

*The **M**ain **I**njector **P**article
Production **E**xperiment (**MIPP**) at
Fermilab*

Rajendran Raja

Presentation to the Fermilab PAC

Format of talk

- Purpose and status of experiment
- Results of director's review of 10-Nov-04
- Run Plan
- Upgrade plans

MIPP collaboration list

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Brief Description of Experiment

- Approved November 2001
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of π^\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 a TPC 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, differential Cherenkov and RICH technologies.
- Open Geometry- Lower systematics. TPC gives high statistics. Existing data poor quality.

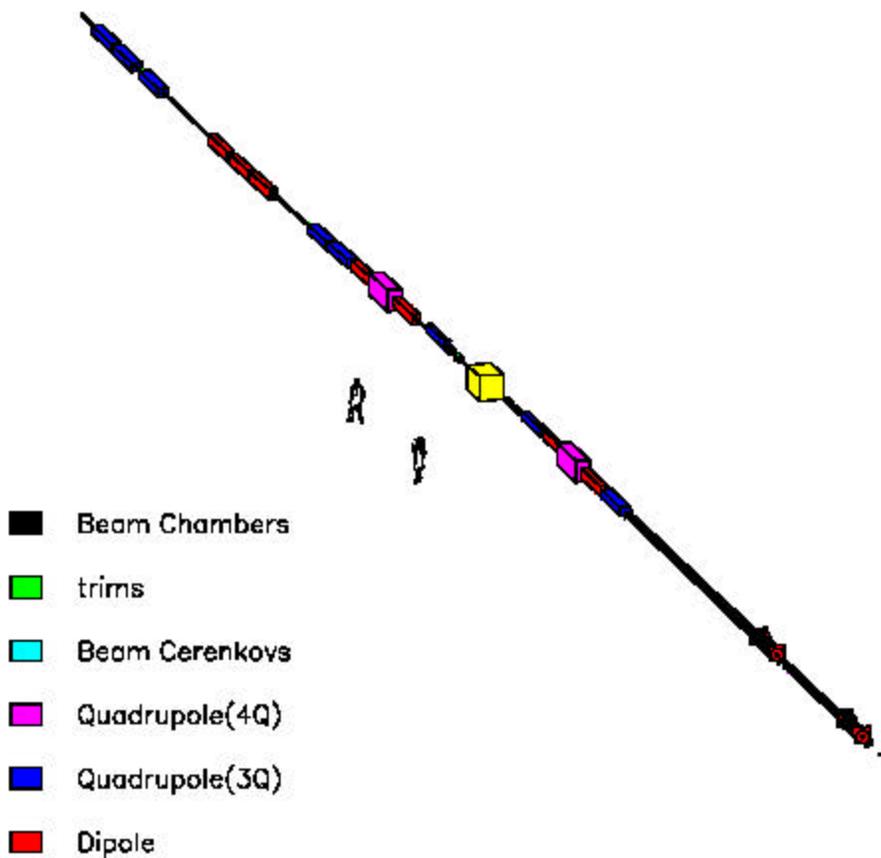
Physics Interest

- 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
 - » Investigate light meson spectroscopy, pentaquarks?, glueballs
- Nuclear Physics
 - » Investigate strangeness production in nuclei- RHIC connection
 - » Nuclear scaling
 - » Propagation of flavor through nuclei
- Service Measurements
 - » Atmospheric neutrinos – Cross sections of protons and pions on Nitrogen from 5 GeV- 120 GeV
 - » Improve shower models in MARS, Geant4
 - » Make measurements of production of pions for neutrino factory/muon collider targets
 - » Proton Radiography– Stockpile Stewardship- National Security
 - » MINOS target measurements – pion production measurements to control the near/far systematics
- HARP at CERN went from 2-15GeV incoming pion and proton beams. MIPP will go from 5-100 GeV/c for 6 beam species π^\pm K^\pm p^\pm -- 420M triggers. 3KHZ TPC.

MIPP Secondary Beam

- Installed in 2003. Delivering slow spill commissioning beam (40GeV/c positives since February 2004). Mixed mode operation working. Average ppp $\sim 1E10$.

MIPP BEAM



MIPP Physics Program

MIPP has 4 distinct clientele for its data, which are interconnected. They are

Liquid H2, D2 –non-perturbative QCD

p-A, proton -radiography (aka SURVEY)

NUMI thin and full target measurements

Liquid N2– Atmospheric neutrinos

Fermilab –MoU calls for 1.3million spill seconds to MIPP.

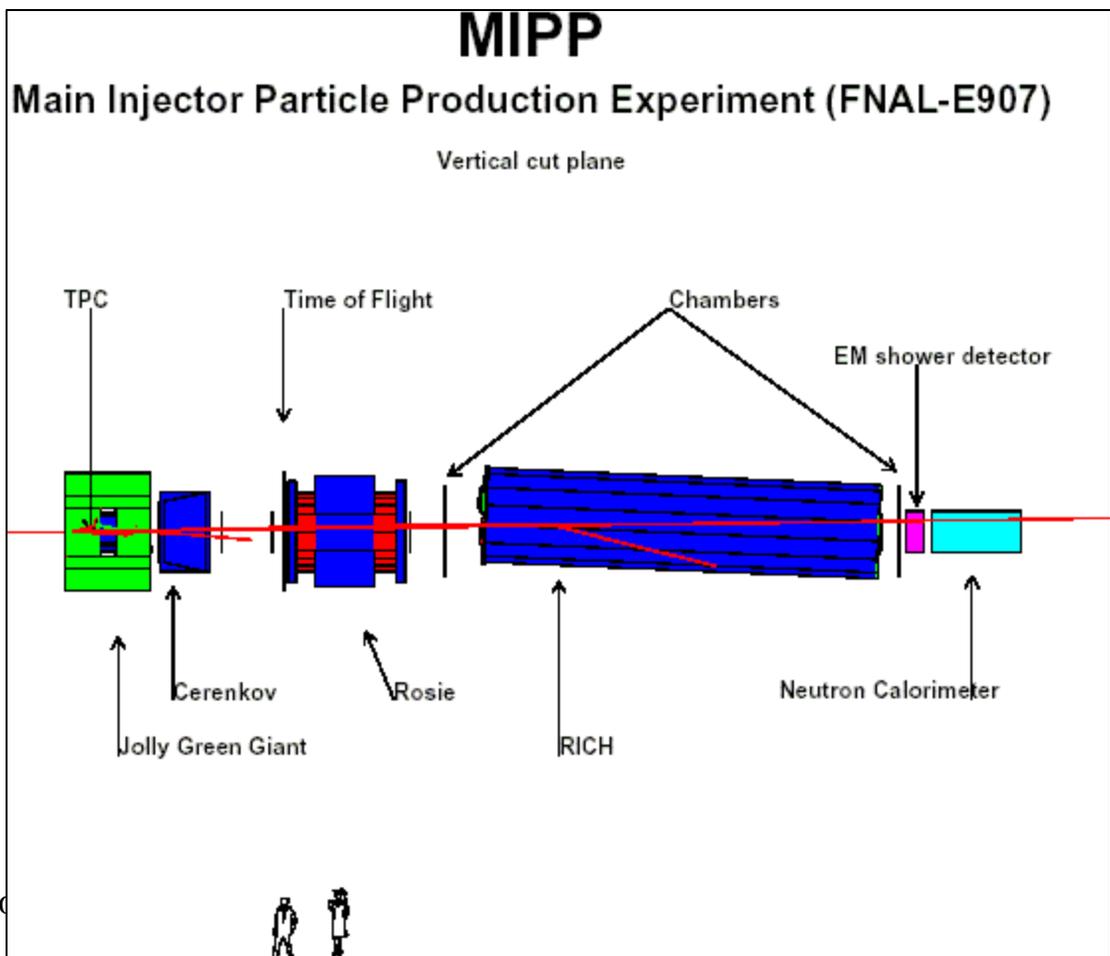
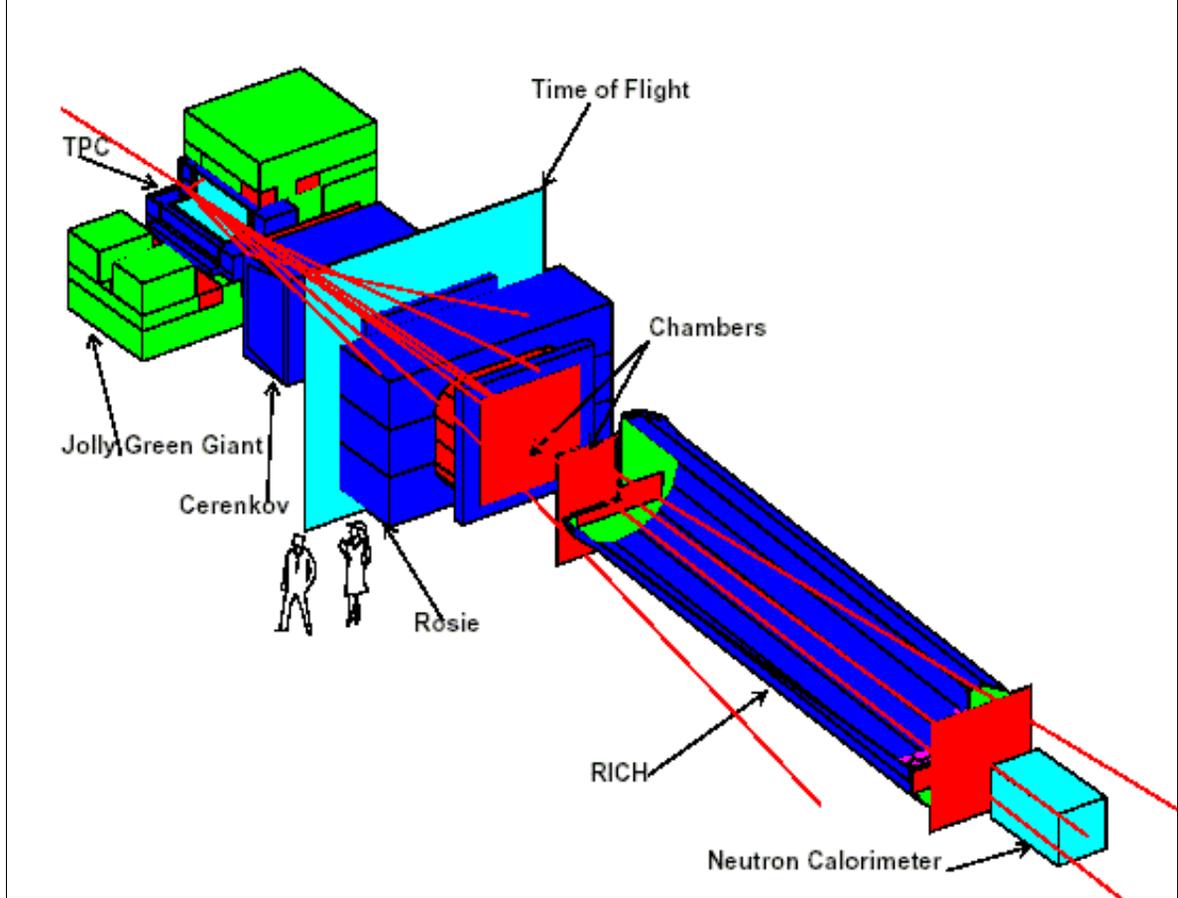
Sum of Mevents	
Program	Total
Atm. Neutrinos	3.00
Commissioning	3.00
MINOS	10.01
pA	17.20
Scaling	24.00
Survey	20.79
Grand Total	78.00

