Muon Detectors at Colliders

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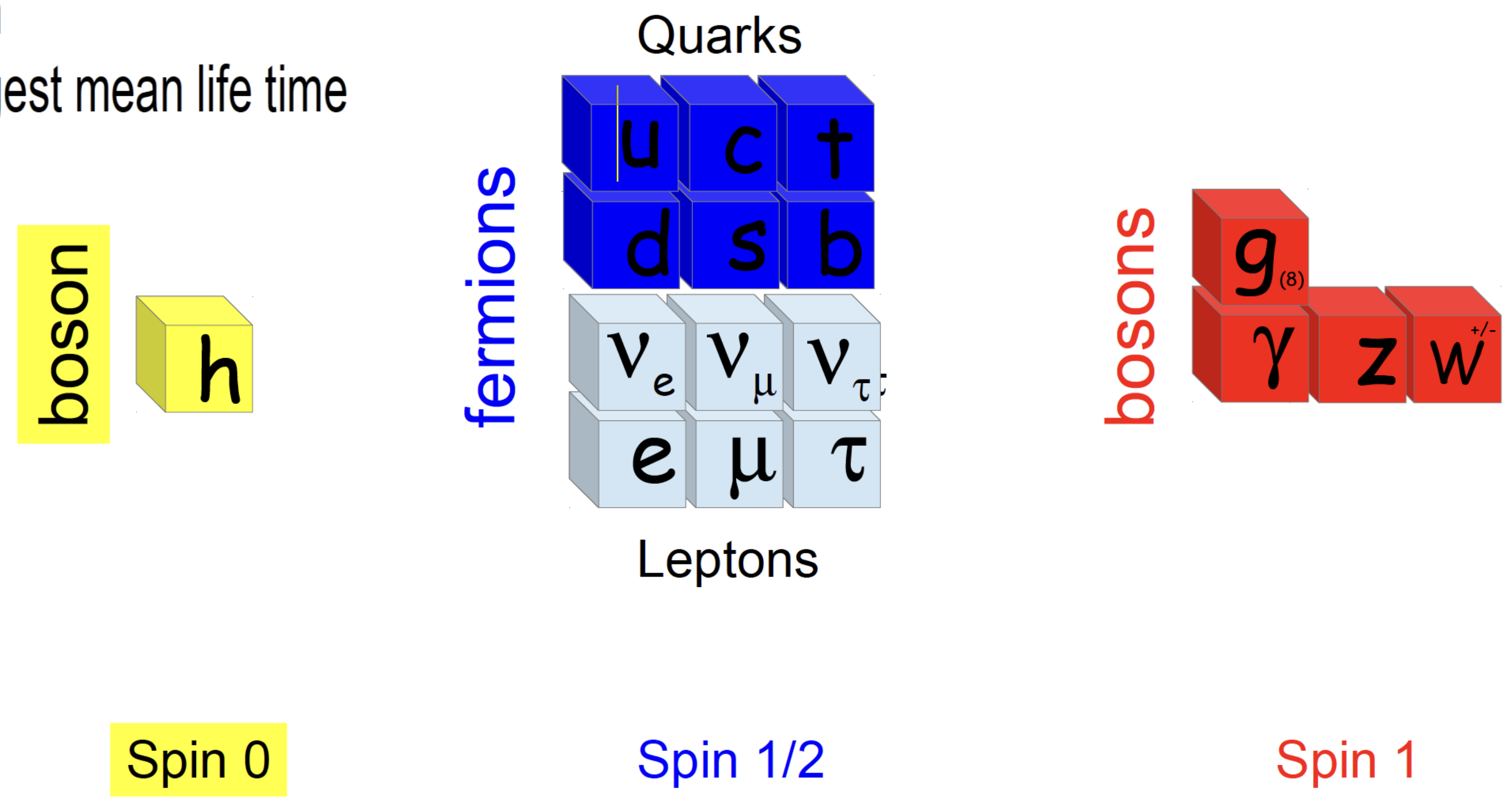
The Muon

Muon

- ~207 times more massive than electron
- ~ 17 times less massive than the tau
- Unstable cτ ~ 660m
  but the second longest mean life time after the neutrons

Standard Model



Muon discovery

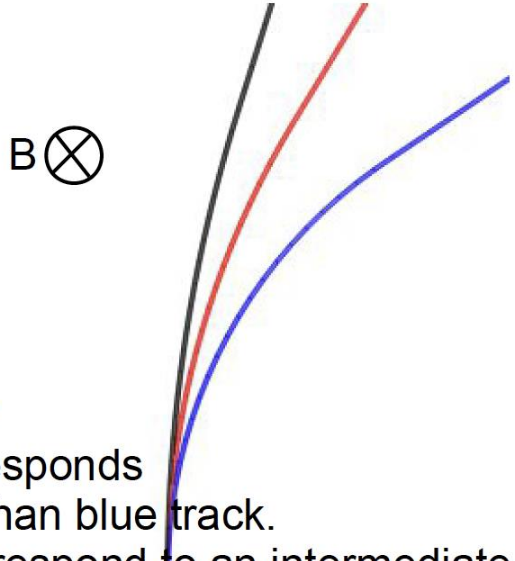
Phys. Rev. 51 (1937) 884

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.[1] 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

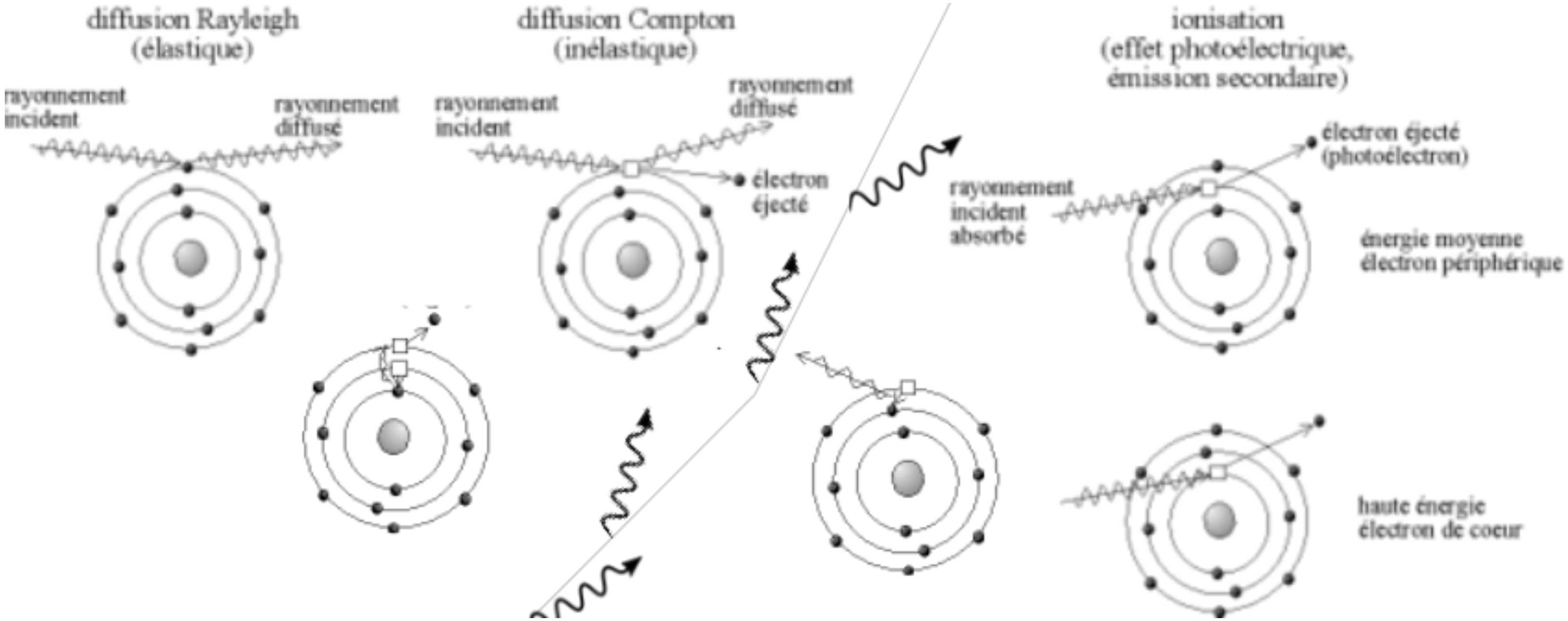


For a given B and P
the black track corresponds
to a heavier object than blue track.
So the red track correspond to an intermediate
mass object

