Hadron Production Experiments

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WIN'03 Lake Geneva

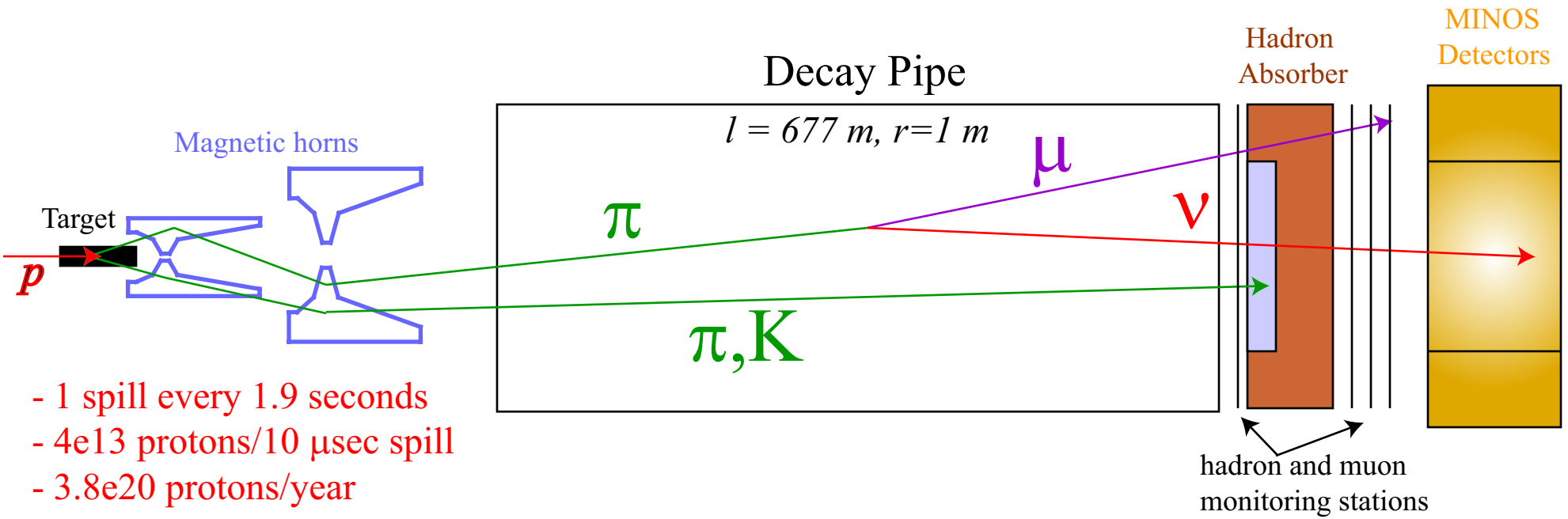
- *Why is more hadron production data needed?*
- *News from HARP*
- *NA49 p-C data*
- *MIPP (FNAL E907) update*

Neutrinos at the Main Injector (NuMI)

120 GeV/c protons strike graphite target

Magnetic horns focus charged mesons (pions and kaons)

Pions and kaons decay giving neutrinos

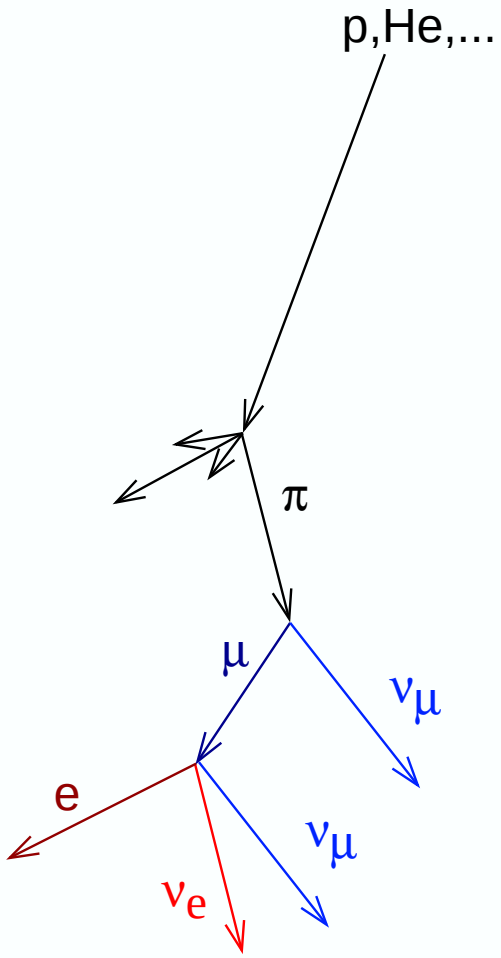


- 1 spill every 1.9 seconds
- 4e13 protons/10 μsec spill
- 3.8e20 protons/year

L = 1.04 km to Near, 735 km to Far Detector

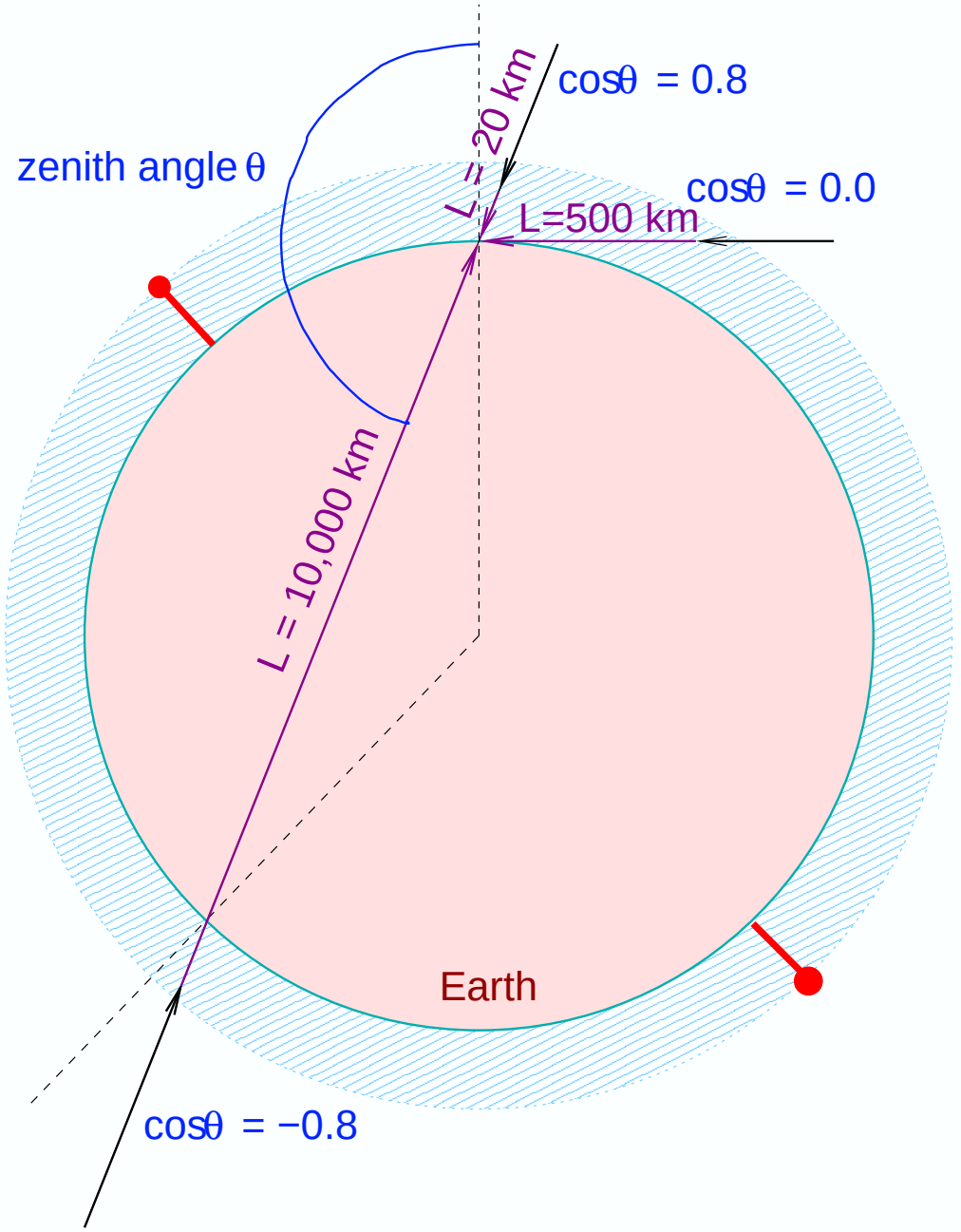
Vary target and horn positions to select
low, medium, and high energy neutrino beams

$$P_{\mu\tau} = \sin^2 2\theta \sin^2\left(1.27\Delta m^2 \frac{L}{E}\right)$$



$$R = \frac{\nu_\mu}{\nu_e} \sim 2$$

(~5% uncertainty)



Flux is ~Up/Down symmetric

Hadron Production

There are basically 2 methods for modeling hadron production yields

MC Models

- MARS / FLUKA / DPMJET/ FRITRIOF / GHEISHA / ...

"Empirical parameterizations"

- BMPT (2001) fits to Atherton+SPY data (450 GeV p-Be)
- Sanford-Wang (1967) fits to Dekkers, Lundy, Baker, Fitch (10-35 GeV p-Be)
- Malensek (1981) fits to Atherton (450 GeV p-Be)

All of these require extrapolations from:

- Different primary momenta
- Different target nuclie

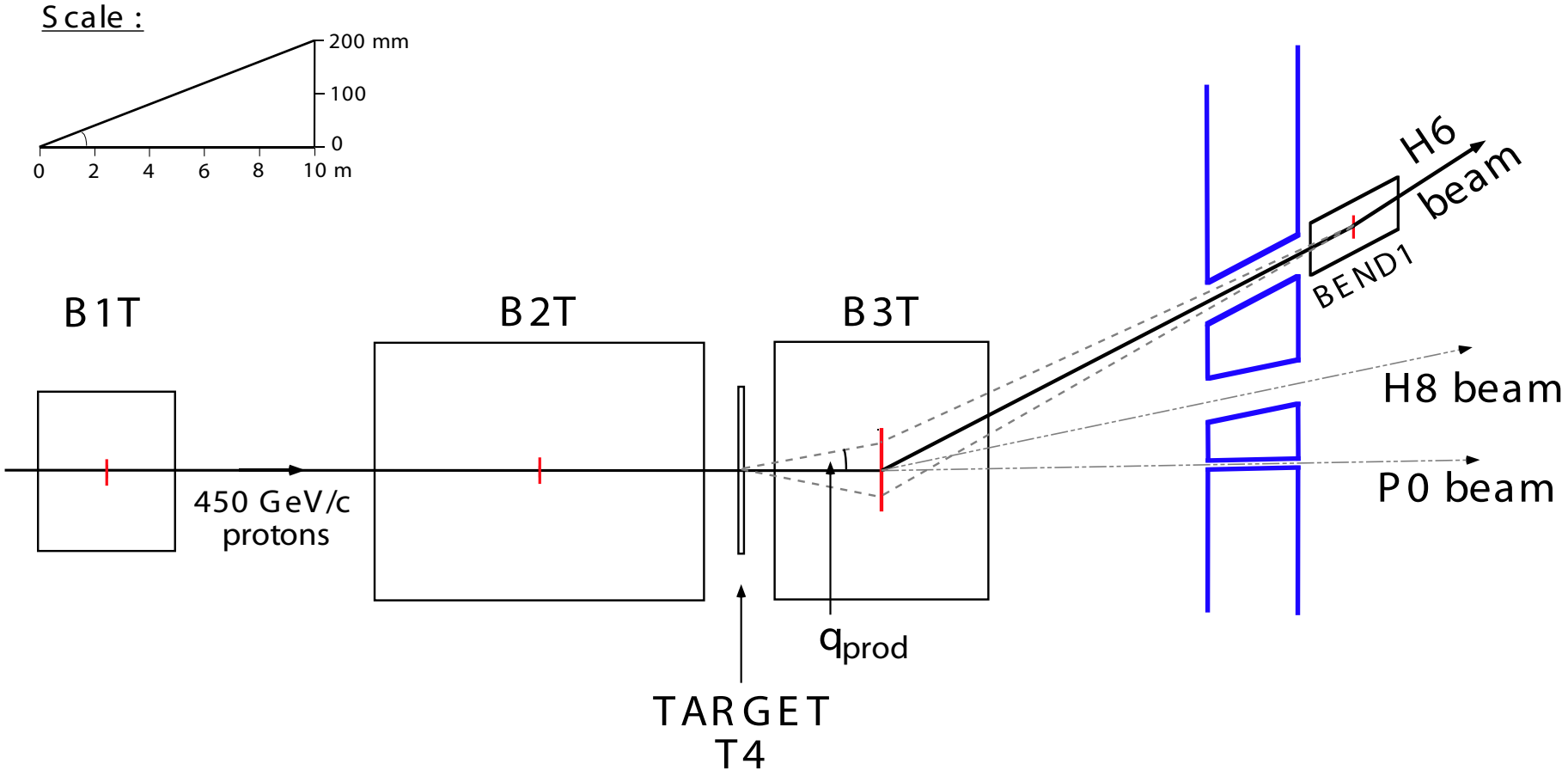
  Barton'82 is only attempt in leterature to scan large number of nuclei.
  All at p=100 GeV/c
- Different target lengths

All the models are driven by the limited data available. Even where data is available, there are differences between experiments

This results in uncertainties for the pion (Kaon, proton, etc.) yields from pA interactions of up to 30%

For neutrino experiments, this sets the limits to which one can measure neutrino cross-sections. Also impact near-far comparison for two detector experiments

Layout of Atherton et al. Experiment



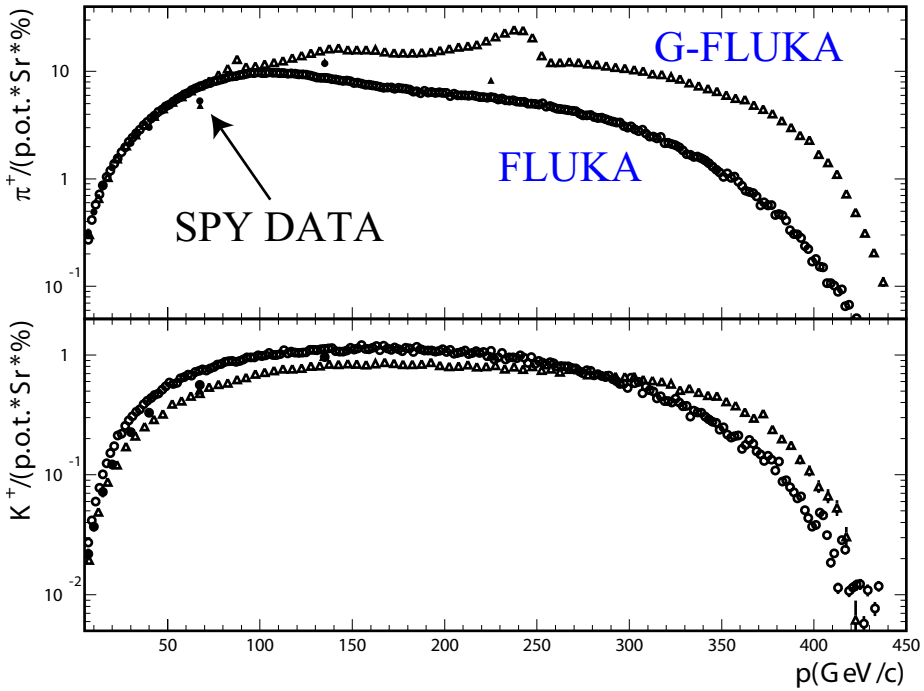
SPY (and others) were fixed arm spetrometers

