



# Development and Construction of a Muon Telescope

Ferienakademie 2024  
Group 3 - Dark Matter and the Cosmos

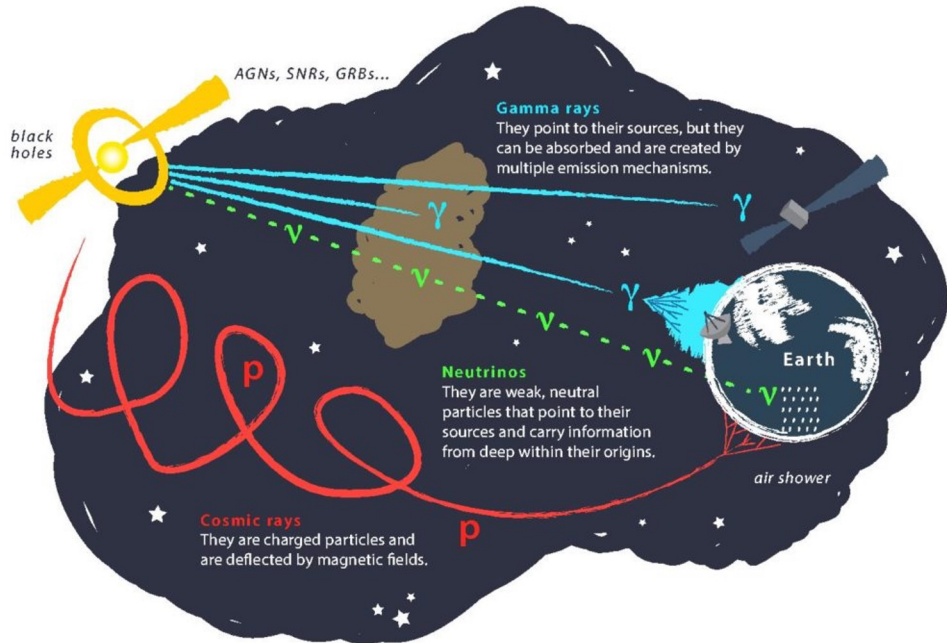
# Index

- Introduction to cosmic rays and muons
- Experimental setups and measurements
- Results and discussion
- Uncertainties and efficiency

The image features a dark night sky filled with stars. A bright star with a four-pointed diffraction pattern is positioned in the upper left. A meteor streaks across the top of the frame. Overlaid on the sky is a complex, branching network of thin white lines that resemble particle tracks or a particle shower. The bottom of the image shows the dark silhouette of a mountain range with some faint lights visible in the valleys.

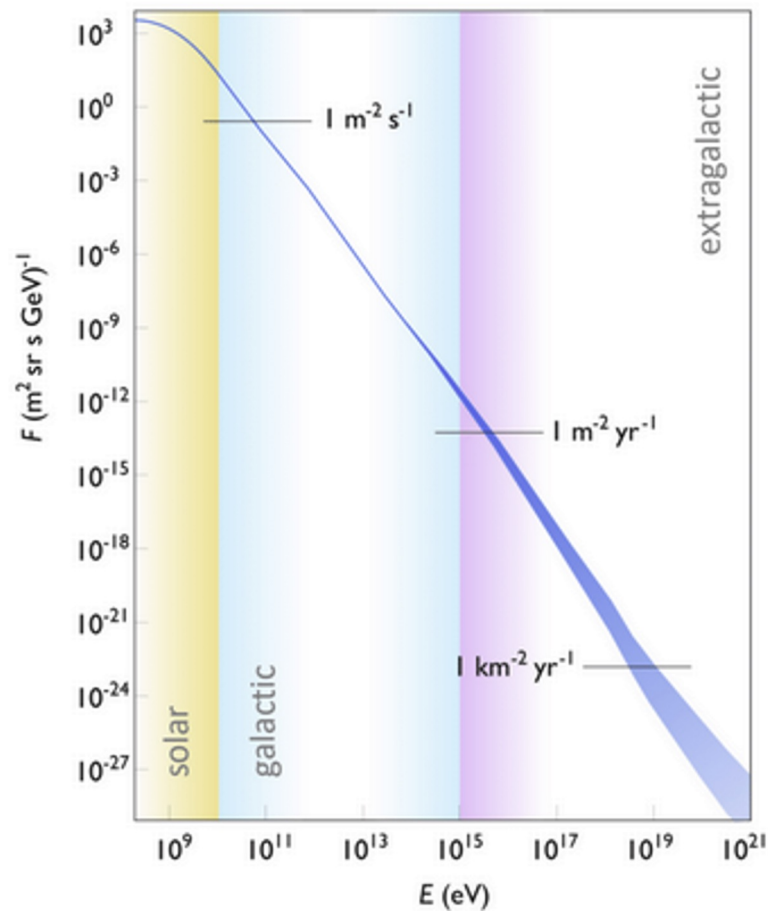
# Introduction to cosmic rays and muons

# Primary cosmic rays

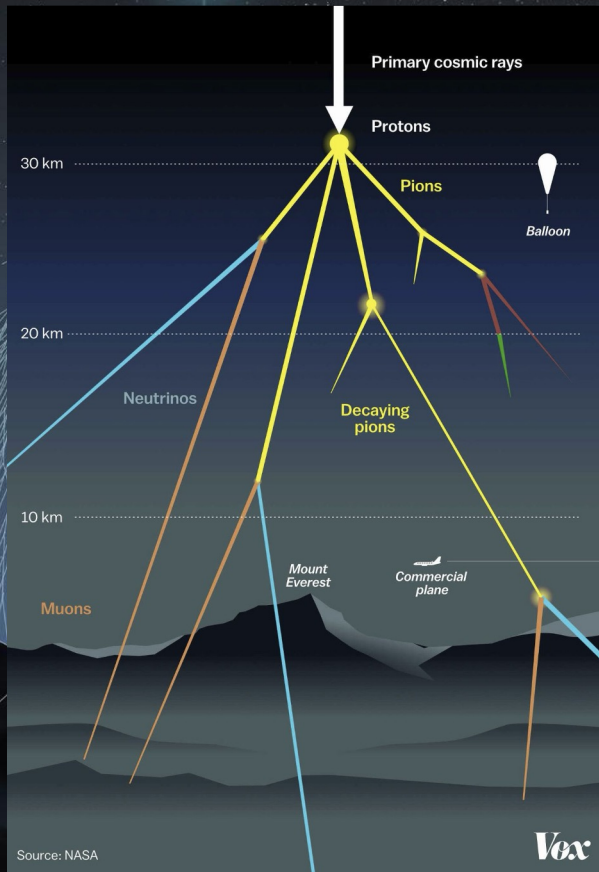


- Particles with (extra)galactic or solar origin e.g.:
  - Fusion processes in sun
  - Supernovas
  - ...
- Primarily protons and  $\alpha$ -particles

# Energy distribution



# Secondary cosmic rays

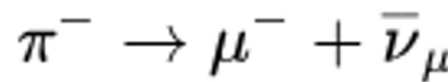
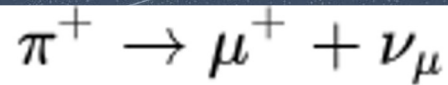


- Reactions of primary cosmic rays in upper atmosphere:

- Production of baryonic matter:

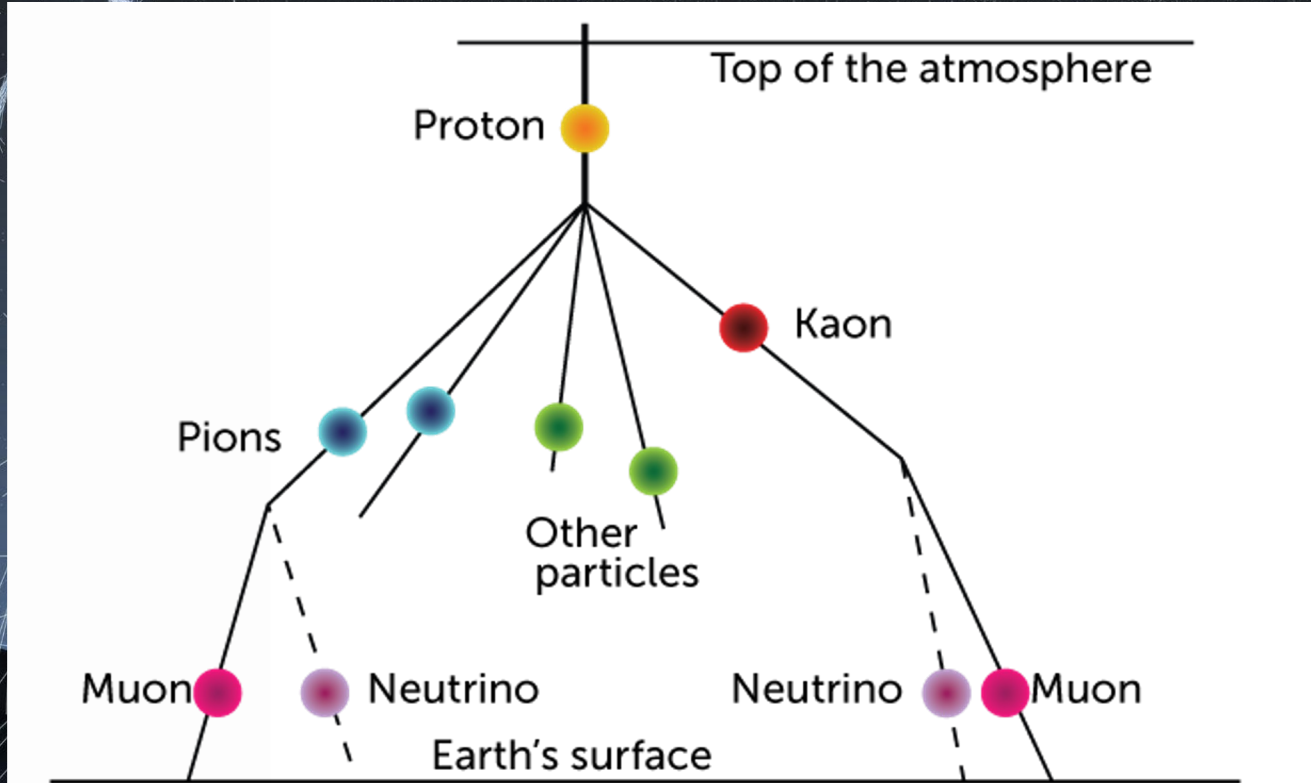
- Protons, Neutrons, **Pions**, **Kaons**

- Decay of Pions and Kaons (very short lived):

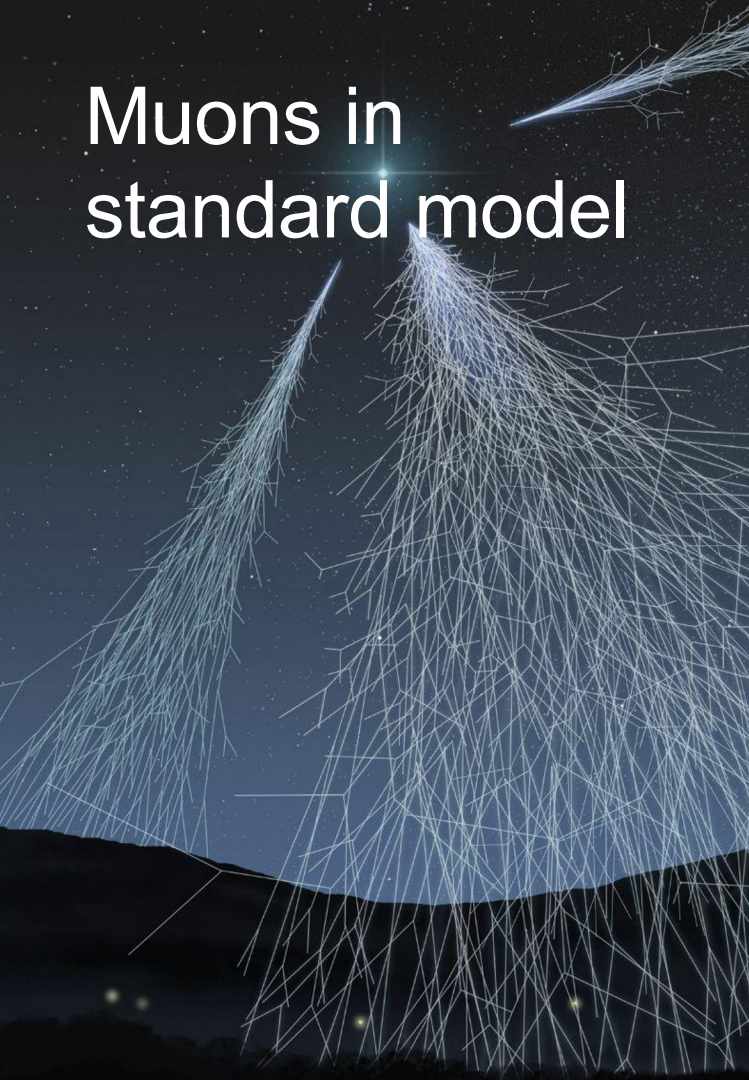


- → Production of muons in upper atmosphere (~10km)

# Secondary cosmic rays



# Muons in standard model



## Standard Model of Elementary Particles

three generations of matter (fermions)			interactions / force carriers (bosons)	
I	II	III		
$=2.2 \text{ MeV}c^2$ $\frac{2}{3}$ $\frac{1}{2}$ <b>u</b> up	$=1.28 \text{ GeV}c^2$ $\frac{2}{3}$ $\frac{1}{2}$ <b>c</b> charm	$=173.1 \text{ GeV}c^2$ $\frac{2}{3}$ $\frac{1}{2}$ <b>t</b> top	$0$ $0$ $1$ <b>g</b> gluon	$=124.97 \text{ GeV}c^2$ $0$ $0$ $0$ <b>H</b> higgs
$=4.7 \text{ MeV}c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ <b>d</b> down	$=96 \text{ MeV}c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ <b>s</b> strange	$=4.18 \text{ GeV}c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ <b>b</b> bottom	$0$ $0$ $1$ <b><math>\gamma</math></b> photon	<b>SCALAR BOSONS</b>
$=0.511 \text{ MeV}c^2$ $-1$ $\frac{1}{2}$ <b>e</b> electron	$=105.66 \text{ MeV}c^2$ $-1$ $\frac{1}{2}$ <b><math>\mu</math></b> muon	$=1.7768 \text{ GeV}c^2$ $-1$ $\frac{1}{2}$ <b><math>\tau</math></b> tau	$0$ $1$ $1$ <b>Z</b> Z boson	
$<2.2 \text{ eV}c^2$ $0$ $\frac{1}{2}$ <b><math>\nu_e</math></b> electron neutrino	$<0.17 \text{ MeV}c^2$ $0$ $\frac{1}{2}$ <b><math>\nu_\mu</math></b> muon neutrino	$<18.2 \text{ MeV}c^2$ $0$ $\frac{1}{2}$ <b><math>\nu_\tau</math></b> tau neutrino	$=80.39 \text{ GeV}c^2$ $\pm 1$ $1$ <b>W</b> W boson	

