The Main Injector Particle Production Experiment (MIPP) at Fermilab

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Fermilab

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Outline

• Overview of the Experiment
  – Beam & detector
  – Data reconstruction & analysis

• Physics Motivation
  – QCD
  – Spectroscopy
  – Nuclear physics
  – Service measurements
    • neutrino experiments
    • hadron shower simulation

• MIPP Upgrade
Brief Description of Experiment

- Approved November 2001
- Situated in Meson Center 7, Fermilab Fixed Target
- Uses 120 GeV Main Injector Primary protons to produce secondary beams of $\pi^\pm$, $K^\pm$, $p^\pm$ from 5 GeV/c to 85 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Using a TPC we measure momenta of $\sim$all charged particles produced in the interaction and identify the charged particles in the final state using a combination of dE/dx, ToF, differential Cherenkov and RICH technologies.
- Open Geometry - Lower systematics. TPC gives high statistics.
- First Physics run - 18 million events in Jan 2005 to Feb 2006.
- Detector upgrade for next run – faster readout, much more data
MIPP Secondary Beam

Excellent performance. Successfully ran 5-85 GeV/c secondaries and 120 GeV/c primary protons. Excellent particle ID capabilities using 2 Beam Cherenkovs. Also use ToF for low momenta. 95 meters long.
MIPP
Main Injector Particle Production Experiment (FNAL-E907)
# MIPP Data Set

## Data Summary

**27 February 2006**

<table>
<thead>
<tr>
<th>Target</th>
<th>Element</th>
<th>Trigger Mix</th>
<th>E (x 10^6)</th>
<th>Total</th>
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<td>Be</td>
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<td>C</td>
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<tr>
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<tr>
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<td>0.21 2.73 0.86 5.48 0.50 13.97 0.96 2.04 4.63 31.38</td>
<td></td>
</tr>
</tbody>
</table>
Particle ID Performance

π/K separation

K/p separation

Red: >3 sigma
Green: 2-3 sigma
Blue: 1-2 sigma
White: <1 sigma
Comparing Beam Cherenkov to RICH for +40 GeV/c beam triggers - No additional cuts!

![Graphs showing distribution of RICH ring radii with proton, kaon, and pion triggers.](image)

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MIPP beam at low momentum

- $+5 \text{ GeV/c}$

- $-5 \text{ GeV/c}$

- $+3 \text{ GeV/c}$

- $-3 \text{ GeV/c}$

- $+1 \text{ GeV/c}$

- $-1 \text{ GeV/c}$

Graphs showing time-of-flight (ToF) distributions for different momentum bins, with peaks for $\pi^+$, $\pi^-$, $p$, and $K^0$.
MIPP Reconstruction Status

• Done: (8 months since end of run)
  - Low level calibrations
  - B-field mapping, ExB corrections in TPC
  - Track reconstruction, Hit association
  - Track based detector alignment
  - RICH ring fits
  - Vertexing
  - Full detector Monte Carlo

• Further improvements: (soon)
  - Kalman, refined PID
MIPP Physics Overview

• Particle Physics
  – Non-perturbative QCD hadron dynamics, Particle fragmentation scaling laws
  – Spectroscopy - Missing baryon resonances, ...

• Nuclear physics
  – Y-scaling (Measure cross sections of hadrons on nucleons in the nuclear medium.)
  – Propagation of strangeness through nuclei

• Service measurements
  – Hadron Shower Models in Geant4, MARS,...
  – Neutrino production (NuMI, atmospheric, ν-factory)
  – Proton radiography, stockpile stewardship, national security applications
Missing Baryon Resonances

- Partial wave analyses of $\pi N$ scattering have yielded some of the most reliable information of masses, total widths and $\pi N$ branching fractions. In order to determine couplings to other channels, it is necessary to study inelastics such as

$$\begin{align*}
\pi^- p &\to \eta n \\
\pi^- p &\to \pi^+ \pi^- n \\
\pi^- p &\to K \Lambda \\
\gamma p &\to \pi^0 p \\
\gamma p &\to \pi^+ \pi^- p \\
\gamma p &\to K^+ \Lambda
\end{align*}$$

- All of the known baryon resonances can be described by quark-diquark states. Quark models predict a much richer spectrum. Where are the missing resonances? F. Wilczek, A. Selem

- “..this could form the quantitative foundation for an effective theory of hadrons based on flux tubes”– F. Wilczek
Why non-perturbative QCD?

