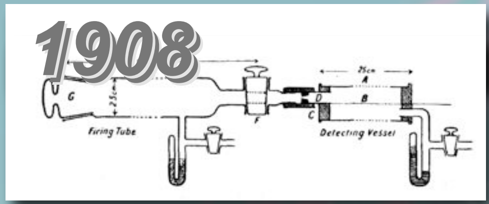
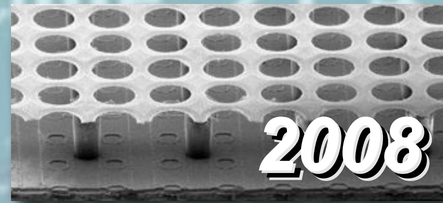




GASEOUS DETECTORS
1908-2008

ONE CENTURY OF SUCCESS AND DISAPPOINTMENTS

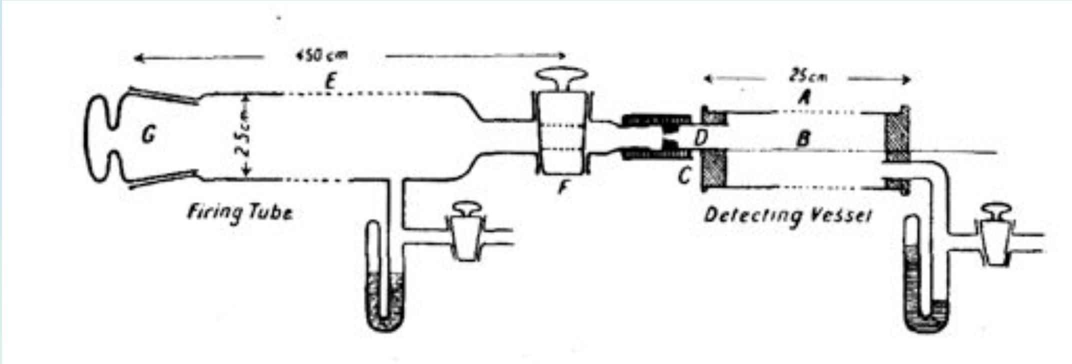
Fabio Sauli
TERA Foundation and CERN

Micro-Pattern Gas Detectors Workshop

Nikhef, Amsterdam, April 16-18 2008

EARLY GASEOUS DETECTORS

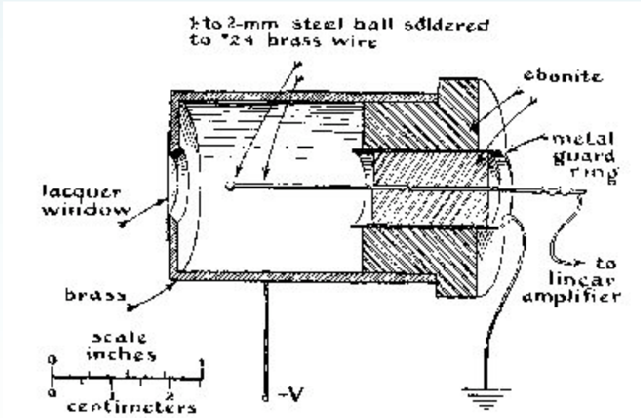
1908: FIRST WIRE COUNTER
USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY



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

1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY

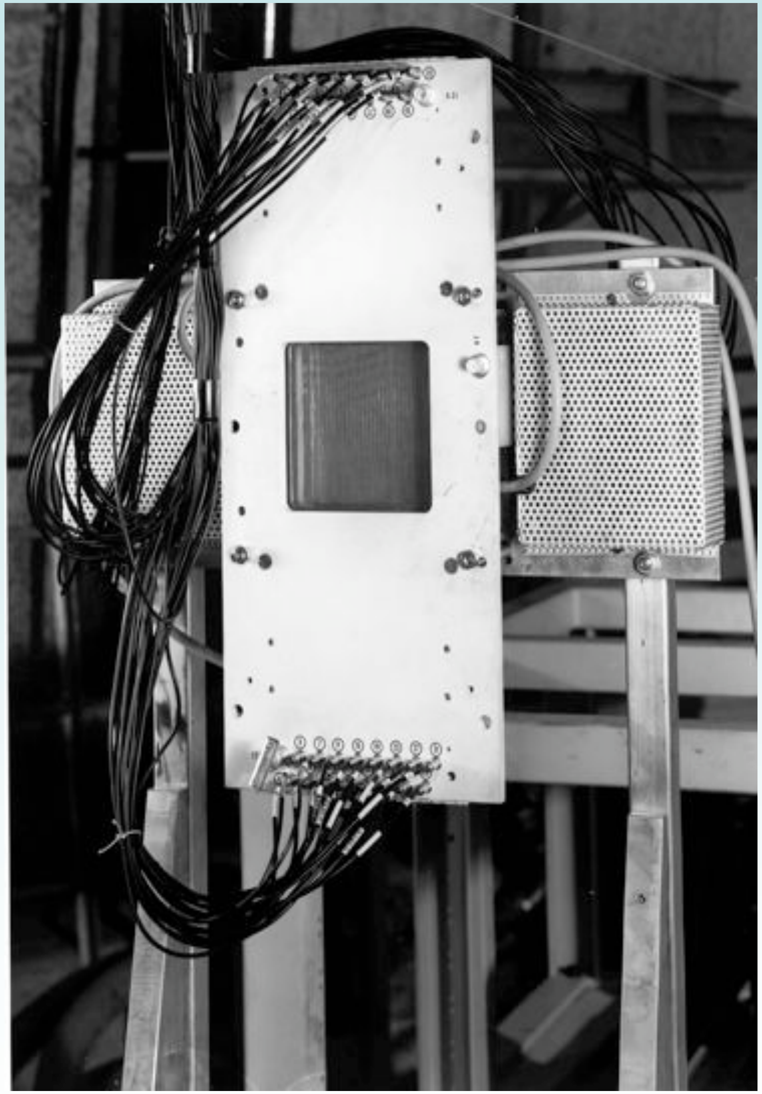
H. Geiger and W. Müller, Phys. Zeits. 29 (1928) 839



Chambres à Etincelles

Spark chambers

Rapporteur **M. CHARPAK**
Reporter CERN - GENEVE (Suisse)



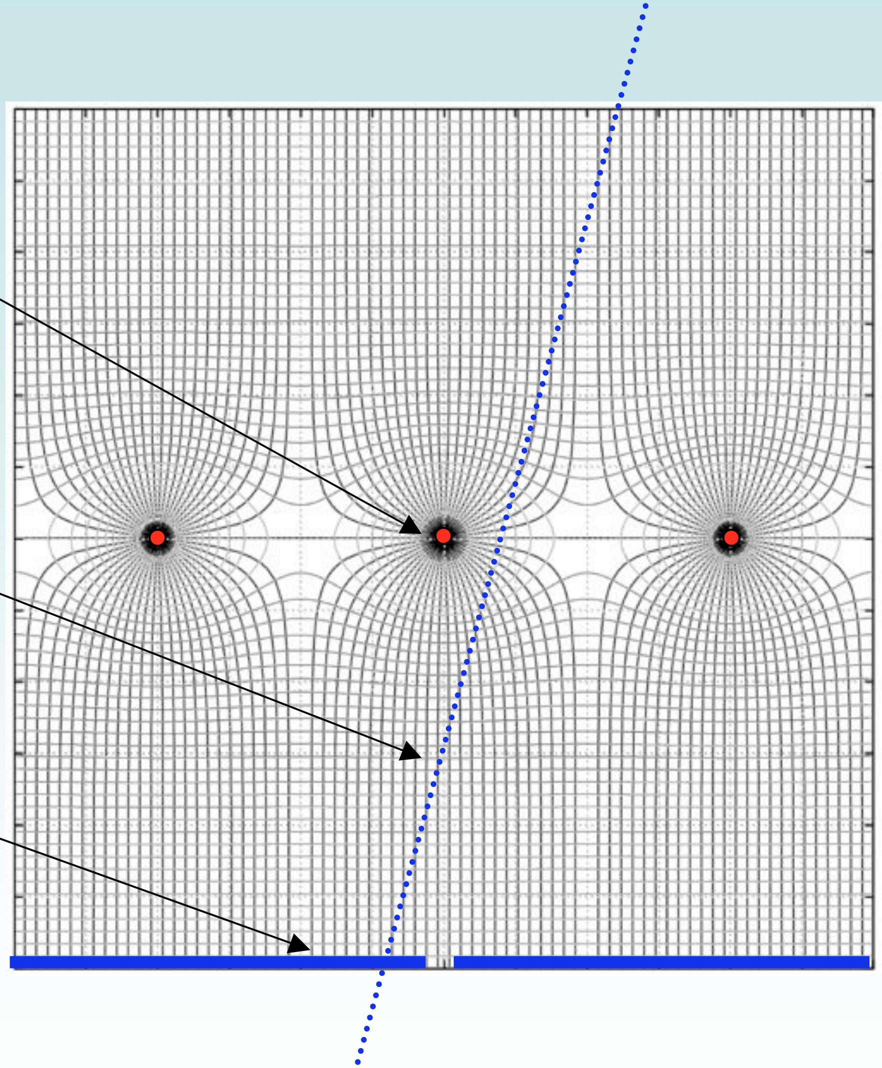
G. Charpak, Proc. Int. Symp. Nuclear Electronics (Versailles 10-13 Sept 1968)

MULTIWIRE DETECTORS: EXPLOITING THE INFORMATION

WIRE COUNT:
DIGITAL MWPC

TIME MESUREMENT:
DRIFT CHAMBERS

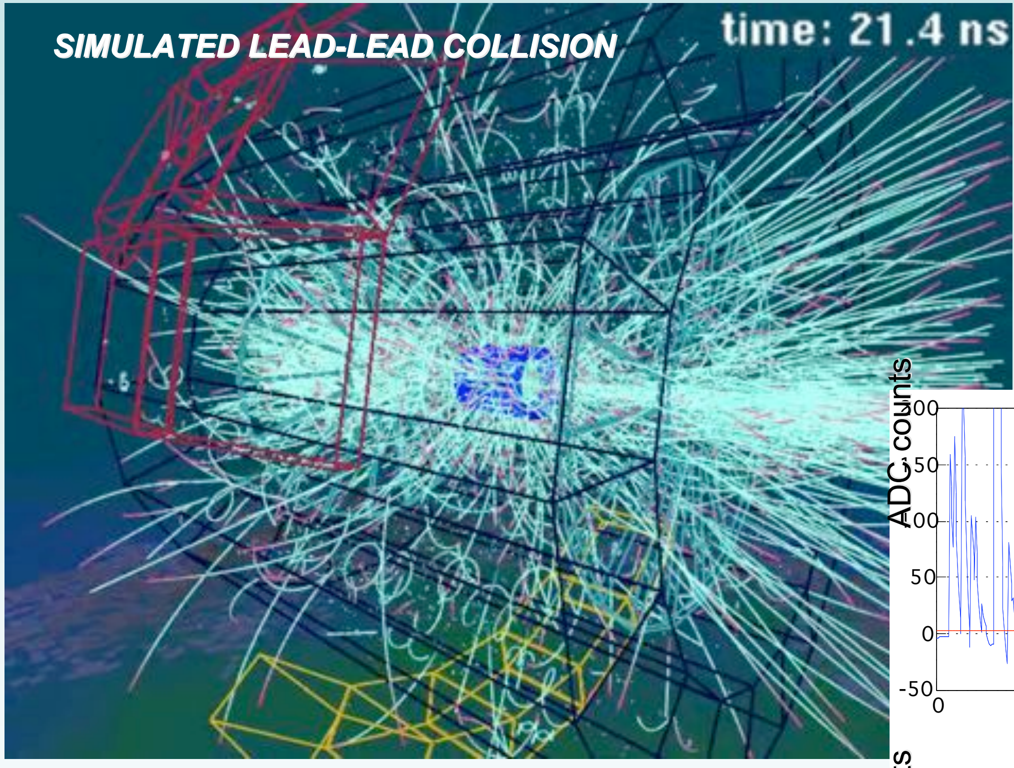
INDUCED CHARGE:
2-D READOUT



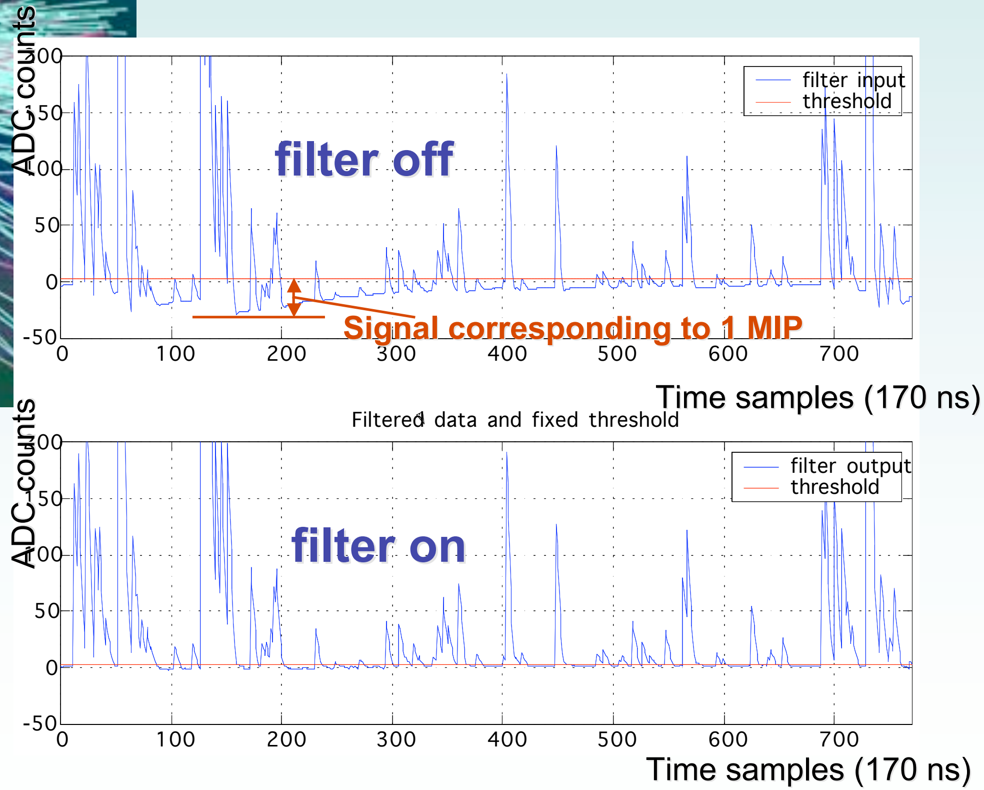
TIME AND INDUCED CHARGE ON PADS:
TIME PROJECTION CHAMBERS

TIME PROJECTION CHAMBRES: HIGH MULTIPLICITY TRACKING

ALICE TPC:



POSITIVE IONS TAIL CANCELLATION: ACTIVE FILTERING IMPROVES TRACK RECOGNITION AT HIGH MULTIPLICITIES:



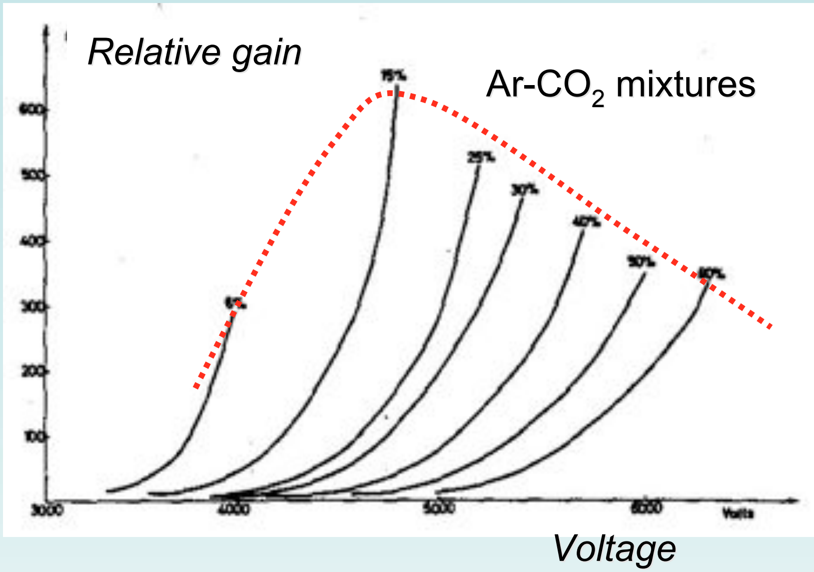
ALTRO
B. Mota et al, Nucl. Instr. and Meth. A535(2004)500

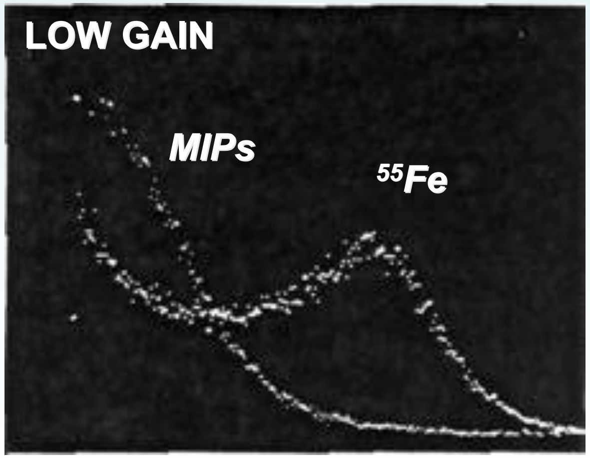
MAXIMUM GAIN IN MWPC

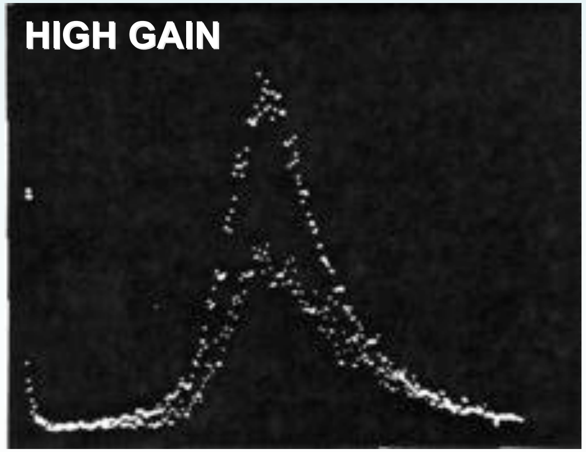
The maximum gain in MWPCs depends on gas and geometry, limited by “natural” discharges.

Using “Magic Gas” ($Ar\text{-}C_4H_{10}\text{-}CF_3Br$) one could reach very high and saturated gains. The mechanism is probably similar to the limited streamer, a self-quenching large avalanche exploited in Streamer Tubes.

Prone to aging and rate-limited; abandoned with the advent of sensitive electronics.



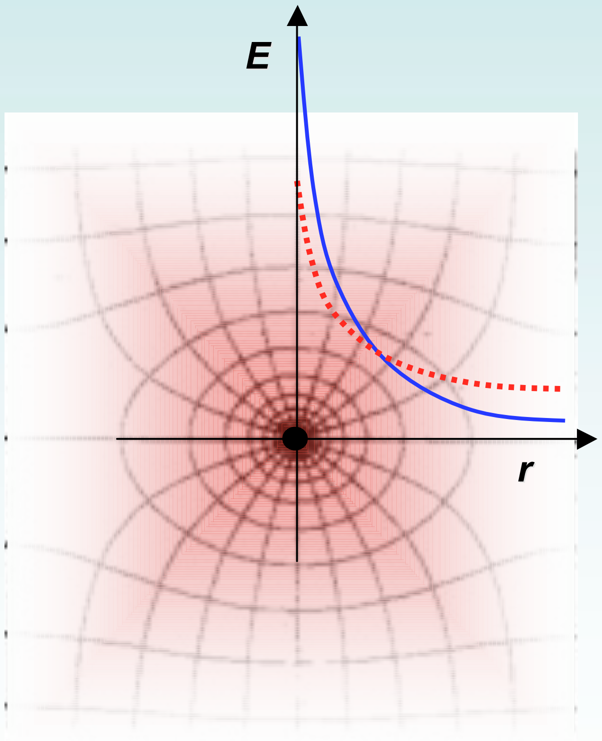


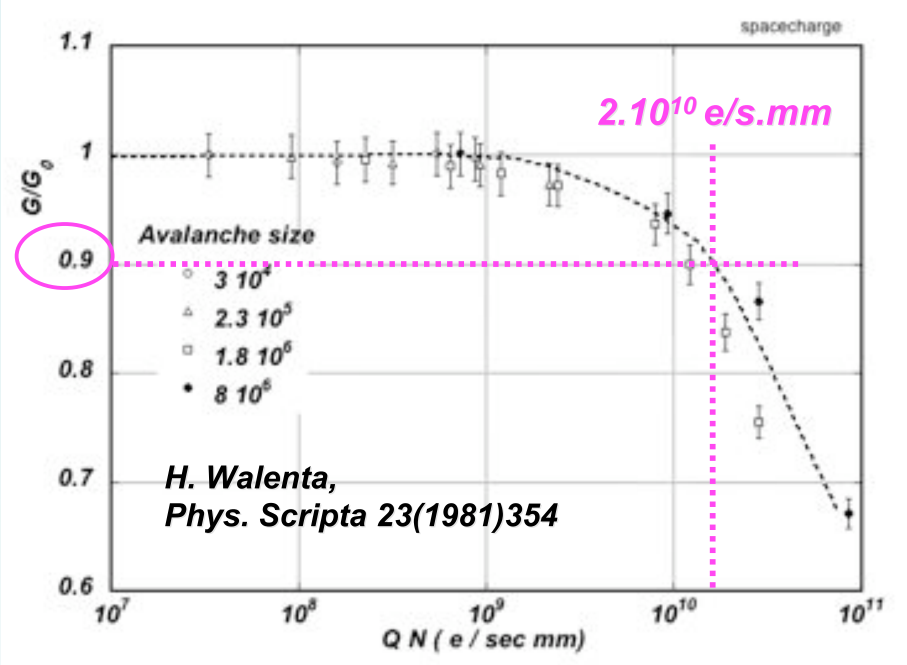


R. Bouclier et al, Nucl. Instr. and Meth. 88(1970)149

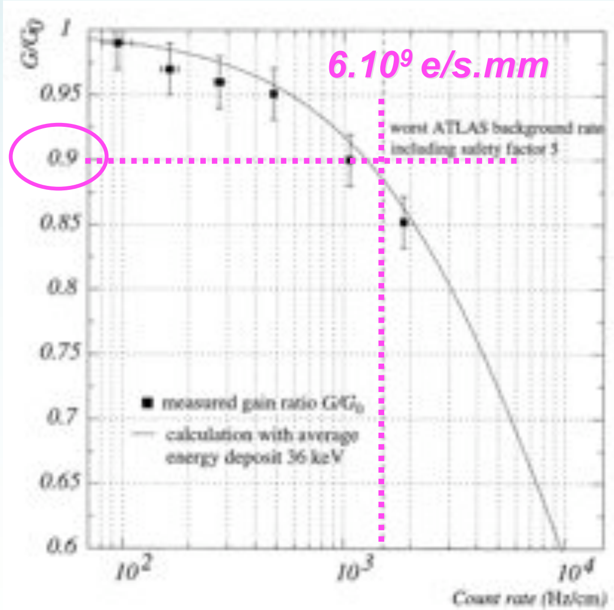
MWPC RATE LIMITATIONS: SPACE CHARGE

Due to the low mobility of ions, the positive charge built-up in the avalanches modifies the field, decreased at the anode, and causes a gain reduction. In general, this prevents the formation of discharges for high rates and high ionization densities.





ATLAS
HIGH RESOLUTION
DRIFT CHAMBERS
3 bar
$G=2.10^4$
$N \sim 2.10^3$ e



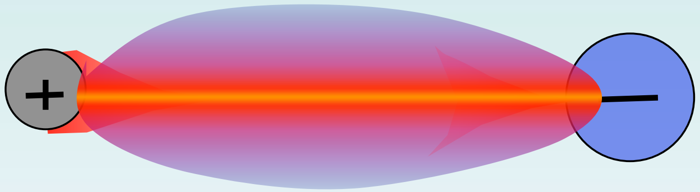
M. Aleksa et al, NIMA446 (2000)435

MWPC: DISCHARGES

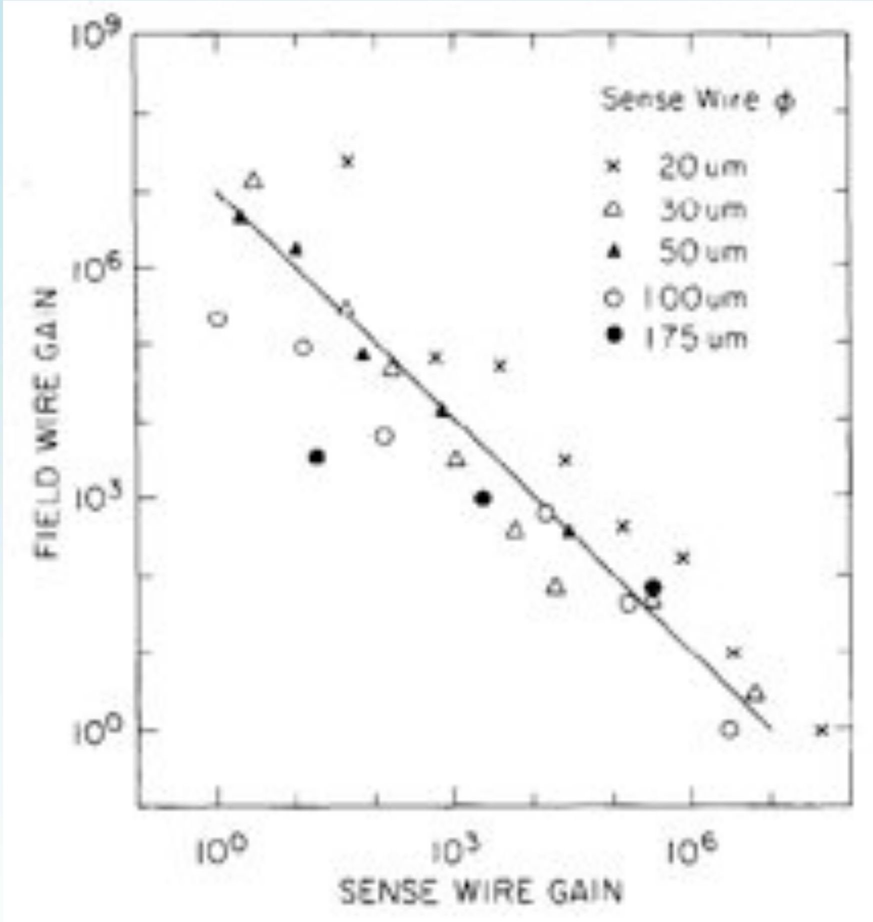
Discharges in MWPCs can be triggered by amplification of electrons released in the high field at the surface or near the cathodes.

NORMAL ANODE AVALANCHE:

REVERSE CATHODE AVALANCHE:



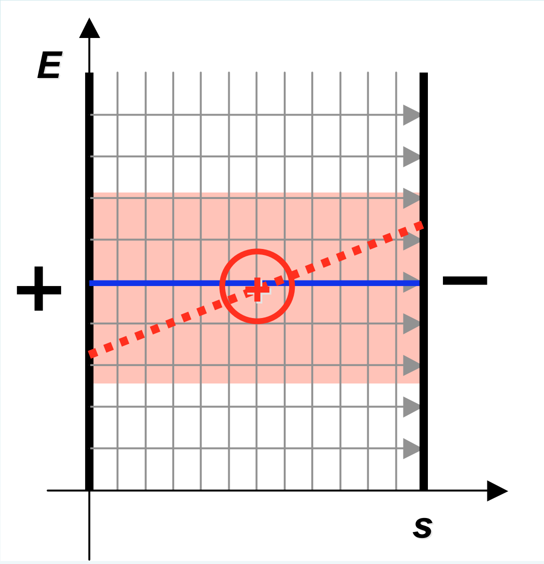
Anode and cathode gains depend on wire diameters; their product at discharge is constant.
Of course, for ionization in the gap one only detects the anode gain.
This is a recurrent and not always well understood limitation in all gaseous detectors.