Cost of MIPP

Lawrence Livermore Lab ~\$2M

Fermilab ~\$2M

Beams Division (for beamline) \$0.5M



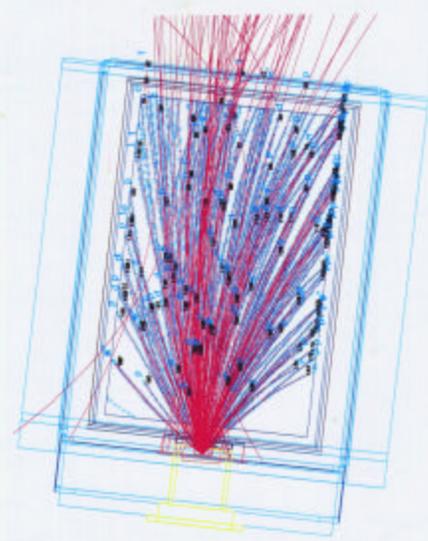
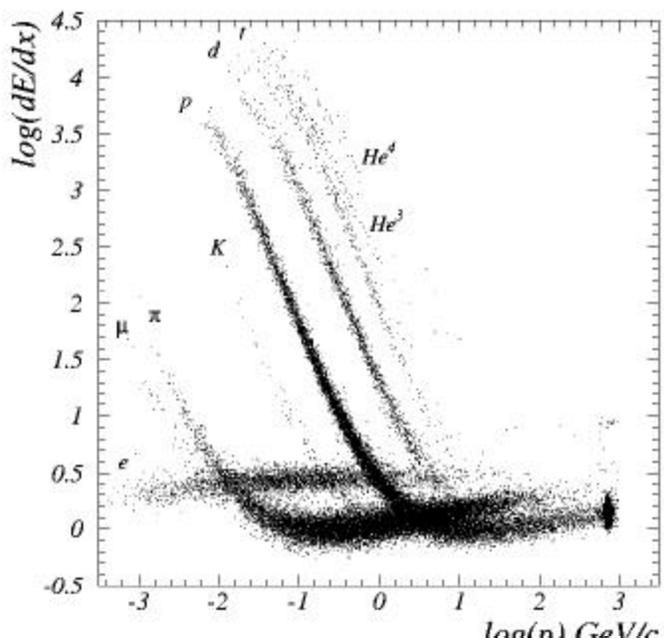
Status of MIPP Now-Collision Hall



TPC installation



TPC dE/dx Particle ID- BNL E910

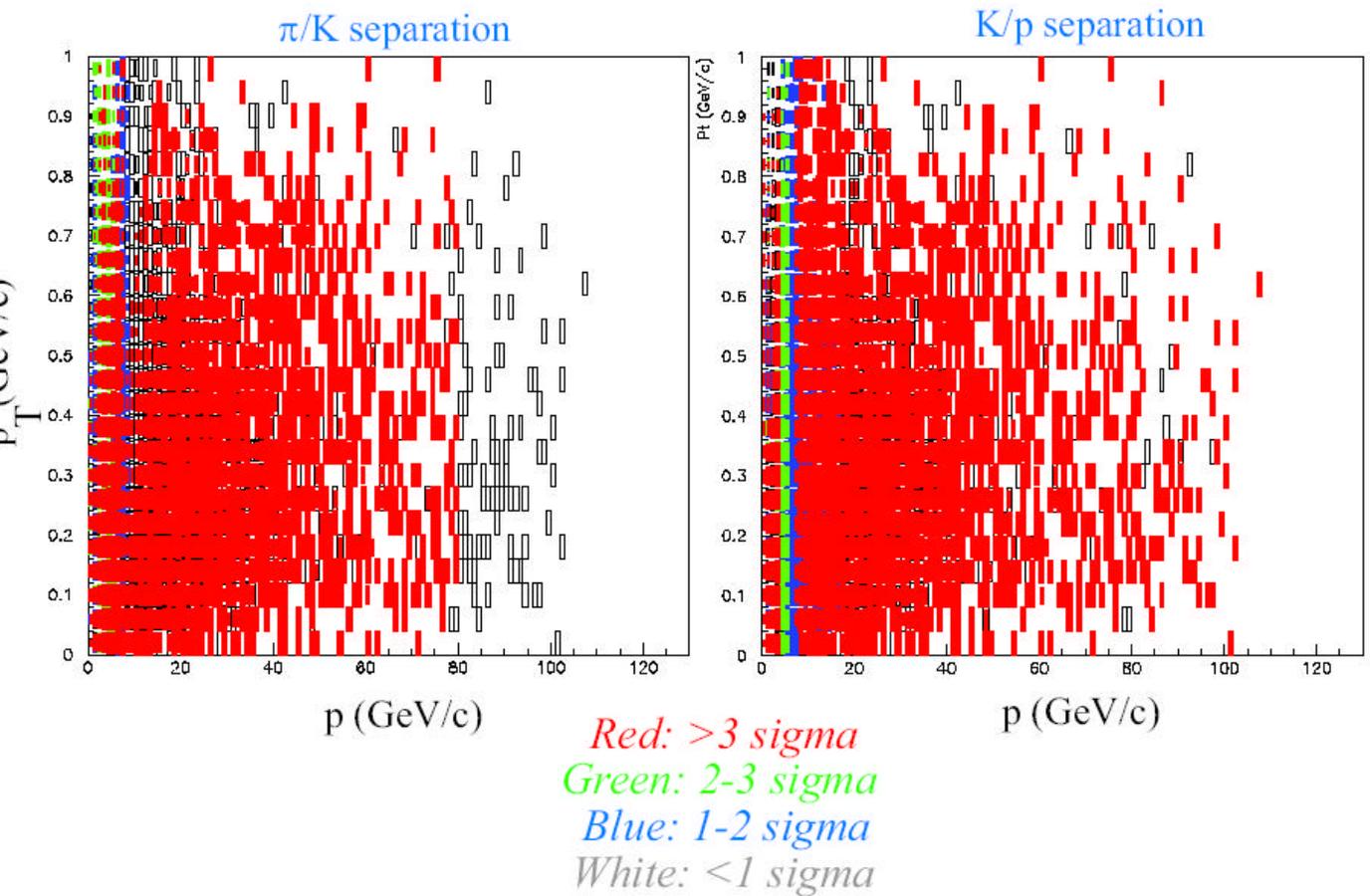


MIPP-TPC

- This Time Projection Chamber, built by the BEVALAC group at given to Fermilab by LBNL. It took approximately \$3million to construct.
- Can handle high multiplicity events. Time to drift across TPC=16 μ s.
- Electronic equivalent of bubble chamber, high acceptance, with dE/dx capabilities. Dead time 16 μ s. i.e unreacted beam swept out in 8 μ s. Can tolerate 10^5 particles per second going through it.
- Can handle data taking rate \sim 60Hz with current electronics. Can increase this to \sim 1000 Hz with an upgrade.
- TPC dimensions of 96 x 75 x 150 cm.

