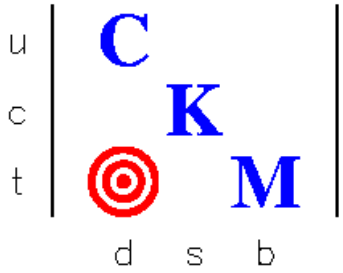


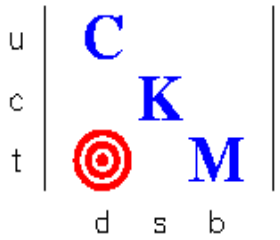
CKM

Charged Kaons at the Main Injector

CKM is a proposal to measure the ultra-rare kaon decay: $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ 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%.

- The physics
- Experimental status
- RF separated K^+ beam
- The experiment
- Present status and expectations

Peter S. Cooper
Fermi National Accelerator Laboratory
September 19, 2000



Charged Kaons at the Main Injector

March 10, 2000

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

J. Frank, S. Kettell, R. Strand
Brookhaven National Laboratory, Upton, NY, USA

L. Bellantoni, R. Coleman, P.S. Cooper*, M. Crisler, T. R. Kobilarcik, C. Milstene, H. Nguyen, E. Ramberg, R. S. Tschirhart, H. B. White, J. Y. Wu
Fermi National Accelerator Laboratory, Batavia, IL, USA

A. Kozhevnikov, 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

M. Campbell
University of Michigan, Ann Arbor, Michigan 48109

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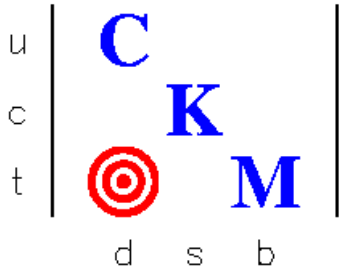
University of Texas at Austin, Austin, Texas 78712

C. Dukes, K. Nelson
University of Virginia, Charlottesville, VA 22901

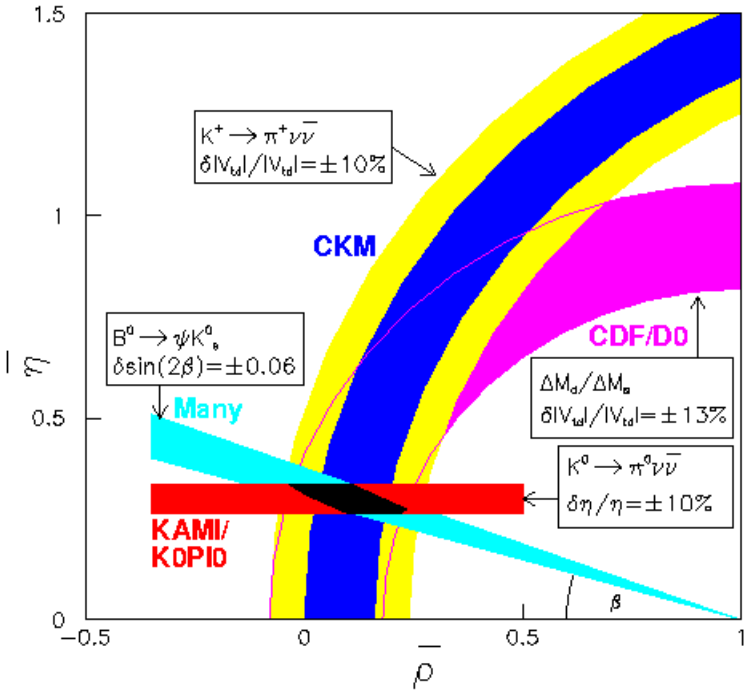
* Spokesman: P.S. Cooper, pcooper@fnal.gov, (630) 840-2629

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

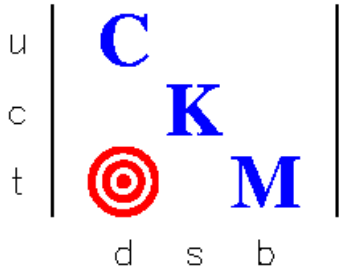
The Physics I



- Measurement of the ultra- rare process $K^+ \rightarrow \pi^+ \nu\nu$ provides clean access to the CP Violating parameters of the Standard Model.
- This process is expected to occur with a branching fraction of $(8 \pm 3 \times 10^{-11})$. One clear candidate event has been observed by BNL-E787 with a branching fraction of $(15\ ^{+34}_{-12} \times 10^{-11})$.
- The CKM experiment proposes to measure this process with a sensitivity of (1×10^{-12}).



The Physics II



- The critical question is: "Are all CP phenomena described by just ρ and η?" Lincoln Wolfenstein, who invented ρ and η, doesn't care what their actual values are – we shouldn't either.

- These 4 measurements are the only accessible possibilities with sufficient theoretical robustness so that a contradiction could call the Standard Model into question.

- There are still theoretical caveats:

  $\Delta M_d / \Delta M_s$ 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)+[~10%](SU_3) = 13%

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

  Together can measure both $F(\rho,\eta)$, and V_{ts} assuming SM. (Nir)

  Alone each requires a theoretically robust measure of V_{ts}.

  K^+ Theoretical uncertainty is dominated by m_{charm} (~8%)