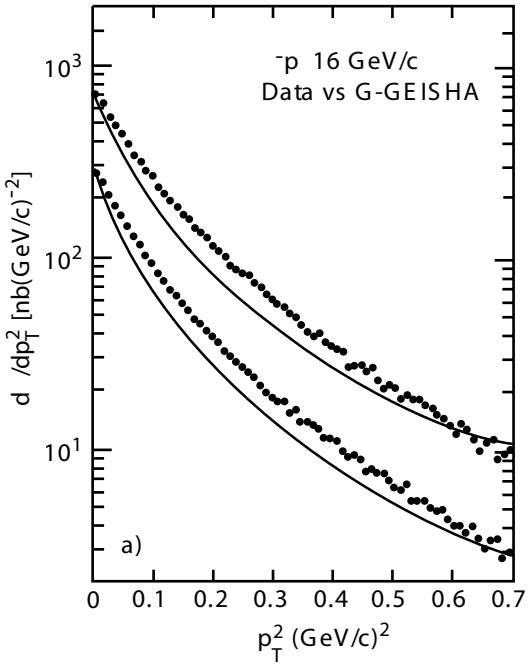
Measured production at only a few values of p_T

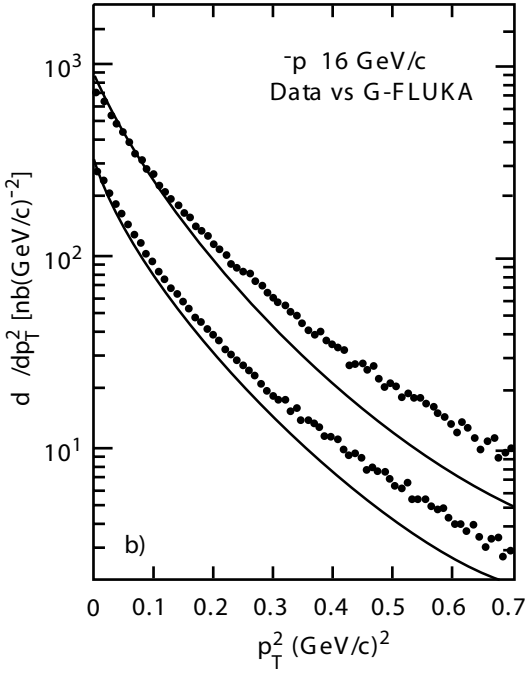
Monte Carlo Generators

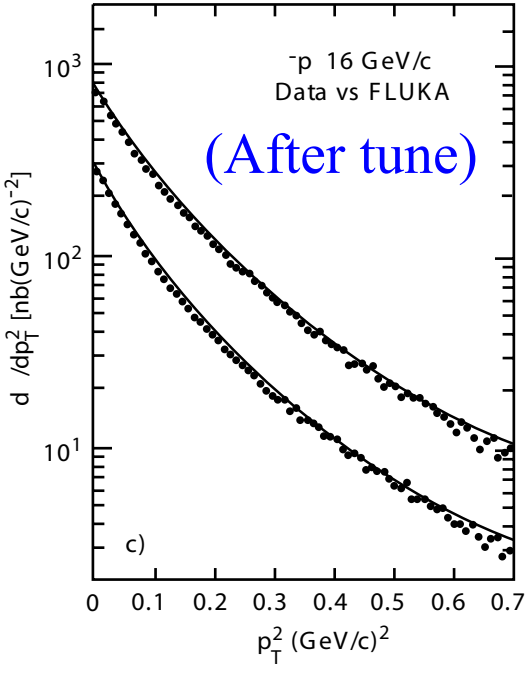
Hadron generators driven by data

Current level of agreement is ~30%

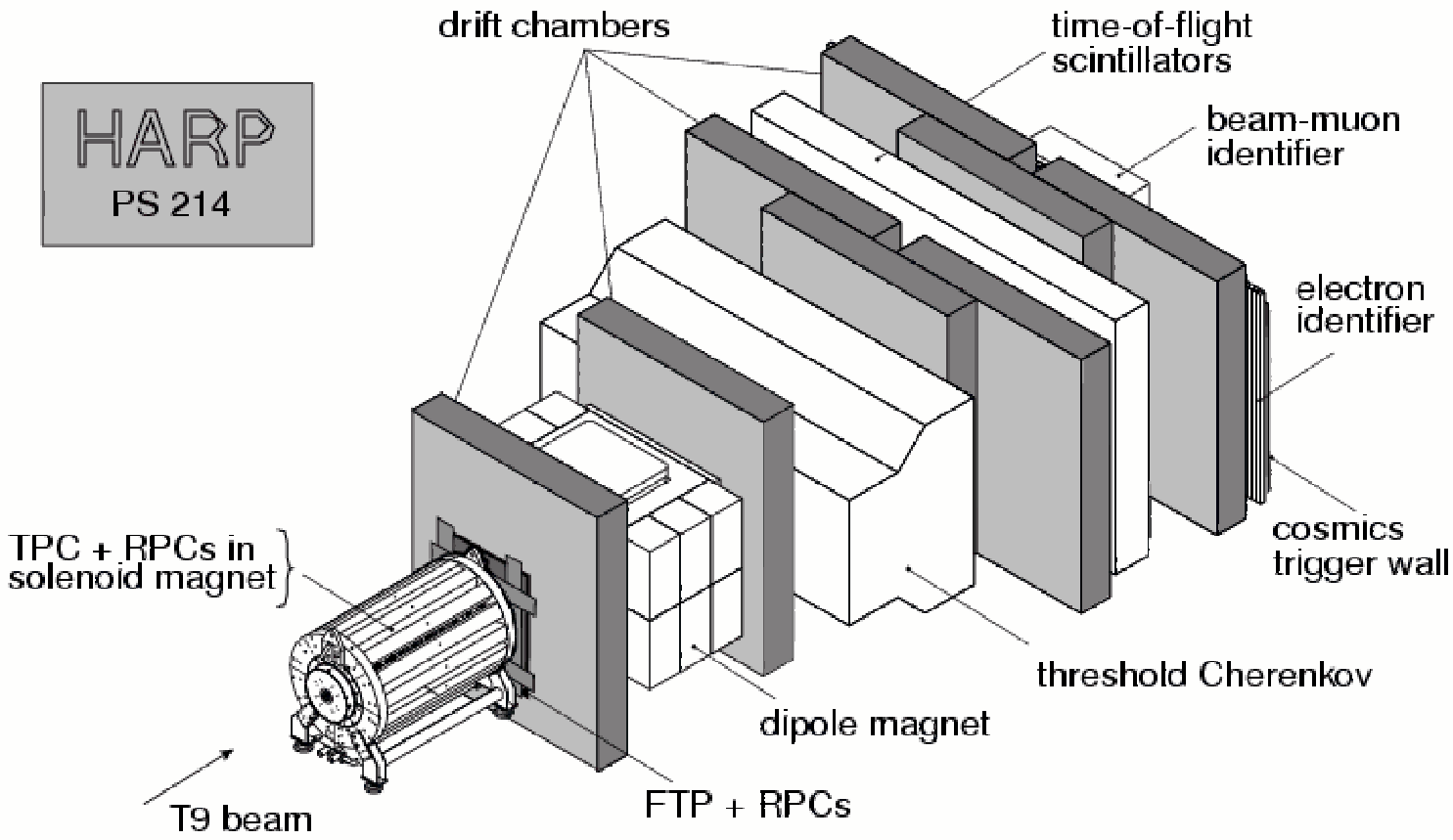








The HARP experiment



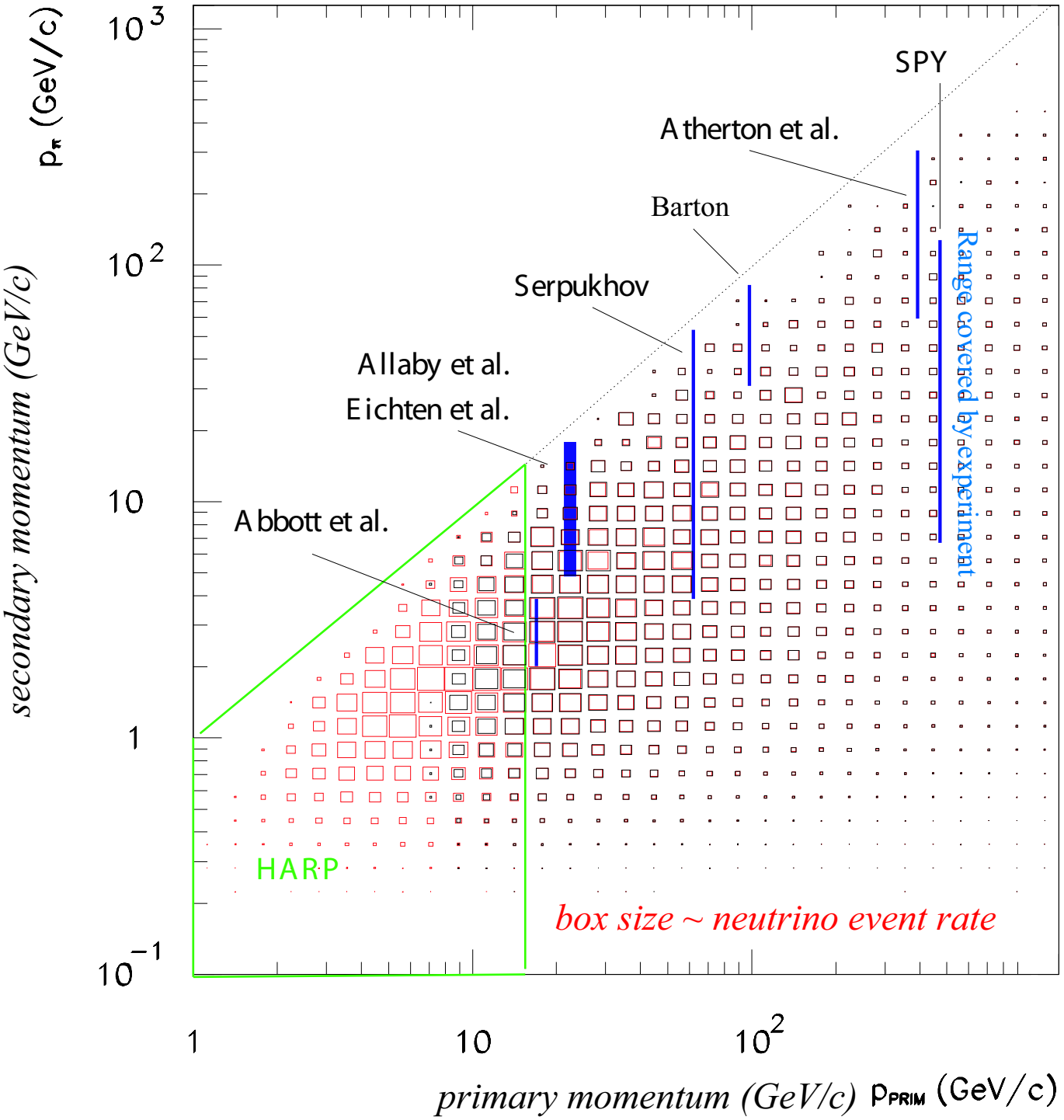
124 people

24 institutes

Physics goals

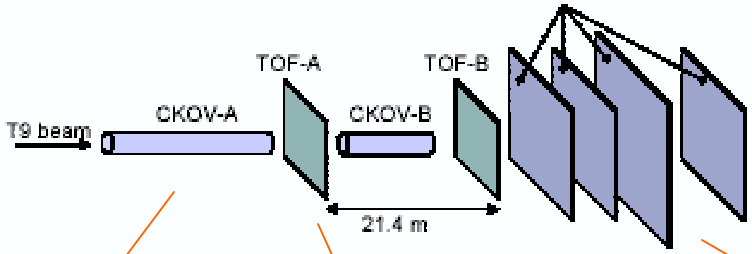
- Systematic study of HAdRon Production:
  - Beam energy: *2-15 GeV*
  - Target: *from hydrogen to lead*
- Motivation:
  - Pion yield for the design of the proton driver of *neutrino factories*
  - Precise calculation of *atmospheric neutrino flux*
  - Prediction of neutrino fluxes for the *MiniBooNE* and *K2K* experiments
  - Input for *Monte Carlo* generators (GEANT4, e.g. for LHC)

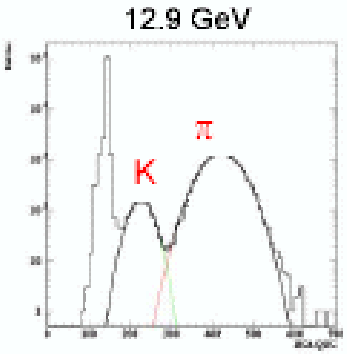
Atmospheric Neutrinos

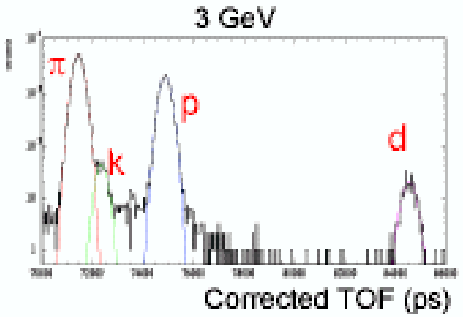


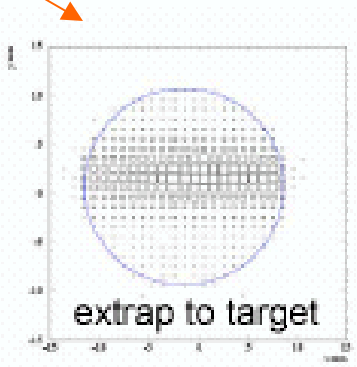
Beam detectors

- Need beam position, profile and composition on event-by-event basis









100% eff. e/π

K > 12 GeV

170 ps res

p/k/π sep. < 5 GeV

96% eff.

<100 μm res.