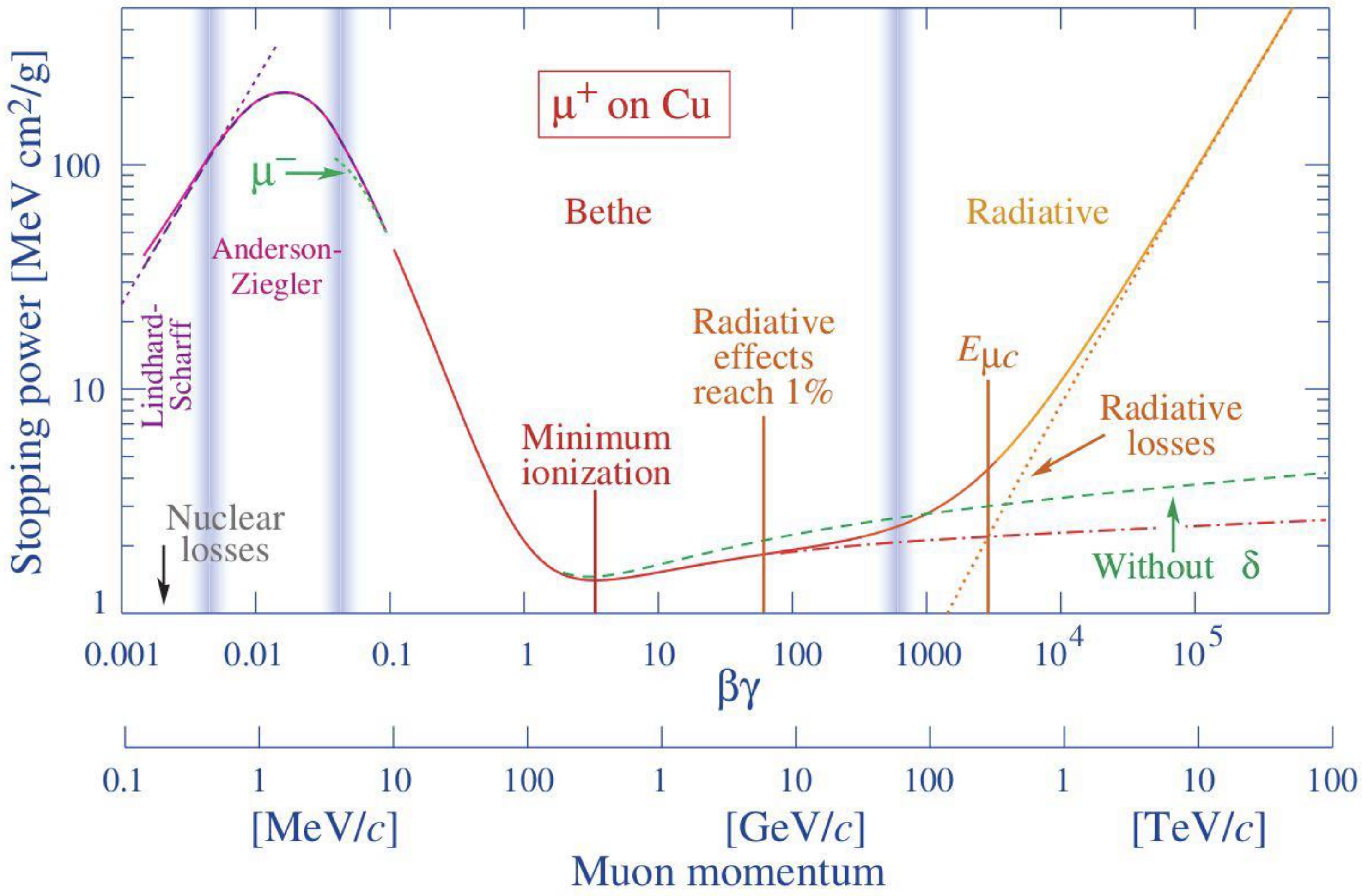
Example:proton,muon,electron

How do muons interact

- In reality, many different processes contribute

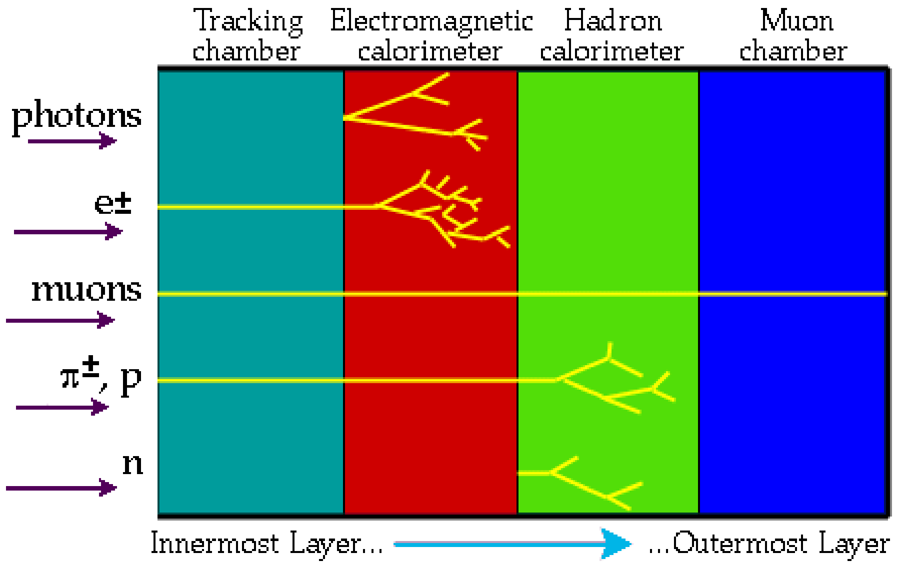


Muon interaction with material



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

Introduction

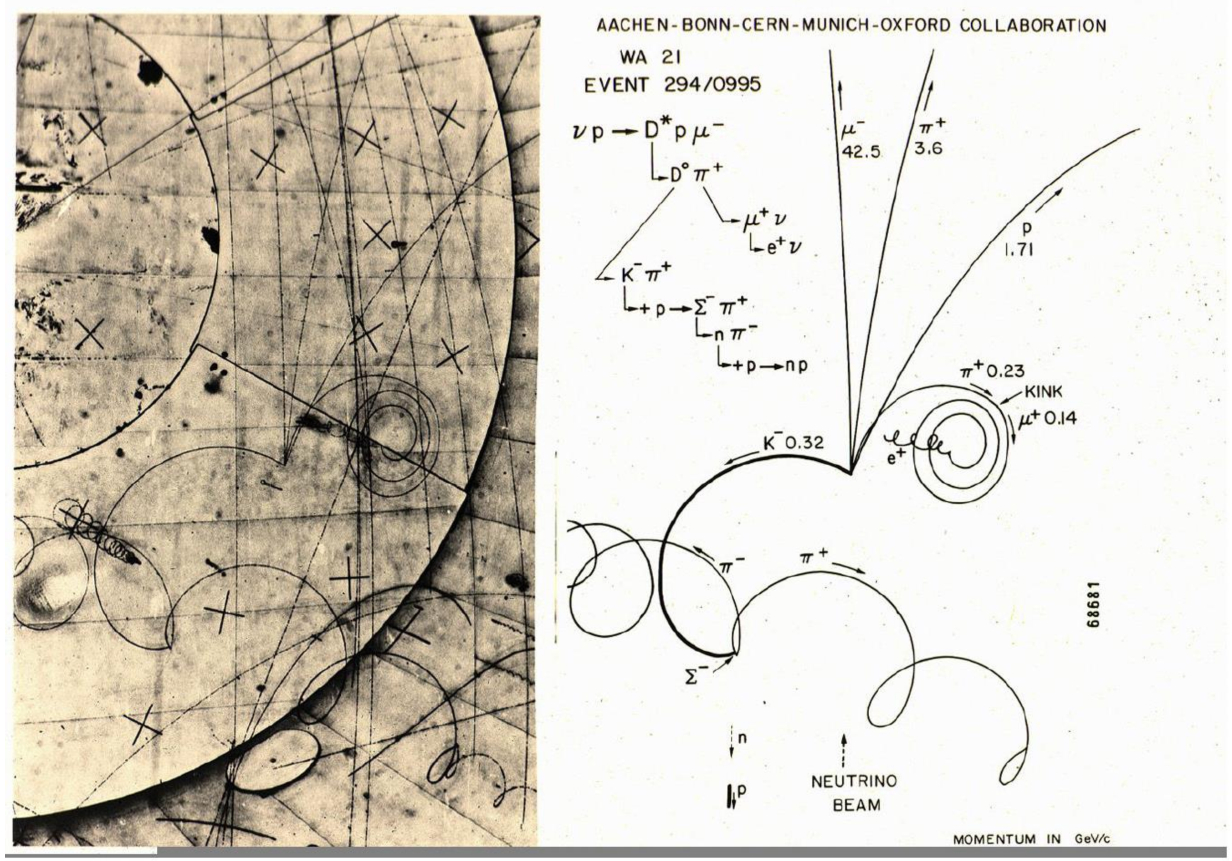


- How to select the interest muon tracks
  - Muon spectrometer
    - Magnets
    - Trackers
- How to optimize the parameters of muon spectrometer
  - Efficiency
  - Radiation hardness
  - Long term stability
  - Costs

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)



analogical

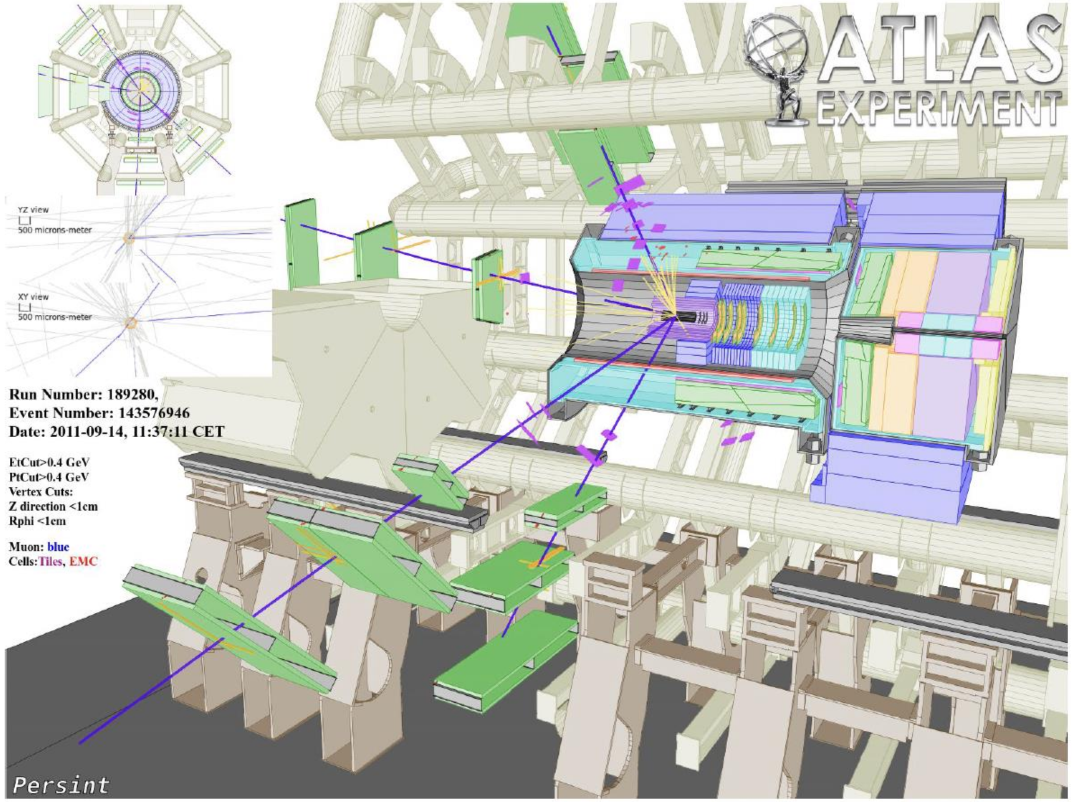
Bubble chambers

Detectors

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

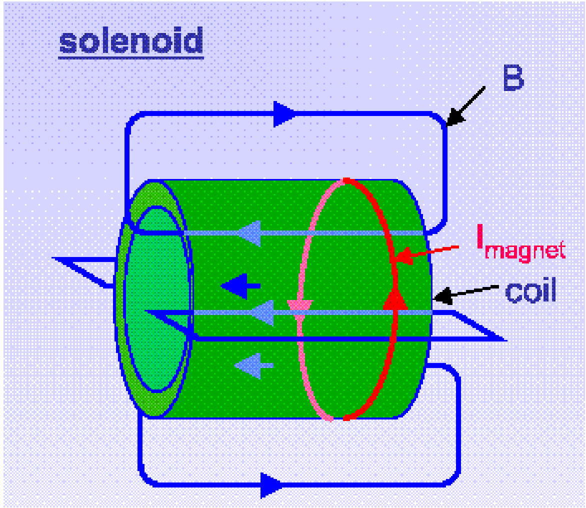
- -different types of particles,
- -different way to interact with matter,
- -fast detectors,
- -precise detectors (spatially)
- -...

