Measurement of π/K Production Ratio in Proton Carbon Interactions

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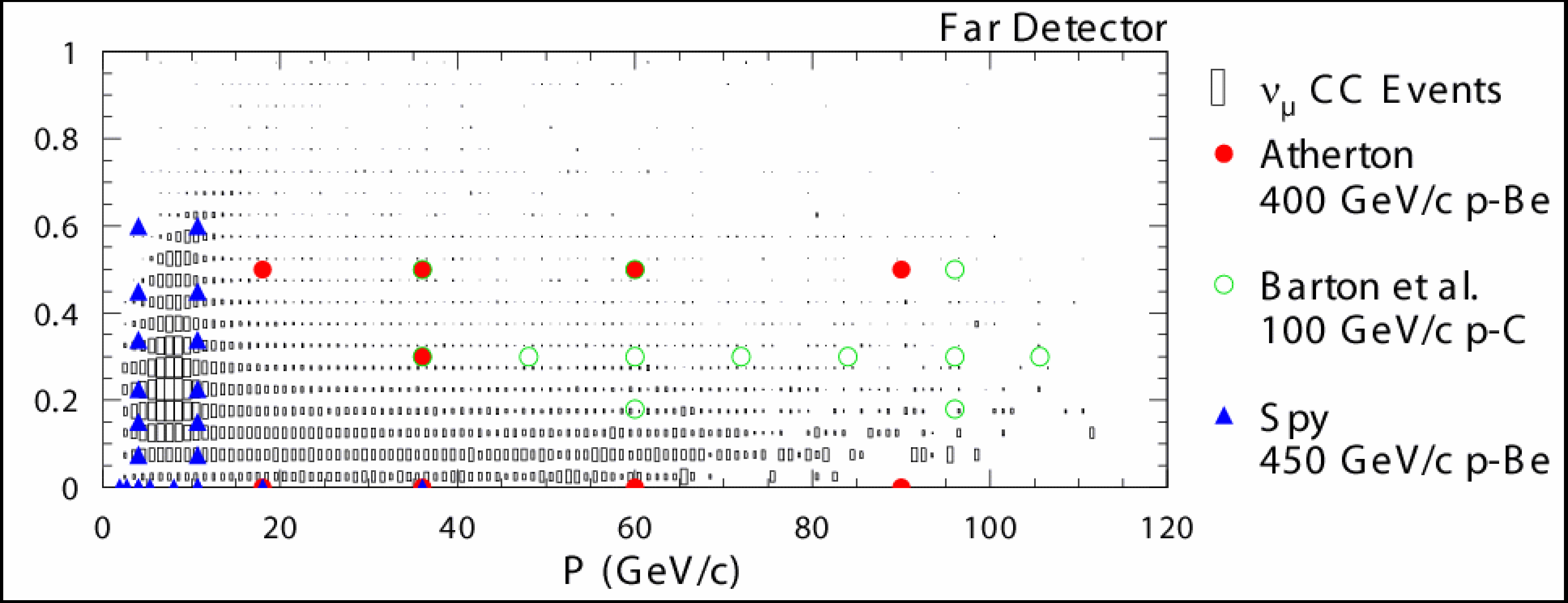
Outline

- Introduction
- MIPP Spectrometer
- Event reconstruction
- Detector Calibration
- Analysis
- Results & Conclusion

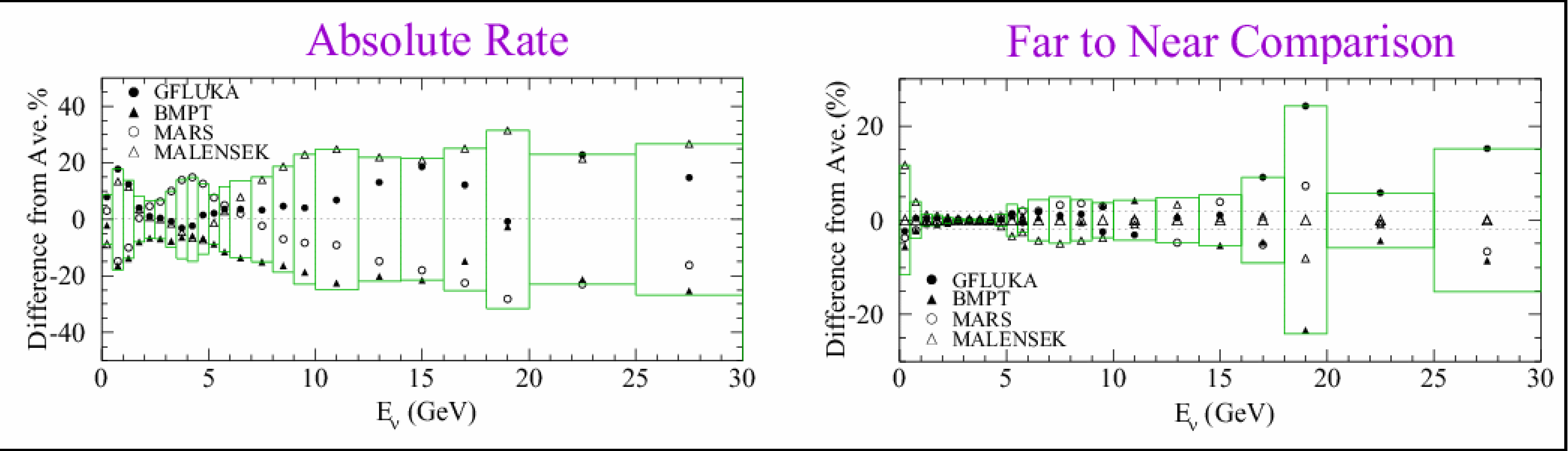
Why Measure Particle Production?

- There is very little data of inclusive particle production
  - Much of it taken with single-arm spectrometers
  - In 2006, NA49 published $\pi^{\pm}$ production from pC at 158GeV/c



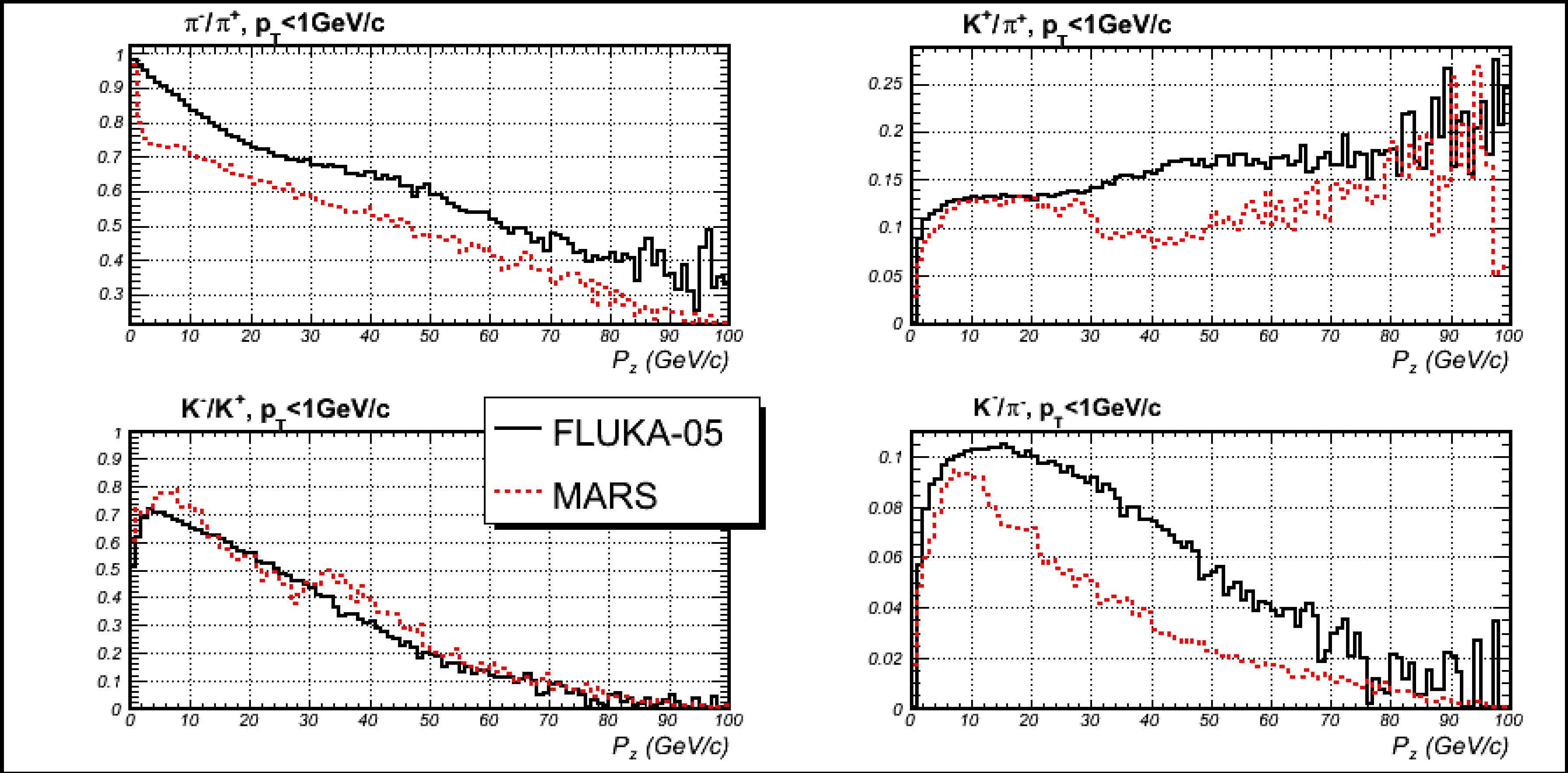
Modeled MINOS Neutrino Flux

- Predictions from different Monte Carlo models differ by up to 20%
- Differences do not cancel completely in near/far comparison



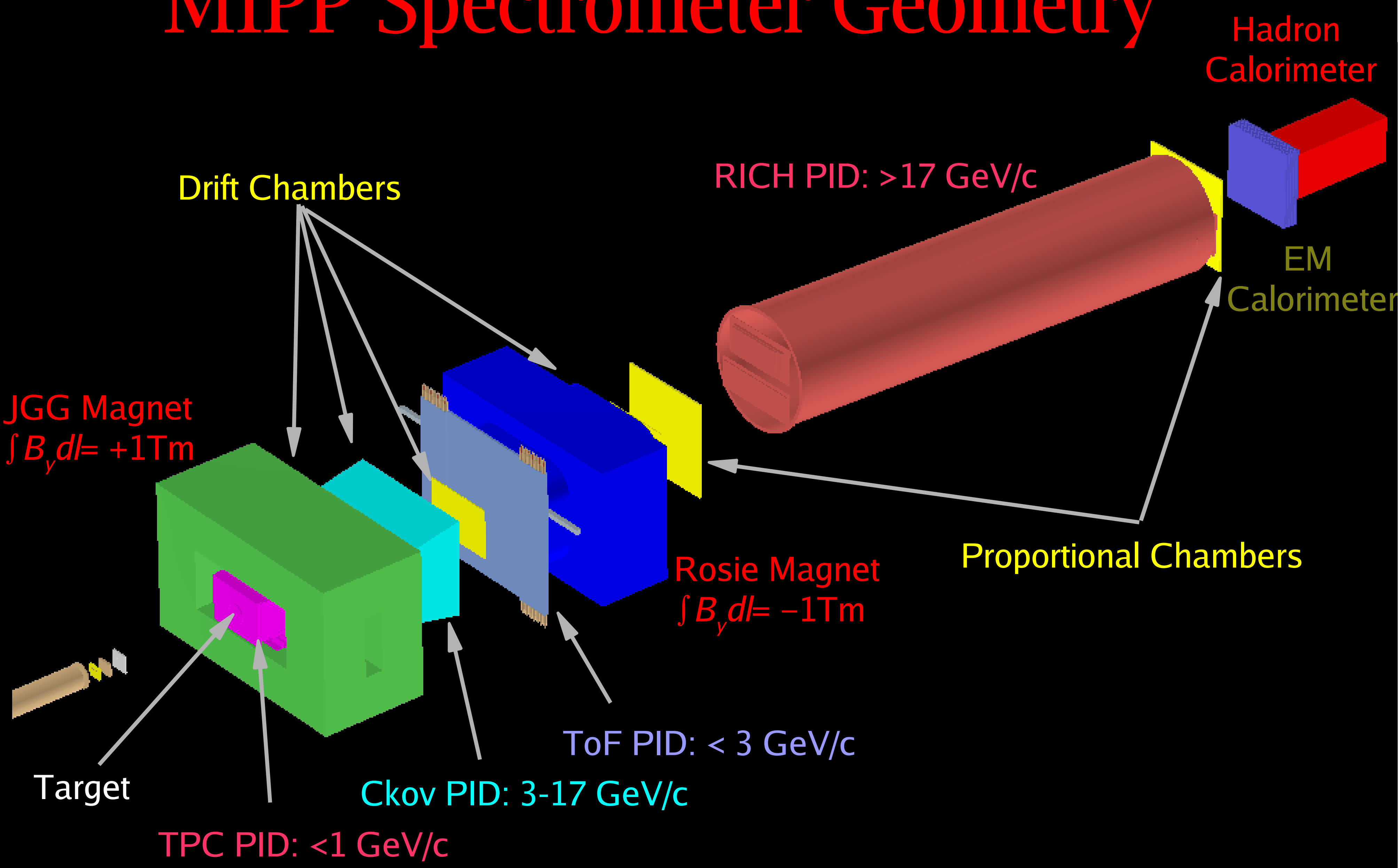
Predicted Production Ratios

- Predicted production ratios are not much better
- For MINOS, kaons matter as they produce ν_μ and ν_e



MIPP Spectrometer

MIPP Spectrometer Geometry



Beamline


Beam Cherenkov on a stand in MC7

- 3 wire chambers
  - Find incoming track
  - 1 mm wire spacing
- 3 scintillator counters
  - Form beam trigger
  - Measure time of flight
- 2 beam Cherenkovs
  - π/K <95 GeV/c
  - K/p <120 GeV/c

Tracking Detectors

TPC on the rails in front of the JGG magnet

- TPC
  - 120×128 pads in xz-plane each 0.8×1.2 cm
  - ~0.5 cm sampling in y
  - Multiplicities up to 200
  - Sits inside the JGG
- 4 drift chambers
  - 3.1-3.4 mm wire spacing
  - 1 ns time measurement
- 2 proportional chambers
  - 3.0 mm wire spacing

Particle Identification

View at the RICH from the far downstream end of MC7

- Energy loss in the TPC
  - <1 GeV/c
- Time of flight wall (TOF)
  - <3 GeV/c
- Segmented Cherenkov (Ckov)
  - <17 GeV/c
- Ring Imaging Cherenkov (RICH)
  - <~100 GeV/c

