Cosmic Rays, Physics, and Relativity

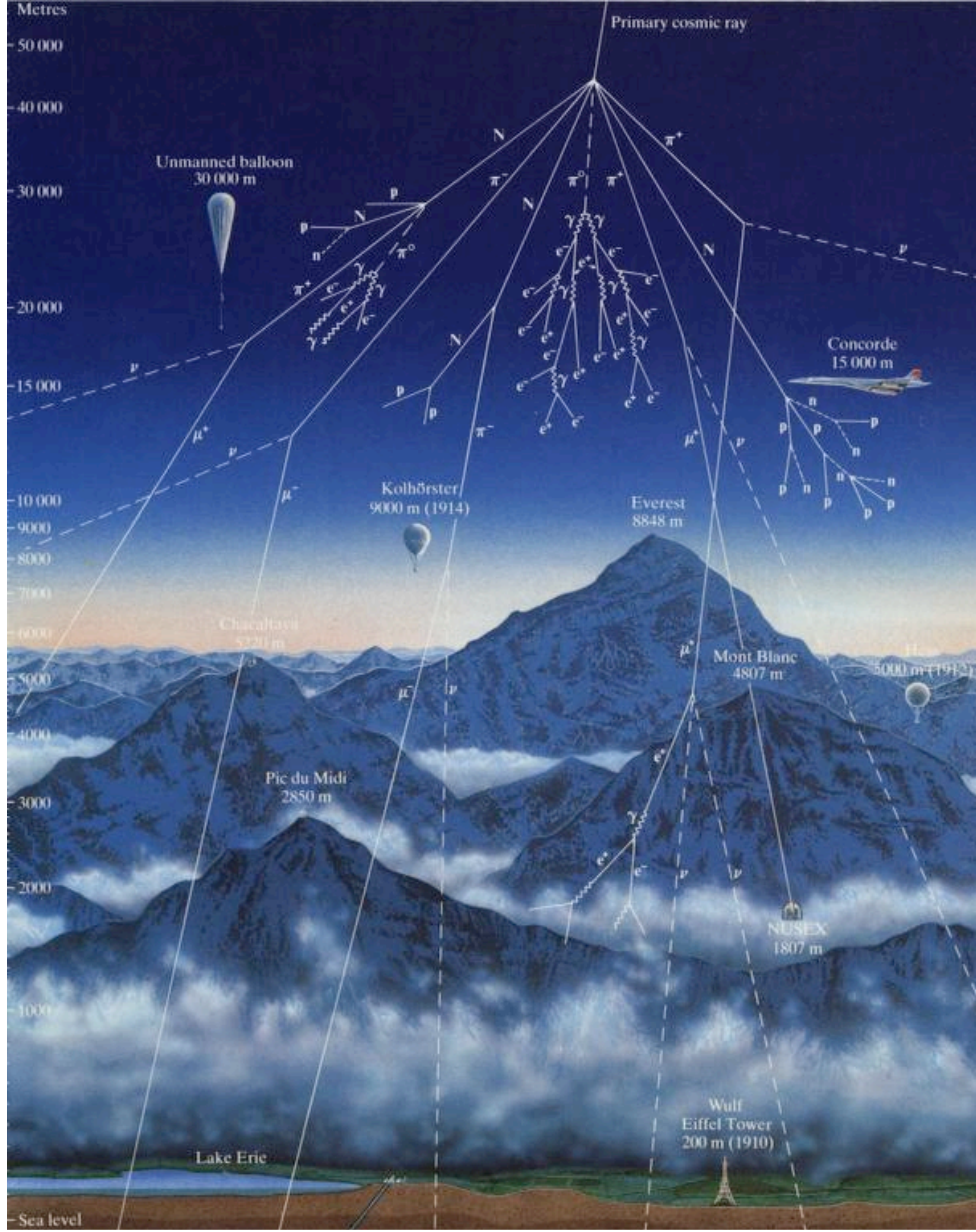
Ryan Reece

ryan.reece@cern.ch

UNIVERSITY OF CALIFORNIA
SANTA CRUZ

for Quark Net at UCSC

July 11, 2014



Outline

- What are cosmic rays?
- Open issues in particle physics and some experiments addressing them (Auger, Fermi, LHC).
- The Standard Model of Particle Physics
- Einstein's Relativity allows cosmic muons (which are unstable) to survive long enough to penetrate the atmosphere.

Cosmic Rays

- High energy particles coming from space (galactic or extragalactic).
- As a natural source of high energy particles, cosmic rays were critical to the discovery of the muon and many other particles in bubble chambers in the 1930s and 40s.
- Radio-carbon dating. Activated carbon created by cosmics:

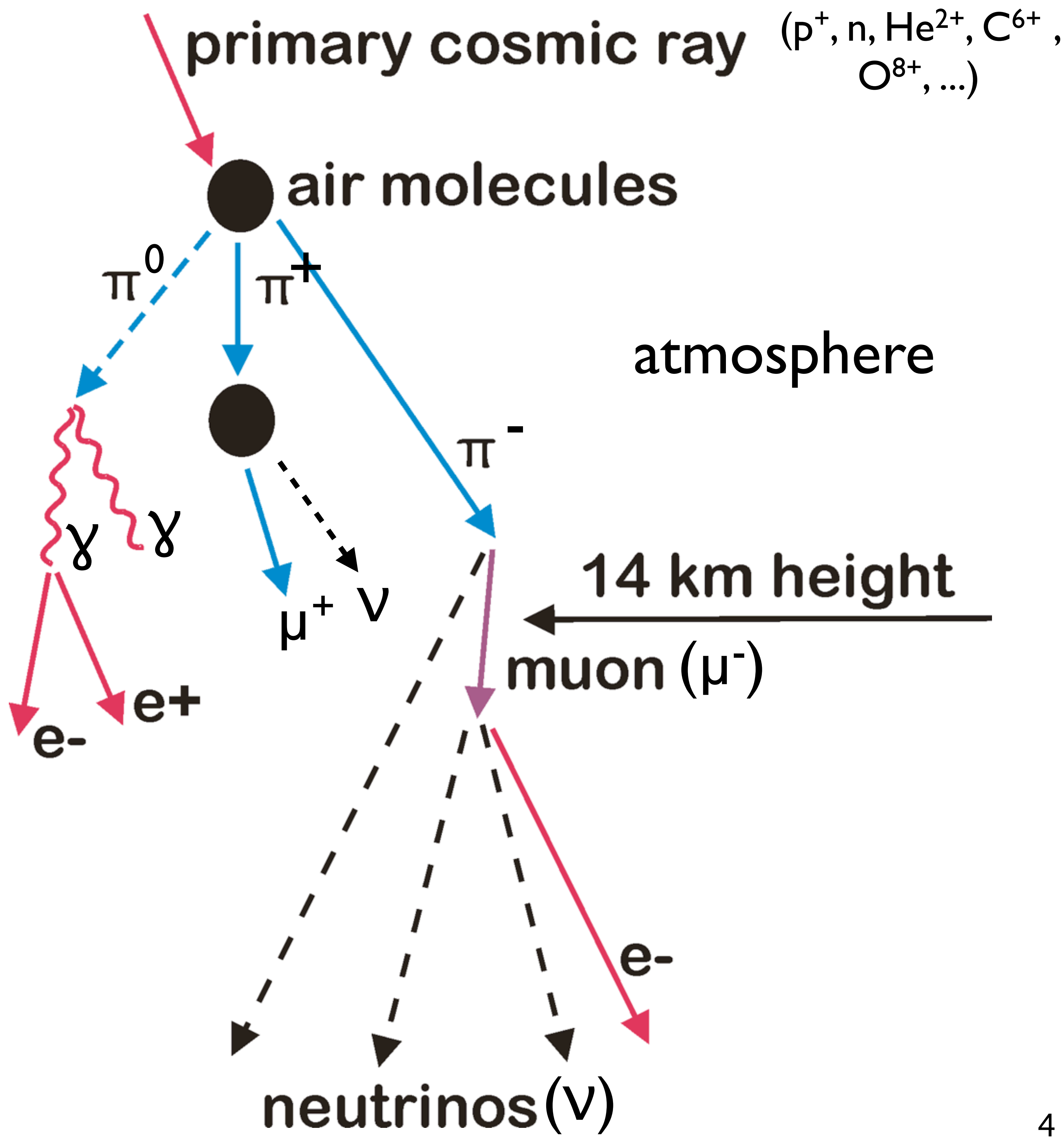
  $$n + {}^{14}N \rightarrow p + {}^{14}C$$

