Hands-on: Cosmic Rays

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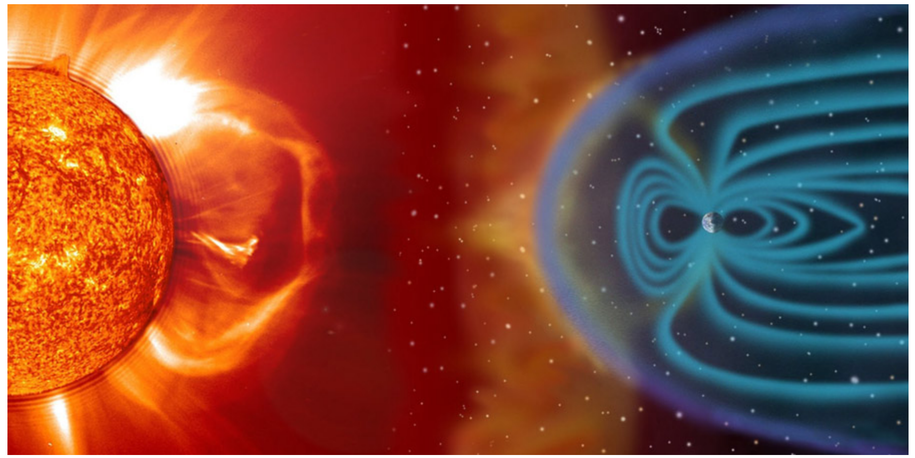
5th Lisbon Mini-School on (Astro)Particle Physics, Caparica, February 6th 2020

Cosmic Rays

- **Cosmic rays**
  - Charged particles accelerated in the cosmos that continuously bombard Earth
  - Essentially, proton, helium, … , up to iron
  - Above iron abundances decrease dramatically



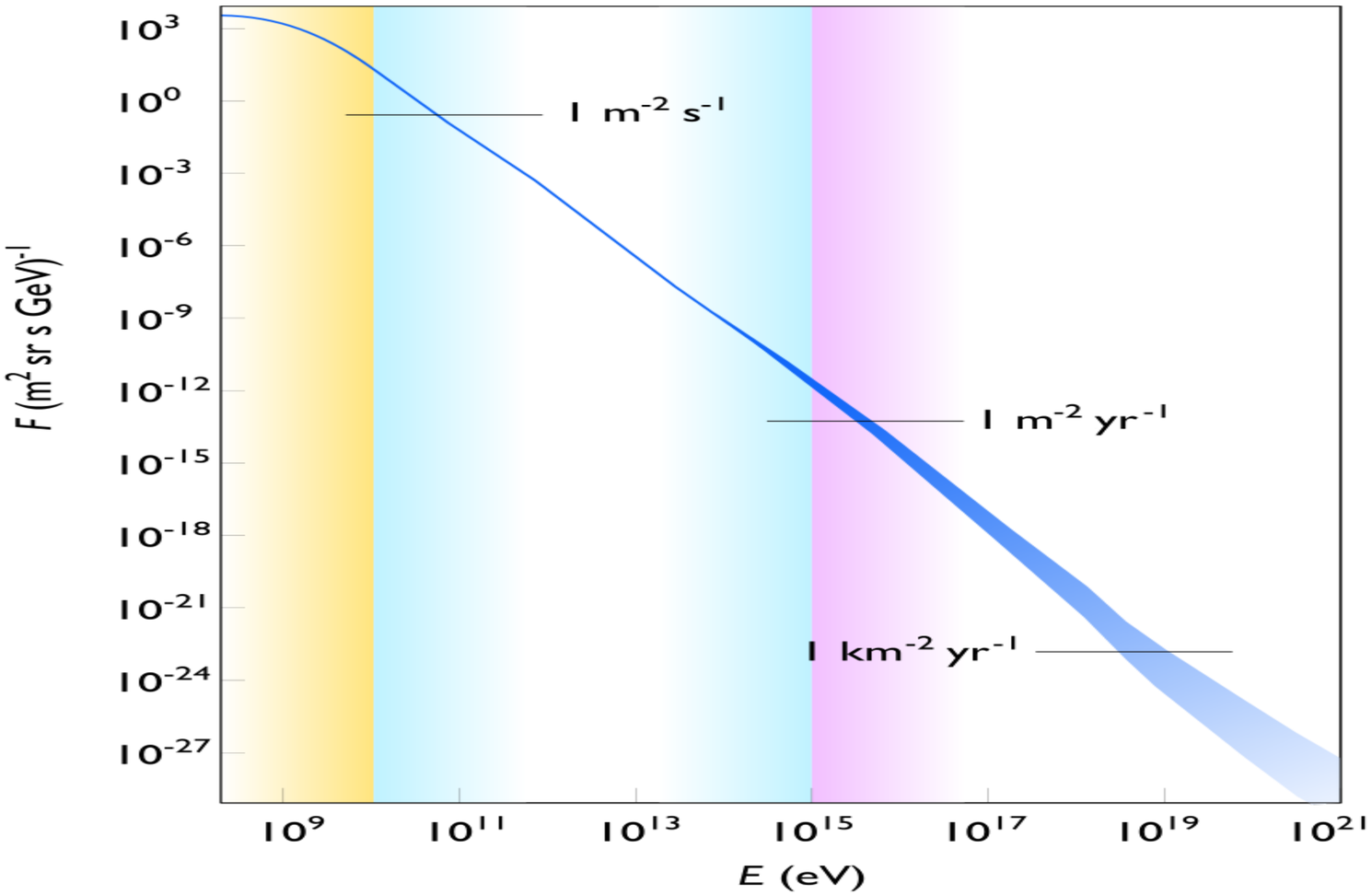
How to observe cosmic rays?

