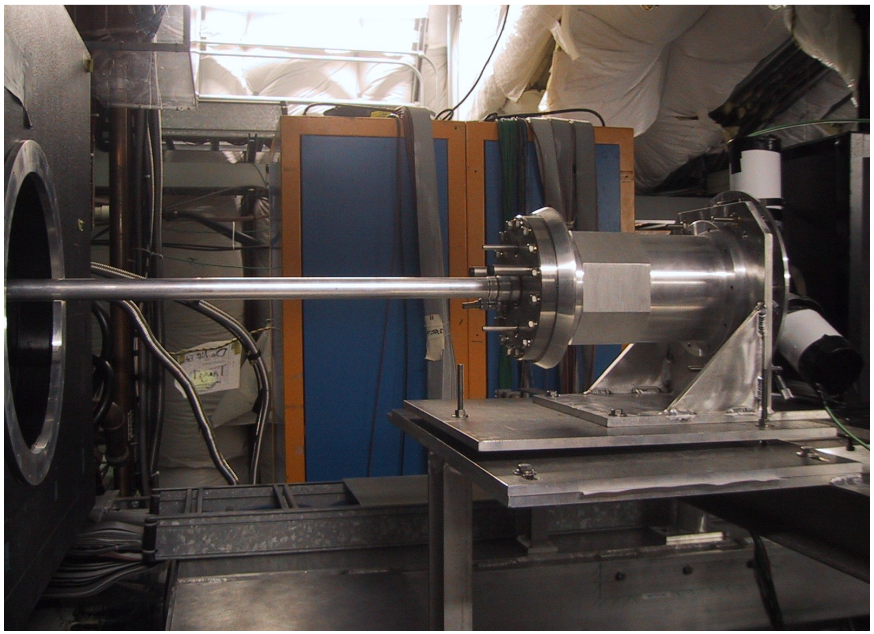
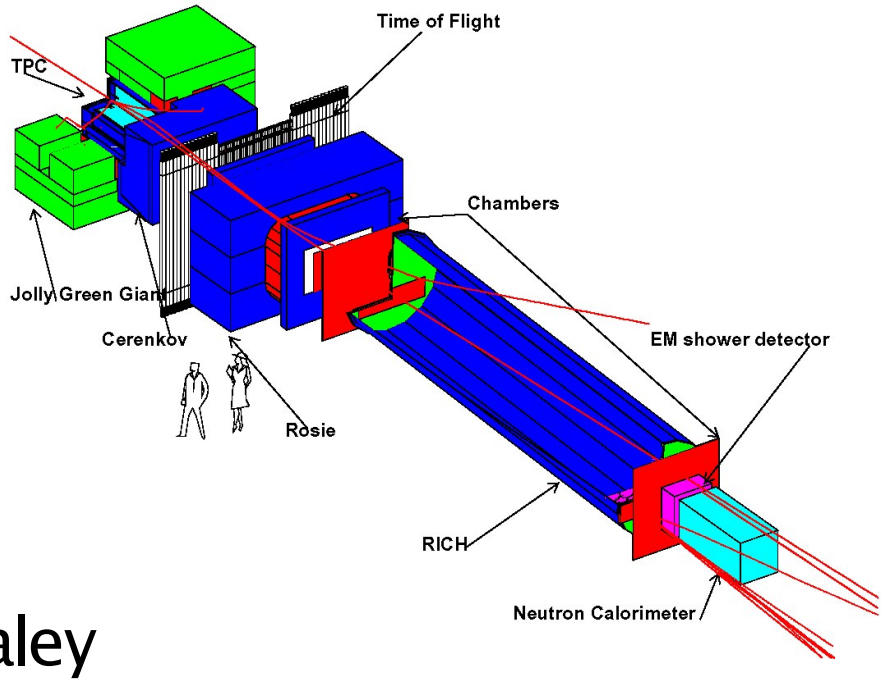
First Results from MIPP





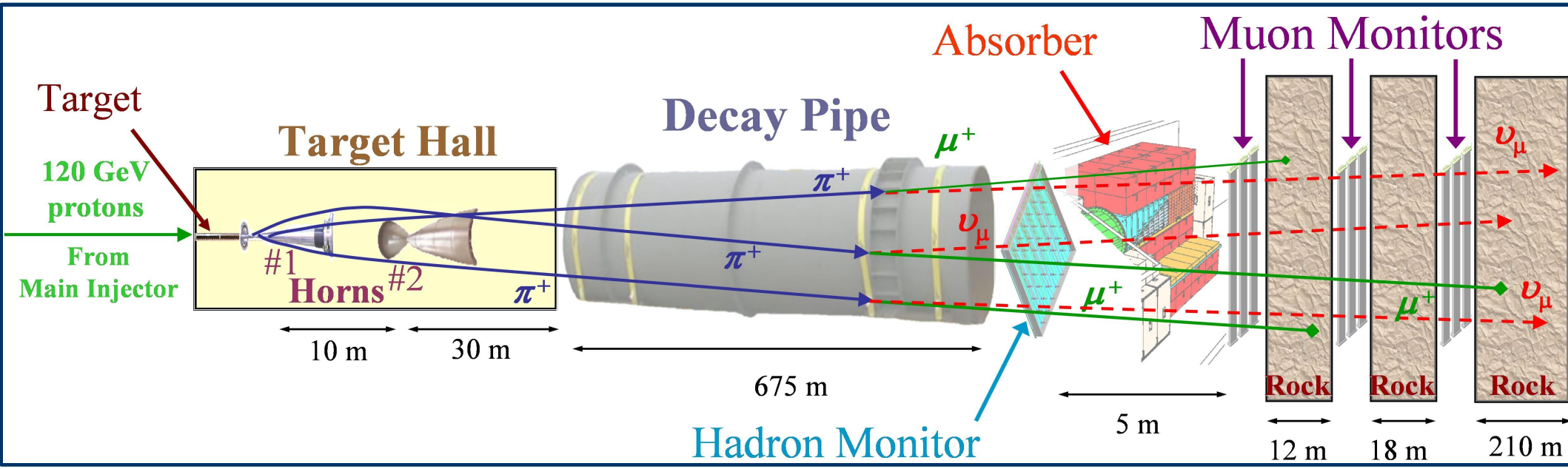
Jonathan Paley

Indiana University

April APS Meeting, St. Louis

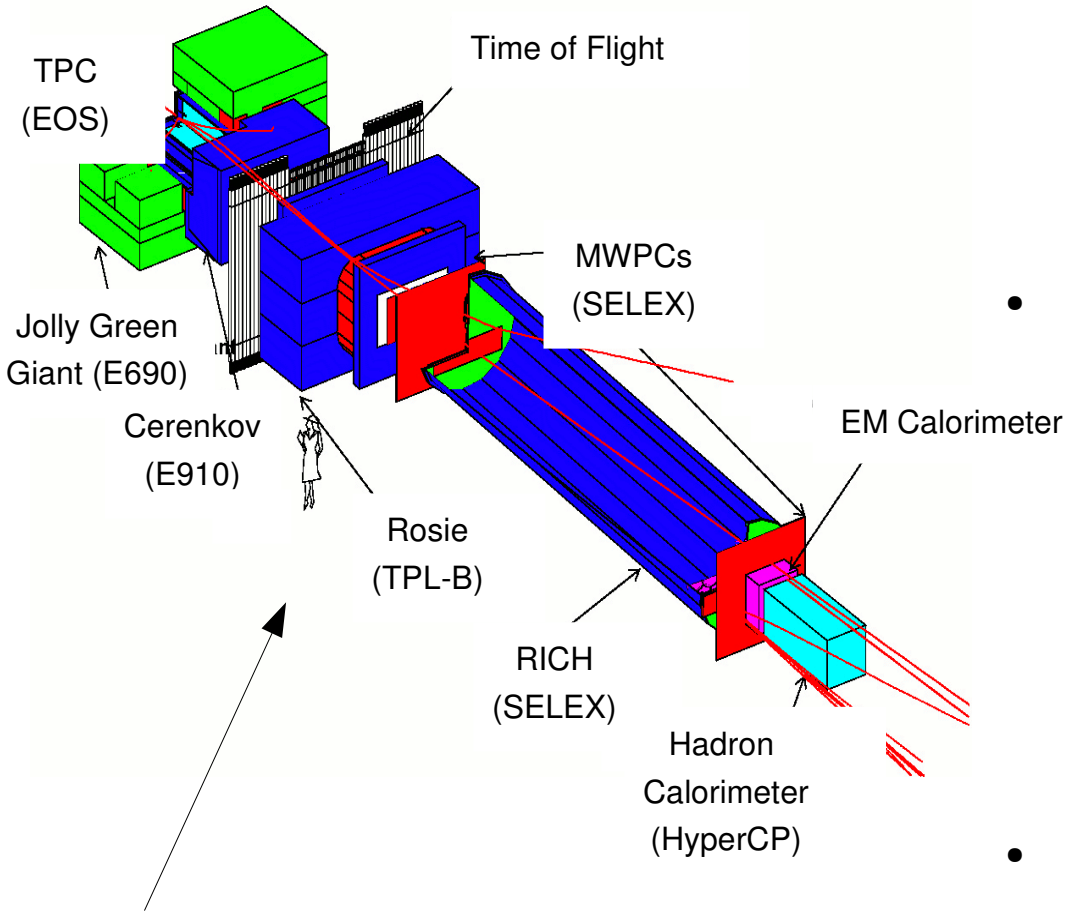
April 14, 2008

Neutrino Production in MINOS



- Neutrinos in MINOS come from hadrons (π's, K's) produced when 120 GeV/c protons from the Main Injector strike a 90 cm long graphite target.
- Very large (~30%) uncertainty in neutrino flux due to lack of data on hadron production at this energy.

The MIPP Spectrometer

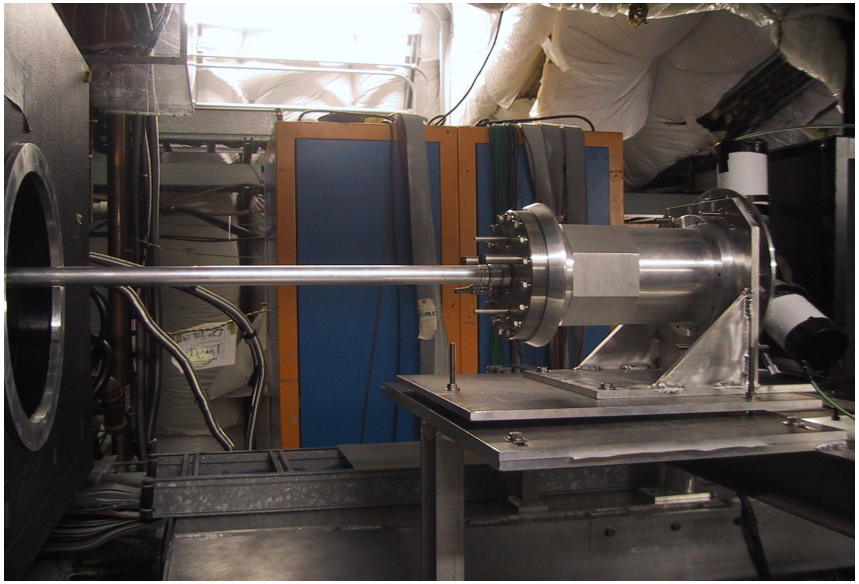


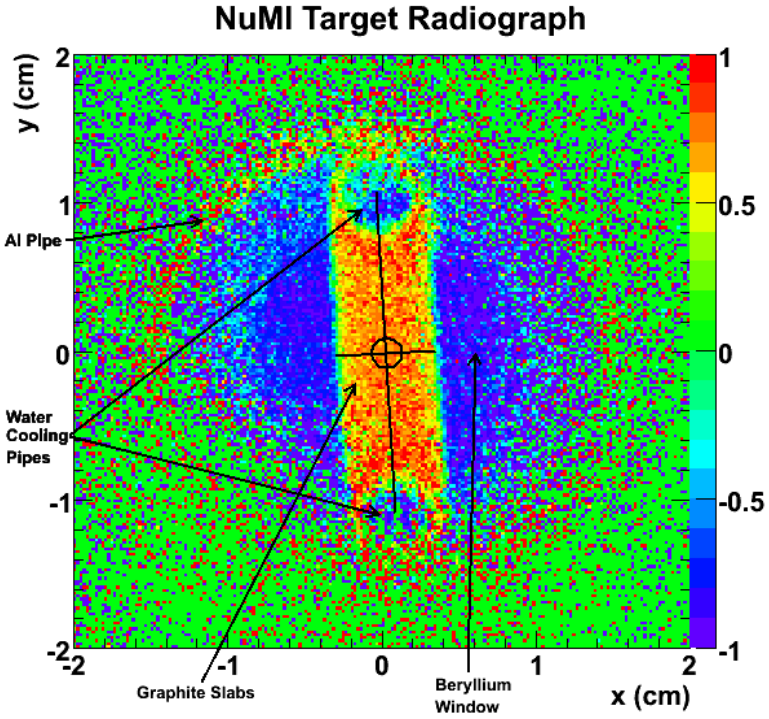
Nearly all detectors taken from previous experiments!

- Full acceptance spectrometer
  - Two analysis magnets deflect in opposite directions
  - TPC + 4 Drift Chambers + 2 PWCs
- Excellent Particle ID (PID) separation (2-3 σ)
  - TPC: < 1 GeV/c
  - ToF: 1-3 GeV/c
  - DCkov: 3-17 GeV/c
  - RICH: 17-80 GeV/c
- Goals of MIPP:
  - Collect comprehensive hadron production cross-section data set.
  - Measure hadron production off of NuMI target, providing ν flux to within ~5%

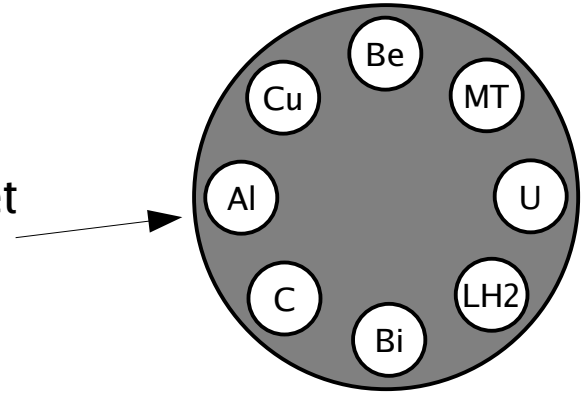
Data Collected

- MIPP began its physics run in December 2004 and ran until February 2006.
- Data collected:
  - ~ 1.6 x 10^6 events of Main Injector 120 GeV/c protons on the MINOS target.
  - ~ 3.2 x 10^6 p's, π's and K's at 120, 60, 35 and 20 GeV/c on thin C and Be targets.
  - Other physics interests: several million events of p's, π's and K's at momenta ranging from 5-120 GeV/c on thin (<2% λ) LH_2, Bi, and U targets.





