The Main Injector Particle Production experiment (MIPP) at Fermilab

Holger Meyer

Fermilab, P.O. Box 500, Batavia, IL 60555, USA

E-mail: hmeyer@fnal.gov

Abstract. The MIPP experiment at Fermilab measures particle production cross sections for a broad range of studies including a general scaling law of inclusive cross sections, meson spectroscopy, and topics in nuclear physics (y-scaling, flavor propagation in nuclei, etc.). It uses a large acceptance, open geometry detector system to measure momenta and identity of all charged particles produced in the reactions of proton, pion, kaon, and anti-proton beams from 5 to 85 GeV/c and 120 GeV/c protons on cryogenic hydrogen, various nuclei, and composite accelerator neutrino experiment targets. This paper describes detector and beam-line performance during the 2005 physics run, outlines the potential of an upgraded MIPP, and presents results from short test runs at momenta from 1 GeV/c to 5 GeV/c.

1. Overview of the MIPP experiment and physics motivation

The Main Injector Particle Production Experiment, FNAL E-907[1], uses protons from the Fermilab Main Injector to generate secondary beams of pions, kaons, and protons and their anti-particles in the Meson fixed target area. Three small wire chambers measure the incoming beam particle trajectory. Beam Čerenkov and beam time of flight detectors provide its identification. The beam particles interact in thin experimental targets. Charged reaction particles are tracked in the MIPP spectrometer with TPC and six wire chambers. TPC dE/dx, ToF, multi-cell threshold Čerenkov, RICH, and Calorimeters provide good particle identification over the entire range of reaction particle momenta. Data was also taken with primary Main Injector protons transported to the experimental targets on thin Carbon and NuMI[1][2] targets.

The experiment was approved in November 2001. Detectors were installed in 2002 and 2003. MIPP had engineering runs in 2004 and collected physics data for 14 months starting January 2005. Approximately 18 million events were recorded on several different targets.

The physics topics are diverse and have been described elsewhere [3]. Here I only add the potential for Cascade (Ξ) particle studies using the kaon beams and searches for missing (or unobserved) baryon resonances predicted by quark models using data with low systematic errors from six different beam probes with good resolution and particle identification.

2. Detector

The MIPP detector is shown in figure 1 and described in [4]. The TPC inside the 0.7 T magnetic field of the JGG magnet measures all charged particle tracks from the target at its front and

[1] NuMI, Neutrinos at the Main Injector, refers to the neutrino beam now used by the MINOS experiment

identifies particles below ∼1 GeV/c by dE/dx. 3 drift chambers in the beam and 6 chambers downstream of the TPC complete the precise particle tracking for good momentum resolution. The ToF wall of vertical 5 cm square scintillator bars provides identification for particles of $\sim 1-3$ GeV/c. A 96 cell threshold Čerenkov detector identifies particles at ∼3 to ∼17 GeV/c. The RICH detector identifies particles at momenta above ∼17 GeV/c. Practically all charged particles are identified. Final states with one neutral particle can be reconstructed through constraint fits because the initial kinematics is known precisely. Figures 2 and 3 show particle id in the TPC and RICH detectors.

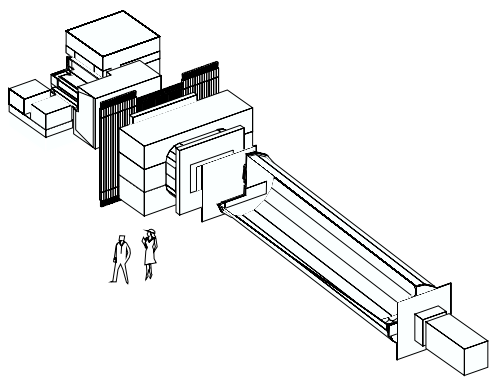

Figure 1. The MIPP detector with (from left to right) TPC inside JGG magnet, threshold Čerenkov, ToF wall, Rosie magnet, RICH, and calorimeters.

