E910, HARP, and E907 Results, Status, and Plans

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NUFACT03
June 9, 2003
Columbia University

• Three Hadroproduction experiments
• All Open Geometry, using TPC’s and good particle ID capabilities. High statistics. What the bubble chamber experiments always wanted but couldn’t in the 70’s and 80’s. Made possible by the “new” technologies of TPC, RICH etc.
• BNL-E910– Recent results
• CERN-HARP- Data taken and status
• Fermilab E907 (MIPP- Main Injector Particle Production)- Status and Plans
Purposes of the experiments

- Particle Physics - To acquire unbiased high statistics data with complete particle id coverage for hadron interactions.
  - Study non-perturbative QCD hadron dynamics, scaling laws of particle production (E910, HARP, MIPP)
  - Investigate light meson spectroscopy (HARP, MIPP)
- Nuclear Physics
  - Investigate strangeness production in nuclei - RHIC connection (E910, MIPP)
  - Nuclear scaling
  - Propagation of flavor through nuclei (MIPP)
- Service Measurements
  - Atmospheric neutrinos - Cross sections of protons and pions on Nitrogen from 5 GeV - 120 GeV (HARP, MIPP)
  - Improve shower models in MARS, Geant4 (E910, HARP, MIPP)
  - Make measurements of production of pions for neutrino factory/muon collider targets (E910, HARP, MIPP)
  - Proton Radiography - Stockpile Stewardship - National Security (MIPP)
  - K2K and MiniBoone target measurements (HARP)
  - MINOS target measurements - pion production measurements to control the near/far systematics (MIPP)
Scaling Law

- Physics behind law is the factorization of 3 body scattering cross section.

- We will be able to test the scaling law for 36 reactions as a function of s and t for various subsets with unprecedented accuracy.

- For each subset, we will be able to test the equality of the branching function for sets of crossed reactions. E.g. \( \pi^- p \rightarrow p + X \) and \( p^- p \rightarrow \pi^- + X \) should have the same set of branching functions \( \beta_{\text{subset}}(M^2) \). One is a diffractive process and the other a central process.
Scaling Law - EHS results
E910 Spectrometer

at the
MPS Facility of the AGS

- MPS Magnet
- EOS TPC
- Downstream tracking:
  - MPS Drift Chambers, Wire Chambers
- PID:
  - TPC dE/dx, TOF, Segmented Cherenkov

- Spring 96 Proton Run at AGS
- Be, Cu, Au, U targets
- 6, 12.5, 18 GeV/c Beam Momenta
- O(15) Million Central and MinBias Triggers
The HARP Detector
MIPP
Main Injector Particle Production Experiment (FNAL-E907)

Horizontal cut plane

TPC
Jolly Green Giant
Cerenkov
Rosie
RICH
EM shower detector
Neutron Calorimeter
### Beam species, momenta and targets - E910

<table>
<thead>
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<th>Beam Target</th>
<th>Total events</th>
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Beam species, momenta and targets - HARP: Solid target program

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<th>Cu</th>
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- ~ 190 settings measured
- Typically 1 - 4 million trigger/setting (depending on target and momentum)
- 100k - 400k (good) proton (pion) interactions for final physics analysis (after selection)
HARP - The cryogenic target programme

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About 80 settings
Typically 0.5 - 4 million trigger/setting
-> about 100k - 200k proton (pion) interactions for final physics analysis after cuts

Targets: 2cm diameter, 6 (18) cm long.
Filling takes 4-6 hours. Emptying takes ~1 hour.
**MIPP secondary beamline**

Table 5 Primary beam rates, secondary beam rates and event yields for a positive secondary beam

<table>
<thead>
<tr>
<th>p GeV/c</th>
<th>Primary p/spill p Hz</th>
<th>K Hz</th>
<th>π Hz</th>
<th>Total Hz</th>
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Table 6 Primary beam rates, secondary beam rates and event yields for a negative secondary beam

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**MIPP secondary beamline**

**Primary Proton Budget**

Table 1 Physics request and proton needs

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<th>Target</th>
<th>Physics</th>
<th>Data Points</th>
<th>Primary proton</th>
<th>Total number</th>
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1 data point = 3 million events.
5,15,25,50,70,90 GeV/c positive and negative momenta
Total number of spills 1330000 Total number of protons 1E16
Number of spills/minute 3
Total time for experiment 308 days No Pi factor
Double slow spill will help considerably.

