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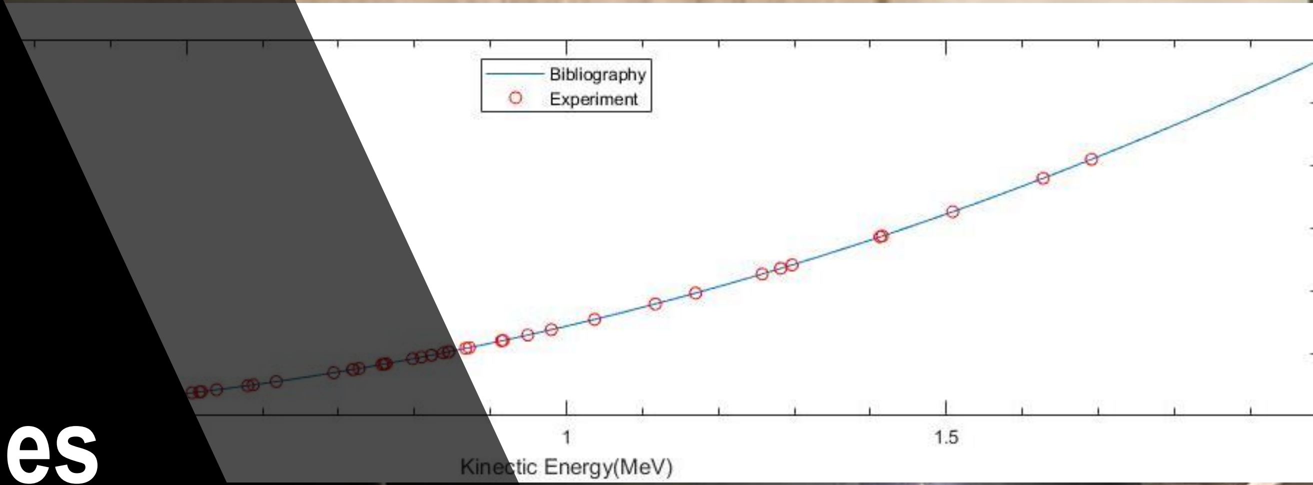

Problem 12

Particle Detectors for Dummies

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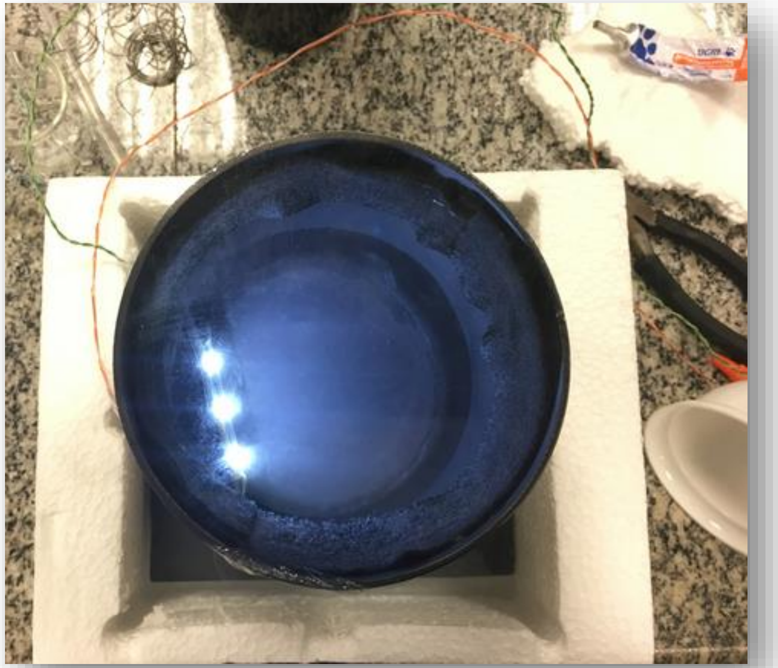
❑ The problem

- Build a **simple device** that can detect cosmic ray particles. **Characterize the particle identification capabilities of your device**. Try to **test your device in different conditions** and also **try to obtain the energy spectrum** of the cosmic ray particles.



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Particle Detector For Dummies