QUARKS

LEPTONS

GAUGE BOSONS  
VECTOR BOSONS

SCALAR BOSONS

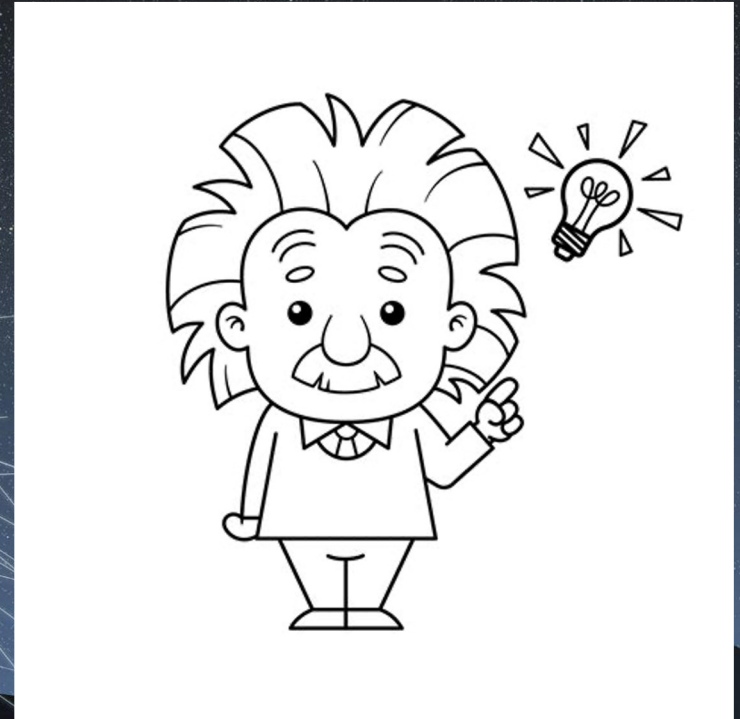


# Muons in standard model

- “Heavy electron”:
  - Charge:  $q = 1.6022 \times 10^{-19} \text{ C} = e$
  - Mass:  $m = 106 \text{ MeV} \sim 200^* m_e$
  - Spin:  $s = 1/2$
- Unstable and short lived:
  - Life time:  $\tau = 2.2 \mu\text{s}$
  - Lets assume:  $v \sim c$ :
  - Mean path:  $L = v \cdot \tau \sim 0.6 \text{ km} ??$

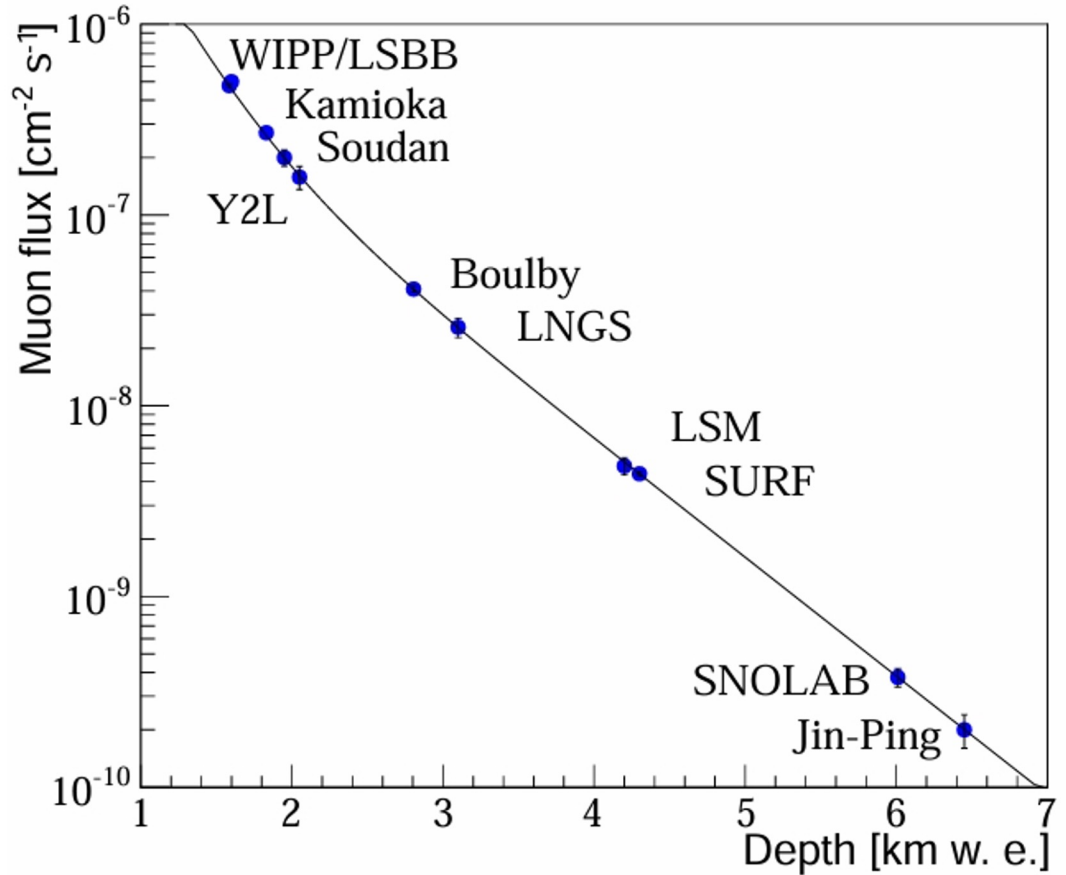
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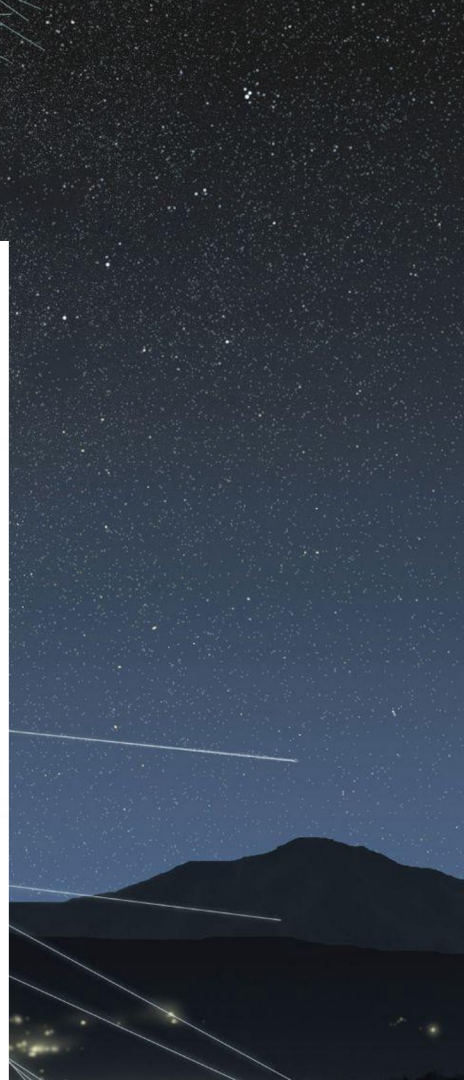
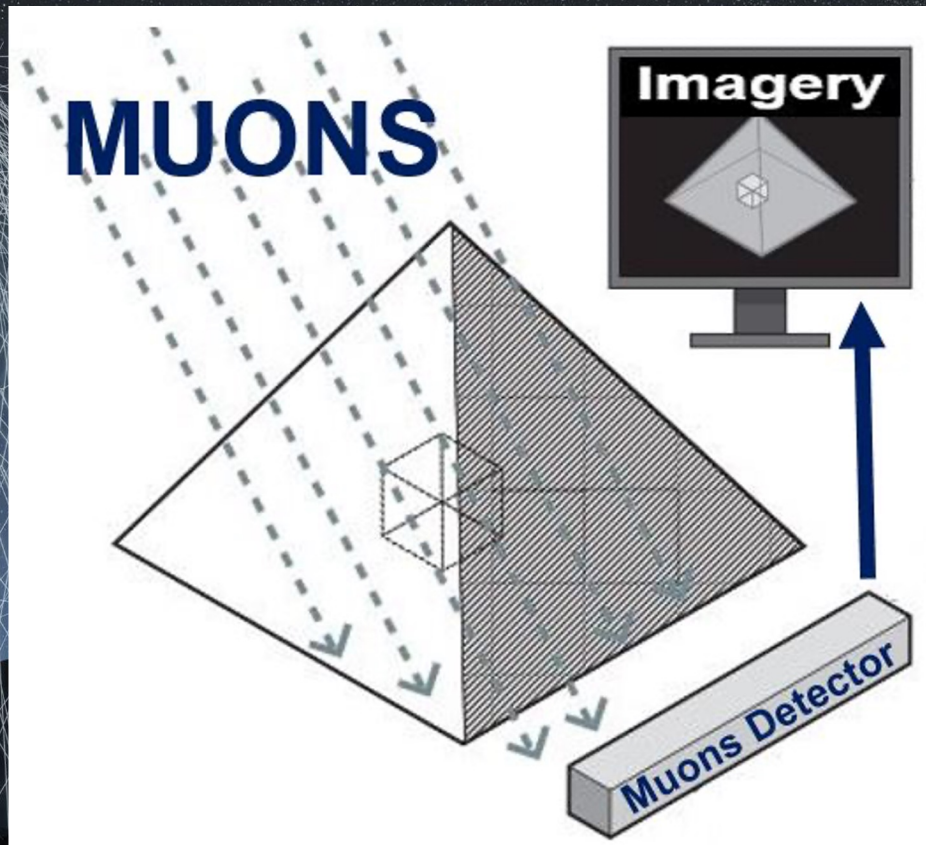