Ballon experiments

Satellite experiments

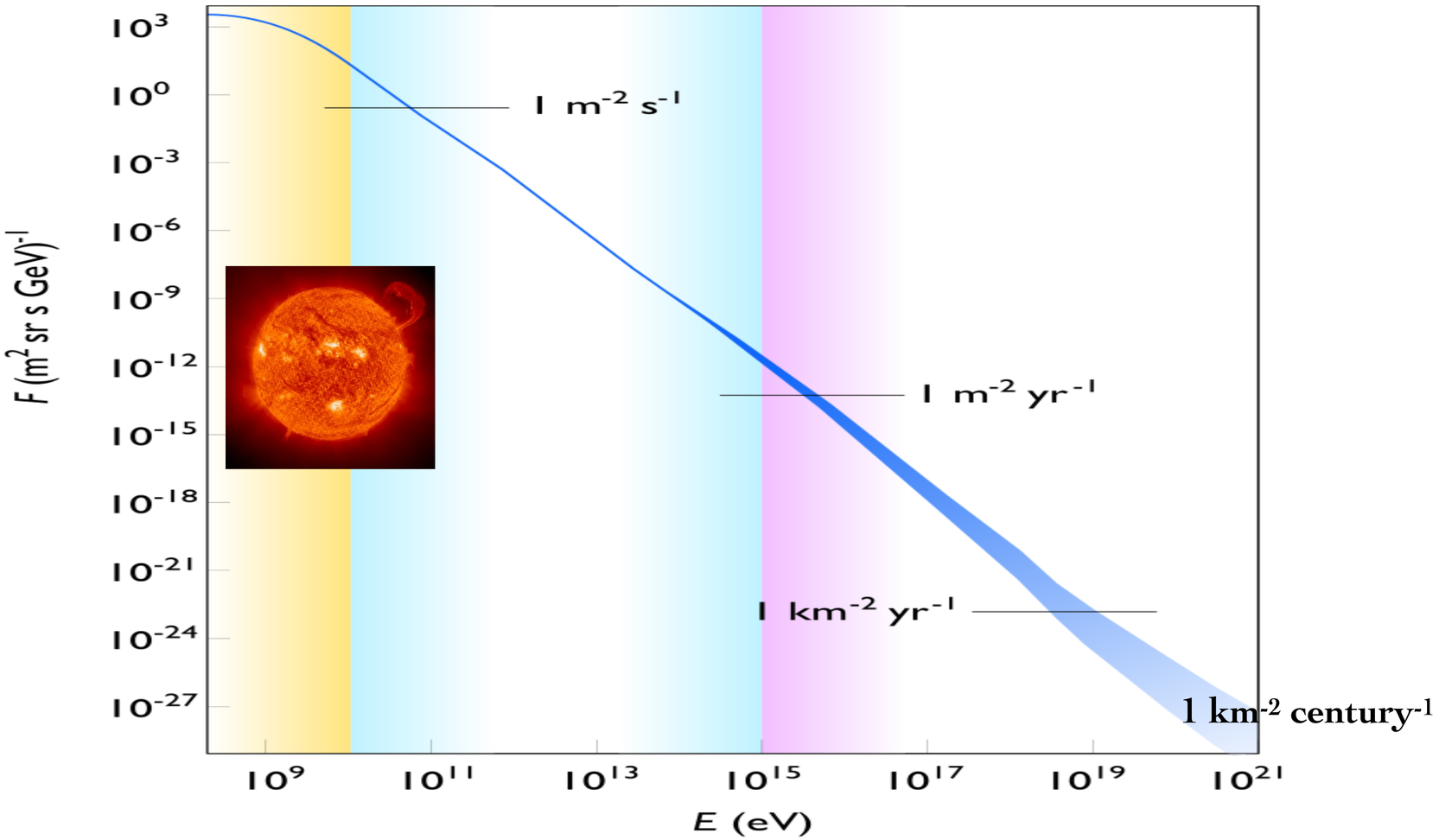
Cosmic ray energy spectrum

Flux - particles per second per area

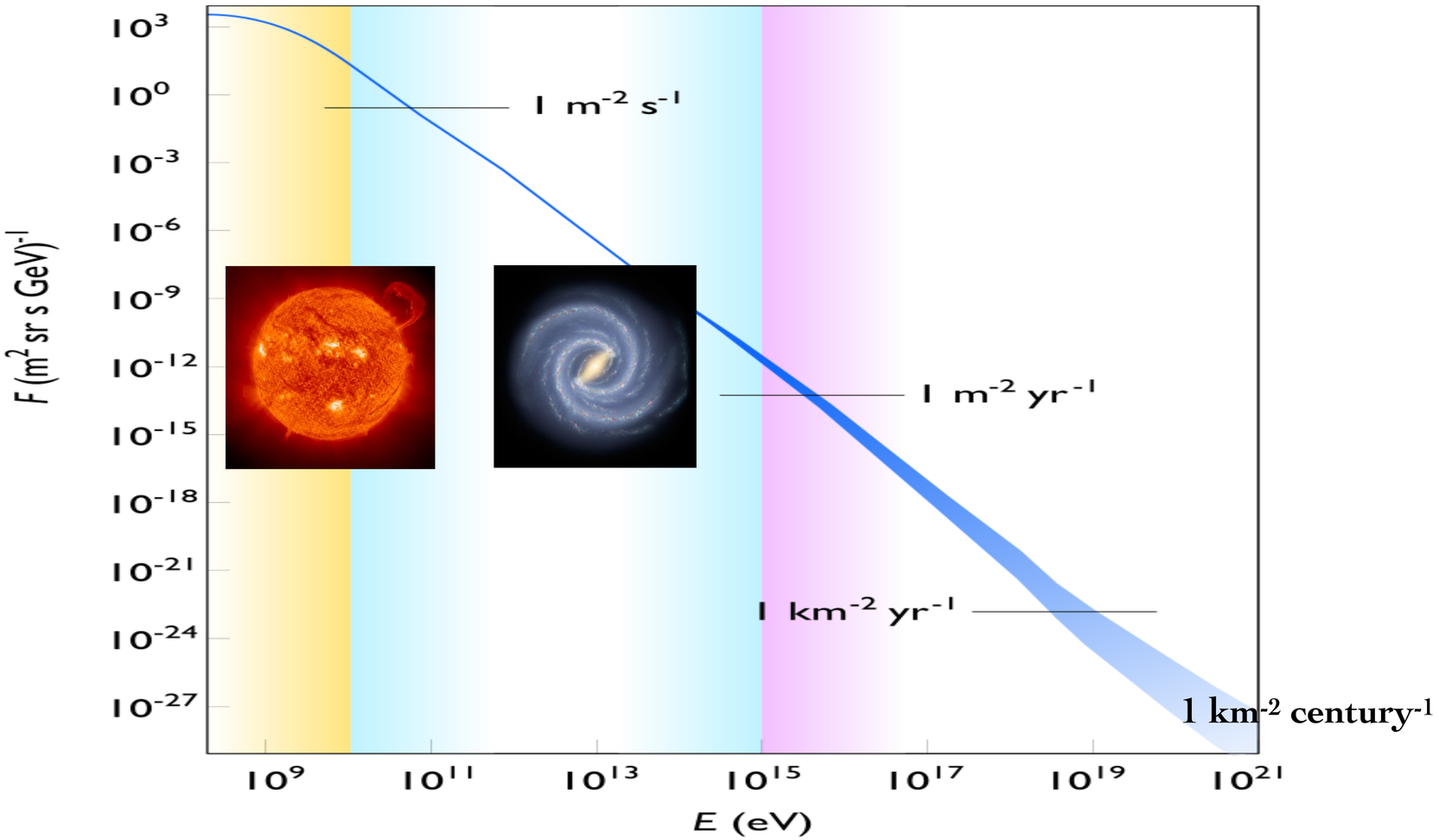


Energy - given in electron Volts

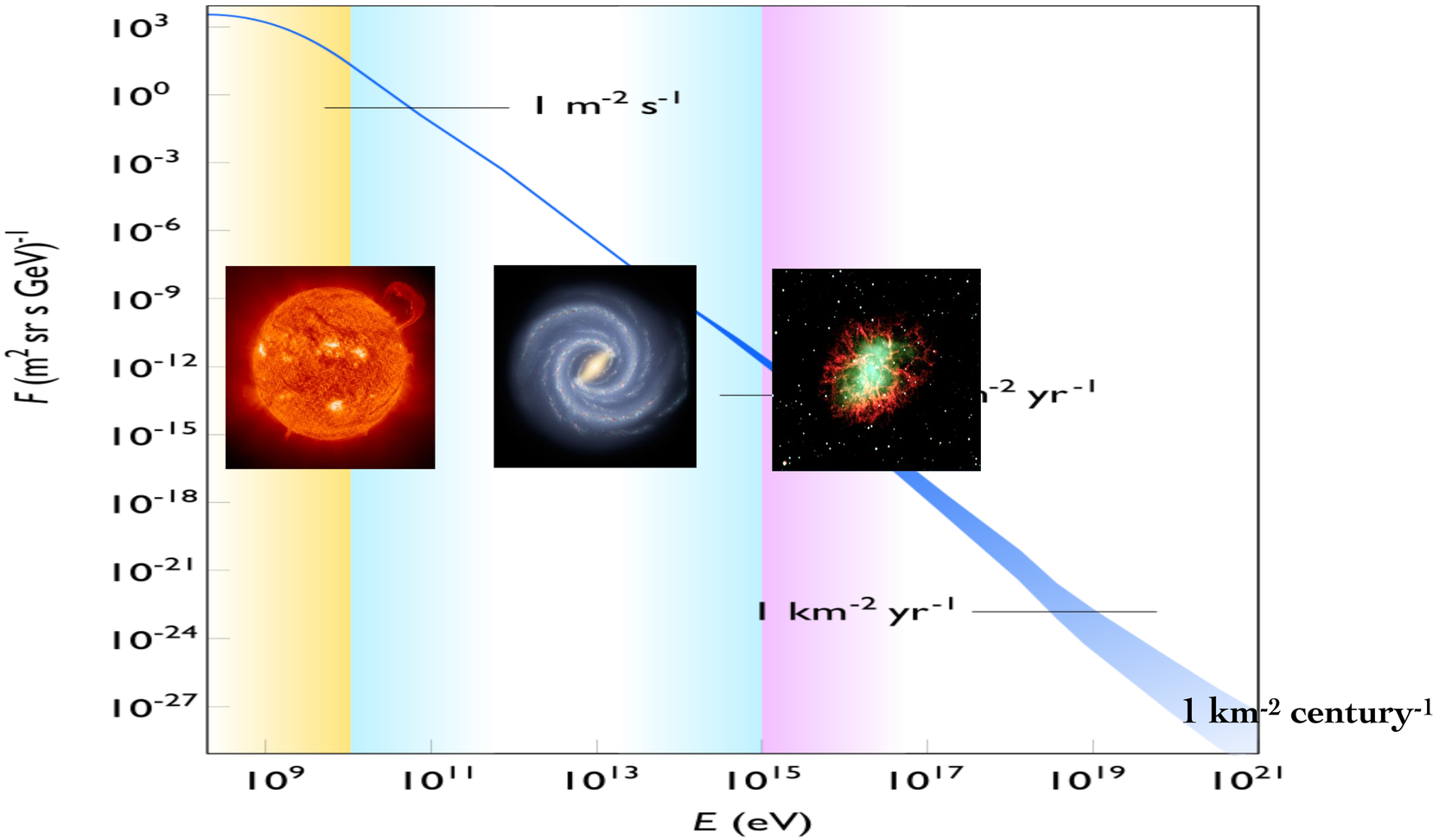
Cosmic ray energy spectrum



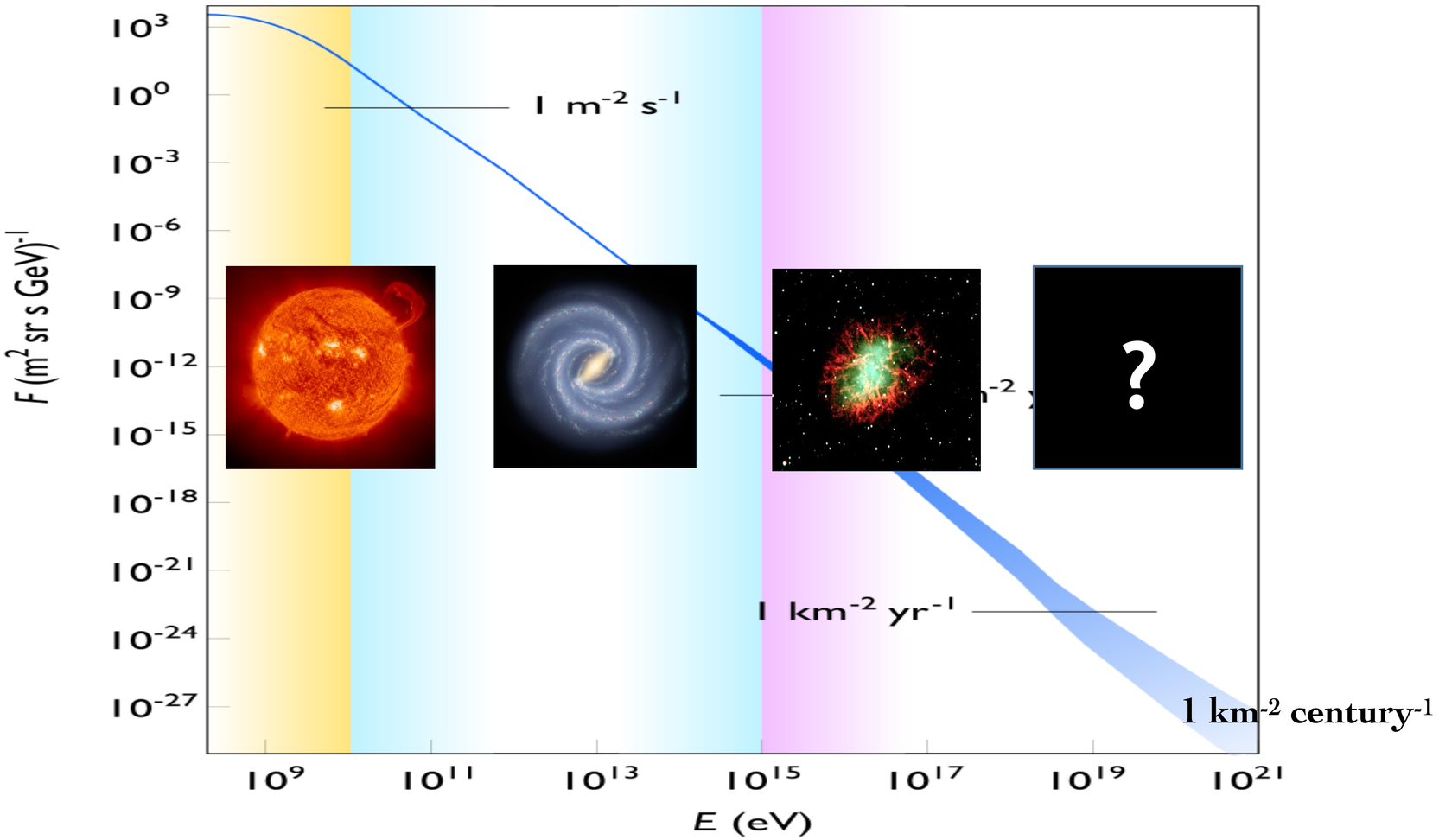
Cosmic ray energy spectrum



