FABIO SAULI
CERN

GASEOUS DETECTORS: CONTINUING SUCCESS STORY

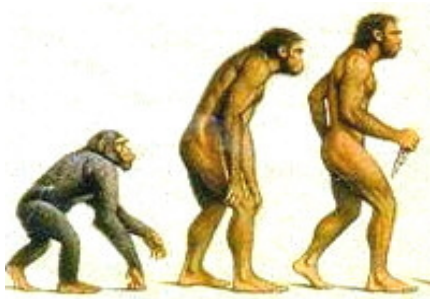
the ART OF EXPERIMENT

A SYMPOSIUM TO CELEBRATE FORTY YEARS OF ADVANCES, 1974–2014

HONORING DAVID NYGREN

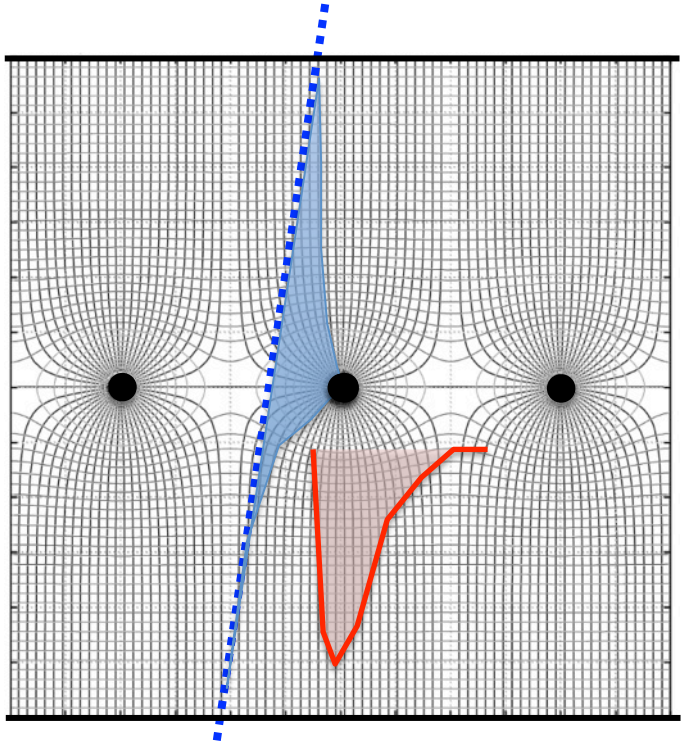
LAWRENCE BERKELEY NATIONAL LABORATORY, MAY 2–3, 2014

THE ORIGINS



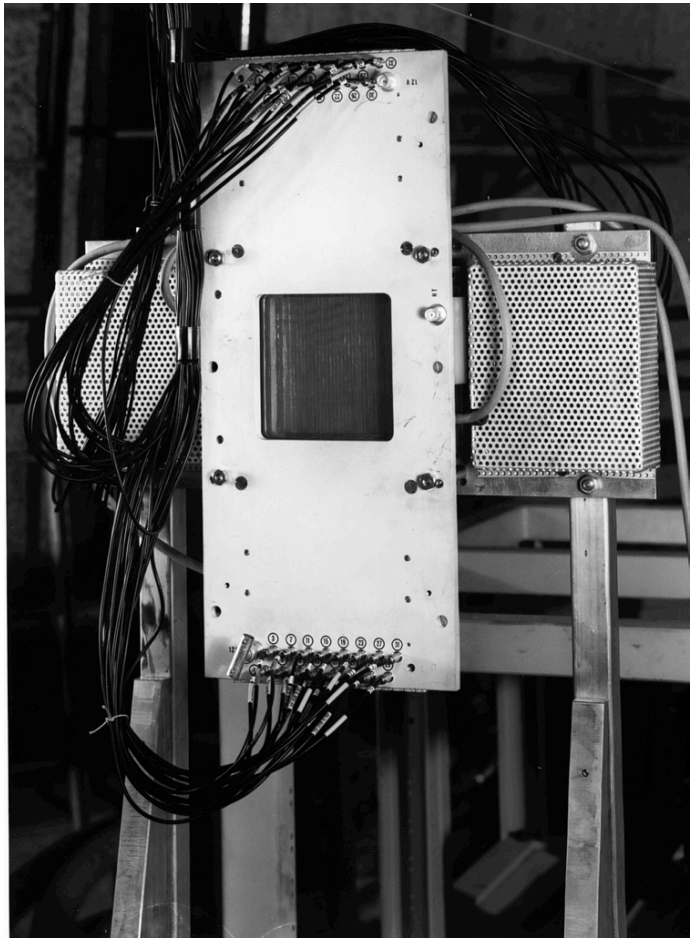
Georges Charpak (1968)

THIN ANODE WIRES BETWEEN TWO CATHODES:



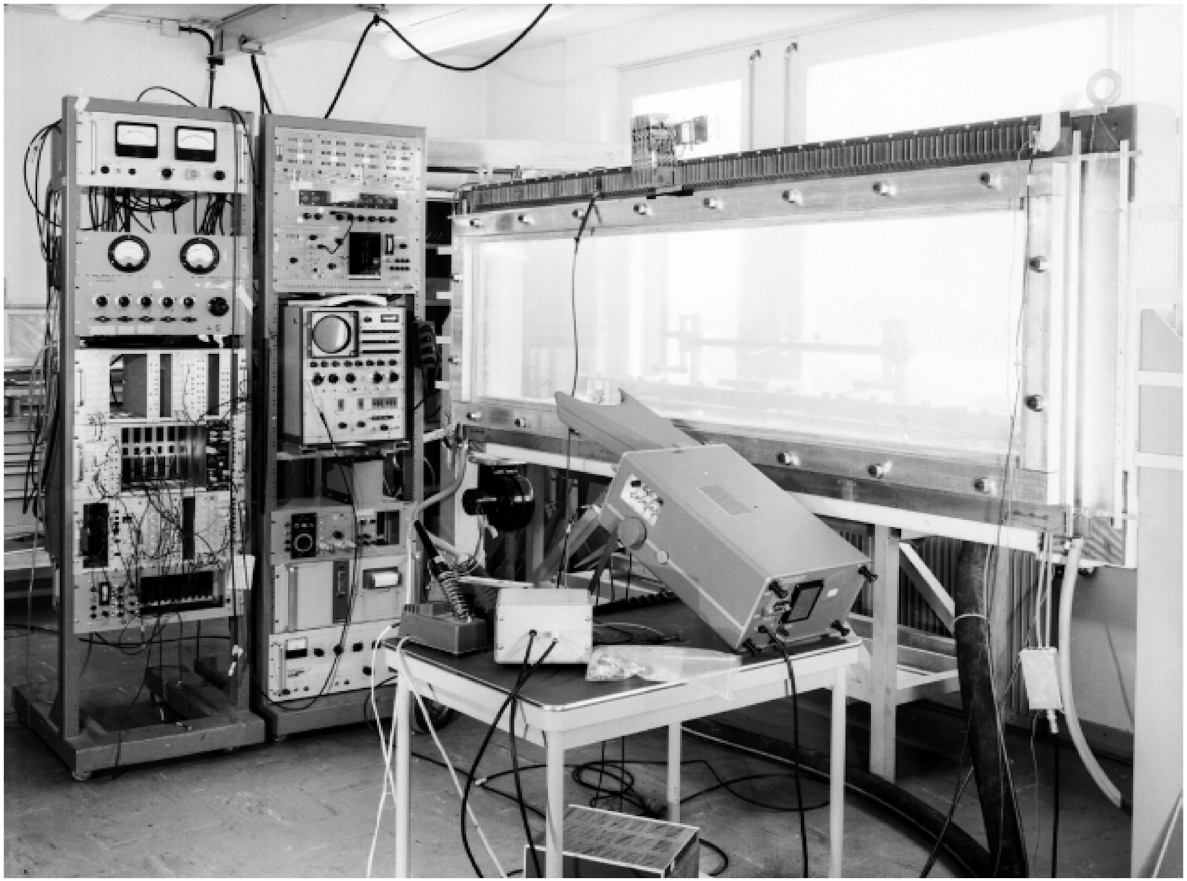
G. Charpak et al, Nucl. Instr. and Meth. 62(1968)262

THE FIRST MWPC (10x10 cm^2)



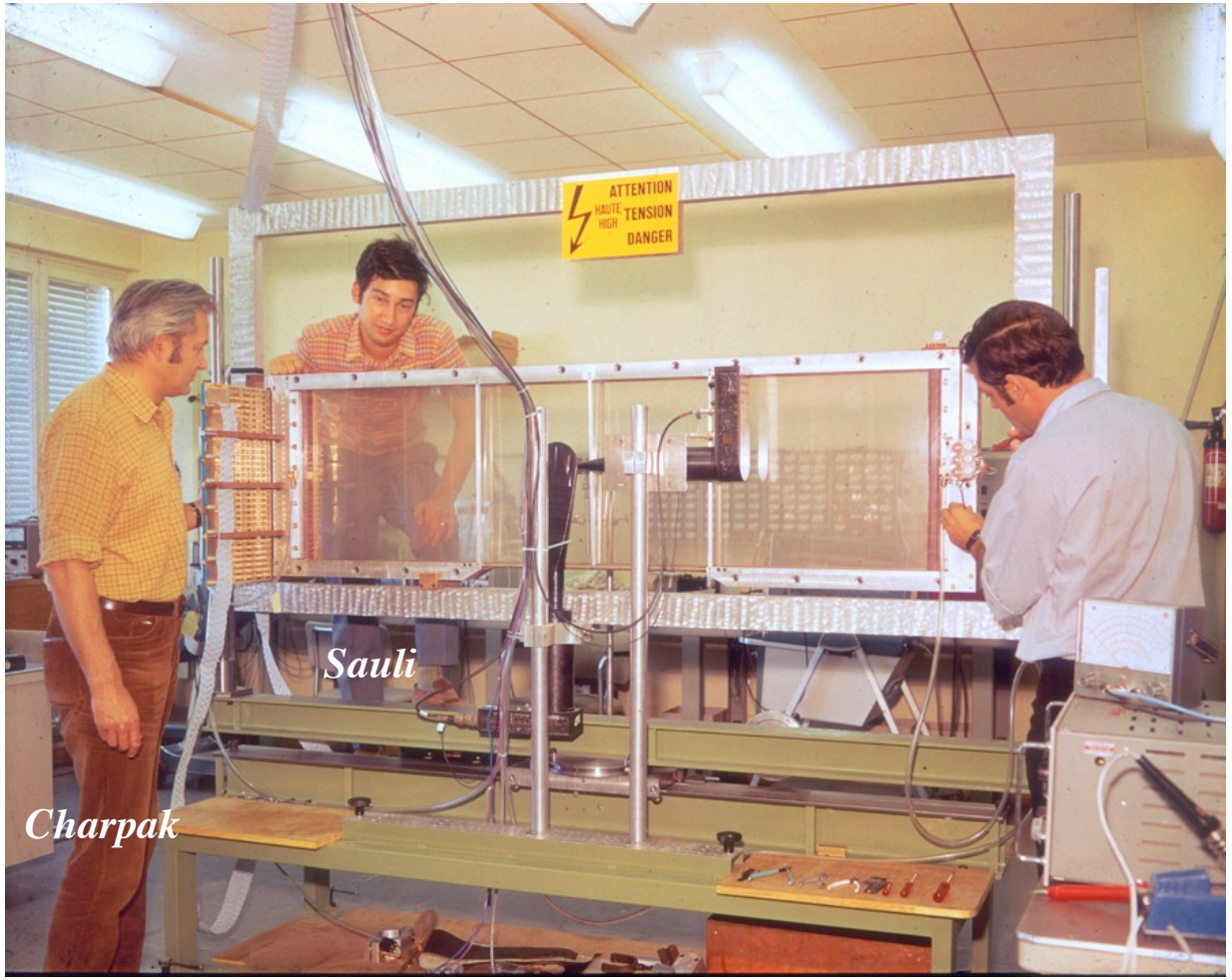
Jack Steinberger (1969)

4-MWPC MAGNETIC SPECTROMETER AT CERN



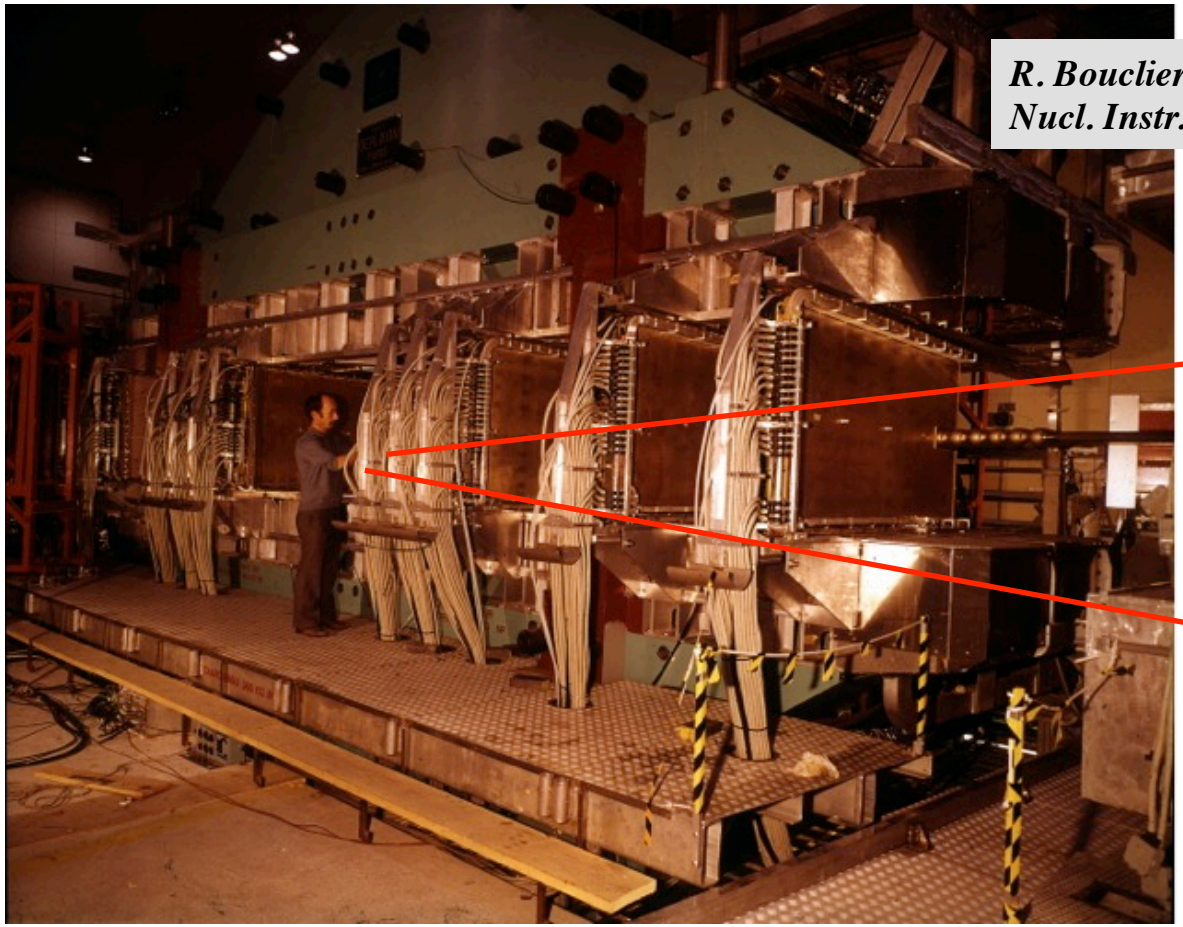
P. Schilly et al, Nucl. Instr. and Meth. 91(1971)221

MWPC PROTOTYPE FOR THE SPLIT FIELD MAGNET DETECTOR AT CERN LEP



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

SPLIT FIELD MAGNET DETECTOR AT CERN ISR (1973)



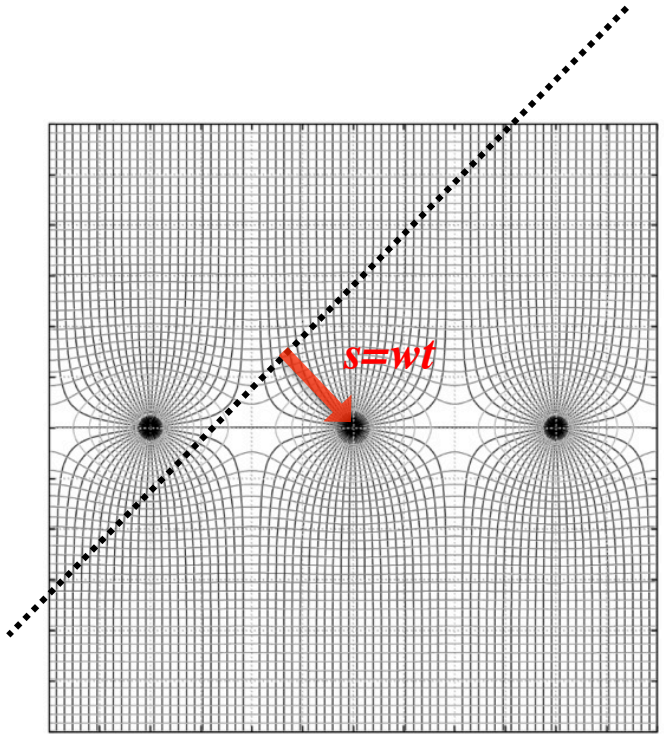
R. Bouclier et al,
Nucl. Instr. and Meth. 115 (1974)235

2/3

1/3

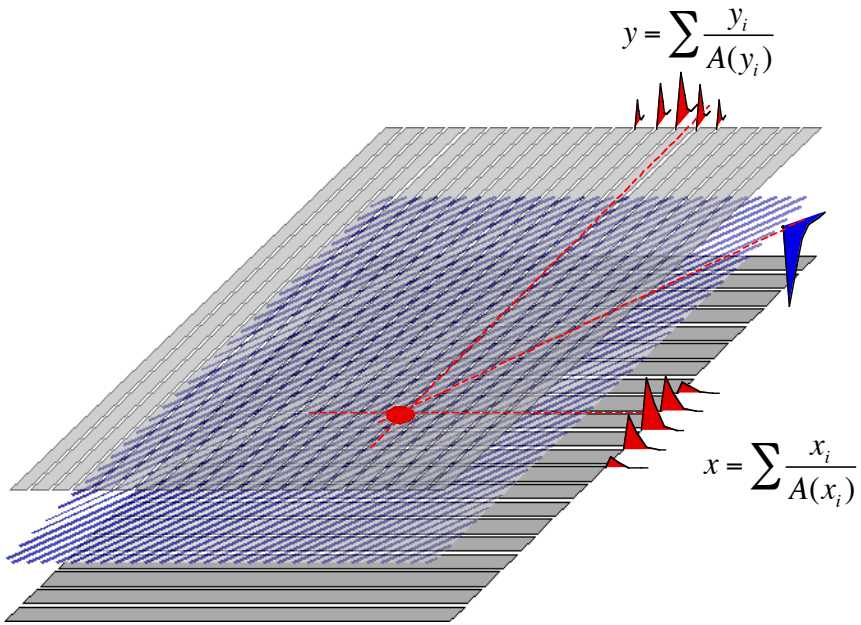
M. Breidenbach, F. Sauli, R. Tirler: Timing properties of MWPC … and efficiency of detection for normal and abnormal particles (quarks). Nucl. Instr. and Meth. 108 (1973)23

