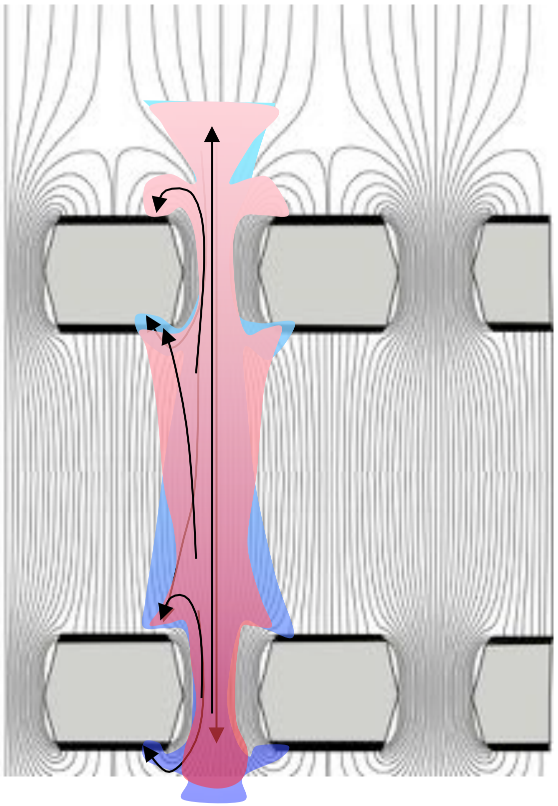


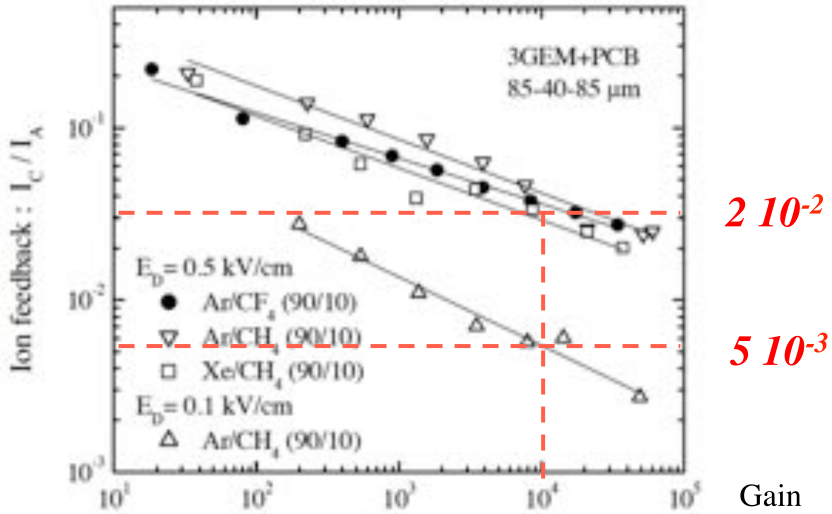




P. Colas et al, Nucl. Instr. and Meth. A535(2004)226

THE IBF VALUE RESULTS FROM THE INTERPLAY OF GEOMETRY, FIELDS, DIFFUSION:



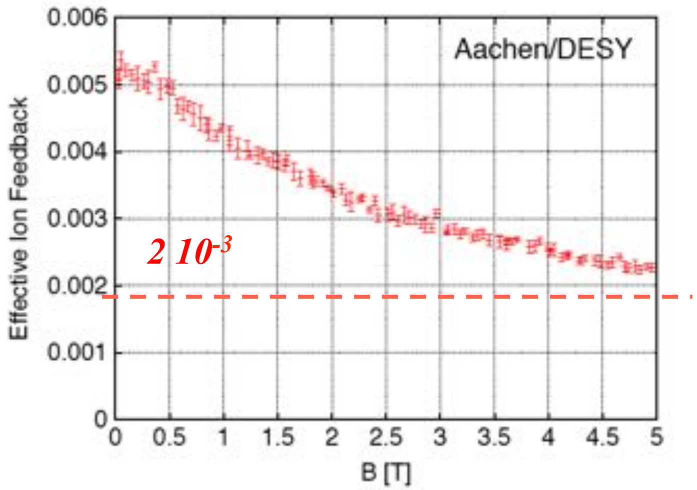


A. Bondar et al, Nucl. Instr. and Meth. A496(2003)325

MAGNETIC FIELD:

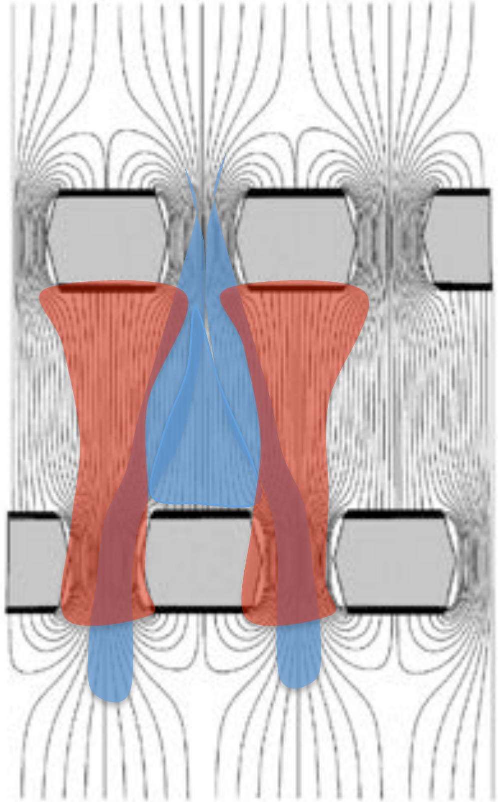
THE WISH:

$$IBF \leq \frac{1}{GAIN} \approx 10^{-4}$$



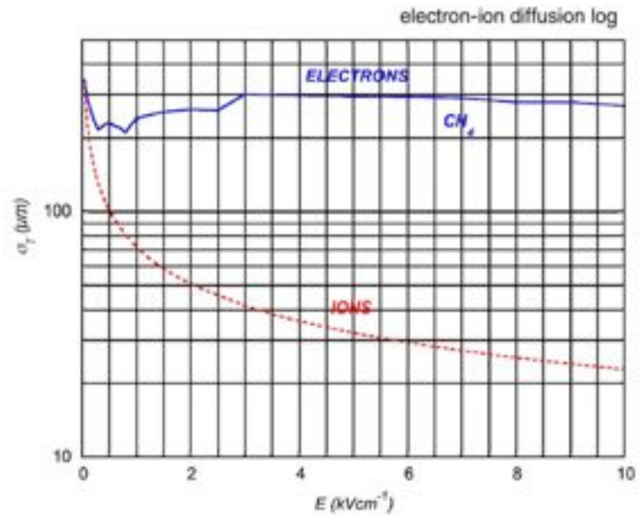
M. Killenberg et al, Nucl. Instr. and Meth. A530(2004)251

