MIPP- (FNAL E907) Main Injector Particle Production Experiment

Rajendran Raja

NuFact02 Presentation

MIPP

Main Injector Particle Production Experiment (FNAL-E907)



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A Brief history of MIPP

- Started as a proposal in the 1997 Workshop on Fixed target physics at the Main Injector. Presented an EOI in July 1997
- Submitted 1st proposal in April 1998- received sufficient • encouragement from PAC to acquire the Bevalac EOS-TPC from BNL after its use in E910
- PAC asked for a new proposal in July 1999 which resulted in a • more detailed proposal in June 2000. Deferred in November 2000 and put into an R&D phase.
- R&D phase Cleaned out Hyper-CP, fixed magnet coil, designed • and build magnet support structure, DAQ+TPC cosmic ray tests.
- Approved November 2001

Format of the Talk

- Review Quality of existing data
- **Review the Physics**
 - Physics motivated measurements
 - Scaling Law tests •
 - Relativistic Heavy Ion Physics
 - Nuclear Scaling
 - Search for exotic resonances •
 - Service measurements **>>**
 - Inclusive Cross sections for simulations –Geant4, Mars, Atmospheric neutrinos
 - Neutrino Factory/ Muon Collider target measurements
 - MINOS target measurements
- Review Progress made in the last year
 - TPC, DAQ, Magnets, Chambers, RICH, Monte » Carlo, Calorimeter, Beam, experimental hall
- Cost of experiment and Funding Issues
- Running time required

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Quality of existing data

- Single arm spectrometers have inherently more systematics than open geometry apparatus such as MIPP. This is because they must change geometry of the single arm frequently and make assumptions in calculating acceptances.
- Also single arm spectrometer data are sparse and for discrete p_t bins. The running time is adjusted to give a certain number of particles in the apparatus for that setting.
- Open geometry experiments (MIPP, HARP,E910 at BNL) sample the phase space uniformly and continuously. They can separate primary pion spectra from pions induced by the decay of kaons etc. They necessarily need a slow spill mode of operation.
- Last open geometry experiment at these beam energies with particle id capabilities was the EHS. Bubble chamber instead of TPC. 3 years to scan and analyze 1 million events. We can do this in less than two days. The HARP experiment is taking data currently but will only go up to ~15 GeV energies. No kaon and antiproton beams contemplated in HARP. MIPP will do 6 beam species (π[±],K [±],p [±]) over the energy range ~5 GeV to 120 GeV.

Purposes of the experiment

- To measure the identities and momenta of particles produced in $\pi^{\pm,}K^{\pm},p^{\pm}$ interactions on various nuclear targets and hydrogen as a function of beam energy from ~5 GeV/c-120 GeV/c with high statistics and make these events public in 4 vector form on mass media such as DVD's. This will be "Fermilab data set".This will enable the user (theorist or experimentalist) easy access to data and help spawn new approaches to understanding these non-perturbative phenomena.
- Physics Topics
 - » Study hadronic fragmentation in particular, test a scaling law of particle fragmentation
 - » Search for exotic resonance such as glueballs
 - » Relativistic heavy ion physics
 - » Medium energy Nuclear physics- Nuclear scaling
- Service measurements
 - Atmospheric neutrinos cross sections of pions and protons on nitrogen and oxygen in the 5 GeV/c-120 GeV/c momentum range
 - » Measure particle spectra with 120 GeV/c protons on the NUMI target on a timescale commensurate with MINOS needs.
 - » Neutrino factory/Muon Collider target measurements
 - Indirect benefit for collider experiments by helping with Geant cross sections. Will help the GEANT4 project enormously to have measured cross sections rather than approximate models if a precision tool is to be built.

General scaling law of particle fragmentation

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

 $\frac{f(a+b\rightarrow c+X_{subset})}{f(a+b\rightarrow c+X)} \equiv \frac{f_{subset}(M^2,s,t)}{f(M^2,s,t)} = \beta_{subset}(M^2)$

- where M²,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.
- The proposed experiment will test the law as a function of s and t for various particle types a ,b and c for beam energies between ~5 GeV/c and 120 GeV/c to unprecedented statistical and systematic accuracy.

