Proposal to upgrade the DAQ for The Main Injector Particle Production Experiment (MIPP) at Fermilab

Rajendran Raja

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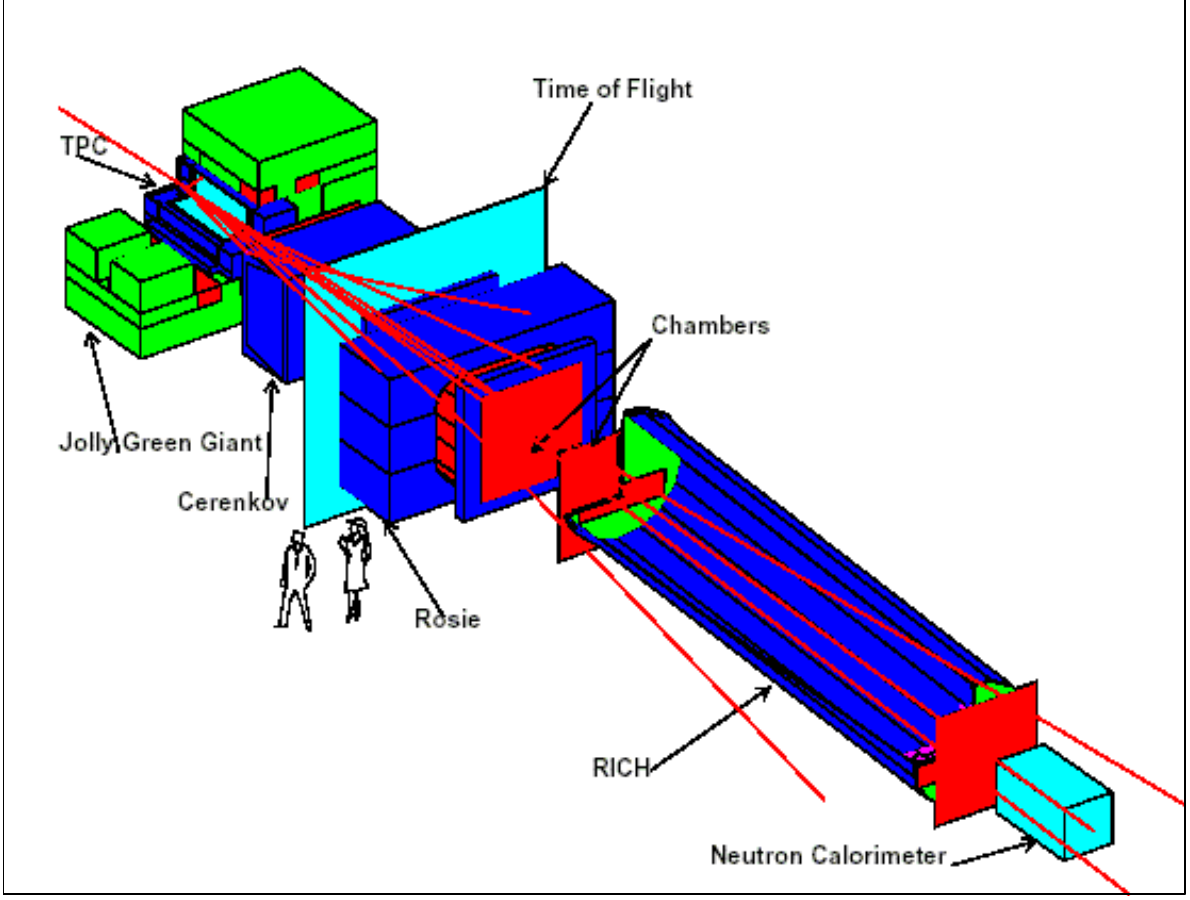
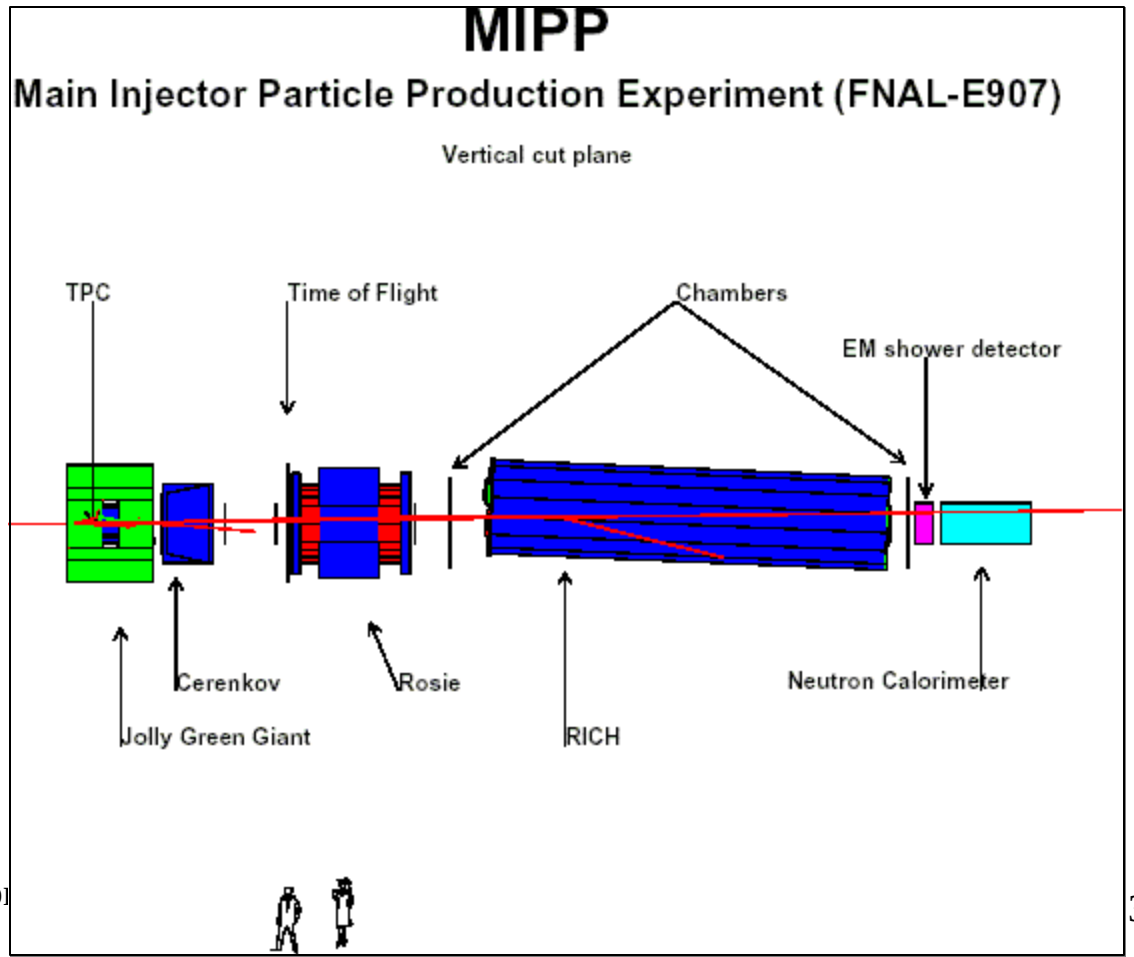
MIPP collaboration list

D.Isenhower, M.Sadler, R.Towell,S.Watson
Abilene Christian University
R.J.Peterson
University of Colorado, Boulder,
W.Baker,D.Carey, C.Johnstone,M.Kostin, H.Meyer, A.Para, R.Raja
Fermi National Accelerator Laboratory
G. Feldman, A.Lebedev, S.Seun
Harvard University
P.Hanlet, O.Kamaev,D.Kaplan, H.Rubin,N.Solomey
Illinois Institute of Technology
U.Akgun,G.Aydin,F.Duru,E.Gulmez,Y.Gunyadin,Y.Onel, A.Penzo
University of Iowa
N.Graf, M. Messier,J.Paley
Indiana University
D.M.Manley,
Kent State University
P.D.BarnesJr.,E.Hartouni,M.Heffner,J.Klay,D.Lange,R.Soltz, D.Wright
Lawrence Livermore National Laboratory
H.R.Gustafson,M.Longo, H-K.Park, D.Rajaram
University of Michigan
K.Hicks,
University of Ohio
S.P.Kruglov,I.V.Lopatin,N.G.Kozlenko,A.A.Kulbardis,D.V.Nowinsky,
A.K.Radkov,V.V.Sumachev
Petersburg Nuclear Physics Institute, Gatchina, Russia
A.Bujak, L.Gutay,D.E.Miller
Purdue University
T.Bergfeld,A.Godley,S.R.Mishra,C.Rosenfeld,K.Wu
University of South Carolina
C.Dukes, C.Materniak,K.Nelson,A.Norman
University of Virginia


Time of Flight
TPC
Chambers
Jolly Green Giant
Cerenkov
Rosie
RICH
Neutron Calorimeter


MIPP
Main Injector Particle Production Experiment (FNAL-E907)
Vertical cut plane
TPC
Time of Flight
Chambers
EM shower detector
Cerenkov
Rosie
RICH
Neutron Calorimeter
Jolly Green Giant

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 85 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.

MIPP Physics Program

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

They are

Liquid H2, D2 –non-perturbative QCD

p-A, p-rad

NUMI thin and full target measurements

LN2– Atmospheric neutrinos

Run Plan-Adopted after dir review Nov 2004

Run Plan v7		Summary by Target and Beam Energy Number of events, x 10^6										
Target		Momentum (GeV/*c*)										Totals
Z	Element	5	13.3	15	20	30	40	50	60	75	120	
1	H	4.40		4.20		4.40		4.20		4.20		**21.40**
1.2	D	0.60		0.60		0.60		0.60		0.60		**3.00**
4	Be	1.00	1.00			1.00		1.81		1.00	6.60	**12.41**
6	C	1.00	1.00		1.57		1.66		1.57		1.58	**8.38**
	NuMI										4.61	**4.61**
7	N	1.00	1.00			1.00						**3.00**
29	Cu					1.00		2.00		1.00	4.00	**8.00**
83	Bi	1.00	1.00			1.00		2.00		1.00	6.60	**12.60**
92	U							2.00				**2.00**
Totals		**9.00**	**4.00**	**4.80**	**1.57**	**9.00**	**1.66**	**12.61**	**1.57**	**7.80**	**23.39**	**75.40**

Run Plan v7			Priority 1 Summary by Target and Beam Energy Number of events, x 10^6							
Target			E							Total
Z	Element	Trigger Mix	13.3	15	30	40	50	75	120	
1	H	Normal		0.80			**0.80**	0.80		**2.40**
4	Be	*p* only							1.00	**1.00**
		Normal					**0.50**			**0.50**
6	C	*p* only	0.40			0.40			0.40	**1.10**
NuMI		*p* only							0.40	**0.40**
83	Bi	*p* only							1.00	**1.00**
		Normal			**0.50**		**1.00**			**1.50**
92	U	Normal					1.00			**1.00**
Total			**0.40**	**0.80**	**0.50**	**0.40**	**3.30**	**0.80**	**2.80**	**8.90**

Performance of physics run so far

- All detectors working. Physics data taking commenced on 17 Jan 2005. From 17Jan-22 March
- Number of .6 sec flattop-272,181
- Data taking (22Hz)-Events more complex-spray problems. Spill problems. All corrected.
- Average rate of spills 6.057/minute
- During 64 calendar days, MIPP was live ofr 31 days 5 hrs. Rest lost largely due to Tevatron shot setup, transfer to recycler. We had a few days down time to install cryotarget.
- We have accumulated 3.63 million events in the above time frame.

Projection for rest of run with MINOS running

- With MINOS Running, and a strict 5% interpretation, MIPP would get 1 four second spill every 2 minutes. Under this scenario, we would accumulate an additional 4.9 million events till October 2005 (currently foreseen shutdown date). MIPP would not get enough beam to fulfill its approved physics (75 million events).