① ELECTRONS DRIFT TIME: DISTANCE FROM WIRES



G. Charpak D. Rahm and H. Steiner, Nucl. Instr. and Methods 80(1970)13

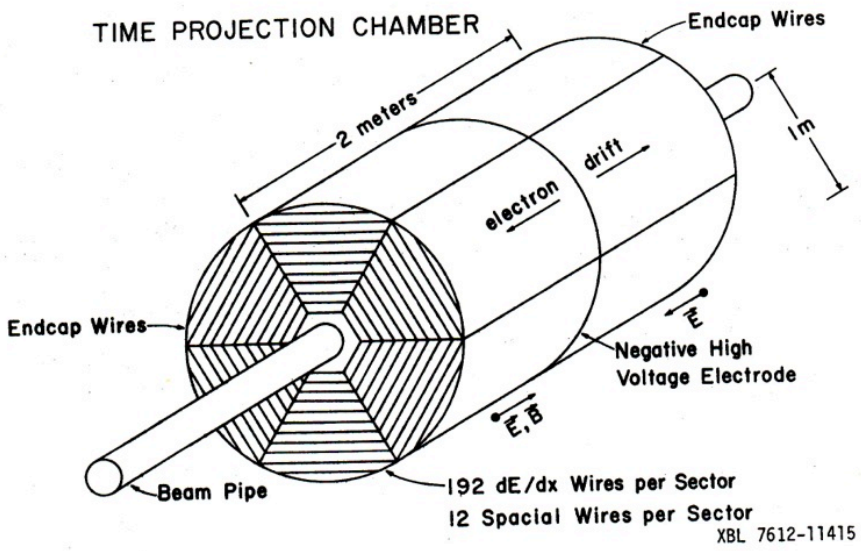
② CHARGE INDUCTION ON CATHODE PLANES: 2-D LOCALIZATION



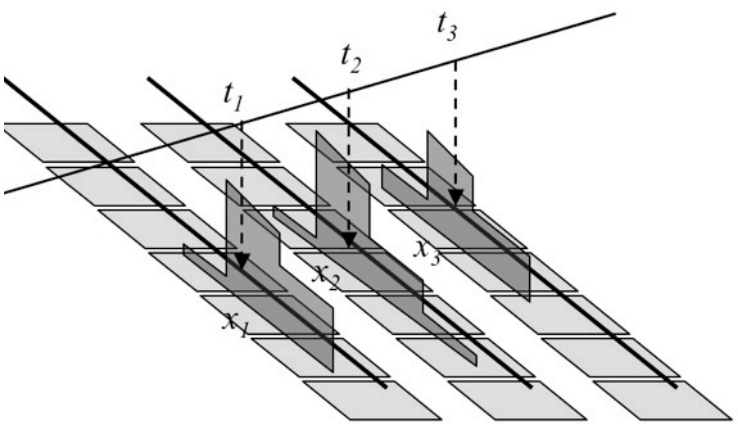
G. Charpak and F. Sauli Nucl. Instr. and Meth. 113(1973)381

David Nygren (1976):

① + ② = ④



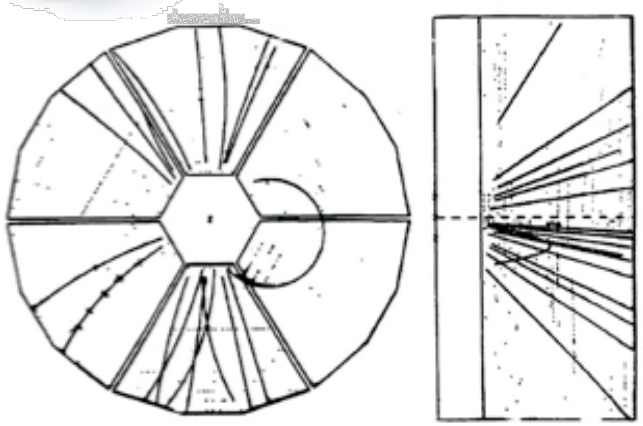
FULL 3-D LOCALIZATION
X: Anode wire
Y: Charge induction on pad rows
Z: Drift Time

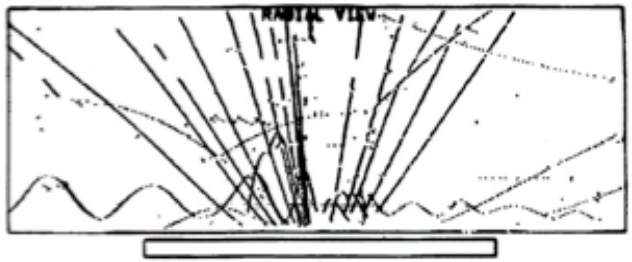


D. Nygren and J, Marx, Phys. Today 31 (1978) 46

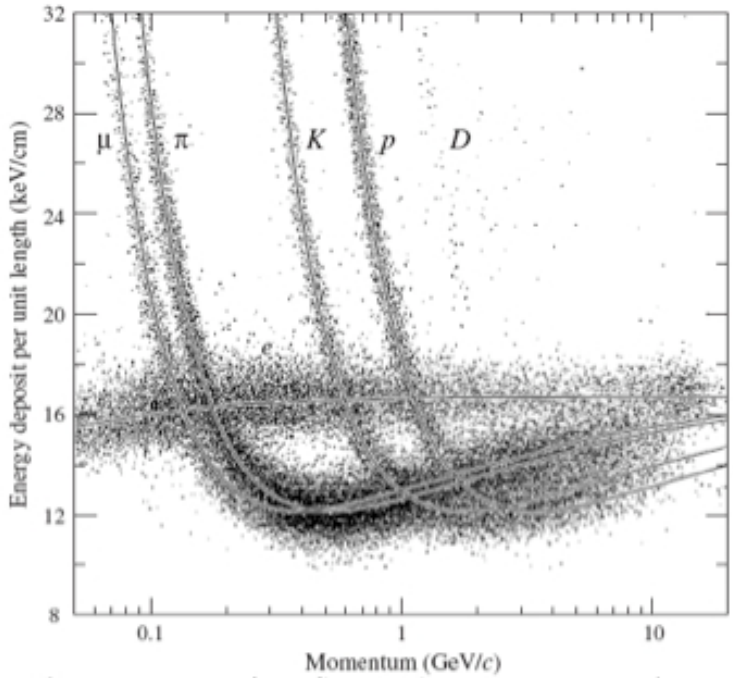
A.R. Clark et al, Proposal for a PEP Facility based on the Time Projection Chamber PEP4 (1976)

EVENT RECONSTRUCTION

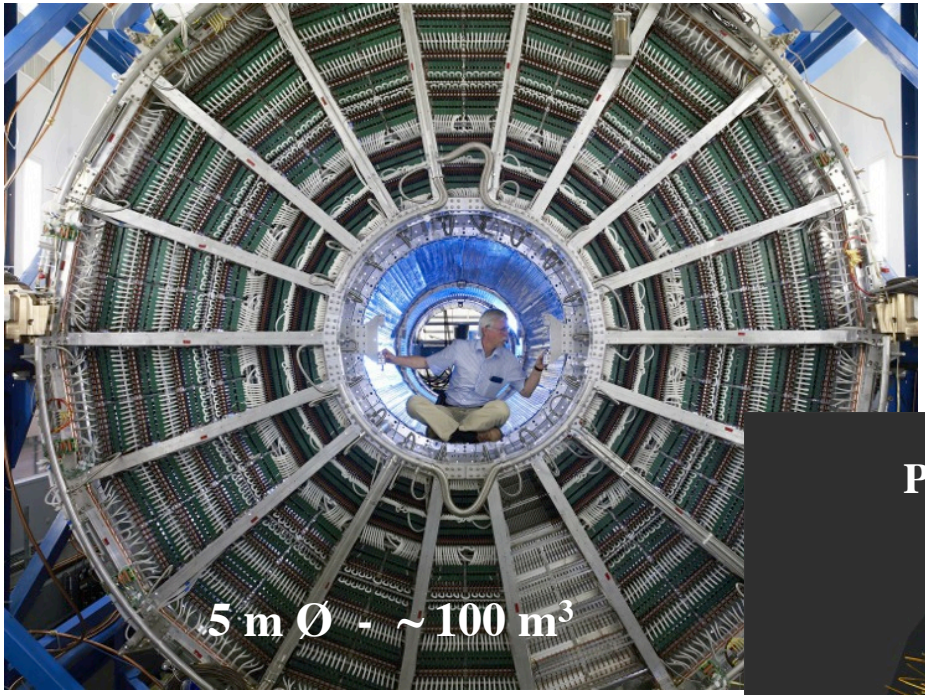




PARTICLE IDENTIFICATION:
dE/dx + MAGNETIC DELECTION

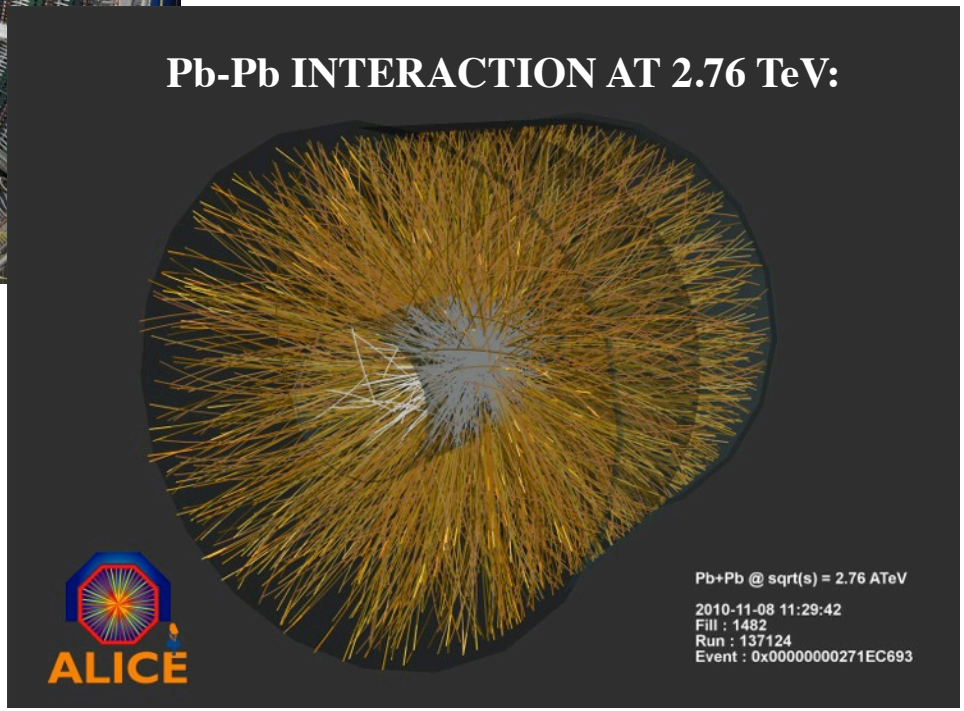


Jay Marx
RECOLLECTIONS OF THE PEP-4/TPC ERA

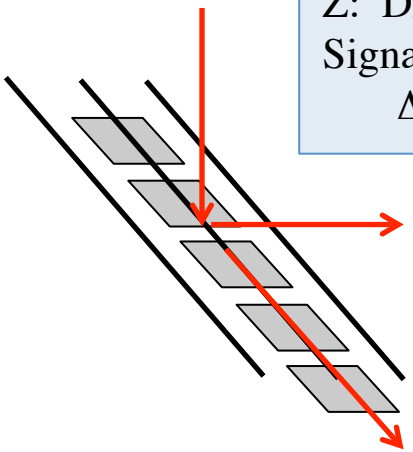


Peter Braun-Munzinger
THE ALICE TPC:

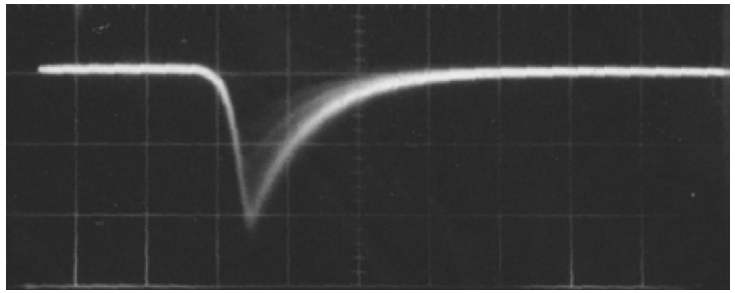
Pb-Pb INTERACTION AT 2.76 TeV:



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

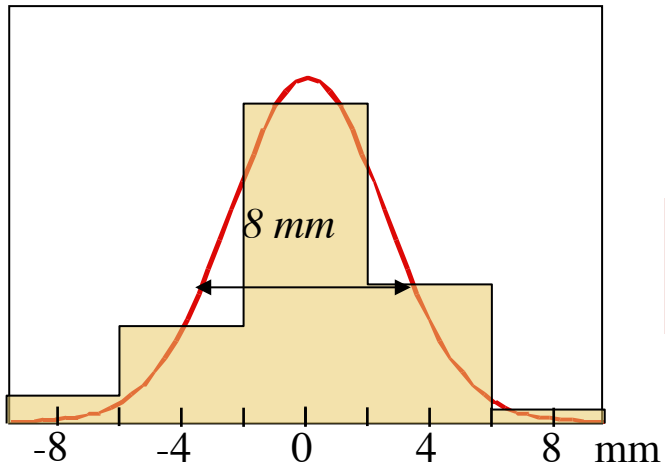


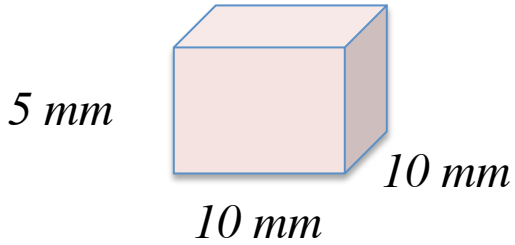
Z: Drift time
Signal width ~ 100 ns
ΔZ ~ 5 mm



Y: Wire spacing
ΔY ~ 10 mm

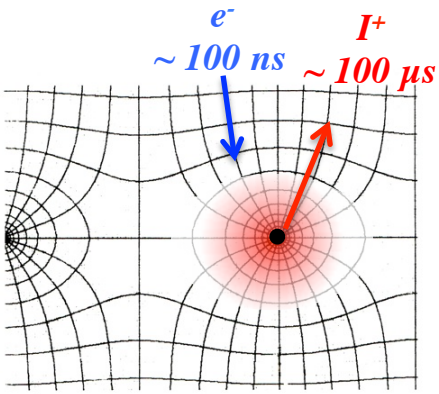
X: Charge induction on pad rows:
ΔX ~ 10 mm

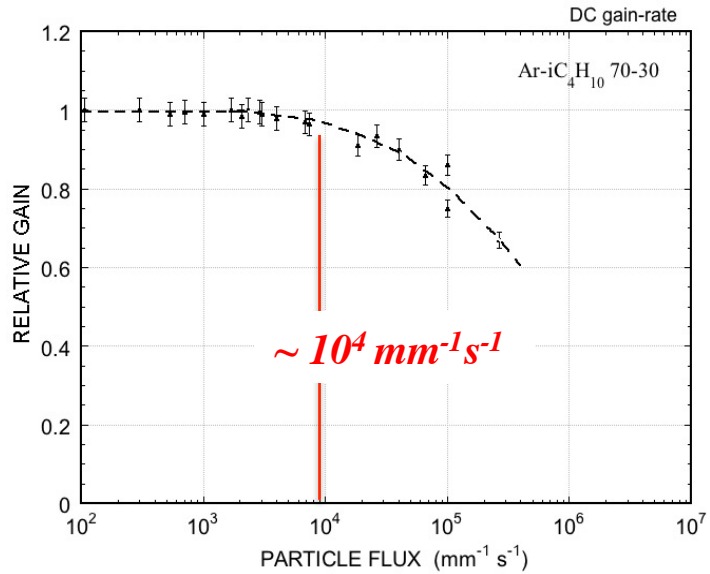




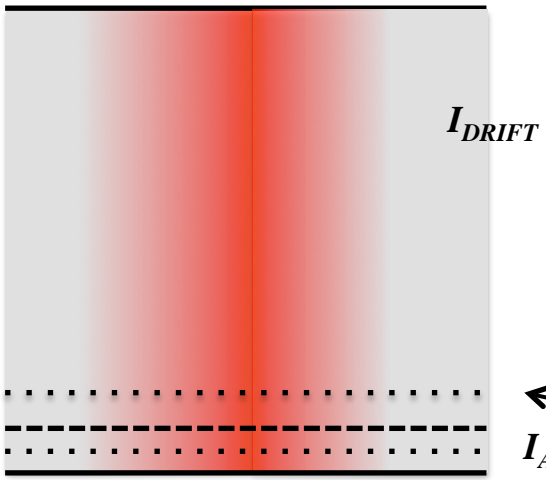
VOLUME RESOLUTION
ΔV~ 50 mm^3

ANODE WIRES: GAIN REDUCTION:





DRIFT VOLUME: FIELD DISTORTION



ION BACKFLOW FRACTION: $IBF = \frac{I_{DRIFT}}{I_{ANODE}}$

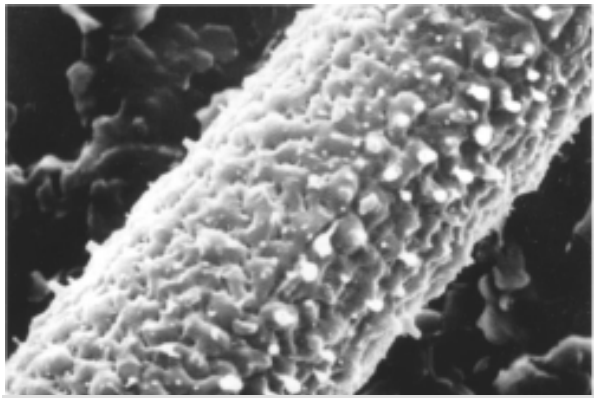
THE WISH:
SECONDARY IONS ~ PRIMARY IONIZATION

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

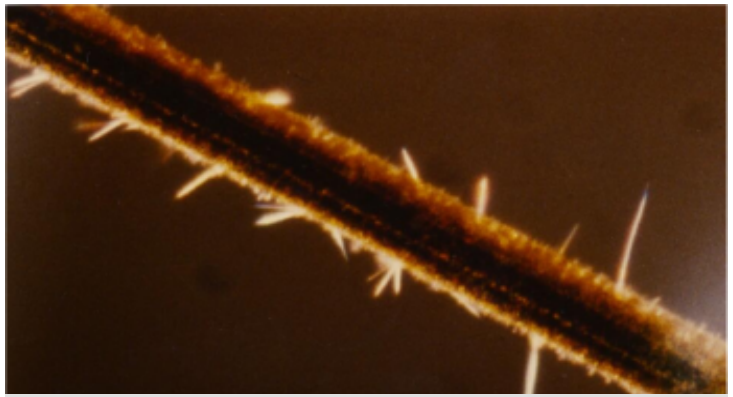
MWPC: IBF ~ 30%

FIRST GENERATION TPC: GATING GRID POSSIBLE AT LOW COLLISION RATES (ELECTRON DRIFT TIME ~ 50 μs)

