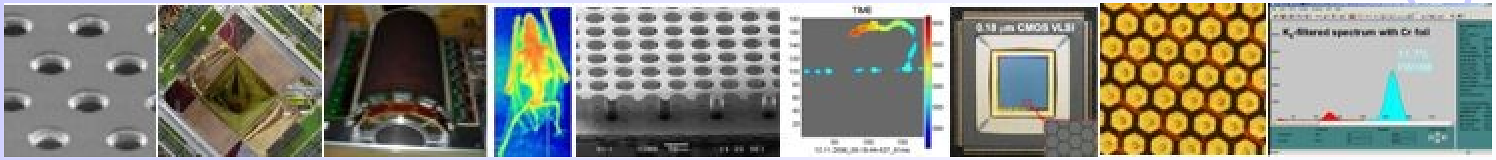
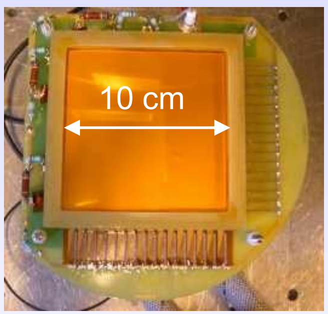
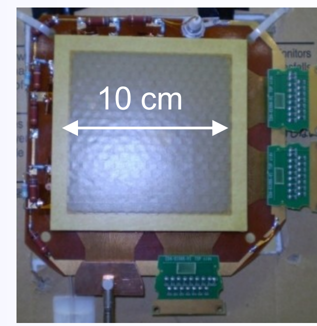


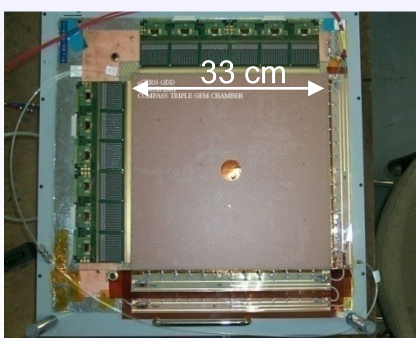
Gaseous Detectors

Introduction

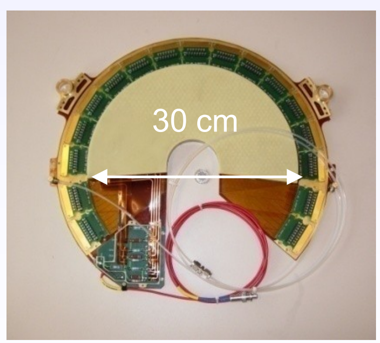


Leszek Ropelewski CERN-PH-DT

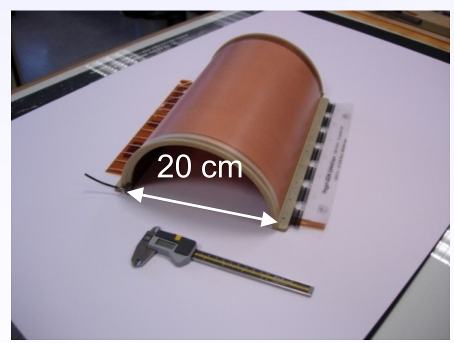




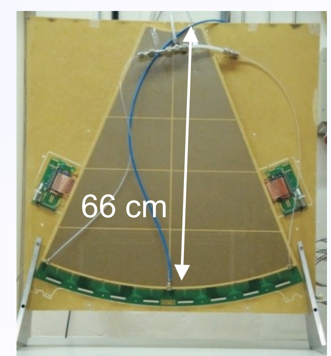
Compass



Totem



NA61

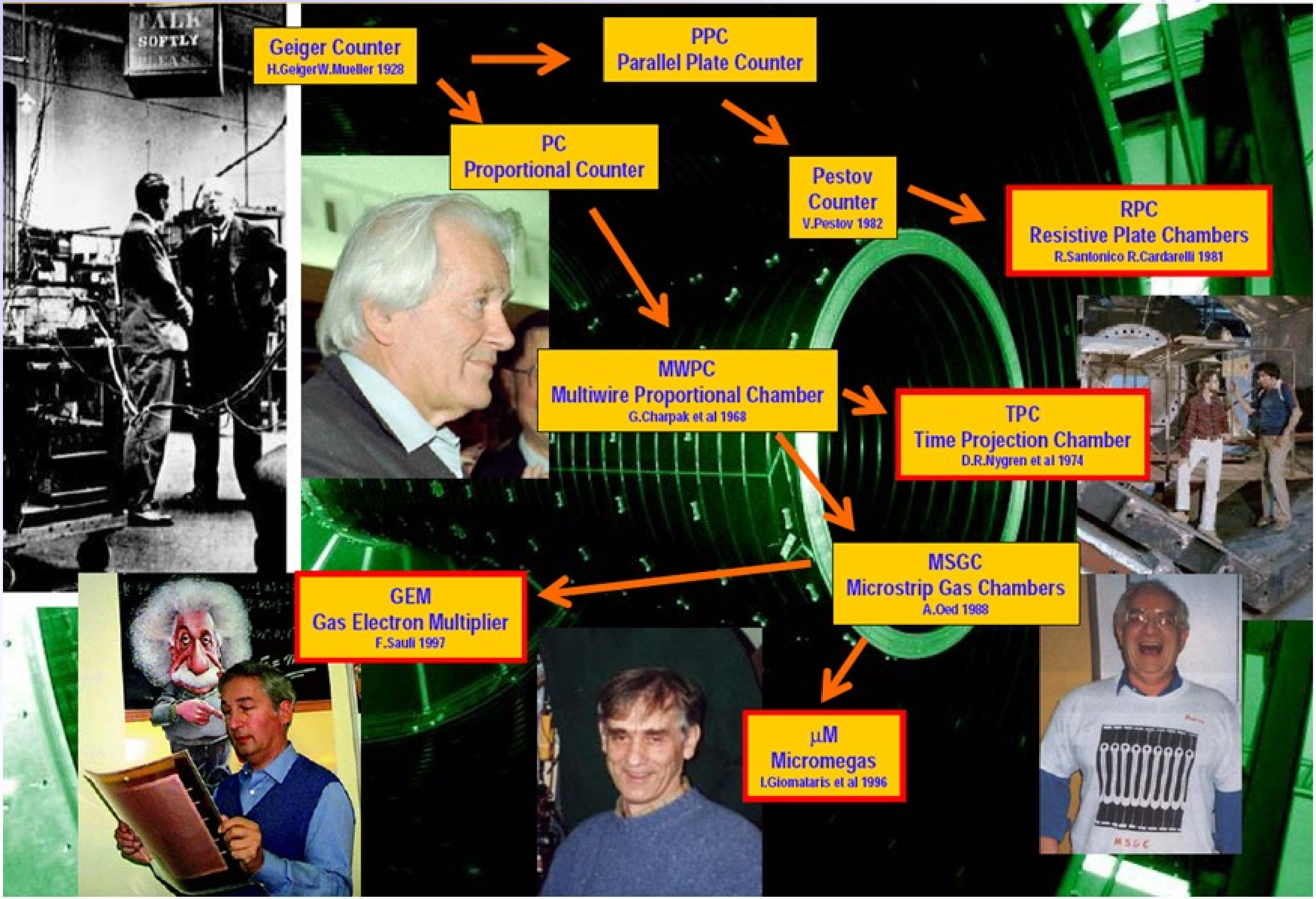


Totem Upgrade

Outline

- **Gaseous Detectors**
  - Ionization of Gases
  - Gas Amplification
  - Single Wire Proportional Chamber
  - Drift Chamber
  - Drift and Diffusion of Charge Carriers in Gases
  - Examples of Detectors (MWPC, CSC, RPC, TPC)
  - New Technologies – Micropattern Detectors (MSGC, Micromegas, GEM)
  - Limitations of Gas Detectors
  - Gas Detectors Simulations
  - Applications
  - Production Aspects

Gas Detectors History



"Classic" Particle Detectors

- **The Geiger-Müller tube (1928 by Hans Geiger and Walther Müller)**
  - **Tube filled with inert gas (He, Ne, Ar) + organic vapour**
  - **Central thin wire (20 – 50 µm ∅) , high voltage (several 100 Volts) between wire and tube**

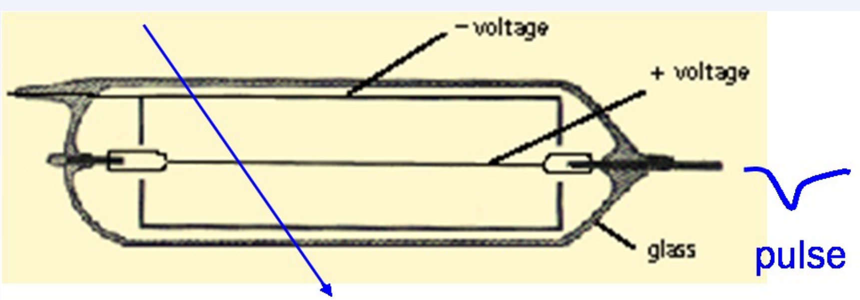
E. Rutherford 1909

H. Geiger 1927

- **Strong increase of E-field close to the wire**
  - electron gains more and more energy
- **above some threshold (>10 kV/cm)**
  - electron energy high enough to ionize other gas molecules
  - newly created electrons also start ionizing
- **avalanche effect: exponential increase of # electrons (and ions)**

measurable signal on wire

- organic substances responsible for "quenching" (stopping) the discharge

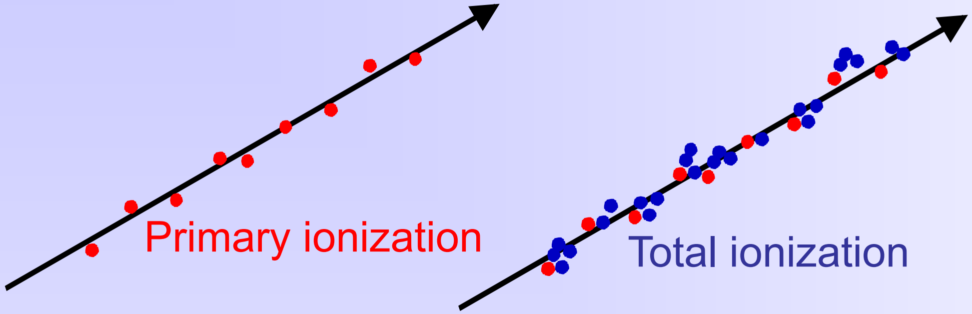


E. Rutherford and H. Geiger, Proc. Royall Soc. A81 (1908) 141

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

First electrical signal from a particle

Ionization of Gases



Lohse and Witzeling, Instrumentation In High Energy Physics, World Scientific,1992

Fast charged particles ionize atoms of gas. Often resulting primary electron will have enough kinetic energy to ionize other atoms.

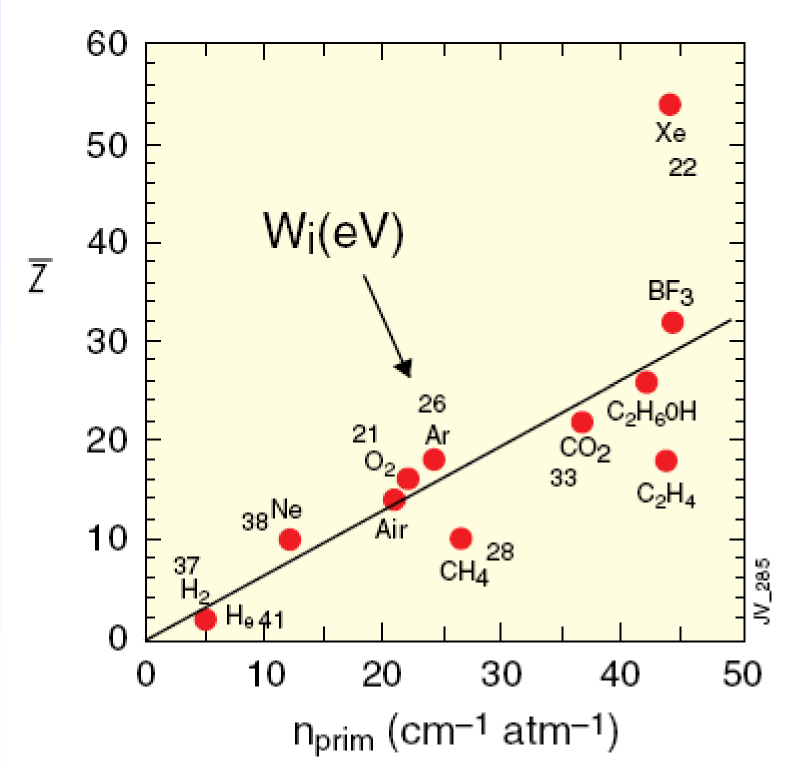
$$n_{total} = \frac{\Delta E}{W_i} = \frac{\frac{dE}{dx}\Delta x}{W_i}$$

$$n_{total} \approx 3 \ldots 4 \cdot n_{primary}$$

n_{total} - number of created electron-ion pairs

ΔE = total energy loss

W_i = effective <energy loss>/pair



Number of primary electron/ion pairs in frequently used gases.

Ionization of Gases

- The actual number of primary electron/ion pairs is Poisson distributed.

$$P(m) = \frac{\bar{n}^m e^{-\bar{n}}}{m!} \qquad \bar{n} = \frac{L}{\lambda} = LN\sigma_i$$

The detection efficiency is therefore limited to :

$$\varepsilon_{\det} = 1 - P(0) = 1 - e^{-\bar{n}}$$

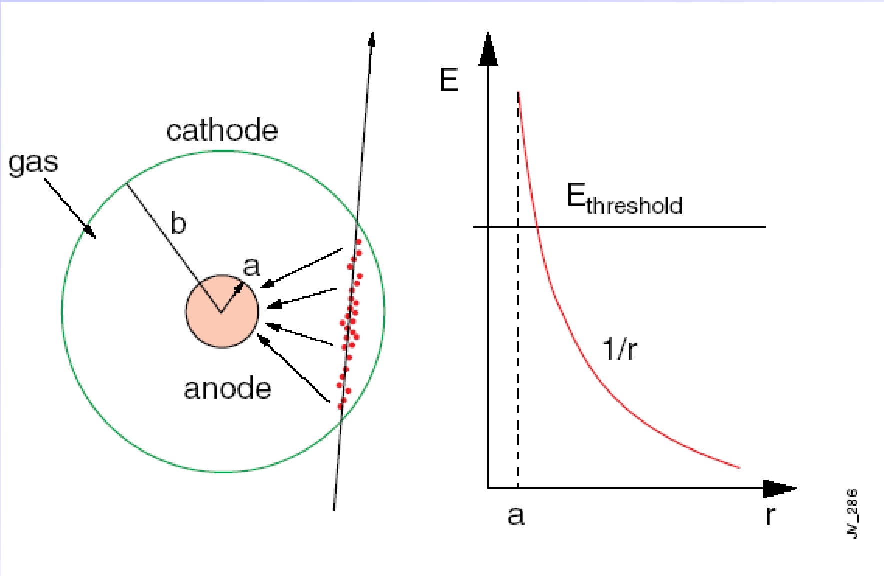
For thin layers ε_{det} can be significantly lower than 1.

For example for 1 mm layer of Ar $n_{primary} = 2.5 \rightarrow \varepsilon_{det} = 0.92$.

- 100 electron/ion pairs created during ionization process is not easy to detect.

  Typical noise of the amplifier ≈ 1000 e^- (ENC) → gas amplification .

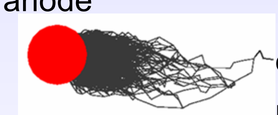
Single Wire Proportional Chamber



Electrons liberated by ionization drift towards the anode wire.

Electrical field close to the wire (typical wire Ø ~few tens of μm) is sufficiently high for electrons (above 10 kV/cm) to gain enough energy to ionize further → avalanche – exponential increase of number of electron ion pairs.

anode



e^-

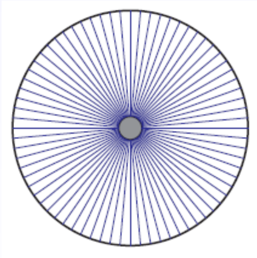
primary electron

$$E(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \frac{1}{r}$$

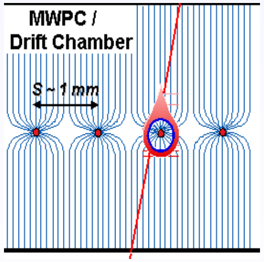
$$V(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \ln\frac{r}{a}$$

C – capacitance/unit length

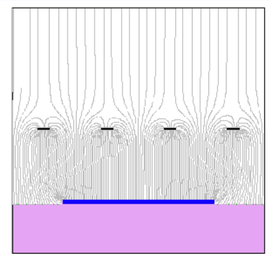
Cylindrical geometry is not the only one able to generate strong electric field:



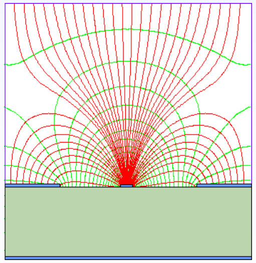
wire



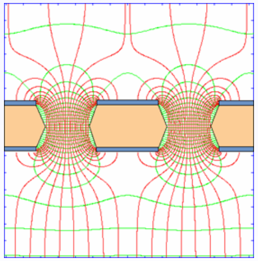
mwpc



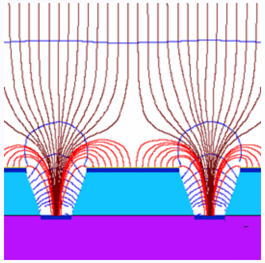
parallel plate



strip



hole



groove/well

Single Wire Proportional Chamber

Multiplication of ionization is described by the first Townsend coefficient $\alpha(E)$

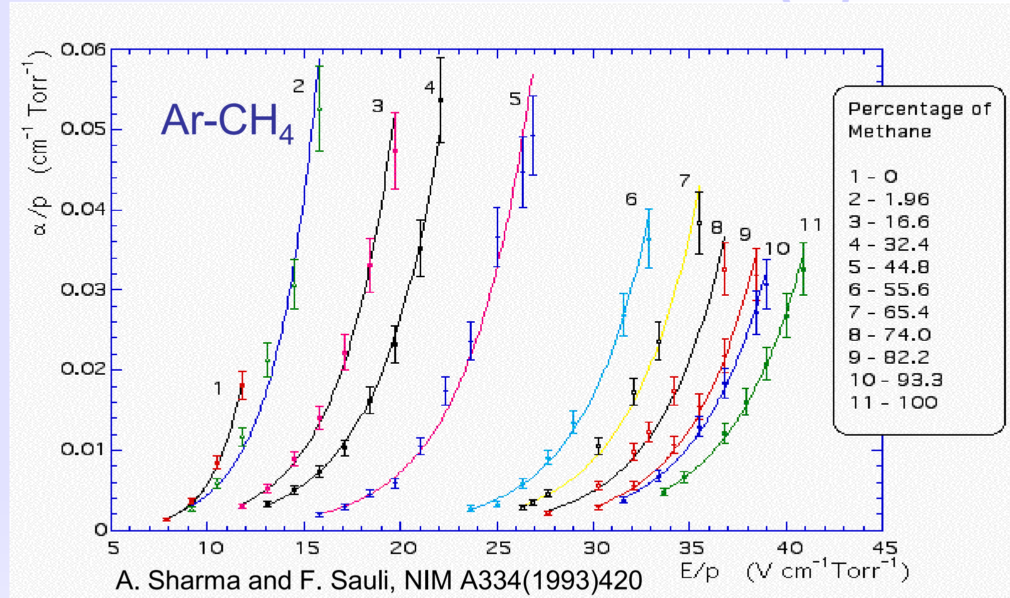
$$dn = n\alpha dx \qquad \alpha = \frac{1}{\lambda} \qquad \lambda \text{ – mean free path}$$

$$n = n_0 e^{\alpha(E)x} \quad \text{or} \quad n = n_0 e^{\alpha(r)x}$$

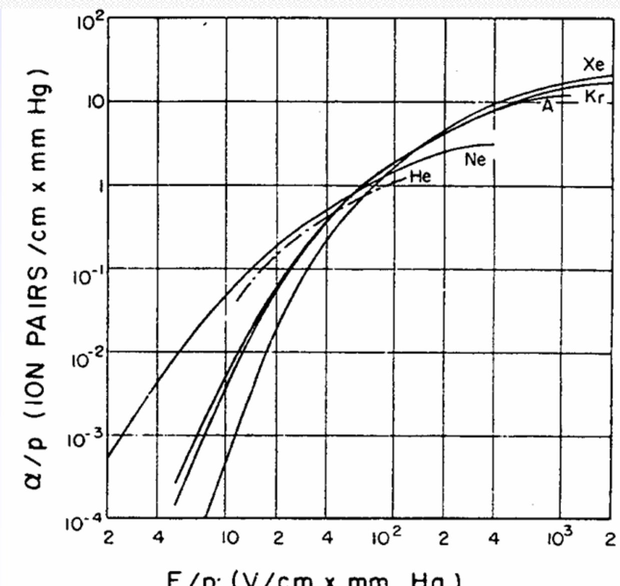
$\alpha(E)$ is determined by the excitation and ionization cross sections of the electrons in the gas.

It depends also on various and complex energy transfer mechanisms between gas molecules.

There is no fundamental expression for $\alpha(E)$ $\rightarrow$ it has to be measured for every gas mixture.



A. Sharma and F. Sauli, NIM A334(1993)420



S.C. Brown, Basic data of plasma physics (MIT Press, 1959)

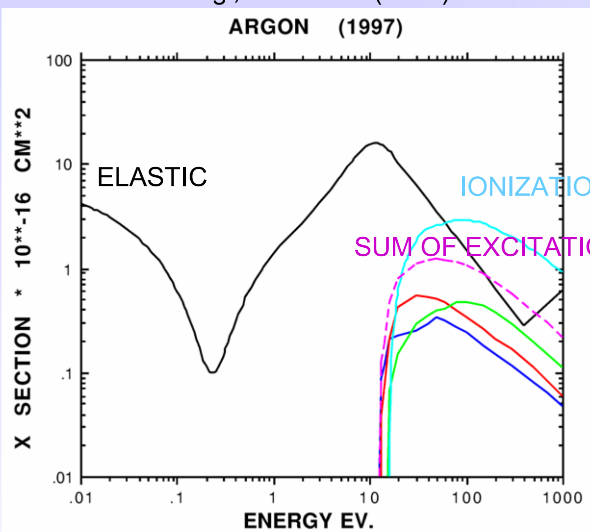
$$M = \frac{n}{n_0} = \exp\left[\int_a^{r_C} \alpha(r)dr\right]$$

Amplification factor or Gain

SWPC – Choice of Gas

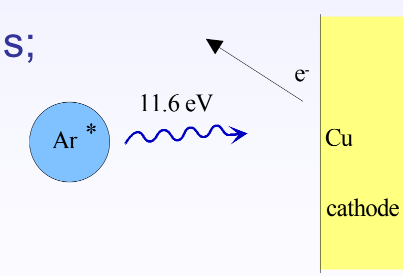
In the avalanche process molecules of the gas can be brought to excited states.

S. Biagi, NIM A421 (1999) 234



De-excitation of noble gases only via emission of photons; e.g. 11.6 eV for Ar.

This is above ionization threshold of metals; e.g. Cu 7.7 eV.



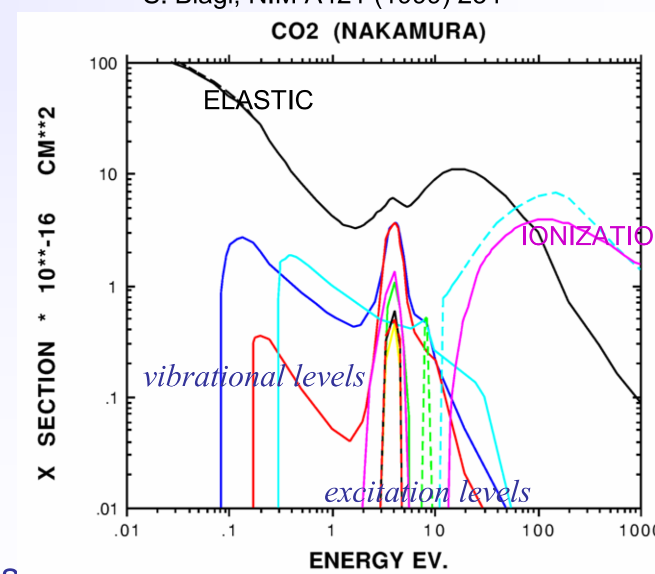
new avalanches → permanent discharges

Solution: addition of polyatomic gas as a quencher

Absorption of photons in a large energy range (many vibrational and rotational energy levels).

Energy dissipation by collisions or dissociation into smaller molecules.

