INFN Sezione di Firenze, 4 May 2012

Cloud and spark chambers for demonstration and outreach purposes: an introduction

Lorenzo Bonechi
S. Paoletti, G. Passaleva, S. Straulino, F. Taccetti

In this "short" seminar…

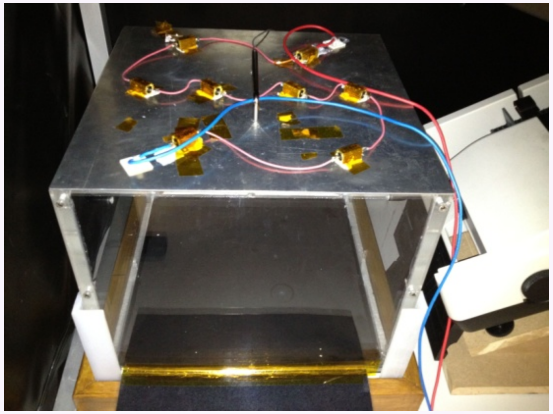
- Introduction
- Principles of operation of a Cloud Chamber
- Principles of operation of a Spark Chamber
- Details of the detectors used for the laboratory sessions
- Experimental activity and simple measurements

Introduction

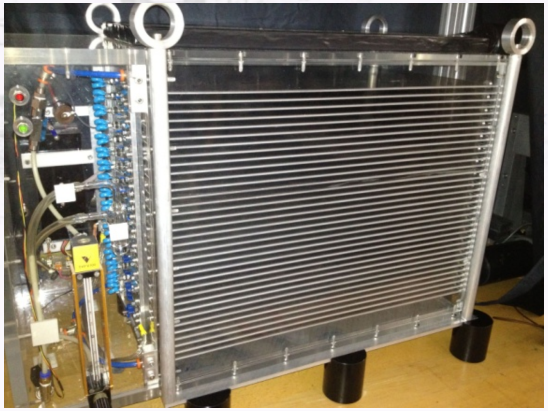
Main motivations

- Exercise with relatively "easy-to-build" setups and limited investment of resources
- typical use cases: education and public exhibitions (with some caveats)
- INFN (like any other research institution nowadays) has strong motivation in exposing its image to the public:
  - ***outreach*** (return on public opinion)
  - ***visibility*** towards industry (stimulate and promote technological transfer)

Proposed experiences



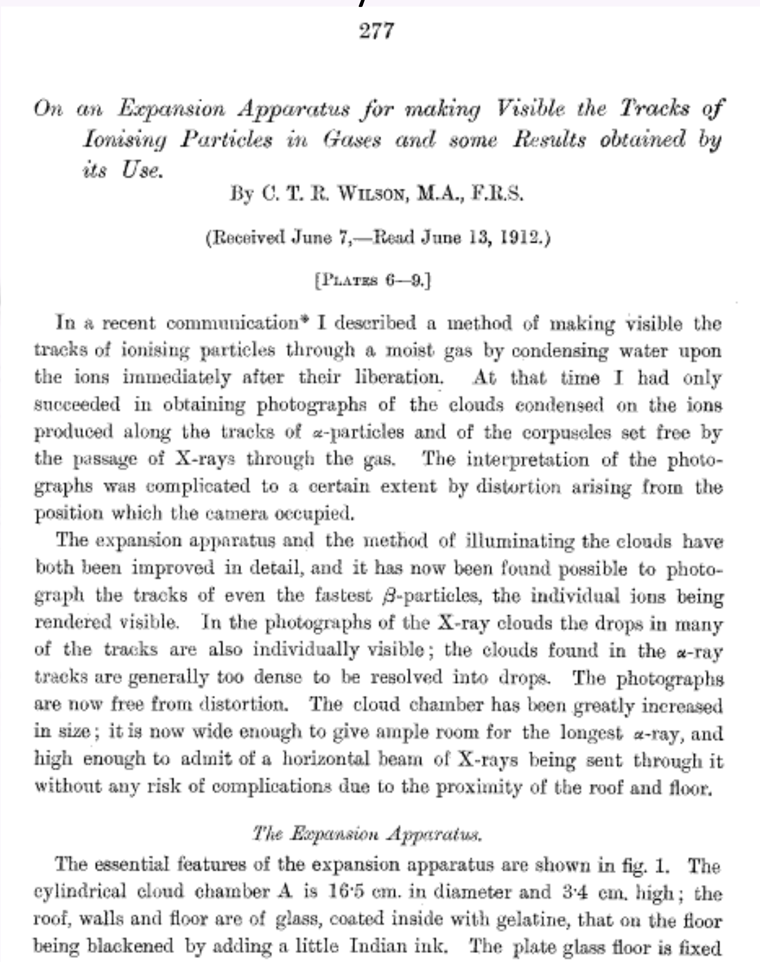
- Cloud Chamber
  - Goal: setup of a particle detector requiring very limited resources (easily available)
  - Results not always very reproducible: this is the name of the game! Better reproducibility and precision can be established with more sophisticated (and expensive) setups. Also out-of-the-shelf commercial solutions available to the market.



- Spark Chamber
  - a bit more complex detector entirely homemade, from design to commissioning;
  - typical deployment: real-time visualization of cosmic ray events at museums, exhibitions or any official events

The birth of the cloud chamber

Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character



277

On an Expansion Apparatus for making Visible the Tracks of Ionising Particles in Gases and some Results obtained by its Use.

By C. T. R. Wilson, M.A., F.R.S.

(Received June 7,—Read June 13, 1912.)

[Plates 6—9.]

In a recent communication* I described a method of making visible the tracks of ionising particles through a moist gas by condensing water upon the ions immediately after their liberation. At that time I had only succeeded in obtaining photographs of the clouds condensed on the ions produced along the tracks of α-particles and of the corpuscles set free by the passage of X-rays through the gas. The interpretation of the photographs was complicated to a certain extent by distortion arising from the position which the camera occupied.

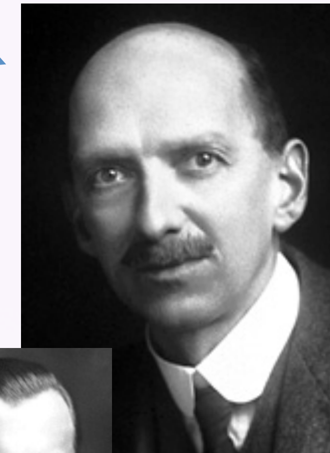
The expansion apparatus and the method of illuminating the clouds have both been improved in detail, and it has now been found possible to photograph the tracks of even the fastest β-particles, the individual ions being rendered visible. In the photographs of the X-ray clouds the drops in many of the tracks are also individually visible; the clouds found in the α-ray tracks are generally too dense to be resolved into drops. The photographs are now free from distortion. The cloud chamber has been greatly increased in size; it is now wide enough to give ample room for the longest α-ray, and high enough to admit of a horizontal beam of X-rays being sent through it without any risk of complications due to the proximity of the roof and floor.

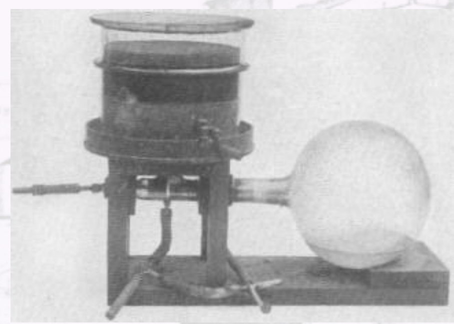
The Expansion Apparatus.

The essential features of the expansion apparatus are shown in fig. 1. The cylindrical cloud chamber A is 16·5 cm. in diameter and 3·4 cm. high; the roof, walls and floor are of glass, coated inside with gelatine, that on the floor being blackened by adding a little Indian ink. The plate glass floor is fixed

<u>**Charles Thomson Rees Wilson**</u>

NOBEL PRICE in 1927 "for his method of making the paths of electrically charged particles visible by condensation of vapour" (price equally shared with Arthur Holly Compton).





