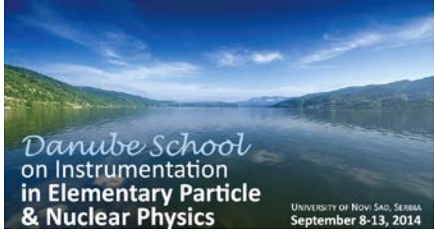
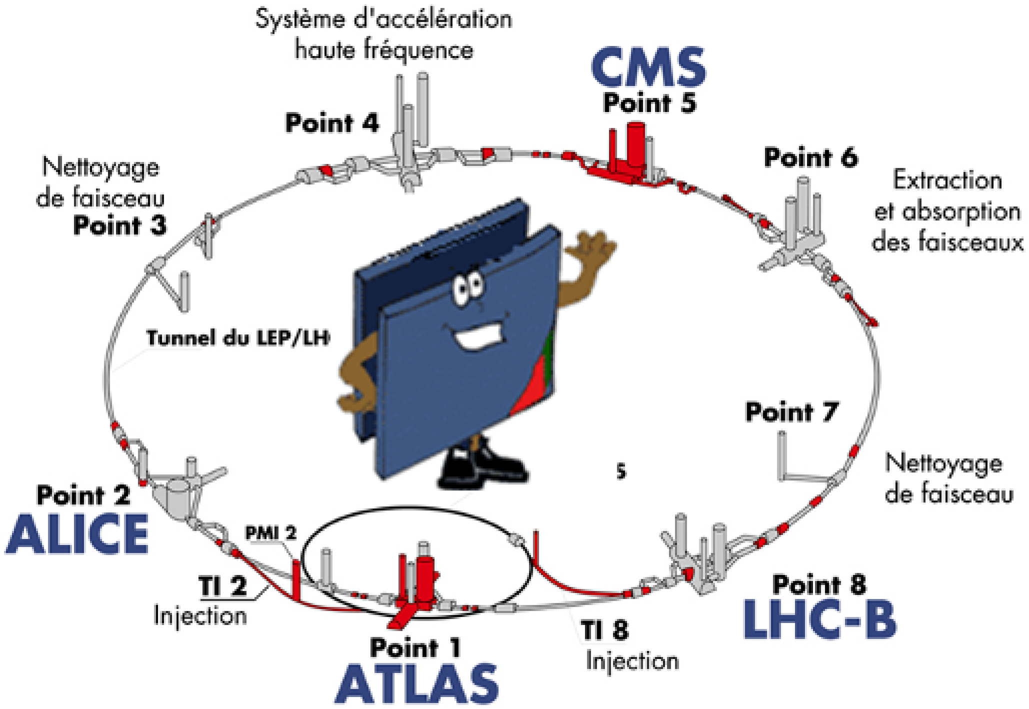
CERN | PH-DT
Detector Technologies



The Resistive Plate Chamber detectors at the Large Hadron Collider experiments

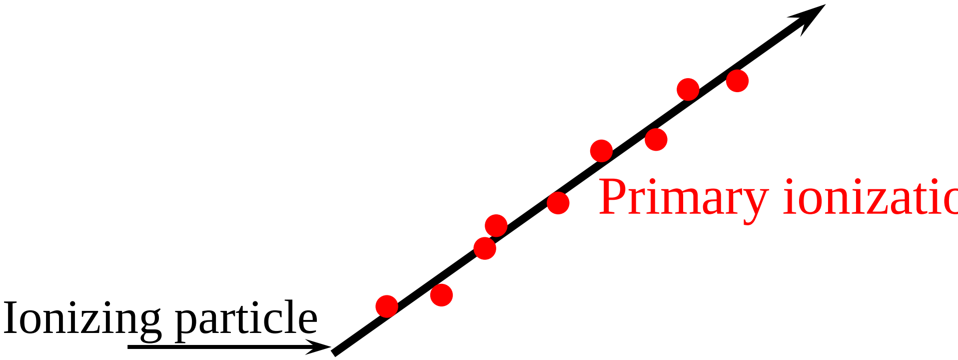


Roberto Guida   PH-DT-DI   Danube School, September 8-13, 2014 – Novi Sad

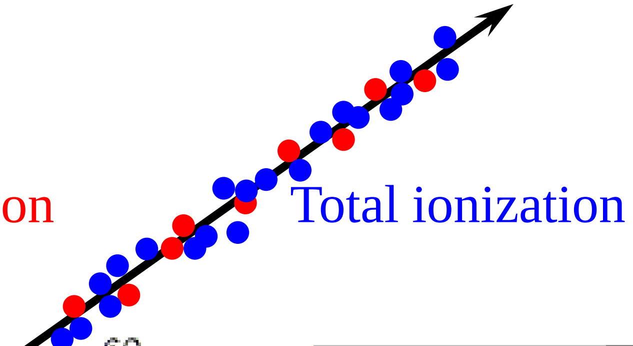
Ionization chambers

Ionizing particles are producing primary ionization (free electrons and ions)

Few primary electrons can gain enough energy to produce further ionization



Primary ionization



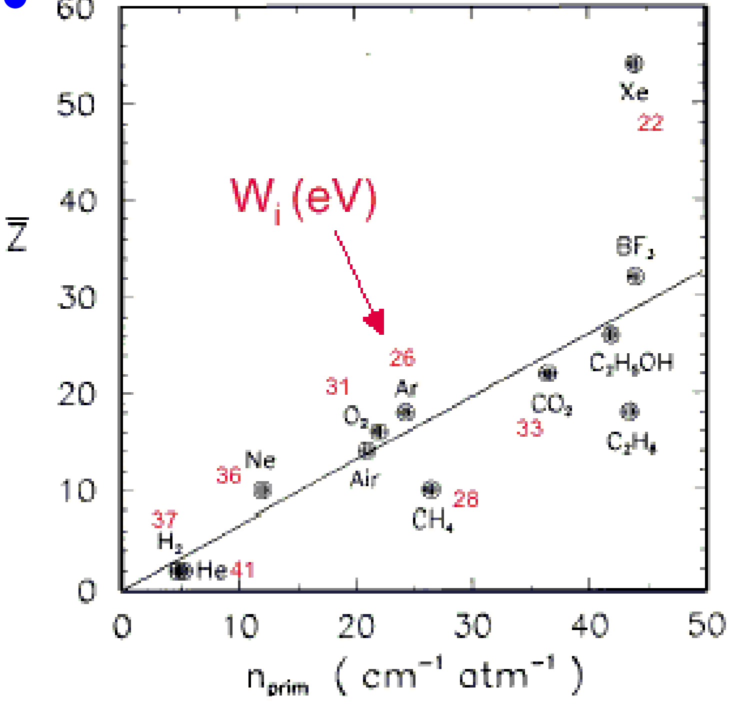
Total ionization

n_{total}: total number e^-/Ion

ΔE: total energy loss

W_i: <energy loss>/(total number e^-/Ion)

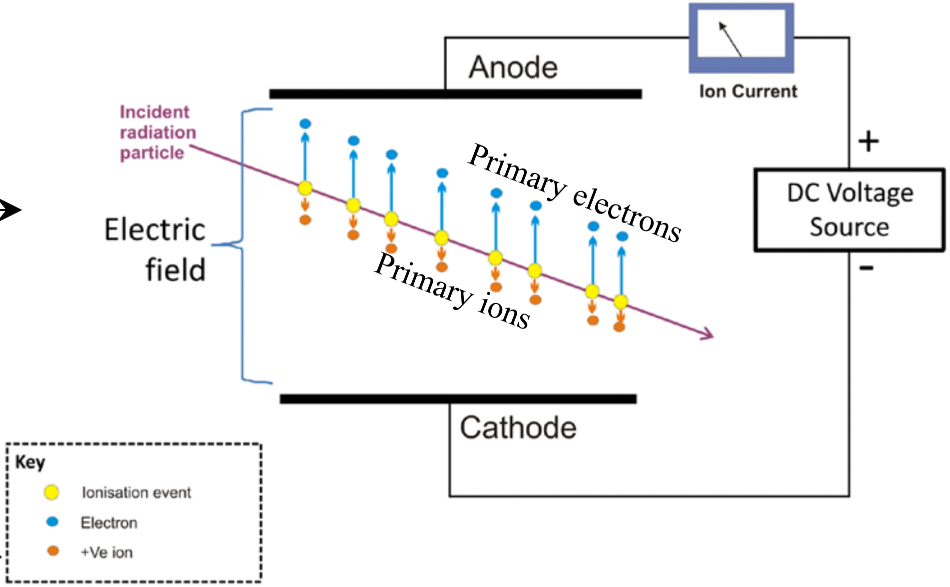
$$n_{total} = \frac{\Delta E}{W_i} = \frac{\frac{dE}{dx}\Delta x}{W_i}$$

