Proposal to measure particle production in the Meson area using Main injector primary and secondary beams

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Abstract

We hereby submit a proposal to measure hadronic particle production with particle identification in the Meson area using primary and secondary beams from the Main Injector off a variety of targets. The purposes of the experiment are threefold; to verify a general scaling law of hadronic fragmentation, to measure particle production off a NUMI target using 120 GeV/c protons with sufficient accuracy to predict the NUMI neutrino spectrum, and to measure proton nucleus cross sections for the purposes of proton radiography. A measurement of low momentum pion production will also be of benefit to the muon collider effort.

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I. INTRODUCTION

In what follows, we will motivate each of the aims of the experiment in some detail. We will then suggest an implementation plan for the experiment. Wherever possible, we will try to use existing equipment so as to minimize the cost and time overhead of the experiment. The key component in the experiment is a $3 million time projection chamber (EOS-TPC) built by the Bevalac group at Berkeley. The chamber was until recently used at Brookhaven National Laboratory in the particle production experiment E-910. Further running at Brookhaven is not foreseen currently. It is important that we express an interest to secure the TPC for use at Fermilab as soon as possible in the experiment proposed herein.

II. SCALING LAW OF HADRONIC FRAGMENTATION

Even though they form more that 90% of the total inelastic cross section, very little is known about the dynamics of minimum bias interactions. The events are of such low Q^2 that perturbative QCD has little predictive power when applied to these interactions. Several scaling laws, such as KNO scaling and Feynman scaling have in the past been proposed to explain the dynamics of minimum bias interactions. These have all been shown to be disobeyed experimentally.

In 1978, a general law of scaling for inclusive reactions was proposed [1]. It was deduced heuristically, from the need to treat charged pions on an equal footing with neutral pions when extracting the annihilation cross sections by considering the difference between $\overline{p}p$ and pp cross sections. There were two Phys. Rev. D papers [2] [1]. The first shows that it is possible to estimate the annihilation component of $\overline{p}p \rightarrow \pi^0$ inclusive reactions by subtracting the corresponding $pp \rightarrow \pi^0$ component. However, this method fails for the channels $\overline{p}p \rightarrow \pi^+/\pi^-$ because of the different CP symmetry of the corresponding pp component. The situation is remedied by postulating a new equation involving charge asymmetry in $\overline{p}p$ annihilation and non-annihilation components. The new equation lets us extract annihilation information for charged as well as neutral pions by comparing $\overline{p}p$ and pp reactions. These equations were shown to work for 12 GeV/c annihilation reactions.

The scaling law in question was proposed in order to explain the physics behind the asymmetry equation. It states that that the ratio of a semi-inclusive cross section to an inclusive cross section involving the same particles is a function only of the missing mass squared (M^2) of the system and not of the other two Mandelstam variables s and t, the center of mass energy squared and the momentum transfer squared respectively.

Stated mathematically, the ratio

$$\frac{f_{subset}(a+b\rightarrow c+X)}{f(a+b\rightarrow c+X)} \equiv \frac{f_{subset}(M^2,s,t)}{f(M^2,s,t)} = \beta_{subset}(M^2) \tag{2.1}$$

i.e. a ratio of two functions of three variables is only a function of one of them. When the subset being considered is annihilations, the asymmetry equation derived in [2] results. The physics behind the scaling law may be understood [1] by considering inclusive cross sections as the analytic continuations of crossed three body interactions, which factorize into a production term that results in the formation of a shortlived fireball of mass M^2, that subsequently decays into the subset in question. The formation is governed by s and t. The decay term is only a function of M^2. It should be noted that the physics in question falls outside the scope of perturbative QCD and as such the scaling law is not currently derivable from QCD considerations.