MIPP Particle ID

Particle ID Performance

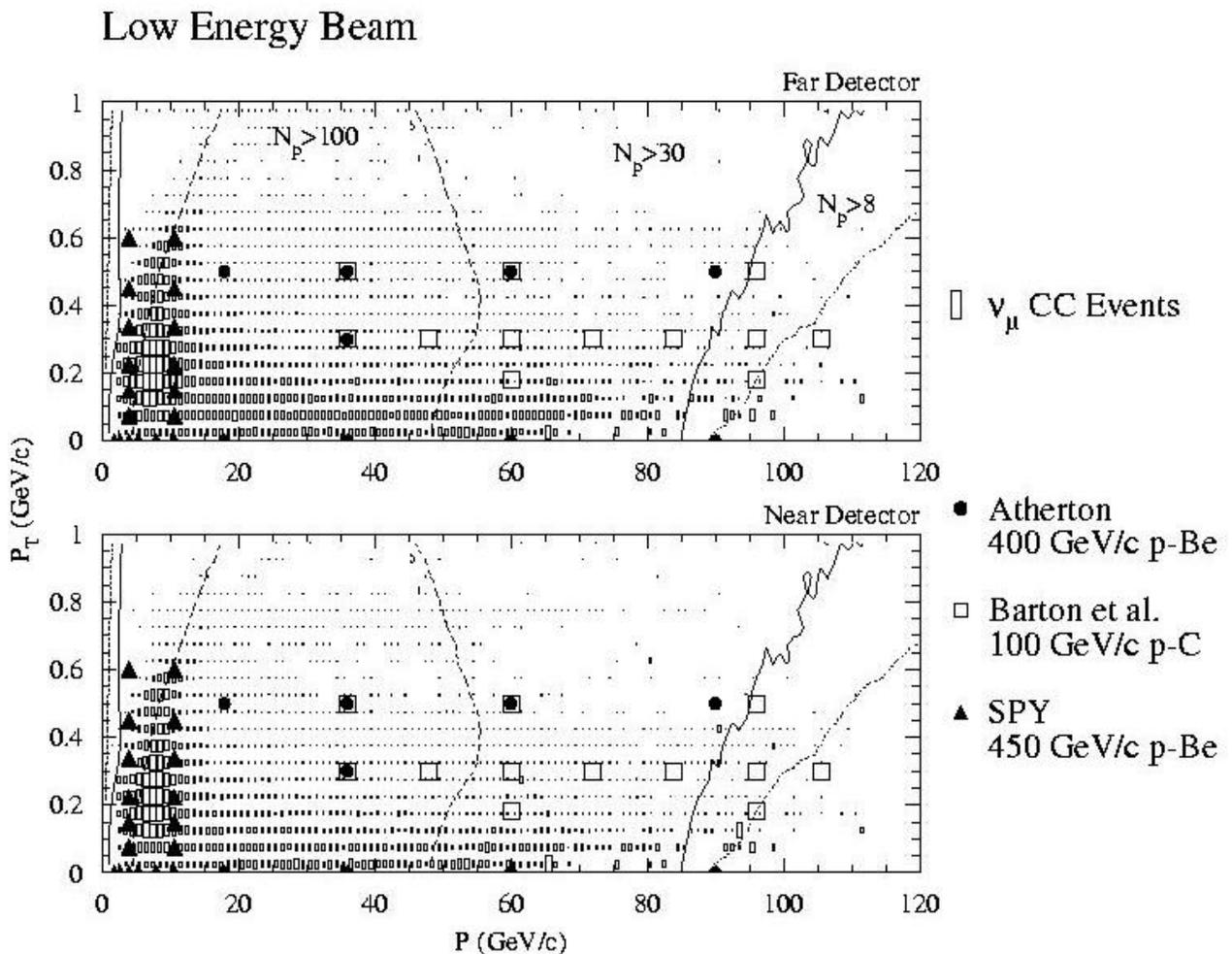


Service Measurements

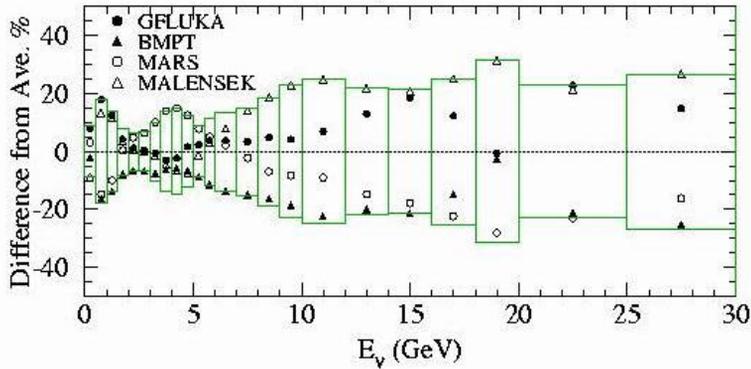
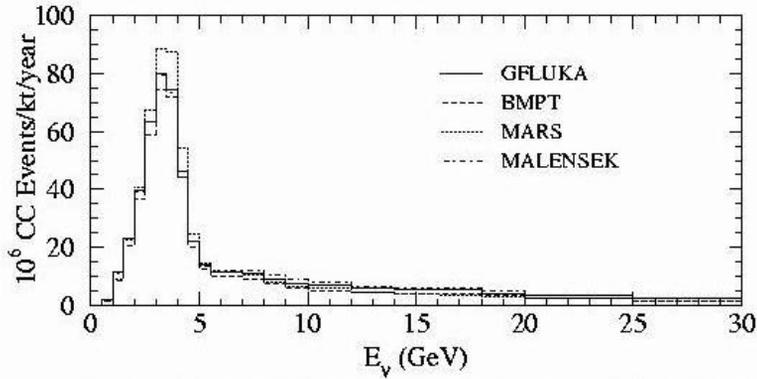
- MINOS needs- The hadro-production spectrum on a MINOS target can be measured with the Main Injector Beam that closely matches the beam emittance used in NUMI. MINOS will not build a hadronic hose that would have ameliorated their far/near flux ratio uncertainties. Hadroproduction measurements such as the ones E907 can provide are crucial.
- Proton Radiography measurements of nuclear cross sections
- 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

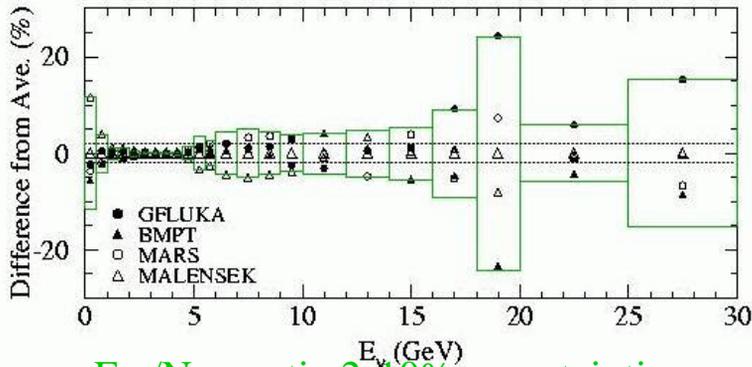
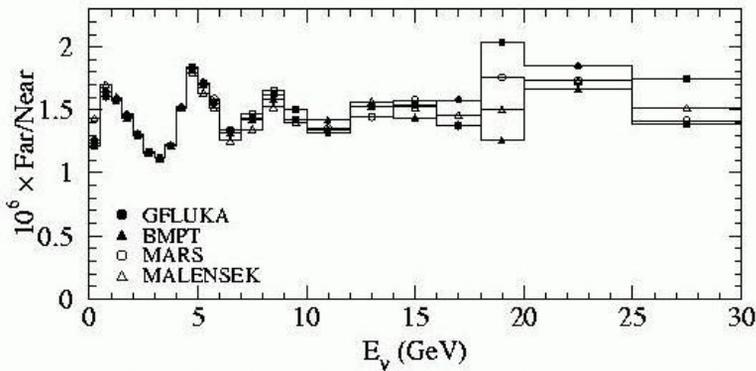
- E907 has MINOS collaborators-J.Hylen,A.Para(FNAL), M.Messier(Indiana),P.D.Barnes Jr.,E.Hartouni,(Livermore), T.Bergfeld,A.Godley,S.R.Mishra,C.Rosenfeld(South Carolina), G.Feldeman,A.Lebedev,S.Seun(Harvard)
- Existing data vs Near and Far detector pion contribution for MINOS



Minos measurements



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



Far/Near ratio 2-10% uncertainties
in near-to-far. Normalization in tail
important.

Importance of LH2 data to the MIPP program

Bias free topological cross sections exist from liquid hydrogen bubble chambers of $p^\pm p$, $K^\pm p$, $\pi^\pm p$ data. This will be invaluable in understanding MIPP beam tagging and trigger efficiencies and final state acceptances as a function of momentum.

pp data is symmetric in the center of mass.

Particle production in inclusive reactions such as

$$pp \rightarrow K^\pm + X, p^\pm + X, p^\pm + X$$

Can be used to relate particle id in the backward hemisphere in the center of mass to the forward hemisphere as a function of beam momentum. This data will help us lower the systematics of our particle id from TPC De/Dx, ToF, CKOV and RICH detectors, since the center of mass moves in the lab as a function of beam momentum.

LH2 data helps us study non-perturbative QCD. Why study non-perturbative QCD?

- Answer:- We do not know how to calculate a single cross section in non-perturbative QCD! This is >99% of the total QCD cross section. Perturbative QCD has made impressive progress. But it relies on structure functions for its calculations, which are non-perturbative and derived from data.
- Feynman scaling, KNO scaling, rapidity plateaus are all violated. We cannot predict elastic cross sections, diffractive cross sections, let alone inclusive or semi-inclusive processes. Regge “theory” is in fact a phenomenology whose predictions are flexible and can be easily altered by adding more trajectories.
- All existing data are old, low statistics with poor particle id.
- QCD theorist states- We have a theory of the strong interaction and it is quantum chromodynamics. Experimentalist asks– what does QCD predict? Almost as bad as the folks who claim string theory is the theory of everything! Experimentalist asks- what does it predict?

General scaling law of particle fragmentation

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

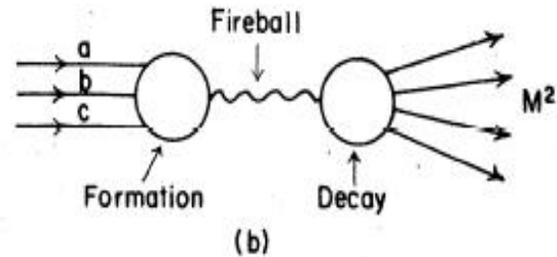
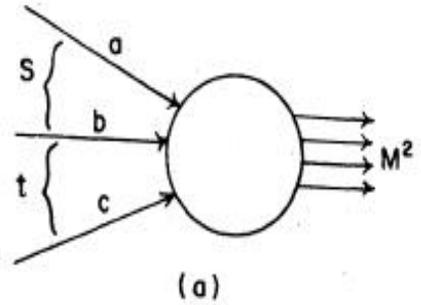
$$\frac{f(a+b \rightarrow c + X_{subset})}{f(a+b \rightarrow c + X)} \equiv \frac{f_{subset}(M^2, s, t)}{f(M^2, s, t)} = \mathbf{b}_{subset}(M^2)$$

- 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 . 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 in 36 reactions.

Scaling Law

$$s(abc \rightarrow X) = F(M^2, s, t) D_X(M^2)$$

$$s(abc \rightarrow X_s) = F(M^2, s, t) D_{X_s}(M^2)$$



$$\frac{s(abc \rightarrow X_{sub})}{s(abc \rightarrow X)} = \frac{F(M^2, s, t) D_{X_{sub}}(M^2)}{F(M^2, s, t) D_X(M^2)} = a_{sub}(M^2)$$