MIPP Data Set

Number of triggers, x 10^6										
	Momentum (GeV/c)									*Total*
Target	**5**	**20**	**35**	**40**	**55**	**60**	**65**	**85**	**120**	
Empty		0.1	0.14			0.52			0.25	**1.01**
K Mass2				5.48	0.5	7.39	0.96			**14.33**
Empty LH1		0.3				0.61		0.31		**7.08**
LH	0.21	1.94				1.98		1.73		
Be			0.1			0.56			1.08	**1.75**
C						0.21				**1.33**
C 2%		0.39				0.26			0.47	
NuMI									1.78	**1.78**
Al			0.1							**0.1**
Bi			0.52			1.26			1.05	**2.83**
U						1.18				**1.18**
Total	**0.21**	**2.73**	**0.86**	**5.48**	**0.5**	**13.97**	**0.96**	**2.04**	**4.63**	**31.38**

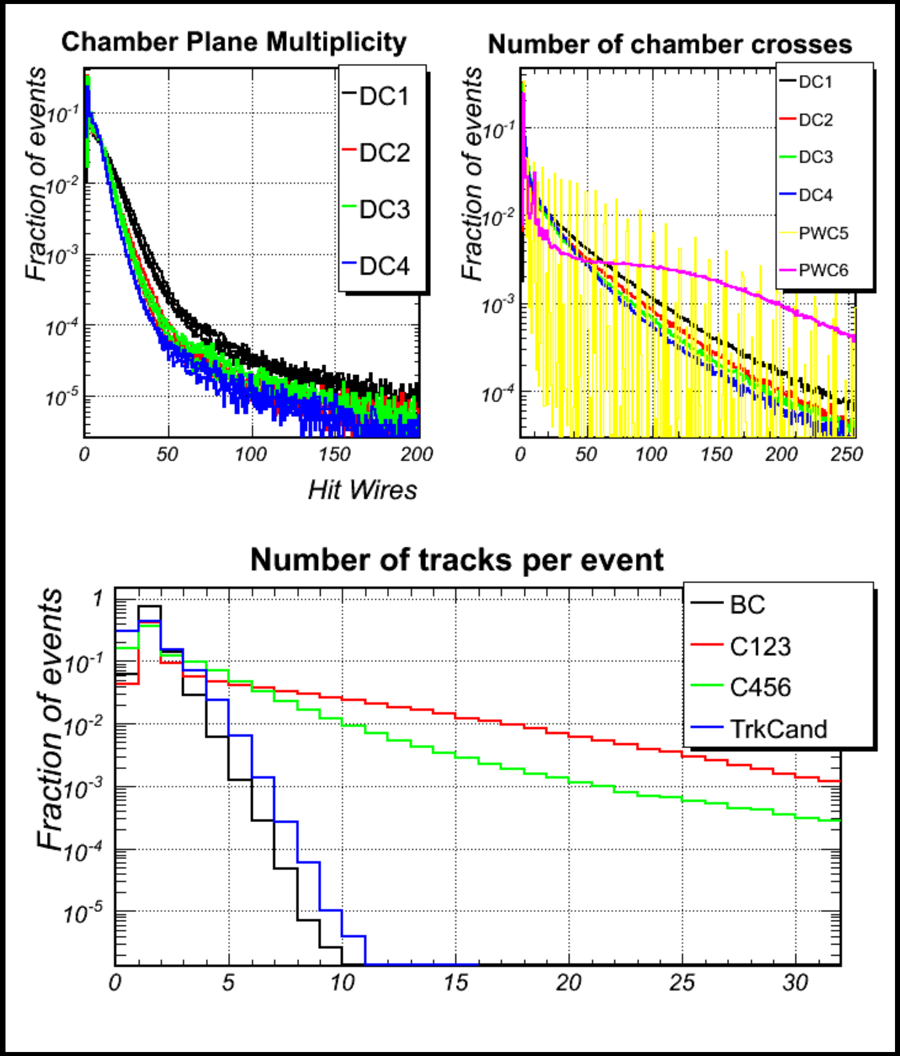
Event Reconstruction

Event Reconstruction Overview

- Find tracks using wire chamber hits
  - BC123, DC123, DC4+PWC56, and C1-6
- TPC track reconstruction
- Global tracks (TPC+chambers)
- Form and fit vertices
- Identify tracks
  - Incident particle identification using beam Cherenkovs
  - TPC dE/dx, TOF time, Ckov light, RICH rings
- Find calorimeter showers

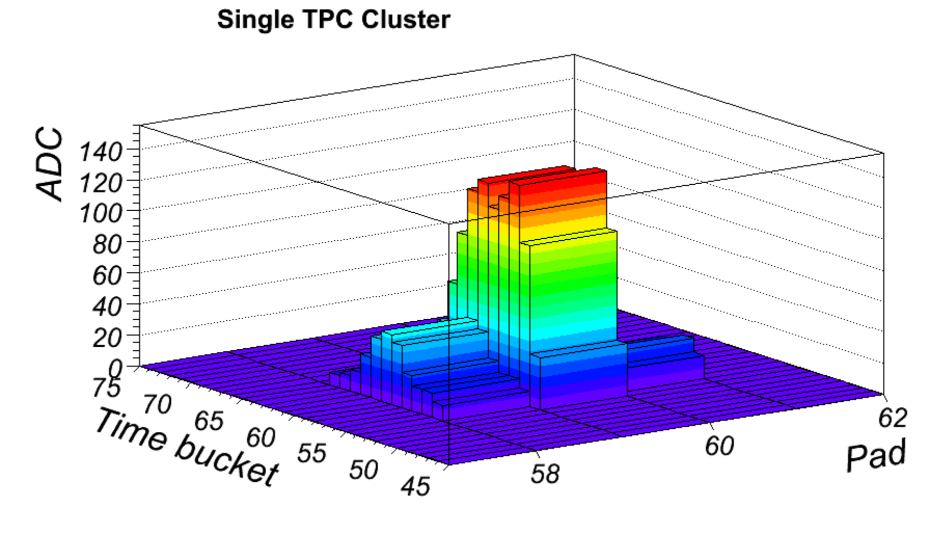
Chamber Tracks

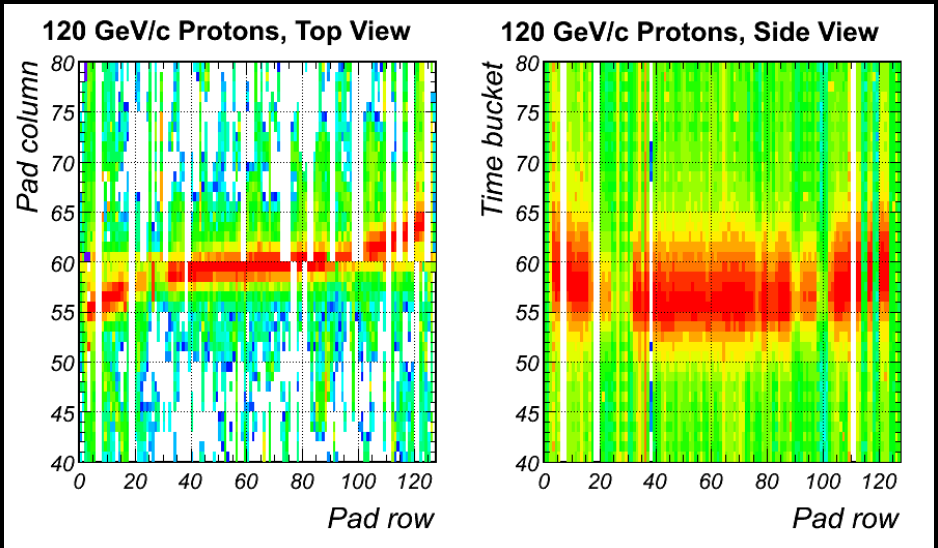
- Wire chamber track segments are found by going through "interesting" combinations of hits
  - Wires→wire clusters
  - Clusters→wire crosses
  - Crosses→track segments
  - Segments→track candidates
- Allows basic tracking without the TPC



TPC Hits

- TPC voxels are clustered into hits
  - Fit 1D time distributions to Gamma function
  - Compute x by fitting a Gaussian or weighted mean
- A quick look at raw TPC data shows that distortions to hit position are large





TPC Distortion Corrections

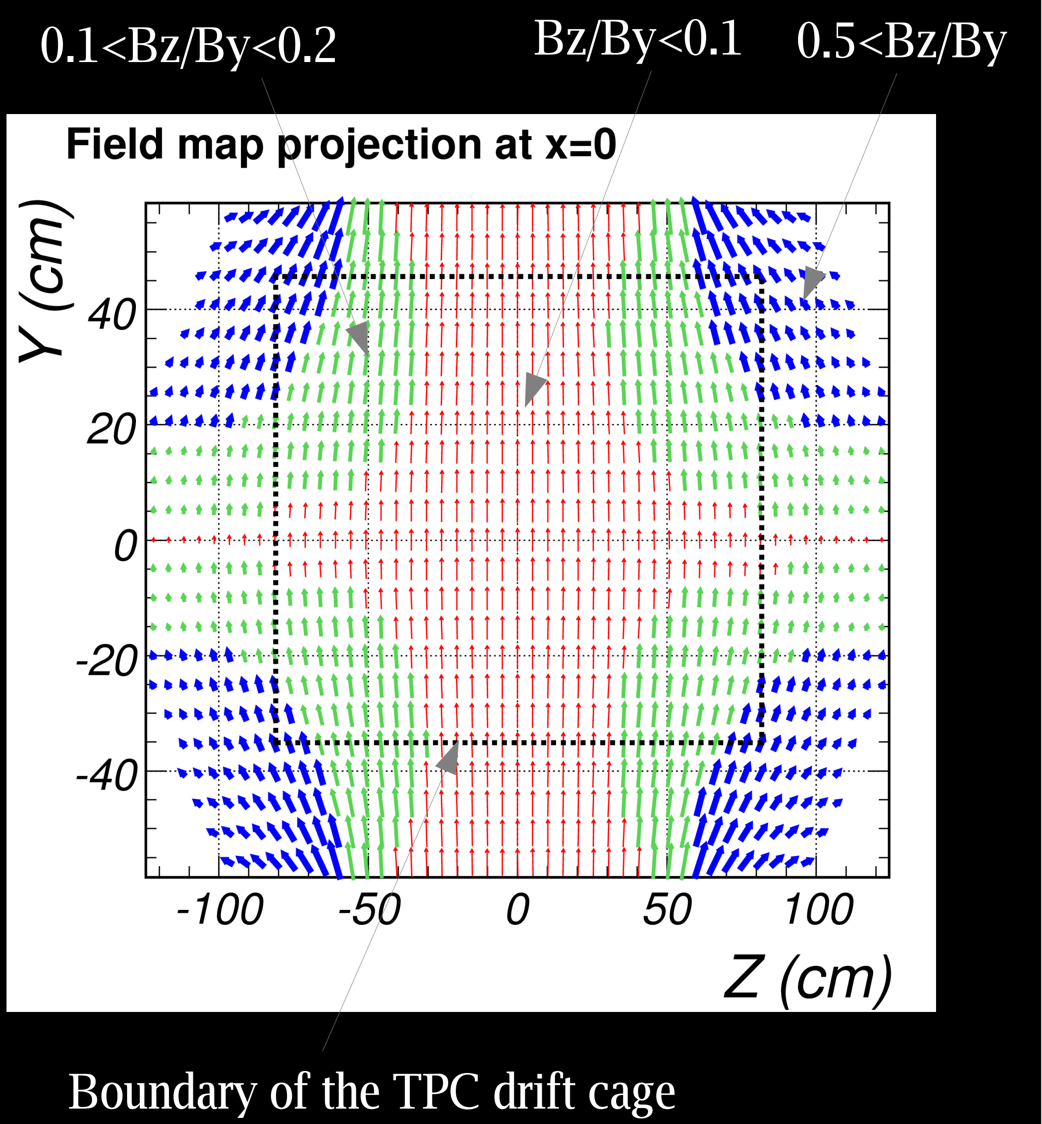
- Distortions result from electron drift in non-uniform magnetic field
- Simplest linear model

$$m\frac{d\vec{v}}{dt}=e\vec{E}+e\vec{v}\times\vec{B}-\frac{1}{\tau}\vec{v}$$

has a solution

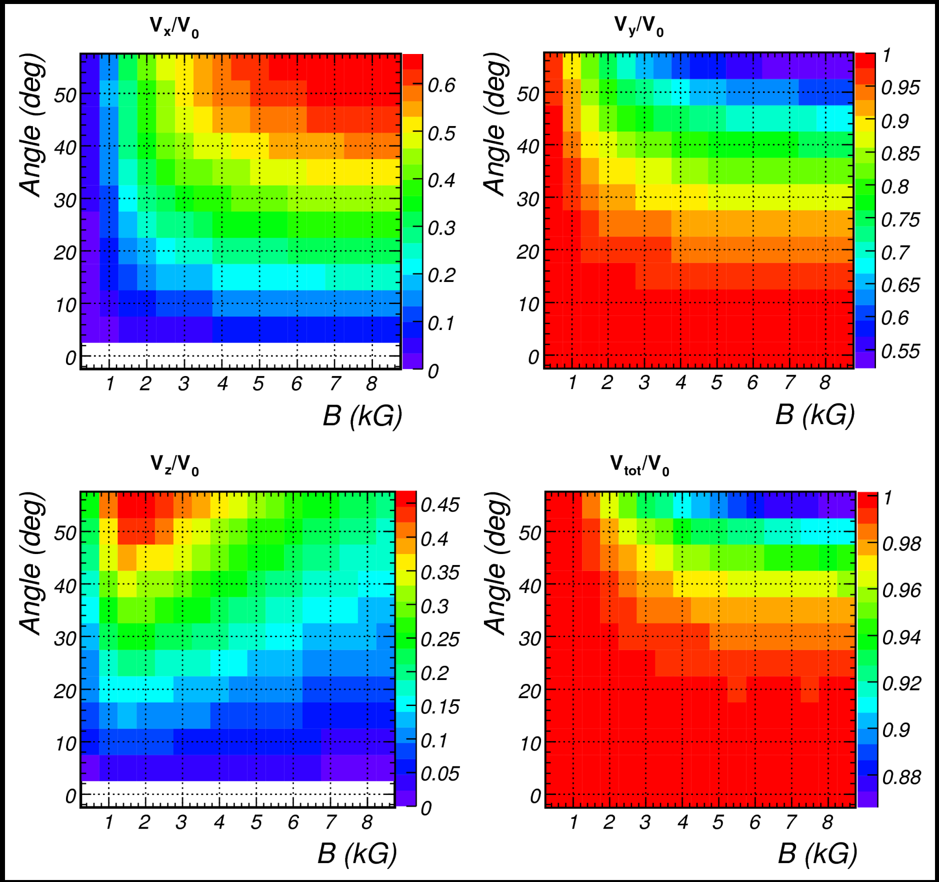
$$\vec{v}=\frac{v_0}{1+\omega^2\tau^2}\left[\vec{E}+\omega\tau\,\hat{E}\times\hat{B}+\omega^2\tau^2(\hat{E}\cdot\hat{B})\,\hat{B}\right]$$

