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

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P907 PAC presentation, Nov 2, 2001
Fermilab

P-907 collaboration list

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A Brief history of P907

- Started as a proposal in the 1997 Workshop on Fixed target physics at the Main Injector. Presented an EOI in July 1997
- Submitted 1st proposal in April 1998- received sufficient encouragement from PAC to acquire the Bevalac EOS-TPC from BNL after its use in E910
- PAC asked for a new proposal in July 1999 which resulted in a more detailed proposal in June 2000. Deferred in November 2000 and put into an R&D phase.

Format of the Talk

- Review Quality of existing data
- Review the Physics
  - » Physics motivated measurements
    - Scaling Law tests
    - Relativistic Heavy Ion Physics
    - Nuclear Scaling
    - Search for exotic resonances
  - » Service measurements
    - Inclusive Cross sections for simulations –Geant4, Mars, Atmospheric neutrinos
    - Neutrino Factory/ Muon Collider target measurements
    - MINOS target measurements
- Review Progress made in the last year
  - » TPC,DAQ,Magnets,Chambers,RICH, Monte Carlo,Calorimeter,Beam,experimental hall
- Cost of experiment and Funding Issues
- Running time required
- Conclusions

Quality of existing data

- Single arm spectrometers have inherently more systematics than open geometry apparatus such as P907. This is because they must change geometry of the single arm frequently and make assumptions in calculating acceptances.
- Also single arm spectrometer data are sparse and for discrete p_t bins. The running time is adjusted to give a certain number of particles in the apparatus for that setting.
- Open geometry experiments (P-907, E910 at BNL) sample the phase space uniformly and continuously. They can separate primary pion spectra from pions induced by the decay of kaons etc. They necessarily need a slow spill mode of operation.
- Last open geometry experiment at these beam energies with particle id capabilities was the EHS. Bubble chamber instead of TPC. 3 years to scan and analyze 1 million events. We can do this in less than two days. The HARP experiment at CERN is taking data currently but will only go up to ~15 GeV energies. No kaon and antiproton beams contemplated in HARP. E907 will do 6 beam species ($\pi^{\pm}$,$K^{\pm}$,$p^{\pm}$) over the energy range ~5 GeV to 120 GeV.

Purposes of the experiment

- To measure the identities and momenta of particles produced in $\pi^{\pm}, K^{\pm}, p^{\pm}$ interactions on various nuclear targets and hydrogen as a function of beam energy from ~5 GeV/c-120 GeV/c with high statistics and make these events public in 4 vector form on mass media such as DVD's. This will be "Fermilab data set".This will enable the user (theorist or experimentalist) easy access to data and help spawn new approaches to understanding these non-perturbative phenomena.
- Physics Topics
  - » Study hadronic fragmentation in particular, test a scaling law of particle fragmentation
  - » Search for exotic resonance such as glueballs
  - » Relativistic heavy ion physics
  - » Medium energy Nuclear physics- Nuclear scaling
- Service measurements
  - » Atmospheric neutrinos cross sections of pions and protons on nitrogen and oxygen in the 5 GeV/c-120 GeV/c momentum range
  - » Measure particle spectra with 120 GeV/c protons on the NUMI target on a timescale commensurate with MINOS needs.
  - » Neutrino factory/Muon Collider target measurements
  - » Indirect benefit for collider experiments by helping with Geant cross sections. Will help the GEANT4 project enormously to have measured cross sections rather than approximate models if a precision tool is to be built.

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.

Nuclear Physics Measurements

- y scaling. y may be thought of as the component of the struck nucleon's momentum along the direction of the momentum transfer. The scaling function is independent of q^2 and represents the nuclear momentum distribution This is verified in ep scattering. We want to extend this to hadron nucleus scattering. It has been tested at KEK with low energy hadron beams (E352). P907 provides the ideal apparatus, without modification, to extend this beyond the resonance region.

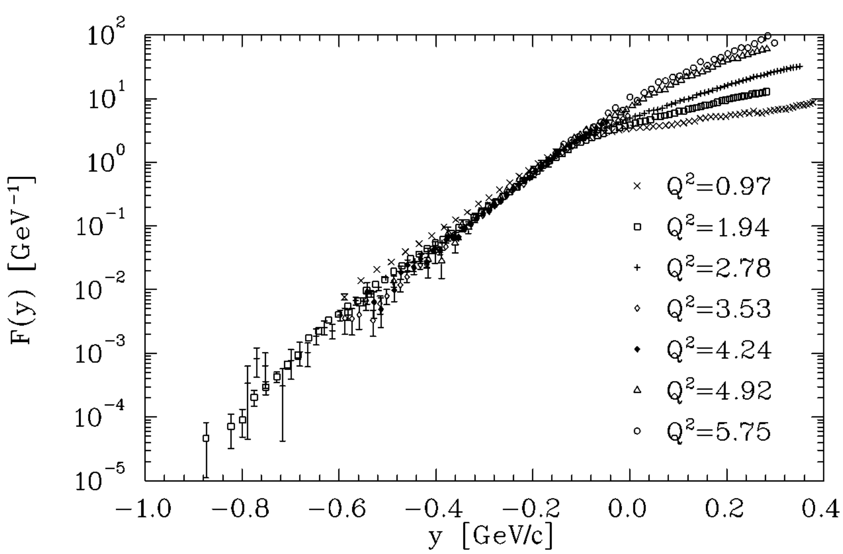
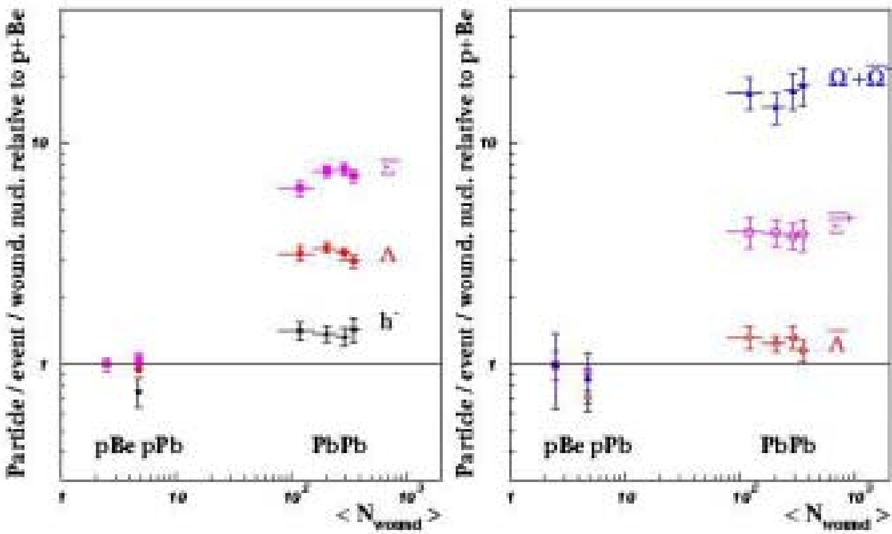
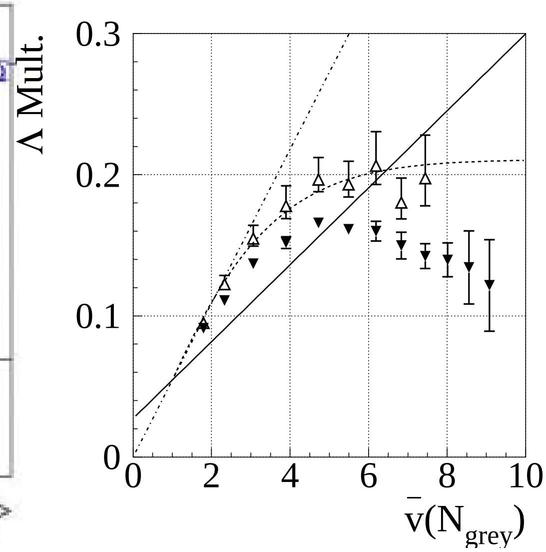


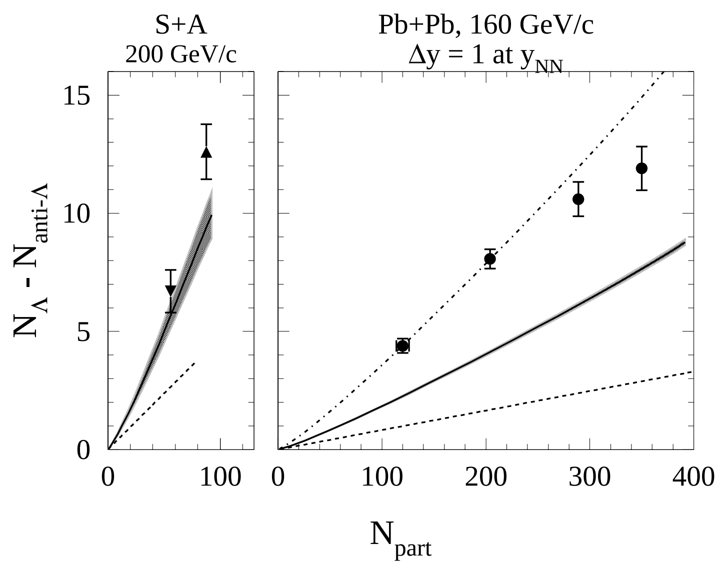
FIG. 2. Scaling function $F(y)$ for Fe. The Q^2 values are given for Bjorken $x = 1$.

Relativistic Heavy Ion Physics Case (E907)





- Extrapolations from BNL E910 purport to explain strangeness enhancement seen at CERN SPS.



