Segunda edición de la propuesta CKM

Reunion Anual DPyC
UNAM, June 28, 2001

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Outline

- What is CKM?
- Short History of CKM – How to get an experiment approved?
- Contributions from IF–UASLP to CKM
- Summary

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What is CKM?

In “Reunion Anual DPyC 1998”: Gave a talk about this experiment

Charged Kaons at the Main Injector

A Proposal for a Precision Measurement of the Decay $K^+ \to \pi^+ \nu \bar{\nu}$ and Other Rare K^+ Processes at Fermilab using the Main Injector

Cabibbo-Kobayashi-Maskawa (CKM) Matrix (Wolfenstein parametrization)

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \qquad V = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$|V| = \begin{pmatrix} 0.9745 - 0.9760 & 0.217 - 0.224 & 0.0018 - 0.0045 \\ 0.217 - 0.224 & 0.9737 - 0.9753 & 0.036 - 0.042 \\ 0.004 - 0.013 & 0.035 - 0.042 & 0.9991 - 0.9994 \end{pmatrix}$$

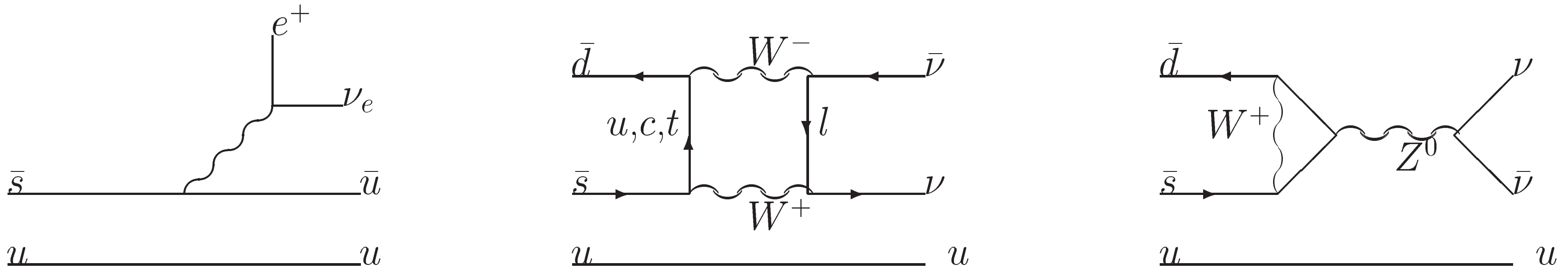
Quantitative Access to CKM parameters

- Goal is to test the Standard Model hypothesis that a single phase in the CKM matrix is the sole source of CP violation.
- This means *over-constraining* the prediction, and testing for consistency. Paraphrasing Wolfenstein: "…I invented the parameters ρ and η, and I don't care what the values are so why should you?? The substance here is to *over-constrain* the model and test for consistency…"[1]
- To falsify the Standard Model hypothesis the only foreseeable results with controlled errors are:
  - B physics: $B_d^0 \to \Psi K_s$, and perhaps x_x/x_d mixing.
  - K physics: $K^+ \to \pi^+ \nu\bar{\nu}$ and $K^0 \to \pi^0 \nu\bar{\nu}$.

[1] Wolfenstein at Kaon'99

$K^+ \to \pi^+ \nu\overline{\nu}$ Theory

Calculated[2] by weak isospin rotation from $K^+ \to \pi^0 e^+ \nu$



$$\frac{B(K^+ \to \pi^+ \nu\bar{\nu})}{B(K^+ \to \pi^0 e^+ \nu)} = \frac{3\alpha^2}{8\pi^2 \sin^4\theta_W} |V^*_{cs} V_{cd} D(X_c) + V^*_{ts} V_{td} D(X_t)|^2 \frac{1}{|V_{us}|^2}$$

$$D(X) = \frac{1}{8}\{1 + \frac{3}{(1-X)^2} - \frac{(4-X)^2}{(1-X)^2}\} X ln(X) + \frac{X}{4} - \frac{3X}{4(1-X)}$$

$$X_j = \{\frac{m_j}{m_W}\}^2; \quad j = c, t.$$

$$Br[K^+ \to \pi^+ \nu\bar{\nu}] = [0.44 \pm 0.15] \times 10^{-10}[(1.4 - \bar{\rho})^2 + \bar{\eta}^2] = (0.9 \pm 0.3) \times 10^{-10}$$