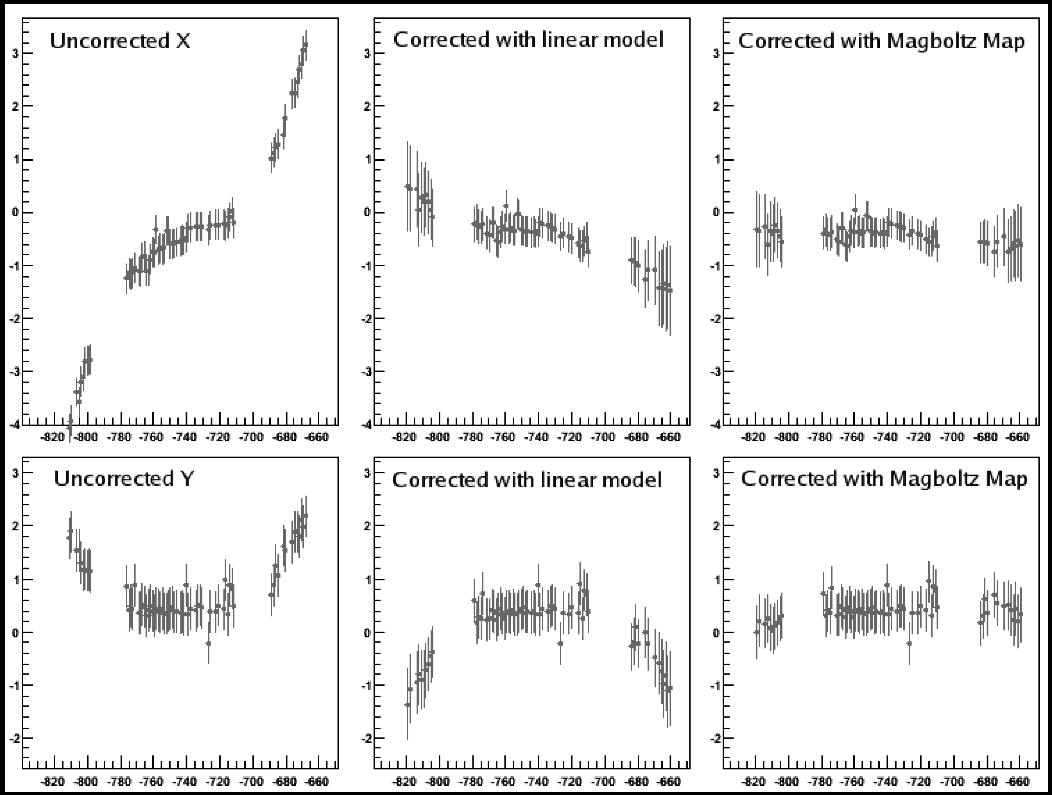
- Does not work well



Distortion Corrections (cont.)

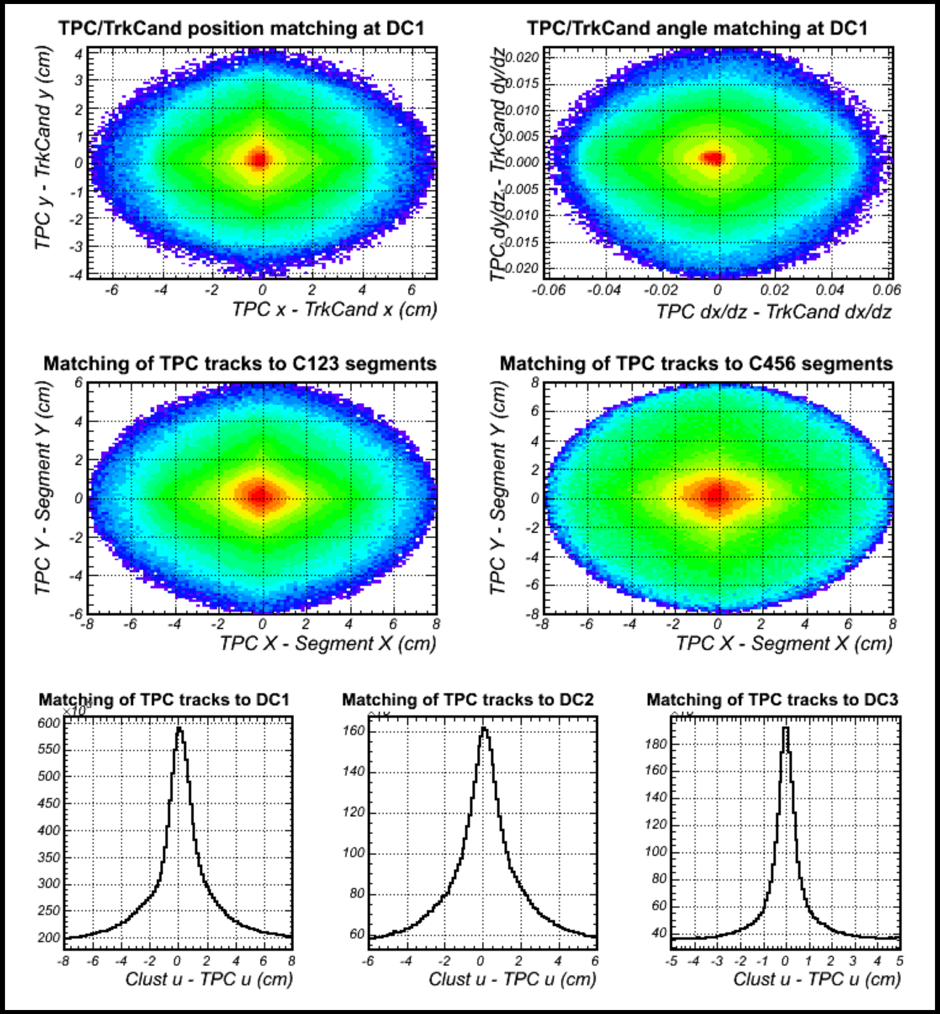
- We use Magboltz MC program to simulate electron drift given E and B vectors





Tracks Reconstruction

- Start TPC tracks with nearest neighbor hits on adjacent padrows
- Fit to helix and continue to include good hits
- Refit the track using magnetic field map
- Connect TPC tracks to chamber candidates, segments, or wire clusters

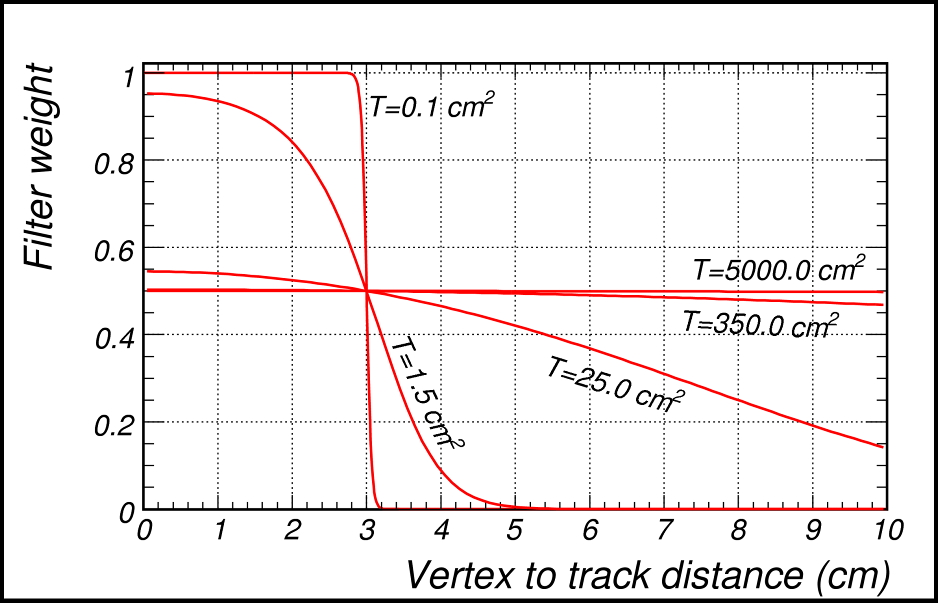


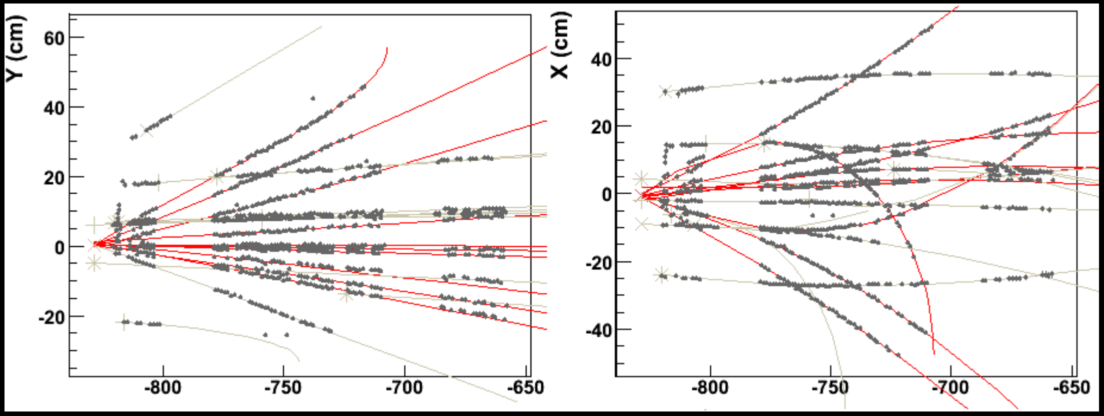
Vertex Finding

- Deterministic annealing filter used to find vertices
- Minimize sum of distance squared to available tracks
  - Track weight is set to

$$w = \left[1 + \exp\left(\frac{D_{trk}^2 - D_c^2}{2\,T_{DAF}} \right) \right]^{-1}$$

- Start with large T_{DAF} and reduce it slowly to 0 to "freeze out" noise

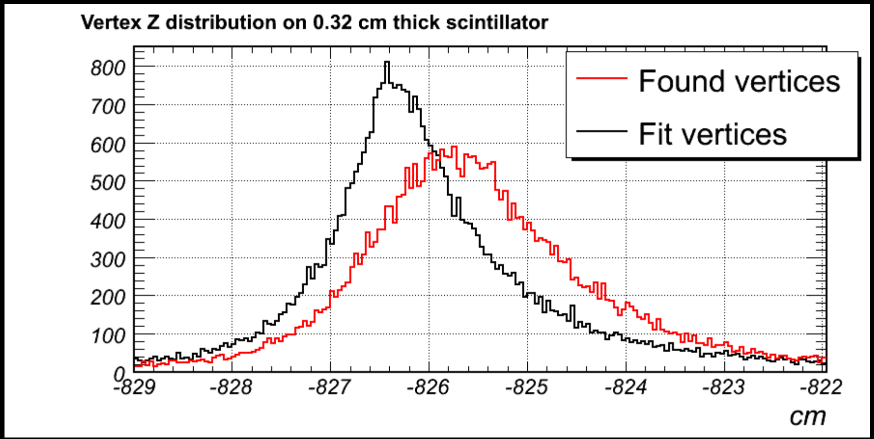


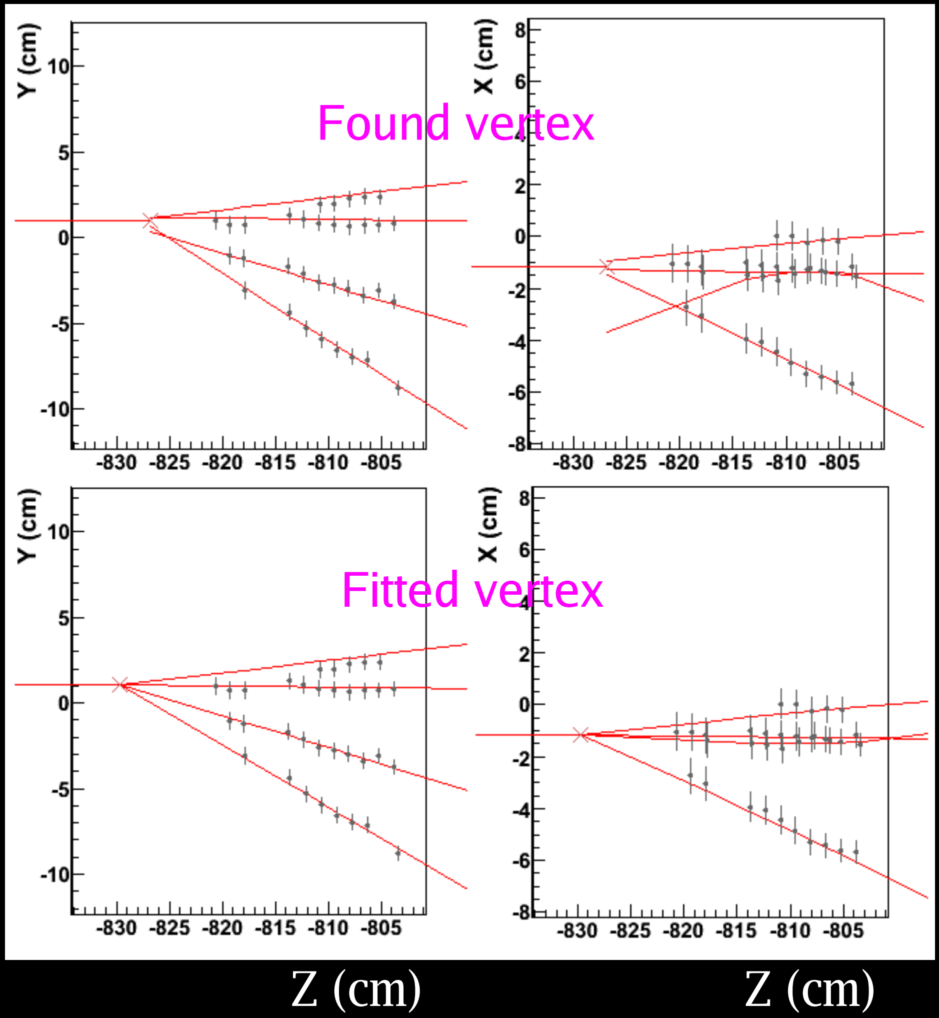


Z (cm) Z (cm)

Vertex Constrained Fit

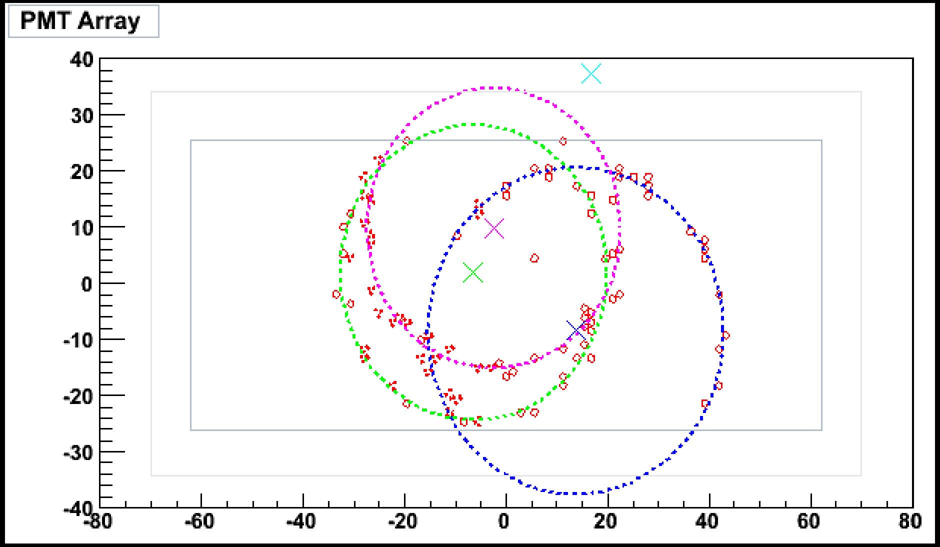
- Problem is linearized for all track parameters and vertex (x,y)
  - Scan Z to find the answer
- Improves reconstructed vertex Z resolution from 2.1 cm to 1.3 cm FWHM