Relativistic Heavy Ion Physics Case (E907)

- Calibrate CERN strangeness results
  (1 of 2 results most often cited as QGP evidence)
- Test specific models for strangeness production
  e.g ``baryon junction model”
- Measure soft physics multiplicity scaling for RHIC
- Repeat other E910 results in SPS energy range
  - » antiproton production
  - » resonance production (Δ,N^*,ρ,ω)
  - » forward pion production and nuclear stopping
  - » strangeness production
- pA is essential to understand nuclear medium and multiple collision effects
- The AGS, SPS and Tevatron have all run pA programs relevant to AA
- pA has always been part of RHIC program (whitepaper)
- pA (dA) stated by BNL PAC as highest priority for RHIC after completion of current AA and spin programs
- pA is best studied with complete coverage (shown by E910)
  - » full acceptance particle id
  - » require nuclear fragmentation to estimate mean nuceon-nucleon scatterings
- Letters of support from Aronson, Busza, Peng and Zajc

Ph.D thesis topics from P907

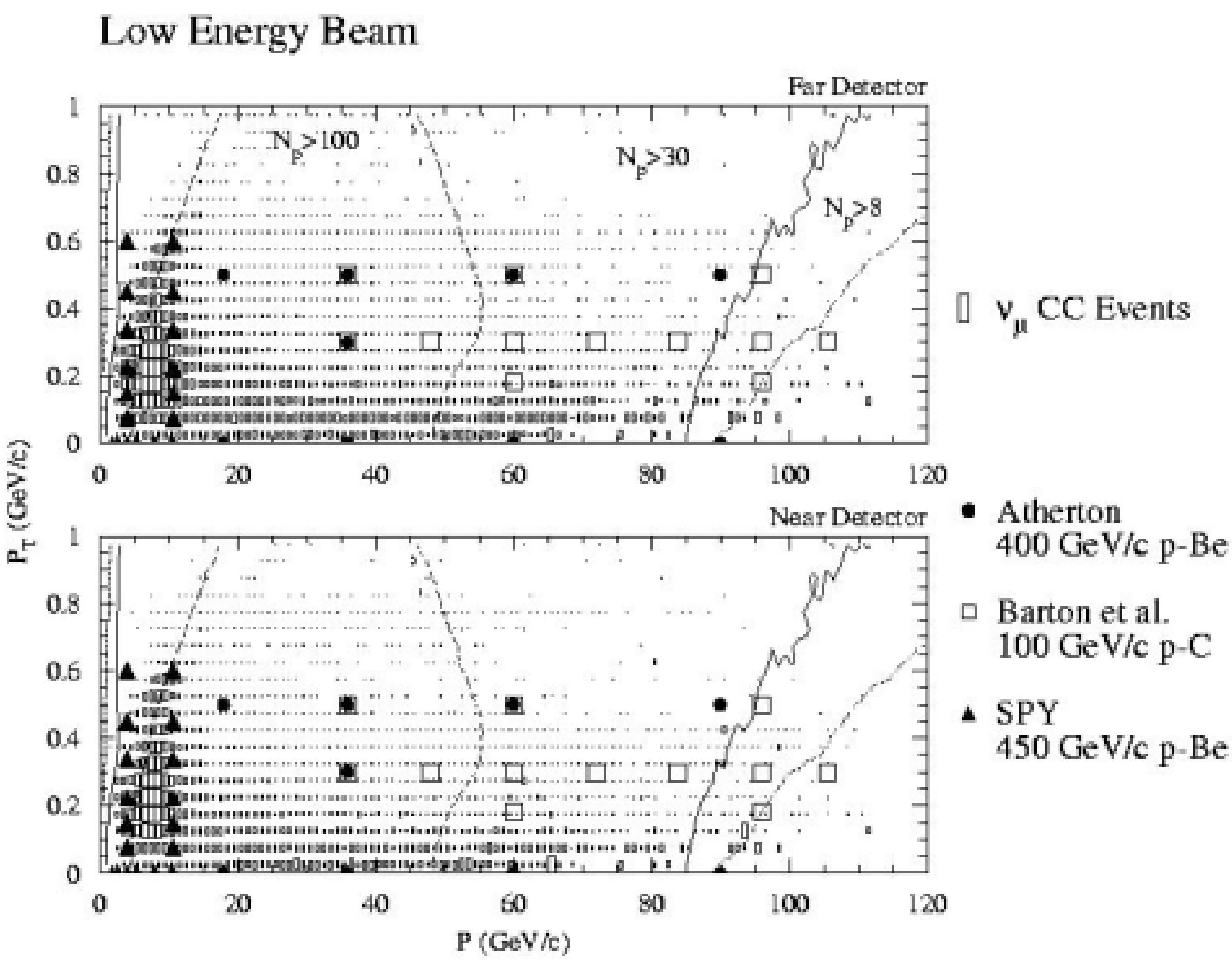
- Relativistic Heavy Ion physics
  - antiproton production
  - resonance production (Δ,N*,ρ,Ω)
  - forward pion production and nuclear stopping
  - strangeness production
  - soft pion production
- Scaling law tests
  - 6 beams species can produce 6 different topics each with 6 different inclusive final states
- Nuclear Scaling
  - Demonstration of y scaling
  - Extraction of in-medium hadron-nucleus cross sections
  - Exploring the physics for y>0
  - Analyzing the large loss inclusive spectra for N* excitations in nuclei
- Glueball searches and hadron dynamics
  - Looking for exotic final states in an open geometry experiment with full particle id
  - Revisit Regge theory with much improved statistics and systematics
- Passage of particles of tagged flavor through nuclear matter. Kaons and antiprotons
- In short, E907 is rich in thesis topics and will provide graduate students training in hardware, software and analysis, since the timescale to do the experiment is once again commensurate with thesis time scale.

Service Measurements

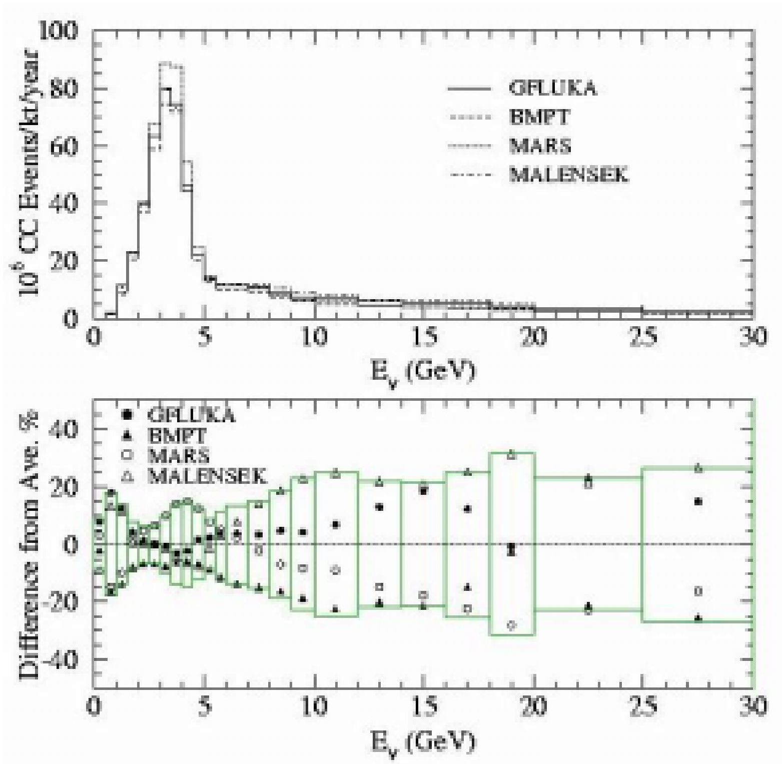
- MINOS needs- The hadro-production spectrum on a MINOS target can be measured with the Main Injector Beam that closely matches the beam emittance used in NUMI. MINOS will not build a hadronic hose that would have emeliorated their far/near flux ratio uncertainties. Hadroproduction measurements such as the ones E907 can provide are crucial.
- Neutrino Factory/ Muon Collider target measurements. Measurements of pion and proton cross sections on targets suited to neutrino factory/muon collider needs are necessary to estimate yields of muons accurately. HARP experiment at CERN will do the low energy part of these measurements. But if a proton source such as BNL AGS or the Japanese JHF is used, P907 data will be of relevance. Biggest uncertainty in BNL Study II muon fluxes for the neutrino factory is due to pion production.
- Atmospheric Neutrinos- Atmospheric Cosmic ray shower models (some of them one dimensional!) use Beryllium cross sections to extrapolate to Nitrogen and Oxygen. HARP will cover the low energy part of these measurements. P907 will cover the complete range in energy ~5 GeV to 100 GeV.

Minos measurements

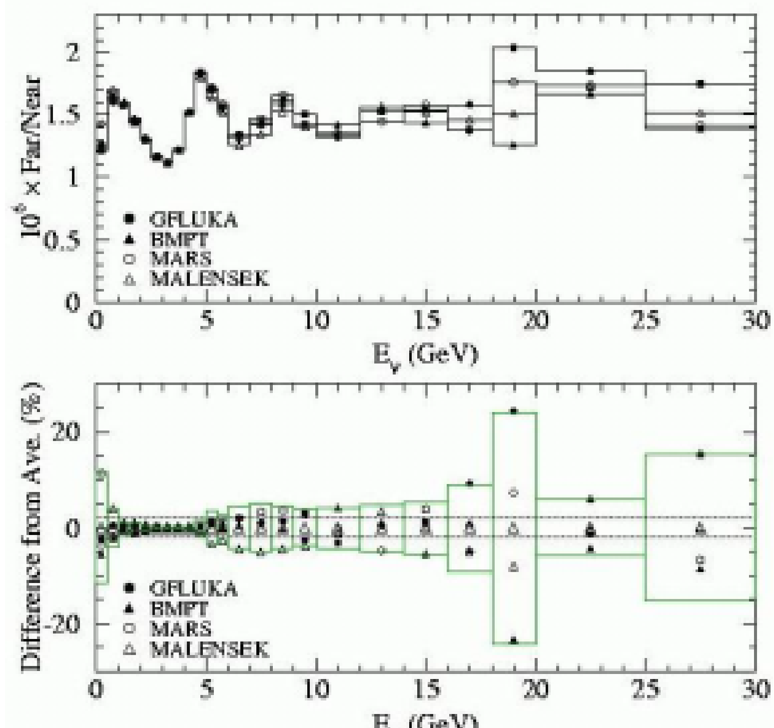
- E907 has MINOS collaborators- J.Hylen,J.Morfin,A.Para(FNAL), M.Messier(Harvard),P.D.BarnesJr.,E.Hartouni,D.Wright,(Livermore), T.Bergfeld,A.Godley,S.R.Mishra,C.Rosenfeld(South Carolina)…
- Existing data vs Near and Far detector pion contribution for MINOS (Courtesy- M.Messier)



Minos measurements



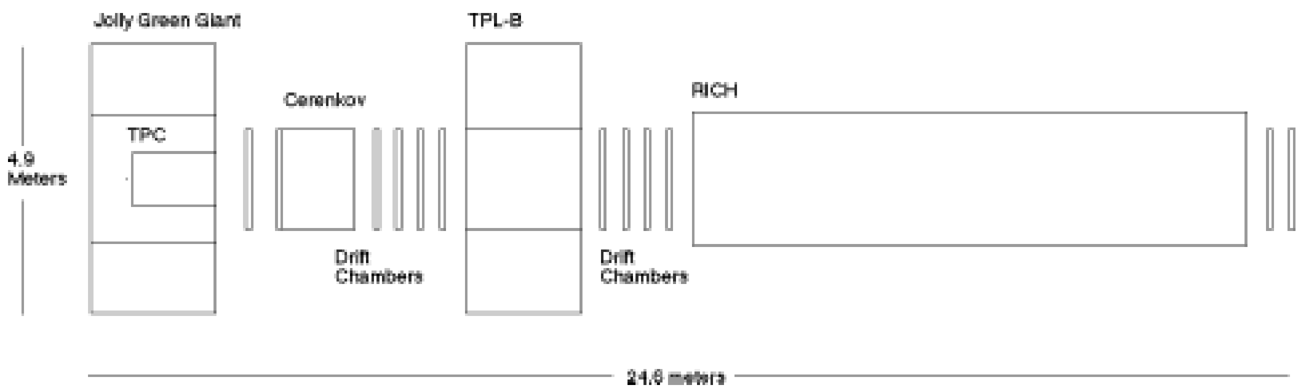
Near detector spectra- Hadronic uncertainties
Contribute 15-20% to absolute rate uncertainty

