

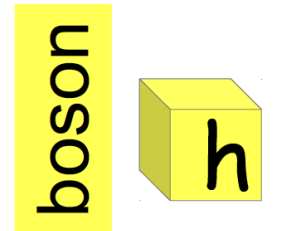
# Muon Detectors at Colliders

Kevin Black

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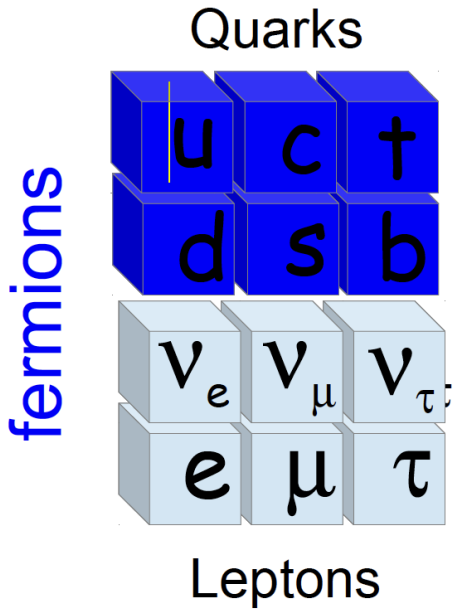
# The Muon

- Muon {
- ~207 times more massive than electron
  - ~ 17 times less massive than the tau
  - Unstable  $c\tau \sim 660\text{m}$   
but the second longest mean life time after the neutrons

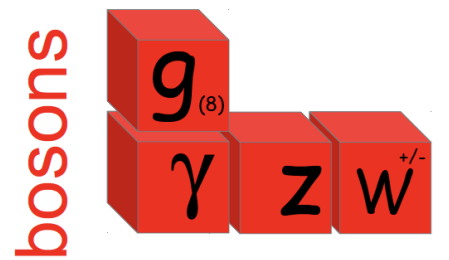


Spin 0

## Standard Model



Spin 1/2



Spin 1

# Muon discovery

Phys. Rev. 51 (1937) 884

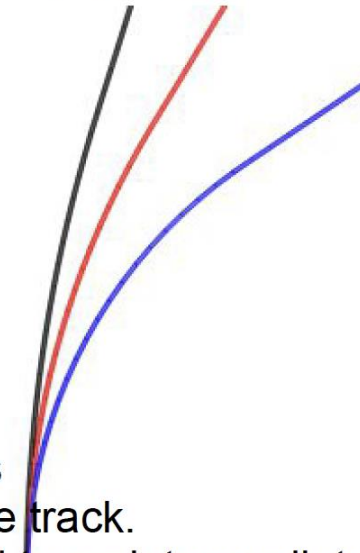
The experimental fact that penetrating particles occur both with positive and negative charges suggests that they might be created in pairs by photons, and that they might be represented as higher mass states of ordinary electrons.

Independent evidence indicating the existence of particles of a new type has already been found, based on range, curvature and ionization relations; for example, Figs. 12 and 13 of our previous publication.<sup>1</sup> In particular the strongly ionizing particle of Fig. 13 cannot readily be explained except in terms of a particle of  $e/m$  greater than that of a proton. The large value of  $e/m$  apparently is not due to an  $e$  greater than the electronic charge since above the plate the particle ionizes imperceptibly differently from a fast electron, whereas below the plate its ionization definitely exceeds that of an electron of the same curvature in the magnetic field; the effects, however, are understandable on the assumption that the particle's mass is greater than that of a free electron. We should like to suggest, merely as a possibility, that the strongly ionizing particles of the type of Fig. 13, although they occur predominantly with positive charge, may be related with the penetrating group above.



Carl David Anderson  
(1905-1991)

Observation

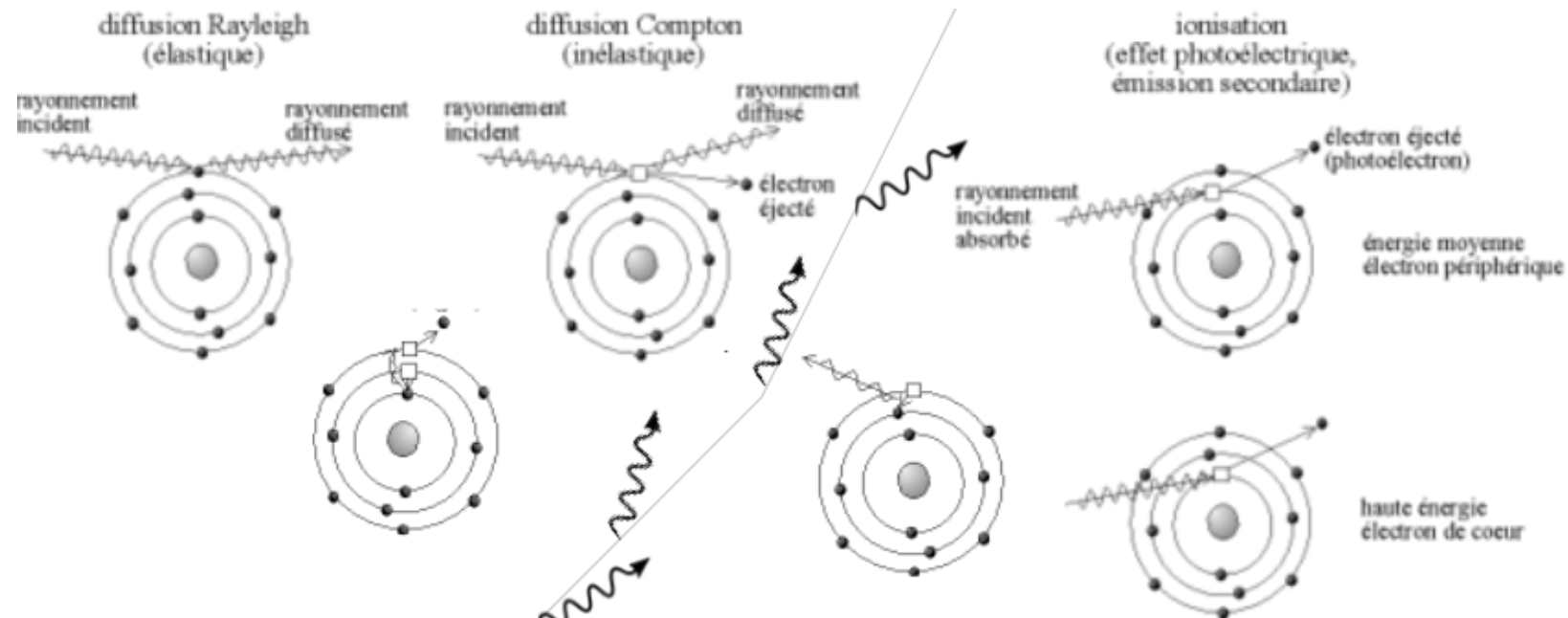


For a given B and P the black track corresponds to a heavier object than blue track. So the red track correspond to an intermediate mass object