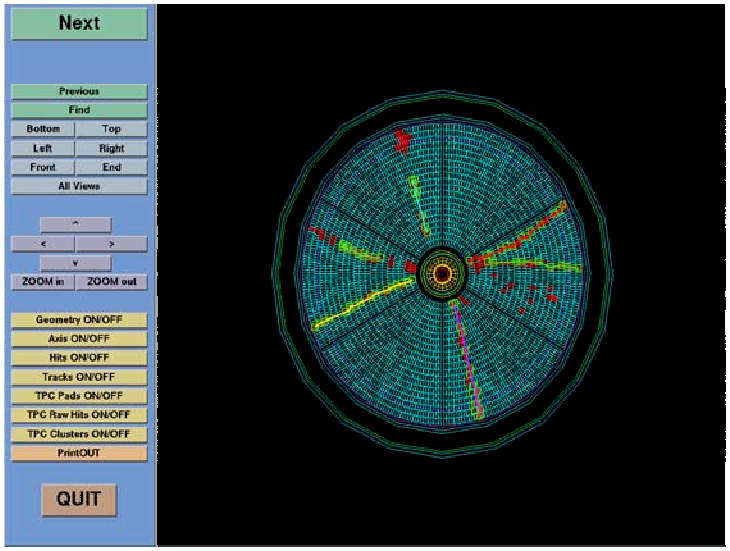
What was done

- 124 people
- 24 institutes
- Data taking in 2001 and 2002
- 30 Tbytes of data
- Targets from hydrogen to lead
- 2-15 GeV beam energy

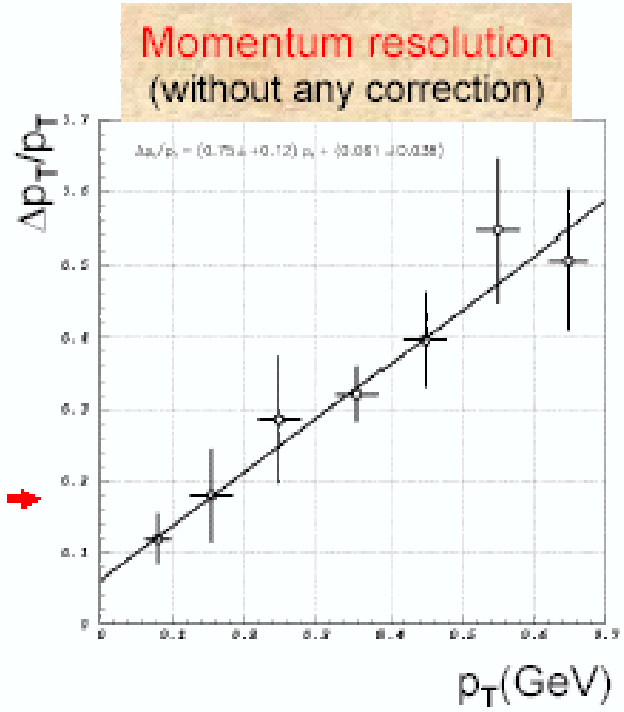
owed

	Target material	Target length (λ%)	Beam Momentum (GeV)	#events (millions)
Solid targets	Be	2 (2001) 5 100	±3 ± 5 ± 8 ± 12 ± 15 Negative only 2% and 5%	
	C			
	Al			
	Cu			
	Sn			
	Ta			
	Pb			
K2K	Al	5, 50, 100, replica	+12.9	
MiniBooNE	Be		+8.9	
Cu "button"	Cu		+12.9, +15	
Cu "skew"	Cu	2	+12	
Cryogenic targets	N_2	6 cm	±3 ± 5 ± 8 ± 12 ± 15	
	O_2			
	D_1			
	H_1			
	H_2	16 cm	±3, ±8, ±14.5	
Water	H_2O	10, 100	+1.5, +8(10%)	

TPC



- Most complex Harp subdetector, for θ>100 mrad
- Some problems due to Xtalk and field distortions are being investigated and will be corrected
- Present momentum resolution expected to dramatically improve

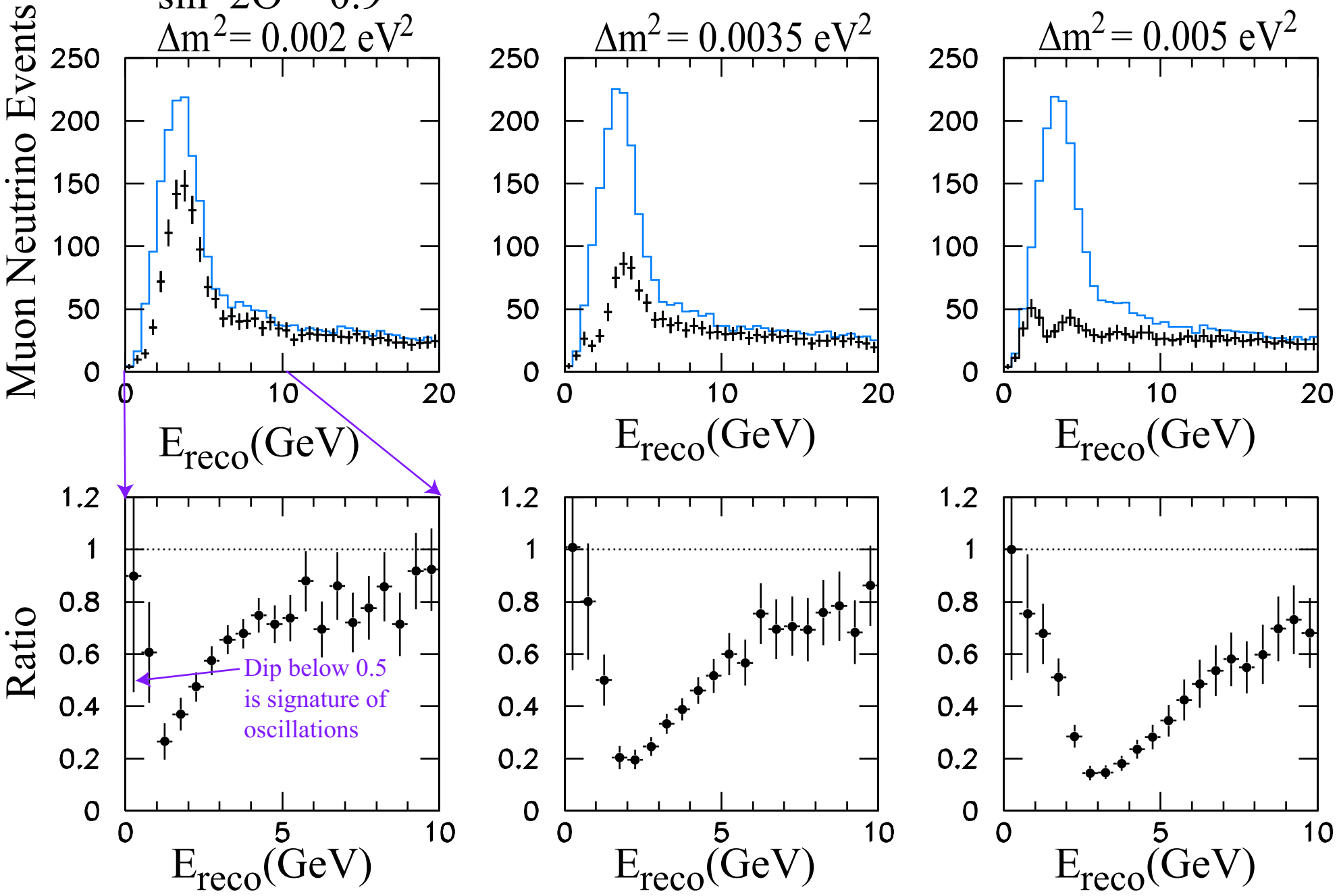


Conclusions

- Data taking programme completed successfully in 2002
- A big effort for the understanding of the TPC is going on
- Software tools in place for data analysis
- All detectors in the forward region are calibrated and their performance understood
- Physics underway…

MINOS Energy Spectra

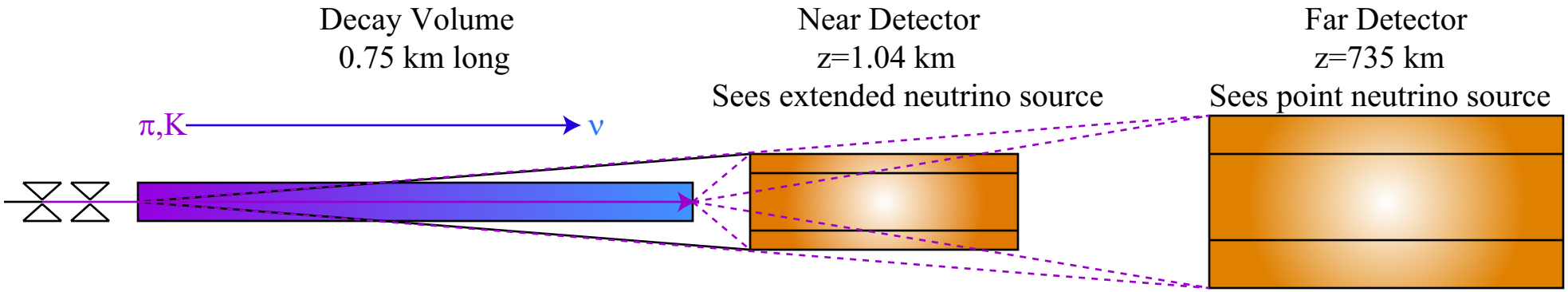
Low Energy Beam
10 kt-yr Exposure *(2 years at 3.8E20 POT/yr)*



Near to Far Spectrum Comparison

MINOS Near and Far detectors are built to be a similar as possible
- iron and scintillator thickness and spacing are same
- average B field

Neutrino flux as two sites is different



Predict far flux by extrapolating high statistics measurement at near detector

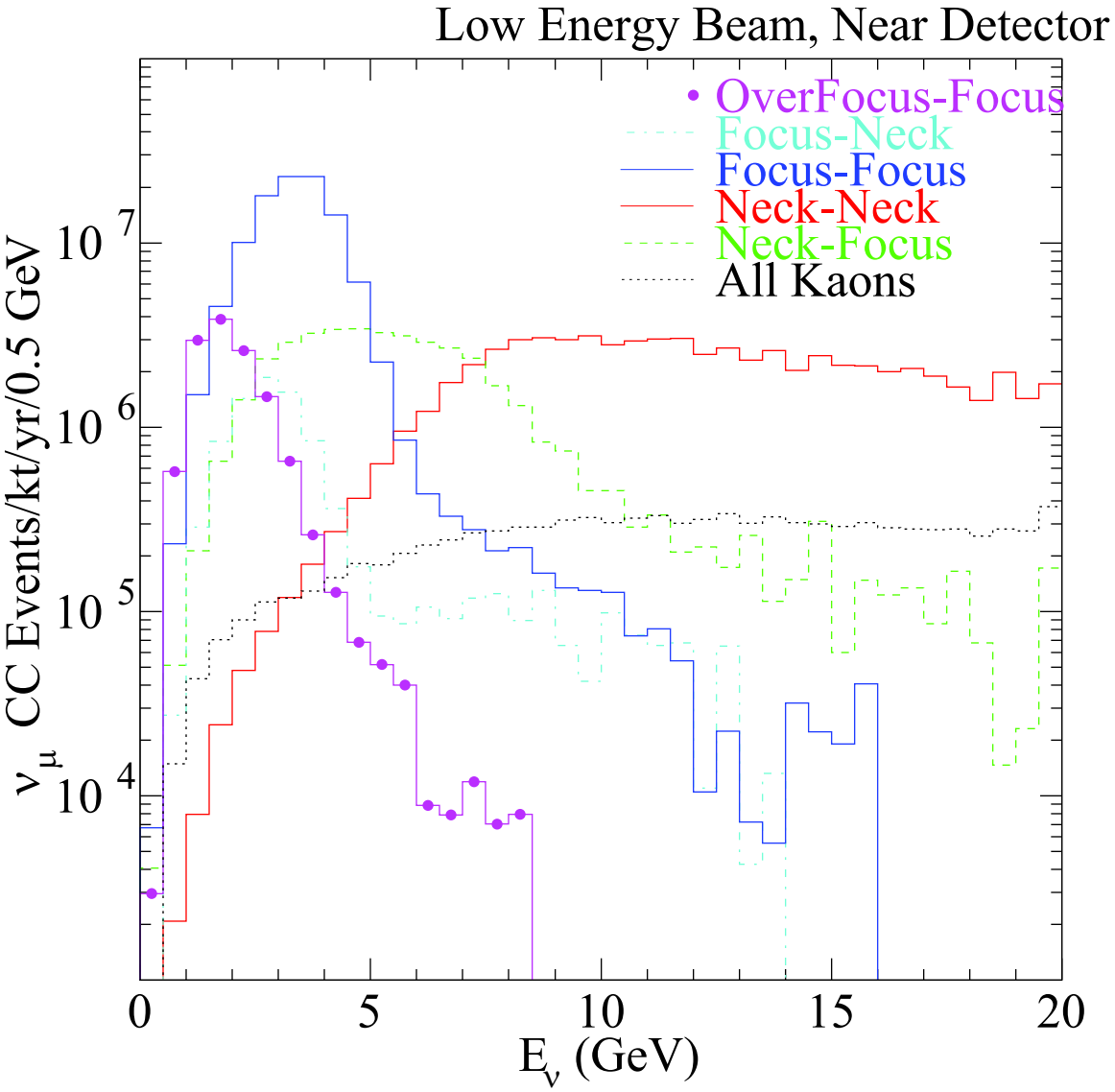
$$N(E)^{predicted}_{FAR} = N(E)^{measured}_{NEAR} \; R(E)^{predicted}_{FAR/NEAR}$$

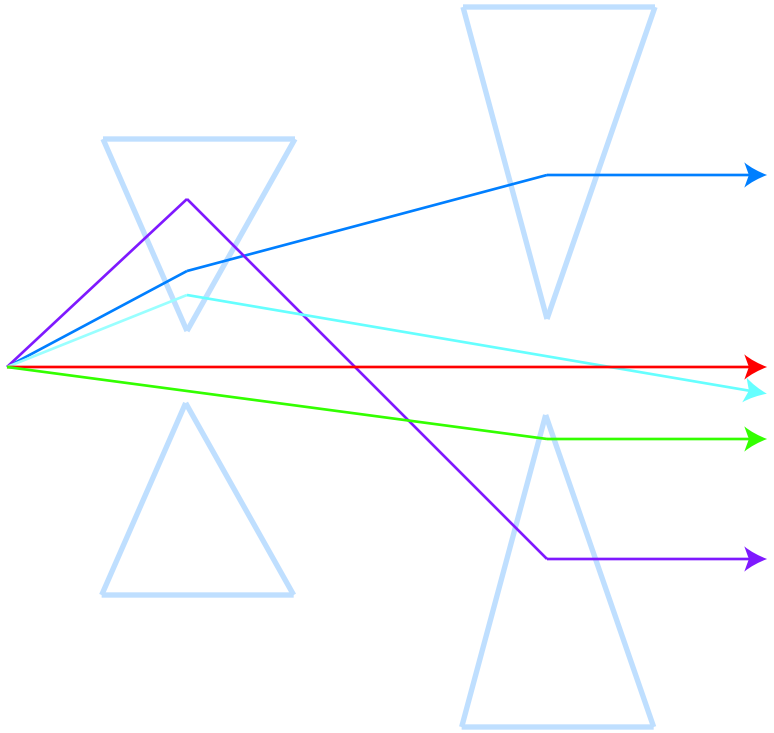
point source: $R(E)^{predicted}_{FAR/NEAR} = Z^2_{NEAR}/Z^2_{FAR} = 1.04^2/735^2 = 2x10^{-6}$

line source: $R(E)^{predicted}_{FAR/NEAR} = \dfrac{\int exp(-z/\gamma c\tau)/(1/(z-z_{far})^2)dz}{\int exp(-z/\gamma c\tau)/(1/(z-z_{near})^2)dz}$