  K^0 and $B_d^0 \rightarrow \psi K_s^0$ are theoretically clean to the ~1% level

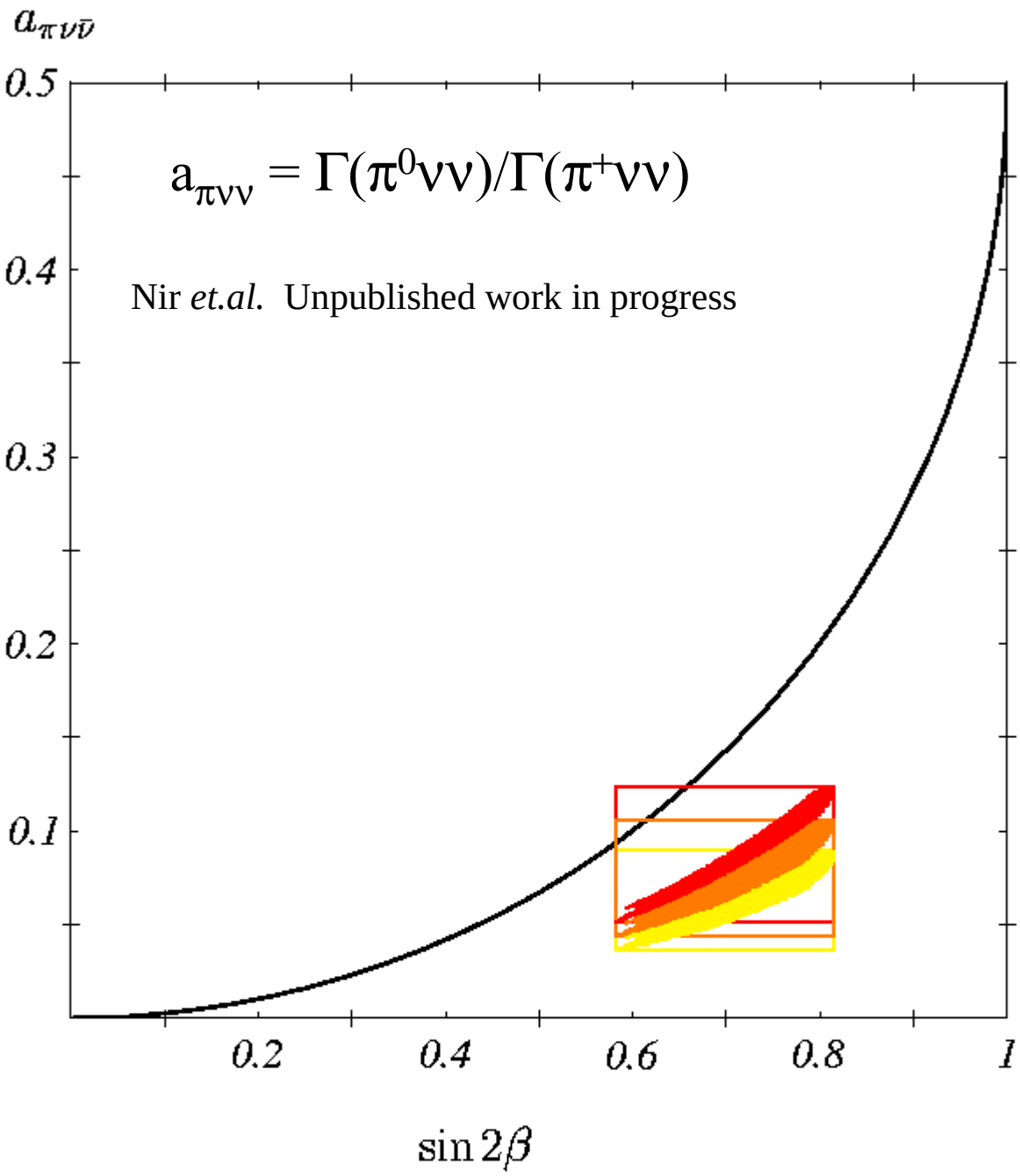
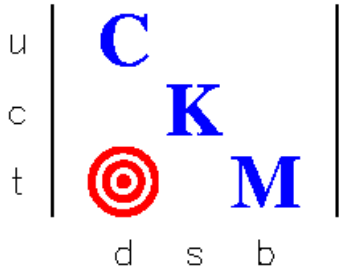


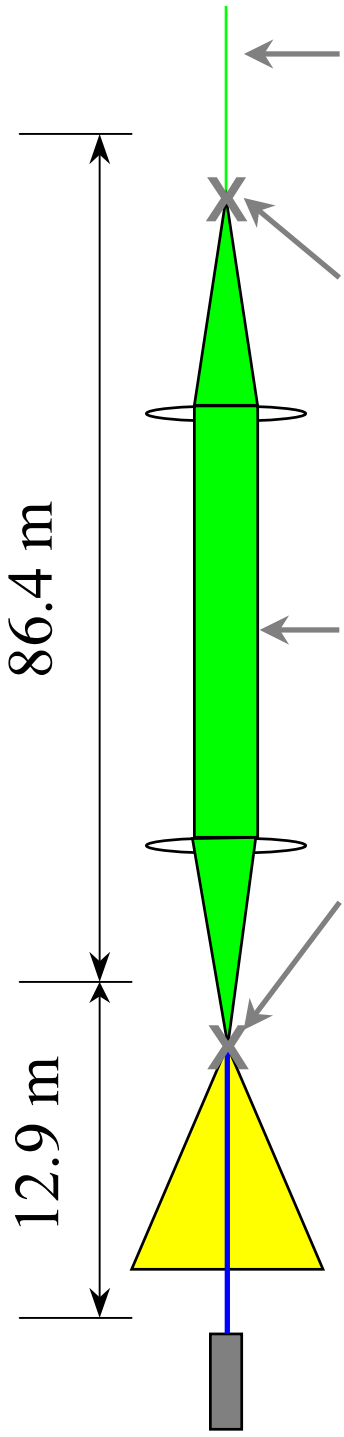
FIG. 3. Relation between $a_{\pi\nu\bar{\nu}}$ and $\sin 2\beta$: The solid curves displays $a_{\pi\nu\bar{\nu}}(\sin 2\beta)$ for $\Delta = 0$. Only in this case there is a one-to-one correspondence between $a_{\pi\nu\bar{\nu}}$ and $\sin 2\beta$. A scan over the presently allowed region for $(\bar{\rho}, \bar{\eta})$ (c.f. Fig. 1) with $\Delta = 0.41$ ($\Delta_{min} = 0.29$, $\Delta_{max} = 0.56$) yields the orange (yellow, red) region in the $\sin 2\beta - a_{\pi\nu\bar{\nu}}$ plane.