  later decays (half-life ≈ 8k years)

  $${}^{14}C \rightarrow {}^{14}N + e^{-} + \nu_e$$

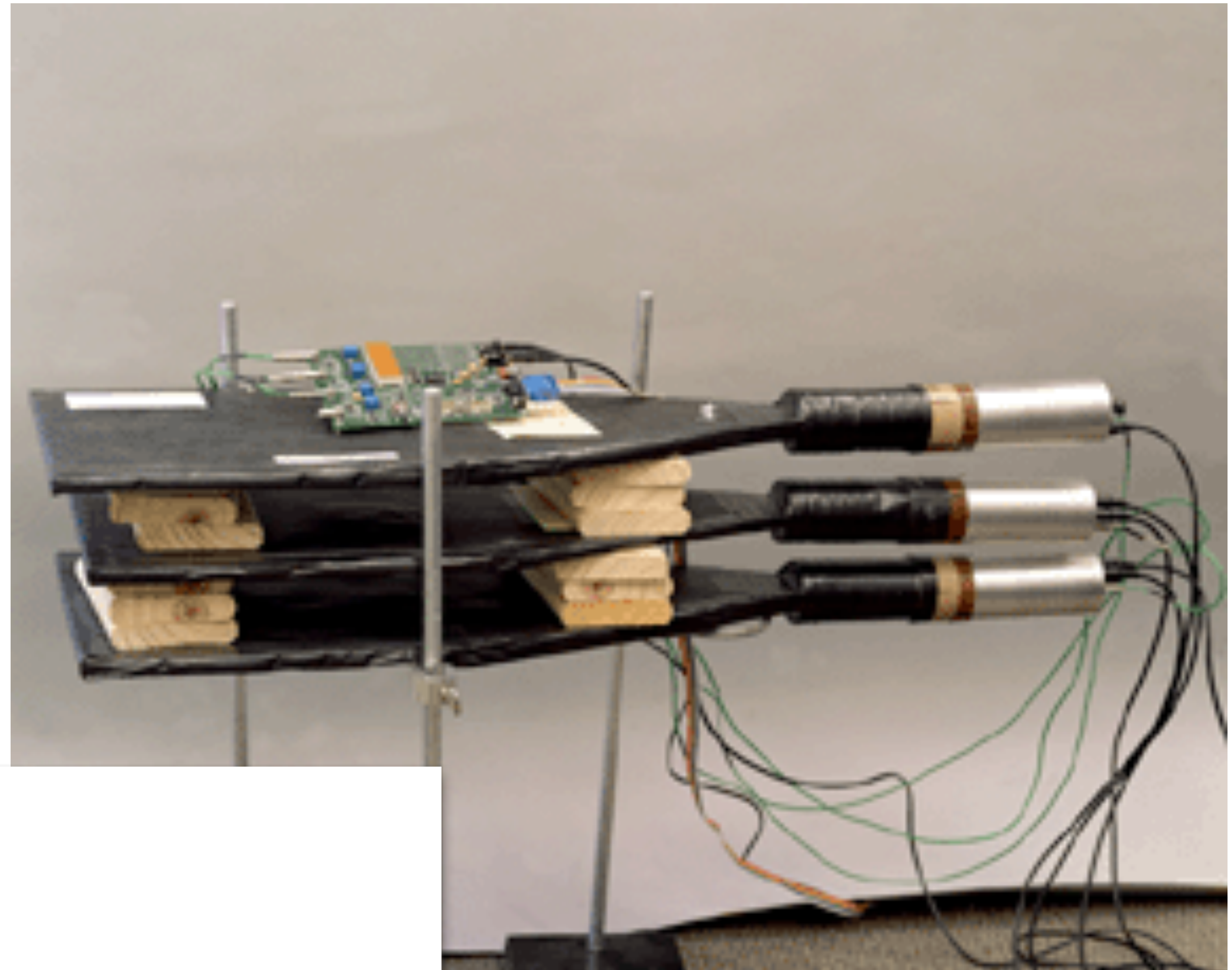
Cosmic Rays

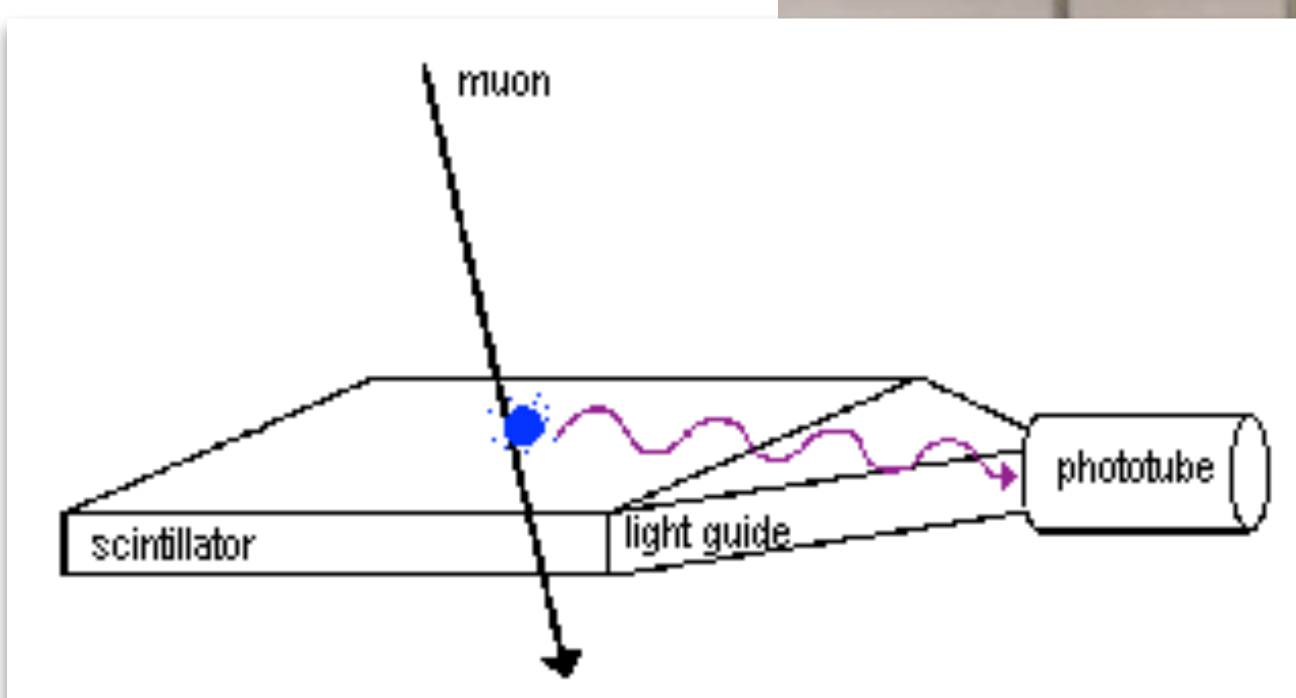
- In the 1930s and 40s, a wide variety of investigations confirmed that the primary cosmic rays are mostly protons, and the secondary radiation produced in the atmosphere is primarily electrons, photons and muons.
- On the ground we detect secondary particles created in a showers in the Earth's atmosphere.



