Particles and Cosmic Rays

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Particles in the wild

- Accelerators
- Radioactivity
- Cosmic rays

Particles in captivity

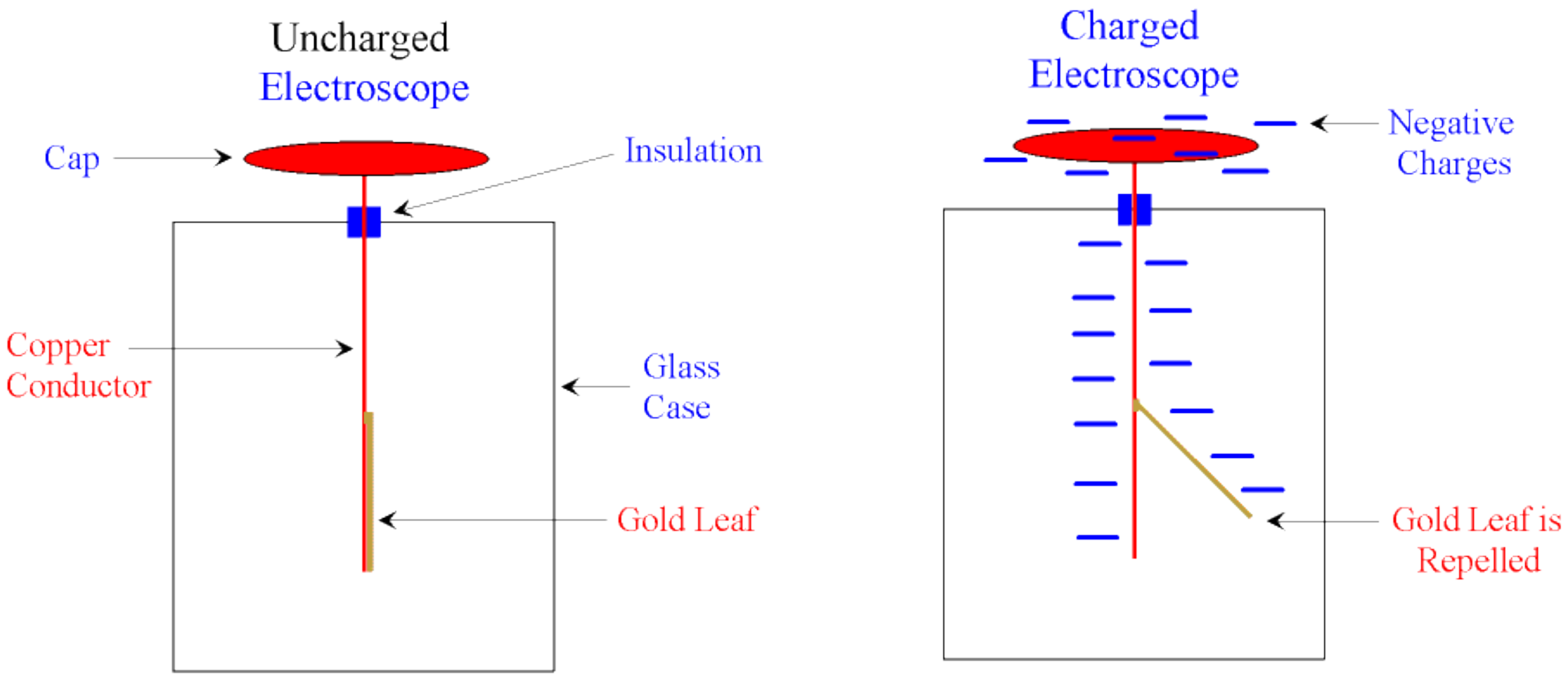
Particles in the wild

$E=mc^2$ Energy ⟷ Matter

New particles are produced

Cosmic Ray discovery

Hess, 1912: Balloon flight



Electroscope would discharge much faster at higher altitude

Cosmic Ray discovery

Balloon flight in near-total eclipse :
Still higher radiation at higher altitude
⇨ Ruled out Sun as radiation source

"The results of my observation are best explained by the assumption that a radiation of very great penetrating power enters our atmosphere from above."

