The main Injector Particle Production Experiment (MIPP) at Fermilab –Status and plans

Rajendran Raja
Fermilab

- Review Status of MIPP
- Present ongoing analysis
- Review plans to obtain higher quality data- MIPP Upgrade FNAL-P-960 –Relevance to cosmic ray physics
- Conclusions

MIPP collaboration list

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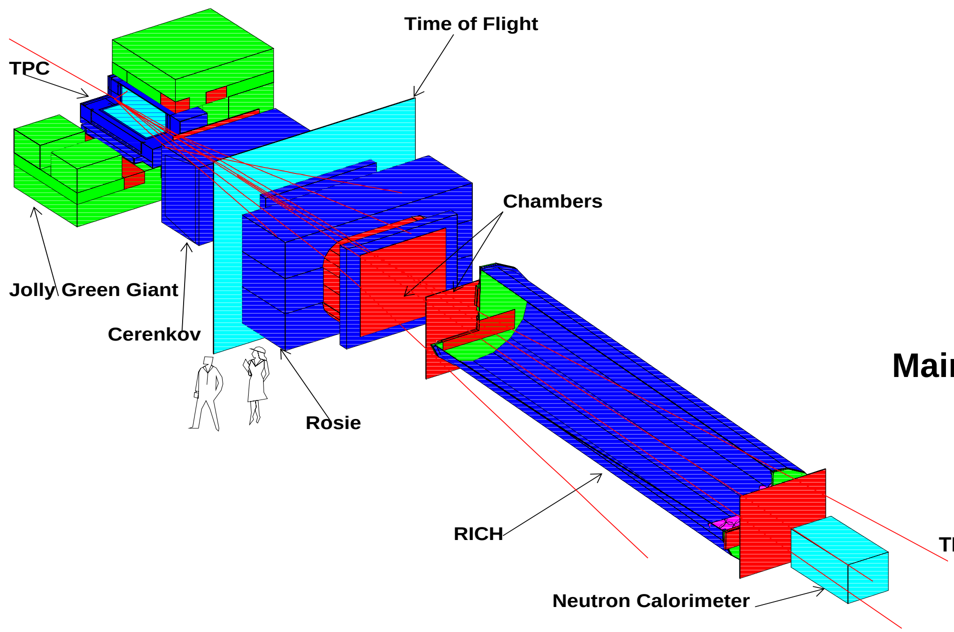
MIPP

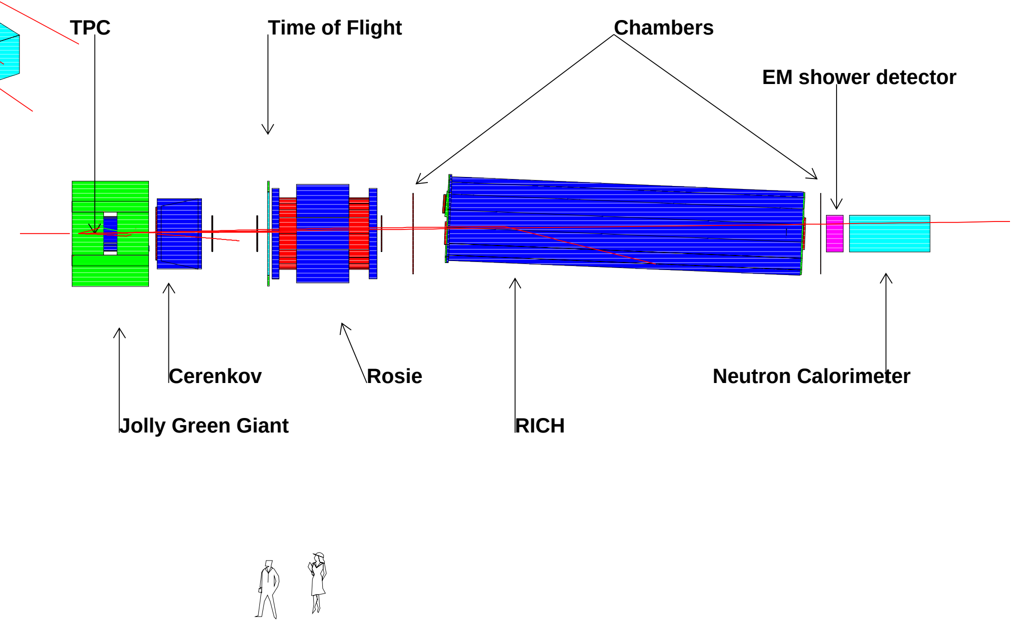
Main Injector Particle Production Experiment (FNAL-E907)



MIPP

Main Injector Particle Production Experiment (FNAL-E907)

Vertical cut plane



Status of MIPP Now-
Collision Hall

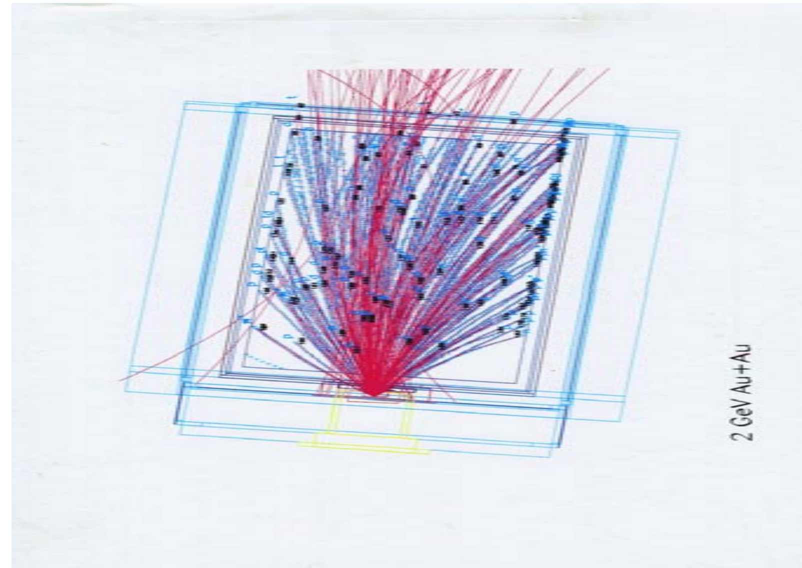
Brief Description of Experiment

- Approved November 2001
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of $\pi^{\pm}$ $K^{\pm}$ $p^{\pm}$ from 5 GeV/c to 100 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Using 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.

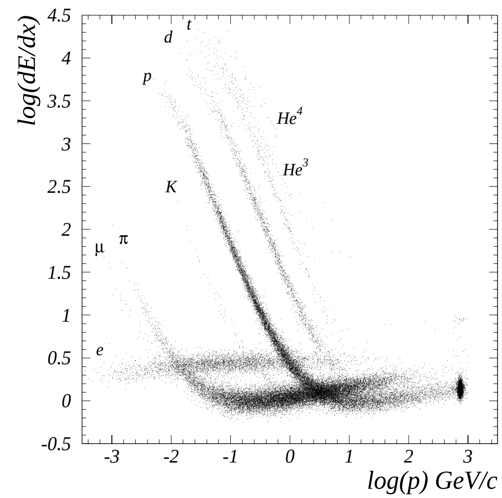
Physics Interest

- 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 $\pi^{\pm}$ $K^{\pm}$ $p^{\pm}$ -- 420M triggers. 3KHZ TPC.