9-June-2003

Rajendran Raja, NUFACT03, Columbia University
E910 Collaboration

PHYSICAL REVIEW C, VOLUME 65, 024904

Inclusive soft pion production from 12.3 and 17.5 GeV/c protons on Be, Cu, and Au

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Differential cross sections are presented for the inclusive production of charged pions in the momentum range 0.1–1.2 GeV/c in interactions of 12.3 and 17.5 GeV/c protons with Be, Cu, and Au targets. The measurements were made by Experiment 910 at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory. The cross sections are presented as a function of pion total momentum and production polar angle \( \theta \) with respect to the beam.

9-June-2003 Rajendran Raja, NUFAC03, Columbia University
The HARP Collaboration

- 24 Institutes
- 9 countries
- 120 physicists

Università degli Studi e Sezione INFN, Bari, Italy
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Institut für Physik, Universität Dortmund, Germany
Joint Institute for Nuclear Research, JINR Dubna, Russia
Università degli Studi e Sezione INFN, Ferrara, Italy
CERN, Geneva, Switzerland
Section de Physique, Université de Genève, Switzerland
Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
Institut de Physique Nucléaire, UCL, Louvain-la-Neuve, Belgium
Università degli Studi e Sezione INFN, Milano, Italy
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Institute for Nuclear Research, Moscow, Russia
Università "Federico II" e Sezione INFN, Napoli, Italy
Nuclear and Astrophysics Laboratory, University of Oxford, UK
Università degli Studi e Sezione INFN, Padova, Italy
LPNHE, Université de Paris VI et VII, Paris, France
Institute for High Energy Physics, Protvino, Russia
Università "La Sapienza" e Sezione INFN Roma I, Roma, Italy
Università degli Studi e Sezione INFN Roma III, Roma, Italy
Dept. of Physics, University of Sheffield, UK
Faculty of Physics, St Kliment Ohridski University, Sofia, Bulgaria
Institute for Nuclear Research and Nuclear Energy, Academy of Sciences, Sofia, Bulgaria
Università di Trieste e Sezione INFN, Trieste, Italy
Univ. de Valencia, Spain

Also:
- K2K
- MiniBooNE
MIPP collaboration list

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EFI, University of Chicago
R.J. Peterson
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E. Swallow
Elmhurst College and EFI

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G. Feldman, A. Lebedev, S. Seun

Harvard University
P. Hanlet, N. Solomey, C. White

Illinois Institute of Technology
M. Messier

Indiana University
D. Asner, P. D. Barnes, J. Gronberg, E. Hartouni, M. Heffner,
S. Johnson, D. Lange, R. Soltz, D. Wright

Lawrence Livermore Laboratory
H. R. Gustafson, M. Longo, D. Rajaram, H.-K. Park

University of Michigan
A. Bujak, L. Gutay, D. E. Miller

Purdue University
T. Bergfeld, A. Godley, S. R. Mishra, C. Rosenfeld

University of South Carolina
C. Dukes, L. C. Lu, K. Nelson, G. Niculescu

University of Virginia
General problem: little experimental data, large uncertainties in calculations

Hadronic generators

→ Thin and thick targets, scan periodic system
Hadronic Monte Carlos

Little experimental data and large uncertainties in calculations in particular for thick and high z target materials and very low primary energies

→ Thin and thick targets, scan periodic system and momenta

NIM-A 472 (2001) 557-560
E910 TPC particle ID capabilities
**HARP Particle ID coverage**

Example: $\pi$-p separation (4$\sigma$) for 15 GeV/c protons on Be target (MC)
MIPP Particle ID capabilities

K/Proton separation analysis using all systems.