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 π⁻p—>p+X and p⁻p —> π⁺ + X should have the same set of branching functions β_{subset}(M²)! One is a diffractive process and the other a central process.

Ph.D thesis topics from MIPP

- Relativistic Heavy Ion physics
 - » antiproton production
 - » resonance production (Δ , N^{*}, ρ , ω)
 - » forward pion production and nuclear stopping
 - » strangeness production
 - » soft pion production
- Scaling law tests
 - » 6 beams species can produce 6 different topics each with 6 different inclusive final states
- Nuclear Scaling
 - » Demonstration of y scaling
 - » Extraction of in-medium hadron-nucleus cross sections
 - » Exploring the physics for y>0
 - » Analyzing the large loss inclusive spectra for N* excitations in nuclei
- Glueball searches and hadron dynamics
 - » Looking for exotic final states in an open geometry experiment with full particle id
 - » Revisit Regge theory with much improved statistics and systematics
- Passage of particles of tagged flavor through nuclear matter. Kaons and antiprotons
- In short, MIPP is rich in thesis topics and will provide graduate students training in hardware, software and analysis, since the timescale to do the experiment is once again commensurate with thesis time scale.
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Service Measurements

- MINOS needs- The hadro-production spectrum on a MINOS target can be measured with the Main Injector Beam that closely matches the beam emittance used in NUMI. MINOS will not build a hadronic hose that would have emeliorated their far/near flux ratio uncertainties. Hadroproduction measurements such as the ones MIPP can provide are crucial.
- Neutrino Factory/ Muon Collider target measurements. Measurements of pion and proton cross sections on targets suited to neutrino factory/muon collider needs are necessary to estimate yields of muons accurately. HARP experiment at CERN will do the low energy part of these measurements. But if a proton source such as BNL AGS or the Japanese JHF is used, MIPP data will be of relevance. Biggest uncertainty in BNL Study II muon fluxes for the neutrino factory is due to pion production.
- Atmospheric Neutrinos- Atmospheric Cosmic ray shower models (some of them one dimensional!) use Beryllium cross sections to extrapolate to Nitrogen and Oxygen. HARP will cover the low energy part of these measurements. MIPP will cover the complete range in energy ~5 GeV to 100 GeV.

Minos measurements

- MIPP has MINOS collaborators-J.Hylen,A.Para(FNAL), G.Feldman,A.Lebedev,M.Messier,S.Seun(Harvard),P.D.BarnesJ r.,E.Hartouni,D.Wright,(Livermore), T.Bergfeld,A.Godley,S.R.Mishra,C.Rosenfeld(South Carolina)...
- Existing data vs Near and Far detector pion contribution for MINOS (Courtesv- M.Messier)



Low Energy Beam

Minos measurements



Near detector spectra- Hadronic uncertainties Contribute 15-20% to absolute rate uncertainty



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Experimental Hall- MC7

- We have paid to clean out Hyper CP experiment.
- M-bottom has to be shored up to support magnets (Complete)
- Concrete Slab (1ft high) in MC7 to spread load of magnets.



EOS-TPC

- This Time Projection Chamber, built by the BEVALAC group at LBL for heavy ion studies currently sits in the E-910 particle production experiment at BNL, that has completed data taking. It took approximately \$3million to construct.
- Can handle high multiplicity events. Dead time 16 microseconds.
- Electronic equivalent of bubble chamber, high acceptance, with dE/dx capabilities. Time to drift across chamber is 16µs. I.e unreacted beam swept out in 8µs. Can tolerate 10⁵ particles per second going through it.
- Can handle data taking rate ~60Hz with current electronics. Can increase this to 100 Hz with an upgrade.
- TPC dimensions of 96 x 75 x 150 cm.
- TPC is sitting in M-TEST clean room built for it by FNAL. Being tested currently with cosmics.
- Successful Cosmic tests
 - » (x) establish slow (bitbus) communication to TPC F.End
 - » (x) read out pedestal data over fiber optic cable
 - » (x)collect ADC pulser data with hardware trigger
 - » (x)read out cosmic ray data









