Argonne NATIONAL LABORATORY

Status of the MIPP NuMI Target Data Analysis

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NuFact 2013, Beijing

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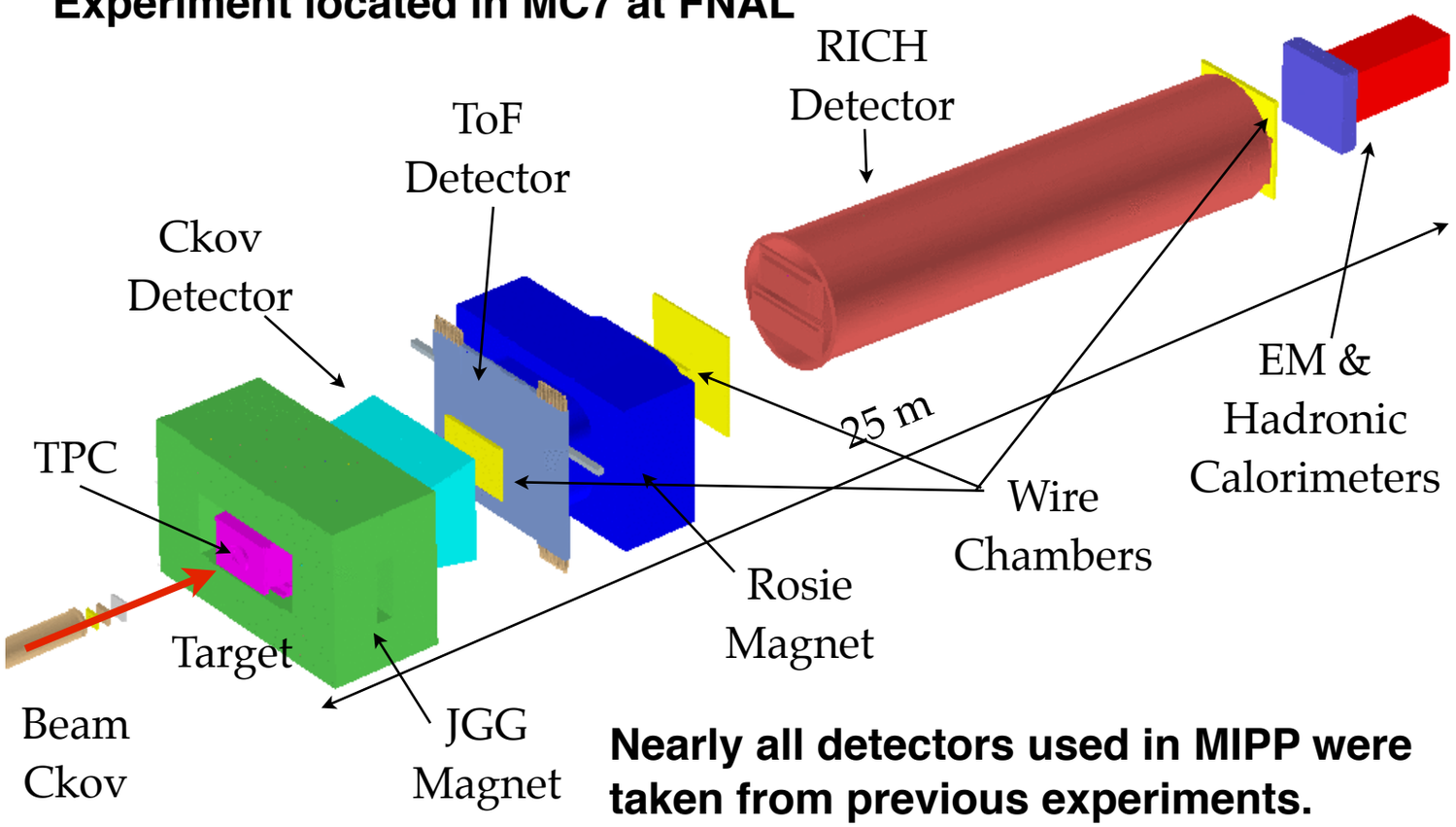
U.S. DEPARTMENT OF ENERGY

Main Injector Particle Production (MIPP) Experiment

Experiment located in MC7 at FNAL

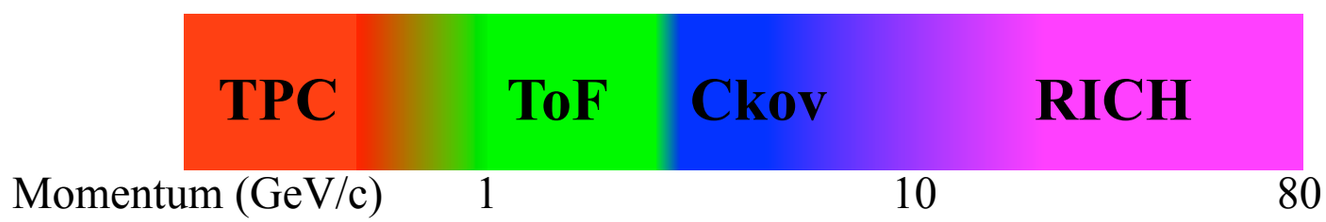


- Goal: collect comprehensive hadron production cross-section data set with particle id using various beams and targets (thick and thin).

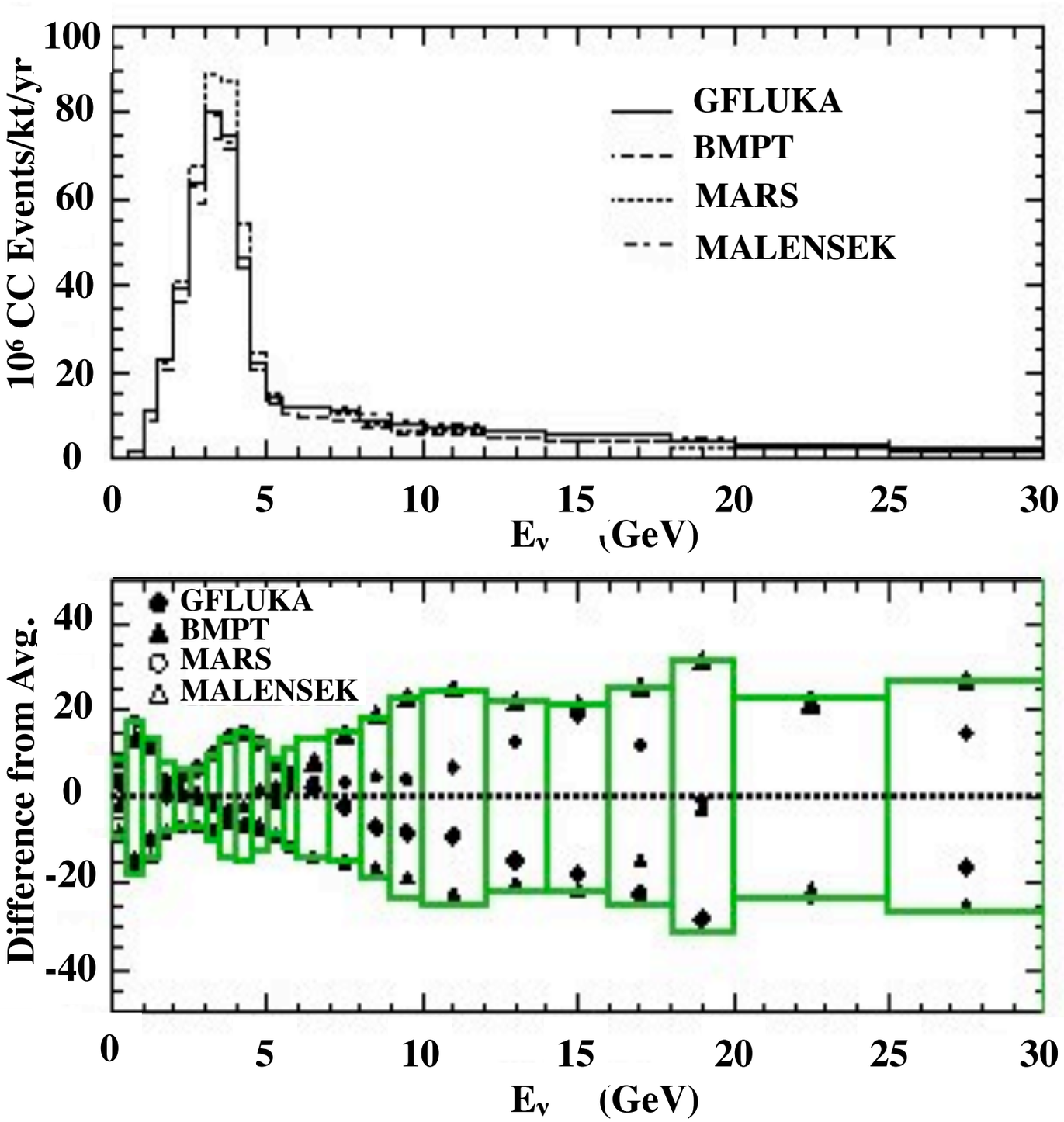
Nearly all detectors used in MIPP were taken from previous experiments.

- Full acceptance spectrometer
- Two analysis magnets deflect in opposite directions
- TPC + 4 Drift Chambers + 2 PWCs

- Designed for excellent particle ID (PID) separation (2-3σ)

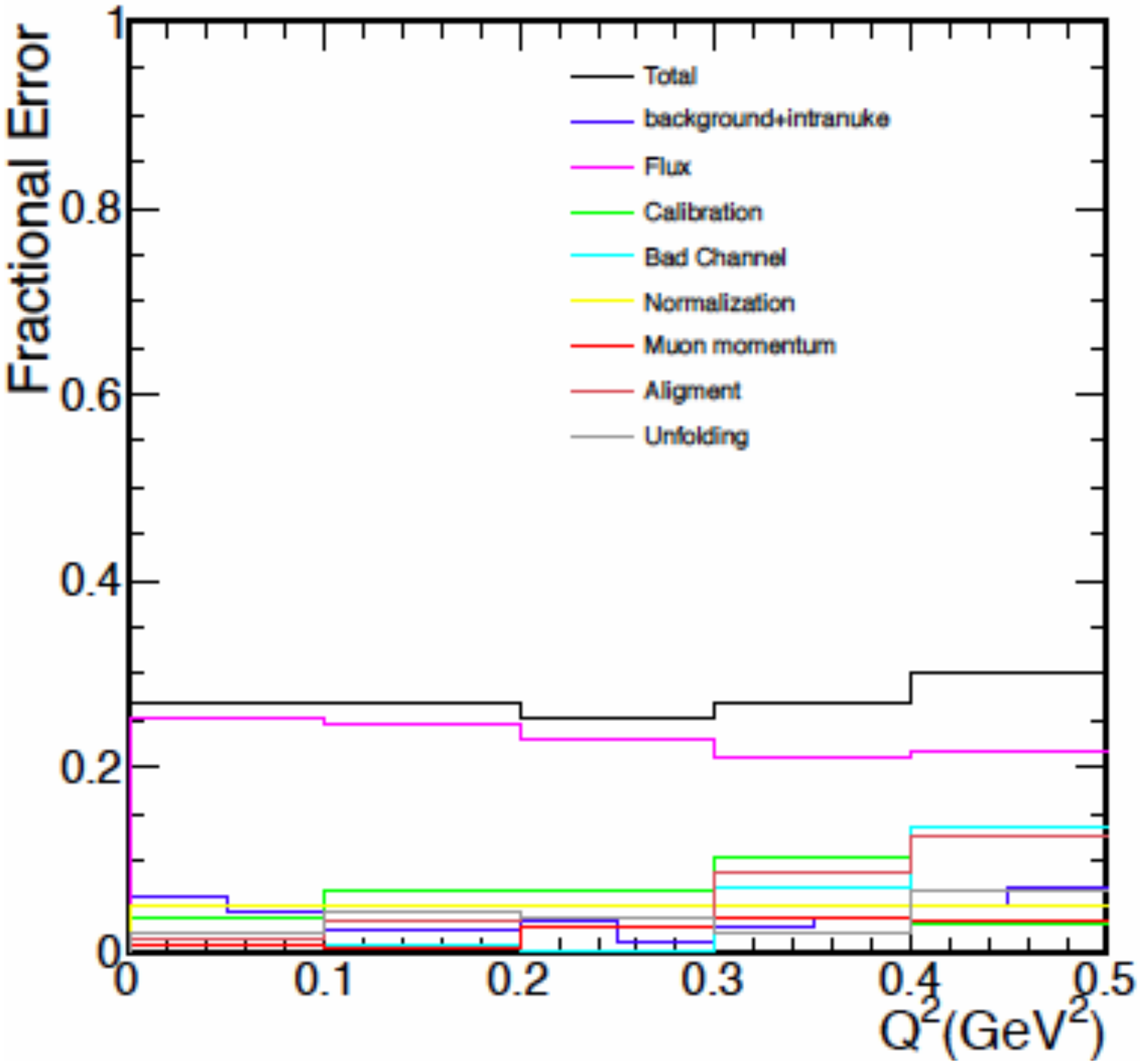


Some Motivation...



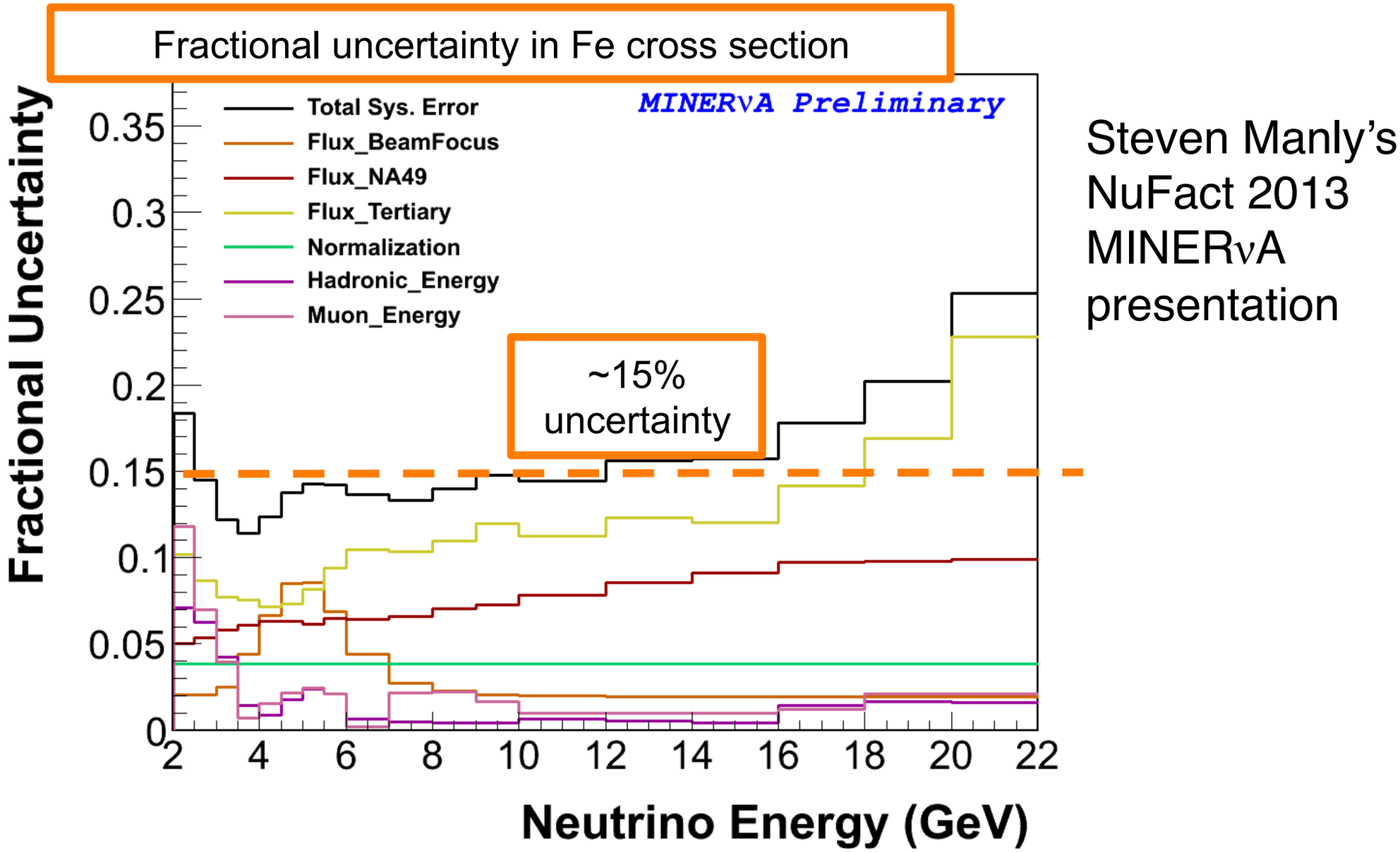
- Highly correlated models give predictions that differ up to 20%

Some Motivation...



