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

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P907 Collaboration meeting Sep 29, 2000
Fermilab

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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.

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.

Nuclear Physics

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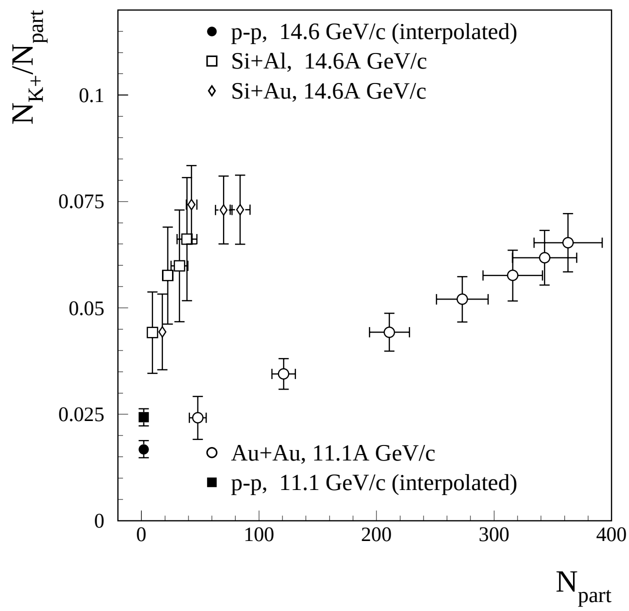

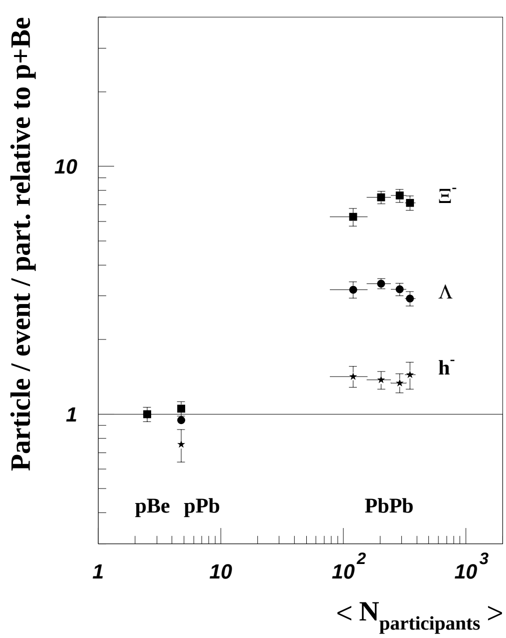

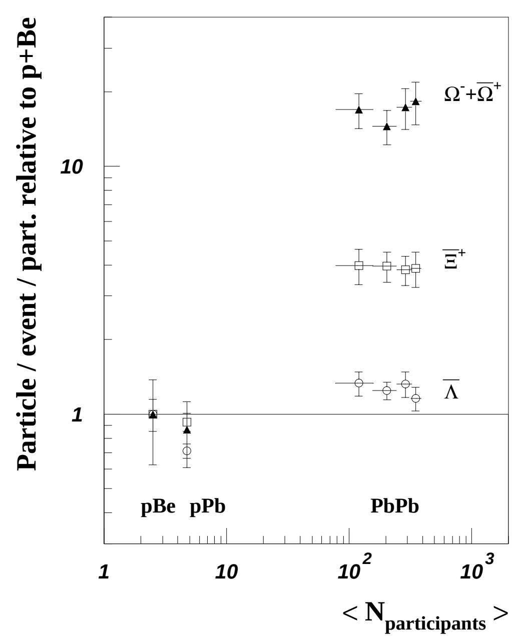

Nuclear Physics

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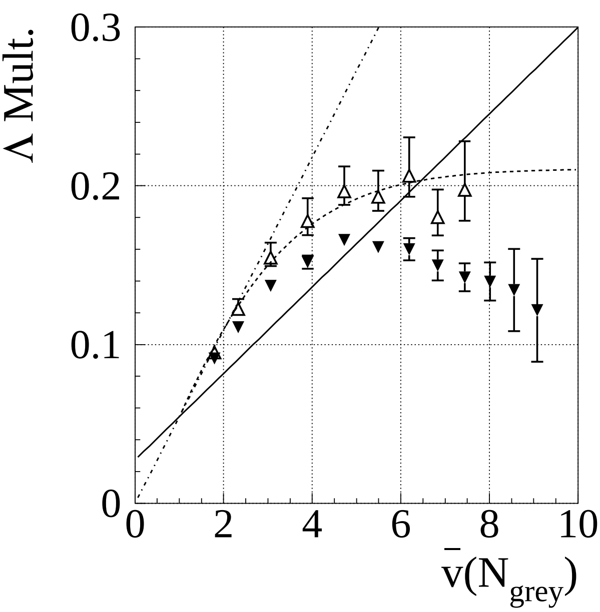
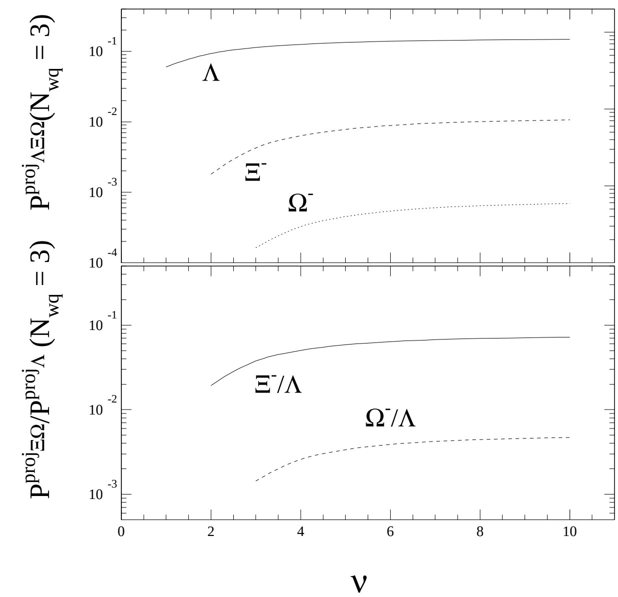
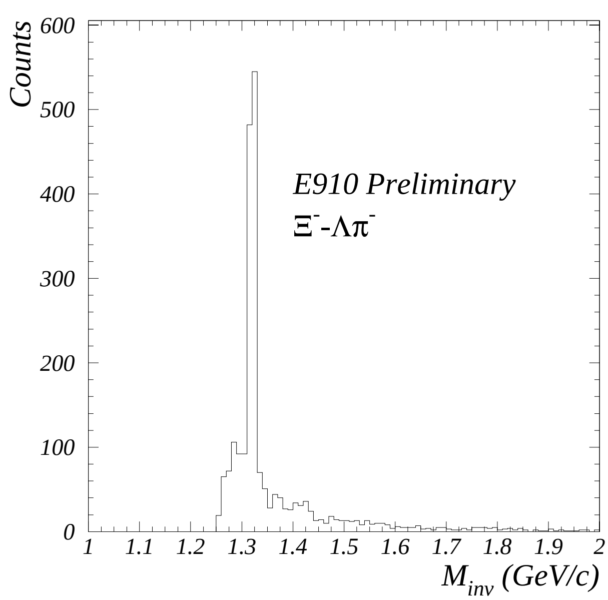
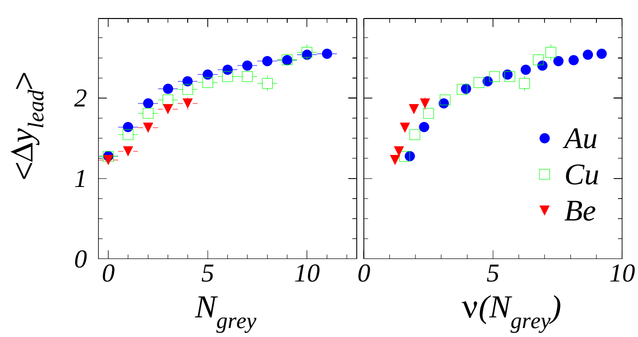


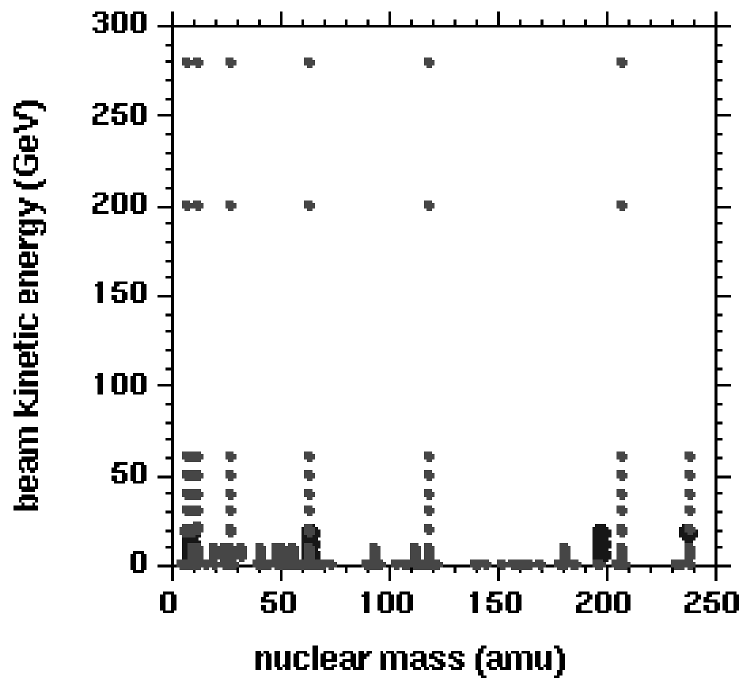






Proton Radiography

- Few measurements in the 50 GeV range.

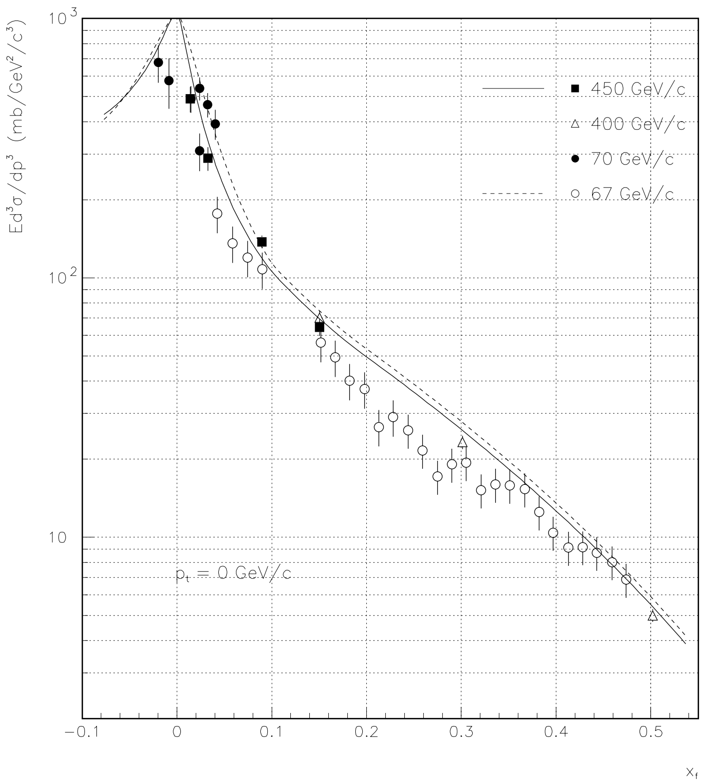


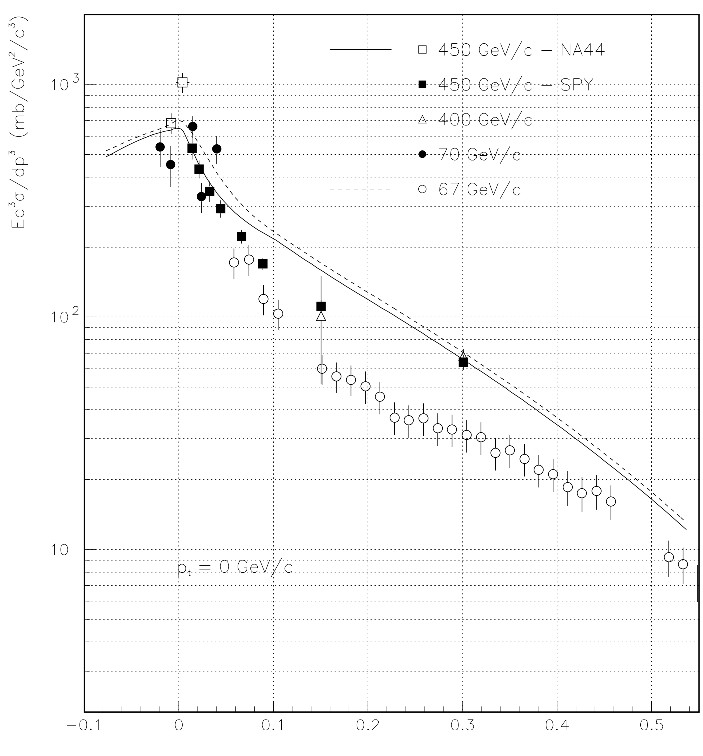
- Data should cover 5 GeV/c to 115 GeV/c in beam momentum with 10 GeV/c spacing. Data sets of 10^5-10^6 minbias interactions along with a sizable fraction of p+A-->p+X in the forward region. Wide variety of nuclear targets. Particle id needed.