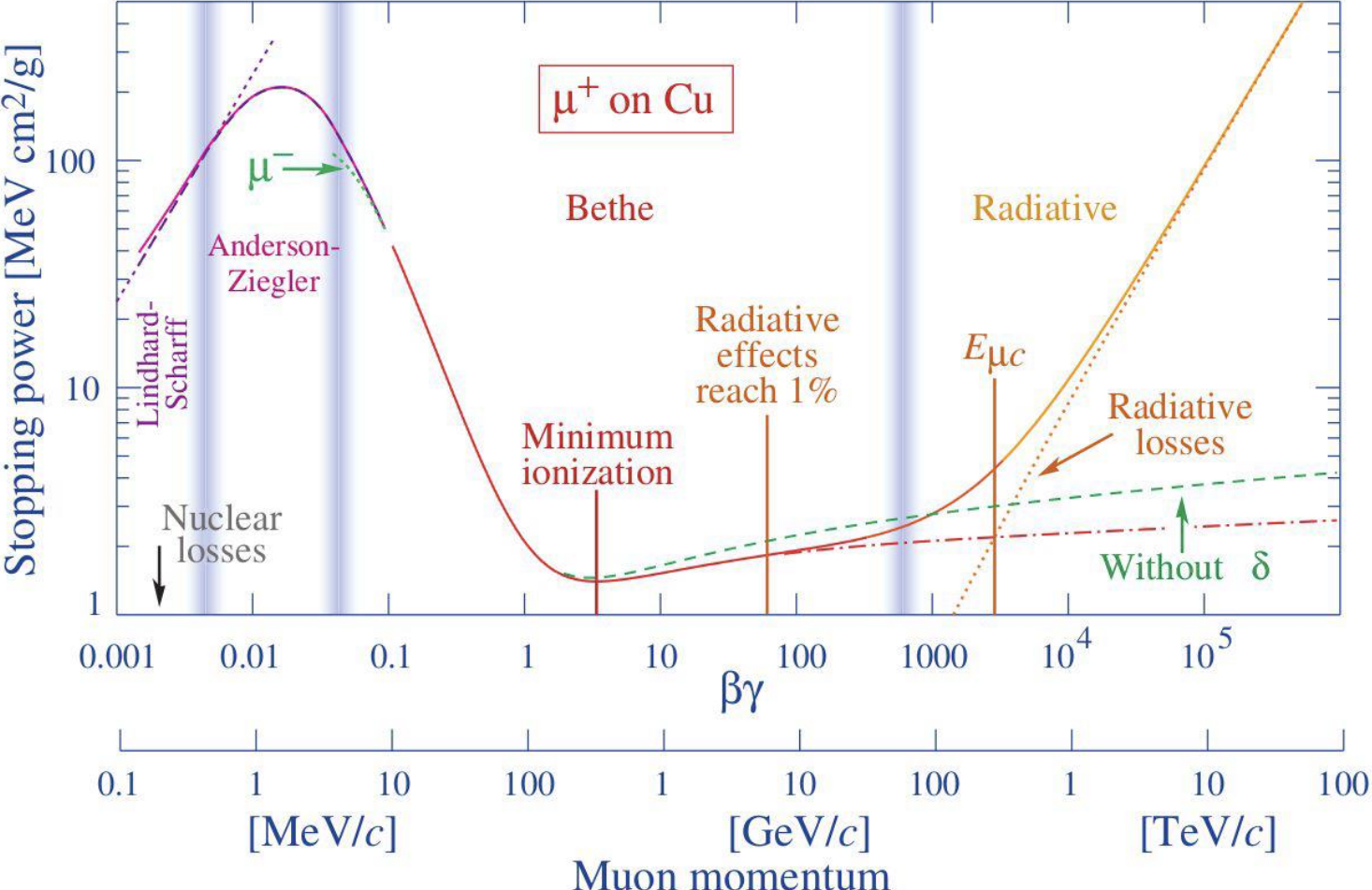
Example: proton, muon, electron

# How do muons interact

- In reality, many different processes contribute

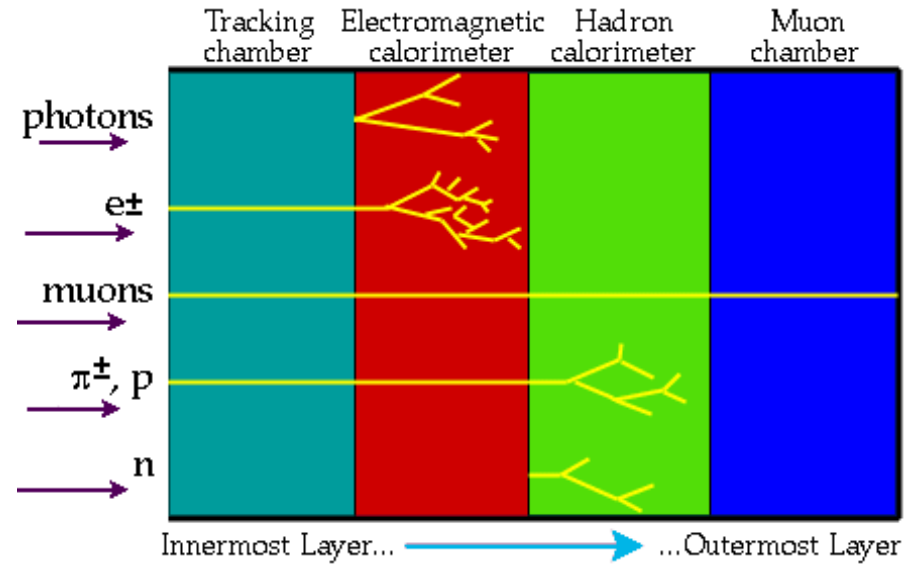


# Muon interaction with material



$$-\frac{dE}{dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

# Introduction



- How to select the interest muon tracks
  - Muon spectrometer
    - Magnets
    - Trackers
- How to optimize the parameters of muon spectrometer
  - Efficiency
  - Radiation hardness
  - Long term stability
  - Costs



# Detectors



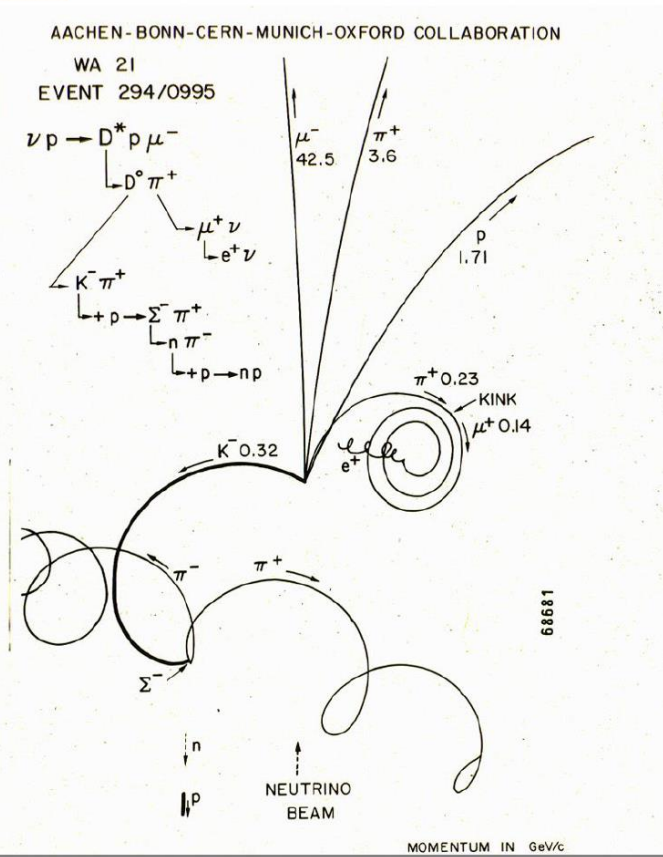
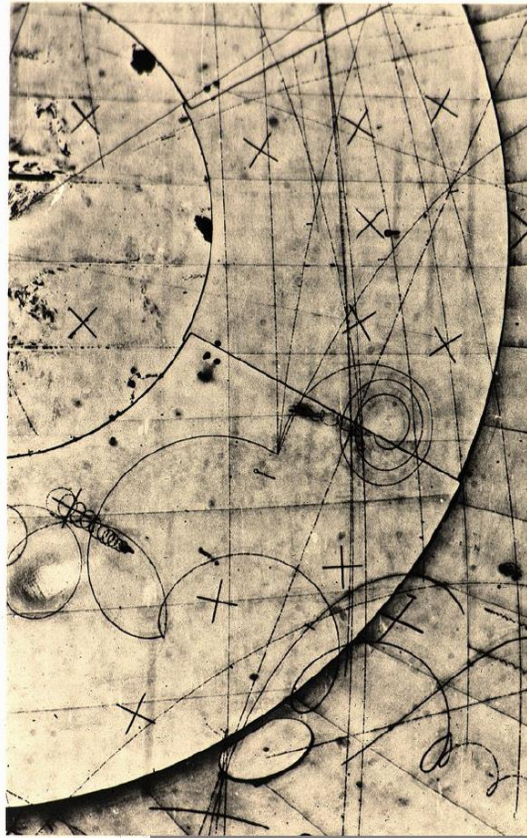
**Definition:**  
a detector is an instrument which is used to keep a track of a phenomenon

- trace in the sand  
(sand is the detector)
- visible light  
(eyes are the detectors)

L'œil était dans la tombe



et regardait Caïn



analogical

Bubble chambers



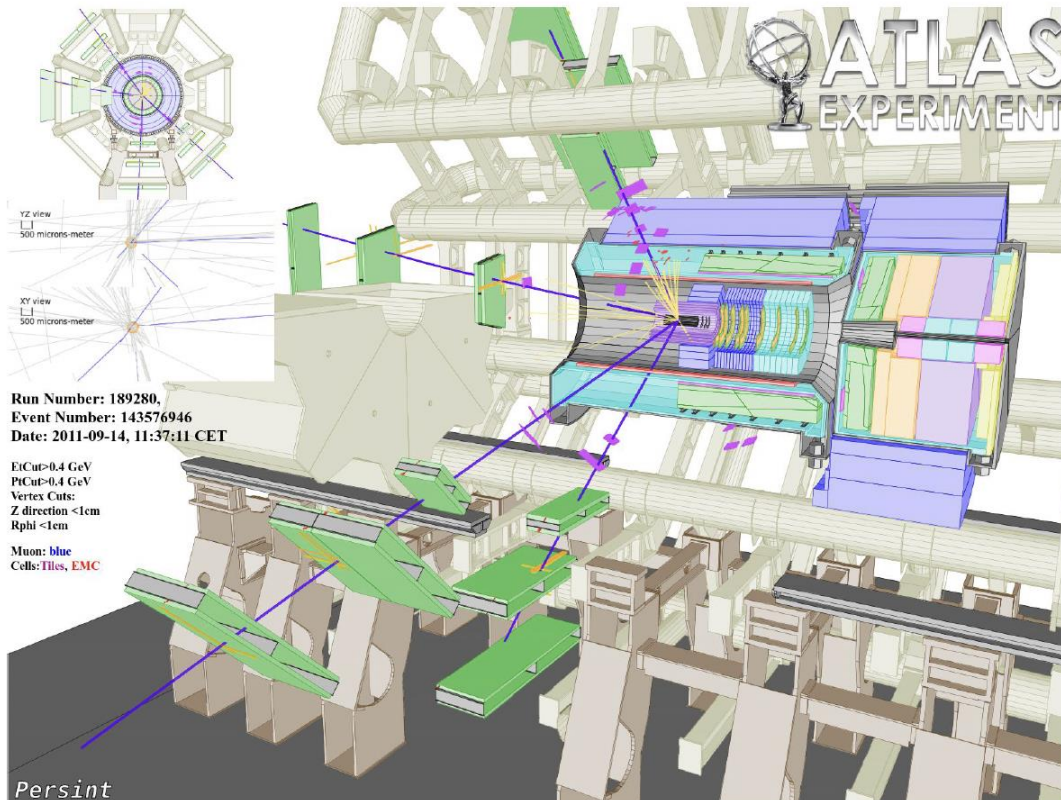
# Detectors



Different types of detectors must be used to understand and to keep the track of a phenomenon:

- different types of particles,
- different way to interact with matter,
- fast detectors,
- precise detectors (spatially)
- ...