NOνA NDOS $\sigma_{\nu\mu}$ CCQE Uncertainties

Some Motivation...

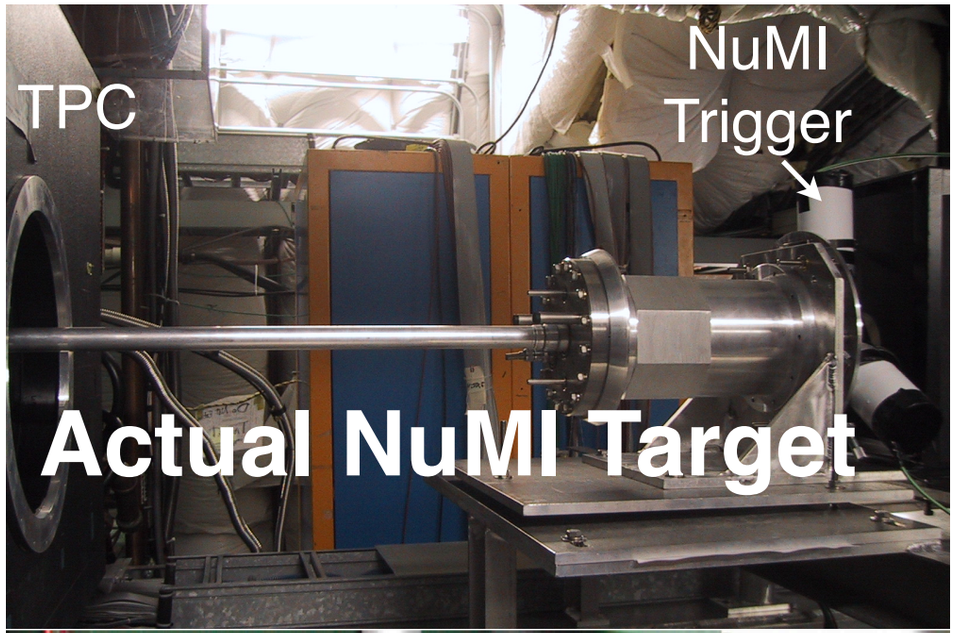


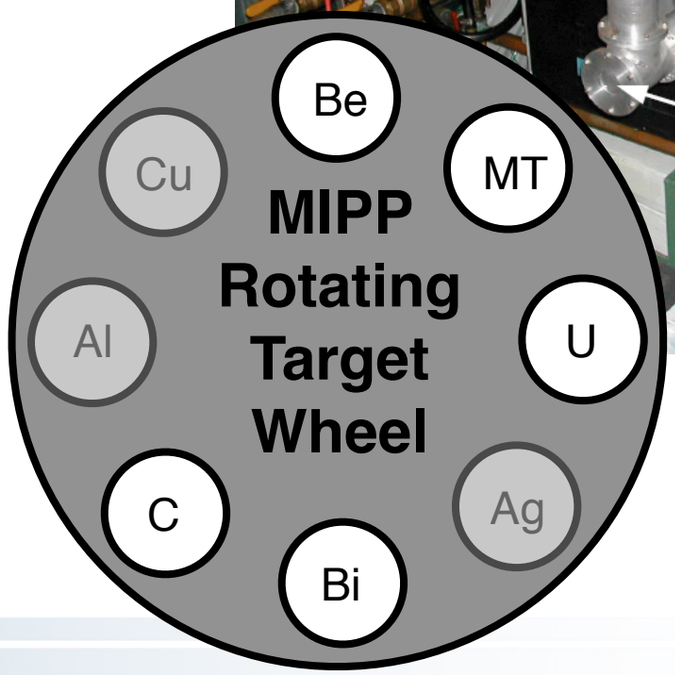
Steven Manly's NuFact 2013 MINERνA presentation

- Despite recent progress and measurements from hadron production experiments over the past 10+ years, we're still talking about 10-20% uncertainties in the hadron production off the NuMI target

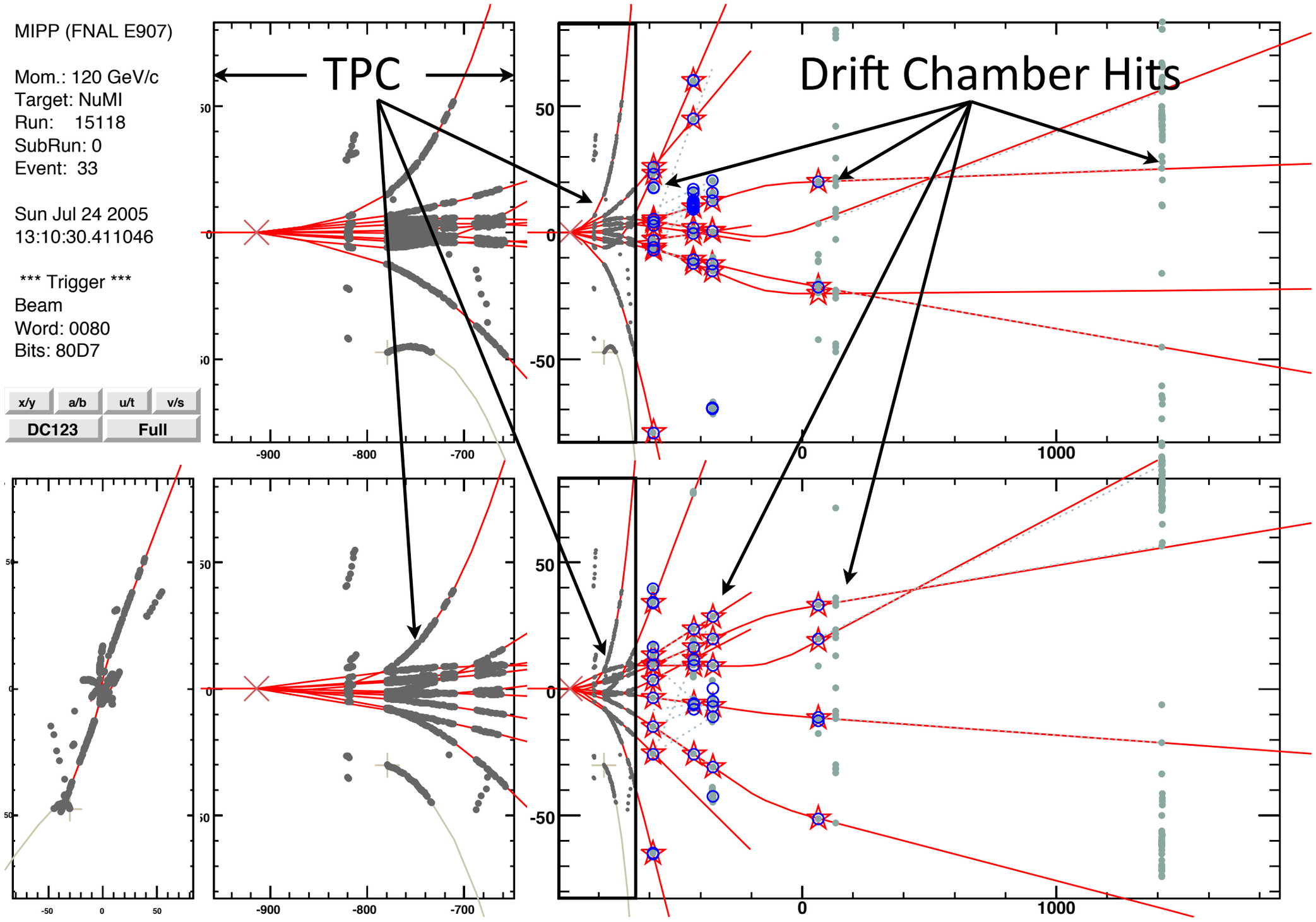
Data Sets

- MIPP began its physics run in December 2004 and ran until February 2006.
- DAQ rate was ~25 Hz, with MIPP receiving ~5% of MI beam.
- Data collected:
- ~1.6 x 10^6 events of Main Injector 120 GeV/c protons on a spare NuMI target.
- ~3.2 x 10^6 π's, K's and p's at 120, 60, 35 and 20 GeV/c on 1-2% λ_L C and Be targets.
  - ~7 x 10^6 π's, K's and p's at 85, 60, 20 and 5 GeV/c on 1% λ_L LH2 target.
  - ~4 x 10^6 π's, K's and p's at 35, 60 and 120 GeV/c on Bi and U targets.



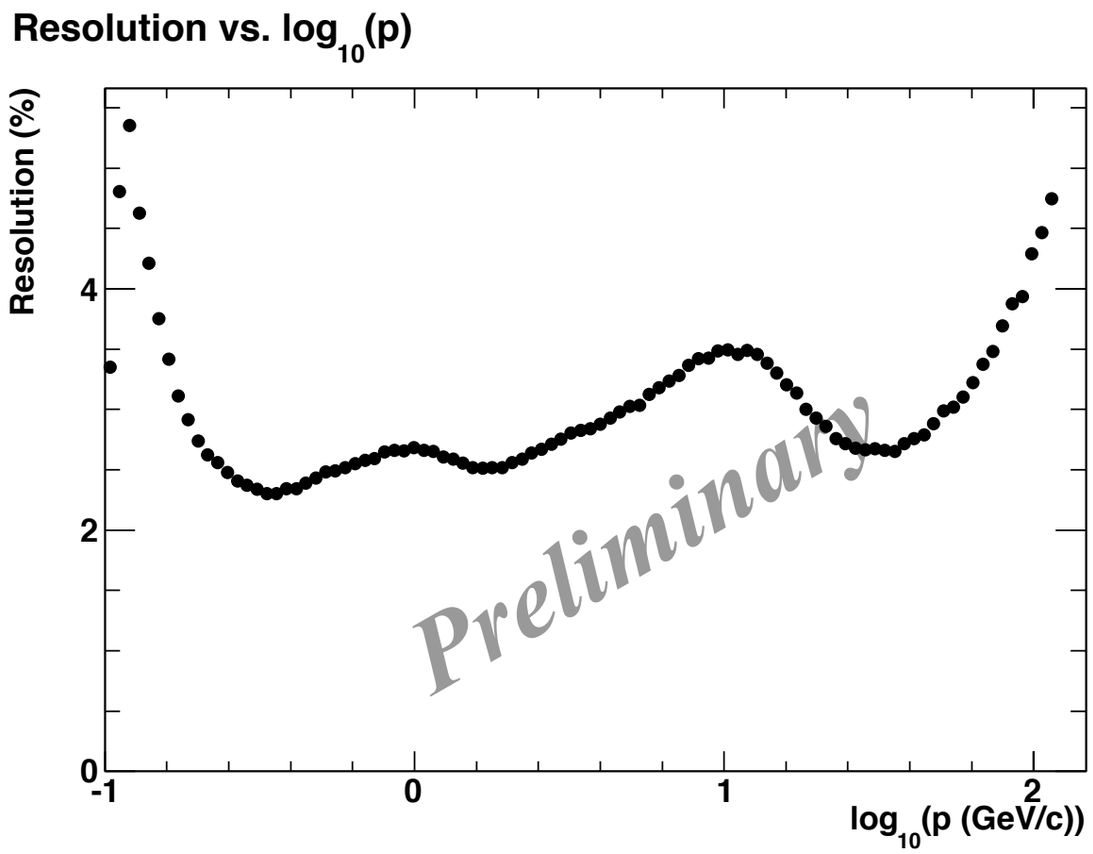


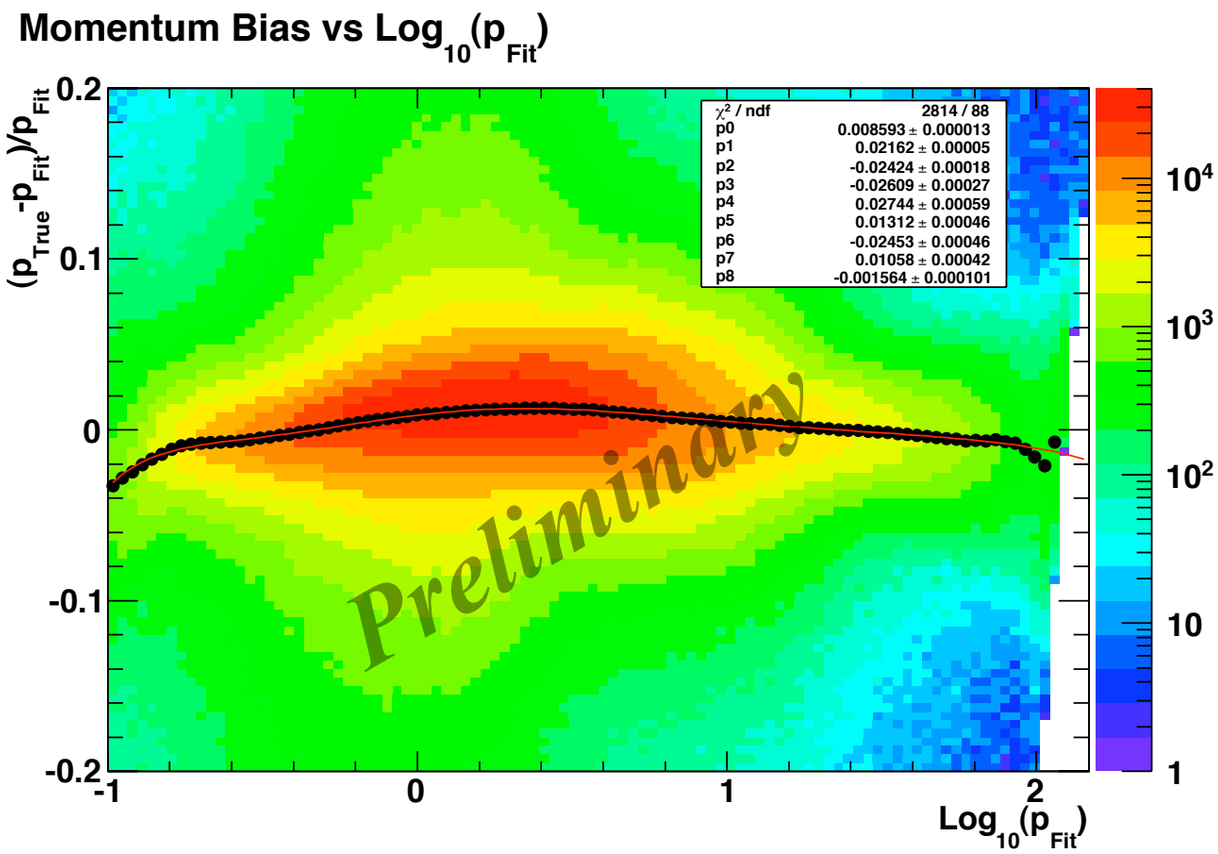
Global Track Reconstruction



TPC track segments are matched to downstream drift chamber hits, momentum is determined from bend in both magnets.