Neutrino factory needs and atmospheric neutrinos

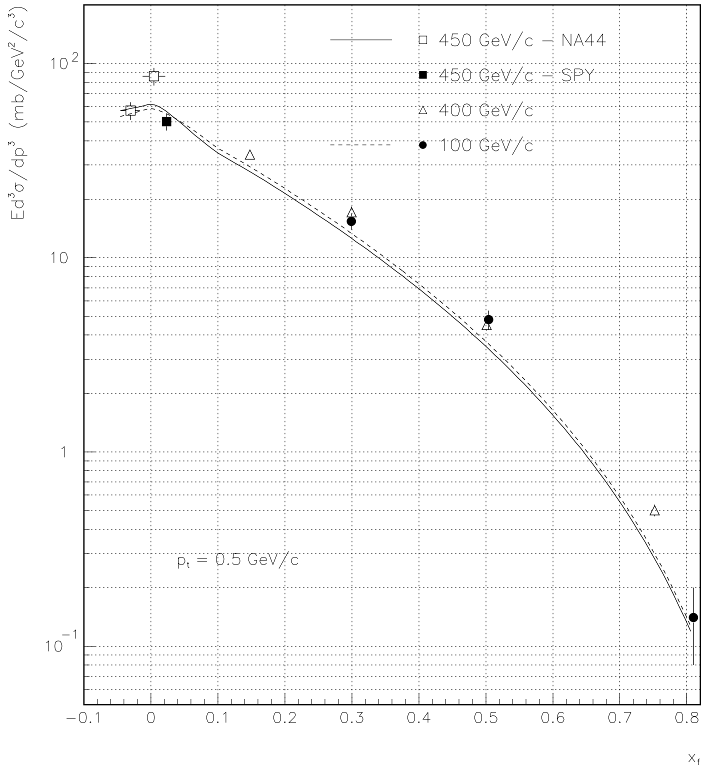
- Neutrino Factory Needs
  - Primary target material not yet decided upon for the muon collider. Theoretical models of particle production off nuclei can be wrong by 20-30%.
  - Nor is the primary beam. E910 at BNL has taken data using 12.5 GeV and 18.5 GeV/c primary protons on Cu and Au targets using 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.
- Atmospheric neutrinos
  - Uncertainty in atmospheric neutrinos comes from Primary flux (5-10%), Hadronic interactions (30-40% in normalization and ~7% in electron/muon neutrino ratios), Neutrino cross sections (20%).
  - We plan to measure proton and pion cross sections on N_2 and O_2 in the range 5 GeV to 110 GeV and can do in one experiment what takes two experiments to do at CERN.

