The Main Injector Particle Production Experiment at Fermilab

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DOE Annual Program Review
17 May 2006

MIPP Experiment · Brief Overview

- Approved in November 2001, installed in Meson Center MC7,
  14 months physics run ended in Februrary 2006
- Use 120 GeV/c Main Injector protons to produce
  · secondary beams of $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ from 5 GeV/c to 90 GeV/c
  · 120 GeV/c proton beam
- Measure particle production cross sections on fixed targets
  · various nuclei including hydrogen and the NuMI target
- Momenta of ~all charged particles measured with TPC and tracking chambers.
  Particle identification with dE/dx, ToF, differential Cherenkov, and RICH technologies.
  Open Geometry · Lower systematics & Higher statistics than existing data.

MIPP Collaboration

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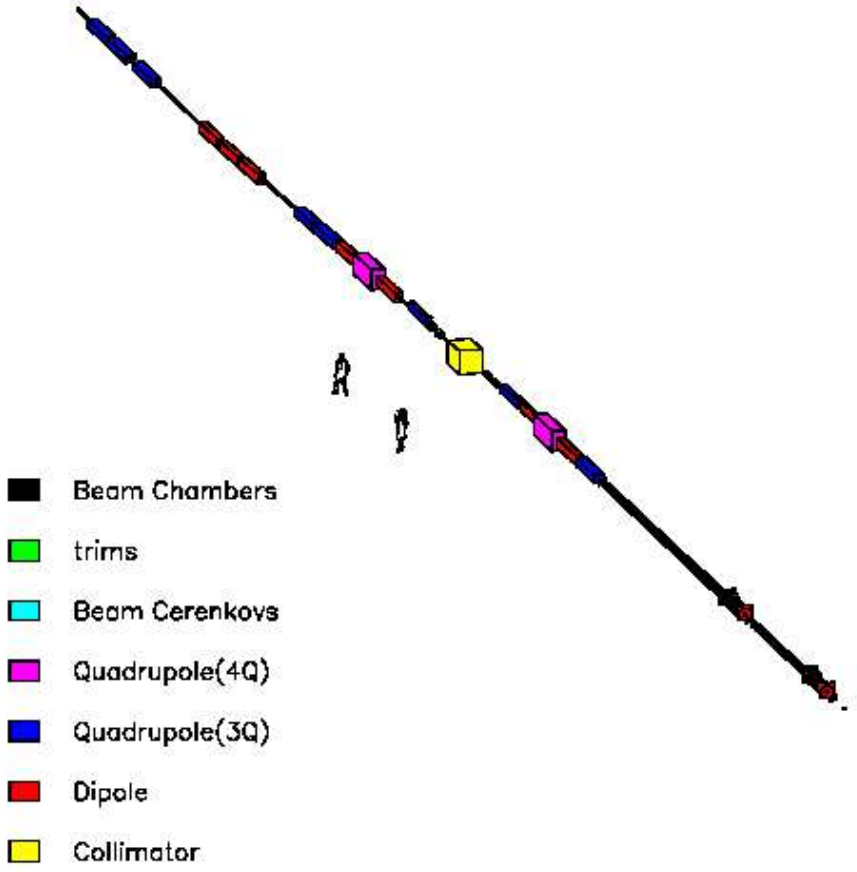
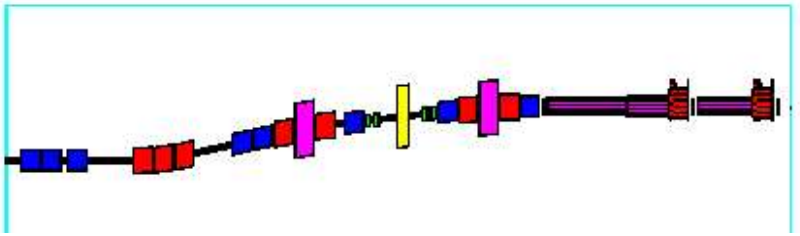
MIPP

MIPP Secondary Beam

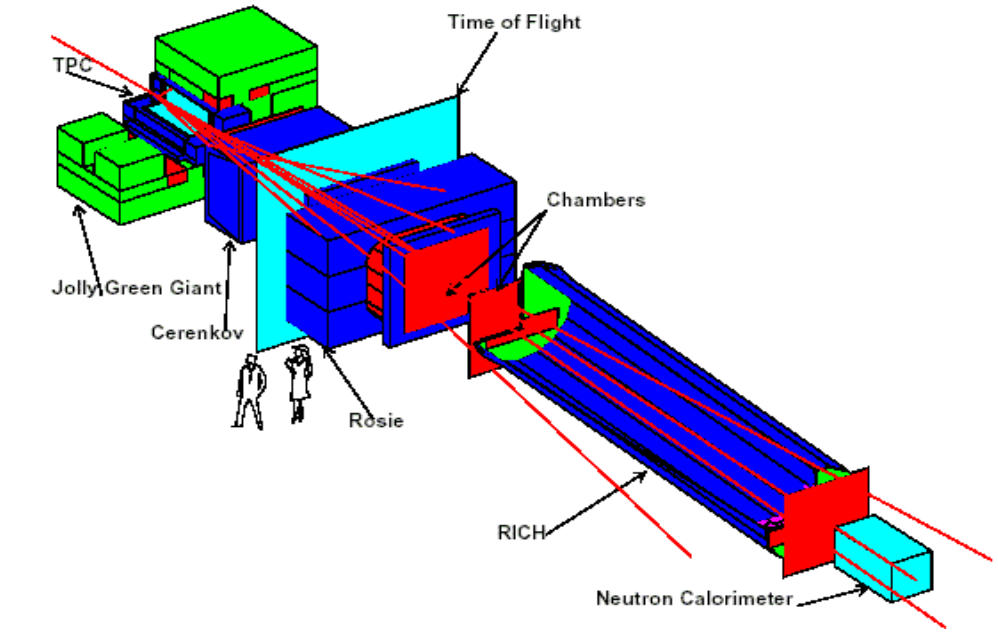
Installed in 2003. Delivered slow spill commissioning beam since February 2004. Finished Engineering run in Aug 2004.