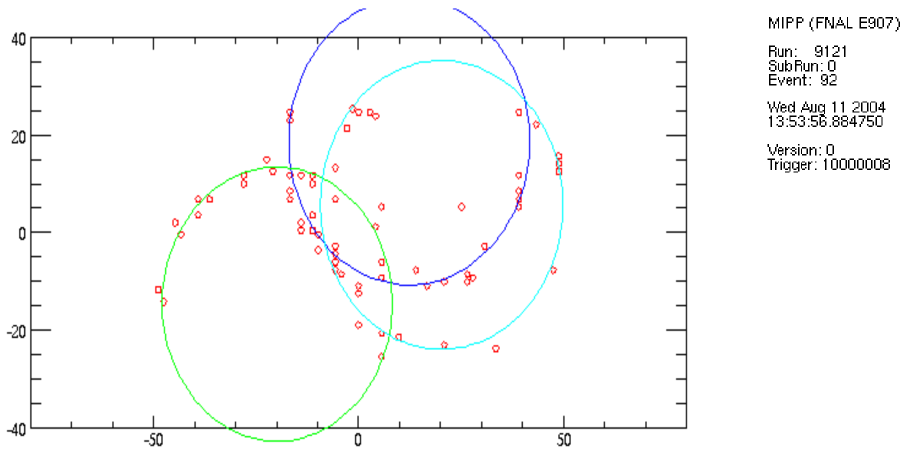
TPC

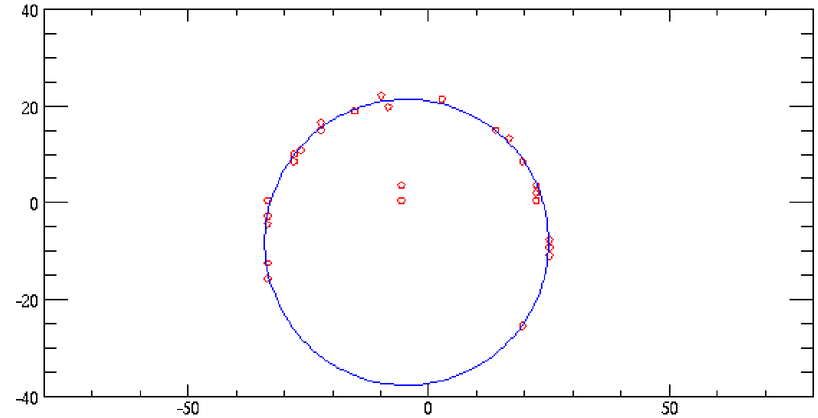


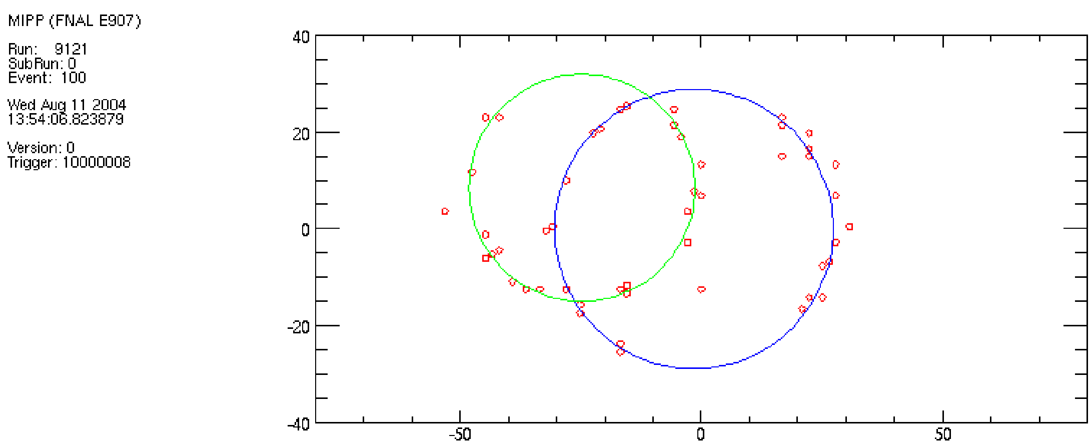
TPC dE/dx Particle ID- BNL E910



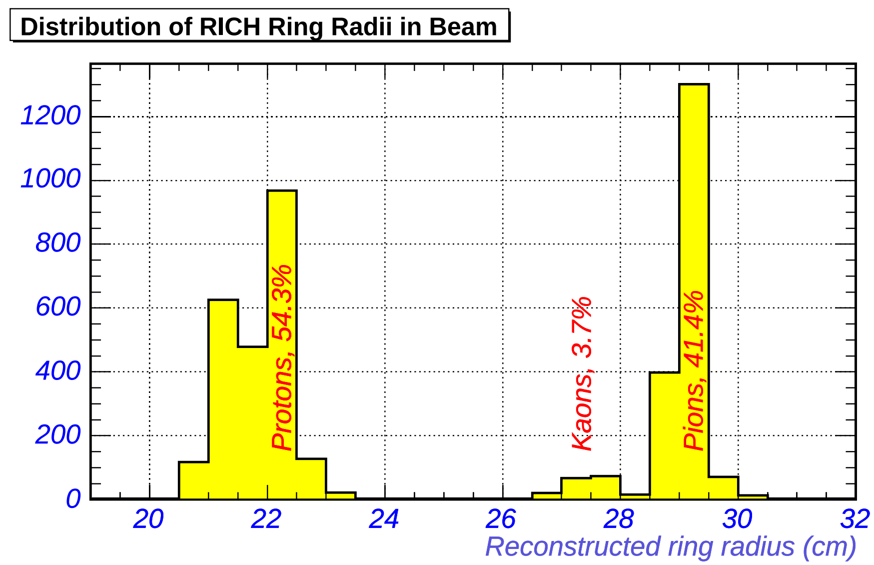
RICH rings pattern recognized



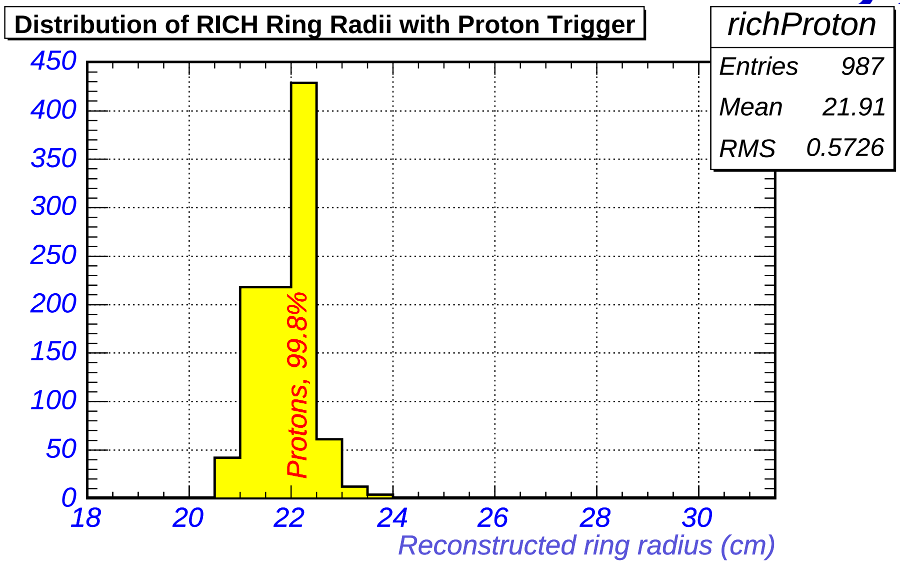


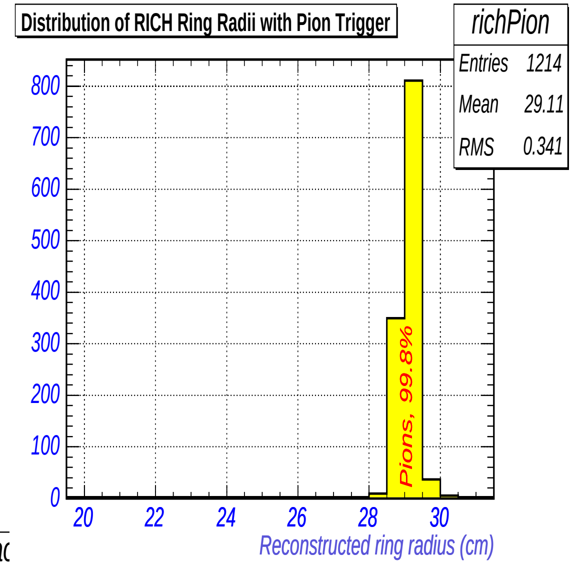


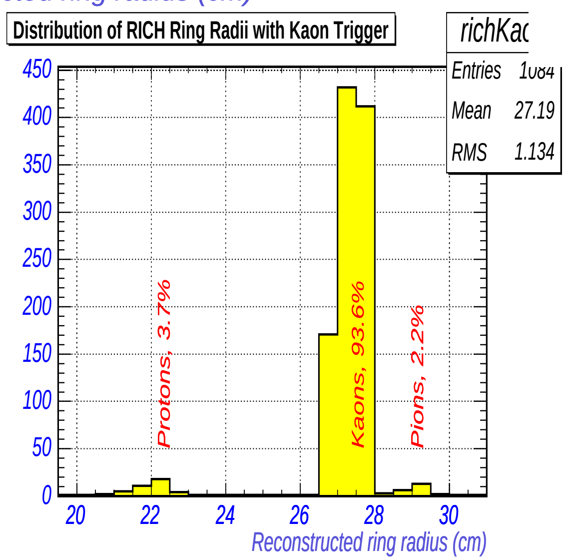
RICH radii for + 40 GeV beam triggers



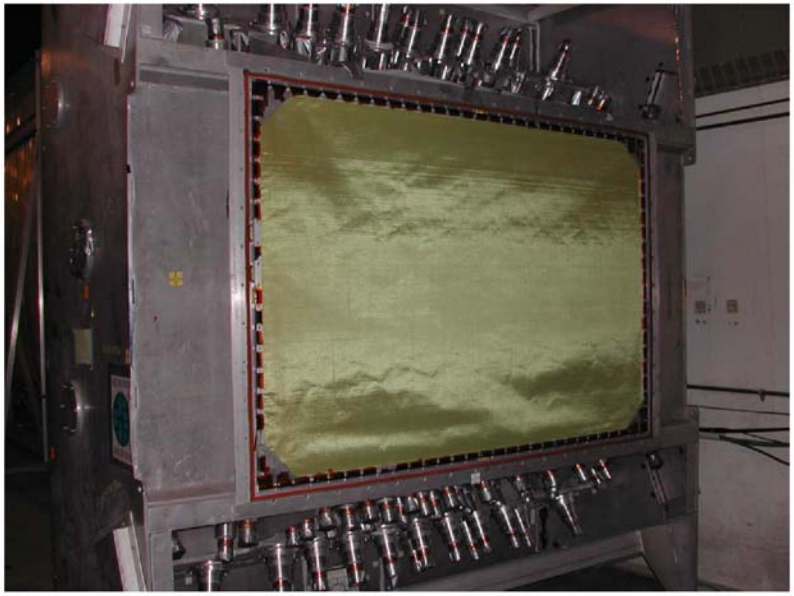
Comparing Beam Cherenkov to RICH for +40 GeV beam triggers-No additional cuts!







MIPP Cherenkov



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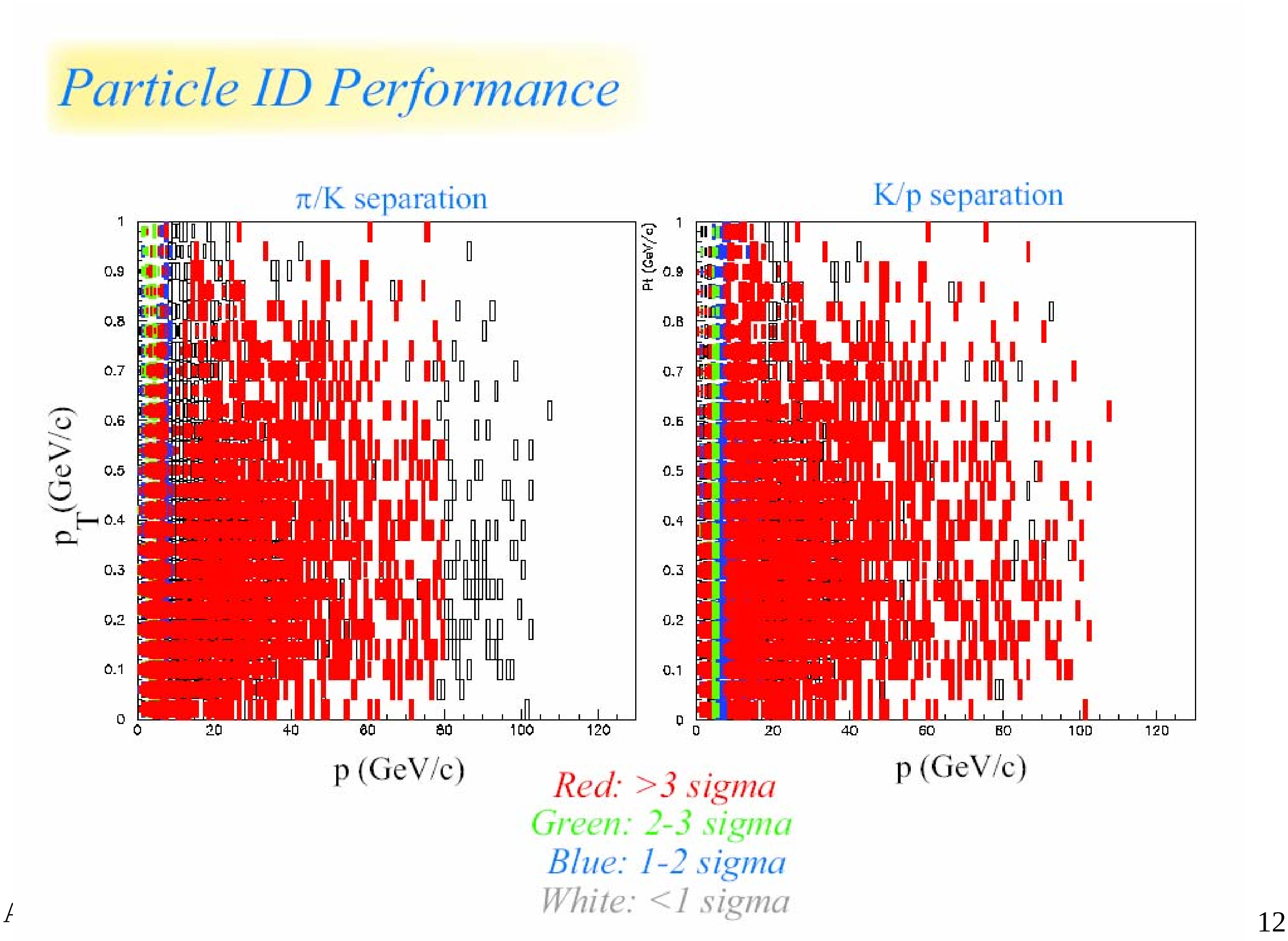
MIPP Particle ID