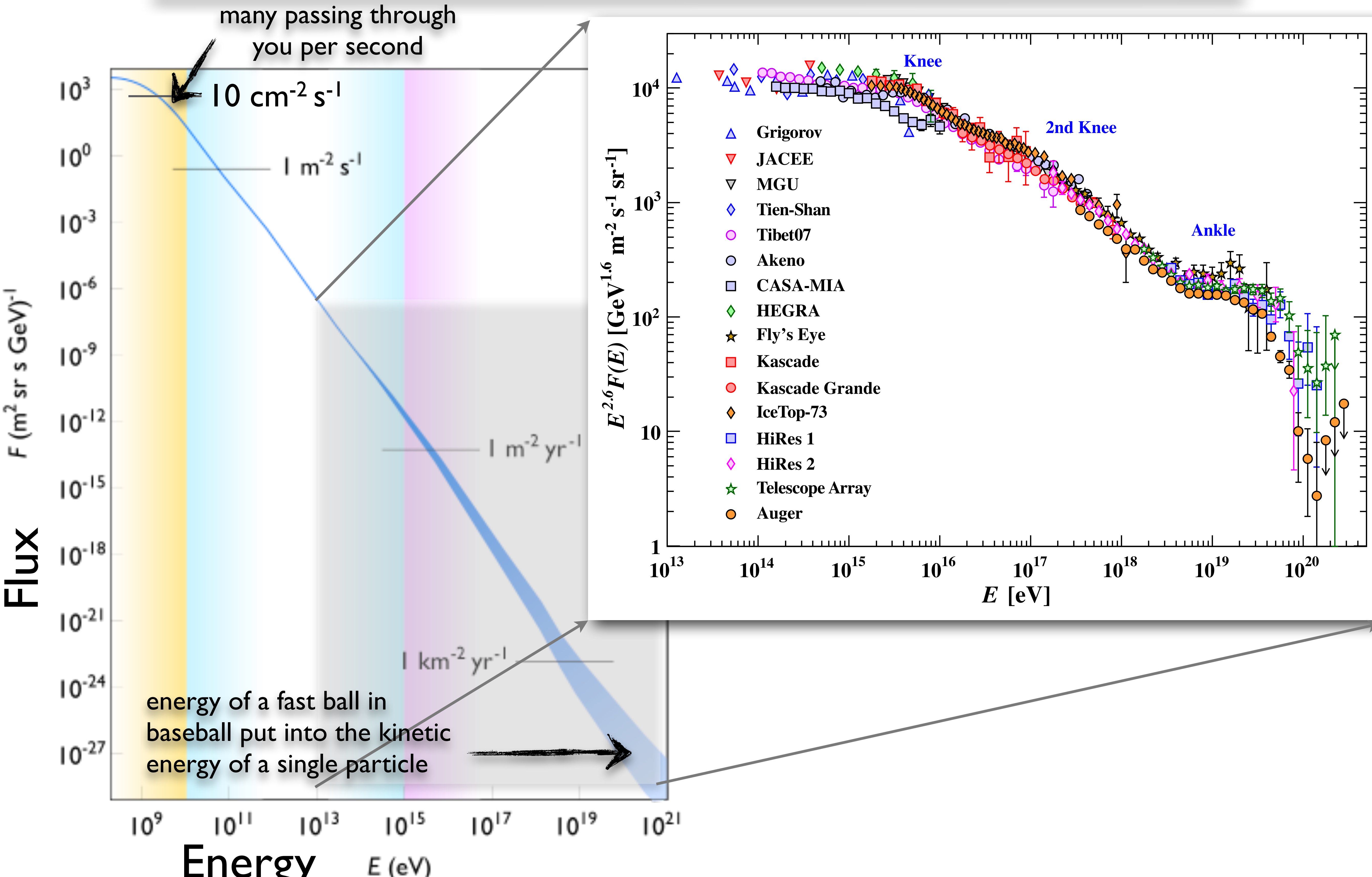
Cosmic Detector

- A muon comes streaking invisibly through the sky.
- It passes through the plastic scintillator, emitting light.
- The light triggers a Photomultiplier Tube (PMT), read by digital electronics.





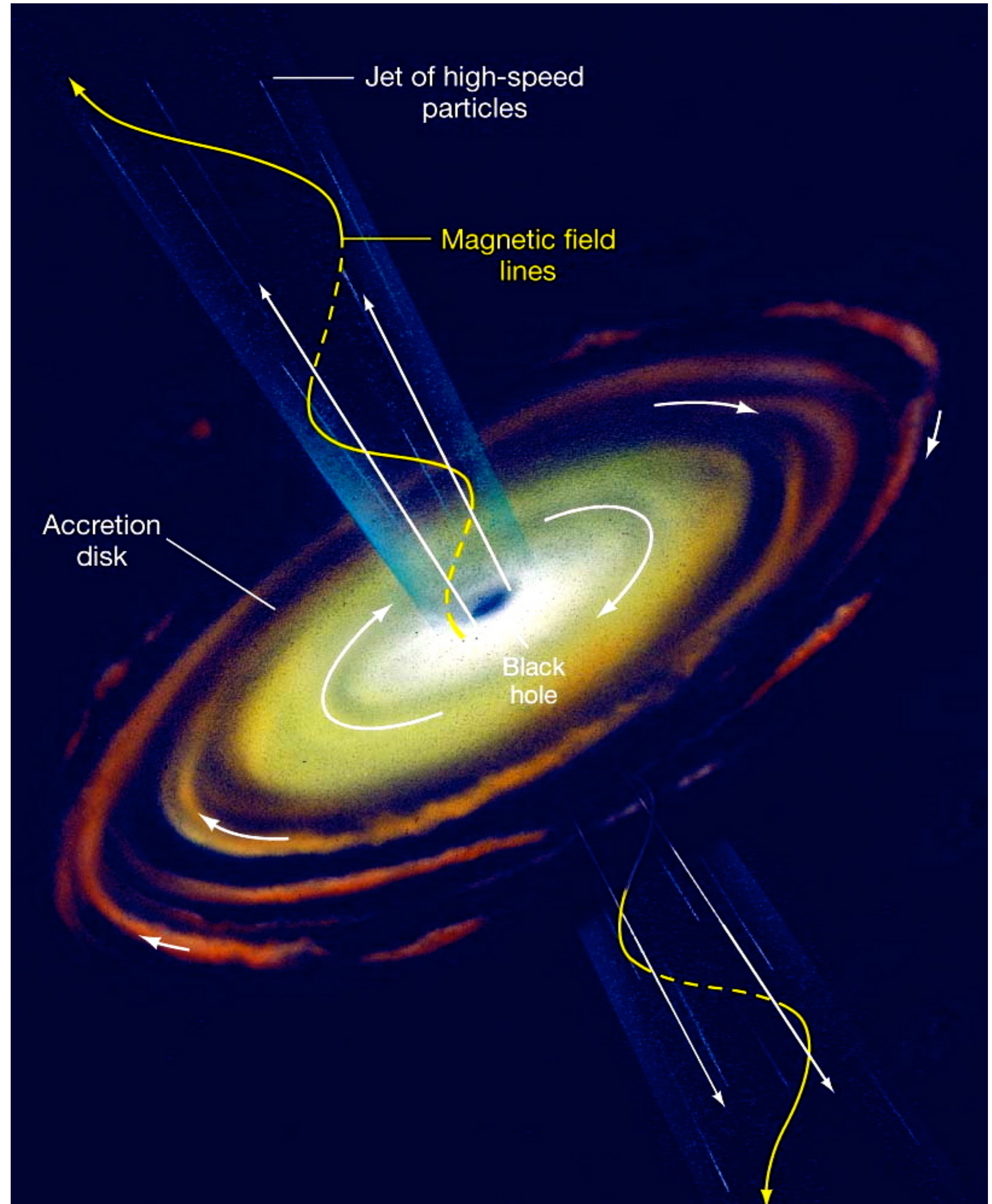
Cosmic Ray Spectrum



Mysteries in Cosmic Rays

Some *unanswered* questions about cosmic rays:

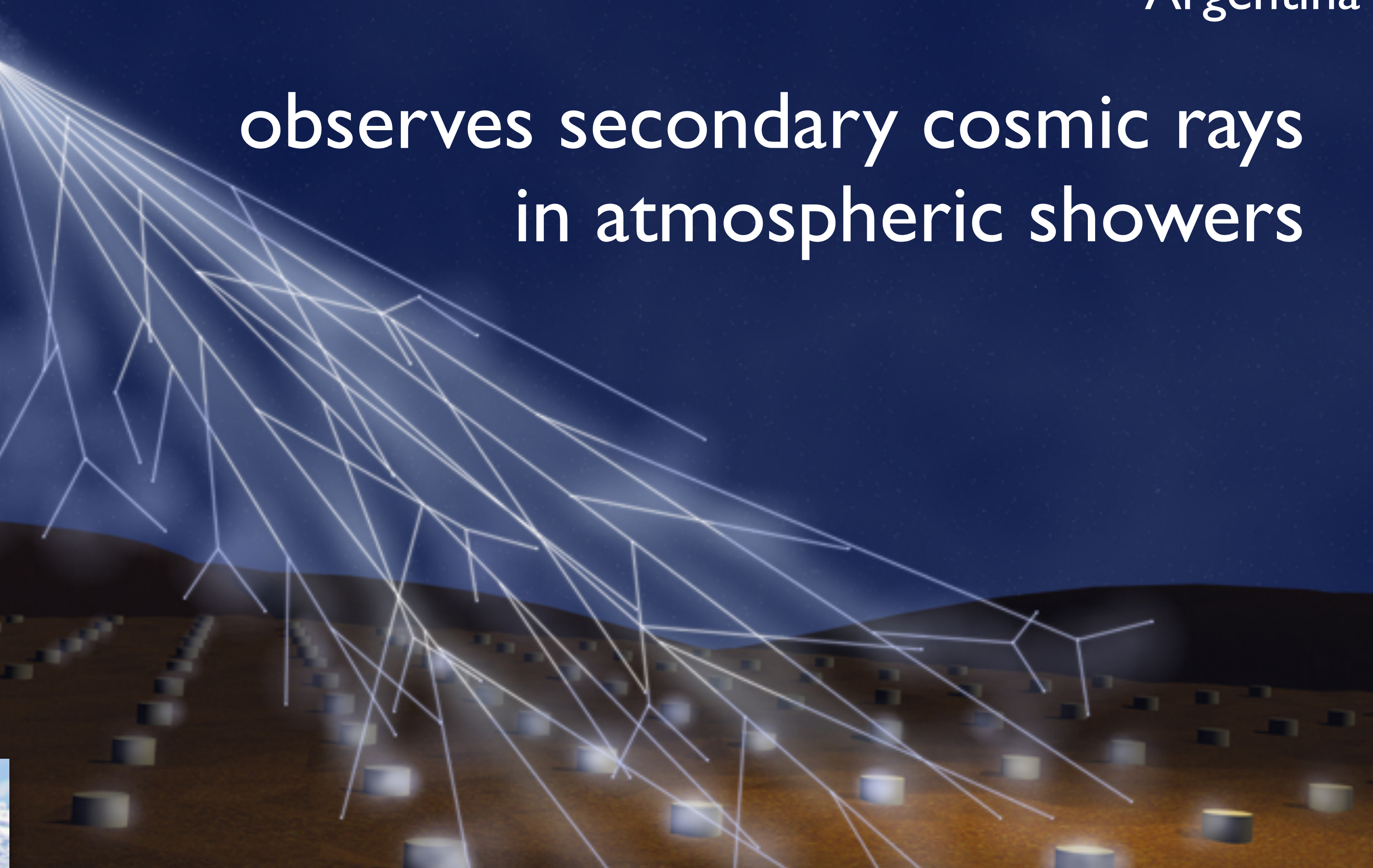
- Are Active Galactic Nuclei (AGN) the source of ultra-high-energy cosmic rays?
- Does dark matter annihilation show up in high-energy cosmic rays? Dark matter is the unexplained part (85%) of matter observed gravitationally to exist in galaxies but hasn't been seen to interact with other matter otherwise.
- Is the Greisen-Zatsepin-Kuzmin (GZK) limit obeyed? A cosmic upper-limit for the energy of a cosmic ray due to interactions with the CMB that would violate Relativity otherwise.