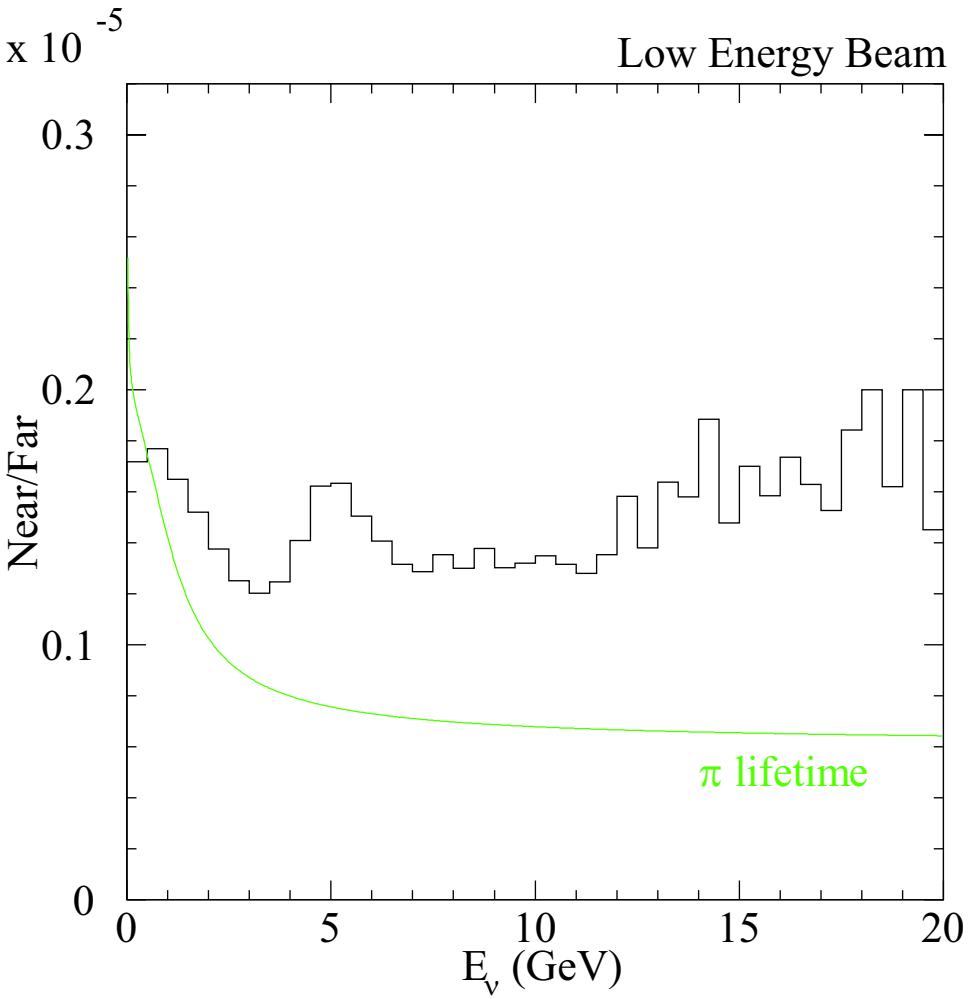
Ultimately need simulation of beam line to account for
- production of particles in target
- horn acceptances
- beam line acceptances