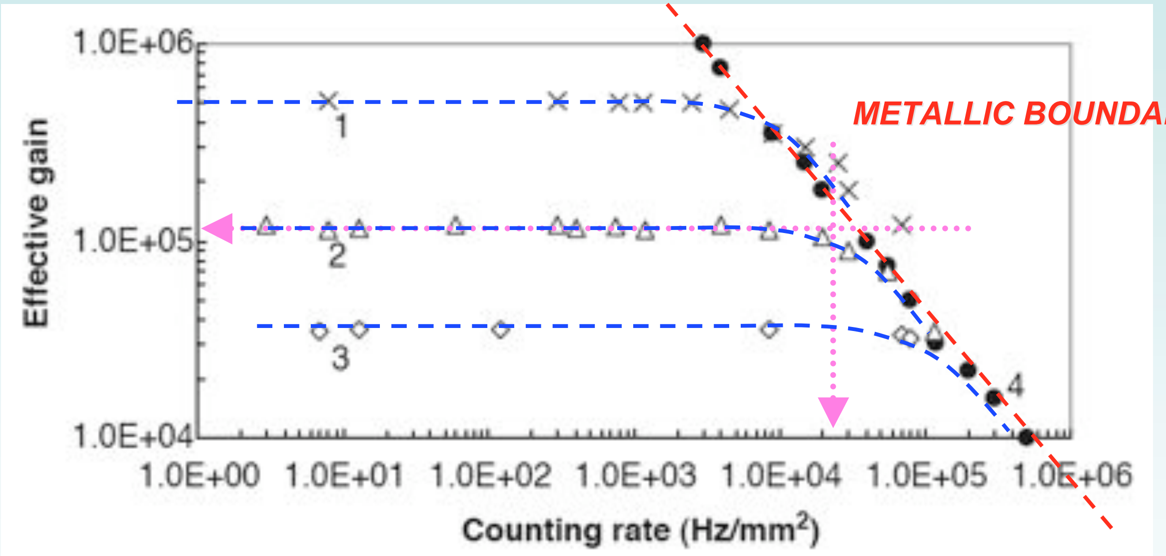
P. Giubellino et al, Nucl. Instr. and Meth. A245(1986)155

PARALLEL PLATE COUNTERS: RATE EFFECTS

In Parallel Plate Counters, the built-up of positive space charge, in first approximation, does not modify the gain, as the lower field on one side is compensated by the higher field on the other.
At high rates or high ionization density the avalanche size reaches the Raether limit (~ 10^8 ion pairs) and makes a transition to a streamer followed by discharge.



GAIN VERSUS RATE FOR PPCS WITH DIFFERENT ELECTRODE RESISTIVITY:



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

The number density of ions per unit volume in a gap L is given by: $N = \frac{n\,R\,L\,M}{w^+}$

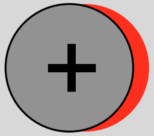
n: ionization electrons per track, R: rate M:gain, w^+: ion drift velocity.
For MIPs in one cm of gas n=100, w^+=2.10^5 cm/s, M=10^5, R=2.10^6 Hz/cm^2 ---> **N~ 10^8**

A single neutron interaction would release ~ 2 MeV (10^5 e); for M=10^3 ---> **N ~ 10^8**

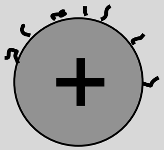
POLIMERIZATION AND MWPC AGING

“Aging”, the formation of deposits on electrodes due to various processes of polymerization results in serious deterioration of performances:

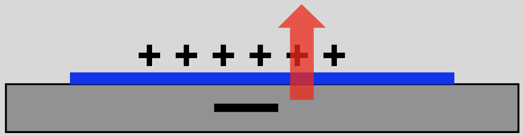
Gain reduction due to deposits on anode (increased wire diameter):



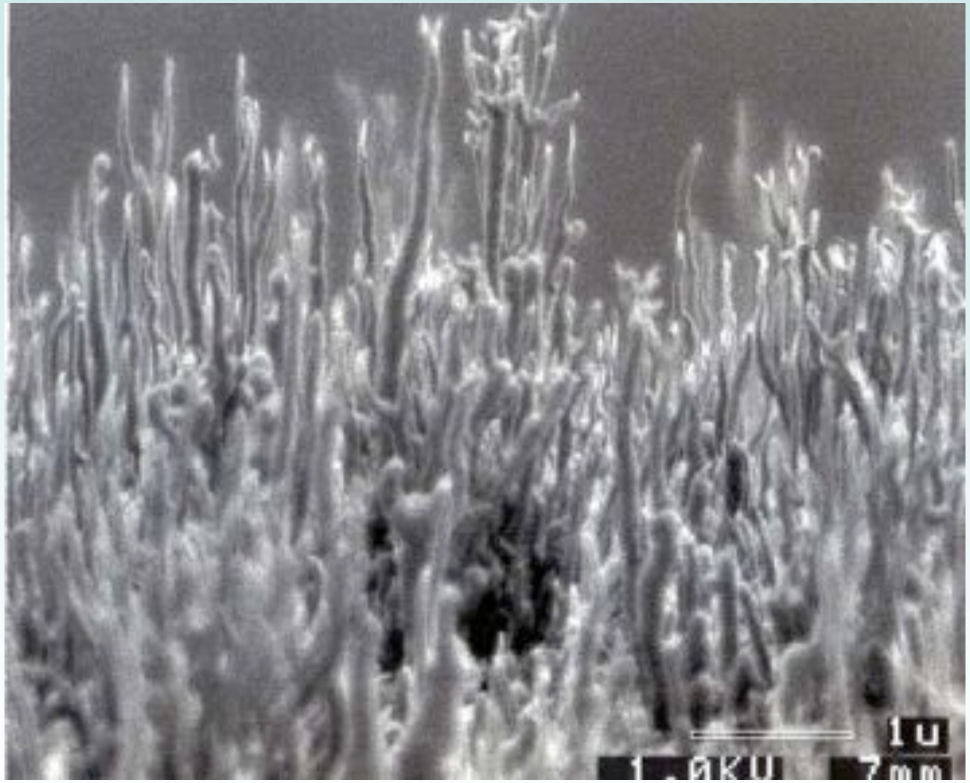
Discharges due to formation of “hairs”:



Secondary electron emission due to the dipole field on cathode deposits (Malter effect):



SILICON FILAMENTS ON AGED ANODE WIRES:

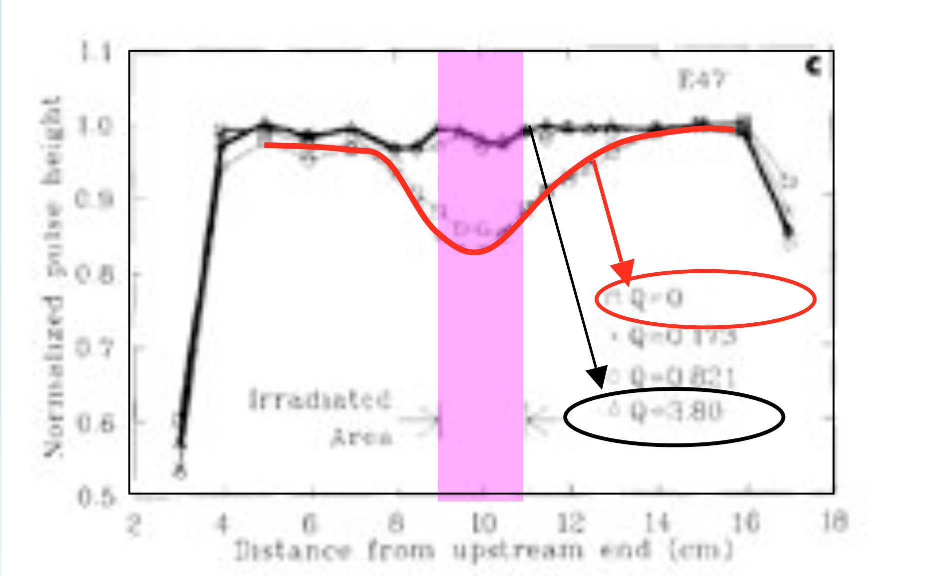


M. Binkley et al, Nucl. Instr. and Meth.A515(2003)53

Carbon Tetrafluoride, a commonly used etchant in silicon industry, has been shown to prevent and even remove deposits.

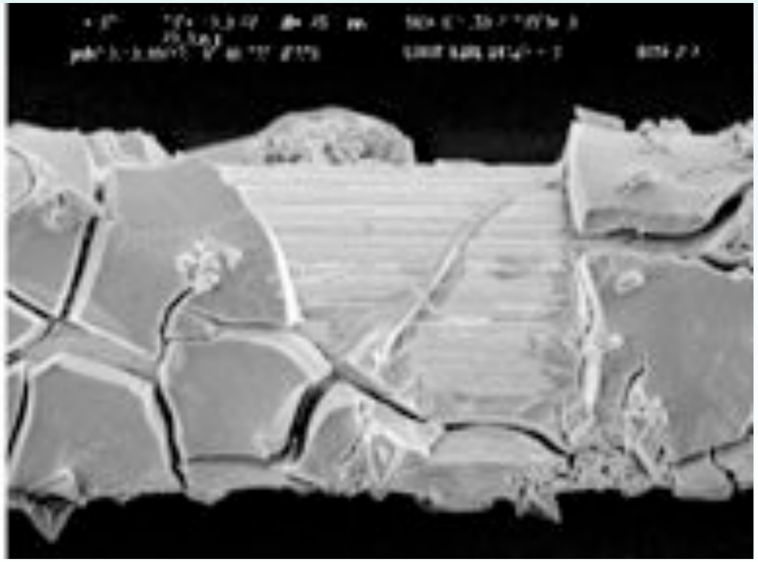
Unfortunately, CF_4 releases very aggressive Fluorine ions and radicals; in presence of water, it forms HF, a very aggressive acid, in particular for glass, fibreglass, epoxies.

RECOVERY IN CF_4-iC_4H_{10}:



R. Openshaw et al,
Nucl. Instr. and Meth. A307(1991)298

WIRE DAMAGED BY CF_4 (ATLAS TRT):



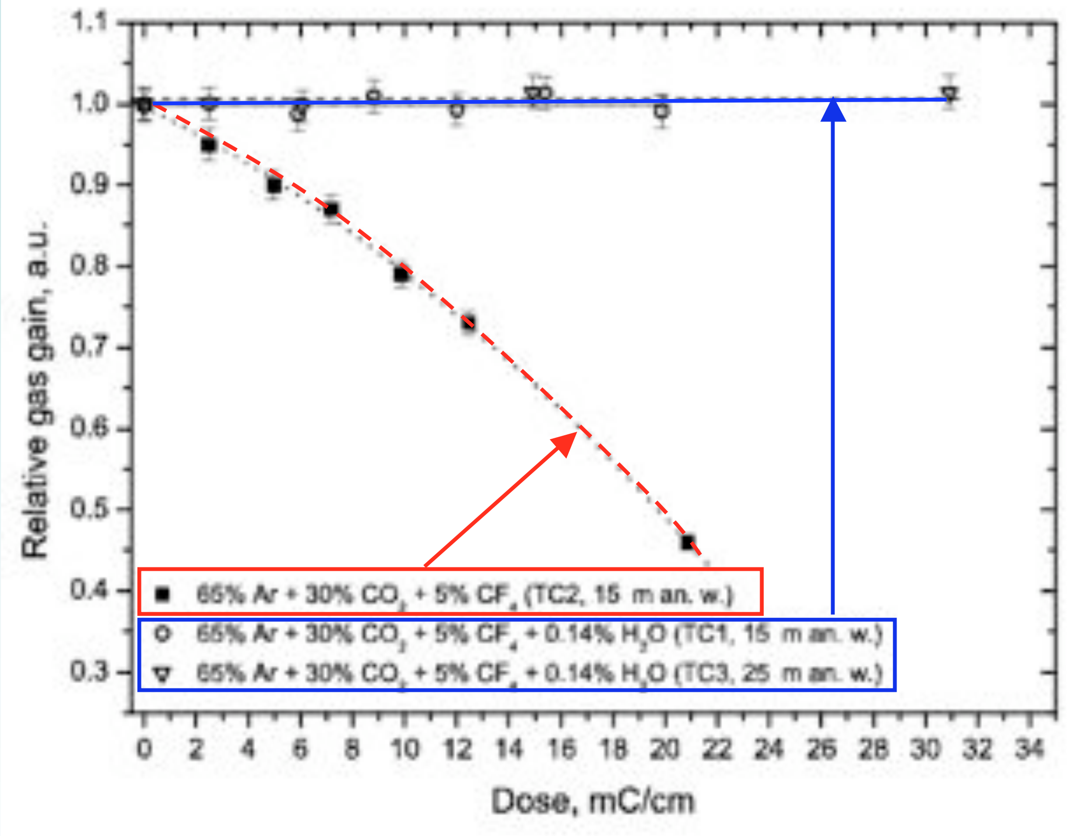
A. Romaniuk et al,
Nucl. Instr. and Meth. A515(2003)166

CF_4 IS BAD!

So, CF_4 is out, particularly if there is residual moisture in the detector, right?

WRONG!