[2] T. Inami and C.S. Lim, Progress of Theoretical Physics **65** (1981) 297-314

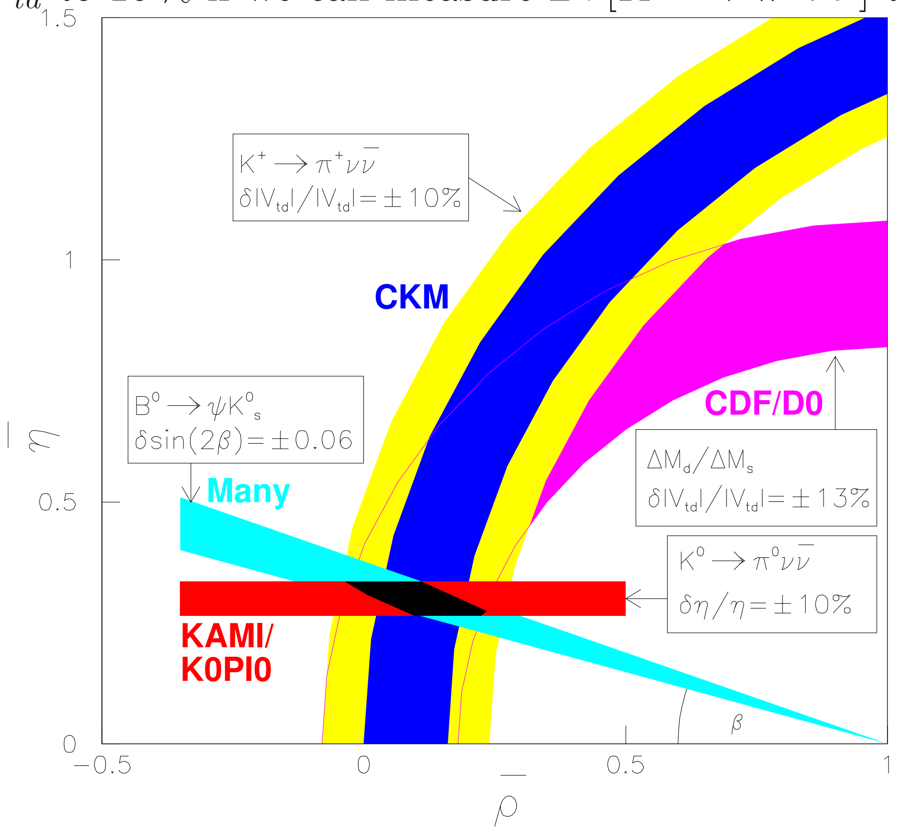
Total theoretical uncertainty of 8 % estimated by Buras, et al.[3]

Dominated by uncertainty in charm quark mass.

Structure of K^+ is put in with measured $K^+ \rightarrow \pi^0 e^+ \nu$ branching ratio.

All other corrections are small and calculated (NLO QCD, isopsin, long distance contributions).

$\Longrightarrow$ We can measure V_{td} to 10 % if we can measure $Br[K^+ \rightarrow \pi^+ \nu \bar{\nu}]$ to 10 % (100 Events).



[3] A.J. Buras, hep-ph/971217

A short estimate for an inflight decay experiment

- $BR = 10^{-10}$
- 100 Events
- Acceptance $\approx 1\,\%$

$\Longrightarrow 10^{14}$ live K^+

- Duty cycle of machine 30 % (Fermilab MI)
- Lifetime of machine and experiment 50 %
- 2 years of running time

$\Longrightarrow$ 30 MHz of K^+

In addition: Only a few background events
$\Longrightarrow$ Suppress background to 10^{-12}

Charged Kaons at the Main Injector

June 4, 2001

A Proposal for a Precision Measurement of the Decay $K^+ \to \pi^+\nu\overline{\nu}$ and Other Rare K^+ Processes at Fermilab Using the Main Injector

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Web Address: www.fnal.gov/projects/ckm/Welcome.html

Measurement Principle

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) \sim 1 \cdot 10^{-10}$$
$$BR(K^+ \to \mu^+ \nu) = 0.635$$
$$BR(K^+ \to \pi^+ \pi^0) = 0.212$$
$$BR(K^+ \to \pi^+ \pi^+ \pi^-) = 0.056$$

