Experimental particle physics

European School of Instrumentation in Particle & Astroparticle Physics

A

kinematics, accelerators
particle interactions,
detector response

A simple shower model

Simple shower model:
[from Heitler]

Only two dominant interactions:
Pair production and Bremsstrahlung ...

γ + Nucleus ➛ Nucleus + e^+ + e^-
[Photons absorbed via pair production]

e + Nucleus ➛ Nucleus + e + γ
[Energy loss of electrons via Bremsstrahlung]

Shower development governed by X_0 ...

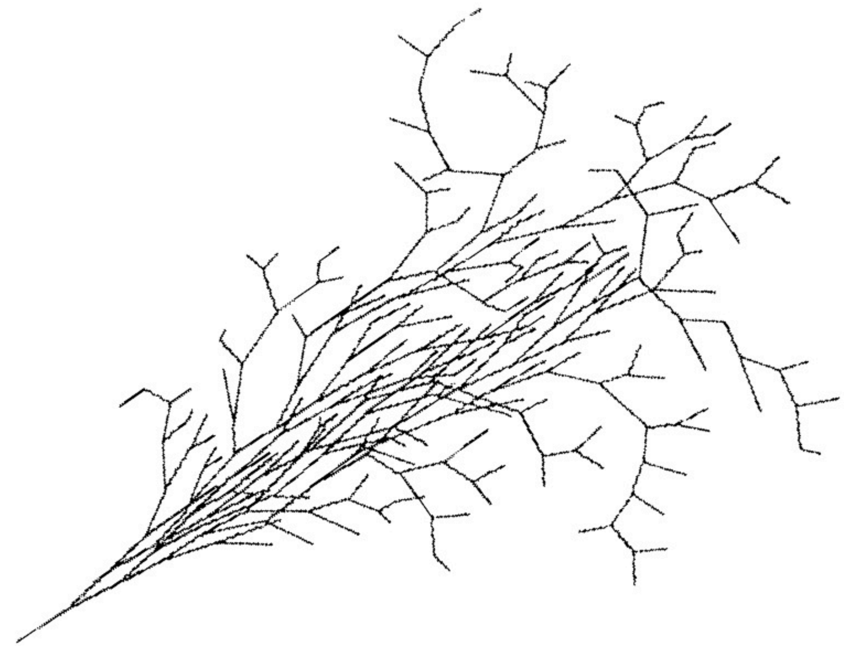
After a distance X_0 electrons remain with only $(1/e)^{th}$ of their primary energy ...

Photon produces e^+e^--pair after $9/7X_0 \approx X_0$ ...

Assume:

$E > E_c$: no energy loss by ionization/excitation

$E < E_c$: energy loss only via ionization/excitation



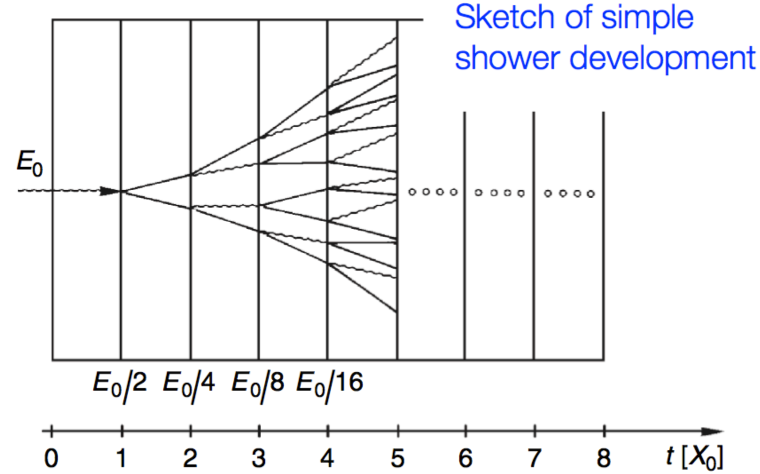
Use
Simplification:

$E_\gamma = E_e \approx E_0/2$
[E_e looses half the energy]

$E_e \approx E_0/2$
[Energy shared by e^+/e^-]

... with initial particle energy E_0

A simple shower model



Simple shower model:
[continued]

Shower characterized by:

Number of particles in shower
Location of shower maximum
Longitudinal shower distribution
Transverse shower distribution

Longitudinal components; measured in radiation length ...

... use: $t = \dfrac{x}{X_0}$

Number of shower particles after depth t:

$$N(t) = 2^t$$

Energy per particle after depth t:

$$E = \frac{E_0}{N(t)} = E_0 \cdot 2^{-t}$$

$$\rightarrow \quad t = \log_2(E_0/E)$$

Total number of shower particles with energy E_1:

$$N(E_0, E_1) = 2^{t_1} = 2^{\log_2(E_0/E_1)} = \frac{E_0}{E_1}$$

Number of shower particles at shower maximum:

$$N(E_0, E_c) = N_{\max} = 2^{t_{\max}} = \frac{E_0}{E_c} \propto E_0$$

Shower maximum at:

$$t_{\max} \propto \ln(E_0/E_c)$$

A simple shower model

Simple shower model:
[continued]

Longitudinal shower distribution increases only logarithmically with the primary energy of the incident particle ...