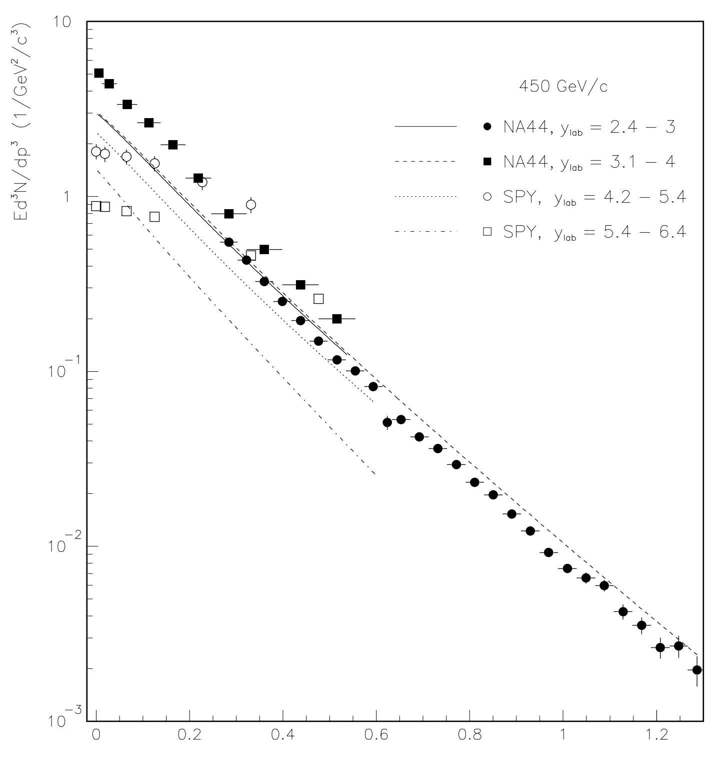
Quality of existing data



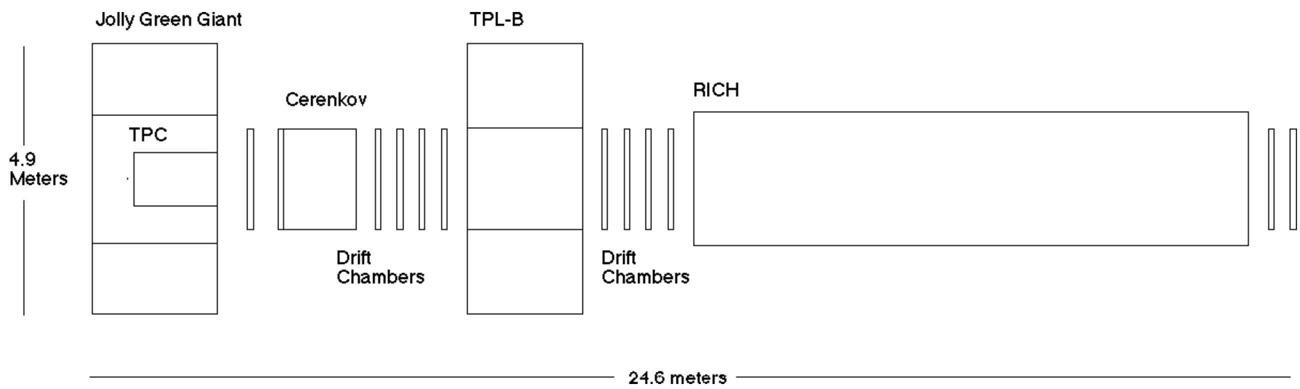


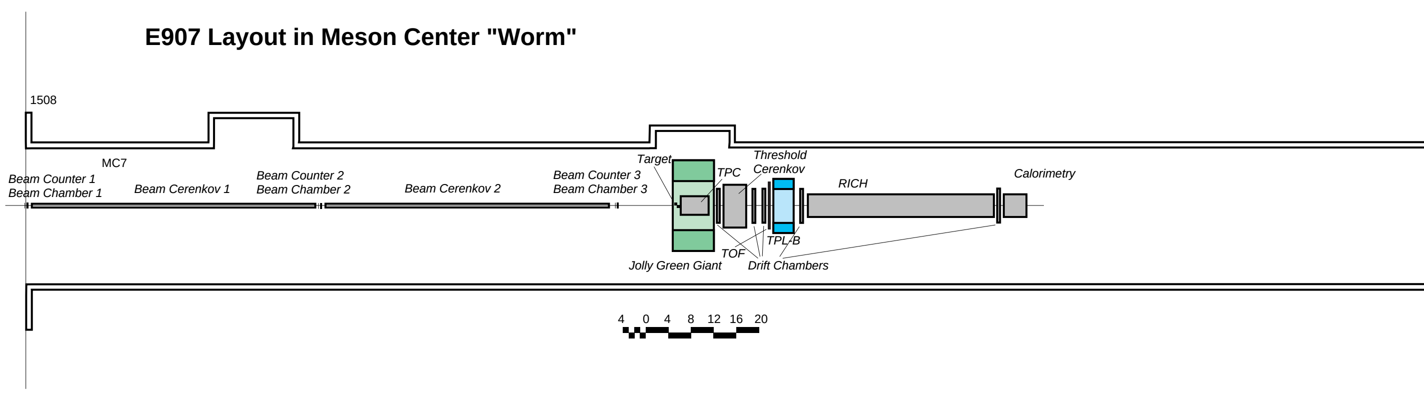
Quality of existing data

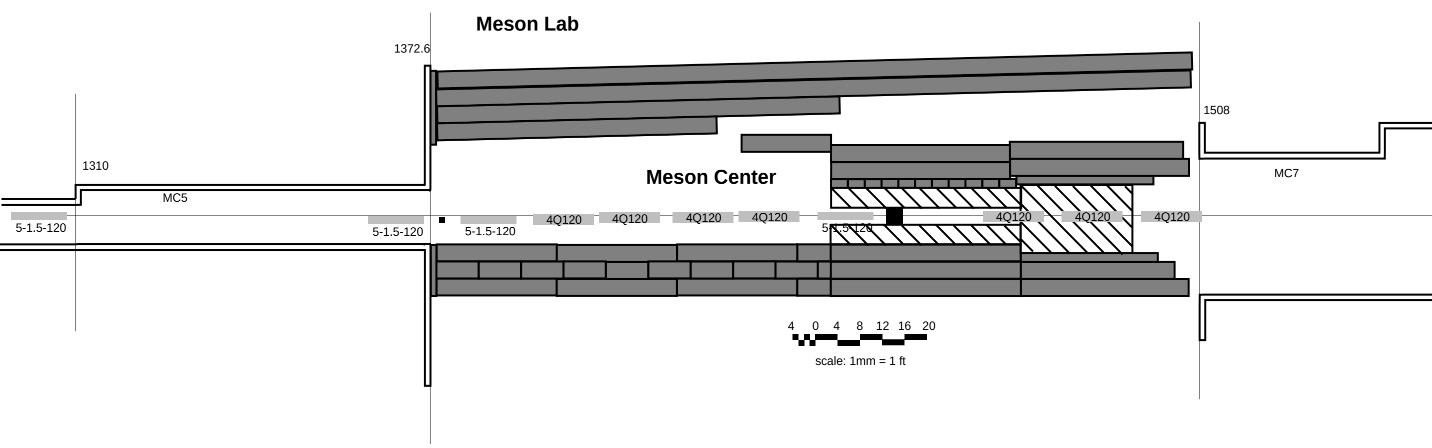




Implementation Scheme



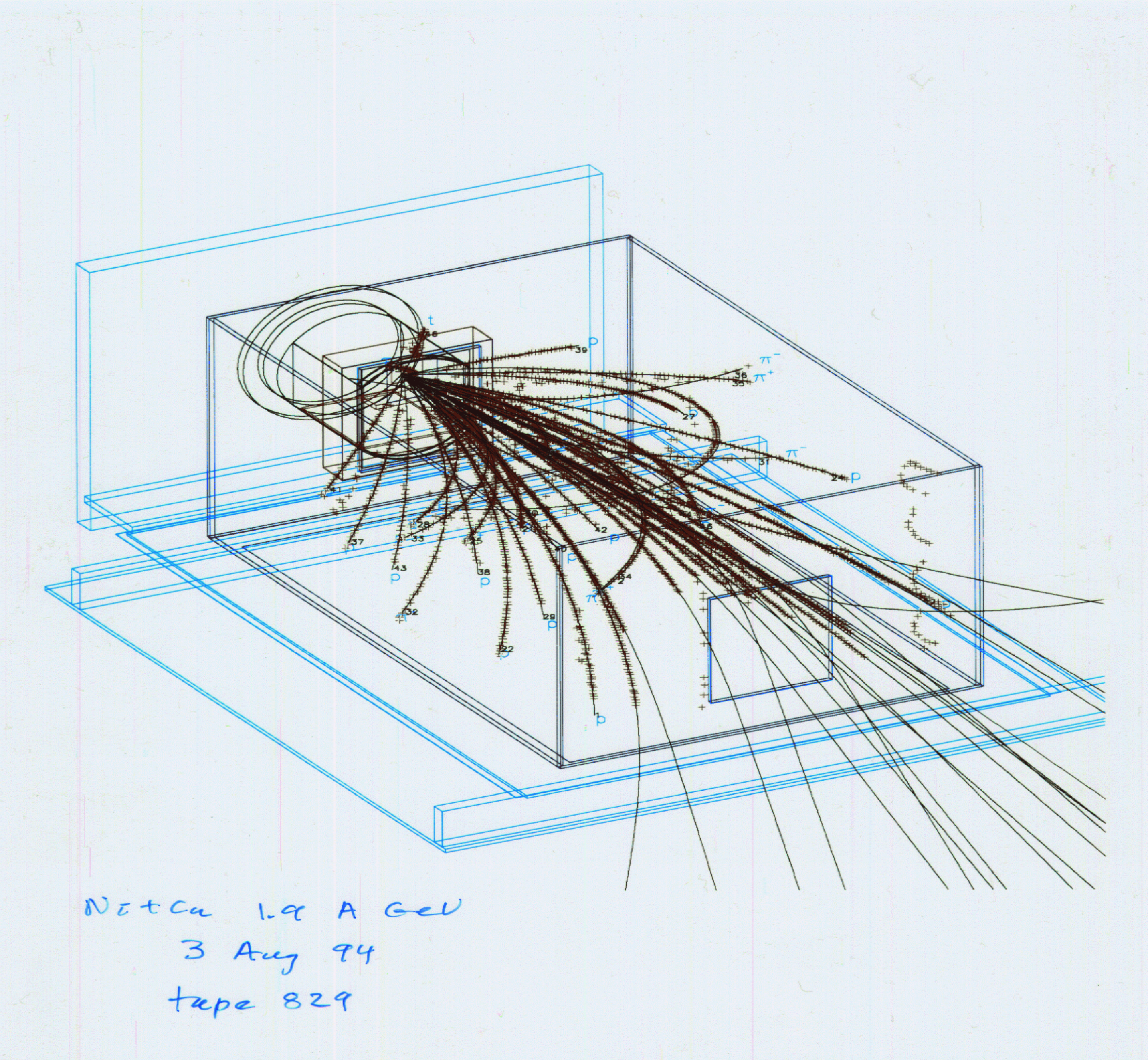




EOS-TPC

- 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 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 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



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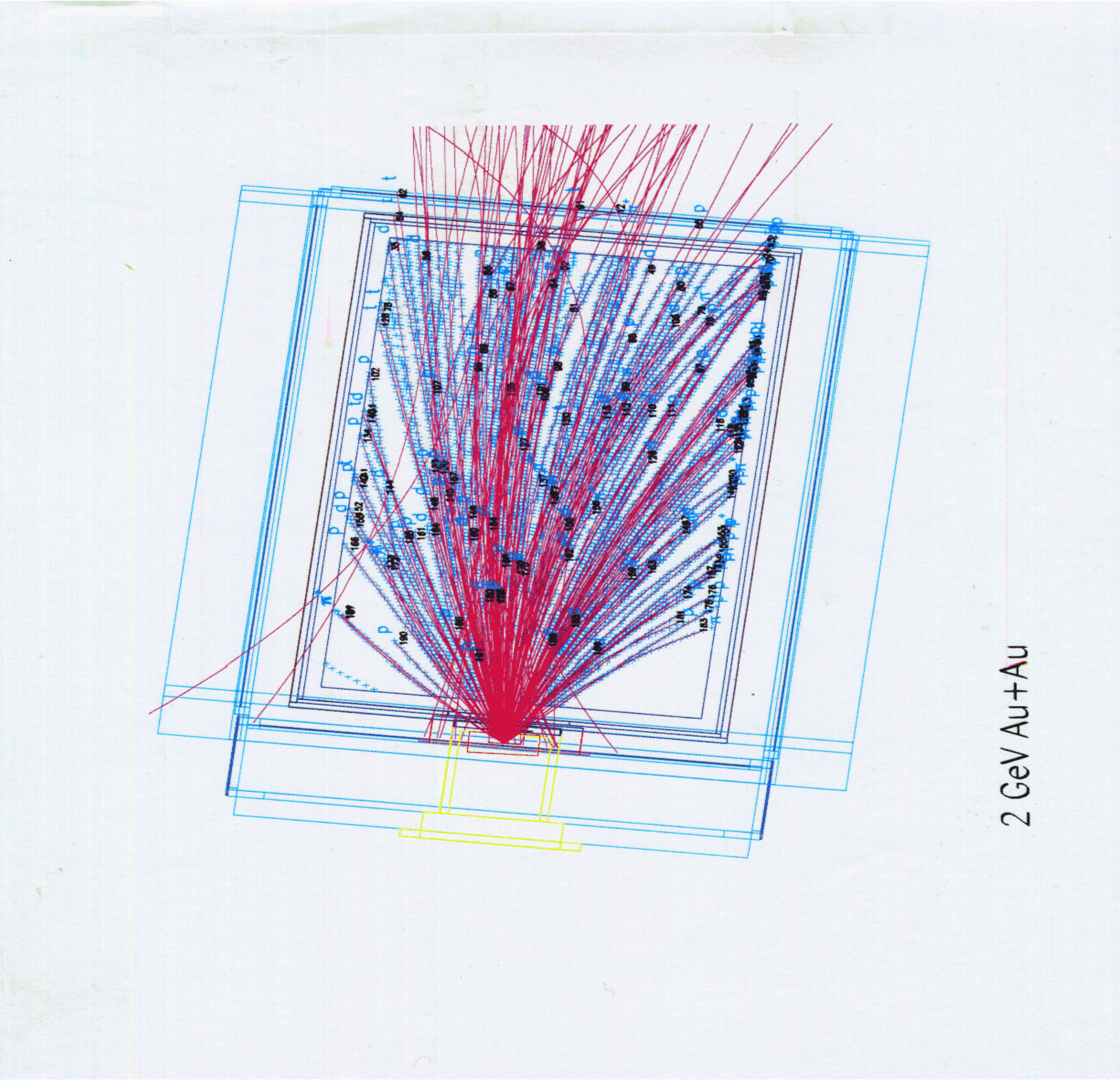
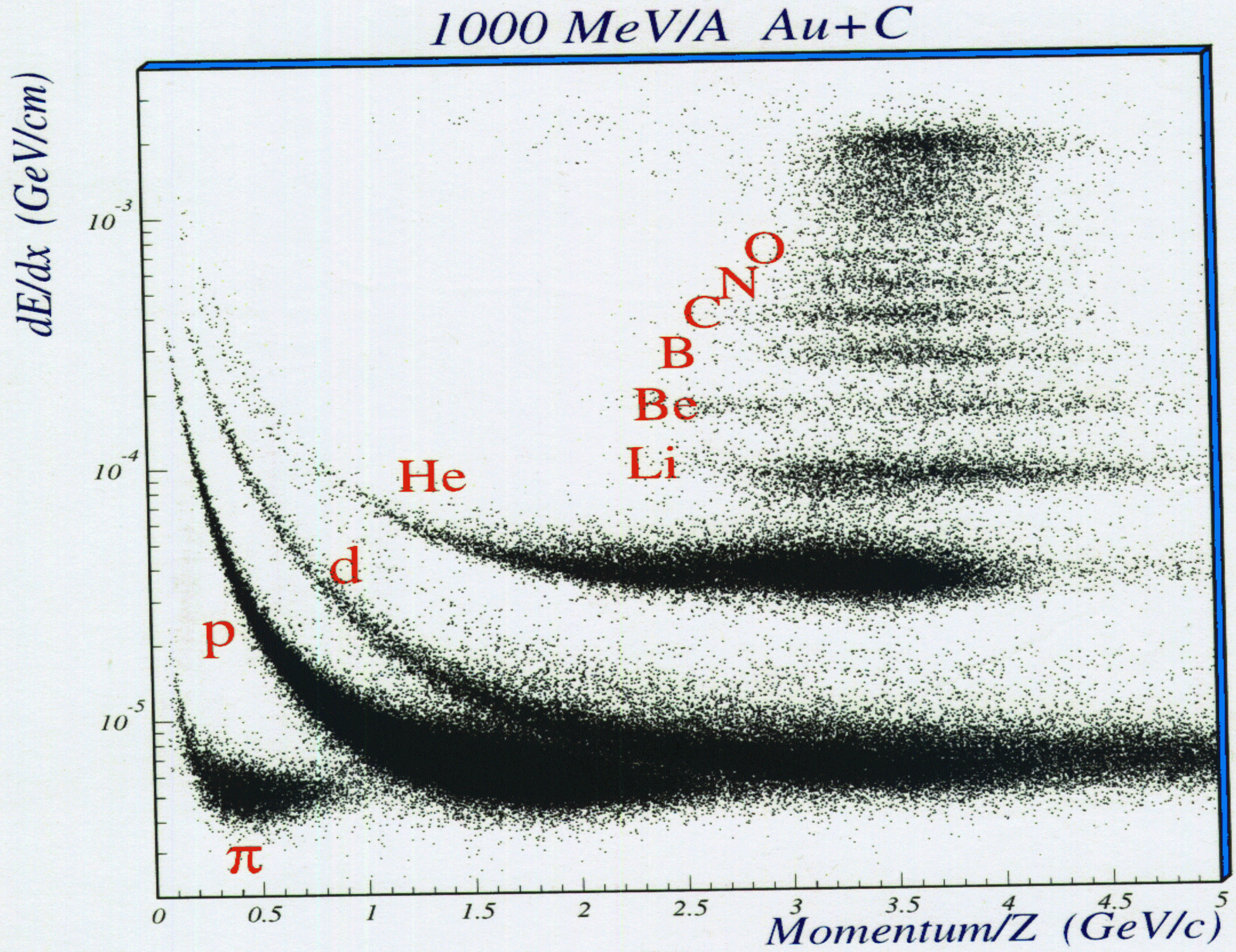
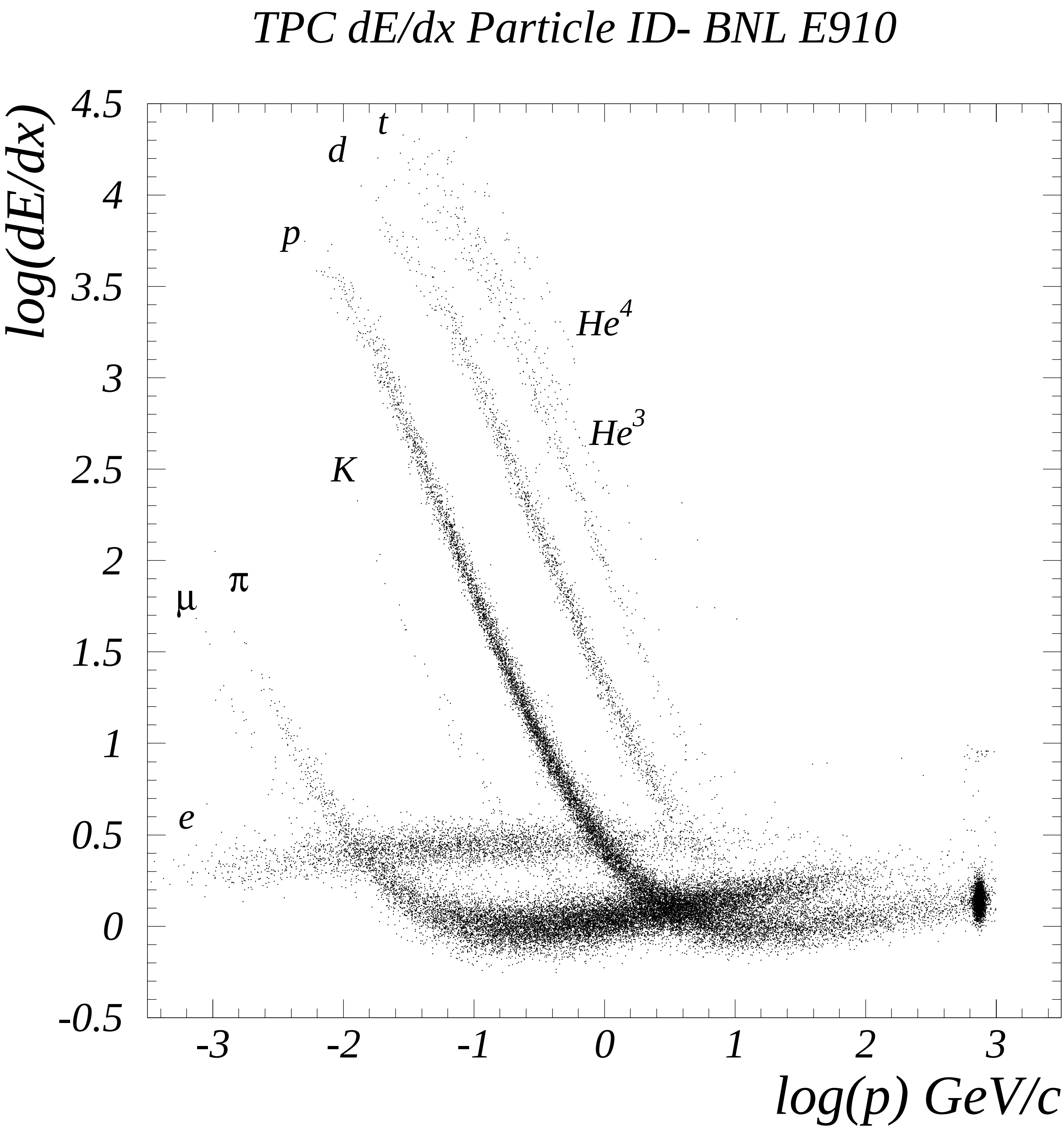


