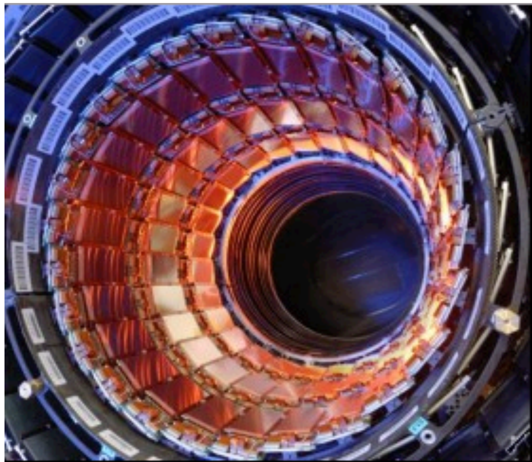


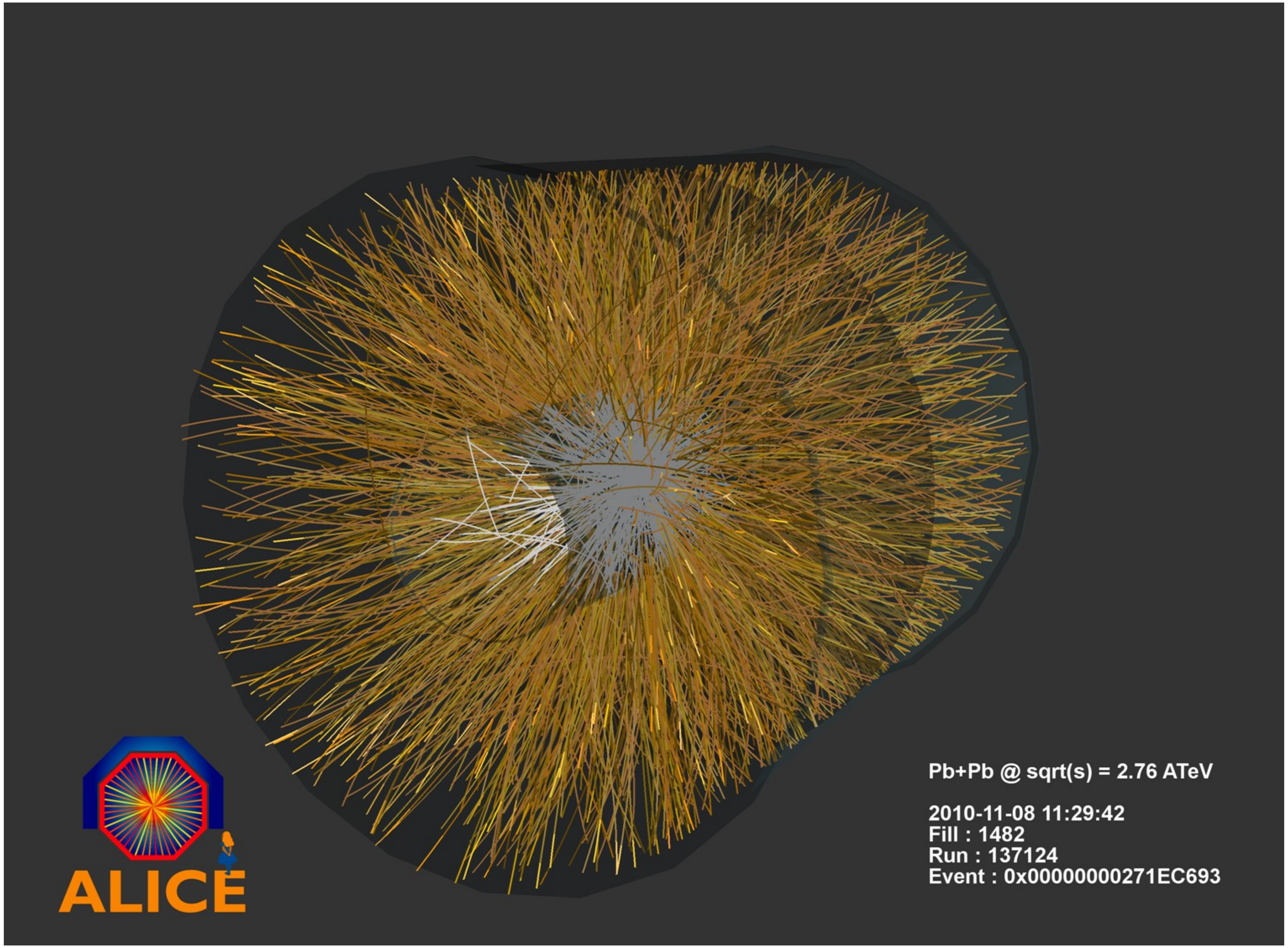
XXV GIORNATE DI STUDIO SUI RIVELATORI
Scuola F. Bonaudi

23-26 Febbraio
Villaggio dei Minatori - Cogne (AO)

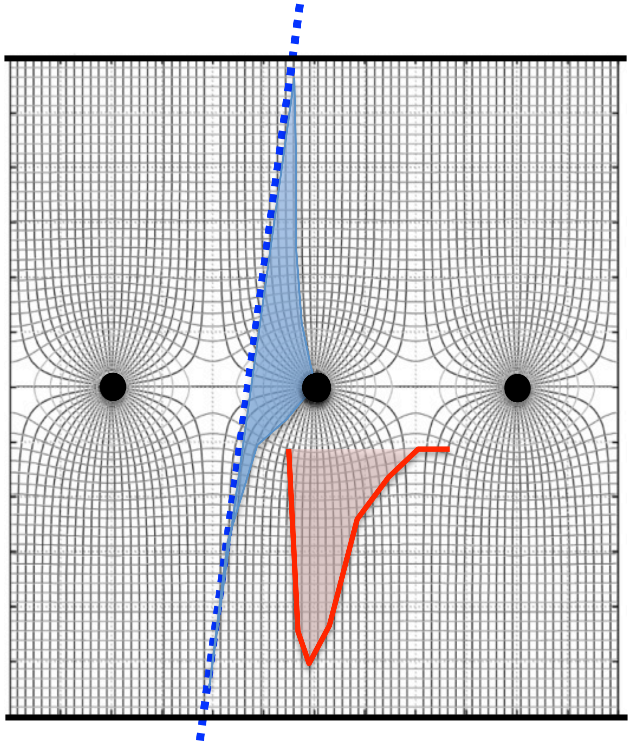
Fabio Sauli
TERA Foundation
CERN

PART 2
PROBLEMS AND SOLUTIONS WITH GASEOUS COUNTERS

ALICE TIME PROJETION CHAMBER (2006)

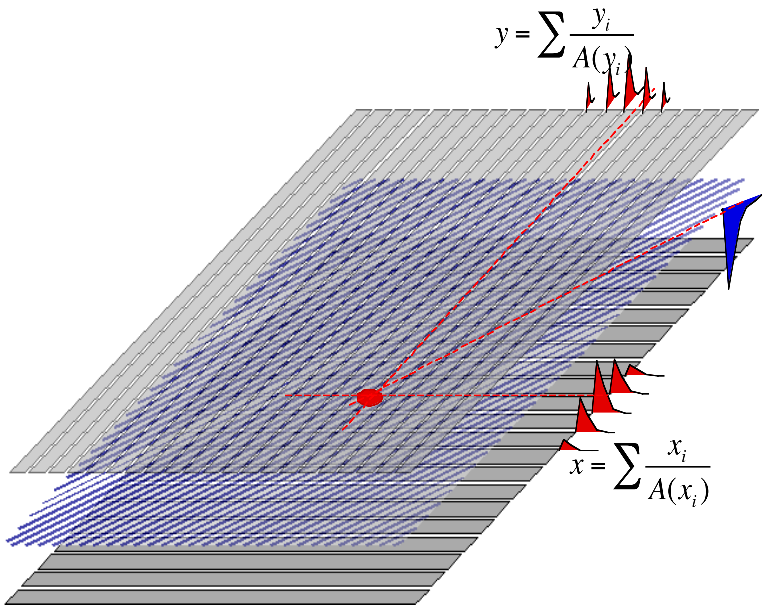


THIN ANODE WIRES BETWEEN TWO CATHODES:



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

CHARGE INDUCTION ON
CATHODE PLANES:
2-D LOCALIZATION

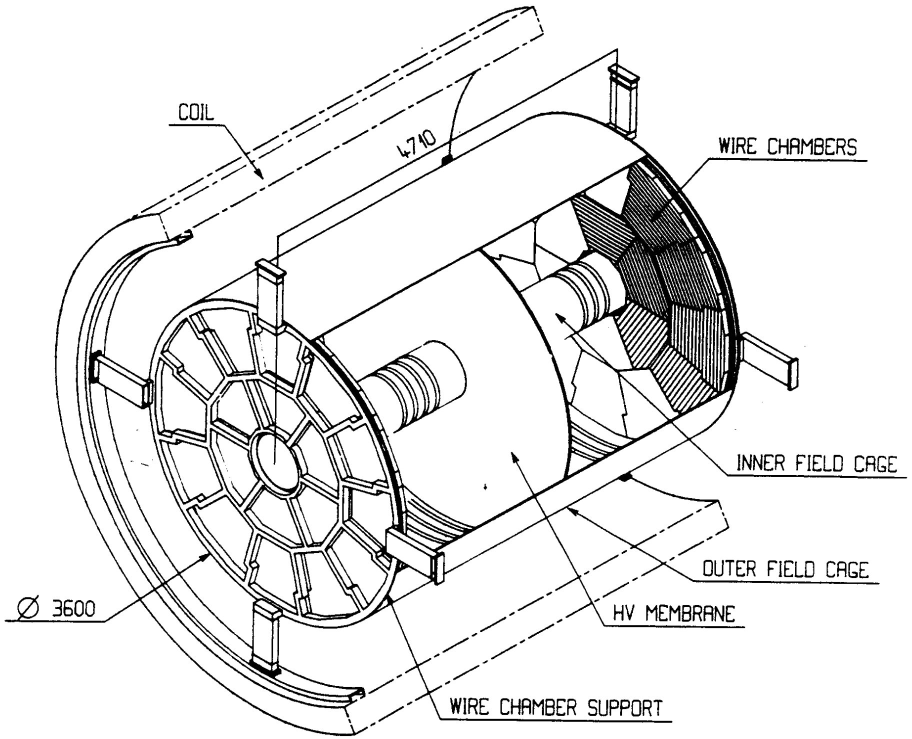


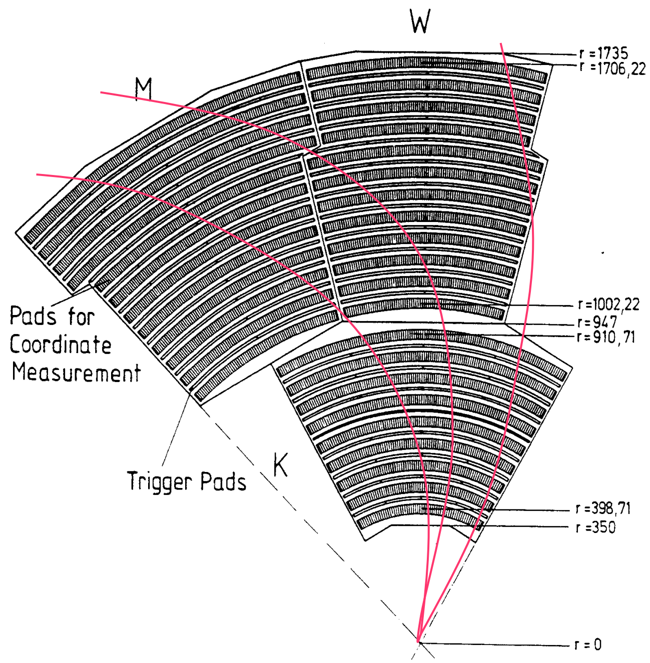
G. Charpak and F. Sauli
Nucl. Instr. and Meth. 113(1973)381

FIRST TPC: PEP-4 AT SLAC (1975)

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

ALEPH TPC AT CERN-LEP (1989)

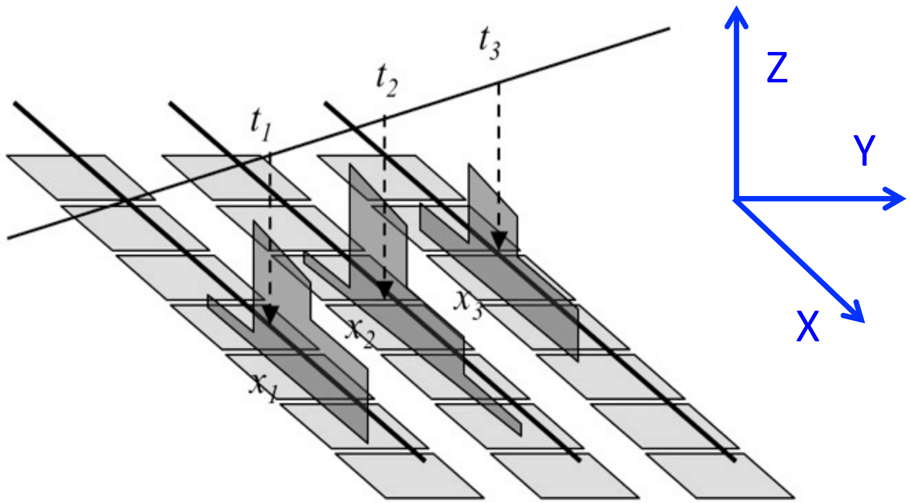




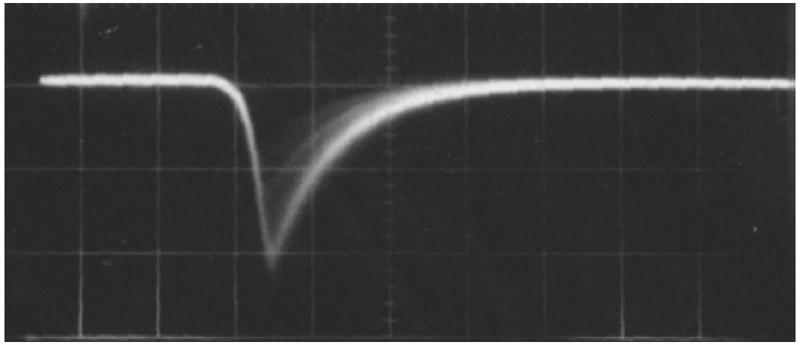
D. Decamp et al,Nucl. Instr. and Meth. A294(1990)125

TIME PROJETION CHAMBER: FULL 3-D LOCALIZATION

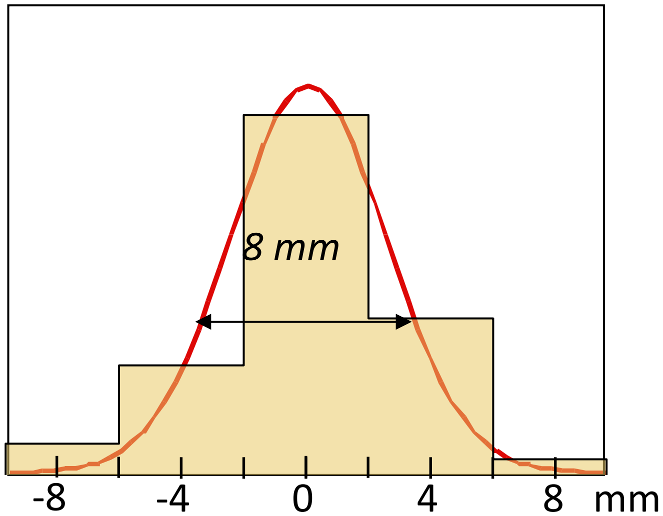
TWO-TRACK RESOLUTION



Z: DRIFT TIME ΔZ ~ 10 mm (200 ns):



X: PAD ROWS ΔX ~ 10 mm:



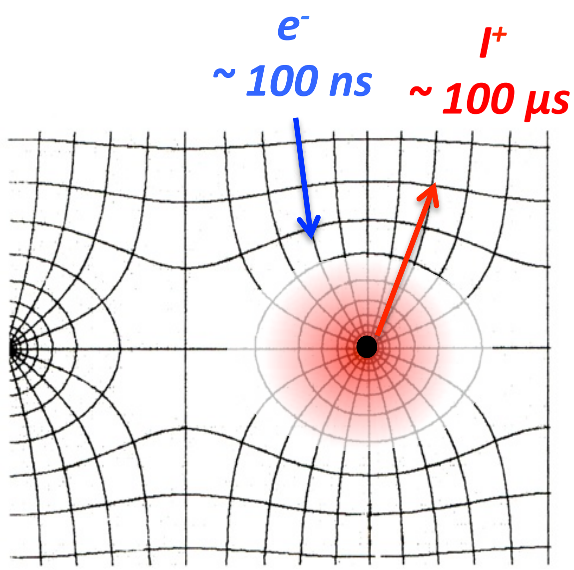
Y: ANODE WIRE
ΔY ~ 4 mm

VOLUME RESOLUTION:
ΔV~ 50 mm^3

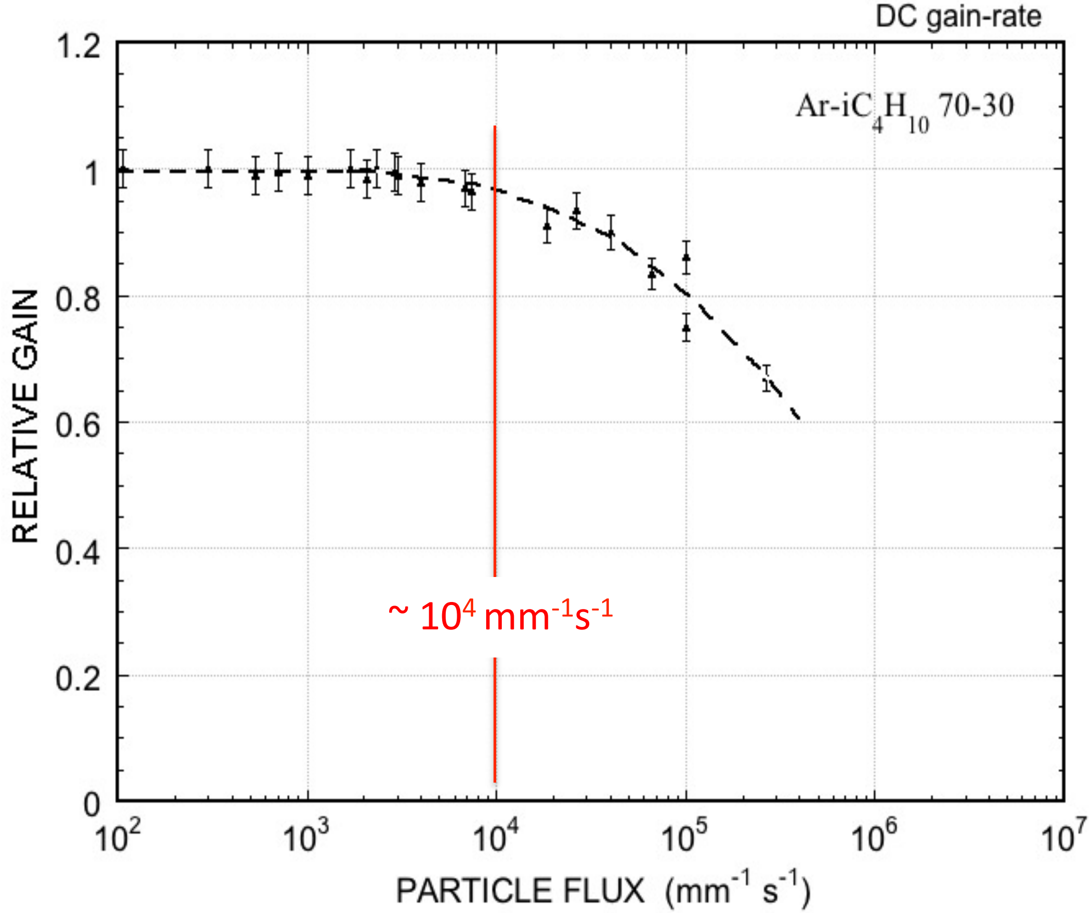
RATE-DEPENDENT GAIN REDUCTION

SPACE CHARGE

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



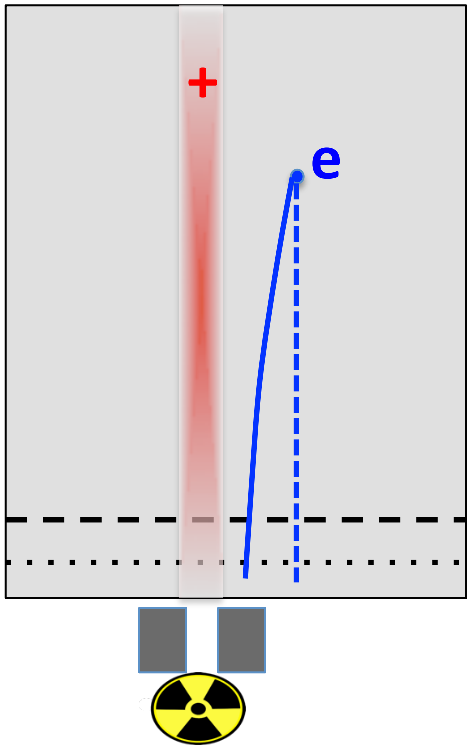
RELATIVE GAIN AS A FUNCTION OF RATE:



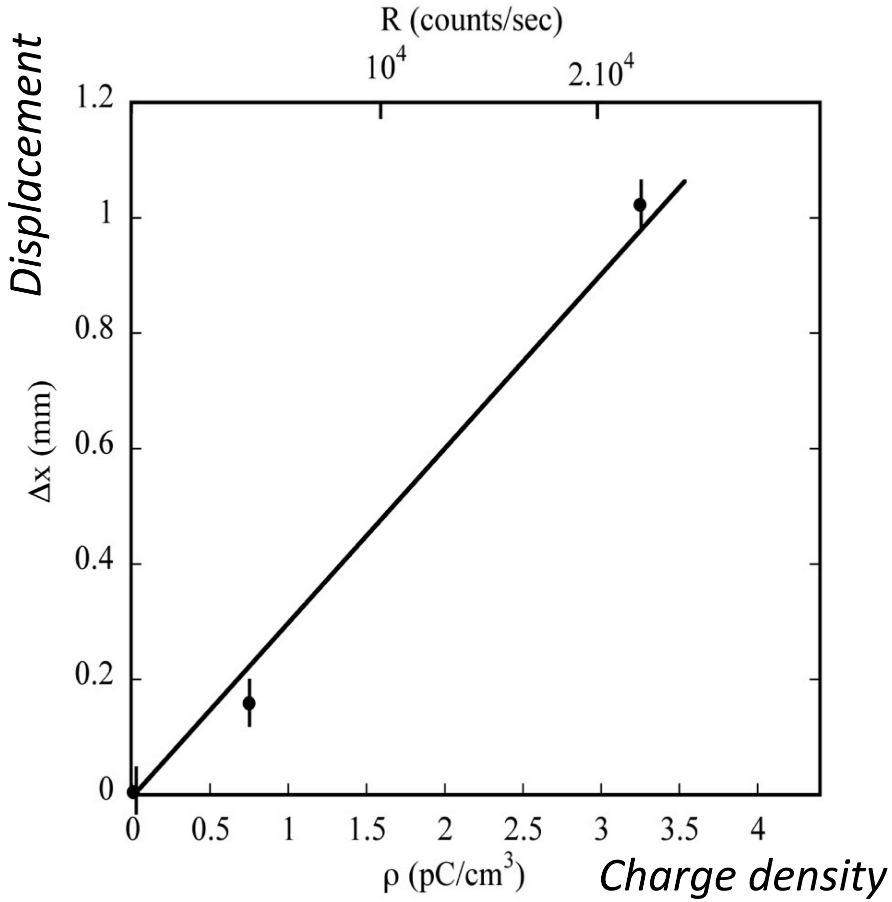
A. Breskin et al, Nucl. Instr. and Meth. 124(1974)189

SPACE CHARGE

LATERAL DISPLACEMENT OF ELECTRONS DRIFTING NEAR A POSITIVE IONS COLUMN



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



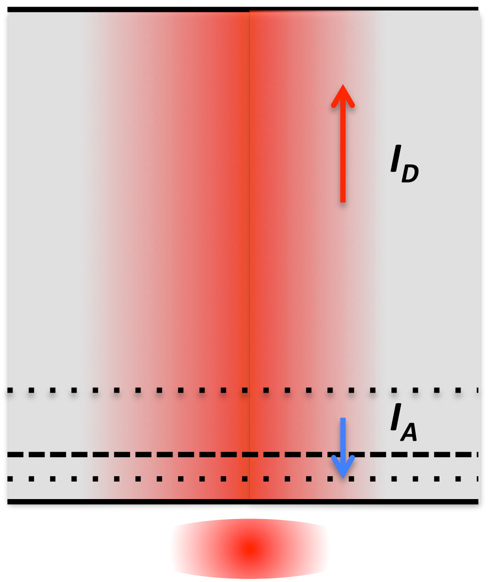
D. Friedrich, et al, Nucl. Instr. and Meth. 158(1979) 81

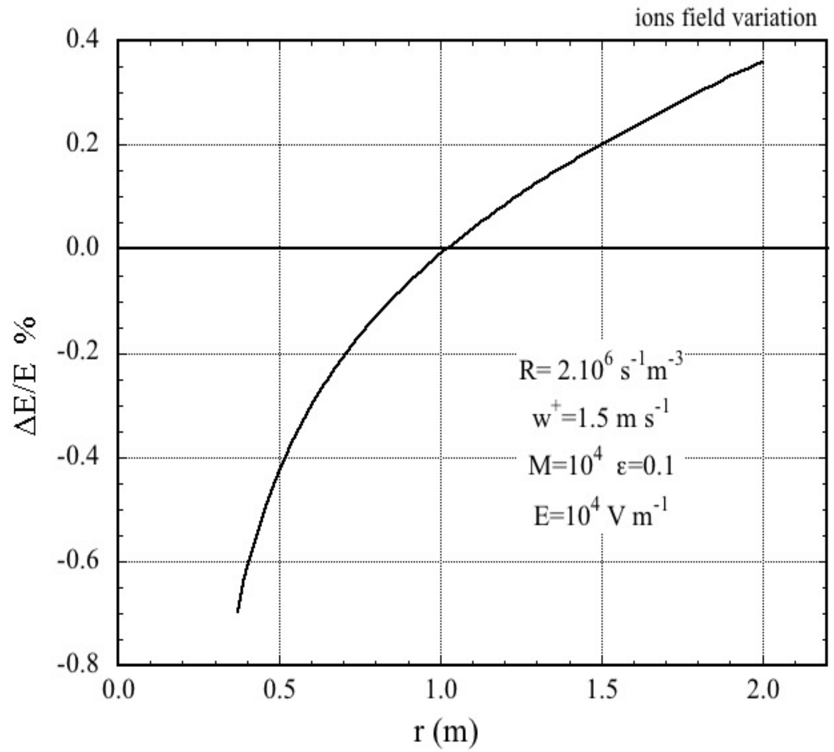
POSITIVE ION BACKFLOW

RELATIVE DRIFT FIELD MODIFICATION (ALEPH MWPC-TPC)

SPACE CHARGE

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





GATING:
ADD A WIRE MESH WITH VOLTAGE-CONTROLLED TRANSPARENCY

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

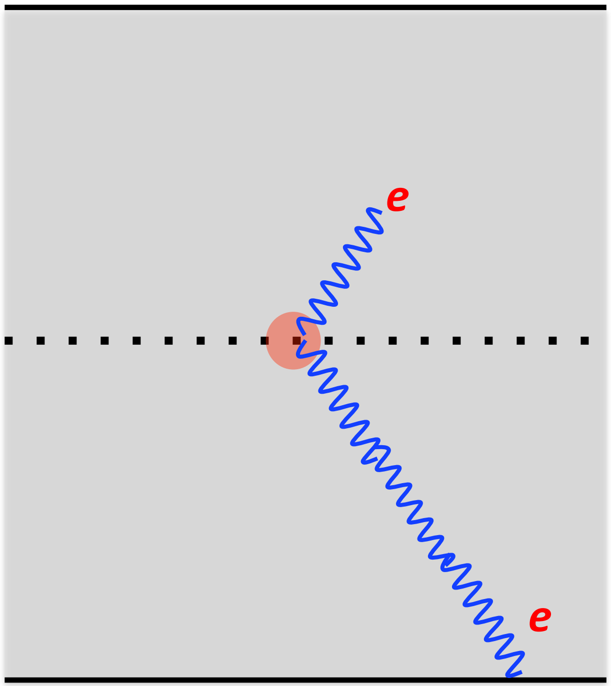
THE WISH: $IBF \leq \frac{1}{GAIN} \approx 10^{-4}$

MWPC: IBF ~ 30%

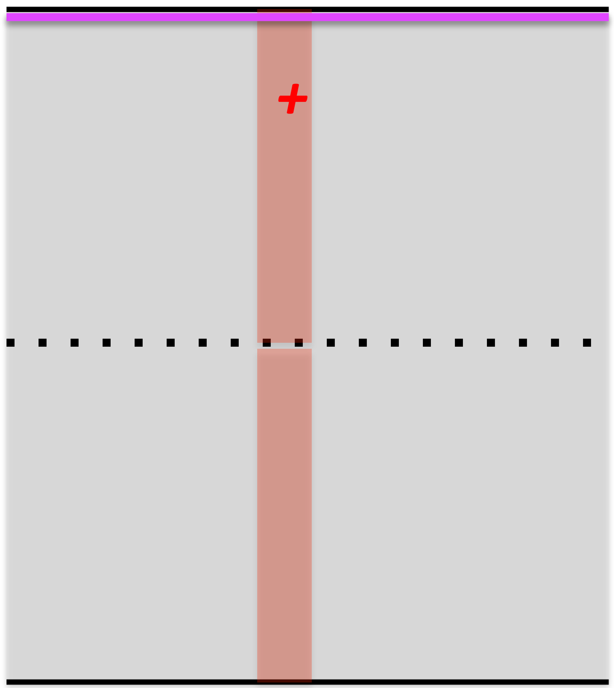
POSSIBLE AT LOW RATES:
Maximum electron drift time
< Time between events

SECONDARY PROCESSES

PHOTONS FEEDBACK:
AVALANCHE SPREAD

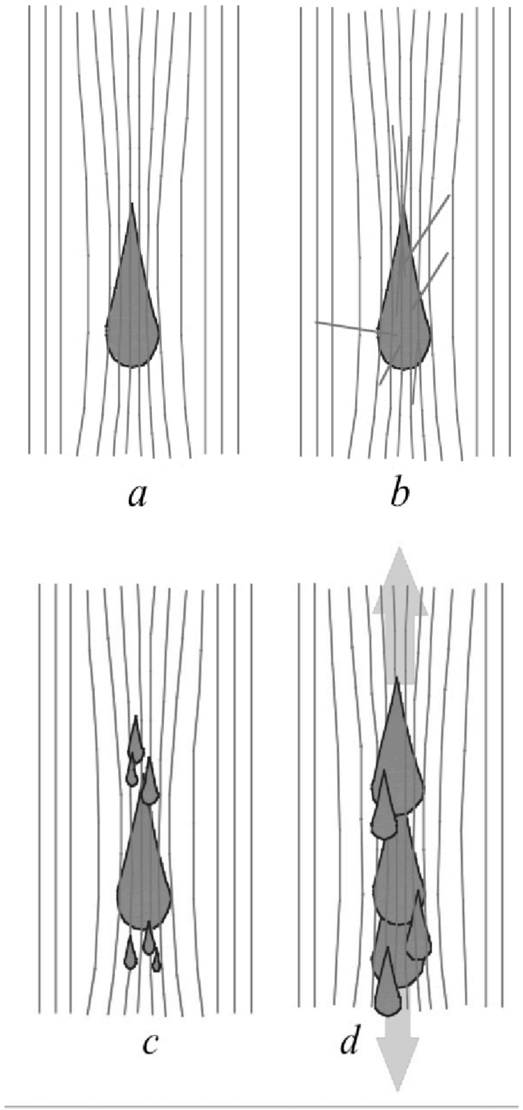


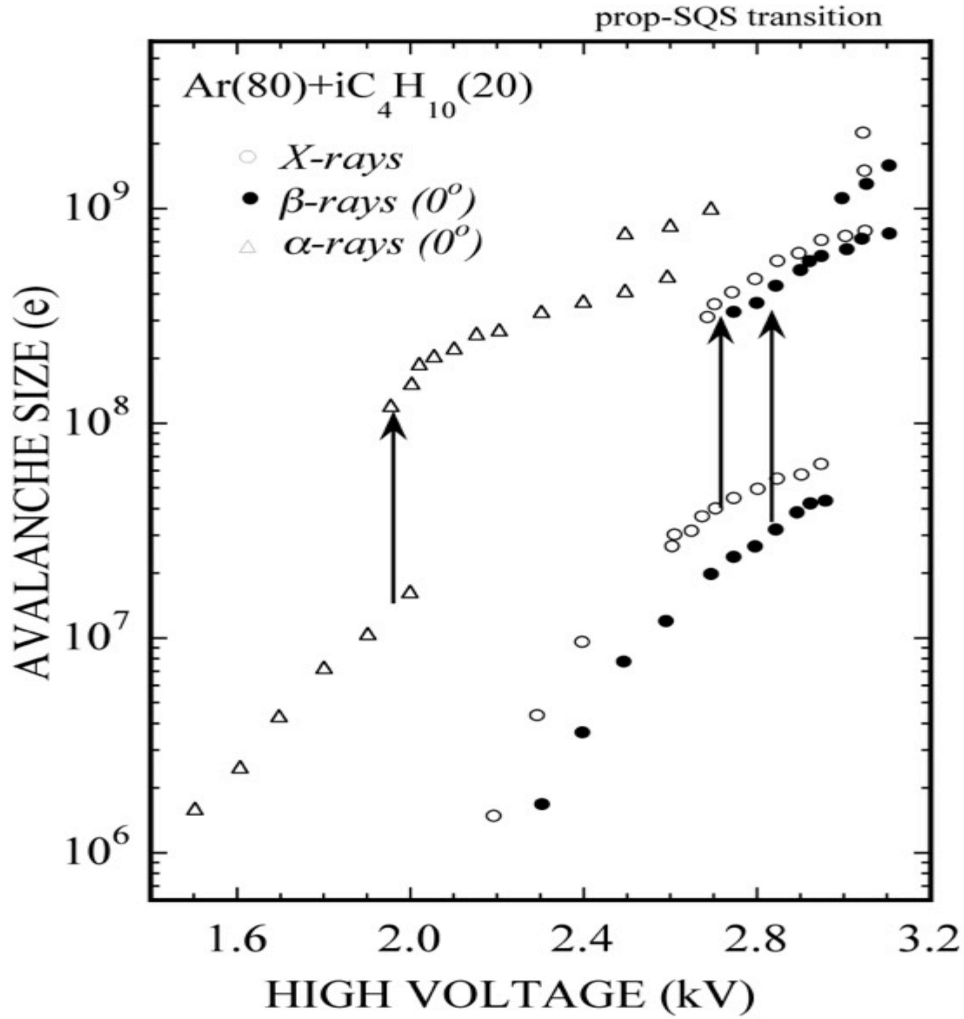
IONS FEEDBACK:
CATHODE DAMAGE, AGING, ...



TRANSITION FROM PROPORTIONAL TO STREAMER

SECONDARY PROCESSES





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

THE RAETHER LIMIT

SECONDARY PROCESSES

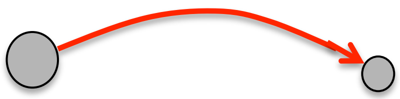
Maximum avalanche size before transition or breakdown:
Q_{MAX}=(Primary ionization)x(Gain) ~ 10^7 e

Typical proportional gain ~ 10^4

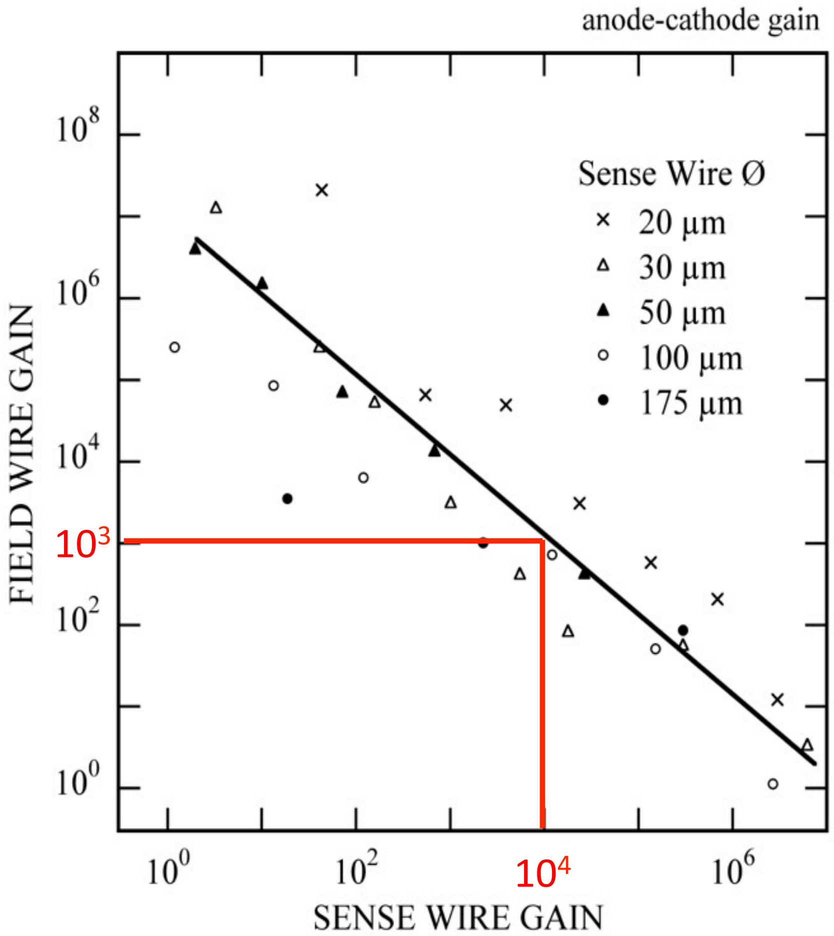
Fast particles ΔE ~ 2 keV:
$Q=(100)x(10^4)=10^6$

