

MI PP Experiment Upgrade

Rajendran Raja
Fermilab

- Beam
- MI PP experiment
 - » Physics
 - » Engineering measurements
- Particle ID
- Some results
- Upgrade plans

MIPP collaboration list

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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. MI PP will go from 5-100 GeV/c for 6 beam species $\pi^\pm K^\pm p^\pm$ -- 420M triggers. 3KHZ TPC.

MI PP Physics Program

MI PP-I has 4 distinct clientele for its data, which are interconnected. They are

Liquid H₂, D₂ -non-perturbative QCD

p-A, p-rad (aka SURVEY)

NUMI thin and full target measurements

LN2- Atmospheric neutrinos

MI PP-Upgrade (100 times faster DAQ) will address

missing hadron resonances problem using low energy beams
(1-5 GeV/c)

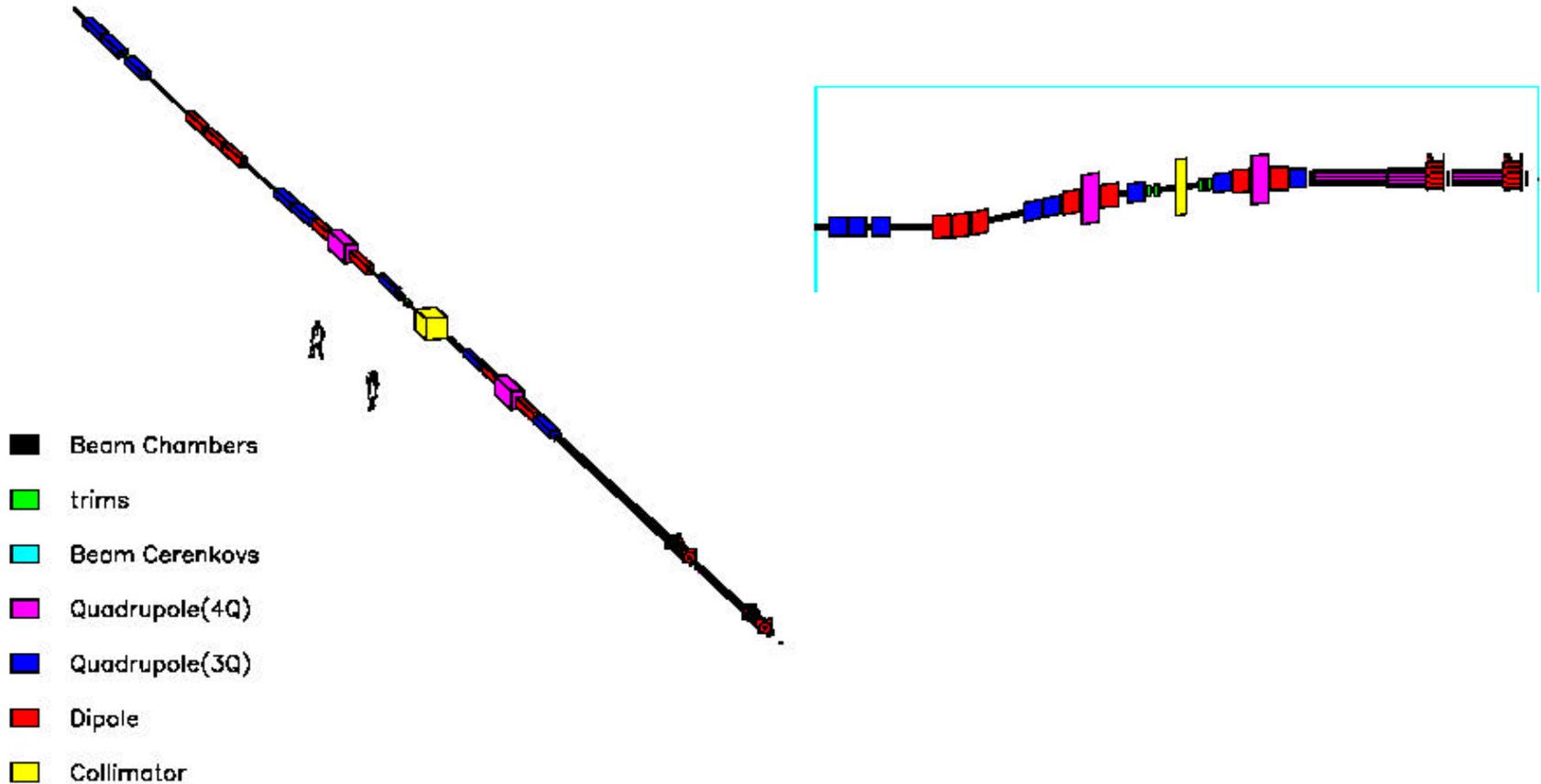
Obtain higher statistics NUMI target data

Solve the hadron shower simulation problem

MIPP Secondary Beam

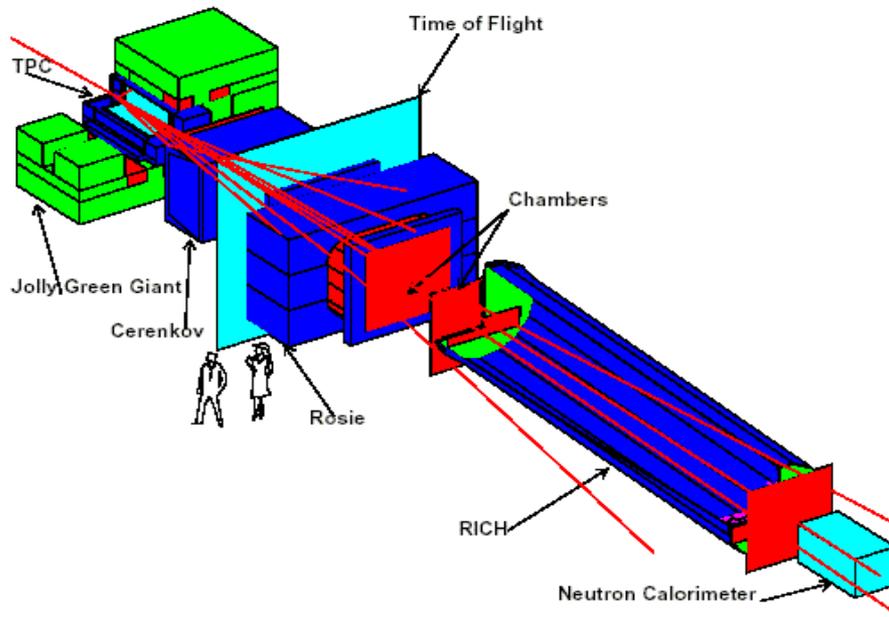
Installed in 2003. Delivering slow spill commissioning beam (40GeV/c positives since February 2004). Finished Engineering run in Aug 2004.

MIPP BEAM



MIPP

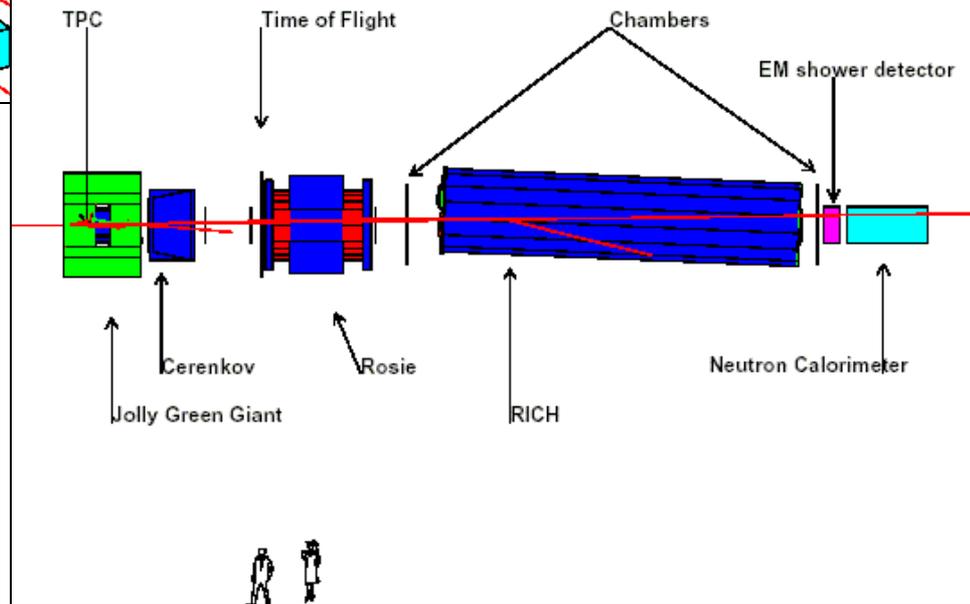
Main Injector Particle Production Experiment (FNAL-E907)



MIPP

Main Injector Particle Production Experiment (FNAL-E907)

Vertical cut plane



Status of MIPP Now- Collision Hall



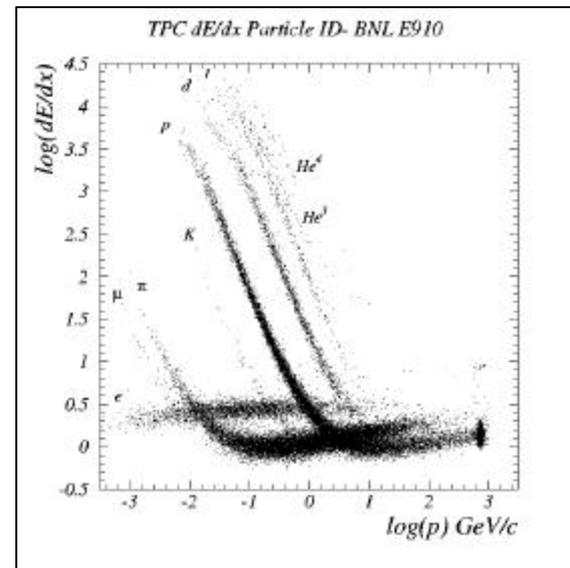
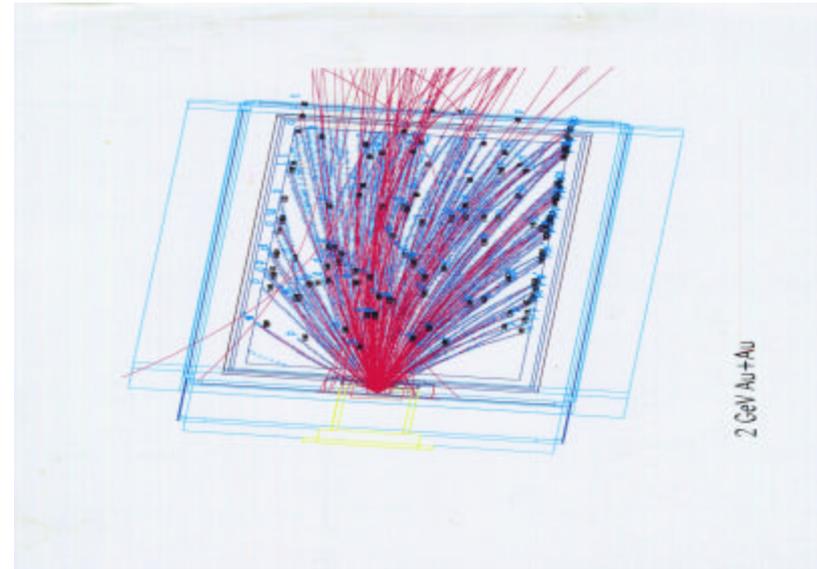
Brief Description of Experiment

- Approved November 2001
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of 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.

MI PP-TPC

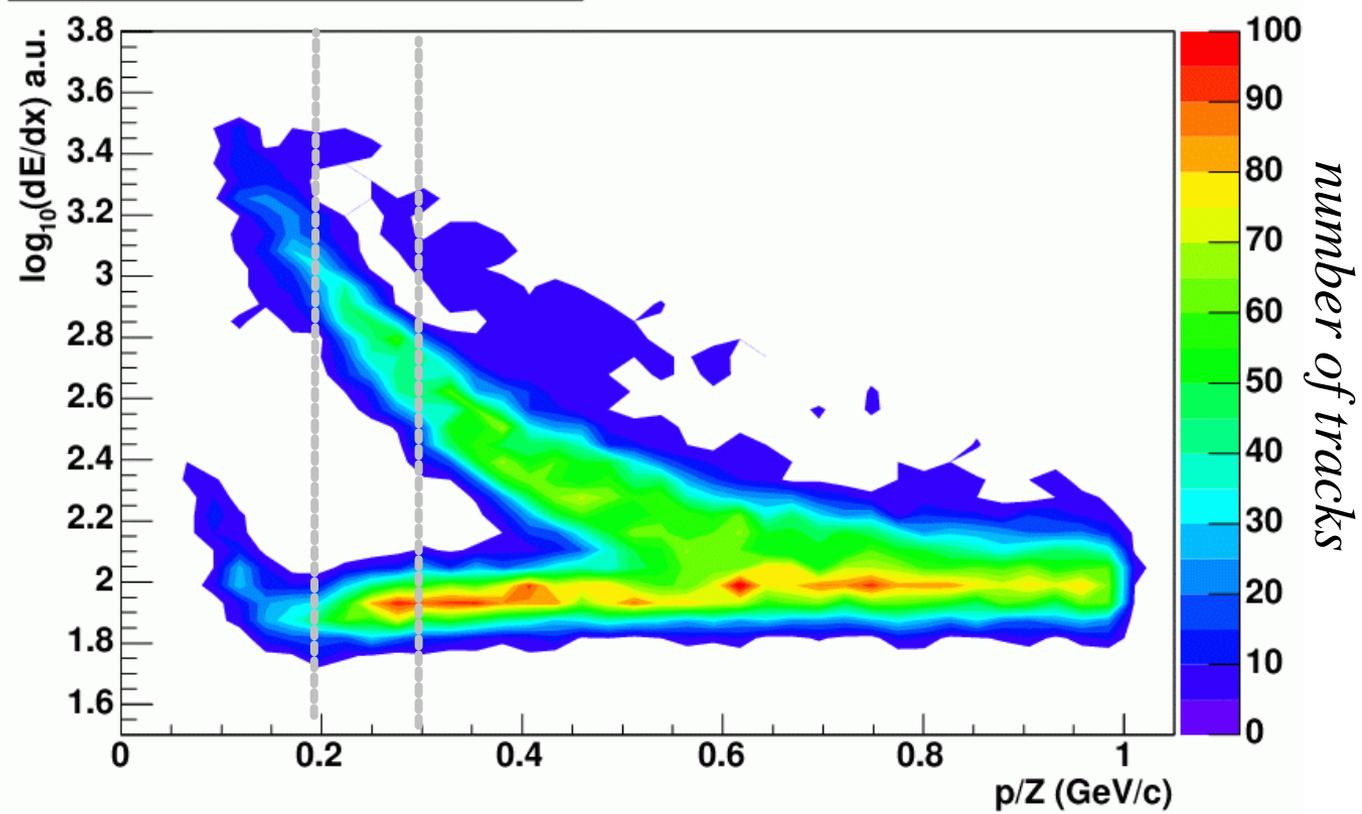
- This Time Projection Chamber, built by the BEVALAC group at LBL for heavy ion studies currently sits in the E-910 particle production experiment at BNL, that has completed data taking. It took approximately \$3million to construct.
- Can handle high multiplicity events. Time to drift across TPC=16 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 ~60Hz with current electronics. Can increase this to ~1000 Hz with an upgrade.
- TPC dimensions of 96 x 75 x 150 cm.

TPC



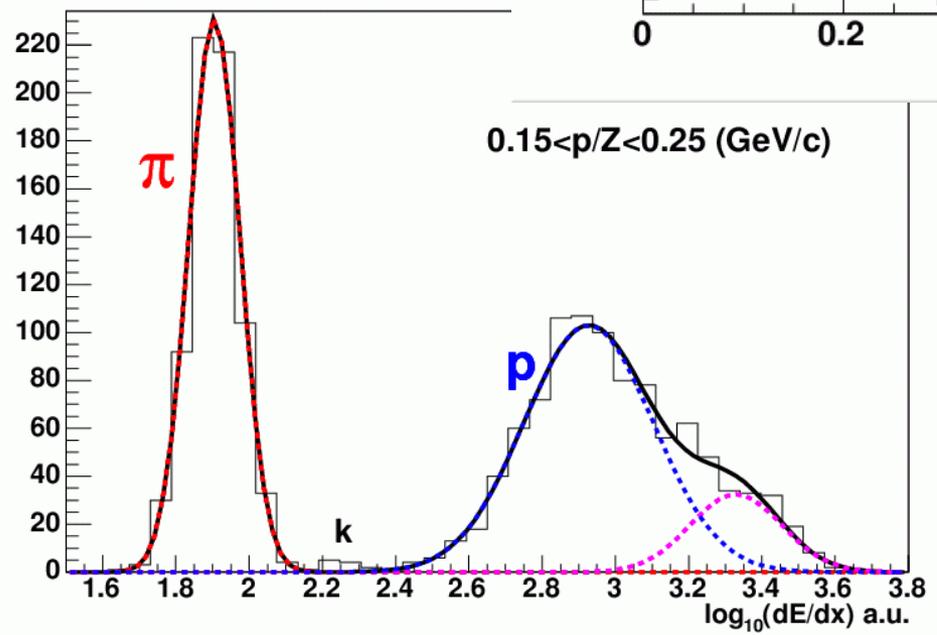
dE/dx in TPC

$\pi, k, p(+20 \text{ GeV}) + \text{Carbon } 2\%$



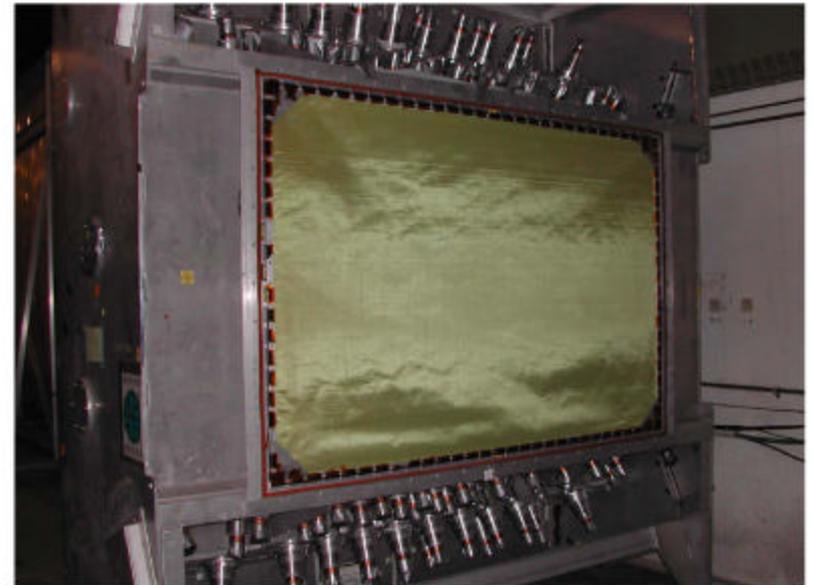
20 GeV $\pi/K/p$ beam
incident on carbon
target