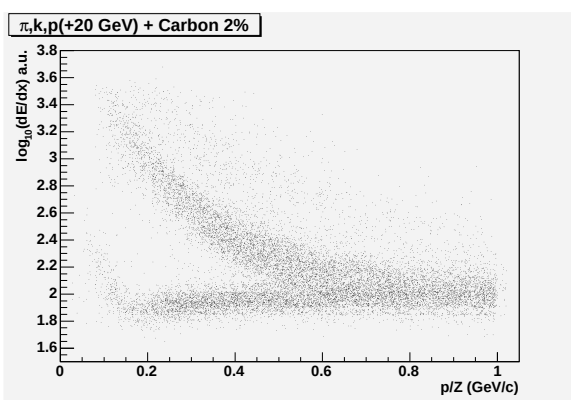

Figure 2. Preliminary TPC dE/dx versus momentum for particles produced in 20 GeV/c proton-carbon interactions. The plot shows proton and pion bands. Kaons can also be identified, but the band does not show due to limited statistics.

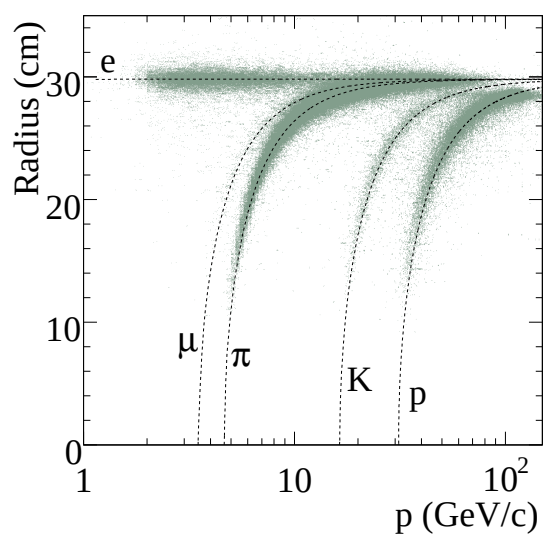

Figure 3. Ring ring radius versus momentum for particles produced in 120 GeV/c proton-carbon interactions. The calculated center of bands for e/μ/π/K/p are superimposed.

3. Beamline

The MIPP beamline was designed and installed in 2003. It successfully provided beam to the experiment since 2004 and ran secondary beams from 5-85 GeV/c and 120 GeV/c protons. Short test runs were taken at momenta of 1 GeV/c to 5 GeV/c.

The beamline consists of a primary target in an absorber cage, 15 dipole and quadrupole magnets, a variable collimator, and beamline instrumentation. It focuses protons from the Main Injector onto the primary target (a copper rod). Secondary particles are bend vertically upward and focused onto a collimator. Particles within a 2-5% momentum bite pass through the collimator, get bend back into the horizontal, and focused to a parallel beam onto the experimental target. The secondary particle charge and momentum is selected using polarity and field strength of the beam line magnets. The variable opening in the collimator determines the momentum bite. Beam particle ID is determined with high accuracy online (see figure 4) and can be further improved with offline cuts. Fractions of pions, Kaons, and protons or anti-protons in the secondary beam depend on momentum. The MIPP trigger can prescale beam particle species to record equal numbers of events for each beam particle type. The primary intensity of slow extracted Main Injector protons is adjusted to saturate the DAQ of the experiment. Data was taken with spills of 0.6 second length every 10 seconds before the start of NuMI operation and with 4 second spills at 2 minute intervals after this.