Cosmic ray energy spectrum



Cosmic ray energy spectrum



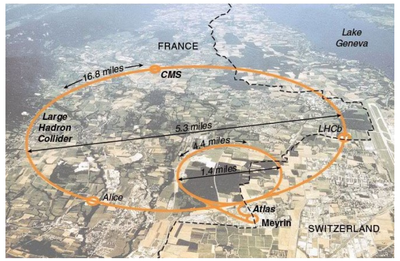
Ultra high energy cosmic rays

- Extremely rare: 1 particle / km^2 / century
- : Highest energy cosmic ray ever observed: $3x10^{20}$ eV

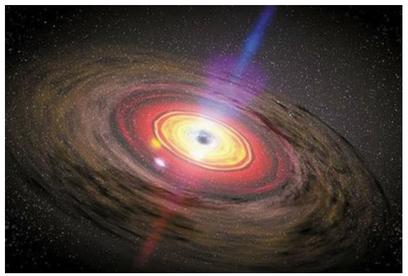
1.5 eV

10 000.0 eV

6 500 000 000 000.0 eV

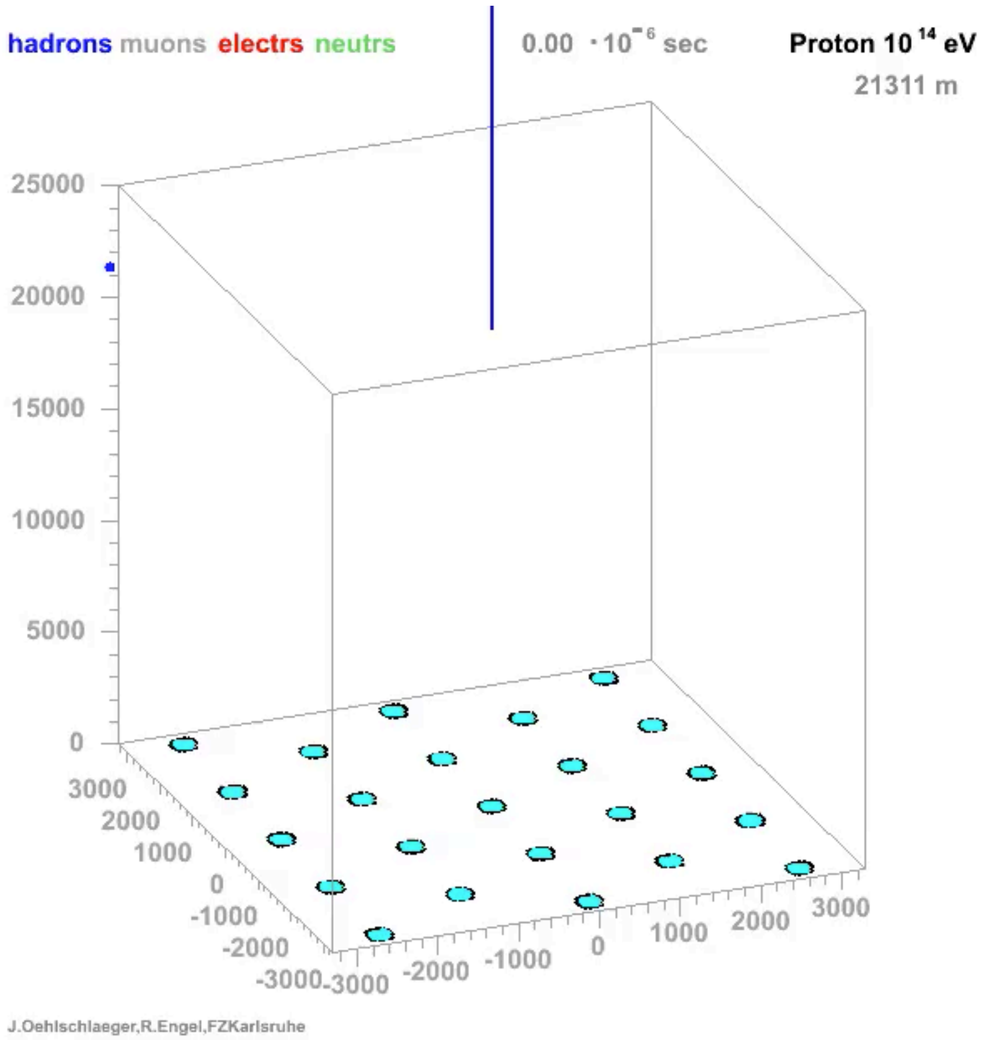