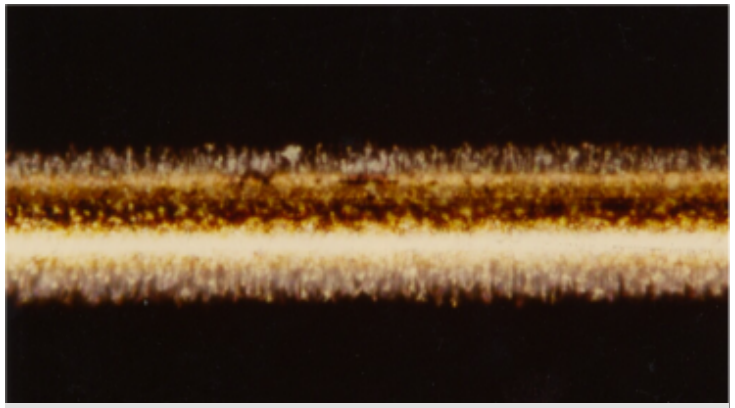
FORMATION OF HEAVY POLYMERS DEPOSITS UNDER IRRADIATION



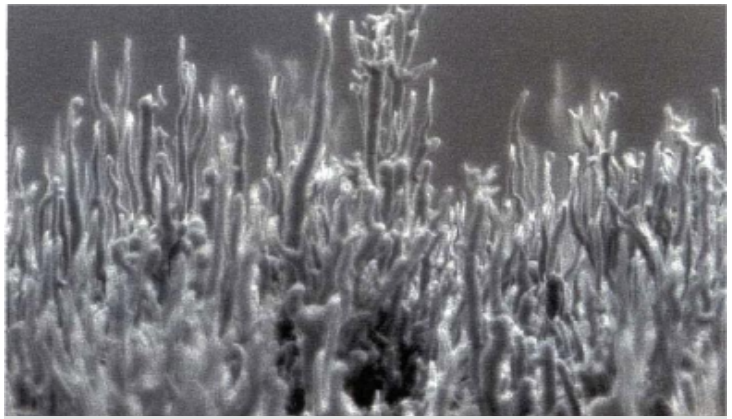
O. Ullaland, LBL-21170 (1986)107



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



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

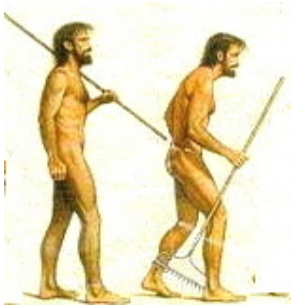


M. Binkley et al, NIMA 515(2003)53

John Kadyk, Proc. Workshop on Radiation Damage to Wire Chambers, LBL 1986

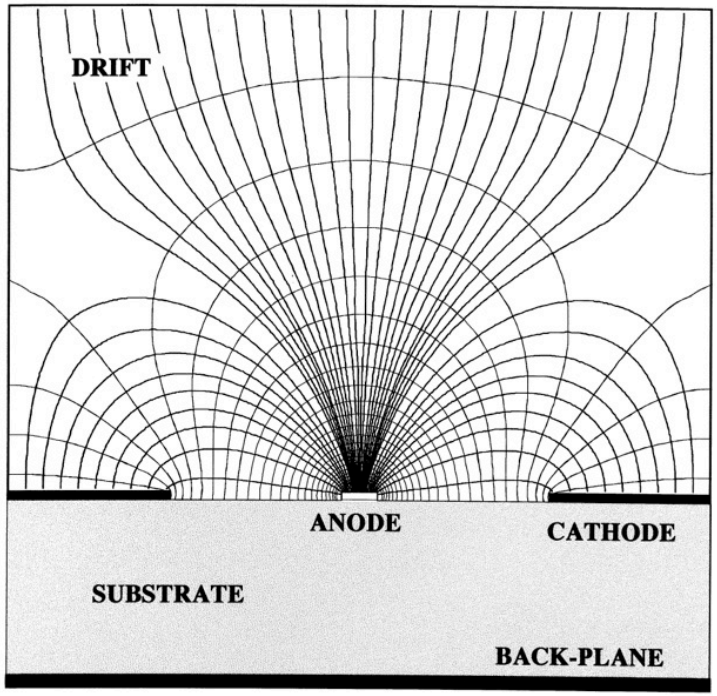
Jerry Va'vra: Physics and Chemistry of aging, Nucl. Instr. and Meth. A515(2003)1

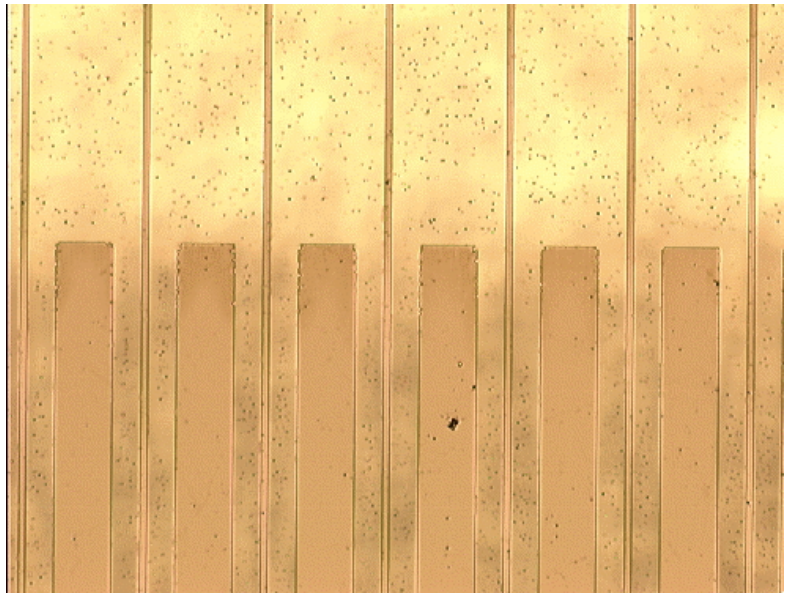
THE NEW APPROACHES: MICRO-PATTERN GAS DETECTORS (MPGD)



Anton Oed (1988)

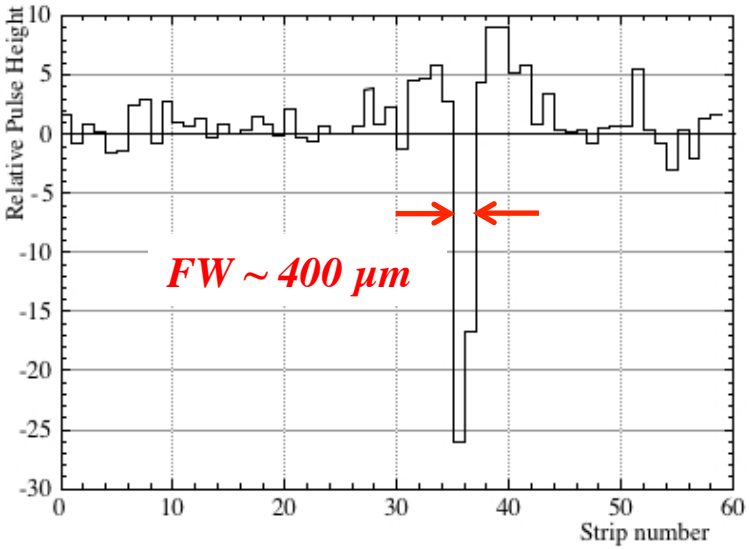
10 μm WIDE ANODE STRIPS
50 μm CATHODE STRIPS AT
100 μm PITCH ON GLASS SUBSTRATE





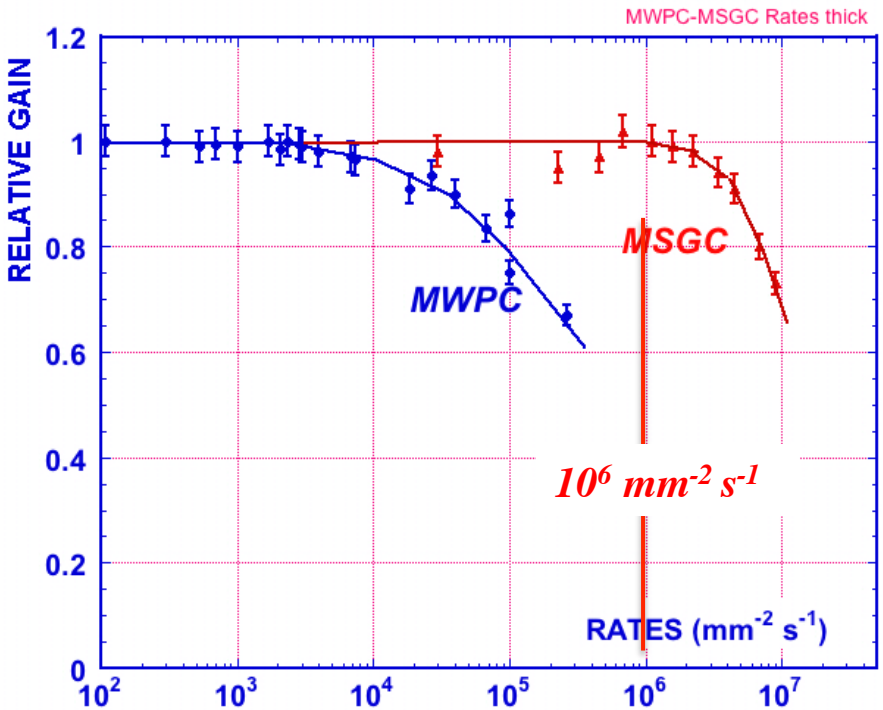
A. Oed, Nucl. Instr. and Meth. A263(1988)351

SINGLE TRACK SIGNAL WIDTH
(TWO-TRACK RESOLUTION):

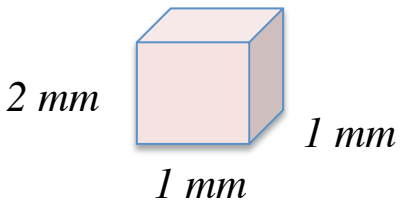


FAST SIGNALS ~ FW 30 ns (1.5 mm)

RATE CAPABILITY: 1 MHz/mm^2



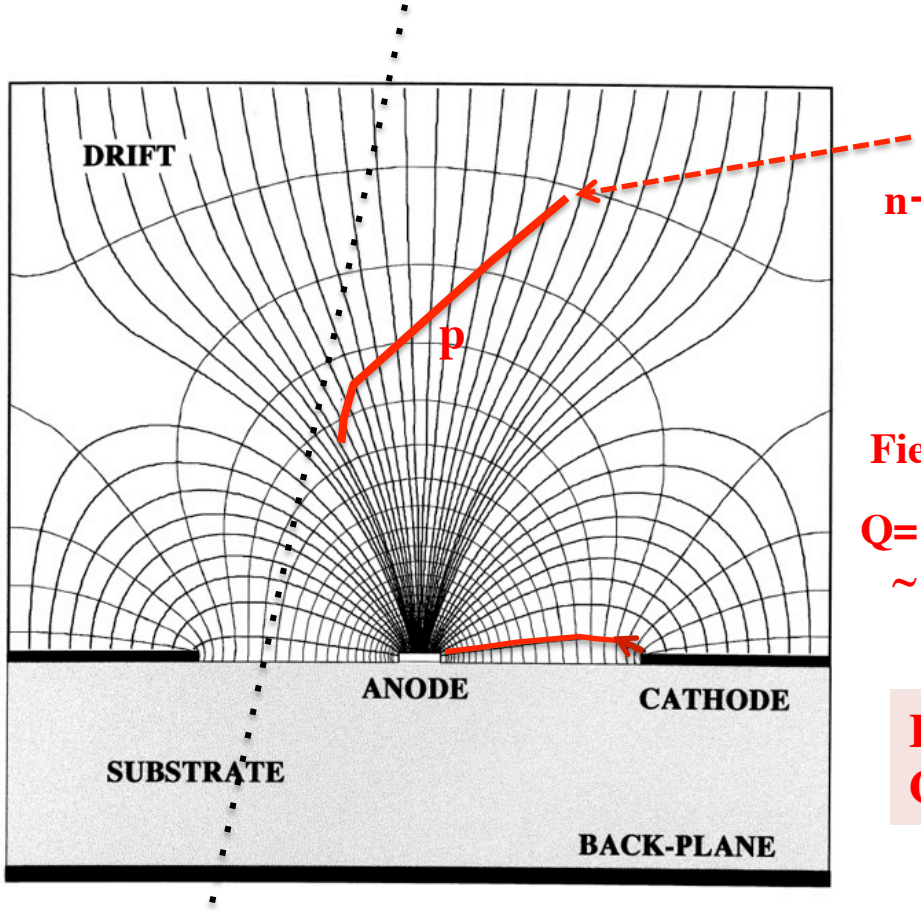
R. Bouclier et al,
Nucl. Instr. and Meth. A367(1995)163



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

AVALANCHE SIZE Q= (IONIZATION)x(GAIN)

MIPs: Q= 100 x10^4=10^6

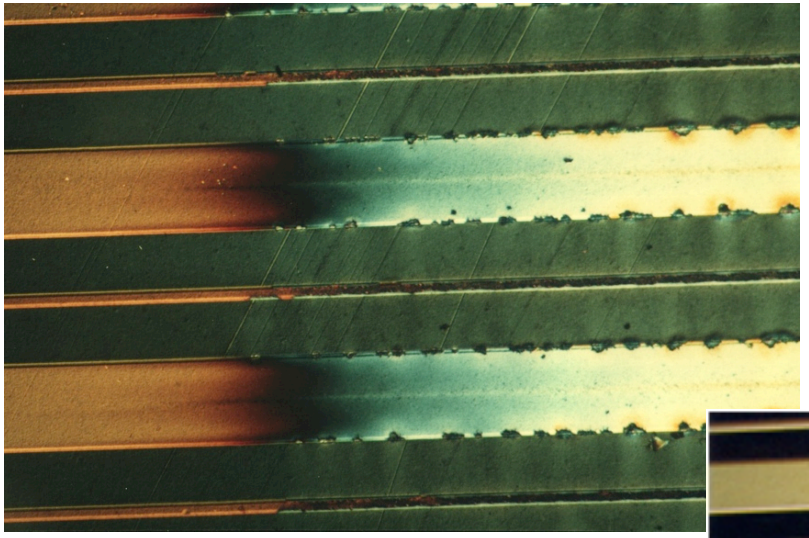


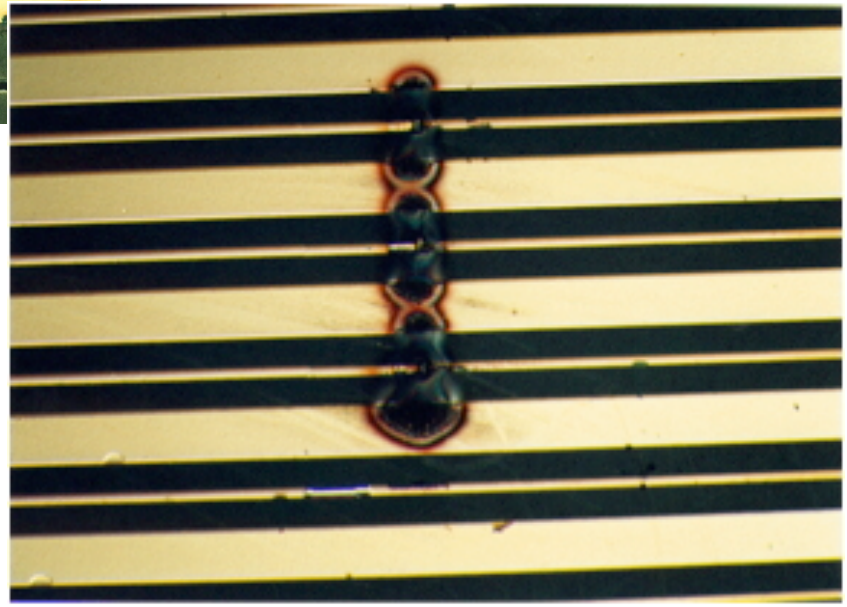
n→ ~ MeV p Q ~ 10^4 x 10^4 = 10^8

Field emission from cathode edge

Q= (EDGE AMPLIFICATION)x(GAIN)
~ 10^4 x 10^4 = 10^8

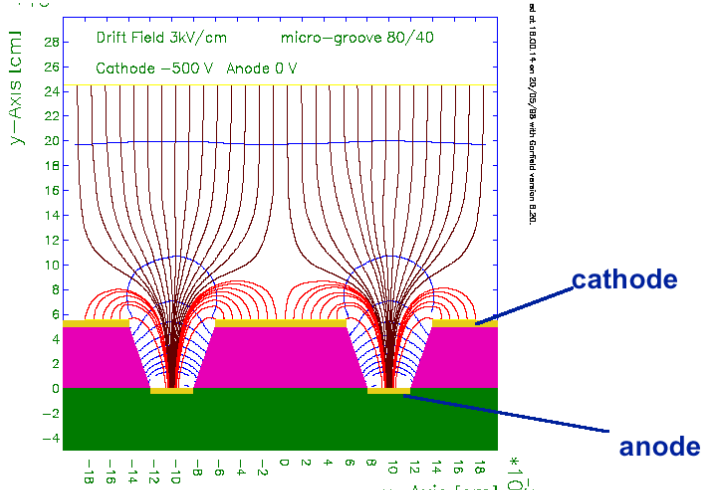
RAETHER LIMIT:
Q > 10^7----> DISCHARGE





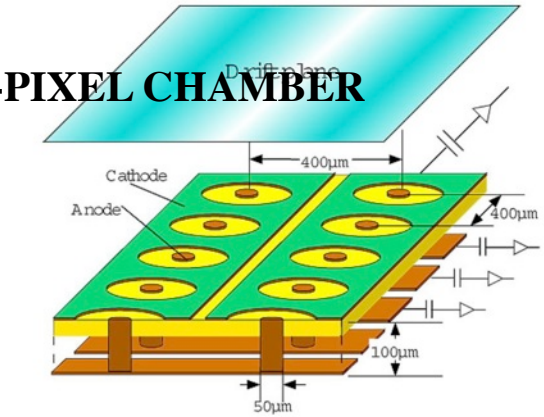
Fabio's Museum of Horrors

MICRO-GROOVE CHAMBER



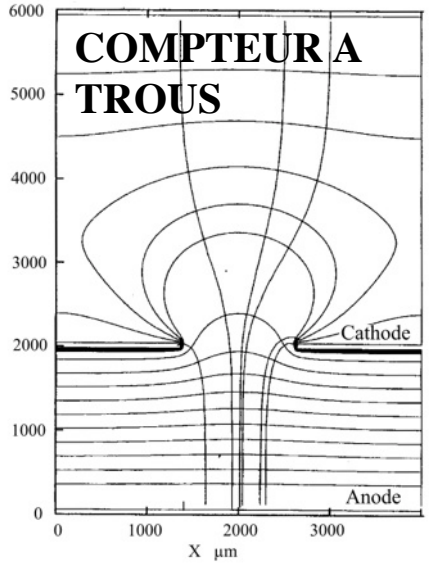
R. Bellazzini et al,
Nucl. Instr. Meth. A424(1998)444

MICRO-PIXEL CHAMBER



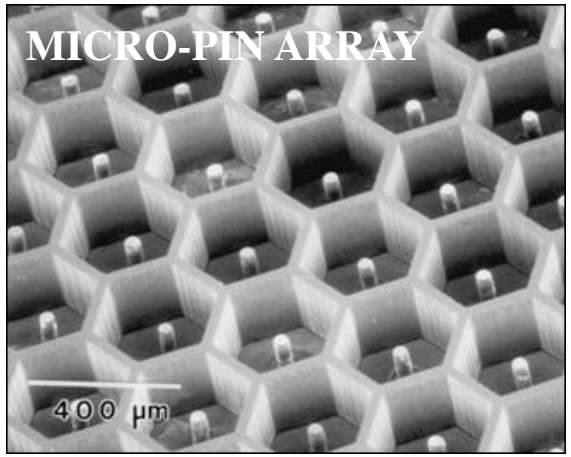
A. Ochi et al,
Nucl. Instr. and Meth. A478(2002)196

COMPTEUR A TROUS



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

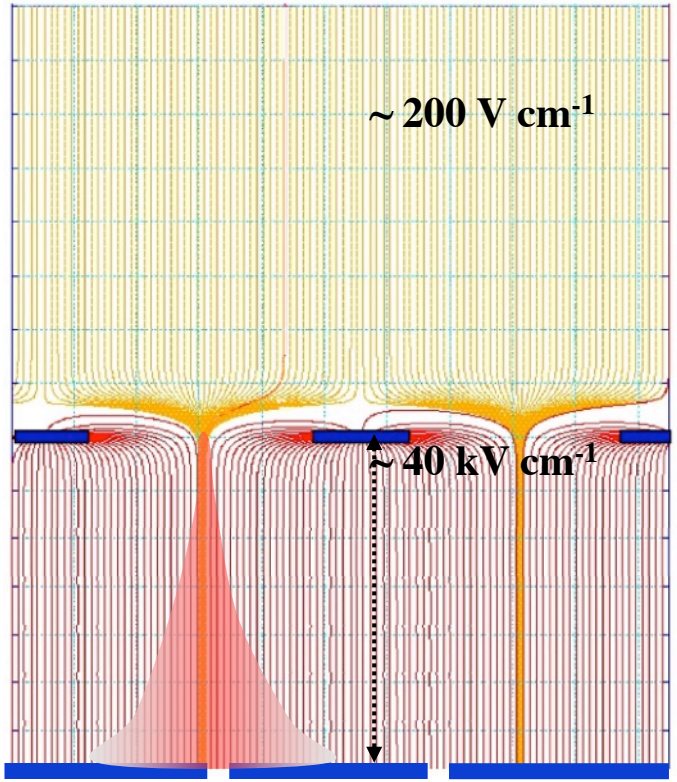
MICRO-PIN ARRAY



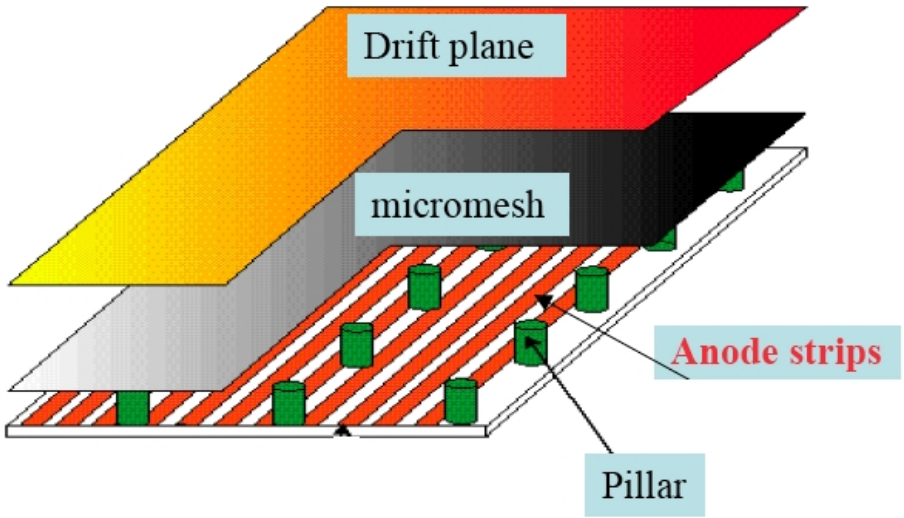
P. Rehak et al
IEEE TNS-47(2000)1426

Ioannis Giomataris (1996)