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

Multiwire structures:
Cathode pre-amplification of field emitted electrons

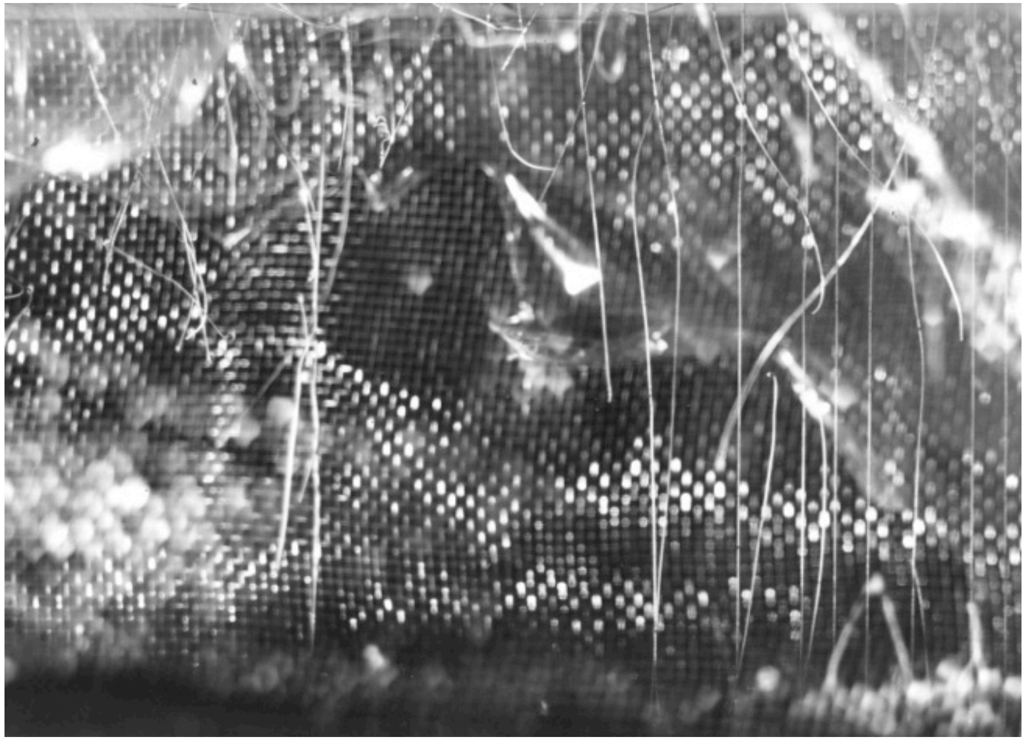


$M=M_C$ x M_A



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

SPARK DAMAGES IN MWPCs:

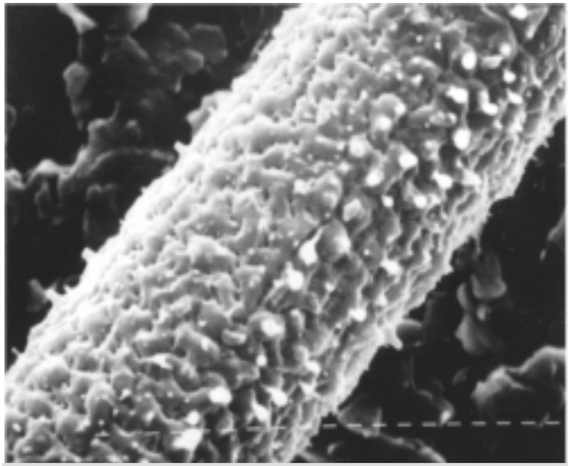


Fabio's Museum of Horrors

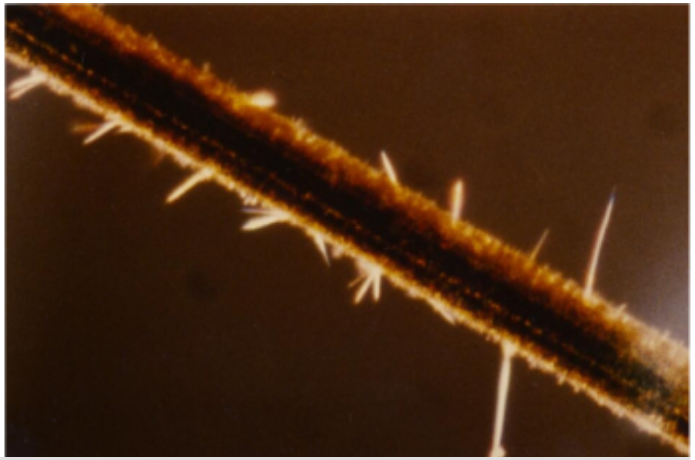
AGING

SECONDARY PROCESSES

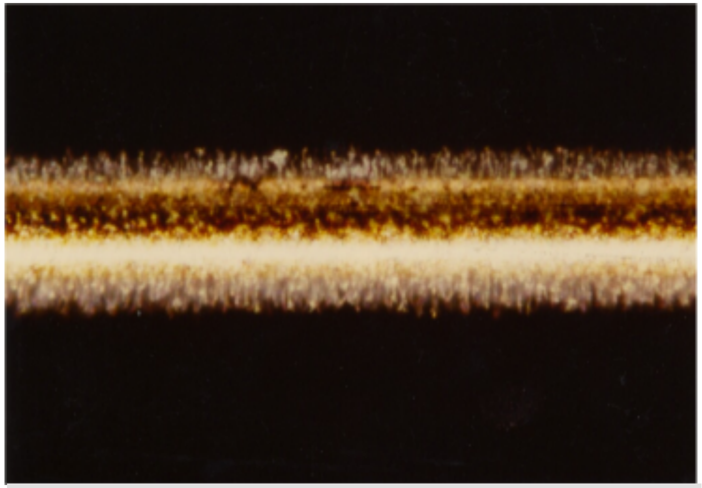
Polymerization of organic compounds with formation of deposits on thin wires:



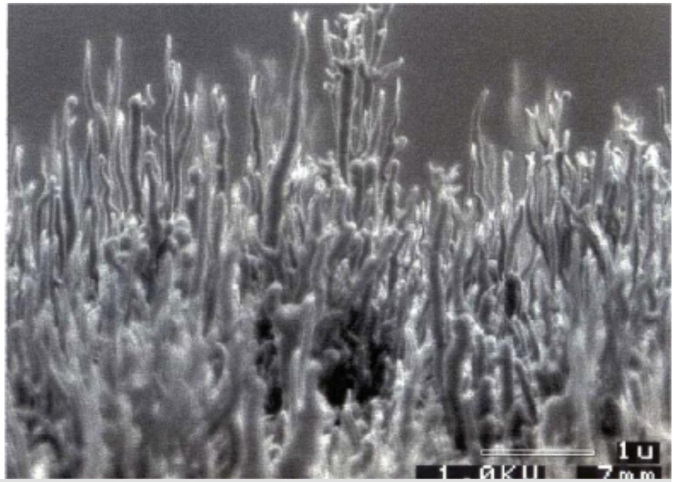
O. Ullaland, LBL-21170 (1986)107



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

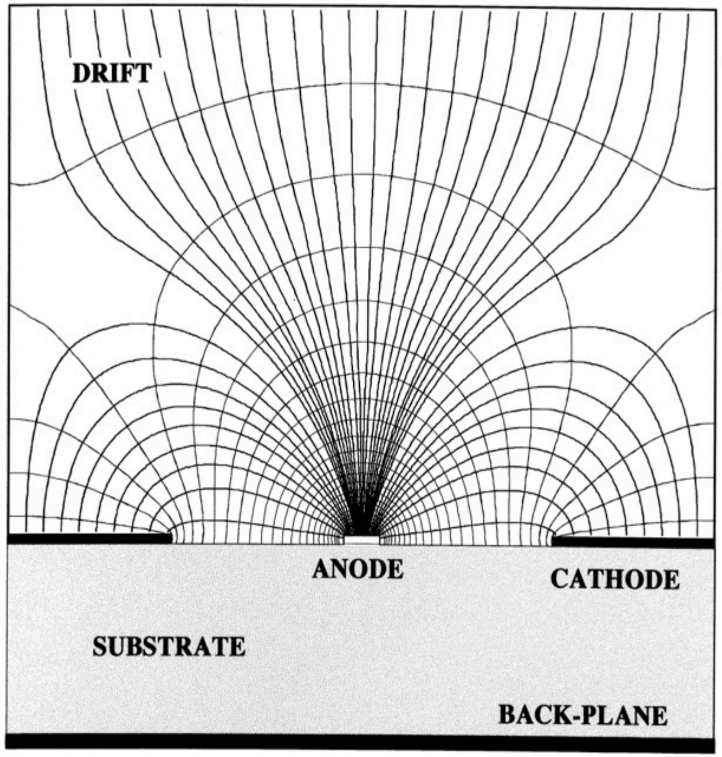


I. Juric and J. Kadyk, LBL-21170 (1986)141

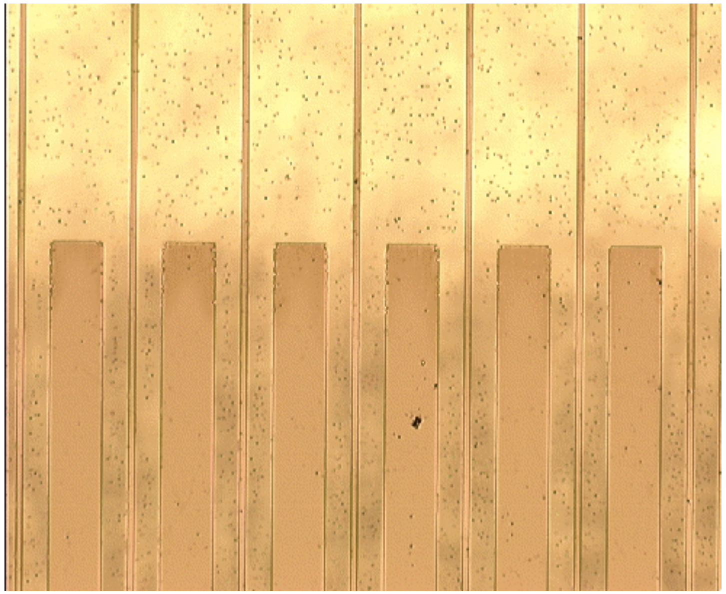


M. Binkley et al,
Nucl. Instr. and Meth. A515(2003)53

Anton Oed, 1988



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

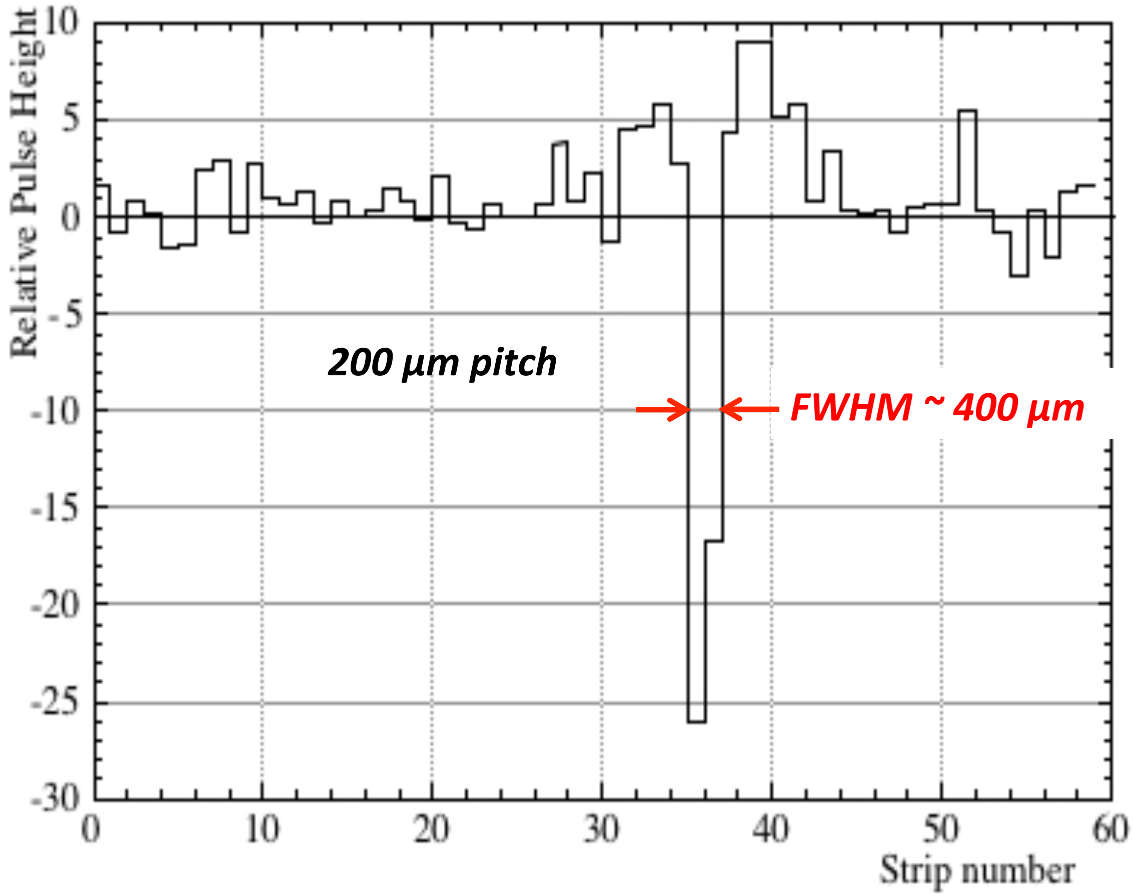


A. Oed, Nucl. Instr. and Meth. A263(1988)351

MSGC TWO-TRACK RESOLUTION

MSGC

SIGNAL WIDTH:



ΔX ~ 1 mm
ΔY ~ 1 mm

FAST SIGNALS ~ 30 ns

ΔZ ~ 2 mm

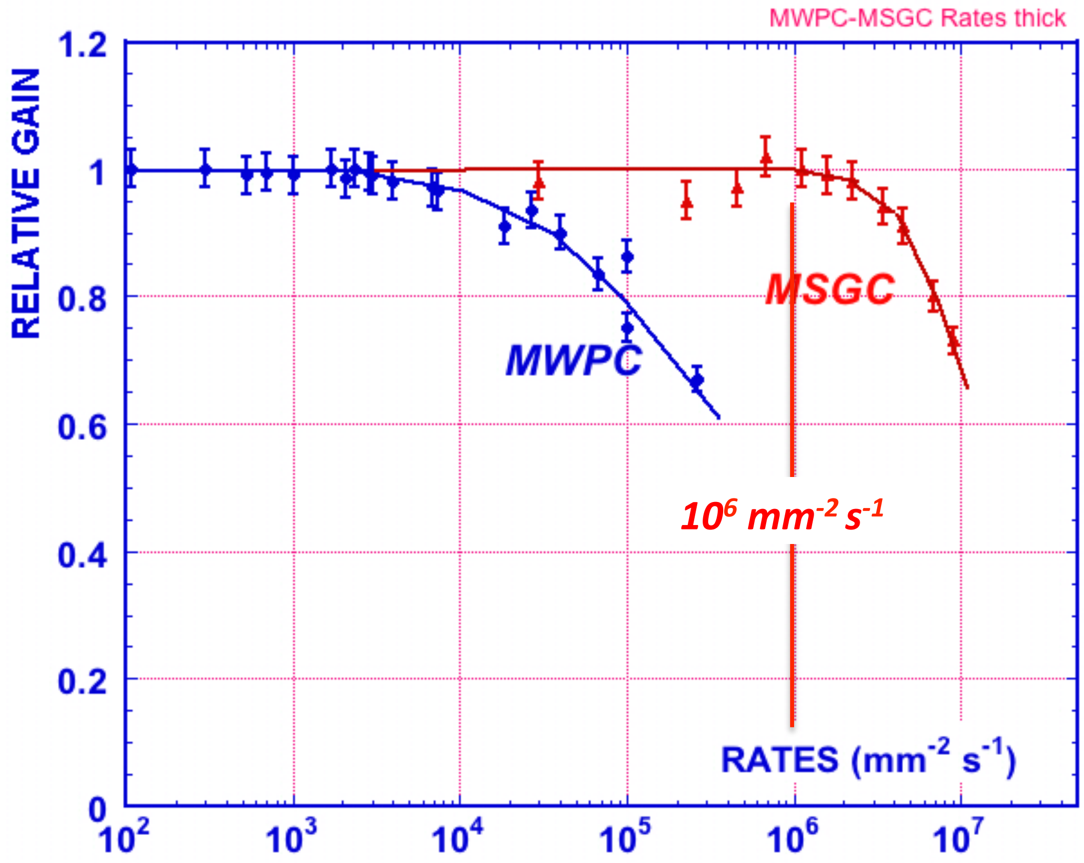
R. Bouclier et al, Nucl. Instr. and Meth. A367(1995)163

Volume resolution
ΔV ~ 1 x 1 x 2= 2 mm^3

MSGC RATE CAPABILITY

MSGC

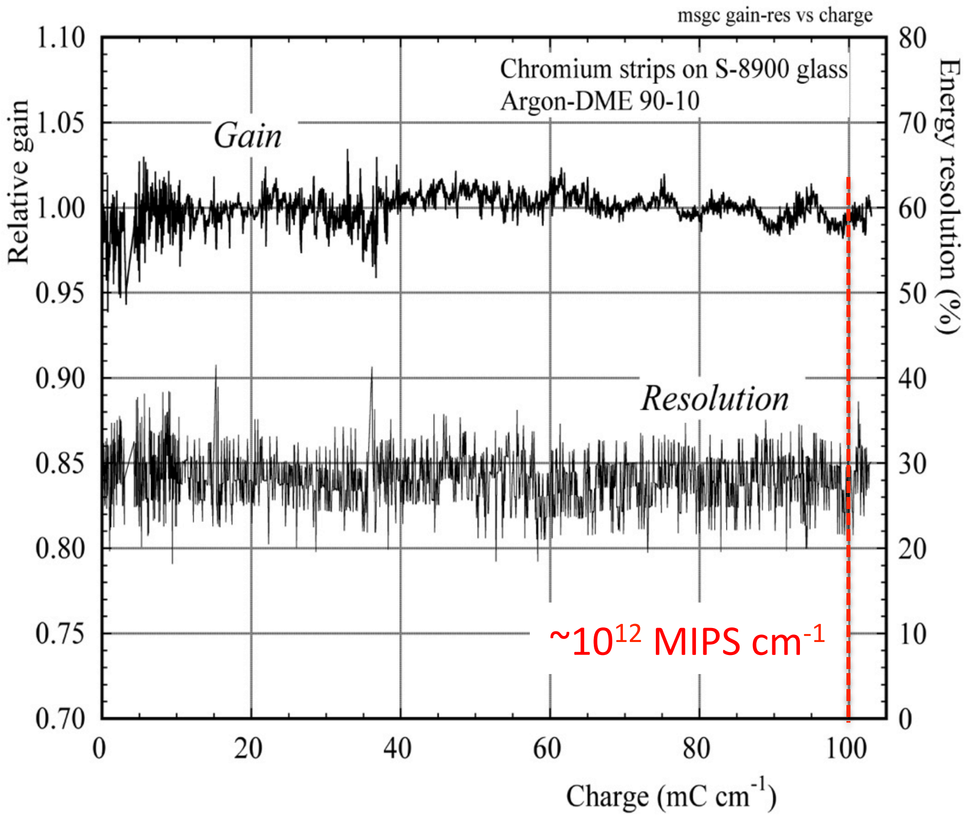
FAST COLLECTION OF MOST IONS ON CATHODE STRIPS:
GAIN VS RATE



R. Bouclier et al, Nucl. Instr. and Meth. 367(1996)328

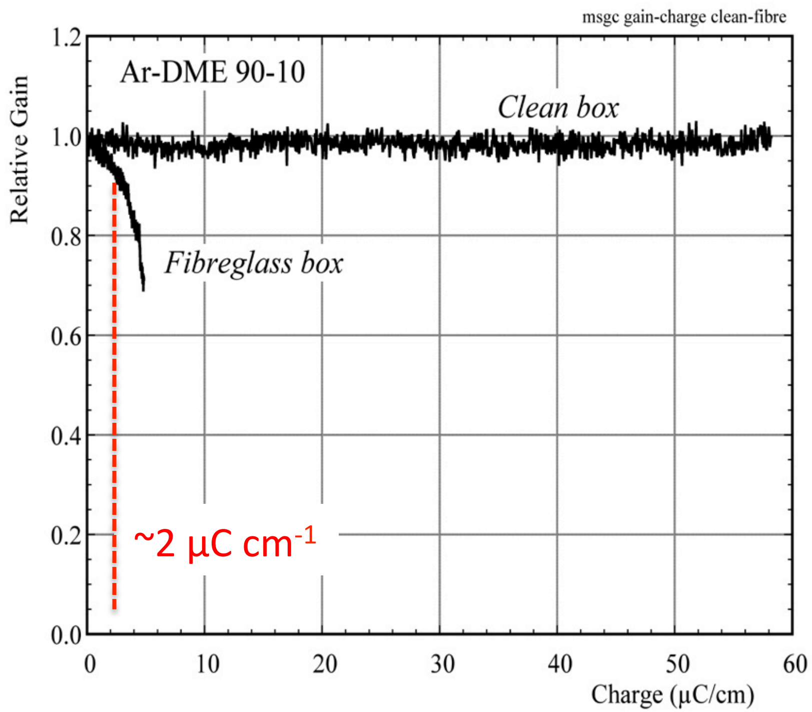
MSGC LIFETIME

MSGC GAIN vs COLLECTED CHARGE:



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

BUT: EXTREME SENSITIVITY TO CONTAMINATIONS



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

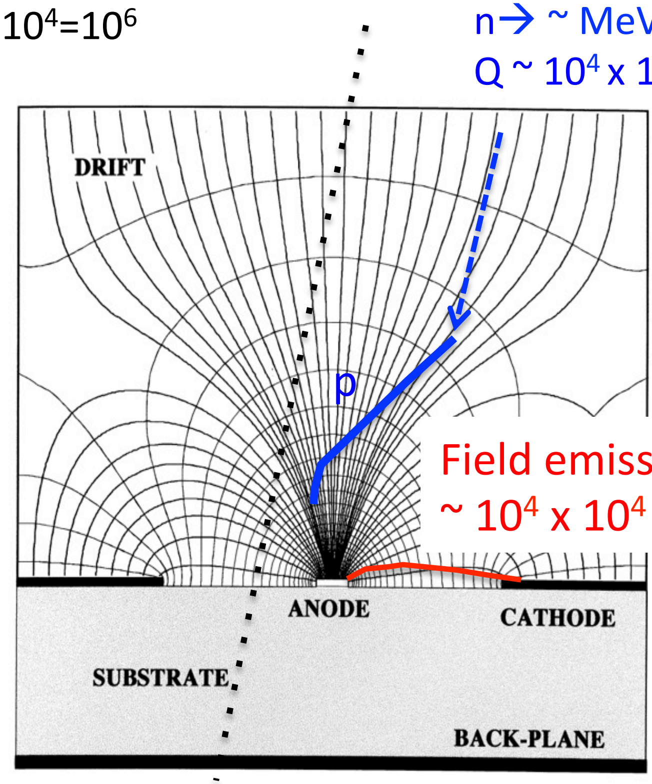
MSGC DISCHARGES

MSGC

PRE-AMPLIFICATION OF ELECTRONS
EMITTED BY CATHODE STRIP EDGES

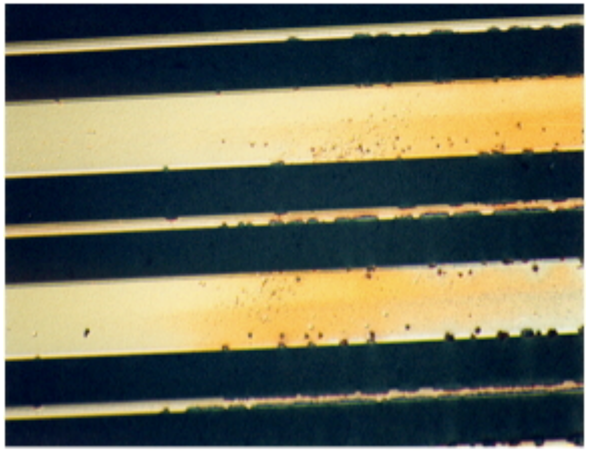
MINIMUM IONIZING
PARTICLES
$Q= 100 \times 10^4=10^6$

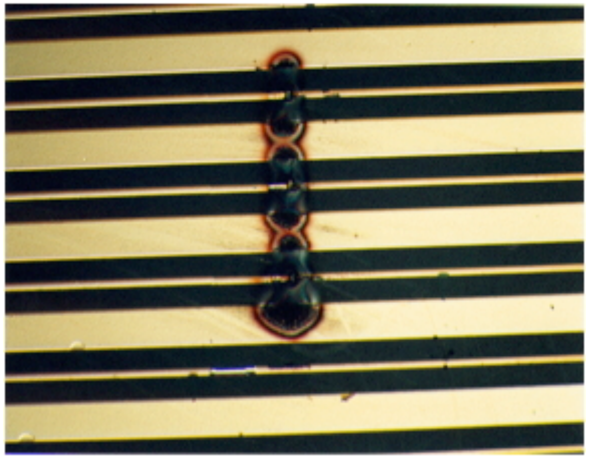
n→ ~ MeV p
$Q \sim 10^4 \times 10^4 = 10^8$



Field emission
$\sim 10^4 \times 10^4 = 10^8$

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

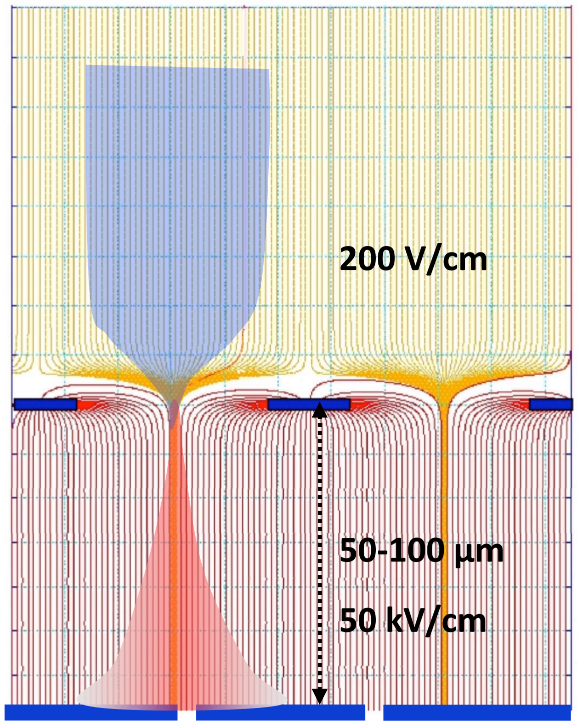




Fabio's Museum of Horrors

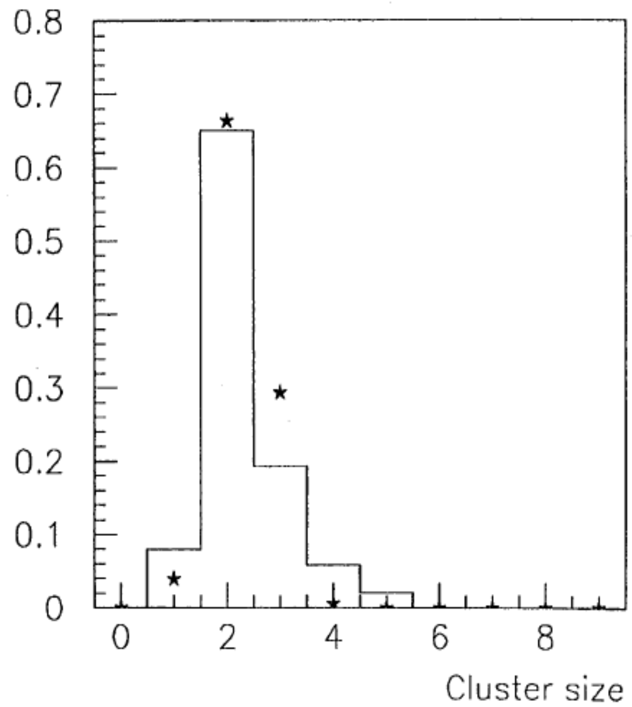
MICROMEGAS

Thin (50-100 μm) multiplication gap:



COLLECTED CHARGE DISTRIBUTION :

~ 200 μm fwhm



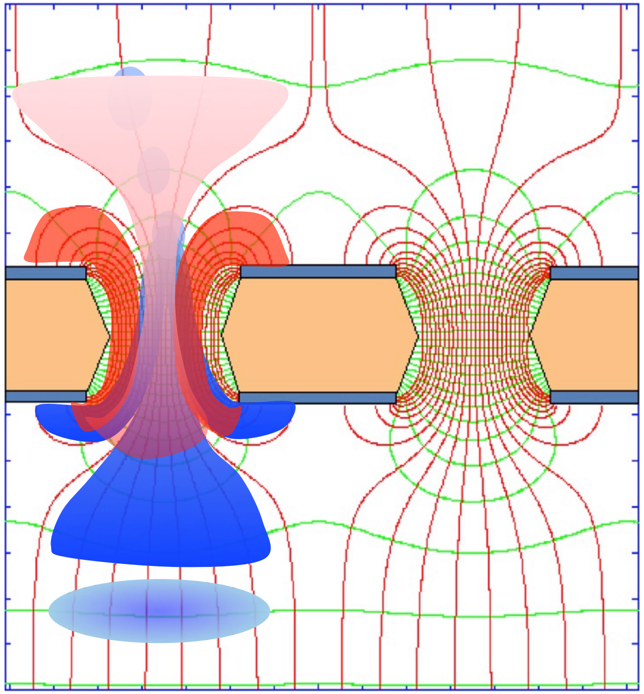
100 μm pitch

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

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

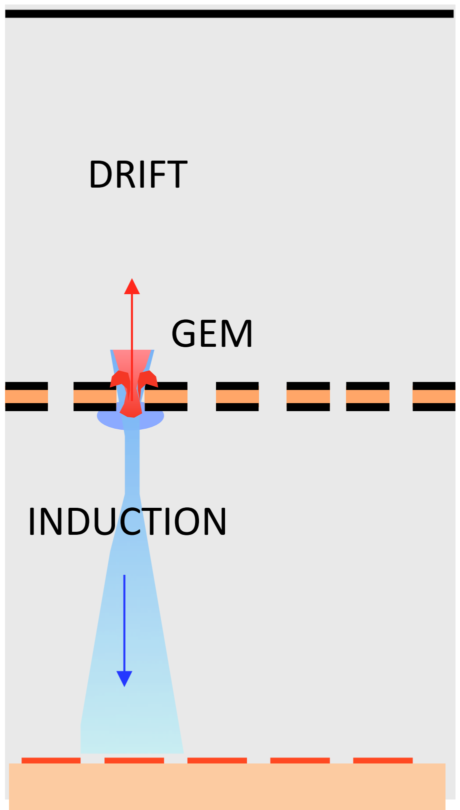
GAS ELECTRON MULTIPLIER (GEM)

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



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

FAST ELECTRON SIGNAL ON ANODE STRIPS (NO ION TAIL):



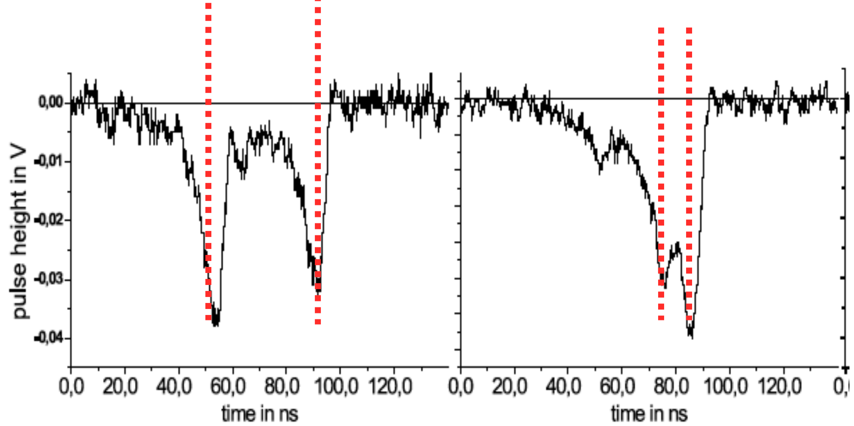
GEM TWO-TRACK RESOLUTION

GEM

TWO-TRACK RESOLUTION
(DRIFT TIME):

30 ns ~ 1.5 mm

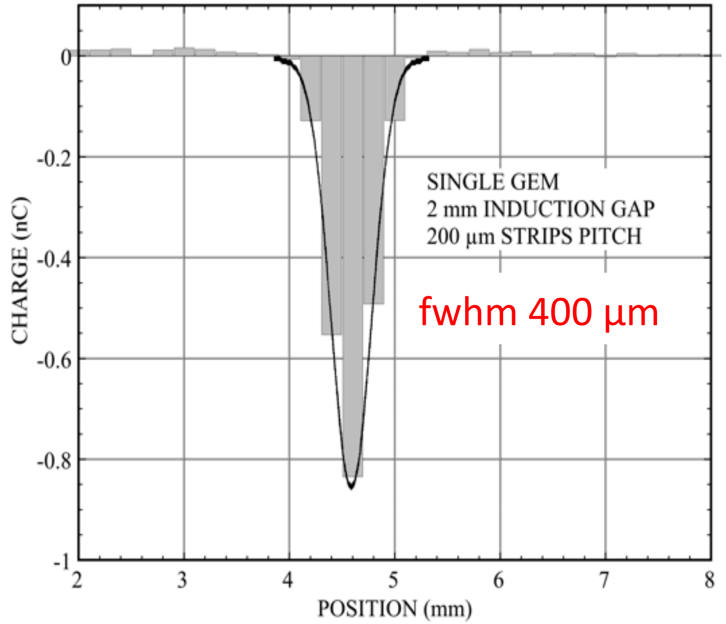
10 ns



M. Ziegler, PhD Zürich Univ. (2002)

VOLUME RESOLUTION ~ 1 mm^3

TWO-TRACK RESOLUTION
(PROJECTION):

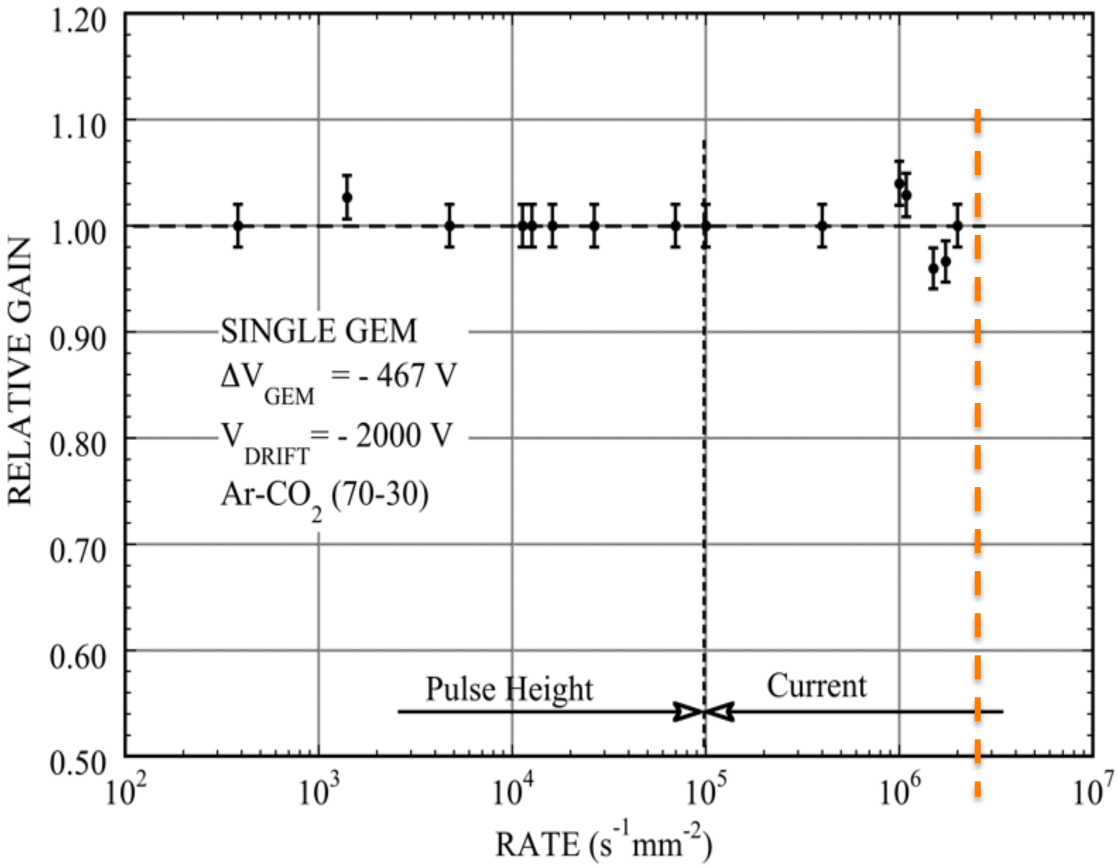


A. Bressan et al, Nucl. Instr. and Meth. A425(1999)262

GEM RATE CAPABILITY

GEM

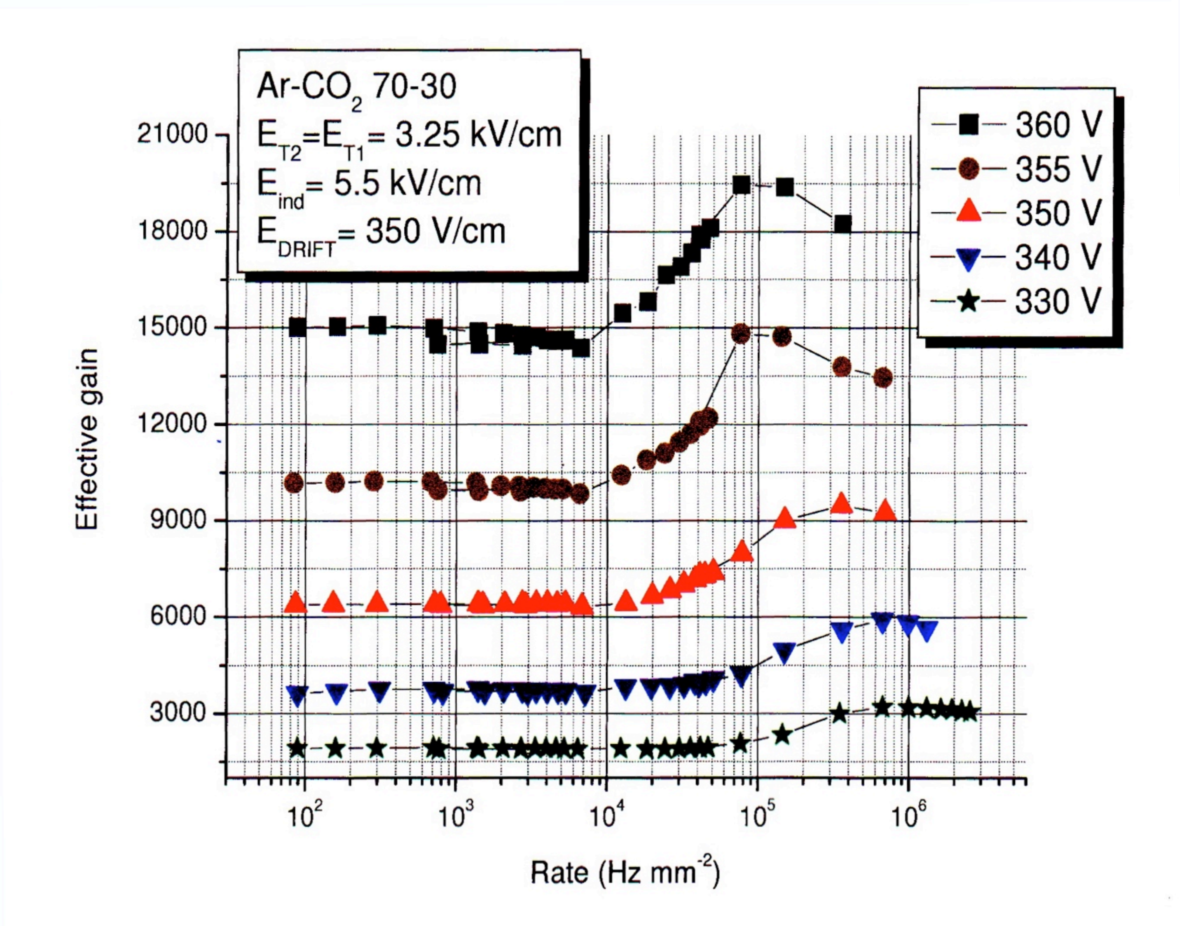
GEM GAIN vs RATE (SOFT X-Rays)