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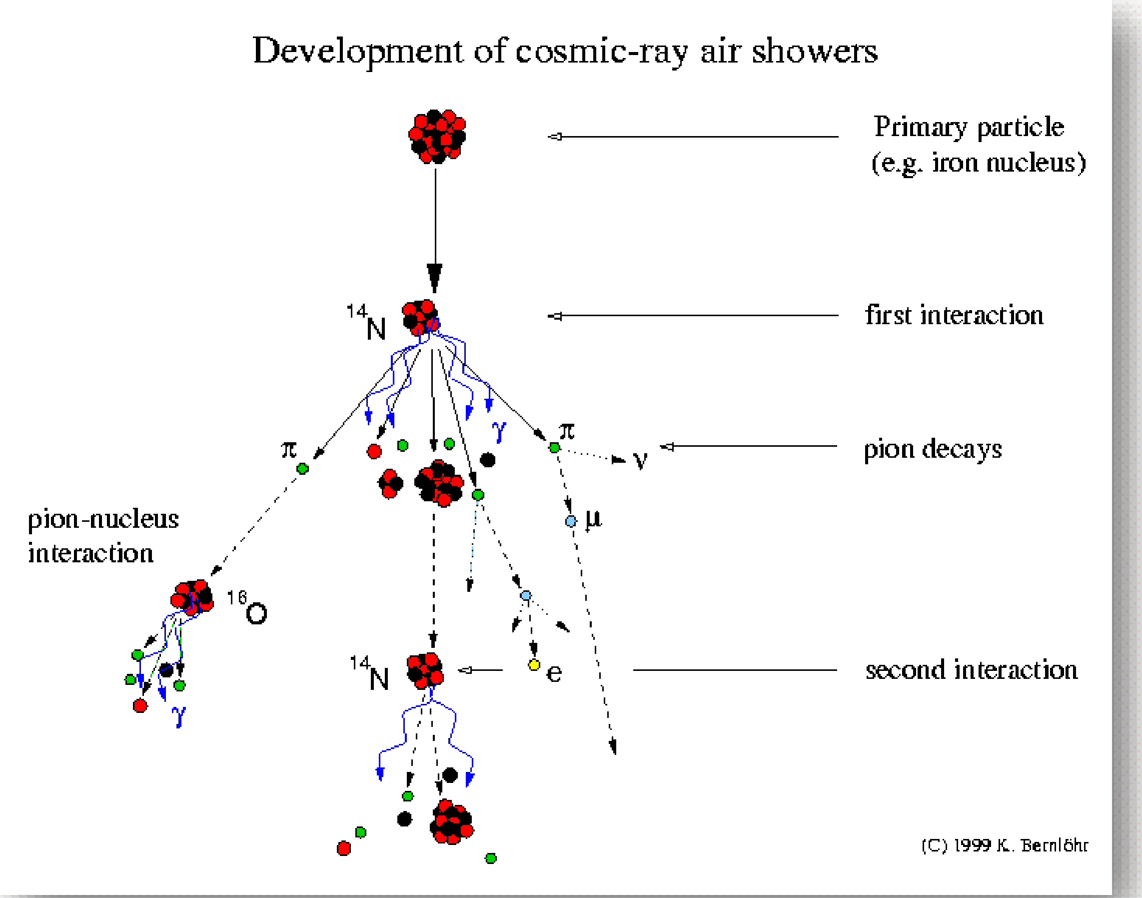
❑ The physical process

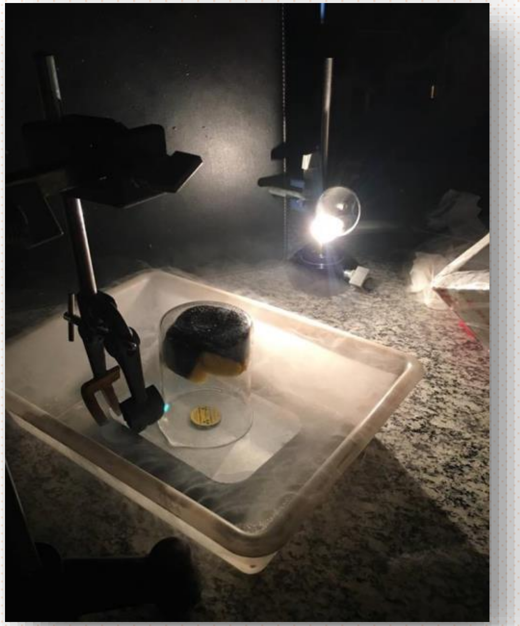
- Cosmic rays are mostly protons or light nuclei from star events that come from outer space, reaches Earth's atmosphere and decay in many others particles in a phenomenon called **particle shower**



❑ Our consideration

- We considered that a **simple cosmic ray** detector is one made by a cloud chamber which enables the visualisation of the particles' trajectory.
  - When a charged particle passes through the cloud chamber, it ionizes the molecules on it's way, condensing droplets of alcohol and making it visible by naked eye.

Example of traces on a cloud chamber



Example of cloud chamber

❑ Particles on a cloud chamber

- From the particles that reaches the Earth's surface, the mostly commons are electrons, muons, protons and pions.
  - Fact related to many particle discoveries such as the one of the pion!

Name	Symbol	Mass(MeV/c^2)	Mean life
Electron	e	0.51	∞
Muon	μ	105	$2.2 \times 10^{-6} s$
Proton	p	938	$> 2.1 \times 10^{29}$y
Pion	π	139	2.6×10^{-8} s

- Not all of them will be **so** common in our cloud chamber due to
  - Size
  - Illumination
  - Environmental conditions
- The most common ones will be low-energetic particles
  - After the decay that happened in the atmosphere

❑ What can we detect?

Equations

$m_0 = rest\ mass$

$v = particle\ velocity$

$c = 299.792.458\ m/s$

- A cloud chamber detects only **relativistic** particles!
  - If they were non-relativistic, particles would not even reach our cloud chamber!
  - We would need a **high** ionization inside the cloud chamber to see these kinds of particles
    - It was not obtained experimentally
- Our explanation is: these kinds of particles would lose all its energy on the path from the atmosphere to the cloud chamber

$$KE = m_0 c^2 \left[\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right]$$

Kinectic energy for relastivistic particles

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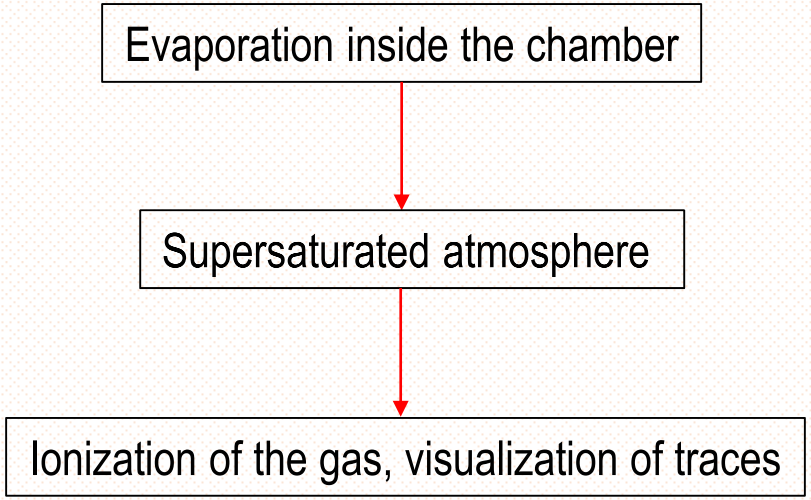
❑ Describing our experimental setup

- A cloud chamber is a box filled with supersatured gaseous substance,
  - a state with more vapour than in the equilibrium.