HIGH/LOW FIELD REGIONS
SEPARATED BY A MESH

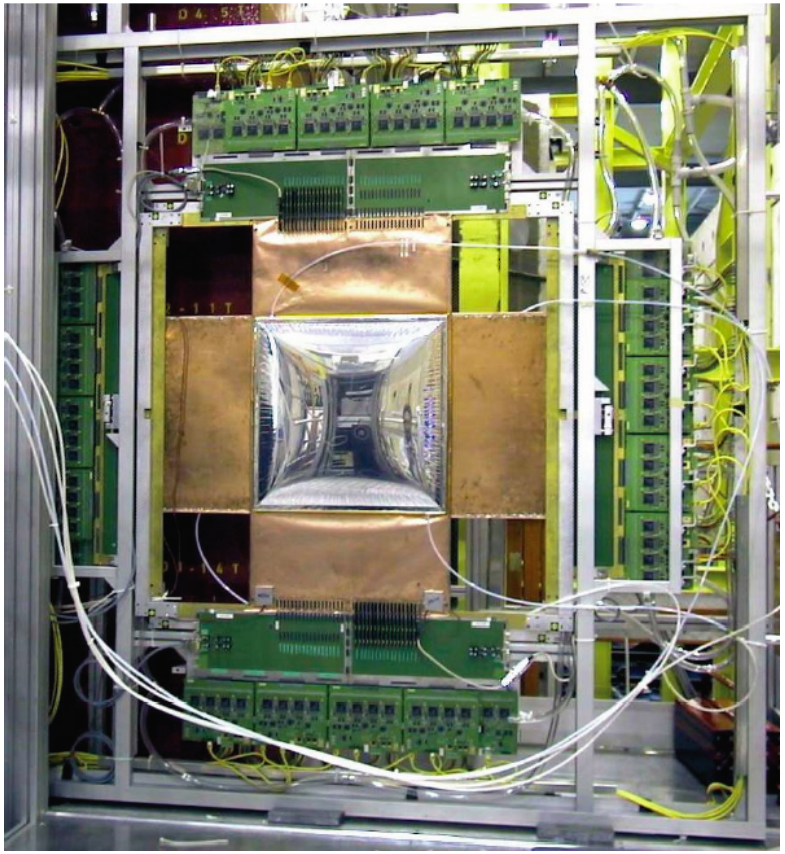


GAP UNIFORMITY:
SPACERS OR PILLARS

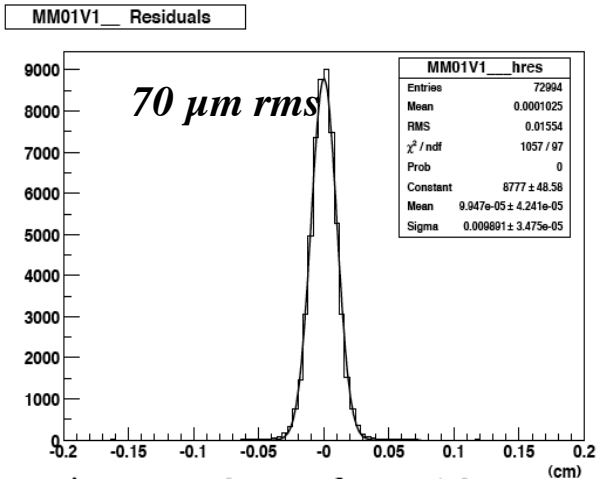


Y. Giomataris et al, Nucl. Instr. and Meth. A 376(1996)29

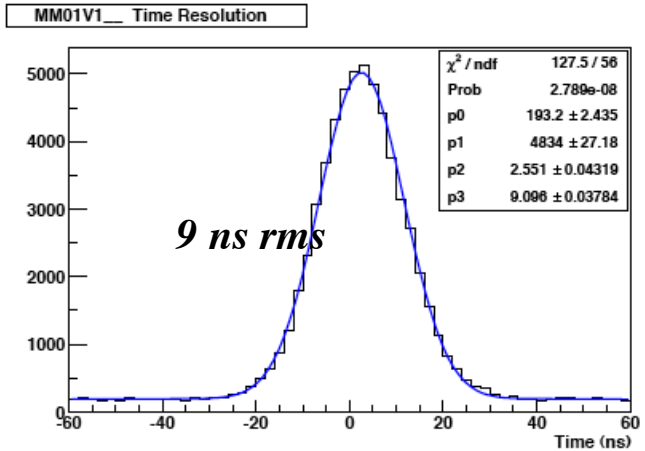
12 planes in 3 stations X,Y, U, V
40x40 cm^2 active
350 μm strips with digital readout



SPACE RESOLUTION:

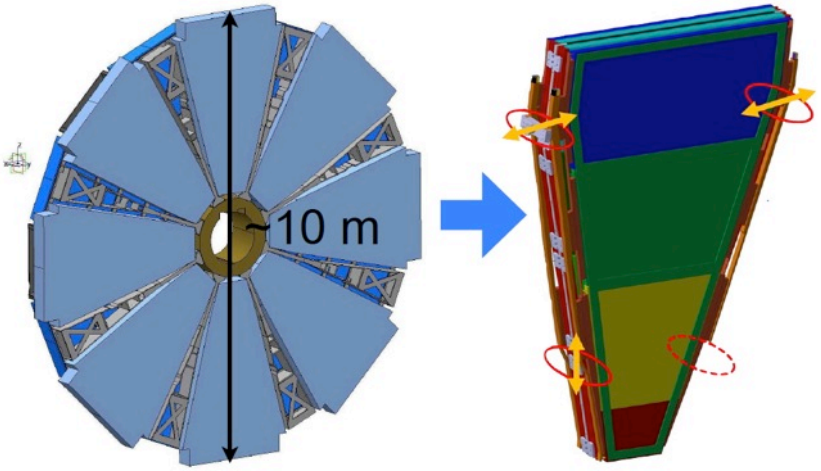


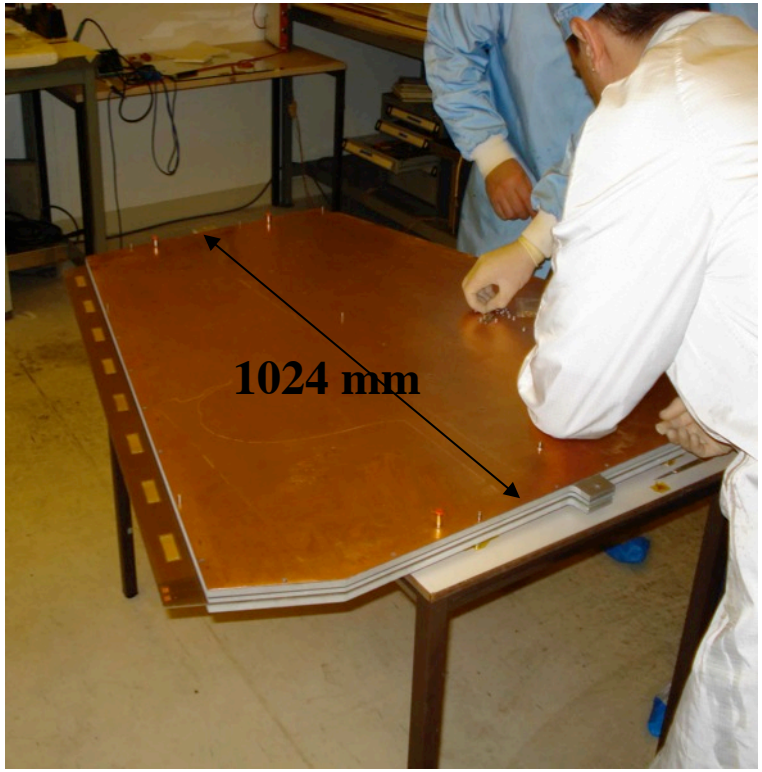
TIME RESOLUTION:

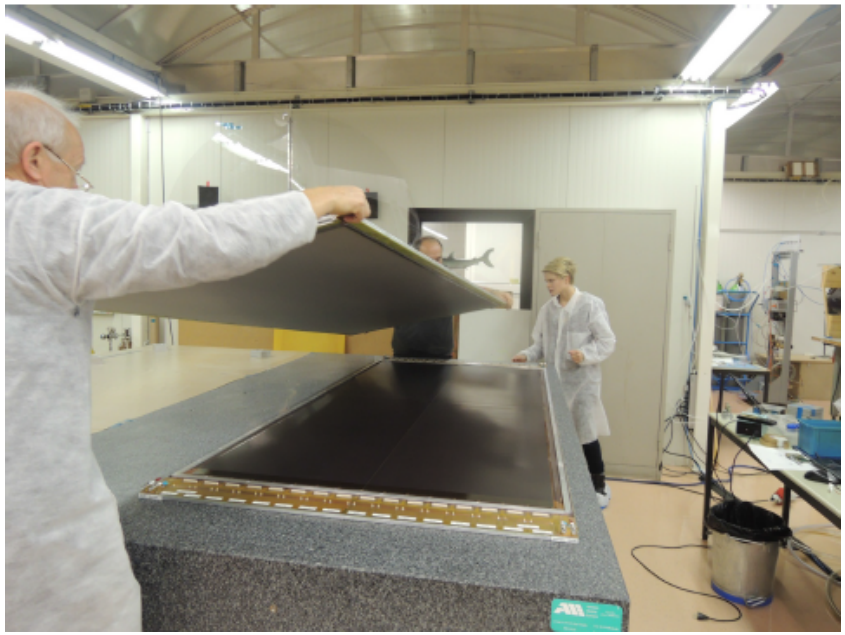


C. Bernet et al, Nucl. Instr. and Meth. A536(2005)61

ATLAS FORWARD MUON UPGRADE:



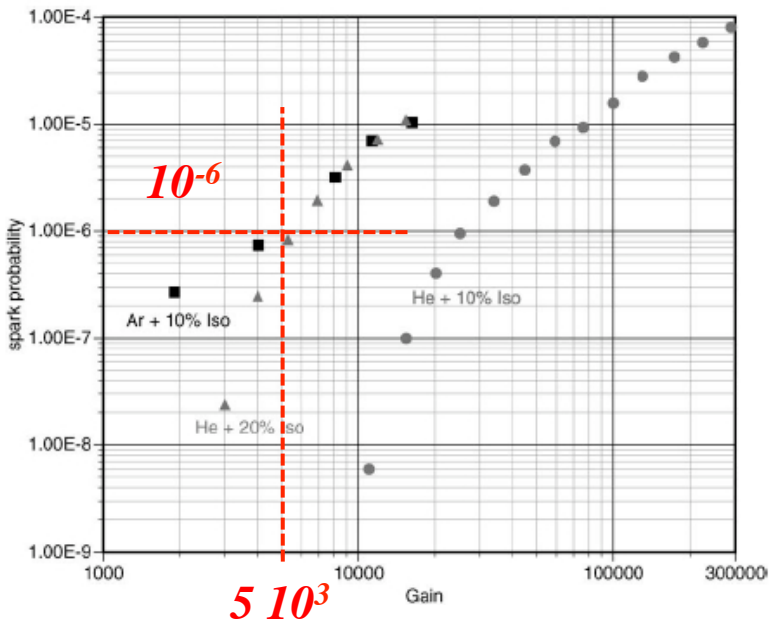




J. Wotschack, RD51 Meeting (CERN 2013)

J. Wotschack, JINST 7, C02021 (2012)

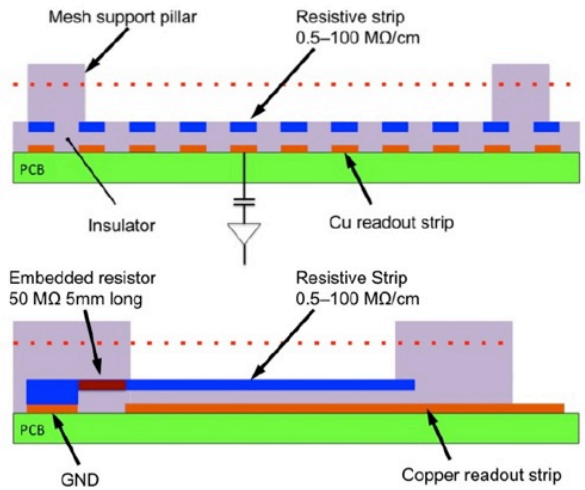
SPARK PROBABILITY IN HADRON BEAM

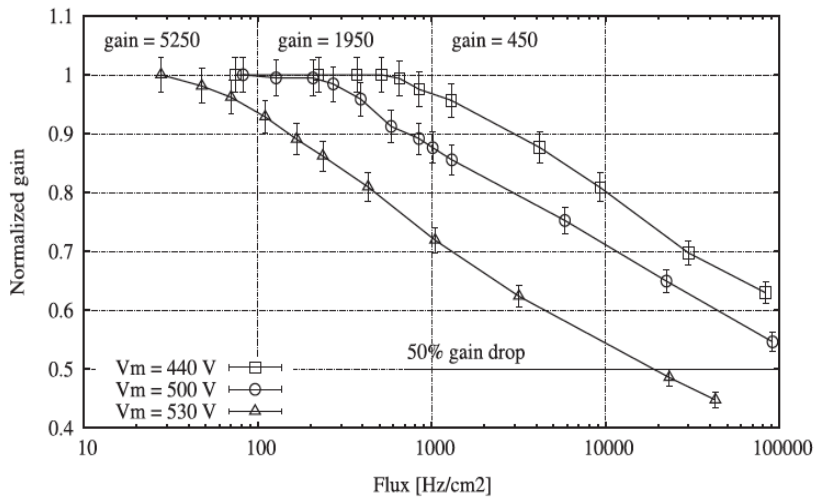


FOR A GAIN OF 5.10^3 , 10^6 PARTICLES s^{-1}:
~ ONE DISCHARGE PER SECOND

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

RESISTIVE MICROMEGAS

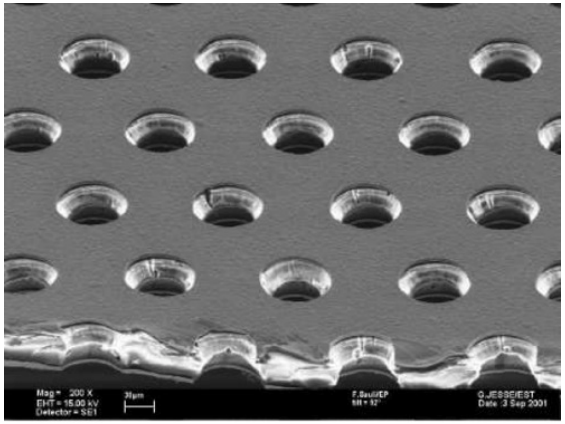




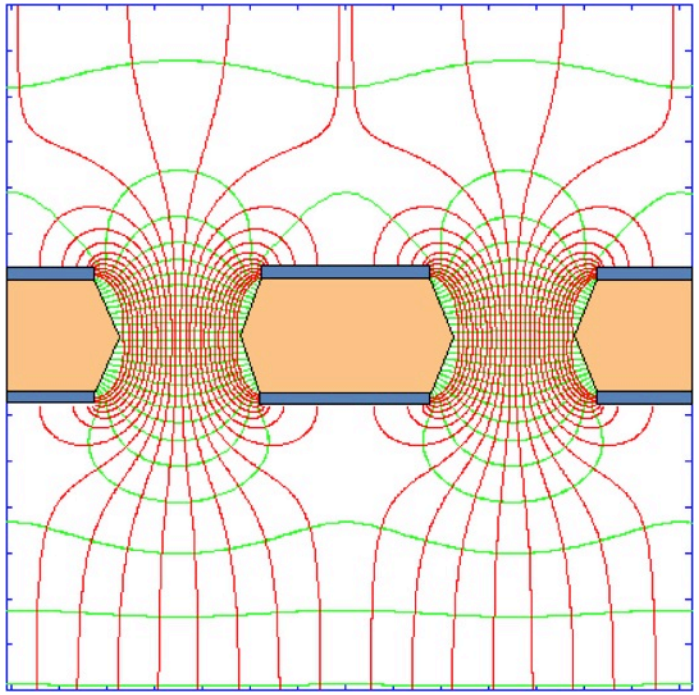
J. Galán et al, Nucl. Instr. and Meth. A732(2013)229

Fabio Sauli (1997)

STANDARD GEM:70 μm Ø at 140 μm PITCH

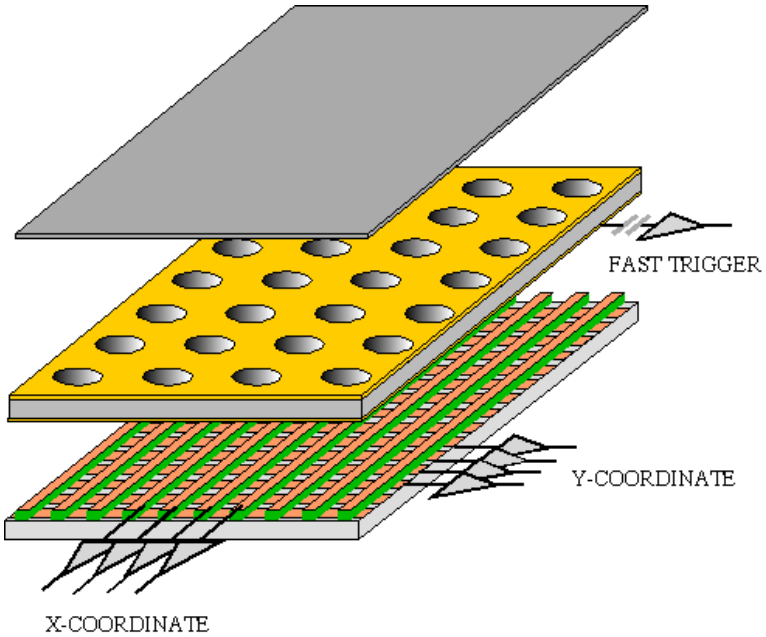


THIN (50 μm) METAL-COATED POLYMER FOIL WITH HIGH DENSITY OF HOLES:



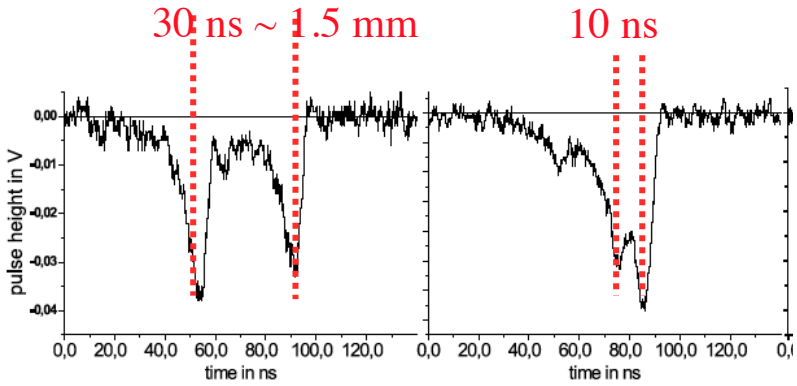
F. Sauli, Nucl. Instr. and Meth. A386(1997)531

SINGLE GEM WITH 2-D READOUT BOARD



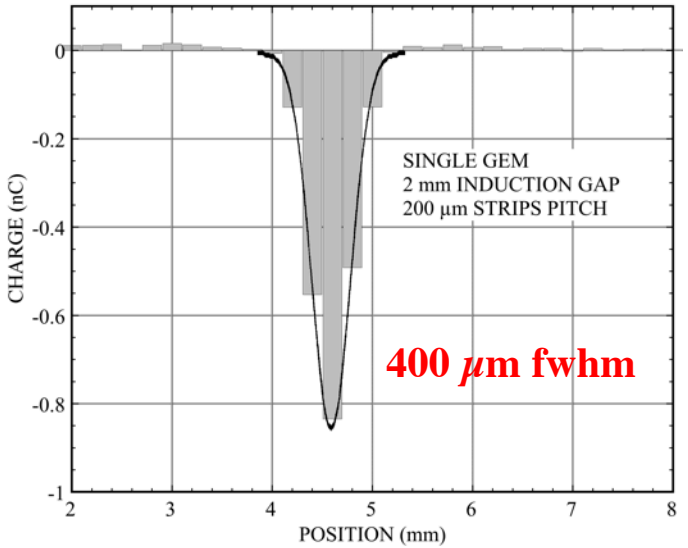
A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254

TWO-TRACK RESOLUTION (DRIFT TIME):



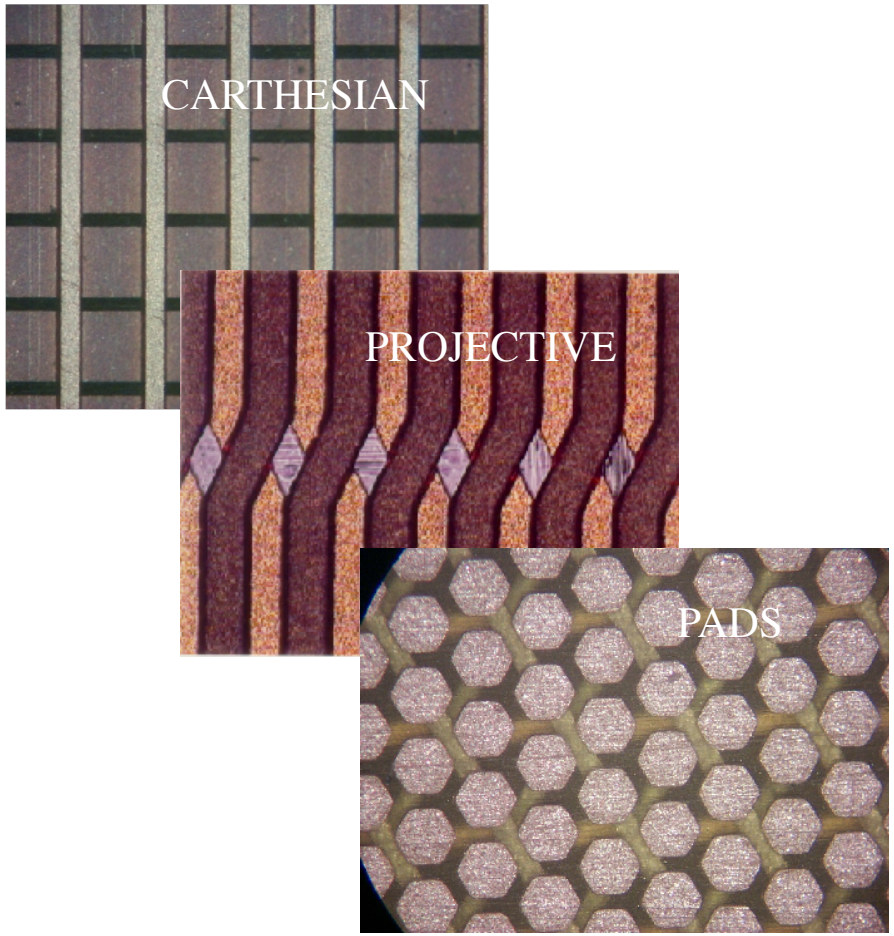
M. Ziegler, PhD Zürich Univ. (2002)

TWO-TRACK RESOLUTION (PROJECTION):



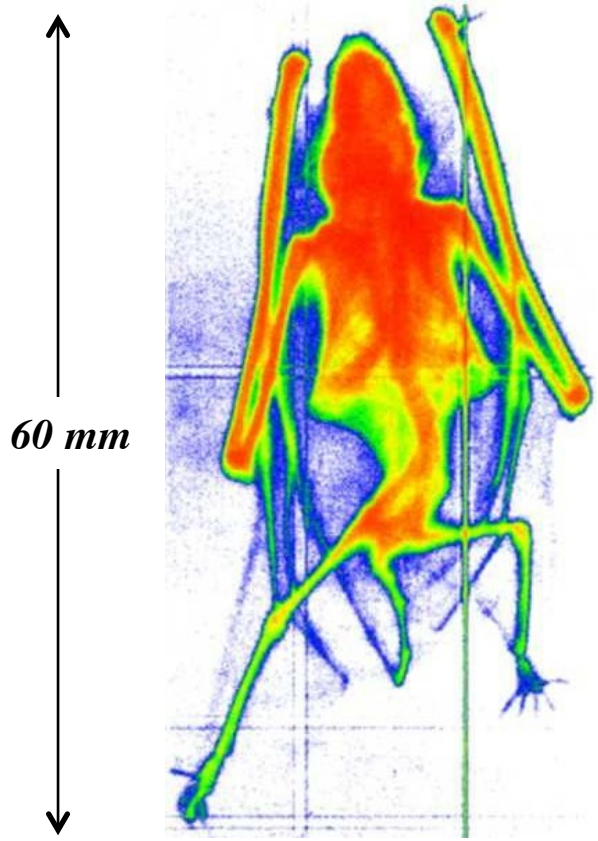
VOLUME RESOLUTION ~ 1 mm^3

FLEXIBLE READOUT GEOMETRY:



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

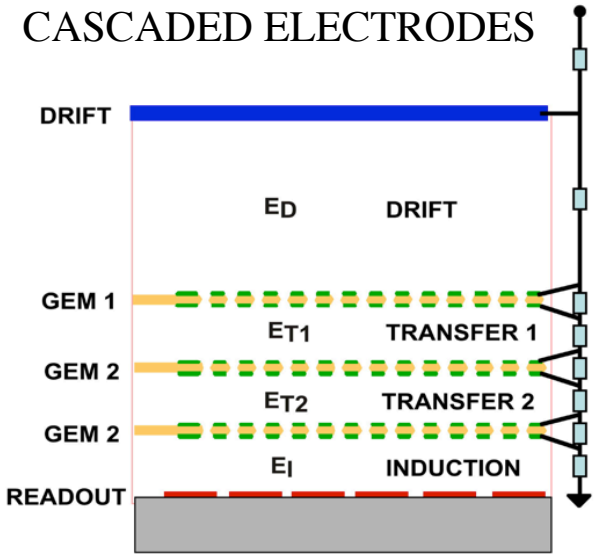
SOFT X-RAY RADIOGRAPHY
SELF-TRIGGERED GEM



F. Sauli,
Nucl. Instr. and Meth. A461(2001)47

MULTI-GEM DETECTORS

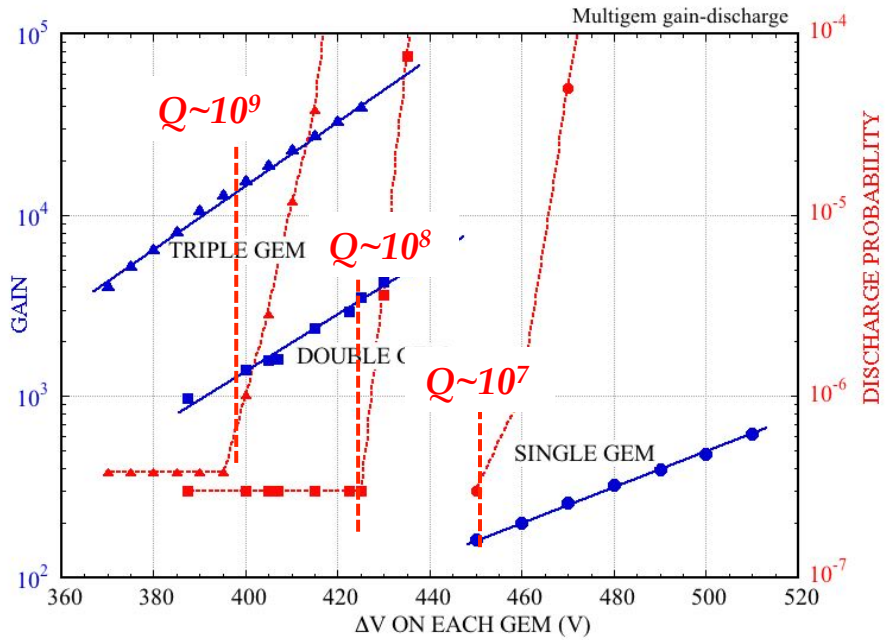
TRIPLE-GEM:
CASCADED ELECTRODES



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

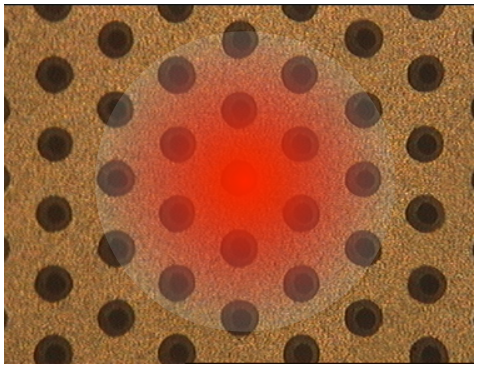
HIGHER GAIN, LOWER VOLTAGE ON EACH GEM

DISCHARGE RATE ON ~ 5 MeV α (10^5 e)

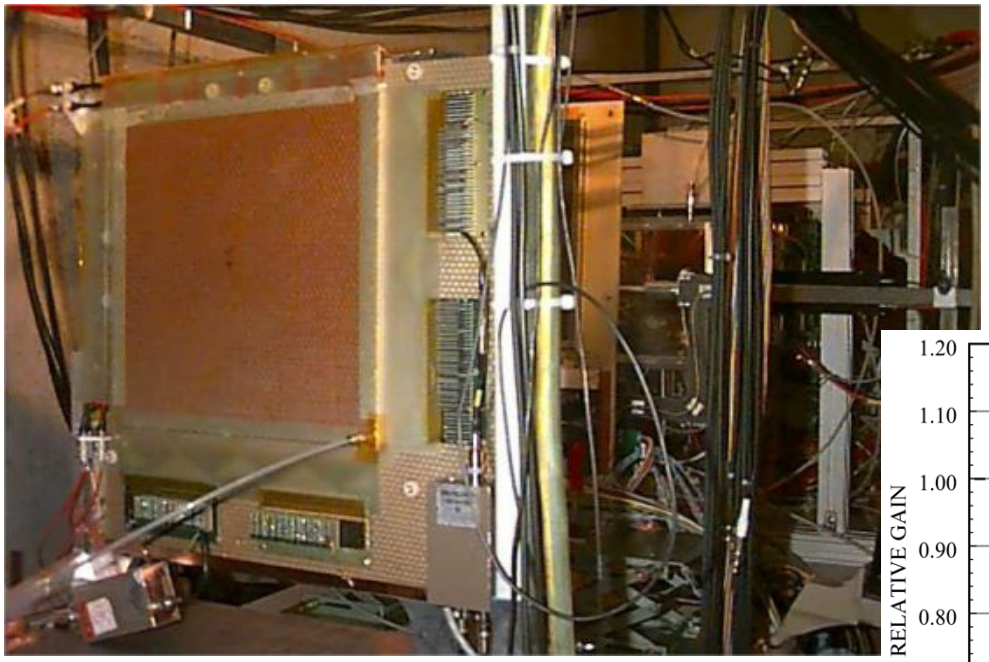


WHAT ABOUT THE RAETHER LIMIT?

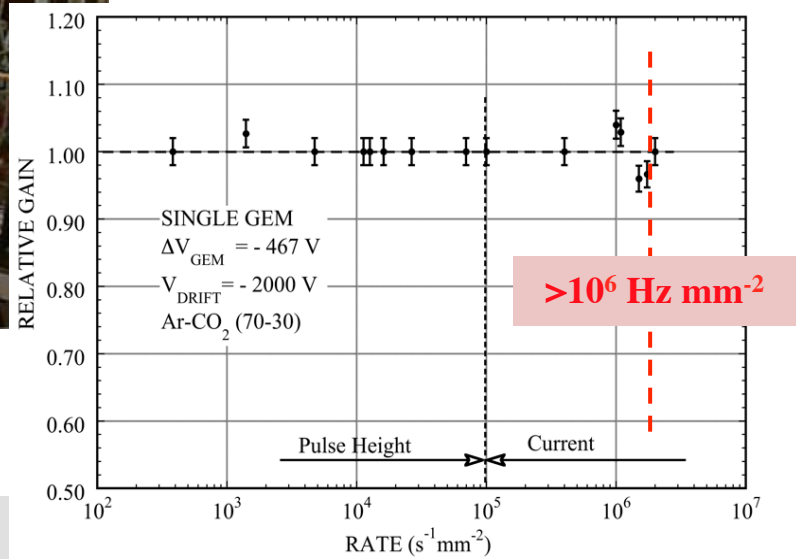
IN MULTI-GEMS, THE CHARGE SPREADS OVER MANY INDEPENDENT HOLES!



22 DETECTORS, OPERATIONAL 2002-2012

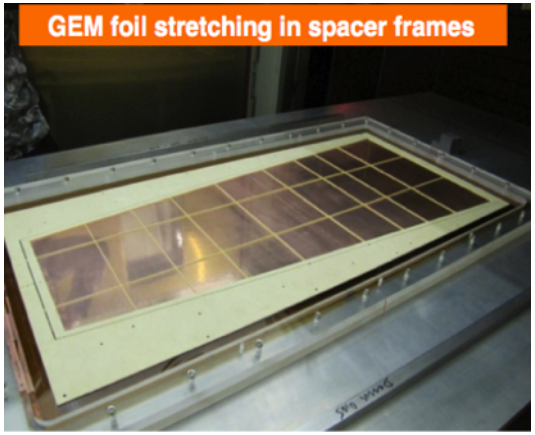


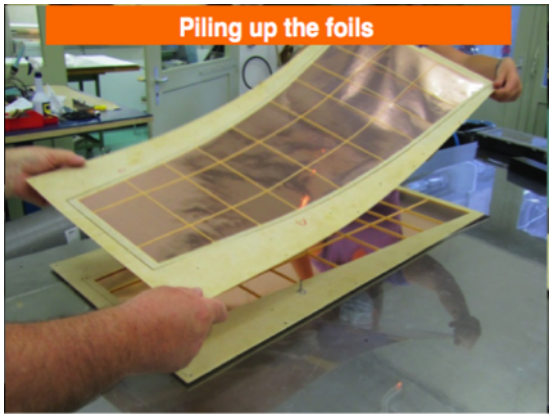
RATE CAPABILITY



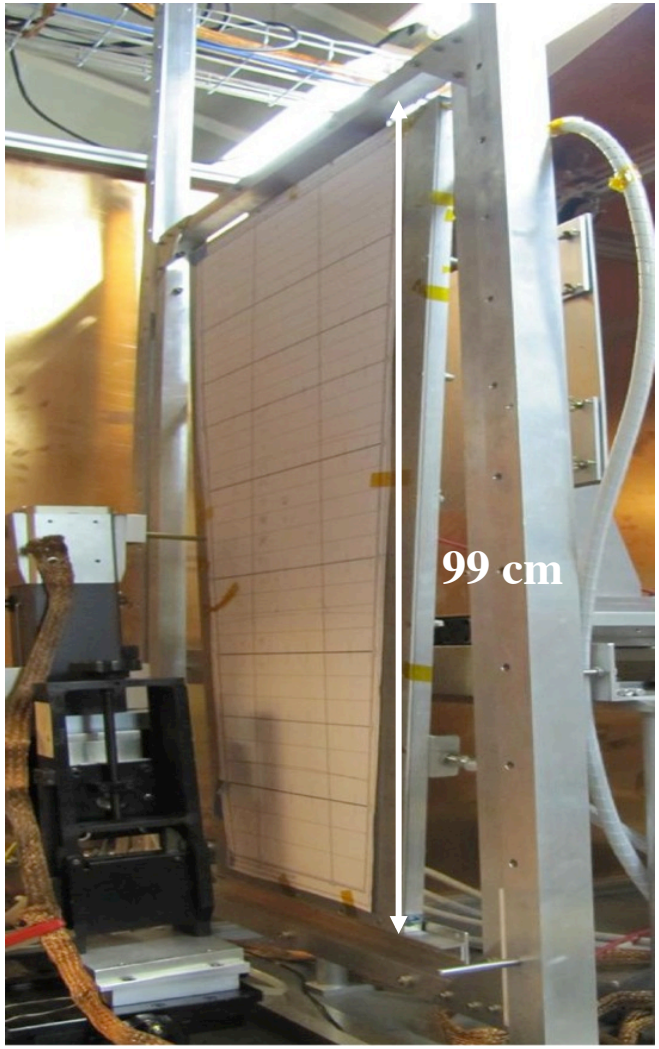
B. Ketzer et al, Nucl. Instr. and Meth. A535(2004)314

