Particle Production Measurements at Fermilab

Dr. Nickolas Solomey

for MIPP, Fermilab

TEV-II Astroparticle Physics Conference

Univ. of Wisconsin, Madison 28-31 Aug., 2006

Particle Production Measurements:

We are studying incident particle of different species interacting with various target elements producing different hadronic flavor particles over a range of momentum. Cross section measurements will be reported for various channels, elastic and total cross section measurements.

$$d^2\sigma/dpd\Omega = N_{pot}^{-1} (A/N_a \rho t)(\Delta N_{part}/\Delta p \Delta\theta_x \Delta\theta_y) G(\theta_x \theta_y) M_i \varepsilon^{-1}$$

where:

N_{pot} is the number of incident particles on target

$(A/N_a \rho t)$ is the target-beam area, number nuclei, density and thickness

$(\Delta N_{part}/\Delta p \Delta\theta_x \Delta\theta_y)$ are the produced particles in reconstructed bins

$G(\theta_x \theta_y)$ Geometric acceptance for experiment

M_i correction for detector element resolution

ε^{-1} efficiency corrections (trigger and detector elements)

The MIPP Experiment Physics goals:

- Particle Physics-To acquire unbiased high statistics data with complete particle id coverage for hadron interactions.
  - Elastic, inelastic and total cross section measurements
  - Study non-perturbative QCD hadron dynamics, scaling laws of particle production
  - Investigate light meson spectroscopy and glueballs
- Nuclear Physics
  - Multiplicity production dependence on momentum, projective species and nuclei.
  - Investigate strangeness production in nuclei, has a RHIC connection.
  - Nuclear scaling
  - Propagation of flavour through nuclei
- Service Measurements
  - Improve shower models in Simulators: MARS, Geant4 ...
  - Proton Radiography– Stockpile Stewardship- National Security
  - MINOS target measurements – pion/kaon production measurements to control the near/far systematics

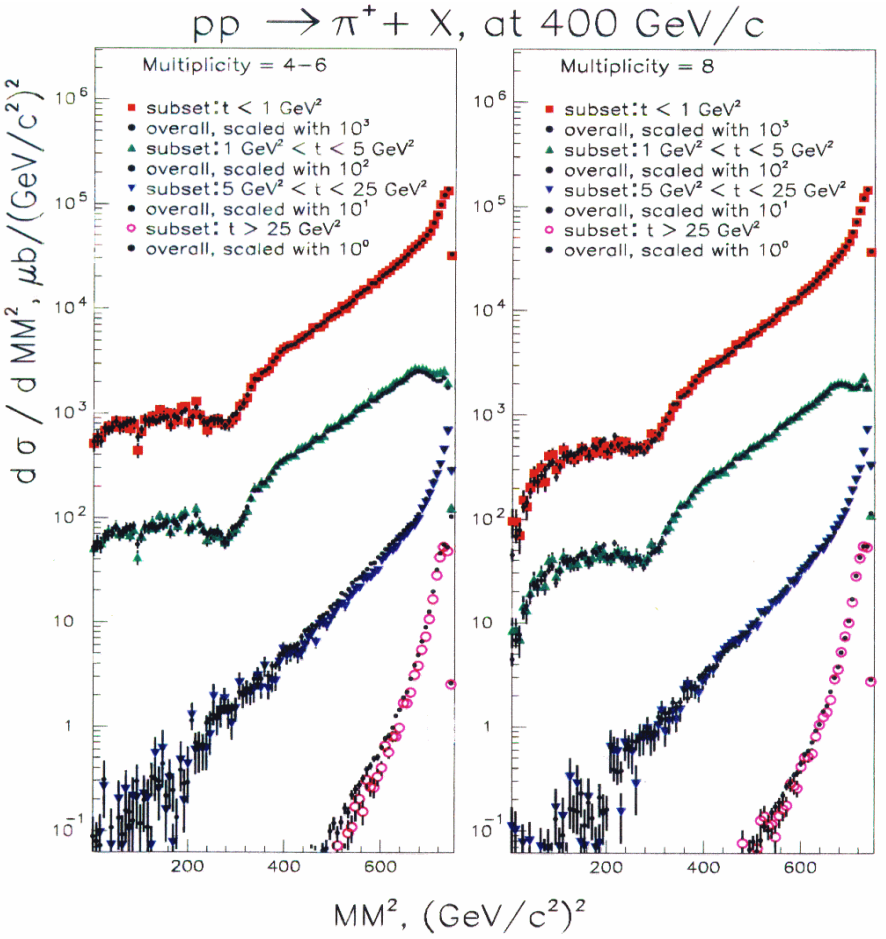
QCD Physics:

Fragmentation Scaling Law Tests: Ratio of a semi-inclusive to inclusive cross section

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

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, PRD v18, p204.

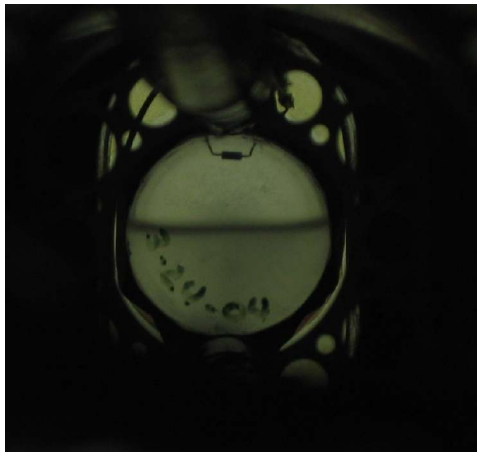
Data from the European Hadron Spectrometer experiment shows this, but needs further confirmation.



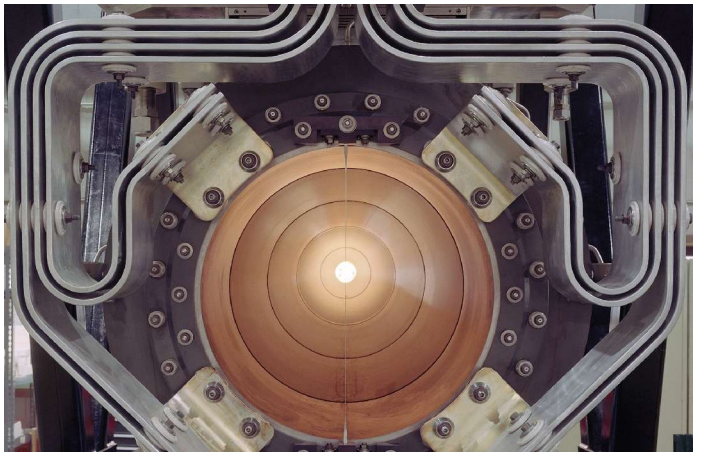
Current Experiment:

The current data from the Fermilab MIPP experiment is being used to study hadronic flavor production:

- which covers the higher momentum range from 5 to 120 GeV/c
- using beams of pions, kaons and protons both positive and negative and we have a major sample of anti-protons.
- targets studied were: Liquid-Hydrogen, Be, C, Cu, Ar, Bi and U
- special study of NuMI target for the MINOS experiment
- took 18 million events from Jan. 2005 to March 2006.