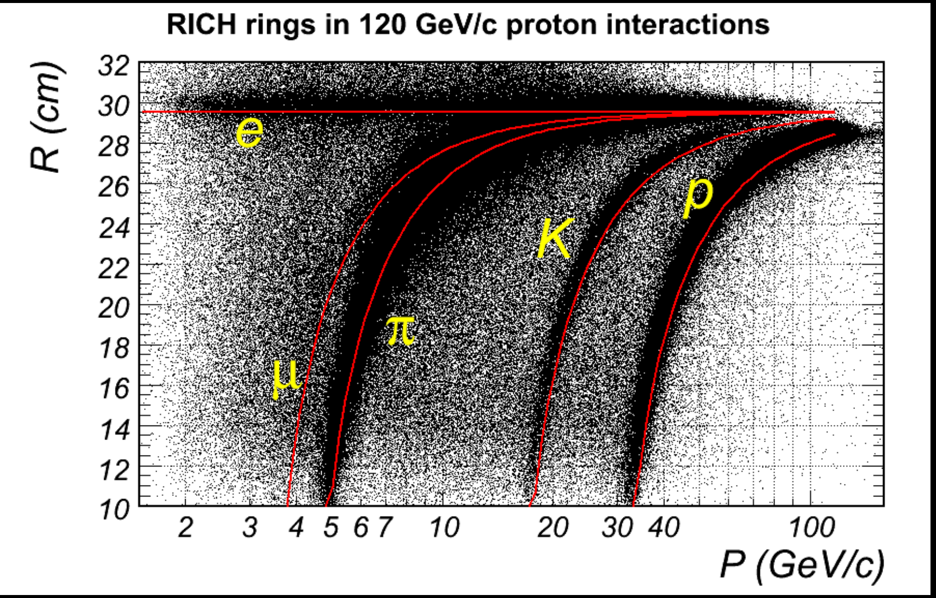




RICH Ring Fits

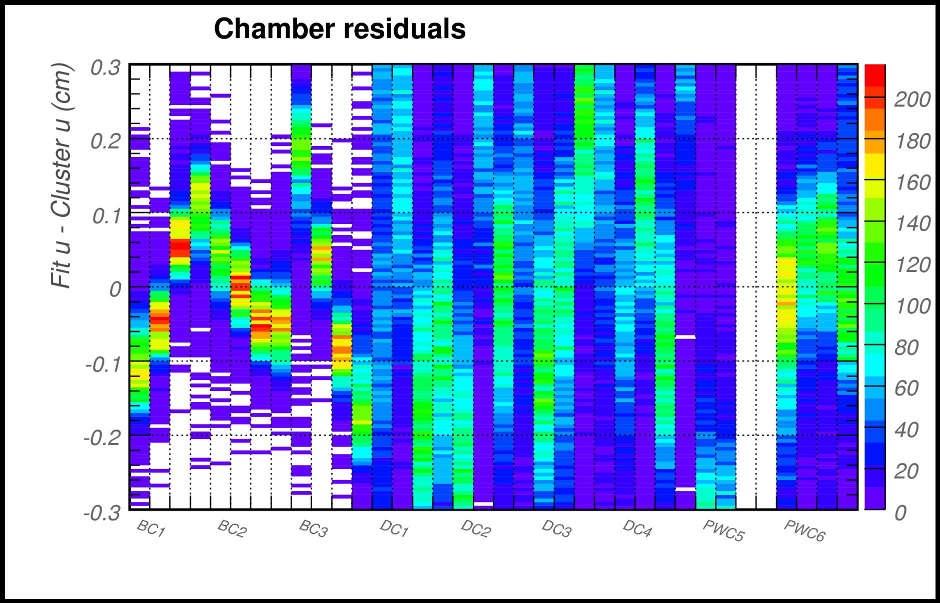
- Select tracks which
  - Go through CO_2 gas
  - Have projected center within 35cm of PMT array
- Fit for ring radius
  - Use DAF to reject noise
  - Share hits among rings: hit weight is proportional to the number of hits with similar distance from ring center

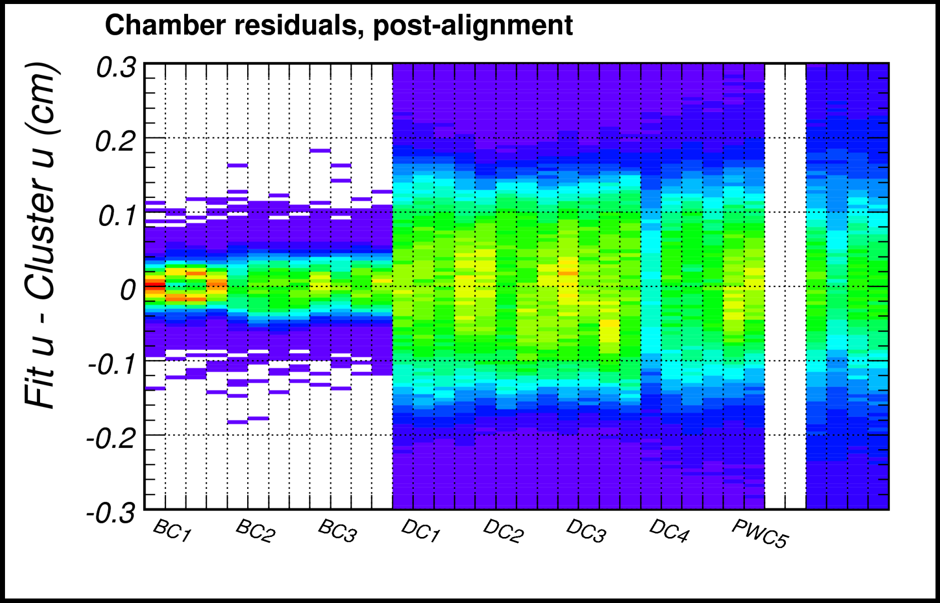




Calibration

Chamber Alignment

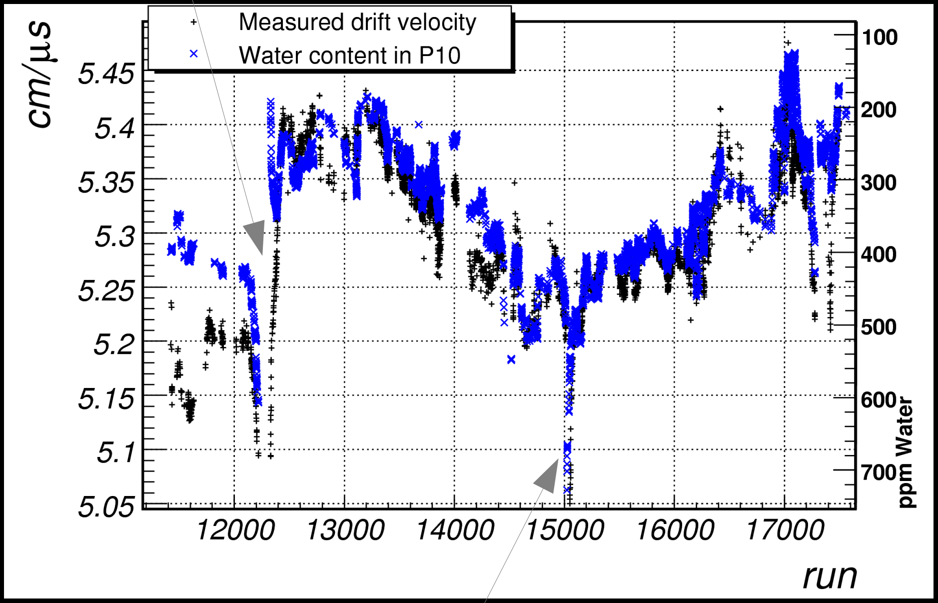




- Wire chamber alignment was possible with reconstructed chamber tracks
  - Found errors in geometry description
  - Corrected magnetic field maps
- Current uncertainty in alignment 2-20% of wire spacing (30-600 micron)

TPC Drift Velocity

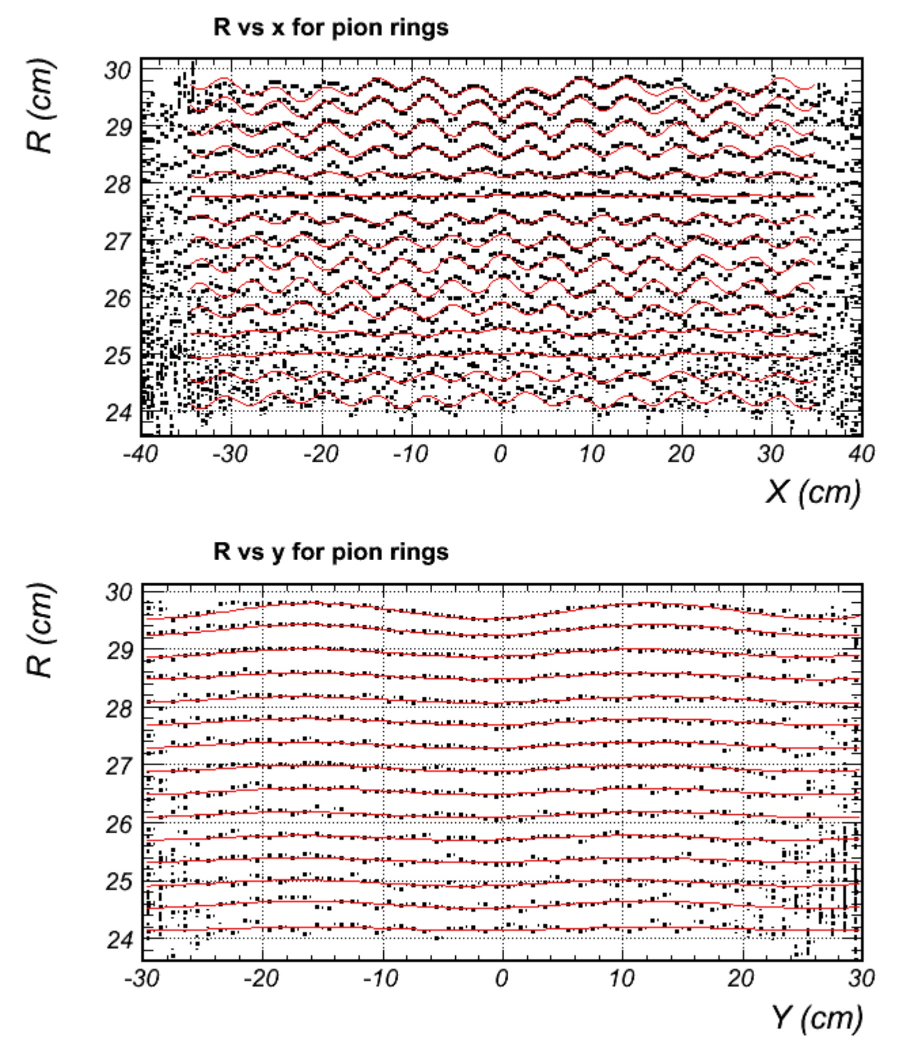
Double the flow of gas



Operator error: shut off exhaust valve prevented proper gas flow

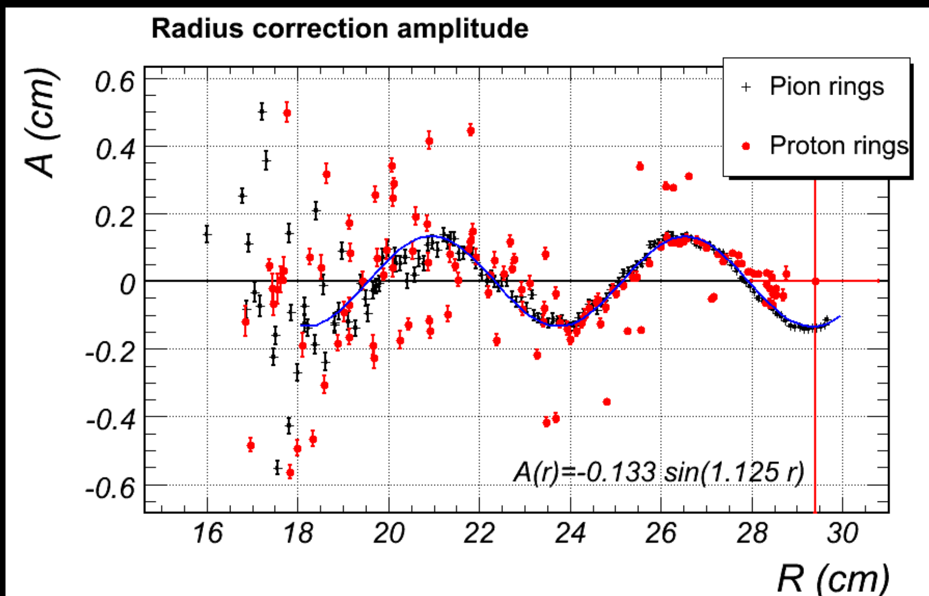
- Drift velocity in the TPC is a strong function of water and oxygen contamination
  - Effects of temperature and atmospheric pressure are much smaller
- We use the center of the TPC volume to measure drift velocity
  - Minimize effect from distortions due to JGG field

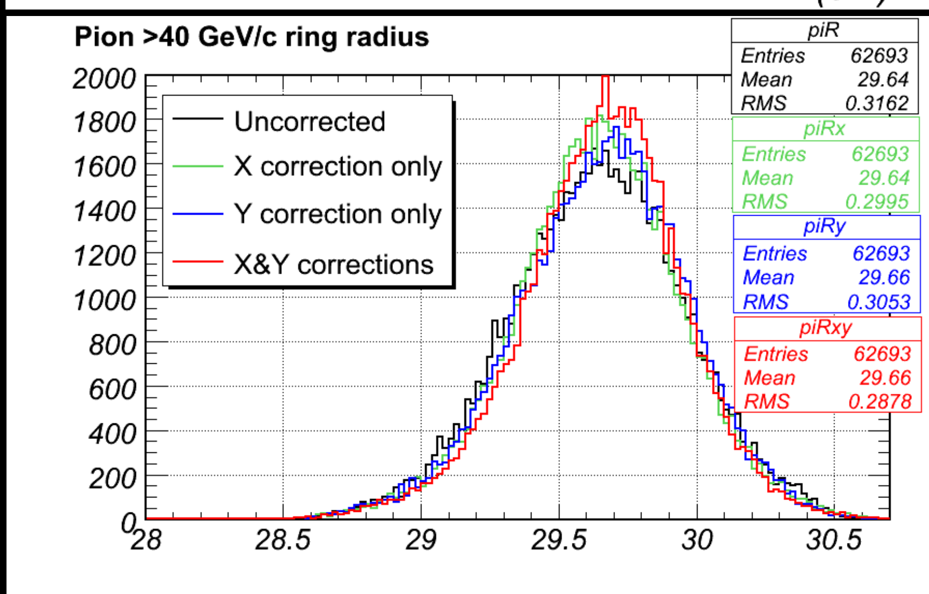
Corrections to RICH Ring Radius



- In March 2004, RICH PMTs caught on fire
- Repaired detector has every fourth column empty
  - 69 of 89 columns are now populated with PMTs
- Result is aliasing of fitted RICH ring radii
  - Fitted radius is a function of true (x, y, R)
  - Corrections are up to 1.3mm

Corrections to RICH Rings (cont.)