One big detectors is made by many sub-detectors with precise tasks



Run Number: 189280,  
Event Number: 143576946  
Date: 2011-09-14, 11:37:11 CET

EtCut>0.4 GeV  
PtCut>0.4 GeV  
Vertex Cuts:  
Z direction <1cm  
Rphi <1cm

Muon: blue  
Cells: Tiles, EMC

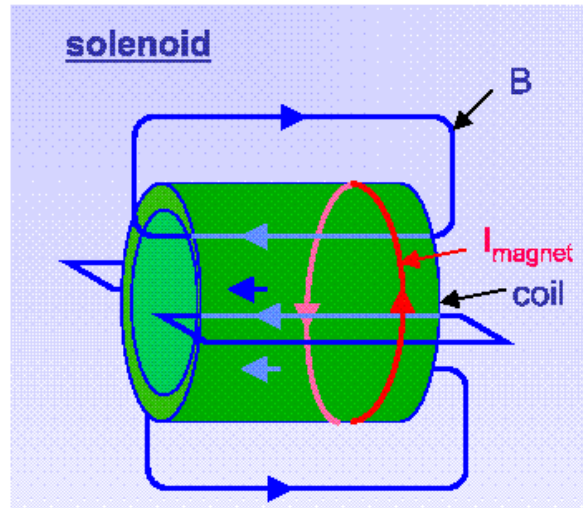
Persint



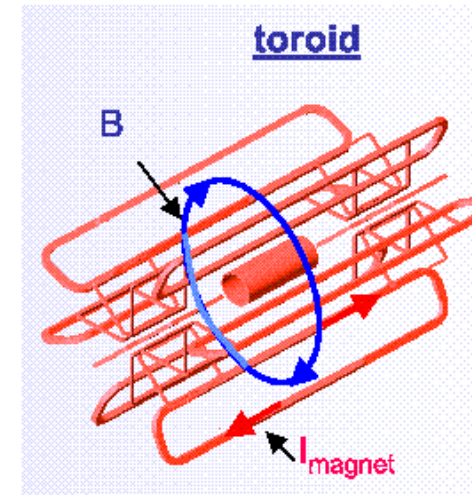
numeric



# Difference of 2 type magnetic fields

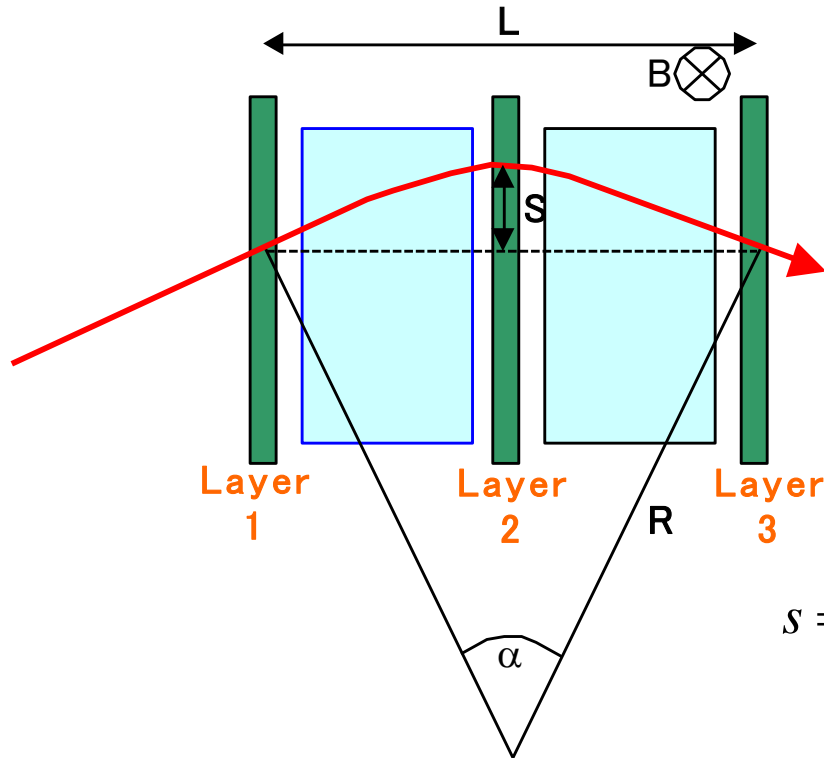


- \*Large Homogenous field inside coil
- \*Weak opposite field in return yoke
- \*Size limited



- \*Large size area with high magnetic field
- \*Non-uniform field
- \*Field always perpendicular to momentum

# How to measure Pt?



Measure the transverse component to B field

$$Pt = qBR \Rightarrow Pt[GeV] = 0.3BR[Tm]$$

$$\frac{L}{2R} = \sin\left(\frac{\alpha}{2}\right) \approx \frac{\alpha}{2} \Rightarrow \alpha \approx \frac{0.3LB}{Pt}$$

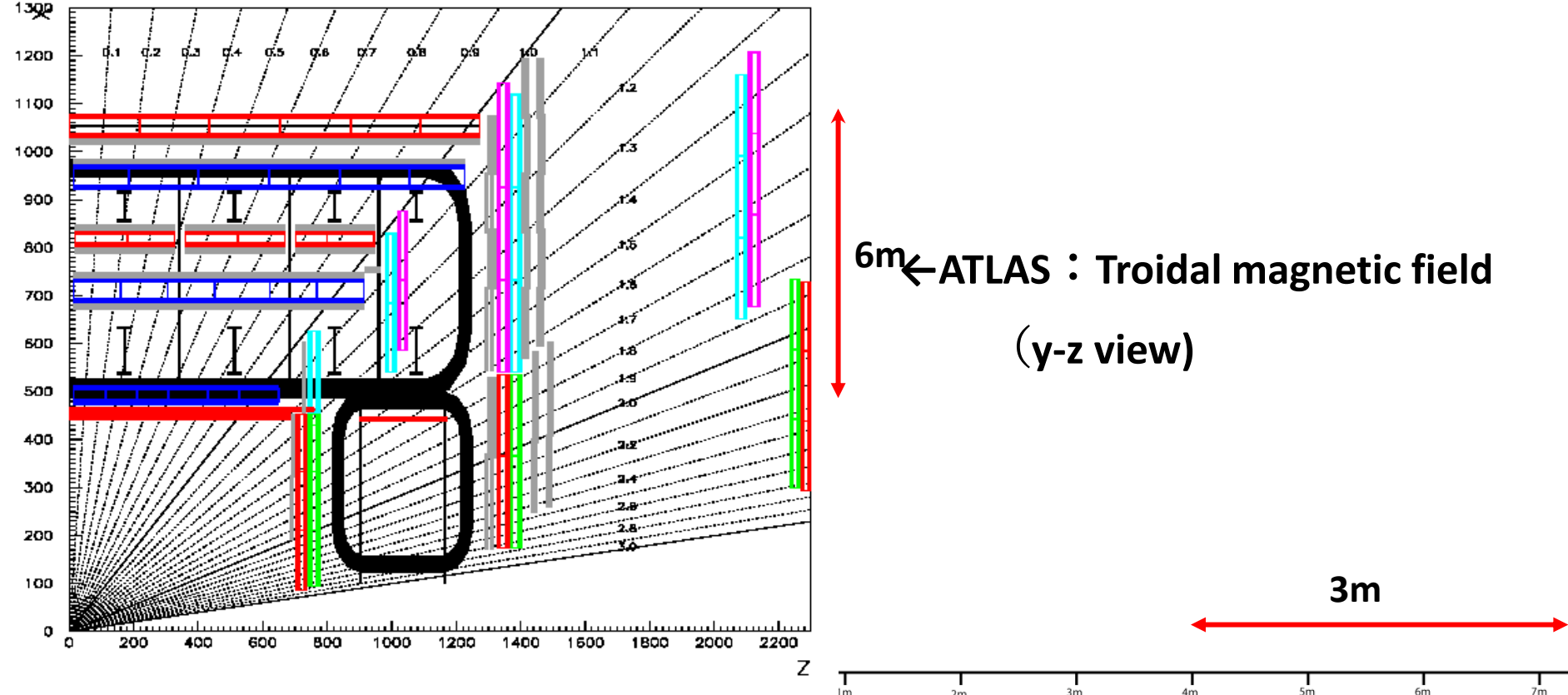
$$s = R(1 - \cos\left(\frac{\alpha}{2}\right)) \approx R \frac{\alpha^2}{8} \frac{L^2 B}{Pt}$$

Position resolution  $\sigma(x)$  for each

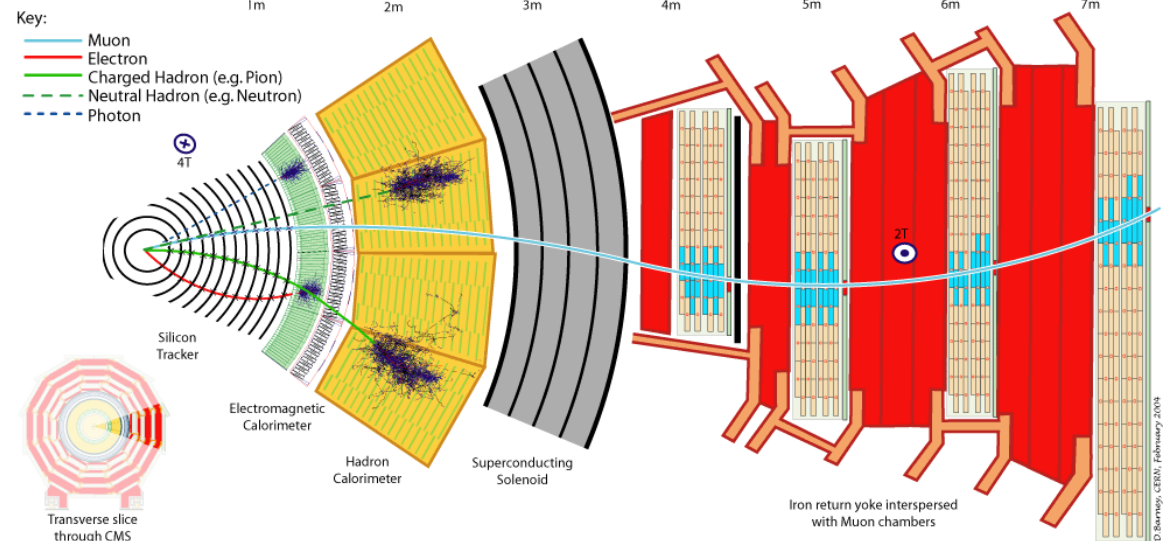
$$s = x_2 - \frac{x_1 + x_3}{2}$$

$$\frac{\sigma(Pt)}{Pt} = \frac{\sigma(s)}{s} = \frac{\sqrt{\frac{3}{2}}\sigma(x)}{s} = \frac{\sqrt{\frac{3}{2}}\sigma(x) \cdot 8Pt}{0.3 \cdot BL^2} \propto \frac{\sigma(x) \cdot Pt}{BL^2}$$