S. Biagi, NIM A421 (1999) 234



SWPC – Operation Modes

High Voltage

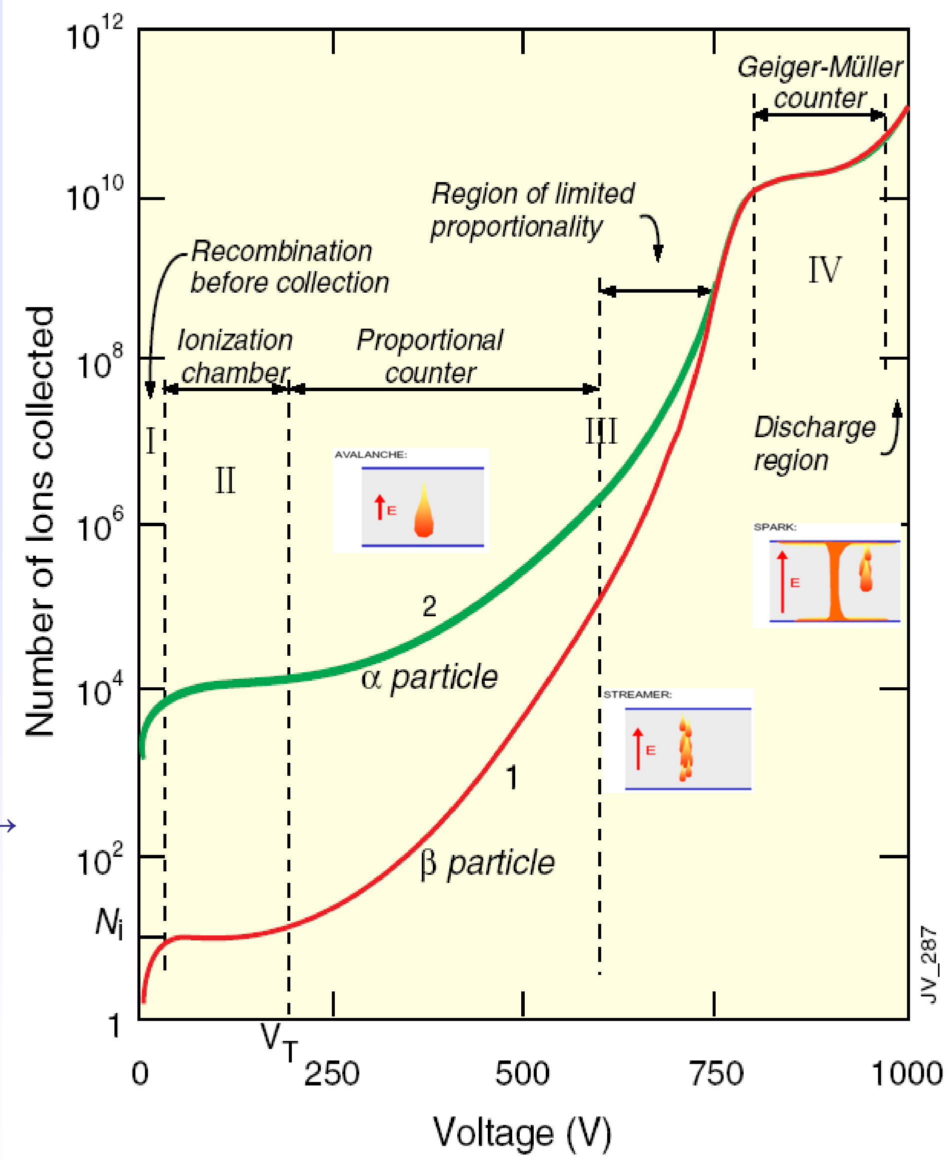
I. no collection – ions recombine before collection

II. ionization mode – full charge collection, but no charge multiplication; gain ~ 1

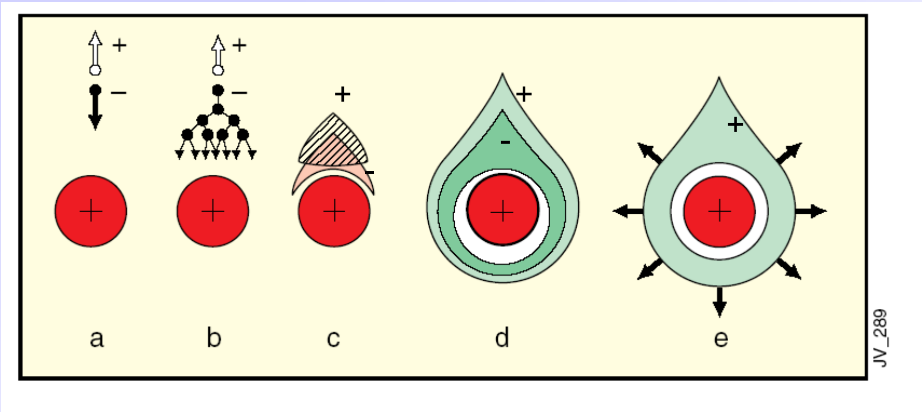
III. proportional mode – multiplication of ionization starts; detected signal proportional to original ionization → possible energy measurement (dE/dx); secondary avalanches have to be quenched; gain ~ $10^4 – 10^5$

limited proportional mode (saturated, streamer) –strong photoemission; secondary avalanches merging with original avalanche; requires strong quenchers or pulsed HV; large signals → simple electronics; gain ~ 10^{10}

IV. Geiger mode – massive photoemission; full length of the anode wire affected; discharge stopped by HV cut; strong quenchers needed as well



SWPC – Signal Formation

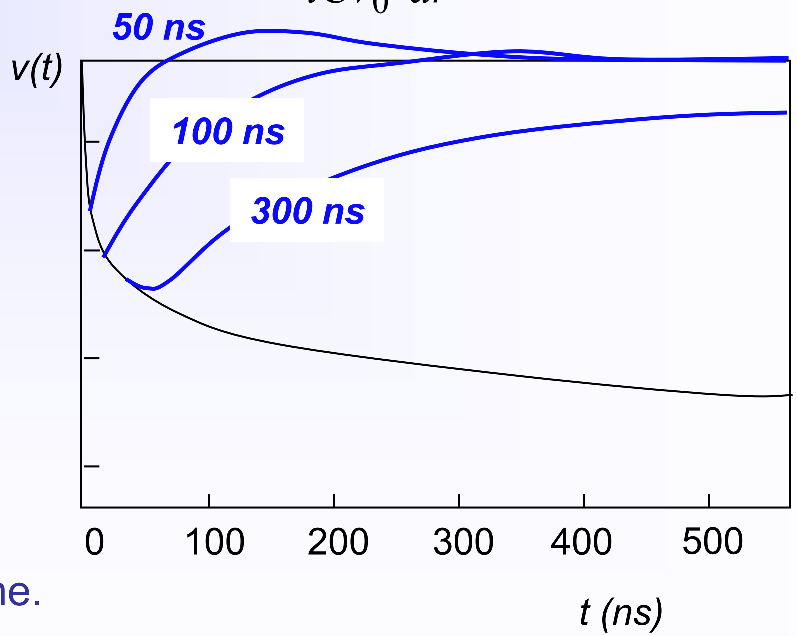


Avalanche formation within a few wire radii and within t < 1 ns.
Signal induction both on anode and cathode due to moving charges (both electrons and ions).

$$dv = \frac{Q}{lCV_0}\frac{dV}{dr}dr$$

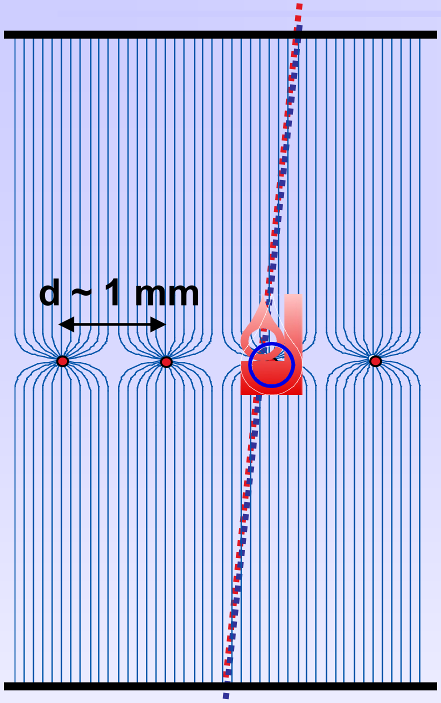
Electrons collected by the anode wire i.e. dr is very small (few μm). Electrons contribute only very little to detected signal (few %).

Ions have to drift back to cathode i.e. dr is large (few mm). Signal duration limited by total ion drift time.



Need electronic signal differentiation to limit dead time.

Multiwire Proportional Chamber

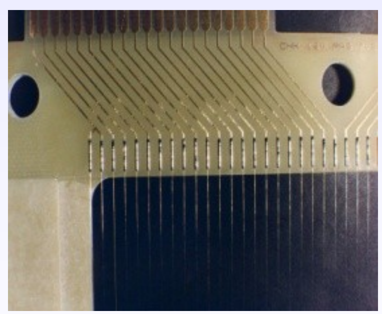


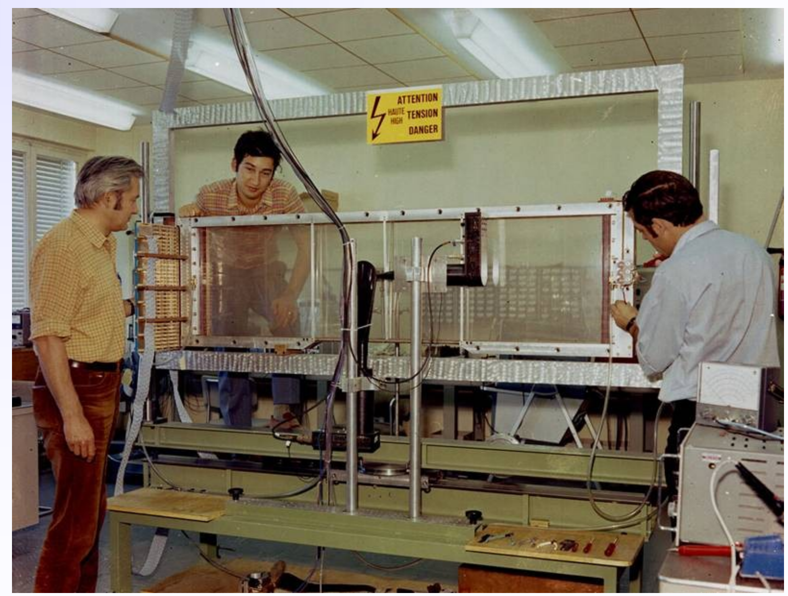
- Simple idea to multiply SWPC cell : Nobel Prize 1992
- First electronic device allowing high statistics experiments !!

Georges Charpak

Typical geometry

5mm, 1mm, 20 μm





G. Charpak, F. Sauli and J.C. Santiard

Normally digital readout :

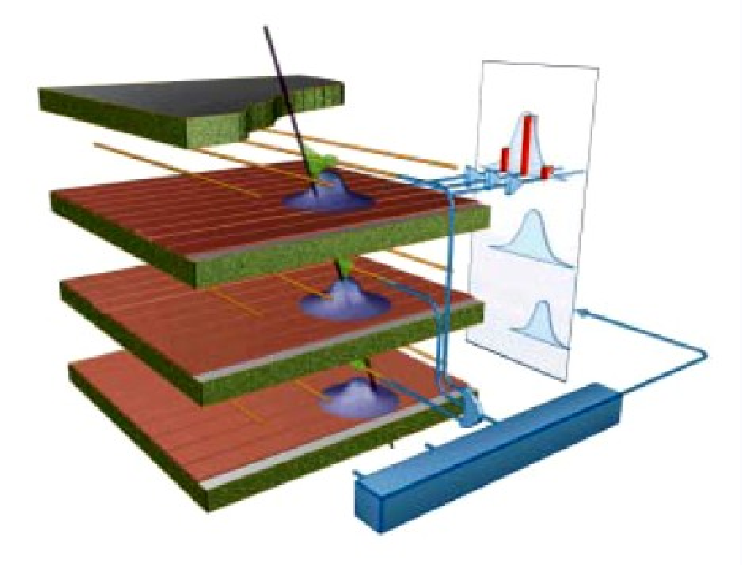
spatial resolution limited to

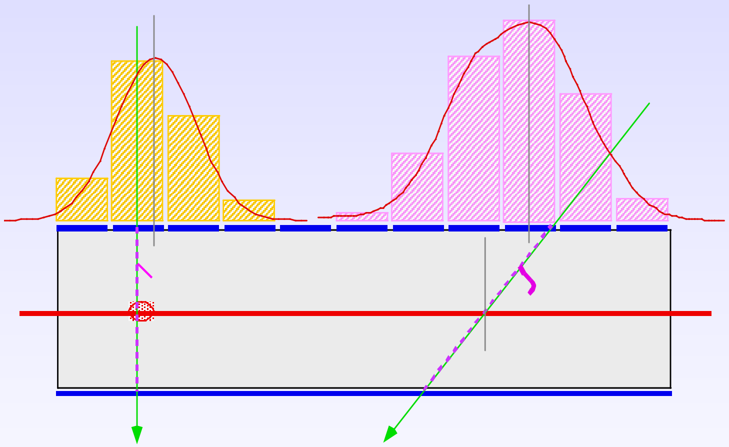
$$\sigma_x \approx \frac{d}{\sqrt{12}}$$

for d = 1 mm σ_x = 300 μm

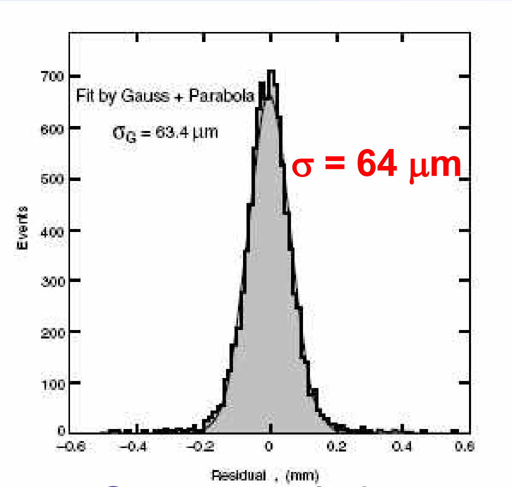
CSC – Cathode Strip Chamber

Precise measurement of the second coordinate by interpolation of the signal induced on pads.
Closely spaced wires makes CSC fast detector.

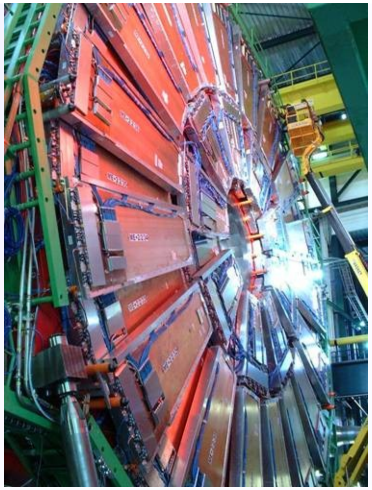




Center of gravity of induced signal method.

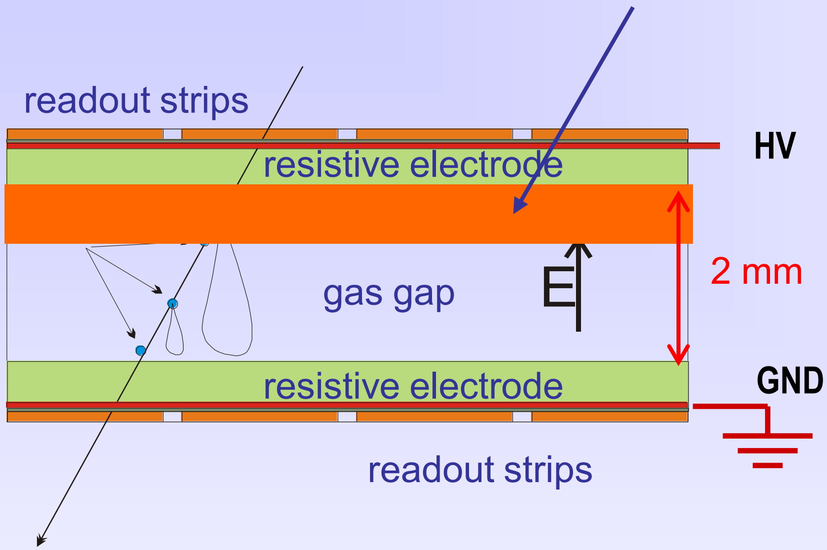


Space resolution



CMS

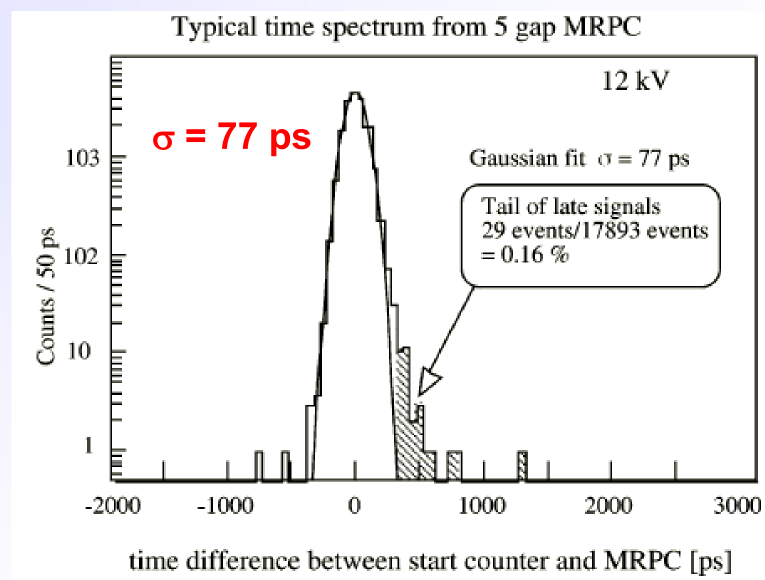
RPC – Resistive Plate Chamber



Rate capability strong function of the resistivity of electrodes in streamer mode.

MRPC

A. Akindinov et al., NIM A456(2000)16

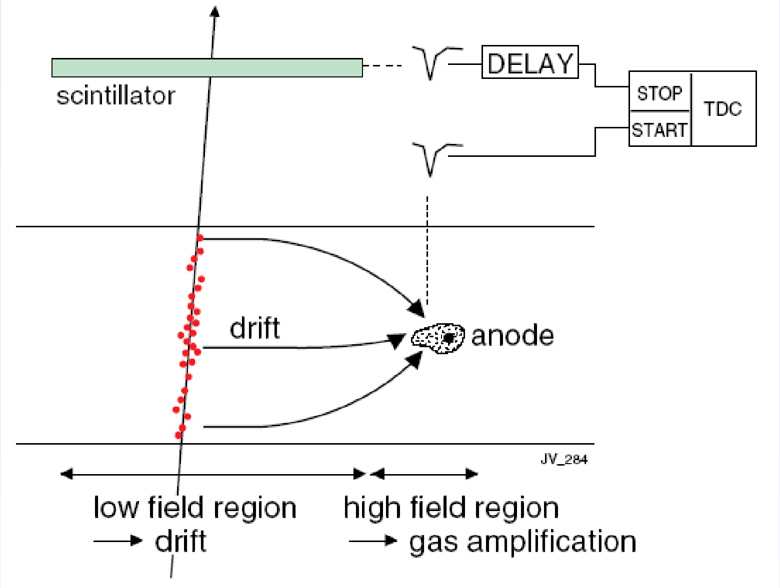


Multigap RPC - exceptional time resolution suited for the trigger applications

Time resolution

Drift Chambers

Spatial information obtained by measuring time of drift of electrons



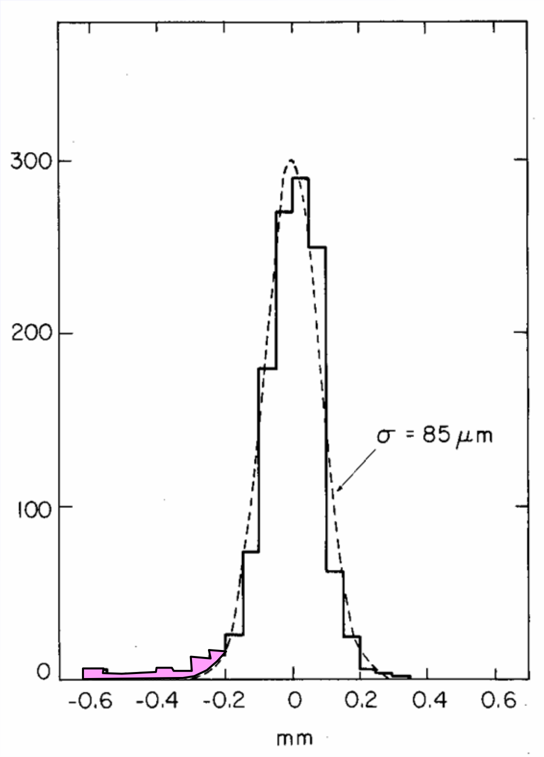
Measure arrival time of electrons at sense wire relative to a time t_0.

Need a trigger (bunch crossing or scintillator).

Drift velocity independent from E.

$$s = \int_{t_{start}}^{t_{stop}} v_D dt$$

F. Sauli, NIM 156(1978)147

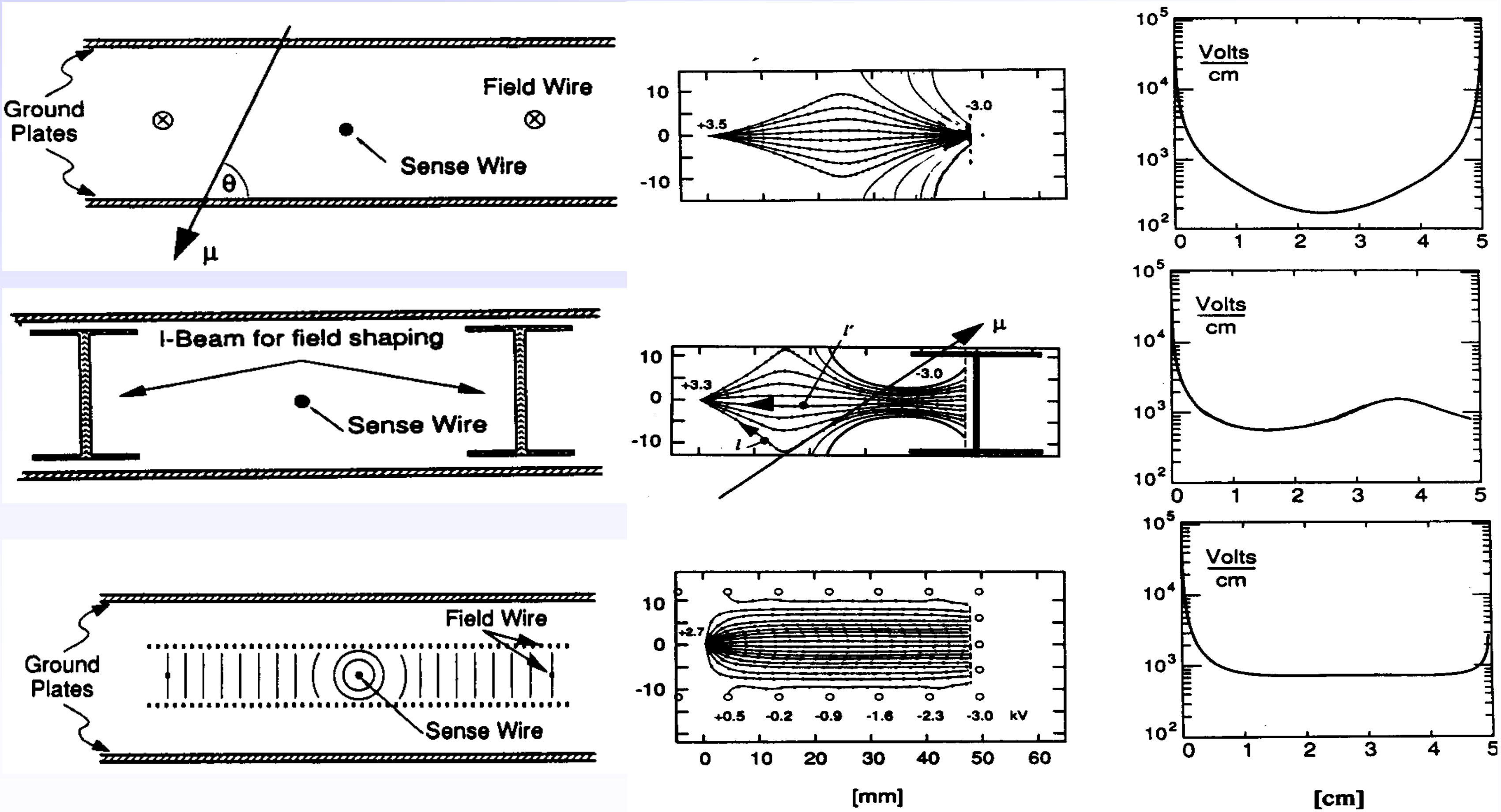


Advantages: smaller number of electronics channels.

Resolution determined by diffusion, primary ionization statistics, path fluctuations and electronics.

Planar drift chamber designs

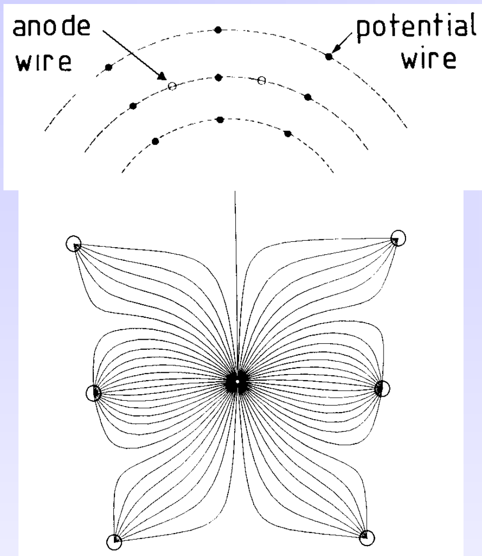
Essential: linear space-time relation; constant E-field; little dpendence of v_D on E.

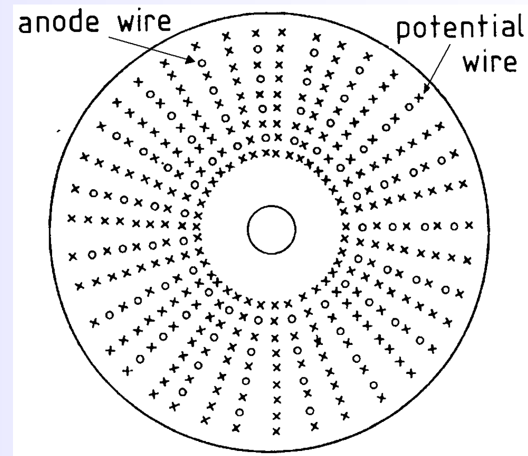


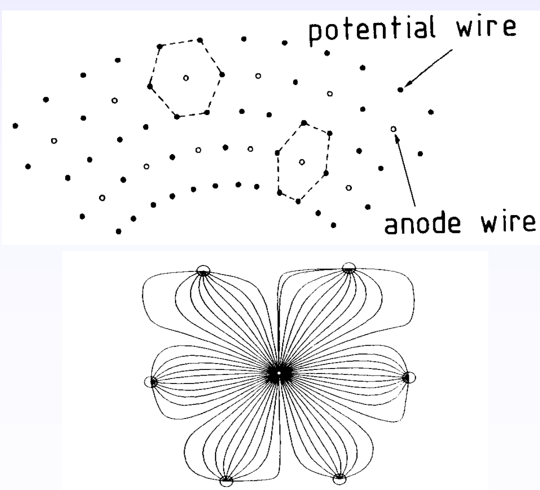
U. Becker in Instrumentation in High Energy Physics, World Scientific

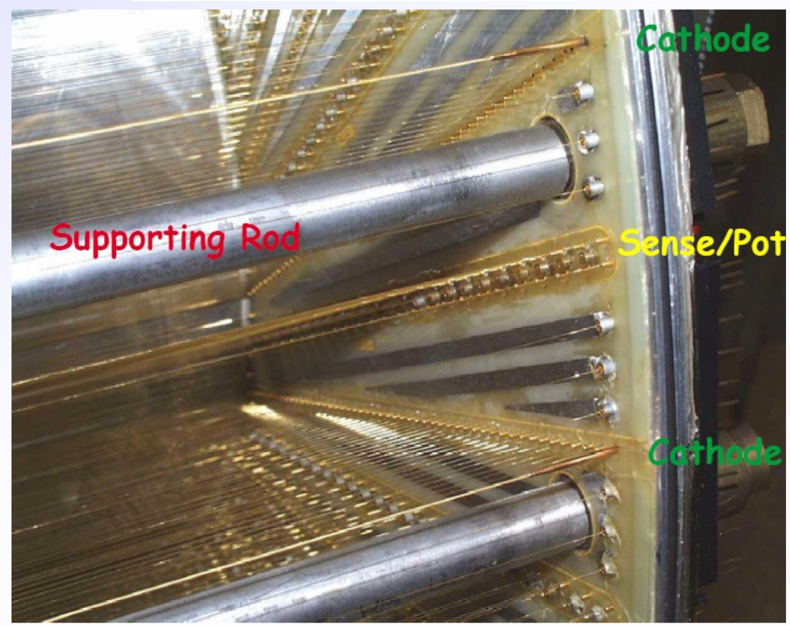
Drift Chambers

Various geometries of cylindrical drift chambers









Diffusion of Free Charges

F. Sauli, IEEE Short Course on Radiation Detection and Measurement, Norfolk (Virginia) November 10-11, 2002

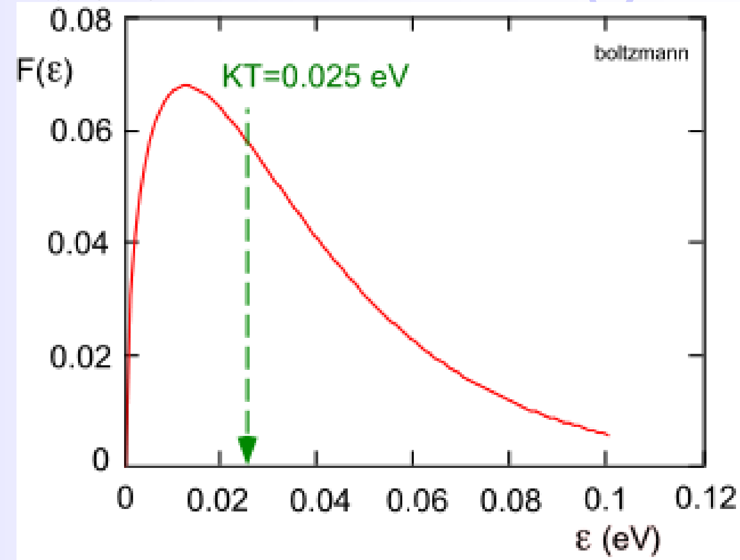
Free ionization charges lose energy in collisions with gas atoms and molecules (thermalization).