MIPP thin-target wheel

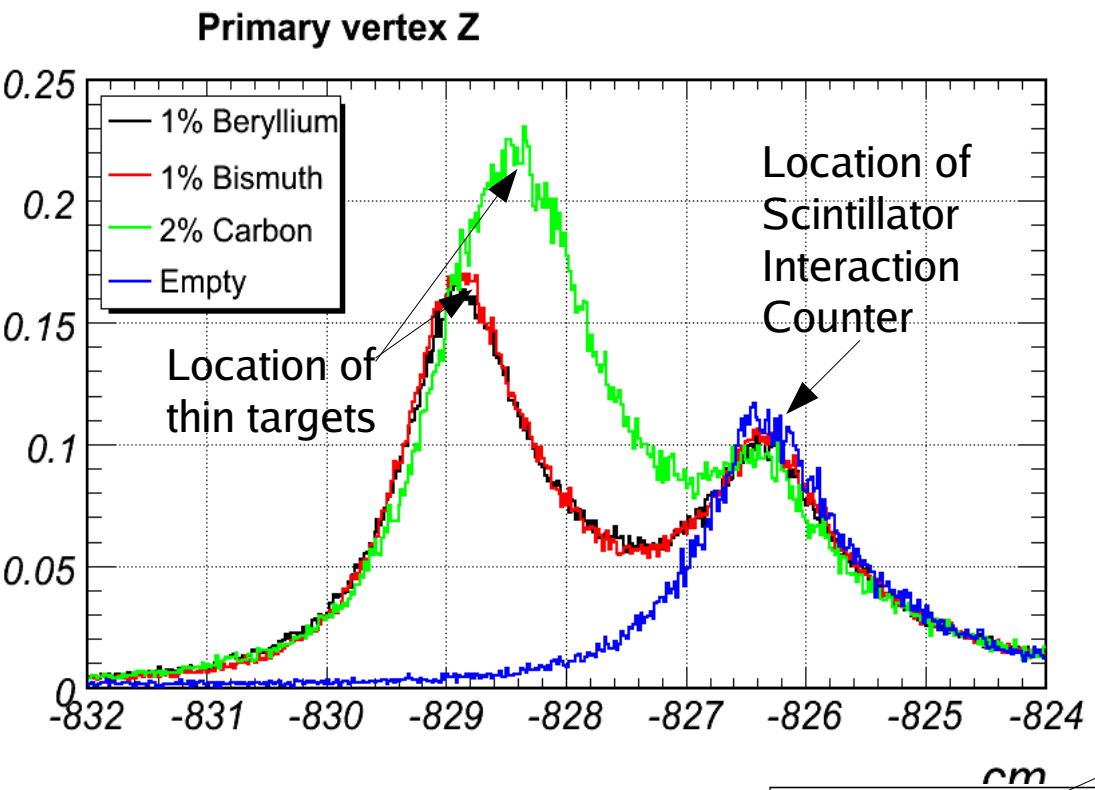


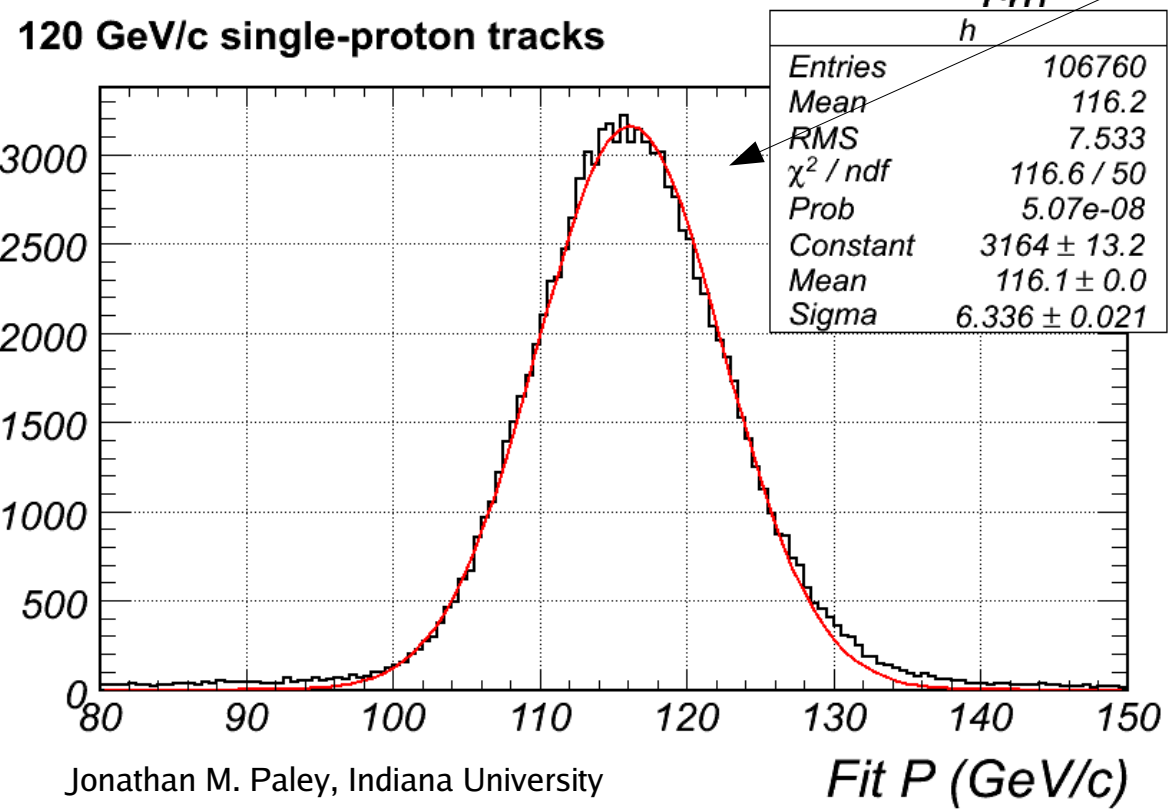
MIPP "Short Term" Analysis Strategy

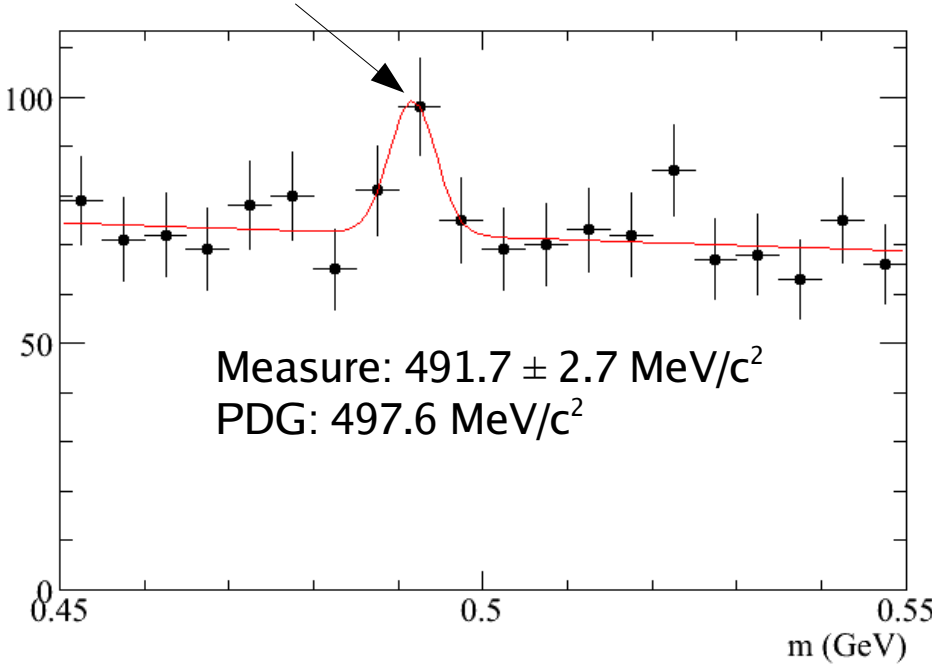
- **Particle production ratios for 120 GeV/c p + thin C target (A. Lebedev's thesis)** ✔
- **Production ratios for 120 GeV/c p + MINOS target (S. Seun's thesis)** ✔
- **Production cross-sections for 120 GeV/c p + MINOS target**
- **n/p Ratio Measurement (all thin targets, all beam momenta)**
- Production cross-sections for 120 GeV/c p + thin C-target (probably thin Be and thin Bi targets as well)
- Production cross-sections for 20, 60 GeV/c p, π and K + thin-C target
- Neutral Kaon Production cross-sections?

Track and Vertex Reconstruction

- Vertex resolution is ~8 mm
- Momentum resolution is ~5%
- Reconstructed track momentum is systematically low by 2-3%
  - Reconstructed 120 GeV/c beam momentum
  - K^0 invariant mass

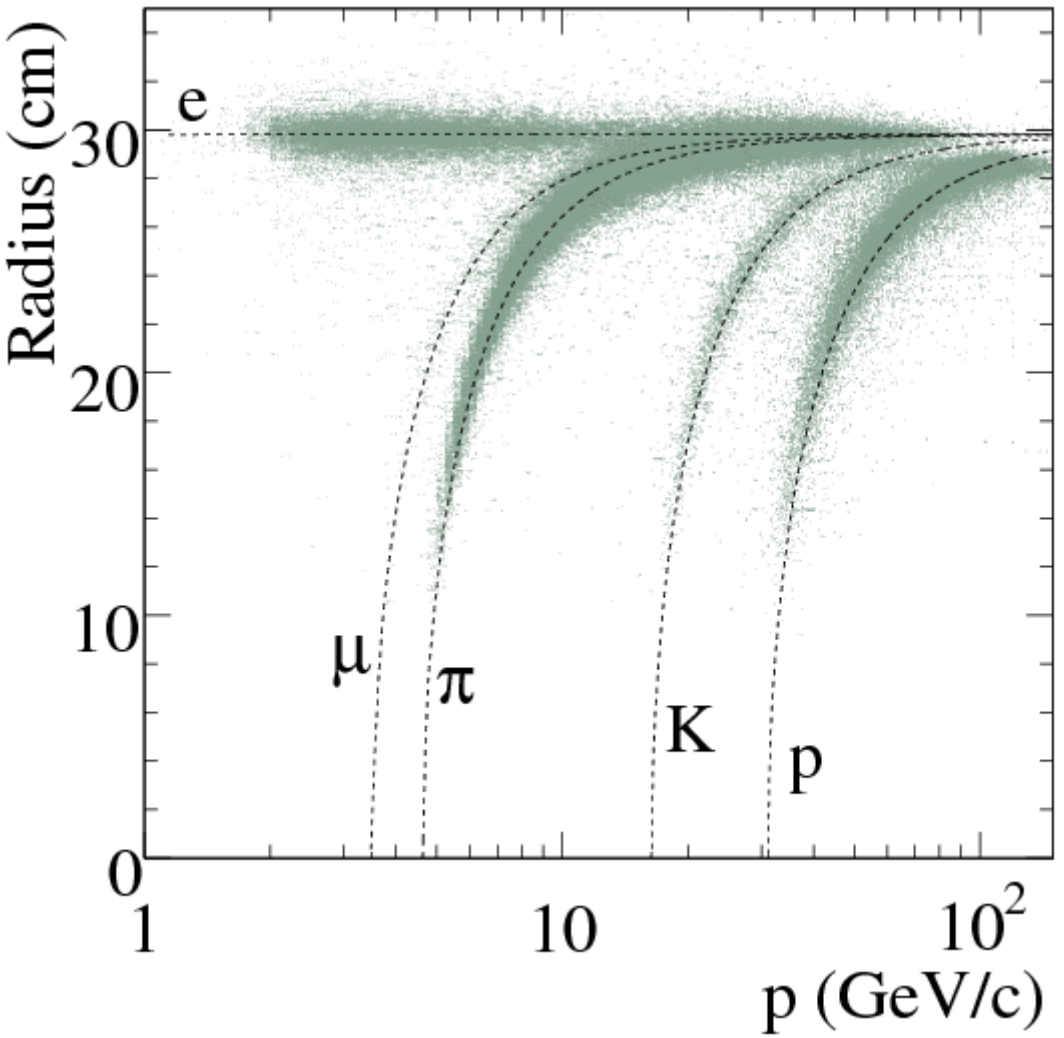






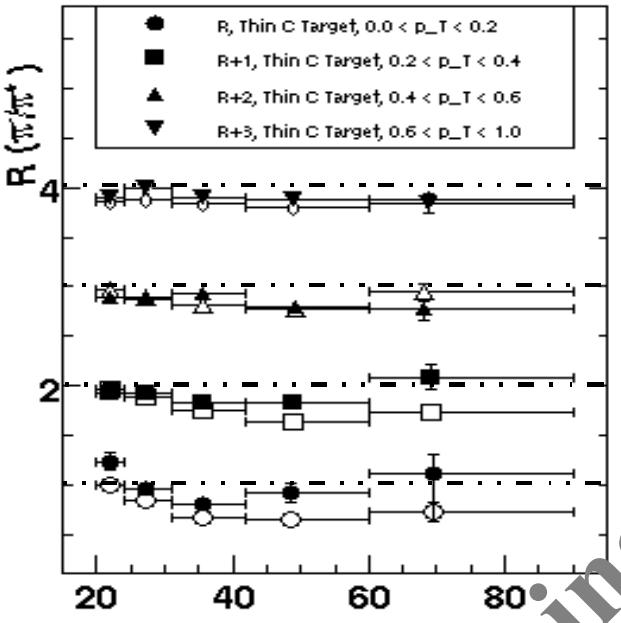
Particle Identification (High Momentum)

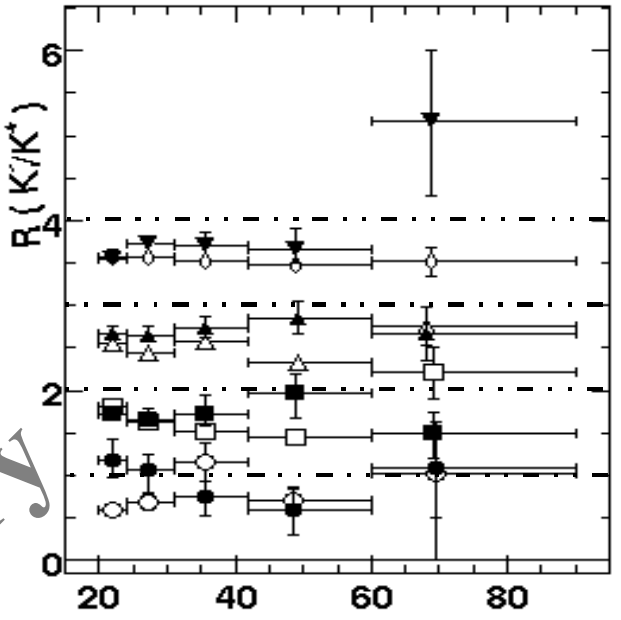
- Cerenkov light strikes spherical mirrors at the upstream end of the RICH detector and is reflected back onto an array of ~2200 ½" PMTs forming a ring.
- The measured ring radius is directly proportional to the Cerenkov light angle, which depends on velocity.
- Measurement of ring radius & momentum gives PID.
- Above ~20 GeV/c, secondary particles may be identified using the RICH detector.



Carbon π/K Ratio Analysis - Results

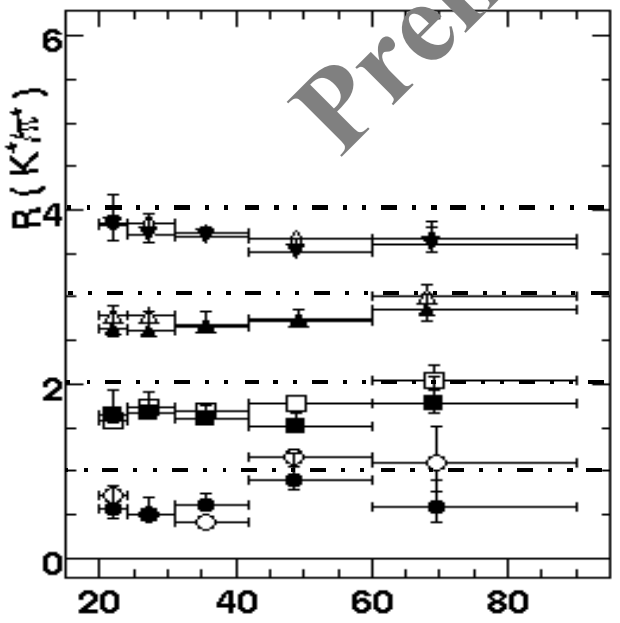
- Using the RICH to identify π's and K's, we form double ratios (eg, $(\pi^-/\pi^+)_{Data} / (\pi^-/\pi^+)_{MC}$).
- Plot on right shows R vs. momentum, 4 bins of pT are offset by 1 with respect to each other.
- Data are consistently low compared to MC prediction.
- Good agreement between thin and thick carbon targets.