3 000 000 000 000 000 000 000.0 eV



Extensive Air Showers

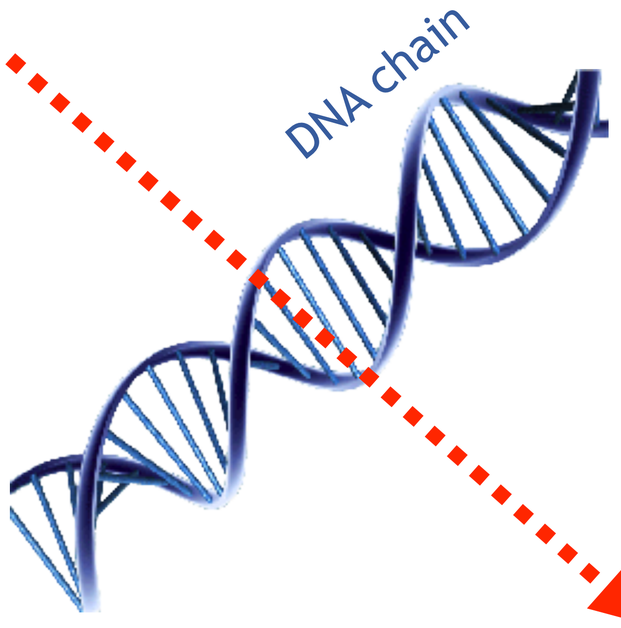
- If the energy of the cosmic ray that enters the atmosphere is sufficiently high it produces a **cascade of particles**
- When **muons** are produced they can reach the Earth surface due to:
  - Low interaction cross-section
  - Special relativity time dilation