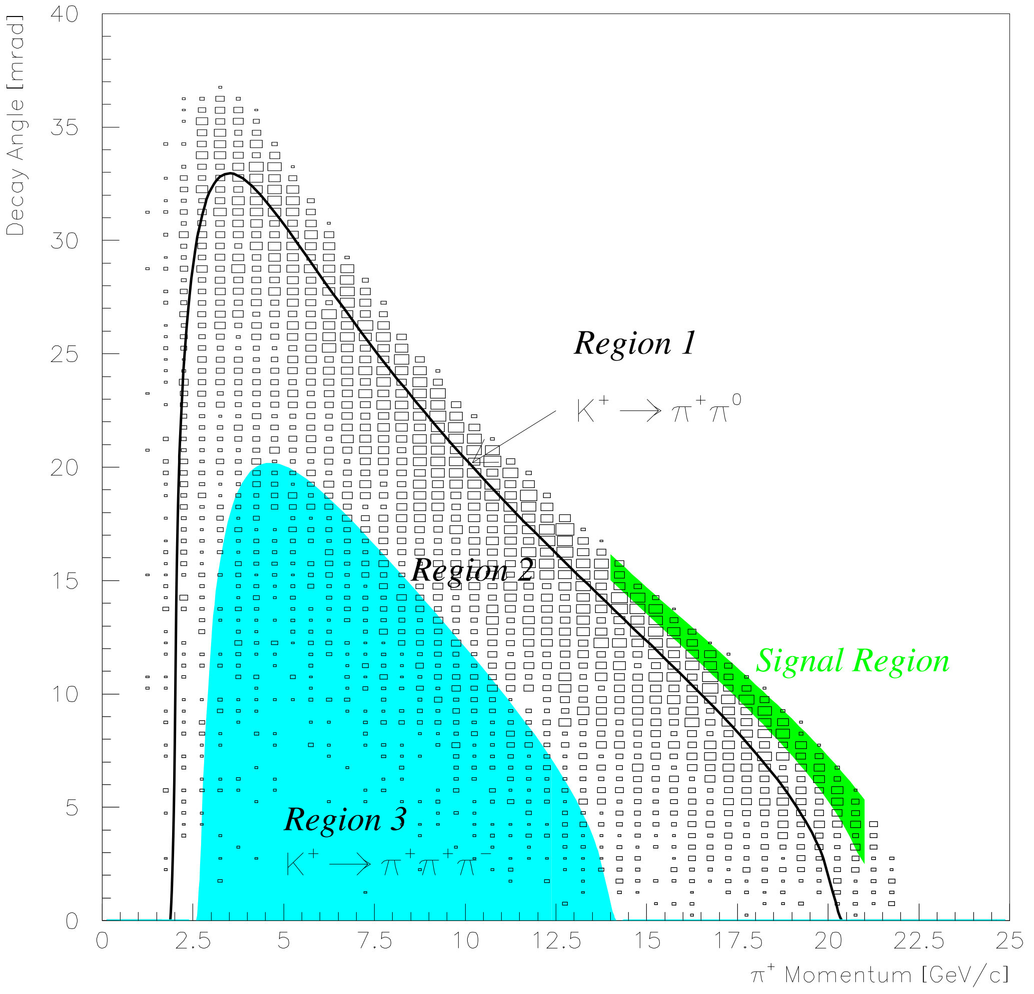
π^0 Rejection via Photon Veto System:
$< 1.6 \cdot 10^{-7}$

Kinematic rejection: $< 3 \cdot 10^{-5}$
From Velocity and Magnetic Spectrometers

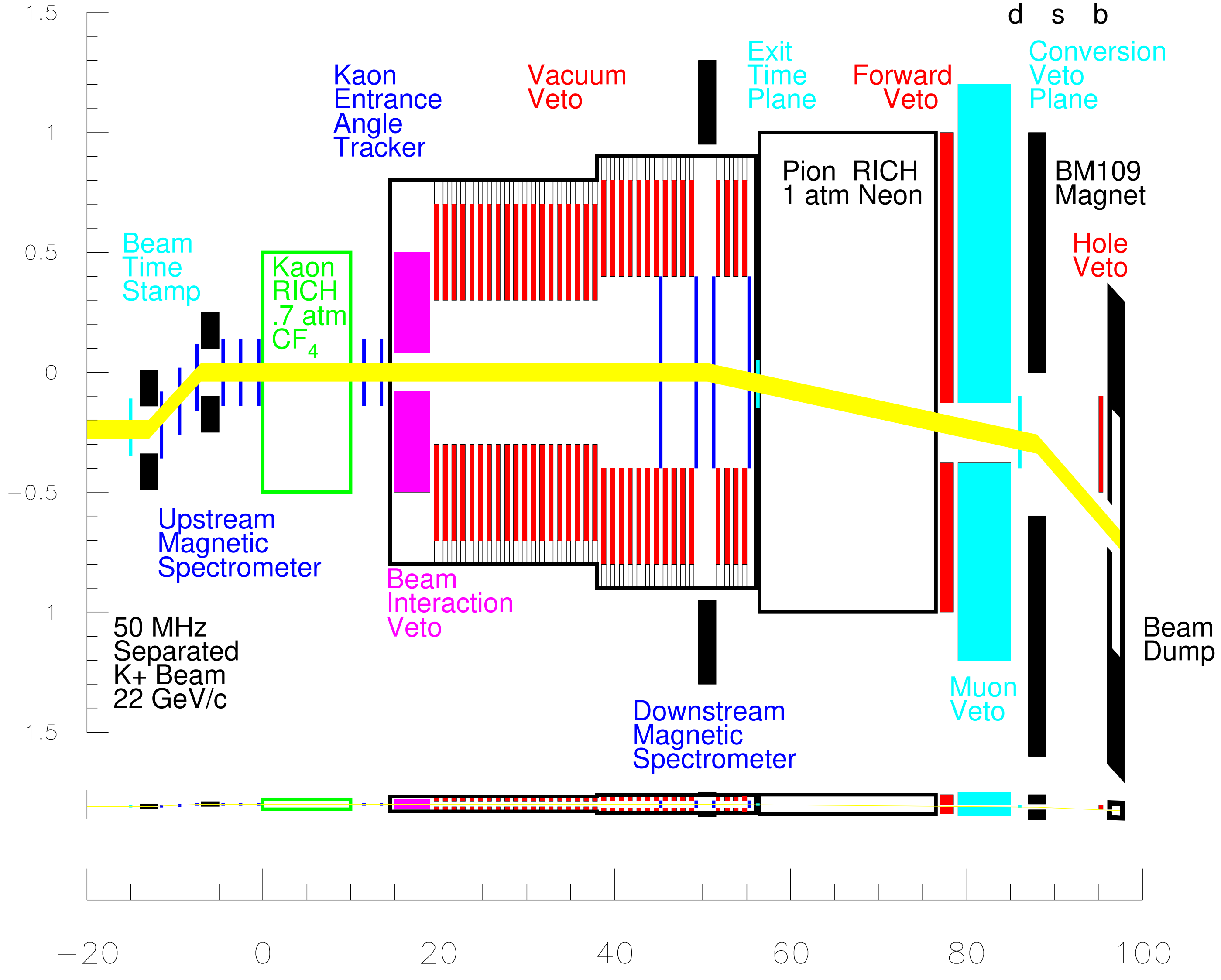
Calculating missing mass:

$$M^2_{\text{miss}} = M^2_K(1 - p/p_K) + m^2(1 - p_K/p) - p p_K \theta^2$$

Resolution in Missing mass:
$\sim M^2_{\pi^0}/10$ for $K^+ \to \pi^+ \pi^0$



CKM Apparatus



Apparatus

- Requirements

  Redundant 1% M^2_{miss} resolution

  2×10^{-7} π^0 rejection

  1×10^{-5} μ^+ rejection

  Rate capability to handle 5 MHz of K^+ decays

  Resolution - $\sigma_p/p \sim 1\,\%$, $\sigma_\theta/\theta \sim 1\,\%$, $\sigma_t \sim 1\,$nsec, are required to control the dominant backgrounds.

- Detector Technology - Use proven systems to the maximum extent possible.

Apparatus (cont.)

- Separated Beam – RF separated 22 GeV/c K^+ beam
- Magnetic Spectrometers
- Velocity Spectrometers

    Ring center and radius measures vector velocity

    Phototube RICH counters for kaon and pions

    Based on experience with Selex RICH

        Low noise

        Non-Gaussian resolution tails at a very low level

        Very high rate capability

        Time resolution to 1 nsec per PMT hit

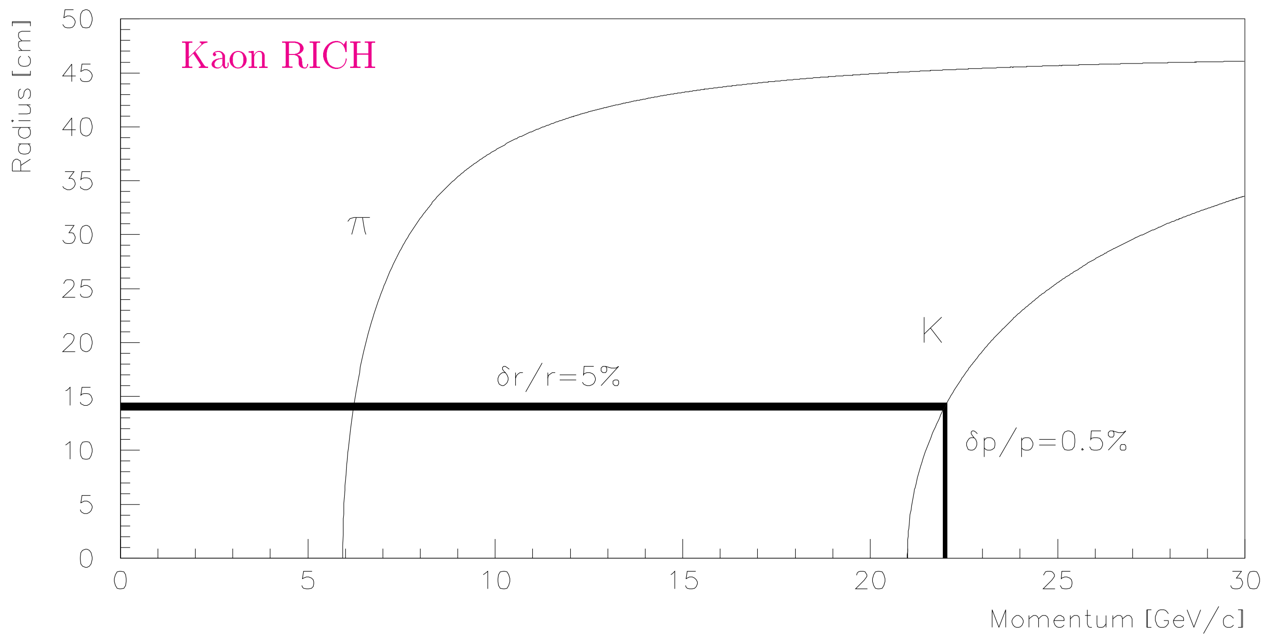
    Kaon RICH ΔP/P ~0.5%   Pion RICH ΔP/P ~1.5%