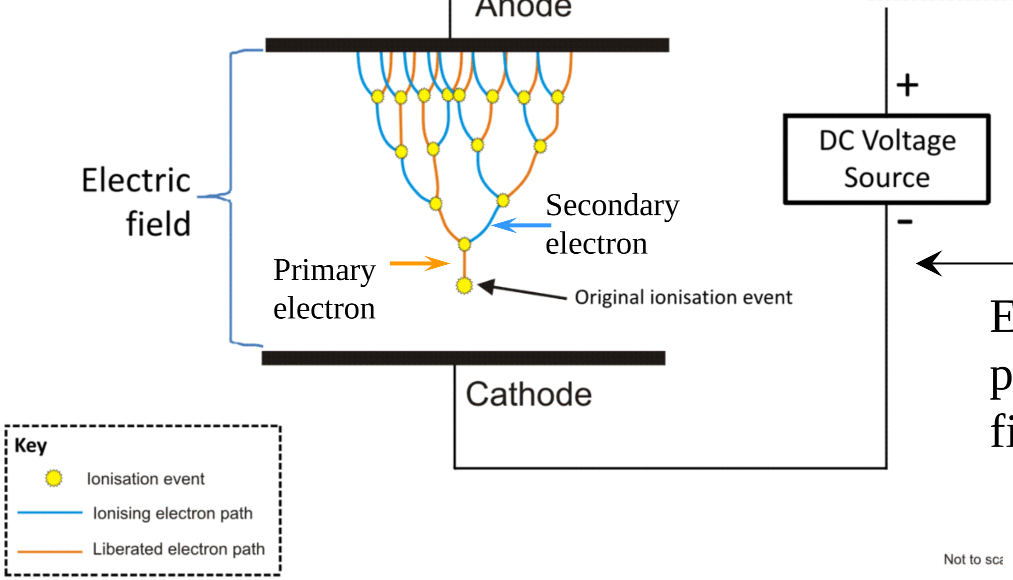


Ionization chambers

Gases for particle detectors

Primary ions/electrons start drifting under the effect of the applied electric field





Electrons can gain enough energy to produce secondary ionization and finally electron avalanche

Ionization chambers

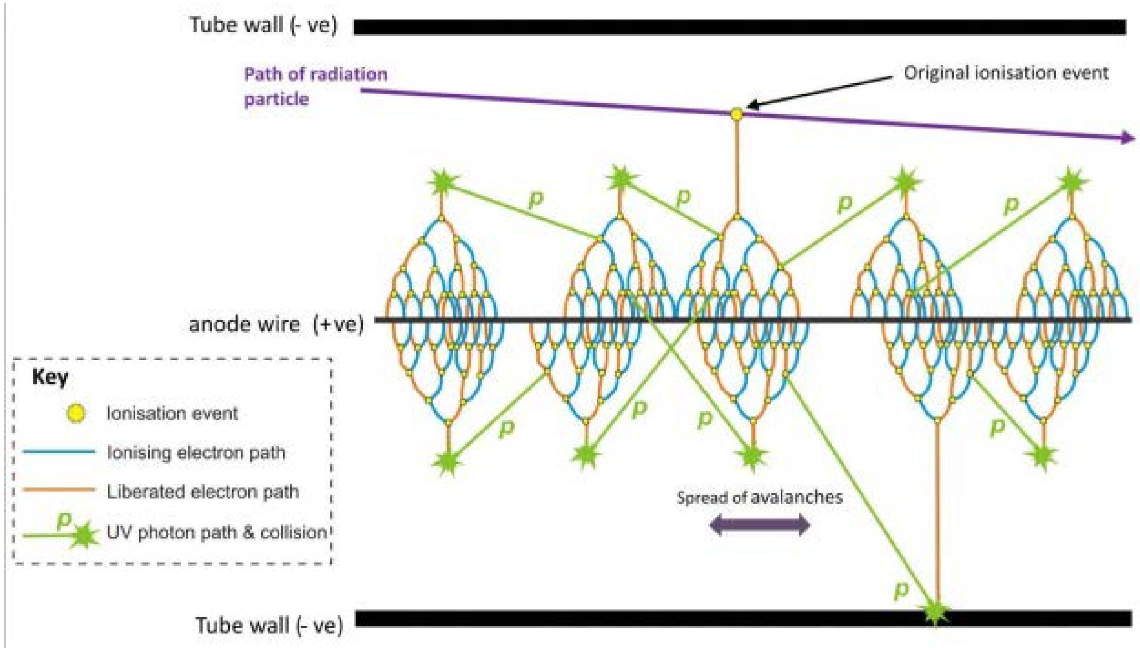
Gases for particle detectors

The ionization process depends strongly on the gas type

- Air is not a good medium ☹
- Right mixture can be quite complex and difficult to find

Typical gas mixture components:

- Bulk gas: Argon – common, not toxic, …
- quenching gas added for stability (photons absorption): CO_2, CH_4, iC_4H_{10}, …
- Others: CF_4, SF_6, …



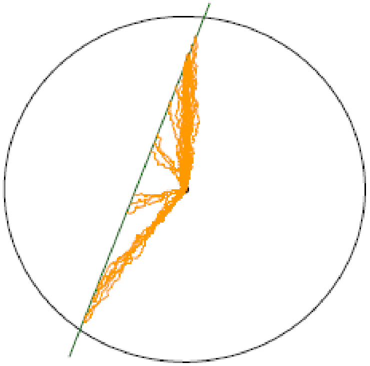
Process is affected even by presence of very low concentration of impurities

Ionization chambers

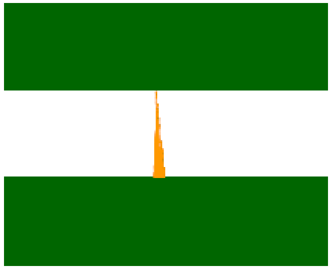
Particle detectors

- Several applications
- Different geometries, gas mixtures, combination of effects, …

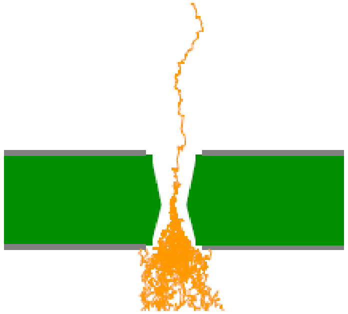
- drift tube



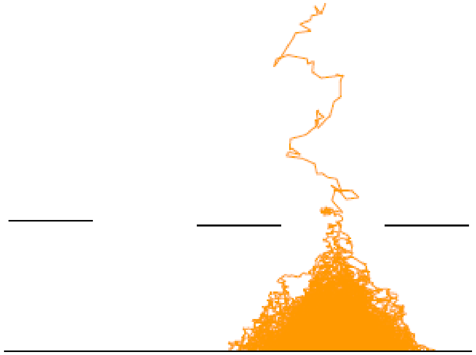
- RPC



- GEM



- Micromegas/InGrid



RPC from prototypes to large systems

1949: Keuffel → first Parallel Plate Chamber

1955: Conversi used the "PPC idea" in the construction of the flash chambers

1980: Pestov → Planar Spark chambers – one electrode is resistive – the discharge is localised