Maxwell - Boltzmann energy distribution:

$$F(\varepsilon) = const\sqrt{\varepsilon}e^{-\frac{\varepsilon}{kT}}$$

Average (thermal) energy:

$$\varepsilon_T = \frac{3}{2}kT \approx 0.040eV$$



Diffusion equation:

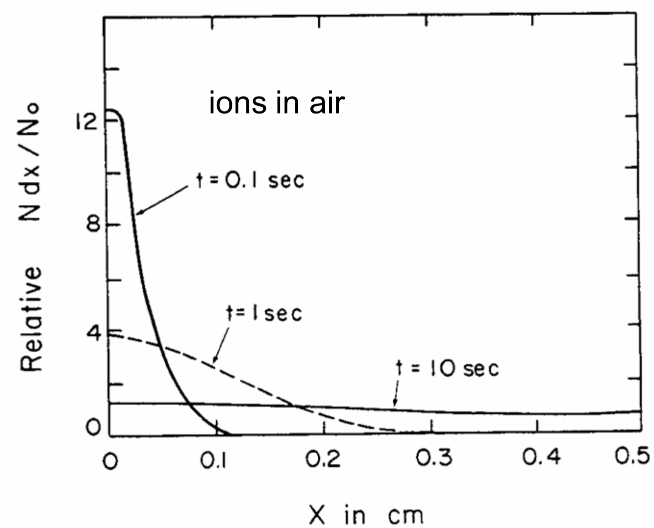
Fraction of free charges at distance x after time t.

$$\frac{dN}{N} = \frac{1}{\sqrt{4\pi Dt}}e^{-\frac{x^2}{4Dt}}dt$$

D: diffusion coefficient

RMS of linear diffusion:

$$\sigma_x = \sqrt{2Dt}$$

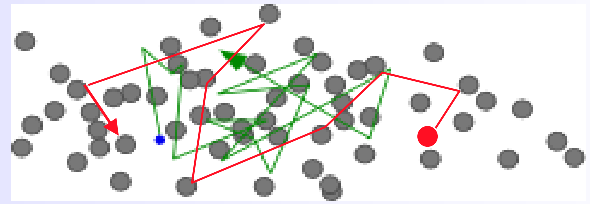


L.B. Loeb, Basic processes of gaseous electronics Univ. of California Press, Berkeley, 1961

Drift and Diffusion in Presence of E field

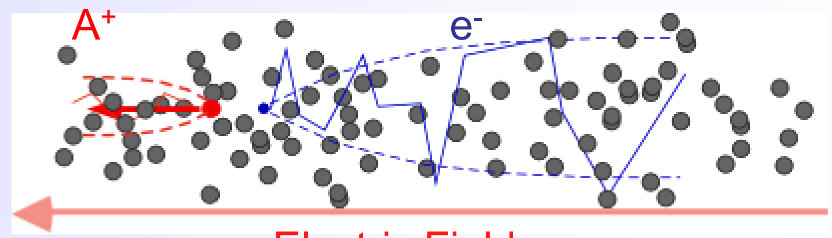
E=0 thermal diffusion

$$\langle v \rangle_t = 0$$



E>0 charge transport and diffusion

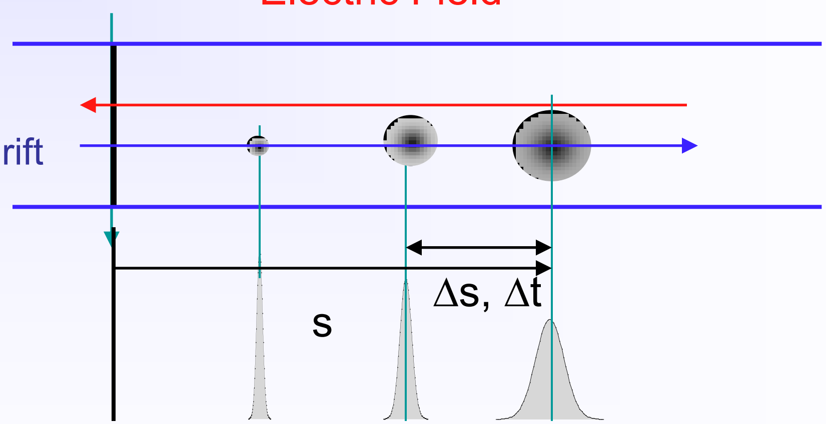
$$\langle v \rangle_t = v_D$$



Electron swarm drift

Drift velocity

Diffusion



$$v_D = \frac{\Delta s}{\Delta t}$$

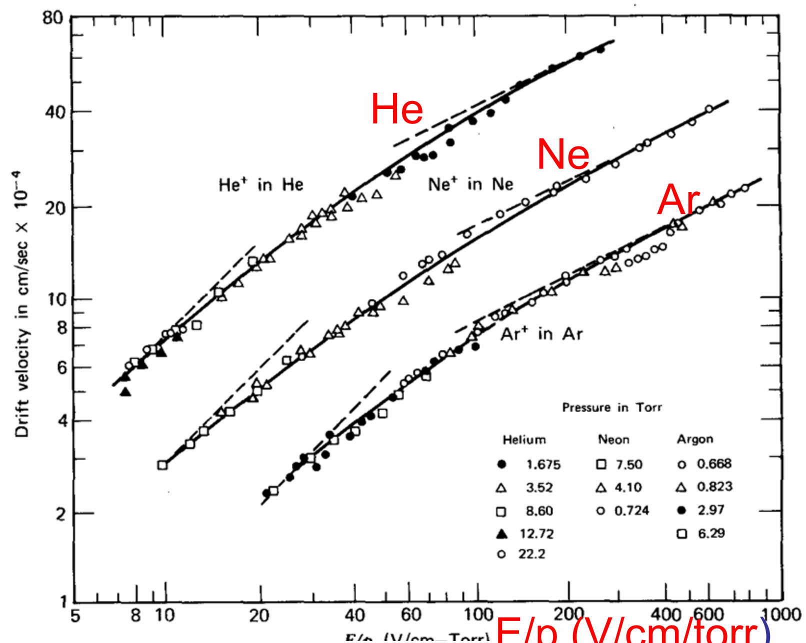
$$\sigma_x = \sqrt{2Dt} = \sqrt{2D\frac{s}{v_D}}$$

Drift and Diffusion of Ions in Presence of E Field

Drift velocity of ions

is almost linear function of E $v_D^{ion} = \mu^{ion} E$

Mobility: $\mu^{ion} = \dfrac{e\tau}{m}$ is constant for given gas at fixed P and T, direct consequence of the fact that average energy of ion is unchanged up to very high E fields.



E. McDaniel and E. Mason
The mobility and diffusion of ions in gases, Wiley 1973

Diffusion of ions

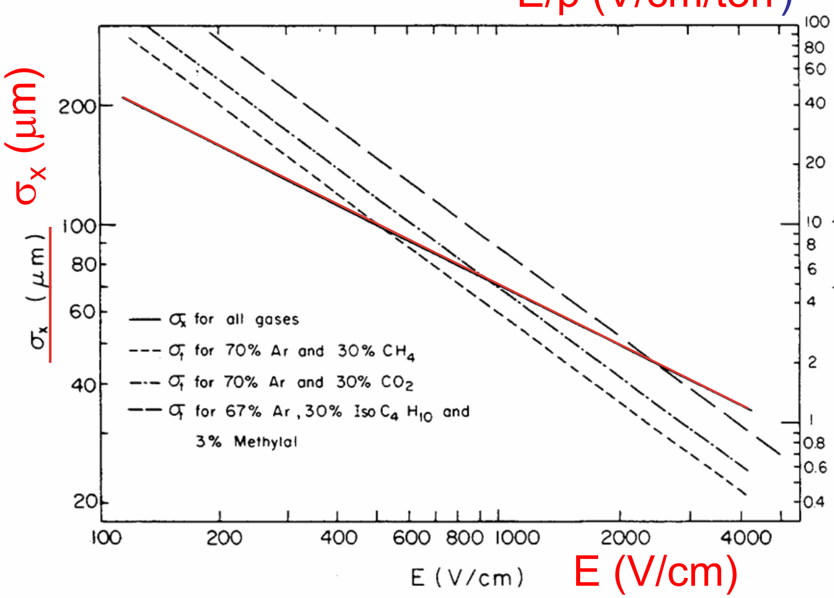
from microscopic picture can be shown:

$$\varepsilon = \frac{3}{2}\frac{De}{\mu}$$

$$\frac{D}{\mu^{ion}} = \frac{kT}{e} \quad \rightarrow \quad \sigma_x^{ion} = \sqrt{\frac{2kT}{e}\frac{x}{E}}$$

thermal limit

the same for all gases !!



Simplified Electron Transport Theory

$$v_D = \mu E = \frac{eE}{m}\tau$$ Townsend expression; acceleration in the field times time between collisions

$$\frac{x}{v_D \tau}\lambda(\varepsilon)\varepsilon_E = eEx$$ balance between energy acquired from the field and collision losses

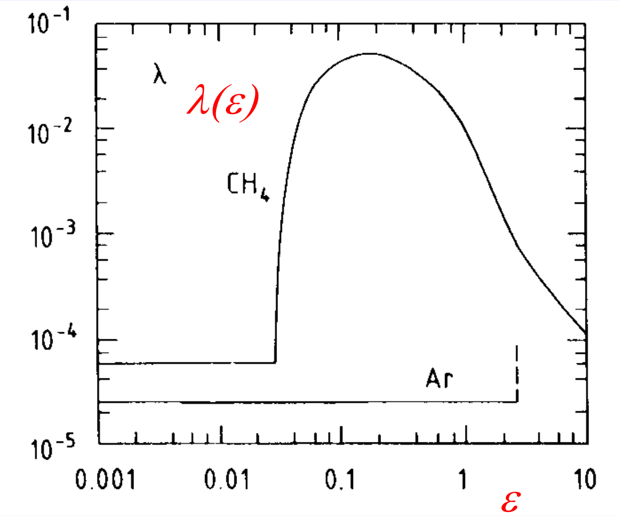
$\frac{x}{v_D \tau}$ number of collisions; $\lambda(\varepsilon)$ fractional energy loss per collision

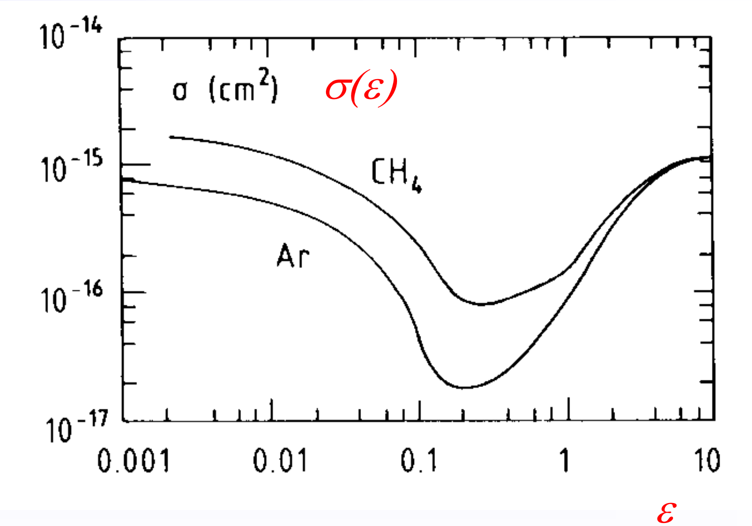
ε_E part of equilibrium energy not containing thermal motion

$$\tau = \frac{1}{N\sigma(\varepsilon)v}$$ time between collisions; v instantaneous velocity

$$\varepsilon_E + \frac{3}{2}kT$$ total energy

$$v_D^2 = \frac{eE}{mN\sigma(\varepsilon)}\sqrt{\frac{\lambda(\varepsilon)}{2}}$$

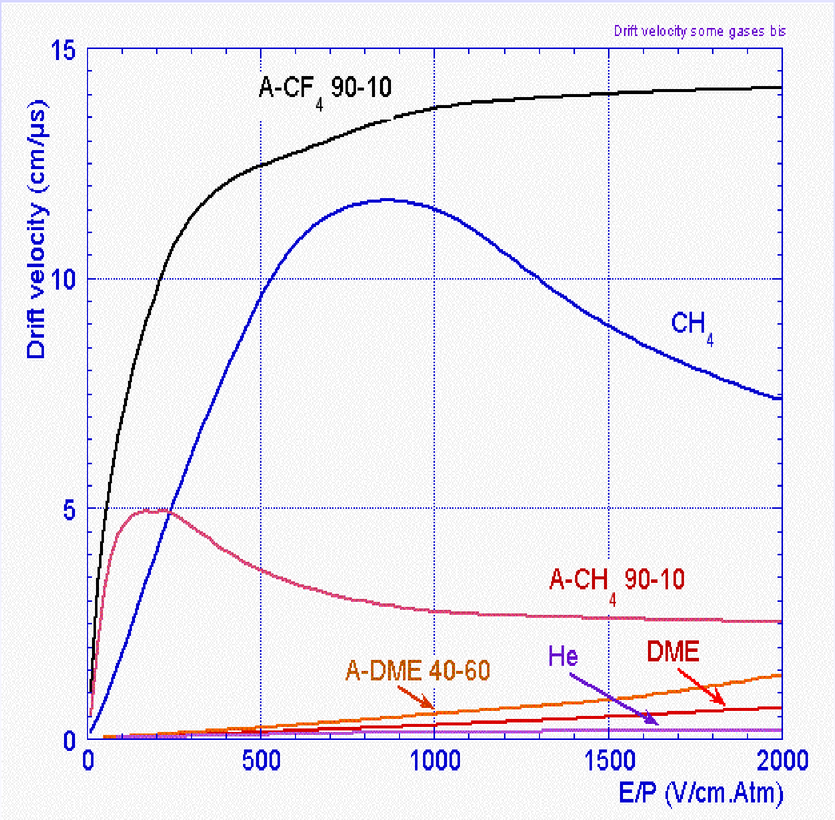


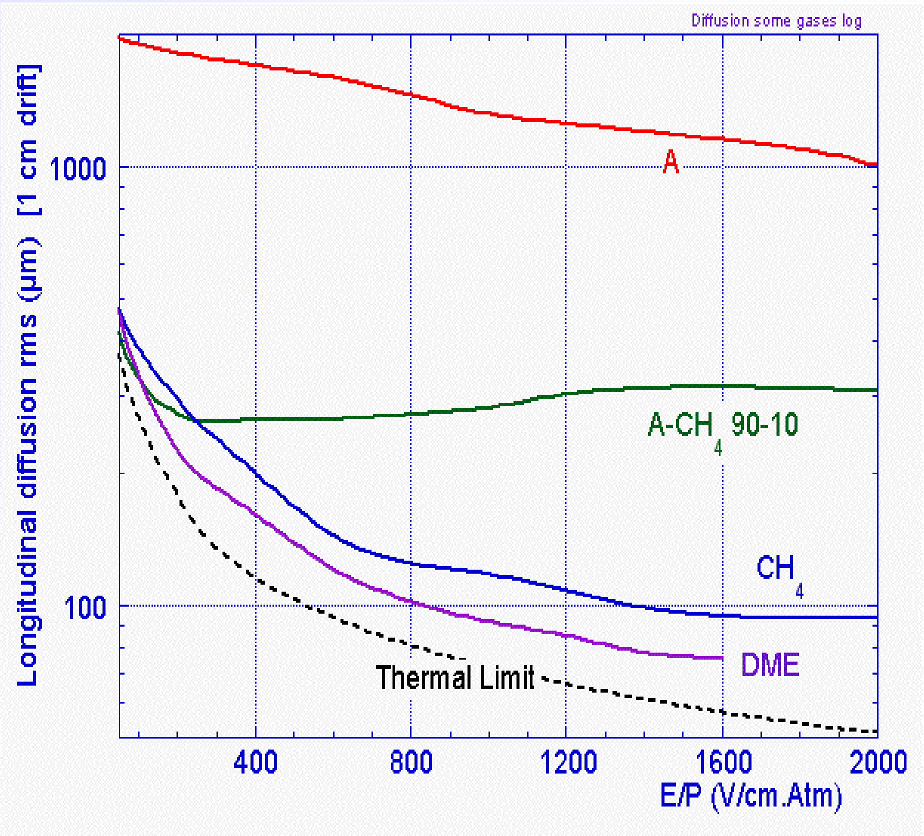


B. Schmidt, thesis, unpublished, 1986

Drift and Diffusion of Electrons in Gases

Large range of drift velocity and diffusion:

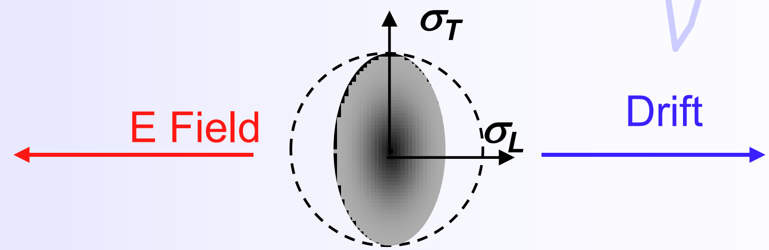


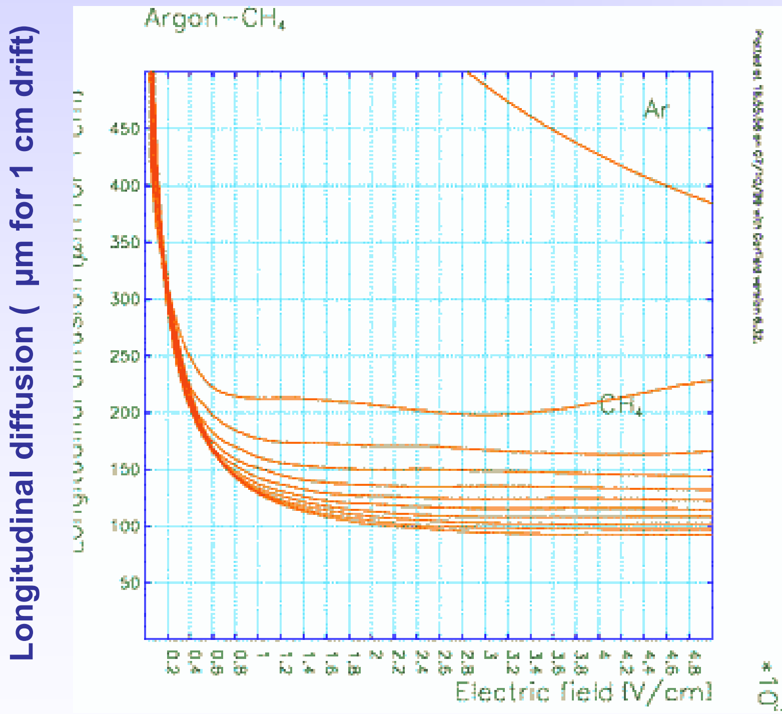


F. Sauli, IEEE Short Course on Radiation Detection and Measurement, Norfolk (Virginia) November 10-11, 2002

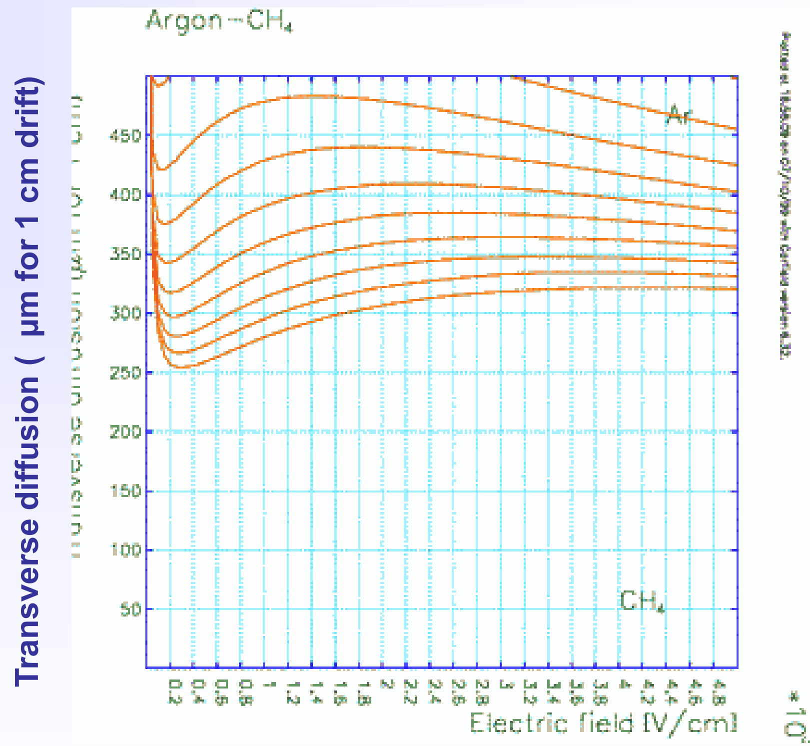
Diffusion Electric Anisotropy

Influence of gas mixture composition on two diffusion coefficients





E (V/cm)



E(V/cm)

S. Biagi http://consult.cern.ch/writeup/magboltz/

Drift in Presence of E and B Fields

Equation of motion of free charge carriers in presence of E and B fields:

$$m\frac{d\vec{v}}{dt} = e\vec{E} + e(\vec{v}\times\vec{B}) + \vec{Q}(t)$$ where $\vec{Q}(t)$ stochastic force resulting from collisions

Time averaged solutions with assumptions: $\vec{v}_D = \langle \vec{v} \rangle = const.$; $<\vec{Q}(t)> = \frac{m}{\tau}\vec{v}_D$ friction force

$$\left\langle \frac{d\vec{v}}{dt} \right\rangle = 0 = e\vec{E} + e(\vec{v}_D \times \vec{B}) - \frac{m}{\tau}\vec{v}_D$$

τ mean time between collisions

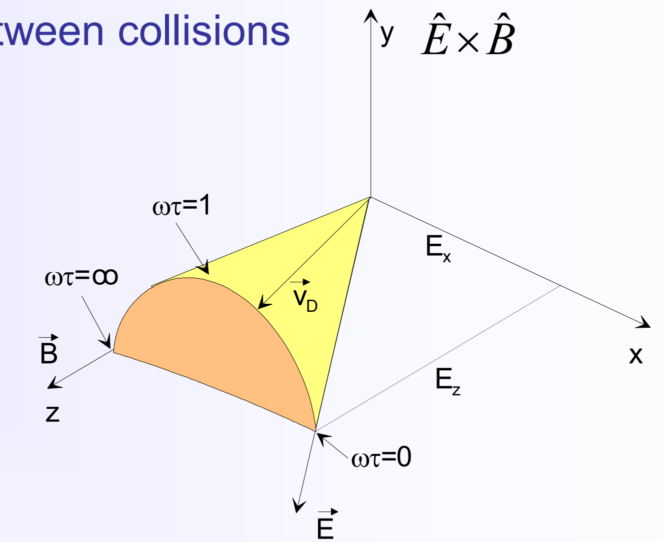
$$\vec{v}_D = \frac{\mu|\vec{E}|}{1+\omega^2\tau^2}\left[\hat{E} + \omega\tau(\hat{E}\times\hat{B}) + \omega^2\tau^2(\hat{E}\cdot\hat{B})\hat{B}\right]$$

$\mu = \frac{e\tau}{m}$ mobility $\omega = \frac{eB}{m}$ cyclotron frequency

$B=0 \rightarrow \vec{v}_D^B = \vec{v}_D^0 = \mu\vec{E}$

$\vec{E} \parallel \vec{B} \rightarrow v_D^B = v_D^0$

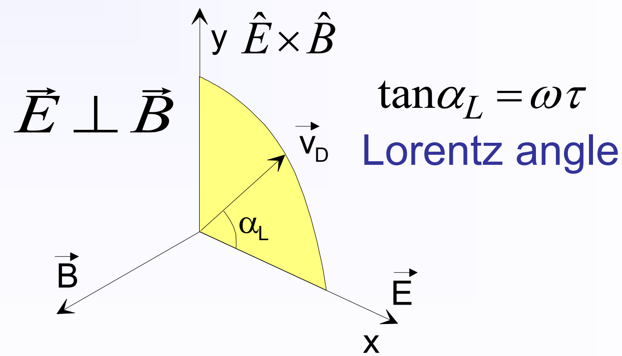
$\vec{E} \perp \vec{B} \rightarrow v_D^B = \frac{E}{B}\frac{\omega\tau}{\sqrt{1+\omega^2\tau^2}}$



In general drift velocity has 3 components: $\parallel \vec{E}; \parallel \vec{B}; \parallel \vec{E}\times\vec{B}$

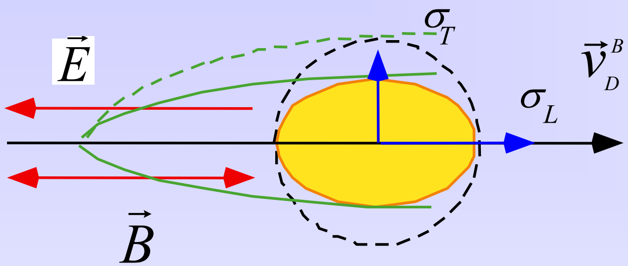
$\omega\tau << 1$ particles follow E-field