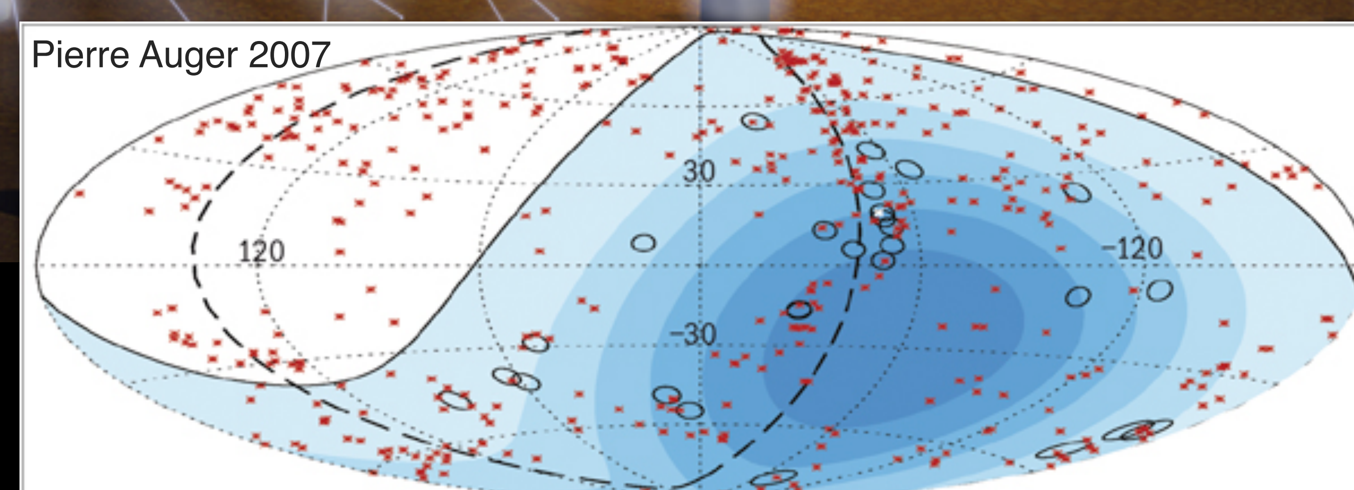
Pierre Auger Observatory

Highest energy cosmic ray observatory

Mendoza Province,
Argentina

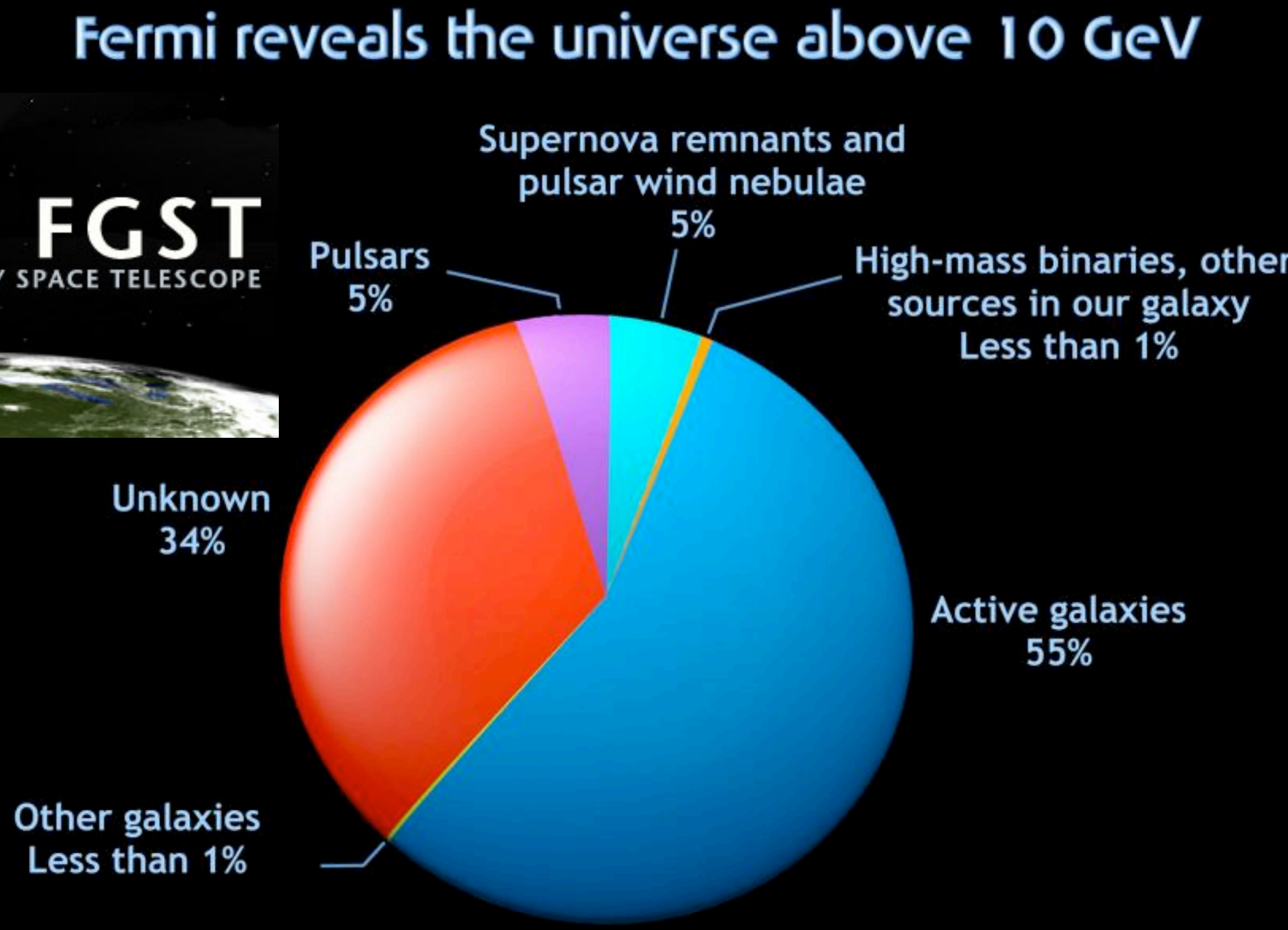


observes secondary cosmic rays
in atmospheric showers



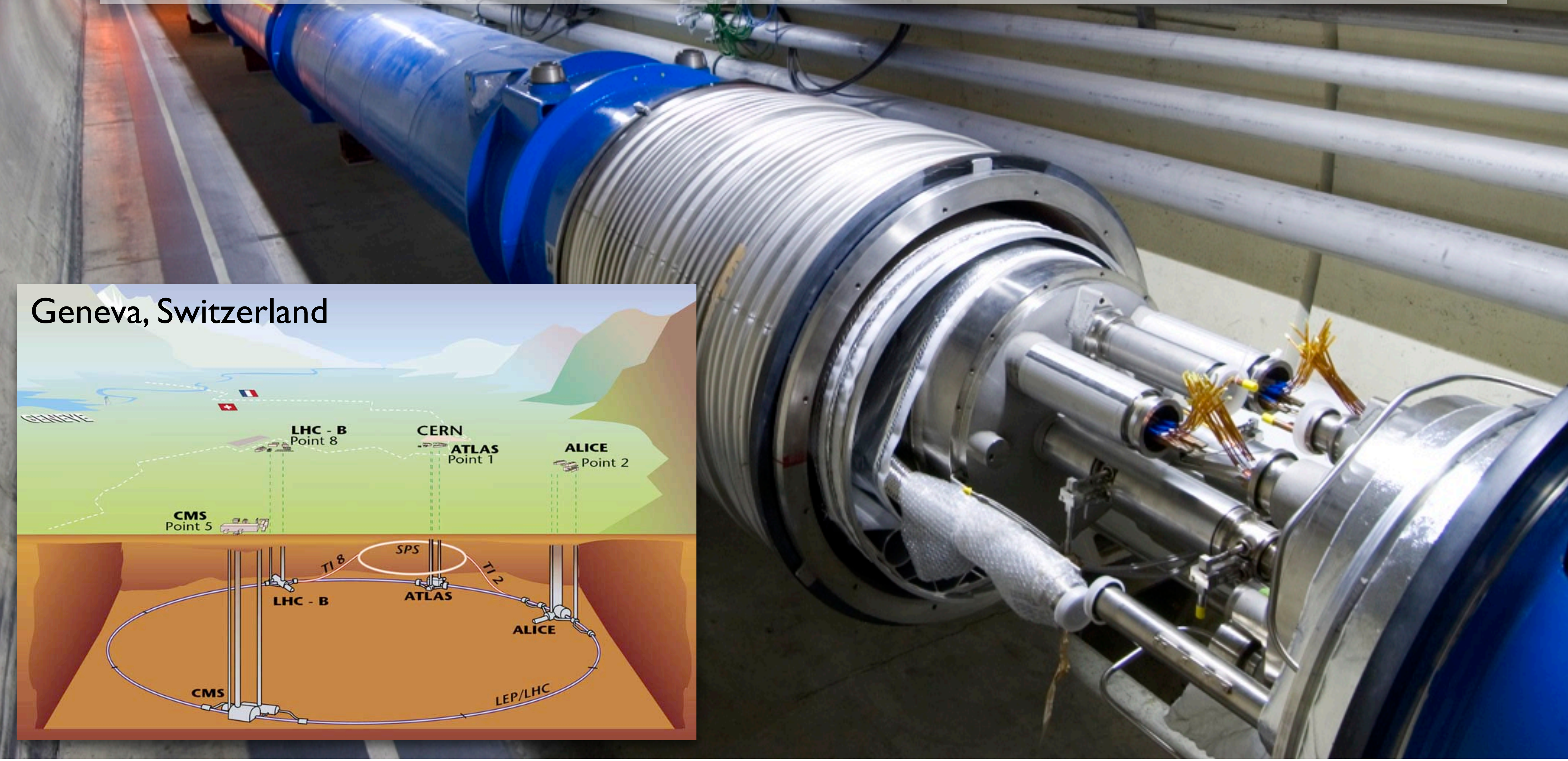
Fermi Gamma-ray Space Telescope

observes primary cosmic photons (gamma-rays) from space

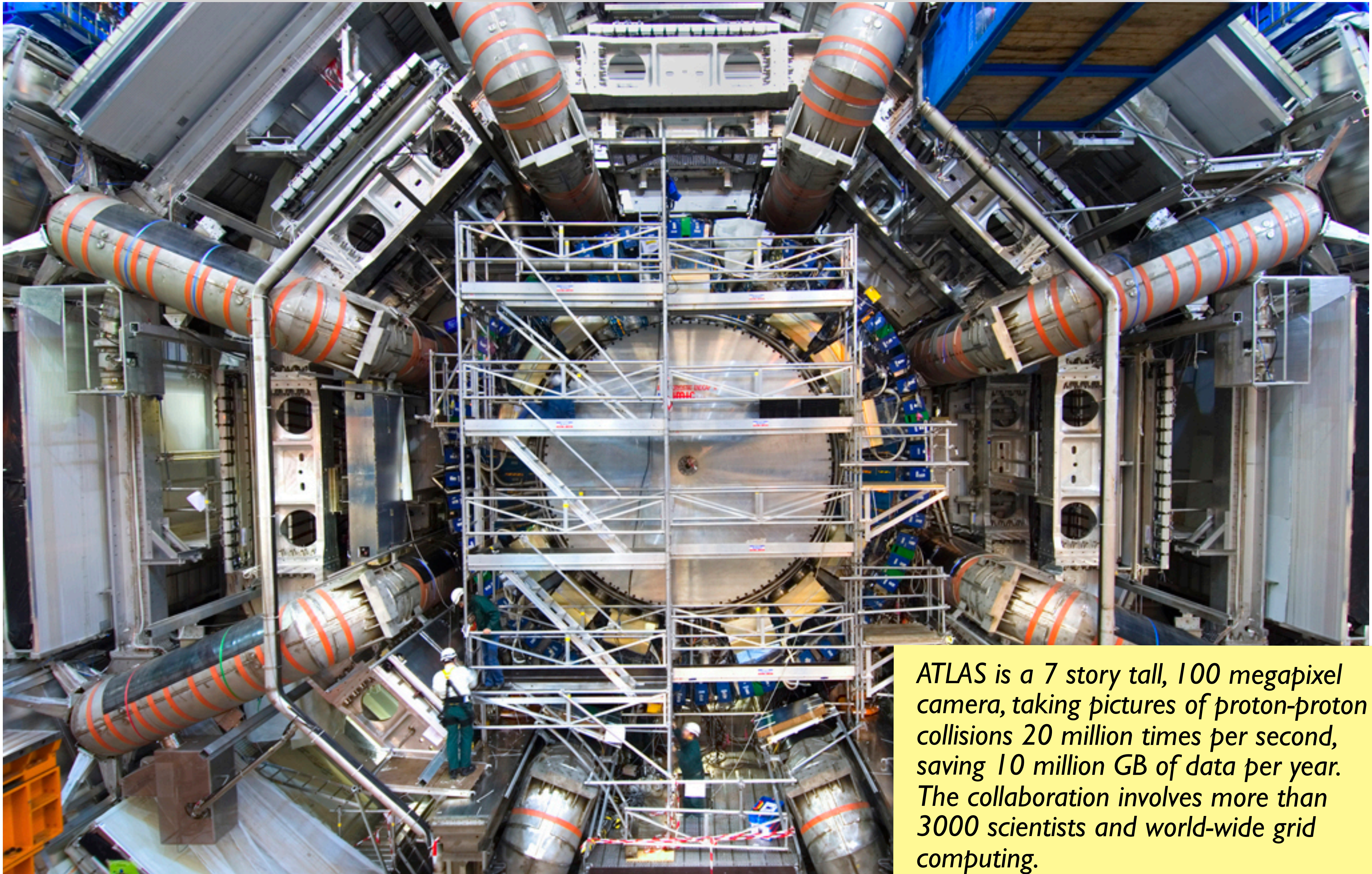


Large Hadron Collider

- 27 km circumference
- 1232 dipoles: 15 m , 8.3 T
- 100 tons liquid He, 1.9 K
- p-p collisions at $\sqrt{s}$ = 7-8 TeV
- inst. luminosity = 10^{32}-10^{34} $cm^{-2}s^{-1}$
- 10^{11} protons / bunch
- 1000 bunches/ beam
- 20 MHz , 50 ns bunch spacing
- 1-40 interactions / crossing
- 0.5 × 10^9 interactions / sec