Experimental Status



- BNL E787 reports 1 clean event
  - $Br\,(K^{+} \rightarrow \pi^{+}\nu\bar{\nu}) = 1.5^{+3.4}_{-1.2} \times 10^{-10}$
- BNL E949 (upgrade of E787) expects to see 5 - 10 events
  - Approved to run in 2001-3
- CKM plans to see 100 events
  - Approved for R&D
  - *"…the core of a 120GeV fixed-target program"*
  - PAC to revisit FT 120 program spring 2001
- BNL / FNAL collaboration

RF separated K^+ beams



Initial momentum-selected beam $\Delta P/P \sim 2\%$

RF deflection: $A\sin(\omega t)$
$A \sim 15$ MeV/c

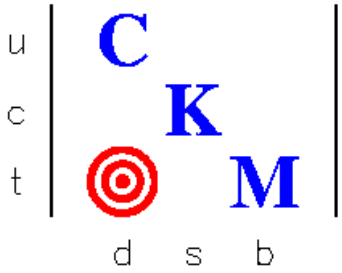
Transport L = (integer)$\beta_\pi c/f$
Δt then integer multiple of $2\pi\omega$ for π^+

2nd RF deflection *e.g.* 180° out of phase: $-A\sin(\omega t+\omega\Delta t)$

For π^+, no net deflection
For K^+, deflection is
$2A \sin(n\beta_K c/2f) \bullet \cos(wt+ n\beta_K c/2f)$

Stop π^+ with beam plug, collect K^+

SCRF cavities



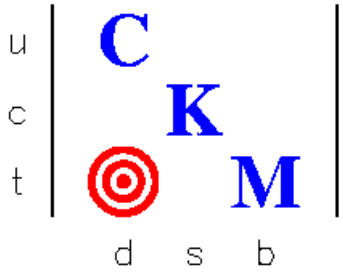
A 2-cell cavity was donated by Cornell to commission our cryogenic test rig

It has since been used for a few studies in surface preparation, Q, and achievable field strength.

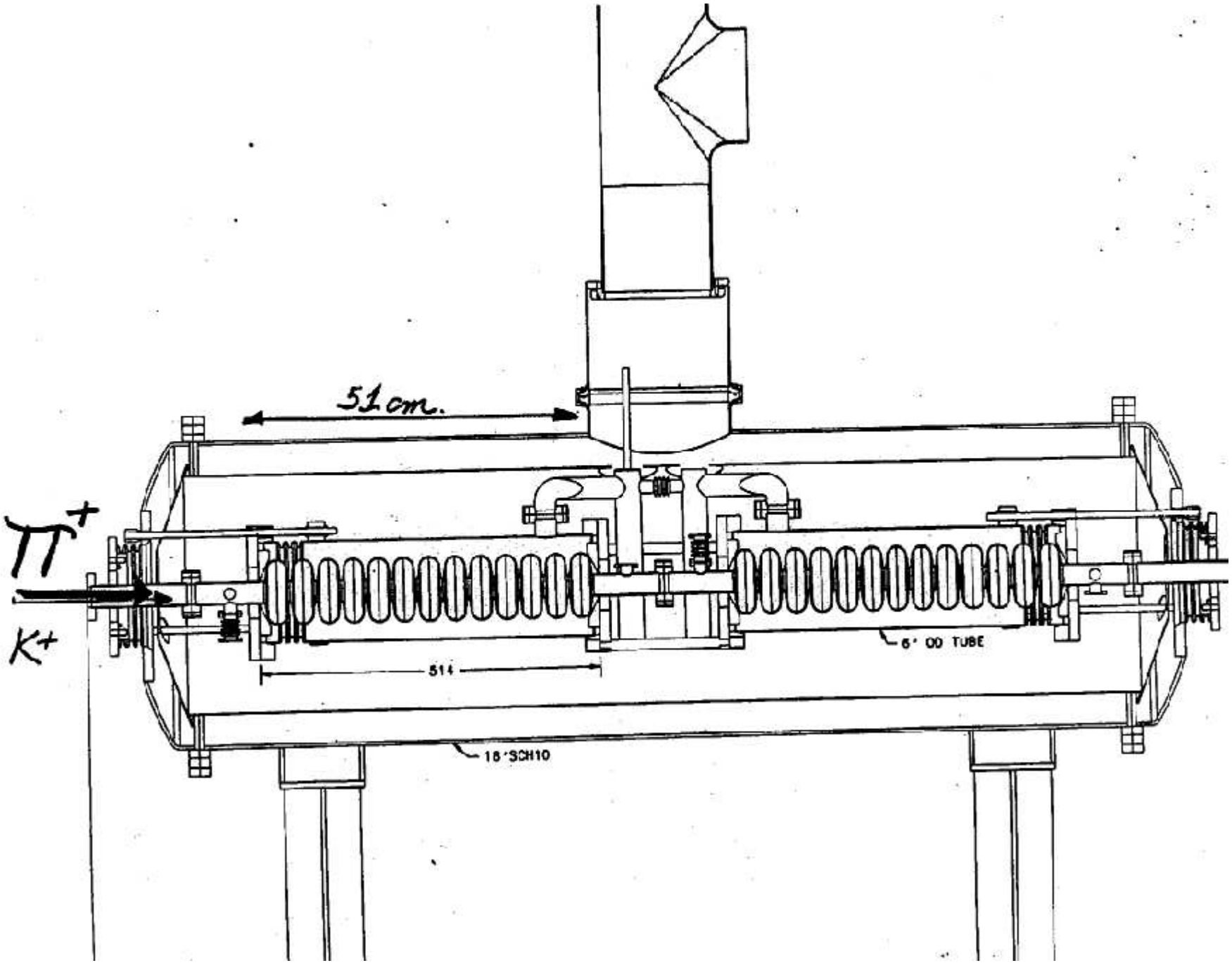
A 5-cell reactor-grade Niobium cavity was assembled to study tooling and electron-beam welding issues