$\pi, k, p(+20 \text{ GeV}) + \text{Carbon } 2\%$

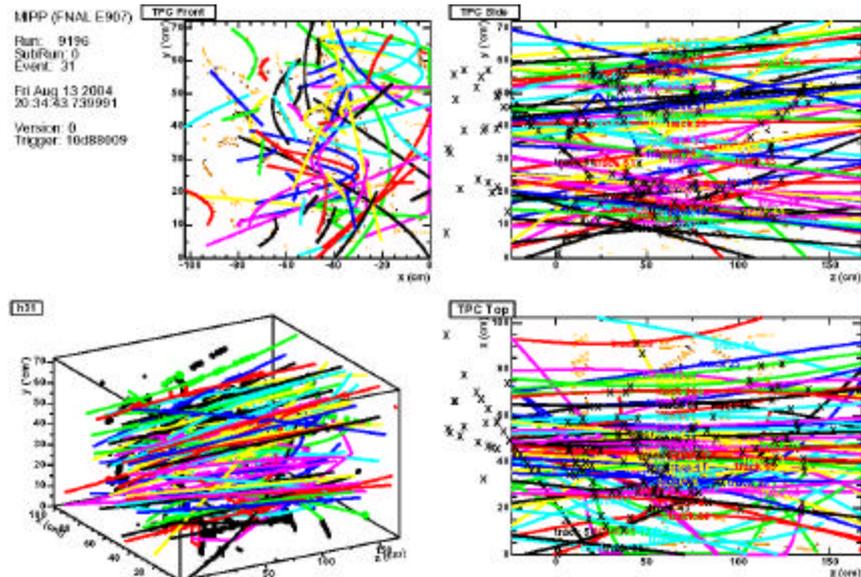
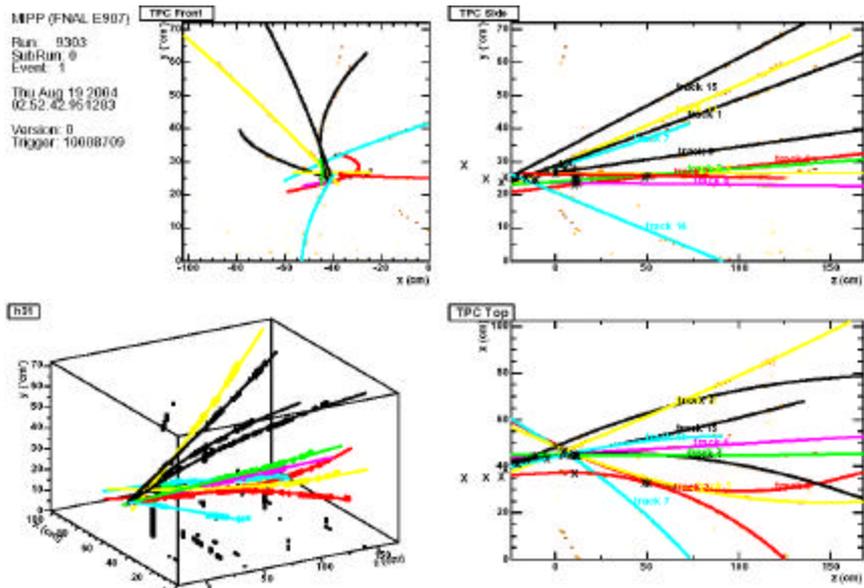
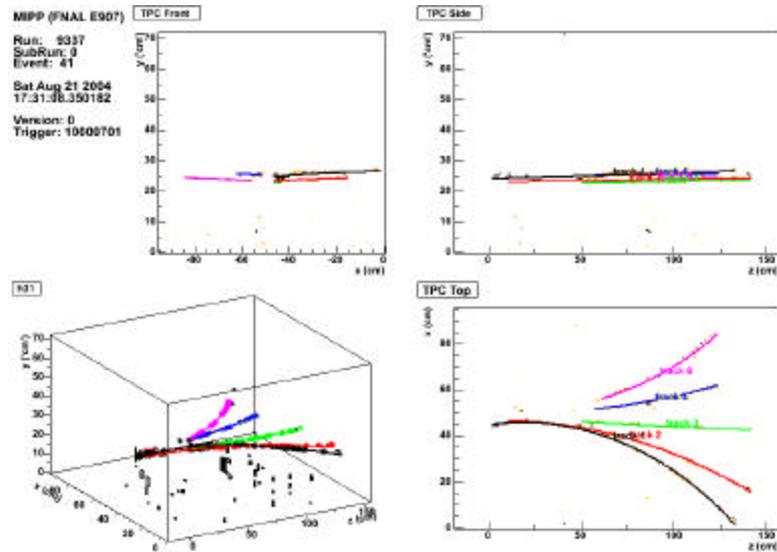
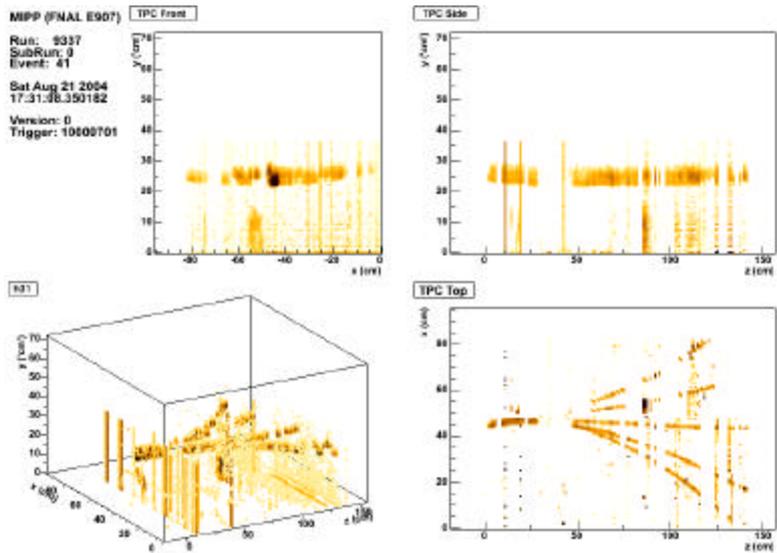


- ? Preliminary calibration of TPC gains
- ? Momentum from helix fits
- ? Slice shows momentum range from 150 to 250 MeV/c

MI PP Cherenkov



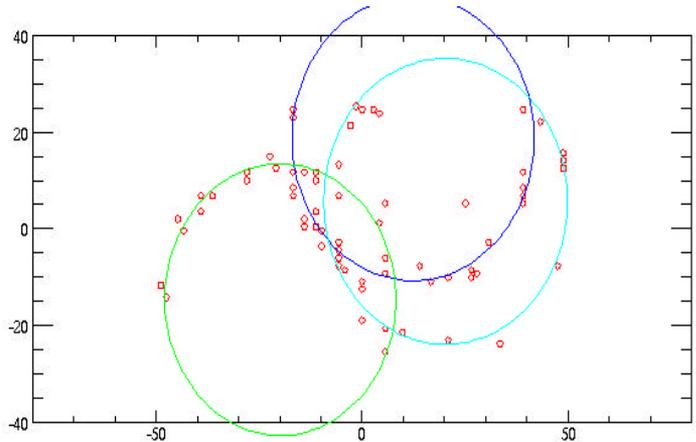
Preliminary results from Engineering run



Sep 16, 2005

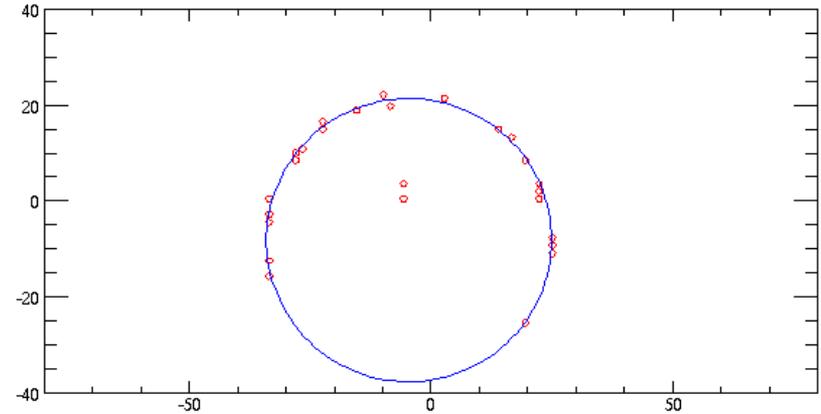
Rajendran Raja, Cavendish Lab, Cambridge

RICH rings pattern recognized



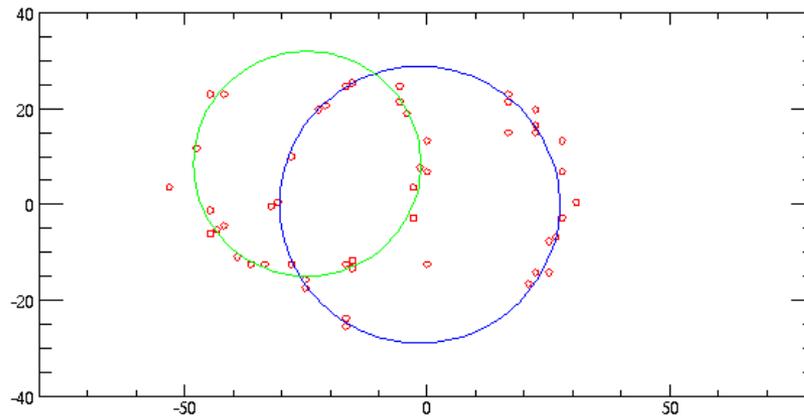
MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 92
Wed Aug 11 2004
13:53:56.884750
Version: 0
Trigger: 10000008

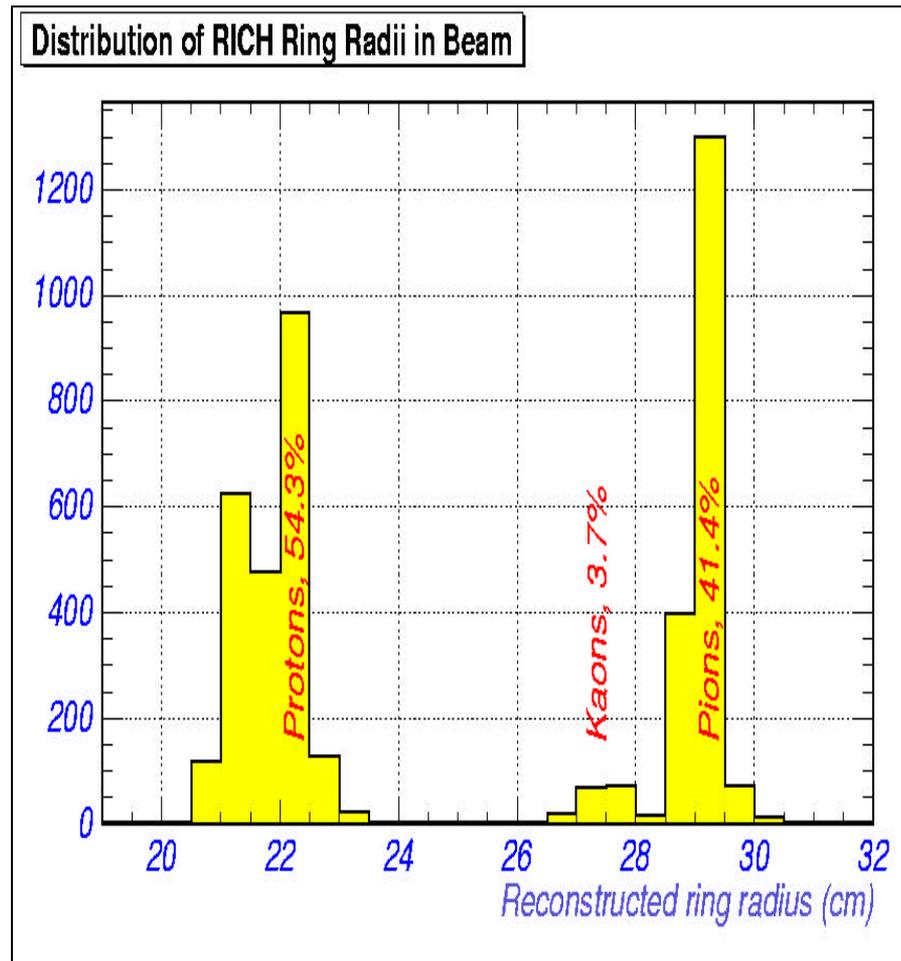


MIPP (FNAL E907)

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SubRun: 0
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Trigger: 10000008

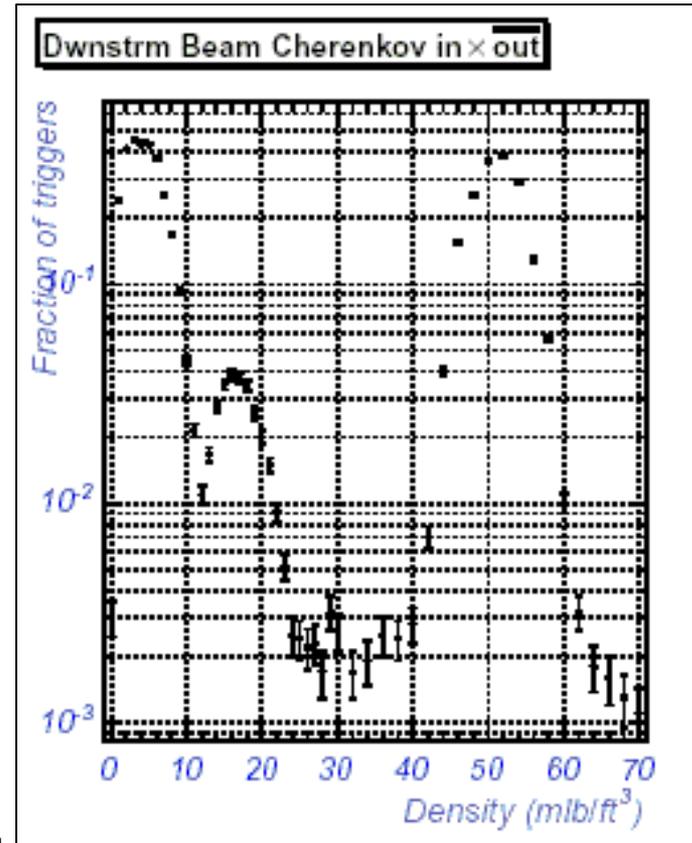
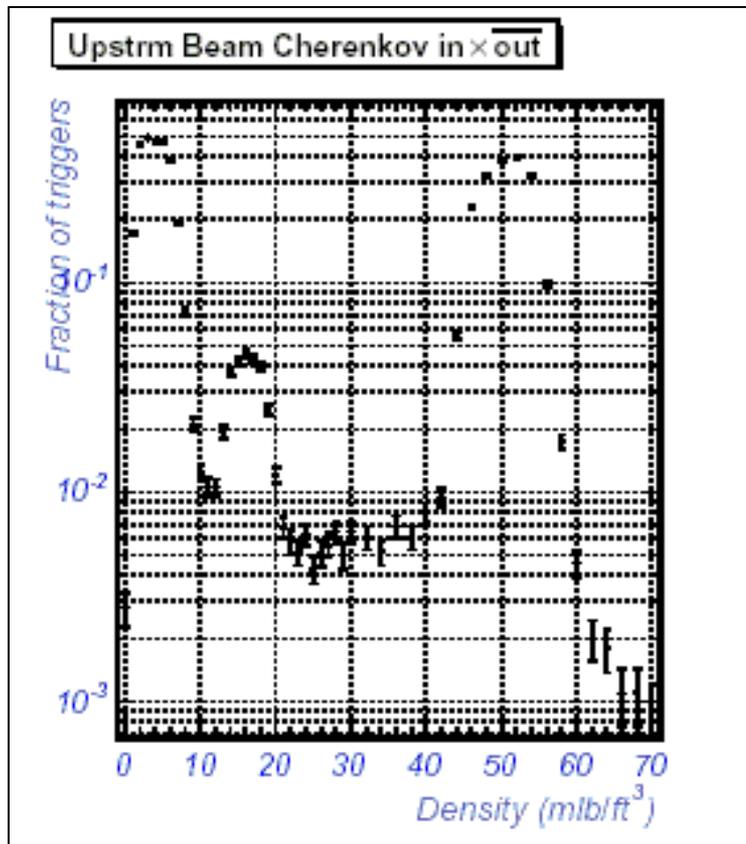


RICH radii for + 40 GeV beam triggers



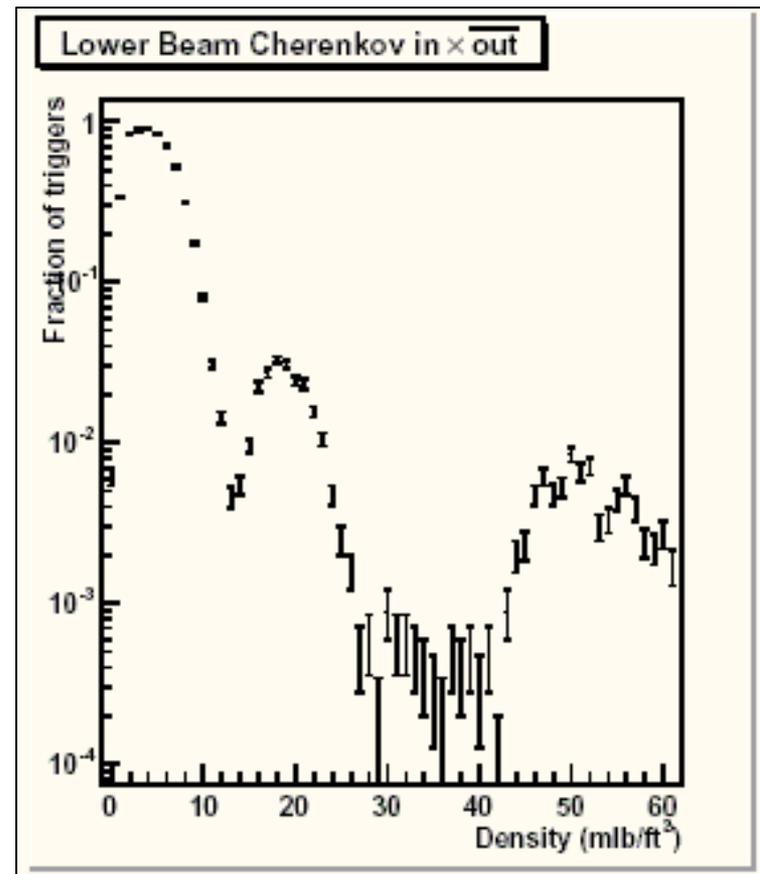
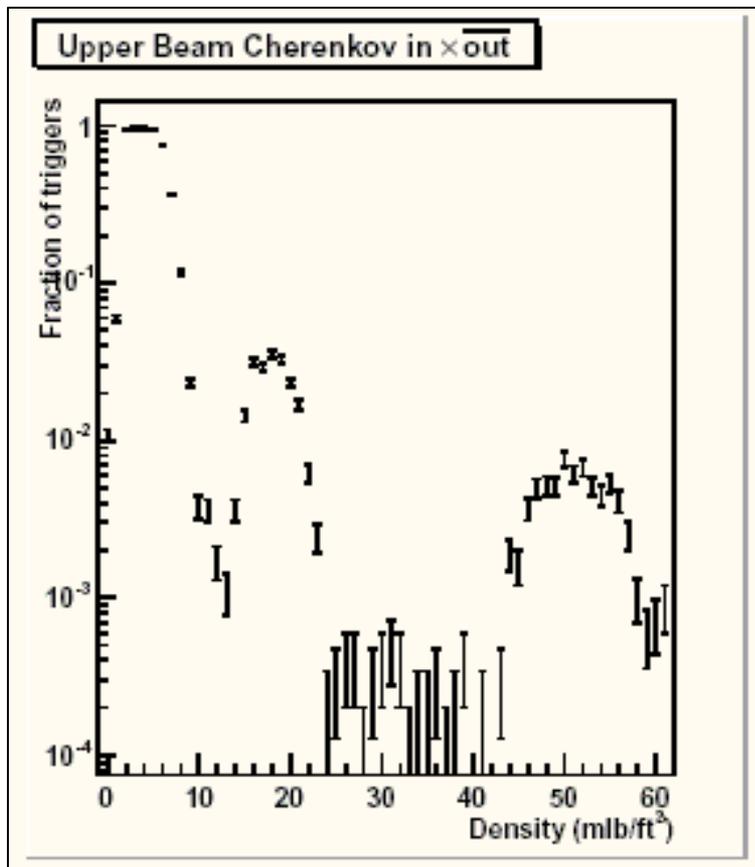
Beam Cherenkovs

- Pressure curve Automated- Mini-Daq- APACS 30 minutes per pressure curve.+40GeV/c beam.