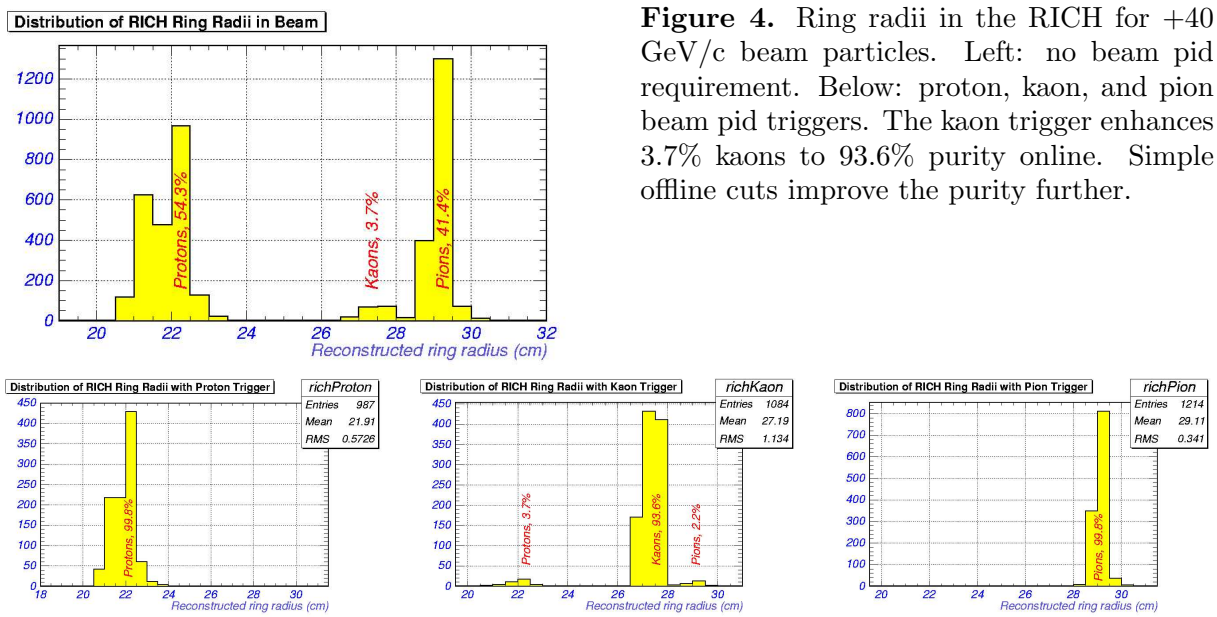

Figure 4. Ring radii in the RICH for +40 GeV/c beam particles. Left: no beam pid requirement. Below: proton, kaon, and pion beam pid triggers. The kaon trigger enhances 3.7% kaons to 93.6% purity online. Simple offline cuts improve the purity further.

3.1. Low momentum beams

The MIPP beam line was designed to produce secondary beam momenta of 5 to 90 GeV/c. At momenta below 5 GeV/c good performance depends on a few considerations that are less important at higher momenta. These are:

- survival of unstable beam particles in the beam line,
- reduction of material in the beam line to reduce multiple scattering,
- accurate regulation of beam line magnet currents at low current settings for tune stability,
- good reproducibility of low magnetic fields in the beam line for tune reproducibility,
- improvements to beam time of flight particle identification.

The survival of pions and kaons in the beam depends on the length of the beam line from the primary target to the experimental target. For low momentum beams this distance needs to be minimized in order to maximize the survival probability. Factors that tend to increase this distance include the space needed for reliable particle identification through both Čerenkov and time of flight methods, the number of beam line magnets needed for a reliable beam optics, need for shielding, and in general lower beam related backgrounds at larger distances from the primary target. The length of the MIPP beam line is 95.85 meters. Survival fractions of pions and kaons at different momenta are given in table 1.

Ideally the beam particles will not encounter any material between primary and secondary targets and the beamline will be under vacuum. In practice this is not completely possible and particles will undergo multiple scattering due to Coulomb interaction on the remaining material. The average scattering angle of beam particles is at leading order proportional to thickness of material in radiation lengths and related to their momentum p, mass m, and velocity β by [5]:

$$\left\langle \theta^2 \right\rangle \propto \frac{(m^2 + p^2)}{p^4 \beta^2} \tag{1}$$

The vacuum is broken in several places along the beam line. The momentum collimator with its variable opening cannot be placed under vacuum. Scintillators and beam chambers are needed in the beam to trigger and measure each particle's trajectory. The beam Čerenkov detector mirrors and entrance windows are also in the beam path. At large beam momenta the multiple scattering in the MIPP beam line is negligible. To reduce multiple scattering below current levels for low momentum beams, material in the beam path needs to be removed or replaced by materials with longer radiation lengths. The beam Čerenkov radiator pipes can be evacuated for low momentum beams because particle identification is done through time of flight instead. Other material reductions need to be considered carefully as they will impact knowledge of the beam particle (scintillators and chambers) or safety (thickness and material of vacuum windows).