Further important developments are due to **Blackett** who made many important discoveries with its cloud chamber: first of all the demonstration of the creation and annihilation of electron-positron pairs.

The birth of the spark chamber

KEUFFEL 1949

Keuffel, J.W.;

Parallel-Plate Counters

Rev. Sci. Inst. 20 (1949) 202;

Abstracts

The counter characteristics of a discharge tube using plane-parallel electrodes have been investigated, particularly with regard to the short time lags inherent in the streamer type of spark which occur with such a geometry at near-atmospheric pressure. Construction details for parallel-plate counters with good counter characteristics are given. Spurious counts were minimized by an argon-xylene filling mixture and the use of a univibrator quench circuit. The uncertainty in the reaction time of the counters is ± 5 x 10-9 sec.

1953 → First published photographs of the spark discharge by Bella and Frazinetti

…

Early 1970's → One of the main detectors used in particle physics experiments

1980's → Replaced by detectors of higher spatial and time resolution, for example drift chambers and silicon detectors.

Principles of operation of the Cloud Chamber

C
L
O
U
D

C
H
A
M
B
E
R

Large formation of Boeing B-17Fs of the 92nd Bomb Group
http://www.nationalmuseum.af.mil/shared/media/photodb/photos/060517-F-1234S-001.jpg

Drop formation and supersaturation

- due to surface tension the saturation vapor pressure (SVP) of a fluid over a curved surface is higher than SVP over a flat surface; the smaller the curvature radius, the higher the ratio (SVP_curved)/(SVP_flat)
- for a drop to be formed a minimum supersaturation S=(SVP_curved)/(SVP_flat) is required, otherwise the drop instantaneously evaporates
- a condensation center larger than some minimal radius is thus required for a drop to be formed. The higher the supersaturation, the smaller the minimum radius
- when drops are positive charged (example: when ions act as condensation centers) electrical forces counter-balance the surface tension allowing drops with smaller radius / smaller supersaturation

Principle of operation

- A region supersaturated with alcohol vapor is created
  - usually: isopropyl alcohol, methyl alcohol are used
- ions created by incoming ionizing particles act as condensation centers
  - both air and alcohol ions (depending on concentration) work as condensation centers
- alcohol vapor condenses around these free ions, forming droplets.
- The droplets form a visible trail.

Obtaining the supersaturated region

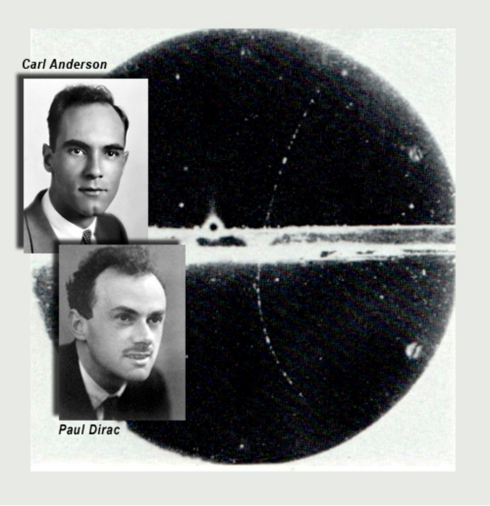
- **Wilson expansion cloud chamber**: fast (adiabatic) expansion (originally water was used)
- **Diffusion cloud chamber**: a steep vertical temperature gradient is established through the chamber with dry ice, liquid nitrogen, or mechanical refrigeration. Alcohol evaporates from the warm top side and diffuses toward the cold bottom. The gravitationally stable temperature distribution permits a layer of supersaturation near the chamber bottom.

VS

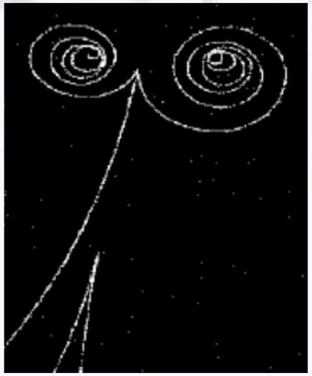
Diffusion cloud chamber operation

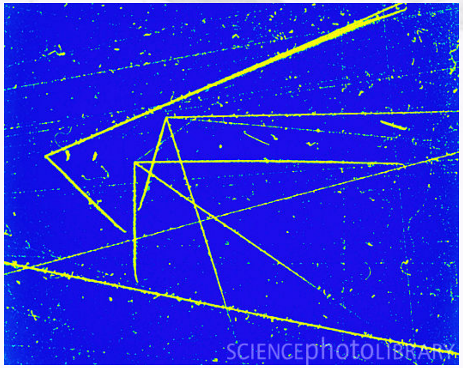
- The **sensitive region** is just above the cold plate almost where alcohol is condensing.
- constant **precipitation caused by condensed alcohol** formed above the sensitive area may interfere with observation
  - a strong electric field may be applied to reduce the "rain" and draw tracks down to the sensitive region
  - lighting conditions (back, lateral, …) have an important role

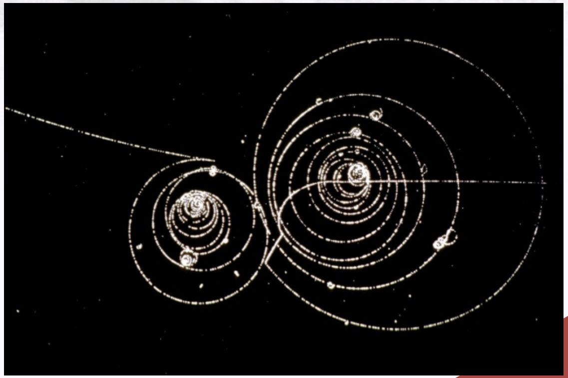
Observations



- Different types of particles leave different trails
  - Alpha particles produce straight dense trails
  - Beta particles leave wispy, irregular trails
  - Cosmic rays produce thin misty trails
- Multiple scattering can be observed in low-energy particles following "curly" paths
- particle decay producing straight paths suddenly shooting of into another direction
- three paths intersecting, often the result of a cosmic ray striking another particle







