Possibility of Charged Kaon Mass Measurement Using the MIPP RICH

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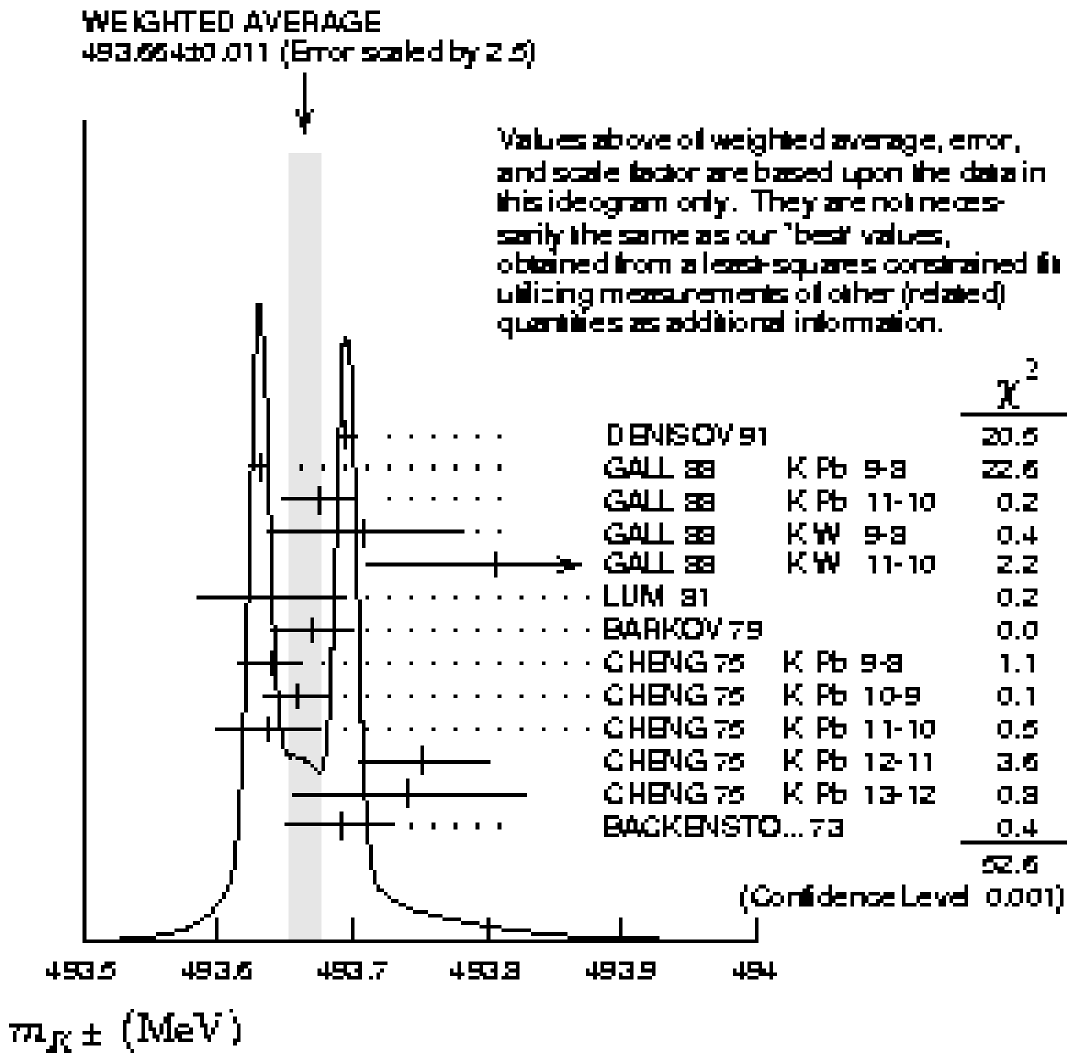
6th International Workshop on Ring Imaging Cherenkov Detectors

October 19, 2007

Current Value in PDG



Source: S. Bidelman et al (Particle Data Group) Phys. Lett. B **592**, 1 (2004)

Currently accepted value of charged kaon mass: 493.677 +/- 0.013 MeV (26 parts per million).

Weighted average of 13 measurements, mostly from kaonic atom x-rays.

Average is dominated by two most recent and precise measurements.

These two measurements, Denisov and Gall, have precisions of 14 and 22 ppm respectively and differ by 122 ppm.

Goal is to help resolve this ambiguity, not compete with the precision of the two best measurements.

Physics Impact

- Affect value of CKM matrix element V_{us} from measurements of the branching ratio of

$K^+ \text{--->} \pi^0 e^+ \nu$

Kaon Mass

Form factor

Phase space integrals

Proportional to B.R.

$$\Gamma_{Kl3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW} (1 + \delta_K^l) |V_{us}|^2 f_+^2(0) I_K^l$$

Radiative Corrections

CKM matrix element

- Impact any particle decay with K^+ in the final state, such as

$K^0 \text{--->} K^+ e^- \nu$

- Branching ratio of the decay

$K^+ \text{--->} \pi^+ \nu \nu$

- Possibly CPT violation using positive and negative data sets?

Basic Concept

Make use of monoenergetic tagged beam of π, K, and p.