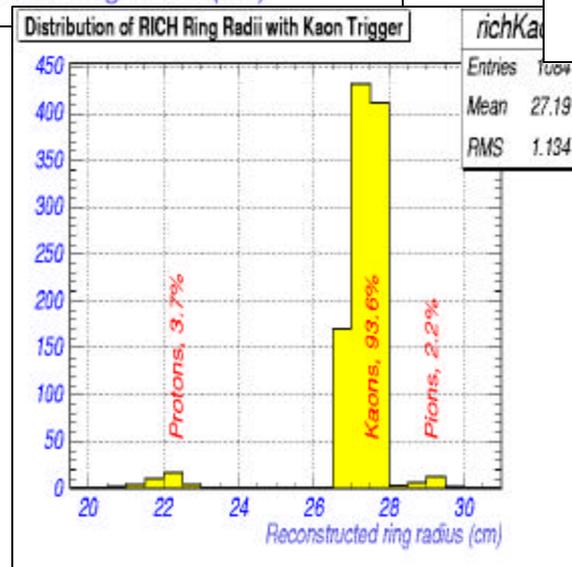
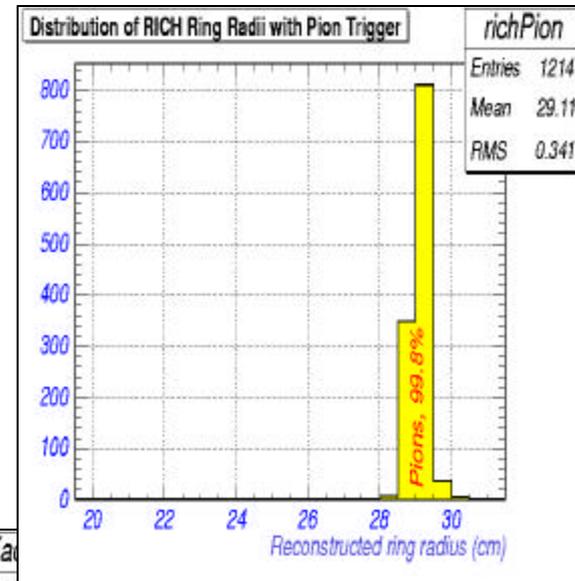
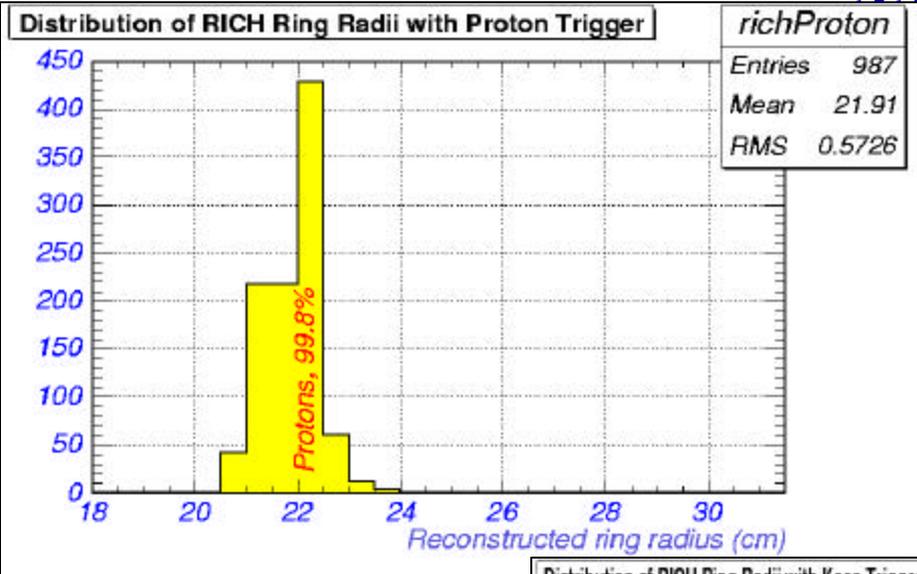


Beam Cherenkovs

- 40 GeV/c negative beam



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

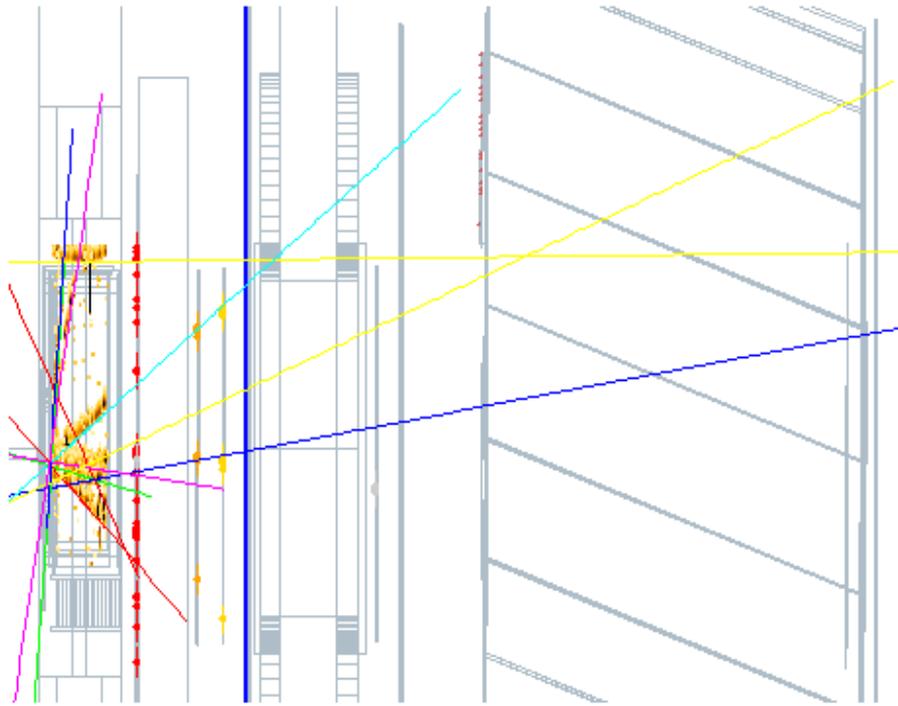
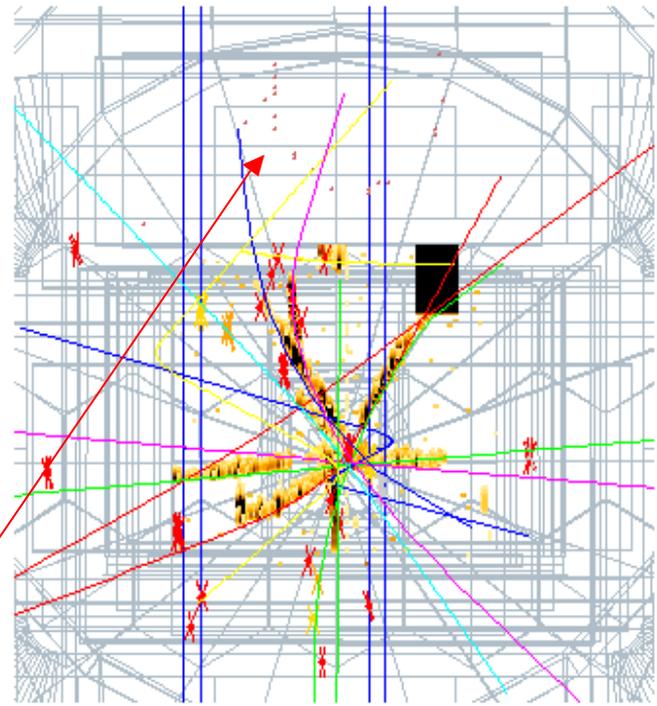


MIPP (FNAL E907)

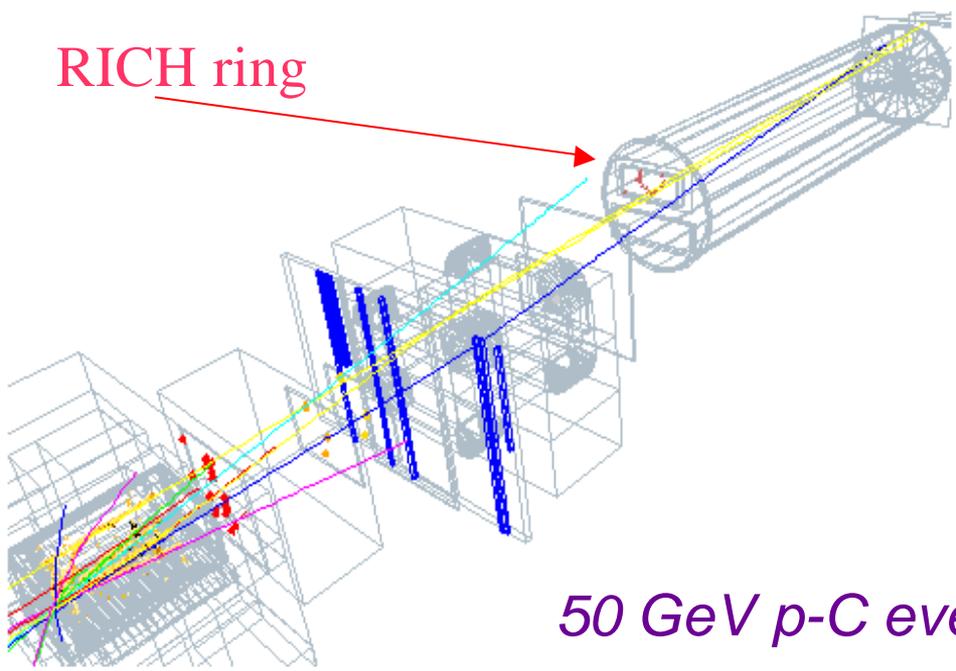
Run: 14129
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Event: 5

Mon May 09 2005
21:26:02.471763

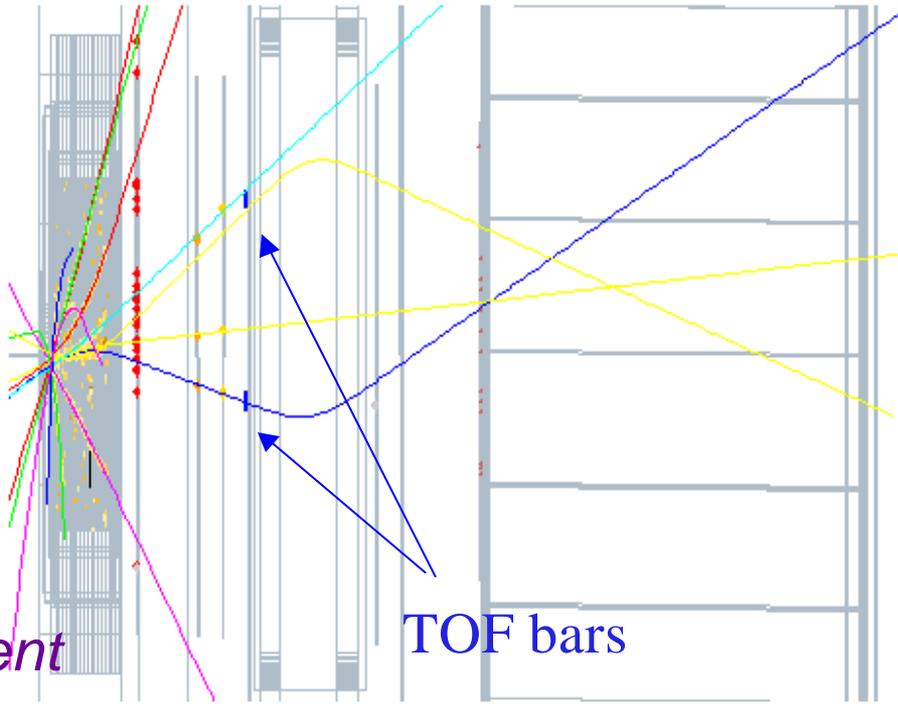
*** Trigger ***
Beam
Word: 0400
Bits: C447



RICH ring



50 GeV p-C event



TOF bars

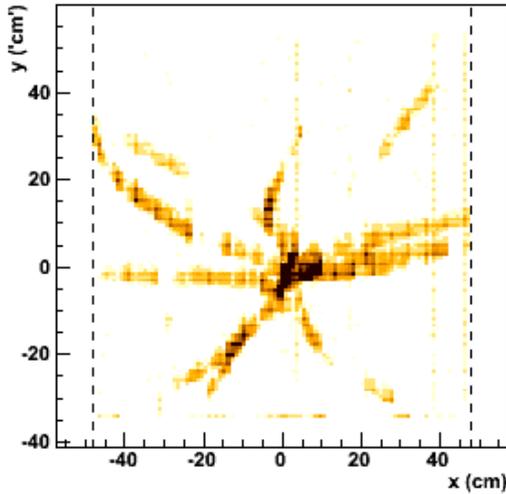
Sample Event On NuMI Target

MIFF (FNAL E907)

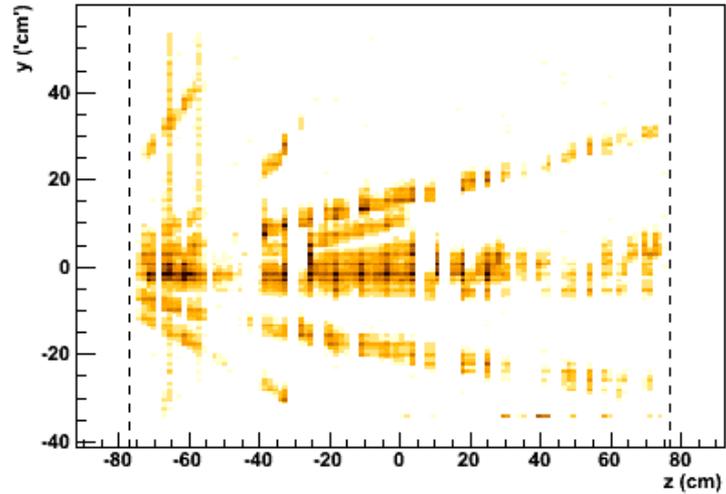
Run: 14928
SubRun: 0
Event: 3337

Mon Jul 11 2005
05:46:56.680148

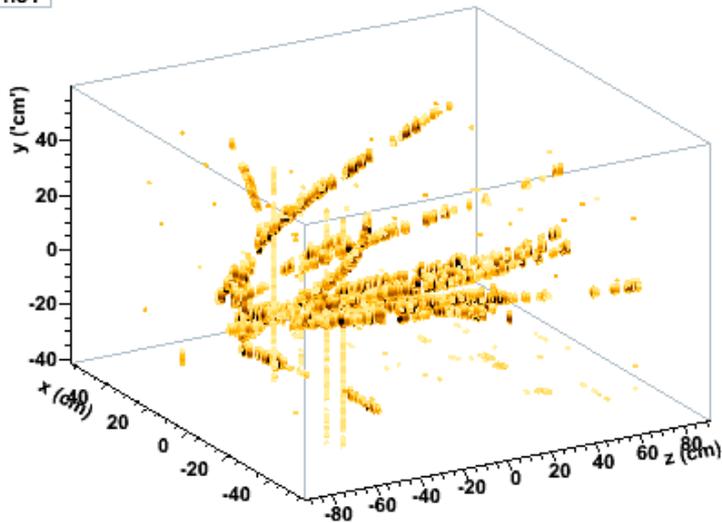
*** Trigger ***
Beam
Word: 0080
Bits: 80D7



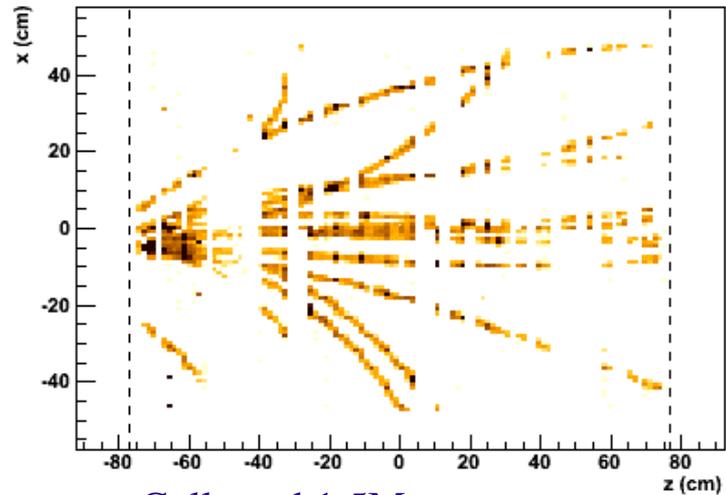
TPC Side



h31



TPC Top



- ? Collected 1.5M events
- ? NuMI target ran in July'05
- ? Target returned to NuMI

First look at NuMI target data

Very preliminary

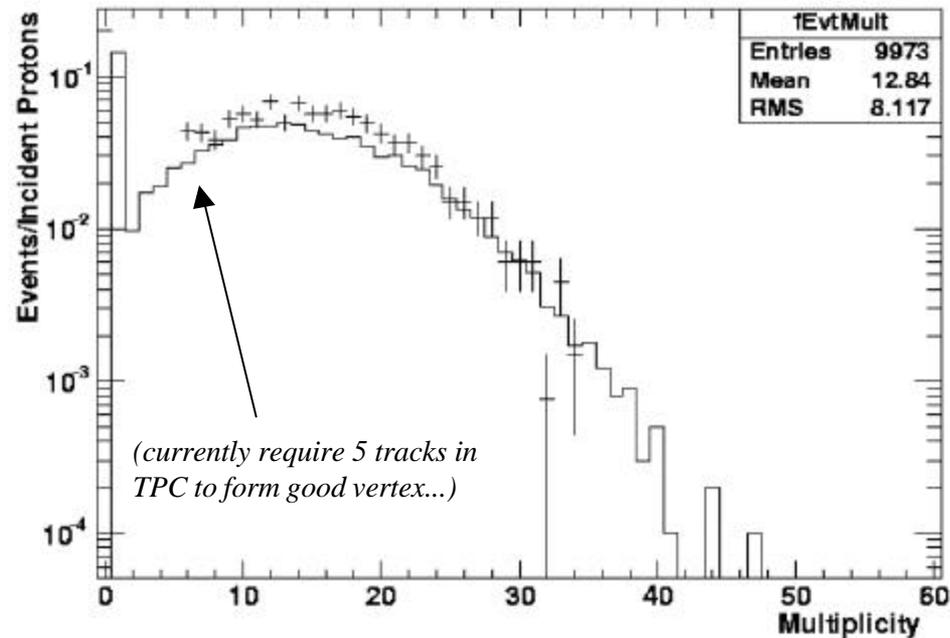
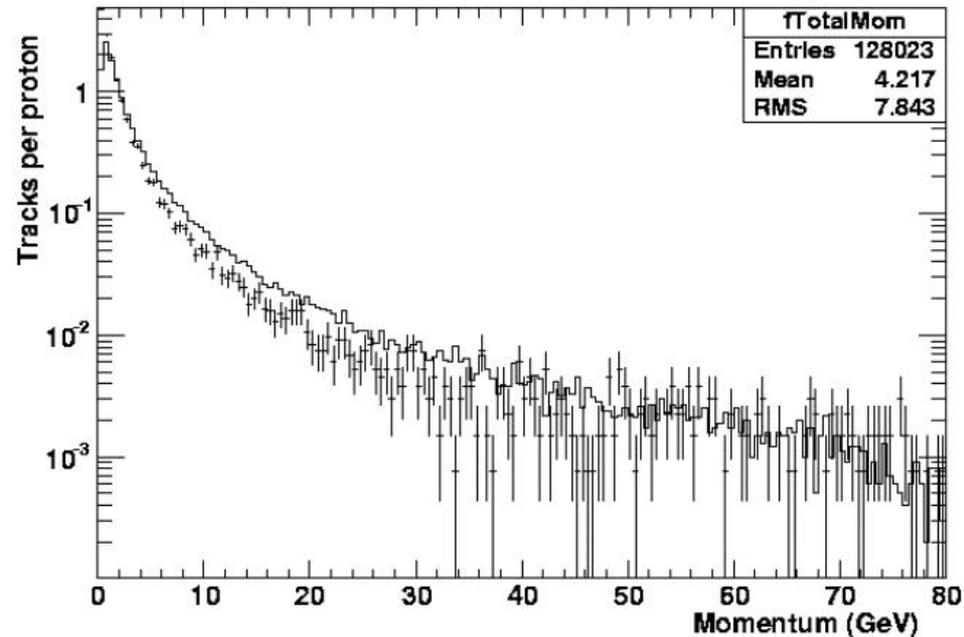
Based on fast TPC-only helix fits

Comparisons are to FLUKA Monte Carlo

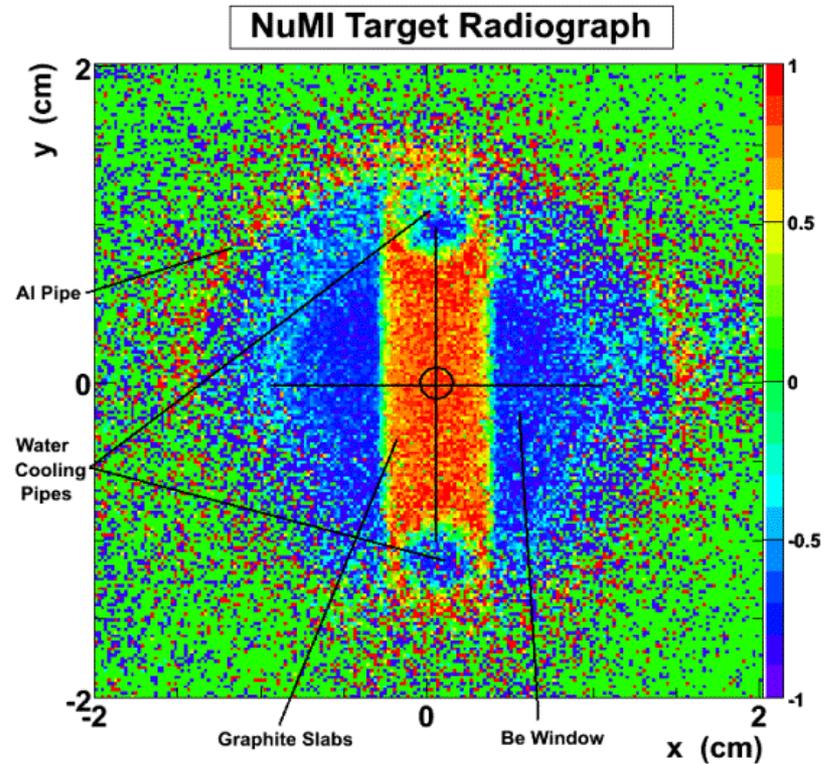
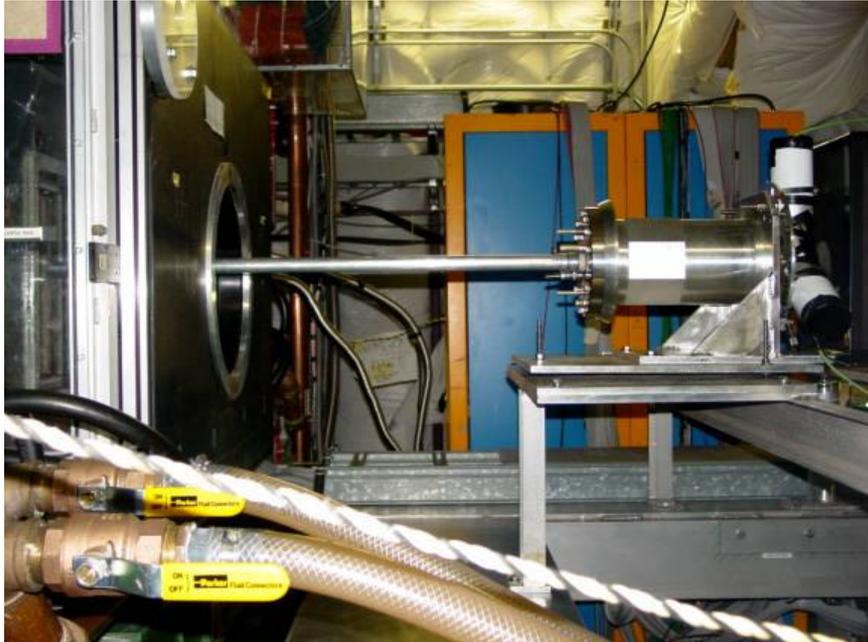
Top: Multiplicity distribution