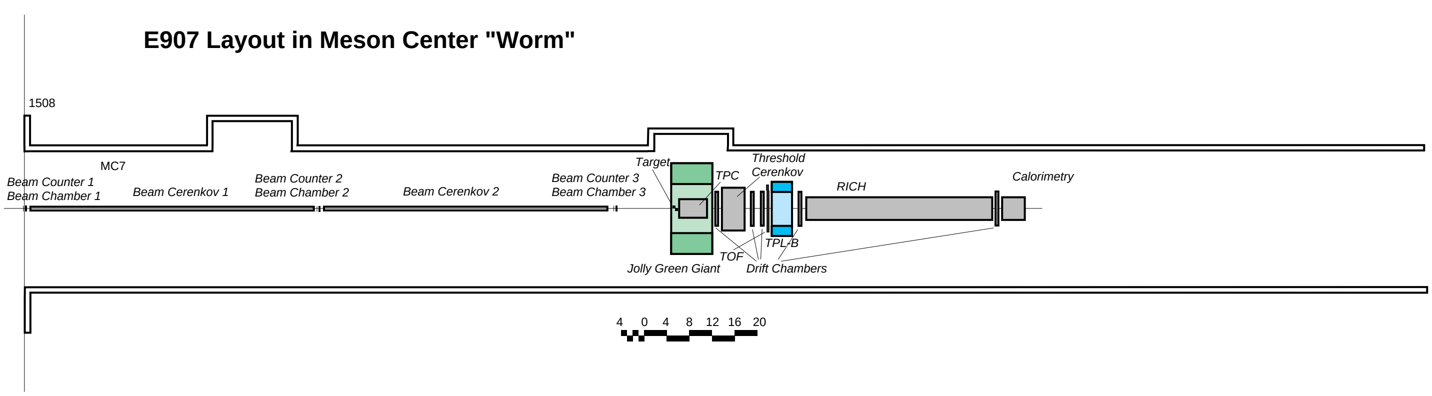


Far/Near ratio 2-10% uncertainties
in near-to-far. Normalization in tail
important.

Experimental Hall- MC7

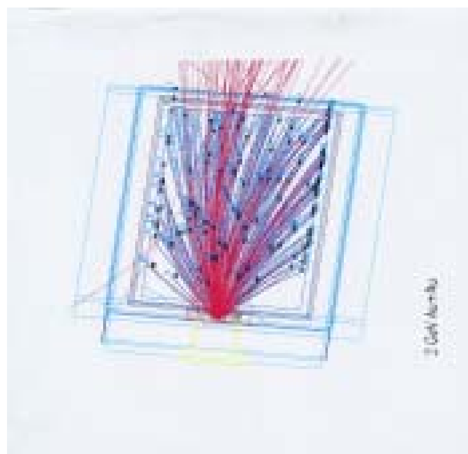
- We have paid to clean out Hyper CP experiment.
- M-bottom has to be shored up to support magnets (Complete)
- Concrete Slab (1ft high) in MC7 to spread load of magnets.

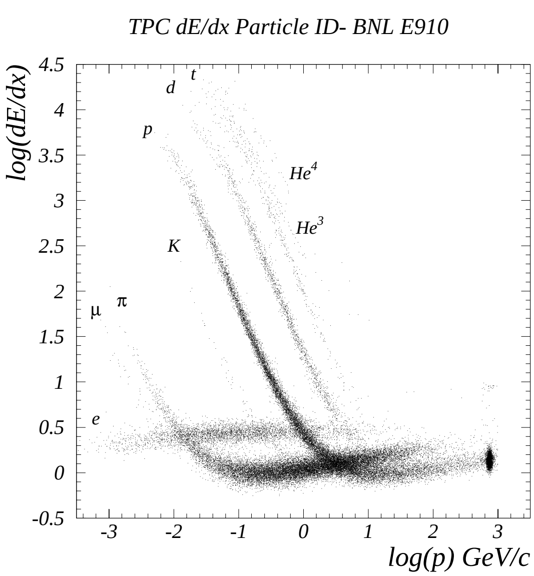


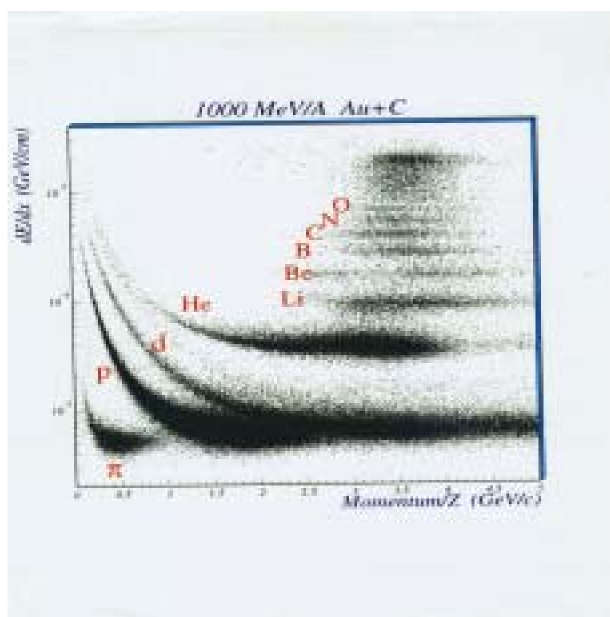


EOS-TPC

- 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. Time to drift across chamber is 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 in M-TEST clean room built for it by FNAL. Being tested currently with cosmics.
- Successful Cosmic tests
  - » (x) establish slow (bitbus) communication to TPC F.End
  - » (x) read out pedestal data over fiber optic cable
  - » (x)collect ADC pulser data with hardware trigger
  - » (x)read out cosmic ray data




TPC dE/dx Particle ID- BNL E910
log(dE/dx)
log(p) GeV/c
d
t
p
He4
He3
K
μ
π
e
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-3
-2
-1
0
1
2
3


1000 MeV/A Au+C
Momentum/Z (GeV/c)
He
d
p
π
Li
Be
B
C
N
O

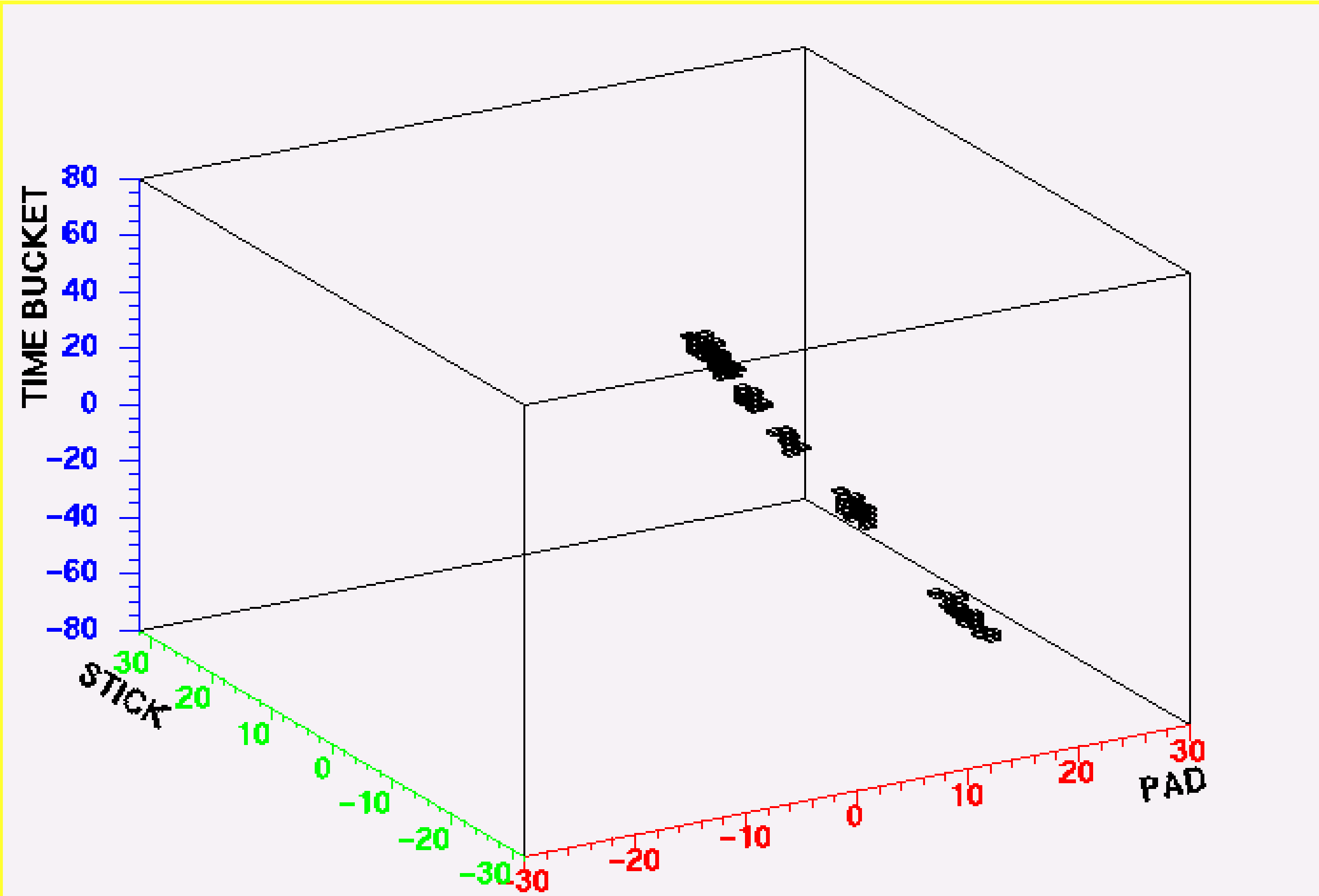
TPC status-October 2001

- Clean Room Constructed.

- Chiller refurbished and hooked up

- Gas system installed. Flowed P5 first and switched to P10 after passing safety review.
- System cabled up. Low voltage supplies checked
- TPC front-end electronics ("Sticks") talking to DAQ
- Cosmic Ray tests under way (P.Barnes + DAQ team)

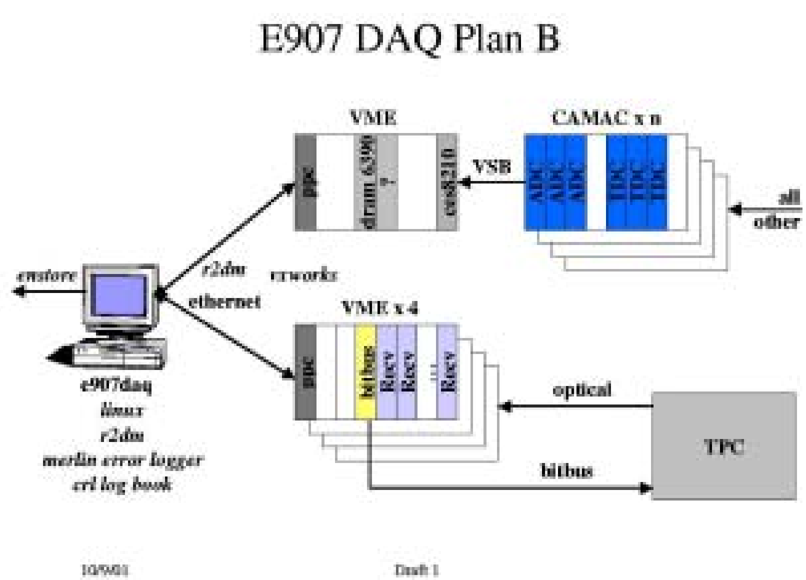
Cosmic Ray Test Results



- The vertical axis is drift time bucket; -80 is the bottom of the chamber. The horizontal axis on the right is 60 pads extending half way across the chamber. The horizontal axis on the left is 64 pad rows; -30 is the center of the chamber; +30 is the downstream end.
- Some noisy sticks and pads have been masked off.
- The chamber currently has P5 gas. The anode wires are at 1250 V, and the cathode plane is at 5 kV, half the nominal value.
- We received pORC (permission) to flow P10 on (30-Oct-2001), and have started flowing it.