Consider the simplified case of representing a ring with a single radius. Then RICH ring radii are correlated via

$$R = F_l \tan(\theta_c) = F_l \sqrt{n^2(\lambda)\beta^2 - 1}$$

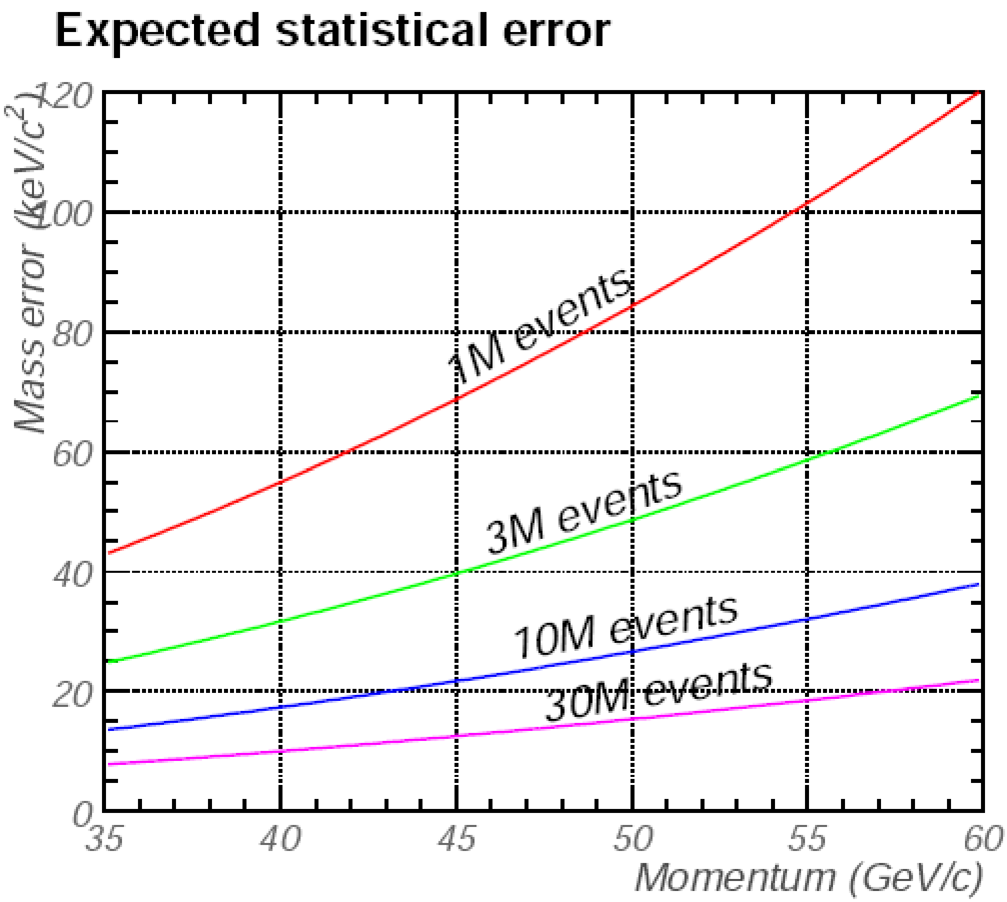
where F_l is the focal length of the mirrors and n is the refractive index of the radiator.

Using the well known proton and pion masses along with the ring radii these particles produce in the RICH is the key to understanding the systematics of this measurement.

Proton Mass : 938.272029 MeV +/- 0.09 ppm
Pion Mass : 139.57018 MeV +/- 2.5 ppm

The precision of these masses is well below what is needed to make an impact on the current charged kaon mass value given the 122 ppm separation of the two dominant measurements.

Expected Statistical Uncertainty



It is best to make measurement at as low momentum as possible. With 10 million events at 40 GeV/c, we expect a statistical uncertainty of 35 ppm, well below the 122 ppm separation of the two best measurements.

Cherenkov angle is approximately

$$\theta = \sqrt{2\left(1 - \frac{1}{n\beta}\right)}$$

Relate two angles by eliminating n

$$\theta_i^2 - \theta_j^2 = \frac{m_j^2 - m_i^2}{p^2}$$

So then express K,p masses as

$$m_K^2 = m_\pi^2 + p^2(\theta_\pi^2 - \theta_K^2)$$

$$m_p^2 = m_\pi^2 + p^2(\theta_\pi^2 - \theta_p^2)$$

Eliminate p to K mass in terms of other two masses and all three angles

$$m_K^2 = m_\pi^2 + (m_p^2 - m_\pi^2)\left(\frac{\theta_\pi^2 - \theta_K^2}{\theta_\pi^2 - \theta_p^2}\right)$$