Proposal to upgrade the TPC DAQ speed

- The MIPP TPC electronics if 1990's vintage. It is highly multiplexed and can run at a maximum of 60HZ for simple events and 20Hz for events of our complexity. There are 15,360 channels on the TPC.
- With more modern electronics (those developed for the ALICE collaboration at the LHC (PASA/ALTRO), we can speed this rate up to 3000HZ. I.e. a factor of 150.
- We propose to join a chip order along with STAR and TOTEM collaborations (this MAY). This will reduce the cost by (sharing the overhead) to ~$8/channel.
- With this upgrade (and the rest of the systems can also be upgraded to run at 3KHZ), and assuming one 4 second spill every 2 minutes and a 50% duty factor,

MIPP upgraded data taking times

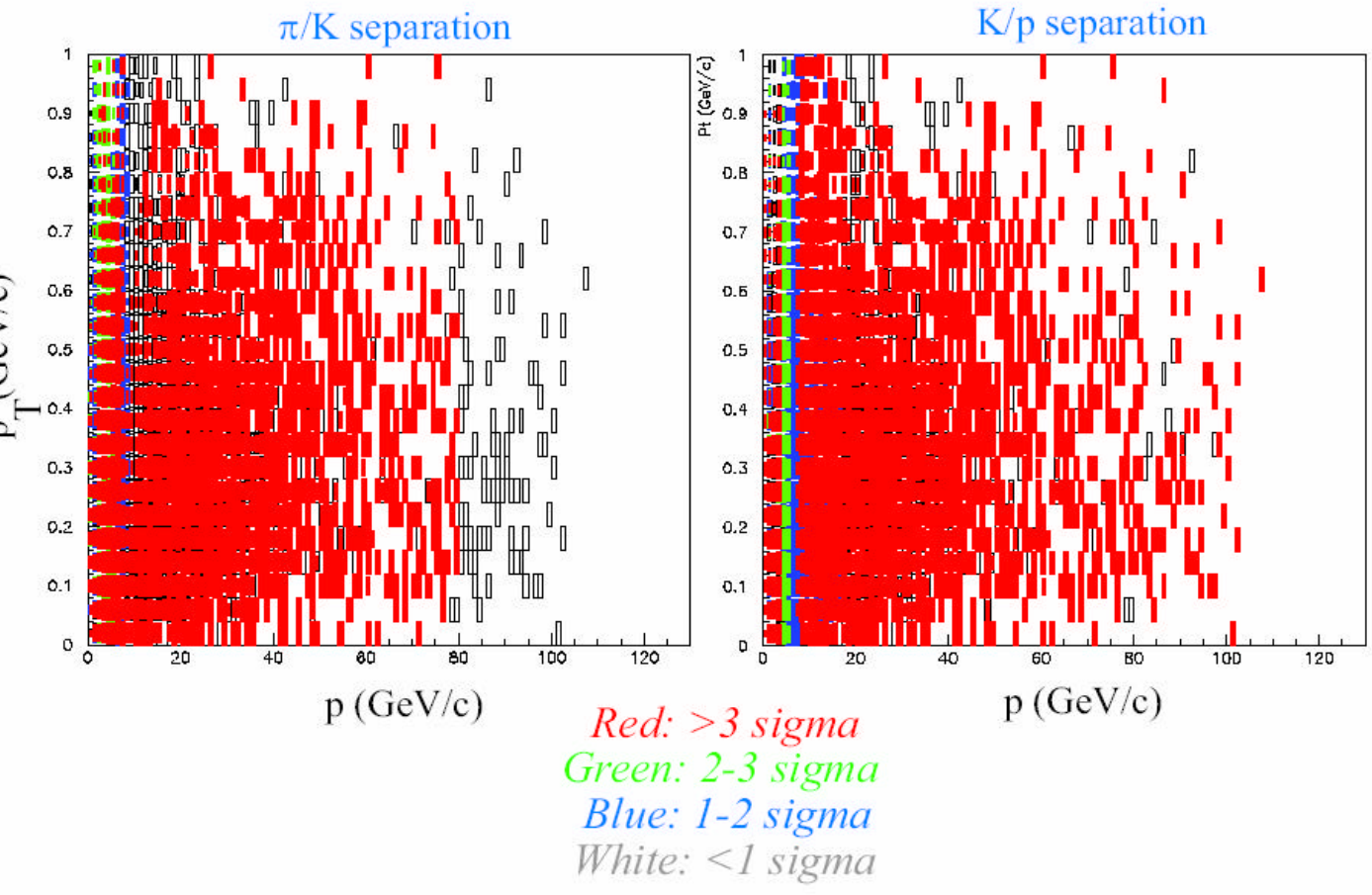
- The entire MIPP I (current run, approved physics)dataset (75 million events) can be acquired in 18.1 calendar days!
- We can also do additional physics which I will describe.
- This has brought in new collaborators, several (4) signing the proposal and several more institutions expressing strong interest.

Approved Physics of current Run

- 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
  - » Proton Radiography– Stockpile Stewardship- National Security
  - » MINOS target measurements – pion production measurements to control the near/far systematics
- Will make DST's available for the public on DVD's after we are done.
- HARP at CERN went from 2-15GeV incoming pion and proton beams. MIPP will go from 5-85 GeV/c for 6 beam species $\pi^{\pm}$ $K^{\pm}$ $p^{\pm}$ -- 420M triggers. 3KHZ TPC.

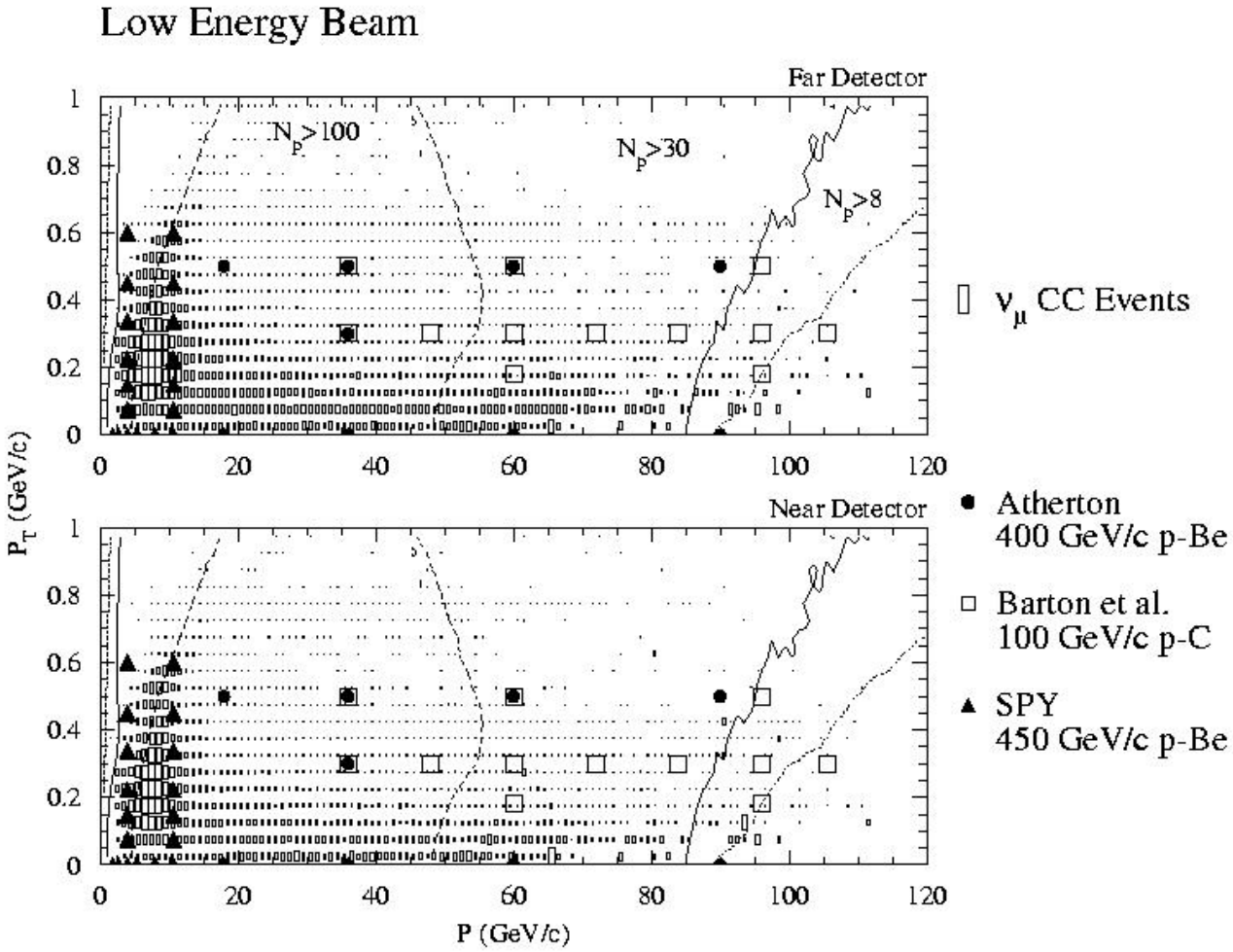
MIPP Particle ID

Particle ID Performance

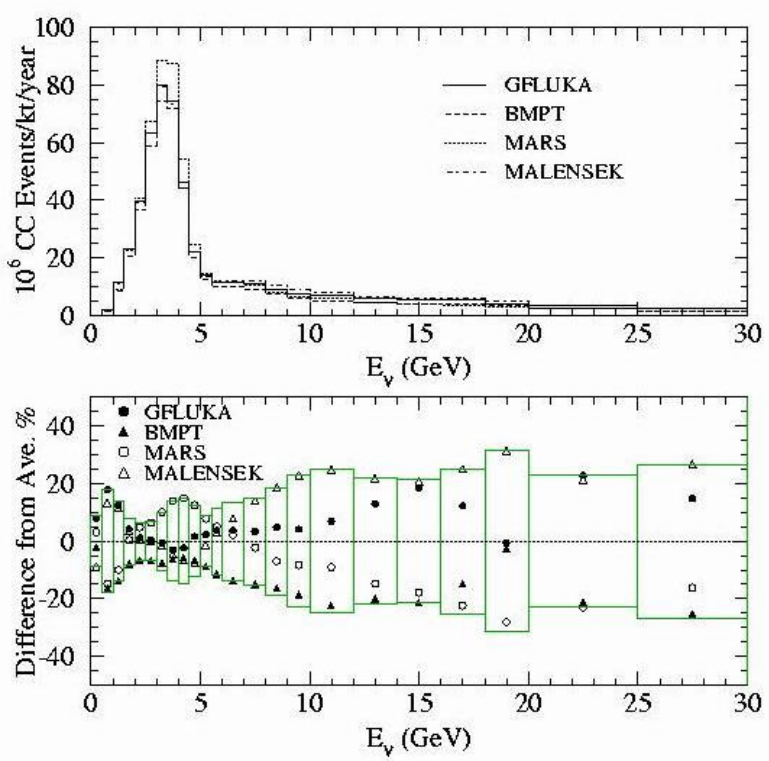


Minos measurements

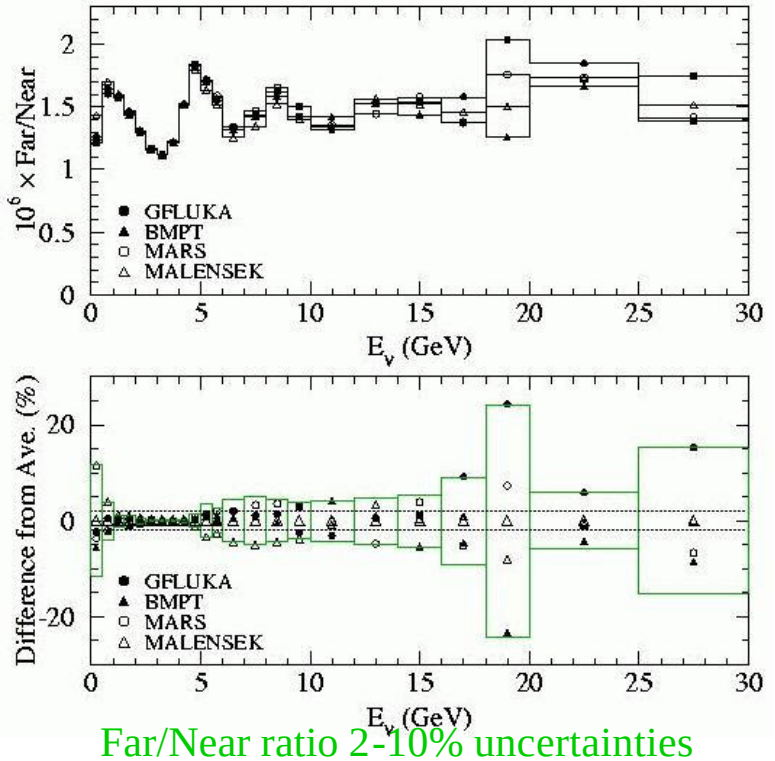
- Pion phase space P_L vs P_T weighted according to the number of neutrino events.
- Overlaid are the locations of existing hadron production measurements.
- In detail the near and the far detector see neutrinos from slightly different pion spectra.