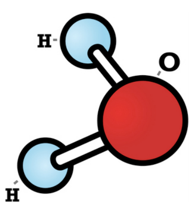
ATLAS



ATLAS is a 7 story tall, 100 megapixel camera, taking pictures of proton-proton collisions 20 million times per second, saving 10 million GB of data per year. The collaboration involves more than 3000 scientists and world-wide grid computing.

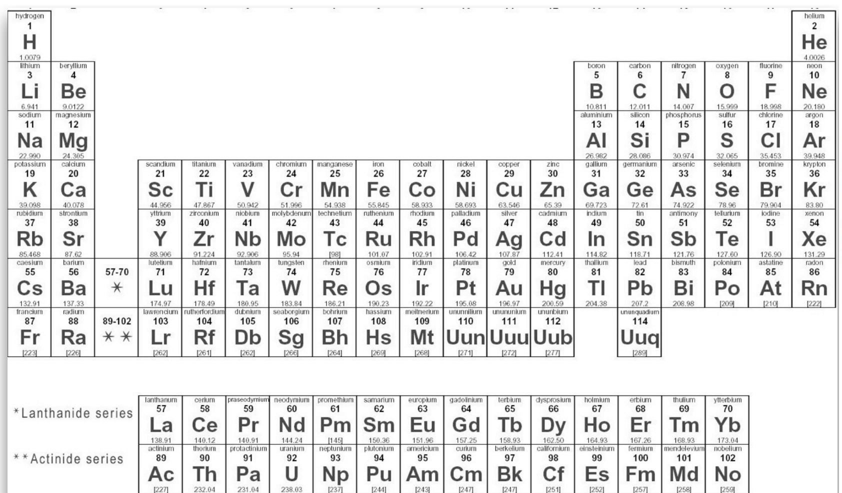
Standard Model of Particle Physics

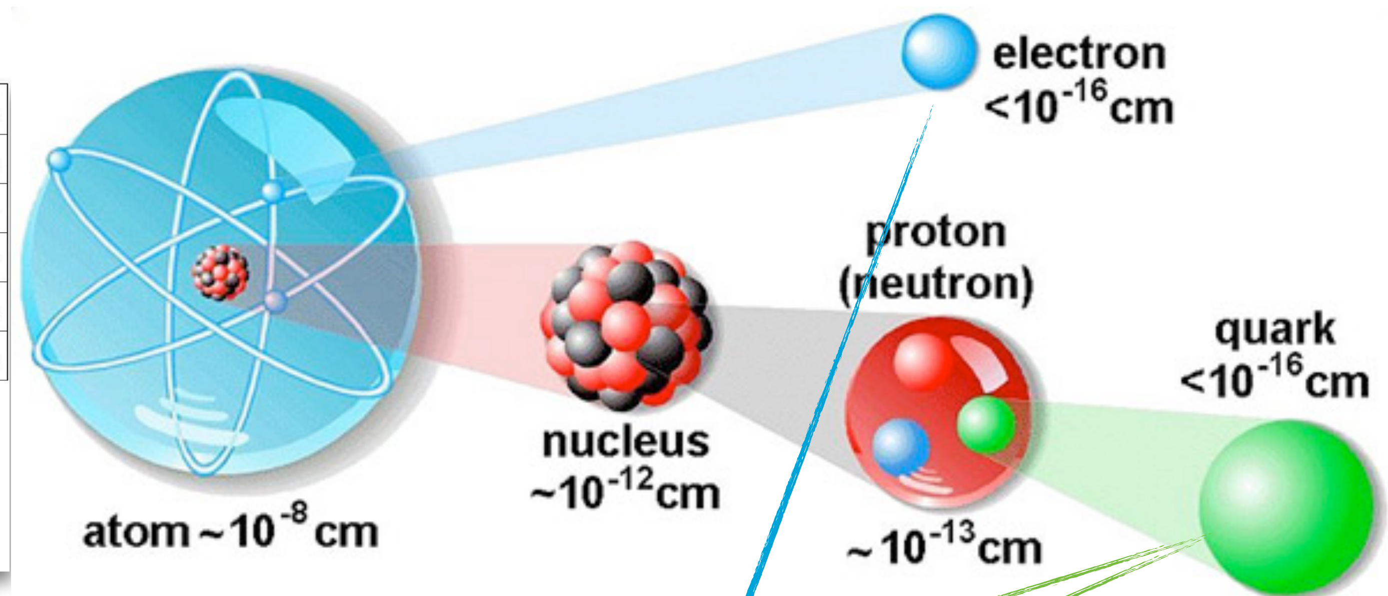
Chemistry deals with interactions among atoms.



H_2O molecule

Periodic Table of Elements





Particle physics deals with the fundamental particles that make up atoms.

Standard Model

Glashow, Salam, Weinberg
(Nobel Prize 1979)

Quarks

u up (1964)	c charm (1974)	t top (1995)
d down (1964)	s strange (1964)	b bottom (1977)

(year discovered)

Leptons

ν_e electron neutrino (1953)	ν_μ muon neutrino (1962)	ν_τ tau neutrino (2000)
e electron (1897)	μ muon (1936)	τ tau (1975)

we are counting cosmic muons

} **Fermions** (matter)

Gauge bosons

g gluon (1979)	$W^{\pm}$ (1983)	Z (1983)	γ photon (1900)

strong weak EM

Higgs boson

H Higgs (2012?)

} **Bosons** (force carriers)

Higgs Boson Discovery

- On July 4, 2012, the ATLAS and CMS experiments at the LHC announced the discovery of a new particle, consistent with the SM Higgs boson.
- The Higgs boson is critical to the SM, and was the last and final particle in the model to be found.
- The LHC is currently shutdown for upgrades but will start "Run 2" next spring (2015).
- The goals include measuring the properties of the Higgs better and continuing to search for new physics.
- It's a very exciting time for particle physics!


The New York Times

Today, sunny to partly cloudy, hot. high 92. Tonight, mostly clear, low 72. Tomorrow, mostly sunny, hot and humid, high 96. Weather map appears on Page B16.