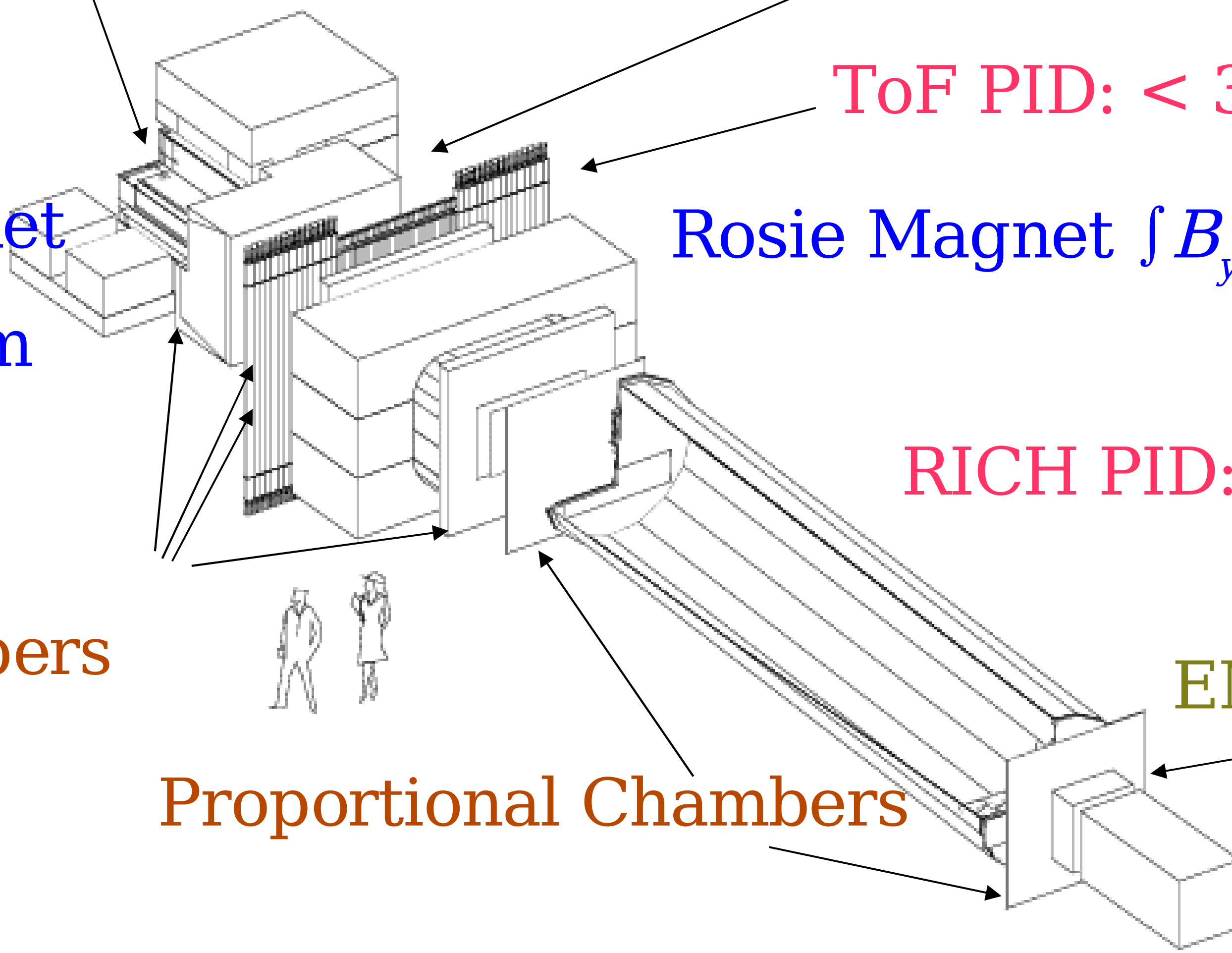
Evaluate derivatives to see that

$$\sigma_{m_K^2} \sim p^2$$

Overview of MIPP

- Main Injector Particle Production (MIPP) is a fixed target experiment at Fermilab.
- Large acceptance spectrometer to measure hadronic particle production.
- Secondary beam of tagged $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ from 5 to 85 GeV/c with various targets such as liquid hydrogen, Be, C, Bi, and U.
- Applictions for data:
  - Improve hadron shower models in Fluka, Geant4, MARS
  - Non-perturbative QCD
  - Relativistic heavy ion physics
  - Nuclear physics
- Primary 120 GeV/c beam from the Main Injector for service measurement of NuMI target.
- Charged kaon mass measurement was proposed as best use of beam when our analysis magnets went down.

Spectrometer Geometry

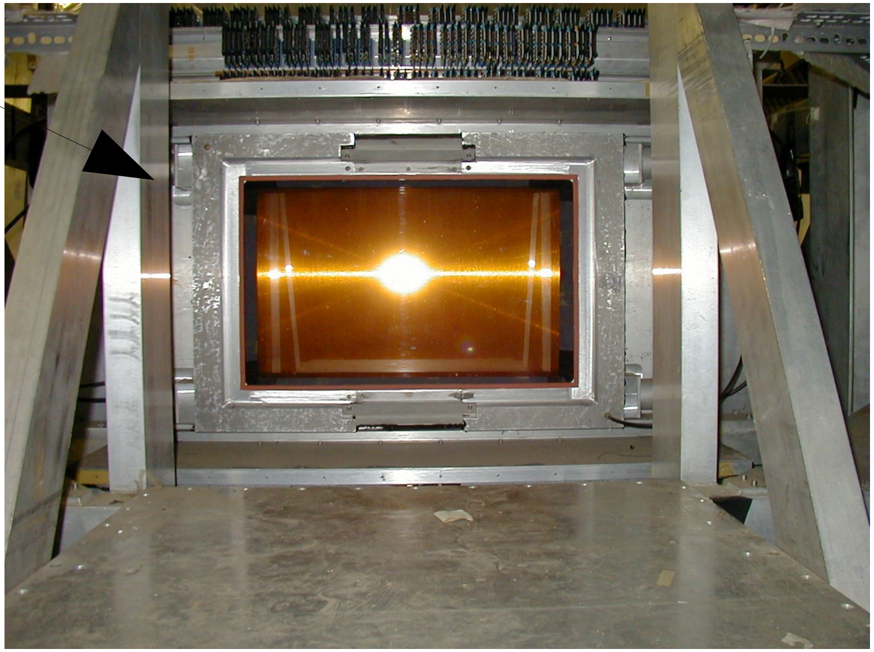


Detectors Used for Kaon Mass

• Beam Cherenkov – Two cylindrical threshold Cherenkov counters tag incoming beam particles.

• Beam Chambers – Three mini drift chambers track beam before it reaches MIPP spectrometer.

• DC – Four drift chambers provide tracking through analysis magnets, which were off for most of dedicated kaon mass running.



• MWPC – Two muti-wire proportional chambers extend tracking through RICH.

• Hadronic Calorimeter

All other detectors turned off to increase data rate.

