The Main Injector Particle Production Experiment (MIPP) at Fermilab

Rajendran Raja

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MIPP collaboration list

Y. Fisyak

Brookhaven National Laboratory

R. Winston

EFI, University of Chicago

M.Austin,R.J.Peterson

University of Colorado, Boulder,

E.Swallow

Elmhurst College and EFI

W.Baker,D.Carey,J.Hylen, C.Johnstone,M.Kostin, H.Meyer, N.Mokhov, A.Para, R.Raja,S. Striganov

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,Y.Gunyadin,Y.Onel, A.Penzo

University of Iowa

N.Graf, M. Messier,J.Paley

Indiana University

P.D.BarnesJr.,E.Hartouni,M.Heffner,D.Lange,R.Soltz, D.Wright

Lawrence Livermore Laboratory

R.L.Abrams,H.R.Gustafson,M.Longo, H-K.Park, D.Rajaram

University of Michigan

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, H.Lane,L.C.Lu,C.Maternick,K.Nelson,A.Norman

University of Virginia

Brief Description of Experiment

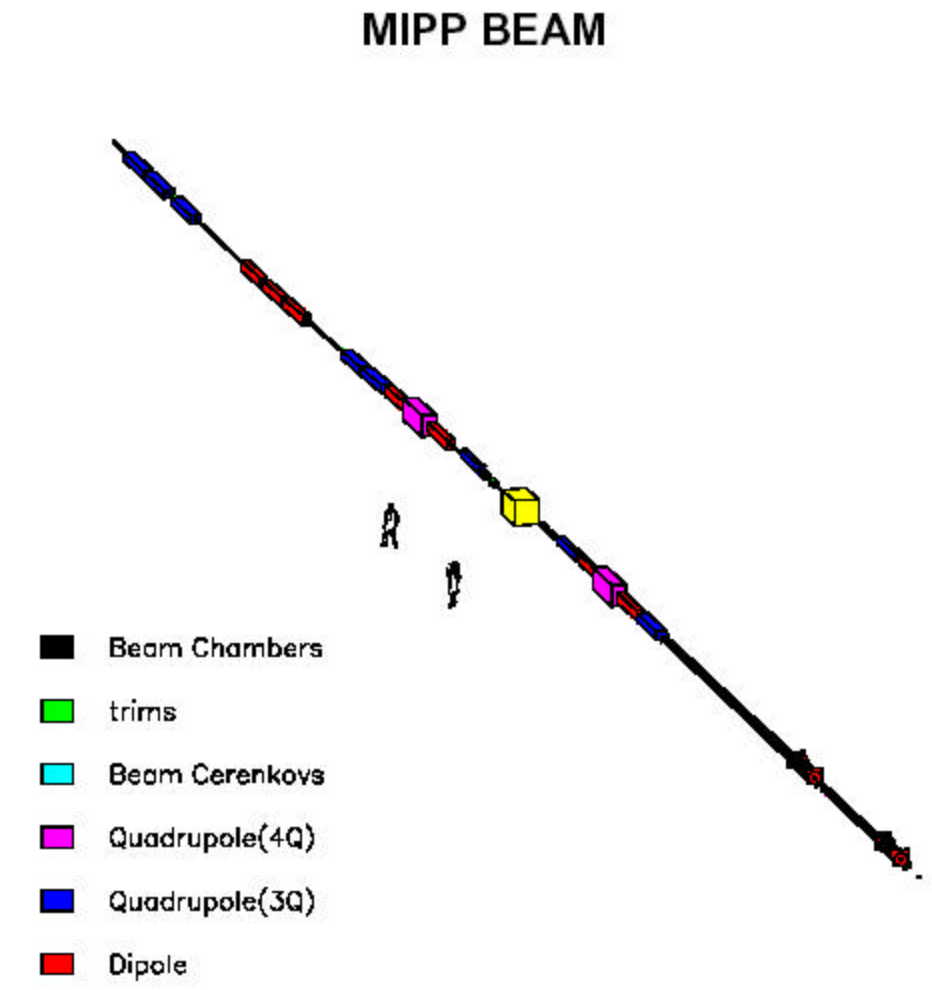
- Approved November 2001
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of $\pi^{\pm}$ $K^{\pm}$ $p^{\pm}$ from 5 GeV/c to 100 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Using a TPC we measure momenta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

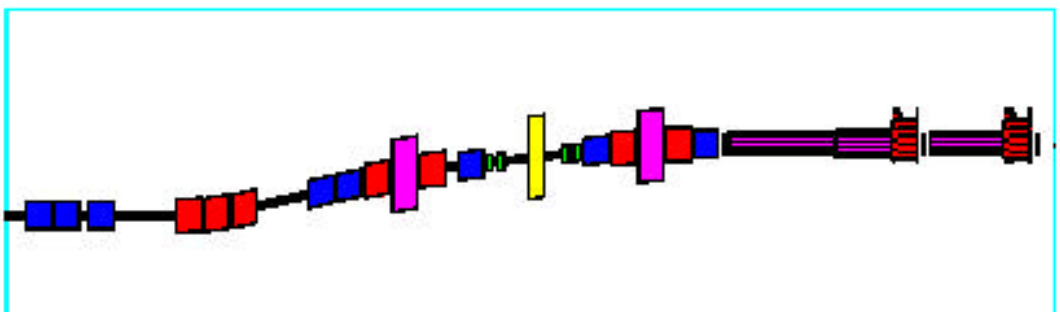
Physics Interest

- 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/Minerva/Nova 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 $\pi^{\pm}$ $K^{\pm}$ $p^{\pm}$

MIPP Secondary Beam

- Installed in 2003. Delivering slow spill commissioning beam (40GeV/c positives since February 2004). Sonn will increase rep rate once we commission the detector.

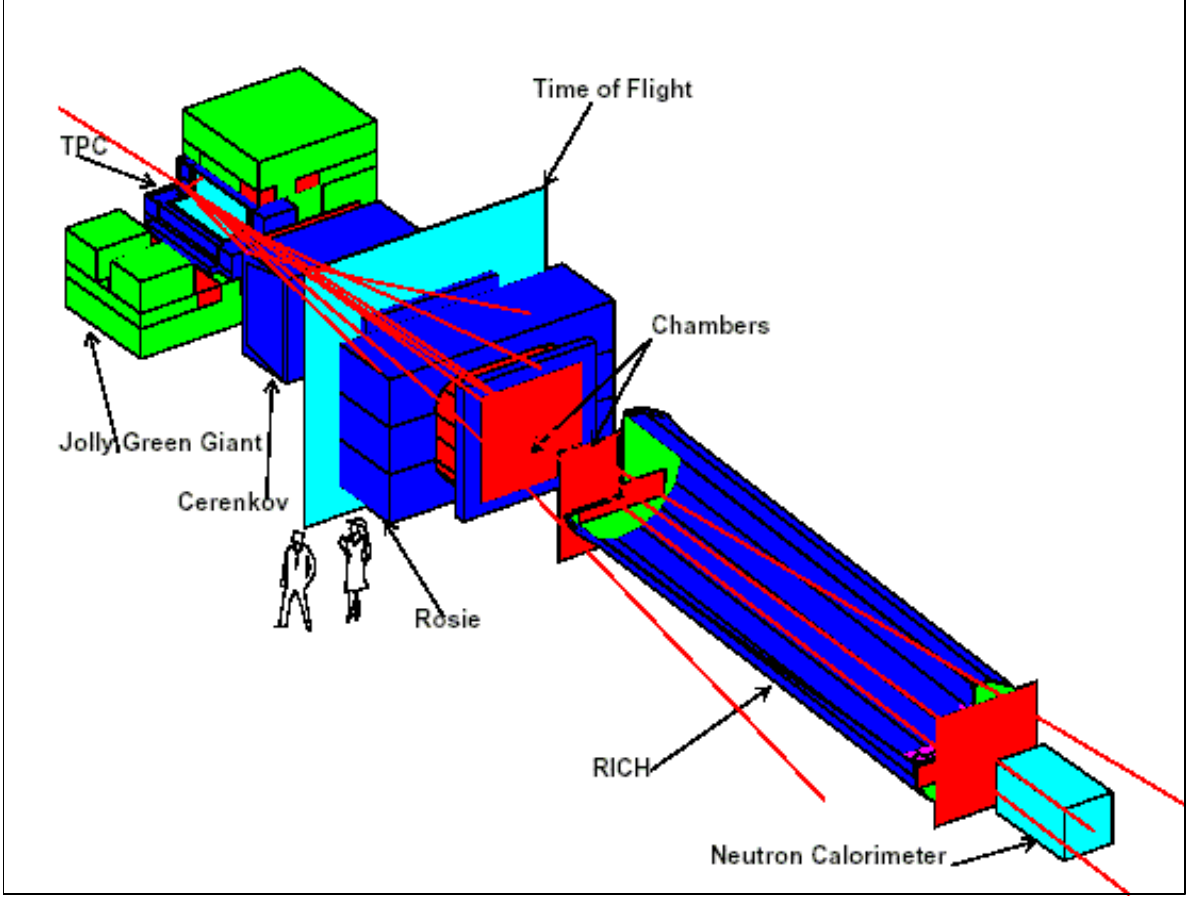


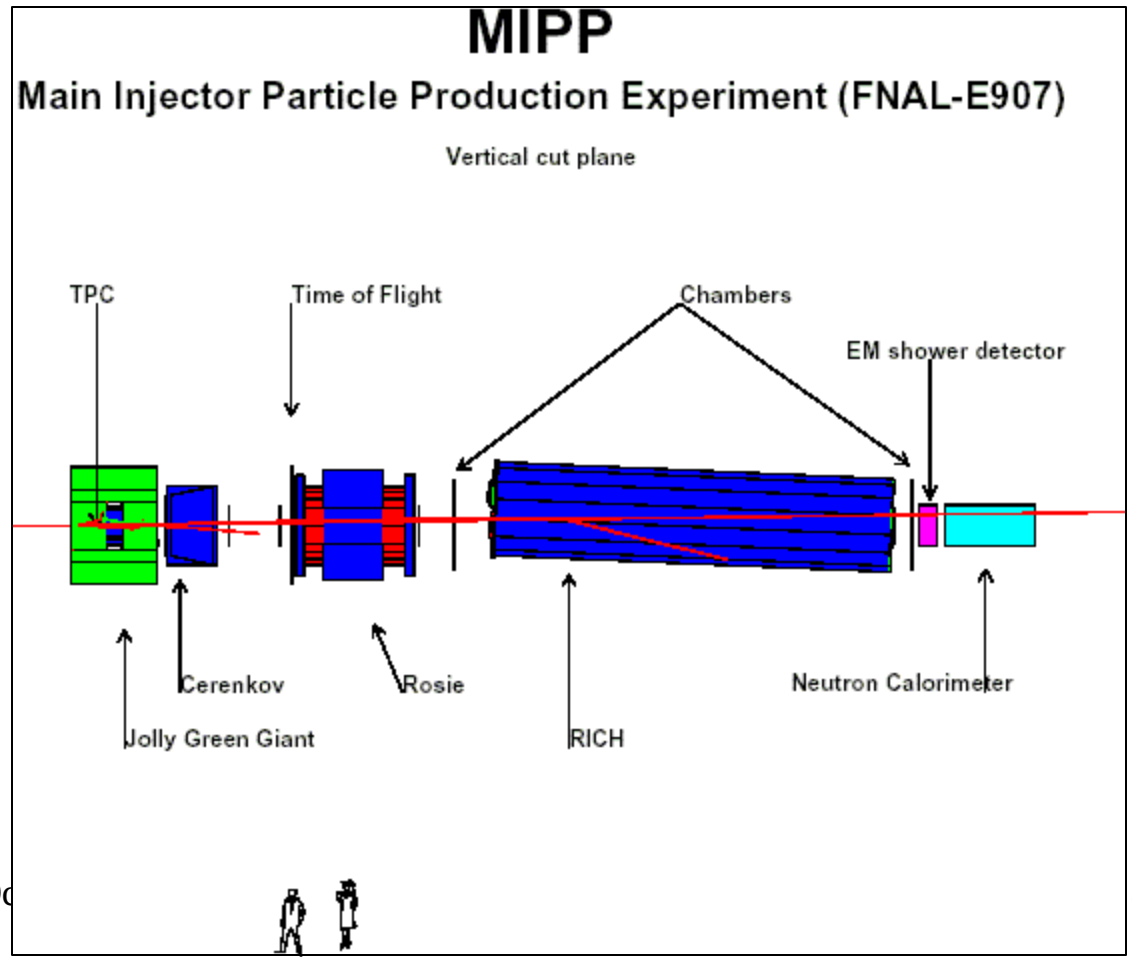


MIPP Beam characteristics

We plan to take 1,330,000 one-second slow spills on a variety of targets for 6 beam species $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ at 5,15, 25,50, 70, 90 GeV/c . We use an average of 1E10 MI protons per spill. We plan to acquire 60 million events of which 18 million are on liquid hydrogen.