**Pt resolution depends on B, L and  $\sigma(x)$  (not R)!**



**CMS: Solenoidal magnetic field**  
**Field →**  
**(r-φview)**

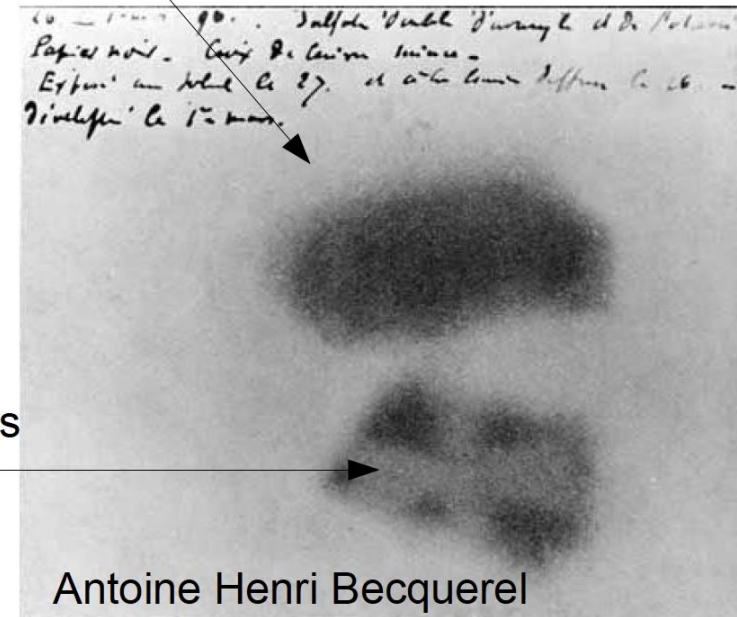


# Detectors

## Different types

- Gaseous
  - Geiger counter, wires chamber (TPC), Micro-Megas
- Liquid
  - Bubbles chamber
- Solid
  - Scintillator, Silicon, Photographic plates
- Mix

Principle: Ionisation

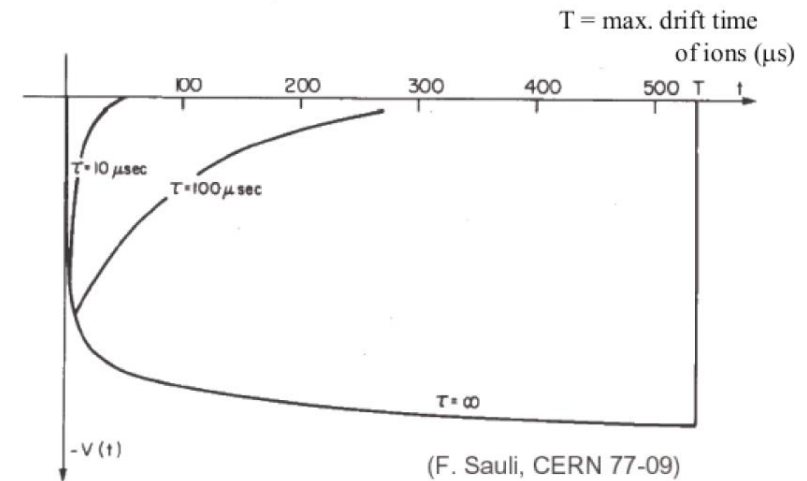
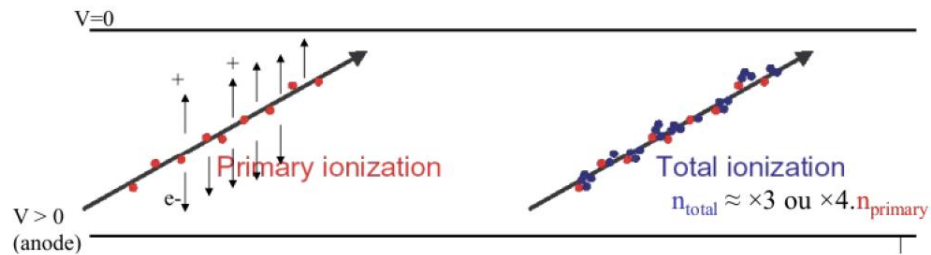
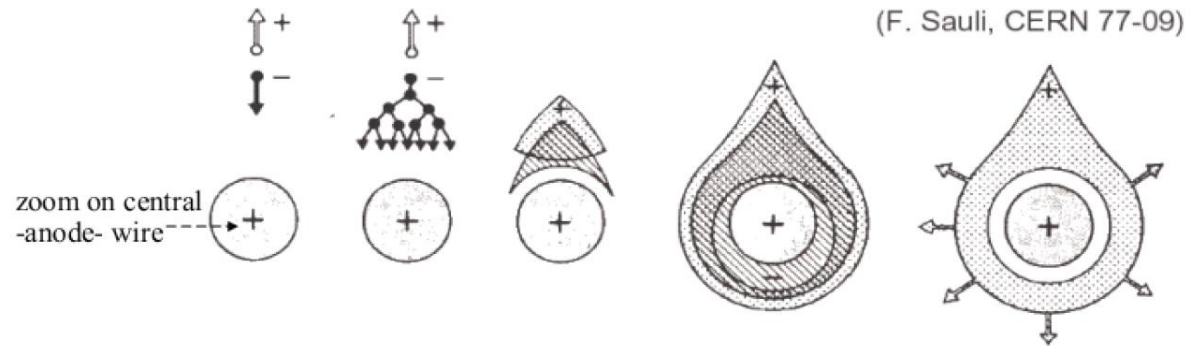




# Detectors (Gaseous)

## Principle:

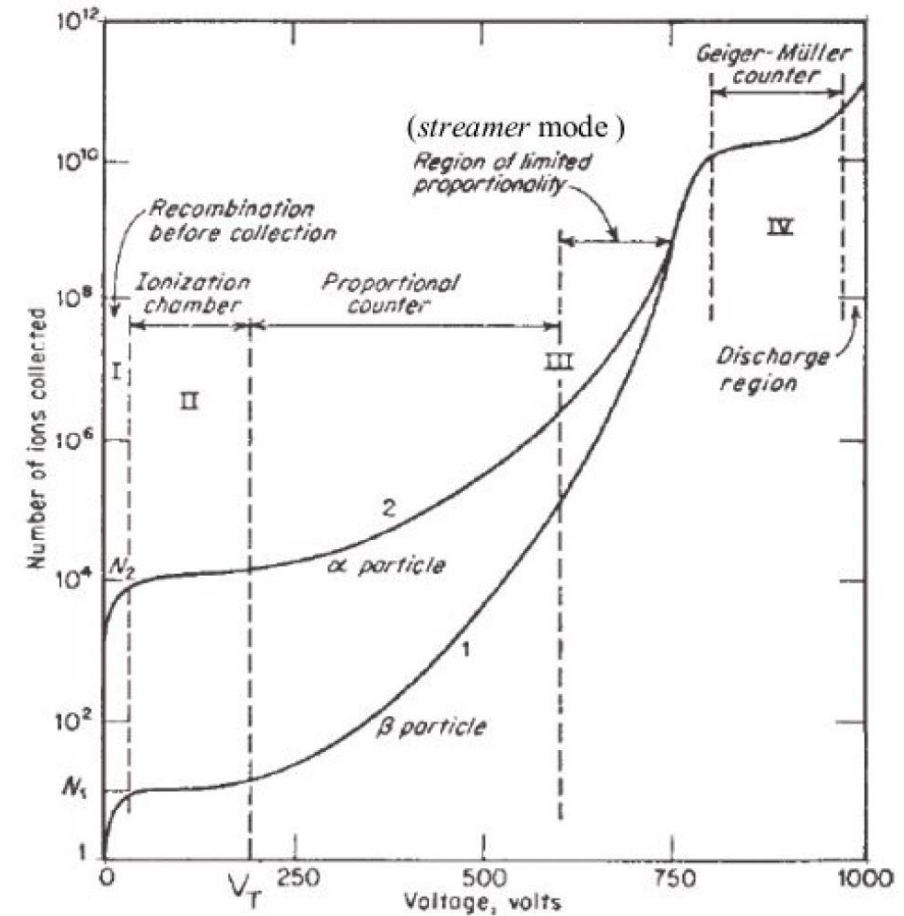
- Primary and secondary ionisation not enough for a measurement
- Electric Field (high!) => Avalanche
  - Electric Field increase the number of electrons
  - The drift of ions induces a variation of the potential, which is measured



# Detectors (Gaseous)

## Gain vs Electric field

- I Potential too weak, pair recombination
- II Ionisation Chamber: no amplification
- IIIa Proportional mode, signal amplification
  - Proportional to ionisation.
  - Gain:  $10^4$  to  $10^5$
- IIIb Streamer mode, secondary avalanches
  - Need “quencher” ( $\text{CH}_4, \text{CO}_2, \dots$ )
- IV Geiger-Muller mode

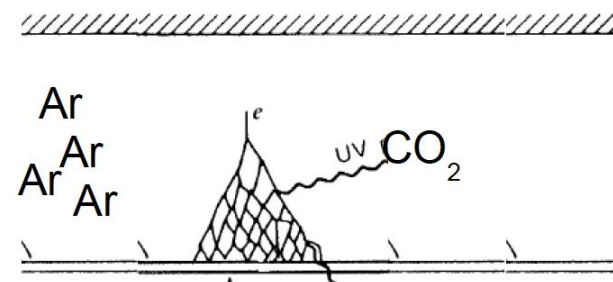


Remark: no electric field => no electrons acceleration: recombination

# Detectors (**Gaseous**)

## Spatial Resolution

- Avoid secondary avalanches
- Photons absorption (UV production)
- Noble gaseous (He,Ar,...)

