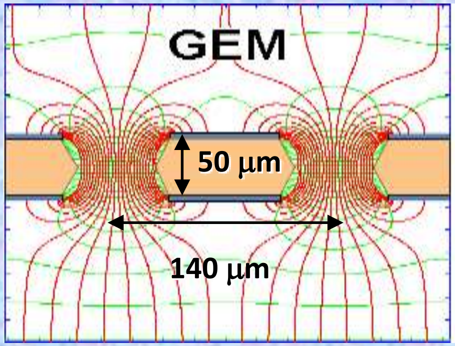
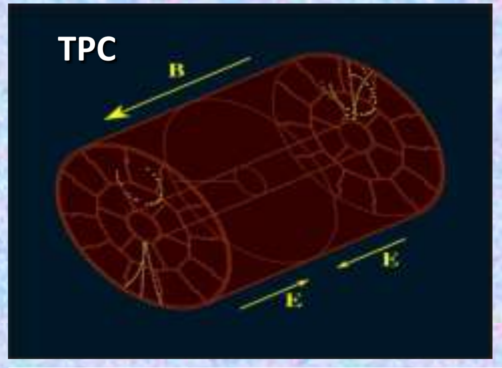
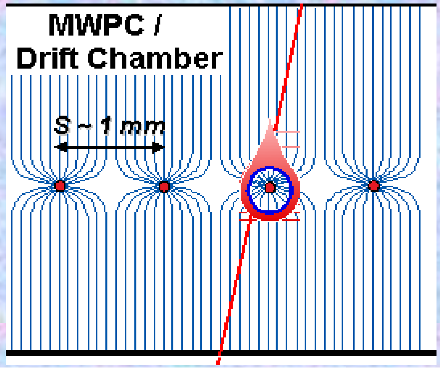
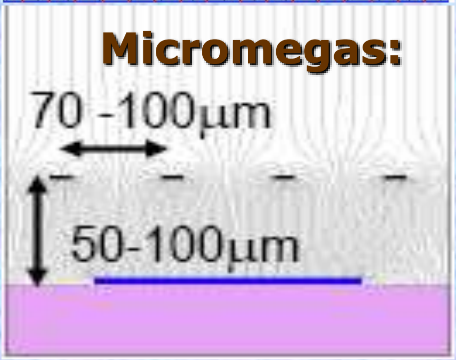






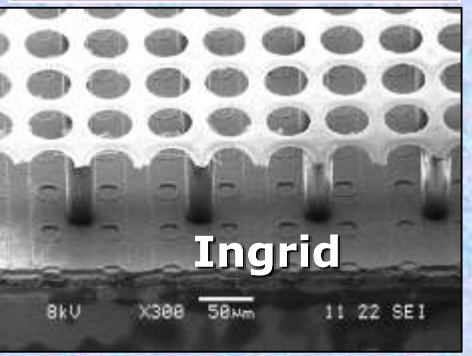
Gaseous Tracking Detectors: From Basic Ideas to Novel Detector Concepts

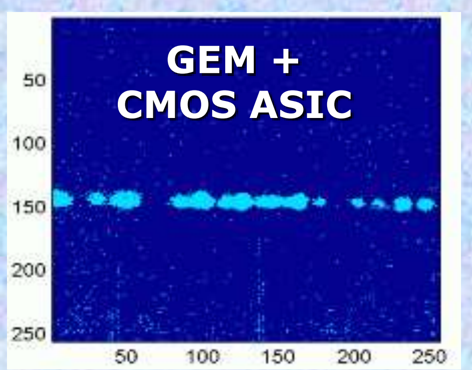
Maxim Titov, CEA Saclay, France



Outline of the Lecture:

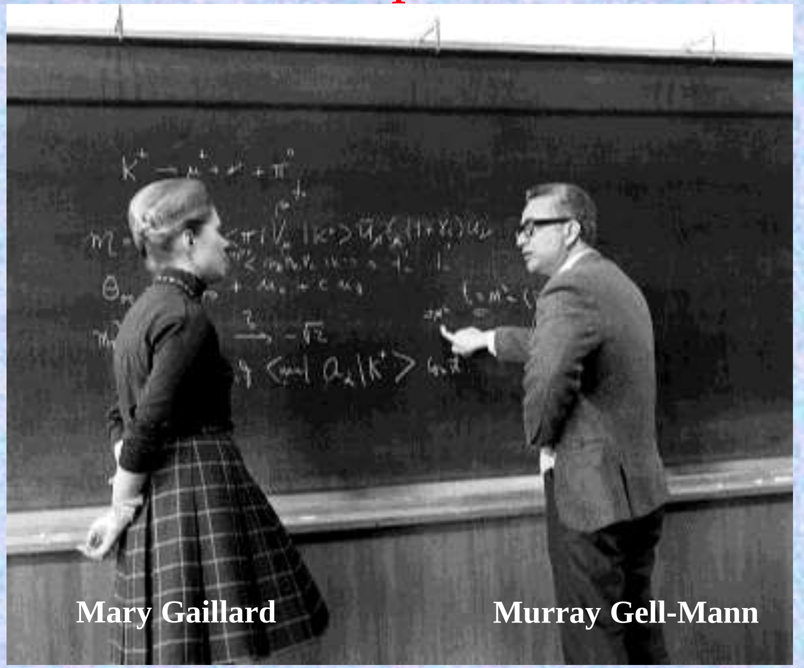
- Introduction: The History of Particle Detection
- Gaseous detector family
- Multi-wire proportional (MWPC) and drift chambers, time projection chamber (TPC)
- Novel Micro-Pattern Gaseous Detectors
- MPGD Applications
- Future Trends





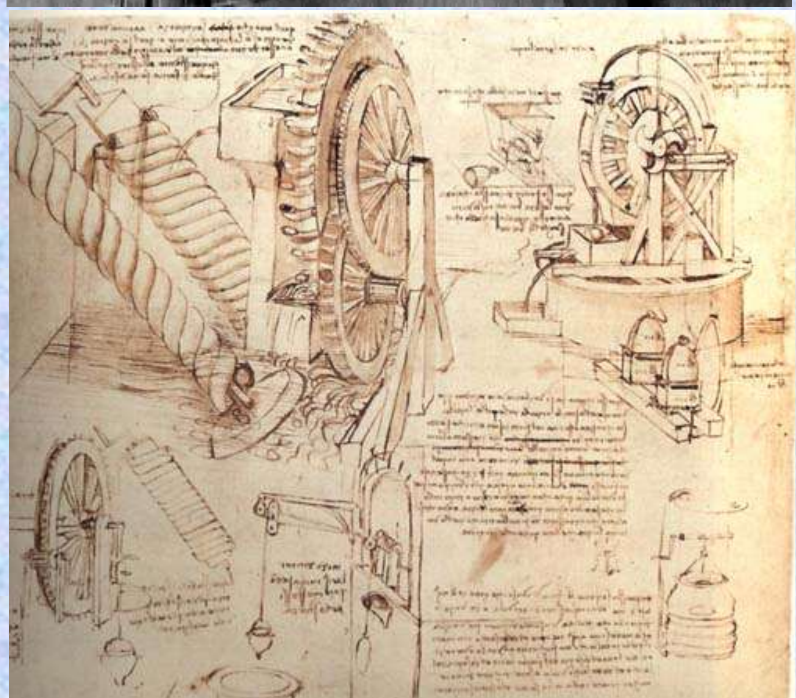
Danube School on Instrumentation in Elementary Particle & Nuclear Physics, Novi Sad, Serbia, September 8-13, 2014

To do a HEP experiment, one needs:

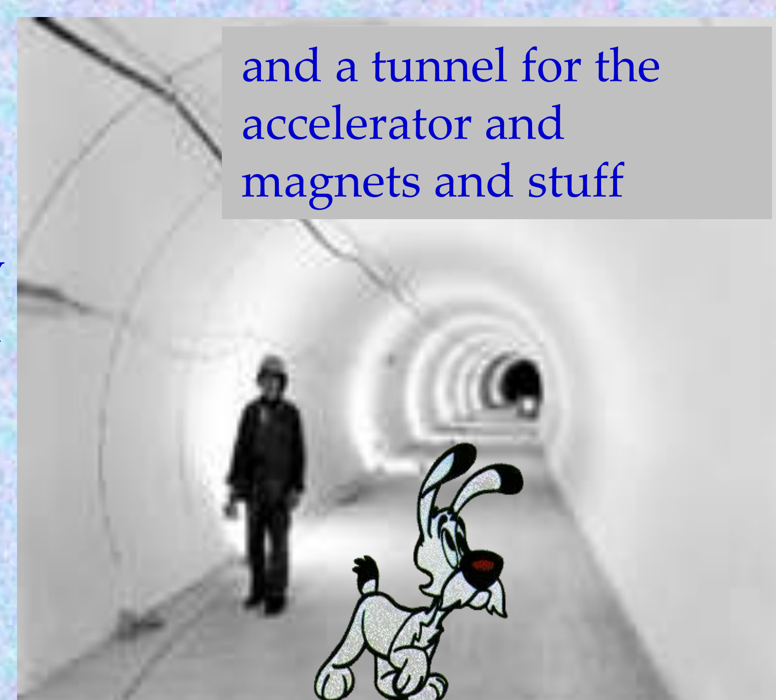


A theory:

and a cafeteria



Clear and easy understandabl e drawings

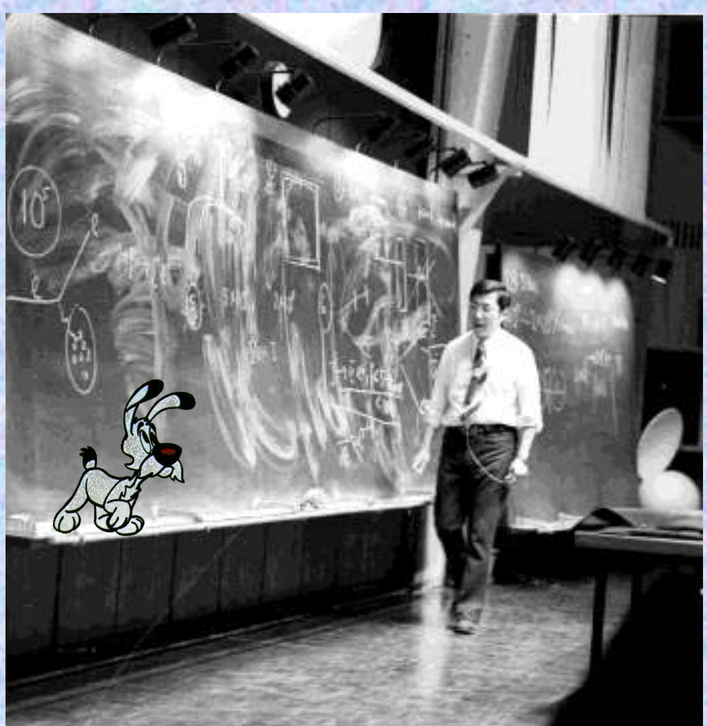


and a tunnel for the accelerator and magnets and stuff

O. Villalona/2006

Easy access to the experiment

Physicists to operate detector/analyze data



and a Nobel prize

We will just concentrate on the gaseous detectors

O. Ullaland/2006

Tracking Detectors: History and Trends

Detect and reconstruct the trajectory of charged of charged particles:

- ➢ Determine direction and momentum
- ➢ Minimize the distortion of the trajectory(as little material as possible)
- ➢ Decay time (lifetime, flavor tagging)

I. History of "Tracking Detectors":

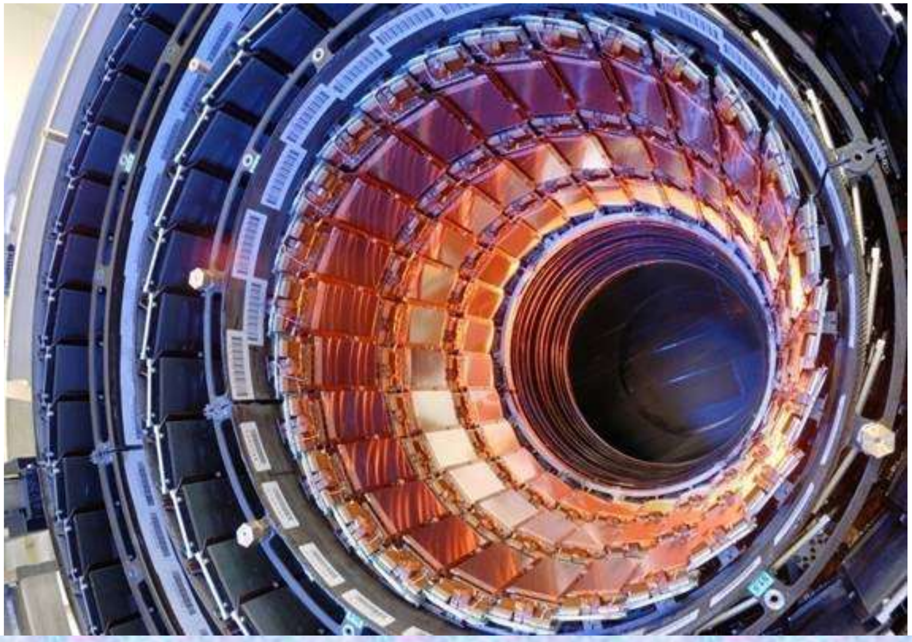
- ❖ Geiger Counter
- ❖ Cloud chamber
- ❖ Nuclear emulsion
- ❖ Bubble chamber
- ❖ … and many others

II. Gaseous Detectors:

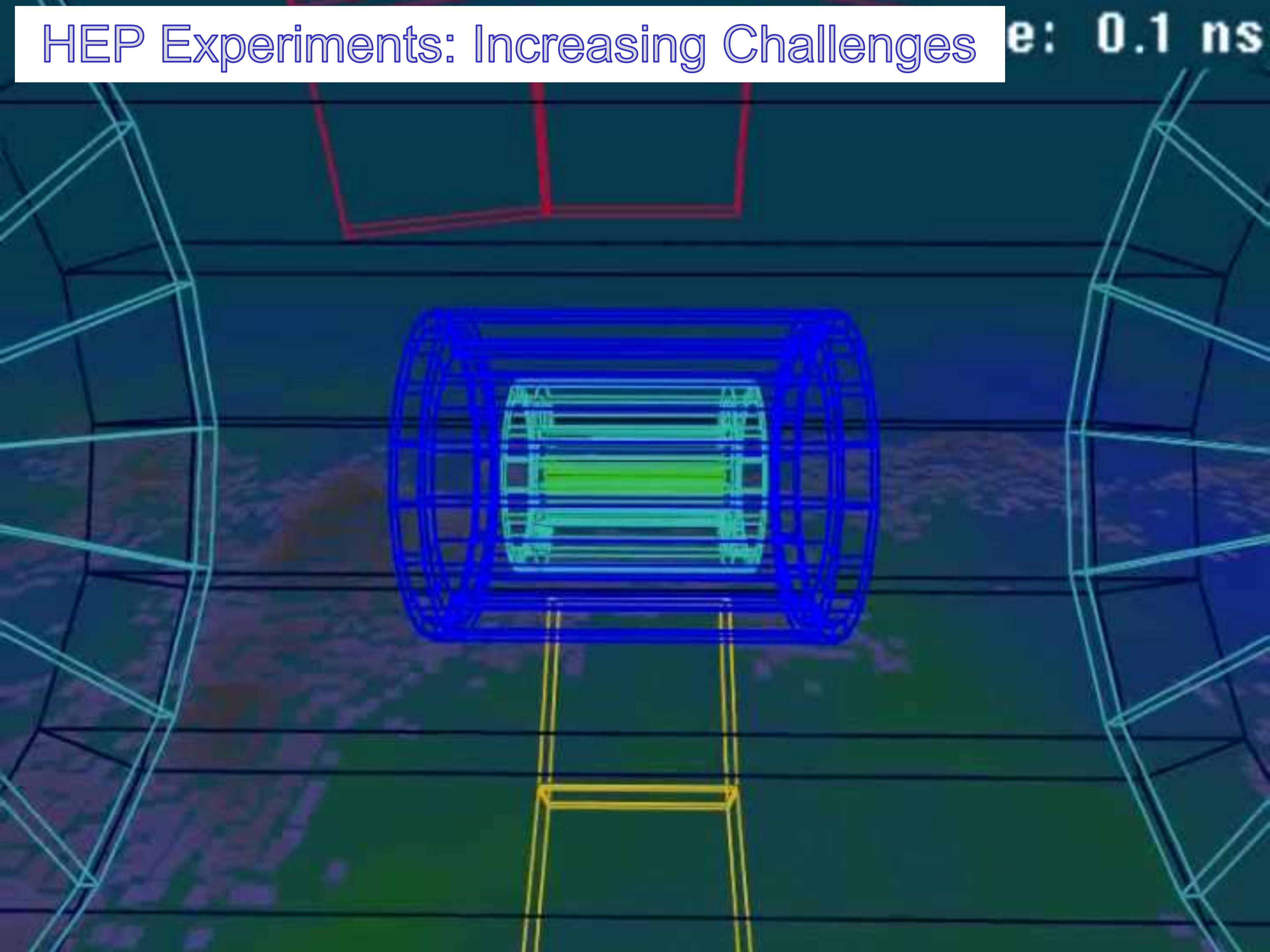
- • Wire Chambers, RPC, TPC
- • Micro-Pattern Gas Detectors

III. Solid State (Si) Detectors:

- • Microstrip/Pixel Detectors
- • 3D technology and integration



HEP Experiments: Increasing Challenges



Particle Interactions with Matter

All interactions of particles with matter involve energy loss, that is seen as either:

→ Ionization, Scintillation light, Cerenkov light, …

Charged particle interaction with matter →

energy (kinetic) loss by Coulomb interaction with the atoms/electrons :

- Excitation : the atom (or molecule) is excited to a higher level

  atom* → atom + γ

  low energy photons of de-excitation

  ➔ light detection

- Ionization : the electron is ejected from the atom

  electron / ion pair

  ➔ charge detection

- Instead of ionization/excitation real photon can be produced under certain conditions

  ➔ Cherenkov or Transition radiation

The History of Instrumentation is VERY Entertaining

- A look at the history of instrumentation in particle physics

  → complementary view on the history of particle physics, which is traditionally told from a theoretical point of view

- The importance and recognition of inventions in the field of instrumentation is proven by the fact that

  → several Nobel Prices in physics were awarded mainly or exclusively for the development of detection technologies

Nobel Prizes in instrumentation ("tracking concepts"):

- 1927: C.T.R. Wilson, Cloud Chamber
- 1960: Donald Glaser, Bubble Chamber
- 1992: Georges Charpak, Multi-Wire Proportional Chamber

History of Particle Detection

Image Detectors

Bubble chamber photograph

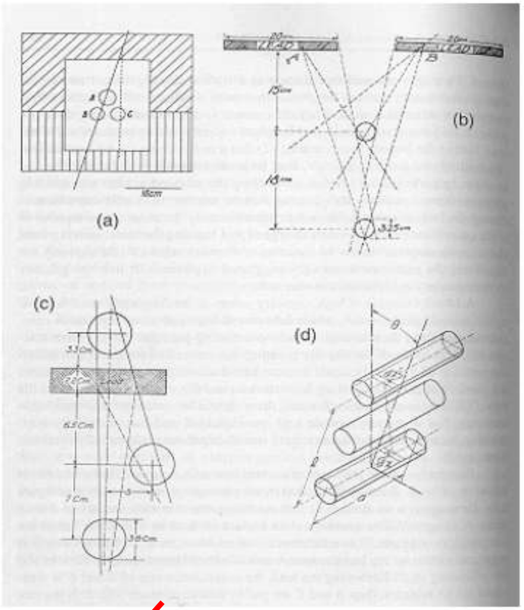
History of 'Particle Detection'

Image Tradition: Cloud Chamber
Emulsion
Bubble Chamber

Logic Tradition: Scintillator
Geiger Counter
Tip Counter
Spark Counter

Electronics Image: Wire Chambers
Silicon Detectors
…

'Logic (electronics) Detectors'

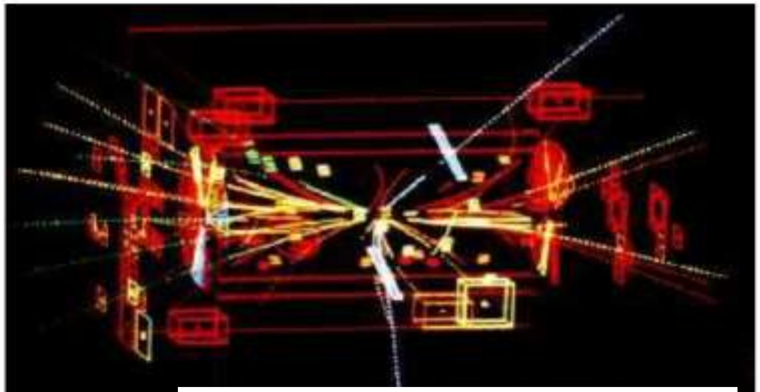


Early coincidence counting experiment

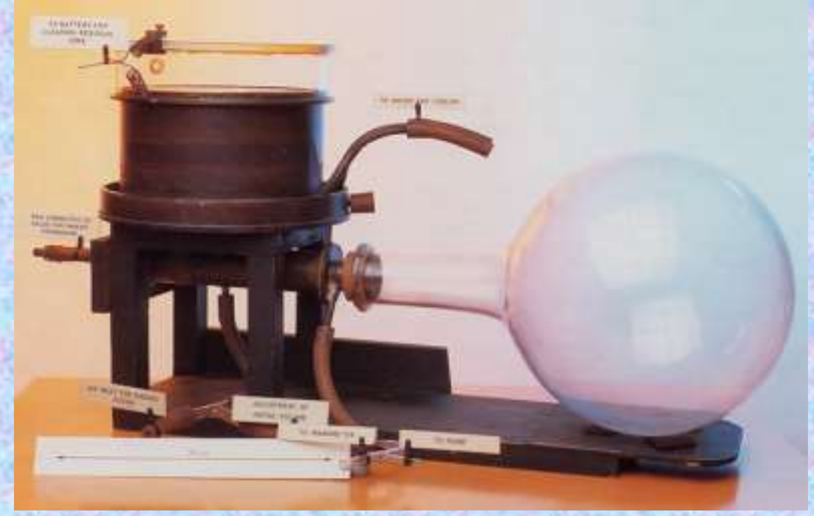
- 1906: Geiger Counter, H. Geiger, E. Rutherford
- 1910: Cloud Chamber, C.T.R. Wilson
- 1912: Tip Counter, H. Geiger
- 1928: Geiger-Müller Counter, W. Müller
- 1929: Coincidence Method, W. Bothe
- 1930: Emulsion, M. Blau
- 1940-1950: Scintillator, Photomultiplier
- 1952: Bubble Chamber, D. Glaser
- 1962: Spark Chamber
- 1968: Multi Wire Proportional Chamber, C. Charpak

Etc. etc. etc.

Both traditions combine into the 'Electronics Image' during the 1970ies



Z-Discovery at UA1 CERN in 1983



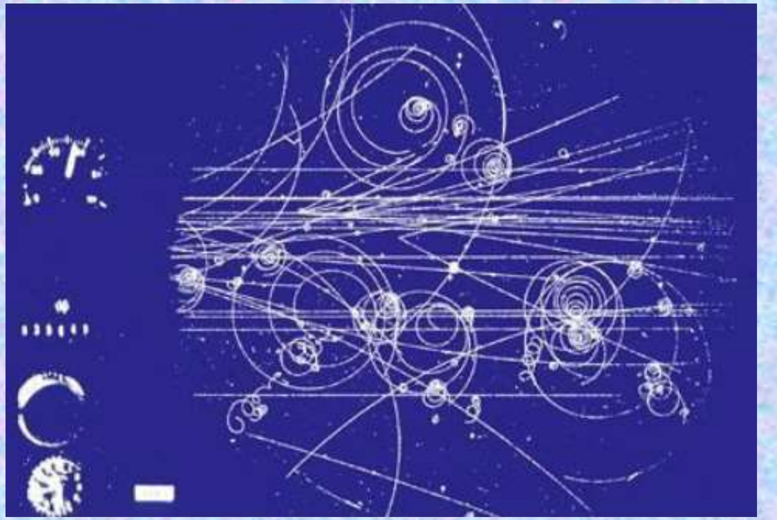
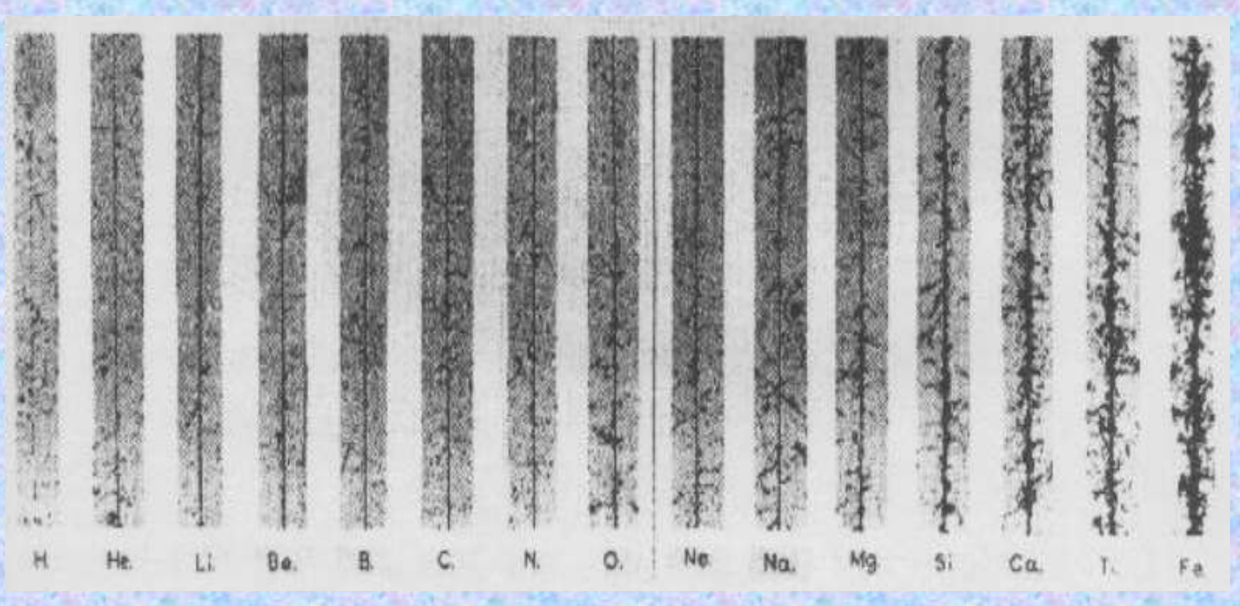
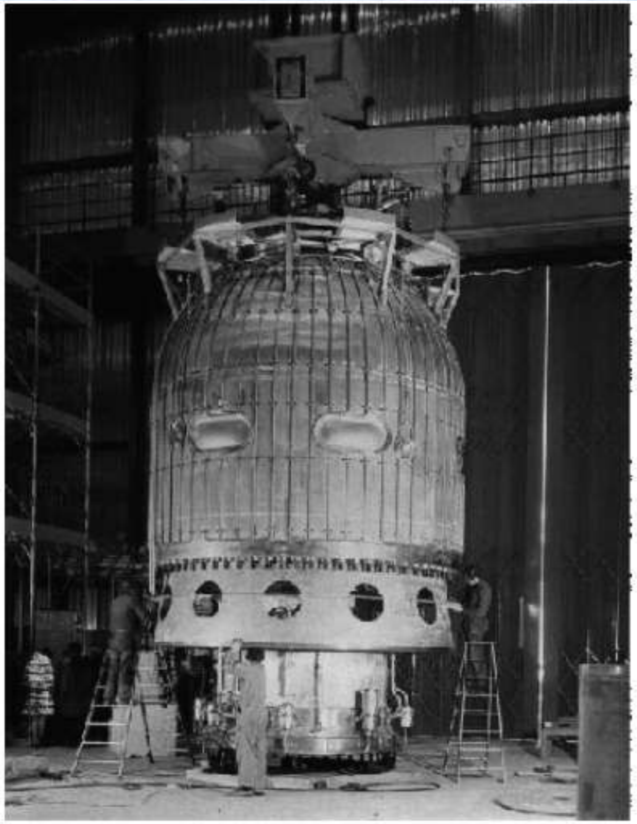


Image Detectors
(Cloud Chamber, Bubble Chamber)





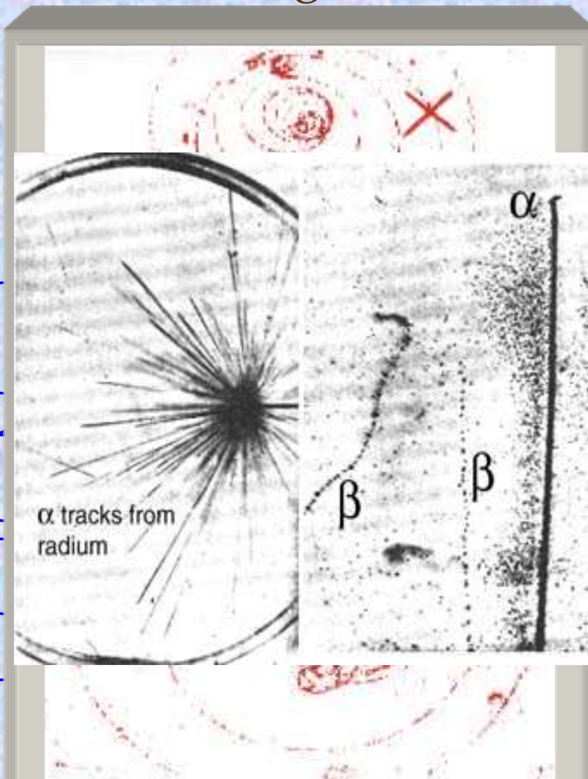
Can be seen outside the Microcosm Exhibition

First Tracking Detector: Wilson Chamber

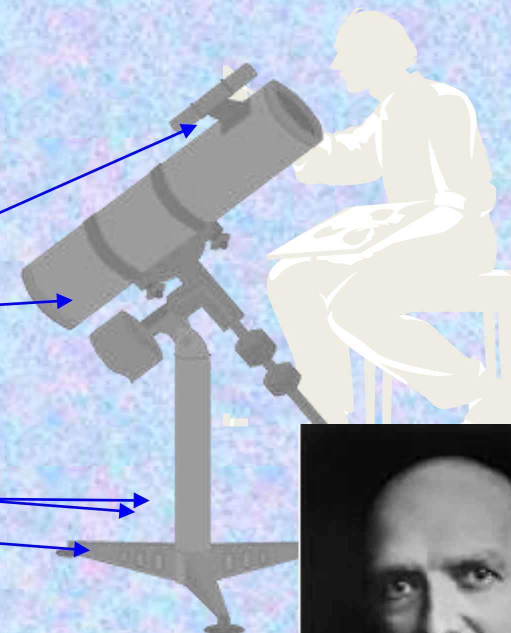
Cloud chamber
(1911 by Charles

NOBEL
Prize in Physics 1927

Cloud Chamber
+ Magnet

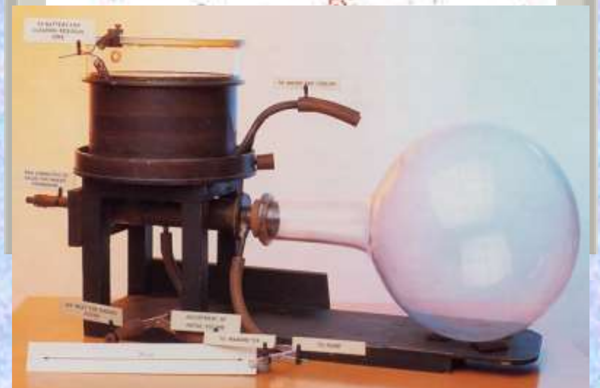


Observer



Flux of particles

Allow water to evaporate in an enclosed container to the point of saturation and then lower the pressure
→ over-saturated volume of air



Passage of charge particle would condense the vapor into tiny droplets, marking the particle's path
→ their number being proportional to dE/dx

O. Ullaland/2006

Discovery of a Positron e+ from Cosmic Rays

1932 C.D. Anderson :

- Particle with positive curvature and minimum ionisation (droplets size)
- Track length is at least 10 times greater than the possible length of a proton path of this curvature
- Energy loss in a 6 mm of Pb: compatible with that of electron

Hypothesis (discovery !) :

- particle with mass ~m_e and charge +1, the positron

❖ *First anti-particle*

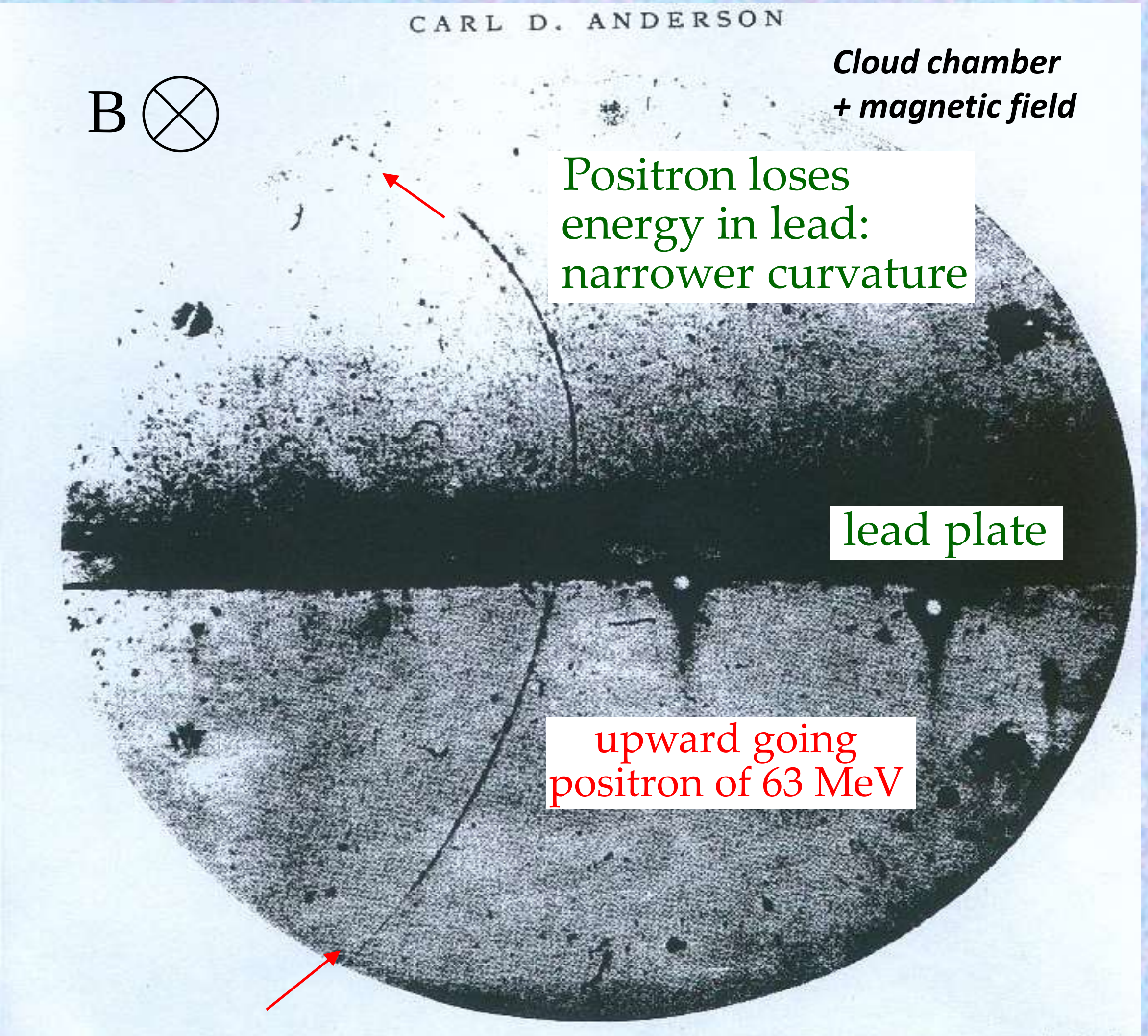


FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plat and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

Discovery of the positron by Cloud Chamber (1932 by Carl Anderson, Noble Prize 1936)

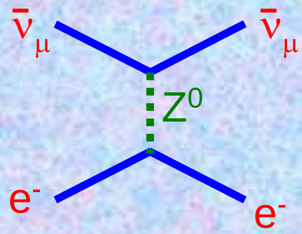
Bubble Chamber

1952 by Donald Glaser, Noble Prize 1960

(4.8 x 1.85 m^2) chamber with liquid (H_2) at boiling point ("superheated")

Similar principle as cloud chamber:

- Instead of supersaturating a gas with a vapor one would superheat the liquid.
- A particle leave a trail of ions along its path → make a liquid boil, and form gas bubbles around ions



was used for discovery of the "neutral current"
(1973 by Gargamelle Collaboration, no Noble Prize)

CERN

Bubble Chamber

- Advantages:

  liquid (hydrogen) is BOTH detector medium AND target

  high precision (~ 5 μm)

- Disadvantages:

  - NO TRIGGER -> has to be in superheated state when particle is entering

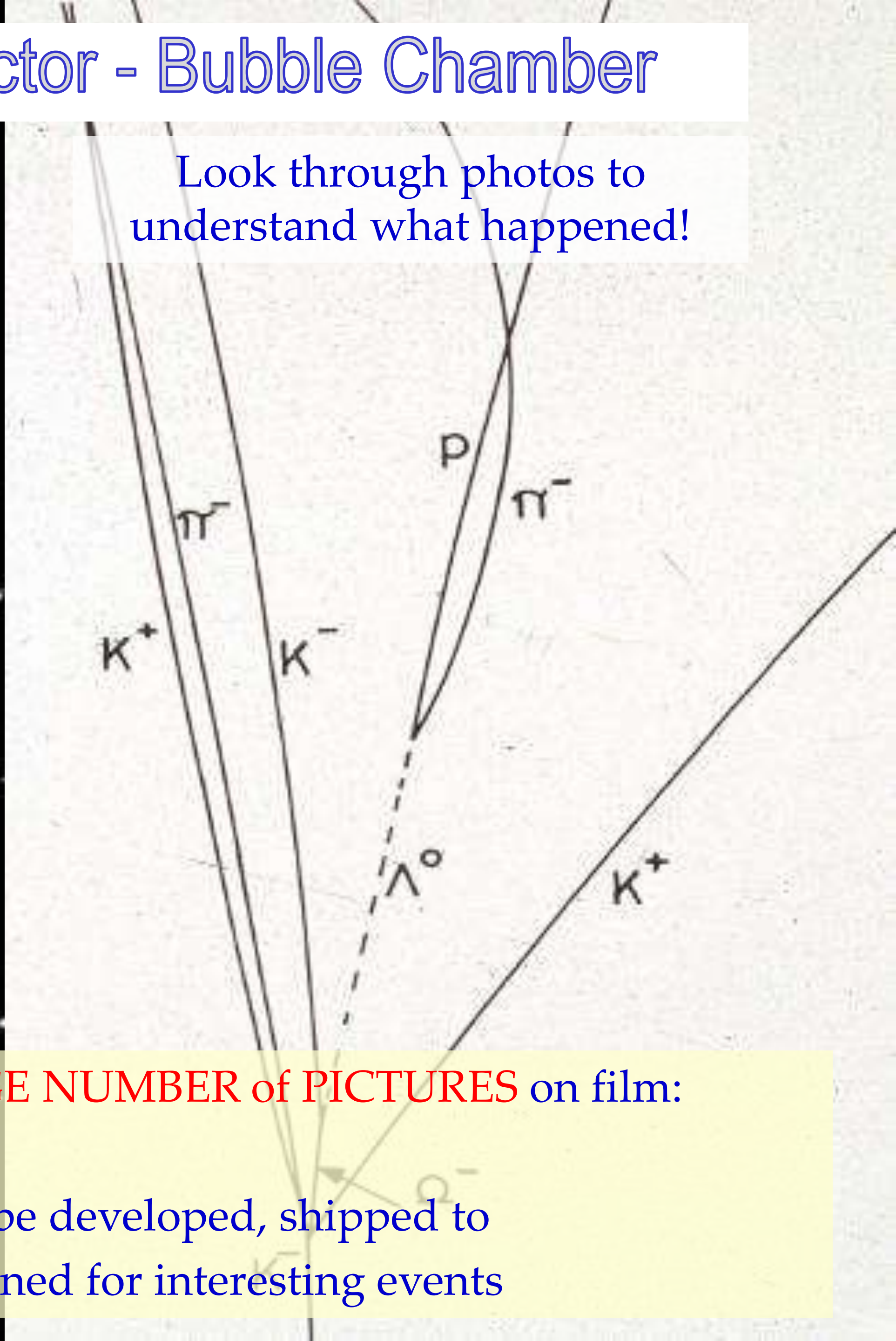
  LOW RATE CAPABILITY Need FASTER detector (electronics !)