EXPLOIT THE DIFFERENCE BETWEEN IONS' AND ELECTRONS' DIFFUSION IN AN OFFSET DOUBLE THICK-GEM

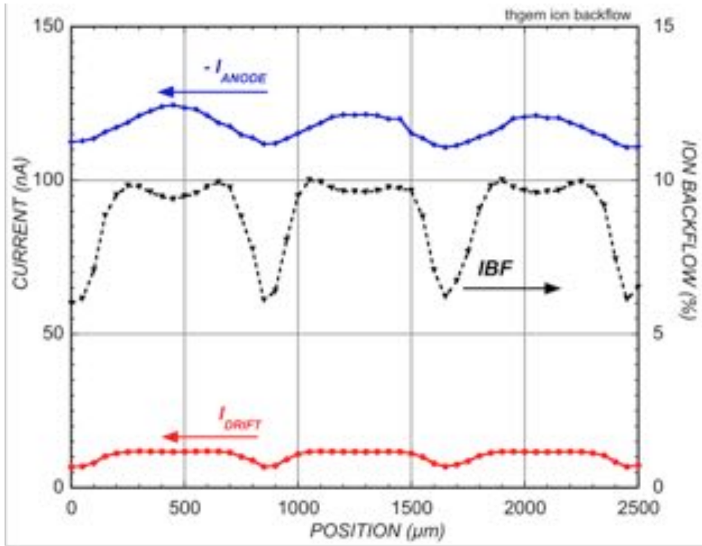


F. Sauli et al, Nucl. Instr. and Meth. A560(2006)269

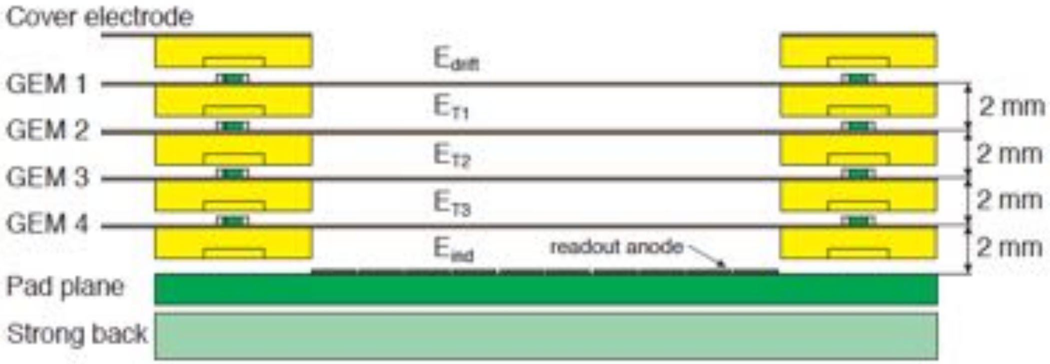
TRANSVERSE DIFFUSION:



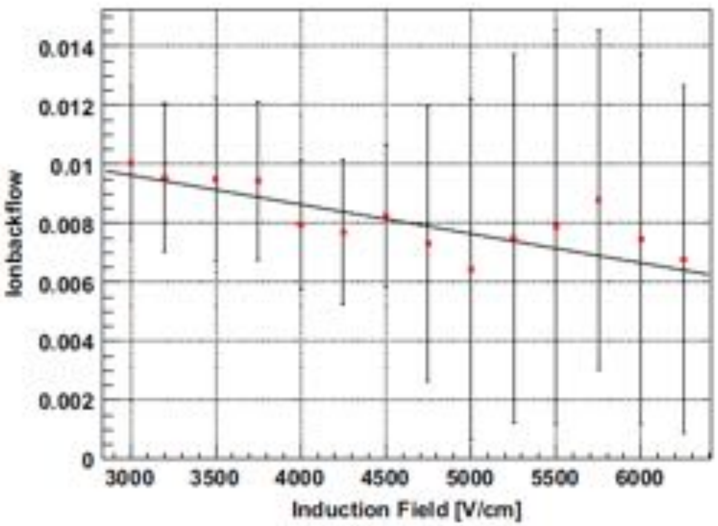
OFFSET SCAN:



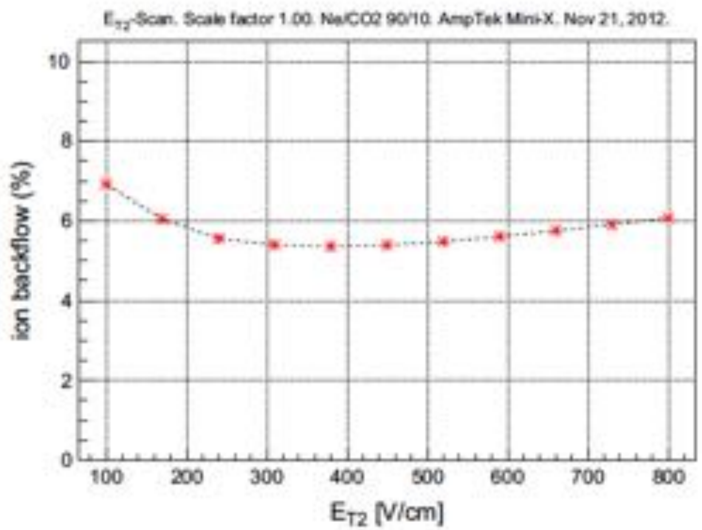
BASELINE: FOUR OFFSET GEMs



Ar-CO_2 70-30: ~ 0.8%



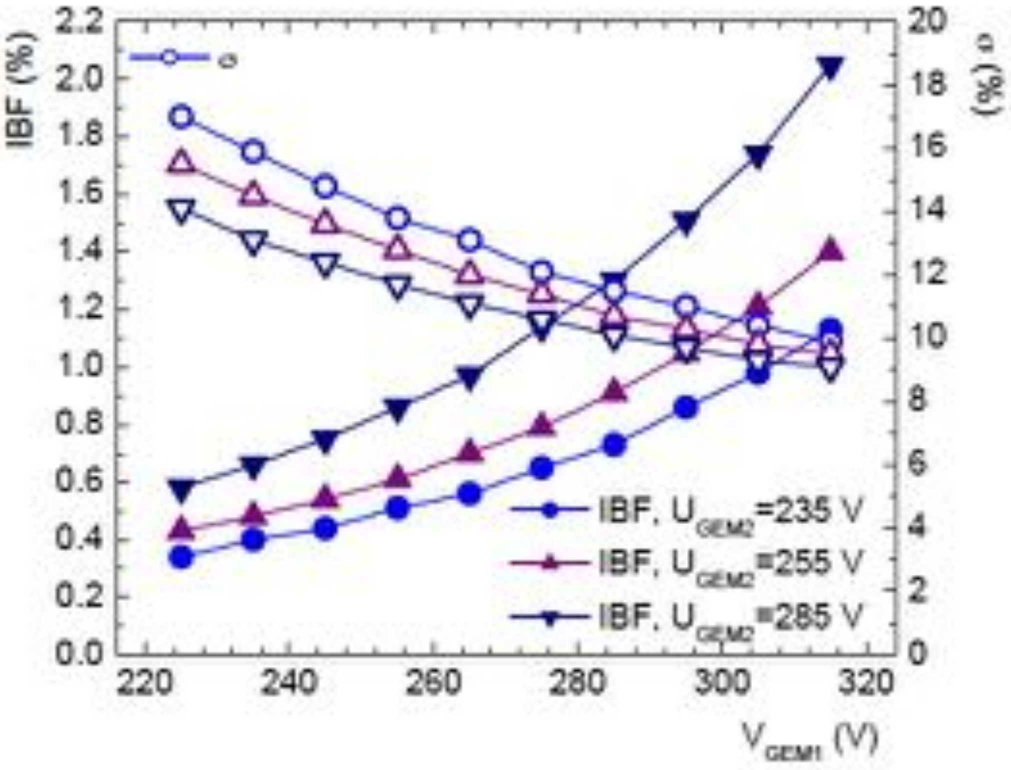
Ne-CO_2 (ALICE): ~ 5%



B. Ketzer et al, Nucl. Instr. and Meth. A732(2013)237

QUAD-GEM WITH ALTERNATING DIFFERENT PITCH

