Designing a particle physics experiment

Data Analysis course 2016 – Group assignment n. 4

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Purpose of this assignment

The purpose of this project is to design a particle physics experiment from scratch.

The foreseen experiment is named *K2Pi* and will study the decay of charged kaons into a charged and a neutral pion:

$$K^+ \to \pi^+ \pi^0$$

The apparatus should be capable of detecting the K decay products.

1 Experimental requirements

The *K2Pi* experiment will be built at the European Centre for Nuclear Physics (CERN) and will use a beam line branched off the Super Proto Synchrotron (SPS), which is the second-largest circular collider at CERN.

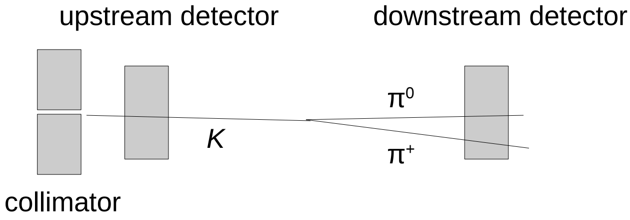
This machine provides a proton beam that is extracted and subsequently dumped on a Beryllium target in order to extract secondary particles such as kaons. A pure K^+ beam with a momentum of $p_K = 75$ GeV/c is prepared by a system of magnets and directed to the experimental area where the apparatus should be built.

The experimental hall available for *K2Pi* is 300 m long. It could be expanded if your simulation proves that an expansion would significantly improve the acceptance of the experiment (i.e. the number of K decays completely detected). Keep in mind that expanding an underground hall involves very expensive civil engineering work.

2 Lifetime of the K meson

The lifetime of the kaon should be estimated by analysing the data recorded by a previous experiment, named *LifeK*, using the same beam line and the same beam momentum. The *LifeK* beam was composed by 16% K^+ and 84% π^+, and the experiment did not have any means to distinguish pions from kaons.

The `dec_lengths.dat` file contains 100000 measurements of the lifetime of a particle decaying in *LifeK*. Knowing the composition of the beam, and knowing that charged pions have a mean life of $\tau_\pi = 2.6 \times 10^{-8}$ s, which translates to an average decay length of $\beta\gamma c\tau_\pi = 4.188$ km with the given beam energy, perform a fit to the experimental data in order to extract the average decay length of the



K^+. Compute the uncertainty on your result, and check if your result is compatible with the Particle Data Group (PDG) estimate, available at pdg.lbl.gov.

3 K2Pi experimental strategy

The researchers who proposed *K2Pi* envisage the use of two sets of detectors: one close to the collimator where the K^+ beam originates, to measure the momentum and direction of the kaons, and another one downstreams, composed of a tracking detector to measure the π^+ and of a calorimeter capable of measuring the subsequent decay of the π^0. Both detectors have a circular cross section with a diameter of 4 m and their centre lies on the z axis.

For the purpose of this project, you can assume that the π^0 is a stable particle and can be detected as it is. At first, assume that the beam of K travels exactly along the z axis, and prepare the full simulation.

Then move to a more realistic configuration: imagine that the beam of kaons has a Gaussian profile, with an angular spread of $\sigma_x = \sigma_y = 1$ mrad. Add this spread in the simulation and compare the results.

Your simulation should be used to determine the best position of the second detector, the downstream one. Remember that you should first determine what are the random processes involved. The steps of the simulation will be:

1. (generating beam kaons, only if adding an angular spread),
2. generating decay vertices,
3. generating kaon decays in the kaon rest frame,
4. boosting the pions to the laboratory frame,
5. checking if both pions are detected (i.e. the K decay is fully reconstructed),
6. determining the position of the downstream detector that maximizes the number of fully reconstructed events.

Appendix: K decay and Lorentz boost

It is convenient to describe our particles in terms of four-vectors:

$$P = (E, p_x, p_y, p_z) \tag{1}$$

Each process preserves the magnitude of the total four-vector, element by element:

$$P_K = P_{\pi^+} + P_{\pi^0} \tag{2}$$

The K decay products are produced isotropically in the rest frame of the mother, with back-to-back momenta. In order to boost the K daughters to the laboratory frame we need the kinematic variables of the mother:

$$\beta = |p_K|/E_K \tag{3}$$
$$\gamma = E_K/m_K \tag{4}$$

where $|p| = \sqrt{p_x^2 + p_y^2 + p_z^2}$.

Then, supposing that the K travels along the z axis, the components of the daugther four-momentum in the laboratory frame are related to those in the K centre-of-mass frame, denoted by *, by:

$$\begin{bmatrix} E \\ p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} \gamma & 0 & 0 & \beta\gamma \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \beta\gamma & 0 & 0 & \gamma \end{bmatrix} \begin{bmatrix} E^* \\ p_x^* \\ p_y^* \\ p_z^* \end{bmatrix} \tag{5}$$

On the other end, if the K direction does not lie exactly on the z axis, you should modify the direction of both children accordingly by performing a rotation.