Momentum Resolution and Bias

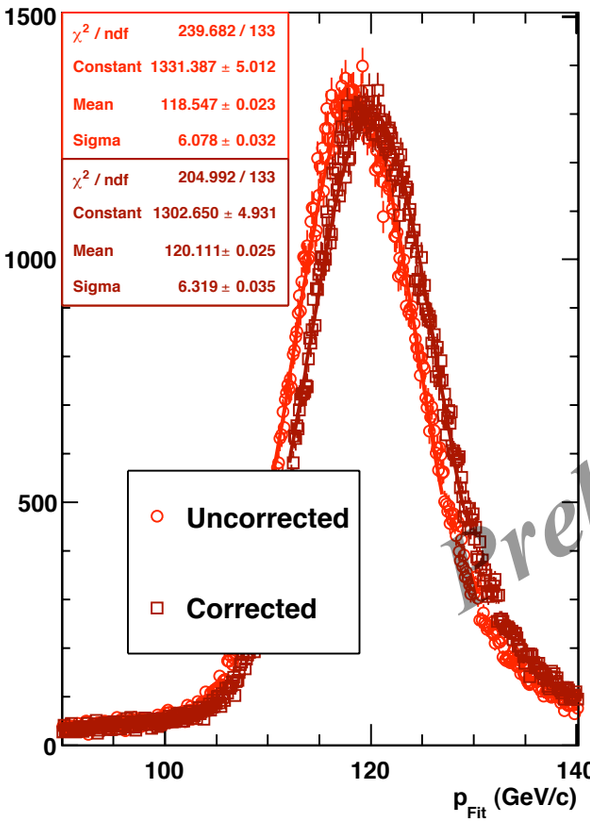




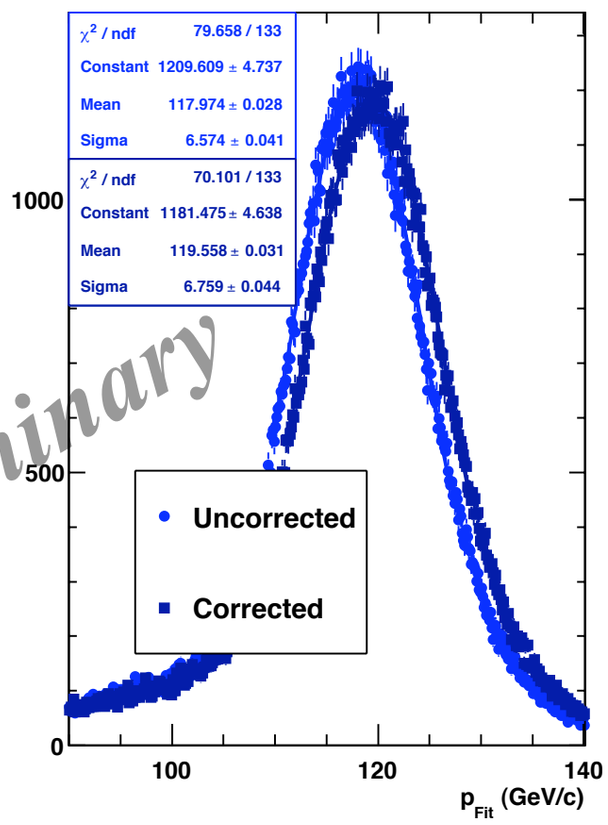
- Black points determined by fitting central peaks of slices of dp/p to Gaussian.
- Momentum resolution is < ~5%
- Bias < ~2%. Correction is applied and has a very small uncertainty.
- Transverse momentum resolution is < 0.02 GeV

Absolute Momentum Scale

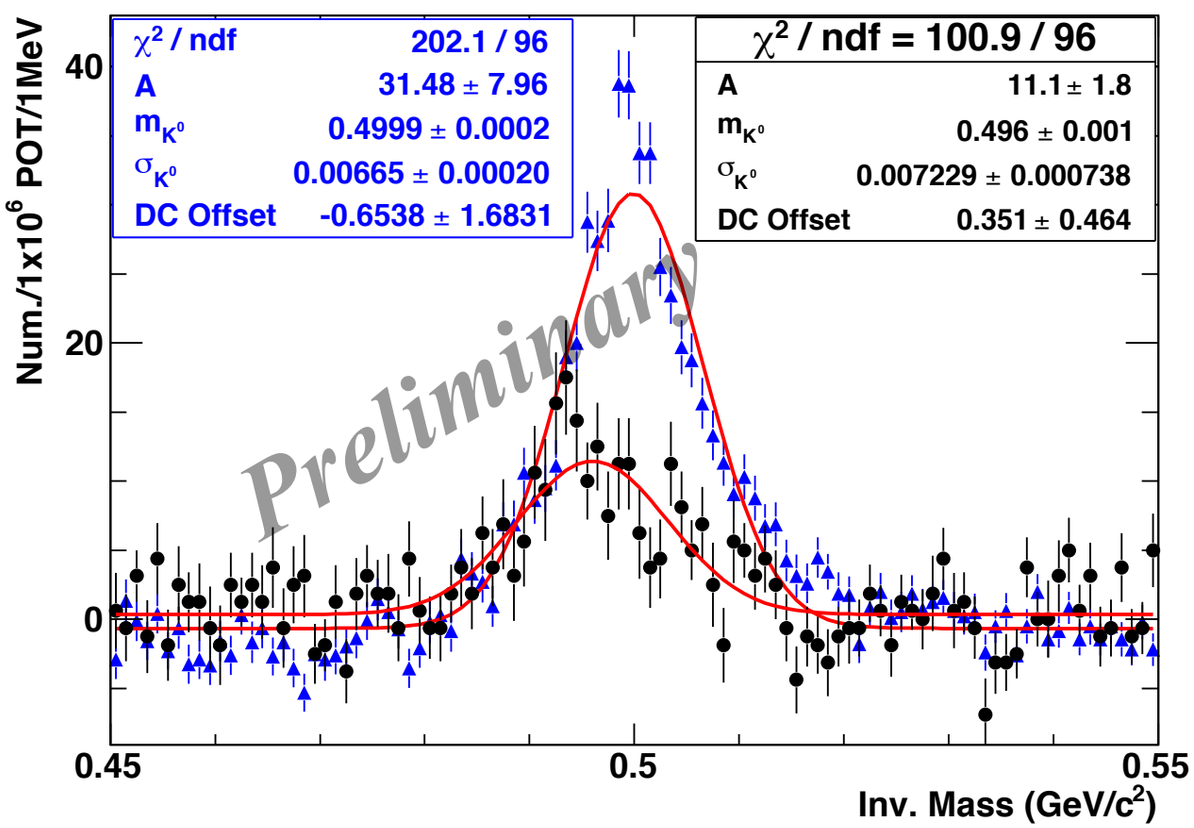
NuMI MC



NuMI Data

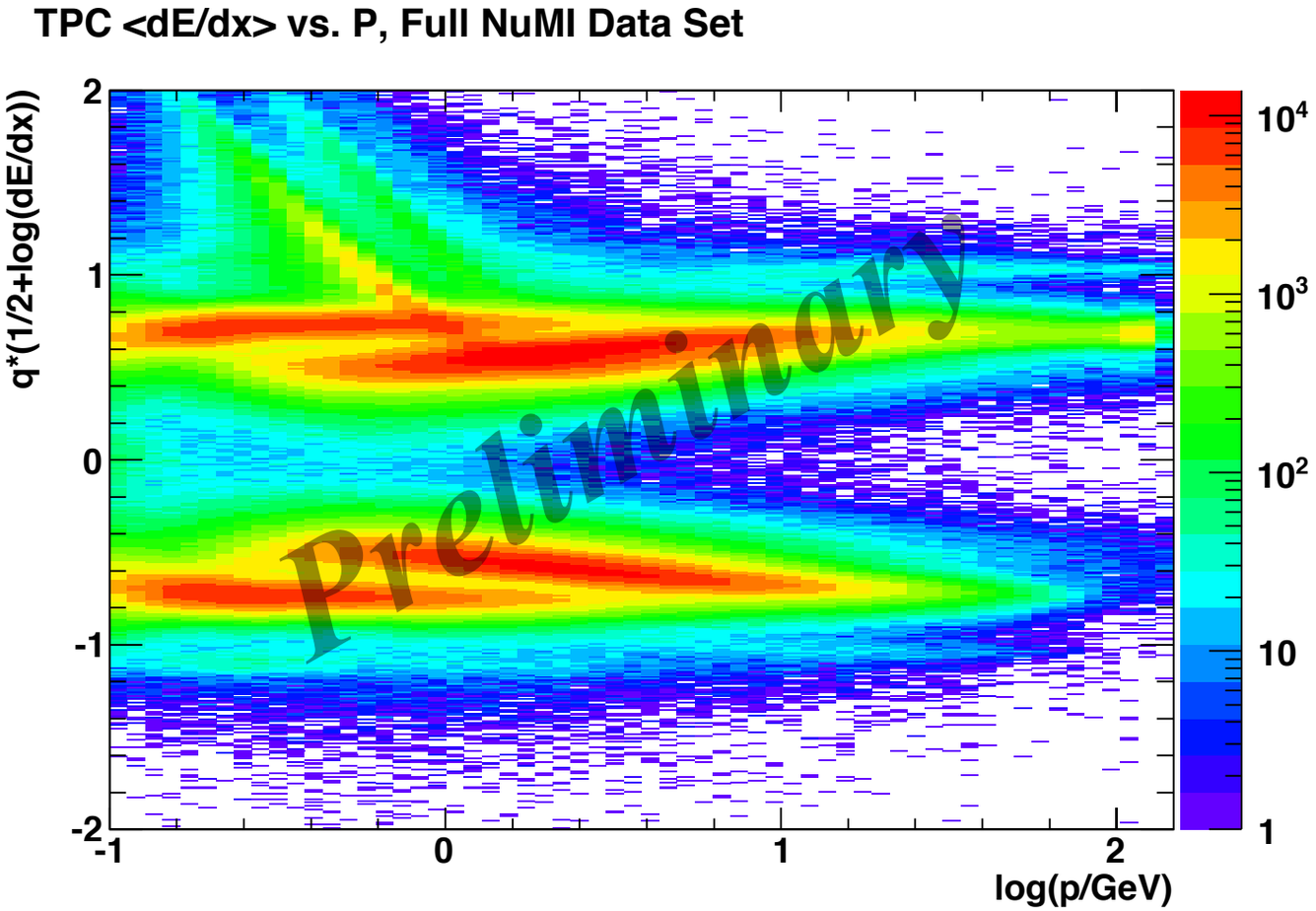


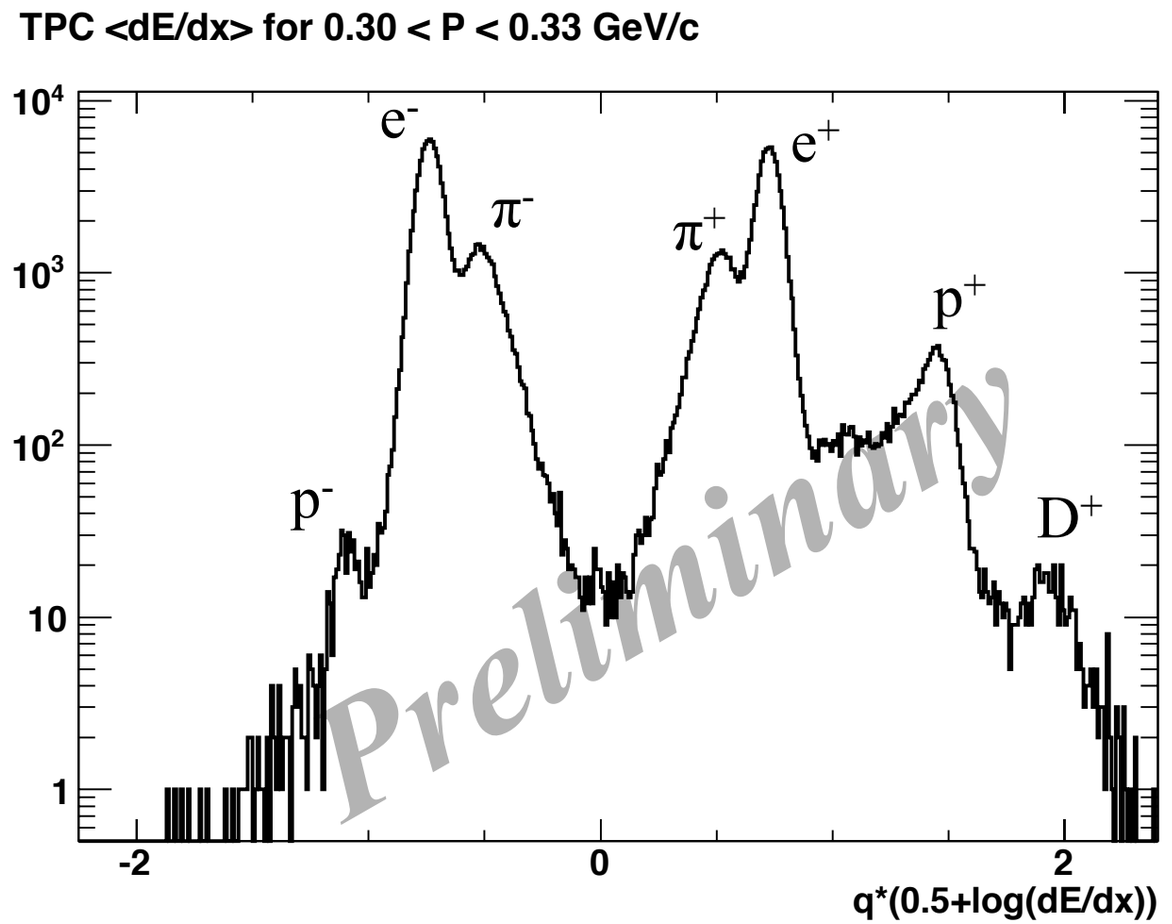
Bkg-Subtracted Inv. Mass Distribution, NuMI MC, dz Cut



- After momentum bias correction, single proton beam data and MC agree.
- Reconstructed K^0 invariant mass using tracks with $p < 2$ GeV/c indicates systematic offset of ~-1%.