The other considerations are of a more technical nature. Simple upgrades to the beam line can address these issues. Power supplies designed to operate well at high current output (typically ~ 1000 A) will not put out low currents with high stability. Power supplies optimized for lower current output need to be used. The two sets of power supplies can be connected through switches so that the beam line can change secondary momentum with minimal downtime. Hysteresis in the beam line magnets is a relatively larger effect at low magnetic fields for low momentum settings. The magnets need to be equipped with Hall probes to monitor the actual magnetic field rather than setting a tune through the current output of the power supplies (which is sufficient at large secondary momenta). The particle identification at low momentum is achieved through beam time of flight measurement. It is highly desirable to prescale triggers based on the beam pid because far fewer kaons and protons than pions are produced in the primary target at low momentum. This requires that the beam time of flight information gets processed in real time rather than being recorded in TDCs for offline analysis only.

4. Beam tests at 1 GeV/c to 5 GeV/c

A short set of test runs was performed on 17 February, 2006 to evaluate the performance of the MIPP beam line at secondary momenta of 1 GeV/c, 3 GeV/c, and 5 GeV/c with both positive and negative secondary beam charge. A few hundred events were recorded at each of the six settings. The beamline magnet currents were set to the scaled values of the default settings at 60 GeV/c. No tuning or optimization was attempted. The results of these test runs should be interpreted as a worst case scenario and certainly do not represent the best possible performance of the beam line at low momentum, especially once the upgrades mentioned above will have been completed.

The MIPP TPC records tracks from interactions by drifting ionization to a readout plane over a time of 16 μs. Beam backgrounds that hit the TPC during this readout window will appear as out-of-time tracks in the TPC data. Thus the TPC allow the study of beam backgrounds over a time of 16 μs over the area of 96×80 cm^2 around the beam. Backgrounds were low at all six momentum settings. It is possible to add a veto wall to the beam line to inhibit triggers when beam backgrounds are present. This may be useful at larger primary intensities.

Events were triggered on the coincidence in time of signals from two scintillators in the beam line, TBD and T01. The Main Injector uses a 53 MHz rf resulting in a 18.9 ns structure in the MIPP beam. The coincidence was adjusted for particles with velocity $\beta = 1$ with a tolerance of 10 ns. Thus protons at 1 GeV/c were not triggered in the present setup. A simple modification to the trigger electronics will allow these slow protons to get recorded. Absence of 1 GeV/c protons in the test run data shown here does not indicate absence of protons in the beam. The time of flight of beam particles is shown in figure 5. Pions, kaons, protons, and anti-protons are observed at 3 and 5 GeV/c. At 1 GeV/c kaons are expected to decay and protons are too slow to be triggered. Only pions are observed with some spread in momentum resulting in the tails.

The test runs show that the MIPP beamline is clearly capable of producing high quality beams at momenta between 1 and 5 GeV/c. Several improvements to the beam line will enhance low momentum beam quality further.

Table 1. Survival probability of pions and kaons in the 95.85 m long MIPP beam line and Time of Flight between TBD and T01 scintillators (37.69 m distance). A sufficient fraction of pions survives to get pion beams at 1 GeV/c but it is hard to get kaon beams below 5 GeV/c. Beam particle identification through tof is possible at and below 10 GeV/c.

Particle	Beam Momentum [GeV/c]					
	1	3	5	10	15	20
	Survival Probability [%] in MIPP beam					
Pion	18.01	56.48	70.98	84.25	89.20	91.79
Kaon	0.00	1.43	7.82	27.96	42.75	52.87
	Time of Flight [ns] between TBD and T01 wrt. $\beta = 1$					
Pion	1.22	0.13	0.05	0.01	0.00	0.00
Kaon	14.48	1.69	0.61	0.15	0.07	0.04
Proton	46.67	6.00	2.19	0.55	0.24	0.14

5. Status of data analysis and MIPP upgrade

The MIPP physics run ended in February 2006. The data reconstruction has been developed and some preliminary physics analyses have been started. We expect that final results from the first MIPP data will be available by summer 2007.