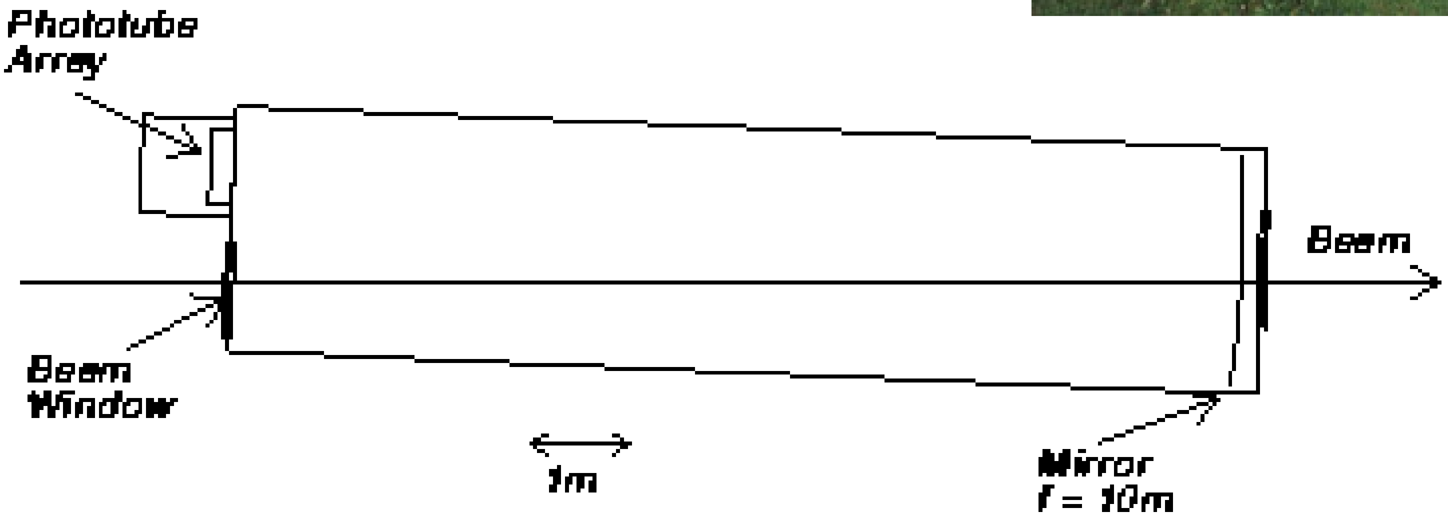
RICH

Built for Selex experiment at FNAL.

Cylindrical steel vessel is 10.22 m long, 93 in. diameter and ½ in. wall thickness. End flanges are 1.5 in. thick aluminum with cutouts for thin beam windows.

Radiator is CO_2 maintained at a pressure of approximately 1.05 atm.

Array of 16 hexagonally shaped spherical mirrors. Focal length deviation of < 5 cm RMS between mirrors.



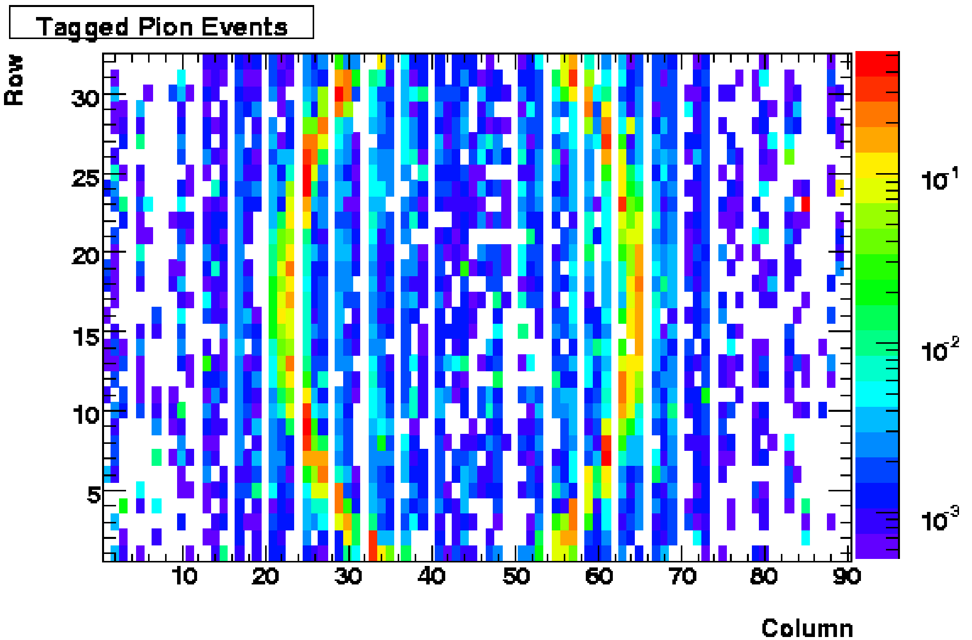
3σ π/K separation up to 80 GeV/c

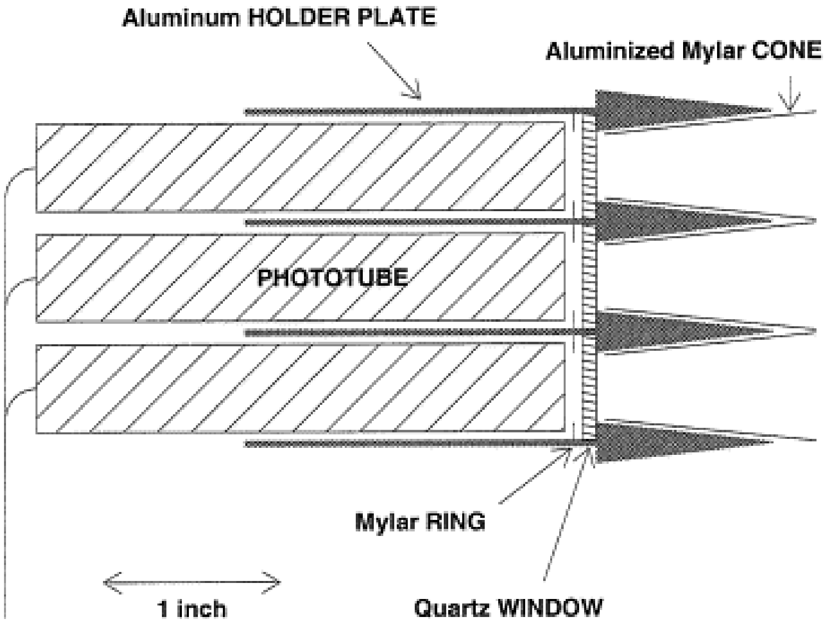
3σ p/K separation up to 120 GeV/c

RICH Phototubes

Array of 2176 ½ inch phototubes in 68 columns of 32 each distributed more densely near the center.

