The Basic Physics of Air Shower

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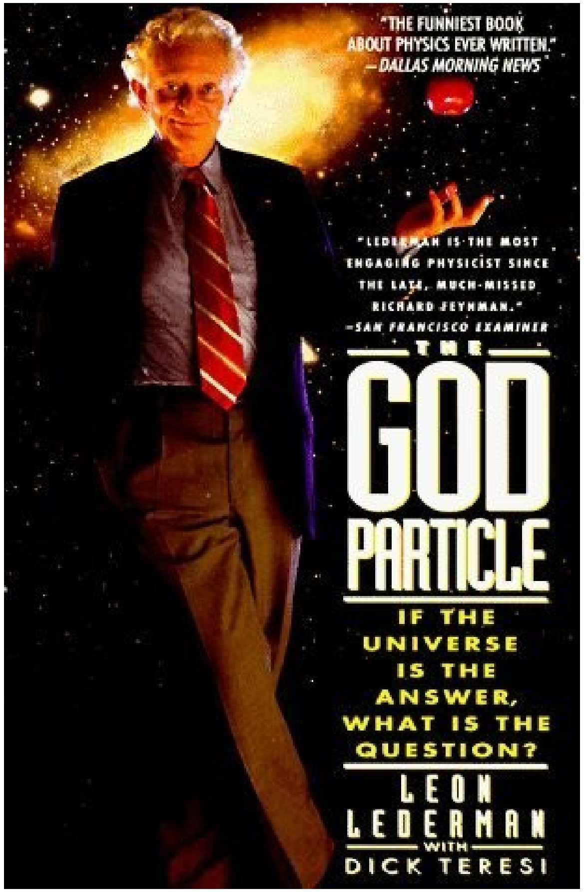
“If the Universe is the answer, what is the question ? “

Leon Lederman



Some References

Many good references and books, can't list all of them...

Oulines of Lectures

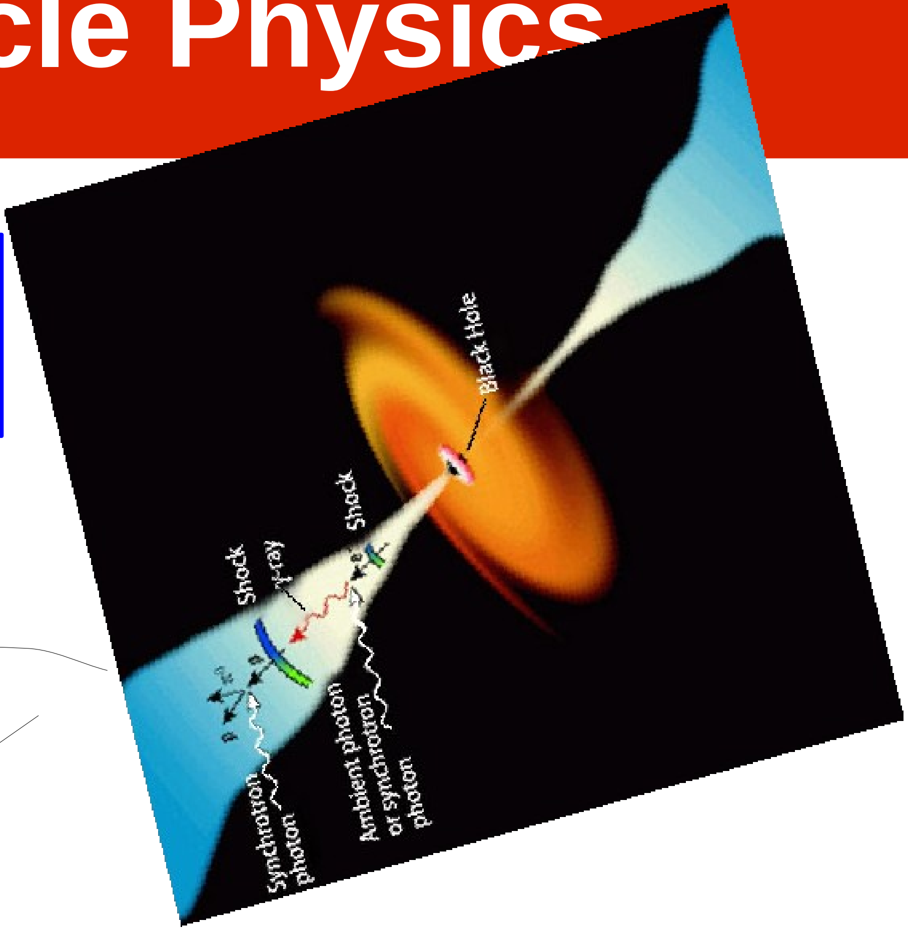
Lecture 1

1. Introduction to Astroparticle physics :
    1. A bit history
    2. Experimental Methods
2. Air shower physics
    1 . EM shower
    2. Hadronic shower
    3. Cherenkov Emission
3. Atmosphere
    1. Basic Models
    2. Light propagation in the atmosphere

Lecture 2

1. Shower Parameters
2. Some simple applications

Astor-Particle Physics



High energy particles (>100 GeV) are produced by non-thermal radiation in the sources.

