Track Reconstruction and Vertex Finding

Goals:

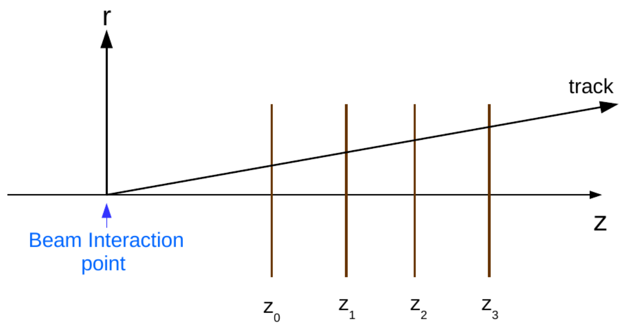
- Introduce the concept of track fitting using the example of a straight line fit
- Understand the meaning of track impact parameter and calculate the dependence of impact parameter resolution on the relevant detector parameters
- Use Monte Carlo techniques to demonstrate that the decay products of long-lived particles can be "tagged" by selecting tracks with high impact parameter
- Use the example of a simple two-body decay to introduce the topic of secondary vertex reconstruction.

Silicon microstrip and pixel detectors play a prominent role in many particle physics experiments. Their good spatial resolution, ability to distinguish near-by particles and radiation hardness make them attractive options. You have studied the position resolution of such detectors in a previous homework. Today, we will learn about how they are used to reconstruct particle trajectories and to identify the decay products of weakly decaying particles.

Track reconstruction is performed in several steps. First, neighboring hits are combined to form space-points. Second, a pattern recognition algorithm is used to associate a set of space-points with a single trajectory. Finally, these space-points are fit to determine track parameters. This problem focuses on the final stage where track parameters are determined.

In this problem we will consider the case of a charged particle traversing multiple silicon strip detectors leaving a straight line trajectory. An example of this case is the LHCb VErtex LOcator (VELO) detector. See
https://lhcb-public.web.cern.ch/lhcb-public/en/detector/VELO2-en.html
In addition, while the ATLAS and CMS trackers are placed in a solenoidal magnetic field, fits in the non-bending plane (r-z in cylindrical coordinates with the B field along the z-axis) will be straight lines.

1. *Track Fitting from Silicon Space Points*



Consider a very simplified model of a tracking detector. The detector will consist of 4 layers of silicon equally spaced with the first layer a distance z_0 from the beam interaction point and a z-spacing between layers of ℓ. The z position of the detectors is perfectly known. The strips are oriented to give a measurement of r in each detector with a resolution σ_r. The track is a straight line, so it can be described as trajectory in the r-z plane

$$r = az + b$$

where the best estimates of a and b are obtained using a χ^2 fit to the 4 spacepoints.

(a) If r_0 through r_3 are the measured hit positions on the 4 layers of silicon, find analytic expressions for the fit values of a and b. Express your answer in terms of the z positions of the sensors and the measured r positions.

(b) Find an expression for the uncertainty on the intercept b.

(c) Generate 1000 tracks all coming from the beam interaction point (these are called "primary tracks") and distributed uniformly in $\cos\theta$ for $-0.25 < \theta < 0.25$. For each track, simulate the measured hit positions using a resolution $\sigma_r = 15$ μm and fit the measured hits to determine m and b. Use the values $z_0 = 5$ cm and $\ell = 10$ cm. Make a histogram of the fit values of b for the tracks and verify that the width of the distribution agrees with your analytic result above.

(d) The track impact parameter d_0 is defined as the distance of closest approach of the track to the the beam interaction point. For a track with trajectory $r = az + b$, find an expression for d_0.

(e) Consider the case of a B^0 meson (mass=5.28 GeV, lifetime=1.52×10^{-12} s) with a momentum of 25 GeV. On average, such mesons will travel about 2000 μm before decaying. Their decay products therefore will not intersect the beam interaction point. We will study the rare decay $B^0 \to \pi^+\pi^-$. Generate 1000 primary B^0 mesons and allow them to decay according to the normal exponential decay formula. For cases where both tracks are produced with $-0.25 < \theta < 0.25$, find the fitted values of b and m for each track and make a histogram of the value of d_0. (Note: the two body decay is isotropic in the B^0 center of mass). Compare (using a log scale for your y-axis) the d_0 distribution of the B^0 decay products to those of primary tracks. Explain how you would select a sample of events enriched in B meson decays.

(f) An even better technique for identifying long-lived particles is to reconstruct a secondary vertex from tracks with large impact parameter. For the B^0 sample generated above, find the position where the two tracks cross and make a histogram of the distance of the decay from the beam interaction point. Generate a sample where each event contains two primary tracks and compare the decay distance distributions of the two samples.