Measurement of the Muon Lifetime

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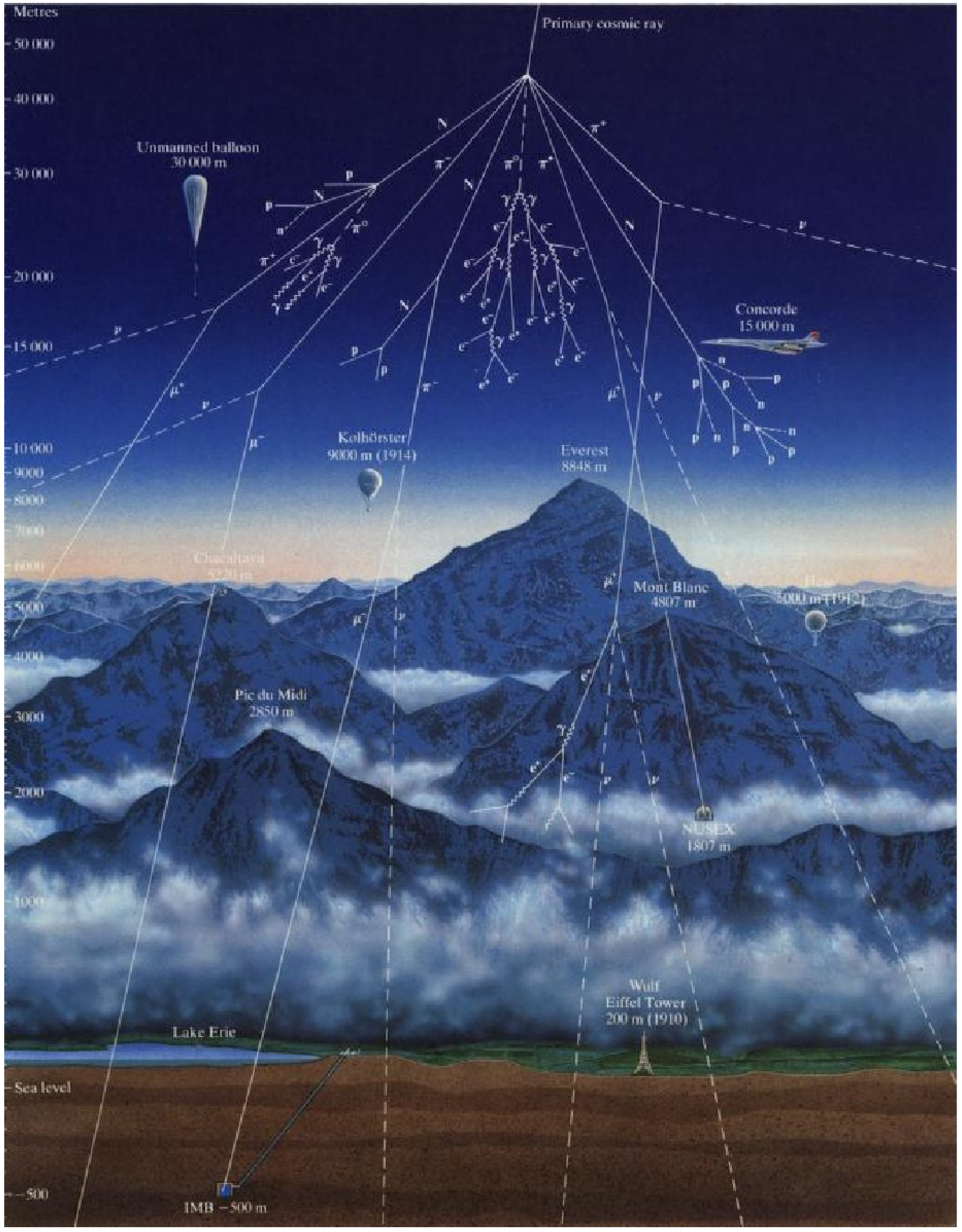