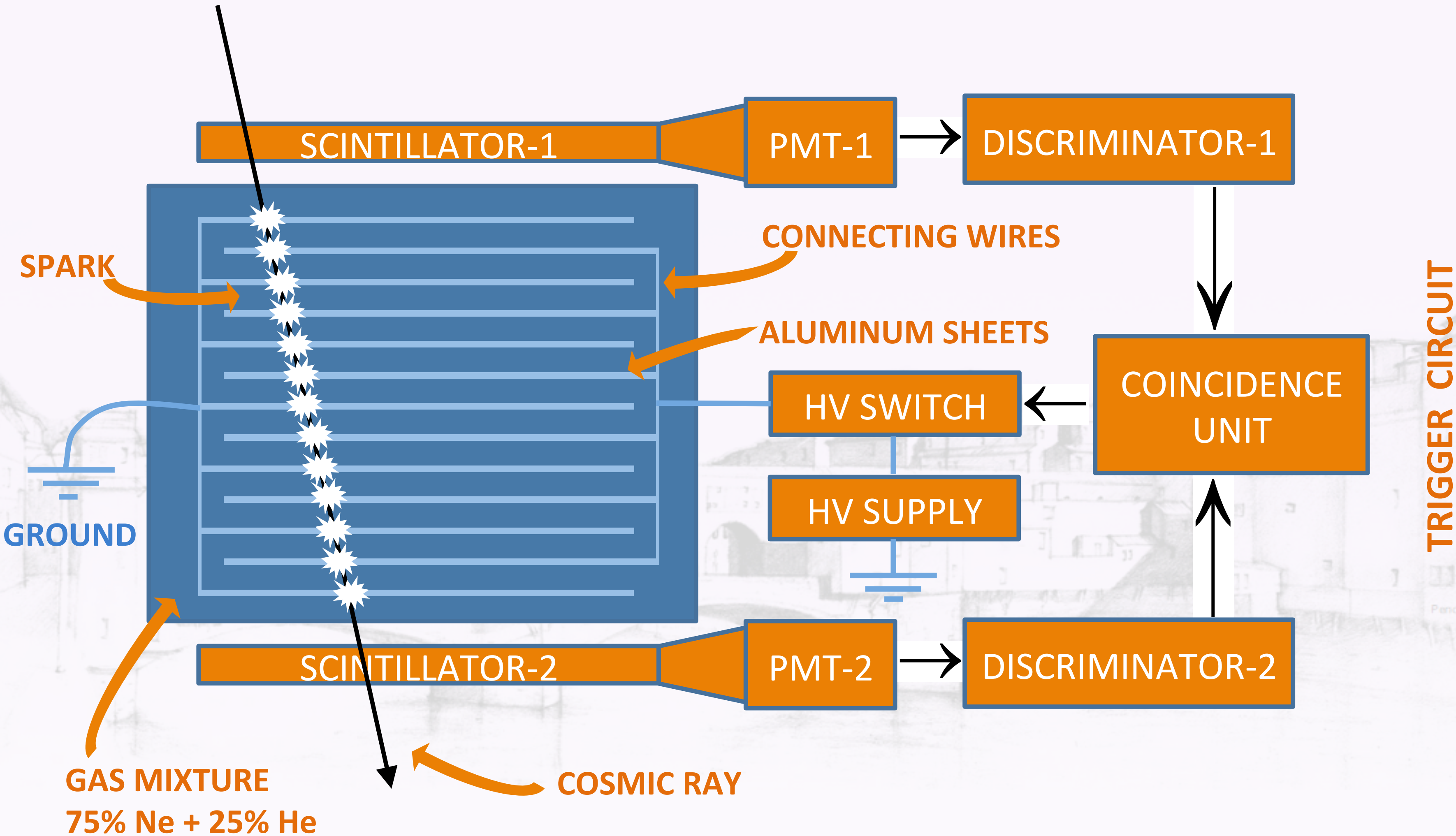
Principles of operation of the Spark Chamber

S
P
A
R
K

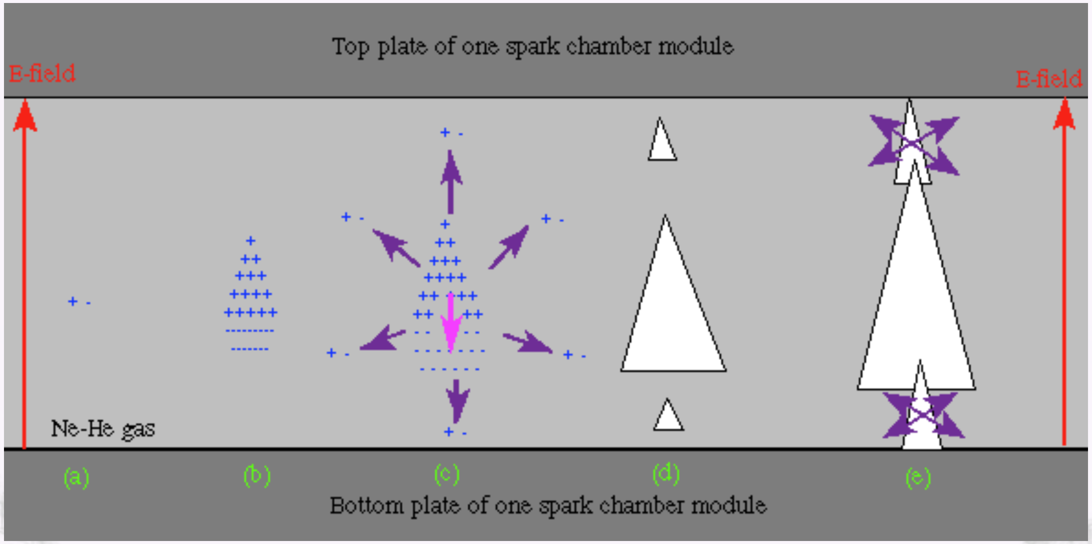
C
H
A
M
B
E
R

Lightning bolts hitting Atlanta skyscrapers
by David Selby

Scheme of the detector



Development of a spark

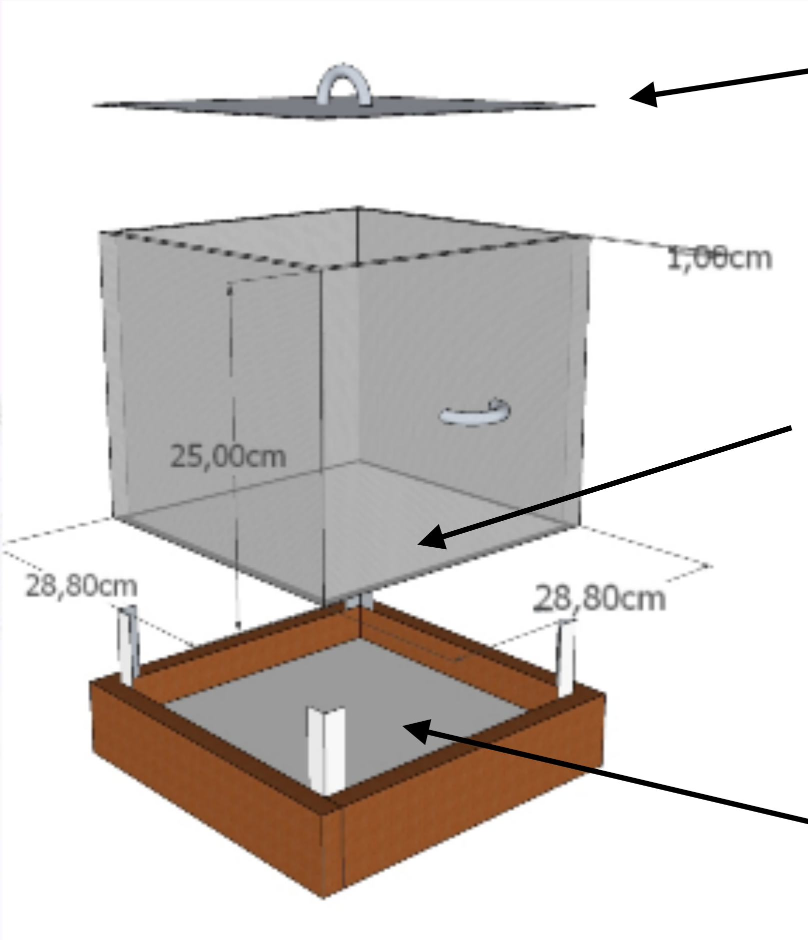


The charged plates discharge through the easiest path, which is the trail of ions left behind in Ne-He gas by the passage of the ionizing particle

1st stage: e^- (created by ionization) is accelerated towards the anode → further ionizations. An "avalanche" rapidly builds up. e^- at the "head" of the avalanche, positive ions at the "tail".
When the number of e/ion pairs is critical (above E^6-E^8) the avalanche first slows down and an electric field within the avalanche is created, opposite to the field created by the plates.
e-ion recombinations occur, emitting photons isotropically and causing ionizations near the original avalanche. The electric field in front and behind the original avalanche is enhanced, whilst the field around the sides is suppressed.
Ahead and behind of the original avalanche new avalanches rapidly form until the old and new avalanches merge, forming a streamer.
The extremities of the streamer grow (in approximately 10ns) until they arrive at the plates.
The two plates are now connected by a low resistance conducting plasma of electrons and positive ions

