Review of Recent and Future Needs in Hadronic Flavor Particle Production Measurements

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Interactions of energetic particles on target nuclei producing secondary particles will be reviewed. Current simulation codes rely upon poorly measured results from the past. While current neutrino experiments, both atmospheric and accelerator based, rely upon Kaon and pion production measurements which are poorly known and dominate their errors. The goal for the current round of experiments are to dramatically improve these measurements while improvments beyond this are still needed. It is not only of interest to neutrino experiments, but also for designing calorimeters for the the International Linear Collider which must achieve unprecedented resolutions for reaching their stated physics goals.

1. Introduction

Two new recently completed experiments studying hadronic flavor particle production, HARP-PS214 at CERN and MIPP-E907 at Fermilab have just completed data taking. The BNL E910 experiment which ended six years ago is still in the data analysis process. Collectively these experiments cover 1 to 120 GeV/c on multiple targets (liquid Hydrogen, K2K and Minos targets and various nuclear targets including Uranium) for six beam species (pion, kaon, protons and their antiparticles). They expand upon the older cross section data and bring a variety of new physics goals: improved hadronic flavor production cross sections, studying fundamental scaling law relationships [1] and nuclear target production studies. Figure 1 shows the large uncertainty using current production cross-section data with a simulated neutrino target for the Fermilab MiniBooNE experiment [2]. This and other neutrino production experiments need substantial improvements, since this is what currently limits advances in neutrino physics.

In these new experiments particle tracking and identification are both paramount, bringing essential information, see figures 2 and 3. These new data set and the broad physics analysis planned with preliminary first results on all of these topics are presented in the next section.

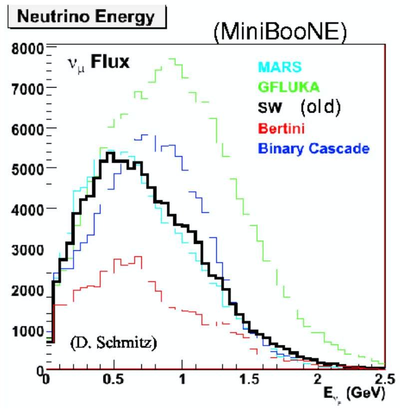

Figure 1. Calculated neutrino fluxes from a simulated MiniBooNE target using various codes and different measurements.

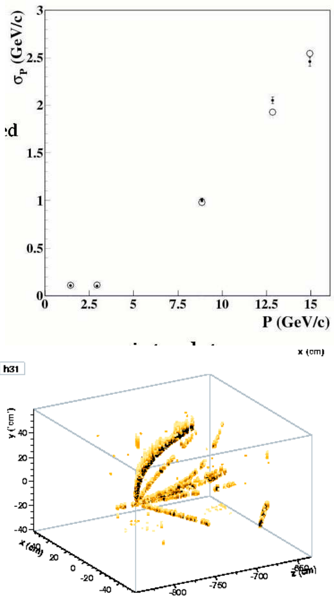

Figure 2. Momentum resolution from the Harp experiment (top) circle are MC and points for data, and an example event (bottom) from the MIPP experiment showing vertexing and high density tracking abilities of the TPC.

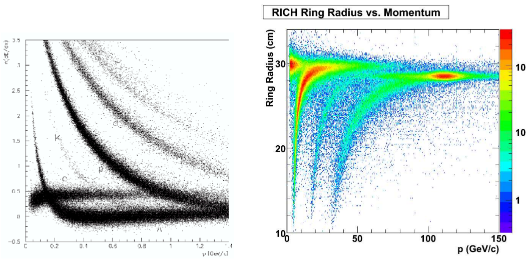

Figure 3. Two examples of the particle identification in these measurements are the E910 TPC using dE/dx on the left (this is the same TPC that is currently in the Fermilab MIPP experiment) and on the right is the MIPP RICH detector.

The proposed future run of an upgraded MIPP detector is of importance to future neutrino physics programs worldwide, such as Ice-Cube, NOνA, Pierre Auger and SuperK/HyperK experiments. By doing a high statistics run including Liquid Nitrogen, for the complete forward production hemisphere with three sigma particle identification, it will permit detailed cross section measurements to refine the Monte-Carlo generators such as Fluka or MARS, which are of major relevance for improving these future neutrino detectors. Current SuperK atmospheric neutrinos results are limited to a 20% error [3] from these uncertainties while the Ice-Cube experiment sees a 30 to 40% [4] impact using the current known cross-sections.

2. Recent results

New results were reported by the Brookhaven National Laboratory E910 experiment within the last two years with 6.4 and 12.3 GeV/c protons on a Beryllium target [5]. The most recent published cross section results come from the Harp (CERN PS214) experiment. They reported two measurements of 12.9 GeV/c proton on Aluminum [6] of interest to the Japanese K2K experiment and 8.9 GeV/c protons on Beryllium [7] which is of interest to the Fermilab MiniBooNE experiment.

NuMI Target Studies for the MINOS Experiment with the MIPP data are well advanced. Crucial π and K production studies that the MINOS analysis will eventually rely upon will be provided by the MIPP experiment using the spare NuMI composite target. A 120 GeV/c beam of pure protons identical to that which hits the NuMI horn target was run in the MIPP experiment for two months and collected 2 million events. These events using the projectile particle tracking and secondary particle production identification and momentum reconstruction show first results from this analysis in figure 4 [8].

The MIPP experiment is also studying particle production multiplicities and its A dependence, see figure 5, for the first tentative results which are in agreement with [9].