Bottom: Momentum distribution

NuMI Target Analysis

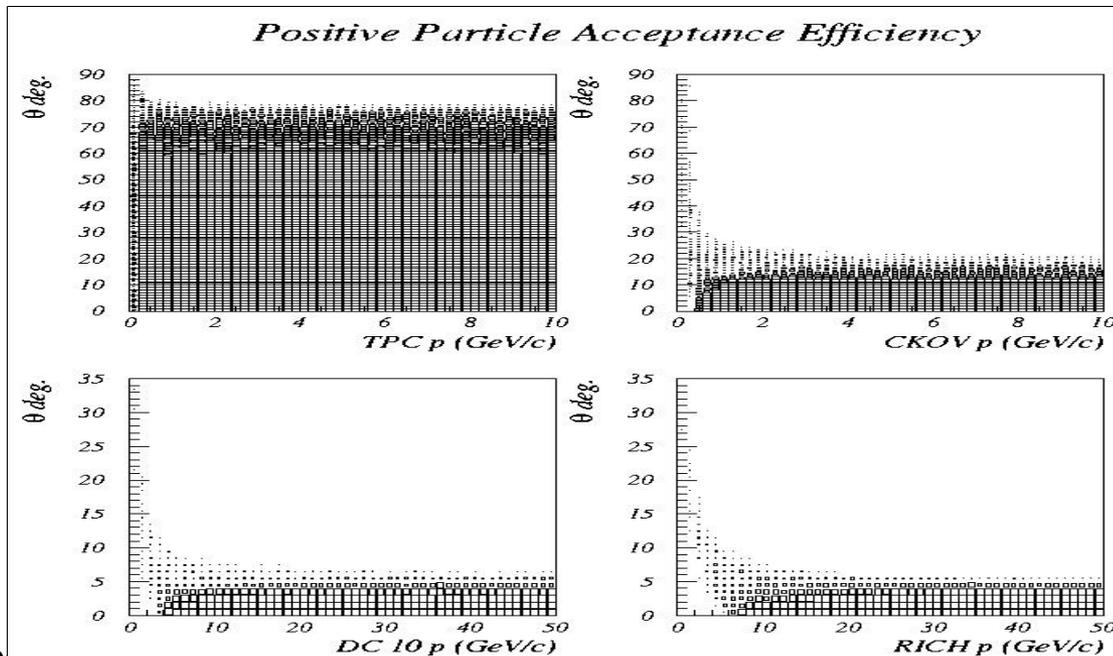


NuMI target pix



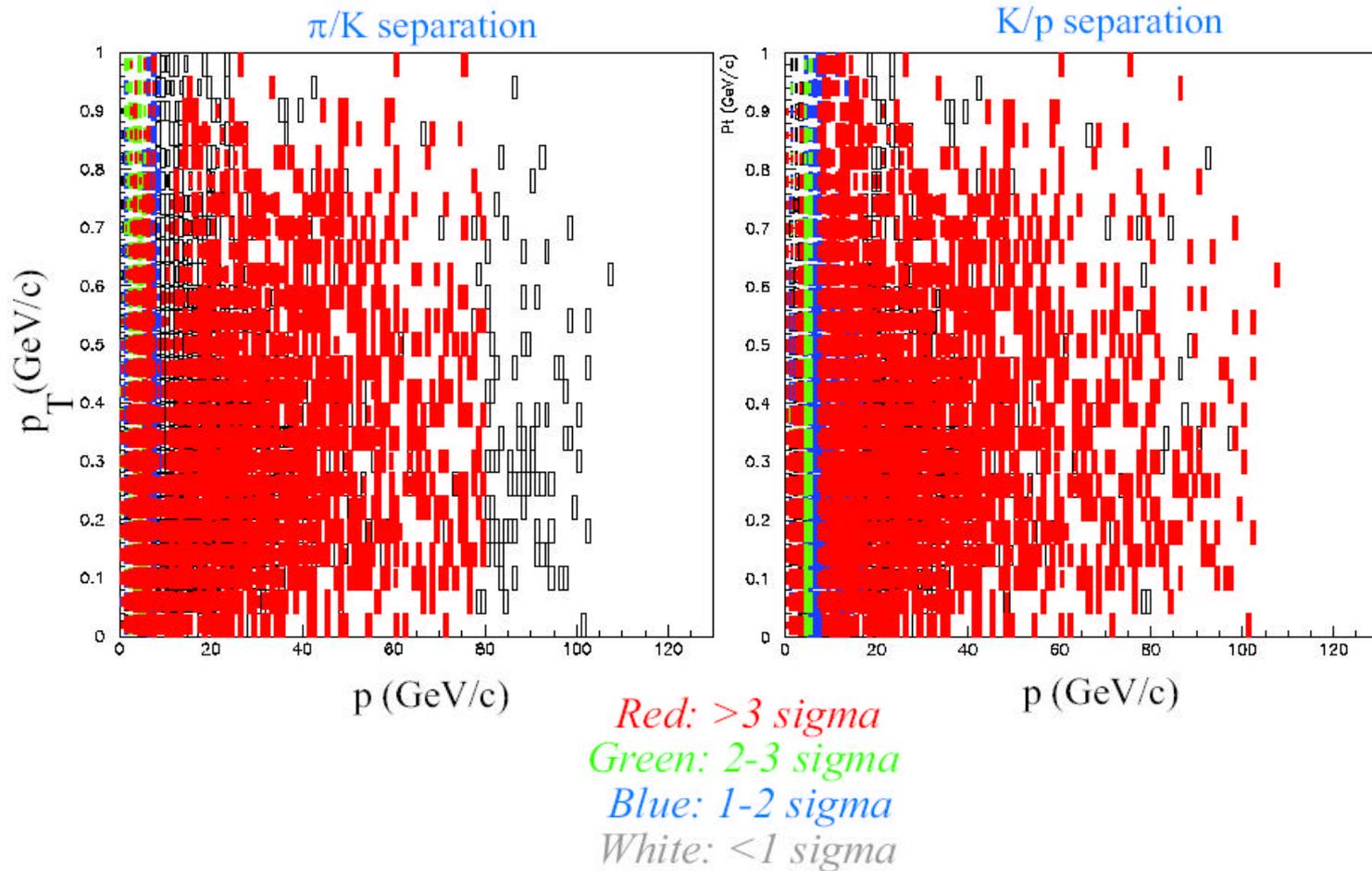
Particle acceptances and resolutions

- a) 10 Hits in TPC
- b) a hit in the Cerenkov
- c) a hit in Drift Chamber 10 (just before RICH)
- d) Passage through mid-Z plane of RICH.
- Regular Target and NUMI target
- Four cases of particles considered
- (Cumulative AND)



MI PP Particle ID

Particle ID Performance



Run Plan-Adopted after dir review Nov 2004

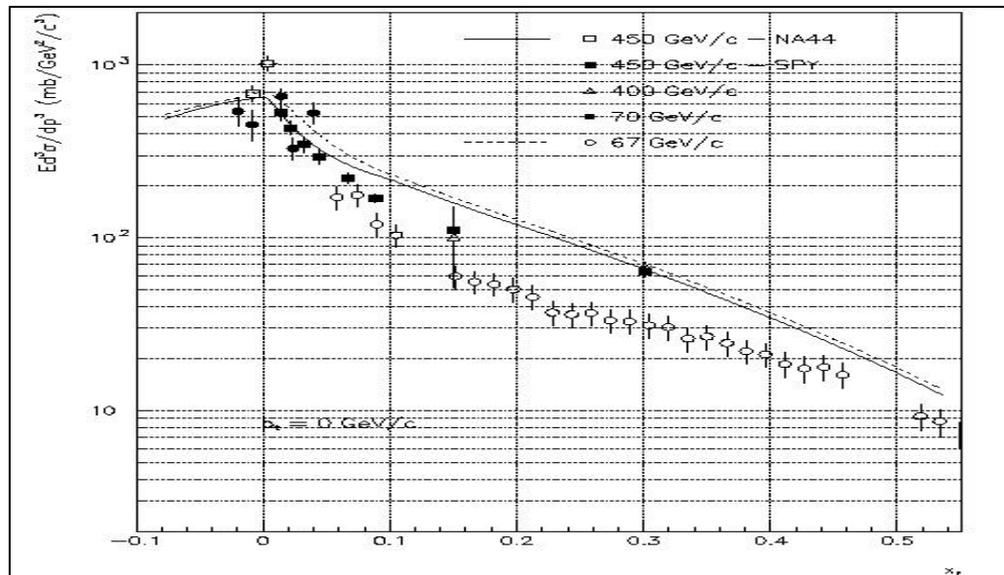
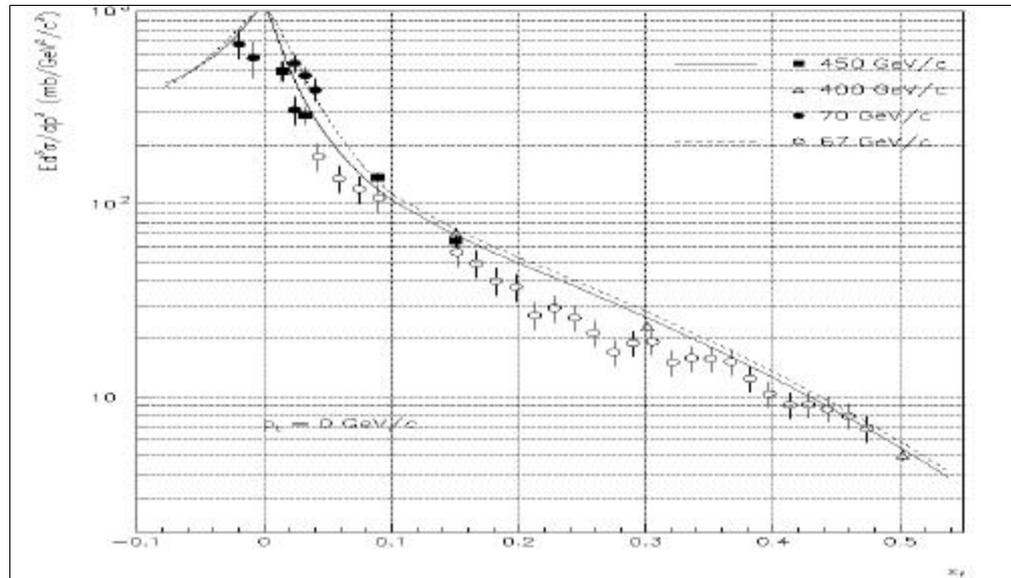
Run Plan v7		Summary by Target and Beam Energy Number of events, x 10 ⁶										
Target		Momentum (GeV/c)										Totals
Z	Element	5	13.3	15	20	30	40	50	60	75	120	
1	H	4.40		4.20		4.40		4.20		4.20		21.40
1.2	D	0.60		0.60		0.60		0.60		0.60		3.00
4	Be	1.00	1.00			1.00		1.81		1.00	6.60	12.41
6	C	1.00	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							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

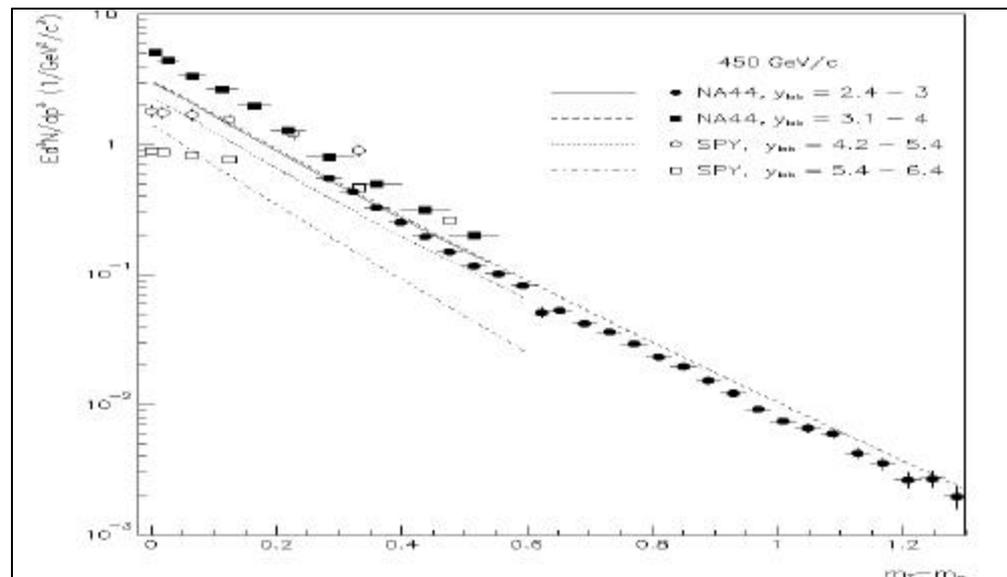
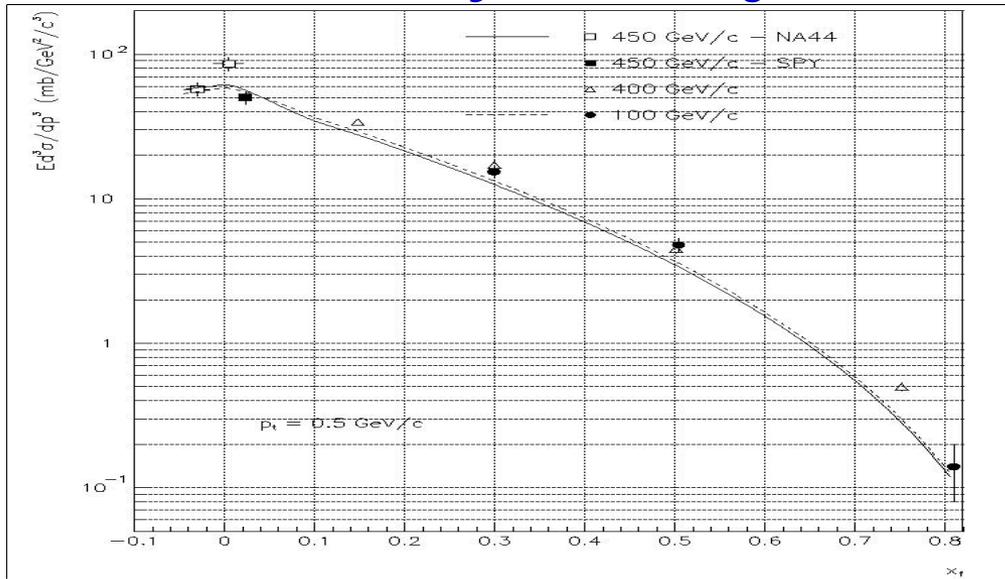
Hadron Shower Simulator problem

- All neutrino flux problems (NUMI , MiniBoone, K2K, T2K, Nova, Minerva) and all Calorimeter design problems and all Jet energy scale systematics (not including jet definition ambiguities here) can be reduced to one problem- **the sorry state of hadronic shower simulators**. MI PP upgrade can solve this problem for once and for all.
- Timely completion of MI PP upgrade program can help CDF/D0 systematics, CMS/ATLAS, CALICE and all neutrino experiments.
- Myth-I Put designed calorimeter in test beam and use the data to tune the simulator_-D0 experience. You need test beam to test the hardware.
- Myth-II Take test beam data at various incident angles and use it to interpolate -H-matrix experience
- In order to have better simulator, we need to measure event by event data with excellent particle ID using 6 beam species (pi,K,P and antiparticles) off various nuclei (LH2 critical) at momenta ranging from 1 GeV/c to ~100 GeV/c. MI PP upgrade is well positioned to obtain this data.
- MI PP can help with the nuclear slow neutron problem.
- Current simulators use a lot of „Tuned theory“. Propose using real library of events and interpolation.