Data Acquisition System

- The Data Acquisition system is being redesigned with the help of Fermilab Computing Division (M.Votava,D.Slimmer and L.Piccoli,D.Berg) E907 Members (M.Heffner, D.Asner ,R.Soltz,B.Cole) working on this. Both sides benefit. Linux based.



- Currently able to download data via the slow path to TPC and also to read out TPC front end electronics via optical fibers (pulser data with hardware trigger).DAQ expected to work at 6 Megabytes/second bandwidth. Being used for Cosmic ray testing with TPC currently.
- More details in
  - » http://ppd.fnal.gov/experiments/e907/TPC/DAQ/e907daq.html

Livermore ICO
(Integrated Contractor Order)

- Lawrence Livermore National Laboratory has issued an ICO (Integrated Contractor Order) for $228,629. This has been used by Fermilab to do the following.

- Fix Jolly Green Giant Coil
- Clean out Hyper CP experiment
- Engineer Support Structure for Shoring Up M-Bottom to support the magnets (Jolly Green Giant and Rosy)
- Build and Install Support Structure in M-Bottom.
- Build 1ft high concrete slab to support magnets.

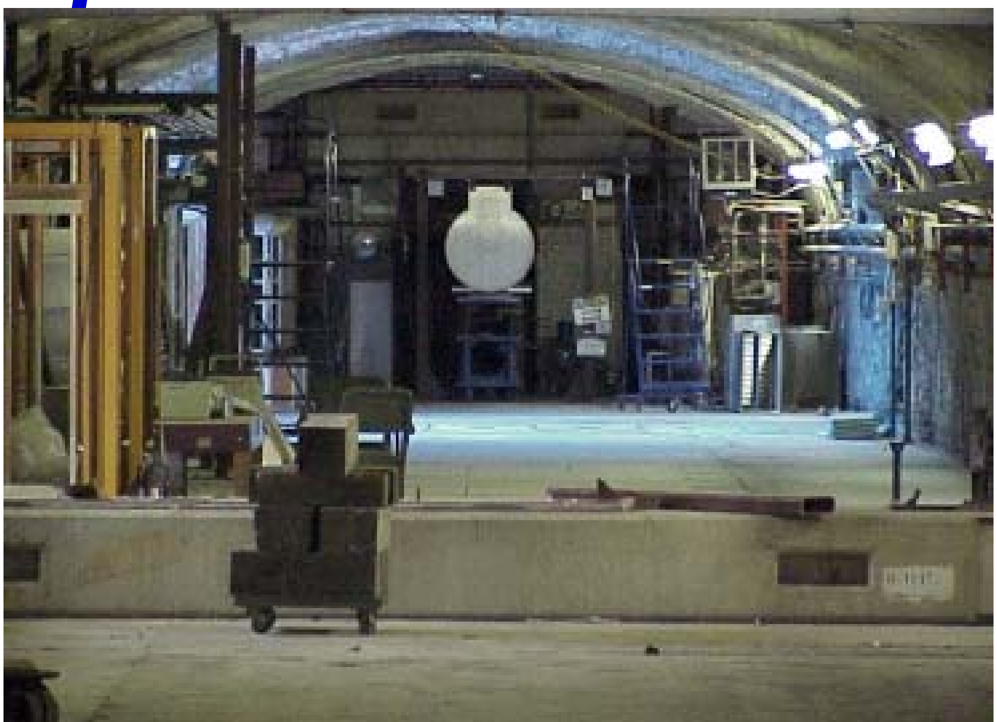
Magnets and chambers

- 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 (262x124x221 cm)to accommodate the TPC. 7 KG field.
- For the forward magnet we propose to use the ROSIE magnet from DONUT.
- One of Jolly Green Giant’s magnet coil had a short in it. We have fixed the short ($91,280=$69,000+engineering support) using the ICO

Jolly Green Giant Magnet Coil fixed

- We have shipped out a faulty coil in the Jolly Green Giant magnet to California. Coil needed to be “Unwound, bad conductor excised, re-insulated, rewound and re-potted’.
- Coil has passed “Ring test”.

Experimental Hall -MC7

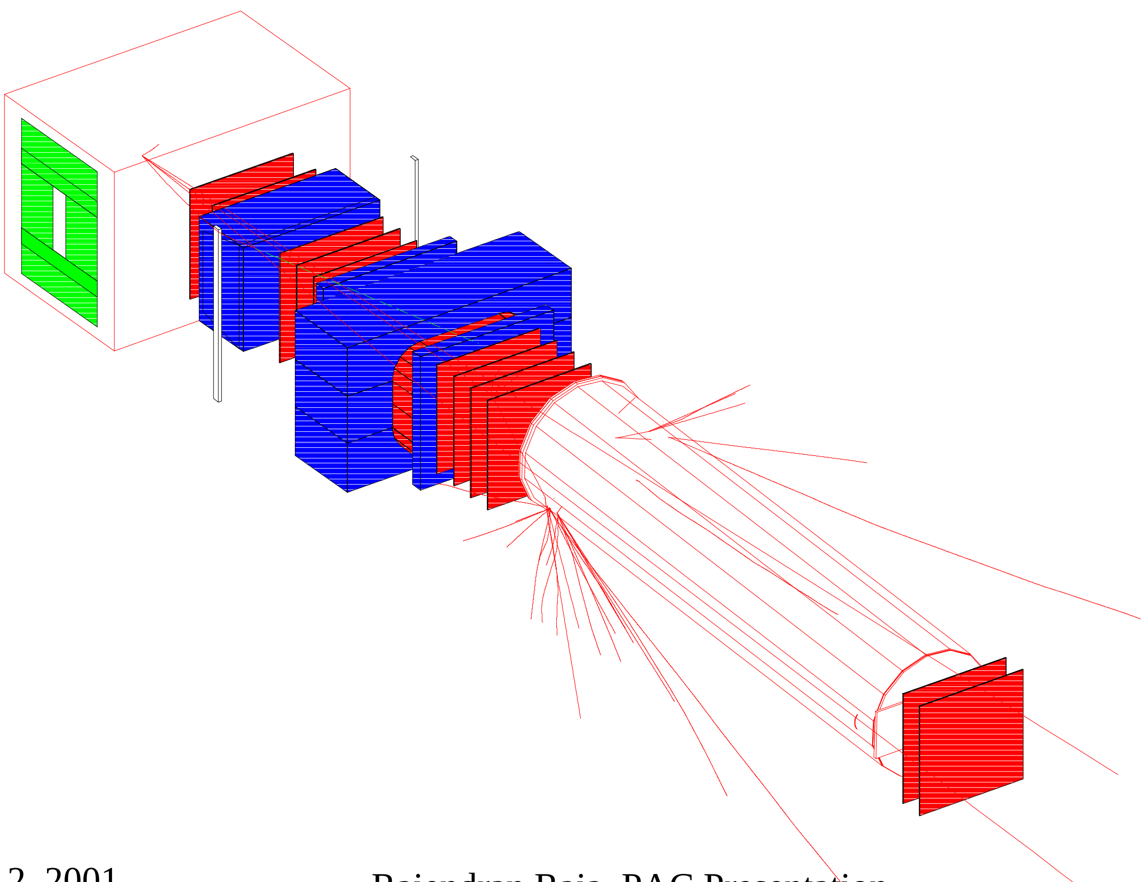


M-Bottom Shoring work

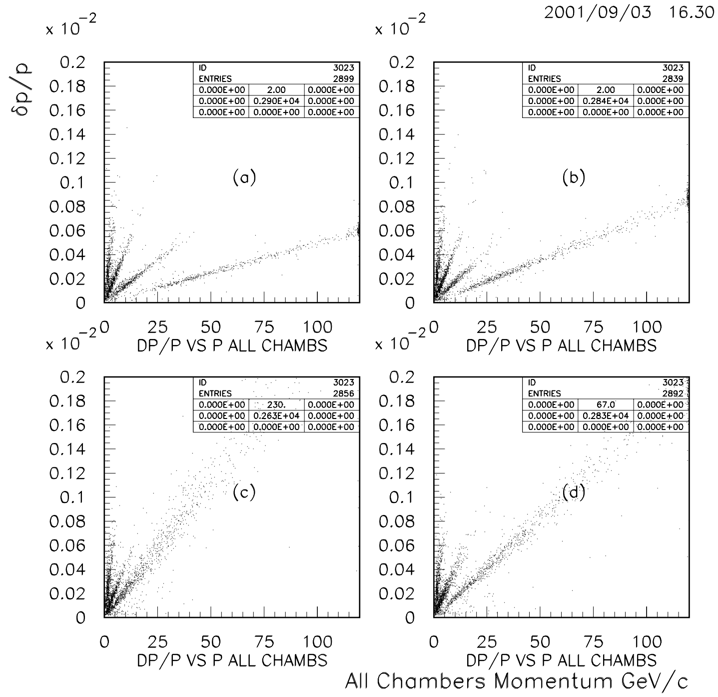
» details at http://ppd.fnal.gov/experiments/e907/MC7Enclosure/MC7_Enclosure.html

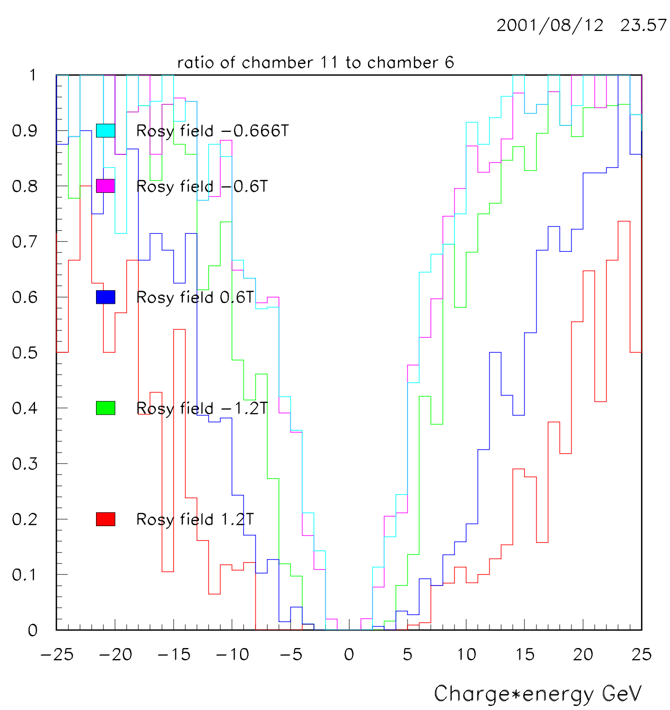
Monte Carlo

- We have a fully functional Geant based MC. Based on D0 Run I RCP based data-driven geometry.
- Used for geometry optimization and TOF studies. More details in
  - » http://ppd.fnal.gov/experiments/e907/MC/e907mc.htm



