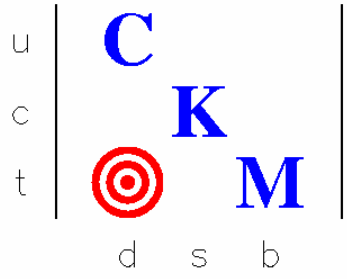
# Redesign of the CKM RICH Velocity Spectrometers for use in a ¼ GHz beam



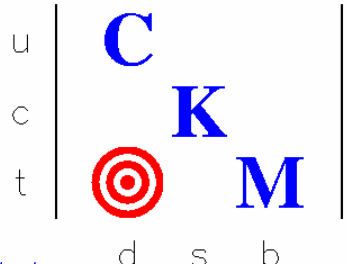

How we're **Still** going to measure $K^+ \to \pi^+ \nu\ \bar{\nu}$

***Peter S. Cooper, Fermilab***

***December 2, 2004***

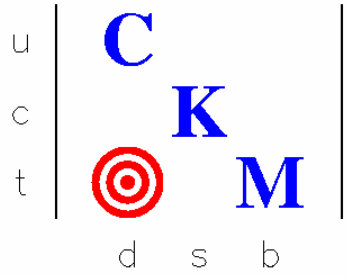
I. Recent history.
II. Physics goals and requirements.
III. Redesigns for the K and π RICHes
IV. Conclusions

# CKM Status and Plans




- CKM(E921) at Fermilab is an approved experiment to measure Br[ $K^+ \rightarrow \pi^+ \nu \nu$ ] with 100 signal / <10 background in a high flux separated kaon beam at 22 GeV/c
- **P5** stops **CKM** - Oct 2003
  - P5 judged *CKM to be an elegant world class experiment* which *based on present budgetary models should not proceed*.
- Adapt to an unseparated ~45 GeV/c beam in KTeV hall - **P940**
  - Demonstration of μMegas in NA48 → tracking in 230MHz tractable
  - Other 3 trackers largely unchanged (2 RICHes + Straws in vacuum)
  - Vetoing photons gets easier ($E_{\pi^0} > 1$ GeV → >7 GeV )
  - Accidental backgrounds?
  - ~1/3 cost of CKM

# Measuring $|V_{td}|$ with $K^+ \to \pi^+ \nu\bar{\nu}$




- $K^+ \to \pi^+ \nu \bar{\nu}$ is the best way to measure $|V_{td}|$ in the Standard Model
  - Structure of $K^+$ controlled by measurement, NO final state interactions.
  - Theoretical uncertainties are small ($m_{charm}$) and robustly estimated. (~8%)
  - Need 100 signal events with <10 background (6%) to match theory error.
- Experimental Challenge
  - Br[ $K^+ \to \pi^+ \nu \bar{\nu}$ ] = $(8 \pm 1) \times 10^{-11}$ (Standard Model)
  - 3 clean events seen in BNL787 /949 (Br = $15\ ^{+13}_{-9} \times 10^{-11}$)
- The tyranny of tiny decay rates
  - 100 events / $10^{-10}$ (Br) / 1% (acc) = $10^{14}$ K decays must be studied
  - $10^7$ sec/year $\to$ $10^7$ K decay /sec to see 100 in 1 year
  - Need to control background to $10^{-11}$ of all $K^+$ decays

# Challenging the Standard Model of CP Violation

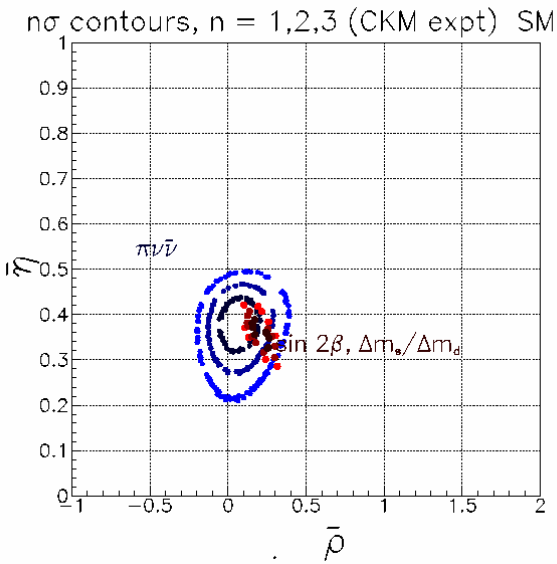
u c t | C K M | d s b

Consider the Quartet of "Golden Mode" measurements:

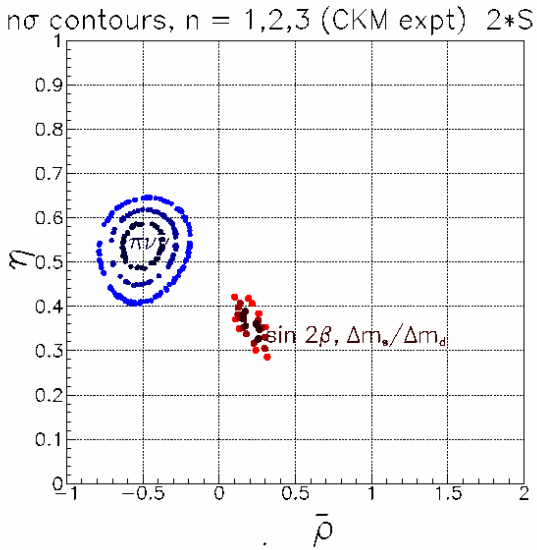
$\sin(2\beta)$, $K^0 \to \pi^0 \nu\bar{\nu}$, $K^+ \to \pi^+ \nu\bar{\nu}$,

$\Delta m_d / \Delta m_s$ in $B_d^0$ and $B_s^0$ Decays

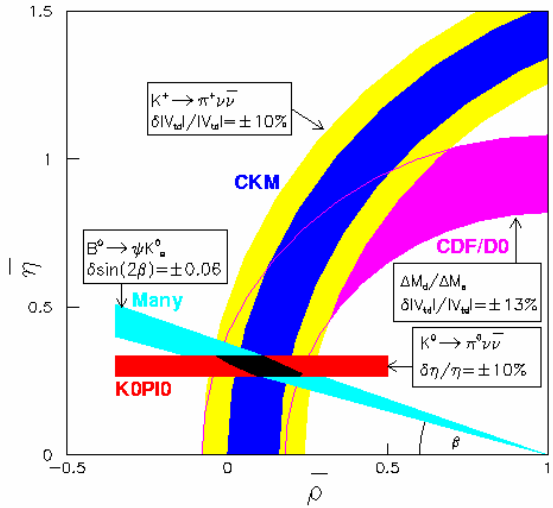
$\Gamma(\pi\nu\nu)$ = SM




$\Gamma(\pi\nu\nu)$ = 2xSM

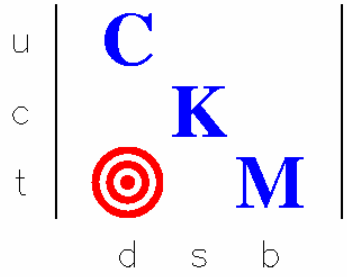



expected sensitivities




CKM Fitter Results, D. Jaffe (BNL).