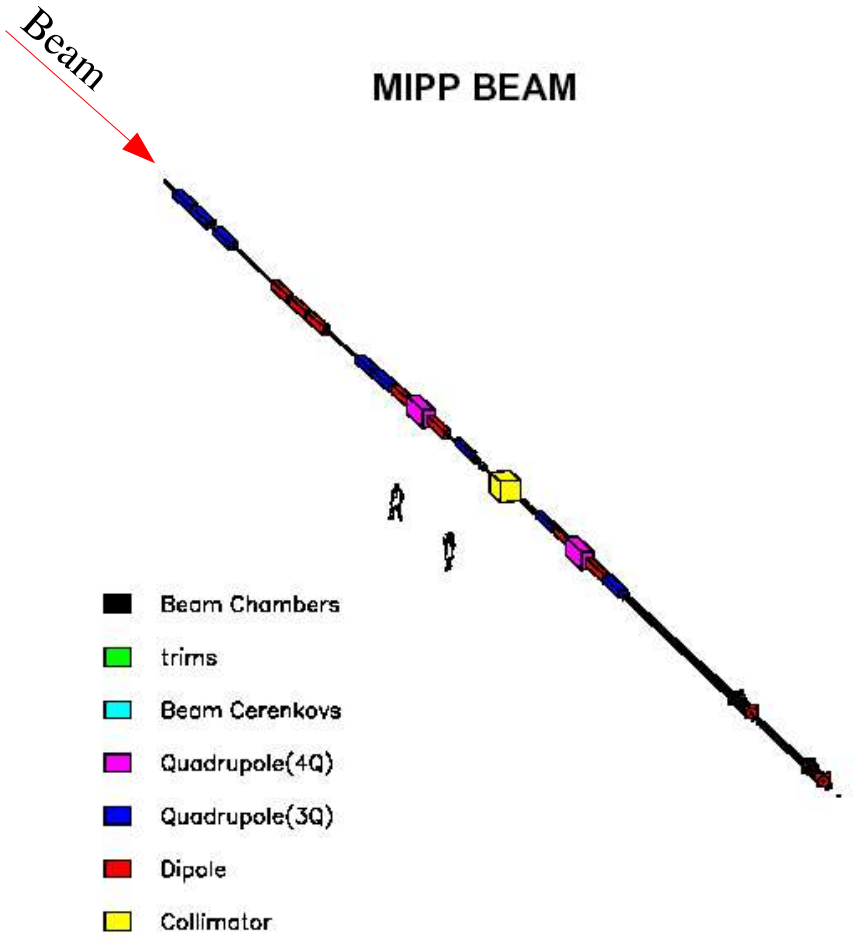


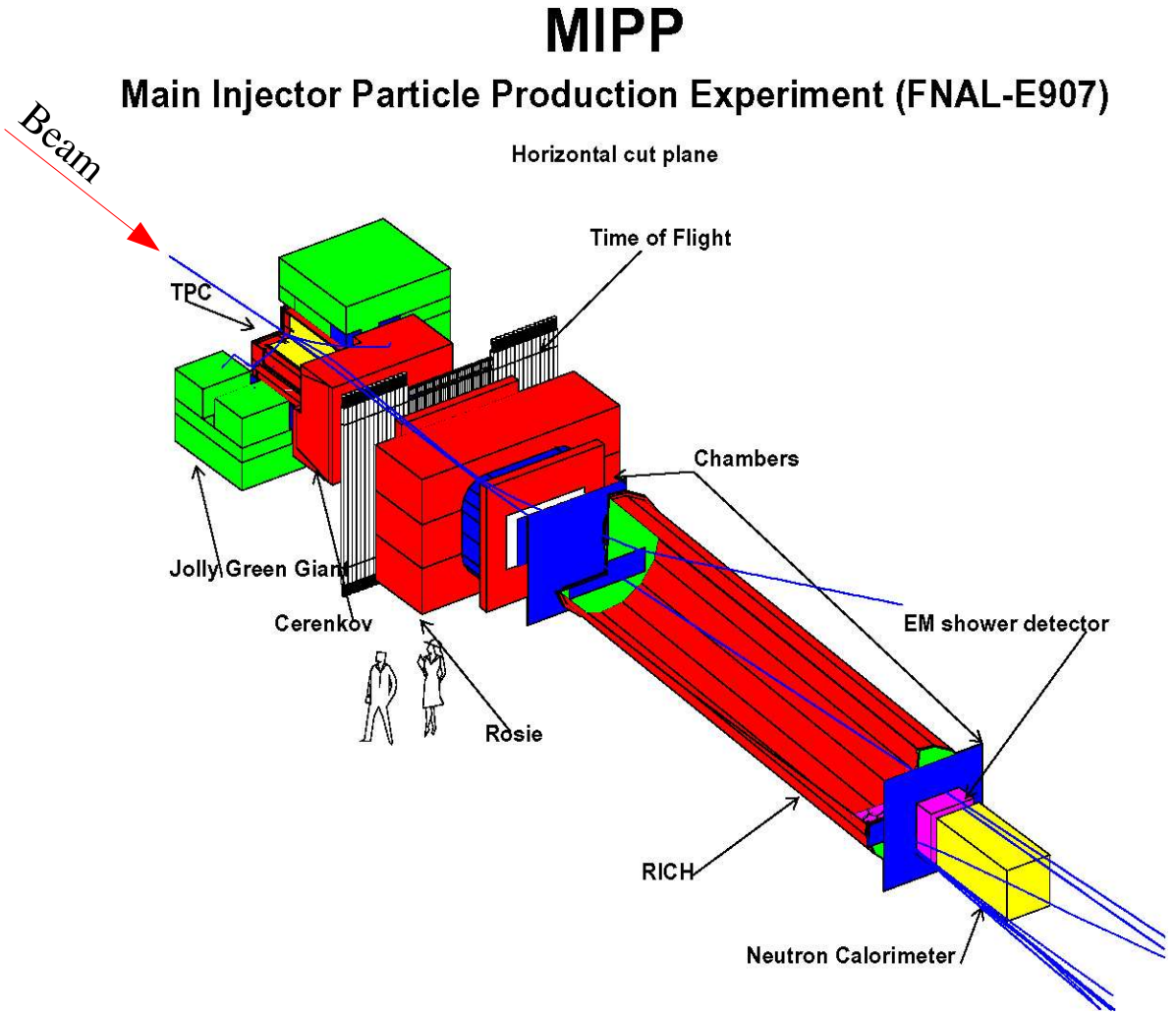
The Liquid Hydrogen target is shown on the left during filling, and the MINOS target on the right.



Current Experiments:

The experiment has two components: a tagged beam and the spectrometer:

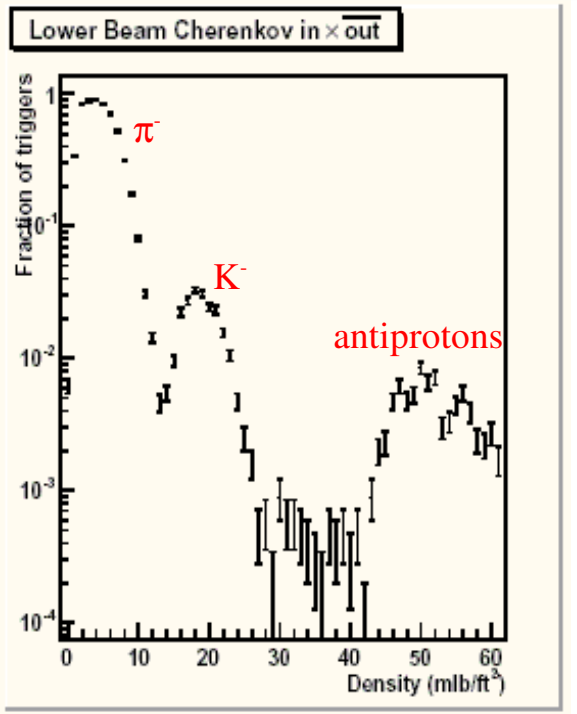




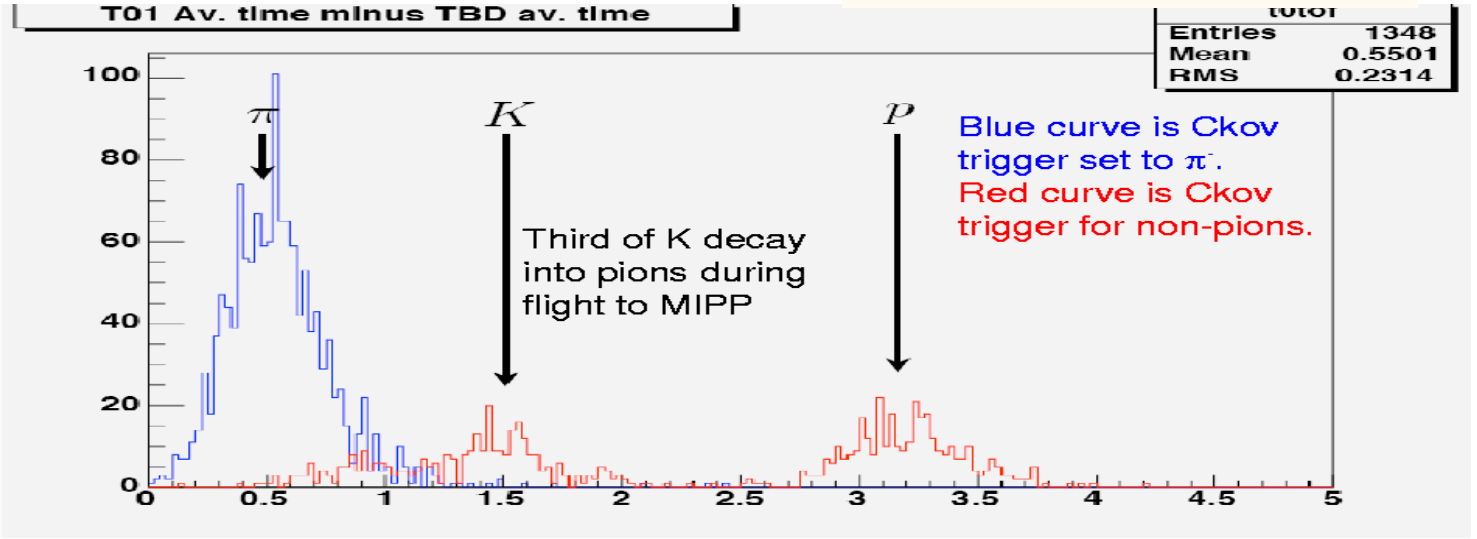
Detector Performance:

Identification of incident beam particle

High momentum beam tagging by Cerenkov shown at 40 GeV/c for negative running condition:



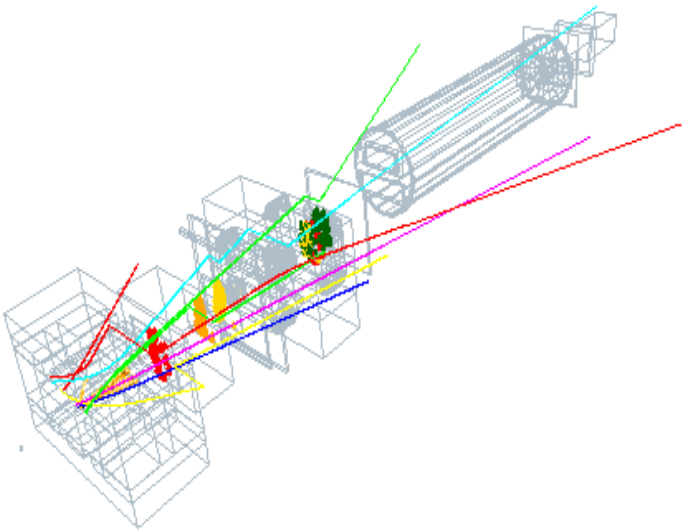
Low momentum beam tagging by TOF shown here for 5 GeV/c:

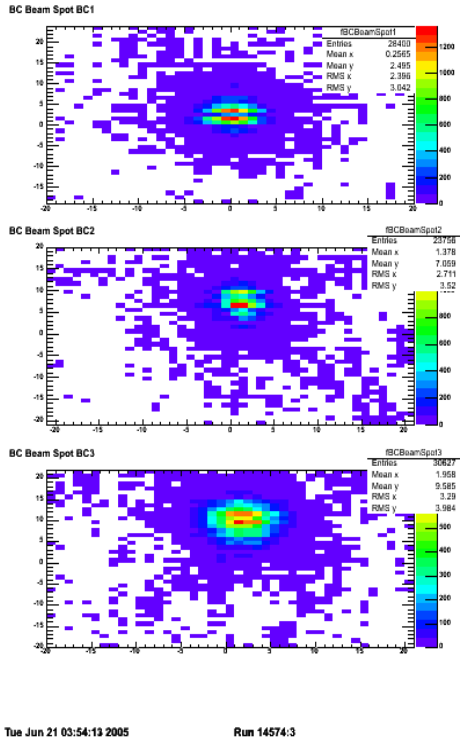


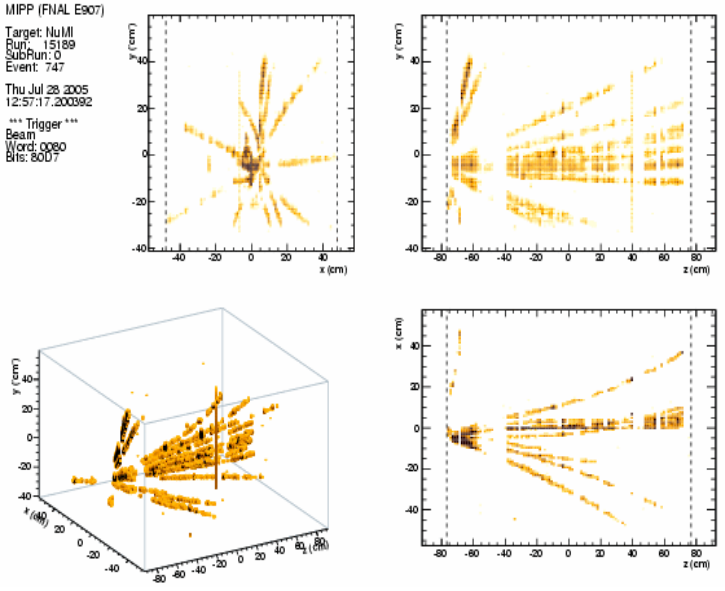
Detector Performance:

Tracking in this experiment has three separate regions of equal importance:

- incident particle orbit before physics target
- low momentum large angle region
- forward high momentum region





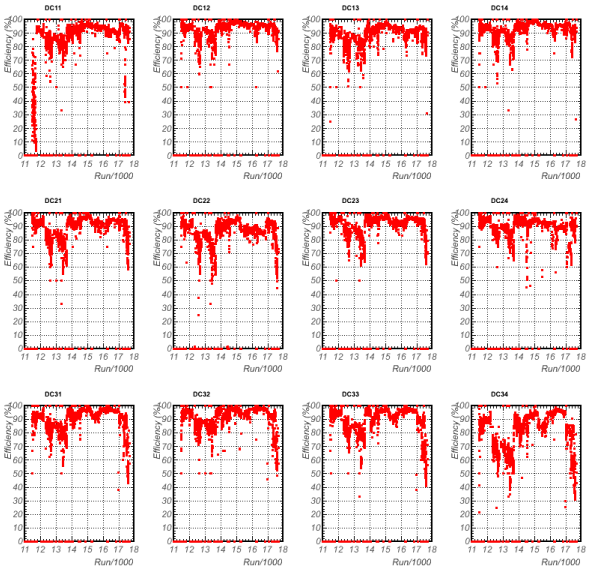


It is used in analysis for:

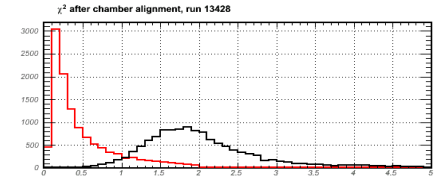
- momentum calculation
- interaction vertex selection
- decay vertex
- background vertex

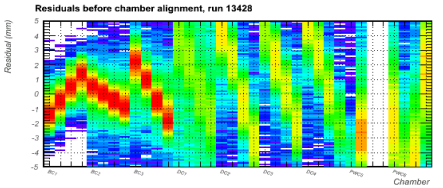
Detector Performance:

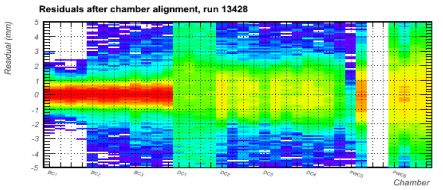
Tracking chamber efficiency are high:



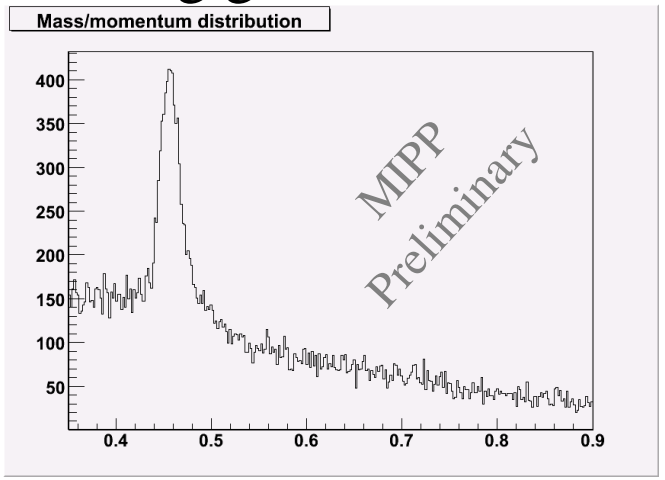
Good tracking position resolution:



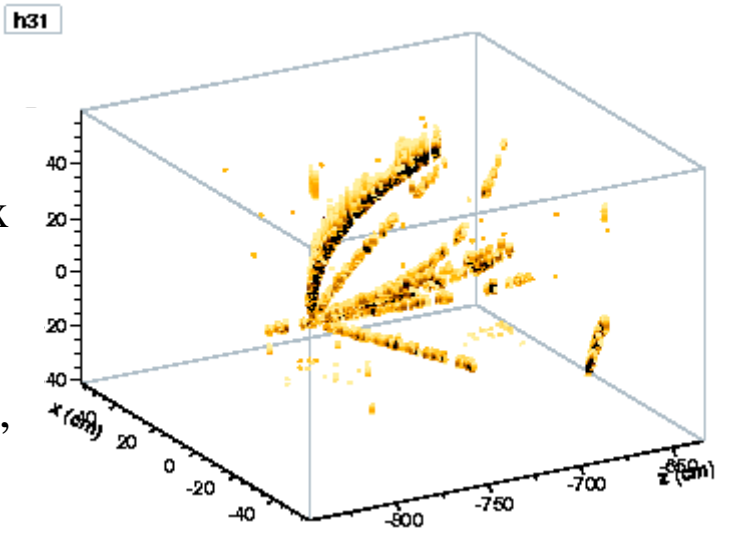




Vertex finding with tracking gives K^0:



MIPP event with Ar gas in TPC shows target vertex selection, but also will permit us to study cross-sections on Argon in, TPC gas, a large data set.



Detector Performance:

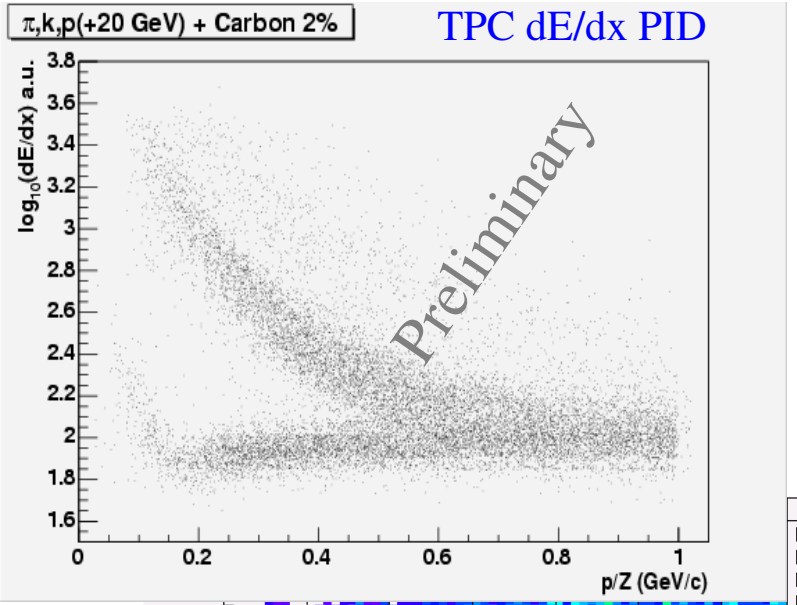
Produced particle identification:

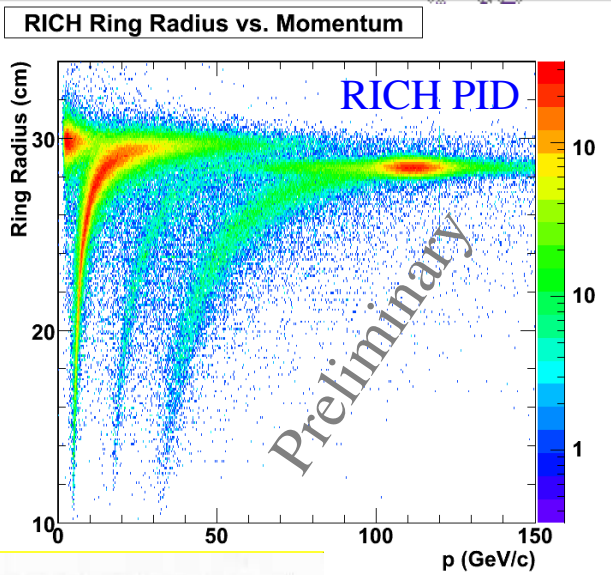
TPC dE/dx <1.25 GeV/c

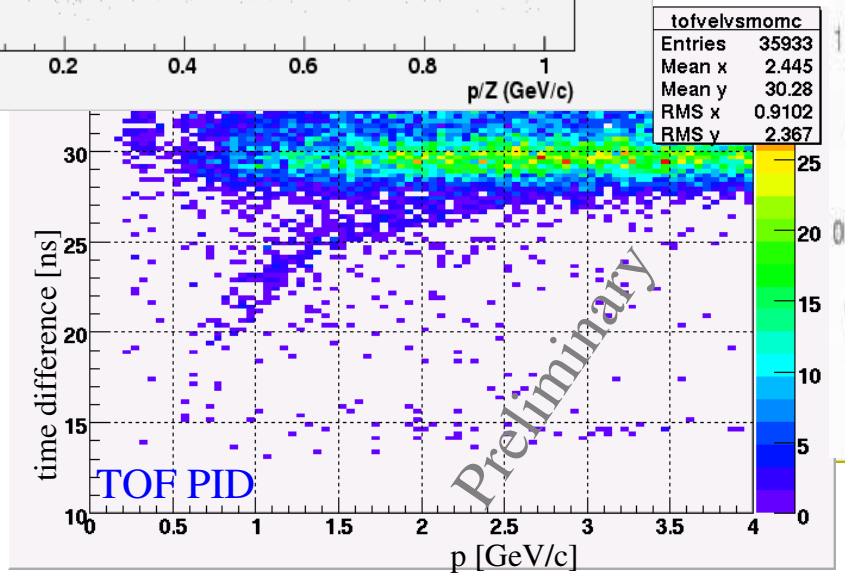
TOF <3 GeV/c

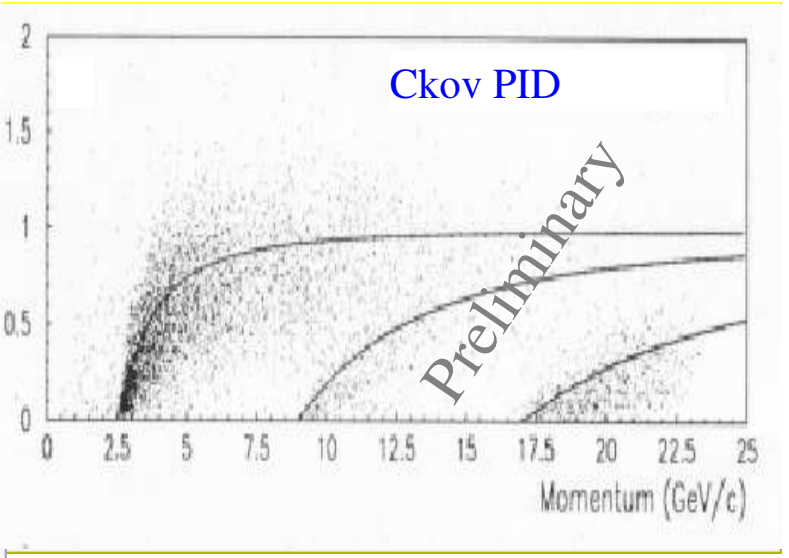
2.5 < Ckov <25 GeV/c

5.2 < RICH <100 GeV/c





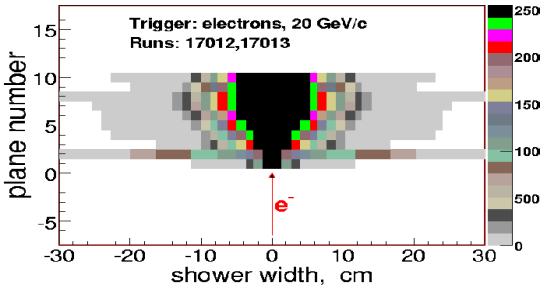




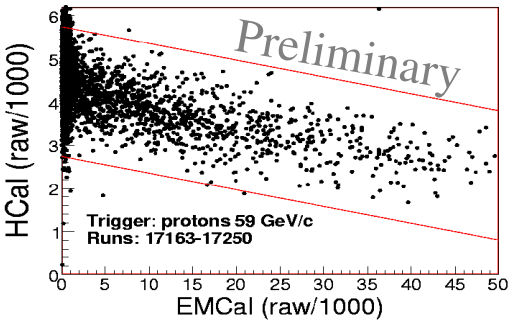
Ckov PID expected

Detector Performance:

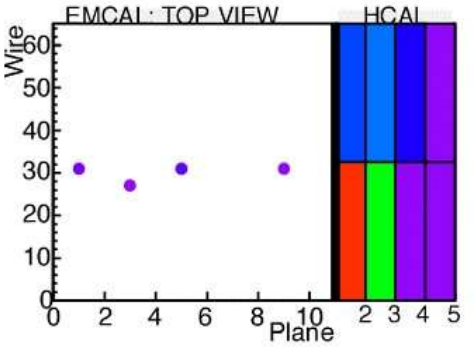
Electromagnetic and Hadronic Calorimeters provide a measure of the forward energy. It is mostly a "zero-degree" type calorimeter to determine the missing beam energy.

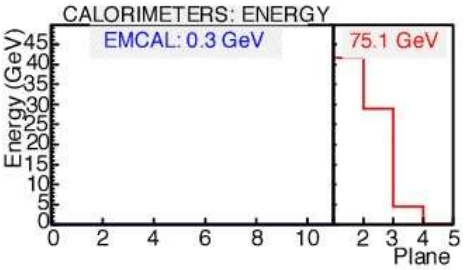


Top view of electron shower in EM Cal. shows expected position resolution for photons.



Both EM and Hadron Cal. preforming well, good momentum resolution and linear.





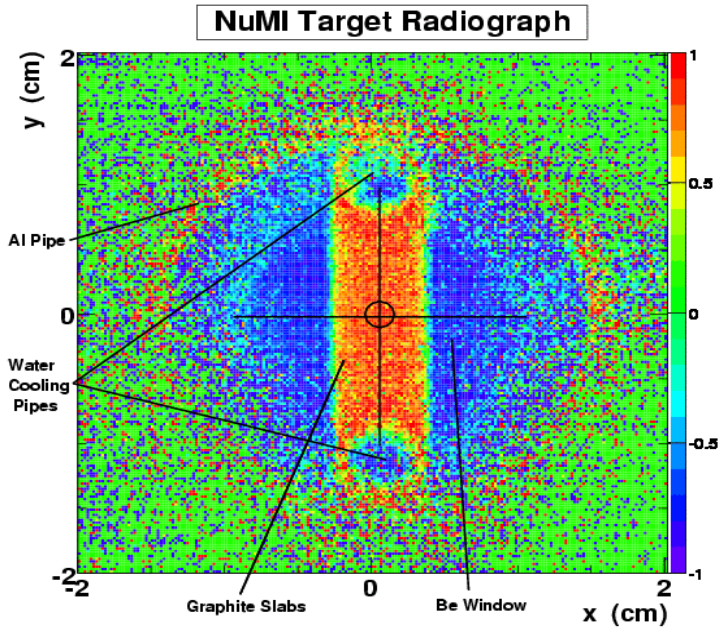
With a 84 GeV/c proton beam, the calorimeters see a 75.1 GeV neutron that deposits a small energy in the EM Cal., but leaves a large energy in the Hadron Calorimeter.

The response of the calorimeter to neutrons and its efficiency is essential to proper calorimeter design. Tagged neutrons off the MIPP target will be able to provide a direct measure of neutron energy and efficiency response. Detailed studies by MIPP (see MIPP note 130 by R. Raja et al.) show that tagged neutrons for energy resolution and efficiency can be readily available.

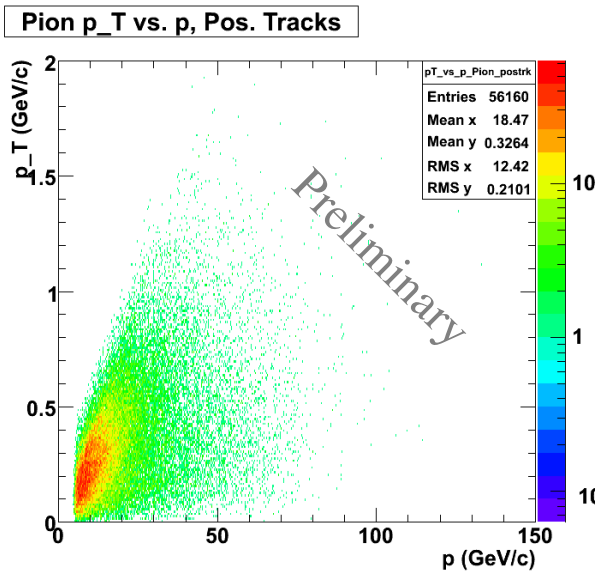
Experimental Results:

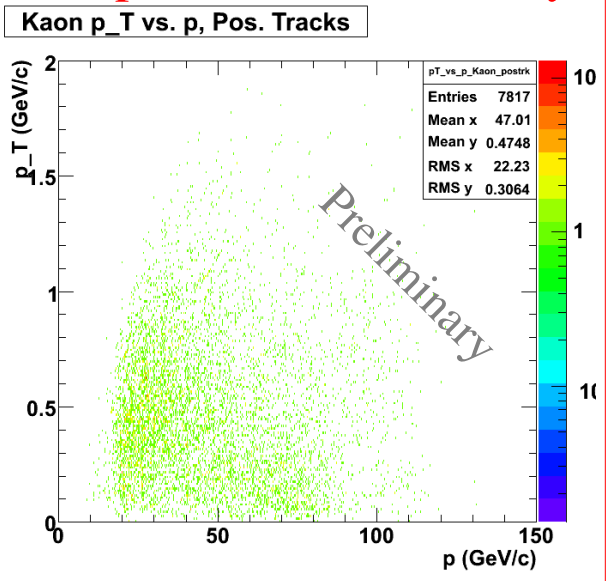
NuMI Target Study for the MINOS Experiment with the MIPP experiment:

Crucial π and K production studies that the MINOS experiment will eventually rely upon are provided by the MIPP experiment data analysis using the composite NuMI target. A 120 GeV/c beam of pure protons identical to that which hits the NuMI horn target was run in the MIPP experiment for two months and 2 million events. These events using the projectile particle tracking and secondary particle production show this analysis of the NuMI target structure.