TPC status

- Clean Room Constructed.
- Prior to approval





- Gas system installed. Flowed P5 first and switched to P10 after passing safety review.
- System cabled up. Low voltage supplies checked
- TPC front-end electronics ("Sticks") talking to DAQ
- Cosmic Ray tests performed

Cosmic Ray Test Results



- The vertical axis is drift time bucket; -80 is the bottom of the chamber. The horizontal axis on the right is 60 pads extending half way across the chamber. The horizontal axis on the left is 64 pad rows; -30 is the center of the chamber; +30 is the downstream end.
- Some noisy sticks and pads have been masked off.
- The chamber has been moved to MC7- the experimental area.

Data Acquisition System

• The Data Acquisition system is being redesigned with the help of Fermilab Computing Division (M.Votava,D.Slimmer and L.Piccoli,D.Berg) MIPP Members (M.Heffner, D.Asner ,R.Soltz,B.Cole) working on this. Both sides benefit. Linux based.

E907 DAQ Plan B



- Currently able to download data via the slow path to TPC and also to read out TPC front end electronics via optical fibers (pulser data with hardware trigger).DAQ expected to work at 6 Megabytes/second bandwidth. Being developed extensively.
- More details in
 - » http://ppd.fnal.gov/experiments/e907/TPC/DAQ/e907daq.html

Livermore ICO (Integrated Contractor Order)

- Lawrence Livermore National Laboratory issued an ICO (Integrated Contractor Order) for \$228,629. This was used by Fermilab to do the following, before the experiment was approved.
- Fix Jolly Green Giant Coil
- Clean out Hyper CP experiment
- Engineer Support Structure for Shoring Up M-Bottom to support the magnets (Jolly Green Giant and Rosy)
- Build and Install Support Structure in M-Bottom.
- Build 1ft high concrete slab to support magnets.

Magnets and chambers

- We need two magnets. One with high aperture to measure the target fragmentation particles. The other to measure the forward high momentum particles.
- We propose to use the Jolly Green Giant magnet for the target fragmentation region. It has enough aperture (262x124x221 cm)to accommodate the TPC. 7 KG field.
- For the forward magnet we propose to use the ROSIE magnet from DONUT.
- One of Jolly Green Giant's magnet coil had a short in it. We have fixed the short (\$91,280=\$69,000+engineering support) using the ICO

Jolly Green Giant Magnet Coil fixed

- We have shipped out a faulty coil in the Jolly Green Giant magnet to California. Coil needed to be "Unwound, bad conductor excised, re-insulated, rewound and re-potted'.
- Coil has passed "Ring test".







M-Bottom Shoring work

» details at

http://ppd.fnal.gov/experiments/e907/MC7Enclosure/MC7_Enclosur e.html





Experimental Hall -MC7



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Monte Carlo

- We have a fully functional Geant based MC. Based on D0 Run I RCP based data-driven geometry.
- Used for geometry optimization and TOF studies. More details in
 - » http://ppd.fnal.gov/experiments/e907/MC/e907mc.htm



MIPP Main Injector Particle Production Experiment (FNAL-E907)

Monte Carlo Studies to Optimize detector





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ToF system

- ToF system is being designed and built by University of South Carolina (T.Bergfeld, A.Godley, S.Mishra, C.Rosenfeld). ~88 counters with 200ps resolution available from CLEO. These are good for the engineering run. Scintillator with better resolution can be purchased in FY03 to enhanced the detector. Details to be found in
 - » http://ppd.fnal.gov/experiments/e907/TOF/TOF.html



Polishing TOF Bars

Compare light transmission through bars from blue LED at center of far end





Rajen

FNAL polished

Diamond mill polish by Saint Cobain (BICRON)