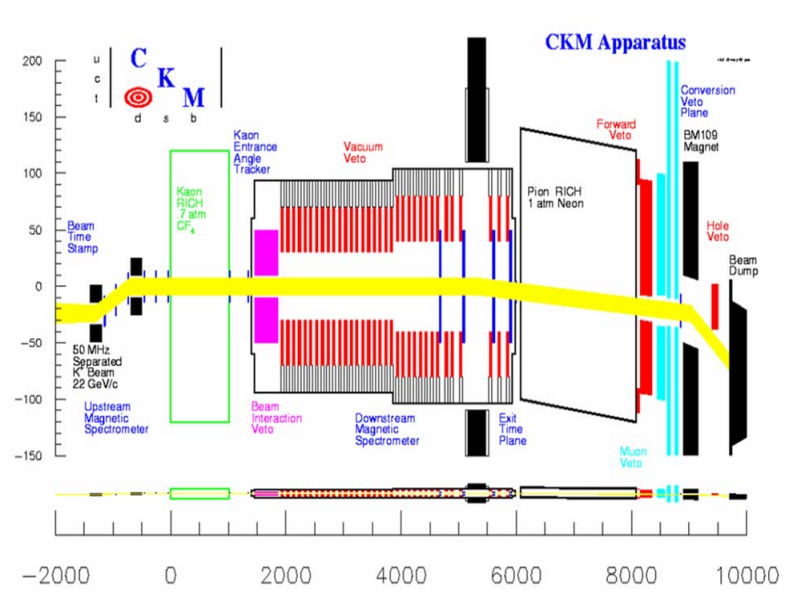
# Experimental Technique

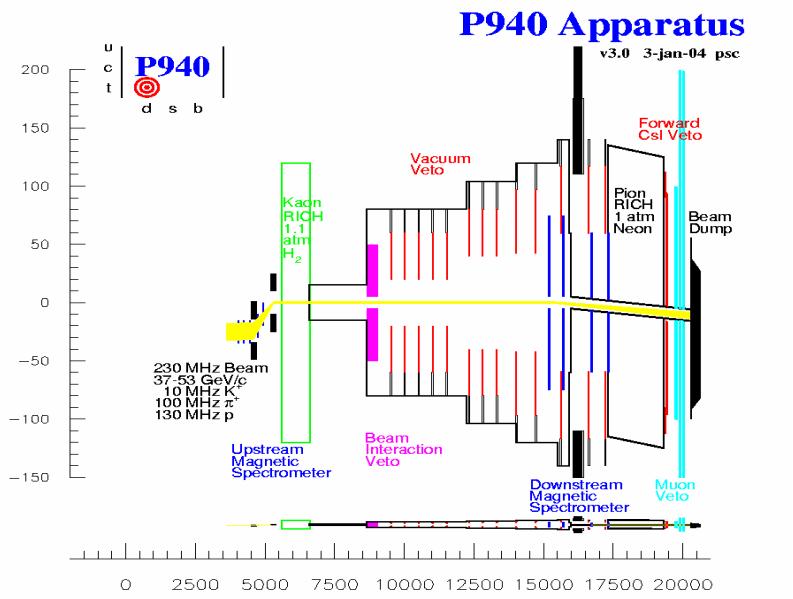



- High Flux Un-separated 37-53 GeV/c Beam - 4% $K^+$
  - Proton / $\pi^+$ : 120 / 100, 230 MHz total, 1x1 $cm^2$, 0.1x0.1 $mRad^2$
  - 10 MHz $K^+$, 1.7 MHz decay in the acceptance.
  - 5 x$10^{12}$ 120 GeV proton /sec in slow spill from the Main Injector to produce the required $K^+$ beam (17% of design intensity)
  - Debunched proton beam required (~10% 53MHz ripple ok).
- Apparatus
  - Decay in flight spectrometer with both velocity (RICH) and momentum (magnetic) spectrometer both both $K^+$ and $\pi^+$.
  - Significant requirements on photon vetoes
  - All detector technologies used are well established
  - **Redundancy** is critical to measure all backgrounds
  - Exploit signal regions on both sides of $K^+ \rightarrow \pi^+\pi^0$.
-

# Apparatus – Old and New Designs

- Decay in flight
- Redundant high rate detectors and veto systems.
- RICHes used as high rate vector velocity spectrometers
- separated 50 MHz K+ beam 22 GeV/c. Un-separated 230MHz + beam 37-53 GeV

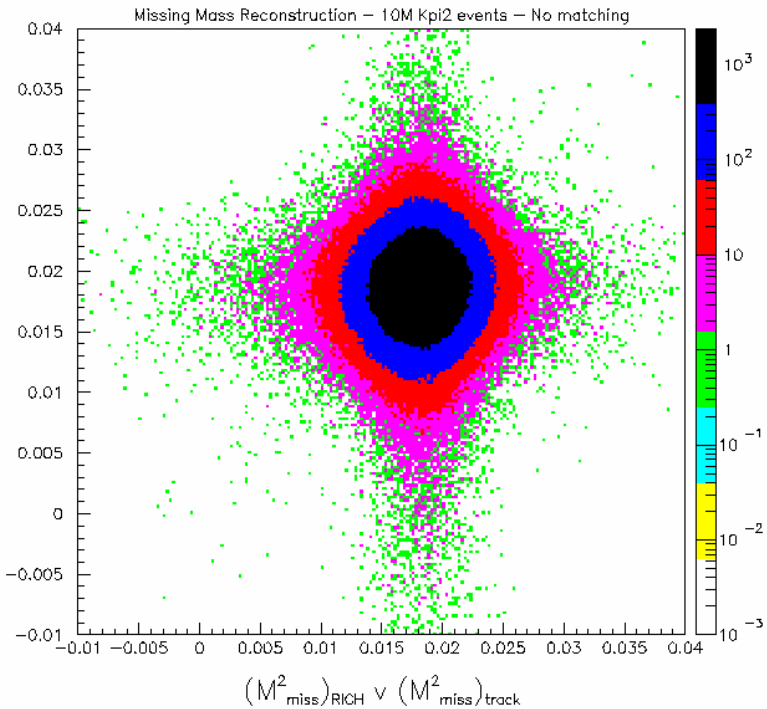


# Simulated Spectrometer Performance

- Missing mass resolution for $M^2_{\pi^0}$ from $K^+ \rightarrow \pi^+ \pi^0$
- Matched resolution from momentum and velocity spectrometers
- Low non-Gaussian tails
- Uncorrelated measurements