Nuclear dE/dx



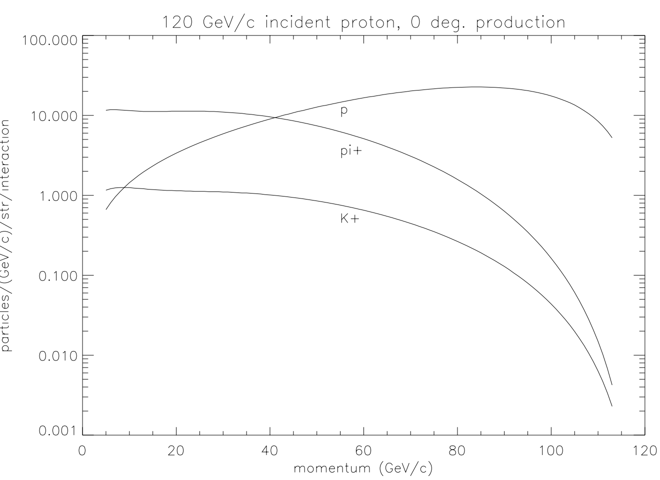
TPC dE/dx capabilities

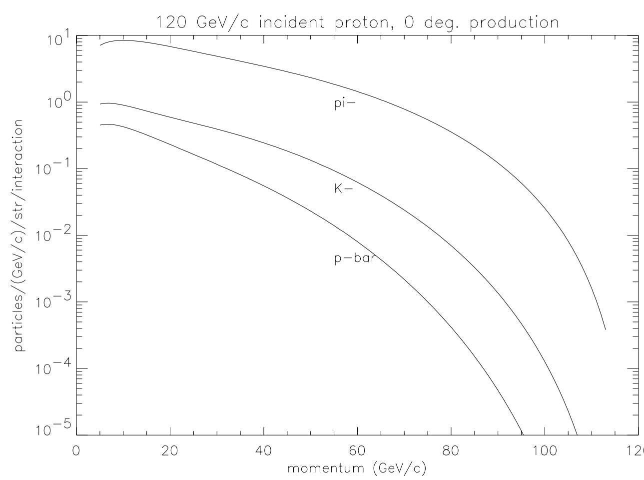


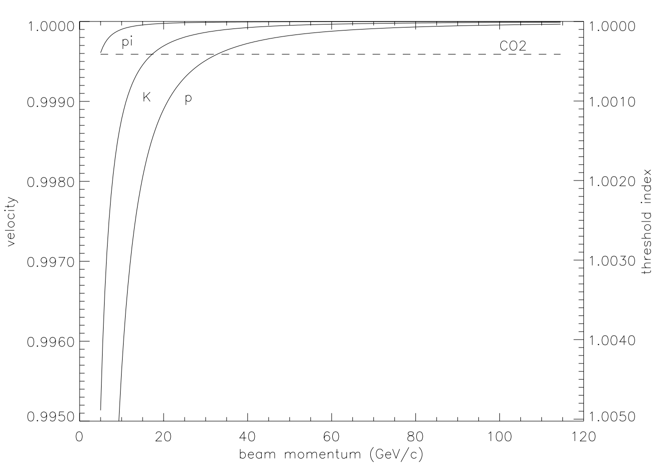
Beam line requirements and design

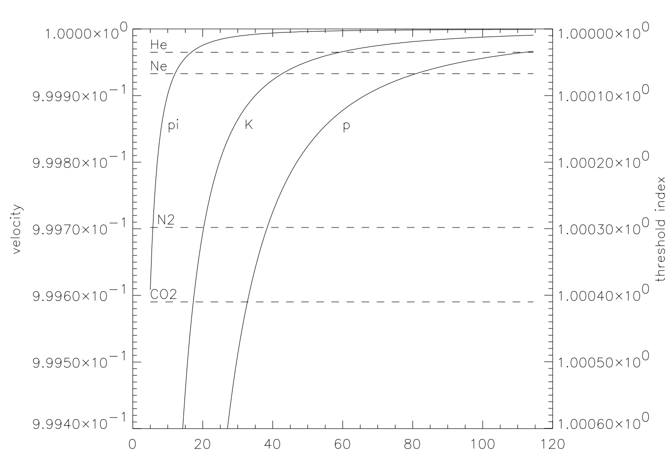
- The secondary beam will be tagged with two threshold Cerenkov counters. The three beam species of π,K and p can be tagged by demanding 1)that π's radiate in the first counter and K's do not, 2) π's and K's radiate in counter 2 and p's do not.

Secondary particle beam production rates and tagging Cerenkov characteristics

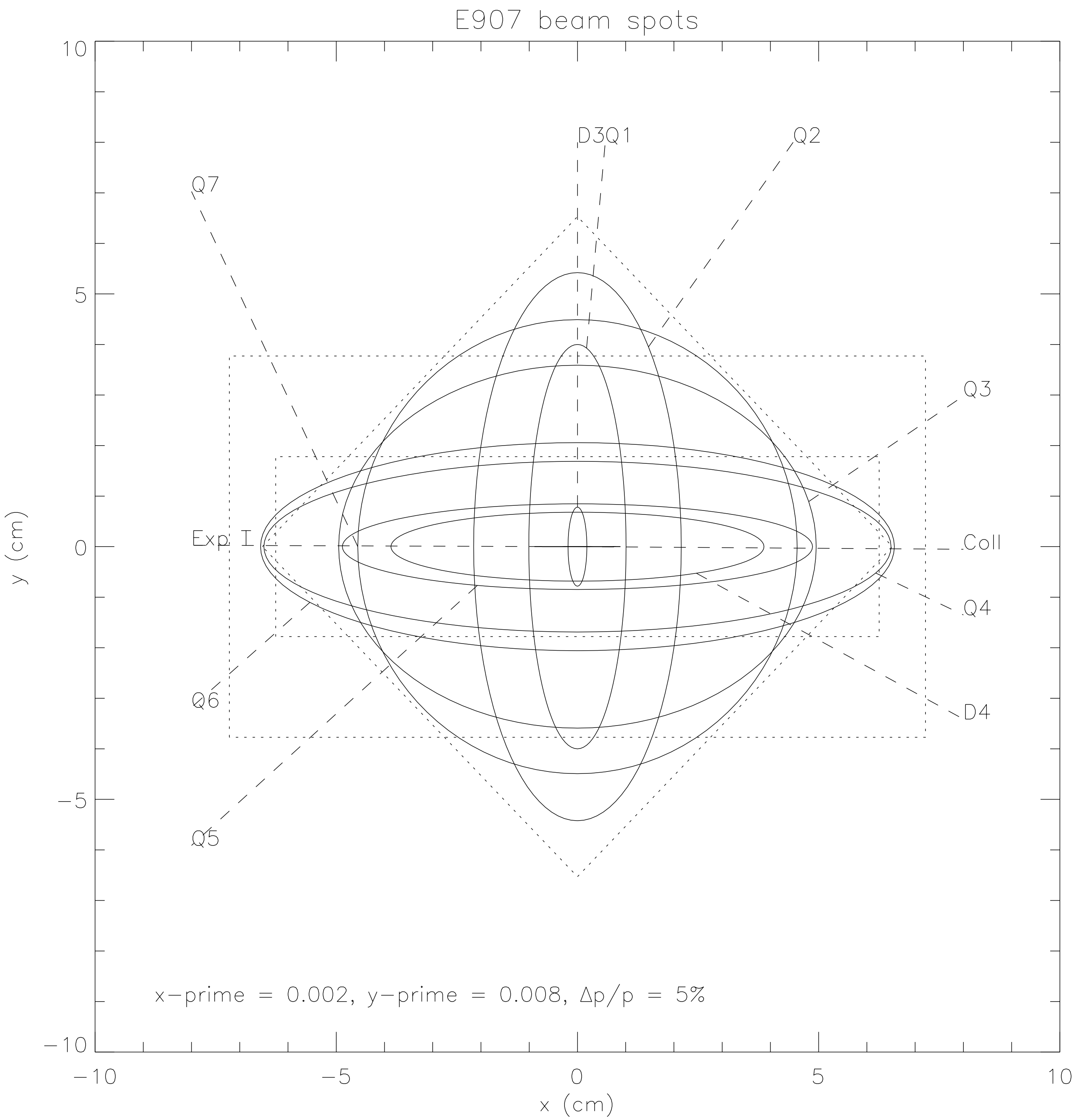








Beam envelope



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

Table 1: Particle rates, prescale factors and event yields for a positive secondary beam.

