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Annual Scientific Report 2004–2005

Proton Radiography: Cross Section Measurements and Detector Development (Grant DE-FG03-03NA00077)

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ABSTRACT

Our research grant provides support for a program to measure forward production of neutrons and photons produced by high-energy proton beams striking a variety of targets. This will provide data essential to proton radiography. This work is carried out in conjunction with the Fermilab E-907 (MIPP) collaboration including physicists from Lawrence Livermore Laboratory.

Our group is responsible for the E907 forward neutron/photon calorimeters. We are taking a leading role in obtaining and analyzing the forward production data and in helping to develop an optimal detector for proton radiography. With the support of our Stewardship Science Academic Alliances Grant DE-FG03-03NA00077, we were able to design, build, and commission the calorimeters on budget and ahead of schedule. E-907 officially started physics running at Fermilab in January 2005. We expect to continue data taking through October 2005. The analysis of the data, which we expect will be challenging because data from many different detector systems must be understood and merged, will take several years.

Our group is in a unique position to complete the measurements, analyze the data, and help set up a database to be used by LLNL and LANL to make this information accessible for proton radiography. This work will be done in conjunction with the Livermore Laboratory High Energy Physics and Computational Nuclear Physics Groups.

The project is meeting or exceeding its technical milestones, while remaining within its budget.