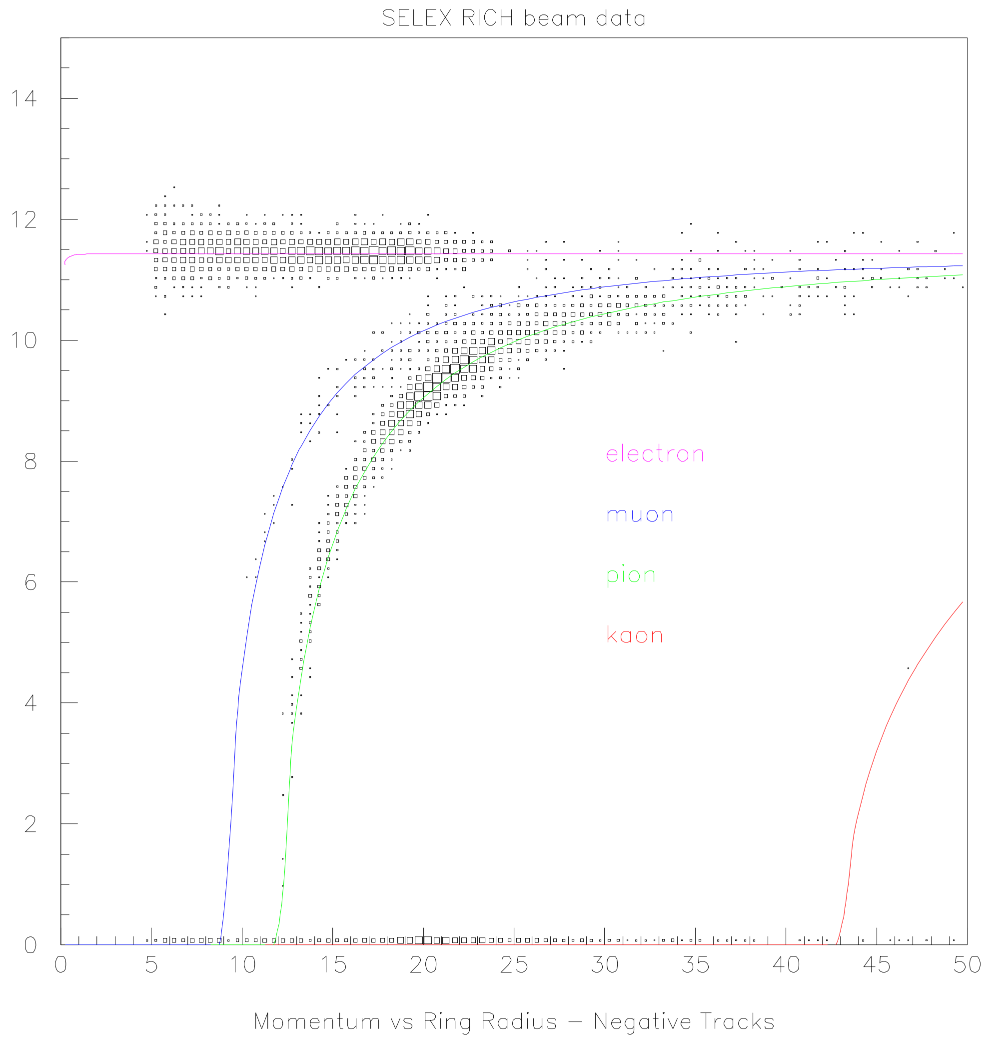
    Cherenkov (Franck, Tamm) equation: $\cos\theta_c = \frac{1}{\beta n}$ $\beta = \frac{v}{c}$