RECOVERY OF THE HERMES WIRE CHAMBERS AFTER WATER ADDITION TO CF_4 MIXTURES:



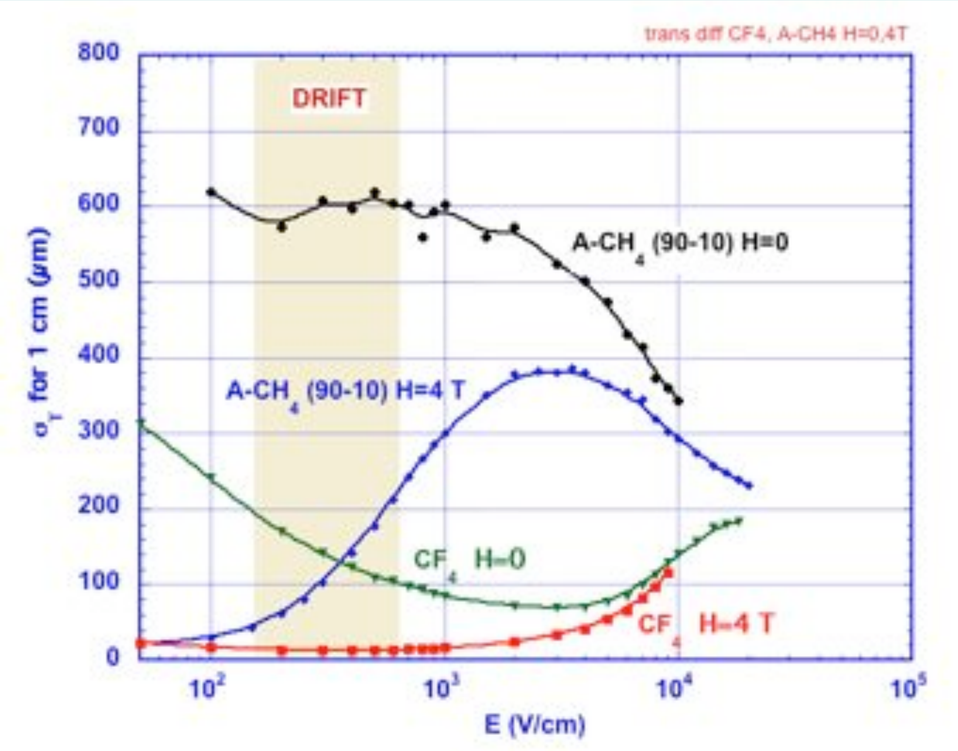
S. Belostotski et al, Nucl. Instr. and Meth. (Accepted March 2008)

CF4 IS GOOD!

CF_4 by itself is a very interesting gas for several reasons:

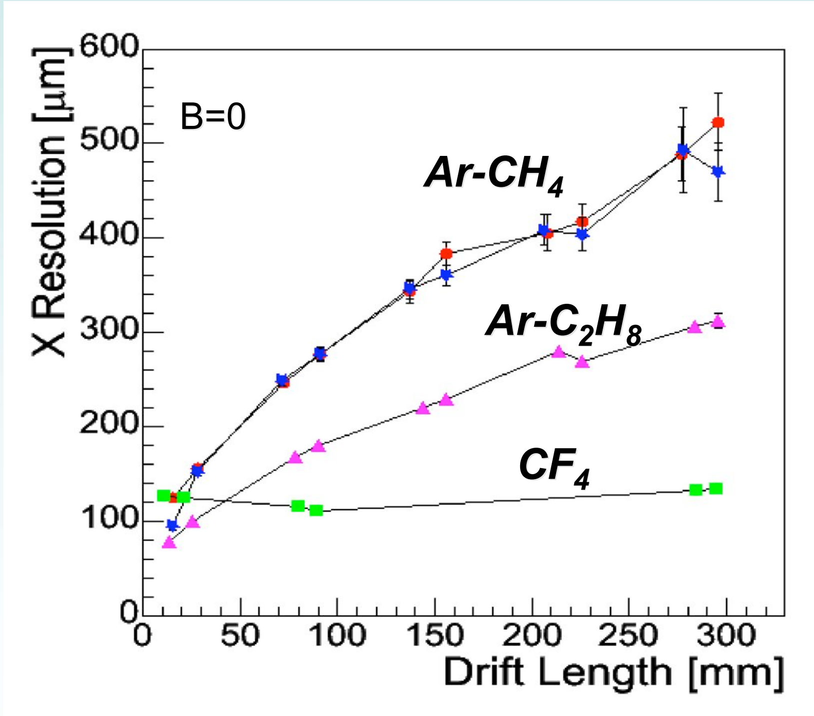
- *NON-FLAMMABLE*
- *HYDROGEN-FREE (NEUTRONS)*
- *VERY FAST DRIFT VELOCITY*
- *VERY SMALL DIFFUSION*
- *SILICON ETCHING*

TRANSVERSE DIFFUSION IN P-10 AND CF_4:



(Computed with MAGBOLTZ)

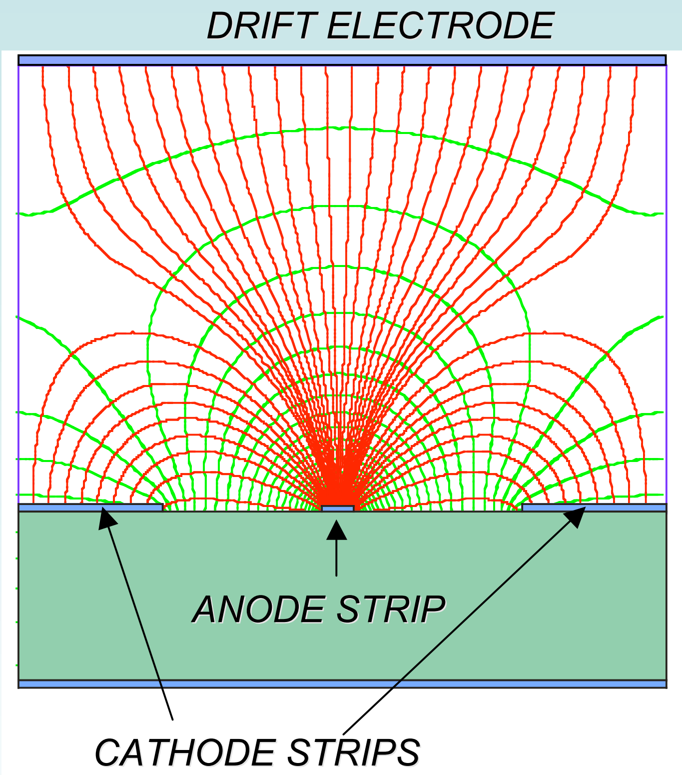
POSITION ACCURACY AS A FUNCTION OF DRIFT LENGTH IN A TPC WITH GEM READOUT: STANDARD MIXTURES VS CF_4



S.X. Oda et al,
Nucl. Instr. and Meth. A566(2006)312

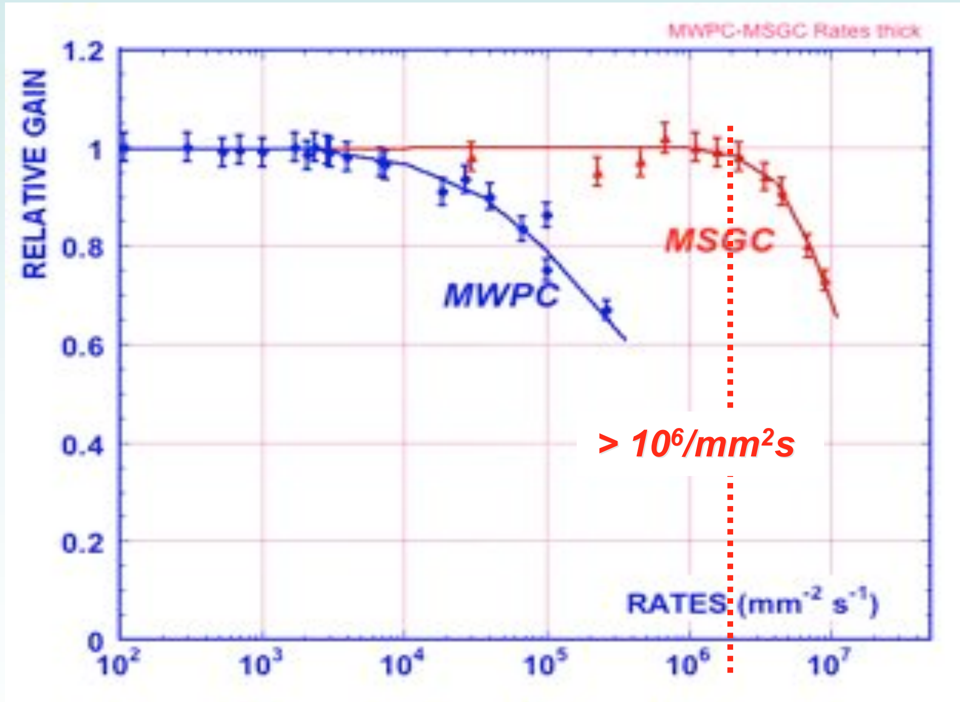
MICRO-STRIP GAS CHAMBERS: ANTON OED (1988)

THIN METAL STRIPS ON INSULATING SUPPORT (GLASS):



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

DUE TO SMALL PITCH AND FAST IONS COLLECTION, MSGC HAVE VERY HIGH RATE CAPABILITY:

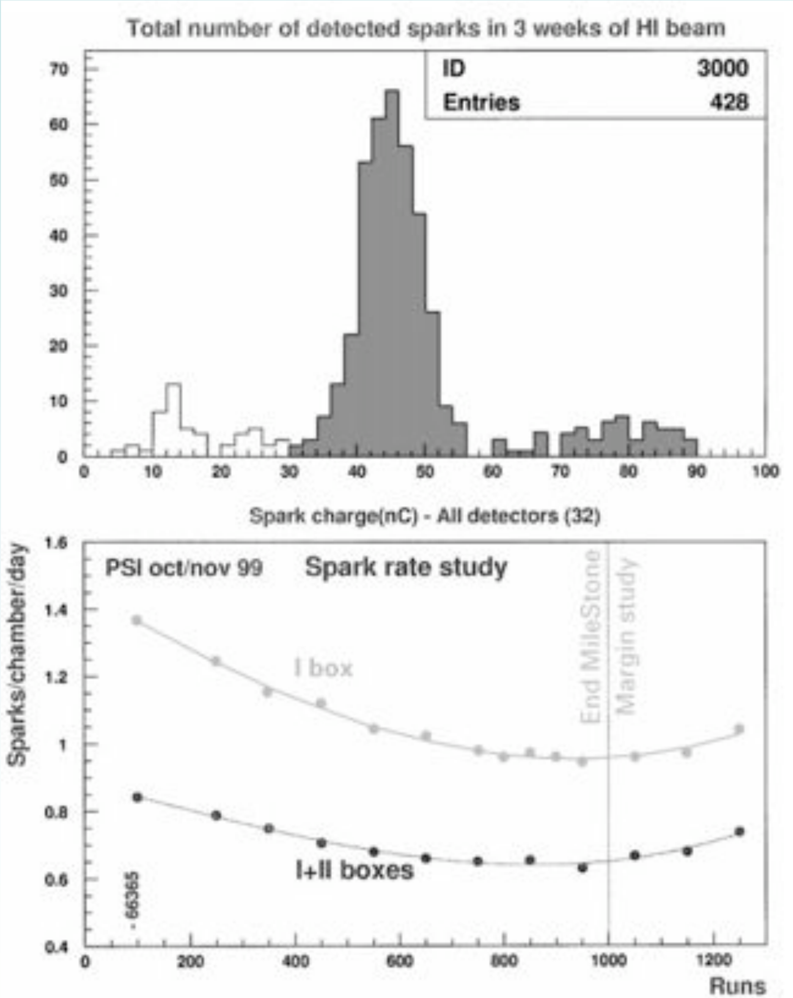


R. Bouclier et al, Nucl. Instr. and Meth. A323(1992)240

MSGC DISCHARGES

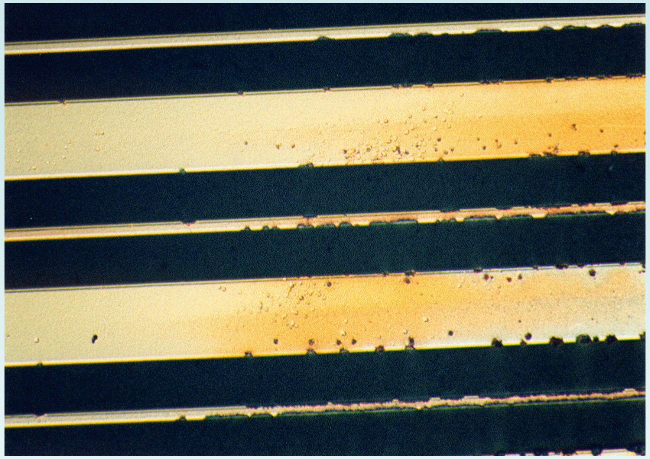
Unfortunately MSGCs are rather prone to discharge, particularly in hostile environments.

