

*Proposal to measure particle
production in the Meson area using
Main Injector primary and secondary
beams P-907*

Rajendran Raja

Fermilab

NUFACT00, Monterey, May 2000

P-907 collaboration updated list

Y. Fisyak,

Brookhaven National Laboratory

A.Godley,S.R.Mishra, C.Rosenfeld,

University of South Carolina

R. Winston,

EFI, University of Chicago

E.Swallow,

Elmhurst College and EFI

J.Hylen, N. Mokhov,J.Morfin, C.T.Murphy, A.Para, R.Raja,

S. Striganov,

Fermi National Accelerator Laboratory

M. Messier,

Harvard University

D.Asner,P.D.Barnes Jr., D.Fujino, E.Hartouni, S.Johnson,R.Soltz, D.Wright,

C.Wuest,

Lawrence Livermore Laboratory

B.Cole,

Nevis laboratories,

L.Gutay,

Purdue University, Lafayette,

S.Chernichenko, Y.Galitsky,Y.Gutnikov,V.Onuchin,E.Melnikov,V.Semenov

IHEP Protvino

S.Wojcicki,

Stanford University

Purpose of the experiment

- Test a scaling law of particle fragmentation
- Measure particle spectra with 120 GeV/c protons on the NUMI target.
- Measure particle production off various nuclei- Useful for Nuclear (RHIC) physics.
- Neutrino factory/Muon Collider type measurements
- Indirect benefit for collider experiments by helping with Geant cross sections.
- Revisit the study of non-perturbative QCD hadron production dynamics by measuring particle interactions with excellent particle identification, high acceptance and rate.

General scaling law of particle fragmentation

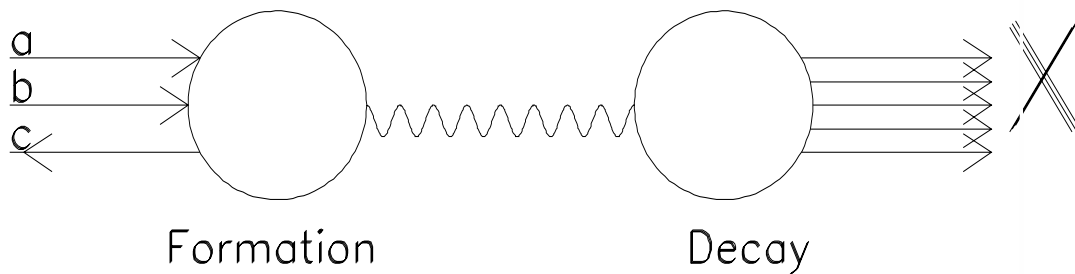
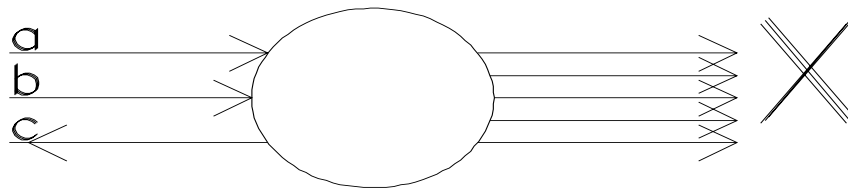
- States that the ratio of a semi-inclusive cross section to an inclusive cross section

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

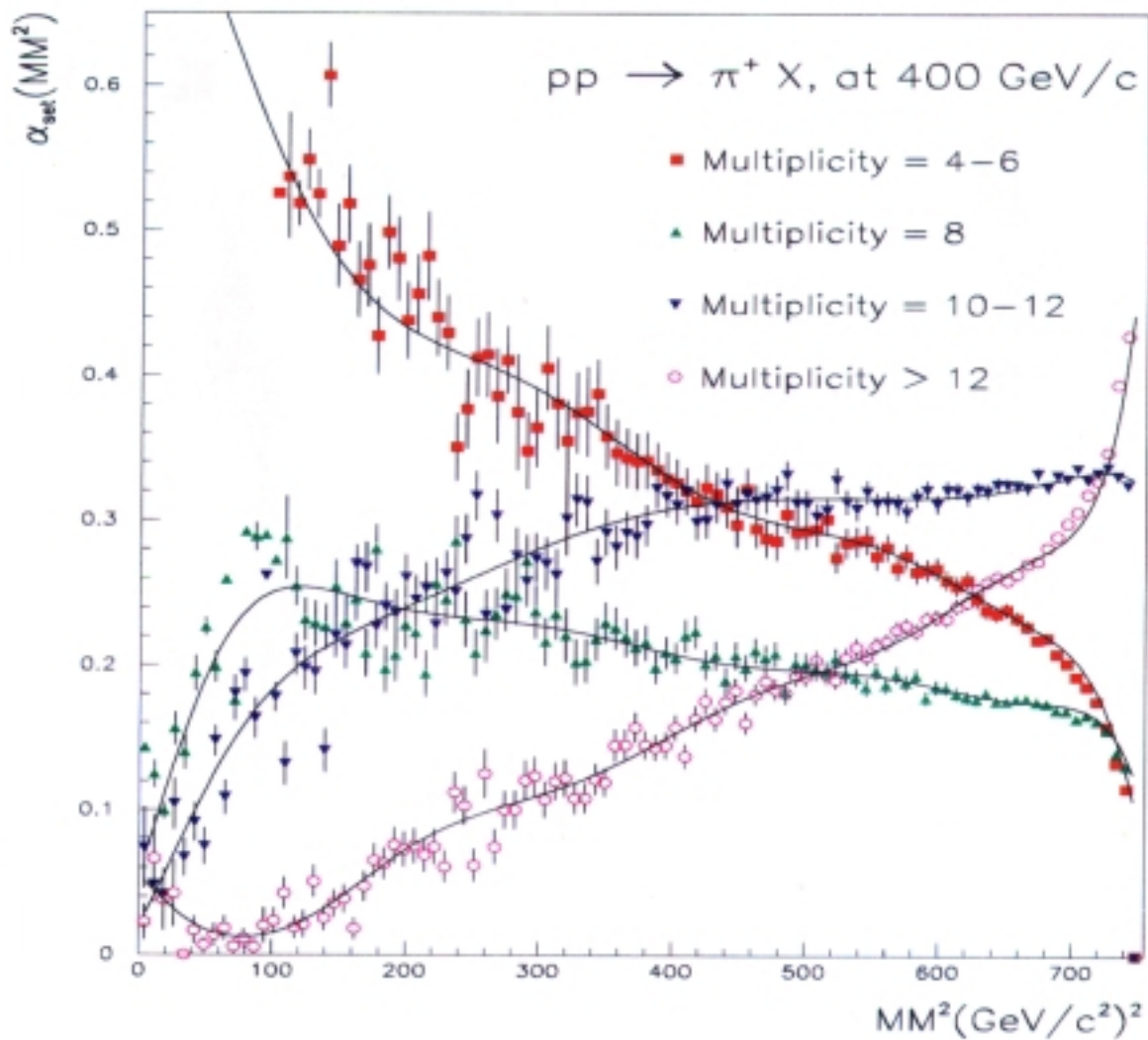
- where M^2, s and t are the Mandelstam variables for the missing mass squared, CMS energy squared and the momentum transfer squared between the particles a and c . PRD18(1978)204.
- Using EHS data, we have tested and verified the law in 12 reactions (DPF92) but only at fixed s .
- The proposed experiment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

Scaling Law

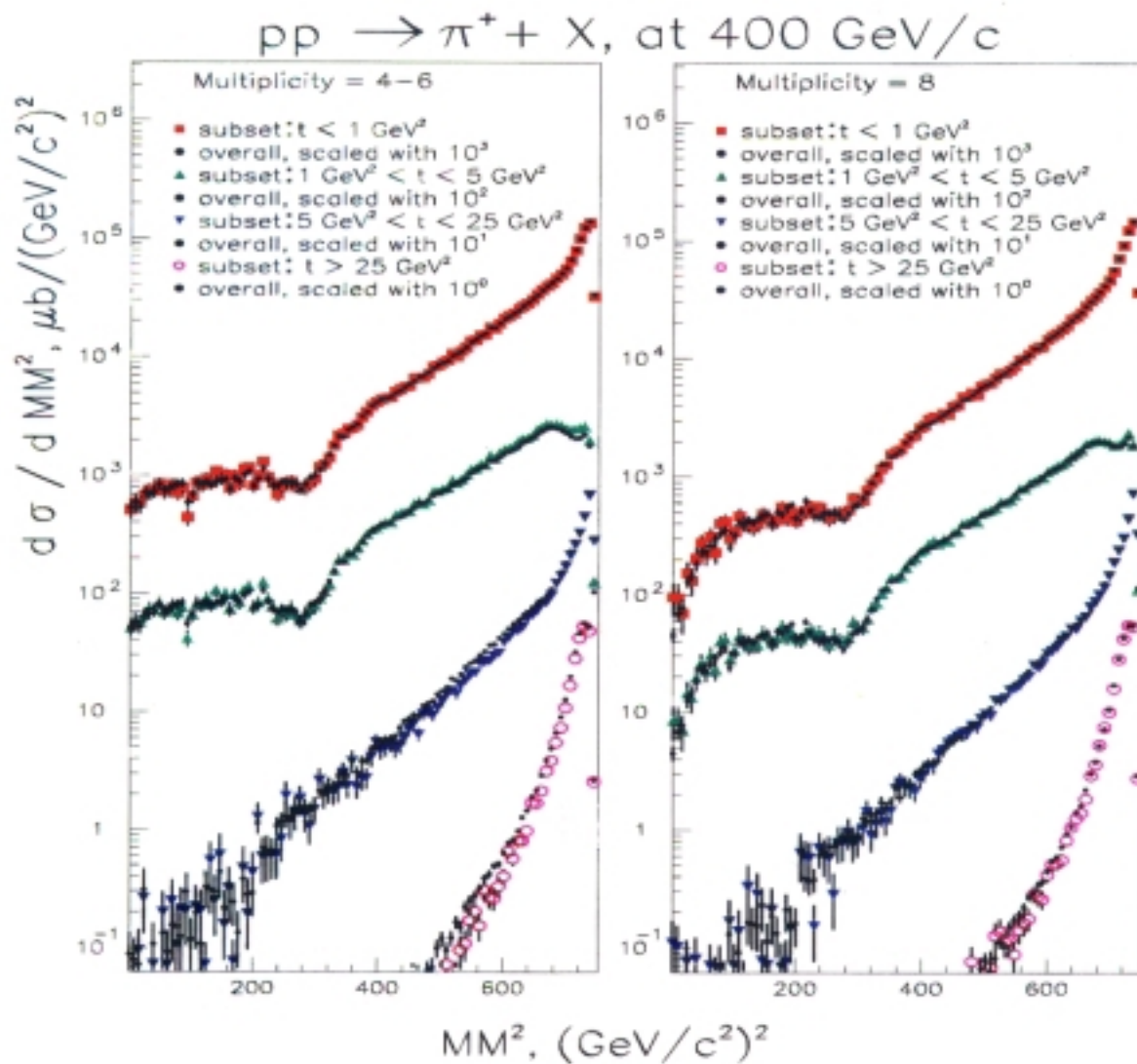
- Physics behind law is the factorization of 3 body scattering cross section.