Muon sparks chamber @ LIP

The big question

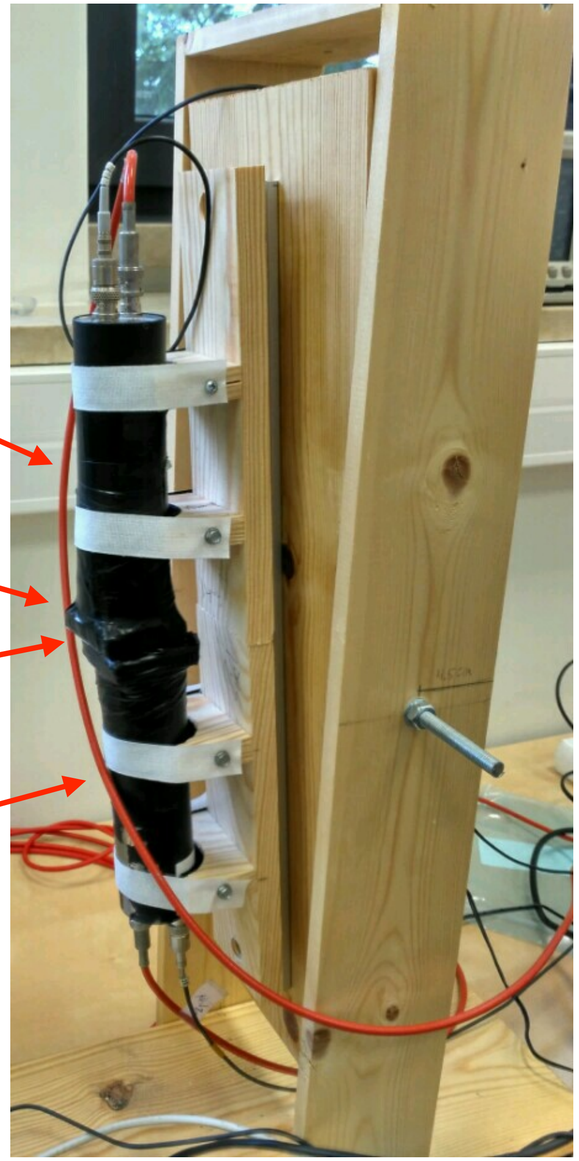
How many muons (radiation) cross my hand per unit of time?



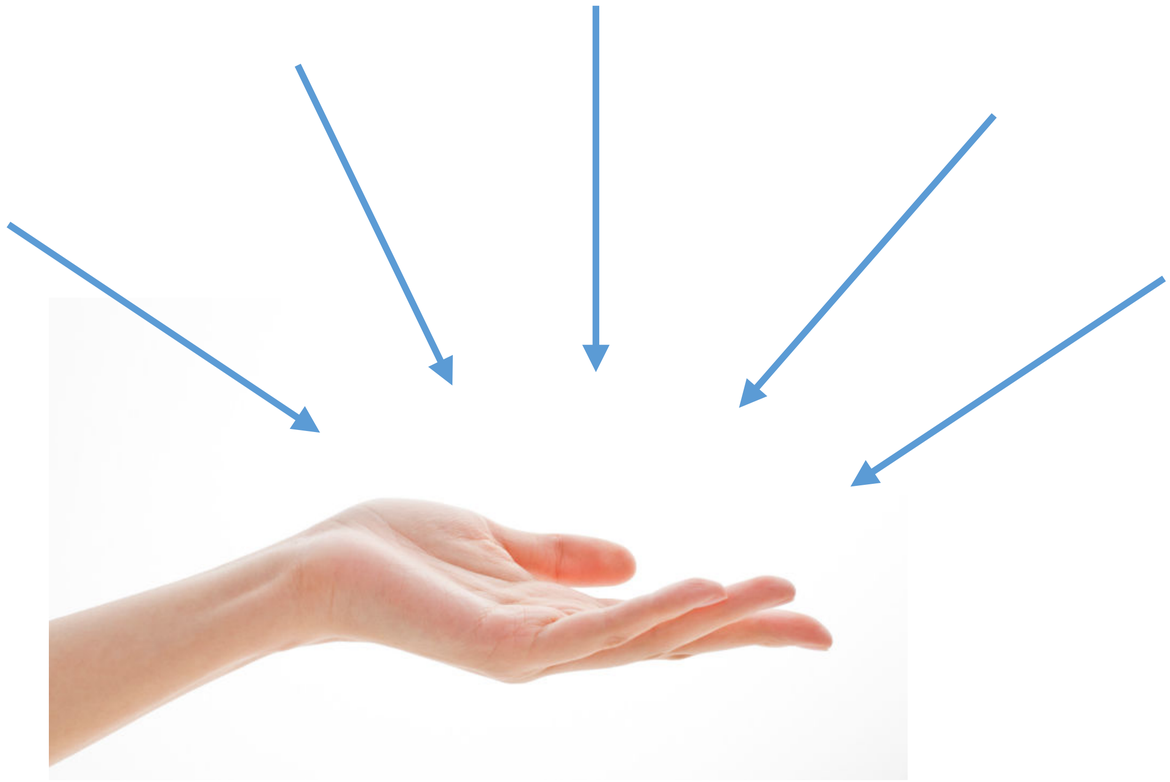
Muon
Ionising radiation!!

What do we have?

- **Telescope**:
  - 2 ***PMTs*** each coupled to a ***scintillator***
    - Why?
  - The systems detects coincidences
  - The system can be moved as a whole and the PMTs can be moved apart
    - Advantages/disadvantages?

