Problem set for the lecture
Particle Detectors, WS 2015/16

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Problem set 2

Deadline: Thursday November 5, 10am
(Please drop into mailbox number 1 on the ground floor of the Gustav-Mie building.)

1. **Muon detector**
A particle detector, consisting of strips with a width of 1 cm and a length of 60 cm, is planned to undergo a functional test before each physics measurement. The test is done using cosmic muons (particle flux $\sim$1 $\text{cm}^{-2}\text{min}^{-1}$).

   (a) How long does one need to measure on average to register 3 muons, assuming a probability of detection of 100%?

   (b) The actual number of registered muons per strip follows the Poisson distribution. What is the probability to erroneously classify a strip as not working (no muon registered), using the measurement time from (a)?

   (c) Strips classified as not working will be masked (not providing data) for the actual experiment, and for a specific measurement the rate of strips masked due to a false negative during the functional test is deemed too high. How long would one need to run the functional test to push the fraction of wrongly masked strips below 0.1%?

   (3 Points)

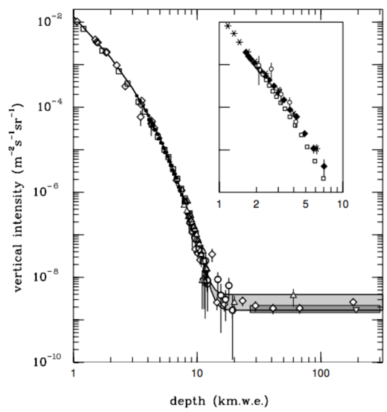
2. **Cosmic muons**
The above muon detector is planned to be installed in an underground facility. While the expected rate of cosmic muons is reduced underground, they can still be a significant background for measurements.

   (a) Calculate the required minimal muon energy (on ground level) as a function of their range in bedrock (density = 3g/cm^3), assuming a constant loss of energy due to ionization ($dE/dx = 1.5$ MeV/(g/cm^2)). What is the range of muons with an initial energy of 10 TeV, considering ionization only?

   (b) For high muon energies bremsstrahlung and e^+e^--pair production can also play a role. Assume the corresponding energy loss to be proportional to the muon energy ($dE/dx = b \cdot E$). Considering this and using the simplified assumption of $b = 7 \cdot 10^{-6}$ cm^2/g, what is the corrected range of 10 TeV muons?

(c) Even deep underground the flux of very high energy muons never drops to zero, pointing at an additional source beside muons 'punching through' the bedrock. Measuring the muon direction, it is found that this component includes horizontal as well as up-wards flying muons. Considering this and the high observed energies, explain the source of these 'cosmic muons'.

(3 Points)



3. **Ionisation**
In a drift chamber filled with Argon gas, in addition to the particle momentum its energy loss dE/dx is measured 10 times, on a length of 5 cm.

$$\frac{dE}{dx} = 0.307 \cdot \frac{Z\,\rho}{A\,\beta^2} \cdot \left[\ln\left(\frac{2\,m_e\,c^2\,\gamma^2\,\beta^2}{I}\right) - \beta^2\right] \left[\frac{\text{MeV}}{\text{cm}}\right]$$

using $Z = 18$, $A = 40$, $\rho = 1.78 \cdot 10^{-3}$ g/cm^3, I=216 eV.

For a particle with a momentum of 0.8 GeV/c, the mean value $dE/dx = 2.82$ keV/cm is found. For the particle type the hypotheses of pion, kaon and proton are considered.

(a) What is the expected fluctuation of the mean values of dE/dx, assuming an energy loss of 30 eV per ionisation?

Hint: Consider the fluctuation of the number of e^- and ion pairs

(b) A particle is considered to be identified if its energy loss is within 3 standard deviations of the theoretical expectation. Which particle hypotheses are statistically compatible with the above measurement?

(4 Points)