Liquid hydrogen “**bubble chamber**”

The hydrogen acts as a target (for incoming particles) and a detection medium

Classical Tracking Detector - Bubble Chamber

Particle colliding with proton in liquid hydrogen

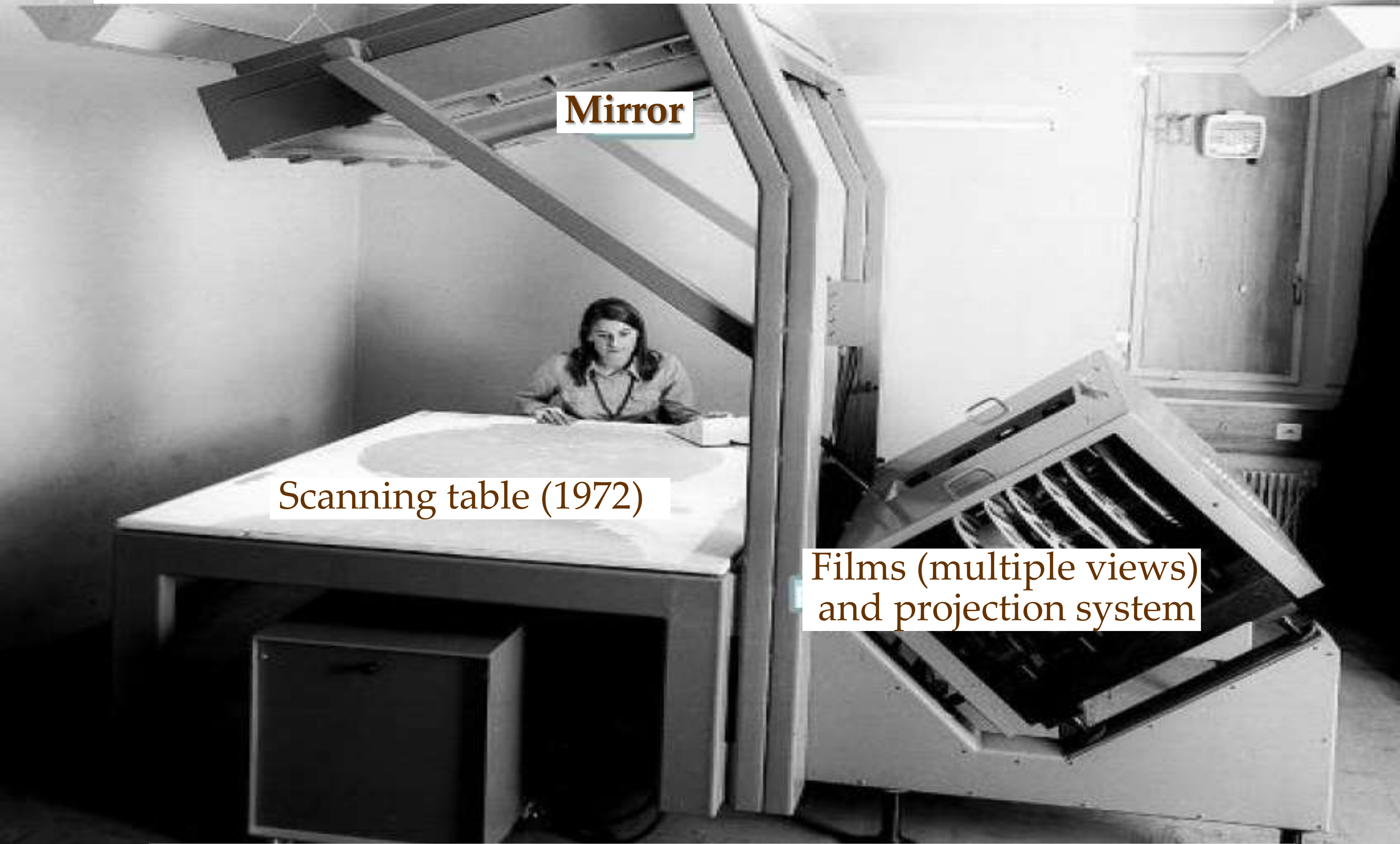


Look through photos to understand what happened!

For DATA ANALYSIS one has to take HUGE NUMBER of PICTURES on film:

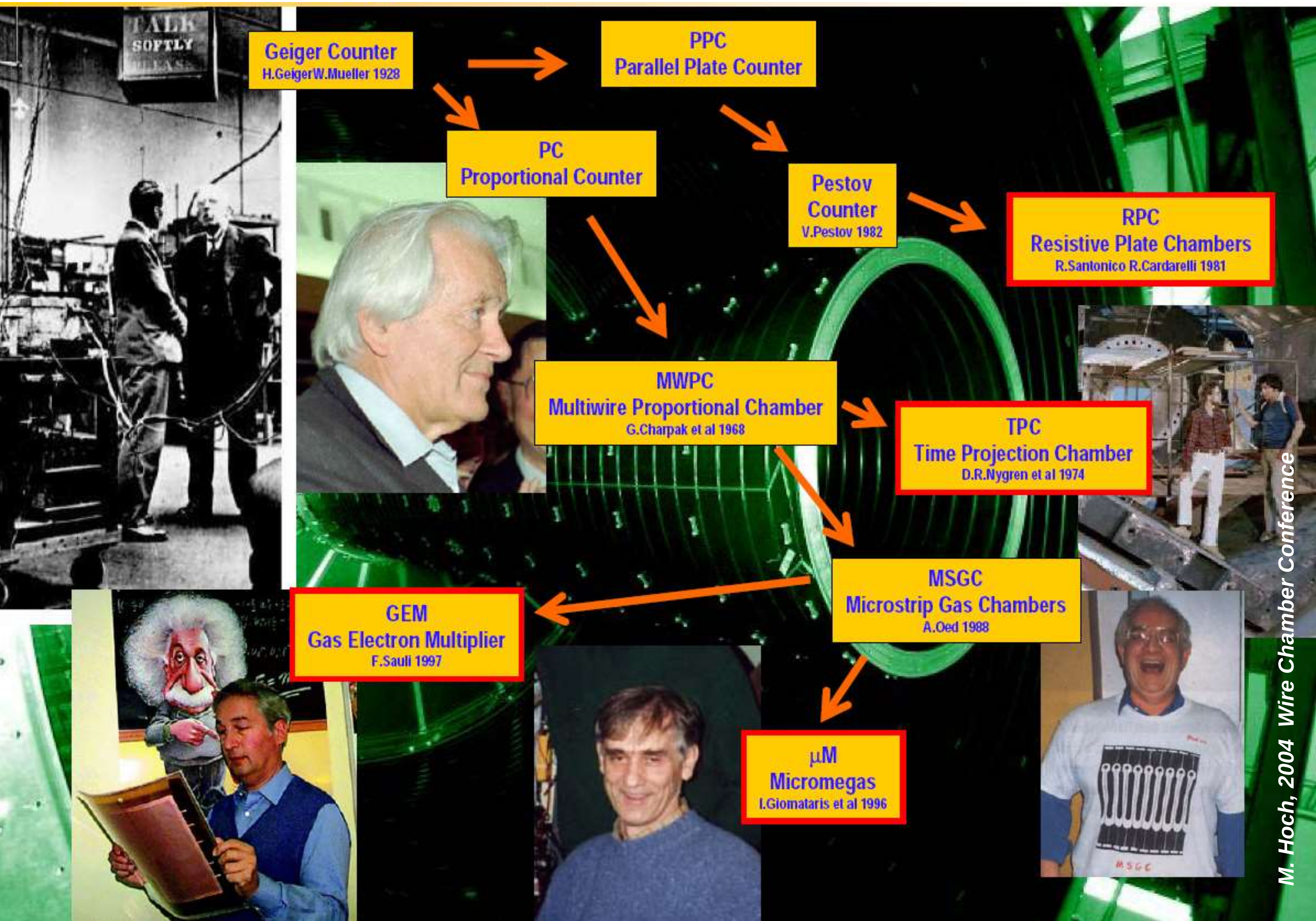
- Many people employed - film needs to be developed, shipped to institutes and optically scanned for interesting events

Social Aspects of the « Bubble Chamber » Era



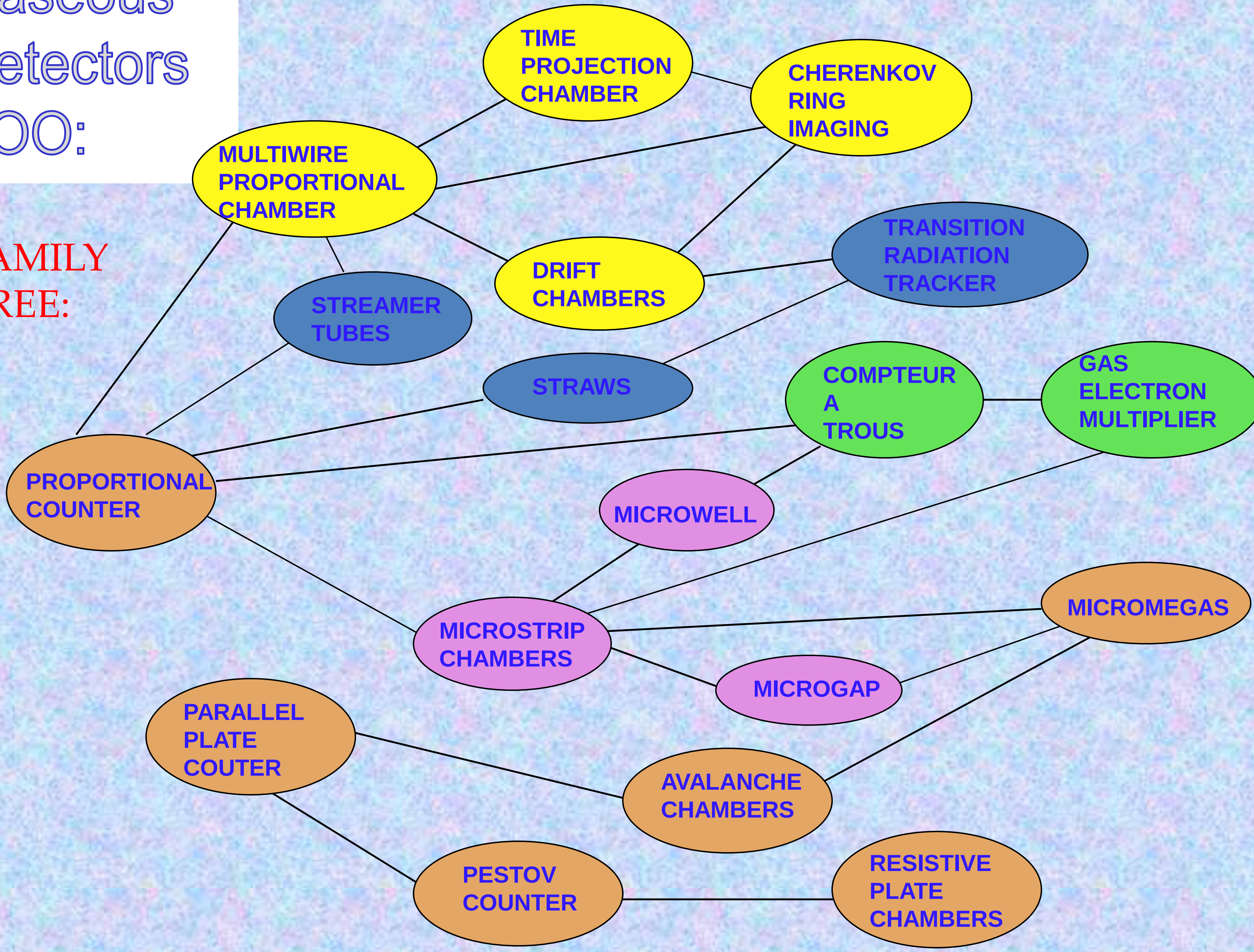
scanning often done by young "scanning girls" (students)...
...who later got married with the physicists...

History of Gaseous Detectors



Gaseous Detectors ZOO:

FAMILY TREE:



Gaseous Detectors: Why do we use gas medium ?

Three states of matter:
Solid, Liquid, Gas – why use Gas as a medium for ionization ?

⚜ **Effectively quite light in terms of gm/cm^2, requirement for reducing multiple scattering in particle physics**

⚜ **Few other technologies can easily realize detectors with as large a sensitive area as gas-filled devices**

⚜ **Gas-filled detectors are relatively cheap in terms of $ per unit area/volume**

⚜ **There are optimized gas mixtures for charged particles detection (high energy and nuclear physics), X-rays (synchrotron physics, astronomy) and neutrons (neutron scattering, national security)**

⚜ **Electron transport characteristics are favorable and well characterized**

⚜ **Gas gain, *M* (electron multiplication factor), can be achieved, over many orders of magnitude (large dynamic range)**

⚜ **Ionization collection or fluorescence emission can form the signal**

Schematic Principle of Gas Detectors

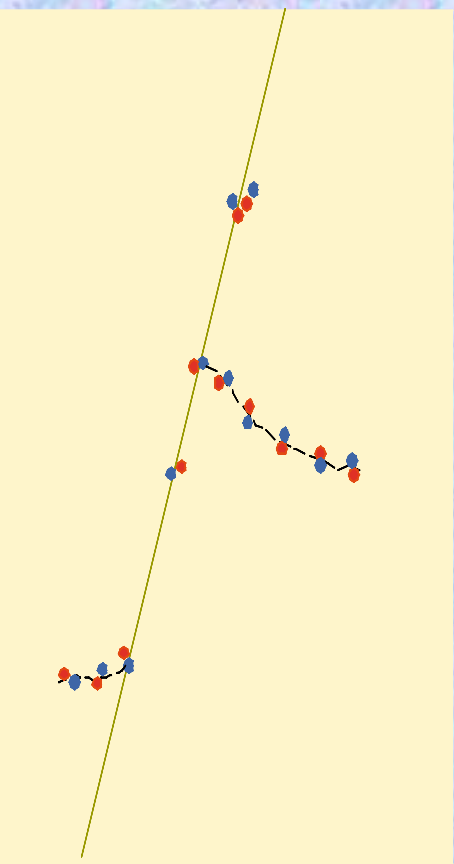
TOTAL IONIZATION:

- Primary electron-ion pairs
- Clusters
- Delta-electrons

Statistics of primary ionization:

Poisson: $$P_k^n = \frac{n^k}{k!} e^{-n}$$

n: average
k: actual number



Relevant Parameters
for gas detectors

Ionization energy	:	E_i
Average energy/ion pair	:	W_i
Average number of primary ion pairs [per cm]	:	n_p
Average number of ion pairs [per cm]	:	n_T

Differences due to δ-electrons

$$\langle n_T \rangle = \frac{L \cdot \left\langle \frac{dE}{dx} \right\rangle_i}{W_i}$$

[about 2-6 times n_p]
[L: layer thickness]

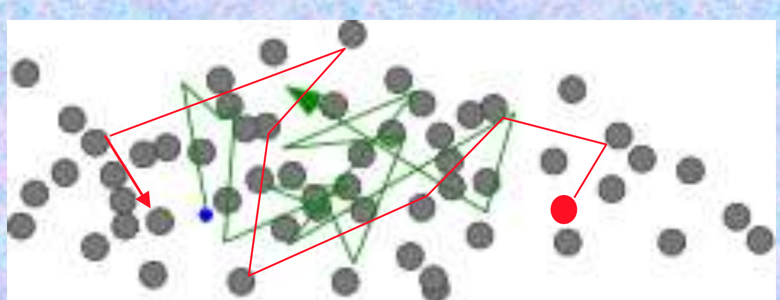
δ-electrons lead to secondary ionization and limit spatial resolution; typical length scale of secondary ionization: 10 µm. Example: kinetic energy: T_{kin} = 1 keV; gas: Isobutane ➔ range: R = 20 µm ...
[using R [g/cm²] = 0.71 $(T_{kin})^{1.72}$ [MeV]; valid for T_{kin} < 100 keV]

Gas	<Z>	ρ [g/cm³]	E_i [eV]	W_i [eV]	dE/dx [keV/cm]	n_p [cm⁻¹]	n_T [cm⁻¹]
He	2	$1.66\cdot10^{-4}$	24.6	41	0.32	5.9	7.8
Ar	18	$1.66\cdot10^{-3}$	15.8	27	2.44	29.4	94
CH_4	19	$6.7\cdot10^{-4}$	13.1	28	1.48	18	53
C_4H_{10}	34	$2.42\cdot10^{-3}$	10.6	23	4.50	46	195

N_{TOTAL} ~ 100 e-ion pairs (typical number for 1 cm of gas) is impossible to detect → the typical noise of very modern pixel ASICs is ~ 100e-
Need to increase number of e-ion pairs → … but ☺ … how ???

Drift and Diffusion of Electrons / Ions in the Gas

ELECTRIC FIELD E = 0: THERMAL DIFFUSION



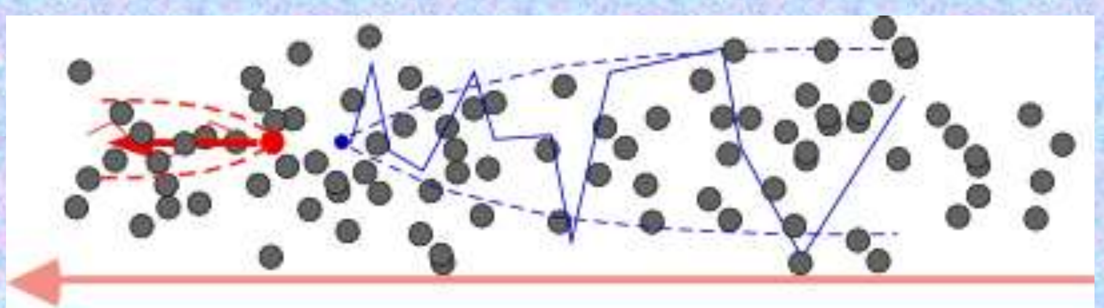
Maxwell energy distribution:

$$F(\varepsilon) = C\sqrt{\varepsilon}\, e^{-\frac{\varepsilon}{KT}};$$ <ε> ~ kT~ 0.025 eV

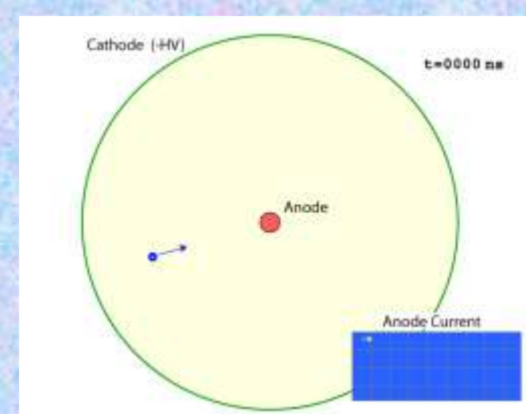
RMS of charge diffusion: $\sigma_x = \sqrt{2Dt}$

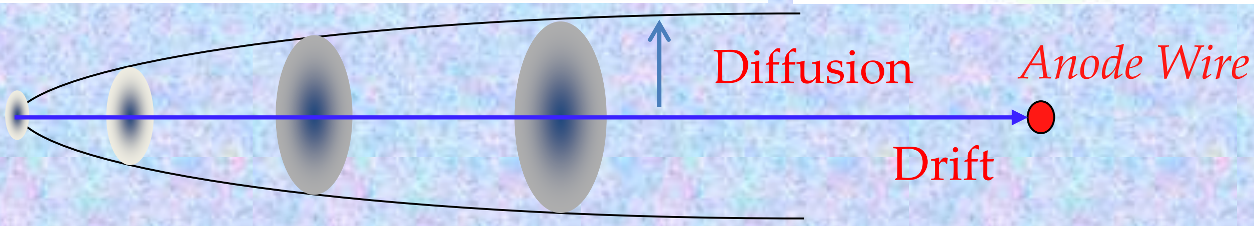
ELECTRIC FIELD E > 0: CHARGE TRANSPORT AND DIFFUSION

IONS ELECTRONS



E





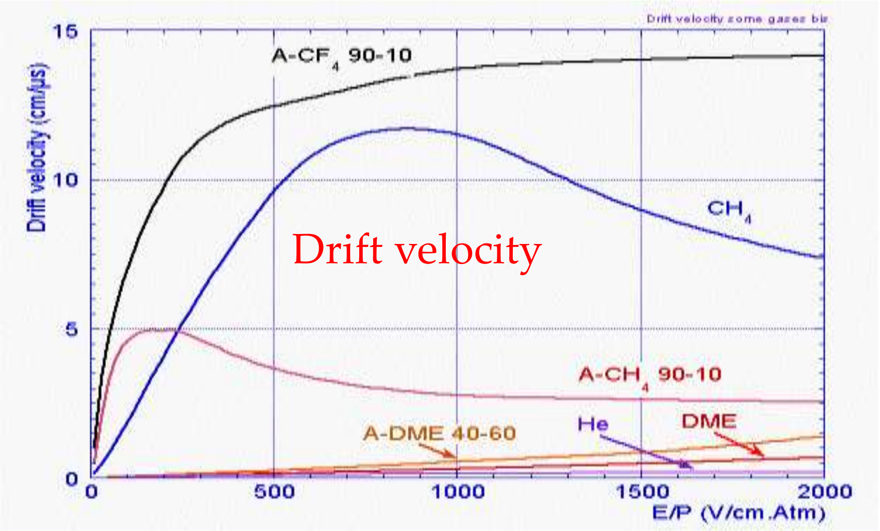
Drift and Diffusion of Electrons in the Electric Field

Electron transport determined by electron-molecule cross section
→ balance between energy acquired from the field and collision losses

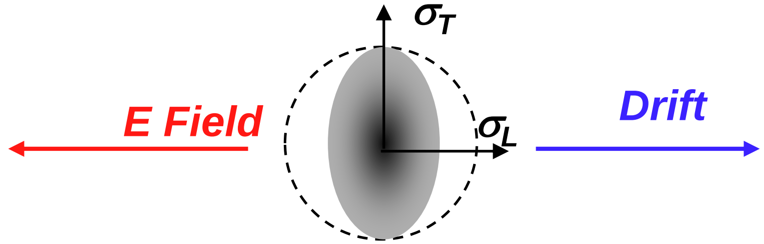
Drift velocity and diffusion of electrons are gas mixture dependent

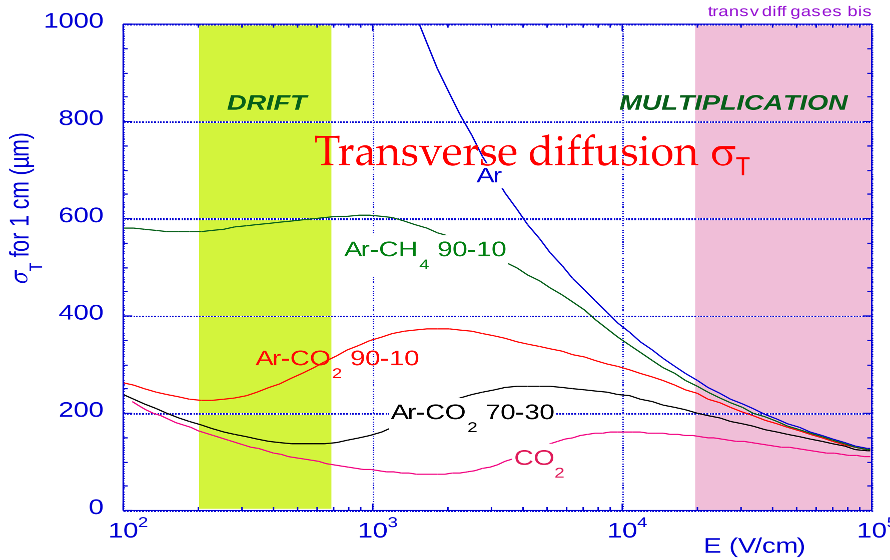
Electron drift velocity (w) $w = \frac{e}{2m} E \tau$
(τ : mean collision time)

$w \sim \frac{E}{\sigma \langle \varepsilon \rangle^{1/2}}$ (σ –total scattering cross section; $\langle\varepsilon\rangle$ - mean electron energy)



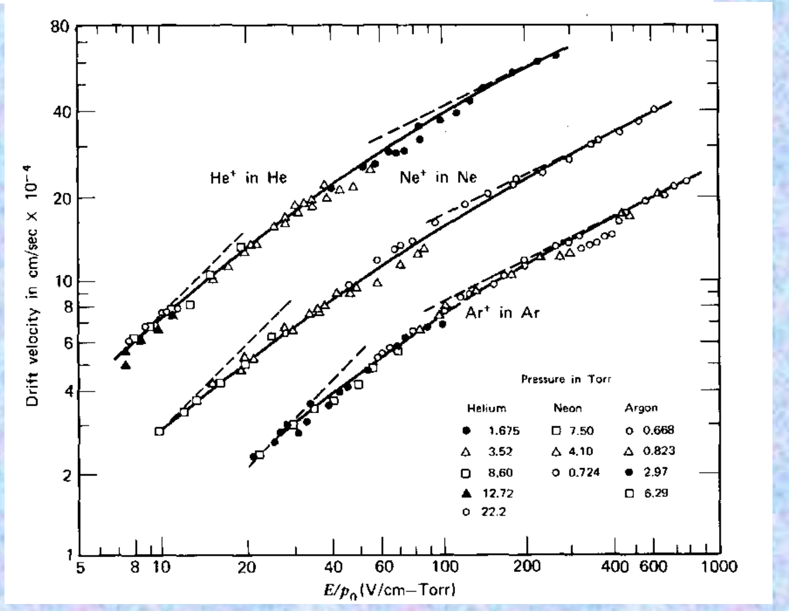
Electric field alters the diffusion
→ it is necessary to introduce two diffusion coefficients σ_L, σ_T





Ion Transport in Electric Fields

Ion Drift Velocity (w):
almost linear function of reduced field E/P
m = w (E/P)$^{-1}$



Mobility (m) ~ constant for a given gas at fixed P,T
(ions remain thermal up to the very high fields)

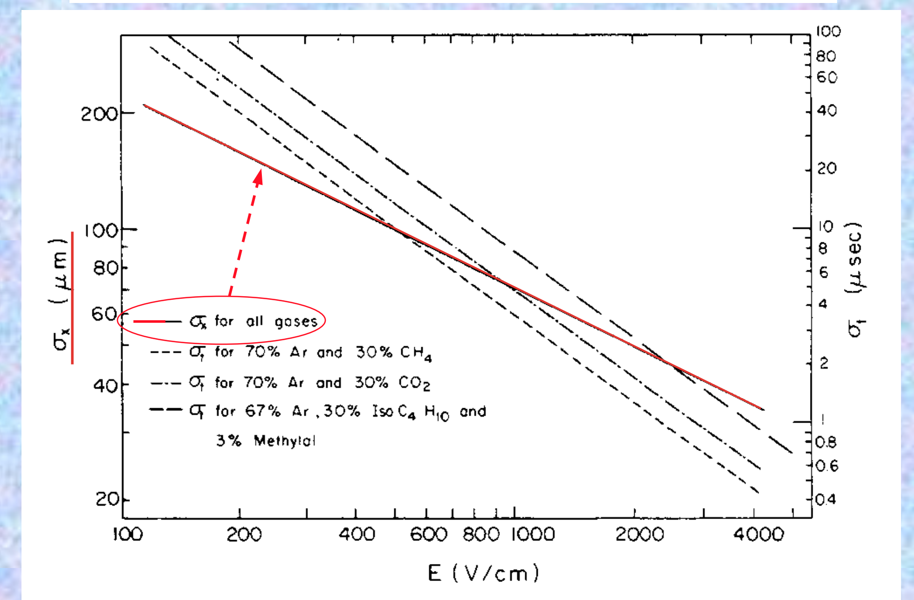
GAS	ION	μ^+ ($cm^2 V^{-1} s^{-1}$)
Ar	Ar^+	1.51
CH_4	CH_4^+	2.26
Ar-CH_4 80-20	CH_4^+	1.61

IONS DIFFUSION (Einstein's law):

$$\frac{D}{\mu} = \frac{KT}{e} \qquad \sigma_x = \sqrt{2Dt}$$

$$\sigma_x = \sqrt{\frac{2KT}{e}\frac{x}{E}}$$

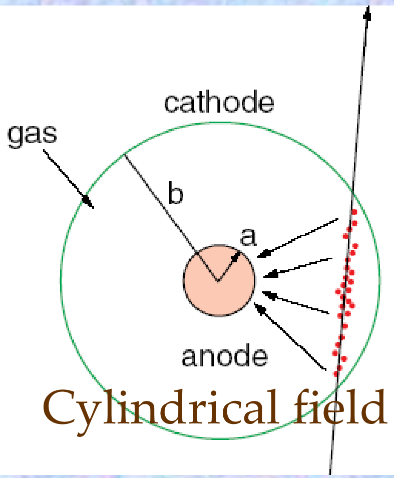
Linear diffusion is independent of the nature of ions and gas !

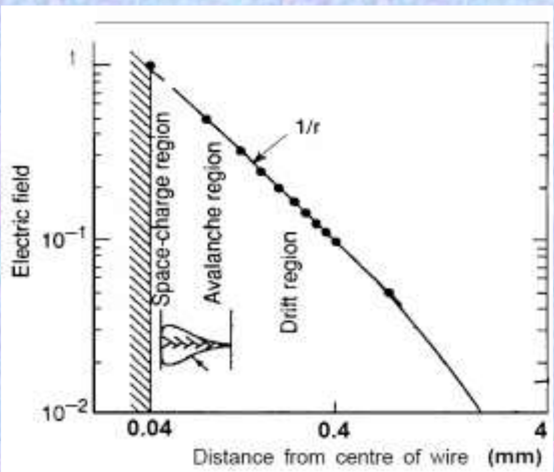


E. McDaniel and E. Mason, The mobility and diffusion of ions in gases (Wiley 1973)
G. Schultz, G. Charpak, F. Sauli, Rev. Physique Appliquee 12, 67 (1977)

Avalanche Multiplication in Gaseous Detectors

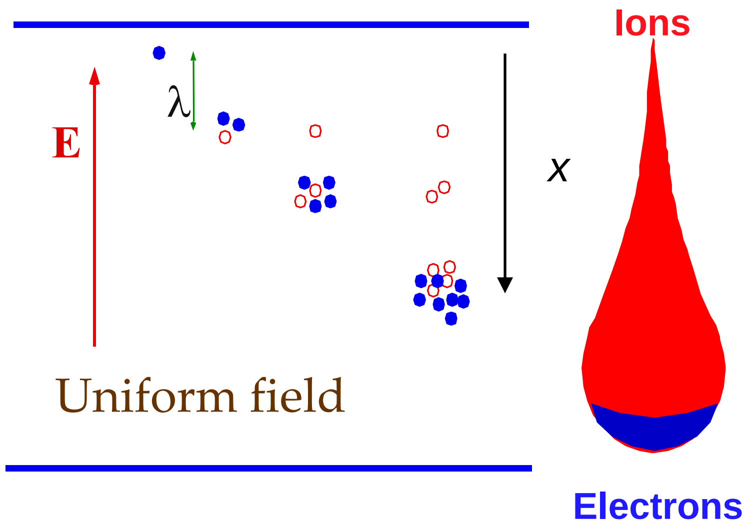
Single Wire Proportional Counter:





- **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

Parallel Plate Chamber :



Mean free path for ionization

$$\lambda = \frac{1}{N\sigma}$$ *N: molecules/cm³*

Townsend coefficient

$$\alpha = \frac{1}{\lambda}$$ *Ionizing collisions/cm*

$$dn = n\,\alpha\,dx \quad ; \quad n(x) = n_0 e^{\alpha x}$$

Multiplication factor or Gain:

$$M(x) = \frac{n}{n_0} = e^{\alpha x}$$

Modes of Operation of Gas Detectors

Ionization mode:

full charge collection
no multiplication; gain ≈ 1

Proportional mode:

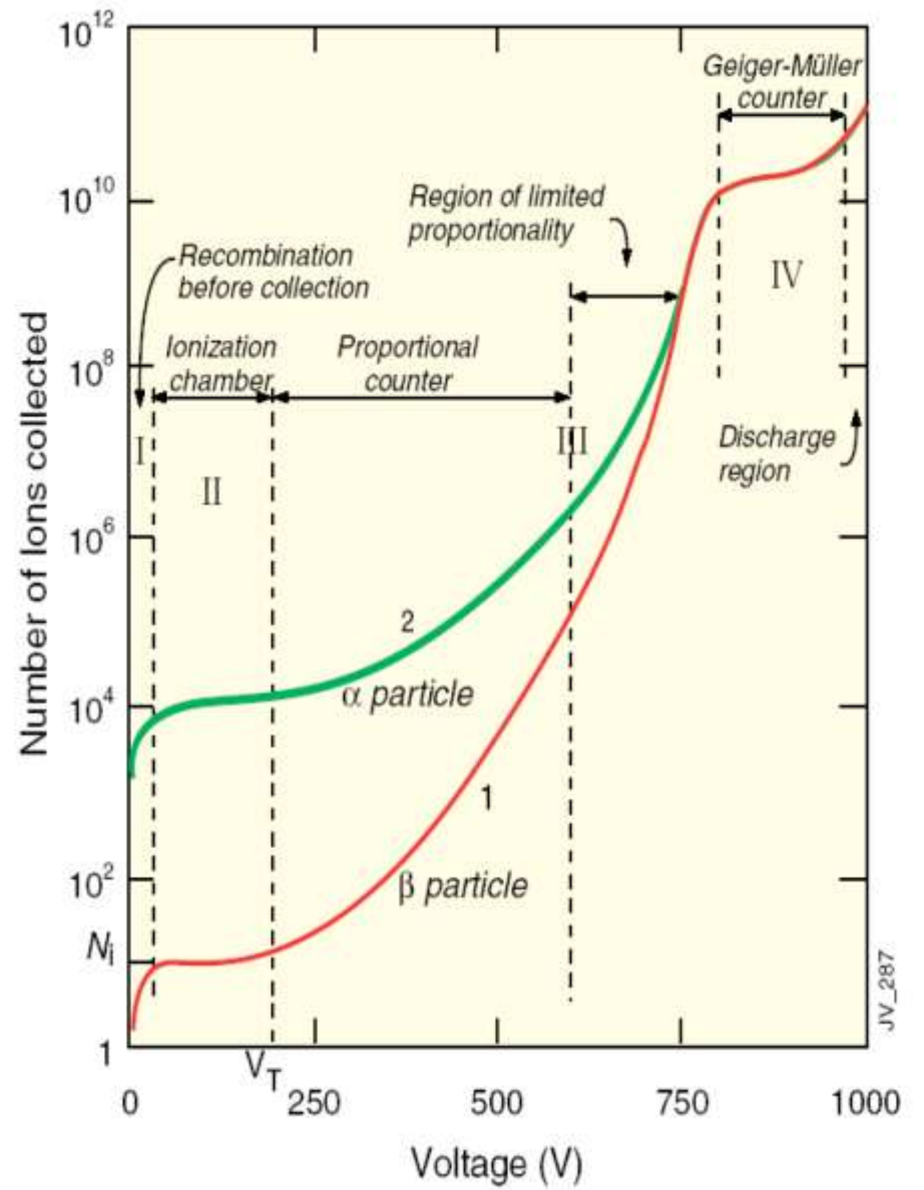
multiplication of ionization
signal proportional to ionization
measurement of dE/dx
secondary avalanches need quenching;
gain ≈ $10^4 - 10^5$

Limited proportional mode:
[saturated, streamer]

strong photoemission
requires strong quenchers or pulsed HV;
gain ≈ 10^{10}

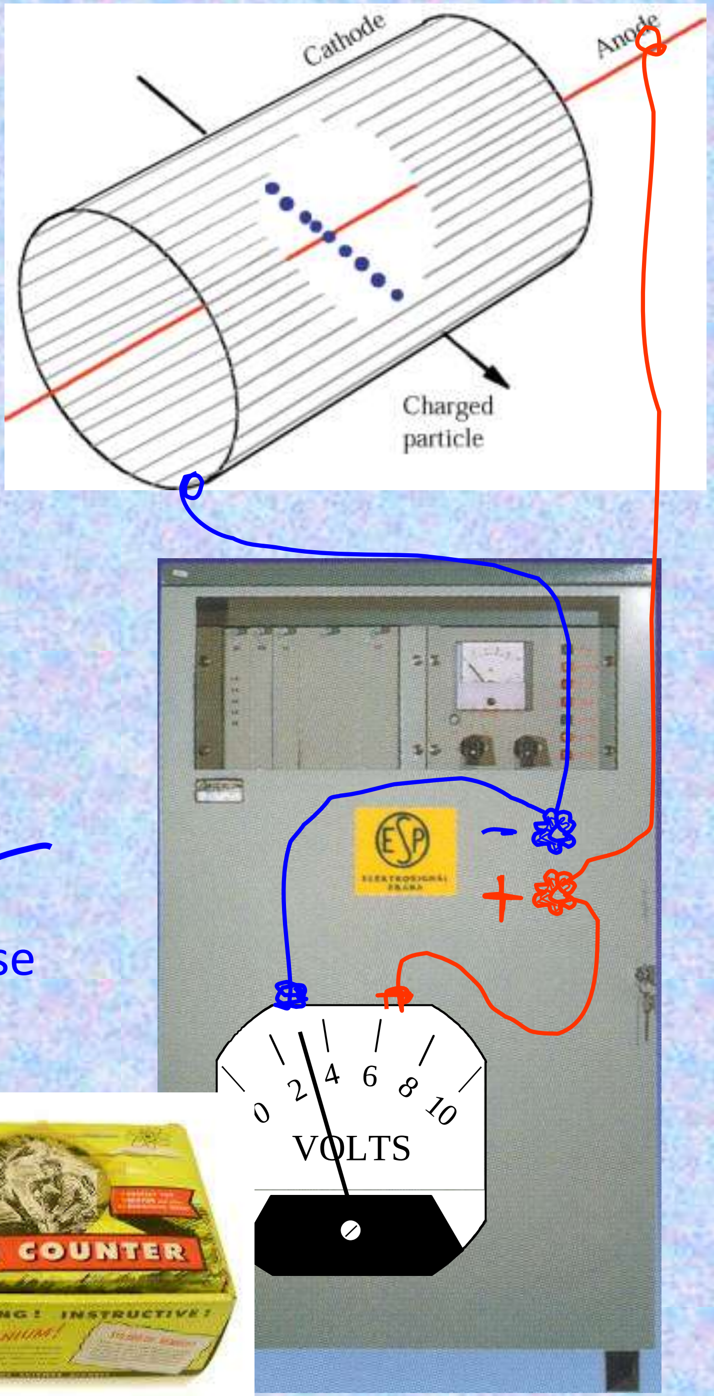
Geiger mode:

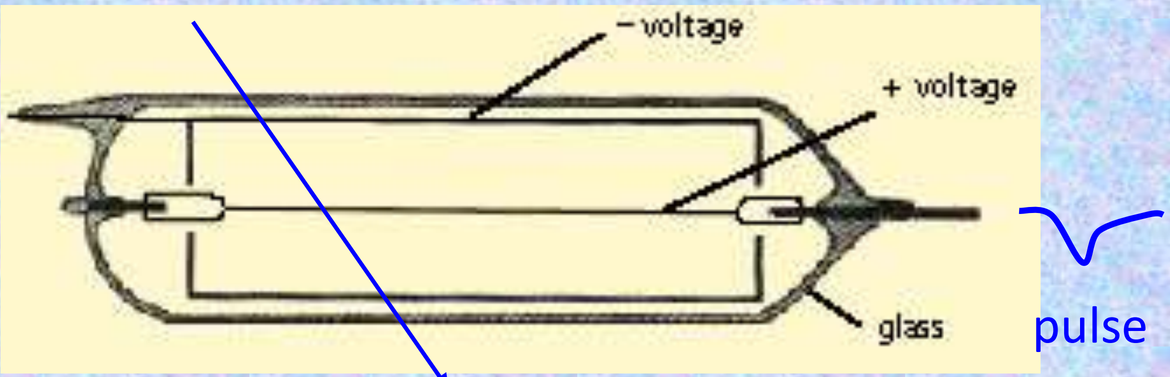
massive photoemission;
full length of the anode wire affected;
discharge stopped by HV cut



Geiger Counter

E. Rutherford ***1909*** ***H. Geiger*** ***1927***





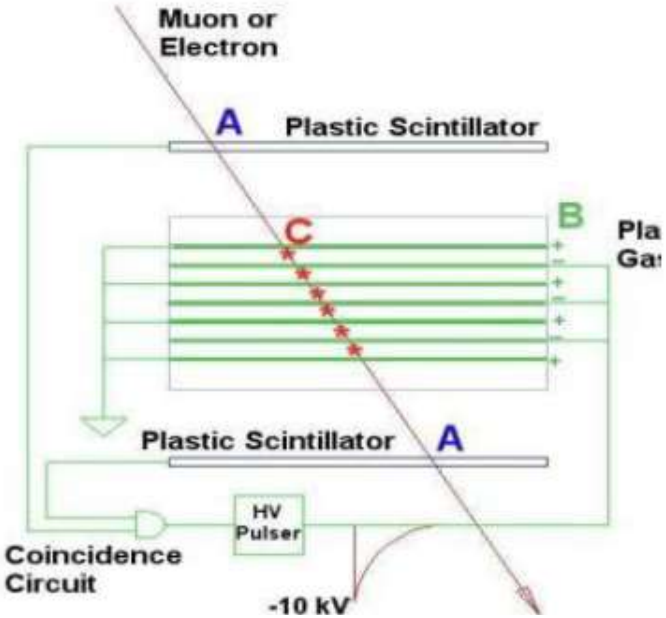
The Geiger counter, later further developed and then called Geiger-Müller counter

First electrical signal from a particle !!!

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

H. Geiiger and W. Müllller, Phys. Zeiits. 29 (1928) 839

Spark Chamber



Beam of the energetic protons to produce π-mesons showers
→Decaying into muons and neutrinos

Only neutrino could pass through a 5,000-ton13-m thick steel wall into gas detector ("Spark Counter")

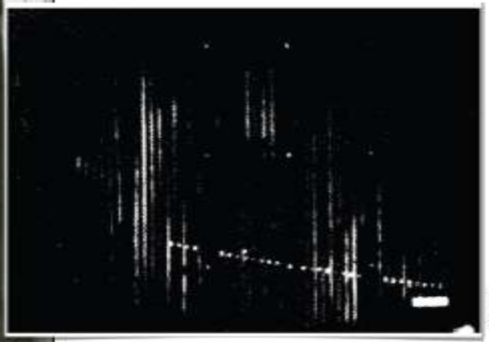
A tiny fraction of neutrinos react in the detector (90 layers of aluminum plates, 10 tons) giving rise to muon spark trails → existence of muon-neutrinos.

The Spark Chamber was developed in the early 60ies.