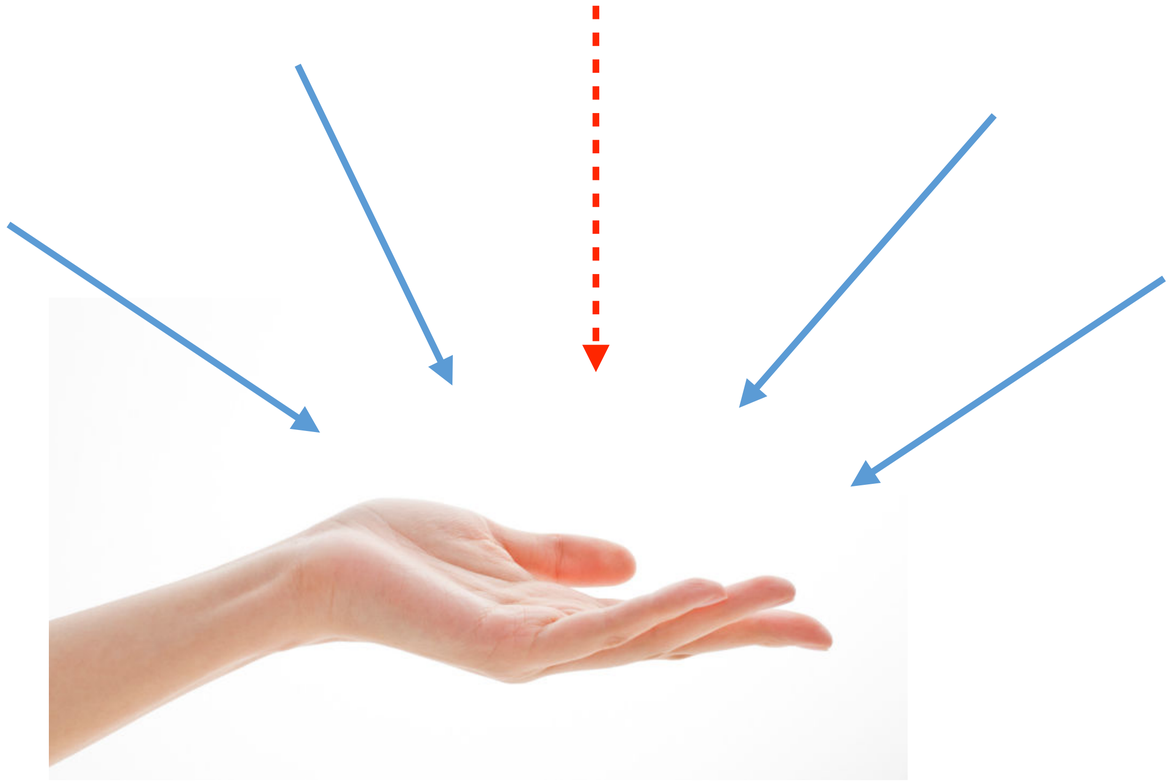


Let’s plan an experiment!



- To know the rate at our hand we need know:
  - Area of the hand
  - Flux for each direction

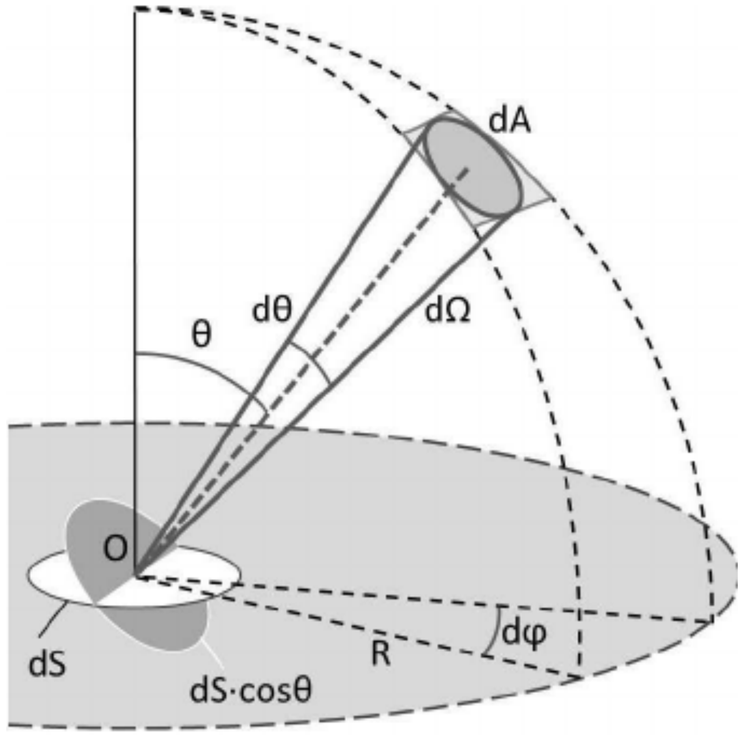
Let’s plan an experiment!



- To know the rate at our hand we need know:
  - Area of the hand
  - Flux for each direction
    - Find the dependence with direction, f(**θ**)
    - Find the vertical flux, I_0

How to compute the rate?

$$\begin{aligned}\text{Rate} &= \int I_0 f(\theta)\cos(\theta) d\Omega dS \\ &= I_0 A_{det} \int f(\theta)\cos(\theta)\sin(\theta) d\theta d\phi \\ &= 2\pi I_0 A_{det} \int_{\theta_{min}}^{\theta_{max}} f(\theta)\cos(\theta)\sin(\theta) d\theta\end{aligned}$$

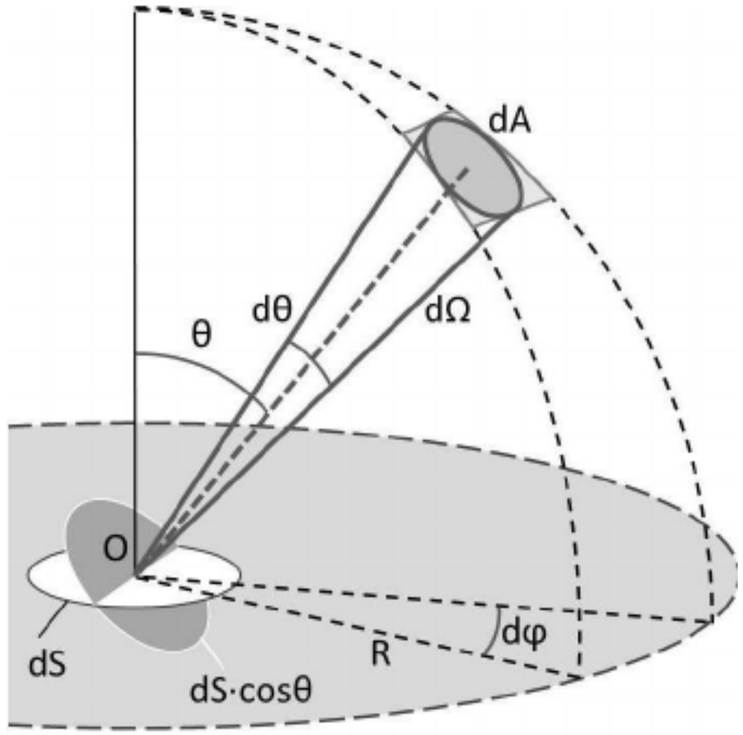


How to compute the rate?

$$\text{Rate} = \int I_0 f(\theta)\cos(\theta) d\Omega dS$$

$$= I_0 A_{det} \int f(\theta)\cos(\theta)\sin(\theta) d\theta d\phi$$

$$= 2\pi I_0 A_{det} \int_{\theta_{min}}^{\theta_{max}} f(\theta)\cos(\theta)\sin(\theta) d\theta$$



Let's start by finding the functional form of f(θ)!!