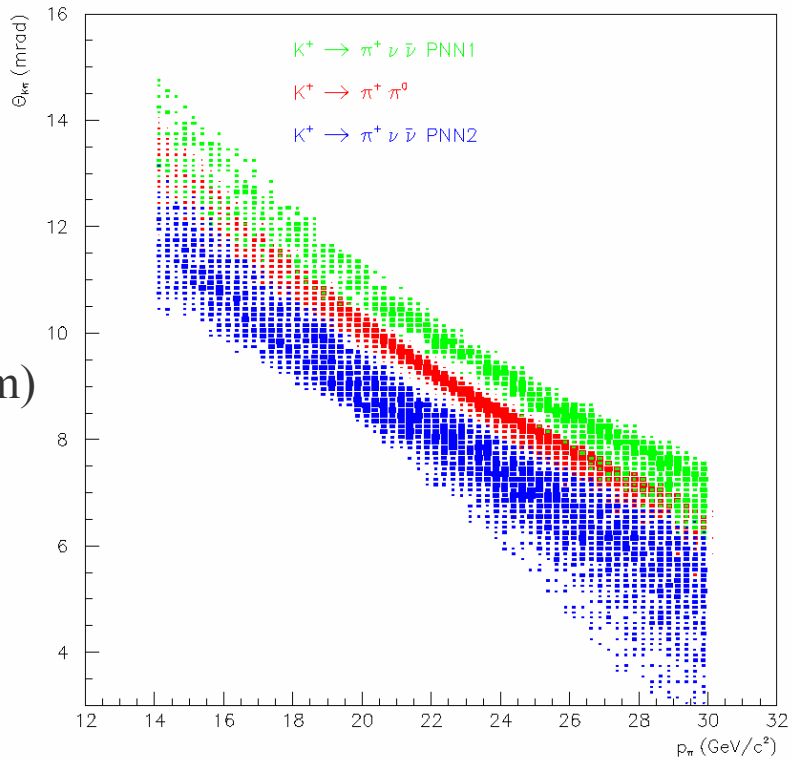
  Backgrounds from Mis-measurements to be studied and quantified from the data
- Study needs to be redone for P940



# Redesign Requirements

**Kaon RICH**

- Minimize material in the 230MHz beam
  - limit interactions
  - minimize kaon scatters (N.G. tails)
- Higher momentum (22 → 45 GeV/c)
- broader momentum bite (±2% → ±15%)
- lower kaon rate (30MHz → 10MHz)
- Fit in a small enclosure ($8x8ft^2$)
- Dispersion still controlled by λ cutoff (>280nm)



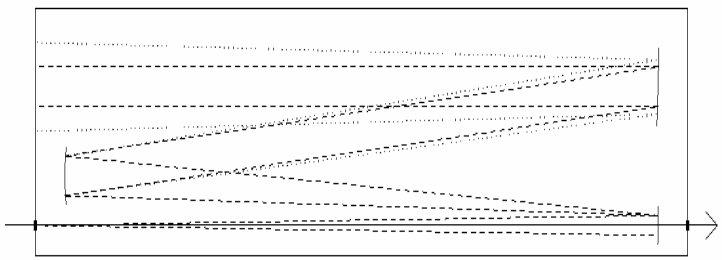

**Pion RICH**

- broader π momentum range (<21→ <30 GeV/c)
- No π's near the beam (>4 mRad)
- beam pipe for 220MHz un-decayed beam

# Kaon RICH Redesign

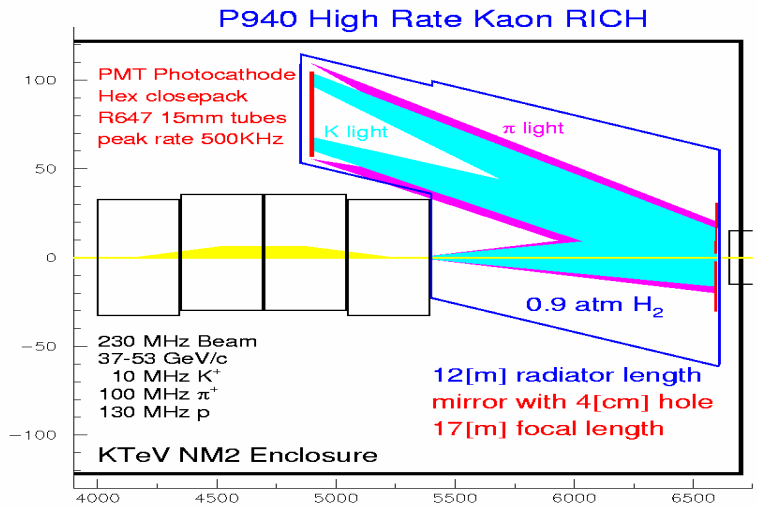
CKM Kaon RICH Design

- 0.7 Atm $CF_4$
- 10m radiator length
- thin flat mirror in beam
- 20m focal length
- Folded optical path
- R647 PMT Photocathode



