Future Kaon Experiments:
The Unitarity Triangle in The Kaon System

Run II B Physics Workshop

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QUESTION - What does it take to falsify The Standard Model hypothesis that to only source of CP violation is the phase of V_{td}?

I. Three is the minimum number of measurements to be made. (Two parameters to be determined + at least 1 test.)

II. Your experiments shall be done properly and work!

III. Your experimental errors must be well and truly estimated.

Professors Possion and Gauss must not be malicious.

IV. Your theoretical assumptions and error estimates shall be without sin or the appearance of sin.

What measurements might satisfy these requirements?

$\sin(2\beta)$ in $B_d^0 \rightarrow \psi K_s^0$

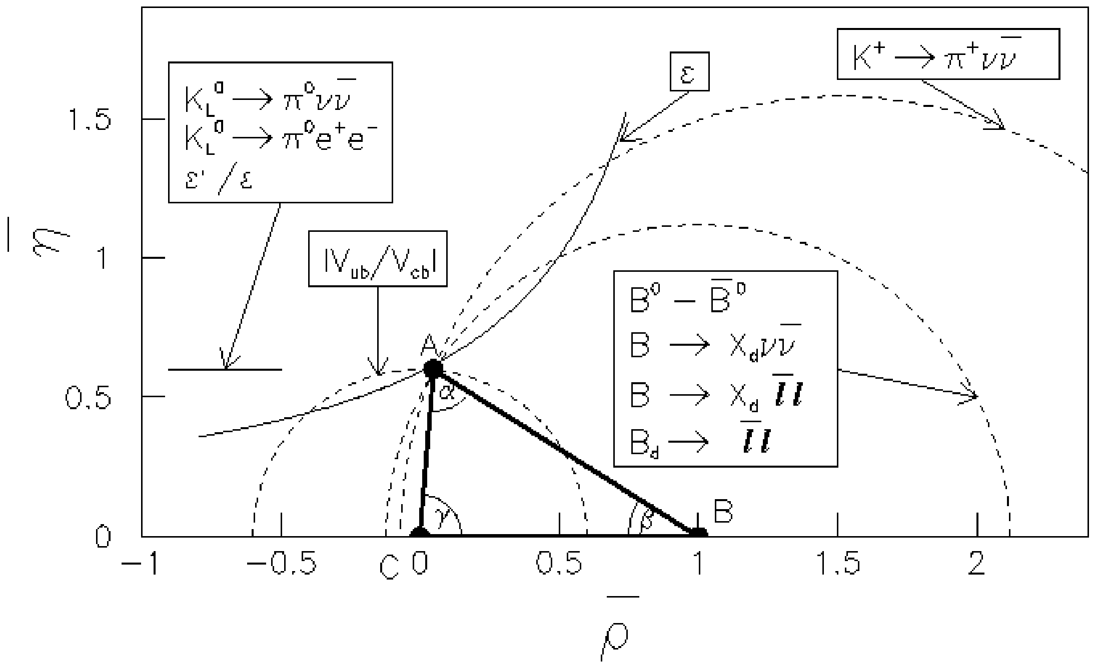
$\Delta M_d / \Delta M_s$ in B_d^0 and B_s^0 Decays

$K^0 \rightarrow \pi^0 \nu \bar{\nu}$

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$

All the others (α, γ, $B \rightarrow \pi\, l^+ l^-$, $K \rightarrow \pi^0\, l^+ l^-$) are either experimentally inaccessible, polluted with backgrounds and/or rely on theoretical calculations (eg: lattice) which aren't robust enough to support the conclusion that the Standard Model is wrong. These measurements can confirm the SM and improve the measurements of [ρ,η]. If $\alpha+\beta+\gamma < 180^0$ no one will believe that the Lattice is right and the SM wrong - even if this is true!

Unitarity Triangle



❍ Idealized unitarity triangle (from Buras)

B Decays - A very brief summary.

$\sin(2\beta)$ in $B_d^0 \to \psi K_s^0$

Everyone agrees that this is theoretically clean.