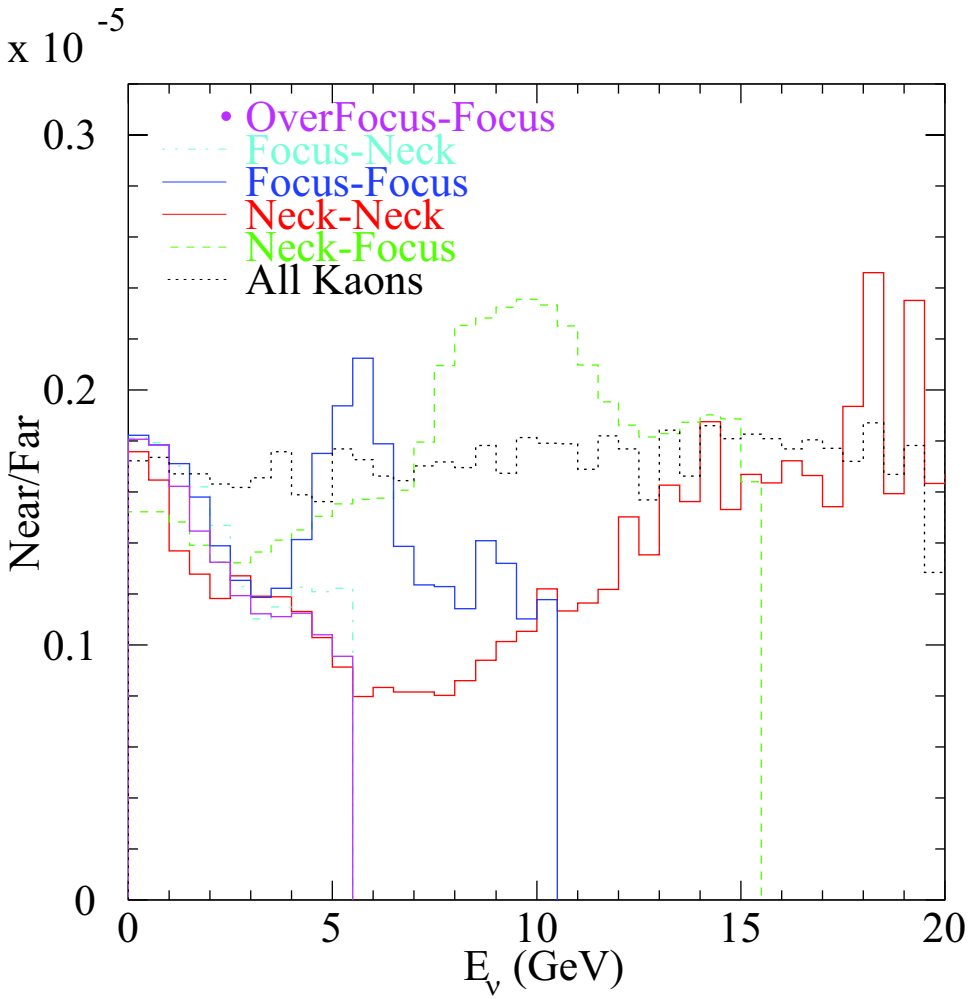
Components of LE Beam



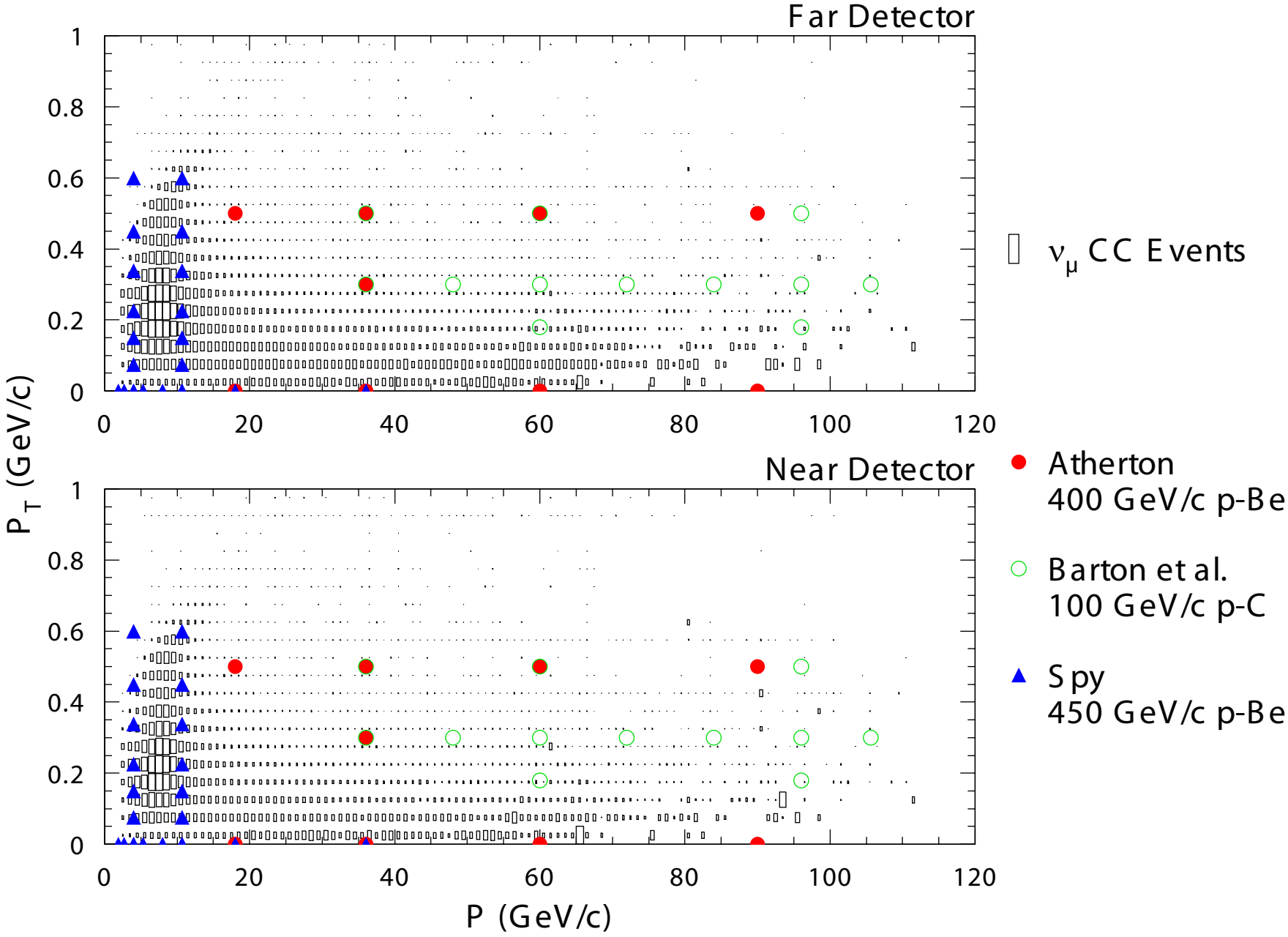


Far/Near By Track Type



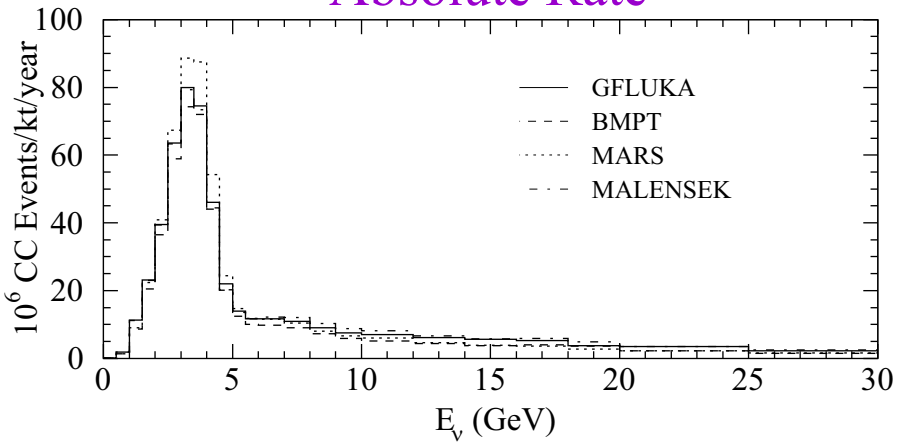


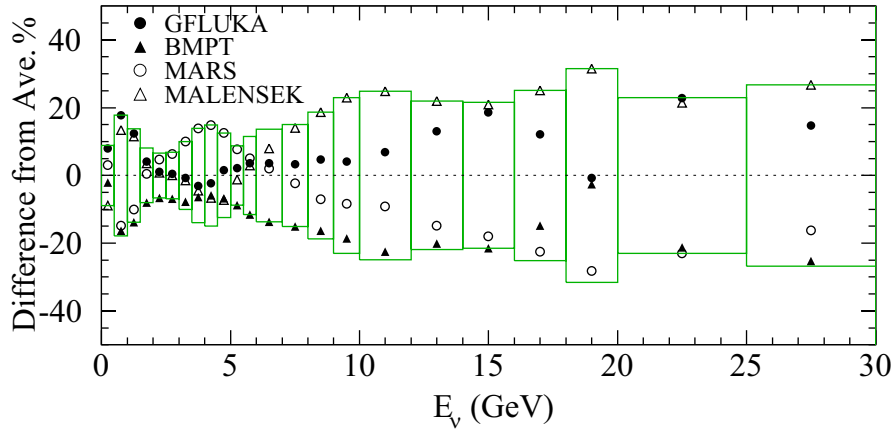
Low Energy Beam π+



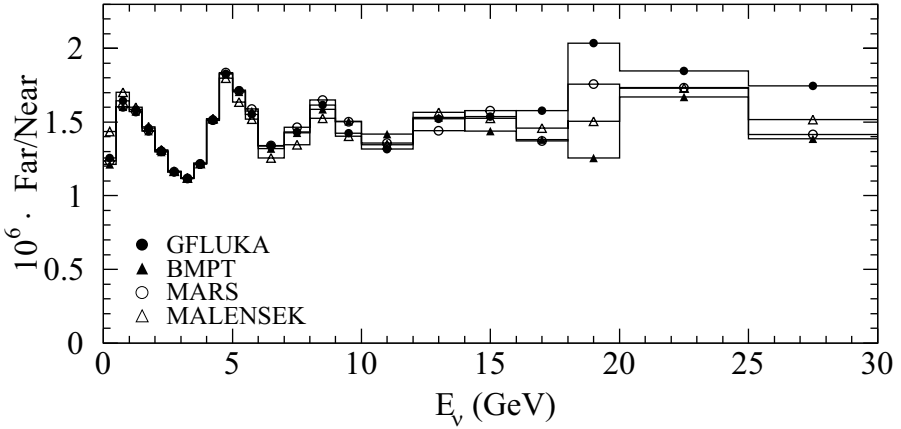
Uncertainties Due To Hadron Production

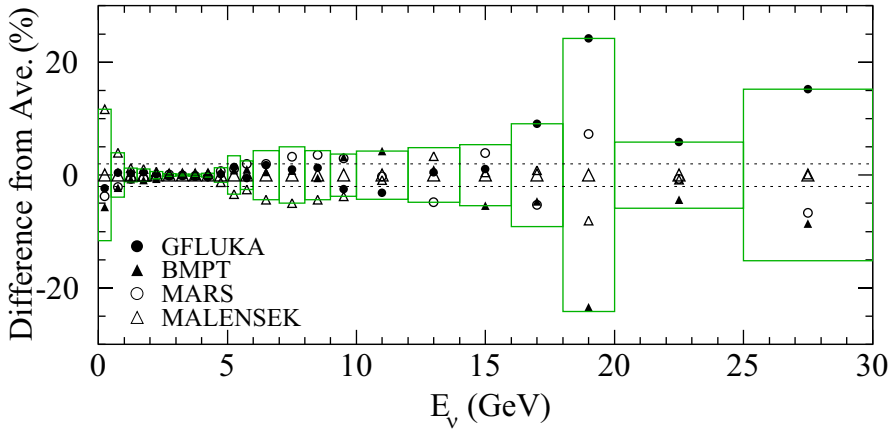
Absolute Rate





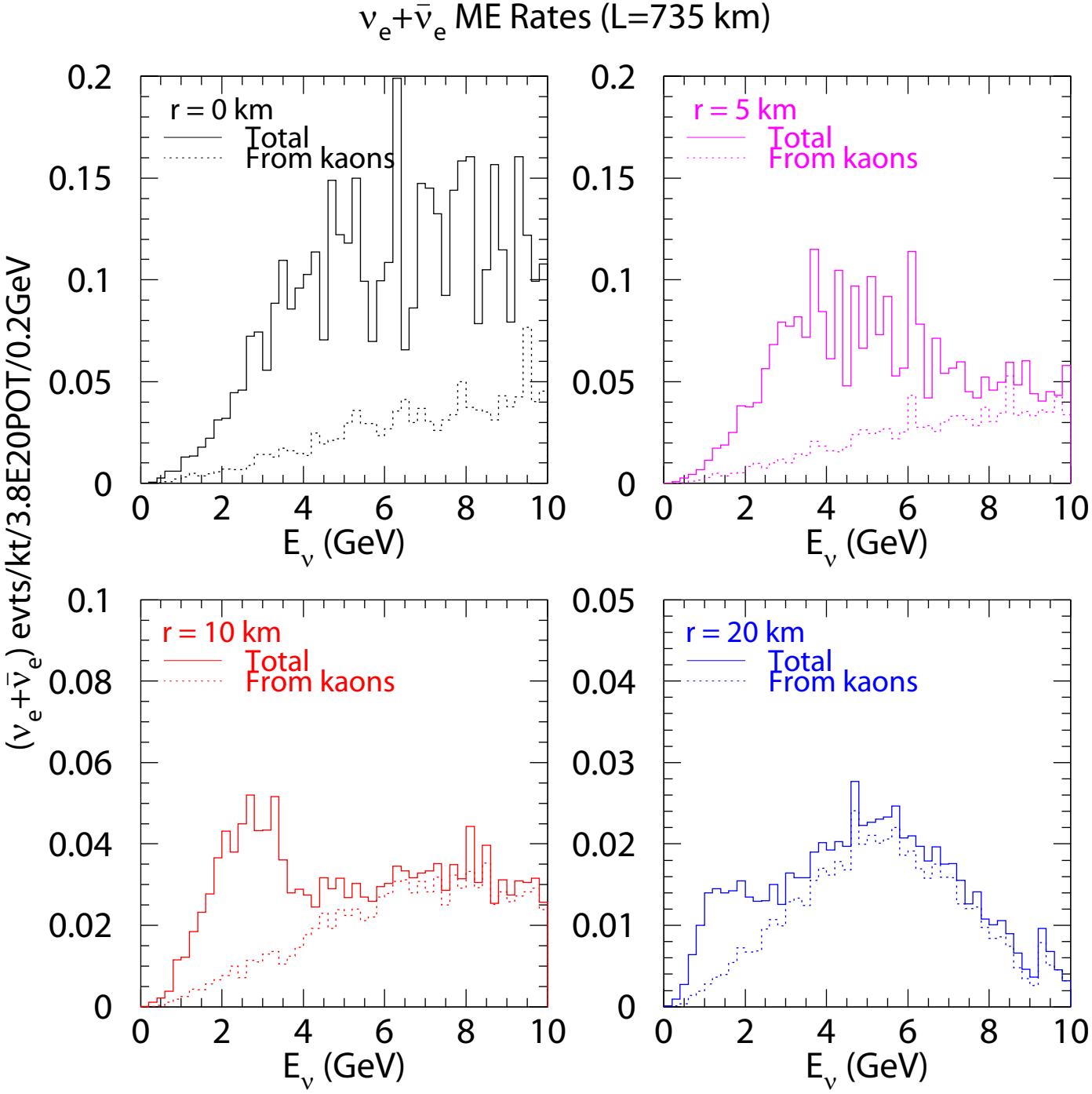
Far to Near Comparison





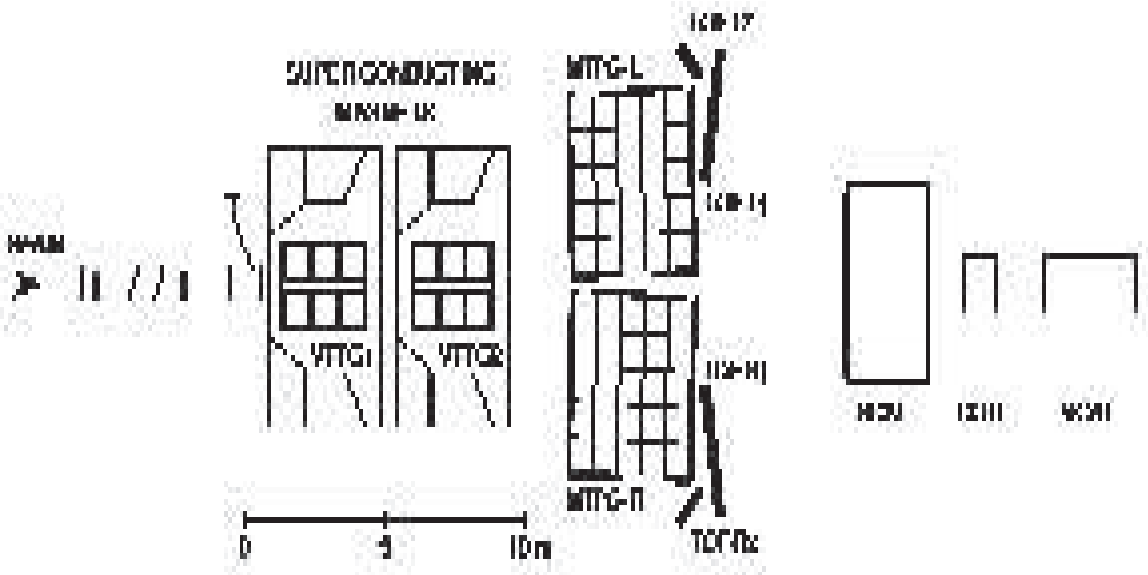
10 to 30% uncertainties in absolute rate

2-10% uncertainties in far to near comparison


$\nu_e+\bar{\nu}_e$ ME Rates (L=735 km)
$(\nu_e+\bar{\nu}_e)$ evts/kt/3.8E20POT/0.2GeV
r = 0 km
Total
From kaons
r = 5 km
Total
From kaons
r = 10 km
Total
From kaons
r = 20 km
Total
From kaons
E_ν (GeV)
E_ν (GeV)
E_ν (GeV)
E_ν (GeV)

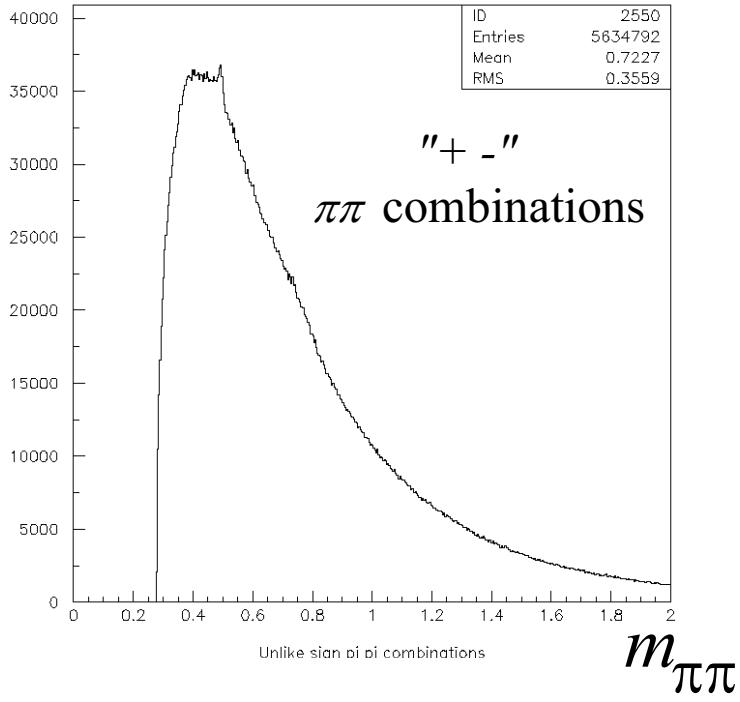
Improve Hadron Production (experimentally)

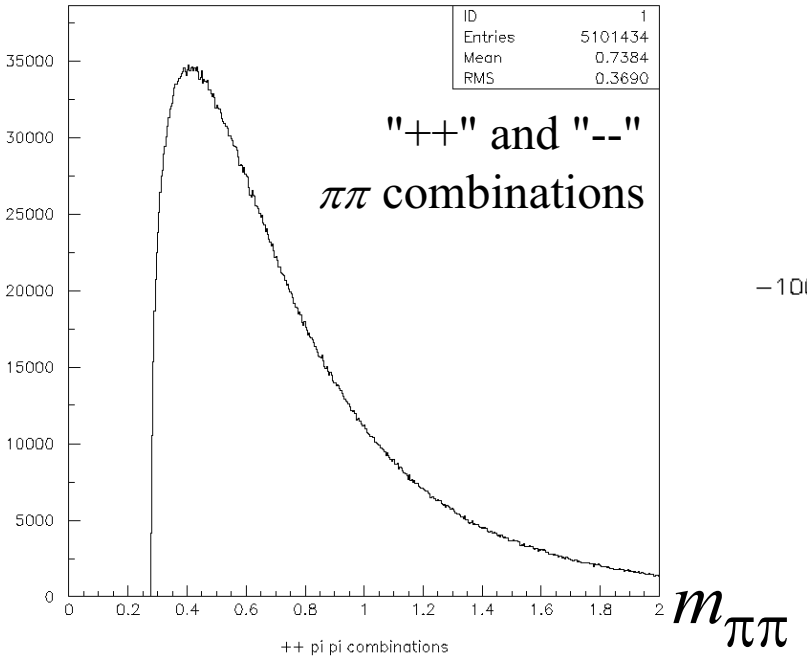
- Joint proposal in 2000 from MINOS and atmospheric neutrino flux calculators to CERN for 12 week run to measure hadrons at NA49 at range of energies 60 - 350 GeV with carbon targets.
- CERN $$$ crisis.
- We got a 1 week run in June 2002 + funding from UK.
  - 158 GeV run, 500k triggers
  - 100 GeV run, 160k triggers
  - 1% interaction length carbon target, proton selected beam (using Cerenkov), TPCs, HCAL, CD, no TOF.
  - Gap TPC added

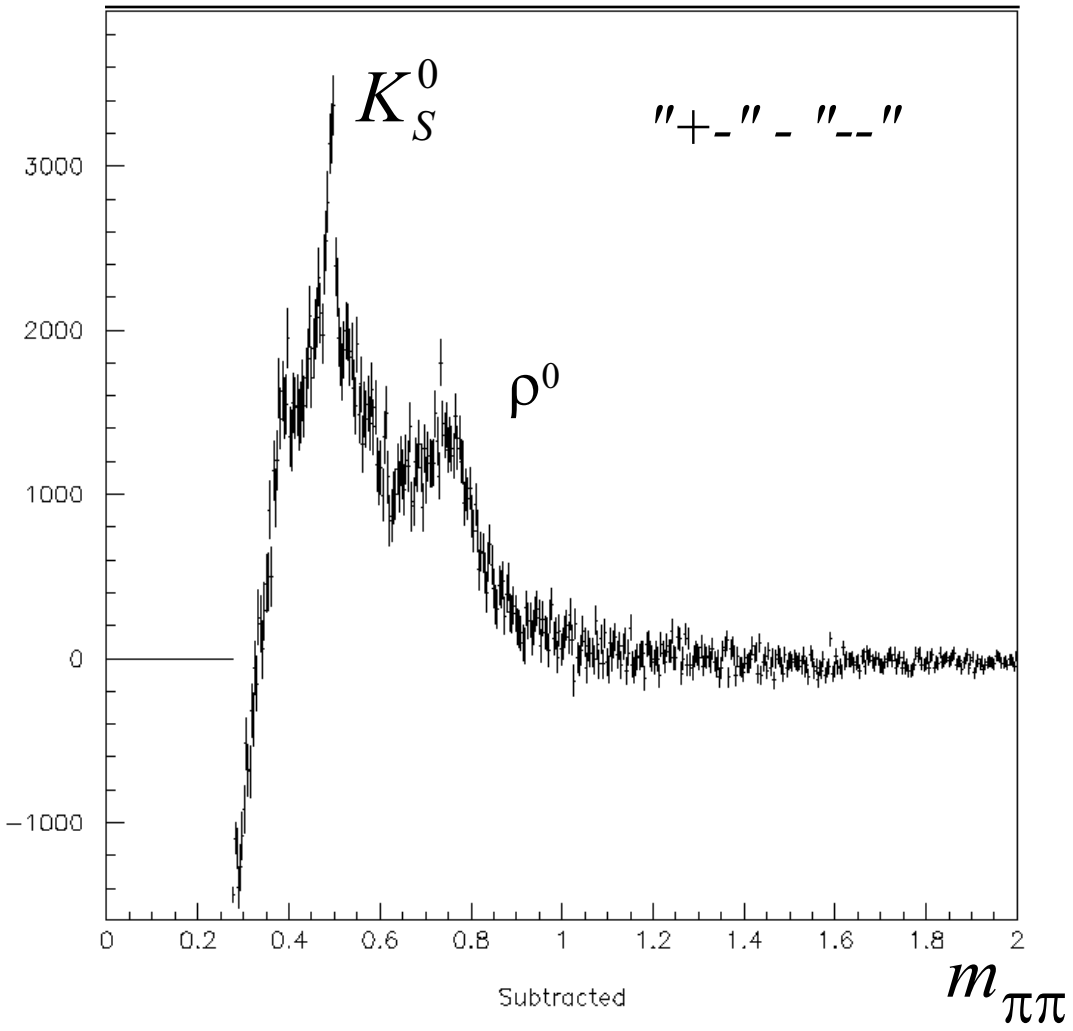


Giles Barr

Very preliminary first look at data







The MIPP Experiment (FNAL E907)

(Main Injector Particle Production Experiment)

- MIPP will make high statistics measurements of the final state of interactions of pions, kaons, and protons with nuclear targets.
- Primary beam momenta between ~10 and 120 GeV/c
- Also will make 'service measurement' of NuMI target

- This data has applications in many areas:
  - Neutrino beams (current NuMI,CNGS, and future JHF,Neutrino Factory)
  - Atmospheric Neutrino calculations
  - Relativistic heavy ion physics (QGP formation eg.)
  - Nuclear physics
  - General purpose Monte Carlos such as MARS/FLUKA/GEANT4

- *E907 given stage 1 approval* at Novemeber 2, 2001 FNAL PAC meeting. MOU with FNAL being drafted
- Installation and construction underway. Data taking summer 2003-2004.