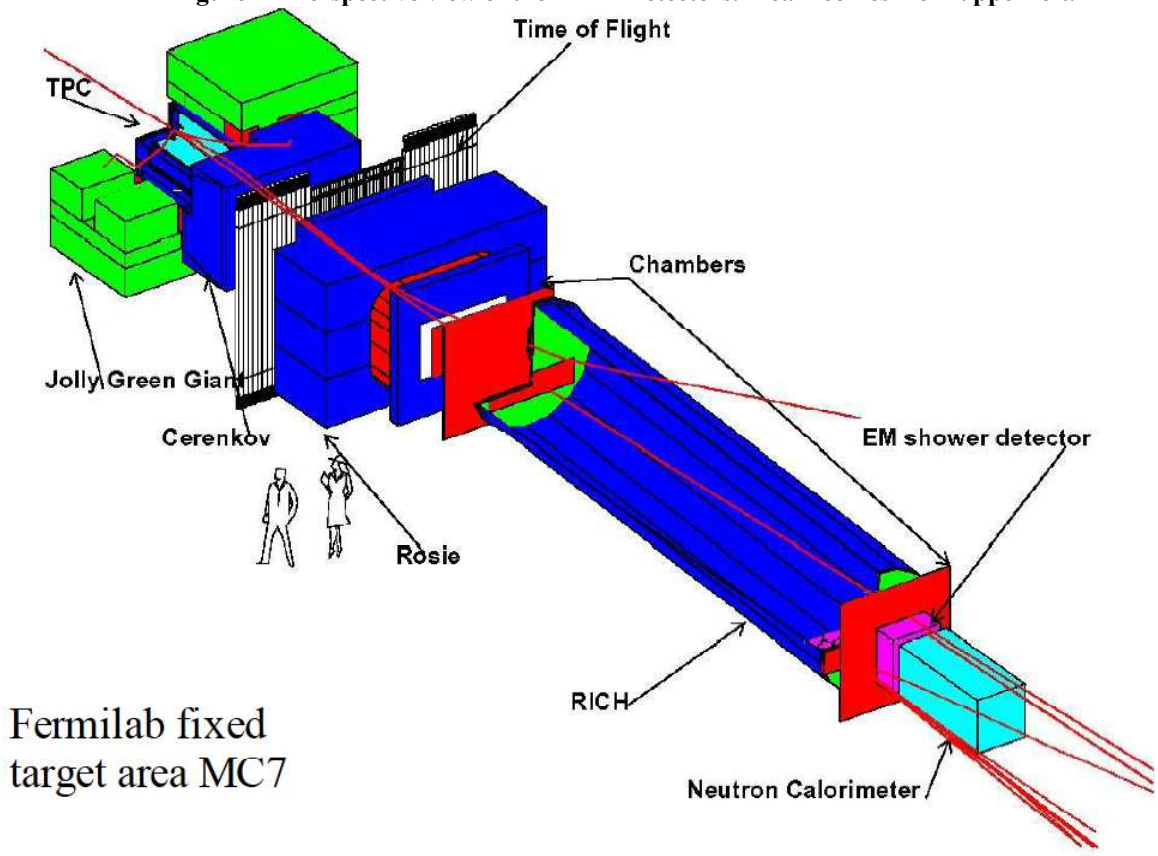
I. Background Information

A perspective layout of the MIPP detectors is shown in Fig. 1 with the beam coming from the upper left. The experiment is set up in the Fermilab Meson Center beam line. Our group has many years of experience with neutron scattering experiments and hadron calorimeters [Refs. 1, 2, 3, 4, 5, 6, 7, 8]. Thus it was natural for the University of Michigan group to take responsibility for the MIPP electromagnetic shower detector (EMCAL) and the hadron calorimeter (HCAL). The purpose of the EMCAL is to detect and measure the angles and energies of forward photons. The HCAL detects neutrons and other hadrons and measures their energies.

Figure 2 shows a side view of the EMCAL and HCAL. The EMCAL uses lead plates interspersed with wire proportional chambers. Photons shower in the lead plates and their energies and locations can be determined by the proportional chambers. Most of the photon energy is contained within the EMCAL. The HCAL consists of 1" thick steel plates interspersed with sheets of plastic scintillator. The light from the plastic scintillators is collected by optical fibers and brought to 8 photomultiplier tubes. The energy of the hadron can be estimated by the total pulse height from the phototubes. Figure 3 shows a plan view of the MIPP detectors with a simulated shower in the EMCAL and HCAL.

Responsibility for the hadron calorimeter is being shared with the University of Virginia group who built the calorimeter originally for the Fermilab HyperCP experiment. Our group has also assumed some of the responsibility for commissioning the large multiwire chambers that are essential for tracking charged particles that enter the EMCAL and HCAL. After considerable effort, these are now working well.

Figure 1 – Perspective view of the MIPP Detectors. Beam comes from upper left.