- In our solution, we used an **isopropil alcohol** cloud chamber
  - ~40 ml of alcohol for a chamber of $(15 \pm 0.05)\mathrm{cm}$ of width and $(20 \pm 0.05)\mathrm{cm}$ of height
  - Felt soaked with isopropyl alcohol at the side of the chamber

Top experimental view



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❑ Experimental data

- While filming the cloud chamber from above, we were able to make the following images,

Detection of a single proton in the experiments made → Short thick line (high energy particle)

- We have observed the trace of forty particles in our videos
- We use these traces to estimate the mean free path with Tracker Software

Detection of electrons → Long thin lines(low energy particle)

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❑ Cosmic rays?

- The particles detected in our setup can be produced by different sources, but to present a high energy, the source must have a very power source or a source very close to the detector;

- There is no radiation sources close to the detector. The particles detected mostly come from nature, such as particles from the ground or from the sky;

- In the ground: radioactive materials such as Uranium and other reactions in the nucleus. Once there is a great material density, most particles do not reach surface.

- From the sky: the cosmic ray particles interact with the atmosphere, generating the Cosmic Shower: primary particles which reach Earth's surface.

❑ For low-energy particles

- Low energy particles show the following differential cross-section scattering

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z\alpha\hbar c}{2T(T + 2m_e c^2 sen^2\frac{\theta}{2}}\right) \times \left((m_e c^2) sen\frac{\theta}{2} + (T + m_e c^2)^2 \cos\frac{\theta}{2}\right) \sim \left(\frac{Z\alpha\hbar c}{E\ sen\frac{\theta}{2}}\right) \quad \text{Eq. 1}$$

- We notice theoretically through these considerations that $\frac{d\sigma}{d\Omega}$ is proportional to $\frac{1}{E^2}$

- Less energy→ higher likelihood of collision, thus ionizing the gas inside the cloud chamber
  - The mean free path obtained is

$$\boxed{l = \frac{1}{\sigma\rho}} \quad \text{Eq. 2}$$

  - Where
    - l is the length of the trace observed in the chamber
    - ρ is the alcohol vapor density
    - σ is the cross-section