Everyone is going to measure it: [Babar, Belle, CDF/D0, ...]

First results are in hand. This will get done well.

$\Delta M_d / \Delta M_s$ in B_d^0 and B_s^0 Decays

$\Delta M_d / \Delta M_s = [m_d B_d f_d^2]/[m_s B_s f_s^2]\,|V_{td}/V_{ts}|^2$

The ratio of Lattice quantities is believed to be under control.

$\Delta\,|V_{td}/V_{ts}| \sim$ [4-6%] (expt) + [5%] (theory) = 8%

(Joe Kroll and Gerhard Buchalla’s slides from Sept).

CDF and D0 will have the first serious shot at these.

K Decays - No final state interactions - Highly suppressed.

$K^0 \rightarrow \pi^0 \nu \nu$

Theoretically clean

Br[$K^0 \rightarrow \pi^0 \nu\nu$] = η^2 x [known stuff] = $(2.8 \pm 1.7) \times 10^{-11}$

current limit Br < 5.9×10^{-7} [90% CL] (KTeV97)

hep-ex/9907014 13 Jul 1999

3 new experiments (BNL, FNAL, KEK/JHF)

$K^+ \rightarrow \pi^+ \nu \nu$

Br[$K^+ \rightarrow \pi^+ \nu\nu$] = $|V_{td}|^2$ x [known stuff] = $[0.9 \pm 0.3] \times 10^{-10}$

The theoretical uncertainty is well quantified and dominated by lack of knowledge of the mass of the charm quark.

1 event observed Br = $(1.5 +3.4 - 1.2) \times 10^{-10}$ (BNL E787)

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2 new experiments (BNL, FNAL)

Future Kaon Experiments

BNL E949

An upgrade and extension to BNL E787 to observe ~10 $K^+ \to \pi^+ \nu \bar{\nu}$ events.

CKM (FNAL E905) Charged Kaons at the Main Injector

CKM is a proposal to measure the ultra-rare kaon decay: $K^+ \to \pi^+ \nu \bar{\nu}$ to a branching fraction precision of 10% to measure the matrix element $|V_{td}|$ with a statistical precision of 5% and an overall precision of 10%.

KAMI (FNAL E804) KAons at the Main Injector

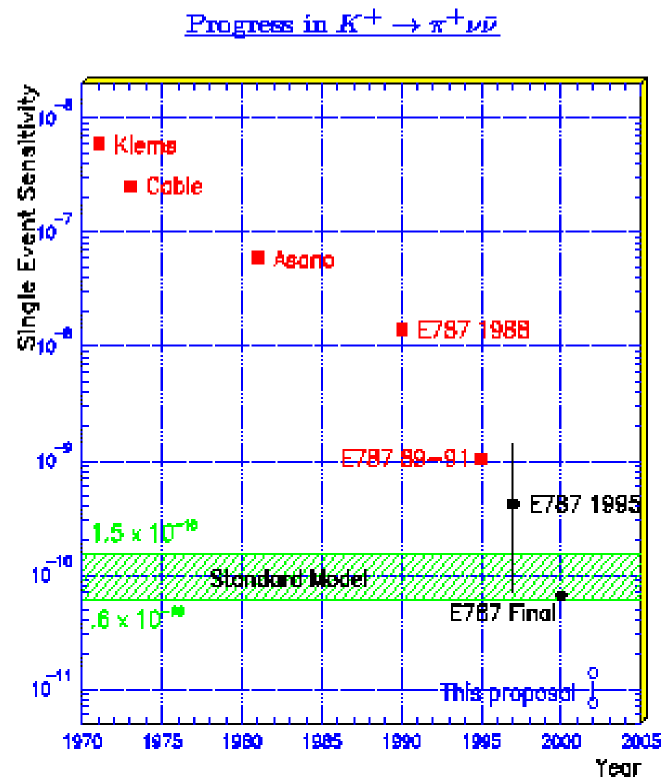
KAMI is a proposal to measure the ultra-rare kaon decay $K_L^0 \to \pi^0 \nu \bar{\nu}$ to a branching fraction precision of 10% to determine the imaginary part of V_{td} with a statistical precision of 5% and to measure other ultra rare K_L^0 decays.