- Red = 3σ or better.
- 3σ < Green < 2σ
- 2σ < Blue < 1σ
- 0σ < White < 1σ
- K/P separation

π/K separation

White boxes or absence of boxes due to low statistics. Not poor particle ID.
HARP Prel. distribution of $P_T$ and $P_L$

All particles, no corrections on cross-talk, momentum-resolution and efficiencies

3GeV/c protons on 100% Ta target, tracks matched by RPC, >9 points
Beam particle selection

- Beam particles are measured by 4 MWPC’s (accuracy <1 mm)
- Particle identification by:
  - Beam Cherenkov, TOF(21 m), Mu-identifier (6.5\(\lambda\))
- Example: Proton selection in the 3 GeV/c beam

![Proton selection: purity > 98.7%](image)

For measurements of total cross section

Provides beam momentum calibration

9-June-2003

Rajendran Raja, NUFACT03, Columbia University
Large Angle region

- **Solenoid**
  - 0.7 Tesla

- **ITC**
  - Scint. fibres
  - around target

- **TPC**
  - R=0.41 m
  - L=1.56 m
  - 4000 pads

- **RPCs**
  - TOF
  - 30 chambers
  - around TPC
Gold

Copper

\[ \frac{d^2\sigma}{dpd\Omega} \text{ [mb/(GeV/c sr)]} \]

\[ p \text{ [GeV/c]} \]

\[ 0, 0.5, 1 \]

\[ 17.5 \text{ GeV/c} \]

\[ 12.3 \text{ GeV/c} \]
E910-protons on Beryllium

- Beryllium
12.3 GeV/c  p Au → $\pi^+$ + X

- E910
- MARS

$d\sigma/d\Omega$, mb/(GeV/c)

Total Momentum, GeV/c

0.0  0.2  0.4  0.6  0.8  1.0  1.2

0  500  1000  1500

0.9–1.0
0.8–0.9
0.7–0.8
0.6–0.7
12.3 GeV/c p Cu → π^+/- + X

Cos(θ) 0.6–1.0

E910 – MARS

\(\frac{d^2\sigma}{dpd\Omega}, \text{mb/(GeV/c)}\)

Total Momentum, GeV/c
$17.5 \text{ GeV/c } p\, \text{Au} \rightarrow \pi^+ + X$

- **E910**
- **MARS**

$d\sigma/d\Omega$, mb/(GeV/c)

Total Momentum, GeV/c
HARP Summary

• HARP was conceived to measure hadron production on different materials, with solid and cryogenic targets, at beam energies of 1.5 - 15 GeV/c
• The experiment was built in 15 months, took data for 2 years, stopped in Nov. 2002 ... and is dismantled now
• The detector worked extremely well and stable (only known major problem: TPC cross-talk)
• 350 M triggers and 30 Tbyte of data recorded
• Detector performance well understood
• Analysis in progress - first physics results in summer (?)
MIPP-Brief Description of Experiment

- Approved November 2001
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of $\pi^\pm K^\pm p^\pm$ from 5 GeV/c to 100 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Using the EOS-TPC (Same as in E910) we measure momenta of ~all charged particles produced in the interaction and identify the charged particles in the final state using a combination of dE/dx, ToF, threshold Cherenkov and RICH technologies.
MIPP Situation at PAC approval (Nov 2001)

• We had cleaned up the previous experiment in MC7 Hyper-CP.
• We had designed and constructed iron struts to support the weight of the magnets Jolly Green Giant and Rosie and installed it in M-Bottom.
• We had installed a 1’ high concrete platform in MC7 to support the magnets.
• We had fixed the Jolly Green Giant coil
Status of MIPP Now-Collision Hall
Status of MIPP Now- Collision Hall
Ziptrack of magnets complete

- We resurrected the Ziptrack system
  - Software recovered by sending out crashed disk to California.
  - Missing Hall probe cart re-made. Measured $B_x$, $B_y$, $B_z$ in a 2” cube grid of points for both JGG and ROSIE over full aperture.
  - Ziptrack now available for CKM and BTeV.
    - JGG $B_y$ component in projections $y=0$, $z=0$ and $x=0$
Installation schedule

- MIPP running time June 2003- Summer Shutdown 2005 (~ two years)
- Experiment will be ready by end of June 2003