$\omega\tau >> 1$ particles follow B-field



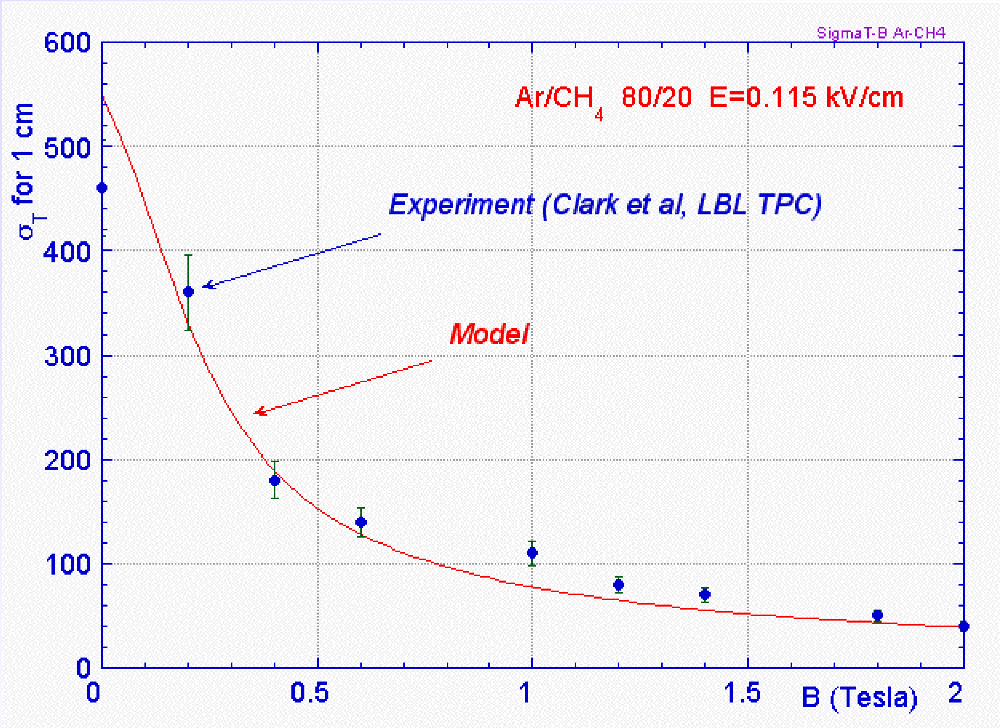
Diffusion Magnetic Anisotropy

$\vec{E} \parallel \vec{B}$



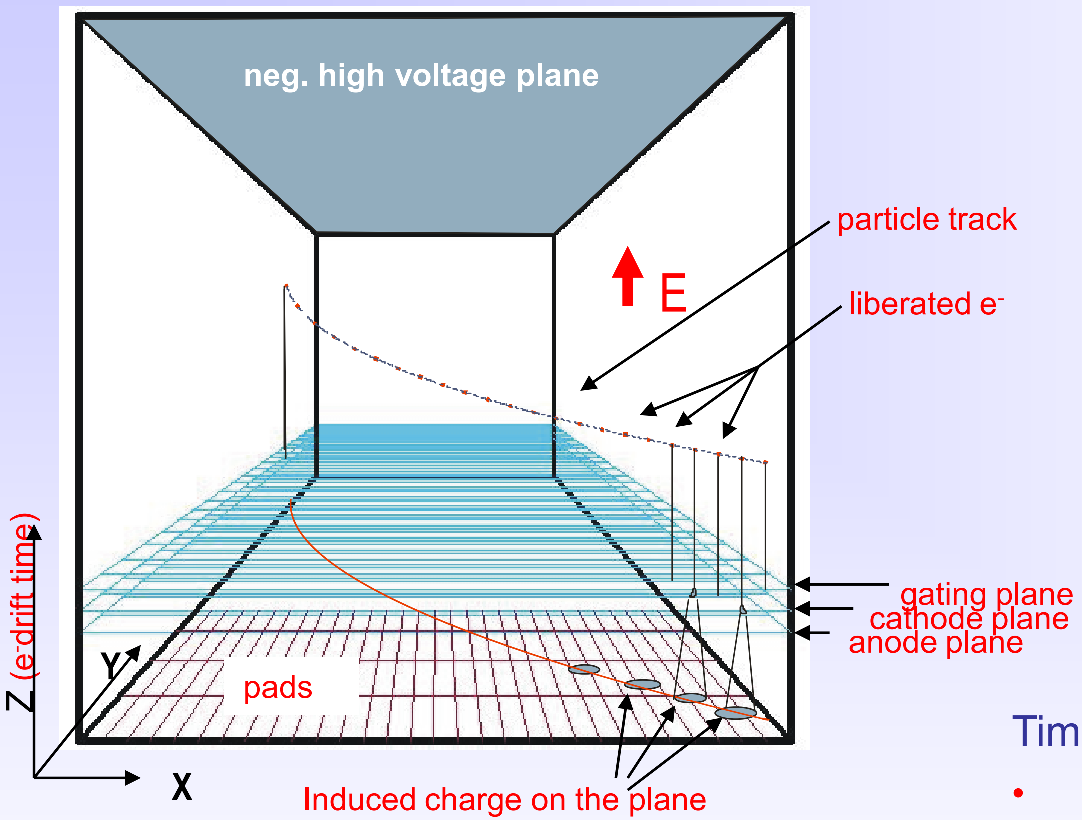
$$\sigma_L = \sigma_0$$

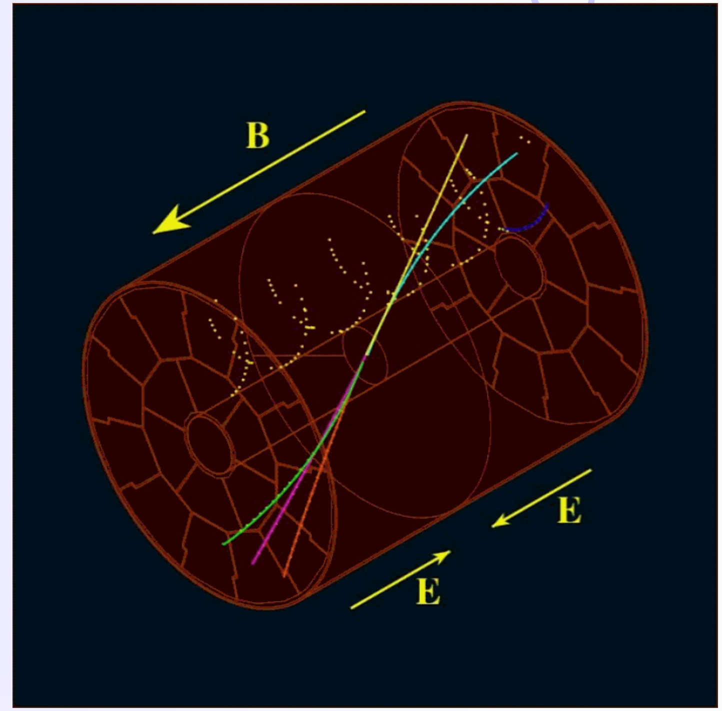
$$\sigma_T = \frac{\sigma_0}{\sqrt{1+\omega^2\tau^2}}$$



F. Sauli, IEEE Short Course on Radiation Detection and Measurement, Norfolk (Virginia) November 10-11, 2002

TPC – Time Projection Chamber

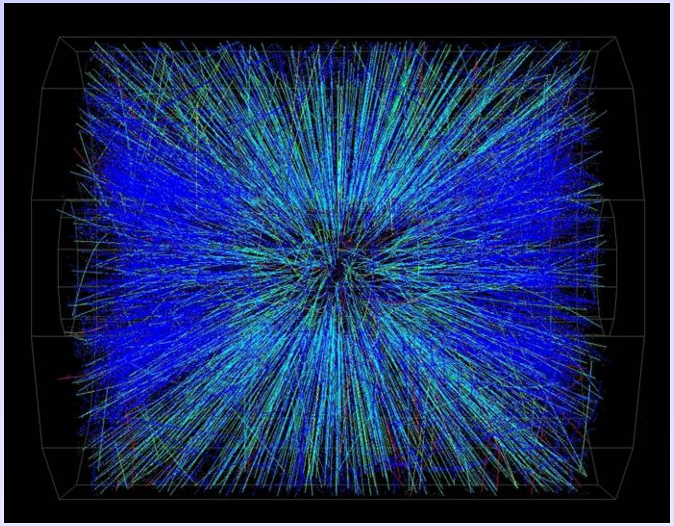


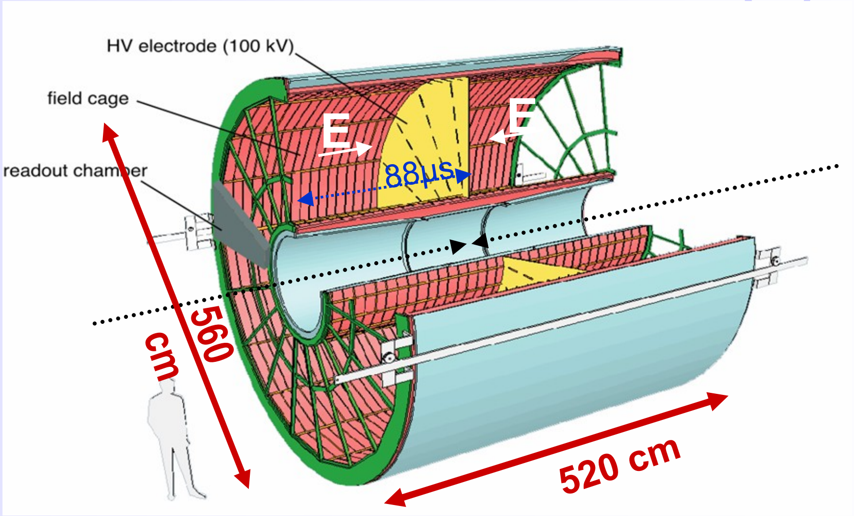


Time Projection Chamber

- full 3D track reconstruction: x-y from wires and segmented cathode of MWPC (or MPGD); $z = v_{drift} \times t_{drift}$ from drift time
- momentum resolution
  space resolution + B field
  (multiple scattering)
- energy resolution
  measurement of primary ionization

TPC – Time Projection Chamber





Alice TPC

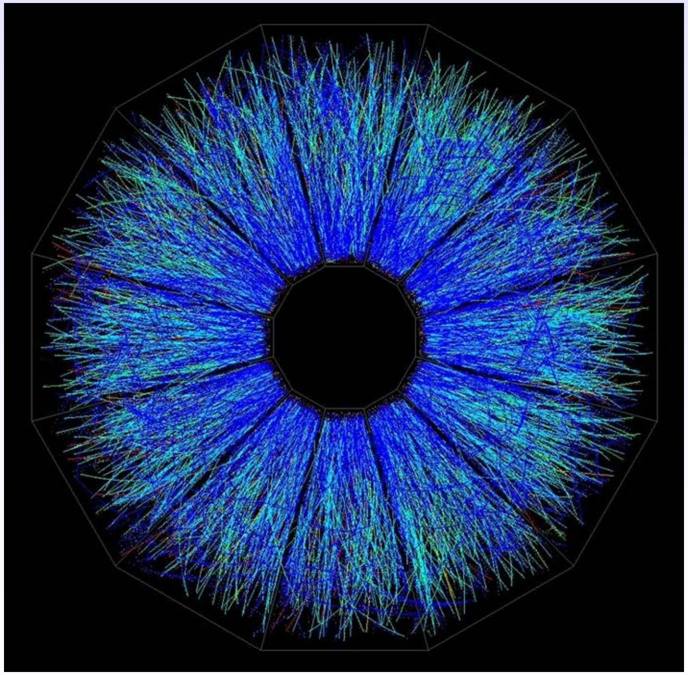
HV central electrode at –100 kV

Drift lenght 250 cm at E=400 V/cm

Gas Ne-CO_2 90-10

Space point resolution ~500 μm

dp/p 2%@1GeV; 10%@10GeV



Events from STAR TPC at RHIC

Au-Au collisions at CM energy of 130 GeV/n

Typically ~2000 tracks/event

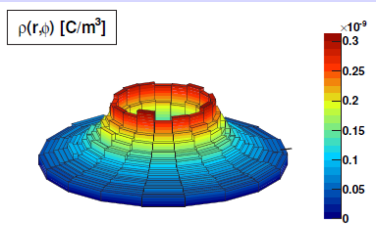
TPC – Time Projection Chamber

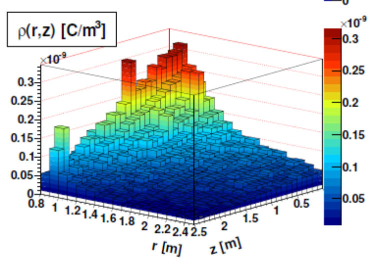
Positive ion backflow modifies electric field resulting in track distortion.

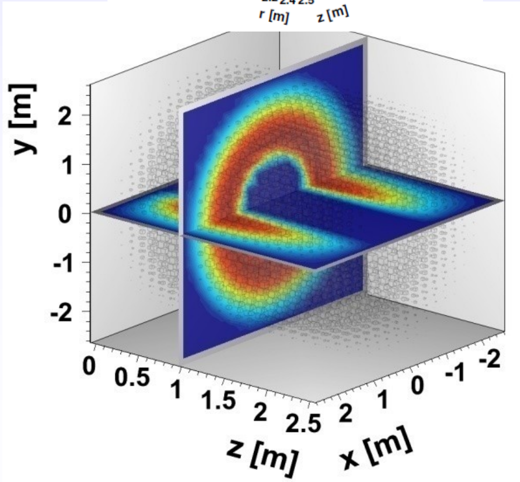
Solution : gating (or GEM)

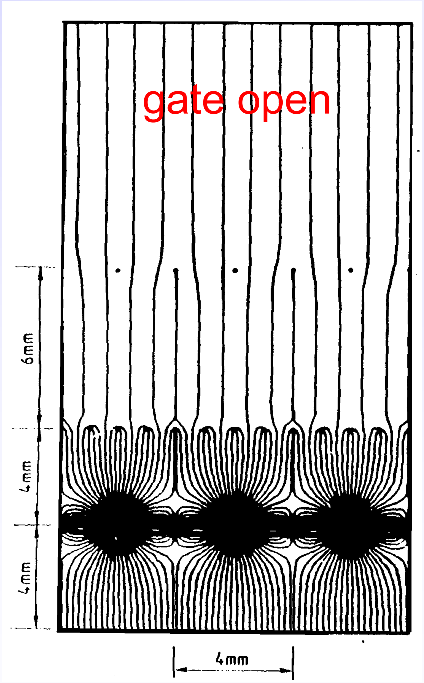
Prevents electrons to enter amplification region in case of uninteresting event;

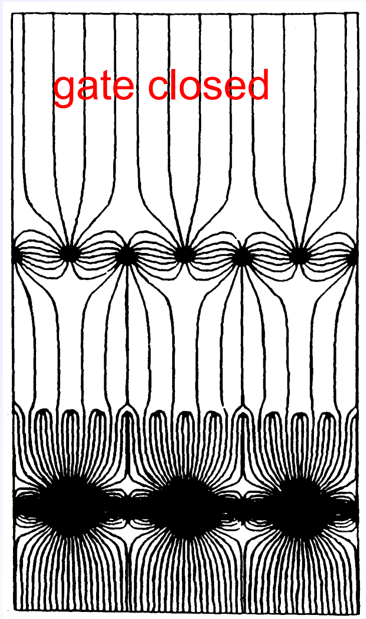
Prevents ions created in avalanches to flow back to drift region.











gating plane

cathode plane

anode wires

readout pads

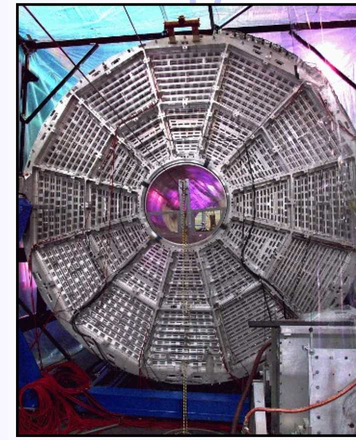
ALEPH coll., NIM A294(1990)121

TPC – Time Projection Chamber

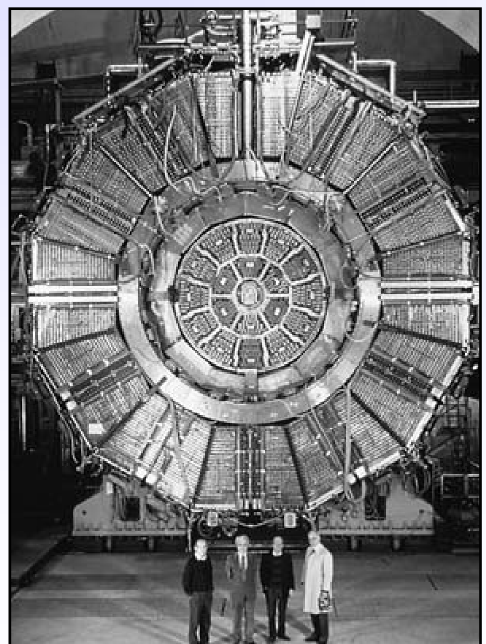
TPC	Reference
PEP4	PEP-PROPOSAL-004, Dec 1976
TOPAZ	Nucl. Instr. and Meth. A252 (1986) 423
ALEPH	Nucl. Instr. and Meth. A294 (1990) 121
DELPHI	Nucl. Instr. and Meth. A323 (1992) 209-212
NA49	Nucl. Instr. and Meth. A430 (1999) 210
STAR	IEEE Trans. on Nucl. Sci. Vol. 44, No. 3 (1997)

PEP4 (SLAC)

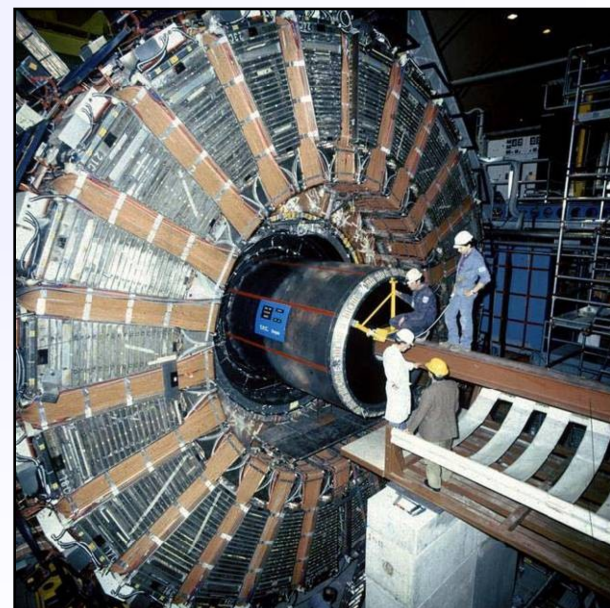
STAR (LBL)



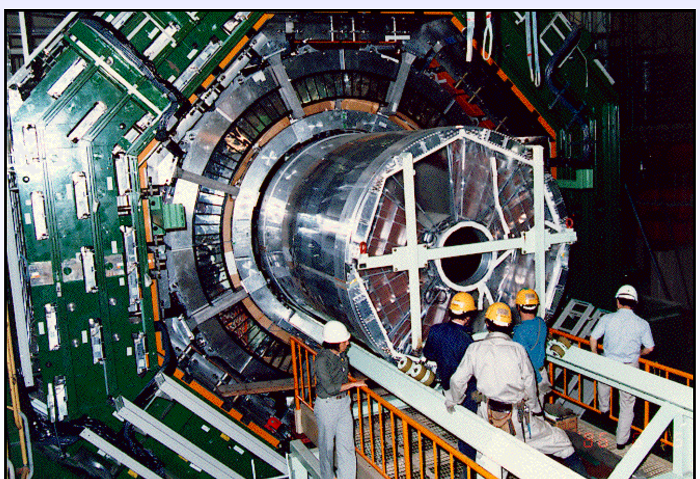
ALEPH (CERN)



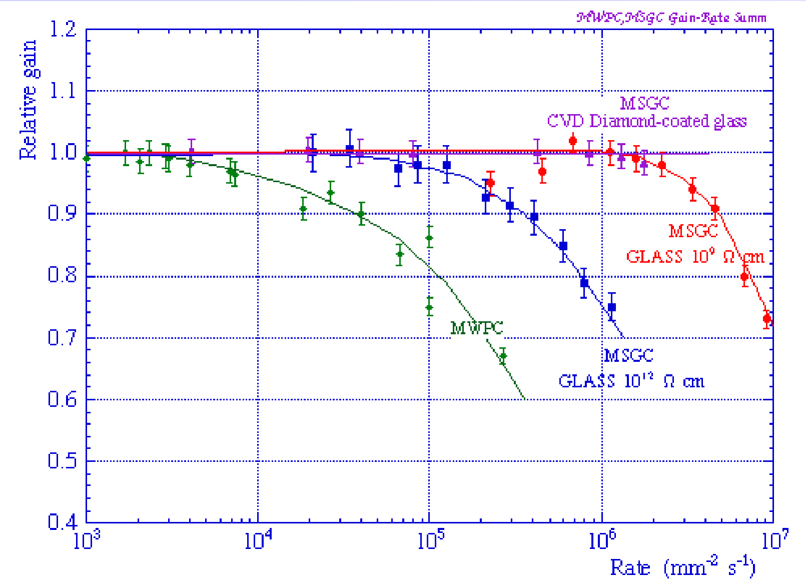
DELPHI (CERN)



TOPAZ (KEK)



Micropattern Gas Detectors



Advantages of gas detectors:

- low radiation length
- large areas at low price
- flexible geometry
- spatial, energy resolution …

Problem:

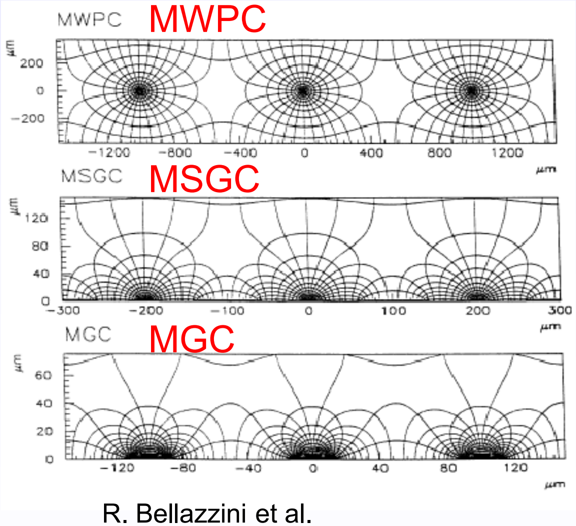
- rate capability limited by space charge defined by the time of evacuation of positive ions

scale factor

1

5

10



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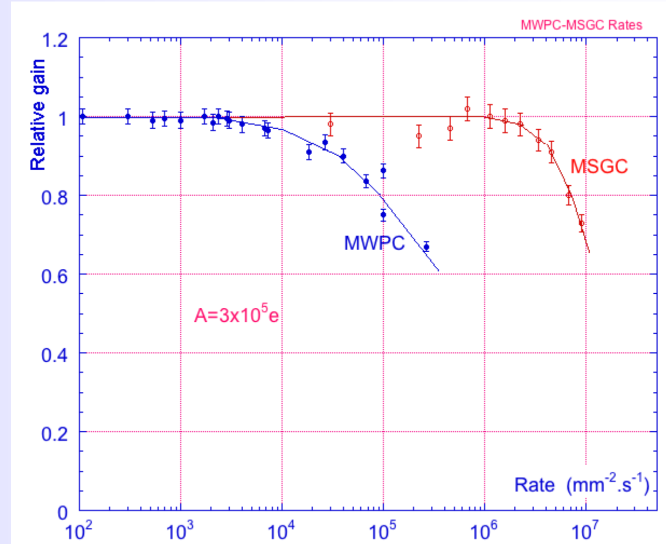
Solution:

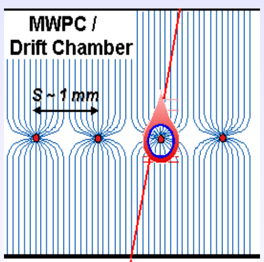
- reduction of the size of the detecting cell (limitation of the length of the ion path) using chemical etching techniques developed for microelectronics and keeping at same time similar field shape.

Current Trends in Micro-Pattern Gas Detectors (Technologies)

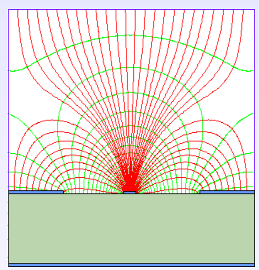
Semiconductor Industry technology:

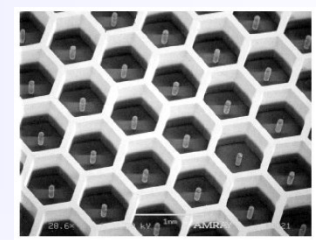
- Photolithography
- Etching
- Coating
- Doping

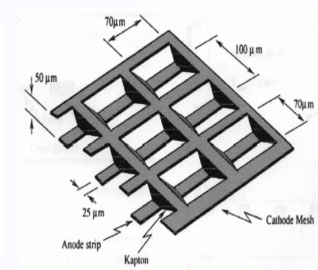


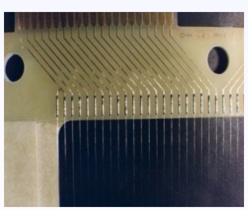


Amplifying cell reduction by factor of 10

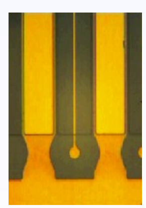






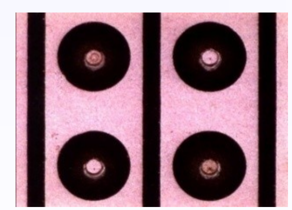


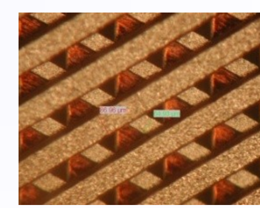
Rate Capability>10^6/mm^2
Position Resolution ~40μm
2-track Resolution ~400μm



Operational instabilities:

Substrate charging-up
Discharges
Polymer deposition (ageing)

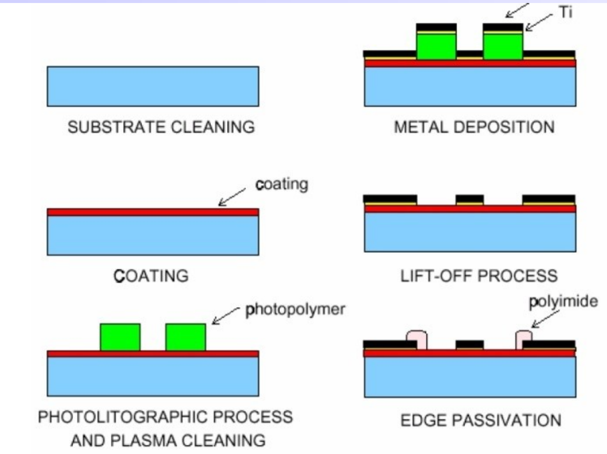




MWPC **MSGC**

MSGC – MicroStrip Gas Chamber

Anton Oed

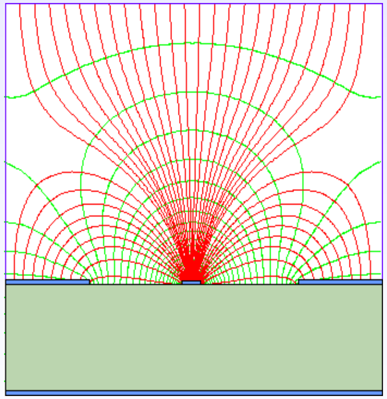


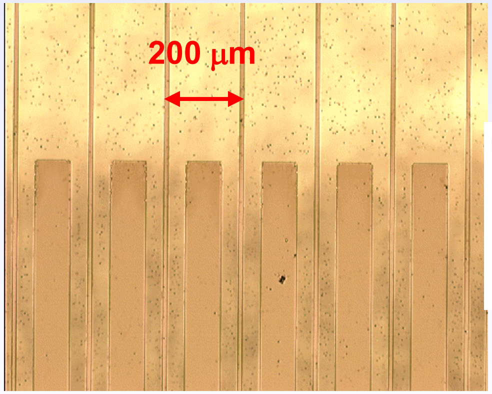
Thin metal anodes and cathodes on insulating support (glass, flexible polyimide ..)

Problems:

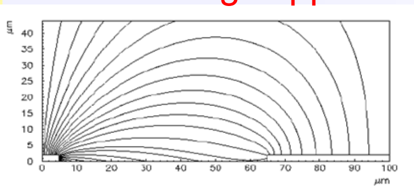
High discharge probability under exposure to highly ionizing particles caused by the regions of very high E field on the border between conductor and insulator.