- Continuing on to physical t values, one gets

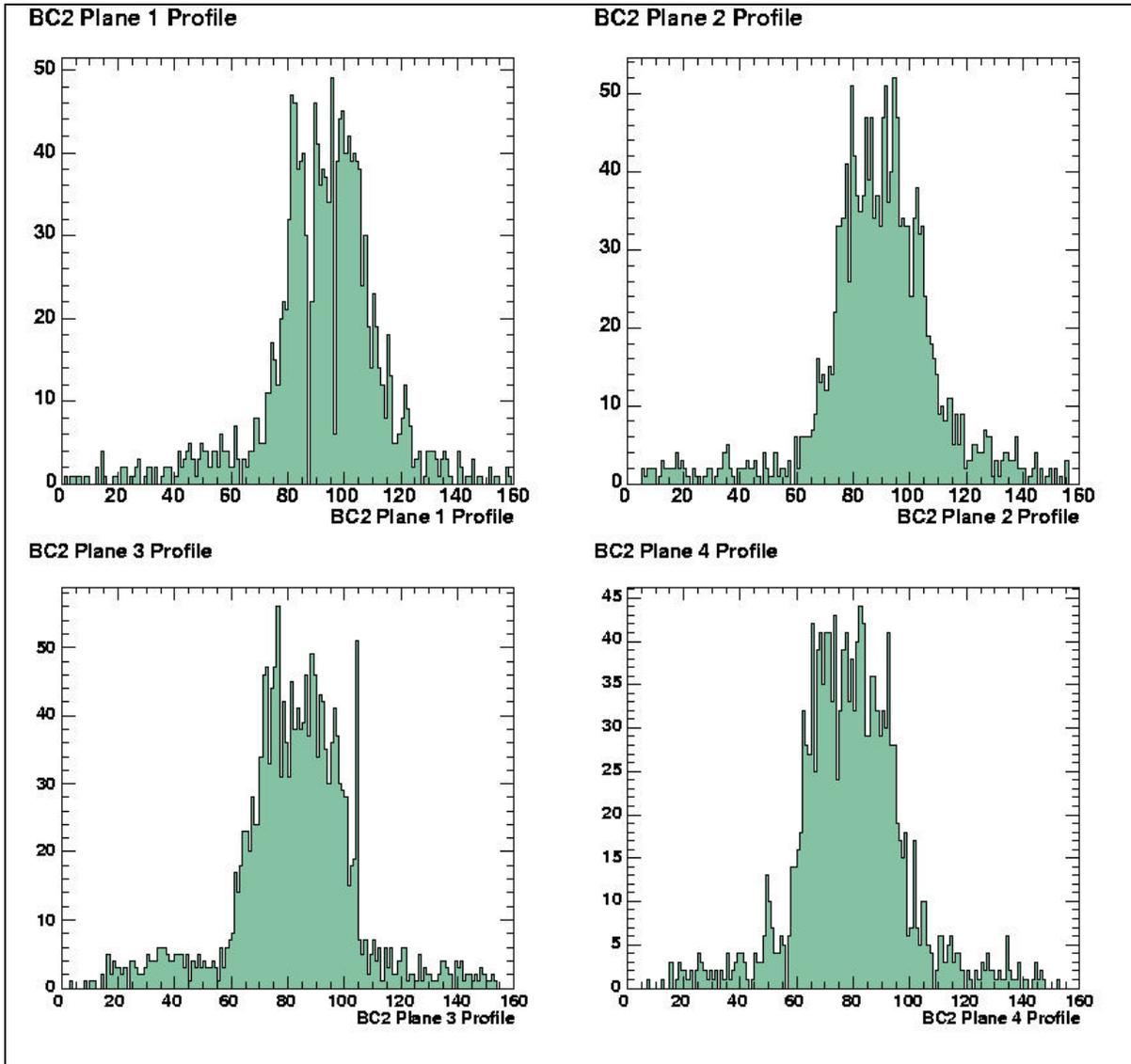
$$\frac{f(ab \rightarrow \bar{c} + X_{sub})}{f(ab \rightarrow \bar{c} + X)} = a_{sub}(M^2)$$

- Will test this in 36 reactions over several subsets s and t independence.

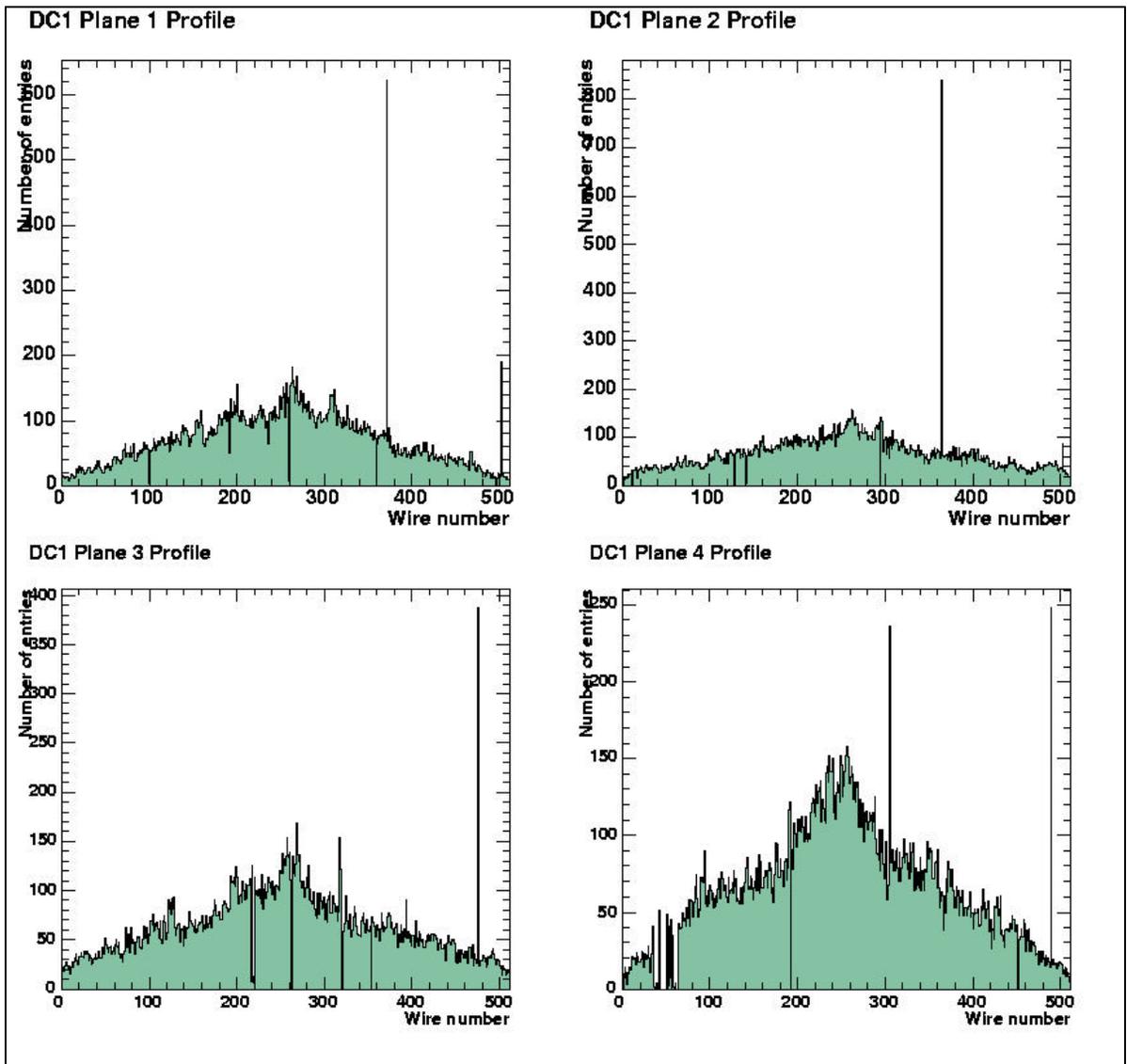
Engineering Run results

- Had RICH fire. Recovered from it 80% of tubes in tact. RICH is now engineered a lot more safely
 - » Flammable tubing on tubes changed
 - » Base soldering corrections redone where needed
 - » HV connections made more robust
 - » VESDA safety trips
 - » HV trips on sparks as well as over-current
 - » Nitrogen purge.
- TPC broke wires– Fixed, Anode HV fixed
- PWC5,6 broke wires- Fixed
- Drift chambers made functional– re-fused.
- BCKOVs auto pressure curves. Worked well
- ToF wall worked
- Calorimeters worked

Beam Chamber profiles- *BC2*



Drift Chamber Profiles- DC1



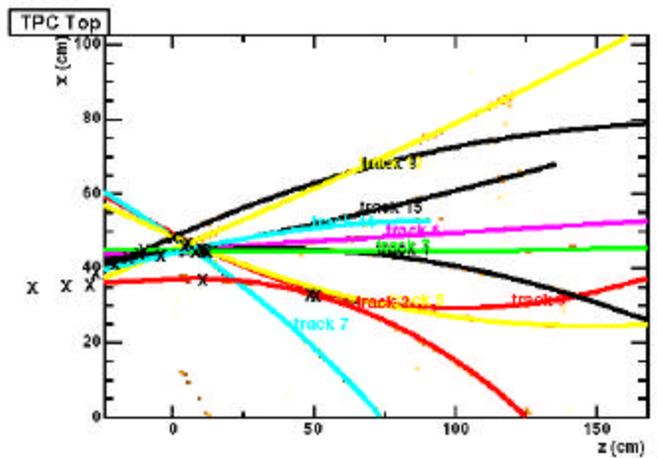
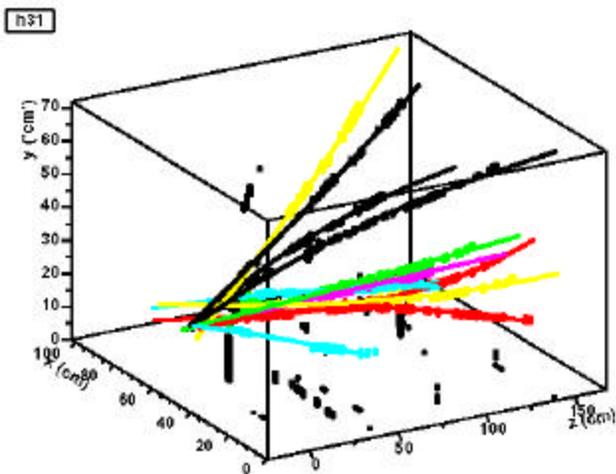
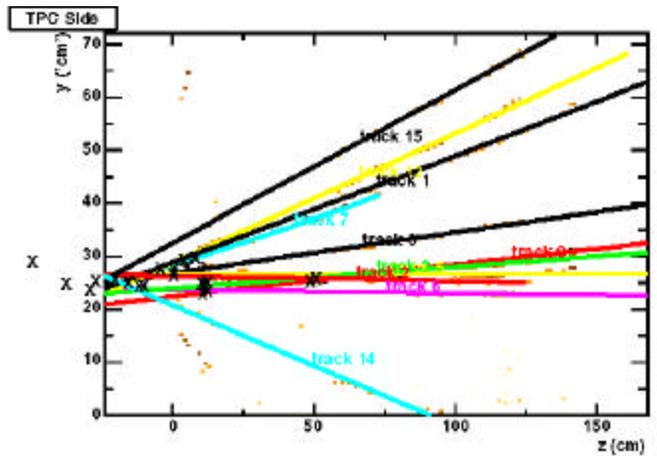
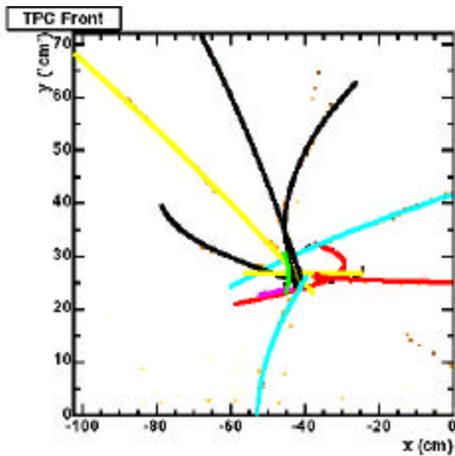
TPC processed event

MIPP (FNAL E907)