RICH

- Refurbishing Selex RICH. Had Russian engineer (who helped build this for SELEX) visit FNAL for 1 month.
- Debugged Phototubes and front-end electronics (need to replace hybrid chips or rebuild piggybacking on CKM)
- Problems were easy to fix
- New front end electronics being designed
- More details at
 - » http://ppd.fnal.gov/experiments/e907/Rich/Rich.html









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RICH Electronics Summary

- Layout of VME readout controller card complete. PO for 5 (4+spare) will be written this week. This is a MIPP-specific board.
- Layout of front end boards will be completed in ~1 week. This board is MIPP-specific, but has many circuits in common between CKM and BTeV
- PowerPC test stand setup at Harvard. Will be used for DAQ development and production testing of front end boards
- First production testing should start in September

Chambers

- E690 chambers (6 of them) extracted from storage. All tested OK for HV with N2 flowing. Gas system designed and passed safety walkthrough. Being refurbished in Lab6. 2 Iowa drift chambers being used.
- A. Bujak, L. Gutay
- Readout needs minor redesign. More chambers available from KTEV, if needed.



E690 Cerenkov

- All pieces in hand. Needs assembly. Details in
 - » http://ppd.fnal.gov/experiments/e907/Cerenkov/Cerenkov.html
 - S F Hartouni D Asner D Wright D I ange

Cherenkov Detector Gas threshold Cherenkov counter Particle thresholds (Freon114): 2.6 GeV/c π 9.0 GeV/c K 17 GeV/c p

96 mirrors/PMTs

Used in E766, E690, E910, E852





Calorimeter

• Hyper-CP calorimeter being recycled. (H.Gustafson,M.Longo)





Offline Software

- Offline software effort just getting underway
- TPC reconstruction code from E910 in hand- C++ based
- Framework will be largely *C*++ based to match existing TPC code
- ROOT I/O selected for data format
- First pass to write/read/reconstruct MC events using framework underway. Will focus on TPC as test case.

Particle Identification

- TPC as shown can provide 3σ separation with dE/ dx up to 0.7 GeV/c for π/K and 1.1 GeV/c for K/p as well as ambiguous additional information in the relativistic rise region.
- TOF system will cover the region between 1GeV and 2.5 GeV.
- In the intermediate region, we propose to use the Cerenkov detector of E690 (E766) currently at BNL E-910. Light is collected by 96 phototubes from reflective mirrors. Filled with Freon 114, the Cerenkov thresholds for π, K, p are 2.5, 7.5 and 17.5 GeV/c.
- Above 7.5 GeV/c, many particles will go through to the RICH counter and be identified. We plan to use a RICH counter of the type used by the SELEX experiment. At SELEX, counter was filled with Neon at 1.05 Atm.

•	Threshold	Ne	N_2	CO_2
•	π	12	5.7	4.9
•	Κ	42	20	17
•	р	80	38	33

Global particle id analysis

 π/K separation analysis using all systems.

- Red = 3σ or better.
- $3\sigma < \text{Green} < 2\sigma$
- $2\sigma < Blue < 1\sigma$





Global particle id analysis

K/Proton separation analysis using all systems.

- Red = 3σ or better.
- $3\sigma < \text{Green} < 2\sigma$
- $2\sigma < Blue < 1\sigma$





Costs and Funding sources

- MIPP needs to find \$454,154 in FY02 and \$496,550 in FY03 for a total of \$950,704, under the above spending scheme. Lawrence Livermore Lab alone will put in \$500,000 each in FY02 and FY03. So if no extra sources of fundings are found, we will be completely setup in ~January 03. If we can get additional funds earlier, we can be ready earlier.
- After we get scientific approval, we plan to explore the following sources of funds.
 - » South Carolina EPSCORE program and South Carolina Commission of Higher education.
 - » NSF support (U.of Houston)
 - » DoE Nuclear Physics (Houston, Columbia and Colorado)
 - » DoE Stockpile Stewardship program for academics. Typical grants are of the order of ~\$500,000.
- We can be ready for an engineering run FY02 Summer, even if no extra funding is obtained by then. The RICH electronics upgrade, extra drift chambers beyond the E690 chambers will have to be put off till FY03. We will make the RICH work with present electronics for the engineering run under this scenario. We are, however, confident of obtaining extra funds, once approved. This can be followed by a Physics run in FY02 and the detector completed (more ToF, recoil detector installed, RICH tubes paid off, electronics upgraded, chambers upgraded) by Jan 03.