Source Physics

Particles propagate through the space.

Particle propagation

Detection on the earth or close to the earth.

Detections

Why Astroparticle Physics ?

Astrophysics:
1. A new windows of looking at our Universe.
2. Probe violent environments in cosmos. Example: strong B (pulsars), large scale particle acceleration (AGNs).
 mostly non-thermal radiations

Particle Physics:
1. Probing the unexplored energy regime of the particle interactions.
2. New (surprise) physics (particles&matters) discoveries.

Astroparticle Physics History

Cosmic Rays: History – 1910-12

~1900: Electroscopes discharge, even if they are shielded from radioactive sources
➔ Rutherford: radioactivity at the walls, etc...

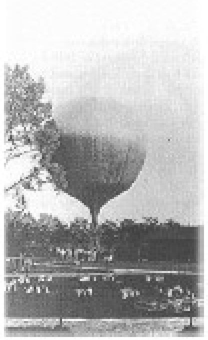
Victor Hess 1912:
There are particles coming from ‚outside' (Cosmos)

The Jesuit padre Theodor Wulf clambers in the year 1910 the Paris Eiffel-Tower to find the source of the ionizing radiation in the Earth's Atmosphere.

at 330m: Ionisation decrease to 60%

(γ-radiation and its absorption coefficient was known
➔ after 80m in air only 50%
➔ Eiffeltower at 330m: no radiation expected)

Finding:
Ionisation increase with height !
(Hess reached 5000m)