MINOS target studies of π and K production underway:

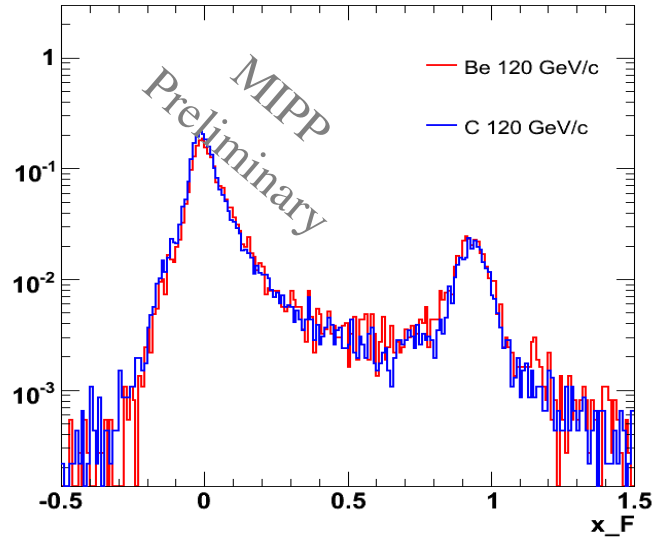




Experimental Results:

MIPP thin and nuclear targets:

x_F Distributions

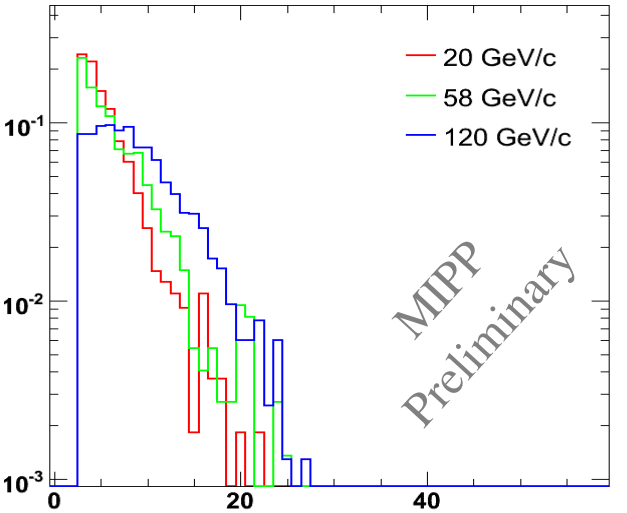


Multiplicity studies for nuclear targets in MIPP are underway.

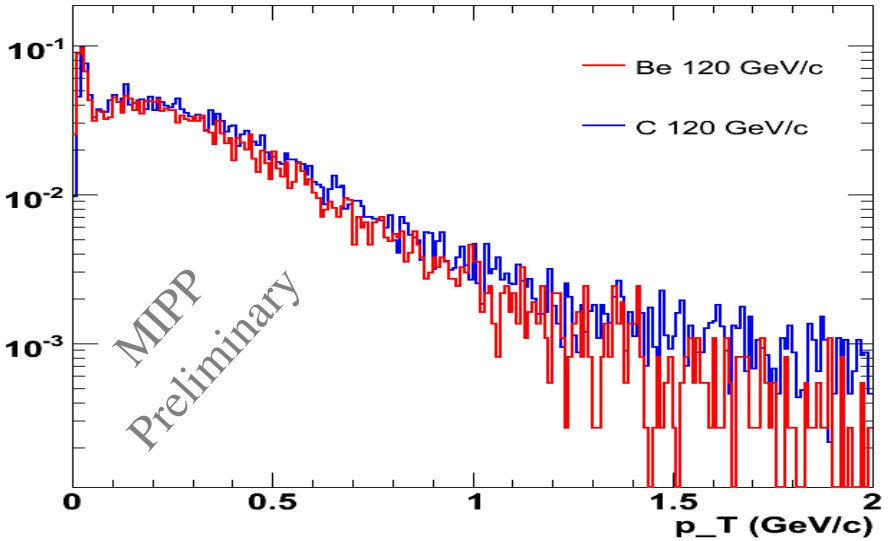
Right is Carbon target with three different momentum.

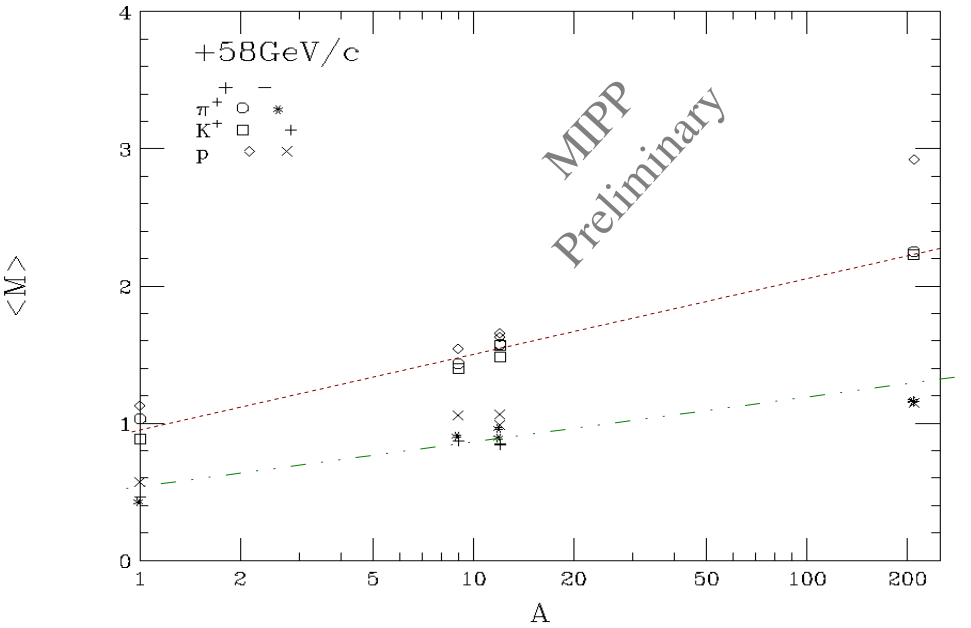
Below is 4 different targets at +58 GeV/c.

p + C Multiplicity Distribution



Reconstructed p_T Distribution





Future Plans:

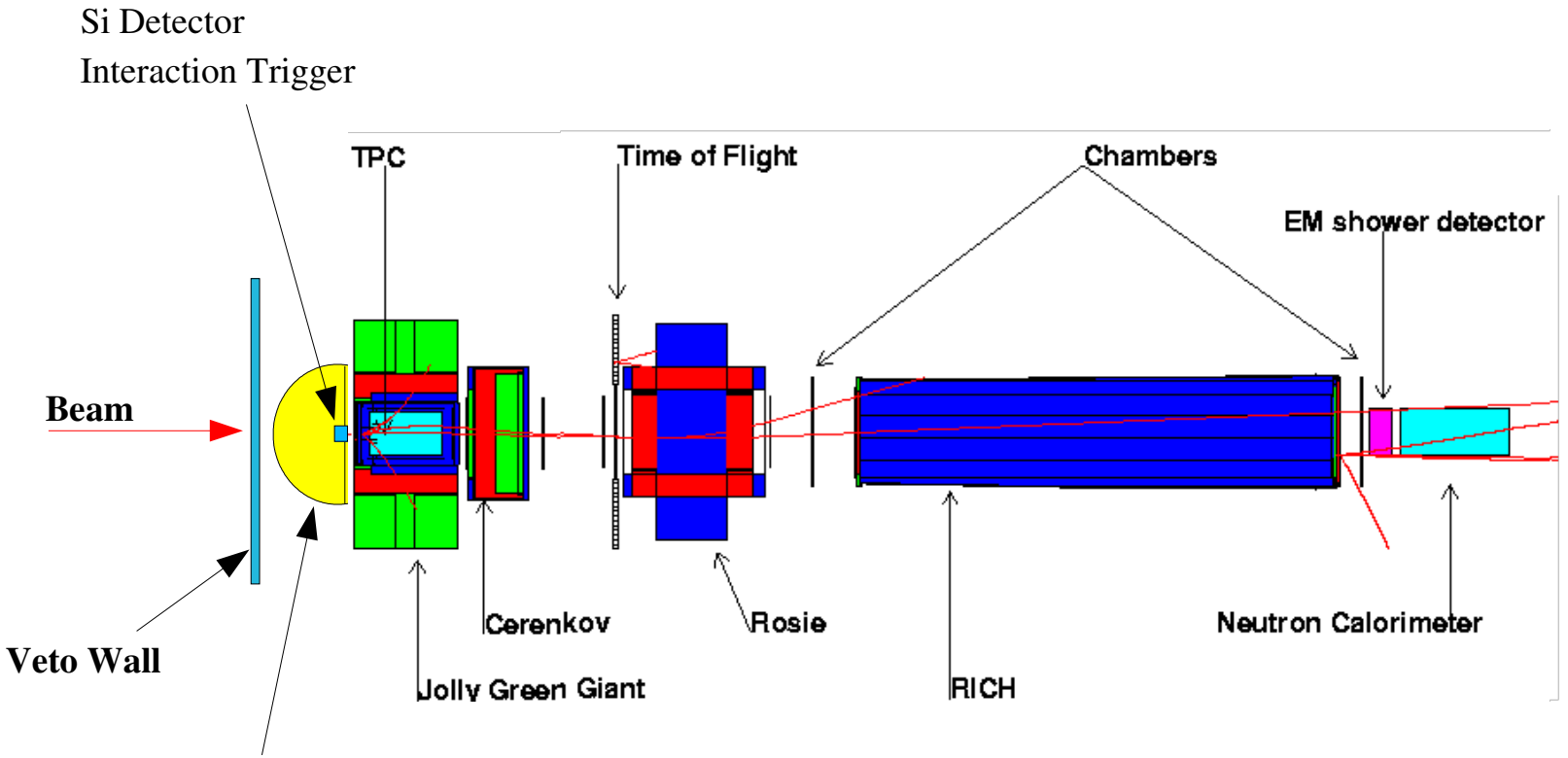
The Fermilab MIPP experiment proposes to have a improved run from 2007 to 2009 with:

- Faster readout of the TPC so that 3 kHz rate can be achieved, 4π acceptance, silicon vertex-interaction trigger and improved calorimeters.
- Special Liquid Nitrogen target for Atmospheric neutrino experiments. This needs a very large data sample so that fine segmentation in angle can be measured for all interaction species.
- Study 40 elements for improvements to hadronic shower simulation code for hadronic Calorimeter design.

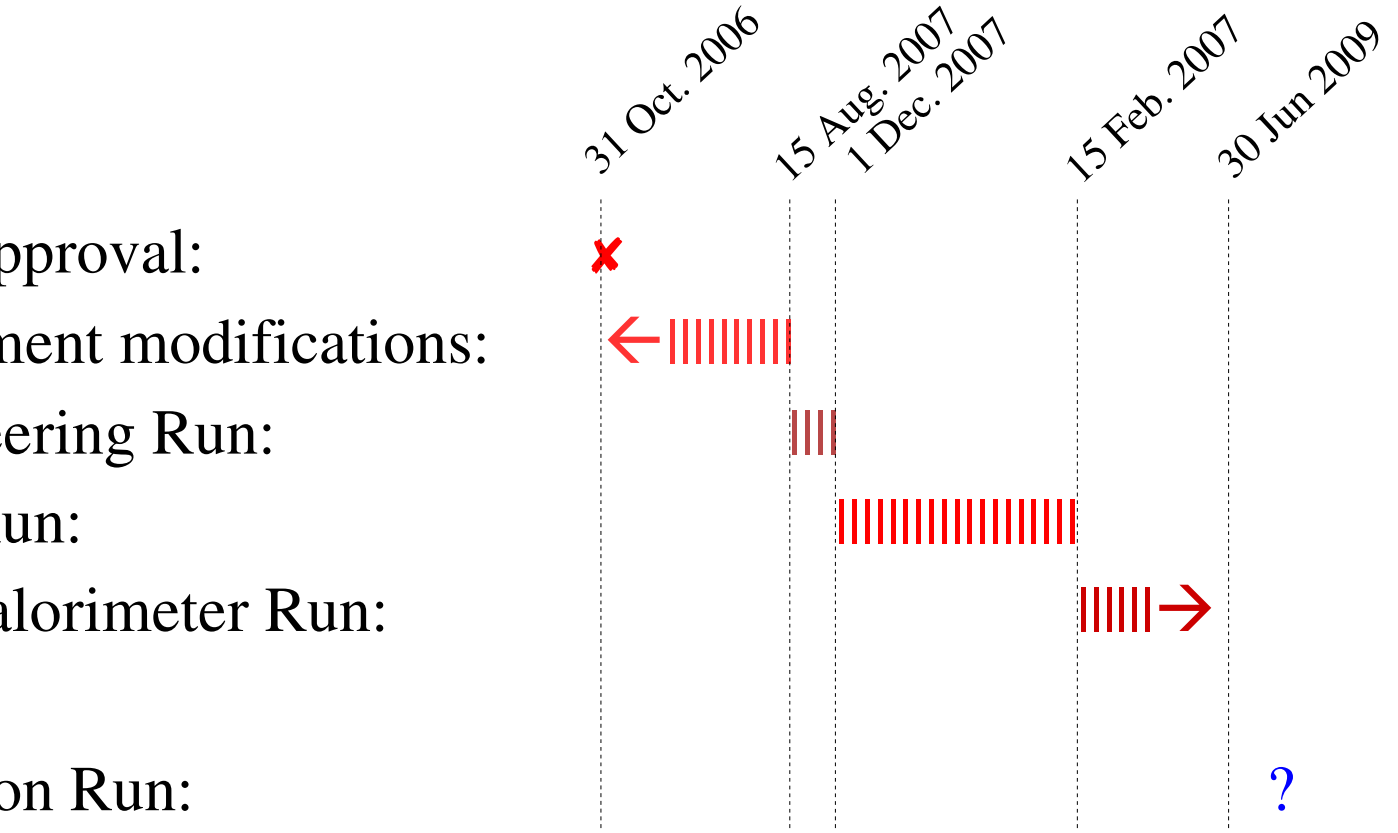
- Costs are small, less than $500,000.
- Time table is only 9 months to improve experiment.
- We welcome new collaborators if interested please contact us.

Future Plans:

The upgraded MIPP experiment looks very similar to the current but with several additions



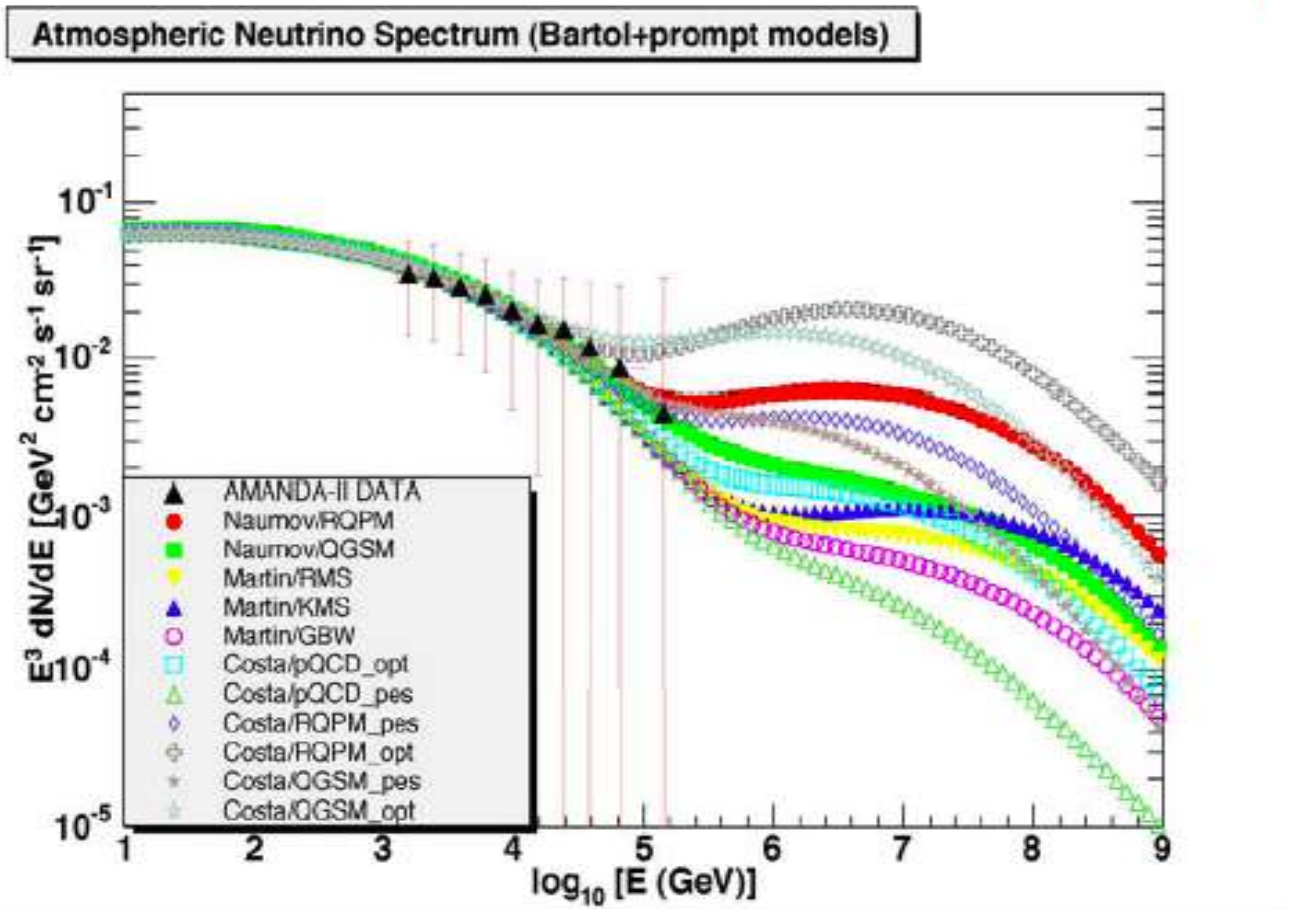
Time-line to Future Data from MIPP:



The MIPP experiment is located in MC7 which has had Tevatron Beam in the past (E731 and E871), after the collider run ends in 2009 there is a small window of opportunity for a new proposal to consider Tevatron Beam onto targets that need higher momentum.