# Muon Flux

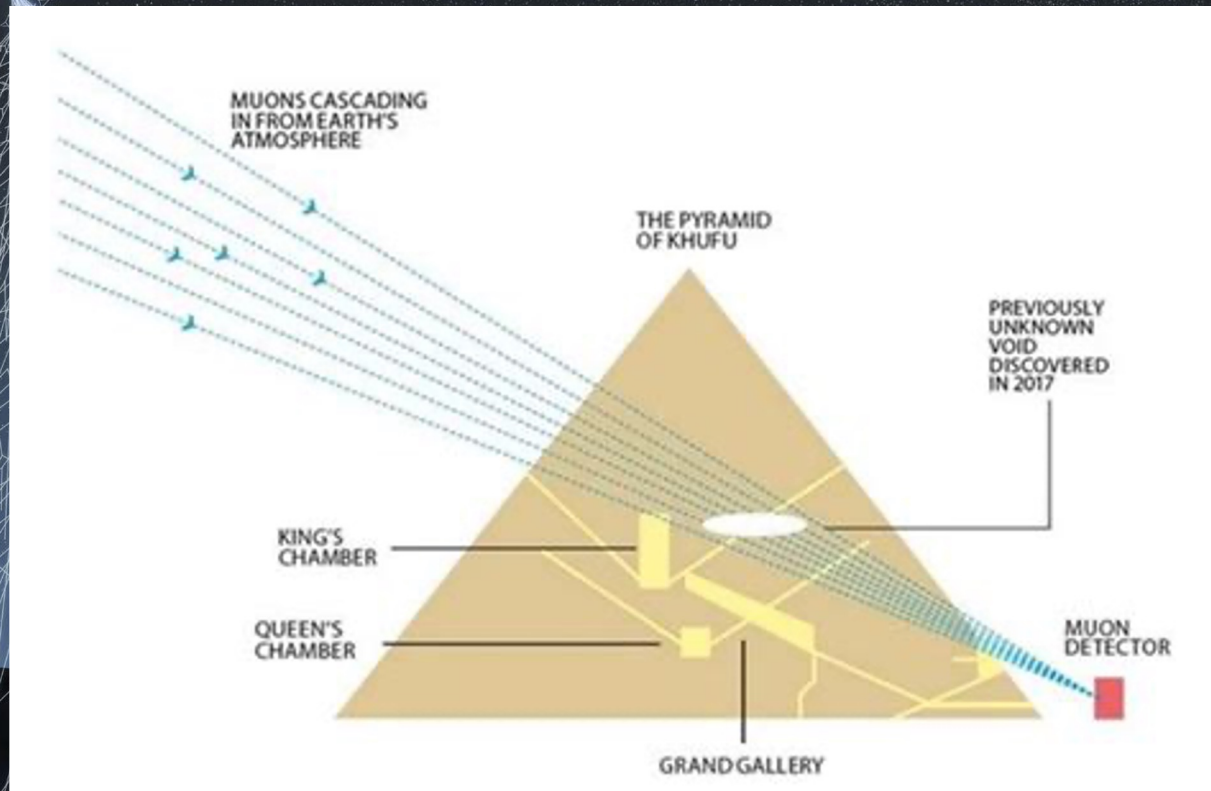
- Muon Flux at sea level:  $1 \text{ cm}^2/\text{s}$
- Minimum Ionizing Particle:  
→ Coincidence rate  
(Later)



# Muongraphy



# Muongraphy



The image features a dark night sky filled with stars. A prominent bright star with a four-pointed diffraction pattern is located in the upper left. A meteor shower is depicted as a dense field of white lines radiating from a point in the sky, with several lines extending downwards towards the horizon. The background shows the dark silhouette of a mountain range and a town with glowing lights at the bottom. The text "Experimental setup" is centered in the middle of the image.

# Experimental setup

# Setup

Power supply

Coincidence module

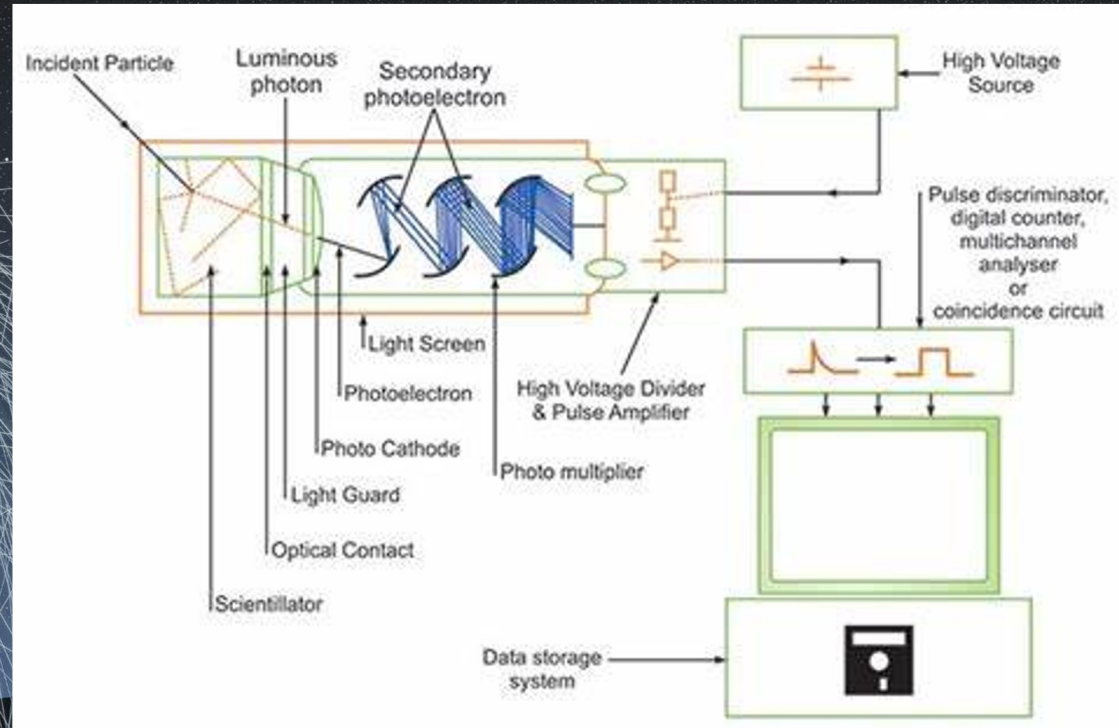
Detection system



# Detection system



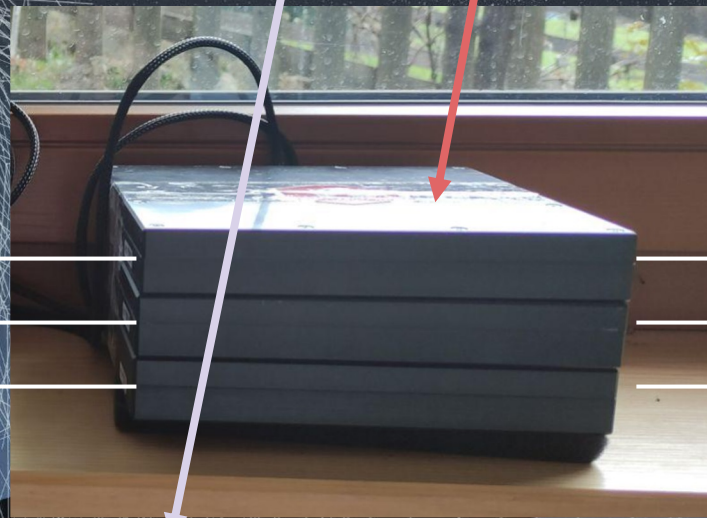
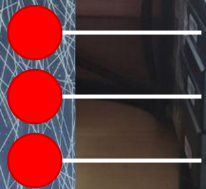
15×15×1 cm<sup>3</sup>,  
plastic scintillator



