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Particles and the Cosmos – 2019/20

Werkcollege 12

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Problem 24 Atmospheric neutrinos

The Super-Kamiokande experiment measured atmospheric neutrinos, generated through interactions of cosmic rays in the atmosphere.

- How does the Super-Kamiokande experiment detect neutrinos?
- How are neutrinos generated through interactions of cosmic arys in the atmosphere?
- What ratio of ν_μ/ν_e do we expect?
- Super-Kamiokande observed the flux of muon neutrinos as a function of zenith angle. Did they measure the expected ratio of ν_μ/ν_e for upward and downward going neutrinos?

Problem 25 Solar neutrinos

For many decades a deficit in the flux of electron neutrinos has been recorded from the Sun. This is known as the solar neutrino puzzle. The breakthrough has been achieved by the SNO experiment.

- Describe the detection principle of the SNO experiment.
- How did the SNO experiment solve the solar neutrino puzzle?

Problem 26 Interactions of high-energy cosmic rays with the cosmic microwave background

High-energy cosmic rays (protons) can interact with the photons of the 3 K microwave background. If the protons exceed a minimum energy E_{GZK}, high-energy pions are produced via the interactions

$$p + \gamma_{3K} \rightarrow \Delta^+ \rightarrow p + \pi^0$$

or

$$p + \gamma_{3K} \rightarrow \Delta^+ \rightarrow n + \pi^+.$$

This effect has been predicted in 1965 by the physicists Greisen, Zatsepin, and Kuz'min. Hence, the name GZK effect. These interactions take place if the energy of the 3 K photons exceeds $m_\Delta c^2 = 1232$ MeV in the rest frame system of the protons.

- Calculate the threshold energy E_{GZK} for a proton.
  Hint: the energy of the photons is given as $\epsilon_\gamma \approx 2.5$ meV.

- Knowing that the density of the 3 K photons is $n_\gamma = 411$ photons/cm^3 and the cross section for the above mentioned interactions is $\sigma_{p\gamma} = 300\ \mu$b (1 b=$10^{-24}$cm^2), calculate the mean free path of the protons in units of [Mpc].

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Lecture web site: http://particle.astro.ru.nl/goto.html?partcos1920