PHY2405 Third Problem Set

February 15, 2024

1) In class we showed that it takes 550 μs for the voltage pulse in a proportional tube to reach its maximum value. However it rises to half this value 1000 times sooner. Suppose we are working with a drift chamber that has a drift velocity of 50 μm/ns and want to have a spatial resolution of 200 μm.

   a) What is the timing resolution required to achieve the desired spatial accuracy?

   b) What fraction, f of its maximum amplitude will a pulse have attained in this length of time? Feel free to choose one of the typical proportional tube dimensions (and wire diameters) from the notes – but please stick with the same one for the rest of the problem – unlike in my notes...

   c) Pick a value of V_{max} and set a threshold at $V = fV_{\max}$ using the value found in part b), above. At what times do pulses with the maximum value $V_{max}/2$ and $2V_{max}$ go over threshold? This is called time slewing, and can result from the Landau fluctuations of the initial charge deposited when the charged particle went through the proportional tube. Particles can easily leave 50% to 200% of their average charge in gaseous volumes. Not knowing which results in something like this degradation in time resolution which translates directly into a degradation of position resolution.

   d) One way to defeat (or at least tame) time slewing is to make a pulse that is half the inverse of the original pulse. One delays this new pulse a time Δt (typically a few ns) and then adds it to the original pulse. One then enables a discriminator that triggers when the composite pulse passes through zero. Show that this firing time is independent of the amplitude of the original pulse (V_{max}) and derive an expression for it.

2) Consider a drift chamber operating at atmospheric pressure with a cool gas. The drift velocity for electrons is given by:

$$w = \mu E \qquad \text{with} \qquad \mu = 5cm/kV/\mu s$$

   The drift cell is 10cm long and has an electric field that is give by:

$$E = a/x \quad \text{for} \quad 0 < x < 1cm$$

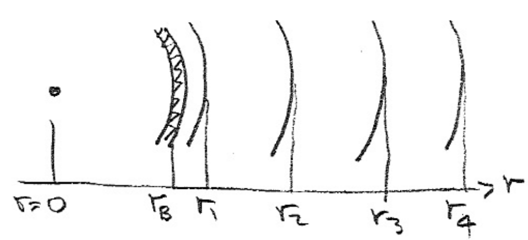
$$E = a \quad \text{for} \quad 1 < x < 10cm$$

   a) Sketch the distribution of drift times from a uniform flux of particles through the chamber.

   b) Assuming the diffusion coefficient, $D = 250\mu\text{m}^2$/ ns is a constant, plot the σ of the ionisation electrons as they arrive at the wire as function of their drift distance x to the wire.

3) Prior to the wide-spread use of silicon vertex detectors , most experiments used very precise gaseous inner trackers. As multiple scattering is more important at lower momenta these remain competitive for low energy experiments – but probably only for experiments that are **lower** in energy than typical B factories these days. The Mark-II experiment at SLAC discovered the J/Ψ meson in the 1970s used a chamber like this. It had the follow rough geometric and physical properties:

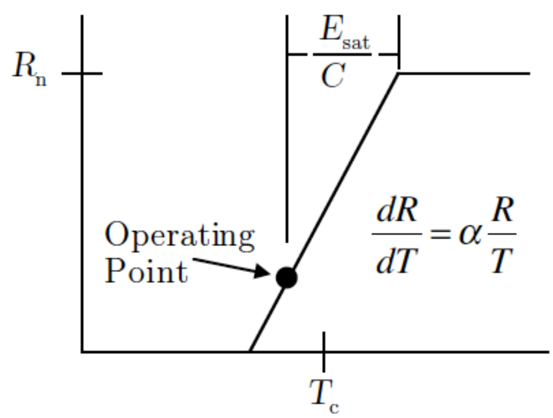
Material	Radius (cm)	Thickness (cm)	Material (X_0)
Beam Pipe	8	0.15	0.006
Chamber Gas	9	5	0.002
Wires	9	5	0.001



The wires are actually arranged in four layers where they could make very precise ($\sigma = 150\mu$m) measurements of the ϕ coordinate. The layers themselves were positioned at $r = 10.0, 11.0, 12.0$ and 13.0 cm. For the purposes of this problem you can assume the radially positions of the measurements are at exactly these radii (ie. radial distortions didn't limit this chambers ability to measure the trajectories of tracks emerging from the collisions at $r = 0$.