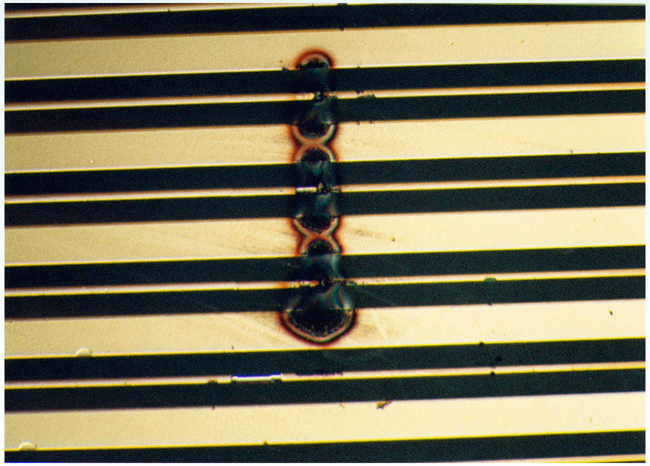
DISCHARGE RATES MEASURED IN THE CMS MSGC PROTOTIPES AT PSI:



R. Bellazzini et al, Nucl. Instr. and Meth. A457(1001)22

STRIP DAMAGES DUE TO MICRO-DISCHARGES AND HEAVY SPARKS:



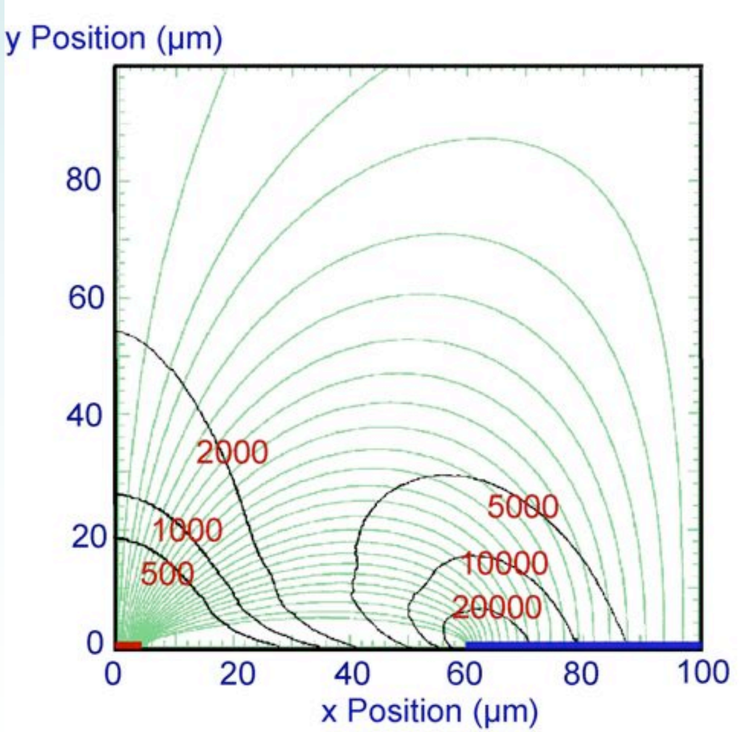


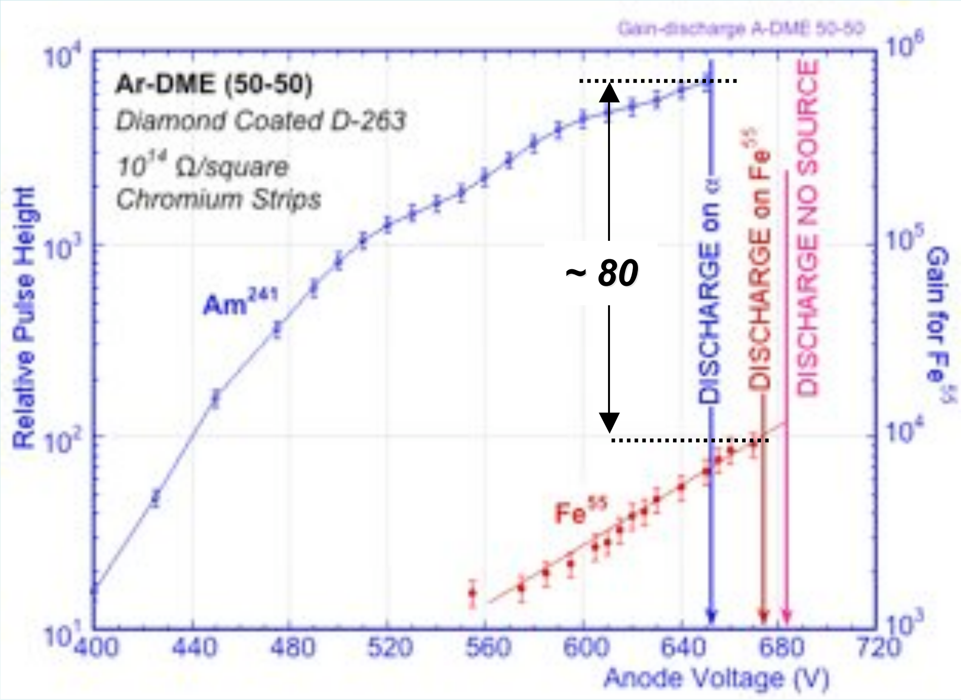
CERN-GDD

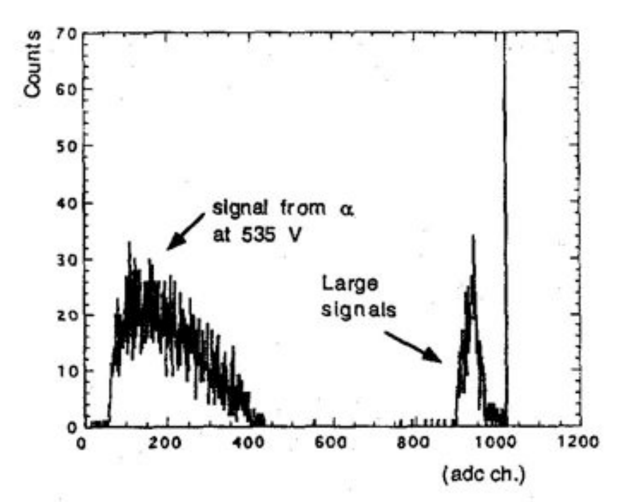
MSGC DISCHARGES

In MSGCs the discharge voltage depends on the ionization density, but less on the total charge as for PPCs. This may be due to the effect of pre-amplification of ionization released in the high field near the cathode strip edges, as shown by the observation of “precursors” (very large signals):

ELECTRIC FIELD AND ESTIMATED EQUAL-GAIN LINES FOR ELECTRONS:



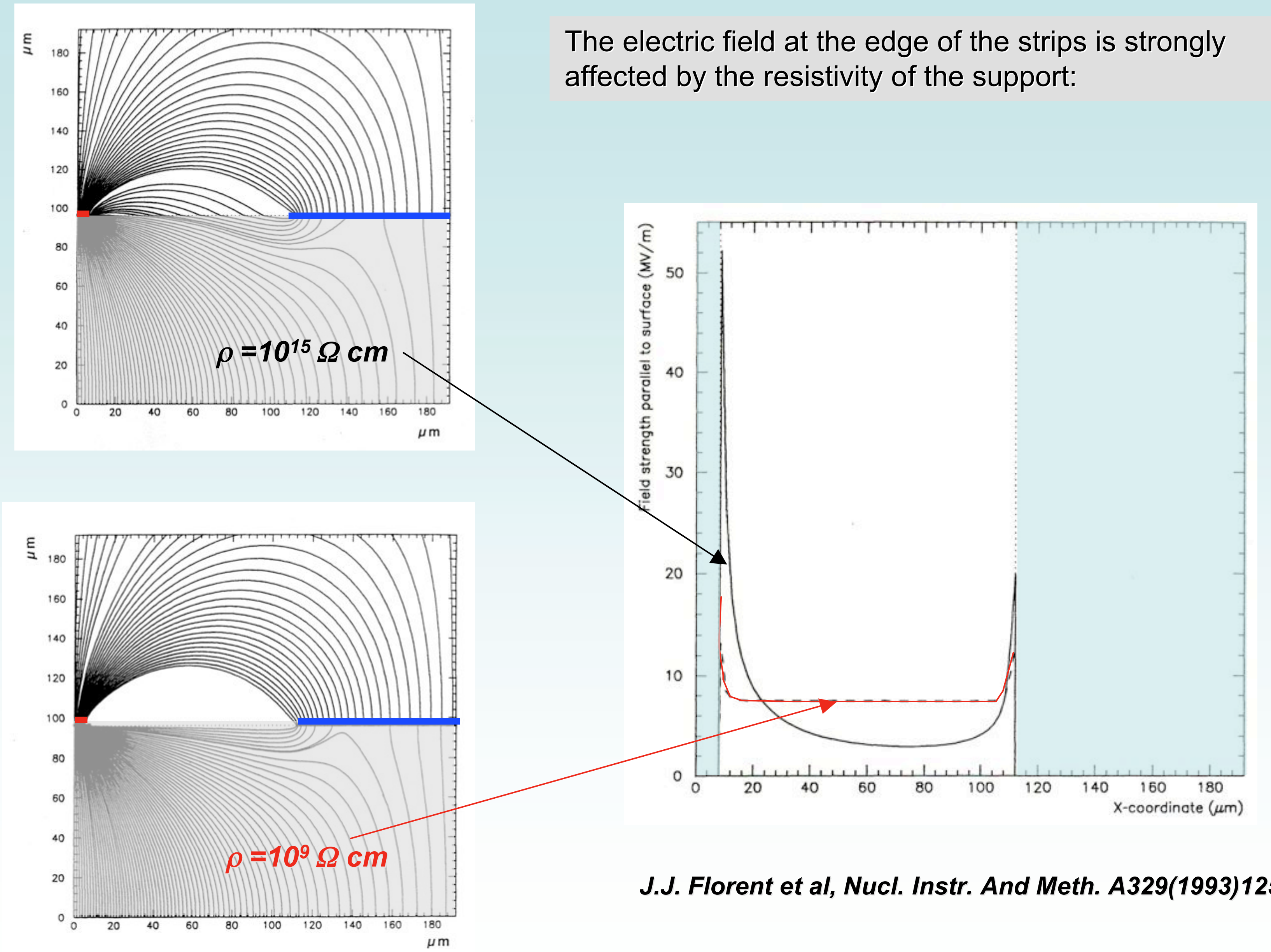




R. Bouclier et al, Nucl. Instr. ad Meth. A365(1995)65

MSGC: STRIP EDGE FIELDS

The electric field at the edge of the strips is strongly affected by the resistivity of the support:

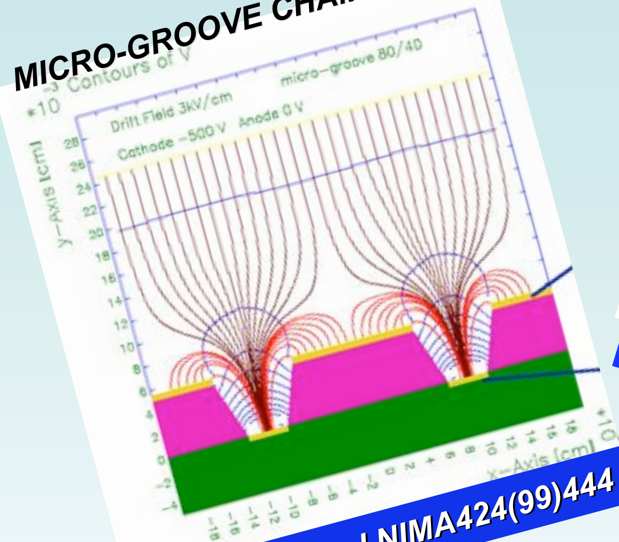


J.J. Florent et al, Nucl. Instr. And Meth. A329(1993)125

NEW DEVELOPMENTS: MICRO-PATTERN GAS DETECTORS

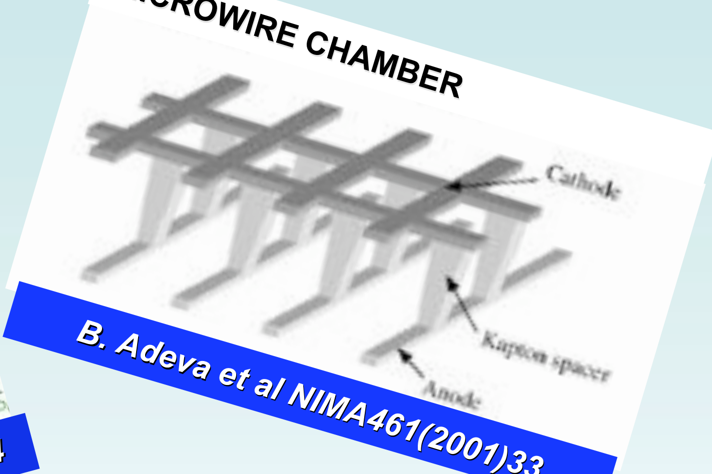
The problems encountered with MSGCs have induced a large effort to develop alternative devices capable of operating at higher rates and irradiation levels:

MICRO-GROOVE CHAMBER



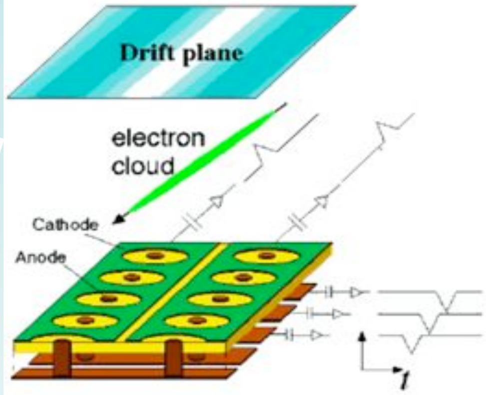
Bellazzini et al NIMA424(99)444

MICROWIRE CHAMBER



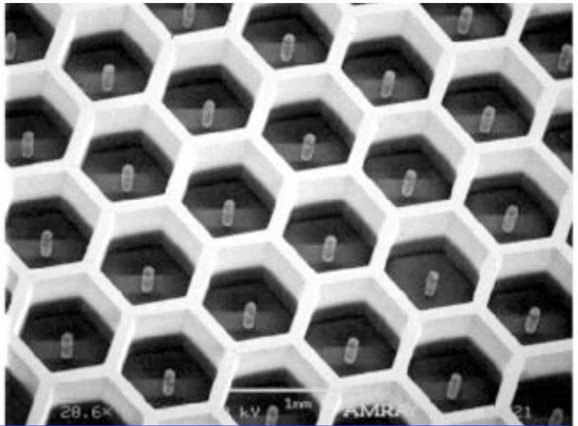
B. Adeva et al NIMA461(2001)33

MICRO-PIXEL CHAMBER



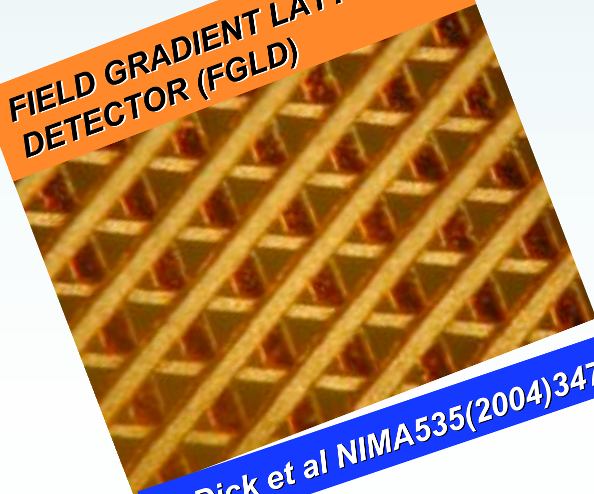
Ochi et al NIMA471(2001)264

MICRO-PIN ARRAY (MIPA)



