# CKM
# Charged Kaons at the Main Injector

- CKM (P905) is a proposal to measure the ultra-rare kaon decay:
  $K^+ \rightarrow \pi^+ \nu \nu$ to a branching fraction precision of 10%.
- This will measure the matrix element $|V_{td}|$ with a statistical precision of 5% and an overall precision of 10%.
- CKM has been approved as an R&D Project within the Particle Physics Division (E905)
- Presentation Outline
  - Review of the CKM physics proposal (submitted April 15, 1998)
  - Progress and plans for the R&D Project approved December 15, 1998
  - Summary and Requests

WEB PAGE: http://www.fnal.gov/projects/ckm/Welcome.html
Email Address: ckm@fnal.gov

# Charged Kaons at the Main Injector

April 15, 1998

**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**


R. Coleman, P.S. Cooper*, M. Crisler, C. Milstene†, E. Ramberg, R. S. Tschirhart
Fermi National Accelerator Laboratory, Batavia, IL, USA

A. Kohzevnikov, V. Kubarovsky, V. Kurshetsov, L. Landsberg, V. Molchanov, V. Obraztsov, V. Polyakov, D. Vavilov, O. Yushchenko
Institute of High Energy Physics, Serpukhov, Russia

J. Engelfried, A. Morelos
Instituto de Fisica, Universidad Autonoma de San Luis Potosi, Mexico

K. Lang, J.L. Ritchie*
University of Texas at Austin, Austin, Texas 78712

† Resident at Fermilab, on leave from Tel Aviv University.

* Cospokesmen: P.S. Cooper, pcooper@fnal.gov, (630) 840-2629
J.L. Ritchie, ritchie@hep.utexas.edu, (512) 471-4488

\+ Hogan Nguyen, Fermilab Wilson Fellow
\- Jack Ritchie - Defector to DOE

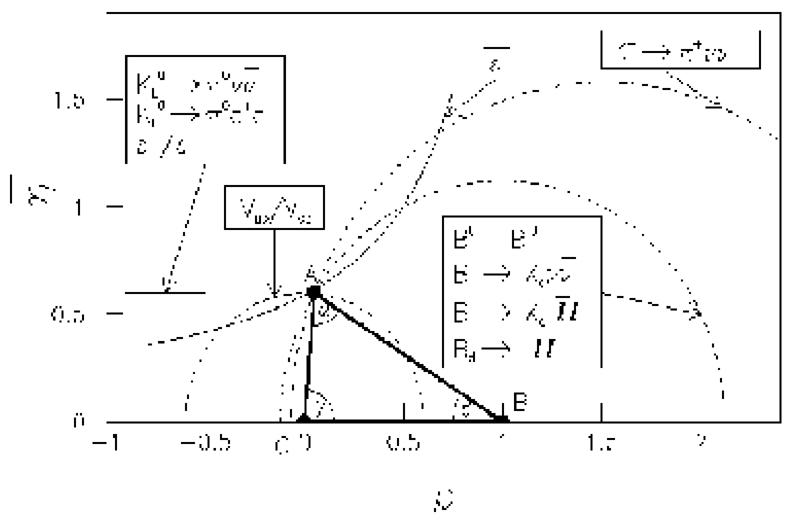
# $K^+ \rightarrow \pi^+\nu\bar{\nu}$ Data and Predictions

- Standard Model
  - $Br[K^+ \rightarrow \pi^+\nu\nu] = |V_{td}|^2$ 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.
- BNL E787 (decay at rest) has observed 1 event
  - B.R.(E787) = $[4.2\,^{+9.2}_{-3.5}] \times 10^{-10}$
  - 2.5x data in analysis - to be reported soon
  - Upgrade proposed (E949) with ~10 event sensitivity
- Next step is a real measurement of this branching ratio to the limit of the theory