15 columns Hamamatsu, 53 FEU which are ~ ½ as efficient and covered with UV shifting coating to match Hamamatsu.





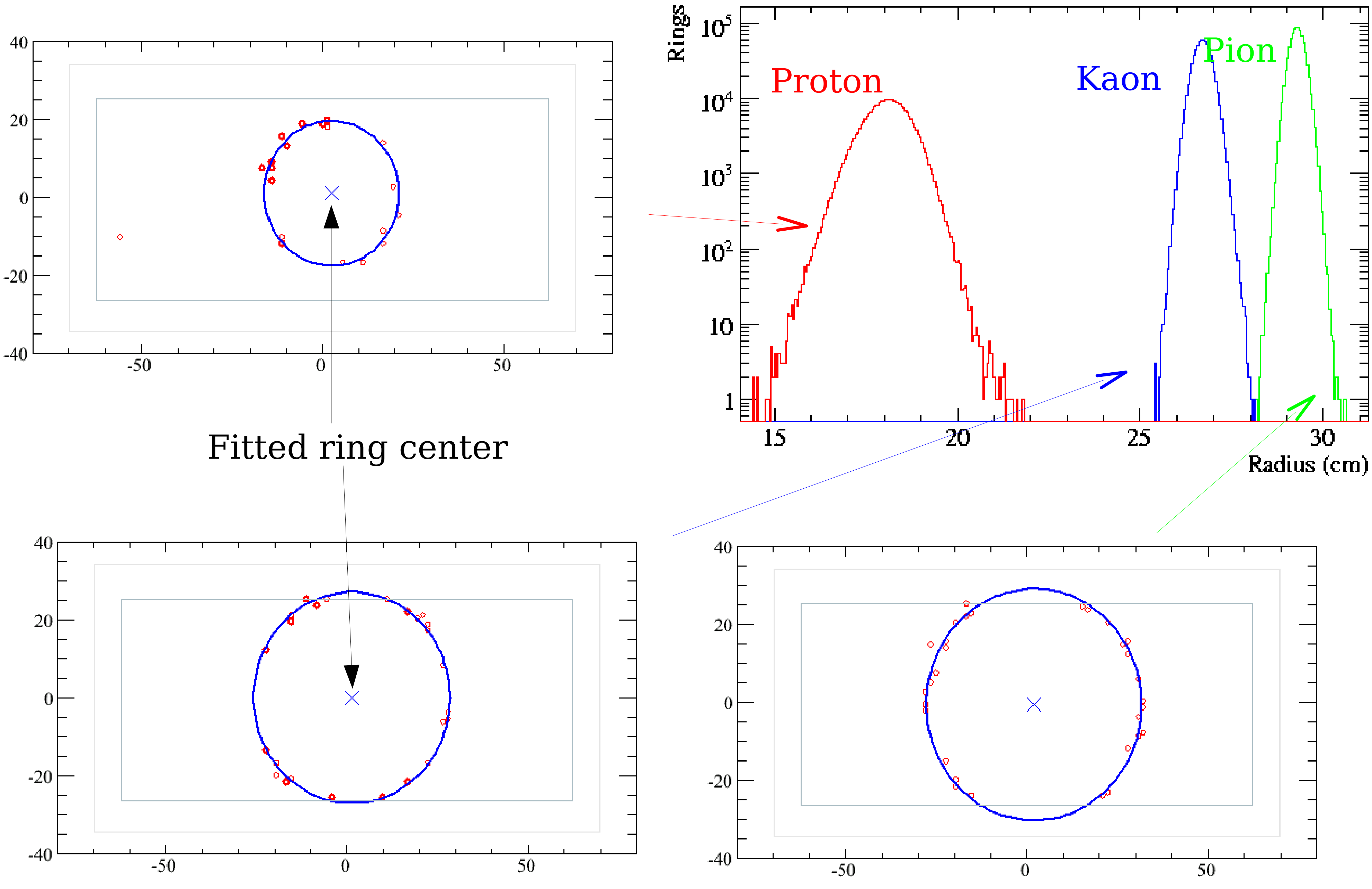
Breakdown of Data

Data for charged kaon mass measurement was taken opportunistically during times in which the analysis magnets were down. As a result there are different momentum settings.