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.

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

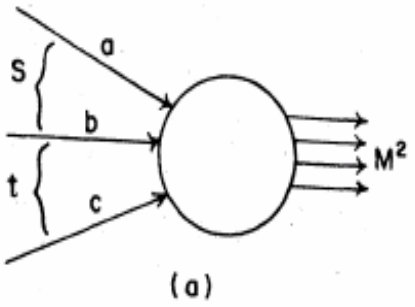
- States that the ratio of a semi-inclusive cross section to an inclusive cross section

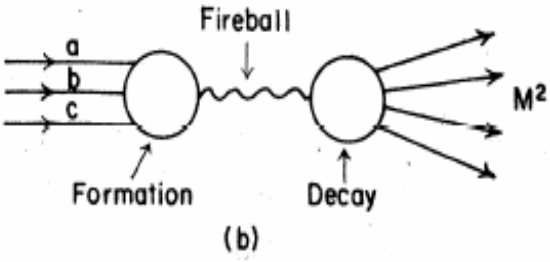
$$\frac{f(a+b\rightarrow c+X_{subset})}{f(a+b\rightarrow c+X)} \equiv \frac{f_{subset}(M^2,s,t)}{f(M^2,s,t)} = b_{subset}(M^2)$$

- 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

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





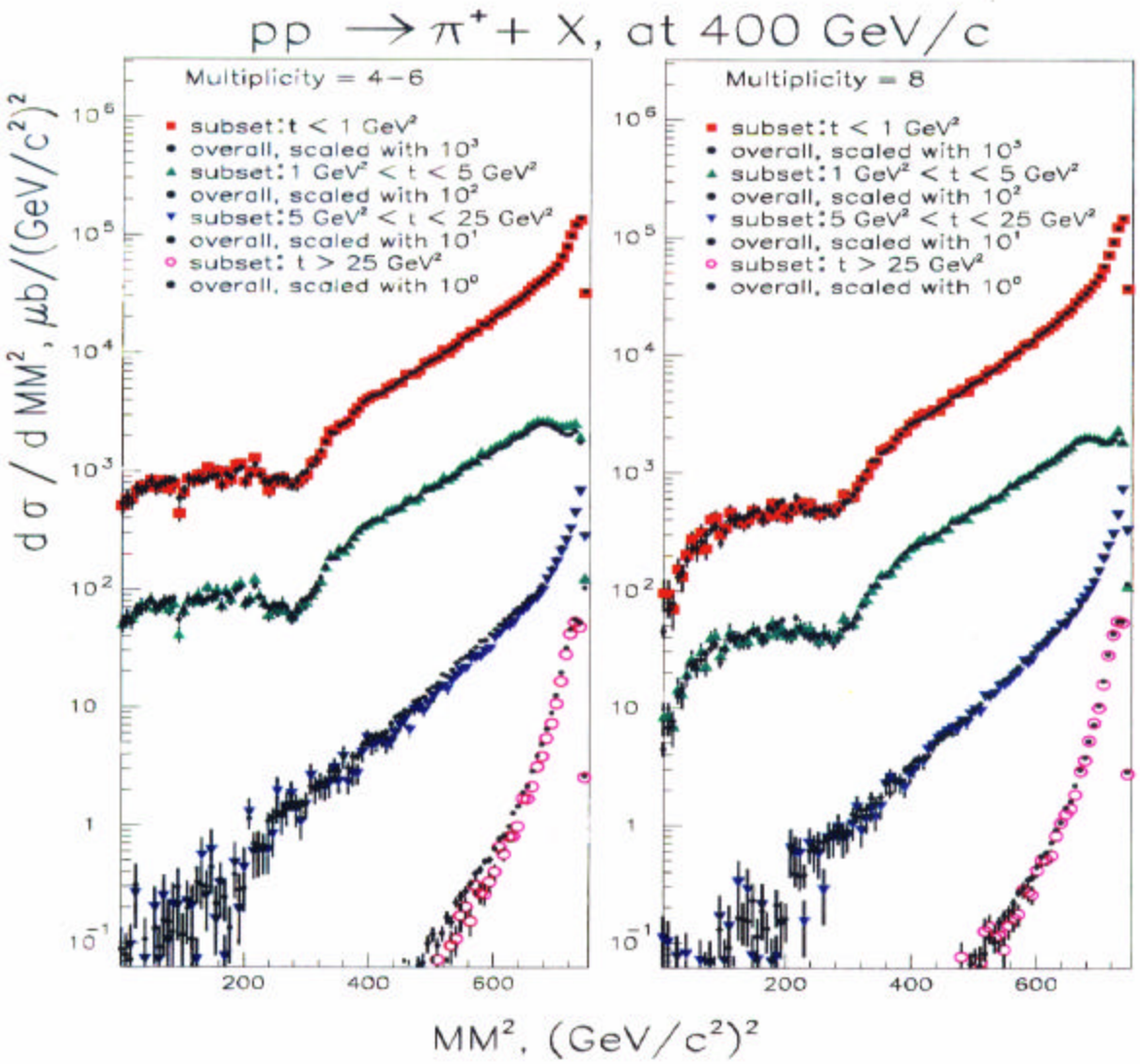
$$\frac{s\,(abc \to X_{sub})}{s\,(abc \to X)} = \frac{F(M^2, s, t) D_{X_{sub}}(M^2)}{F(M^2, s, t) D_X(M^2)} = a_{sub}(M^2)$$

- Continuing on to physical t values, one gets

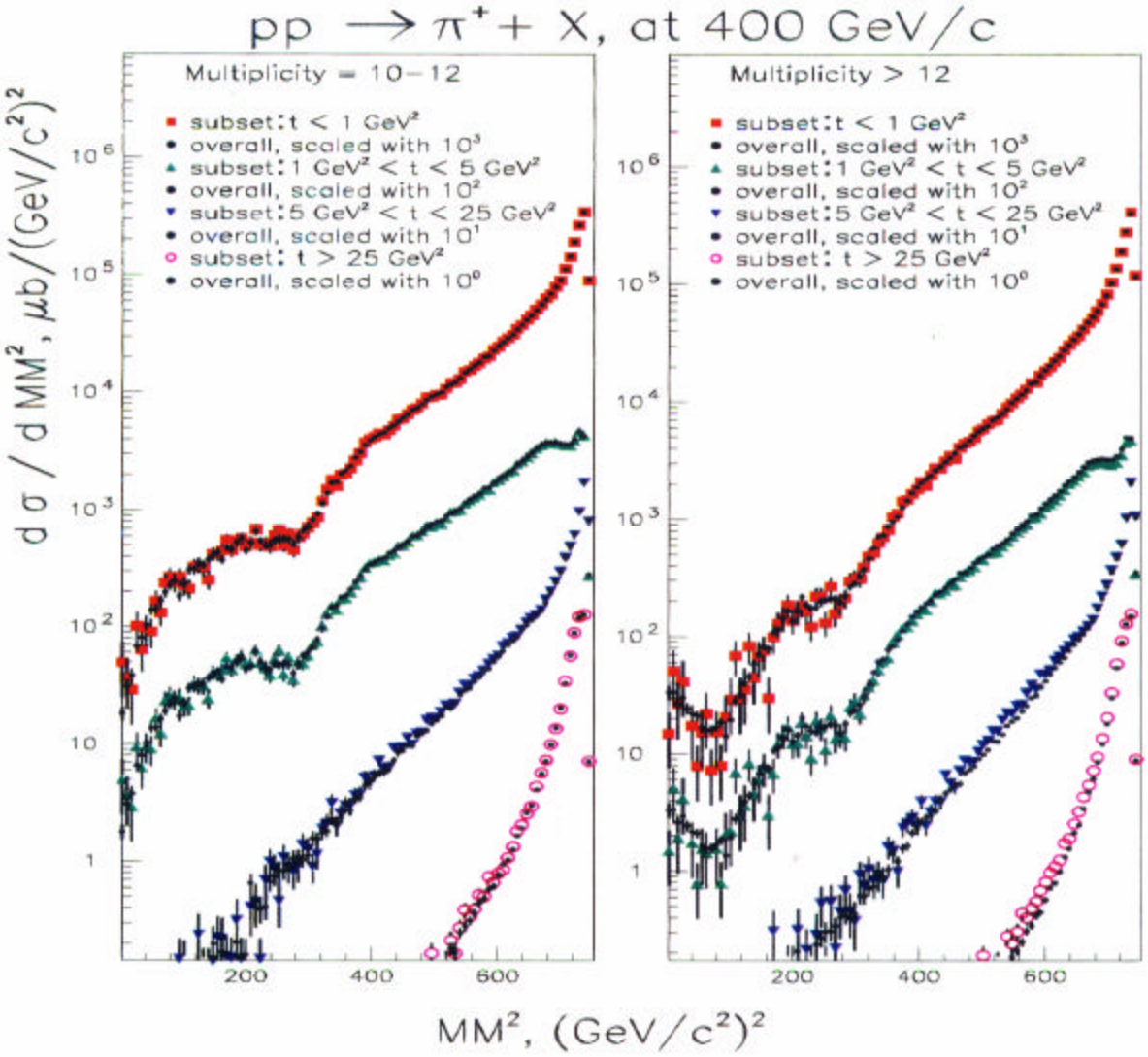
$$\frac{f\,(ab \to \bar{c} + X_{sub})}{f\,(ab \to \bar{c} + X)} = a_{sub}(M^2)$$