Charging up of the insulator and modification of the E field → time evolution of the gain.

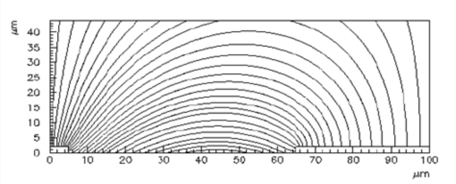




insulating support



slightly conductive support



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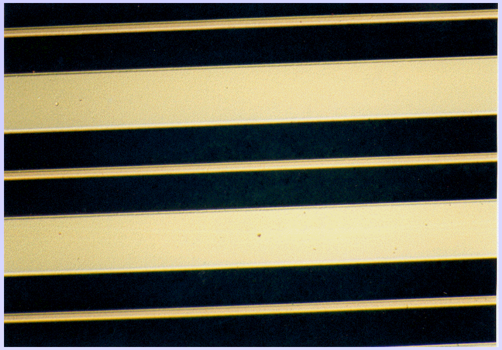
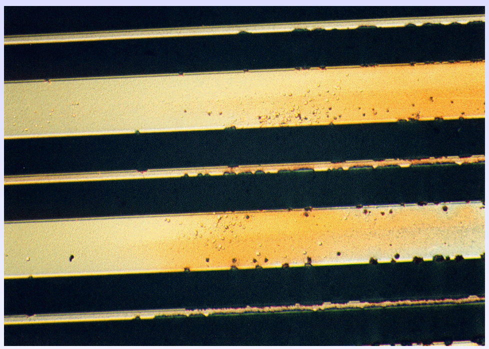
Solutions:

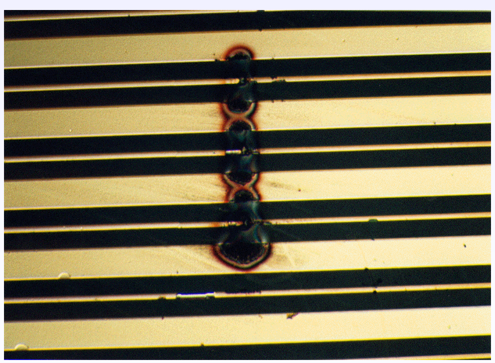
slightly conductive support

multistage amplification

MSGC – MicroStrip Gas Chamber







Surface charging

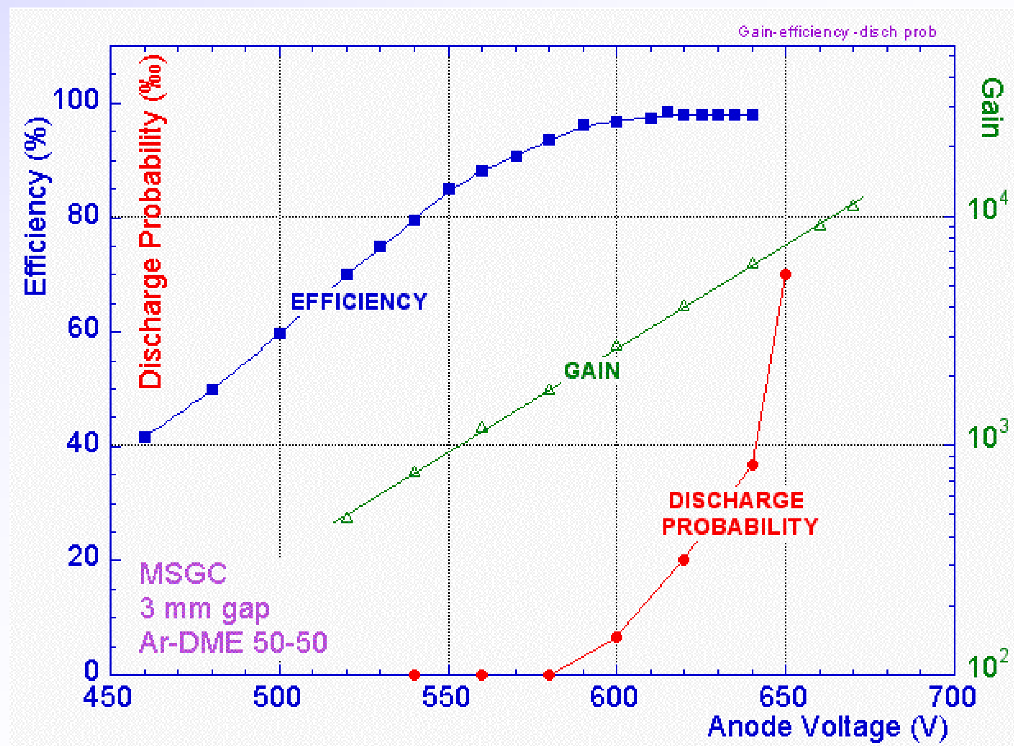
Bulk resistivity of the support material

Surface modification by doping or deposition

Ageing

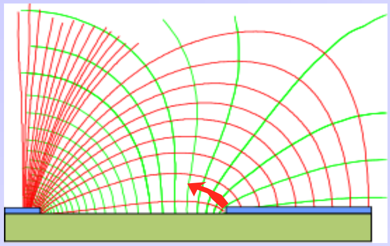
Gas, Gas system, MSGC support, Construction material

Discharges

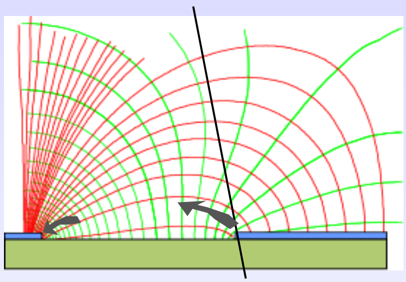


MSGC – MicroStrip Gas Chamber

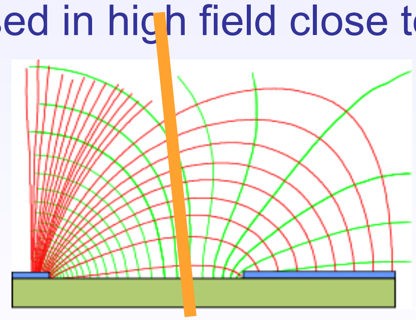
MSGC: Discharge mechanisms



Field emission from the cathode edge



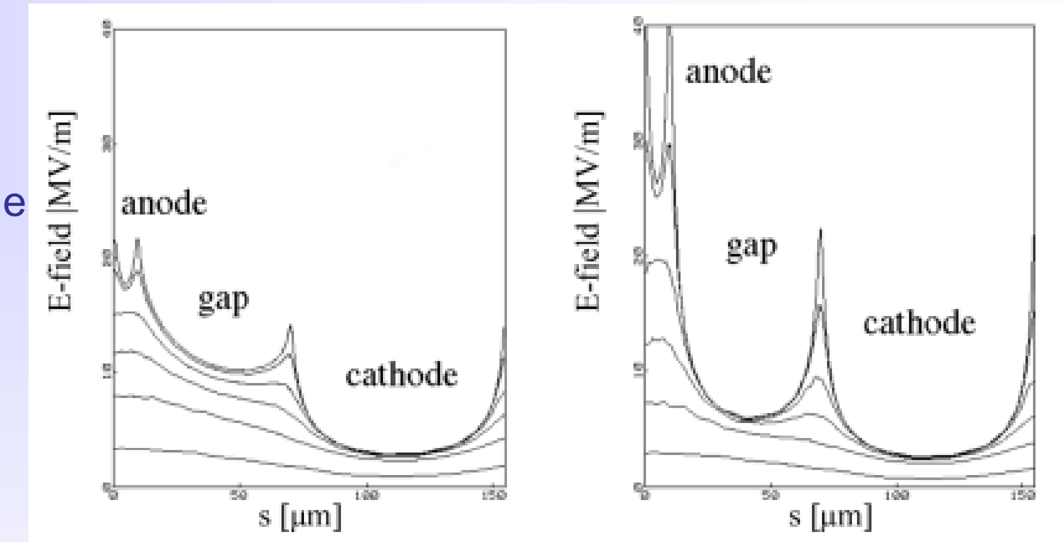
Charge pre-amplification for ionization released in high field close to cathode



Very high ionization release: avalanche size exceeds Reather's limit

Q 10^{7}

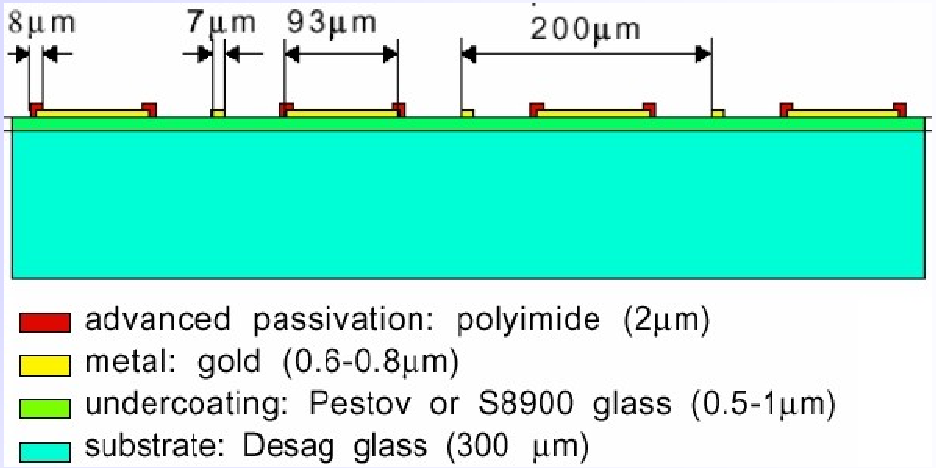
Electric field strength close to support plane in MSGC

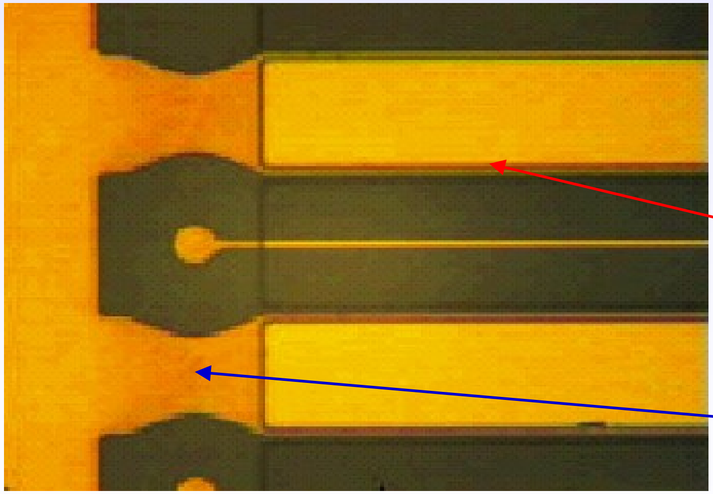


Coated MSGC **Uncoated MSGC**

Surface resistivity modification

Cathode edge passivation





Advanced passivation

Standard passivation

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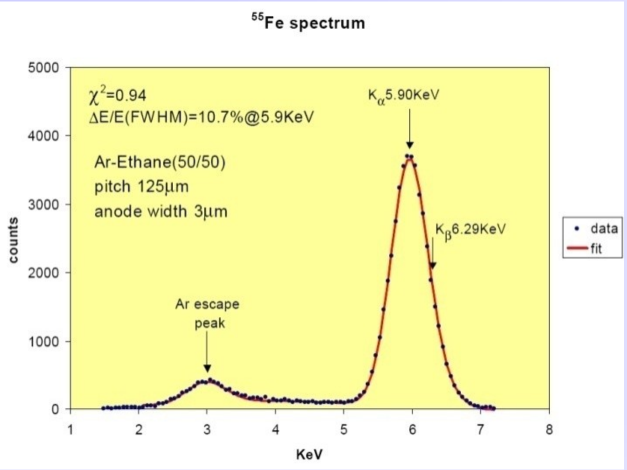
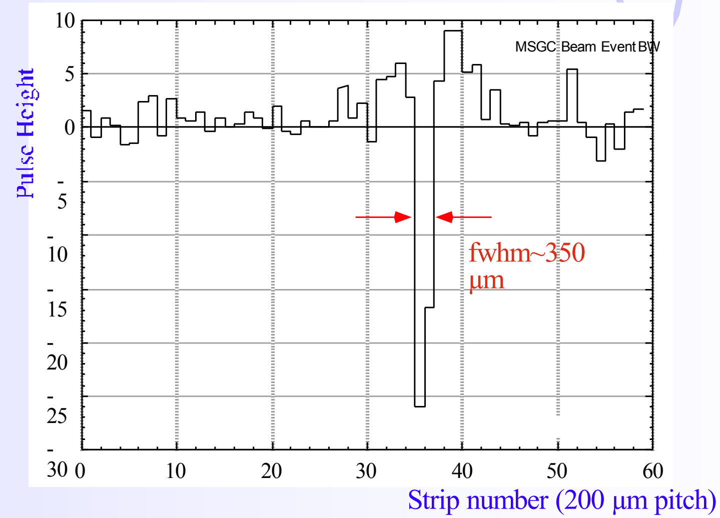
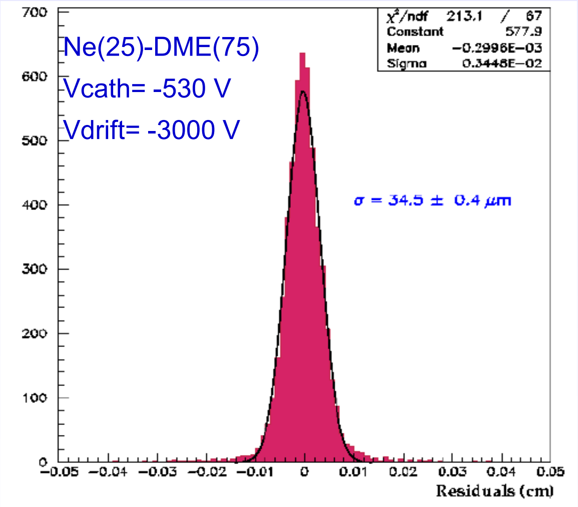
MSGC – MicroStrip Gas Chamber



Energy resolution ~11% for 5.9 keV

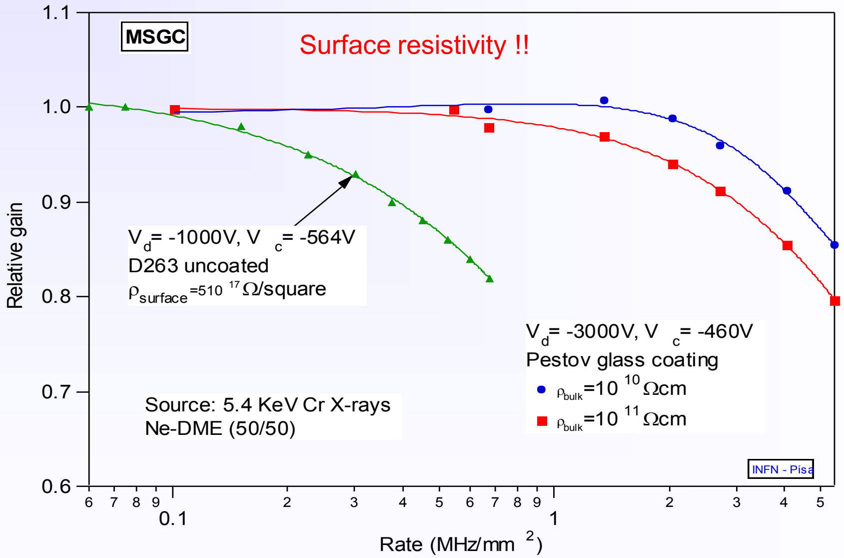


Single event wire map



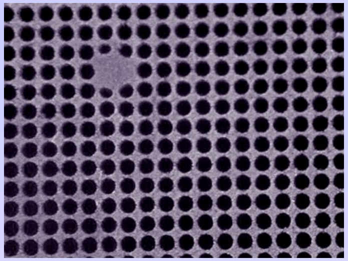
Spatial resolution = 34.5 ± 0.4 μm

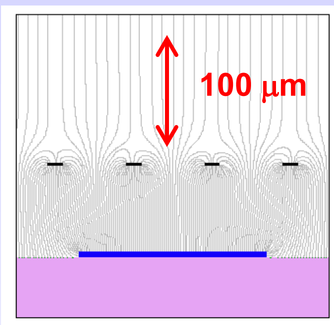
2-track resolution ~400 μm

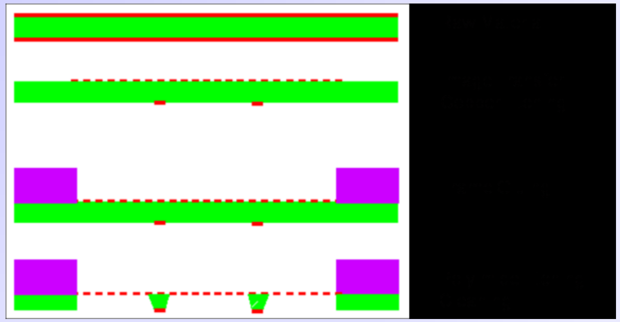


Rate capability > 1 MHz/mm^2

Micromegas – Micromesh Gaseous Structure



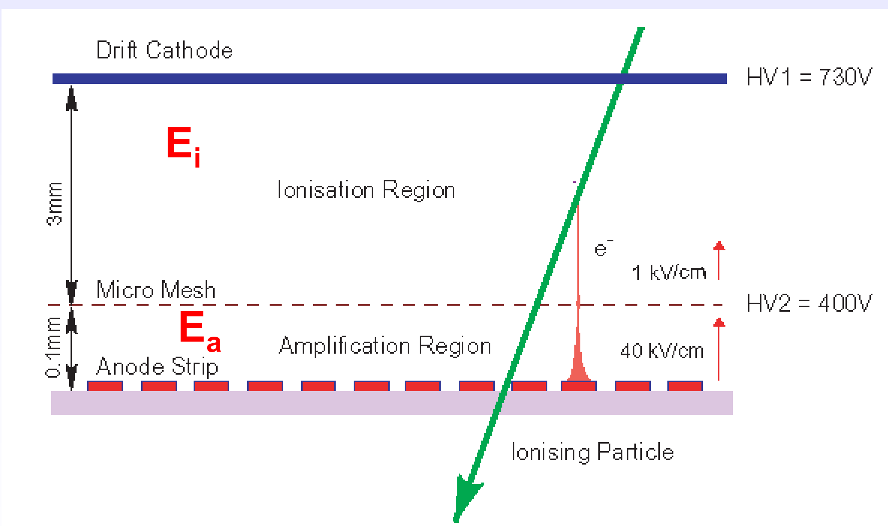


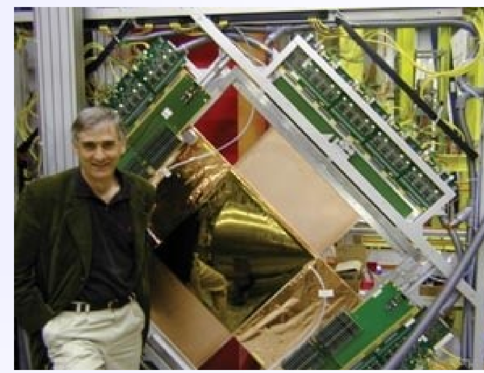


Micromesh mounted above readout structure (typically strips).

E field similar to parallel plate detector.

E_a/E_i ~ 50 to secure electron transparency and positive ion flowback supression.

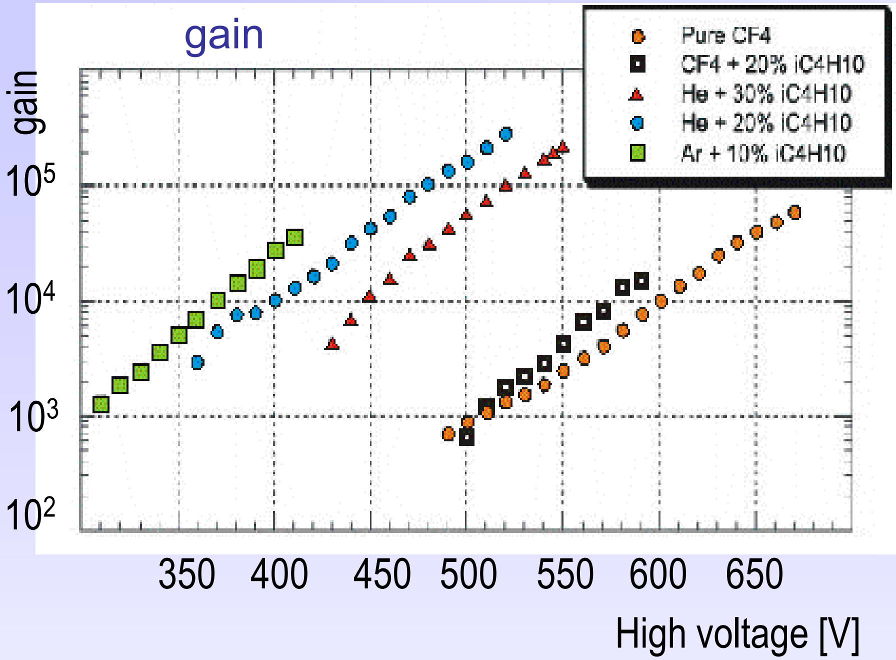


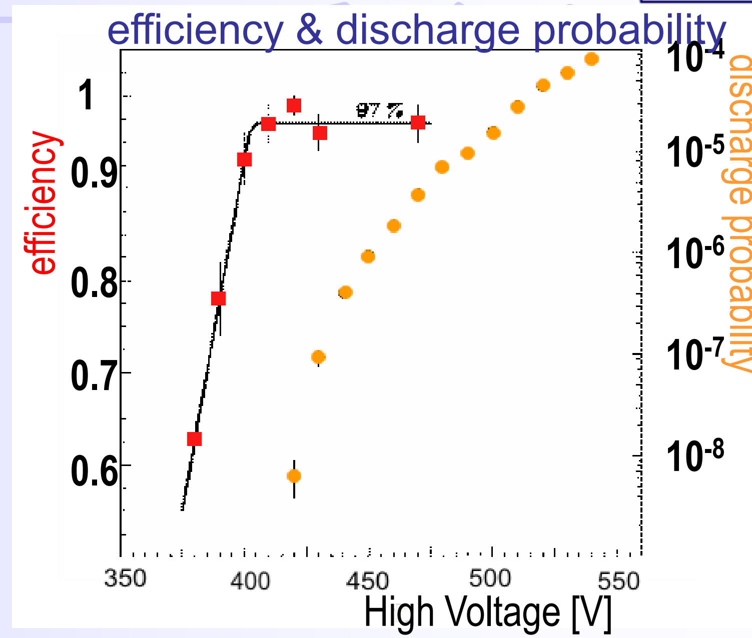


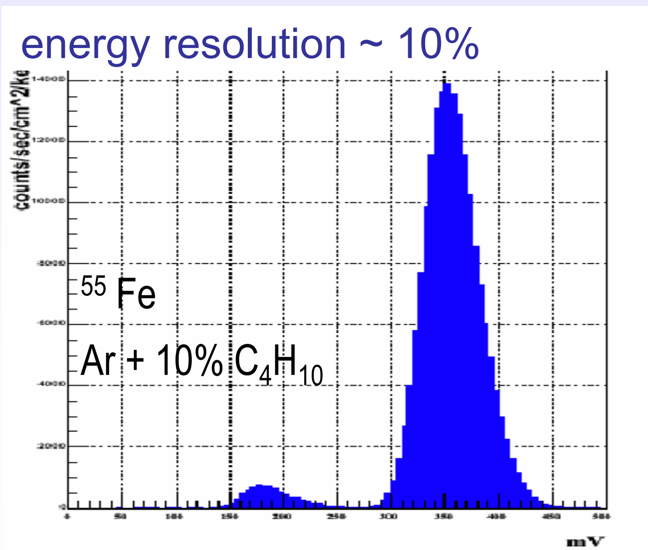
Ioannis Giomataris

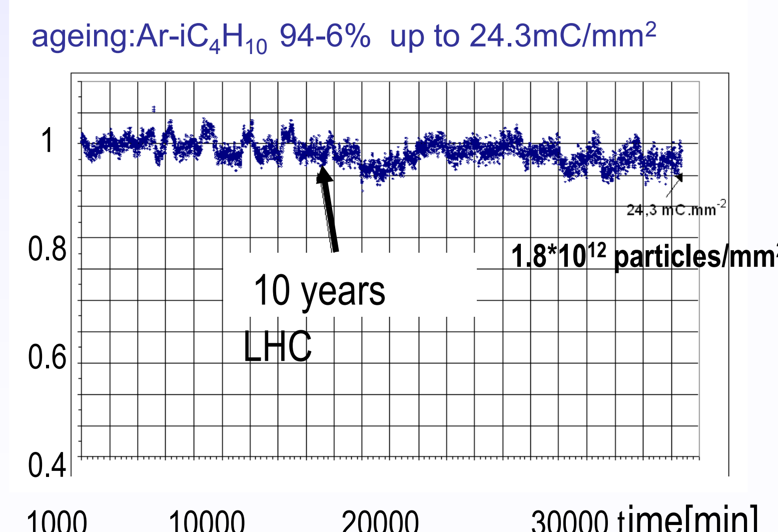
Y.Giomataris et al, NIM A 376 (1996) 29

Micromegas – Micromesh Gaseous Structure



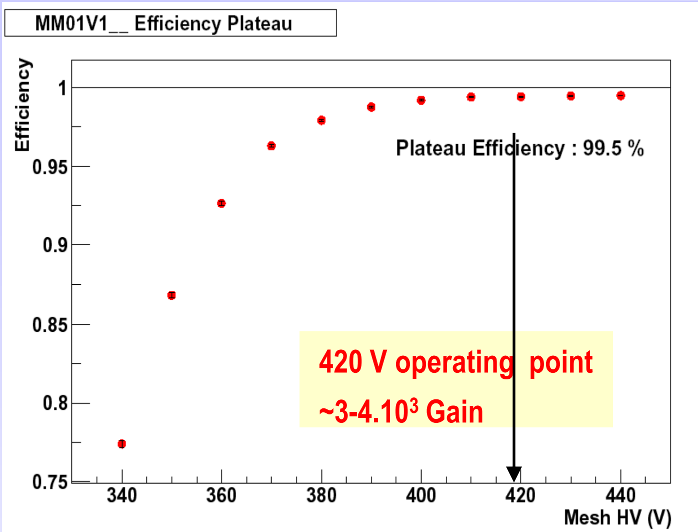




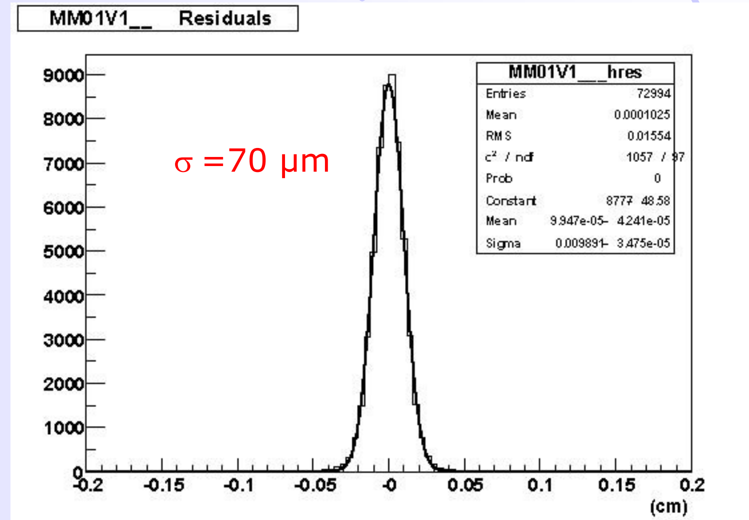


D.Thers et al NIM A 469 (2001) 133

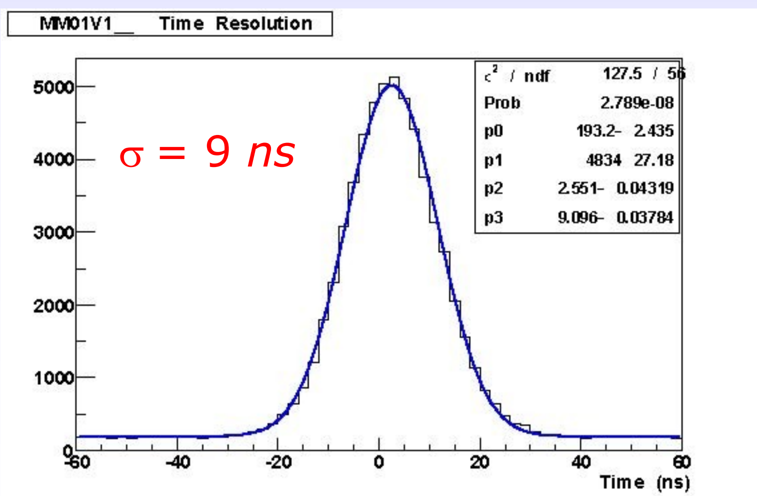
Micromegas – Micromesh Gaseous Structure