- Photon Vetos
- μ Vetos
- Others

Velocity Spectrometer
Ring Imaging Cherenkov Counters

Design and Performance estimates based on data from SELEX RICH



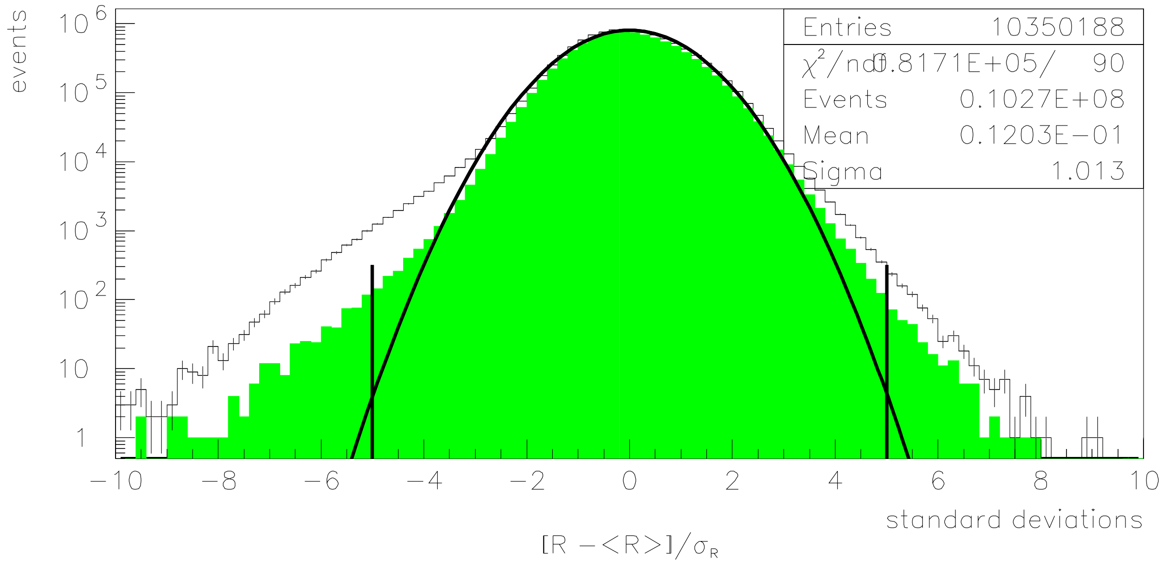


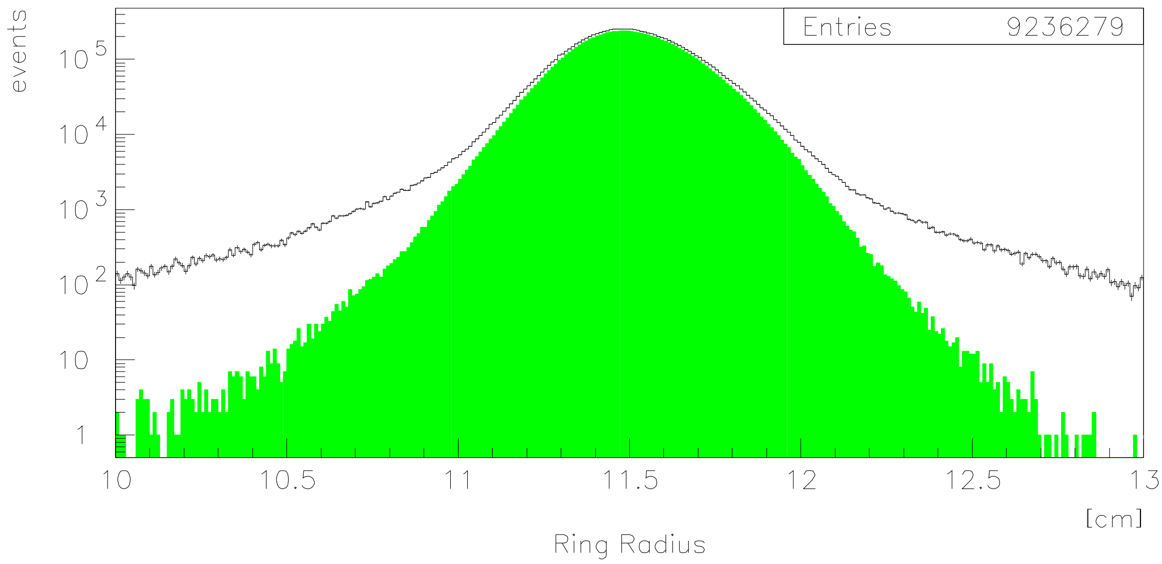
Ring Radius:
velocity

Ring Center:
angles

Study with SELEX single track data

Solid histogram gives already enough rejection





Other possible measurements

10^{-12} in single event sensitivity is a long way.
There are a lot of interesting modes to be picked up.
This list is NOT finished, and is open to more suggestions.