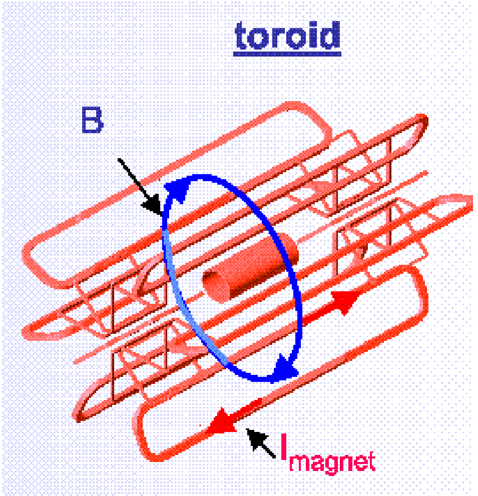
One big detectors is made by many sub-detectors with precise tasks



numeric

Difference of 2 type magnetic fields

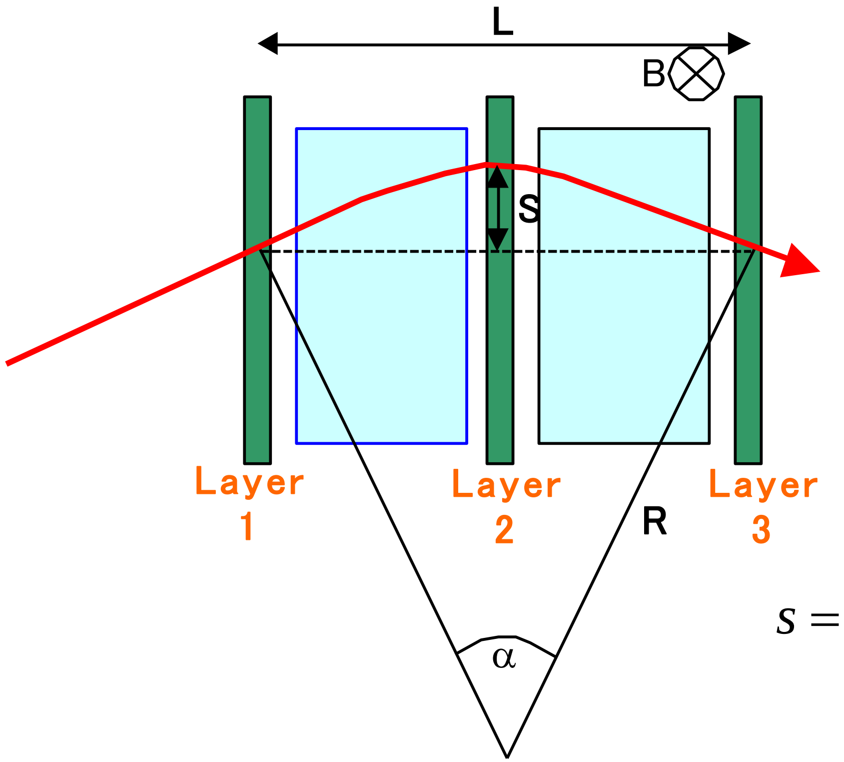




***Large Homogenous field inside coil**
***Weak opposite field in return yoke**
***Size limited**

***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

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

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

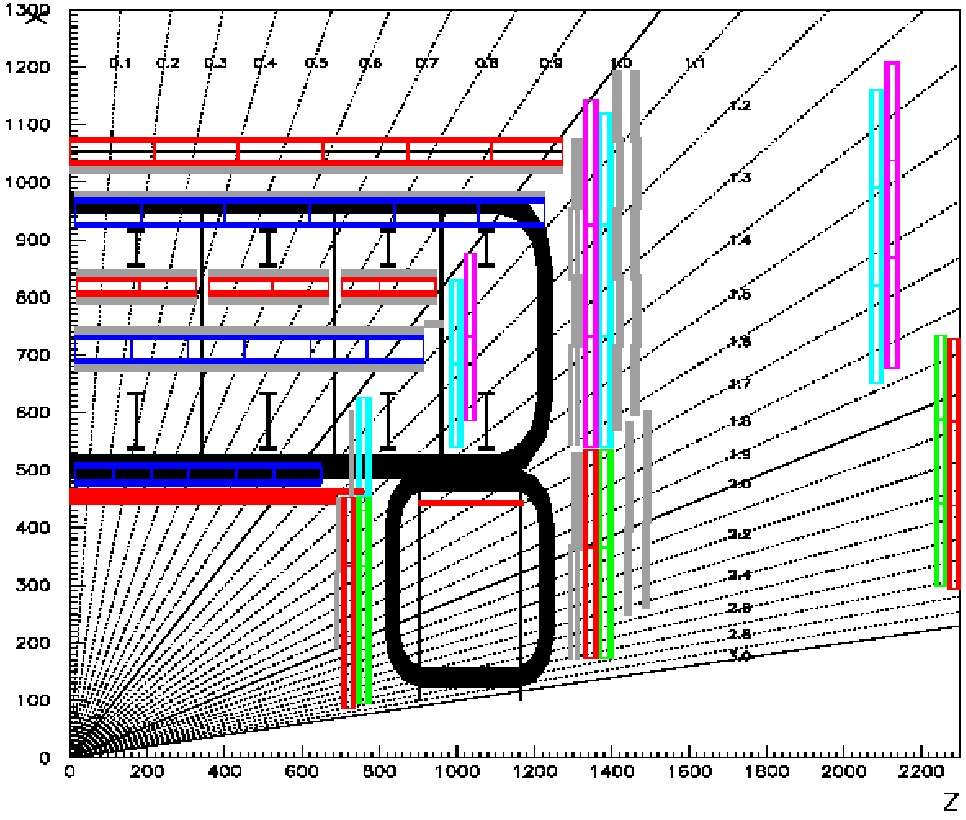
$$s = R(1-\cos(\frac{\alpha}{2})) \approx R\frac{\alpha^2}{8}\frac{L^2B}{Pt}$$

Position resolution σ(x) for each

$$s = x2 - \frac{x1+x3}{2}$$

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

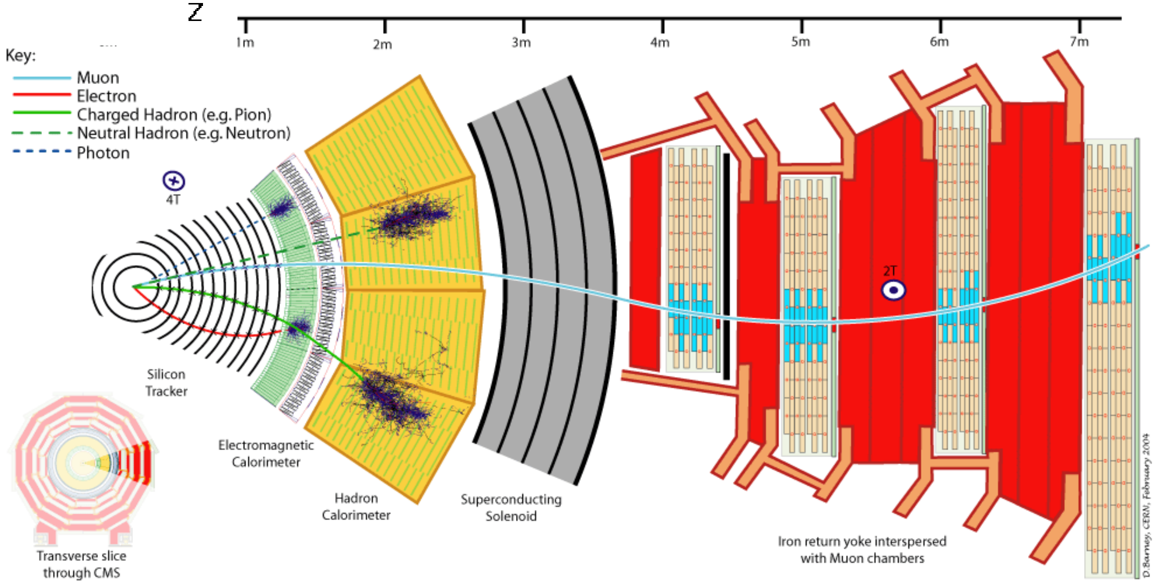
Pt resolution depends on B, L and σ(x) (not R)!



6m ← ATLAS：Troidal magnetic field

（y-z view)

3m



CMS: Solenoidal magnetic Field →

(r-ϕview)