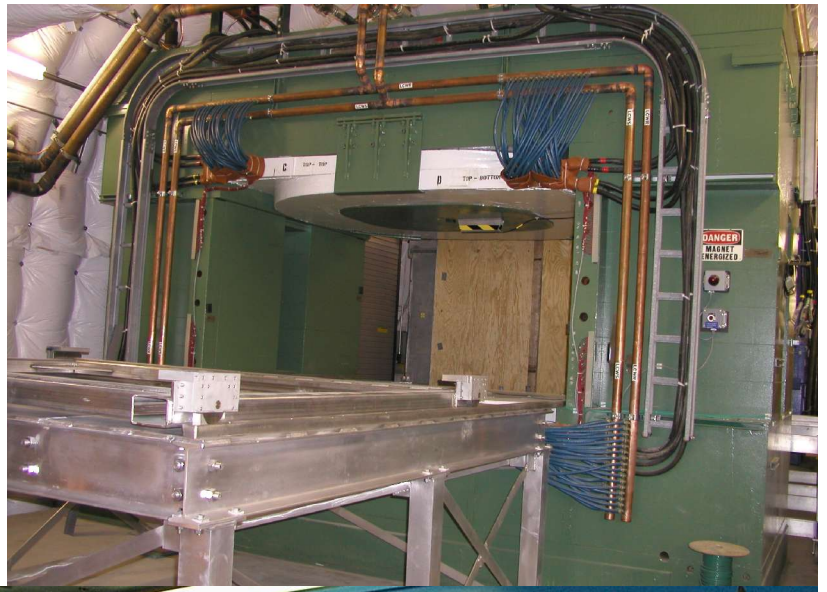


TPC

MIPP Detector · Tracking

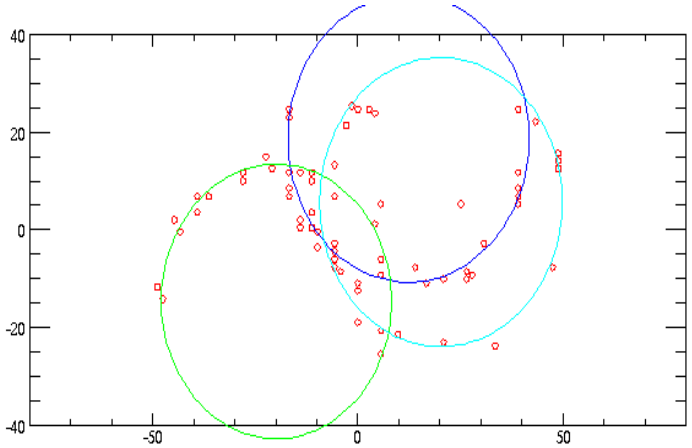


JGG



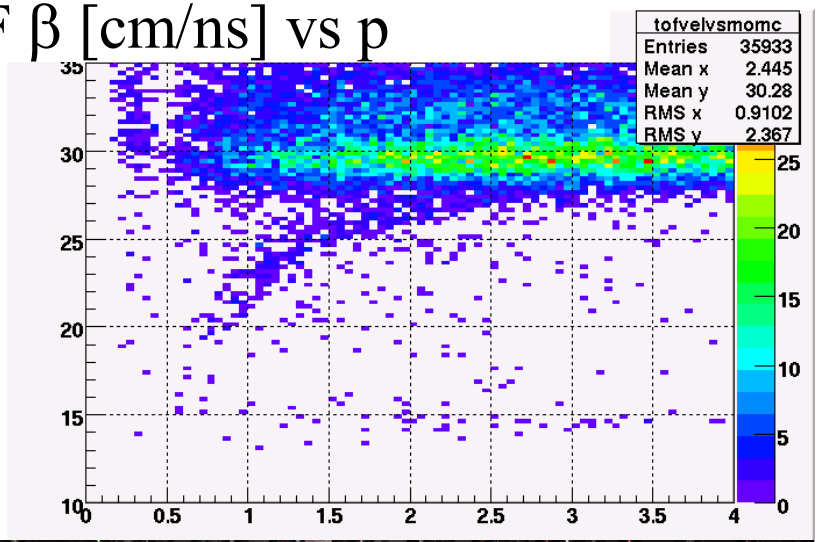
TPC

MIPP Detector · Particle ID



RICH rings and vessel

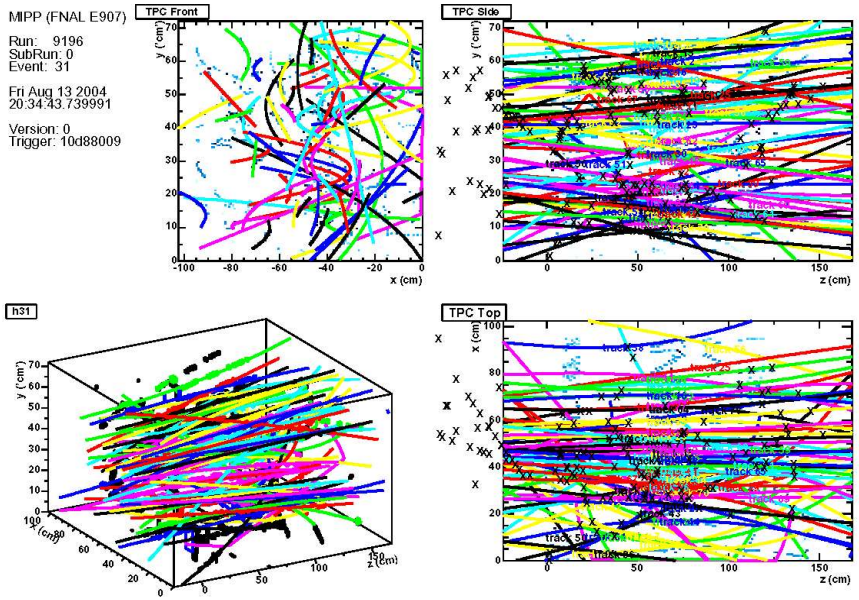
ToF β [cm/ns] vs p



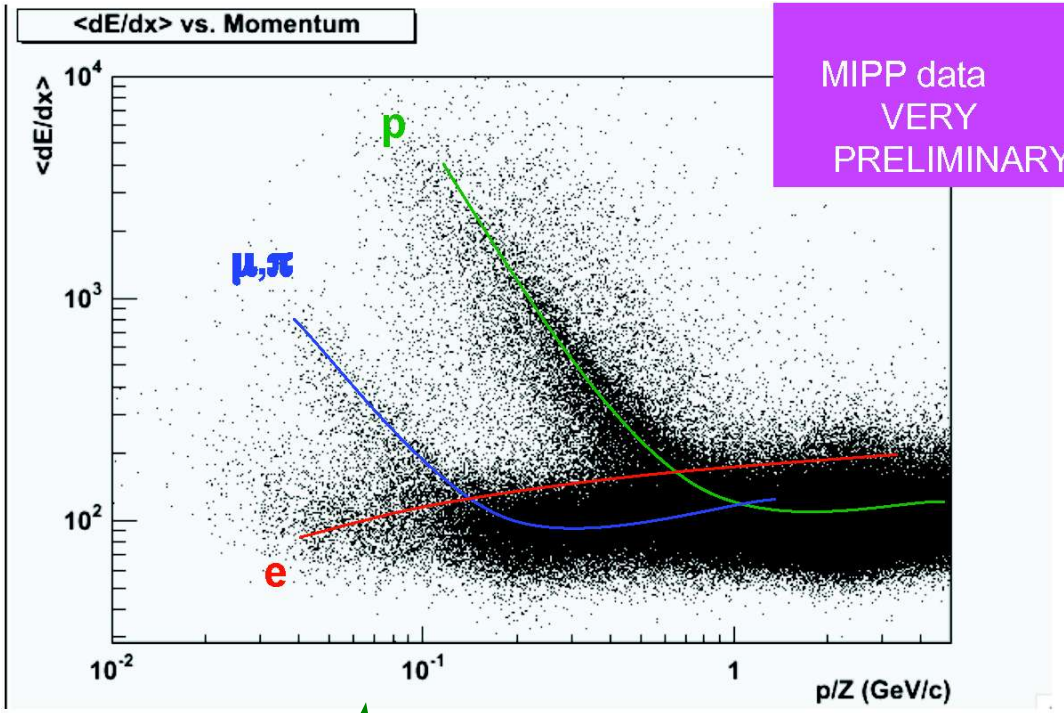
Segmented threshold Ckov

MIPP Detector · TPC

TPC originates at BEVALAC group at LBL, then BNL-E910
- currently limiting DAQ to 60Hz (1990's electronics)
- drift time is 16 μs



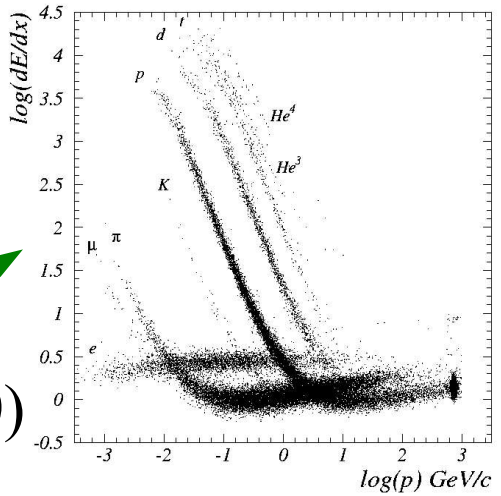
All tracks are reconstructed
- even in bad events



TPC dE/dx:

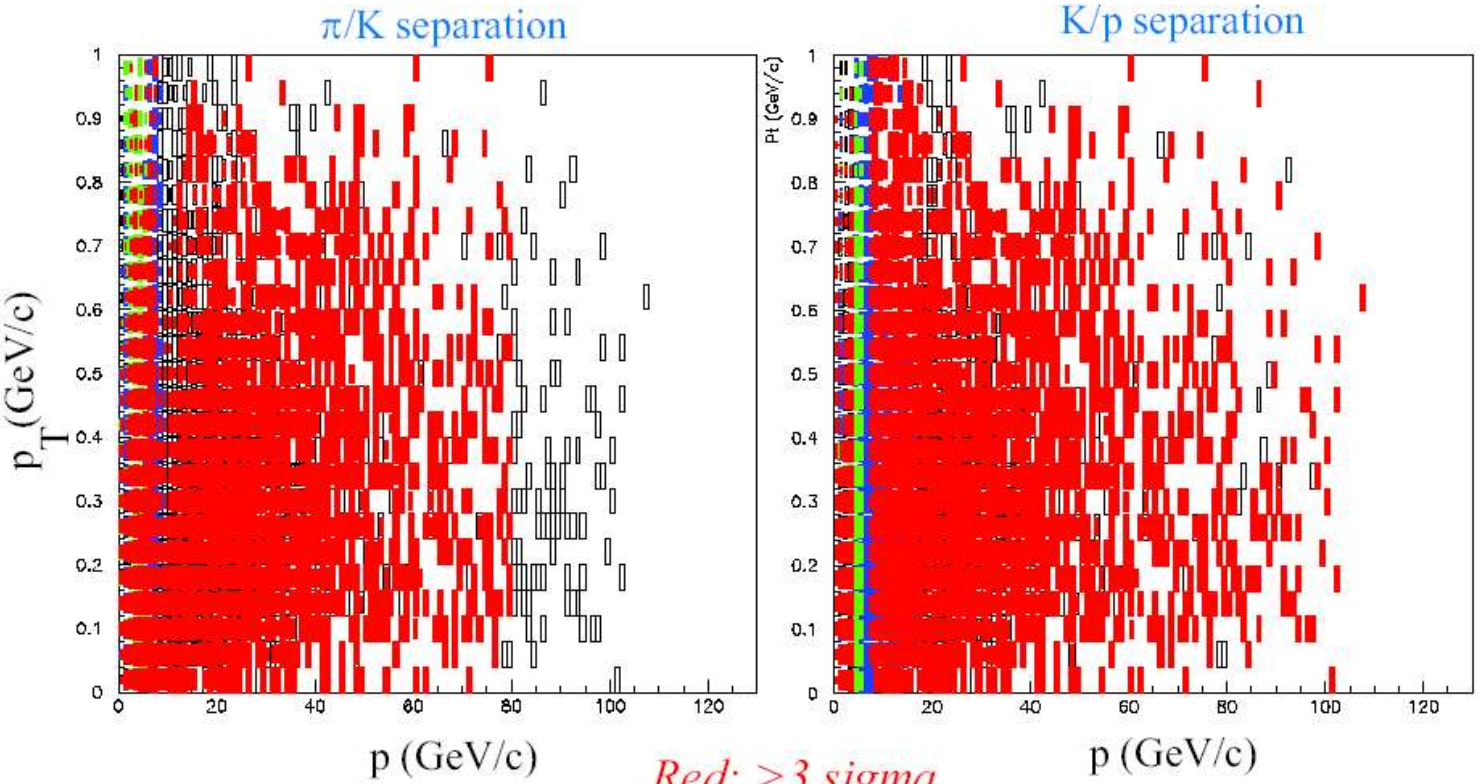
- MIPP first pass

- final capability (from BNL-E910)



MIPP Particle ID

Particle ID Performance



Red: >3 sigma
Green: 2-3 sigma
Blue: 1-2 sigma
White: <1 sigma

MIPP Physics

- 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
  - Charged Kaon mass measurement
- Nuclear Physics
  - Investigate strangeness production in nuclei
  - 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 and Calorimetry
  - Proton Radiography· Stockpile Stewardship- National Security
  - MINOS target · pion production measurements to control the near/far systematics
- Will make DSTs available for the public on DVDs 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 $^{\pm}$

MIPP Data Set

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

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

- 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.