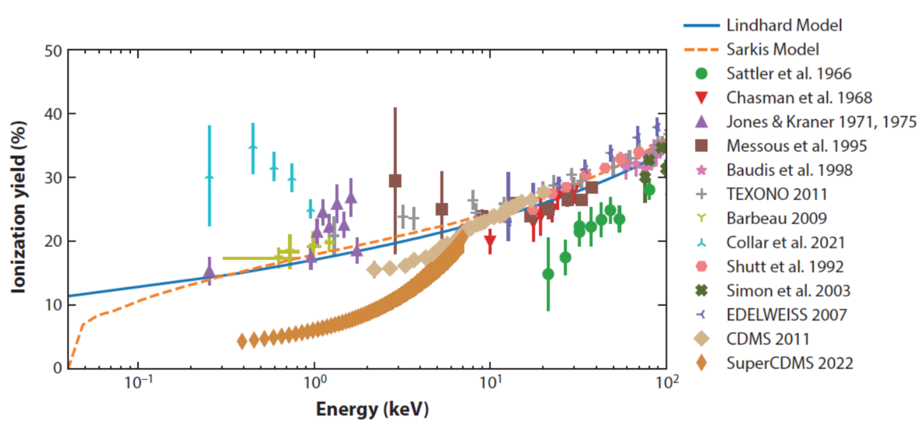
Find the uncertainty on the projected track position at $r = 0$ due to the measurement uncertainties and the multiple scattering and hence the total projection uncertainty. The goal was to make this small enough to distinguish particles produced along the beamline, from secondary particles resulting from the decay of long-lived charm mesons.

4) Assume an simplified TES transition curve like below. For a TES biased in the middle of its transition, calculate the saturation energy (E_{sat}) as a function of the TES heat capacity (C), TES critical temperature (T_c), and α. Prove that the TES energy resolution scales as $\Delta E_{rms} \propto \sqrt{E_{sat}}$.



5) The measurements of germanium nuclear recoil ionization yield are in an interesting state. Three different experiments are in strong conflict with each other.

(a) Take a quick glance over the four measurements at the low energy end, Collar 2021, Barbeau 2009, Jones&Kraner 1975, and SuperCDMS 2022, and comment on what could be causing the discrepancy. Are there strong assumptions made in each analyses or systematic uncertainties not fully considered?



(b) For a 2 GeV WIMP recoiling on germanium, 400 eV is around the tail of the recoil energy. If such a recoil happens in a SuperCDMS Ge HV detector operating at 100 V crystal bias voltage, given the three scenarios (Collar, Lindhard/Barbeau/Jones, SuperCDMS yield models), what are the expected phonon energies? A better than 10% precision "read off the graph" ionization yield in each scenario would be good enough.

(c) For a (hopefully more precise) measurement of germanium ionization yield, we have constructed the NEXUS facility, which includes a D-D neutron generator with collimator, a dilution refrigerator, and an array of secondary neutron detectors (made of plastic scintillators with SiPM readout) under construction. Following the classical scattering experiment as shown below, assume the dimension of the target detector is negligible, with a 10 eV phonon resolution, can can operate at 100 V crystal bias. Further assume the neutron beam from D-D generator is monoenergetic and perfectly collimated, and the neutron detectors are located 1 meter from the target detector. What are the requirements on the secondary neutron detectors to ensure a definitive distinctiveness among the three scenarios? (What is the uncertainty required at 400 eV to tell which curve is correct, and how to achieve that?)