P. Rehak et al TNS NS47(2000)1426

FIELD GRADIENT LATTICE DETECTOR (FGLD)

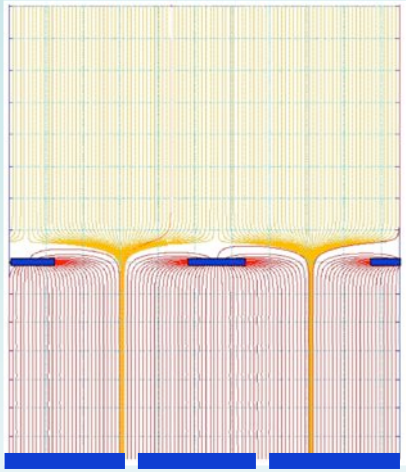


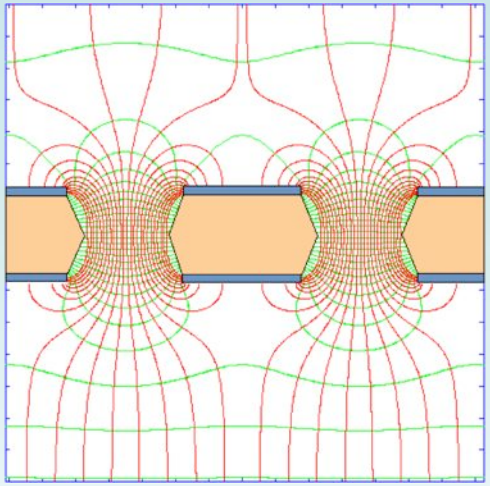
L.Dick et al NIMA535(2004)347

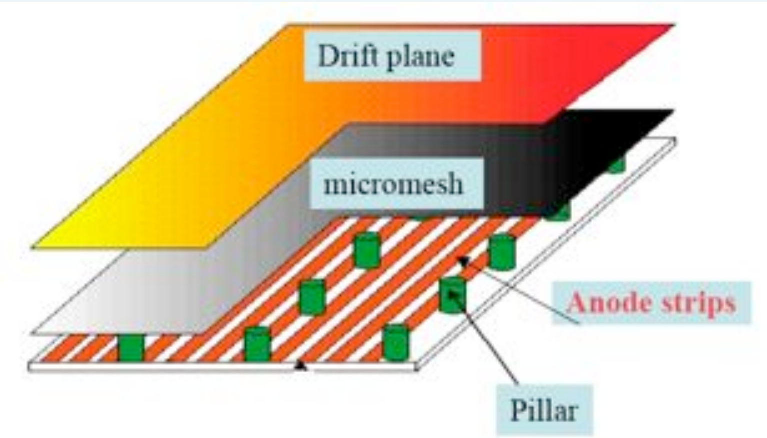
MICROMEGAS AND GEM

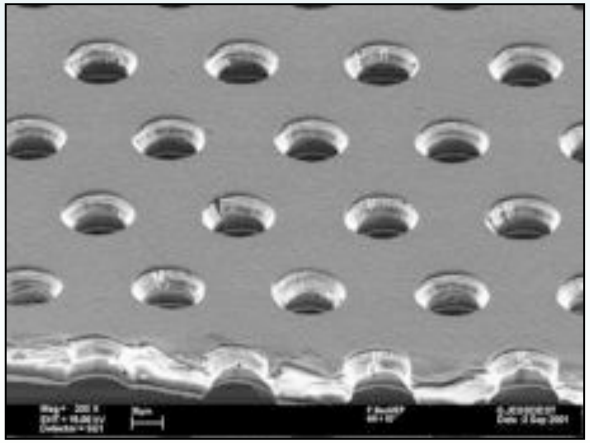
MICROMEGAS
Narow gap (50-100 µm) PPC with thin cathode mesh
Insulating gap-restoring wires or pillars

GAS ELECTRON MULTIPLIER (GEM)
Thin metal-coated polymer foils
70 µm holes at 140 mm pitch









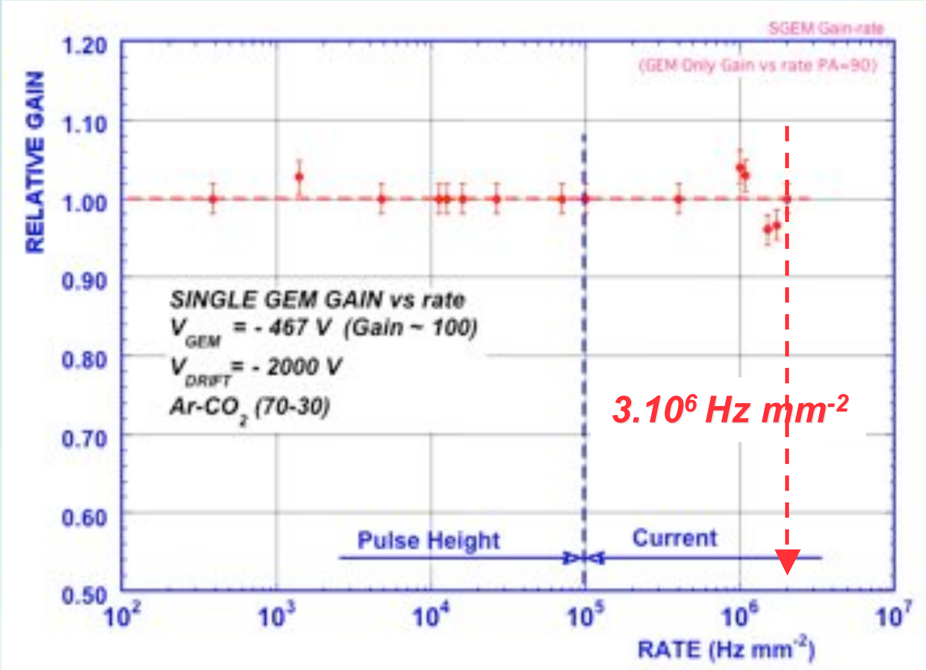
Y. Giomataris et al, Nucl. Instr. and Meth. A376(1996)239

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

HIGH RATES - GEM

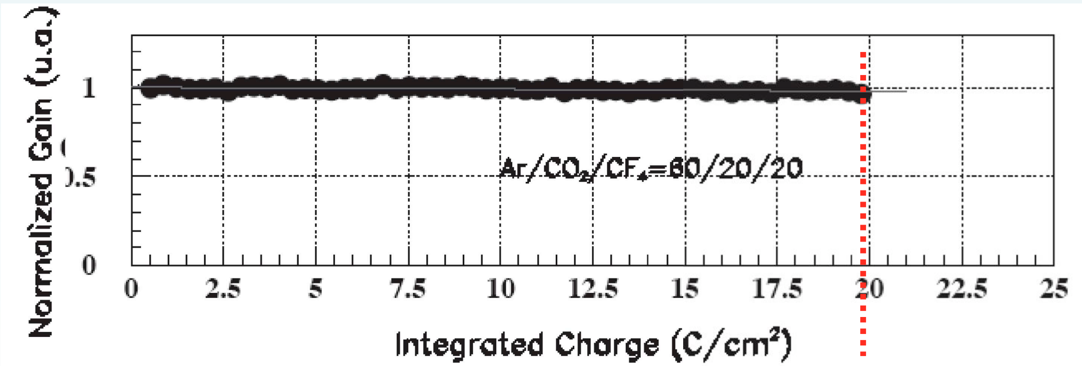
Due to the small gaps and fast ion collection, MPGDs have very high rate capability.
The radiation hardness has been verified up to a collected charge of 20 C cm^{-2}, corresponding to an integrated flux of 4.10^{14} minimum ionizing particles.

GEM RATE CAPABILITY:



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

GEM RADIATION HARDNESS:



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

M. Alfonsi et al, NIMA518(2004)106

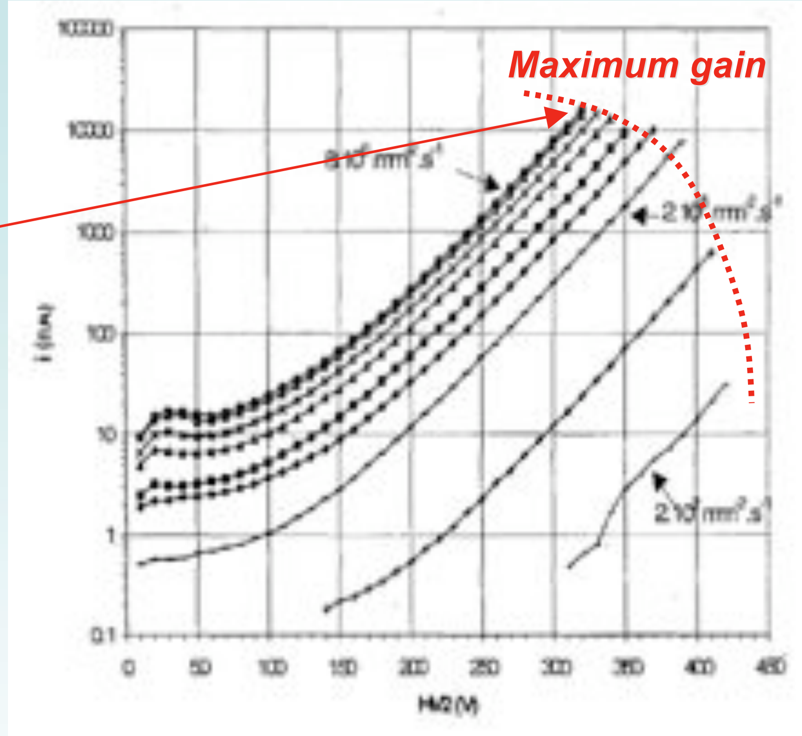
LHCb MUON TRIGGER:
Triple GEM with fast gas mixture (Ar-CO_2-CF_4 45-15-40)
Fluorine kapton etching observed in low gas flow-high rates

HIGH RATES - MICROMEGAS

High-flux experiments (COMPASS) deploy GEM and Micromegas detectors since several years without change in performances.

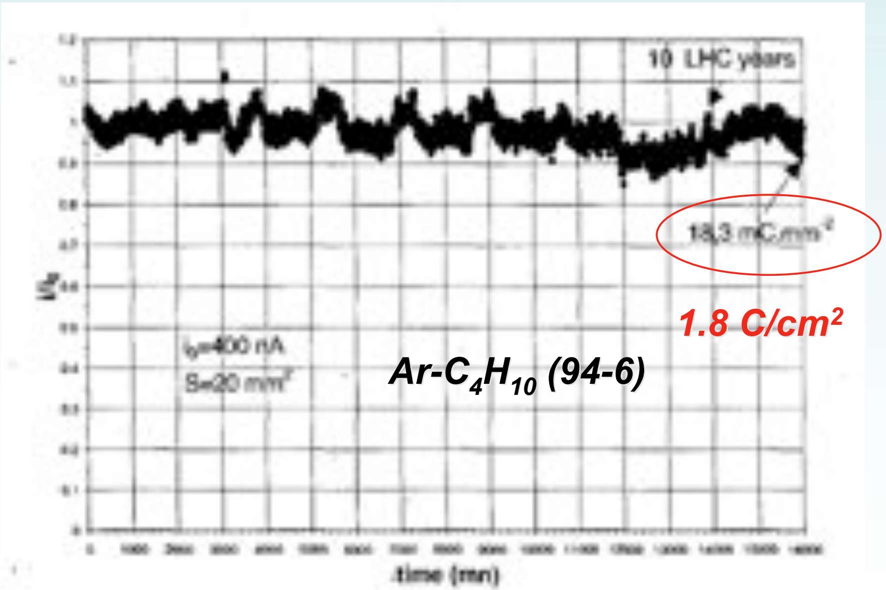
$Q = I.T^{+} \sim 10^{-5}\ 10^{-6} = 10^{-11} C \sim 10^{8}$

MICROMEGAS RATE CAPABILITY CURRENT VS X-RAY FLUX:



Proportionality: the current is proportional to the flux and the curves are parallel up to 8.10^{6} $mm^{-2}s^{-1}$
The maximum gain depends on flux: at 10^{6} $mm^{-2}s^{-1}$ it is about 10^{3}.