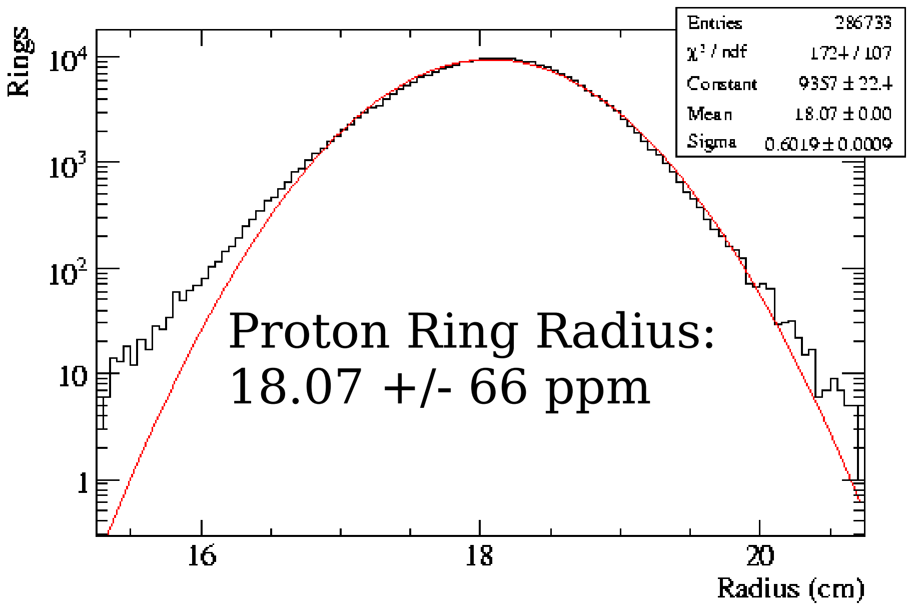
Beam Momentum Setting	Kaon Triggers	Pion Triggers	Proton Triggers	Beam Triggers	Total
40 GeV/c	0.90	1.01	0.93	0.38	2.88
37.5 GeV/c	0.59	0.60	0.48	0.02	1.69
42.5 GeV/c	0.28	0.28	0.34	0.01	0.91
60 GeV/c	0.90	1.10	0.73	1.96	4.69
56 GeV/c	0.12	0.12	0.71	0.18	0.50
63 GeV/c	0.17	0.19	0.18	0.42	0.96
-60 GeV/c	0.61	0.50	0.53	1.07	2.70
Total	3.59	3.79	3.26	3.69	14.33

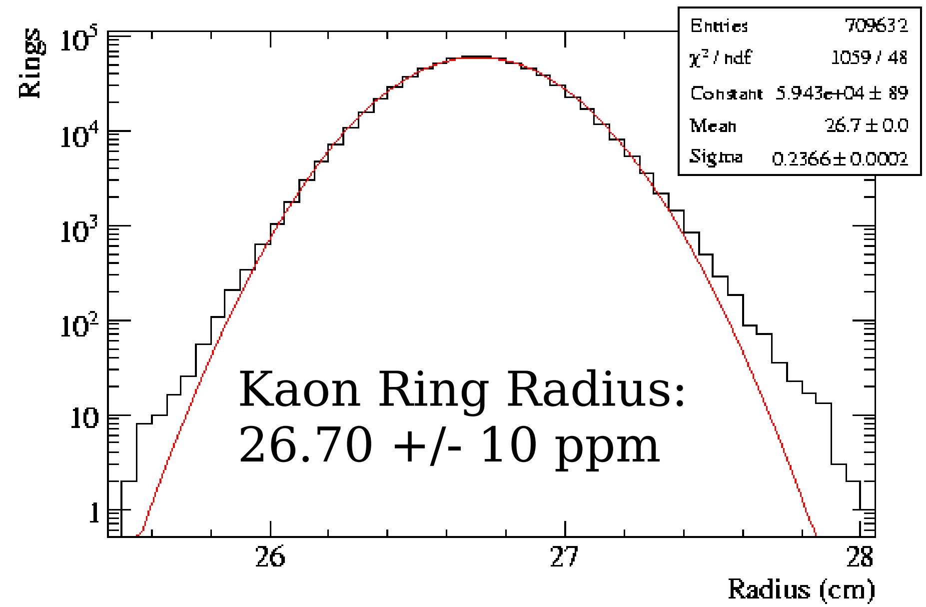
Total of 14.3 million events from dedicated running. More beam data from the rest of the MIPP data set is available for analysis if time permits.