Some numbers: $E_c \approx 10$ MeV, $E_0 = 1$ GeV ➛ $t_{max} = \ln 100 \approx 4.5$; $N_{max} = 100$
$E_0 = 100$ GeV ➛ $t_{max} = \ln 10000 \approx 9.2$; $N_{max} = 10000$

$$t_{\max}[X_0] \sim \ln \frac{E_0}{E_c}$$

Muon lifetime and acceleration

- How long muon lifetime be in a muon beam of 200 GeV momentum?
- If we inject 10^{10} of such muons in a storage ring of R = 100 m, how many rounds would they do before beam intensity get reduced by a 10^6 factor?

Cosmic rays

- Protons with energy above the pion production threshold can produce them interacting with photons from relic cosmic radiation:
  - ✓ $E_\gamma \sim 10^{-3}$ eV

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

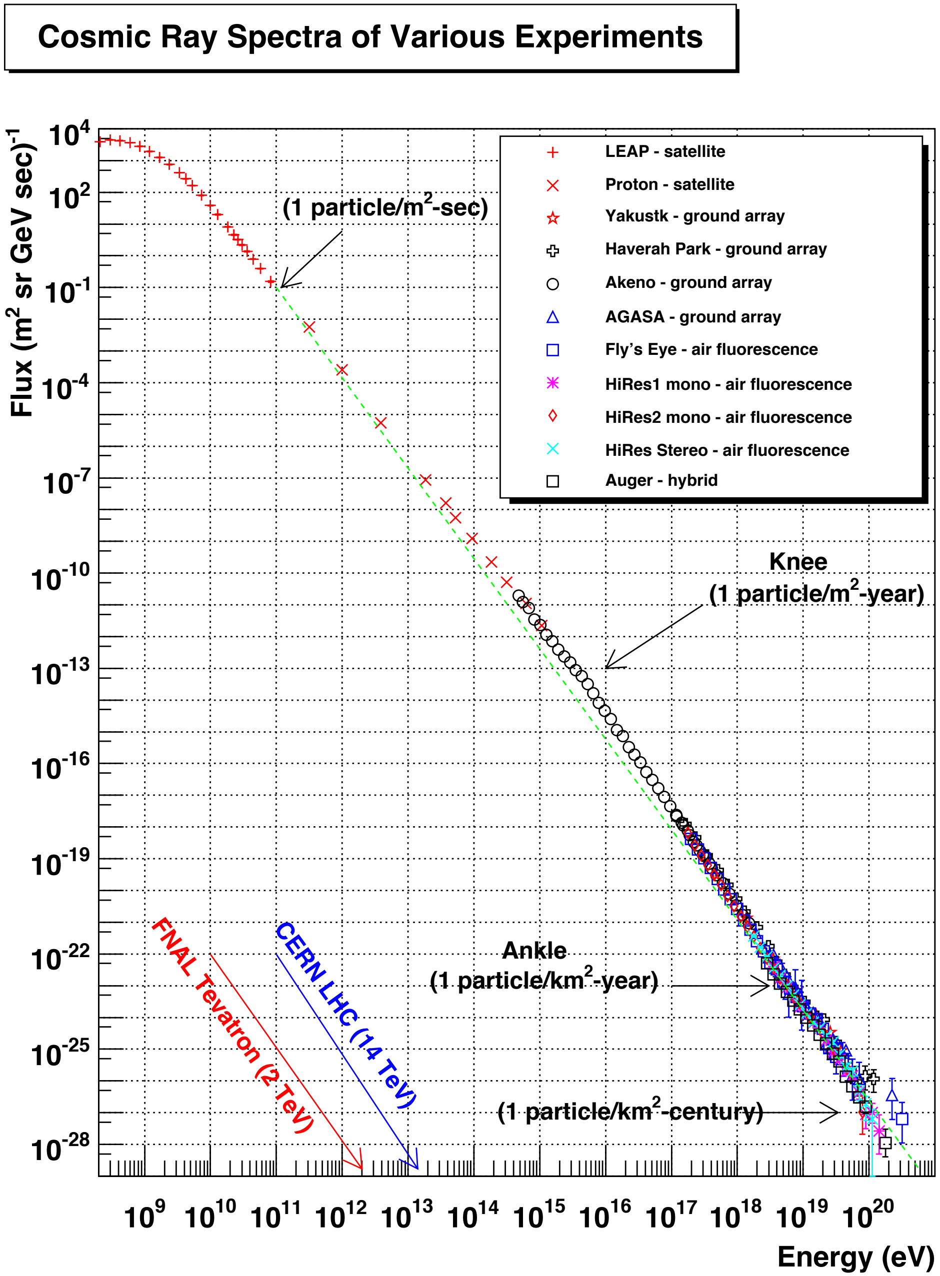
What is the maximum energy for a proton in the cosmic rays?