Details of the detectors used for the laboratory sessions

Building the cloud chamber

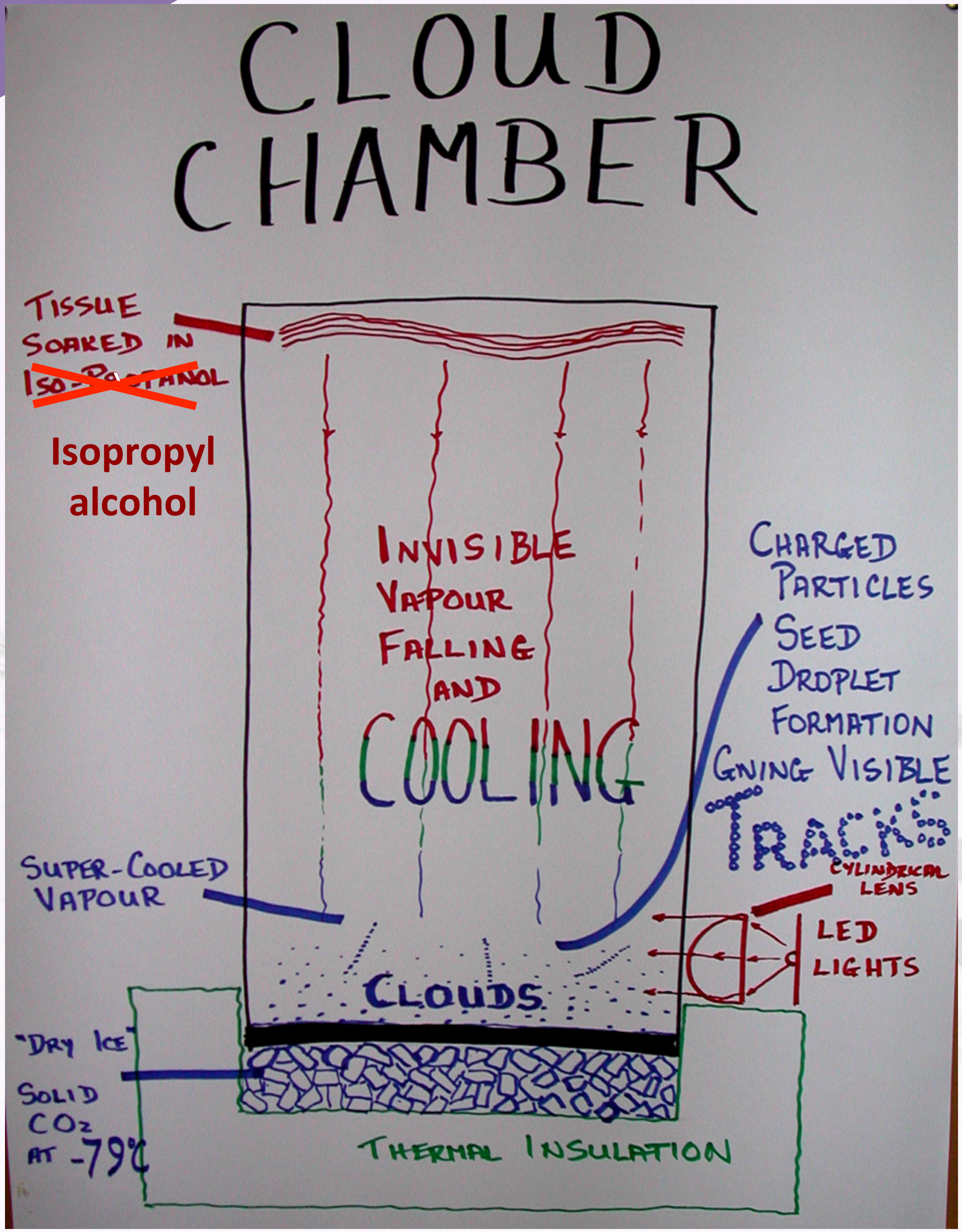


top electrically heated in order to increase temperature gradient

metal base (black anodized Al) for thermal conductivity painted in black (for better contrast of clouds)

dry ice: $T_0 \sim -78.5\ ^0C$

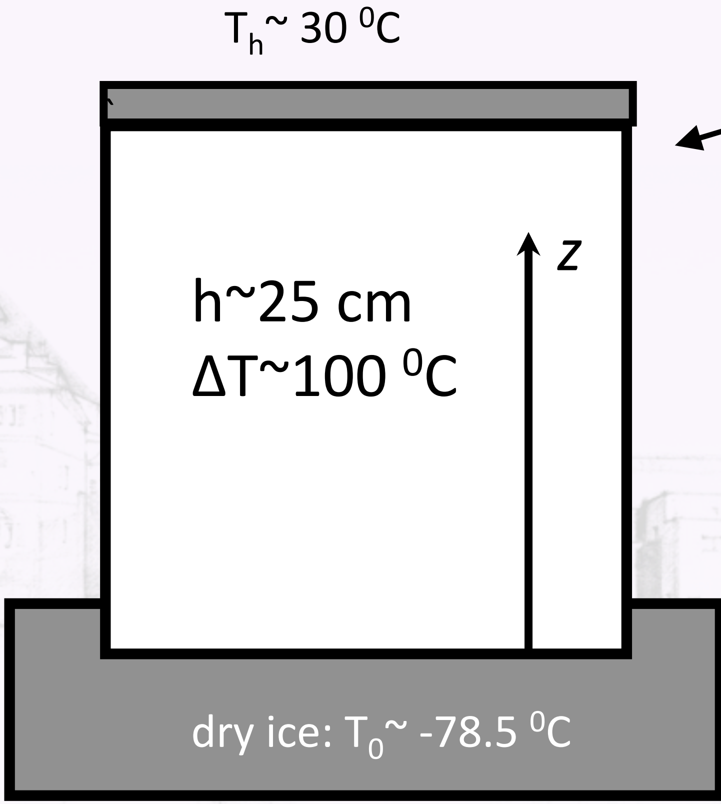
Reference: L. Miccinesi 's thesis (see later)



- **Some suggestions**:
  - Temperature gradient
    Switch on the cover heater well before establishing the thermal contact between the chamber and the the dry ice
  - Time
    Wait for at least 15/30 minutes before the chamber begins to work properly
  - Light conditions
    Optimize very carefully the visibility of the tracks over the background given by the falling alcohol rain: the light quality is very important (dark room, intensity and direction of light source)

http://www.hep.phy.cam.ac.uk/outreach/images/CloudChamberSketch-5cm72dpi.jpg

Conditions for supersaturation in this diffusion cloud chamber



Pressure Ph here is the standard saturation vapor pressure (P_{sat}) at T_h = 30^{0}C

hypothesis:

-linear T gradient $T(z) = T_0 - (T_0 - T_h)\frac{z}{h}$

-linear P gradient $P(z) = P_0 - (P_0 - P_h)\frac{z}{h}$

$$P_{sat}(T_1) = P_{sat}(T_2) \cdot e^{\frac{LM_r(T_1 - T_2)}{RT_2^2}}$$

$$M_r = 60.10 \times 10^{-3}\ \mathrm{kg/mol}$$

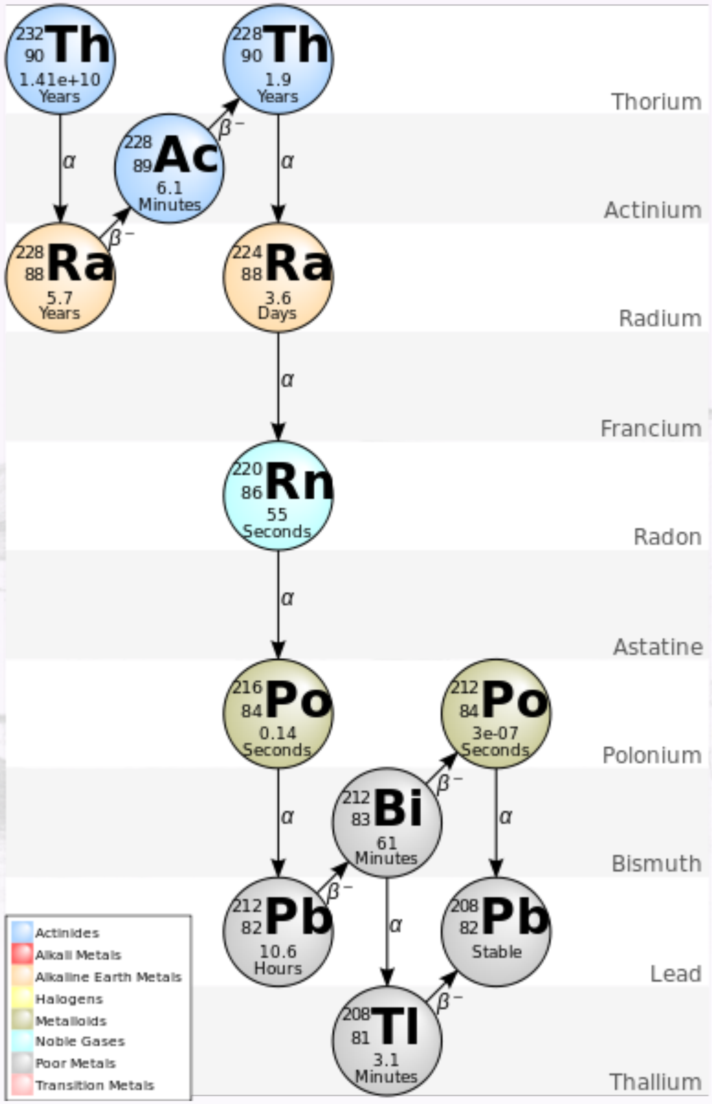
$$L = 6.66 \times 10^{-5}\ \mathrm{J/kg}$$