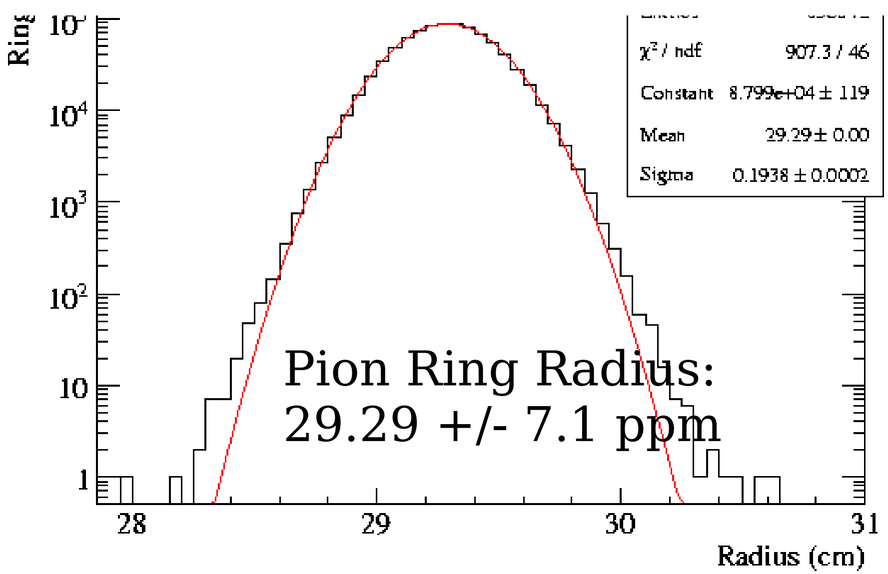
Sample Events



Radius Distributions







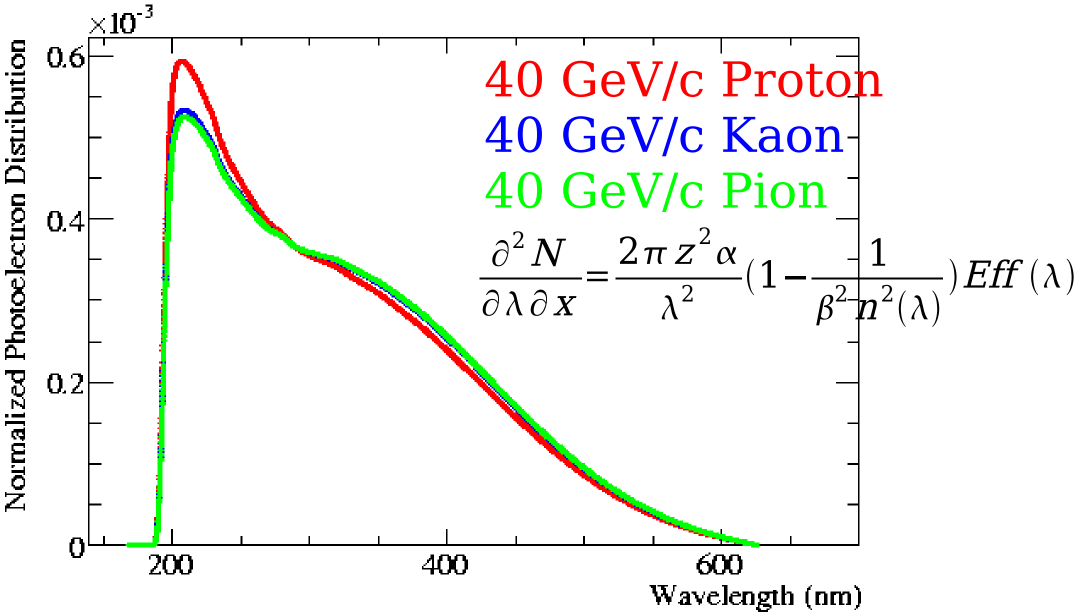
Distributions are for 40 GeV/c data set. With only 3 million events, pion and kaon radii can be measured to at least 10 ppm statistical uncertainty.

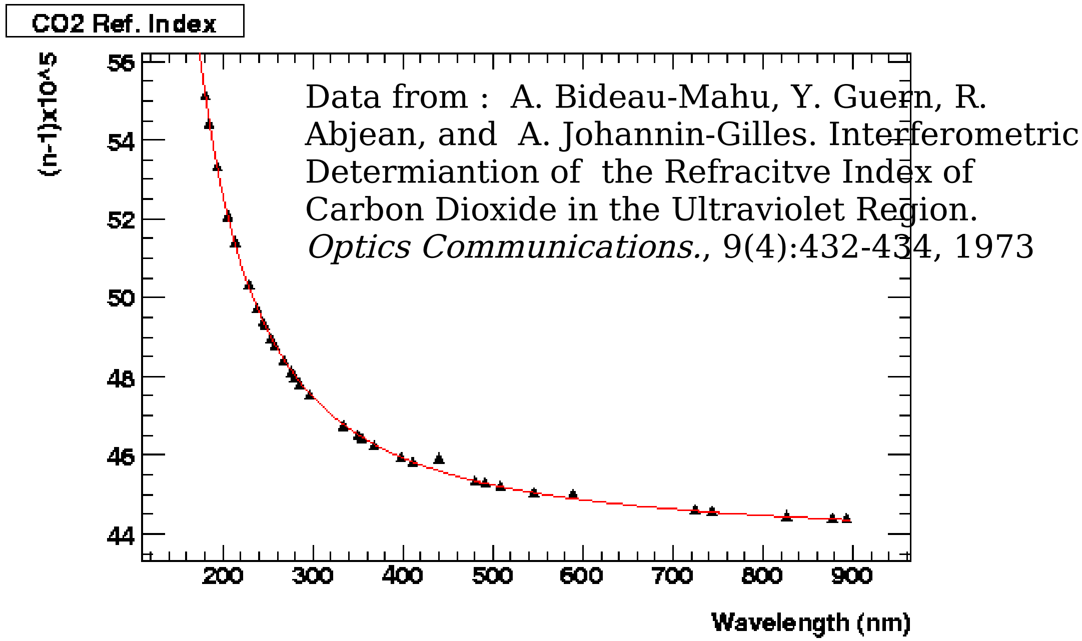
Proton radius is less well known, though combining with other data sets will reduce statistical uncertainty on final charged kaon mass value.

Systematic Uncertainties

Proton, pion masses key to fully understanding systematics, which are under study.

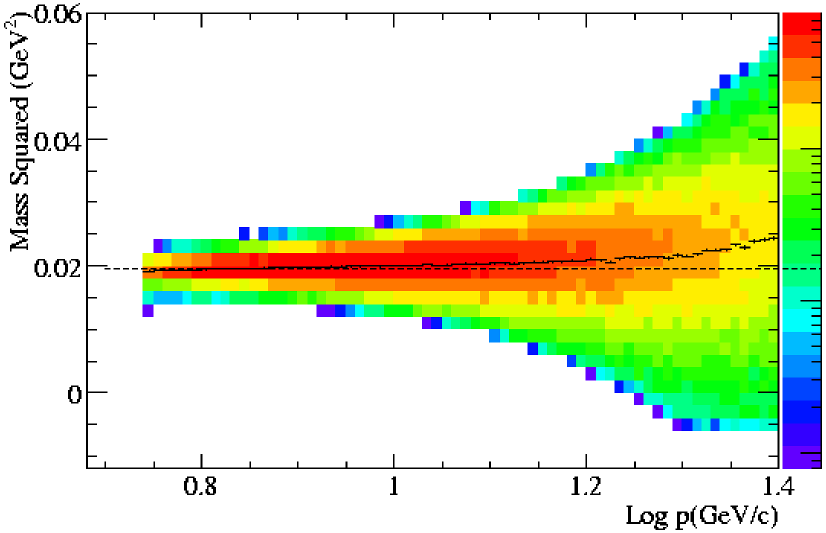
- Effects of dispersion in the radiator.
- Light sharing between adjacent mirrors with different focal lengths.
- Differences in π, K, p production spectra from primary target.
- Scattering of photons.
- Ring Fitter Bias
- Air contamination and variations in gas density affect index of refraction.
- Spurious PMT hits from noise.