Run: 9303
SubRun: 0
Event: 1

Thu Aug 19 2004
02:52:42.951283

Version: 0
Trigger: 10008709



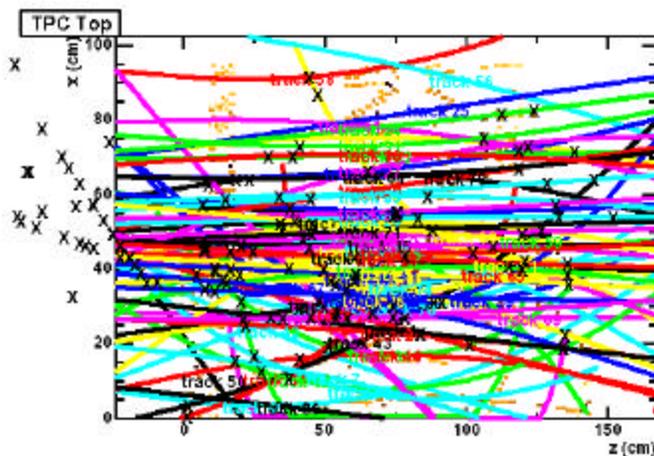
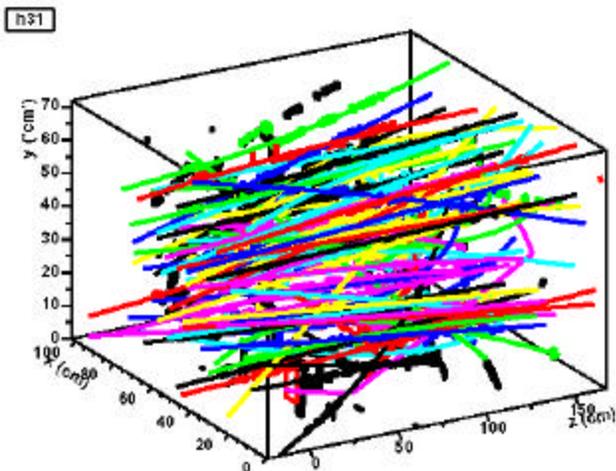
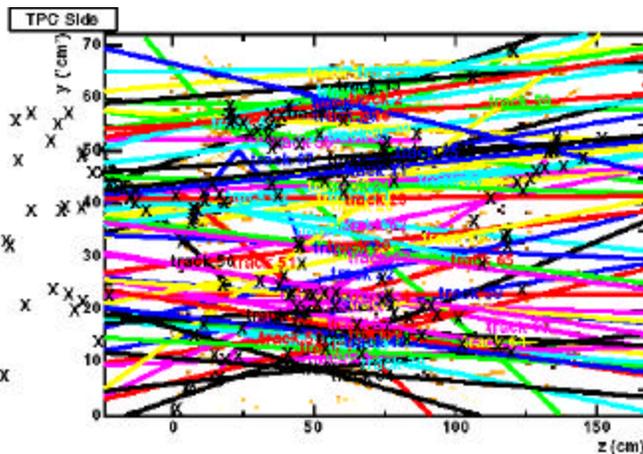
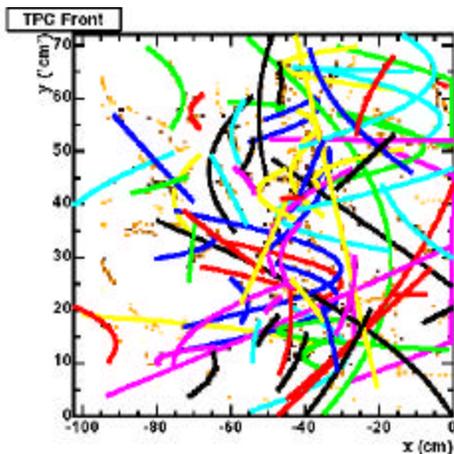
TPC event- Upstream interaction!

MIPP (FNAL E907)

Run: 9196
SubRun: 0
Event: 31

Fri Aug 13 2004
20:34:43.739991

Version: 0
Trigger: 10d88009

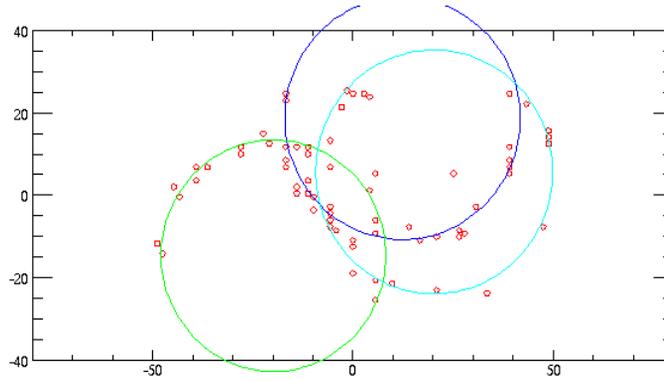


MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 73

Wed Aug 11 2004
13:53:37.257279

Version: 0
Trigger: 10000008

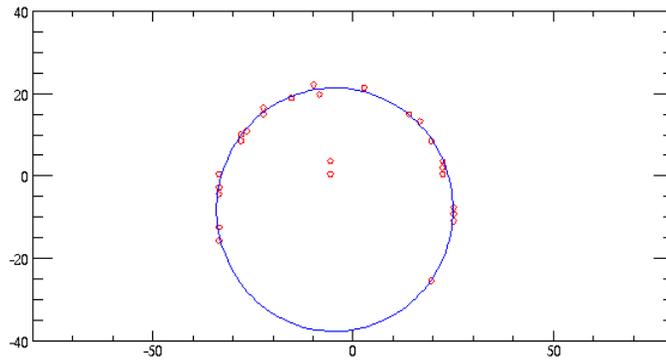


MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 92

Wed Aug 11 2004
13:53:56.884750

Version: 0
Trigger: 10000008

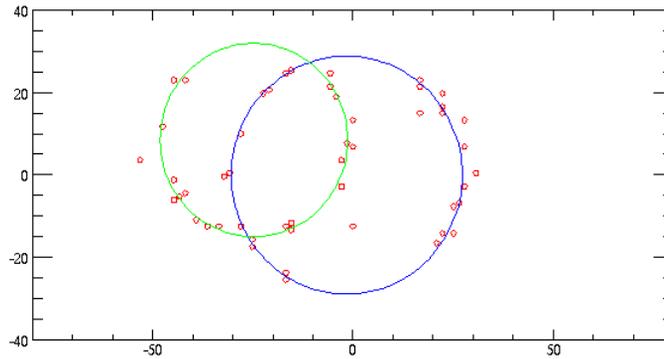


MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 100

Wed Aug 11 2004
13:54:06.823879

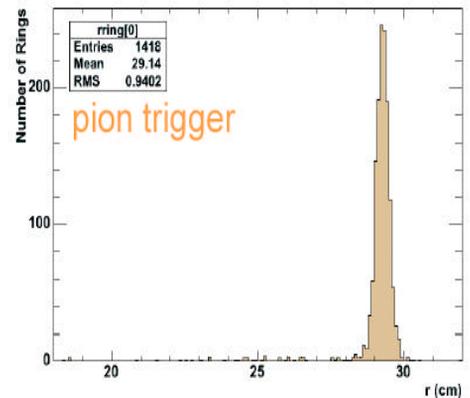
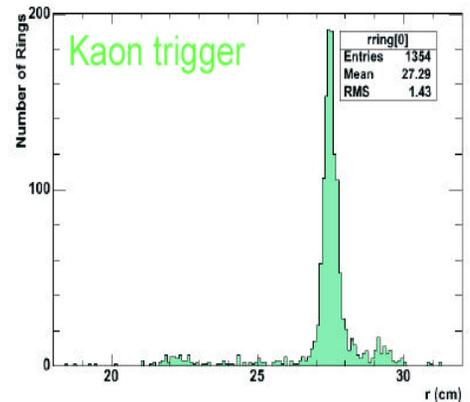
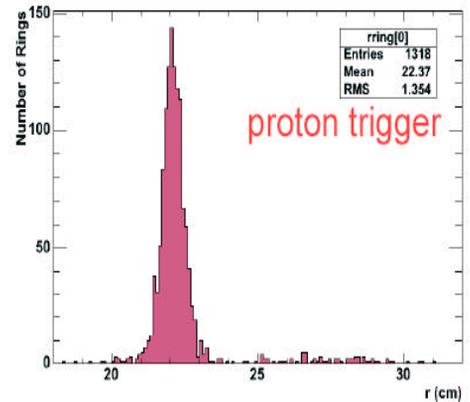
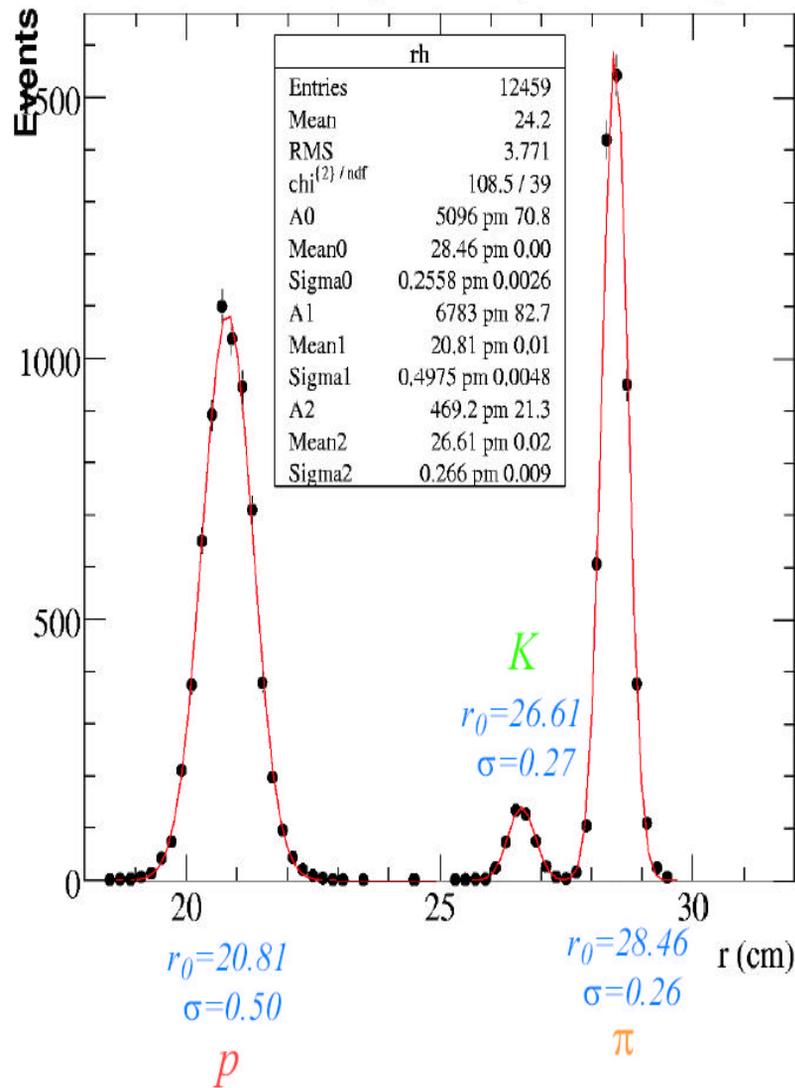
Version: 0
Trigger: 10000008



RICH radii

RICH Ring Radii

80 GeV - Target out (Run 8836)



Runs 9099-9103 40 GeV target out

MIPP Director's review

Observations:

The committee was impressed by the progress made by the MIPP collaboration towards commissioning the spectrometer and writing the necessary software. In particular:

- It was gratifying to see that the TPC track reconstruction and vertex finding package is largely working.
 - Equipment repairs and upgrades, including the fabrication of a liquid hydrogen target, are close to finished, and should all be done by December 1, 2004.
 - The collaborators estimate that 20 days of beam time will be required to finish commissioning and calibrating the spectrometer, and commissioning the trigger.
-
- 120 GeV beam commissioning for MIPP may take some time. This may make it problematic to schedule 120 GeV running during the initial 11 weeks.