Beam line requirements and rates

- E907 beam is part of Switch Yard 120. Chuck Brown in charge. Beam design nearly complete (C.Brown, E.Hartouni, T.Kobilarcik).
- The secondary beam will be tagged with two threshold Cerenkov counters. The three beam species of π,K and p can be tagged by demanding 1)that π's radiate in the first counter and K's do not, 2) π's and K's radiate in counter 2 and p's do not.
- Assume 60Hz data taking for TPC
- 1% target for protons
- 10⁵ particles per spill
- One spill every 3 seconds
- 1 Year = 10^7 seconds
- Total number of interactions to tape = 3×10^{6} , a million for each particle type of beam. This will take 126 hours of elapsed time.
- For most of the positive beam running, we need primary proton intensities of 10⁸ – 10⁹ particles per spill. This is ~ 10⁻⁴ – 10⁻³ of a booster batch of 5x10¹² protons!

New Double Slow Spill Scheme

- The pure pbar cycle, where one booster batch is sent to anti-proton takes 1.467 seconds and results in 2455 shots to Pbar per hour.
- In the old "Single Slow spill" scheme, one would send a booster batch to pbar at the beginning of the slow spill and use the remaining booster batches for slow resonant extraction to Meson. This results in 1200 pbar shots per hour, reducing pbar luminosity by a factor of 2. This would give 1200 seconds of Slow spill per hour to Meson. Unacceptable!
- Single Booster batch = 5E12 protons. E-907 wants 10⁸ to 10⁹ protons most of the time. Increases to 10¹¹ when running negatives.
- E-907 has proposed a new slow spill scheme "Double Slow Spill" that provides two booster batches to anti-proton production in a period of ~ 3secs. We inject two booster batches. At the beginning of the flat-top, we give one batch to pbar and extract ~5-10% of the second batch to Meson. We then go off resonance. We have shown with simulation and actual measurement that the emittance of the batch returns to normal when we switch off the resonance circuits. We then give this batch to pbar. Details in FNAL-TM-2131.

New Double Slow Spill Scheme-Simulation results

• Ramp Structure

Emittance Before resonance





- Emittance at resonance
- •



Emittance after resonance switched off.



Beam line requirements and rates

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- Total number of interactions to tape = 3×10^{6} , a million for each particle type of beam. This will take 126 hours of elapsed time.

Total amount of running time

- 1 data point = $3x10^6$ events takes 126 hours elapsed time with 1 sec flat-top every 3 secs.
- 26 data points will take 4.4 months with the rates in the proposal.
- With the new Double slow spill (Scheme #11, 1 pure pbar cycle alternating with one double spill), this time increases to 6.0 months.

Target	Physics	Beam	Beam	Factor(3 million	data
		Energies	Charges	events/data point)	points
Cu	Engineering run	3	2	0.5	3.0
H2	scaling	12	2	1.0	6.0
N2	atm. Neutrinos	3	2	0.5	3.0
O2	atm. neutrinos	3	2	0.5	3.0
Be	p-A	1	1	2.0	2.0
Be	survey	5	2	0.1	1.0
С	survey	5	2	0.1	1.0
Cu	p-A	1	1	2.0	2.0
Cu	survey	5	2	0.1	1.0
Pb	p-A	1	1	2.0	2.0
Pb	survey	5	2	0.1	1.0
Various	Nucl. Scaling	5	2	0.1	1.0
Total					26.0

A MINOS target run after this will require 3.3 data points (10⁷) events and is expected to take ~400 hrs. (2003-2004 time frame)

MINOS fast spill and MIPP running

- When MINOS starts running (Early 2005), they will use a scheme whereby one booster batch gets sent to pbar and the remaining 5 booster batches get sent to MINOS in a fast spill. This spill has a cycle time of 1.87 sec. MINOS running alone will reduce the pbar- rate by by 21.6%.
- Running a slow spill concurrently with MINOS will impact MINOS luminosity. MINOS running and MIPP running are incompatible.
- MIPP should be completed before MINOS turns on.