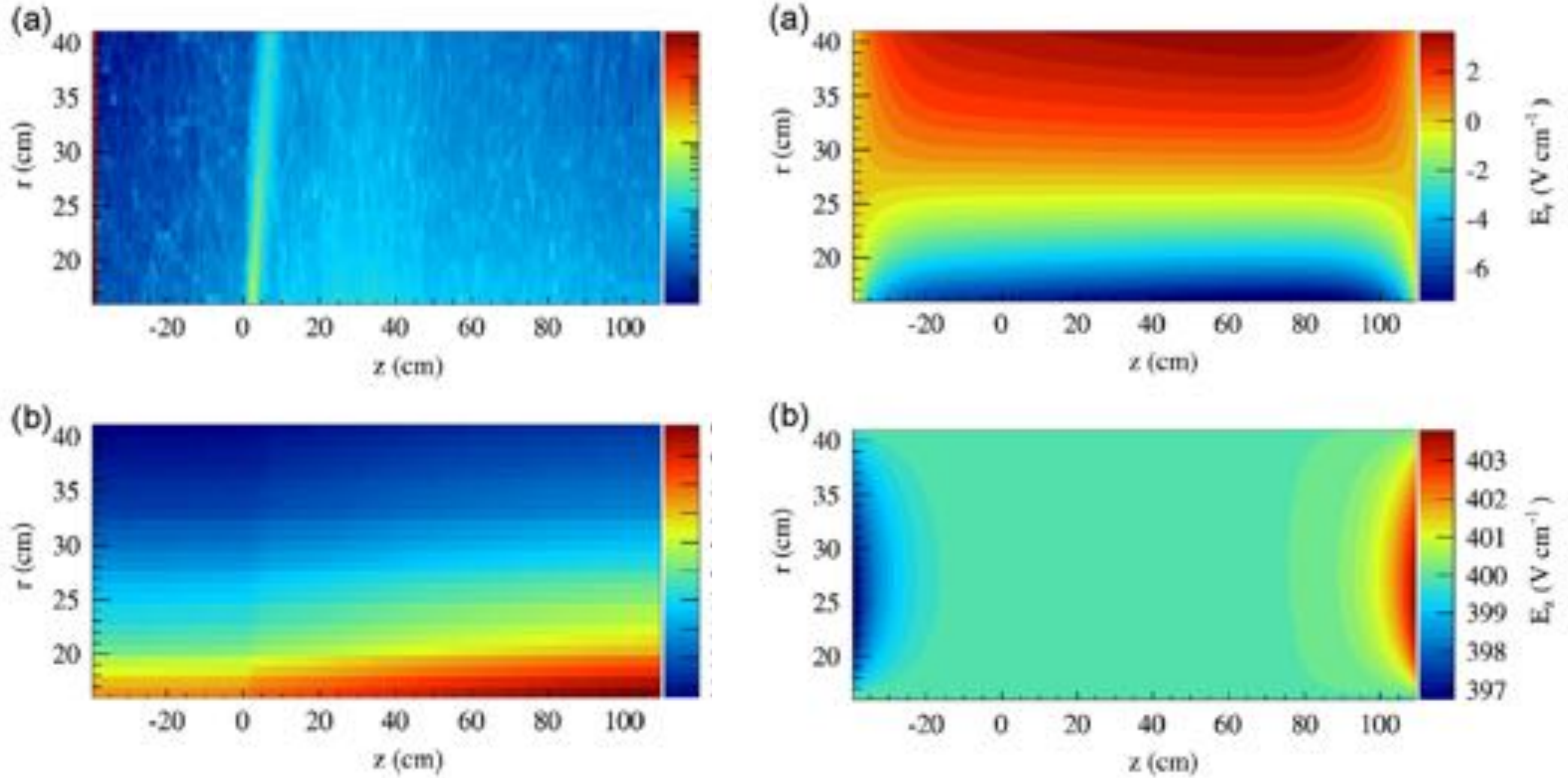
IBF AND ENERGY RESOLUTION VS VOLTAGE ON THE FIRST GEM:



ALICE TDR CERN-LHCC-2013-020

SIMULATION STUDIES FOR PANDA: TRIPLE GEM OPERATED IN Ne-CO_2 90-10
2 10^7 p-p ANNIHILATIONS GAIN M=2000 IBF 2.5 10^{-3}

SPACE CHARGE DENSITY: ELECTRIC FIELD DISTORTIONS:

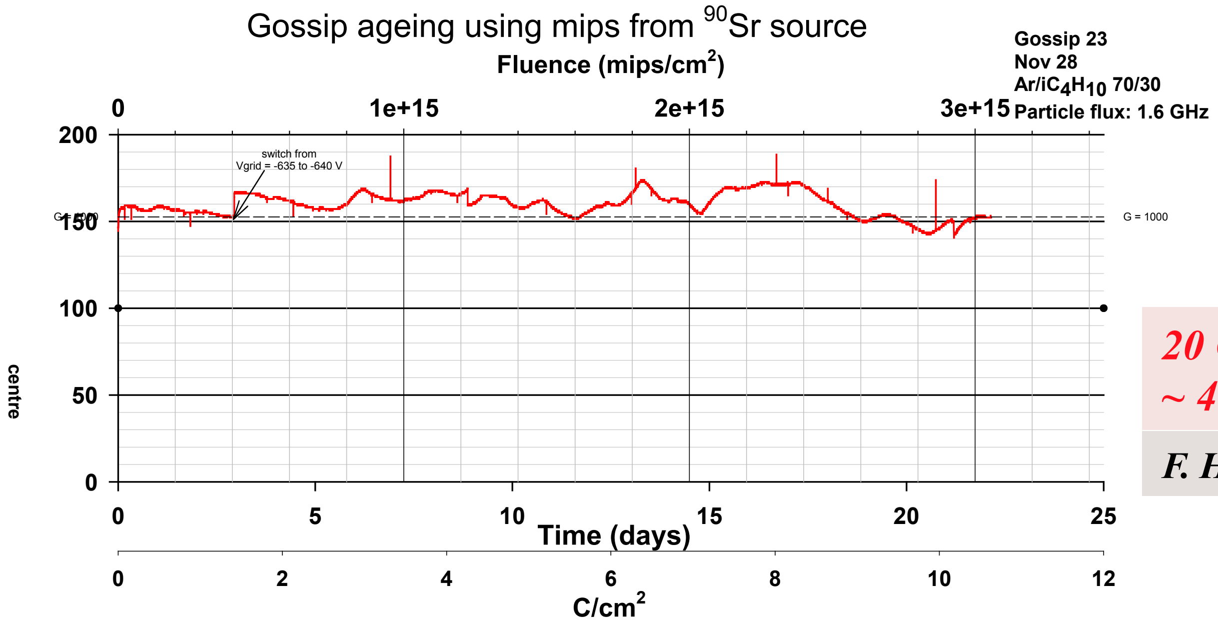


F.W. Bohmer et al,Nucl. Instr. and Meth. A719(2013)101

SYSTEMATIC IRRADIATION OF SMALL PROTOTYPES:

Irradiation with	Charge Deposit (mC/cm^2)	HL-LHC Equivalent	Results
X-Ray	225	5 HL-LHC years equivalent	No evidence of ageing
Neutron	0.5	10 years HL-LHC years equivalent	No evidence of ageing
Gamma	14.84	10 years HL-LHC years equivalent	No evidence of ageing
Alpha	2.4	5 x 10^8 sparks equivalent	No evidence of ageing