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

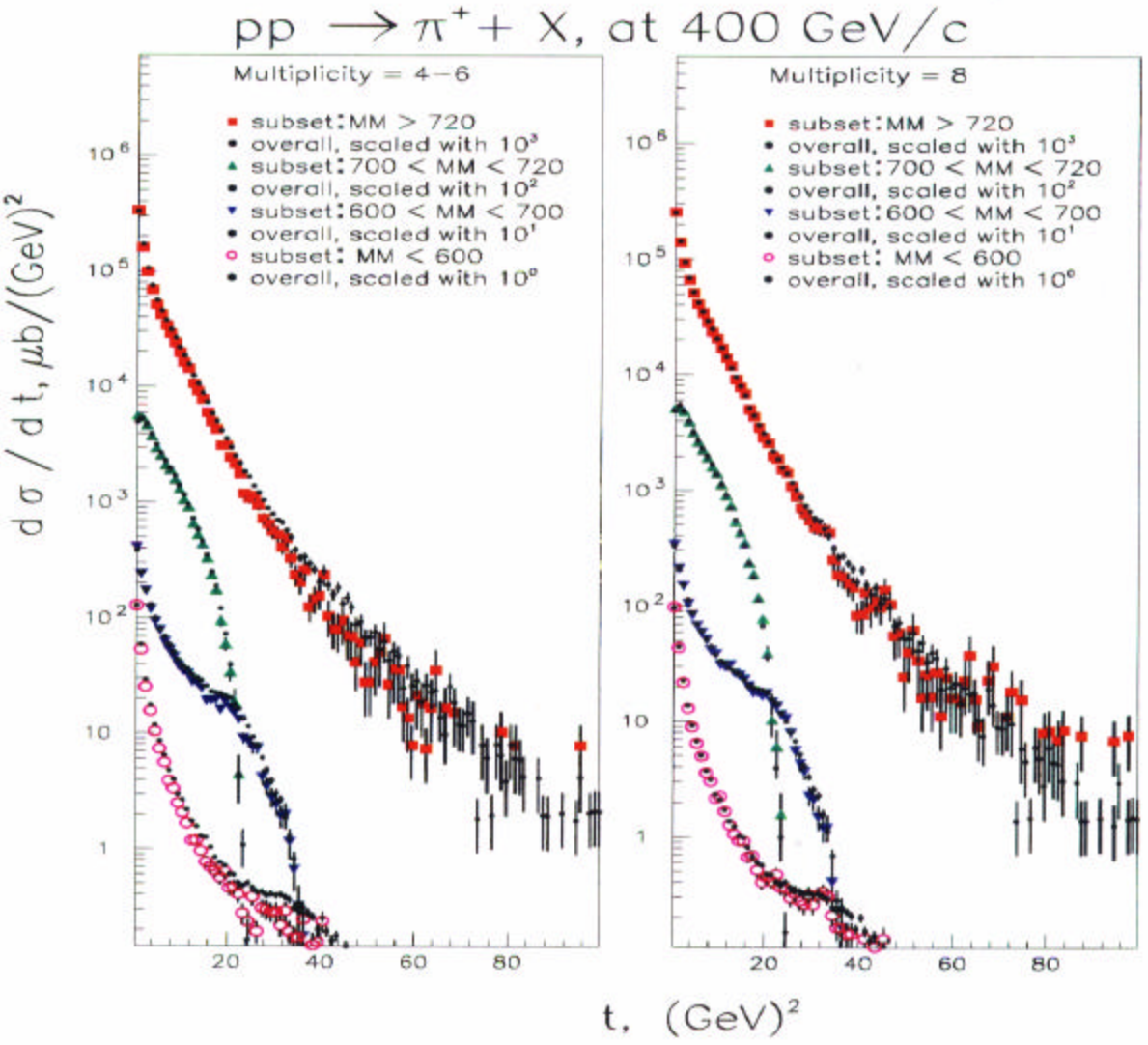
Scaling Law-EHS results



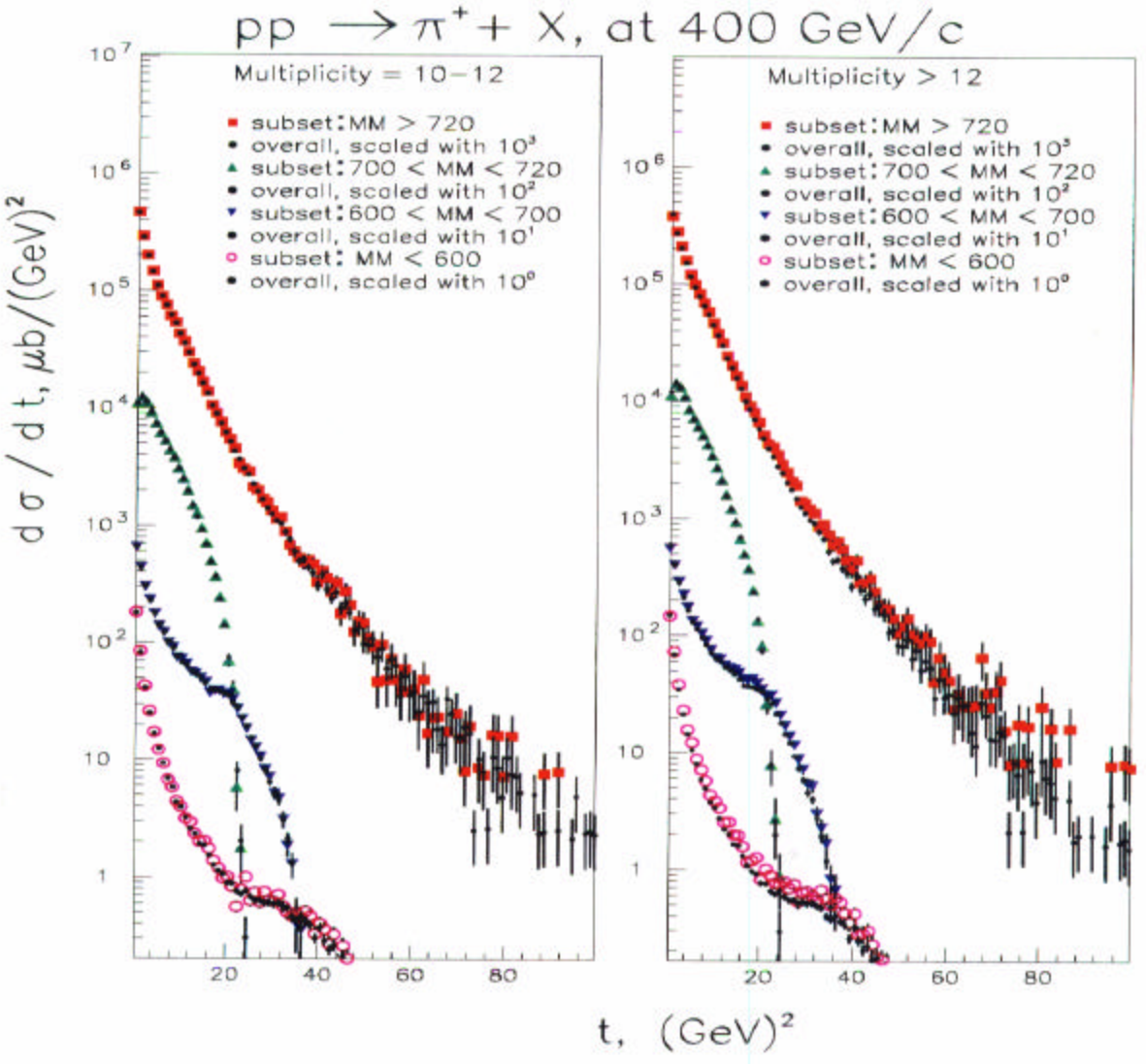
Scaling Law-EHS results



Scaling law -EHS results



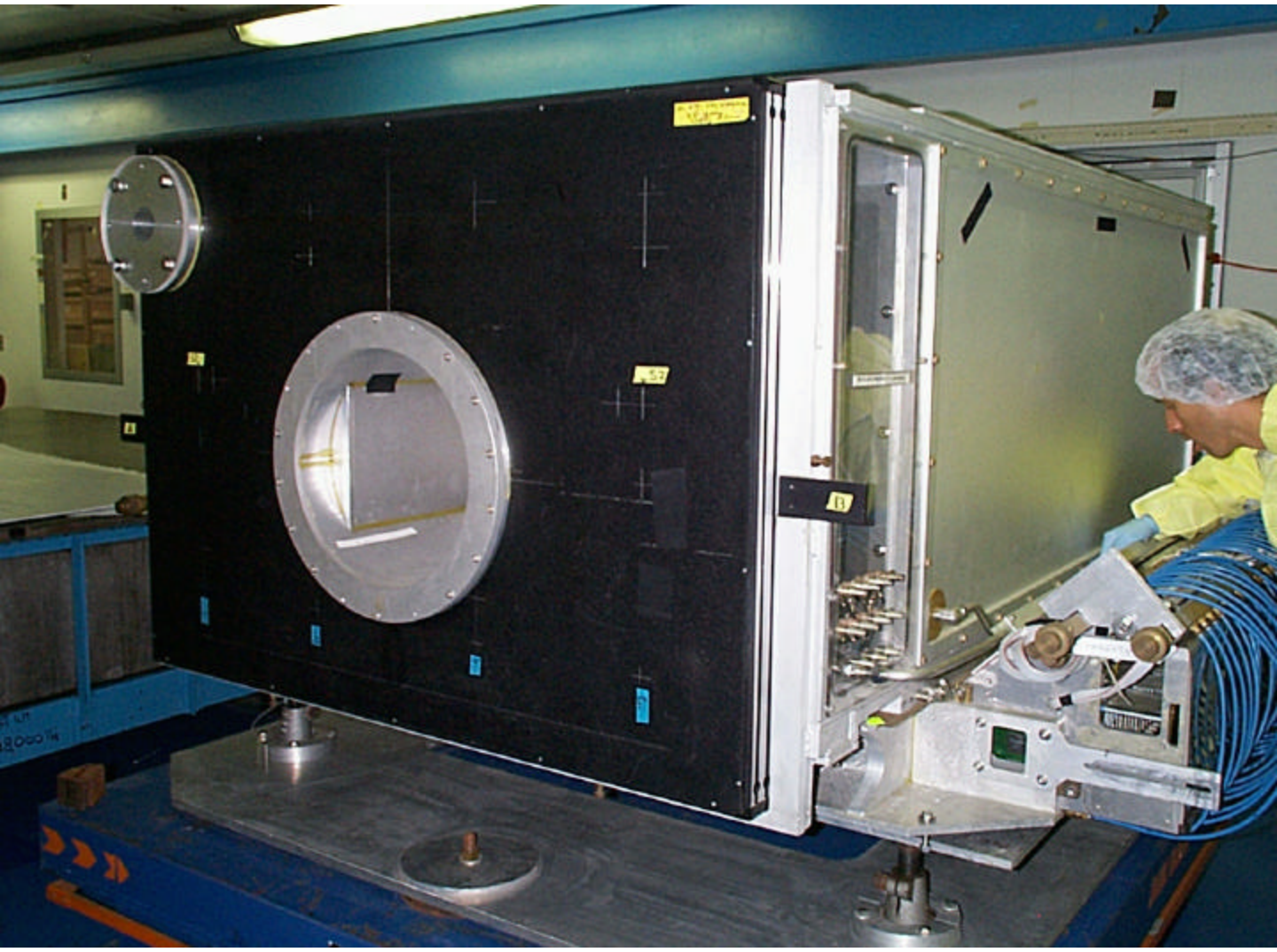
Scaling Law -EHS results

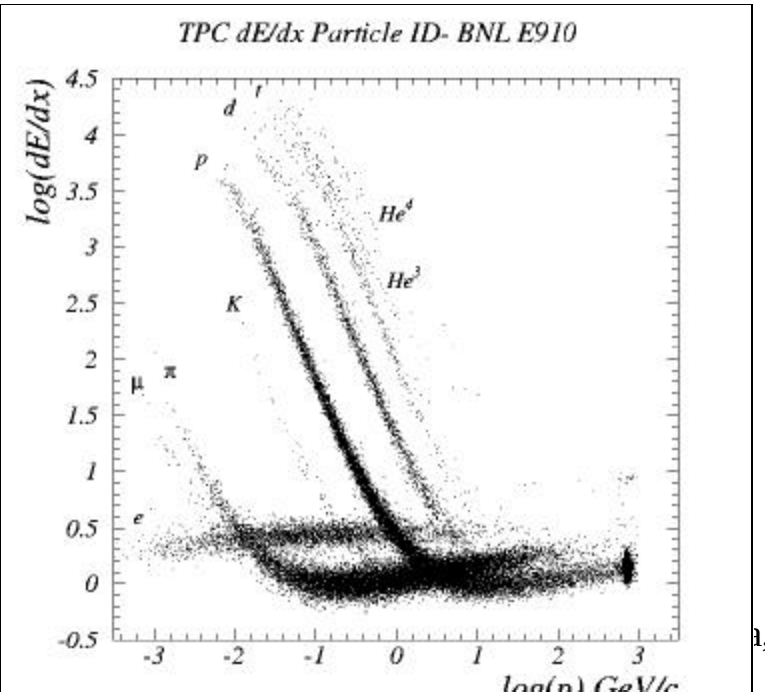


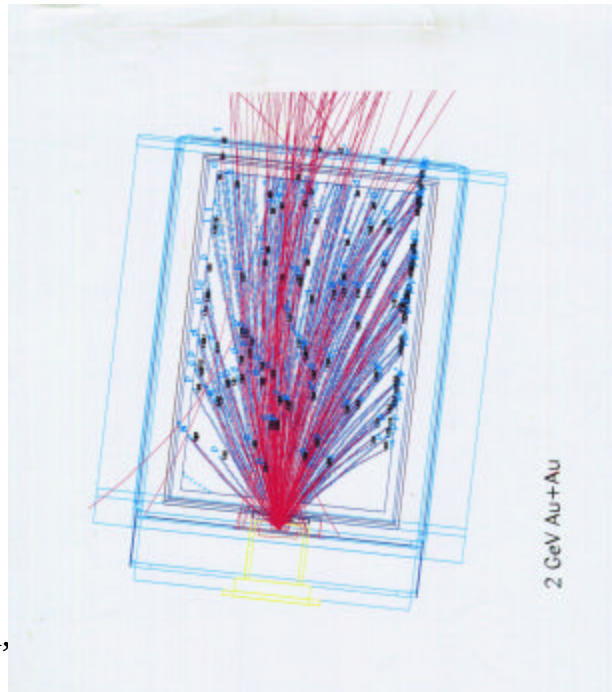
MIPP-TPC

- 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. Time to drift across TPC=16 μs.