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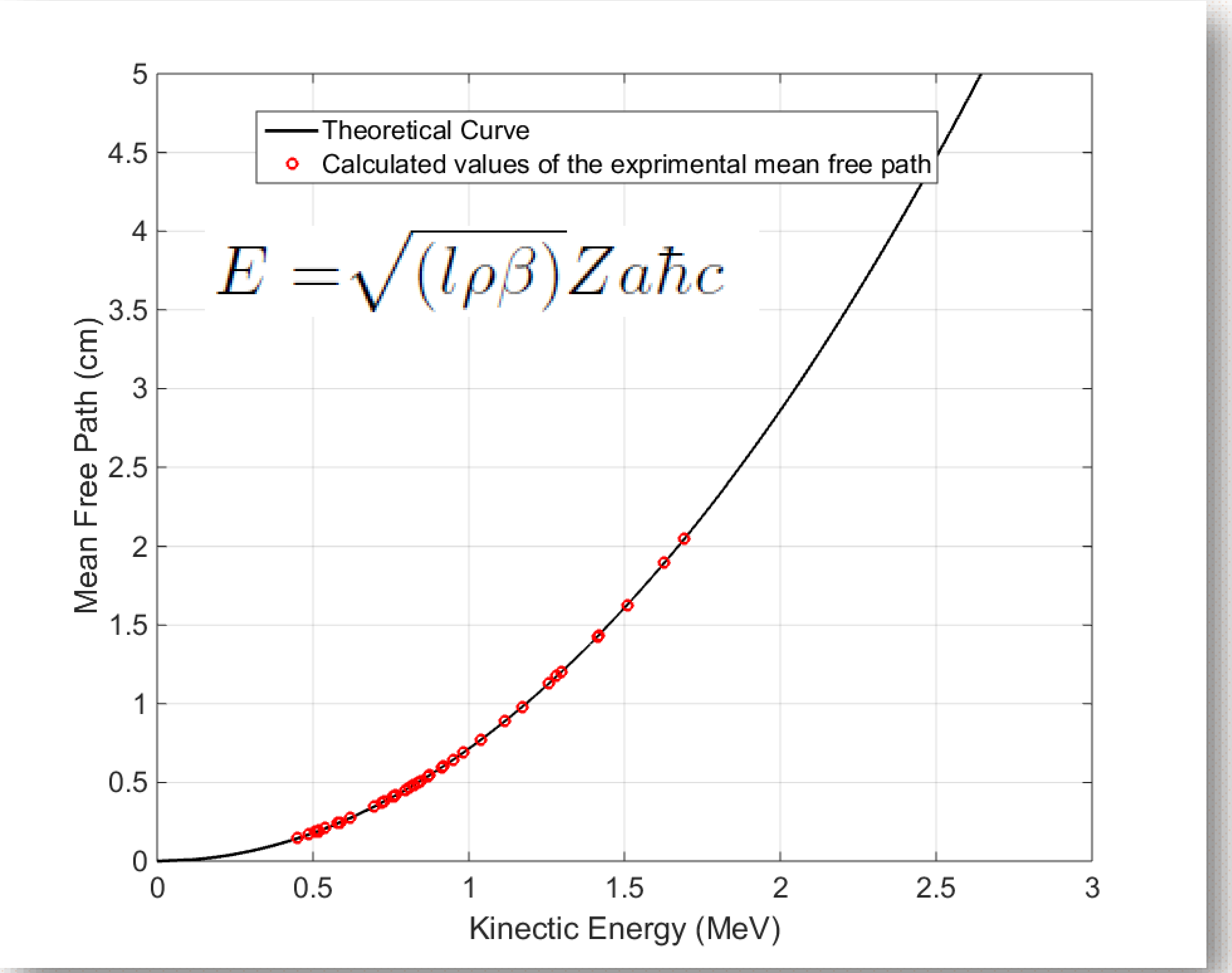
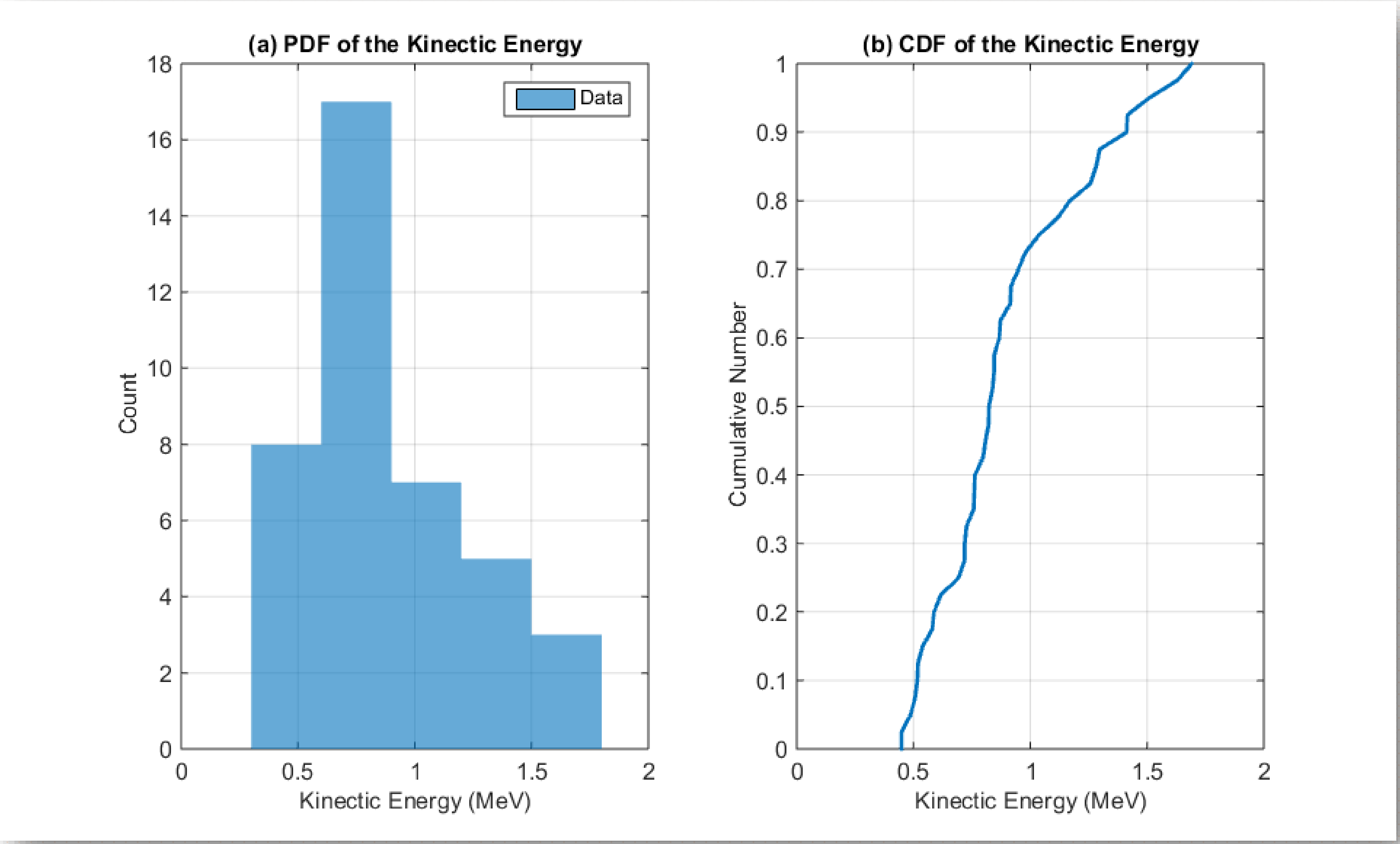
❑ Kinetic Energy of observed particles

Solving the Eq.1 and application of the Eq.2, we simulate theoretical curve and calculate de EK of particles detected