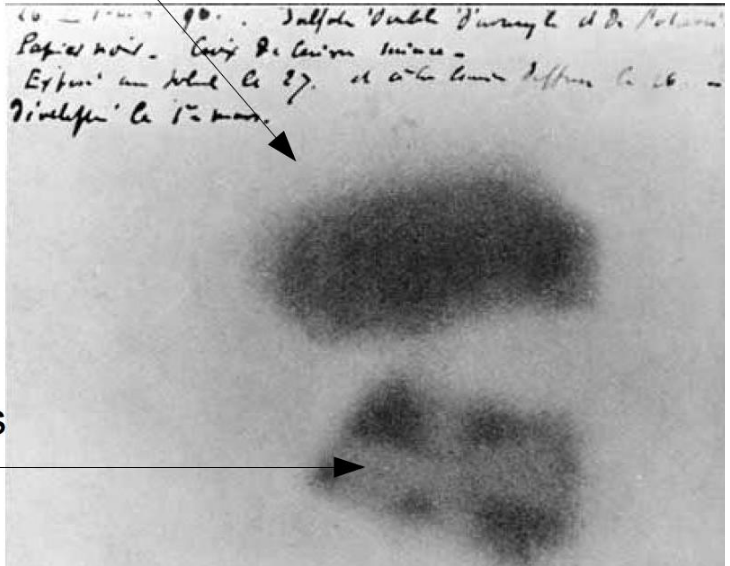
Detectors

Different types

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

Principle:Ionisation

image of a copper cross



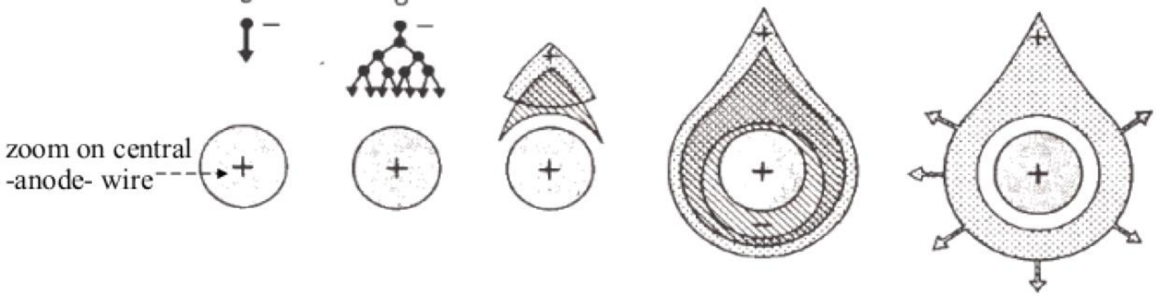
Antoine Henri Becquerel

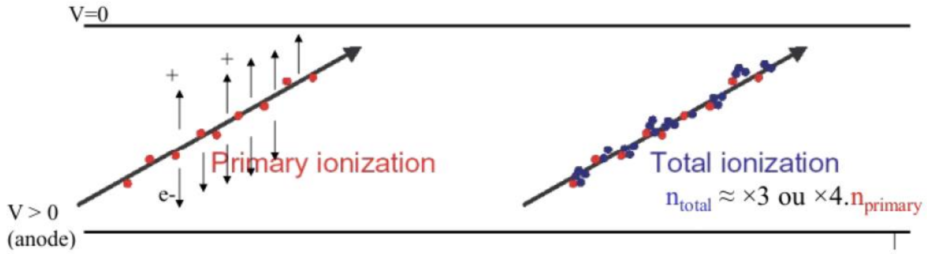
Detectors (Gaseous)

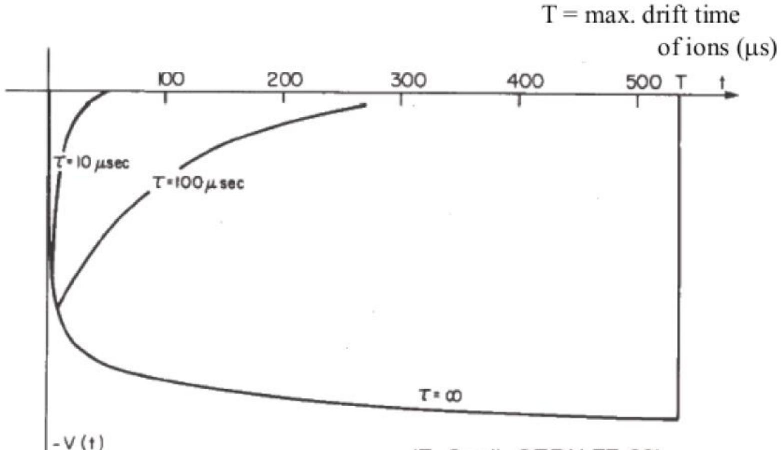
Principle:

- 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

(F. Sauli, CERN 77-09)





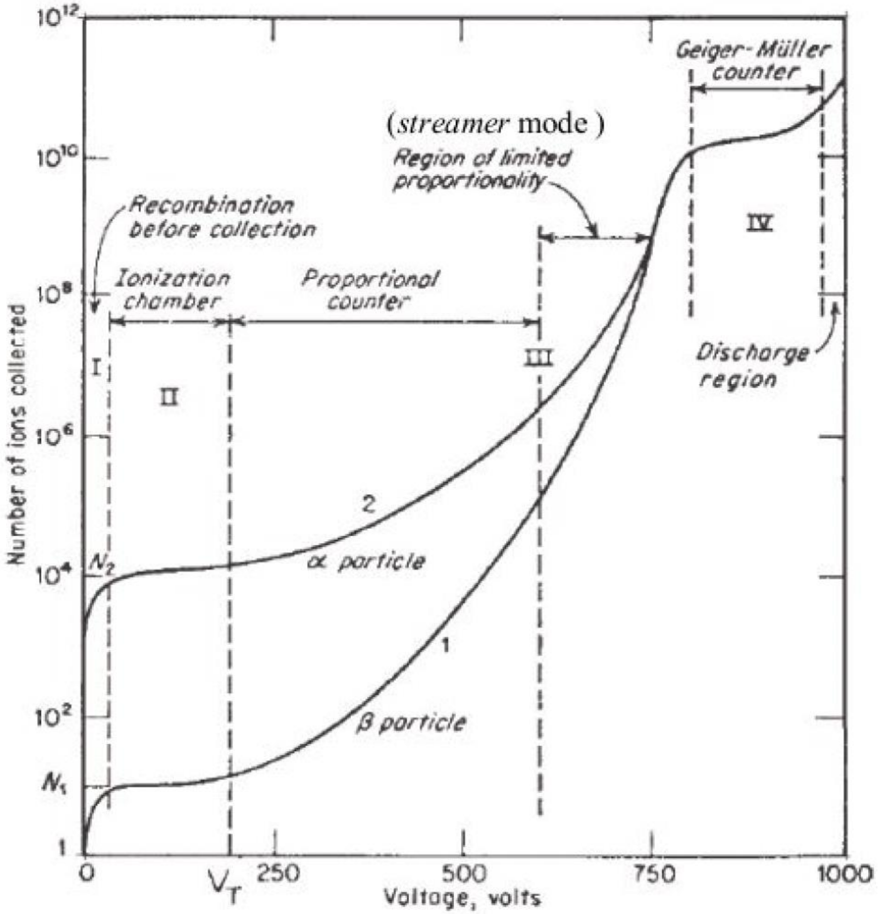


(F. Sauli, CERN 77-09)

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” (CH_4,CO_2,...)
- IV Geiger-Muller mode

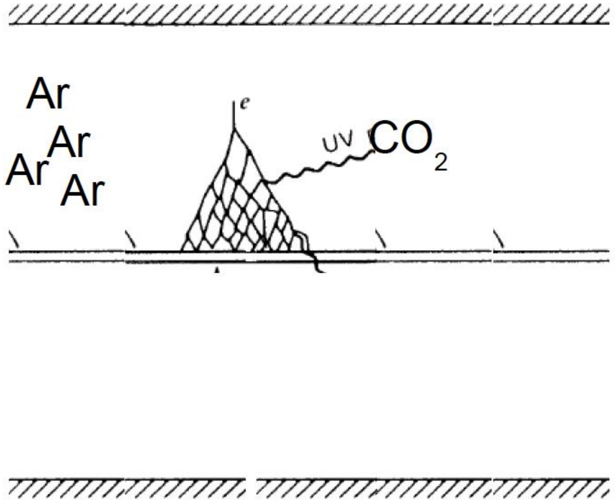


Remark: no electric field => no electrons acceleration: recombination

Detectors (Gaseous)

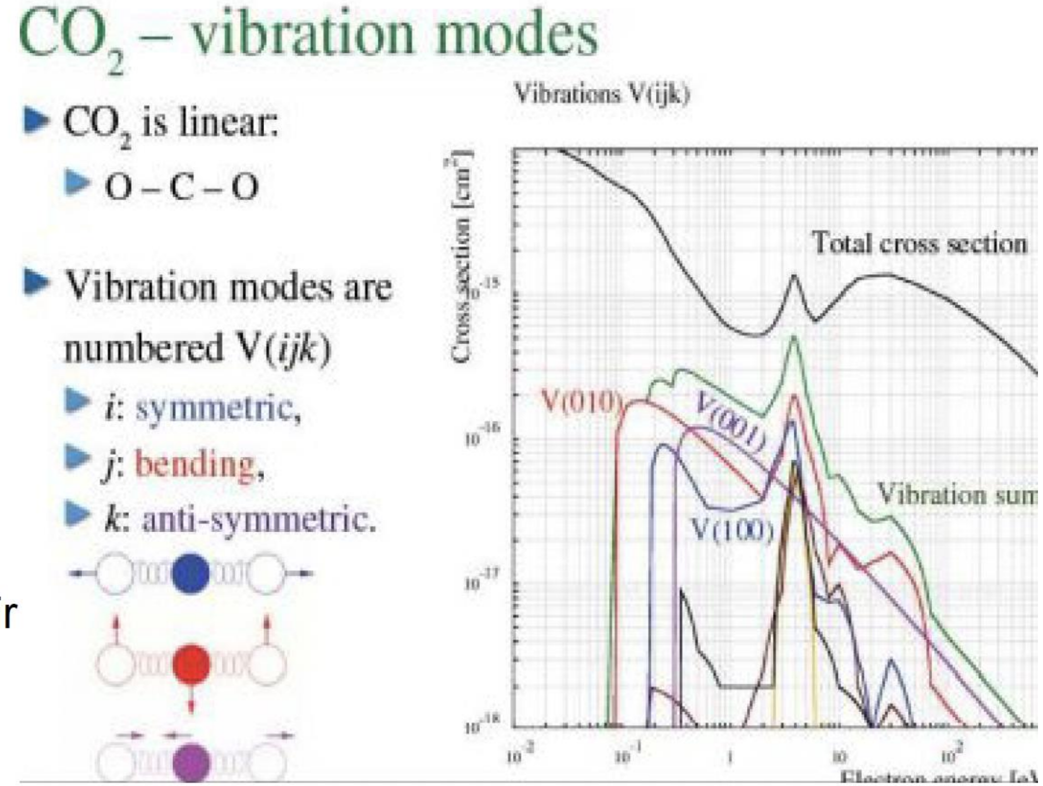
Spatial Resolution

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



"Quencher"

- Polyatomic gaseous:
  - ex: CH_4,C_4H_{10},CO_2
- Photons absorption by vibration or molecule rotation
- No easy solution: should be tested
  - Ex: 70%Ar, 29.6%C_4H_{10} , 0.4% Fr



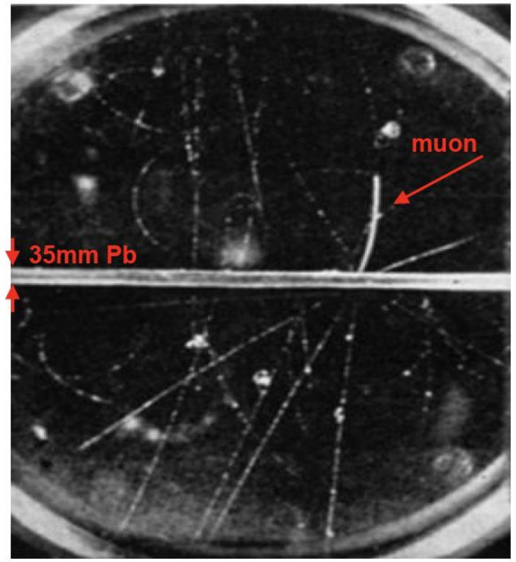
R.Veenhof (Garfield) http://cern.ch/garfieldpp