# CKM Goal - Measure $|V_{td}|$

- Decay in Flight Experiment at The Fermilab Main Injector
- ~100 $K^+ \rightarrow \pi^+ \nu\nu$ events with <10% background in 2 years of data taking yields 5% statistical and 10% total precision on $|V_{td}|$
- If BNL E787 confirms their present high branching ratio there is new physics which can only be identified and understood with enough events (~400 for CKM) to study distributions
- If BNL E787 confirms a Standard Model like branching ratio measuring $|V_{td}|$ to the limits of theoretical uncertainty requires CKM's statistics

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

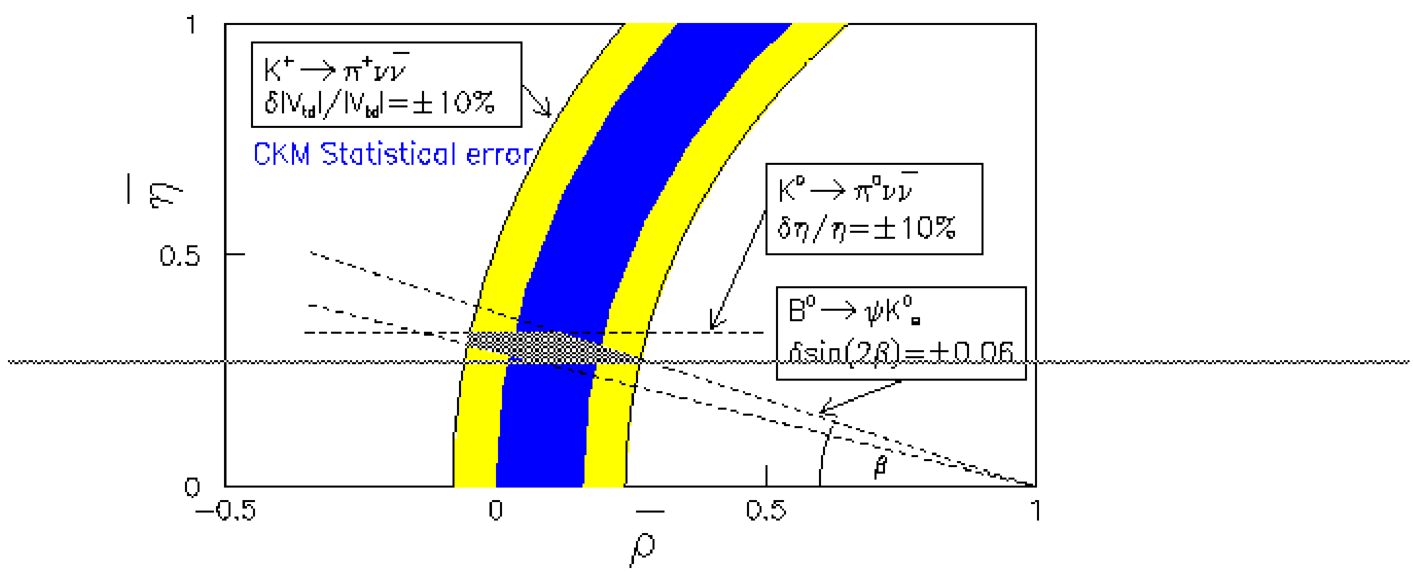



❍ Idealized unitarity triangle (from Buras)

# Related $K^0_L$ and B Measurements

- Goal is to test the Standard Model hypothesis that $\eta$ is to sole source of CP violation
- To confirm the Standard Model hypothesis
  - All observables where the theory is reliable and the measurement can be made will contribute
  - Both B and K sector results have to give the same answer
- To falsify the Standard Model hypothesis the only foreseeable results with controlled errors are:
  - Kaons $K^+ \to \pi^+ \nu\nu$ (CKM), $K^0_L \to \pi^0 \nu\nu$ (KAMI)
  - B system $B^0_d \to \Psi K^0_S$ , and perhaps $x_s/x_d$ mixing
- 3 Independent measurement are required for a test