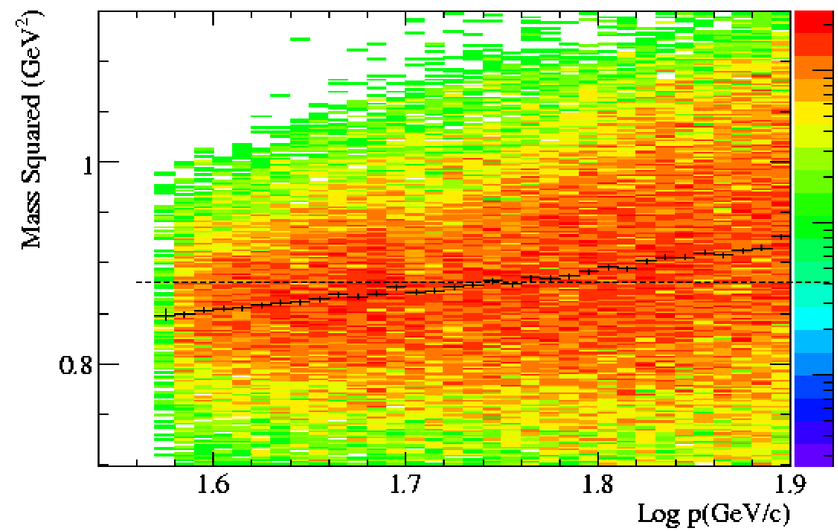


RICH Density Calibration

Results of RICH density calibration using secondaries from the entire MIPP data set show an improvement in calculated proton and pion mass squared.

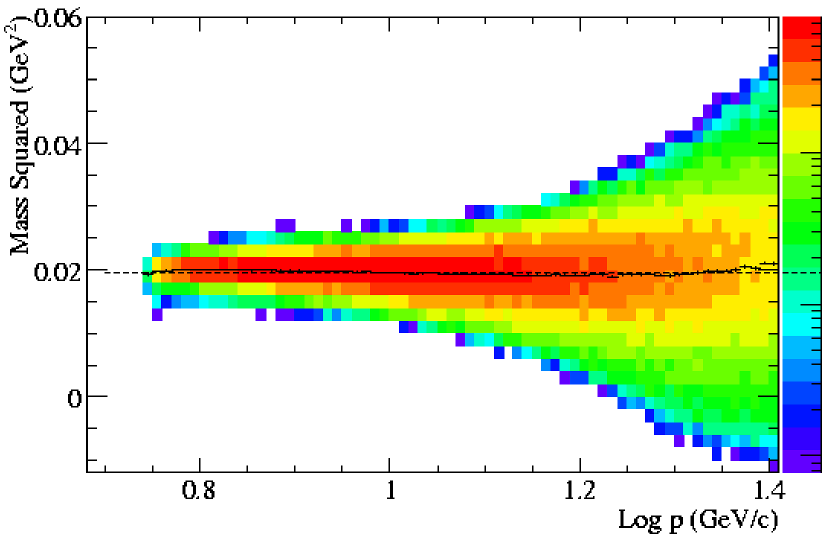


Before Calib.

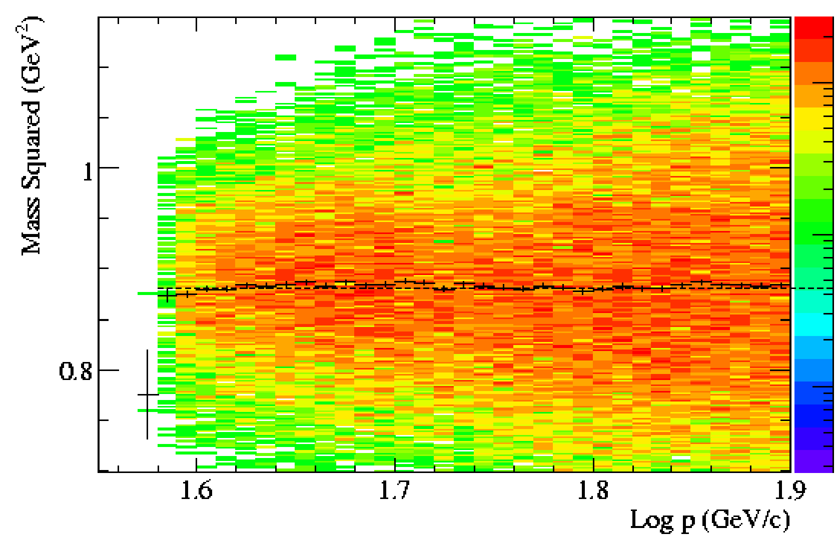


Pion Mass Squared

Proton Mass Squared



After Calib.



Summary

- The charged kaon mass is dominated by two precise measurements (14 and 22 ppm respectively) which disagree by 122 ppm.

- A better knowledge of K^+ mass will have an affect on V_{us} from the decay: $K^+ \dashrightarrow \pi^0 e^+ \nu$.

- Given the amount of statistics available to MIPP it is possible to make a measurement using the RICH with a small enough statistical uncertainty to have an impact.

- The well known values of proton and pion mass are the key to making this measurement and understanding the systematics, which are currently under study.

- Goal is to have the final result by the end of this fall.