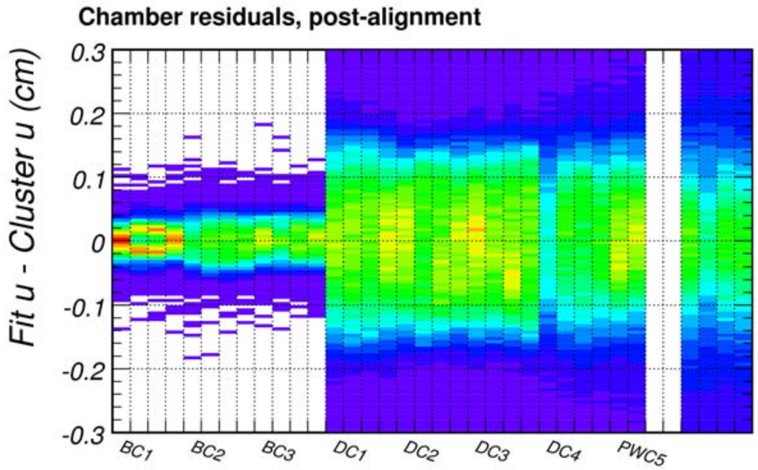


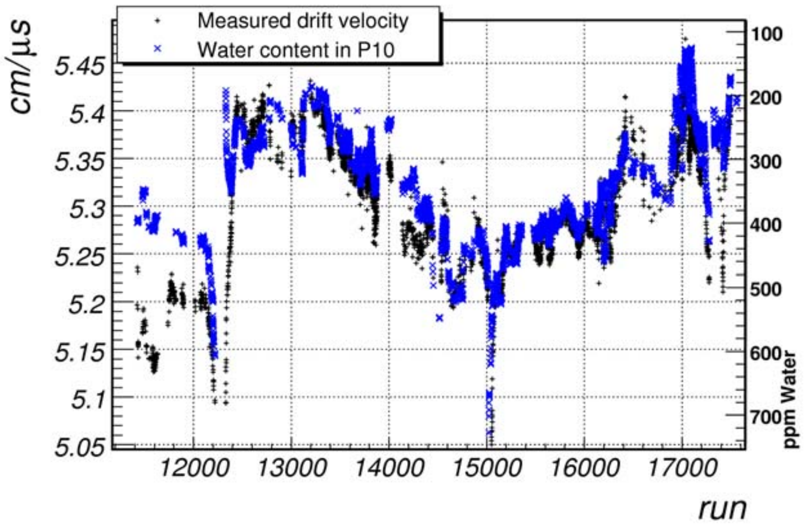
Data Taken In current run

Data Summary 27 February 2006			Acquired Data by Target and Beam Energy Number of events, x 10^6									
Target			**E**									**Total**
Z	**Element**	**Trigger Mix**	**5**	**20**	**35**	**40**	**55**	**60**	**65**	**85**	**120**	
0	**Empty**[1]	**Normal**		*0.10*	*0.14*			*0.52*			*0.25*	***1.01***
	***K* Mass**[2]	**No Int.**				*5.48*	*0.50*	*7.39*	*0.96*			***14.33***
	Empty LH[1]	**Normal**		*0.30*				*0.61*		*0.31*		**7.08**
1	**LH**	**Normal**	0.21	**1.94**				**1.98**		**1.73**		
4	**Be**	***p* only**									1.08	**1.75**
		Normal			0.10			0.56				
6	**C**	**Mixed**						**0.21**				**1.33**
	C 2%	**Mixed**		**0.39**				**0.26**			**0.47**	
	NuMI	***p* only**									**1.78**	**1.78**
13	**Al**	**Normal**			*0.10*							***0.10***
83	**Bi**	***p* only**									1.05	**2.83**
		Normal			0.52			1.26				
92	**U**	**Normal**						1.18				**1.18**
Total			**0.21**	**2.73**	**0.86**	**5.48**	**0.50**	**13.97**	**0.96**	**2.04**	**4.63**	**31.38**

Ongoing analysis-Spectrometer Calibration

- Chamber alignment done for every run
  - » Helped to find bugs in geometry description and refine magnetic field maps
- TPC electron drift velocity measured for every run
  - » Strong correlation with water vapor contamination

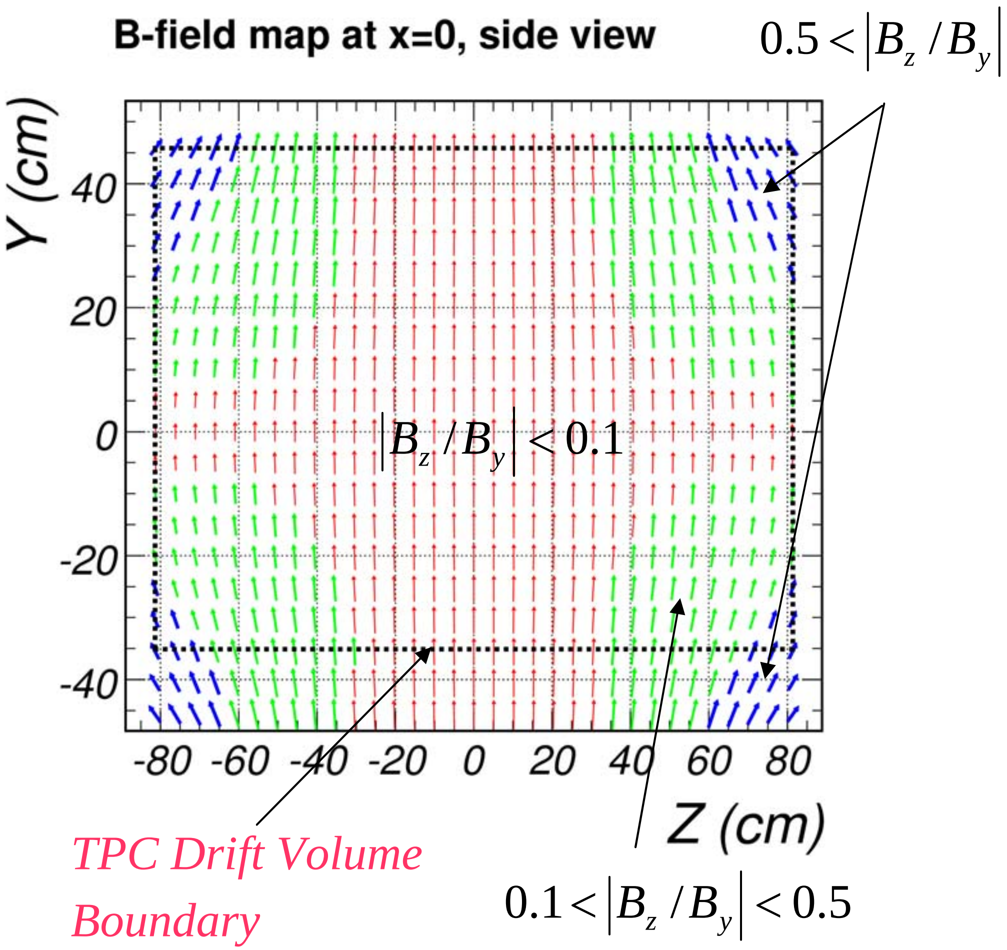




TPC Hit Reconstruction

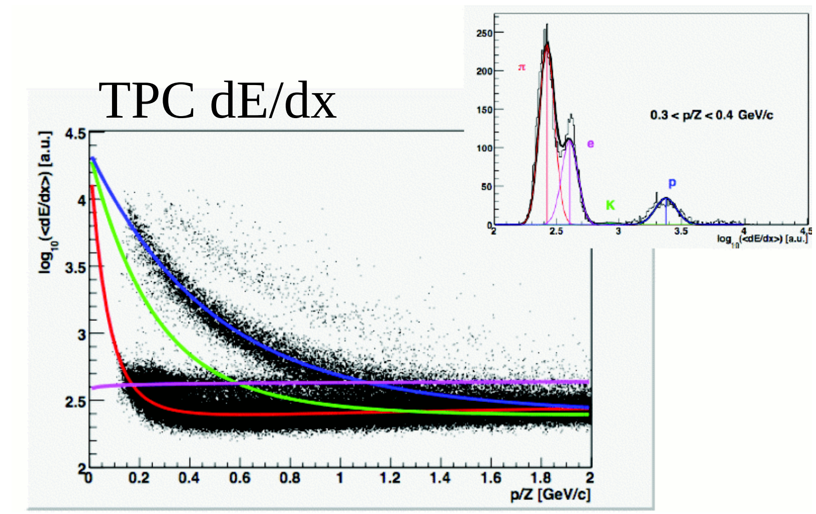
- JGG field is non-uniform
  - » Enormous effect on electron drift in Ar/CH_4
- Previous experiments applied corrections based on steady state solution to linear model

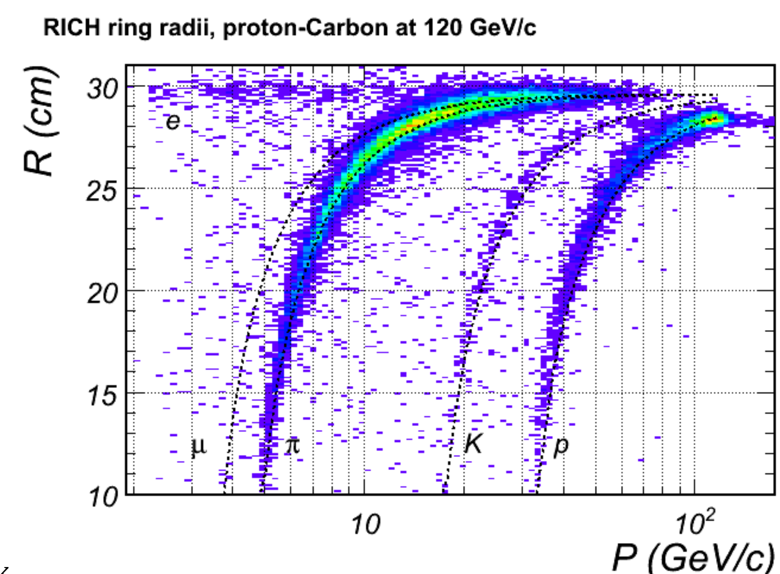
$$m\frac{d\vec{v}}{dt} = e\vec{E} + e\vec{v}\times\vec{B} - \frac{1}{\tau}\vec{v}$$