> 1 MHz mm^{-2}

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

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

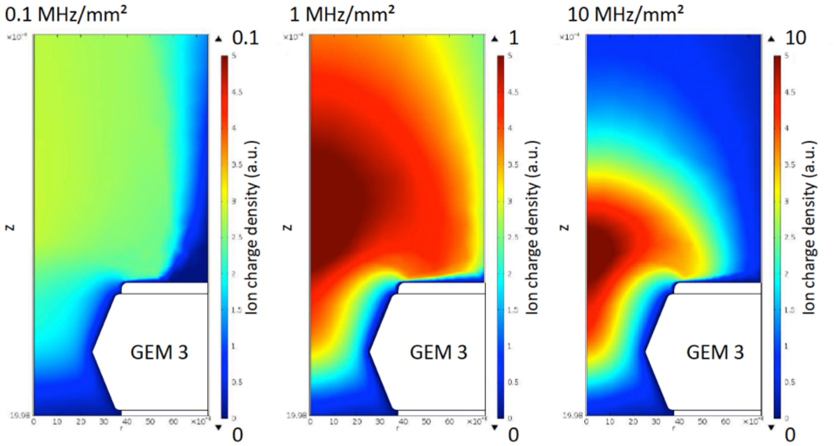


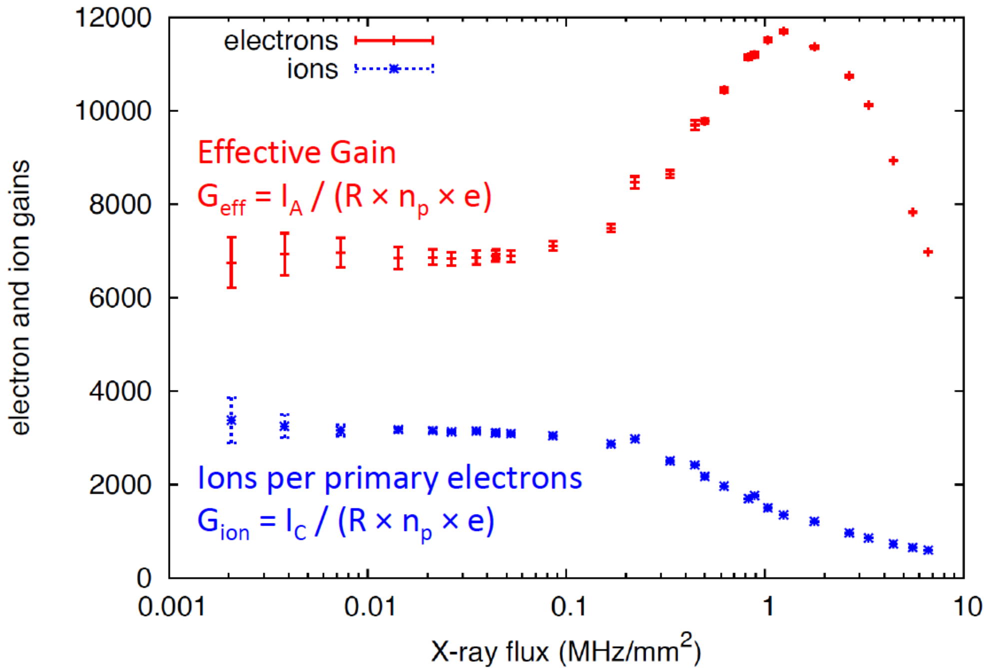
Peter Everaerts, PhD Thesis Gent University (2006)

GEM RATE CAPABILITY (SIMULATION)

- COMSOL Finite Element Analysis
- GARFIELD

SPACE CHARGE BUILDUP:

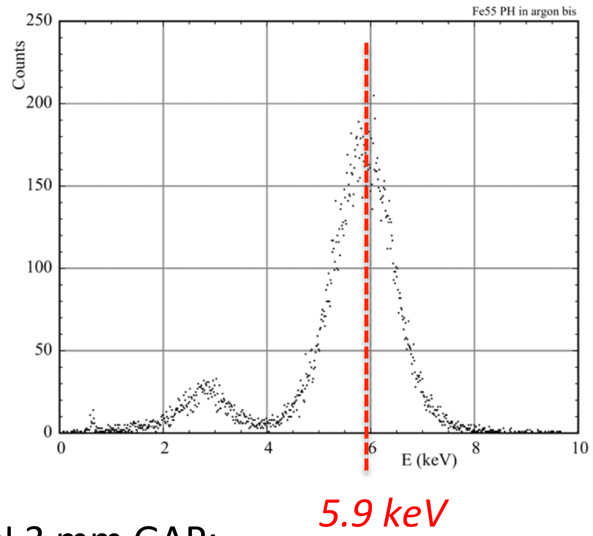




S. Franchino et al, IEEE Nucl. Sci. Symposium (San Diego, Oct. 31, 2015)

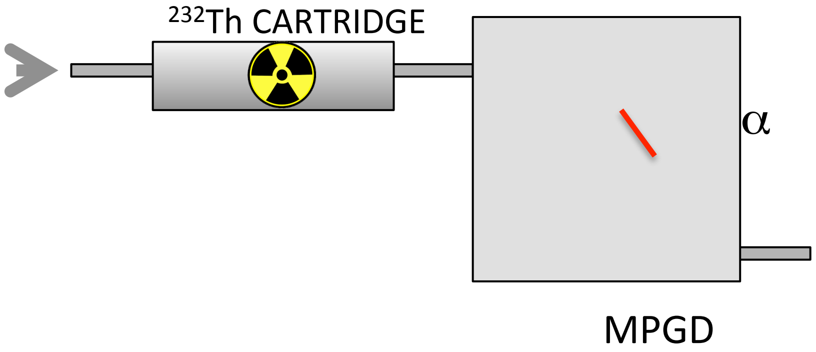
MPGD DISCHARGE STUDY AND CERTIFICATION

- TEST BEAM: EFFICIENCY AND DISCHARGE RATE VS VOLTAGE
- LABORATORY: MEASURE GAIN WITH 5.9 keV X-RAY SOURCE, DISCHARGE RATE ON EXPOSURE TO HEAVILY IONIZING SOURCE

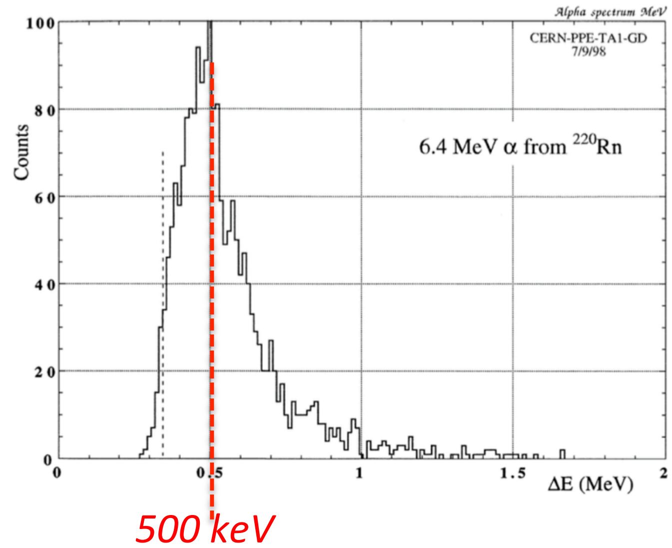


INTERNAL OR EXTERNAL ^{243}Am SOURCE
(REQUIRES THIN WINDOW)

GASEOUS α SOURCE: ^{232}Th->^{232}Rn+α (6.4 MeV):

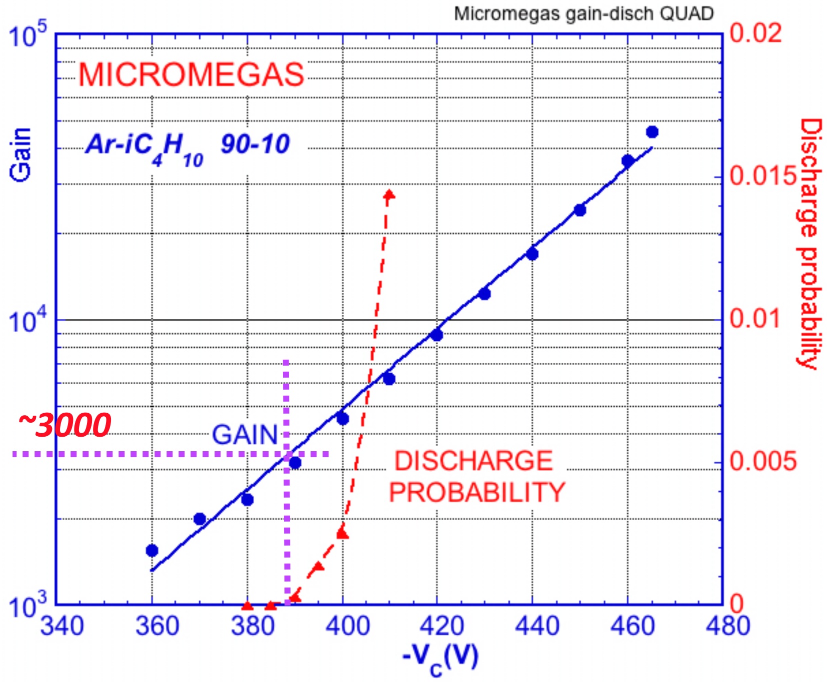


ENERGY LOSS IN 3 mm GAP:

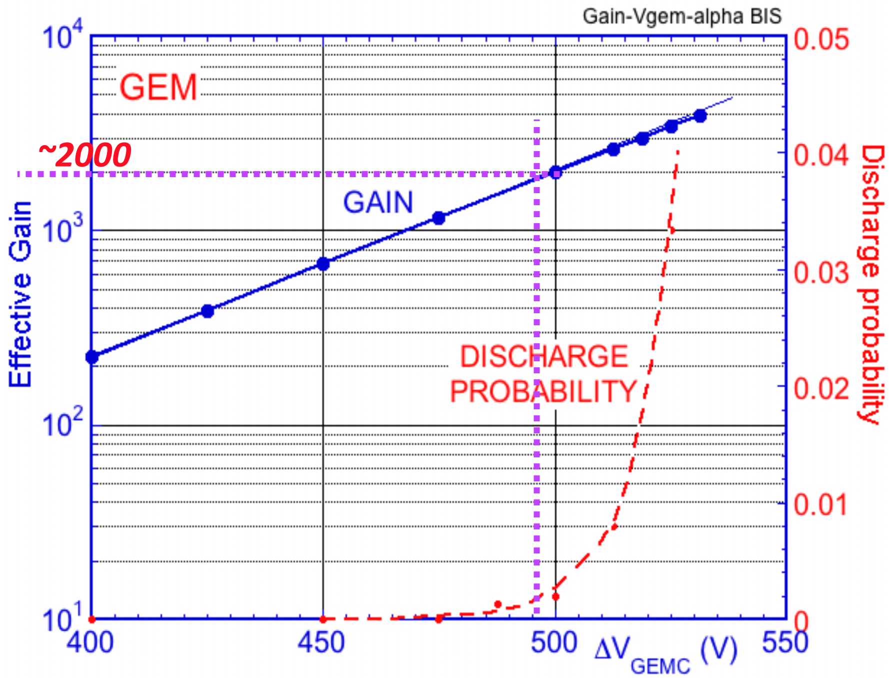


LABORATORY TESTBENCH FOR MPGDs

MICROMEGAS:



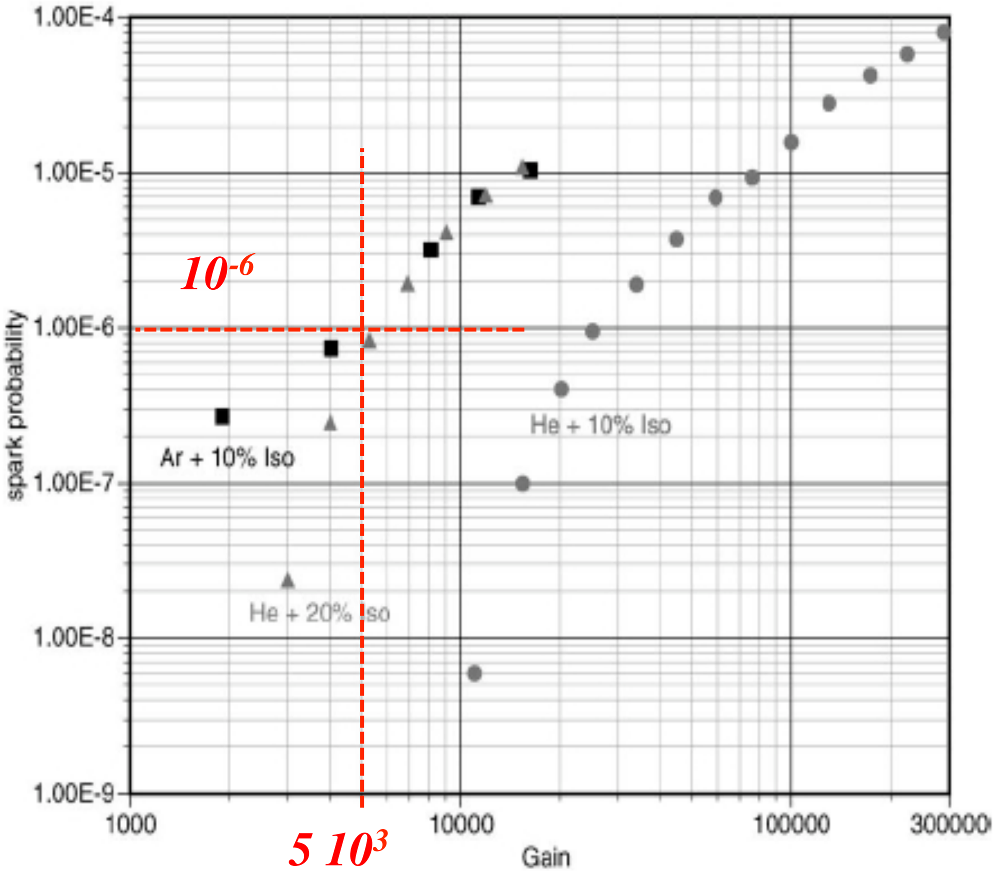
GEM:



A. Bressan et al.Nucl. Instr. and Meth. A424(1999)321

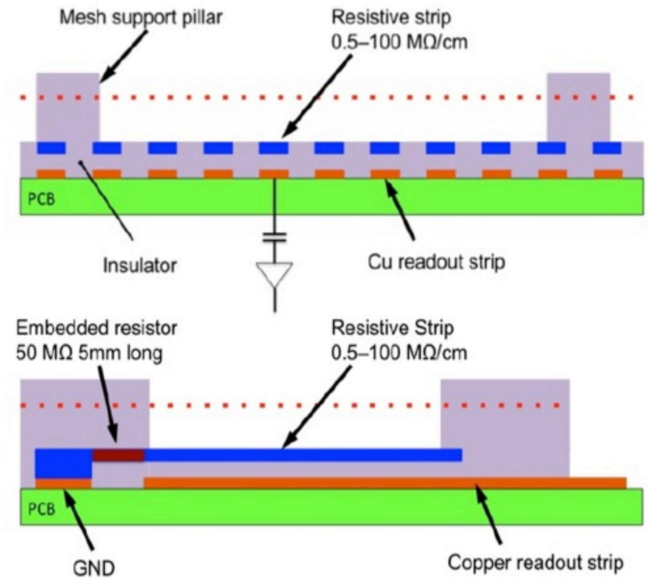
SPARK PROBABILITY IN HADRON BEAM

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

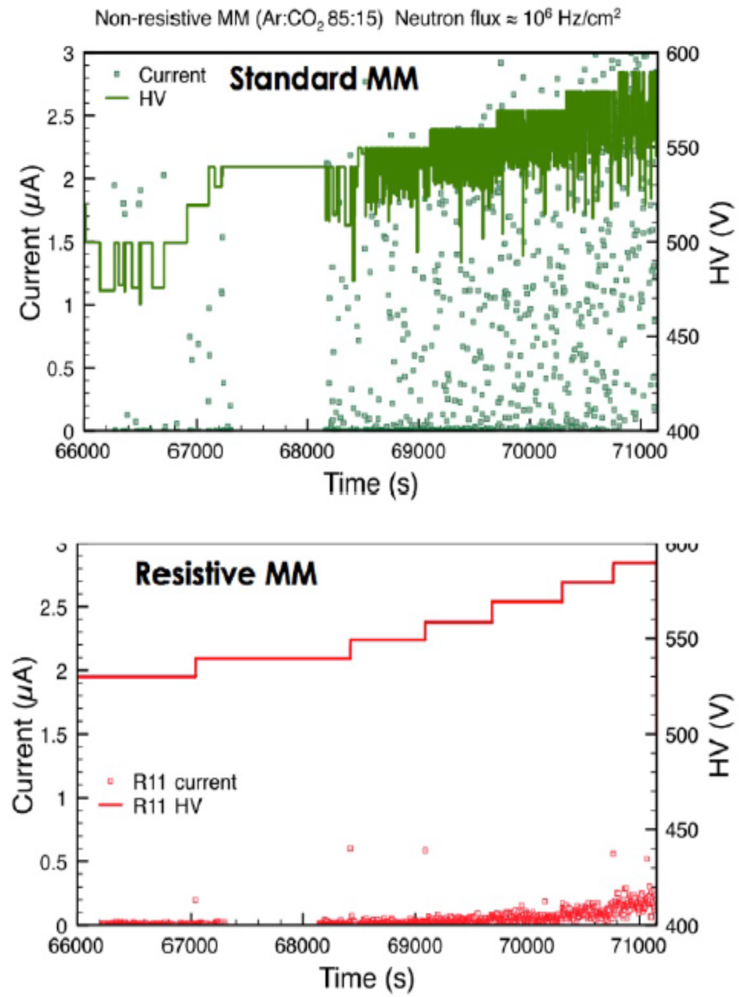


A. Delbart et al, Nucl. Instr. and Meth. A478(2002)205

BUILT ON A HIGH-RESISTIVITY POLYMER

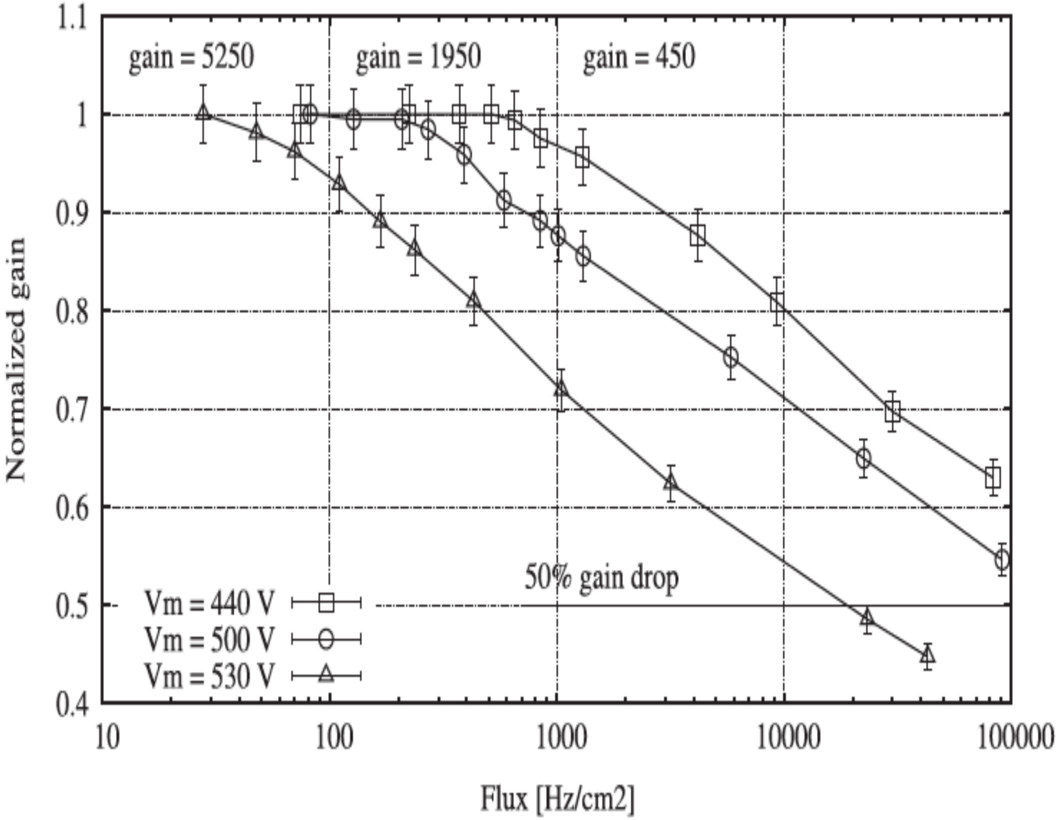


SPARK RATES IN NEUTRON BEAM EXPOSURE:



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

GAIN REDUCTION AS A FUNCTION OF RATES:

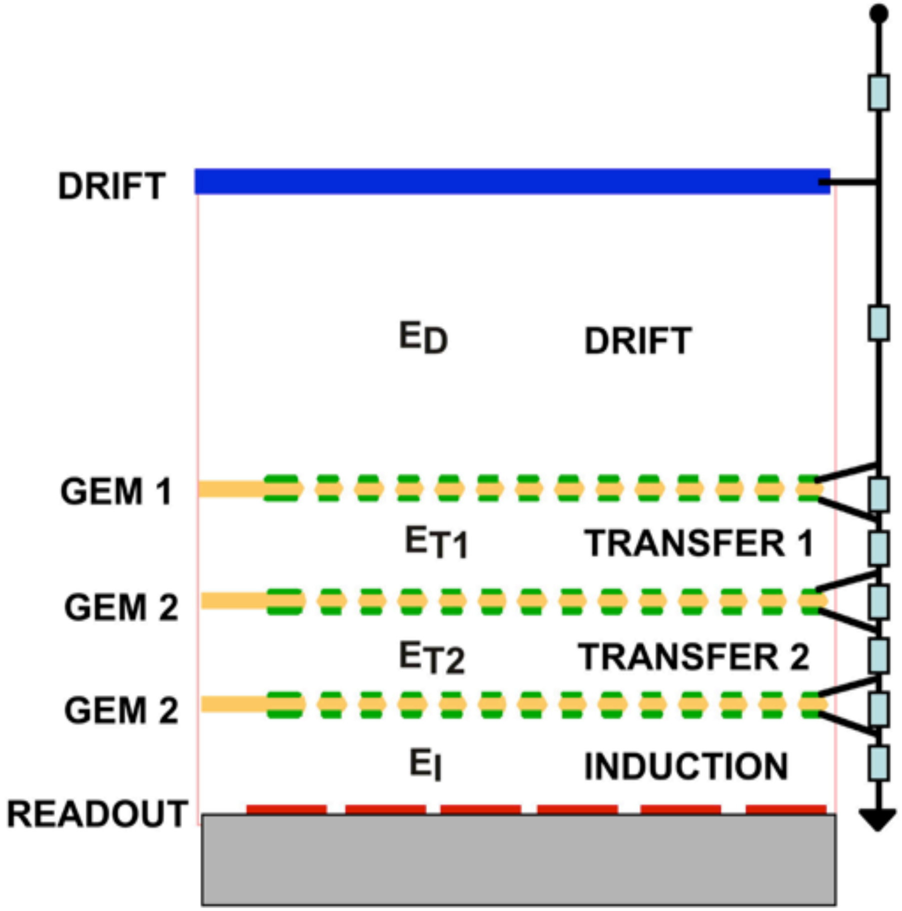


J. Galán et al, Nucl. Instr. and Meth. A732(2013)229

DISCHARGES: MULTI-GEM

MULTI-GEM

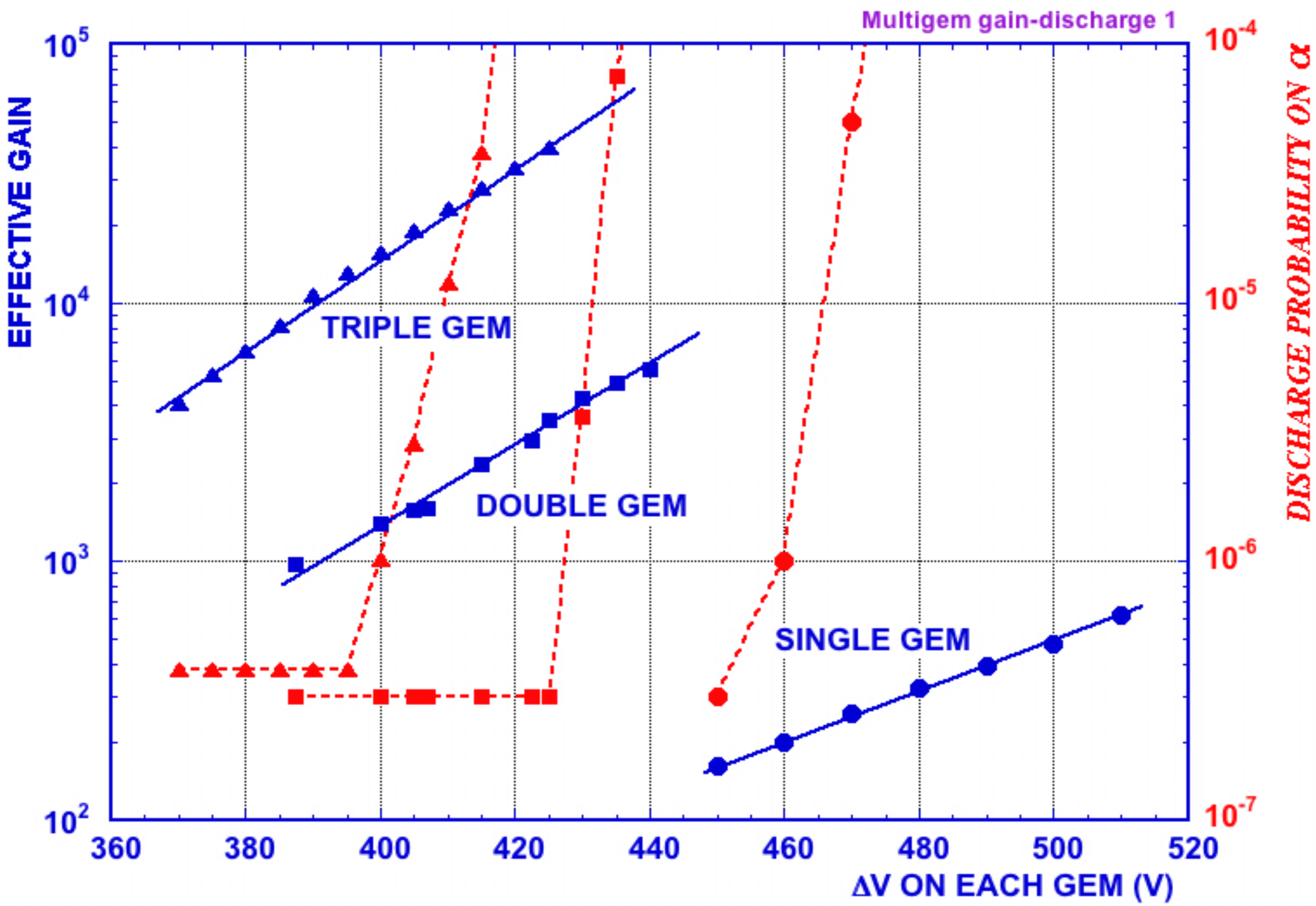
TRIPLE-GEM (TGEM): CASCADED GEM ELECTRODES



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

DISCHARGES: MULTI-GEM

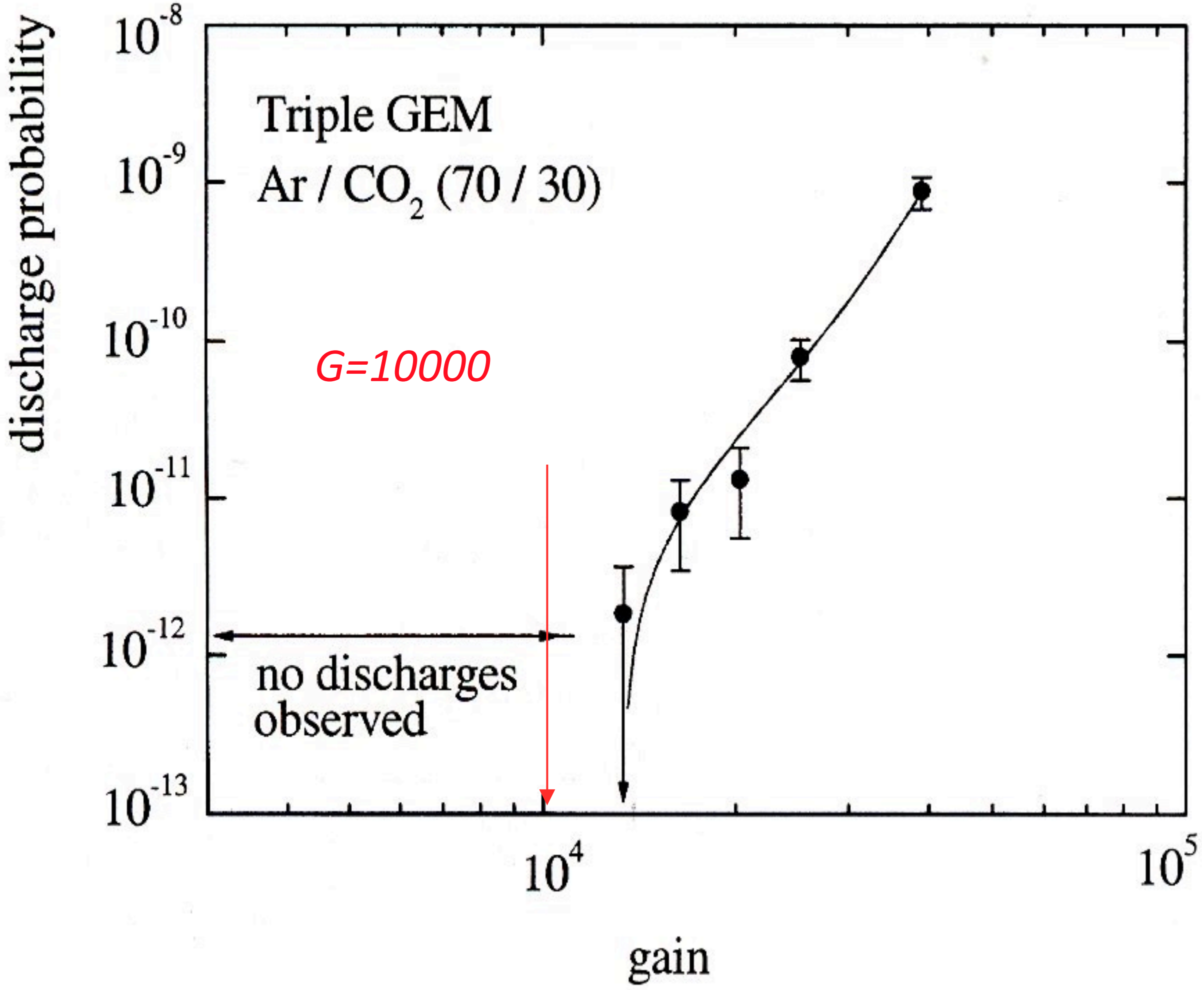
MULTI-GEM



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

COMPASS TRIPLE-GEM IN HADRON BEAM

MULTI-GEM



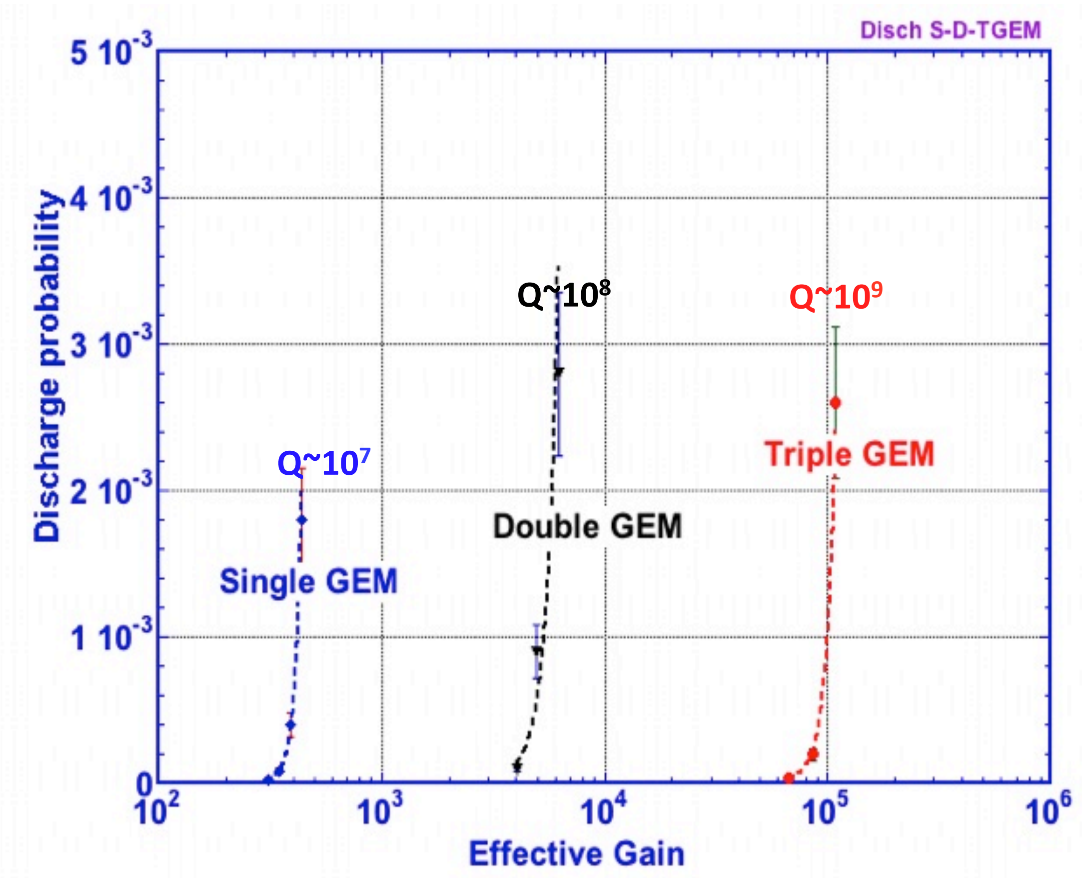
S. Bachmann et al, Nucl. Instr. and Meth. A470(2001)548

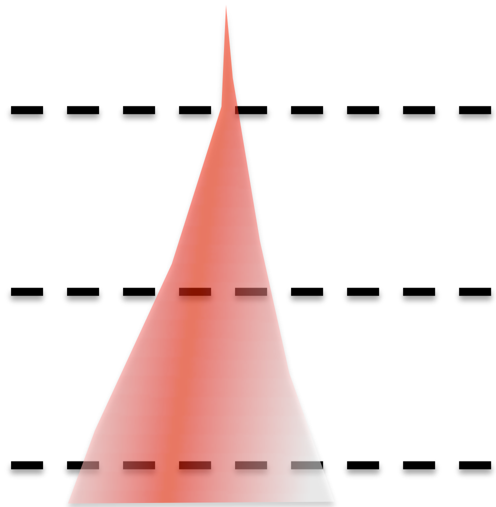
DISCHARGES: MULTI-GEM

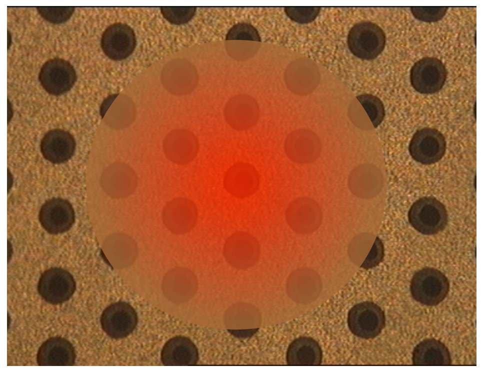
WHAT ABOUT THE RAETHER LIMIT?

DISCHARGE PROBABILITY VS GAIN:

IN MULTI-GEMs, THE CHARGE SPREADS BY DIFFUSION OVER MANY INDEPENDENT HOLES!