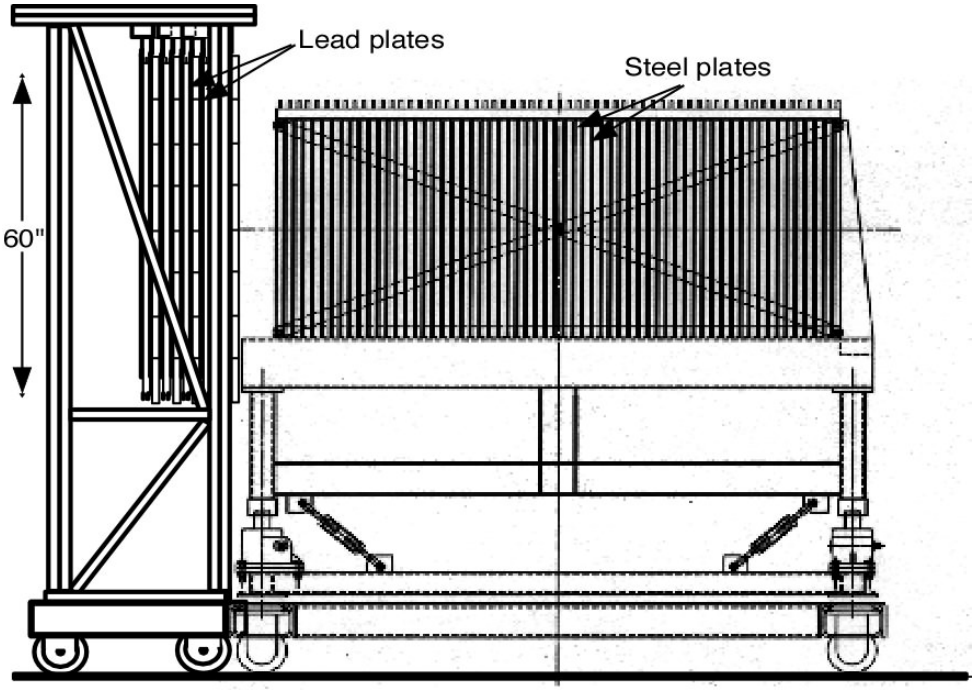


Figure 2 – Side view of the EMCAL and HCAL

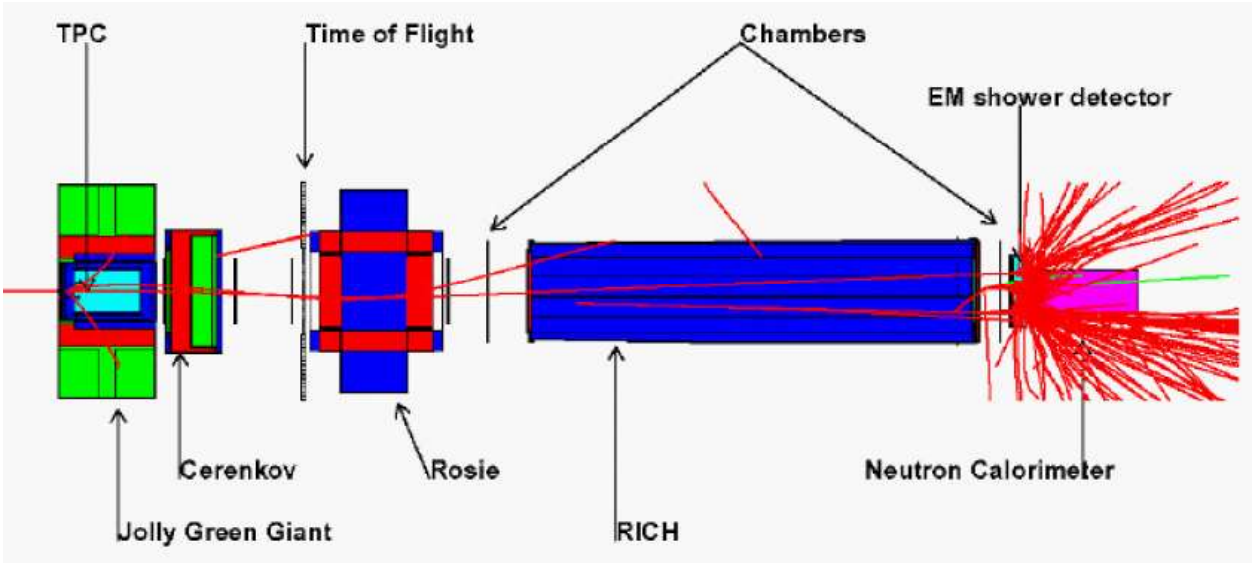


Fig. 3 Schematic plan view of MIPP showing Monte Carlo generated showers in the EMCAL and HCAL

II. Recent Results and Accomplishments

The EMCAL and Time of Flight scintillator array were the only two detector systems that were built specifically for MIPP. The TPC, HCAL, Cerenkov counters, and chambers were all recycled from previous experiments.

The EMCAL was designed by M. Longo. D. Rajaram and H. K. Park, with the assistance of undergraduate students and technicians, assembled 5 vertical and 5 horizontal wire proportional chamber planes onto the lead sheets that make up the EMCAL absorber (Fig. 2). They built the support frame and installed the EMCAL in the Meson Center beam line (Fig. 4).

The EMCAL readout was designed by H. R. Gustafson and debugged by Gustafson and Rajaram. The hadron calorimeter, originally built by the University of Virginia group, was refurbished and installed in the beam line.

Fig. 4 The HCAL and EMCAL in the Meson Center beam line looking upstream, Feb. 2003.

Both the EMCAL and HCAL were ready and in the beam line by February 2003. Some beam was brought to MIPP before the September 2003 shutdown. In February 2004, after the shutdown, commissioning of the beam and detectors was started. Table I shows the data accumulated as of February 28, 2005.

The EMCAL and HCAL performed reliably during this entire period. Some important calibration issues remain for both, especially the EMCAL.

Target	Momentum	Total Events	Target	Momentum	Total Events
Aluminum	-50	35k	Carbon	-50	35k
Aluminum	-30	20k	Carbon	30	81k
Aluminum	30	47k	Carbon	40	10k
			Carbon	50	195k
Beryllium	-50	313k	Copper	-50	22k
Beryllium	30	2k	Copper	-20	22k
Beryllium	50	276k	Copper	15	11k
			Copper	40	17k
Bismuth	-50	684k	Silver	15	3k
Bismuth	-30	214k	Silver	20	5k
Bismuth	30	276k	Silver	30	5k
Bismuth	50	372k	Silver	40	6k
Empty	-50	141k	Empty	40	13k
Empty	-30	50k	Empty	50	190k
Empty	30	83k			

Table I Accumulated MIPP data as of Feb. 28, 2005.