Quality of existing data

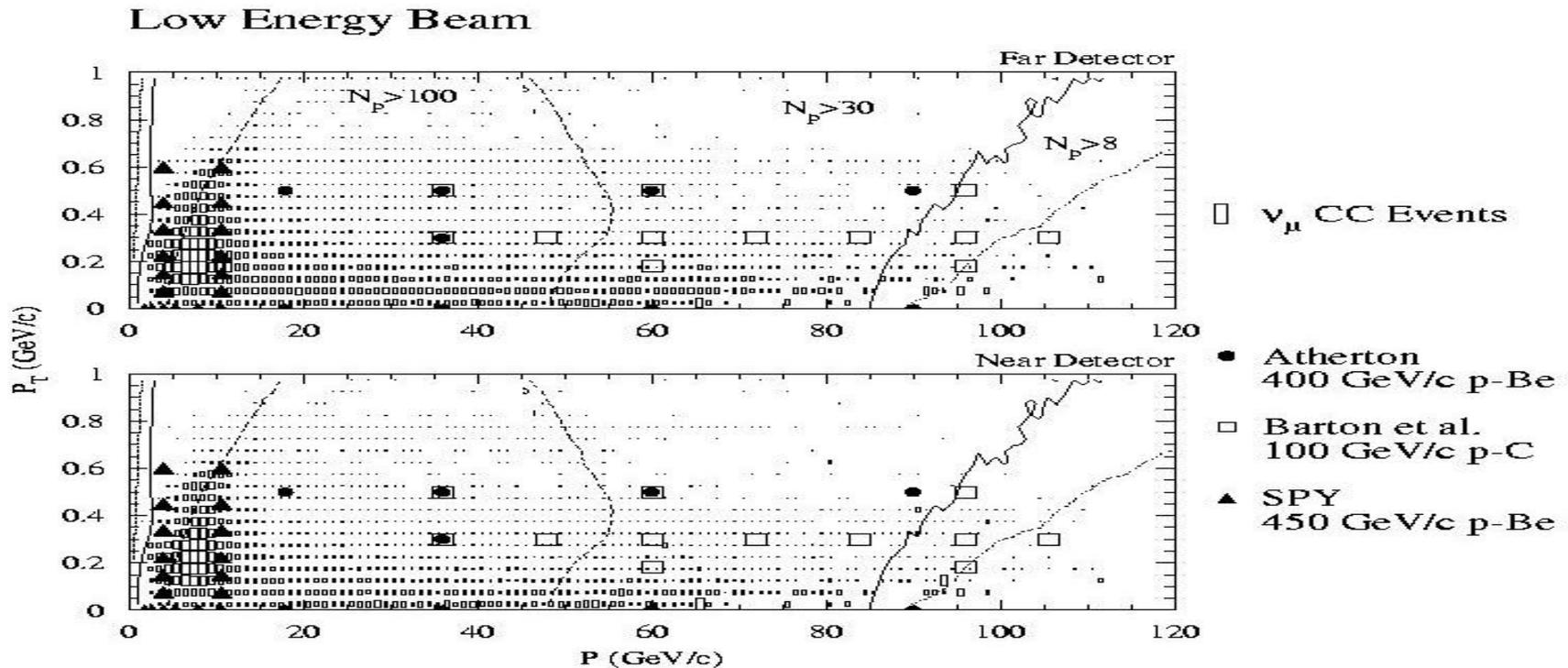


Quality of existing data

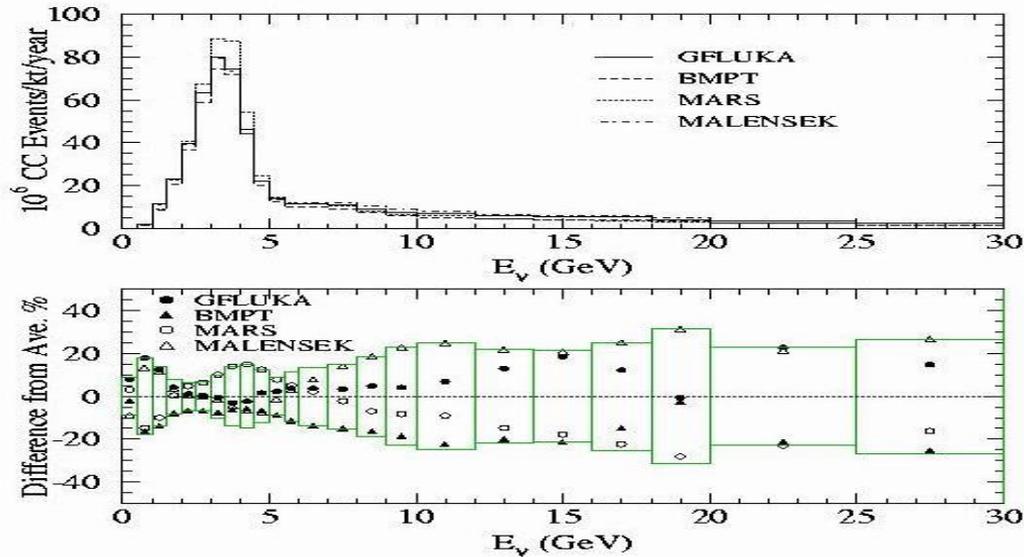


Minos measurements

- 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

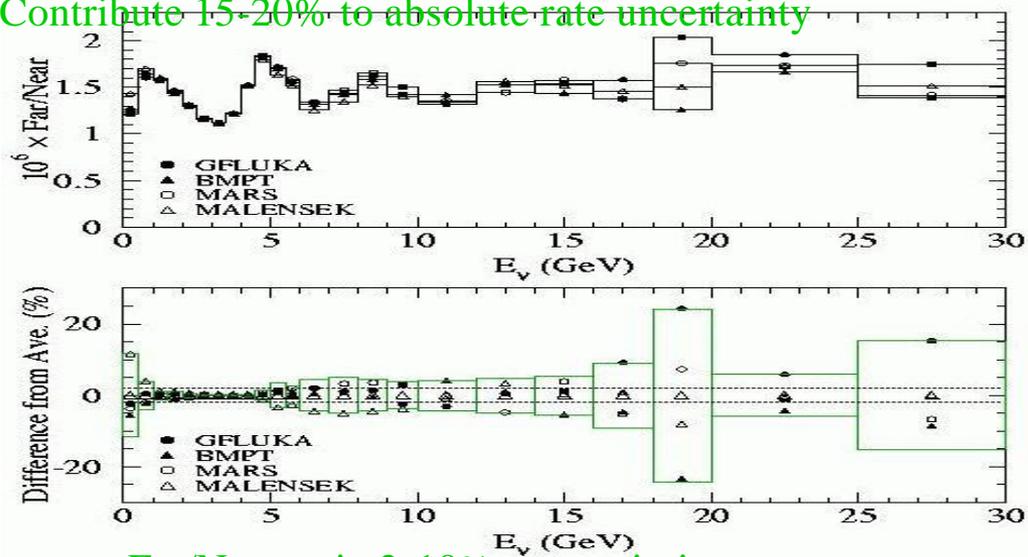


Minos measurements



Near detector spectra- Hadronic uncertainties

Contribute 15-20% to absolute rate uncertainty



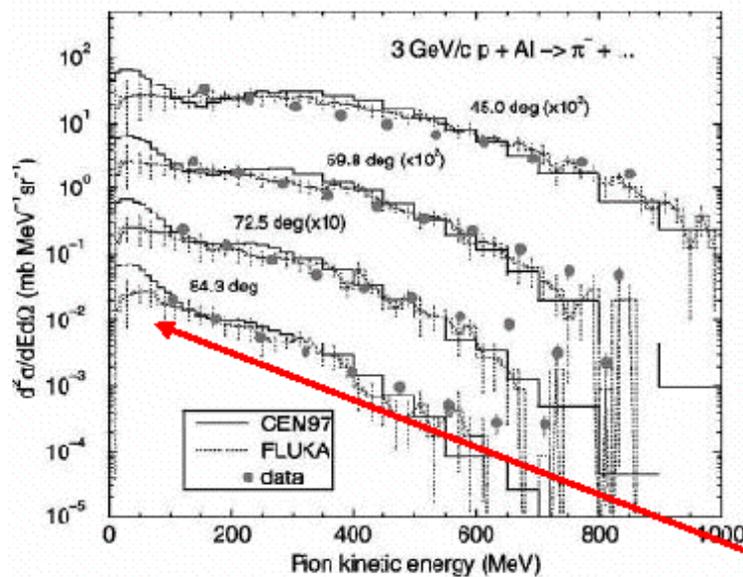
Far/Near ratio 2-10% uncertainties

in near-to-far. Normalization in tail important.

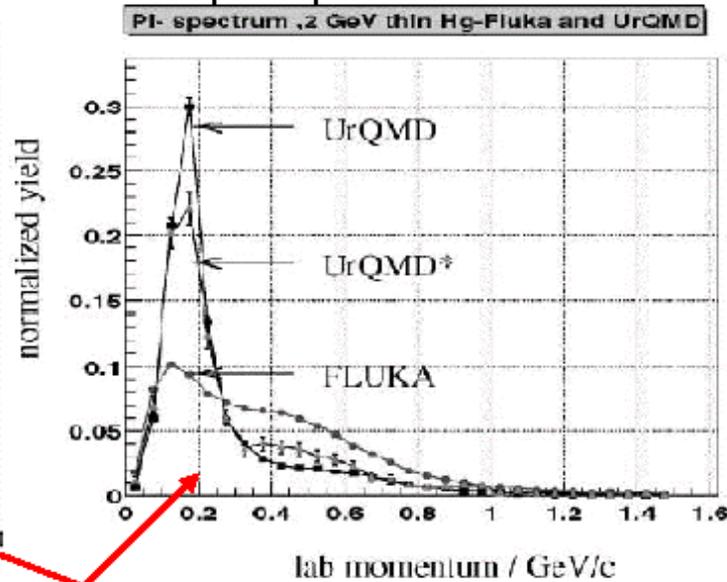
Discrepancies between hadronic generators

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



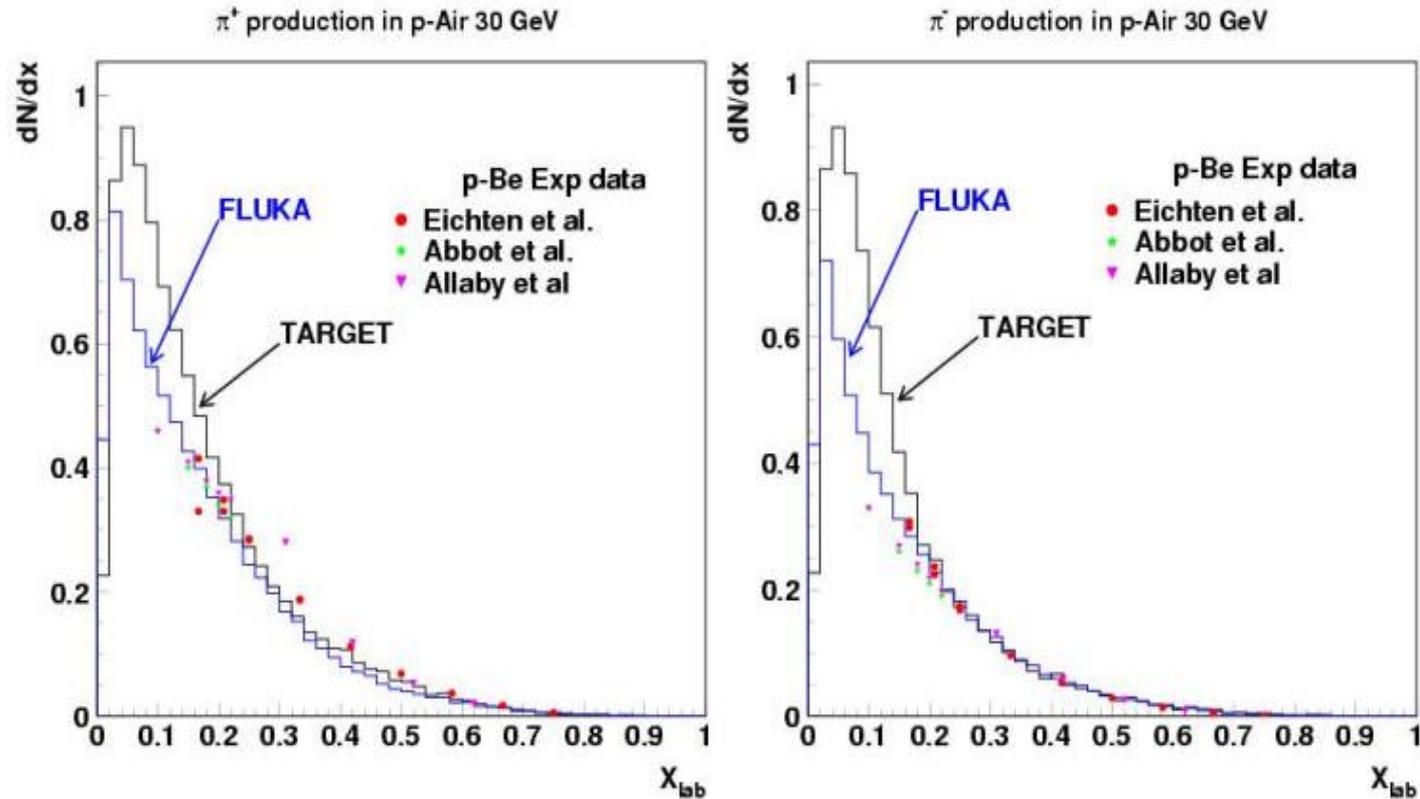
NIMA472(2001)5

NO DATA !

→ Thin and thick targets, scan in Z

Discrepancies between hadronic generators

27



G. Battistoni

Historical overview (from M. Catenesi NUFACT04)

- Mostly based on measurement of particle yields along beam lines
- Experiments done making (smart) use of existing facilities
 - » No experiments built on-purpose
- Low ($\sim 20\text{GeV}/c$) and high ($\sim 400\text{GeV}/c$) primary proton momenta, forward angular region ($< 150\text{mrad}$)
- Low statistics and/or limited number of data points
 - » J. Allaby et al., CERN-70-12
 - p-nuclei (B4C, Be, Al, Cu, Pb) and p-p collisions at $19.2\text{ GeV}/c$
 - Single arm spectrometer
 - » G. Eichten et al., Nucl. Phys. B44(1972) 333
 - p, K production in p-nuclei collisions (Be, B4C, Al, Cu, Pb targets) at $24\text{ GeV}/c$
 - Single arm magnetic CERN-Rome spectrometer

PARTICLE PRODUCTION IN PROTON INTERACTIONS IN NUCLEI AT 24 GeV/c

T. EICHTEN and D. HAIDT

III. Physikalisches Institut, Aachen, Germany

J.B.M. PATTISON, W. VENUS, H.W. WACHSMUTH and O. WÖRZ

CERN, Geneva, Switzerland

T.W. JONES

UCL, London, England

B. AUBERT, L.M. CHOUNET and P. HEUSSE

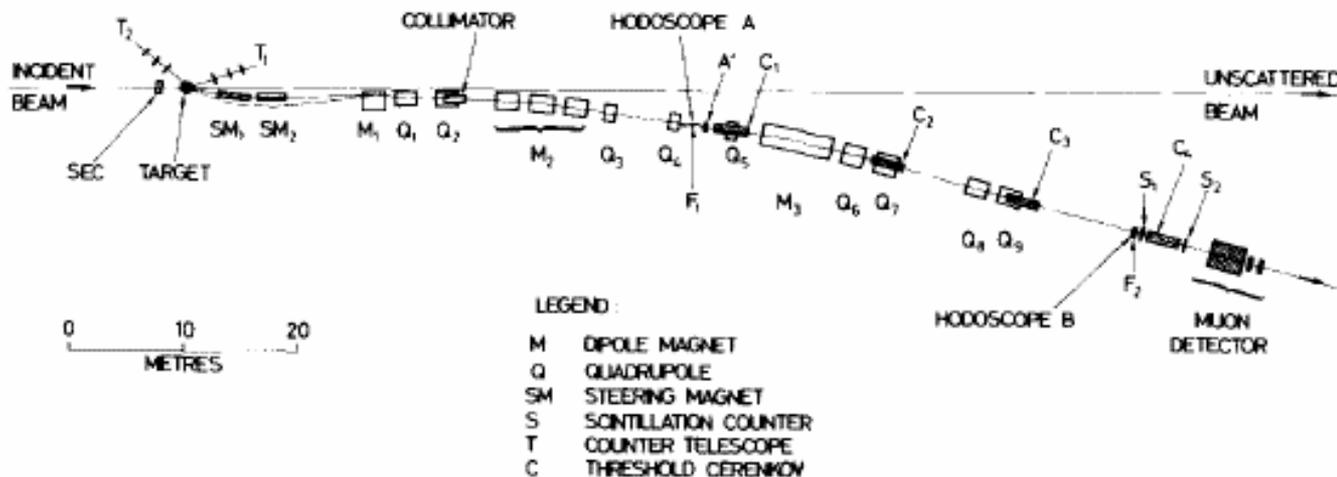
Laboratoire de l'Accélérateur Linéaire, Orsay, France

C. FRANZINETTI

University of Torino, Italy

Received 15 March 1972

Abstract: Particle production by 24 GeV/c protons from Be, B₄C, Al, Cu and Pb has been measured. Pion, kaon, proton and antiproton production spectra measured over a range of angles from 17 to 127 mrad and momenta from 4 to 18 GeV/c are given in a table.



- Motivations and scope

The aim of the present experiment was to measure pion and kaon production in proton-nucleus collisions at 24 GeV/c primary proton momentum. The measurements cover the secondary momentum range 4–18 GeV/c and the angular range 17–127 mrad. These data are essential for the estimation of the neutrino spectrum for the present CERN neutrino experiment.

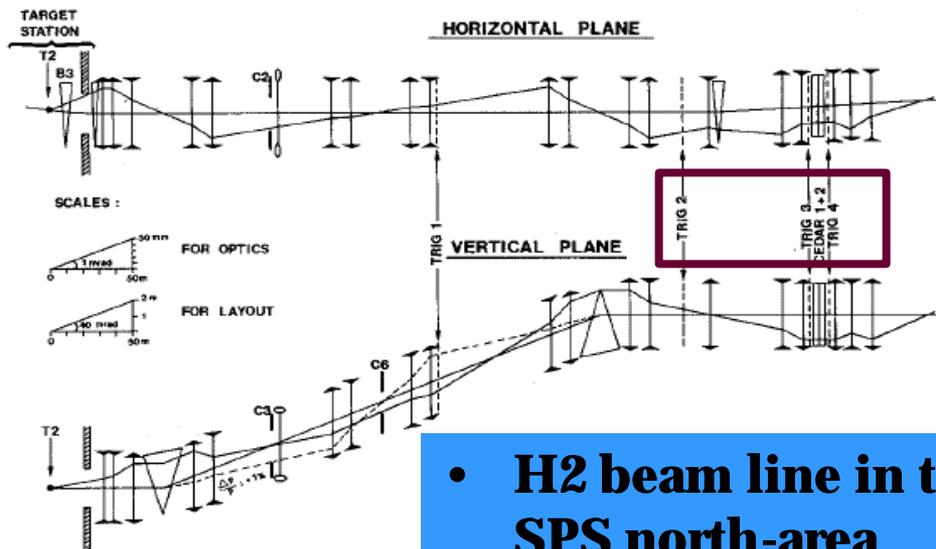
- Experiment's uncertainties

The statistical errors were nearly always negligible compared to the systematic errors. The overall scale error arising from the uncertainties in the spectrometer acceptance and in the absolute calibration of the primary proton beam intensity (by Al activation) is estimated to be 15% [4]. The systematic errors of individual data points are determined by the irreproducibility of a given spectrometer (setting (about 5%) and by the uncertainties in the corrections applied (2–5% depending on momentum). Ratios obtained from one and the same spectrometer setting (K/ π ratios and ratios between different targets) are much more accurate (total error generally less than 4%), as most systematic errors drop out. Details of the data evaluation have been given in refs. [5, 6].

- **Secondary energy scan:
60,120,200,300 GeV**

List of targets

Length (in beam direction) (mm)	Width (horizontal) (mm)	Height (vertical) (mm)
500	160	2.0
300	160	2.0
300	160	1.5
100	160	2.0
40	160	2.0



- **H2 beam line in the
SPS north-area**

Overall quoted errors
 Absolute rates: ~15%
 Ratios: ~5%
 These figures are typical of this
 kind of detector setup

Fig. 1 Layout and optics of H2 beam

The total measurement error is dominated by the following three systematic errors:

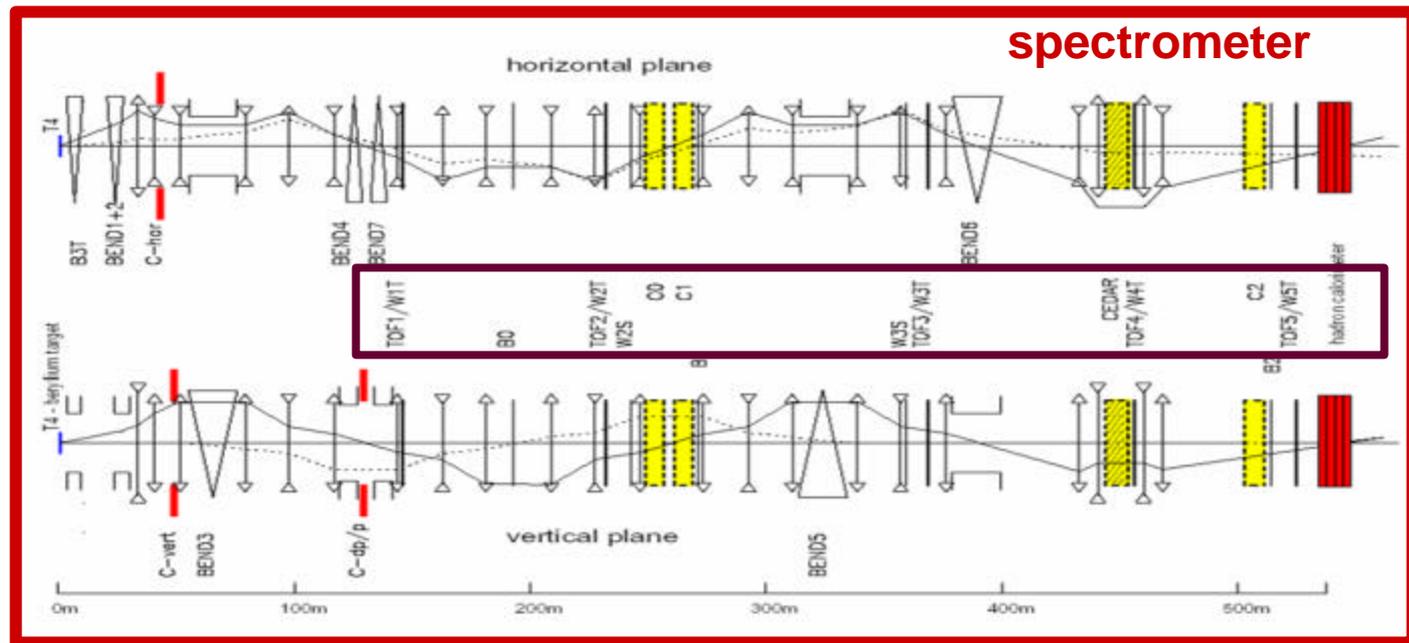
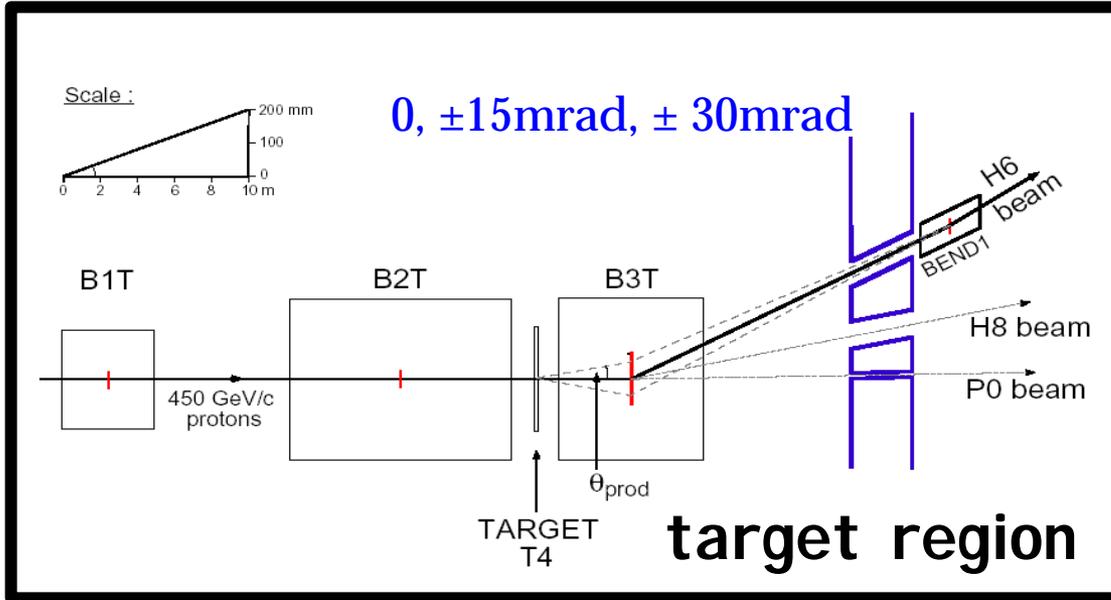
- i) SEM calibration, see Section 3.2.1 $\approx 5\%$
- ii) errors in beam optics, see Section 3.1.4 $\approx 4\%$
- iii) collimator opening uncertainty $\approx 1-4\%$.

All other corrections are of the order of or less than 1%.