supersaturation: $P(z)/P_{sat}(T(z))$

S > 4 (droplet formation) → sensitive region is ~ 20 cm thick

$$\Rightarrow \quad s(z) = e^{\frac{LM_r(h-z)(T_0 - T_h)}{hRT_h^2}}$$

Using a radioactive source



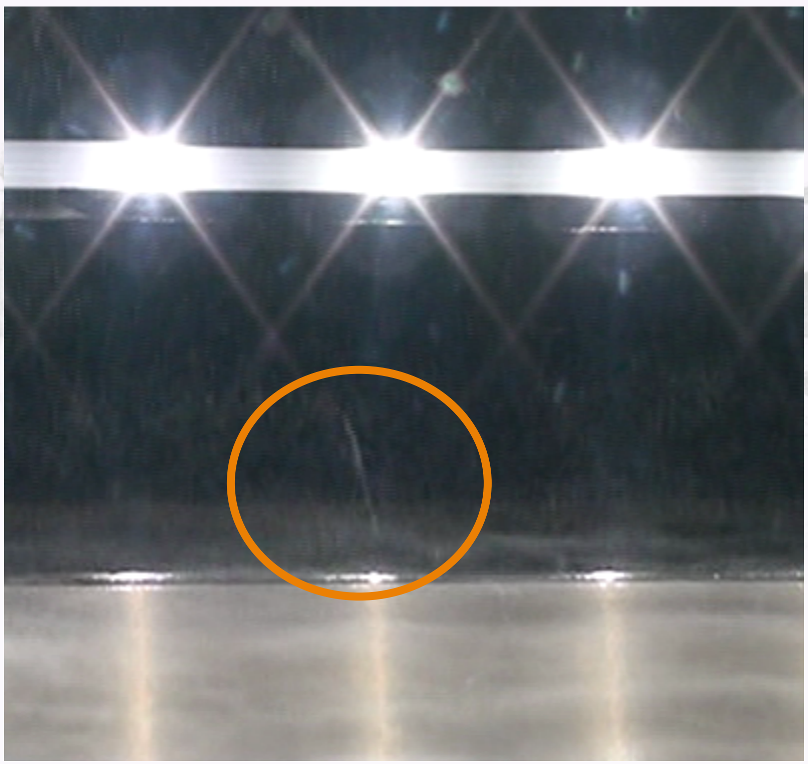
Other possible radioactive sources

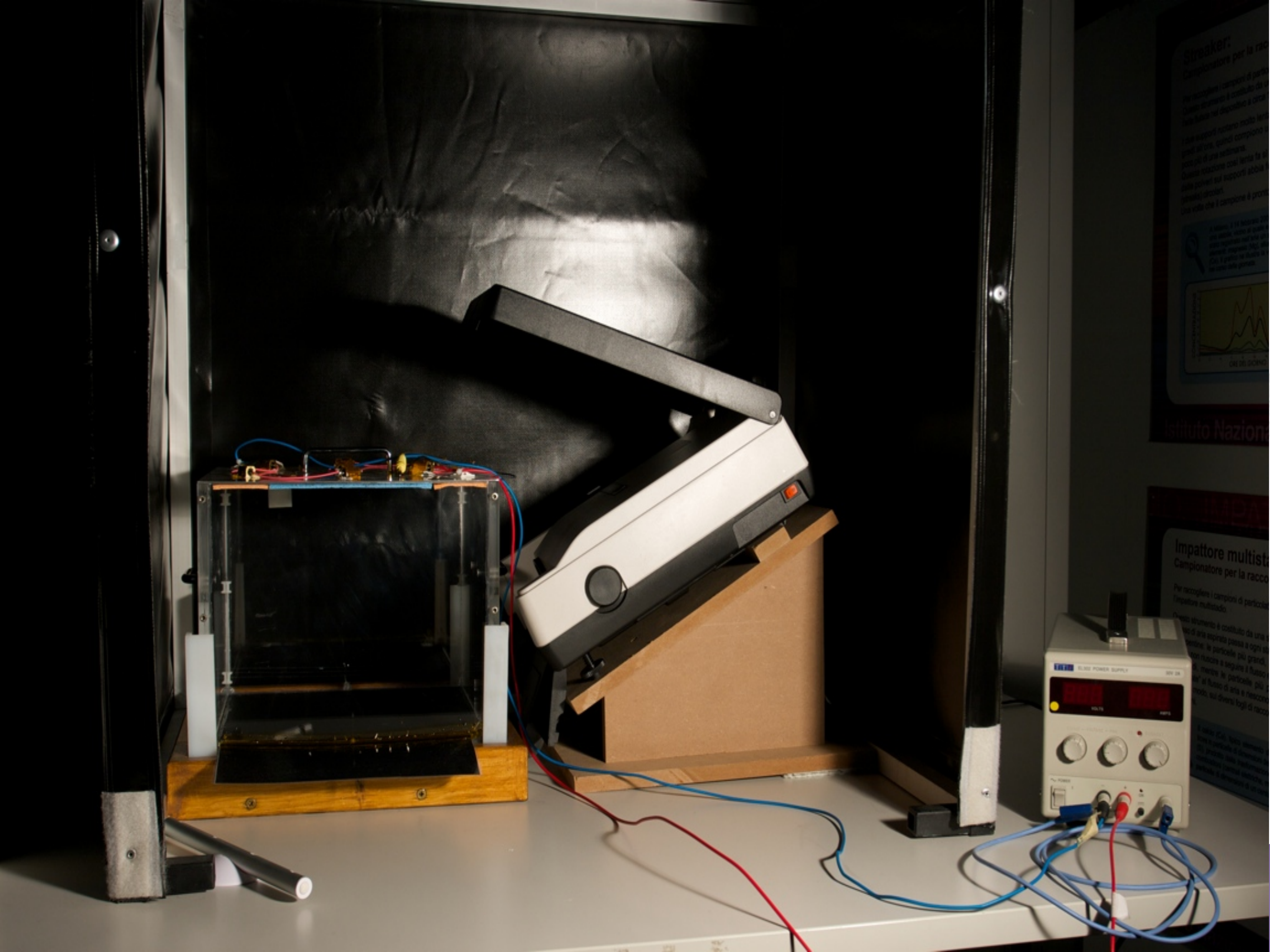
- The “trick” is in finding a relatively safe radioactive sample:
  - old luminous watch and clock hands (Radium, Tritium)
  - older glassware (true Cobalt blue) and ceramics glazes
  - some mantles for gas camping's lanterns (containing Thorium)
  - welding rods (Thorium)
  - beware dismantling smoke detectors (seen on YouTube): Americium is actually fairly dangerous to handle


A lot of horizontal tracks can be seen by using an appropriate radioactive source!!!