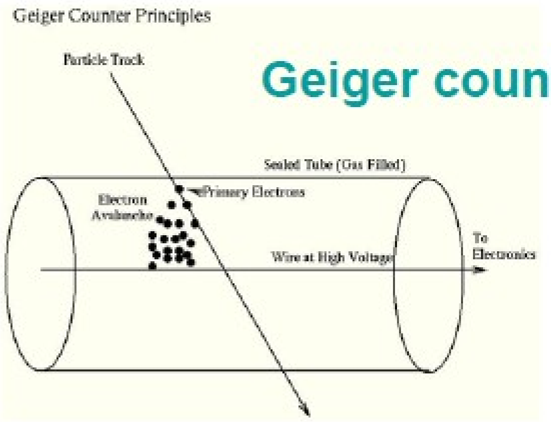


CR History: II

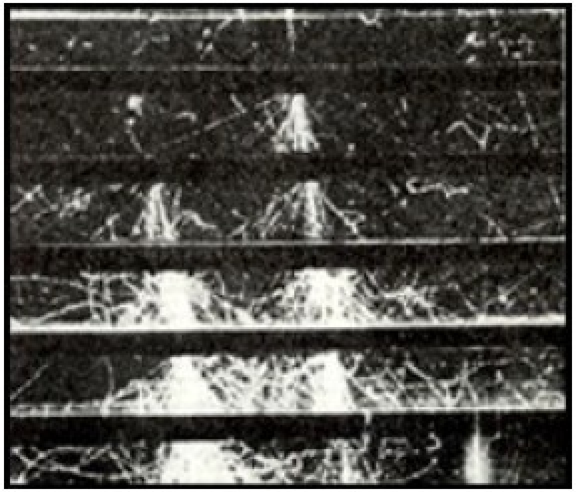
Cosmic Rays: History – 1912-50

Start of the development of:
Particle detectors – particle physics

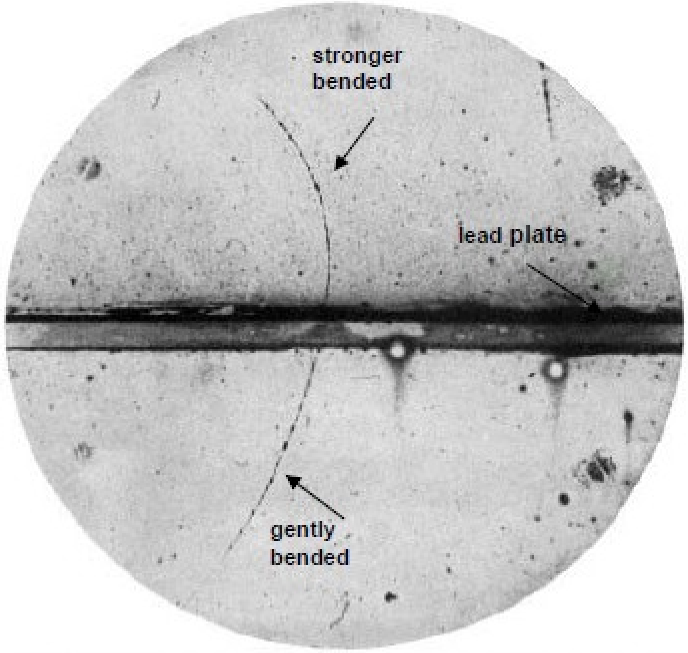
Geiger counter



Spark
chamber



Cosmic Rays ==>
Discovery of new particles

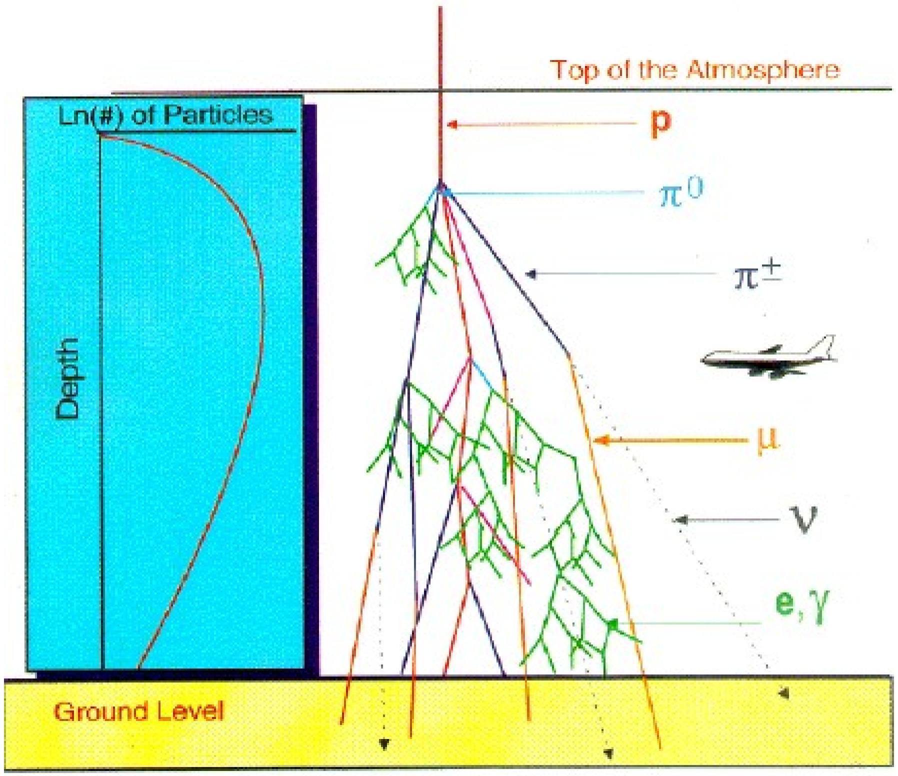


Positron, 1933

CR History: III

Cosmic Rays: History – 1930-40

==> First Detection of extended air-showers!



Extensive Air Showers

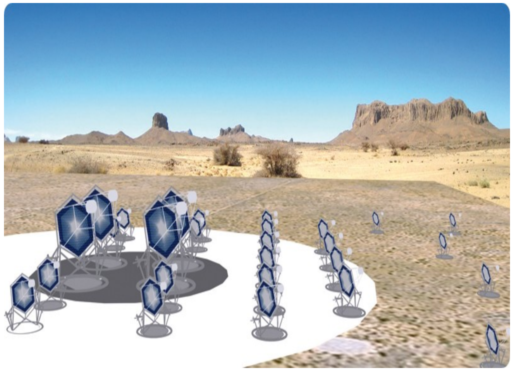
1936: coincidence measurement at the Jungfraujoch
By Pierre Auger et al., and Werner Kolhörster et al.

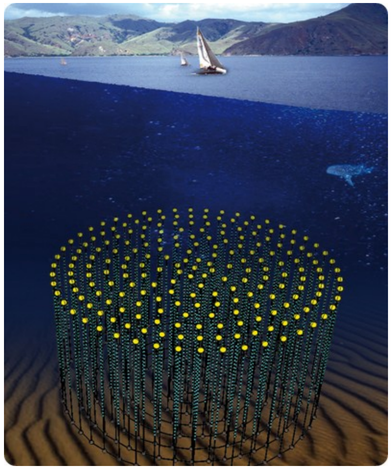
Pierre Auger

Werner Kolhörster

Astro-particle physics getting hot!

The magnificent Seven in EU.





AStro Particle ERAnet (ASPERA) network

1. CTA
2. KM3NET
3. Very big scale dark matter detectors
4. Very big scale detector to determine the fundamental physics of neutrino ex: mass
5. A very big-scale detector for the search for proton decay, neutrino astrophysics and the investigation of neutrino properties (LAGUNA)
6. A large array for the detection of charged cosmic rays
7. A third-generation underground gravitational antenna.

Particle Propagation

Particles propagate through the (inter-) galactic space, may interact with the materials (or fields) in between.

→ The original information may be lost.

Particles: γ, μ, p, Fe.. ν, e^{+-}...

E, B (usually unknown)