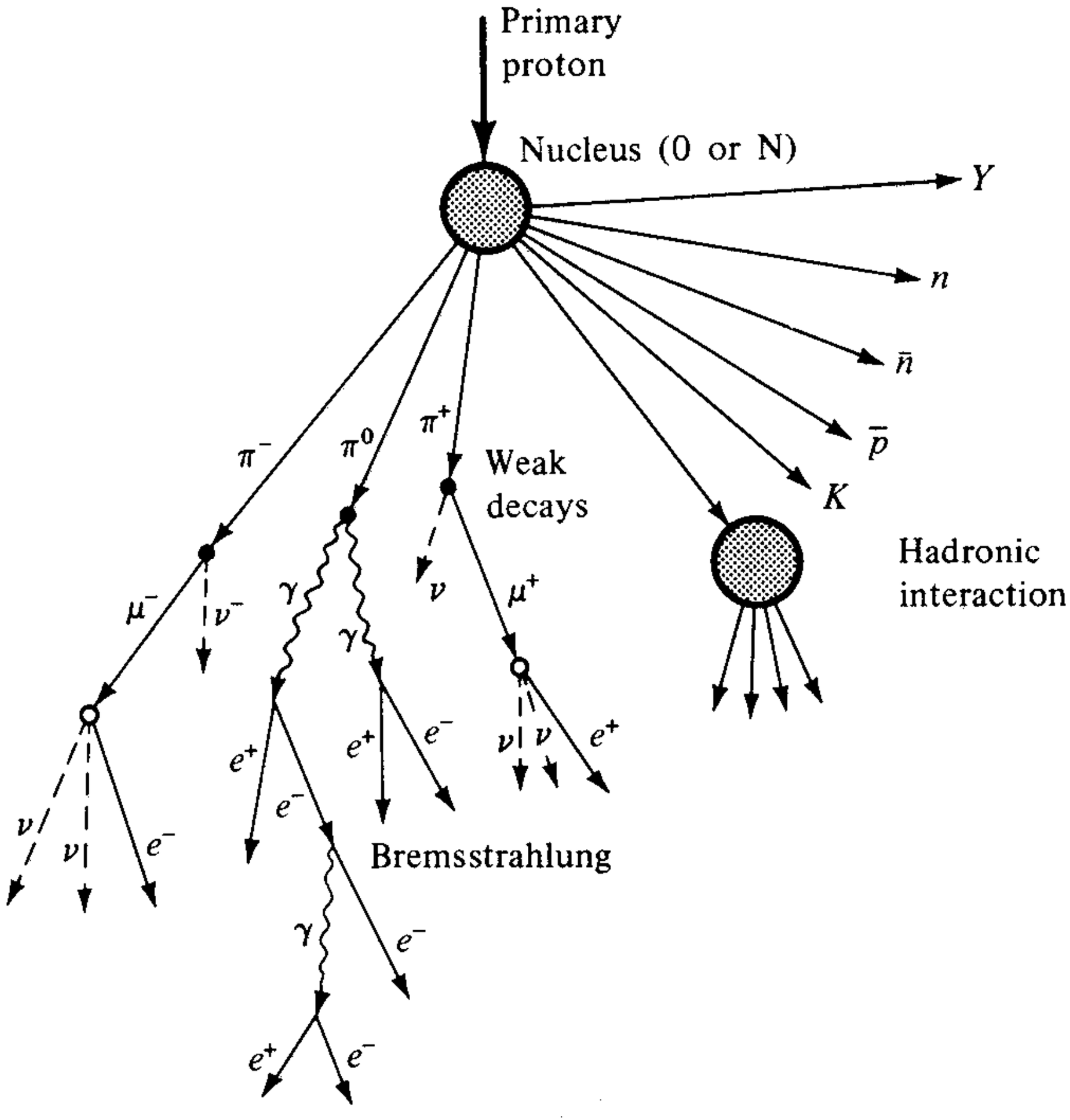
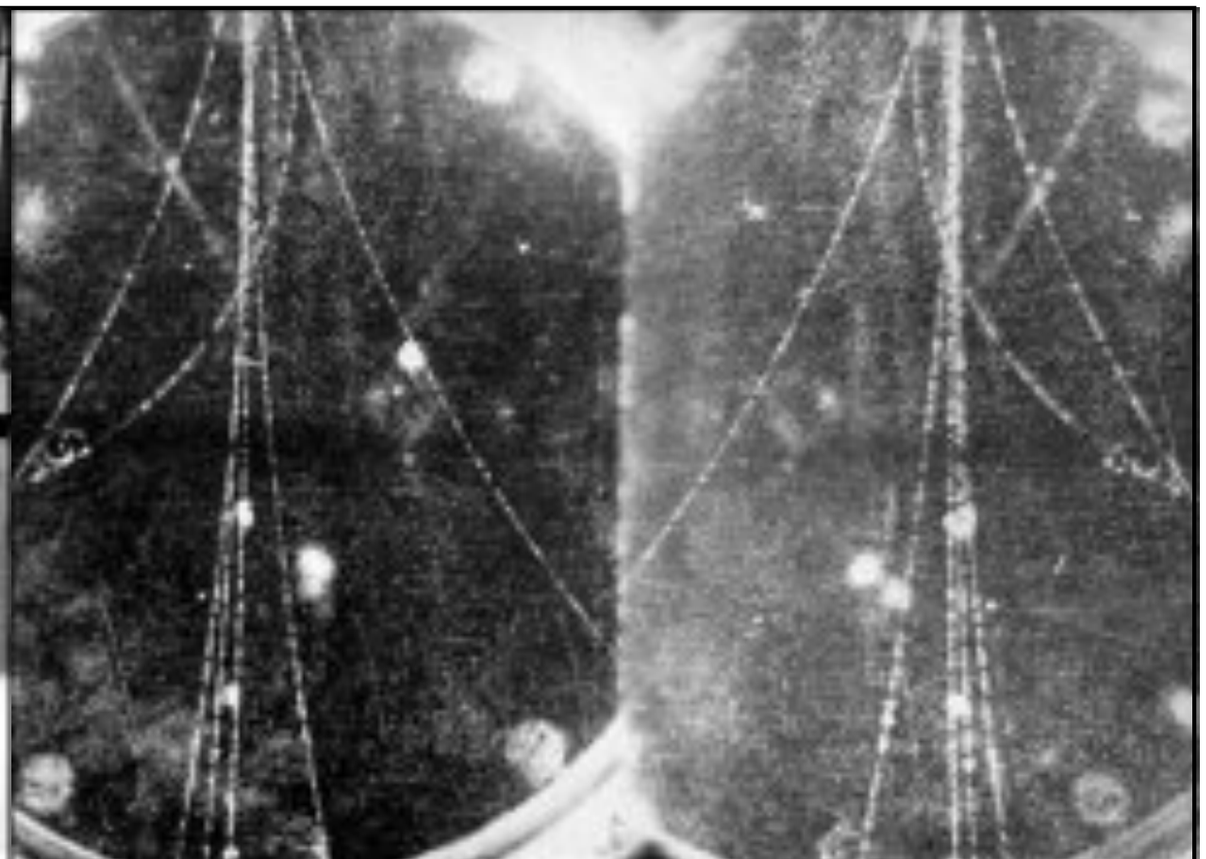
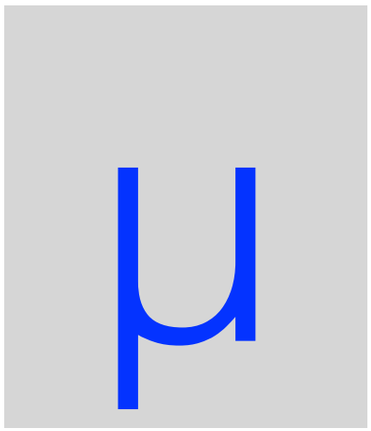