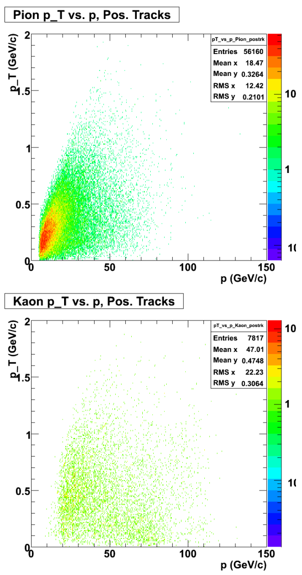

Figure 4. Preliminary study of π (top) and K (bottom) production by 120 GeV/c proton beam on the NuMI target in the MIPP experiment.

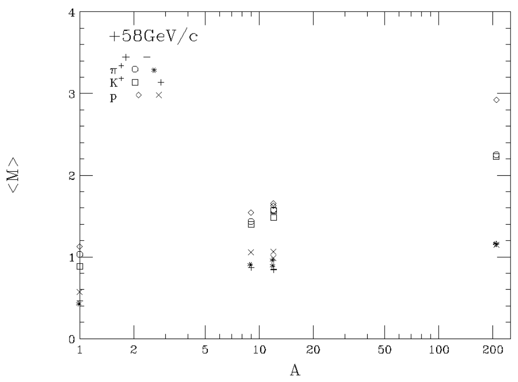

Figure 5. Preliminary MIPP results on the charged particle multiplicity from 0.15 to 1.0 GeV/c particles for beam particles at +58 GeV/c with tagged π, K and protons on nuclear targets from A=1 hydrogen to A=206 Bismuth, the data has been corrected for empty target runs.

3. Future improved measurements

The Fermilab MIPP experiment proposes to have an upgraded run from 2007 to 2009 with a faster readout of the TPC so that a 3 kHz rate can be achieved, 4π acceptance by installing a backward hemisphere detector, a new silicon vertex-interaction trigger, an improved calorimeters which is a cooperation with the International Linear Collider and other minor but essential modifications.

An extensive run with a Liquid Nitrogen target with a large data sample so that fine segmentation in angle can be measured for all interaction species, this is explicitly needed for the atmospheric neutrino experiments such as: IceCube and Hyper-K, to improve their neutrino flux from π and K decays. Figure 6 shows the current limitation to the small Amanda experiment above 4 GeV/c, this comes from the Cosmic Ray uncertainties of atmospheric production of Kaons and pions [10]. Current models are uncertain above 5 GeV/c. Members of the IceCube experiment from the Univ. of Wisconsin and Fermilab members of the Pierre Auger Experiment will be joining the MIPP upgraded experiment. It plans to study different elements for improvements to hadronic shower simulation code for hadronic calorimeter design. These measurements are vital to improving Hadron Calorimetry, which is the most important detector in the ILC. See figure 7 which shows the difference between a $60\%/\sqrt{E}$ and $30\%/\sqrt{E}$ resolution, a crucial necessity to separating the two jet background from W and Z.

Hadron Calorimetry designs rely upon Monte-Carlo codes where the detector materials are not well known. The upgraded MIPP experiment will study 40 nuclei from 1 to 100 GeV/c. The response of the ILC test calorimeter to neutrons and its efficiency is essential to the Particle Flow algorithms. By putting the ILC hadron calorimeter in the MIPP beam line they will be able to provide a direct measure of neutron energy and efficiency response with tagged neutrons [11]. It will also provide a unique opportunity for tagged K^0 and $\bar{K}^0$ physics program.

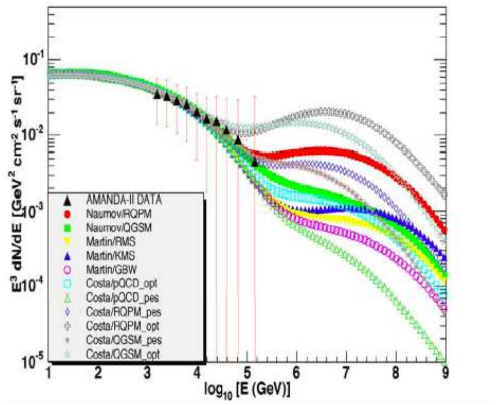

Figure 6. Errors in atmospheric neutrino production based upon current Nitrogen kaon production cross-section.

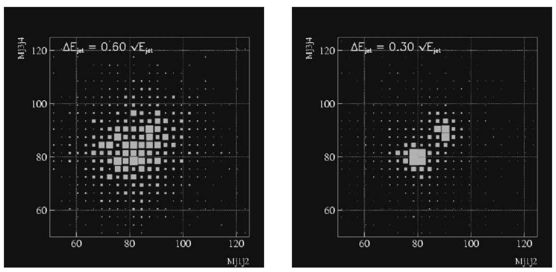

Figure 7. Hadronic calorimeter energy resolution at $60\%/\sqrt{E}$ (left) and $30\%/\sqrt{E}$ (right) for the sum of two jets on the x and y axis.

4. Conclusion

The E910, MIPP and Harp experiments with current improvements to the hadronic flavor production studies has greatly helped make improved cross-sections. Future data from the upgraded MIPP experiment will be a guiding light for both atmospheric and accelerator based neutrino experiments, without which there is little or no reason to continue neutrino studies. A great improvement in anti-proton interactions and charm production is also planned. Future data and analyzed results are excitingly awaited.

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