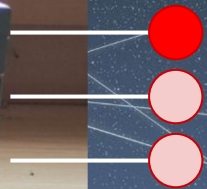


# Coincidence module

Coincident



Not coincident



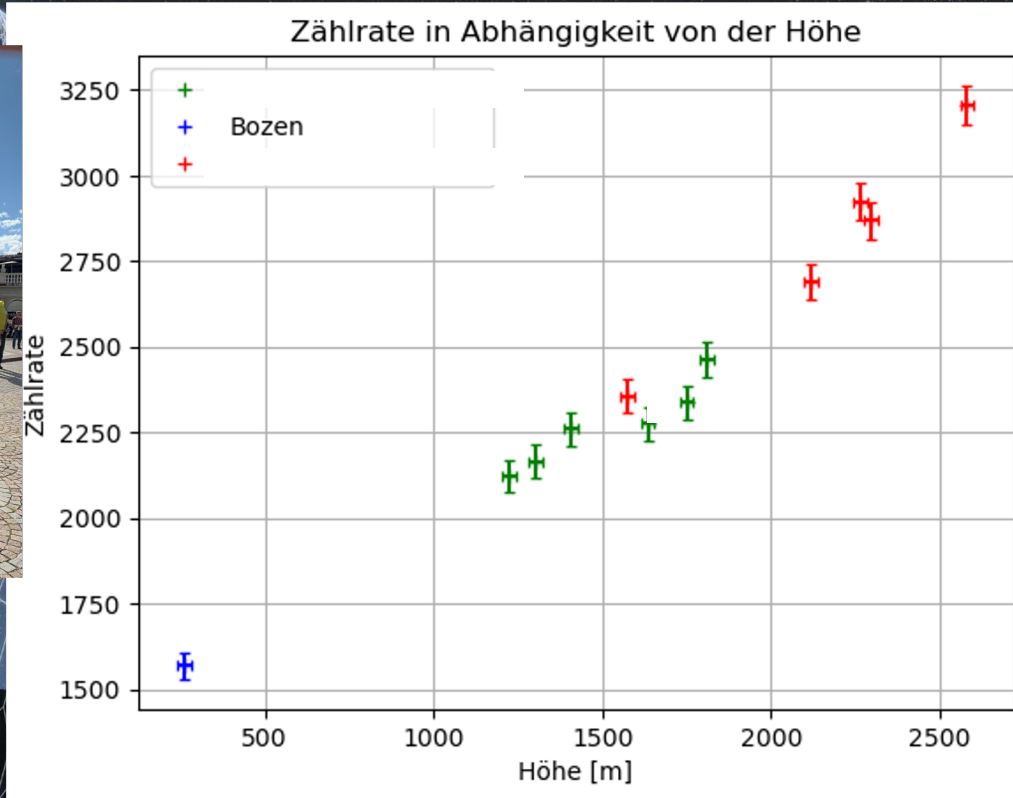
# Measurements

Date	Location	Setup, measurements
25th September	Feldrand	Separated, different angles
26th September	Mine	Stacked, @ different depths
27th September	Bozen, Waltherplatz	Stacked
28th September	Feldrand	Separated, different angles
28th September	Mairwald - Staubecken	Stacked, @ different depths
29th September	Reinswald-Kassianspitze- Latzfonser Kreuz	Stacked, @ different depths
29th-30th Sept.	Feldrand	Stacked, long run
30th-31st Sept.	Feldrand	Efficiency and random coincidence

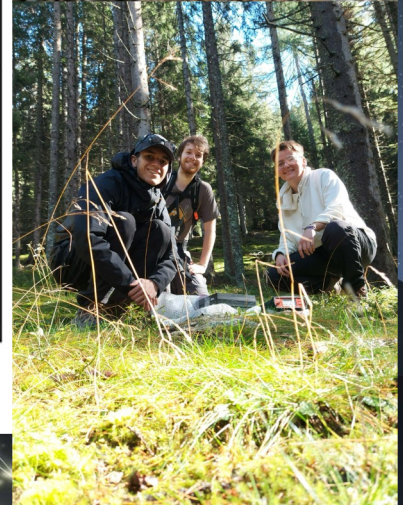
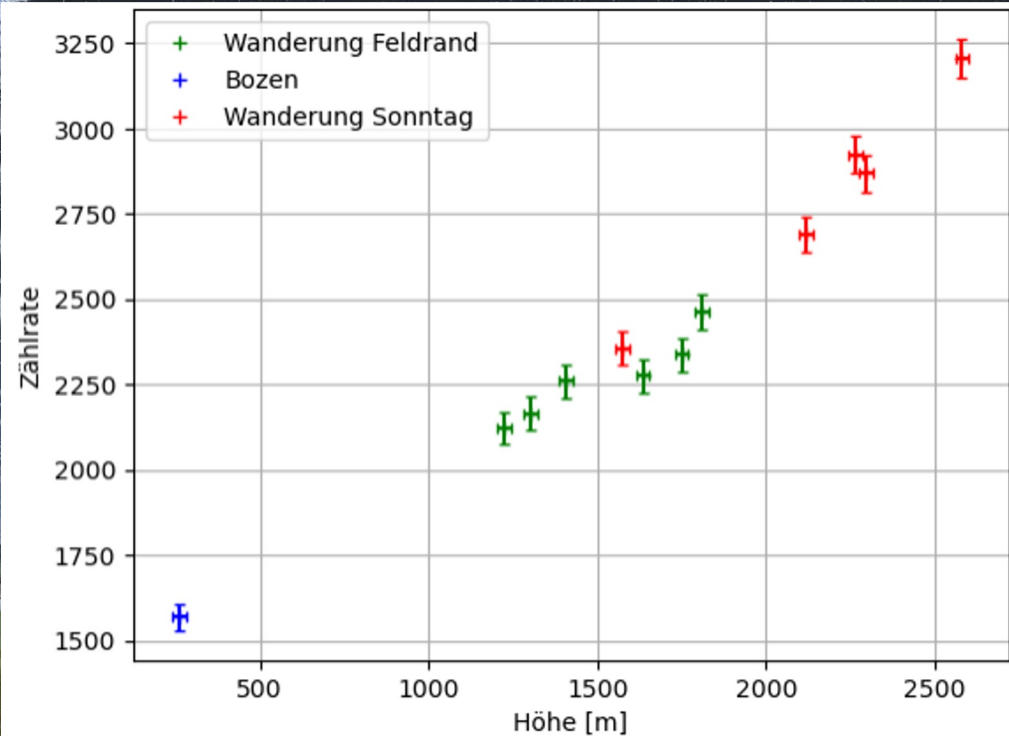
A night sky with a star and a meteor shower. The sky is dark blue with many small white stars. A bright star is visible in the upper left. A meteor shower is shown as a dense field of white lines radiating from a point in the sky. The lines are of varying lengths and directions, creating a fan-like shape. The background shows a dark horizon with silhouettes of hills and some distant lights.