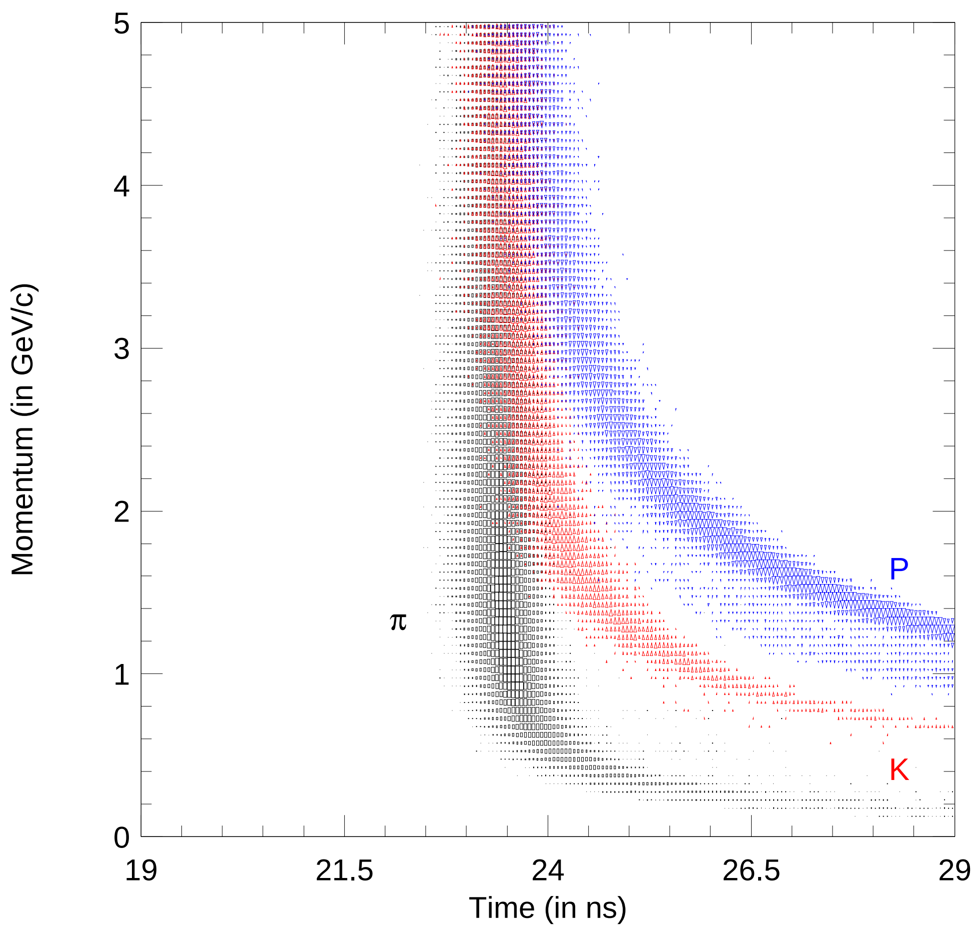
Monte Carlo Studies to Optimize detector





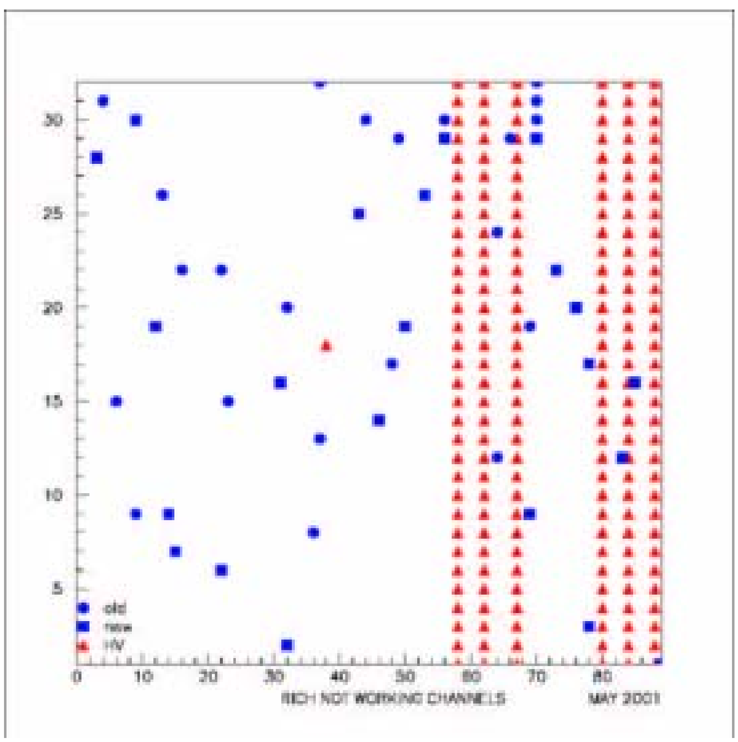
ToF system

- ToF system is being designed and built by University of South Carolina (T.Bergfeld, A.Godley, S.Mishra, C.Rosenfeld). ~88 counters with 200ps resolution available from CLEO. These are good for the engineering run. Scintillator with better resolution can be purchased in FY03 to enhanced the detector. Details to be found in
  - » http://ppd.fnal.gov/experiments/e907/TOF/TOF.html



RICH

- Refurbishing Selex RICH. Had Russian engineer (who helped build this for SELEX) visit FNAL for 1 month.
- Debugged Phototubes and front-end electronics (need to replace hybrid chips or rebuild piggybacking on CKM)
- Problems were easy to fix
- Tested readout with PCOS latches available from PREP
- R.Winston, E.Swallow + Postdoc.
- More details at
  - » http://ppd.fnal.gov/experiments/e907/Rich/Rich.html

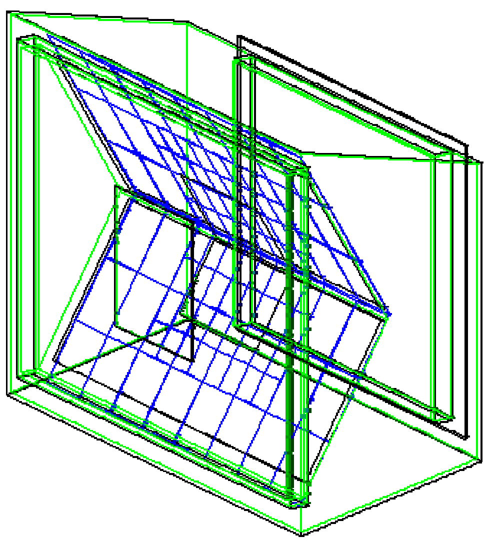


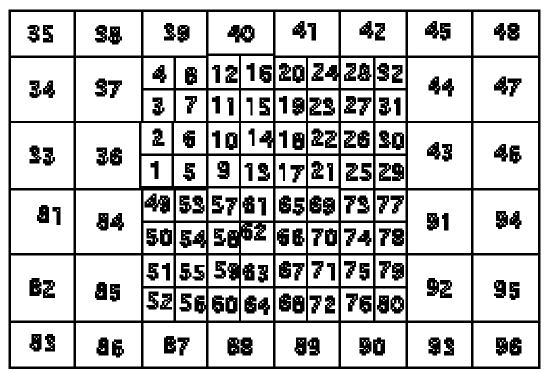
Chambers

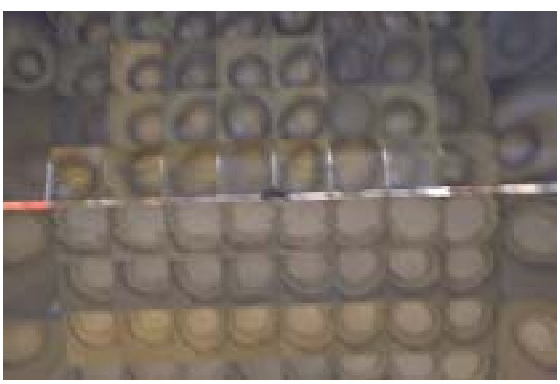
- E690 chambers (6 of them) extracted from storage. All tested OK for HV with N2 flowing. Gas system designed and passed safety walkthrough. Plan cosmic test in Nitrogen..
- (B.Mayes,L.Pinsky,J.Peterson,J.Brack)
- Readout needs minor redesign. More chambers available from SELEX, if needed.

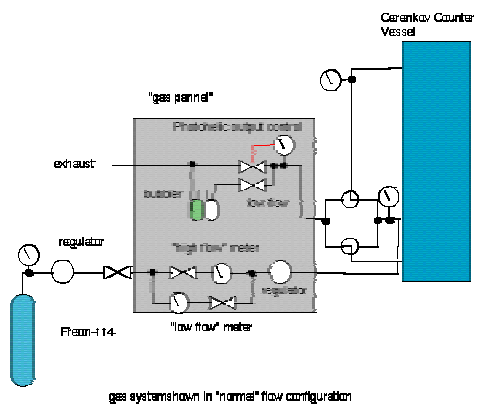
E690 Cerenkov

- All pieces in hand. Needs assembly. Details in
  - » http://ppd.fnal.gov/experiments/e907/Cerenkov/Cerenkov.html
  - » E.Hartouni, D.Asner,D.Wright, D.Lange.