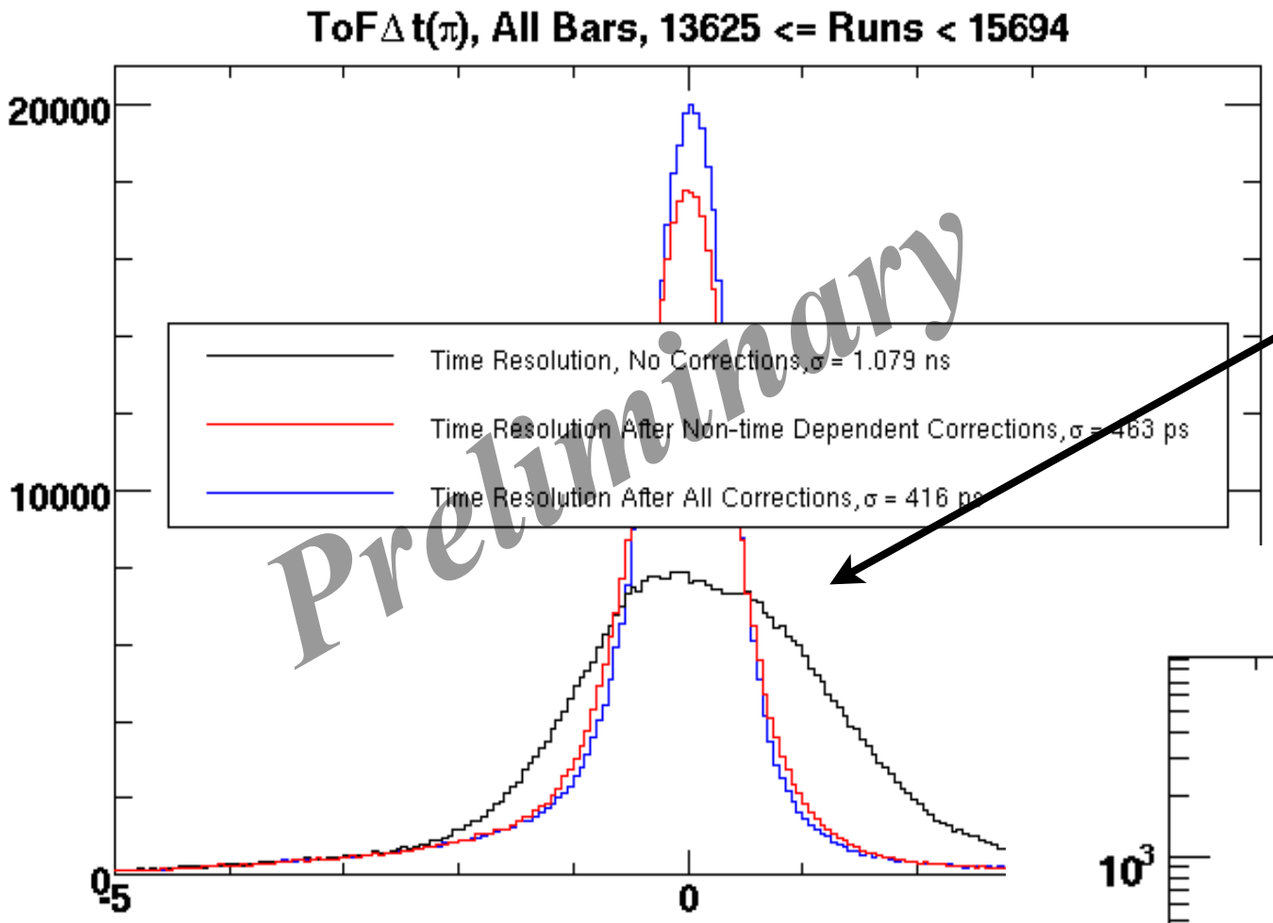
TPC PID Performance



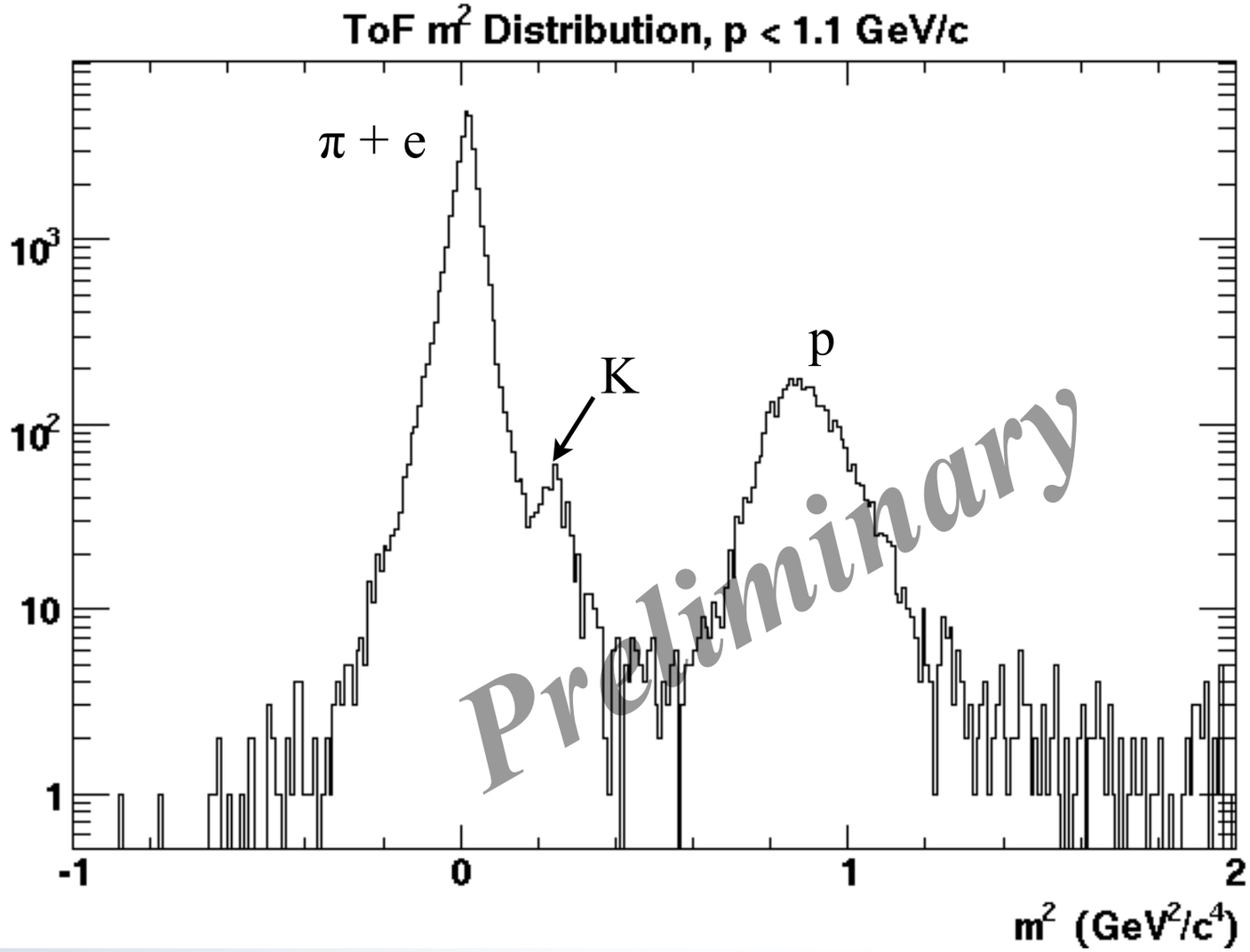


- TPC data are calibrated such that <dE/dx>(π) is 1 for p = 0.4 GeV/c and give expected Bethe-Bloch functional form.
- <dE/dx> resolution ~10%.
- Clean π, p separation between 0.2 and 1.2 GeV/c.

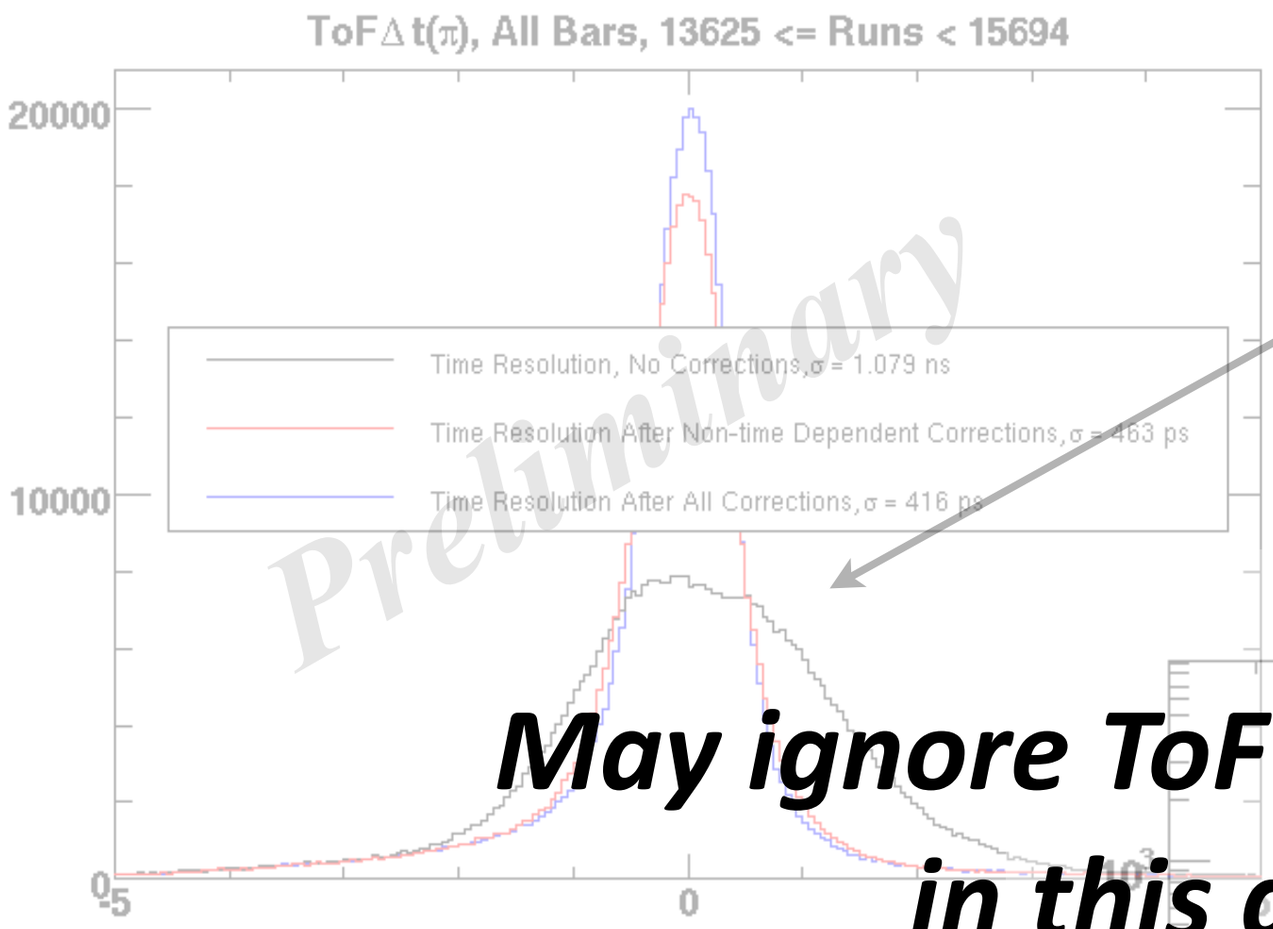
ToF PID Performance



Data-driven calibration improved timing resolution by about a factor of 2.5



ToF PID Performance



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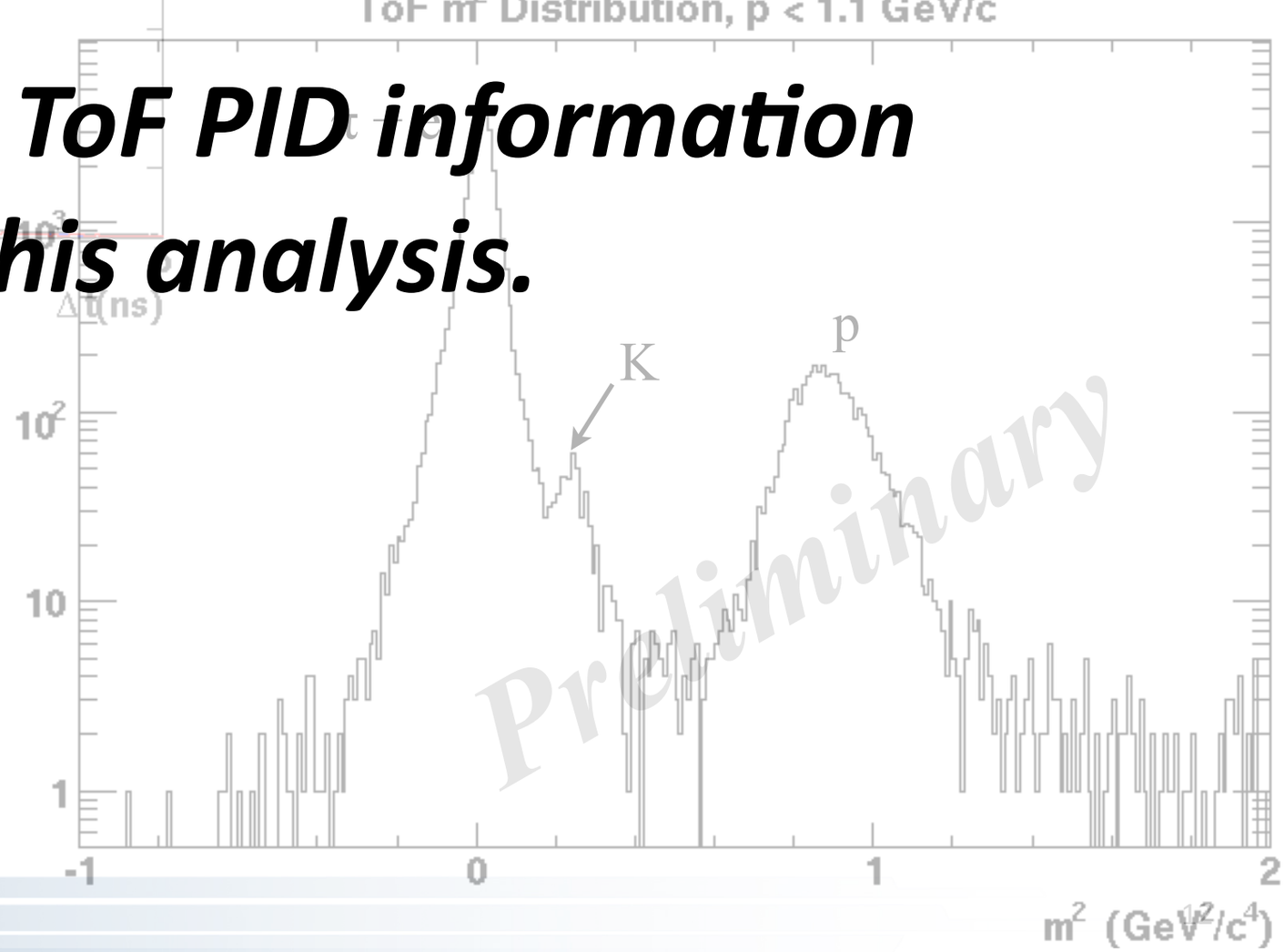
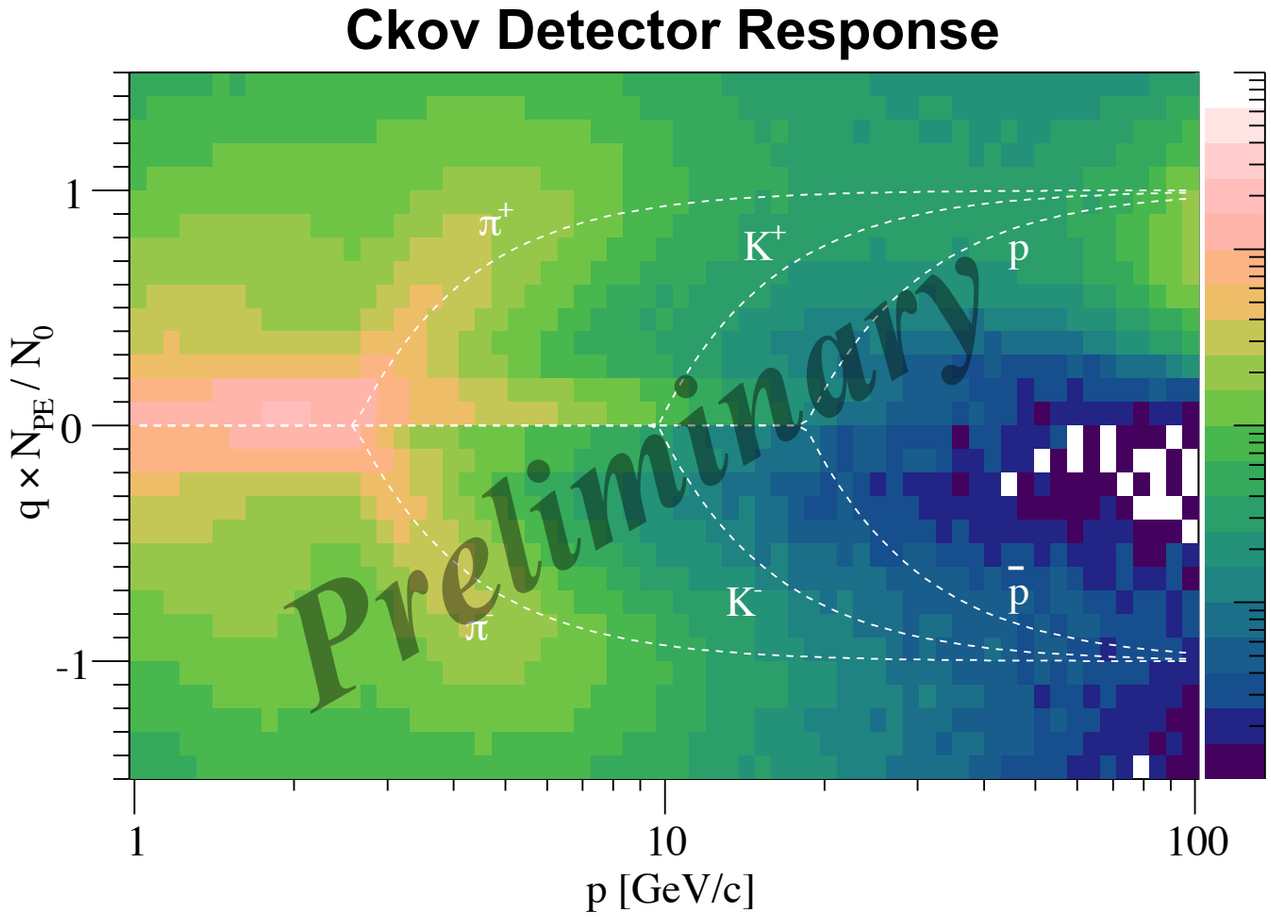
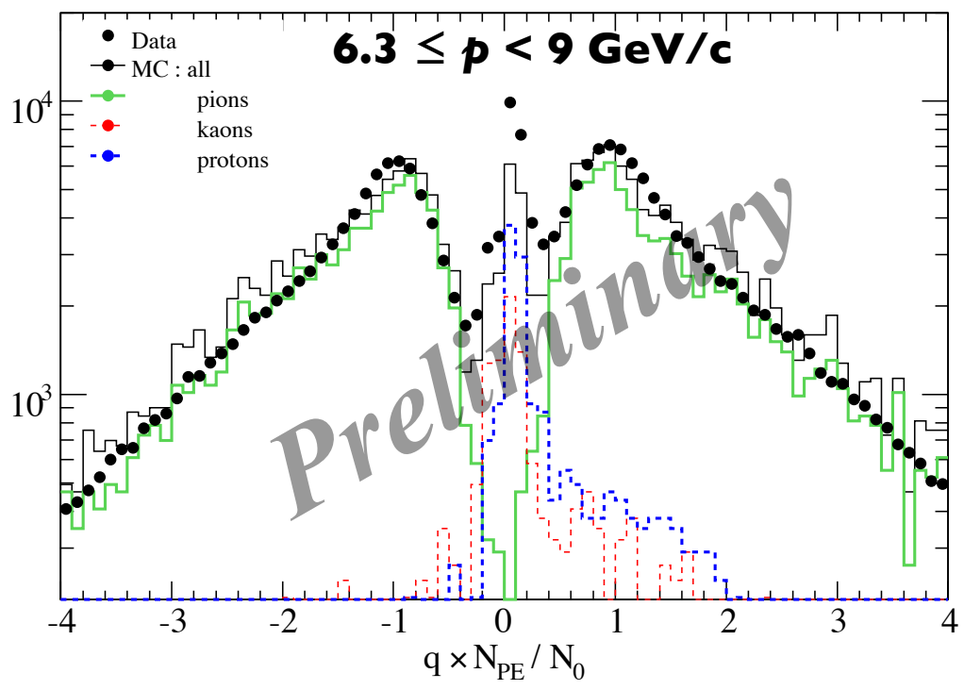


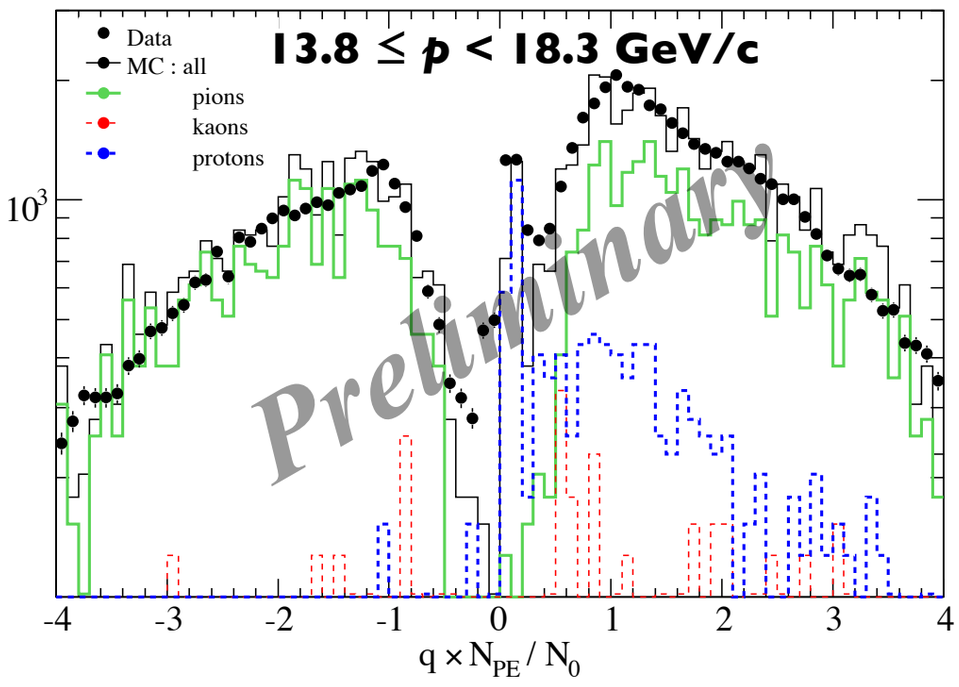
May ignore ToF PID information in this analysis.