General scaling law of particle fragmentation

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

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

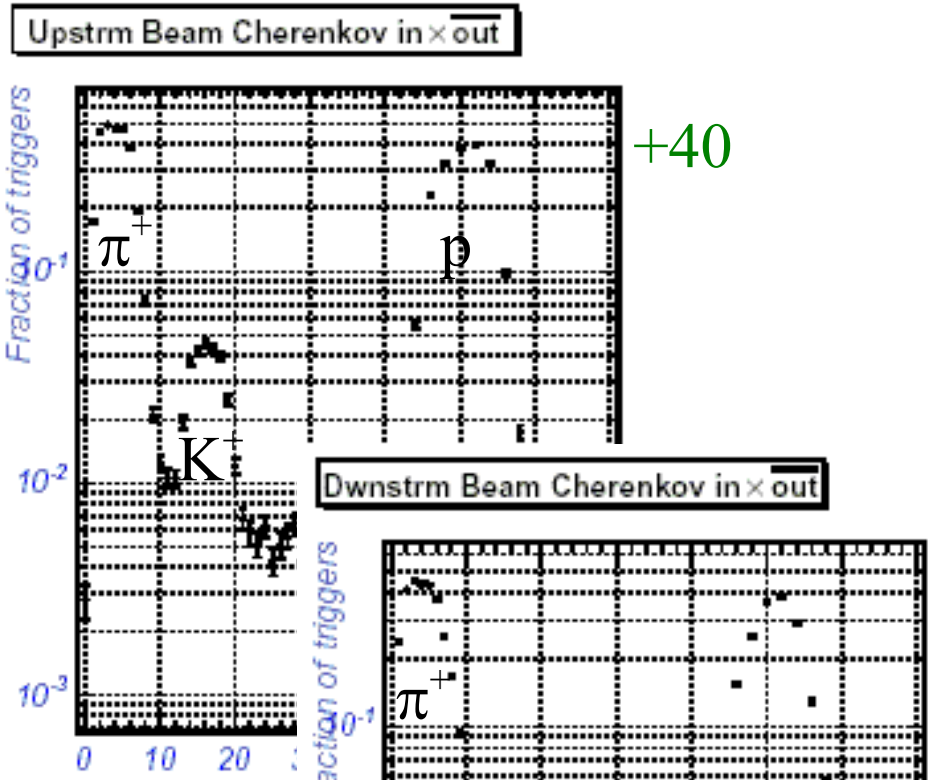
- where M^2, s and t are the Mandelstam variables for the missing mass squared, CMS energy squared and the momentum transfer squared between the particles a and c. PRD18(1978)204.
- Using EHS data, we have tested and verified the law in 12 reactions (DPF92) but only at fixed s.
- MIPP will test the law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

Summary

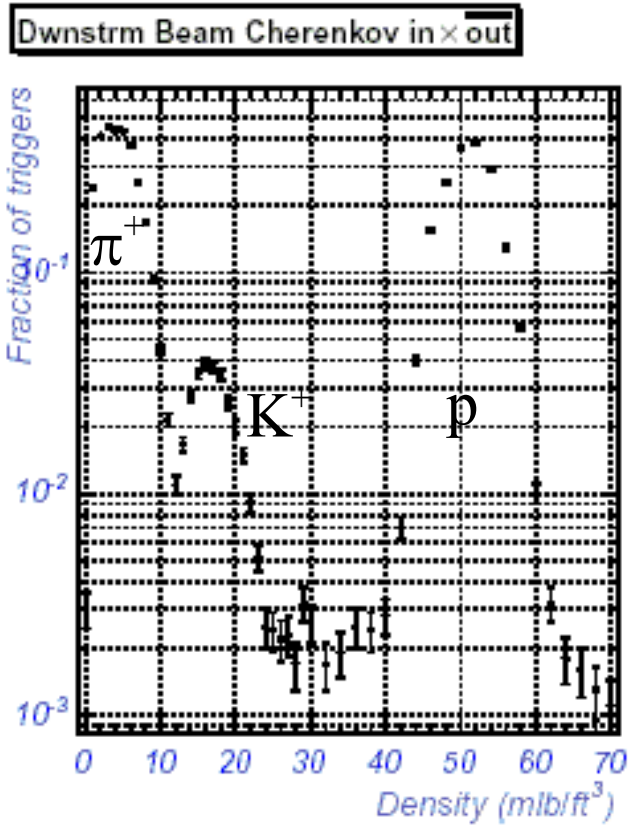
- MIPP finished taking data in February 2006.
  Data analysis is in progress and first results are expected soon.
- A future run (if approved) will improve statistics and physics reach further.
- MIPP is a very versatile experiment.
  - Interesting physics on its own
  - MIPP data is an important input for *many* other experiments
    - Atmospheric Neutrinos & Cosmic Rays: PIERRE AUGER, ICE CUBE
    - CDF/D0, CMS/Atlas (hadronic energy scale)
    - MINOS/MINERνA/NOνA, Super K/Hyper K (neutrino spectra)
    - CALICE (hadronic energy scale/resolutions)

