# Electromagnetic Cascades

Jonathan F. Ormes

Space Sciences Director, GSFC, Emeritus

University of Denver

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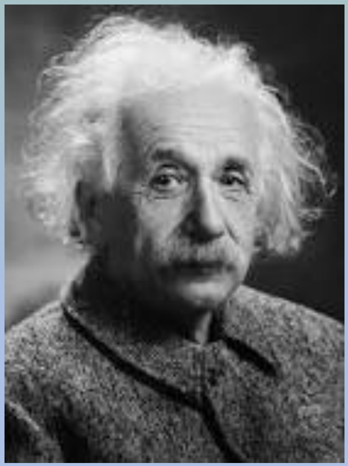
Wind Crest Learners

Academy for Lifelong Learning

# Cosmic rays in atmosphere

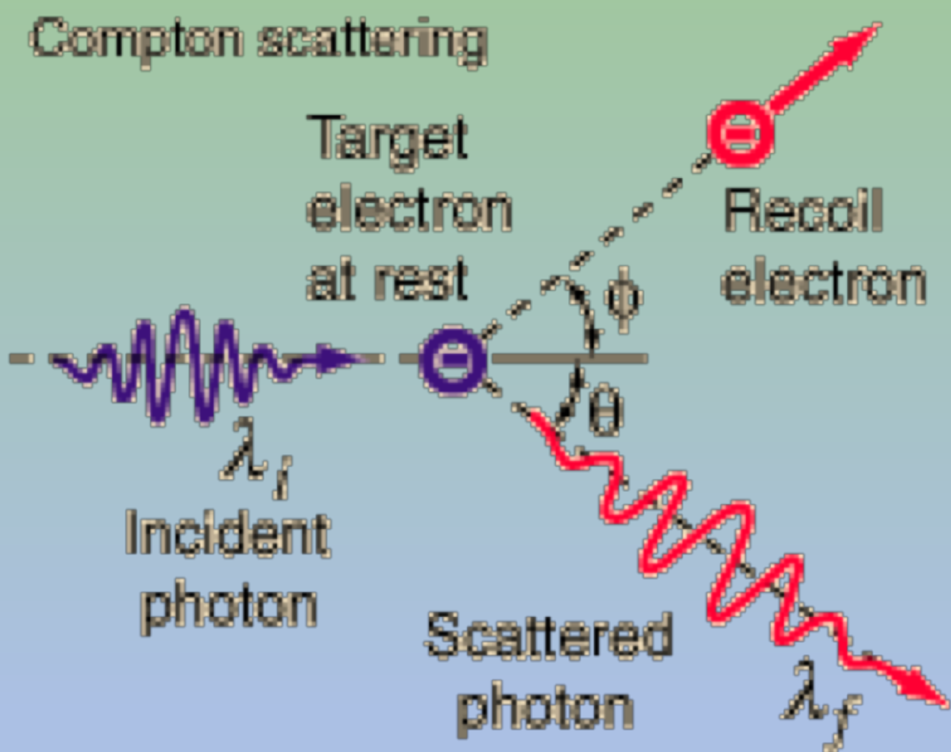
- Highly penetrating – must have enormous energies
  - It was soon realized that the particles were moving at essentially the speed of light.
    - Experiments done on Mt. Evans - plaque
  - Effects of special relativity had to be taken into account
    - Time dilation allows the particles to survive their travel through the atmosphere
  - **v ~ c – we use $\beta$ = v/c – velocity as a fraction of the light speed**
    - ½ $mv^2$ does not work; must use more complex relativistic equations