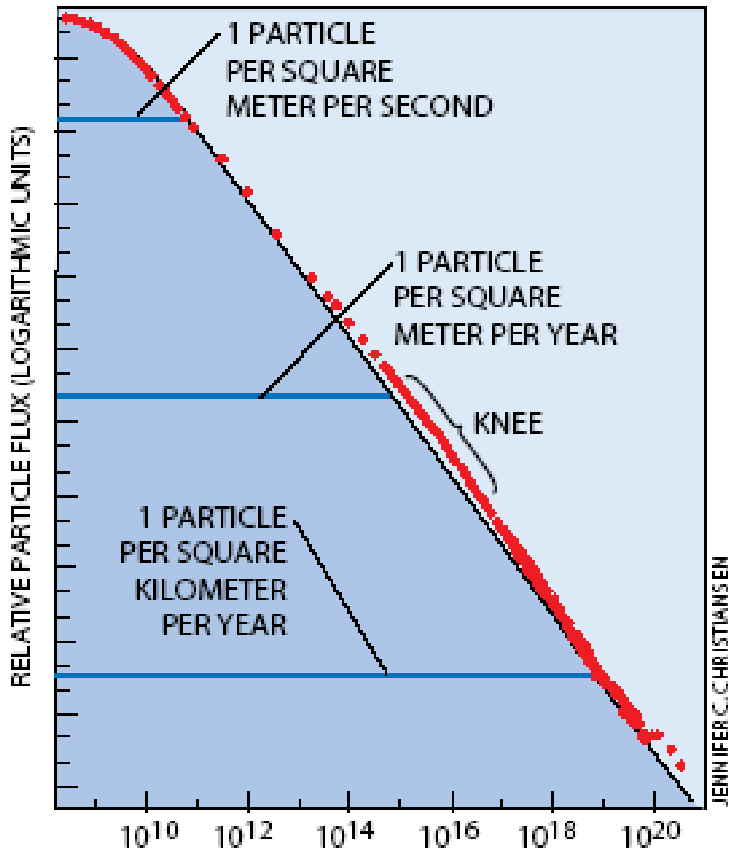
While the particles are approaching (entering) the earth, they interact with the earth atmosphere.

→ Some of the original information may be lost.

Long-Standing Mystery

Where come HE and VHE cosmic rays ? What are the origins ?
current status: there are several possible objects, but we are not sure. (there is no experimental evidence)

Scientific American, (c) 1998



Experimental Methods

Astro-particle experiments

Direct measurement

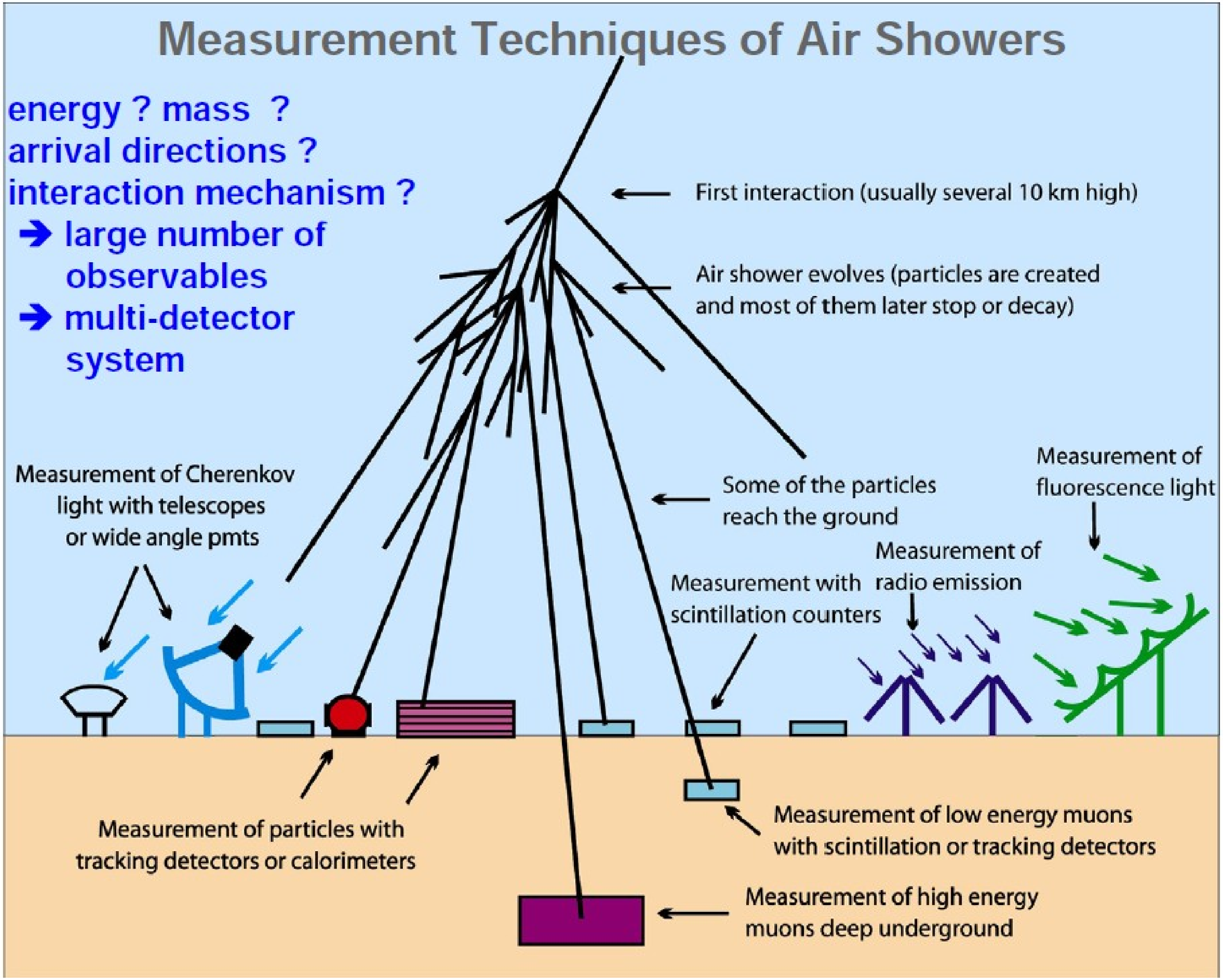
Balloons,
Satellites.....