❑ The distribution of Kinetic Energy



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Experimental observations

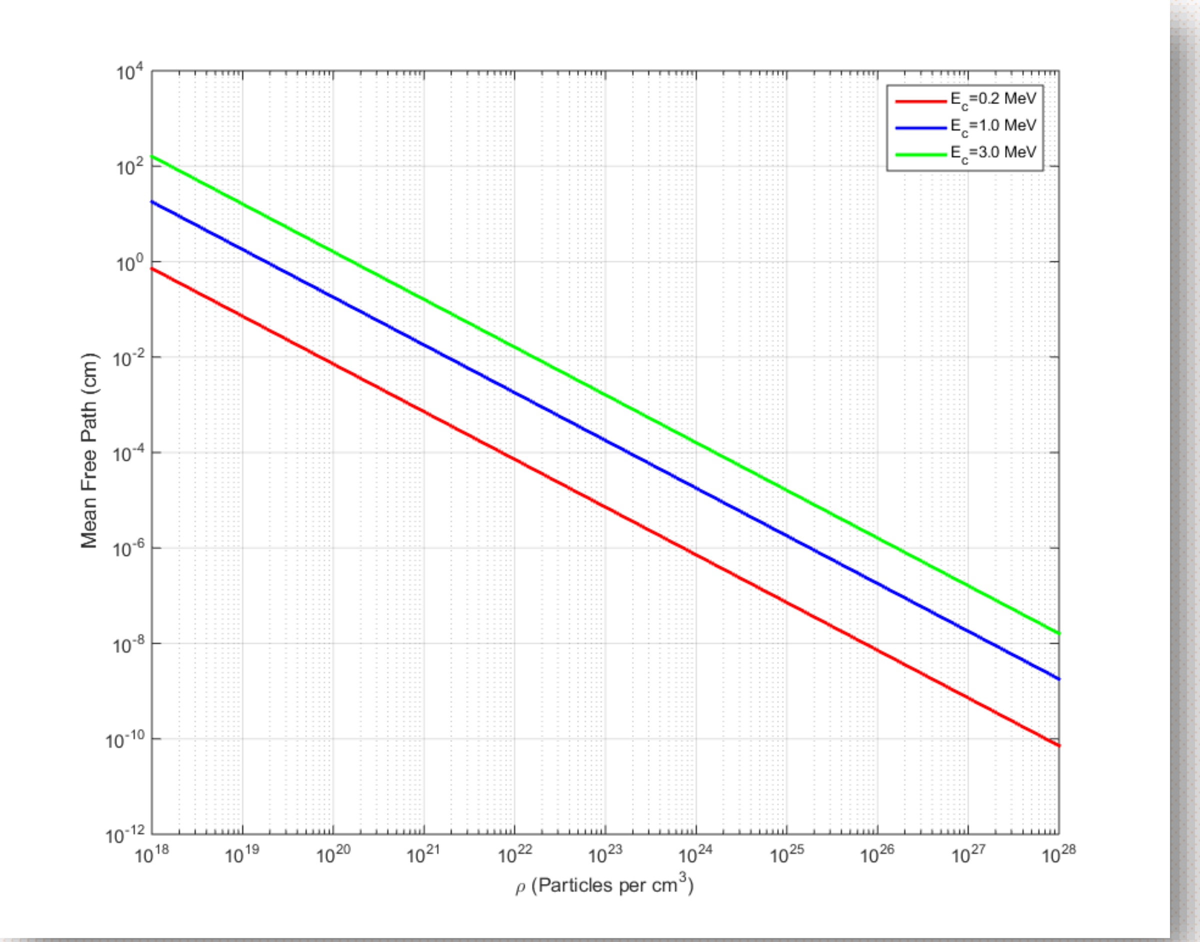
- Considering the temperature gradient between the bottom of the chamber (with liquid nitrogen) and the mean free path
  - Lowering the height of the chamber, the mean free path would be decreased in a given surface area!
- Mean free path was already defined as l:

$$l = \frac{1}{\sigma\rho}$$

- Why is the air density an important parameter to visualize the particles?

❑ Mean free path and density ρ

- With the experimental observation about the behavior for different concentrations of ionized gas molecules
  - We made a simulation considering main free path and density



$$l = \frac{1}{\sigma\rho}$$

Considering different densities we obtain different free paths

Influences directly in the energy we can observe experimentally with our cloud chamber