# Results

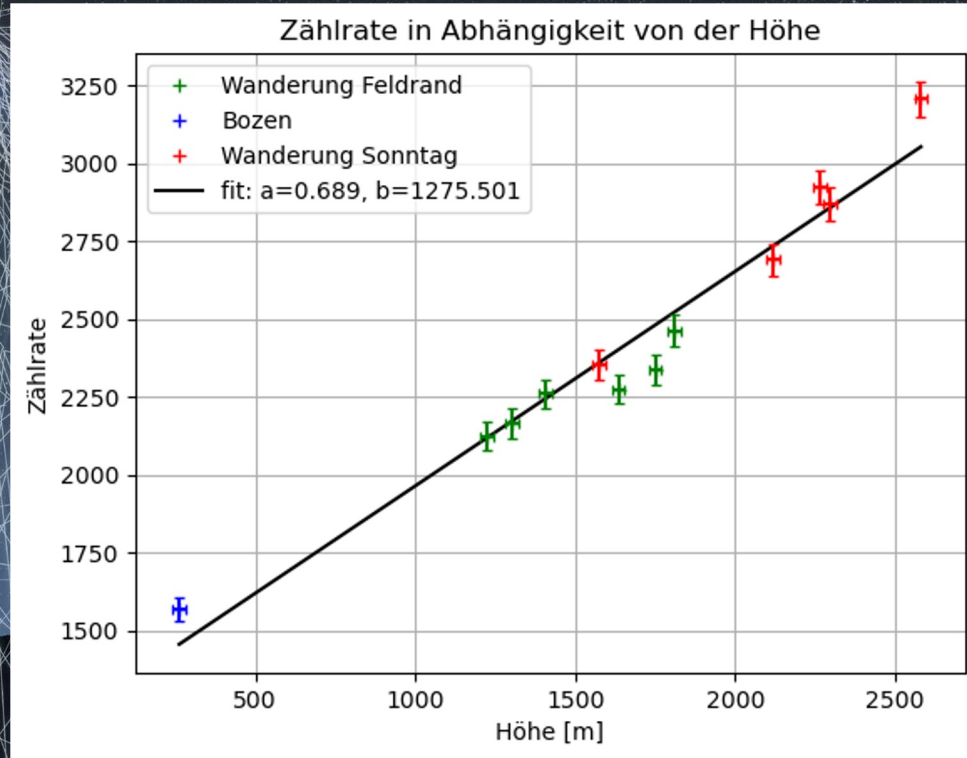
# Count rate VS altitude



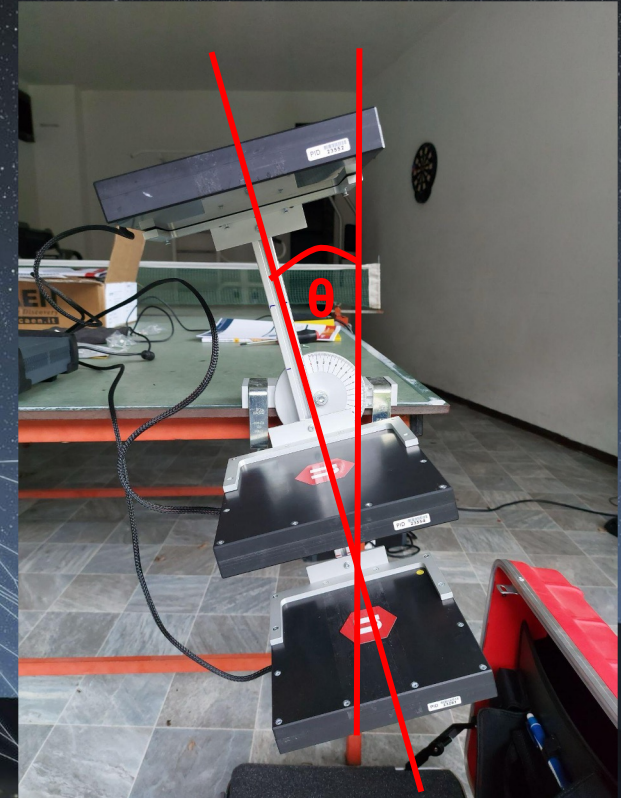
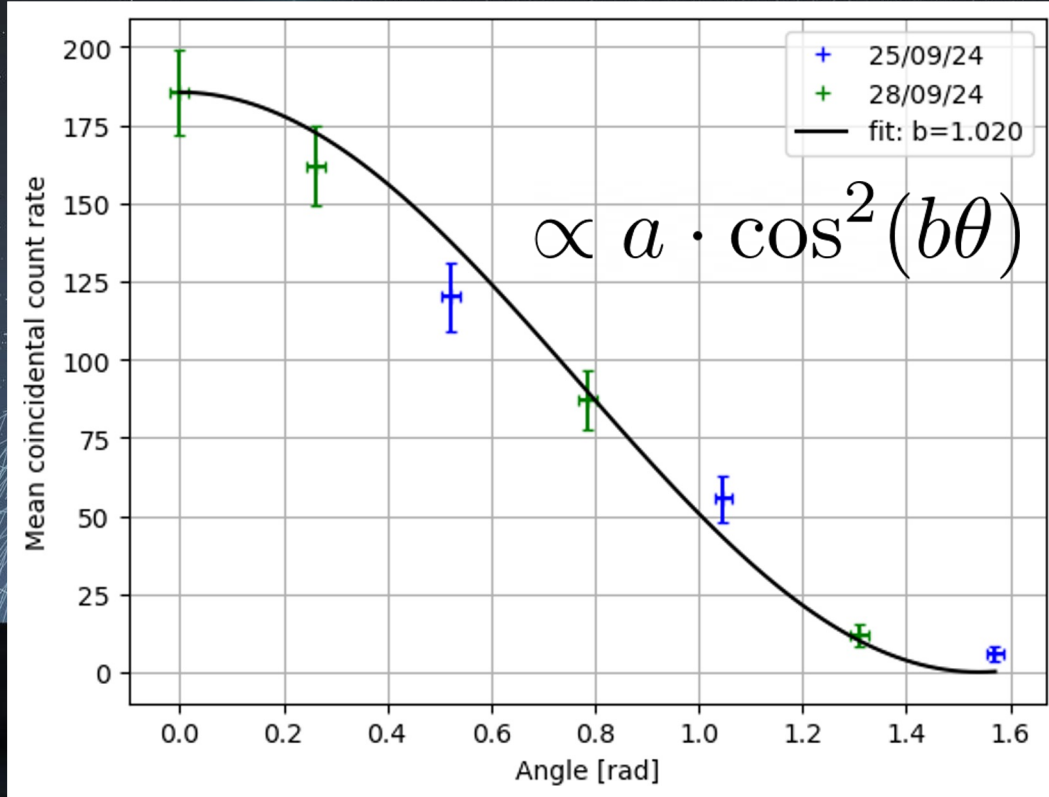
# Count rate VS altitude