Examples of vertical events

- These events were recorded by L. Miccinesi for his thesis (level I)





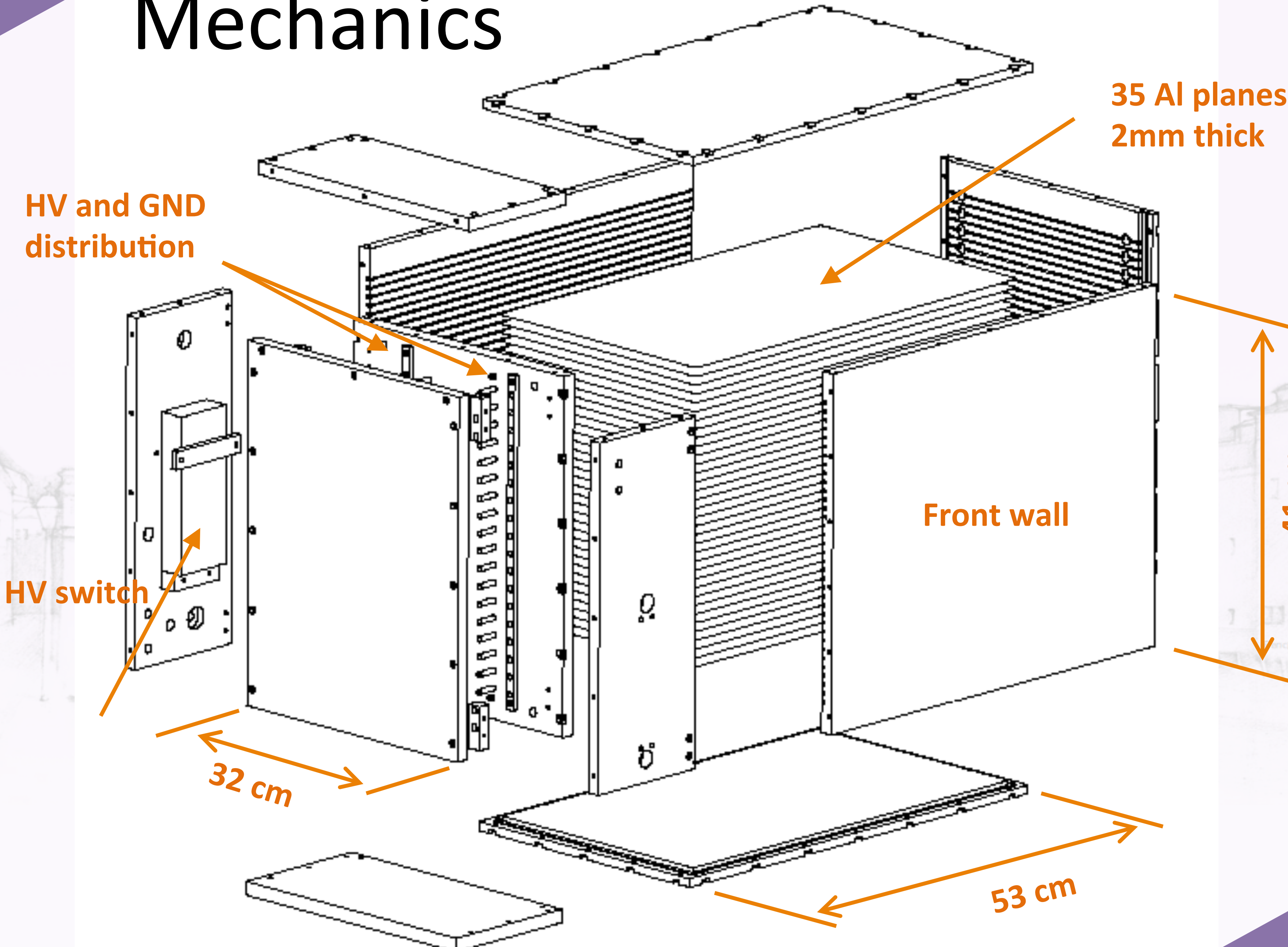
References

- A quite comprehensive review article:
  - Rev. Mod. Phys. 18, 225–290 (1946): N. N. Das Gupta and S. K. Ghosh: "A Report on the Wilson Cloud Chamber and Its Applications in Physics"
- Tesi di Laurea in Fisica di I livello di Lapo Miccinesi
  - Titolo "Costruzione di una camera a nebbia e sua applicazione per misure di raggi cosmici", AA 2010/2011, Università degli studi di Firenze

Building the spark chamber

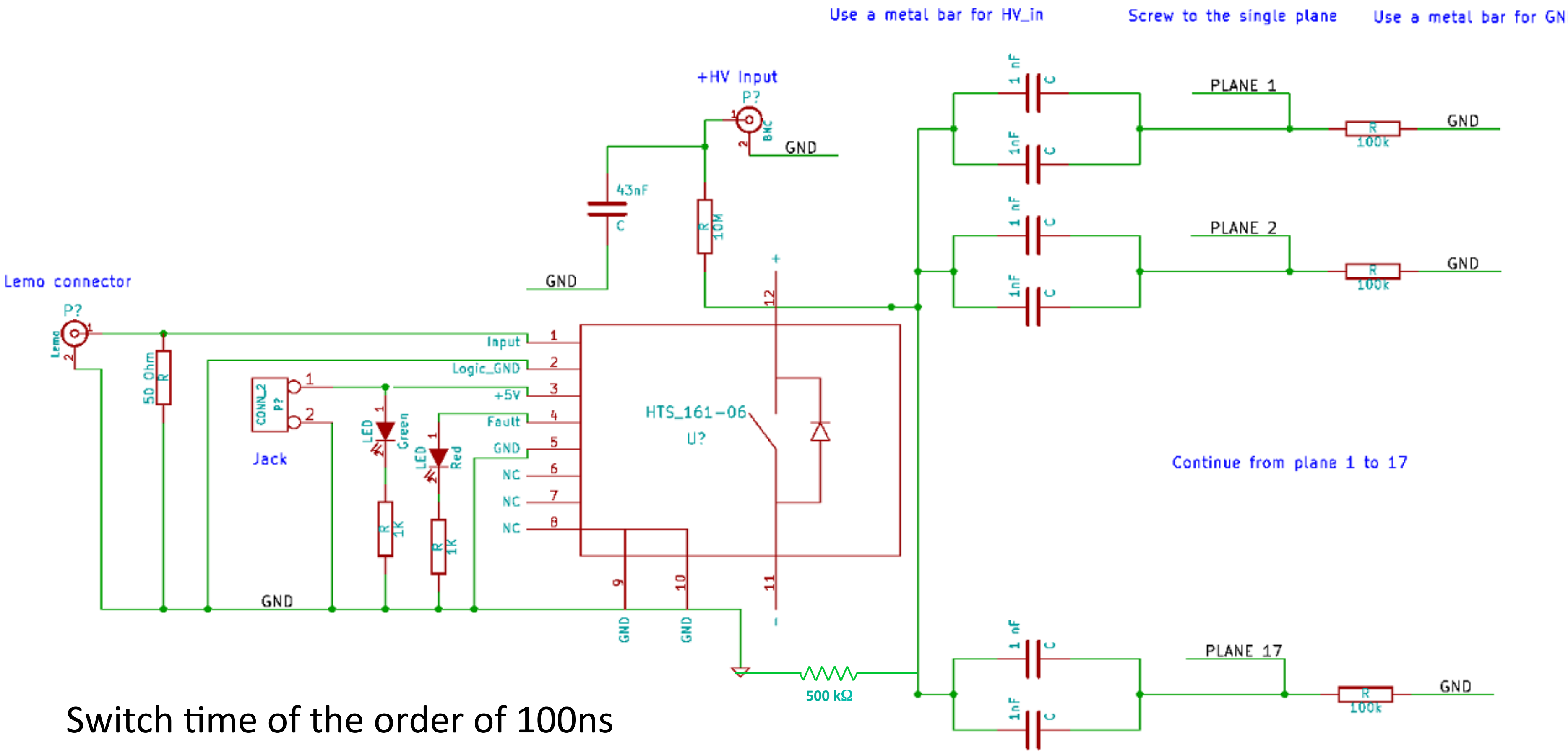
- Use of Ne (75%) + He (25%) mixture at pressure slightly greater than the atmospheric pressure
  - Low HV (~4kV → SHV cables/connectors are OK)
  - Avoid losses along the gas distribution (He); o-rings fixed to the mechanical plates to limit the losses from the chamber itself (if the chamber has not to be unmounted, it is better to use glue or silicon)
- Care in avoiding unwanted discharges due to HV
  - Clean surfaces (handling with gloves)
  - Insulating materials (plexiglas)
  - Rounding of conductors