NEW YORK, THURSDAY, JULY 5, 2012 — $2.50

Physicists Find Elusive Particle Seen as Key to Universe

ROMNEY NOW SAYS HEALTH MANDATE BY OBAMA IS A TAX

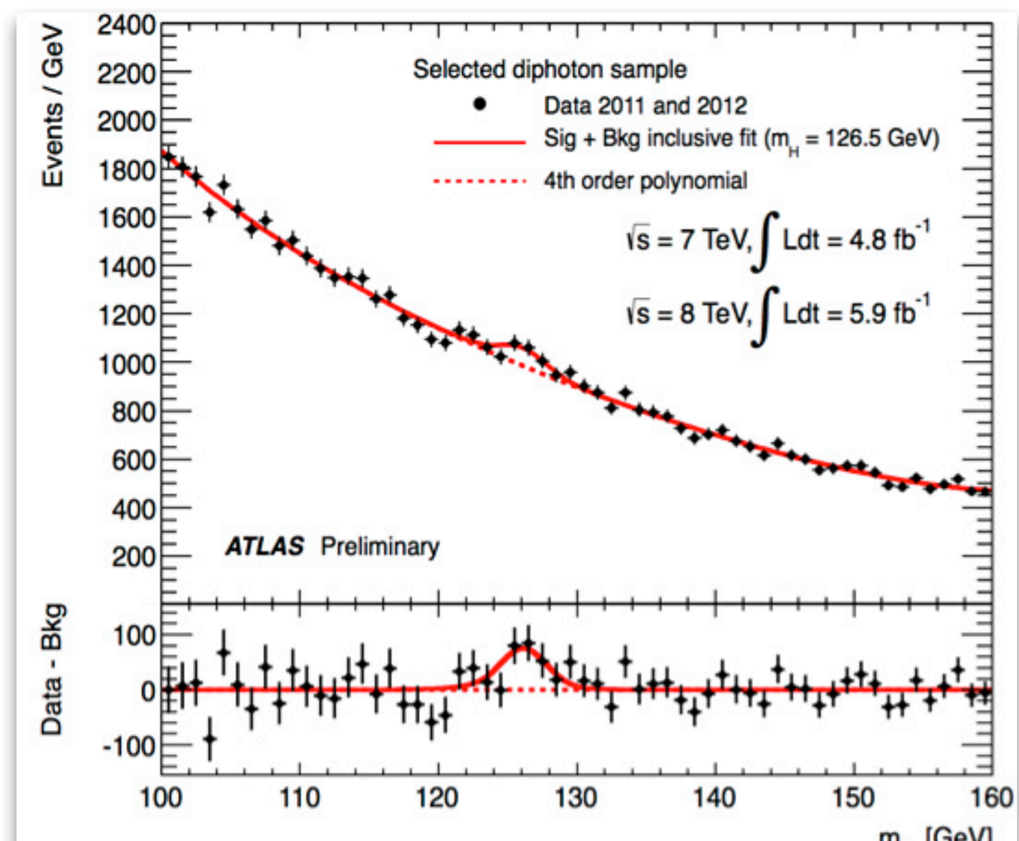
SHIFT RENEWS CRITICISM

Move Aligns Him With Conservative Voices Within His Party

By JEREMY W. PETERS

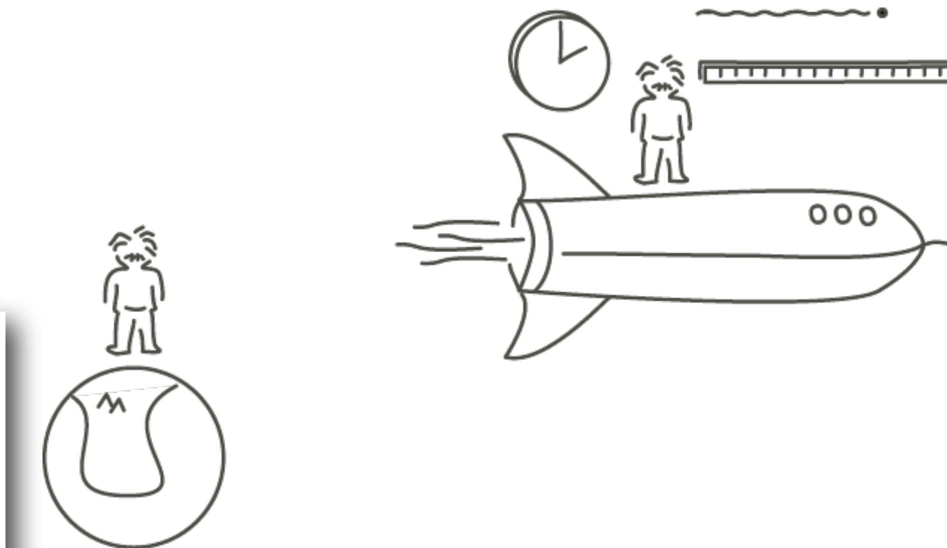
WOLFEBORO, N.H. — Mitt Romney declared on Wednesday that President Obama's health care mandate was in fact a tax, shifting his campaign's characterization of the law and aligning himself with the conservative voices in his party.

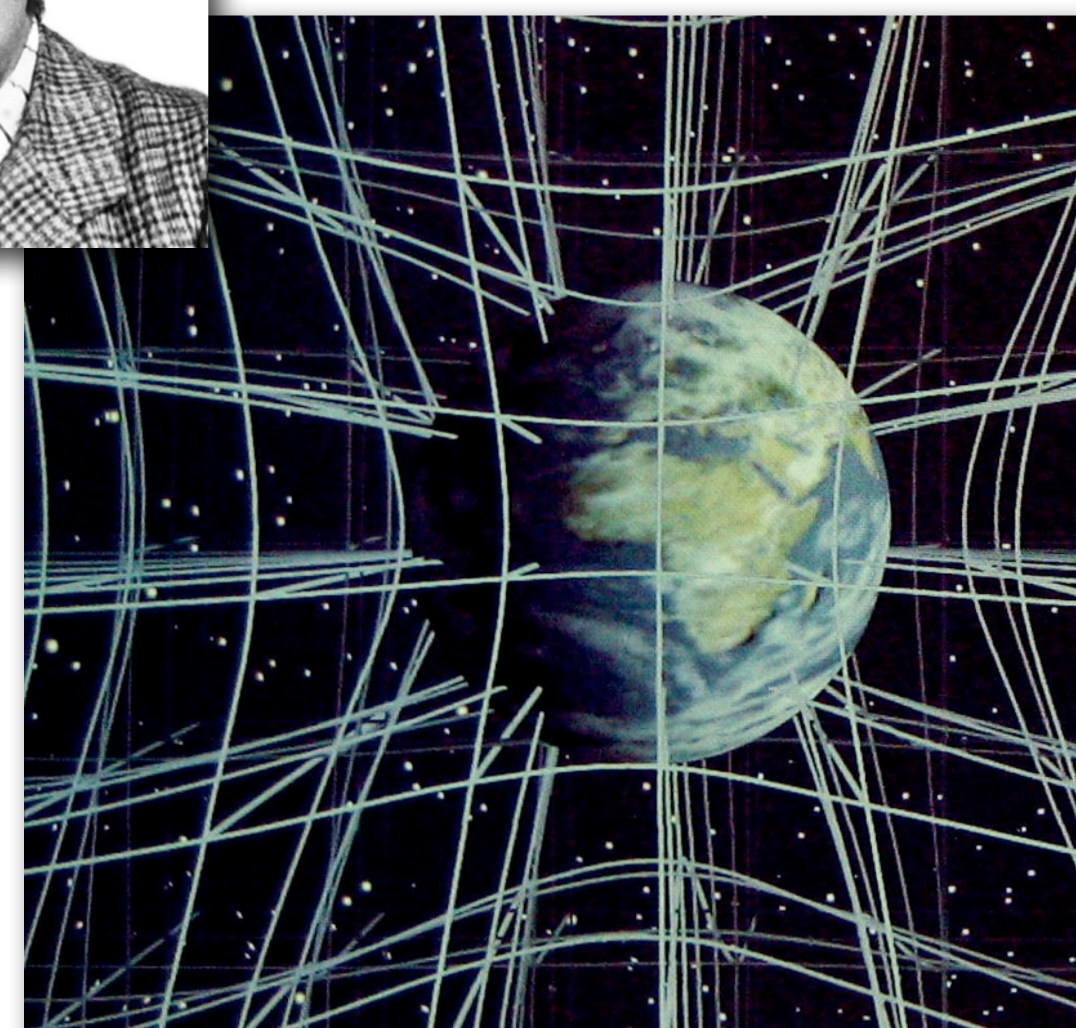
Mr. Romney's remarks, made in a hastily arranged interview with CBS News on a national holiday, prompted renewed crit-



Einstein's Relativity

- In 1905, Einstein revolutionized our understand of space and time by realizing that they are part of a combined manifold, spacetime.
- His studies were motivated by trying to understand how the speed of light and the equations of EM could be invariant in any frame of reference.
- In 1916, Einstein extended this to account for gravitational effects in the **general theory of relativity**.
- *Clocks tick slower (time differences are smaller) in a moving frame of reference or in a gravitational potential well.*