Calorimeter

- Hyper-CP calorimeter being recycled. (H.Gustafson,M.Longo)
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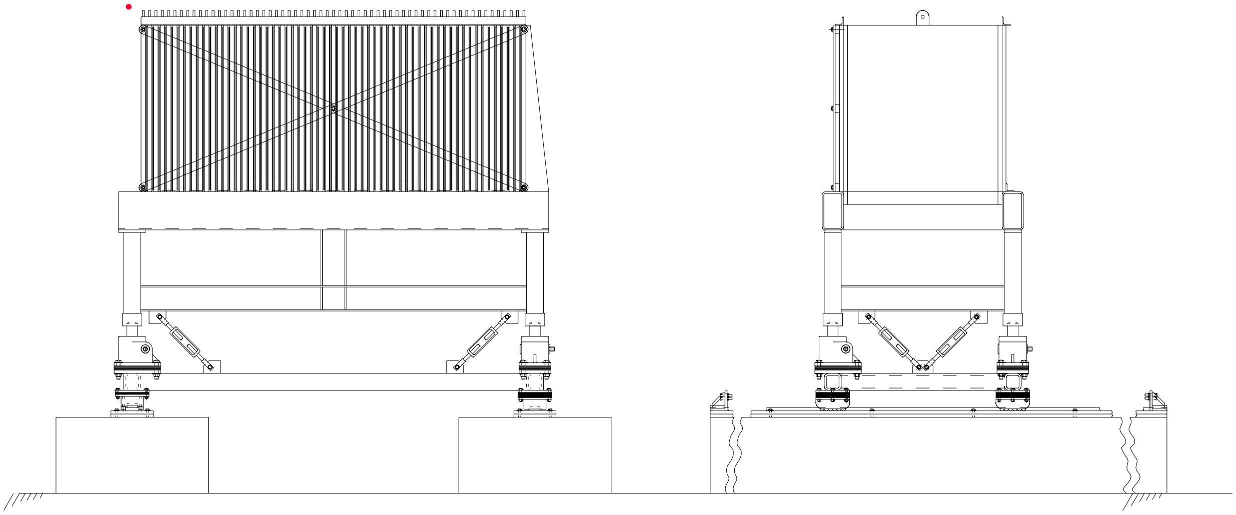
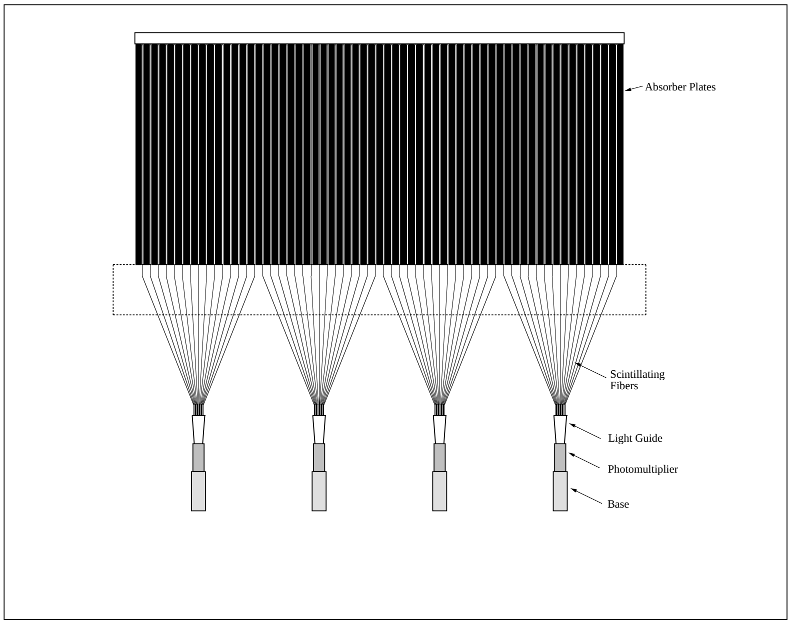




Particle Identification

- 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.
- TOF system will cover the region between 1GeV and 2.5 GeV.
- 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.

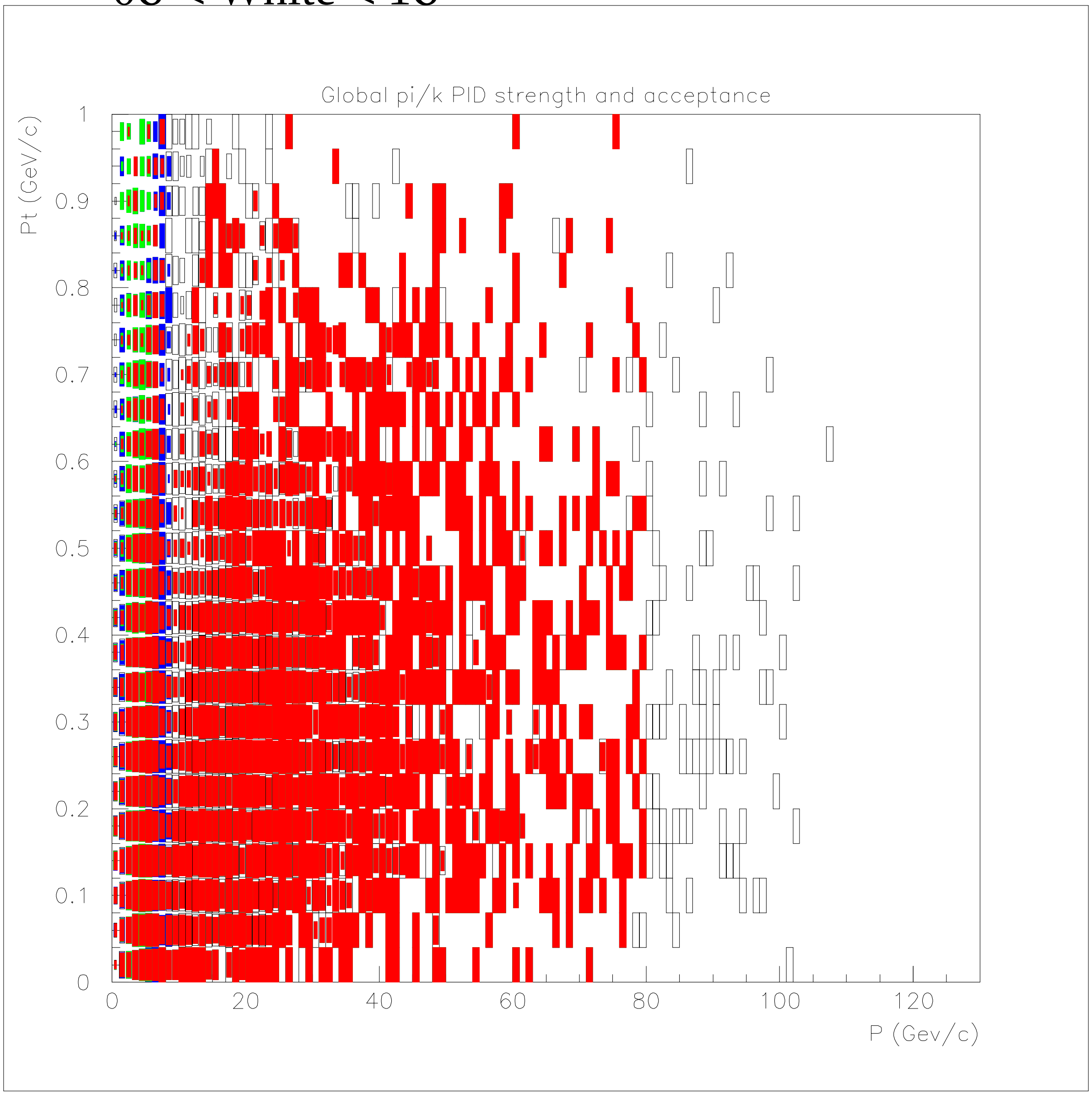
Threshold	Ne	N_2	CO_2
π	12	5.7	4.9
K	42	20	17
p	80	38	33

Global particle id analysis

π/K separation analysis using all systems.

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

0σ < White < 1σ

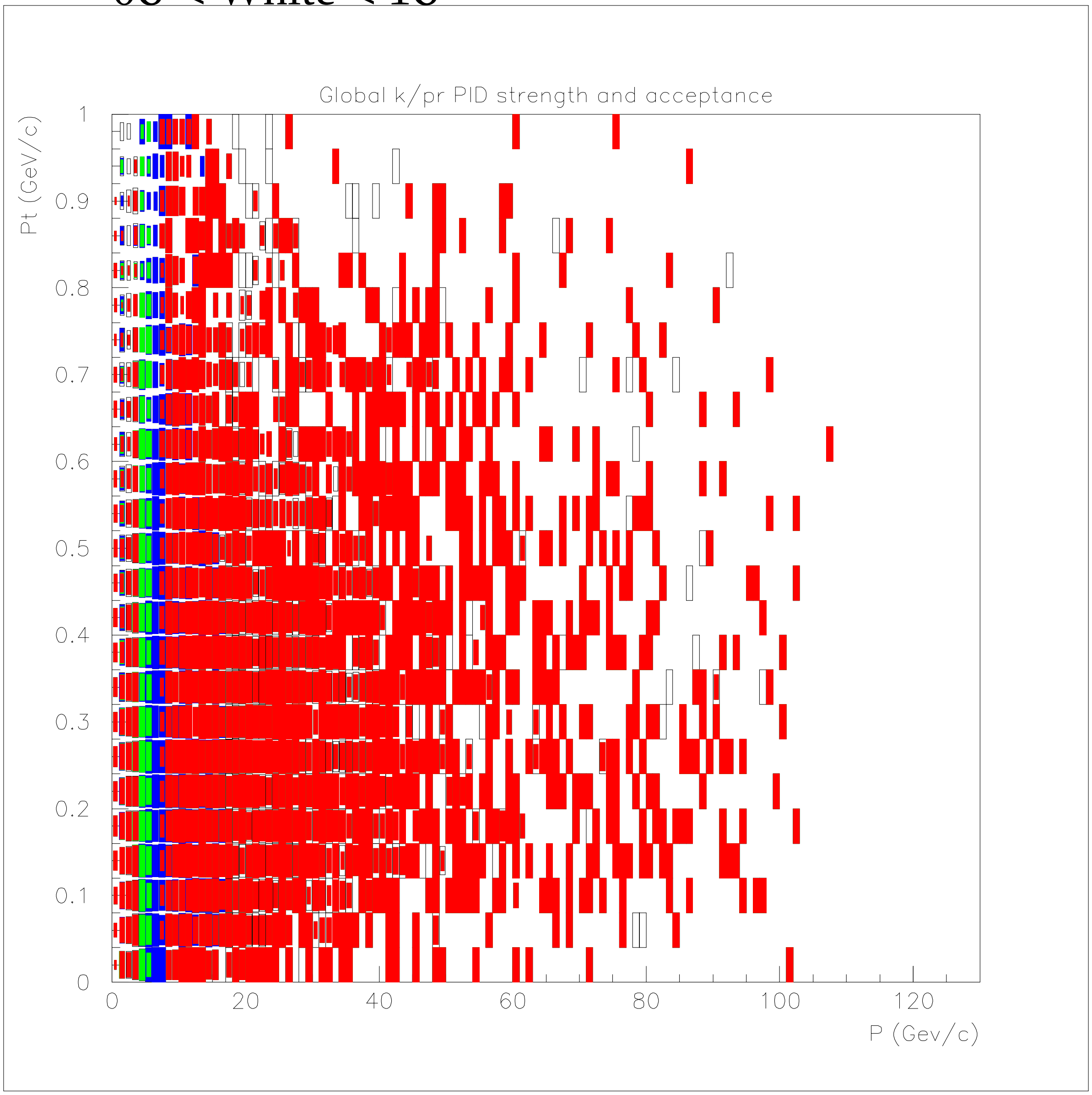


Global particle id analysis

K/Proton separation analysis using all systems.