indirect measurement

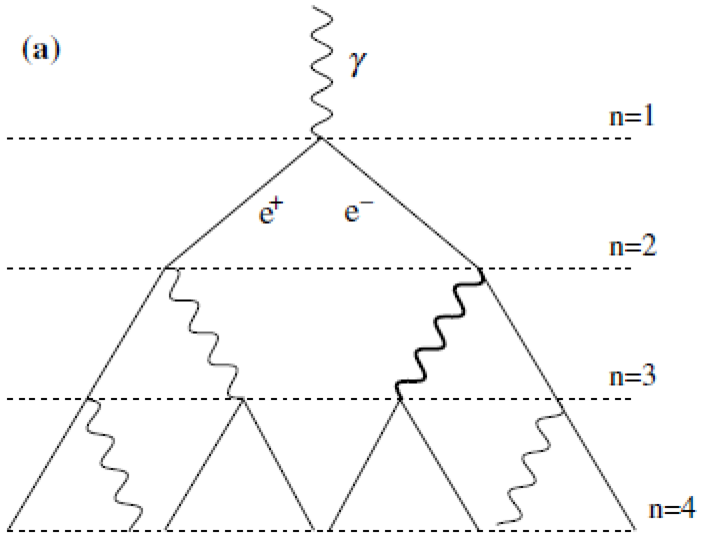
Particle arrays,
Emulsion experiments,
Cherenkov/fluorescence light experiments
Radio
Underground experiments

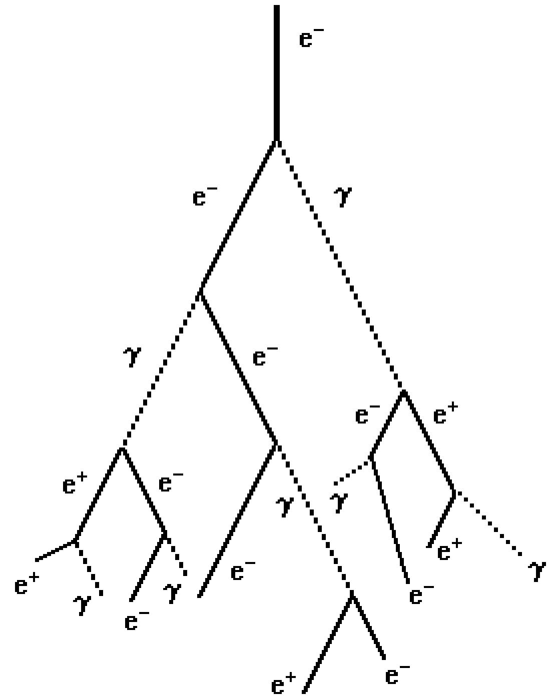
Energy spectrum,
Element compositions,
directional information,
hadronic interactions,
new physics ?

In-Direct Detections



Air Showers (EM) :close look





Radiation length (for bremsstrahlung): the mean distance traversed in a medium over which a high energy electron loses all but 1/e of its energy. **Xair ~ 36.6 g/cm^2** (depending on the air composition)

Air Showers : EM Showers

Similar things in photon :

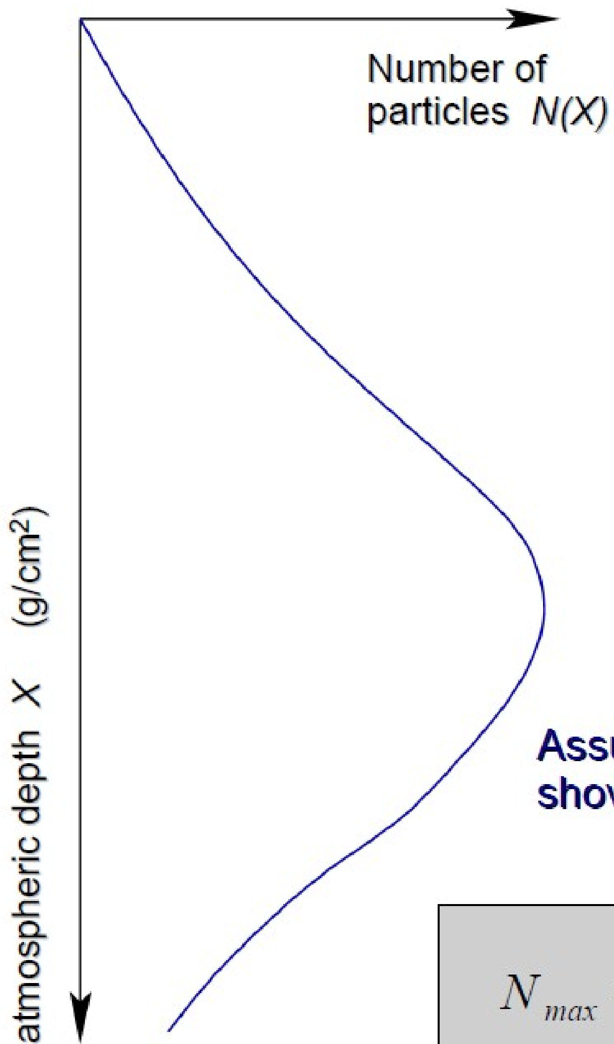
Pair production by photon to lose energy to its 1/e is