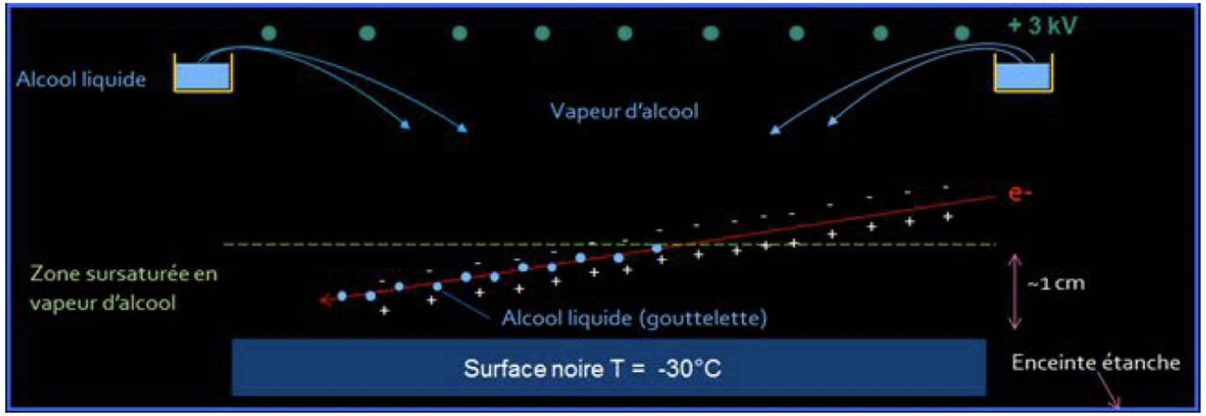
Detectors

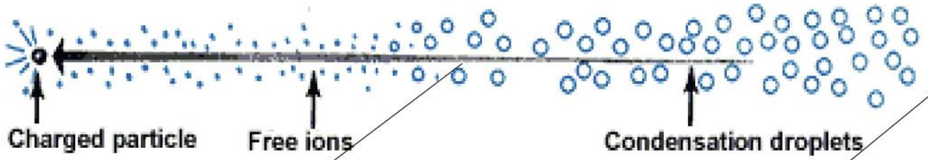
Clouds Chamber: Gaseous/Liquid

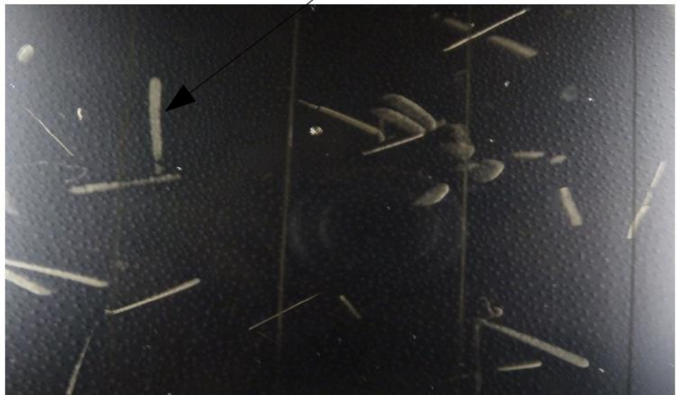
- C.T. R. Wilson 1911
- C.Anderson positron discovery 1932

Muon discovery 1936

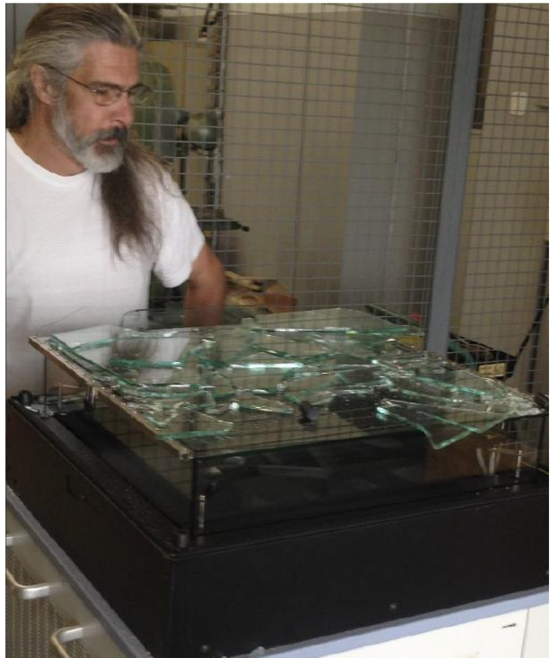








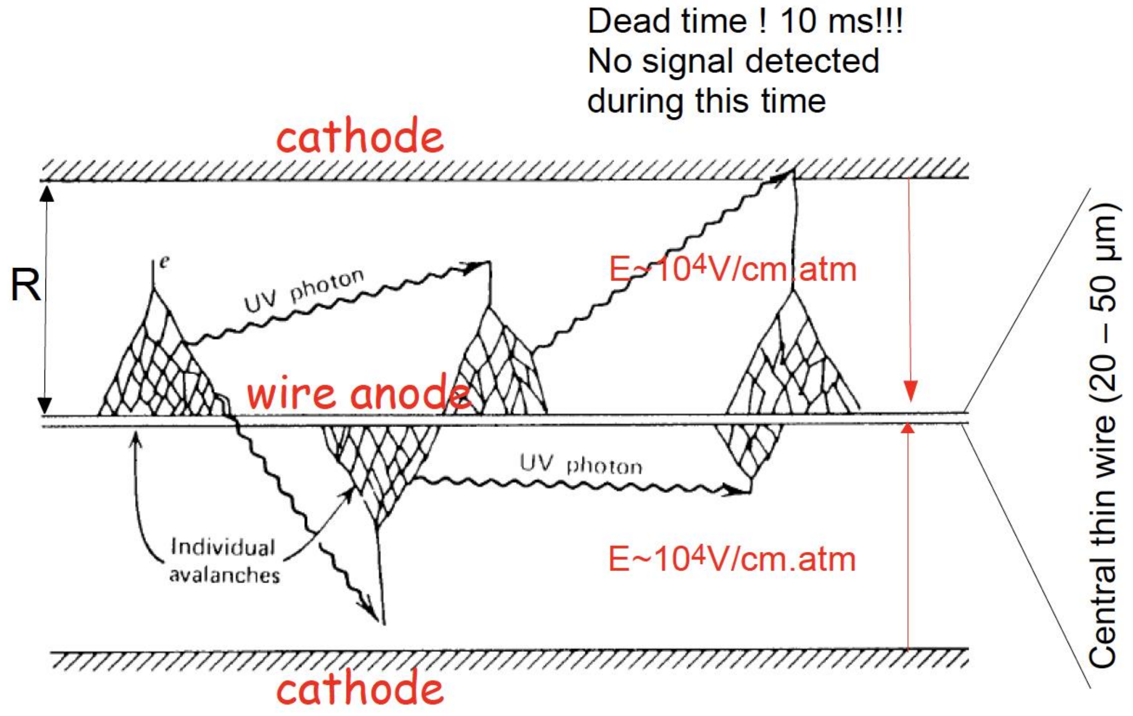
Broken cloud chamber
Physicist sad!



Detectors(Gaseous)

Geiger Counter

- H.Geiger-Muller 1928
  - Detection: Alpha(He), Beta (e+/e-), Gamma(photon), Muons
  - Gaseous: He, Ne, Ag
  - Avalanche: $n = n_0 e^{\alpha(E)x}$ (α 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