<table>
<thead>
<tr>
<th>WBS</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
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<td>5.2.4</td>
<td>Beam Cerenkov</td>
<td>37 days</td>
<td>4/7/03</td>
<td>5/27/03</td>
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<td>5.5</td>
<td>Cerenkov</td>
<td>52 days</td>
<td>3/27/03</td>
<td>6/6/03</td>
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<td>5.7.1</td>
<td>Target Wheel</td>
<td>35 days</td>
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<td>5.8.5</td>
<td>TPC Installation</td>
<td>33 days</td>
<td>4/7/03</td>
<td>5/21/03</td>
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<td>5.1</td>
<td>Time of Flight</td>
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<td>8/28/03</td>
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<td>5.16</td>
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<td>5.15</td>
<td>DAQ</td>
<td>30 days</td>
<td>5/5/03</td>
<td>6/13/03</td>
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- See above chart in detail at http://ppd.fnal.gov/experiments/e907/Project/E907_v2.05_Install.det.pdf
• Alignment of mirrors complete. PMT’s need to be tested, installed and wired up. Completion by end of June 2003
TPC installation

- TPC in the Jolly Green Giant magnet this week. Cabling up will proceed shortly. Will be completed in June 2003
Time of Flight

- Time of flight ($220K) . Univ. S. Carolina responsibility. Scintillator and tubs on order.

5.10 Time-of-Flight (TOF) 99 days 4/14/03 8/28/03
5.10.1 TOF Module Frame Design 10 days 4/14/03 4/25/03
5.10.2 TOF Module Fabrication 4 mons 4/28/03 8/15/03
5.10.3 TOF Module Installation 5 days 8/18/03 8/22/03

5cm x 5cm square scintillator bars in Rosie aperture, 10cm x 10cm outside. ~ 150ps resolution.
Ring Imaging Cherenkov

- Selex RICH - We acquired all phototubes from the Russians - total of ~ 3000 phototubes
- The old electronics, with its Russian chips had a high death rate. Completely redesigned the front end electronics - 5 VME boards and ~100 (32 channel) readout boards. VME boards complete.
- 100 (32 channel boards) manufactured and delivered.
- Ready for beam in June 2003
Calorimeters and Wire Chambers

Hadron Calorimeter schedule

EM calorimeter schedule
We are building a lead sheet- gas tube EM calorimeter. Assembly to be completed in June.

Re-using E690 Drift Chambers. 4 have been refurbished. 3 beam chambers from E690 will also be used. Being installed and cabled up currently. U. Of Iowa large wire chambers being installed and cabled up currently.


Monte Carlo

- Geant3.21 based data driven Geometry. Details can be found at http://ppd.fnal.gov/experiments/e907/MC/e907mc.htm
- Have used it to study acceptances, resolutions and ToF design.
- Work to be done- Digitize wire chambers, Implement calorimeters and beam Cherenkovs.

Offline Software

Monte Carlo Geometry transported to ROOT.
Offline C++, ROOT IO. MIPP has benefited enormously from the ability to use the same geometrical data-base in Monte Carlo and Reconstruction. Result of discussions during ACAT2000 conference held at Fermilab.
Event Display
MIPP Secondary Beam

- MC7 Hyper CP beam line removed. Target pile cleaned up.
- Beamline group of MIPP collaborators and Switchyard 120 personnel. Have examined 4 beam designs (using TRANSPORT, MAD and MARS (calculates showering backgrounds). Have decided on a design. MIPP beamline installation has started and will be complete by end of June- Beginning of July.- Safety Assessment still needs passing.
Mars study of beam

Angle at secondary target

![Graphs showing Beta Function and Dispersion](image-url)
Prompt Dose

Estimated from a simplified model prompt dose after 15’ of soil
= 4 mrem / hr (+− 50%)

Main contribution from scraper 1. Dose will be reduced to be below the radiation area limit (5 mrem/hr) by putting the scraper inside of the target shielding and adding one extra steel plate to the top of shielding.

Expected prompt dose in the Meson Building 20 mrem / hr with 2m of concrete and 0.8m of steel around hot spot (scraper 2).
Conclusions

• MIPP will complete data taking my middle of 2005. MIPP data along with HARP and E910 will add significantly to our understanding of MINBIAS non-perturbative QCD interactions (>99% of cross section)