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

0σ < White < 1σ



Costs and Funding sources

WBS	Activity	FY02	FY03	Prior Years		
2,3	**E907 Beam (FNAL)**	$265,754				
4	**Exp. Hall Prep.**	$180,060		$172,310		
5	**E907 Experimental setup**					
5.1	**MC7 design**	$11,680		$1,856		
5.2	**Upstream beam line**	$33,820				
5.3	**Jolly Green Giant**	$34,020	$4,235	$93,600		
5.4	**Rosie**	$22,736	$4,235	$2,320		
5.5	**E690 CKOV**	$63,088		$7,692		
5.7	**Targets**	$4,850	$28,070			
5.8	**Target Recoil Detector**		$52,880			
5.9	**TPC Installation**	$28,800	$0	$19,992		
5.10	**Time of Flight**	$14,680	$145,600	$0		
5.11	**RICH**	$24,410	$124,120	$11,144		
5.12	**Chambers**	$16,610	$120,600			
5.13	**Neutral Calorimeter**		$25,280			
5.14	**Trigger**	$13,220				
5.15	**DAQ**	$19,400				
	E907 funds	$467,374	$505,020	$308,914		$1,281,308
	Fermilab funds	$265,754				$265,754
					Total	$1,547,062

Costs and Funding sources

- E907 needs to find $454,154 in FY02 and $496,550 in FY03 for a total of $950,704, under the above spending scheme. Lawrence Livermore Lab alone will put in $500,000 each in FY02 and FY03. So if no extra sources of fundings are found, we will be completely setup in ~January 03. If we can get additional funds earlier, we can be ready earlier.
- After we get scientific approval, we plan to explore the following sources of funds.
  - » South Carolina EPSCORE program and South Carolina Commission of Higher education.
  - » NSF support (U.of Houston)
  - » DoE Nuclear Physics (Houston, Columbia and Colorado)
  - » DoE Stockpile Stewardship program for academics. Typical grants are of the order of ~$500,000.
- We can be ready for an engineering run FY02 Summer, even if no extra funding is obtained by then. The RICH electronics upgrade, extra drift chambers beyond the E690 chambers will have to be put off till FY03. We will make the RICH work with present electronics for the engineering run under this scenario. We are, however, confident of obtaining extra funds, once approved. This can be followed by a Physics run in FY02 and the detector completed (more ToF, recoil detector installed, RICH tubes paid off, electronics upgraded, chambers upgraded) by Jan 03.

Manpower Issues

- The Nuclear physics institutions, Colorado and Houston have tried to apply to DoE Nuclear Physics for funds to take part in the 907 R&D phase. They requested funding for travel and post-docs. They were deferred due to the fact that P-907 was deferred.
- Once approved, we hope to get postdocs and graduate students from our collaborators. (Houston, Colorado, Michigan, Columbia, Fermilab). We are confident that we can mount the experiment and take data using the existing manpower fortified by 2 or 3 postdocs.
- In addition, several physicists have inquired about joining the collaboration and are awaiting the PAC's recommendation. We need to get beyond the present "chicken and egg" state of affairs.

Beam line requirements and rates

- Once the Main Injector extraction system works satisfactorily (with full quadrupole contingent), for the test beam, all we need is a handful of shifts in the control room to make the double spill scheme work. It will benefit the test beam effort as well.
- 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.
- Assume 60Hz 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 = $3x10^{6,}$ a million for each particle type of beam. This will take 126 hours of elapsed time.
- For most of the positive beam running, we need primary proton intensities of $10^8 – 10^9$ particles per spill. This is ~ $10^{-4} – 10^{-3}$ of a booster batch of $5x10^{12}$ protons!

Total amount of running time

1 data point = 3×10^6 events takes 126 hours elapsed time with 1 sec flat-top every 3 secs.

26 data points will take 4.4 months with the rates in the proposal.

With the new Double slow spill (Scheme #11, 1 pure pbar cycle alternating with one double spill), this time increases to 6.0 months.

Target	Physics	Beam Energies	Beam Charges	Factor(3 million events/data point)	data points
Cu	Engineering run	3	2	0.5	3.0
H2	scaling	12	2	1.0	6.0
N2	atm. Neutrinos	3	2	0.5	3.0
O2	atm. neutrinos	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
Various	Nucl. Scaling	5	2	0.1	1.0
Total					26.0

A MINOS target run after this will require 3.3 data points (10^7) events and is expected to take ~400 hrs.

(2003-2004 time frame)

MINOS fast spill and E907 running

- When MINOS starts running (November 2004), they will use a scheme whereby one booster batch gets sent to pbar and the remaining 5 booster batches get sent to MINOS in a fast spill. This spill has a cycle time of 1.87 sec. MINOS running alone will reduce the pbar- rate by by 21.6%.
- Running a slow spill concurrently with MINOS will impact MINOS luminosity. MINOS running and E907 running are incompatible.
- E907 should be completed before MINOS turns on.

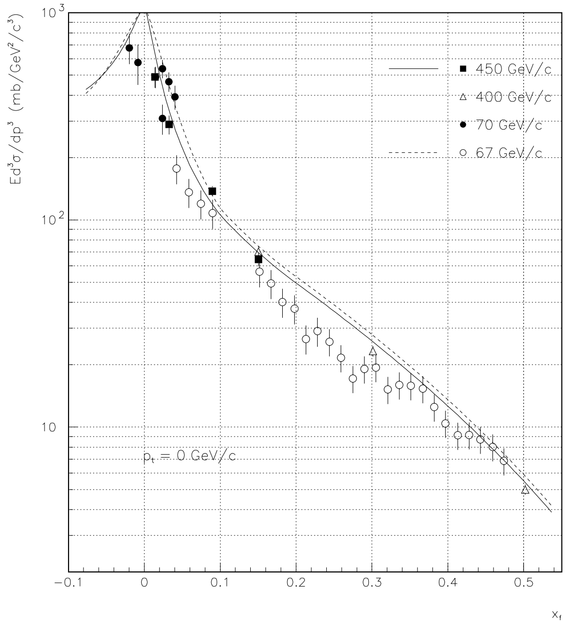
Conclusions

- We have proposed a low cost, high statistics , low systematics experiment to measure particle production on various targets with various beam momenta and types.
- The particle identification, rate, energy range and beam species capabilities of P-907 are unmatched by its competitors.
- We have made considerable progress in getting the experiment on the floor during the last year of R&D.
- The time window appropriate for the mounting and completion of E-907 would be 2002-2004.
- The measurements made would benefit our understanding of particle production dynamics in minimum bias interactions (99% of cross section), and in nuclear interactions.
- The measurements would also benefit the study of atmospheric neutrino interactions, Muon Collider/Neutrino factory target choices and also the MINOS experiment.
- The experimental team of proponents has had considerable experience in hadro-production experiments.
- In addition to the hardware, large portions of software can be inherited from previous experiments (E-910 and SELEX) and reused.
- We have addressed the questions expressed by the PAC of Nov 2000, namely
  - » We have assurances of funding outside FNAL (Livermore)
  - » We have presented a detailed plan for installing, commissioning and running the detector.
  - » With the help of MINOS collaborators, we have produced a running scenario for producing the MINOS measurements.
  - » We have developed the nuclear physics/heavy ion case in writing and provided strong letters of endorsement from the leaders of that. community.

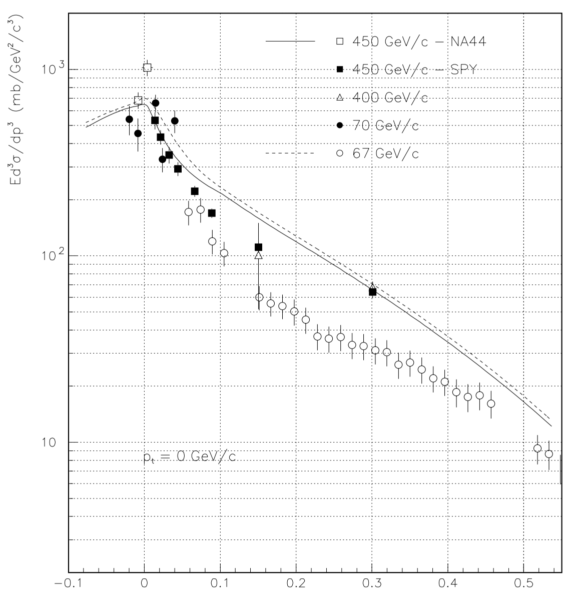
Extra slides

- We include extra slides for more info. These slides will not be shown during the talk, unless prompted by discussion.

Quality of existing data

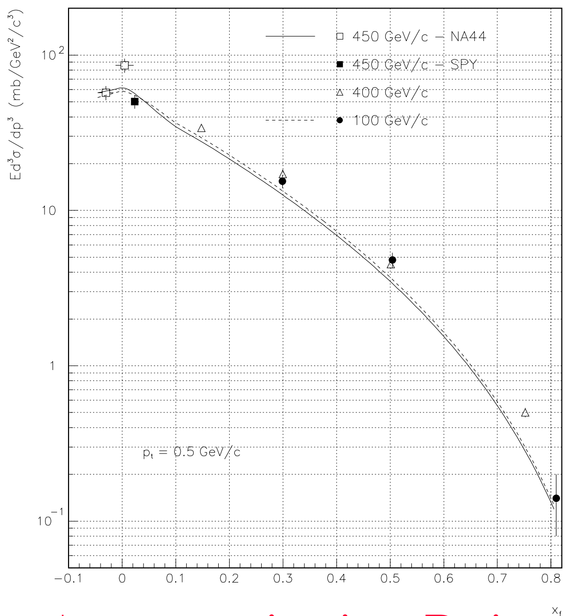


- Invariant π^- cross section in p Be interactions as a function of Feynman x at p_t=0 GeV/c

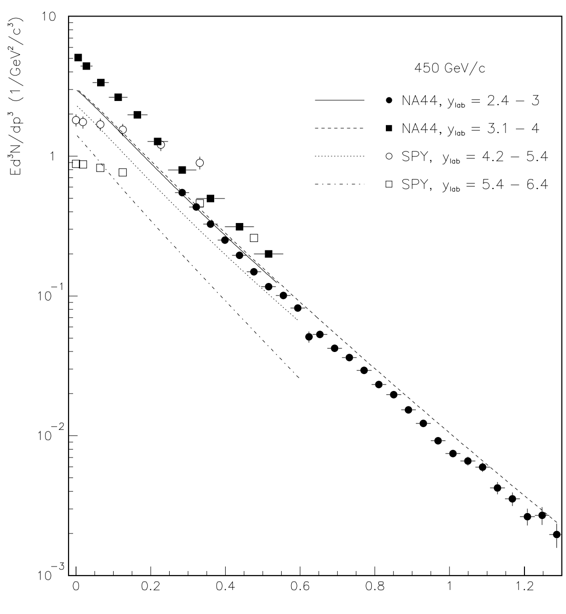


- Invariant π+ cross section in p Be interactions as a function of Feynman x at p_t=0 Gev/c

Quality of existing data



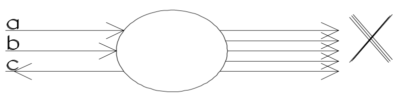
- Invariant π^+ cross section in p Be interactions as a function of Feynman x at p_t=0.5 GeV/c

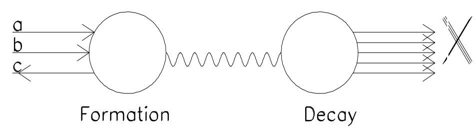


- Invariant π+ cross section in p Be interactions as a function of pion transverse mass.More fitting going on.