Target	Physics	Data Points	Primary proton Average Intensity/spill	Total number of Primary Protons
Numi 1	MINOS	3.3	125000	2.06E+10
NUMI 2	MINOS	3.3	125000	2.06E+10
H2	Scaling	6	9.76E+09	2.93E+15
N2	Atmospheric ν	4	9.76E+09	1.95E+15
Be	pA	2	9.76E+09	9.76E+14
Be	Survey	1	9.76E+09	4.88E+14
C	Survey	1	9.76E+09	4.88E+14
Cu	pA	2	9.76E+09	9.76E+14
Cu	Survey	1	9.76E+09	4.88E+14
Pb	pA	2	9.76E+09	9.76E+14
Pb	Survey	1	9.76E+09	4.88E+14
Total		26.6		9.76E+15

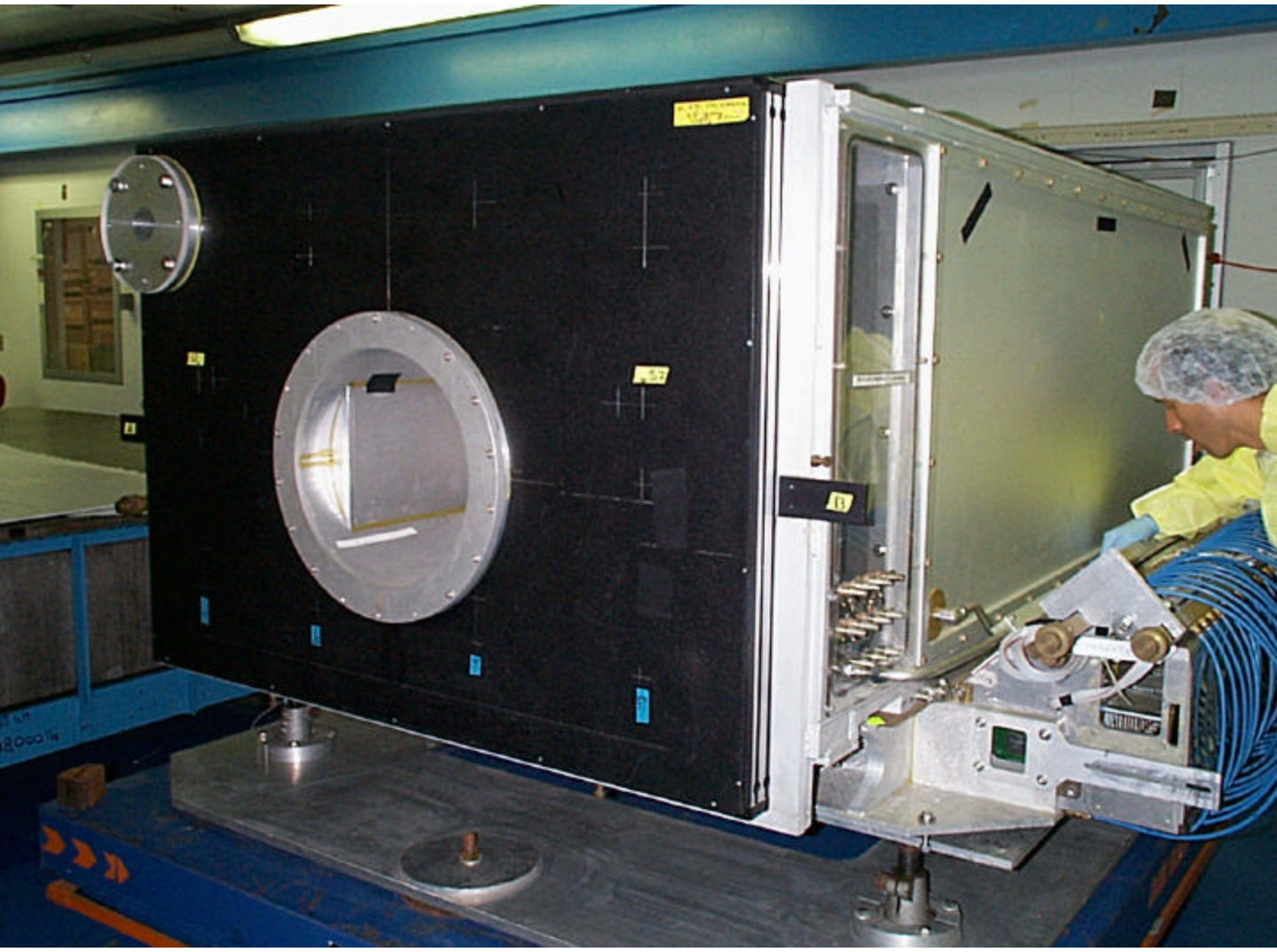

Time of Flight
TPC
Chambers
Jolly Green Giant
Cerenkov
Rosie
RICH
Neutron Calorimeter

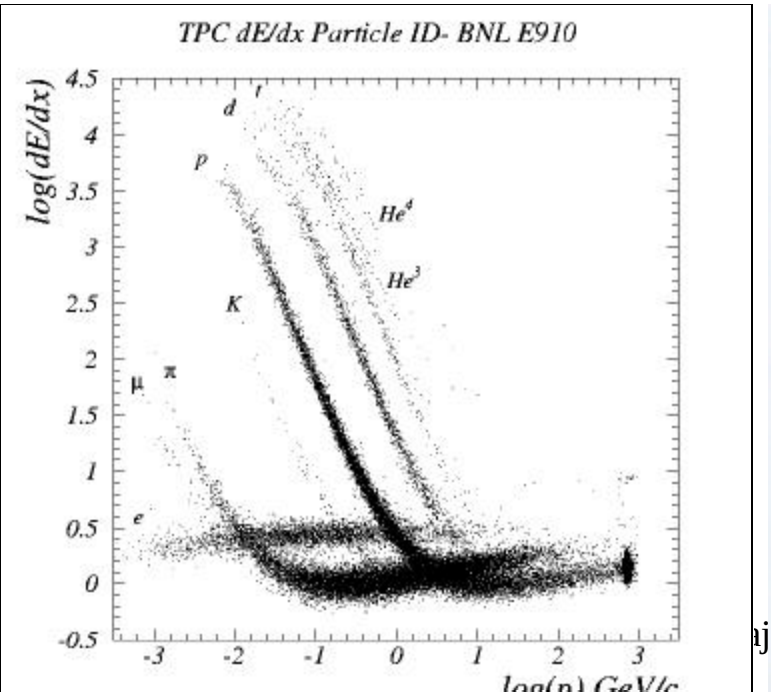

MIPP
Main Injector Particle Production Experiment (FNAL-E907)
Vertical cut plane
TPC
Time of Flight
Chambers
EM shower detector
Cerenkov
Rosie
RICH
Neutron Calorimeter
Jolly Green Giant

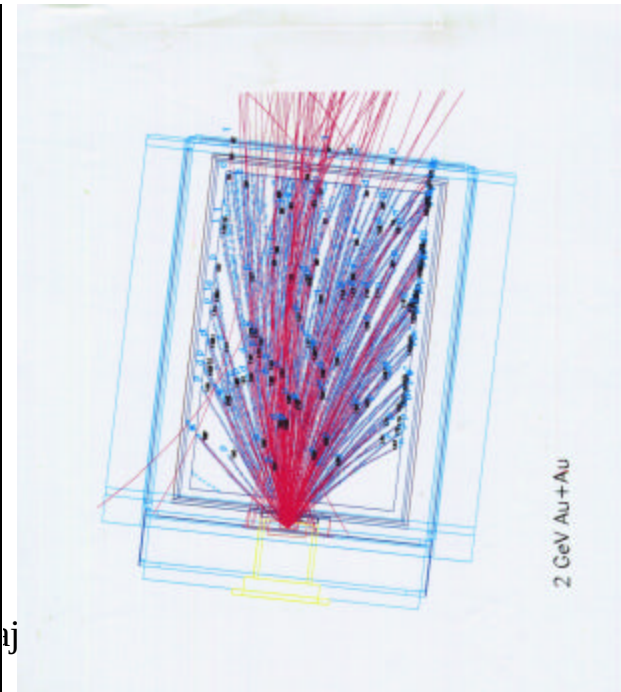
Status of MIPP Now- Collision Hall

Status of MIPP Now- Collision Hall

TPC installation



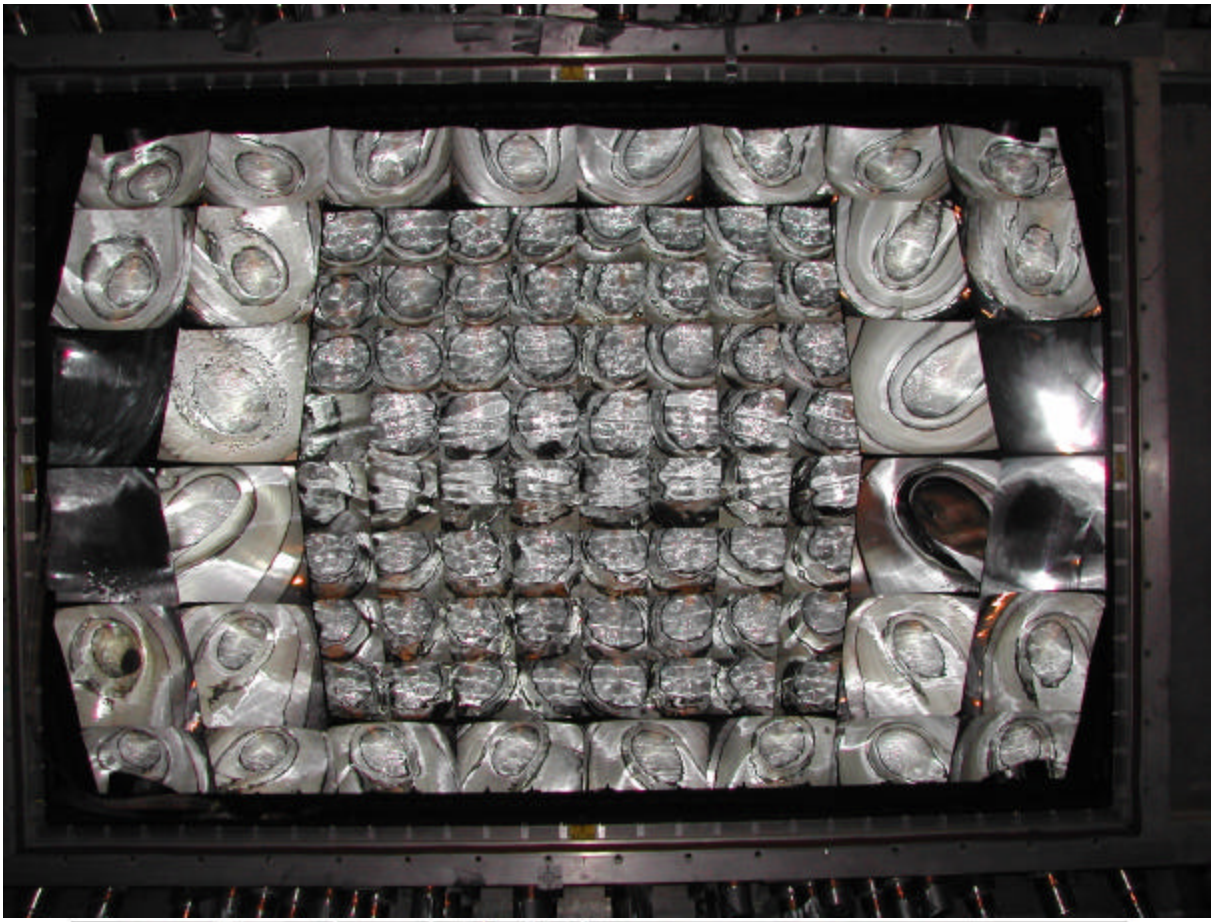


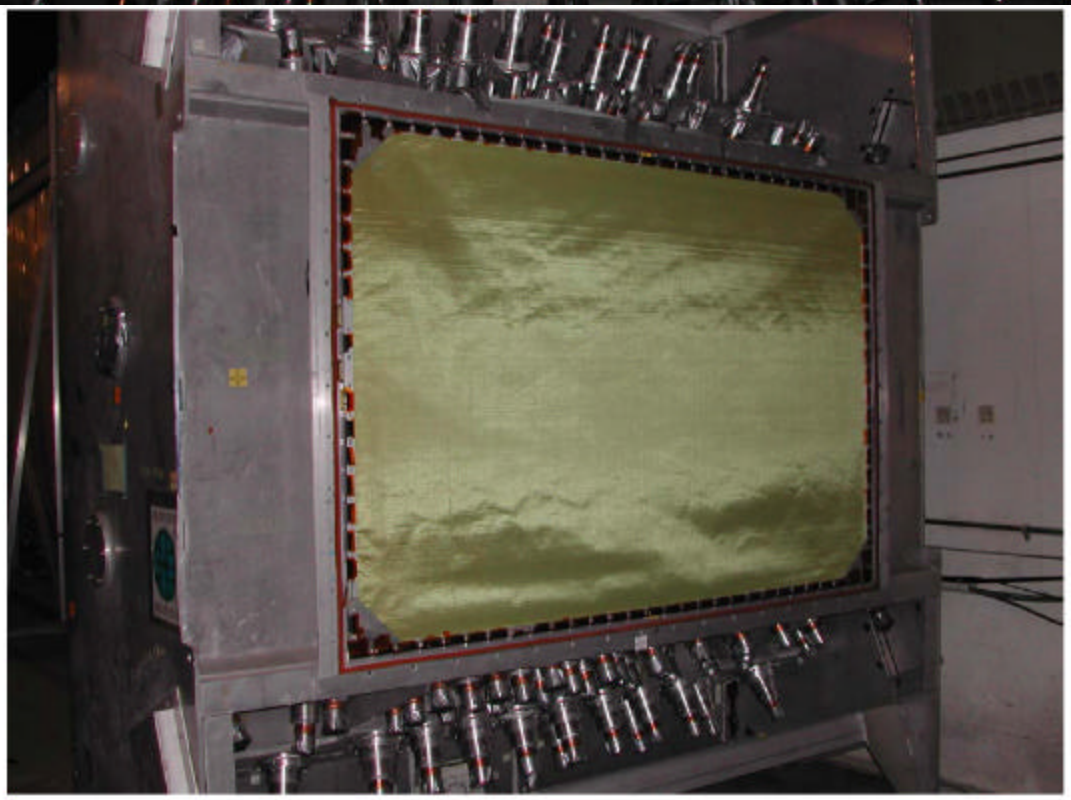


MIPP-TPC

- 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 ~60Hz with current electronics. Can increase this to ~1000 Hz with an upgrade.
- TPC dimensions of 96 x 75 x 150 cm.