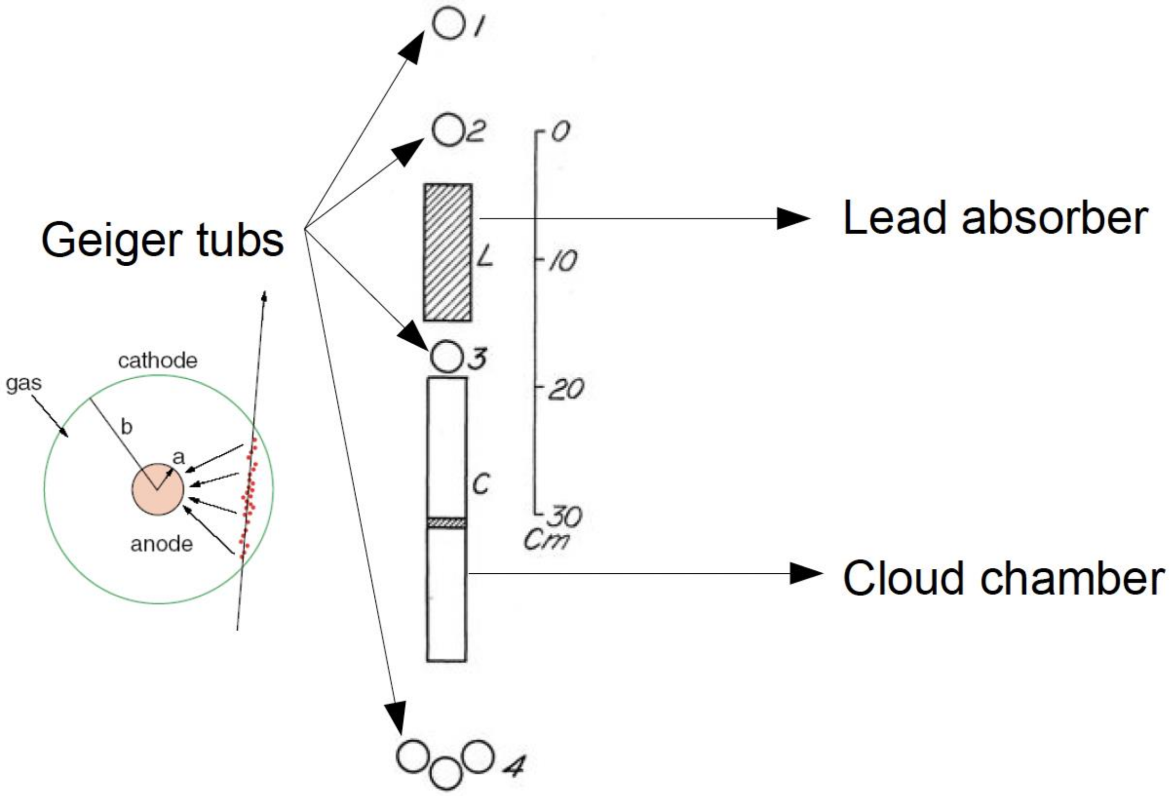
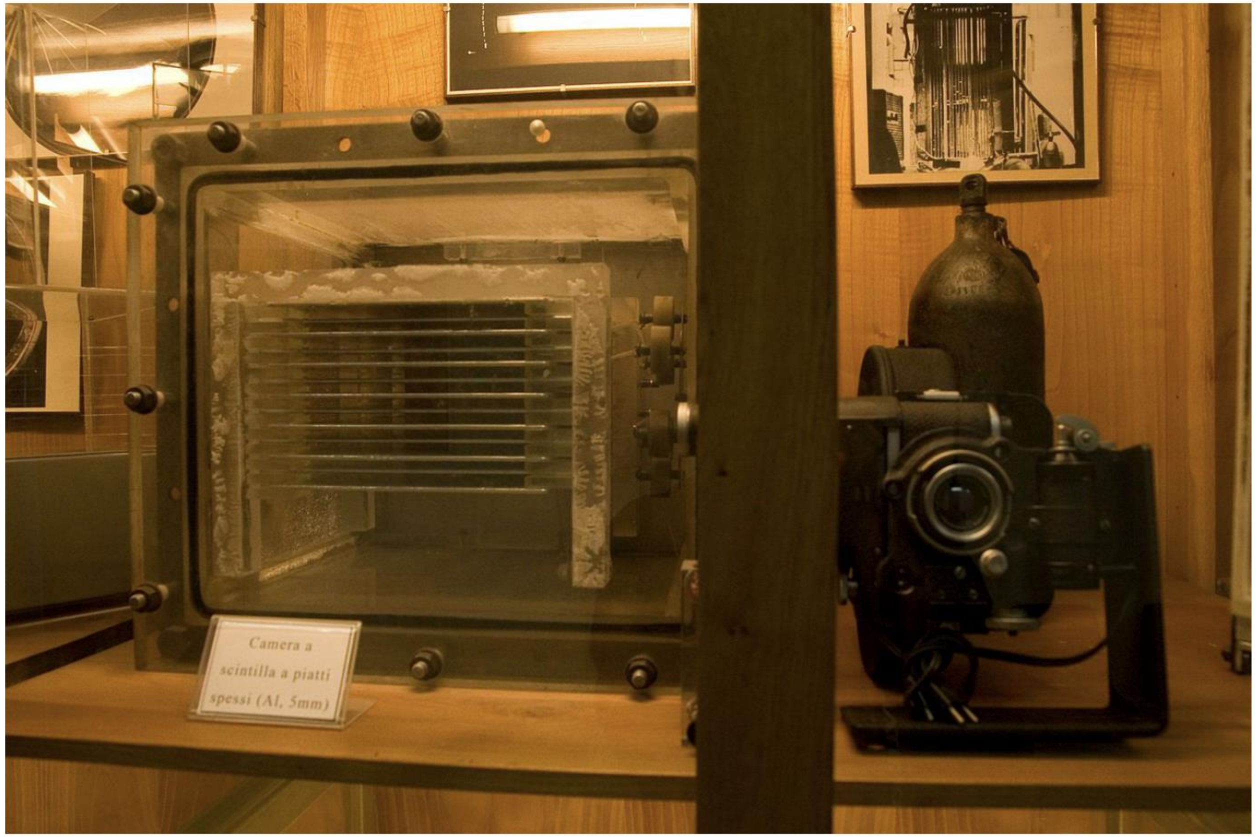


FIG. 1. Geometrical arrangement of apparatus.

Detectors(Gaseous)

Spark Chambers

- Pairs of metal plates are connected to a HV ~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.



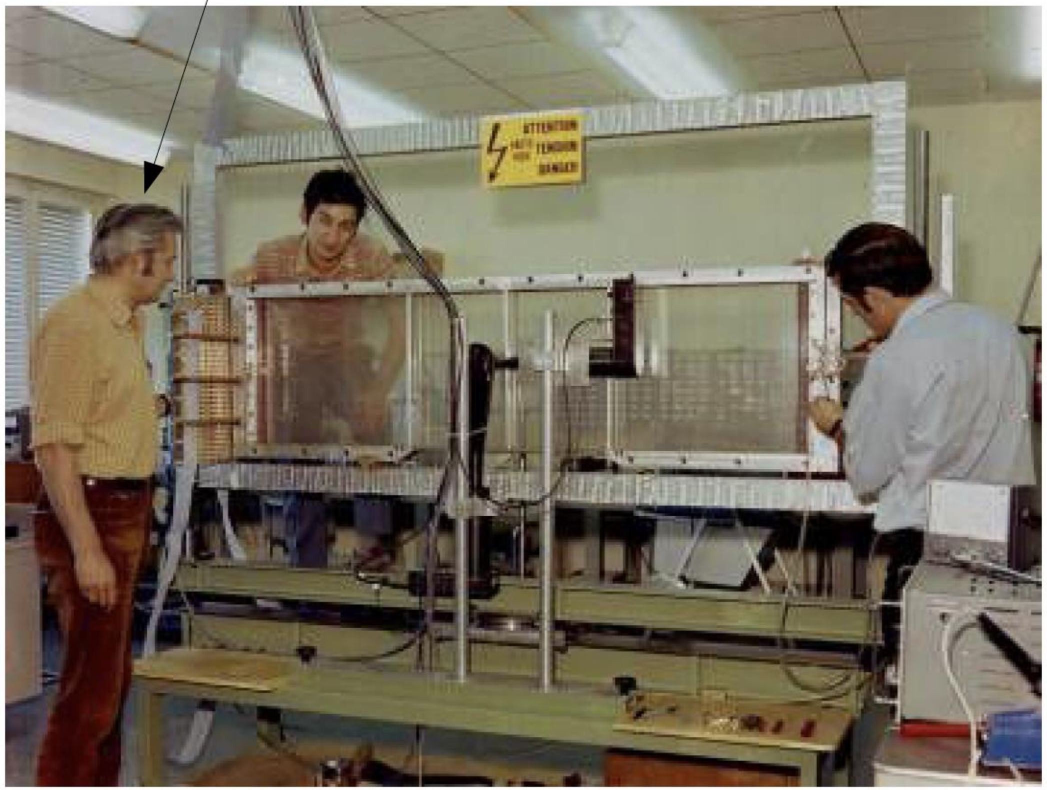
A spark chamber at the physics museum of the Sapienza University of Rome

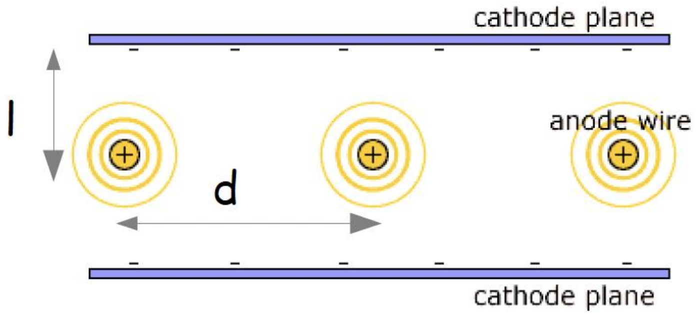
Remark:
HV applied 0,1 s à 1 μs
to avoid saturation

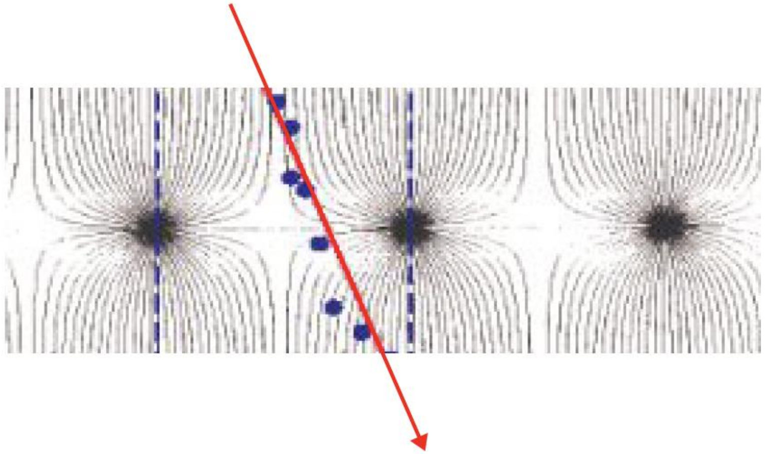
Detectors(Gaseous)

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~5mm, d~1mm, E~50 V/mm



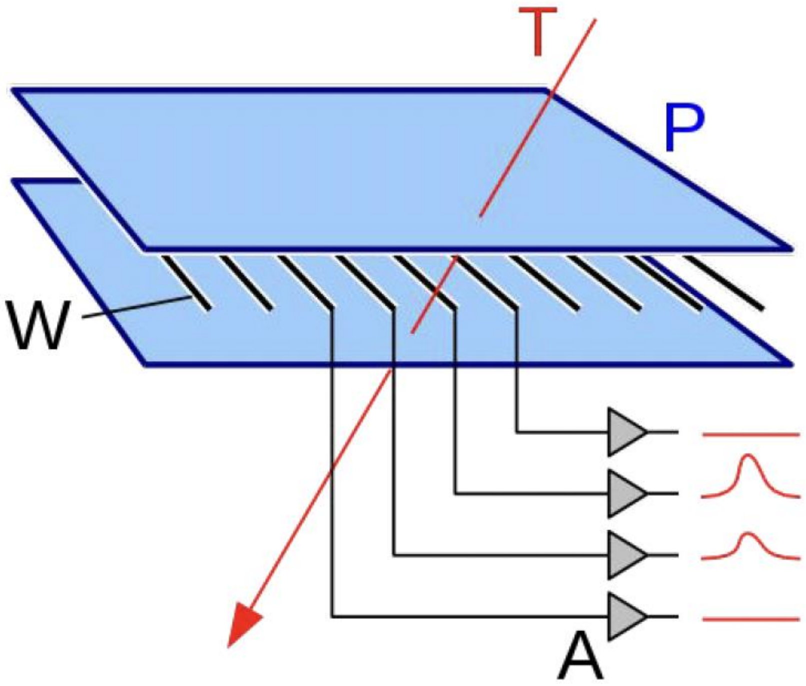




Detectors(Gaseous)