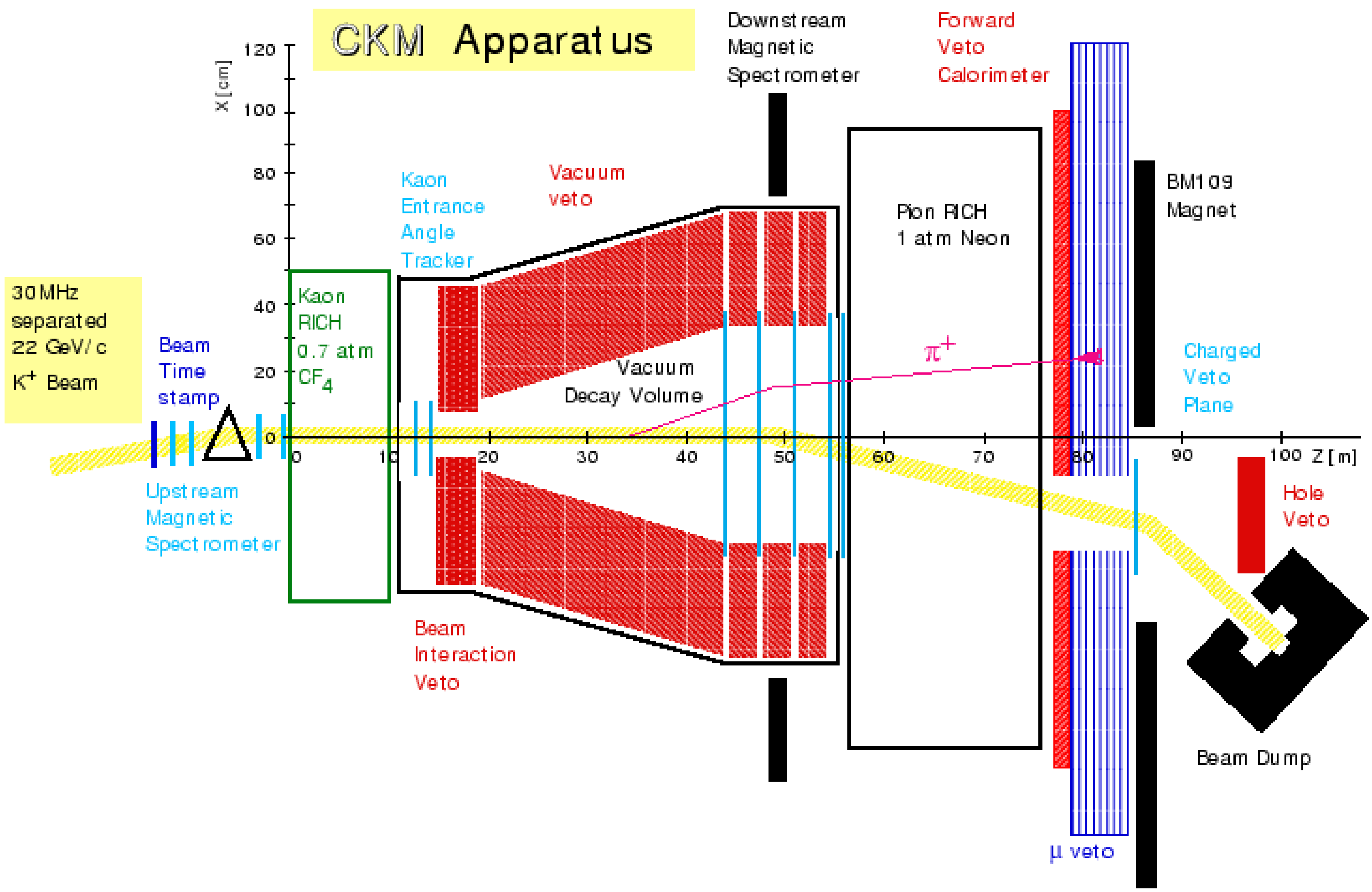
CKM measures a curve in the ρ - η plane, orthogonal to the sin(2β) measurement:



# Experimental Methods

- Control of backgrounds is the whole game
  - $K^+ \to \pi^+ \nu\nu$ ($1x10^{-10}$), $K^+ \to \pi^+ \pi^0$ (21%), $K^+ \to \mu^+ \nu$ (63%)
- Observables
  - Vector momentum and velocity of $K^+$ and $\pi^+$
  - Relative time of both tracks
  - Veto everything else (photons, muons)
- REDUNDENT high resolution measurements
  - $\sigma_P/P$~1%, $\sigma_V/V$~1%, $\sigma_t$~1 nsec require to control the dominant backgrounds.
- High rates to achieve sensitivity
  - 5 MHz $K^+$ decays
  - $2x10^7$ life seconds (2 years)
  - Implies 30 MHz $K^+$ flux through CKM => Main Injector

The CKM apparatus uses proven detector technology:



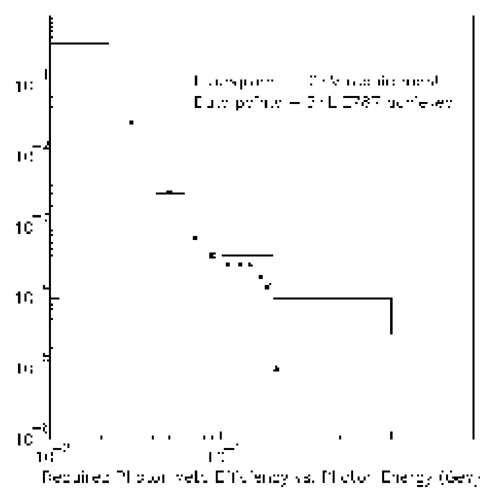
# Separated Charged Kaon Beam

- CKM Beam Requirements
  - 45 MHz of charged beam @22 GeV/c
  - Purity - $K^+/\pi^+ \geq 2/1$
  - 6 MHz of $K^+$ decays in the vacuum decay volume
  - $5 \times 10^{12}$ 120 GeV Main Injector protons are required
  - Slow spill, debunched proton beam
  - Beam energy and phase space options have been studied in detail in the past year.
- Super-conducting RF Separated beam
  - beam line is shared with CP/T
  - Is an R&D project in the Beams Division
  - Presented previously to PAC

# The Photon Veto System

- A major experimental challenge for CKM is developing a high efficiency photon veto system.
- Brookhaven E787 has achieved the required performance in a veto detector for $E_{\gamma}$<225 MeV.
- CKM requirements are based on the E787 results.