MIPP Cherenkov



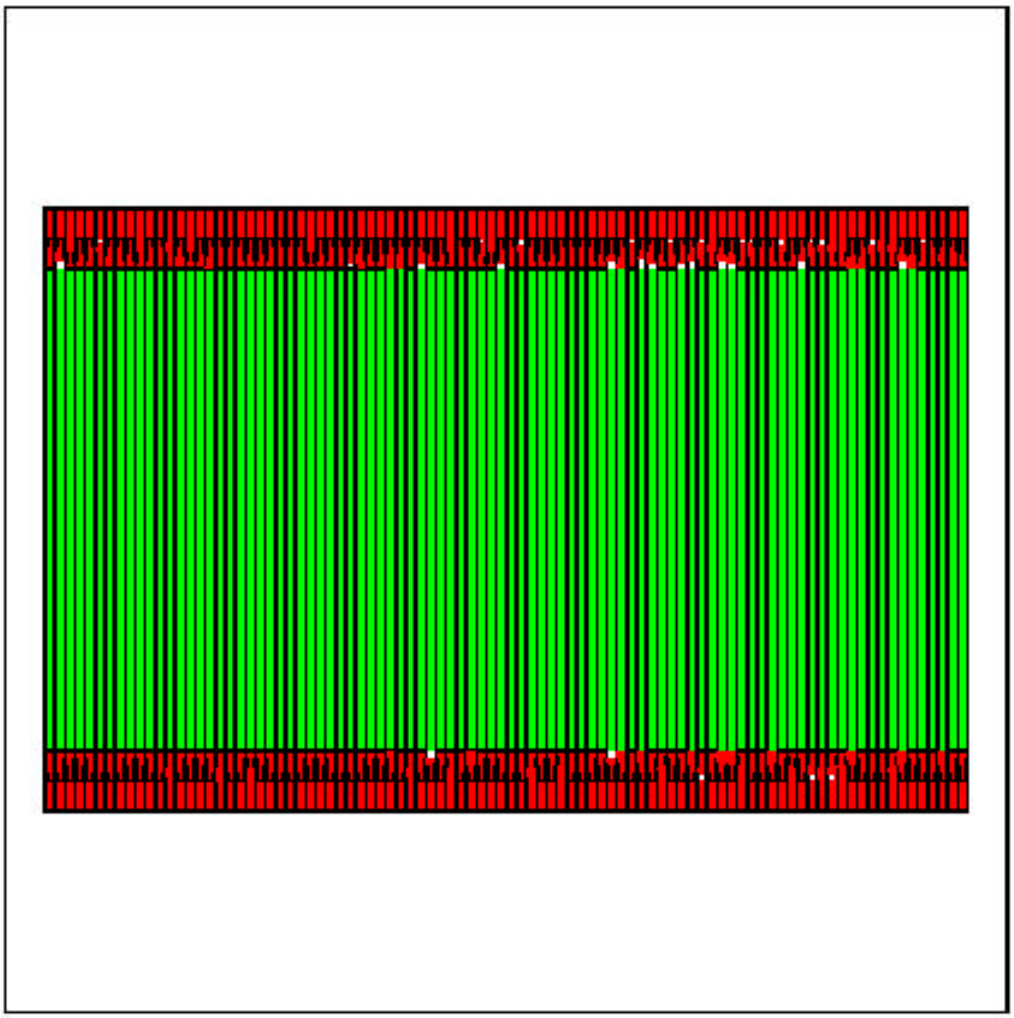


Time of Flight

- Time of flight ($220K) . Designed and built by MIPP

5cmx 5cm square scintillator bars in Rosie aperture, 10cmx10cm outside. ~ 150ps resolution.

MIPP- Time of flight system



Calorimeters

EM calorimeter followed by hadron calorimeter

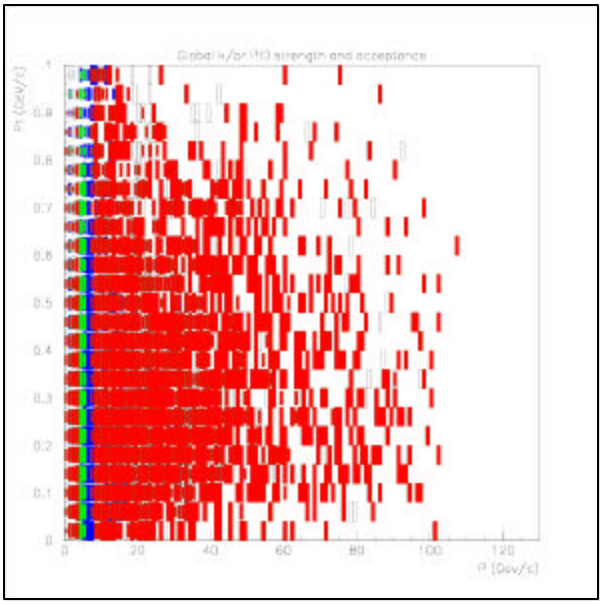
MIPP Particle ID capabilities

K/Proton separation analysis using all systems.

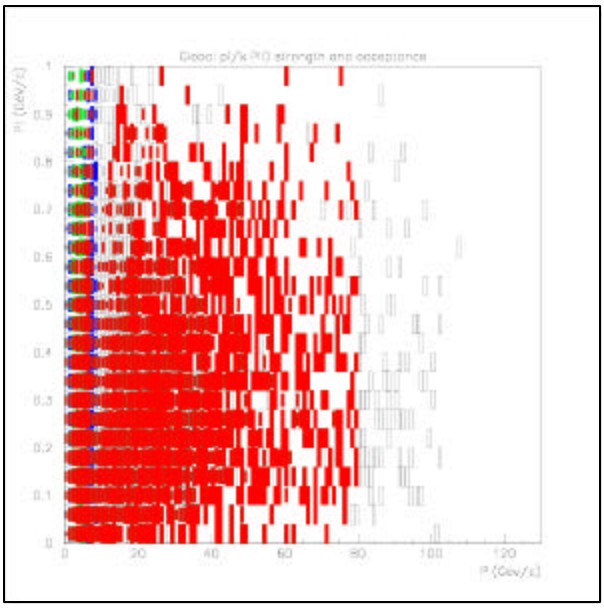
- Red = 3σ or better.
- 3σ < Green < 2σ
- 2σ < Blue < 1σ

0σ < White < 1σ

K/P separation



π/K separation



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 ($\pi^{\pm}$,$K^{\pm}$,$p^{\pm}$)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 MIPP QCD data

- Examples of exclusive channels are

$\pi^+ p \to A_1(1270) p$	Resonance production and diffractio n
$\pi^+ p \to K^+ \Sigma^+$	Strangenes s production
$K^+ p \to pp\overline{\Lambda}$	strangenes s and Baryon number production
$K^+ p \to \Delta^+ K^0 \pi^+$	charge exchange and resonance production
$p^+ p \to pp K^+ K^-$	Difraction , strangenes s production
$p^+ p \to pp\pi^+\pi^-$	Diffractiv e Dissociati on, Pomerons
$\pi^- p \to \pi^0 n$	Classic ρ exchange reaction
$\pi^- p \to K_*^0(892)\Lambda$	Strangenes s resonance production
$K^- p \to K_\zeta^{*-}(1780) p$	Exotic resonance production
$K^- p \to p K^-$	Strange Baryon exchange
$p^- p \to 3\pi^+ 3\pi^-$	Annihilati on
$p^- p \to p\overline{n}\pi^-$	$\overline{\text{p}}$ diffractio n (4C if we detect $\overline{\text{n}}$, else 1C)

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

http://ppd.fnal.gov/experiments/e907/notes/MIPPnotes/public/pdf/MIPP0010/MIPP0010.pdf

Uses of MIPP 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 strangness 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 MIPP to take data at 1000HZ instead of the current 60HZ. This will enhance the physics potential of MIPP.

General scaling law of particle fragmentation

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

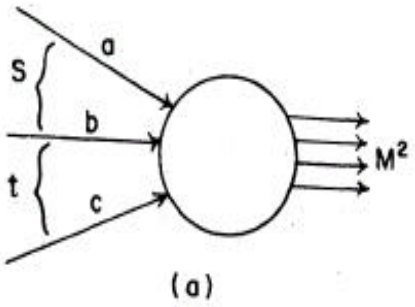
$$\frac{f(a+b\rightarrow c+X_{subset})}{f(a+b\rightarrow c+X)} \equiv \frac{f_{subset}(M^2,s,t)}{f(M^2,s,t)} = b_{subset}(M^2)$$

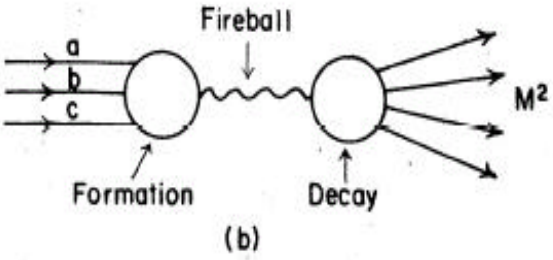
- where M^2,s and t are the Mandelstam variables for the missing mass squared, CMS energy squared and the momentum transfer squared between the particles a and c. PRD18(1978)204.
- Using EHS data, we have tested and verified the law in 12 reactions (DPF92) but only at fixed s.
- The proposed experiment 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

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

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





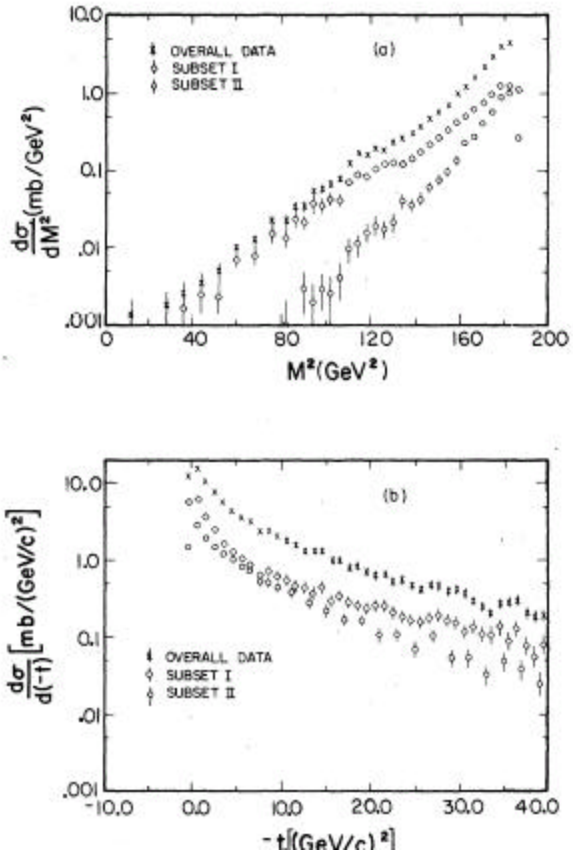
$$\frac{s\,(abc \to X_{sub})}{s\,(abc \to X)} = \frac{F(M^2, s, t) D_{X_{sub}}(M^2)}{F(M^2, s, t) D_X(M^2)} = a_{sub}(M^2)$$

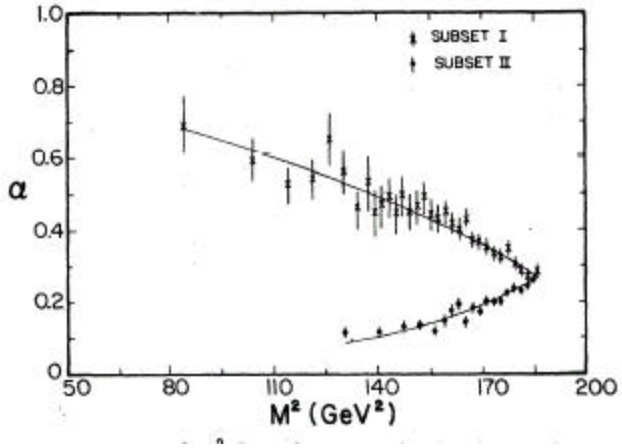
- Continuing on to physical t values, one gets

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

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





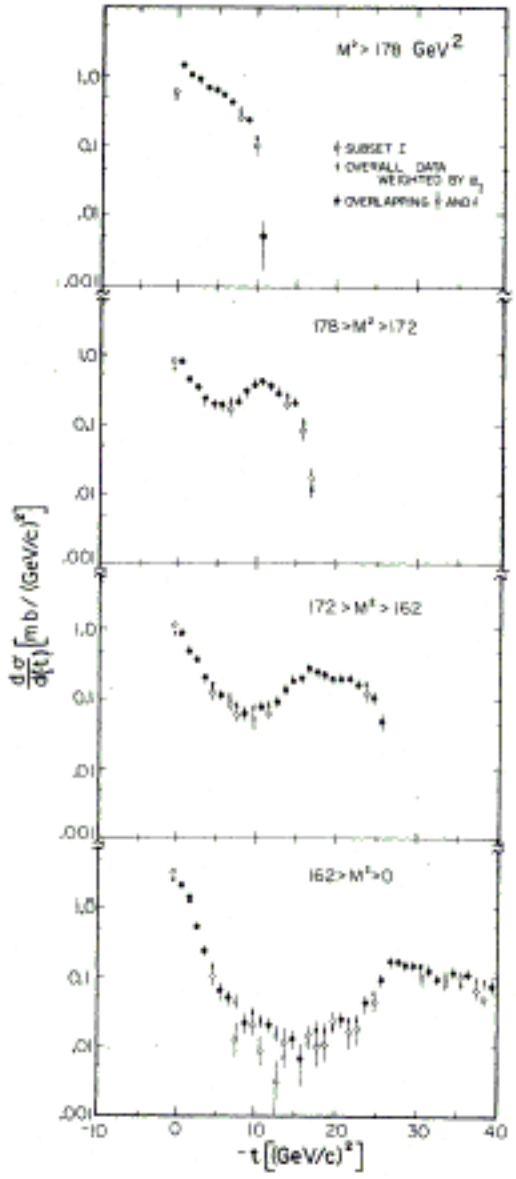


FIG. 4. Comparison of the t distribution for subset I with overall data weighted by $\alpha_I(M^2)$ for various M^2 ranges.