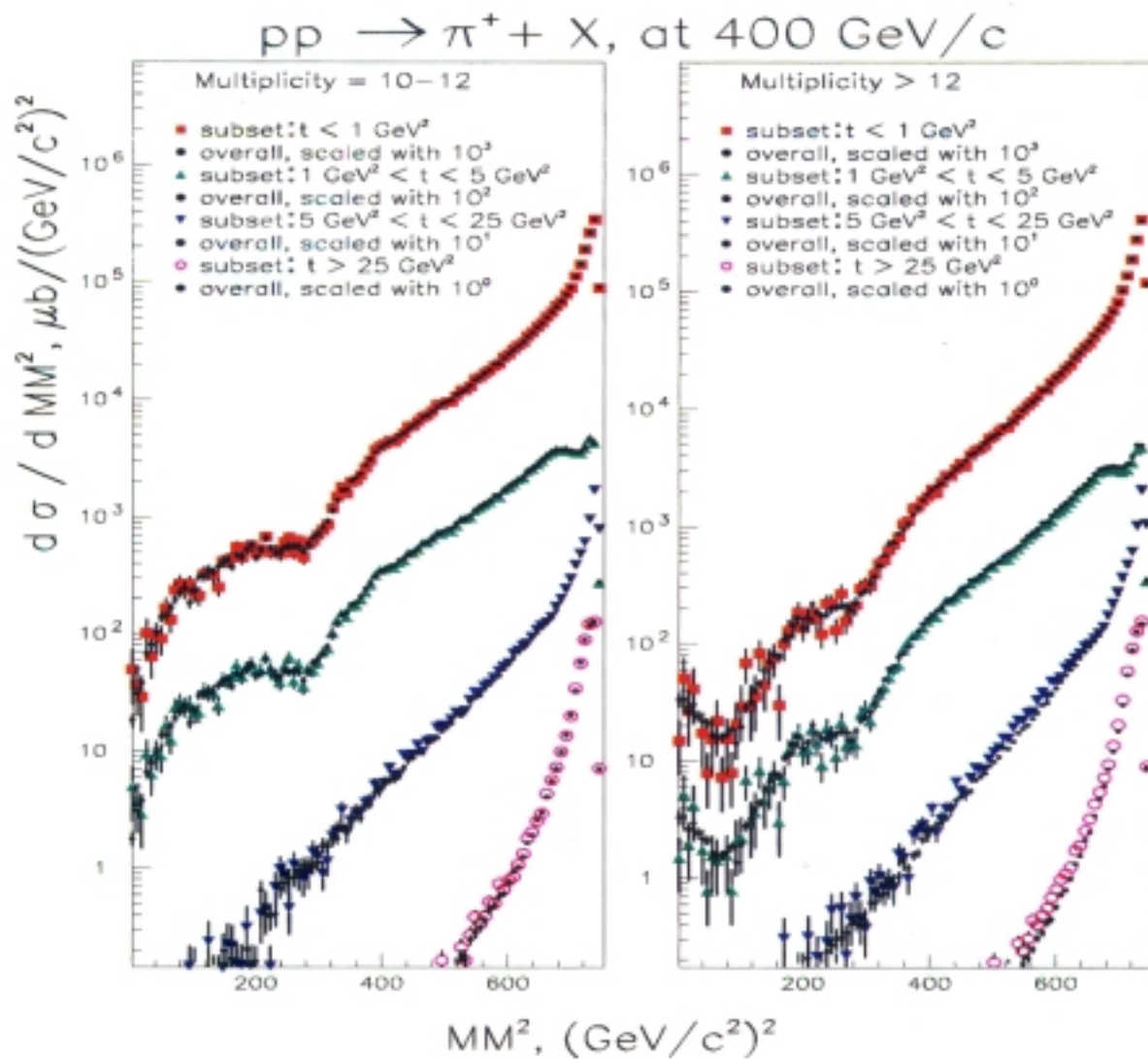
Scaling law-EHS results



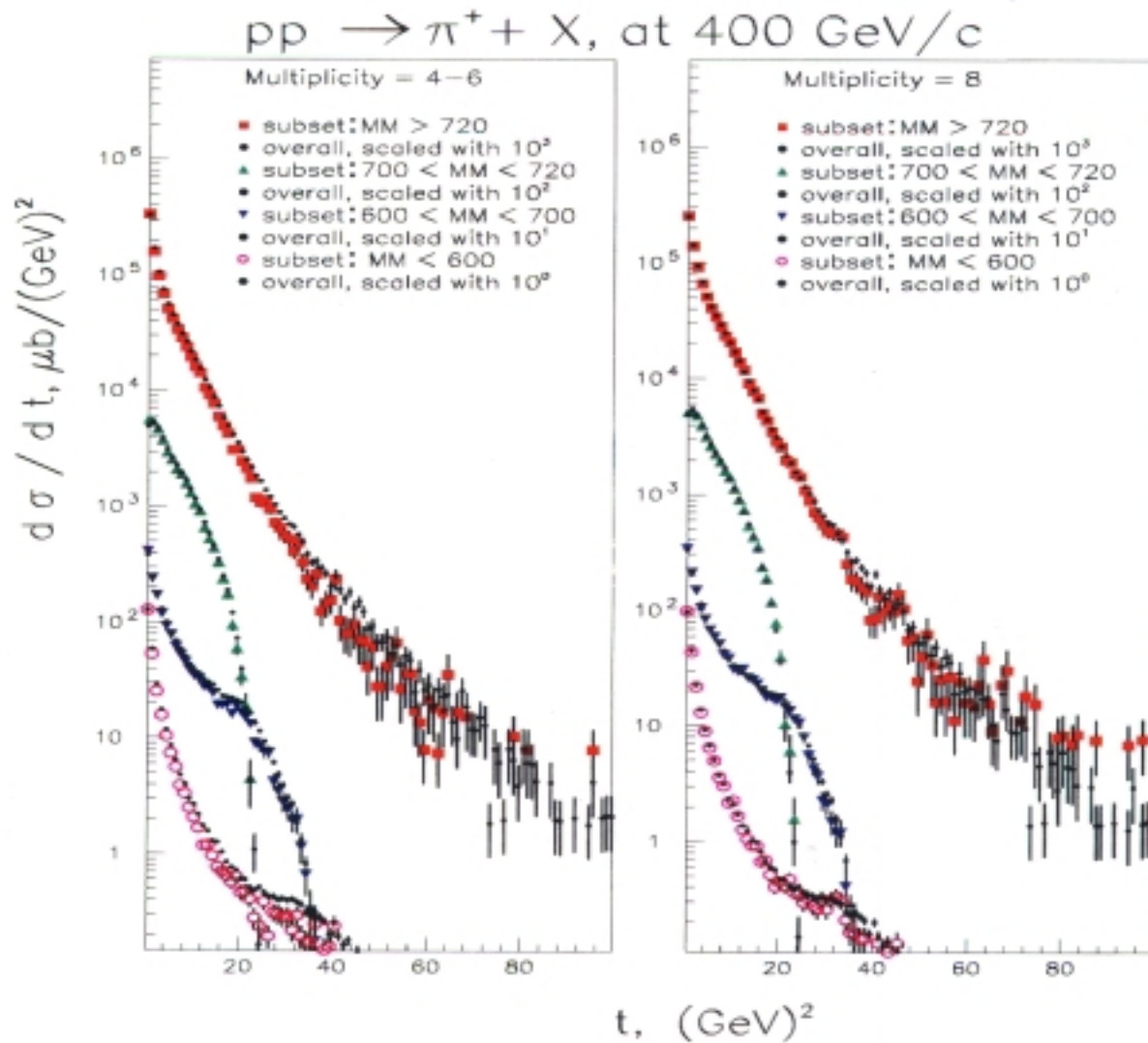
Scaling Law-EHS results



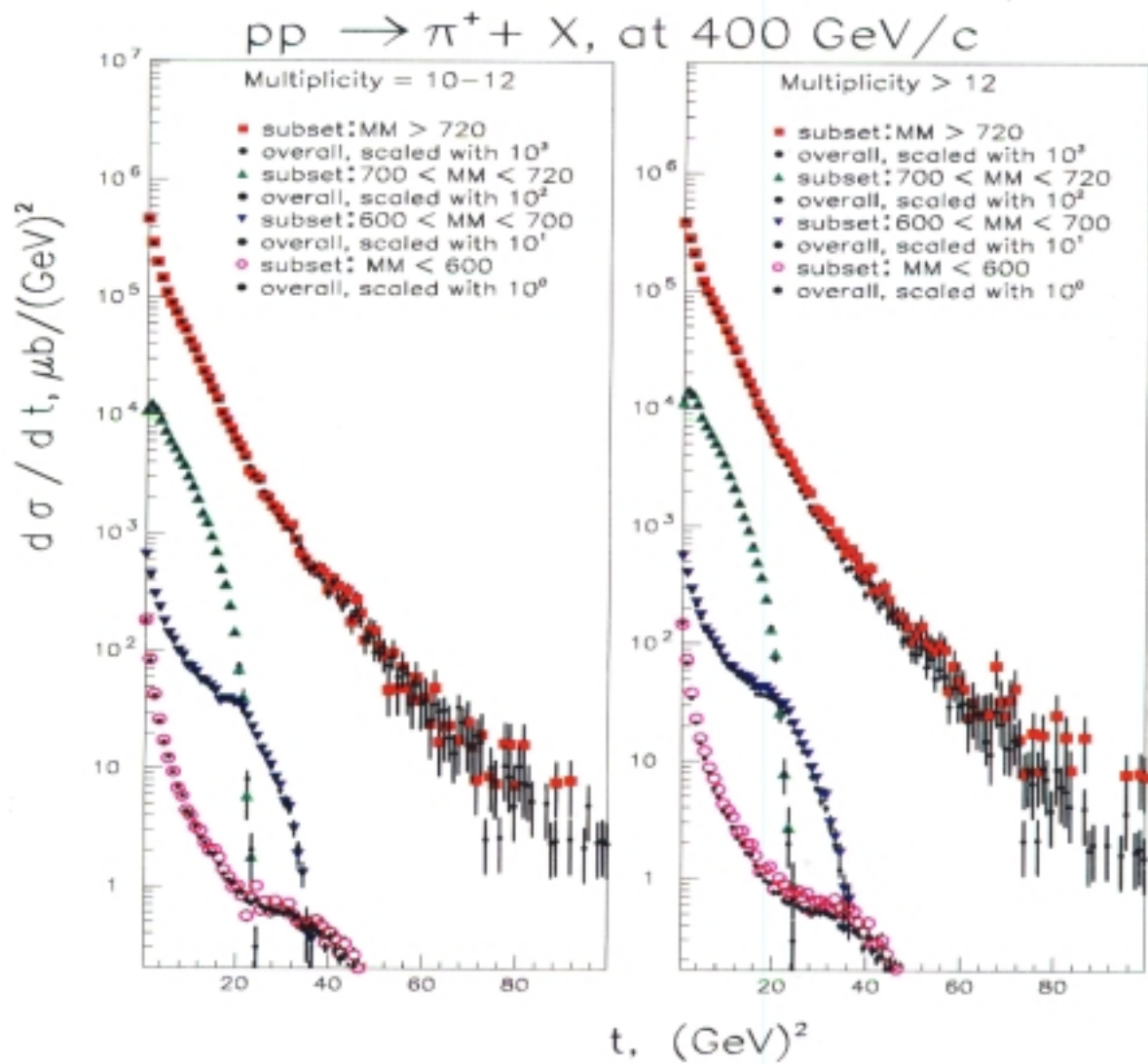
Scaling Law-EHS results



Scaling law -EHS results



Scaling Law -EHS results



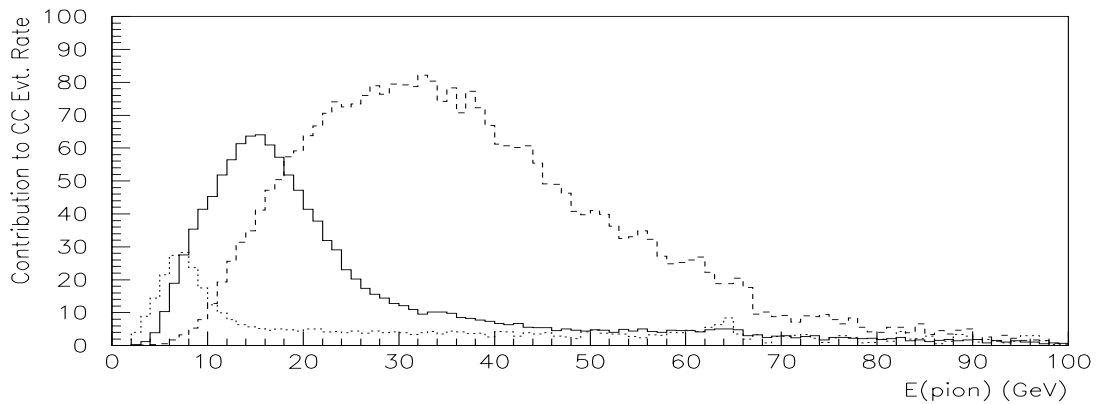
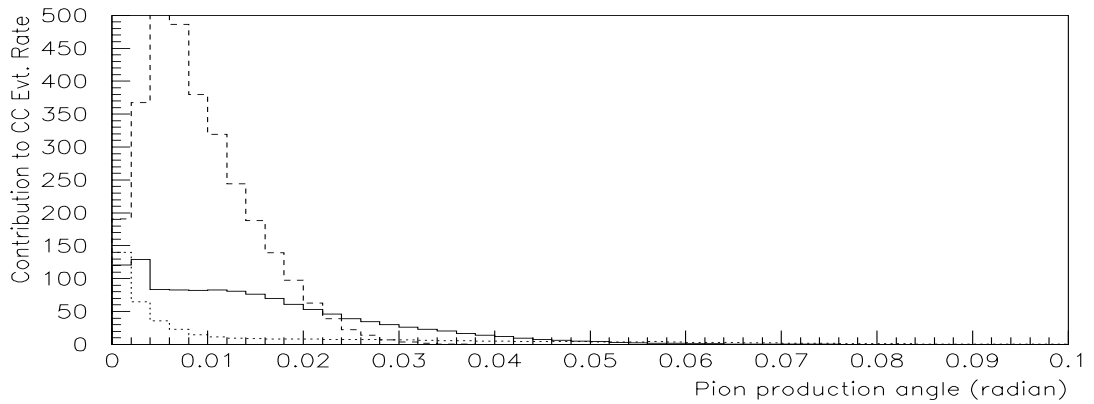
MINOS requirements