1981: Santonico → development of Resistive Plate Chamber – both electrode are resistive

RPC applications:

'85: Nadir (n-n\bar oscillation) – 120 m^2 (Triga Mark II – Pavia)
'90: Fenice (J/Ψ → n-n\bar) – 300 m^2 (Adone – Frascati)
'90: WA92 – 72 m^2 (CERN SPS)
'90: E771– 60 m^2; E831 – 60 m^2 (Fermilab)

1992: development of RPC for high particle rate → towards application at LHC

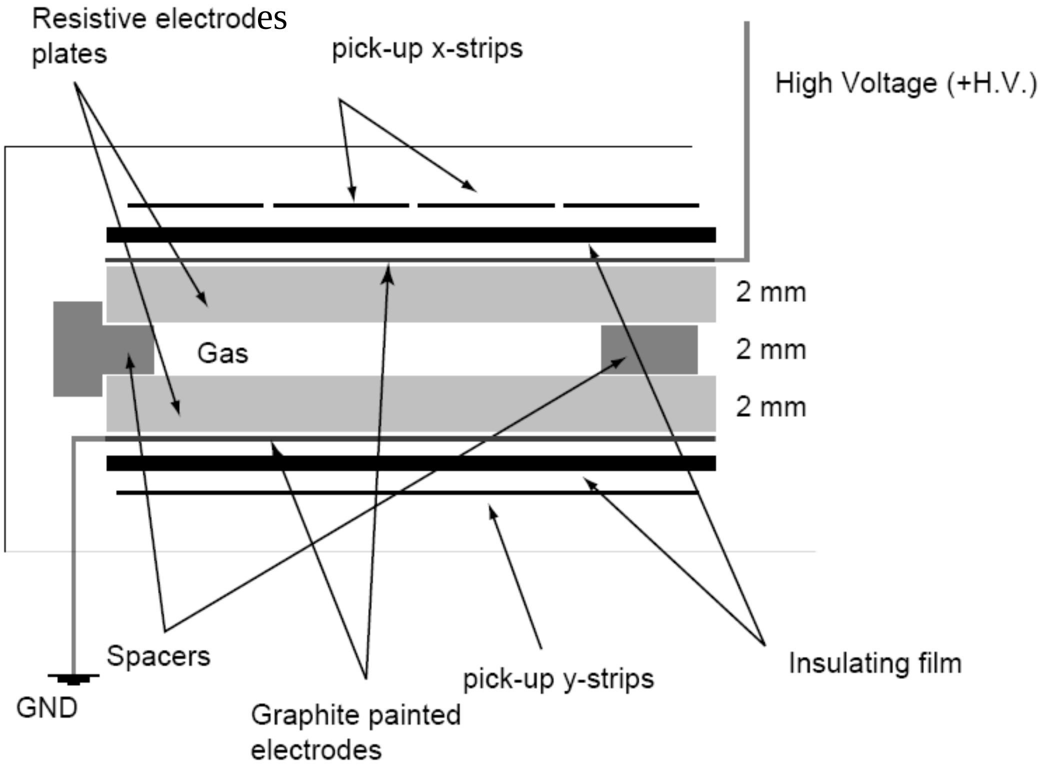
1994-1996: L3 – 300 m^2 (CERN-LEP)
1996-2002: BaBar – 2000 m^2 (SLAC)

Identikit of RPC detectors for LHC

RPC-Introduction

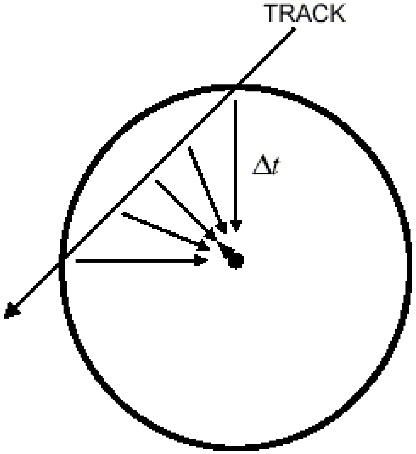
Basic parameter for a detector design:

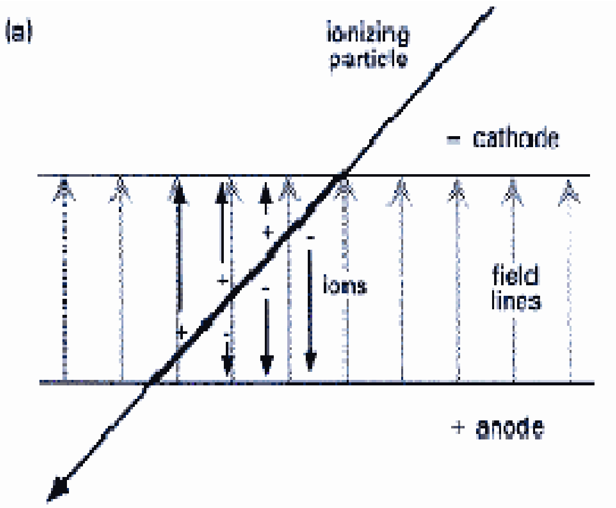
- Gap width
- Single gap/double gap/multi gap design
- Gas mixture
- Gas flow distribution
- Bakelite bulk resistivity
- Linseed oil electrode coating



Why RPC?

RPC-Introduction





Drift chambers (cylindrical geometry) have an important limitation:
Primary electrons have to drift close to the wire before the charge multiplication starts
→<u>limit in the time resolution ~ 0.1μs</u>
→<u>Not suitable for trigger at LHC</u>

+ In a parallel plate geometry the charge multiplication starts immediately (all the gas volume is active).
+ much better time resolution (~ 1 ns)
+ less expensive (~ 100 €/m^2)

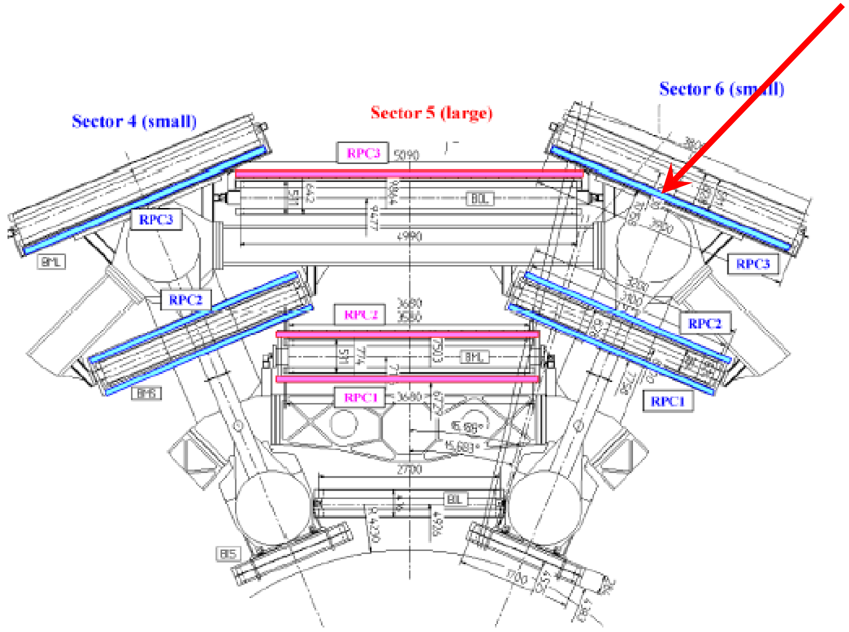
However:

-Smaller active volume
-Electrical discharge may start more easily
-Relatively expensive gas mixture
-Quite sensitive to environmental conditions (T and RH)

