Homework: Kinematic Fitting in Hadron Physics

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1 Introduction

Goal of this assignment is to make you familiar with the kinematic fitting technique in physics data analysis. You will have two weeks to solve this homework (starting from this Friday: 04/10/2020). It is highly encouraged to work in groups, but the answers to this homework have to be submitted individually. Please do not hesitate to contact Daniel (`dlersch@jlab.org`) if you have any questions or need further assistance.

1.1 What is provided

A collection of different data sets (.root files with .root trees), that will help you to answer the questions below. Furthermore, you will be given an example analysis code in case you do not want to start from scratch.

1.2 What you need to provide

A document (latex, word, excel, whatever you prefer ..) summarizing your answers and conclusions. You should provide all calculations you make (if any!) in detail and describe the plots you produce.

2 The Data Set

You will analyze the same data we discussed in the lecture, i.e. $pp \to ppX$, $X = \pi^+\pi^-$, $X = \pi^+\pi^-\pi 0[\pi^0 \to \gamma\gamma]$ and $X = \eta[\eta \to \pi^+\pi^-\pi 0[\pi^0 \to \gamma\gamma]]$. The beam kinetic energy is: $T = 1.7\,\mathrm{GeV}$ (slightly higher than discussed in the lecture). In the folder **kfit_homework**, you will find four subfolders:

- **gen_data**: One file for each reaction with generated four momenta. The names of the files are attached to the underlying reaction.
- **rec_data**: Again one file for each reaction, containing the generated and reconstructed four momenta (in case you need/want to check residuals). **Note:** The trees for each file are filled after requiring a "trigger" condition: 2 protons, one π^+, one
pi^- and two photons in the final state
- **ana_data**: Same as above, but including the kinematic fit values (probability, pulls and fitted four momenta). Four kinematic fits have been performed in this analysis:
    i) $pp \to pp\pi^+\pi^-\pi 0[\pi^0 \to \gamma\gamma]$ + energy and momentum conservation
    ii) $pp \to pp\pi^+\pi^-$ + energy and momentum conservation
    iii) $pp \to pp\pi^+\pi^-\pi 0[\pi^0 \to \gamma\gamma]$ + energy and momentum conservation + constraint on $M(\gamma_1, \gamma_2) = m_{\pi^0}$
    iv) $pp \to pp\pi^+\pi^-\pi 0[\pi^0 \to \gamma\gamma]$ + energy and momentum conservation + constraint on $M(\pi^+, pi^-, \gamma_1, \gamma_2) = m_\eta$
- **pp_data_set**: **This is the data you will analyze!** Technically, you do not need the other sets. But I thought you might be interested in looking into them. This data set contains a combination of the analyzed and fitted pp reactions with different abundances: $N(\pi^+\pi^-) > N(\pi^+\pi^-\pi 0[\pi^0 \to \gamma\gamma])$ $> N(\eta[\eta \to \pi^+\pi^-\pi 0[\pi^0 \to \gamma\gamma]])$

3 Analysis

In the folder **kfit_homework** you will find a simple analysis program called **simple_analysis.C**. If executed in a root-session, it will analyze data from **pp_data_set** and produce a minimal set of plots, in order to give you a first impression.

If you wish the program to run faster, simply compile it: .x simple_analysis.C++ . When solving the tasks listed below, it is up to you whether to use the fitted or reconstructed particle 4-momenta. I advise to look at both, because it helps you to understand the fitter and the data.

4 Reaction Kinematics

4.1 Getting Started (5pts)

Plot the squared missing mass of the: p_{beam}, p_{target}, p_1,p_2, π^-,γ_1 and γ_2 system. What do you expect to see? And what do you actually see?

4.2 Missing energy vs. missing momentum (5pts)

Calculate the missing energy and missing momentum for the reaction: $pp \rightarrow pp\pi^+\pi^-$ (the dominating one in your data set) and generate the missing momentum vs. missing energy plot we discussed in the lecture. What is difference between the plot you generated and the one shown in the lecture? (Hint: The one in the lecture was made under a different assumption)

4.3 Understanding the Data I (10pts)

Perform a cut on on the two photon invariant mass (i.e. select a π^0) and look again at the missing momentum vs. missing energy plot you create before. What do you see and why?

4.4 Understanding the Data II (10pts)

Calculate and plot the missing mass of the: p_{beam}, p_{target}, p_1,p_2, π^- and π^+ system. What do you expect to see? If you compare it to the $M(\gamma_1, \gamma_2)$ invariant mass, what difference(s) do you notice? And why?

5 Understanding the Kinematic Fitter

5.1 The Probability Distribution (5pts)

Plot the probabilities from each fitter into one histogram and compare. What do you see?

5.2 Correlation between the χ^2- and Probability-Distribution (5pts)

Pick your favorite fitter (i.e. either with or without constraint ...) and plot the corresponding χ^2-distribution. How does this distribution change if you perform the following cuts on the corresponding probability: $P \geq 0.01$, $P \geq 0.1$, $P \geq 0.5$ and $P \geq 0.9$?

5.3 Pull Distributions I (10pts)

Plot the pull distributions (for all particles!) of the fitter you picked before. Determine the mean and sigma (does not have to be fancy, calling the corresponding TH1 function is fine). What do you see? How would you judge the fitter performance so far?

5.4 Pull Distributions II (10pts)

Perform 10 different probability cuts (e.g. 0.0, 0.1,0.2,...) and determine the sigma and mean of each pull-distribution for each cut. Finally, plot the mean/sigma of each pull as a function of the corresponding probability cut. What do you see and why?

6 Data Analysis

6.1 Inspecting π^0-Yields I (5pts)

Choose the P4 kinematic fitter (i.e. no mass-constraints) and perform different cuts on the probability. For each cut, look at the $M(\gamma_1, \gamma_2)$ distribution and determine the number of π^0 (which should somewhat scale to the number $\pi^+\pi^-\pi^0$ final states) events within the π^0-peak. Plot this number as a function of the kinematic fit probability cut. What do you see?

6.2 Inspecting π^0-Yields II (5pts)

Repeat the task above for all kinematic fitter and compare the results.

6.3 Analysis of $\eta \to \pi^+\pi^-\pi^0$ (20pts)

Analyze the pp data set with and without kinematic fit and try to estimate the number of η-final states. **Note:** Please do not try to match any PDG-values. Just get a rough feeling on how many $\eta \to \pi^+\pi^-\pi^0$ decays might be in the data set.