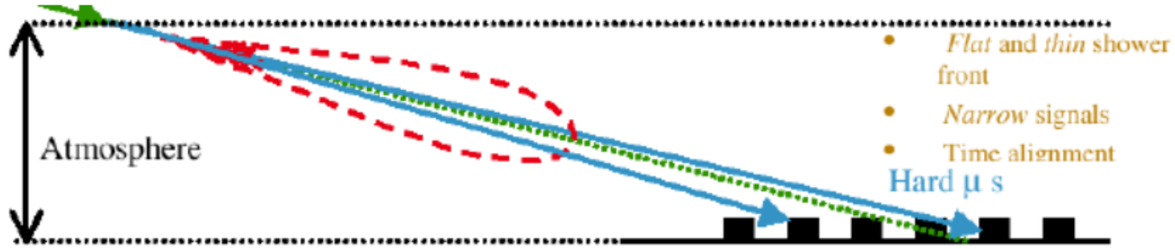
The measurement

Inclination	Time Interval	Number of events	Rate (Hz)	Error in Rate
0°				
30°				
60°				
90°				

- Time to fill this table
  - First two columns : *measure using the telescope*
  - Last two columns : *compute using measured data*

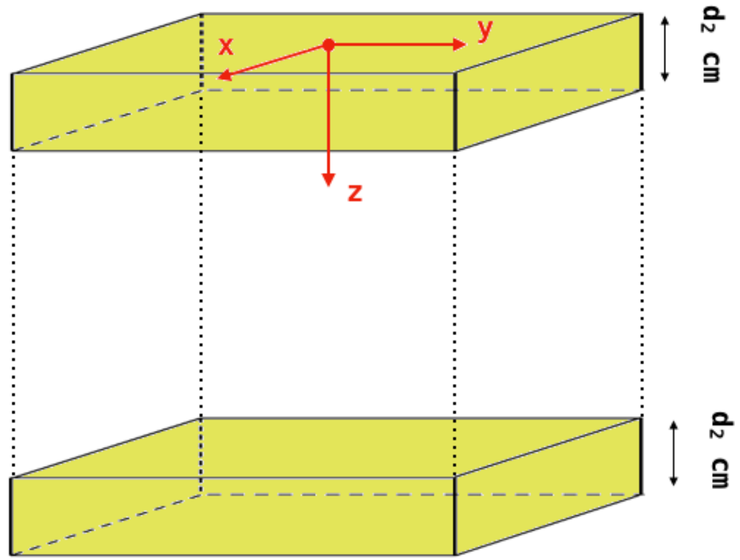
Dependence with zenith angle

- Obtain the functional form of f(θ)
  - Lets try:
    - $f(\theta) = a\cos^{\gamma}(\theta) + b \quad \text{with } \gamma \in [0, 4]$
    - Use this function to fit Rate vs. Zenith angle



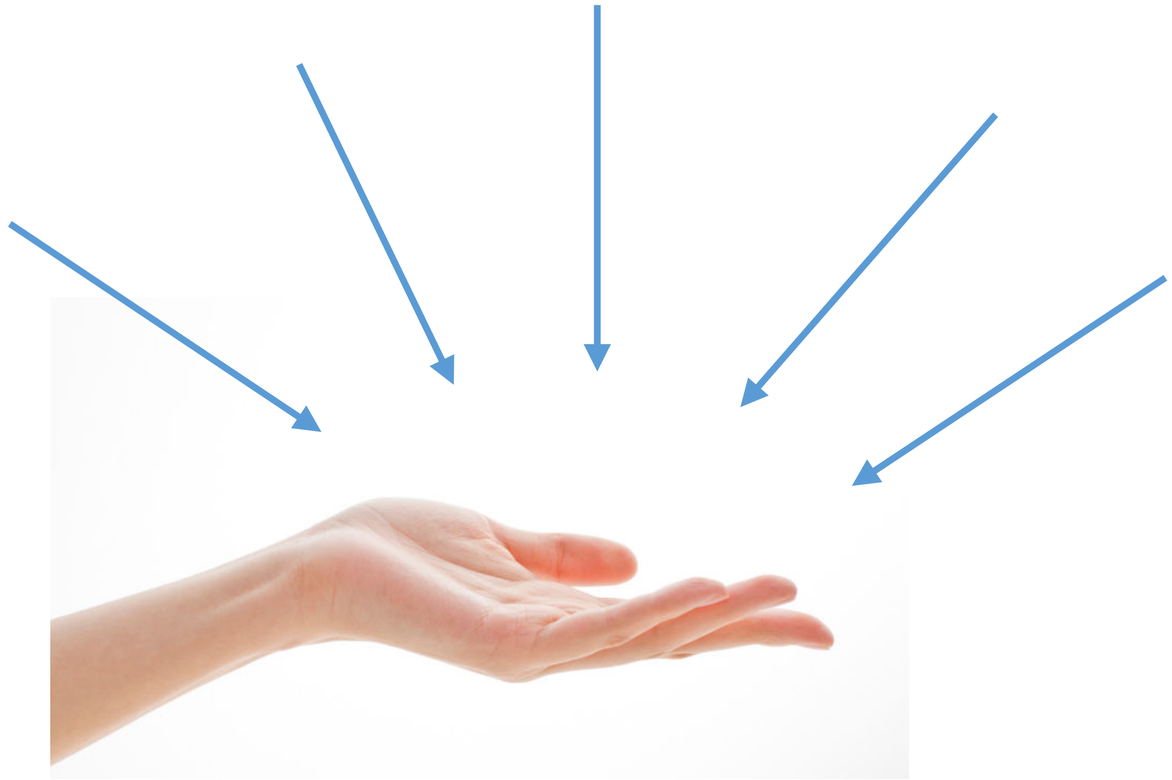
Knowing f(θ) compute I_0

$$\text{Rate} = 2\pi I_0 A_{det} \int_{\theta_{min}}^{\theta_{max}} \boxed{?} \cos(\theta)\sin(\theta)d\theta$$



- Value taken from literature:
  - $I_0 \approx 70\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1} \quad \text{for} \quad E_\mu > 1\,\mathrm{GeV}$