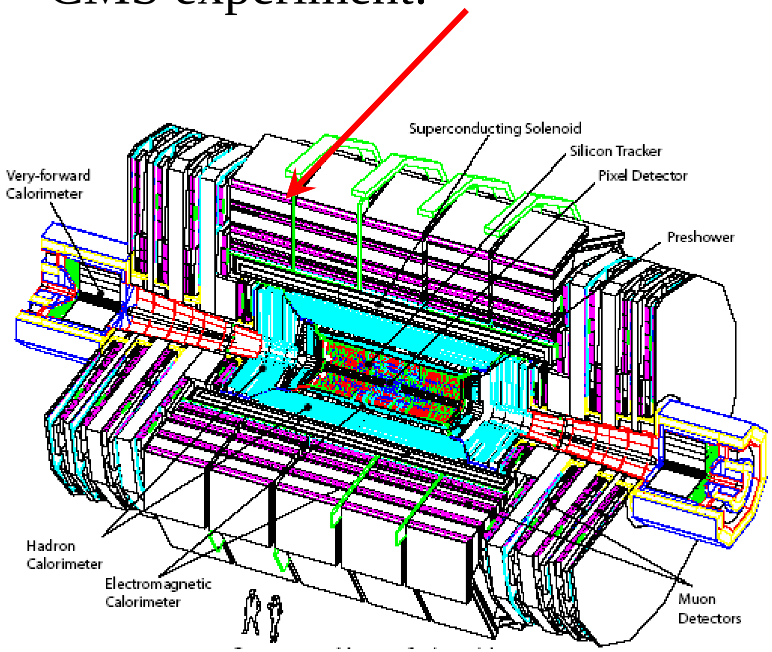
RPCs for LHC experiments

Where are the RPCs systems at LHC?

ATLAS experiment:



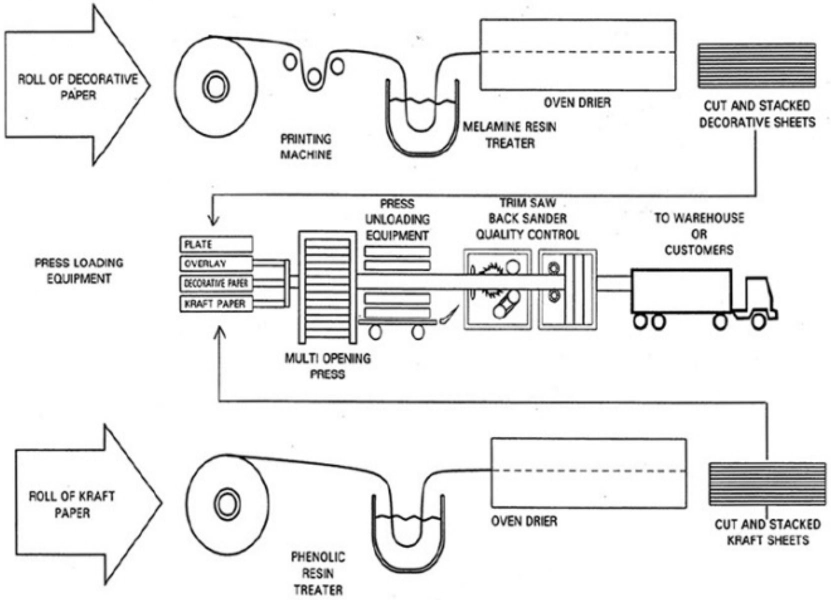
CMS experiment:

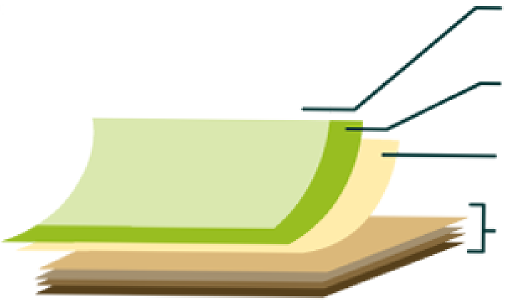


- Active surface 4000 m^2
- Gas Volume 16 m^3
- Expected rate ~ 10 Hz/cm^2

- 94.7% $C_2H_2F_4$; 5% iC_4H_{10}; 0.3 % SF_6
- 40% Relative humidity
- gas re-circulation systems

RPC electrodes: HPL





Overlay
Transparent melamine film
- For additional protection

Decor Paper
Plain colour or printed paper
- Melamine impregnated

Underlay
Only for plain colour
- Melamine impregnated

Core
Saveral layers of sodium kraft paper
- Phenolic impregnated
- To achieve required thinkness of final product

RPC: resistive electrodes

RPC-Introduction

The detector rate capability is strongly dependent on the Bakelite resistivity. At high particle rate (r) the current through the detector can become high enough to produce an important voltage drop (V_d) across the electrode:

s: electrode thickness
$<Q_e>$: average pulse charge
ρ: bakelite resistivity

In order not to lose efficiency → $V_d < \sim 10$ V

Therefore → $\underline{\rho \sim 10^{10}\ \Omega\ \mathrm{cm}}$

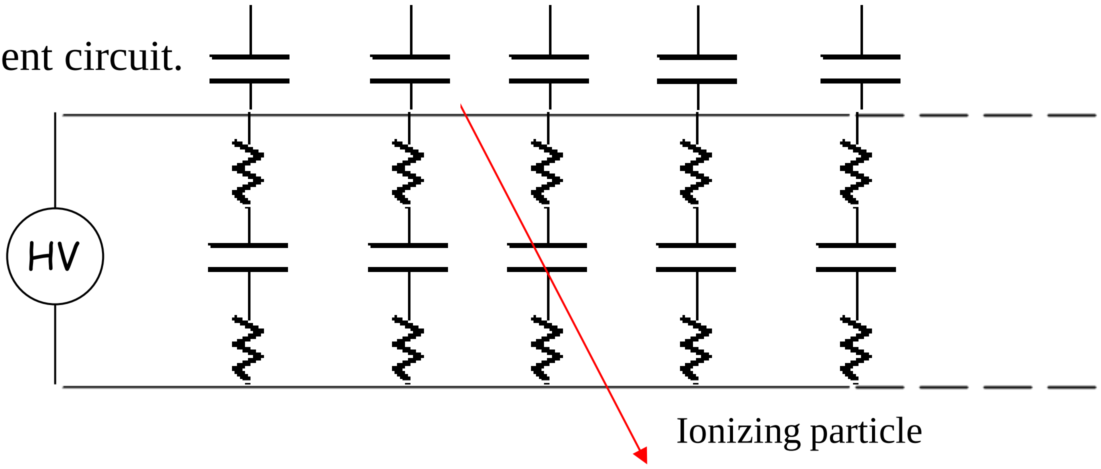
The time constant of an elementary cell is lower at lower resistivity:

the cell is recovering faster (it is quicker ready again) after a discharge took place inside it.

RPC: resistive electrodes

It is the most important improvement with respect to previous generations

RPC equivalent circuit.