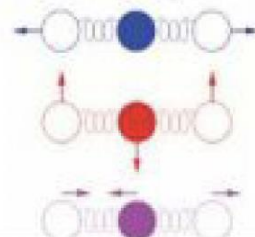


## “Quencher”

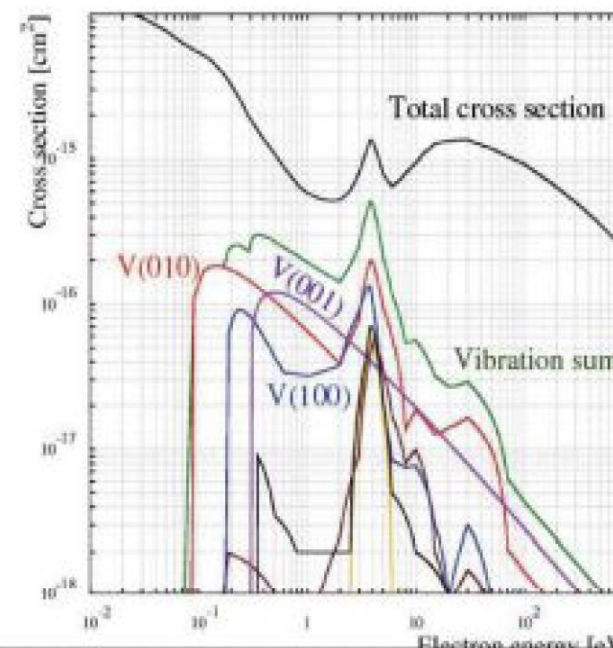
- Polyatomic gaseous:
  - ex:  $\text{CH}_4$ ,  $\text{C}_4\text{H}_{10}$ ,  $\text{CO}_2$
- Photons absorption by vibration or molecule rotation
- No easy solution: should be tested
  - Ex: 70%Ar, 29.6% $\text{C}_4\text{H}_{10}$ , 0.4% Fr

## $\text{CO}_2$ – vibration modes

- ▶  $\text{CO}_2$  is linear:
  - ▶ O – C – O
- ▶ Vibration modes are numbered  $V(ijk)$ 
  - ▶  $i$ : symmetric,
  - ▶  $j$ : bending,
  - ▶  $k$ : anti-symmetric.



Vibrations  $V(ijk)$



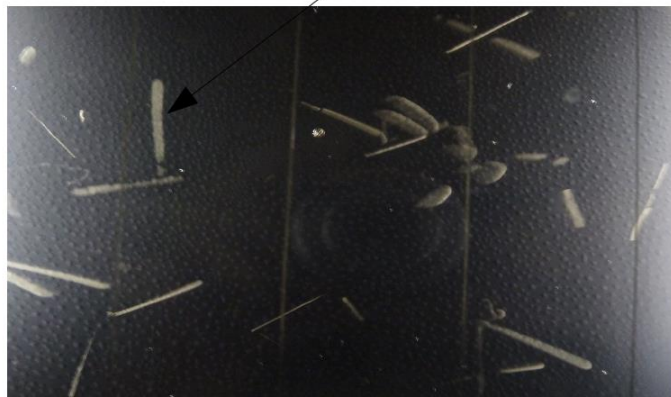
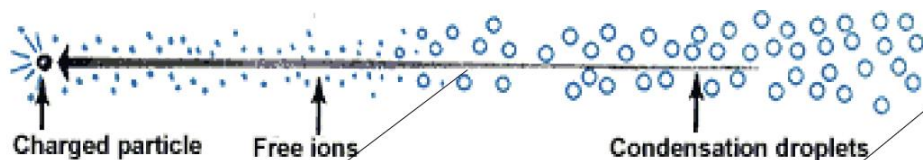
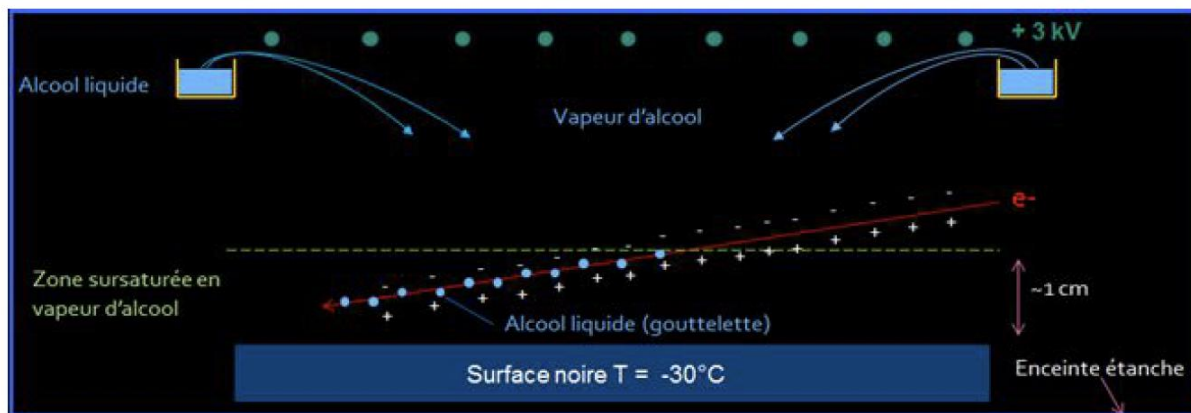


# Detectors

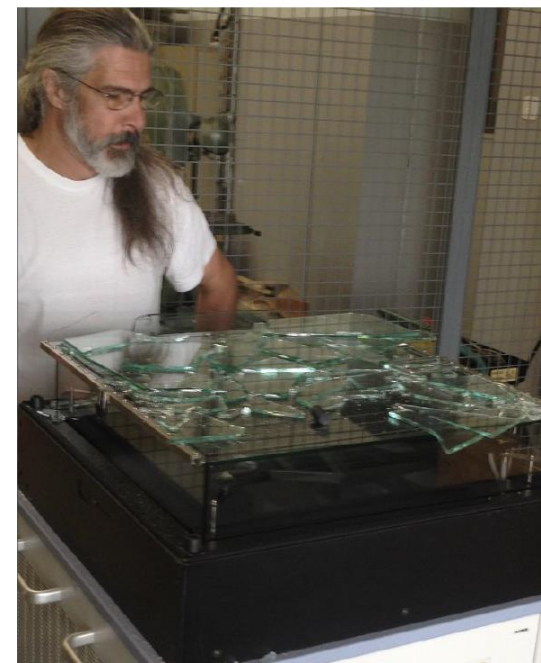
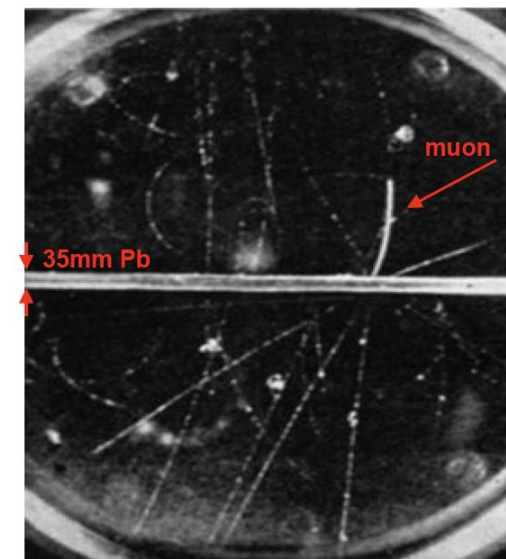
## Clouds Chamber: Gaseous/Liquid

- C.T. R. Wilson 1911
- C.Anderson positron discovery 1932

Muon discovery 1936



Broken cloud chamber  
Physicist sad!

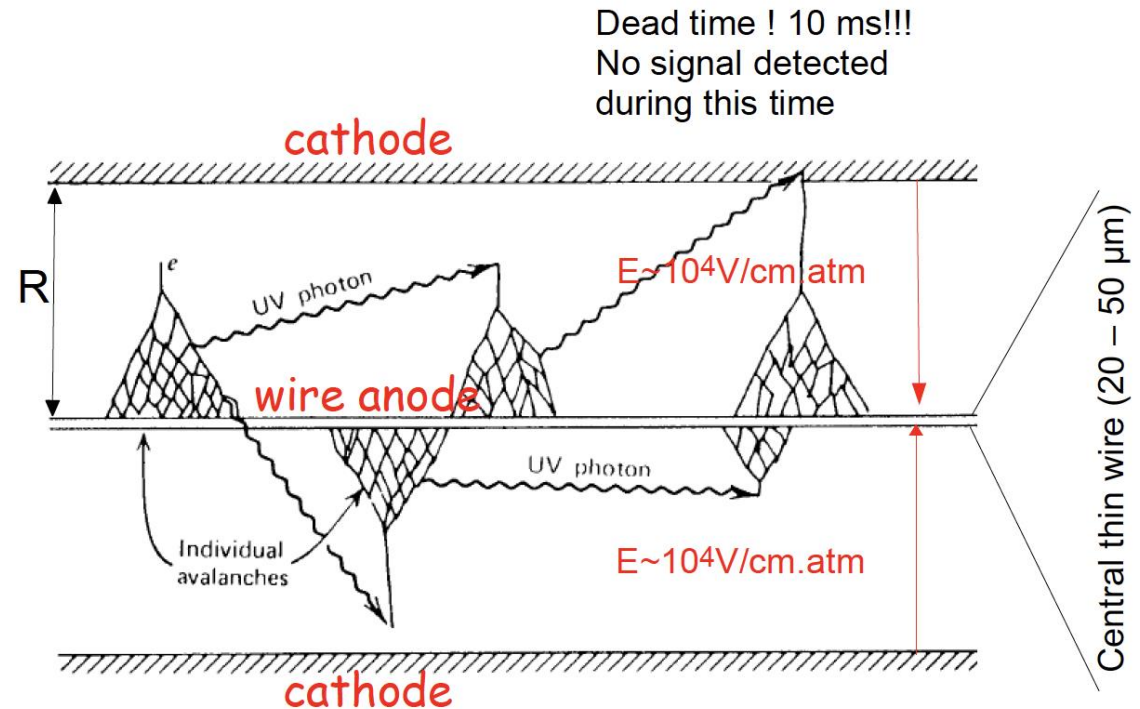




# Detectors(Gaseous)

## Geiger Counter

- H.Geiger-Muller 1928
  - Detection: Alpha(He), Beta (e+/e-), Gamma(photon), **Muons**
  - Gaseous: He, Ne, Ag
  - Avalanche:  $n = n_0 e^{\alpha(E)x}$  ( $\alpha$  Townsend coeff. function E or R)
  - $> 10^8$  electrons: sparks!!!
  - **Particles counting only:**
    - **no measurement : position,energy,...**



# Detectors(**Gaseous**)

## Geiger Counter

- Used as a Trigger device

New Evidence for the Existence of a Particle of Mass Intermediate  
Between the Proton and Electron