- Neutrino oscillations cause distortions in the energy spectrum of neutrinos in the far detector compared with those in the near detector.
- Monte Carlo studies have shown that the largest contributor to the systematic error in the prediction of the shape of the energy spectrum in the far detector is the uncertainty of the particle production spectra at the target.
- In the neutrino energy range 8 GeV to 24 GeV, there will be ~2000 Charged Current events per 1 GeV bin in the Soudan detector for a two year run.
- Detector resolution is 23%. So natural scale for detecting shape changes is a few GeV. One seeks a statistical accuracy of 1% - 2% for a few GeV wide wiggles. This demands the prediction of the Soudan spectrum to 1-2% to match the statistical accuracy of the data sample.
- This demands the measurement of the π/K spectra at the NUMI target to 1%-2% accuracy.

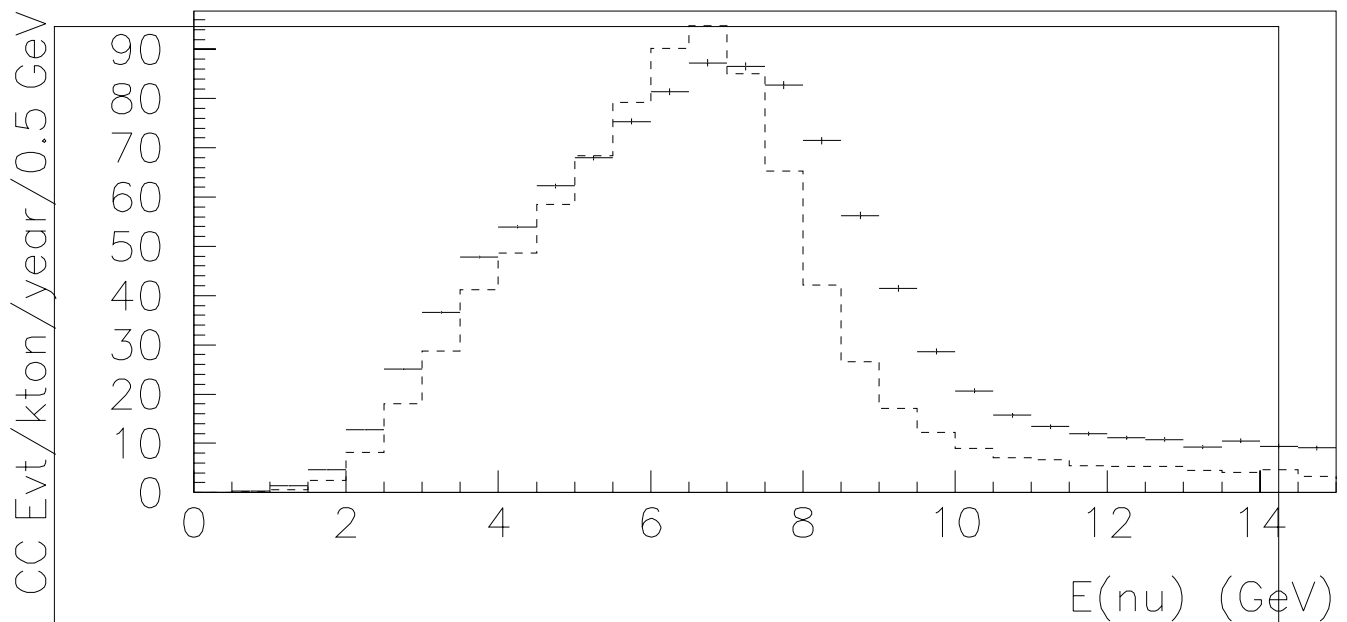
MINOS requirements

- Beam must be 120 GeV protons.
- Target must be the same as the NUMI target. Pencil target , cylindrical, 8 graphite segments of 12.5 cm long, 2mm radius with 8 cm gap between segments.
- Target exit points of hadrons need to be measured as well as their momenta and identity in the range 5 GeV - 80/100 GeV.
- Forward acceptance needs to be at least 100 mrad.
- Approximate 10^7 interactions.
- Upper Figure on next slide shows angular distribution of pions contributing to the neutrino spectrum weighted by the relative event rate. Solid curve to the baseline medium energy beam and others to the high and low energy options.
- Lower figure next page shows momentum spectrum of the pions contributing to the neutrino spectrum and sets the required momentum acceptance and particle Id range for P-907 from Minos requirements.

Minos requirements

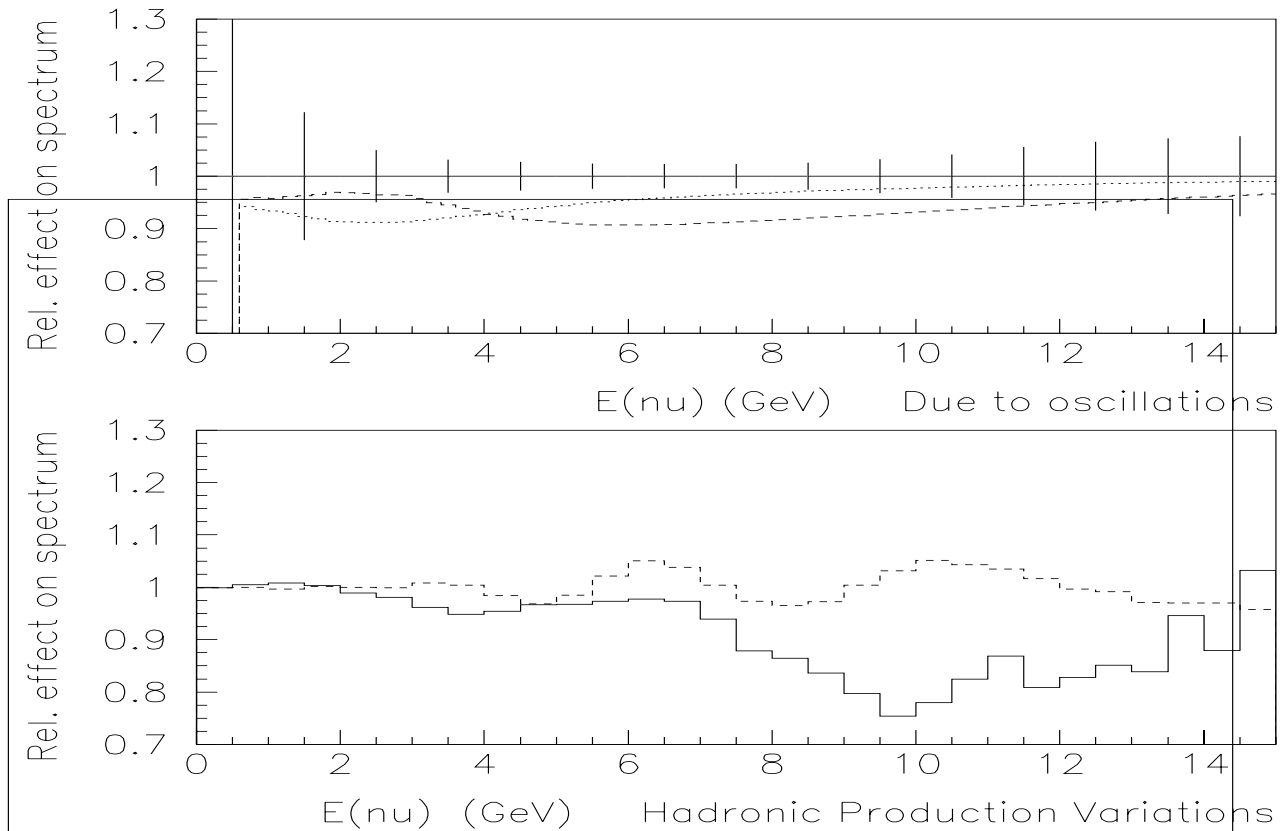


MINOS requirements



- Two magnetic focusing horns and a target that can be moved to produce spectra which peak at different energies. Initial running with “medium energy” configuration
- Neutrino Charged Current events vs neutrino energy at near(dashed histogram. Normalized $0.863E-6$) and far(solid histogram) detectors. No oscillations.

MINOS requirements



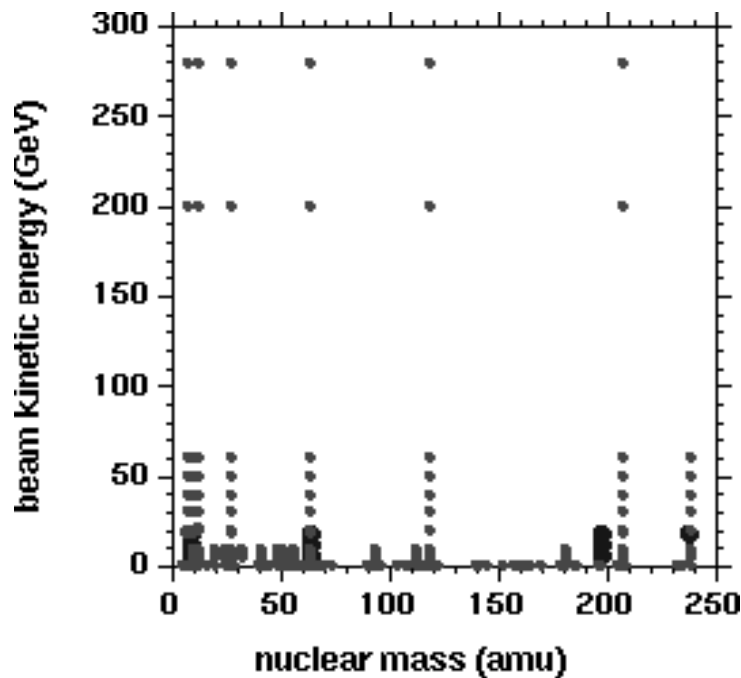
- Upper figure shows relative spectral changes that would be induced by oscillations $\sin^2(2\theta)=0.1$ and $\delta m^2=0.010\text{eV}^2$ (dashed line) and 0.005 eV^2 (dotted line). Statistical errors from a 2GeV run shown.
- Lower figure shows spectral distortions from a couple of variations of the Monte Carlo production model. Solid curve is GEANT/FLUKA vs GEANT/FLUKA with mean P_π of pions modified to that found in the NUADA and PBEAM Monte Carlos. Dashed curve shows the result of an arbitrary 20% P_π spectrum change of pion production in GEANT/FLUKA.

Nuclear Physics

- We held a workshop at LBNL 3 months ago to see what interest there is in p-A physics. Expected 30 people, 55 showed up.
- Upshot of the meeting – pA physics is important in itself but also to understand RHIC data.
- As RHIC gets to work, we expect nuclear physicists to join p-907. (~end of 2000)

Proton Radiography

- Few measurements in the 50 GeV range.