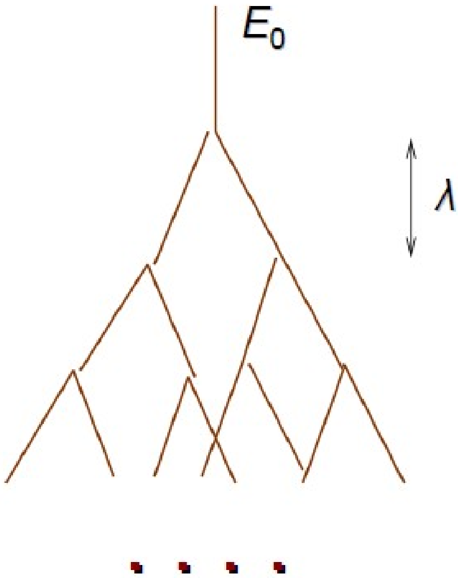
$$X_{photon} = 9/7\ X_{brems}$$

On average, a photon travels a longer track in the medium before creating an electron-positron pair then an electron to undergo bremsstrahlung. (Coulomb bremsstrahlung)

Critical Energy: **Ebrem = Eion** **@ air** **Ecrit ~ 84 MeV.**

Air Showers : Heitler's Model





Primary particle: photon

2^n particles after n interactions

$$n = X / \lambda$$

$$N(X) = 2^n = 2^{X/\lambda}$$

$$E(X) = E_0 / 2^{X/\lambda}$$

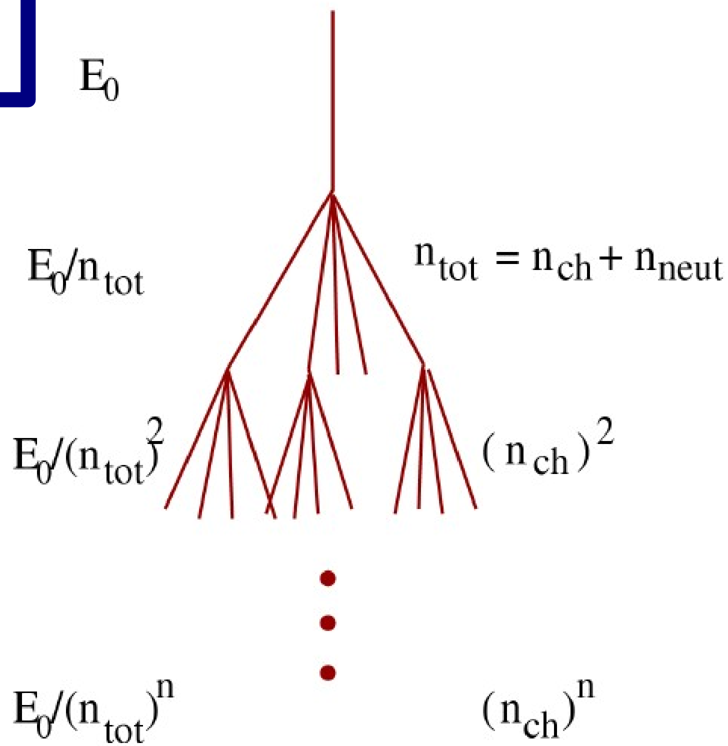
Assumption:
shower maximum reached if $E(X) = E_c$

$$N_{max} = E_0 / E_c \qquad X_{max} \sim \lambda \ln(E_0 / E_c)$$

Air Showers : Hadronic Showers

Muon production in had. showers

Charm Decay …



Primary particle: proton

π^0 decay immediately

Only charged pions initiate new hadronic cascades

Cascade ends with decay at energy E_{dec}

$$E(X) = E_0/(n_{tot})^n = E_{dec}$$

$$N_\mu = (n_{ch})^n$$

$$N_\mu = \left(\frac{E_0}{E_{dec}}\right)^\alpha, \quad \alpha = \frac{\ln n_{ch}}{\ln n_{tot}} \approx 0.82 \ldots 0.95$$

Air Showers : Hadronic Showers

Application: superposition model

Proton shower characteristics:

$$N_{max} = E_0 / E_c \qquad N_\mu = \left(\frac{E_0}{E_{dec}} \right)^\alpha$$

$$X_{max} = \lambda_e \ln(E_0)$$

Assumption:

nucleus of mass A and energy E_0 acts

like A independent nucleons with energy $E_n = E_0/A$

$$N_{max}^A = A\ E_n / E_c = E_0 / E_c \qquad N_\mu^A = A \left(\frac{E_0 / A}{E_{dec}} \right)^\alpha = A^{1-\alpha} N_\mu$$

$$X_{max}^A \sim \lambda_e \ln(E_0 / A)$$

Hadronic interaction models

High energy models:

DPMJET II.5 and III (Ranft / Roesler, RE & Ranft)

neXus 2 and 3 (Drescher, Hladik, Ostapchenko, Pierog & Werner)

QGSJET 01 and II (Kalmykov & Ostapchenko / Ostapchenko)

SIBYLL 2.1 (Engel / RE, Fletcher, Gaisser, Lipari & Stanev)

Low/intermediate energy models:

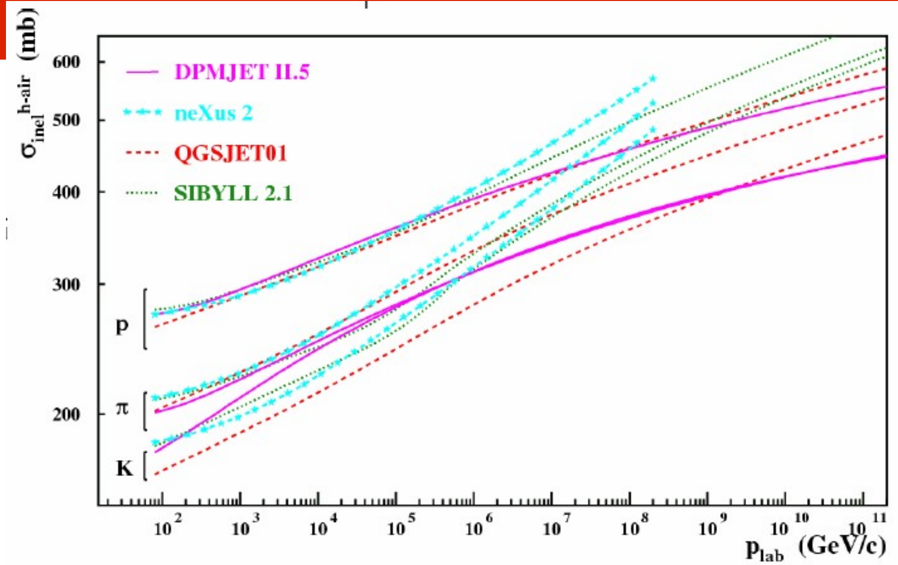
GHEISHA (Fesefeldt)

Hillas' splitting algorithm (Hillas)

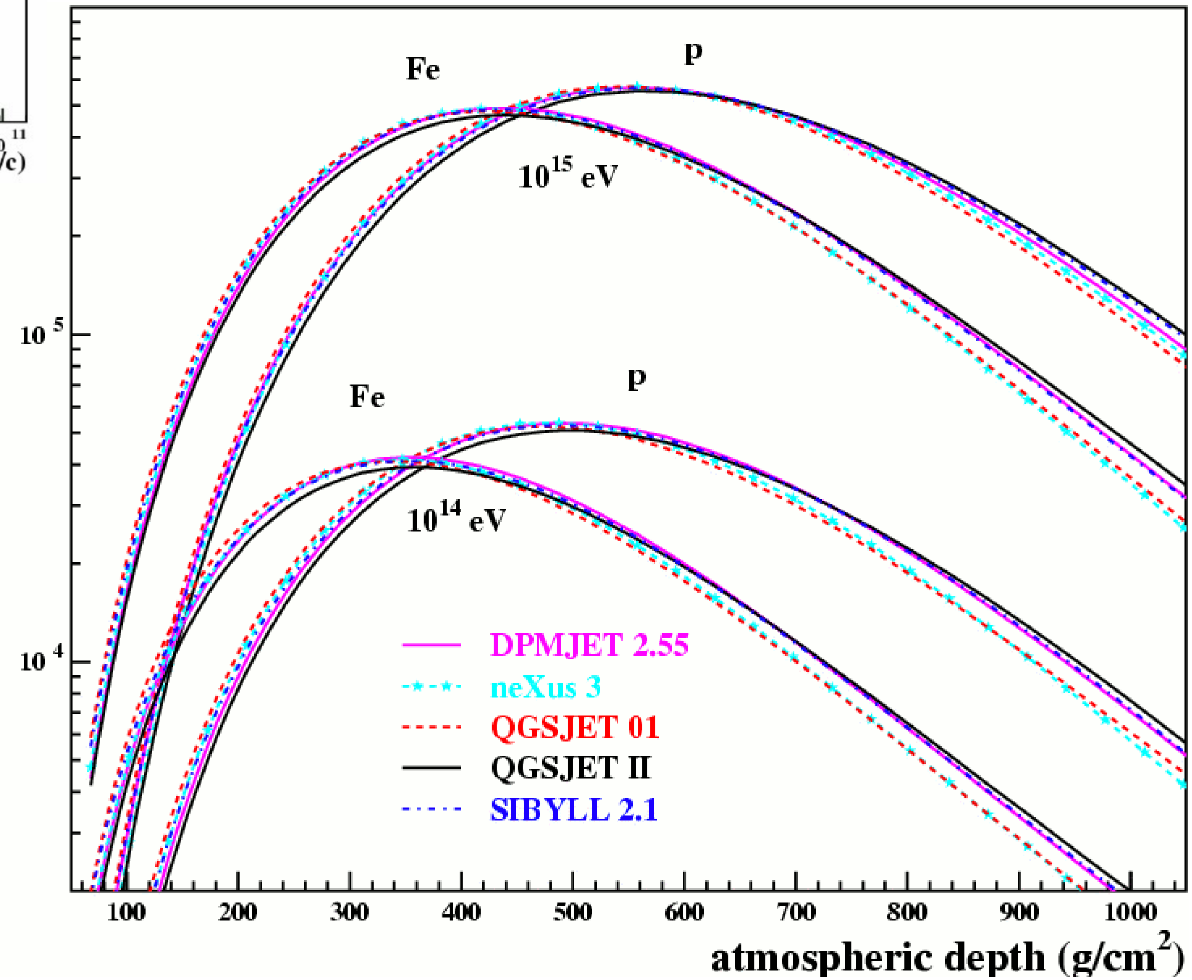
FLUKA (Fasso, Ferrari, Ranft, Roesler &Sala)