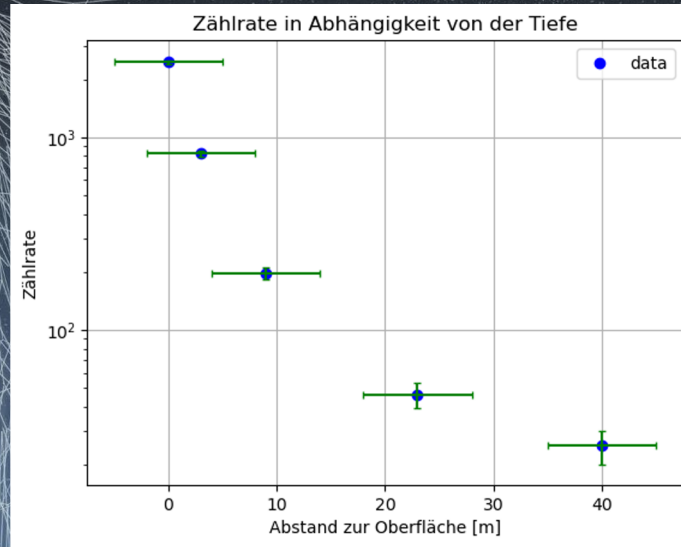
# Count rate VS altitude



# Winkelabhängigkeit

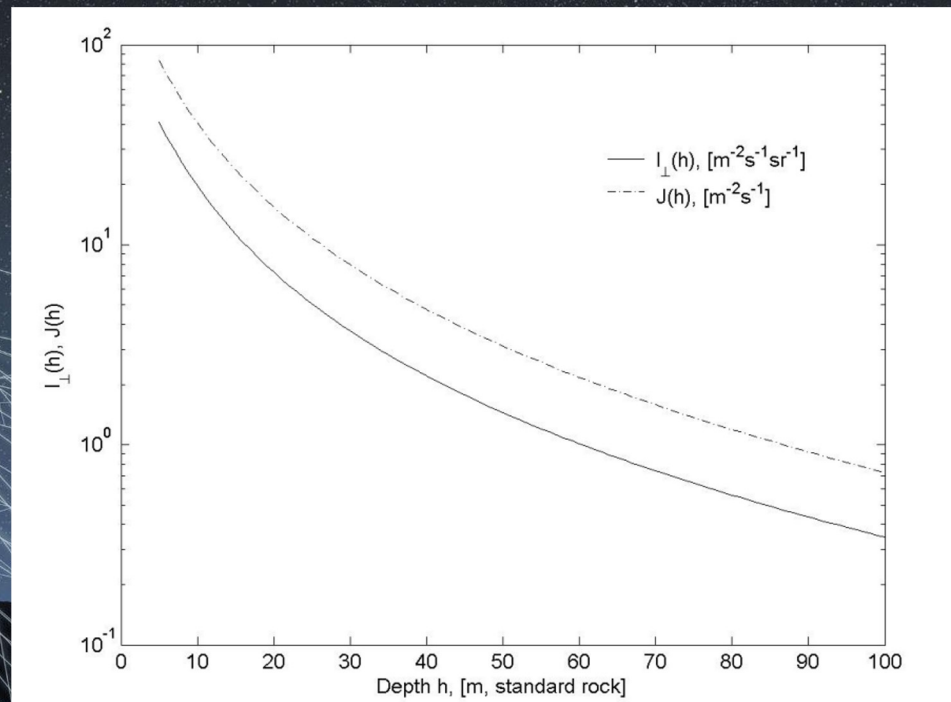
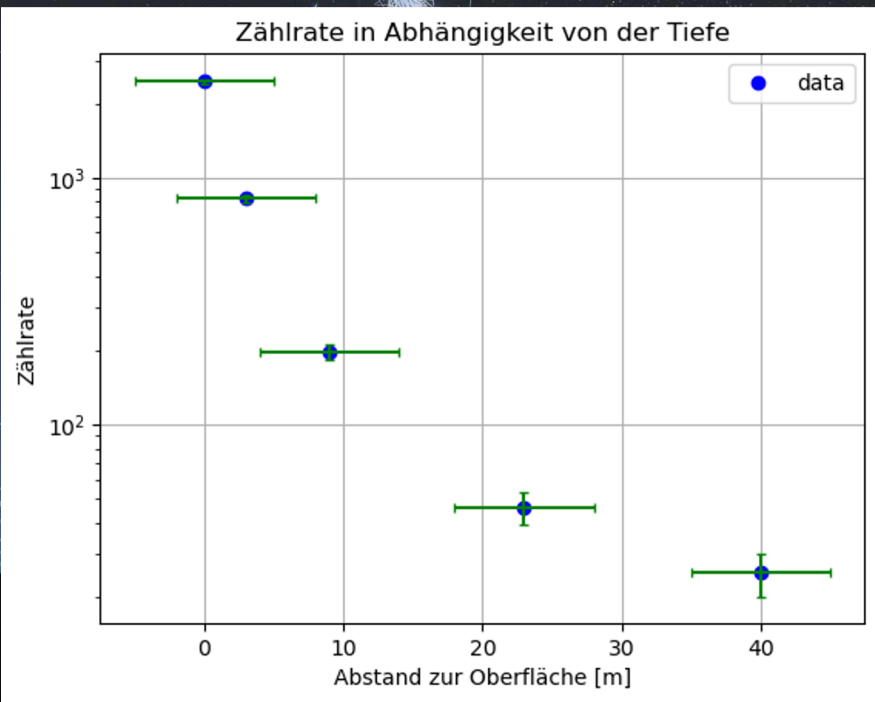