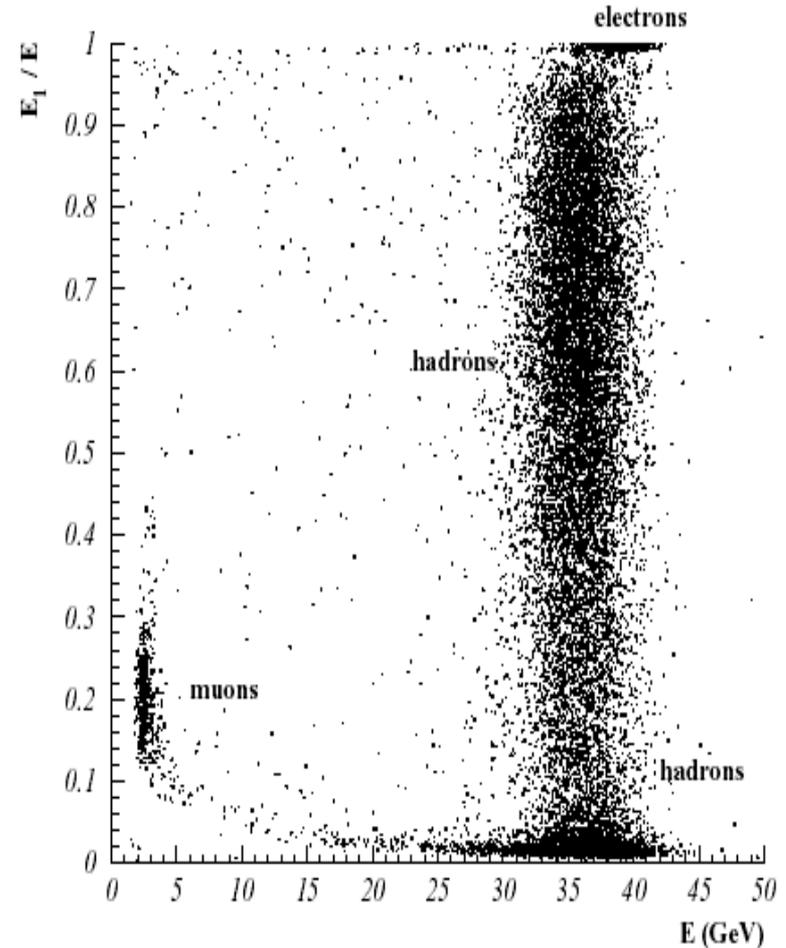
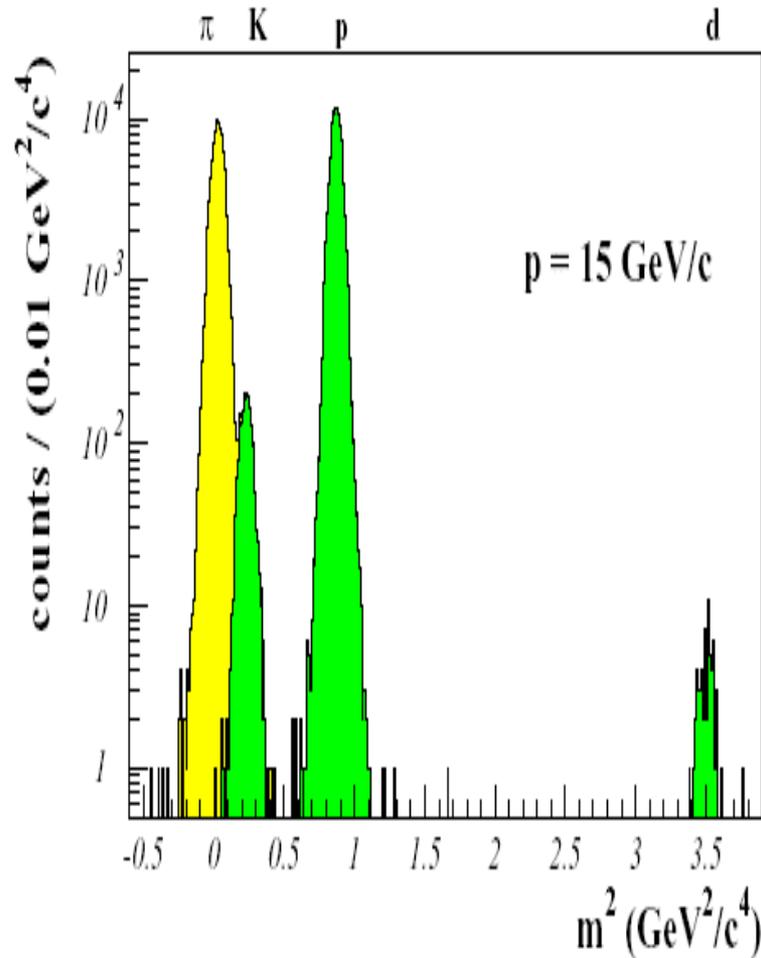
SPS: NA56/SPY

- Most likely the most advanced study done with instrumented beam line experiments
- Dedicated to WANF (CHORUS/NOMAD) (and CNGS) experiments
- To address discrepancies beam spectrum, shape and composition as measured in CHORUS/NOMAD compared to MC predictions.
- 450GeV/c incident protons, 7→135 GeV/c secondaries (overlap with Atherton)
- Exploits TOF / Cherenkov / Calorimetry

SPY:1996

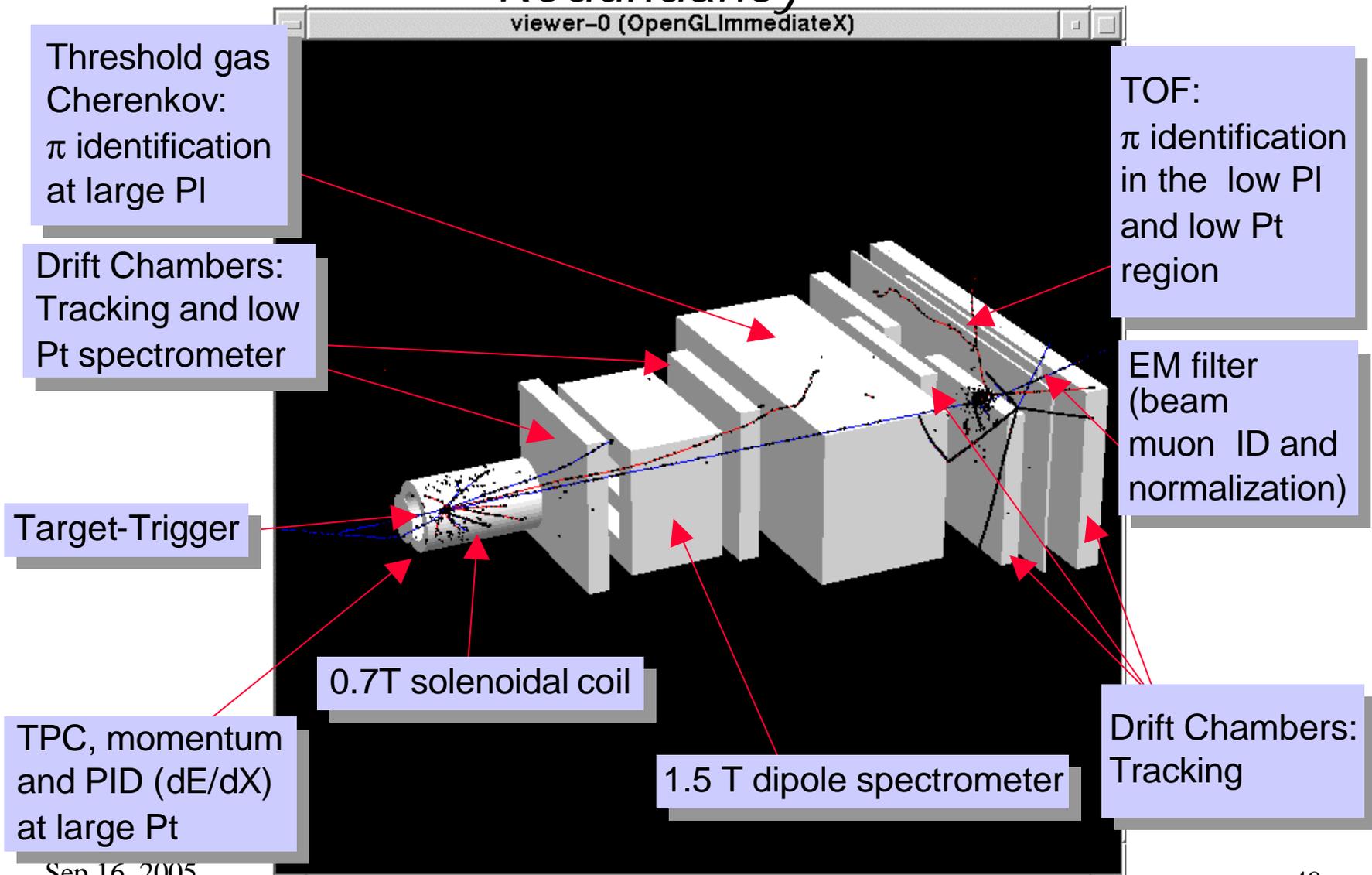


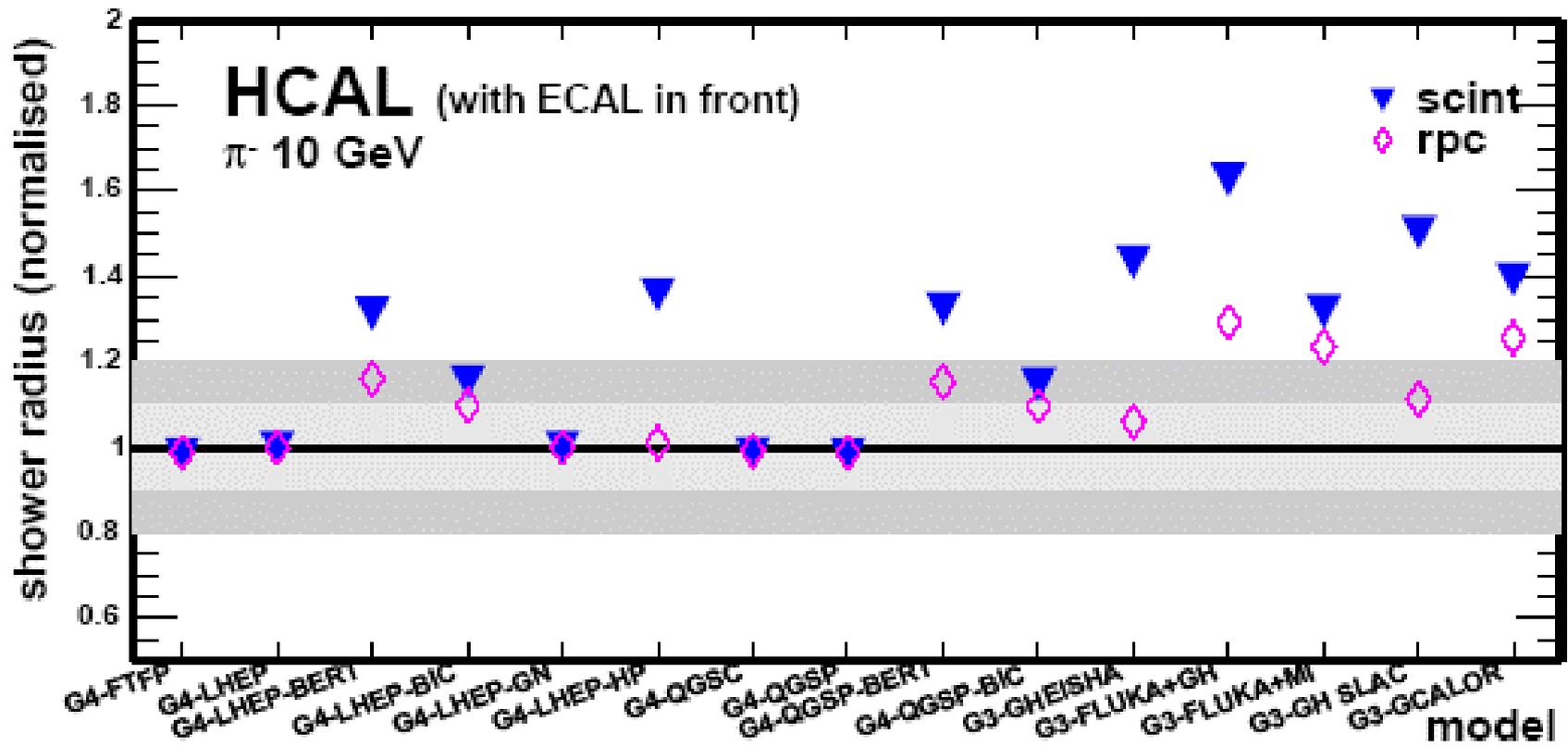
SPY measurement principle



- TOF + Cherenkov, cross-check with calorimetry.

The Harp detector: Large Acceptance, PID Capabilities, Redundancy





QCD Physics with MIPP

Rajendran Raja

Presentation to the QCD at Tevatron Workshop

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?

Uses of MIPP QCD data

- Mostly will come from Liquid H2 target.
- We plan to take 18 million events on LH2 with 6 beam species (π^\pm, K^\pm, p^\pm) over a momentum range that spans 5 GeV/c to 90 GeV/c.
- We also plan to run Liquid deuterium, which will add np cross sections.
- We plan to re-open the study of non-perturbative QCD by publishing datasets with full particle ID in DST form in DVD's. Any person interested in testing his theory can obtain a dataset.
- We can study exclusive particle reactions with unprecedented accuracy and particle id using constrained fitting.

Uses of MI PP QCD data

- Examples of exclusive channels are

$\pi^+ p \rightarrow A_1(1270)p$	Resonance production and diffraction
$\pi^+ p \rightarrow K^+\Sigma^+$	Strangeness production
$K^+ p \rightarrow pp\bar{\Lambda}$	strangeness and Baryon number production
$K^+ p \rightarrow \Delta^+ K^0 \pi^+$	charge exchange and resonance production
$p^+ p \rightarrow ppK^+ K^-$	Diffraction, strangeness production
$p^+ p \rightarrow pp\pi^+ \pi^-$	Diffraction, Pomeron
$\pi^- p \rightarrow \pi^0 n$	Classic ρ exchange reaction
$\pi^- p \rightarrow K_s^0(892)\Lambda$	Strangeness resonance production
$K^- p \rightarrow K_s^+(1780)p$	Exotic resonance production
$K^- p \rightarrow pK^-$	Strange Baryon exchange
$p^- p \rightarrow 3\pi^+ 3\pi^-$	Annihilation
$p^- p \rightarrow p\bar{n}\pi^-$	\bar{p} diffraction (4C if we detect \bar{n} , else 1C)

A more complete list of exclusive channels in all the beam species is available at

<http://ppd.fnal.gov/experiments/e907/notes/MI PPnotes/public/pdf/MI PP0010/MI PP0010.pdf>

Uses of MI PP QCD data

- Missing neutral channels are available as 1C fit.
- Diffraction in 6 beam species with particle id.
- Annihilation as a function of beam momentum
- Flavor propagation in nuclei K^\pm propagating through nuclei. How fast is strangeness exchanged?
- Exotic resonances such as glueballs and pentaquarks can be searched for. Unprecedented particle ID and acceptance capabilities as well as the presence of 6 beam species in one experiment will help unravel the nature of the found objects.
- Upgrading the TPC electronics will enable MI PP to take data at 1000HZ instead of the current 60HZ. This will enhance the physics potential of MI PP.

General scaling law of particle fragmentation

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

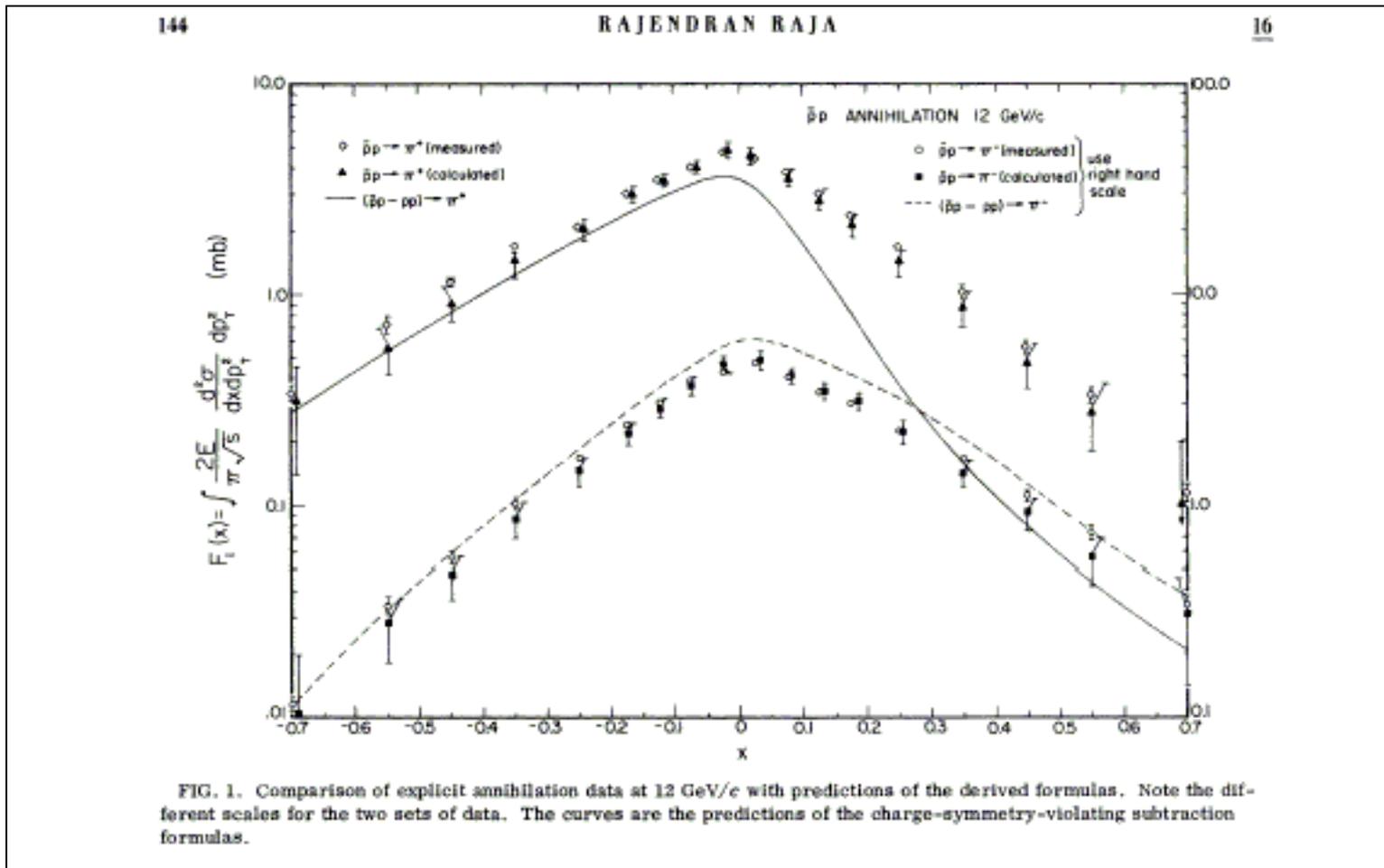
$$\frac{f(a+b \rightarrow c + X_{subset})}{f(a+b \rightarrow c + X)} \equiv \frac{f_{subset}(M^2, s, t)}{f(M^2, s, t)} = \mathbf{b}_{subset}(M^2)$$

- 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.

Estimation of the Annihilation component in $p\bar{p}$ - p interactions

- **R.Raja, Phys.Rev.D16:142,1977**
- Conventional method is to subtract pp cross section from $p\bar{p}$ - p cross sections. Works well for total cross section, and multiplicity cross sections. Works for neutral pion inclusive cross sections but **FAILS** for charged pion inclusive cross sections.

Estimation of the annihilation component



Estimation of the annihilation component

$$\bar{p}p \rightarrow \mathbf{p}^+ + X \equiv \bar{p}^+ ; \bar{p}p \rightarrow \mathbf{p}^- + X \equiv \bar{p}^-$$

$$\bar{p}p \rightarrow \mathbf{p}^+ + X(\text{ann.}) \equiv \bar{p}_A^+ ; \bar{p}p \rightarrow \mathbf{p}^- + X(\text{ann.}) \equiv \bar{p}_A^-$$

$$pp \rightarrow \mathbf{p}^+ + X \equiv p^+ ; pp \rightarrow \mathbf{p}^- + X \equiv p^-$$

Denote by Π the Parity inversion operator

Then

$$\Pi\bar{p}^+ = \bar{p}^- ; \Pi\bar{p}^- = \bar{p}^+ ; \Pi p^+ = p^- ; \Pi p^- = p^+$$

$$\Pi\bar{p}_A^+ = \bar{p}_A^- ; \Pi\bar{p}_A^- = \bar{p}_A^+$$

whereas for $\mathbf{p}^{0\text{s}}$, both $\bar{p}p$ and pp are even under inversion.