Cosmic Ray discovery

1920: Millikan called them "cosmic rays"
and believed they were energetic photons

1927: evidence of variation of cosmic ray
intensity with altitude indicating
deflection by geomagnetic field
⇨ Charged particles

1937: Rossi and Auger
Primary and secondary cosmic rays

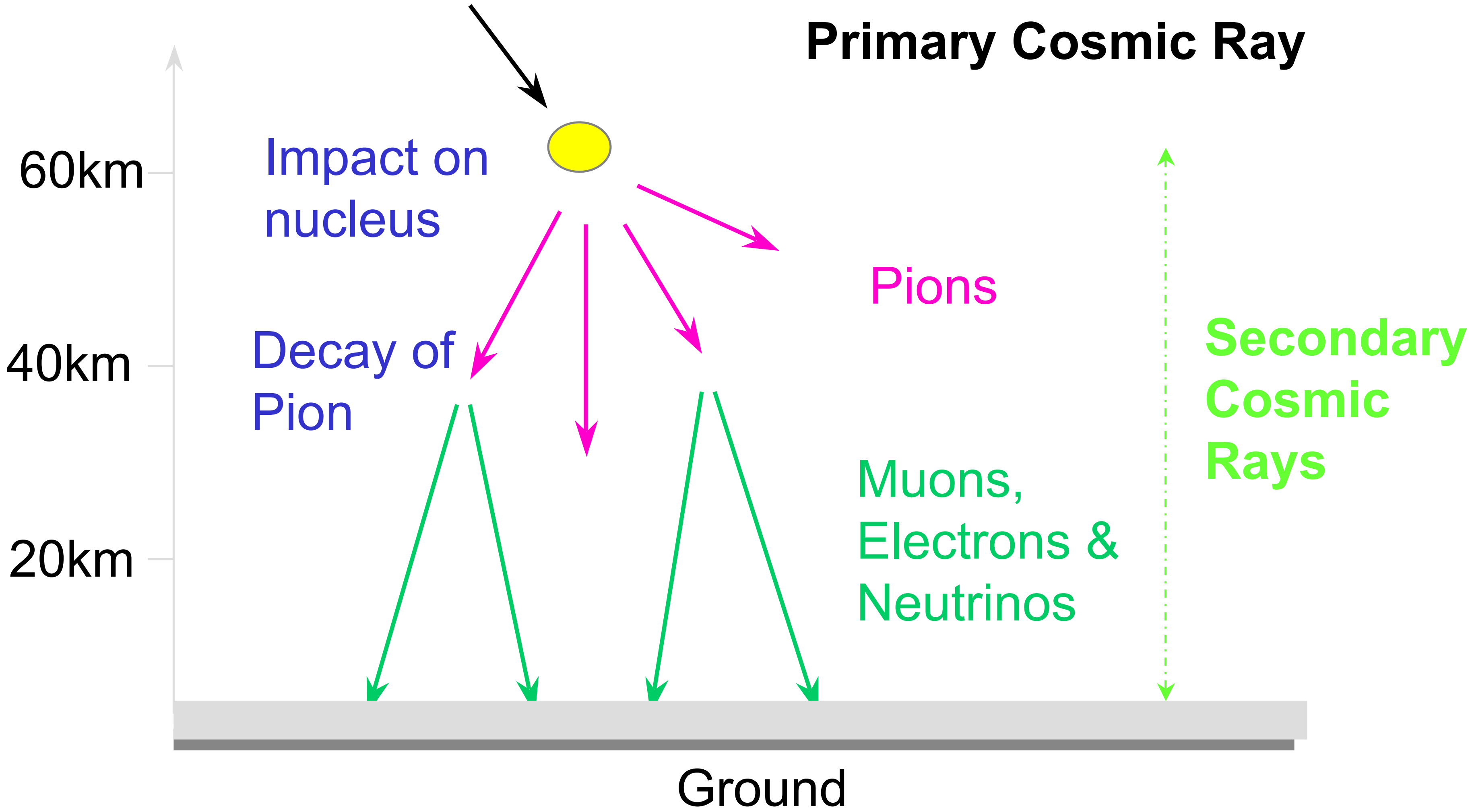
Cosmic rays

The field of Particle Physics originated from
cosmic ray research

Muon, pion, positron, kaon, Lambda
all discovered in cosmic rays

- Cosmic rays: Proof of special relativity !