# Depth Measurements

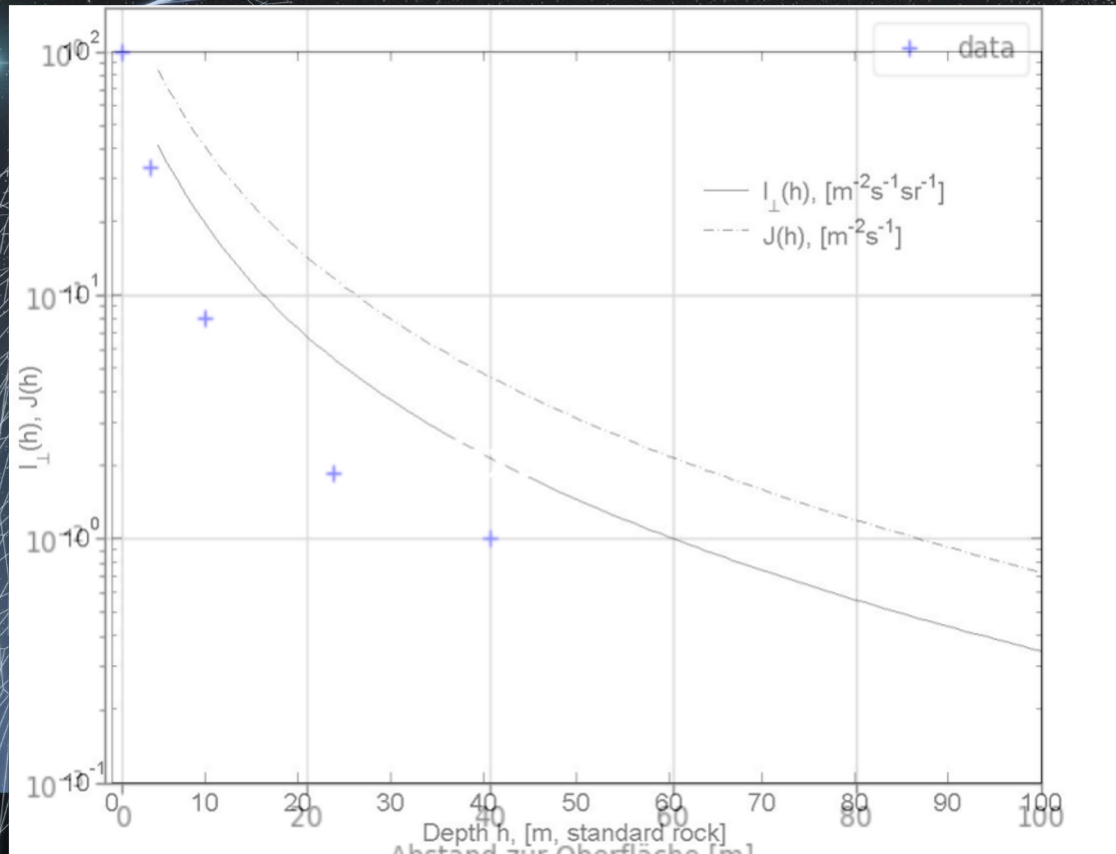




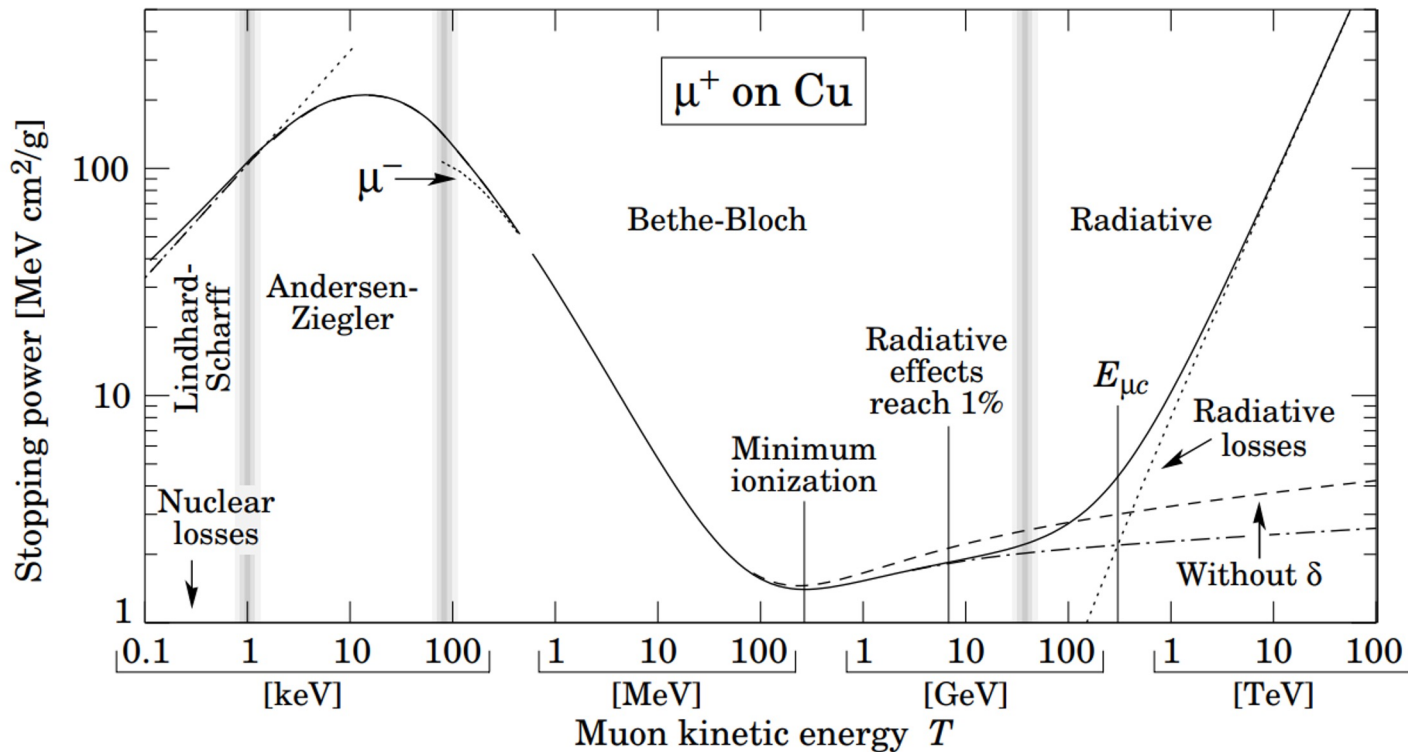
# Depth Measurements



[1] Cosmic muon flux at shallow depths underground.,  
Bogdanova, Gavrilov, Kornoukhov, Starostin

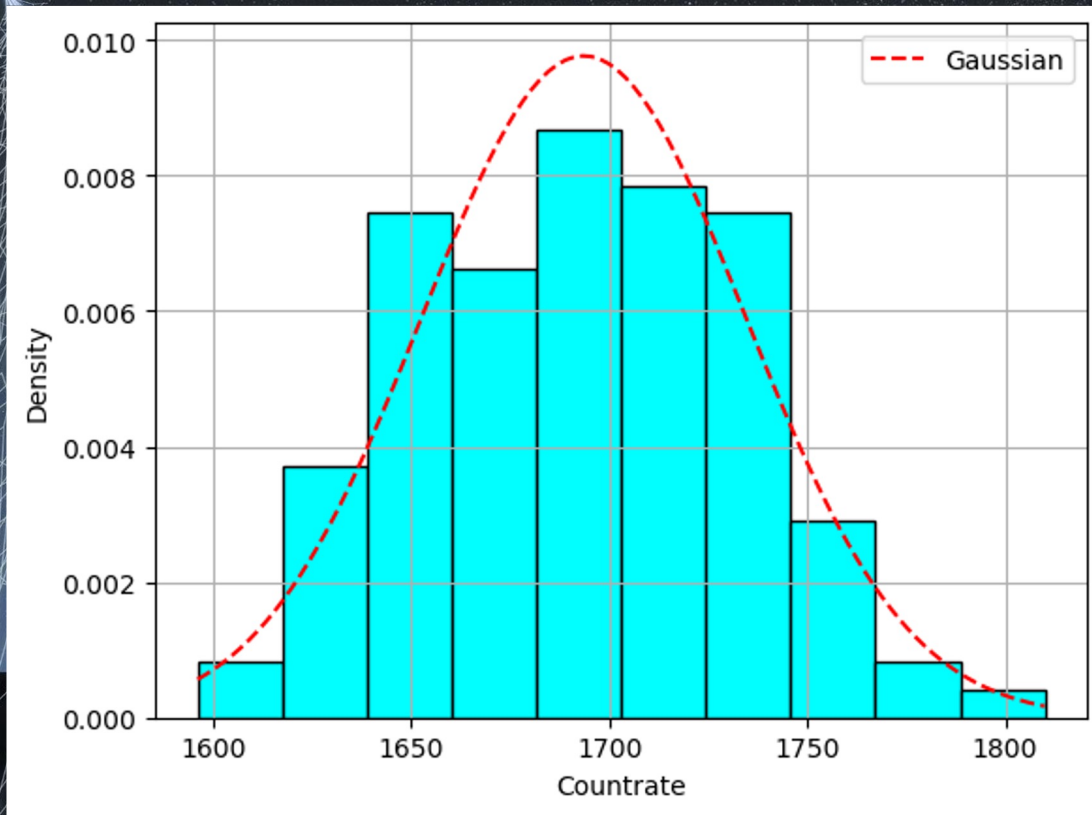


# Bethe-Bloch Curve



# Long run measurement

Avg = 1693.5  
Var = 1668.3



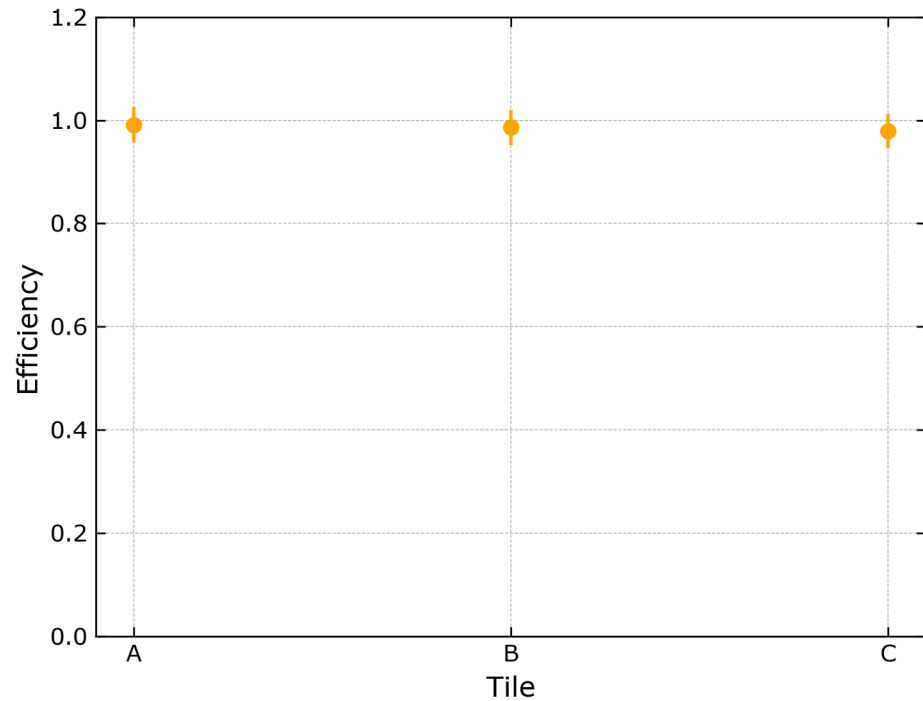
A night sky with a star and a meteor shower, overlaid with a complex network of white lines. The background is a dark blue night sky filled with stars. A bright star is visible in the upper left quadrant. A meteor shower is depicted as a dense field of white lines radiating from a point in the sky, with some lines extending towards the bottom of the frame. The bottom of the image shows a dark silhouette of a landscape with some distant lights.

# Uncertainties and efficiency

# Efficiency

$$\epsilon_A = \frac{N_{ABC}}{N_{BC}}$$

A	99,1%
B	98,6%
C	97,9%



# Random coincidences