- So π^0 production in annihilation information is available by subtraction

$$\bar{p}_A^0 = \bar{p}^0 - p^0$$

- but not π^\pm . $\bar{p}_A^\pm \neq \bar{p}^\pm - p^\pm$

Estimation of the annihilation component

- However, the sum of π^+ and π^- is even under inversion, so we can write

$$\bar{p}_A^+ + \bar{p}_A^- = (\bar{p}^+ + \bar{p}^-) - (p^+ + p^-)$$

- However, the term $\bar{p}_A^+ - \bar{p}_A^-$ is odd under parity inversion and cannot be obtained from pp data. An expression that can be written for the odd term that treats annihilation and non-annihilation symmetrically is

$$\frac{\bar{p}_A^+ - \bar{p}_A^-}{\bar{p}_A^+ + \bar{p}_A^-} = \frac{\bar{p}_N^+ - \bar{p}_N^-}{\bar{p}_N^+ + \bar{p}_N^-} = \frac{\bar{p}^+ - \bar{p}^-}{\bar{p}^+ + \bar{p}^-}$$

Estimation of the annihilation component

- This leads to

$$\bar{p}_A^+ = \left(\frac{(\bar{p}^+ + \bar{p}^-) - (p^+ + p^-)}{(\bar{p}^+ + \bar{p}^-)} \right) \bar{p}^+$$

- And
-

$$\bar{p}_A^- = \left(\frac{(\bar{p}^+ + \bar{p}^-) - (p^+ + p^-)}{(\bar{p}^+ + \bar{p}^-)} \right) \bar{p}^-$$

Explanation for the charge asymmetry relation

- See "Observation of New regularity in hadronic spectra", R.Raja Phys.Rev.D 18 (1978)204.
- The relation

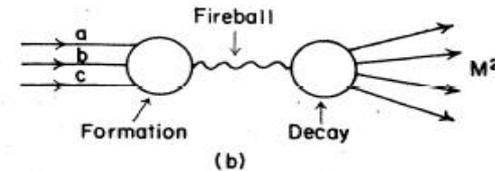
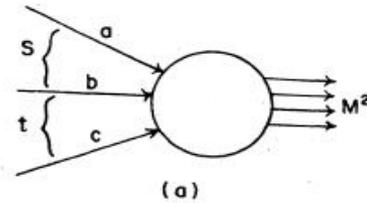
$$\frac{\bar{p}_A^+ - \bar{p}_A^-}{\bar{p}_A^+ + \bar{p}_A^-} = \frac{\bar{p}_N^+ - \bar{p}_N^-}{\bar{p}_N^+ + \bar{p}_N^-} = \frac{\bar{p}^+ - \bar{p}^-}{\bar{p}^+ + \bar{p}^-}$$

can be explained if one posits that the three body scattering happens in two steps. Formation of the fireball followed by its decay. Similar to the Bohr Compound nucleus hypothesis

Scaling Law

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

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



$$\frac{\mathcal{S}(abc \rightarrow X_{sub})}{\mathcal{S}(abc \rightarrow X)} = \frac{F(M^2, s, t) D_{X_{sub}}(M^2)}{F(M^2, s, t) D_X(M^2)} = \mathbf{a}_{sub}(M^2)$$

- Continuing on to physical t values, one gets

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

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

Scaling law

- Applying to annihilations, one gets

$$\frac{\bar{p}_A^+(M^2, s, t)}{\bar{p}^+(M^2, s, t)} = \mathbf{a}_A^+(M^2)$$

$$\frac{\bar{p}_A^-(M^2, s, t)}{\bar{p}^-(M^2, s, t)} = \mathbf{a}_A^-(M^2)$$

$\mathbf{a}_A^+(M^2) = \mathbf{a}_A^-(M^2)$ due to C symmetry

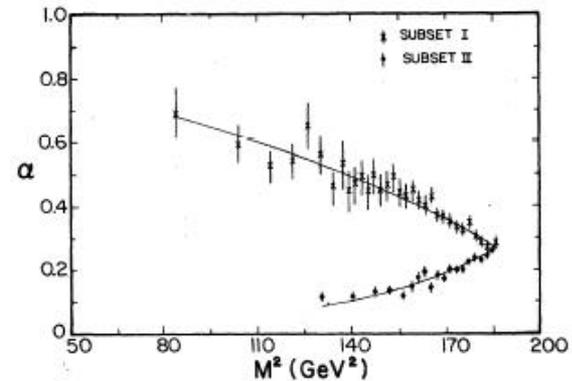
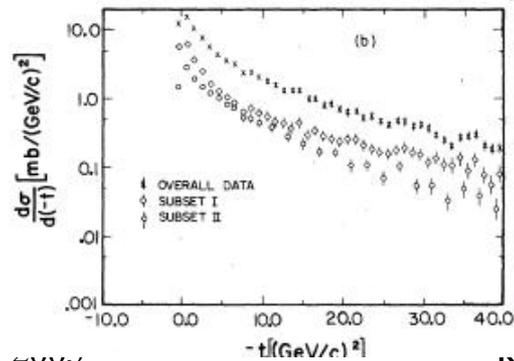
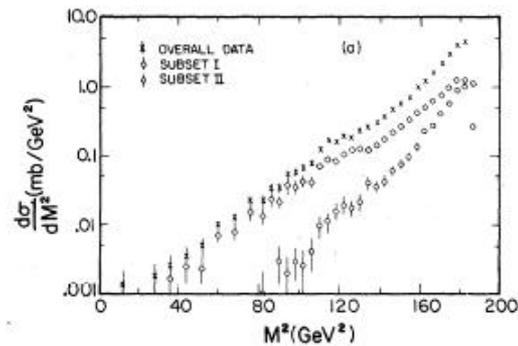
leading to

$$\frac{\bar{p}_A^+ - \bar{p}_A^-}{\bar{p}_A^+ + \bar{p}_A^-} = \frac{\bar{p}_N^+ - \bar{p}_N^-}{\bar{p}_N^+ + \bar{p}_N^-} = \frac{\bar{p}^+ - \bar{p}^-}{\bar{p}^+ + \bar{p}^-}$$

- This factorization and decay is general. So does it apply to other subsets? The answer is yes!

Scaling Law

- 100 GeV/c $\bar{p}p$ data is divided into 2 subsets of multiplicity.
- Subset I = multiplicities 2,4,6
- Subset II = multiplicities 12,14,16



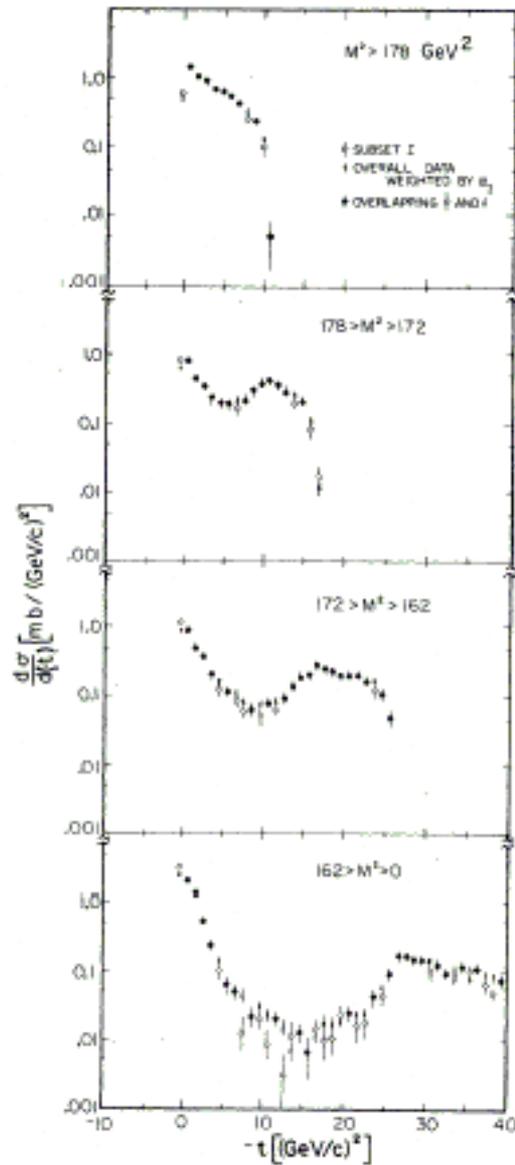


FIG. 4. Comparison of the t distribution for subset I with overall data weighted by $\alpha_I(M^2)$ for various M^2 ranges.

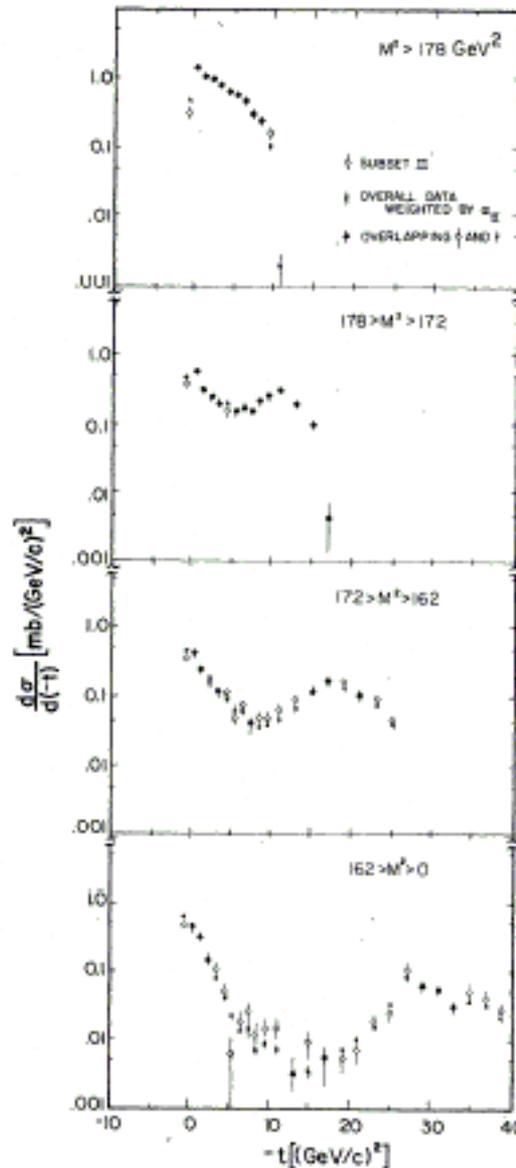


FIG. 5. Comparison of the t distribution for subset II with overall data weighted by $\alpha_{II}(M^2)$ for various M^2 ranges.

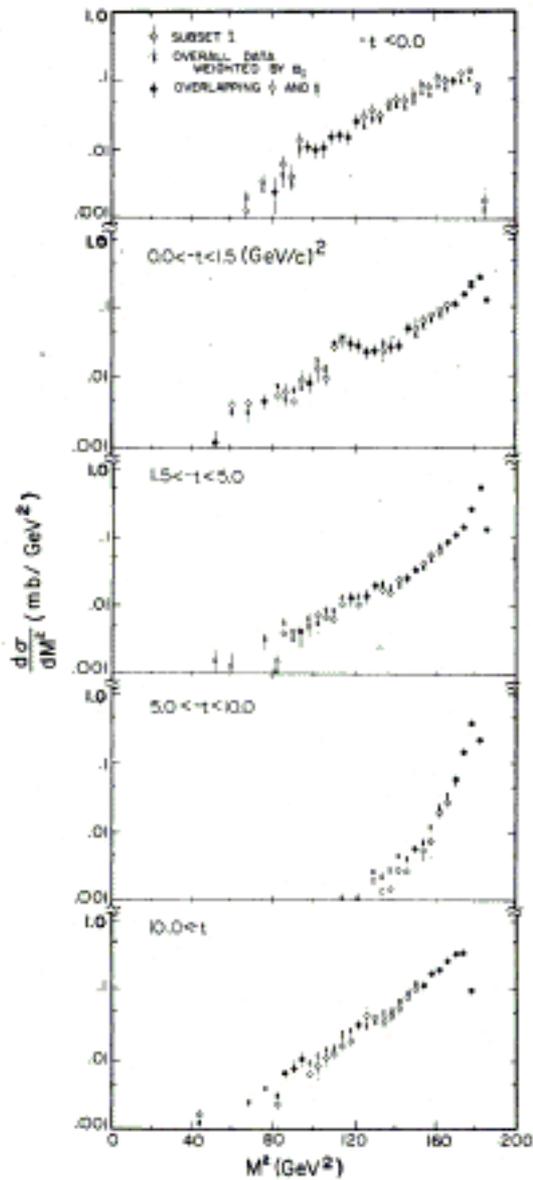


FIG. 6. Comparison of the M^2 distribution for subset I with overall data weighted by $\alpha_I(M^2)$ for various t ranges.

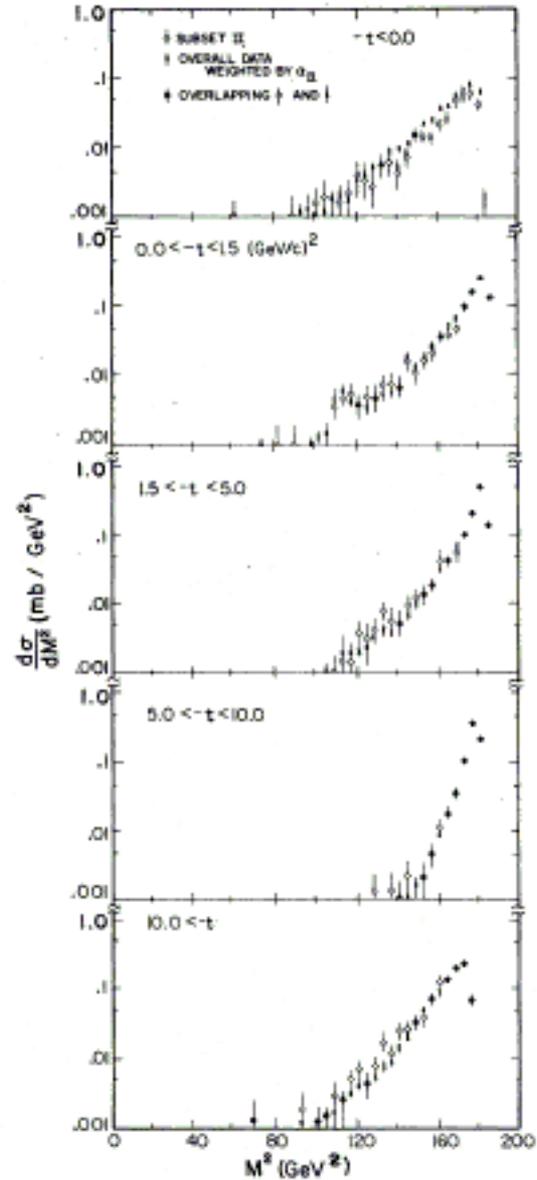


FIG. 7. Comparison of the M^2 distribution for subset II with overall data weighted by $\alpha_{II}(M^2)$ for various t ranges.

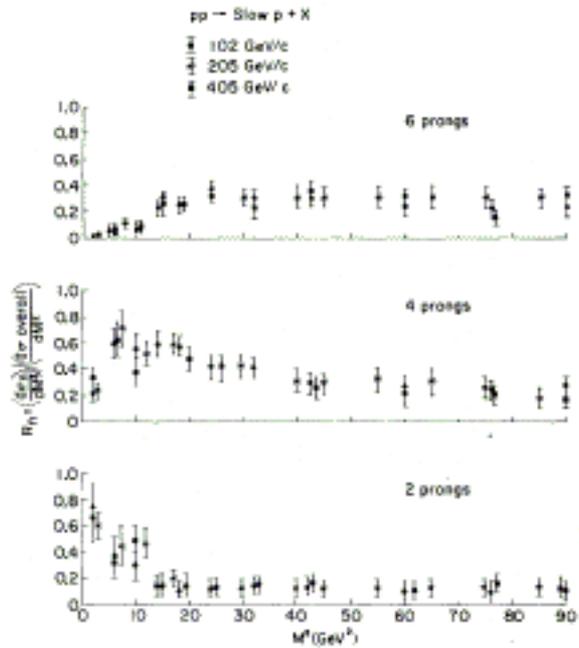
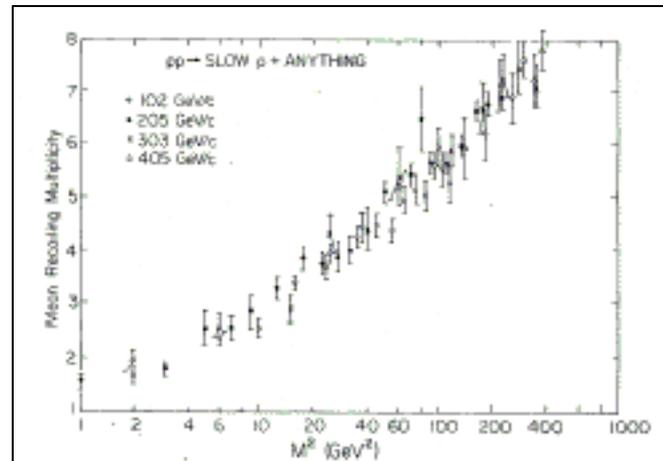


FIG. 9. The ratio of the semi-inclusive cross section to the overall cross section vs M^2 for 2, 4, and 6 prongs at beam momenta 102, 205, and 405 GeV/c.



$$\begin{aligned} & \frac{1}{2} - 0.15 < t < 0 \\ & \frac{1}{2} - 0.4 < t < -0.15 \\ & \frac{1}{2} \quad t < -0.4 \quad (\text{GeV}/c)^2 \end{aligned}$$

pp → p + X 205 GeV/c

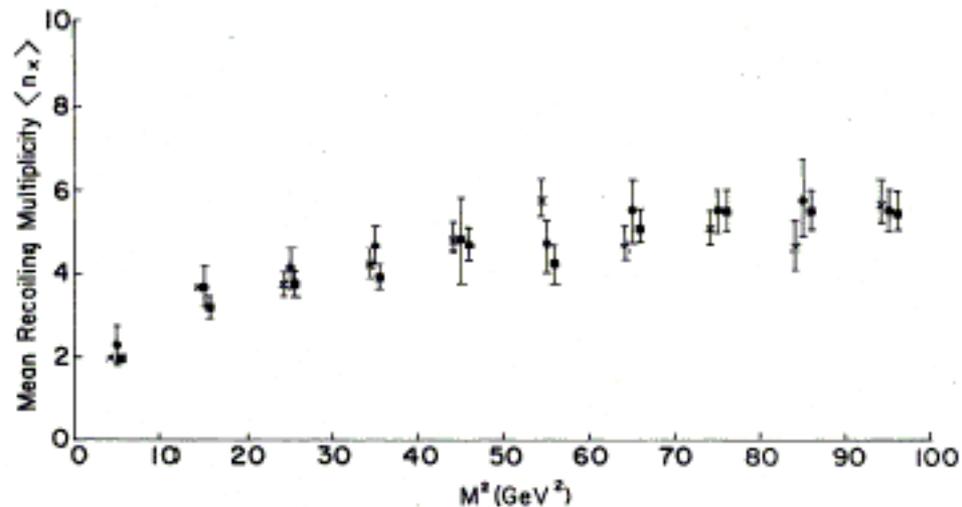
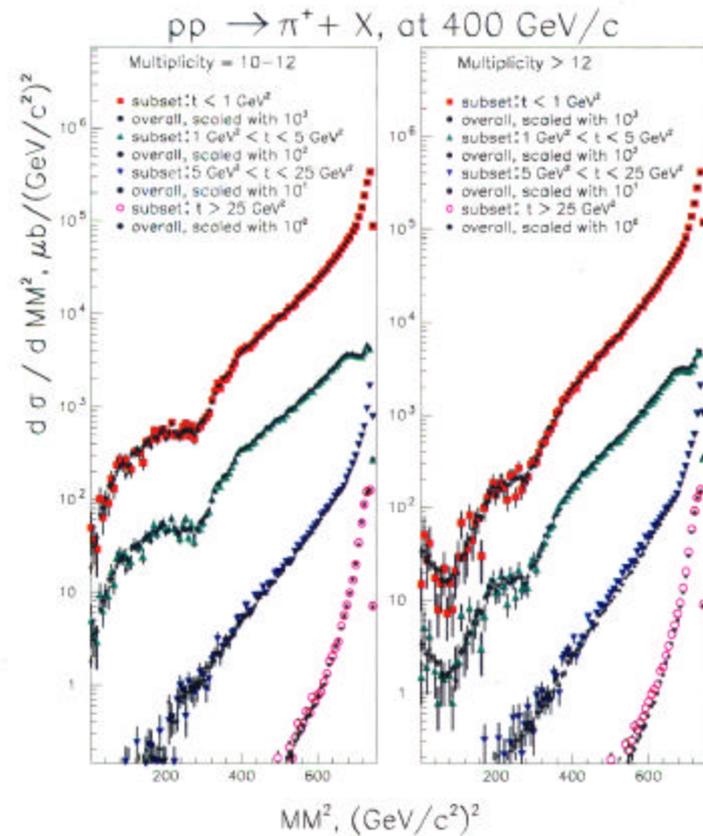
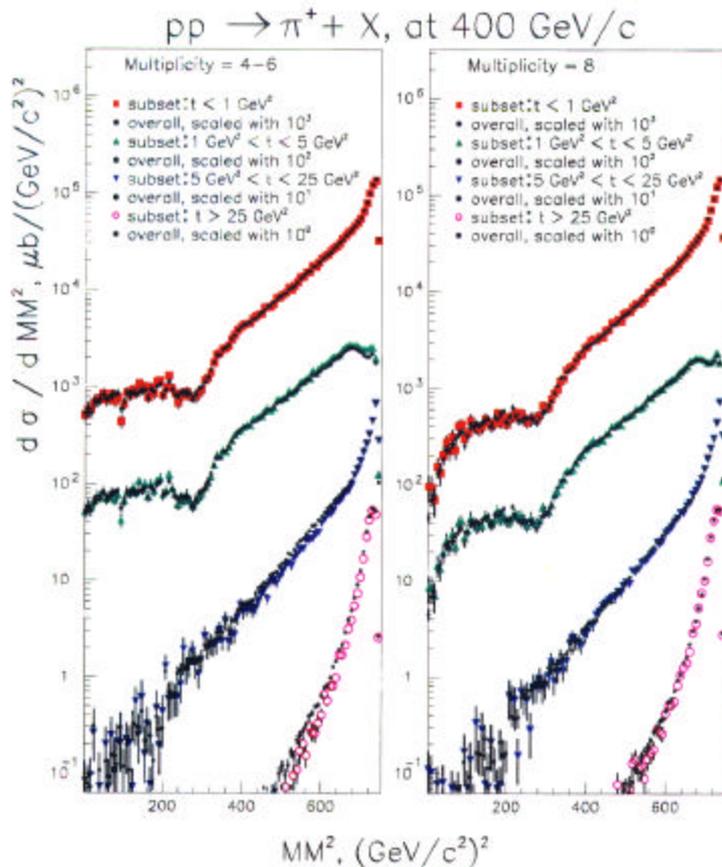


FIG. 10. The mean recoiling multiplicity as a function of M^2 for various t ranges at 205 GeV/c.