Time Dilation

Lorentz transformations along 1-spatial dimension

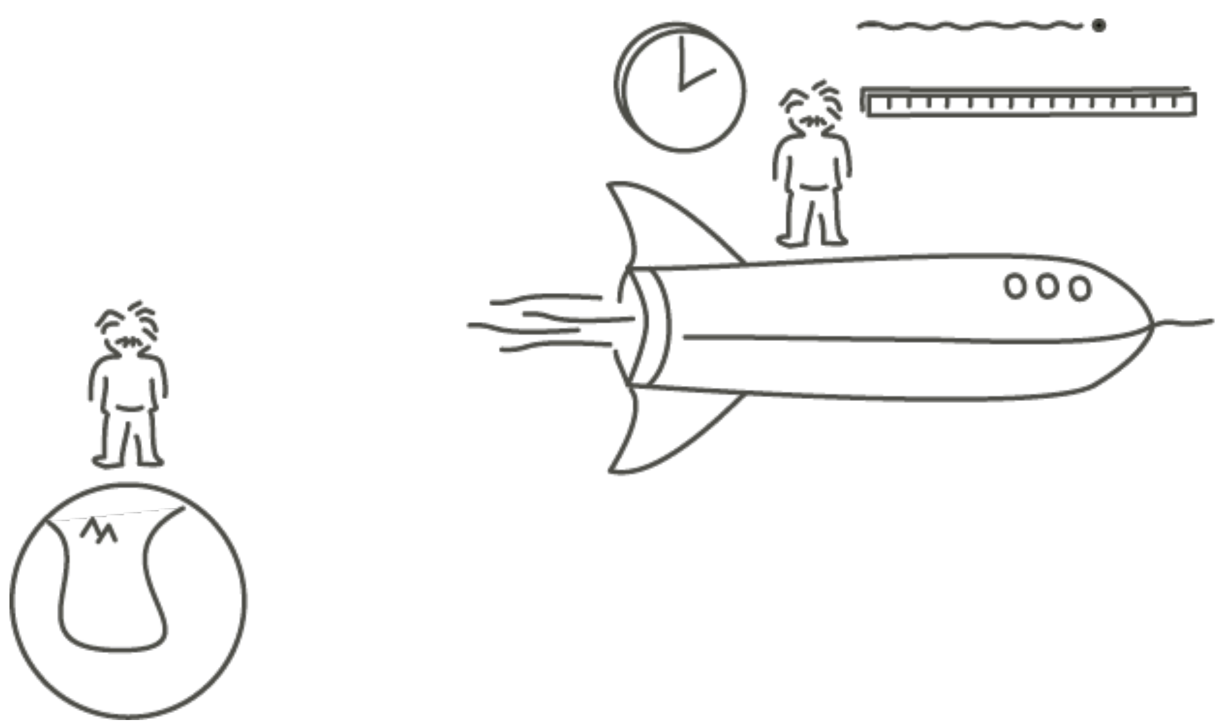
$$\begin{pmatrix} t' \\ x' \end{pmatrix} = \gamma \begin{pmatrix} 1 & -\frac{v}{c^2} \\ -v & 1 \end{pmatrix} \begin{pmatrix} t \\ x \end{pmatrix}$$

$$\text{where } \gamma = \frac{1}{\sqrt{1-(\frac{v}{c})^2}} = E/(mc^2) \geq 1$$

$$t' = t\gamma - \gamma x v/c$$

$$\Delta t' = t'_2 - t'_1 = \gamma\, \Delta t$$

Since γ ≥ 1, time the boosted (lab) frame always measures a longer time than the rest frame.



Time Dilation

Note that muons are unstable. The average lifetime of a muon in its rest-frame is $\tau = 2.2\times10^{-6}$ s.

Even if they were traveling at approximately the speed of light:
$c\tau \approx 650$ m

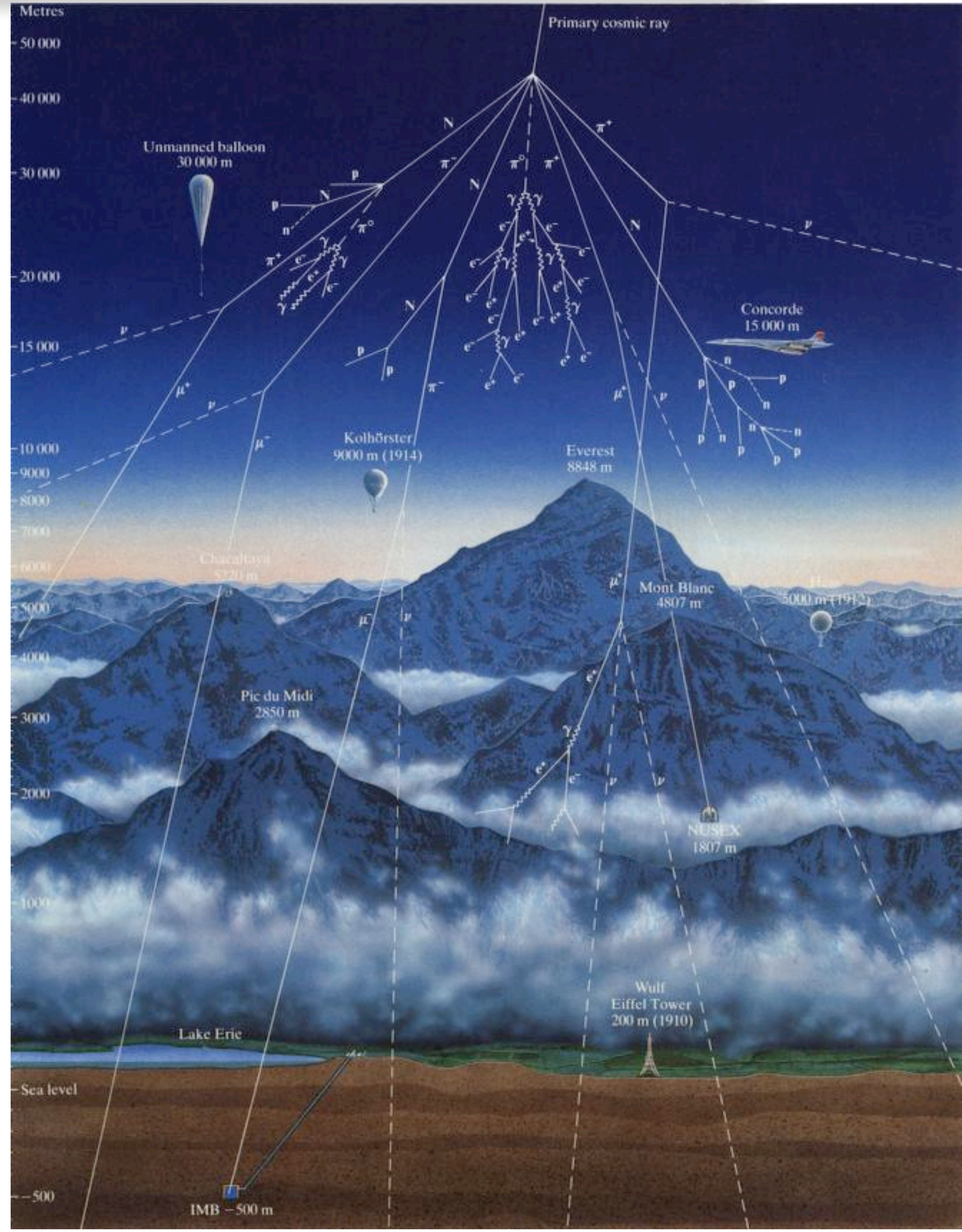
So naively, most muons that get created in cosmic showers ~ 10 km high in the atmosphere, should have decayed before reaching earth.

But for a muon with E=1 GeV,
$\gamma = E/m = 1\text{GeV}/100\text{MeV} = 10$

$$\Delta t' = \gamma\, \Delta t$$

⇒ time dilation stretches out the

observed lifetime of the muons by a factor of 10:
$\gamma\, c\tau \approx 6.5$ km



Ryan Reece (UCSC)

Summary

- Cosmic rays have historical importance in discoveries in particle physics, as the particle accelerator nature gave us for free.
- They are also related to unanswered questions in physics and astronomy now.
- The two modern pillars of physics are **quantum mechanics** (particles physics) and **relativity** (Einstein's theory of space-time).
- For those of you that want to learn more physics, nature has told us a really cool and surprising story that will rock your intuition.