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



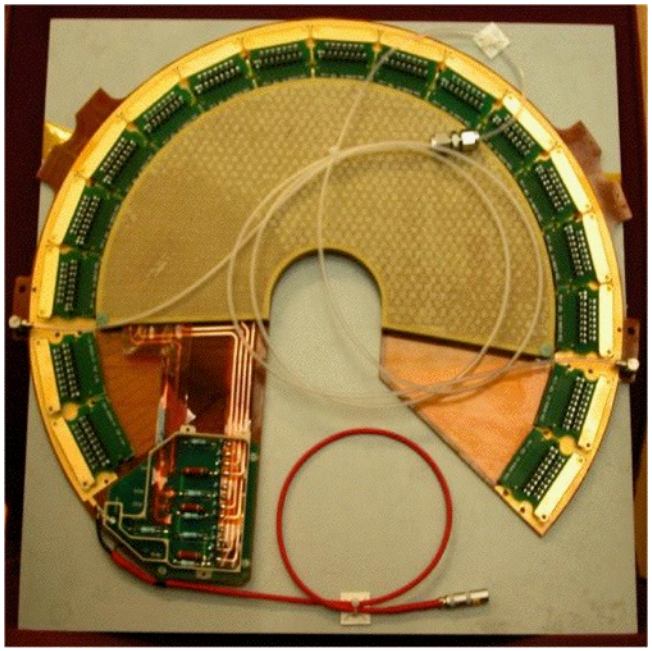


M. Tytgat, MPGD 2013

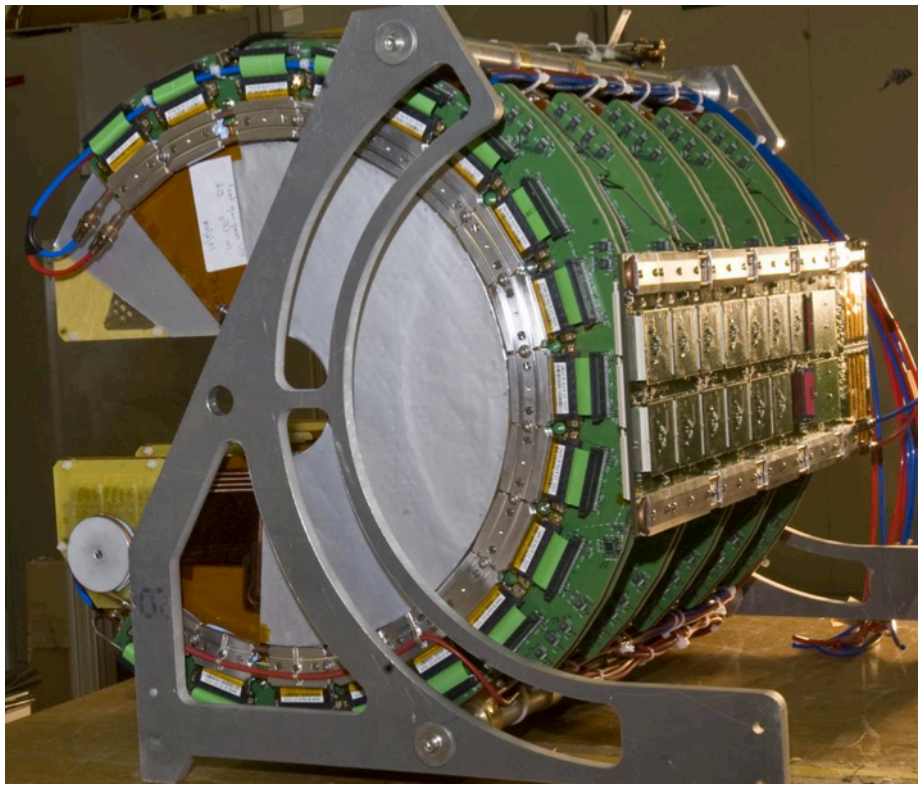


D. Abbaneo et al, JINST 9(2014)C01053

SEMI-CIRCULAR MODULES

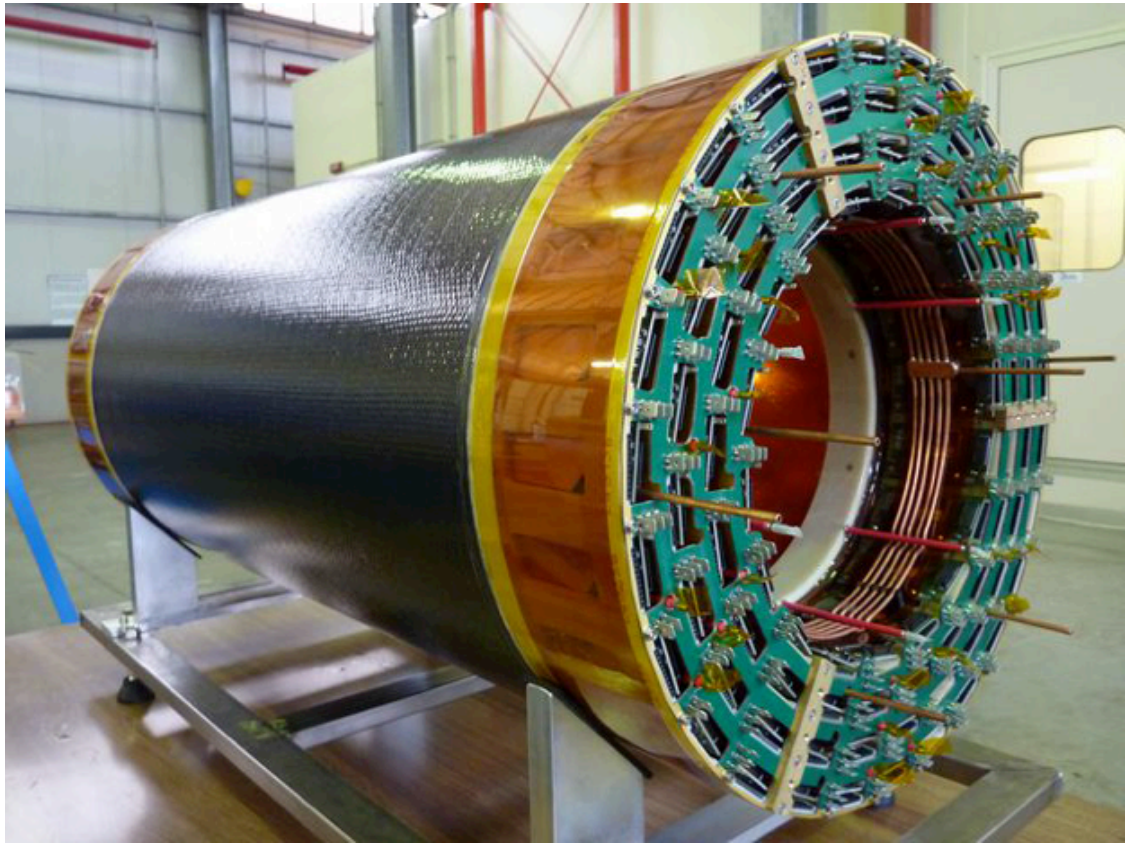


FULL SINGLE-ARM DETECTOR



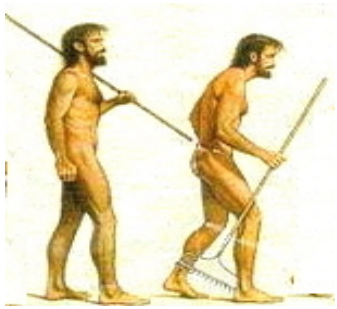
M.G. Bagliesi et al, Nucl. Instr. And Meth. A617(2010)134

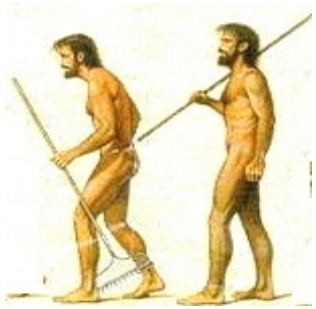
KLOE-2 INNER TRACKER: THREE LAYERS OF TRIPLE-GEM DETECTORS



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

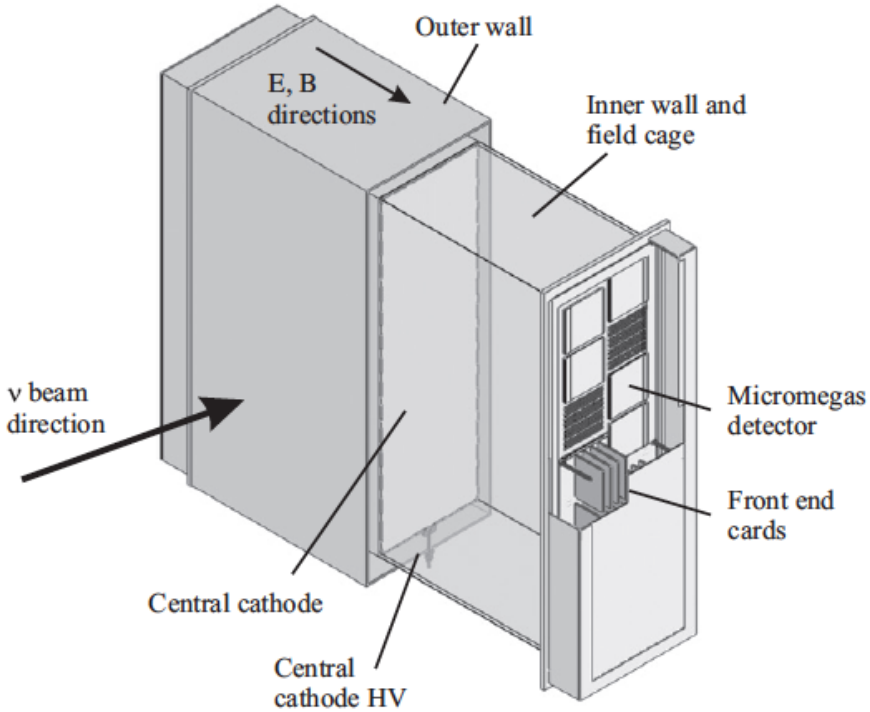
BACK TO THE TPC: MPGD END-CAP READOUT



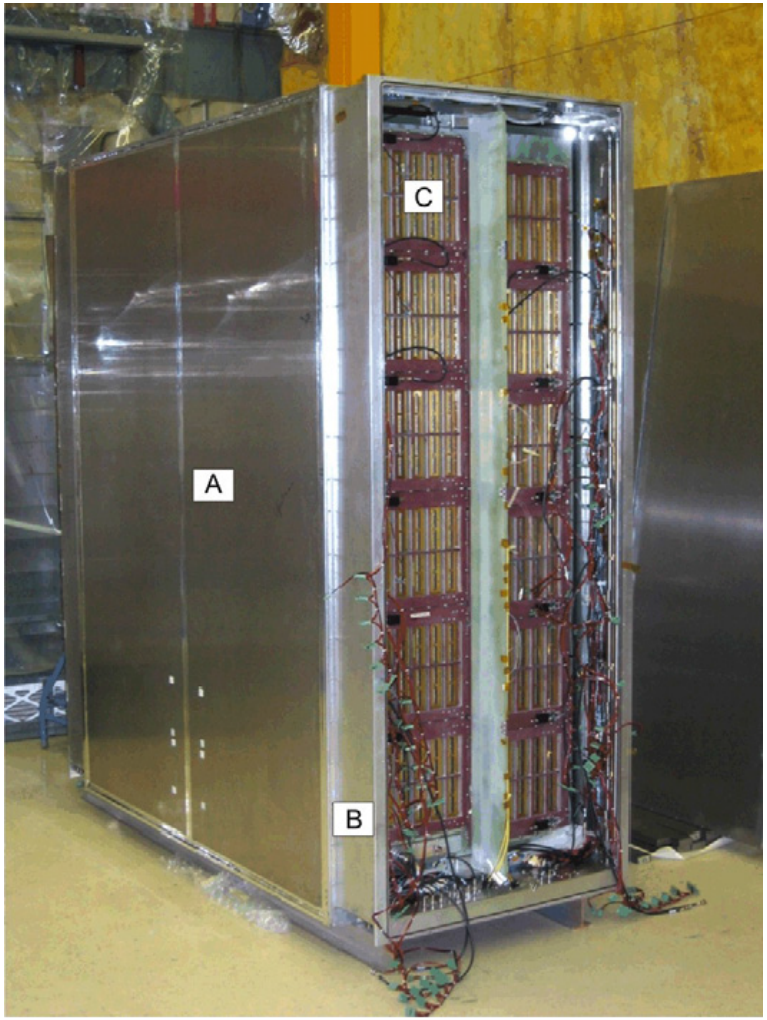


72 MICROMEGAS MODULES (35x36 cm^2)

READOUT: 36x48 PADS of 9.7x6.9 mm^2

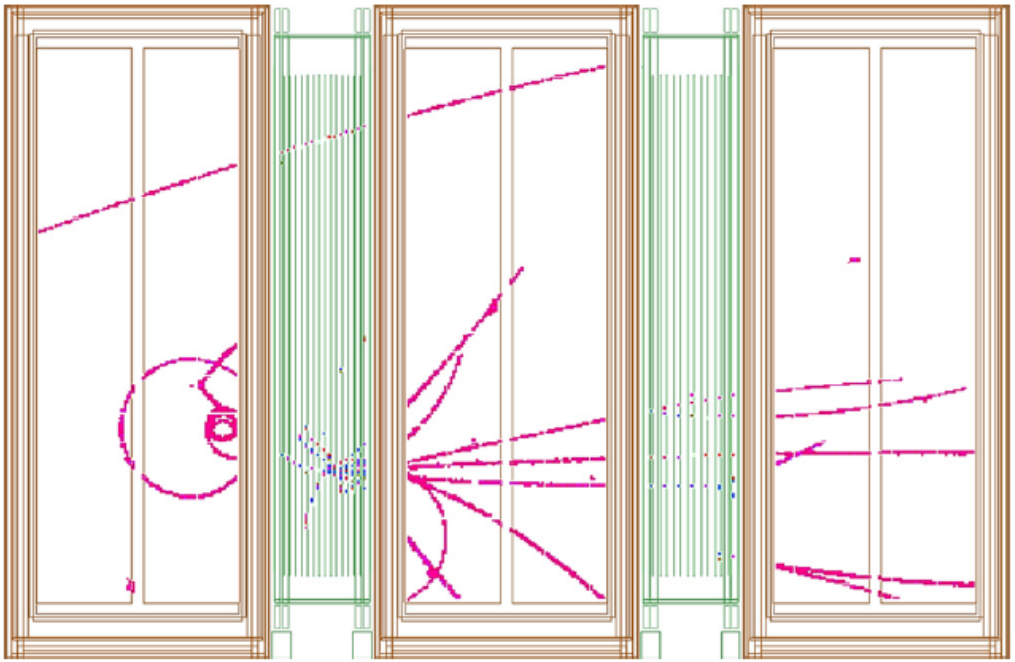


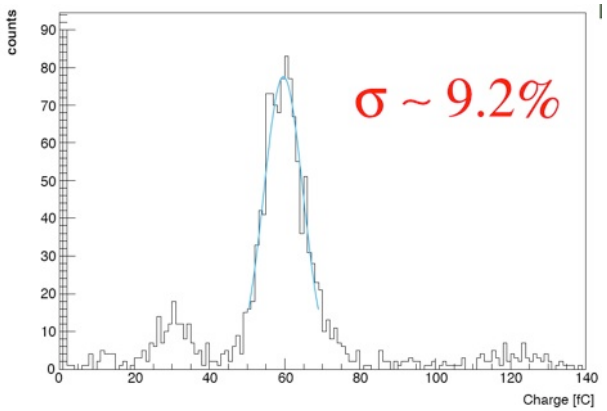
A. Delbart, Nucl. Instr. and Meth. A623(2010)105

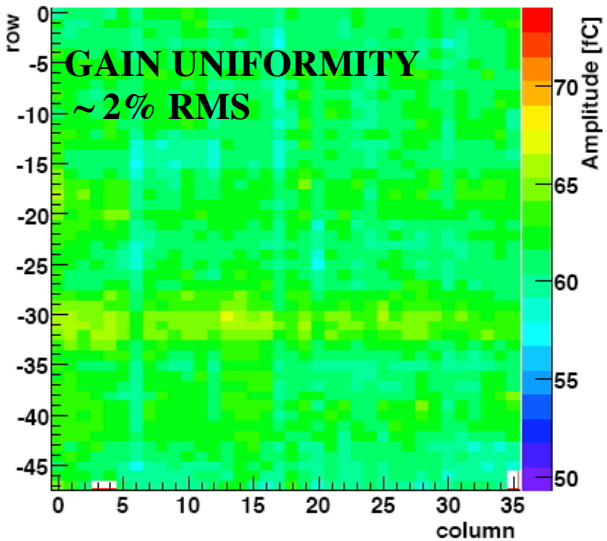


N. Abragall et al, Nucl. Instr. and Meth. A637(2011)25

ENERGY RESOLUTION ON ^{55}Fe:

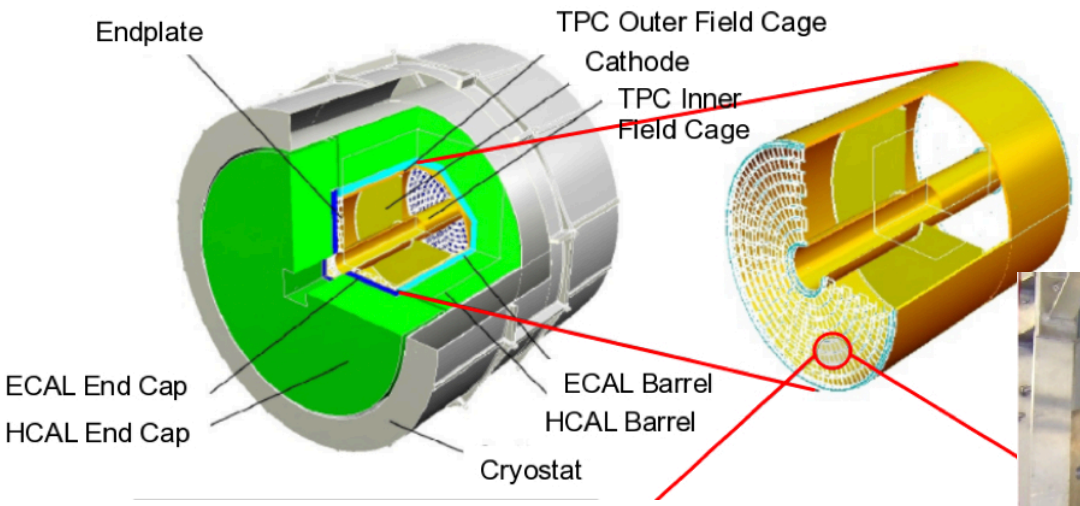


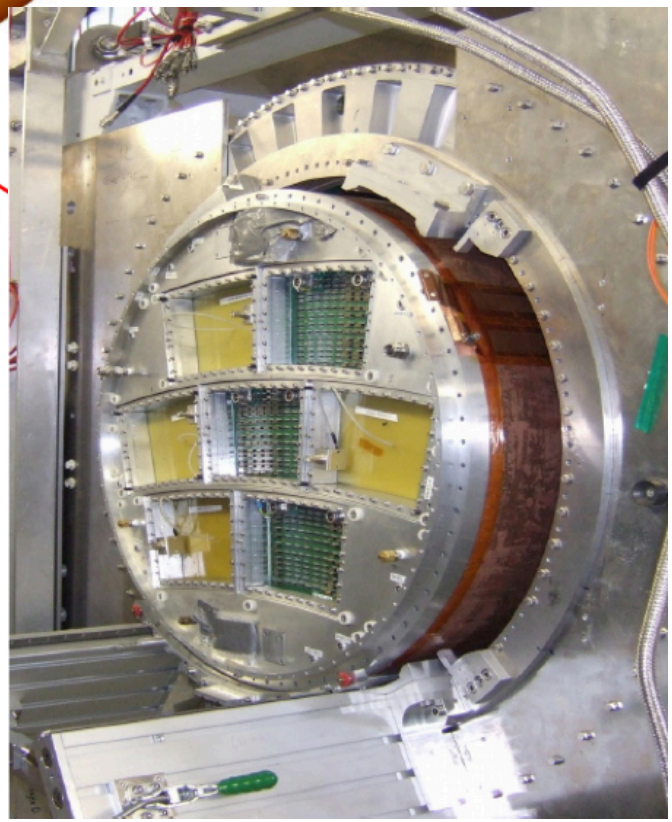




N. Abragall et al, Nucl. Instr. and Meth. A637(2011)25

MPGD TPC FOR THE INTERNATIONAL LINEAR COLLIDER



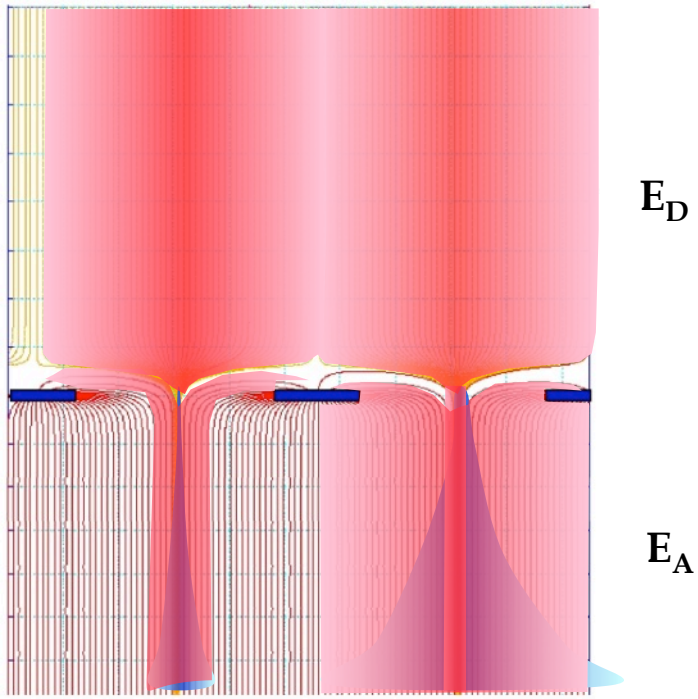


GENERAL PURPOSE END-CAP
FOR PROTOTYPE ASSEMBLY AND TEST

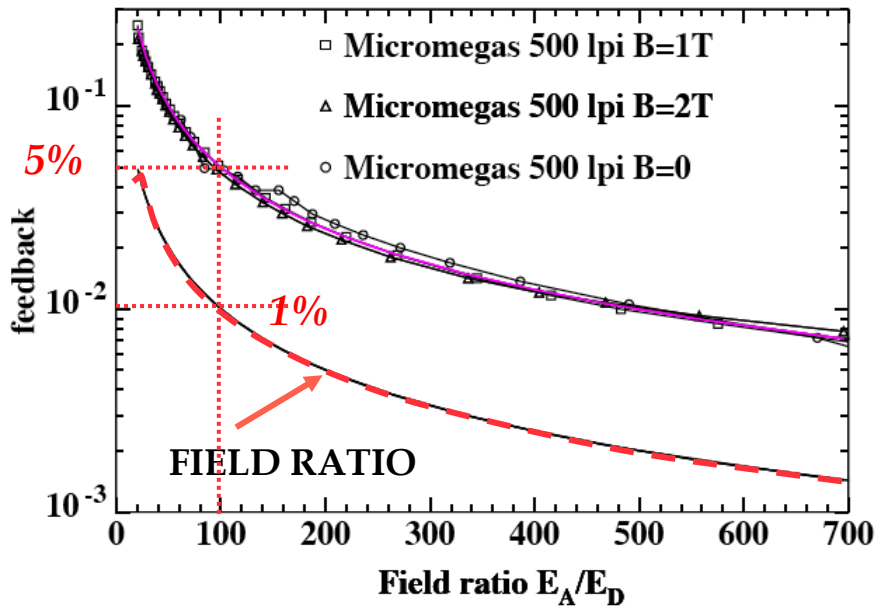
K. Dehmelt, Nucl. Instr. and Meth. A623(2010)97

