Problem set for the lecture

Particle Detectors, WS 2015/16

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Problem set 12

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

1. **Water Cherenkov Detector**
   Consider neutrino detection in a cylindrical tank filled with ultrapure water via the scattering process $\nu + e \to \nu + e$, with part of the neutrino energy being transferred to the electron. Photomultipliers with a quantum efficiency of 0.2 cover 40% of the detector wall to detect Cherenkov photons radiated by relativistic recoil electrons.
   (a) Electrons in the MeV range lose about 2 MeV of energy per cm in water, predominantly due to ionization, and produce $\sim$220 Cherenkov photons per cm. Estimate the number of detected Cherenkov photons per MeV of initial electron energy.
   (b) Using momentum and energy conservation, formulate an expression for the angle between the direction of the scattered electron and the direction of the incident neutrino, in terms of electron mass m_e, electron kinetic energy T_e and incident neutrino energy E_ν.
   Hint: The angle of the outgoing neutrino can be eliminated using a trigonometric identity. For this exercise energy conservation is best expressed using T_e, and the electron momentum p_e only expressed in T_e and m_e at the very end.
   (c) Calculate the maximum electron angle for a maximum solar neutrino energy of about 20 MeV and a minimum observable electron energy of 4.5 MeV. How does this help detection of solar neutrinos?

   (4 Points)

2. **Detector Design**
   Design a detector with the goal of measuring two categories of beauty hadron decays:
   - $B_s^0 \to \mu^+\mu^-$ - This rare decay is very sensitive to physics beyond the Standard Model.
   - $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ - The study of time dependant CP asymmetries in these two decays provides important measurements for the determination of Cabibbo-Kobayashi-Maskawa angles.

   The detector is to be built into the beam line of a proton-proton collider. In high energy proton-proton collisions the production of hadrons strongly peaks at low angles to the incident beams, hence it is sufficient to instrument an angle of $\approx$0.8 radian, centered on the beam line and on one side only (similar to a fixed target experiment). The detector should measure charged particles with momenta from a few hundred MeV to about 80 GeV, in particular being able to distinguish charged hadrons starting from momenta around 1-2 GeV. The detector needs to be able to perform lifetime measurements and provide flavour tagging. While meeting the design goals try to be realistic and cost efficient.

(a) Make a sketch with annotations, describe the characteristics and dimensions of subdetectors and components and justify your choices.

(b) Provide some information about the expected performance of the subdetectors in terms of efficiency and resolution.

Note: This exercise counts as 3 points for the point total of this problem set, while up to 6 points can be earned, allowing to 'recover' points missed on previous problem sets.

(3+3* Points)