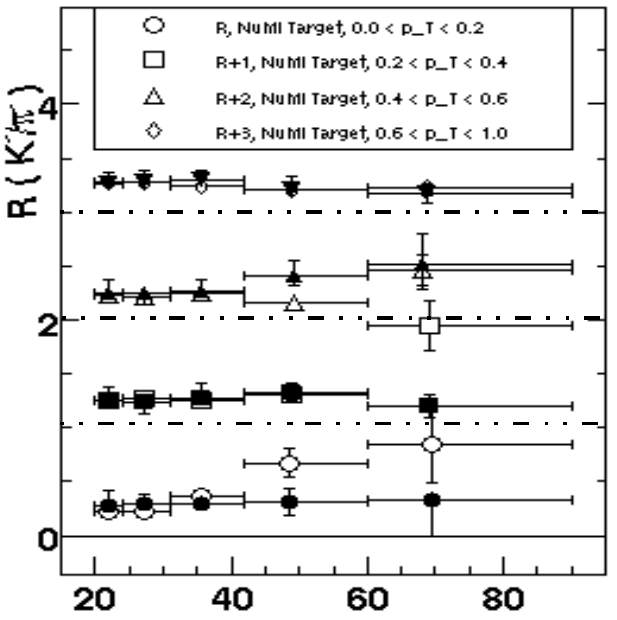




$$R(p_1/p_2) = (p_1/p_2)_{Data} / (p_1/p_2)_{MC}$$

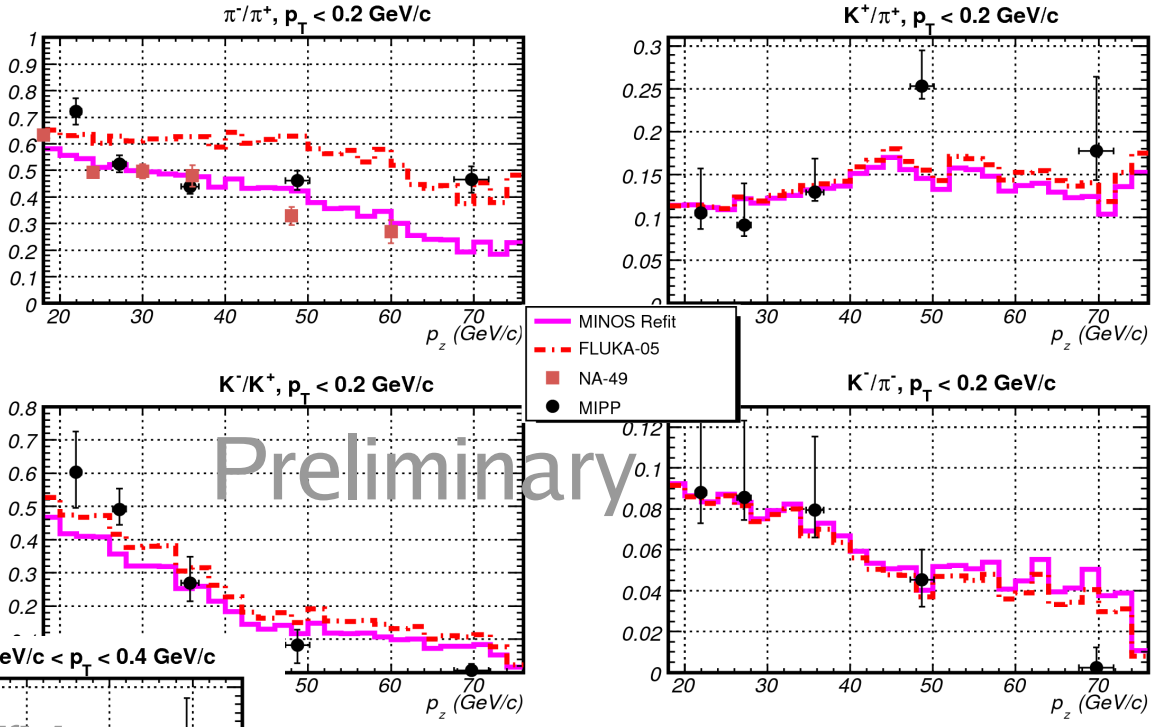
Preliminary

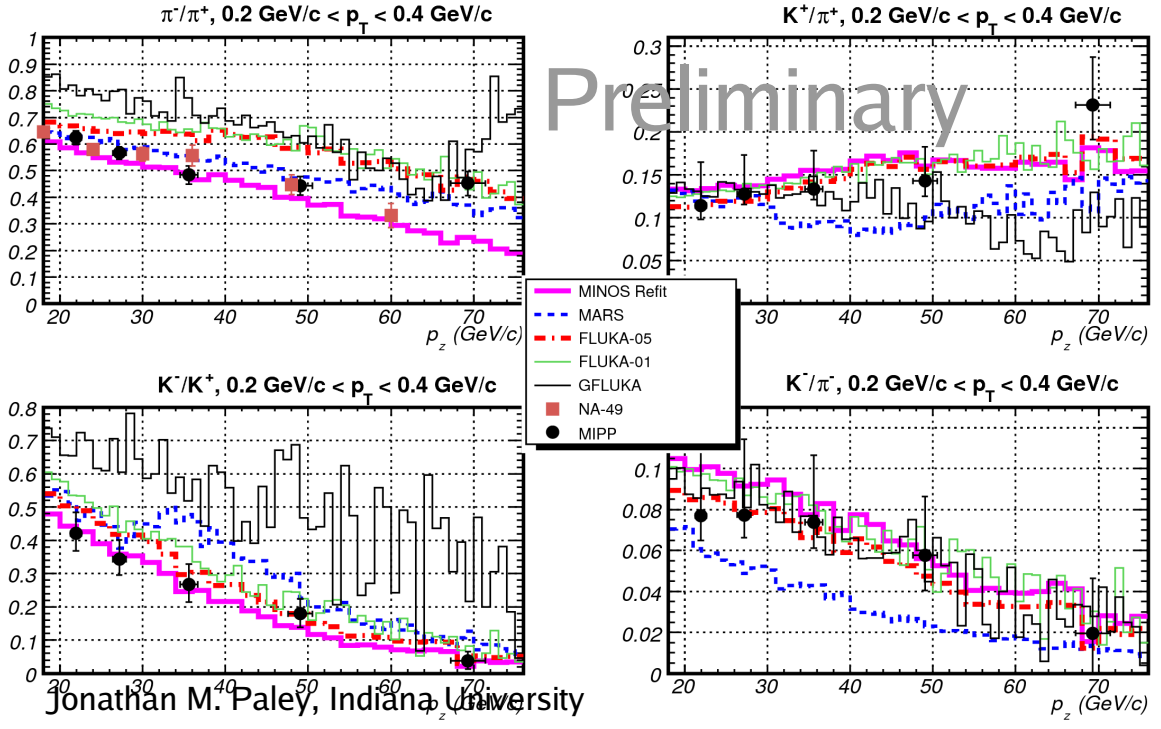




Comparison to MINOS Ratios

- Comparison to ratios used by MINOS to ratios in this analysis are valid for high momentum production (primary interactions)

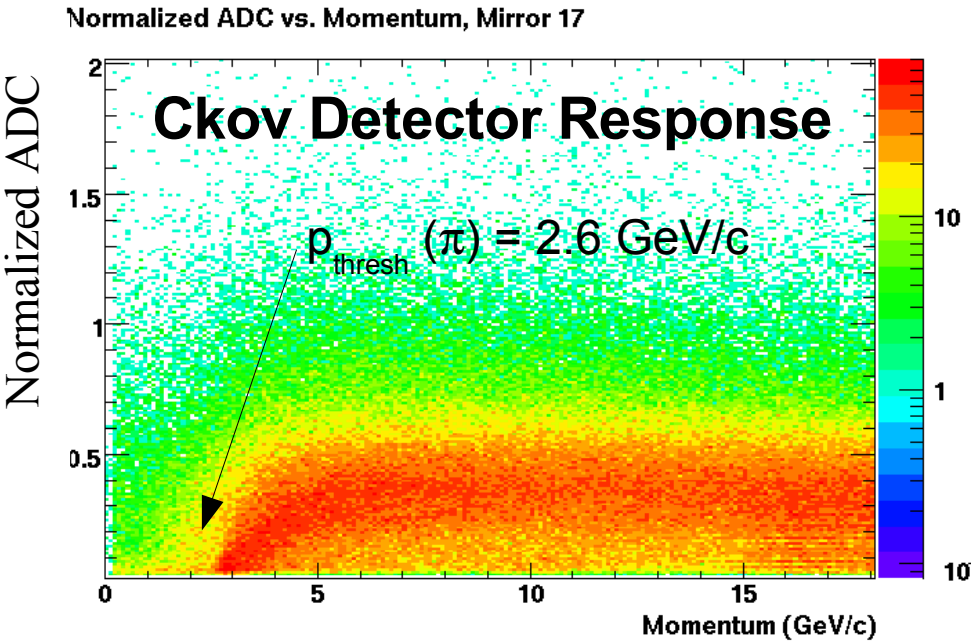


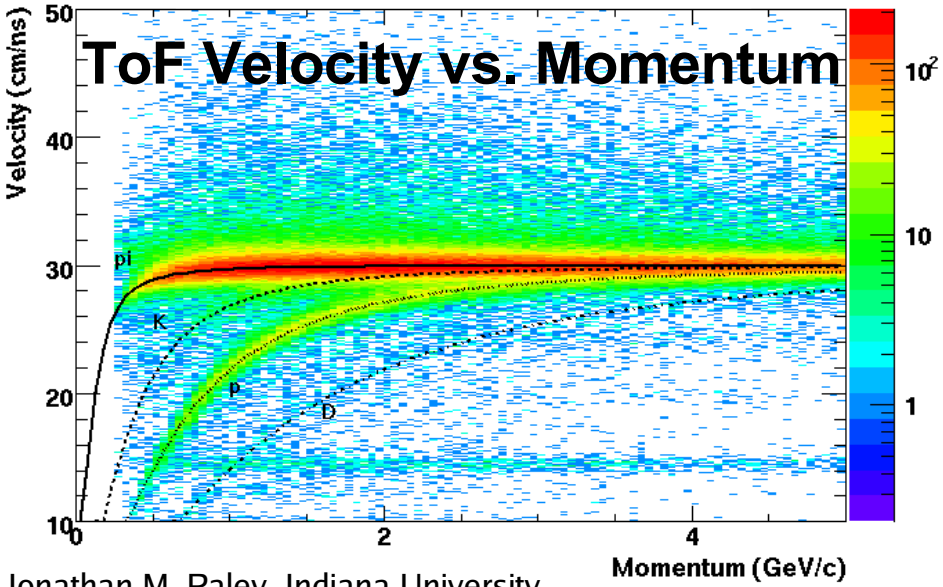


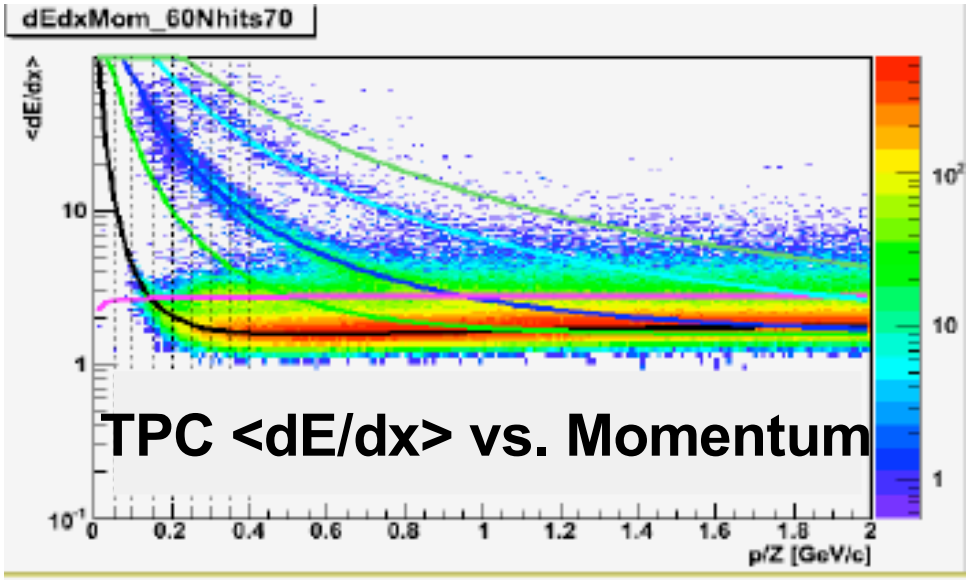
- The MIPP data agree quite well with expectations from MINOS

Future Prospects

- All PID detectors are now calibrated.
- The collaboration is currently working on the hadron production measurement off of the NuMI target for the full (pz,pT) phase space.
- Results expect by mid-summer 2008.





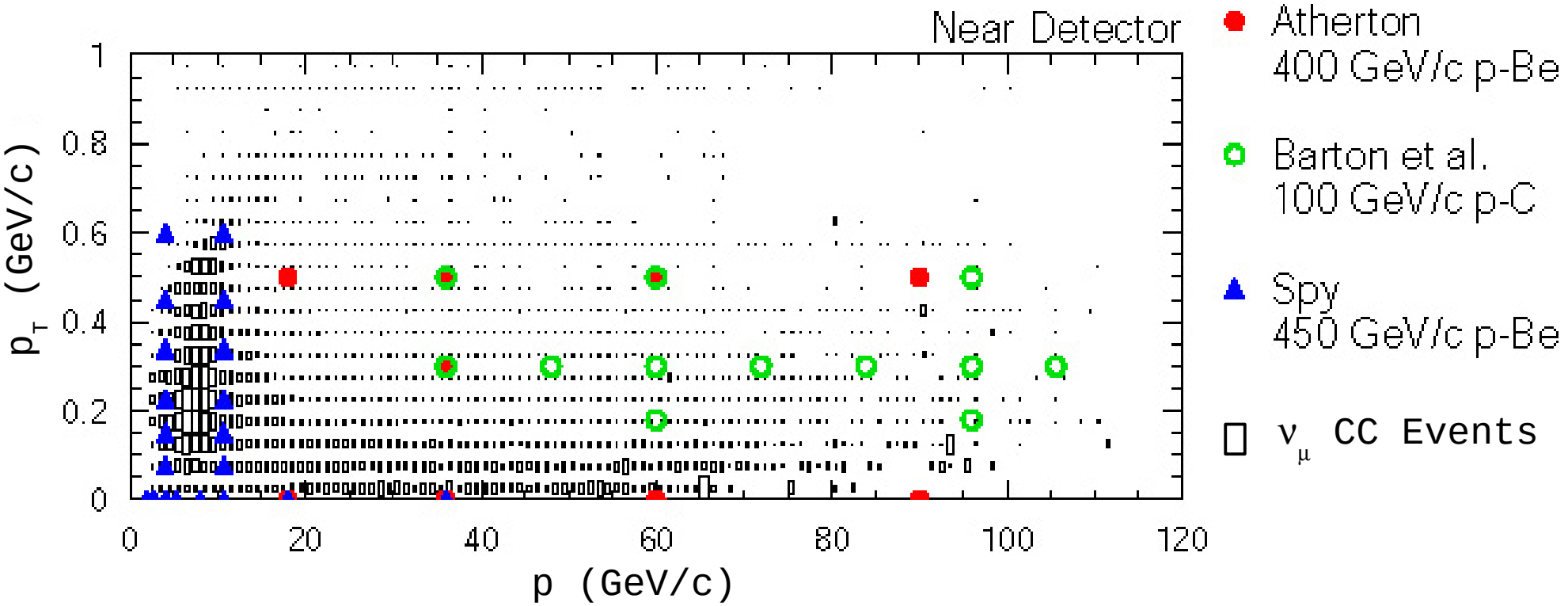


Summary and Outlook

- Preliminary results using RICH PID look very promising; estimation of systematic uncertainties will be improved.
- PID for lower momentum tracks will come from Ckov, ToF, and TPC; collaboration is focused on understanding these detectors.
- MIPP aims to have NuMI target production measurement available to MINOS by mid-summer, followed by thin-target inclusive cross-sections for 120 GeV/c p+C later in the year.
- Interesting n/p measurement in also being worked on; results possibly available by the end of this summer.
- Proposal has been submitted for an upgrade to the experiment that would increase our DAQ rate by x50 (among other improvements). Under these conditions, one could measure hadron production off of any target using π, K, p beam of momentum ~1 < p < 120 GeV/c in a matter of days!

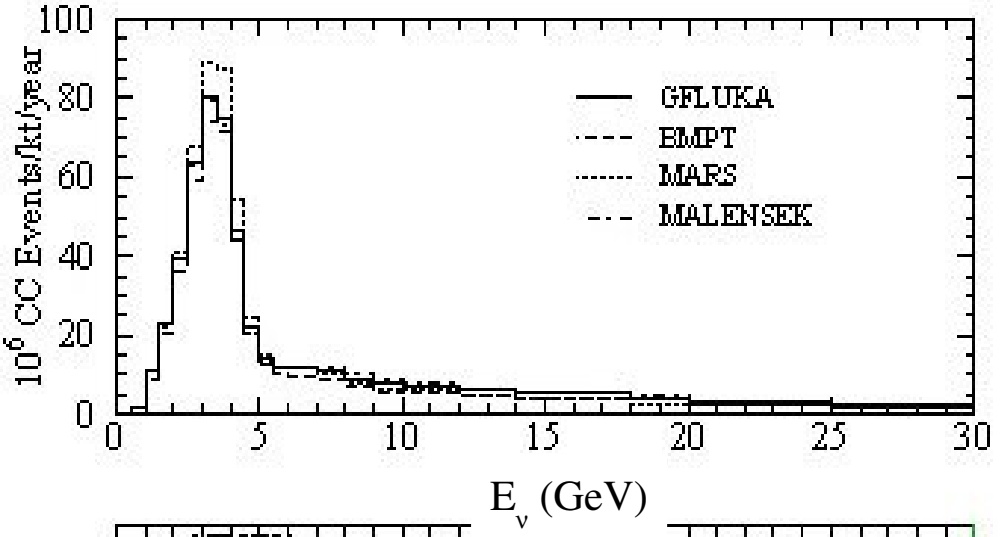
Backup Slides

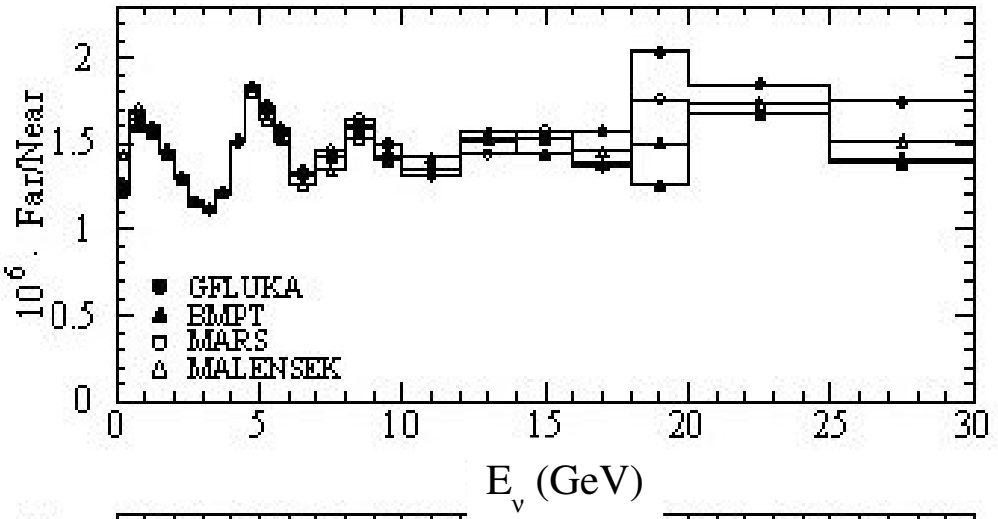
Existing Data

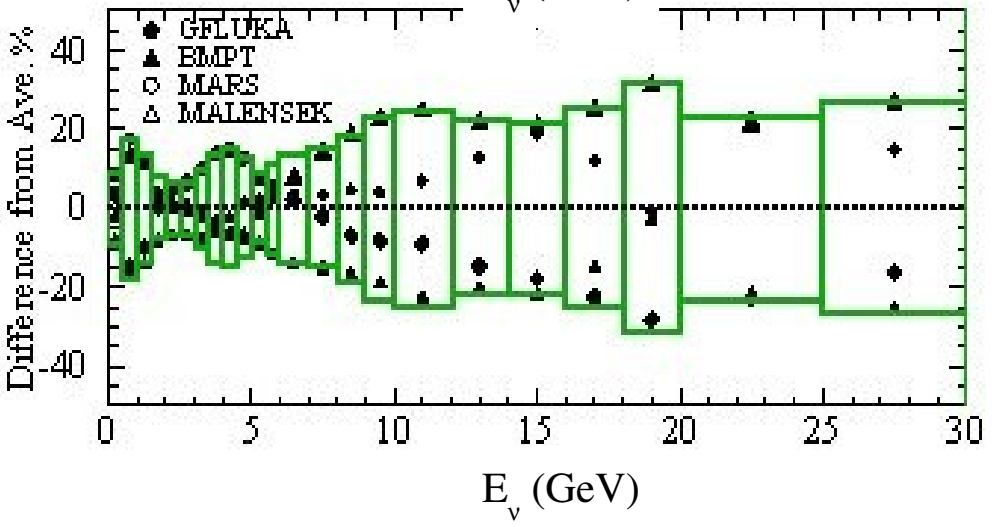


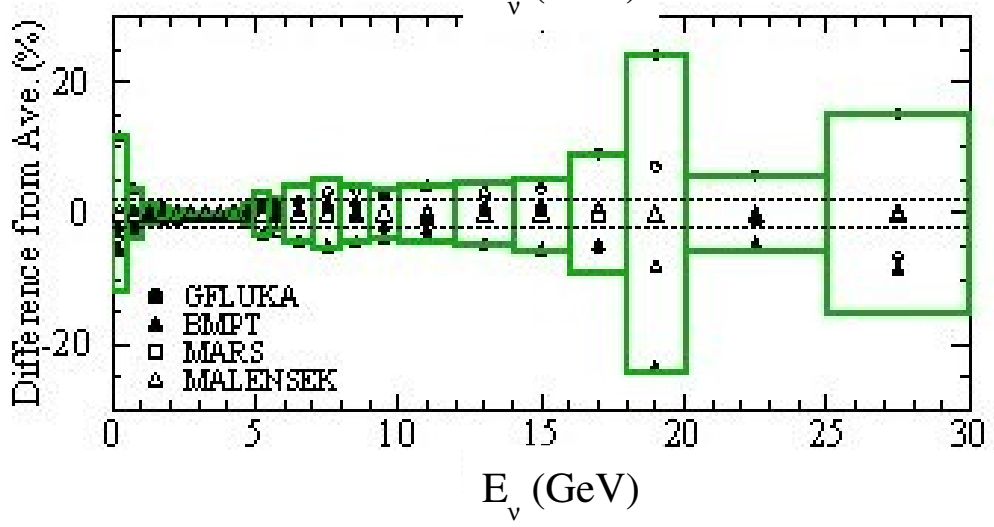
- Size of box is proportional to number of ν_μ CC events produced from a pion of that (p,p_T) value coming off of the MINOS target.
- Previous experiments used single-arm spectrometers, giving only single (p,p_T) flux measurements.
- New results from NA49 experiment of 158 GeV/c p-p and p-C have improved the situation.