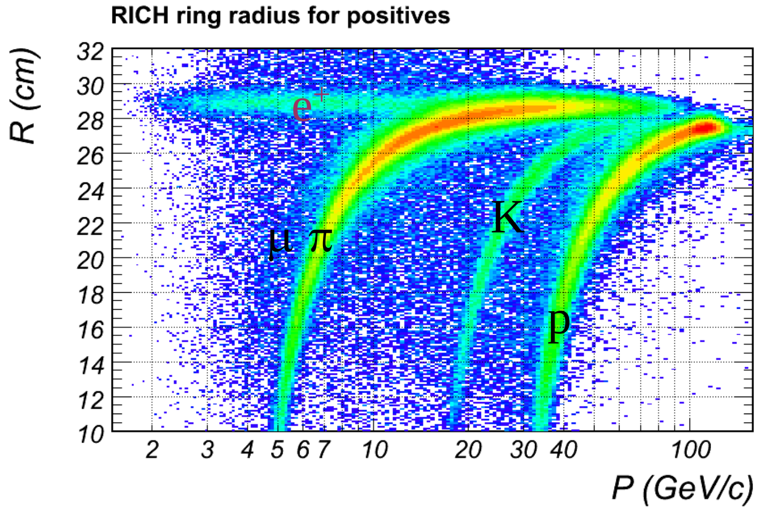
Particle ID status

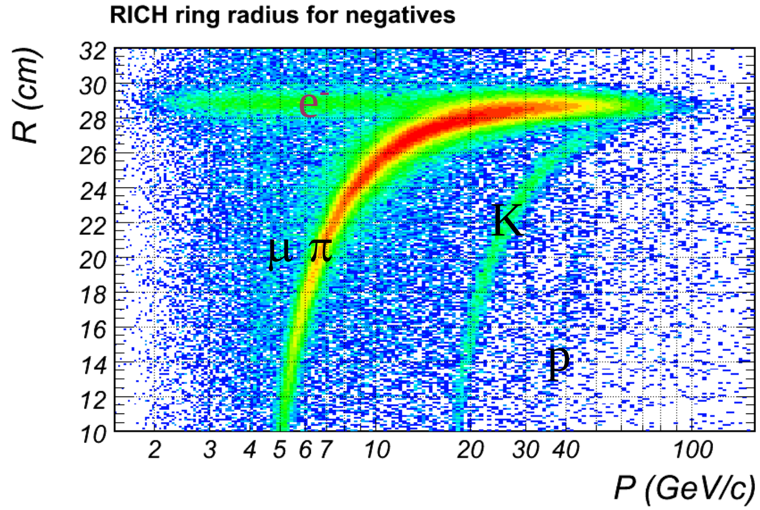
- TPC dE/dx calibration is in progress,
  - Results to-date are promising
- TOF cable delays to be determined soon
- Cherenkov light calibration is largely done
- RICH calibration and likelihood calculation are nearly complete





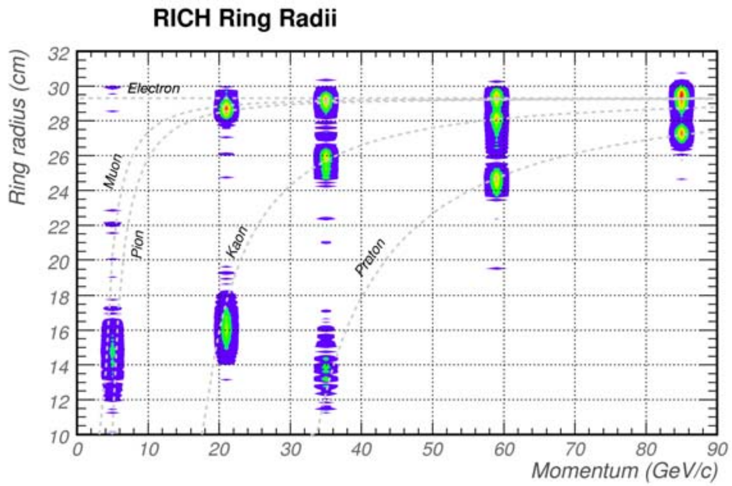
Particle ID (cont.)

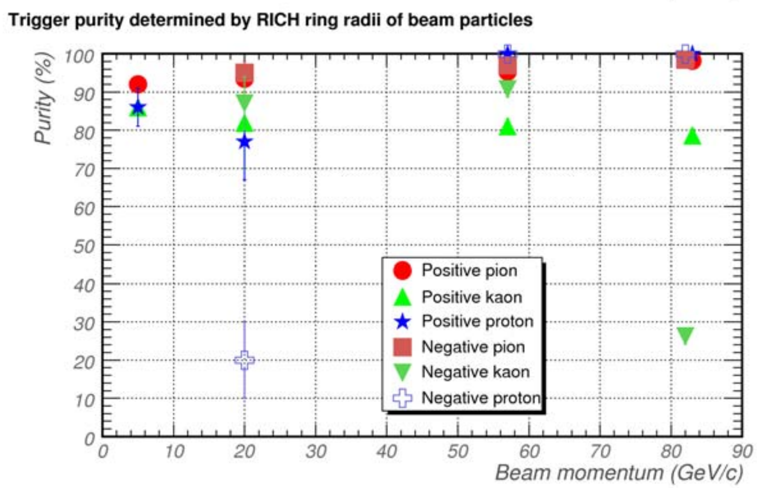




- RICH ring radius gives very good particle ID within acceptance
  - » e/μ/π to 12 GeV/c
  - ≈ π/K/p to 100 GeV/c
- Detector is calibrated and well understood

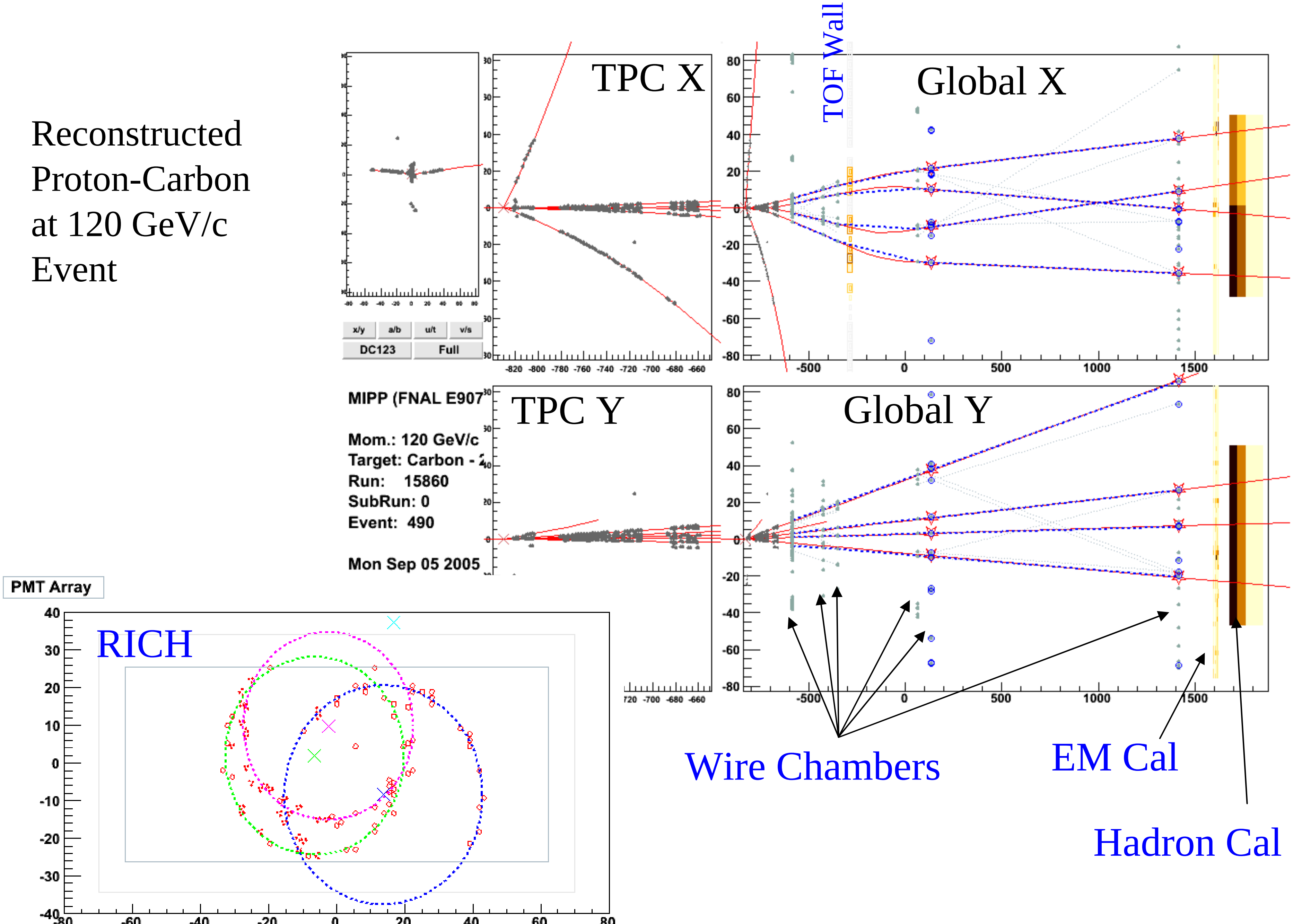
Secondary Beam Particle ID





- 2 beam Cherenkov threshold counters separate π/K/p from 20 to 90 GeV/c
  - » N_2 for momenta above 30 GeV/c
  - » C_4F_8O for proton at 20 GeV/c
- Trigger purity measured with the RICH is typically above 80% for minority particle