Backup Slides

Beam Cherenkov Pressure Curves



+40



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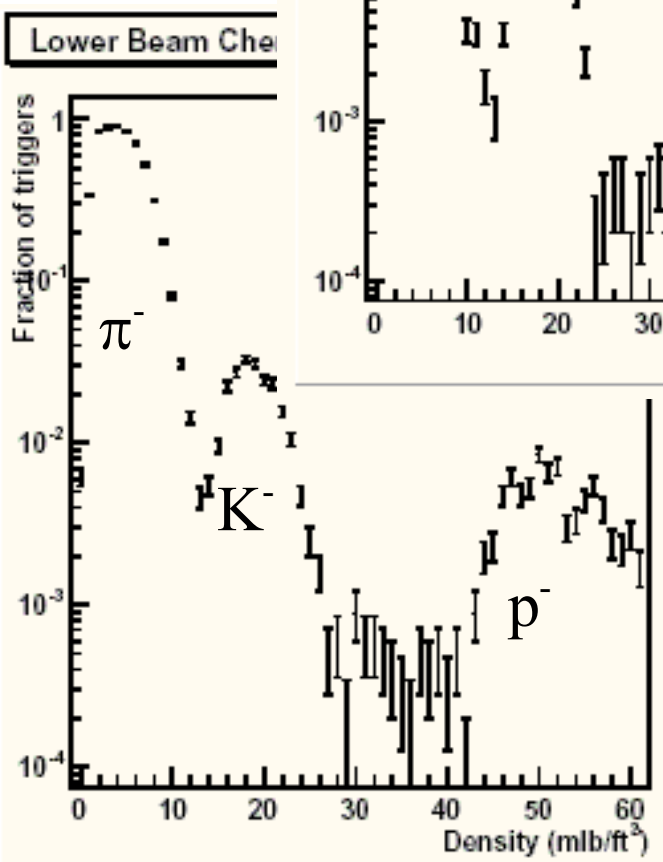
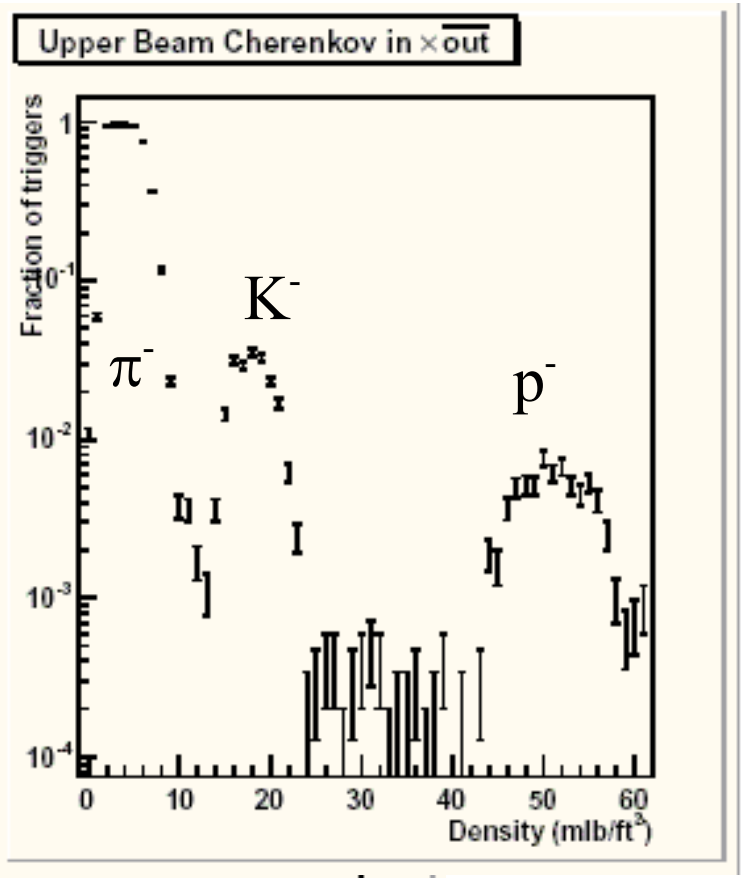
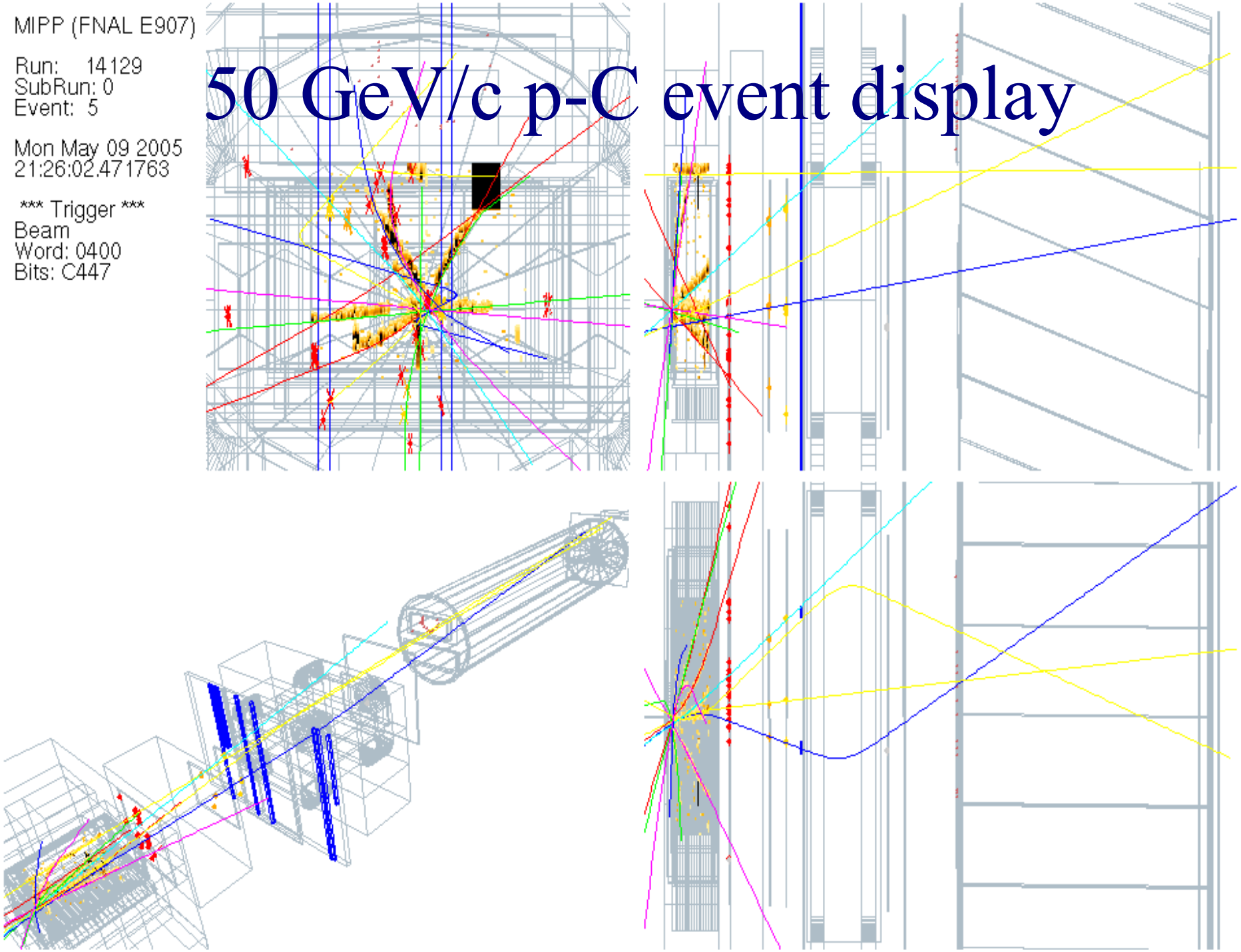