Mechanics


35 Al planes
2mm thick
HV and GND
distribution
HV switch
Front wall
41 cm
32 cm
53 cm

Electric scheme for HV distribution

HV SWITCH: BEHLKE HTS 161-06 (http://www.behlke.de/pdf/331-06.pdf)



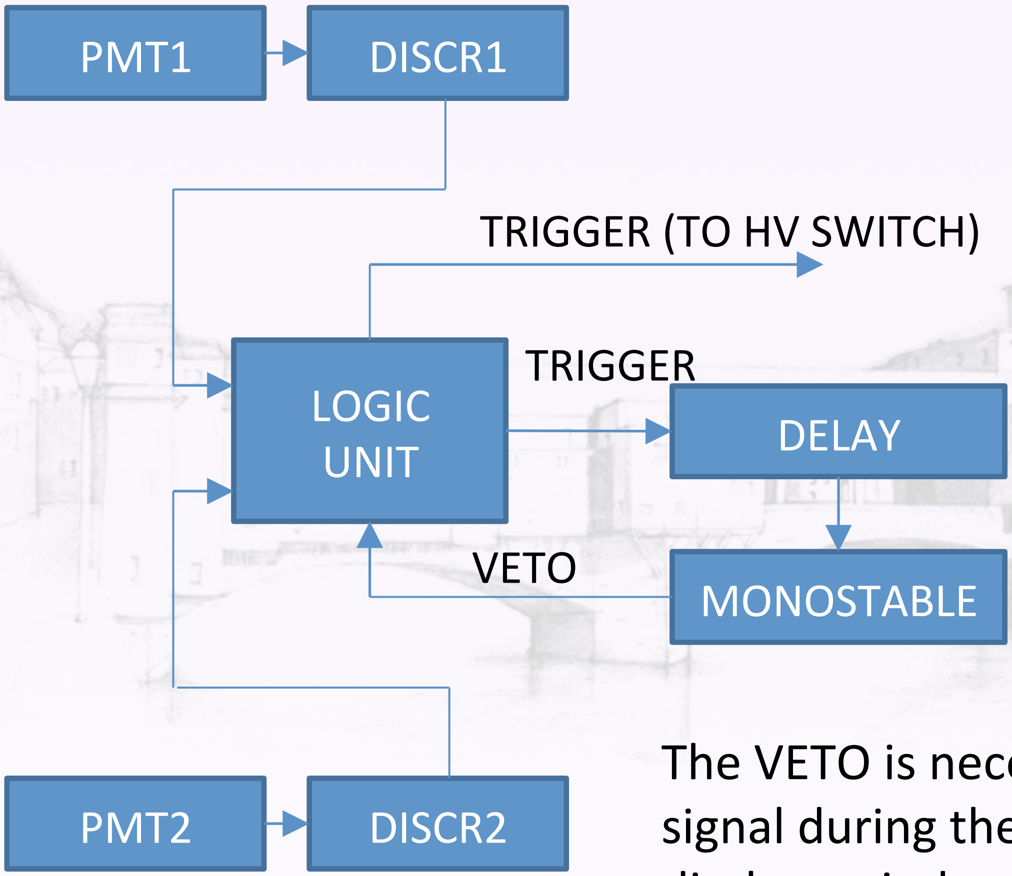
Switch time of the order of 100ns

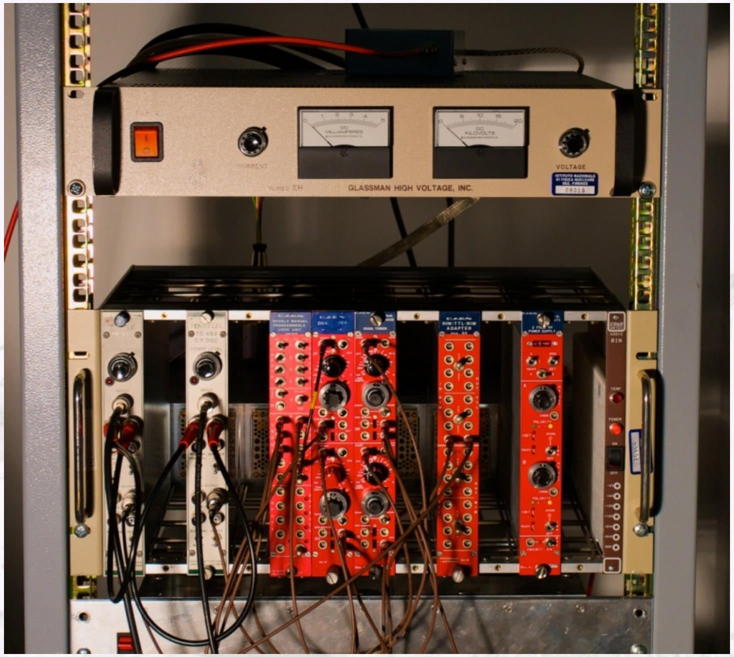
Time comstant RC ≅ 200μs to maintain the HV applied to the planes