p GeV/c	p Hz	K^+ Hz	π^+ Hz	p prescale factor	K^+ prescale factor	π^+ prescale factor	p events	K^+ events	π^+ events
5	52.28	58.58	631.37	0.38	0.34	0.03	1000000	1000000	1000000
10	226.54	108.44	1105.01	0.09	0.18	0.02	1000000	1000000	1000000
20	1062.36	165.98	1878.38	0.02	0.12	0.01	1000000	1000000	1000000
30	2783.73	212.66	2507.73	0.01	0.09	0.01	1000000	1000000	1000000
40	5686.32	236.62	2698.51	0.00	0.08	0.01	1000000	1000000	1000000
50	9994.11	229.28	2453.26	0.00	0.09	0.01	1000000	1000000	1000000
60	15691.44	195.47	1925.14	0.00	0.10	0.01	1000000	1000000	1000000
70	22257.07	146.18	1297.94	0.00	0.14	0.02	1000000	1000000	1000000
80	28311.92	93.58	728.22	0.00	0.21	0.03	1000000	1000000	1000000
90	31299.95	48.26	314.94	0.00	0.41	0.06	1000000	1000000	1000000
100	27631.13	17.26	87.21	0.00	1.16	0.23	1000000	862861	1000000
110	14636.48	2.61	8.43	0.00	7.65	2.37	1000000	130727	421312

Table 2: Particle rates, prescale factors and event yields for a negative secondary beam.

p GeV/c	$\bar{p}$ Hz	K^- Hz	π^- Hz	$\bar{p}$ prescale factor	K^- prescale factor	π^- prescale factor	$\bar{p}$ events	K^- events	π^- events
5	37.41	41.42	407.83	0.53	0.48	0.05	1000000	1000000	1000000
10	70.42	69.36	852.41	0.28	0.29	0.02	1000000	1000000	1000000
20	76.32	77.66	1180.99	0.26	0.26	0.02	1000000	1000000	1000000
30	57.68	69.32	1146.29	0.35	0.29	0.02	1000000	1000000	1000000
40	36.55	52.79	997.96	0.55	0.38	0.02	1000000	1000000	1000000
50	19.09	33.64	789.31	1.05	0.59	0.03	954290	1000000	1000000
60	7.95	17.72	554.05	2.52	1.13	0.04	397365	885985	1000000
70	2.51	7.49	334.65	7.96	2.67	0.06	125665	374417	1000000
80	0.55	2.38	165.75	36.26	8.41	0.12	27575	118952	1000000
90	0.07	0.50	61.34	285.46	40.35	0.33	3503	24786	1000000
100	0.00	0.05	13.68	5902.56	406.28	1.46	169	2461	684028

Beam rates for positive and negative beams

Table 3: Primary beam rates, secondary beam rates and event yields for a positive secondary beam.

p GeV/c	primary protons per spill	p Hz	K^+ Hz	π^+ Hz	total Hz	p events	K^+ events	π^+ events	total events
5	7.65×10^8	2000	5211	41642	48853	1000000	1000000	1000000	3000000
10	3.69×10^8	4178	4651	35138	43967	1000000	1000000	1000000	3000000
20	2.41×10^8	12801	4651	39024	56476	1000000	1000000	1000000	3000000
30	1.88×10^8	26180	4651	40663	71495	1000000	1000000	1000000	3000000
40	1.69×10^8	48062	4651	39325	92038	1000000	1000000	1000000	3000000
50	1.69×10^8	84655	4517	35828	125000	1000000	971069	1000000	2971069
60	1.28×10^8	100766	2919	21315	125000	1000000	627637	1000000	2627637
70	1.01×10^8	112025	1711	11264	125000	1000000	367873	1000000	2367873
80	8.39×10^7	118817	913	5269	125000	1000000	196370	1000000	2196370
90	7.82×10^7	122437	439	2124	125000	1000000	94390	615986	1710376
100	8.99×10^7	124144	180	676	125000	1000000	38768	195914	1234682
110	1.71×10^8	124824	52	124	125000	1000000	11149	35931	1047079

Table 4: Primary beam rates, secondary beam rates and event yields for a negative secondary beam.

p GeV/c	primary protons per spill	$\bar{p}$ Hz	K^- Hz	π^- Hz	total Hz	$\bar{p}$ events	K^- events	π^- events	total events
5	1.07×10^9	2000	5149	37592	44741	1000000	1000000	1000000	3000000
10	5.77×10^8	2031	4651	42376	49057	1000000	1000000	1000000	3000000
20	5.24×10^8	2000	4733	53356	60089	1000000	1000000	1000000	3000000
30	6.94×10^8	2000	5591	68534	76125	1000000	1000000	1000000	3000000
40	1.09×10^9	2000	6717	94139	102856	1000000	1000000	1000000	3000000
50	1.71×10^9	1636	6707	116657	125000	924377	1000000	1000000	2924377
60	2.49×10^9	989	5128	118882	125000	558816	1000000	1000000	2558816
70	4.19×10^9	526	3647	120827	125000	297365	911704	1000000	2209069
80	8.57×10^9	236	2370	122394	125000	133454	592393	1000000	1725847
90	2.34×10^{10}	82	1347	123571	125000	46250	336739	1000000	1382989
100	1.05×10^{11}	18	604	124378	125000	10095	150918	1000000	1161013

Total amount of running time

- 3000 hours/year allows 24 data points.
- 1 data point = $3x10^6$ events

Table 5: Running time requirements for various aspects of E907 running.

Target	"Physics"	Beam Energies	Beam Charges	factor (3×10^6 events/data point)	data points
NuMI 1	MINOS	1	1	3.3	3.3
NuMI 2	MINOS	1	1	3.3	3.3
H_2	scaling	12	2	1.0	24.0/4
N_2	atm. ν	3	2	0.5	3.0
O_2	atm. ν	3	2	0.5	3.0
Be	p-A	1	1	2.0	2.0
Be	survey	5	2	0.1	1.0
C	survey	5	2	0.1	1.0
Cu	p-A	1	1	2.0	2.0
Cu	survey	5	2	0.1	1.0
Pb	p-A	1	1	2.0	2.0
Pb	survey	5	2	0.1	1.0
total					26.6

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

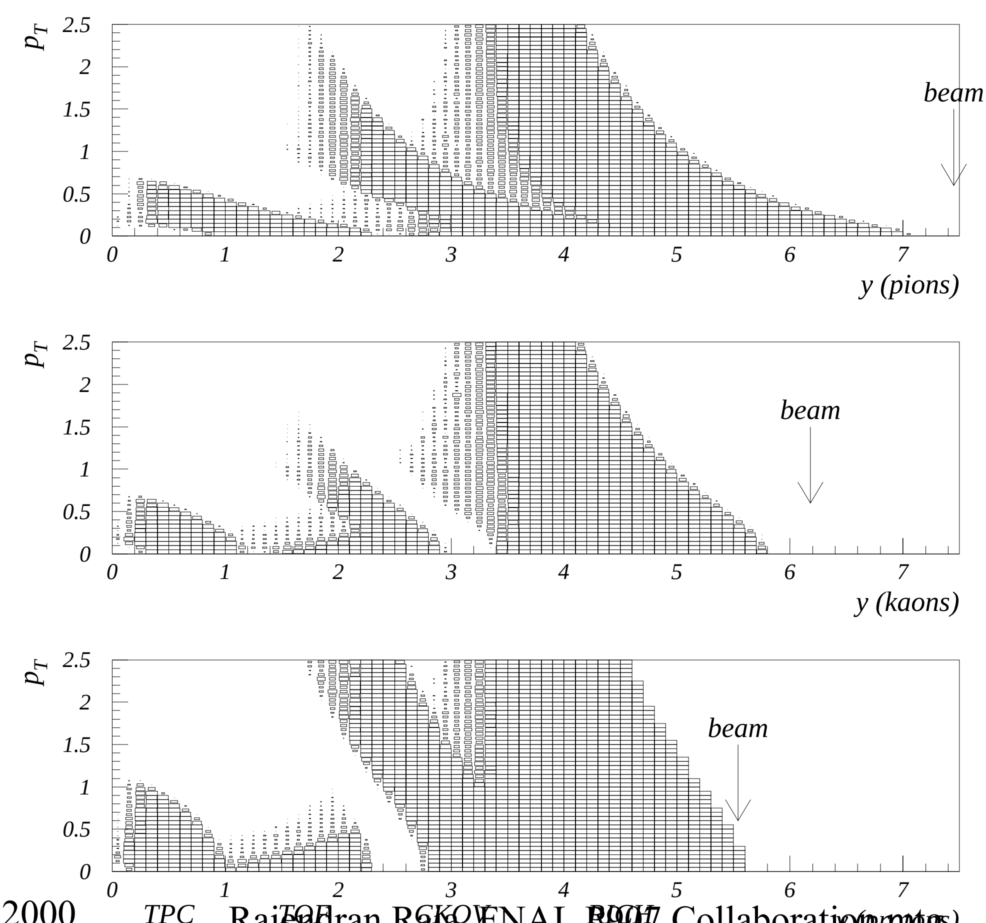
- TPC as shown can provide 3σ separation with dE/dx up to 0.7 GeV/c for π/K and 1.1 GeV/c for K/p as well as ambiguous additional information in the relativistic rise region.
- In the intermediate region, we propose to use the Cerenkov detector of E690 (E766) currently at BNL E-910. Light is collected 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