KOPIO (BNL E926) A Search for $K_L^0 \to \pi^0 \nu \bar{\nu}$

A low momentum (800 MeV/c^2) neutral $K_L^0 \to \pi^0 \nu \bar{\nu}$ experiment using TOF to measure the K_L^0 momentum. Same reach as KAMI.

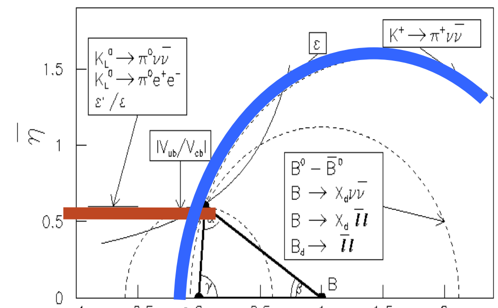
BNL E949 10 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events

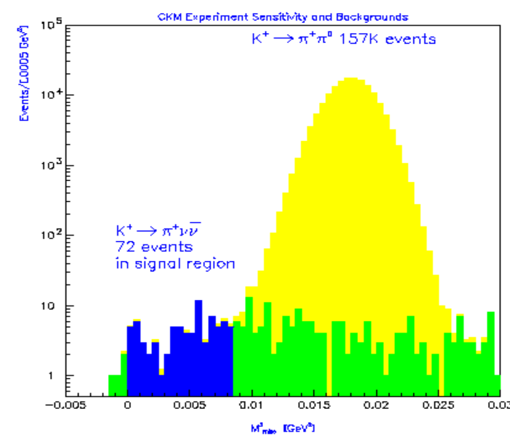
- BNL, FNAL, Fukui U., IHEP Moscow, INR Moscow, KEK-Tanashi, KEK Tsukuba, Kyoto, UNM,RCNP-Osaka, TRIUMF
- Status
  - Approved August 26, 1999
  - Scheduled for data taking in 2001-3
- Physics Agenda
  - Get 10 events with small backgrounds
  - Try to increase sensitivity by exploiting the region below the $K\pi2$ peak.



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

- BNL, Fermilab (Cooper), IHEP, Michigan, Virginia, UASLP, U.Texas
- Status
  - Proposed April 15, 1998
  - R&D Project approved November 11, 1998
- Physics Agenda
  - Measure $|V_{td}|$ to the limits of the theory
    - $Br[K^+ \to \pi^+ \nu\nu] = |V_{td}|^2$ x [known stuff] = $[0.9 \pm 0.3] \times 10^{-10}$
    - The theoretical uncertainty is well quantified and dominated by lack of knowledge of the mass of the charm quark.
    - Need ~100 events with backgrounds <10%. This required 2 years of data taking.
  - Other searches and measurements in K^+ decay.





CKM Measuring $|V_{td}|$ with $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

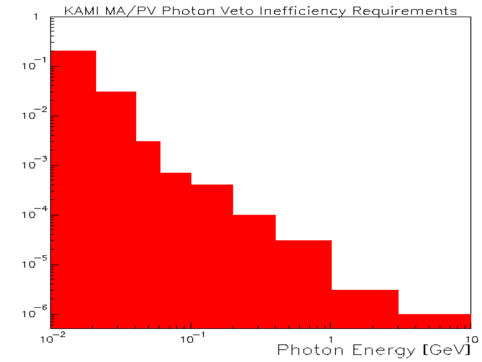
- Apparatus
  - Decay in flight spectrometer with both velocity (RICH) and momentum (magnetic) spectrometer both both K^+ and π^+.
  - Significant requirements on photon vetos
  - All detector technologies used are established
- Beam is a new SCRF separated 22 GeV/c^2 beam
  - 30 MHz K^+ $K^+/\pi^+ > 2$
  - 6 MHz decay in the acceptance.
  - Debunched proton beam required.