These are just a few examples we where thinking of:

- $K^+ \to \mu^+ \nu_\mu \gamma$ Form Factor: Test of Chiral Perturbation Theory
- $K^+ \to \pi^+ e^+ e^-$, $K^+ \to \pi^+ \mu^+ \mu^-$, Form Factor and Branching Ratio:
  Test of Chiral Perturbation Theory
- $K^\pm \to \pi^\pm \pi^+ \pi^-$, $K^\pm \to \pi^\pm \pi^0 \pi^0$, $K^\pm \to \pi^\pm \pi^0 \gamma$, $K^\pm \to \pi^\pm \gamma\gamma$:
  Test of Chiral Perturbation Theory, Search for Direct CP Violation in $K^\pm$ decays.
- $K^+ \to \pi^0 e^+ \nu$, $K^+ \to \pi^0 \mu^+ \nu$ Branching Ratio: Measurement of V_{us}

Short History of CKM
How to get an experiment approved?

April 1996: Expression of Interest (EOI) with corresponding PAC presentation

July 1997: PAC presentation

Response by J. Peoples:

The physics motivation of the experiments to measure $K \to \pi\nu\bar{\nu}$ decay rates is strong; that for the measurement of $\Phi^{\pm}$ less so. We recommend that the proponents continue design studies towards the preparation of proposals. However, resources are limited, there are substantial commitments to approved experiments, and this program will compete with other proposals. As a consequence, the threshold for approval will be high.

Both this experiment and the CPT experiment rely on the separated beam, and the collaboration is encouraged to continue design and R&D for this beam, especially in the area of superconduction RF cavities. The Committee looks forward to hearing about progress on this beam and the novel spectrometer concepts.

History (cont.)

April 1998: Proposal submitted (PAC presentation)

Response by J. Peoples:

Thank you for your presentation to the Physics Advisory Committee (PAC) of P-905 (CKM). The Committee has considered your proposal along with other proposals for fixed-target experiments at the Main Injector. The Committee's general comments on a fixed-target program at the Main Injector are as follows:

While these experiments are far from approval, they suggest that there could be a vigorous fixed-target program at the Main Injector. The Laboratory should continue to study the option for such a program, and should be receptive to additional proposals. In addition, a superconducting RF- separated K+ beam could be a useful facility, and the Lab should continue development of this technology.

The Committee also made a comment specific to the CKM proposal:

The CKM experiment would be a long-term pursuit of a difficult goal. The collaboration should pursue tests of photon vetoing and simulations of backgrounds and acceptance.

I plan to have further discussions on a Main Injector fixed-target program with the PAC at its June meeting at Aspen. After the meeting I will announce a timetable and the process by which the Laboratory and users will work together to build a solid fixed-target program with 120 GeV protons in the Meson Area. I expect that you will play a major role in this effort. I would also like for you to be involved in the development of the RF separated K+ beam. My expectation is that the planning of a 120 GeV program will begin in earnest next spring. The earliest time that such a program could begin is roughly the year 2001. By that time, the CDF and D0 upgrades will be complete and the MINOS experiment will be largely funded. Once the laboratory can see past these ambitious projects, it will be possible to consider new projects.

All the new projects, including Run III upgrades, BTeV and 120 GeV experiments will have to compete for the same pot of money.

History (cont.)

Sept/Oct 1998: R&D project submitted, presented and approved

May 1999: Status report presented to PAC

October 1999: R&D project financed

April 2000: Status report presented to PAC

November 2000: Status report presented to PAC

April 2001: Submission and presentation of 2nd edition of Proposal
Presentation in $4 \times 15\,\mathrm{min}$, JE gave one part.

May 2001: Technical review (2 full days)

June 2001: 1.5 days discussion of PAC in Aspen (**APPROVAL!**)

Fermilab

November 11, 1998

Peter Cooper
MS 122

Dear Peter,

Thank you for the presentation of the CKM R&D plan at the recent PAC meeting. The Committee recommended approval of the R&D plan, and I accept that recommendation. Their comments follow:

The physics addressed by measuring $K_L^0 \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ is important. Both of these decay modes allow measurement of CP violation parameters in a way that is relatively free of theoretical uncertainty. These measurements will allow testing of the Standard Model of CP violation in the kaon system. A measurement of the decay $K_L^0 \to \pi^0 \nu\bar{\nu}$ would determine the parameter η. A measurement of $K^+ \to \pi^+ \nu\bar{\nu}$ would determine a contour in the $\rho\eta$ plane. The theoretical uncertainties are expected to be on the order of 10% or less.