Recommendations:

- The collaboration should commission the spectrometer so that high quality data can be collected as soon as possible.
- During the time that 50000 spill-seconds/week are available, high priority should be given to collecting physics data.

MIPP plan of action

MIPP will proceed with commissioning the 120 GeV beam and getting it safety approved.

MIPP will commission experiment Dec 1- Dec31 2004

MIPP will use the period Jan 1- Apr 1, 2005 for secondary beam running

MIPP will run the 120 GeV data points after Apr 1, 2004. This will give us a total of $\sim 0.5E5$ spill seconds.

MIPP will run till the next shutdown currently estimated at Aug 1, 2005.

MIPP upgrade plans

MIPP upgrade---MIPP area is open till ~2008

We are limited by TPC DAQ rate of 60Hz. TPC elect

We have a unique apparatus with unprecedented abilities in data rate, particle id and particle beams. Currently the only beamline on the planet with π^\pm K^\pm p^\pm beams.

Fermilab recently hosted a workshop sponsored by the APS topical Group on Hadronic Physics. A great deal of interest in MIPP from experimenters interested in completing the baryon spectrum (Sigma resonances for example) using MIPP Kaon beams to others interested in using the MIPP beams and energies to explore the pentaquark question further. Will put together a detailed proposal by the next PAC meeting, with more collaborators.

MIPP upgrade to the TPC electronics will result in the TPC running at 3KHZ as opposed to 60 HZ.

MIPP upgrade plans

- One 4 second spill every two minutes is equivalent to 100 spill seconds at 60HZ. We can do a great deal of physics with such an apparatus.
- U. of Virginia group have explored this question and come up with using the custom chip developed by the ALICE collaboration. Well tested chip. ALICE plans a major CHIP run this December. If we can get in on this, we can have our chips for ~\$100K. Other options are more expensive. Total cost ~\$200K with other DAQ improvements.
- I have included documentation on the upgrade plans in the handout.

Conclusions

- MIPP is ready for its first physics run. Excellent platform for students and postdocs to obtain experience on a wide variety of HEP techniques.
- It hopes to improve our knowledge of non-perturbative QCD significantly (The Higgs mechanism may turn out to be non-perturbative!)
- MIPP will get high quality data that will reduce the systematics of experiments (MINOS, MINERVA, NoVA) in the Numi beam.
- MIPP will obtain excellent data on various targets and nuclei of hitherto unprecedented quality and statistics.
- MIPP performance can be greatly improved by small additional investments in student and postdoc support.

Proposal for A High Speed Data Acquisition System for
Experiment E907

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Charlottesville, VA 22904

MIPP-NOTE-GEN-42
November 2004

1 Introduction

The Fermilab Main Injector Particle Production (MIPP) experiment E907 spectrometer is a large aperture, general purpose, open acceptance detector system designed to investigate a plethora of modern topics in medium and high energy particle physics. The experimental apparatus and beam line optics are designed to select and operate with charged particle beams of selectable incident momentum between 5-120 GeV/c. In this energy range, the MIPP beam line triggering system is designed to identify and tag the full range of incident beam particle species, resulting in the ability to perform the outlined physic programs with tagged π^+/π^- , K^+/K^- , p/\bar{p} and the possibility of low energy electron beams. For each beam species and polarity the full range of interaction processes can be examined through the use of both low and high Z target materials. The current target program includes dedicated time on liquid hydrogen and liquid deuterium target cells for detailed examination of exotic states as well dedicated service measurements on nitrogen and oxygen, thin carbon targets and full target prototypes for the current and future programs in neutrino physics at U.S. based accelerator facilities.

The MIPP experiment provides a unique opportunity to continue a rich program of investigation into the nature of strong interactions and strong production mechanisms for exotic states. Minor upgrades to this running detector system will ensure the availability of a large physics rich data set that can continue to provide a basis for investigations into hadronic structure and interactions for years to come.

2 TPC Electronics Upgrade

The current design of the design of the MIPP apparatus relies on a 15,360 channel time projection chamber (TPC) to determine with high precision, in three dimensions, charged particle tracks emerging from the target station mounted on the front aperture of the detector. This chamber has the ability to independently records over 3,800,000 individual data points for a single interaction event and forms the basis of the precision momenta and dE/dx measurements for each particle trajectory. The original device that was refurbished for E907 was designed with a readout system that limited the total data acquisition rate to a maximum of 60Hz. Redesign and updating of the TPC front end electronics, replacing the aging 20 year old components with new high density components, is projected to allow a 50 fold increase in the maximum readout rate of the detector to a theoretic limit of 3kHz.

Currently the readout of the TPC is limited by the multiplexed serial readout system which operates on non-zero suppressed data samples for each given event. In this manner the maximum readout speed is limited to 60Hz, due to the high channel count readout and slow (1Mhz) multiplexing/digitization system. The observed occupancy however, for a typical interaction event in the TPC is only on the order of 5% of

the total channel count. This results in the possibility of greatly increasing the readout capabilities of the detector by performing the initial data filtering on board the front end electronics and reducing by at least an order of magnitude the data throughput that is currently required for a single system read. The readout can be further enhanced by improving the digitization time required for each pad row and increasing the overall parallelization of the readout system.

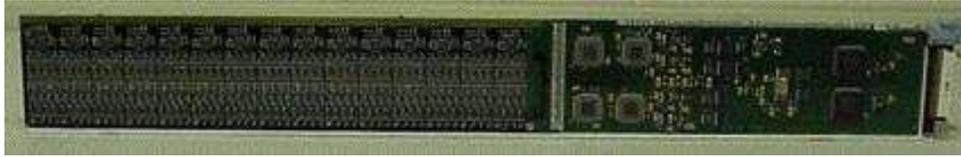
The design goal of the proposed electronics upgrade is to bring the speed of the readout system to a level where it matches or exceeds the maximum frequency at which the detector gating grid can be pulsed. The design limitation on the gating grid sets this upper limit at 3kHz for normal operation of the system. Operation of the system at 3kHz requires that sustained readout of the chamber be accomplished in less than 0.3ms. Non-uniformities in event rate induced by beam structure, restricts this rate in such a manner that the operational time for full event readout should not exceed 0.2ms during burst operation for sustained high speed data acquisition.

The average zero suppressed data size for events as measured during the '04 commissioning run was determined to be on the order of 115kb for multi-track interaction event. The raw data rate when combined with transaction overhead results in the requirement that the output data pathway be designed to accommodate a single spill burst data rate of 575mb/s. The proposed upgrade addresses this throughput via a minimum 5-way parallelization of the output data-way, resulting in a requirement of only 115mb/s per primary data pathway which is compatible with commercial data bus implementations.

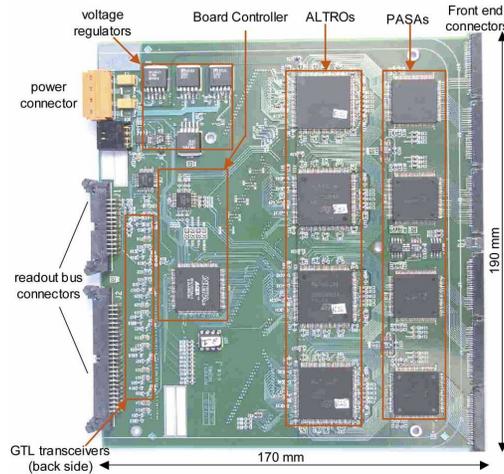
Upgrade of the TPC front end cards (FECs) to meet these requirements has been examined using two separate design solutions. The first method for redesigning the front end cards relies on a pair of custom designed ASICs that have been engineered, tested and produced for the A Large Ion Collider Experiment (ALICE) collaboration at the LHC for use in their more than 570,000 channel time projection chamber. The system incorporates two separate chips, "PASA" an analog preamp/shaper and "ALTRO" a fast ADC/filter which provides event buffering, baseline corrections, signal filtering and zero suppression. The two chips are integrated in a standardized front end card with a dedicated data bus that is synchronized to the main data acquisition system via a series of readout control units (RCUs). The system has also been adopted by the BONUS collaboration for use in their TPC in Hall B of Jefferson Lab, as well as by the TOTEM experiment at CERN.

The second upgrade solution is based upon a combination of a fast high density analog to digital converter, paired with a FPGA on the FEC to perform zero suppression and tail corrections. The readout to the main data acquisition is performed via an on board gigabit over copper Ethernet transceiver connected to a series of high speed switches that feed into VME style signal board computers.

These upgrade options are detailed in sections 2.1 and 2.2.



(a) E907 TPC front end electronics “stick”



(b) ALICE TPC front end electronics card

Figure 1: TPC front end electronics boards for E907 and ALICE. The difference in physical form factor requires a redesign of the ALICE board to match the E907 cold plates and connectors

2.1 ALICE ASICs

To accommodate the readout of 570,136 charge collection pads, each sampling at a maximum of 1000 samples per event, the ALICE collaboration designed and engineered two custom ASICs to operate in the high rate environment of the LHC heavy ion program. The ALICE readout design, as would be incorporated into the upgrade of the E907 TPC would replace both the analog and digital portions of the current front end electronics cards. Each of the existing 128 analog/digital electronic “sticks” as shown in Fig. 1(a) would be removed and replaced in a one to one manner with an ALICE FEC as shown in Fig. 1(b), redesigned to match the physical dimensions of the aluminum cold plate upon which the current electronics are mounted. Additionally the cards would be fitted to use zero insertion force (ZIF) socket compatible with the current TPC chamber connections and interlocks. This redesigned FEC follows in all other respects the electrical design and characteristics of the current CERN board layouts.