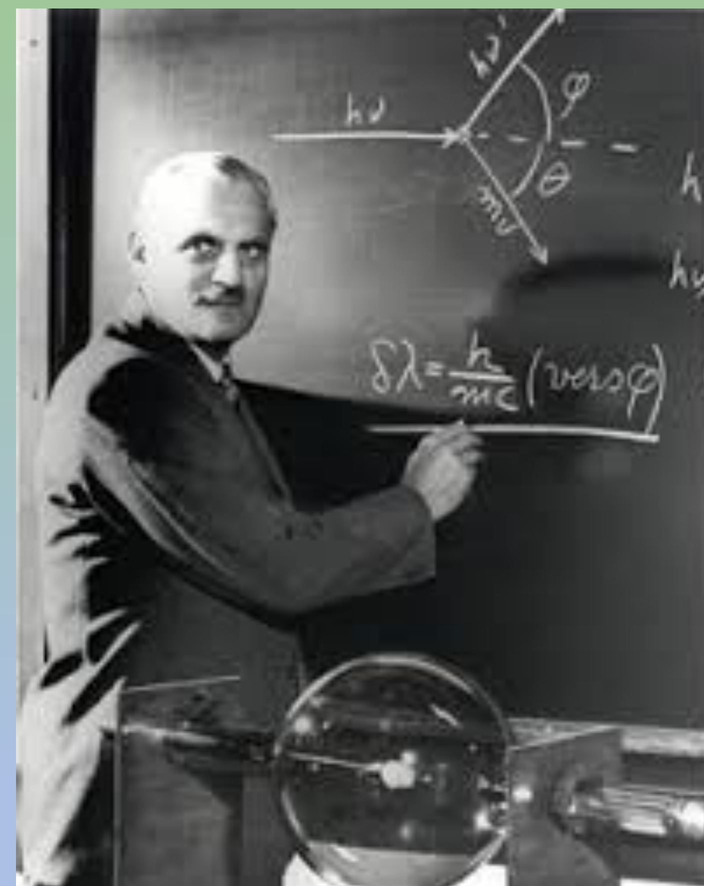


- Many different kinds of ionizing particles
  - Discoveries of the first 1/3 of the $20^{th}$ century
  - Origin of high energy physics
- Includes electrons and gamma-rays

# Arthur Holly Compton

He showed how photons can collide with $e^-$ as balls on a pool table.



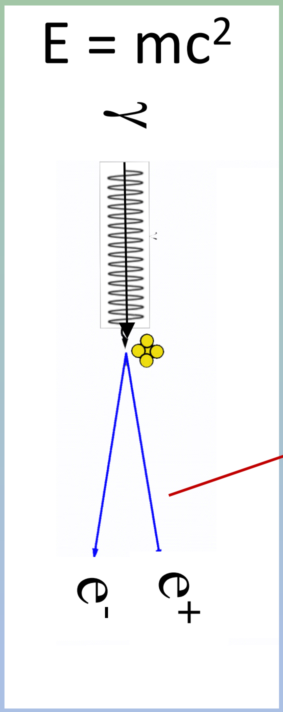



This theory is known as Compton Scattering

# What happens when the energy of the photon, $h\nu$, is much higher, say 1 GeV?

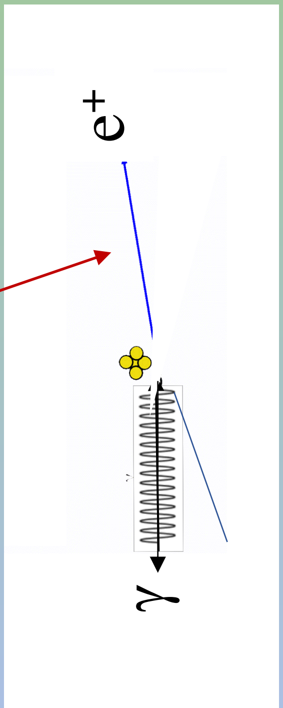
$E_\gamma = h\nu = 1$ GeV

Pair production




The $\gamma$ has enough energy to make 2 electrons), give the electrons some kinetic energy and still have plenty of energy left to continue life as a gamma ray photon with lots of energy.