Time constant for charge development is related to drift velocity and multiplication $\tau_{discharge} = 1/\eta v_d \sim 10$ ns

Time constant for recharge the elementary cell is related to the RC $\tau_{recharge} = \rho\varepsilon \sim 10$ ms

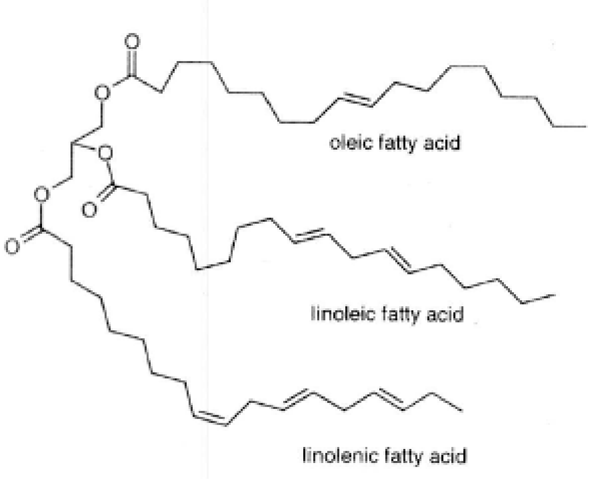
→ $\tau_{discharge} \ll \tau_{recharge}$

Since $\tau_{recharge} \gg \tau_{discharge}$ the arrival of the electrons on the anode is reducing the electric field and therefore the discharge will be locally extinguished.
→the electrode are like insulator after the first charge development
→Self-extinguish mechanism

RPC: resistive electrodes

What is the linseed oil:

- ➢Drying oil (consists basically of triglycerides)
- ➢Drying is related to C=C group in fatty acid
- ➢Cross-linking (polymerization) in presence of air (O_2 play important role) due to C=C



RPC electrodes are usually treated with linseed oil:

- ➢better quality of the internal electrode surface
- ➢it acts as a quencher for UV photons
- ➢better detector performance

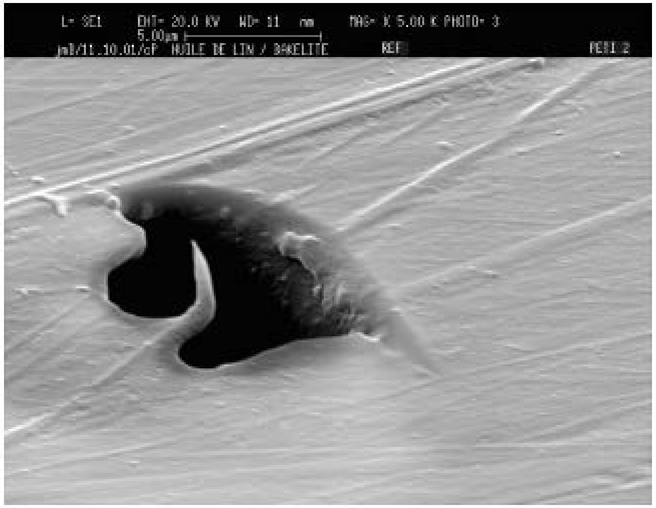
…but…

- ➢More time needed during construction
- ➢Ageing problems? (Not observed)

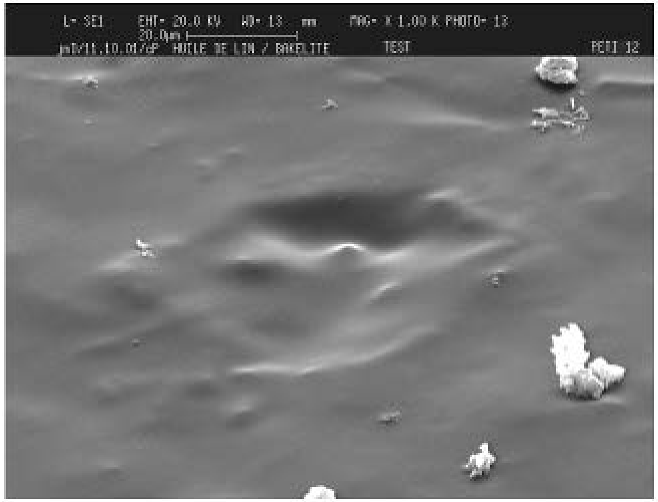
RPC: resistive electrodes

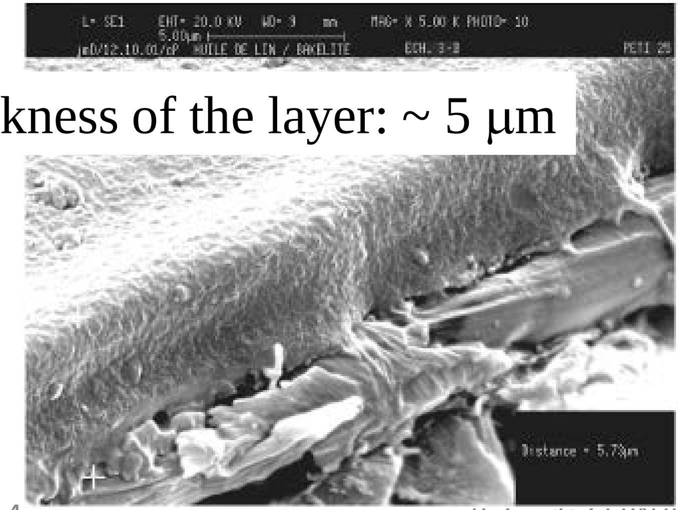
Few SEM photos (S.Ilie, C.Petitjean EST/SM-CP EDMS 344297):

Defect on Bakelite surface

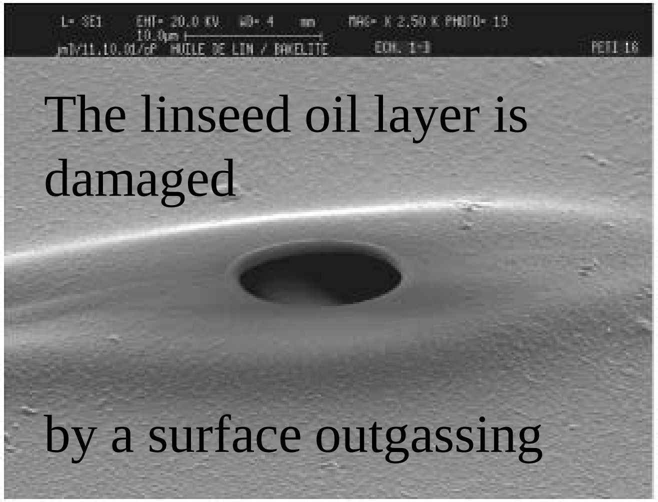


possibly covered with linseed oil





Thickness of the layer: ~ 5 µm



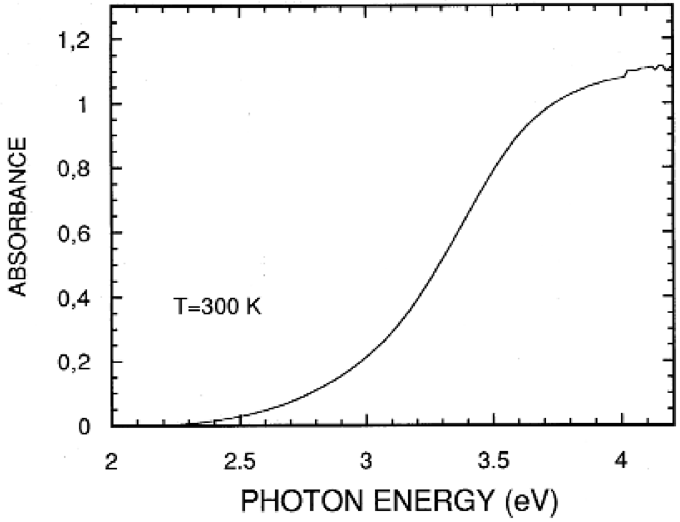
The linseed oil layer is damaged

by a surface outgassing

RPC: resistive electrodes

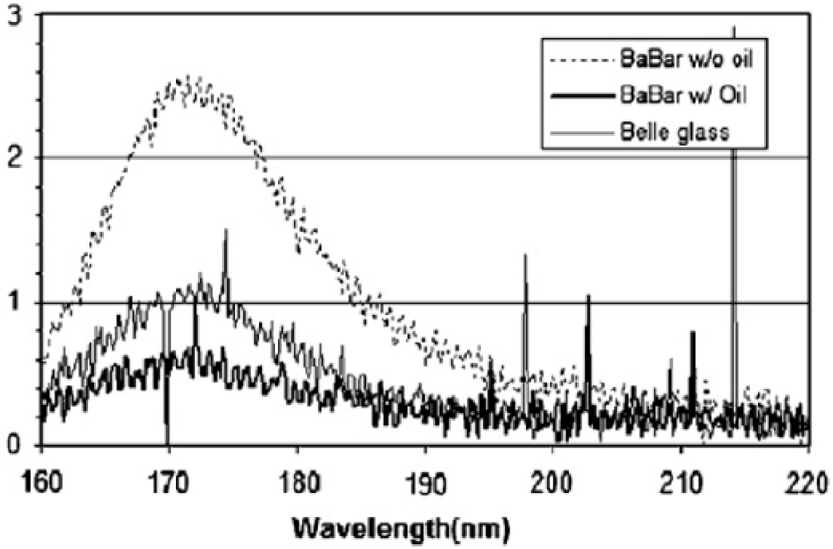
Effect on UV photons hitting the electrode internal surface:

Linseed oil absorbance



P.Vitulo NIMA 394 13-20

UV sensitivity for coated and non coated Bakelite



8 eV ← → 5.6 eV

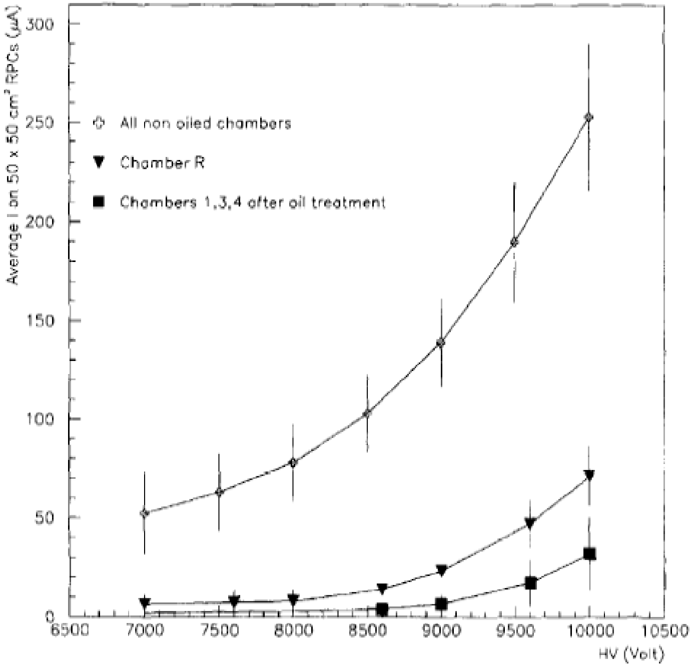
C.Lu NIMA 602 761-765

RPC: resistive electrodes

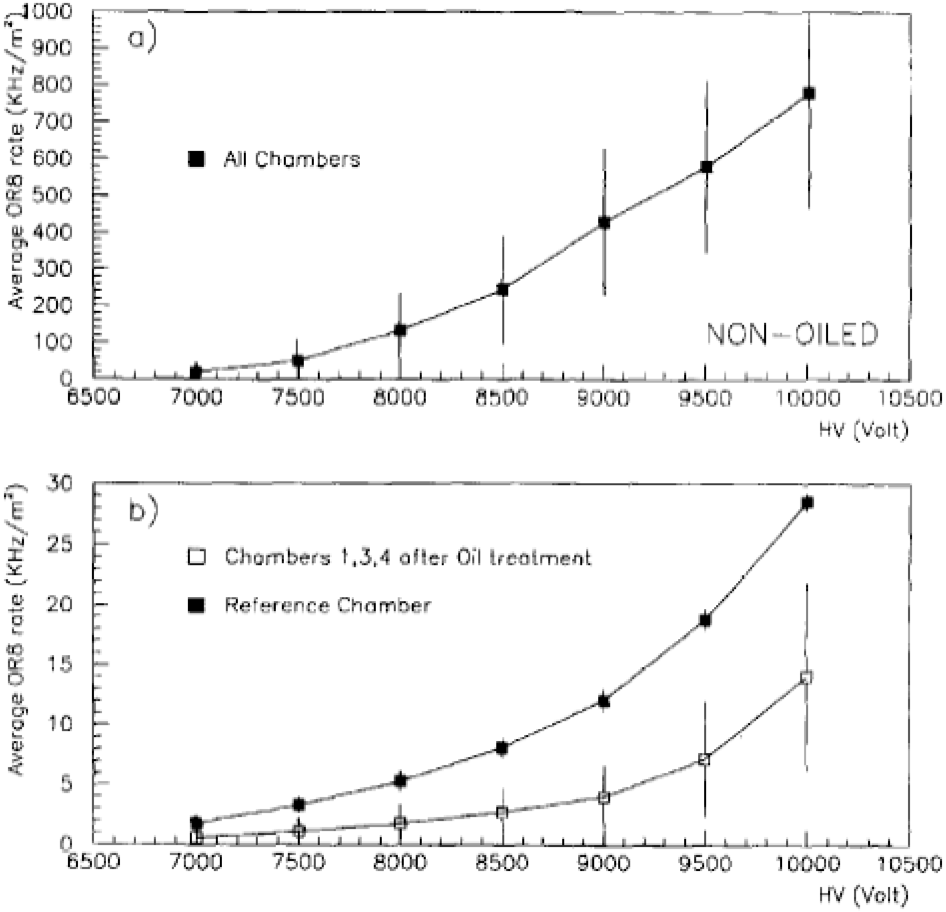
RPC-Introduction

Chamber Performance:

- With linseed oil coated electrodes
- Lower current (~1/10)
- Lower noise rate (~1/10)



M. Abbrescia et al. NIMA 394 13-20



Lab session: Goals

Lab session - Goals

Goals for the lab session:

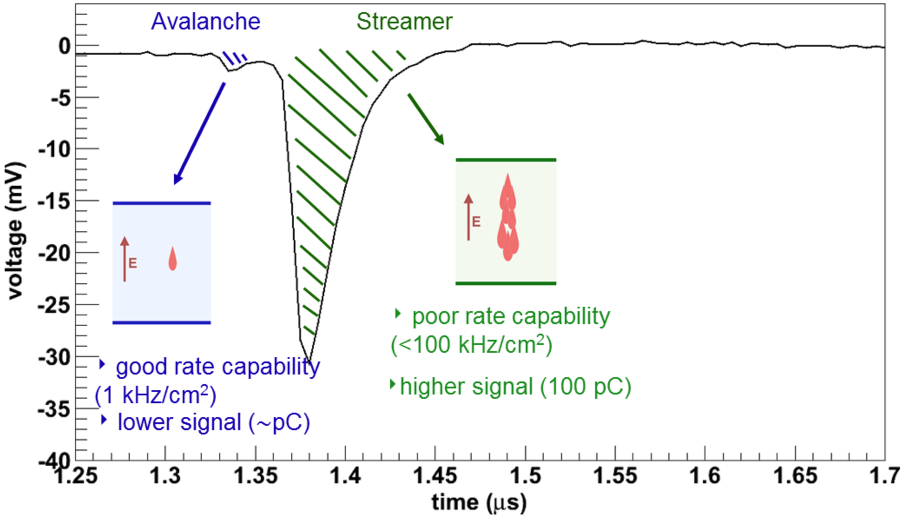
- Introduction to RPC detector
- Importance of mixture composition
- Analysis of RPC signals with different gas mixtures
- Principle of gas analysis and gas systems

RPC features analyzed:

- Signal from detectors operated with different gas mixtures
- Average charge for the avalanche and streamer region.
- Average total charge.
- Event frequency for the avalanche and streamer region.