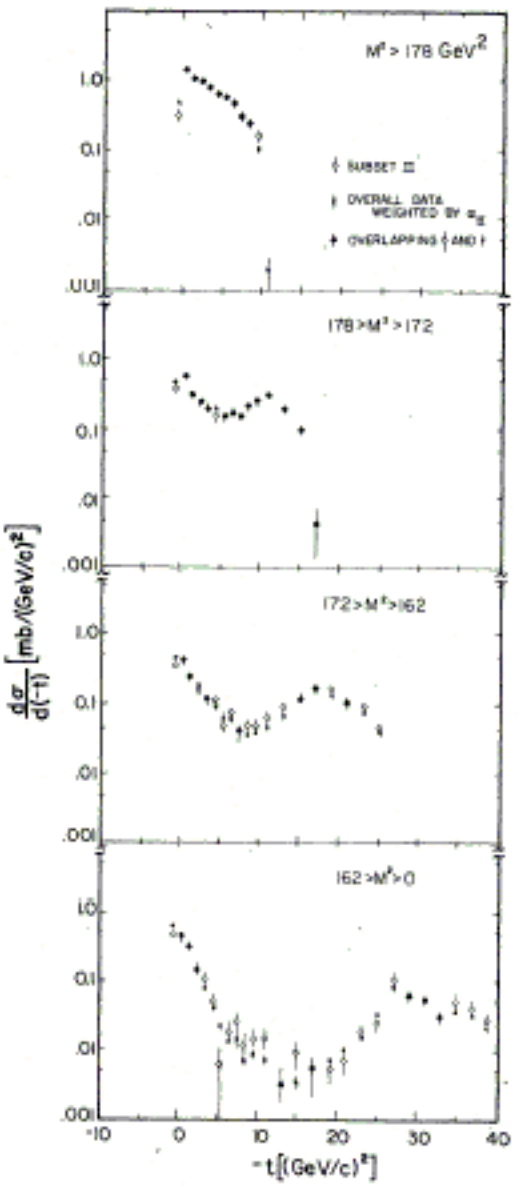


FIG. 5. Comparison of the t distribution for subset II with overall data weighted by $\alpha_{II}(M^2)$ for various M^2 ranges.

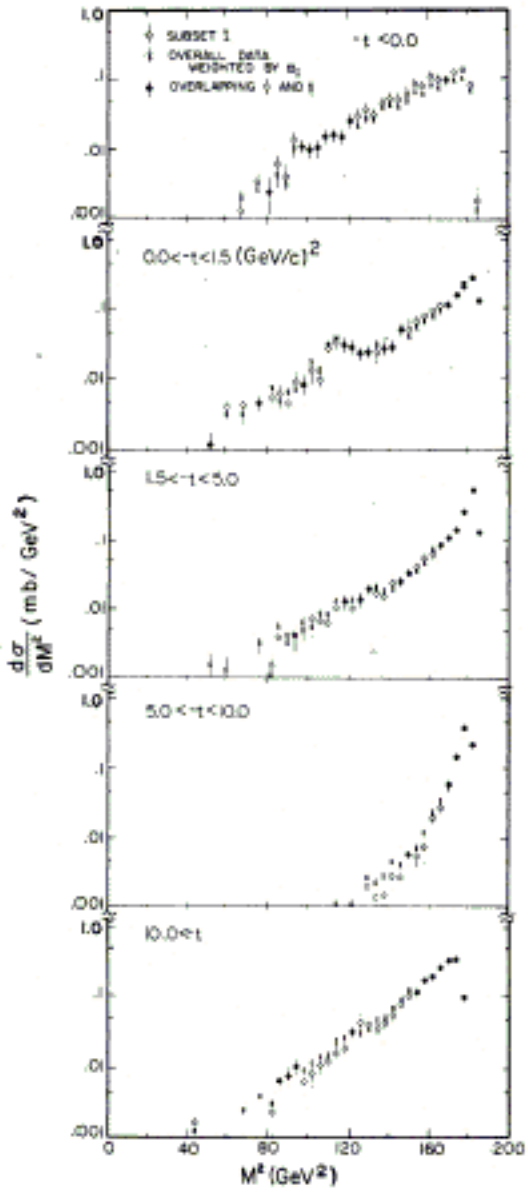


FIG. 6. Comparison of the M^2 distribution for subset I with overall data weighted by α_I (M^2) for various t ranges.

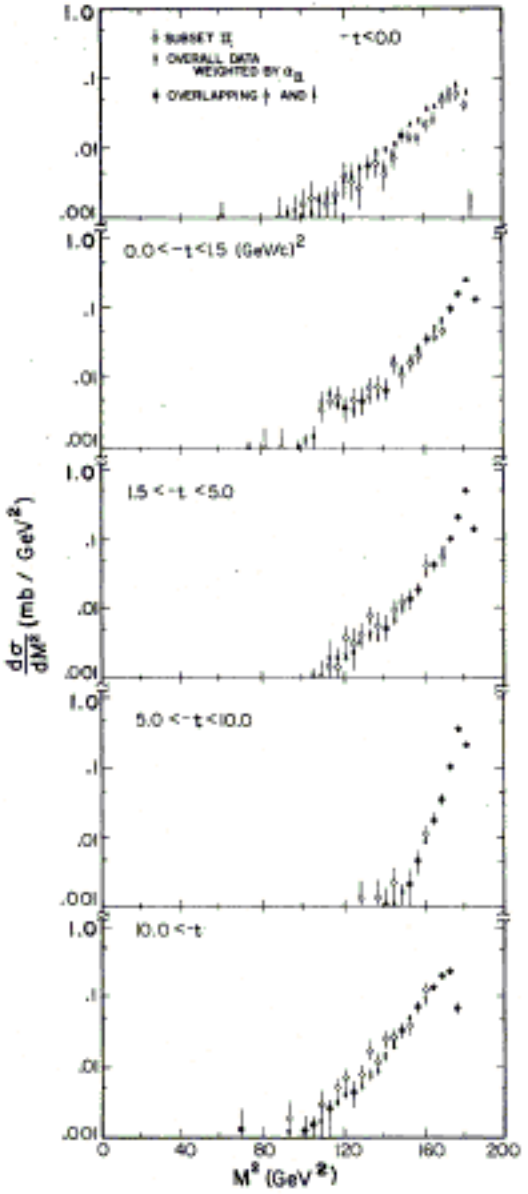


FIG. 7. Comparison of the M^2 distribution for subset II with overall data weighted by α_{II} (M^2) for various t ranges.

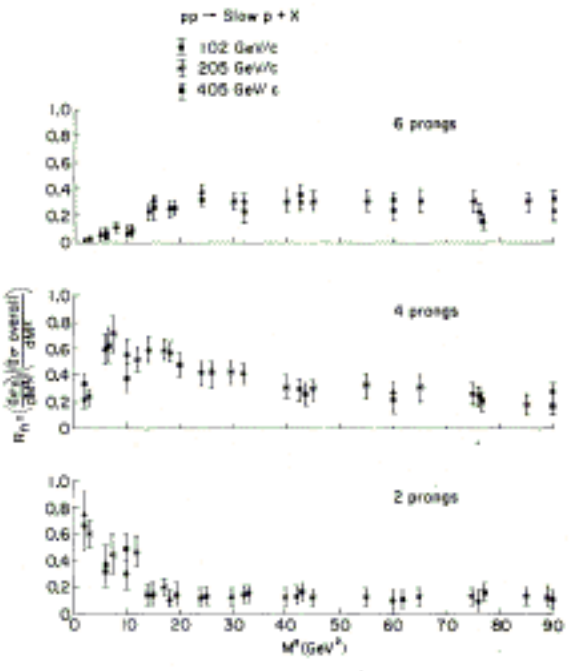


FIG. 8. The ratio of the semi-inclusive cross section to the overall cross section vs M^2 for 2, 4, and 6 prongs at beam momenta 102, 205, and 405 GeV/c.

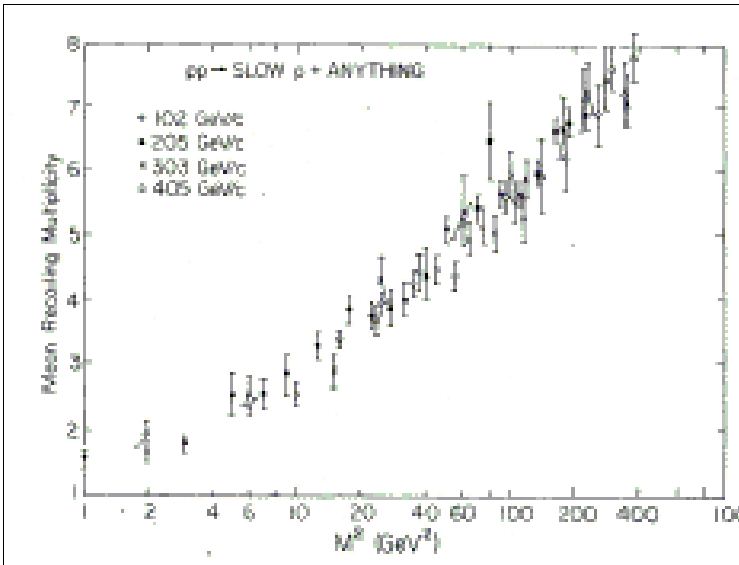


FIG. 9. The mean recoiling multiplicity as a function of M^2 at beam momenta 102, 205, 303, and 405 GeV/c.

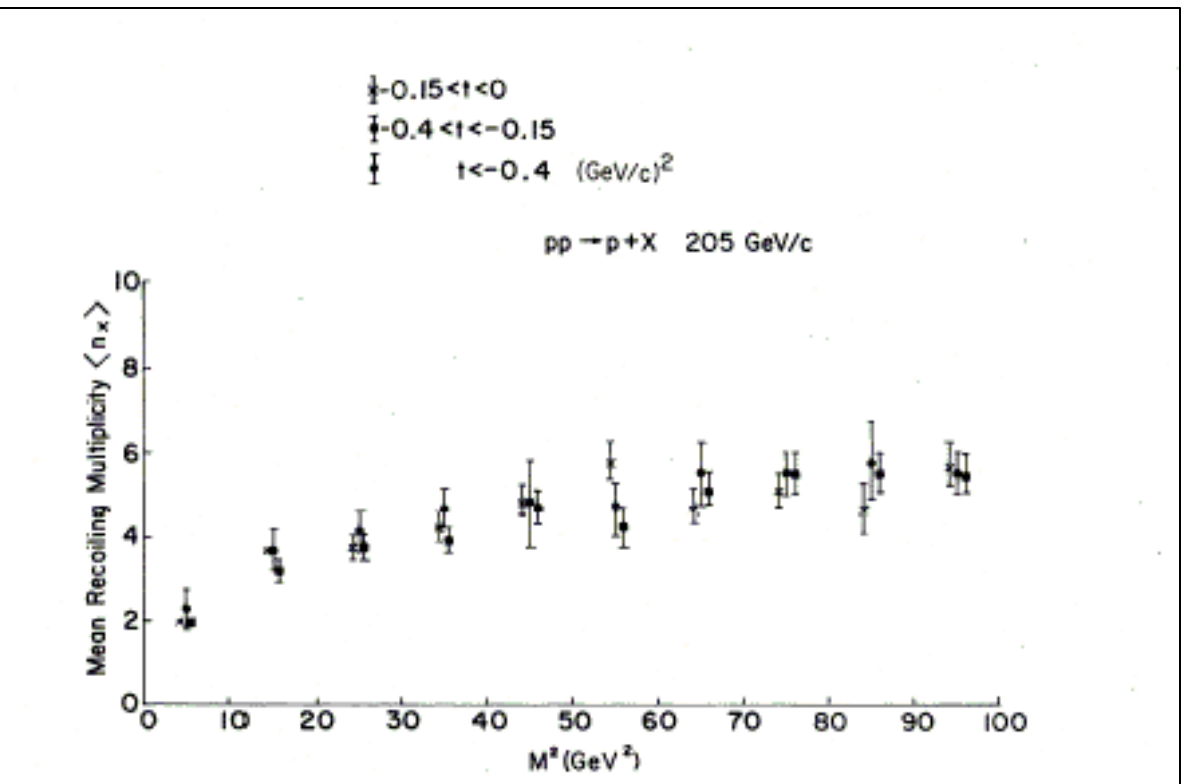
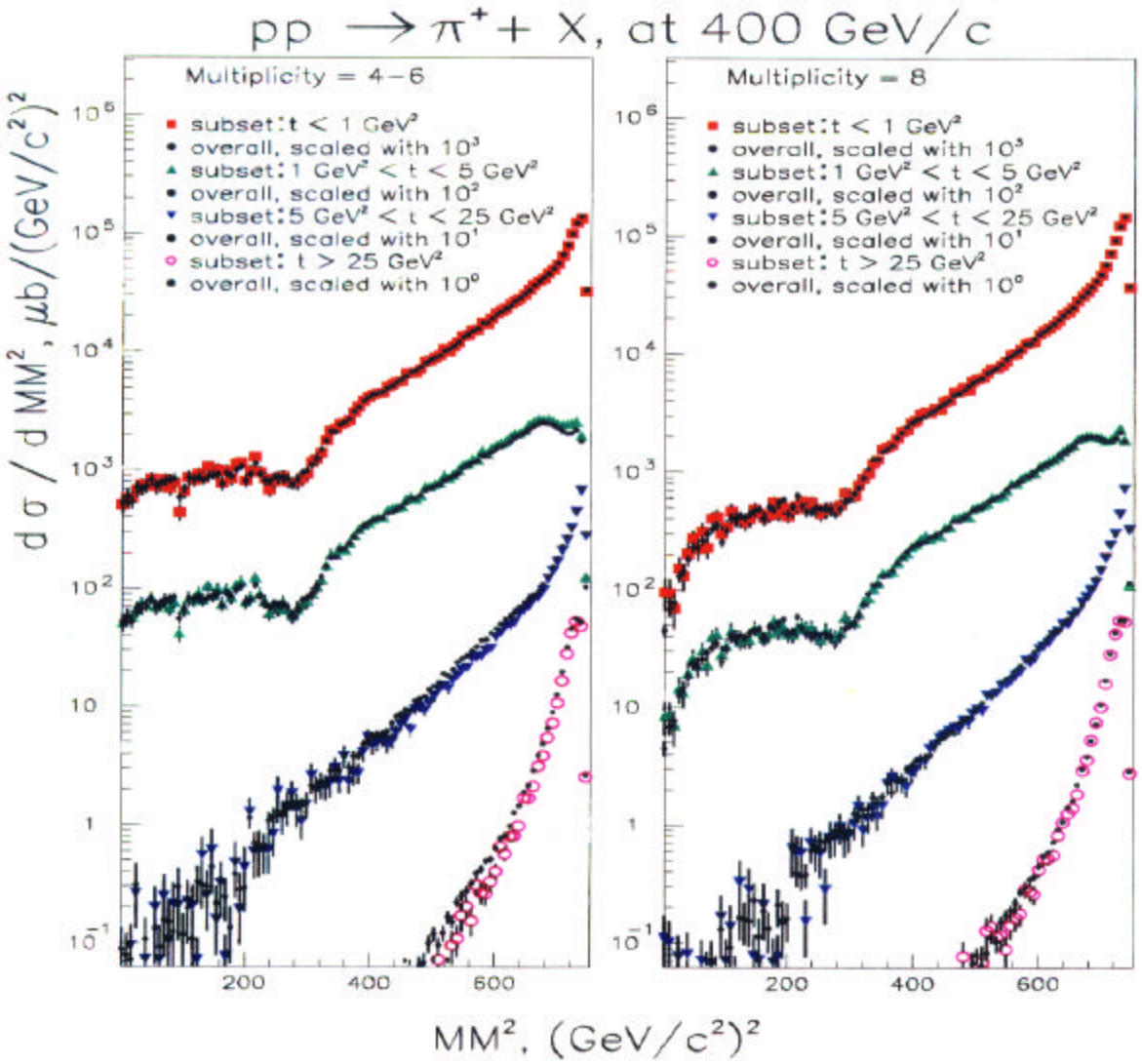


FIG. 10. The mean recoiling multiplicity as a function of M^2 for various t ranges at 205 GeV/c.