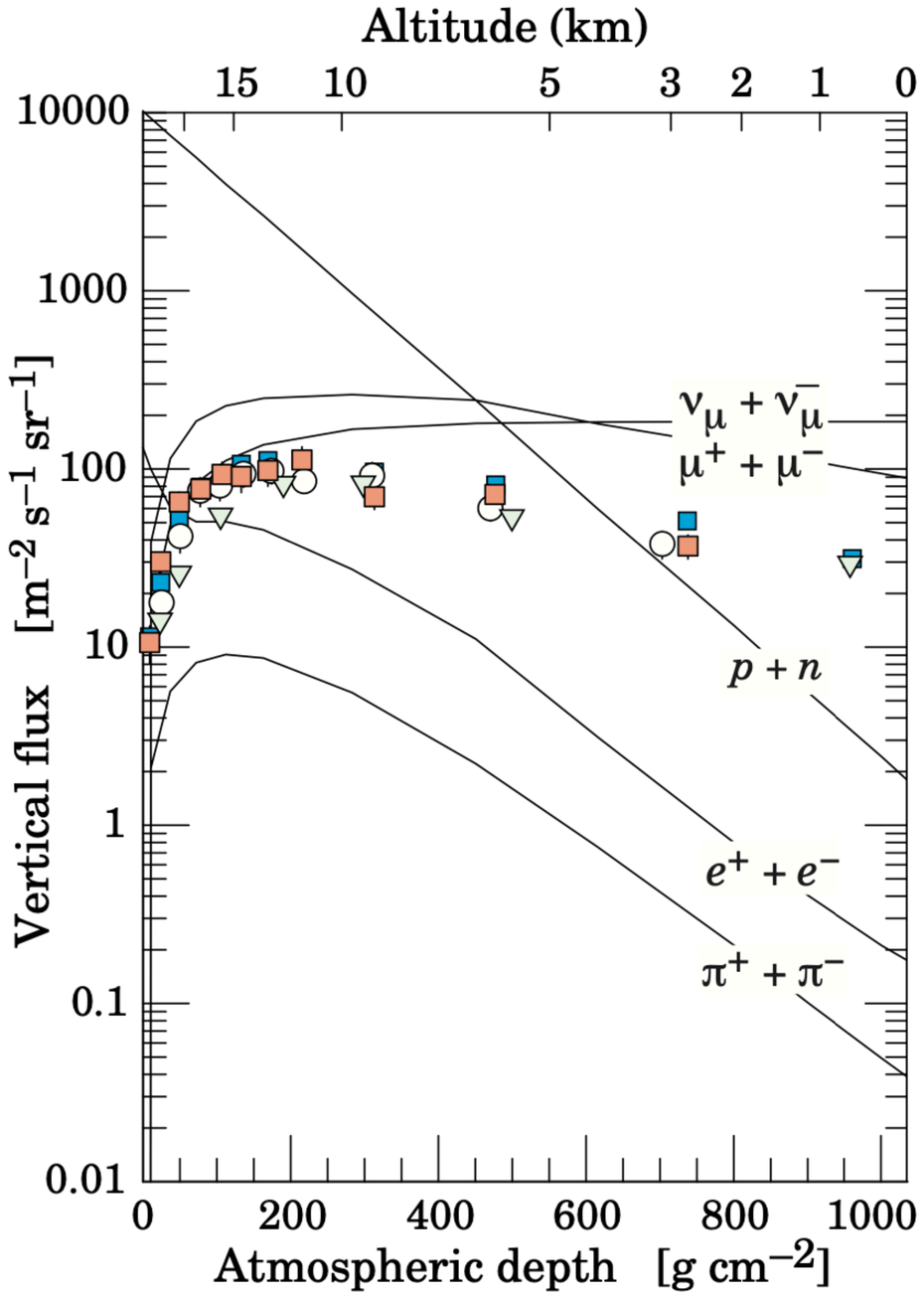
So… How many muons pass by your hand per unit of time?



$$\text{Rate} = 2\pi I_0 A_{det} \left[-\frac{1}{4}\cos^4(\theta) \right]_0^{\frac{\pi}{2}} \quad [\text{muons/s}]$$

Particles flux vs. Altitude

(taken from the PDG)



Acknowledgements

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REPÚBLICA PORTUGUESA

LIP

TÉCNICO LISBOA

Backup slides

Acceptance variation with zenith angle

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In[28]:= Plot[Evaluate[Integrate[(Cos[x])^3 Sin[x], {x, 0, y Degree}]], {y, 0, 90}]
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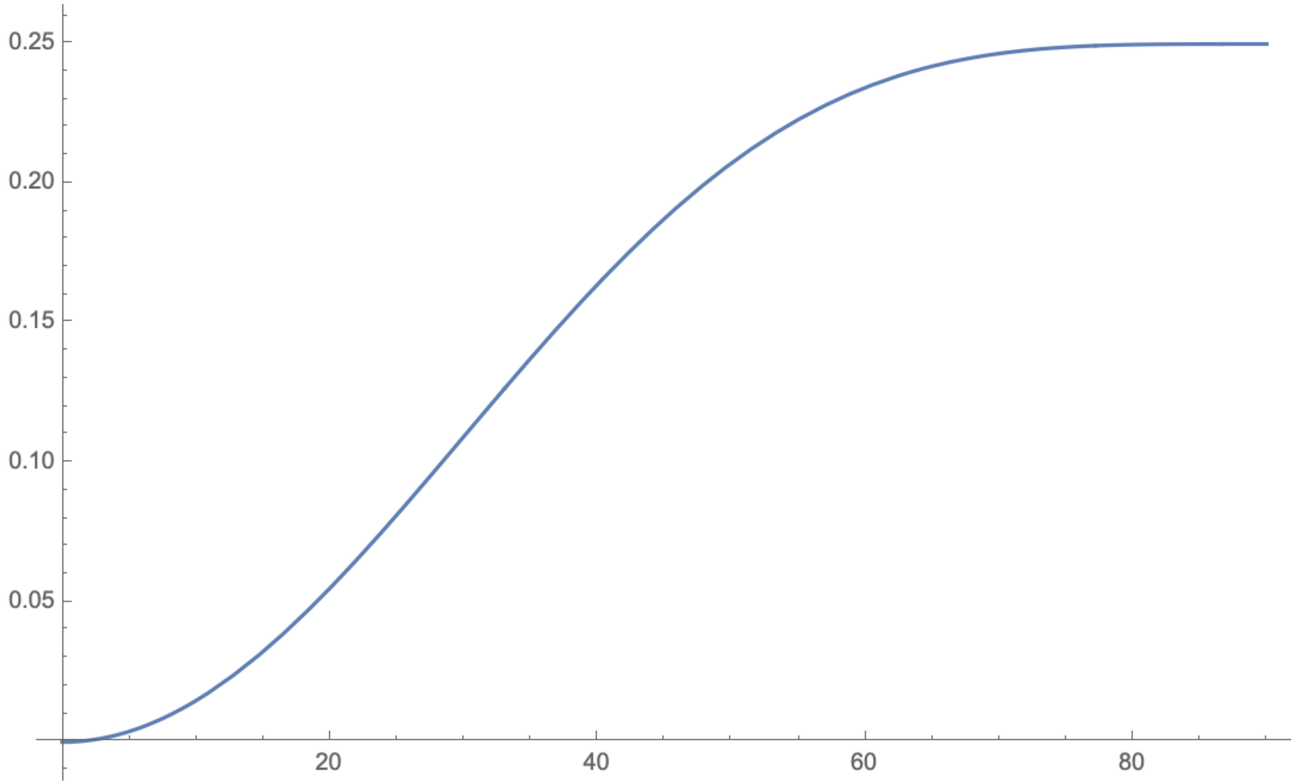
Out[28]=



Zenith Angle

Extensive Air Showers