It has since proven useful in studying cavity tuning and other RF related issues

Preliminary Specs

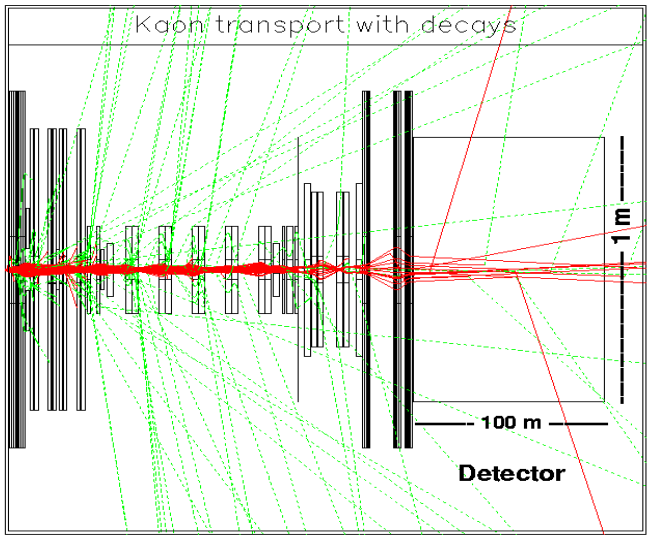


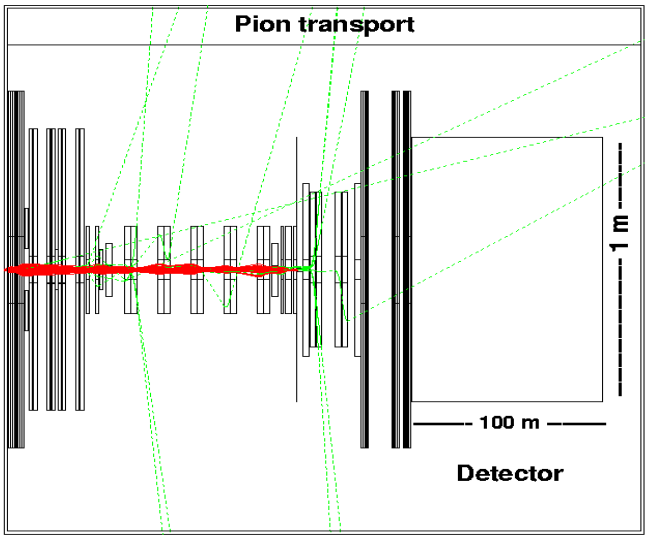
- 3.9 GHz, TM_{110} π mode
  - ♦ 15mm iris radius
  - ♦ 47mm equator radius
  - ♦ 38mm cell length
- 26 cells per meter
- 5 MeV/m $P_{\perp}$ kick;
  15 MeV/station
- E_{peak}= 22MV/m B_{peak}= 0.1T
- Stored energy 0.92 J/m
- Q: 2.2×10^9 (unloaded)
  6.0×10^7 (loaded)


51 cm.
π+
K+
51¼
6" OD TUBE
18" SCH10

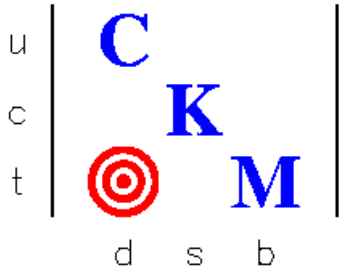
Beamline Design

- **Baseline design using 2 RF stations simulated in Turtle/GEANT:**
  - Debunched 22GeV/c beam ($\Delta p/p$ $\pm$2%)
  - 30 MHz of K^+ per 5 x 10^{12} ppp [of 3 x 10^{13} ppp in Main Injector]
  - 70% Kaon purity
  - Achieves baseline CKM requirements
  - Simulation being used to assess detector rates

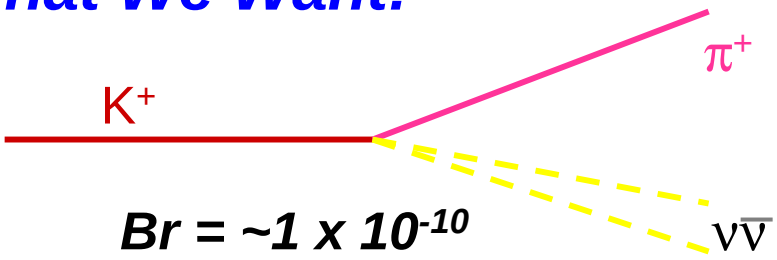




The Experiment Backgrounds



What We Want:

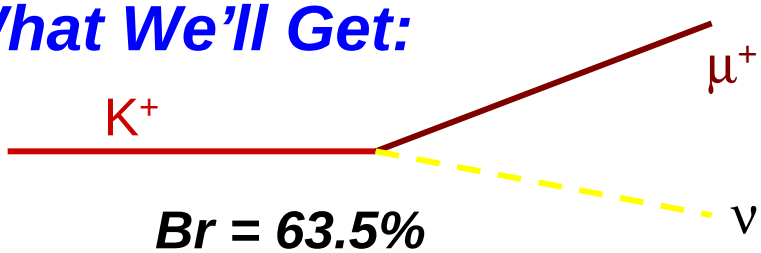


Br = ~1 x 10^{-10}

Kinematics

Velocity, **M**omentum, position of K^+ and π^+

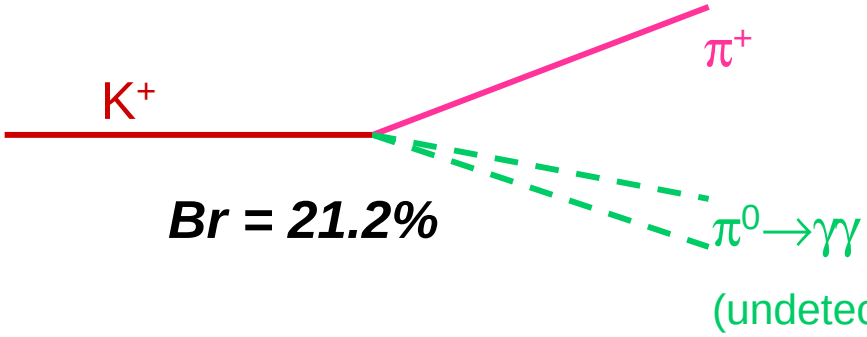
What We'll Get:



Br = 63.5%

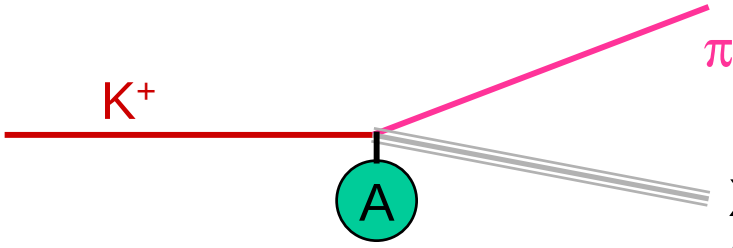
Also K+→$\mu^+\nu\gamma$

μ^+ Veto

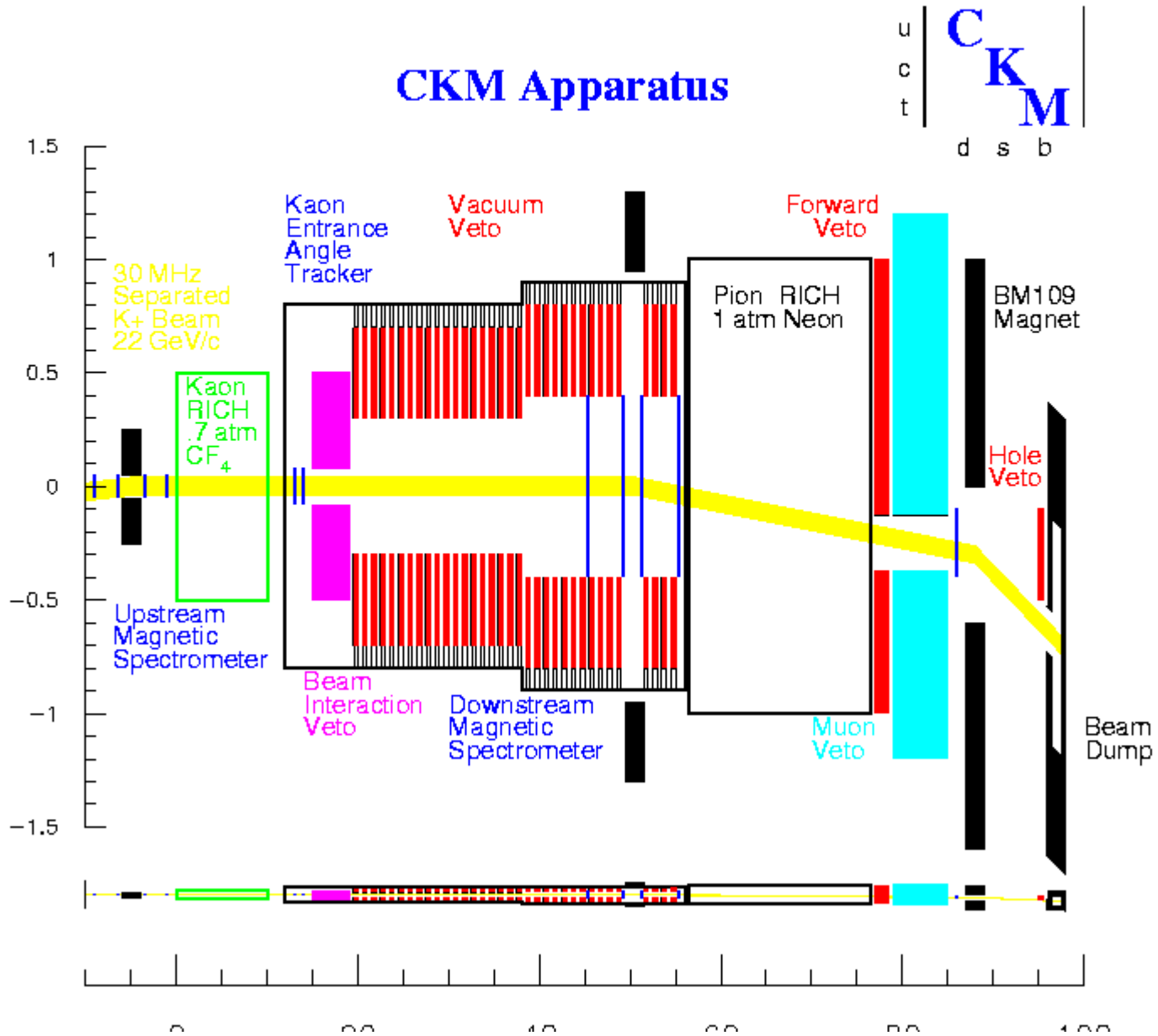


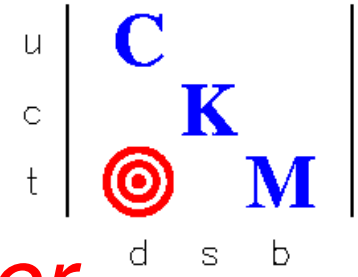
Br = 21.2%

γ Veto



Charged Veto
Low Material


CKM Apparatus
u
c
t
C K M
d s b
1.5
1
0.5
0
−0.5
−1
−1.5
30 MHz
Separated
K+ Beam
22 GeV/c
Kaon
RICH
.7 atm
CF_4
Upstream
Magnetic
Spectrometer
Kaon
Entrance
Angle
Tracker
Vacuum
Veto
Beam
Interaction
Veto
Downstream
Magnetic
Spectrometer
Pion RICH
1 atm Neon
Forward
Veto
Muon
Veto
BM109
Magnet
Hole
Veto
Beam
Dump



Upstream Spectrometer and Entrance Tracker

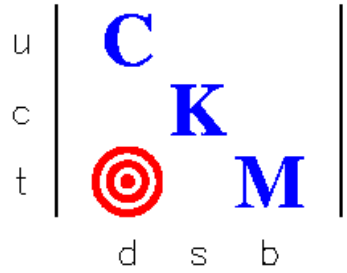
- ±0.5% Momentum resolution
  150μm Position resolution

- Proposal suggested 4 double sided 50μm pitch Si strip detectors

- BTeV pixel detector would reduce tracking ambiguity but introduces 50% more material