MINOS MC Flux Predictions



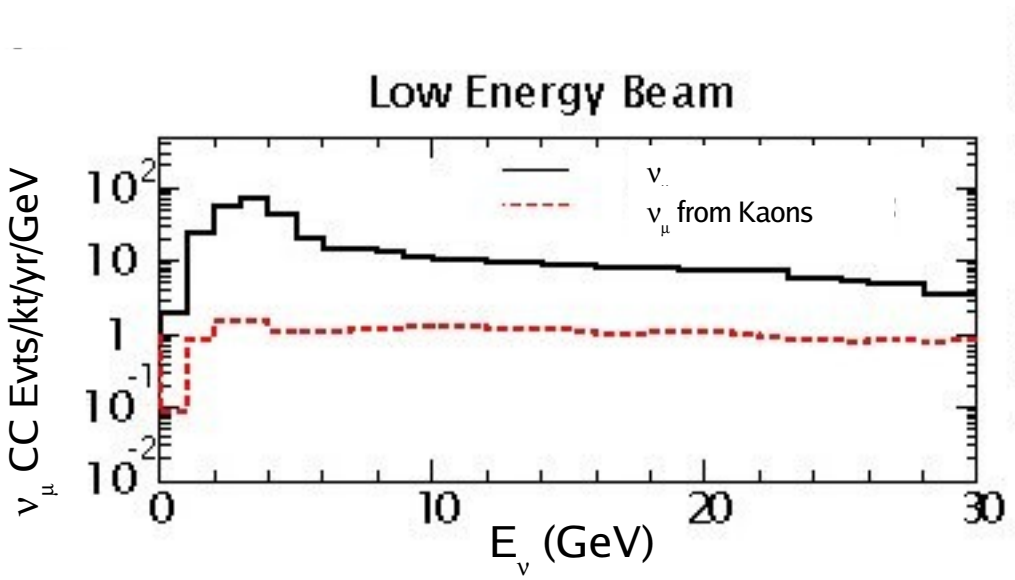


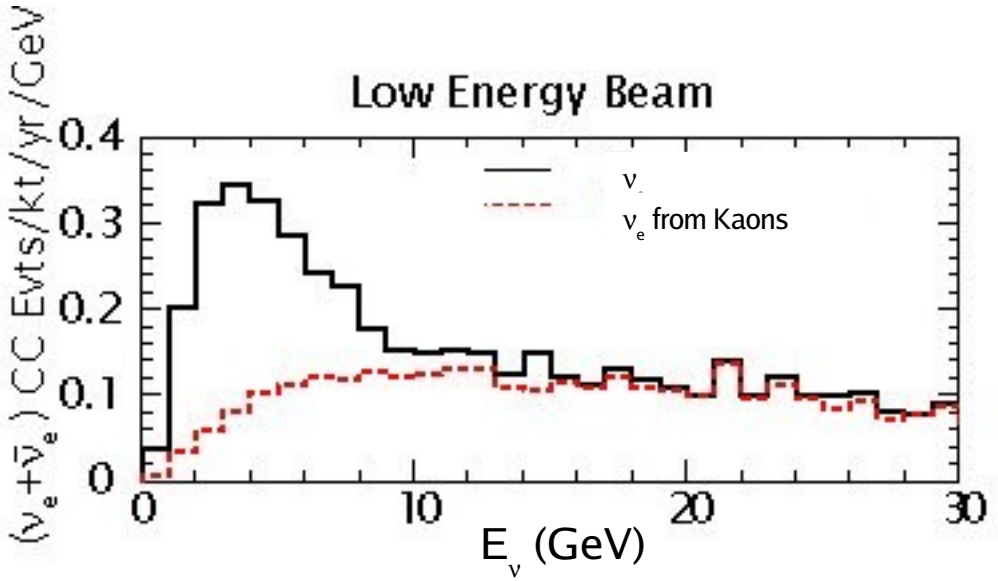


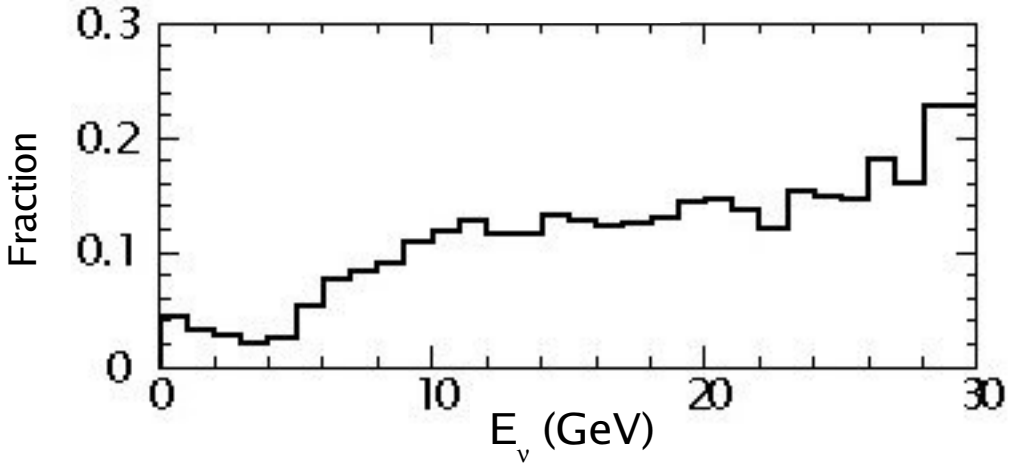


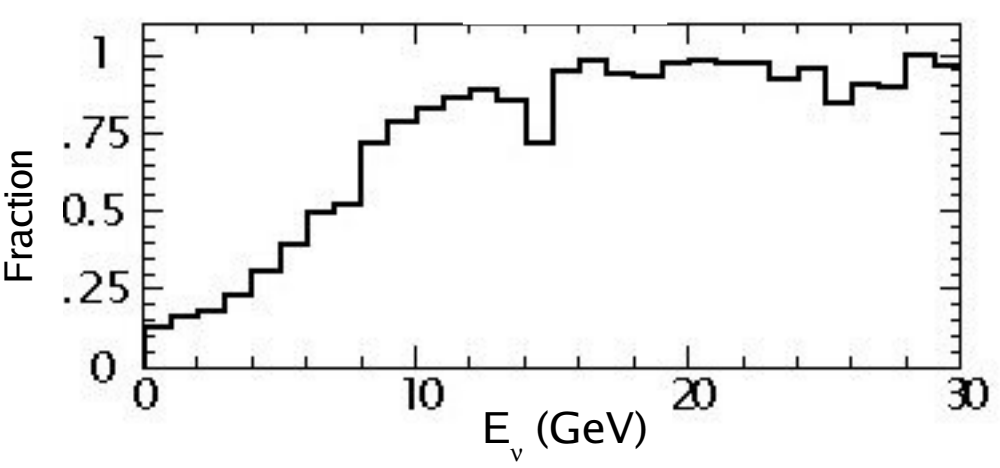
Highly correlated models result in predictions that differ by up to ~20%...

Prediction of Kaon Content





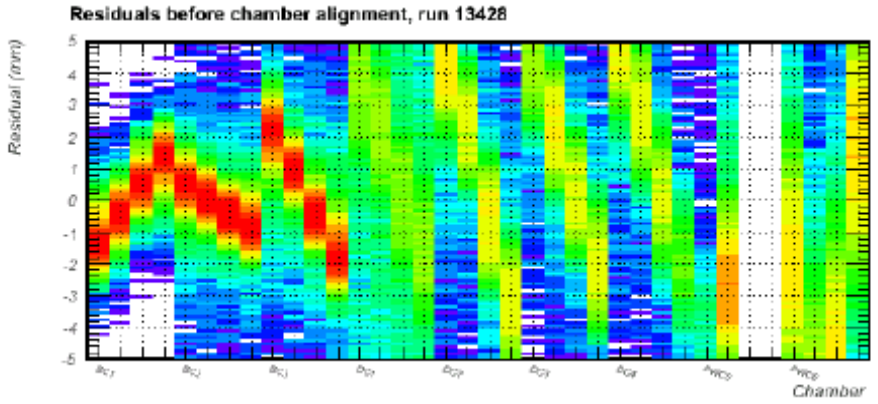


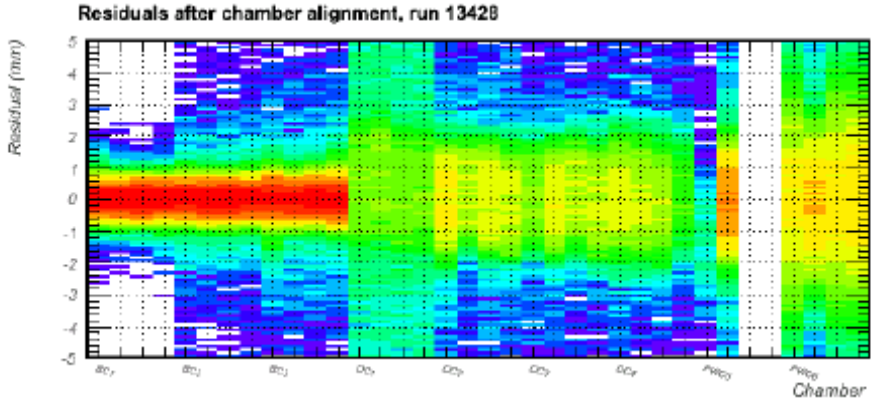


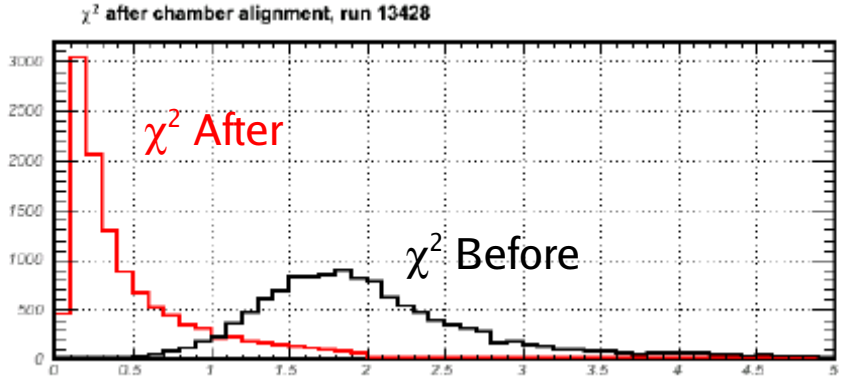
Significant fraction of ν_μ's and ν_e's come from K-decays;

Kaon flux not very well measured.

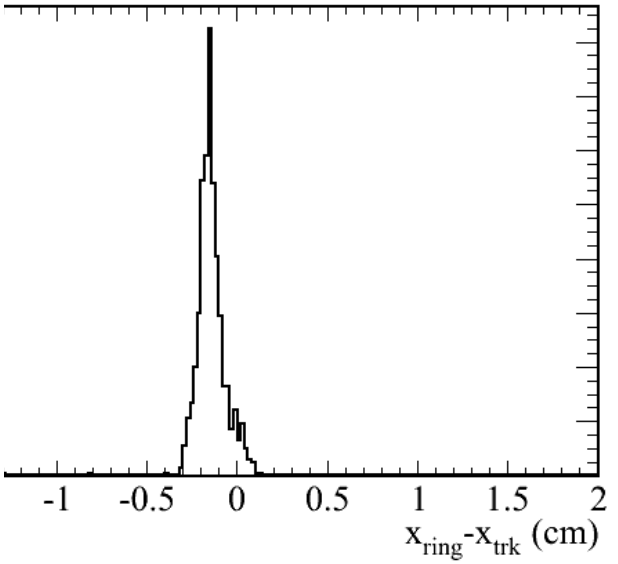
Detector Alignment

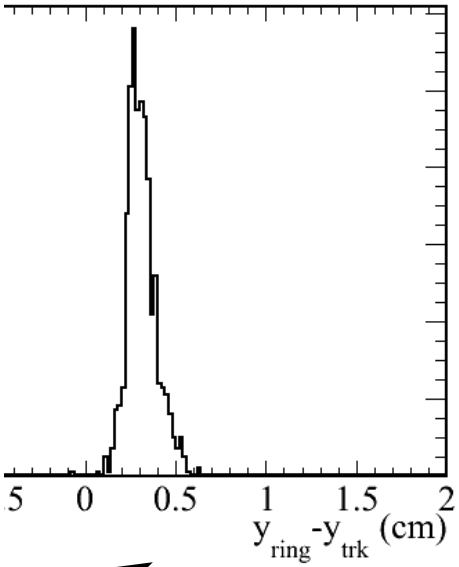






Track x(y) position at RICH – RICH ring center



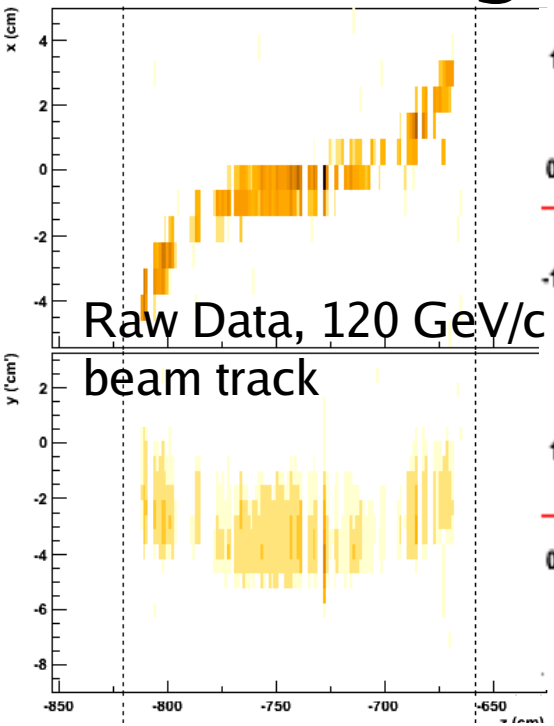


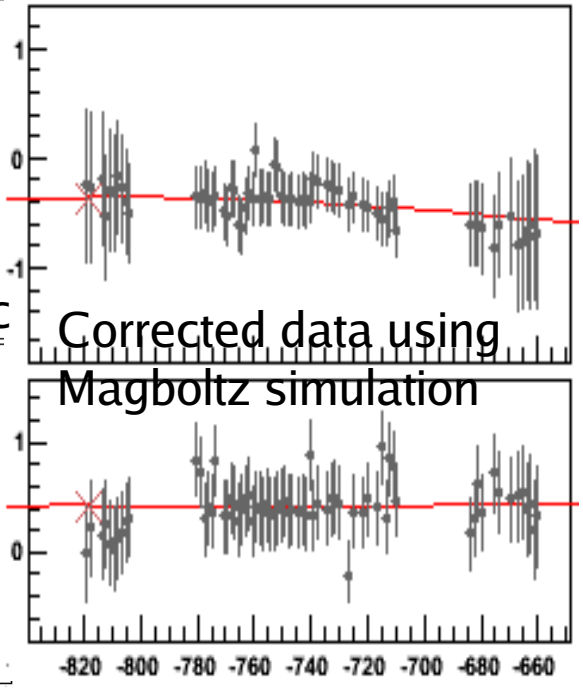
RICH alignment – mirrors aligned to within a few mm

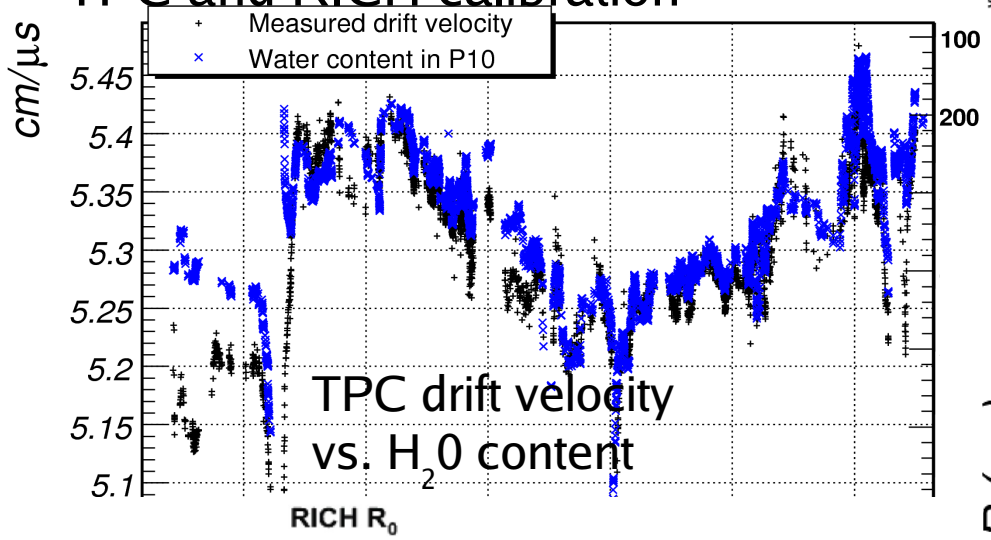
Drift chamber alignment – analysis in-progress will align wire chambers to within 0.2 wire-spacing.