Compton collision



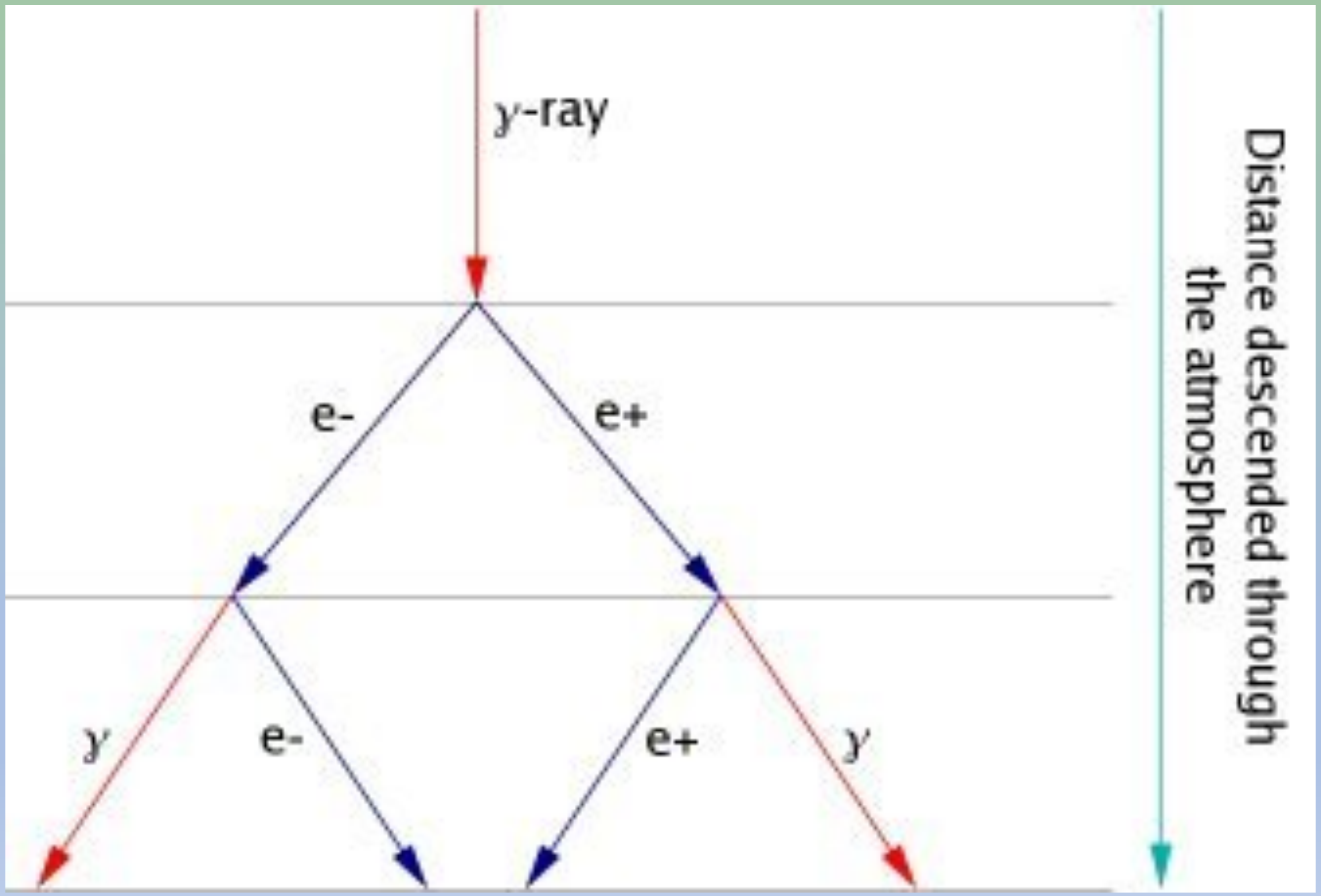

The electron still has lots of kinetic energy. It can transfer part of this energy to another photon.

This is kind of Compton Collision.

$$h\nu_1 = 2m_ec^2 + h\nu_2 + \text{motion energy of the electrons}$$

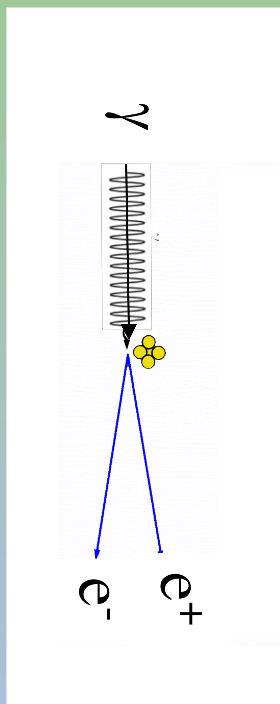
$$1\text{ GeV} - 2 \times 0.511\text{ MeV} = 0.8\text{ GeV} + \tfrac{1}{2}m_e(v)^2$$