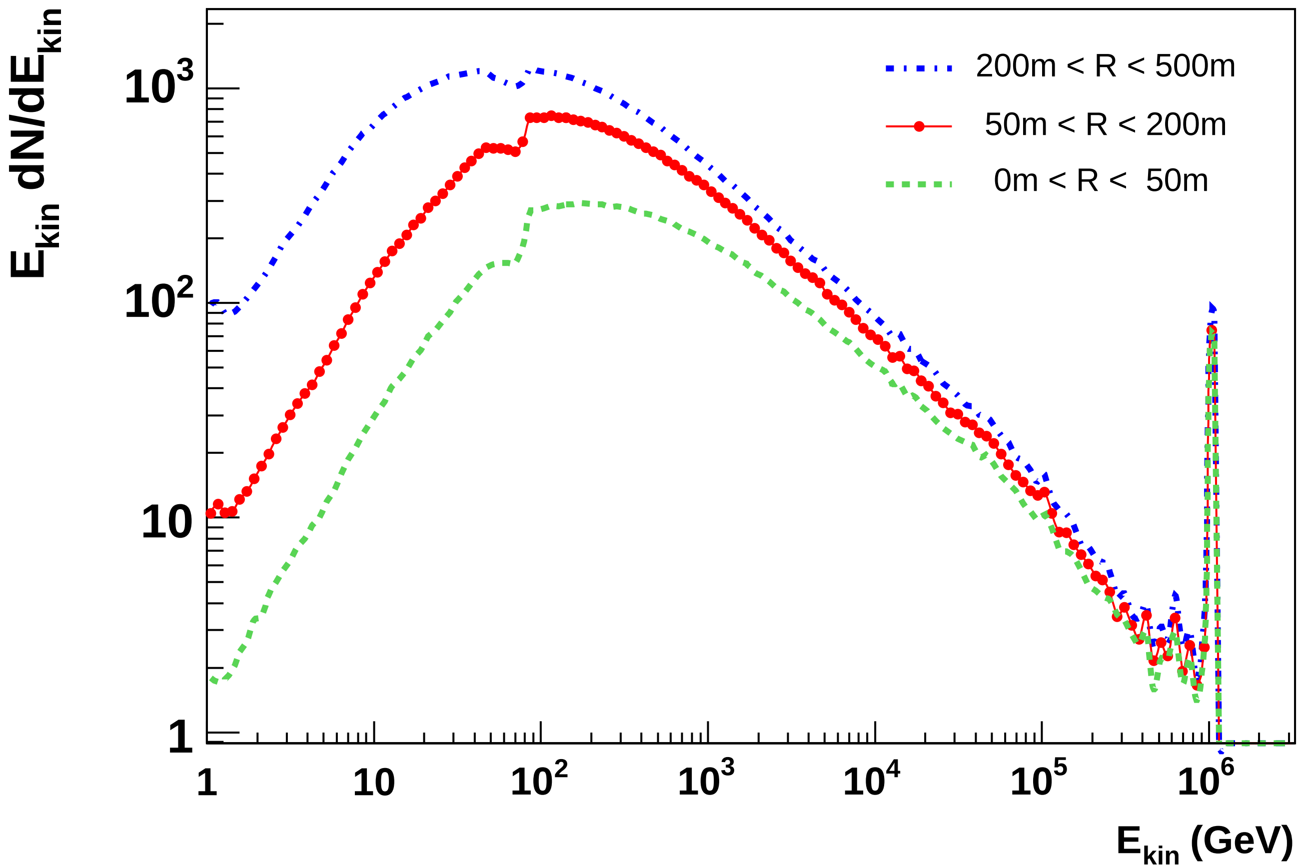
Reconstructed Proton-Carbon at 120 GeV/c Event



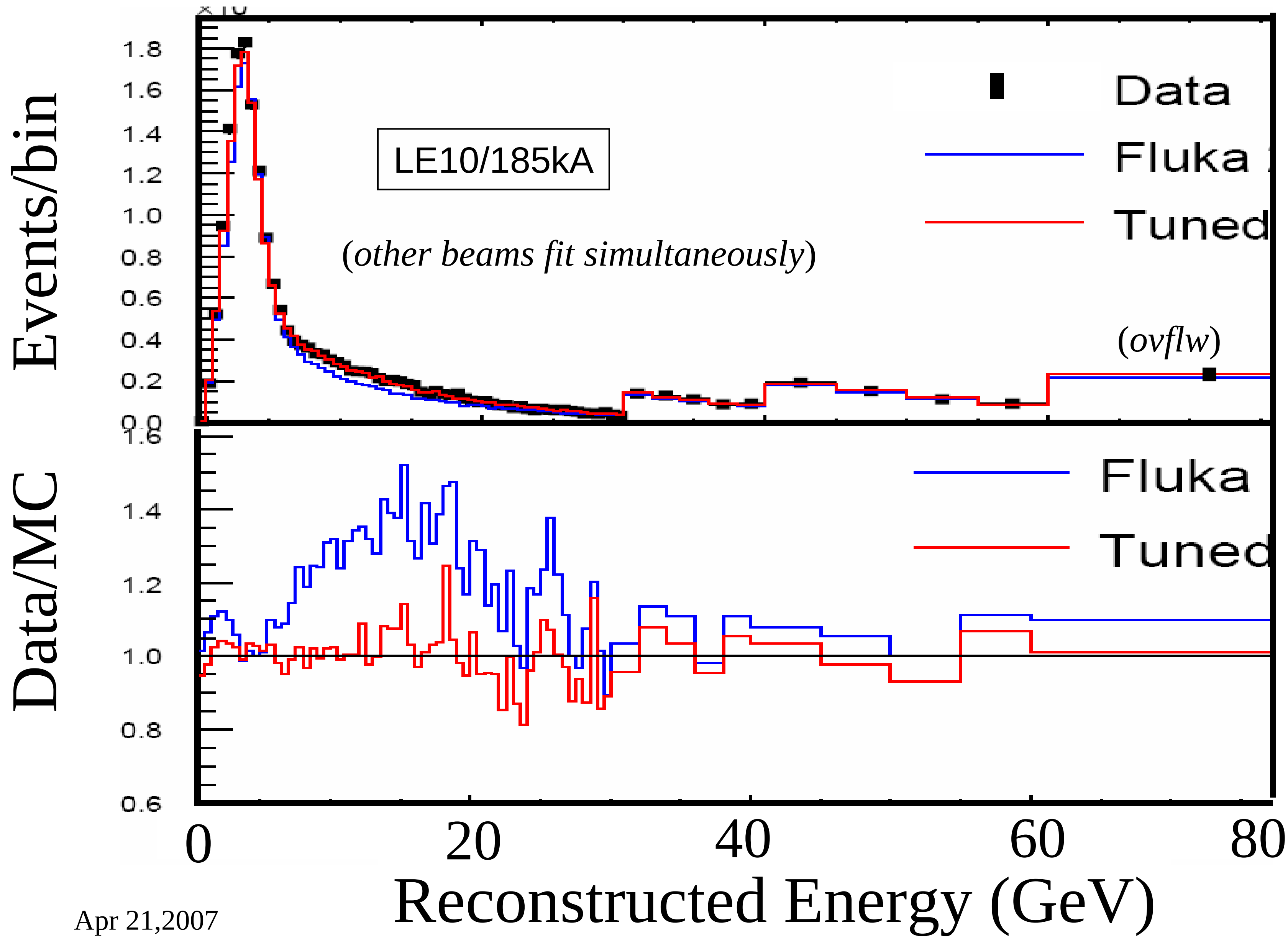
Hadronic Shower Simulation Problem-We have a theory of the strong interaction—in theory

- 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.
- Most 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?

Meurer et al –Cosmic ray showers Discontinuity-Gheisha at low energies and QGSJET at higher energies-Simulation of air showers



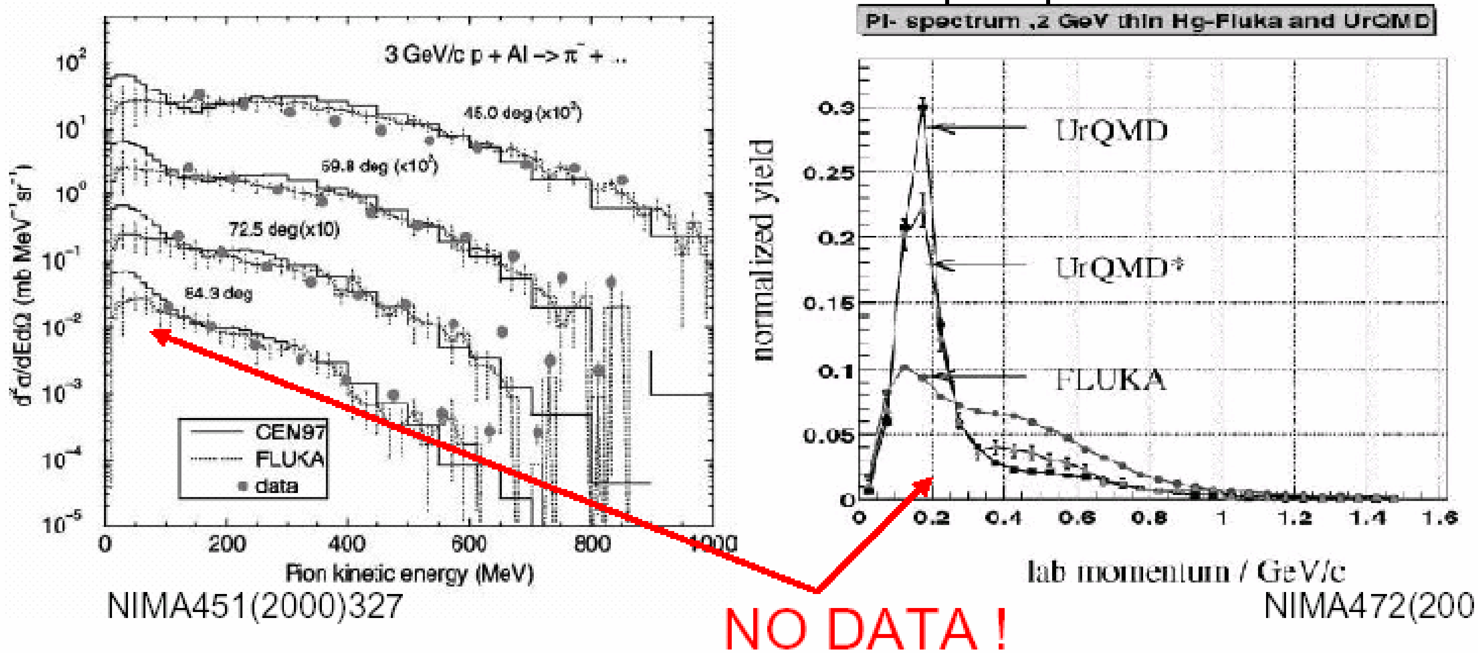
Results (Including >30 GeV)-S.Kopp



Discrepancies between hadronic generators

Lack of experimental data and large uncertainties in the calculations,
in particular for thick and high Z target materials

Differential distributions for pion production:



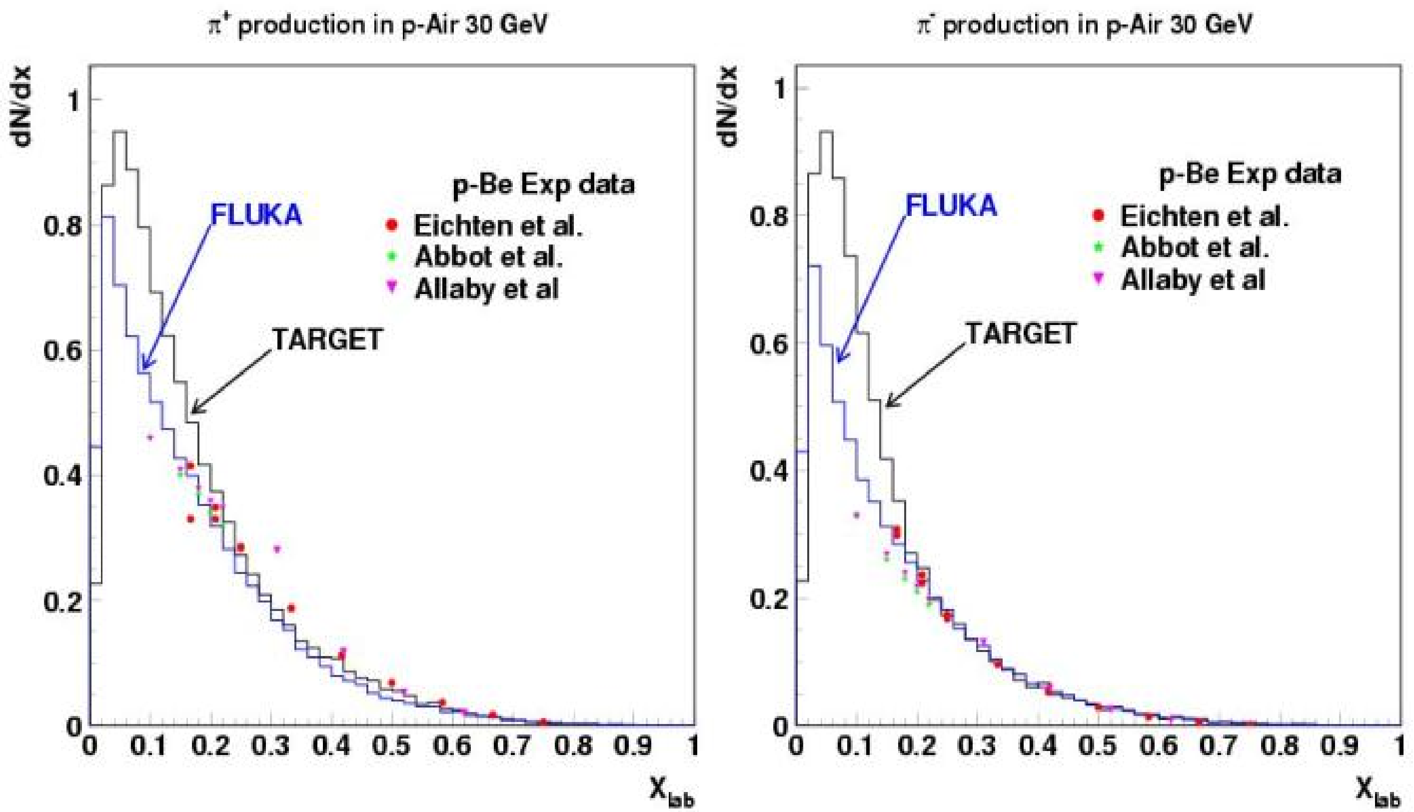
NIMA451(2000)327

NIMA472(2001)5

➔ Thin and thick targets, scan in Z

Discrepancies between hadronic generators- Testing particle production off nitrogen(Be extrapolated)

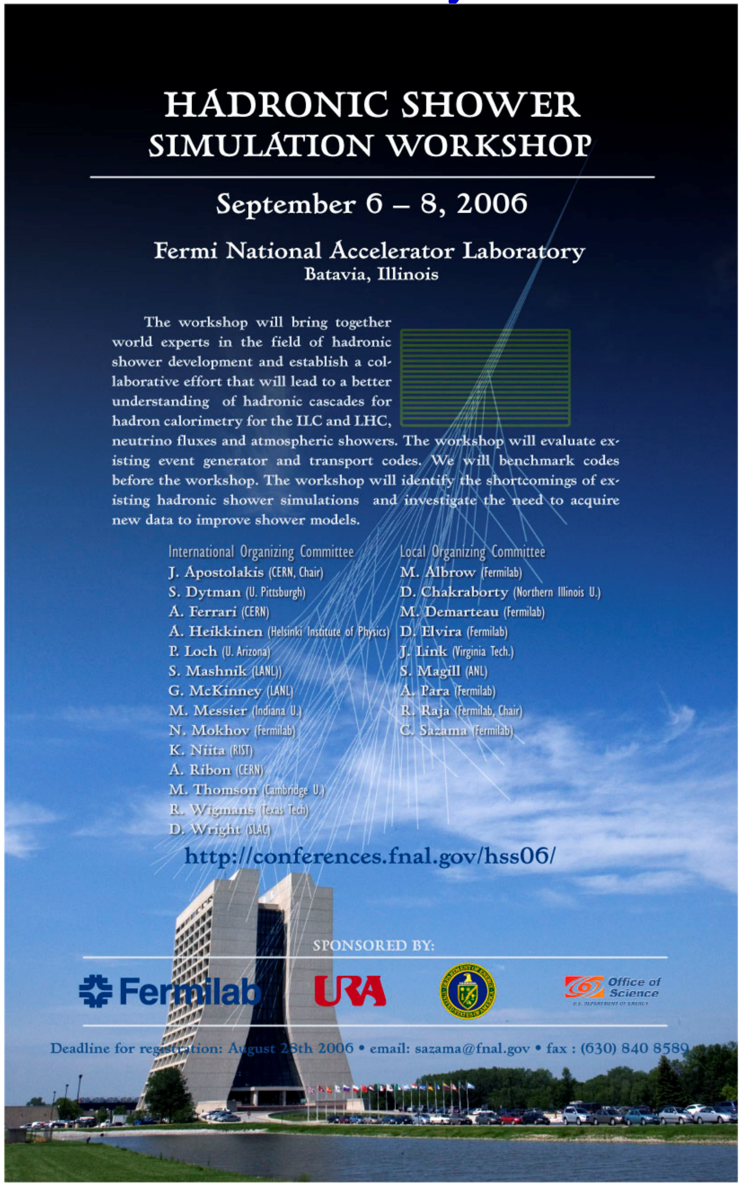
27



G.Battistoni

Hadronic Shower Simulation Workshop HSSW06

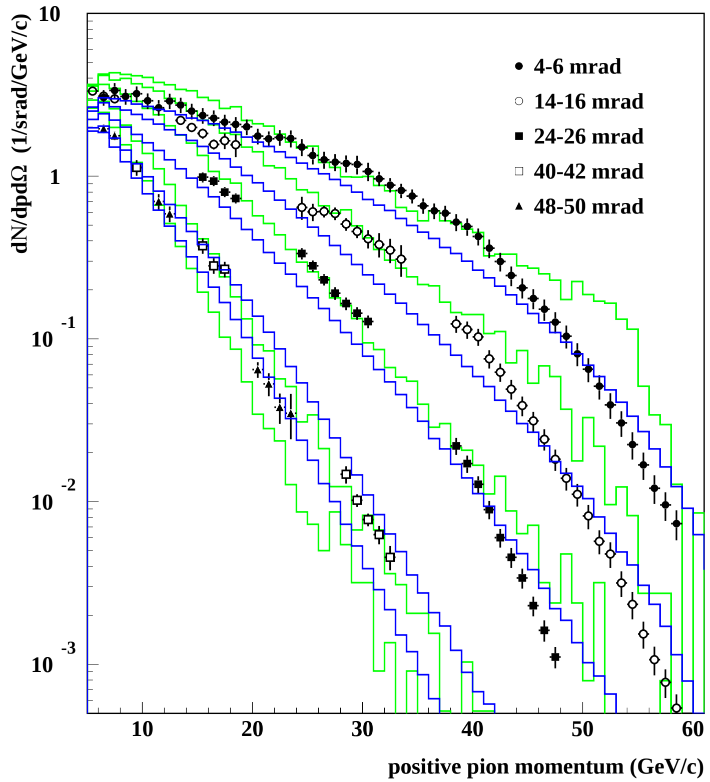
- Venue—Fermilab September 6-8, 2006
- Experts from GEANT4, FLUKA, MARS, MCNPX, and PHITS attended as well users from Neutrino, ILC, Atlas, CMS communities. Goal is to reduce systematics between various models and arrive at a suite of programs that can be relied on.

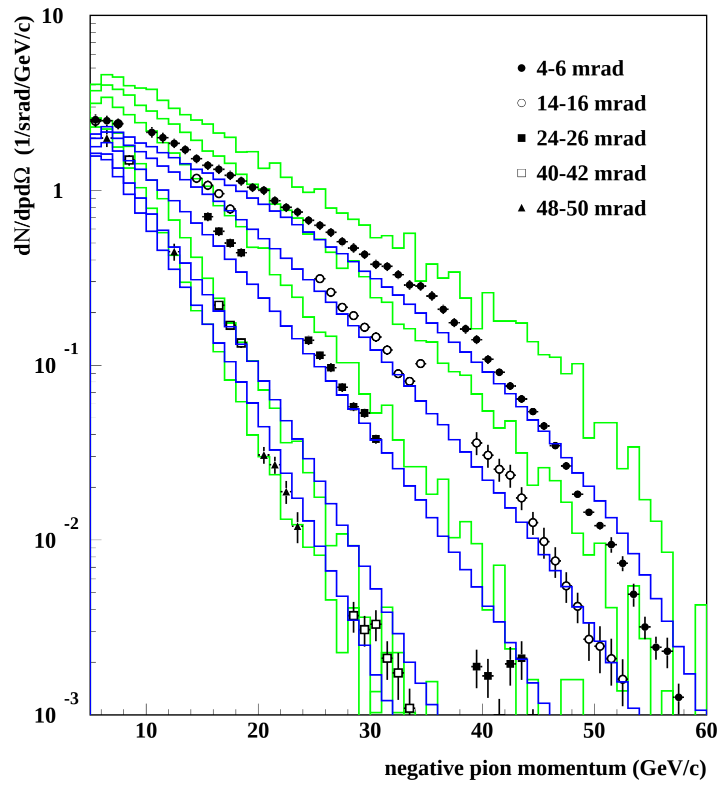


HSSW06 benchmark test 60cm Al target- Data from Protvino

Pion data. Blue curve MARS. Green curve PHITS.

Monte Carlos disagree with each other and the data!