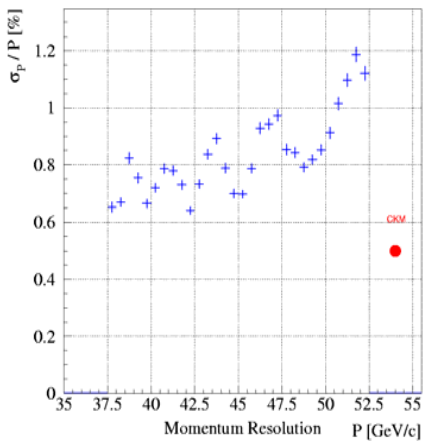
P940 Kaon RICH Redesign

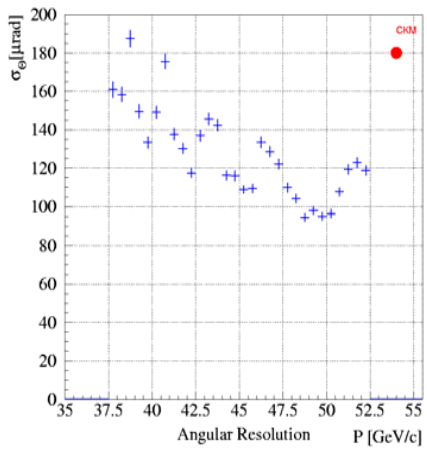
- 0.9 Atm Hydrogen
- 12m radiator length
- Thick spherical mirror 4cm beam hole
- 17m focal length
- R647 PMT Photocathode

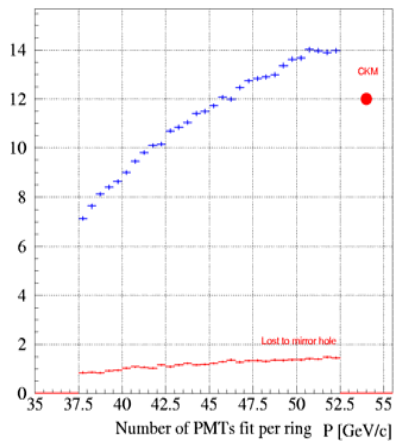


# Kaon RICH simulated performance

| parameter | CKM ($CF_4$) | P940 ($H_2$) |
|---|---|---|
| Beam flux [MHz] | 50 | 230 |
| Kaon | 30 | 10 |
| Radiation Lengths (x1e-3) | 78.1 | 3.8 |
| Interaction Lengths (x1e-3) | 16.6 | 3.7 |
| Maximum PMT rate [KHz] | 1400 | 500 |
| Vessel diameter [m] | 2.44 (8ft) | 1.22 (4ft) |



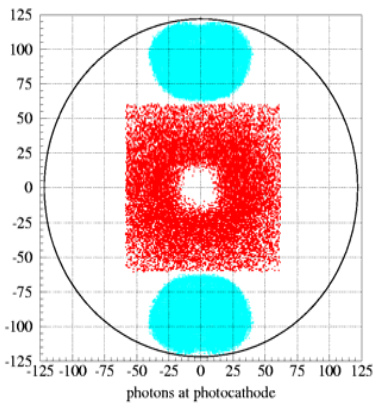



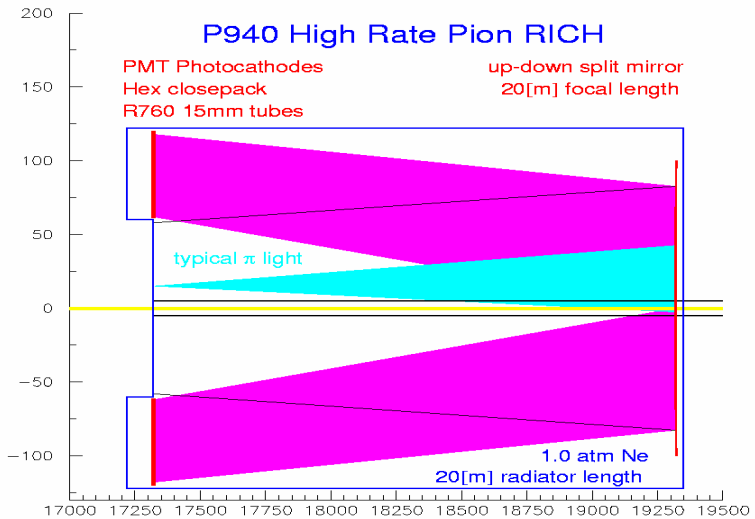



# Pion RICH Redesign

P940 Pion RICH Redesign

- 1 Atm Neon
- 20m radiator length
- Up-down split multi segment spherical mirror
- 20m focal length
- R760 PMT Photocathodes (2x~1500 tubes)
- Quartz tubes & windows (180nm)