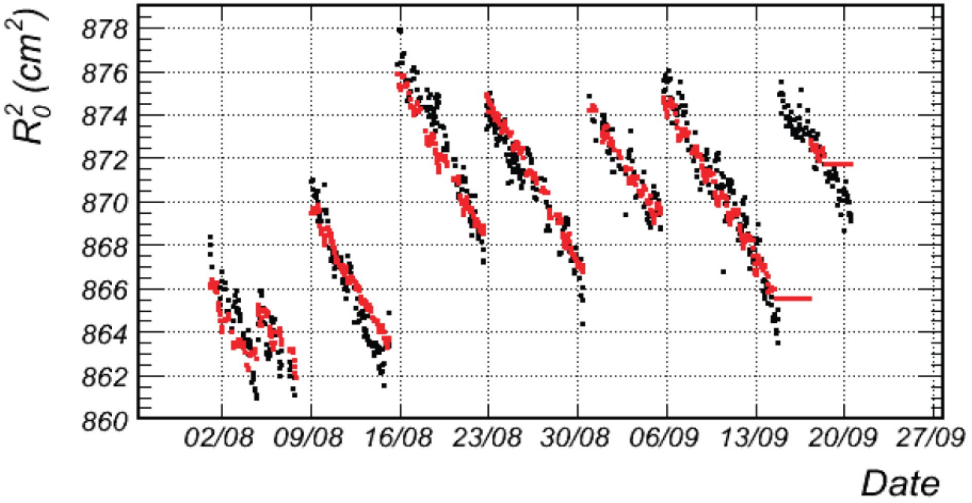
Detector Calibration and Alignment

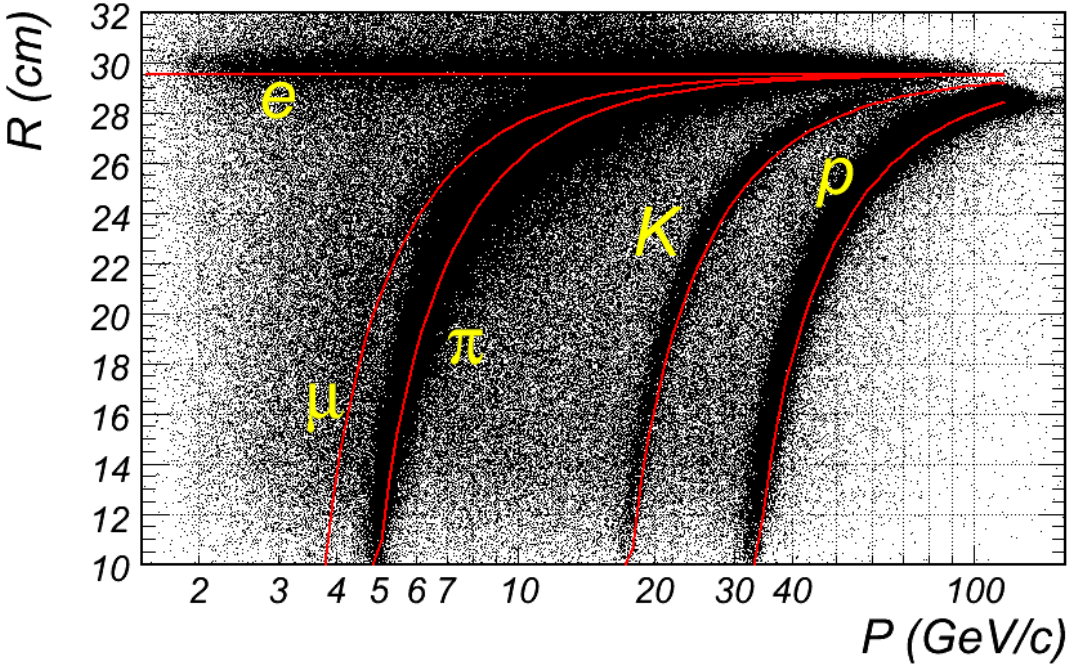
- TPC data are "distorted" due to non-uniform magnetic field. Distortions are corrected to within 10%.
- Wire chamber and TPC alignment
- TPC and RICH calibration



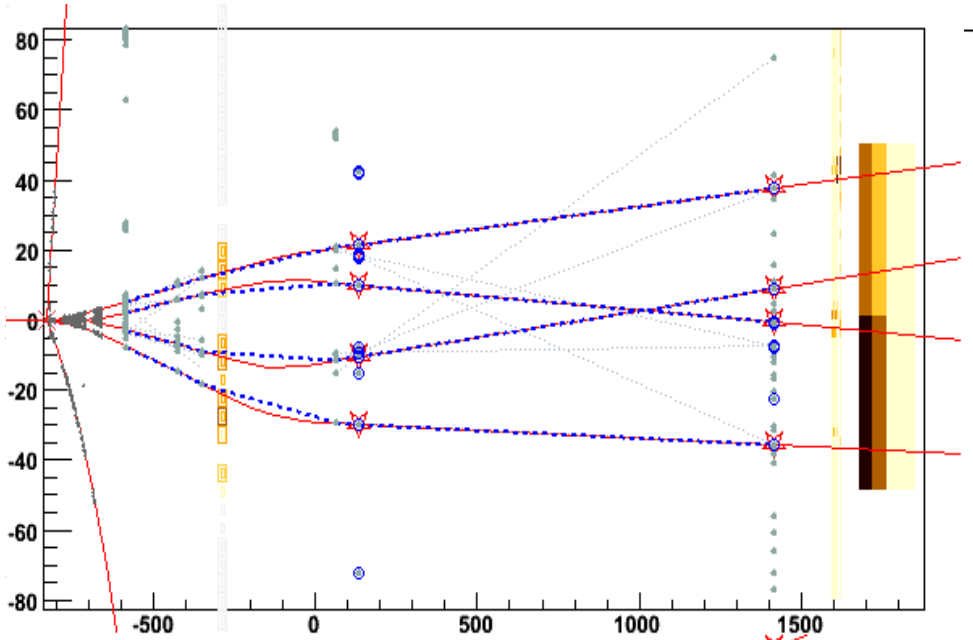


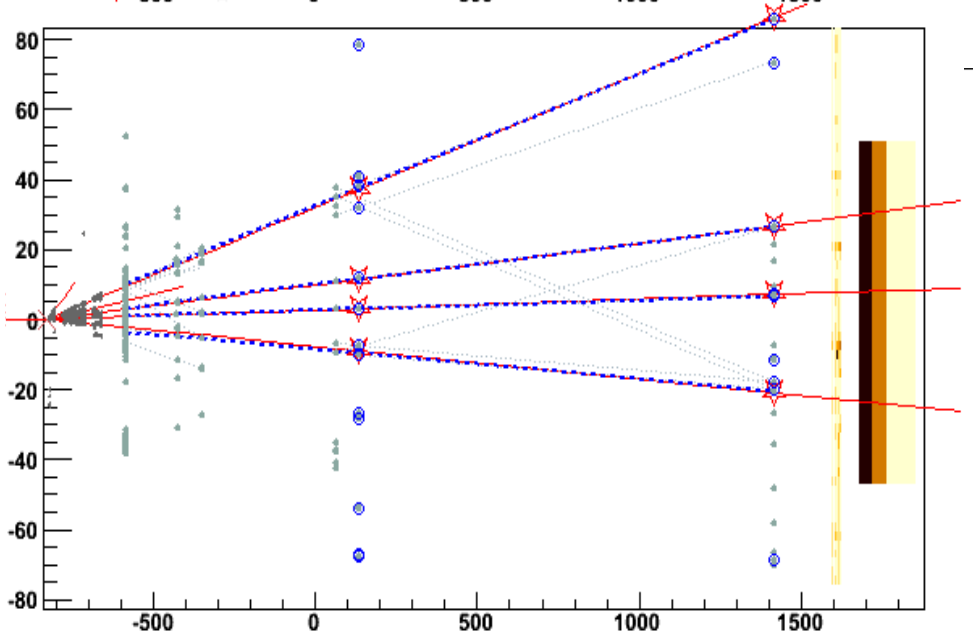




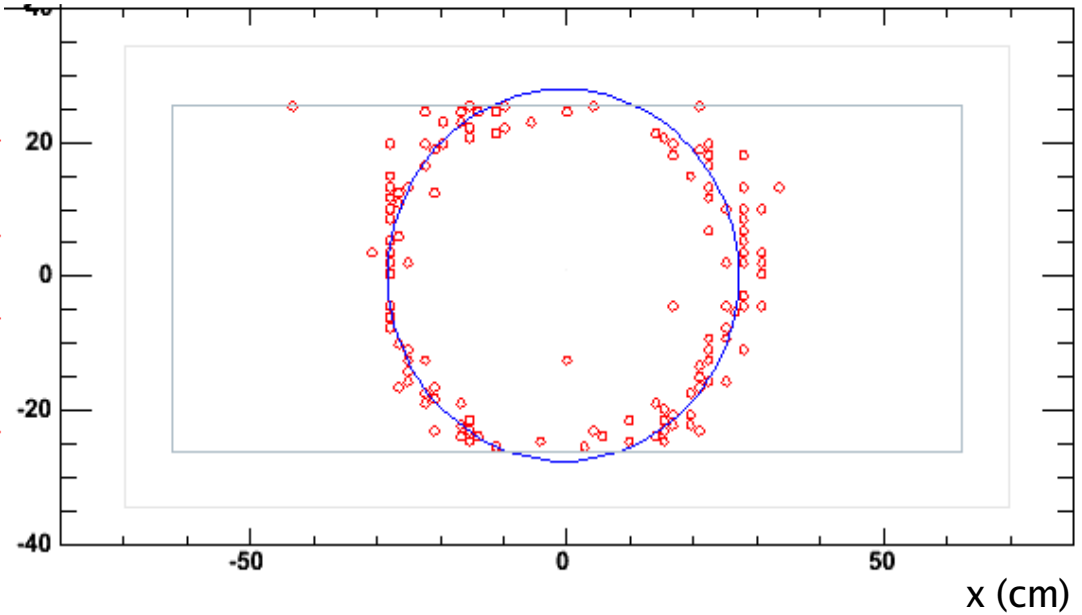


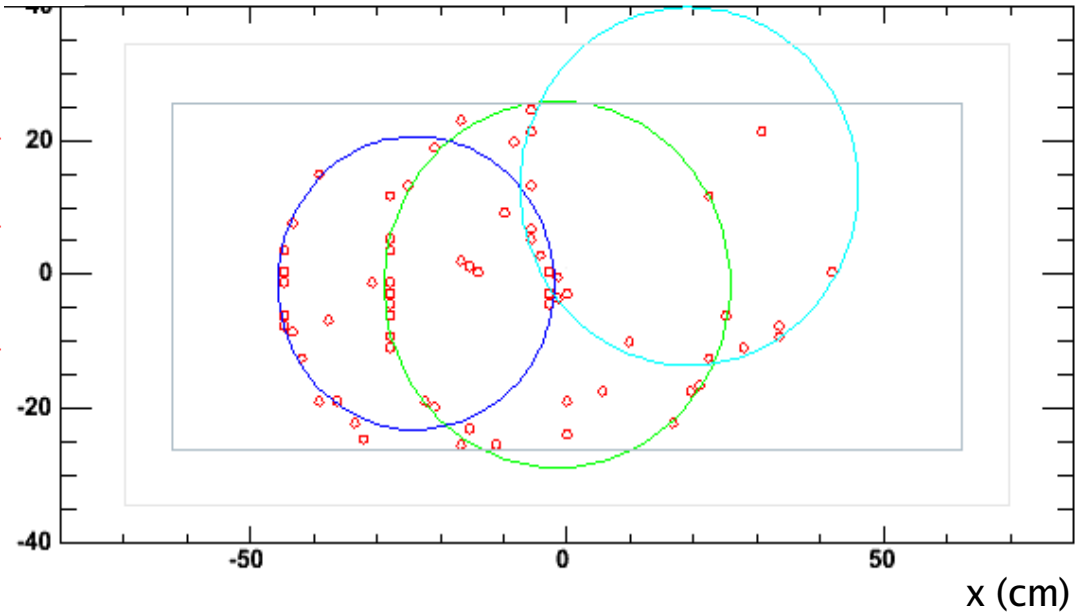
Typical 120 GeV/c p+C(2%) Event





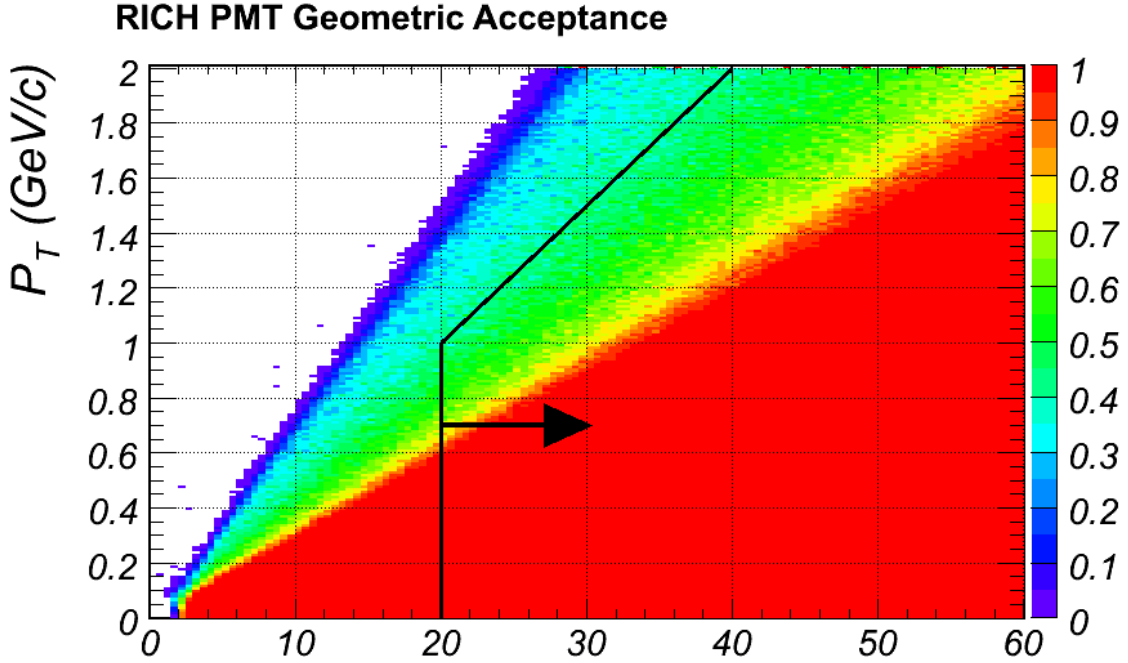
Reconstructed RICH Rings

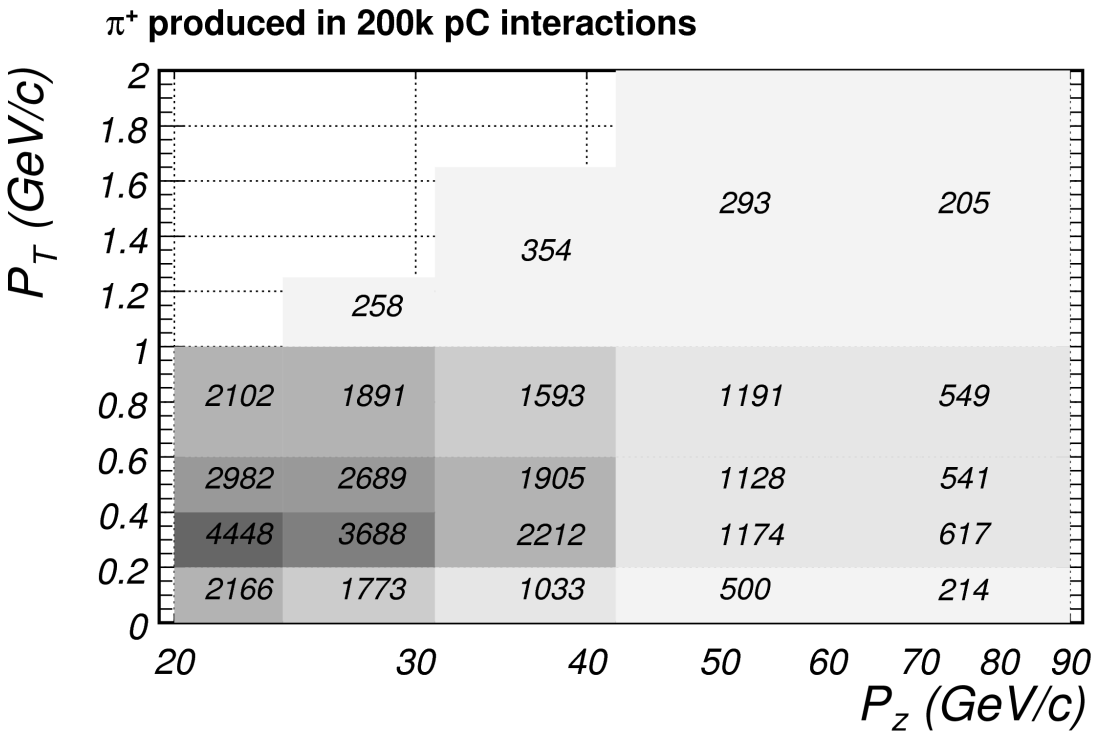




Charged π,K Production Ratio Analyses

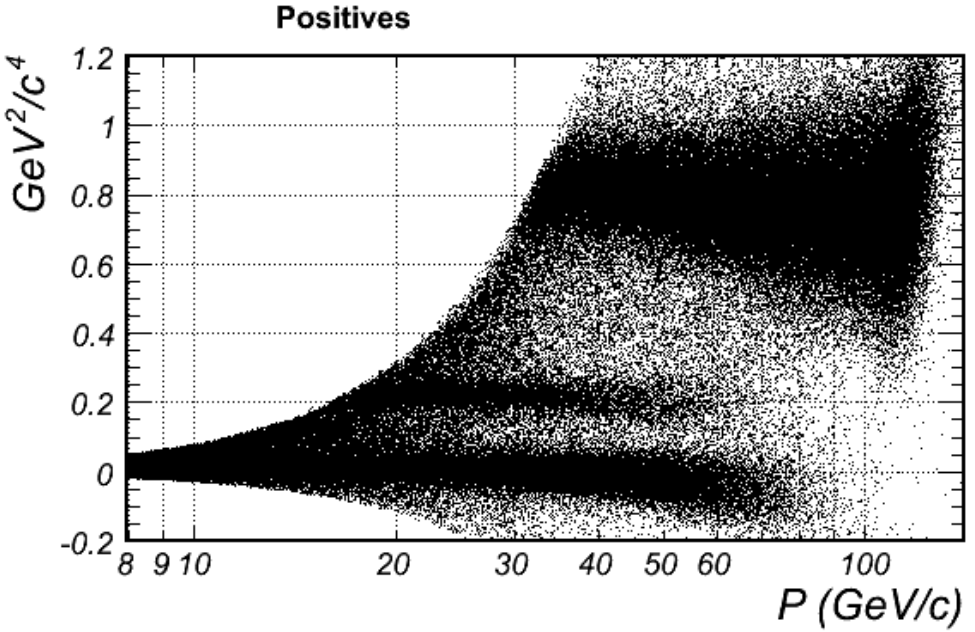
- Charged π,K production ratios in 120 GeV/c p + C (2%) and MINOS target interactions using RICH PID (p > 20 GeV/c)
- Analyses (theses) by Andre Lebedev (thin C-target) and Sin Man Seun (MINOS target).
- Bins are rectangular in (p_z,p_T)
  - Min. p_z (20 GeV/c) is just above Kaon threshold (17 GeV/c)
  - Regions of phase space with >50% RICH acceptance are used
  - Widths determined by statistics (for thin-C analysis)