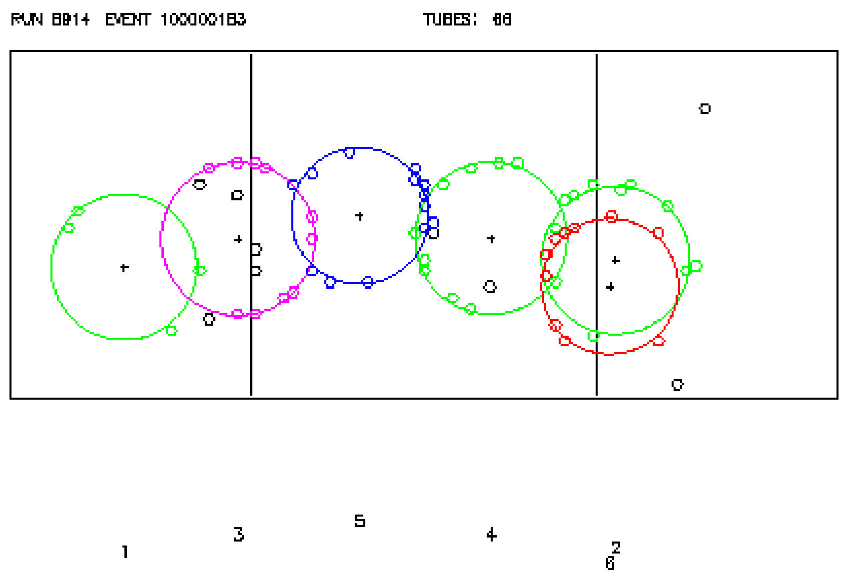
Photon Veto Requirements

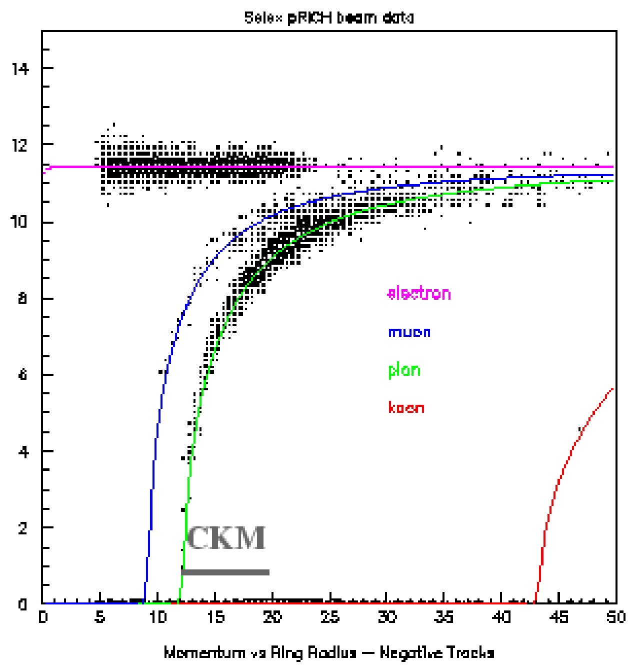


# Charged Particle Spectrometers

- Momentum
  - Upstream Magnetic Spectrometer
    Silicon microstrips with last beamline dipole
  - Downstream Magnetic Spectrometer
    Strawtubes (in vacuum) with a wide aperture magnet
- Velocity
  Based on photo-tube Ring Imaging CHerenkov counters pioneered by Selex.
  - 1 nsec time resolution on each PMT, 10 nsec pulse pair resolution
  - Kaon RICH
    $CF_4$ at 0.77 atm so that Kaons are just above threshold
  - Pion RICH
    - A clone of the Selex RICH (Neon at 1 atm)
    - twice the length & resolution

# SELEX event display showing phototube hits in the RICH

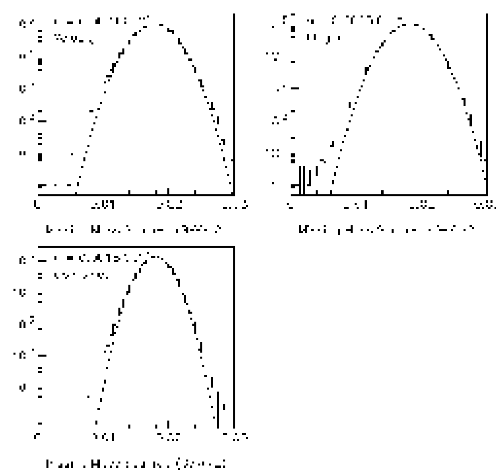





- Selex took beam trigger data in a 25 GeV/c beam
- The RICH gave good rejection and resolution in the CKM energy regime.
- The CKM Pion RICH is designed to have twice better resolution.