Schwartz, Steinberger and Lederman used it in discovery of the muon neutrino

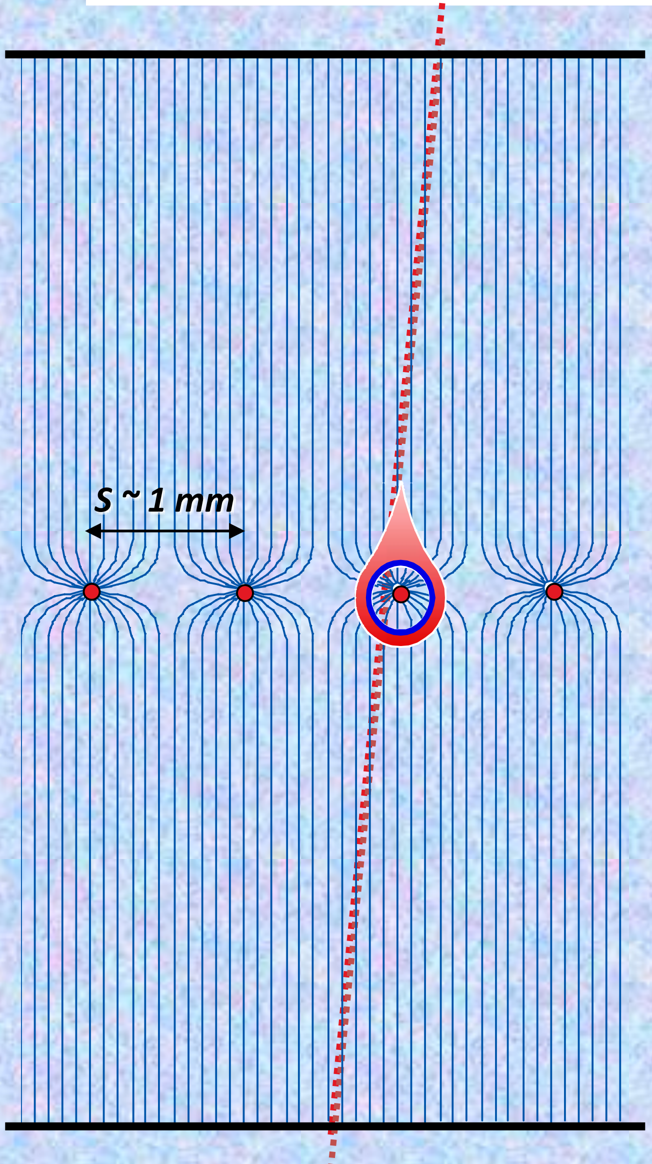
Discovery of Muon Neutrino by Spark Chamber
(1962 by Lederman, Schwartz, Stainberger;
Noble Prize 1988)

Melvin Schwartz in front of the spark chamber used to discover the muon neutrino



Single muon event from original publication

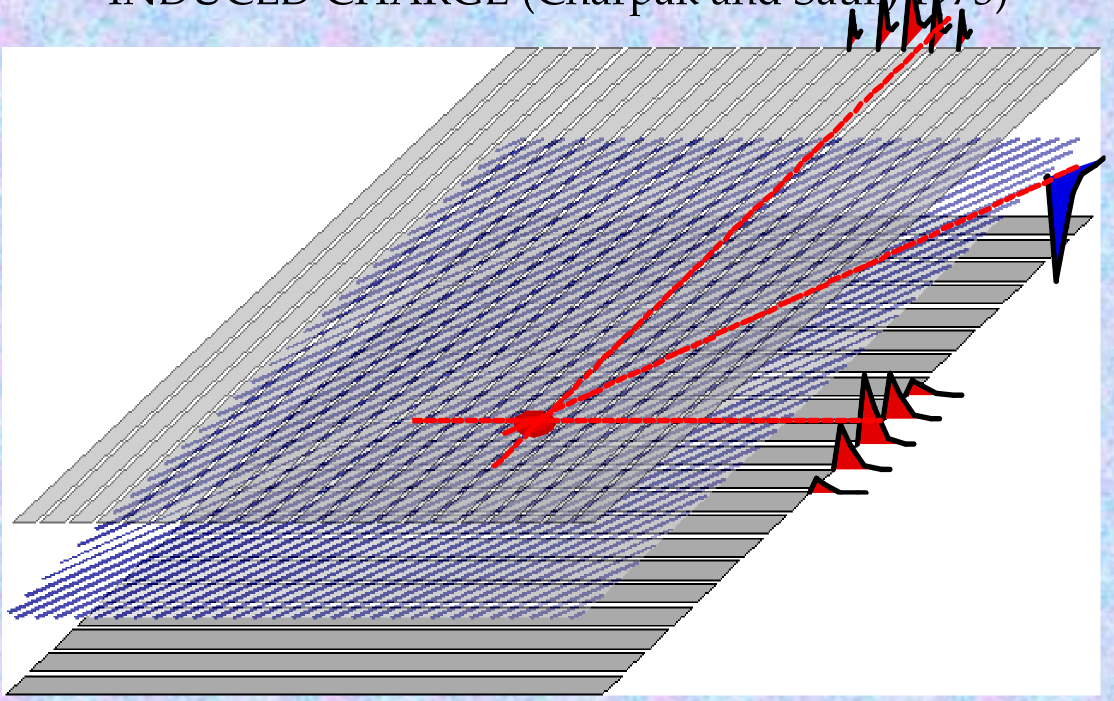
Multi-Wire Proportional Chamber (MWPC)



High-rate MWPC with digital readout:

Spatial resolution is limited to $\sigma_x \sim s/\mathrm{sqrt}(12) \sim 300\ \mu m$

TWO-DIMENSIONAL MWPC READOUT CATHODE INDUCED CHARGE (Charpak and Sauli, 1973)



Spatial resolution determined by: Signal / Noise Ratio

Typical (i.e. 'very good') values: S ~ 20000 e: noise ~ 1000e

Space resolution < 100 μm

Resolution of MWPCs limited by wire spacing

better resolution → shorter wire spacing → more (and more) wires...

1968: Multi-Wire Proportional Chamber (MWPC)

NUCLEAR INSTRUMENTS AND METHODS 62 (1968) 262–268; © NORTH-HOLLAND PUBLISHING CO.

THE USE OF MULTIWIRE PROPORTIONAL COUNTERS TO SELECT AND LOCALIZE CHARGED PARTICLES

G. CHARPAK, R. BOUCLIER, T. BRESSANI, J. FAVIER and Č. ZUPANČIČ

CERN, Geneva, Switzerland

Received 27 February 1968

Properties of chambers made of planes of independent wires placed between two plane electrodes have been investigated. A direct voltage is applied to the wires. It has been checked that each wire works as an independent proportional counter down to separations of 0.1 cm between wires.

Counting rates of 10^5/wire are easily reached; time resolutions of the order of 100 nsec have been obtained in some gases; it is possible to measure the position of the tracks between the wires using the time delay of the pulses; energy resolution comparable to the one obtained with the best cylindrical chambers is observed; the chambers operate in strong magnetic fields.

1. Introduction

Proportional counters with electrodes consisting of many parallel wires connected in parallel have been used for some years, for special applications. We have investigated the properties of chambers made up of a plane of independent wires placed between two plane electrodes. Our observations show that such chambers offer properties that can make them more advantageous than wire chambers or scintillation hodoscopes for many applications.

2. Construction

Wires of stainless steel, 4×10^{-3} cm in diameter, are stretched between two planes of stainless-steel mesh, made from wires of 5×10^{-3} cm diameter, 5×10^{-2} cm apart. The distance between the mesh and the wires is 0.75 cm. We studied the properties of chambers with wire separation $a = 0.1$, 0.2, 0.3 and 1.0 cm. A strip of metal placed at 0.1 cm from the wires, at the same potential (fig. 1), plays the same role as the guard rings in cylindrical proportional chambers. It protects the wires against breakdown along the dielectrics. It is

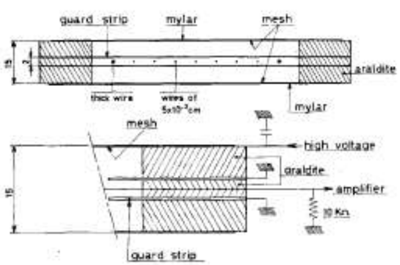


Fig. 1. Some details of the construction of the multiwire chambers.
A copper shield protects the wires at their output from the chamber and contains the solid state amplifiers.

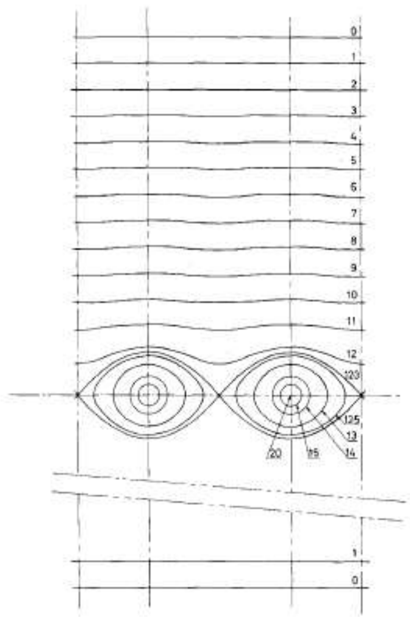
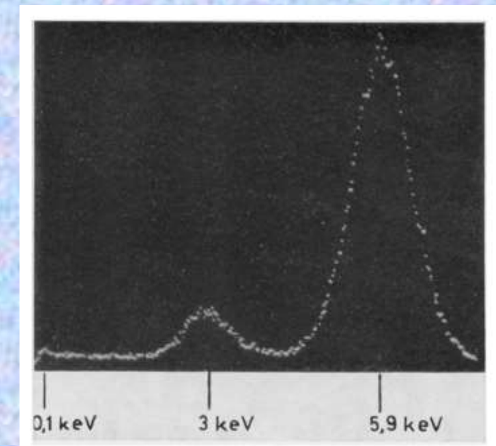
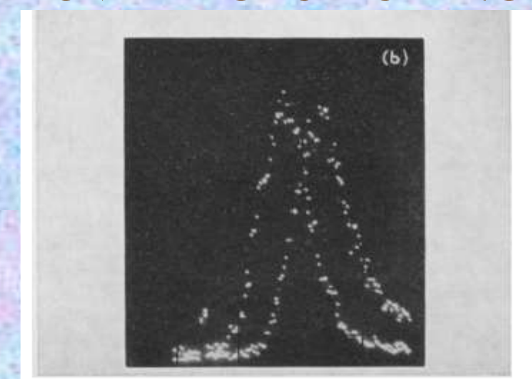


Fig. 2. Equipotentials in a chamber.
Wires of 4×10^{-3} cm diameter, 0.3 cm separation, and 1.5 cm total thickness. 20 V applied between the wires and the external mesh. Results from an analogic method.

ENERGY RESOLUTION ON 5.9 KeV:



DEPENDENCE OF COLLECTION TIME FROM TRACK'S DISTANCE:



→ DRIFT CHAMBERS

G. Charpak,R. Bouclier, T. Bressan,J. Favier and C. Zupancic: The use of Multiwire Proportional Counters to select and localize Charged Particles, Nuc. Instr. and Meth. 62(1968)262

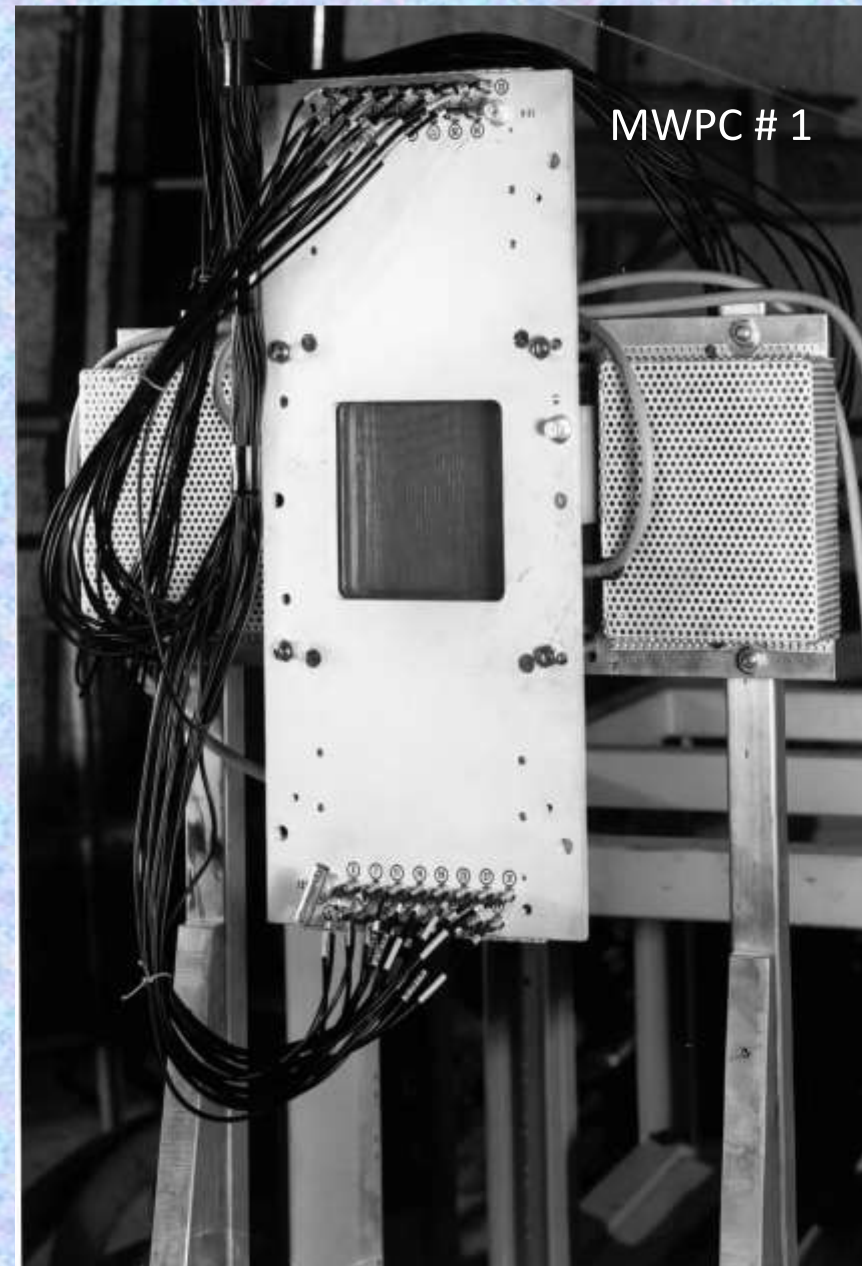
First Public Presentation of the Multi-Wire Proportional Chamber

colloque
international
sur
l'électronique
nucléaire

VERSAILLES,
10-13 September 1968

*

international
symposium
on
nuclear
electronics

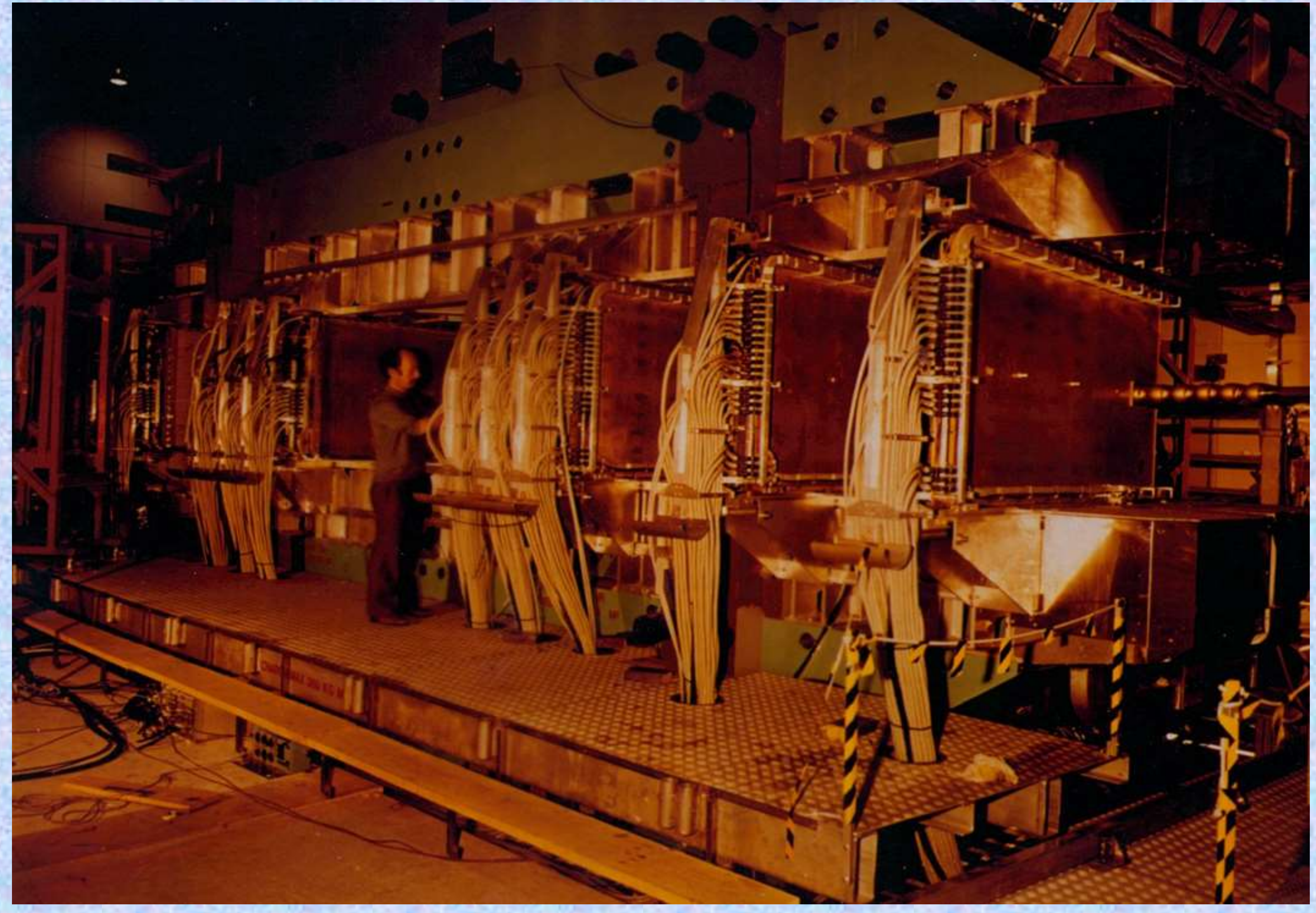


Chambres à Etincelles
Spark chambers

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

Secrétaire scientifique Scientific Secretary — **M. FEUVRAIS** Faculté des Sciences - Lyon (France)

First Large Experiment with MWPCs



1972-1983: SPLIT FIELD MAGNET DETECTOR

40 LARGE AREA MWPCs AT CERN ISR:

Multi-Wire Proportional Chamber (MWPC): Electronics Imaging Device

The 1st "Large Wire Chamber":

Georges Charpak with Fabio Sauli, Jean Claude Santiard

The invention revolutionized particle detection and High Energy Physics, which passed from the manual to the electronic era.

MWPC:

1968 by Georges Charpak;
Noble Prize 1992

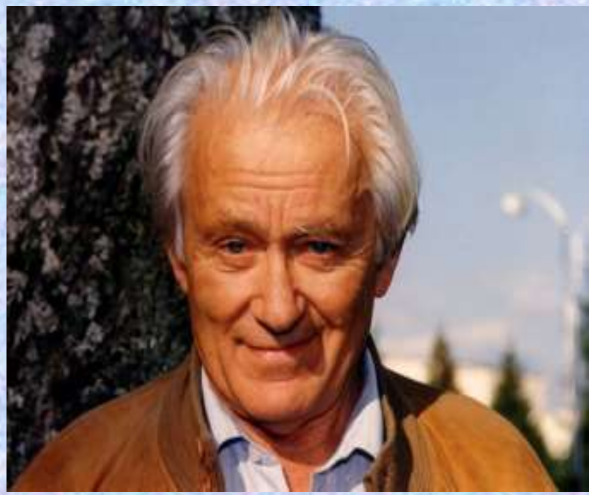
A Tribute to Georges Charpak

Four Seas Conference: « Physique-sans-Frontières »

- “Physique-sans-Frontières” (PSF) was born in 1992, during the war in Bosnia when many scientists felt the necessity to "do something" for their colleagues of South East of Europe

- Georges CHARPAK has kindly accepted to preside "Physics-without-Borders” and supported the effort of the association to set up the “Four-Seas-Conference”

- The 1st Trieste-95 conference was a real success, despite the renewed war in Bosnia : 150 physicists, half of them from the South-Eastern Europe; all the countries of the Balkanic area were represented, despite the existing state of war between some of them



A Tribute to Georges Charpak

Four Seas Conference: Physics in Service of Mankind

- Five conferences were organized (Trieste-95, Sarajevo-98, Thessaloniki-02, Istanbul-04, Iasi, Romania-07) to give opportunity for scientists, mainly the youngest ones, to hear about the most recent developments in sciences and technologies

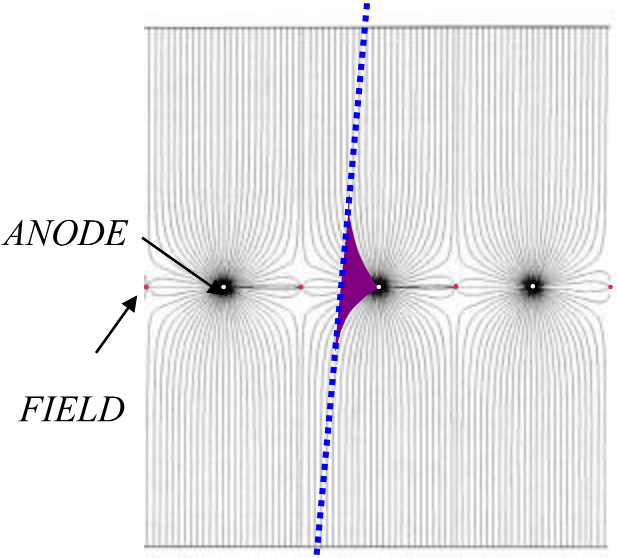
- Served as a way to express the solidarity of the scientific community with all those who, under difficult conditions, seek to keep alive the diverse intellectual and cultural links that constitute the essence of our civilization

2014: CERN is celebrating
"60 Years of Science for Peace!"

Drift Chambers

FIRST DRIFT CHAMBER OPERATION (H. WALENTA ~ 1971)
HIGH ACCURACY DRIFT CHAMBERS (Charpak-Breskin-Sauli ~ 1973-75)

THE ELECTRONS DRIFT TIME PROVIDES THE DISTANCE OF THE TRACK FROM THE ANODE:



Measure drift time t_D
[need to know t_0; fast scintillator, beam timing]

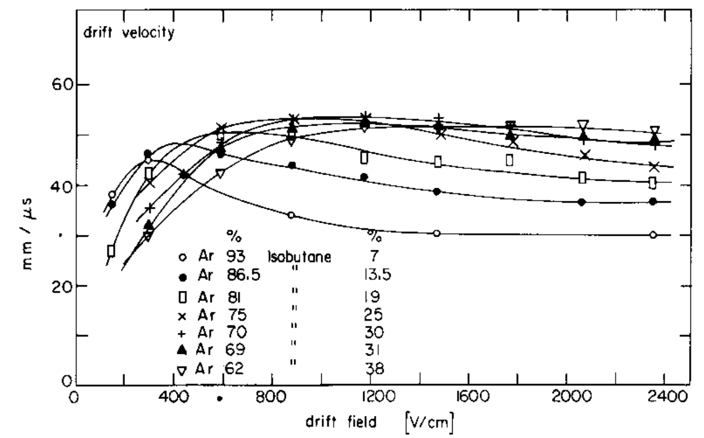
Determine location of original ionization:

$$x = x_0 \pm v_D \cdot t_D$$
$$y = y_0 \pm v_D \cdot t_D$$

If drift velocity changes along path:

$$x = \int_0^{t_D} v_D \, dt$$

In any case:
Need well-defined drift field ...

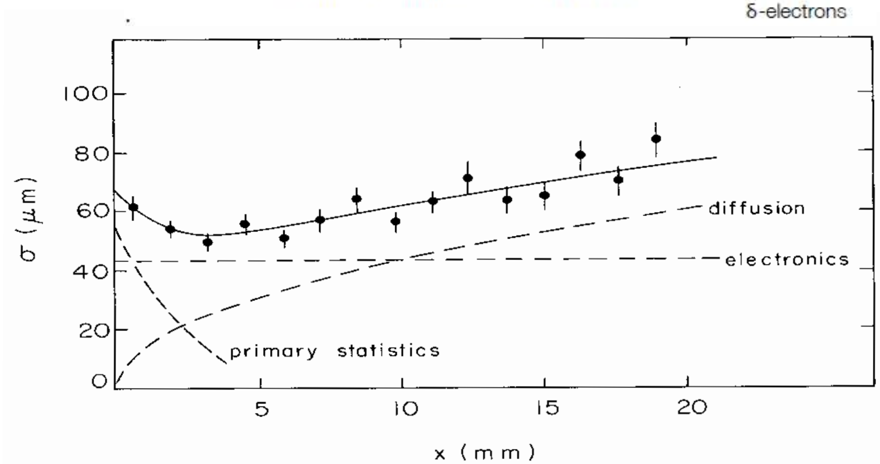


The spatial resolution is not limited to the cell size

$$\sigma_x^2 = \underbrace{\left(\frac{1}{64N^2}\right) \cdot \frac{1}{x^2}}_{1^{st}\text{ ionization statistics}} + \underbrace{\frac{2D}{v_d} \cdot x}_{\text{diffusion}} + \underbrace{\sigma_{\text{const}}^2}_{\substack{\text{electronics} \\ \delta\text{-electrons}}}$$

Factors affecting spatial resolution:

- Distribution of primary ionization
- Diffusion
- Readout electronics
- Electric field (gas amplification)
- Range of 'delta electrons'



“Enormous Wire Chambers”: Wide-Spread Tool in HEP for > 40 Years

Nobel Prize: W, Z - Discovery at UA1/UA2 (1983)

UA1 used the largest imaging drift chamber of its day
(5.8 m long, 2.3 m in diameter)

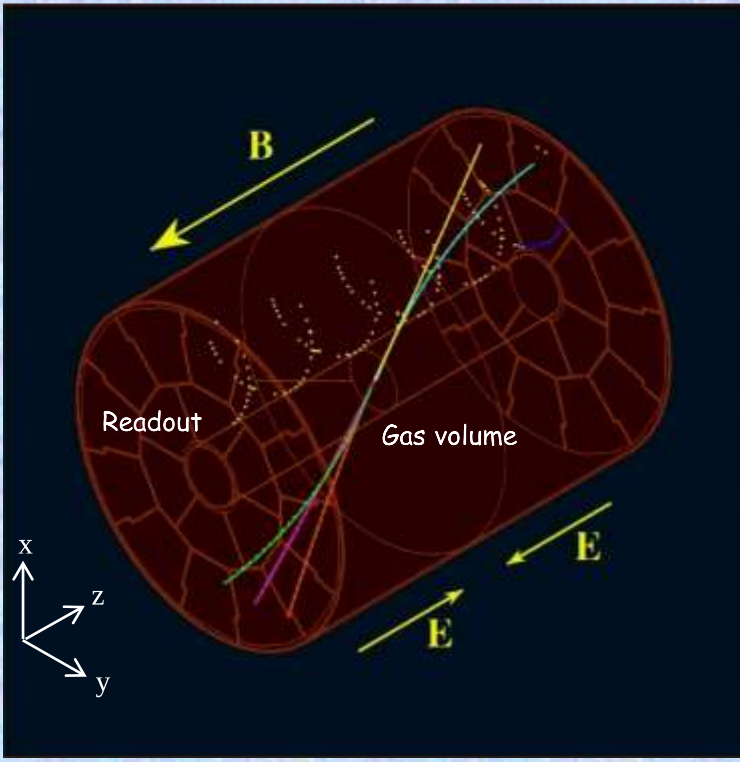
It can now be seen in the CERN Microcosm Exhibition

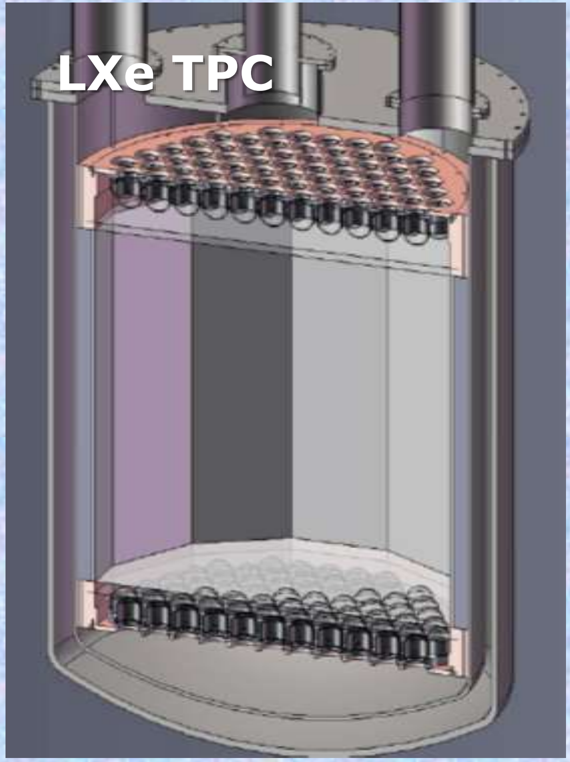
Particle trajectories in the CERN-UA1
3D Wire Chamber
Discovery of W and Z bosons
C. Rubbia & S. Van der Meer Nobel 1984

Z $\rightarrow$ ee (white tracks)

Time Projection Chamber (TPC)

The TPC is a gas-filled cylindrical chamber with 1 or 2 endplates (D. Nygren, 1974)



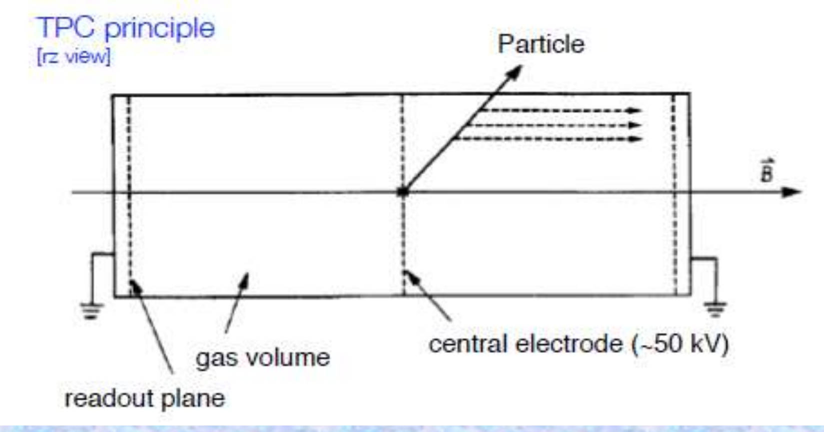


Separate two regions:

- Long drift along z ~ 1-3 m;
- Amplification at the end plate

Challenges:

Long drift time; limited rate capability



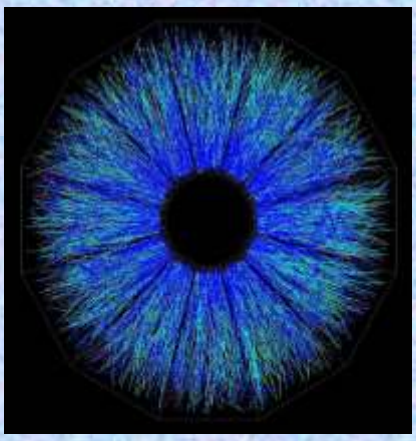
TPC Characteristics

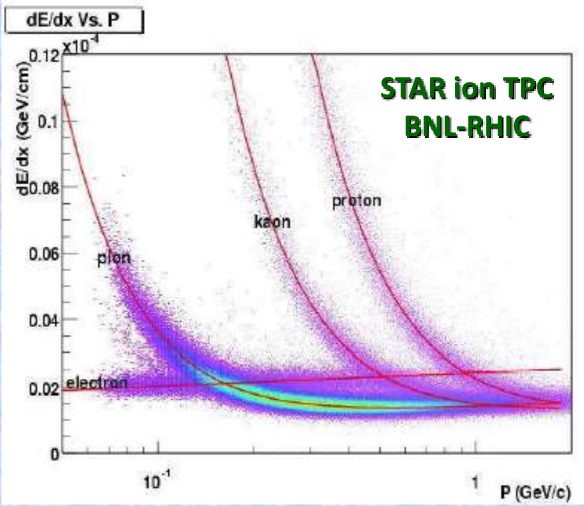
- Track point recorded in 3-D

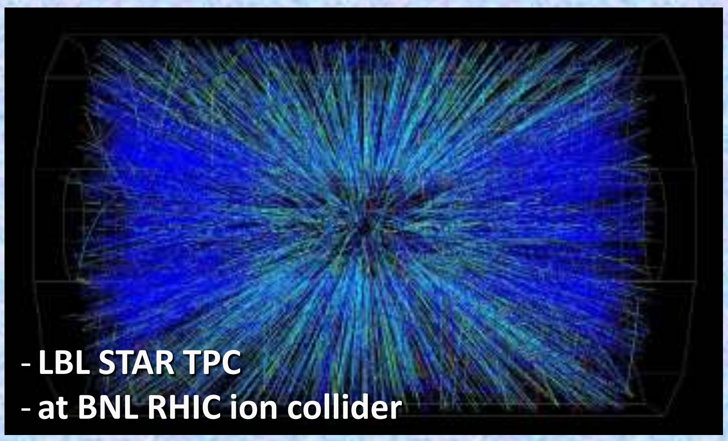
  (2-D channels in x-y) x (1-D channel in z = $v_{drift} \times t_{drift}$)

- Particle identification by dE/dx

  long ionization track, segmented in 100-200 measurements







	STAR	ALICE	ILC
Inner radius (cm)	50	85	32
Outer radius (cm)	200	250	170
Length (cm)	2 * 210	2 * 250	2 * 250
Charge collection	wire	wire	MPGD
Pad size (mm)	2.8 * 11.5 6.2 * 19.5	4 * 7.5 6*10(15)	2 * 6
Total # pads	140000	560000	1200000
Magnetic field [T]	0.5	0.5	4
Gas Mixture	Ar/CH4 (90:10)	Ne/CO2 (90:10)	Ar/CH4/CO2 (93:5:2)
Drift Field [V/cm]	135	400	230
Total drift time (µs)	38	88	50
Diffusion $\sigma_T (\mu m/\sqrt{cm})$	230	220	70
Diffusion $\sigma_L (\mu m/\sqrt{cm})$	360	220	300
Resolution in rφ (µm)	500-2000	300-2000	70-150
Resolution in rz (µm)	1000-3000	600-2000	500-800
dE/dx resolution [%]	7	7	< 5
Tracking efficiency[%]	80	95	98

<u>Powerfull tool for:</u>

- ➢ Lepton Colliders
- ➢ Modern heavy ion collisions
- ➢ Liquid and high pressure noble gases for neutrino and dark matter physics program

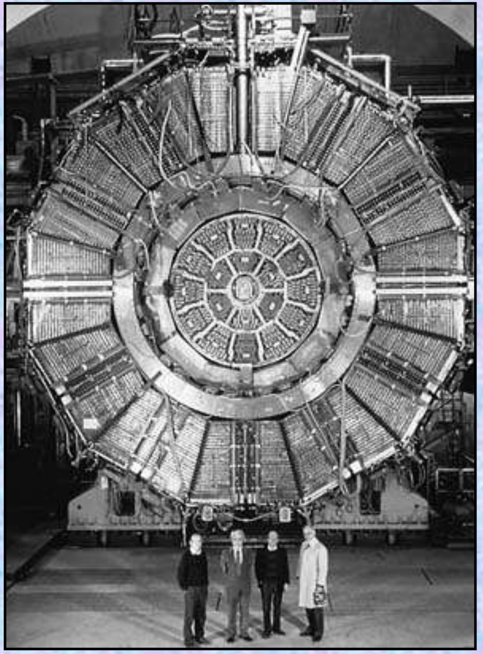
Some Detectors in Particle and Ions Physics using a TPC

PEP4 (SLAC)

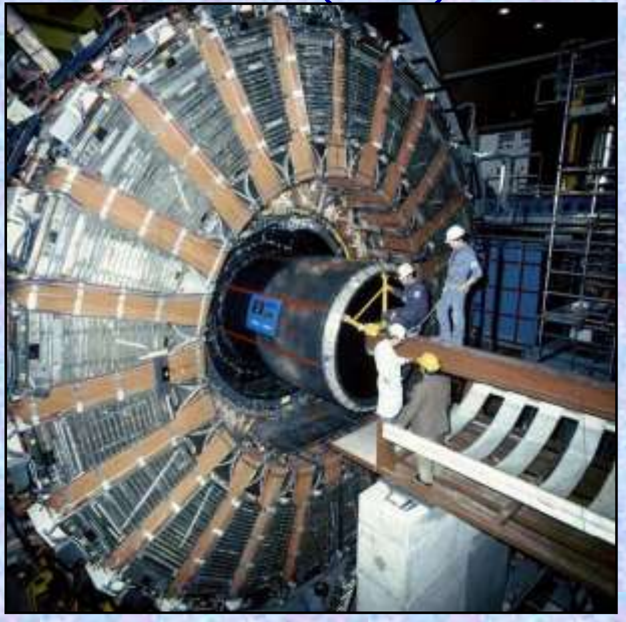
TPC	Reference
PEP4	PEP-PROPOSAL-004, Dec 1976
TOPAZ	Nucl. Instr. and Meth. A252 (1986) 423
ALEPH	Nucl. Instr. and Meth. A294 (1990) 121
DELPHI	Nucl. Instr. and Meth. A323 (1992) 209-212
NA49	Nucl. Instr. and Meth. A430 (1999) 210
STAR	IEEE Trans. on Nucl. Sci. Vol. 44, No. 3 (1997)

STAR (LBL)

ALEPH (CERN)



DELPHI (CERN)



TOPAZ (KEK)

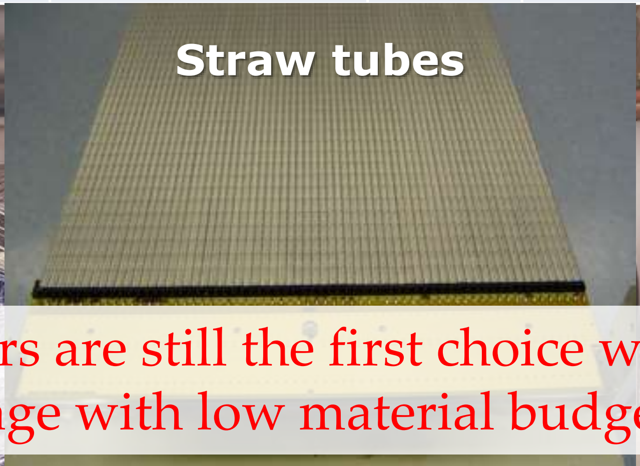
Time Projection Chamber in the ALICE/CERN Experiment

Highly increased system complexity and size

Achieving intrinsic gas detector performance, even in large systems
→ with control of systematics

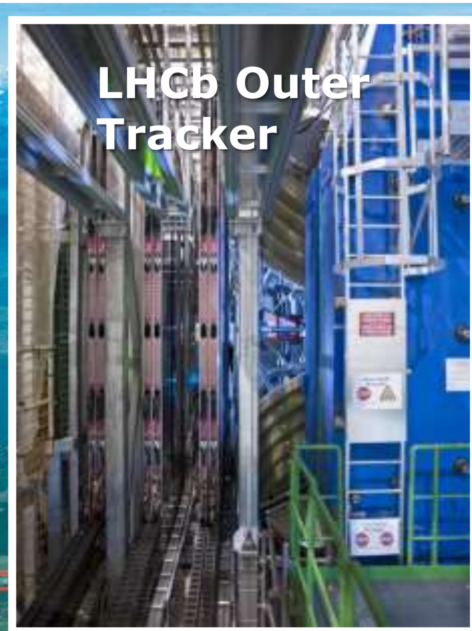
Gaseous Detectors in LHC Experiments

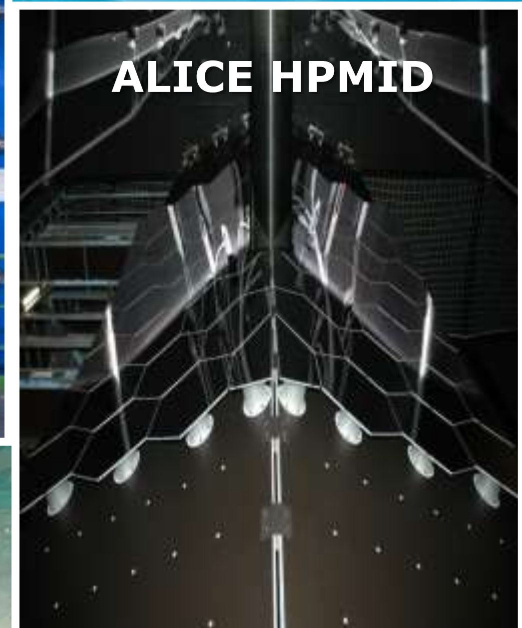
	Vertex	Inner Tracker	PID/ photo-det.	EM CALO	HAD CALO	MUON Track	MUON Trigger
ATLAS	-	TRD (straws)	-	-	-	MDT (drift tubes), CSC	RPC, TGC (thin gap chambers)
CMS ----- **TOTEM**	-	-	-	-	-	Drift tubes, CSC ----- GEM	RPC, CSC ----- GEM
LHCb	-	Straw Tubes	-	-	-	MWPC	MWPC, GEM
ALICE	-	TPC (MWPC)	TOF(MRPC), PMD, HPMID (RICH-pad chamber), TRD (MWPC)	-	-	Muon pad chambers	RPC