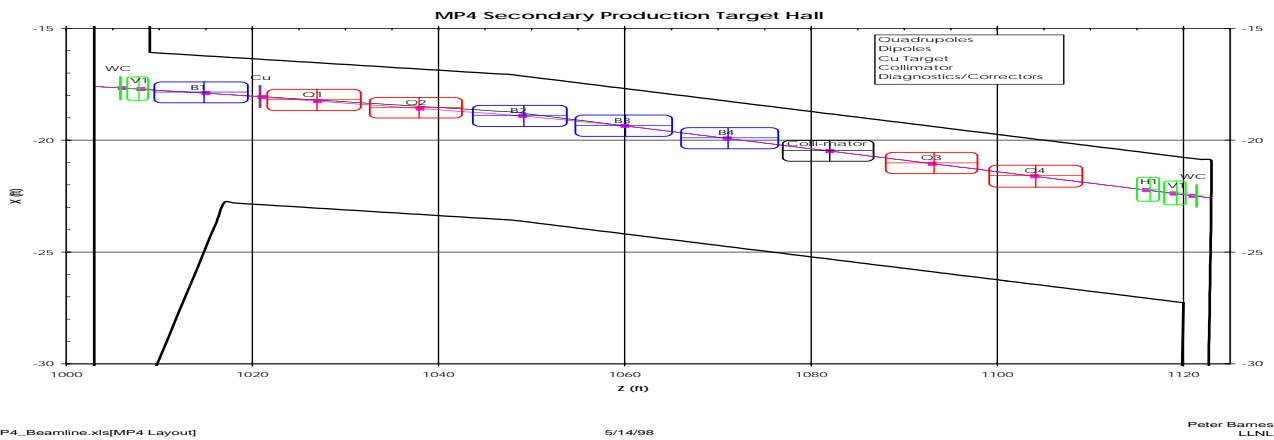
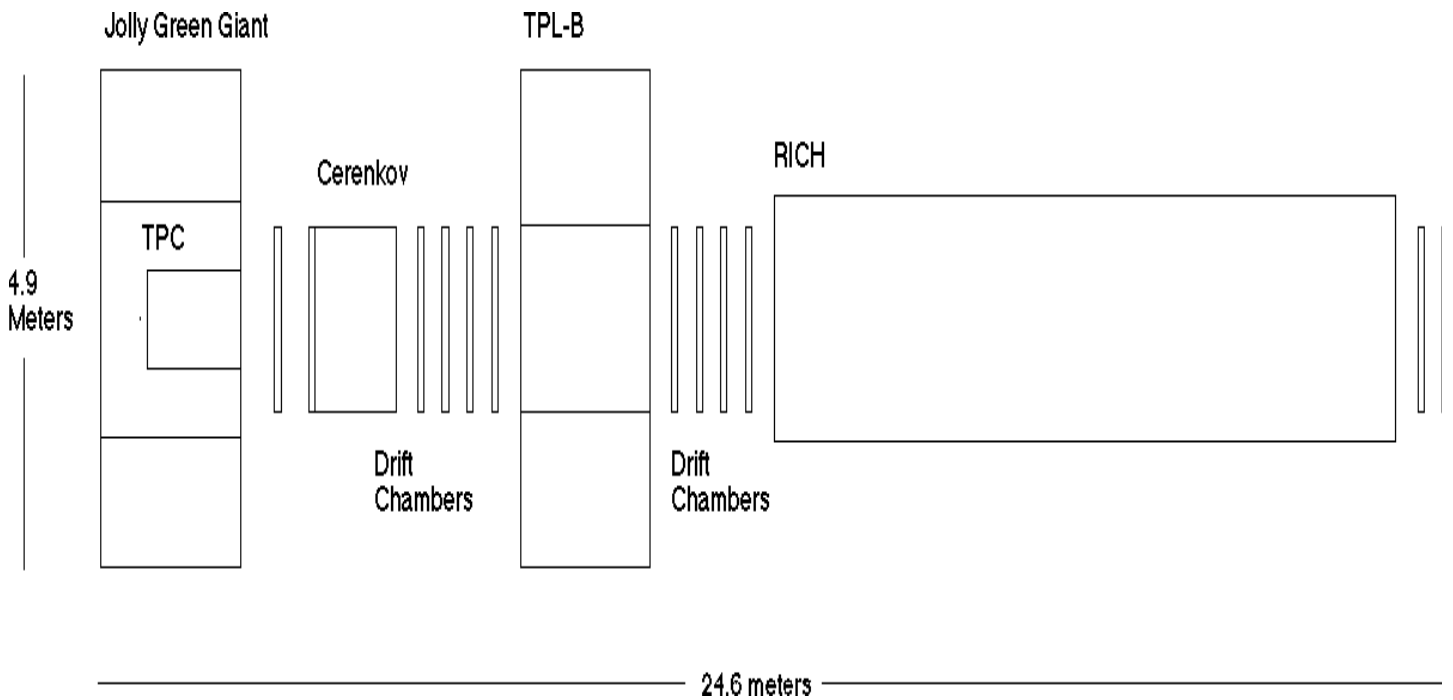


- Data should cover 5 GeV/c to 115 GeV/c in beam momentum with 10 GeV/c spacing. Data sets of 10^5 - 10^6 minbias interactions along with a sizable fraction of $p+A \rightarrow p+X$ in the forward region. Wide variety of nuclear targets. Particle id needed.

Neutrino factory needs

- Primary target material not yet decided upon for the muon collider. Theoretical models of particle production off nuclei can be wrong by 20-30%.
- Nor is the primary beam. E910 at BNL has taken data using 12.5 GeV and 18.5 GeV/c primary protons on Cu and Au targets using the TPC under discussion here.
- It would be good to make measurements for 8 GeV/c (FNAL booster) and 30 GeV/c (AGS) beam momenta.

Implementation Scheme



Meson-Polarized enclosure MP4



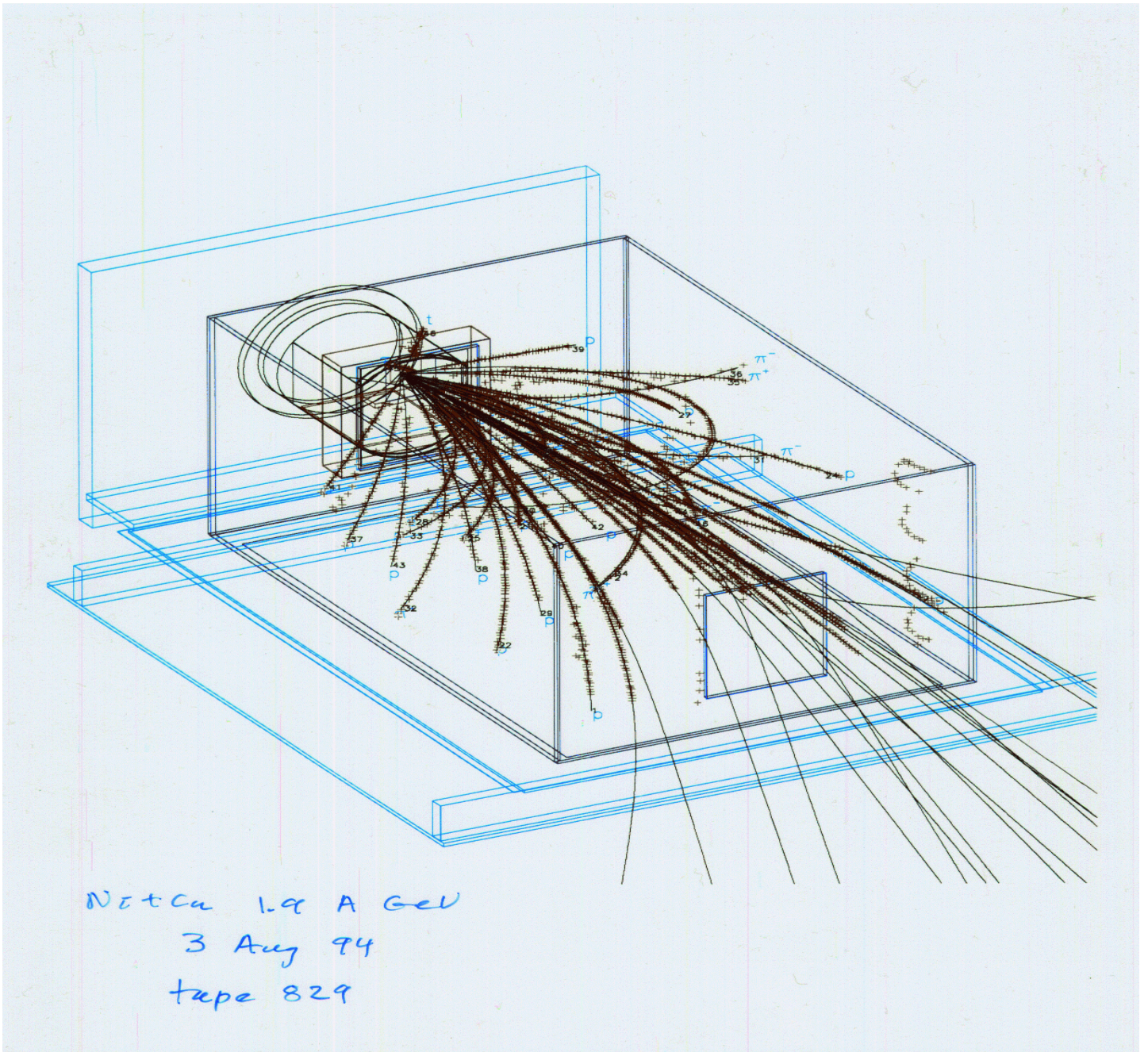
May 25, 2000

Rajendran Raja, Nufact00

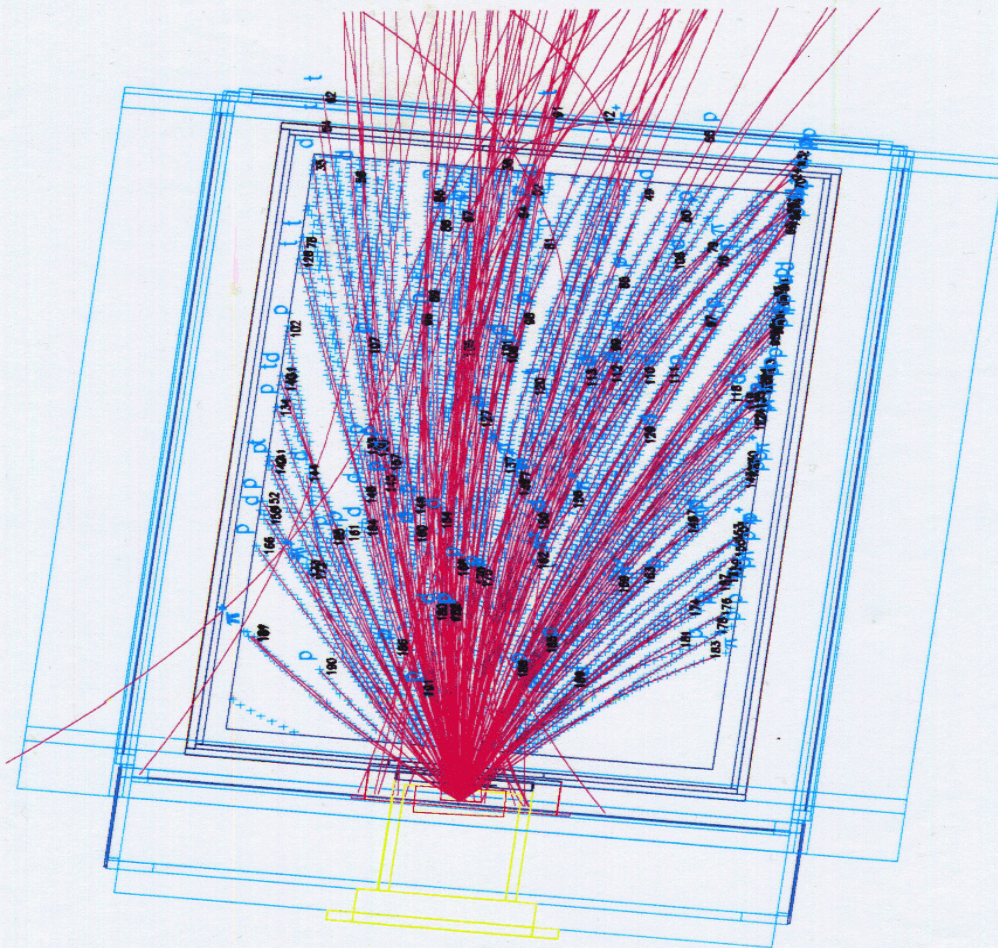
EOS-TPC

- 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. Dead time 16 microseconds.
- 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 100 Hz with an upgrade.
- TPC dimensions of 96 x 75 x 150 cm.
- TPC is sitting at P-Central flowing Nitrogen. It will be worked on later in May to make sure that it survived the journey and be placed in Lab 7 till P-907 sets up.