# Pion RICH simulated performance

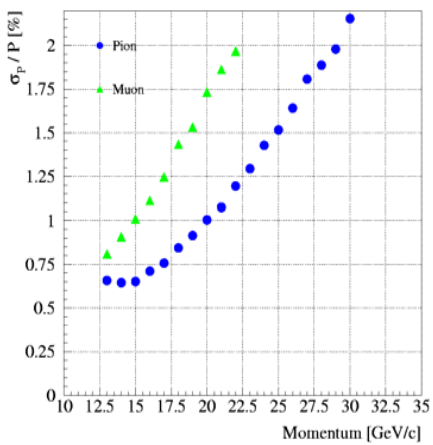
Only changes are

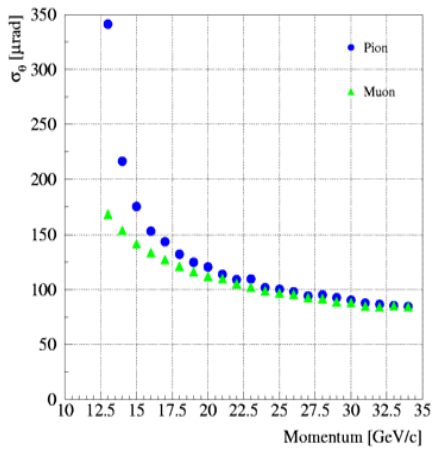
- Vacuum beam pipe
- Up-down split mirror
- Split photo-cathode

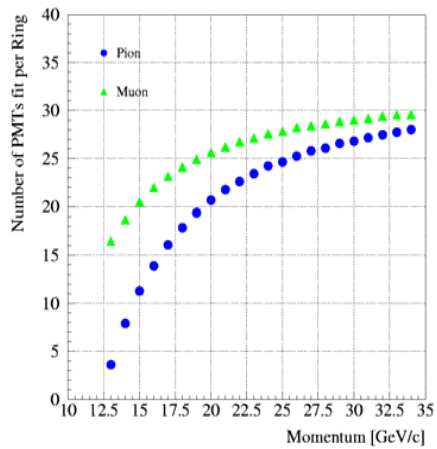
2% of photons lost to pipe

Performance essentially identical

| parameter | CKM / P940 (Ne) |
|---|---|
| flux [MHz] | ~2 |
| Radiation Lengths (x1e-3)<br>Interaction Lengths (x1e-3) | 63<br>208 |
| Maximum PMT rate [KHz] | ~30 |
| Vessel diameter [m] | 4.44 (8ft) |



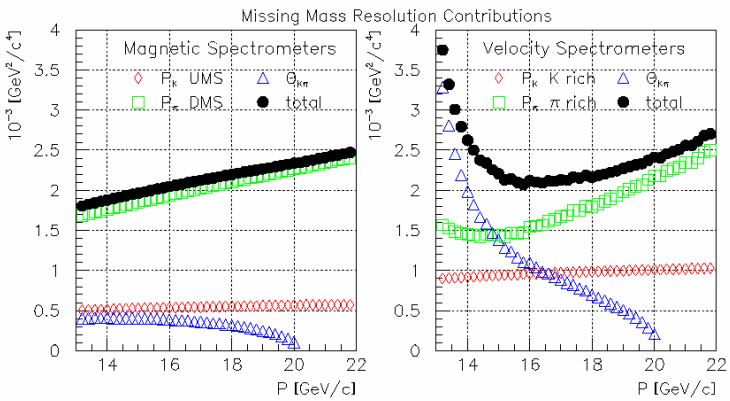



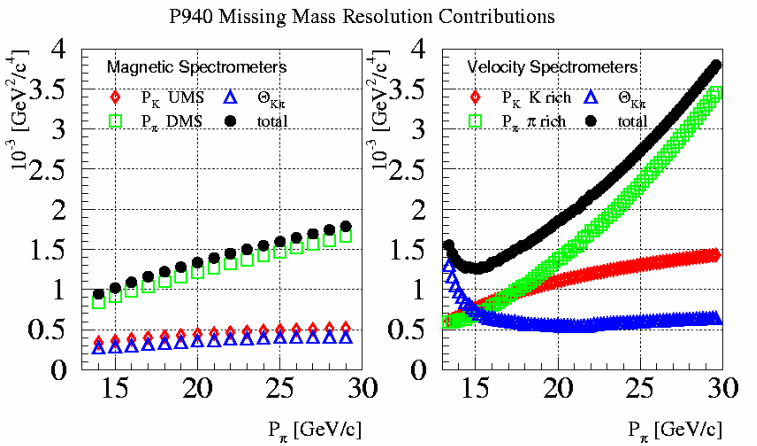
# Kinematic Resolution

The critical resolution is the missing-mass squared in $K^+ \rightarrow \pi^+ x$

- The scale is set by $M_{\pi^0} = 18.2 \times 10^{-3}$ MeV/c$^2$
- The average values for the CKM and P940 designs are similar (~$2.5 \times 10^{-3}$)
- The variations with $P_\pi$ are quite different.
- The magnetic spectrometer resolution is improved by ~30%.