Future needed improvements:

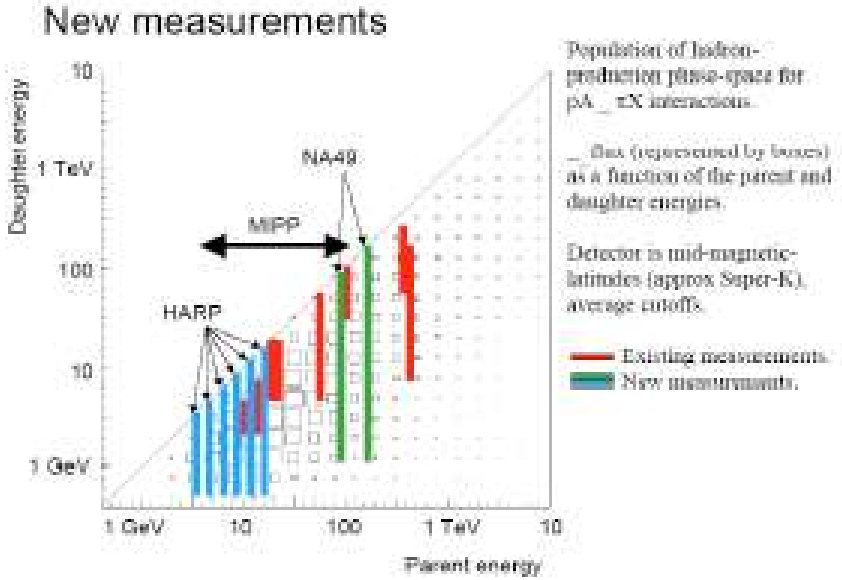
An extensive run with a Liquid Nitrogen target is needed for the atmospheric neutrino experiments such as: Ice-Cube and Hyper-K, to improve their neutrino flux from π and K decays. The graph at right shows the current limitation to the small Amanda experiment. Above 4 GeV/c errors grow, this comes from Cosmic Ray uncertainties of atmospheric production of Kaons and pions. Current models are uncertain above 5 GeV/c. Members of the Ice-Cube experiment from the Univ. of Wisconsin and Fermilab's Pierre Auger members will join the upgrade.



Future needs:

From the Amanda and Ice-Cube experiment:

"We are interested in improvements of hadronic models at the highest achievable energies in laboratory"



We foresee to use MIPP data for benchmarks Target/FLUKA

Future needs:

From the Pierre Auger Experiment:

Improvements in simulation of cosmic ray showers

C. Meurer et al.

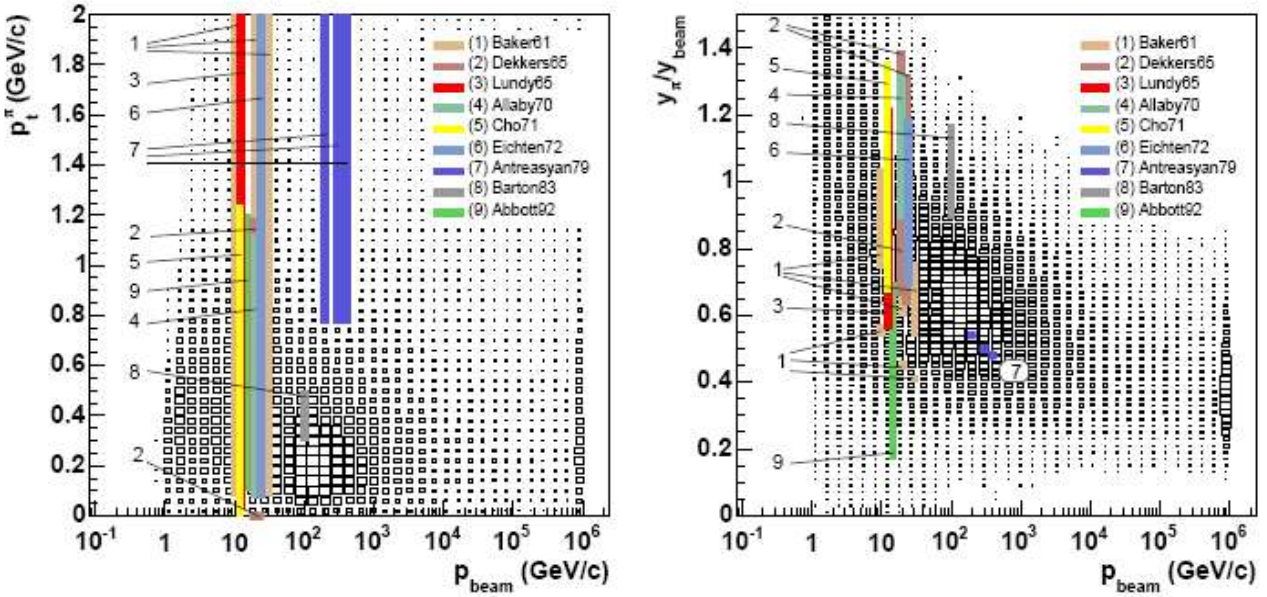


Fig. 9. Compilation of the phase space regions covered by fixed target data given in transverse momentum and rapidity of secondary particles and the phase space regions covered by the $\theta - p_{sec}$ data (see Fig. 8), whereas an approximate conversion of the covered phase space has been done. Left panel: transverse momentum of secondary pions vs. total momentum of proton projectiles. Right panel: rapidity of secondary pions normalized by the beam rapidity vs. beam momentum.

Future needs:

An important goal of the upgraded MIPP experiment would be anti-protons for studying:

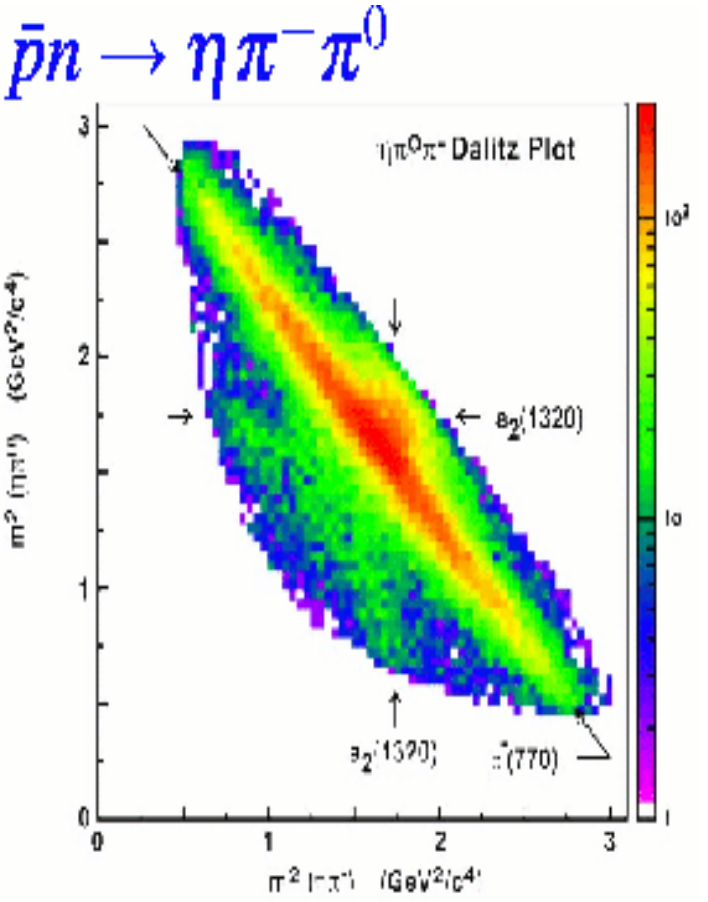
1) Anti-protons on H, D, He, Li and B.

Of importance for early universe production Cosmology.

2) Charm production cross section

3) Fundamental Nuclear physics

4) Several experiments have seen exotic states unexplained by the current models but expected by the quark-model. MIPP's unique open geometry would be a first to permit resolving this question.



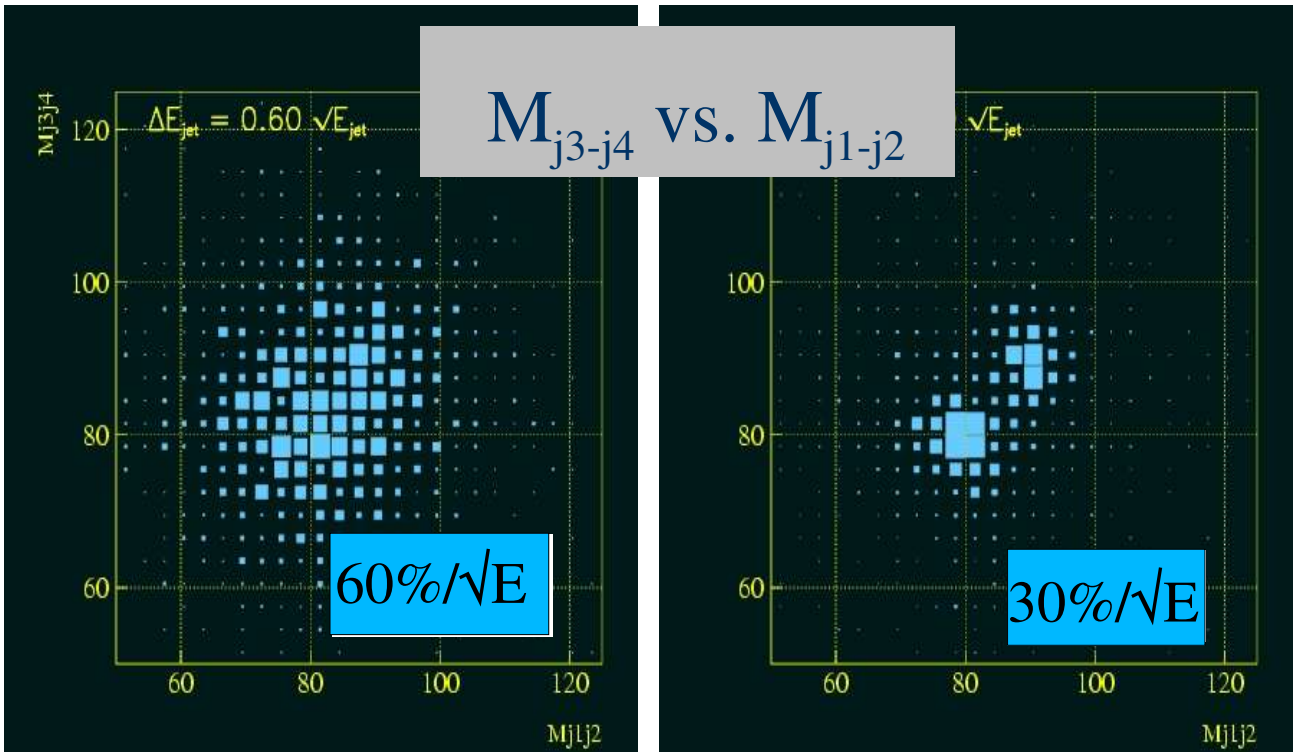
Future needs:

The future MIPP experiment run will have a major component to help provide measurements vital to improving Hadron Calorimetry, this is the most important detector in the ILC. As can be seen the difference between a 60%/ √E and 30%/ √E resolution is crucial to separating the two jet background from W and Z:

$$e^+e^- \to WW\nu\bar{\nu} \quad , \quad e^+e^- \to ZZ\nu\bar{\nu}$$

Current Hadron Calorimetry designers rely upon Monte-Carlo codes where the various detector materials are not well known. The MIPP experiment will study 40 nuclei from 1 to 100 GeV/c.

The response of the ILC test calorimeter to neutrons and its efficiency is essential to the Particle Flow algorithms. By putting the ILC hadron calorimeter in the MIPP beam line we will be able to provide a direct measure of neutron energy and efficiency response.

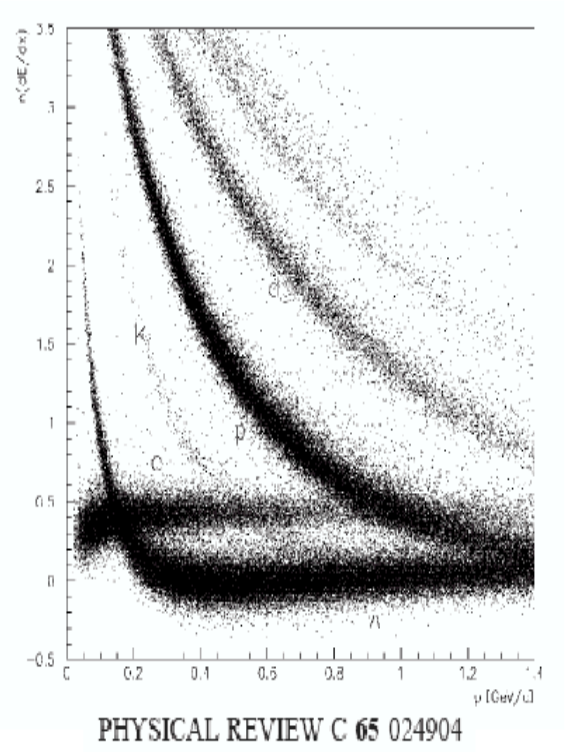


Conclusion:

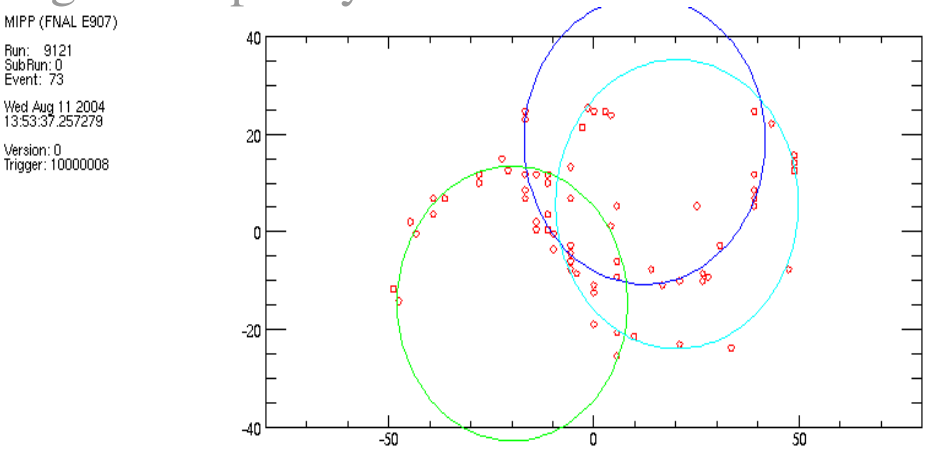
- Analysis of both current MIPP data and planning for a future run are underway and looks very promising.
- Goal is to resolve some questions and provide greatly improved cross sections including improved neutrino flux for neutrino experiments.
- We all look forward to seeing the current data sets fully published over the next two years.
- A study of fundamental physics with the data is clearly possible and will challenge the Hadronic Fragmentation Scaling Laws.
- Even though both the Harp and the MIPP experiment had successful runs, the data is still limited and further necessary improvements are clearly needed before other future experiments such as Ice-Cube, NOvA, Hyper-K and ILC, to name only a few, can be built.

Backup Slides:

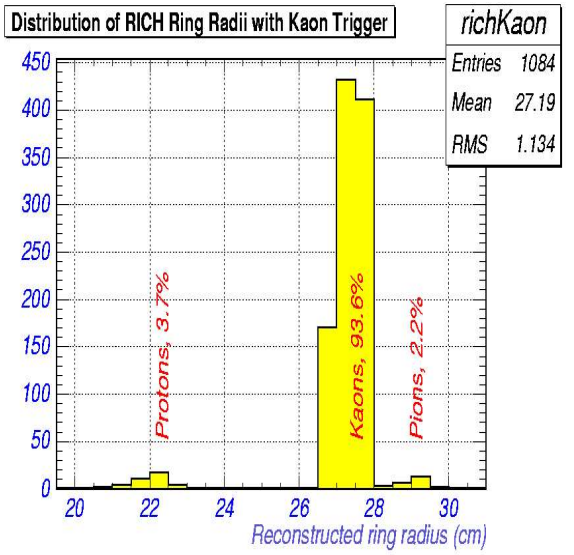
E910 Final Calibration, this is the TPC in MIPP and we should get similar performance.



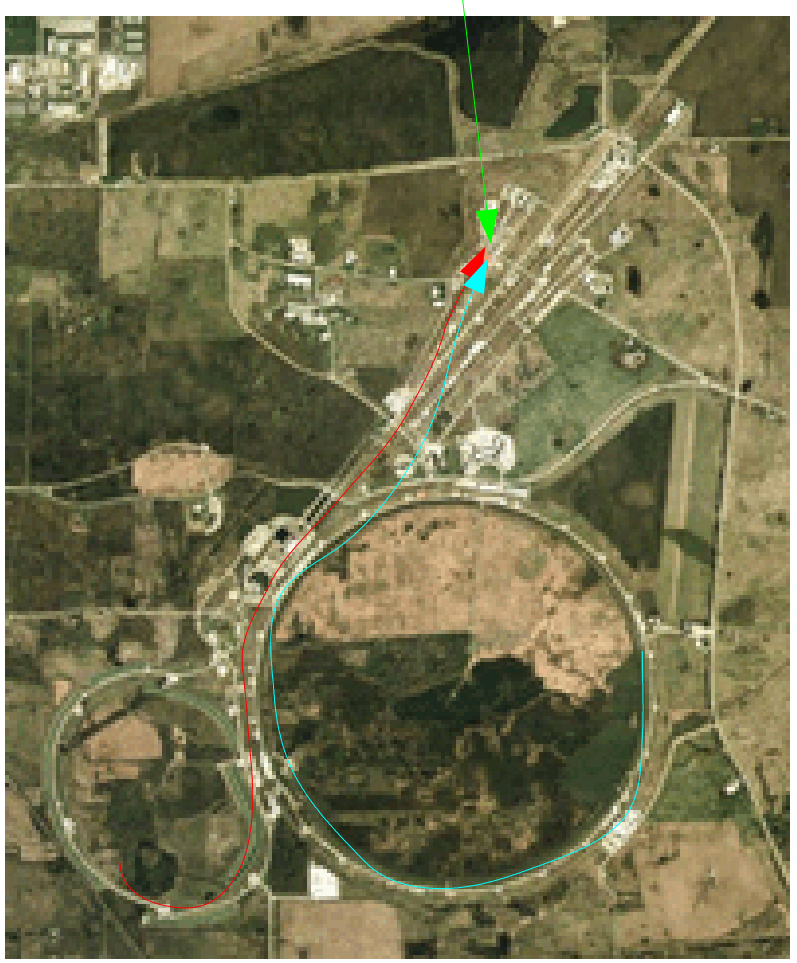
RICH and TPC working well with high multiplicity.



Trigger purity with Beam Ckov studied with RICH



Backup Slides:



Red Main Injector and Blue Tevatron beam.

MIPP is in MC7 beamline

Currently we only have Main Injector protons on primary target at 120 GeV/c.

From this we make tagged beams of lower momentum. Transport works up to 150 GeV/c.

Tevatron beam up to 900 GeV/c is possible but needs the collider run to end and modifications to Tevatron:

1) Move extraction kicker magnet.
2) Resurrect Tevatron beam-transport line. (unused since Feb. 2000)
3) Proton beam at any momentum fine, but if one needs tagged π, K and p beam then a new secondary beamline is also needed.