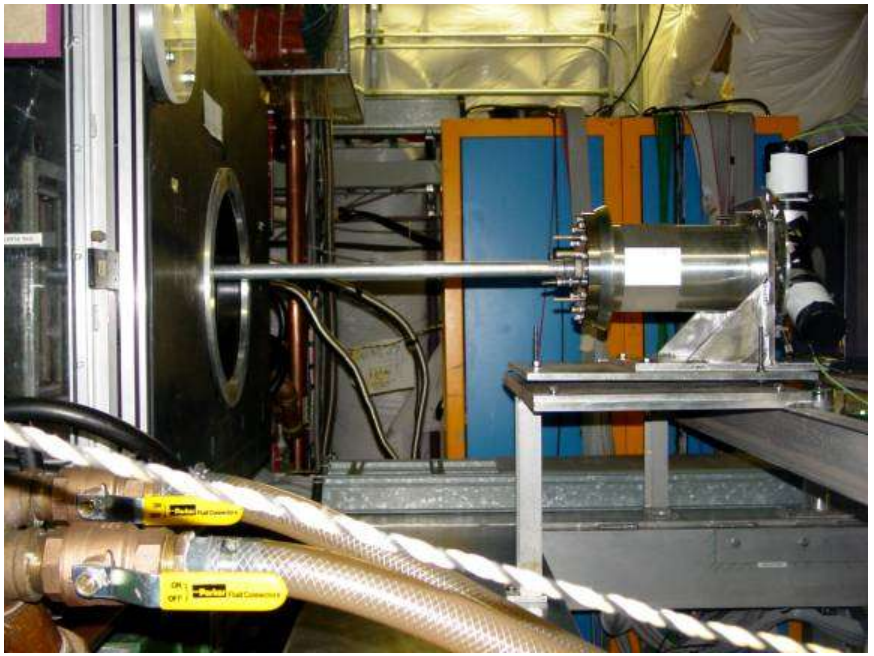


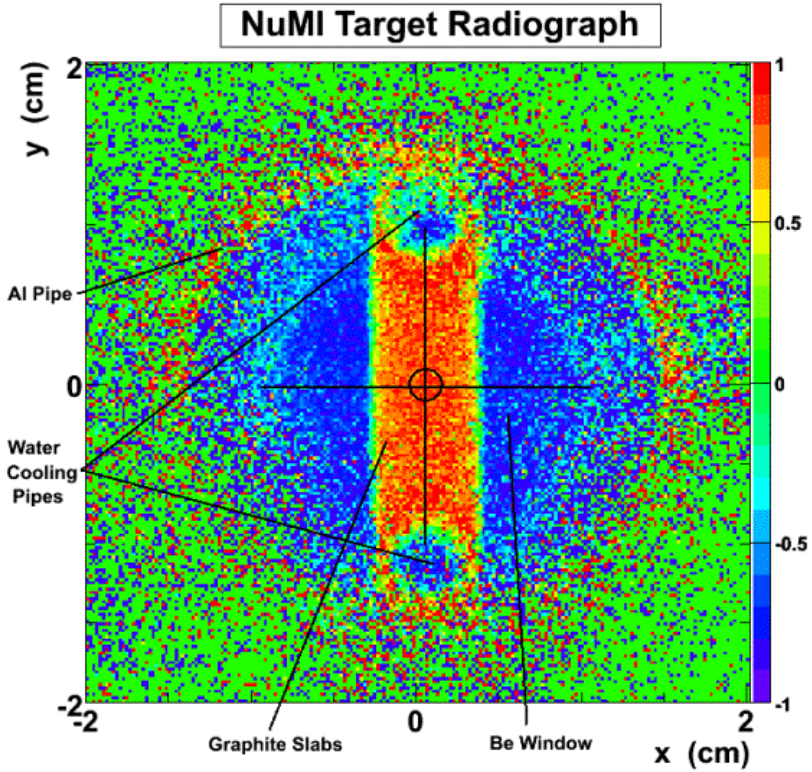
MIPP

50 GeV/c p-C event display



NuMI target in MIPP





First look at NuMI target data

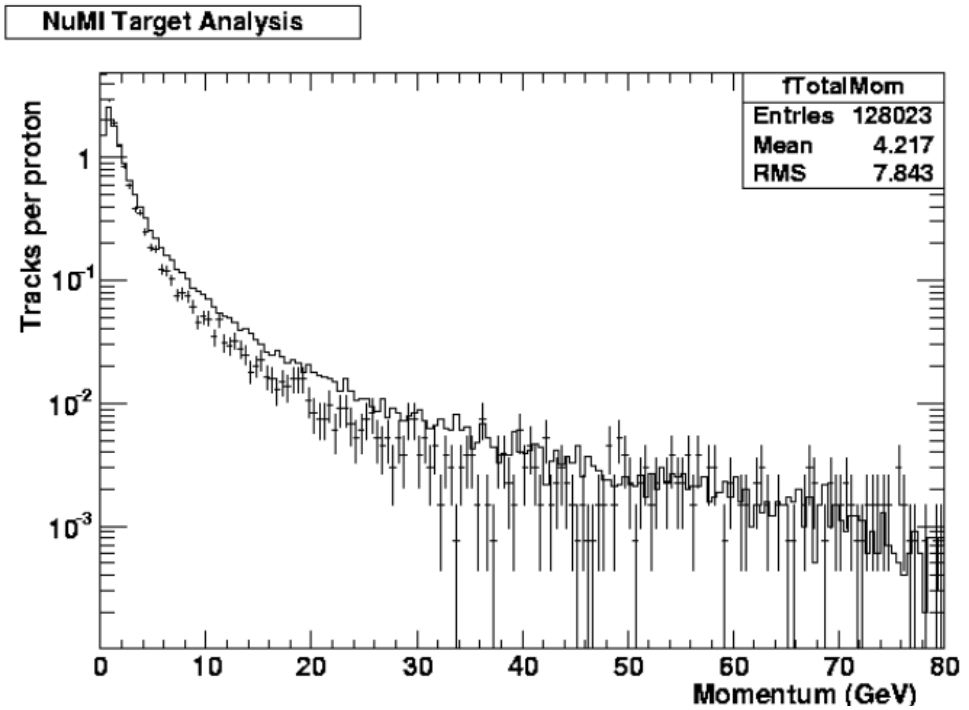
Very preliminary

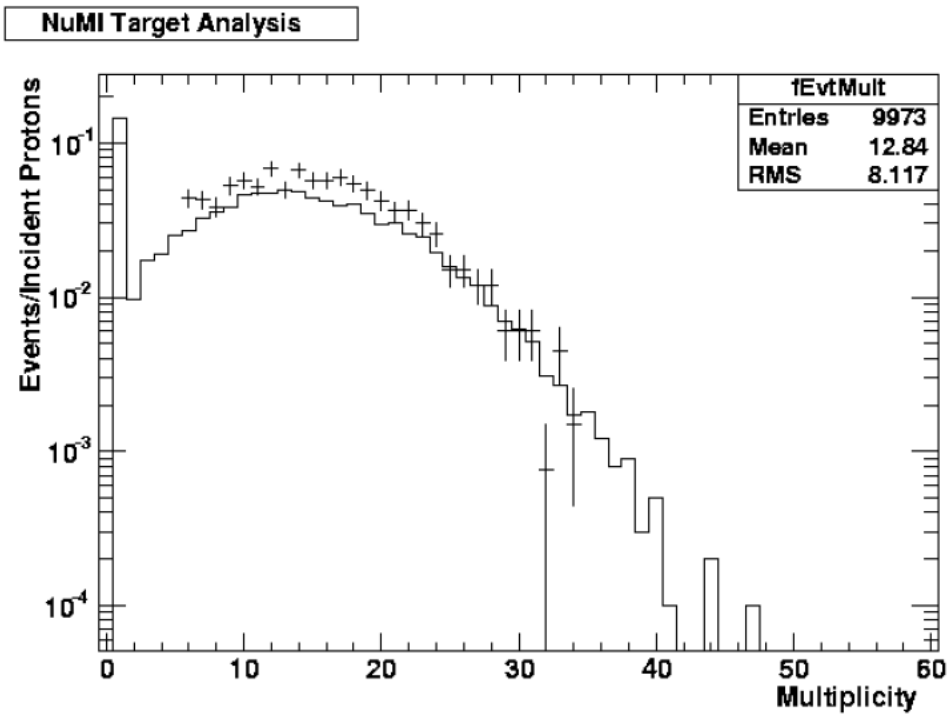
Based on fast TPC-only helix fits

Comparisons are to FLUKA Monte Carlo

Top: Multiplicity distribution

Bottom: Momentum distribution





Charged Kaon Mass in MIPP

- RICH ring radius of tagged π, K, p beam particles measures K mass relative to well know masses of π, p.