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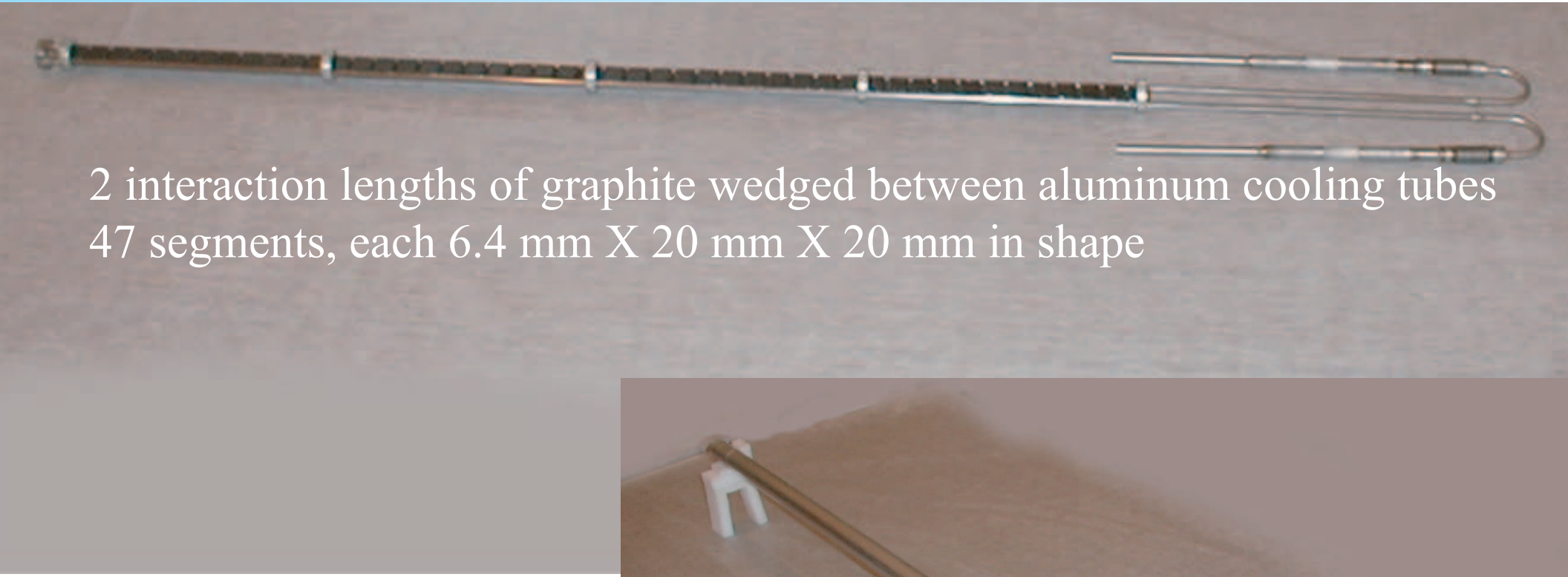
S.Wojcicki
Stanford University

(*) deceased

~50 Particle, Nuclear, and Relativistic Heavy Ion Physicists

15 institutions

NuMI Low Energy Target

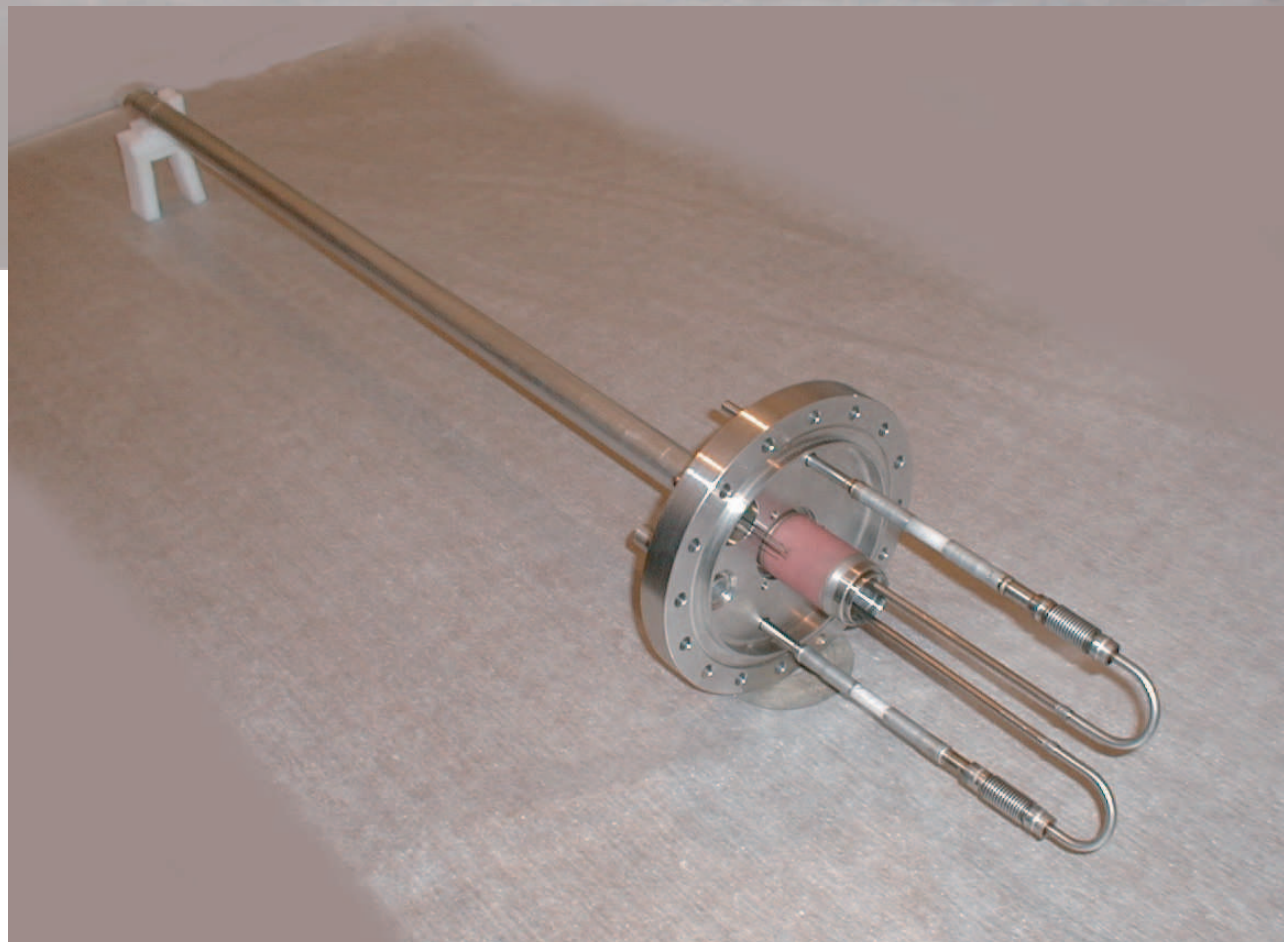


2 interaction lengths of graphite wedged between aluminum cooling tubes
47 segments, each 6.4 mm X 20 mm X 20 mm in shape

Fully assemled target:

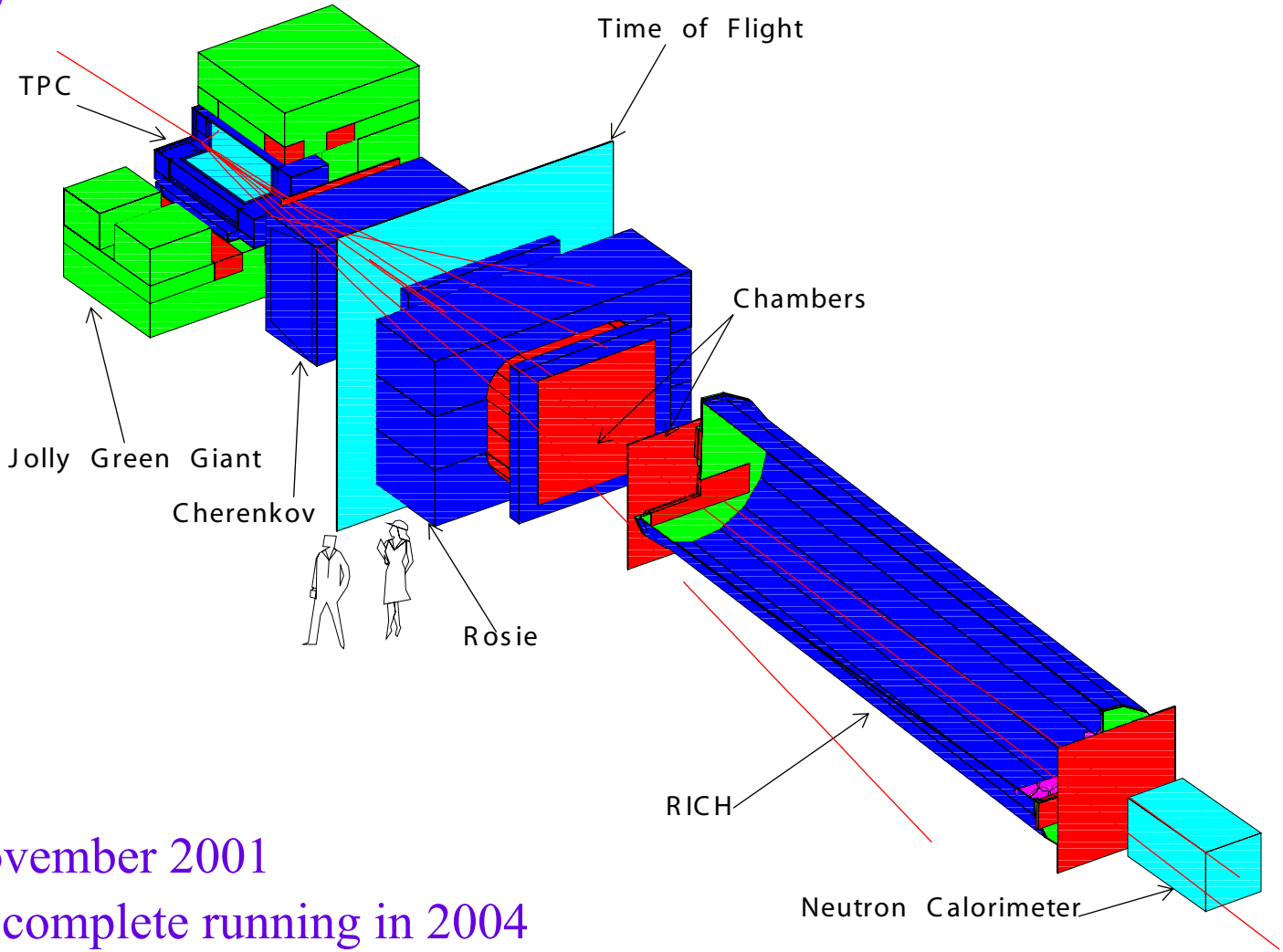
In storage at FNAL

MIPP will use identical spare taret for measurements

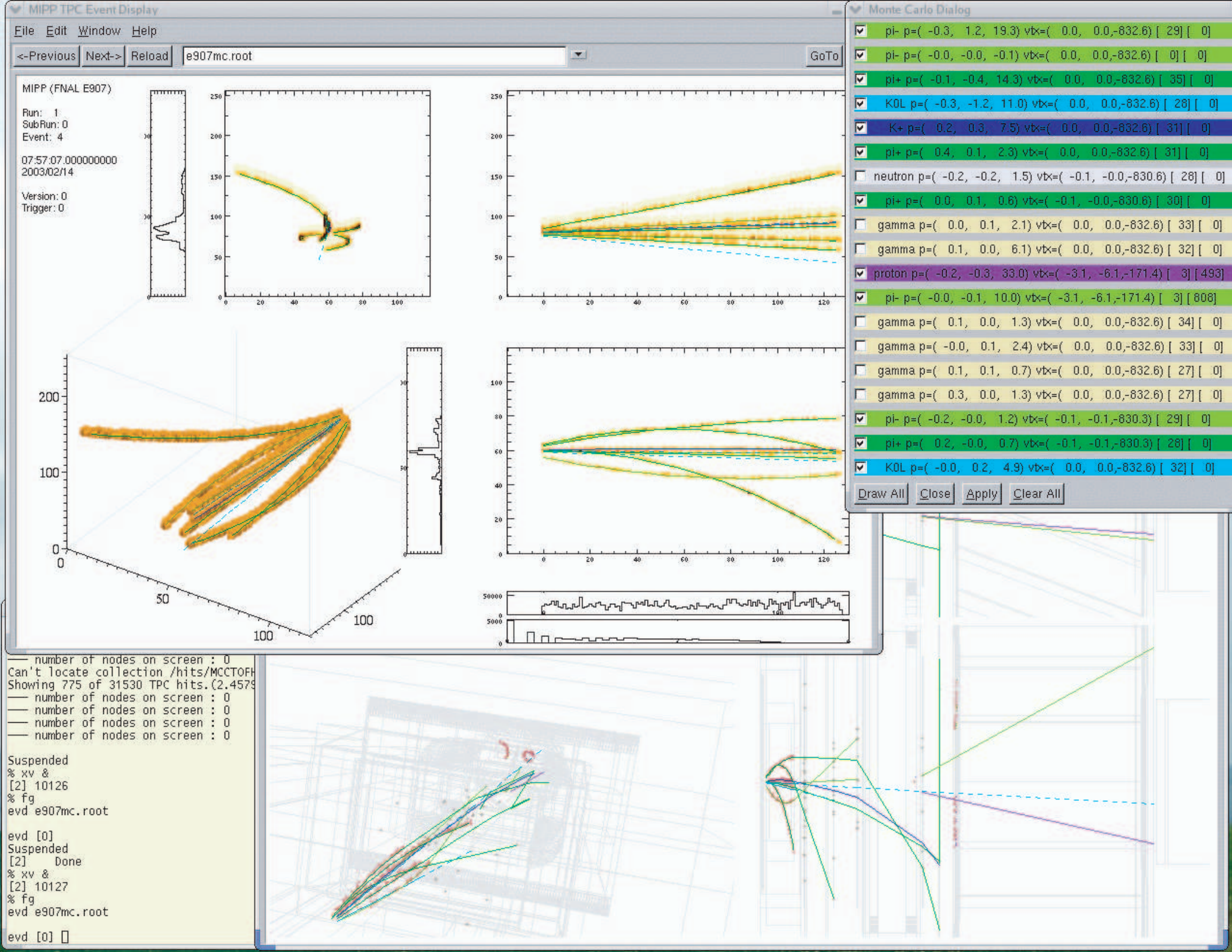


MIPP Experiment

Main Injector Particle Production Experiment
Fermilab E907



Approved November 2001
Scheduled to complete running in 2004
Expects to accumulate 1E7 events with NuMI Target
Also study variety of 1-2% targets


MIPP TPC Event Display
File Edit Window Help
<-Previous Next-> Reload e907mc.root GoTo
MIPP (FNAL E907)
Run: 1
SubRun: 0
Event: 4
07:57:07.000000000
2003/02/14
Version: 0
Trigger: 0
Monte Carlo Dialog
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pi- p=(-0.0, -0.0, -0.1) vtx=(0.0, 0.0,-832.6) [0] [0]
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K0L p=(-0.3, -1.2, 11.0) vtx=(0.0, 0.0,-832.6) [28] [0]
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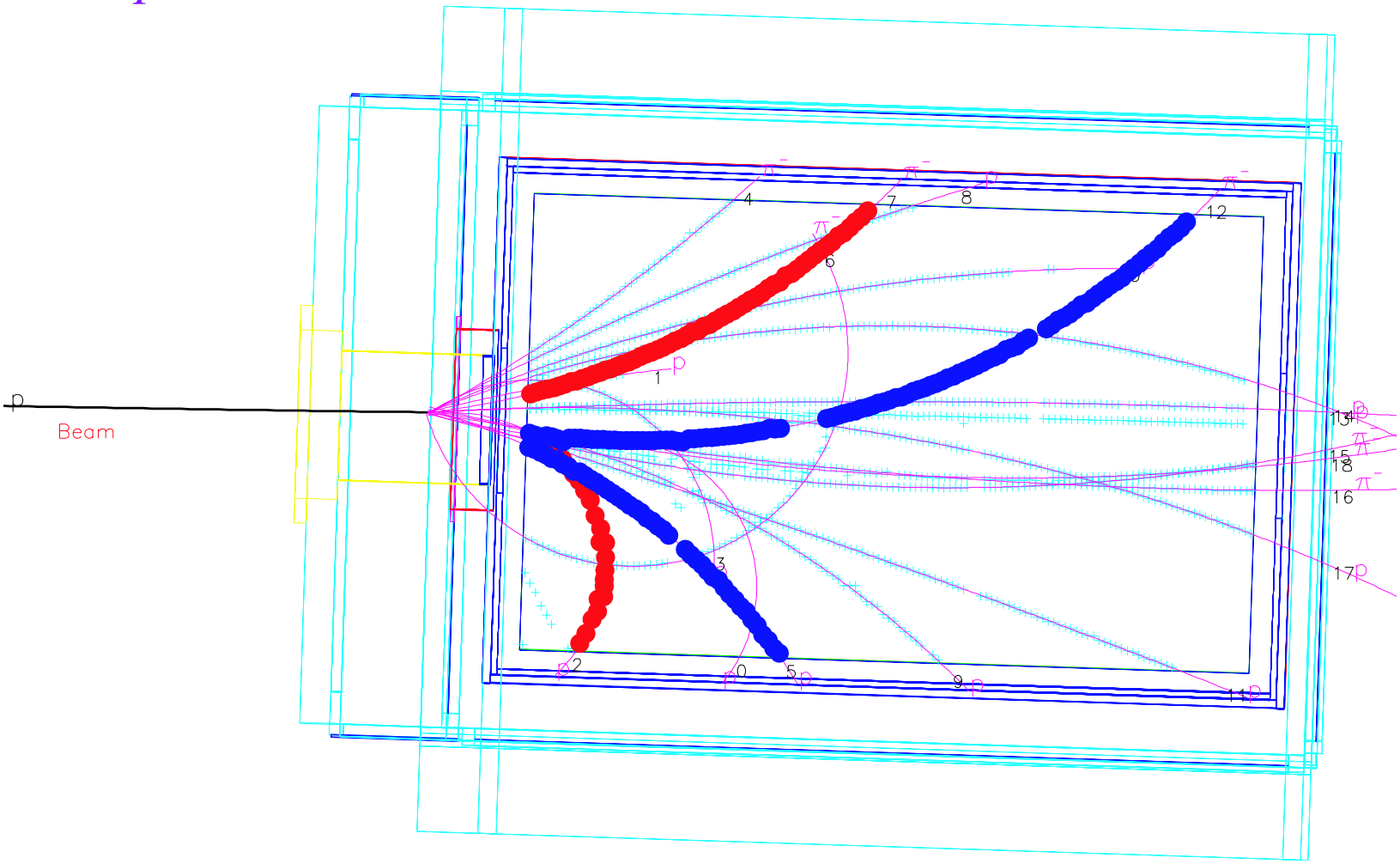
pi- p=(-0.2, -0.0, 1.2) vtx=(-0.1, -0.1,-830.3) [29] [0]
pi+ p=(0.2, -0.0, 0.7) vtx=(-0.1, -0.1,-830.3) [28] [0]
K0L p=(-0.0, 0.2, 4.9) vtx=(0.0, 0.0,-832.6) [32] [0]
Draw All Close Apply Clear All
—— number of nodes on screen : 0
Can't locate collection /hits/MCCTOFH
Showing 775 of 31530 TPC hits.(2.457
—— number of nodes on screen : 0
—— number of nodes on screen : 0
—— number of nodes on screen : 0
—— number of nodes on screen : 0
Suspended
% xv &
[2] 10126
% fg
evd e907mc.root
evd [0]
Suspended
[2] Done
% xv &
[2] 10127
% fg
evd e907mc.root
evd [0]