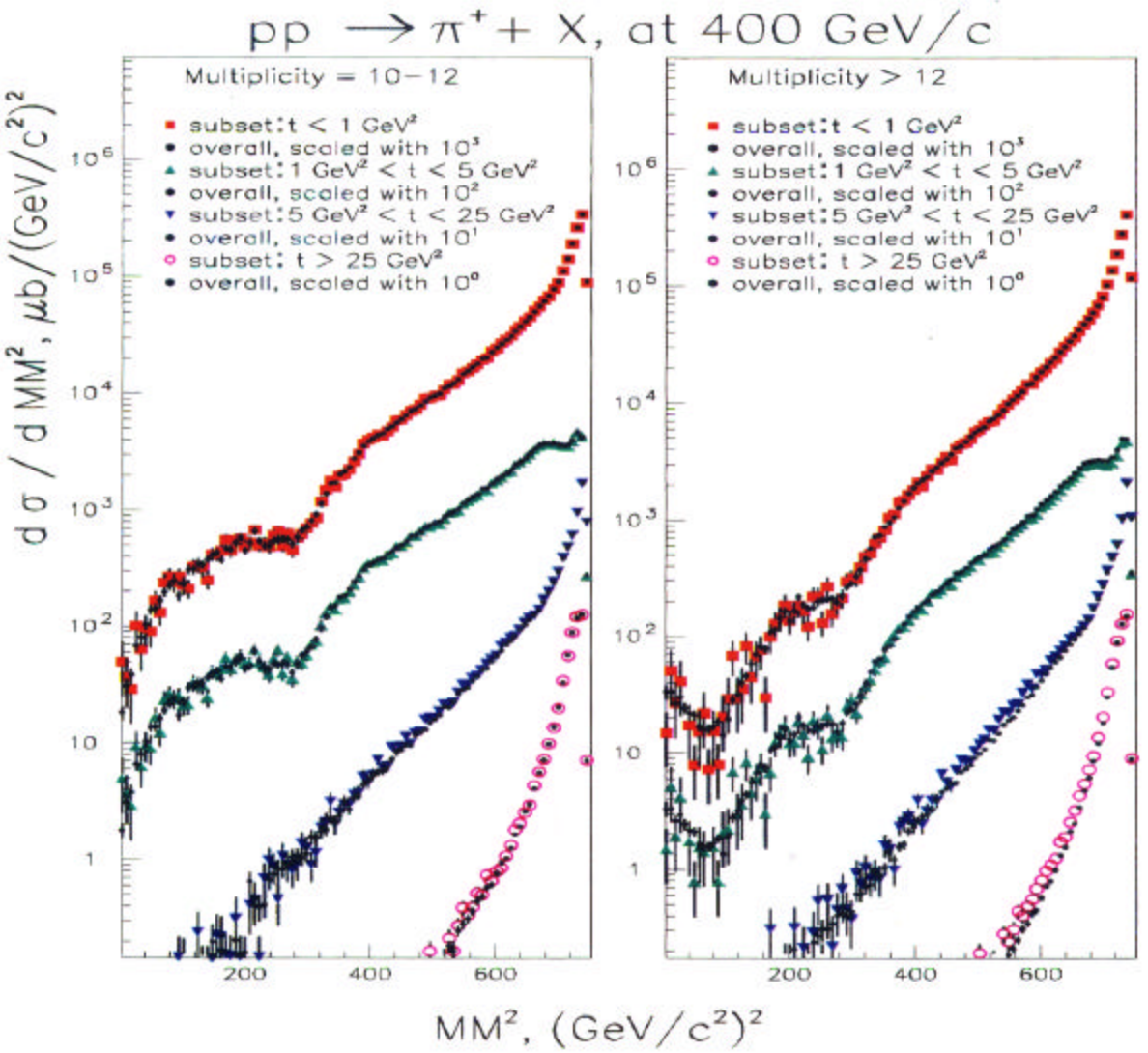
European Hybrid Spectrometer data

- 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 MIPP ~ 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)