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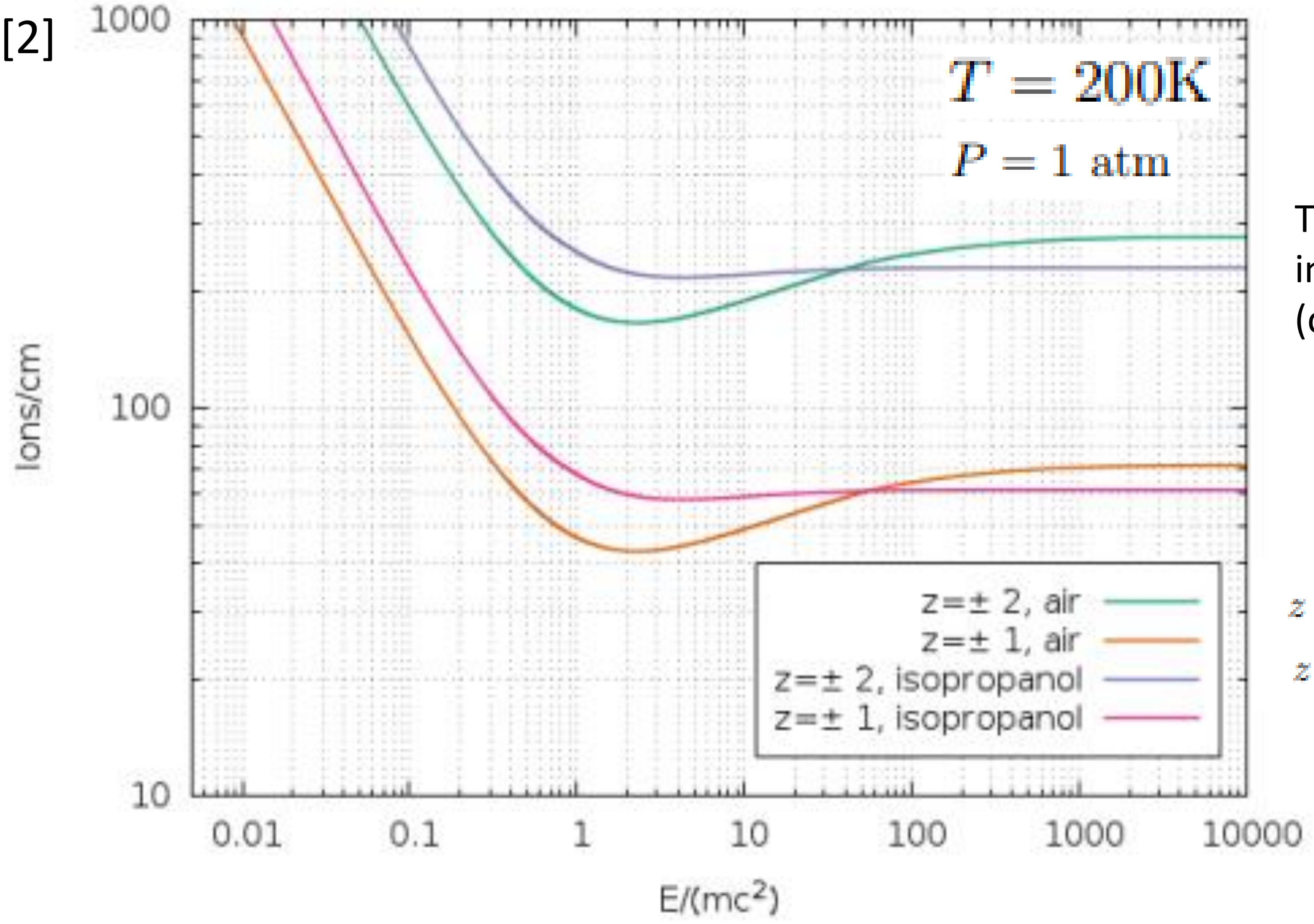
❑ Influence of chamber gas

By ref [2]



Specific ionisation for different charges and absorbing media. The intersection between the air and isopropanol curves is due to the density effect factor.

The chamber gas influences on ionization (creation of ion)

$z = \pm 1$ (e.g., $e^{\pm}$ and $\mu^{\pm}$)

$z = 2$ (e.g., α particles)

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Conclusion

- We demonstrate how to make an apparatus to detect particles;
- We can use this apparatus to measure energy spectrum from particles;
- We have made some considerations regarding the chamber gas
- It is more likely that these are cosmic ray particles, once there is no source close to it. But the exactly origin of each single particle is not possible to be determined.

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References

- [1] Lagana, C. "*Estudo de raios cósmicos utilizando uma câmara de nuvens de baixo custo*", RBF, v33, n3, (2011).
- [2] Muñoz, I. E. "Detection of particles with a cloud chamber", Zientzia eta Teknology Fakultatea, ZTF, (2015).

❑Appendix

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Low-energy particles

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z\alpha\hbar c}{2T(T + 2m_e c^2 sen^2 \frac{\theta}{2}}\right) \times \left((m_e c^2) sen \frac{\theta}{2} + (T + m_e c^2)^2 \cos\frac{\theta}{2}\right) \sim \left(\frac{Z\alpha\hbar c}{E\ sen \frac{\theta}{2}}\right)$$

Symbol	Description	Value
Z	Carbon atomic number	6
α	Fine structure	1/137
$\hbar c$	Constant	197.3 MeV fm
m_e	Electron mass	$0.51 MeV/c^2$
ρ	Vapor density	2.52×2.517^{19}
K/A	Constant	$0.0051 MeV\,cm^2/g$
I	Ionization energy	-
T	Kinectic Energy	-
E	Total energy	-

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❑ Low-energy particles

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z\alpha\hbar c}{2T(T + 2m_e c^2 sen^2\frac{\theta}{2}}\right) \times \left((m_e c^2) sen\frac{\theta}{2} + (T + m_e c^2)^2 \cos\frac{\theta}{2}\right) \sim \left(\frac{Z\alpha\hbar c}{E\ sen\frac{\theta}{2}}\right)$$

Solving $\frac{d\sigma}{d\Omega}$ differential cross-section and integration on θ from 3 ° to 357° by the consideration in the ref [1]