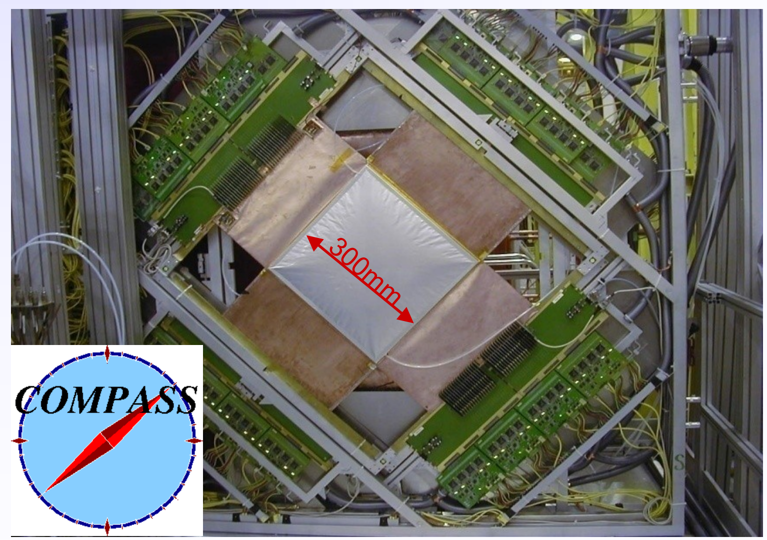
Large efficiency plateau > 40 V



Spatial resolution < 70 μm

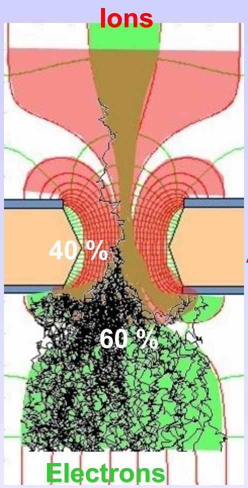


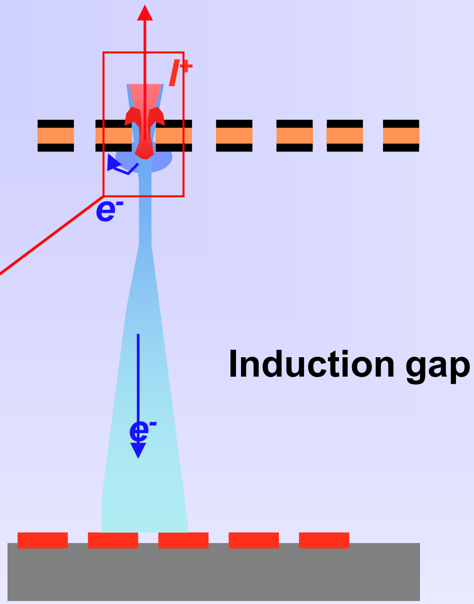
Time resolution : 9 ns

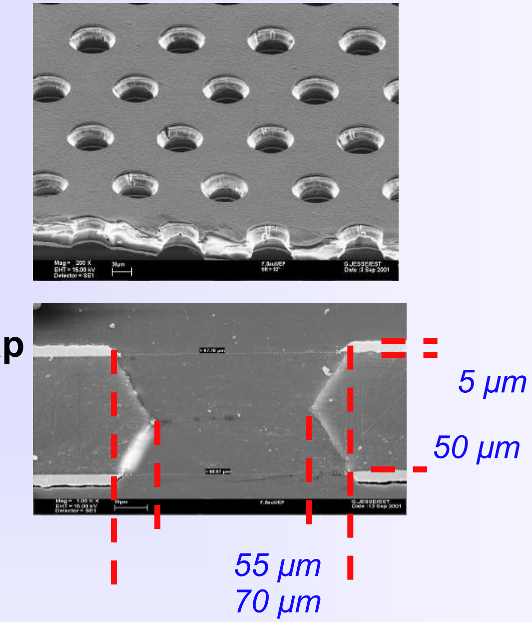


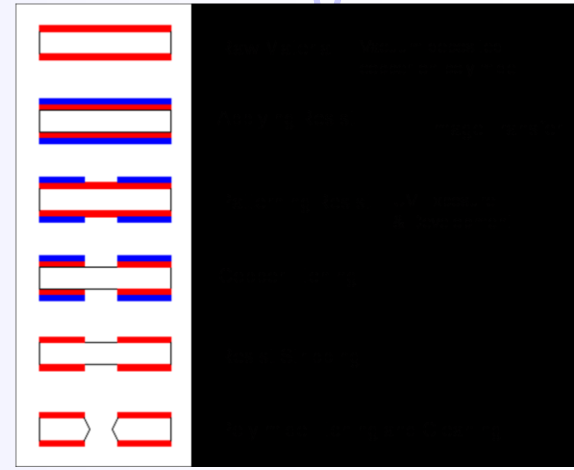
D.Thers et al NIM A 469 (2001) 133

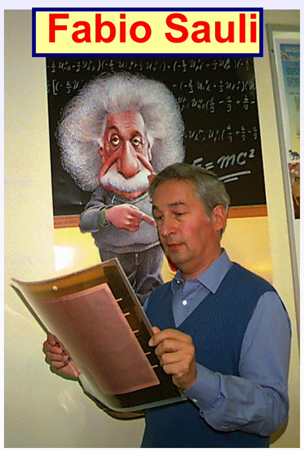
GEM – Gas Electron Multiplier







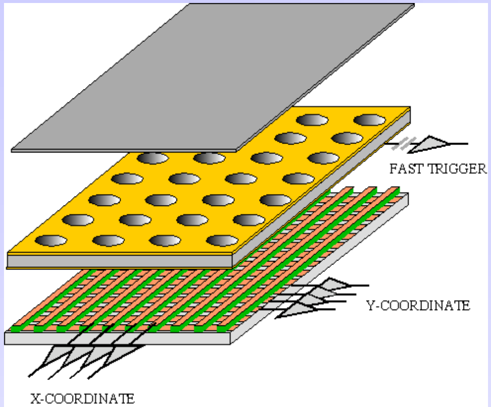




Thin, metal coated polyimide foil perforated with high density holes.

Electrons are collected on patterned readout board.
A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.
All readout electrodes are at ground potential.
Positive ions partially collected on the GEM electrodes.

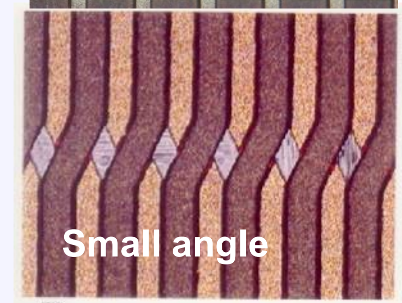
GEM – Gas Electron Multiplier

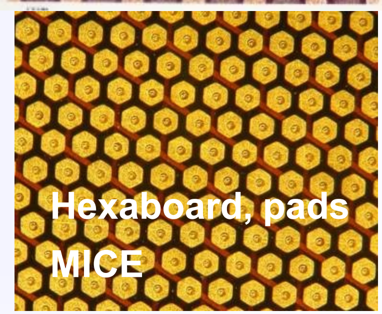


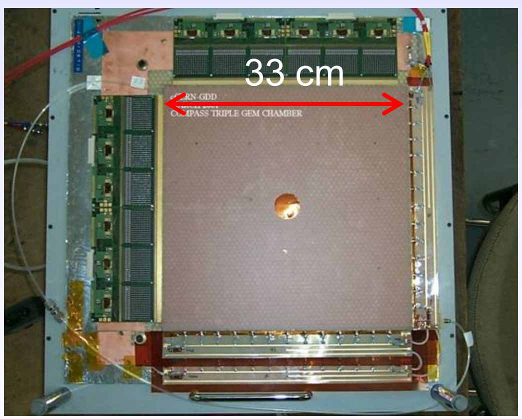
Full decoupling of the charge amplification structure from the charge collection and readout structure.

Both structures can be optimized independently !

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





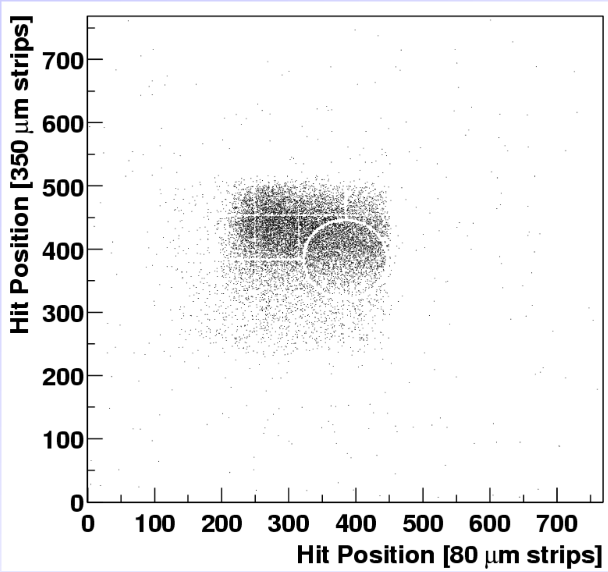


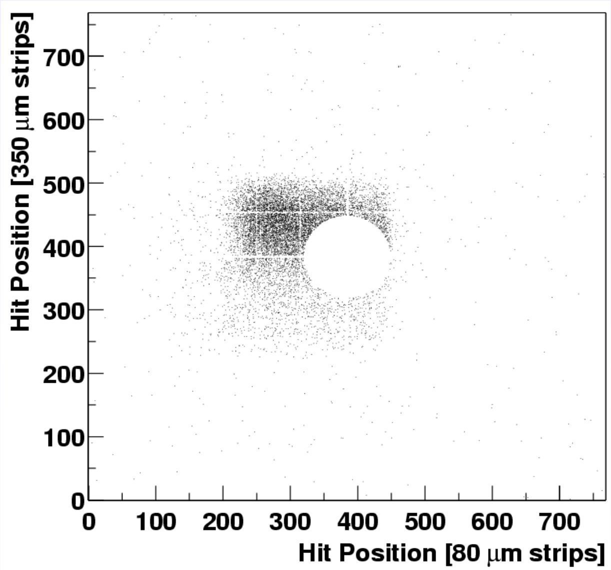
Compass

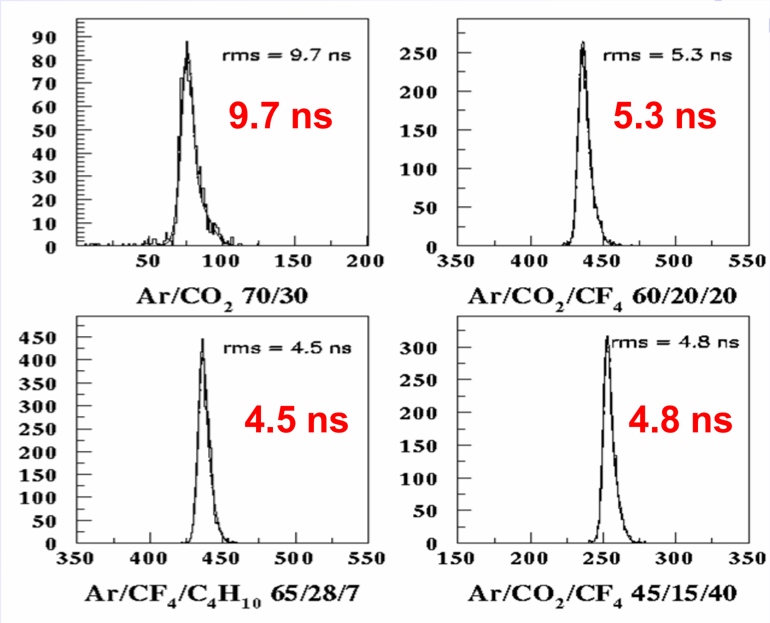
Totem

Both detectors use three GEM foils in cascade for amplification to reduce discharge probability by reducing field strenght.

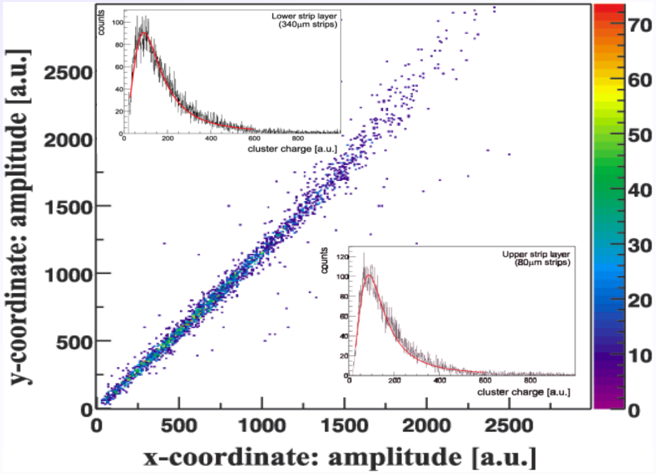
GEM – Gas Electron Multiplier







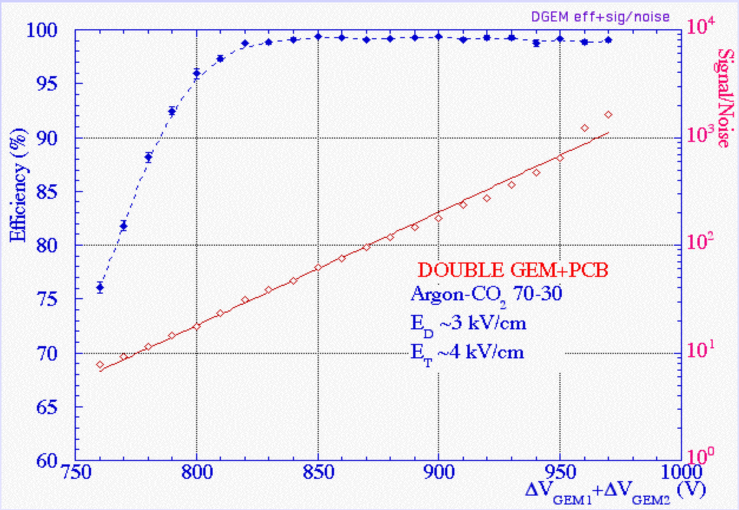
Time resolution



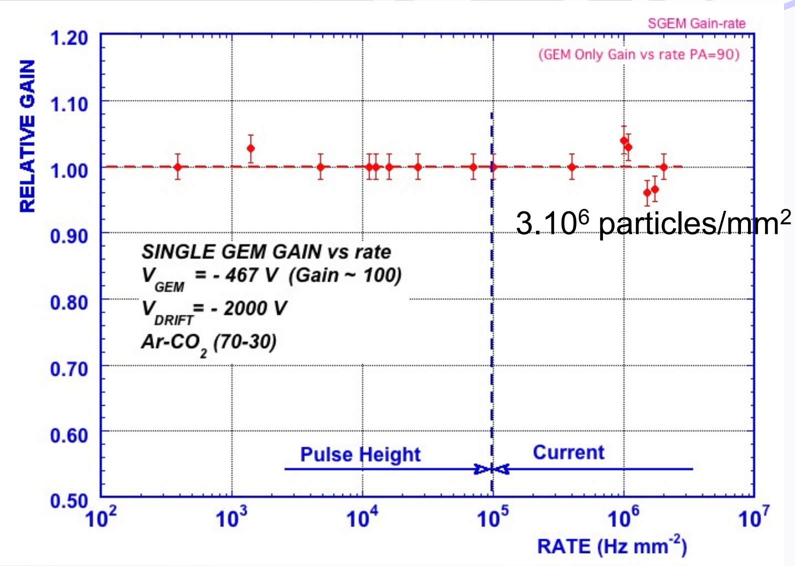
Charge corellation (cartesian readout)

GEM – Gas Electron Multiplier

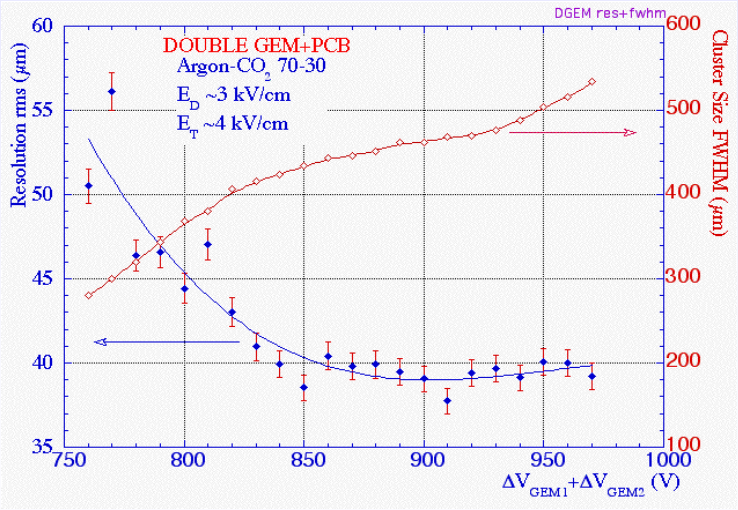
A. Bressan et al, Nucl. Instr. And Meth. A425(1999)262



Efficiency for minimum ionizing particles with 3 mm gap

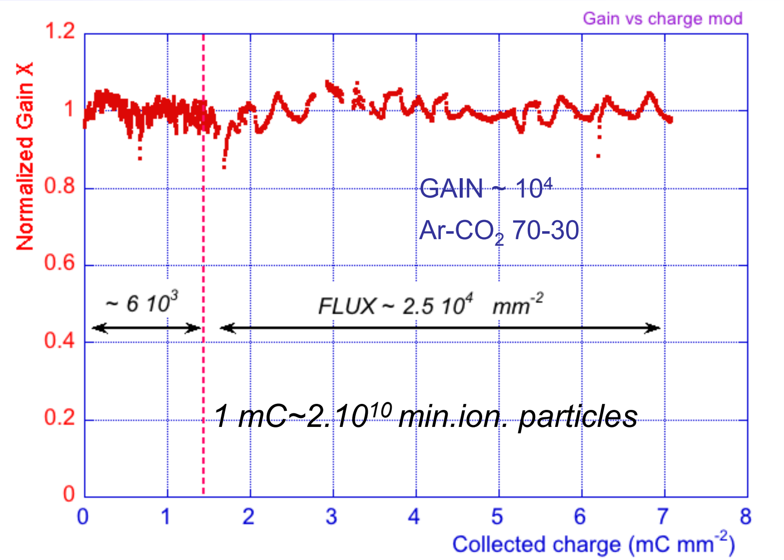


Rate capability > 10^6 Hz mm^{-2}



Space resolution ~ 40 μm rms

Cluster size ~ 500 μm FWHM

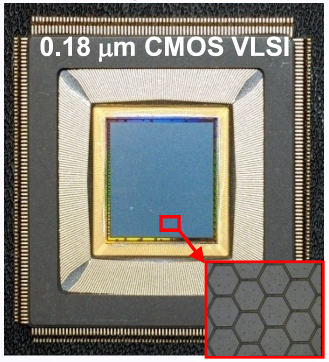


C. Altunbas et al, DESY Aging Workshop (Nov. 2001) Nucl. Instr. and Meth. A

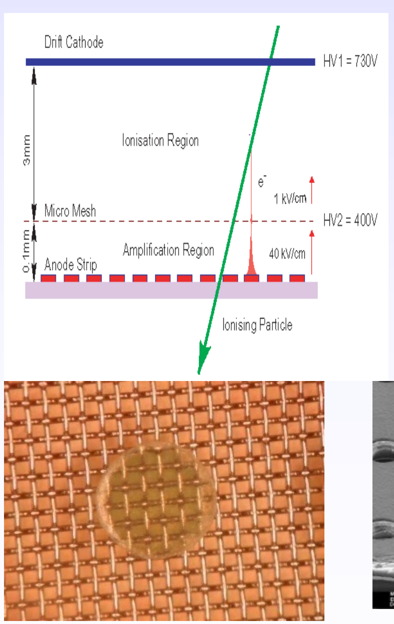
J. Benlloch et al, IEEE NS-45(1998)234

Current Trends in Micro-Pattern Gas Detectors (Technologies)

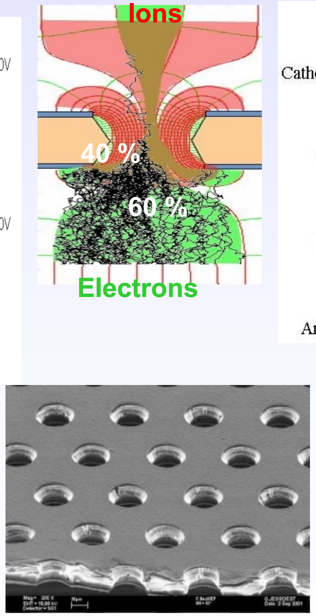
- **MSGC**
- **Micromegas**
- **GEM**
- **Thick-GEM, Hole-Type Detectors and RETGEM**
- **MPDG with CMOS pixel ASICs**
- **Ingrid Technology**



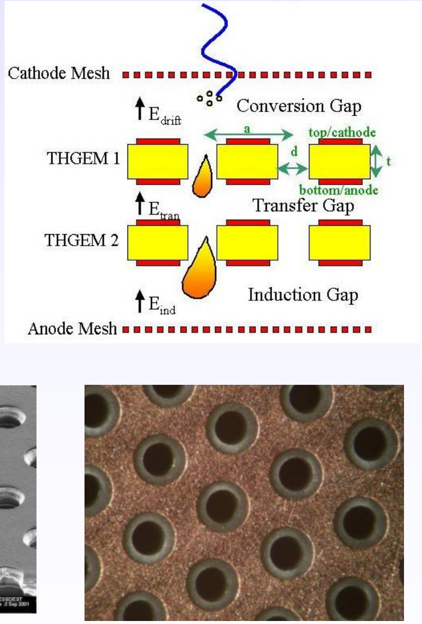
CMOS high density readout electronics



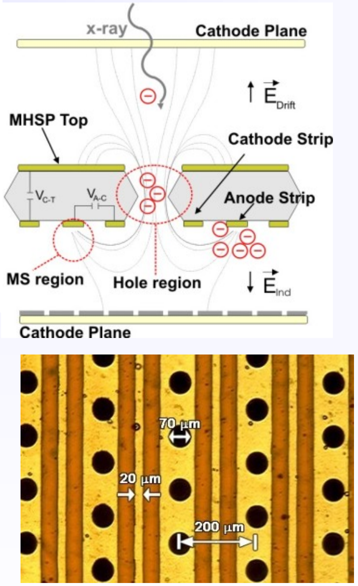
Micromegas



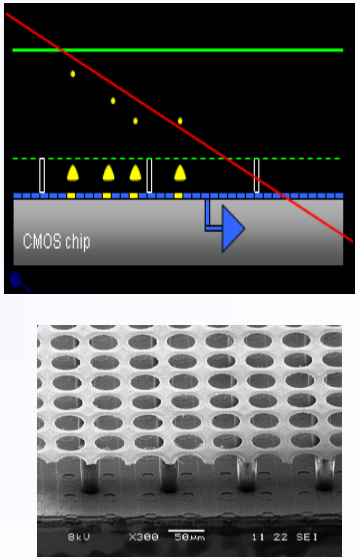
GEM



THGEM



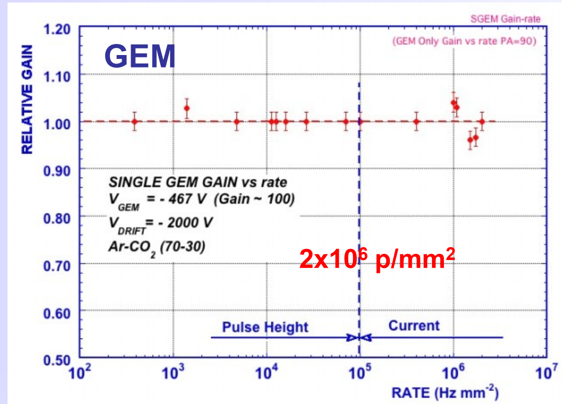
MHSP

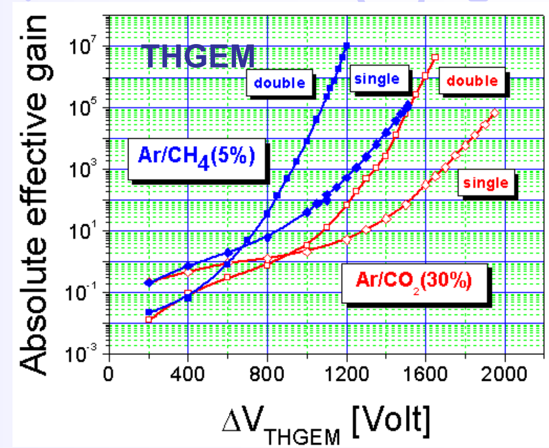


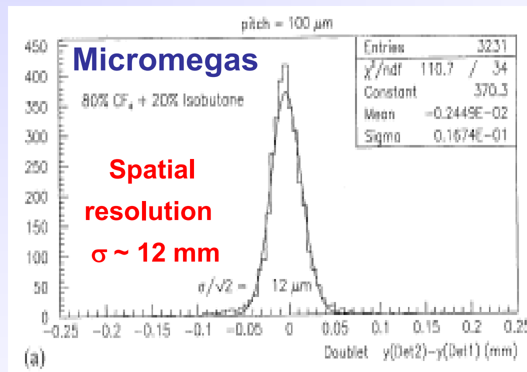
Ingrid

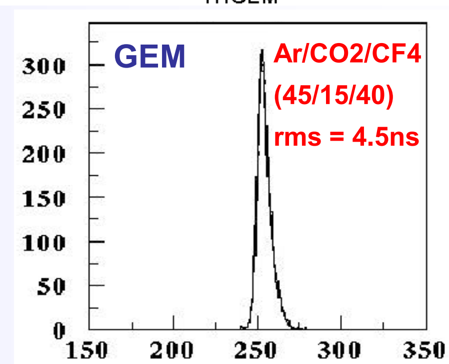
Current Trends in Micro-Pattern Gas Detectors (Performance)