A Cosmic Shower

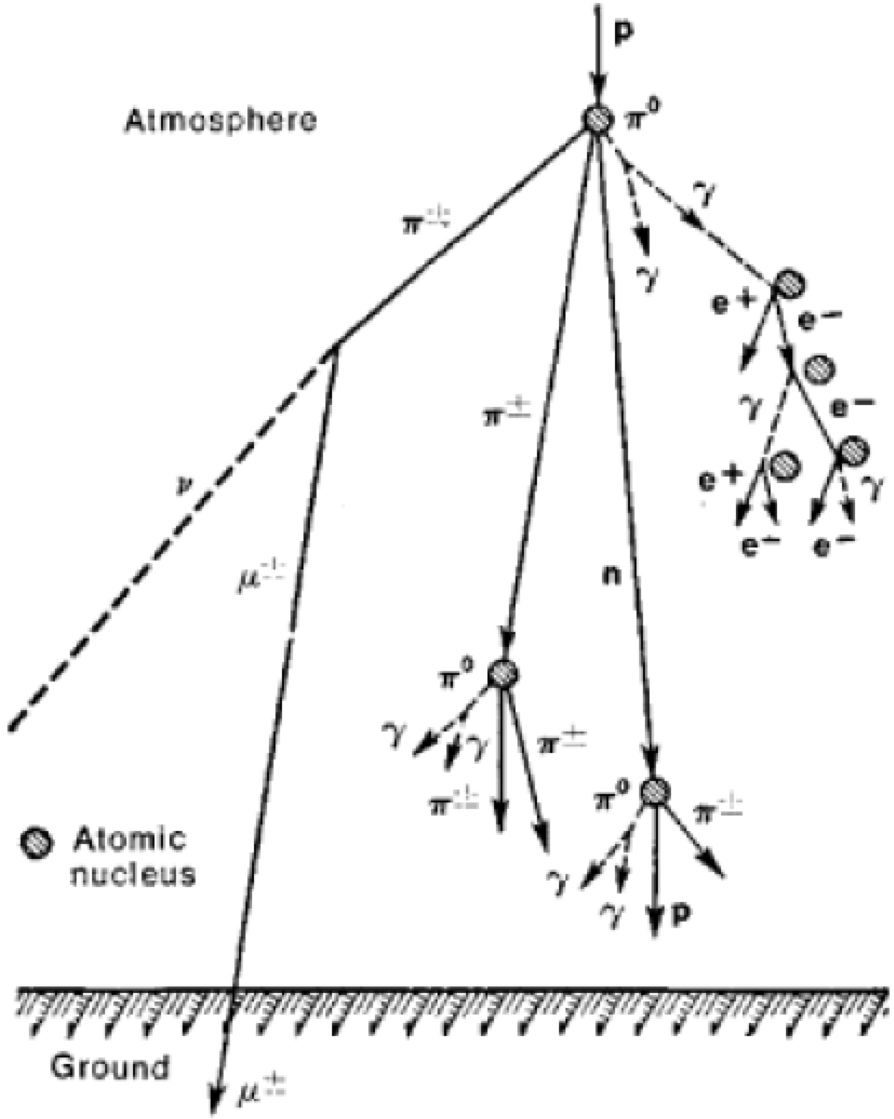


Particles in the wild

Particles in the wild

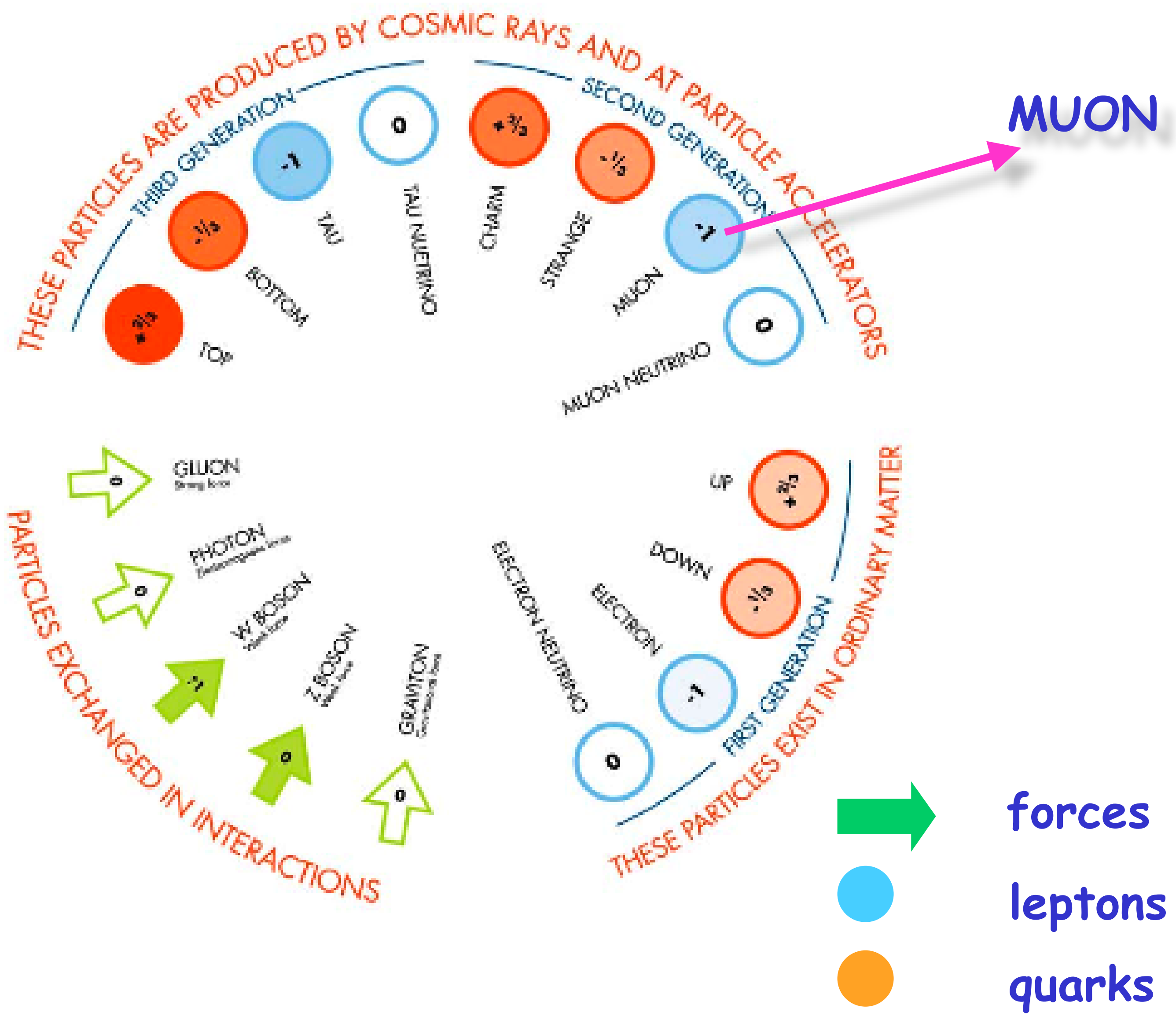
- Primary high energy cosmic ray in upper atmosphere :
  - 85% protons
  - 12% alpha particles
  - 2% electrons
  - Neutrinos, heavier nuclei
- Collision with nucleus
- Initiates "cascade"
  - Secondary cosmic rays
  - Higher energy primary
    - ⇒ larger secondary shower
- Charged particles at Earth's surface are mainly <u>muons</u>.