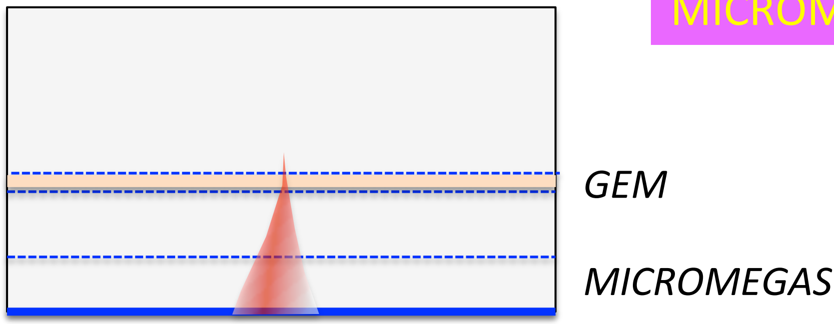




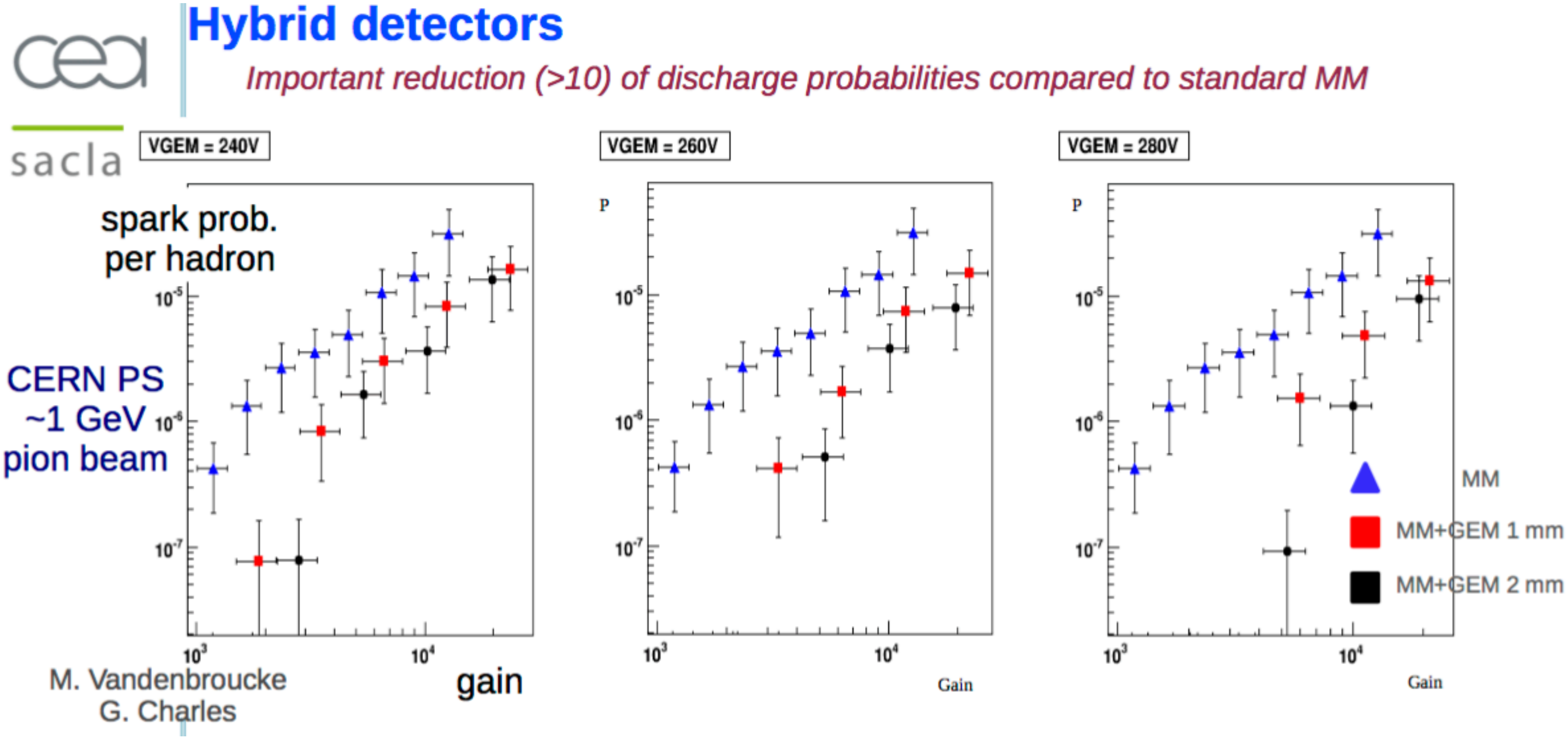


MICROMEGAS+GEM

MICROMEGAS+GEM



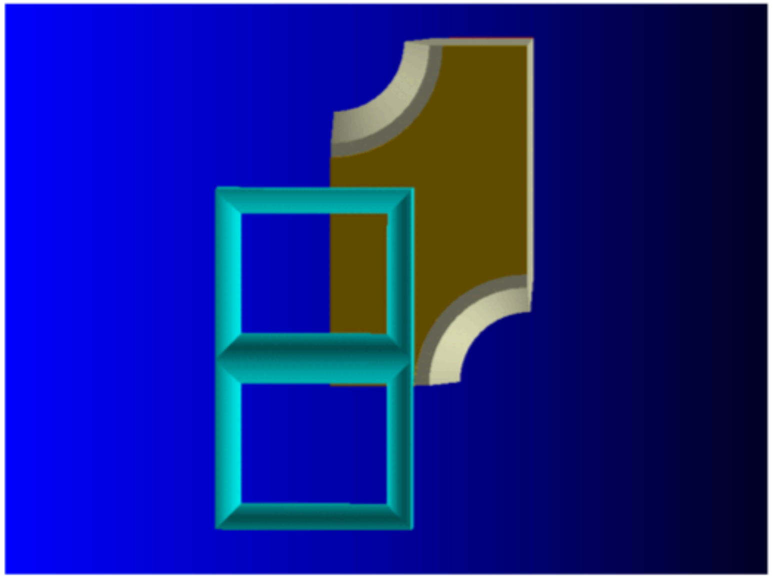
TEST BEAM COMPARISON:

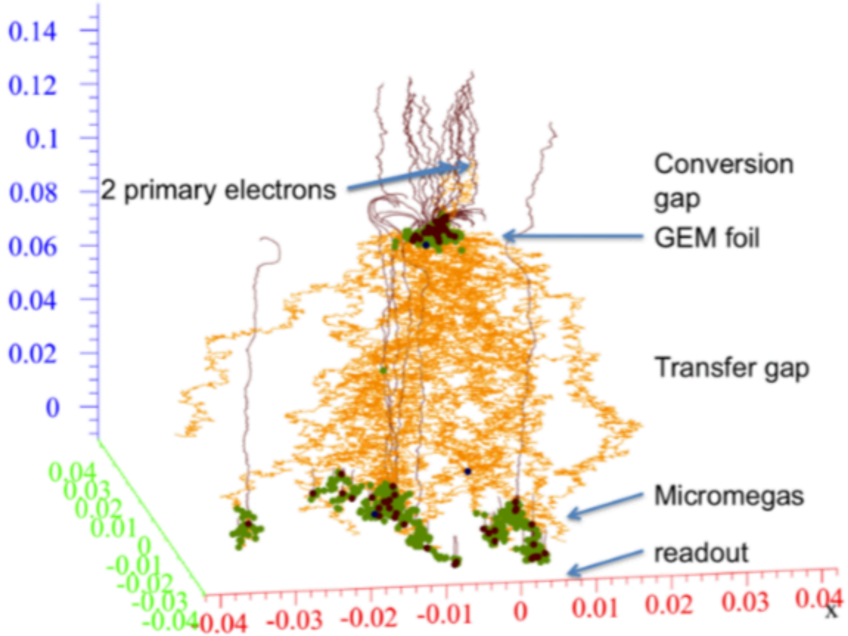


S. Procureur et al, Nucl. Instr. and Meth. A659(2011)91

AVALANCHE SIMULATION: MICROMEGAS + GEM

MICROMEGAS+GEM

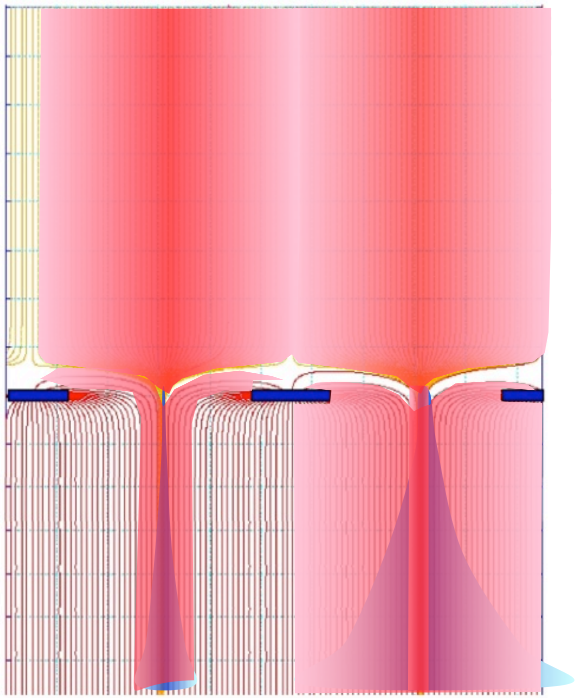




M. Vandenbroucke, JINST 7(2012)C05014

POSITIVE IONS BACKFLOW: MICROMEGAS

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

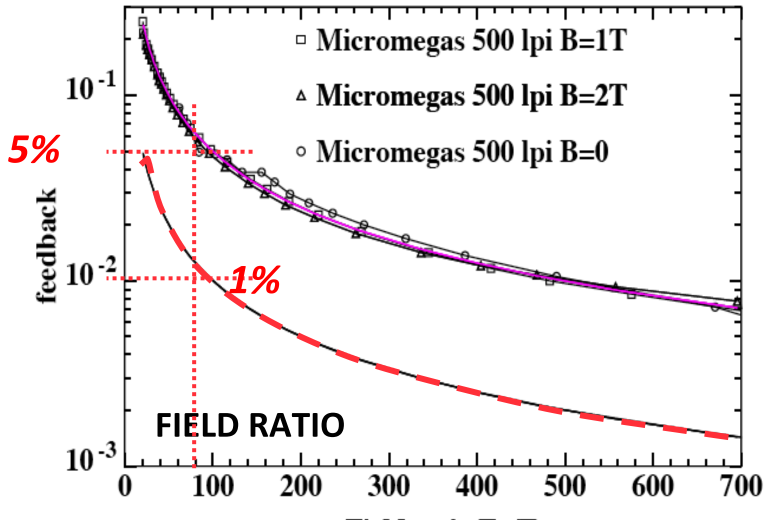


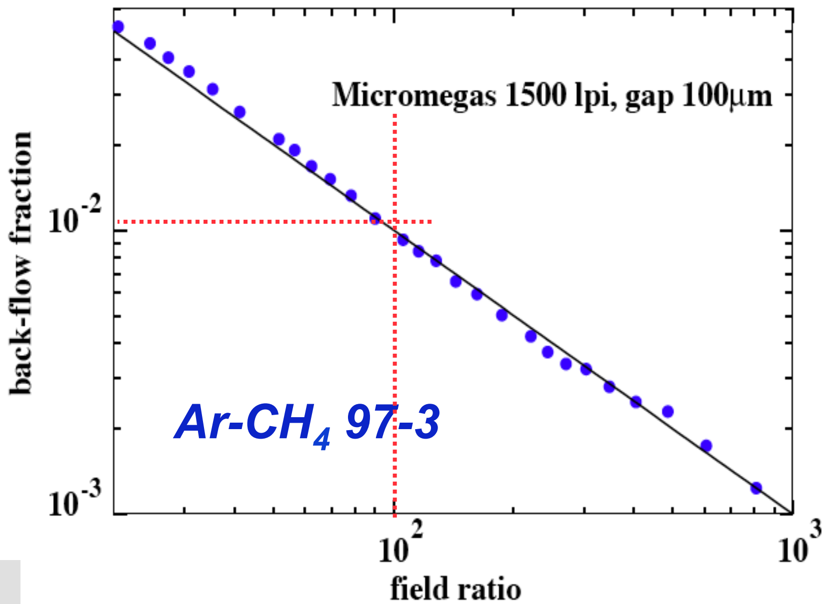
E_D~ 400 V cm^{-1}

E_A~ 40 kV cm^{-1}

GAS 1 | *GAS 2*
Low diffusion | *High diffusion*

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

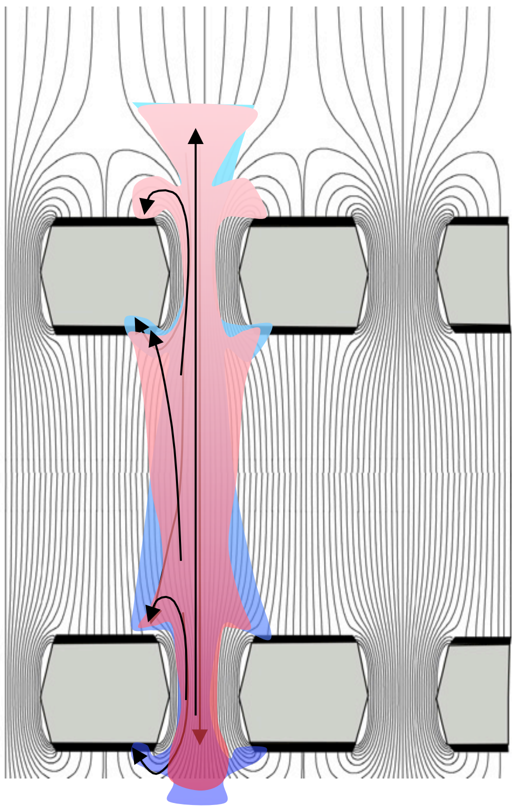




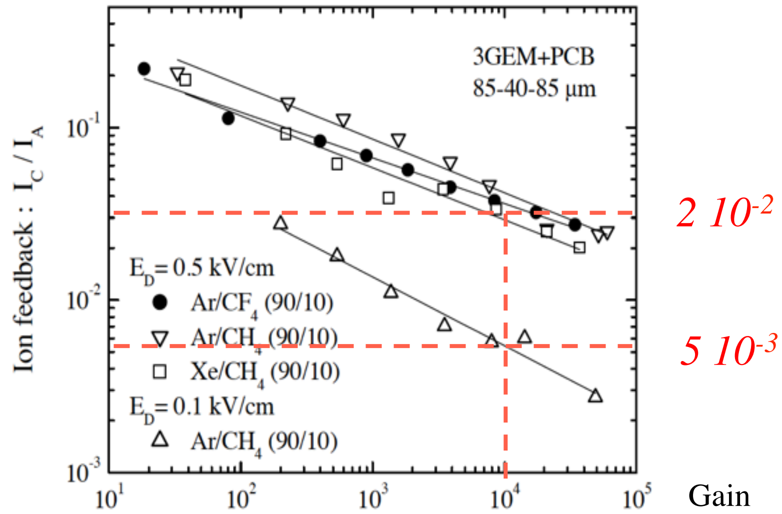
POSITIVE IONS BACKFLOW: MULTI-GEM

MULTI-GEM

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

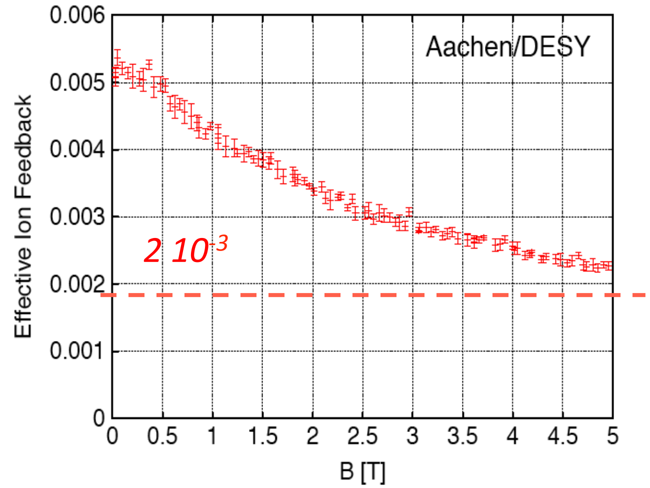


IBF AS A FUNCTION OF GAIN:



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

MAGNETIC FIELD:



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

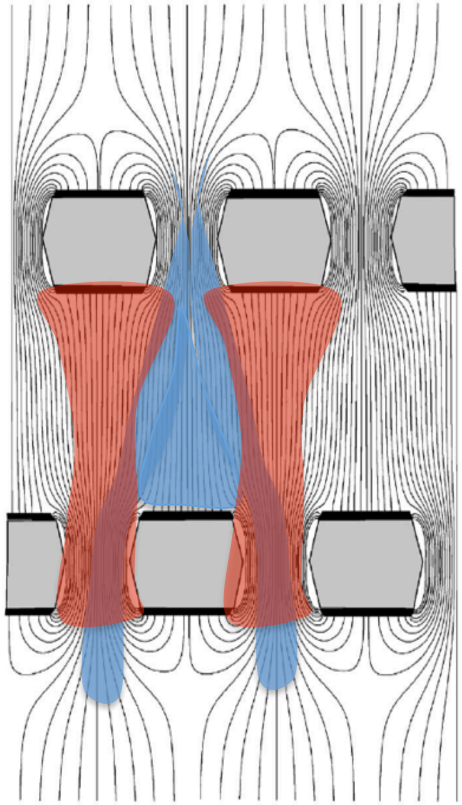
THE WISH:

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

POSITIVE IONS BACKFLOW: GEM WITH OFFSET HOLES

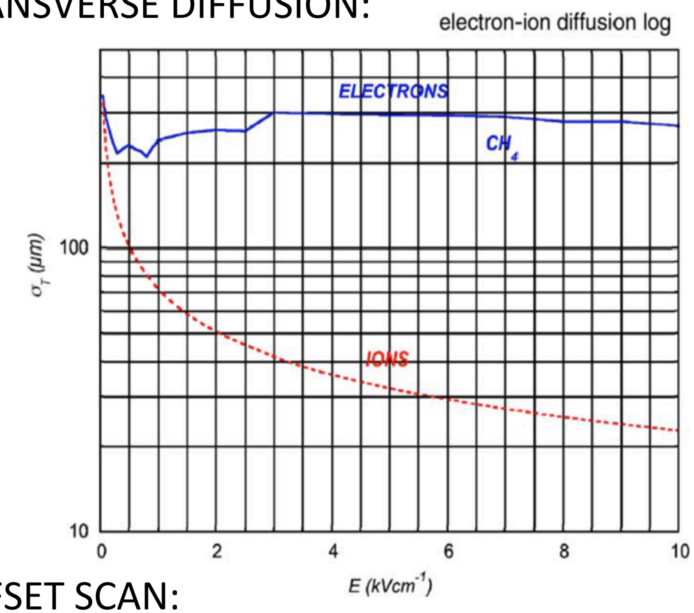
MULTI-GEM

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

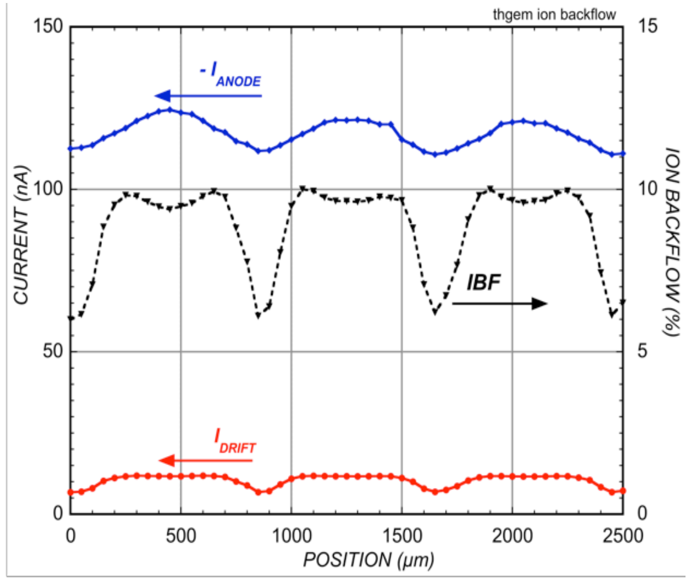


F. Sauli et al, Nucl. Instr. and Meth. A560(2006)269

TRANSVERSE DIFFUSION:



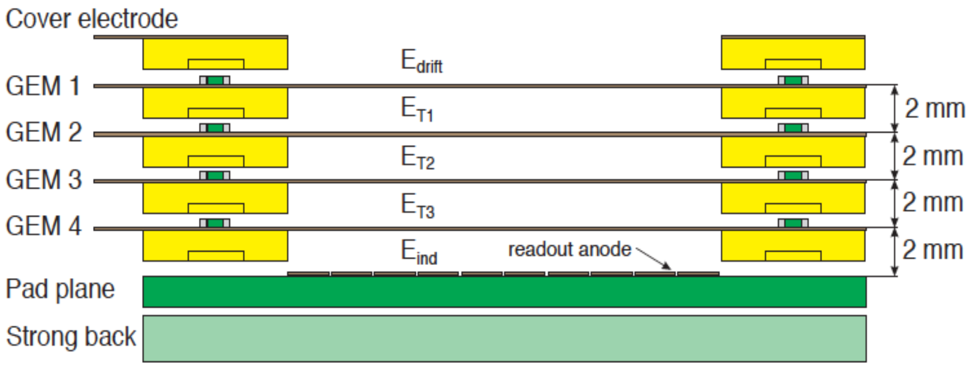
OFFSET SCAN:



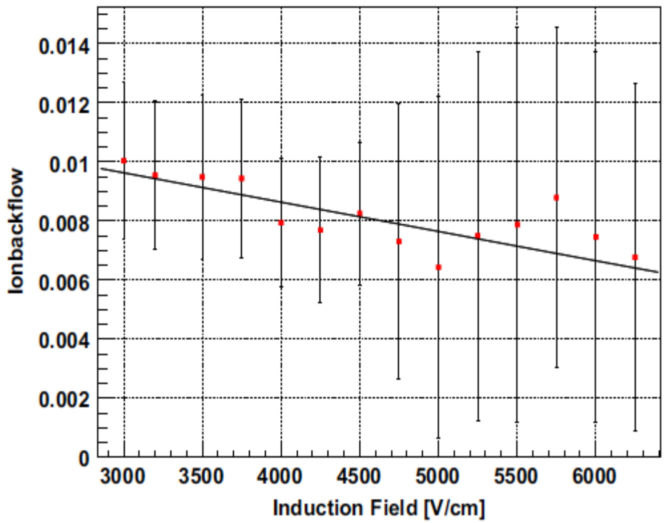
IONS BACKFLOW: ALICE TPC GEM UPGRADE

MULTI-GEM

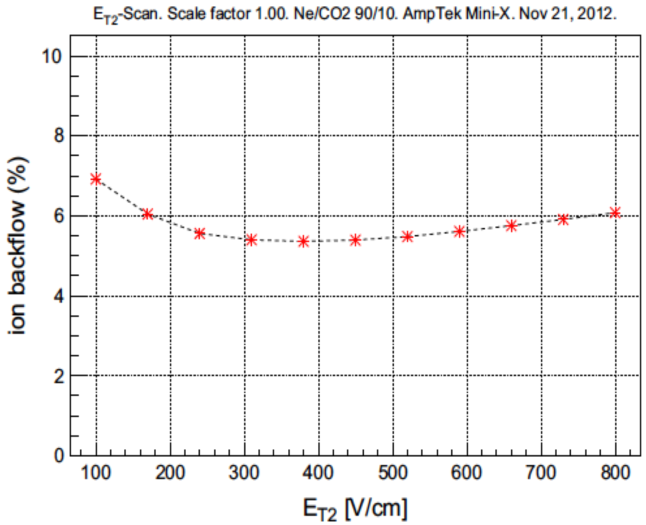
BASELINE: FOUR OFFSET GEMs



Ar-CO_2 70-30: ~ 0.8%



Ne-CO_2 (ALICE): ~ 5%



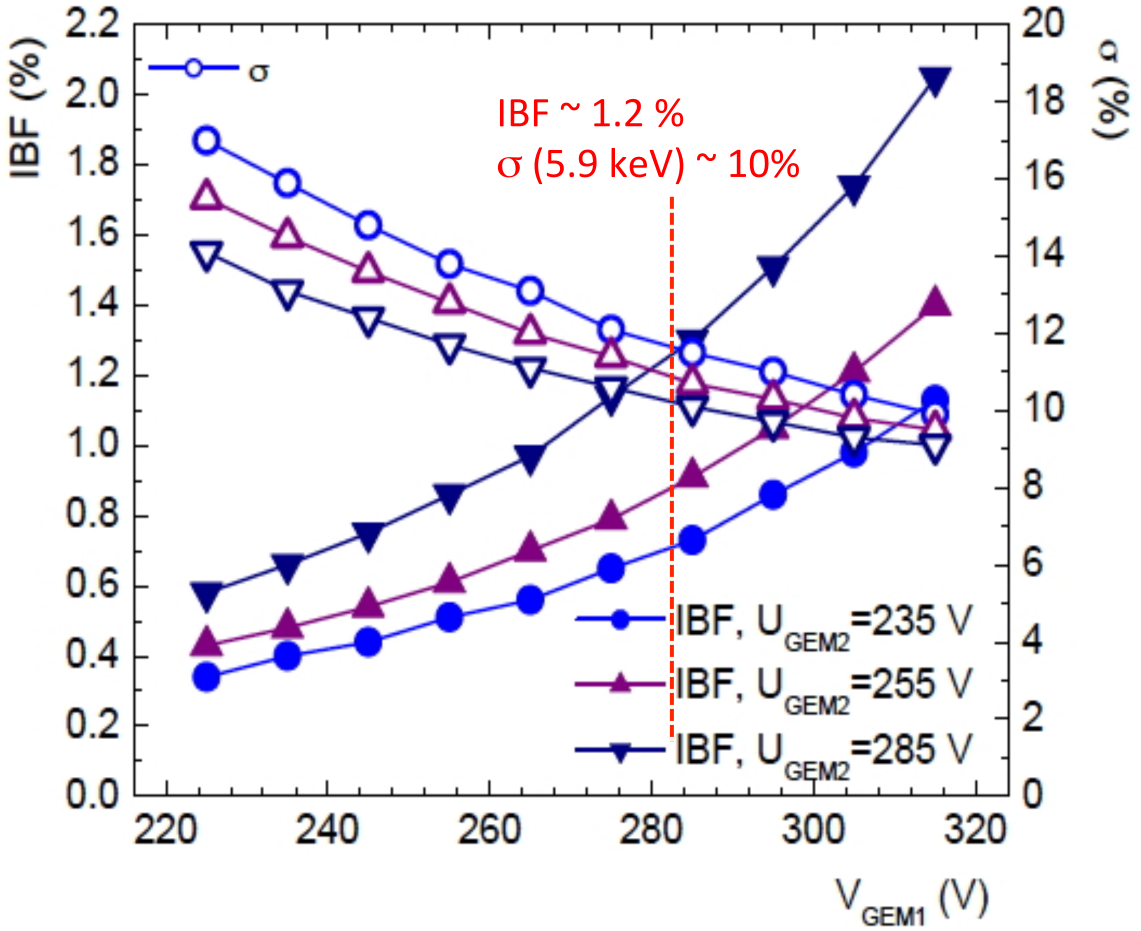
B. Ketzer et al, Nucl. Instr. and Meth. A732(2013)237

IBF: ALICE TPC GEM UPGRADE

MULTI-GEM

QUAD-GEM WITH ALTERNATING DIFFERENT PITCH (140-280-280-140 µm)

IBF AND ENERGY RESOLUTION VS VOLTAGE ON THE FIRST GEM:



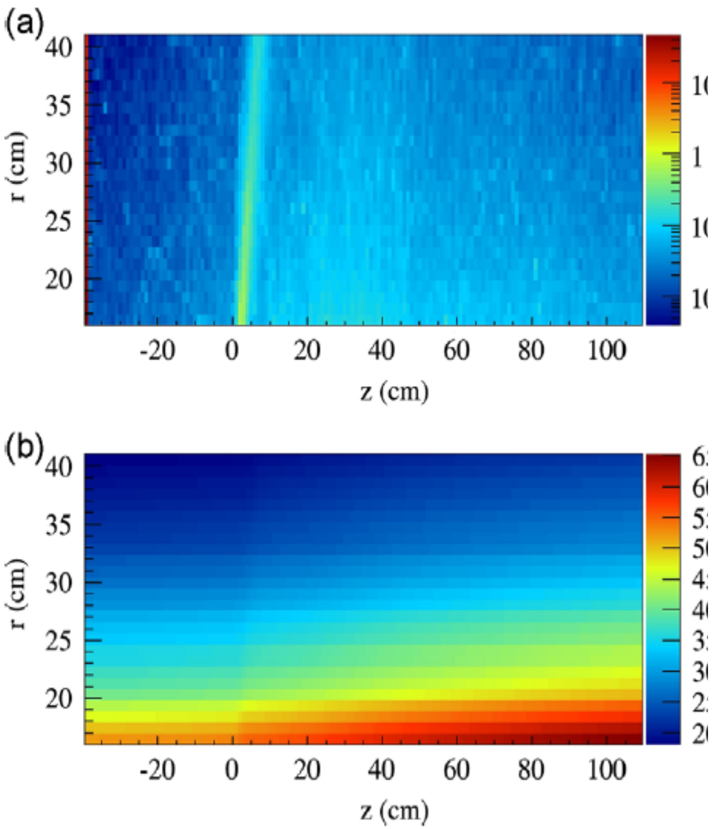
ALICE TDR CERN-LHCC-2013-020

IBF SIMULATION STUDIES FOR PANDA

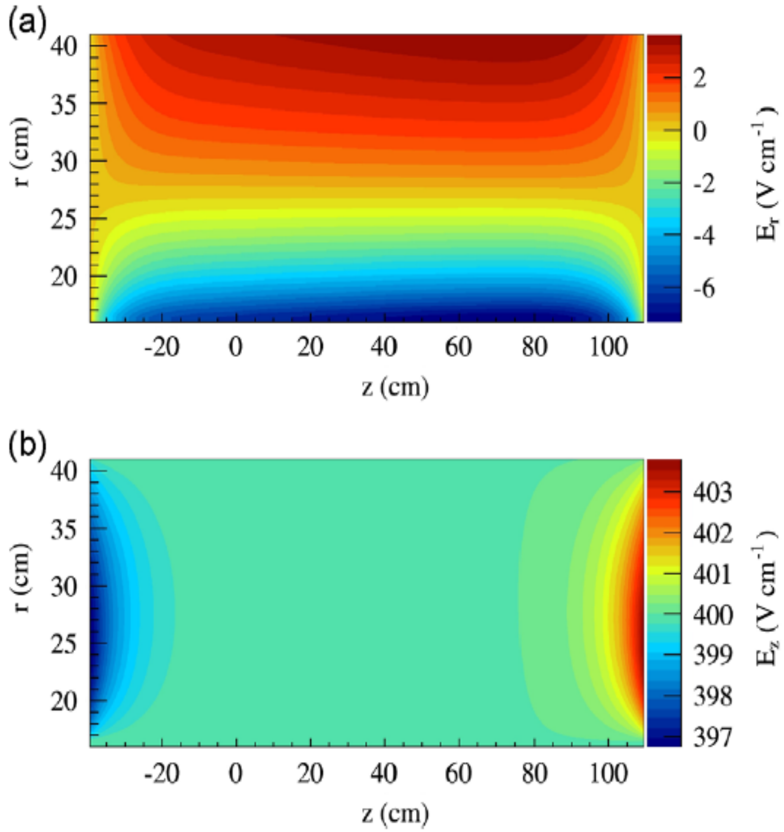
MULTI-GEM

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:

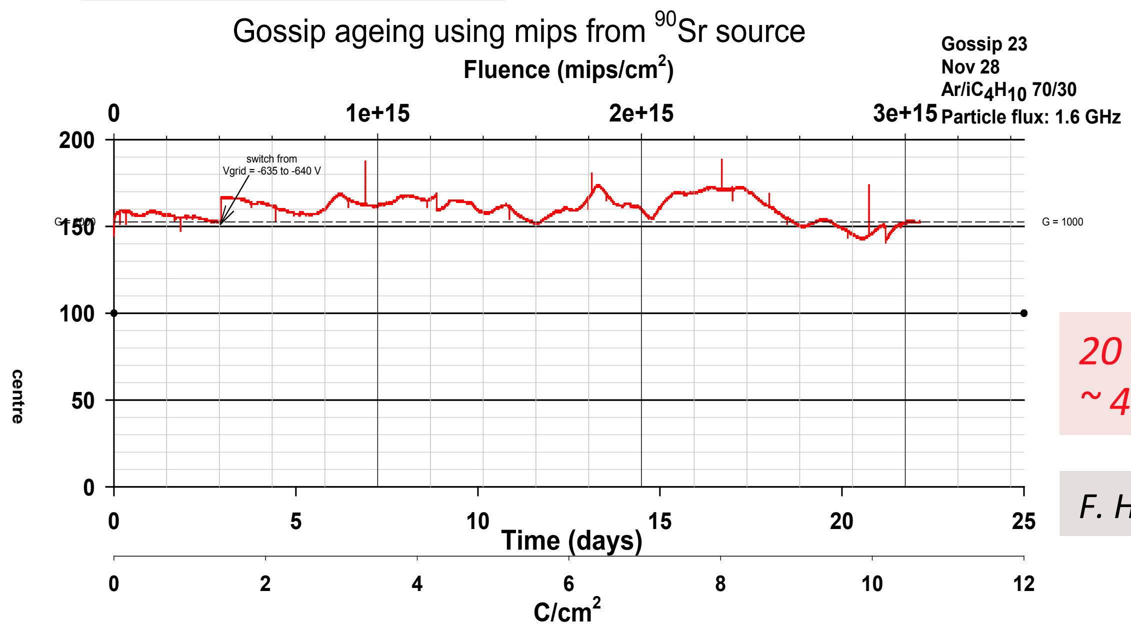


F.W. Bohmer et al,Nucl. Instr. and Meth. A719(2013)101

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}

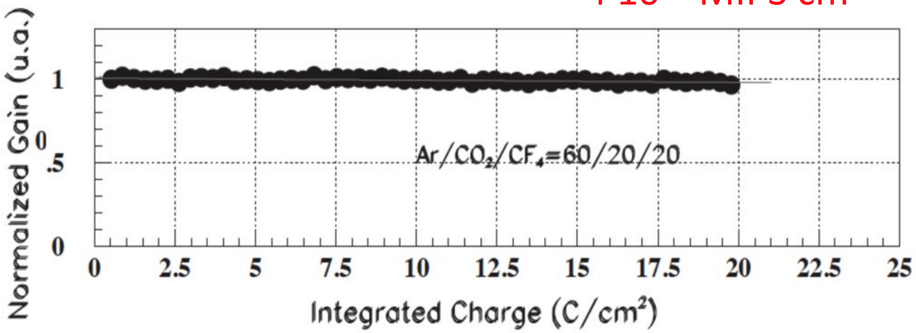
F. Hartjes, MPGD 2009

RADIATION RESISTANCE: GEM

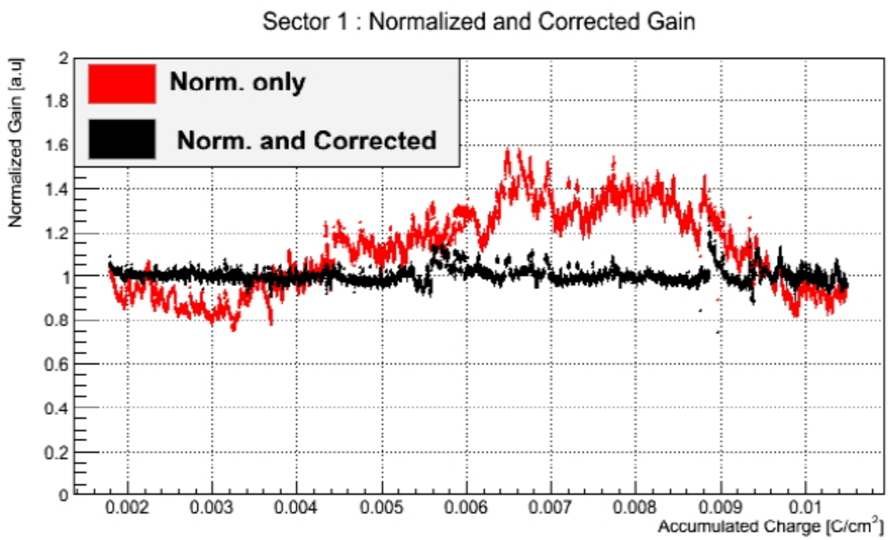
MULTI-GEM

LHCb TRIGGER:

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



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



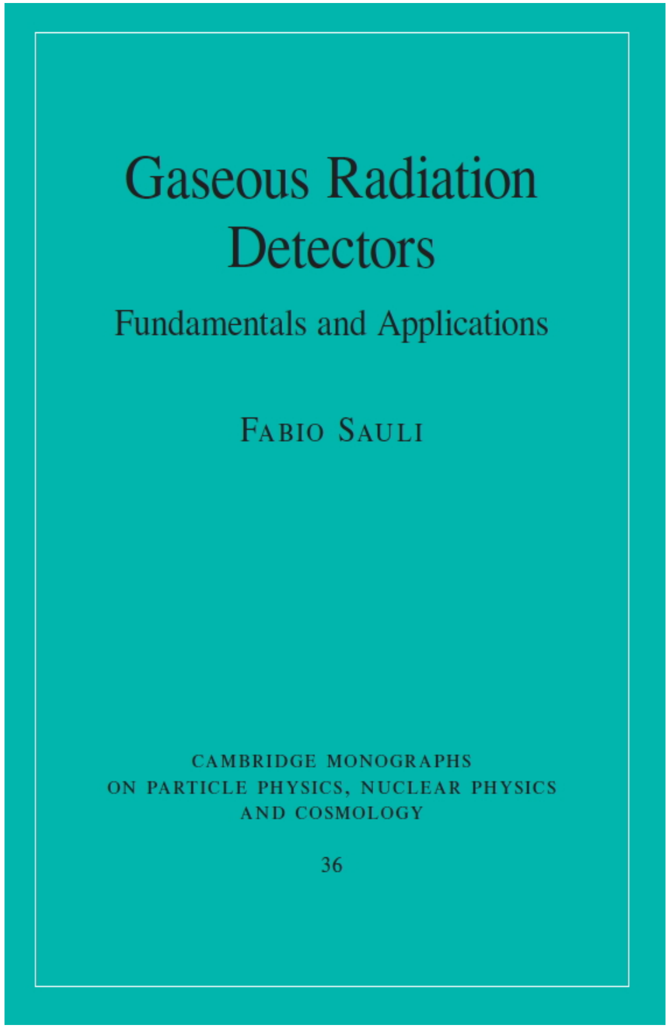
A. Sharma and M. Tytgat, CMS Technical Design Report, (2014)

AND IF YOU WANT TO KNOW MORE…

F. Sauli
Gaseous Radiation Detectors

http://www.cambridge.org/F4GASEOUS

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



THANKS FOR YOUR ATTENTION