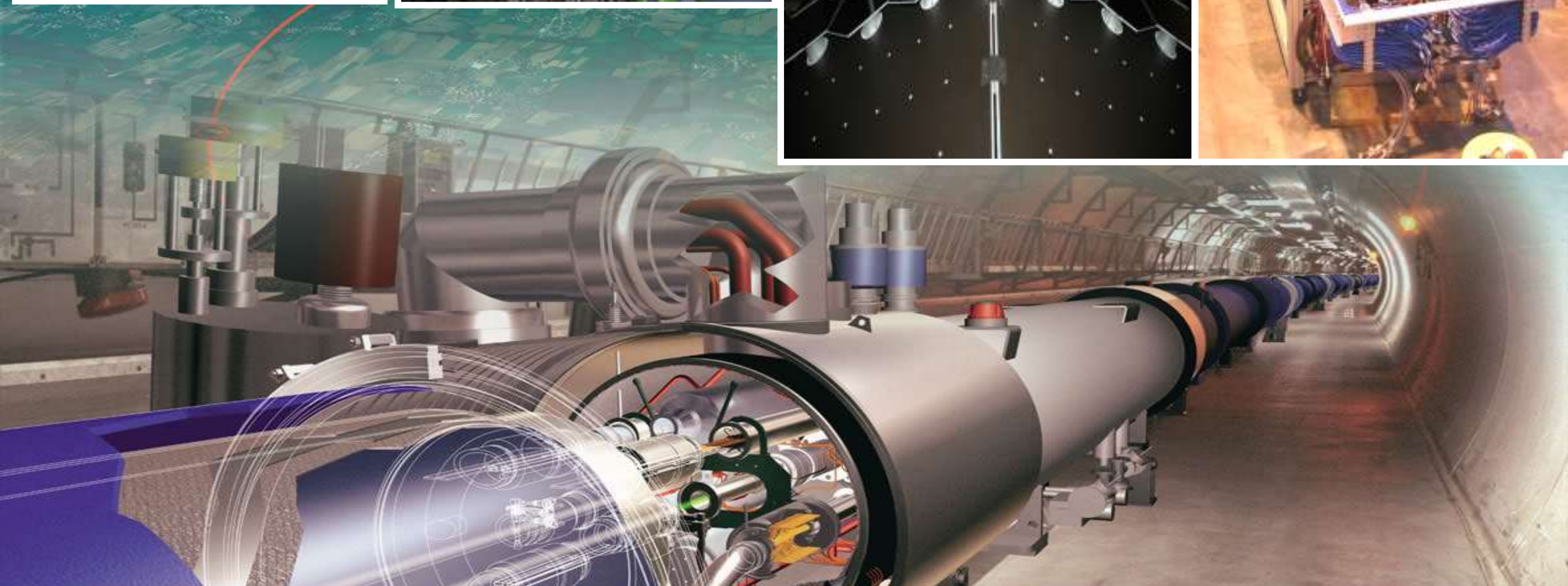


Gaseous detectors are still the first choice whenever the large-area coverage with low material budget is required

Gaseous Detectors in LHC Experiments





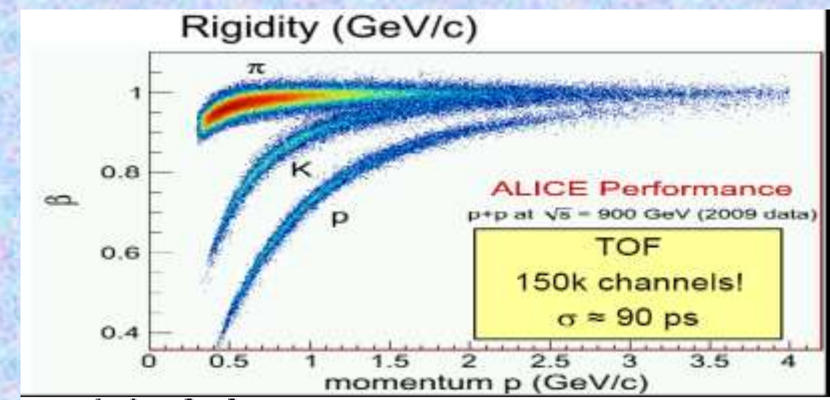


ALICE Multi-Gap RPC: Timing Resolution

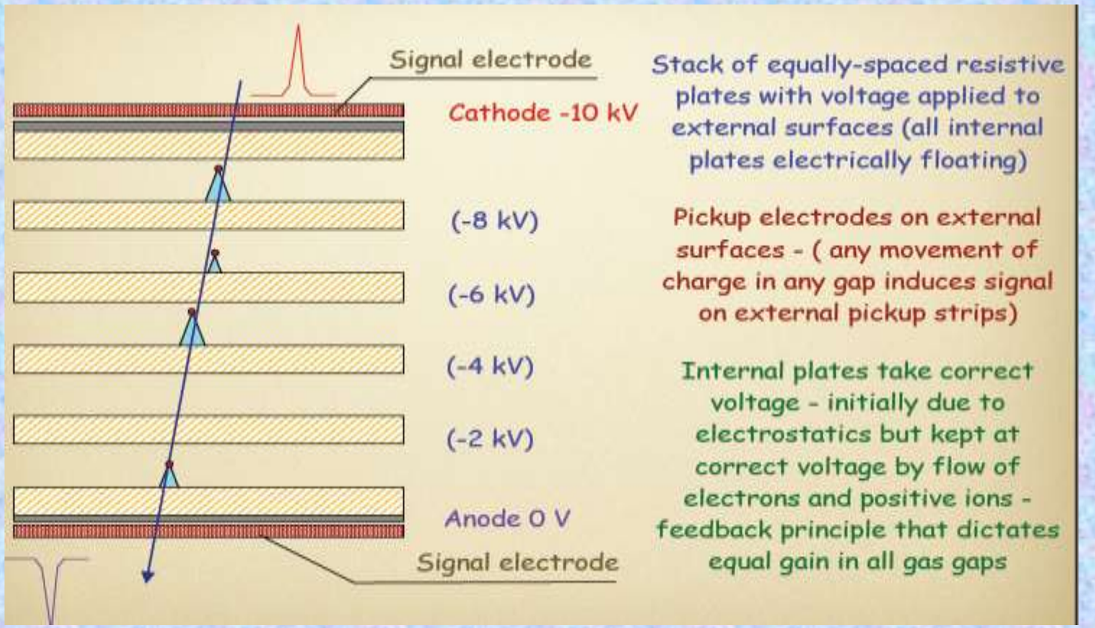
- Relevant scale in HEP: t ~ L(m)/c ~ o(ns)

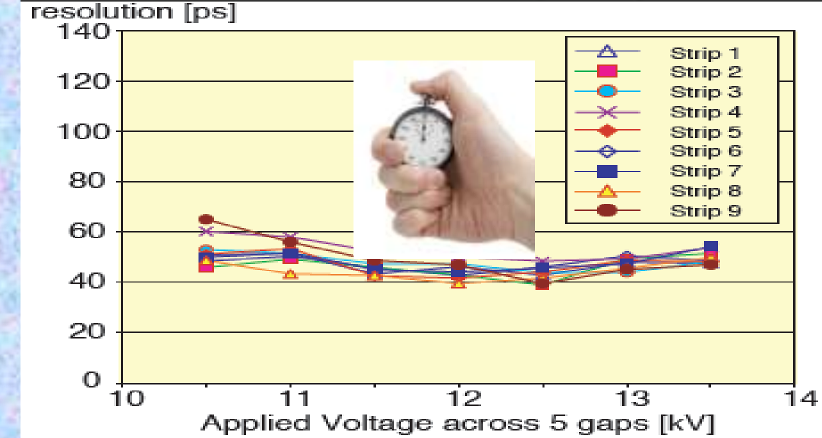
$$T_1 - T_2 = \frac{L}{c}\left(\frac{1}{\beta_1}-\frac{1}{\beta_2}\right) = \frac{L}{c}\left(\sqrt{1+m_1^2/p^2} - \sqrt{1+m_2^2/p^2}\right) \cong (m_1^2 - m_2^2)L/2cp^2$$

- Traditional technique:
  - Scintillator + PMT ~ *o* (100 *psec*)
- Breakthrough with a spark discharge in gas
  - Pestov counter → ALICE MRPC ~ 50*psec*



Multi-Gap Resistive Plate Chamber: Basic Principle





Technology	Time resolution
• Pestov Counter	30-50 ps
• RPC	~ 1-5 ns (MIP)
• MultiGap RPC	~ 50 ps (MIP)
• GEM	~ 1-2 ns (UV) ~ 5 ns (MIP)
• Micromegas	~ 700 ps (UV) ~ 2-5 ns (MIP)

C. Williams, CERN Detector Seminar "ALICE Time of Flight Detectors": http://indico.cern.ch/conferenceDisplay.py?confId=149006

ALICE Multi-Gap RPC: Timing Resolution

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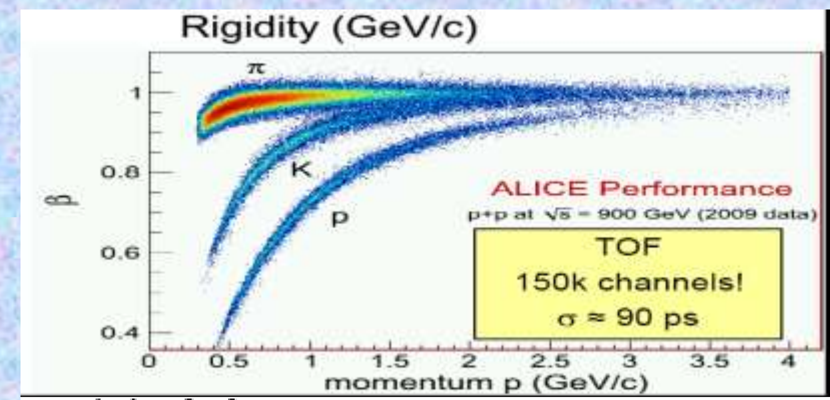
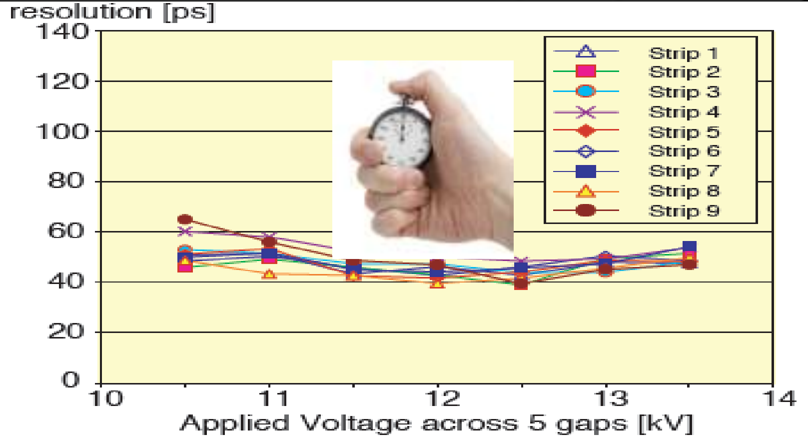
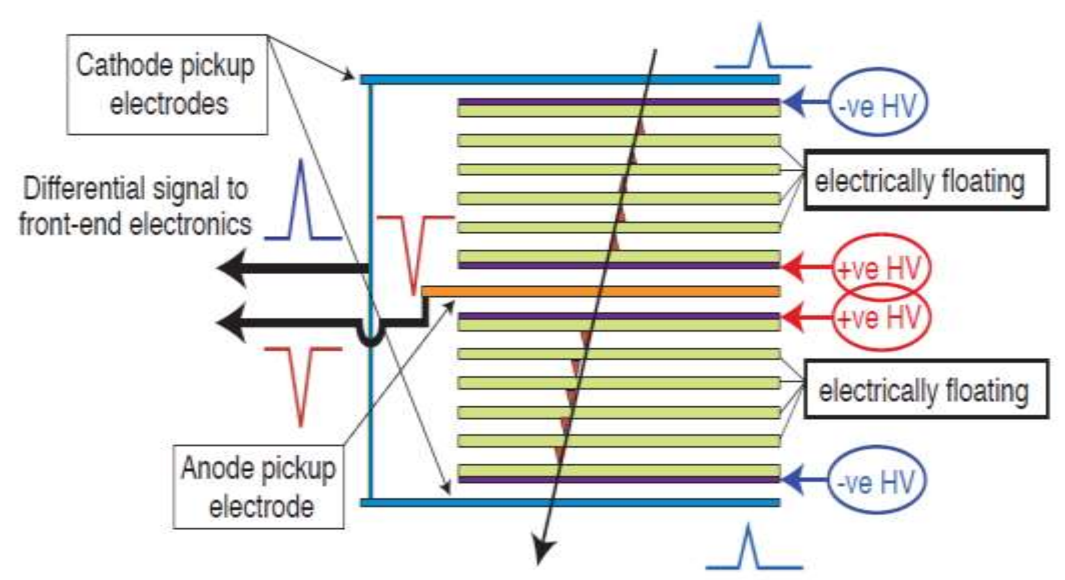
- Breakthrough with a spark discharge in gas
  - Pestov counter → ALICE MRPC ~ 50*psec*





ALICE-TOF has 10 gaps (two stacks of 5 gas gaps); each gap is 250 micron wide



C. Williams, CERN Detector Seminar "ALICE Time of Flight Detectors": http://indico.cern.ch/conferenceDisplay.py?confId=149006

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ATLAS Muon Detector: Modern Large-Volume Spectrometer

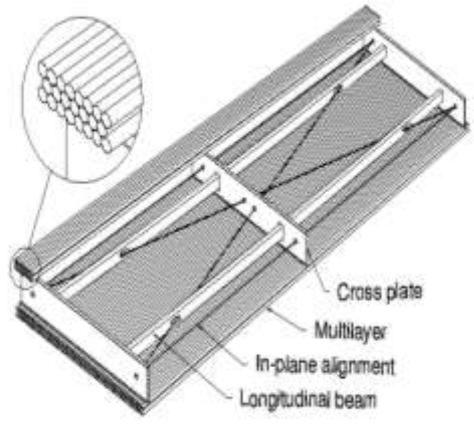
L3 Muon Spectrometer (LEP):

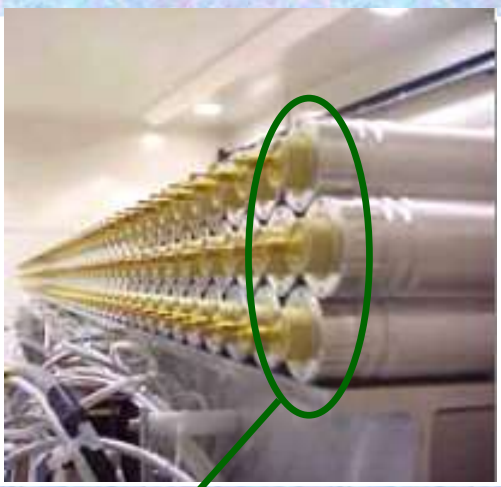
~ 40000 chan. ; σ (chamber) < 200 μm

ATLAS Muon Drift Tubes (LHC):

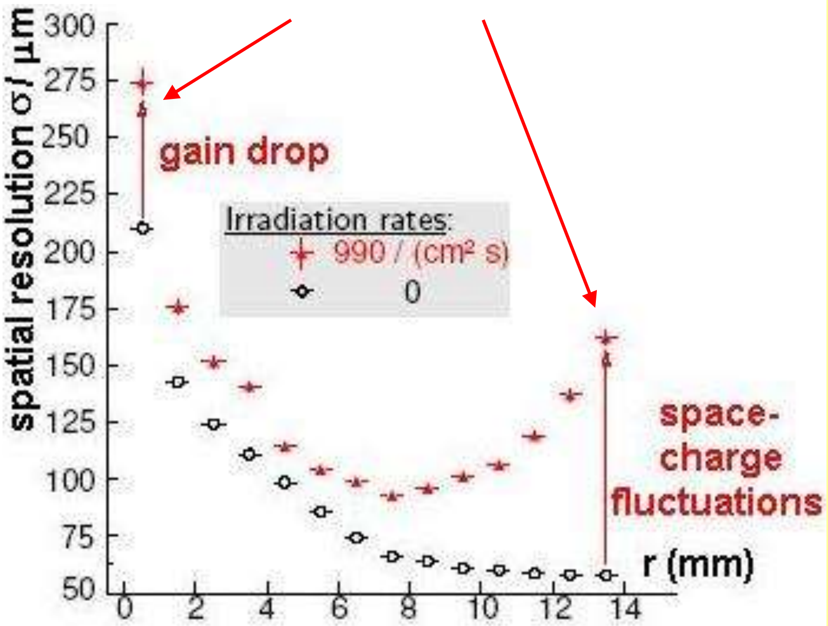
~ 1200 chambers, σ (chamber) ~ 50 μm

- 370000 tubes, 740000 end-plugs
- 12000 CCD for optical alignment



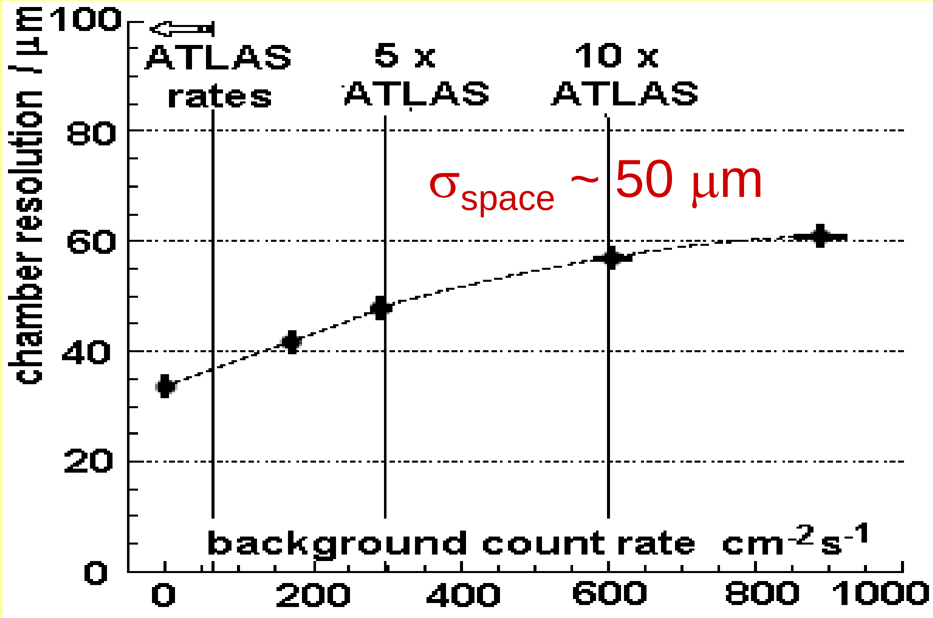


Intrinsic limitation of wire chambers:
(resolution degradation at high rates):

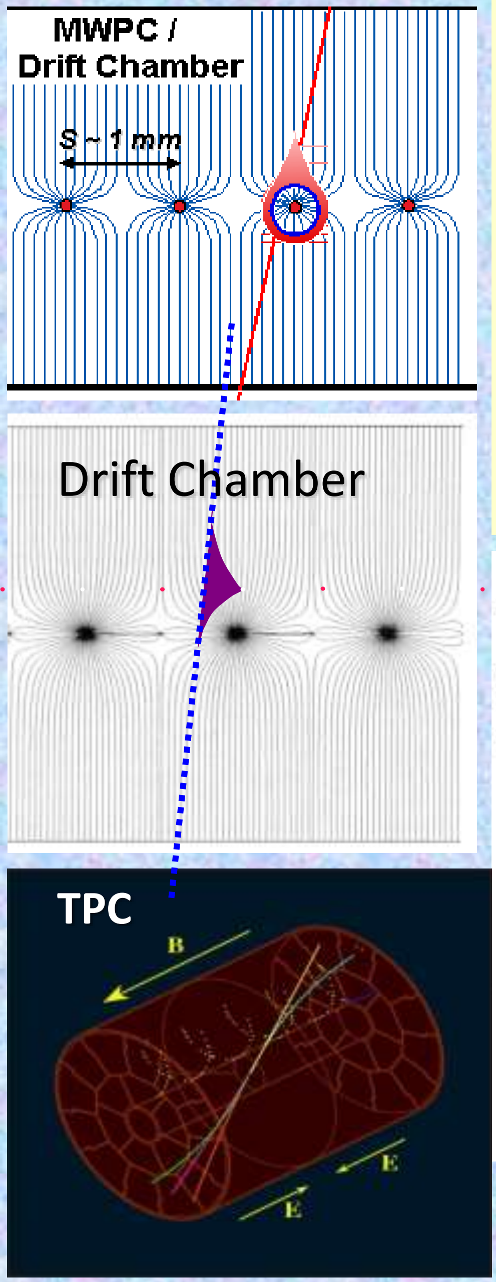


1 chamber → 2 layers of 3 drift tubes

Spatial resolution /chamber (2 layers of 3 drift tubes)



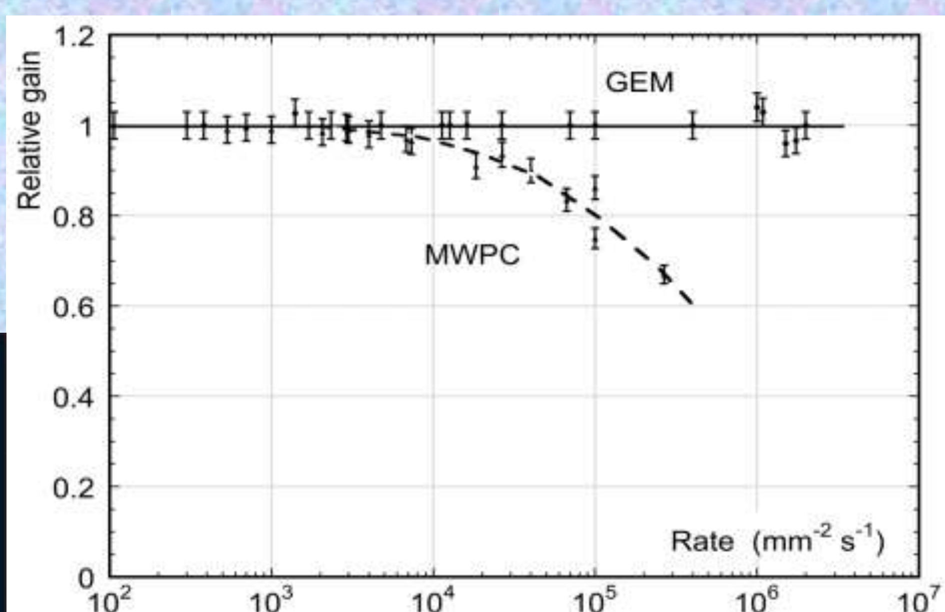
Why do Tracking Detectors Change ?



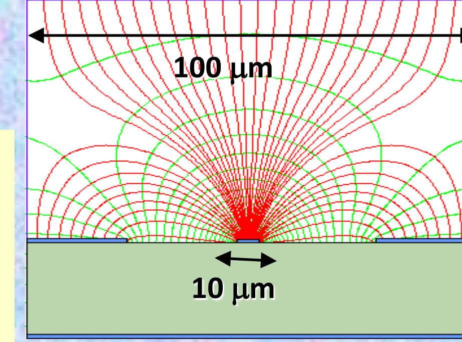
Higher Rate, enormous occupancy:
1D easily saturated → 2D → 3D

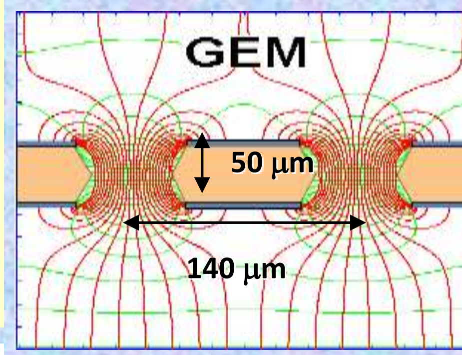
➢ Silicon detectors:
Strips →Pixels (2D)→ 3D det-electr. integ.

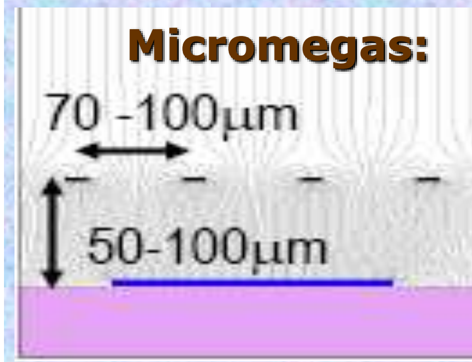
➢ Gaseous detectors
Wire Chamber → Wireless MPGD (2D)
→ InGrid/Timepix (3D)

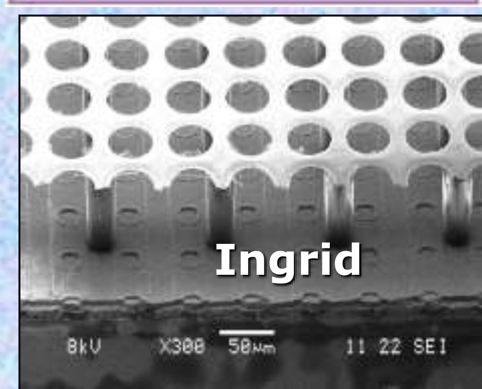


Advances in Micro-electronics & Etching Technology → Micro pattern Gaseous Detectors





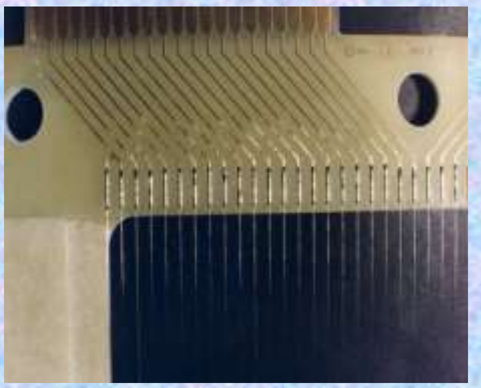


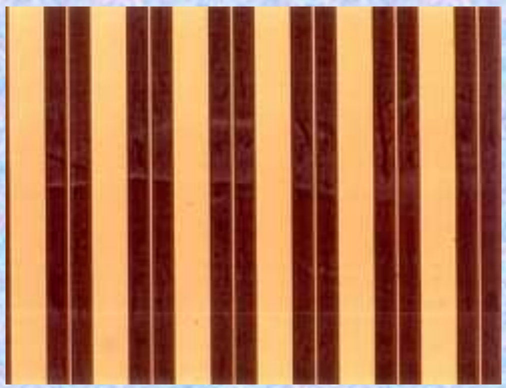


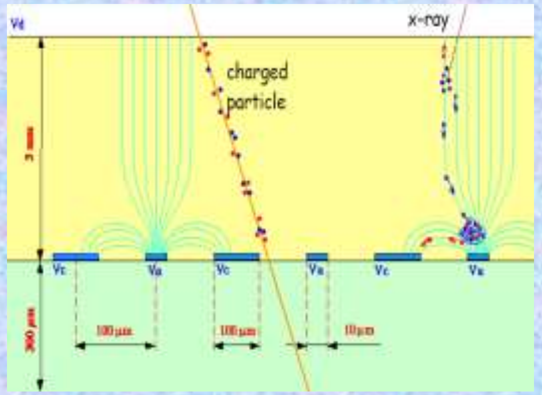
Micro-Strip Gas Chamber (MSGC)

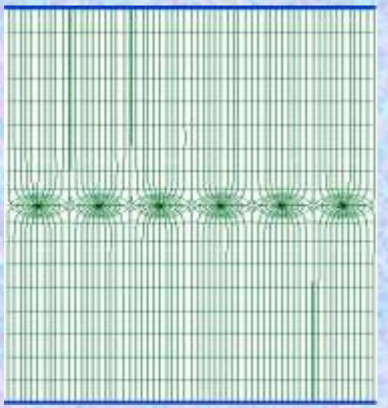
MWPC

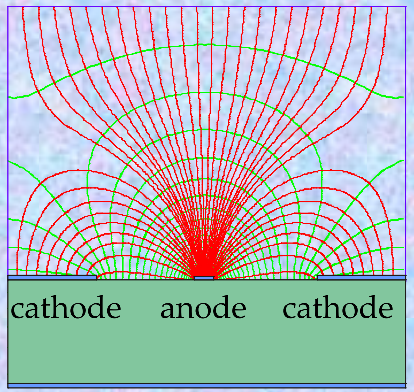
MSGC



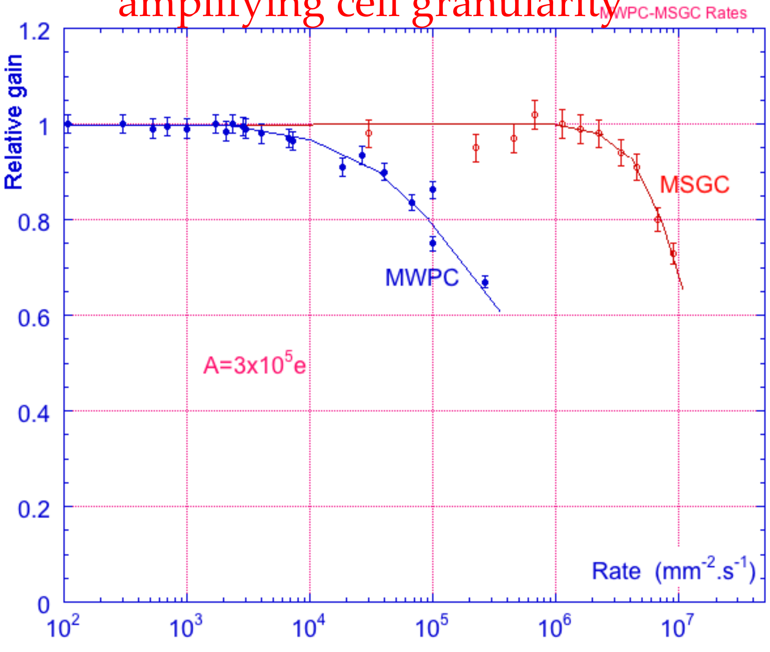








Rate capability limit due to space charge overcome by increased amplifying cell granularity



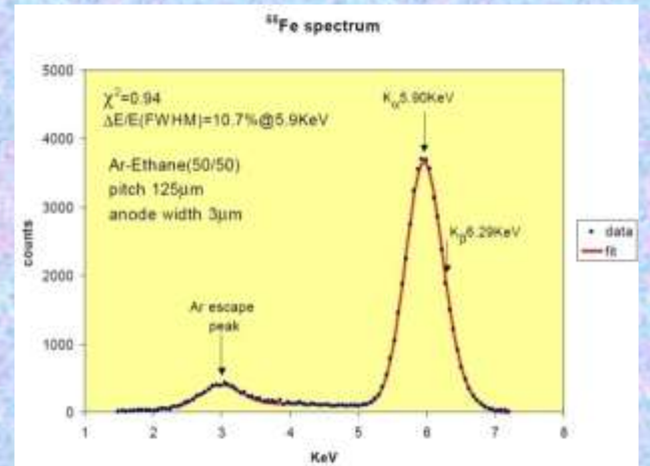
Typical distance between wires limited to 1 mm due to mechanical and electrostatic forces

Typical distance between anodes 200 mm thanks to semiconductor etching technology

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

MSGC Performance

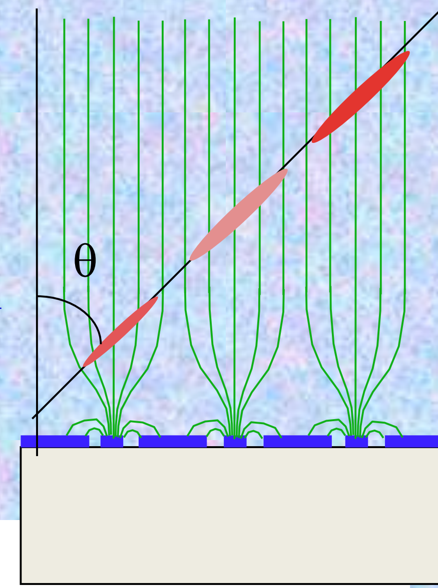
EXCELLENT RATE CAPABILITY, SPATIAL AND MULTI-TRACK RESOLUTION



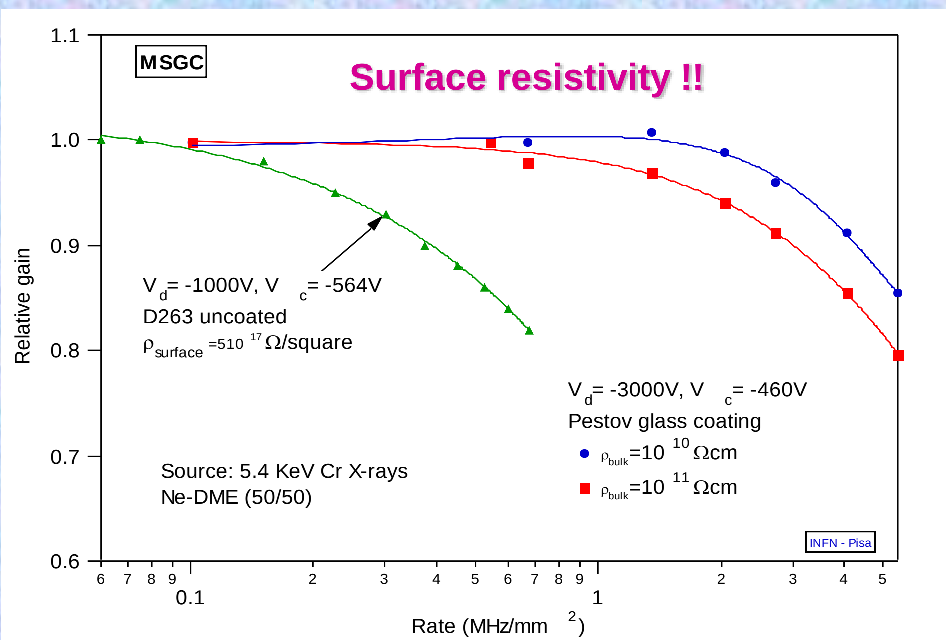
RATE CAPABILITY > $10^6/mm^2$ s

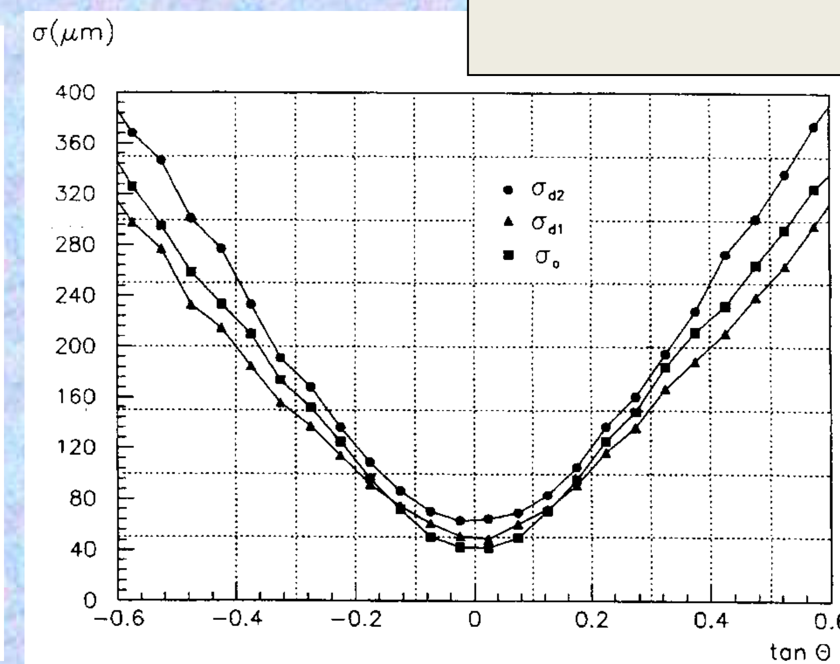
SPACE ACCURACY ~ 40 μm rms

2-TRACK RESOLUTION ~ 400 μm



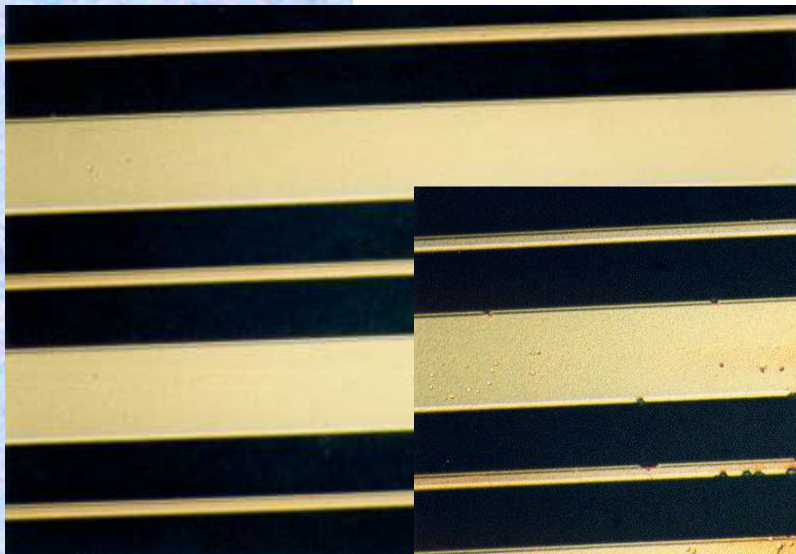
ENERGY RESOLUTION ~11% for 5.9 keV



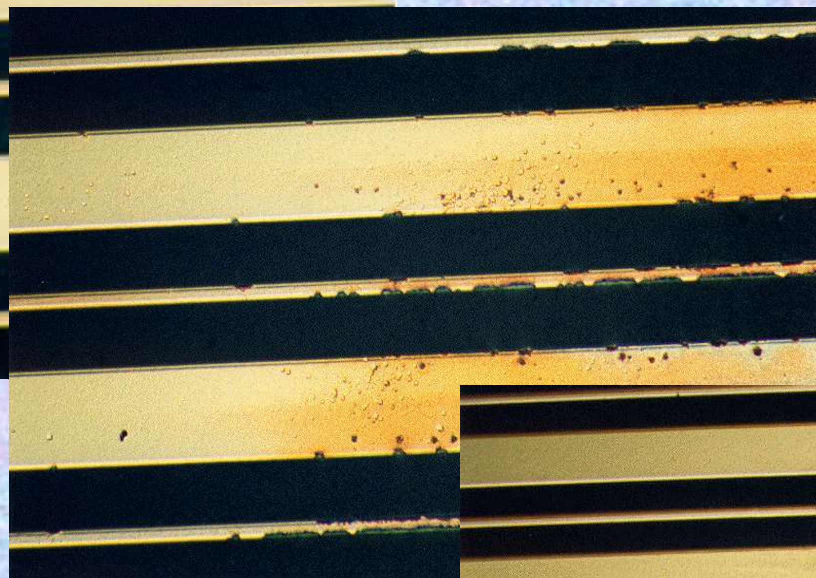


F. Van den Berg et al, NIMA A349 (1994) 438

MSGC Discharge Problems



Discharge is very fast (~ns)
Difficult to predict or prevent

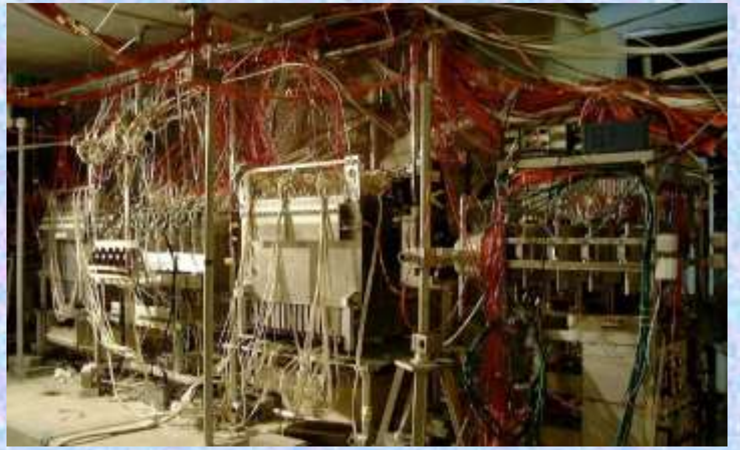


MICRODISCHARGES

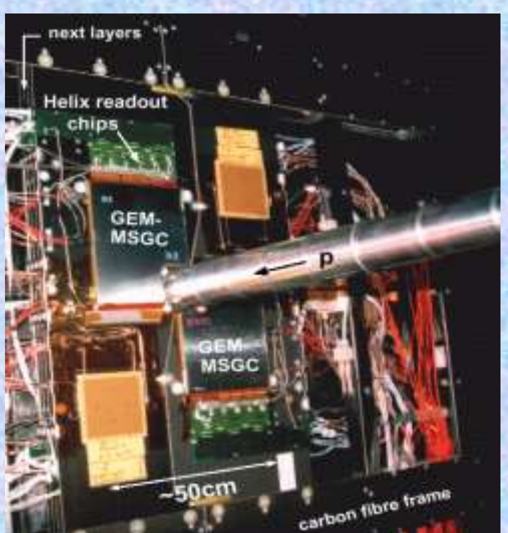
Owing to very small distance between anode and cathode the transition from proportional mode to streamer can be followed by spark, discharge, if the avalanche size exceeds
RAETHER'S LIMIT
Q ~ $10^7 - 10^8$ electrons

FULL BREAKDOWN

Micro-Strip Gas Chamber (MSGC)



Telescope of 32 MSGCs
tested at PSI in Nov99
(CMS Milestone)



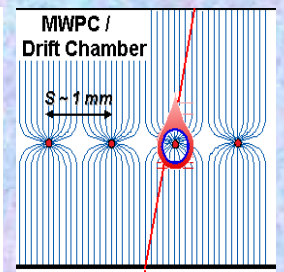
HERA-B Inner Tracker
MSGC-GEM detectors
R_{min} ~ 6 cm
$\Rightarrow 10^6$ particles/cm^2 s
300 µm pitch
184 chambers: max 25x25 cm^2
~ 10 m^2; 140.000 channels