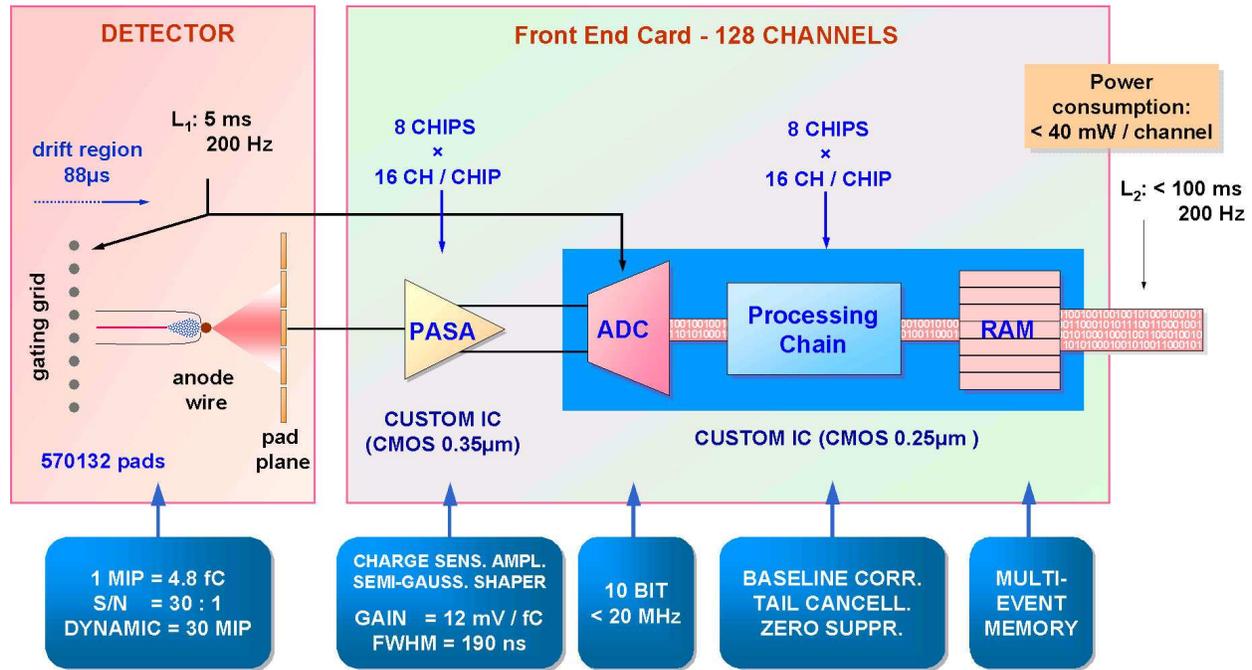


Figure 2: ALICE front end card and readout system block diagram[Musa et al.(2003)]

The ALICE system as shown in Fig. 2 is divided into two stages. The raw signals from the detector pad rows are first fed into a custom designed integrated circuit referred to as “PASA” which serves as the preamp and pulse shaper for each channel[Mota et al.(2000)Mota, Musa, Esteve, and Jimenez de Parga]. The raw charge collected from the sample window is reshaped into a sharply peaked output distribution of width $\mathcal{O}(190ns)$, as shown in Fig. 3, which is matched to the input requirements of the ALTRO chip for accurate digitization. Each PASA chip services 16 readout pads and is matched to the ADC inputs of the ALTRO chips shown schematically in Fig. 4 for a single digitization channel. The ALTRO ASIC as shown in Fig. 5 is a 16 way parallel system including on each channel a 10MHz ADC, digital signal processor, and memory buffer. The operation of the chip is compatible with normal fixed-target data acquisition operation. Although the signals are sampled continuously the data is processed (pedestal subtraction, shaping and sparsification) only upon receipt of a Level 1 trigger signal. The processed data is stored in the memory buffer upon receipt of a Level 2 accept signal or otherwise discarded. The chips are controlled over a 40bit wide “ALTRO BUS” developed at CERN [Subiela et al.(2002)Subiela, Engels, and Dugoujon][Musa et al.(2003)] for communication with with a Readout Control Unit (RCU).

The RCU system, as shown in Fig. 6, serves as the interface between the experimental acquisition and control software and the front end cards. Each RCU is designed to interface with a set of 12 front end cards

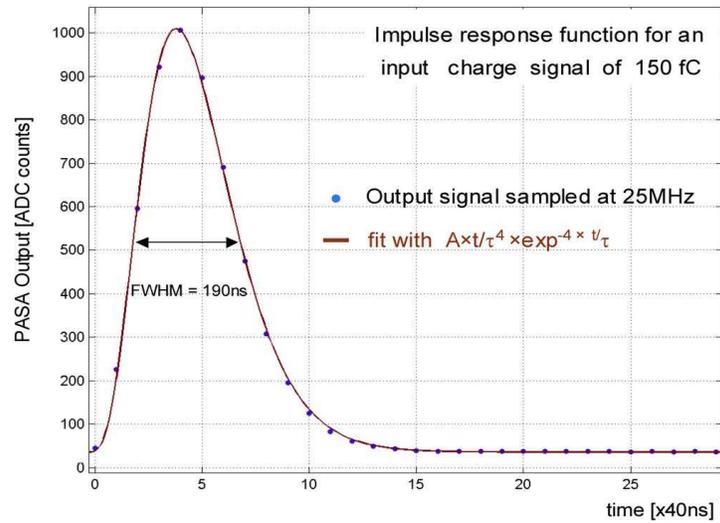


Figure 3: PASA output function for an initial test charge of 150fC[Bosch et al.(2003)Bosch, Parga, Mota, and Musa]

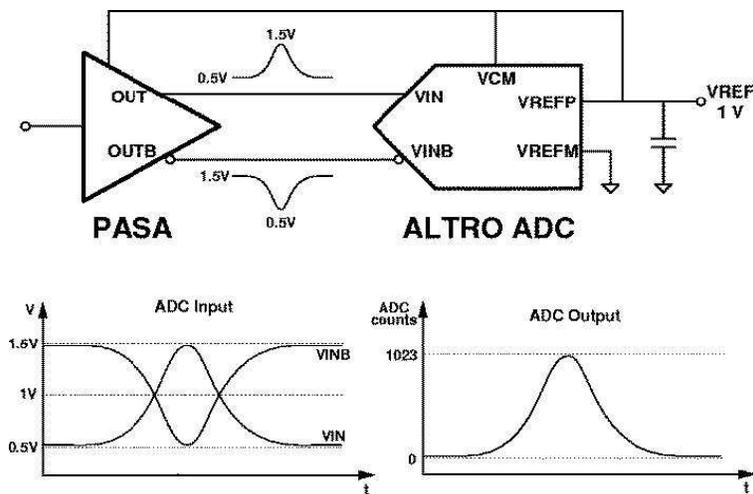


Figure 4: PASA to ALTRO digitization logic[Campagnolo et al.(2003)]

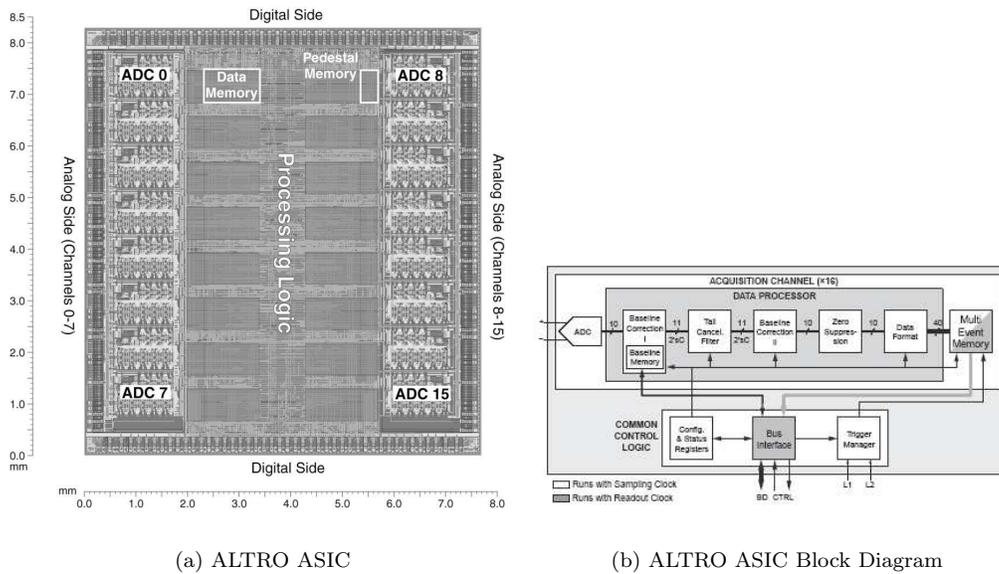


Figure 5: The ALTRO chip developed at CERN services the readout of 16 channels by integrating a fast ADC, signal processing and event buffering in a single package with interface to a high speed data bus and programming lines

providing a single high speed data pathway for the zero suppressed event data. The protocol of the output data path is customizable and has been shown to operate both with the high speed serial link protocols developed at CERN, as well as the more common USB protocol and peripheral connection interface (PCI) to bridge the data directly into single board computer memories for further processing. Prototypes of the various RCU interface cards as shown in Fig. 7 and Fig. 8 and have been built and tested both by the ALICE and BONUS collaborations using standard PC based test stands like the one pictured in Fig. 9. The current prototyped RCUs would need no further adaptations to interface directly with the current VME signal board computer system used in the E907 system.

