BEAMLINE DESIGN FOR PARTICLE PRODUCTION EXPERIMENT, E907, AT FNAL*

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Abstract

Experiment 907 at Fermilab will be conducted in the Meson Center beam enclosure. The purpose of this experiment is to measure cross sections for hadron production from nuclear interactions using pions, kaons and proton beams in the momentum range from 5 to 120 GeV/c. Light to heavy targets will be used to study the scaling laws of hadronic fragmentation and light meson and baryon spectroscopy. Design aspects for the experiment's beamline are presented. The lattice, in particular the secondary beamline design, the primary target, and the collimation system are covered.

INTRODUCTION

MIPP (FNAL E-907) stands for Main Injector Particle Production Experiment. A low-cost experiment, it uses existing hardware to measure particle production off hydrogen and other nuclear targets including the NuMI targets, with excellent initial and final state particle identification. The resolution and statistics projected for the experimental data represent a significant improvement over existing measurements. Analysis of the experimental results will provide:

- A test of the accuracy of and energy range over which a general scaling law of fragmentation applies given each particle type,
- A measurement of particle production off NuMI targets with sufficient accuracy to predict the neutrino spectra at the near and far detectors in MINOS,
- A starting point for the study of the dynamics of non-perturbative QCD and its associated resonances,
- A better understanding of the propagation of particles in nuclei.
- Improvement in the predictions of atmospheric neutrino fluxes,
- Advance the design of accelerator-based neutrino factories,
- Improvement of hadronic shower models in collider simulation programs (GEANT and MARS, for example).

A key feature of this experiment is the high-precision identification of the produced particle species across the entire kinematic range that can be accessed using the 120-GeV primary proton beam from the Fermilab Main Injector. Precise particle identification is critical to accomplish the goals stated above. The experiment achieves nearly complete resolution for π, K, and p at a the secondary energy from 0.1-120 GeV/c by measuring energy loss in a TPC, threshold Cerenkov radiation combined with ring-imaged Ĉerenkov radiation, and time of flight.

Most the experimental beamtime will be spent in survey mode running. The secondary beamline (in Meson Center) will allow acquisition of data at one rigidity for K, and p simultaneously for one sign of the charge. The incident secondary beam species will be tagged by threshold Ĉerenkov counters upstream of the 1% interaction length experimental (or secondary) target. In 126 hours of beamtime, one million events will be acquired per incident particle species. The momentum range from 5-110 GeV/c will be scanned over a set of experimental targets that span the periodic table from hydrogen to lead.

Further primary data will be acquired at 120 GeV/c by directing the Main Injector primary beam directly onto the NuMI targets. In this way, the pion production spectrum can be measured to 1% across the entire range relevant for MINOS, which is 1-50 GeV/c. Since kaons are produced at approximately 10% of the rate for pions, and both exhibit a fairly flat longitudinal spectrum, particle identification across this momentum range is critical for the measurement.

THE PRIMARY AND SECONDARY BEAMLINES

The length available to the experiment for primary beam control and the secondary beamline totals only 128m, with 41m reserved for the threshold and ring-imaging Ĉerenkovs. Due to enclosure restrictions and the need for primary beamline magnets in this section (no superconducting magnets are used), the primary portion must remain at least 20 m long. Less than 100 meters is left to accommodate the necessary secondary line optics—optics appropriate for momentum selection and which also meet the beam envelope and divergence criteria for the experiment. A picture of the physical layout of both lines, plan and elevation view, is given in Figure 1.

Primary Beamline Layout

The primary beamline extends for well over a thousand meters through various beam splits back to the Main Injector. Control over primary beam characteristics is

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established through a focusing quadrupole doublet and adjustable collimators located roughly 300 and 200 m upstream of the primary target, respectively. Intensity on