Phys. Rev. 52, 1003 – Published 1 November 1937

Muon

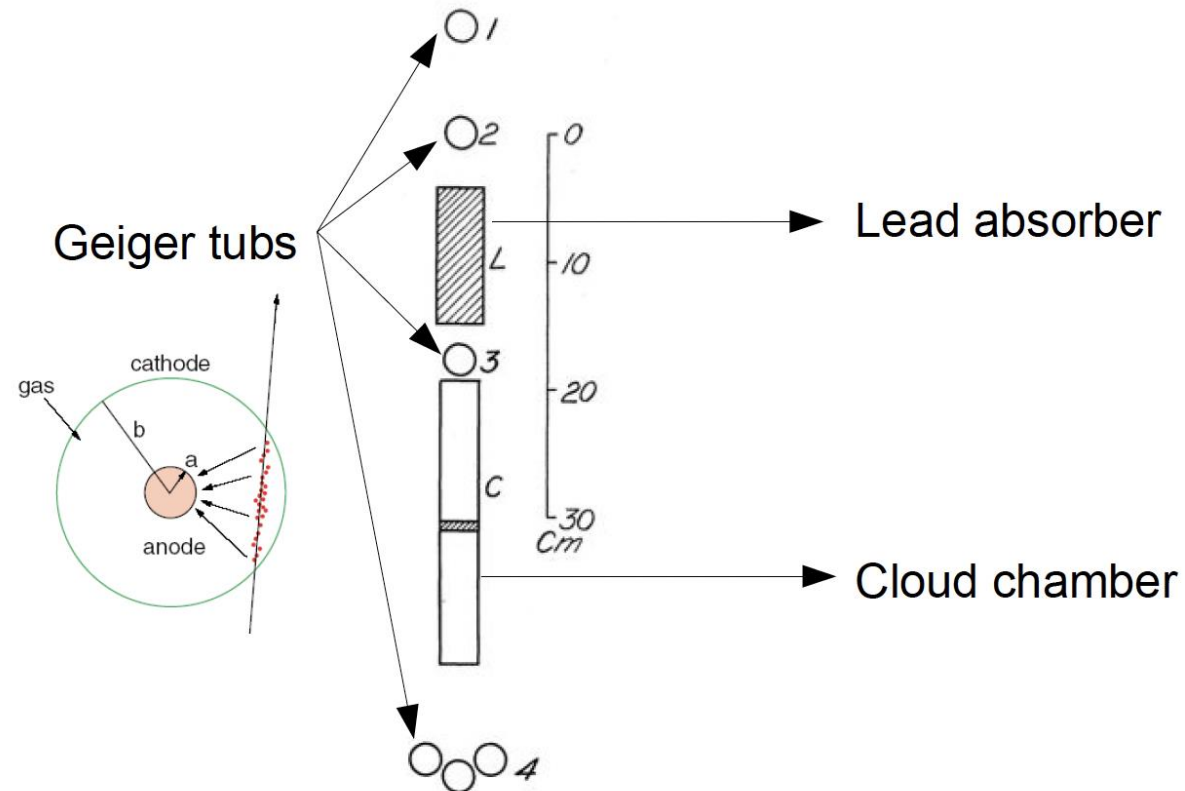


FIG. 1. Geometrical arrangement of apparatus.



# Detectors(**Gaseous**)

## Spark Chambers

- Pairs of metal plates are connected to a HV  $\sim 10$  kV creating a strong electrical field between the plates.  
Charged particles passing across the plates ionize the gas and create a conducting trace that leads to a spark between the two plates which is then photographed.



A spark chamber at the physics museum of the Sapienza University of Rome

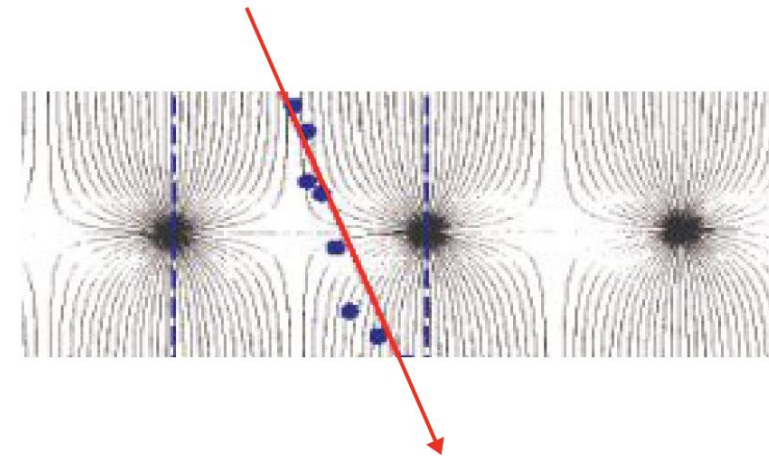
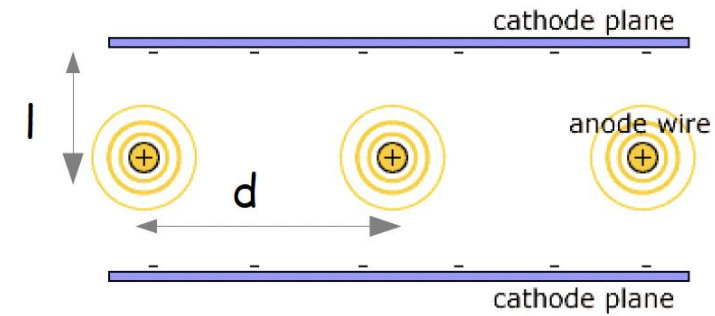


Remark:  
HV applied 0,1 s à 1  $\mu$ s  
to avoid saturation

# Detectors(Gaseous)

## Wires Chamber

- G.Charpak 1968
  - Multi Wires Proportional Chamber (MWPC)
  - flattening of the proportional counter
  - Time resolution : 200 ns
  - Spatial resolution: < mm
  - Signal on wire: ns
  - $l \sim 5\text{mm}$ ,  $d \sim 1\text{mm}$ ,  $E \sim 50\text{ V/mm}$

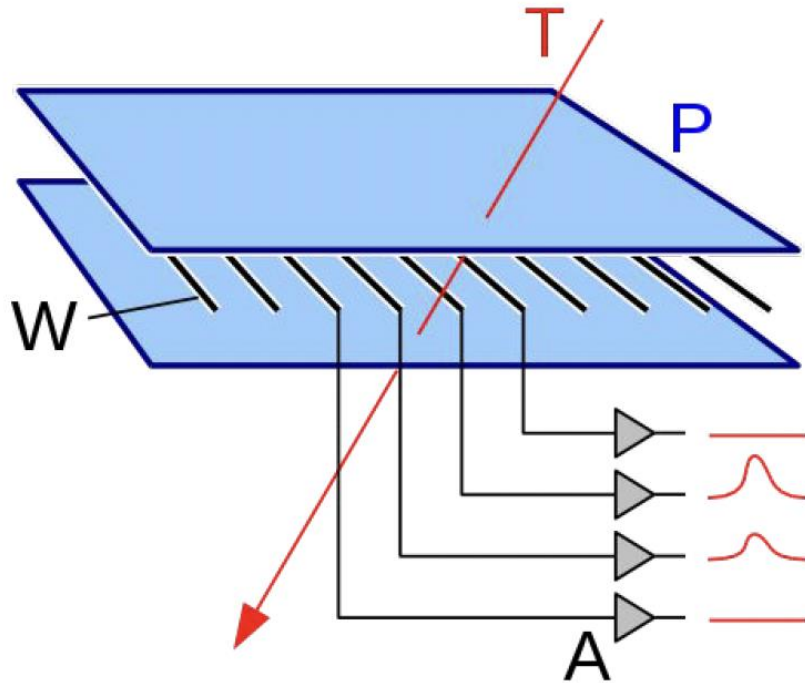




# Detectors(Gaseous)

## Wires Chamber

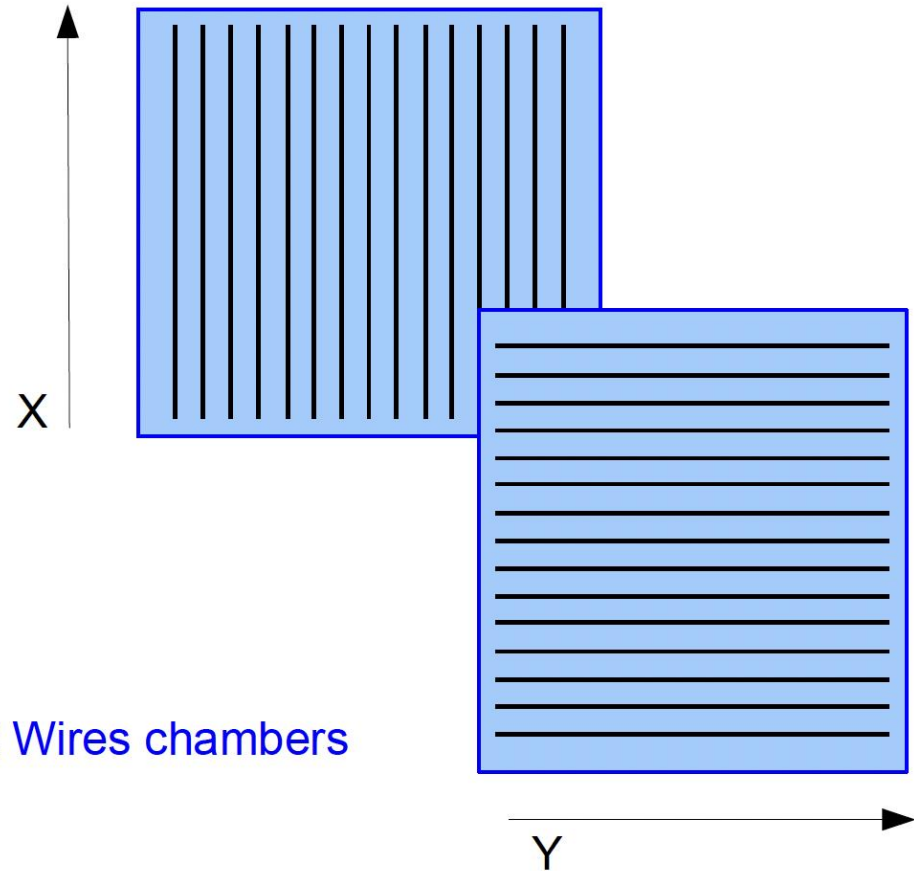
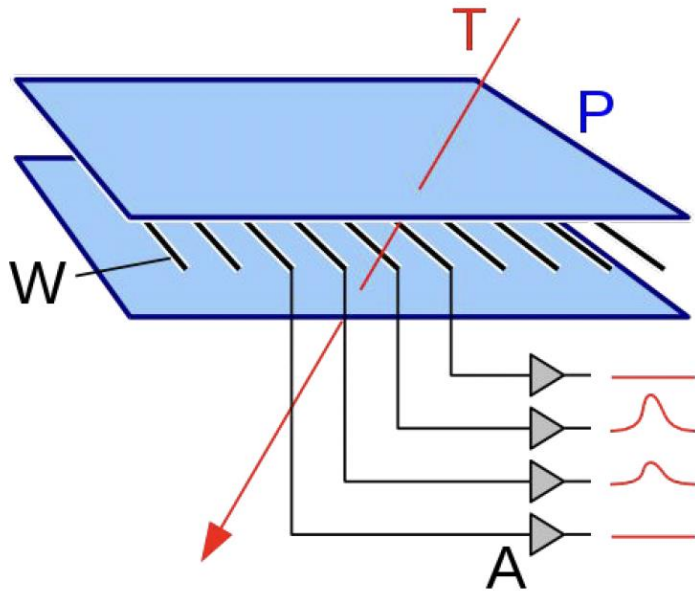
- Large area (and volume) tracking detectors
- Accuracy is function of the wire distance,  $\sim 1$  to  $2$  mm  
Spatial resolution =  $d/\sqrt{12}$  (for  $d=1$  mm,  $\sigma \sim 300$   $\mu\text{m}$ )
- Wires measure only one coordinate!!!