MICROMEGAS RADIATION HARDNESS:



G. Puill et al, IEEE Trans. Nucl. Sci. NS46(1999)1894

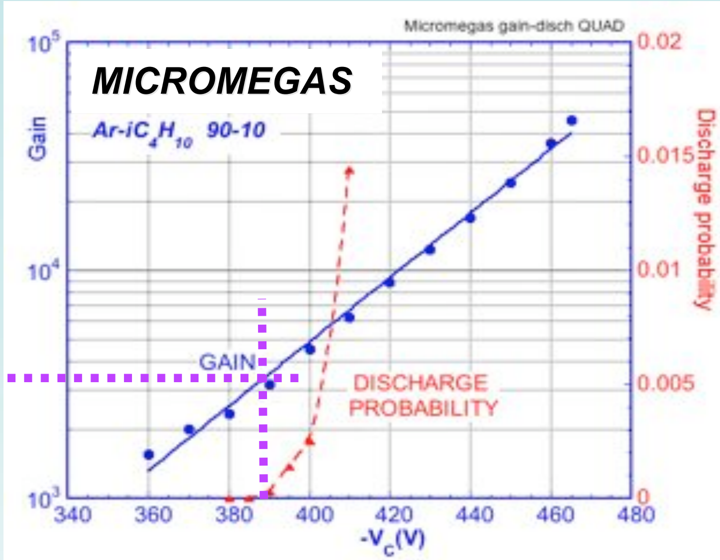
MPGD CERTIFICATION

MEASURE GAIN WITH ^{55}Fe X-RAYS AND DISCHARGE PROBABILITY WITH INTERNAL ALPHA SOURCE FROM ^{220}Rn

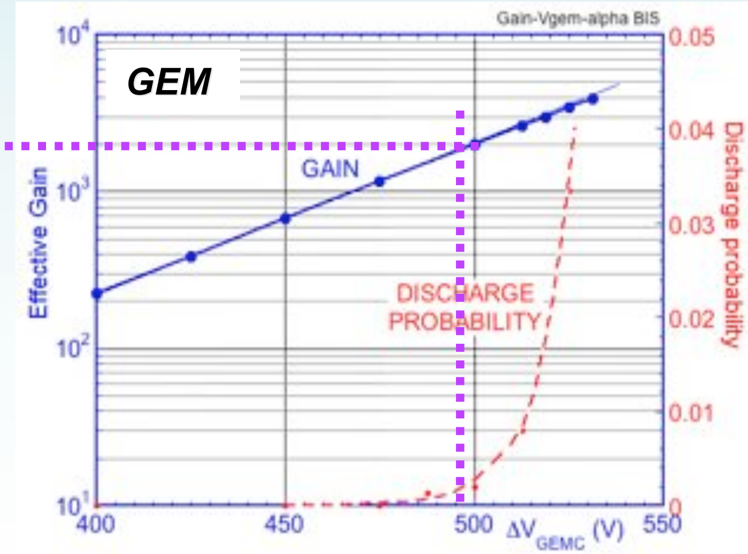
The maximum gain before discharge is almost the same for all MPGD tested:

DETECTOR	MAX GAIN	MAX CHARGE
MSGC	2000	$4\ 10^7$
ADV PASS MSGC	1000	$2\ 10^7$
MICROWELL	2200	$4.4\ 10^7$
MICROMEGAS	3000	$6\ 10^7$
GEM	2000	$4\ 10^7$

~3000



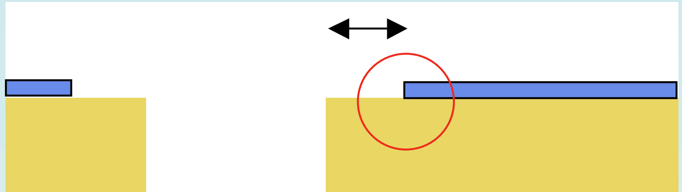
~2000

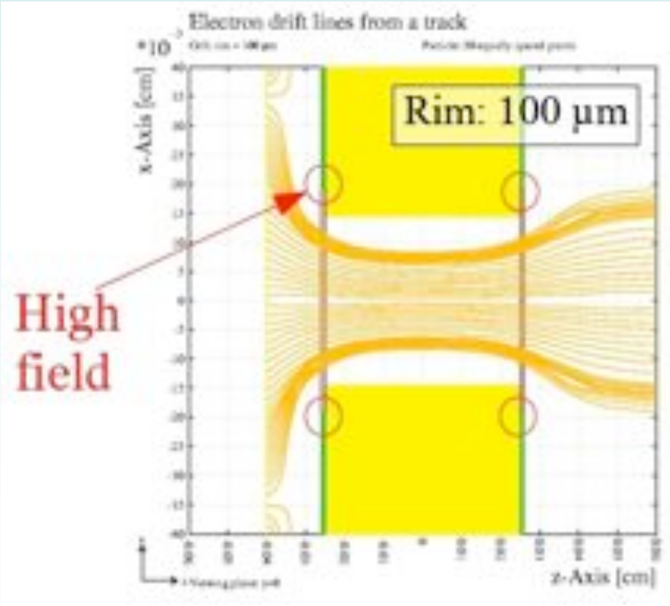


S. Bachmann et al, Nucl. Instr. and Meth. A479(2002)294

MPGD: ELECTRODE EDGES

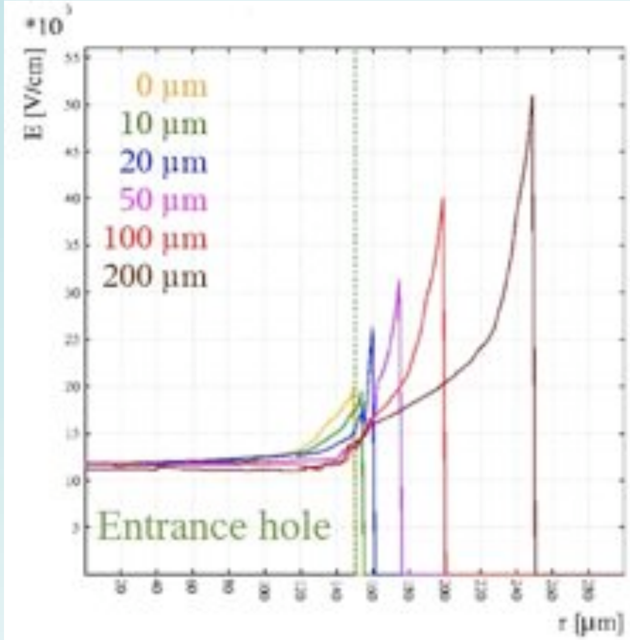
In GEM, there is a region of high field at the metal edge of the holes; the field strength depends from the width of the "rim" (retreat of the metal). The field increases for large rims.



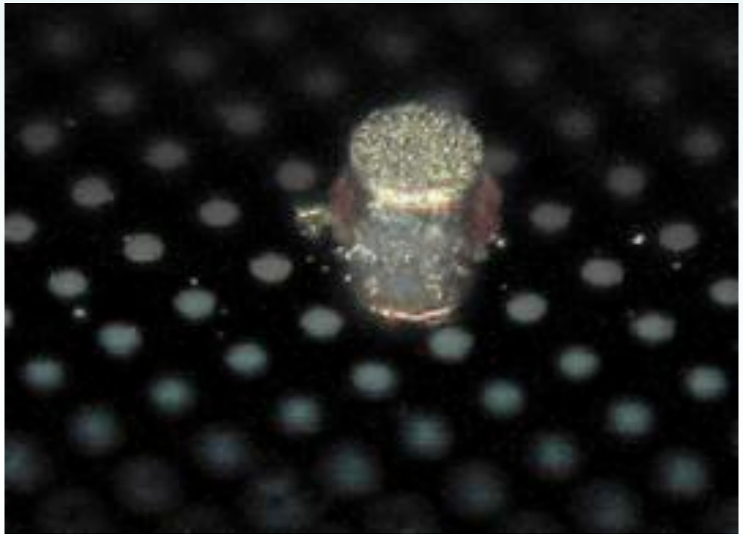


Simulation by Rob Veenhof

--> Thick GEM (Fulvio Tessarotto)

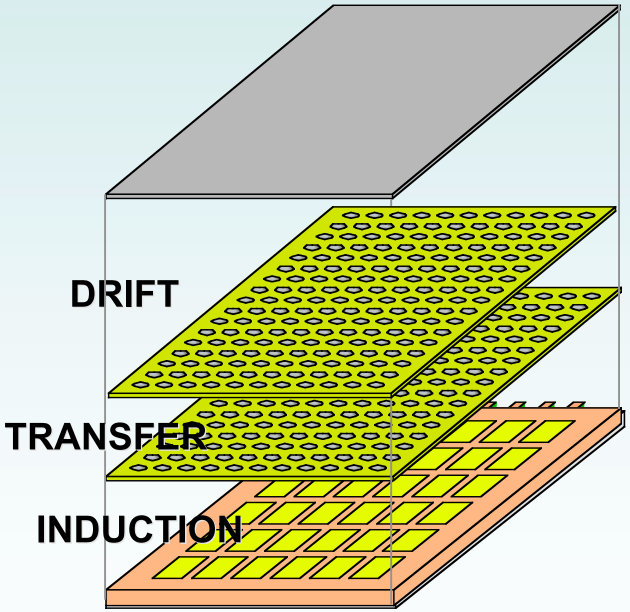


MICROMEGAS: PILLARS!

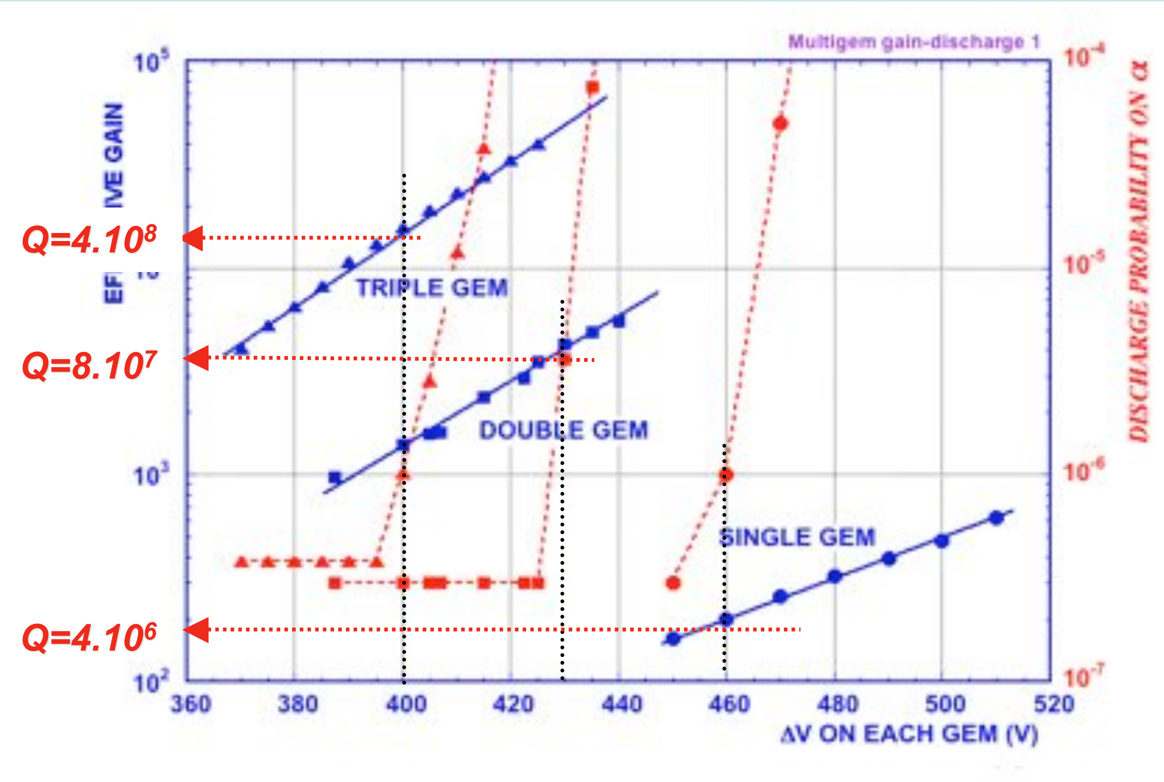


CAN ONE DEFEAT RAETHER?

Cascading several GEMs reduces the voltage needed on each foil for the same gain, and largely increases the maximum gain



^{241}Am a particles ~ 2.10^4 e-I$^+$ pairs



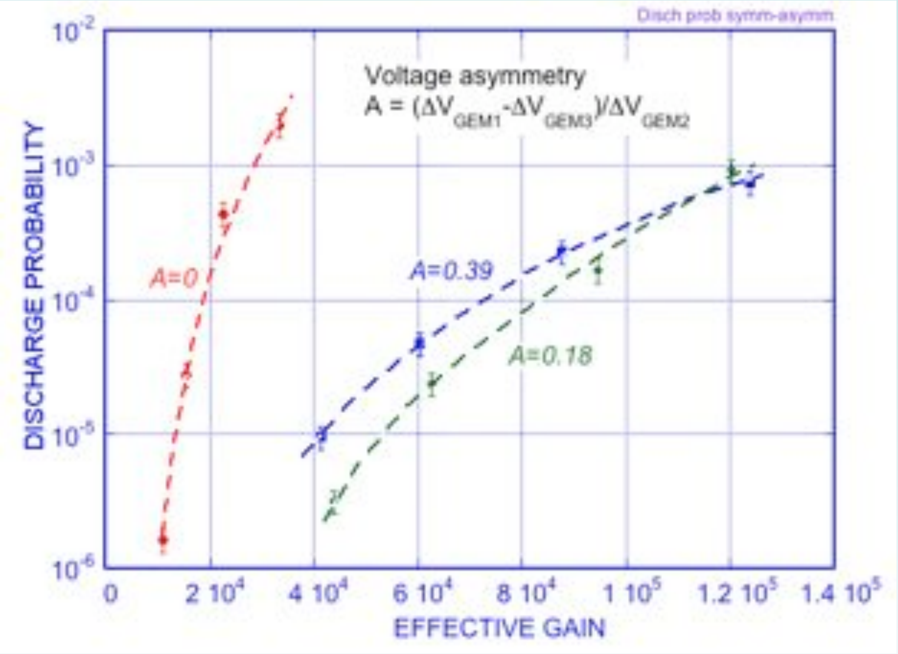
S. Bachmann et al, Nucl. Instr. and Meth. A479(2002)294

WHY ARE MULTIGEM BETTER?