- Also looking at high rate PWCs a la HyperCP

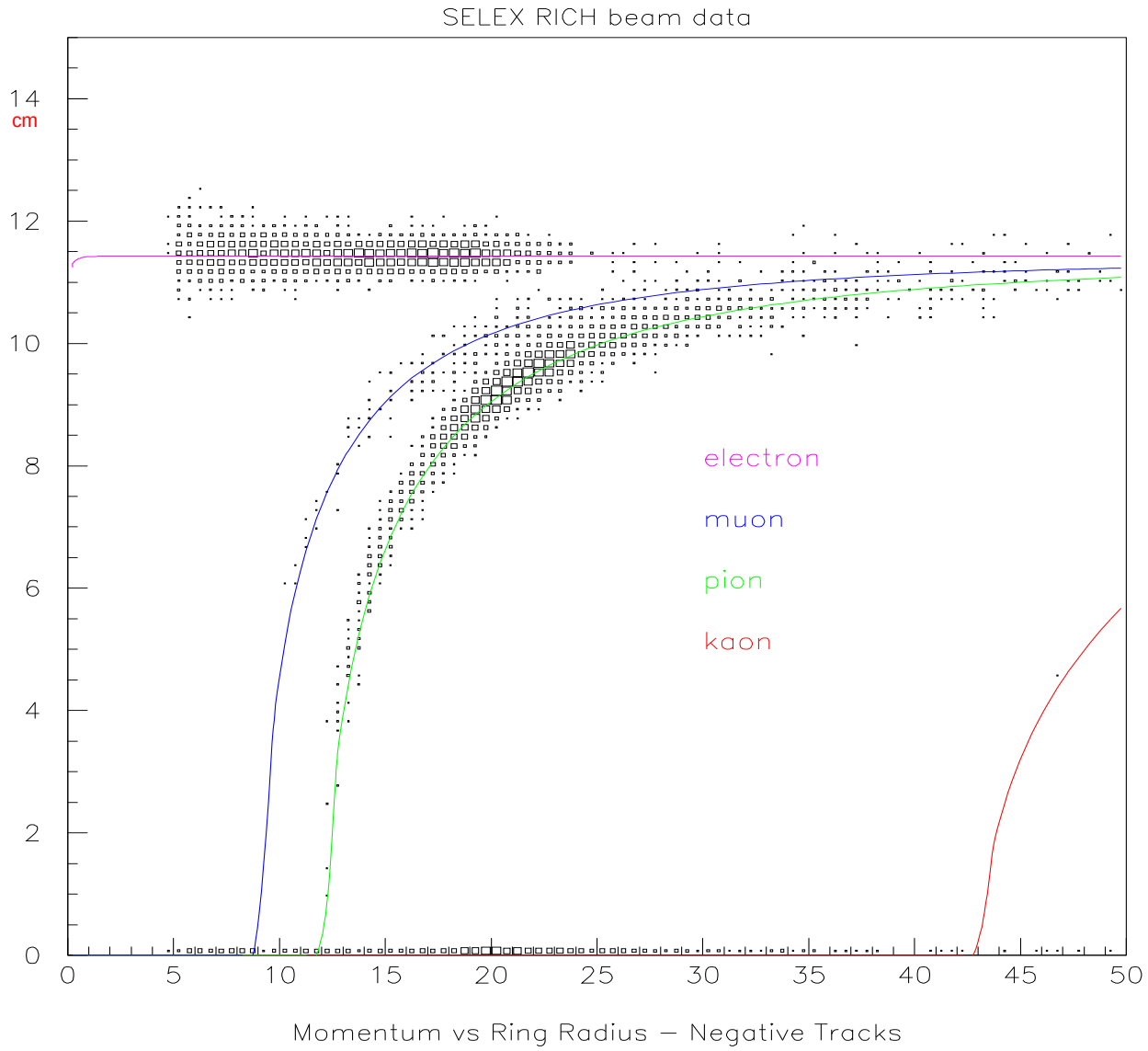
K^+, π^+ RICHs



- Vector velocity spectrometers
- 22GeV beam gives K^+ resolution in ($\gamma\beta$) to 0.5%
- K^+ RICH is 10m long CF_4 (or N_2) radiator with ~10 detected photons
- π^+ RICH ($\gamma\beta$) resolution ~1.0%

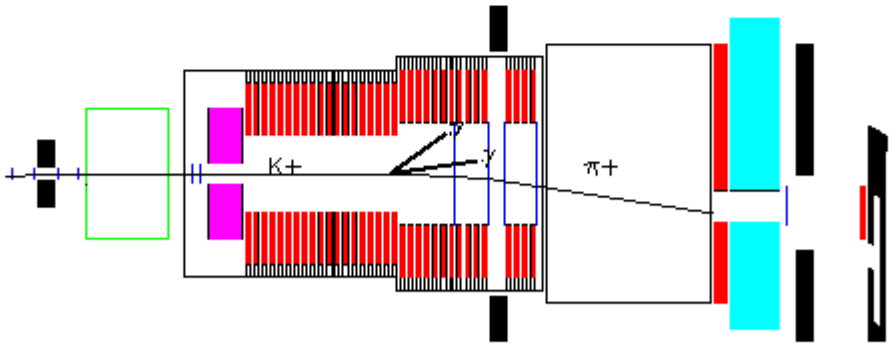
  20m long Ne radiator with 3000 PMTs
- Challenges include:
  - Need 0_2 contamination at $\mathcal{O}(10^{-6})$
  - Low mass mirrors
  - High rate (~1MHz) photomultiplier tubes
  - Gaussian tails in resolution to 5 orders of magnitude
- Drawing heavily on the SELEX experience