- Electronic equivalent of bubble chamber, high acceptance, with dE/dx capabilities. Dead time 16μs. i.e unreacted beam swept out in 8μs. Can tolerate ~10^5 particles per second going through it.
- Can handle data taking rate ~20Hz with current electronics. Will increase this to ~3000 Hz with the upgrade.
- TPC dimensions of 96 x 75 x 150 cm.

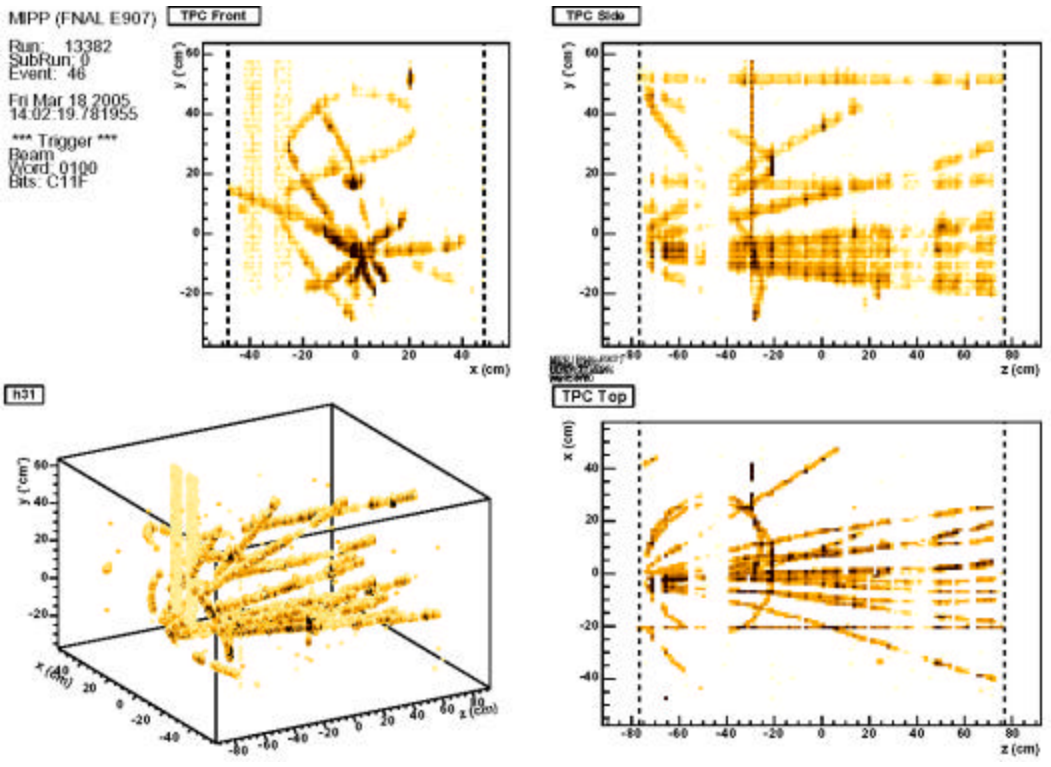
TPC installation

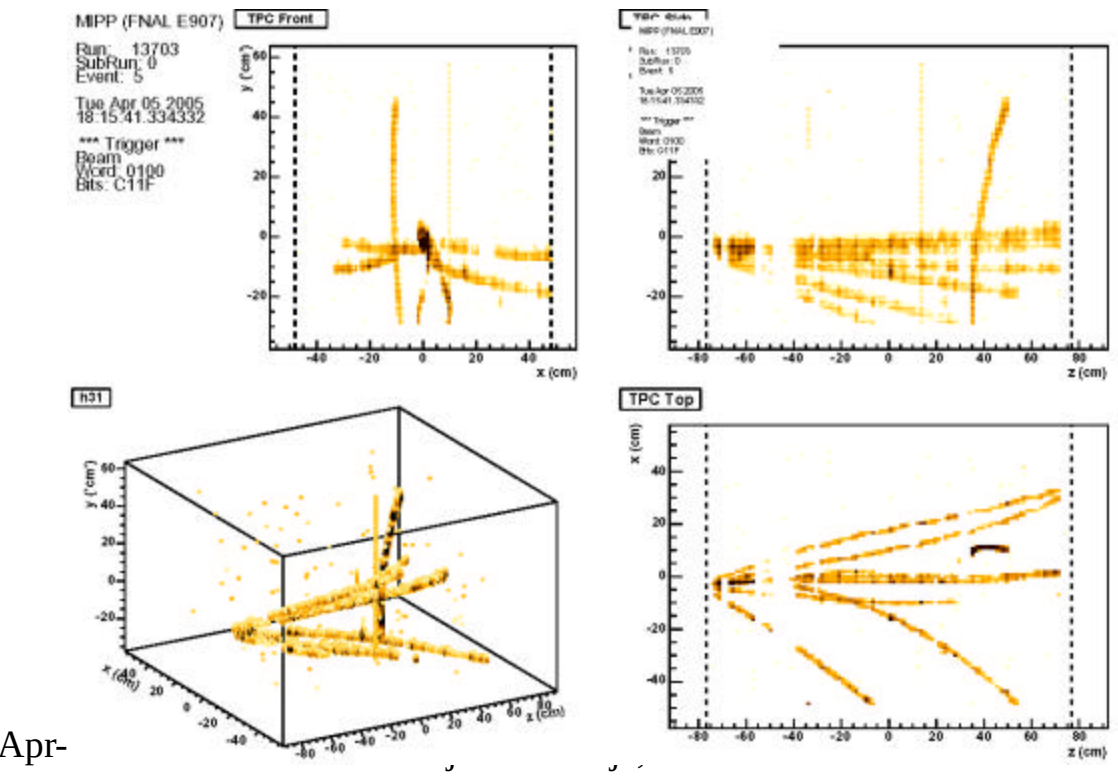




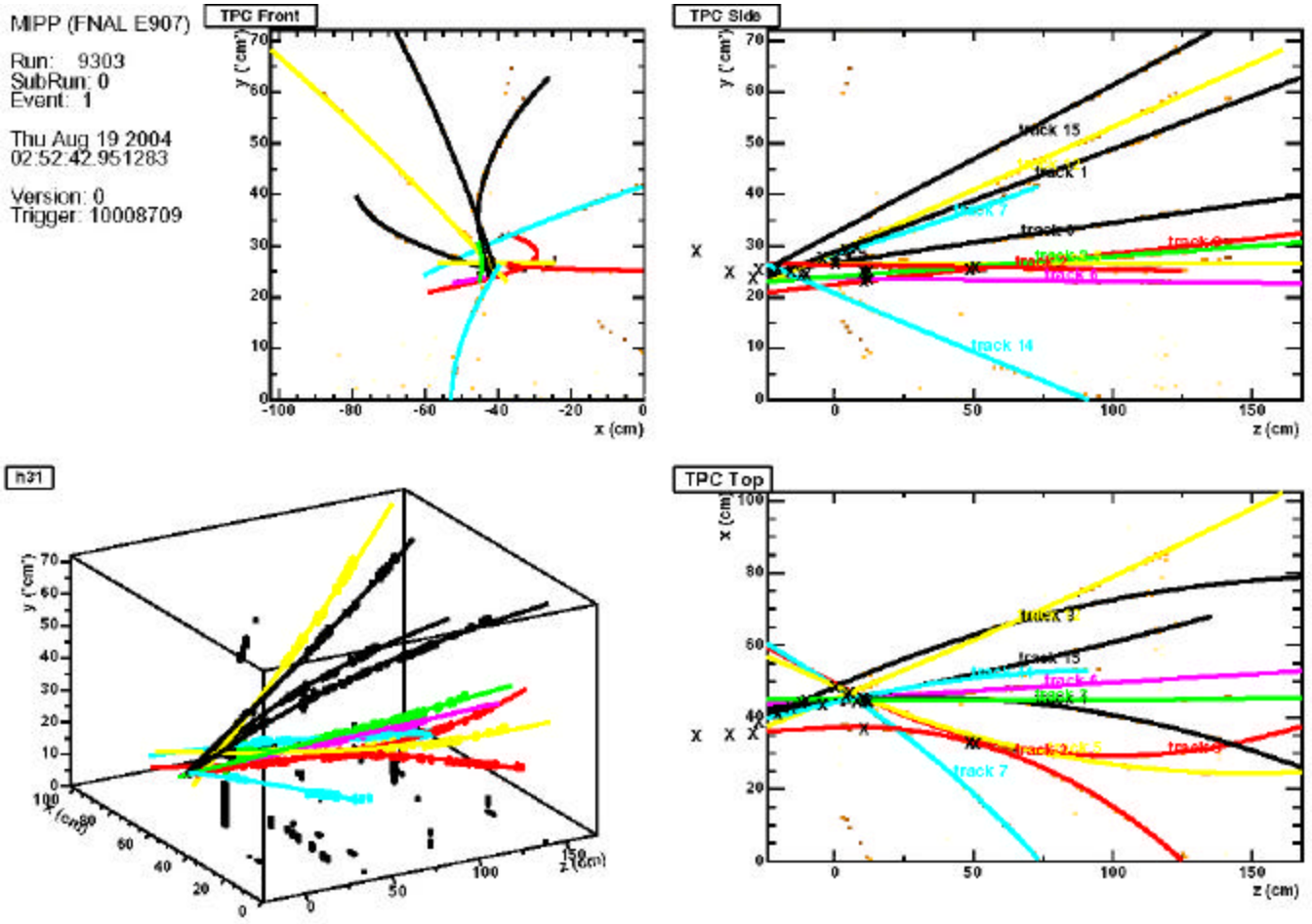


TPC events
50 GeV, -85 GeV cryo target(bottom)