Figures 5, 6, & 7 show event displays for "typical" interactions in the EMCAL and HCAL. Parti-

cles enter from the left. The side view of the EMCAL is shown above. The middle plot shows the top view of the EMCAL and the HCAL, which is read out by only 4 pairs of phototubes. The lower plot shows the energy deposited per layer in the EMCAL and HCAL. Estimates of the total energy deposited in the EMCAL and HCAL are shown.

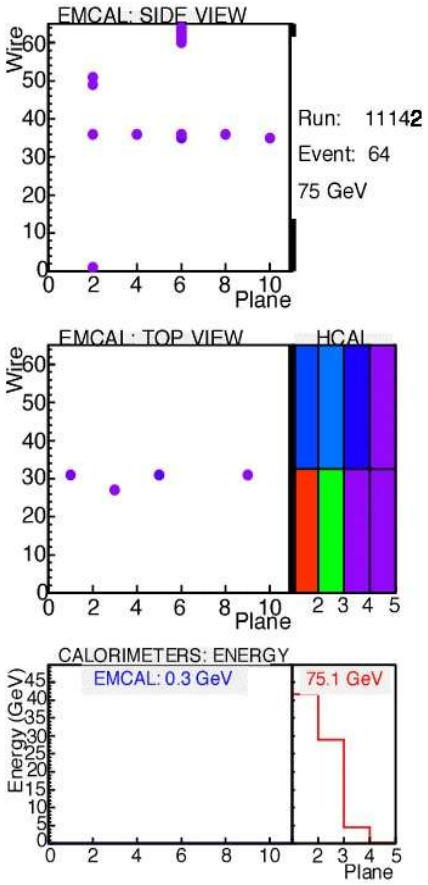


Fig. 5 A high-energy neutron that deposits most of its energy in the HCAL. The leading neutron carries most of the energy of the beam proton.

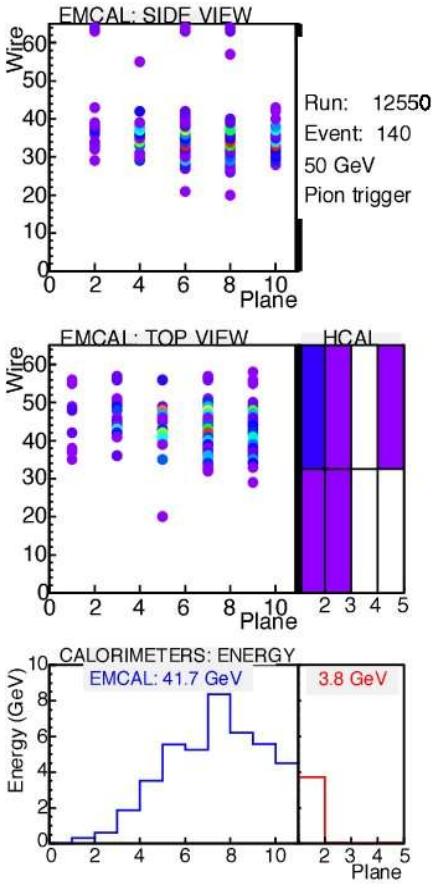


Fig. 6 An electromagnetic shower that leaves most of its energy in the EMCAL. This may be a photon that converts in material upstream.