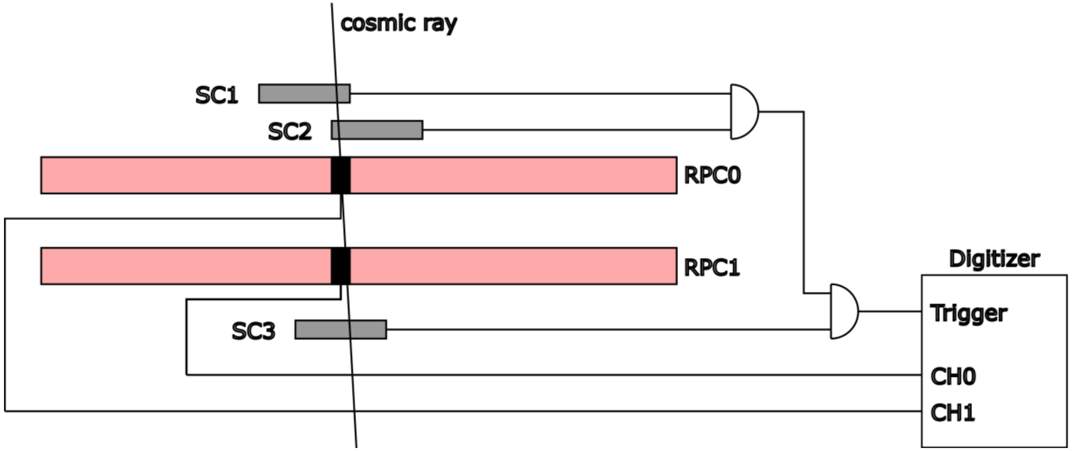
RPC signal parameters studied:

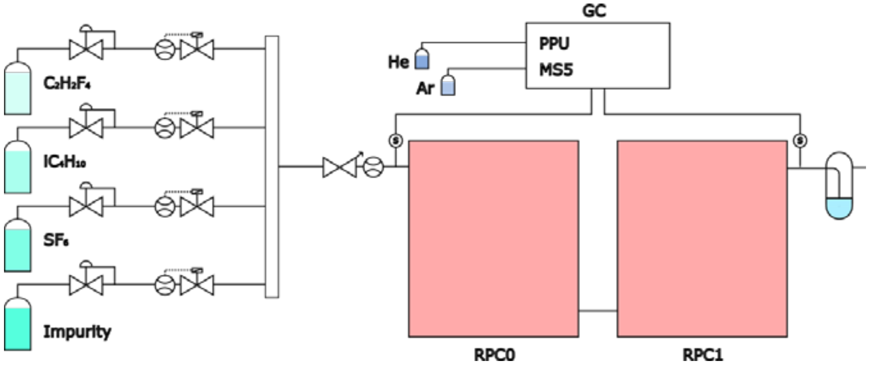
- Pulse integrated charge
- Pulse height
- Event time



Setup description

- Standard high pressure laminate RPCs
- Scintillators (SC) for trigger on cosmic muon
- NIM modules for trigger logic and coincidences
- Data acquisition by Desktop Waveform Digitizer





- Gas mixture composition is measured by means of a Gas Chromatograph (GC)
- Dedicated gas system for controlled injection of gas and different types of impurities

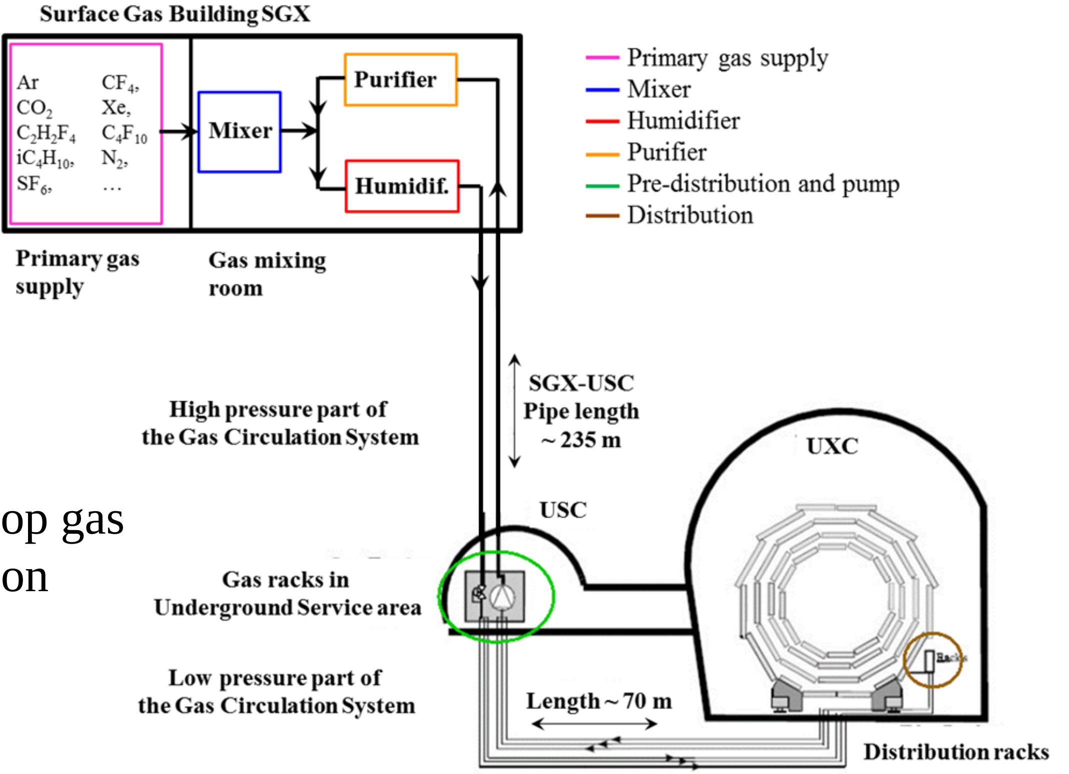
Gas systems for particle detectors

Gas systems

Gas systems extend from the surface building to the service balcony on the experiment following a route few hundred meters long.

- Primary gas supply point is located in surface building
- Gas system distributed in three levels:
    - Surface (SG)
    - Gas Service room (USC)
    - experimental cavern (UXC)

Large detector volume (from m^3 to several 100 m^3) and use of expensive gas components:
→
The majority is operated in closed loop gas circulation with a recirculation fraction higher than 90-95 %.

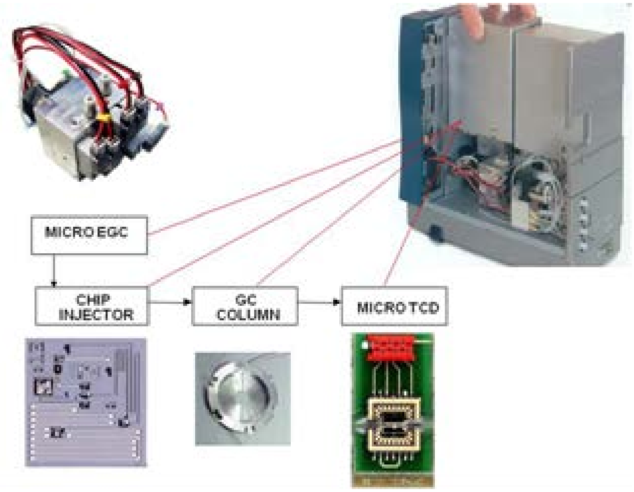


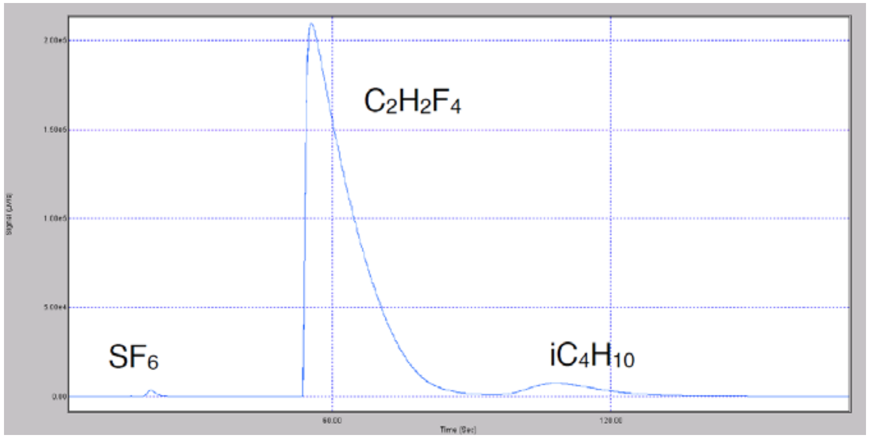
Study of different mixtures

Lab session - Measurement

- Setup the gas mixer for the following gas mixtures:
- Argon only
- Argon/CO_2 (70%-30%) or Argon/iC_4H_{10} (95%-5%)
- Argon/CO_2/SF_6 (69.5%-30%-0.5%) or Argon/iC_4H_{10}/SF_6 (94.5%-5%-0.5%)
- R134a/CO_2/SF_6 (69.5%-30%-0.5%) or R134a/iC_4H_{10}/SF_6 (94.5%-5%-0.5%)