TPC with nuclear interactions

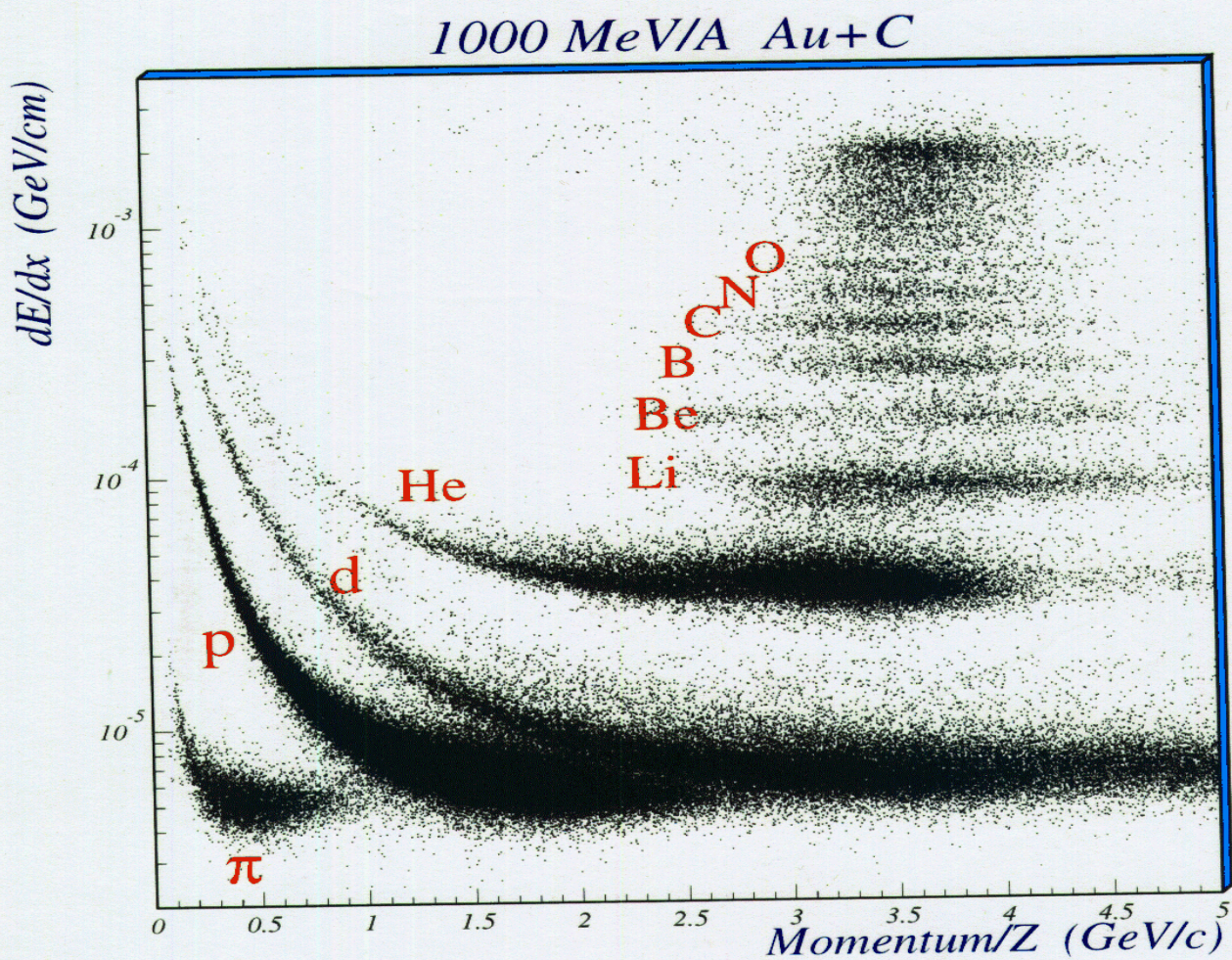


TPC with nuclear interactions



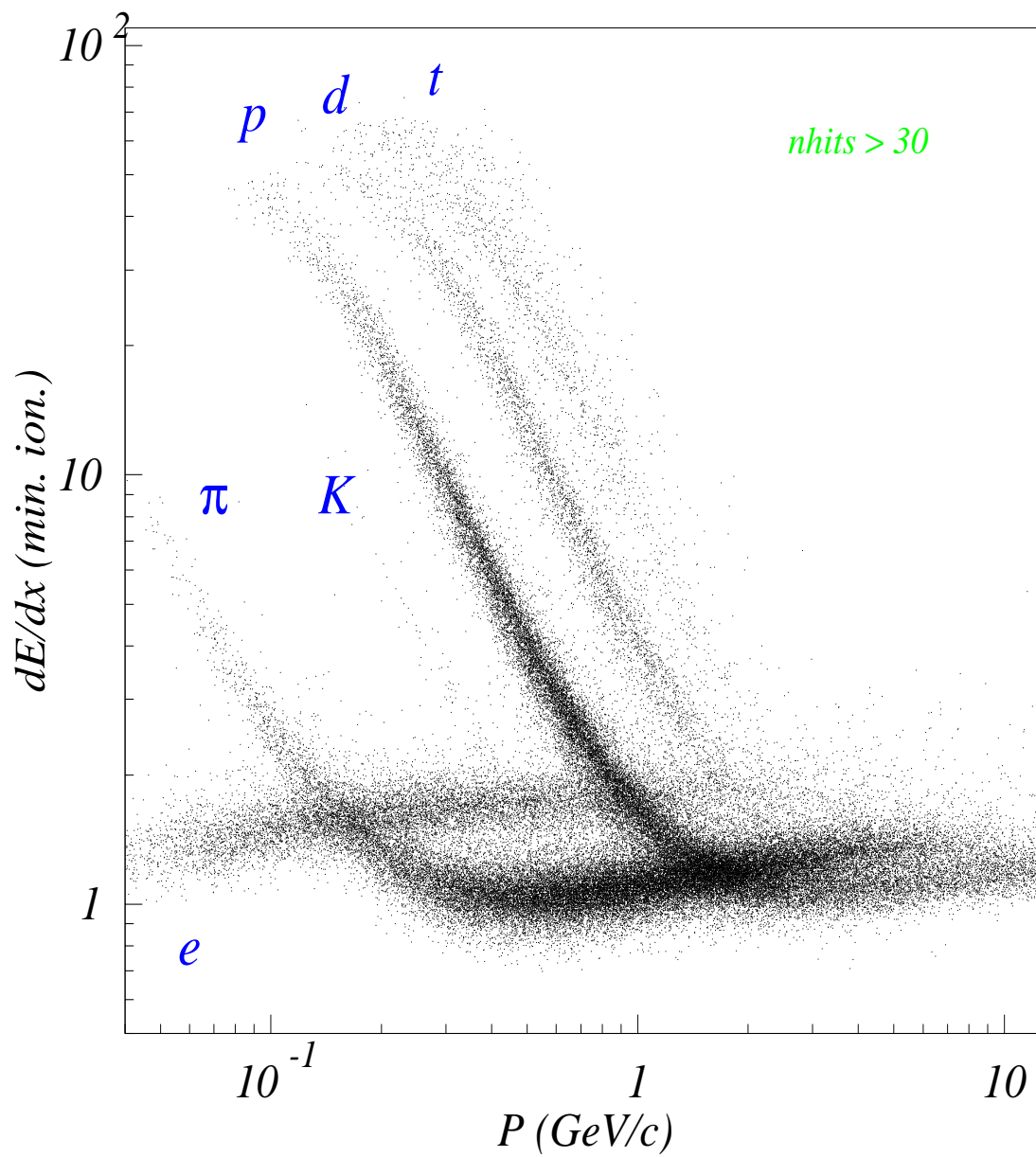
2 GeV Au+Au

Nuclear dE/dx



TPC dE/dx capabilities

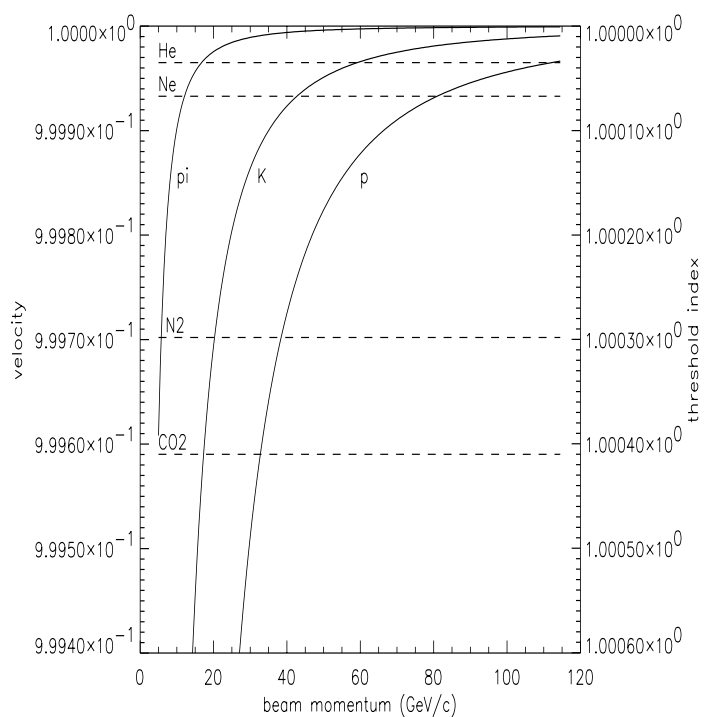
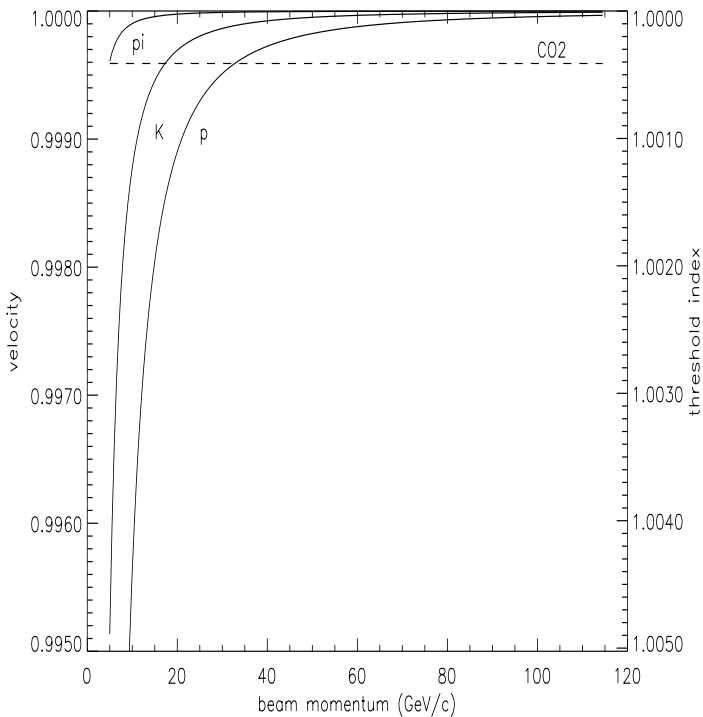
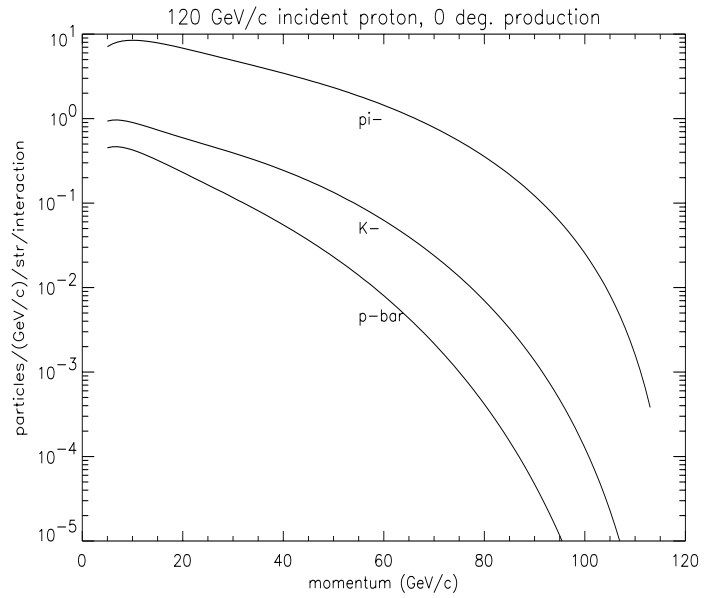
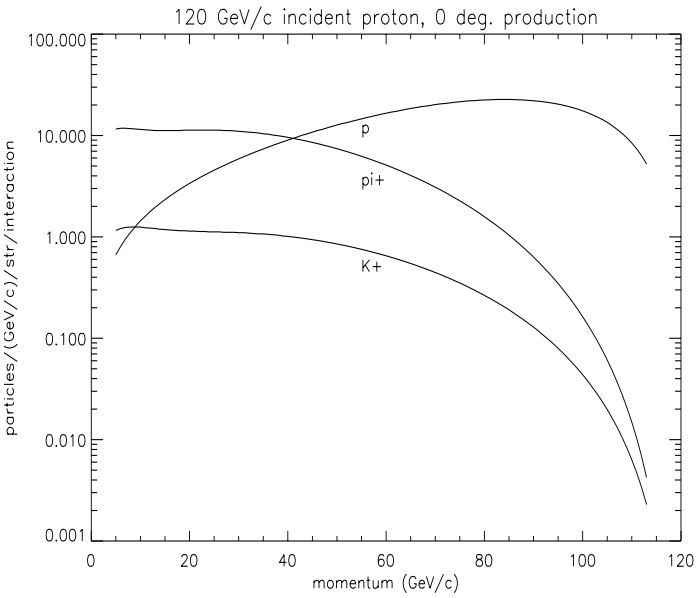
E910 18 GeV/c p+Au