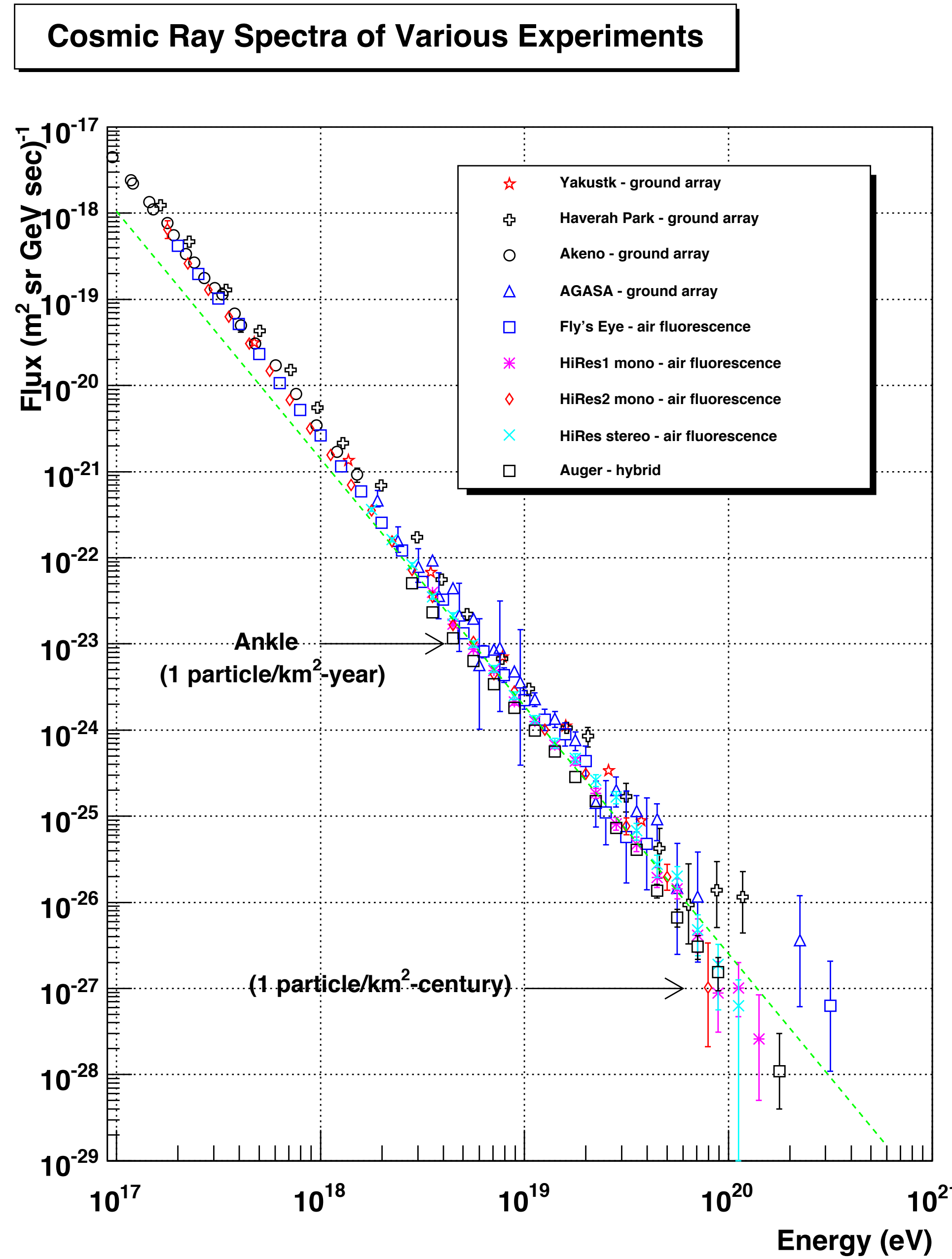
This energy is called the GZK (Greisen–Zatsepin–Kuzmin) cut-off: protons above this energy see the space as a opaque medium, and decelerate…

- *Read this: First Observation of the Greisen-Zatsepin-Kuzmin Suppression*

Did we observed any extremely high-energetic cosmic rays above the GKZ cut-off?

- *Read this: The Particle That Broke a Cosmic Speed Limit*


Cosmic Ray Spectra of Various Experiments
Flux (m^2 sr GeV sec)$^{-1}$
Energy (eV)
LEAP - satellite
Proton - satellite
Yakustk - ground array
Haverah Park - ground array
Akeno - ground array
AGASA - ground array
Fly's Eye - air fluorescence
HiRes1 mono - air fluorescence
HiRes2 mono - air fluorescence
HiRes Stereo - air fluorescence
Auger - hybrid
(1 particle/m^2-sec)
Knee
(1 particle/m^2-year)
Ankle
(1 particle/km^2-year)
(1 particle/km^2-century)
FNAL Tevatron (2 TeV)
CERN LHC (14 TeV)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