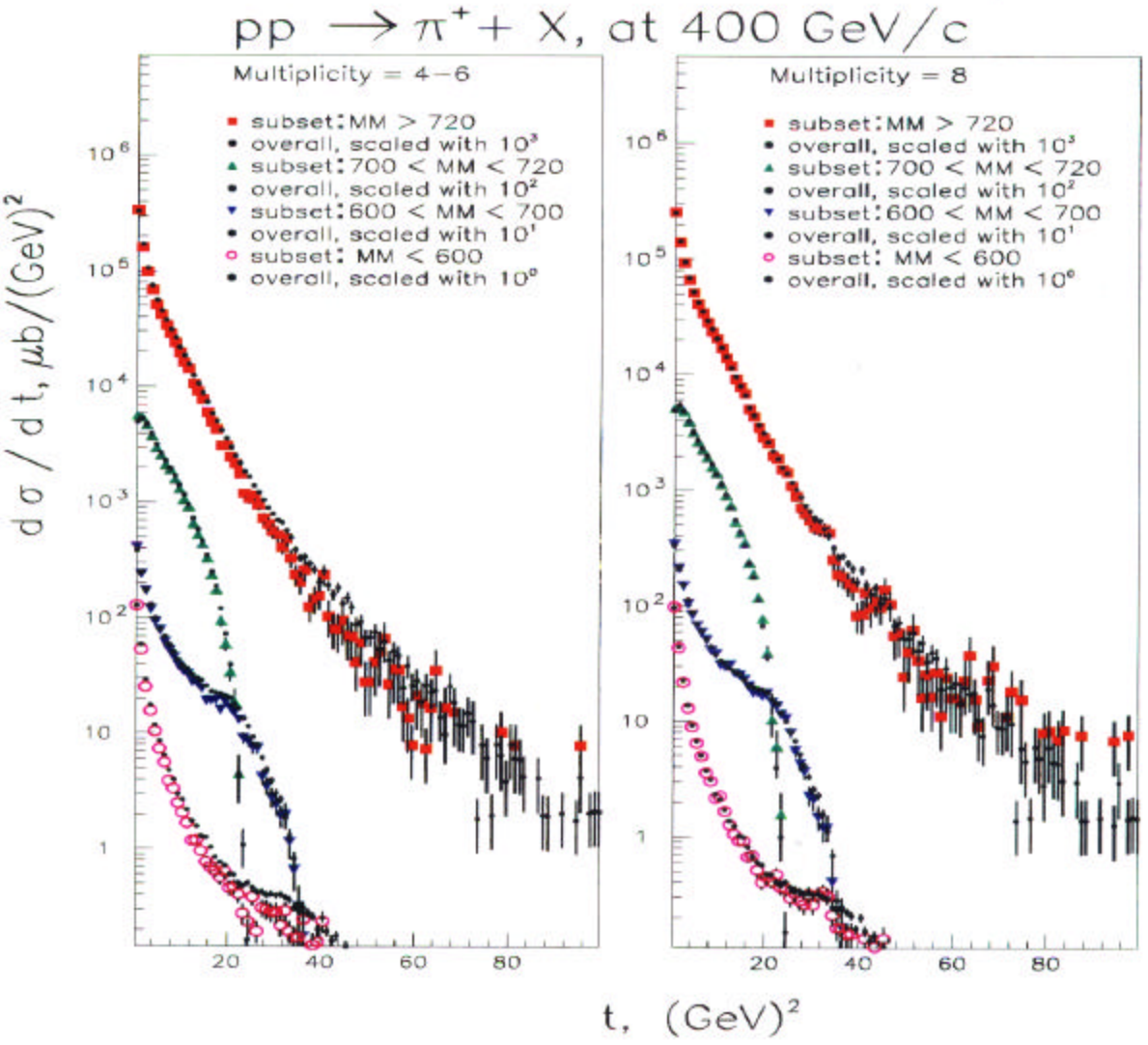
Scaling Law-EHS results



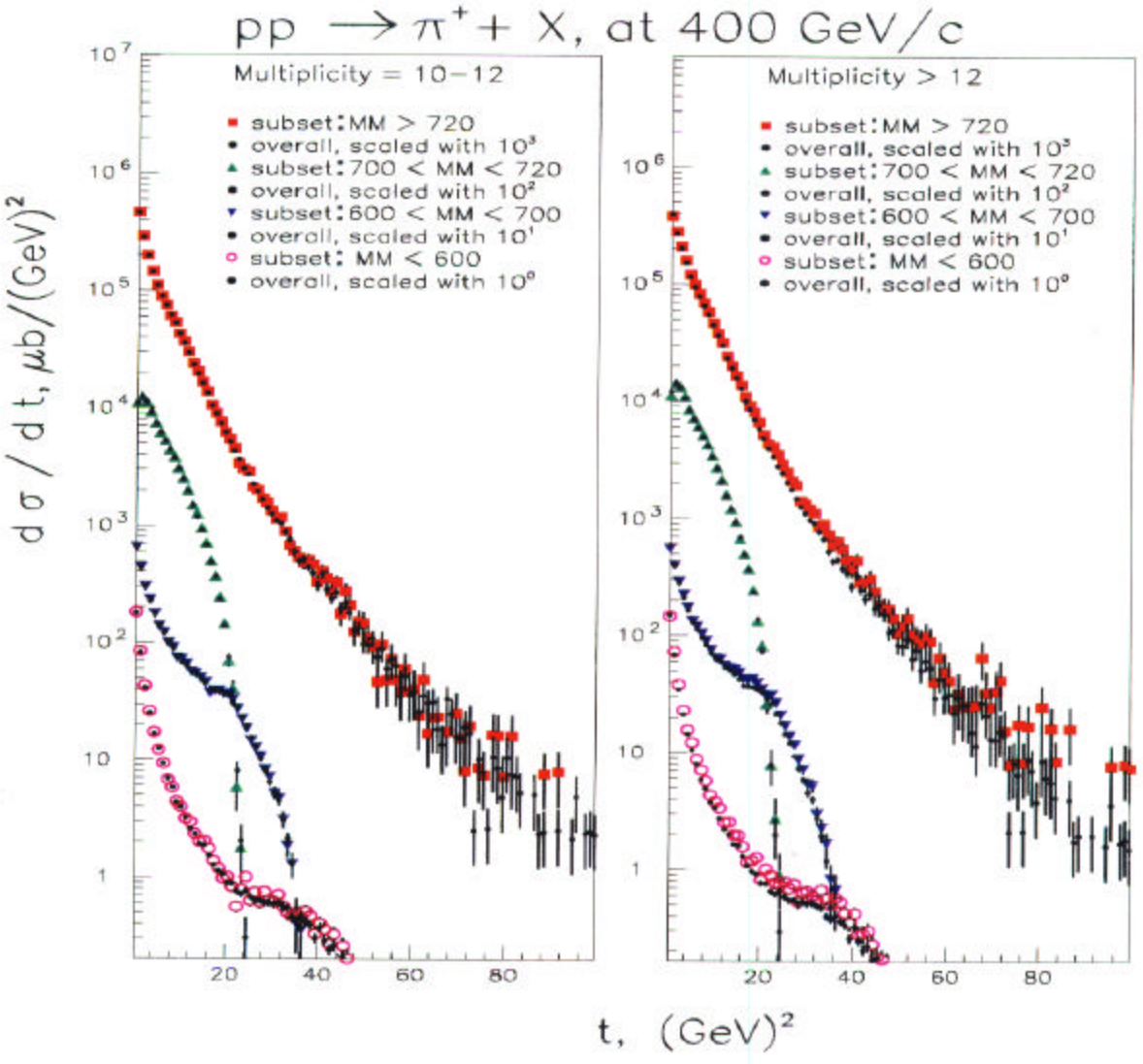
Scaling Law-EHS results



Scaling law -EHS results



Scaling Law -EHS results



Scaling Law tests with MIPP

- MIPP 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 MIPP

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 MIPP

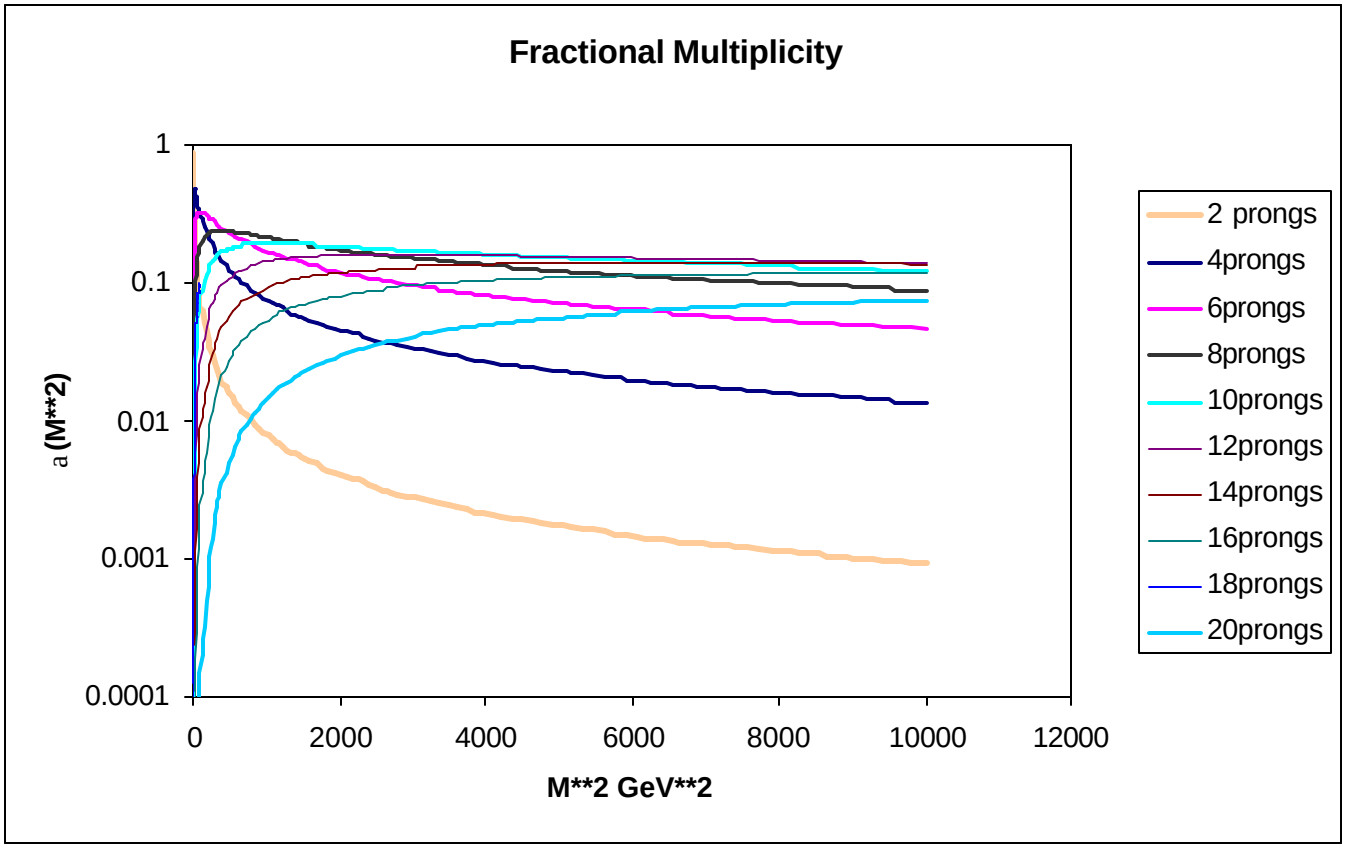
- For instance the functions $\alpha_s(M^2)$ by crossing symmetry must be the same for $\pi^+ p \rightarrow \pi^+ + X$ and $\pi^- p \rightarrow \pi^- + X$.
- Similarly

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

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

Scaling law tests with MIPP

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 $\alpha_{sub}(M^2)$ 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 se 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

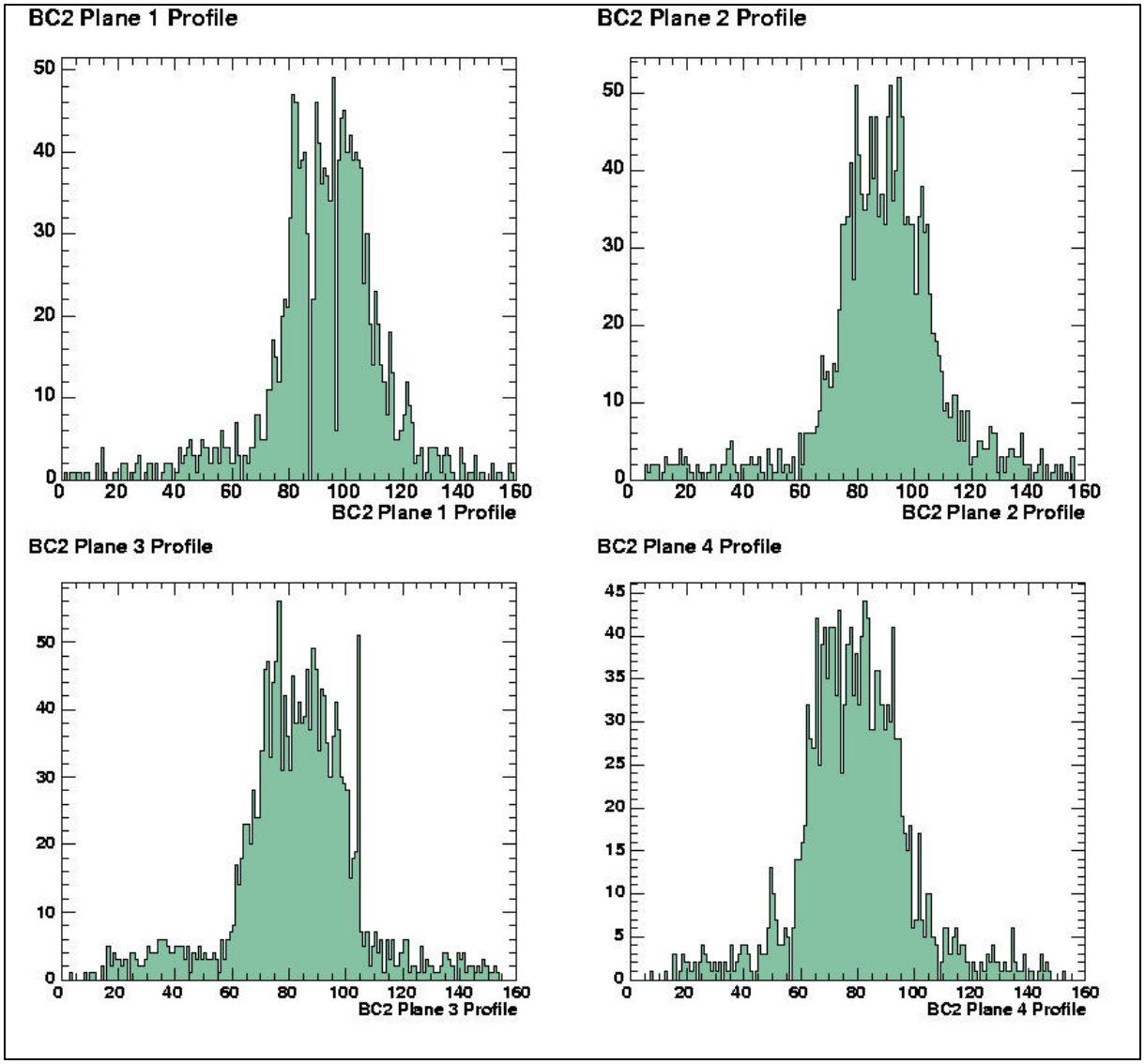
- Implies that the pseudo-resonance states x behave as particles, there is fast equilibrium upon scattering. Argues against independent quark fragmentation in DIS. Argues for promoting the state X to have a structure that varies with M^2. Leads to a new dynamics.
- I believe that if MIPP can establish 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.

MIPP schedule

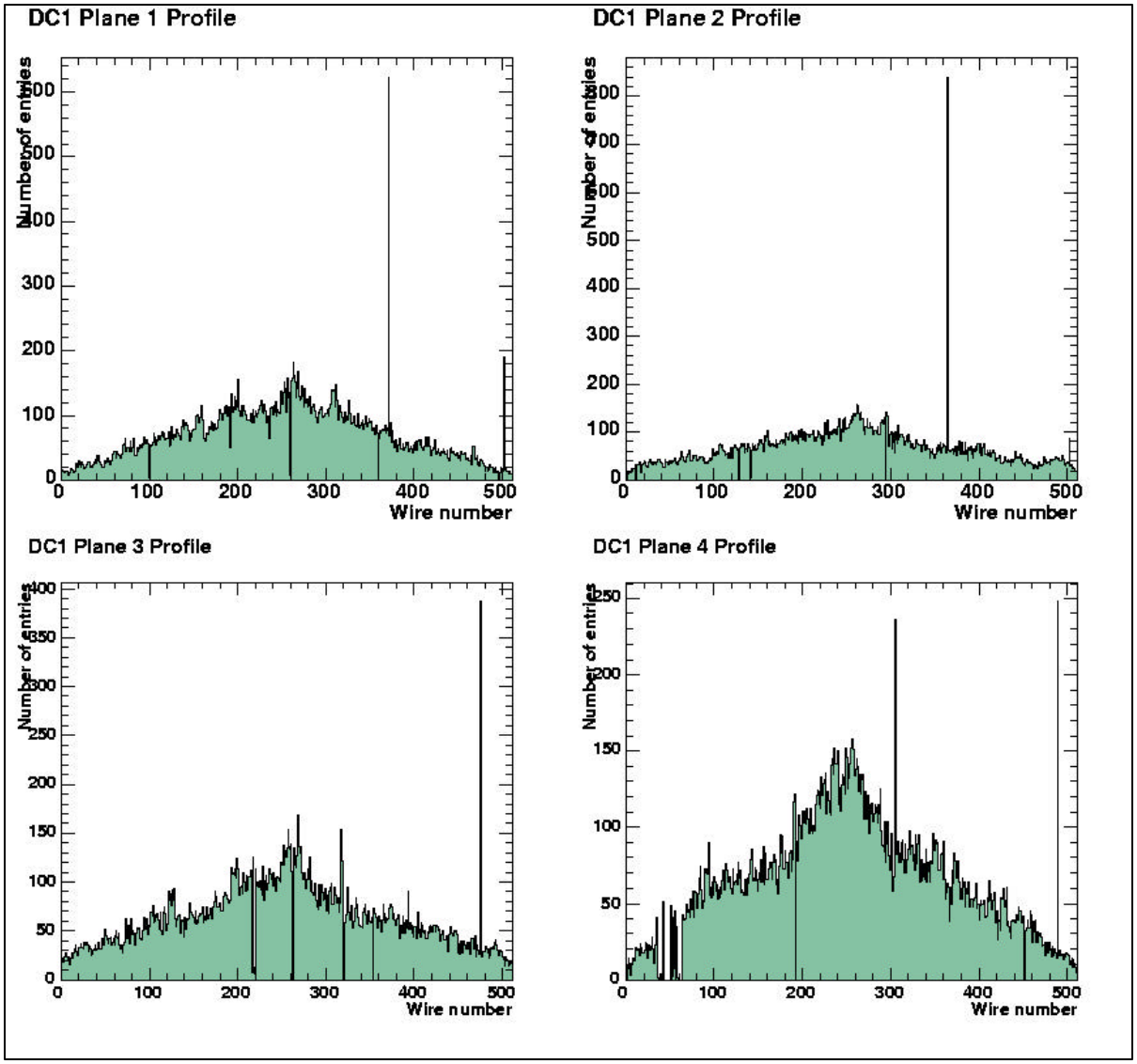
- Just finished engineering run.
- Getting ready to do Physics RUN when shutdown ends.
- Will run till the next shutdown (July 05?).

Will propose upgrade to TPC + DAQ to improve our daq rate by a factor of 20.