P. Schade et al, Nucl. Instr. and Meth. A628(2011)128

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

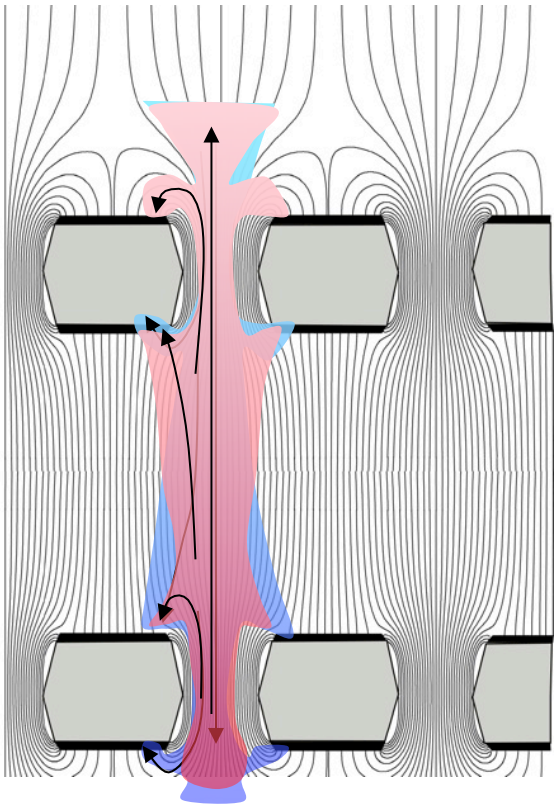


E_D~ 400 V cm^{-1} E_A~ 40 kV cm^{-1}

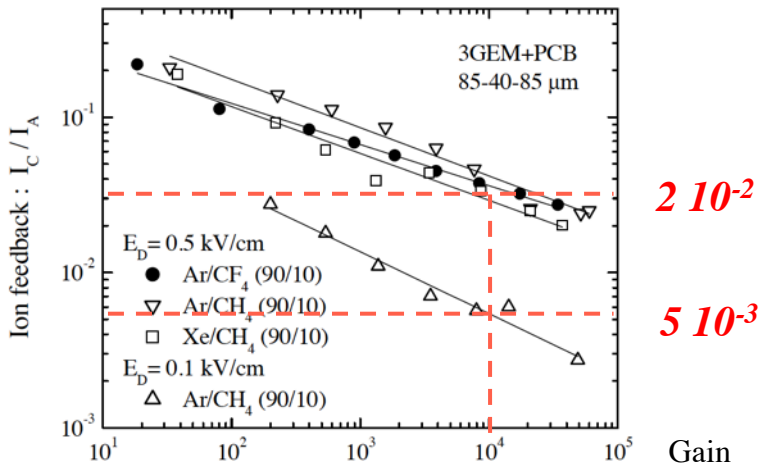


P. Colas et al, Nucl. Instr. and Meth. A535(2004)226

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

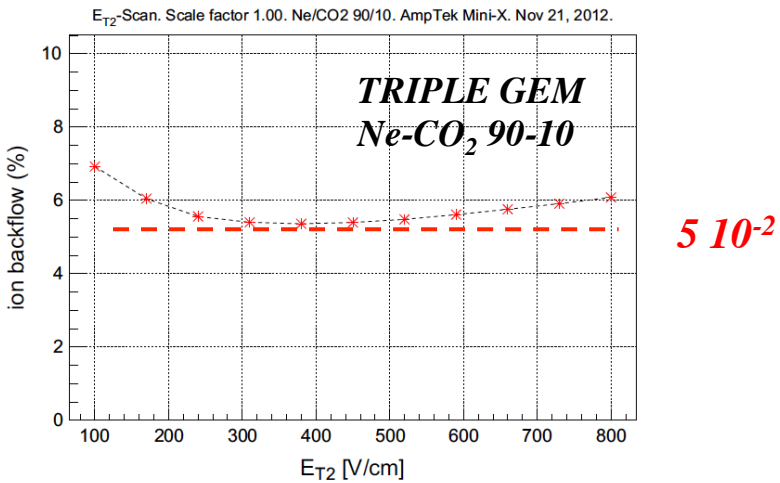


FIELDS:



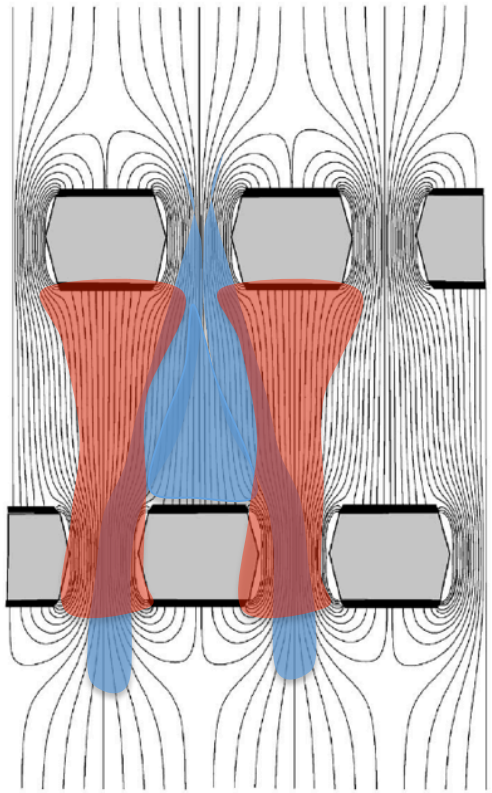
A. Bondar et al, Nucl. Instr. and Meth. A496(2003)325

GAS:



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

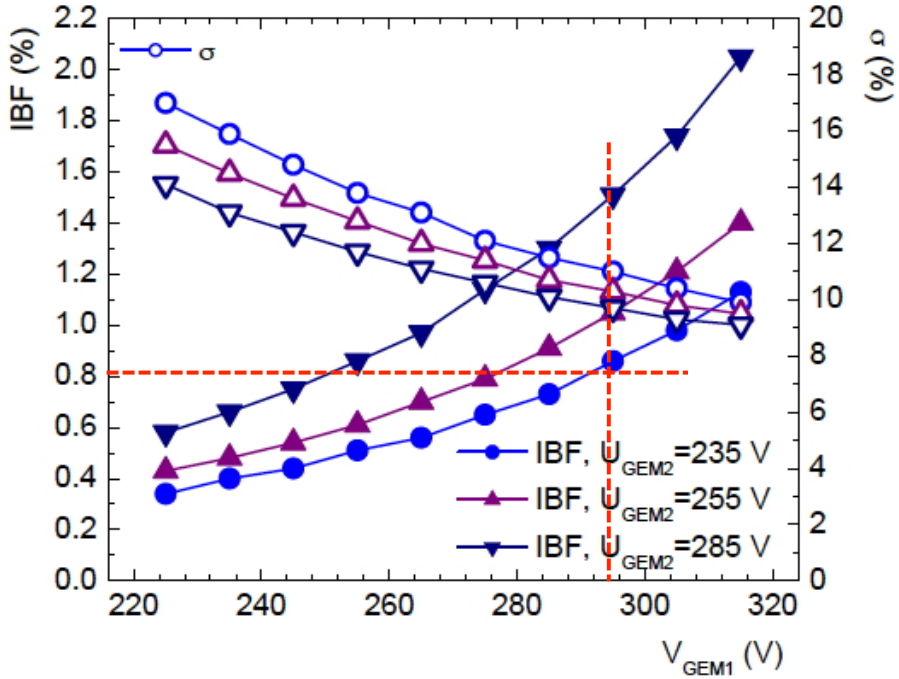
EXPLOITING THE DIFFERENCE BETWEEN IONS' AND ELECTRONS' DIFFUSION:



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

ALICE UPGRADE: QUAD-GEM WITH ALTERNATING DIFFERENT PITCH

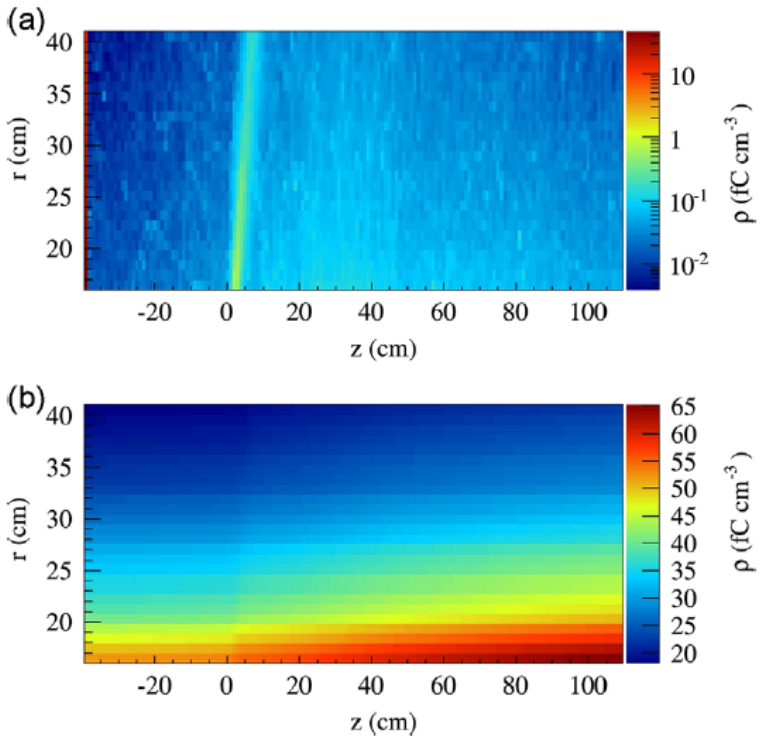
IBF AND ENERGY RESOLUTION VS VOLTAGE ON THE FIRST GEM:



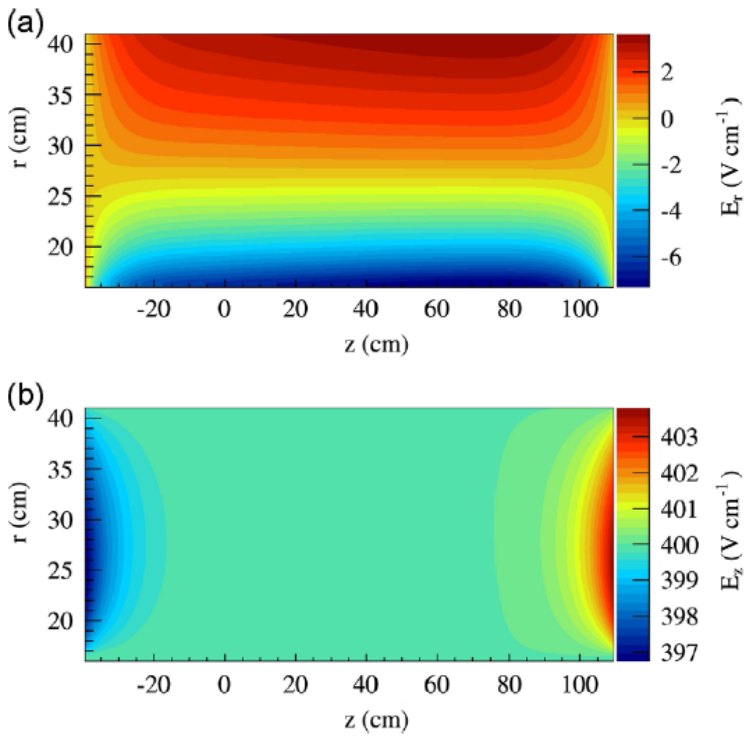
ALICE TDR CERN-LHCC-2013-020

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:

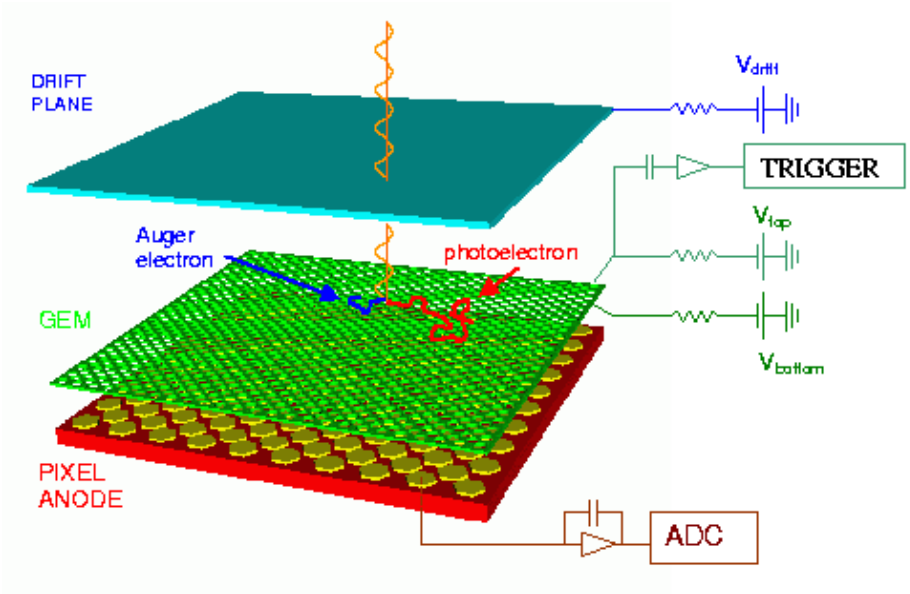


F.W. Bohmer et al,Nucl. Instr. and Meth. A719(2013)101

GATING REVISITED ? (Howard Wieman)

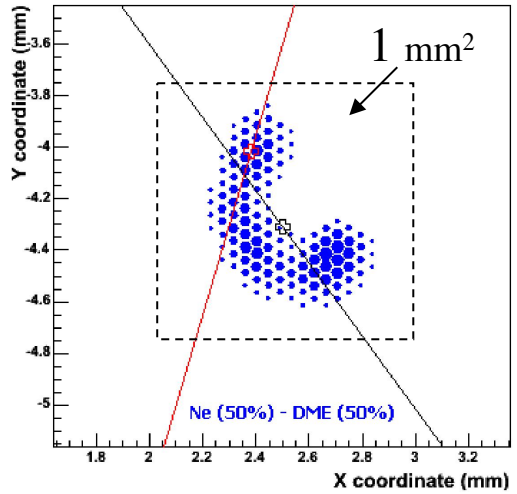
THE ULTIMATE TPC: GAS MEETS SILICON

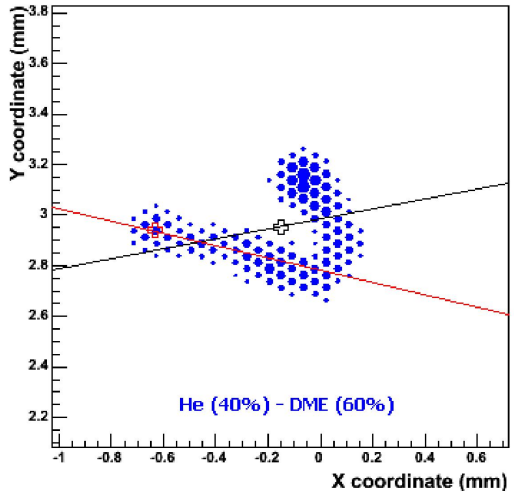
GEM AMPLIFIER WITH ASIC PIXEL ELECTRONICS READOUT



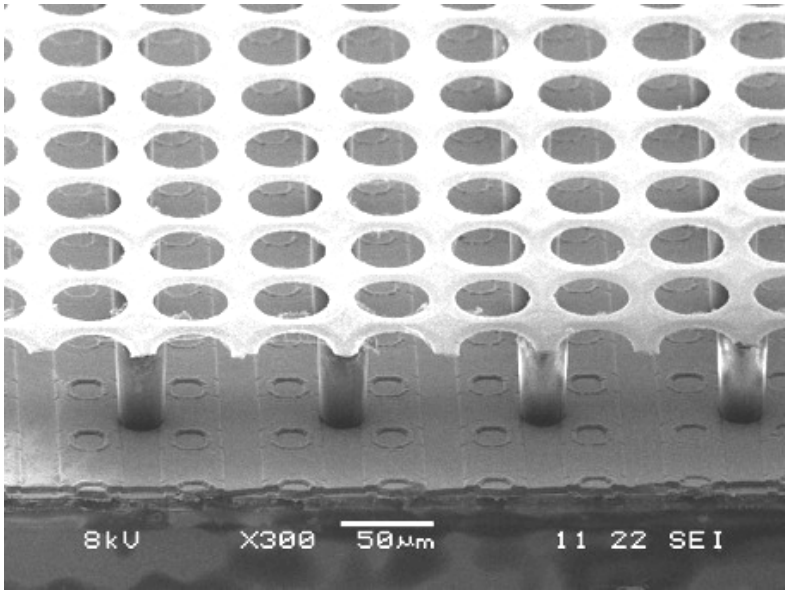
R.Bellazzini et al, Nucl. Instr. And Meth. A572(2007)160

5.9 keV PHOTOELECTRONS:

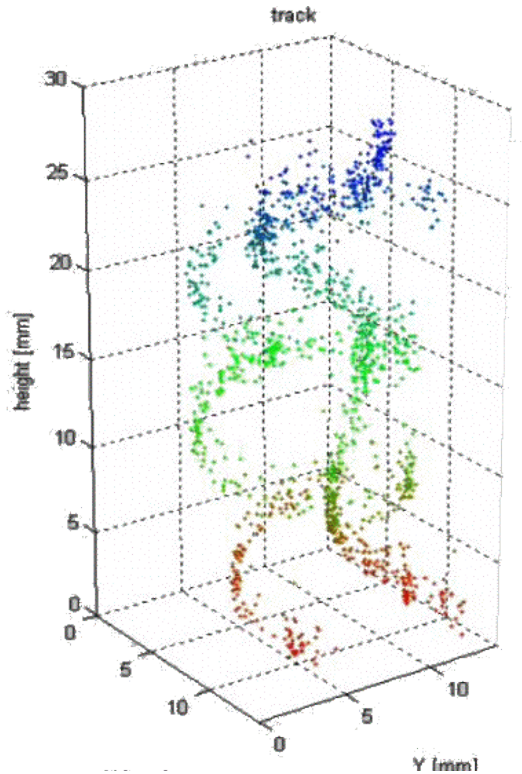




MICROMEGAS OR GEM BUILT OVER A SILICON PIXEL READOUT: MEDIPIX, TIMEPIX



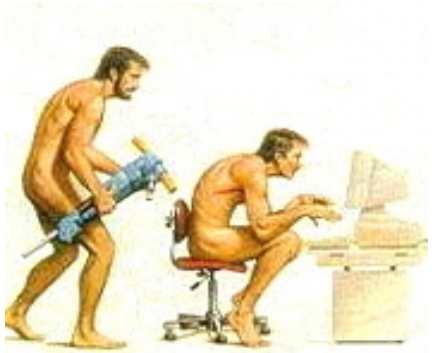
ELECTRON TRACKS FROM ^{90}Sr IN MAGNETIC FIELD (0.2 T):