G. Iakovidis, MPGD 2013

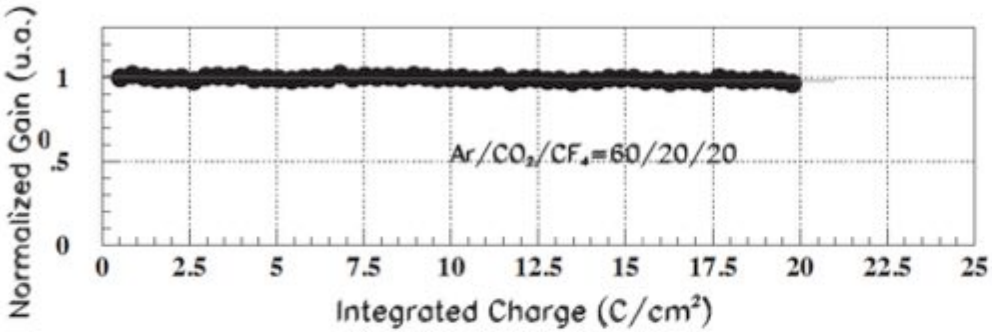


20 C cm^{-2}
~ 4 10^{14} MIPS cm^{-2}

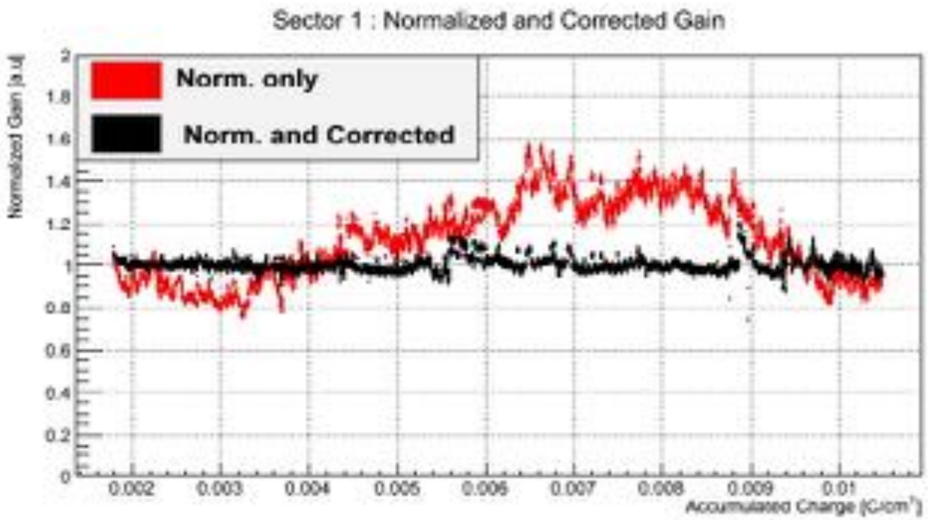
F. Hartjes, MPGD 2009

LHCb TRIGGER:

20 C/cm²
~ 4 10^{14} MIPS cm^{-2}



M. Alfonsi et al, Nucl. Instr. and Meth. A518(2004)106

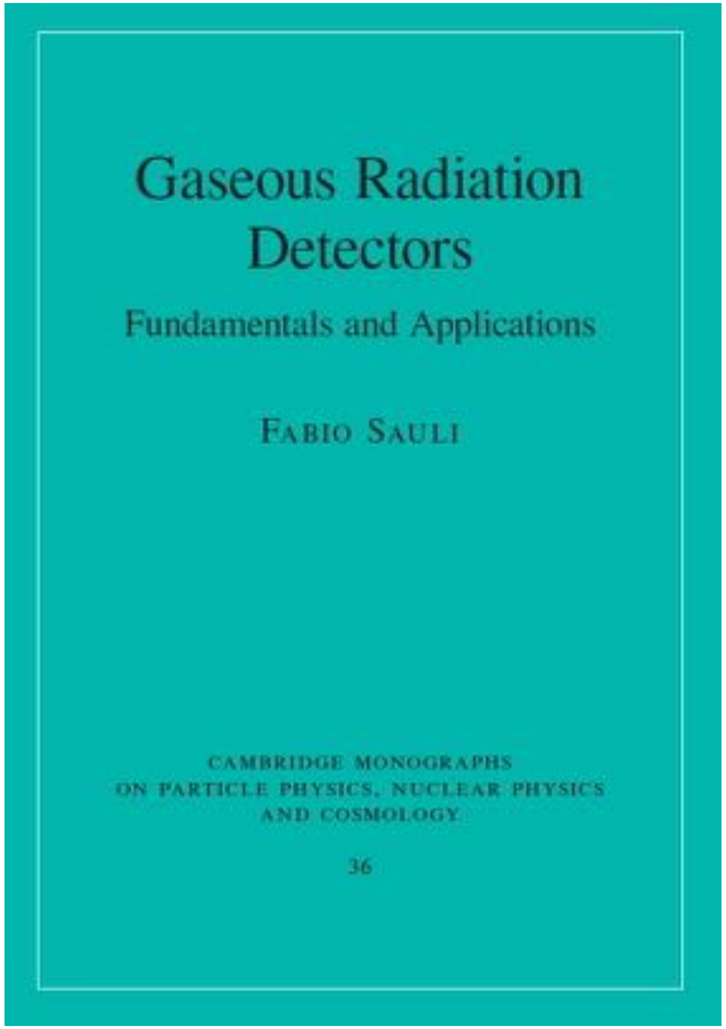


A. Sharma and M. Tytgat,
CMS Technical Design Report, (2014).

AND IF YOU WANT TO KNOW MORE…

http://www.cambridge.org/F4GASEOUS

F. Sauli
The gas electron multiplier (GEM): Operating principles and applications
Nucl. Instr. and Meth. In Press (7 Aug. 2015)




THE END
THANKS FOR YOUR ATTENTION