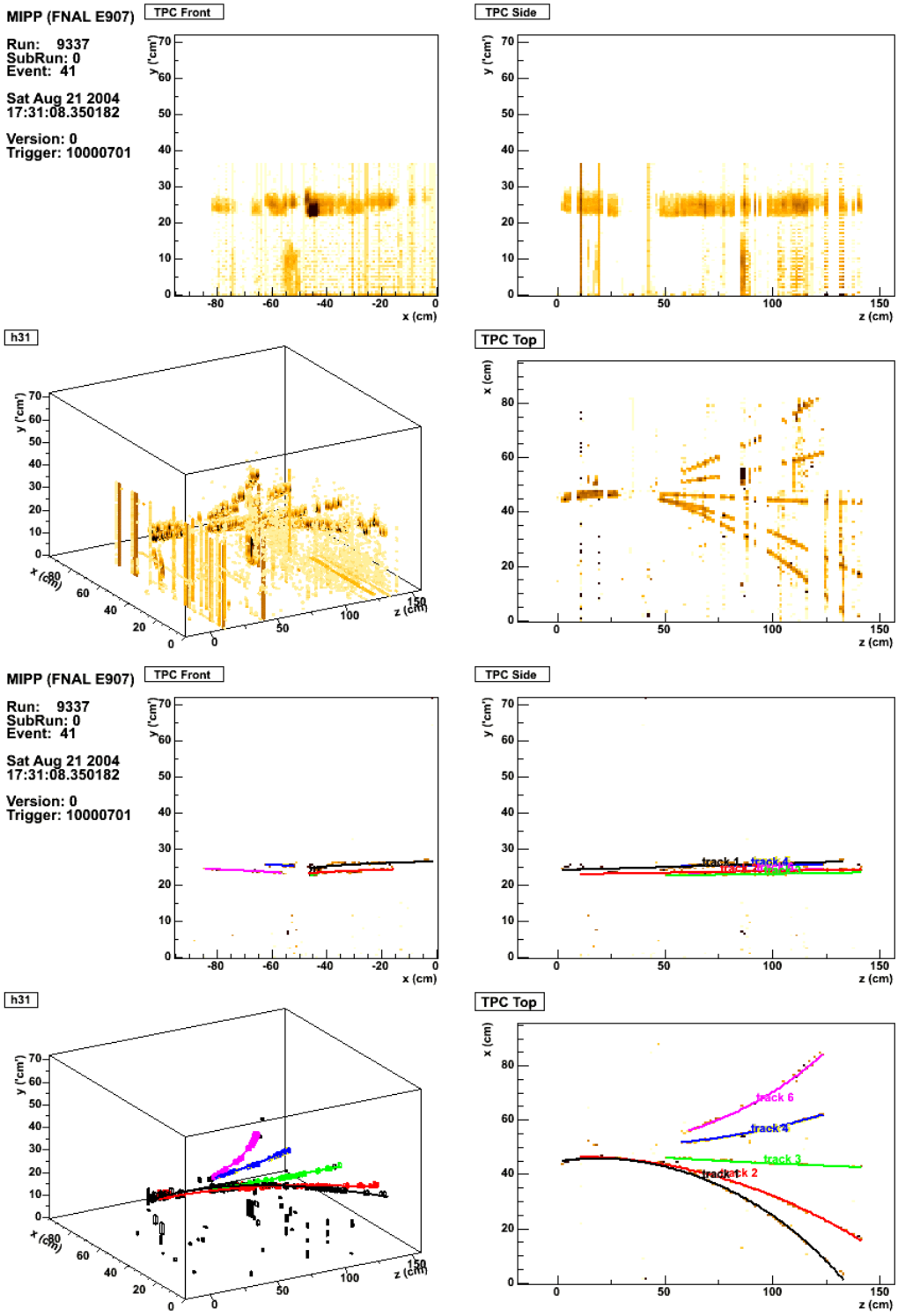
Beam Chamber profiles- BC2

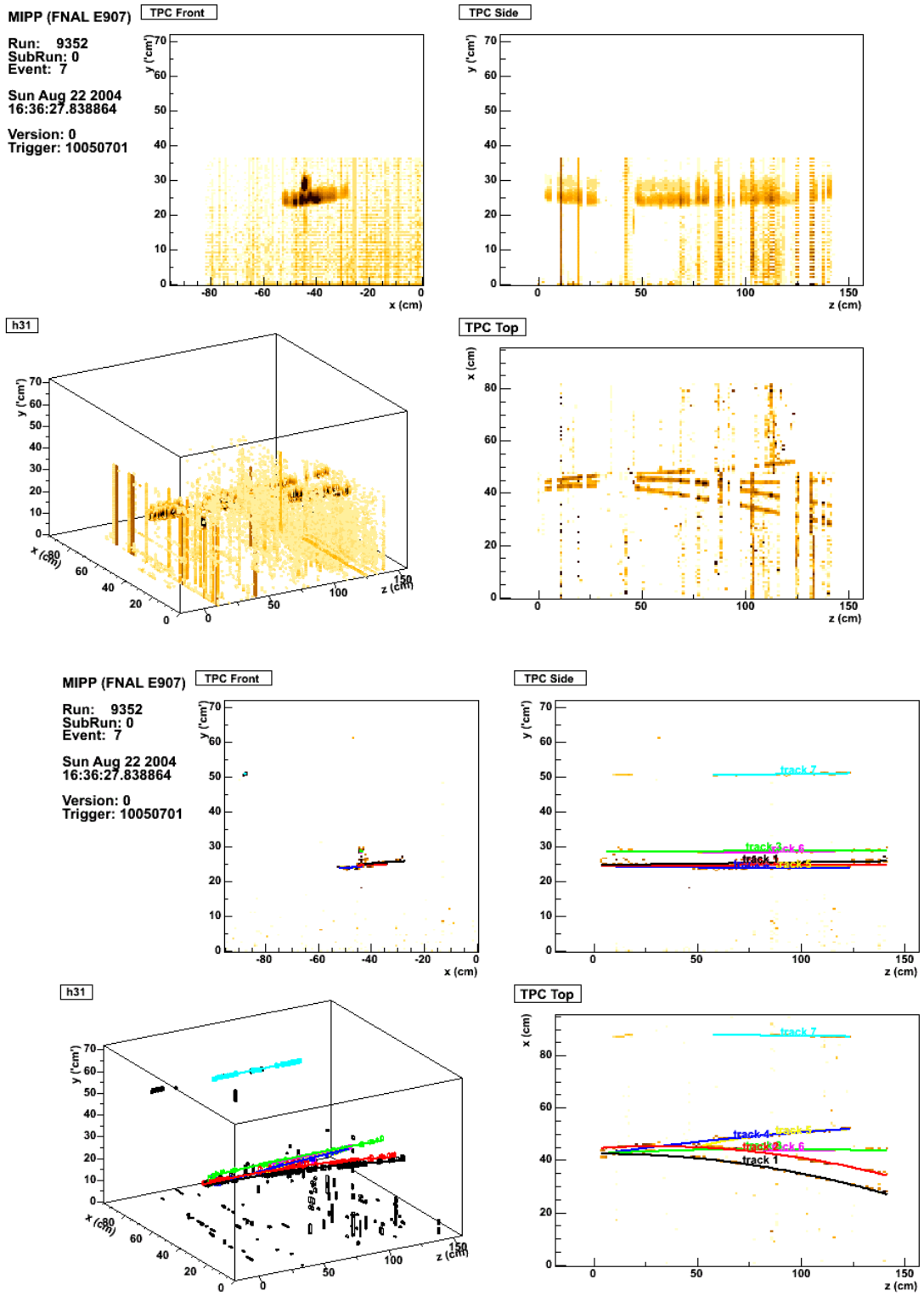


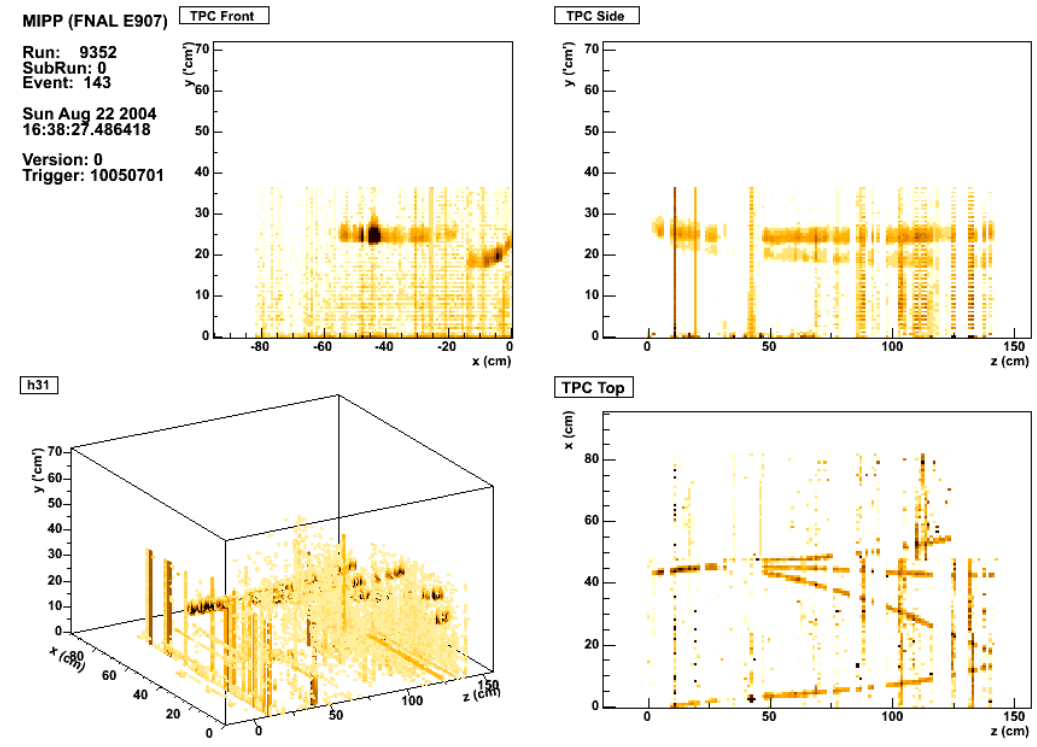
Drift Chamber Profiles- DC1

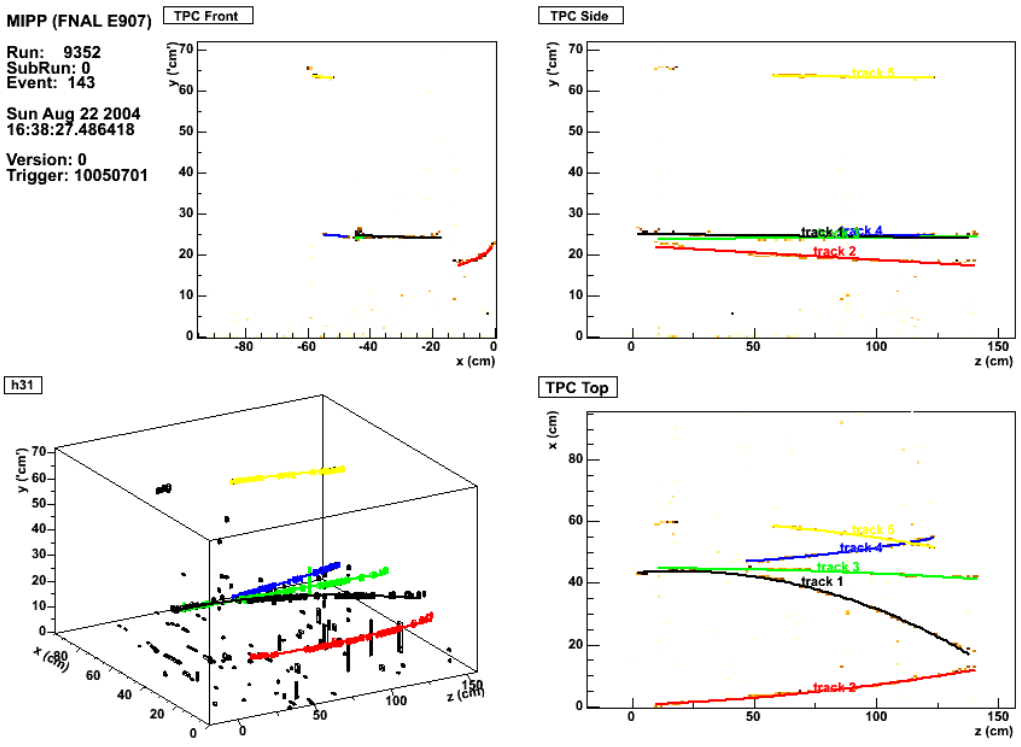


Preliminary results from Engineering run




MIPP (FNAL E907)
Run: 9352
SubRun: 0
Event: 7
Sun Aug 22 2004
16:36:27.838864
Version: 0
Trigger: 10050701
TPC Front
TPC Side
h31
TPC Top
y ('cm')
x (cm)
z (cm)
track 7
track 4
track 3
track 6
track 1


MIPP (FNAL E907)
Run: 9352
SubRun: 0
Event: 143
Sun Aug 22 2004
16:38:27.486418
Version: 0
Trigger: 10050701
TPC Front
TPC Side
h31
TPC Top
y ('cm')
x (cm)
z (cm)

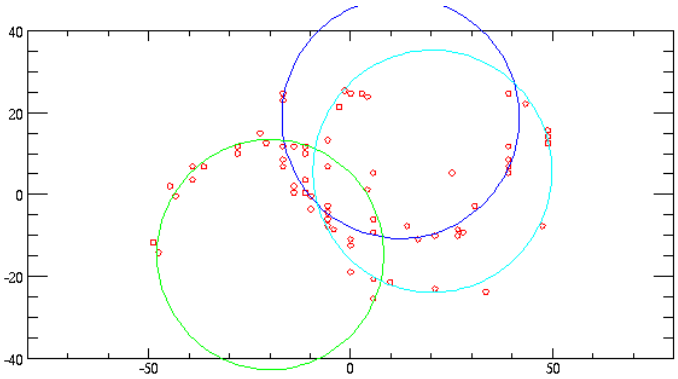

MIPP (FNAL E907)
Run: 9352
SubRun: 0
Event: 143
Sun Aug 22 2004
16:38:27.486418
Version: 0
Trigger: 10050701
TPC Front
TPC Side
track 5
track 4
track 3
track 2
track 1
h31
TPC Top
y ('cm')
x (cm)
z (cm)

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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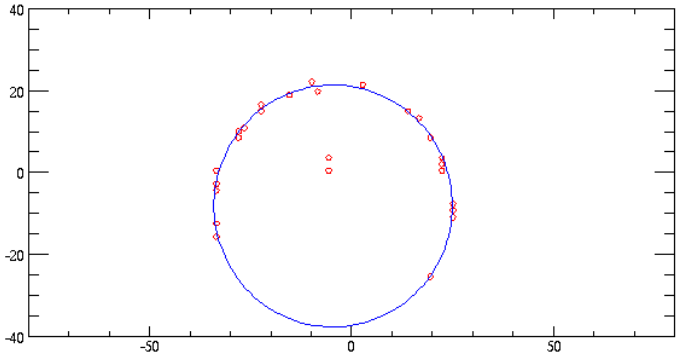
13:53:56.884750