Scaling Law

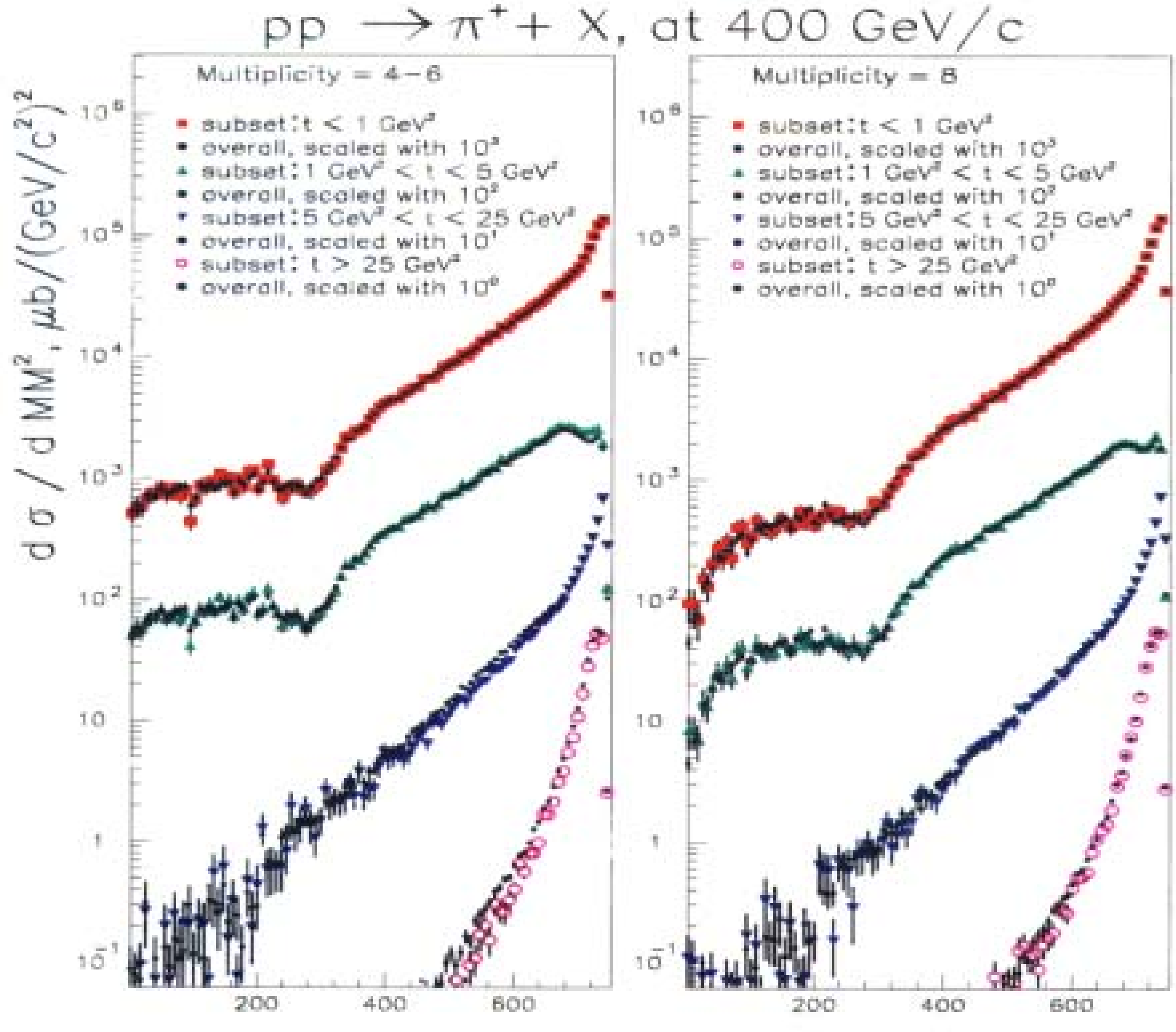
- Physics behind law is the factorization of 3 body scattering cross section.



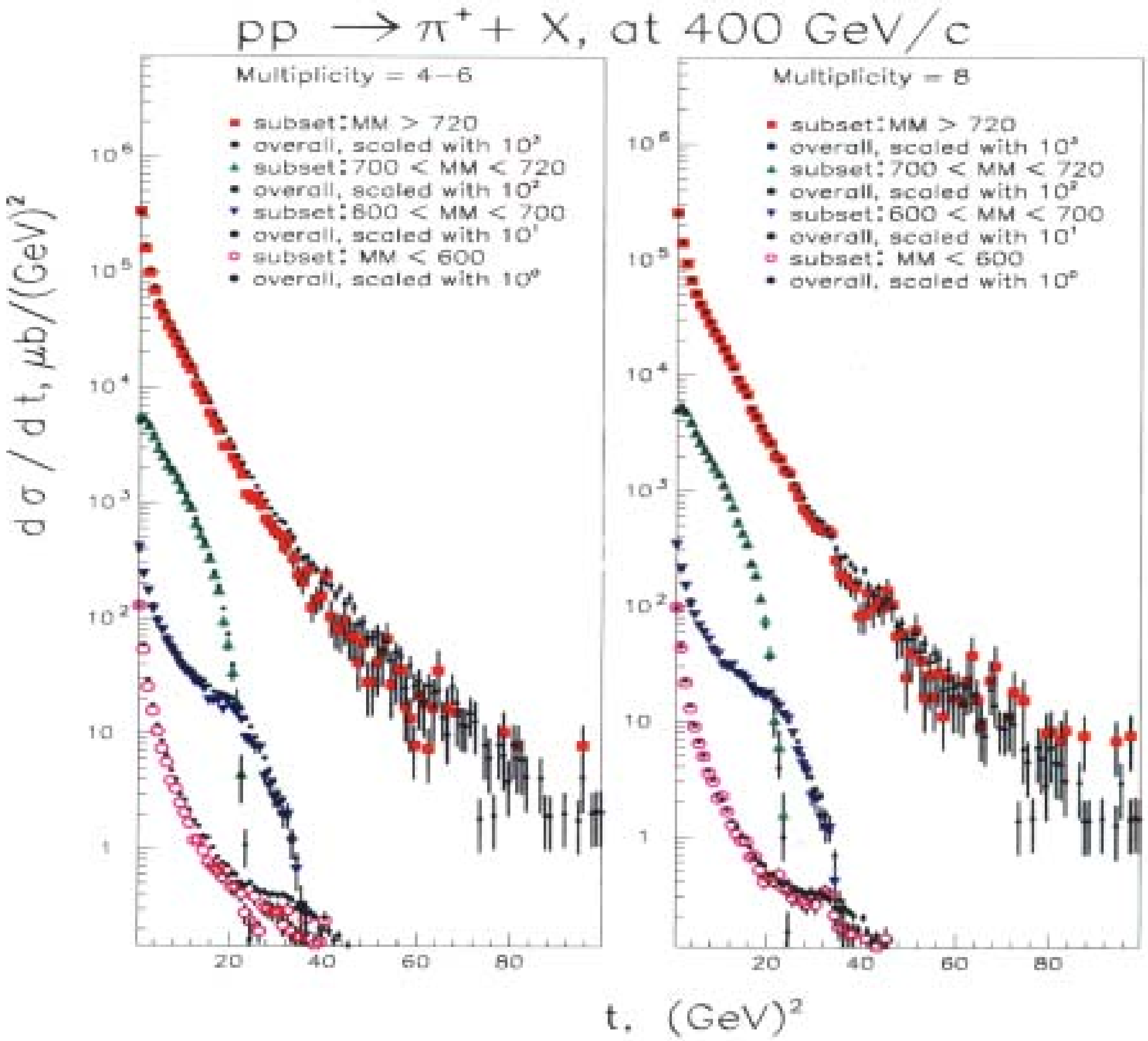


- We will be able to test the scaling law for 36 reactions as a function of s and t for various subsets with unprecedented accuracy.
- For each subset, we will be able to test the equality of the branching function for sets of crossed reactions. E.g $\pi^- p \rightarrow p+X$ and $\bar{p}\, p \rightarrow \pi^+ + X$ should have the same set of branching functions $\beta_{subset}(M^2)$! One is a diffractive process and the other a central process.

Scaling Law-EHS results



Scaling law -EHS results



Nuclear Physics Measurements

- Another type of scaling is called "Superscaling" and is derived from "Relativistic Fermi Gas model" of the nucleus. The scaling function is independent of nucleus. Observed in ep scattering. P907 will extend these tests to hadron beams. Donnelly and Sick, Phys. Rev. Lett. 82:3212-3215, 1999

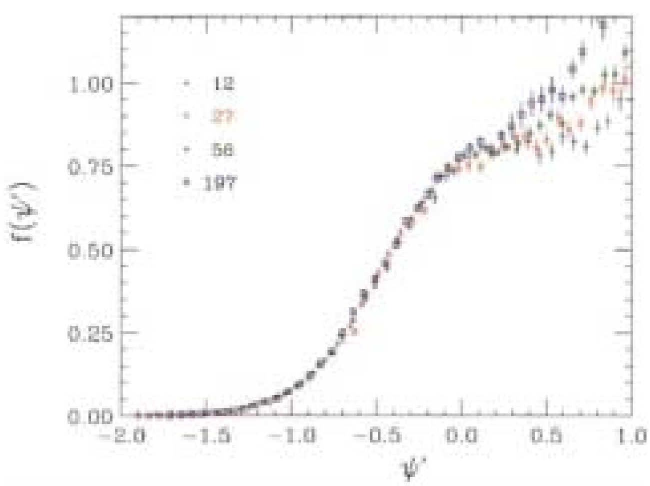


FIG. 3. (Color) Scaling function for C, Al, Fe, and Au and fixed kinematics ($q \approx 1000$ MeV/c).

- See reference for further details.

Below we summarize the essential RFG developments and refer the reader to [8,9] for more detail, including the relationships between the RFG formalism and the usual y-scaling analysis. As seen in the work cited, a dimensionless scaling variable ψ naturally emerges:

$$\psi = \frac{1}{\sqrt{\xi_F}} \frac{\lambda - \tau}{\sqrt{(1+\lambda)\tau + \kappa\sqrt{\tau(1+\tau)}}} \tag{2}$$

where $\xi_F = \sqrt{1+\eta_F^2} - 1$ and $\eta_F = k_F/m_N$ are the dimensionless Fermi kinetic energy and momentum, respectively. Here we employ dimensionless variables $\kappa \equiv q/2m_N$, $\lambda \equiv \omega/2m_N$ and $\tau \equiv \kappa^2 - \lambda^2 > 0$. Additionally, to allow for the fact that nucleons are knocked out of all

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