SELEX *RICH*

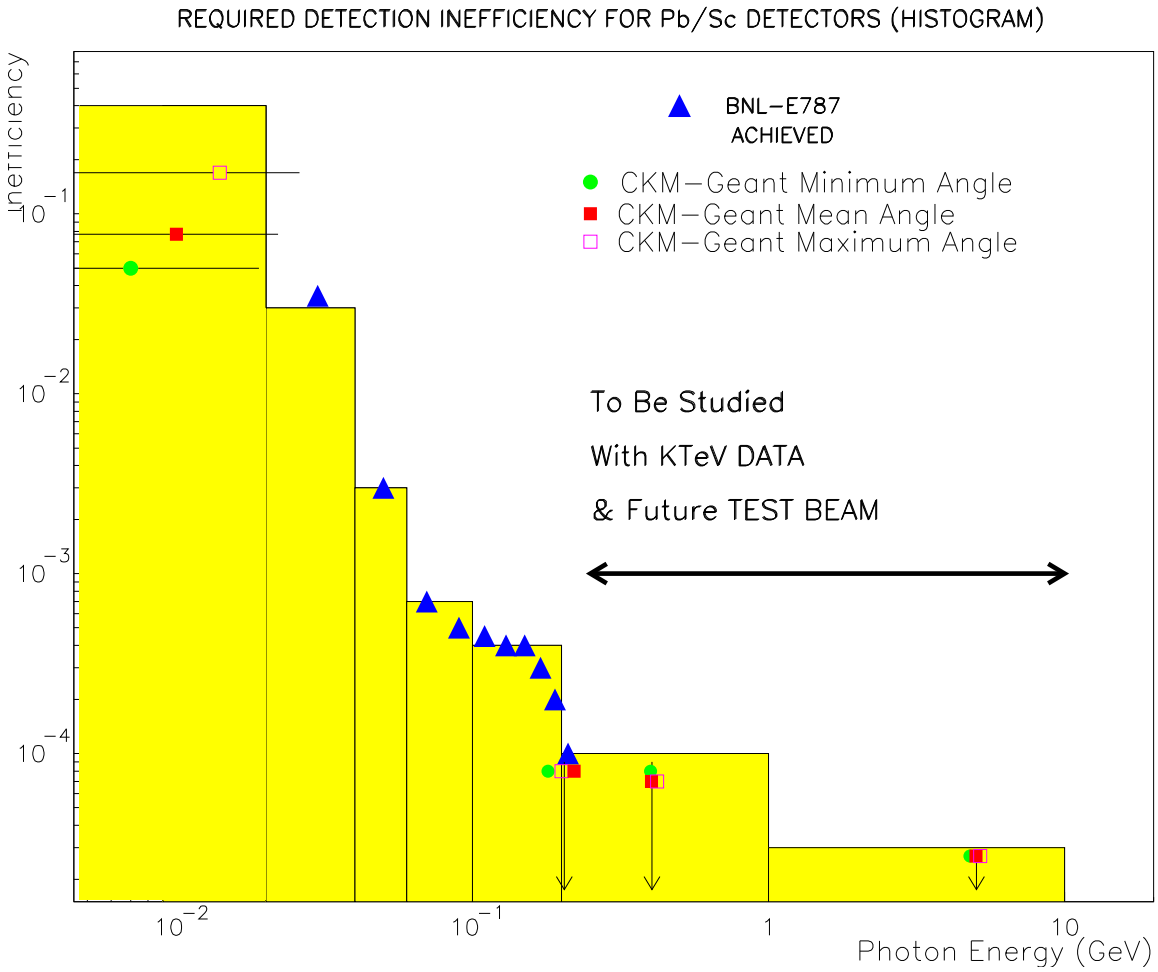

SELEX RICH beam data
14
cm
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
electron
muon
pion
kaon
Momentum vs Ring Radius – Negative Tracks

CKM Photon Veto Design Strategy

- The design assumes the demonstrated performance of the BNL-E787 (1mm Pb/5mm Scint) system for vetoing low energy (20 MeV-200 MeV) photons.
- Benchmark the high energy performance of the design with studies of electrons (1-10 GeV) on Pb/Scint KTeV veto structures. A special KTeV data set was collected in the '99 Fixed Target run that serves as a laboratory for these studies.
- Base the engineering of the vacuum decay-volume veto system on the proven success of the KTeV vacuum veto system.



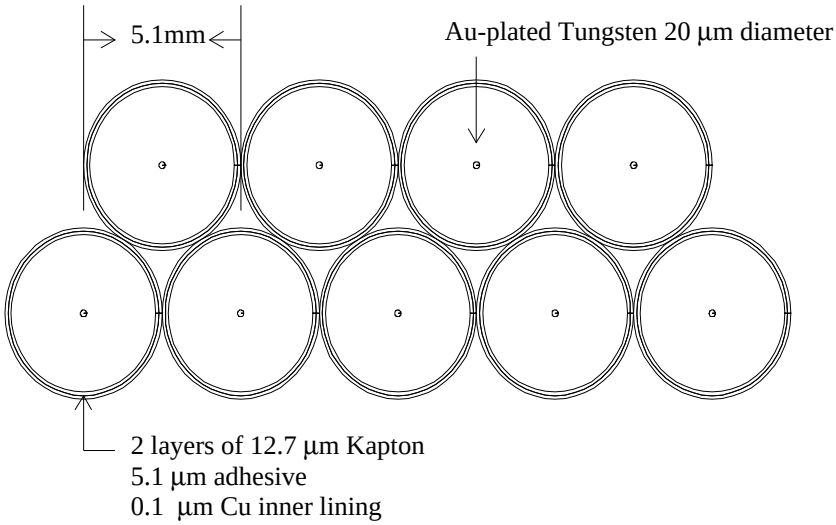
Photon Veto System



Design assumes the demonstrated performance of BNL-E787 system (1mm Pb / 5mm Scintillator) for vetoing low energy (20 - 200 MeV) photons

Prototypes under construction

Straw Tracking System



5-8 straw layers per chamber (X,Y,U,V)
4 x 10^{-4} X_0 per layer
150 μm hit resolution per layer
25 nsec charge collection time
Chamber gain reduced in beam region
Operation in vacuum decay volume

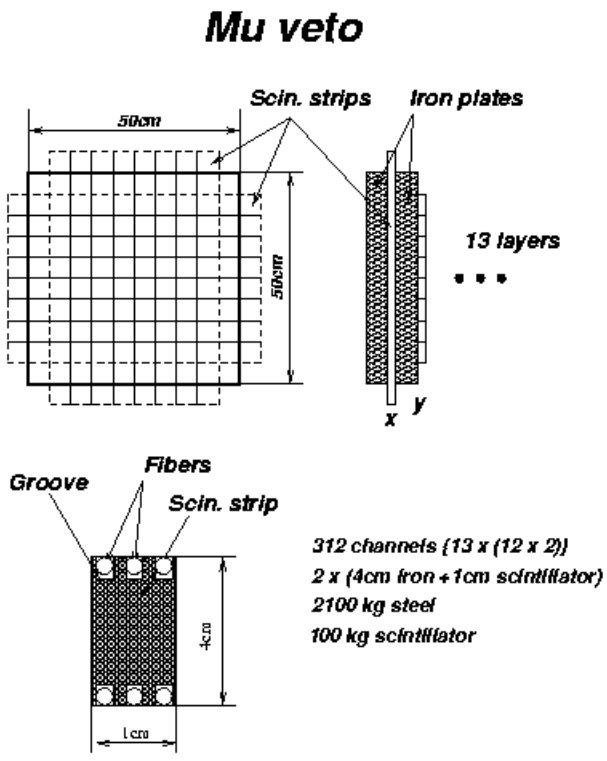
- **Studied mechanical properties at ~1 atm overpressure; now testing under vacuum**
- **GEANT simulations of scattering**
- **Commissioned BNL-871 straw chamber for study of signal gains/shapes.**
- **Measured leak rate of straws (0.1 l/sec/straw @10^{-6})**
- **Need overall design, assembly procedure, cost estimate**