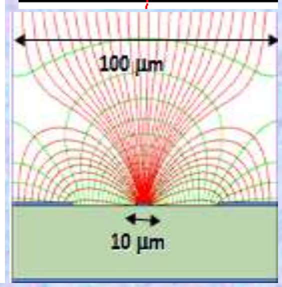
DIRAC
4 planes MSGC-GEM
Planes 10x10 cm^2

The D20 diffractometer MSGC is working since Sept 2000
1D localisation
48 MSGC plates (8 cm x 15 cm)
Substrate: Schott S8900
Angular coverage : 160° x 5,8°
Position resolution : 2.57 mm (0,1°)
5 cm gap; 1.2 bar CF4 + 2.8 bars 3He

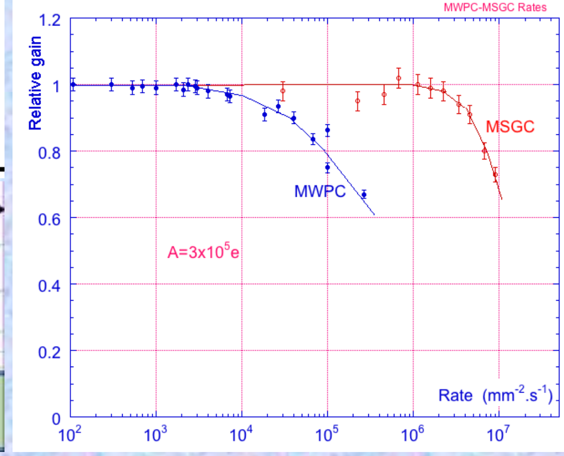
Micro-Pattern Gaseous Detector Technologies for Future Physics Projects

- Micromegas
- GEM
- Thick-GEM, Hole-Type and RETGEM
- MPDG with CMOS pixel ASICs ("InGrid")
- Micro-Pixel Chamber (µPIC)

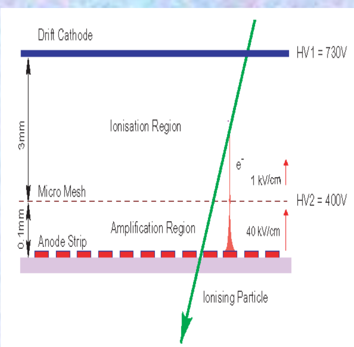




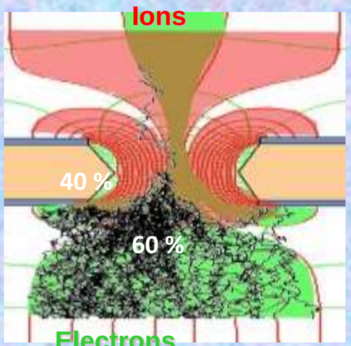
Rate Capability:
MWPC vs MSGC



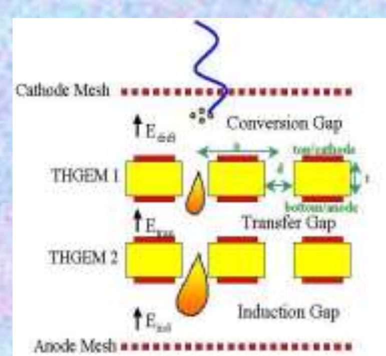
Micromegas



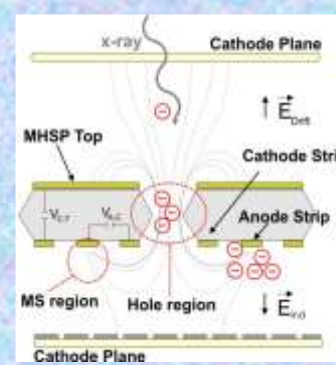
GEM

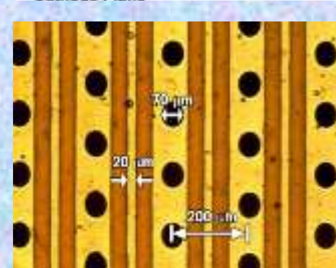


THGEM

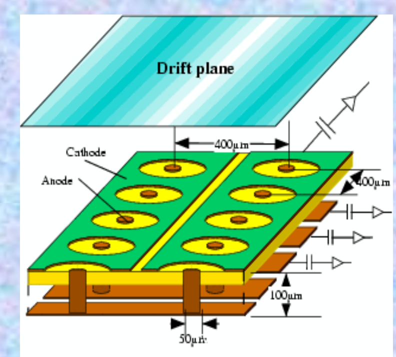


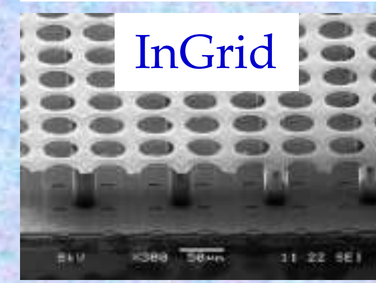
MHSP





µPIC



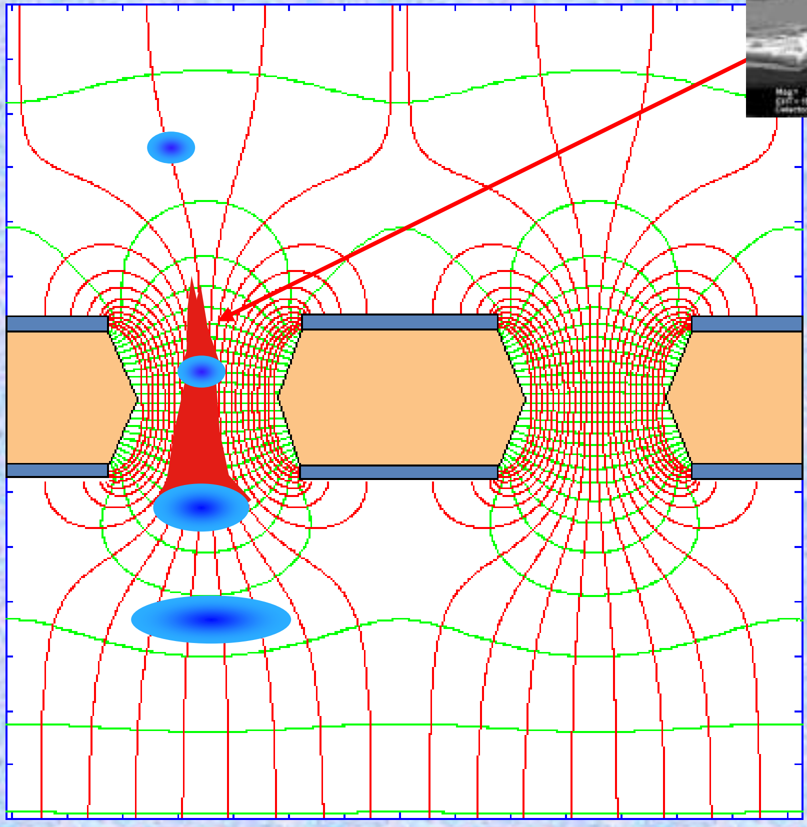


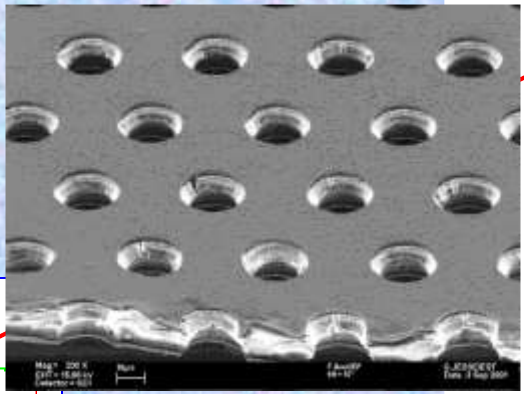
GEM (Gas Electron Multiplier)

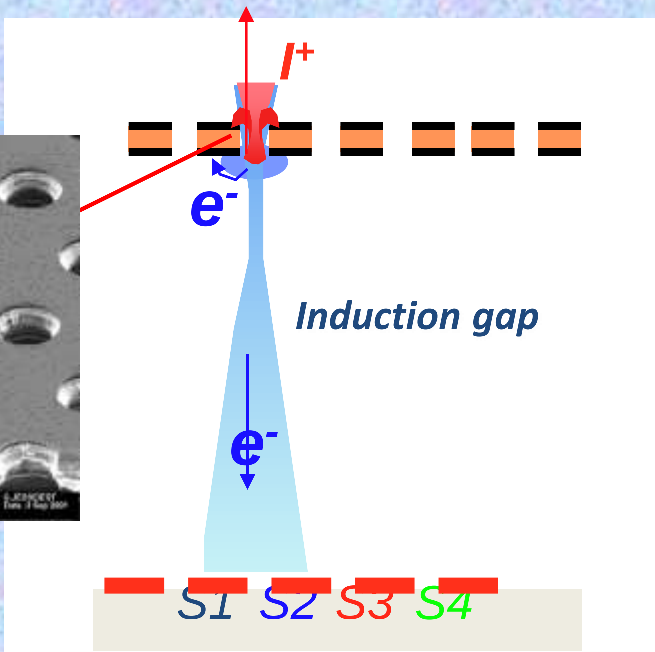
Thin metal-coated polymer foil chemically pierced by a high density of holes

A difference of potentials of ~ 500V is applied between the two GEM electrodes.

→the primary electrons released by the ionizing particle, drift towards the holes where the high electric field triggers the electron multiplication process.







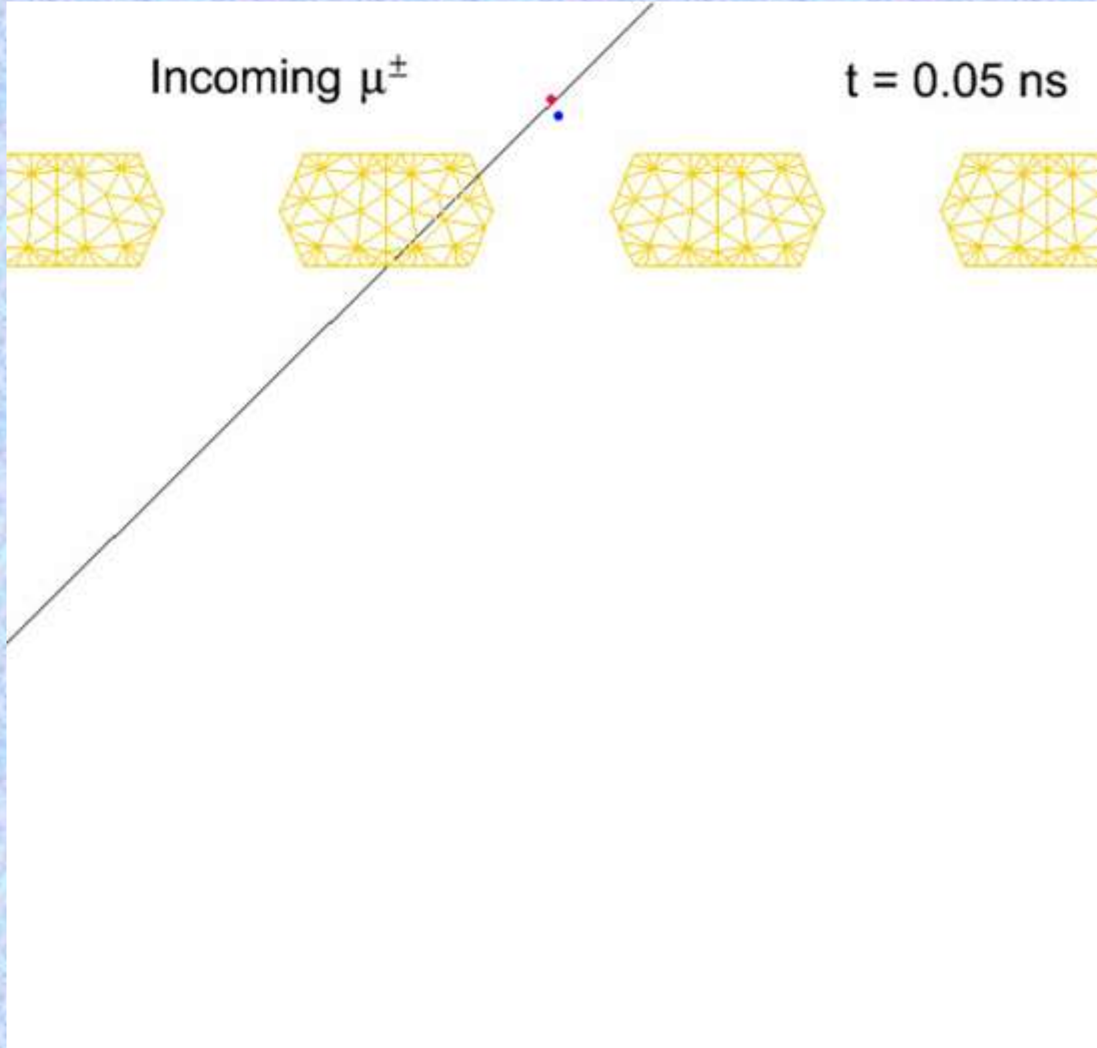
- Electrons are collected on patterned readout board.
- A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.
- All readout electrodes are at ground potential.

F. Sauli, Nucl. Instrum. Methods A386(1997)531
F. Sauli, http://www.cern.ch/GDD

MPGD Simulation Tools (Avalanche Simulation in GEM)

Animation of the avalanche process (monitor in ns-time electron/ion drifting and multiplication in GEM):

electrons are blue, ions are red, the GEM mesh is orange



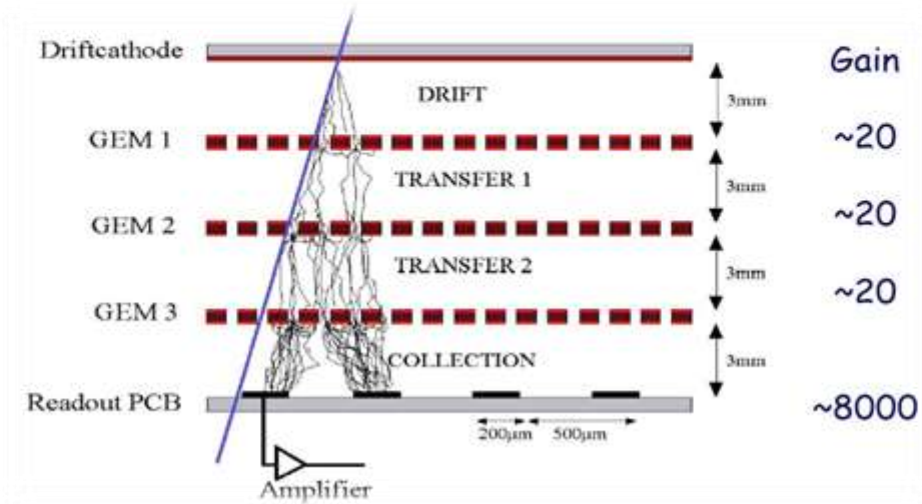
- ANSYS: field model
- Magboltz 8.9.6: relevant cross sections of electron-matter interactions
- Garfeld++: simulate electron avalanches

http://cern.ch/garfieldpp/examples/gemgain

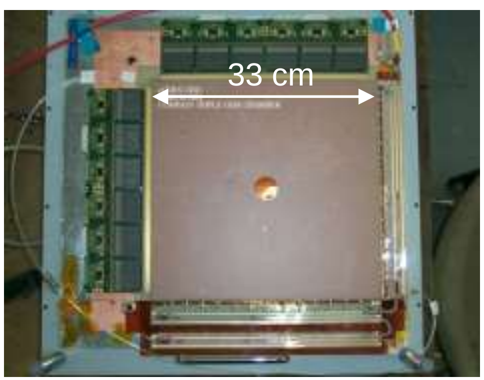
Gas Electron Multiplier (GEM)

F. Sauli, NIM A386(1997) 531;
F. Sauli, http://www.cern.ch/GDD

Full decoupling of amplification stage (GEM) and readout stage (PCB, anode)

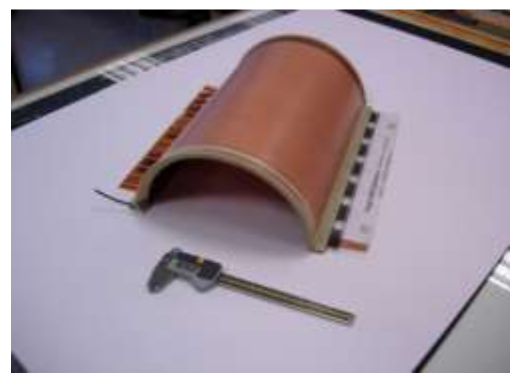


Amplification and readout structures can be optimized independently !

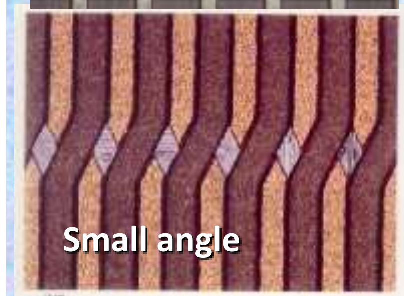


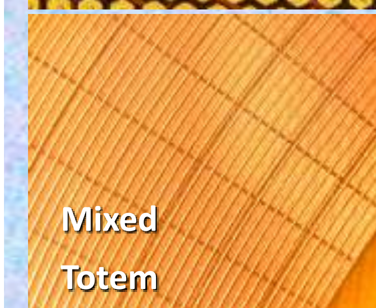
Compass

Totem



NA49-future

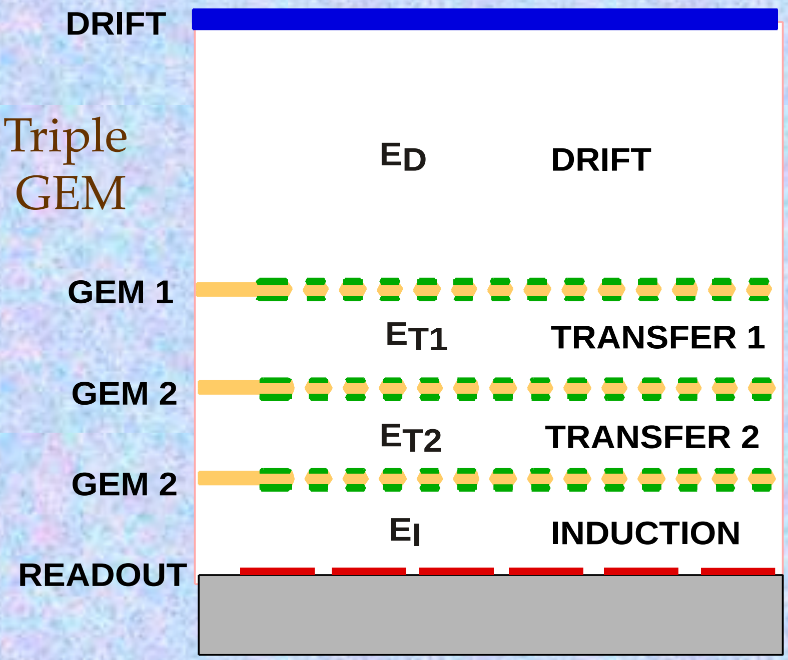


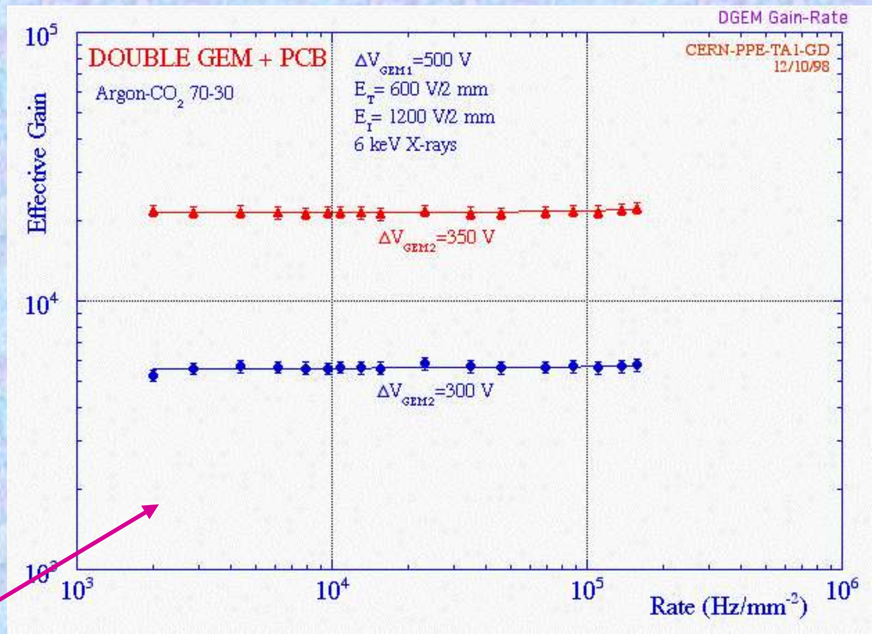


Multiple GEM Structures

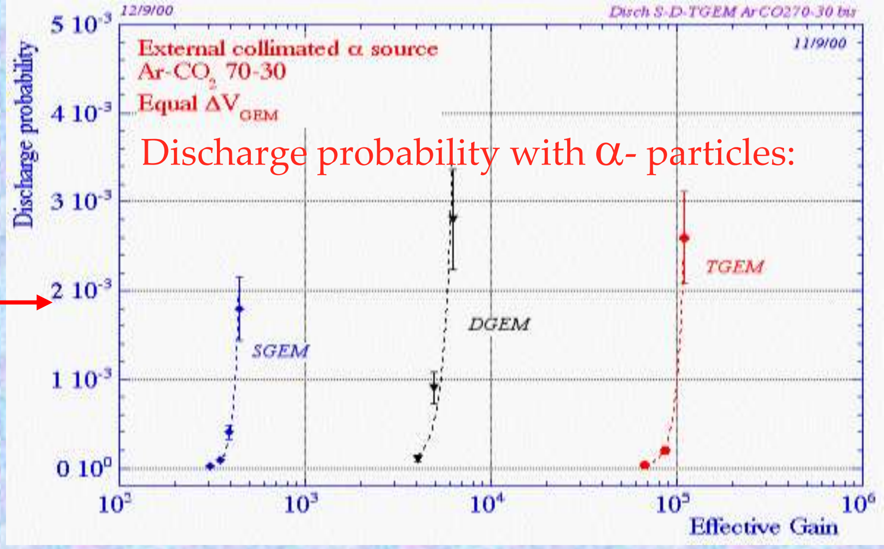
Cascaded GEMs achieve larger gains and safer operation in harsh environments

Triple GEM





High-rate capability > 10^5 Hz/mm^2;
No space-charge phenomena



Discharge probability with α- particles:

Multiple GEM structure strongly reduces probability of discharges

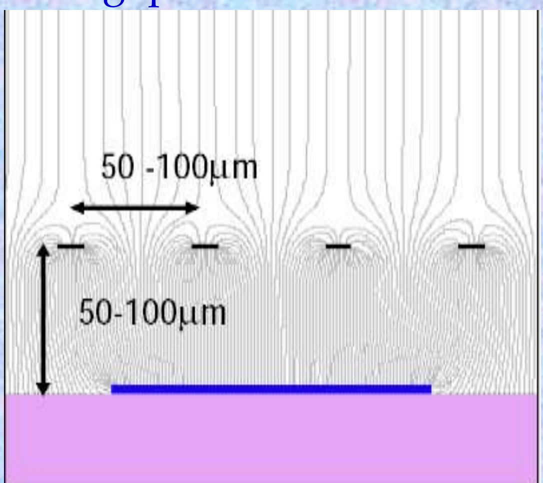
S. Bachmann et al, NIM A 479(2002)294

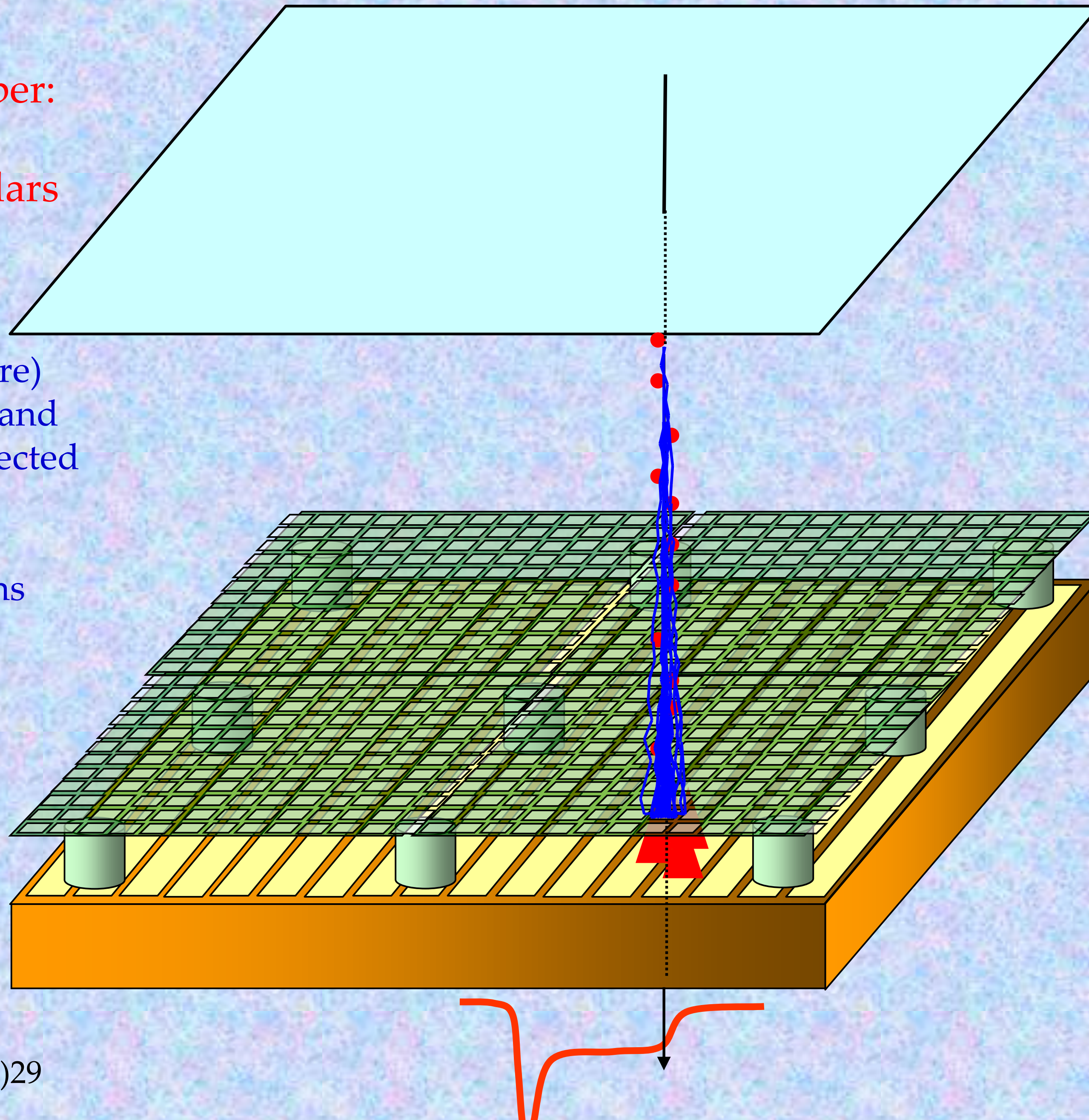
MICro MEsh GAseous Structure (MICROMEGAS)

Micromesh Gaseous Chamber:
micromesh supported
by 50-100 μm insulating pillars

Multiplication (up to 10^5 or more) takes place between the anode and the mesh and the charge is collected on the anode (one stage)

Small gap: fast collection of ions



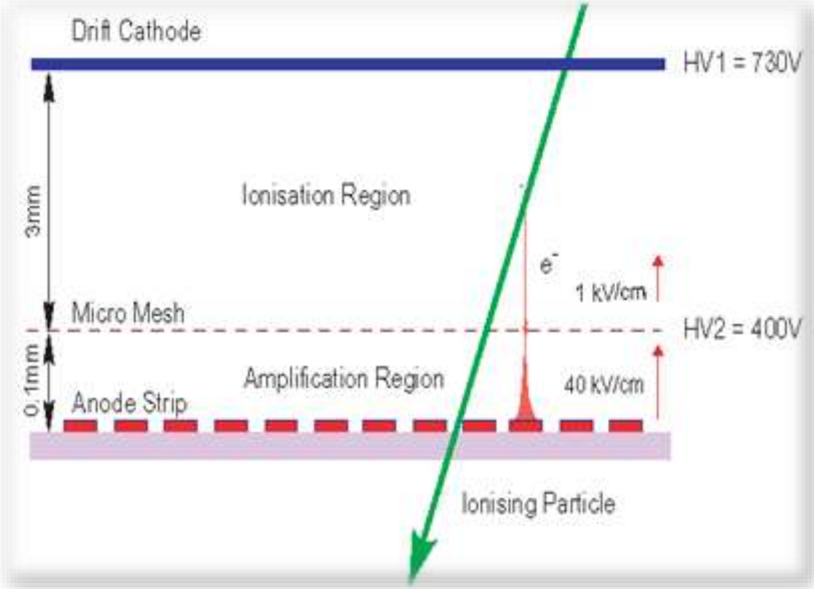


Y. Giomataris et al, NIM A376(1996)29

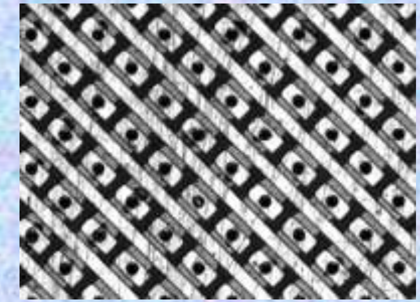
MICROMEGAS

Y. Giomataris et al, NIM A376(1996)29

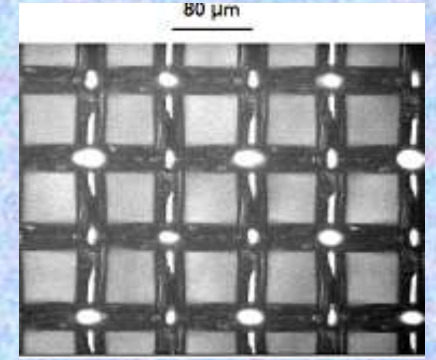
Parallel plate multiplication in thin gaps between a fine mesh and anode plate

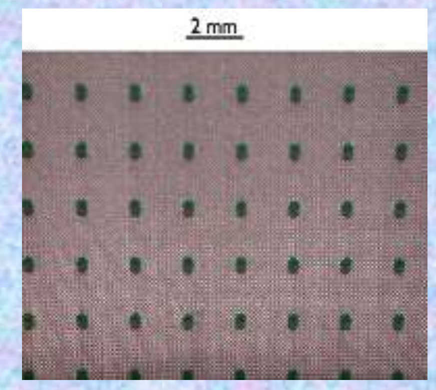


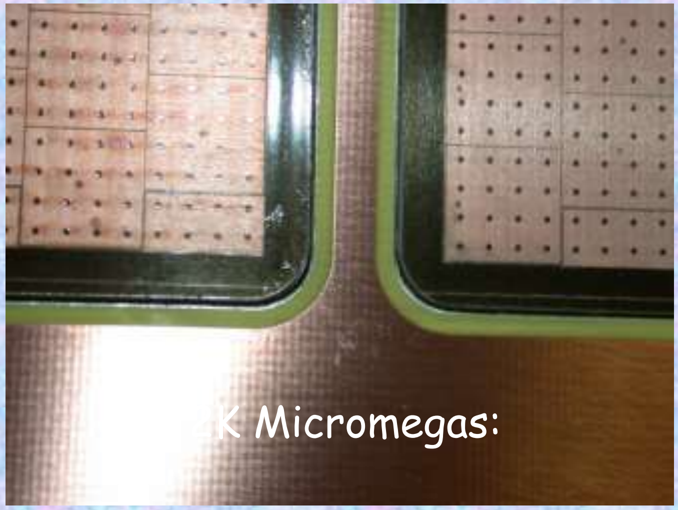
CAST readout:



"Bulk" Micromegas:

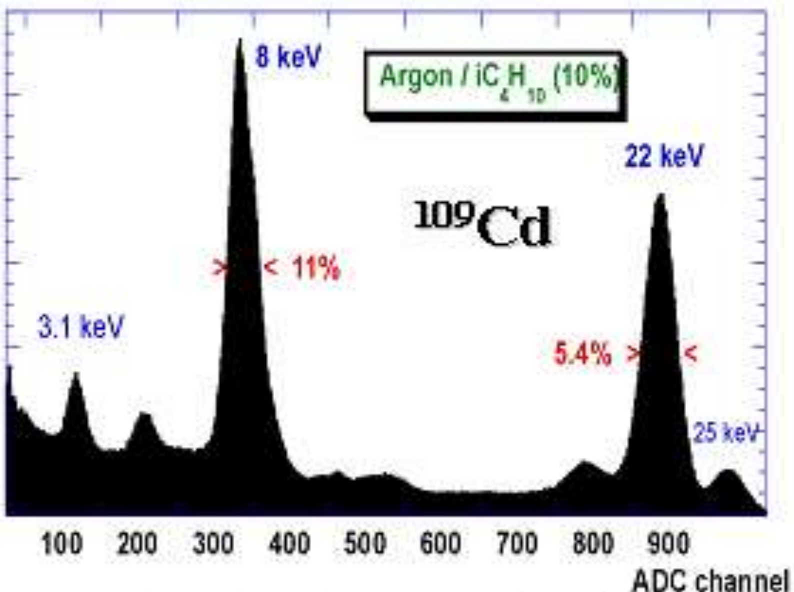






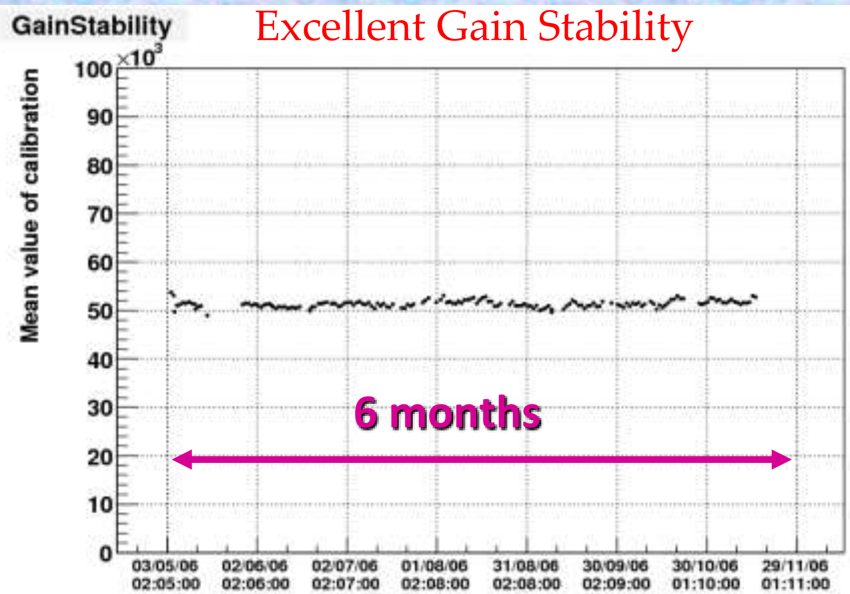
Micromegas Performance

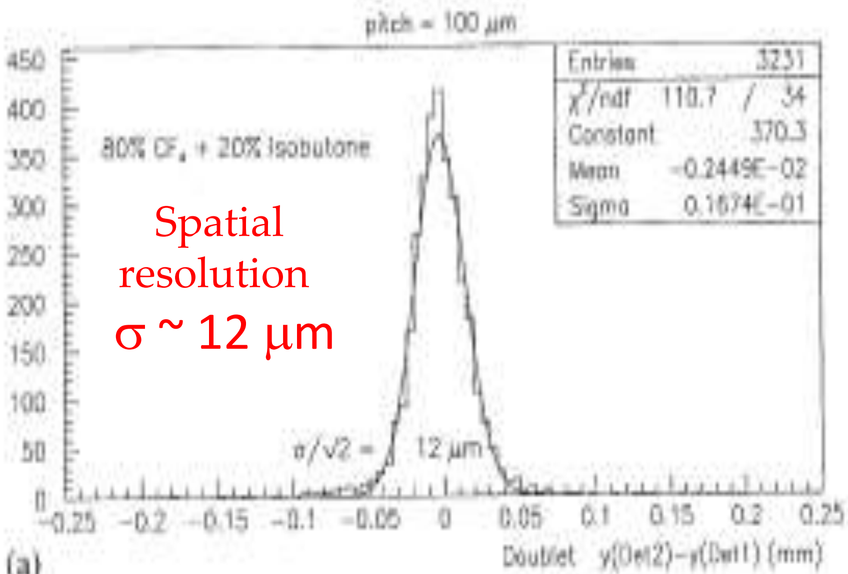
Small gap→ good energy resolution



G. Charpak et al., NIMA478 (2002) 26

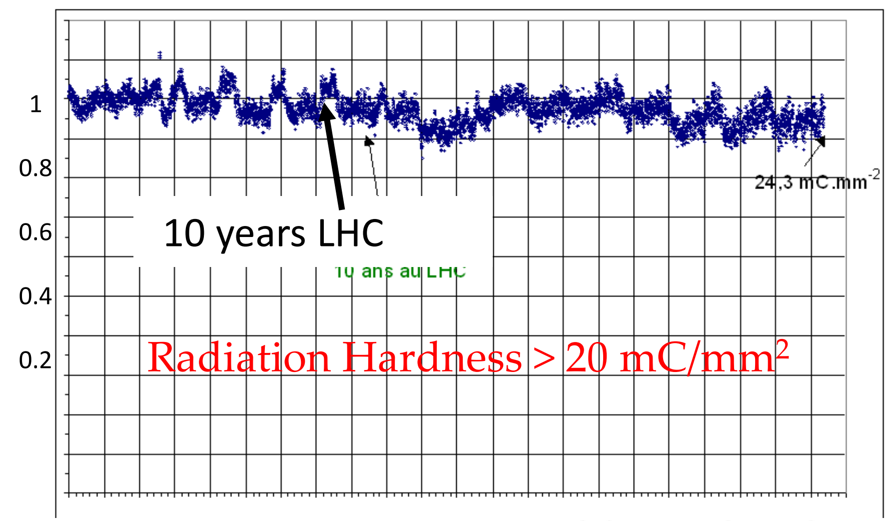
Excellent Gain Stability





J. Derre et al, NIM A459 (2001) 523

ageing:Ar-iC$_4$H$_{10}$ 94-6% up to 24.3mC/mm^2



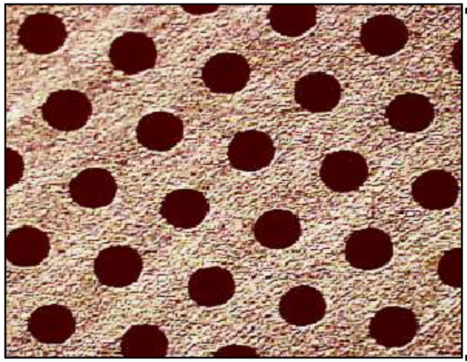
G. Puill et al., IEEE Trans. Nucl. Sci. V.46(6), 1894 (1999)

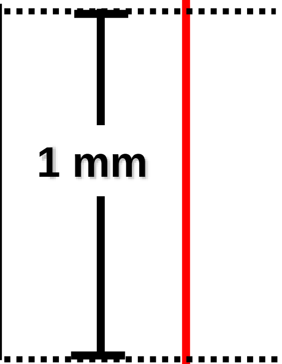
J. Derre et al., NIM A449 (2000) 314

Thick-GEM Multipliers (THGEM)

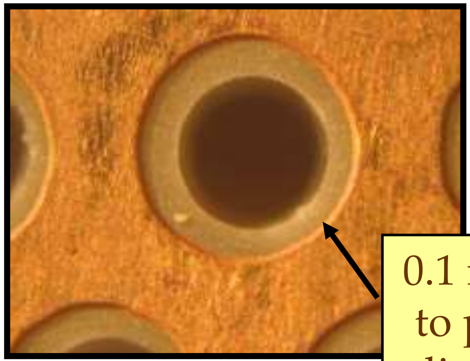
Simple & Robust → Manufactured by standard PCB techniques of precise drilling in G-10 (and other materials) and Cu etching

STANDARD GEM
10^3 GAIN IN SINGLE GEM





THGEM
10^5 gain in single-THGEM



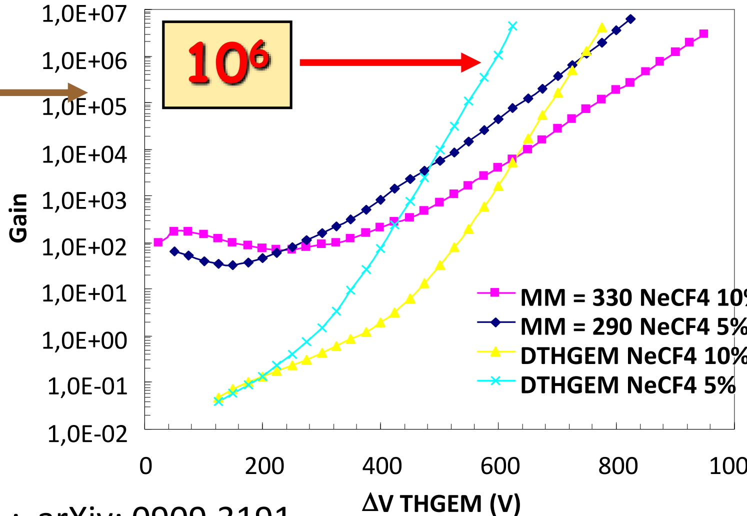
0.1 mm rim to prevent discharges

Other groups developed similar hole-multipliers:

- *Optimized GEM: L. Periale et al., NIM A478 (2002) 377.*
- *LEM: P. Jeanneret,*
- *PhD thesis, 2001.*

- Effective single-electron detection (high gas gain ~10^5 (>10^6) @ single (double) THGEM)
- Few-ns RMS time resolution
- Sub-mm position resolution
- MHz/mm^2 rate capability
- Cryogenic operation: OK
- Gas: molecular and noble gases
- Pressure: 1mbar - few bar

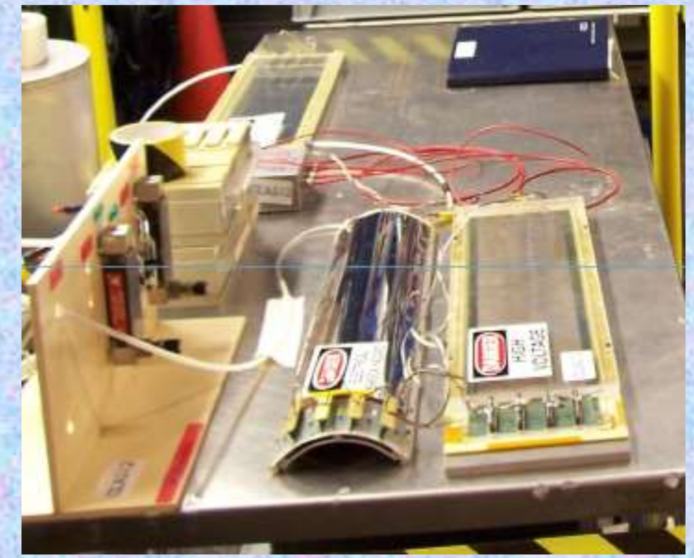
Double THGEM or THGEM/Micromegas

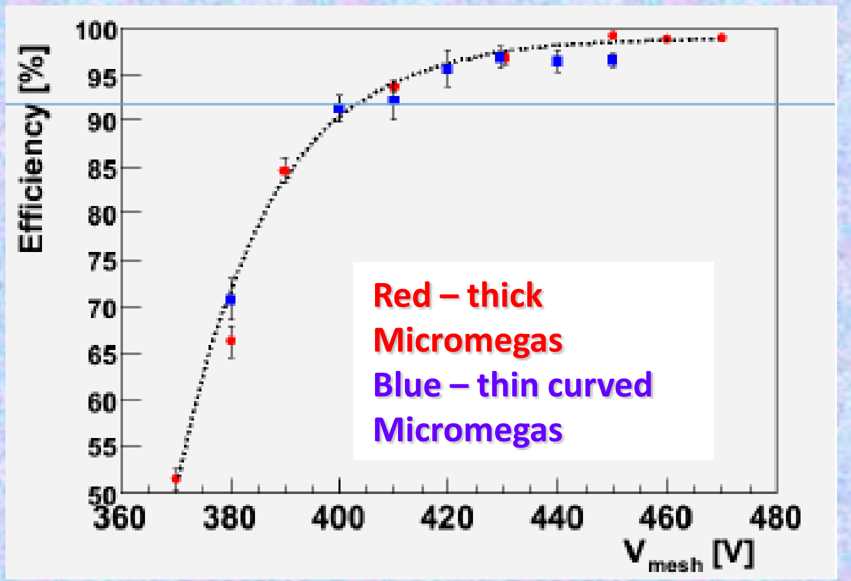


C. Azevedo et al.; arXiv: 0909.3191

Advancing Concepts: Cylindrical Tracking Detectors

Thin Curved Micromegas for CLAS12

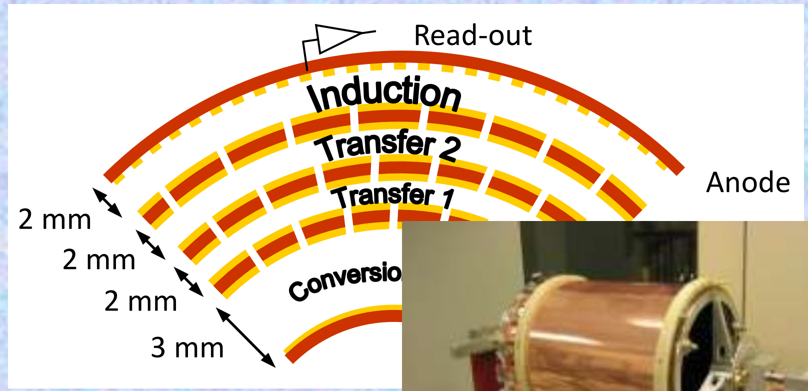


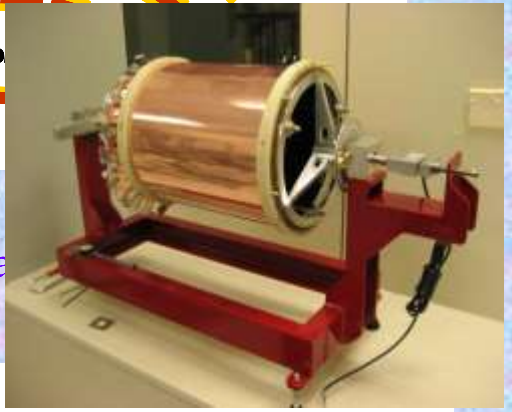


D. Nygret, RD51 Collab. Meet., Nov.23-25, 2009, WG7 Meeting

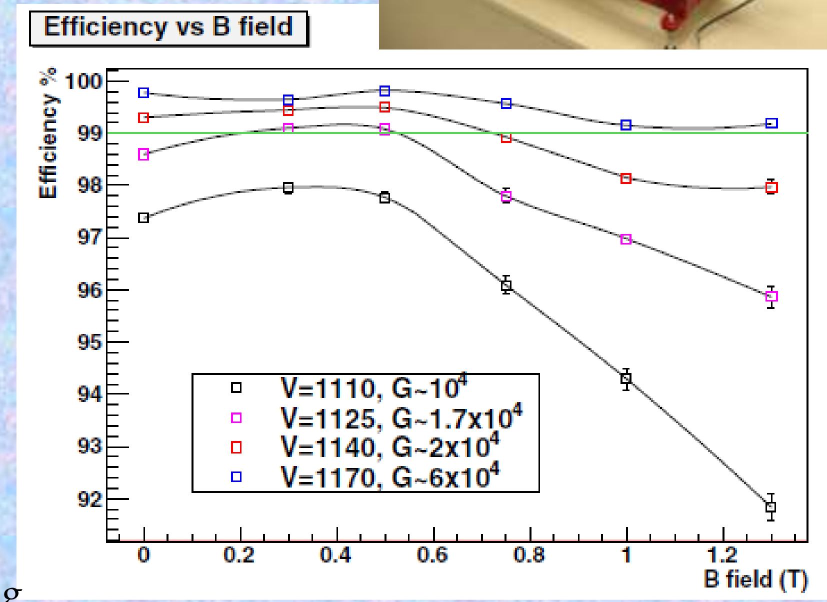
S. Aune, Proc. of the MPGD Conf., Crete, June 2009

Cylindrical GEM for KLOE2 Inner Tracker:





Increase of ma
larger spread of



A. Balla et al., 2009 IEEE NSS/MIC Conference Record.

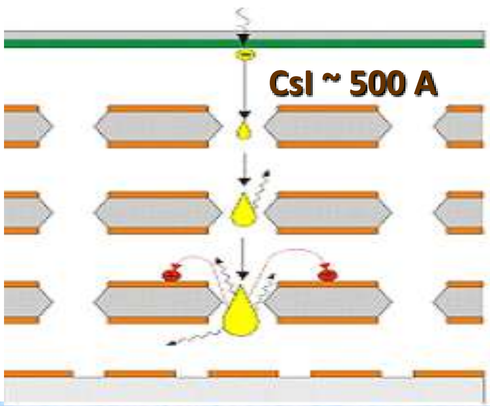
MPGD-Based Gaseous Photomultipliers (GPM)

GEM Gaseous Photomultipliers (GEM+CsI photocathode) to detect single photoelectrons

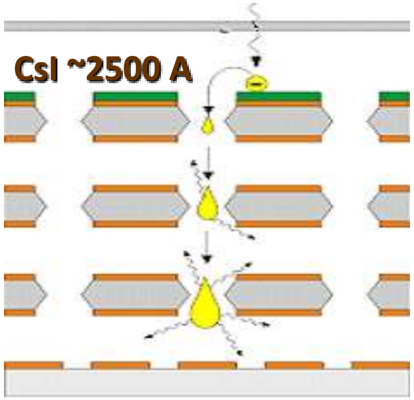
Multi-GEM Gaseous Photomultipliers:

- Largely reduced photon feedback (can operate in pure noble gas & CF_4)
- Fast signals [ns] → good timing
- Excellent localization response
- Able to operate at cryogenic T

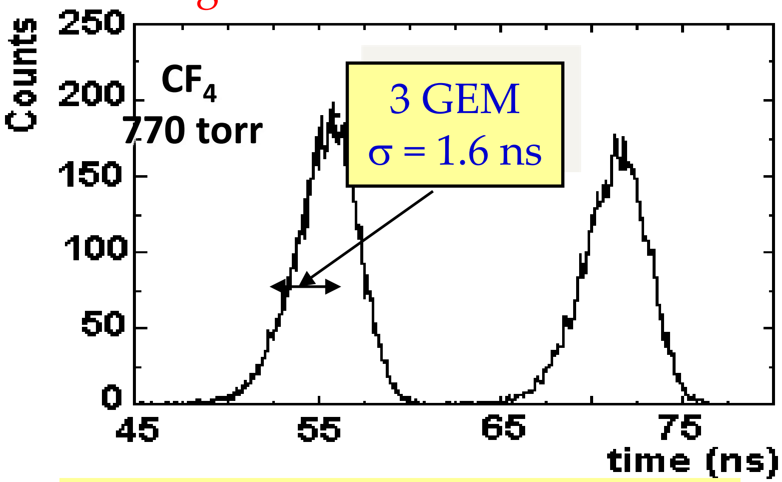
Semitransparent Photocathode (PC)



Reflective Photocathode (PC)

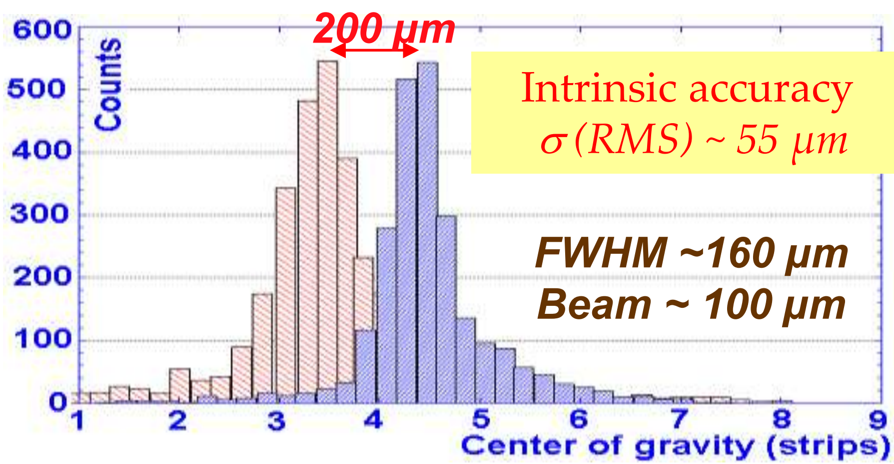


Single Photon Time Resolution:



Micromegas: σ ~ 0.7 ns with MIPs

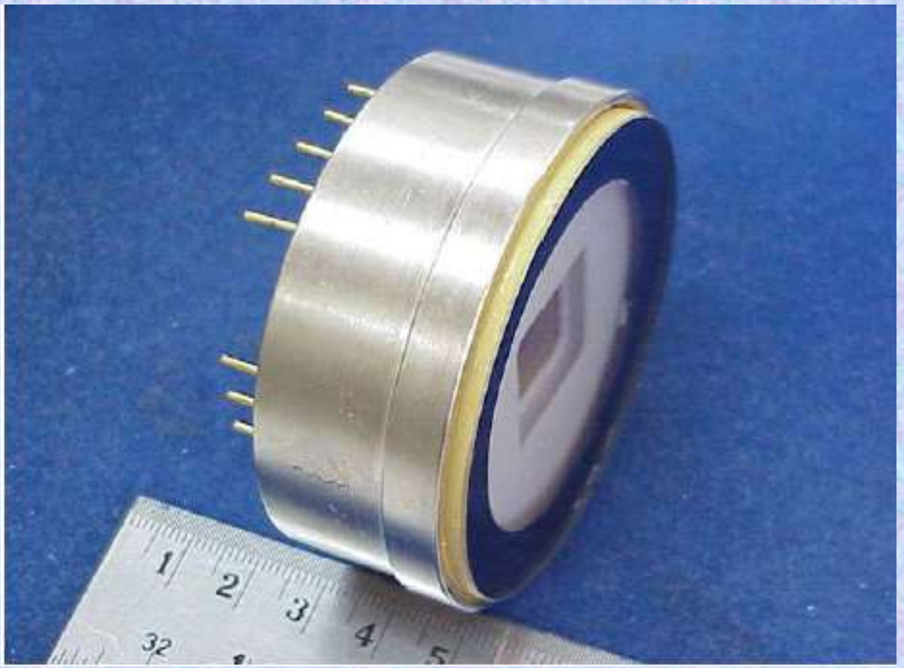
Single Photon Position Accuracy:



E.Nappi, NIMA471 (2001) 18; T. Meinschad et al, NIM A535 (2004) 324; D.Mormann et al., NIMA504 (2003) 93

Sealed GEM-based Gaseous Photomultiplier

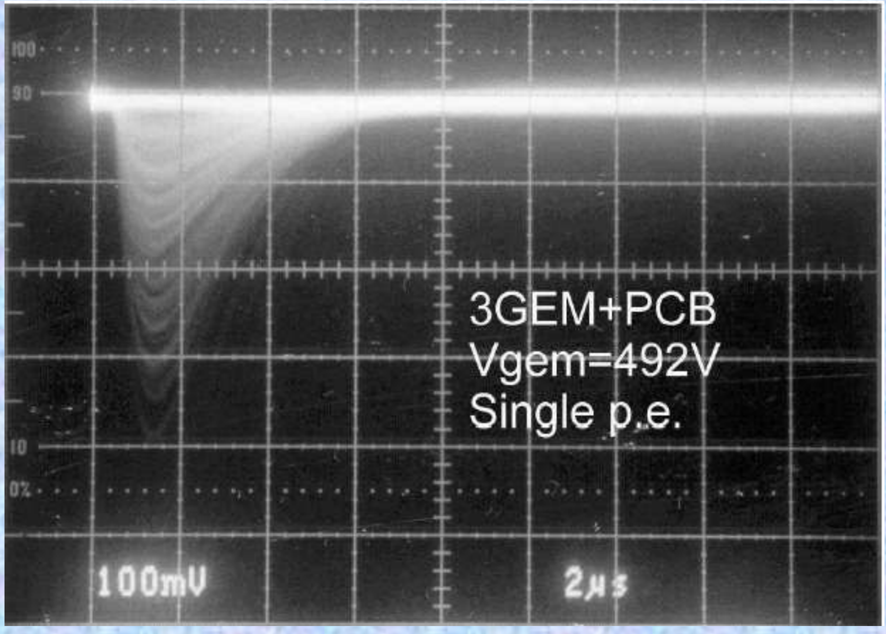
Semi-transparent CsI photocathode: towards large area, position-sensitive photomultipliers



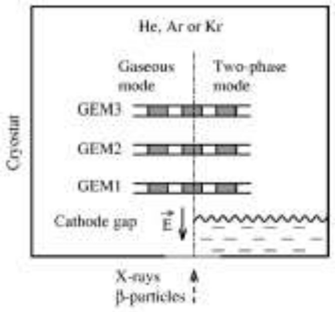
A. Breskin et al, Nucl. Instr. and Meth. A478(2002)225
F. Sauli, http://www.cern.ch/GDD

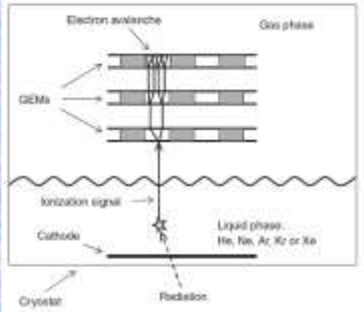
Number of advantages over vacuum photomultipliers: insensitivity to magnetic field, large active area, excellent localization response, flat-panel geometry and low cost

Single photo-electron signals:

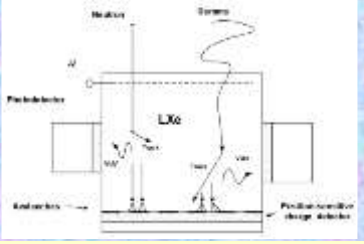


MPGD-Based Cryogenic Avalanche Detectors: Concept Gallery

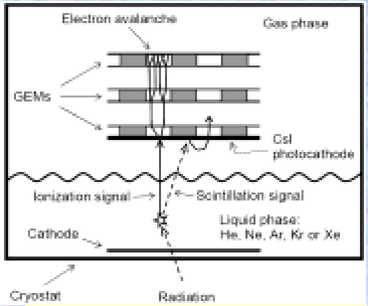




A.Buzulutskov et al, IEEE TNS 50 (2003) 2491;
A.Bondar et al, NIMA 524 (2004) 130

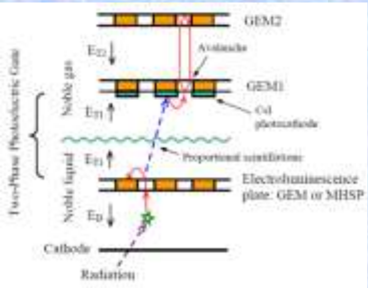


L.Periale et al, IEEE TNS 52 (2005) 927

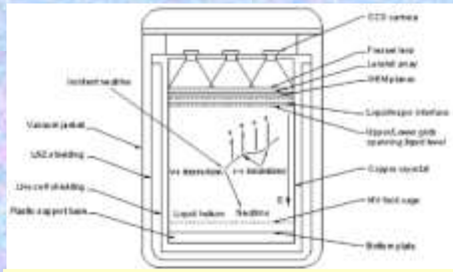


A.Bondar et al, NIMA 556 (2006) 273

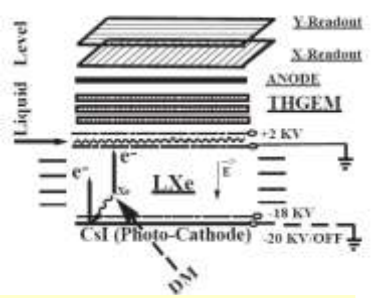
A.Rubbia, J. Phys. Conf. Ser. 39 (2006) 129



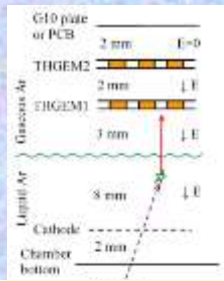
A.Buzulutskov, A.Bondar, JINST 1 (2006) P08006



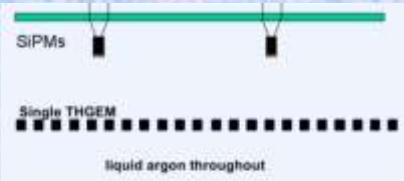
Y.L.Ju et al, Cryogenics 47 (2007) 81



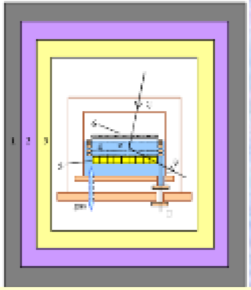
M.Gai et al, Eprint arxiv:0706.1106 (2007)



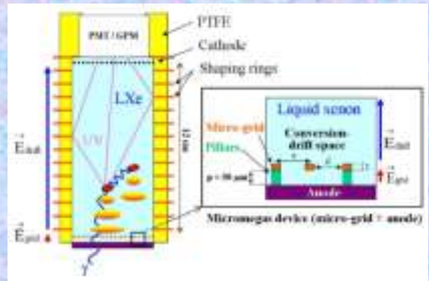
A.Bondar et al, JINST 3 (2008) P07001



P.K.Lightfoot et al, JINST 4 (2009) P04002
N.McConkey et al, IPRD 2010, Siena, Italy; Nucl. Phys. B Proc. Suppl. 215 (2011) 255

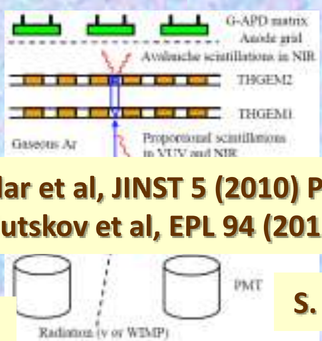


D.Akimov et al, JINST 4 (2009) P06010

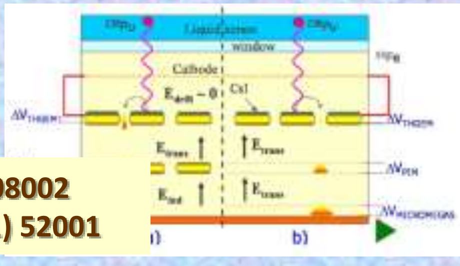


S. Duval et al, JINST 4 (2009) P12008

D.Akimov, NIMA 628 (2011) 50



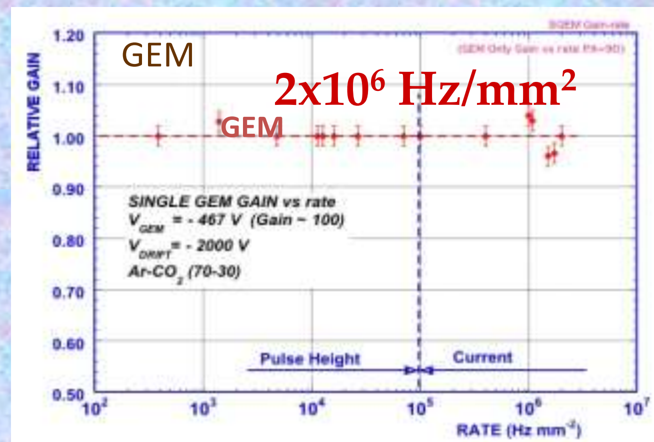
A. Bondar et al, JINST 5 (2010) P08002
A.Buzulutskov et al, EPL 94 (2011) 52001

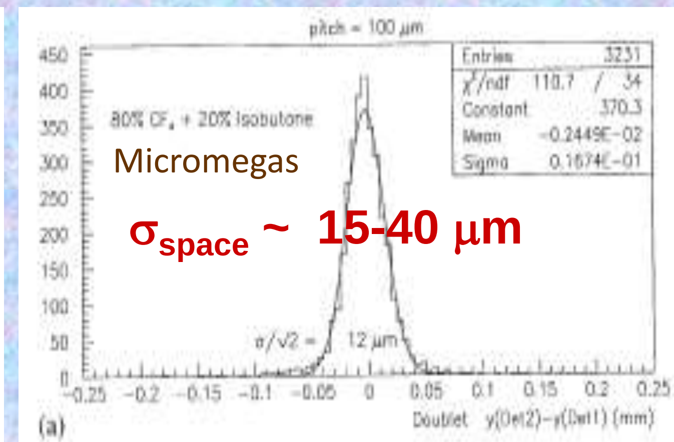


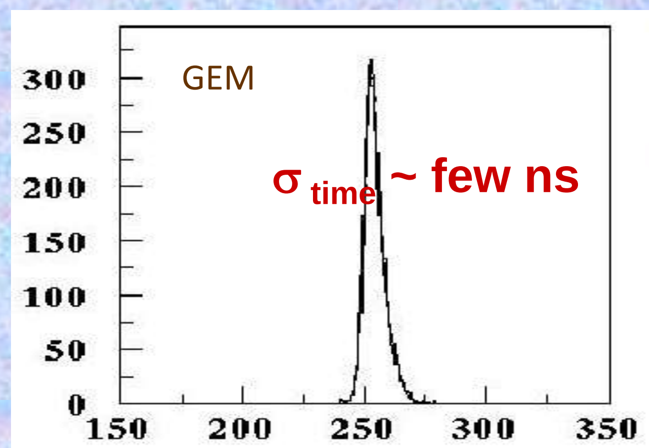
S. Duval et al, JINST 6 (2011) P04007

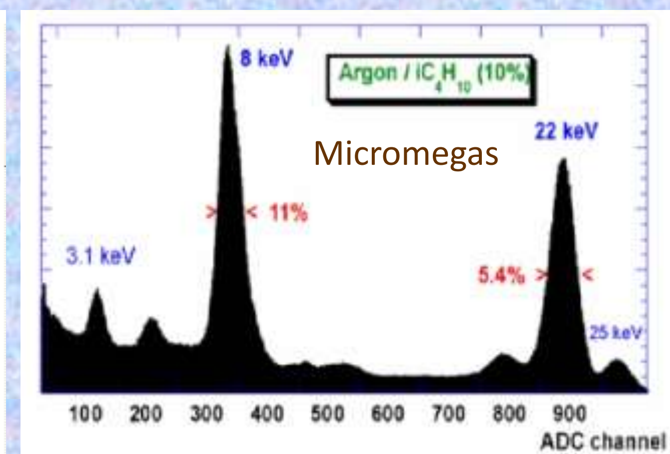
Why Micro-Pattern Gaseous Detectors are so attractive …

- High Rate Capability
- High Gain
- High Space Resolution
- Good Time Resolution
- Good Energy Resolution
- Excellent Radiation Hardness
- Ion Backflow Reduction
- Photon Feedback Reduction









One of the recent reviews describing the progress of the MPGD technologies:

Modern Physics Letters A
Vol. 28, No. 13 (2013) 1340022 (25 pages)

DOI: 10.1142/S0217732313400221

World Scientific
www.worldscientific.com

MICRO-PATTERN GASEOUS DETECTOR TECHNOLOGIES AND RD51 COLLABORATION

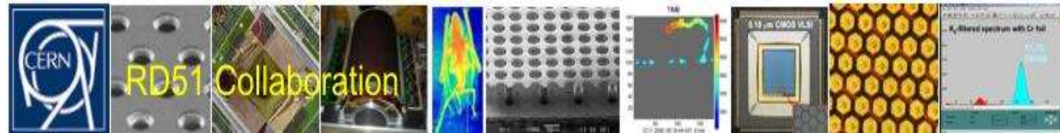
MAXIM TITOV

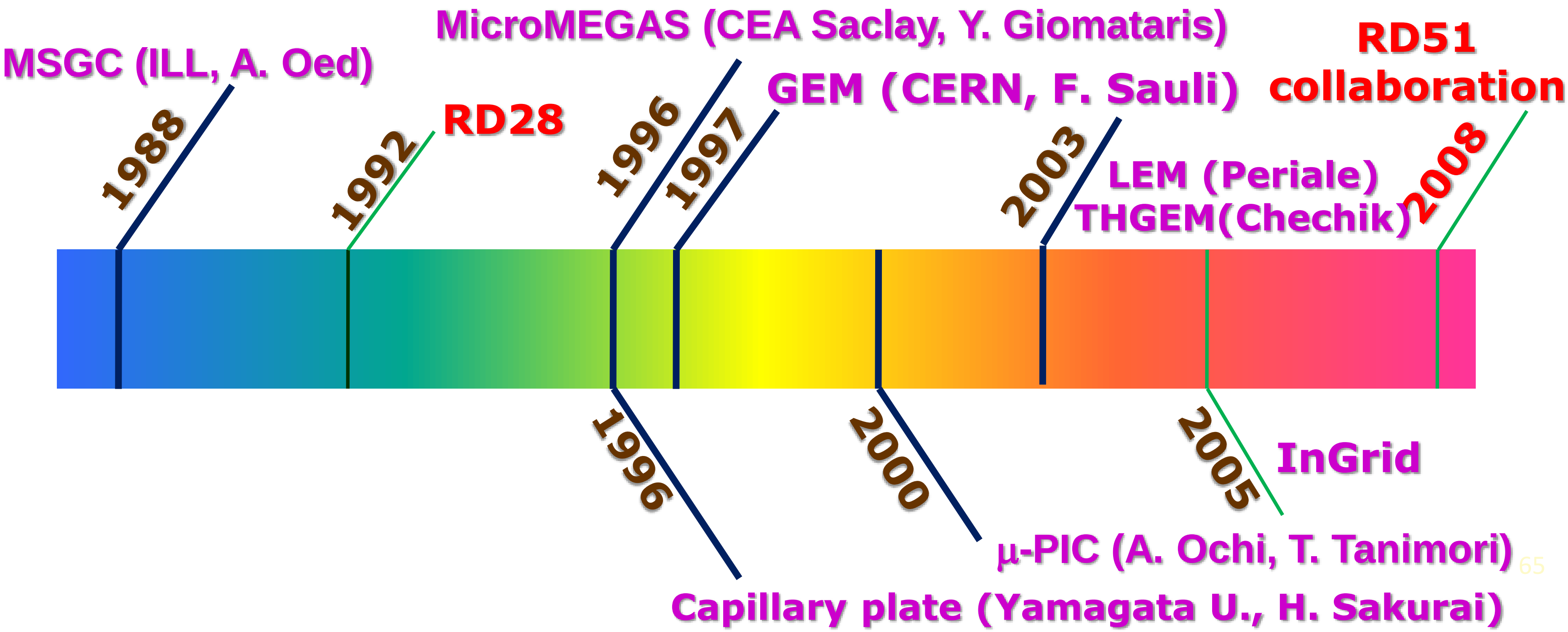
CEA Saclay, DSM/IRFU/SPP, 91191 Gif sur Yvette, France
maxim.titov@cea.fr

LESZEK ROPELEWSKI

CERN PH, CH-1211, Geneva 23, Switzerland
leszek.ropelewski@cern.ch

Historical Roadmap of the MPGD Technologies and RD51 Collaboration





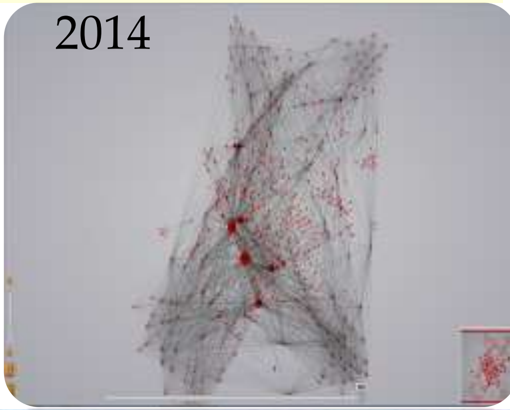
- Many of the Micro-Pattern Gaseous Detector Technologies were introduced before the RD51 Collaboration was founded
- With more techniques becoming available (or affordable), new detection concepts are being introduced and the existing ones are substantially improved

RD51 – Development of Micro-Pattern Gaseous Detector Technologies

The main objective is to advance MPGD technological development and associated electronic-readout systems, for applications in basic and applied research"

http://rd51-public.web.cern.ch/rd51-public

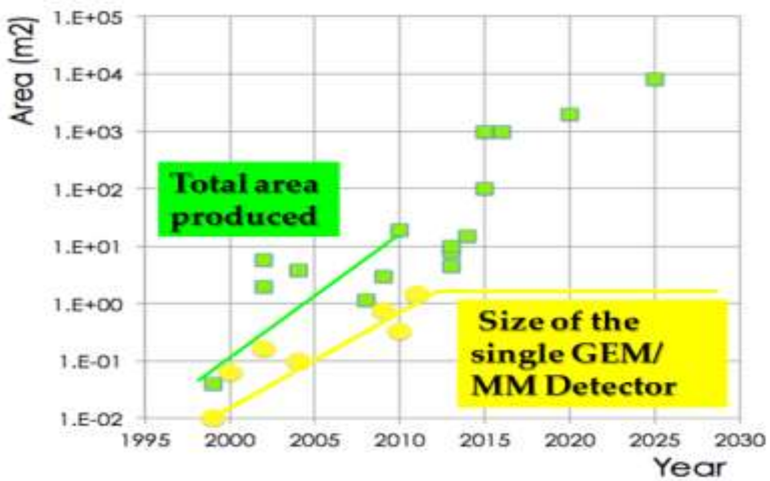
A fundamental boost is offered by RD51: from isolate MPGD developers to a world-wide net



World-wide Collaboration for the MPGD Developments →
RD51 (91 institute, > 500 people):

- Large Scale R&D program to ***advance MPGD Technologies***
- Access to ***the MPGD "know- how"***
- Foster ***Industrial Production***

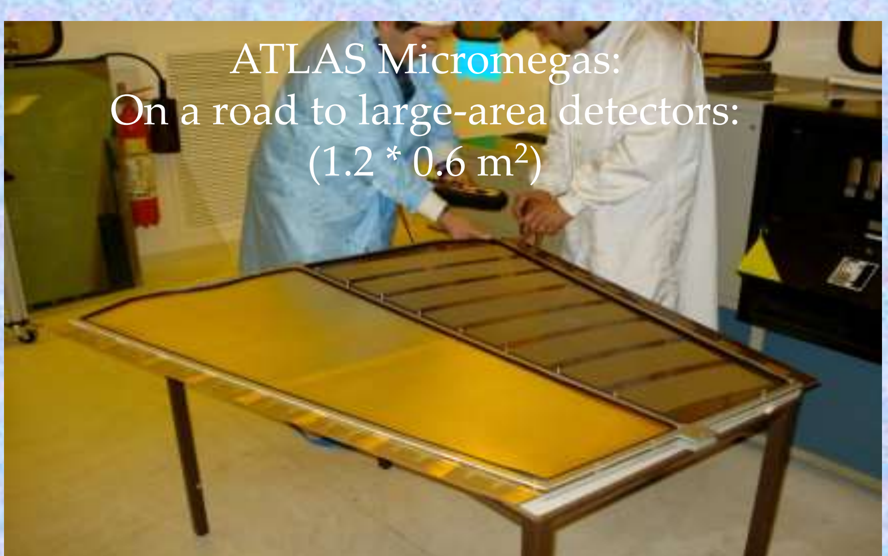
Advances in photolithography →
Large Area MPGDs (~ m^2 unit size)

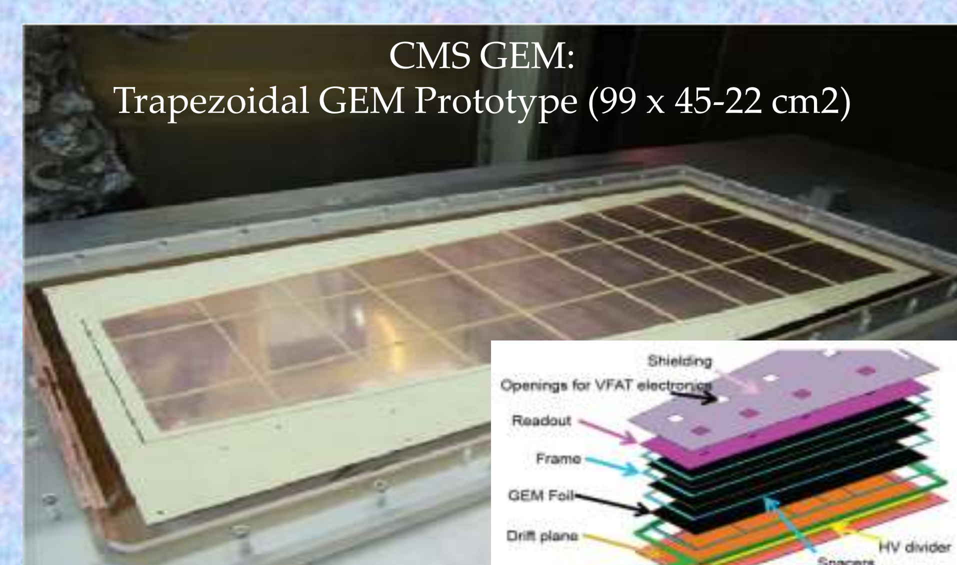


MPGD Technologies for Energy Frontier (HL-LHC, LC)

Ongoing R&D Projects using MPGDs in the framework of HEP Experiments

	Vertex	Inner Tracker	PID/ photo-det.	EM CALO	HAD CALO	MUON Track	MUON Trigger
ATLAS	GOSSIP/ InGrid	GOSSIP/ InGrid				Micromegas	Micromegas
CMS						GEM	GEM
ALICE		TPC (GEM)	VHPMID (CsI-THGEM)				
Linear Collider		TPC(MM, GEM, InGrid)			DHCAL (MM,GEM, THGEM)		



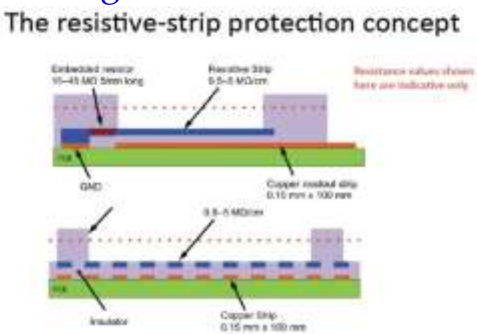


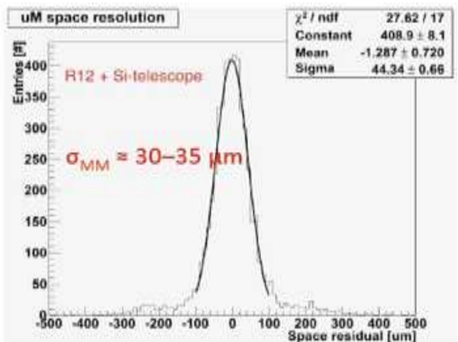
MPGDs: Technology Developments Highlights

MM for the ATLAS Muon System Upgrade:

R&D Started in 2007 within the RD51 collaboration:

Standard Bulk MM suffers from limited efficiency at high rates due to discharges induced dead time:





ATLAS small wheels upgrade project resistive MicroMegas prototype (~ 1 m²)

❖ During LS2, a New Small Wheel containing ~ 1000 m² of resistive MM will be installed in ATLAS → the largest MM system, ever built

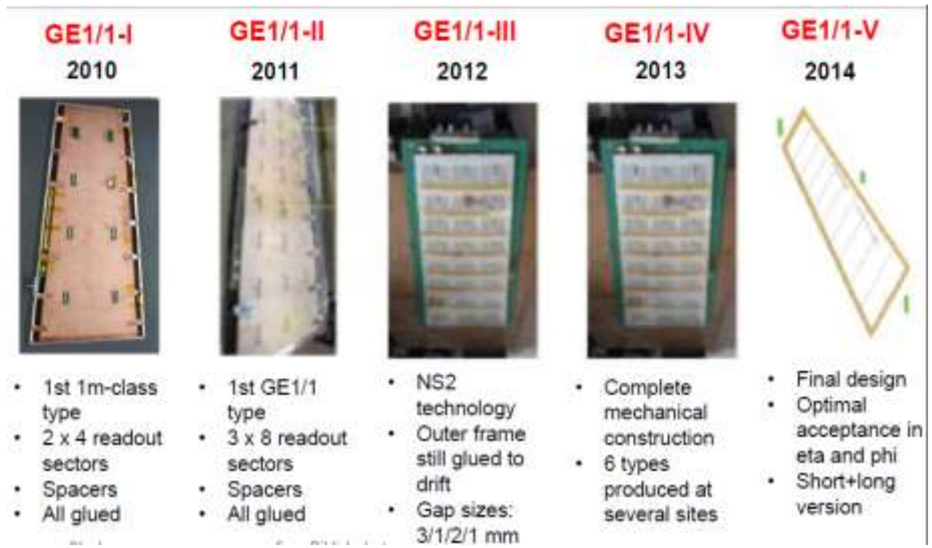
FOSTER INDUSTRIAL PRODUCTION NEEDS

GEMs for the CMS Muon System Upgrade:

R&D Started in 2009 within the RD51 collaboration:

Single-mask GEM technology (instead of double-mask)
→ Reduces cost /allows production of large-area GEM

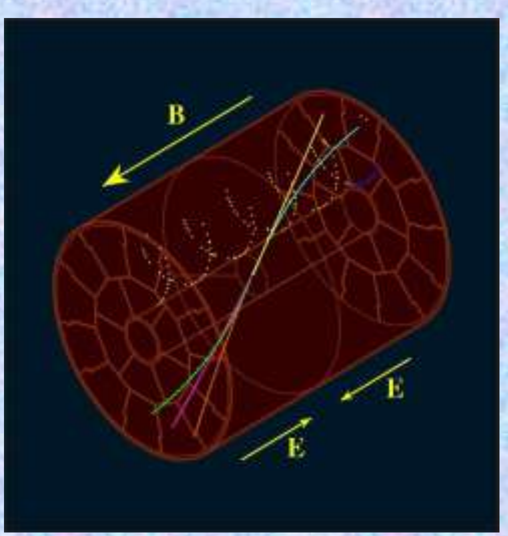
Self-stretching technique: assembly time reduction from 3 days → 2 hours



❖ During the LHC End-Year stop of 2016/2017, two GEM super-chamber demonstrators will be installed

MPGD-based Time Projection Chambers: Technology Highlights

2nd HEP Revolution: TPC proposal for PEP4/LBL (1976)