# Notice how this can multiply the number of particles in the shower.



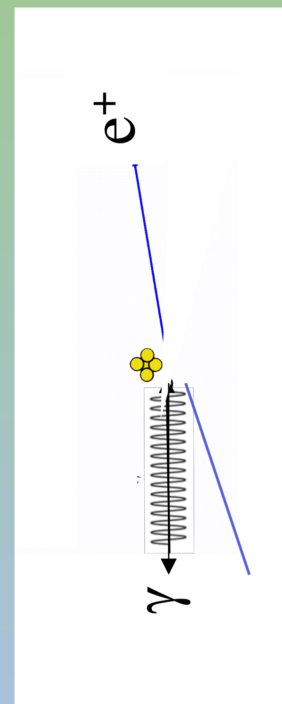
# We call this an electromagnetic cascade.

Pair production




High energy $\gamma$-photons make electrons pairs ($e^+$ $e^-$ ) and transfer energy to electrons. The $\gamma$-photon may retain enough energy to repeat this over and over. The $\gamma$-photons can also transfer energy to electrons ($e^-$ ) by Compton Collisions.

Compton collision



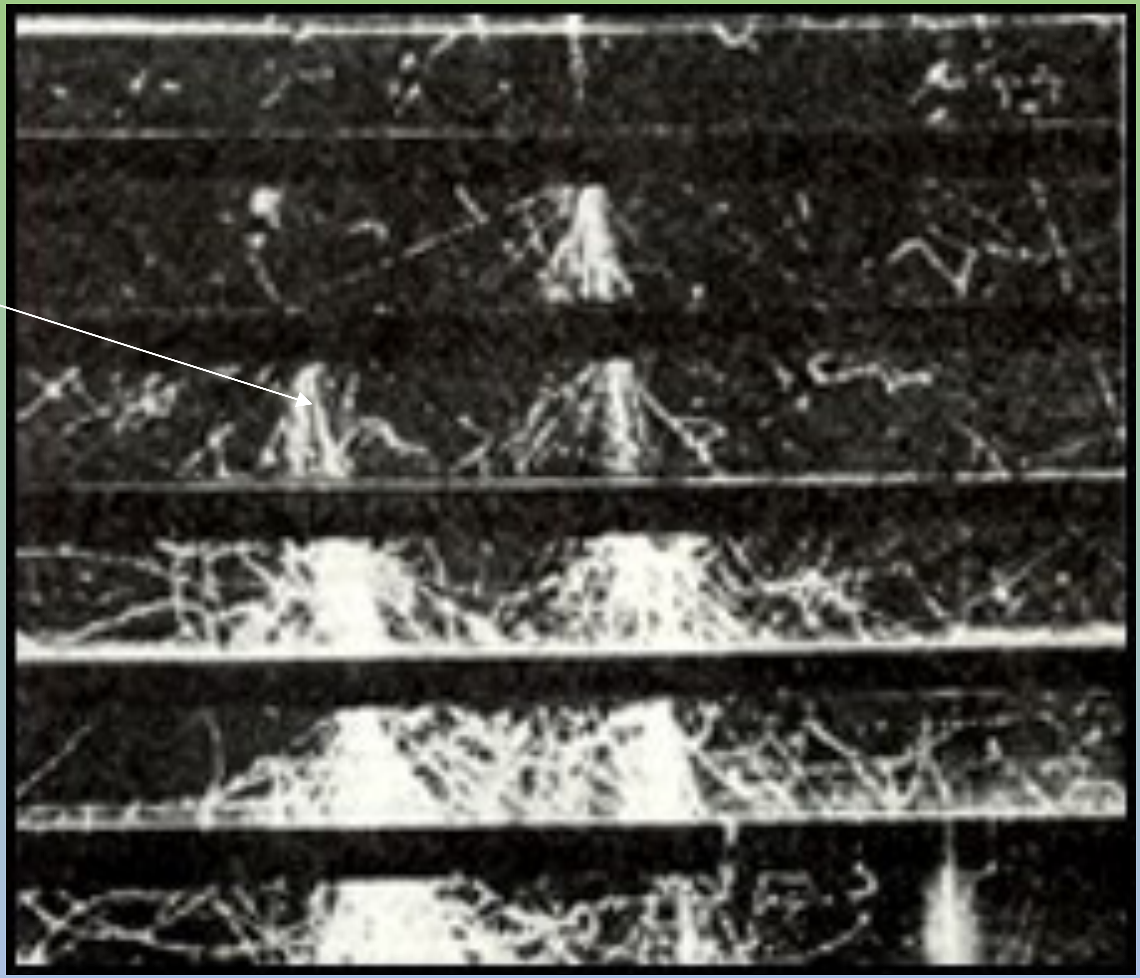

Energetic $e^+$ or $e^-$ can also transfer energy to a $\gamma$-ray.