Showers



Some spreading
But tends to maintain
original direction

Particle wheel



Muons

Muons: Minimum ionising particles
Hence long, straight tracks
200 times more massive than electron

Sea level: 150 muons/sec
per 1 square metre

Earth time

Proper time

$$\Delta t = v\Delta\tau = 2.2\ \mu\text{s} \times 0.99\ c = 650\ \text{m}$$

classically

$$\Delta t = \Delta\tau/\sqrt{1 - v^2/c^2}$$

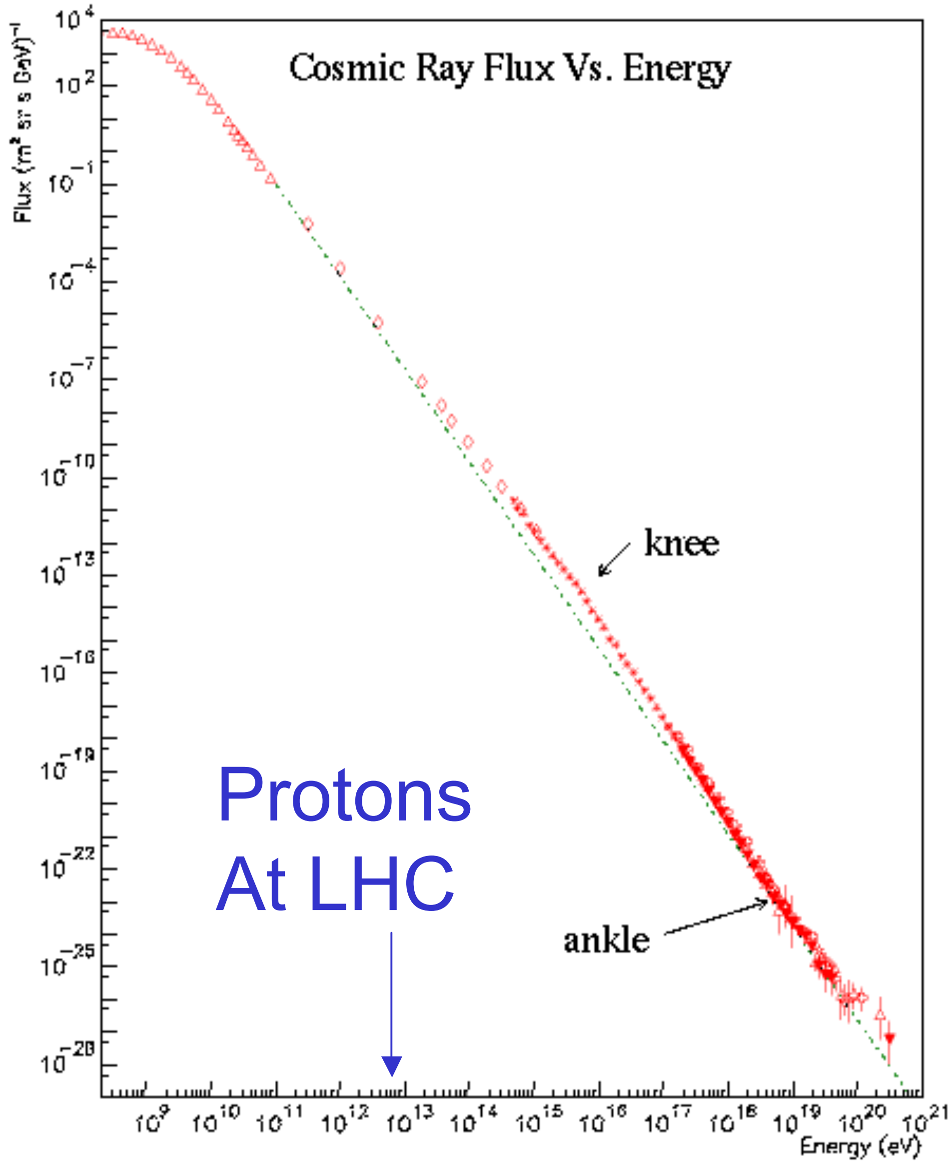
relativistically

$$\Delta t = v\Delta\tau/\sqrt{1 - v^2/c^2} = 2.2\ \mu\text{s} \times 0.99\ c\ /\ 0.14 = 4.7\ \text{km}$$

Cosmic rays measurements

- Flux of cosmic rays
- Detector geometry dependence
- Angle wrt vertical
- Muon lifetime

Vast energy range



Where they come from

Possible sources,
in order of energy:

- The Sun's solar wind
  - neutrinos
  - photons
  - Electrons, positrons

Fusion reactions, only lower energy

- Shock-waves around supernovae in Milky Way

Can't leave Milky Way due to
Vast magnetic fields

- Unknown : extra-galactic ? Neutron stars ? Accelerated by something ?