Version: 0
Trigger: 10000008



MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 100

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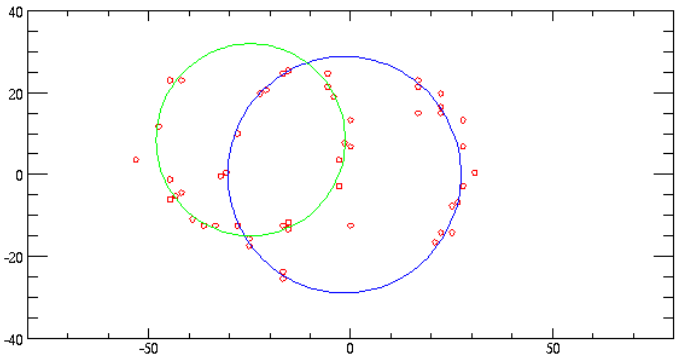
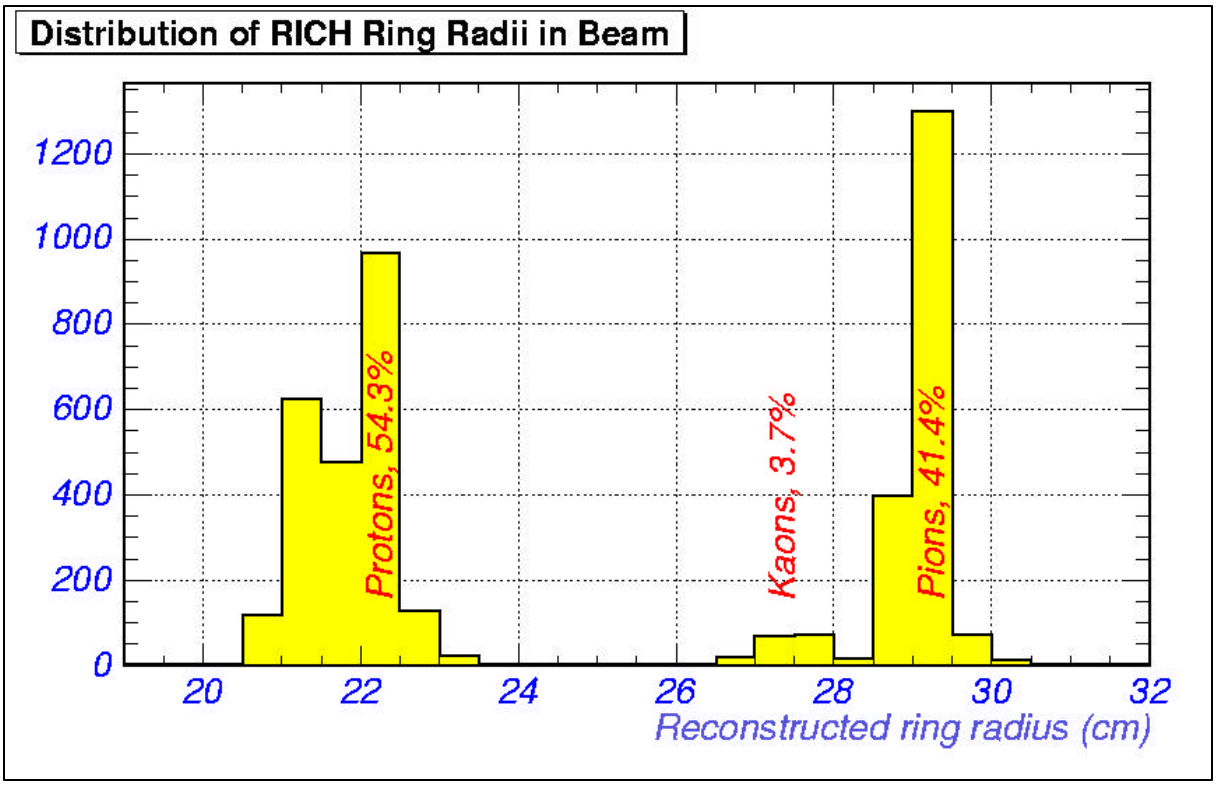
13:54:06.823879

Version: 0
Trigger: 10000008

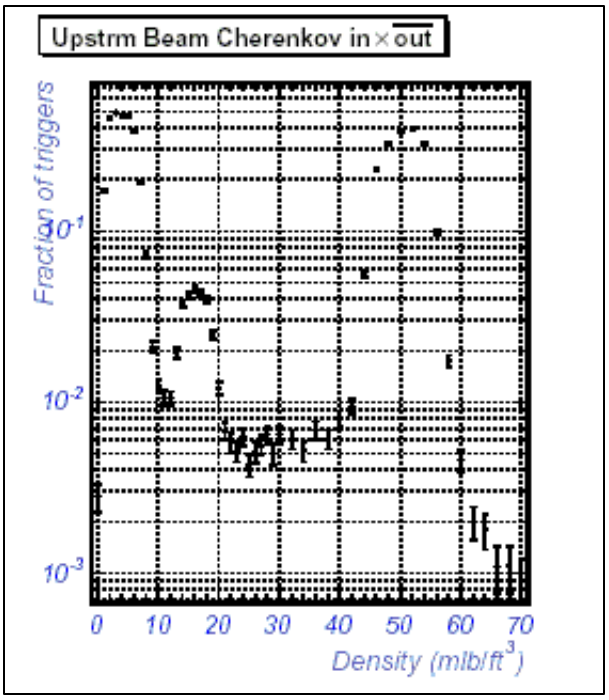


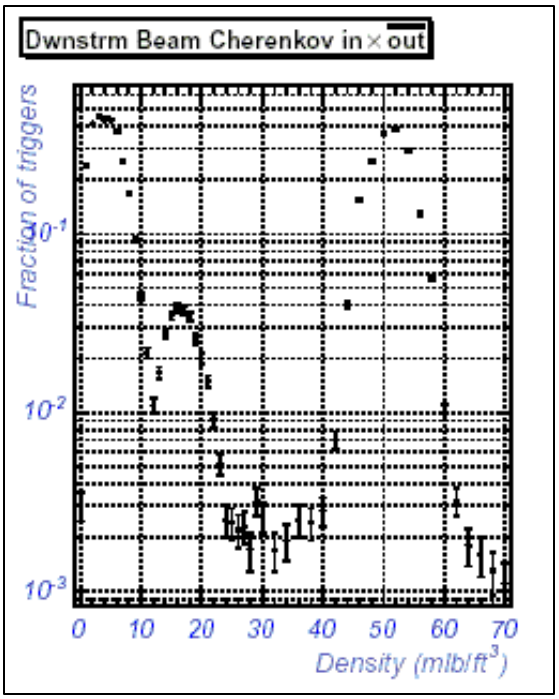
RICH radii for + 40 GeV beam triggers



Beam Cherenkovs

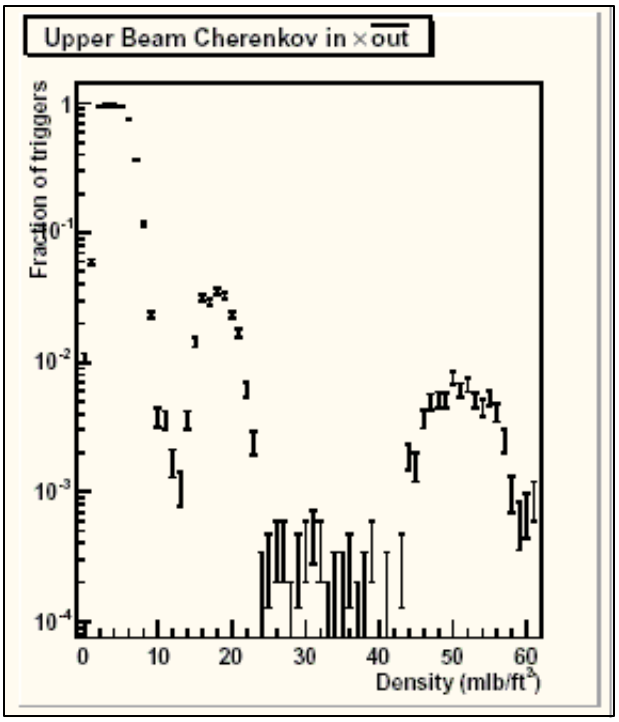
- Pressure curve Automated- Mini-Daq-APACS 30 minutes per pressure curve.+40GeV/c beam.

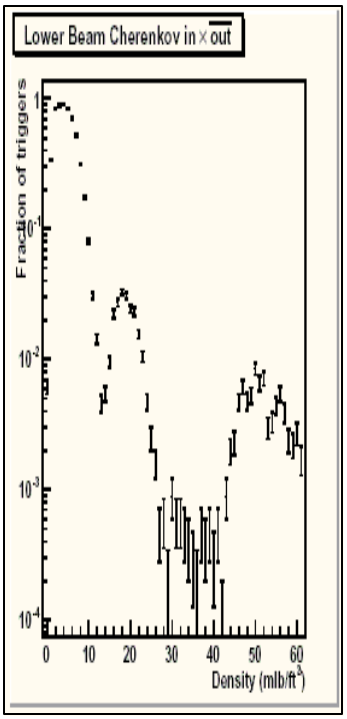




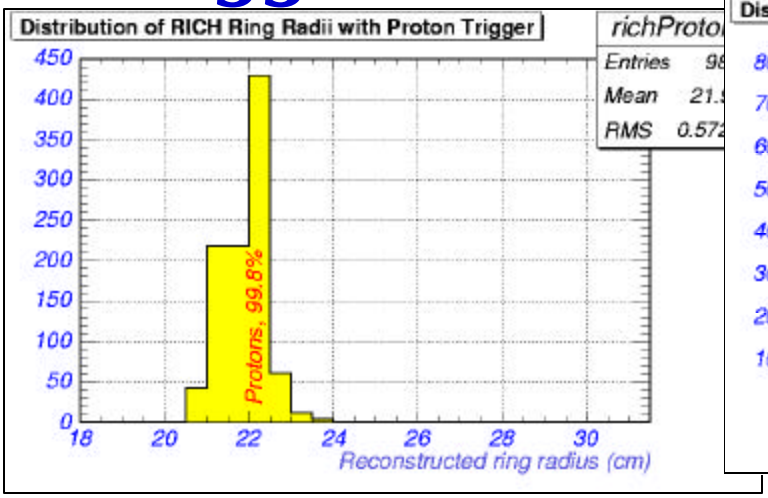
Beam Cherenkovs

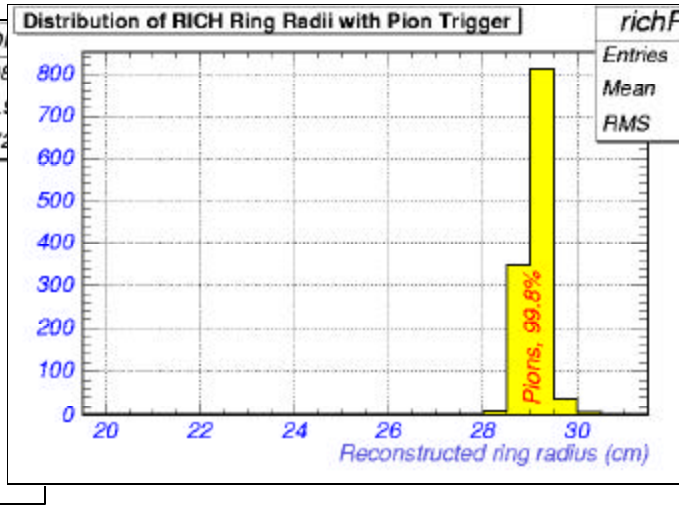
- 40 GeV/c negative beam

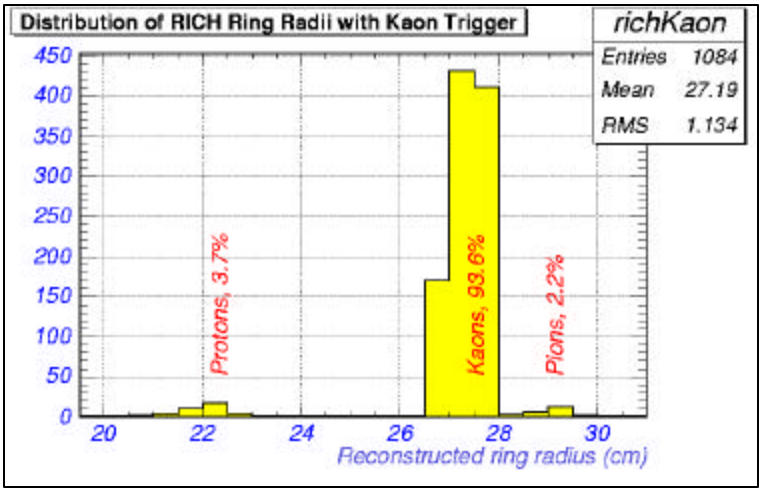




Comparing Beam Cherenkov to RICH for +40 GeV beam triggers-No additional cuts!







Upgrade to the DAQ

TPC Requirements for High Speed Readout

Readout limited to maximum operational frequency of the gating grid.

- High speed, 3kHz, readout requires: Fast digitization and zero suppression of 15,360 channels.
- Maximum single event transaction time $< 300\mu s$ with a design goal $< 200\mu s$ to allow for non-uniformities in trigger rates.
- Will operate in a burst acquisition mode matched to accelerator extraction cycle, 1 second live 125kHz spill w/ 59 seconds interspill.
- The average zero suppressed event size is 115kb, resulting in a total burst data throughput of 575Mb/s. Data volume is split over a minimum of 5 data pathways resulting in 115Mb/s upper limit per primary data branch.

Upgrade plans

TPC Upgrade (Electronics)

The requirements for high speed readout of the TPC are easily achieved by adapting electronics designed for the ALICE TPC.

- ALICE TPC uses a series of custom designed ASICs for the analog and digital front end systems.
- Each "PASA" chip serves as the preamp and shaper for 16 channels.
- Each "ALTRO" chip is a fast ADC, performs baseline correction, zero suppression, limited event buffering.
- A single front end card incorporates 8 PASA and 8 ALTRO combinations to instrument 128 channels.
- There are 120 front end cards required for the re-instrumentation of the TPC, totaling 960 of each chip.
- The Jan '05 production run for ALICE and BONUS is estimated to have $\approx$ 1050 extra chips which would be available for an upgrade.

TPC Upgrade (Readout/Data Handling)

- Data extraction path is modeled after ALICE and BONUS
- Readout Control Units (RCU) developed at CERN service blocks of 12 front end cards and provide an interface to standard high speed buses. (e.g. S-Link64 at 800Mb/s)
- Data volume prior to filtering is estimated at 0.86 Tbytes/day
- Preliminary work has begun on adapting the front end boards to match the physical geometry of the current E907 TPC electronics.
- New front end electronics and readout boards could be ready for installation as early as Sept '05.

General Spectrometer Readout at 3kHz

System wide 3kHz acquisition rates requires minor modifications:

- All systems must digitize and store an event in $< 200\mu s$.
- VME Dual port memory units (FIFOs) buffer a full spill of data (3000 events) on a detector by detector basis.
- Slow systems (TDC banks) are split on crate boundaries to independent buffers and readout branches.
- Single board VME computers flush FIFOs on the interspill and off load data packets to event building queues.
- Allows an average 19ms per event for event building and filtering when using a single pipeline.
- Multi-pipeline (parallel) event event processing is available via additional single board computers.