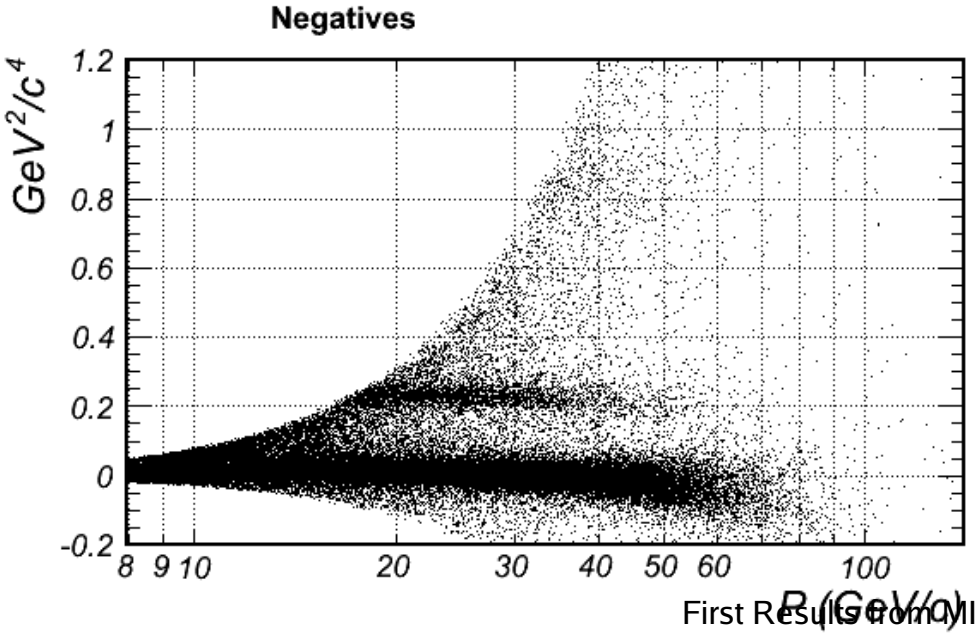




120 GeV/c p + C(2%) Ratio Analysis Particle Id Variable

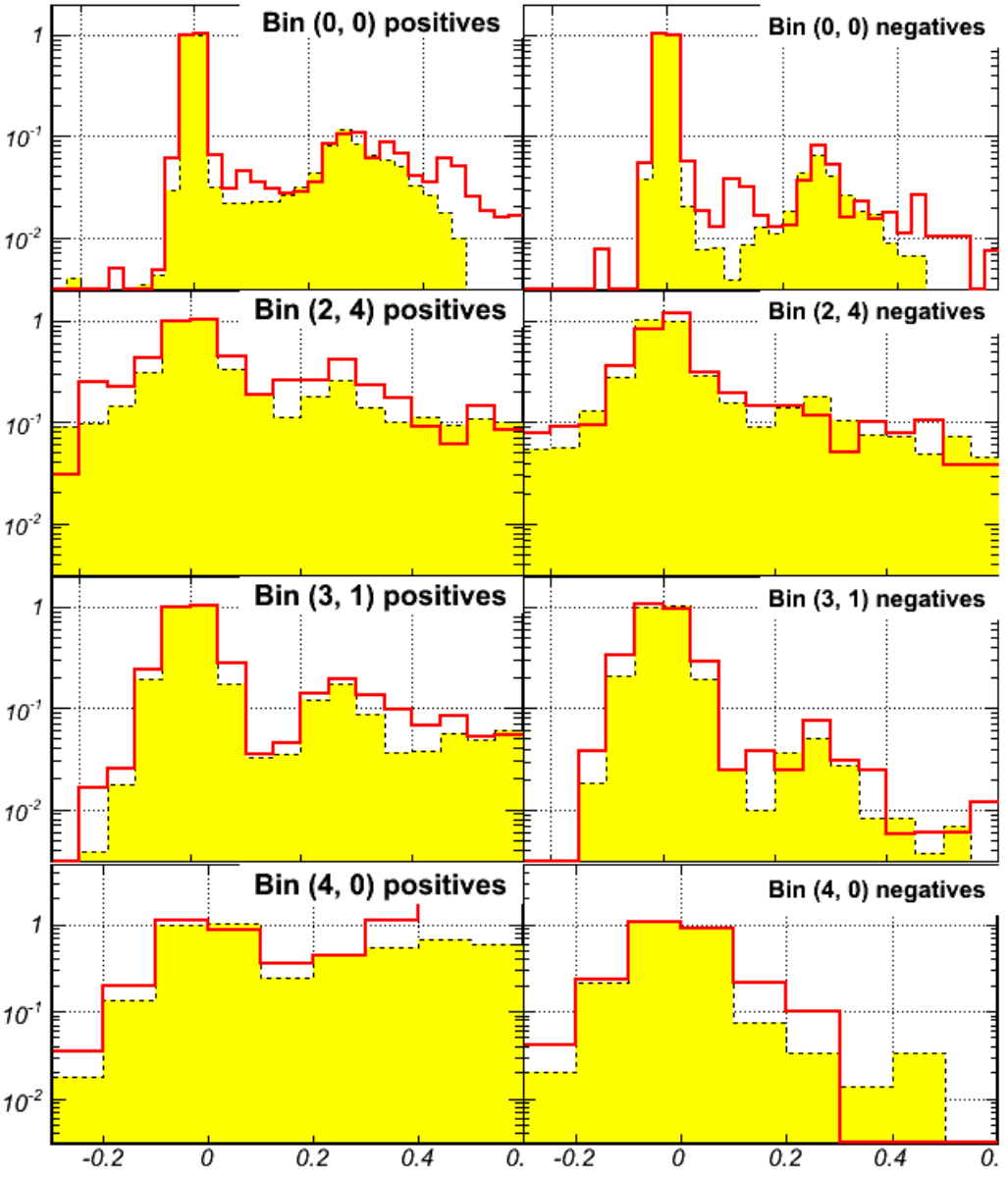
- Analysis is based on matching of reconstructed RICH rings; ring radii are converted to m^2.
- We observe a momentum-dependence of m^2, not reproduced in MC.
- Define a RICH PID variable
  - $\pi \equiv 0$
  - $K \equiv 0.265$
  - $p \equiv 1$
- The m^2 distributions in each (p_z,p_T) bin are stretched and shifted such that PID variable peaks are aligned across all bins.





Thin-C Ratio Analysis – Background Modeling, MC Comparison

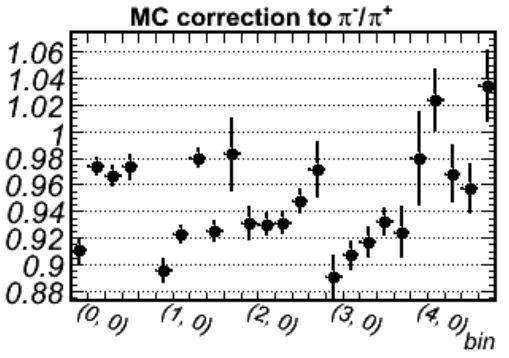
- Corrections and backgrounds determined from MC:
  - Interactions in the spectrometer
  - Decay in flight: 10% of 20 GeV/c Kaons decay before RICH
  - Large angle multiple scattering: > 100 GeV/c protons can be reconstructed wit p < 70 GeV/c
  - This analysis assumes a 50% uncertain on these corrections.
- Background in data are greater than in MC
- Data PID peaks are wider than MC
- Syst. uncertainties from background are very large, ~50% for some bins.

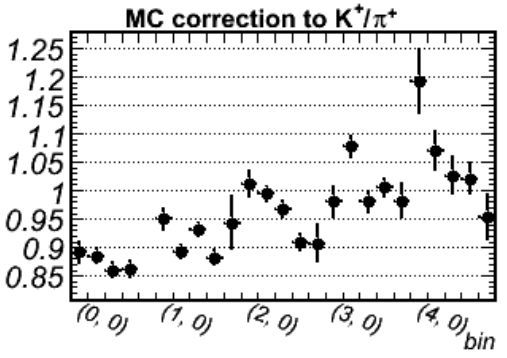


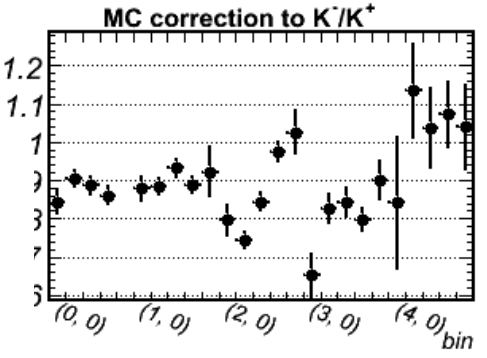
Data: red line; MC: yellow area

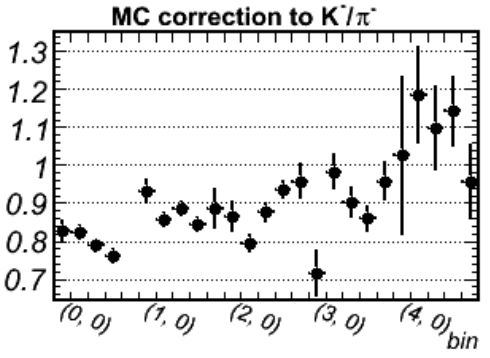
Thin-C Ratio Analysis
MC Corrections and Background Uncertainties

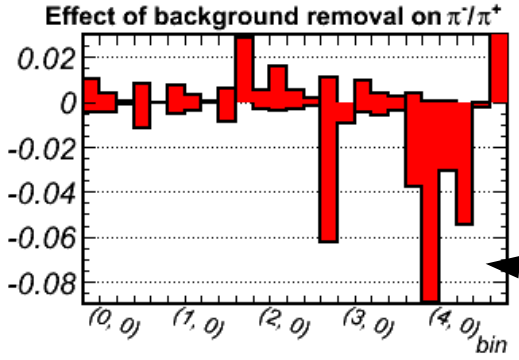
- MC corrections are order 10%
- We assume a 50% uncertainty on the MC correction

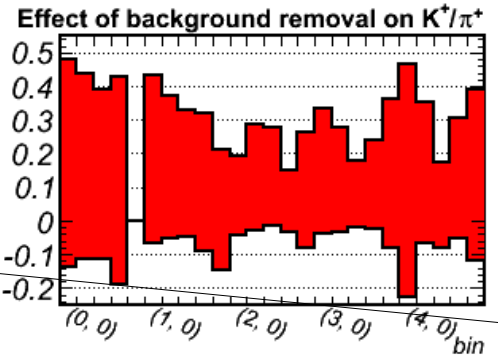


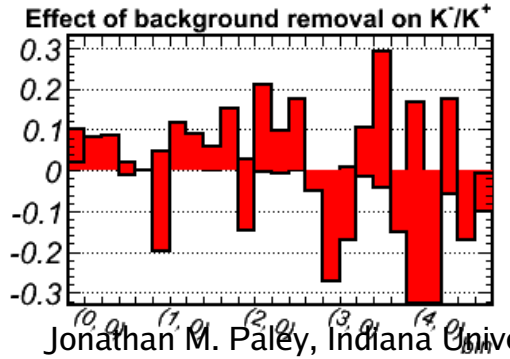


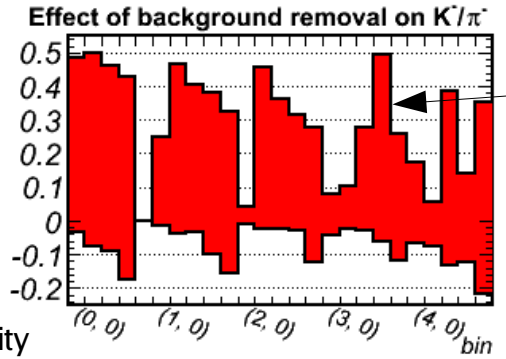








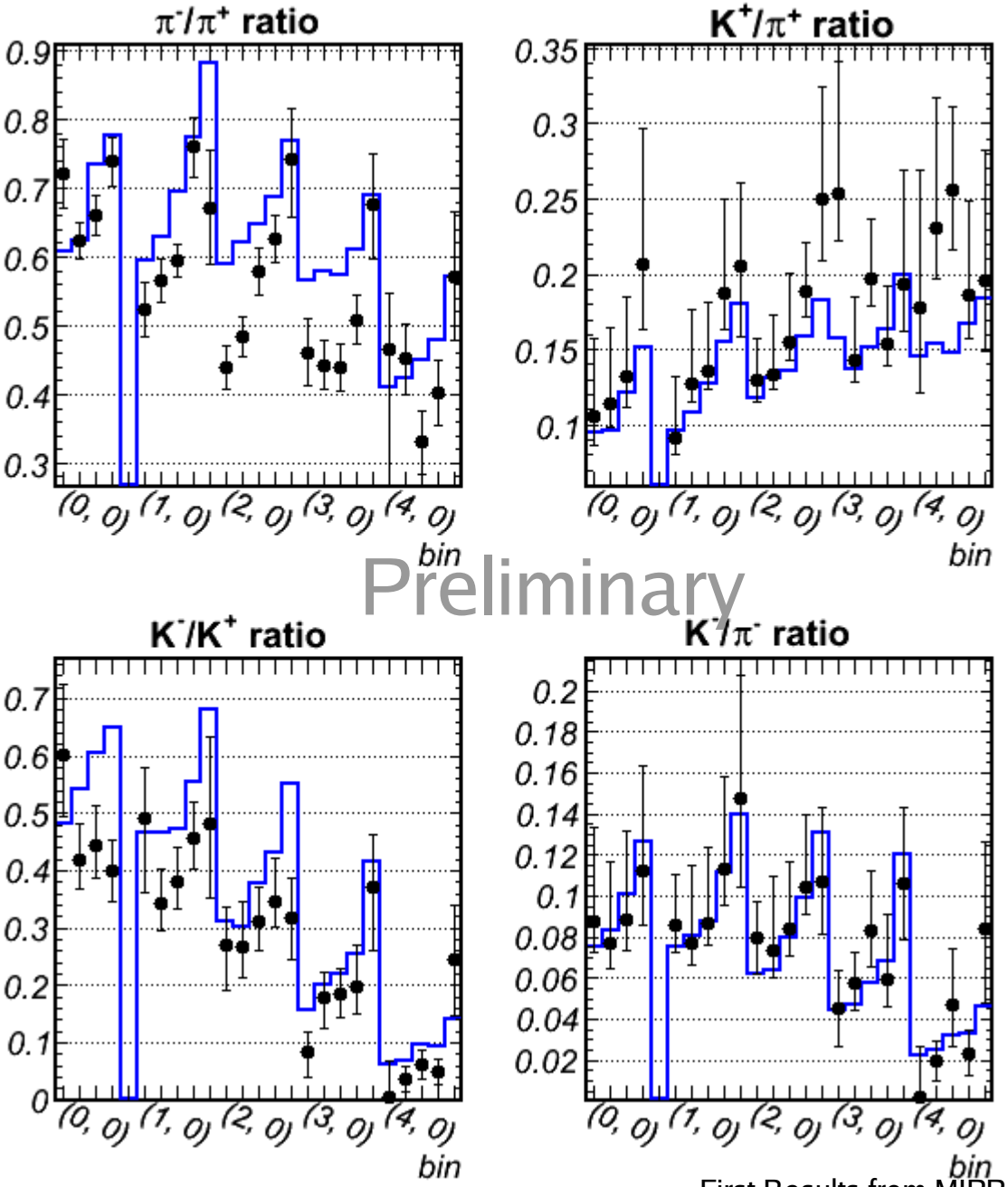




- Uncertainty on background modeling measured with data.
- Errors are asymmetric where background is large

Thin-C Ratio Analysis - Results

- Good K/π agreement between MIPP result and Fluka MC.
- π^-/π^+ and K^-/K^+ ratios differ from Fluka MC by up to 50%.
- Errors on π^-/π^+ ratios are systematics-limited.
- Errors on π/K ratios are dominated by understanding of backgrounds.