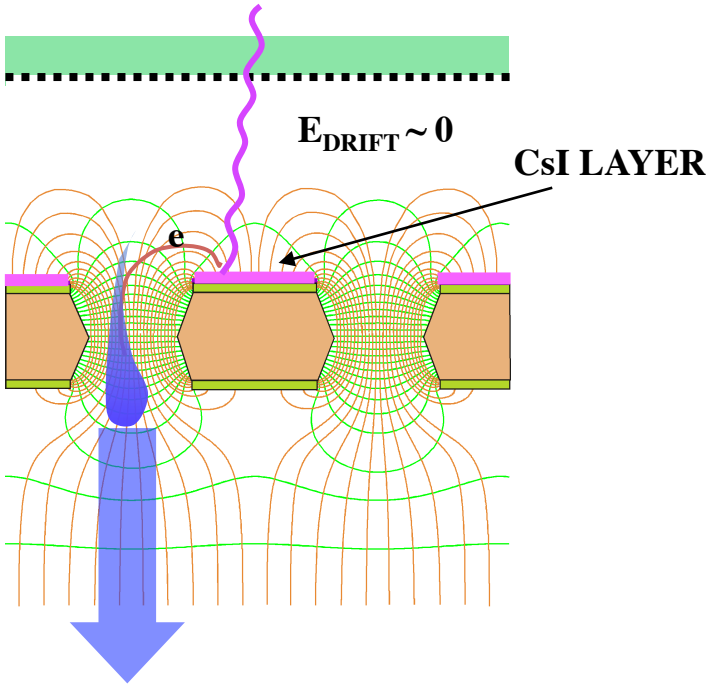
μ-TPC (~ cm^3)
SINGLE ELECTRON DETECTION

H. Van der Graaf, Nucl. Instr. and Meth. A628(2011)27

MPGD APPLICATIONS



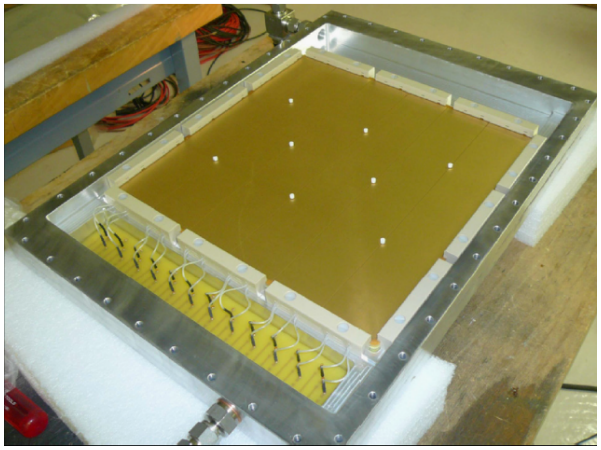
REFLECTIVE CsI PHOTOCATHODE COATING

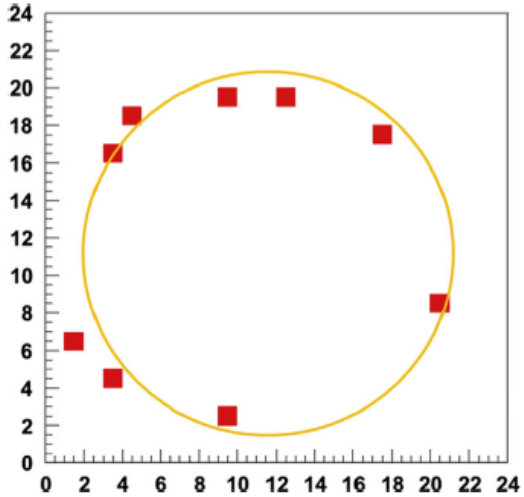


Further amplification

D. Mormann et al, Nucl. Instr. and Meth. A478(2002)230

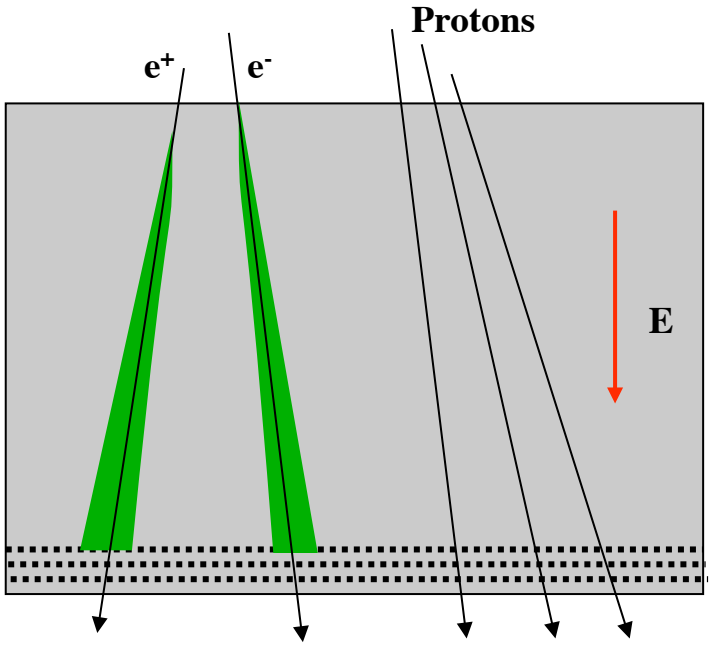
COMPASS RICH UPGRADE
TRIPLE-THICK GEM CsI-COATED 30x30 cm^2





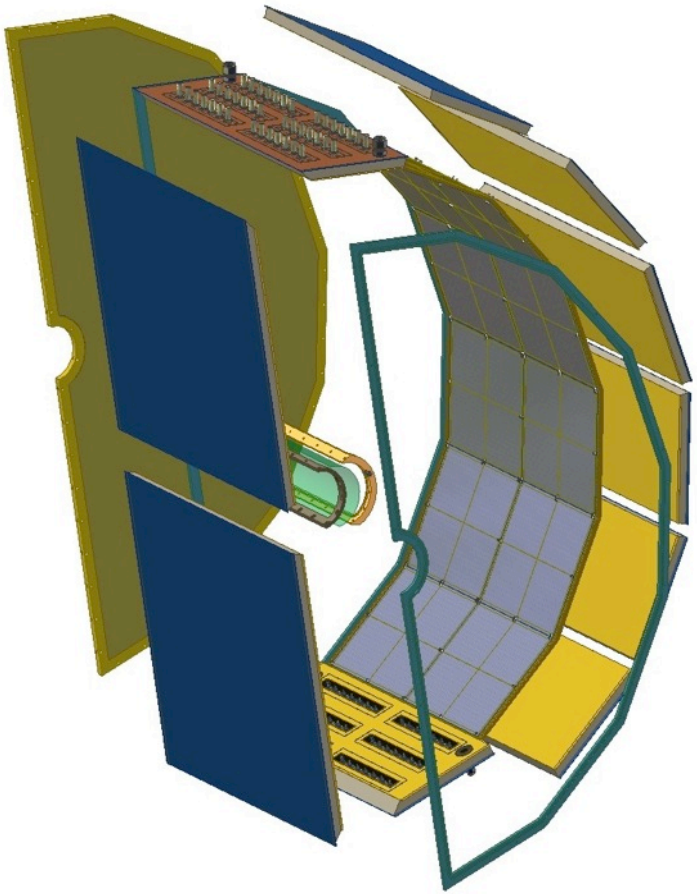
M. Alexeev et al, Nucl. Instr. and Meth. A732(2013)264

INVERTED FIELD TPC:
NO CHARGE COLLECTION
UV PHOTON BLOB EMITTED BY ELECTRONS



C. Aidala et al,
Nucl. Instr. and Methods A502(2003)200

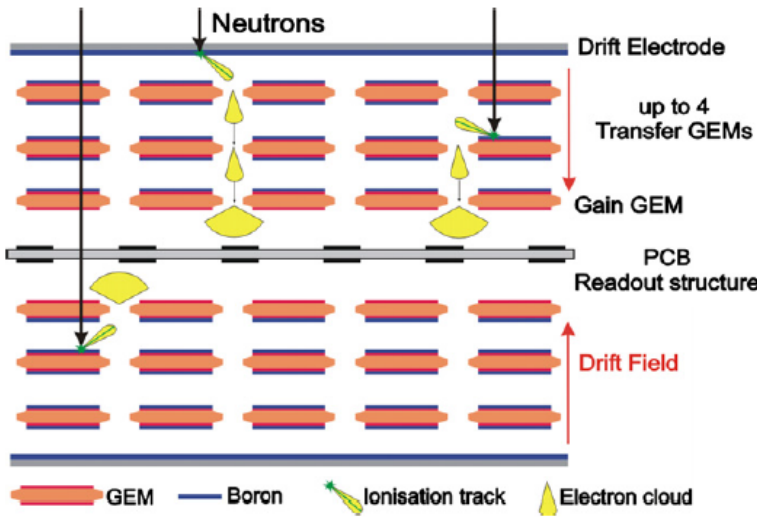
Z. Fraenkel et al,
Nucl. Instr. and Methods A546(2005) 466



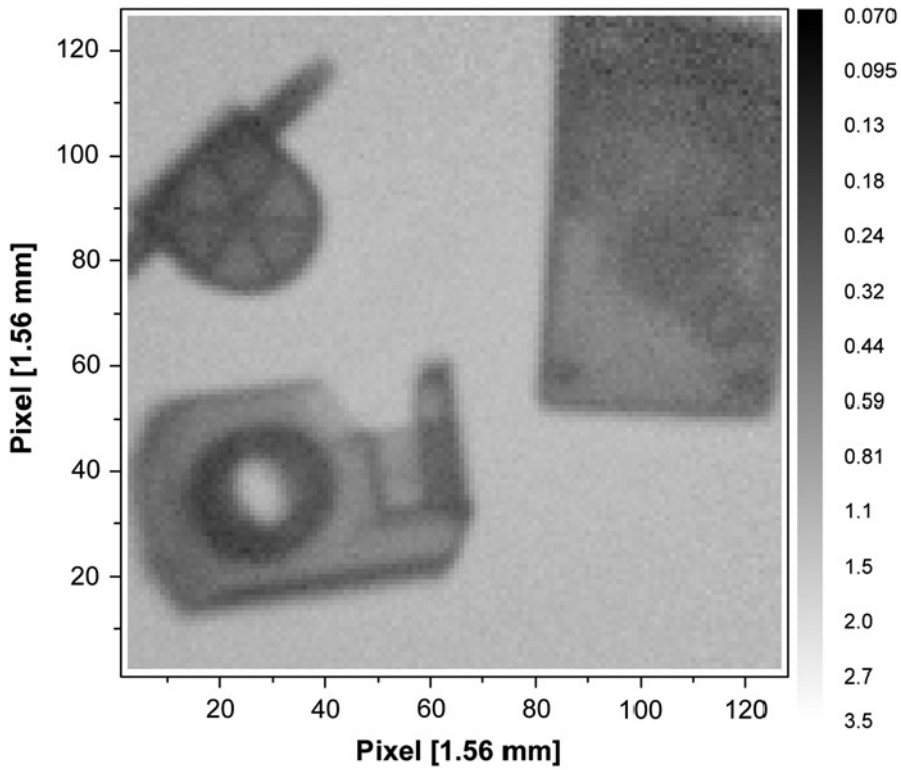
TRIPLE-GEM MODULES 268x221 mm^2
HEXAGONAL PADS READOUT
GAS FILLING: PURE CF_4

CASCADE

^{10}B-COATED GEM ELECTRODES



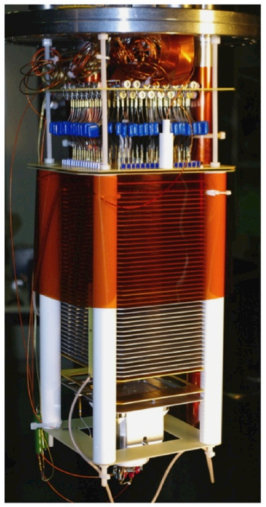
EXAMPLE OF NEUTRON RADIOGRAPHY

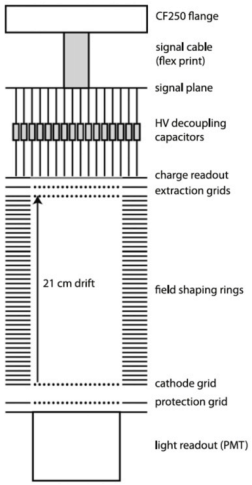


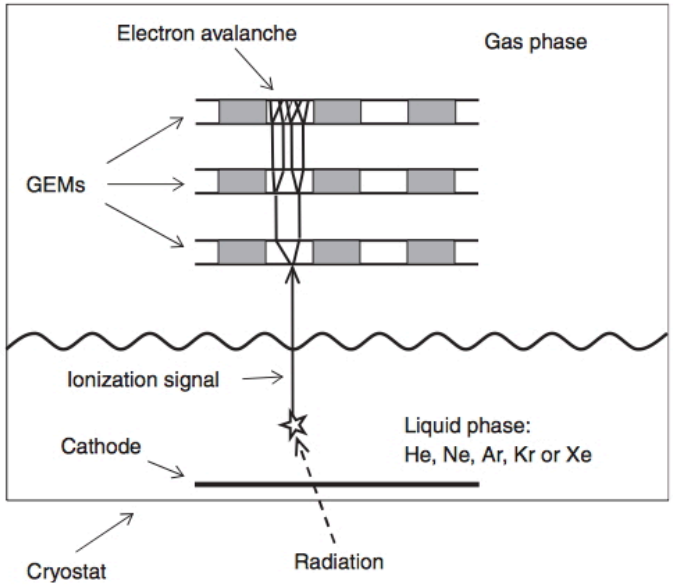
M. Klein and Ch. Schmidt,
Nucl. Instr. and Meth. A628(2011)9

IONIZATION ELECTRONS ARE EXTRACTED FROM THE LIQUID, AMPLIFIED AND DETECTED

LIQUID ARGON TPC LARGE ELECTRON MULTIPLIER (LEM)

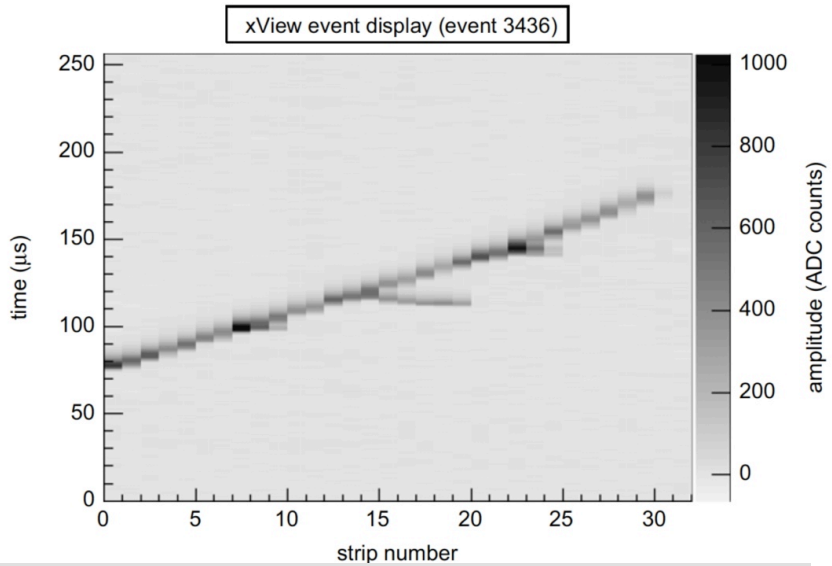






A. Bondar et al,
Nucl. Instr. and Meth. A556(2006)273

MUON TRACK



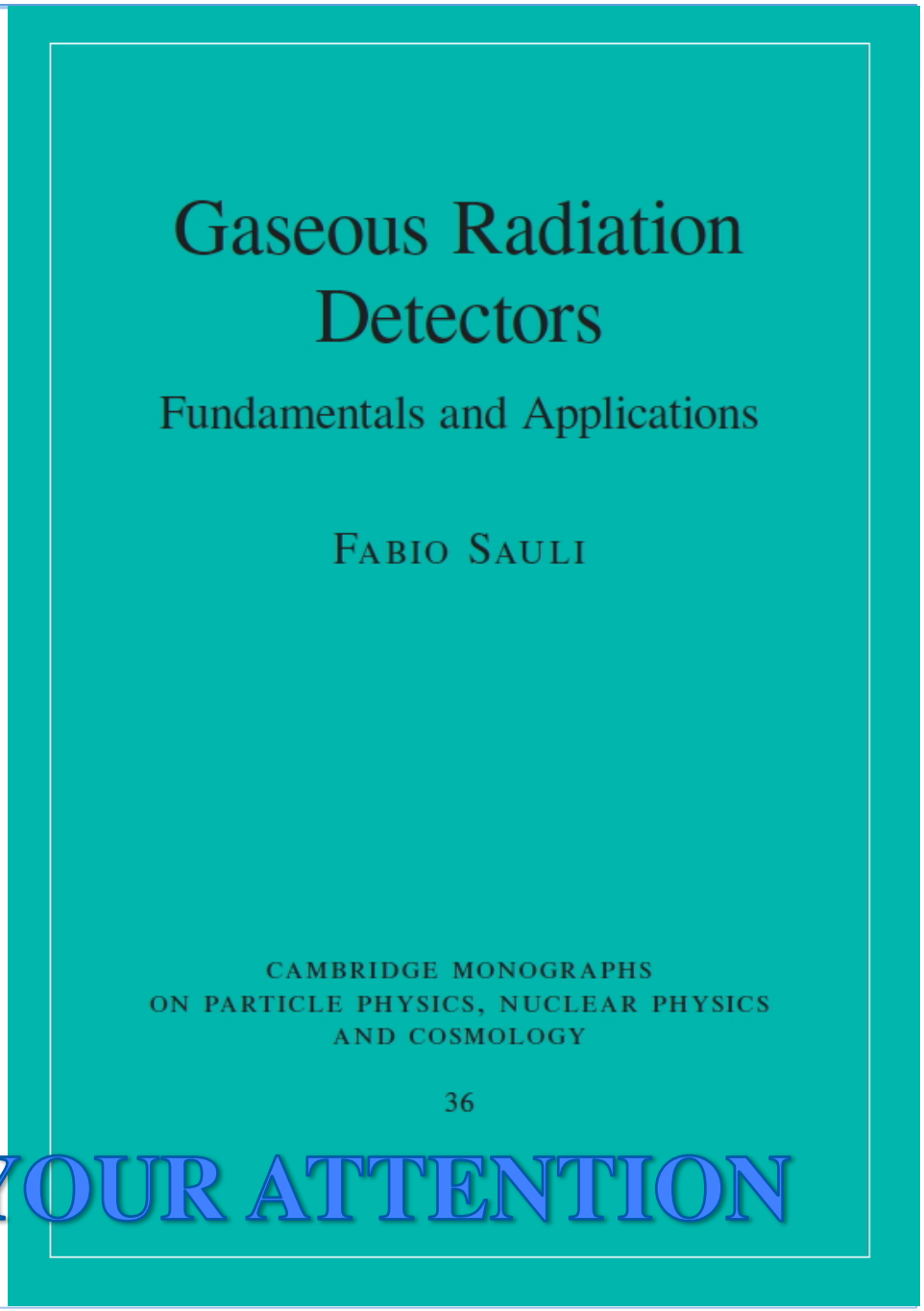
A. Badertscher et al, Nucl. Instr. and Meth. 641(2011)48

GASEOUS DETECTORS: A LONG (IN) SUCCESS STORY….

……. TO BE CONTINUED!

AND IF YOU WANT TO KNOW MORE…

… COMING SOON



THANKS FOR YOUR ATTENTION