The TPC in the MIPP experiment is read out through electronics that limit the DAQ to 30 events per second. With new electronics the TPC can be read out much faster and the DAQ will be able to record data at a rate of ~ 3 kHz. This large improvement in DAQ rate will allow MIPP to collect 5 million events per day with the small amount of beam of 4 seconds of spill per 2 minutes. The TPC electronics upgrade and other related upgrade tasks as well as the physics motivation to do so are described in the MIPP FNAL-P960 proposal [6]. The upgrade was presented to the PAC in October 2006. A decision on the upgrade was deferred until more final results from the existing dataset are published, the collaboration is strengthened, and the

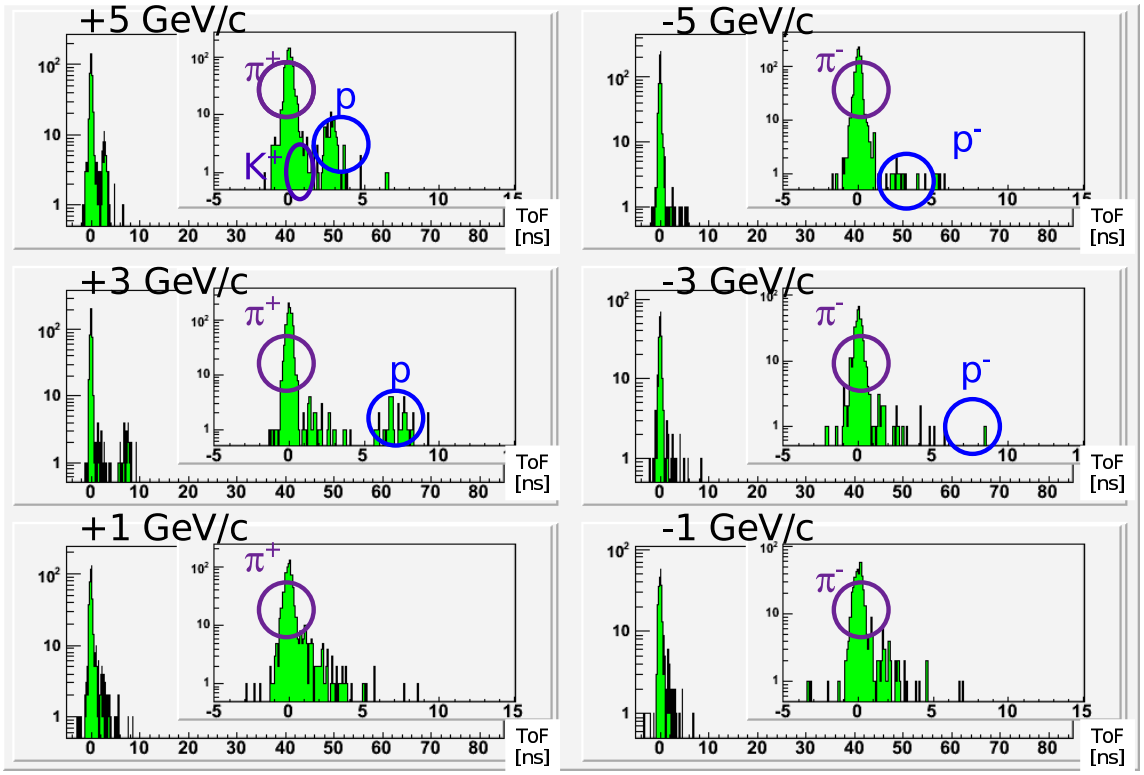

Figure 5. Beam time of flight distribution for six secondary beam momentum settings. The time of flight is shifted so that a $\beta = 1$ particle is at 0 ns. The plots show that particles with beam tof > 10 ns are not observed. The insets show the region near $\beta = 1$. The peaks are marked with the particle types (c.f. table 1)

impact of the new data is quantified in more detail. However, the chips needed for the TPC electronics upgrade and new coils to fix the JGG magnet have been purchased.

References

[1] Information on the MIPP collaboration is linked on the MIPP web pages at http://ppd.fnal.gov/experiments/e907/

[2] Information on the NuMI beam and MINOS experiments is available at http://www-numi.fnal.gov/

[3] Meyer H 2005 Physics of the MIPP Experiment *Nucl, Phys.* B (Proc. Suppl.) **142** 453–8

[4] Raja R 2005 The Main Injector particle production experiment (MIPP) at Fermilab *PNucl.Instrum.Meth.* A**553** 225–30

[5] Rossi B 1952 High-Energy Particles, New York, NY, Prentice Hall.

[6] Akgun U *et. al.* (MIPP upgrade collaboration) 2006 Proposal to upgrade the MIPP experiment, MIPP Note 138, http://ppd.fnal.gov/experiments/e907/notes/MIPPnotes/public/pdf/MIPP0138/MIPP0138.pdf