This process of transfer of energy from $\gamma$ to e and back happens over and over until the energy is dissipated and the electrons come to rest.

The e can be seen via energy loss in Cloud Chambers.

The gamma-ray photons are not visible.

Gamma-initiated shower.



Lead plates

Using the Wilson cloud chamber, in 1927, Dimitr Skobelzyn photographed the first ghostly tracks left by cosmic rays.

# Someone can ask

OK, Mr smarty pants Professor, where did the gamma-ray come from?

It took a while to sort that out.  It wasn't until 1947 that Cecil Powell and Guiseppi Occhialini from the University of Bristol in England found charged pions ($\pi^-$ and $\pi^+$) in nuclear emulsions exposed in the Pyrenees at Pic du Midi de Birgorre and at Chacultaya in the Andes.  This technique allowed them to see very short lived particles were decaying into the muons.

# What produced the first gamma-rays?

Something was producing the gamma-rays, the soft component in the cosmic ray showers. It wasn't until 1950 that their source was first identified at the cyclotron at Berkeley and shortly thereafter found in nuclear emulsions carried on high altitude balloons.

The signature was the appearance of 2 gamma-ray showers originating at the same place in the emulsion. They called this invisible particle the $\pi^o$.

We knew by then that the cosmic rays are extremely energetic protons and heavier nuclei coming into the top of the atmosphere from some unknown sources in the cosmos.

The $\pi^o$ particles are produced in the collisions of the cosmic rays with atmospheric nuclei, mostly $N_2$. The 3 pions are carriers of the nuclear force as Yukawa had predicted.

# Nobel Prizes

Hideki Yukawa

1907 - 1981

1949 “for his prediction of the existence of mesons on the basis of theoretical work on nuclear forces.”

Cecil Powell

1903 - 1969

1950 "for his development of the photographic method of studying nuclear processes
and his discoveries regarding mesons made with this method"