- It is not understood.
  - >99% of the total QCD cross section is non-perturbative. We cannot calculate these cross sections. Perturbative QCD has made impressive progress. But it relies on structure functions, which are non-perturbative and derived from data.
  - Feynman scaling, KNO scaling, rapidity plateaus are all violated. Regge theory is in fact phenomenology with flexible predictions that can be altered by adding more trajectories.

- Existing data are sparse, low statistics, poor particle id
- MIPP will publish its data set
  - Test your own theory
General Scaling Law of Particle Fragmentation

• States that the ratio of a semi-inclusive cross section to an inclusive cross section

\[
\frac{f_{a+b \rightarrow c+X_{\text{subset}}}}{f_{a+b \rightarrow c+X}} = \frac{f_{\text{subset}}}{f} \frac{M}{M} \frac{s}{s} \frac{t}{t} = \beta_{\text{subset}} \frac{M}{M}
\]

• where \( M^2, s \) and \( t \) are the Mandelstam variables for the missing mass squared, CMS energy squared and the momentum transfer squared between the particles \( a \) and \( c \). PRD18(1978)204.

• Using EHS data, we have tested and verified the law in 12 reactions (DPF92) but only at fixed \( s \).

• MIPP will test this in 36 reactions. MIPP upgrade can extend these scaling relation tests to two particle inclusive reactions which requires more statistics.
Scaling Law tests in MIPP

- 36 reactions (6 beam species on LH$_2$, 6 different particles in final state)
- 15 Crossing symmetry and 3 Charge symmetry relations among these 36 reactions
  - These should have same scaling behavior
- For example:
  - $\pi^+ p \to \pi^+ + X$ and $\pi^- p \to \pi^- + X$
  - $\bar{p} \ p \to \pi^+ + X$ and $\pi^- p \to p + X$

  - Links diffractive process to central production process!
Target Fragmentation Multiplicities

+58 GeV/c Incident Beam

\[ A \text{ vs. } N_{\text{tr}} \]

- \( \pi^+, \text{pos. tracks} \)
- \( \pi^+, \text{neg. tracks} \)
- \( K^+, \text{pos. tracks} \)
- \( K^+, \text{neg. tracks} \)
- \( p^+, \text{pos. tracks} \)
- \( p^+, \text{neg. tracks} \)

Additional markers:
- Triangles: \( p^+ \) in LHC, lower A
- Circles: \( \pi^+ \) in LHC
- Crosses: \( K^+ \) in RHIC

Preliminary
Particle ID on NUMI Target

Pion $p_T$ vs. $p$, Pos. Tracks

Kaon $p_T$ vs. $p$, Pos. Tracks

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Preliminary Comparison of NUMI target to FLUKA predictions

RICH Rings from NUMI target
Summary

• MIPP acquires unbiased high statistics data with complete particle id coverage
  – test a particle fragmentation scaling law and provide data for the study of non-perturbative QCD
  – address a broad range of physics topics
• Results from the first run are expected in next few months
• The upgrade with faster DAQ and other improvements will open up even more interesting opportunities
  – Collaborators welcome!
Backup Slides
Livermore dropped out. Rest still on proposal. 7 new institutions have joined. More in negotiations.
# Beam Survival Probability and ToF

## Beam particle decay and ToF in the MIPP beam line

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<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass [GeV/c²]</th>
<th>Livetime [ns]</th>
<th>Survival Probability [%] in MIPP beam:</th>
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<td>0.73  0.95  0.98  1.00  1.00  1.00</td>
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<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass [GeV/c²]</th>
<th>Livetime [ns]</th>
<th>Time of Flight [ns] between TBD and T01:</th>
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<tr>
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<th>Particle</th>
<th>Mass [GeV/c²]</th>
<th>Livetime [ns]</th>
<th>Time of Flight [ns] between TBD and T01 wrt beta=1:</th>
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