Conclusions

- We have proposed a low cost, high statistics, low systematics experiment to measure particle production on various targets with various beam momenta and types.
- The particle identification, rate, energy range and beam species capabilities of MIPP are unmatched by its competitors.
- We have made considerable progress in getting the experiment on the floor during the last year of R&D.
- The time window appropriate for the mounting and completion of MIPP would be 2002-2004.
- The measurements made would benefit our understanding of particle production dynamics in minimum bias interactions (99% of cross section), and in nuclear interactions.
- The measurements would also benefit the study of atmospheric neutrino interactions, Muon Collider/Neutrino factory target choices and also the MINOS/JHF experiments.
- The experimental team of proponents has had considerable experience in hadro-production experiments.
- In addition to the hardware, large portions of software can be inherited from previous experiments (E-910 and SELEX) and reused.

•

New Double Slow Spill Scheme-Main Injector Measurements



Emittance Before resonance

• Emittance at resonance

Emittance after resonance switched off.





Quality of existing data



• Invariant π cross section in p Be interactions as a function of Feynman x at $p_t=0$ GeV/c



• Invariant π + cross section in p Be interactions as a function of Feynman x at $p_t=0$ Gev/c



• Invariant π^+ cross section in p Be interactions as a function of Feynman x at $p_t=0.5$ GeV/c



• Invariant π + cross section in p Be interactions as a function of pion transverse mass. More fitting going on.

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Scaling Law-EHS results



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Scaling law -EHS results



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Layout of RICH electronics





Nuclear Physics Measurements

 y scaling. y may be thought of as the component of the struck nucleon's momentum along the direction of the momentum transfer. The scaling function is independent of q² and represents the nuclear momentum distribution This is verified in ep scattering. We want to extend this to hadron nucleus scattering. It has been tested at KEK with low energy hadron beams (E352). MIPP provides the ideal apparatus, without modification, to extend this beyond the resonance region.



FIG. 2. Scaling function F(y) for Fe. The Q^2 values are given for Bjorken x = 1.

Relativistic Heavy Ion Physics Case (MIPP)



• Extrapolations from BNL E910 purport to explain strangeness enhancement seen at CERN SPS.





Relativistic Heavy Ion Physics Case (MIPP)

- Calibrate CERN strangeness results (1 of 2 results most often cited as QGP evidence)
- Test specific models for strangeness production e.g ``baryon junction model''
- Measure soft physics multiplicity scaling for RHIC
- Repeat other E910 results in SPS energy range
 - » antiproton production
 - » resonance production (Δ , N^{*,} ρ , ω)
 - » forward pion production and nuclear stopping
 - » strangeness production
- pA is essential to understand nuclear medium and multiple collision effects
- The AGS, SPS and Tevatron have all run pA programs relevant to AA
- pA has always been part of RHIC program (whitepaper)
- pA (dA) stated by BNL PAC as highest priority for RHIC after completion of current AA and spin programs
- pA is best studied with complete coverage (shown by E910)
 - » full acceptance particle id
 - » require nuclear fragmentation to estimate mean nucleon-nucleon scatterings

MIPP DAQ status

- The MIPP Daq uses standard FNAL supported tools
 - » r2dm event builder
 - » Merlin error logger
 - » control room logbook
 - » run control product (under construction)

Successful tests

- » ppc linux kernel booted
- » linux latency tests performed
- » r2dm event builder ported from VxWorks to linux and tested
- » camac readout tested for Cerenkov Counter example

• Future

- » full test event chain from camac to archival storage scheduled for early fall
- » TPC readout port from VxWorks to linux
- » addition of other detectors