$\pi^{o}$ : mass = 135 MeV/$c^2$  lifetime = 8.4 x $10^{-18}$ s

$\pi^{+}$ : mass = 139 MeV/$c^2$  lifetime = 2.6 x $10^{-8}$ s

$\pi^{-}$ : mass = 139 MeV/$c^2$  lifetime = 2.6 x $10^{-8}$ s

# Particle zoo

collision
p+p -> $\pi^+ + \pi^- + \pi^o$

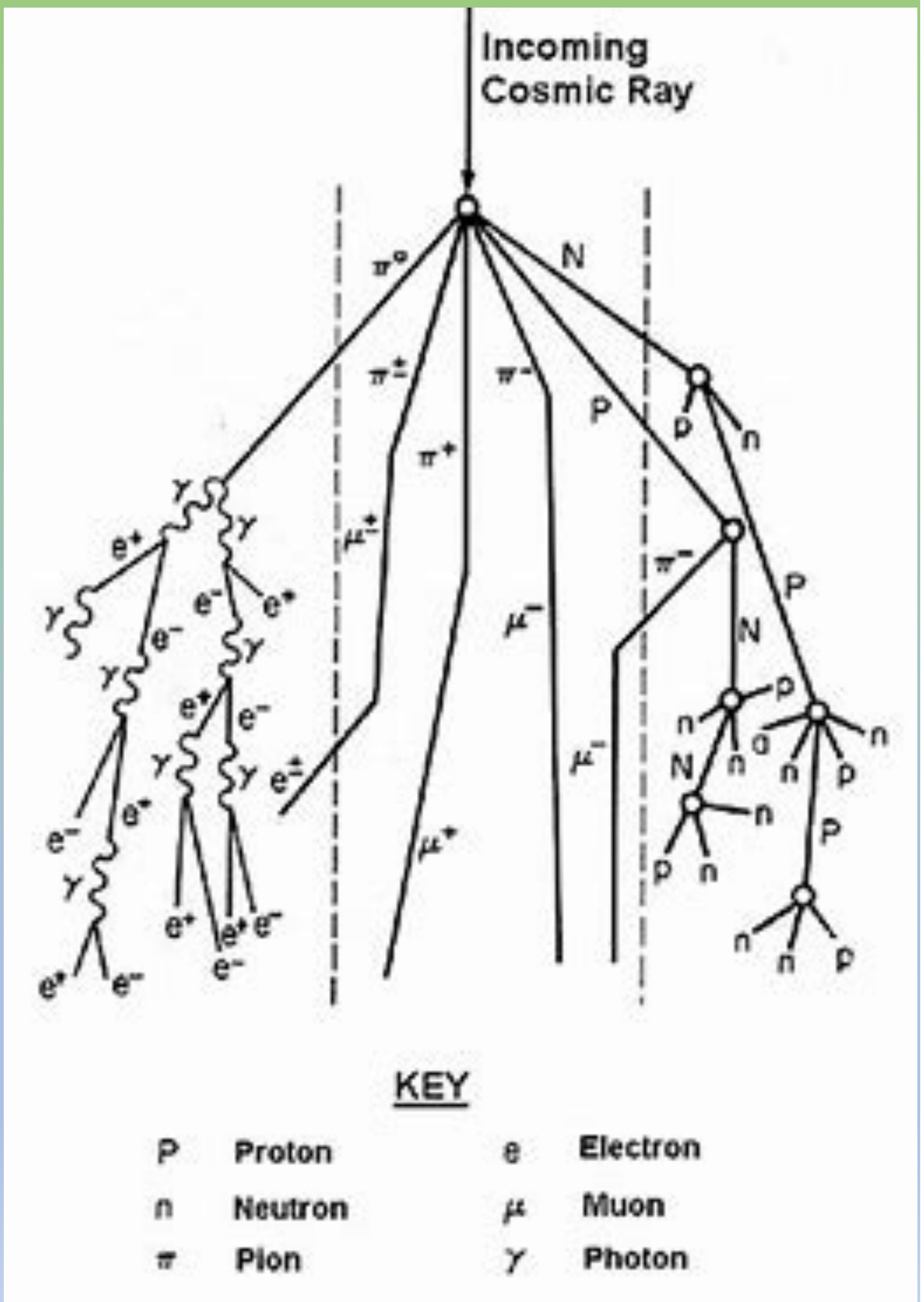
unstable particles decay

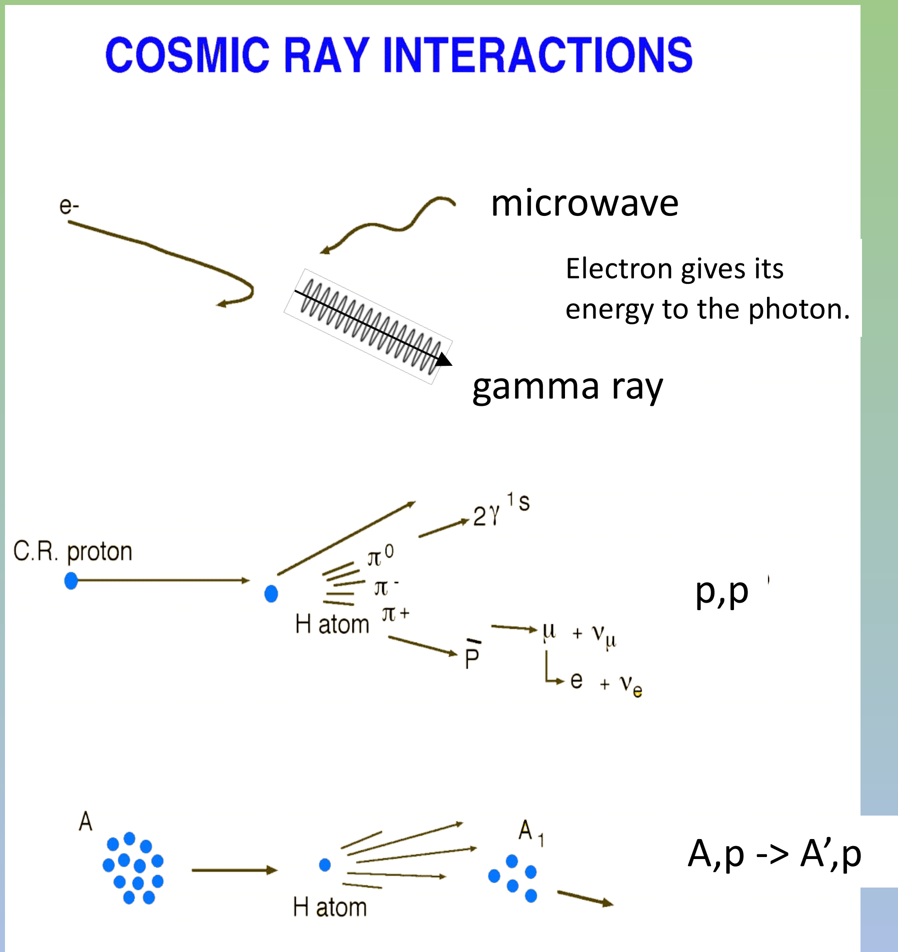
$\pi^+ \rightarrow \mu^+$ and $\pi^- \rightarrow \mu^-$