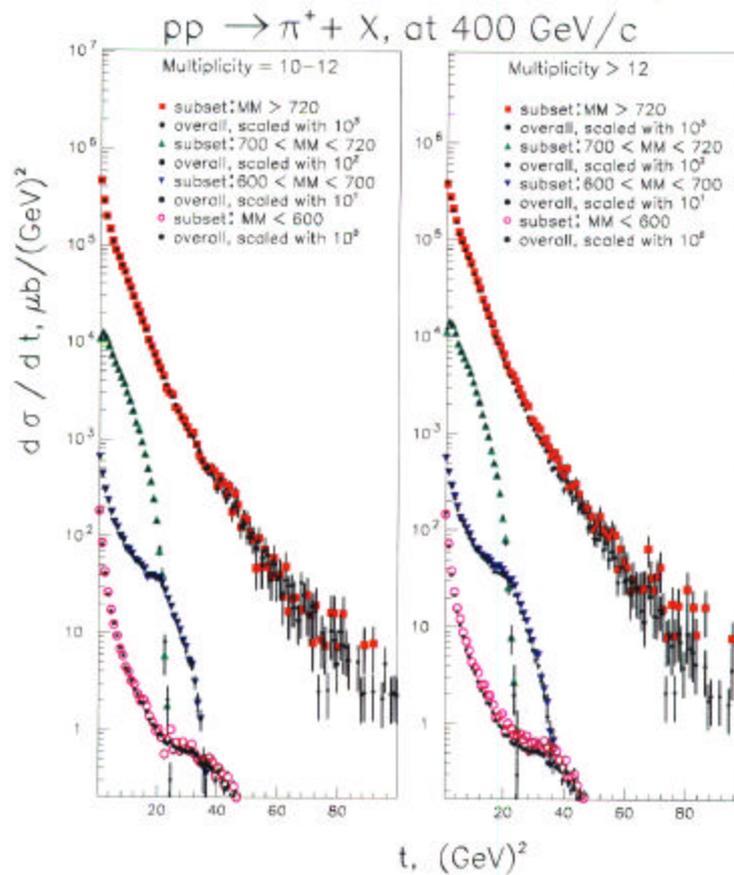
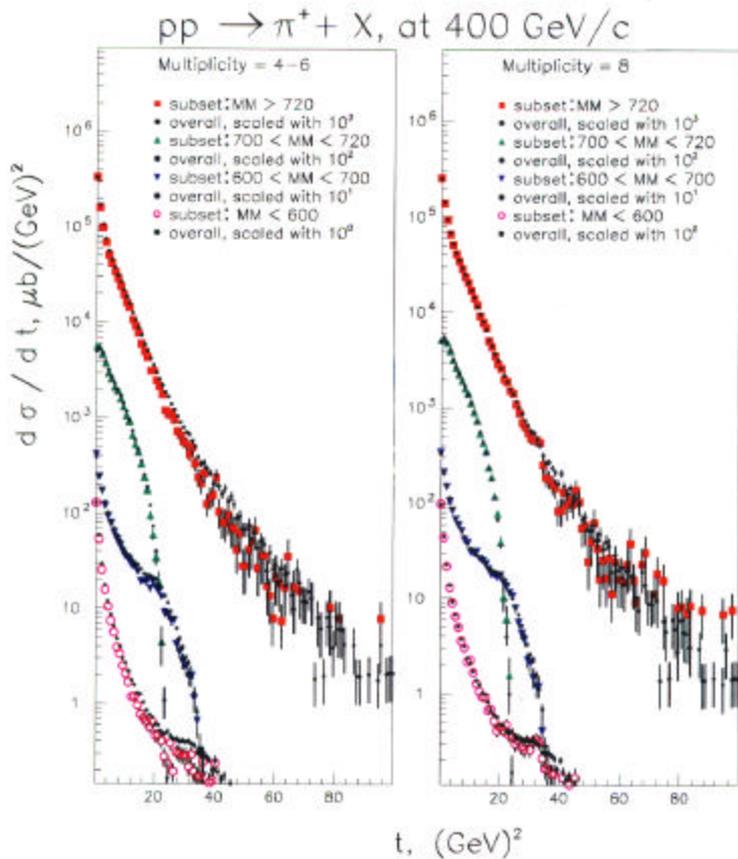
European Hybrid Spectrometer data

- 1 million events in EHS would have taken 3 years to analyze- Scan measure and track match. Incomplete particle id. Only data available at fixed s. Can test t independence. It takes MI PP ~ 8 hours to acquire 1 Million events, fully track matched and particle id'd.
- We have verified the scaling law in 12 reactions using EHS data at fixed s. (Y.Fisyak,R.Raja, Proceedings of the DPF1992 conference)

Scaling Law-EHS results



Scaling law -EHS results



Scaling Law tests with MI PP

- MI PP will test the scaling law with 36 reactions both in s and in t.
- Positive beam reactions

1	p ⁺	+	p	----->	p ⁺	+	X
2	p ⁺	+	p	----->	K ⁺	+	X
3	p ⁺	+	p	----->	p	+	X
4	p ⁺	+	p	----->	p ⁻	+	X
5	p ⁺	+	p	----->	K ⁻	+	X
6	p ⁺	+	p	----->	p ⁻	+	X
7	K ⁺	+	p	----->	p ⁺	+	X
8	K ⁺	+	p	----->	K ⁺	+	X
9	K ⁺	+	p	----->	p	+	X
10	K ⁺	+	p	----->	p ⁻	+	X
11	K ⁺	+	p	----->	K ⁻	+	X
12	K ⁺	+	p	----->	p ⁻	+	X
13	p	+	p	----->	p ⁺	+	X
14	p	+	p	----->	K ⁺	+	X
15	p	+	p	----->	p	+	X
16	p	+	p	----->	p ⁻	+	X
17	p	+	p	----->	K ⁻	+	X
18	p	+	p	----->	p ⁻	+	X

Scaling law tests with MI PP

Negative beam reactions

19	p^-	+	p	----->	p^+	+	X
20	p^-	+	p	----->	K^+	+	X
21	p^-	+	p	----->	p	+	X
22	p^-	+	p	----->	p^-	+	X
23	p^-	+	p	----->	K^-	+	X
24	p^-	+	p	----->	p^-	+	X
25	K^-	+	p	----->	p^+	+	X
26	K^-	+	p	----->	K^+	+	X
27	K^-	+	p	----->	p	+	X
28	K^-	+	p	----->	p^-	+	X
29	K^-	+	p	----->	K^-	+	X
30	K^-	+	p	----->	p^-	+	X
31	p^-	+	p	----->	p^+	+	X
32	p^-	+	p	----->	K^+	+	X
33	p^-	+	p	----->	p	+	X
34	p^-	+	p	----->	p^-	+	X
35	p^-	+	p	----->	K^-	+	X
36	p^-	+	p	----->	p^-	+	X

Among the 36, there are 15 crossing symmetry relations and 3 C symmetry relations

Scaling law tests with MI PP

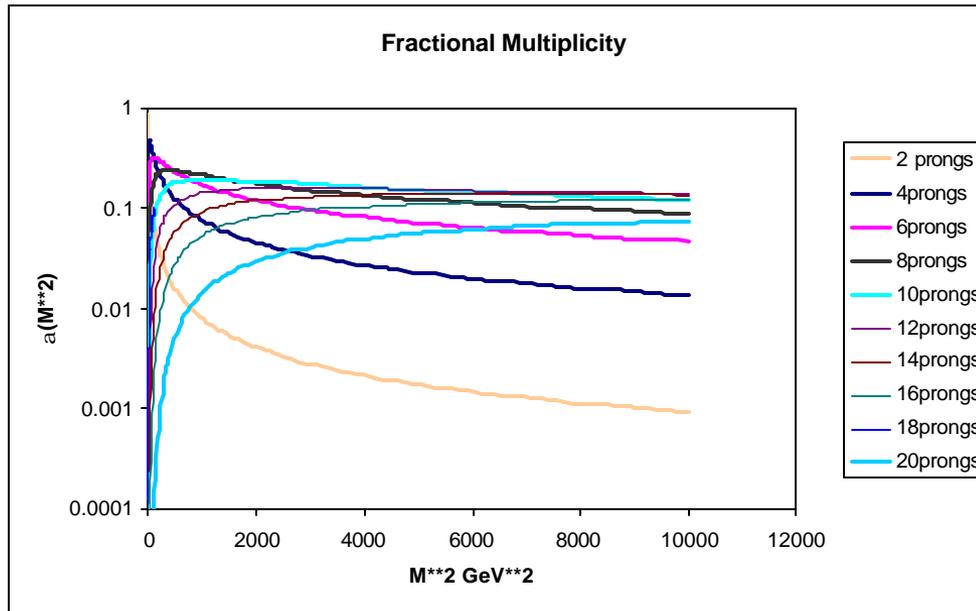
- For instance the functions $\alpha_s(M^2)$ by crossing symmetry must be the same for $\pi^+p \rightarrow \pi^+X$ and $\pi^-p \rightarrow \pi^-X$.
- Similarly

$$\bar{p}p \rightarrow p^+ + X \text{ and } p^- p \rightarrow p + X$$

Have the same $\alpha_s(M^2)$. So a diffractive process is linked to a central production process!

Scaling law tests with MIIP

These are the branching fractions of the fireball as a function of M^2 . Central production reactions peak at $x=0$.



Since $x \approx 1 - \frac{M^2}{s}$, central production cross sections will move in the above plot with s . Diffraction cross sections will peak at small M^2 and will not change significantly with s .

Implications of the scaling law

- Semi-inclusive central production cross sections can show large s dependence. If $\alpha_{\text{sub}}(M^2)$ falls with M^2 , then that subset will fall with s and vice-versa. Central production subsets that fall with s will also exhibit a broader Feynman x distribution.
- Should extend this to see if 4 body scattering (two particle inclusive final state) and higher numbers exhibit similar behavior.
- Can use scaling law to look for resonances. Scaling applies to a continuum of states that populate the cut in M^2 plane. If X is also a resonance in some subset, then interference will occur between signal and background for that mass range and will result in deviations from scaling. This can be used to look for resonances. E.g A1.

Implications of scaling law

- Implies that the pseudo-resonance states X behave as particles, there is fast equilibrium upon scattering. Argues against independent quark fragmentation in DIS. Argues for promoting the state X to have a structure that varies with M^2 . This leads naturally to scale breaking.
- I believe that if MIPP can establish this scaling to better than a percent or so in all 36 channels, we have to take these views seriously and alter our theories in accordance.

Additional Physics with upgraded MI PP

- Non-Perturbative QCD
 - » Test scaling in two particle inclusions- 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 current. 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

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

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

- 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 $gp \rightarrow K^+ \Lambda$
- 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 $pN \rightarrow K\Lambda$

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

Missing Baryon Resonances

- Resonances fall into four well defined regions.
 - » $P_{33}(1232)$ region
 - » C.m energy $\sim 1.5\text{GeV}$ $P_{11}(1440)$ /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 $1.9-2.0\text{GeV}$. 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 $N=4$. MI PP upgrade can explore these regions.

Missing Baryon Resonances

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

pN elastic scattering

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

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

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

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

- 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

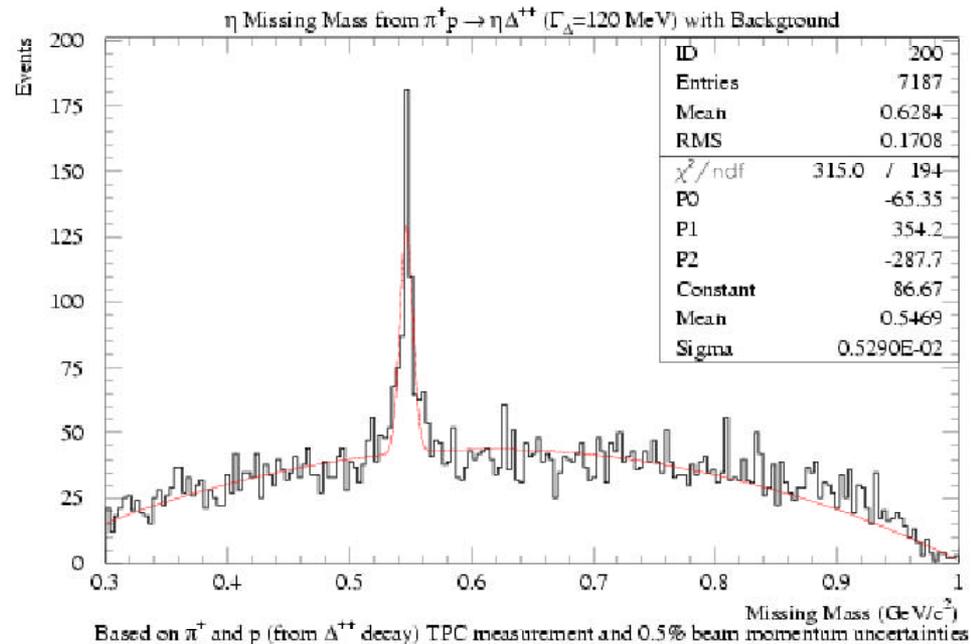
$$p^- p \rightarrow K^0 \Lambda \text{ (Pure } I = 1/2 \text{ reaction)}$$

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

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

$$p^+ p \rightarrow hp^+ p \text{ (} h \text{ by MM)}$$

$$p^+ p \rightarrow p^+ wp$$

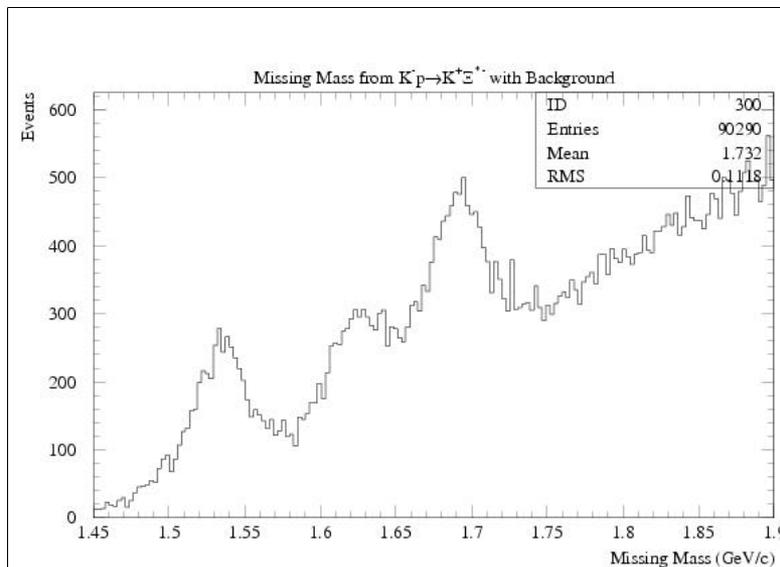


Run time needed for low momentum pion running

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. $K^- p \rightarrow K^+ \Xi^*$

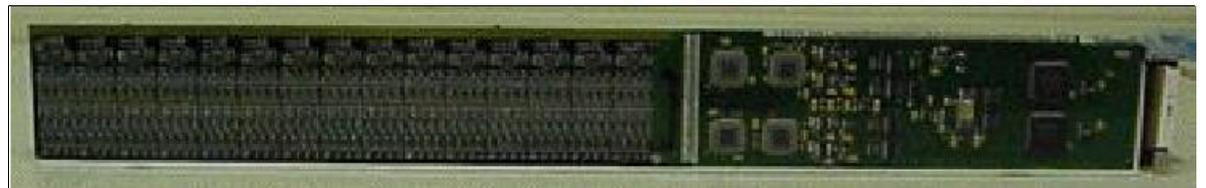


TPC Upgrade Proposal

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

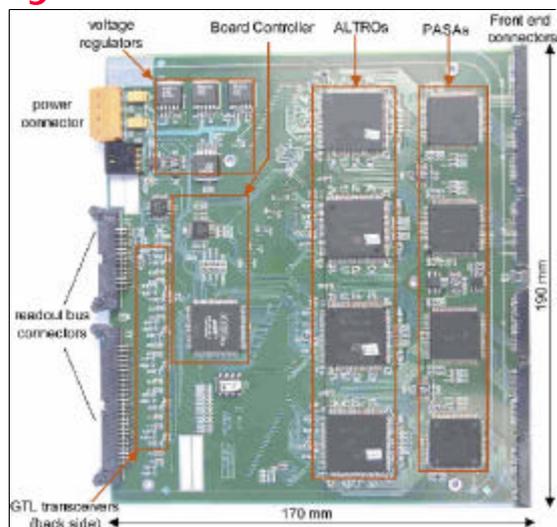


MI PP STICK



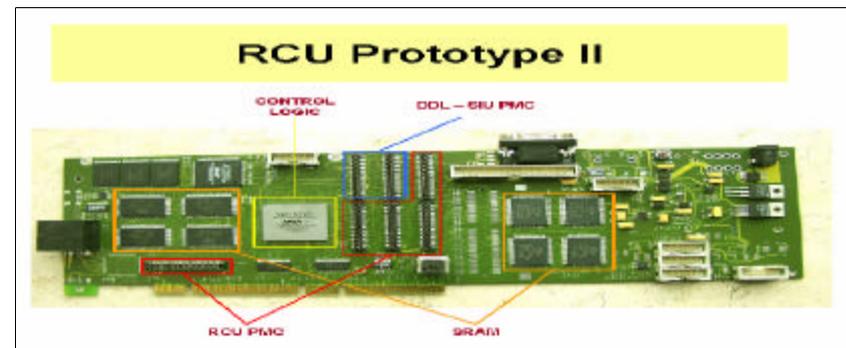
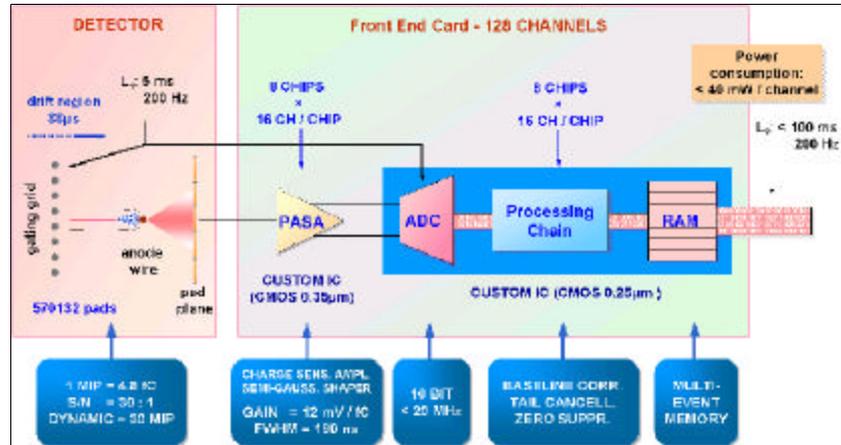
ALICE PASA/ALTRO Chip

- 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, MI PP and being used by BONUS.



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

ALTRO/PASA chips



Labor needed to fabricate the MIIP 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.

- RI CH 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 ~Sep 2006.

Conclusions

- MI PP 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 MI PP to explore the areas of missing baryon resonances, pentaquarks, missing cascade resonances with an apparatus whose capabilities are unique.
- Will solve Hadron simulator problem once and for all.
- Lots of thesis topics