Joined Physics Analysis Center

Summer Workshop on the Reaction Theory
Exercise sheet 5

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Classwork

The goal of this exercise to explore some of the practical issues associated with experimentally measuring various reactions. All real detectors have a limited geometrical acceptance and therefore imperfect detection efficiency. Common detection techniques used in typical hadron spectroscopy experiments utilize ionization of material (useful for detecting charged particles) or electromagnetic cascades (useful for detecting photons). Consequently metastable particles such as neutrons or K^0_L mesons are difficult to detect.

Assume that our beam and detector have these properties, which are somewhat similar to those of the GlueX experiment at Jefferson Lab.

- An 8-9 GeV photon γ beam that is incident on a fixed proton p target. Polar angle in the laboratory is given by θ as measured from the incident beam direction.
- An average detection efficiency over all angles of 95% for photons.
- An average detection efficiency for long-lived charged particles of 90%.
- Charged kaons can be identified with 50% efficiency.

In order to conduct an amplitude analysis of experimental data it is necessary to isolate events that are most likely associated with a particular reaction. This is easiest to do when all the decay products produced by the reaction are detectable. This allows for *exclusive* reconstruction of the reaction, and requiring that the total four-momentum of the final state particles is equal to the four-momentum of the initial state (within detector resolution) is a powerful discriminator against backgrounds. If a reaction has a single undetectable particle, like a neutron, then one typically requires that the massing mass, or magnitude of the missing four-momentum, be within detector resolution of the known mass of the neutral particle. This is typically a less-powerful constraint and such reactions are often subject to higher levels of background, where the word “background" means some other reaction took place in the detector and it has been mistakenly reconstructed as the signal reaction. Finally, reactions with multiple undetectable particles in the final state are almost impossible to uniquely separate from other events.

- **Detection and selection of events.** For each of the reactions below, write down the list of metastable particles that are produced. Which of these particles are detectable? Some reactions have multiple decay modes. Write down the two or three most dominant decay modes and estimate the product of the branching fraction and detector efficiency for each.
  (a) $\gamma p \to \omega p$
  (b) $\gamma p \to \eta' \pi^+ n$
  (c) $\gamma p \to \pi^0 \Delta^+$
  (d) $\gamma p \to K^*(892)^+ \Lambda$

- **Statistics.** Often one wants to study various kinematic variables of interest, *e.g.*, t, $M(\eta'\pi^0)$, $\cos(\theta_{GJ})$, etc., when analyzing a reaction. In order to do this one needs enough events to populate these variables with suitable statistical precision. It is therefore useful to be able to make order of magnitude estimates of event yields in experimental data sets.

  (a) Assume that you have liquid hydrogen target that is 30 cm long, in the direction of the beam. (The transverse dimension is larger than the beam and is therefore not relevant.) Show that the density of target protons in this configuration is about 1.3 b^{-1}.

  (b) Let's assume a beam flux of 10^7 γ/s in the energy region of interest and assume that the experiment takes an integrated data set equivalent to 20 continuous days of beam on target. If a particular reaction has a cross section of 1 μb, how many events of this type are produced during the data taking period?

  (c) Use the compilation of photoproduction cross sections that is posted on lecture web site to *estimate* the number of detected events for several of the reactions in the first part of this exercise. (You may notice many of the cross sections of interest are not measured in the 8-9 GeV region.)

  (d) Consider specifically the case of $\gamma p \to \eta'\pi^+ n$ where one might want to search for exotic mesons decaying into $\eta'\pi^+$. Suppose one wants to study study the production of various $\eta'\pi^+$ partial waves as a function of both t and the $\eta'\pi^+$ invariant mass, and does so by dividing the data into 5 and 100 bins of each, respectively. About how many events remain in each bin? Consider how that might be sufficient to constrain a model with about ten different partial interfering partial waves.

- **"Needle in a haystack."** During the spring of 2017, the GlueX experiment operated such that the flux of photons in the region 8.2 - 8.8 GeV of energy was about 2×10^7 γ/s. During this period of data taking, the rate at which the detector was collecting collision events was about 35 kHz. The integrated data set amounted to about 20 continuous days of beam on target.

  (a) Again, using the compilation of cross sections, estimate what fraction of this 27 kHz data rate was from $\gamma p \to$ *hadrons* in the region of 8.2 - 8.8 GeV. (The remainder of the events are produced mainly from photons with lower energies or electromagnetic interactions, and are somewhat easier to separate. One route to optimizing the problem illustrated in the following steps of this exercise is to be more selective in which events are recorded, but this must be done with great care as the discarded events can never be recovered.)

  (b) What fraction of the total collected event sample are some of the reactions listed in the first exercise? The presence of narrow intermediate states, *e.g.*, π^0, η, ω, or unique event topologies, like the displaced vertex of a Λ or K_S^0 are useful in developing algorithms to select these events from all collected events.

  (c) Each collected event is about 17 kB in size. Compute the rate that the detector is producing data and the size of the size of the raw data set.

  (d) The first step in the data analysis is to use "reconstruction" algorithms that examine individual "hits" on detector elements that are stored in the raw event and convert these into four-vectors that represent the particles produced in the event. If a single computing core can execute this algorithm such that it processes events at a rate of 20 Hz, how many core-years are required to reconstruct the data set? If we want the data available to analyze in 6 weeks to prepare for fall conferences, how many computing cores are needed? Note that reconstructing the data is only the first step in the process. One then has to analyze the reconstructed data and select signal events.