Time comstant RC ≅ 170ms to reset the HV capacitors

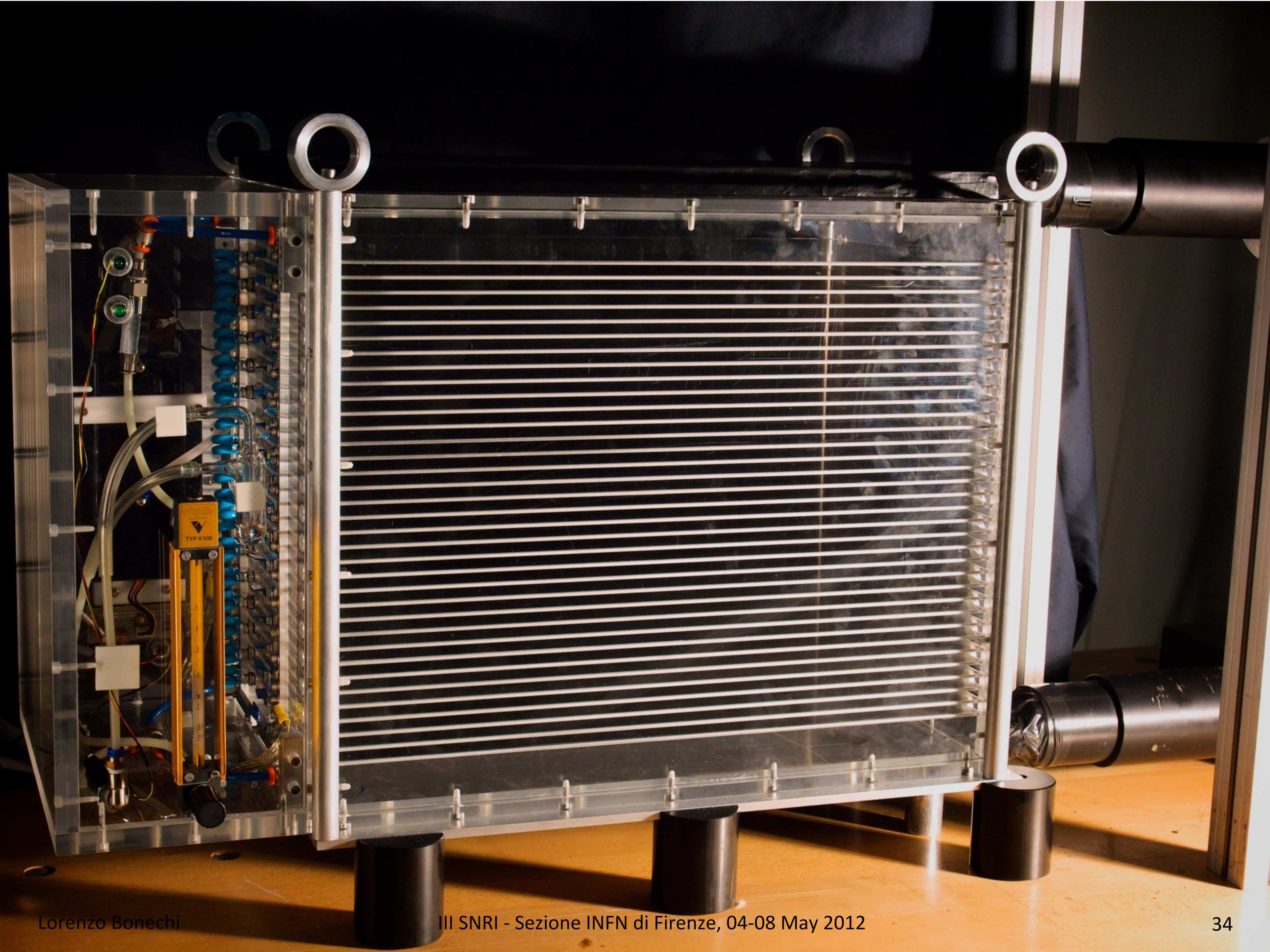
Electric scheme for trigger

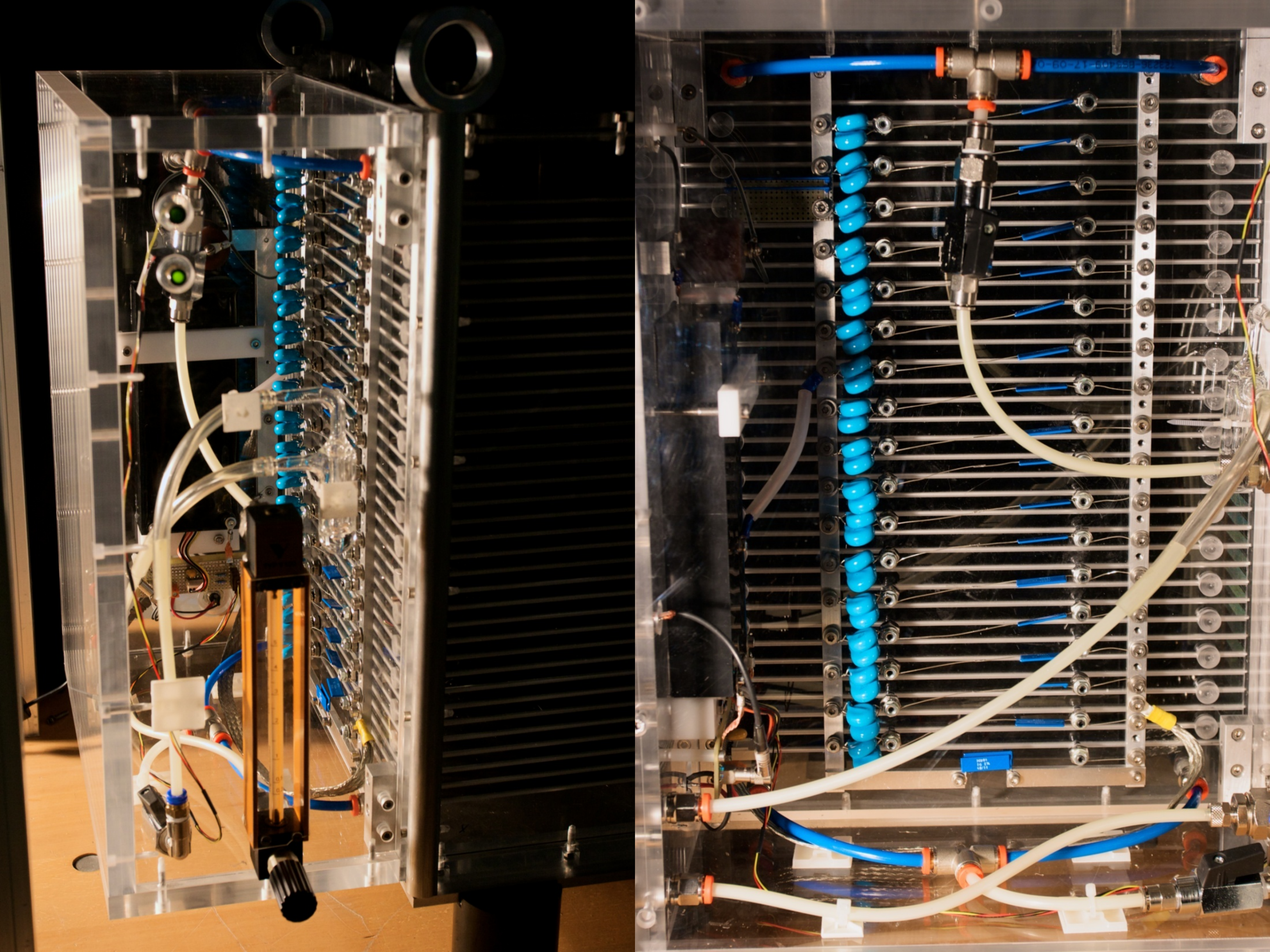
Trigger system is implemented by means of NIM modules





The VETO is necessary to suppress a new trigger signal during the setting up of the detector after discharge induced by a previous trigger


TYP V100



That’s not a toy!!!

- Always beware the risks and responsibility connected with handing detectors to the public
- Cloud Chamber:
  - dry-ice and isopropyl alcohol: handling precautions
  - when sources are used (like alpha): beware source deterioration in the cold volume rich of alcohol vapor (YouTube can be a bad teacher)
- Spark Chamber:
  - high voltages are applied to conductors located inside the chamber, but easily accessible
  - gases, usually inert, contained in high pressure vessels

Experimental activities and simple measurements

With the cloud chamber…

- The cloud chamber is very simple and can be seen in every details very easily
  - **Setup of the detector**
    - Heating the cover plate
    - Filling with Isopropyl alcohol
    - Placing the dry ice in the apposite box
  - **Observation of the tracks** with and without the radioactive source
    - The camber is active for more than one hour
    - Vertical CR tracks are more difficult to see (use the fan to keep the lower part of the front wall dry

With the spark chamber…

- Two chambers will be running after few hours of gas filling (filling is done right now… I hope…)
- After that one of these, the one newly produced in Florence for this purpose, can maybe carefully dismounted and analyzed in its details
- With the other (or both?), simple measurements can be implemented
  - **Measure of the efficiency**: study the ratio between the number of visible tracks and the number of real trigger events
  - **Study of the angular dependence of the CR flux** by making a movie and analyzing the frames by hand (this is maybe a too long work)

OTHER REQUESTS OR IDEAS FOR SIMPLE MEASUREMENTS ARE WELCOME

Thanks-ringraziamenti

Desidero ringraziare gli studenti Lapo Miccinesi, Michele Carlà e Alessio Tiberio per il lavoro svolto sui due rivelatori, sia dal punto di vista della progettazione che del loro sviluppo, l'officina del Dipartimento di Fisica di Firenze per la produzione di tutta la meccanica e Oscar Adriani, Marco Manetti e Marco Montecchi per il contributo alla progettazione e realizzazione della camera a scintille.

Infine, un ringraziamento va alla sezione INFN di Trieste che ha messo a disposizione un modello funzionante di camera a scintille (anch'esso fatto "in casa") occupandosi della preparazione in loco dell'apparato.