Metres
50 000
40 000
30 000
20 000
15 000
10 000
9000
8000
7000
6000
5000
4000
3000
2000
1000
500
Sea level
Primary cosmic ray
Unmanned balloon
30 000 m
Kolhörster
9000 m (1914)
Everest
8848 m
Concorde
15 000 m
Chacaltaya
5220 m
Mont Blanc
4807 m
Pic du Midi
2850 m
NUSEX
1807 m
Wulf
Eiffel Tower
200 m (1910)
Lake Erie
IMB – 500 m


Primary
proton
Nucleus (0 or N)
Y
n
$\bar{n}$
$\bar{p}$
K
π^-
π^0
π^+
Weak
decays
μ^-
ν
γ
ν
μ^+
e^+
e^-
ν
ν
e^-
Bremsstrahlung
Hadronic
interaction

Discovery of Muon



Left: Carl Anderson working on his cloud chamber. Right: A cloud chamber photograph of a cosmic ray min-shower, in which electrons and positrons curve in opposite directions.



- name: Muon
- mass: 105.66 MeV/c^2 (207 m_e)
- Mean life time τ: 2.19 μs
- cτ: 658.6 m
- Electric charge: -1e
- Spin: 1/2
- Antiparticle: antimuon (μ^+)
- Decay: $\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$ ($\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$)

Source of Muon

- Interactions of protons or heliums with the nuclei of the atoms that constitute our atmosphere (nitrogen, oxygen, argon)
- Pions, charged and neutral particles
- Pion decays to a muon and a muon neutrino
- produced 15 km in the atmosphere
- The original muon energy: ~6 GeV
- Energy loss from the production to the Earth surface: ~ 2 GeV
- Mean energy of muon at the sea level: 4 GeV
- Rate: the order of several hundred per square meter per second (~ 1 μ/10 cm^2·s)
- Time dilation (Earth frame observer), Length contraction (muon rest frame)

Vertical fluxes of cosmic rays

(Particle Data Book)