Ckov PID Performance



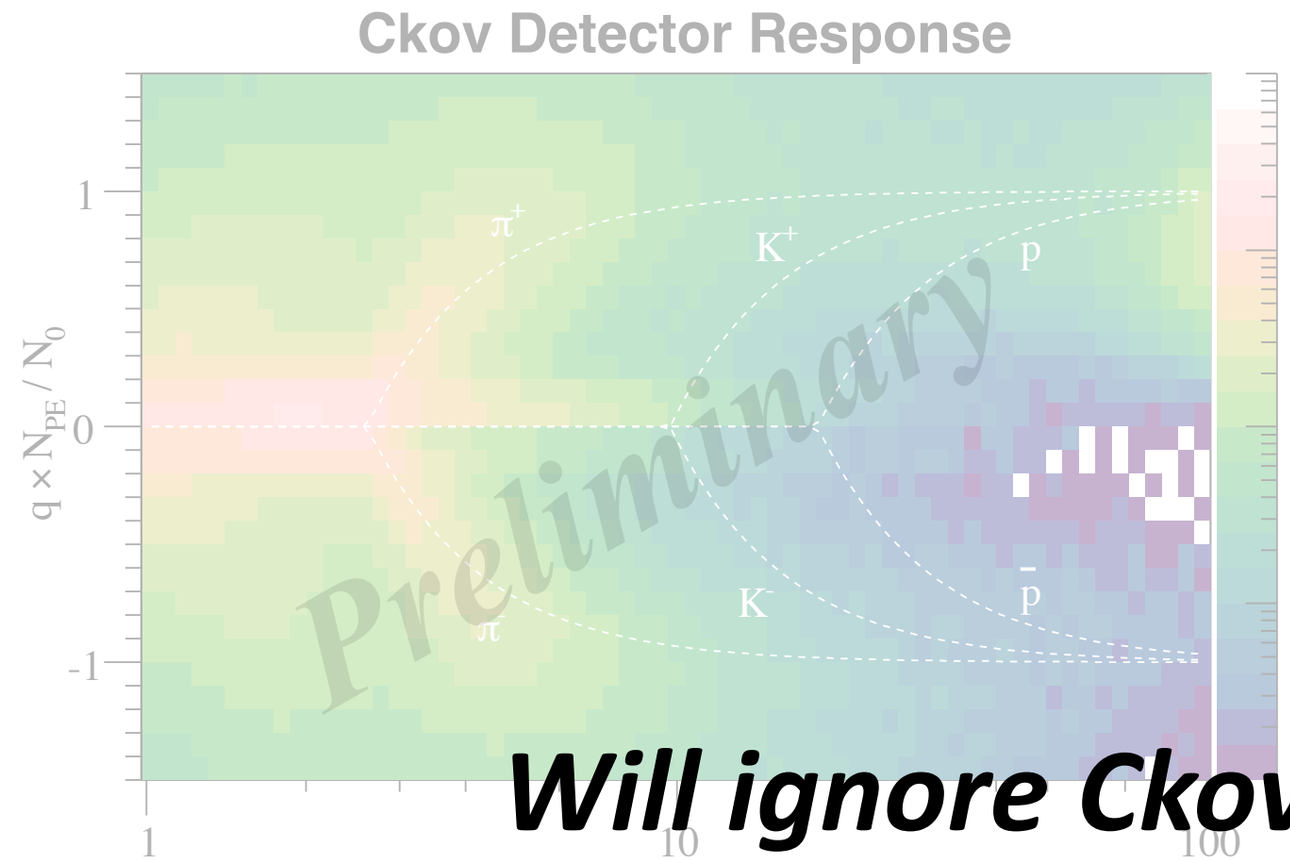
- Since all mirrors have a different response, each measurement of Npe is normalized to that of a β=1 particle.
- Pion "turn-on" clearly visible; proton "turn-on" also visible in slices of momentum.
- Shape of normalized response dist. in MC agrees very well with data.
- Data-driven calibration of 96 mirrors found detector response gives <10 pe/β=1 track.





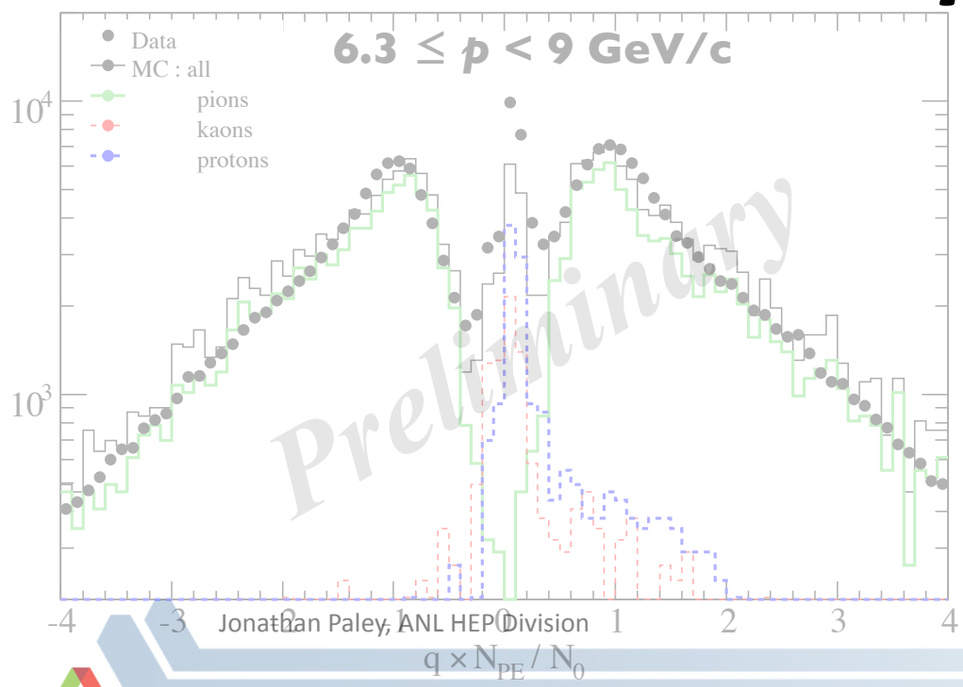
- Must only consider "isolated" tracks passing through mirrors; reject ~50% of Ckov PID data.

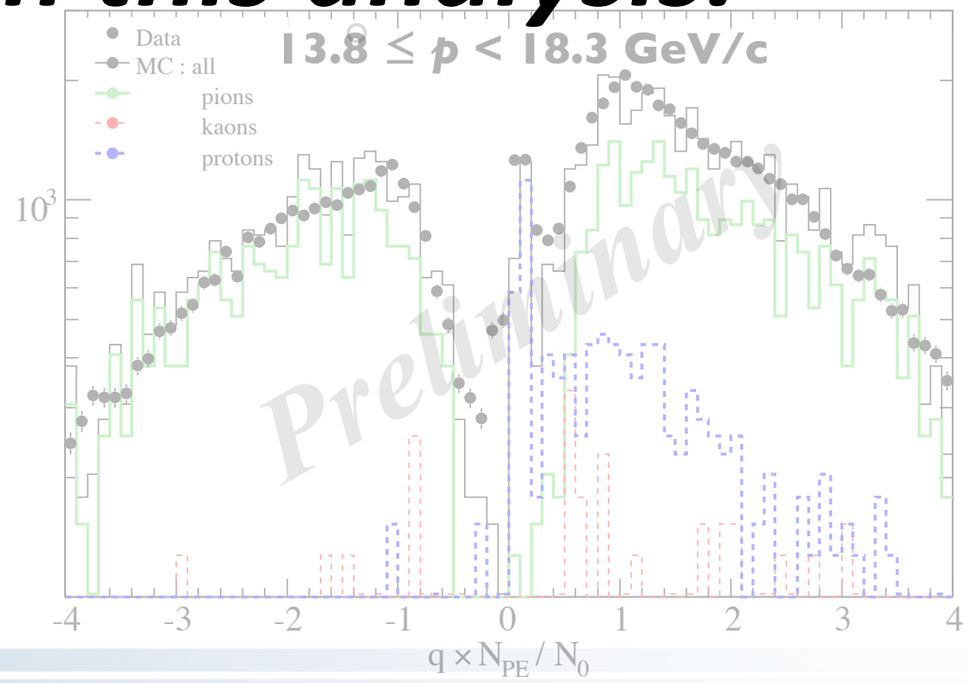
Ckov PID Performance



- Since all mirrors have a different response, each measurement of Npe is normalized to that of a β=1 particle.
- Pion "turn-on" clearly visible; proton "turn-on" also visible in slices of momentum.
- Shape of normalized response dist. in MC agrees very well with data.
- Data-driven calibration of 96 mirrors found detector response gives 10 pe/β=1 track.

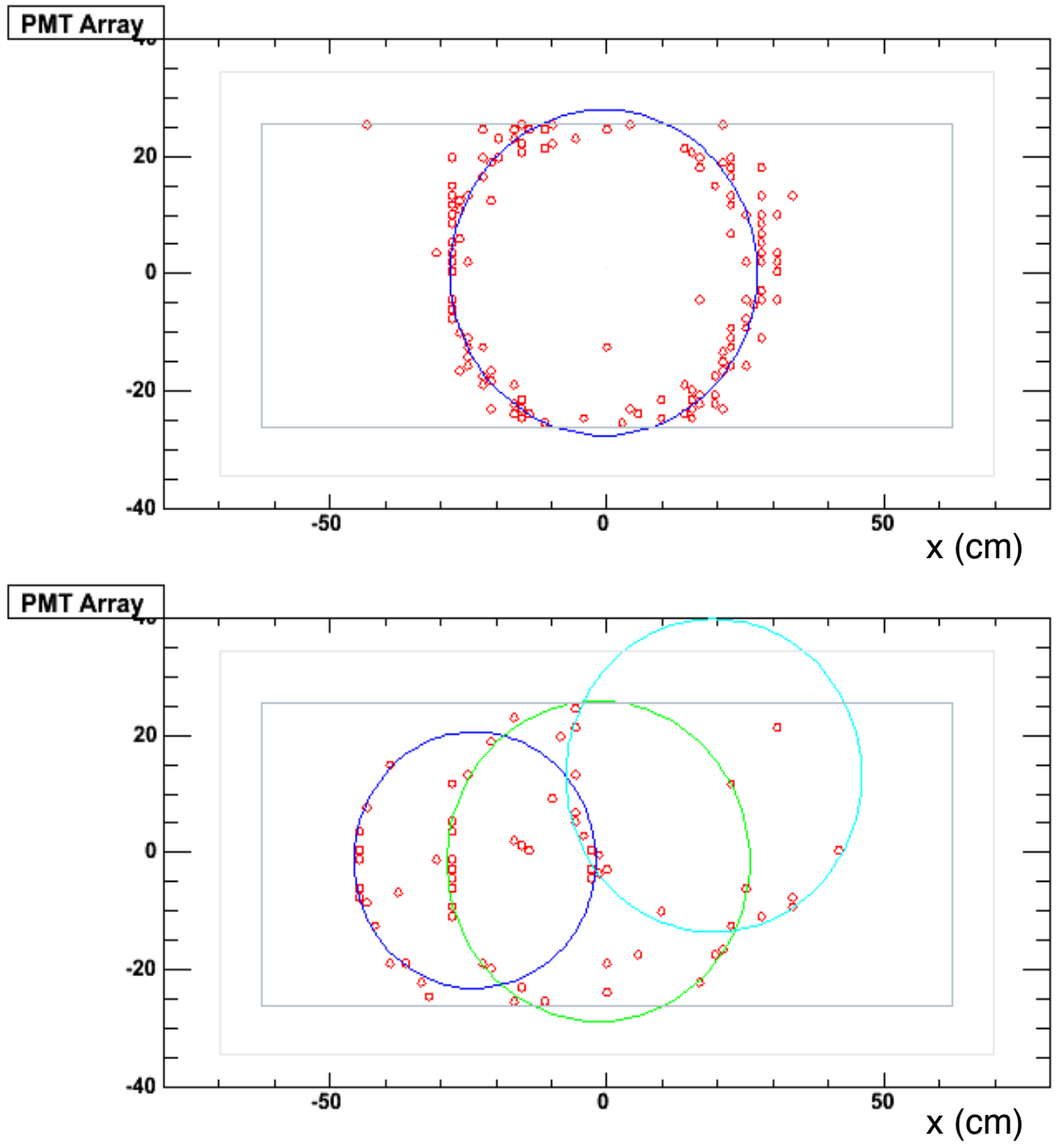
Will ignore Ckov PID Information in this analysis.

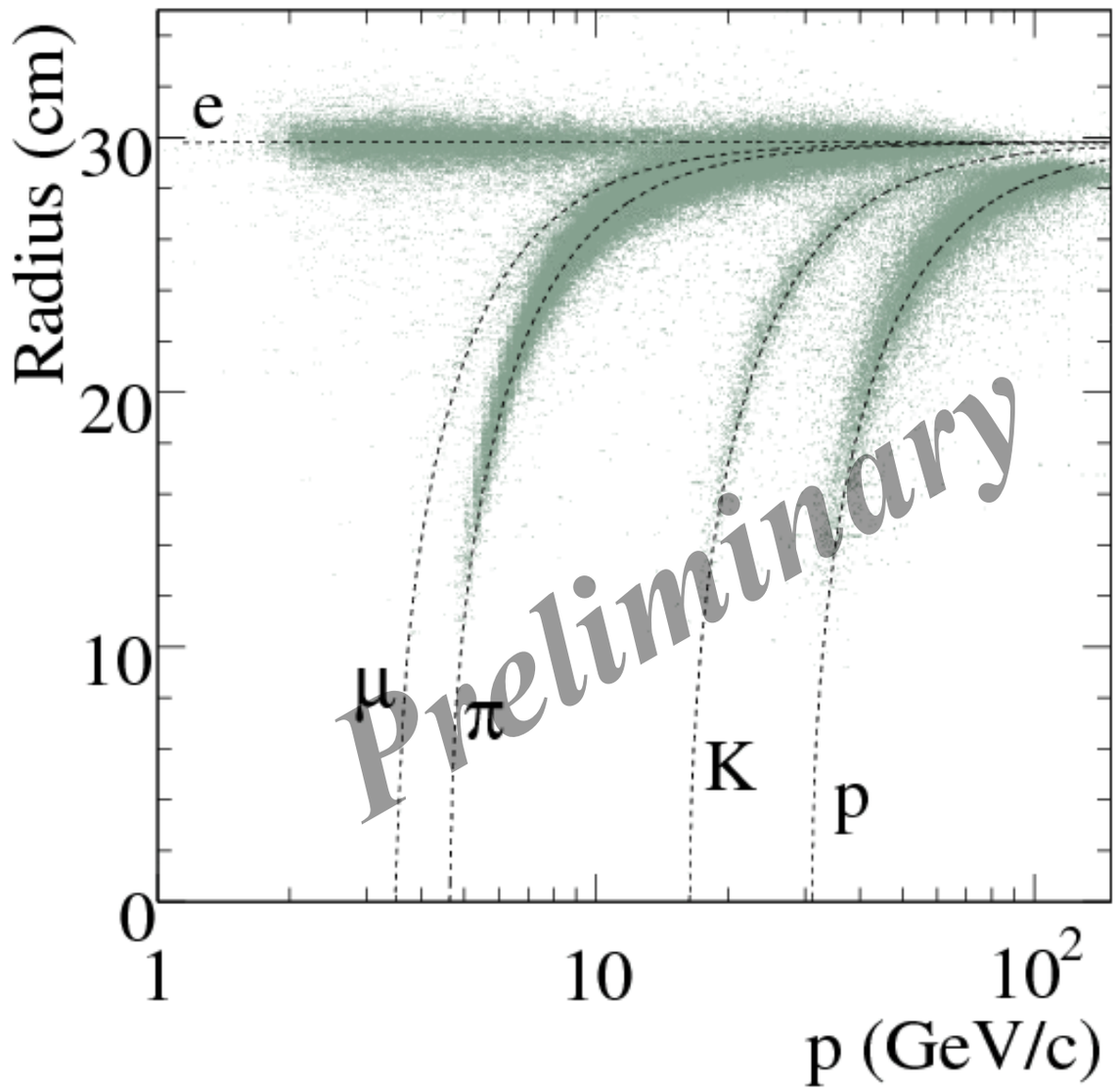




- Must only consider "isolated" tracks passing through mirrors; reject ~50% of Ckov **PID** data.