# Detectors(Gaseous)

## Wires Chamber

- Large area (and volume) tracking detectors
- Accuracy is function of the wire distance,  $\sim 1$  to  $2$  mm  
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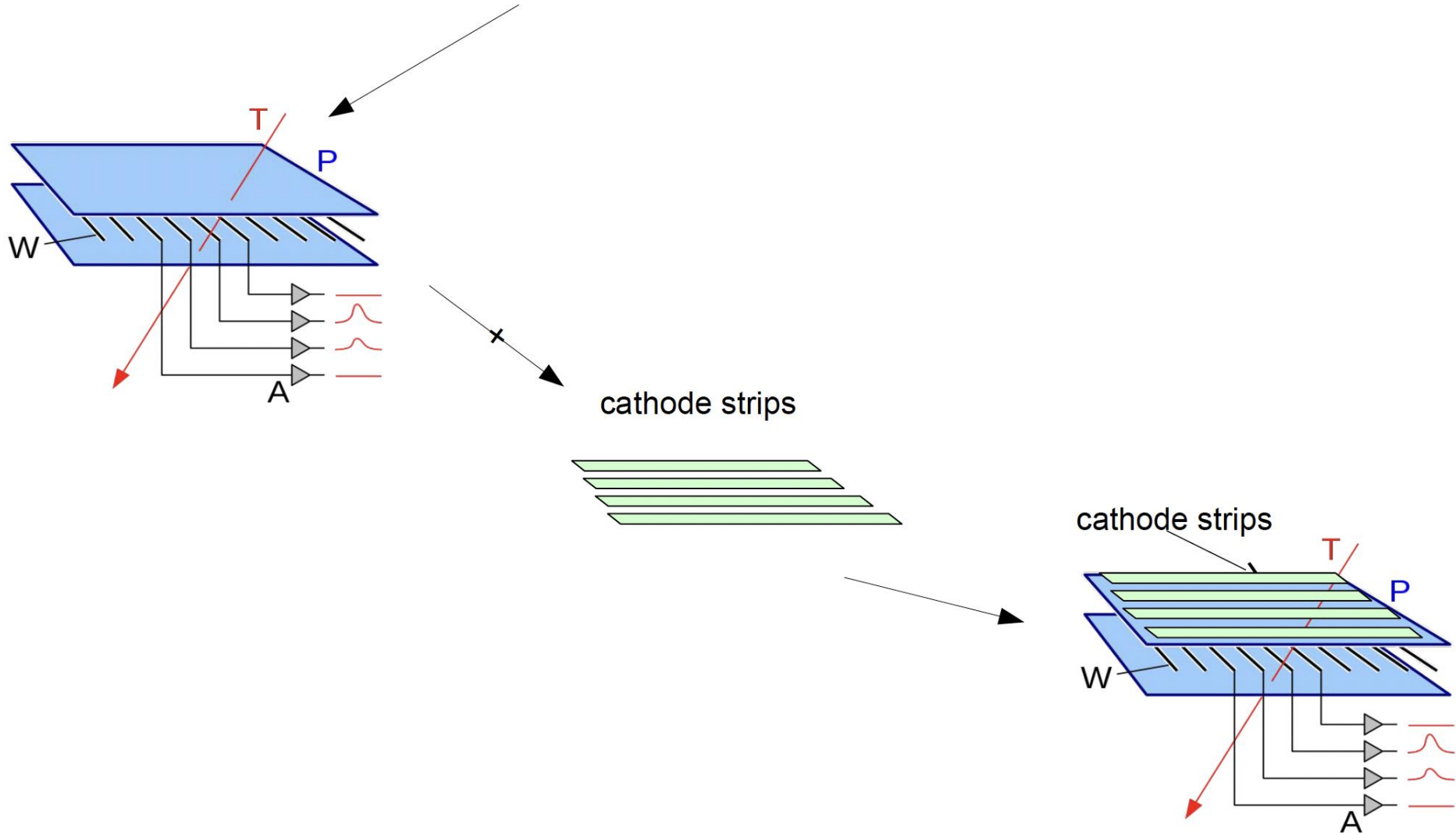


To get the second coordinate: 2 Wires chambers

# Detectors(Gaseous)

## TGC\*

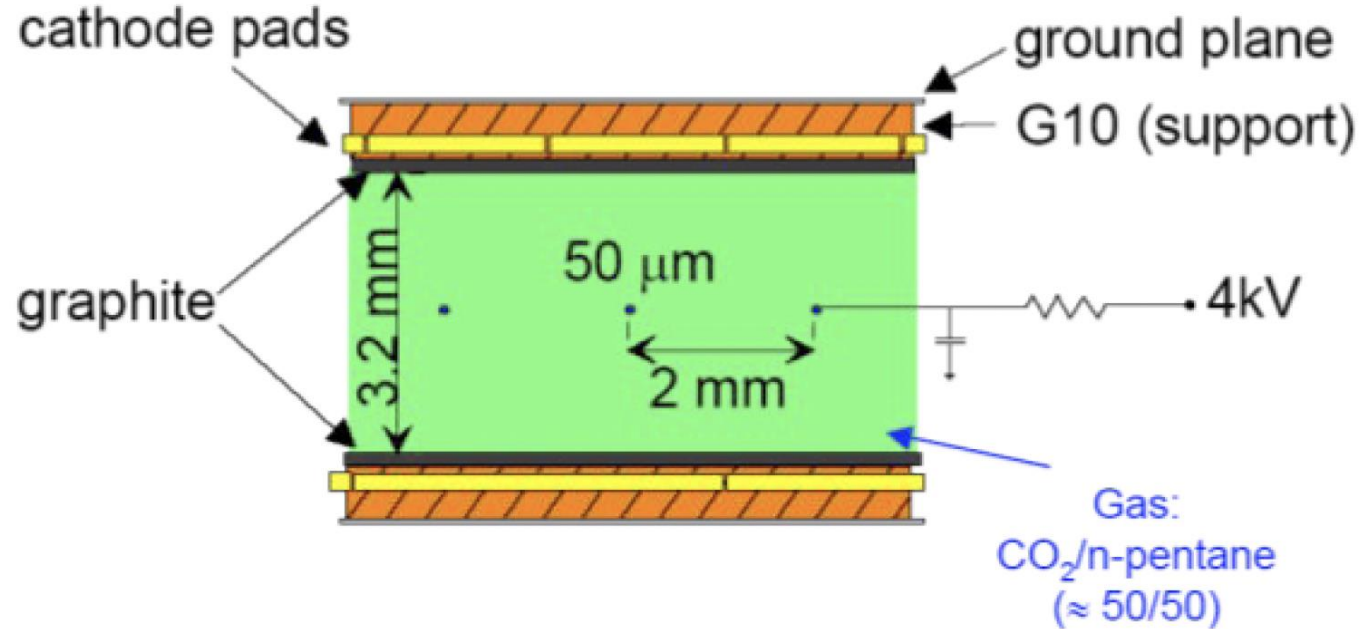
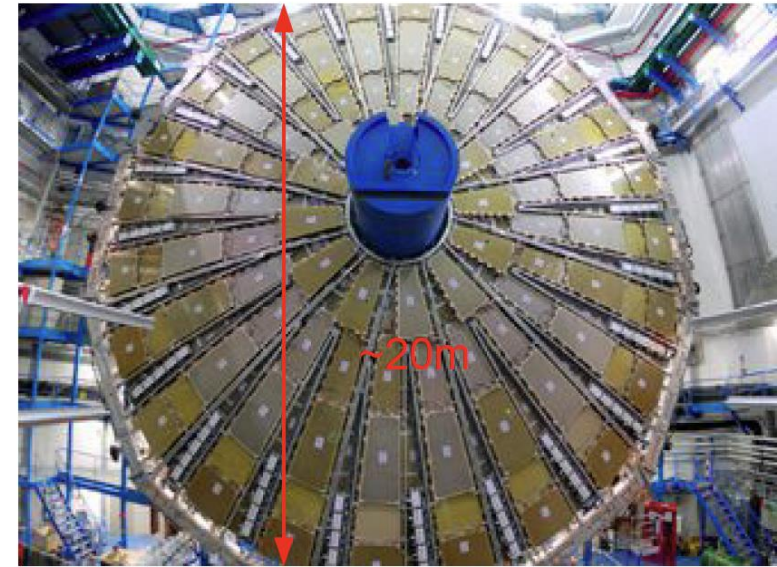
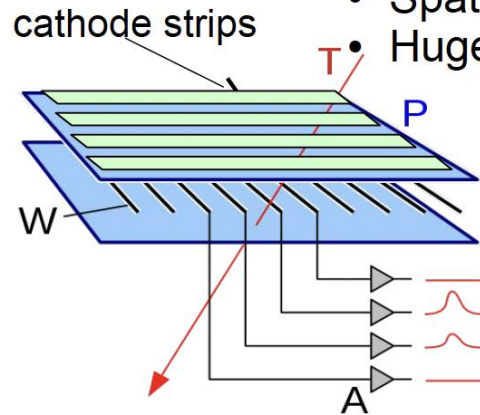
- Thin Gap Chamber
- Go back to MWPC