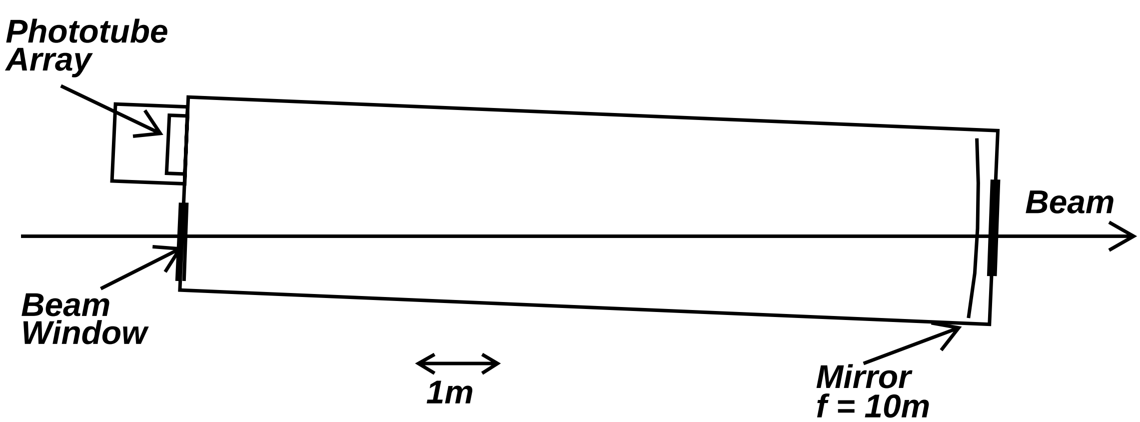
TOF System and PID acceptances

- 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



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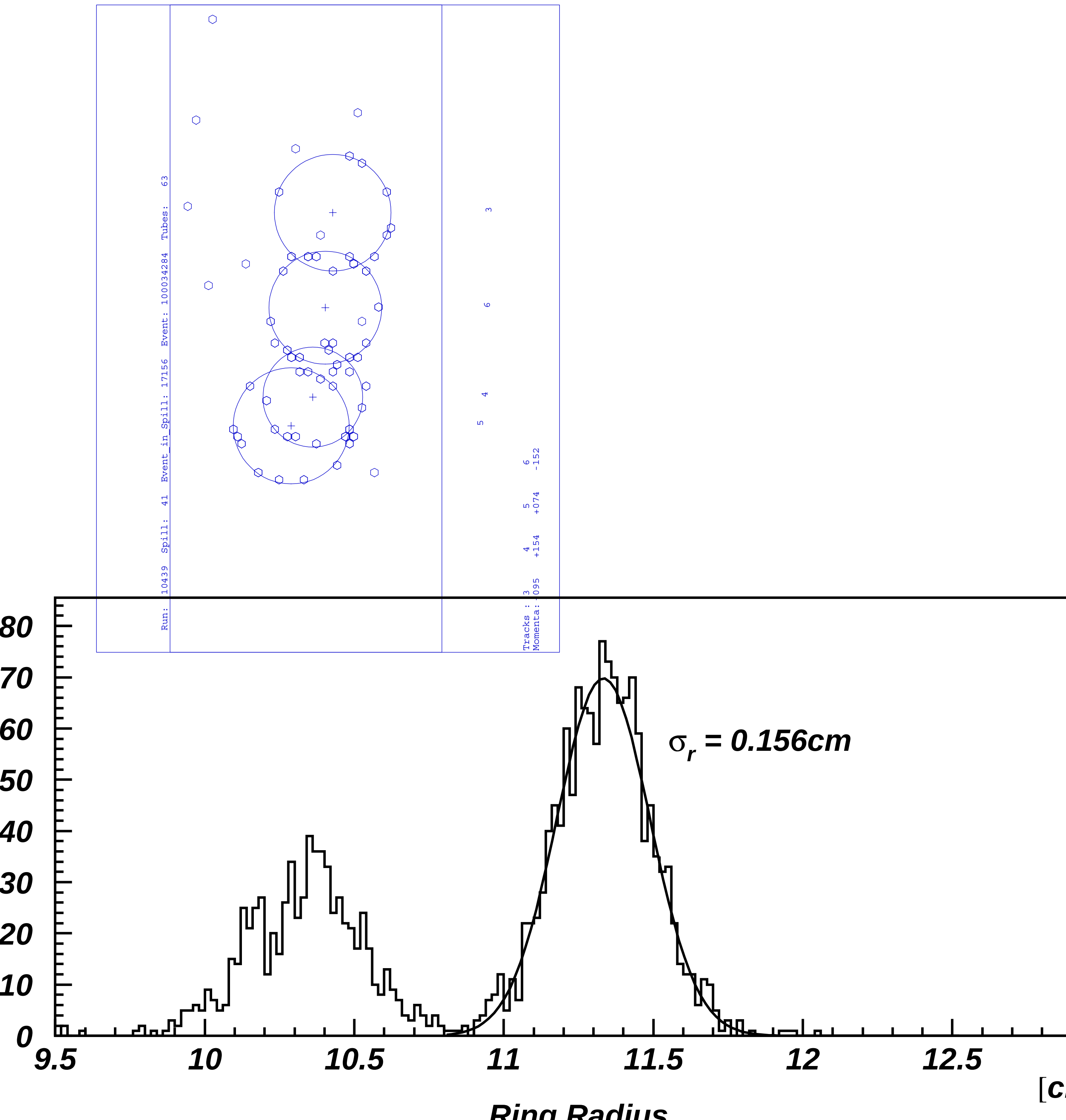

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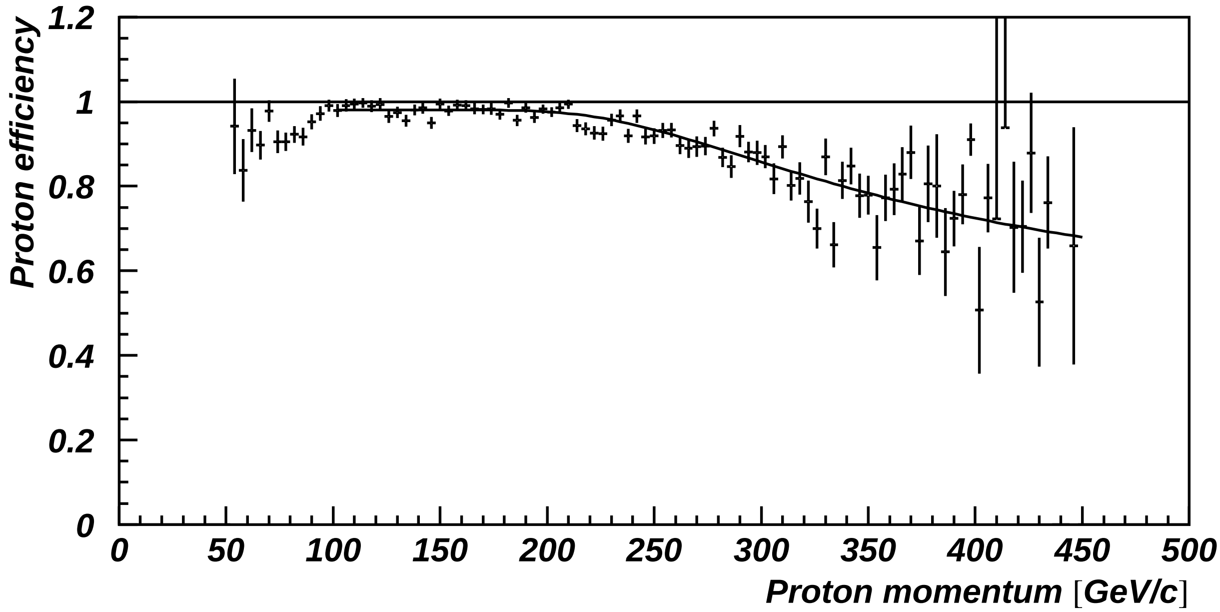
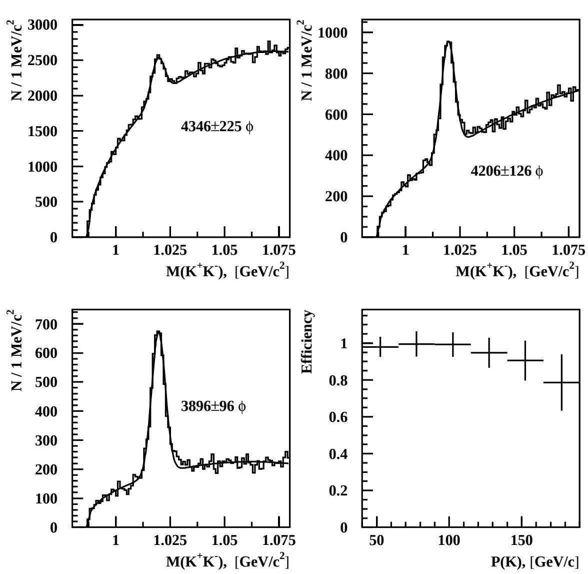
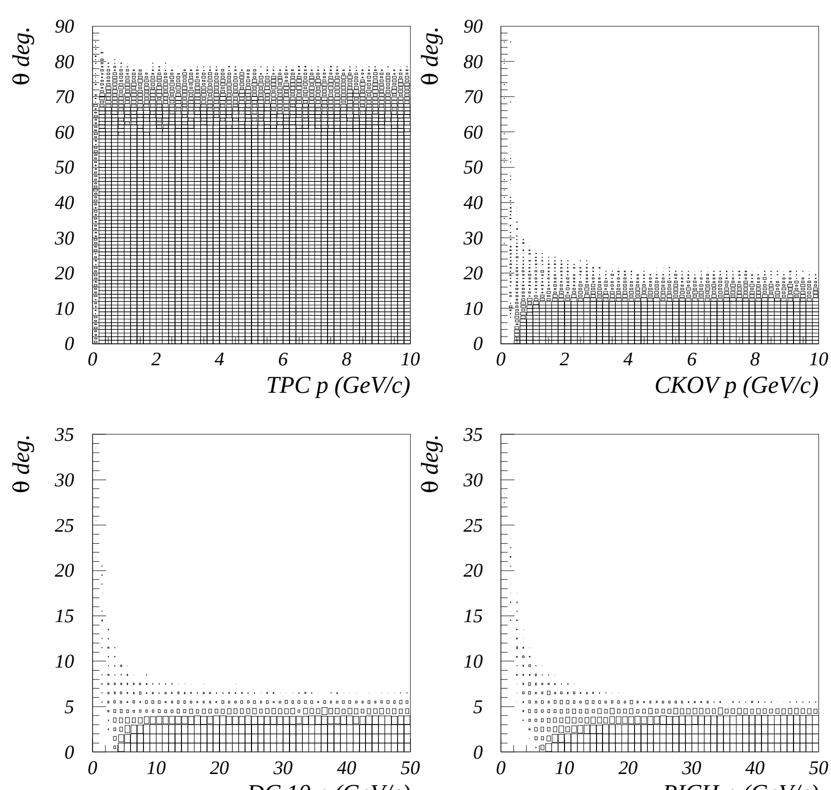