TPC processed event

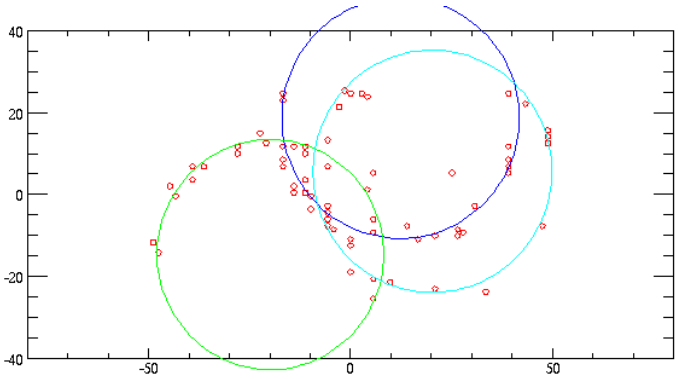


MIPP (FNAL E907)

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

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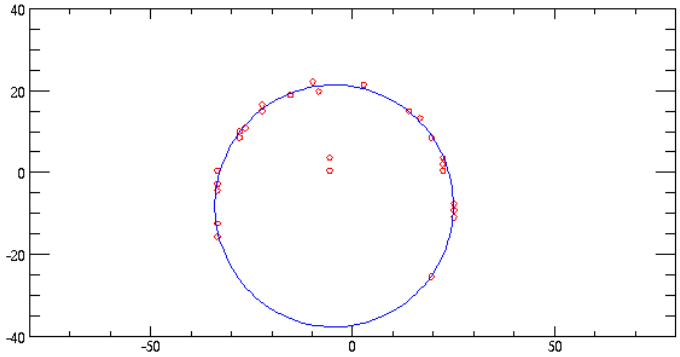
13:53:56.884750

Version: 0
Trigger: 10000008



MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 100

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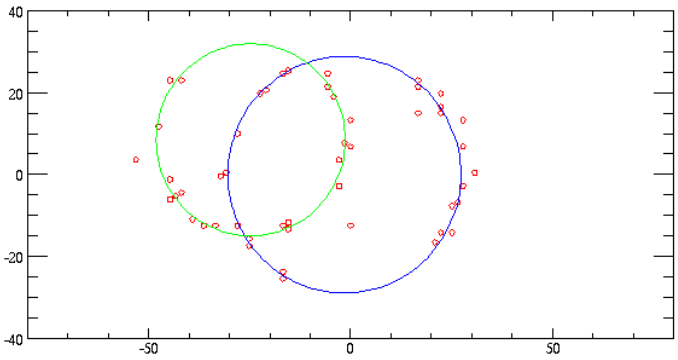
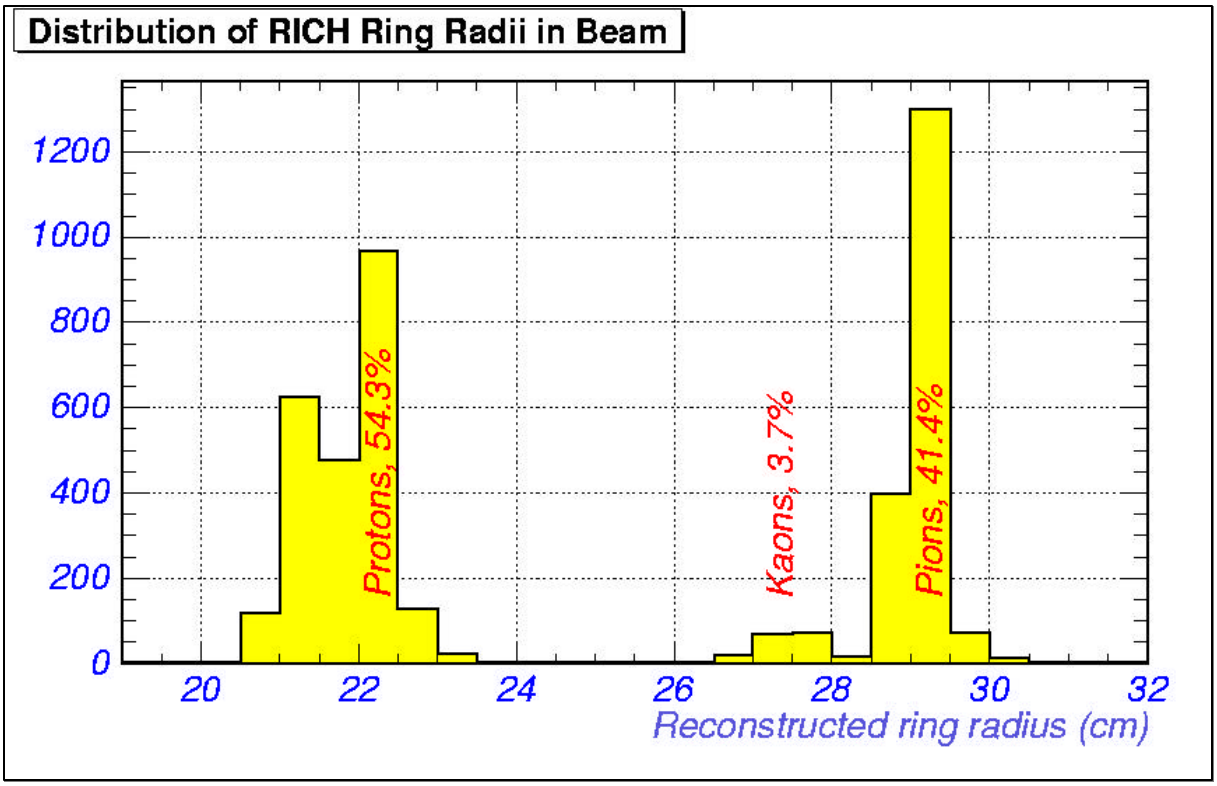
13:54:06.823879

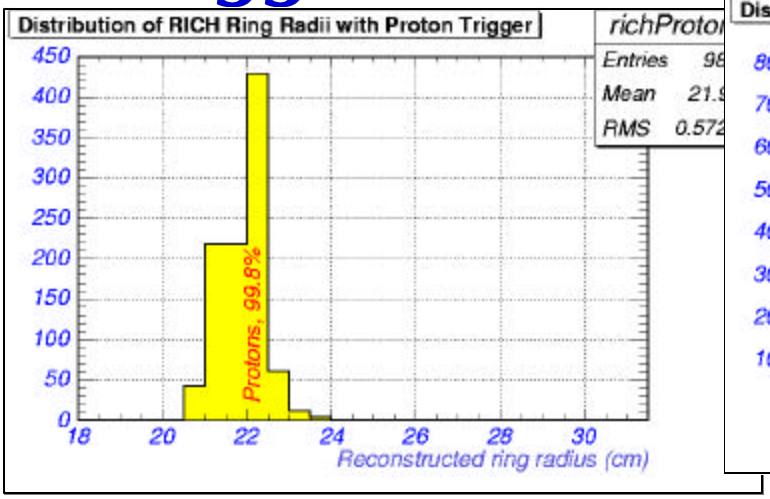
Version: 0
Trigger: 10000008

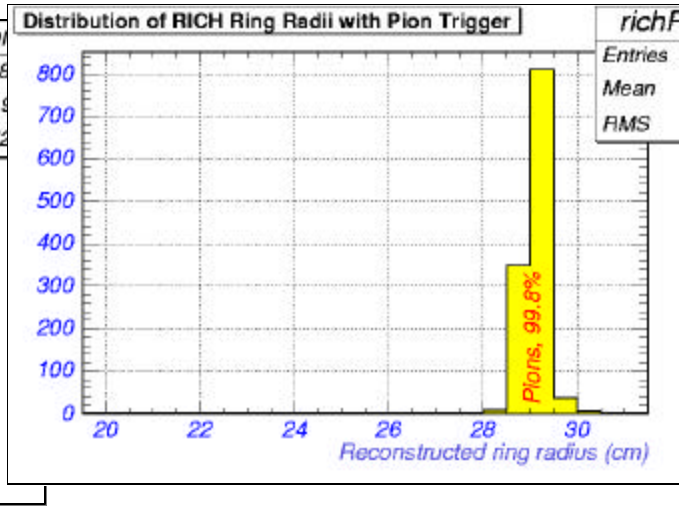


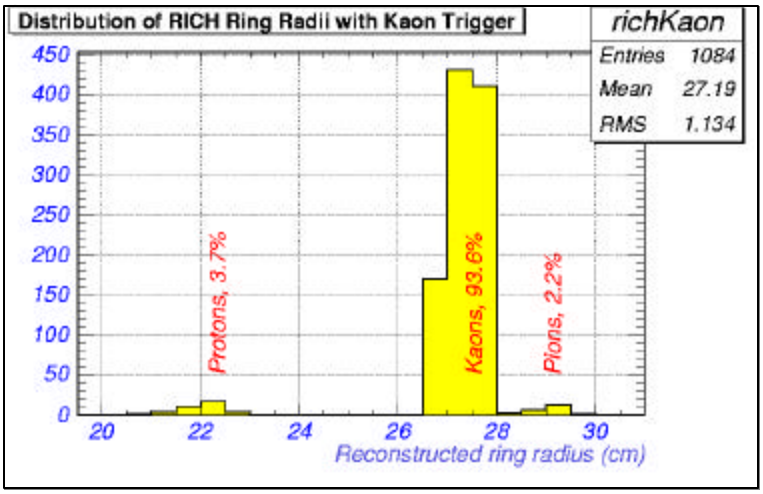
RICH radii for + 40 GeV beam triggers



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







Additional Physics with upgraded MIPP

- Non-Perturbative QCD
  - » Test scaling in two particle inclusives- More variables. Need more statistics.
- More nuclei can be measured
- Future Neutrino experimental targets-FINESSE, T2K
- Low Momentum Pion and Kaon Physics. Pion beams of 1 GeV/c and Kaon beams of 5 GeV/c and greater are possible.

Missing baryon Resonances

- Low momentum pions (<5 GeV/c) need new power supplies that regulate at such low currents. J.Lentz proposes using trim element supplies (plentiful at the lab) and switching between the two sets as running conditions demand.
- Partial wave analyses of πN scattering have yielded some of the most reliable information of masses, total widths and πN branching fractions. In order to determine couplings to other channels, it is necessary to study inelastics such as

$$p^- p \to hn; p^- p \to p^+ p^- n; p^- p \to K^0 \Lambda$$

$$gp \to p^0 p; gp \to K^+ \Lambda; gp \to p^+ p^- p$$

- All of the known baryon resonances can be described by quark-diquark states. Quark models predict a much richer spectrum. Where are the missing resonances?

Missing Baryon Resonances

- A)They do not exist
- B)not been seen because they couple weakly to πN channel. So look for them in $gp \to K^+\Lambda$ (J-Lab)
- If you find any, then one would like to determine the state's helicity amplitudes in order to make comparisons to quark model predictions. To do this, you need high statistics data in πN elastics and $pN \to K\Lambda$ (MIPP)

Such data do NOT exist and MIPP can provide this if upgraded.

Missing Baryon Resonances

- Resonances fall into four well defined regions.
  - » $P_{33}(1232)$ region
  - » c.m energy ~1.5GeV $P_{11}(1440)$/Roper Resonance, $D_{13}(1520)$,$S_{11}(1535)$
  - » c.m. energy of 1.7GeV Nine resonances $S_{11}(1650)$,$D_{15}(1675)$,$F_{15}(1680)$,$D_{33}(1700)$, $P_{11}(1710)$,$P_{33}(1600)$,$S_{31}(1620)$,$D_{33}(1700)$
  - » c.m.energy 1.9-2.0GeV. Includes contributions from 7 resonances, most importantly $F_{37}(1950)$. There are approximately nine missing positive-parity resonances in this N=2 band.
- Not much is known above this region. One expects the region near 2.2 GeV to be populated by several N=3 negative parity states and some N=4. MIPP upgrade can explore these regions.