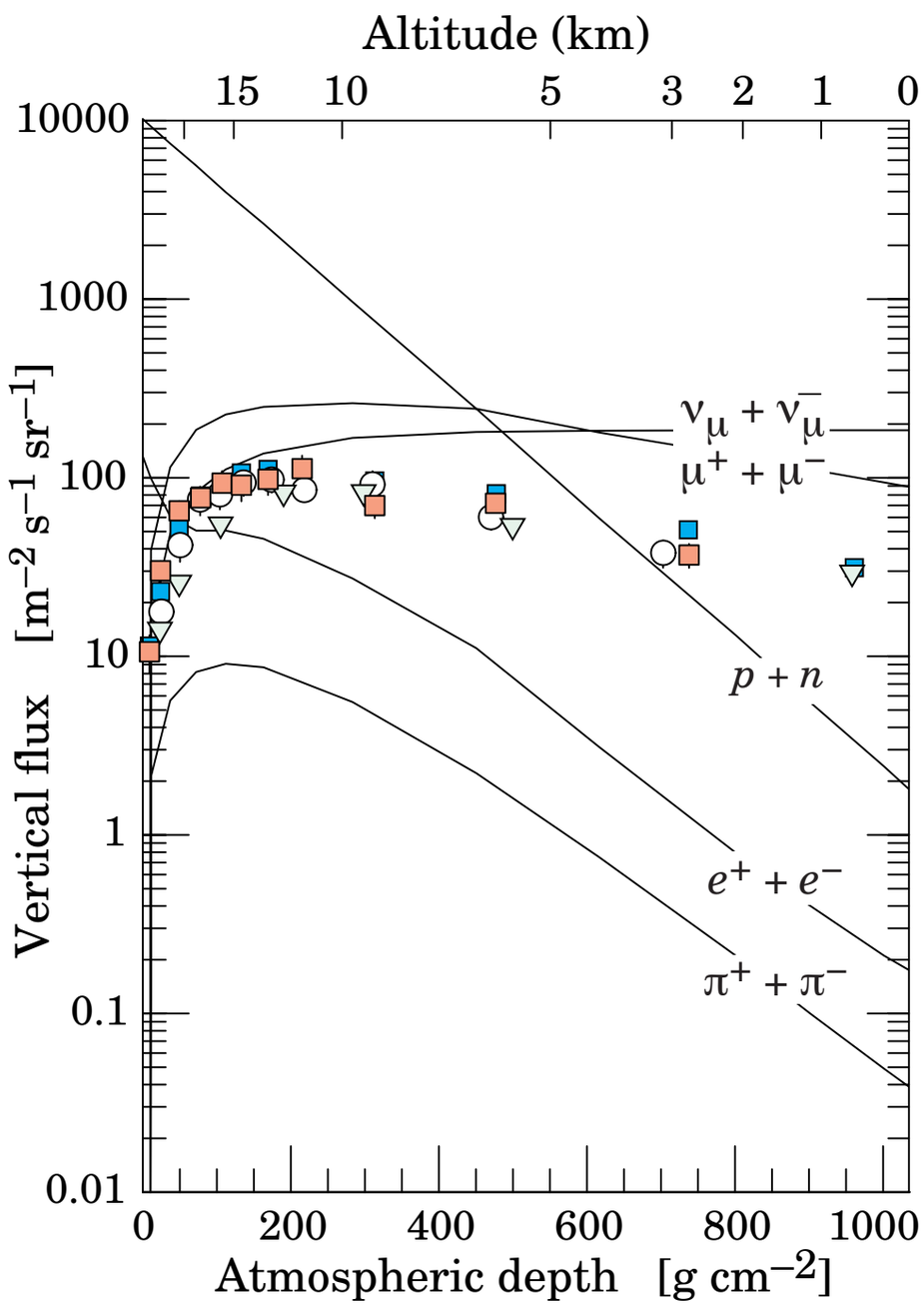
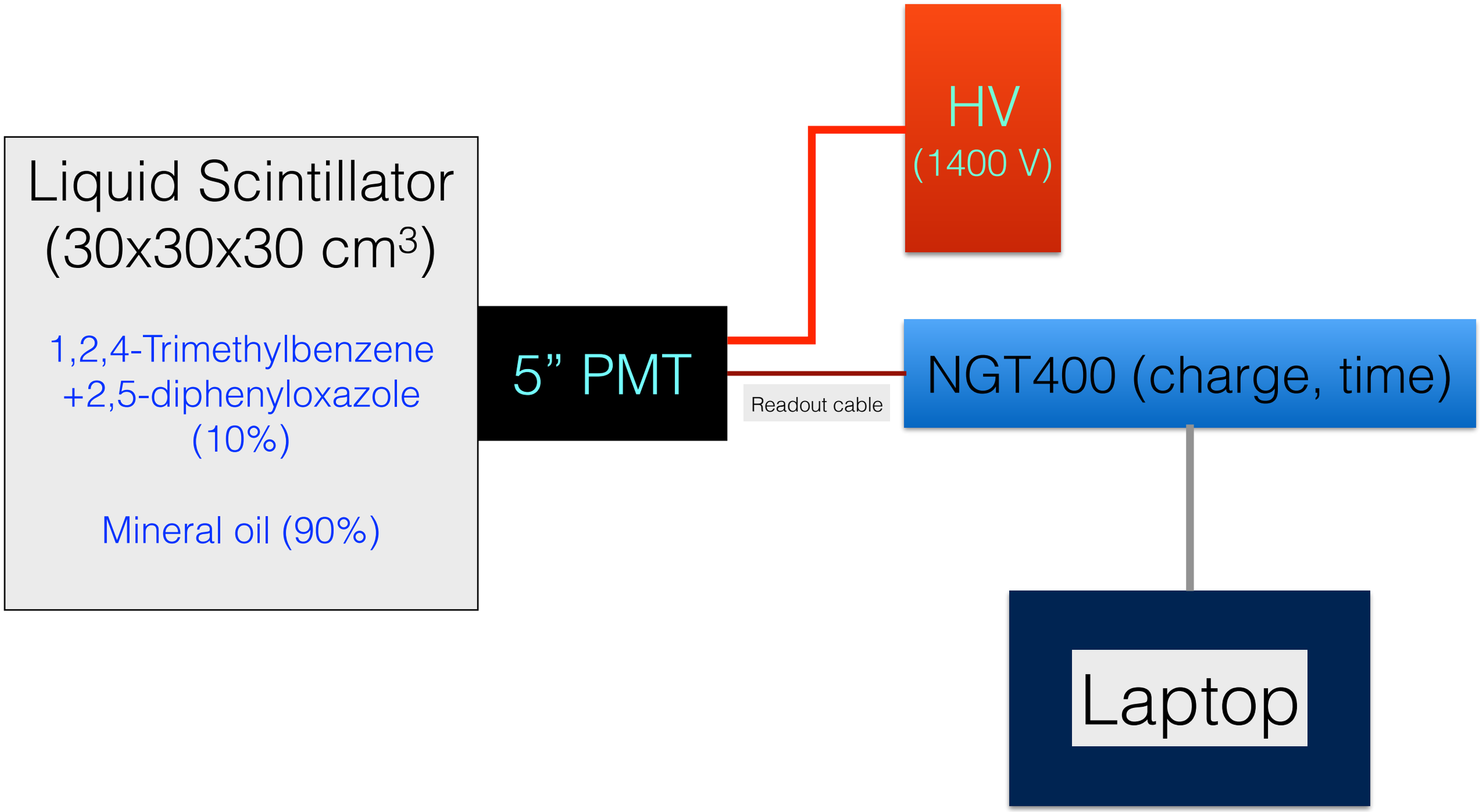


Figure 24.3: Vertical fluxes of cosmic rays in the atmosphere with $E > 1$ GeV estimated from the nucleon flux of Eq. (24.2). The points show measurements of negative muons with $E_\mu > 1$ GeV [32–36].