Implementation of the ALICE front end electronics in the E907 TPC require that several additional modifications be made to match the operational needs of the existing hardware. The time window for event scanning and digitization will be reduced from 1000 samples per event to 250 samples to match the drift time over the active volume of the detector. The reduced number of samples then allows for additional segmenting of the ALTRO event buffer in such a manner that the FEC cards will be able to fully buffer 8 events at a once. To ensure that the heat load generated by the new front end boards is compatible with the existing cold plates and water cooling system, provisions have been made to operate the ALTRO bus at 20 MHz instead of the 40MHz design frequency. These modifications are projected to both increase stability

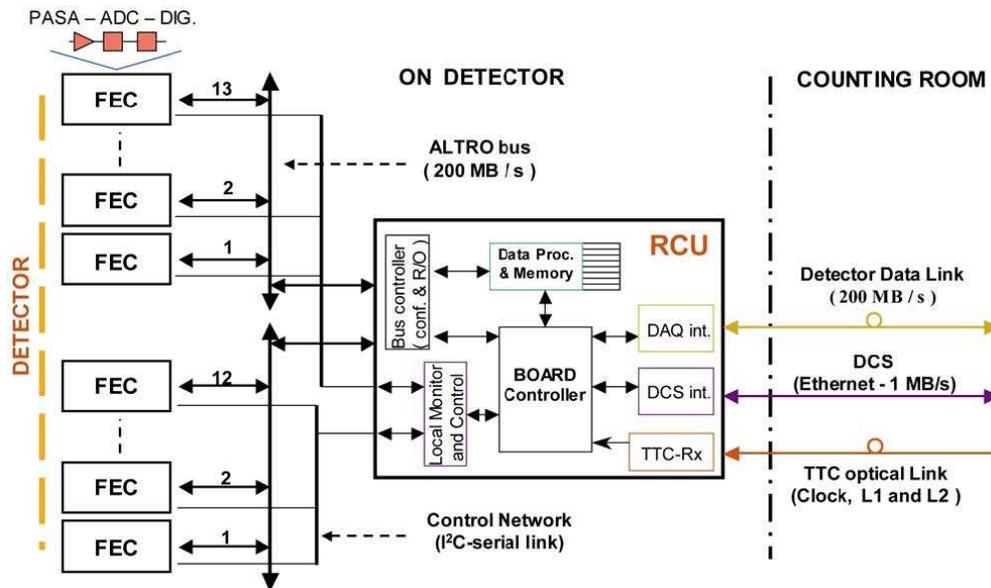


Figure 6: Readout control unit interface between front end cards and main data acquisition system[bosch et al.(2002)]

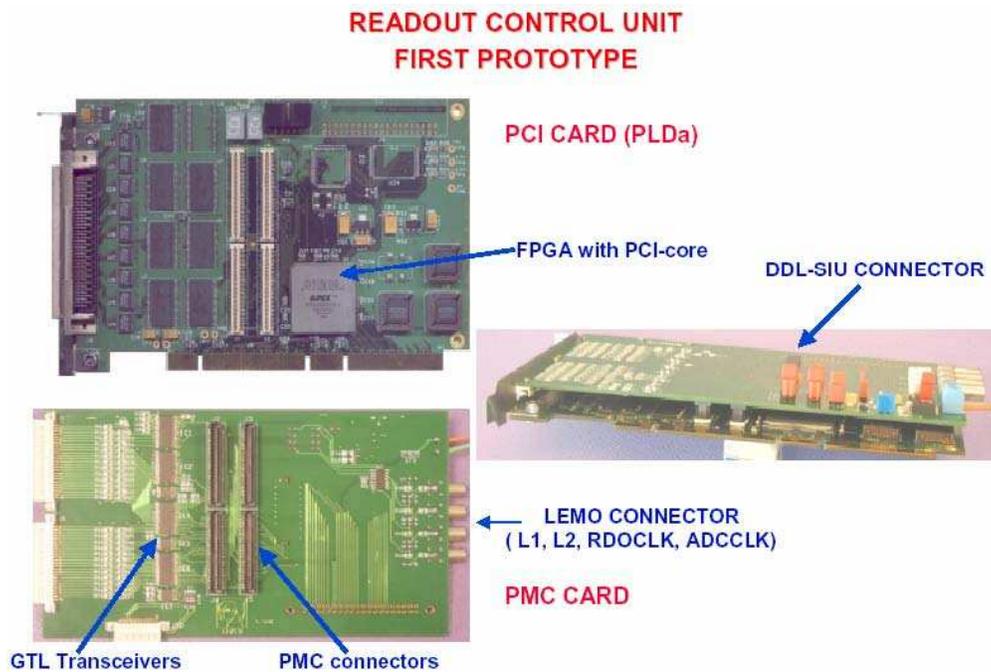


Figure 7: Readout control unit PCI interface prototype[bosch et al.(2002)]

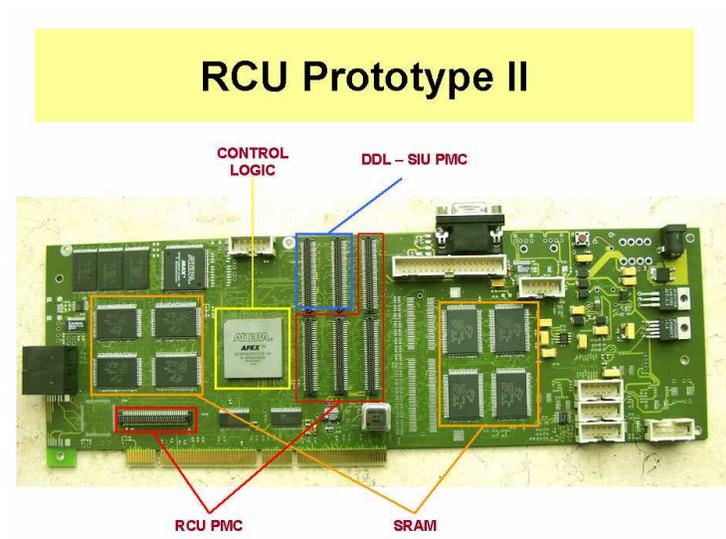


Figure 8: Readout control unit alternate interface prototype[bosch et al.(2002)]

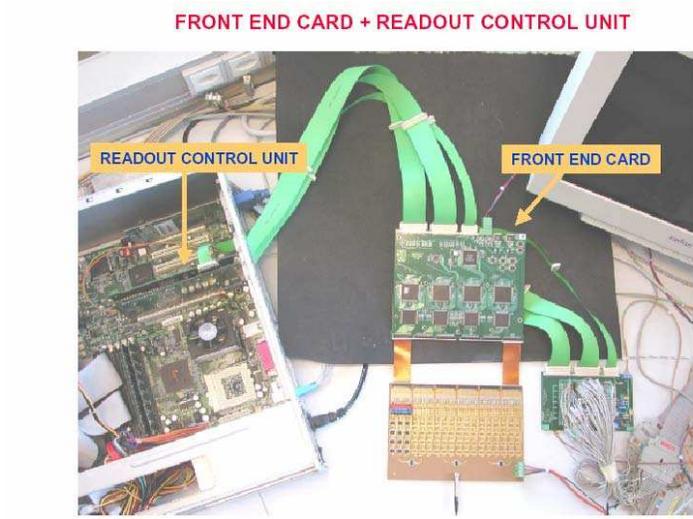


Figure 9: Readout control unit test station[bosch et al.(2002)]

Component	Channels	# Per FEC	Total Required
Front End Circuit Board	120	1	128
ZIF Sockets		1	128
Preamp/Shaper (PASA)	16	8	960
ADC/Filter/Memory (ALTRO)	16	8	960
Readout Control Units (RCU)	1536	1:12	10
Single Board VME PCs	1536	1:12	10
PCI Mezzanine Receivers	1536	1:12	10
Gigabit Network Switch			1

Table 1: Component requirements for upgrade of the E907 time projection chamber for operation at 3kHz.

and retain the utility of as much of the existing equipment as is possible.

The component requirements for the full system upgrade of the time projection chamber are listed in Table 1. The projected yield for the PASA and ALTRO wafers based upon the previous production run is estimated at 82%. When yield is included, it is estimated that 1200 raw dies would be required to obtain enough components to instrument the detector.

The cost per channel for the ALTRO electronics solutions, dependent upon chip yield, is estimated at \$10 per channel based upon the electronics costs for instrumenting the BONUS TPC at Jefferson lab. The total cost of the front end electronics modifications is estimated at a direct cost of \$155,000 without contingency. Additional cost is incurred in the procurement of 10 single board VME style computers for event filtering and synchronization. Each single board processor is estimated to cost \$1800-2000 dependent upon final specifications and memory buffering requirements. The total cost of the VME processor boards is expected to be \$20k. The total direct cost of equipment for upgrading the E907 time projection chamber is estimated at \$175k without contingency.

The above cost estimates assume that the ALTRO and PASA chips needed by MIPP would be part of a larger production run. The next production run is slated for the end of 2004 or early 2005. Of that run approximately 1300 bare chips are uncommitted, as of September 2004. After packaging it is estimated that approximately 1060 chips will pass testing. The testing would be done by institutions in the ALICE collaboration, who have developed custom test stands for verification of ALTRO and PASA chips. In order to be able to obtain the chips for an upgrade of the E907 TPC from the ALICE production run and to have these items tested along with the bulk of the ALICE production run, it is necessary to have funding by the end of 2004 to secure the afore mentioned 1300 uncommitted bare dies. The amount needed for procurement of packaged and tested PASA and ALTRO chips is approximately \$105k.

Component	Channels	# Per FEC	Total Required
Front End Digital Boards	120	1	128
High Speed Flash ADC	8	15	1920
FPGA (Filtering, Evt. Buffer)	8	15	1920
FPGA (Readout Control)	120	1	128
PROM (FPGA Programming)	120	2	248
Ethernet Controller	120	1	128
Ethernet Transceiver	120	1	128
Single Board VME PCs	1536	1:8	16
PCI Mezzanine Receivers	1536	1:8	16
Gigabit Network Switch			2

Table 2: Component requirements for secondary upgrade design of the E907 time projection chamber.

2.2 Discrete ADCs and FPGAs

In the event that the ALICE front end electronics are available due to limited production runs of the PASA and ALTRO ASICs, a second upgrade design is possible using discrete components to mimic the functionality of the ALICE electronics. In this solution the existing front end electronics boards are severed at the interface between the analog and digital portions of the PCB via removal of the existing solder junctions that connect the stick halves. The analog electronics including the zero insertion force socket and the corresponding interlock mechanism are retained and joined to a new digital board containing upgraded electronics for the digitization of the detector signals as well as for filtering, buffering and zero suppression.

The new design of the digital front end boards use high speed, high density flash analog to digital converters (ADCs) that are commercially available in eight channel packages to perform the initial digitization of the pad signals. Each discrete ADC chip is mated to a Field Programmable Gate Array (FPGA) which is programmed to operate as a sample and event buffer for each of the eight ADC channels. Zero suppression is performed within the FPGA using the event's sample buffer and an algorithm similar to that which is currently used in the digital signal processing phase of the TPC readout system. The resulting sparsified data is transferred to a secondary FPGA which merges the outputs of the 15 processing chains for a front end card and then transmitted along a standard high speed protocol to a VME type single board computer for further processing and event reconstruction.

In addition to the ADCs and FPGAs the design requires a series of programmable memories for storing instruction code for the FPGAs, and a set of standard Ethernet transceivers for interfacing the front end boards to the VME processors that serve as the primary output data pathways. The estimated major components which drive the secondary upgrade design are listed in Table 2.

The secondary design has an estimated component cost of roughly \$40 per channel driven by the cost of the high density FPGAs. In addition due to the complexity of the readouts, the design requires a larger

number of single board computer to serve as the receiving stations for the event data. The minimum number of VME single board computers is estimated at sixteen units, each servicing the readout of eight front end cards, and is driven by the availability of commercially available receivers. The total cost of the secondary upgrade path is estimated at \$620k for the discrete components and \$32k for the single board computers. These costs exclude the required engineering for development of the FPGA programming and board design.

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