Similar background rejection is expected – awaiting full a simulation



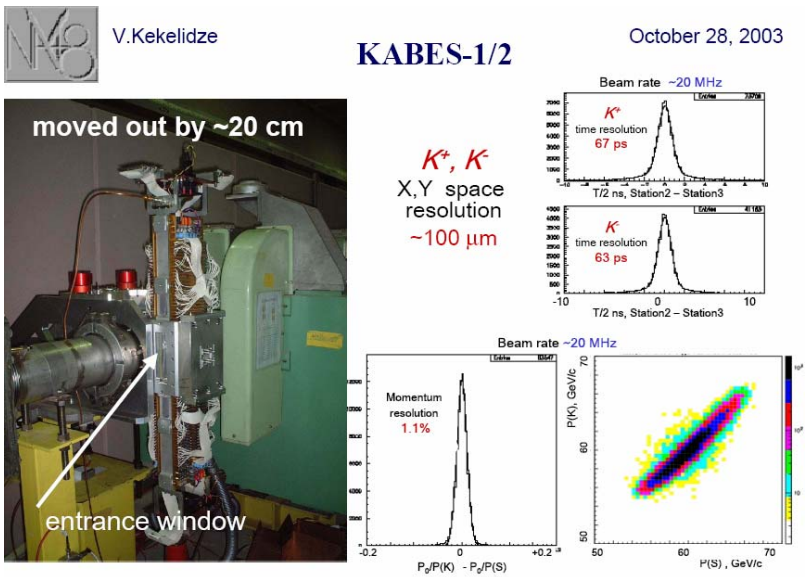



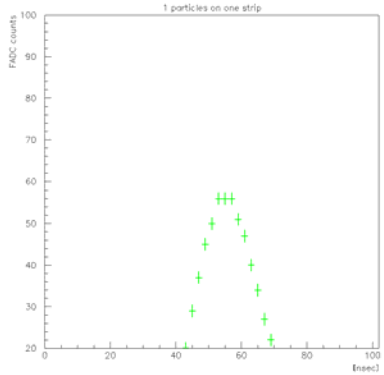
# NA48 KABES data

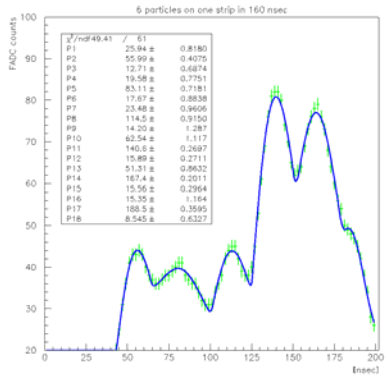
The Saclay group at NA48 has developed an ultra high rate MircoMEGAS TPC chamber

- Run successfully at >10 MHz/cm$^2$
- tested at fluxes up to 1 GHz

This is a much larger departure from the CKM design that the changes to the RICHes

