Particle Physics Methods

MPAGS

2019-2020

Assessment

Problem 1

Assume a spherically symmetric gaseous detector consisting of two concentric metal electrodes: a stain-less steel sphere of radius r_a at the centre of the detector, and a spherical copper shell of inner radius r_b. The sphere is at voltage V_0, while the shell is grounded. The detector is filled with an Ar:CO_2 mixtures in proportions 90% to 10%.
For this configuration calculate:

a) the electric field in the sensitive volume.
b) the weighting field of each of the two electrodes.
c) the capacitance matrix and the capacitance of the detector.

Assume an X-ray photon of 5.9 keV from the decay of ^{55}Fe:

d) what would be the main interaction of the X-ray with the sensitive volume of the detector?
e) how far in the gas does the photon travel on average before it interacts?
f) how many ionisation electrons will be produced per X-ray interaction?

Assume that the 5.9 keV photon interacts near the metallic shell, and that for the detector: $r_a = 1.4\,\text{cm}$, $r_b = 1.3\,\text{m}$, $V_0 = 12\,\text{kV}$, mobility of Argon ions $\mu_{Ar^+} = 2\,\text{cm}^2/\text{s/V}$, drift velocity of electrons $u_D = 9\,\text{cm}/\mu\text{s}$, gain is 10^3 and all multiplication happens in one step at radius $r_{av} = 1.6\,\text{cm}$. Ignore diffusion.

g) estimate the induced current on the metallic sphere as a function of time, explaining the different stages.

Problem 2

A search for a new particle is performed in a signal region where a single source of background is contributing. The expected number of background events is $N_b \pm \delta N_b$, and N_{obs} events were observed in the experiment. The parameter of interest is the number of signal events.

a) Write the likelihood function of this experiment: i) ignoring the background uncertainty; and ii) including the Gaussian uncertainty on the background.
b) Assuming $N_b = (10 \pm 2)$ and $N_{obs} = 13$, plot the profile likelihood ratio $-2\log\left(\frac{\mathcal{L}(N_S)}{\mathcal{L}(\hat{N}_S)}\right)$: i) ignoring the background uncertainty; and ii) including the Gaussian uncertainty on the background.
c) Assuming the asymptotic approximation, estimate the 95% confidence level upper limit for the signal production rate: i) ignoring the background uncertainty; and ii) including the Gaussian uncertainty on the background.

Problem 3

A cosmic ray telescope consists of two identical plastic scintillators in coincidence. The plastic scintillators are rectangular in shape with length 1 m and width 20 cm, and are placed on top of each other at a distance L. The angular distribution of cosmic ray muons is proportional to $\cos^2\theta$, where θ is the zenith angle, and their rate is $1\text{cm}^{-2}\text{min}^{-1}$. Estimate, using the Monte-Carlo technique, the rate of coincidences in the telescope for the following values of L: 0.1 m, 0.5 m, 1.0 m. Assume that the scintillators are fully efficient and ignore accidental coincidences.