- Scan ring radius selecting pions within a small range momenta
  - Scan proton rings for sanity check
- Dominant ripples in X are well described by

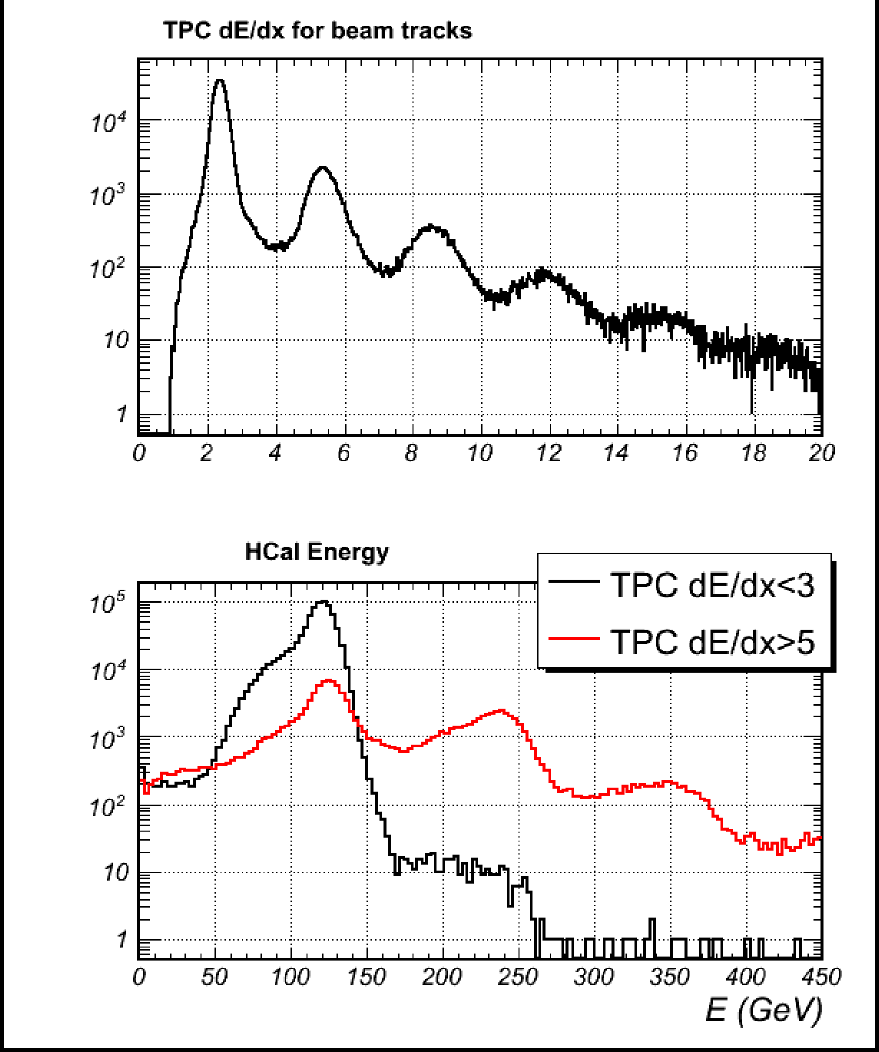
$$A(x,R)=A_0\sin(2\pi r/D_4)\cos(2\pi x/D_4)$$

- Seen in Monte Carlo
- Correction makes peaks 10% narrower

Production Ratios Analysis

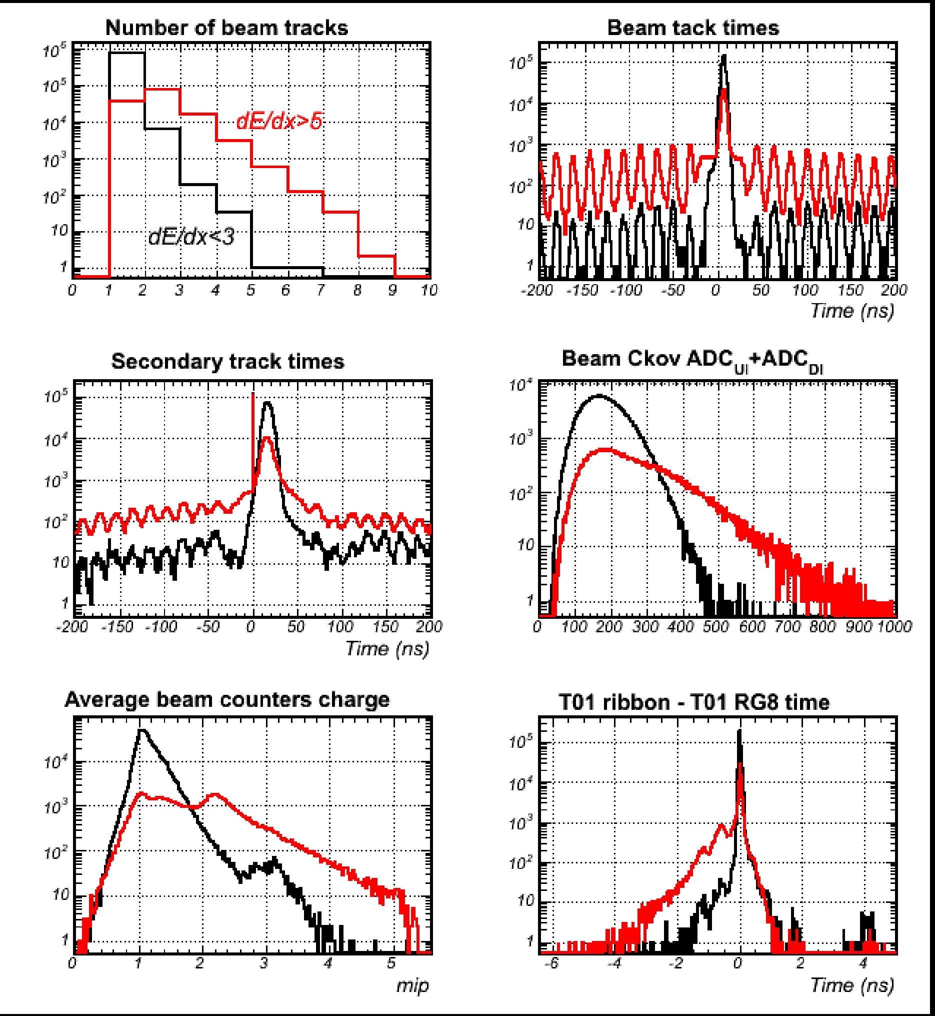
Pileup Removal

- Pileup is two or more incident protons in the same event
- Needs to be removed
  - Not modeled in MC
  - Can interfere with vertex finding and fitting
- Do as much as possible with beamline detectors
- TPC dE/dx in single-proton events identifies pileup



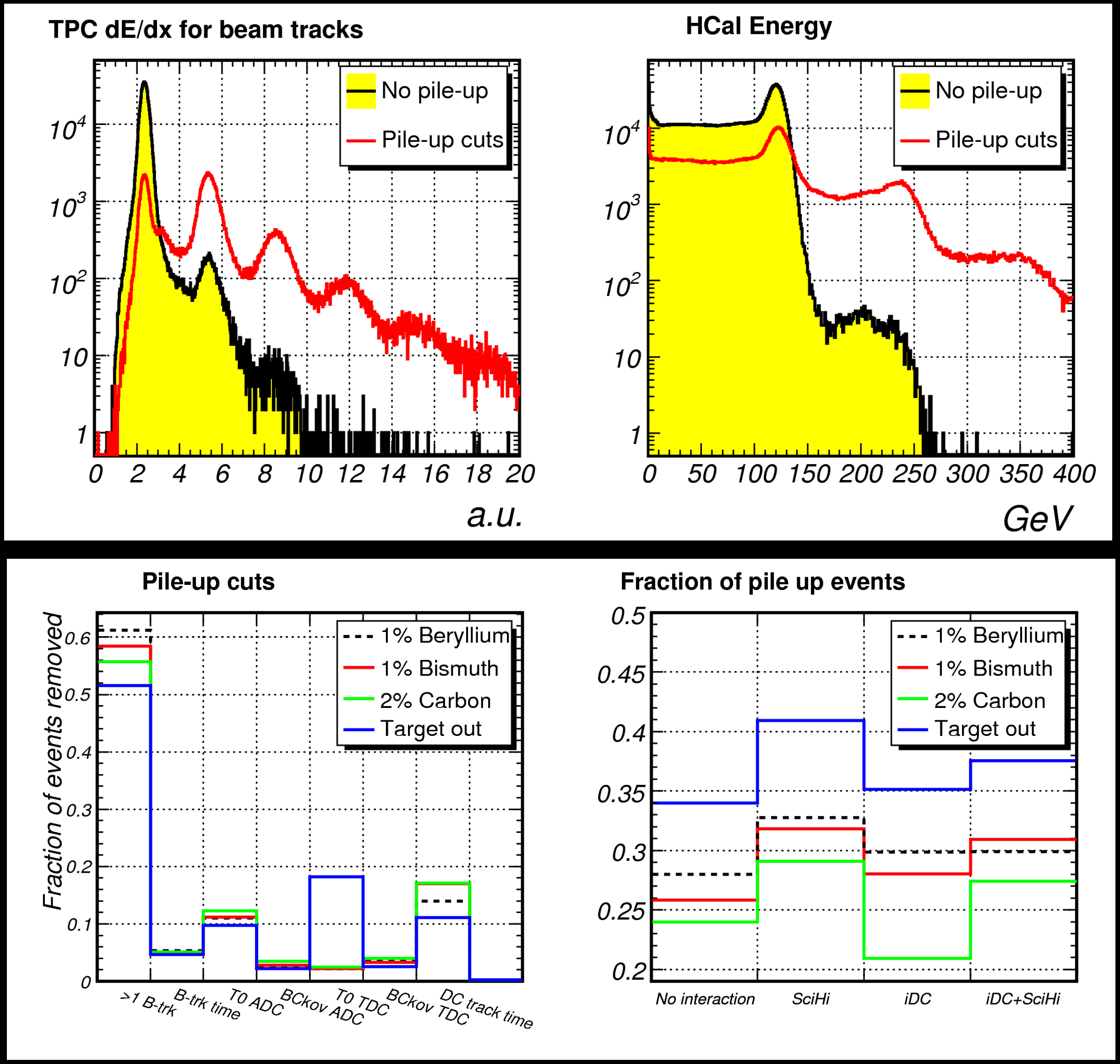
Pileup (cont.)

- A number of variables are used to reject pileup events
  - Number of beam tracks
  - Time of beam track
  - Time of secondary tracks
  - Total charge in beam Cherenkov PMTs
  - Total charge in scintillator beam counters
  - Time differences of beam counters

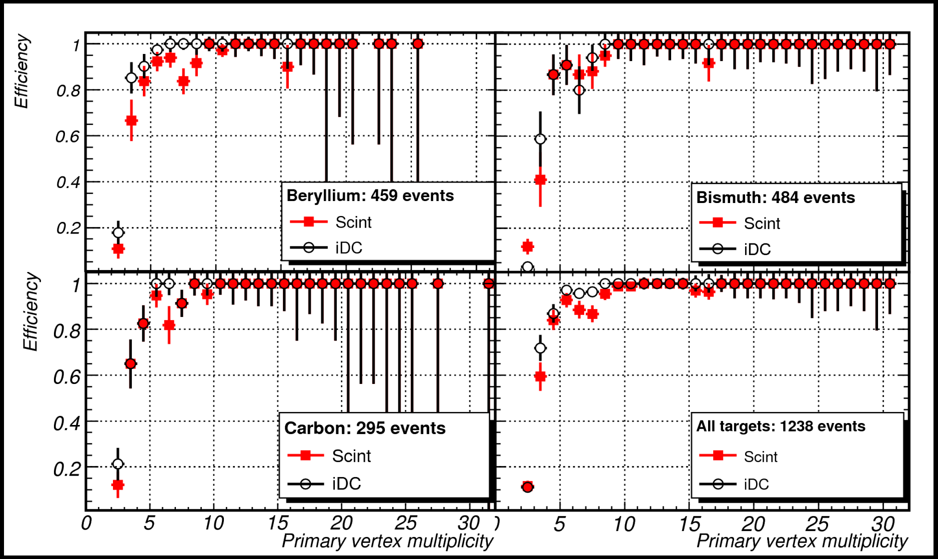


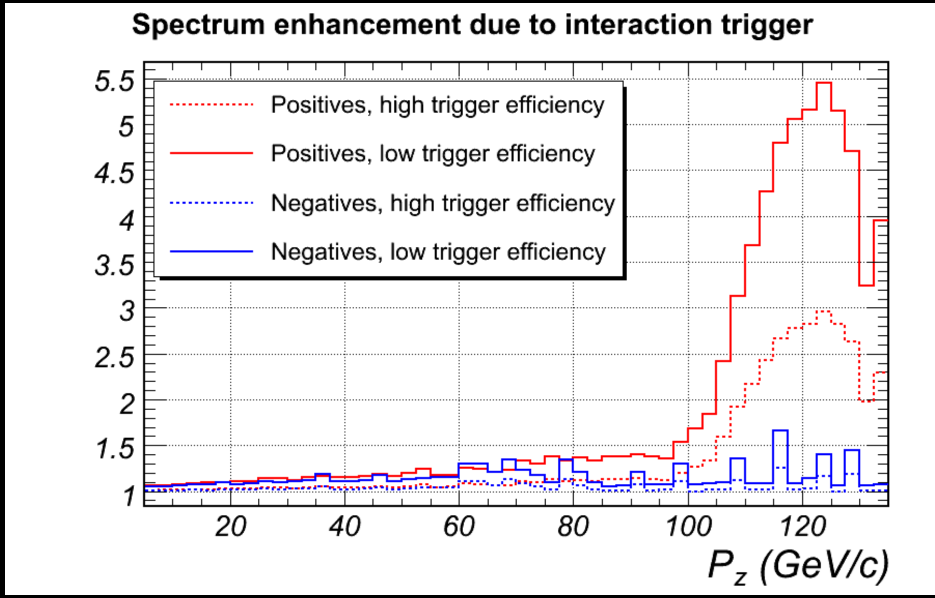
Pileup (cont.)