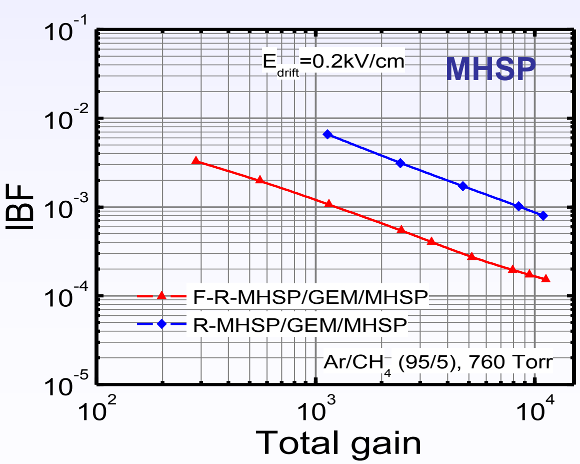
- **Rate Capability**
- **High Gain**
- **Space Resolution**
- **Time Resolution**
- **Energy Resolution**
- **Ageing Properties**
- **Ion Backflow Reduction**
- **Photon Feedback Reduction**

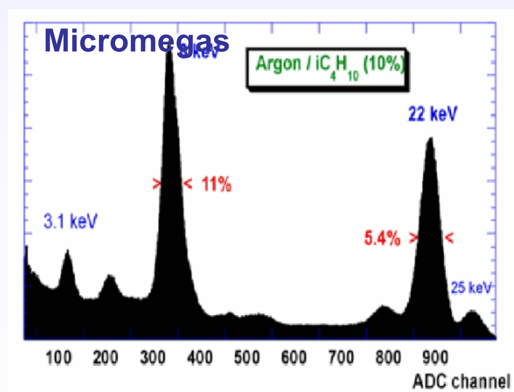


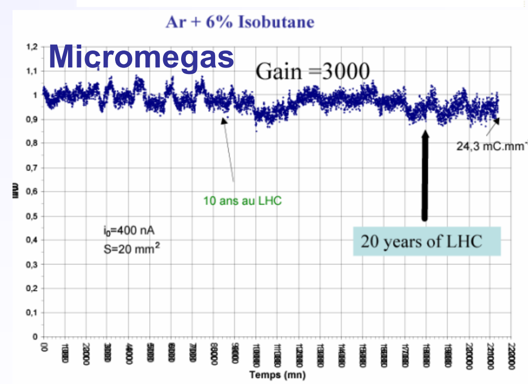








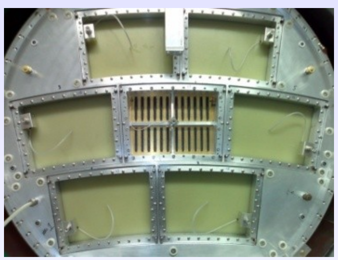




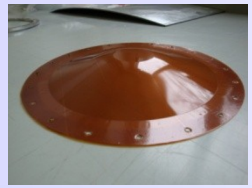
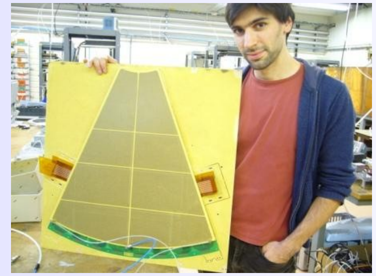
Development of large-area MPGDs

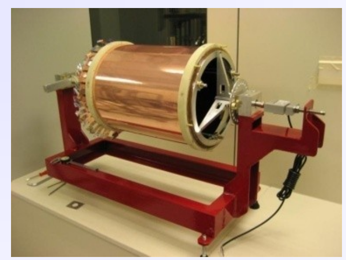
Bulk Micromegas



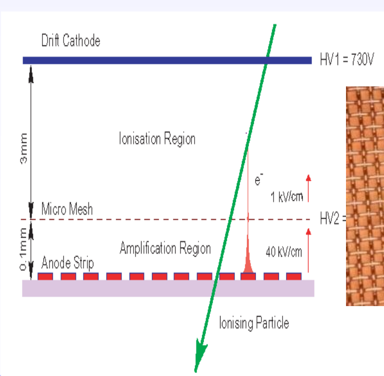


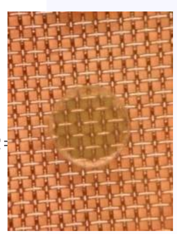
Single mask GEM

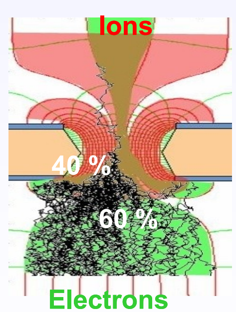



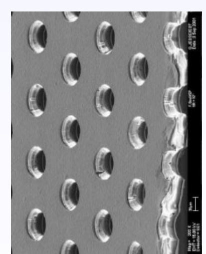


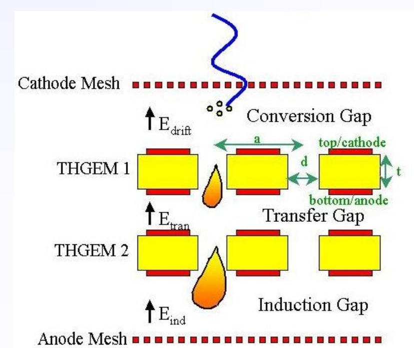
THGEM

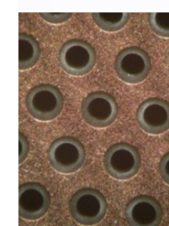






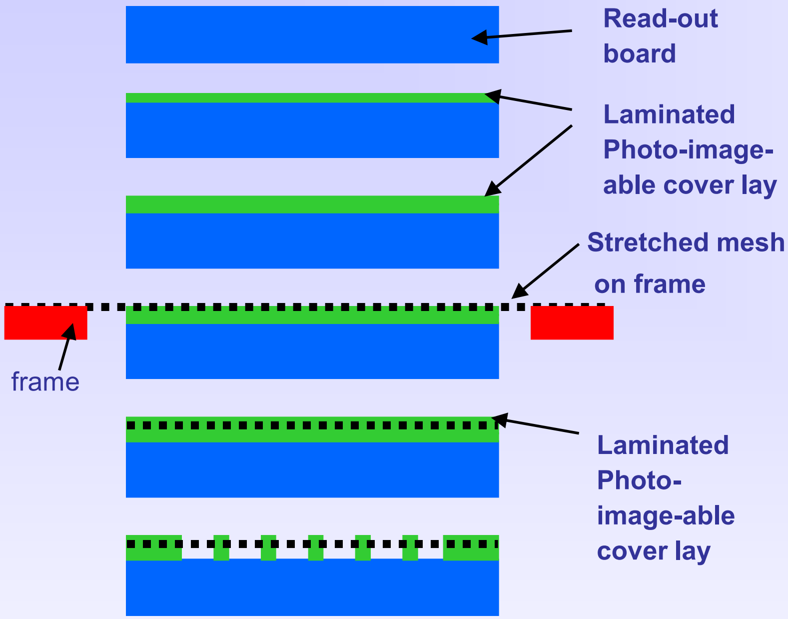




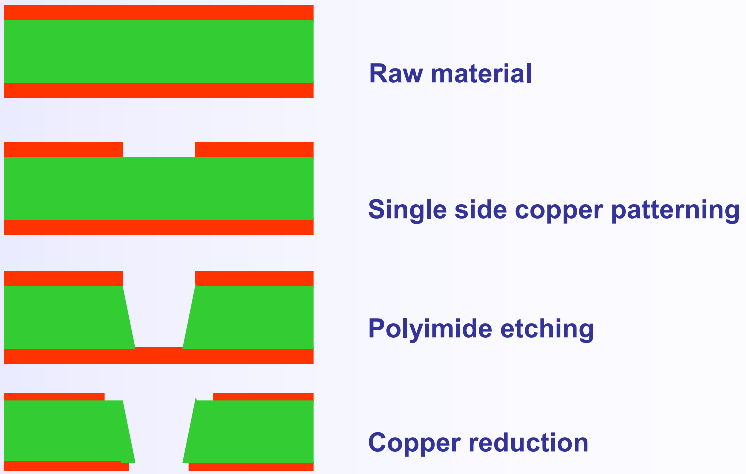


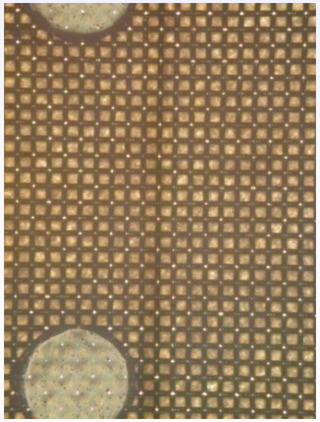
Development of large-area Micro-Pattern Gas Detectors

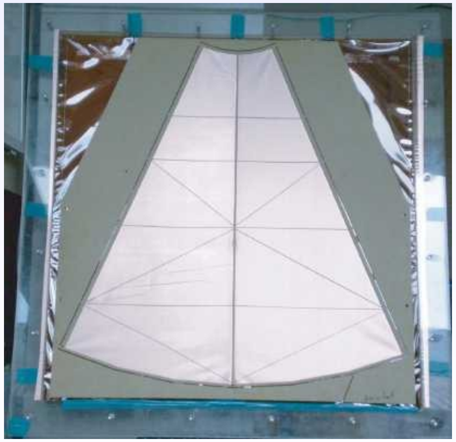
Bulk Micromegas

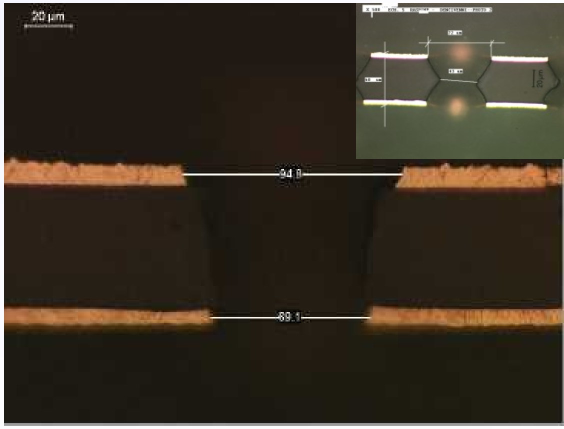


Single mask GEM









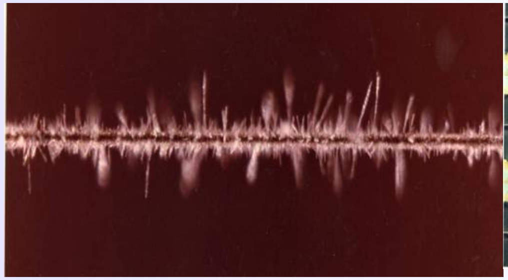
Limitations of Gas Detectors

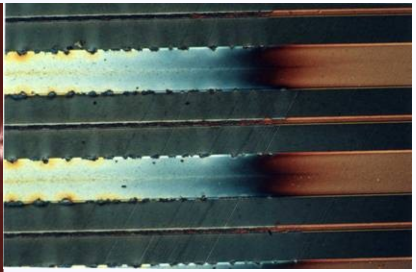
Classical ageing

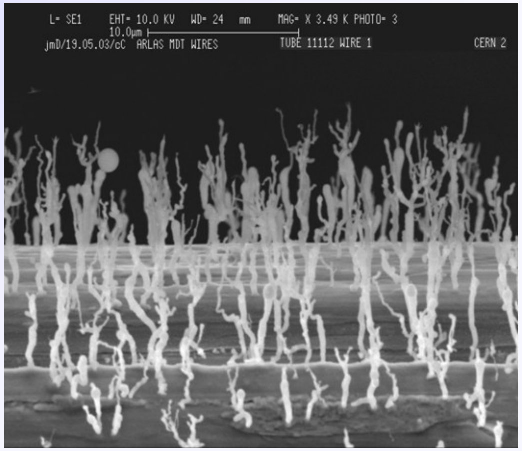
Avalanche region → plasma formation

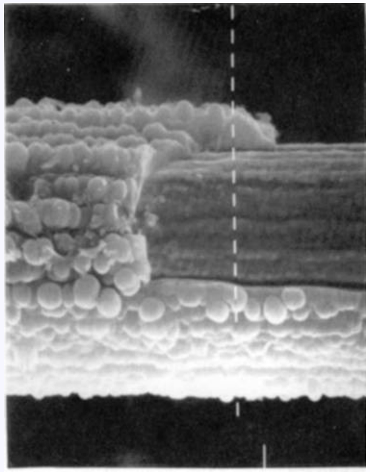
(complicated plasma chemistry)

- Dissociation of detector gas and pollutants
- Highly active radicals formation
- Polymerization (organic quenchers)
- Insulating deposits on anodes and cathodes

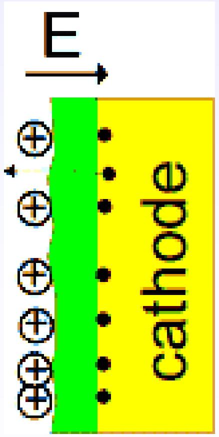








Anode: increase of the wire diameter, reduced and variable field, variable gain and energy resolution.



Cathode: formation of strong dipoles, field emmision and microdischarges (Malter effect).

Limitations of Gas Detectors

Solutions: carefull material selection for the detector construction and gas system, detector type (GEM is resitant to classical ageing), working point, non-polymerizing gases, additives supressing polymerization (alkohols, methylal), additives increasing surface conductivity (H_2O vapour), clening additives (CF_4).

Creation of database of "radiation-hard" materials &

detectors depending on application, commercially available materials

Source	Product	Outgas	Effect in G.D.	Note
CERN/GDD	STYCAST 1266 (A+B)	NO	NO	Long curing time
HERA-B/OTR	STYCAST 1266 (A+Catalyst 9)	NO	NO	In Use
CERN/GDD	HEXCEL EPO 93L	NO	NO	Out of production
HERA-B/ITR	ECCOBOND 285	NO	NO	In Use
CERN/GDD ATLAS/TRT	ARALDITE AW103 (Hardener HY 991)	NO	NO	In Use
ATLAS/TRT	TRABOND 2115	NO	NO	In Use

Low Outgassing room-T epoxies

Source	Product	Outgas	Effect in G.D.	Result
CERN/GDD ATLAS/TRT	ARALDITE AW 106 (Hardener HV 935 U)	YES		BAD
CERN/GDD	DURALCO 4525	YES	YES	BAD
CERN/GDD	DURALCO 4461	YES	YES	BAD
CERN/GDD	HEXCEL A40	YES	-	BAD
CERN/GDD	TECHNICOLL 8862 + (Hardener 8263)	YES	-	BAD
CERN/GDD	NORLAND NEA 155	YES	-	BAD
CERN/GDD	EPOTEK E905	YES	-	BAD
CERN/GDD	NORLAND NEA 123 (UV)	YES	-	BAD

Outgassing room-T epoxies

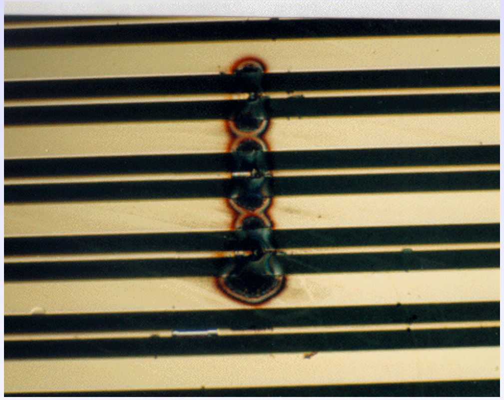
Limitations of Gas Detectors

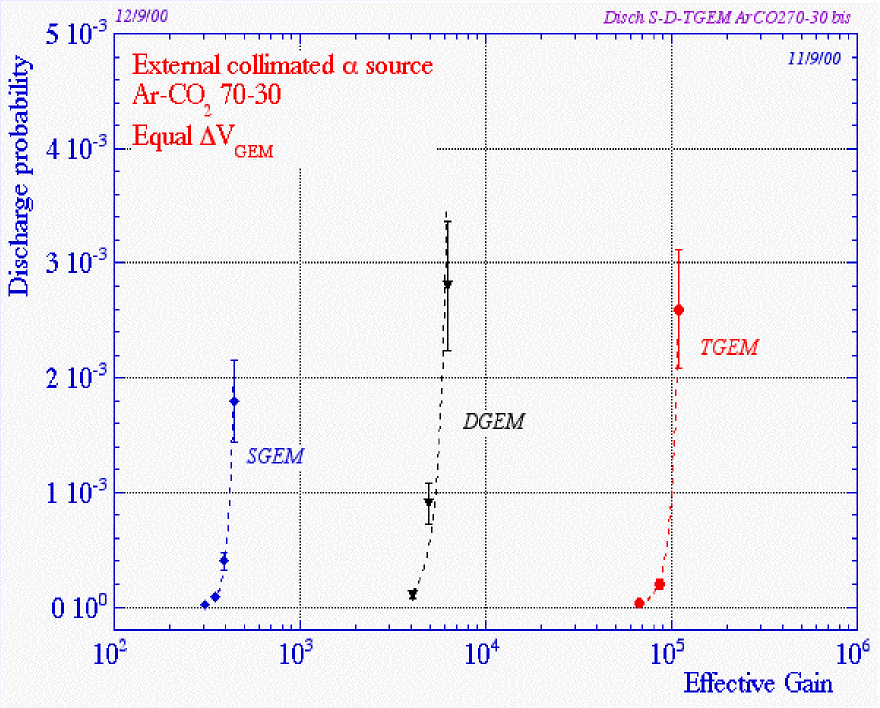
Discharges

Field and charge density dependent effect.

Solution: multistep amplification

resistive electrodes





Insulator charging up resulting in gain variable with time and rate

Solution: slightly conductive materials

Computer Simulations

MAXWELL *(Ansoft)*

electrical field maps in 2D& 3D, finite element calculation for arbitrary electrodes & dielectrics

HEED *(I.Smirnov)*

energy loss, ionization

MAGBOLTZ *(S.Biagi)*

electron transport properties: drift, diffusion, multiplication, attachment

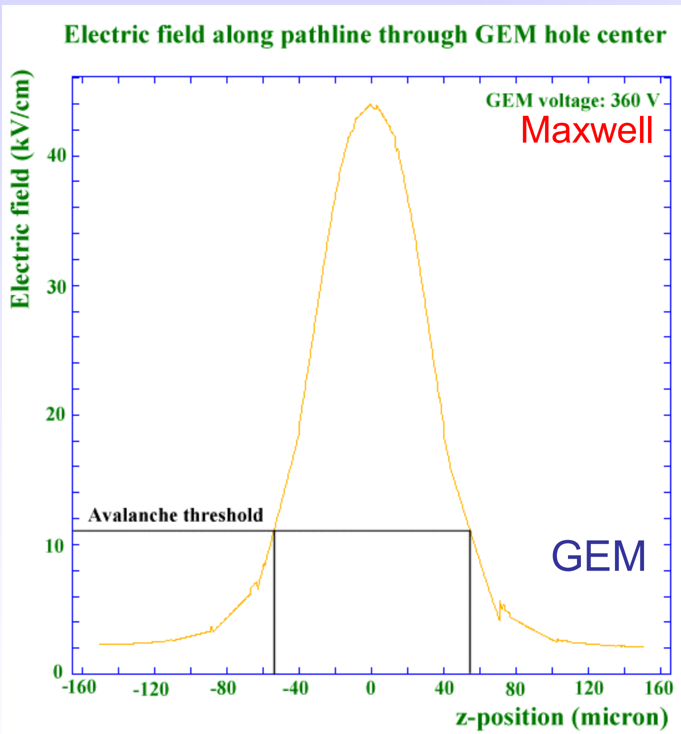
Garfield *(R.Veenhof)*

fields, drift properties, signals (interfaced to programs above)

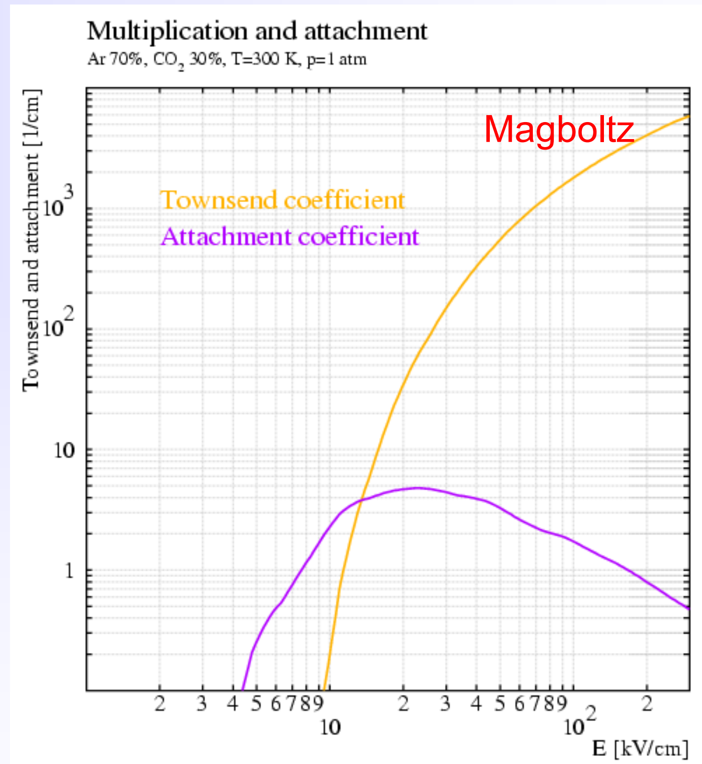
PSpice *(Cadence D.S.)* electronic signal

Computer Simulations

Input: detector geometry, materials and elctrodes potentials, gas cross sections.



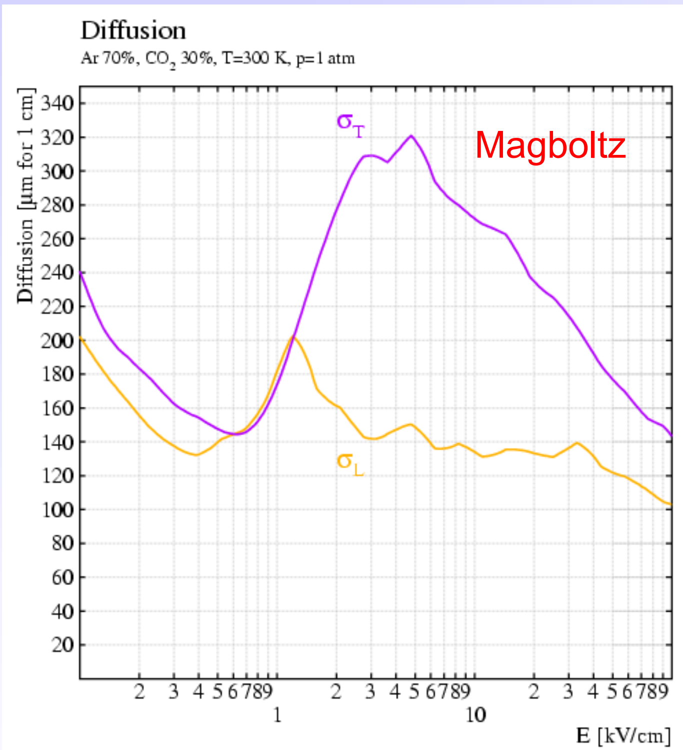
Field Strenght



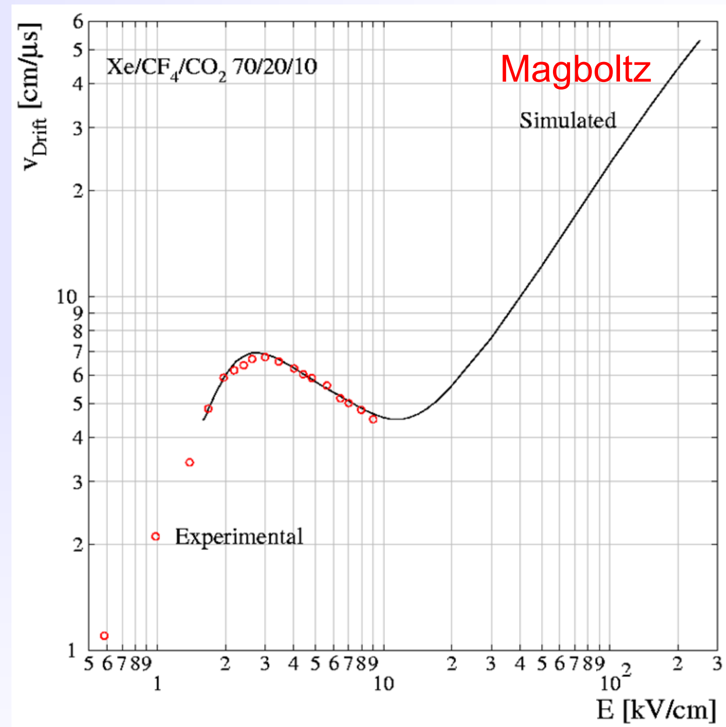
Townsend coefficient

P. Cwetanski, http://pcwetans.home.cern.ch/pcwetans/

Computer Simulations



Longitudinal, transverse diffusion

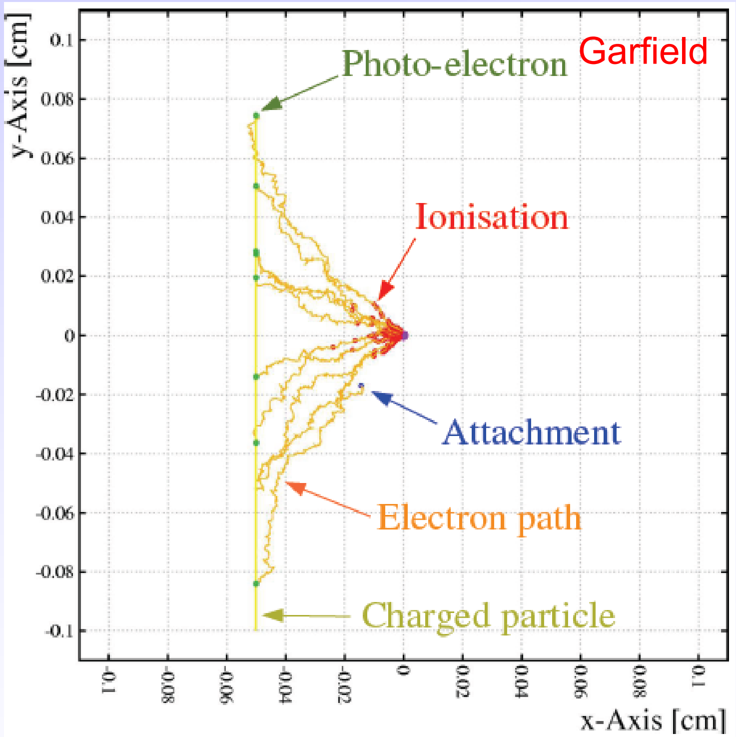


Drift velocity

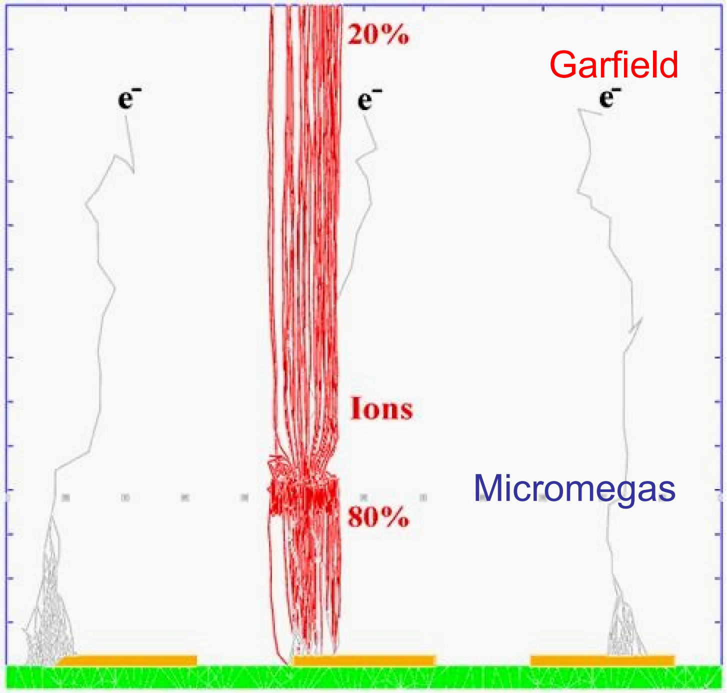
P. Cwetanski, http://pcwetans.home.cern.ch/pcwetans/