# Detectors(Gaseous)

## TGC\*

- ATLAS
  - Saturated mode operation (Geiger)
  - Time response:  $\sim 2$  ns : Trigger
  - Counting rate: 100 Hz
  - Spatial resolution  $\sim$ mm
  - Huge surface

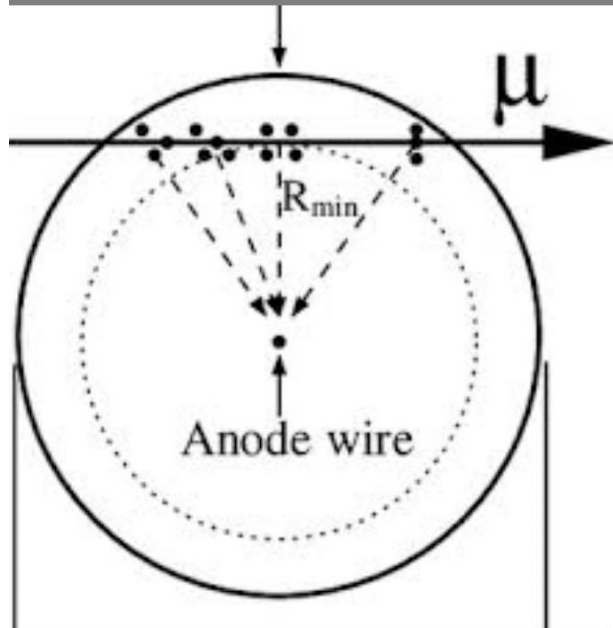


TGC used in ATLAS  
for muon trigger

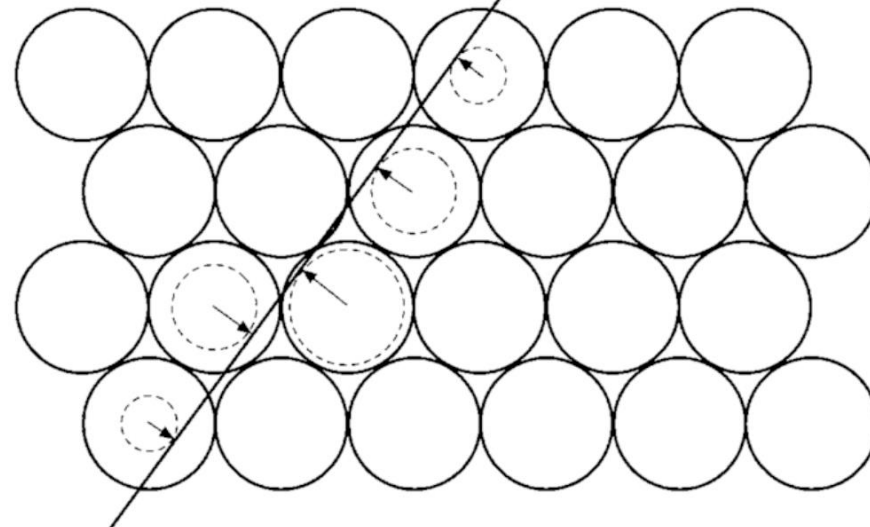


# Monitored drift tubes

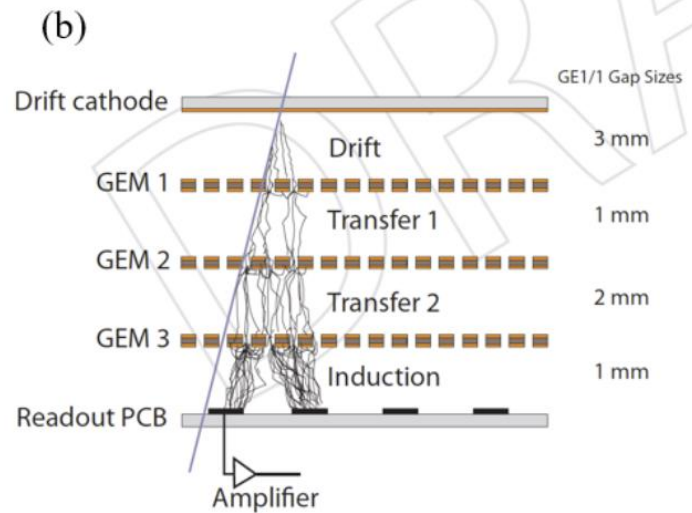
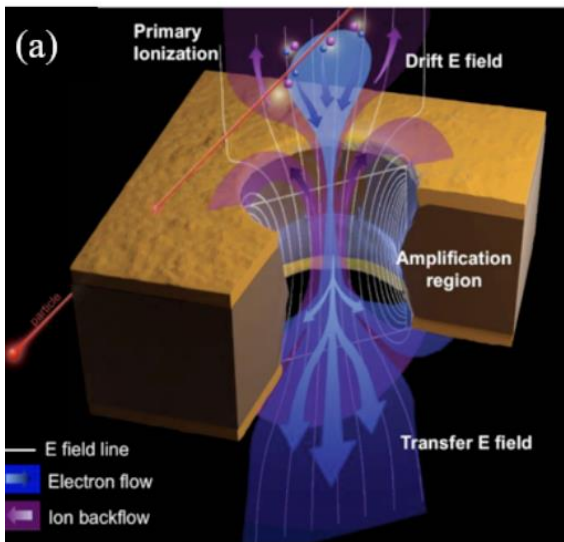
$r=1.5\text{cm}$ . 700 ns drift time. AR-Ethane 93-7.  $80\mu$  resolution



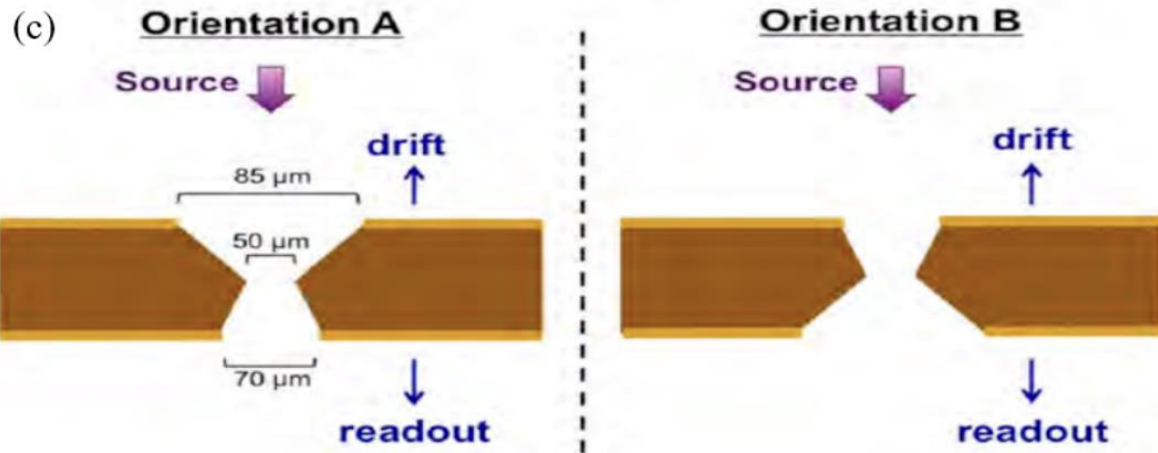
Beam cross every 25ns.



# GEM: CMS Muons



Many stages - each with modest gain

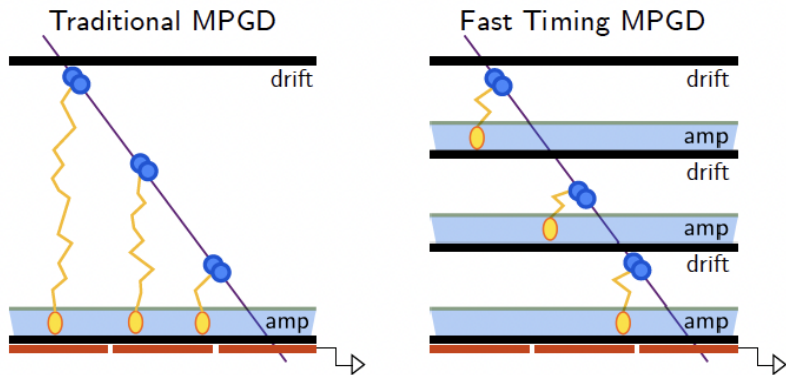


## 2.1.1 Requirements on GE1/1 chamber performances and design specifications

The desired trigger and physics performances outlined in the introduction and detailed in Chapter 6 impose the following fundamental requirements on the detection performance of the GE1/1 chambers:

- Maximum geometric acceptance within the given CMS envelope.
- Rate capability of 10 kHz/cm<sup>2</sup> or better.
- Single-chamber efficiency of 97% or better for detecting minimum ionizing particles.
- Angular resolution of 300 μrad or better on  $\Delta\phi = \phi_{GE1/1} - \phi_{ME1/1}$
- Timing resolution of 10 ns or better for a single chamber.
- Gain uniformity of 15% or better across a chamber and between chambers.

## Future Directions



- Micropattern detectors have improved spatial resolution
- Future directions include
  - Improving timing resolution  $\sim 10$ s of picoseconds
  - Improved radiation hardness
  - Integrated readout/trigger (improve bandwidth constrains)