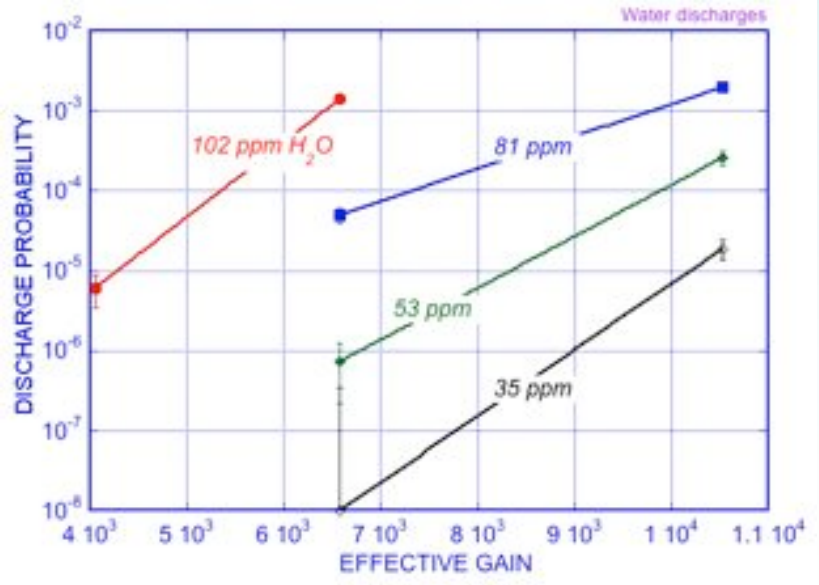
Possible explanations:
- the additional avalanche spread due to diffusion decreases the charge density in each hole
- to get the same gain in cascaded electrodes, each foil operates at a voltage much below the natural discharge point.

For the same total gain, the discharge probability is much smaller with asymmetric voltage distribution (the first GEM in the cascade having higher voltage than the last), probably a demonstration of the voltage dependence of the Raether limit.

TRIPLE GEM: DISCHARGE PROBABILITY VS VOLTAGE ASYMMETRY



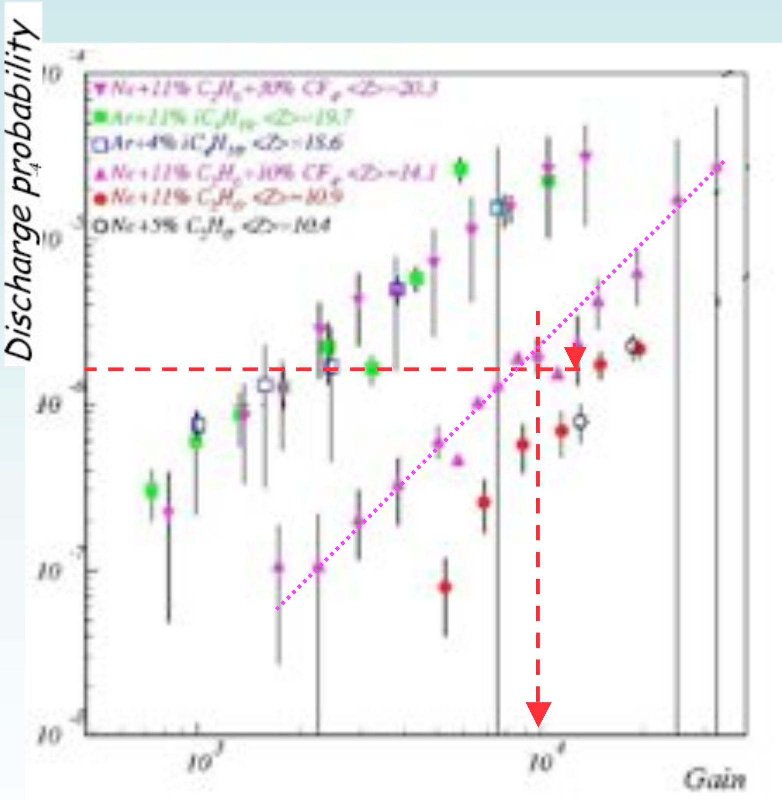
C. Altumbas et al, Nucl. Instr. and Meth. A490(2002)177



EFFECT OF WATER CONTENT ON DISCHARGE PROBABILITY

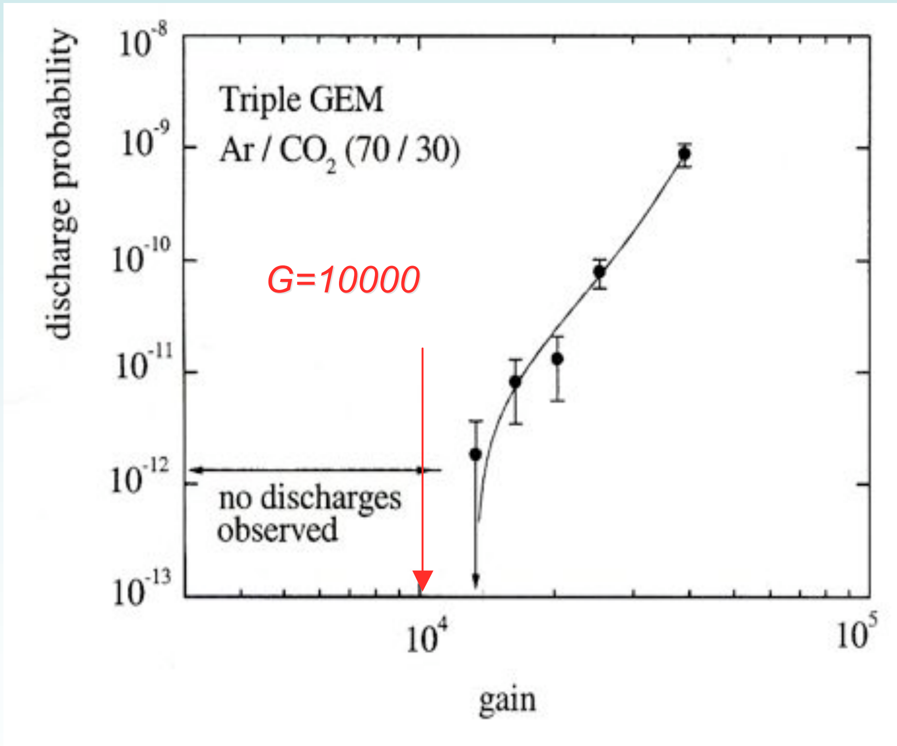
DISCHARGE PROBABLITY: COMPASS TRACKER

MICROMEGAS:
The discharge probability normalized to beam flux ~ 10^{-6}
Detector and electronics fully protected
No damages, 1 ms dead time



D. Thers et al,
Nucl. Instr. and Meth. A469(2001)133

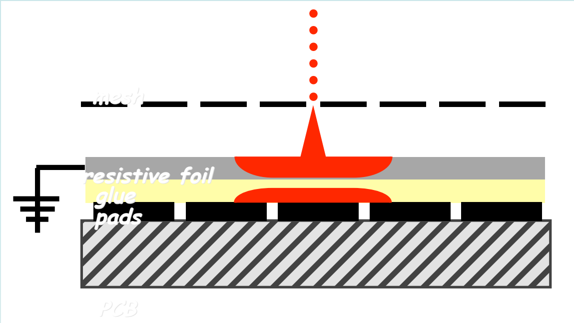
TRIPLE-GEM:
Discharge probability <10^{-12}



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

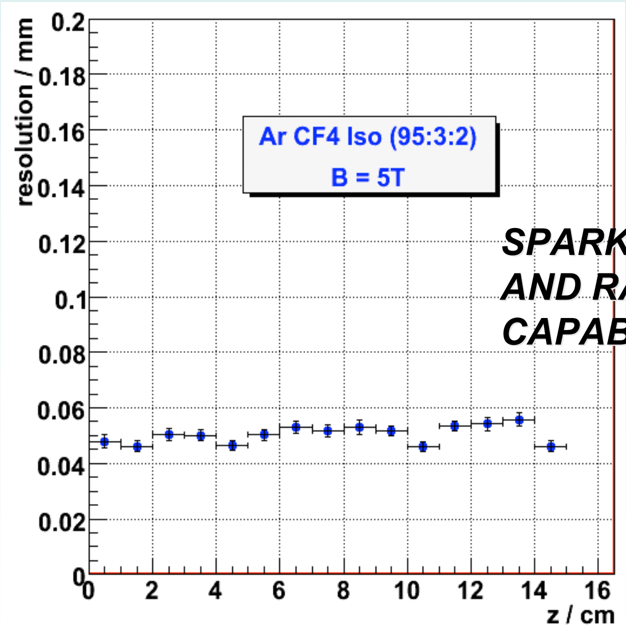
MPGD WITH RESISIVE ELECTRODES

RESISTIVE ANODE: CHARGE DISPERSION READOUT



1 MΩ/☐ plastic foil

EXCELLENT POSITION ACCURACY:

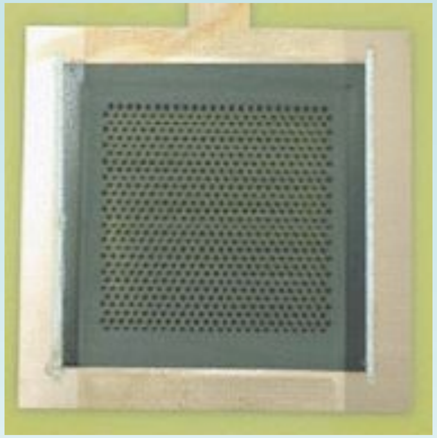


M. Dixit et. al, Nucl. Instr. and Meth. A581, 254 (2007)

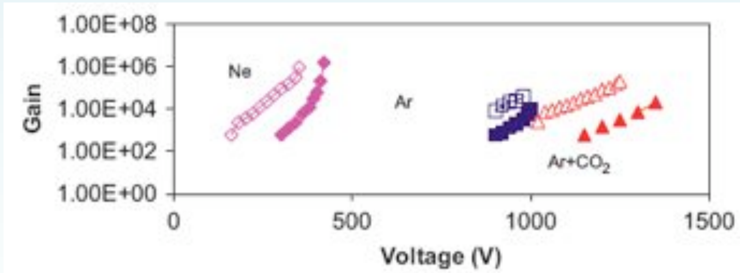
SPARK PROTECTION AND RATE CAPABILITY?

RTGEM: RESISTIVE ELECTRODE THICK GEM

3÷10 GΩ/☐ copper oxide layer



GAIN OF RETGEM IN VARIOUS GASES:

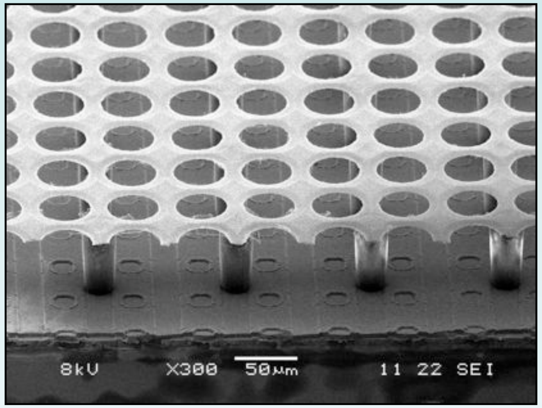


A. Di Mauro et al, Nucl. Instr. and Meth. A581(2007)225

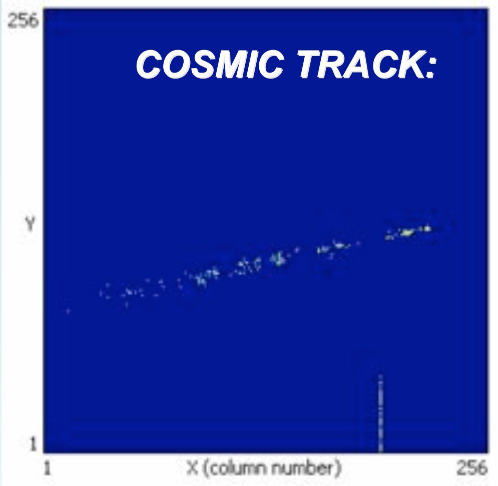
THE ULTIMATE MPGD: INTEGRATING DETECTOR AND ELECTRONICS

Using silicon foundry technology, the MPGD is built directly over the silicon pixel readout chip. The high gain-small pixel size allows single electron detection.
Recently, addition of a resistive silicon layer over the active chip demonstrated the full protection for discharges induced by α particles.

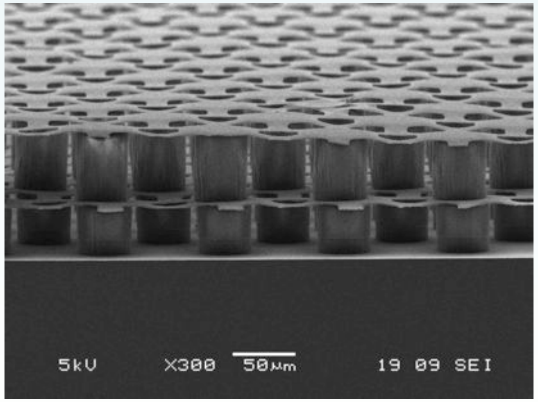
SINGLE MICROMEGAS:



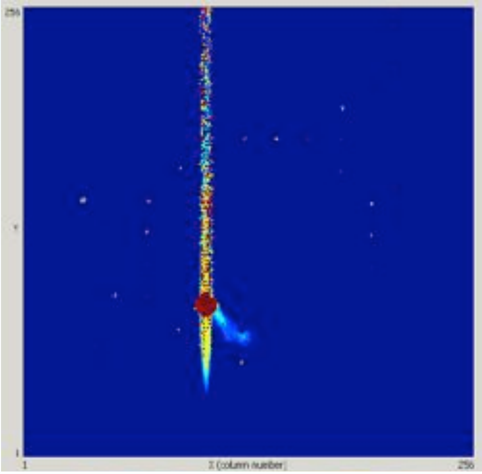
COSMIC TRACK:



TWO-STAGES:



DISCHARGE EVENT:



H. van der Graaf, MPGD Workshop (IEEE-NSS Honolulu 2007)

SO MUCH FOR problems…..

….LET'S SEE THE GOOD SOLUTIONS!