- When all the cuts are made
  - 20-40% of events are rejected
  - ~1% of pileup events remain in the sample



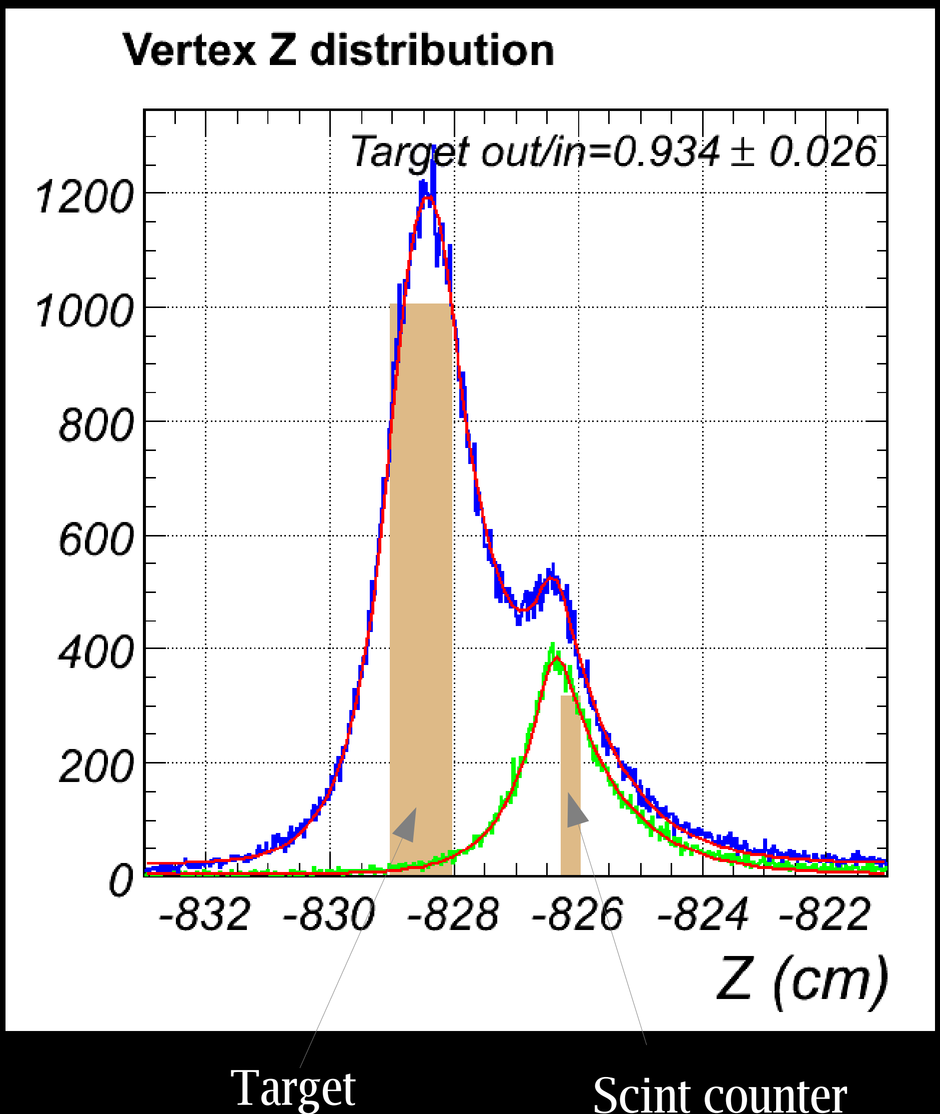
Interaction Trigger Efficiency





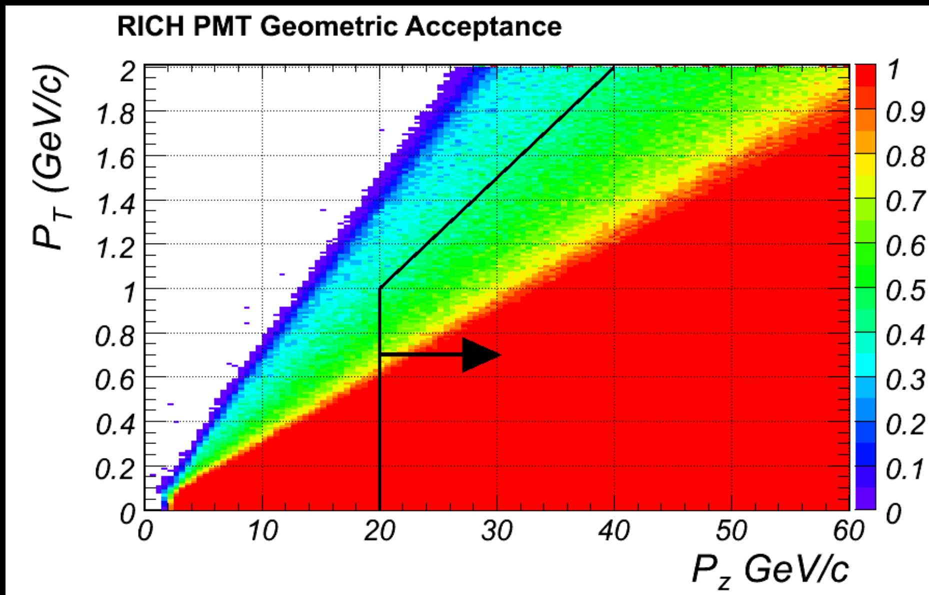
- Interaction trigger efficiency is measured from minimum bias trigger
  - Statistics is quite low
- Uncertainty in spectrum enhancement up to 30% for particles of interest
  - Small systematic error on the ratios

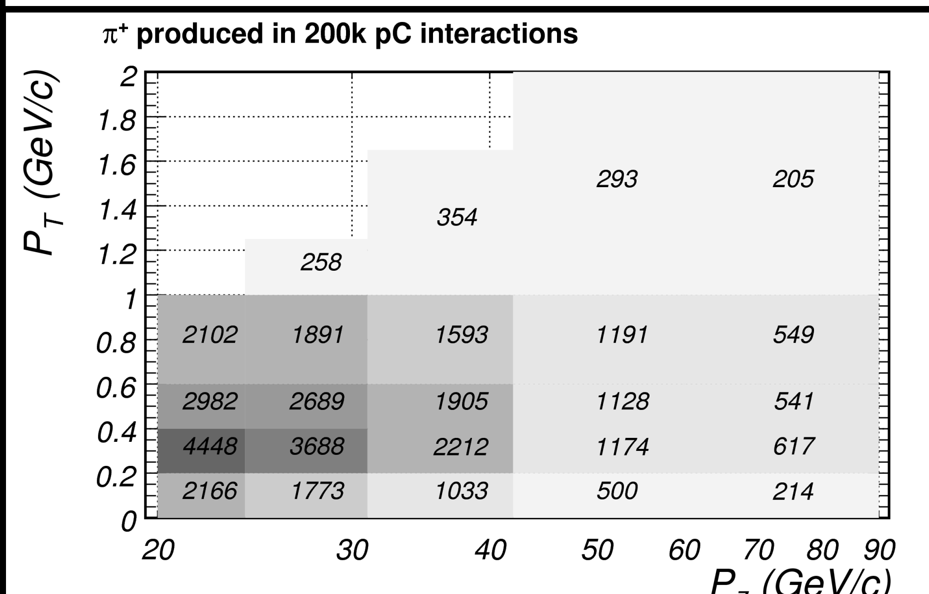
Empty Target Subtraction



- Given our vertex z resolution, we have to subtract target out data
- Distribution in z is modeled well by Gaussian with exponential tails
- Fit target-out spectrum
- Fit target-in spectrum by holding the shape of Scint counter constant

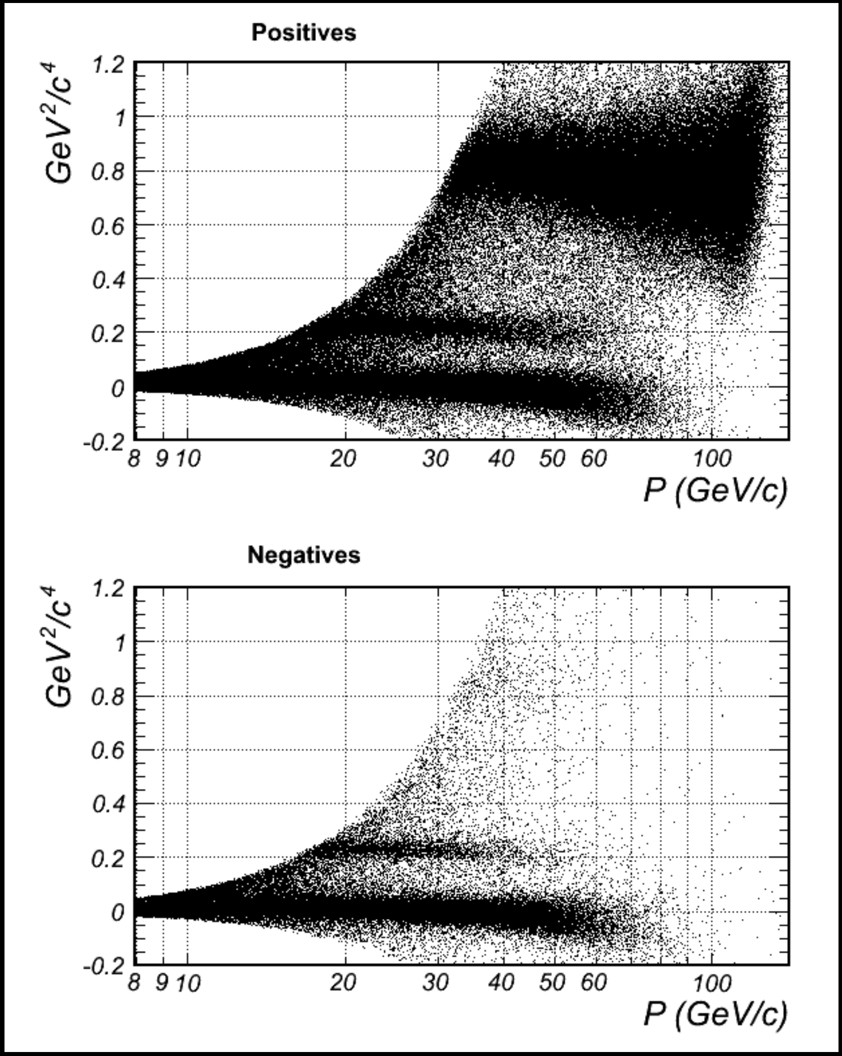
Data Binning





- Factors on bin selections
  - Geometric acceptance of RICH PMTs
  - RICH kaon threshold
  - Statistics
- 20 GeV/c is sufficiently above 17 GeV/c threshold
- Make rectangular (p_z, p_T) bins avoiding regions with <50% acceptance
- Use FLUKA06 π^+ flux to set bin sizes

Particle ID Variable

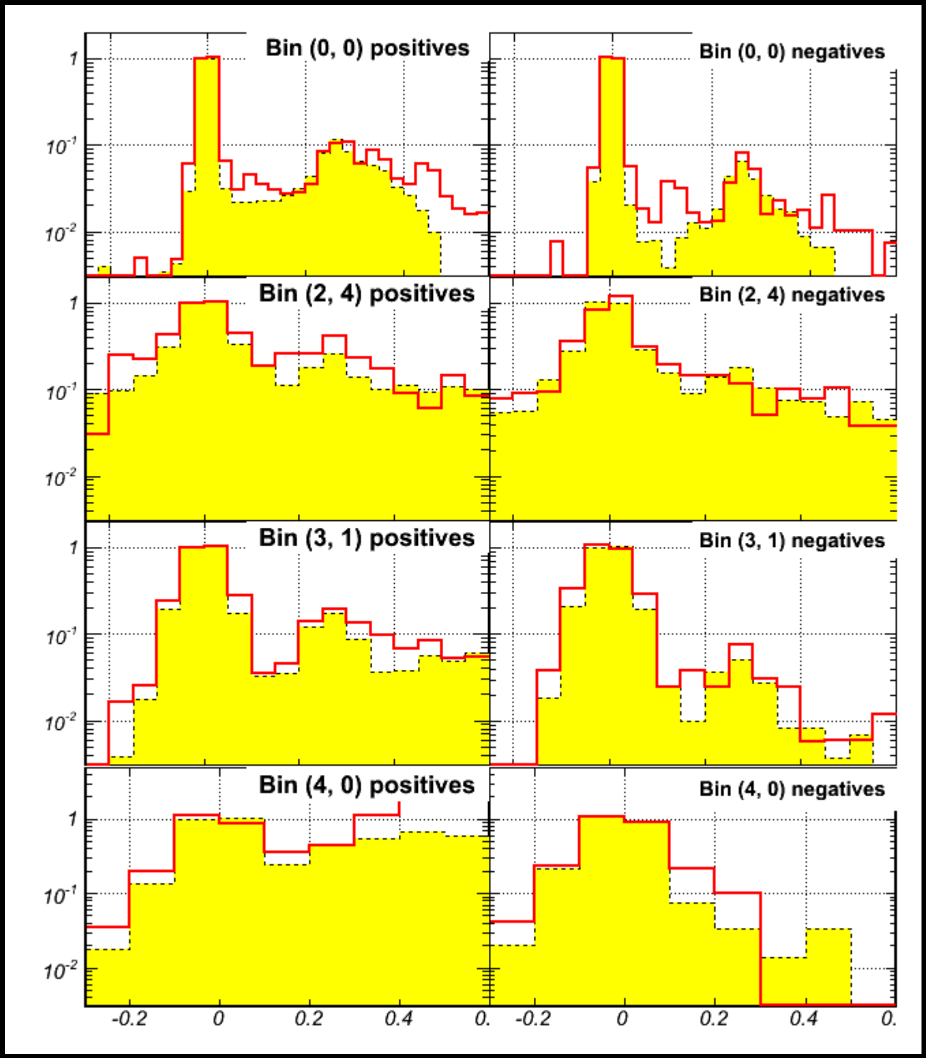


- Measured mass squared depends on particle p_z and p_T
  - Not observed in MC
- Define particle ID variable
  - $0 \equiv \pi$, $1 \equiv p$, puts K=0.265
- Stretch and shift m^2 distributions in each (p_z,p_T) bin in data and MC

Need For Background Modeling

- Important effects
  - Interactions in the spectrometer
    - ~10% of particles interact before the RICH
    - ~10% more interact if they do not pass through the RICH window
  - Decay in flight
    - 10% of 20 GeV/c kaons decay before the RICH
  - Large angle multiple scattering
    - >100 GeV/c protons can be reconstructed with $p<70$ GeV/c
- Depend on
  - FLUKA-06 for proton carbon interactions
  - GEANT 3.21 for particle transport