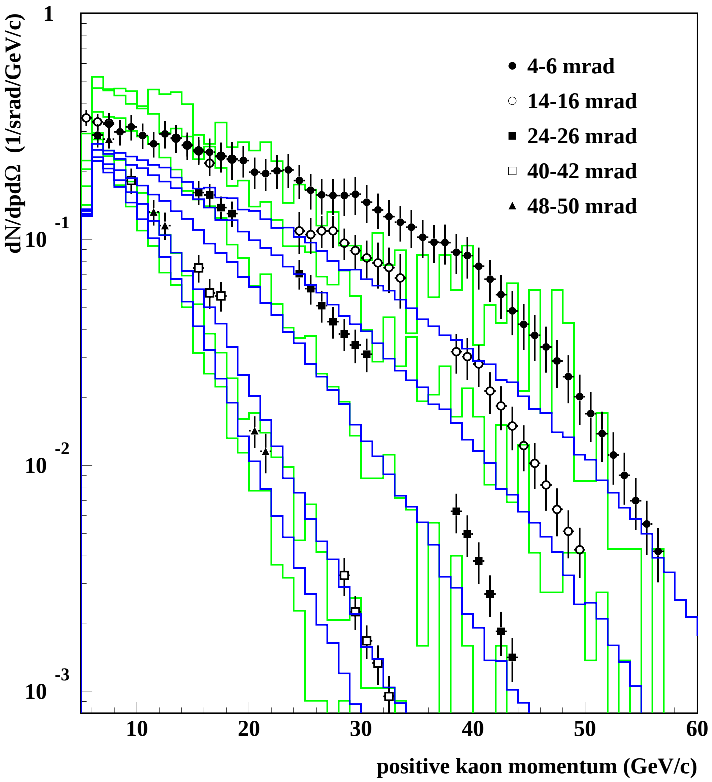


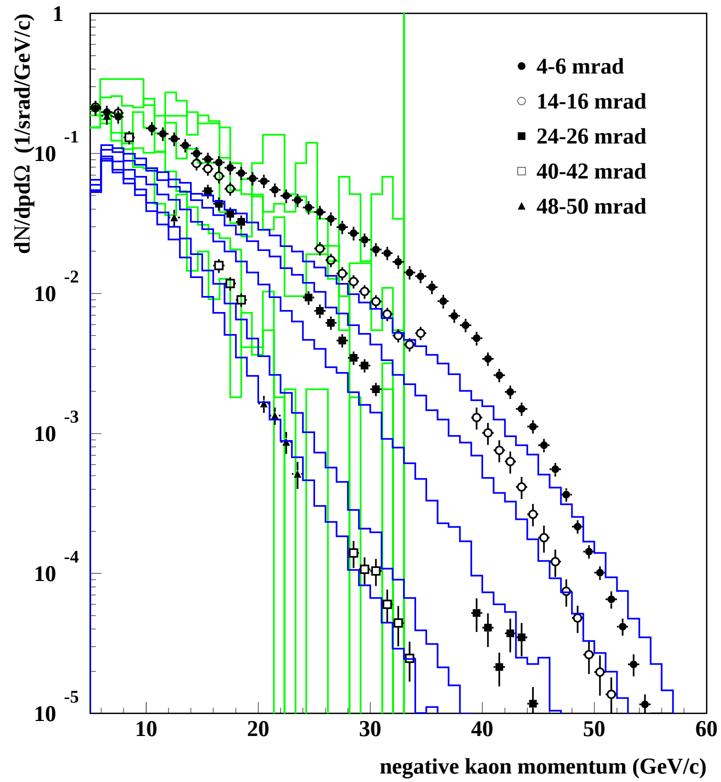


HSSW06 benchmark test 60cm Al target- Data from Protvino

Kaon data. Blue curve MARS. Green curve PHITS.

Monte Carlos disagree with each other and the data!





MIPP Upgrade collaboration list

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University of Virginia
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University of Wisconsin, Madison
P.Sokolsky, W.Springer
University of Utah

Livermore dropped out. Rest still on proposal. 10 new institutions have joined. More in negotiations. Previous collaboration built MIPP up from ground level. Less to do this time round. More data.

The Proposal in a nutshell

- MIPP one can take data at ~30Hz. The limitation is the TPC electronics which are 1990's vintage. We plan to speed this rate up to 3000Hz using ALTRO/PASA chips developed for the ALICE collaboration.
- Beam delivery rate– We assume the delivery of a single 4 second spill every two minutes from the Main Injector. We assume a 42% downtime of the Main Injector for beam manipulation etc. This is conservative. Using these figures, we can acquire 5 million events per day.
- Jolly Green Giant Coil Replacement- Towards the end of our run, the bottom two coils of the JGG burned out. We have decided to replace both the top and bottom coils with newly designed aluminum coils that have better field characteristics for the TPC drift. The coil order has been placed ($200K).
- Beamline upgrade- The MIPP secondary beamline ran satisfactorily from 5 5GeV/c-85GeV/c. We plan to run it from ~1 GeV/c to 85 GeV/c. The low momentum running will be performed using low current power supplies that regulate better. Hall probes in magnets will eliminate hysteresis effects.
- TPC Readout Upgrade-We have ordered 1100 ALTRO/PASA chips from CERN ($80K). The order had to go in with a bigger STAR collaboration order to reduce overhead. We expect delivery in the new year of tested chipsets.

The Proposal in a nutshell

- MIPP- Recoil detector- GSI- Darmstadt / KVI Groningen have joined us. They will bring the plastic ball detector (a hemisphere of it) which will serve to identify recoil (wide angle) neutrons, protons and gammas from our targets.
- Triggering system- We propose to replace the MIPP interaction trigger (scintillator/wire chamber) with 3 planes of silicon pixels based on the B-TeV design. Will enable us to trigger more efficiently on low multiplicity events.
- Drift Chamber/ PWC electronics- These electronics (E690/RMH) worked well for the first run. They are old (1990's). RMH will not do 3kHz. We will replace both systems with a new design that utilizes some of the infrastructure we developed for the RICH readout.
- ToF/CKOV readout-Plan to build new readout based on TripT chip (Used by Minerva) and a high resolution TDC chip. Will use the VME readout cards in common with RICH, TPC
- RICH detector and the Beam Cerenkovs will work as is.
- Calorimeter Readout- Switch to FERA ADC's (PREP).
- DAQ software upgrade- Front end DAQ software needs to be developed. The MIPP DAQ control software+ Data base can be kept as is.
- Plan is to store one spill's worth of data on each detector and read out the whole lot at end of spill.

Nuclei of interest- 1st pass list

- The A-List
- H_2,D_2,Li,Be,B,C,N_2,O_2,Mg,Al,Si,P,S,Ar,K,Ca,,Fe,Ni,Cu,Zn,Nb,Ag,Sn,W,Pt,Au,Hg,Pb,Bi,U
- The B-List
- Na, Ti,V, Cr,Mn,Mo,I, Cd, Cs, Ba
- On each nucleus, we can acquire 5 million events/day with one 4sec beam spill every 2 mins and a 42% downtime.
- We plan to run several different momenta and both charges.
- The libraries of events thus produced will be fed into shower generator programs which currently have 30 year old single arm spectrometer data with high systematics

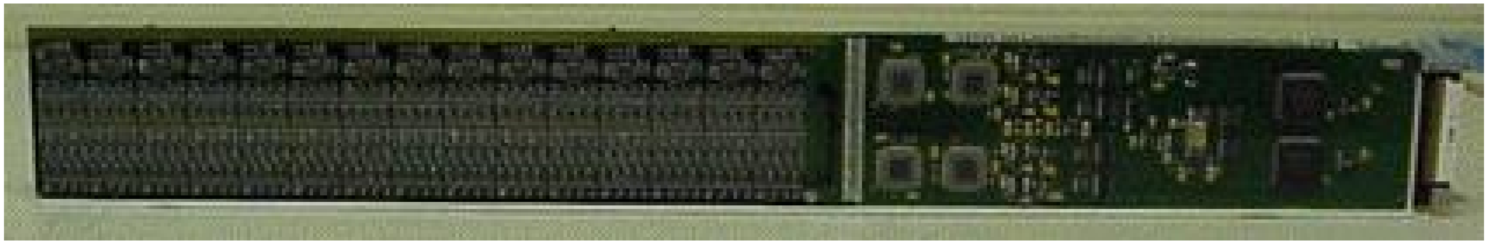
Can we reduce our dependence on models?

- Answer- Yes- With the MIPP Upgrade experiment, one can acquire 5 million events per day on various nuclei with six beam species ($\pi^{\pm}$,$K^{\pm}$,$p^{\pm}$) with beam momenta ranging from 1 GeV/c-90 GeV/c. Full acceptance over phase space, including info on nuclear fragmentation
- This permits one to consider random access event libraries that can be used to generate the interactions in the shower.

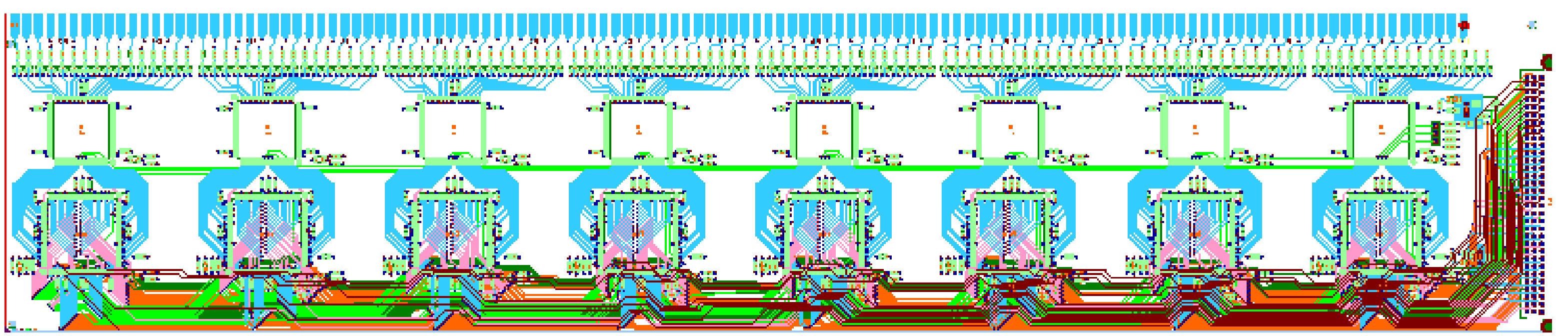
New JGG coils being wound April 07

TPC electronics upgrade

- Old MIPP TPC "Stick" – 120 of these.

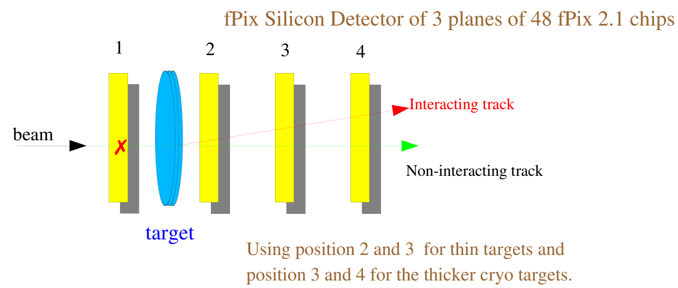


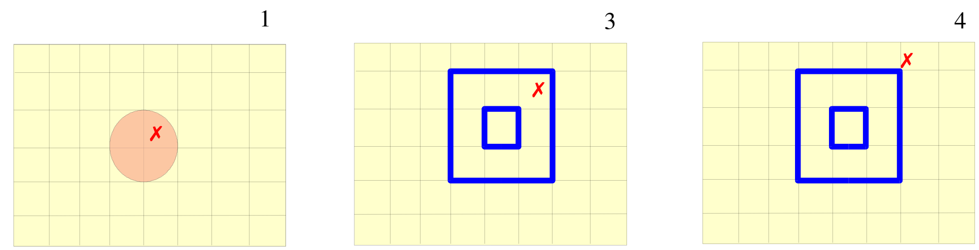
- New MIPP TPC "stick" layout using ALTRO/PASA chips.



MIPP Trigger Upgrade

- Beam sizes are large in MIPP due to the "low divergence" condition needed for beam CKOV's.
- Previous trigger of SCINT counter + 1st drift chamber wire signals performed satisfactorily for MIPP -I physics but needs improvement at low multiplicities—Landau tails.
- We propose to use silicon pixel counters (B-TEV, Phenix).
- Use a "Bull's Eye" system to detect absence of beam particle in final state to signal interactions. Also use the multiplicity in the final state as an additional piece of information.