- With higher statistics this could resolve the disagreement between existing measurements, see PDG. Important for V_{US}.

The main disagreement is between the two most recent and precise results,

$$m_{K^\pm} = 493.696 \pm 0.007 \text{ MeV} \quad \text{DENISOV 91}$$

$$m_{K^\pm} = 493.636 \pm 0.011 \text{ MeV (S = 1.5)} \quad \text{GALL 88}$$

$$\text{Average} = 493.679 \pm 0.006 \text{ MeV}$$

$$\chi^2 = 21.2 \text{ for 1 D.F., Prob. } = 0.0004\% , \quad (3)$$

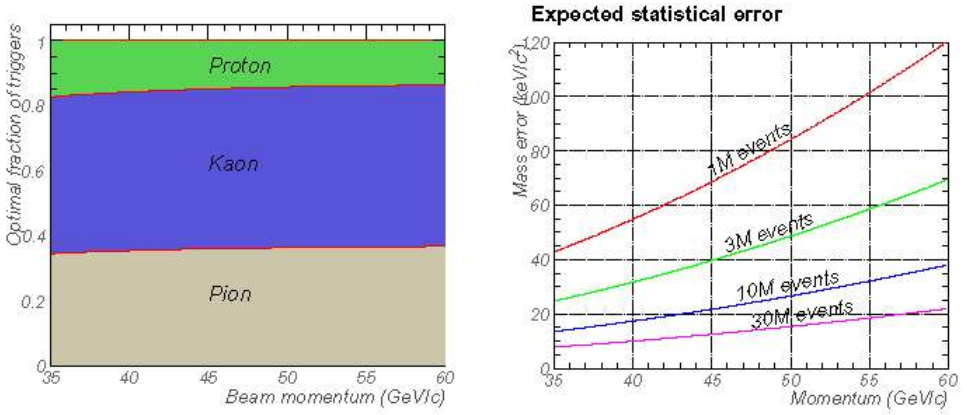
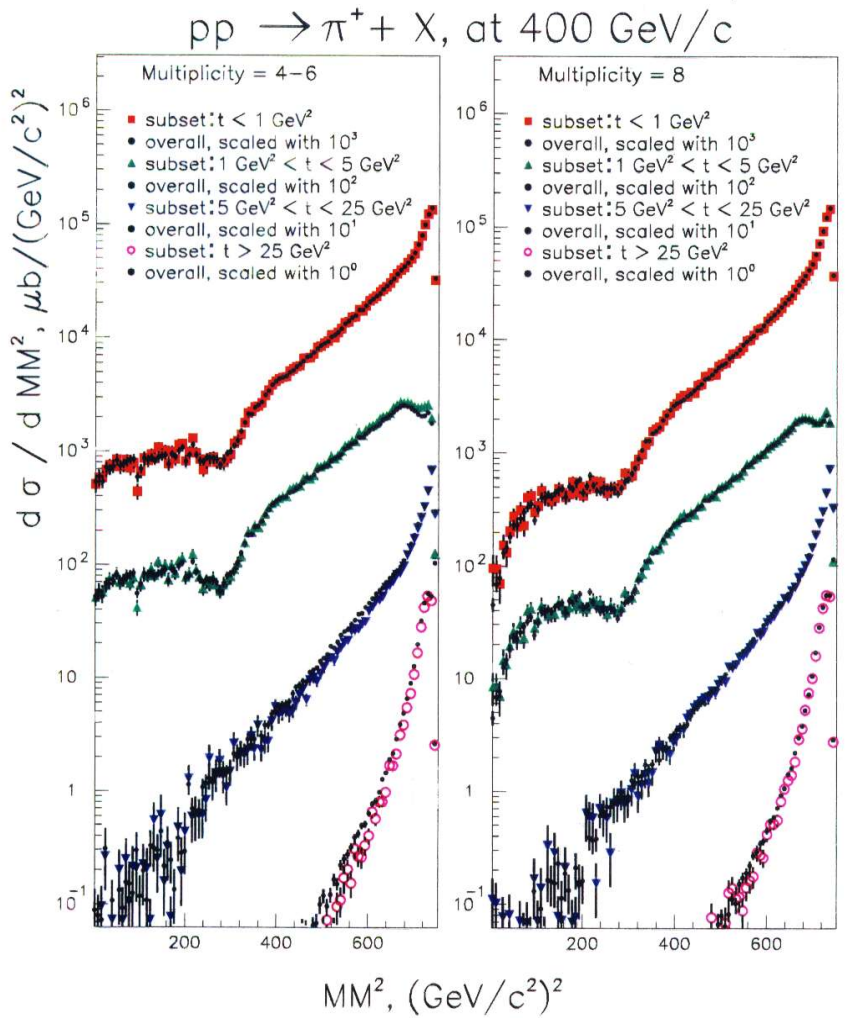