# 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

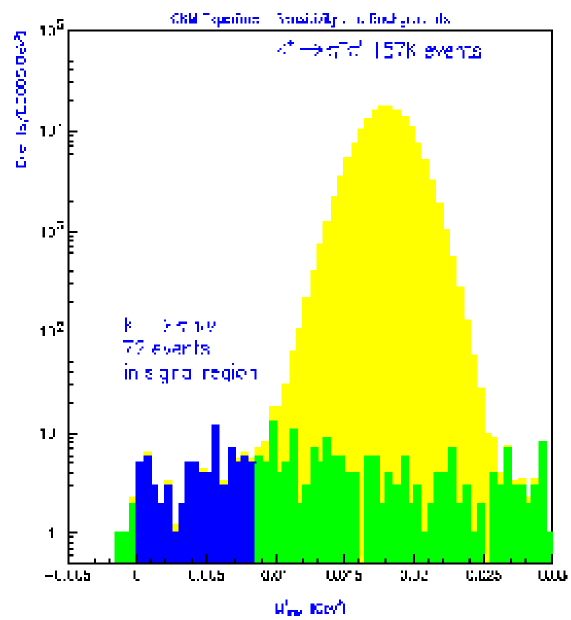


# Background Processes

| Background Source | Effective BR ($\times 10^{-12}$) |
|---|---|
| $K^+ \rightarrow \mu^+ \nu_\mu$ | < 0.04 |
| $K^+ \rightarrow \pi^+ \pi^0$ | 3.7 |
| $K^+ \rightarrow \mu^+ \nu_\mu \gamma$ | < 0.09 |
| $K^+A \rightarrow xK_L \rightarrow \pi^+ e^+ \nu$ | < 0.14 |
| $K^+A \rightarrow \pi^+X$ (trackers) | < 4.0 |
| $K^+A \rightarrow \pi^+X$ (gas) | < 2.1 |
| Accidentals | 0.51 |
| TOTAL | < 10.6 |

# Expected Signal and Background

- 72 signal events in a background free region
- $K^+ \rightarrow \pi^+ \pi^0$ is the main background
- 2 years of data taking is assumed

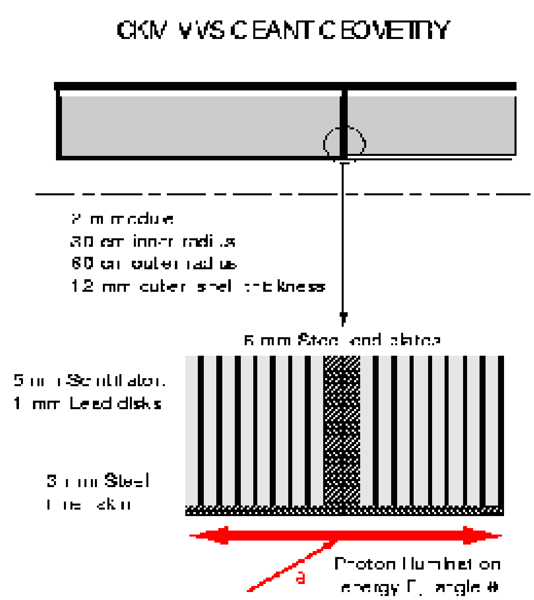


# R&D Project Progress and Plans

# Designing the Vacuum Veto

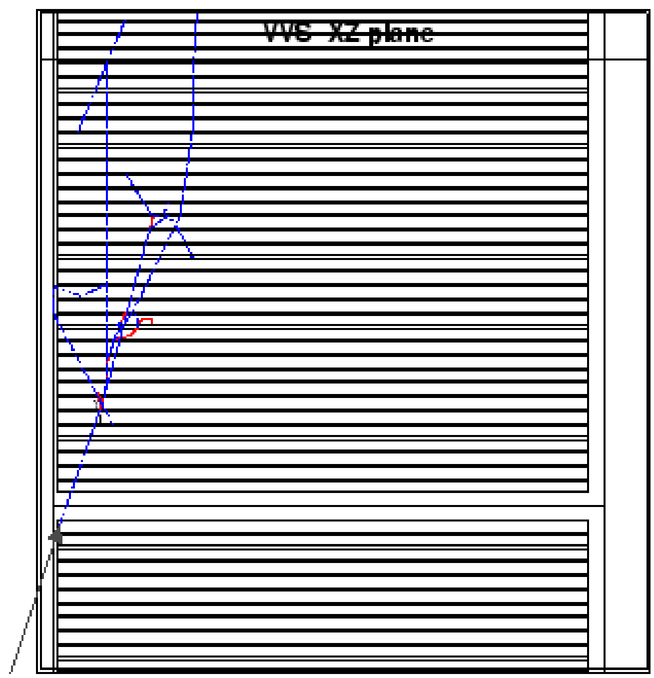
- We have a first pass at a mechanical structure for the vacuum photon veto based upon KTeV's design