The law was verified in 100 GeV $\overline{p}p$ interactions by considering multiplicity subsets of the reaction $\overline{p}p \rightarrow \pi + X$. It was possible to verify the t independence of the ratio β_{subset} for a variety of subsets with an excellent degree of accuracy. The paper [1] also establishes the s independence of β_{subset} for a variety of $pp \rightarrow p + X$ reactions in the beam energy range of 200 to 400 GeV/c. Again, good agreement was obtained between the predictions of the law and data. Recently, the law has been verified in 12 reactions using data from the European Hybrid Spectrometer [3] with various beam particles and final states. Figures 1 and 2 show the test of the law for the reaction $pp \rightarrow \pi^+ + X$ for 400 GeV/c proton beam for 4 multiplicity subsets 4-6 prongs, 8 prongs, 10-12 prongs and >12 prongs. Figure 1 shows the agreement between the predictions of the scaling law and subset data as a function of M^2 for various t ranges. Figure 2 shows the agreement between the predictions of the scaling law and subset data as a function of t for various M^2 ranges. The agreement between the predictions of the scaling law and data is excellent in the data tested so far. If the law is an exact one, as there is reason to believe it may be, then it is clearly of fundamental importance in understanding hadronic fragmentation.

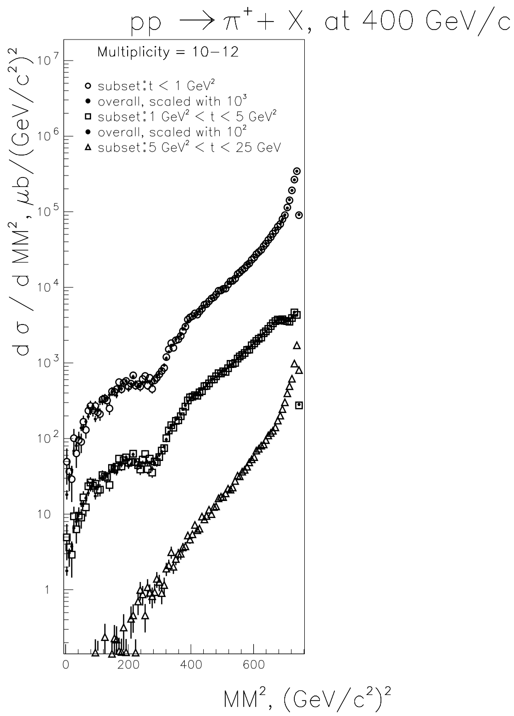
The problem with existing data is that it is usually sparse as bubble chambers were being used. *It is very difficult to test the law using existing data for s independence, since only rarely has the same apparatus been used to study the same reaction at multiple energies.*

We propose to measure particle production off hydrogen and other targets as a function of beam energy for various secondary beams ($\pi^{\pm}, K^{\pm}, p, \bar{p}$), for a variety of beam momenta ranging from 5 GeV/c to 120 GeV/c. At each beam momentum, the data taking rate has to be such that approximately a million unbiased events should be recorded for analysis.

III. SYSTEMATIC ERRORS IN NUMI/MINOS MEASUREMENTS OF NEUTRINO OSCILLATION PARAMETERS

One of the methods for measuring neutrino oscillation parameters (i.e., neutrino generation mass differences and mixing angles) in the MINOS experiment is to observe a distortion in the neutrino energy spectrum observed in the "far" detector located in the Soudan mine in Minnesota. To observe such a distortion it is necessary to be able to predict with good precision the shape of the neutrino energy spectrum at Soudan in the absence of oscillations. This is done through a combination of measuring the spectrum at a "near" detector (on the Fermilab site) in concert with various NuMI beam monitoring measurements.

Monte Carlo studies have shown that the largest contributor to the systematic error in the prediction of the shape of the neutrino energy spectrum at the far detector is the uncertainty in the production spectra at the target. That is, the uncertainties in the p_T and x_F distributions of the pions and kaons produced in the target (as well as their relative


pp → π⁺ + X, at 400 GeV/c
Multiplicity = 10−12
subset: t < 1 GeV²
overall, scaled with 10³
subset: 1 GeV² < t < 5 GeV²
overall, scaled with 10²
subset: 5 GeV² < t < 25 GeV
d σ / d MM², μb/(GeV/c²)²
MM², (GeV/c²)²