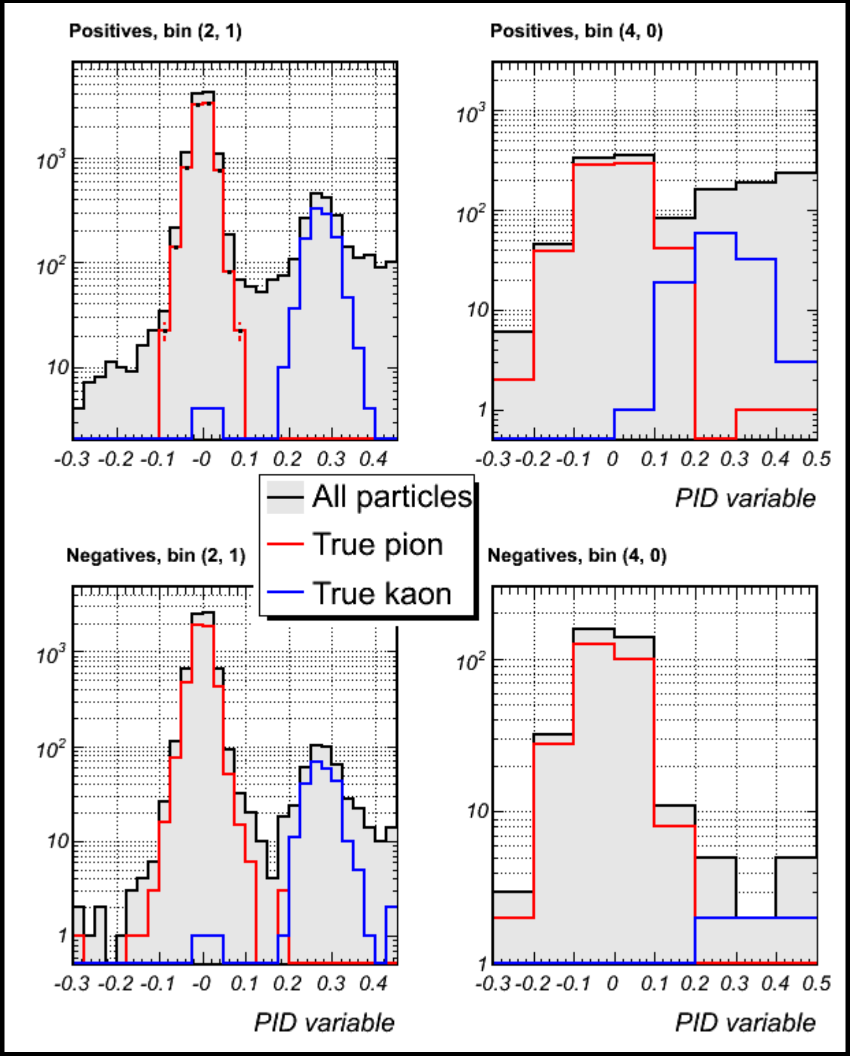
Data – Monte Carlo Comparison



Data: red line; MC: yellow area

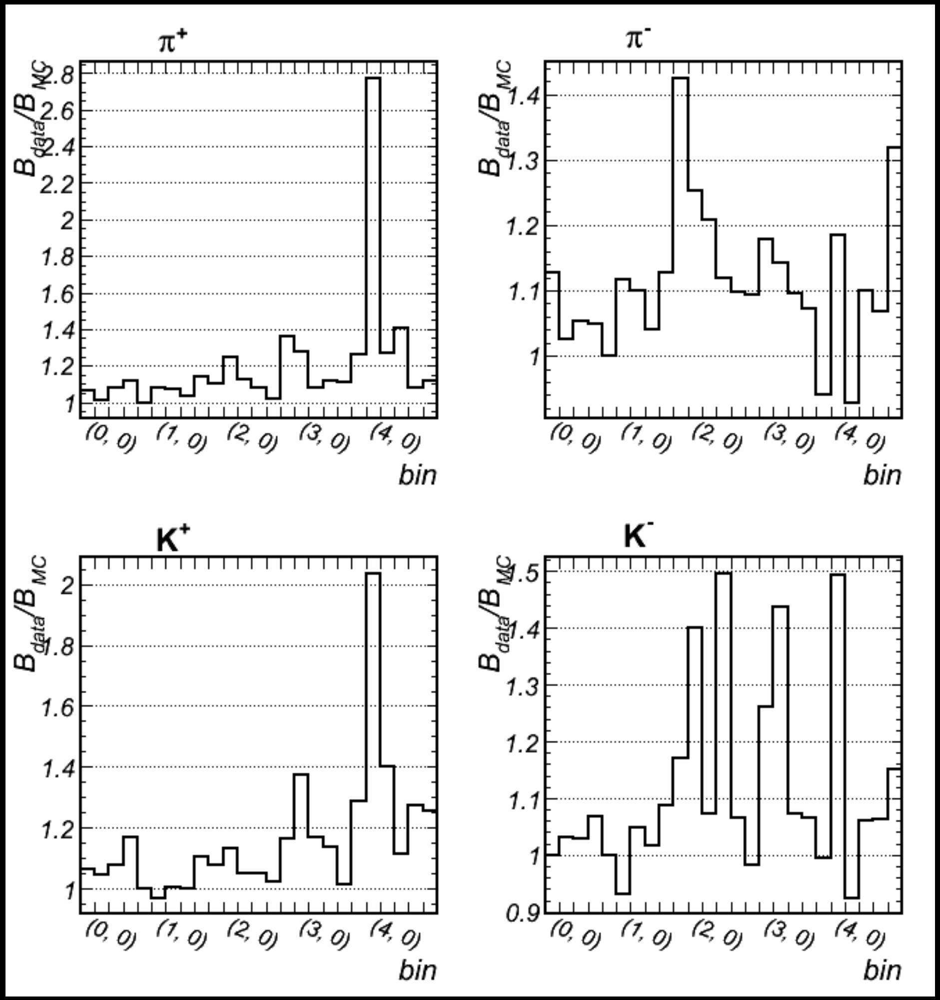
- Data and MC particle ID variable distributions agree reasonably well
- More background in data
- Data peaks are wider
- High momentum positive bins are affected differently in data and MC

True Particle Occupancy



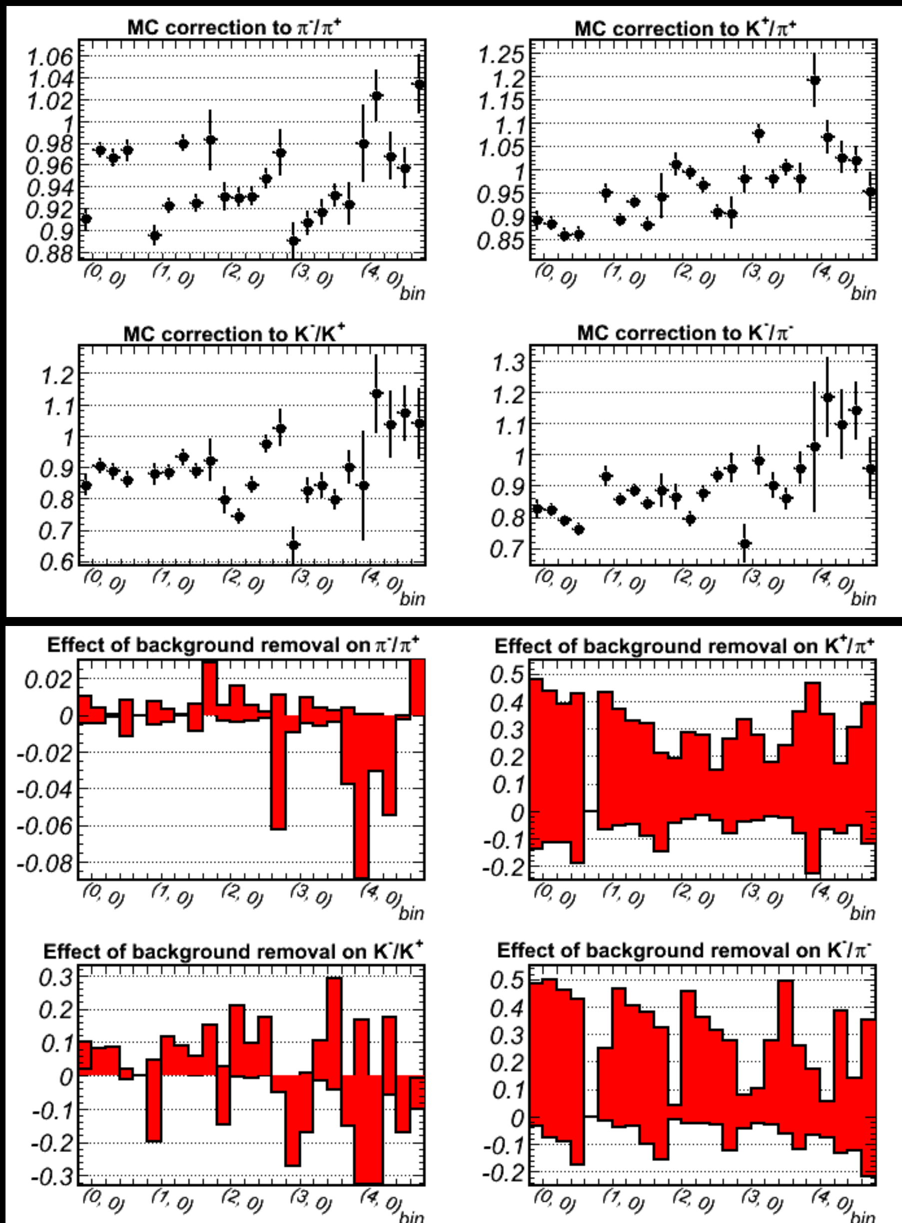
- Define occupancy *o* as the fraction of true pion/kaon with fit momentum within 4σ of true momentum
  - Ratio of red/blue histogram and shaded histogram
- At lower momenta, the peaks are well separated
- At higher momenta we depend on FLUKA+GEANT

Data vs MC Background



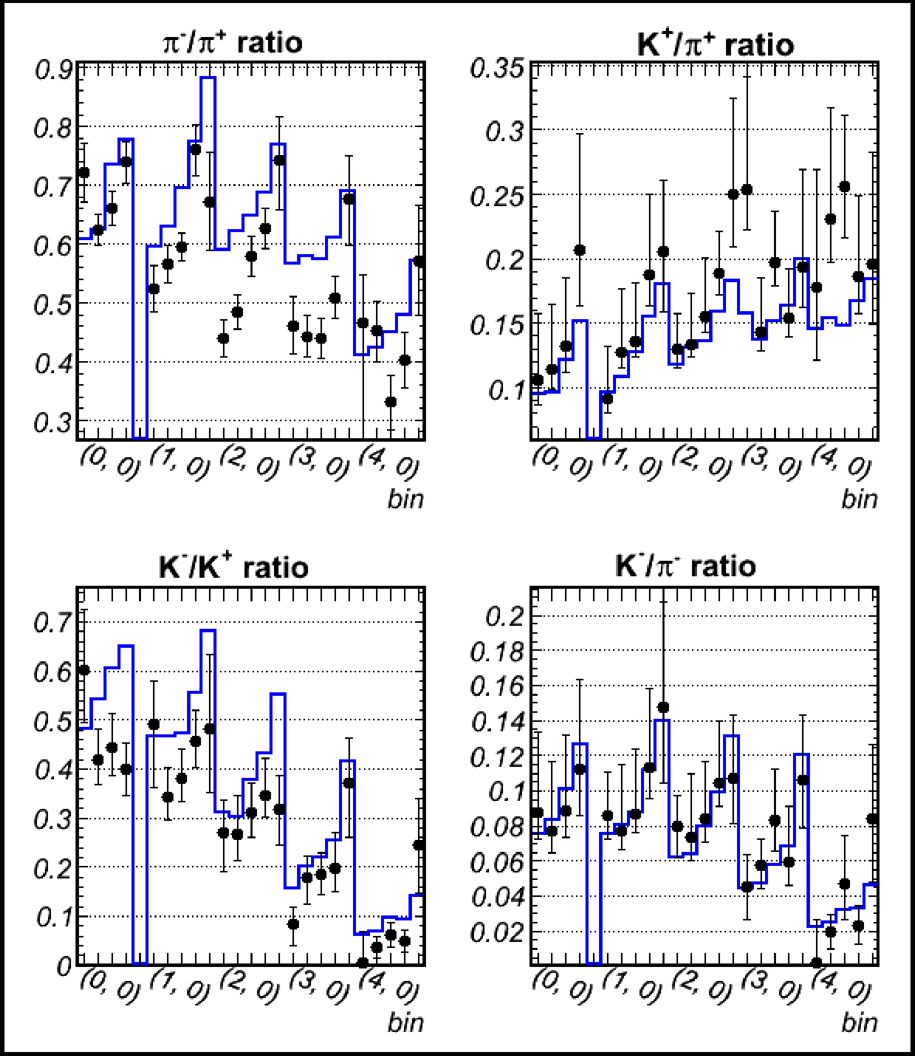
- To compare data/MC, compute the ratio of data and MC background
- Average of the ratio over all bins is 1.1
- Compute systematic error due to background removal by scaling (1-*o*) up and down by at least 1.1 or by the ratio from the data/MC background comparison

Monte Carlo Corrections and Error



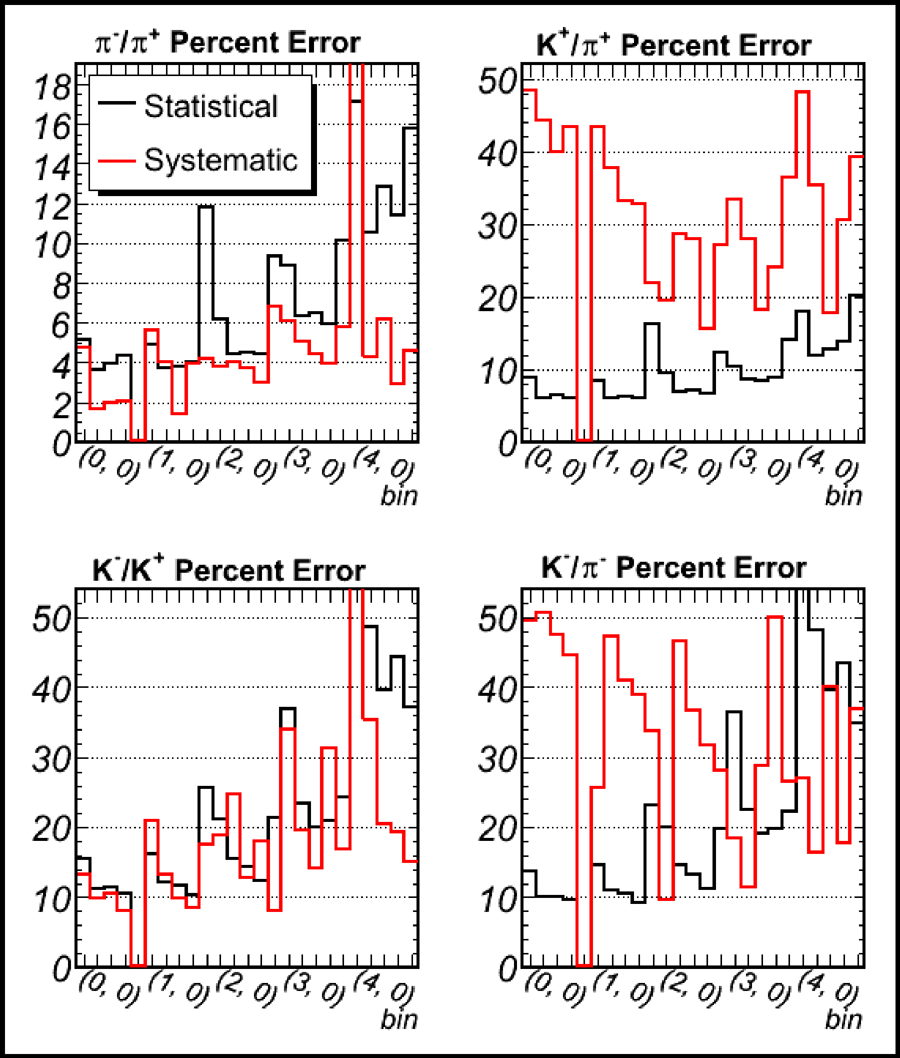
- Assume 50% error on MC correction
  - Corrections are motivated by physics, but are not very well understood yet
- Error on background modeling measured with data
- Errors are asymmetric where background is large