Missing Baryon Resonances

- Reactions which permit coupled channel partial wave analyses but which need much higher statistics.

  pN elastic scattering

  $p^- p \rightarrow p^- p^0 p$ (detect p^0 by MM)

  $p^+ p \rightarrow p^+ p^0 p$ (detect p^0 by MM)

  $p^- p \rightarrow p^+ p^- n$ (detect n by MM)

  $p^+ p \rightarrow p^+ p^+ n$ (detect n by MM)

- Entire data set for above consist of 241,000 events. Above 1600 MeV PWA becomes noisy, due to low statistics. MIPP will produce an order of magnitude more statistics

Missing baryon Resonances

- Strangeness production

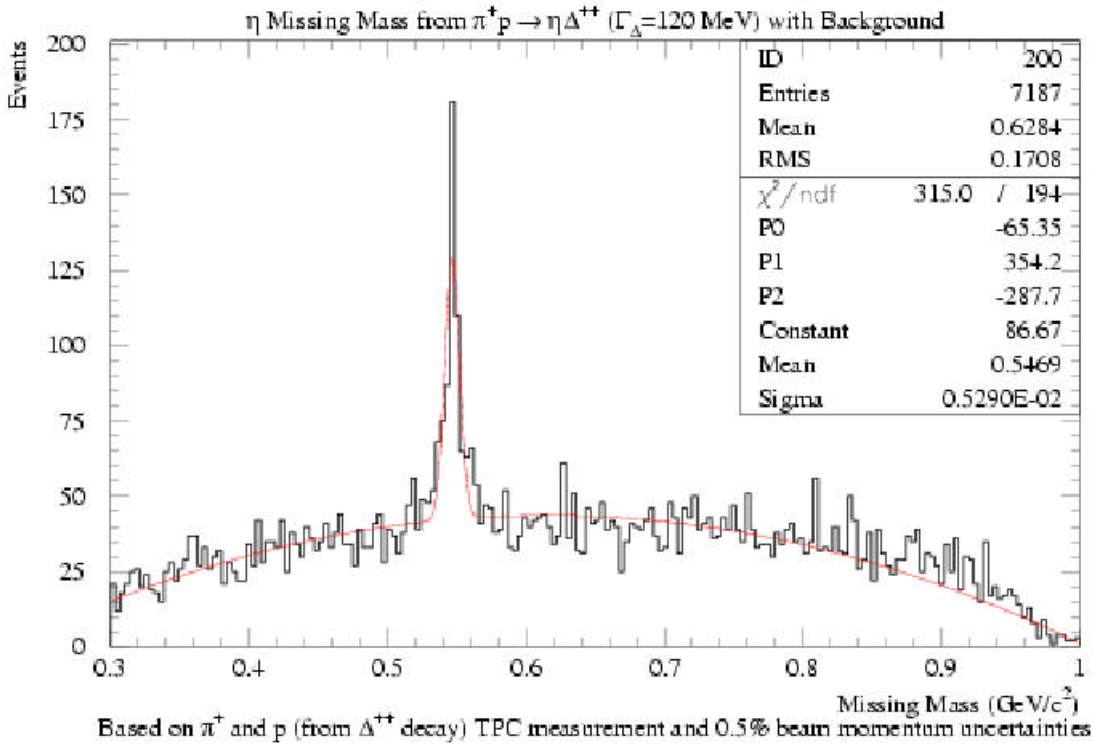
$p^- p \rightarrow K^0 \Lambda$ (Pure I = 1/2 reaction)

$p^- p \rightarrow K^0 \Sigma^0; \Sigma^0 \rightarrow \Lambda g$ (g by MM)

$h\Delta$ and $w\Delta$ resonances (I = 3/2)

$p^+ p \rightarrow h p^+ p$ (h by MM)

$p^+ p \rightarrow p^+ w p$

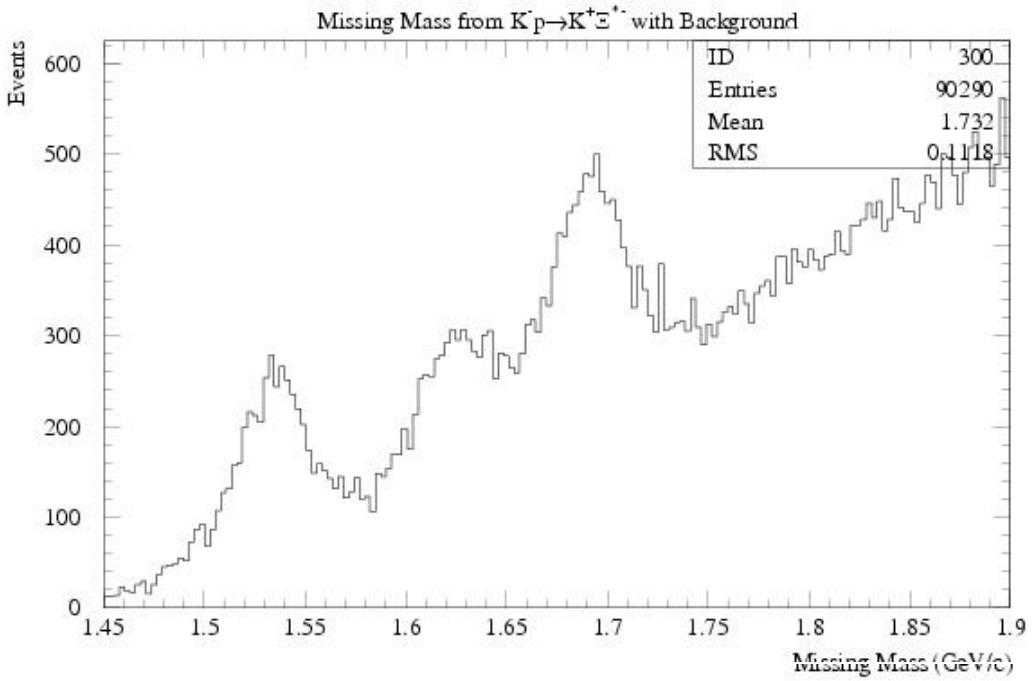


Run time needed for low momentum pion running

Momentum	W	Time p^+	Time p^-	Momentum	W	Time p^+	Time p^-
GeV/c	(GeV)	(Hours)	(Hours)	(GeV/c)	(GeV)	(Hours)_	(Hours)
0.80	1.557	170	124	1.55	1.955	22	32
0.85	1.586	109	76	1.60	1.978	21	29
0.90	1.615	106	54	1.65	2.002	20	27
0.95	1.644	78	41	1.70	2.025	19	25
1.00	1.672	61	32	1.75	2.048	18	23
1.05	1.699	50	27	1.80	2.071	18	22
1.10	1.726	42	22	1.85	2.093	18	22
1.15	1.753	36	19	1.90	2.115	17	22
1.20	1.780	31	17	1.95	2.137	17	22
1.25	1.806	27	15	2.00	2.159	17	22
1.30	1.831	25	15	2.10	2.202	17	23
1.35	1.857	23	15	2.20	2.244	18	23
1.40	1.881	24	17	2.30	2.286	18	23
1.45	1.906	24	19	2.40	2.326	19	23
1.50	1.930	23	23	2.50	2.366	20	24

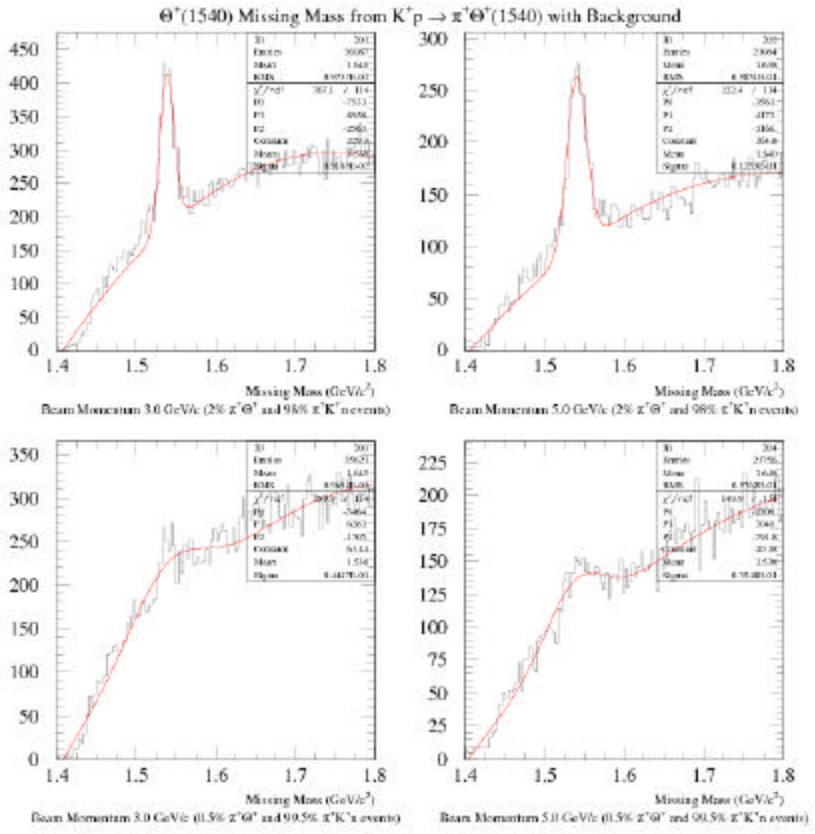
Missing Cascade Resonances

- Similar situation here-
- PDG " Not much is known about Cascade resonances…"
- There are 11 Ξ resonances (including ground state listed in PDG), 44 are predicted. 5 GeV/c Kaons. $K^- p \to K^+ \Xi^*$



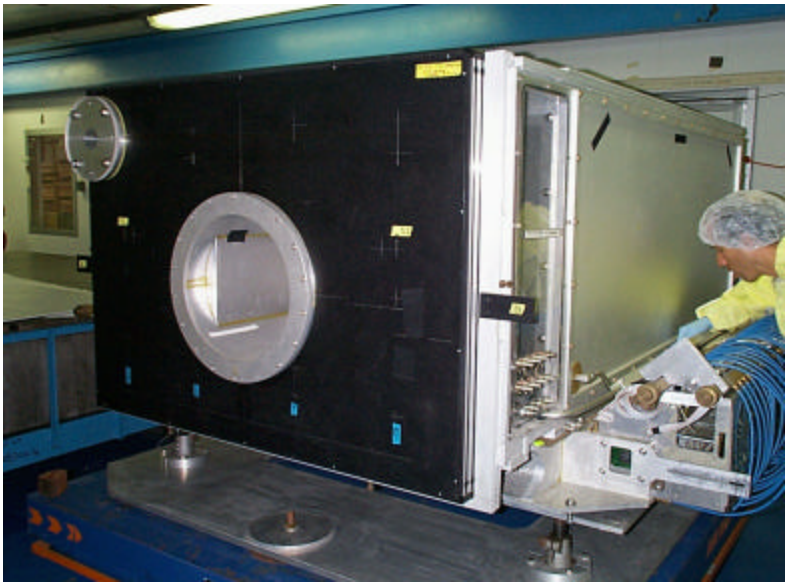
Pentaquarks

- Pentaquarks are “controversial”. Several experiments claim to see them and several others do not. MIPP can look at the channel $K^+ p \rightarrow p^+ q^+$
- MIPP’s acceptance is a factor 100 higher than 11 GeV/c LASS exp Hep-ex/0412031(2004) for this channel
- Missing Mass with 2% signal/backgd and .5% in MIPP for 3 and 5 GeV/c K+ beam momenta. In 12 days of running we can obtain sensitivity 2 orders of magnitude higher than LASS expt.