Wires Chamber

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



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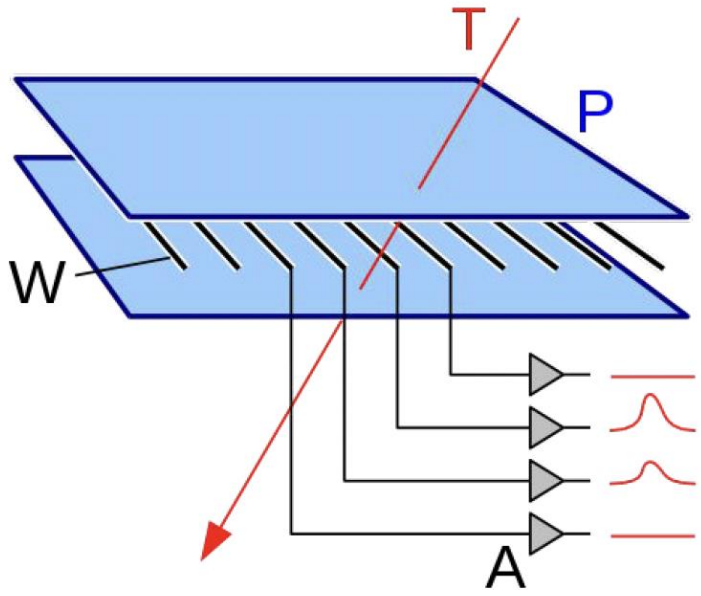
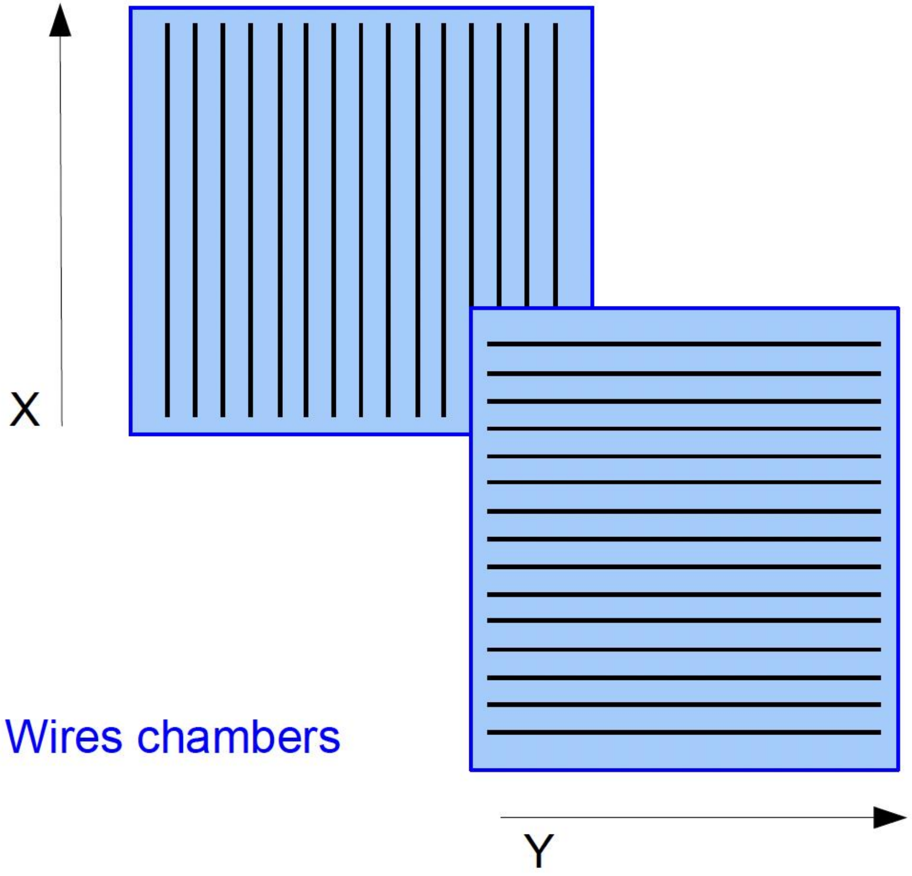


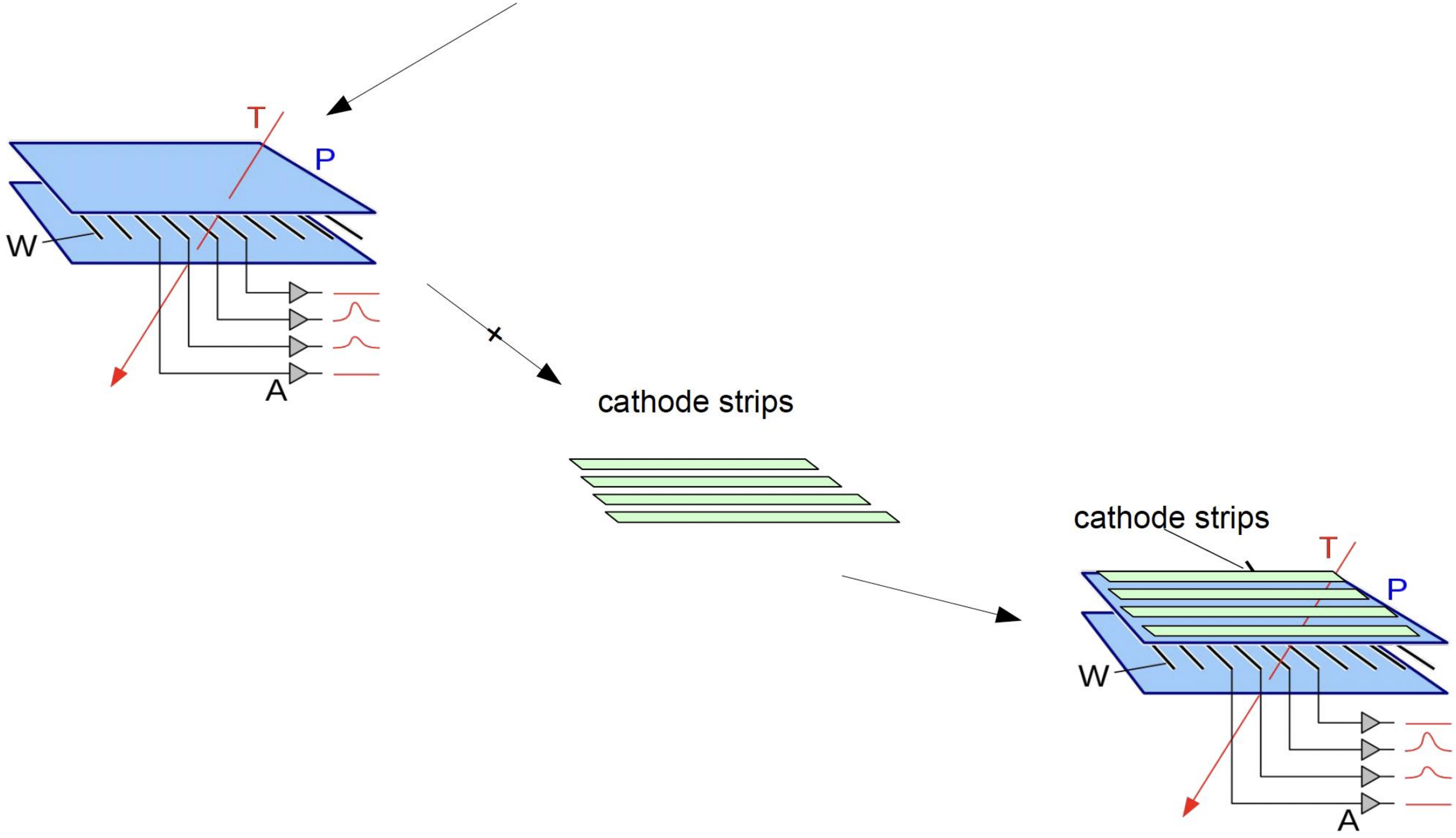


To get the second coordinate: 2 Wires chambers

Detectors(Gaseous)