$$E = \sqrt{(l\rho\beta)} Z\alpha\hbar c$$

❑ Bete Bloch's equation

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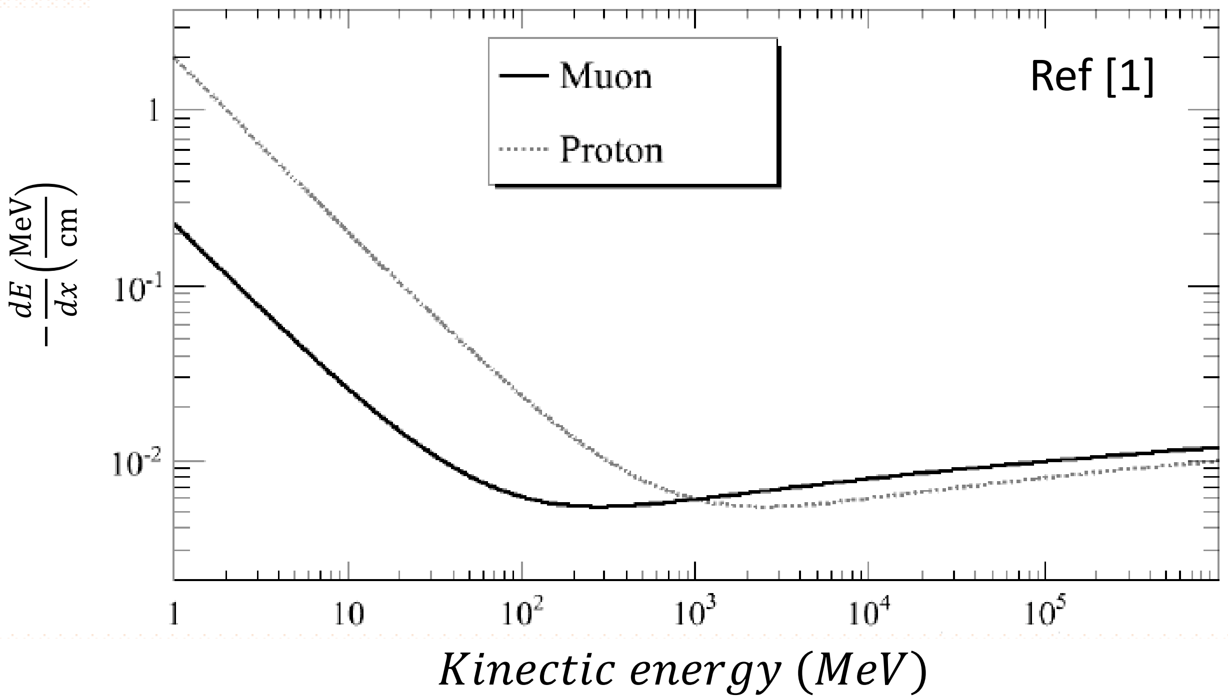
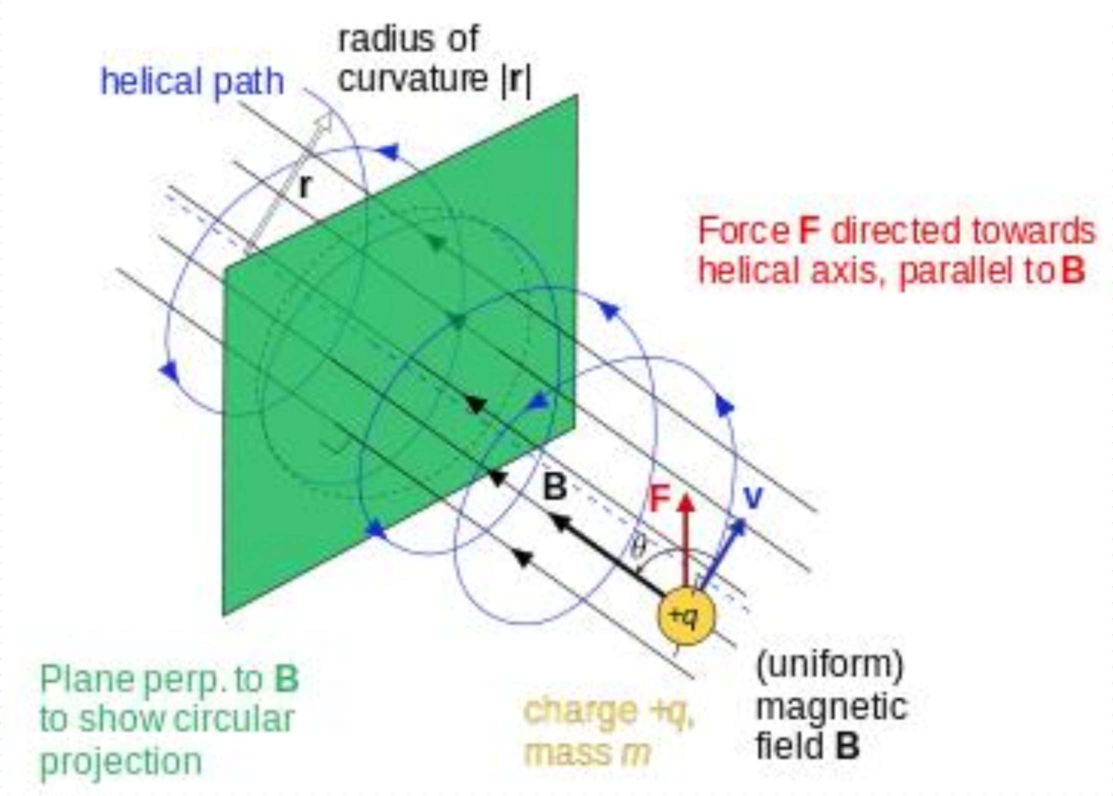
- What is the equation that describes transition to higher energies in our cloud chamber?

$$-\frac{dE}{dx} = \frac{\rho K Z}{A}\left[\frac{\ln\left(\frac{2m_e c^2}{I}\left[\left(1+\frac{T}{mc^2}\right)^2 - 1\right]\right)}{1-\left(\frac{T}{mc^2}+1\right)^{-2}} - 1\right]$$



❑ Determining the mass of particles

- We can use a Lorentz force to measuring the mass of particles:



$$\vec{F} = q(\vec{v} \times \vec{B})$$

$$\vec{F} = \frac{mv^2}{\rho}$$

For perpendicular magnetic field:

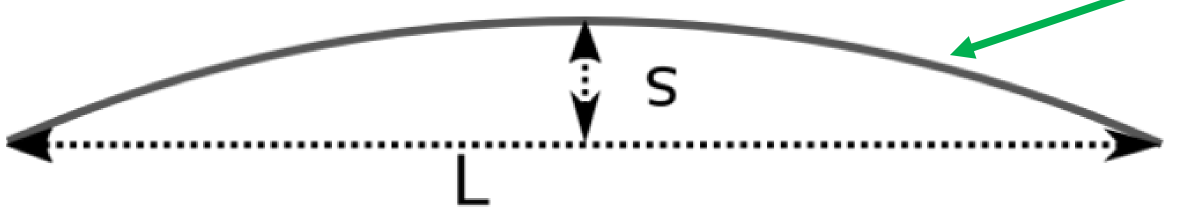
$$qvB = \frac{mv^2}{\rho}$$

Experimentally the B field must be homogeneous in the chamber, but this is not enough!