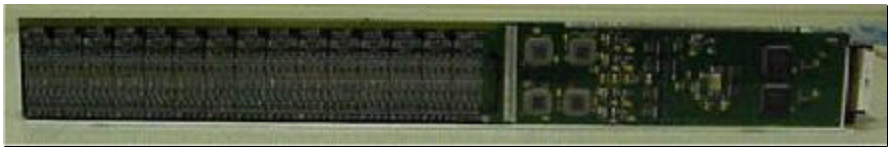


TPC Upgrade Proposal

MIPP TPC. 128 sticks each of which services a pad row. Each pad row has 120 pads. Total number of channels=15360 channels.

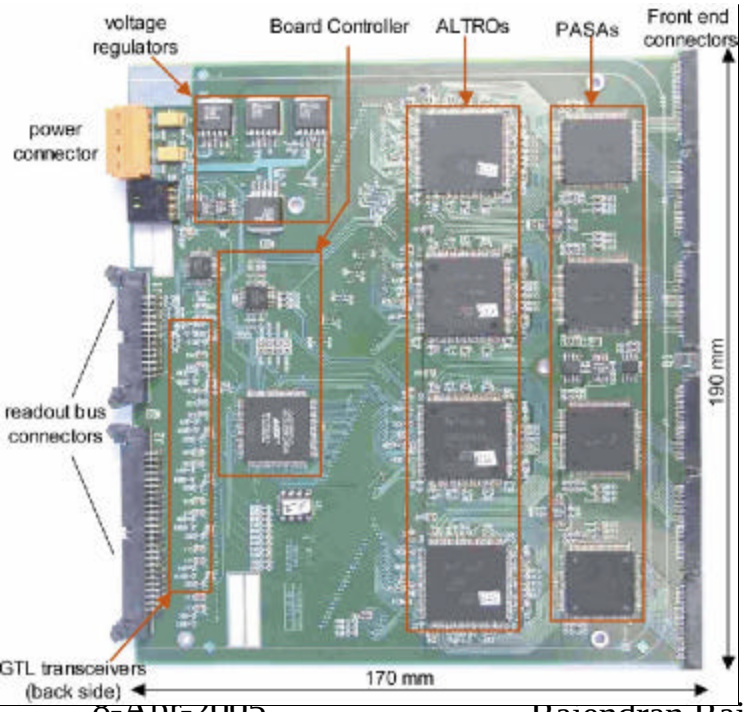


MIPP STICK



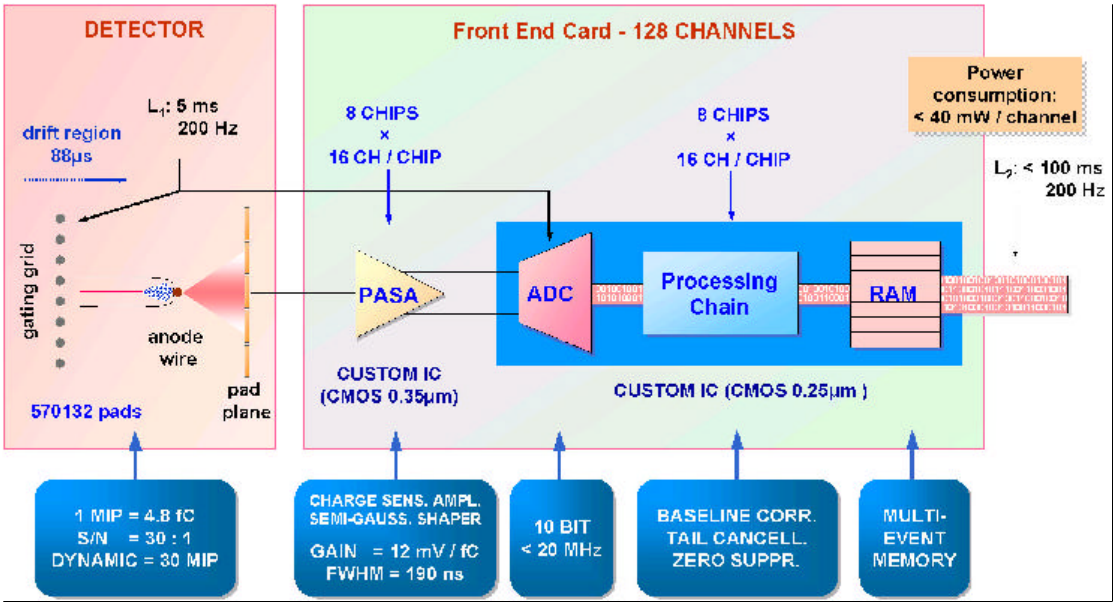
ALICE PASA/ALTRO Chip

- PASA-Preamp/Pulse shaper One chip=16 pads.
- ALTRO-Digitizes,memory buffer. Controlled by ALTRO bus (40bits wide) with a Readout Control Unit.
- Thoroughly debugged and tested for ALICE. Needed by STAR, TOTEM, MIPP and being used by BONUS.

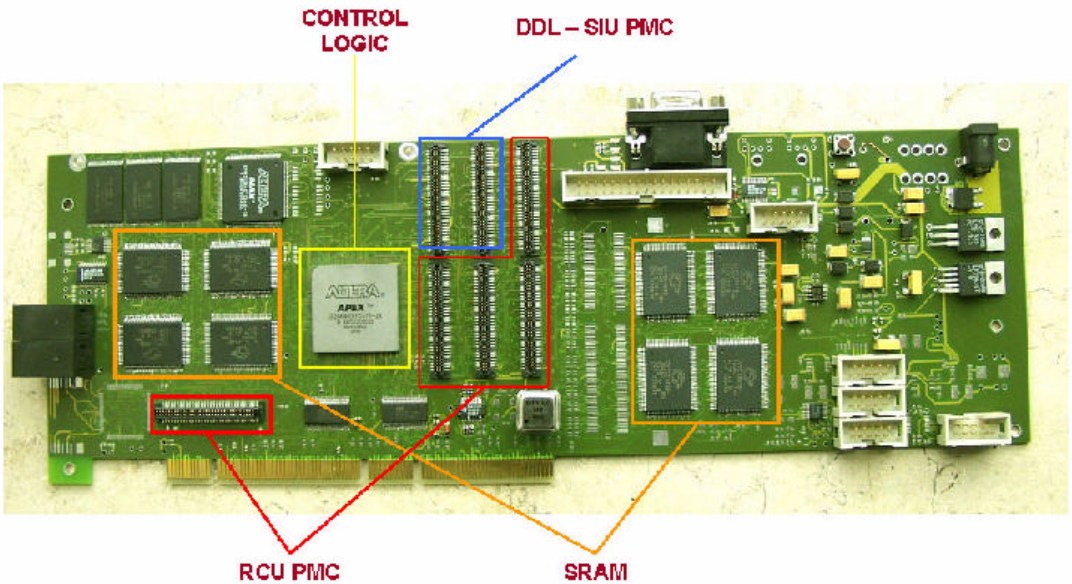


ALICE Front end card needs to be rearranged to look like a stick.

ALTRO/PASA chips



RCU Prototype II



Labor needed to fabricate the MIPP upgraded "Sticks"

Job	Time	Person
Writing FPGA code for both boards	1 month	engineer
Design front end circuit board	1 month	engineer
Layout	3 weeks	electrical drafting group
Assembly of prototype	1 week	technician
Debug/testing of prototype	3 weeks	engineer/technician
Design controller board(s)	1 month	engineer
Layout	1 month	electrical drafting group
Assembly of prototype	1 week	technician
Debug/testing of prototype	1 month	engineer/technician
Design of test injection card	1 week	engineer
Layout	1 week	electrical drafting group
Assembly of test card	1 week	technician
Debug/testing of card	1 week	engineer
Software for test stand	1 month	software engineer (or physicist?)
Running production tests on front boards	2 weeks	engineer/technician
repair of failed front end boards	2-4 weeks	technician
Testing readout controllers	1 week	technician
repairing failed controller boards	1 week	technician
oversight of entire procurement process	2 weeks	technician
parts, contract assembly etc.		
Document preparation, updating	2 weeks	engineer/technician

Other components needed- total cost

Component	Channels	no. 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

Acquire 1100 ALICE Altro/Pasa chips (tested at Lund)	**$105,000**
Cost of other items in above table	$50,000
TPC total Front end electronics cost	$155,000
VME processor boards	$20,000
Test stand	$30,000
Total TPC electronics upgrade cost	$205,000
Contingency (10\%)	$20,500
Total TPC electronic upgrade cost	$222,500
Cost to upgrade the rest of the MIPP DAQ	$50,000
Total DAQ upgrade cost	$275,500
Jolly Green Giant Coil Fix	$145,000
Total	**$420,000**

Upgrading the DAQ of the rest of MIPP to run at 3kHz.

- RICH and Hadron Calorimeter-Will work as is
- EM Cal- Use Lacroy FERA ADC's from Prep.
- Proportional Chambers-Use Hyper CP electronics-5000 channels
- Multi Cell Cerenkov-Use FERA bus to readout the 96 channels faster.
- Time of Flight system-~100 channels. Zero suppress, FERA bus.
- Drift chambers-7808 channels for drift chambers and 1920 for beam chambers.-CDF or KTEV electronics
- DAQ software-Improve interrupt handling,Write better VME drivers, Make use of DMA on the VME bus.

Jolly Green Giant Coil Fix

- One of the bottom coils has developed shorts. We are running with several turns shorted out. After the October shutdown, we propose to fix the coil.

Labor and costs in repairing the JGG coil

Equipment	Action	Manpower	Manweeks	M&S
BCKOV				
	secure & disconnect vacuum	2 techs, 2 weeks	4	
	re-install vacuum & test	3 techs, 3 weeks	9	
	remove cable tray & hardline	2 techs, 1 week	2	
	re-install cable tray & hardline	3 techs, 2 weeks	6	
	M&S purchases	$2K		$2,000
Beam pipe				
& concrete supports	move to side	4 techs, 1 week	4	
	re-install	4 techs, 2 weeks	8	
LH2 Target	Move LH2 target equipment out	2 techs 1 week	2	
TPC				
	De-cable	By experimenters		
	Re-cable	By experimenters		
	remove electrical conduit	M&S $4K		$4,000
	re-install electricalconduit	M&S $8K		$8,000
	move out TPC & support st&	3 techs, 1 week	3	
	re-install TPC & support st&	3 techs, 1 week	3	
JGG				
	de-cable	2 techs, 2 days		
	re-cable	2 techs, 3 days	1	
	de-hose	1 tech, 1 day		
	re-hose	1 tech, 4 days	1	
	remove coil	M&S $15K	1	$15,000
	install coil	M&S $6K	1	$6,000
Repair JGG coil				
	M&S	$90K		$90,000
	OH	$20K		$20,000
	total man-weeks		45	
	total M&S			**$145,000**

- Optional Upgrades

Cryogenic target -Extra cryo cooler	$32,000
TPC Rewind (M&S)	$10,000
RICH phototube upgrade (Hamamatsu tubes, bases)	$204,000

Total Running time requested

Physics Topic	Run Time (days)
MIPP -I	18.1 days
New neutrino experiment target (10 million events)	2.3 days
Additional Nucleus (5 million events)	1.15 days
Two particle inclusive scaling (100 million events)	23.1 days
Pentaquark search (K+ beam)	12 days
Cascades search (K- beam)	15 days
Missing baryon search using low momentum pions	82 days

Timeline

- Run till next shutdown (Oct 2005)in current configuration.
- Acquire Altro/Pasa chips tested by Lund along with the STAR order in May.
- Design and fabricate the FEC (May-January 2006)
- Remove the TPC , fix the JGG coil Nov-2005-Jan06.
- Upgrade the rest of DAQ, trigger and be ready to take data April 2006.

Conclusions

- MIPP has proposed a low cost upgrade to its TPC + DAQ system, that would guarantee the acquisition of the data it has been approved for.
- Making the upgrade operational would enable MIPP to explore the areas of missing baryon resonances, pentaquarks, missing cascade resonances with an apparatus whose capabilities are unique.