Beam line requirements and design

- The secondary beam will be tagged with two threshold Cerenkov counters. The three beam species of π , K and p can be tagged by demanding
 - 1) that π 's radiate in the first counter and K's do not,
 - 2) π 's and K's radiate in counter 2 and p's do not.

Secondary particle beam production rates and tagging Cerenkov characteristics



Beam rates for positive and negative beams

- Assume 100Hz data taking for TPC
- 1% target for protons
- 10^5 particles per spill
- One spill every 3 seconds
- 1 Year = 10^7 seconds
- Total number of interactions to tape = 10^6 . To write 10^6 interactions to tape requires 8.3 hrs i.e 25hrs real time.
- *The TPC as is can do 60Hz. With electronic upgrade it is expected to do 100 Hz.*

Beam rates for positive and negative beams

Mom	P	K	π	Presc. p	Presc. k	Presc π	Time p hrs	Time K hrs	Time π hrs
5.0	56.	44.	520.	0.59	0.76	0.06	44.4	57.1	25.0
10.0	110.	41.	490.	0.30	0.81	0.07	25.0	60.6	25.0
20.0	210.	35.	437.	0.16	0.94	0.08	25.0	70.6	25.0
30.0	322.	28.	377.	0.10	1.18	0.09	25.0	88.3	25.0
40.0	474.	24.	290.	0.07	1.37	0.12	25.0	102.5	25.0
50.0	615.	19.	211.	0.05	1.80	0.16	25.0	135.1	25.0
60.0	715.	15.	155.	0.05	2.27	0.21	25.0	170.4	25.0
70.0	841.	9.	85.	0.04	3.56	0.39	25.0	267.0	29.4
80.0	925.	5.	39.	0.04	6.44	0.86	25.0	482.9	64.3
90.0	968.	3.	16.	0.03	12.73	2.05	25.0	955.0	154.1
100.0	988.	1.	6.	0.03	33.71	5.65	25.0	2528.3	423.8
110.0	997.	0.	1.	0.03	77.49	31.31	25.0	5811.7	2348.1

Mom	p- bar	K ⁻	π^-	Presc. p-bar	Presc. K ⁻	Presc π^-	Time p-bar hrs	Time K ⁻ hrs	Time π^- hrs
5.0	47.	46.	522.	0.71	0.72	0.06	53.2	53.9	25.0
10.0	38.	43.	532.	0.88	0.77	0.06	65.8	58.0	25.0
20.0	34.	40.	539.	0.99	0.84	0.06	74.5	62.8	25.0
30.0	23.	35.	551.	1.47	0.94	0.06	110.3	70.5	25.0
40.0	15.	29.	564.	2.28	1.15	0.06	170.7	86.6	25.0
50.0	9.	25.	572.	3.56	1.31	0.06	266.9	98.1	25.0
60.0	5.	20.	582.	6.66	1.69	0.06	499.7	127.1	25.0
70.0	2.	12.	594.	13.64	2.88	0.06	1022.8	216.3	25.0
80.0	1.	10.	597.	27.09	3.30	0.06	2031.8	247.3	25.0
90.0	0.	5.	604.	73.80	6.21	0.06	5534.7	466.1	25.0
100.0	0.	2.	607.	254.22	13.51	0.05	19066.5	1013.0	25.0

Primary Beam flux requirements

- 10^5 secondary particle beams requires $\sim 10^9$ primary protons on target-25hrs per point= 10^9 primary protons.
- Positive beam running- π^+ 's take 25 hrs per point 5GeV/c to 70 GeV/c, then run out of flux. K^+ 's take 25 hrs per point 5GeV/c to 40 GeV/c, then run out of steam. Protons can be done from 5-120GeV/c in 25hrs.
- Negative beam running- π^- 's take 25hrs per point through out, K^- 's run out of flux by 30GeV/c and pbars by 20 GeV/c.
- By tolerating superimposed beam particles and employing thicker targets(2-3%), we can increase the range of the heavier beam particles. Maximum primary flux seen is 10^{12} protons for these special runs.
- Scaling Law running requirements 900 hrs positives, 900hrs negatives. 75 days
- Minos Running times – 10^7 interactions 250hrs. 12 days.
- Nuclear Physics running-142 days.

Magnets and chambers

- We need two magnets. One with high aperture to measure the target fragmentation particles. The other to measure the forward high momentum particles.
- We propose to use the **Jolly Green Giant** magnet for the target fragmentation region. It has enough aperture (230x170x225 cm) to accommodate the TPC. 4 KG field, with a P_T kick of 0.2 GeV/c.
- For the forward magnet we propose to use the **TPL-B** magnet from the tagged photon lab. It can run with 10KG field, with a P_T kick of ~ 1 GeV/c. Dimensions (83x32x208 cm)
- Drift Chambers can be recycled from E-690. Dimensions 180x120cm., with 200Microns resolution. There are others in surplus at the lab.
- May be necessary to have a proton recoil detector. TPC does a good job on this. This decision must await Monte Carlo optimization.

Particle Identification

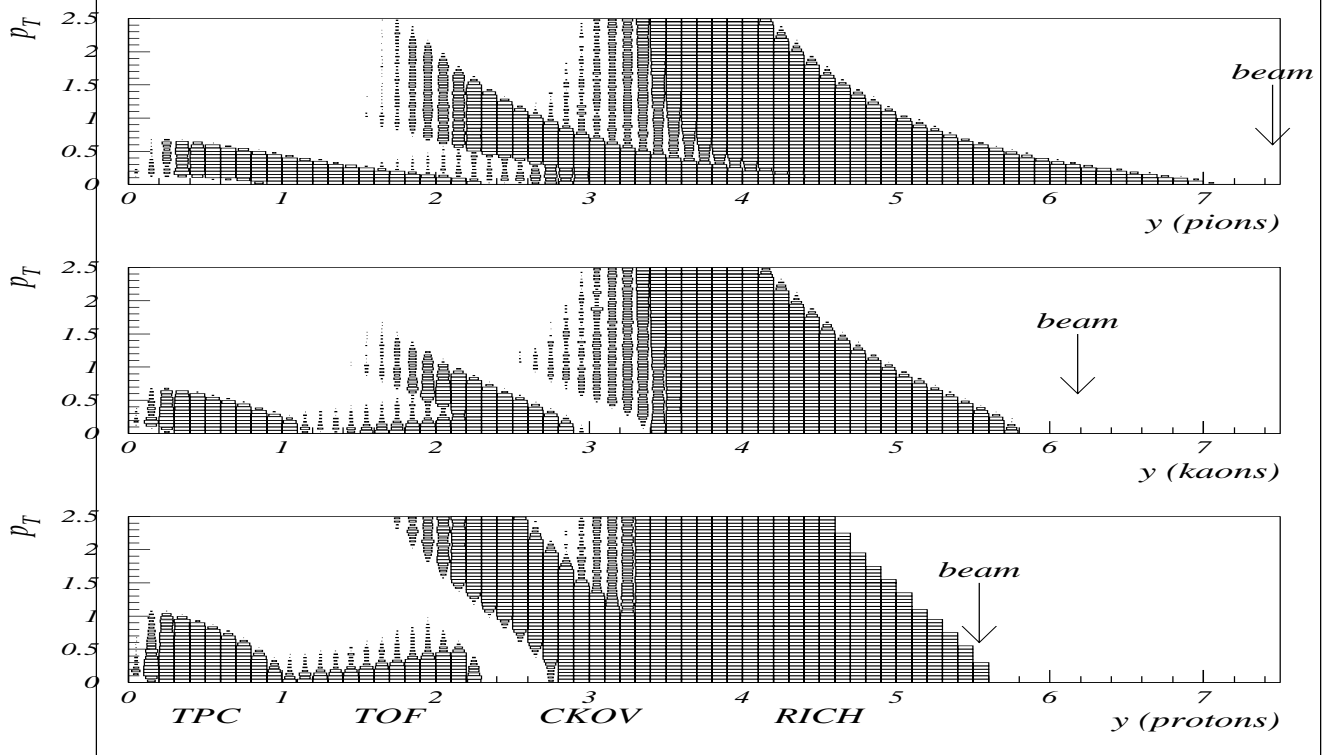
- TPC as shown can provide 3σ separation with dE/dx up to 0.7 GeV/c for π/K and 1.1 GeV/c for K/p as well as ambiguous additional information in the relativistic rise region.
- In the intermediate region, we propose to use the Cerenkov detector of E690 (E766) currently at BNL E-910. Light is collected by 96 phototubes from reflective mirrors. Filled with Freon 114, the Cerenkov thresholds for π , K , p are 2.5, 7.5 and 17.5 GeV/c.
- Above 7.5 GeV/c, many particles will go through to the RICH counter and be identified. We plan to use a RICH counter of the type used by the SELEX experiment. At SELEX, counter was filled with Neon at 1.05 Atm.

• Threshold	Ne	N ₂	CO ₂
• π	12	5.7	4.9
• K	42	20	17
• p	80	38	33

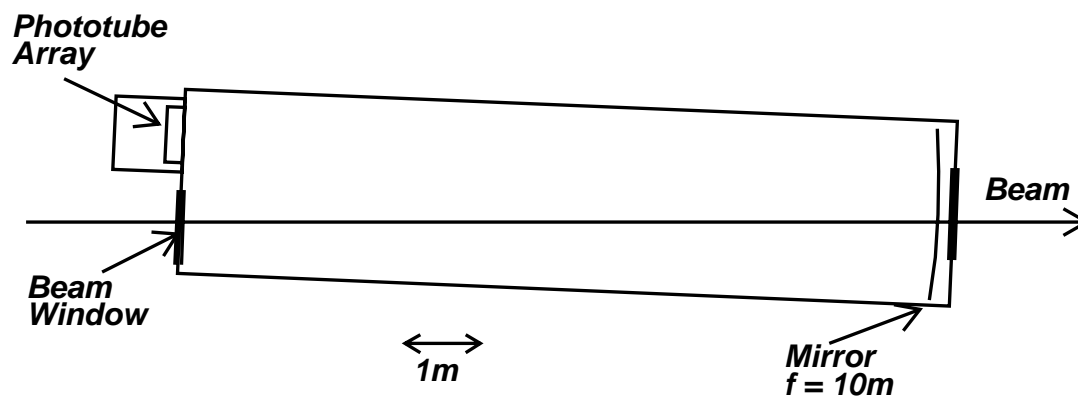
TOF System and PID acceptances

- In order to bridge the gap in Particle id between the TPC and Cerenkov systems, we plan to put in a TOF counter system with 100 ps resolution which would provide 3σ separation π/K up to 2.7 GeV/c and K/p up to 4.6 GeV/c, nearly filling the present particle id gap. Further Optimization studies are in progress.