Computer Simulations

P. Cwetanski, http://pcwetans.home.cern.ch/pcwetans/
R. Veenhof – CERN detector seminar



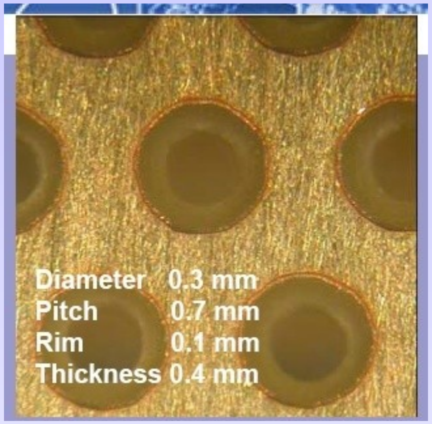
CSC-microtracking in Garfield

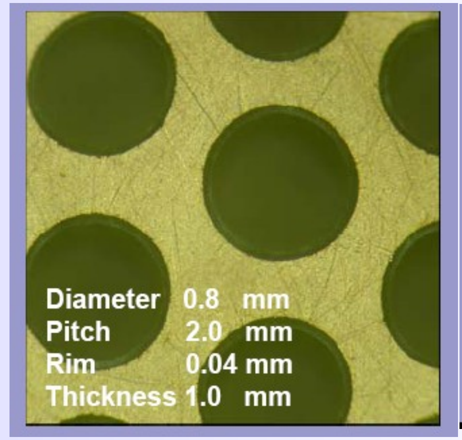


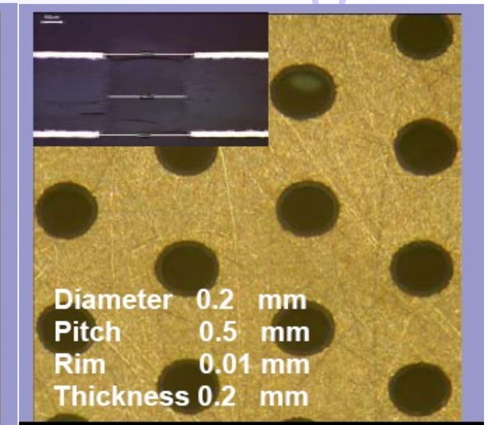
Positive ion backflow

Conclusion: we don’t need to built detector to know its performance

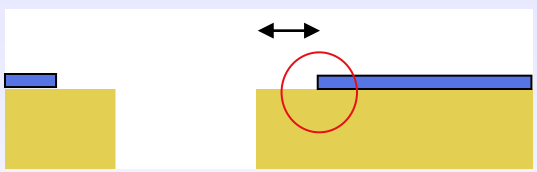
THGEM Example

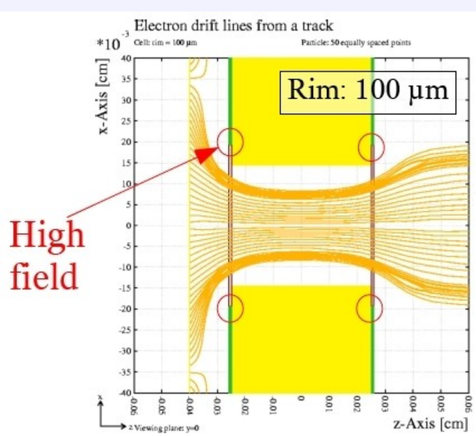


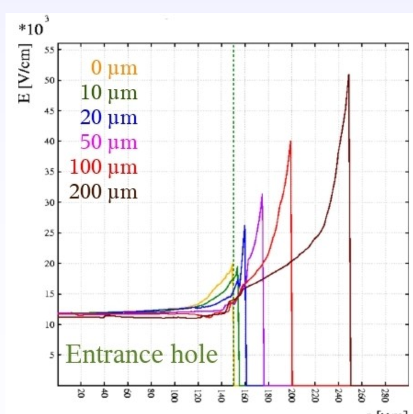




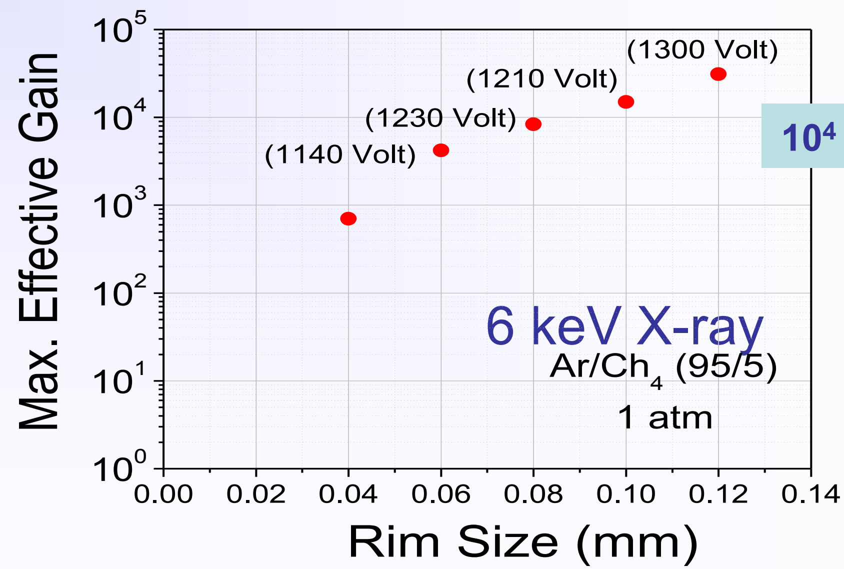
Mask etching + drilling; rim = 0.1mm





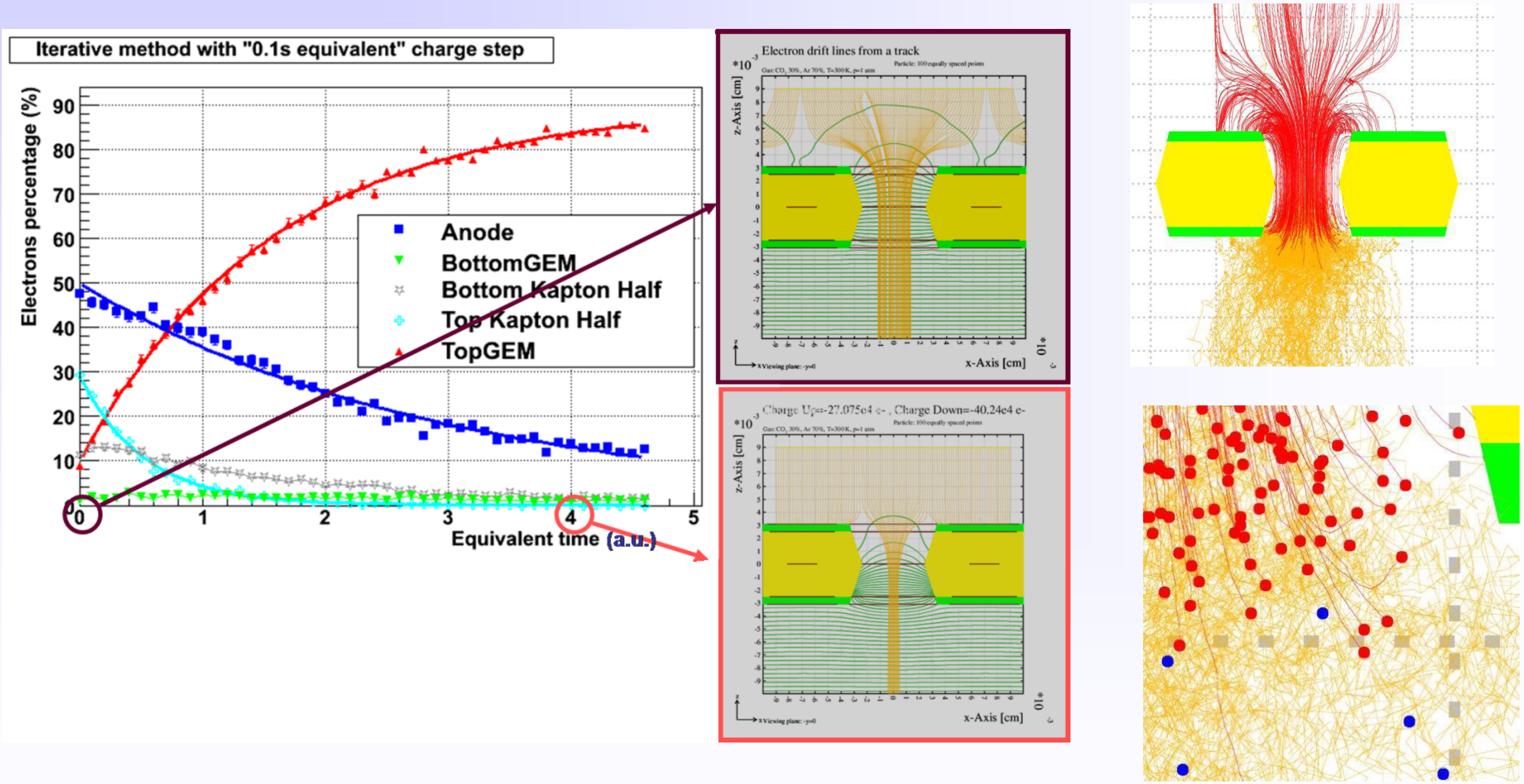


Drilling + chemical rim etching without mask



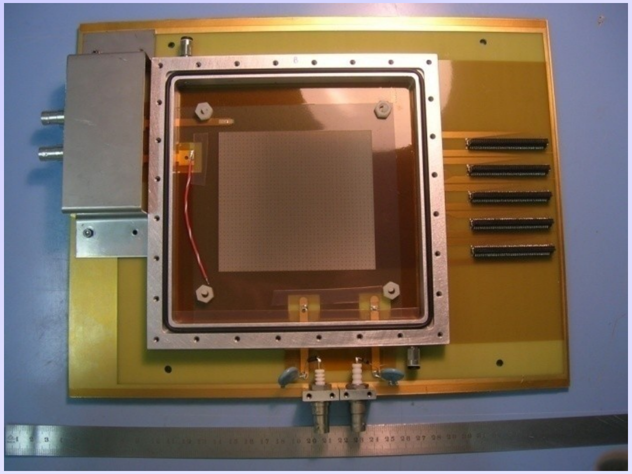
pitch = 1 mm; **diameter** = 0.5 mm;
rim=40; 60; 80; 100; 120 µm

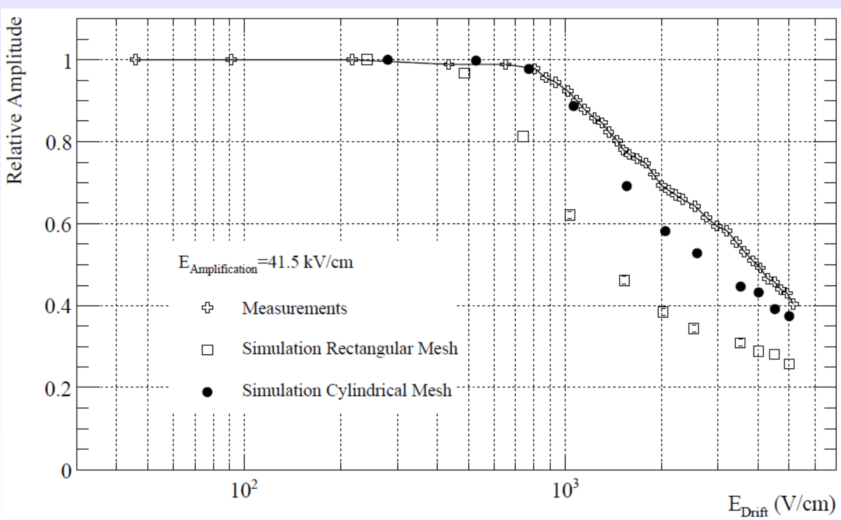
GEM charging up simulations

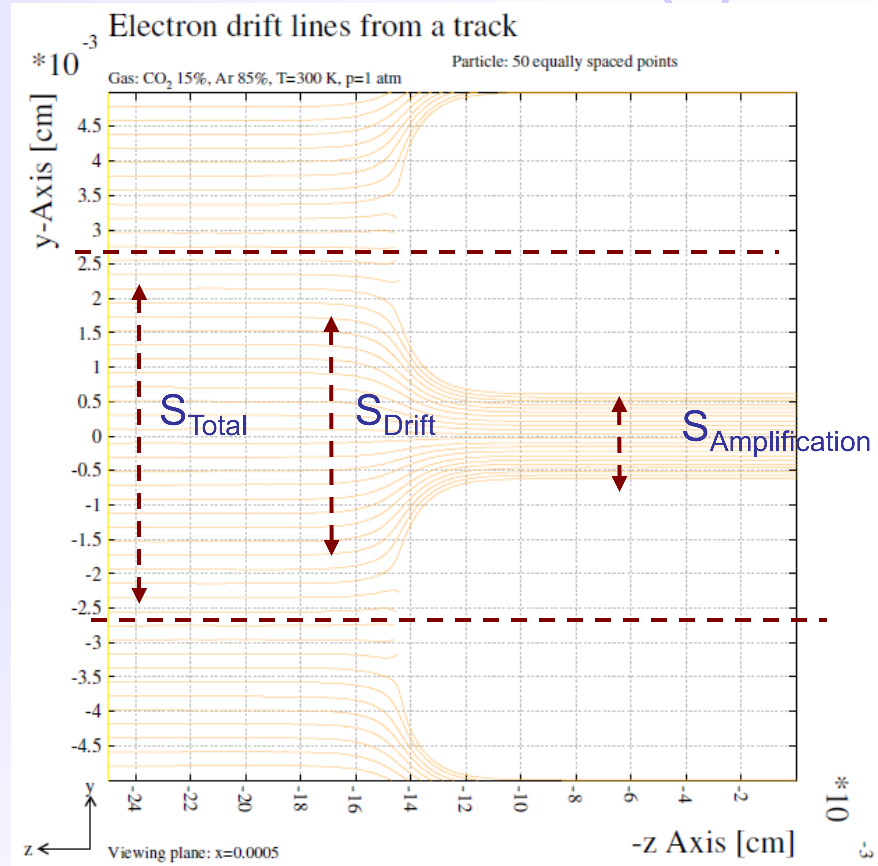


G. Croci (CERN) - 3rd RD51 collaboration meeting - Crete - 16-17 June 2009

Micromegas Electron Transparency : Simulation vs Measurements







P(e-collection) = S_{Drift} / S_{Total}

=$S_{Amplification}$ × Field-Ratio / S_{Total}

~ (hole diameter)^2 ~ (wires pitch)^2

Efficiency decrease starts at same drift field with the data (Ea/Ed ~ 55)

- Predicted efficiency in the falling slope within 10% from the measurement

Gas Detectors in LHC Experiments

ALICE: TPC (tracker), TRD (transition rad.), TOF (MRPC), HMPID (RICH-pad chamber), Muon tracking (pad chamber), Muon trigger (RPC)

ATLAS: TRD (straw tubes), MDT (muon drift tubes), Muon trigger (RPC, thin gap chambers)

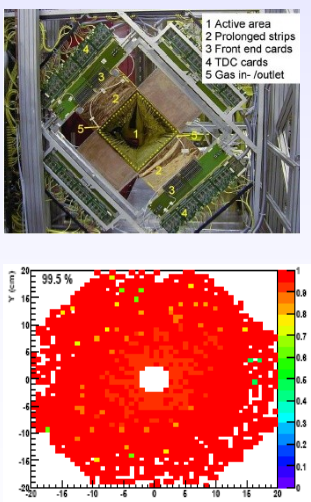
CMS: Muon detector (drift tubes, CSC), RPC (muon trigger)

LHCb: Tracker (straw tubes), Muon detector (MWPC, GEM)

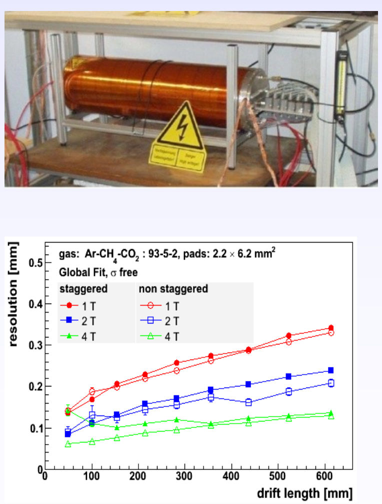
TOTEM: Tracker & trigger (CSC , GEM)

Current Trends in Micro-Pattern Gas Detectors (Applications)

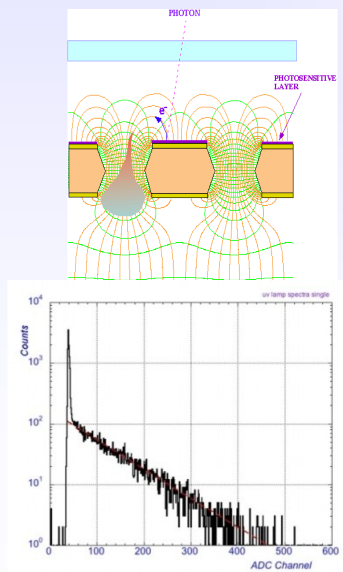
- **High-Rate Particle Tracking and Triggering**
- **Time Projection Chamber Readout**
- **Photon Detectors for Cherenkov Imaging Counters**
- **X-Ray Astronomy**
- **Neutron Detection and Low Background Experiments**
- **Cryogenic Detectors**
- **Medical Applications**
- **Homeland Security and Prevention of Planetary Disasters**



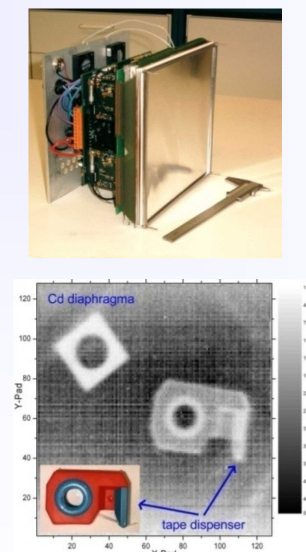
Tracking - Micromegas



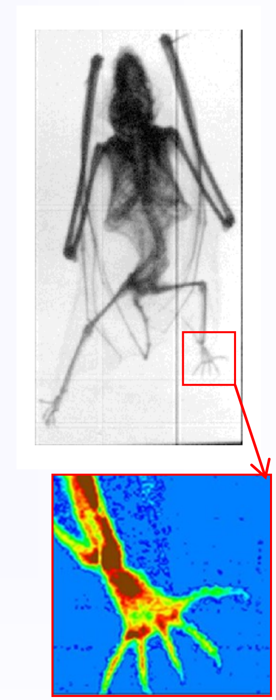
TPC readout - GEM



UV photon detection - GEM



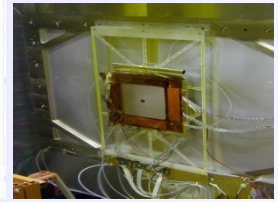
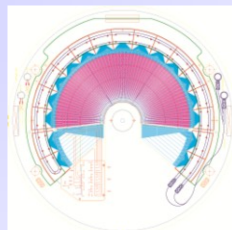
Neutron detection - GEM

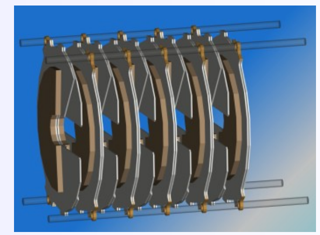


Radiography - GEM

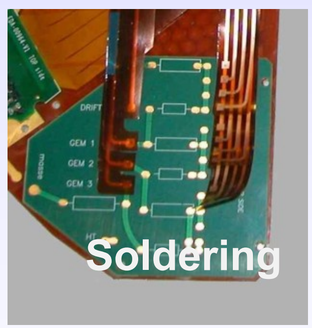
Production Aspects

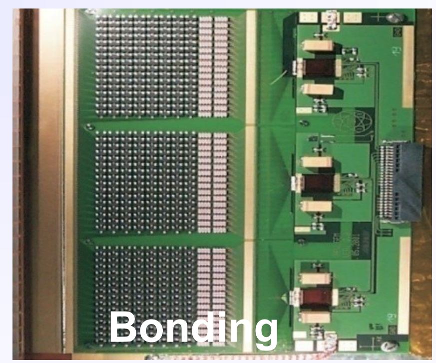
Detector Design

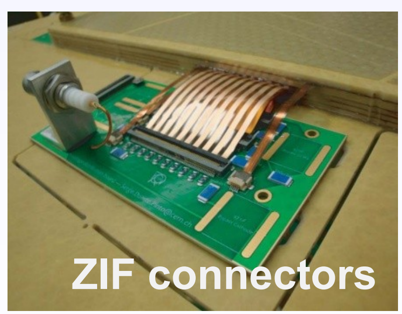




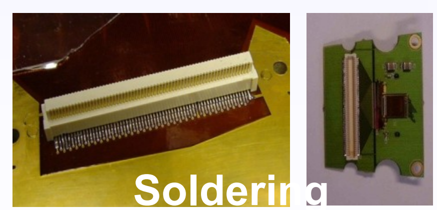



Services and Connectivity



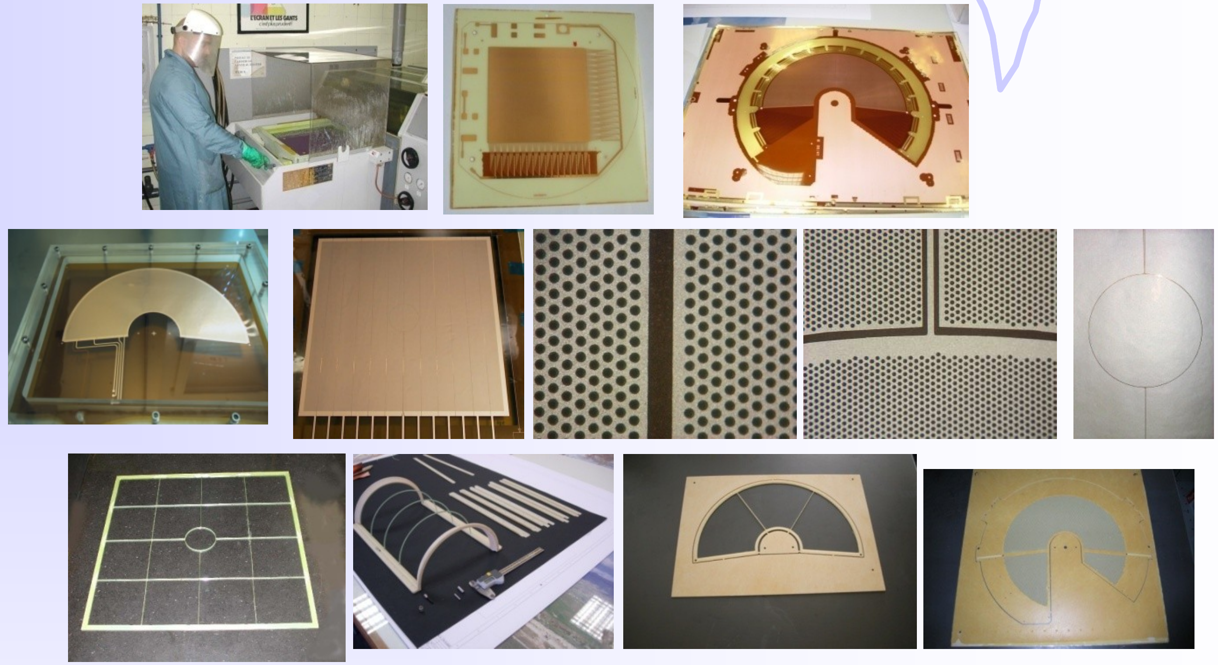




Production Aspects

Component Production

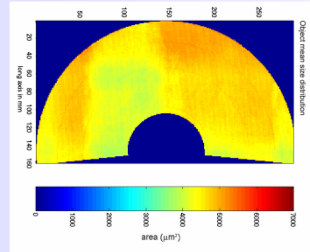


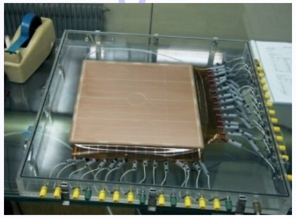
Infrastructure

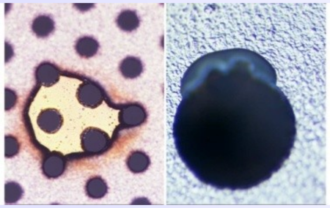
and Assembly Tools

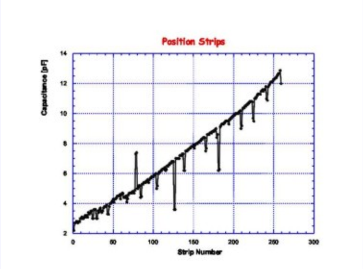
Production Aspects

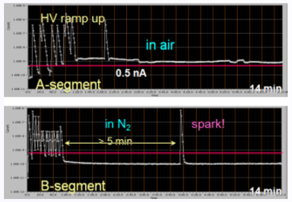
Component Quality Control



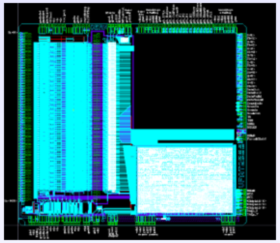


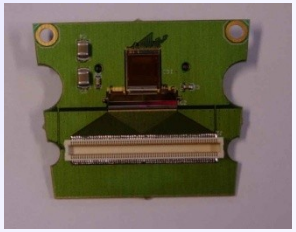


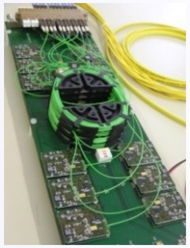




Electronics

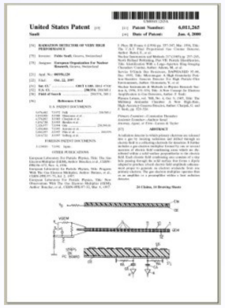






APV
VFAT
GP5
ALTRO
MEDIPIX

Industrialization



PANalytical
3M
TechEtch
Techtra
Centronic
G&A

Acknowledgments

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