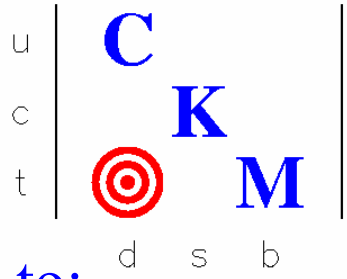


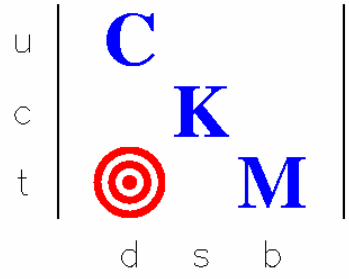

30MHz on one 0.8mm strip

# Conclusions



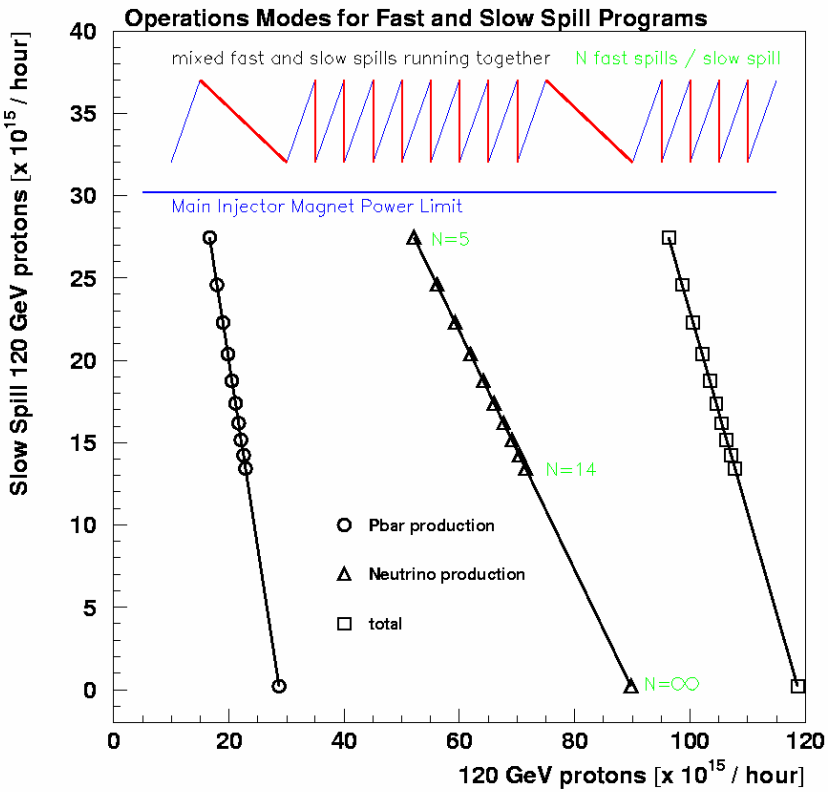

- We are in the middle of this redesign now – we need to:
  - Complete the beamline and detector (re)designs
  - Re-evaluate backgrounds and acceptance
  - Re-assess losses from deadtime, reconstruction, …
- Our Plan
  - Complete the list above
  - Return to Fermilab and the PAC with a vetted re-design
  - Time scale of spring 05
- NA48/3
  - The NA48 collaboration is proposing the same experiment at 70 GeV/c in the NA48 beam and detector at CERN
  - Redesigning the RICHes for 3x the CKM beam momentum would be as straightforward as the 2x demonstrated here.

# Extra Slides



# Proton Economics

- We require debunched protons from the Main Injector (10% 53MHz ripple is OK).
- Separate fast (neutrino+Pbar) and slow spill Main Injector cycles make these different modes of operation independent by timesharing
- N=8 fast cycles / slow cycle gives both fast and slow spill 2/3 of the maximum available to either.
- Setting N in this model is a program planning decision.



# P5

- The **P**article **P**hysics **P**roject **P**rioritization **P**anel (**P5**) reviewed BTeV, CKM and the Tevatron detector upgrades; concluding for CKM:

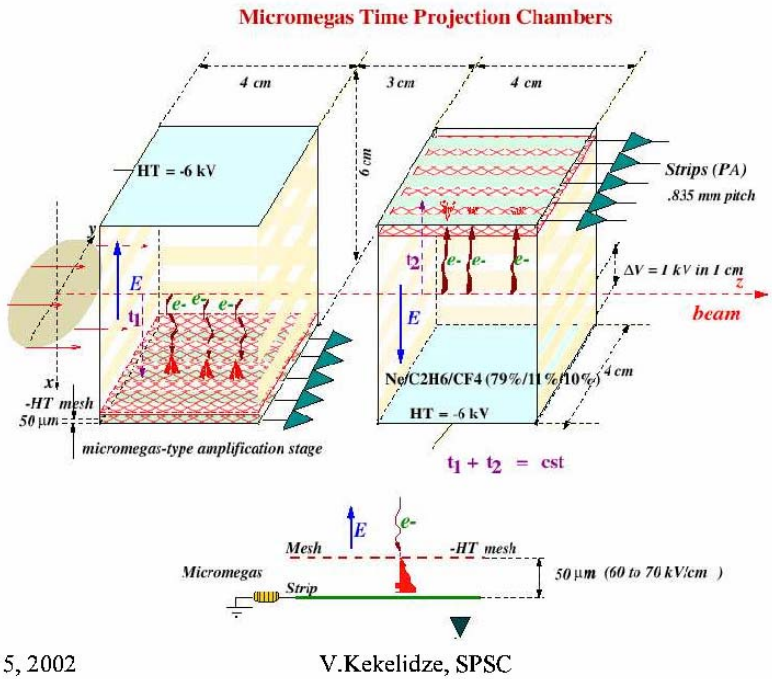
> **Evaluation** – The subpanel was impressed with the excellent work of the proponents on the design of the experiment and their successful prototyping results. CKM is an elegant world-class experiment, which would be able to produce important physics results. However, the committee assigns it a lower priority than the BTeV experiment. The main reason is that BTeV has a much broader physics program at a comparable cost.
>
> **Suggestions Based on Prioritization** – The present Fermilab plan calls for a similar funding profile and time-line for BTeV and CKM construction, with both starting to take data around 2009. The P5 Subpanel believes that this plan is likely to be too ambitious given the need to optimize the physics from the Tevatron Collider, as well as the desire to have BTeV completed promptly. *Based on current budgetary models, P5 does not recommend proceeding with CKM.*

# KABES μMEGAS from NA48

*V.Kekelidze*

**New elements for NA48/2**

**Beam Spectrometer KABES (TPC micromegas)**




November 5, 2002 V.Kekelidze, SPSC