TGC*

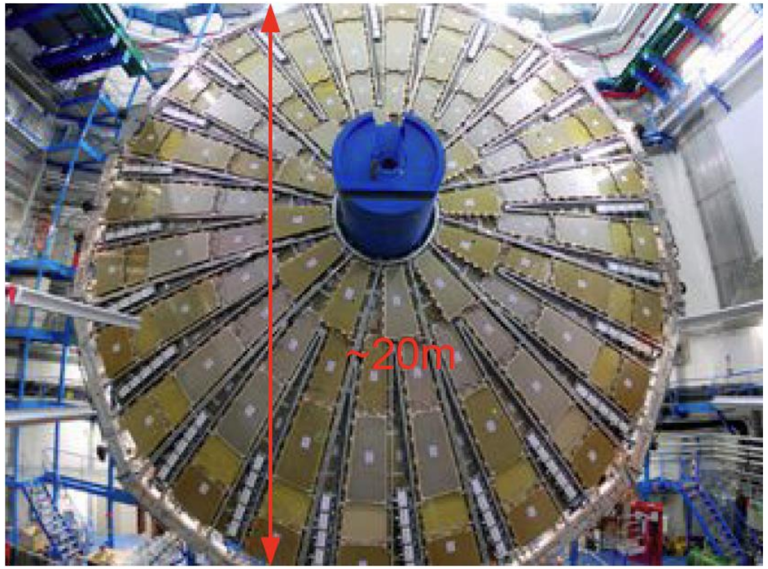
- Thin Gap Chamber
  - Go back to MWPC

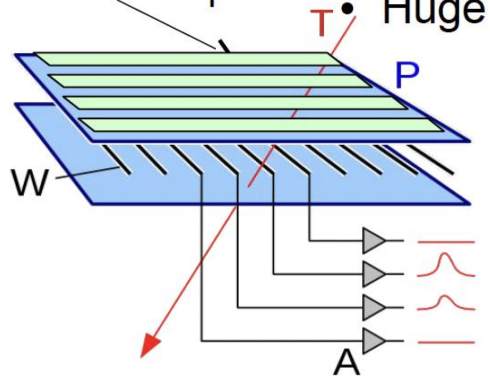


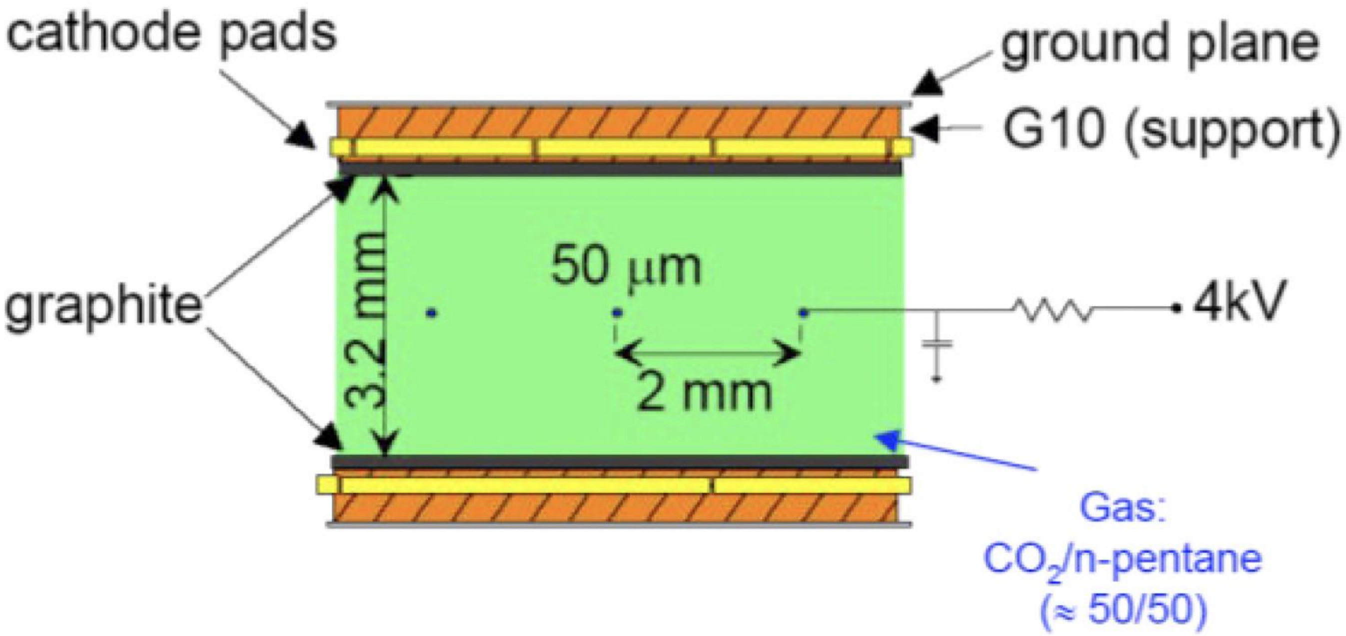
Detectors(Gaseous)

TGC*

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



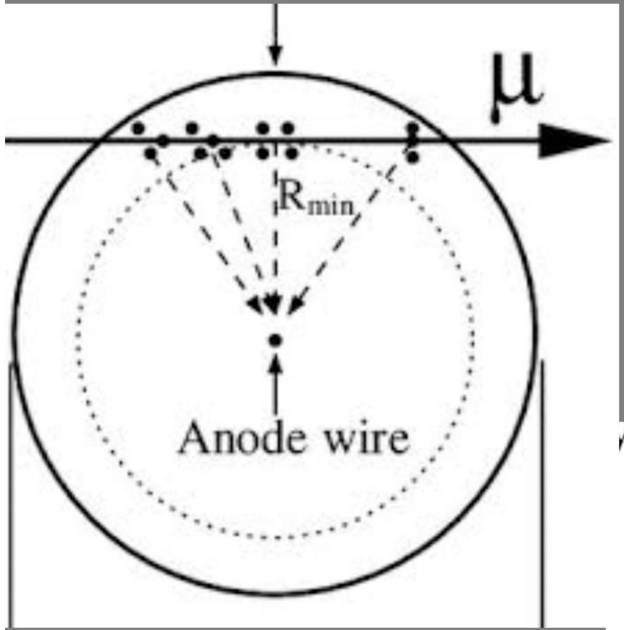




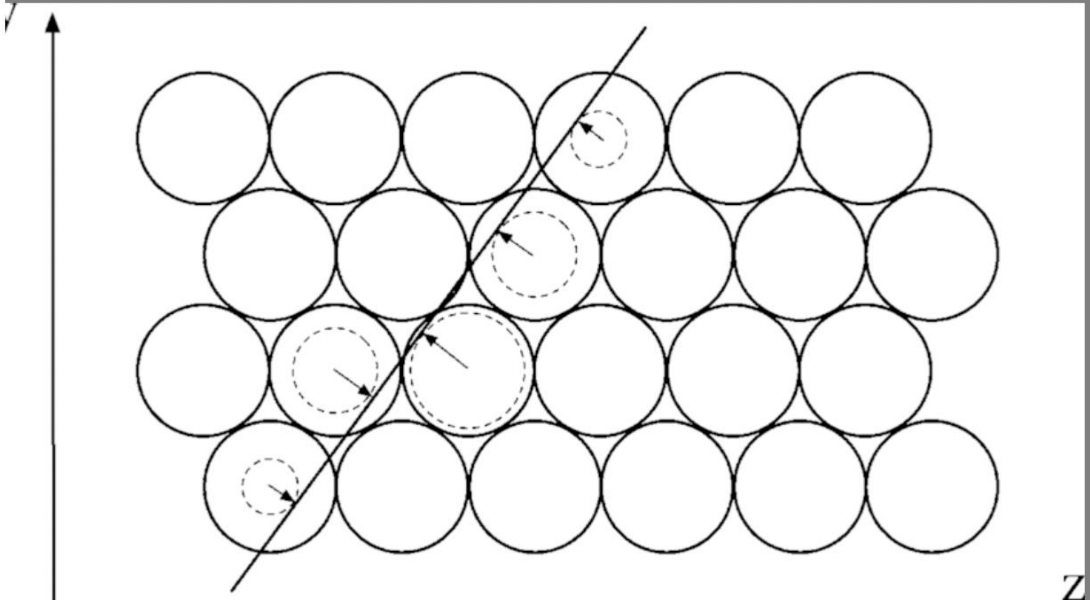
TGC used in ATLAS
for muon trigger

Monitored drift tubes

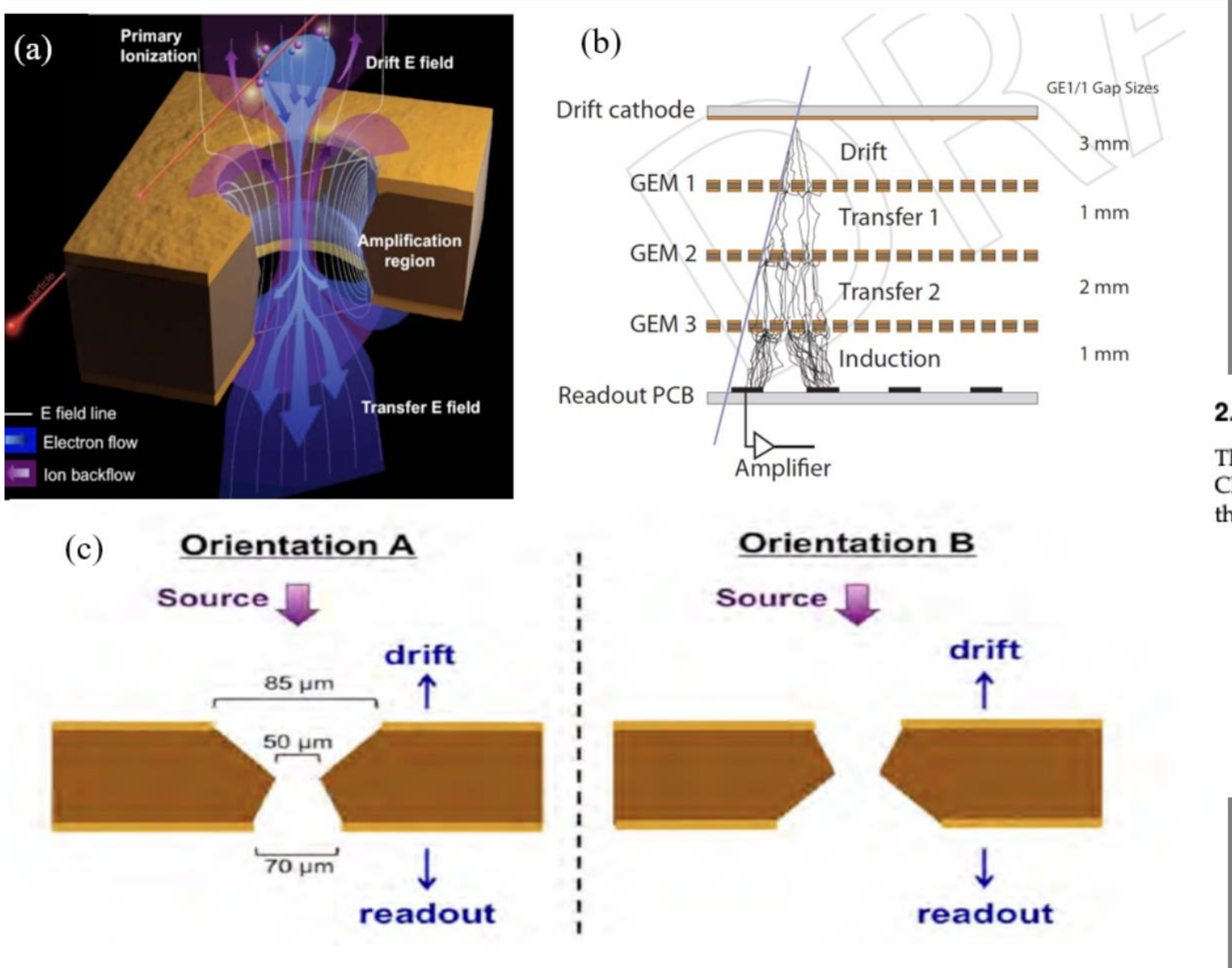
r=1.5cm. 700 ns drift time. AR-Ethane 93-7. 80μ resolution



Beam cross every 25ns.



GEM: CMS Muons



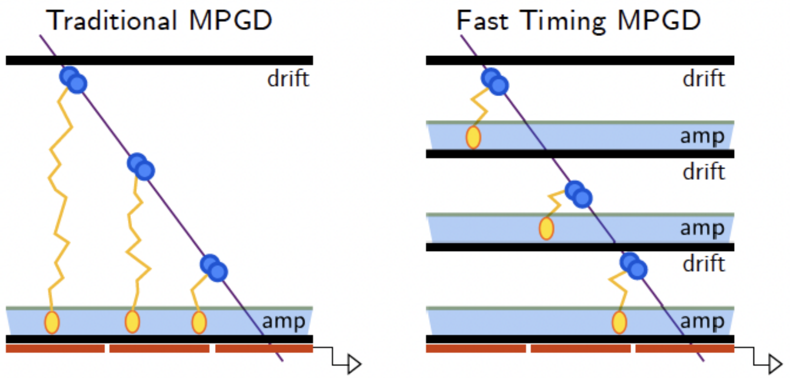
Many stages - each with modest gain

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^2 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 ~10s of picoseconds
  - Improved radiation hardness
  - Integrated readout/trigger (improve bandwidth constrains)