❑ Influence of a magnetic field applied to the chamber

- How to define the value of magnetic field to observe the mass particles for a limited chamber?
- Using the Sagitta method, we approximated s as the resolution we obtain experimentally with the Tracker software!

Trace of particle in chamber



Measuring S and L we can obtain the ρ radius of particle curve

$$s = \rho\left[1 - \sqrt{1 - \left(\frac{L}{2\rho}\right)^2}\right] \approx \frac{L^2}{8\rho} + \mathcal{O}\left(\frac{L^4}{\rho^3}\right)$$

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Kinetic energy of relativistic particles

$$KE = m_0 c^2 \left[\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1 \right]$$

$$(a+x)^n = a^n + na^{n-1}x + \frac{n(n-1)}{2!}a^{n-2}x^2 + \ldots$$

$$\left(1-\frac{v^2}{c^2}\right)^{-1/2} = 1 + \frac{1}{2}\frac{v^2}{c^2} + \frac{\frac{-1}{2}\frac{-3}{2}}{2!}\frac{v^4}{c^4} + \ldots$$

$$KE = \frac{1}{2}m_0 v^2 + \frac{3}{8}\frac{m_0 v^4}{c^2} + \frac{5}{16}\frac{m_0 v^6}{c^4} + \ldots$$

$$KE \approx \frac{1}{2}m_0 v^2 \quad for \quad v \ll c$$

❑ Temperature variation with chamber height

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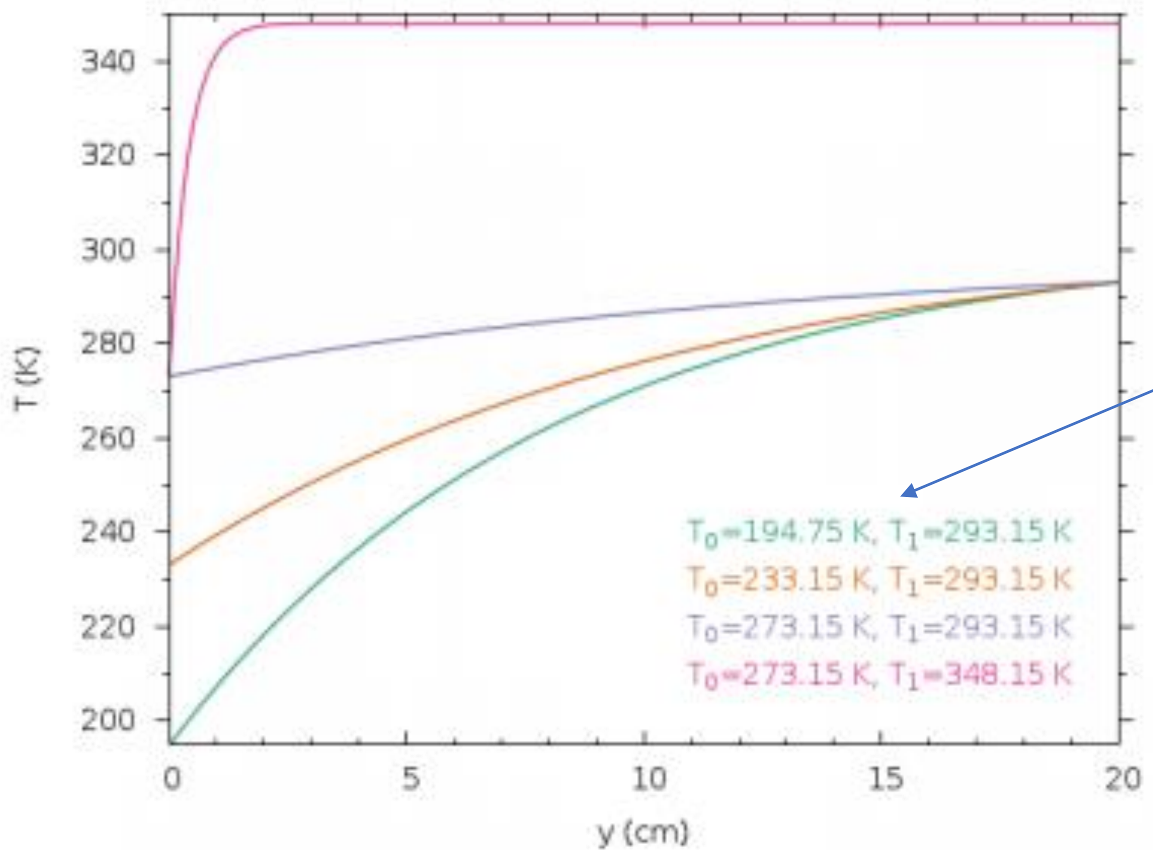
By ref[2]



Gradient temperature

Figure 2.6: Temperature distribution inside a diffusion cloud chamber for different bottom and top temperatures. Data for isopropanol and $h = 20$ cm has been used.