- Use of gas chromatography techniques to measure the gas mixture composition





- Measurement of the pulse charge at stable mixture composition

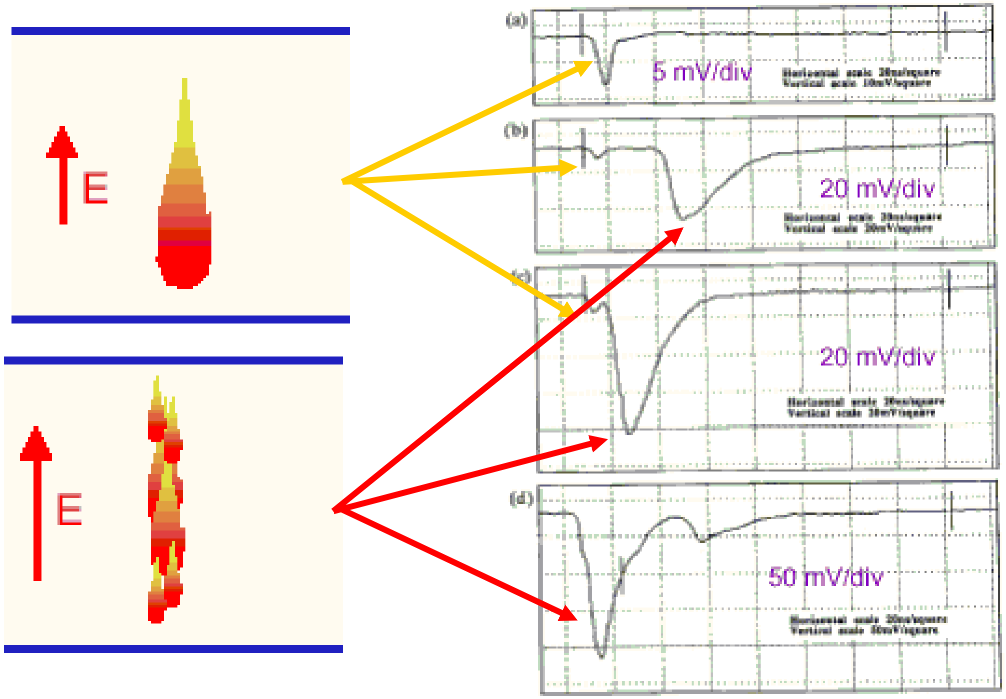
RPC: resistive electrodes

Originally RPC were operated in *Streamer mode*:

- ➢Ar-based mixture
- ➢Higher signal (100 pC) but also high current in the detector
- ➢Voltage drop at high particle rate → loss of efficiency → **poor rate capability (< 100 Hz/cm^2)**

Operation with high particle rate possible in *Avalanche mode*:

- ➢Freon-based mixture
- ➢lower signal (~ pC) but also lower current in the detector
- ➢Less important high voltage drop at high particle rate → **good rate capability (~ 1 kHz/cm^2)**



Avalanche signal

Streamer signal

R. Santonico et al.
ATLAS Muon TDR

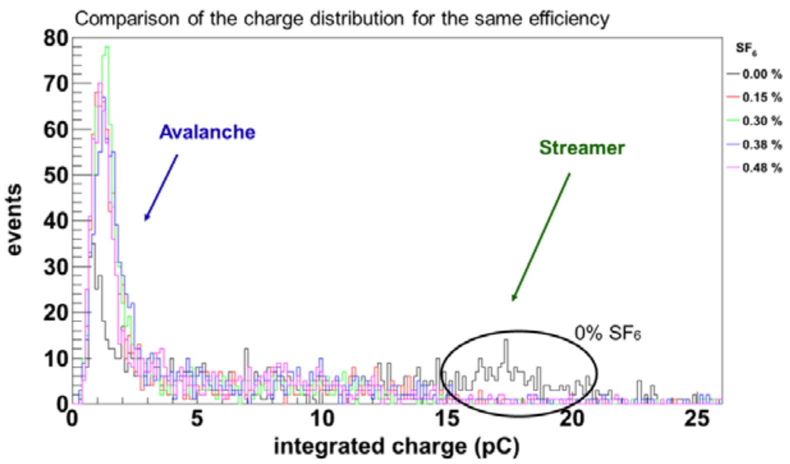
Measurement

Discovering the setup

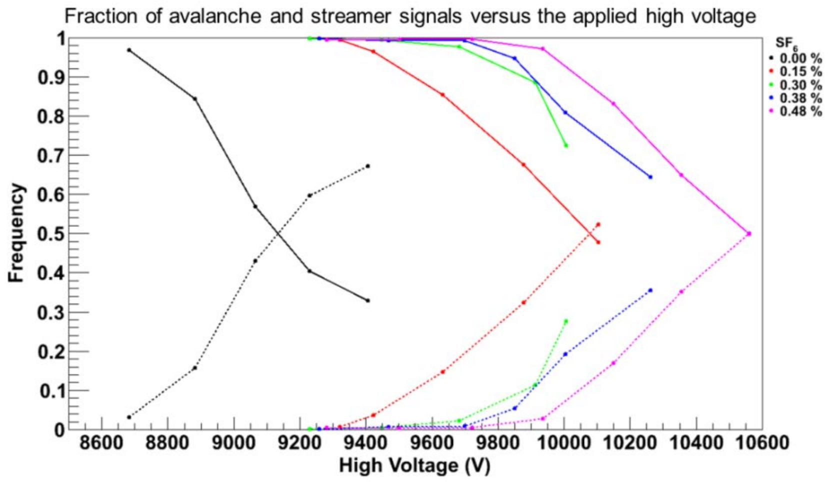
- HV, DAQ and detectors (scintillators and RPCs) will be available.
- Trigger logic and DAQ will be setup during the lab session
- Looking at RPC signals with an oscilloscope

The effect of different SF_6 will be studied in detail

- Acquisition of pulse charge spectrum
- Frequency of the avalanche and streamer signals at given RPC efficiency.
- With less SF_6 the number of streamer signals is higher (at the same efficiency).
- With the increasing of the high voltage the streamer signals become predominant.



Comparison of the charge distribution for the same efficiency



Fraction of avalanche and streamer signals versus the applied high voltage

Learning goals

- Detector for triggering: RPC example
- Characteristic RPC:
    - impact of detector geometry
    - Resistive electrode
    - Signals
    - Signals vs different gas mixtures
    - Time resolution
    - Efficiency vs high voltage
    - Rate capability

- Principles of gas analysis and gas systems
- Impact of gas mixture quality and/or composition on RPC detector performances
- Extend consideration to gas detector in general

References

- R. Santonico, “Development of resistive plate counters”, Nucl.Instr. and Meth. A 187 (1981) 377-380.
- R. Guida, “The Resistive Plate Chamber detectors at the Large Hadron Collider experiments”, PH-DT Detector Seminar (https://indico.cern.ch/conferenceDisplay.py?confId=68937)
- R. Guida et al., “Optimization of a closed-loop gas system for the operation of Resistive Plate Chambers at the Large Hadron Collider experiments”, Nucl.Instr. and Meth. A 661 (2012) 214-221.
- B. Mandelli et al., “Systematic study of RPC performances in polluted or varying gas mixtures compositions: an online monitor system for the RPC gas mixture at LHC”, CERN PH- EP-Tech-Note-2012-002.