- Mechanical engineering is required here



# GEANT Inefficiency Simulation

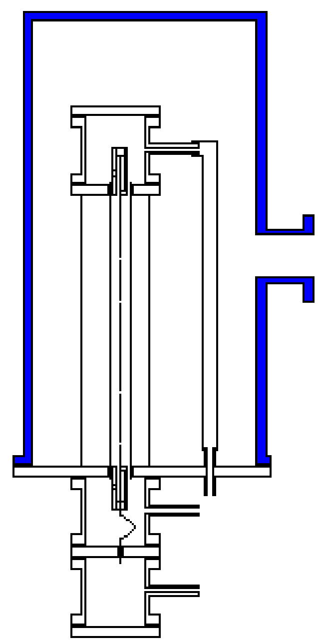
A GEANT simulation of our current design is giving results on the veto inefficiency as a function of photon energy and angle.




A 50 MeV photon hitting the boundary between veto modules.

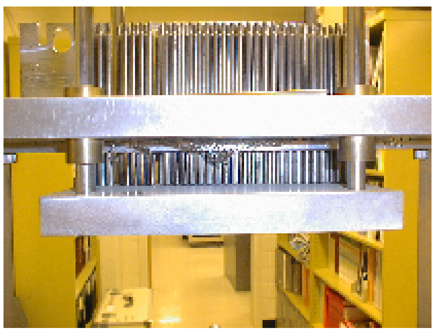
# Progress on Straw Tubes in Vacuum

- Scattering is the biggest cause of background.  Low mass straw tubes are the preferred option.
- A CKM goal is to prove the viability of straw tubes in a vacuum environment.
- This fixture must be built.

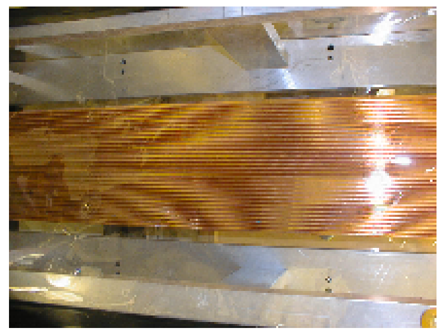


Fixture design for testing straw tube vacuum characteristics at Fermilab.

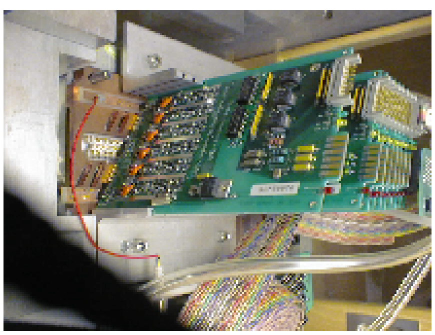
# Learning about straw tubes from BNL E871
# (a visit to University of Texas)



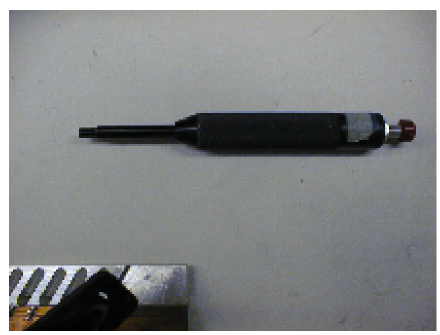
The assembling fixture for an array of straw tubes



An array of straw tubes in place



The readout electronics for a chamber



A device to help in stringing straw tubes

# Interaction with BNL E949

- BNL E949 is an upgrade/extension of BNL E787 with the goal of ~10 Standard Model events.

- CKM and E949 have, with the encouragement of the Fermilab and BNL managements, discussed the possibility of joining each other in order to strengthen the overall commitment toward pursuing this physics.

- We seek the PAC's advice and support for making such an alliance.

# Summary

- The hypothesis that the CKM matrix is the sole source of CP violation cannot be tested unless three independent precision measurements are made.
- CKM has the potential for a theoretically robust measurement on the $\rho-\eta$ plane comparable to those expected in the B systems from B factories and Hadron Collider experiments.