Muon Veto System

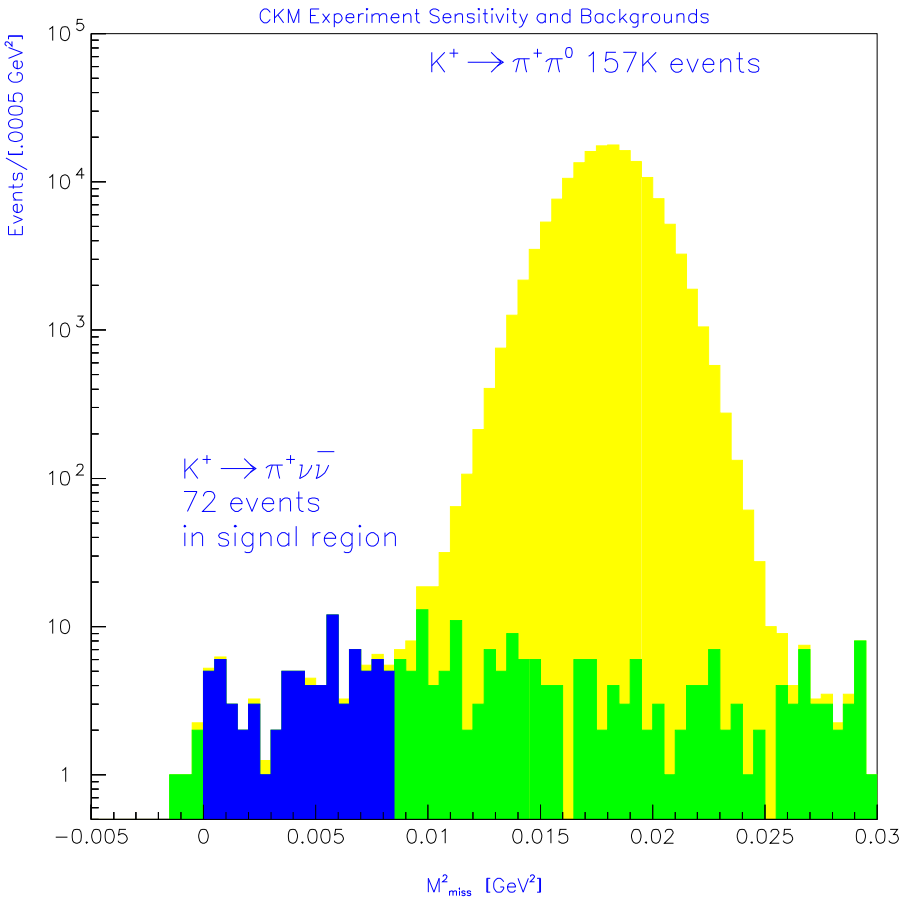
- Must not mis-id μ^+ as π^+ at the 10^{-5} level.
- Mis-id mechanisms are Bremsstrahlung, decay and deep inelastic scattering.
  All OK according to Geant.
- Test data from μs in UCAL - KAMI test

  Bremstralung important – well modeled

  DIS seen at ~ expected rate
- Prototype test at IHEP Protvino next month



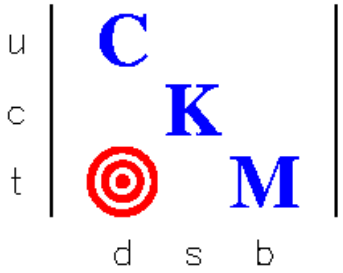
When it all works…



$$M^2_{MISS} = M^2_K(1 - p_\pi/p_K) + m^2_\pi(1 - p_K/p_\pi) - p_\pi p_K \theta^2$$

But a great deal needs to be done to get there…

Present Status and Plans I



Main Injector

Jun 99 Main Injector commissioned. Delivers beam for last 800 GeV fixed target run

Jan 00 150 GeV slow spill delivered to KAMI

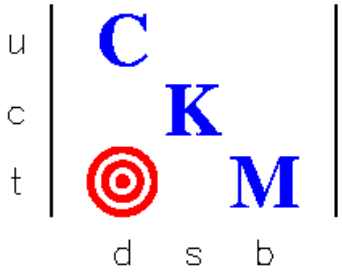
Feb 02 120 GeV Main Injector slow spill to Meson lab (test beams)

Proton Economics

CKM requests <20% of 3 x 10^{13} ppp with ~1 sec spill – debunched beam

Beams division is presently studying possible operating modes to balance collider, neutrino and fixed target. All theory - so far.

Present Status and Plans II



PROPOSAL

KAON99 encouragement but no commitment

"…CKM and KAMI, if proven technically feasible, would from the core of a 120 GeV fixed target program" Fermilab PAC May 1999

Now encouragement, resources and a plan

May 00 Fermilab requests proposal

Nov 00 PAC – questions for proposal

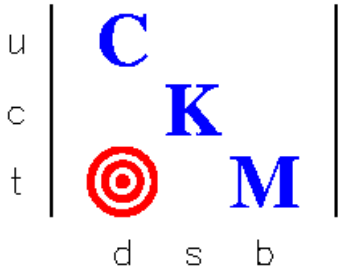
Apr 01 PAC – proposal preview

May 01 proposal submission

June 01 proposal reviewed at Aspen by PAC

July 01 decision (if we're like BTeV);
more questions (if we're not)

Present Status and Plans III



Experiment

- Good technical progress no "show stoppers"
- Full simulations, small prototypes and test beam activities are underway now.
- We are working on a 2nd, more technical, edition of our 1998 proposal for the Fermilab PAC's consideration in May 2001.

Collaboration

29 people from 7 institutions – and growing

Summary

We believe it is very likely that we will have to do this measurement!