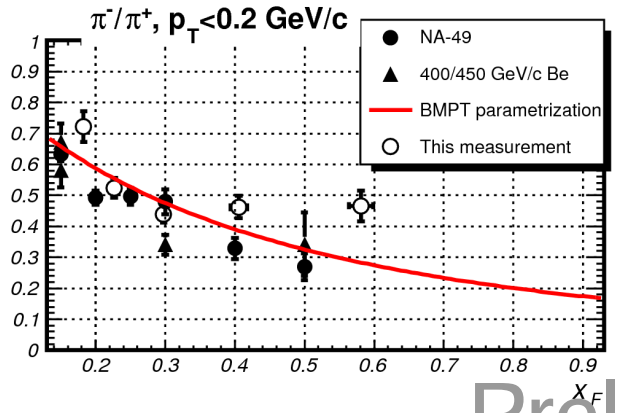


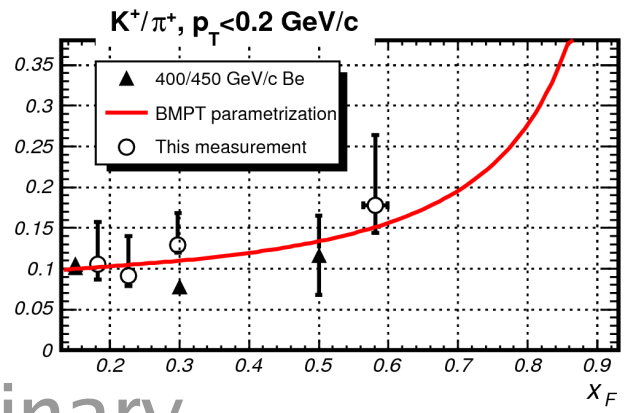
Bin mapping in (pz,pT) space

	p_z (GeV/c)				
p_T (GeV/c)	20-24	24-31	31-42	42-60	60-90
0-0.2	(0,0)	(1,0)	(2,0)	(3,0)	(4,0)
0.2-0.4	(0,1)	(1,1)	(2,1)	(3,1)	(4,1)
0.4-0.6	(0,2)	(1,2)	(2,2)	(3,2)	(4,2)
0.6-1	(0,3)	(1,3)	(2,3)	(3,3)	(4,3)
>1		(1,4)	(2,4)	(3,4)	(4,4)

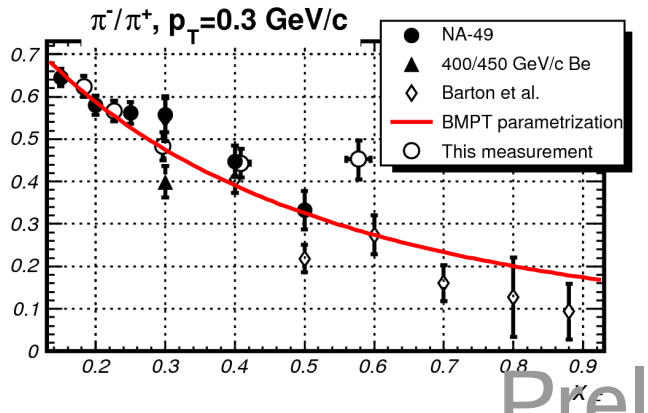
Thin-C Analysis – Comparison to Previous Measurements

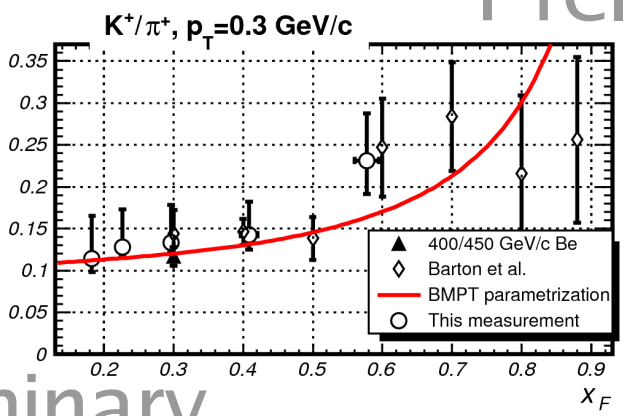
- Data agree well with overlapping data from previous measurements

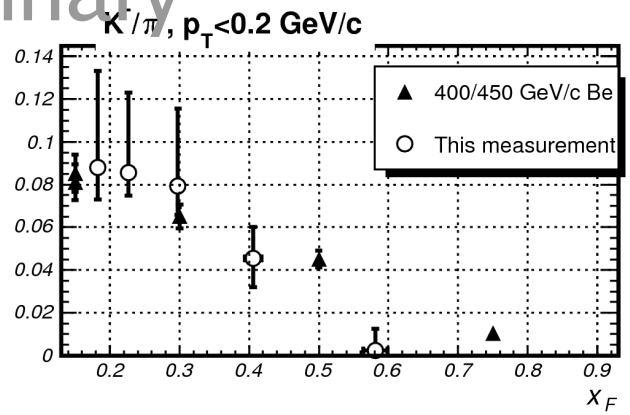




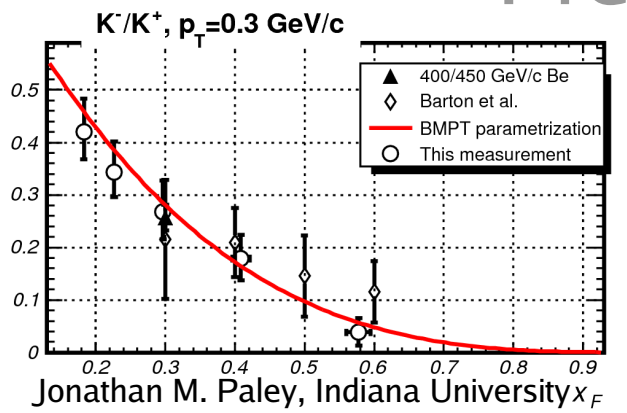
Preliminary

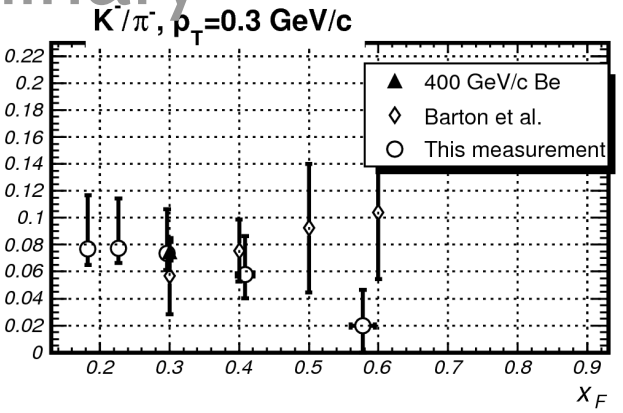






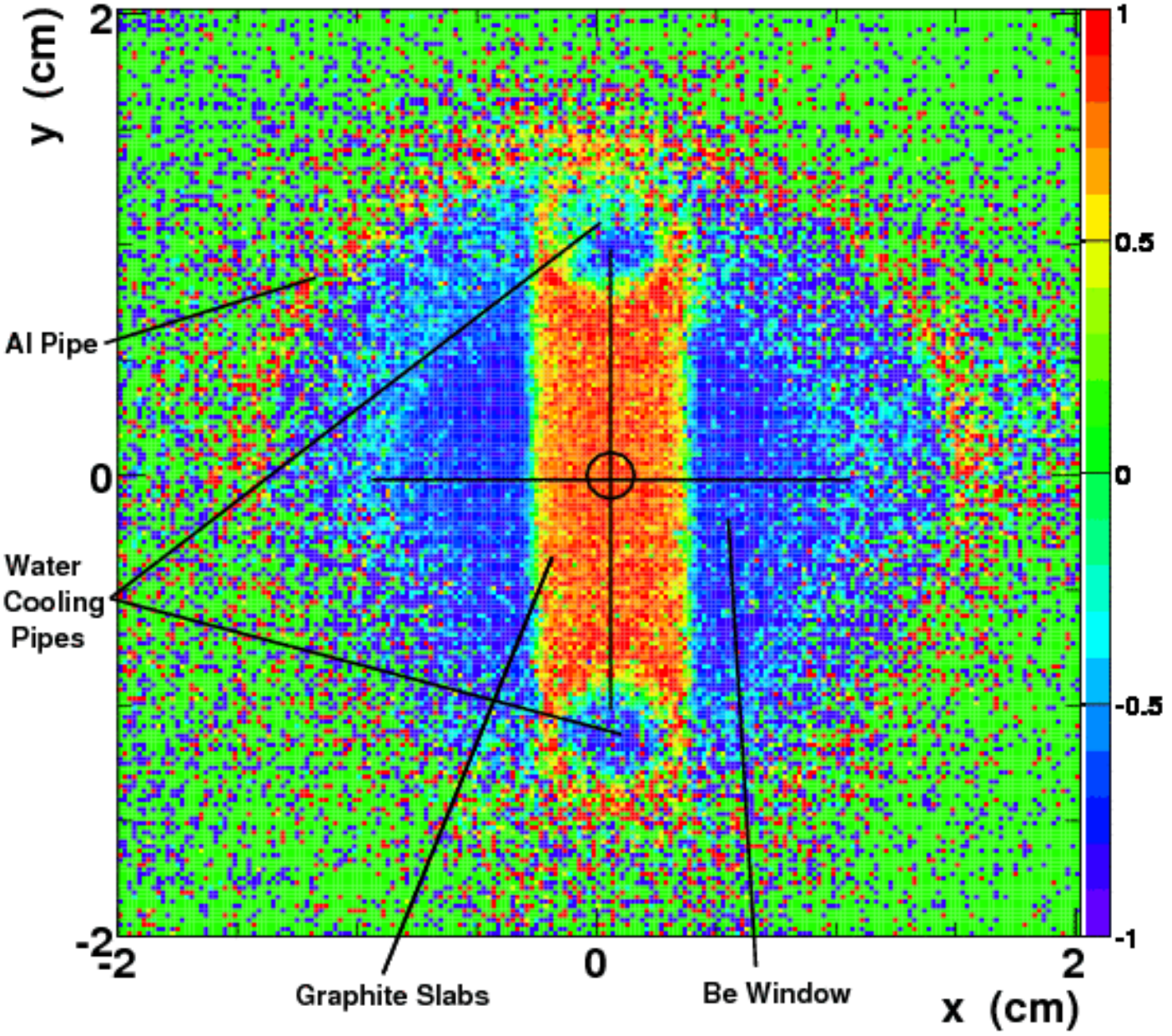
Preliminary





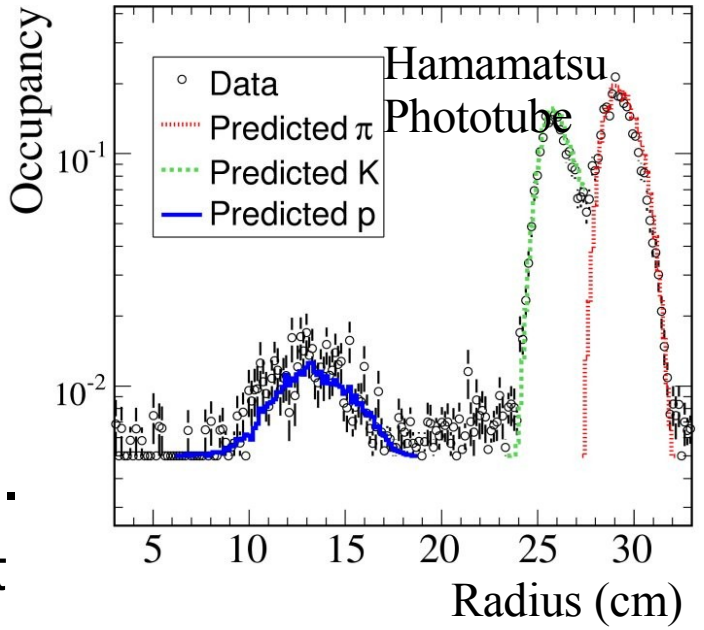
Beam Alignment on MINOS Target

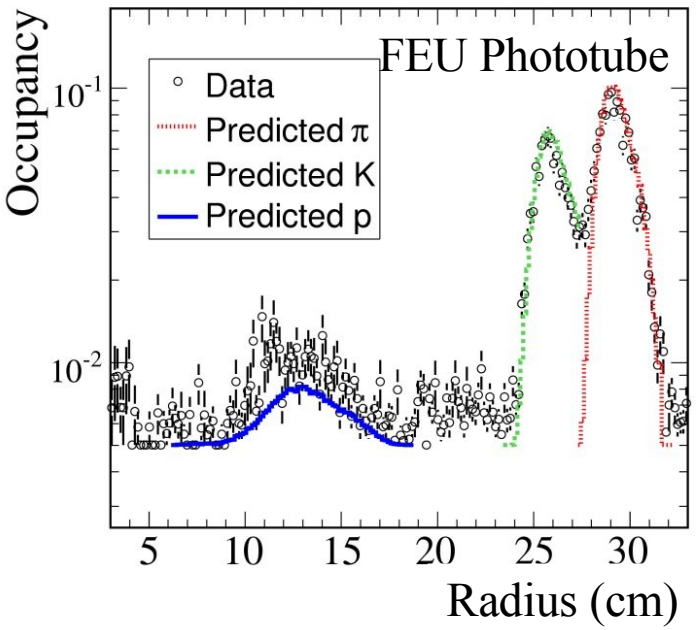
- Beam aligned on target:
  - $\Delta x = 0.02$ mm,
  - $\Delta y = 0.51$ mm
- Matches MINOS alignment extremely well.



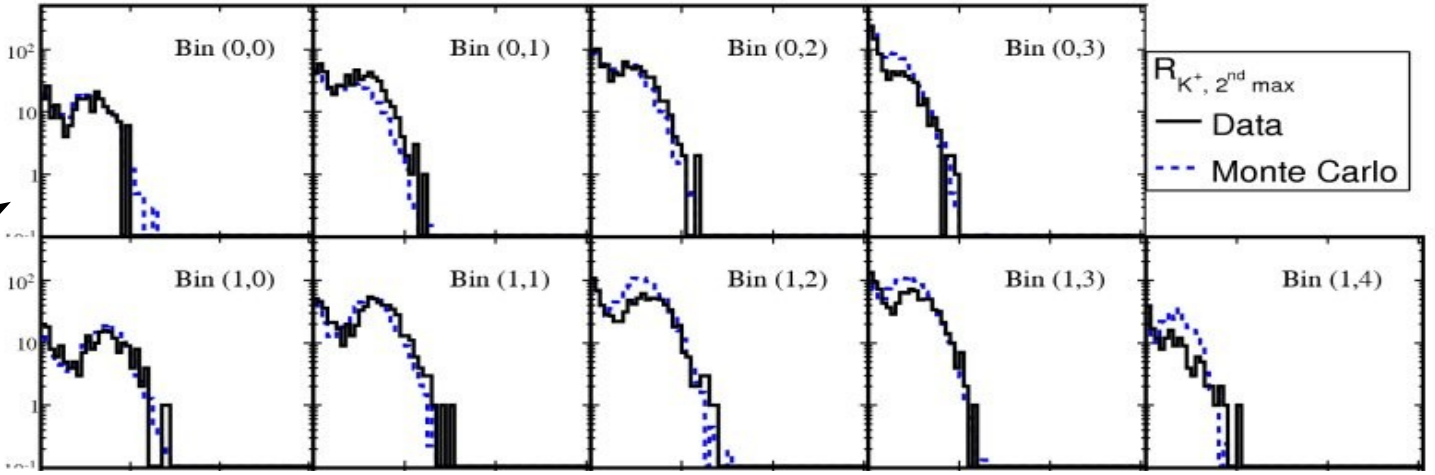
120 GeV/c p + NuMI Target Ratio Analysis - Log-likelihood Particle Id

- Analysis is based on log-likelihood method.
- Prediction of photostatistics agrees well with data after response of the two PMT types were tuned.
- Momentum-dependent cuts on log-likelihood differences are used in the event selection:



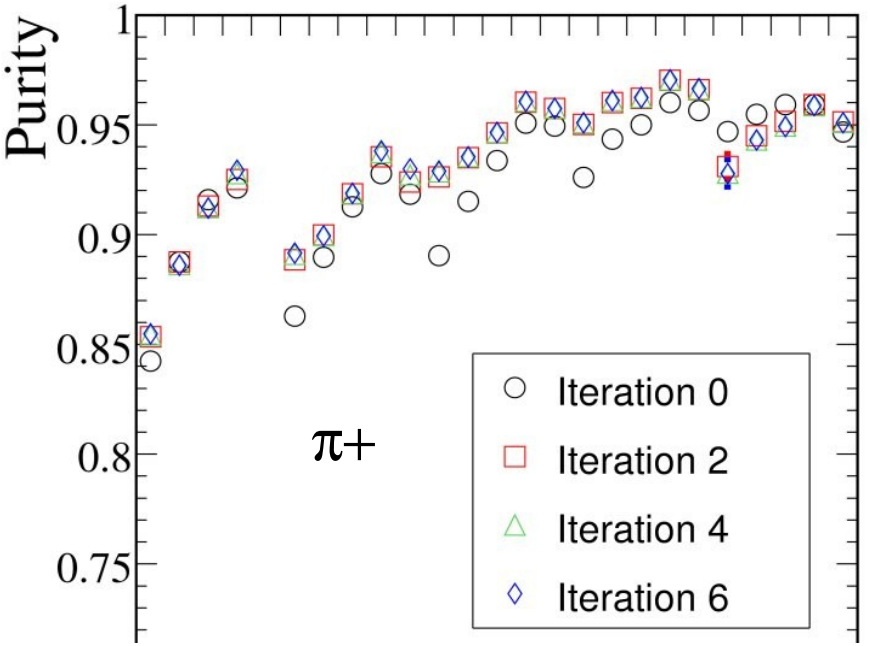


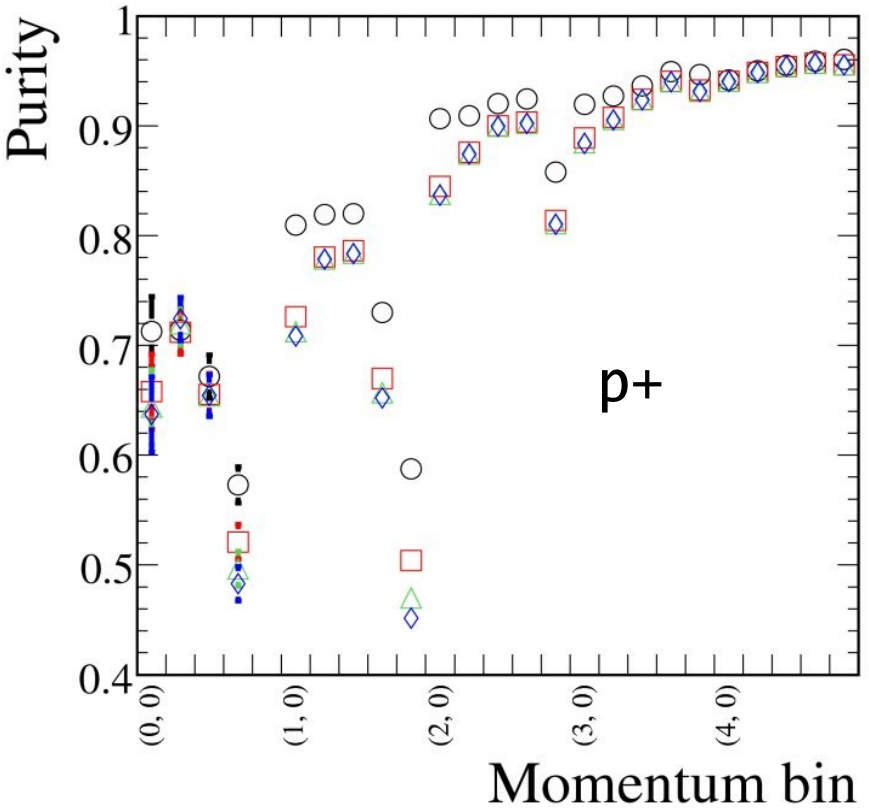
LL difference between K^+ and the next largest LL.



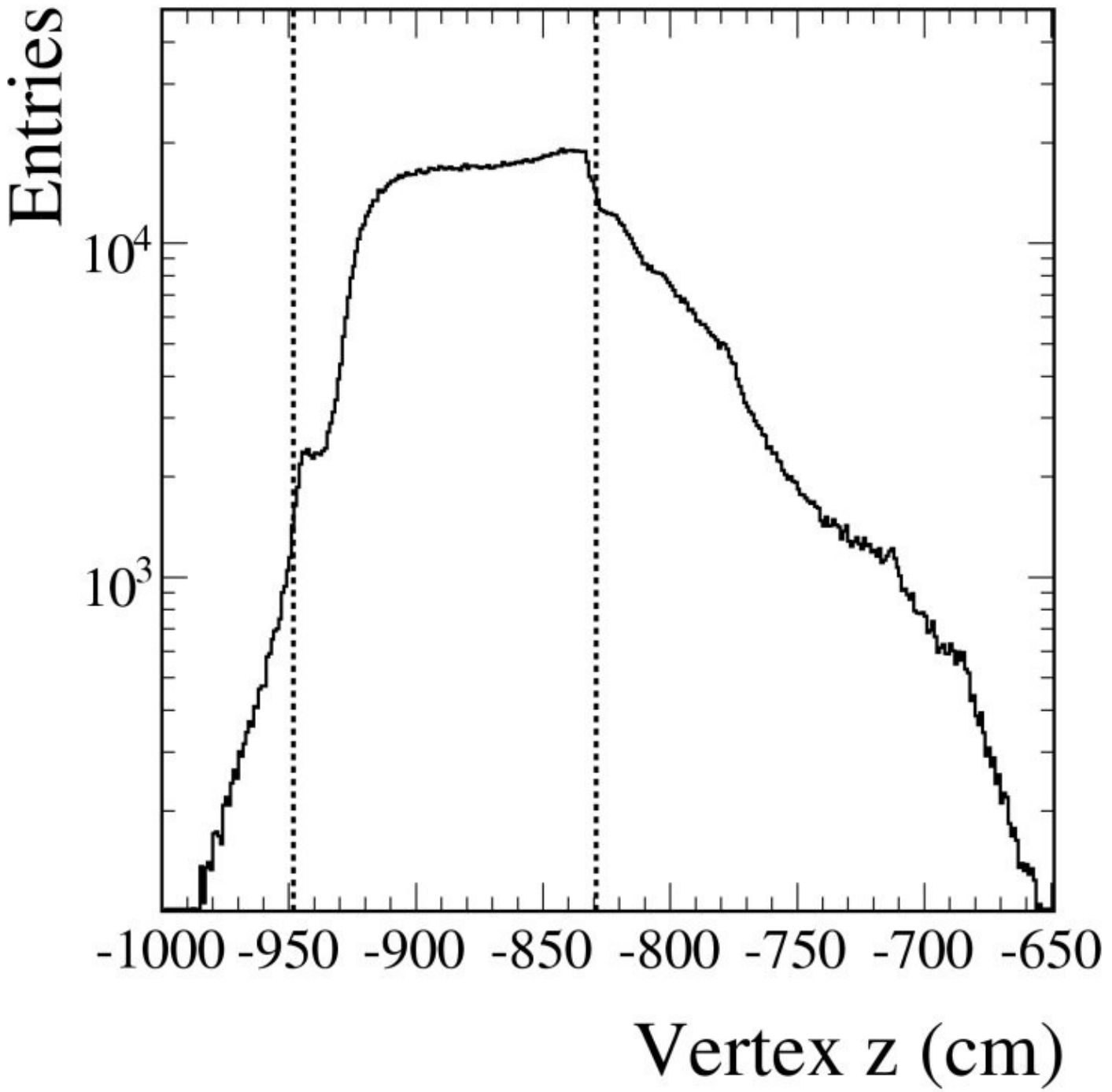
NuMI Target Ratio Analysis Background Modeling, MC Comparison

- The thin-target analysis relied on the MC out-of-the box to determine uncertainties due to backgrounds.
- But we know the MC does not necessarily have the correct particle yields, so the background estimates are likely off.
- This analysis therefore renormalized the MC particle yields using an iterative, data-driven approach to better agree with the data.
- Only background and PID cuts are affected by this, all other corrections can be determined from MC.
- In this analysis, most systematics found were much less than 10%, except where particle yields are low.

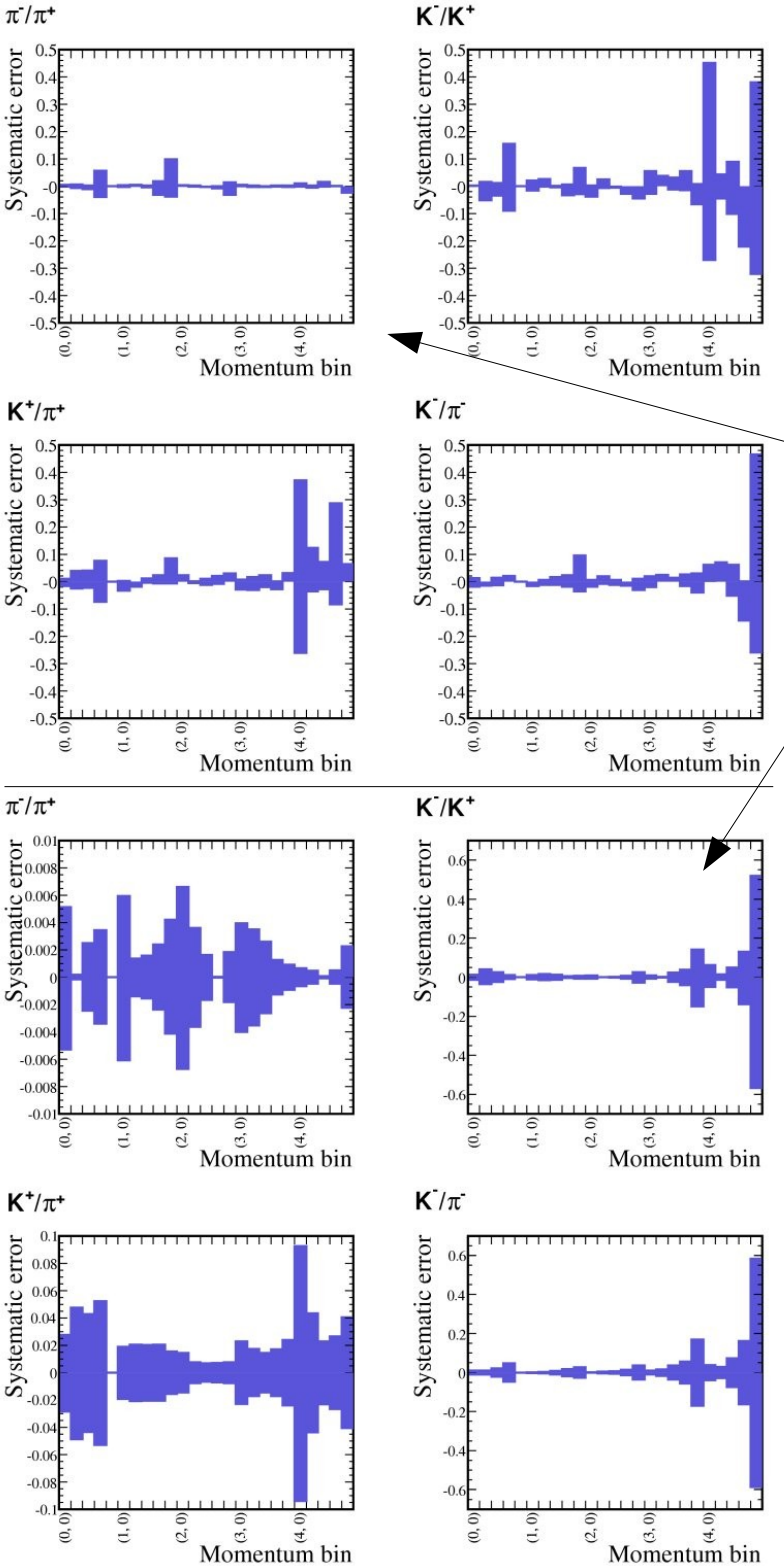




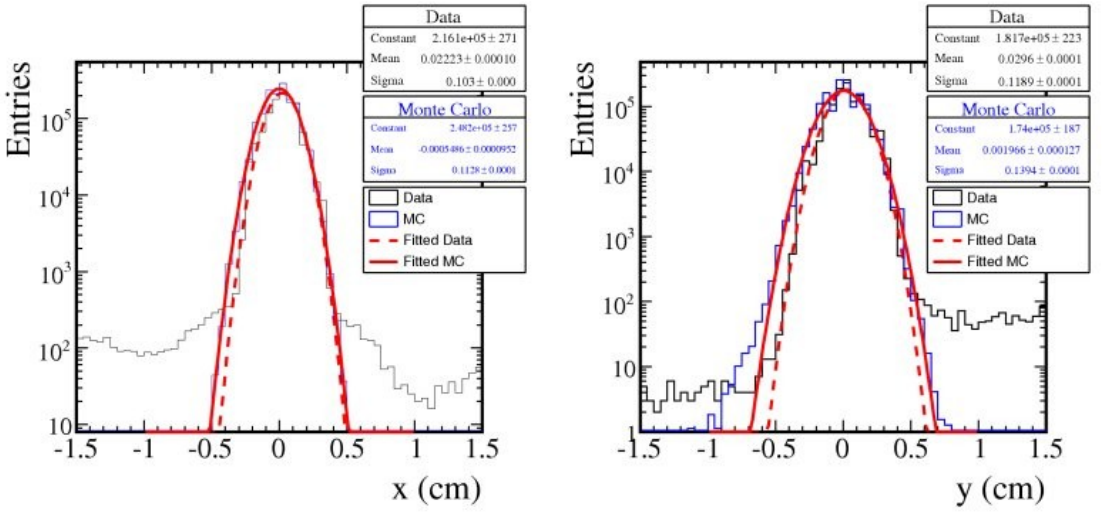
NuMI Target Analysis Vertex-z Cut



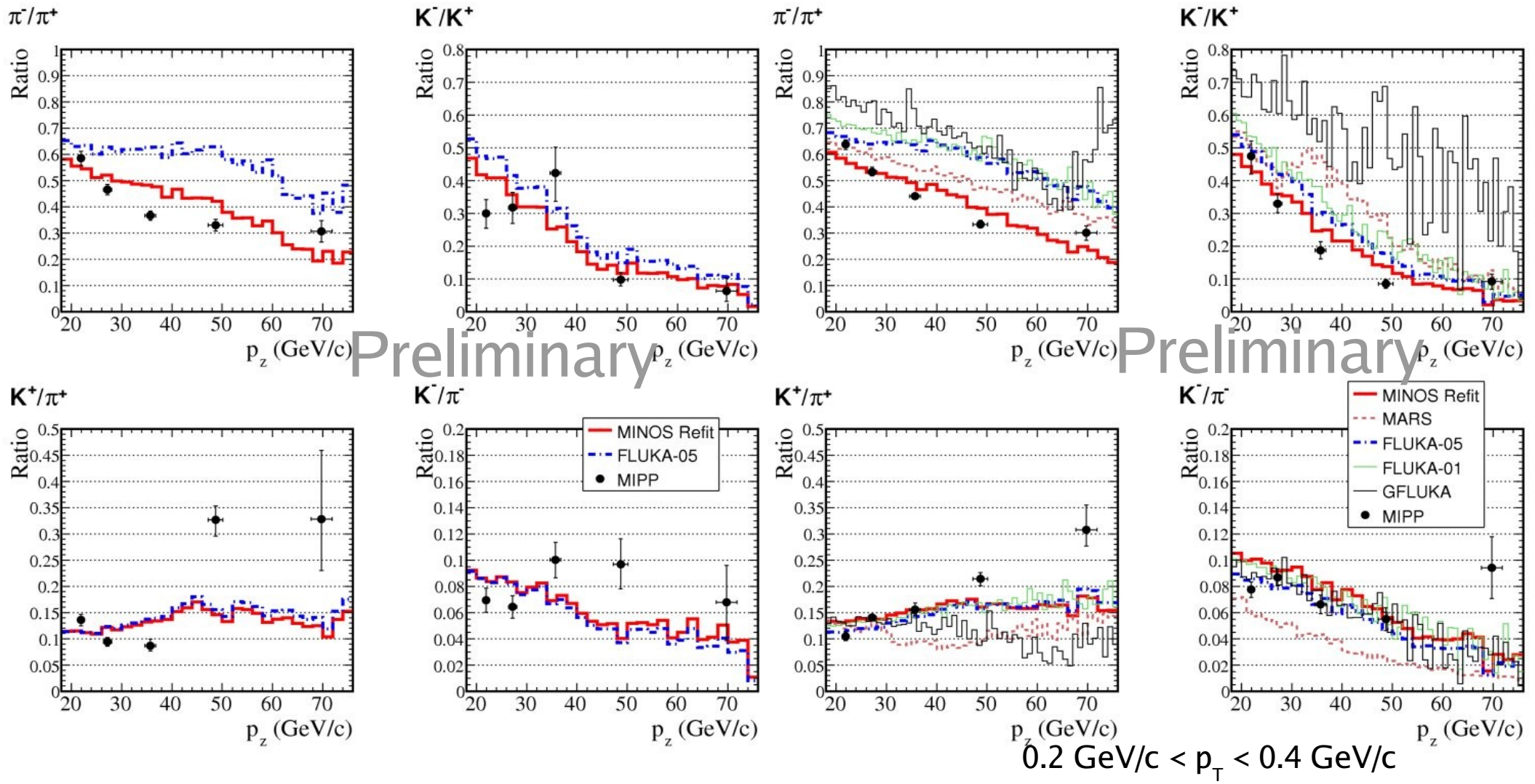
NuMI Target Ratio Analysis MC Corrections and Background Uncertainties



- Change in PID cut by ΔLL = ±10 typically results in < 10% syst. errors (but large where particle yields are small)
- ±10% changes in purity results in < 10% syst. uncertainties in ratios (again, except where yields are small).
- Other uncertainties due to beam position, width, and momentum scale are < 10%.



NuMI Target Analysis – MINOS Comparison



0.2 GeV/c < p_T < 0.4 GeV/c

Again, the MIPP data agree well with expectations from MINOS; a few outliers need to be investigated.

MIPP Upgrade

- MIPP was severely limited by DAQ rate, dominated by the TPC readout time (~30 Hz). This resulted in MIPP only collecting ~1/5 of desired statistics for the MINOS target run.
- An upgrade of the TPC electronics, using the ALICE ALTRO chip, can increase this readout time by up to a factor of 50. Other improvements would result in:
  - more stable TPC performance
  - greatly reduced ExB effects in the TPC
  - an improved beamline for low (~1 GeV/c) momentum running
- An upgraded MIPP would allow for the measurement of hadron production for any target (eg, MINOS, NOνA, T2K, etc.) in a matter of just a few days!
- FNAL has purchased ALTRO chips for the TPC upgrade and repair of the JGG dipole magnet has begun.
- **MIPP is looking for new institutions to join the upgrade effort, and would greatly benefit from involvement of the accelerator-based neutrino community!**