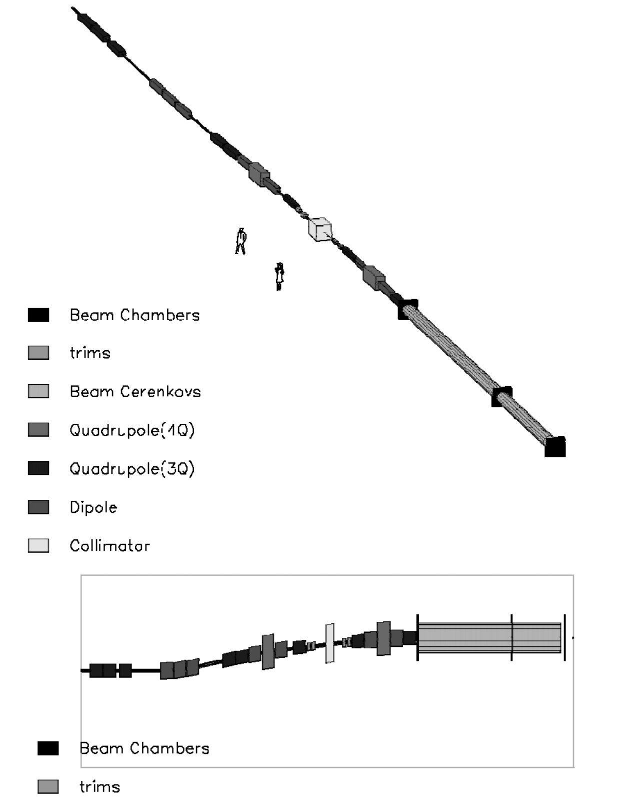

Figure 1. The plan and elevation view of the MIPP primary and secondary beamlines.

the primary target will be attenuated by adjusting both beam optics and the collimator aperture to achieve 10^{11} protons/spill, or less, with a spill occurring about every sec into this line from the Main Injector. Control over primary optics combined with collimator aperture is necessary for proper secondary beamline operation—a spot size of ±2 mm (95%) at the primary target must be maintained. (This requirement will be discussed further in the following section.) The primary line will be tuned and collimated accordingly to maintain a consistent spot size over a large range in primary intensity. The primary intensity will depend on the secondary beam energy and desired event rate.

Secondary Beamline

Several considerations challenged the design of the secondary beamline, a beamline which must accommodate both the demanded momentum resolution and the precision in particle identification. The former requires the momentum-dispersed beam size to be larger than the transverse beam size and the latter requires low divergence at the Ĉerenkov detectors. At the experimental target dispersion must be cancelled to contain the spot size on the secondary target and associated detectors.

The challenge in meeting the required momentum resolution arose from the fixed civil construction of the experimental and beamline enclosures. The primary and secondary beamlines are straight horizontally with only a slight increase in elevation at the experiment of 0.86 m relative to the primary beamline. Significant dipole bend fields, or weaker fields but longer distances, are required to produce significant separation of beam momenta. In the absence of either, only small separation of particles of different momentum can be achieved; in the case here only 0.3 m of vertical dispersion could be installed in the secondary line and still respect the length and height constraints. In order to make an accurate momentum cut, the transverse beam size must be smaller than the desired momentum resolution otherwise particles with momenta outside the cut overlap spatially. For this experiment a desired momentum resolution was needed of about 1%. When combined with the low value of dispersion (a 1% change in momentum represents only a 3 mm shift in the in particle coordinates), this implied the transverse beam size at the momentum cut or collimator must be less than or comparable to this shift. Hence, the beam spot size at this point must be ~3 mm across, which is less than or comparable to the primary target beam size. This criterion implies point to point focusing, or slight demagnification of the primary beam spot, further implying a strong sensitivity to the actual transverse size of the beam on the primary target.

Due to the limitations in length of the secondary beamline, the quadrupole focusing in the secondary line is strong and achromatic. With a focal length of only about 10 m at 100 GeV/c, most of the quadrupoles must operate at or near their peak fields to achieve the beam sizes depicted in Figure 2. The resulting large chromaticity of the line limits the momentum window to about 2-3% in practice.

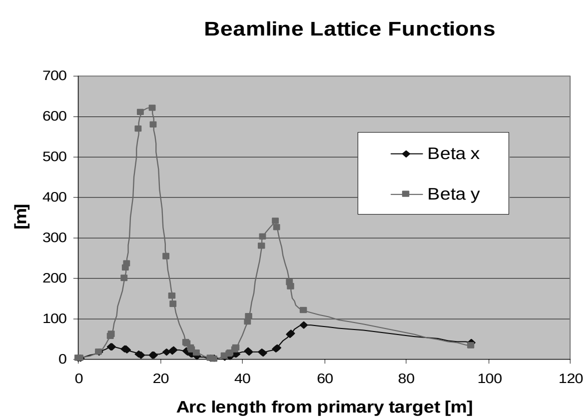

Figure 2. Beamline lattice functions: beam size is determined using an emittance of 3-5π mm-mr.

Accurate particle identification further restricted the divergence of the secondary beam to about 0.3-0.5 mr in the region of the Ĉerenkov. When coupled with a beam size at the experimental target of about 1 cm in radius, the beam emittance which produces an acceptable beam envelope is about 3-5π mm-mr. To restrict the beam envelope it was found necessary to scrape the emittance of the secondary beam just after the primary target, and before the momentum collimator to this value. The effect of secondary absorbers was to reduce significantly the ratio of background to signal at the secondary target, although at a price of reduced secondary beam intensity. The results of extensive simulations of this beamline are given in the next section.