Experimental Setup



μ

e

ν

ν

Scintillation signals

5” PMT

Stopped Muon

Electron

PMT (Photomultiplier tubes)

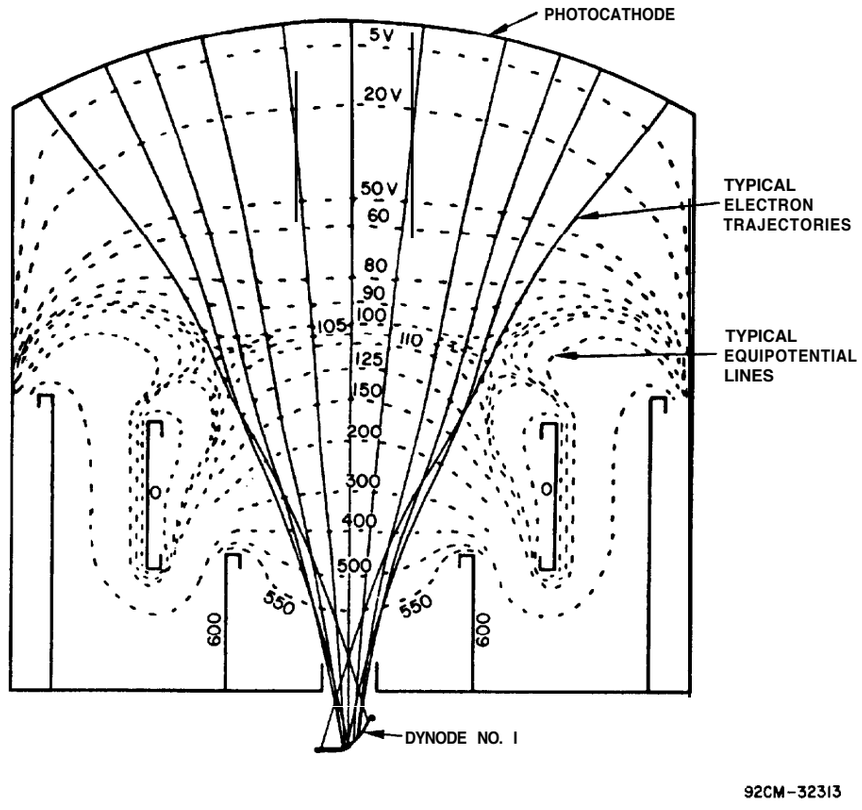
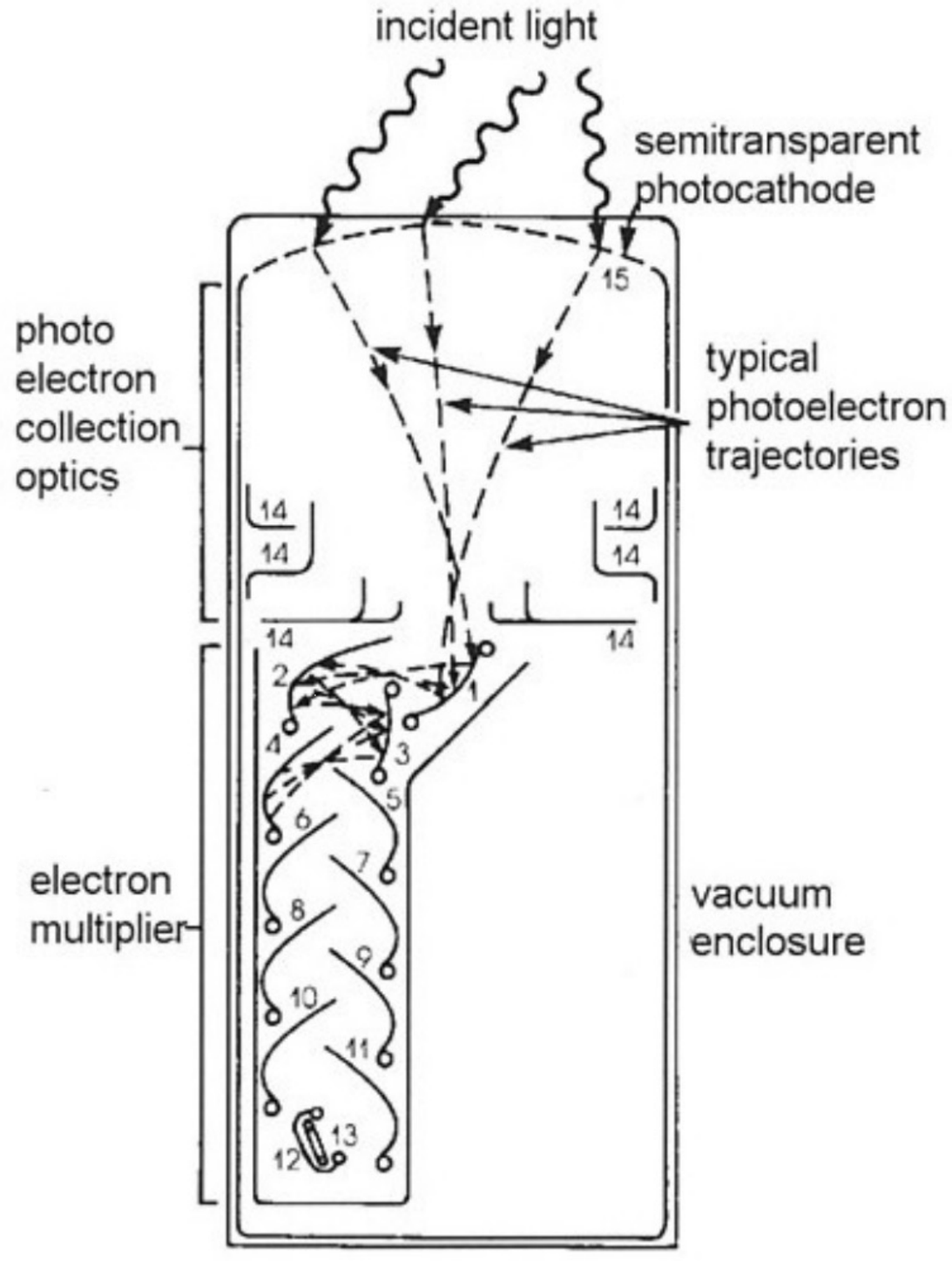