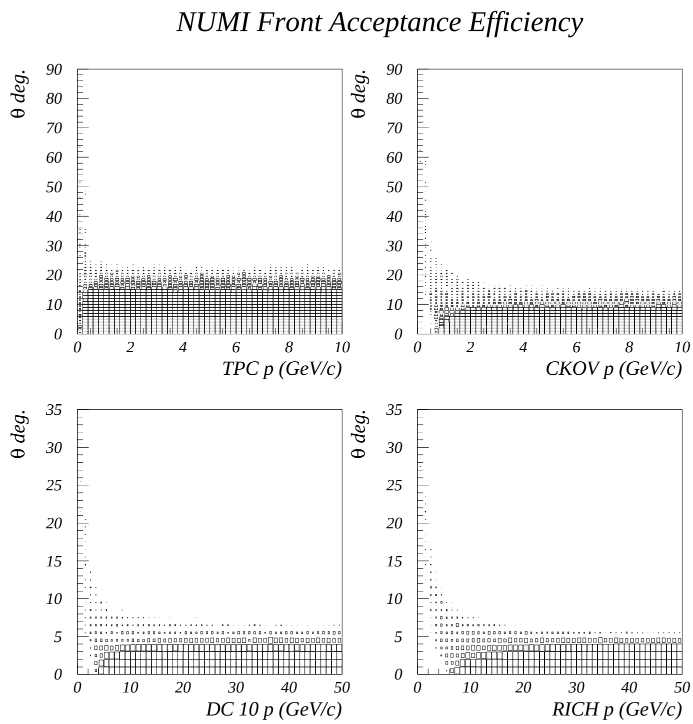
Particle acceptances and resolutions

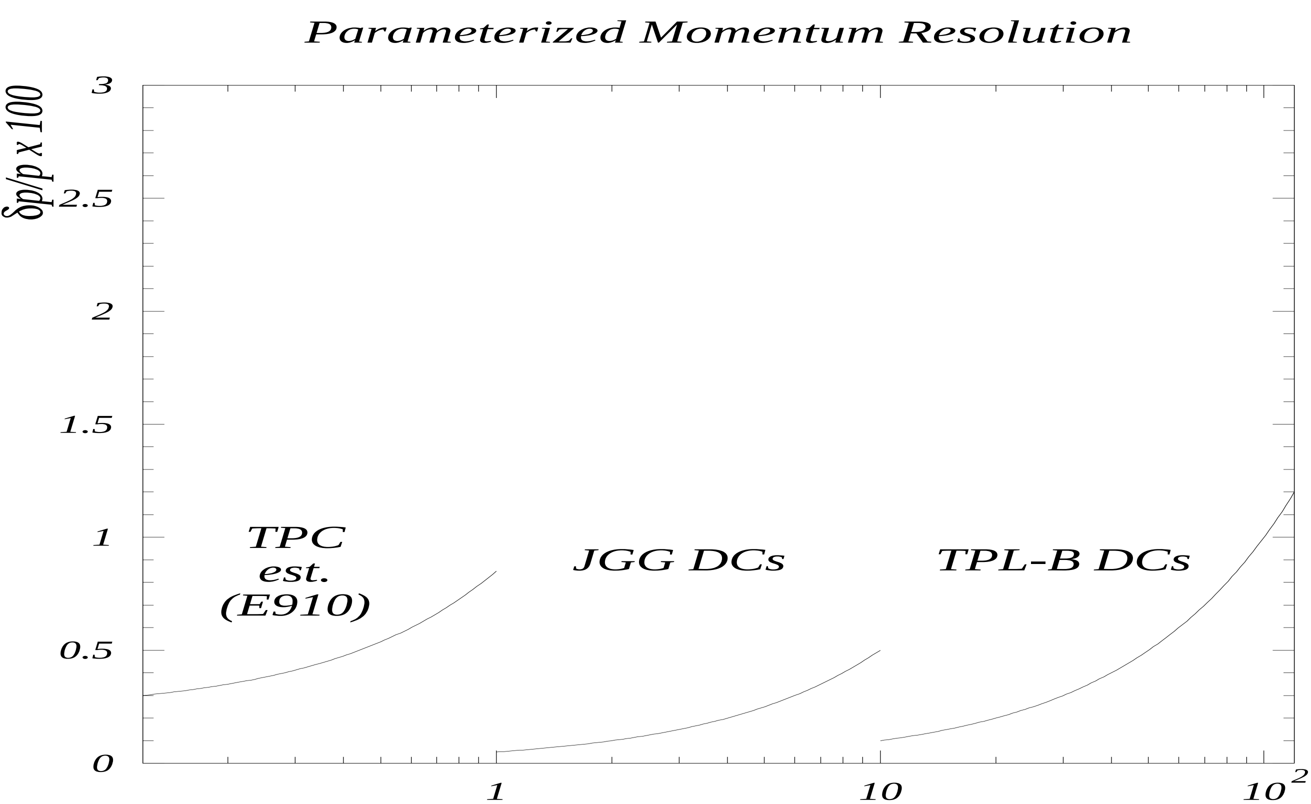
- a)10 Hits in TPC
- b)a hit in the Cerenkov
- c)a hit in Drift Chamber 10 (just before RICH)
- d)Passage through mid-Z plane of RICH.
- Regular Target and NUMI target
- Four cases of particles considered
- (Cumulative AND)

Positive Particle Acceptance Efficiency

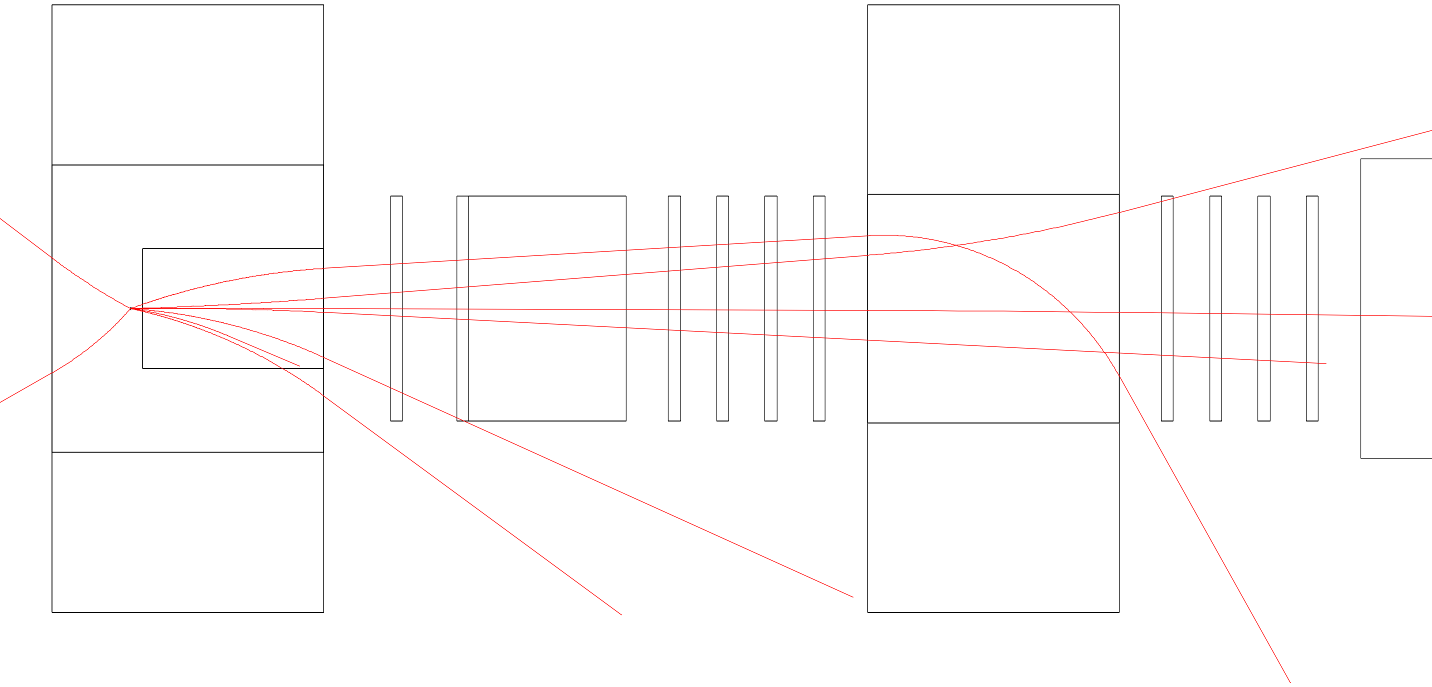


Particle acceptances and resolutions NUMI case





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 ,pbar-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

WBS	Task Name	EDIA	Labor	NAL & E907	FNAL | T&M	M&S	T&M	Other M&S	Total Cost
0	**Fermilab E907**	**$138,160**	**$295,894**	**258488**	**37406**	**$536,100**	**277500**	**258600**	**$970,154**
1	Experiment Design	$0	$0	0	**0**	$0	0	0	$0
2	**Meson Hall (MC6) Preparation**	**$1,760**	**$26,408**	**3480**	**22928**	**$100,000**	**100000**	**0**	**$128,168**
2.1	MC6 Cleanout Planning	$1,760	$0	0	**0**	$0	0	0	$1,760
2.2	MC6 Clear Storage from Top of Piles	$0	$15,180	0	**15180**	$0	0	0	$15,180
2.3	**Open and Clear Pretarget Enclosure (P**	**$0**	**$9,520**	**2784**	**6736**	**$50,000**	**50000**	**0**	**$59,520**
2.3.1	PTE Remove Concrete Lid Blocks	$0	$0	0	**0**	$37,500	37500	0	$37,500
2.3.2	PTE Remove Steel Lid	$0	$0	0	**0**	$12,500	12500	0	$12,500
2.3.3	PTE Remove Steel Side Walls	$0	$5,060	0	**5060**	$0	0	0	$5,060
2.3.4	PTE Disconnect Magnets	$0	$2,784	2784	**0**	$0	0	0	$2,784
2.3.5	PTE Remove Magnets	$0	$1,676	0	**1676**	$0	0	0	$1,676
2.4	**Open and Clear Target Pile (TP)**	**$0**	**$1,708**	**696**	**1012**	**$50,000**	**50000**	**0**	**$51,708**
2.4.1	TP Remove Concrete Lid Blocks	$0	$0	0	**0**	$25,000	25000	0	$25,000
2.4.2	TP Remove Steel Plugs	$0	$0	0	**0**	$12,500	12500	0	$12,500
2.4.3	TP Remove Downstream Concrete Bl	$0	$0	0	**0**	$12,500	12500	0	$12,500
2.4.4	TP Disconnect Magnet	$0	$696	696	**0**	$0	0	0	$696
2.4.5	TP Remove Magnet	$0	$1,012	0	**1012**	$0	0	0	$1,012
3	**E907 Beamline (in MC6)**	**$0**	**$15,200**	**10140**	**5060**	**$100,000**	**100000**	**0**	**$115,200**
3.1	**Secondary Beamline (BEAM) Magnet In**	**$0**	**$10,140**	**10140**	**0**	**$0**	**0**	**0**	**$10,140**
3.1.1	BEAM Install 3 Dipoles	$0	$6,180	6180	**0**	$0	0	0	$6,180
3.1.2	BEAM Install 4 Quadrupoles	$0	$2,060	2060	**0**	$0	0	0	$2,060
3.1.3	BEAM Survey	$0	$1,900	1900	**0**	$0	0	0	$1,900
3.2	**Close Pretarget Enclosure**	**$0**	**$5,060**	**0**	**5060**	**$50,000**	**50000**	**0**	**$55,060**
3.2.1	PTE Replace Steel Side Walls	$0	$5,060	0	**5060**	$0	0	0	$5,060
3.2.2	PTE Replace Steel Lid	$0	$0	0	**0**	$12,500	12500	0	$12,500
3.2.3	PTE Replace Concrete Lid Blocks	$0	$0	0	**0**	$37,500	37500	0	$37,500
3.3	**Close Target Pile**	**$0**	**$0**	**0**	**0**	**$50,000**	**50000**	**0**	**$50,000**
3.3.1	TP Replace Downstream Concrete Bl	$0	$0	0	**0**	$12,500	12500	0	$12,500
3.3.2	TP Replace Steel Plugs	$0	$0	0	**0**	$12,500	12500	0	$12,500
3.3.3	TP Replace Concrete Lid Blocks	$0	$0	0	**0**	$25,000	25000	0	$25,000
4	**Meson Worm (MC7) Preparation**	**$0**	**$13,726**	**9056**	**4670**	**$31,500**	**22500**	**9000**	**$45,226**
4.1	**Remove or Stage Hyper-CP Detectors**	**$0**	**$4,560**	**4560**	**0**	**$0**	**0**	**0**	**$4,560**
4.1.1	MC7 Stage 9 PWC	$0	$3,800	3800	**0**	$0	0	0	$3,800
4.1.2	MC7 Remove 2 HODO	$0	$760	760	**0**	$0	0	0	$760
4.2	**Remove BM109 Magnets**	**$0**	**$5,526**	**2756**	**2770**	**$22,500**	**22500**	**0**	**$28,026**
4.2.1	MC7 Disconnect BM109 Magnets	$0	$1,030	1030	**0**	$0	0	0	$1,030
4.2.2	MC7 Prep Outside Area for Crane	$0	$2,770	0	**2770**	$0	0	0	$2,770
4.2.3	MC7 Move Utilities	$0	$1,030	1030	**0**	$0	0	0	$1,030
4.2.4	MC7 Open Worm	$0	$696	696	**0**	$0	0	0	$696
4.2.5	MC7 Rig Out BM109 Magnets	$0	$0	0	**0**	$22,500	22500	0	$22,500
4.3	**Close MC7 Worm**	**$0**	**$3,640**	**1740**	**1900**	**$9,000**	**0**	**9000**	**$12,640**
4.3.1	MC7 Restore Utilities	$0	$1,740	1740	**0**	$0	0	0	$1,740
4.3.2	MC7 Replace Panels and Insulation	$0	$1,900	0	**1900**	$9,000	0	9000	$10,900