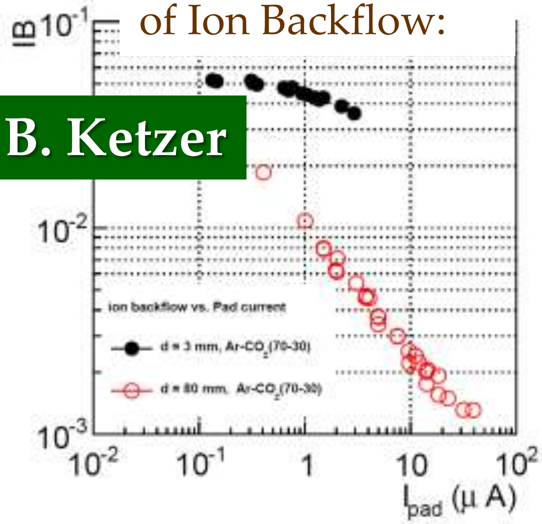
	STAR	ALICE	ILC
Inner radius (cm)	50	85	32
Outer radius (cm)	200	250	170
Length (cm)	2 * 210	2 * 250	2 * 250
Charge collection	wire	wire	MPGD
Pad size (mm)	2.8 * 11.5 6.2 * 19.5	4 * 7.5 6*10(15)	2 * 6
Total # pads	140000	560000	1200000
Magnetic field [T]	0.5	0.5	4
Gas Mixture	Ar/CH4 (90:10)	Ne/CO2 (90:10)	Ar/CH4/CO2 (93:5:2)
Drift Field [V/cm]	135	400	230
Total drift time (μs)	38	88	50
Diffusion σ_T(μm/$\sqrt{\text{cm}}$)	230	220	70
Diffusion σ_L(μm/$\sqrt{\text{cm}}$)	360	220	300
Resolution in rφ(μm)	500-2000	300-2000	70-150
Resolution in rz (μm)	1000-3000	600-2000	500-800
dE/dx resolution [%]	7	7	< 5
Tracking efficiency[%]	80	95	98

ILCTPC with MPGD-Readout:
(spatial resolution < 100 µm @ 5T)

- Laser-etched GEMs 100µm thick ('Asian GEMs')
- Resistive MM with dispersive anode
- GEM + pixel readout
- InGrid (integrated Micromegas grid with pixel readout)
- Wet-etched triple GEMs

ALICE TPC Upgrade (replace MWPC with GEMs)

Space-charge dep. of Ion Backflow:

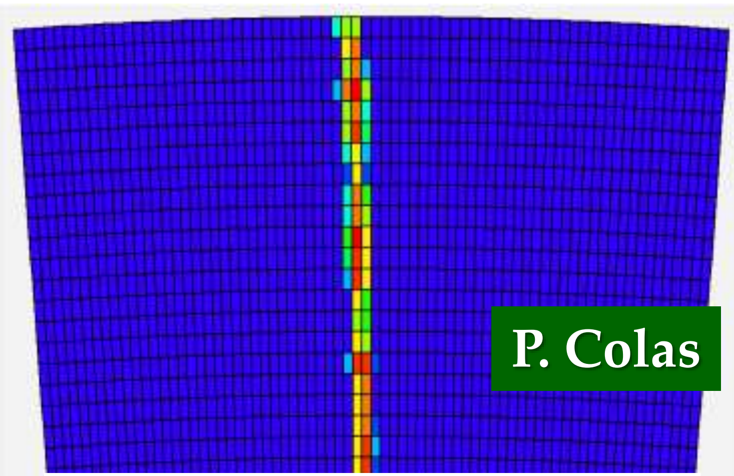


B. Ketzer

Major R&D Effort:

- 4-GEM detector to meet IB requirements
- IB < 1%, energy: σ(E)E < 12% achieved
- Continuous readout at 50 kHz (TPC – analog event pipilibe)

TPC/Micromegas "Goes Resistive:



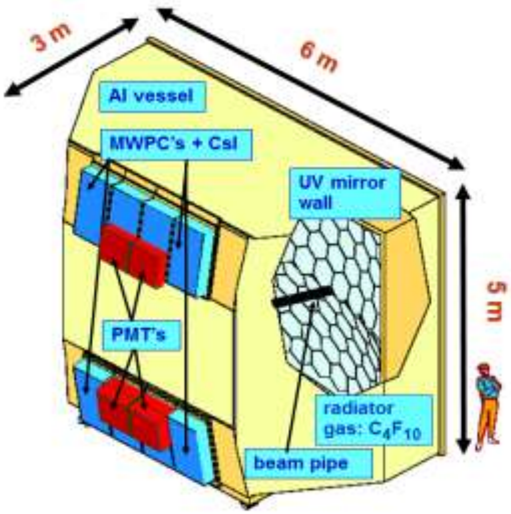
P. Colas

Studies of 2-phase CO_2 Cooling (Feb. 2014) – DESY Test-Beam

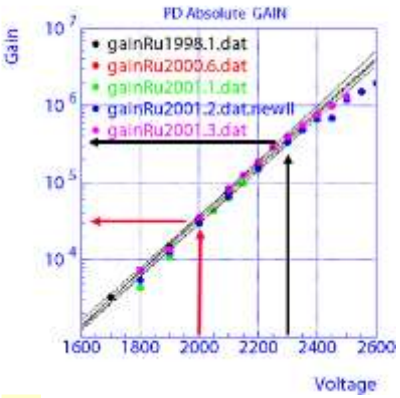
COMPASS RICH: Long-Term Experience, Performance and Upgrades

❖ COMPASS RICH I:

➢ 1999-2000: 8 MWPC with CsI (RD26 @ CERN)



After a long-term fight for increasing electrical stability at high rates: robust operation is not possible at gain~10^5 because of photon feedback, space charge & sparks



❖ beam off: stable operation up to > 2300 V

❖ beam on: stable operation possible only up to ~2000 V

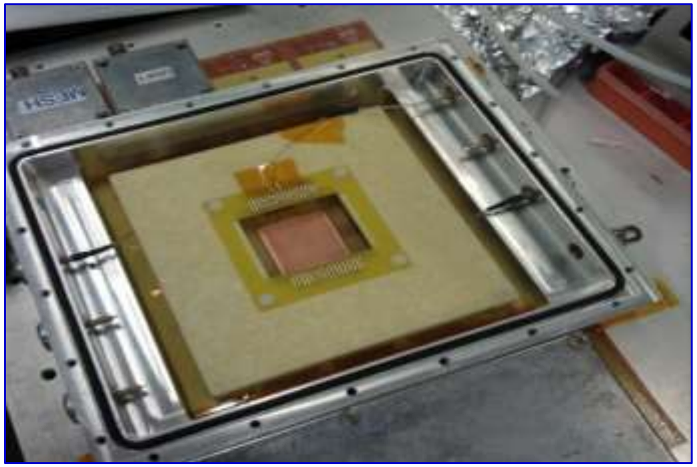
❖ 2006: 4 central CsI+cathodes: remove and insert frames with MAPMTs and lense telescopes

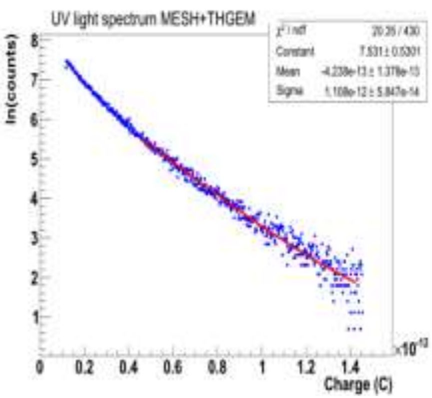
PMTs not adequate → only small demagnification factor allowed; 5 m² of PMTs not affordable.

❖ UPGRADE OF COMPASS RICH I:

➢ MPGD-Photon Detectors are the best option

→ Micromegas +THGEM, the hybrid architecture structure, is one of the most advanced scheme:





E_{mesh} ~ 30 kV/cm

E_{trans} = 1.2 kV/cm

ΔV = 1575 V

E_{drift} = 0 V/cm

Gain ~10^6

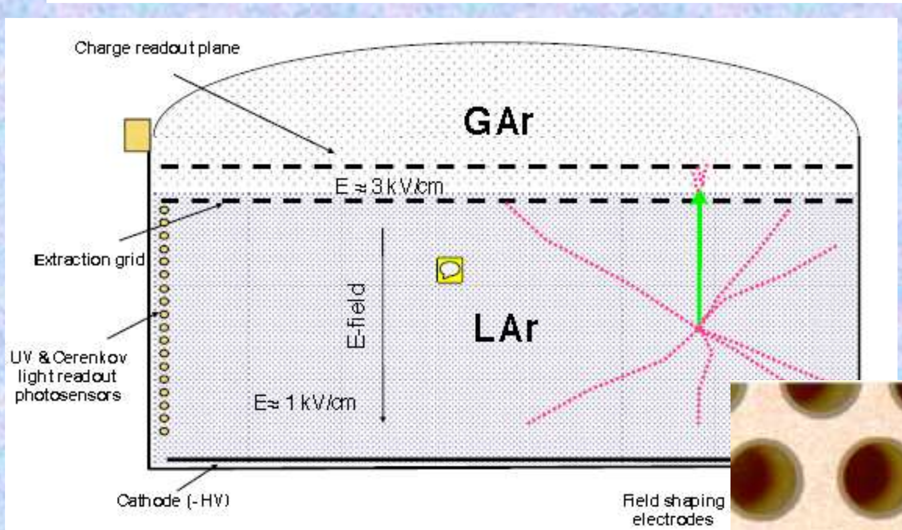
IBF ~ 4%

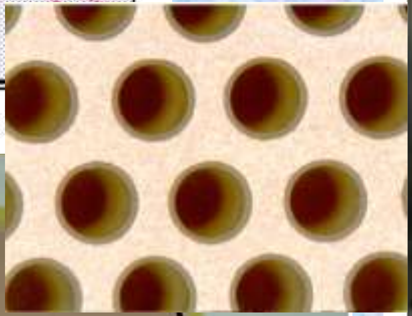
Higher performance reached with the MM + THGEM architecture (than multiple-THGEM structures)

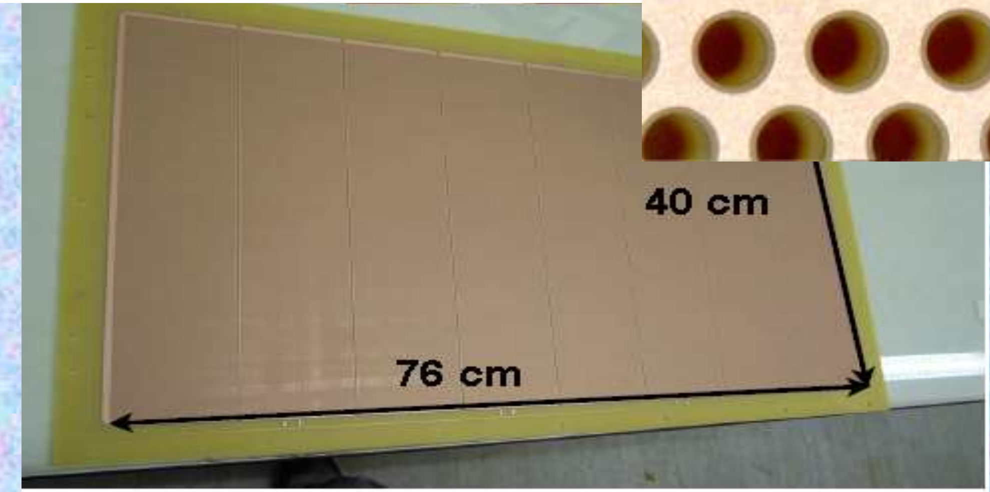
Advancing Concepts: Double Phase Ar LEM/TPC for Neutrino Physics

Giant Liquid Argon Charge Imaging ExpeRiment

GLACIER (hep-ph/0402110) is a proposed giant liquid argon multi-purpose next-generation underground neutrino observatory at the 100 kton scale.

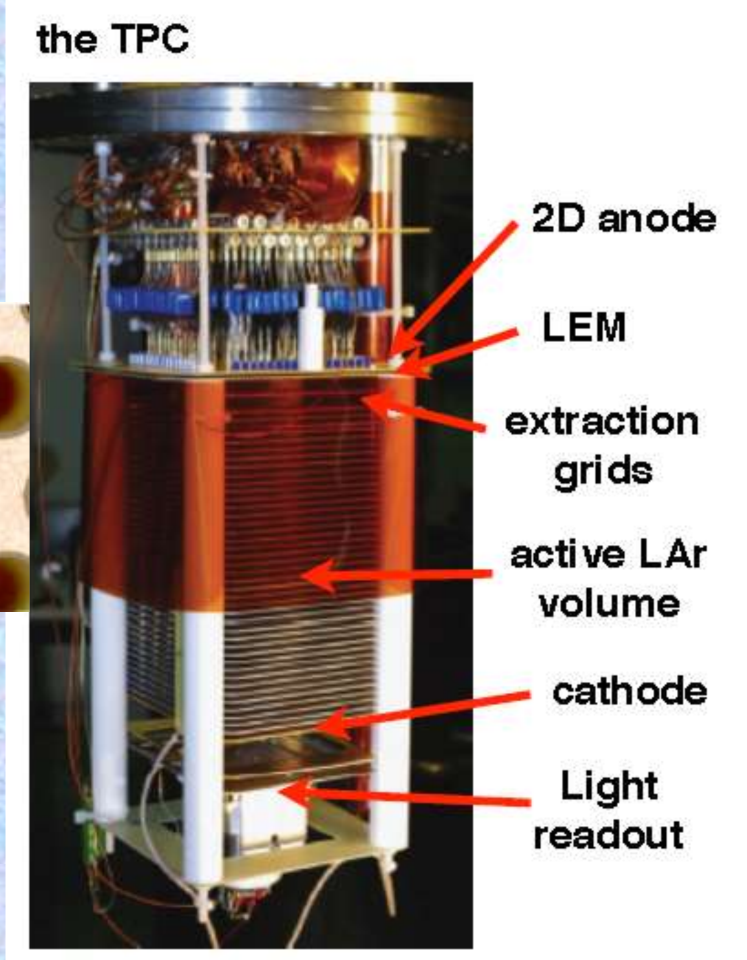


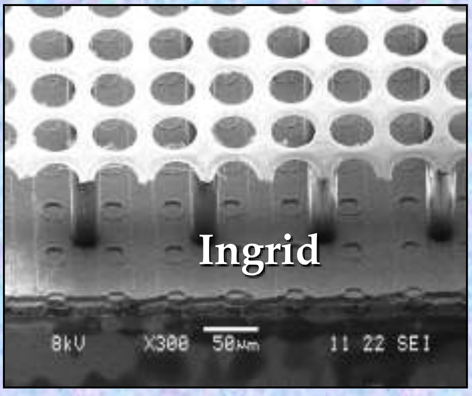


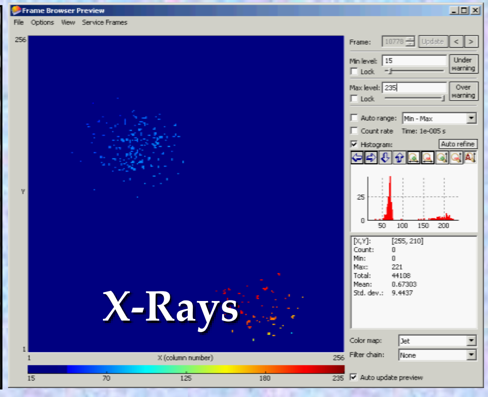


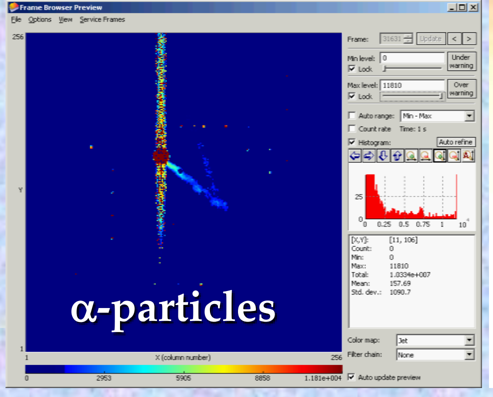
produced by CERN TS/DEM group & ELTOS company (I)

Double-phase Ar LEM TPC

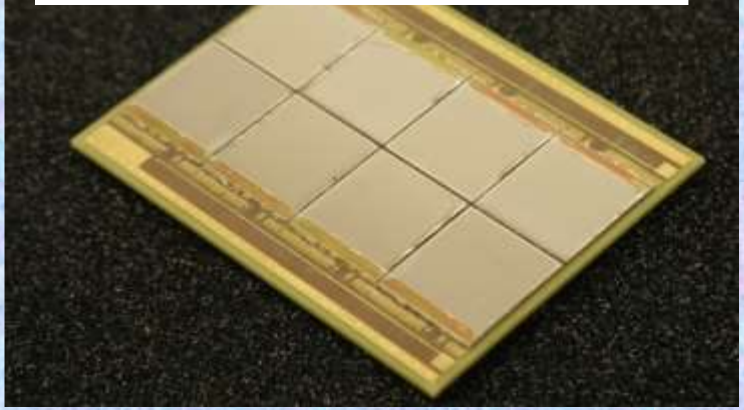






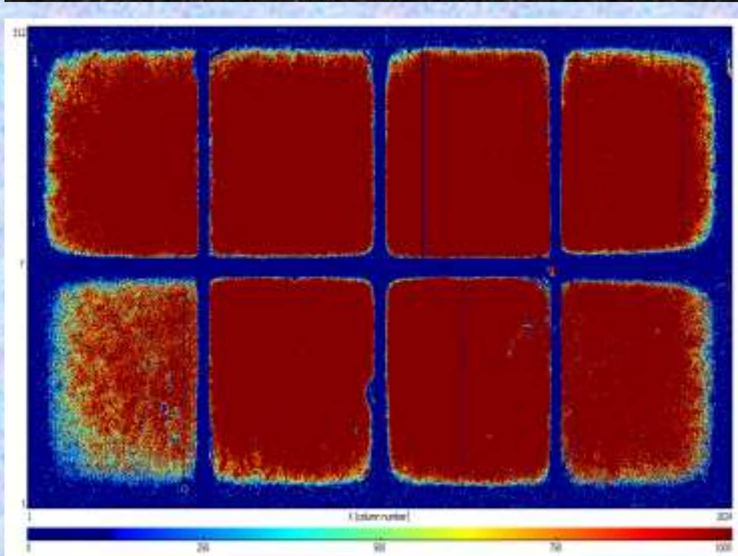


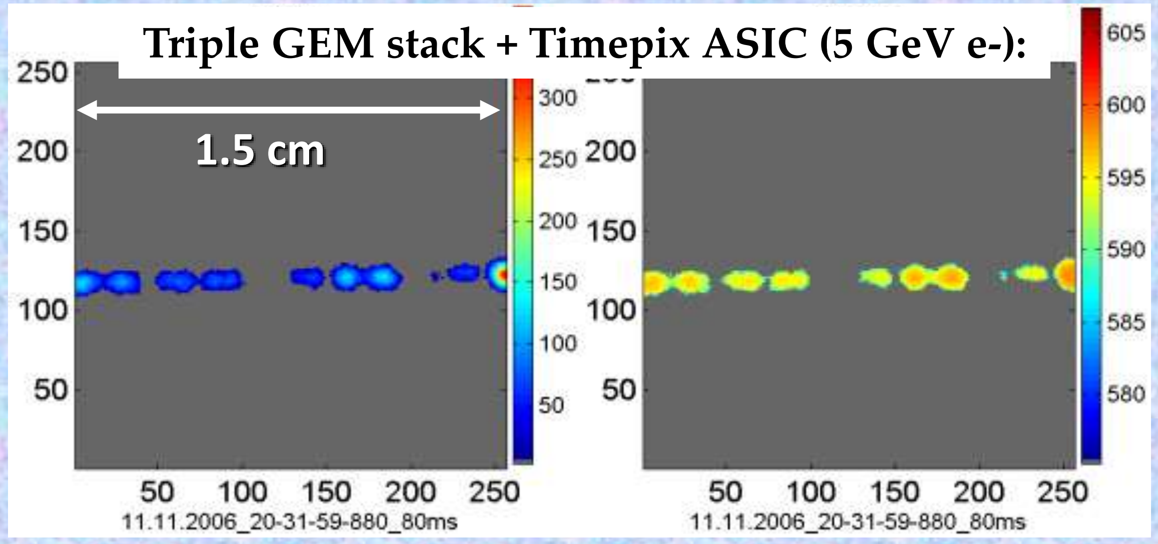
“Octopuce” (8 Timepix ASICs):



INSTRUMENTATION FRONTIER:

PIXEL READOUT OF MPGDs – Ultimate Gas-Silicon Detector Integration

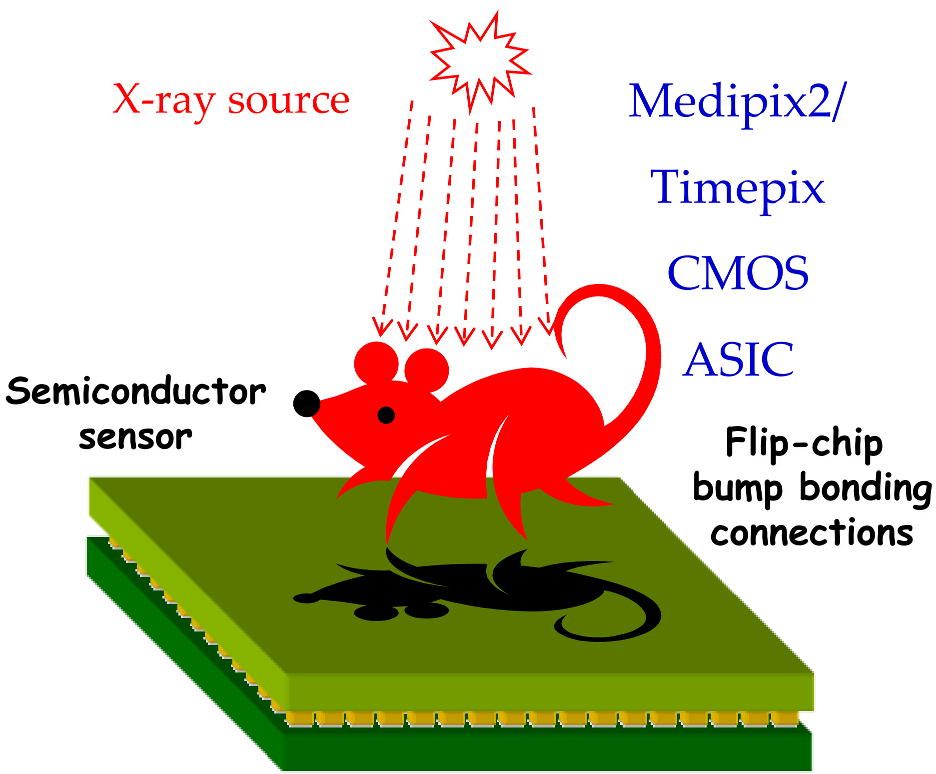




Pixel Readout of Micro-Pattern Gaseous Detectors: Ultimate Integration

Use a CMOS Pixel ASIC (w/o Si sensor), assembled below MPGDs (GEM/Micromegas), as charge collecting anode and fully integrated readout electronics for a TPC at LC

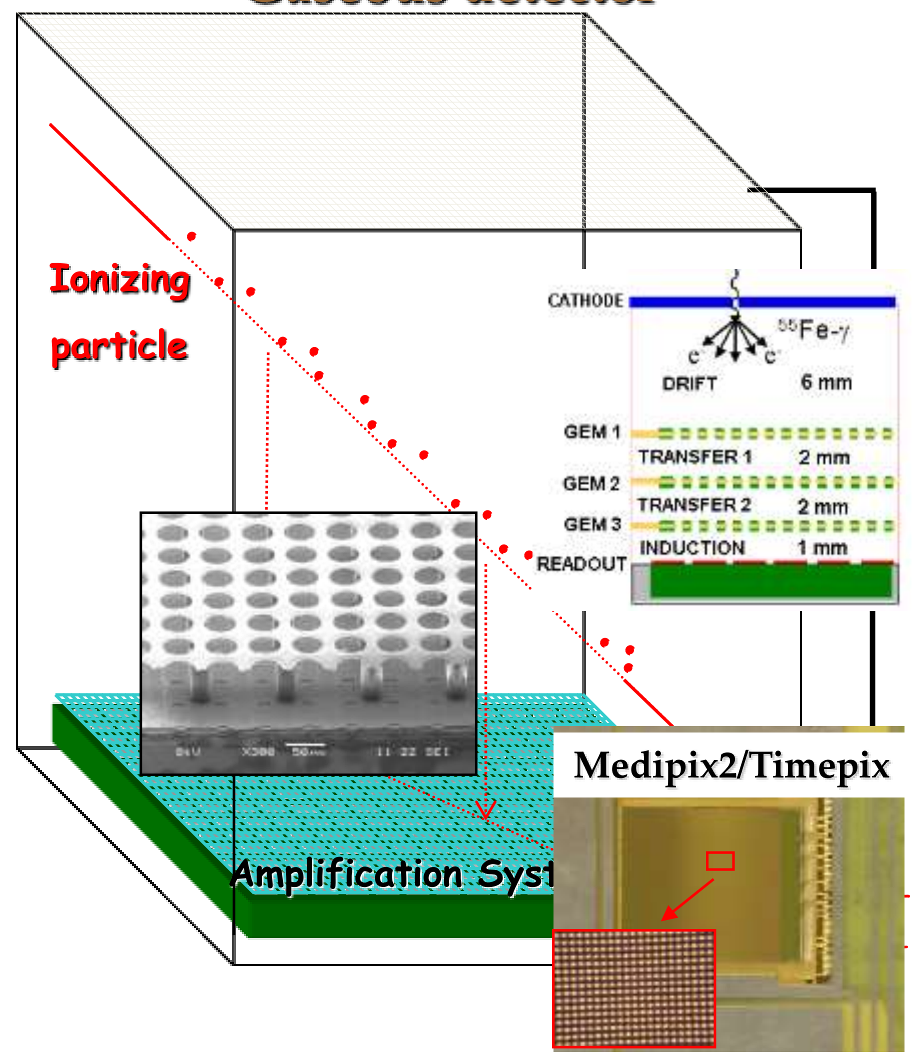
Solid state pixel detector



Medipix2 / Timepix ASIC (0.25 µm –IBM/CMOS)

- 256 × 256 pixels of 55 × 55 µm^2 size
- Medipix2: digital with 2 THR (low and high)
- Timepix: 2 modes (TOT ≈ integrated charge
  TIME = Time between hit and shutter end)

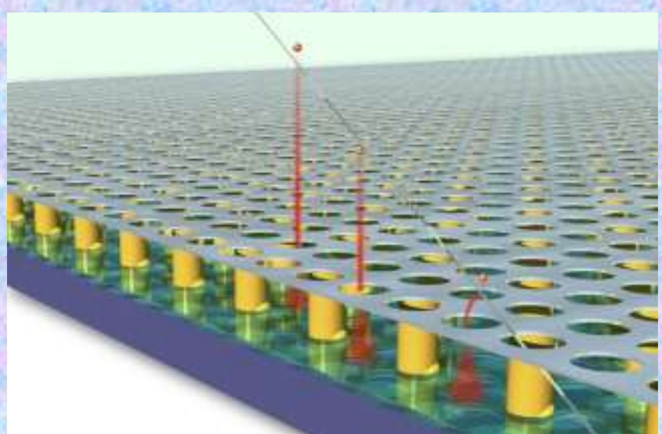
Gaseous detector

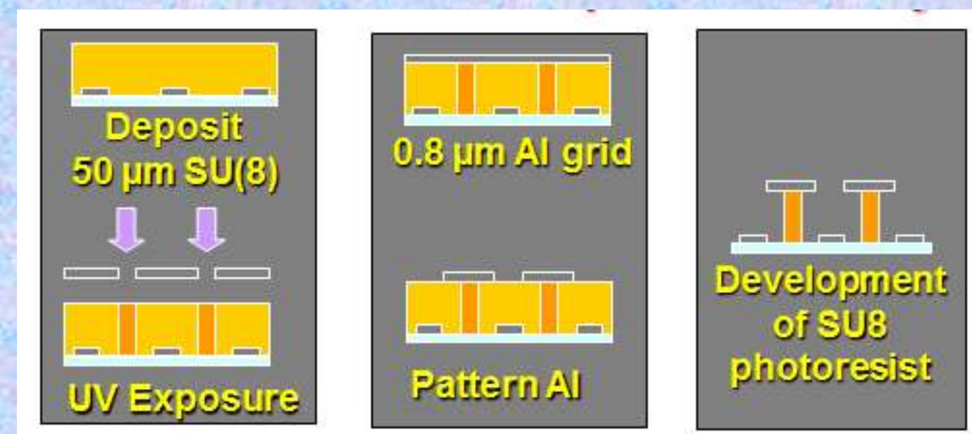


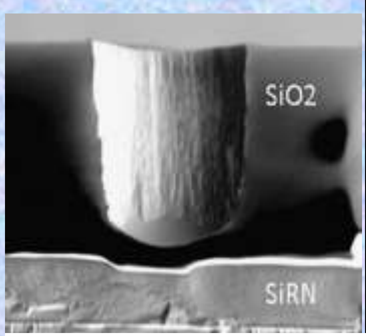
Pixel Readout of MPGDs: "InGrid" Concept

"InGrid" Concept: By means of advanced wafer processing-technology INTEGRATE MICROMEGAS amplification grid directly on top of CMOS ("Timepix") ASIC

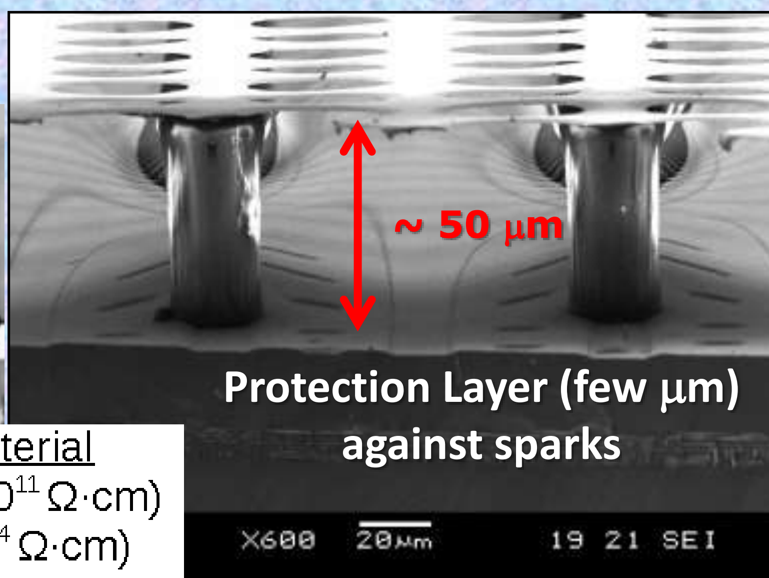
3D Gaseous Pixel Detector → 2D (pixel dimensions) x 1D (drift time)

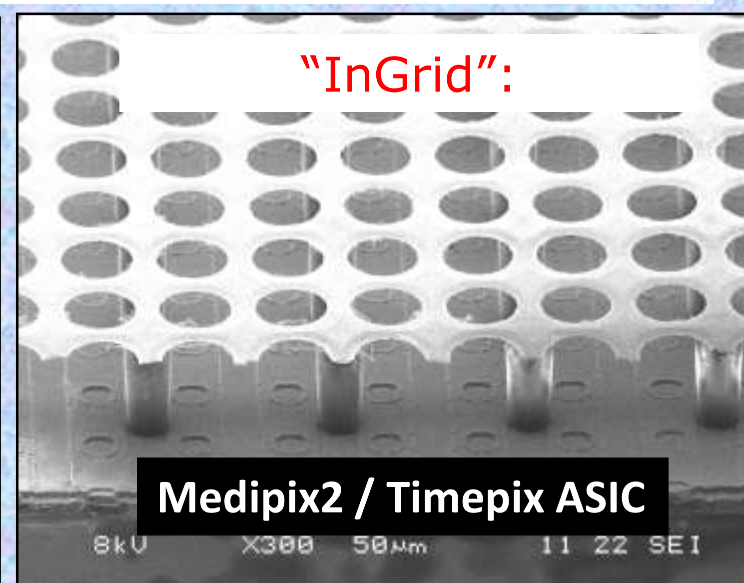






high resistive material
15 µm aSi:H ($\sim 10^{11}\ \Omega\cdot$cm)
8 µm Si_XN_Y ($\sim 10^{14}\ \Omega\cdot$cm)





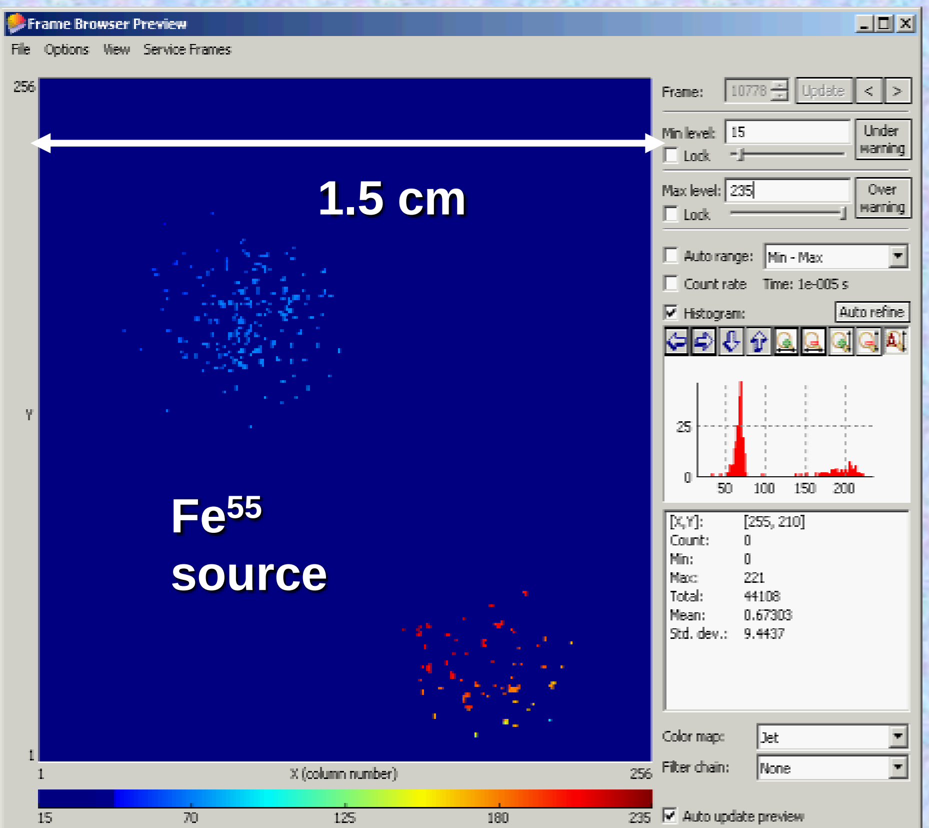
"InGrid" Detector: Single Electron Response and Discharges

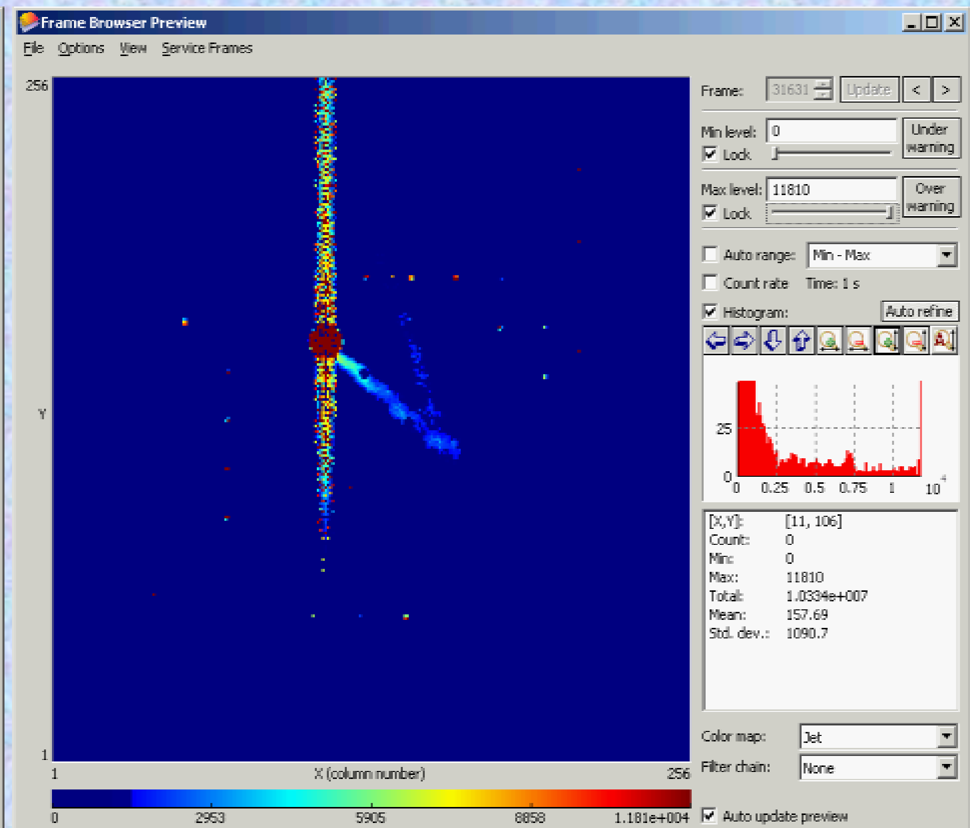
Observe electrons (~220) from an X-ray (5.9 keV) conversion one by one and count them
in micro-TPC (6 cm drift)

→ Study single electron response

Provoke discharges by introducing small amount of Thorium in the Ar gas - Thorium decays to Radon 222 which emits 2 alphas of 6.3 & 6.8 MeV

→ Round-shape images of discharges



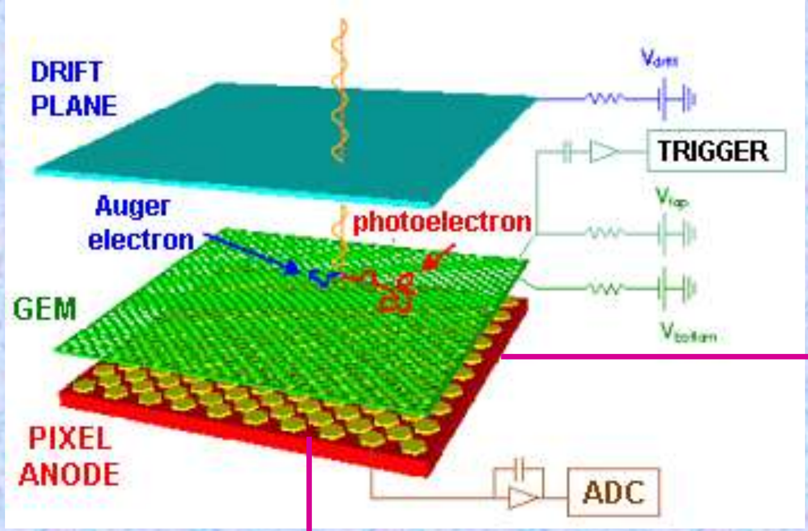


P. Colas, RD51 Collab. Meet., Jun.16-17, 2009, WG2 Meeting

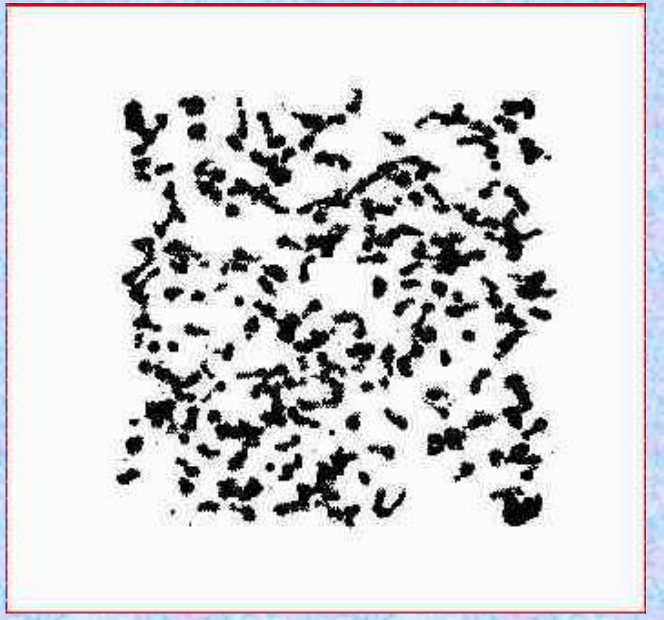
M. Fransen, RD51 Collab. Meet., Oct.13-15, 2008, WG2 Meeting

GEM and VLSI pixel ASIC @ INFN Pisa

Direct coupling of pixellazed readout to GEM

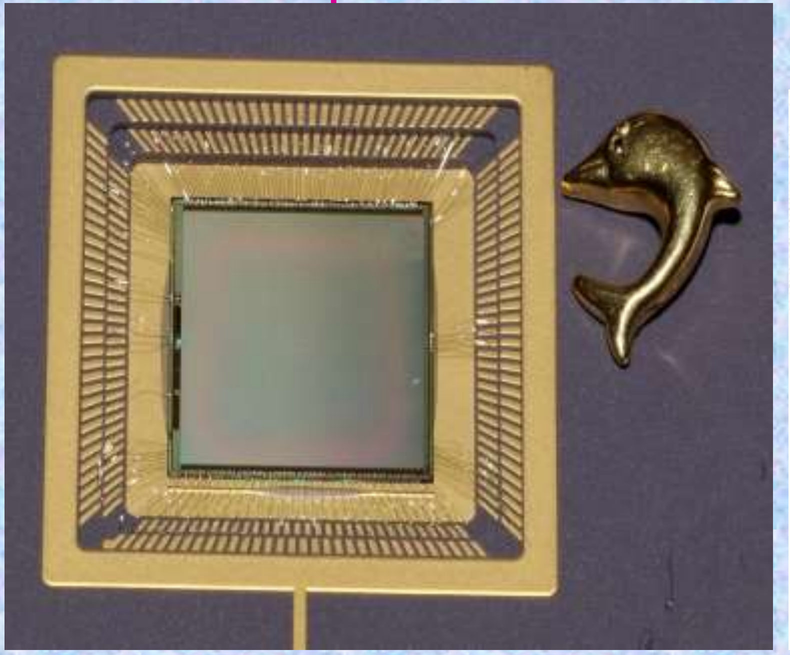


REAL photo-electron tracks recorded by 105k ASIC

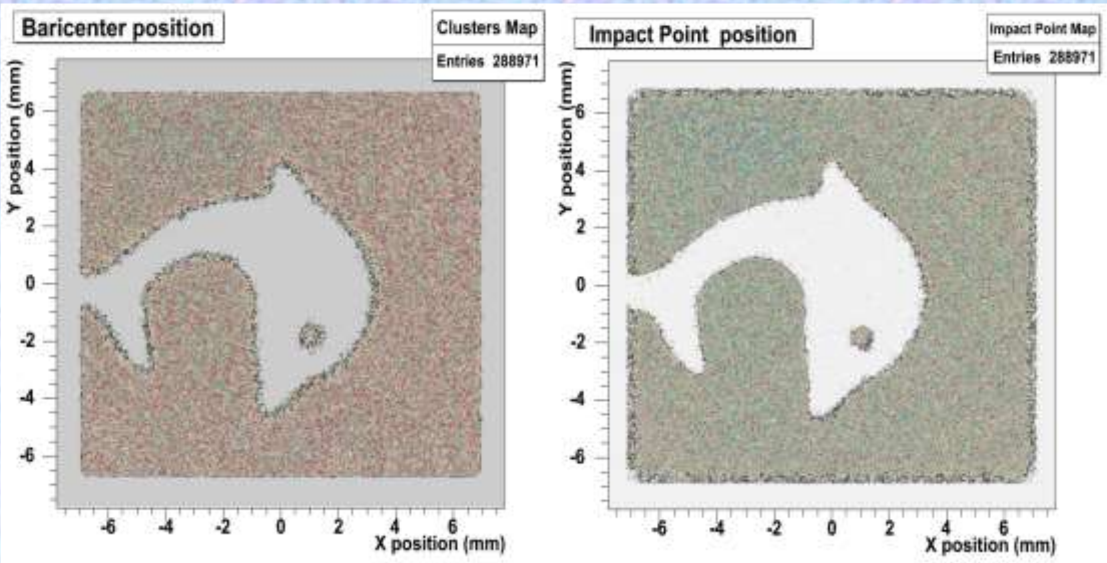


GEM pitch: 50 mm
He/DME (40:60)

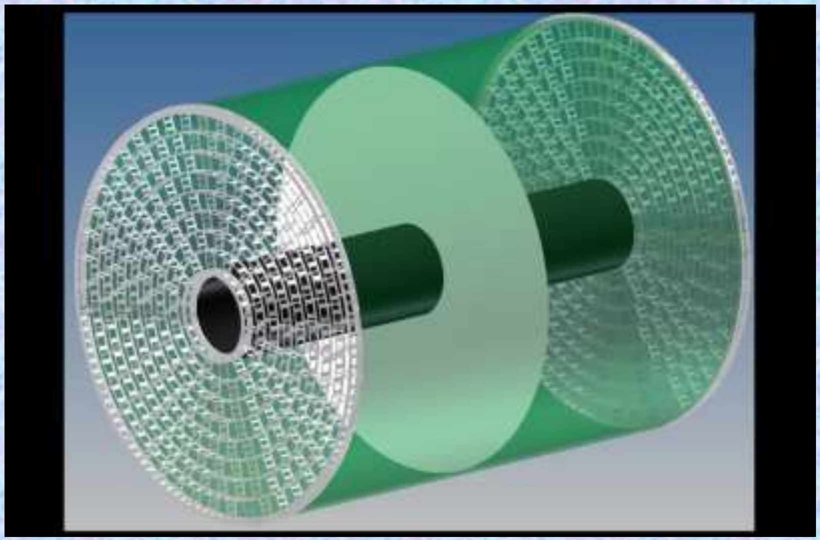
http://glast.pi.infn.it/pixie/pixie.html

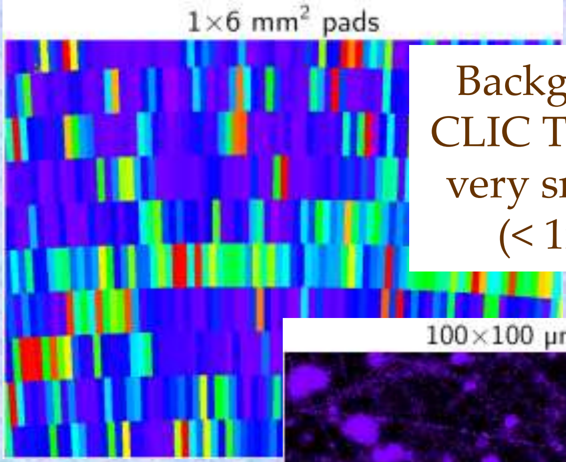


EXCELLENT IMAGING CAPABILITIES:
Barycenter vs Conversion point reconstruction

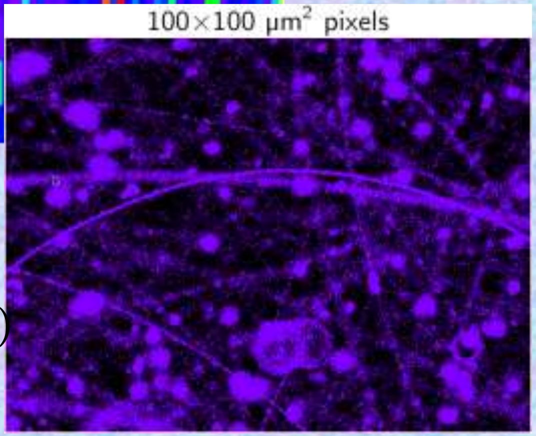


Pixel Readout for Time Projection Chamber at the ILC or CLIC





Backgrounds in CLIC TPC requires very small pixels (< 1x1 mm²)



CLIC TPC Simulation (M. Killenberg)

MPGDs are foreseen as TPC readout for ILC or CLIC (size of endcaps of ~ 10 m²):

- Standard pads (1x 6 mm²): 8 rows of detector modules (17×23 cm2); 240 modules per endcap
- Pixel (55x 55μm²): ~100-120 chips per module → 25000-30000 per endcap

Potential advantages of pixel TPC (55x 55μm²):

→ very good point + momentum resolution

→ dE/dx via cluster counting

→ frontend electronics automatically integrated ('active endplate')

Potential concerns:

→ diffusion will limit resolution (gas!): how small is necessary?