PID Acceptance (positives)

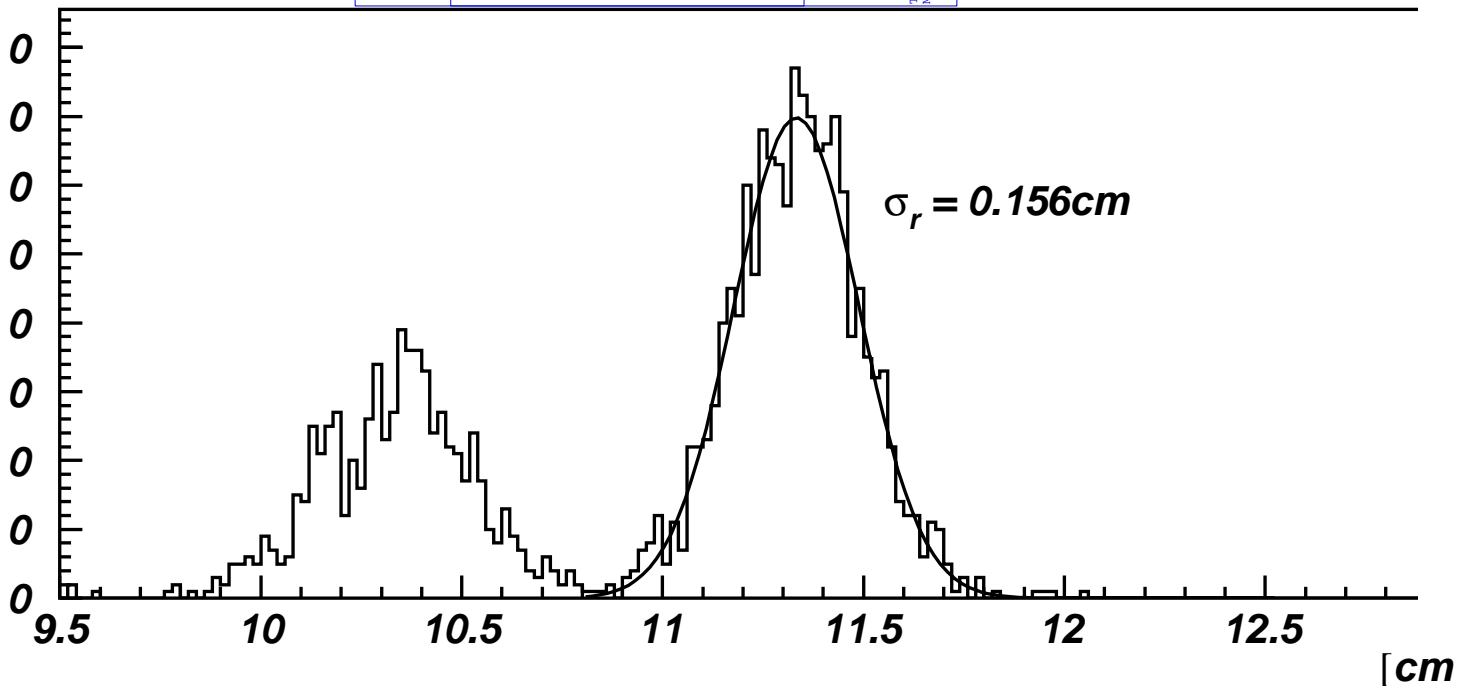
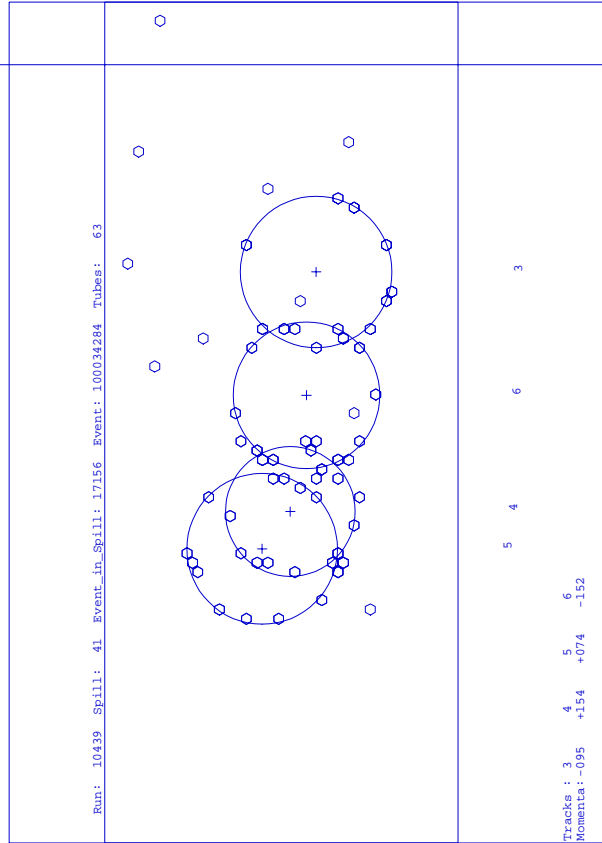


SELEX RICH characteristics
J.Engelfried et. al, NIM A431:53-69, 1999

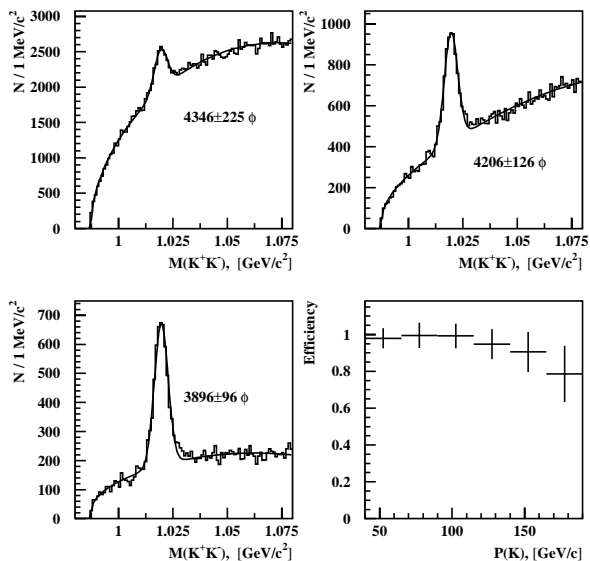
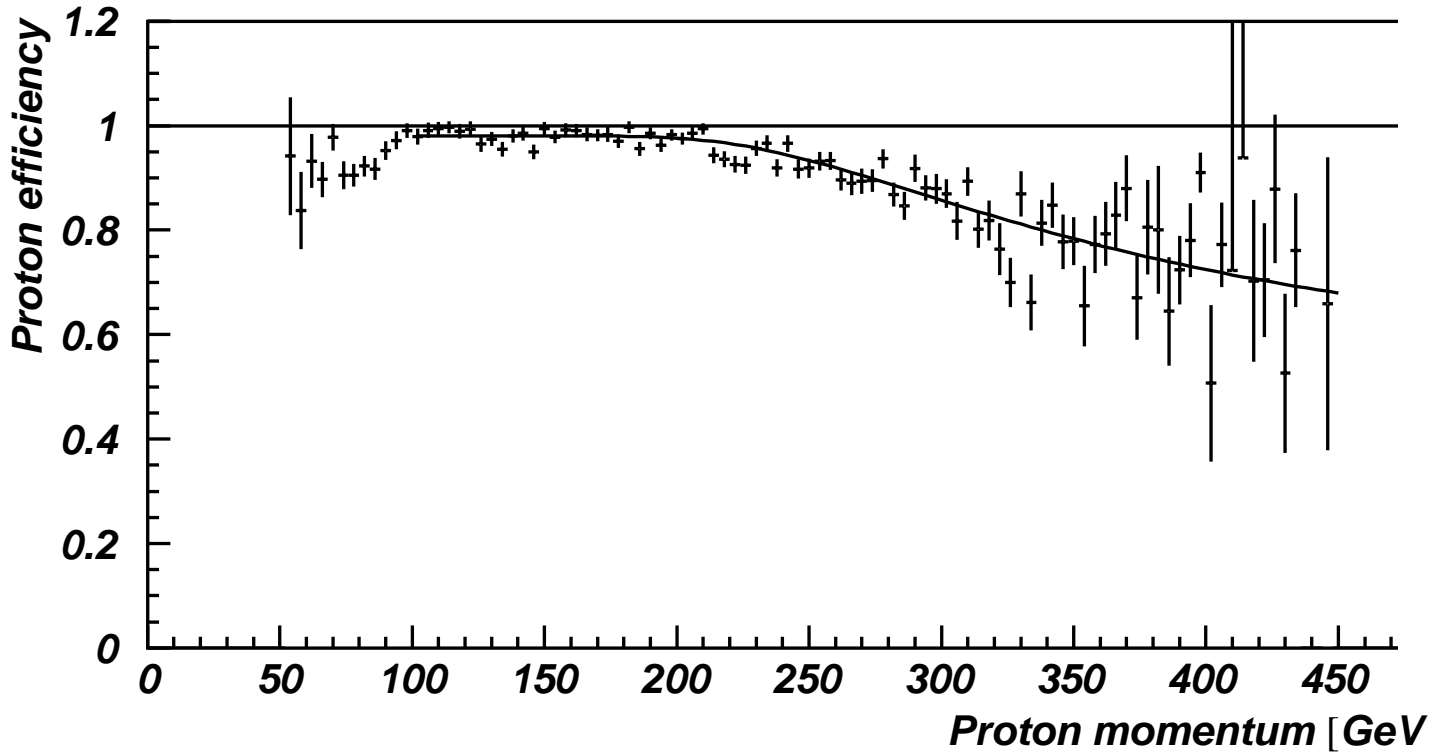


SELEX RICH characteristics

J.Engelfried et. al, NIM A431:53-69, 1999



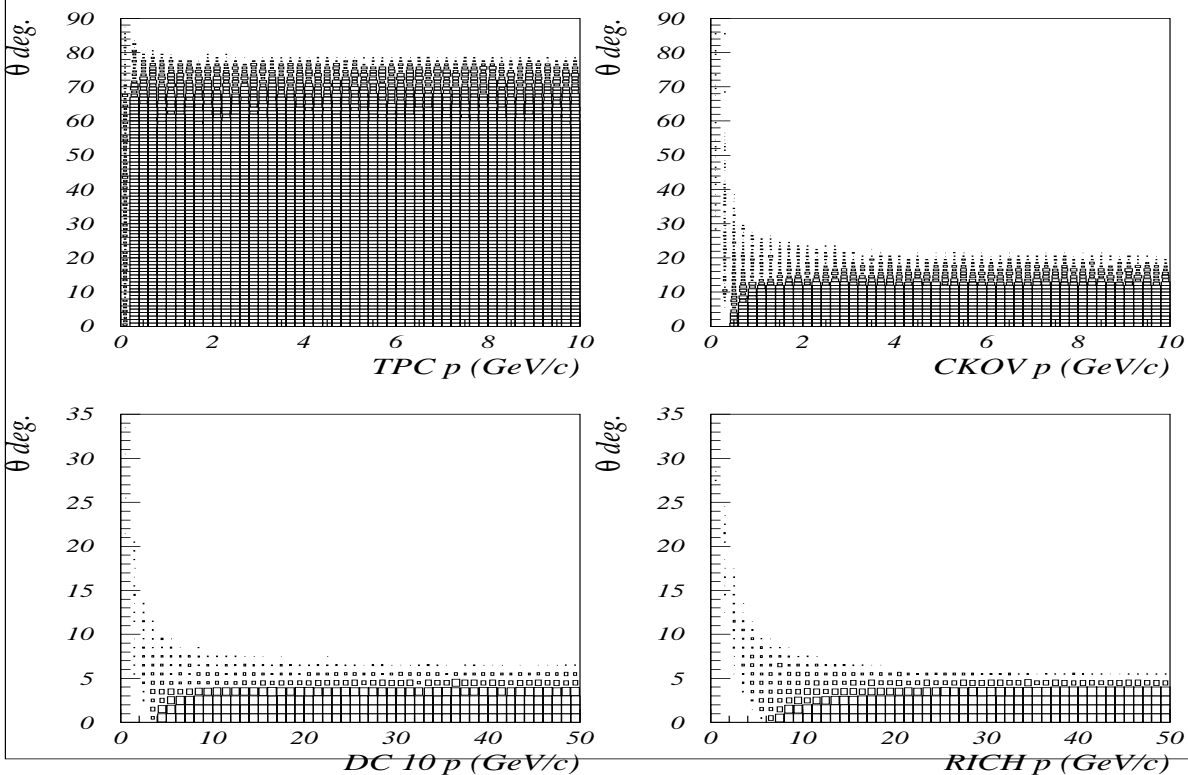
SELEX RICH characteristics
J.Engelfried et. al, NIM A431:53-69, 1999