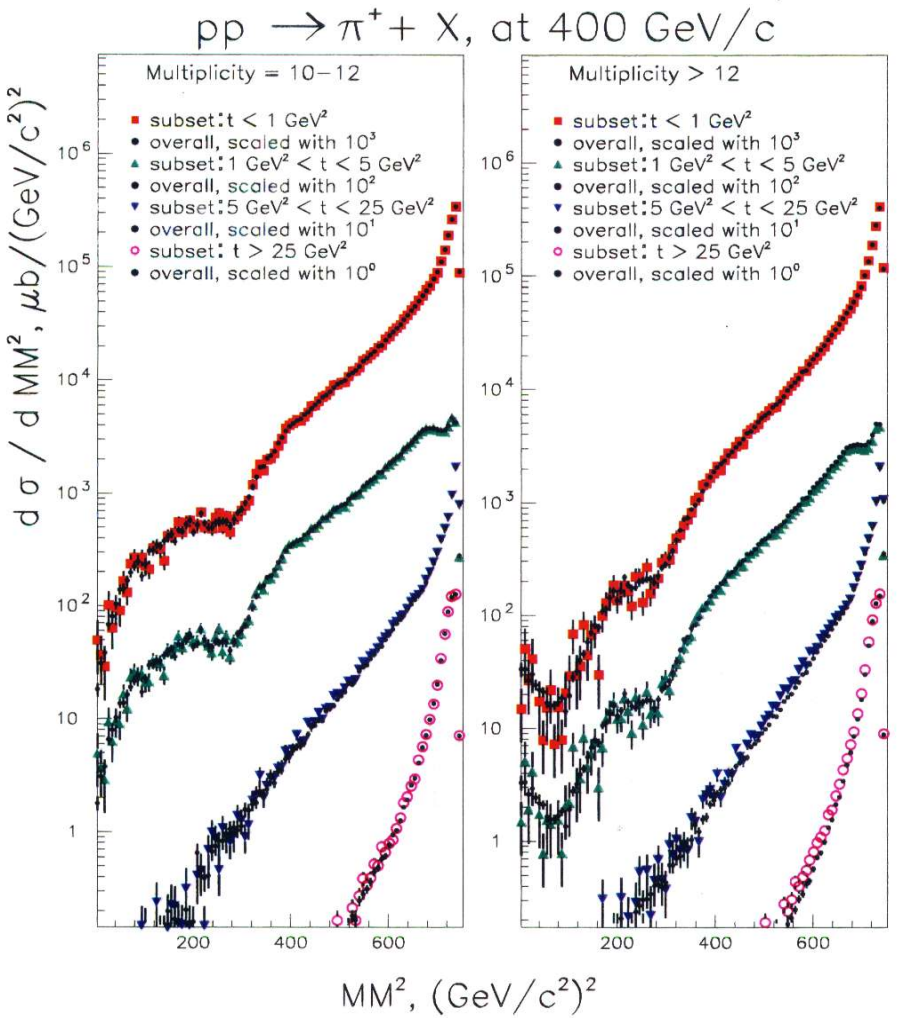
Figure 1: Optimal fraction of pion, kaon, and proton triggers (left), and expected statistical error for different total number of triggers, assuming optimal distribution of events in the sample (right).

Data taken for Kaon mass

Momentum	Magnets	Number of beam spills	Number of events
-60	Off	3203	2701458
37.5	Off	1114	1687073
40	Off	2146	2884920
42.5	Off	618	911701
56	On	460	497633
59	Off	2017	2735482
59	On	673	738983
60	On	940	1212856
63	On	847	957474
Total:		12018	**14327580**

Particle fragmentation scaling law · EHS results





Simulation of cosmic ray showers · Existing data is sparse

C. Meurer et al.

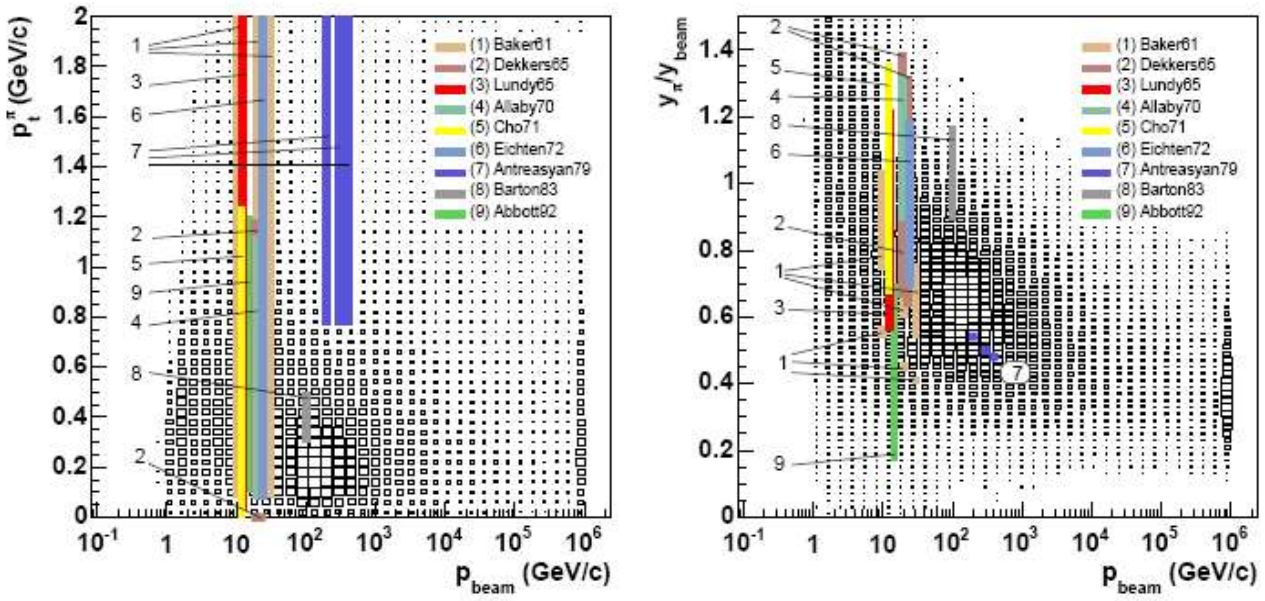


Fig. 9. Compilation of the phase space regions covered by fixed target data given in transverse momentum and rapidity of secondary particles and the phase space regions covered by the $\theta - p_{sec}$ data (see Fig. 8), whereas an approximate conversion of the covered phase space has been done. Left panel: transverse momentum of secondary pions vs. total momentum of proton projectiles. Right panel: rapidity of secondary pions normalized by the beam rapidity vs. beam momentum.