RICH PID Performance



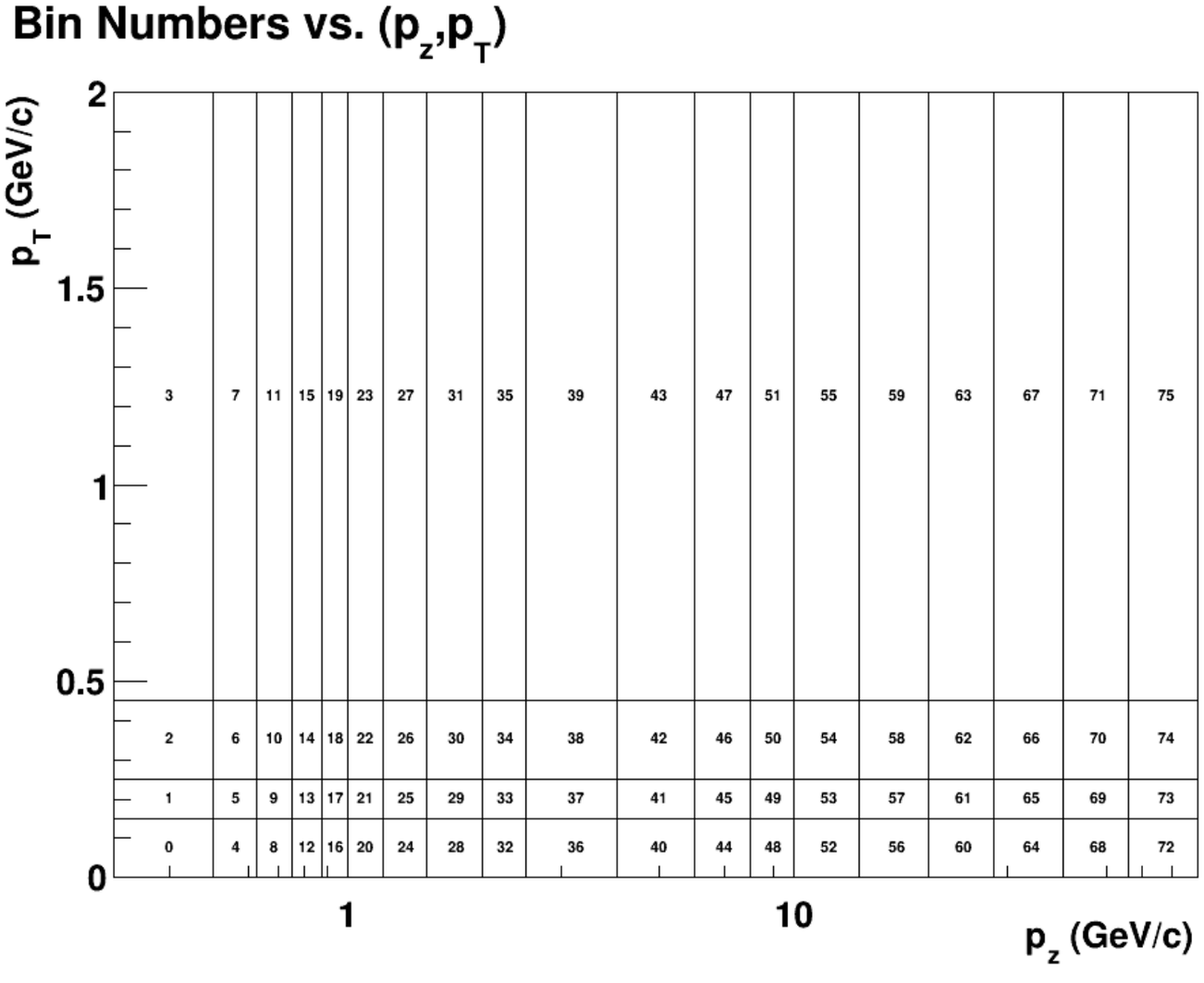


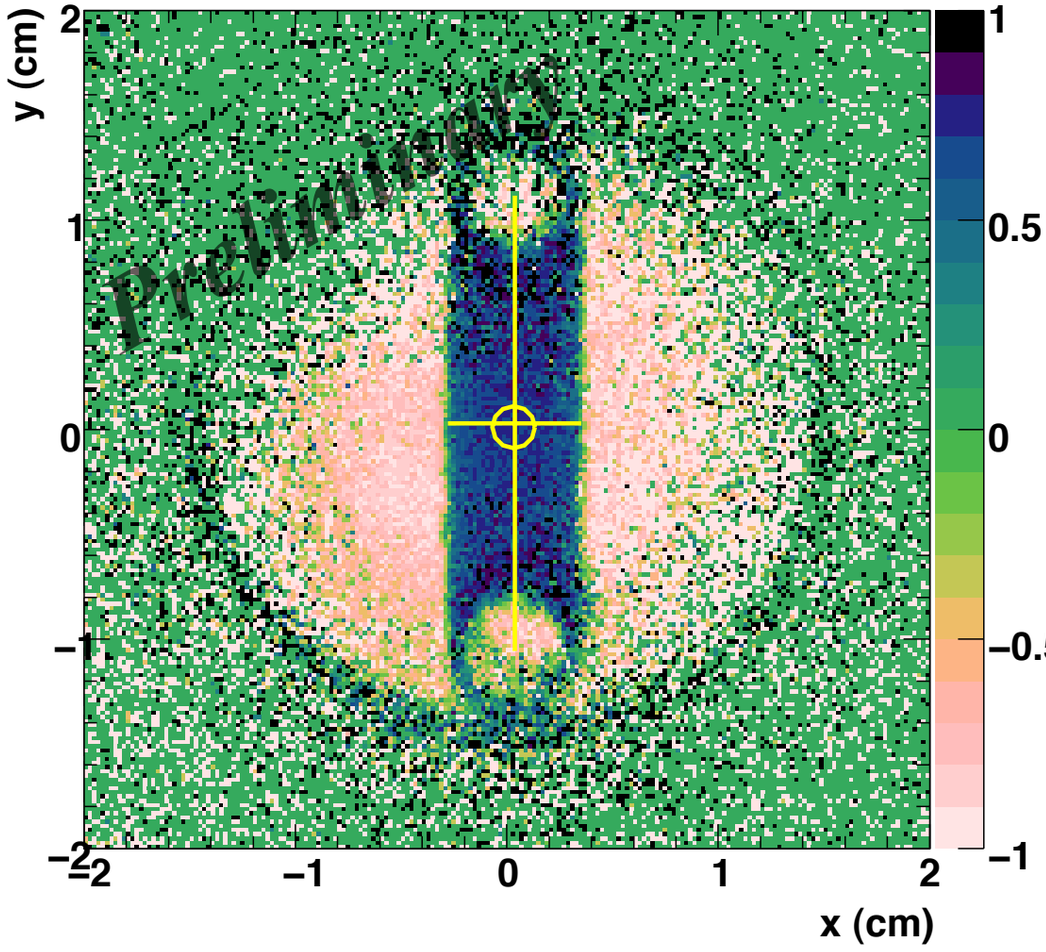
- Ckov light ring formed on array of ~2300 1/2” PMTs.
- Ring radius ~ Ckov angle ~ velocity.
- 3σ π/K and 3σ p/K separation up to 80 GeV/c

NuMI Target Analysis

NuMI Target Analysis

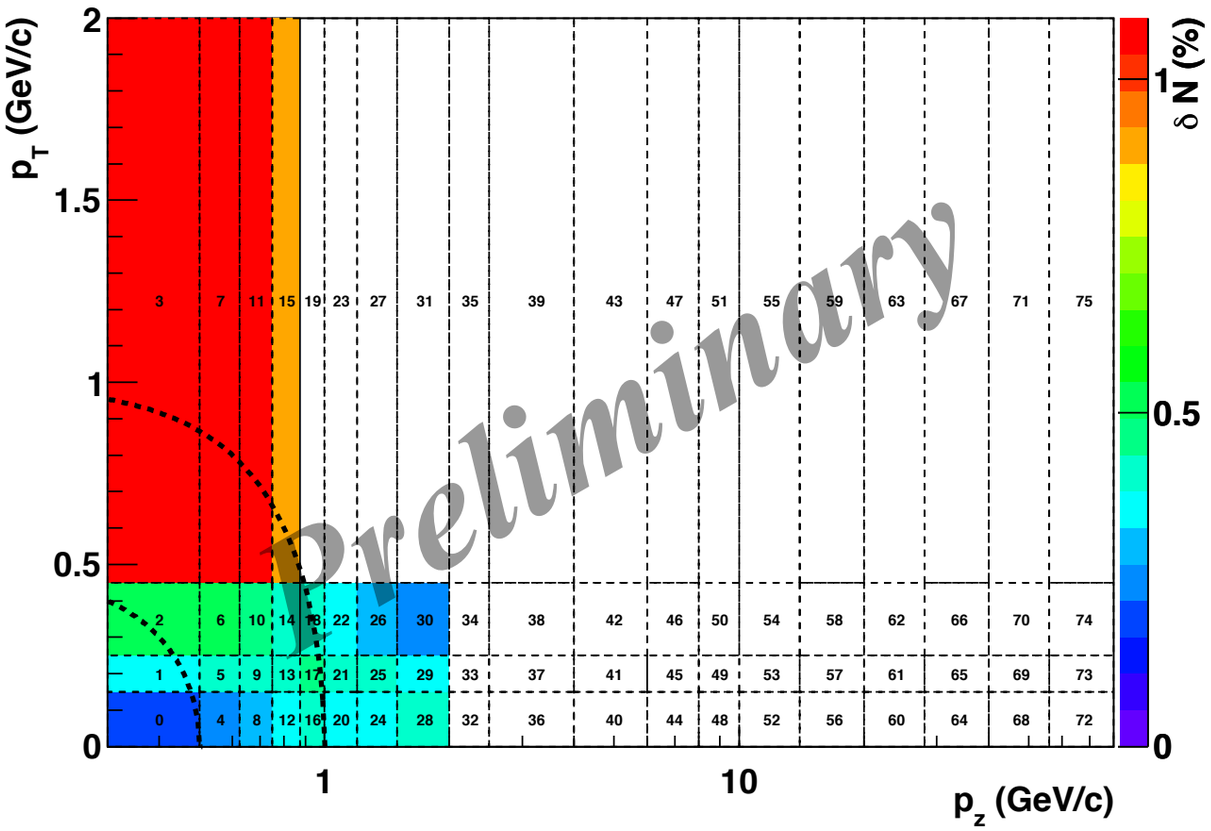
- Measure pion yield off surface of NuMI target (120 GeV/c p + NuMI).
- $N(\pi^{\pm})/POT$ binned in (p_z,p_T), currently we have 76 bins.



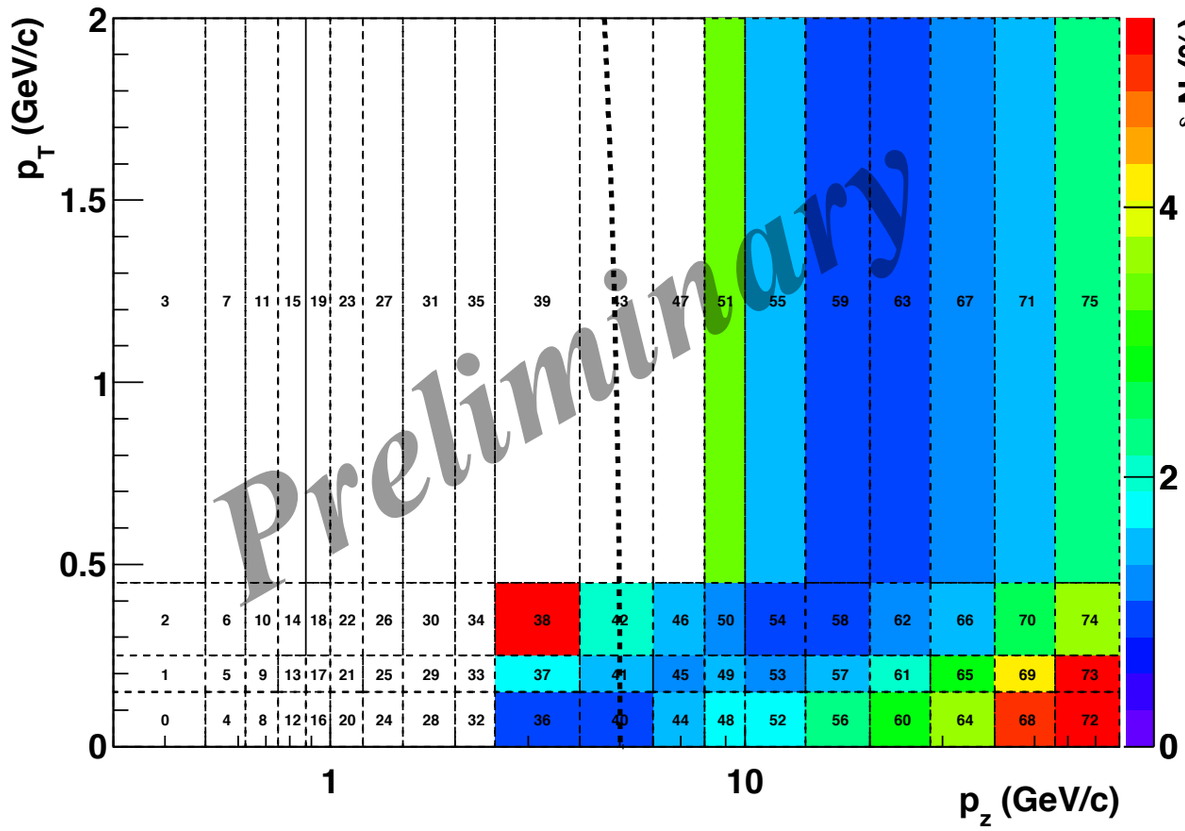


- Event selection finalized
- Will use TPC and RICH particle identification measurements; will investigate possibility of including ToF data

Estimated Statistical Uncertainties



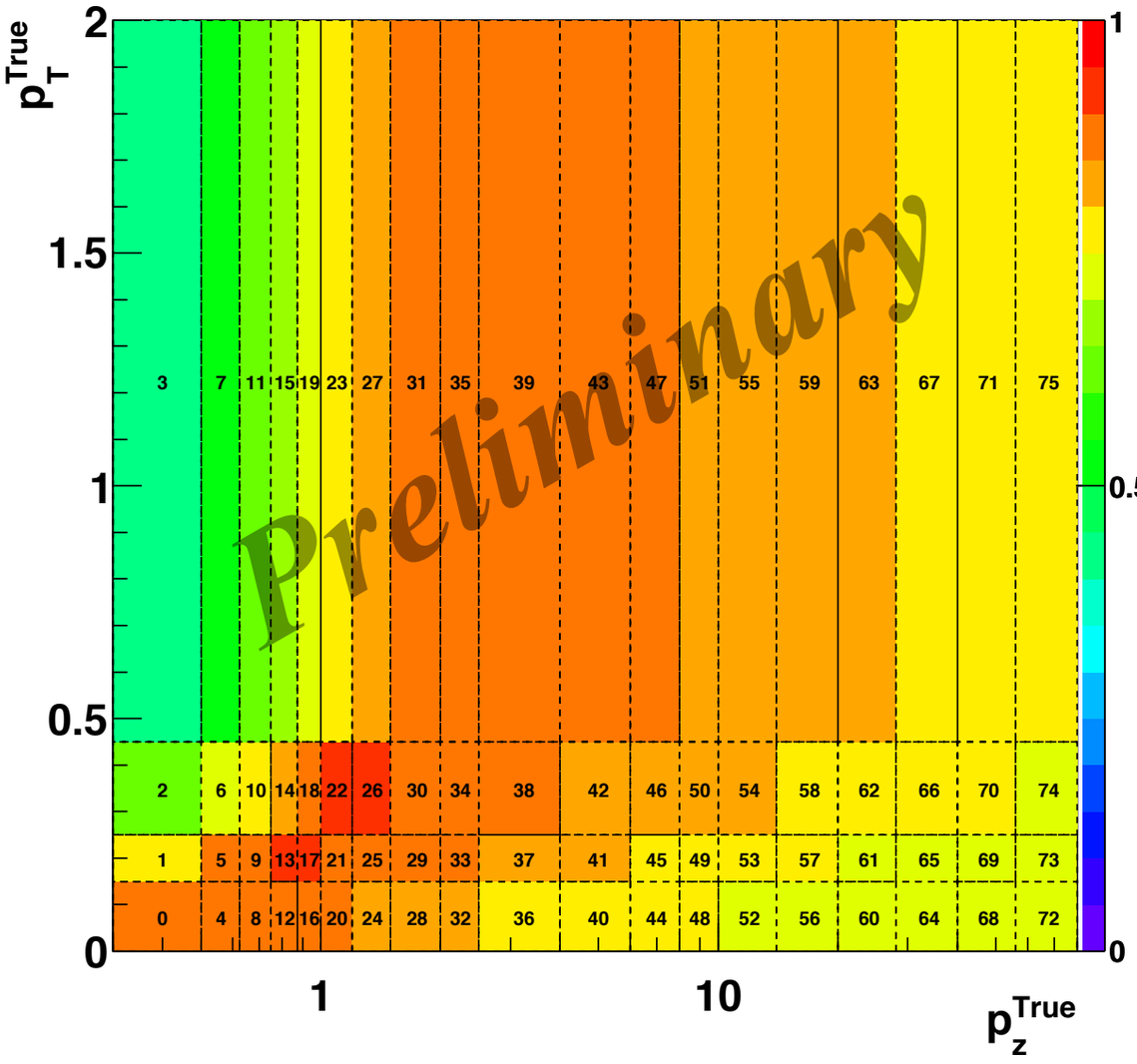
Maximum statistical uncertainty
based on number of TPC tracks.