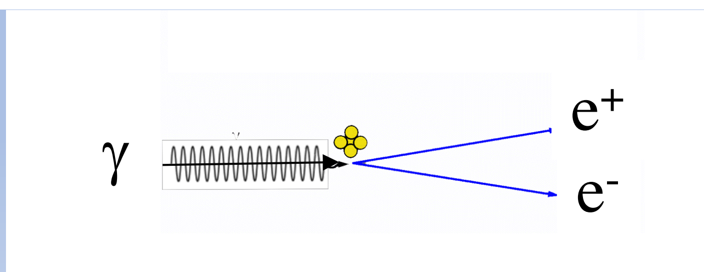
$\pi^o \rightarrow 2\gamma$

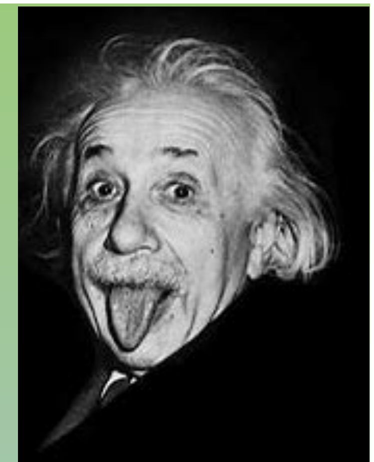
The spectrum of the gamma-rays has a peak at 90 MeV.

The muons proceed to penetrate the atmosphere and into the ground.