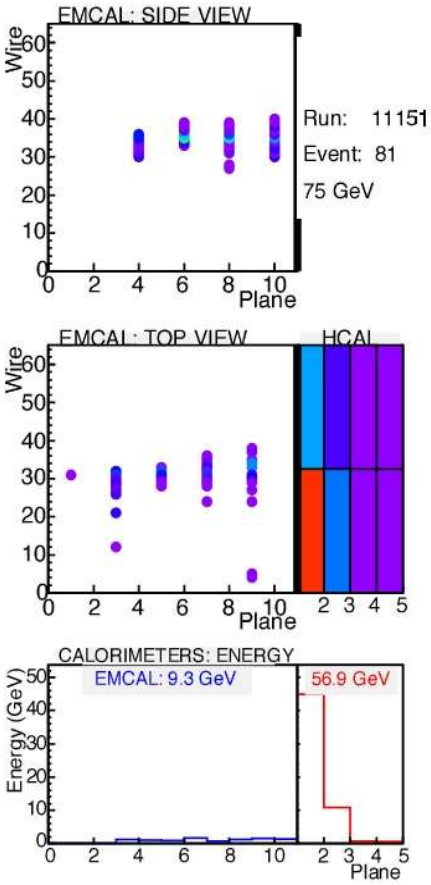


Fig. 7 A shower that starts in the EMCAL but leaves the bulk of its energy in the HCAL.

III. Personnel

The group consists of Principal Investigator Michael J. Longo, Senior Research Scientist H. R. Gustafson, postdoctoral research scientist Durga Rajaram, part-time undergraduate students, and a part-time technician. Rajaram, who resides near Fermilab, has been working full time on MIPP since November, 2002. MJL receives 2 months summer salary from the grant. HRG receives 1 month's salary. Technicians have typically received 2 months salary/year. We have all done our share of data-taking shifts on MIPP. Rajaram, one of the few people working full time on MIPP, has done much more than his share.

Stockpile Stewardship/Proton Radiography Personnel FY 2004

Principal Investigator: Michael J. Longo, University of Michigan

Proton Radiography – Research time spent on this grant				
Type of Position	**Name**	**Research Time on Funded Work**	**# Months funded by this grant**	**Comments**
Faculty	Michael Longo	>>2 month	2	
Res. Scien.	H. R. Gustafson	> 1 month	1	
Postdoc	D. Rajaram	All	12	
Postdoc	H.K. Park	50%	6	
Undergrads			4	
Technician	D. Northacker		2	

IV. Financial Status

Large purchases this year:

Computer and Monitor	$3500

Funds remaining at the end of this reporting period: ~$0

References

1) Neutron Proton Elastic scattering from 1-GeV to 6-GeV. By M.N. Kreisler, F. Martin, M.L. Perl, M.J. Longo, S.T. Powell. Phys. Rev. Lett.16:1217-1220,1966.

2) Neutron Total Cross sections on Protons and Nuclei in the 10 to 30 GeV/c Momentum Range. By L.W. Jones, M.J. Longo, T.P. McCorriston, E.F. Parker, S.T. Powell, M.N. Kreisler. Phys. Lett. B36:509-512,1971.

3) Inclusive Neutron Production. By M.R. Whalley, H.R. Gustafson, K. Heller, L.W. Jones, M.J. Longo, T.J. Roberts. Kyoto 1979, Proceedings, 16th International Cosmic Ray Conference, Vol.6, 34-39.

4) Neutron Nucleus Inelastic Cross Sections from 160-GeV/c to 375-GeV/c. By T.J. Roberts, H.R. Gustafson, L.W. Jones, M.J. Longo, M.R. Whalley, Nucl. Phys. B159:56-66,1979.

5) Inclusive Neutron Production by 400-GeV Protons. By L.W. Jones, M.R. Whalley, H.R. Gustafson, K. Heller, M.J. Longo, T.J. Roberts. Goa Sympos.1979:71.

6) Neutron-Proton Differential Cross Sections at Fermilab Energies. By C.E. DeHaven, Jr., C.A. Ayre, H.R. Gustafson, L.W. Jones, M.J. Longo, P.V. Ramana Murthy, T.J. Roberts, M.R. Whalley . Phys. Rev. Lett. 41:669,1978.

7) Neutron Total Cross Sections on Nuclei at Fermilab Energies. By P.V. Ramana Murthy, Cyril A. Ayre, H. Richard Gustafson, Lawrence W. Jones, Michael J. Longo. Nucl. Phys. B92:269-308, 1975. TOPCITE = 100+

8) A Calorimeter for 300 GeV Neutrons and Protons. By L.W. Jones, J.P. Chanowski, H.R. Gustafson, M.J. Longo, P.L. Skubic, J.L. Stone, Bruce Cork. Nucl. Instrum. Meth. 118:431,1974.