Abundance of elements similar
to Earth, except for large quantity
of Lithium, Beryllium and Boron

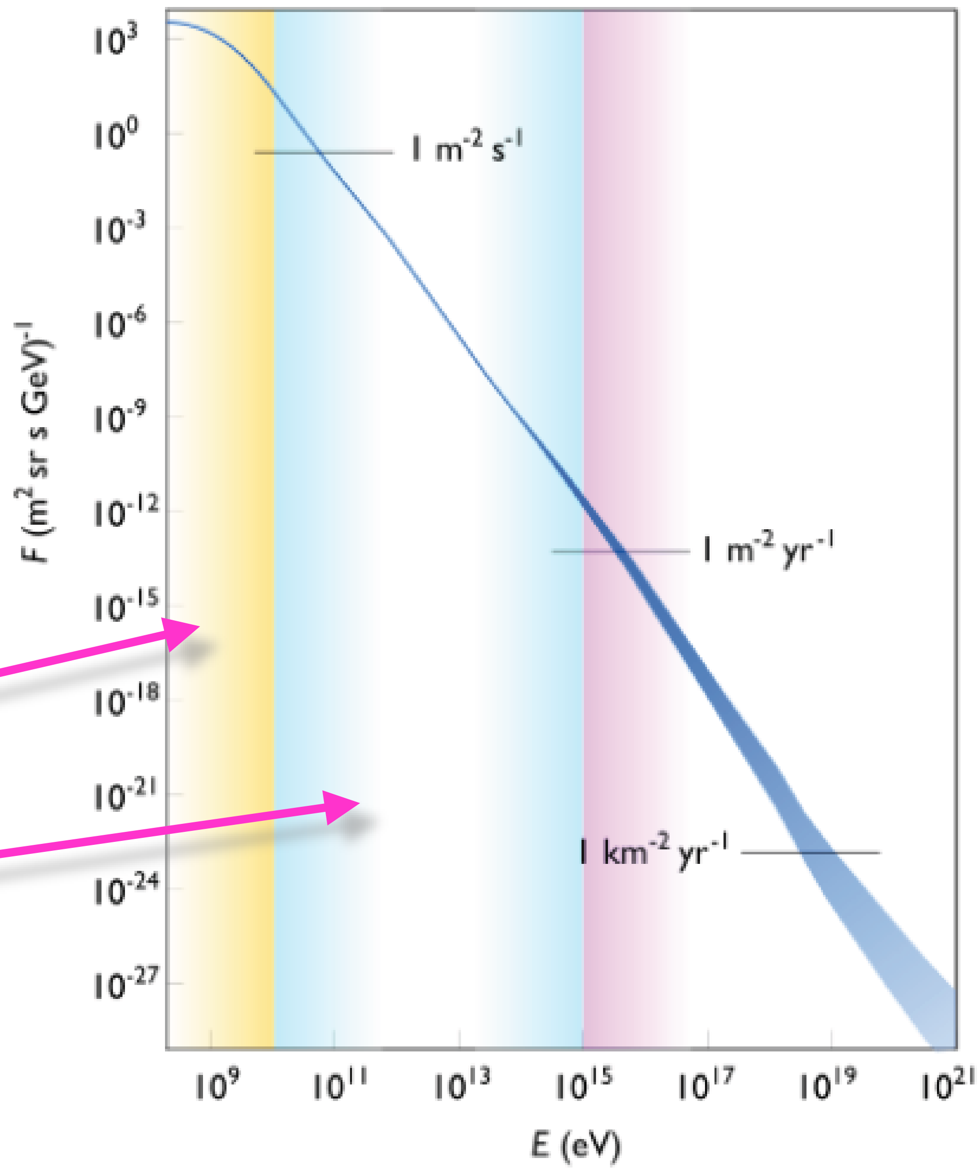
Energy

In 1 m^2
~1 particle/sec with 1 GeV

1 per km^2
1 particle/year with 10^{20} GeV
10^8 time the LHC energy

Solar wind

shockwave



GZK cutoff

Cosmic microwave background, 2.7 K : n=400 photons per cm^3

Protons in cosmic rays may interact with photons:

$p + \gamma \rightarrow \pi^0 \, p$

$p + \gamma \rightarrow \pi^+ \, n$

Threshold energy above which the interaction is possible:
Particles produced at rest

$$E_p = \frac{m_\pi c^4 (2m_n + m_\pi)}{2E_\gamma} = 10^{20}\ \mathrm{eV}$$

$$\sigma = 2 \times 10^{-28}\ \mathrm{cm}^2$$

Cross-section

$$\lambda = \frac{1}{n\sigma} = 10\ \mathrm{Mpc} = 32.6 \times 10^6\ \mathrm{light\ years}$$

Mean free path

~650 times the radius of Milky Way

Cosmic showers measurements