The Committee believes that it is important to maintain the option of a vigorous kaon decay program in the Main Injector era. Both the KAMI and CKM collaborations presented their plans for R&D. The Committee finds the R&D plan of the KAMI experiment to be sensible and necessary for demonstrating the feasibility of the experiment's measurement of $K_L^0 \to \pi^0 \nu\bar{\nu}$. Accordingly, the Committee recommends approval of R&D for this project. The Committee finds the R&D plan of the CKM experiment to be sensible and necessary for demonstrating the feasibility of the experiment's measurement of $K^+ \to \pi^+ \nu\bar{\nu}$. Accordingly, the Committee recommends approval of R&D for this project. The KAMI and CKM groups should be encouraged to collaborate on joint R&D projects where possible, for example, for photon vetoing.

Funding for this R&D will be difficult to provide in FY 1999; however, we will attempt to meet your most pressing needs. We may need to depend on our annual appeal to the Division of High Energy Physics for these funds. Please work with Ken Stanfield to negotiate a Memorandum of Understanding. Upon signing of an MOU, the R&D effort will be designated E-905 - CKM R&D.

Sincerely,

John Peoples

cc: A. Kronfeld
K. Ellis
A. Firestone
J. O'Fallon

Fermilab

April 25, 2001

Peter Cooper
MS 122

Dear Peter,

Thank you for your presentation of P-921 (CKM) to the Physics Advisory Committee (PAC) at its recent meeting. The PAC discussed the kaon program and had the following comments and questions.

General Comments on Kaon Program

The proponents of two rare kaon experiments, KAMI and CKM, gave presentations summarizing their recent 2nd-edition proposals. The Committee received further information in response to questions, and looks forward to receiving the following additional input to the Aspen meeting:

1. *A Laboratory analysis of cost, schedule, and resource issues;*

2. *A Laboratory analysis of proton economics during the relevant time period;*

3. *The report from the upcoming Technical Review Committee in May; and*

4. *A preliminary analysis of data storage and computing needs from the Computing Division.*

The Committee also requests from the Laboratory an analysis of the impact on the Laboratory of mounting various combinations of the proposed fixed-target experiments. The Committee expects to make recommendations on KAMI and CKM at Aspen.

Questions specific to CKM

The Committee was favorably impressed with the level of effort that went into the CKM proposal, and looks forward to the assessment of the technical review committee and the cost and schedule review.

In advance of this, the Committee developed the following questions.

1. *Analyze the degradation of the signal if any of the elements of the detector or beam do not meet their performance specifications, including resolutions, efficiencies, stability, mechanical tolerances, and defects in beam structure.*

History (cont.)

Date: Fri, 22 Jun 2001 15:48:22 -0500
From: Peter Cooper <pcooper@fnal.gov>
To: CKM Collaboration <ckm@fnal.gov>
Cc: Peter Cooper <pcooper@fnal.gov>
Subject: CKM will be formally approved next week

Dear Colleague,

Bob Tschirhart and I have just returned from a meeting with Mike Witherell and Mike Shaevitz. They told us that by a strong consensus the PAC has recommended to them that CKM be given scientific approval. They plan to accept to this recommendation. We can expect a formal letter of approval from the director in about a week.

We were told that the PAC was impressed the strength of both the collaboration and the the technical case for the experiment. They were particularly impressed with the levels of redundancy in the design. They are convinced that we have good prospects to successfully carry out the measurement of the branching ratio of K+ -> pi+ nu nu_bar as we have proposed. We are encouraged to further strengthen our collaboration and to continue pressing the critical technical issues.

Work in San Luis Potosí

- Design work on Kaon and Pion RICH
- Responsible for implimentation of Velocity Spectrometer
- Maintenance of Monte Carlo Software
- Monte Carlo studies
- Construction of flat, thin mirror for Kaon RICH
- Tests and Classifications of Photomultipliers
- (Maybe:) Supervision of spherical mirror production (in Mexico?)

What to do next?

Experiment is approved, but money situation at Fermilab looks bad (CDF, D0 upgrades terminated late, MINOS cost overrun, ...)

Even small contributions (money, man-power) can make a HUGE impact

We are looking forward to strengthen our collaboration

Running date: All speculations are open.

Conclusion

$K^+ \to \pi^+ \nu \bar{\nu}$ provides theoretically clean measurement of V_{td}
to test $\mathcal{CP}$ Violation description in Standard Model.

CKM experiment at Fermilab will measure $\approx$ 100 events

EXPERIMENT IS APPROVED

UASLP is significantly involved in this experiment

- Detector R&D
- Software Development
- Organizational Aspects

More information at
`http://www.fnal.gov/projects/ckm/Welcome.html`