UrQMD (Bleicher et al.)

Air Showers : Hadronic Showers

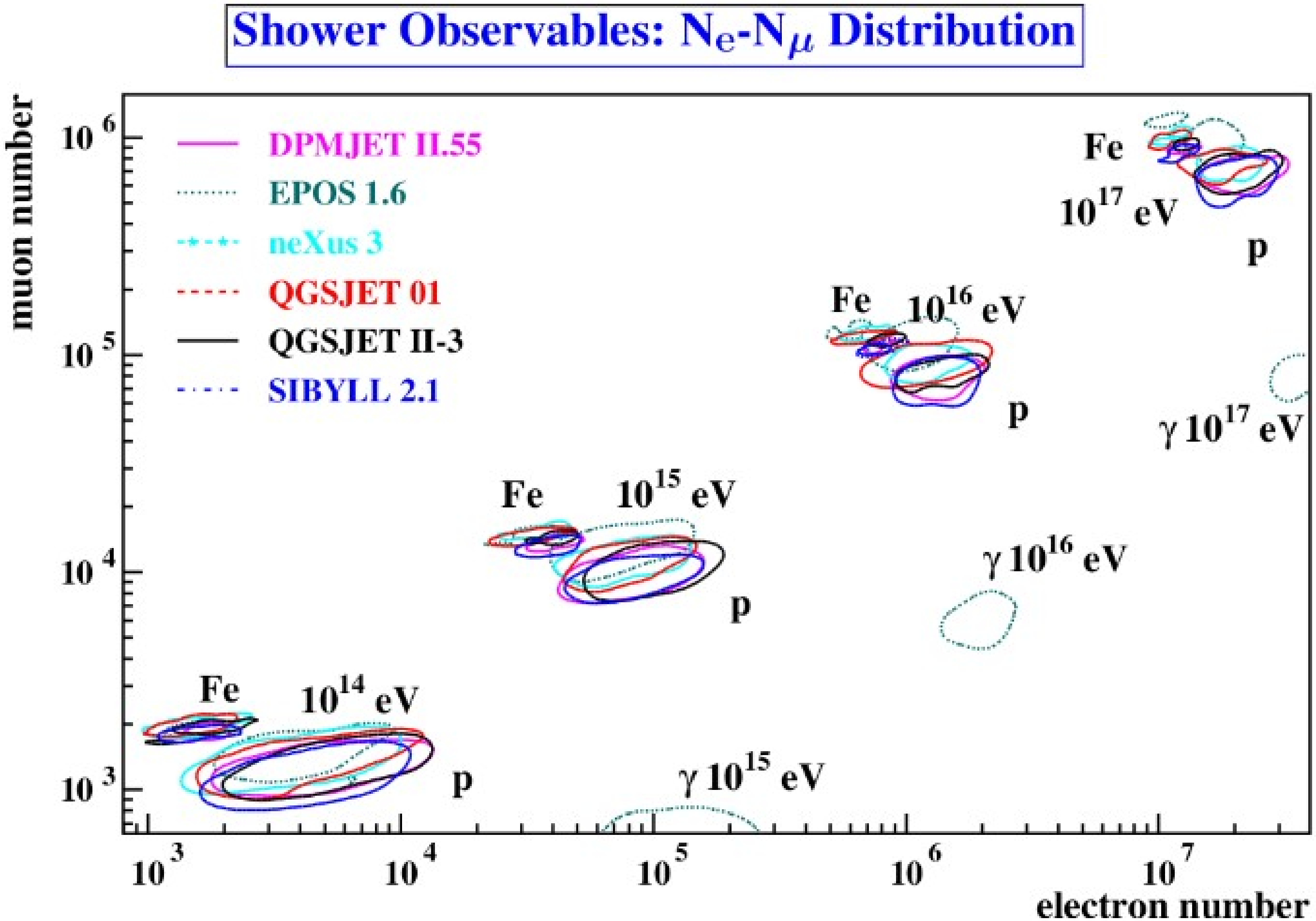


Size at maximum
nearly model independent



Model dependence
more pronounced at
large depth (distance)
from shower maximum

Hadronic Shower: Applications



N_e-N_μ distributions for *proton* and *iron* induced vertical showers of 10^{14} to 10^{17} eV.

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