How many cosmic particles with an energy above 10^{16} eV reach the earth?

Where do they come from? Are there sources in our Milky Way?

Can one determine the GZK-cut-off?

Variation with latitude, altitude; Night/Day variation; Seasonal variation

Further research

Improve shower models

Influences from the atmosphere

Correlation with weather

Correlation with Sun activity

International project HiSPARC on cosmic showers detectors
for schools: reached ~20 schools in UK
If you are interested, please contact me

Interaction of charged particles

Basic physics:

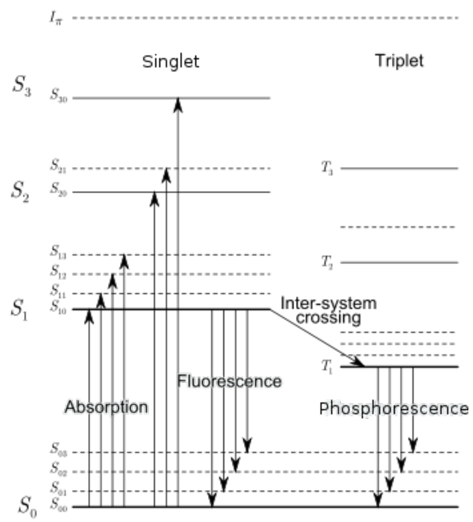
When a high-energy charged particle crosses a material, it may transfer energy to the electrons in the material's atoms

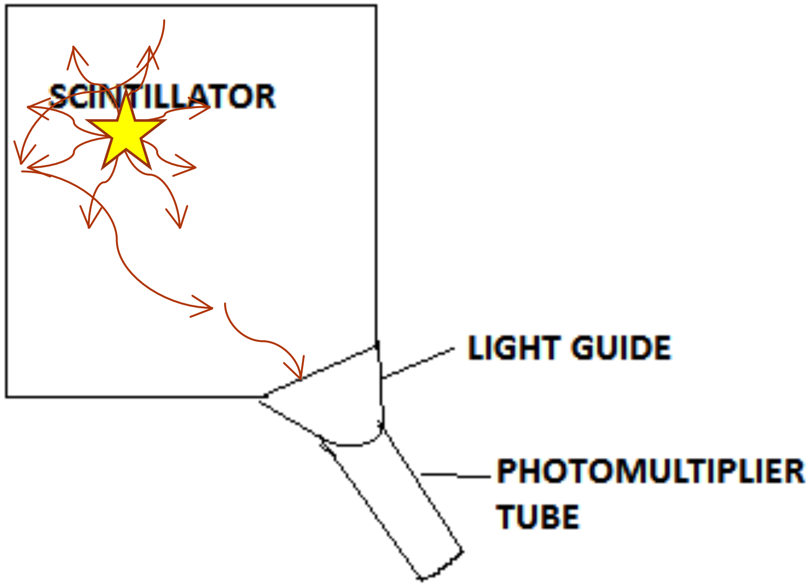
This may result into excitation of the atom into a higher energy level; the excited state immediately decay emitting a scintillation photon