Particle acceptances and resolutions

- Four cases of particles considered
- (Cumulative AND)
- 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

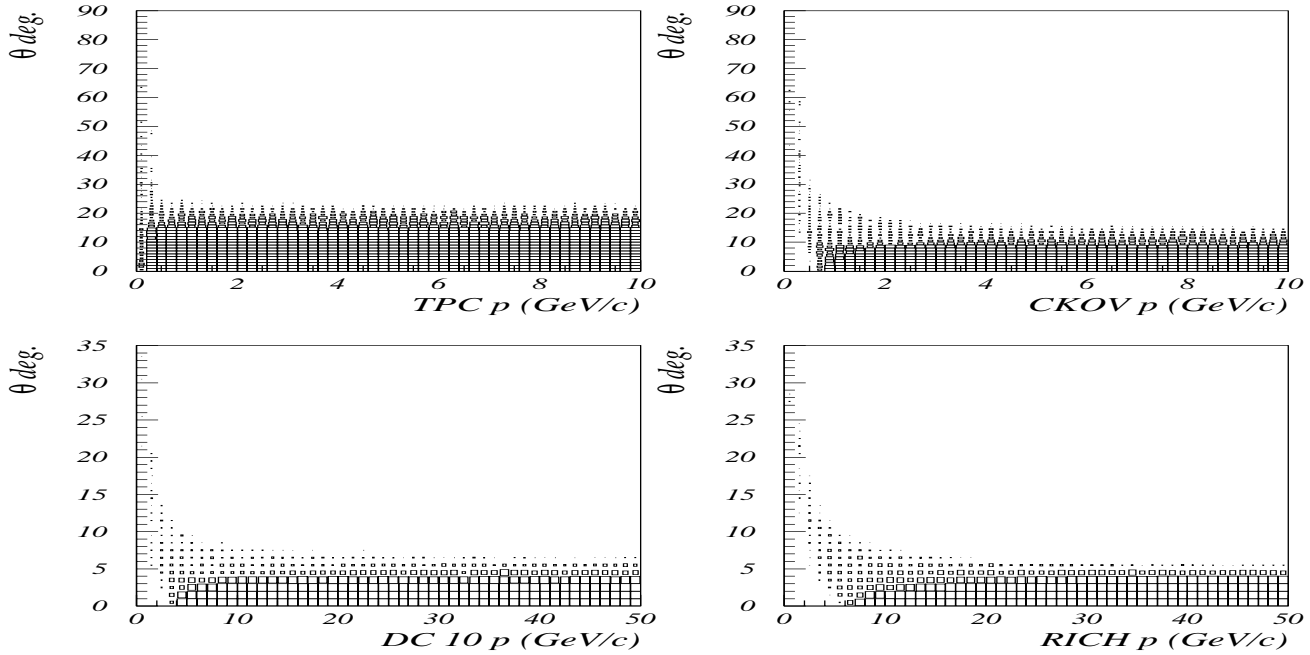
Positive Particle Acceptance Efficiency



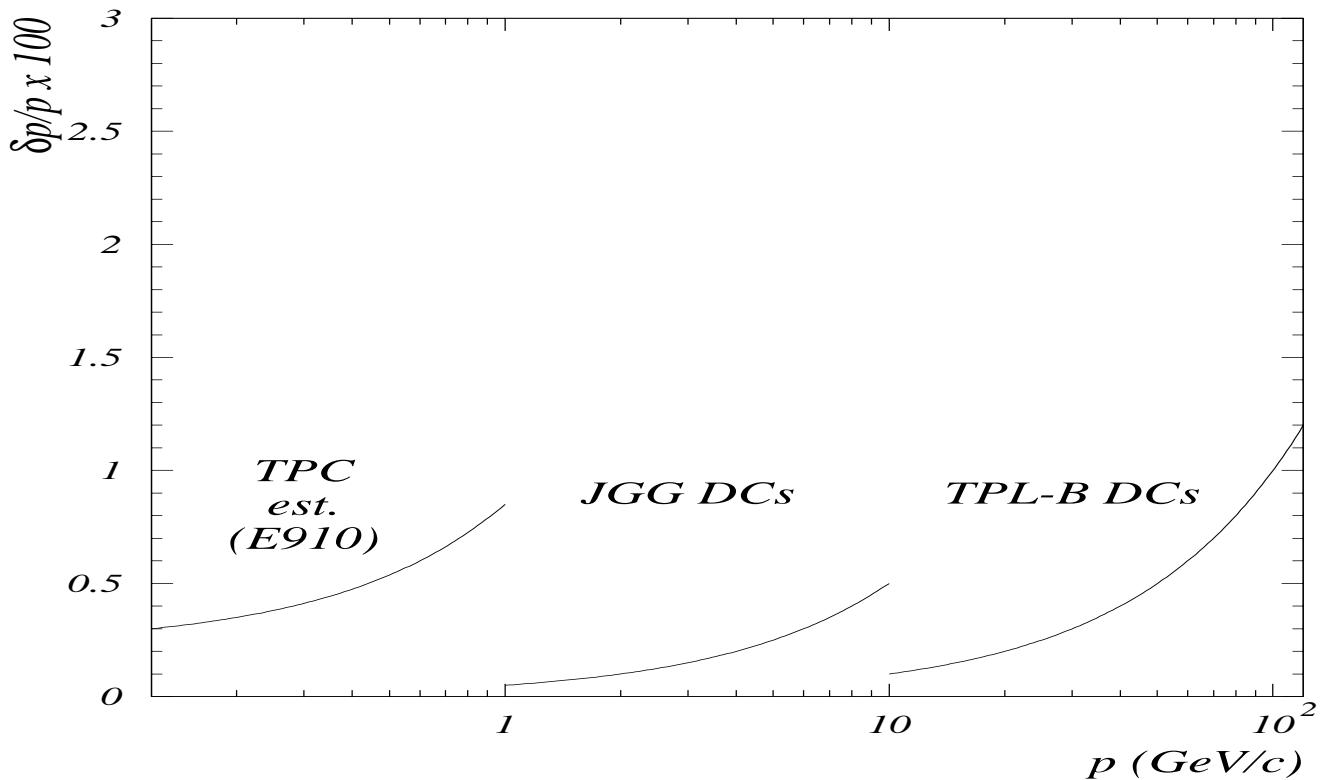
Particle acceptances and resolutions

NUMI case

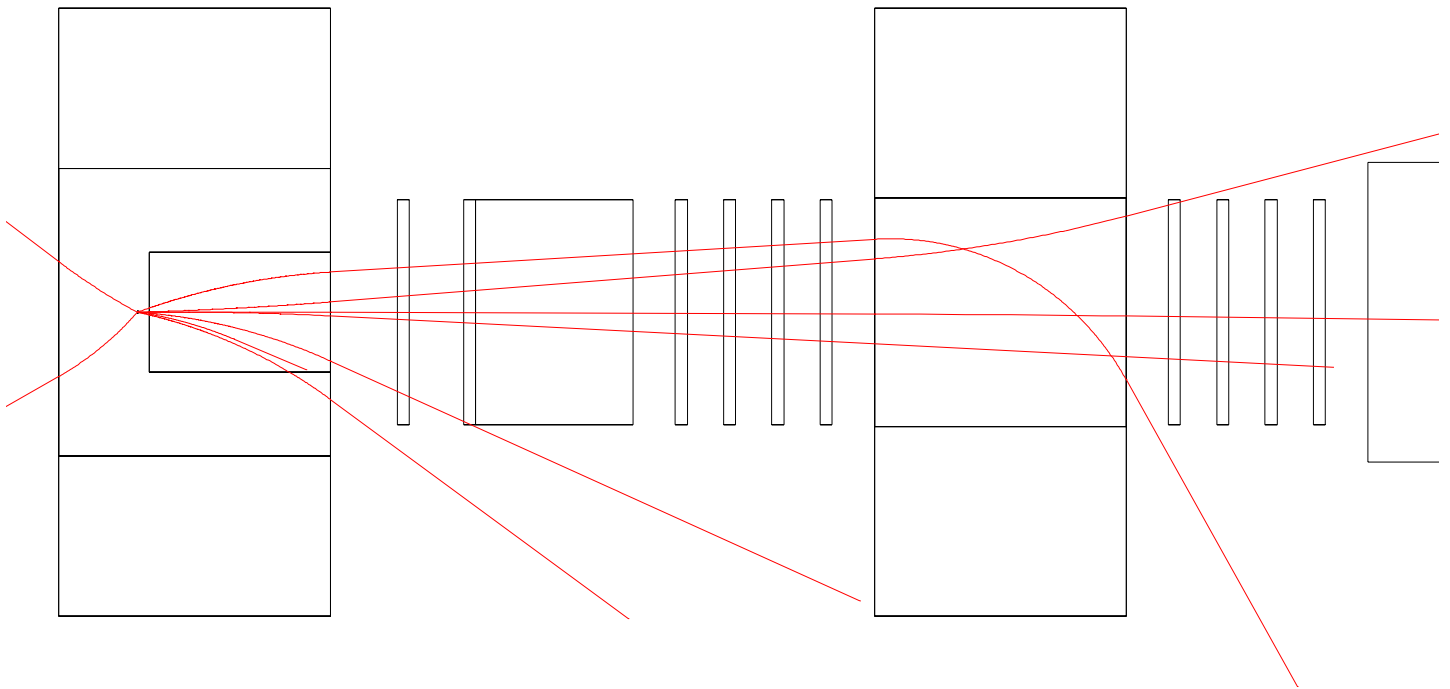
NUMI Front Acceptance Efficiency



Parameterized Momentum Resolution



Event Display



Schedule

- Proposal to the PAC May 19th-Will contain detailed simulation and cost analyses
- Approval (expected) in the Fall.
- Begin Setting up the experiment in MESON M-Central area in 2001.
- First Beams expected – End of 2001.

Conclusions

- We have proposed a low cost solution to measuring particle production spectra with excellent particle identification with hitherto unachieved statistical precision.
- The experiment is of high importance to the study of hadron production dynamics, scaling laws, as well as resonances and non-perturbative QCD of which little is known. More than 90% of the total inelastic cross section however is in this regime.
- The unique capabilities of the TPC (high event rate, large acceptance, dE/dx) and the SELEX RICH counter make P-907 a powerful spectrometer.
- p -A, \bar{p} -A, K -A, π -A physics
- The experiment would be useful for the muon storage ring production measurements as well as for atmospheric neutrinos.
- Particle id is the name of the game. Systematics in different experiments are hard to understand fully. It would be good to have two independent experiments.
- P-907 setup will serve us a backbone for further proposals at Fermilab.

Costs

- Preliminary estimate of costs. Details in proposal.
 - TPC transport etc \$ 50,000(done)
 - Magnets (JGG+ TPL-B) \$190,000
 - Drift chambers \$150,000
 - E-690 Cerenkov \$ 50,000(in process)
 - Data Acquisition \$200,000
 - Total \$640,000
-
- SELEX RICH counter is available.
 - Container + Mirror system
 - ~3K Phototubes at \$350 per tube is the major cost
 - Some tubes and electronics Russian owned. (\$60K)
 - Some FNAL owned. CKM might need some parts from this such as the gas system.