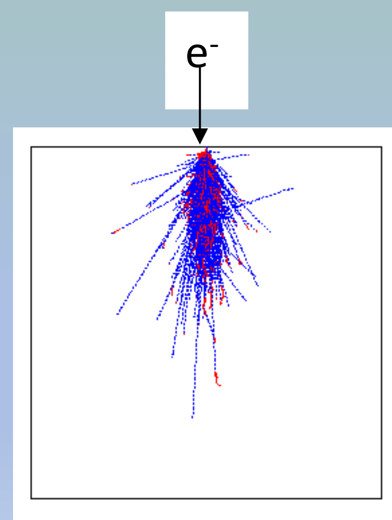



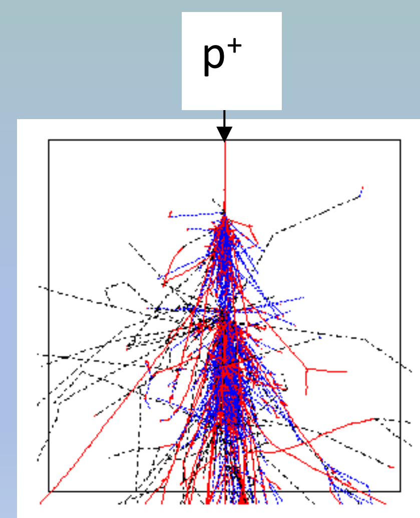
$E = mc^2$

$\pi^o$ -> energy

$\gamma$ -> 2 electrons

Mass energy = $E/c^2$



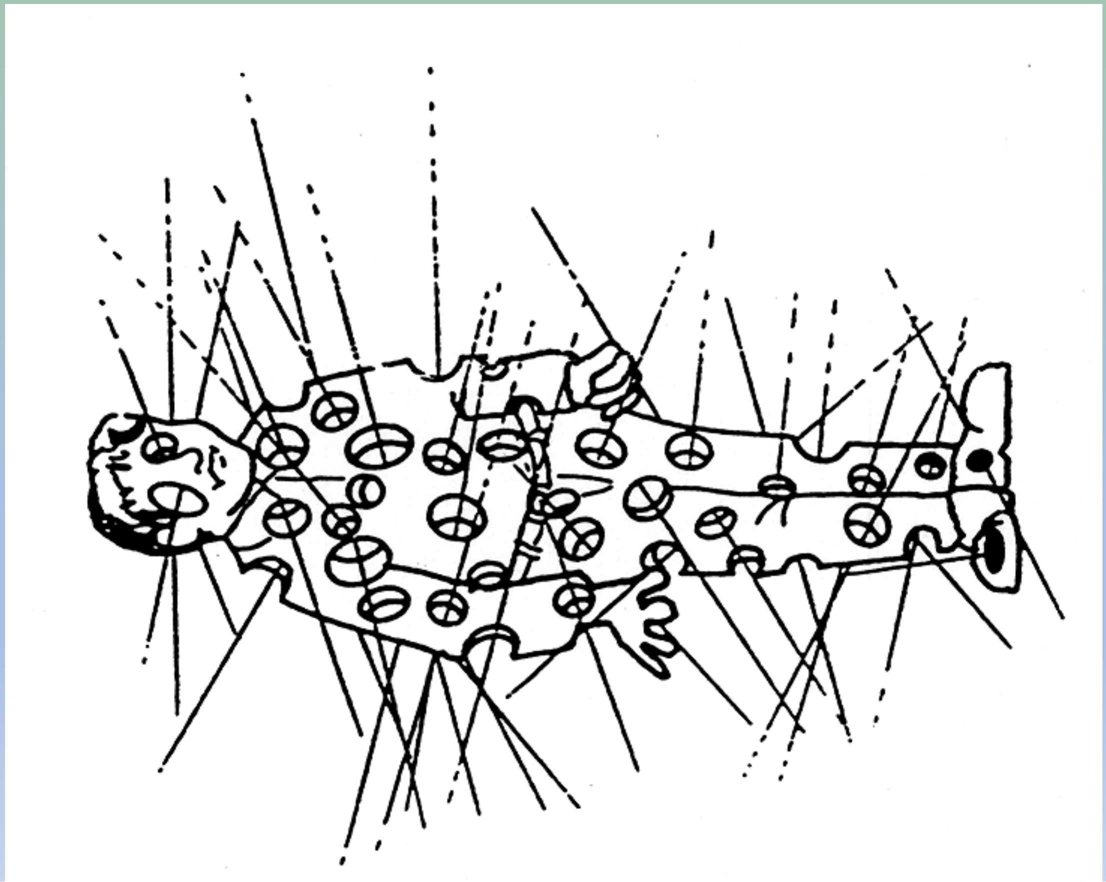




Block of matter

# What we came to understand by the end of the 1950s

- Cosmic rays at ground level
  - Most abundant are electrically charged muons, $\mu^+$ and $\mu^-$, which penetrate through the atmosphere, moving at the speed of light
    - Their lifetimes are extended by special relativity so they survive the journey to the ground
    - The $\pi$ mesons with 2 order of magnitude less lifetime decay
  - The "soft component" consists of $e^-$ and $e^+$ and is easily removed with some lead shielding
  - There are some neutrons and a few protons.

There was an old lady named Wright
who could travel much faster than light.
She departed one day
in a relative way
and returned on the previous night.



No wonder
I can't sleep

# What are cosmic rays in space?

OK, that was a 20 year quest to find out that cosmic rays were ordinary protons, albeit ones of tremendous energy coming from beyond the solar system.

Cosmic ray turns out to be an inappropriate names.  Rays are usually neutral.

Now we faced a new set of questions, usually known as “What is the origin of cosmic rays?

- Where do they come from?
- How do they get their tremendous energy?