This may also result in ionization if an electron gains enough energy to escape from its orbit, leaving behind a positively charged ion

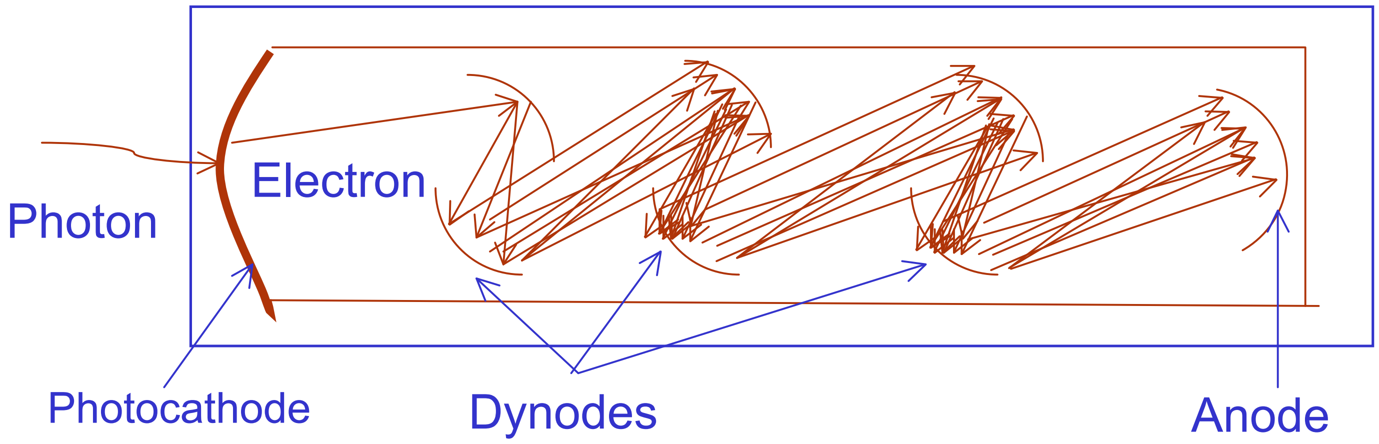
The Scintillation Counter

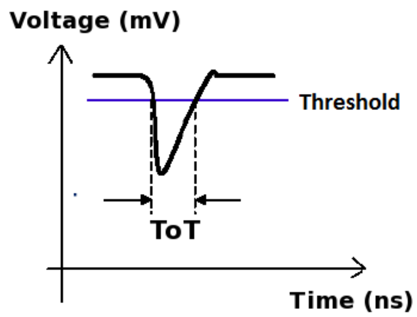
- Charged particle passes through plastic scintillator leaving a trail of ionisation
- Ionisation recombines, emitting light in all directions.
- Light bounces around scintillator and some fraction enters light guide.
- The perspex light guide directs the light on to the photomultiplier tube (PMT).





Photomultiplier Tube





- Photons hit PMT window (metallised glass): cathode.
- Via the Photoelectric Effect, electrons are emitted

$$\gamma + \text{atom} \rightarrow \text{ion} + e^-$$

- Electrons are attracted to 1st dynode and from one dynode to the next by an electric field
- at each collision with a dynode, 2 or 3 electrons are emitted, i.e. amplification at each stage
- Electrical signal produced at anode.

Detecting cosmic rays

- If a charged particle (e.g. a cosmic ray) passes through both scintillators, it will produce an electrical pulse from each
- If these signals occur almost exactly a the same time, we assume that these “coincidences” have been produced by a charged particle passing through both scintillators.
- The electronics counts how many coincidences have been detected
- This counter tells us directly how many cosmic rays have passed through the two scintillators in a given time.

Conclusions

Cosmic rays offer a natural laboratory

Real-science experiments can be done with the detectors shown

Great way to start with particle physics !