Fig. 27 - Cross section of a photomultiplier showing equipotential lines and electron trajectories that were plotted by computer.



Event Information

- body0: ADC counts of the early signal
- body: ADC counts of the late signal
- dt: time difference between two signal peaks

Mean Lifetime for Particle Decay

The probability for decay

$$f_{decay}(t) = Ae^{-\lambda t}$$

$$\int_0^\infty f_{decay}(t)dt = \int_0^\infty Ae^{-\lambda t}dt = -\frac{1}{\lambda}Ae^{-\lambda t}\Big|_0^\infty = \frac{A}{\lambda} = 1 \quad so \quad A = \lambda$$

The probability that a particle will remain at time t

$$P_u(t) = 1 - \int_0^t \lambda e^{-\lambda t'}dt' = 1 + e^{-\lambda t'}\Big|_0^t = e^{-\lambda t}$$

The mean lifetime

$$\langle t \rangle = \tau = \frac{\int_0^\infty te^{-\lambda t}\,dt}{\int_0^\infty e^{-\lambda t}\,dt} = \frac{\int_0^\infty te^{-\lambda t}\,dt}{\frac{1}{\lambda}\left[-e^{-\lambda t}\right]_0^\infty} = \lambda\int_0^\infty te^{-\lambda t}\,dt = 1/\lambda$$

From the experiment, can you:

- see the muon and electron signals with the oscilloscope?

- draw signal distributions of the muons and electrons in ADC counts?

- make a plot for the time difference between two signal peaks?

- obtain the mean lifetime of muons by fitting the plot obtained in the previous step?