KAMI Measuring Im[V_{td}] with $K^0 \rightarrow \pi^0 \nu \bar{\nu}$

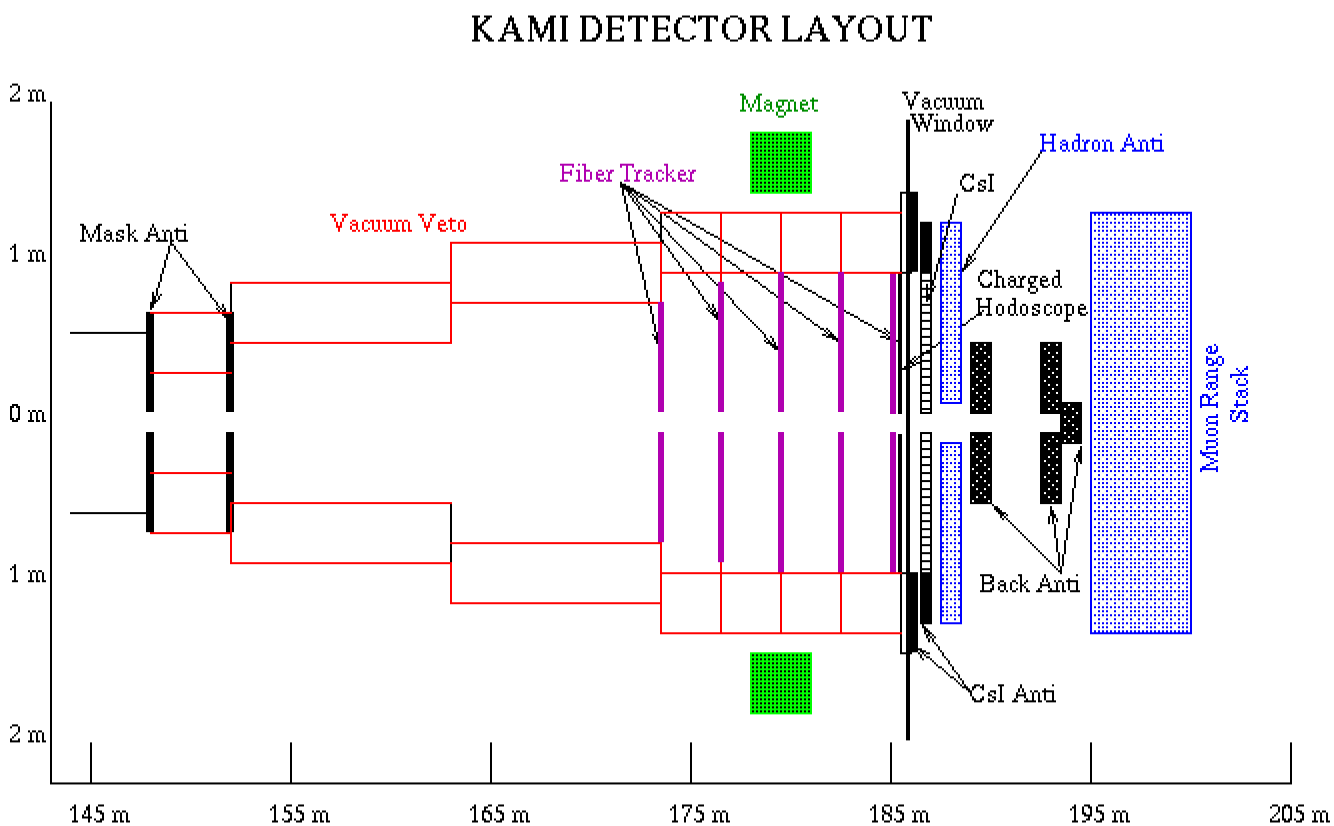
- Arizona, UCLA, Campinas, Chicago, Colorado, Fermilab (Ron Ray), Osaka, Sao Paulo, Virginia
- Status
  - EOI September 22, 1997
  - R&D Project approved November 11, 1998
  - Mostly, the next generation of KTeV
- Physics Agenda
  - Detect the ultra rare DIRECT CP Violating decay $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ to measure η_{CKM} to an accuracy of about 5%. The Standard Model expected branching ratio for this decay is $(2.8 \pm 1.7) \times 10^{-11}$
  - Study many other ultra rare K_L^0 decays to the ~10^{-13} level: $K_L^0 \rightarrow \pi^0 e^+ e^-$, $\pi^0 \mu^+ \mu^-$, $\pi^0 \mu^+ e^-$, $\pi^+ \pi^- e^+ e^-$, etc.