BEAMLINE SIMULATION

The primary and secondary beamline were designed using MAD[1] given the specific beam spot size at the primary target and a phase ellipse constrained by the needs of the experiment at the Ĉerenkov and secondary targets of 3-5π mm-mr. However, collimators, momentum selection and actual performance of the secondary line were simulated in the MARS code[2] using the primary beam distribution and secondary particle production. The secondary particle distribution is ray-traced through the entire beamline locating high loss points for radiation shielding design and showing the effect of collimation and the size and divergence of the beam as it progresses along the secondary line. This proved to be a very effective approach to verification of the optics design of the line. The histograms in Figure 4 show the performance of secondary beamline for a large momentum bite, and for a more restrictive one which involves additional phase space collimation.

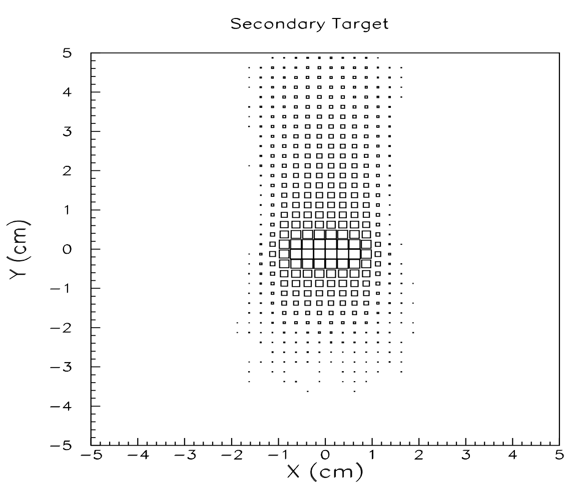

Figure 3. Beam profile on the 1-cm radius secondary target as simulated by MARS[2]

It is interesting to note the effect of a tighter momentum bite and scraping or secondary collimation of the beam to the design ellipse is to reduce the signal to background significantly at the expense of secondary intensity for a given primary intensity. Since we are not currently at intensity limits for the primary beam, more severe cuts are not a problem.

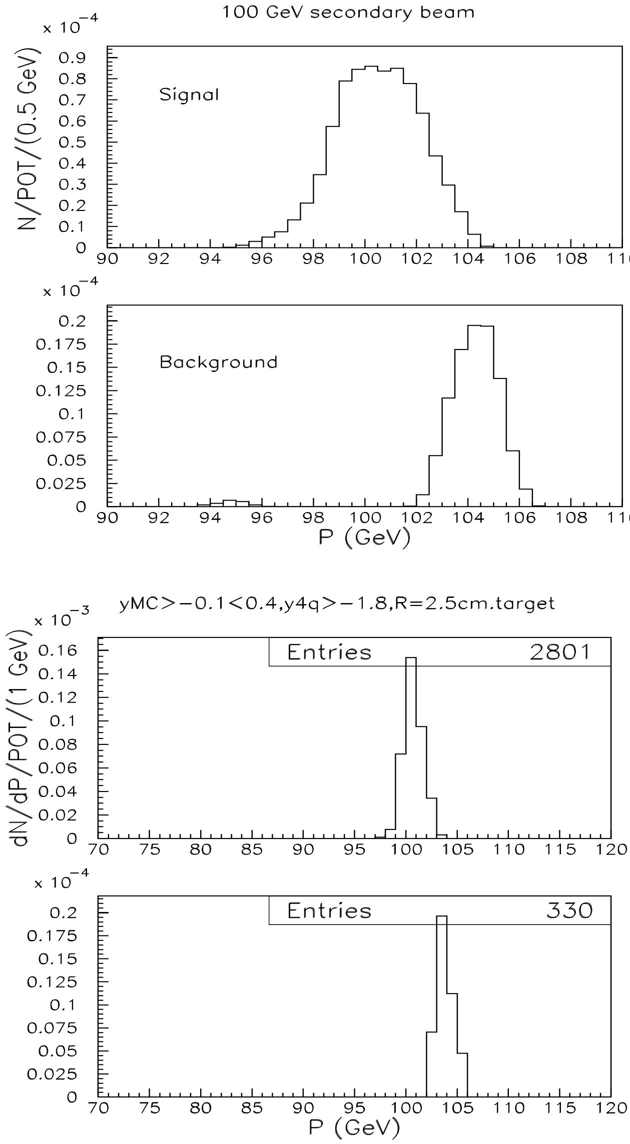

Figure 4. Histograms showing the performance of the secondary beamline and target for a ±5% dp/p at the momentum collimator: the signal and background events for a 1 cm radius detection area at the secondary target and no secondary collimation (8×10^{-4} signal protons and 10^{-4} background protons are detected for every proton on the primary target). The second set of histograms show a more restrictive, ±1% dp/p momentum cut, and additional collimation in the secondary line.

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