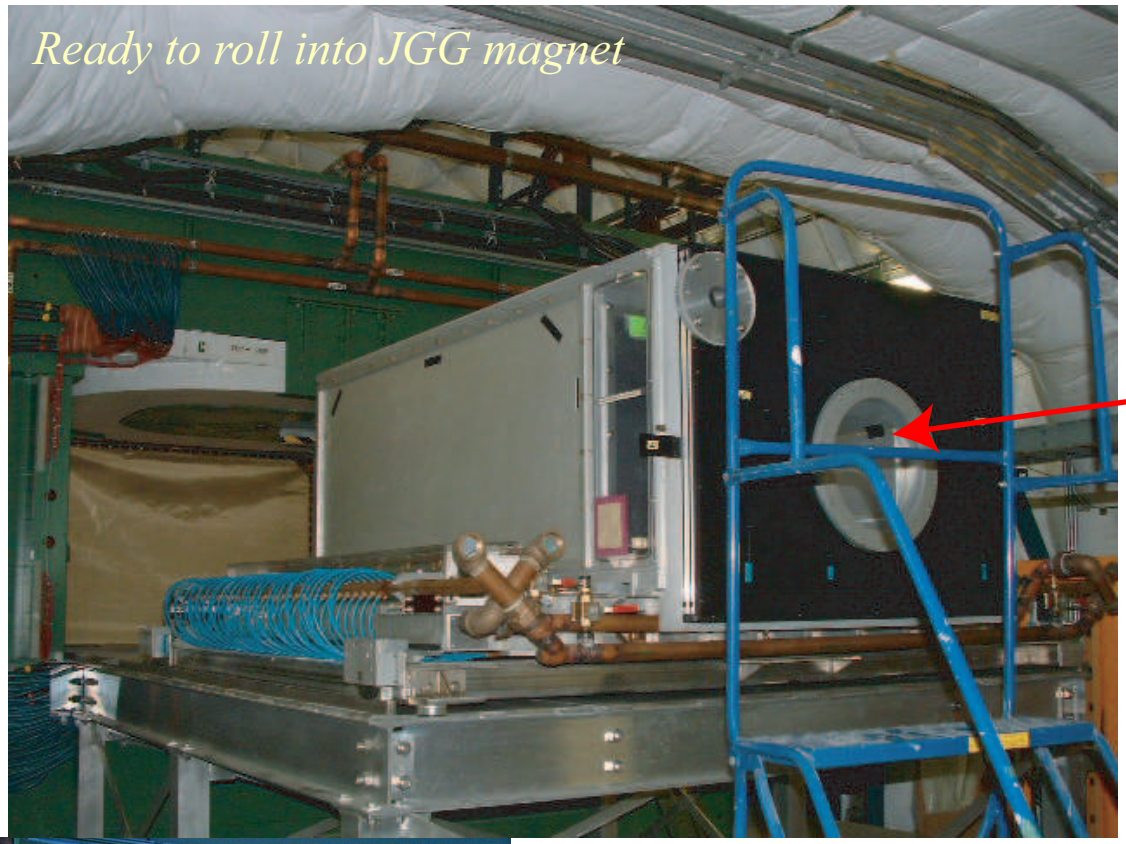
Example p-Au Collision from E910

$$p + Au \rightarrow \pi^0 + \pi^0 + X$$



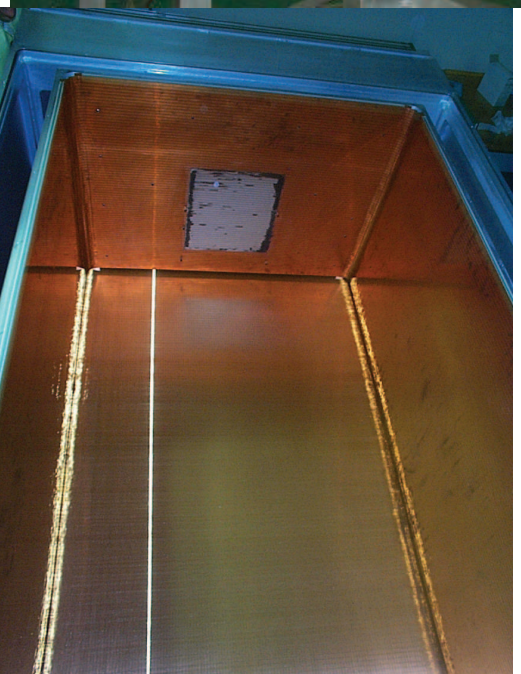
Time Projection Chamber

Built by BEVALAC group at LBL
Most recently used in BNL E910

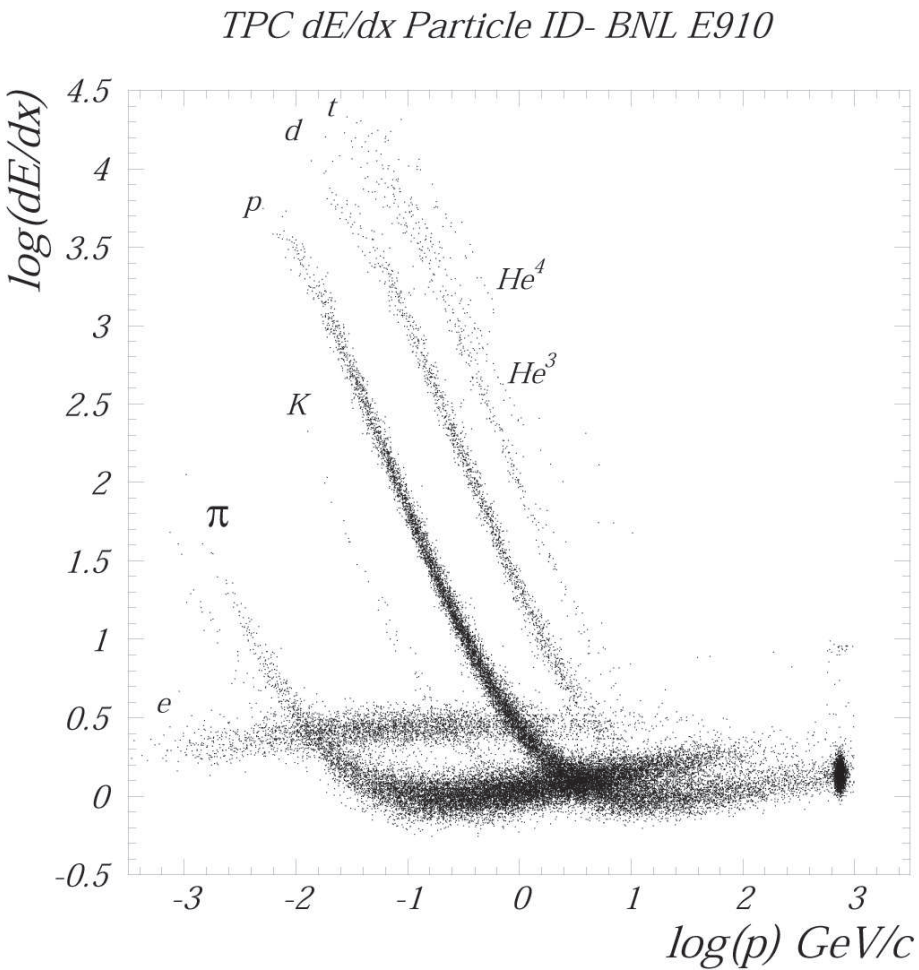


3-D tracking
Particle ID via dE/dx below 1 GeV

Target alcove

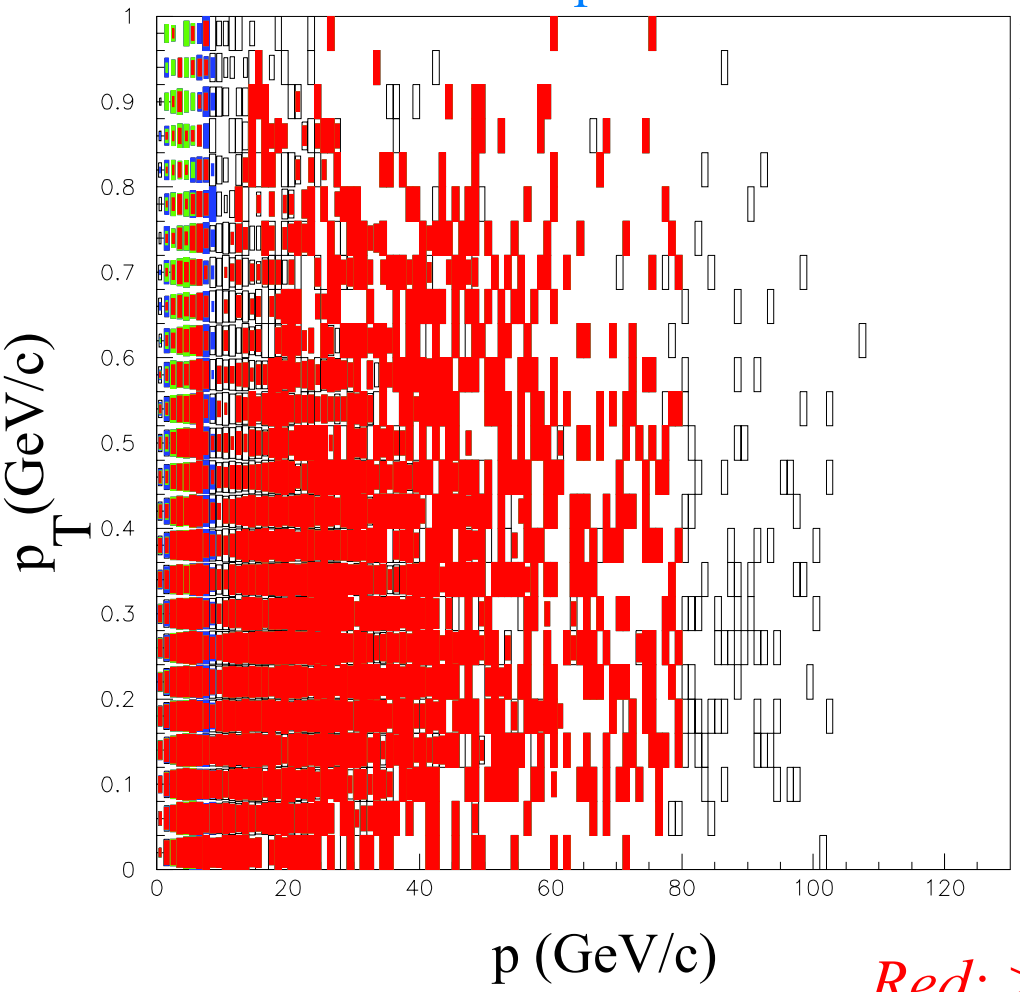


- 16 usec deadtime
- Data rate limited to 60 Hz. Sets limit for experiment

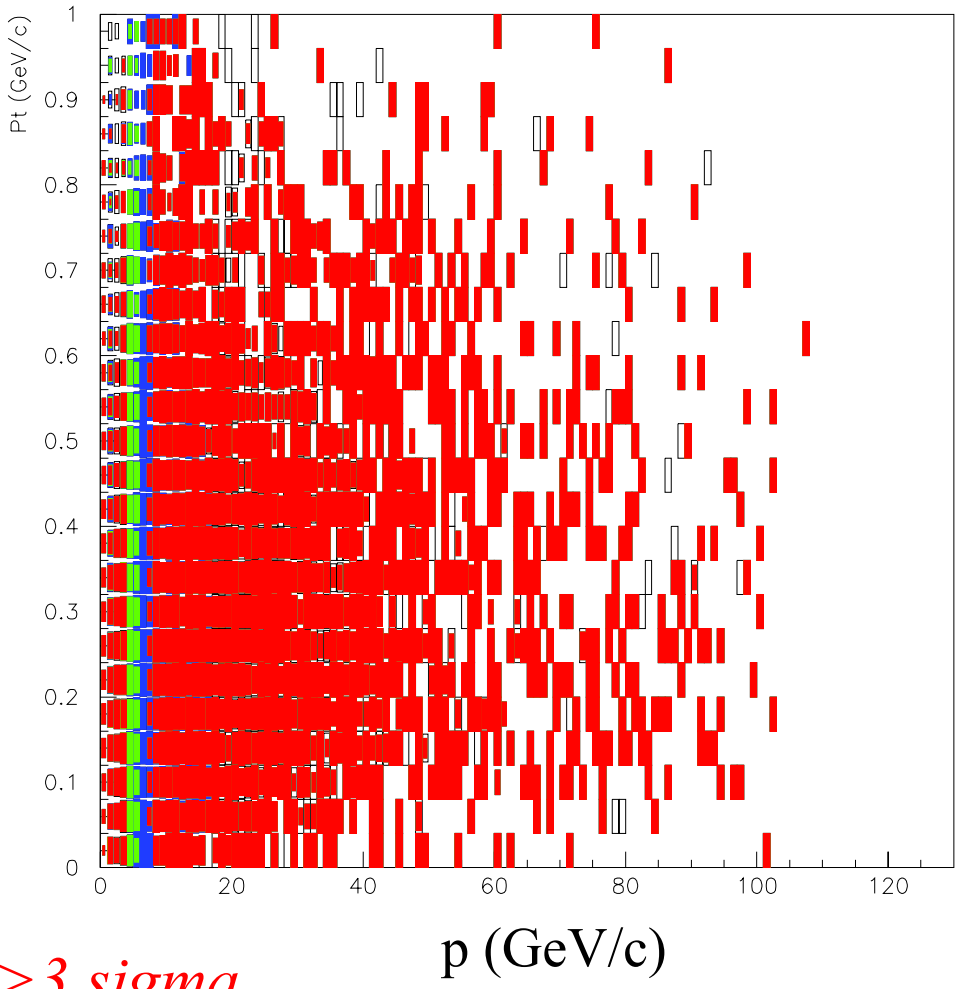


Particle ID Performance

π/K separation



K/p separation



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

MIPP Status Summary

All sub-detectors at >~80%

TPC readout still to be completed
Drift chambers have some noise issues
Cherenkov: PMT's tested, ready to install
TOF being assembled
RICH ready to go, still a few bad tubes to replace
Calorimeters ready to roll into place and cable
Magnets mapped and ready to go