costs

WBS	Task Name	EDIA	Labor	NAL & E907	FNAL | T&M	M&S	T&M	Other M&S	Total Cost
5	E907 Experiment (in MC7)	$136,400	$240,560	235812	4748	$304,600	55000	249600	$681,560
5.1	Upstream Beamline Detectors (UBL)	$7,040	$26,780	26780	0	$0	0	0	$33,820
5.1.1	UBL Design	$7,040	$0	0	0	$0	0	0	$7,040
5.1.2	UBL Secondary Production Target Fa	$0	$8,240	8240	0	$0	0	0	$8,240
5.1.3	UBL Tracking Chamber Refurbishmen	$0	$4,120	4120	0	$0	0	0	$4,120
5.1.4	UBL Threshold Cerenkov (tCKV) Fabr	$0	$8,240	8240	0	$0	0	0	$8,240
5.1.5	UBL Installation	$0	$6,180	6180	0	$0	0	0	$6,180
5.1.5.1	UBL Pretarget Enclosure Detecto	$0	$4,120	4120	0	$0	0	0	$4,120
5.1.5.2	UBL Target Pile Detectors Installa	$0	$2,060	2060	0	$0	0	0	$2,060
5.2	Experimental Targets (ETGT)	$12,320	$20,600	20600	0	$0	0	0	$32,920
5.2.1	Target Wheel (TGTW)	$1,760	$3,090	3090	0	$0	0	0	$4,850
5.2.1.1	TGTW Design	$1,760	$0	0	0	$0	0	0	$1,760
5.2.1.2	TGTW Fabrication	$0	$2,060	2060	0	$0	0	0	$2,060
5.2.1.3	TGTW Installation	$0	$1,030	1030	0	$0	0	0	$1,030
5.2.2	Cryogenic Target (CTGT)	$7,040	$12,360	12360	0	$0	0	0	$19,400
5.2.2.1	CTGT Design	$7,040	$0	0	0	$0	0	0	$7,040
5.2.2.2	CTGT Fabrication	$0	$8,240	8240	0	$0	0	0	$8,240
5.2.2.3	CTGT Installation	$0	$4,120	4120	0	$0	0	0	$4,120
5.2.3	NuMI Target Sample (NTGT)	$3,520	$5,150	5150	0	$0	0	0	$8,670
5.2.3.1	NTGT Design	$3,520	$0	0	0	$0	0	0	$3,520
5.2.3.2	NTGT Fabrication	$0	$4,120	4120	0	$0	0	0	$4,120
5.2.3.3	NTGT Installation	$0	$1,030	1030	0	$0	0	0	$1,030
5.3	Target Recoil Detector (TRD)	$28,160	$24,720	24720	0	$0	0	0	$52,880
5.3.1	TRD Design	$28,160	$0	0	0	$0	0	0	$28,160
5.3.2	TRD Fabrication	$0	$12,360	12360	0	$0	0	0	$12,360
5.3.3	TRD Installation	$0	$12,360	12360	0	$0	0	0	$12,360
5.4	Time Projection Chamber (TPC)	$10,560	$16,962	16962	0	$22,300	0	22300	$49,822
5.4.1	TPC Move to FNAL	$0	$7,692	7692	0	$12,300	0	12300	$19,992
5.4.2	TPC Assess Condition	$0	$1,030	1030	0	$0	0	0	$1,030
5.4.3	TPC Installation Design	$10,560	$0	0	0	$0	0	0	$10,560
5.4.4	TPC Installation	$0	$8,240	8240	0	$10,000	0	10000	$18,240
5.5	Jolly Green Giant (JGG)	$7,040	$4,235	4235	0	$85,000	25000	60000	$96,275
5.5.1	JGG Move & Installation Design	$7,040	$0	0	0	$0	0	0	$7,040
5.5.2	JGG Replacement Coil	$0	$0	0	0	$60,000	0	60000	$60,000
5.5.3	JGG Assembly	$0	$0	0	0	$25,000	25000	0	$25,000
5.5.4	JGG Connections	$0	$4,235	4235	0	$0	0	0	$4,235
5.6	Differential Cerenkov (CKOV)	$14,080	$29,400	28292	1108	$27,300	0	27300	$70,780
5.6.1	CKOV Move & Installation Design	$7,040	$0	0	0	$0	0	0	$7,040
5.6.2	CKOV Move	$0	$7,692	7692	0	$2,300	0	2300	$9,992
5.6.3	CKOV Undercarriage Fabrication	$3,520	$8,240	8240	0	$10,000	0	10000	$21,760
5.6.4	CKOV Freon Recovery Fabrication	$3,520	$8,240	8240	0	$10,000	0	10000	$21,760
5.6.5	CKOV Locate in Position	$0	$1,108	0	1108	$0	0	0	$1,108
5.6.6	CKOV Connections	$0	$4,120	4120	0	$5,000	0	5000	$9,120
5.7	Time-of-Flight (TOF)	$10,560	$16,480	16480	0	$0	0	0	$27,040
5.7.1	TOF Design	$10,560	$0	0	0	$0	0	0	$10,560
5.7.2	TOF Fabrication	$0	$8,240	8240	0	$0	0	0	$8,240
5.7.3	TOF Installation	$0	$8,240	8240	0	$0	0	0	$8,240
5.8	TPL-B Magnet (TPL-B)	$7,040	$4,235	4235	0	$25,000	25000	0	$36,275
5.8.1	TPL-B Move & Installation Design	$7,040	$0	0	0	$0	0	0	$7,040
5.8.2	TPL-B Assembly	$0	$0	0	0	$25,000	25000	0	$25,000
5.8.3	TPL-B Connections	$0	$4,235	4235	0	$0	0	0	$4,235
5.9	Ring Imaging Cerenkov (RICH)	$9,680	$30,198	26557	3640	$45,000	5000	40000	$84,878
5.9.1	RICH Move & Installation Design	$7,040	$0	0	0	$0	0	0	$7,040
5.9.2	RICH Extraction from PC4	$880	$12,626	11170	1456	$5,000	5000	0	$18,506
5.9.2.1	RICH Downstream Flange Stan	$880	$2,930	2930	0	$0	0	0	$3,810
5.9.2.1.1	RICH D/S Flange Stand Desi	$880	$1,030	1030	0	$0	0	0	$1,910
5.9.2.1.2	RICH D/S Flange Stand Fabr	$0	$1,900	1900	0	$0	0	0	$1,900
5.9.2.2	RICH Remove PMTs	$0	$4,120	4120	0	$0	0	0	$4,120
5.9.2.3	RICH Open End Flanges	$0	$1,456	0	1456	$0	0	0	$1,456
5.9.2.4	RICH Remove Mirrors	$0	$2,060	2060	0	$0	0	0	$2,060
5.9.2.5	RICH Disconnect Support Equipm	$0	$2,060	2060	0	$0	0	0	$2,060
5.9.2.6	RICH Lift Components Through P	$0	$0	0	0	$5,000	5000	0	$5,000
5.9.3	RICH New Tank	$1,760	$0	0	0	$40,000	0	40000	$41,760
5.9.4	RICH Position New Tank in MC7	$0	$728	0	728	$0	0	0	$728
5.9.5	RICH Install Mirrors	$0	$1,998	1997	0	$0	0	0	$1,998
5.9.6	RICH Close End Flanges	$0	$1,456	0	1456	$0	0	0	$1,456
5.9.7	RICH Install Support Equipment	$0	$4,120	4120	0	$0	0	0	$4,120
5.9.8	RICH Gas Clean & FIll	$0	$1,030	1030	0	$0	0	0	$1,030
5.9.9	RICH Install PMTs	$0	$4,120	4120	0	$0	0	0	$4,120
5.9.10	RICH Install Electronics	$0	$4,120	4120	0	$0	0	0	$4,120

Costs and effort

WBS	Task Name	EDIA	Labor	NAL & E907	FNAL | T&M	M&S	T&M	Other M&S	Total Cost
5.10	**Drift Chambers (DC)**	$5,280	$31,930	31930	0	$100,000	0	100000	$137,210
5.10.1	DC Move & Installation Design	$5,280	$3,090	3090	0	$0	0	0	$8,370
5.10.2	DC Move	$0	$8,240	8240	0	$0	0	0	$8,240
5.10.3	DC Parts Fabrication	$0	$12,360	12360	0	$100,000	0	100000	$112,360
5.10.4	DC Installation	$0	$8,240	8240	0	$0	0	0	$8,240
5.11	**Neutral Hadron Calorimeter (NCAL)**	$10,560	$16,480	16480	0	$0	0	0	$27,040
5.11.1	NCAL Design	$10,560	$0	0	0	$0	0	0	$10,560
5.11.2	NCAL Fabrication	$0	$8,240	8240	0	$0	0	0	$8,240
5.11.3	NCAL Installation	$0	$8,240	8240	0	$0	0	0	$8,240
5.12	**Trigger (TRG)**	$7,040	$6,180	6180	0	$0	0	0	$13,220
5.12.1	TRG Design	$7,040	$0	0	0	$0	0	0	$7,040
5.12.2	TRG Fabrication	$0	$4,120	4120	0	$0	0	0	$4,120
5.12.3	TRG Installation	$0	$2,060	2060	0	$0	0	0	$2,060
5.13	**Data Acquisition (DAQ)**	$7,040	$12,360	12360	0	$0	0	0	$19,400
5.13.1	DAQ Design	$7,040	$0	0	0	$0	0	0	$7,040
5.13.2	DAQ Fabrication	$0	$8,240	8240	0	$0	0	0	$8,240
5.13.3	DAQ Installation	$0	$4,120	4120	0	$0	0	0	$4,120
6	**Data Taking (DATA)**	$0	$0	0	0	$0	0	0	$0
6.1	DATA Engineering Run	$0	$0	0	0	$0	0	0	$0
6.2	DATA 1% Targets	$0	$0	0	0	$0	0	0	$0
6.3	DATA NuMI Target Running	$0	$0	0	0	$0	0	0	$0
7	**Core Analysis**	$0	$0	0	0	$0	0	0	$0
7.1	**Analysis Development**	$0	$0	0	0	$0	0	0	$0
7.1.1	UBL Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.2	TRD Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.3	TPC Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.4	JGG Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.5	CKOV Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.6	TOF Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.7	TPL-B Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.8	RICH Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.9	DC Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.10	NCAL Analysis Development	$0	$0	0	0	$0	0	0	$0
7.1.11	TRG/DAQ Analysis Development	$0	$0	0	0	$0	0	0	$0
7.2	**Tracking & PID Integration**	$0	$0	0	0	$0	0	0	$0
7.2.1	UBL-TGT-TRD-TPC Tracking	$0	$0	0	0	$0	0	0	$0
7.2.2	TPC-CKOV Tracking & PID	$0	$0	0	0	$0	0	0	$0
7.2.3	CKOV-TOF Tracking & PID	$0	$0	0	0	$0	0	0	$0
7.2.4	TOF-RICH Tracking & PID	$0	$0	0	0	$0	0	0	$0
7.2.5	RICH-NCAL Tracking	$0	$0	0	0	$0	0	0	$0
7.3	Core Analysis Production	$0	$0	0	0	$0	0	0	$0
8	Project Management	$0	$0	0	0	$0	0	0	$0

WBS	Task Name	Physicist	Engineer	Technician
0	**Fermilab E907**	573.9	78.5	280.65
1	Experiment Design	39	0	0
2	**Meson Hall (MC6) Preparation**	0	1	26.6
3	**E907 Beamline (in MC6)**	1	0	15
4	**Meson Worm (MC7) Preparation**	0	0	14.6
5	**E907 Experiment (in MC7)**	88.9	77.5	224.45
5.1	**Upstream Beamline Detectors (UBL)**	5	4	26
5.2	**Experimental Targets (ETGT)**	1.75	7	20
5.3	**Target Recoil Detector (TRD)**	16	16	24
5.4	**Time Projection Chamber (TPC)**	9	6	11
5.5	**Jolly Green Giant (JGG)**	1	4	4.5
5.6	**Differential Cerenkov (CKOV)**	1.4	8	23.2
5.7	**Time-of-Flight (TOF)**	8	6	16
5.8	**TPL-B Magnet (TPL-B)**	1	4	4.5
5.9	**Ring Imaging Cerenkov (RICH)**	6.25	5.5	30.25
5.10	**Drift Chambers (DC)**	1.5	3	31
5.11	**Neutral Hadron Calorimeter (NCAL)**	4	6	16
5.12	**Trigger (TRG)**	10	4	6
5.13	**Data Acquisition (DAQ)**	24	4	12
6	**Data Taking (DATA)**	288	0	0
6.1	DATA Engineering Run	32	0	0
6.2	DATA 1% Targets	224	0	0
6.3	DATA NuMI Target Running	32	0	0
7	**Core Analysis**	144	0	0
7.1	**Analysis Development**	96	0	0
7.2	**Tracking & PID Integration**	40	0	0
7.3	Core Analysis Production	8	0	0
8	Project Management	13	0	0