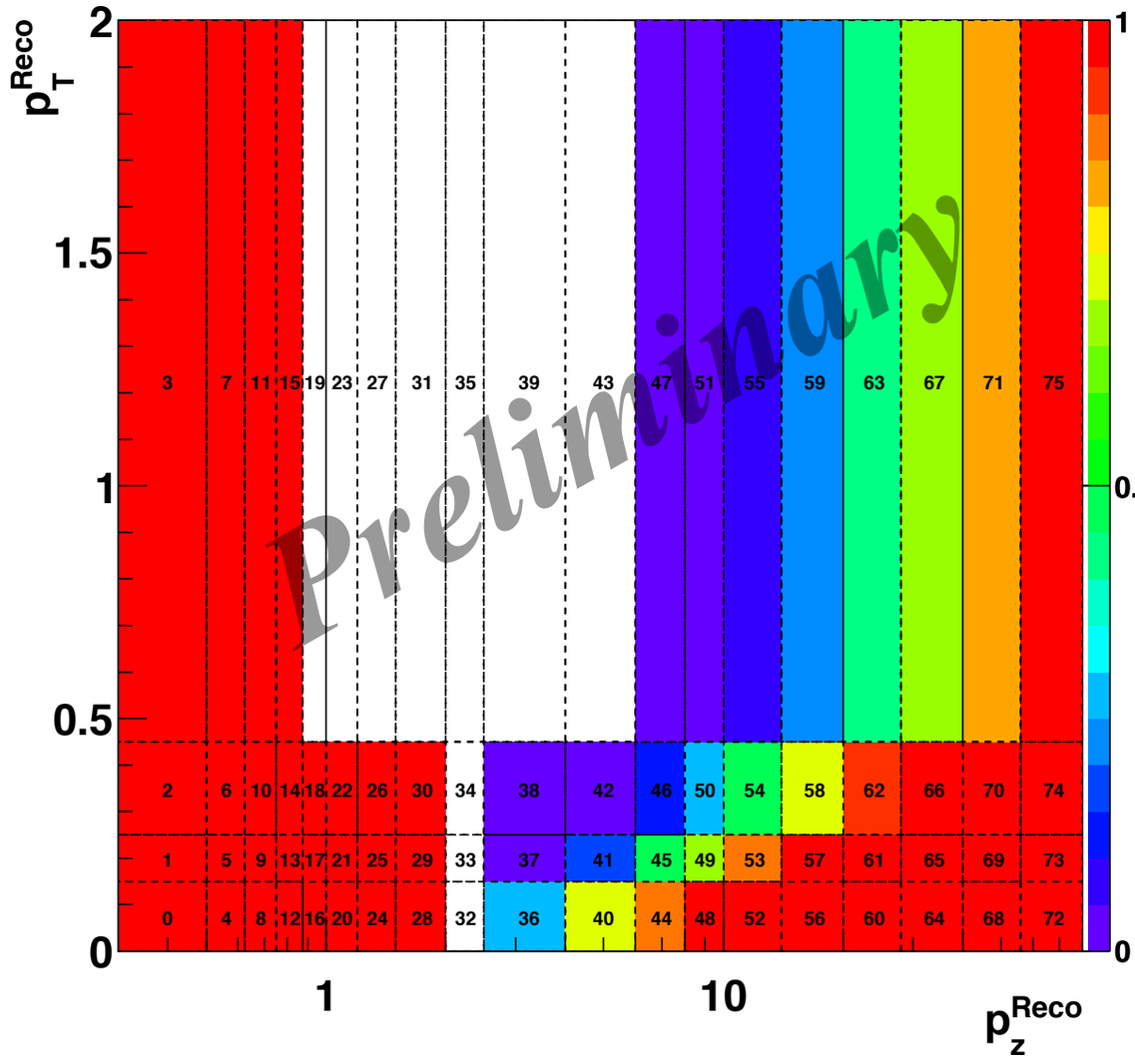


Maximum statistical uncertainty
based on tracks matched to RICH rings.

- To get an idea of how well we can do in each bin, we assume 70% of tracks that have PID information is a pion.
- Expected statistical uncertainties are below 6% everywhere for *positively charged* tracks with TPC and RICH PID information. Negatively charged tracks are slightly worse.

Acceptance Corrections





- Geometric acceptance (fraction of true particles matched to a reconstructed track) is typically 75-85%

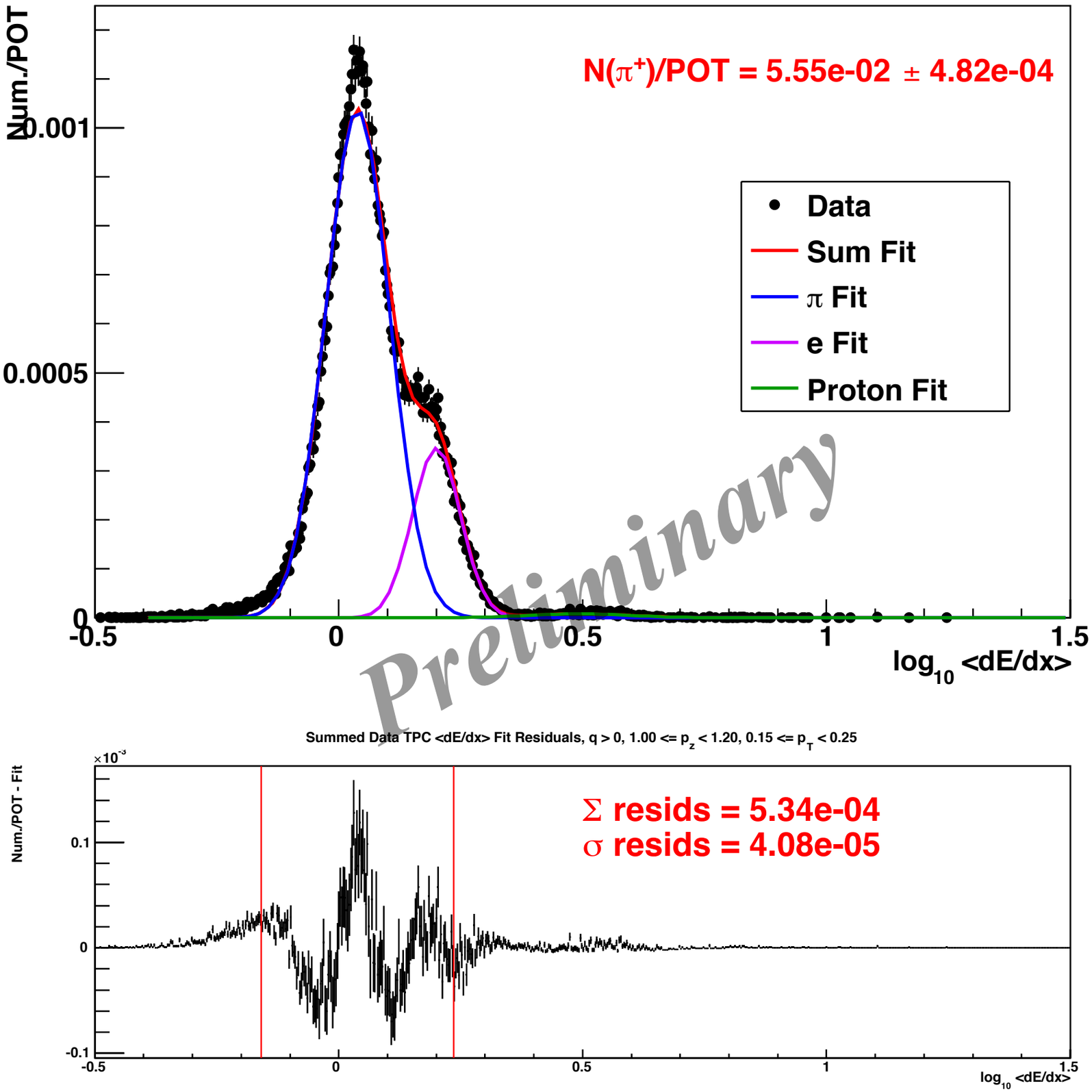
- PID acceptance is the fraction of reconstructed tracks that made it into a PID detector. Acceptance for TPC tracks is 100% by definition.

TPC PID Measurements

- *log(<dE/dx>)* distributions appear to be Gaussian in bins of p_{TOT}, and "very" Gaussian in most (p_z,p_T) bins.
- Approach is to fit these distributions to sum of 4 Gaussians
- TPC fits: function is 3-Gaussian sum, kaons are negligible

$$N(x) = A_\pi \left(f_{e\pi} \exp(\frac{(x-x_e)^2}{2\sigma_e^2}) + \exp(\frac{(x-x_\pi)^2}{2\sigma_\pi^2}) + f_{p\pi} \exp(\frac{(x-x_p)^2}{2\sigma_p^2}) \right)$$

  - "x" = log(<dE/dx>)
  - $f_{e\pi} = A_e/A_\pi$, $f_{p\pi} = A_p/A_\pi$
  - widths are constrained to be "physical", means are constrained to be close to expected values from MC
- Positive and negative particle distributions are fit independently for now.



- N(π) = integral of Gaussian corresponding to pion peak. Uncertainty derived from fit parameter uncertainties.
- The extent to which any non-Gaussian feature(s) of the distribution effects the N(π) can be estimated by looking at the integral of the residuals over the range of the pion peak. Very small effect observed.

RICH PID Measurements

- These measurements can trivially be converted to m^2 distributions, but do not appear to be very Gaussian.
- Approach is to "cut and count". Split m^2 distribution in each (p_z,p_T) bin into three regions: 1 "mostly" signal + 2 "mostly background" sidebands.

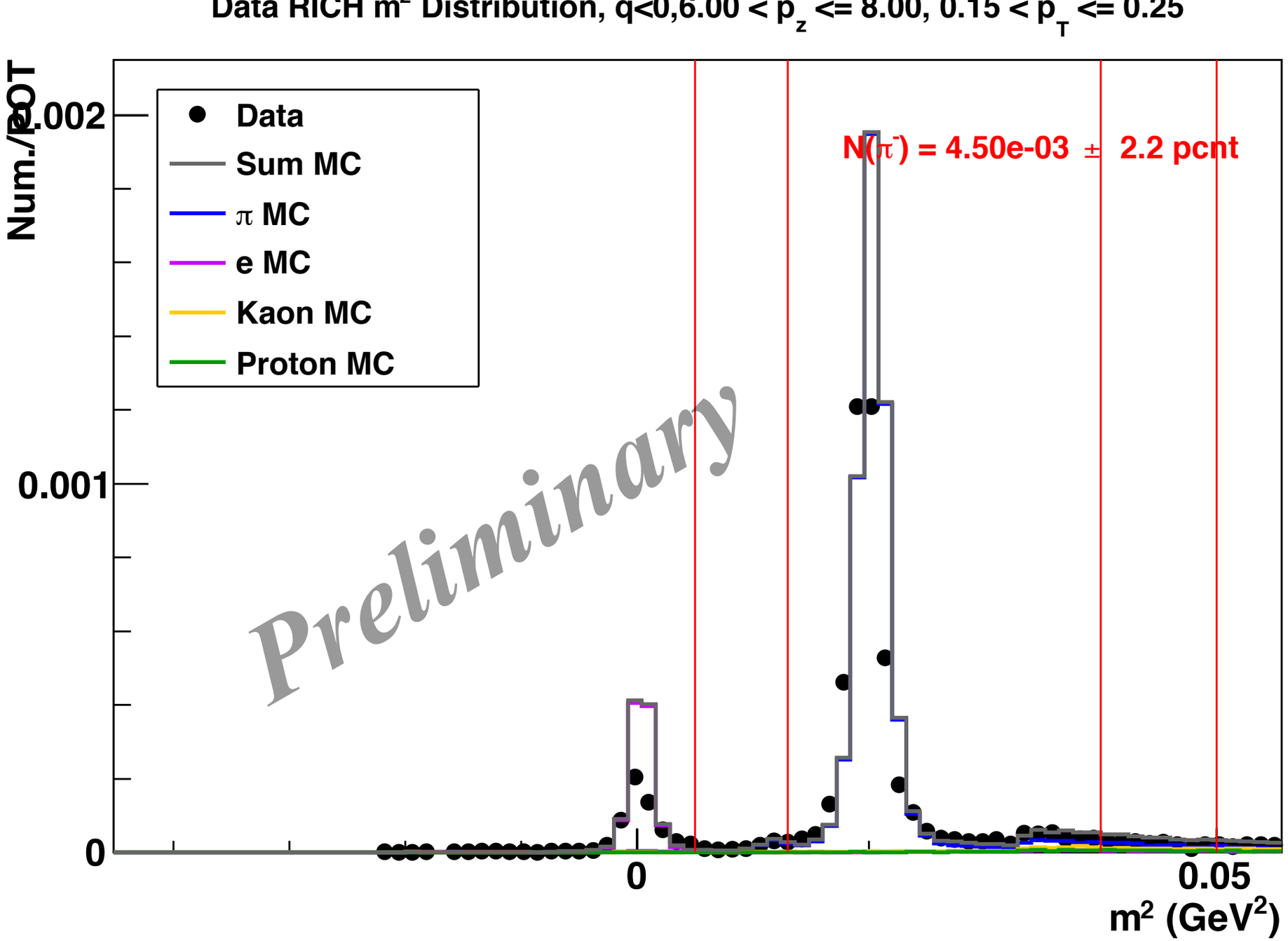
$$N_\pi = \sum_i N_{\pi_i} \qquad \sigma_\pi^2 = \sum_i \sigma_{\pi_i}^2$$

$$N_{\pi_i} = N_i - b_i \bar{N}_i \qquad b_i = \frac{B_i}{\bar{S}_i + \bar{B}_i}$$