KAMI Measuring Im[V_{td}] with $K^0 \rightarrow \pi^0 \nu \bar{\nu}$

- The Spectrometer is KTeV with much enhanced photon veto and tracking systems.
  - Approach stresses open geometry, low rates and high precision photon detection and a broad physics program.
  - Achieving the required photon detection inefficiencies is the major challenge.
  - Inefficiency tests on prototype vetos have already begun (at INS, Tokyo). Design specs are already exceeded.
- The beam line is that now used by KTeV
  - 2 week 150 GeV/c beam test just completed with KTeV detector. K flux and K/n ratio were measured
  - Prototype beam hole veto was tested



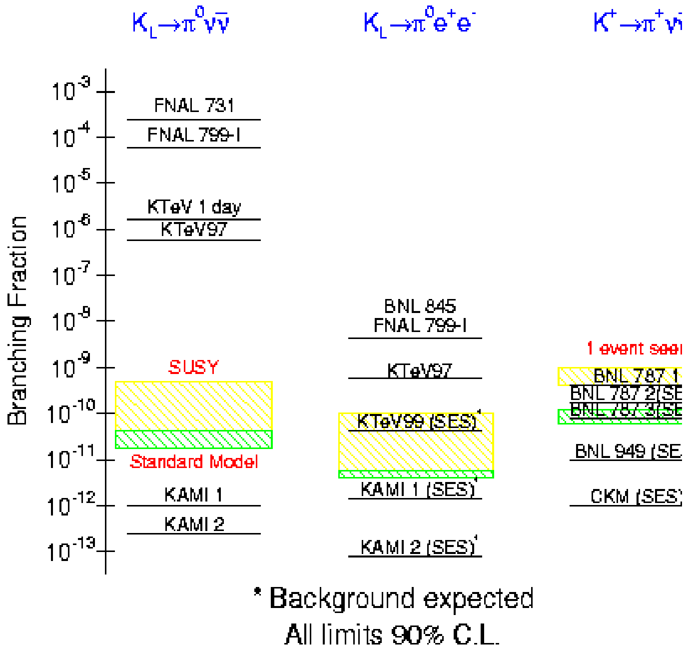
KAMI Apparatus - formerly KTeV



KOPIO - A Search for $K_L^0 \rightarrow \pi^0 \nu \nu$

- BNL, Cincinnati, INR Moscow, Kyoto, VPI, UNM, JLAB, TRIUMF/UBC(Bryman), Yale(Zeller), Zurich
- Status
  - NSF Proposal November 1998
- Physics Agenda
  - Measurement with low background and $1x10^{-13}$ single event sensitivity. $K_L^0 \rightarrow \pi^0 \nu \nu$ 50 signal events expected.
  - A low momentum (800 MeV/c^2) neutral beam at 45^0 production angle. Protons are micro-bunched with the accelerator to produce a time structured neutral beam.
  - experiment uses TOF to measure the K_L^0 momentum
  - Ultra efficient low energy photon vetoes are critical.

Combined K/B Physics Program Reach



- Colangelo and Isidori, hep-ph/9808487 claimed up to 2 orders of magnitude enhancement over SM from SUSY penguin
- Buras and Silvestrini, hep-ph/9811471 said maybe a factor of 7