Measurement vs FLUKA-06



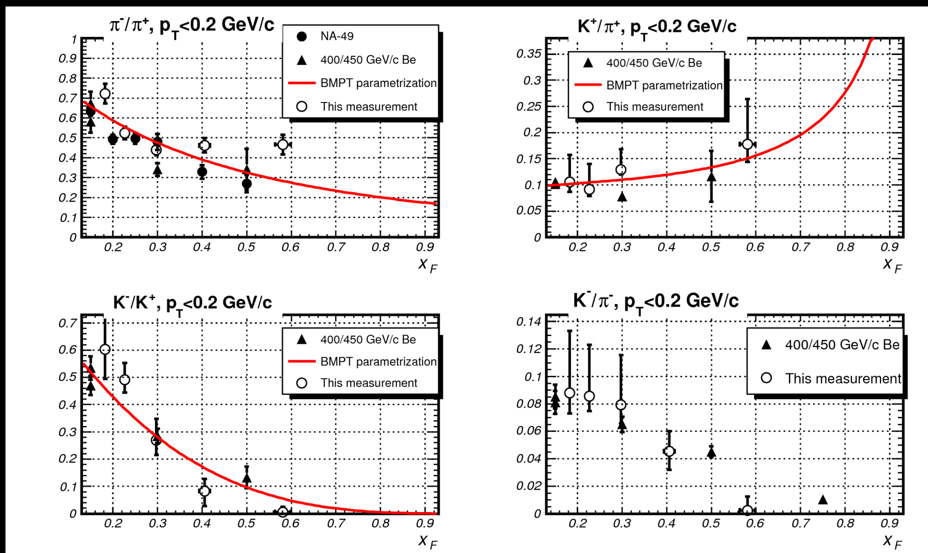
- The measurement agrees with FLUKA in π/K ratios quite well
- Predicted π^-/π^+ and K^-/K^+ ratios are different by up to 50%

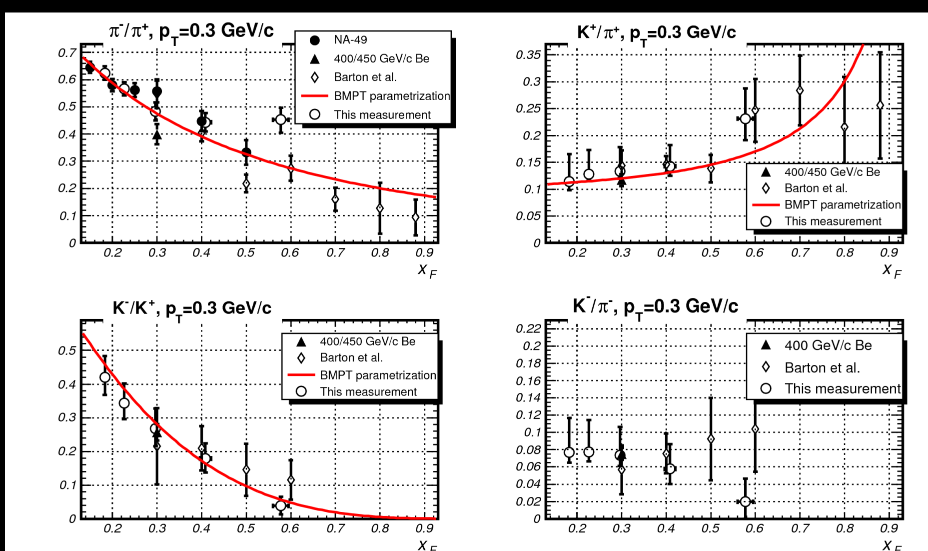
Sources of Error



- Statistical errors on π^-/π^+ ratios are already at or below systematic
  - Need better understanding of background in high p_z bins
- Errors on π/K ratios are dominated by understanding of background
  - Can be reduced with better tuned Monte Carlo

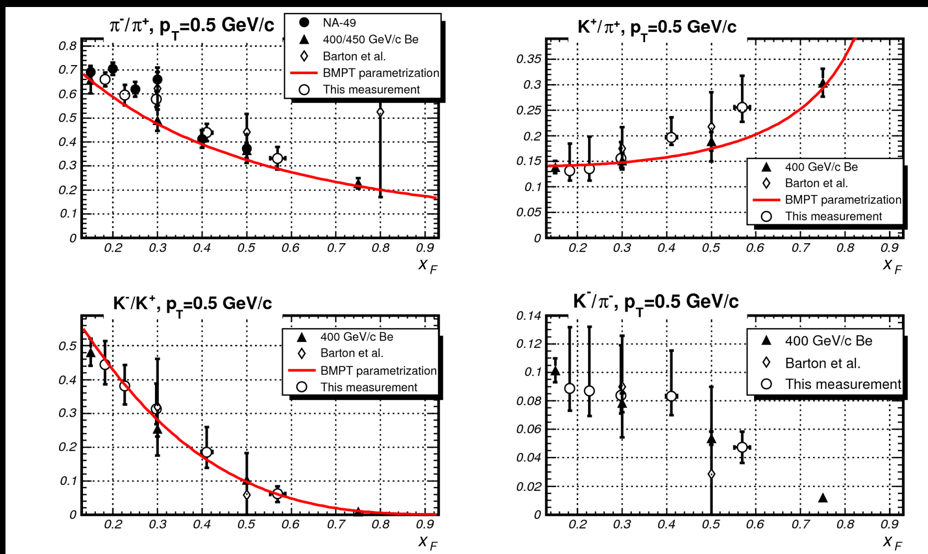
Comparison to Existing Data

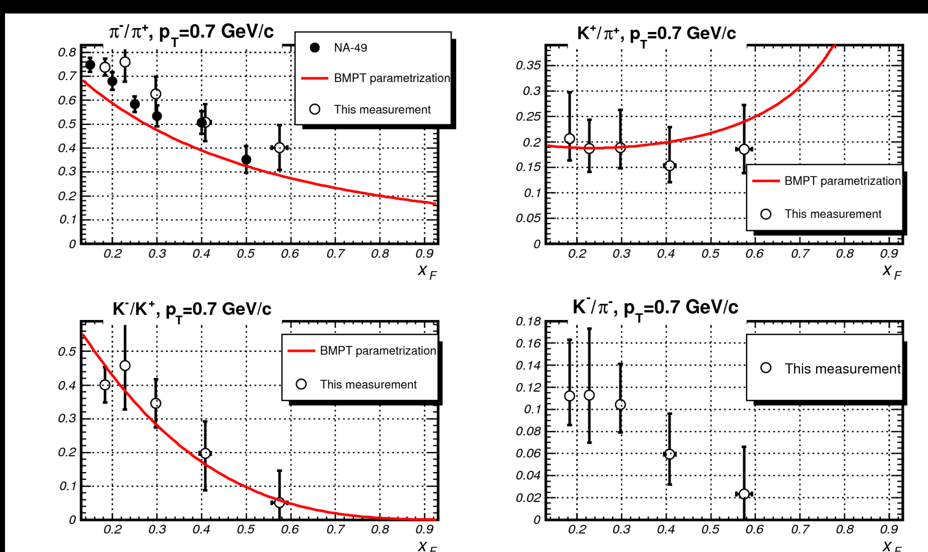




- Agreement between this and previous measurements is good
- Exception is p_Z>60 GeV/c and p_T<0.4 GeV/c
  - Apparent deficiency of π^+
  - Need very good understanding of
    - Scattered protons
    - Interactions of protons in the spectrometer

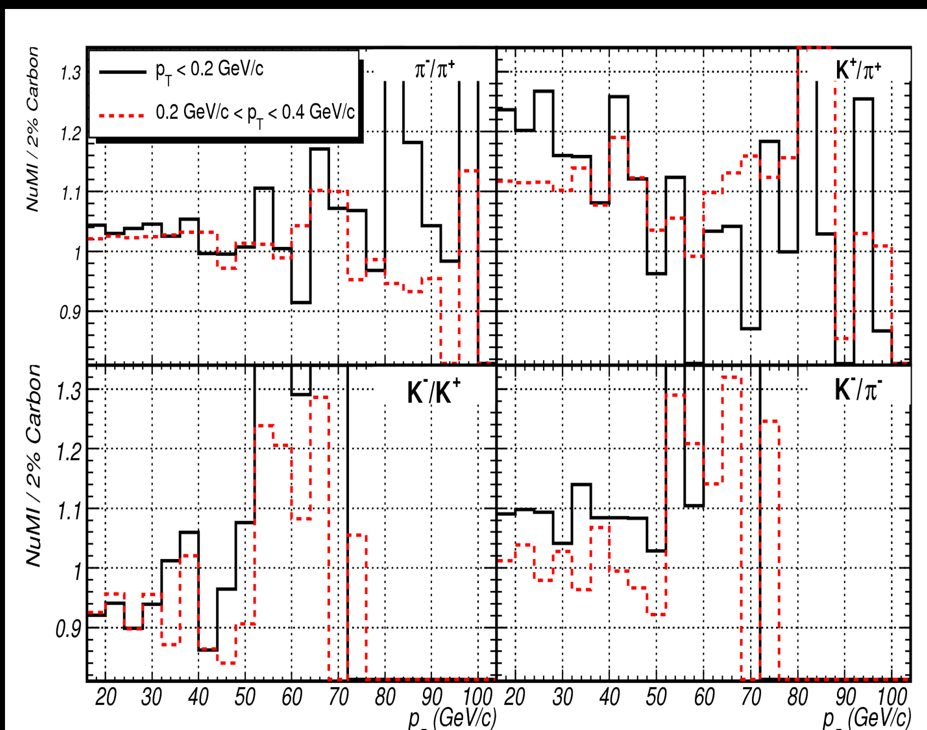
Comparison to Existing Data (cont.)





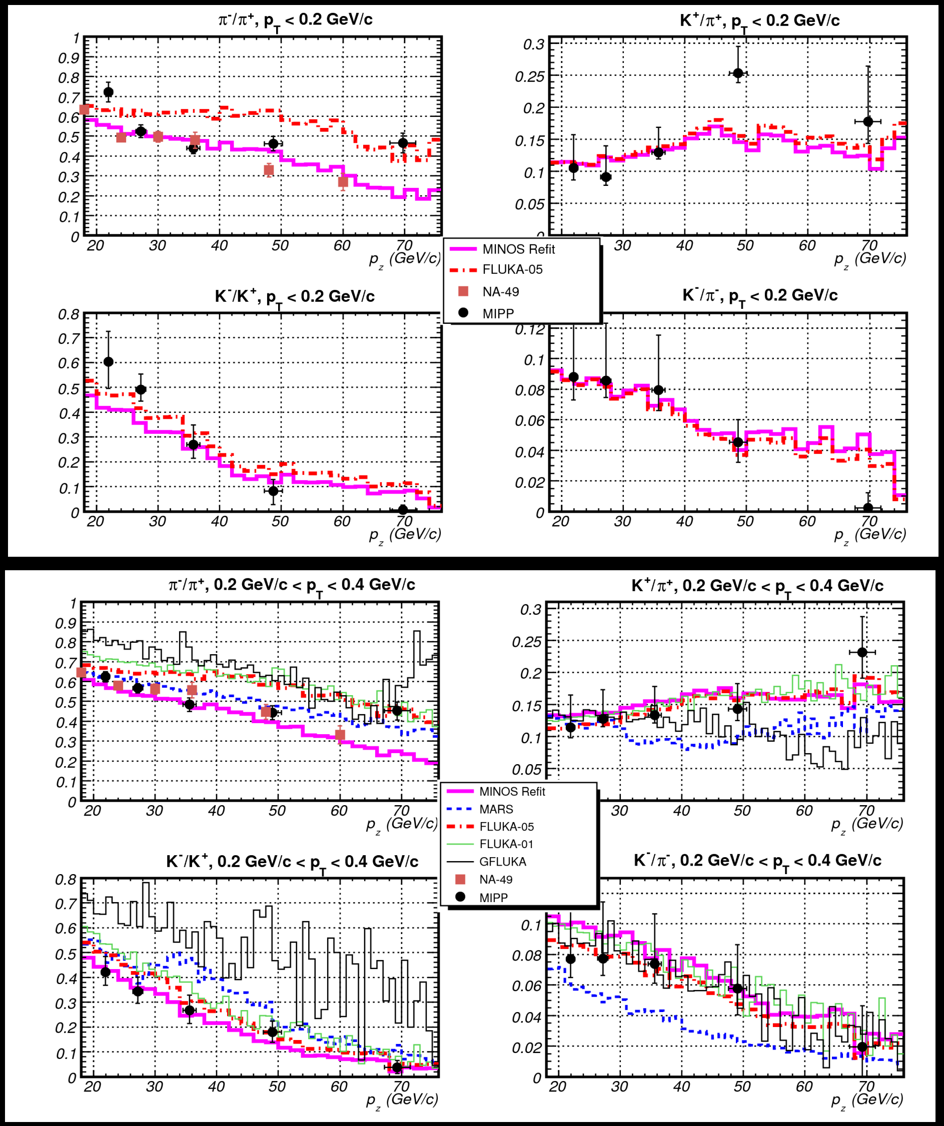
- At higher p_T
  - There is no kaon data to compare to!
  - The proton problem is not there for p_z>60 GeV/c
- p_T-independent BMPT parametrization of π^-/π^+ is not correct

Comparison with NuMI Target Ratios



- At high momenta production is dominated by primary interactions, so comparison of ratios from NuMI target is valid
- MINOS beam systematics group fits π/K production spectrum
  - Target position wrt horns changes hadron p_z
  - Horn currents change hadron p_T

Comparison to Fitted MINOS Ratios



- Prior to this measurement, MINOS found that their fits favor NA49 π^-/π^+ ratio over FLUKA-05
- Good agreement is found between MINOS fits and this measurement
- Higher statistics NuMI target data set is being analyzed

Summary

- The first physics analysis using MIPP data is presented
- The measurement agrees with the existing data and covers hereto unexplored (p_z, p_T) space of kaon production
- Good cross check of fit results from MINOS beam systematics group
  - NuMI target analysis will further help the group
- Better tuned Monte Carlo simulation and understanding of background are needed to reduce systematic error below statistical

Backup Slides

Cross Section Measurement

- Double-differential cross sections are the goal. To do that, we need
  - Better understanding of interaction trigger efficiency
  - Measurement of track finding efficiency
  - Particle ID for all ranges of momenta