Data → N_i, $\bar{N}_i$; MC → B_i, $\bar{S}_i$, $\bar{B}_i$

$$\sigma^2_{N_{\pi_i}} = N_i + \bar{N}_i b_i^2 (1 + \bar{N}_i \delta b_i)$$

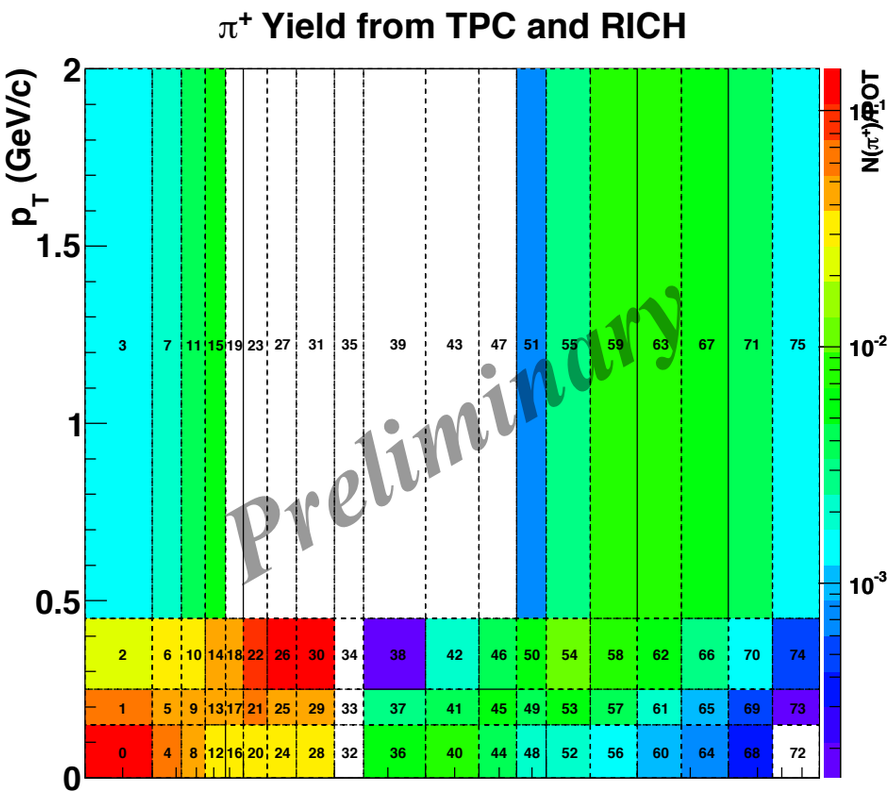
- Set δb_i = 30%

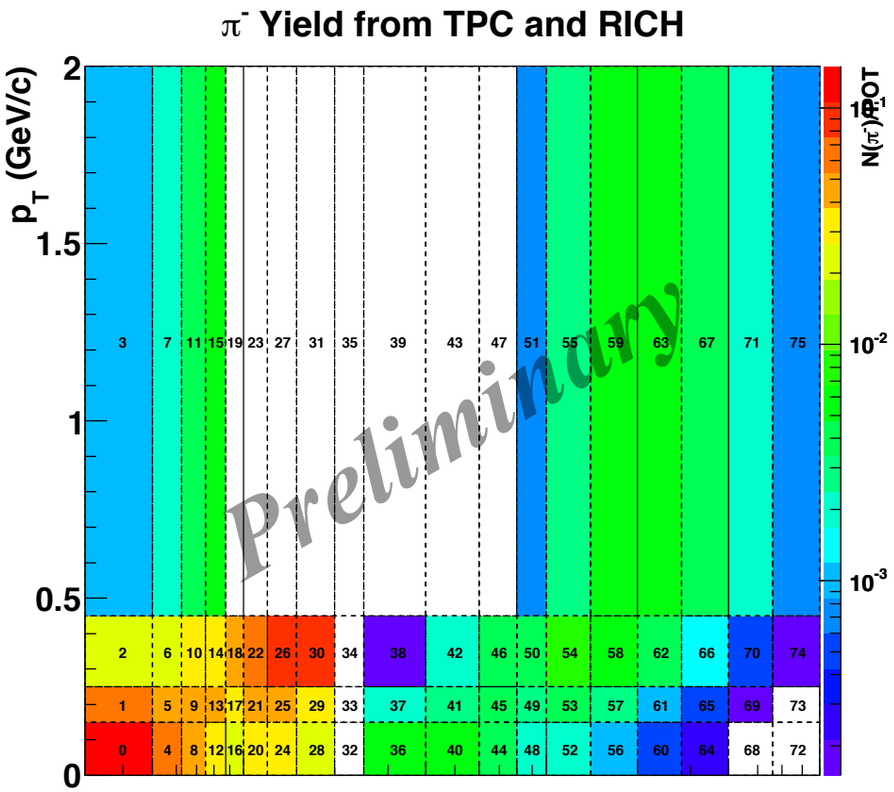


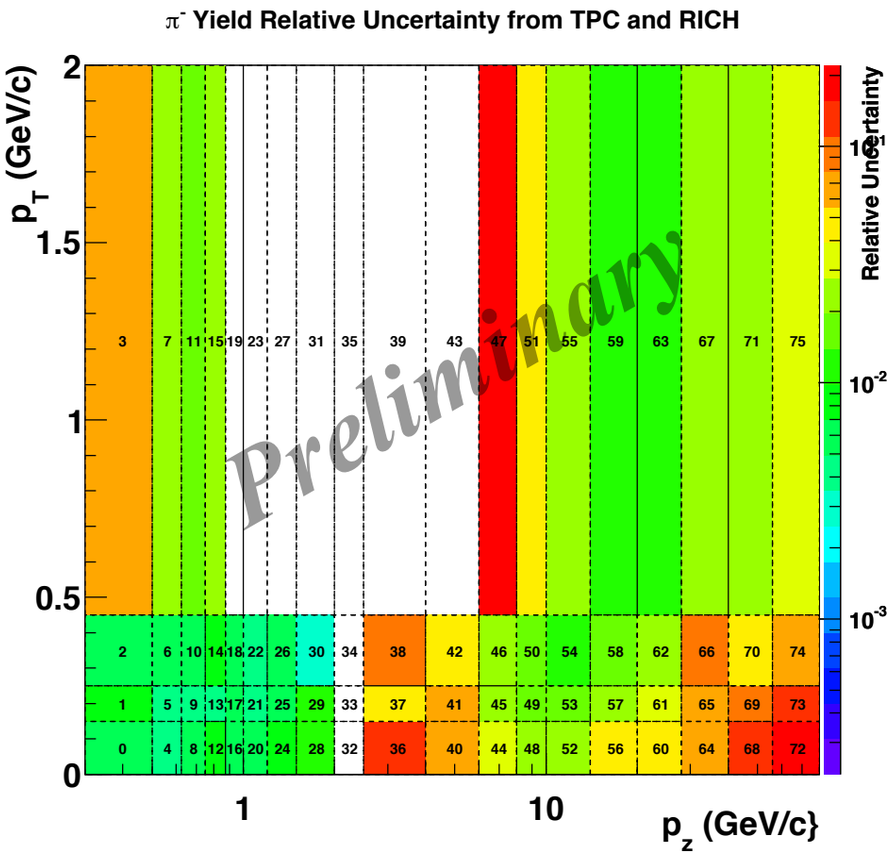
- MC is used to determine ranges for cut-and-count approach, as well as to estimate backgrounds in the 3 regions defined by the red lines.

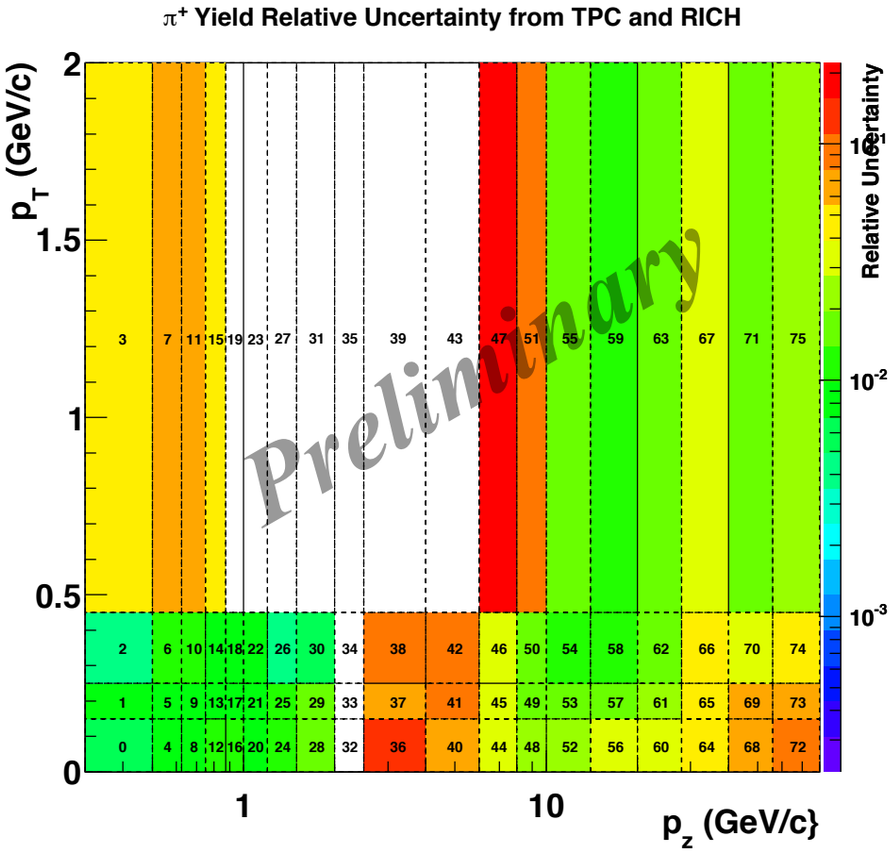
- Error shown here is combined statistical and systematic (background subtraction).

Uncorrected π Yields and Uncertainties



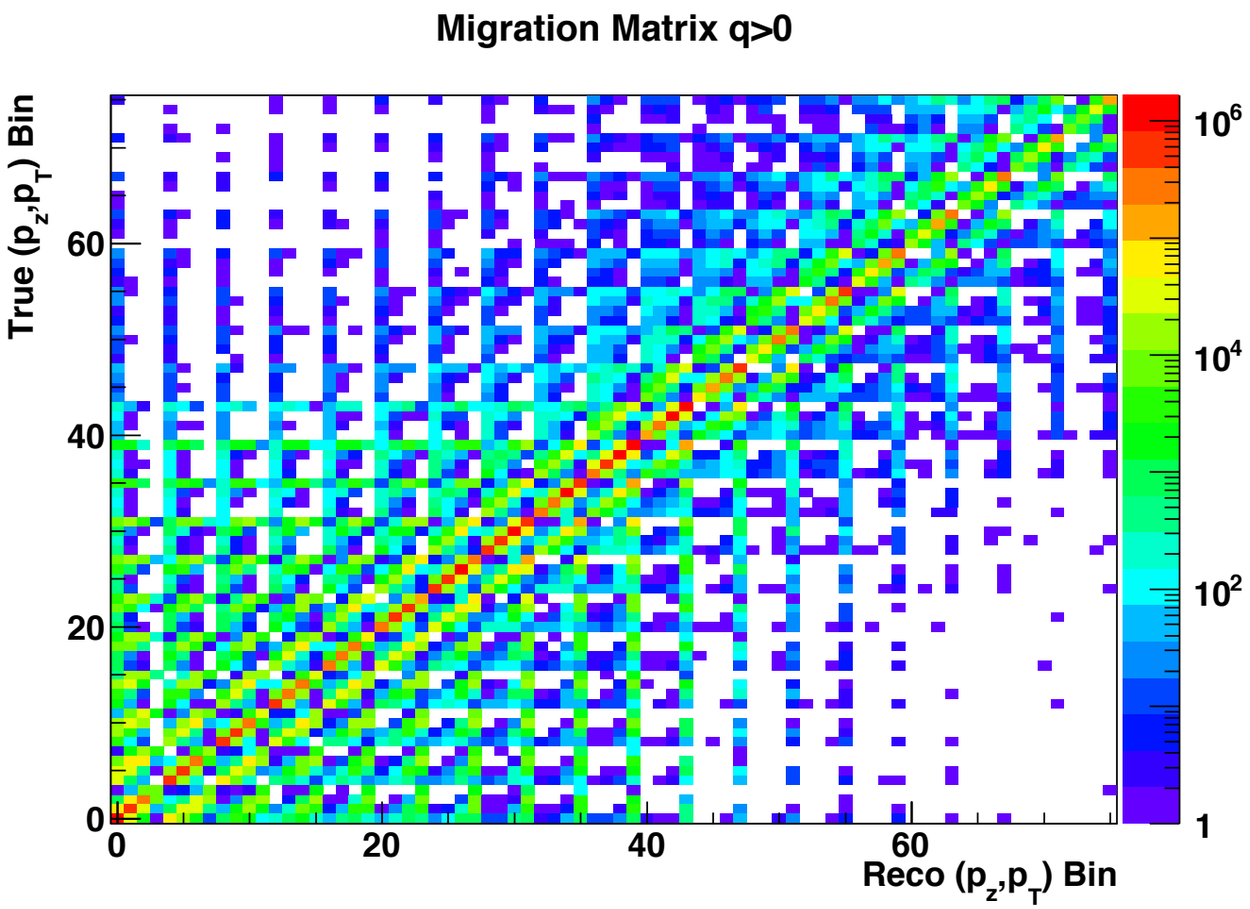


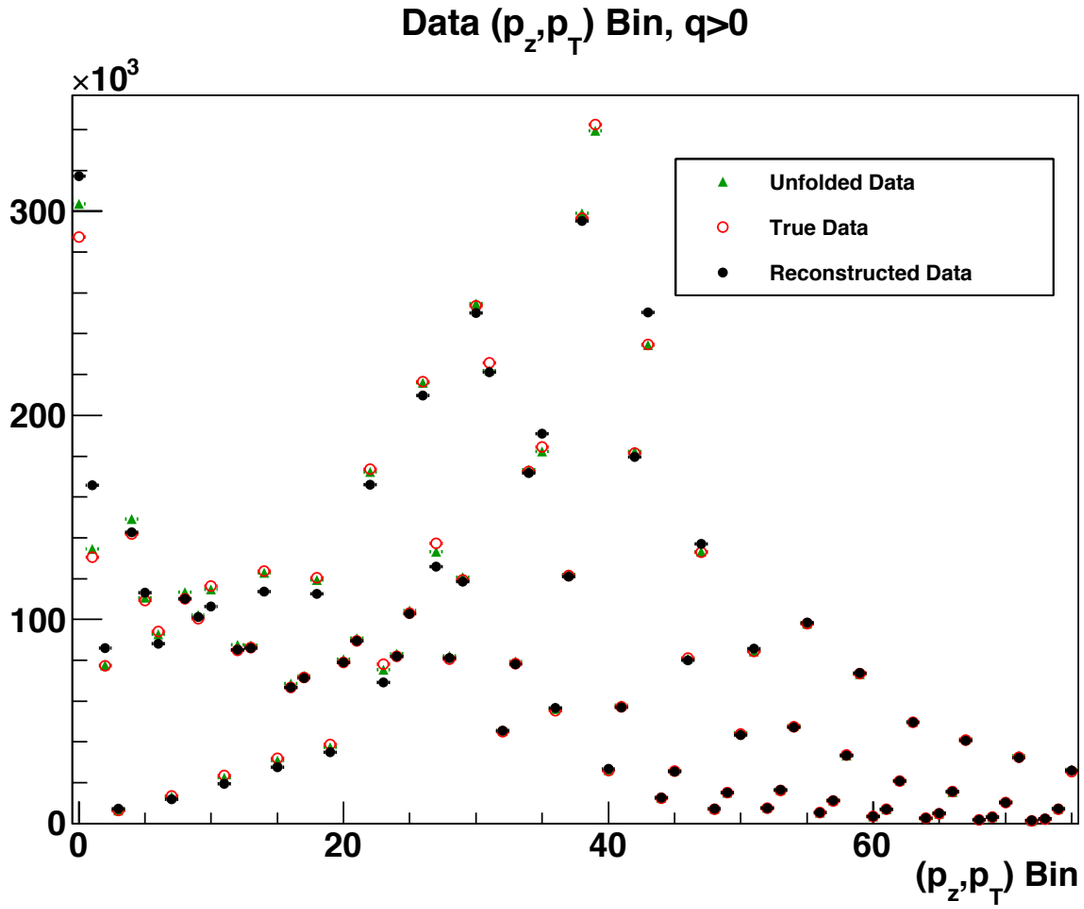




- Uncorrected for acceptance, etc.
- Uncertainties are combination of statistics and systematic of contribution from non-pion background
- Relative uncertainties are mostly < 10%
- Uncertainties > 10% dominated by statistics.

Reco → True Unfolding





- Make use of Root's TSVDUnfold
- Assume that $N(p_z,p_T)_i^{Reco} \rightarrow N(p_z,p_T)_i^{True}$ is good approximation for $N(\pi)_i^{Reco} \rightarrow N(\pi)_i^{True}$
- MC study shows that true and unfolded distributions agree to within 1%.

Summary

- MIPP collected several millions of events of π, K and p beams at various momenta incident on various targets, 1.6 x 10^6 120 GeV protons on an actual NuMI target.
- All MIPP sub-detector systems have been calibrated and the MC tuned to the data. MC/Data PID agreement looks reasonable, but some further fine-tuning is needed.
- Most pieces of the analysis of the NuMI target data are in place for measurement of pion yield across a very broad range of momenta from ~0.5 - 80 GeV/c (> 60 bins of (p_z,p_T)).
- Typical statistical uncertainty in each bin of (p_z,p_T) is <10%
- Systematics still need to be assessed, but expected to be well below 10%
- Plan to also determine kaon production above 20 GeV/c
- Promising independent K^0_s analysis underway (Amandeep Singh)