Beam

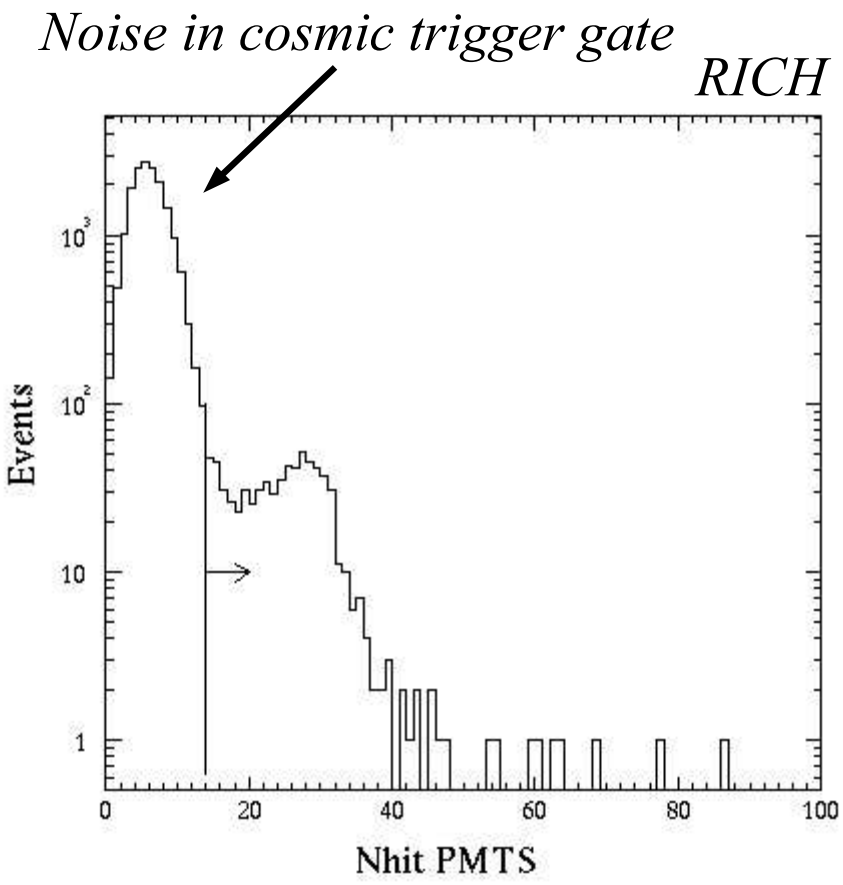
Beam has been extracted to M-TEST (last station before MIPP hall)
Need to finalize extraction plan to keep p-bar impact small
Safety and shielding reviews
Plan to start with 30 GeV secondary beam

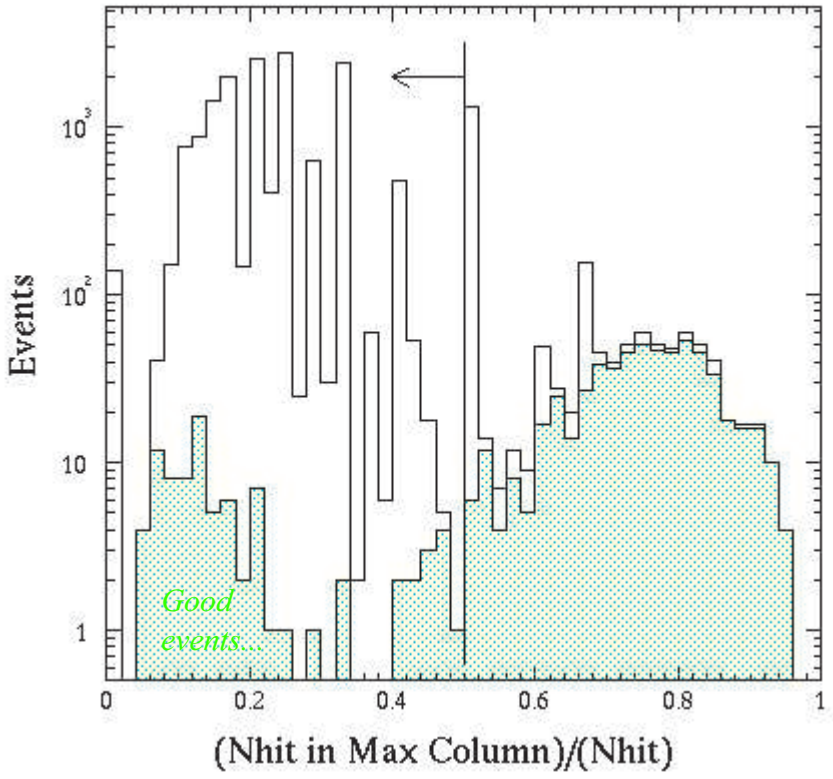
Target Wheel in place

empty, CH2, C, Al, Cu, Ag, N, Be, Bi, Au, CD2
Running with NuMI target scheduled for end of run

First data!

During M-Test tuning just prior to Fermilab shutdown we set up a trigger to look for muons coming out of the M-Test dump upstream of the MIPP detector. Also had cosmic trigger around one drift chamber.





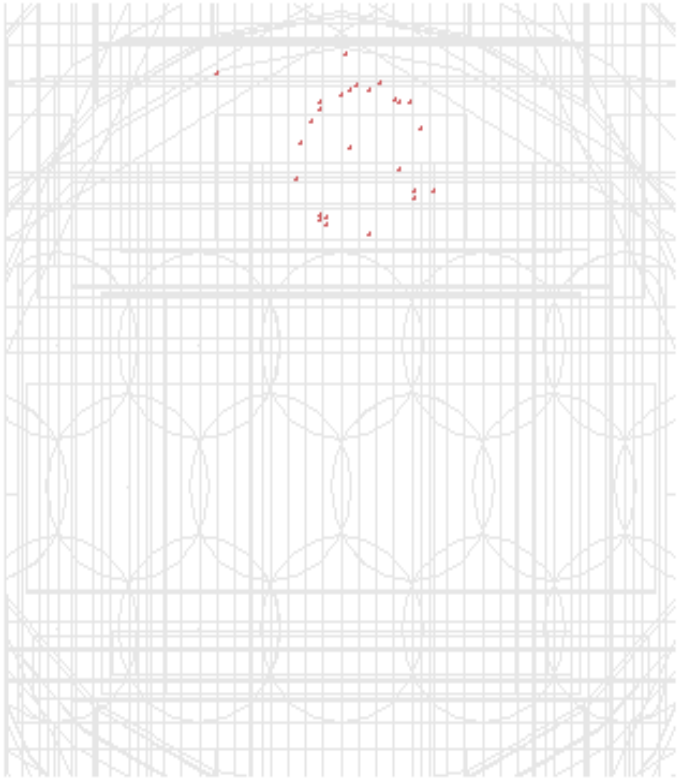
Fraction of hits in a single column. Lots of cross-talk due to very low thresholds on front end boards

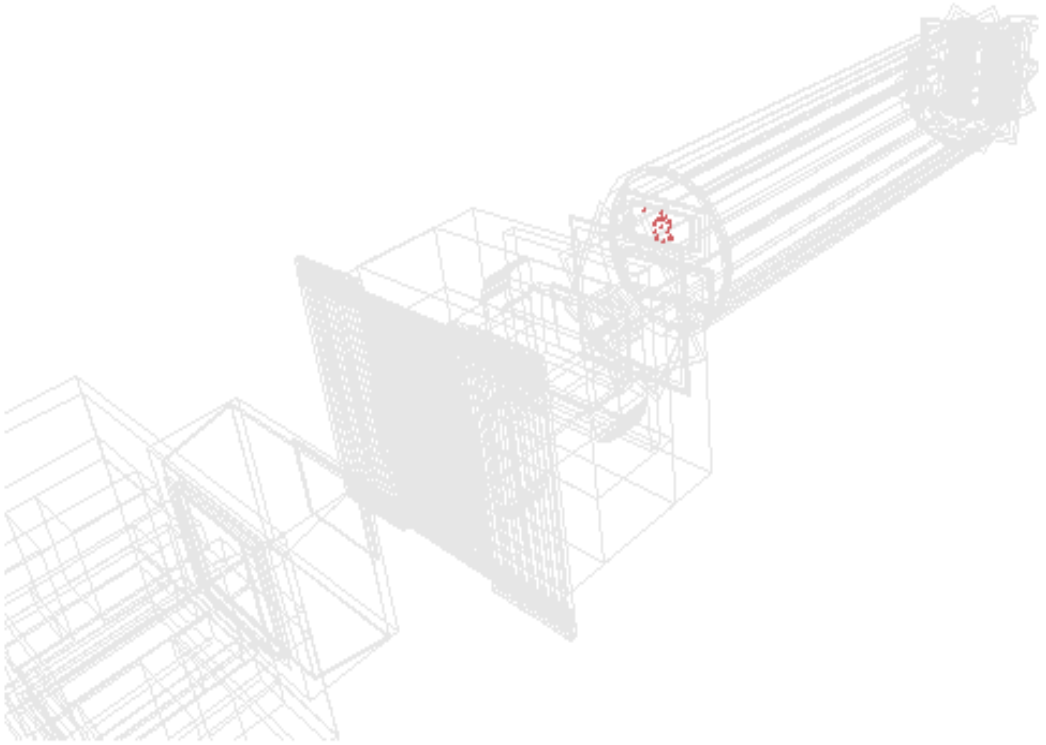
MIPP (FNAL E907)

Run: 3000
SubRun: 0
Event: 3848

Sat Sep 06 2003
21:54:15.261539

Version: 0
Trigger: 0



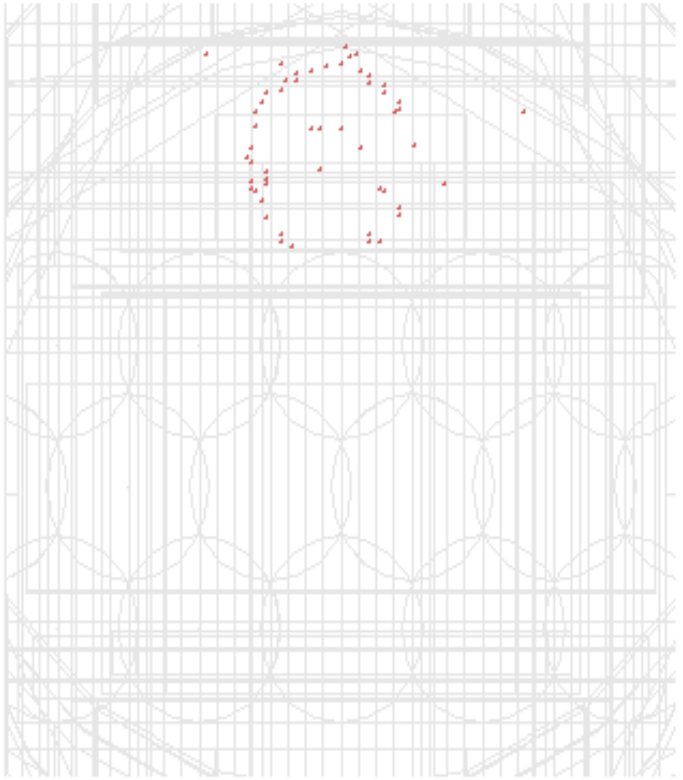


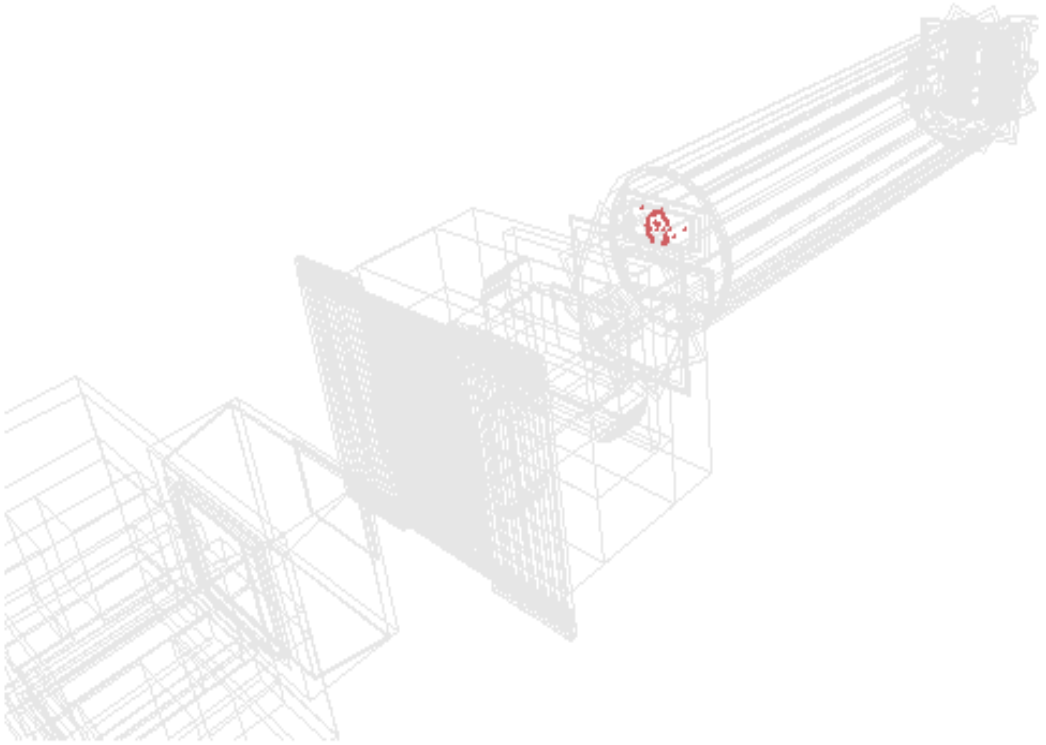
MIPP (FNAL E907)

Run: 3000
SubRun: 0
Event: 4542

Sat Sep 06 2003
23:04:21.783803

Version: 0
Trigger: 0





Data Taking Schedule

1 data point is 3e6 events and takes roughly 126 hours (elapsed) assuming 1 sec flat top every 3 seconds

26 data points will take ~6 months

Momenta in range from ~20-120 GeV

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

NuMI Target run is an additional 3.3 data points (1e7 events) and will take 400 hours

Summary and Conclusion

There is currently very large investments made in neutrino beams
K2K, BooNE, MINOS, CNGS, JPARC, NuMI Off-Axis,
FINeSE, MINERVA,...
The understanding of conventional neutrino beams is limited
by our knowledge of hadron production from p-A interactions

HARP has a large data set in hand for 3-15 GeV range which
is relevant to K2K, miniBooNE, atmospheric neutrinos, and
neutrino factory design
Starting in Dec'03-Jan.'04 MIPP will start taking data in the
10-120 GeV range.
Relevant for NuMI, K2K, miniBooNE, JPARC