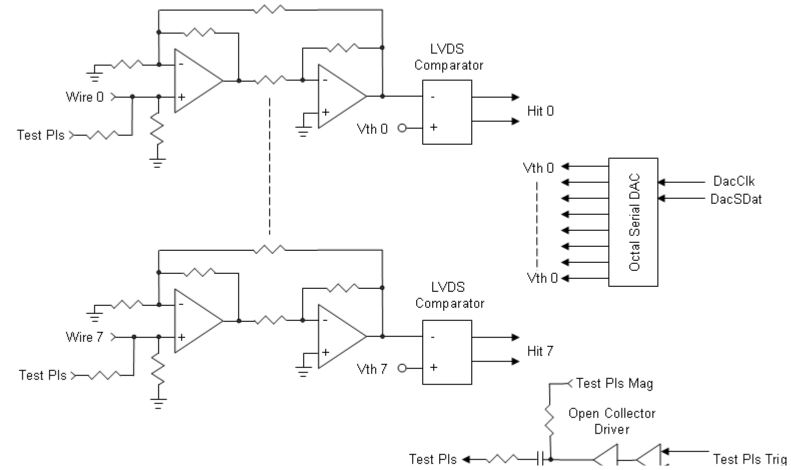
First layer before target tags where beam is and that there was only 1 hit cell. Brown circle represents where 86% of the beam hits the 4 cells in the center.

A bulls eye target, shown in blue, is made around the one cell hit location of plane1.

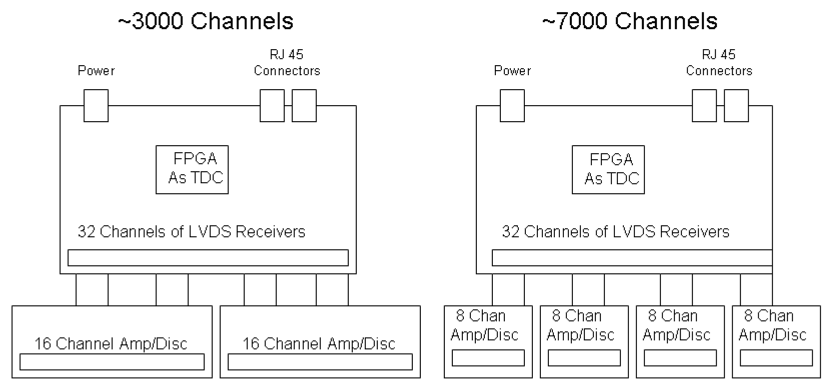
Drift Chamber/ PWC readout Upgrade

- Large PWC's use old CERN RMH electronics- Needs replacement.
- E690 electronics will work at these speed, if CAMAC DMA is implemented. The electronics are also aging and also put out a lot of heat.
- MIPP proposes a unified scheme for reading out both sets of chambers using a system that modifies the MIPP RICH readout cards by changing the latch to a TDC.
- Preamp cards being replaced Preamp/Discriminator front end cards.
- The RICH cards will store an entire spill's worth of events, which are readout in between spills.
- WBS task 4.2 M&S $121.2K, Labor $28.7K. Newest of the design efforts. Probably need to add 50% contingency.

8 Channel Amp/Disc – One per 8 channel Card, Two per 16 channel Card

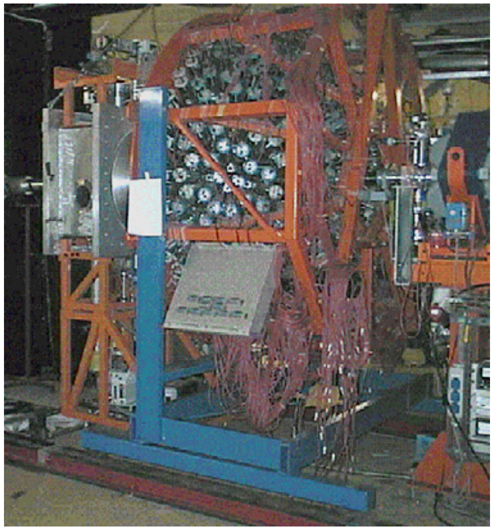


High-Speed Differential Interfaces
"Cyclone II devices can transmit and receive data through LVDS signals at a data rate of up to 640 Mbps and 805 Mbps, respectively. For the LVDS transmitter and receiver, the Cyclone II device's input and output pins support serialization and deserialization through internal logic."



Plastic Ball Recoil detector

- Plastic ball detector is avaliable. GSI/KVI have joined MIPP. We will install a hemisphere in MIPP. Mounting details to be worked out. Need the ability to remove the detector to repair it and the TPC.
- Transportation to Fermilab.
- GSI/KVI will play a lead role in making this happen
- Detector will help in all aspects of MIPP data including tagged neutral beams, missing baryon resonances and hadronic shower simulation data.



Picture of the full plastic ball at KVI

WBS task 10 Fermi M&s $0

Labor $25.9K, In Kind $55K

WBS	Task Name	Fermi M&S Cost	Fermi Labor Cost	Base Cost in FY06 $	In Kind	Total Project Cost
0	MIPP Upgrade Totals	$1,214,456	$566,628	$1,781,084	$205,000	$2,003,844
1	Project Management	$55,000	$0	$55,000	$0	$55,000
2	Jolly Green Giant Repair	$279,000	$141,884	$420,884	$0	$438,644
2.1	Jolly Green Giant disassembly/assembly	$80,000	$94,380	$174,380	$0	$192,140
2.2	JGG coil design and fabrication	$199,000	$25,524	$224,524	$0	$224,524
2.3	Ziptrack JGG magnet	$0	$21,980	$21,980	$0	$21,980
3	Improvements on detector hardware	$128,600	$109,114	$237,714	$150,000	$387,714
3.1	Gas System and Slow Controls Upgrade	$40,500	$29,868	$70,368	$0	$70,368
3.1.1	RICH vessel fill automation	$2,500	$5,610	$8,110	$0	$8,110
3.1.2	Methylal bath fill automation	$5,000	$7,228	$12,228	$0	$12,228
3.1.3	P10 supply upgrade	$5,000	$6,664	$11,664	$0	$11,664
3.1.4	TOF wall thermal instrumentation	$2,000	$4,232	$6,232	$0	$6,232
3.1.5	Replacement of CKOV pressure sensors	$2,000	$412	$2,412	$0	$2,412
3.1.6	Beam Ckov vacuum system	$3,000	$1,340	$4,340	$0	$4,340
3.1.7	Calibration and maintenance	$0	$2,952	$2,952	$0	$2,952
3.1.8	Slow Controls infrastructure upgrade	$21,000	$1,430	$22,430	$0	$22,430
3.2	Cryogenic System Upgrade	$68,000	$75,598	$143,598	$0	$143,598
3.2.1	Hydrogen Target transfer line	$13,000	$38,120	$51,120	$0	$51,120
3.2.2	Nitrogen Target	$10,000	$23,260	$33,260	$0	$33,260
3.2.3	Spare Cryocooler	$45,000	$14,218	$59,218	$0	$59,218
3.3	TPC rewind	$9,000	$0	$9,000	$0	$9,000
3.4	Chamber wire repairs	$1,100	$3,648	$4,748	$0	$4,748
3.5	Ckov Photomultiplier tubes	$10,000	$0	$10,000	$0	$10,000
3.6	RICH Photomultiplier tubes	$0	$0	$0	$150,000	$150,000
4	Detector Readout Upgrades	$362,920	$197,918	$560,838	$0	$568,513
4.1	TPC Electronics	$225,920	$150,847	$376,767	$0	$384,442
4.2	Drift Chamber/Wire Chamber electronics	$121,250	$28,718	$149,968	$0	$149,968
4.3	ToF + CKOV electronics board design	$15,750	$18,352	$34,102	$0	$34,102
4.4	Calorimeter migration to Fera electronics	$15,000	$0	$15,000	$0	$15,000
5	Trigger System Upgrade	$145,900	$51,400	$197,300	$0	$208,300
5.1	Interaction Trigger Fpix	$137,100	$38,800	$175,900	$0	$186,900
5.2	Interaction Trigger Board	$8,800	$12,600	$21,400	$0	$21,400
5.3	Other Trigger Upgrades	$0	$0	$0	$0	$0
6	DAQ Software and Hardware Upgrade	$46,686	$38,952	$85,638	$0	$85,638
7	Offline farm Upgrade	$0	$0	$0	$0	$0
8	Beam Line Upgrade	$56,000	$0	$56,000	$0	$56,000
9	Enhanced Veto Wall	$20,110	$1,440	$21,550	$0	$21,550
10	Recoil Detector	$0	$25,920	$25,920	$55,000	$80,920
11	Visitor Support for Russian collaborators	$105,240	$0	$105,240	$0	$105,240

Run Plan

Phase 1 Run Plan			
Target	Number of Events (Mllions)	Running Time (Days)	Physics Need Group
NuMI Low Energy target	10	2	MINOS MINERVA
NuMI Medium Energy Target	10	2	MINERVA NOVA
Liquid Hydrogen	20	4	QCD PANDA DUBNA
Liquid Nitrogen	10	2	ICE CUBE
12 Nuclei			Nuclear Physics
D2 Be C Al Si Hg Fe Ni Cu Zn W Pb	60	12	Hadronic Showers
Total Events	110	22	
Raw Storage	11 TBytes		
Processed Storage	55 TBytes		

Phase 2 Run Plan			
Target	Number of Events (Millions)	Running Time (Days)	Physics Need Group
18 Nuclei			
Li B O2 Mg P S Ar K Ca			Nuclear Physics
Ni Nb Ag Sn Pt Au Pb Bi U	90	18	Hadronic Showers
10 Nuclei B-list			Nuclear Physics
Na Ti V Cr Mn Mo I Cd Cs Ba	50	10	Hadronic Showers
Total Events	140	28	
Raw Storage	14 TBytes		
Processed Storage	70 TBytes		

Phase 3 – Tagged Neutral beams for ILC 5 million events/day LH2 target

Missing baryon resonance search may request additional running depending on what is found.

Conclusions

- The MIPP Upgrade Collaboration has proposed a cost effective way to upgrade the experiment to speed up the DAQ by a factor of 100.
- We propose to add a recoil detector that will enhance the physics reach of the experiment.
- We propose to measure the NUMI LE/ ME targets.
- As well as 30 nuclei to benefit hadron shower simulators and the cosmic ray community.
- This and the tagged neutral beams will benefit the ILC PFA algorithm studies.
- We propose to increase the momentum range of the beams (down to 1 GeV/c) that will benefit the hadron shower simulators and permit the search for missing baryon resonances.
- Measurements will benefit cosmic ray physics –LN2 + Oxygen. Collaboration needs strengthening.
- We need quantitative answers on how much LN2 will help cosmic ray analyses.