→ cost ?

→ stable operation possible ?

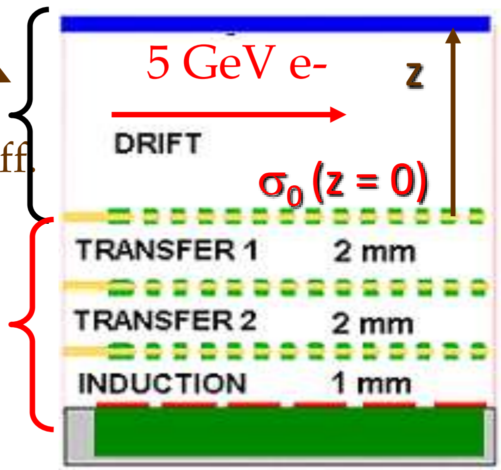
- Demonstrate operability of the concept; Measure & understand (details of) charge cloud

Triple-GEM Detector with Medipix2 and Timepix CMOS ASICs

$$\sigma^2_{mean} = \sigma^2_0 + \frac{D^2_t * z}{n^{el}_{cl}}$$

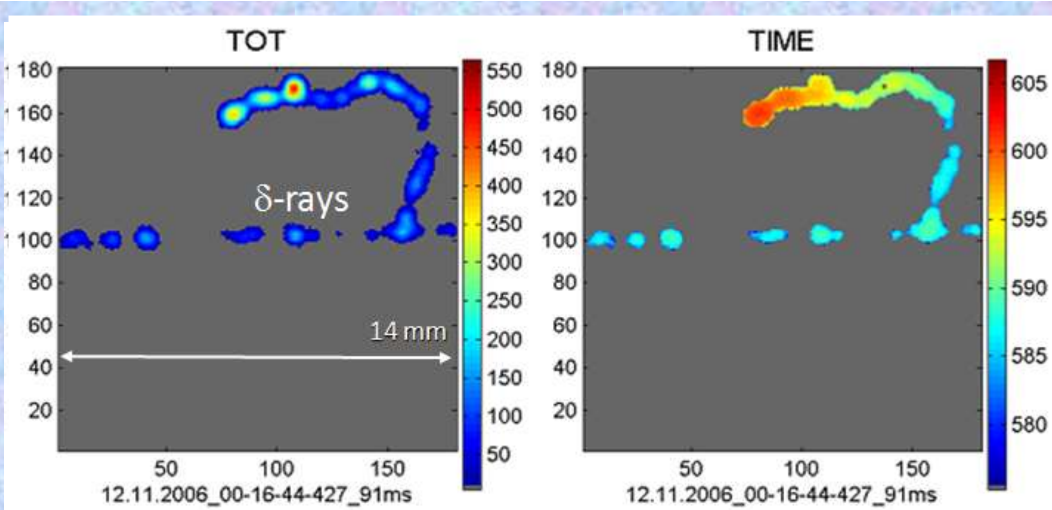
D_t: transverse diffusion coeff.
n^{el}_{cl}: primary e- per cluster
z: drift distance

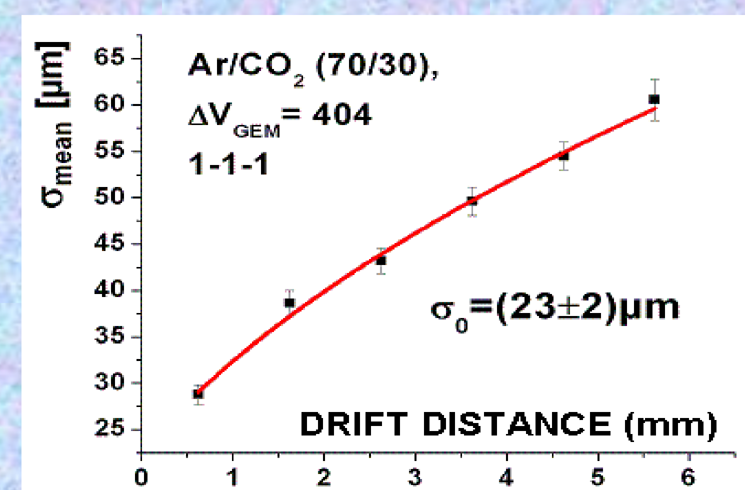
σ_0: INTRINSIC RESOLUTION (3-GEM DEFOCUSSING)



Single point resolution (σ_0) :

Gas mixture	Detector Configur. (mm)	MEDIPIX2 σ_0 (μm)	TIMEPIX σ_0 (μm)
Ar/CO_2 (70:30)	2-2-1	---	24 ± 2
	1-1-1	23 ± 2	---
He/CO_2 (70:30)	2-2-1	32 ± 2	30 ± 2
	1-1-1	29 ± 4	---



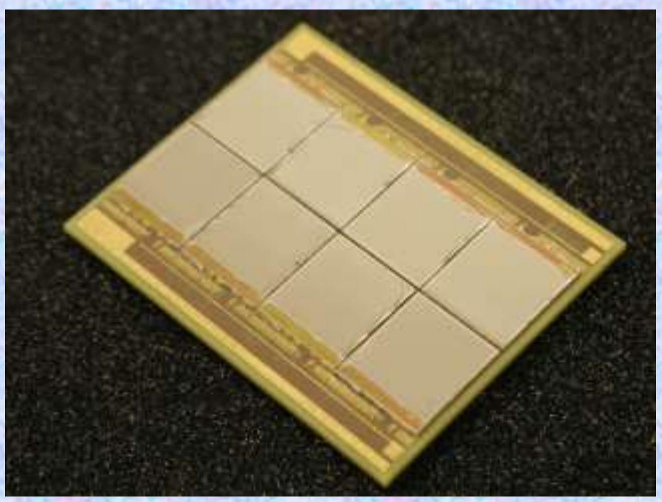


M. Titov, NIMA581 (2007) 25

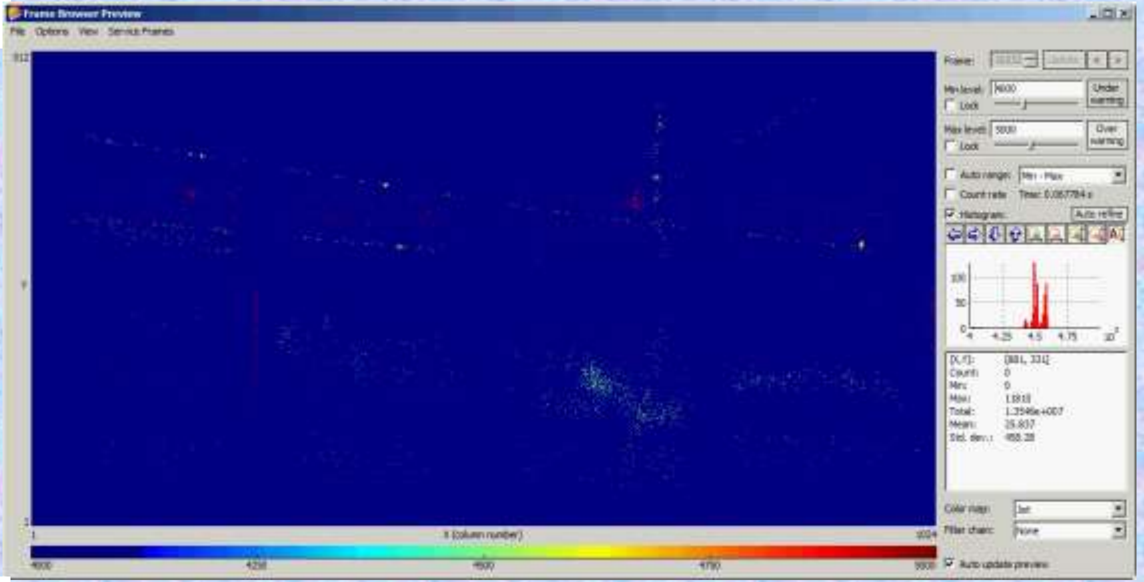
- ADVANTAGES: superior spatial & double track resolution; identification of δ-rays
- DISADVANTAGE: charge cloud diffuses over ~ 100 pixels in 3GEM; single electron sensitivity hard to achieve; estimates ~20%(~45%) for Ar(He) mixture at gas gain $5*10^4$

Development of Large Area Detectors with Pixel Readout

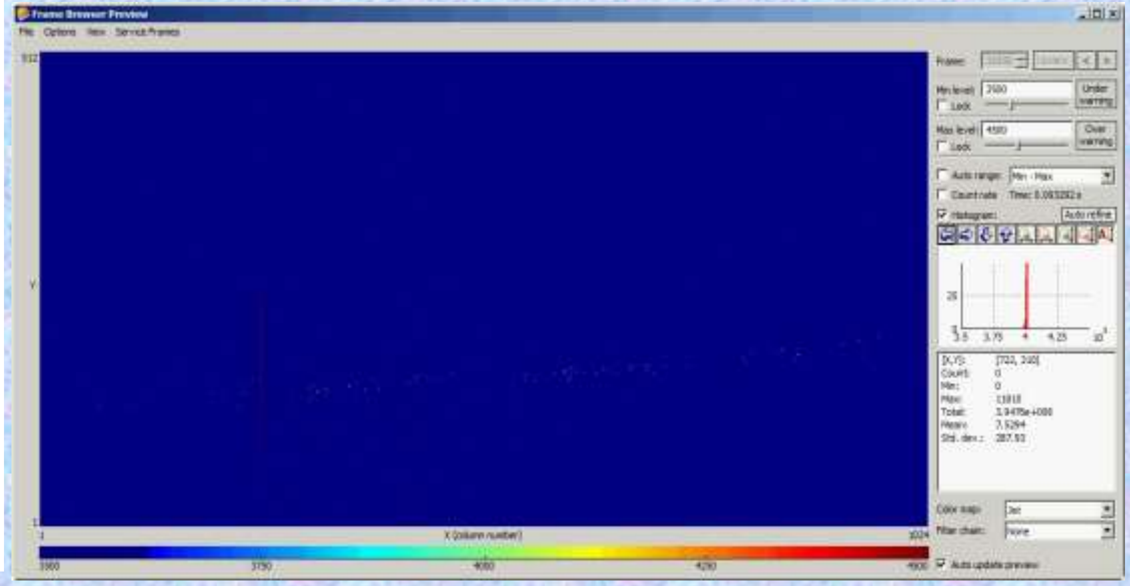
Octopuce Board (8 "Ingrid" Detectors
Readout Matrix (~ 3* 6 cm^2)



5 GeV electrons (B = 0 T)



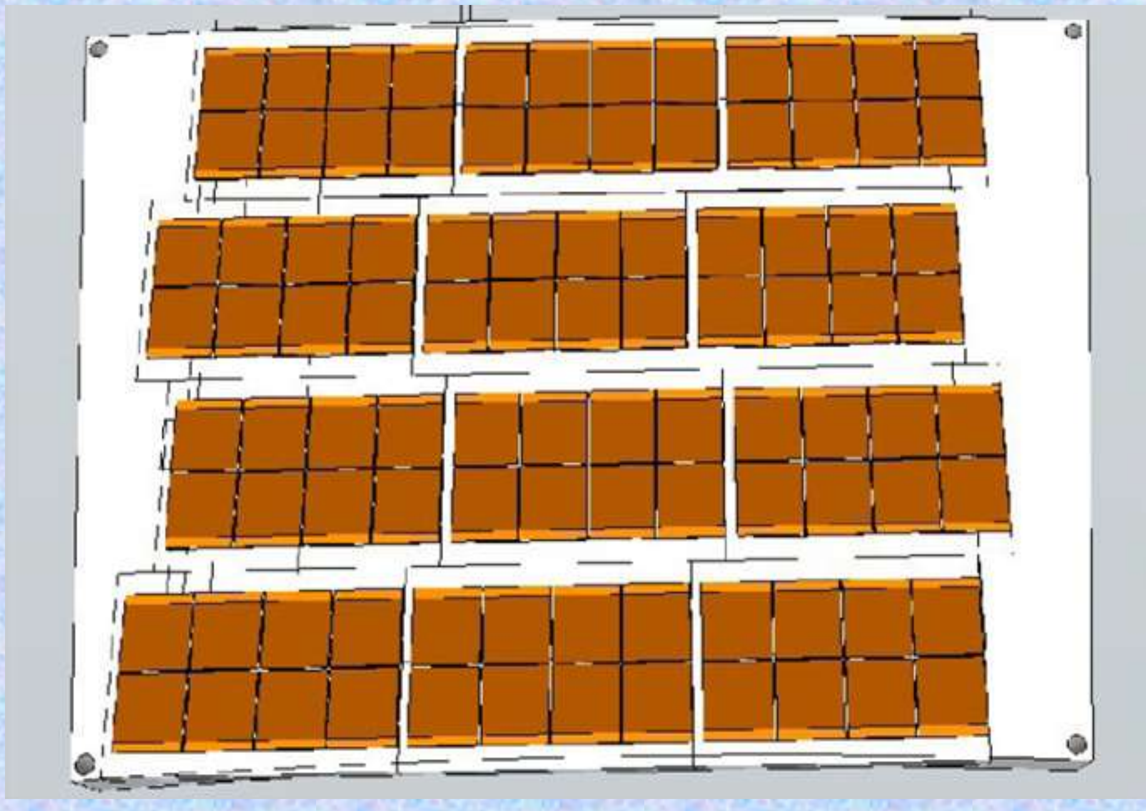
5 GeV electrons (B = 1 T)



DETECTOR and ELECTRONICS INTEGRATION FOR MILLIONS CH.:

- Truly 2D / 3D image (high rate capability)
- 2D high density readout plane (~50 mm)
- No long signal routine lines (low noise)

Pixel Readout of MPGD: Proof-of-Principle of Si-TPC



Mid-term plan (3 years):

Develop and equip a full LCTPC module (~100 chips) with "InGrid"s, using "Octopuce" module as the basic building block

Pixel LC-TPC Consortium:
Bonn, Saclay, NIKHEF, DESY, LAL, Kyiv University

- Improved mass production of "InGrid"s (less dead area, higher yield, protection)
- Minimize field distortions in the « Octopuce » plane; work on more realisitic cooling and power pulsing
- Develop simulation chain to compare momentum resolution, double track resolution, dE/dx and pattern recognition to pad-based readout and to optimize the geometry
- Experimental dE/dx study by cluster counting using InGrid at the LAL/PHIL facility

Advancing MPGD Concepts for Future Projects

Applications :

- HEP and Nuclear Physics
- Neutrino Experiments
- Dark Matter
- Ground-based Astroparticle
- Space Experiments
- Spin-off outside HEP field

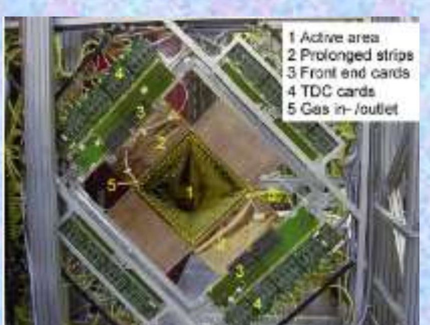
(some) experimental requirements:

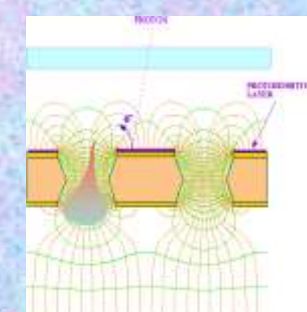
HL-LHC (LHC luminosity upgrade)
→ radiation, pileup, backgrounds

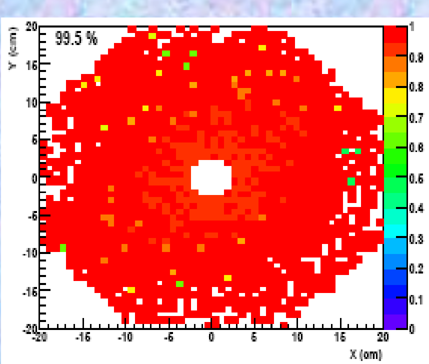
ILC
→ high precision, hermeticity

Neutrino Facilities
→ sensitivity (mass, size), efficiency, purity

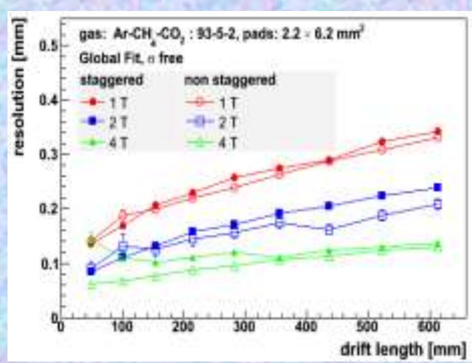
Dark Matter
→ purity, low bkg, large sensitive areas



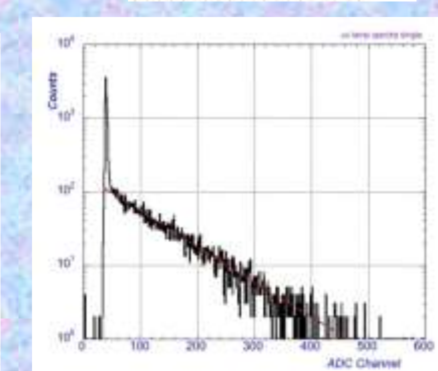




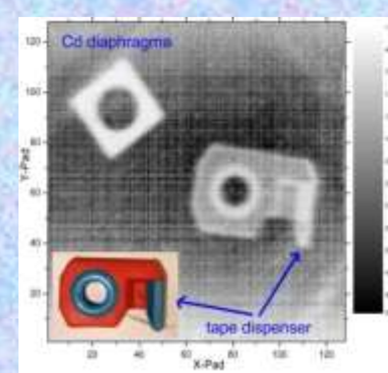
Tracking



TPC readout



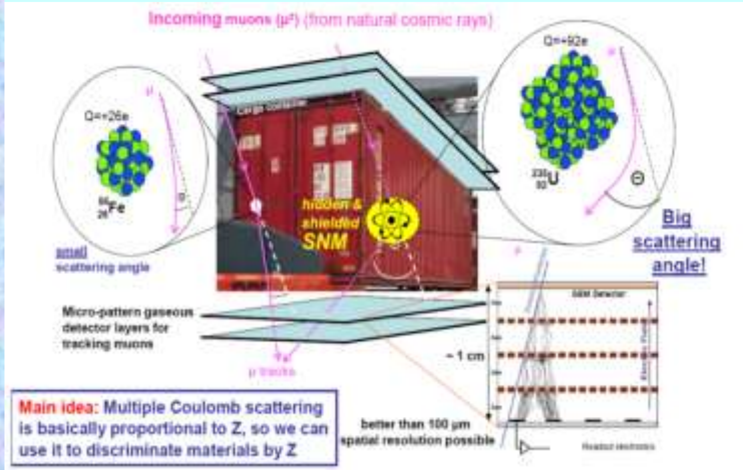
UV photon detection



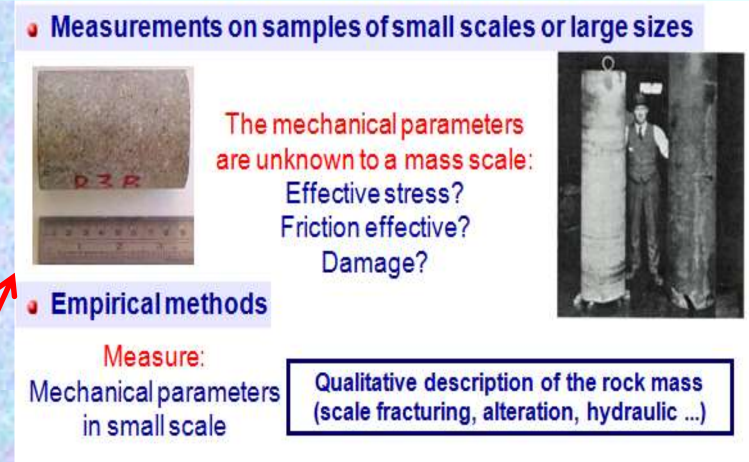
Neutron detection

Spin off is important key word for the HEP labs to survive ...

Cosmic Ray Muon Tomography Using GEMs for Homeland security

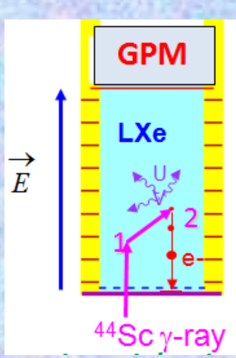


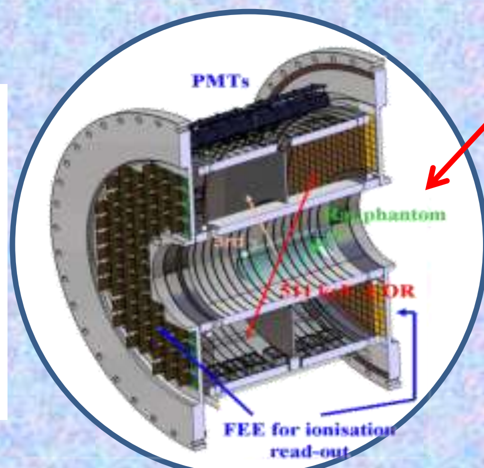
T2DM2: Temporal Tomography Densitometric by the Measure of Muons



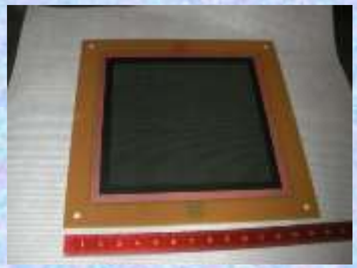
MPGD

Technology





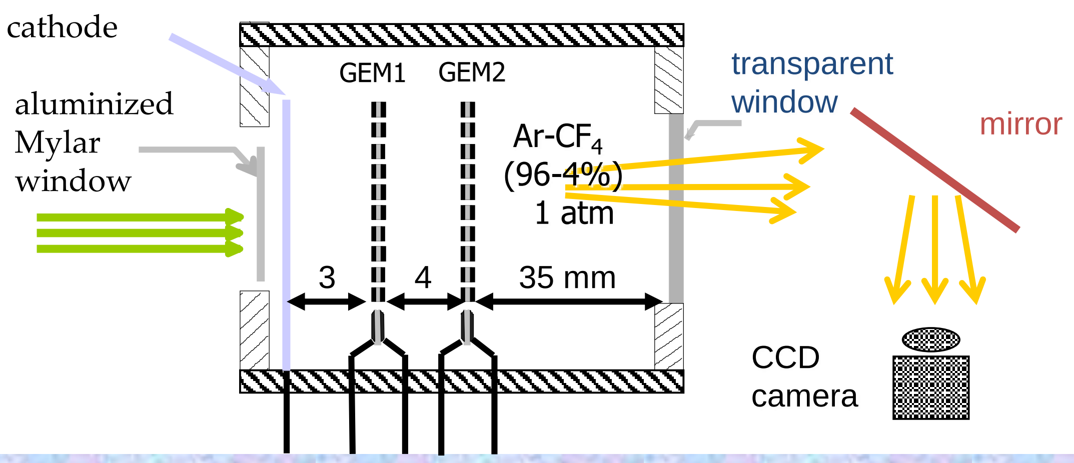
Liquid xenon detectors for functional medical imaging



CsI-RETGEM for UV flame detection

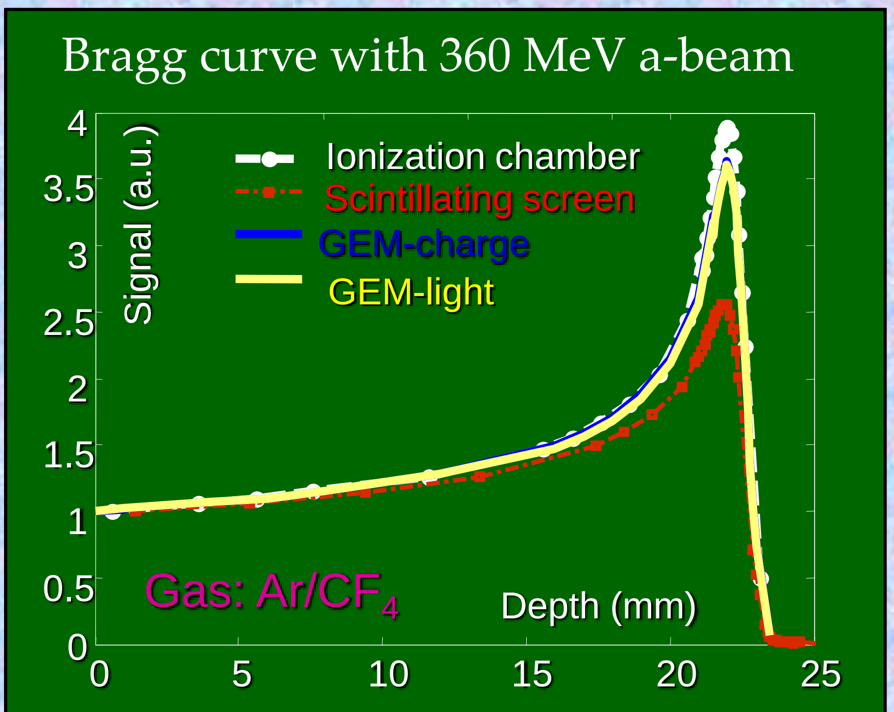
A Scintillating GEM for Dose Imaging in Radiotherapy

Scintillation light (optical) & charge Readout:



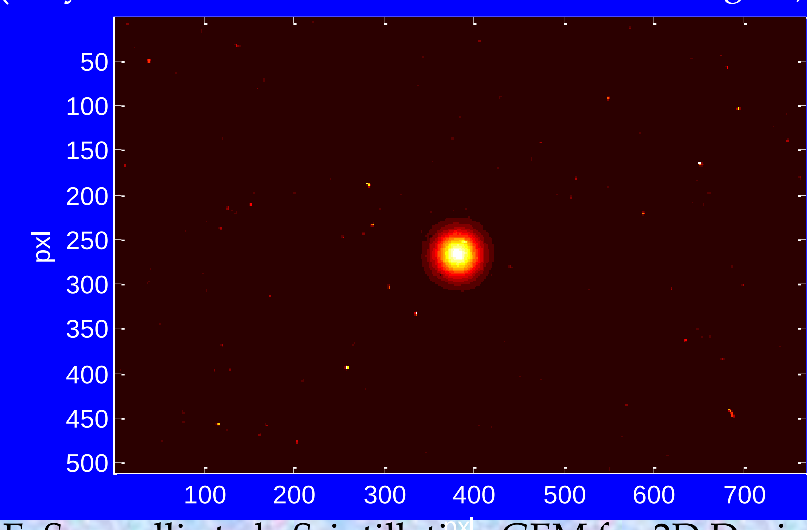
Light output for 138 MeV protons:

Scintillation type	Gas gain	Light signal (CCD) at 1Gy proton dose (ADU)
Screen (Gd_2O_2S:Tb)		2670
Ar/CO_2 (90:10)	3000	270
Ar/CF_4(90:10)	1400	2350
Ar/CF_4 (95:5)	1300	4000
Ar/CF_4 (97,5:2,5)	770	2000



LIGHT SIGNAL FROM GEM:

(only 4% smaller than ionization chamber signal)

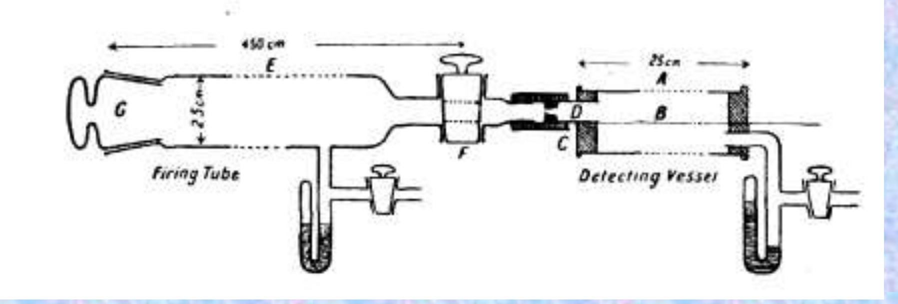


E. Sevaralli et al., Scintillating GEM for 2D Dosimetry in a-beam, submitted to IEEE TNS
S. Fetal et al., NIMA513 (2003) 42

In the Family of Gaseous Detectors with a glorious tradition

1st Revolution: The invention of the MWPC revolutionized particle detection and HEP, which passed from the manual (optical) to the electronic era.

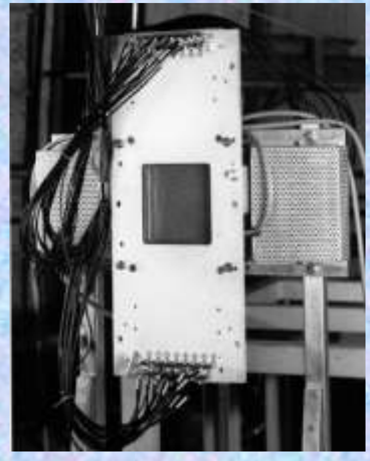
1908: FIRST WIRE COUNTER USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY

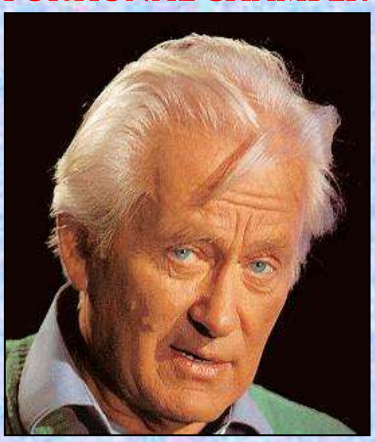


E. Rutherford and H. Geiger ,
Proc. Royal Soc. A81 (1908) 141

Nobel Prize in Chemistry in 1908

1968: MULTIWIRE PROPORTIONAL CHAMBER

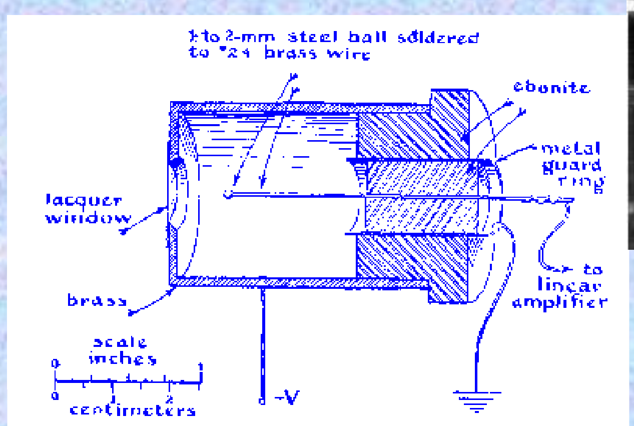




Nobel Prize in 1992

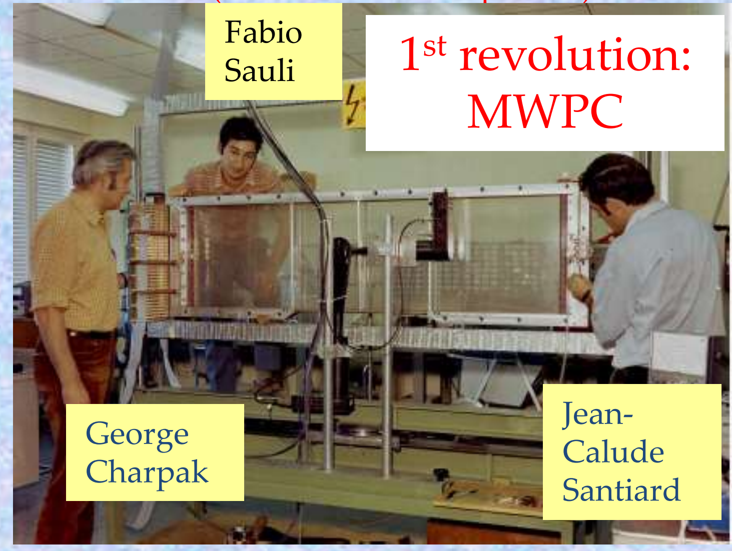
G. Charpak, Proc. Int. Symp. Nuclear Electronics (Versailles 10-13 Sept 1968)

1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY



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

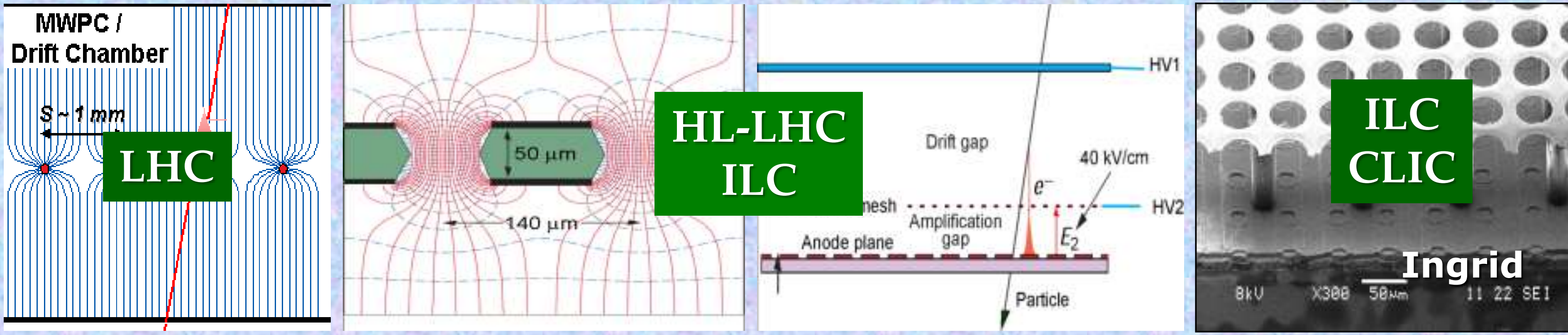
Walther Bothe
Nobel Prize in 1954 for the "coincidence method"



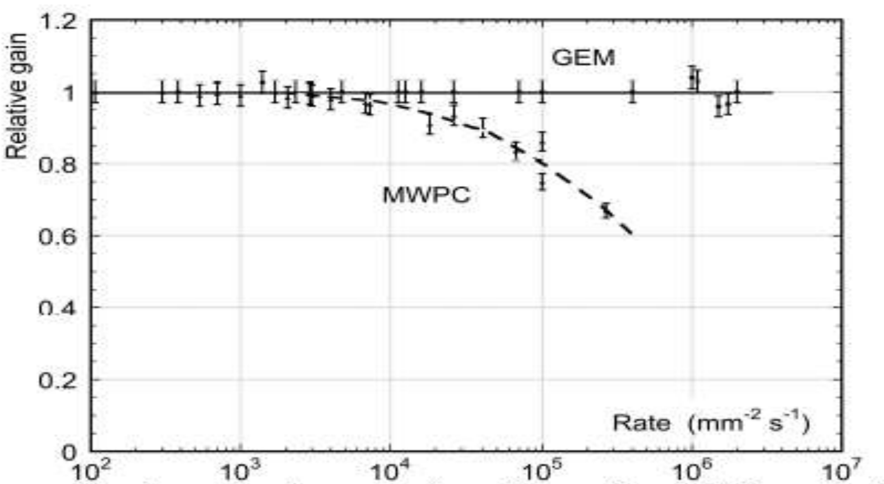
Gaseous Tracking: Detector-Electronics Integration Trends

Wire Chambers, TPC, RPC → MPGD (GEM, Micromegas) → InGrid (3D)

YESTERDAY: — INTEGRATION → **TODAY:** — INTEGRATION → **FUTURE:**



- High rate capability ~10^6 Hz/mm^2
- Spatial res. ~ 30-50 μm (TRACKING)
- Time res. ~ 3-5 ns (TRIGGER)



Advances in photolithography →
Large Area MPGDs (~ m^2 unit size)