Kplus – A Cost Effective and Competitive Precision Measurement of the Decay $K^+ \to \pi^+ \nu \bar{\nu}$

April 8, 2005

Robert Tschirhart, Fermilab

I. The compelling physics case.

II. Some History.

III. What is needed to succeed

Peter S. Cooper, Fermilab

IV. A new technique and its challenges

V. R&D Project

VI. Requests

"The Physics is Compelling…"
Fermilab PAC April 2004

- B physics has been probed at the scale of λ^2 and λ^3 and there is no clear evidence today for new physics.

- $K\rightarrow\pi\nu\nu$ decays are highly supressed (λ^5) and represent an unexplored window for new physics that could be relatively large in $\mathbf{s\rightarrow d}$ transitions.

- New physics at the LHC will unfold like the top-quark discovery…evidence for new states but little information about the new flavor structure.

Isidori's Formulation

Towards a model independent approach to the flavour problem:

non-grey entries = th. error $\lesssim 10\%$

(grey oval) = exp. error $\lesssim 10\%$

(white oval) = exp. error ~ 30%

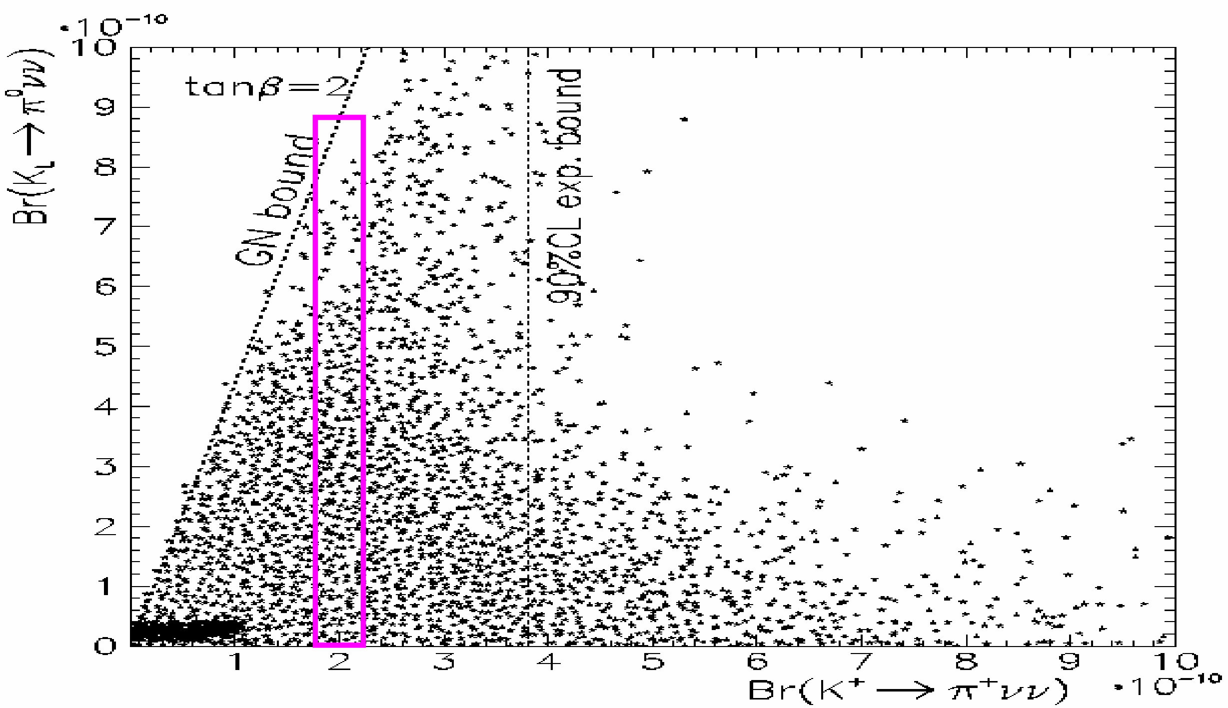
FLAVOUR COUPLING:

ELECTROWEAK STRUCTURE	$b \to s$ $(\sim\lambda^2)$	$b \to d$ $(\sim\lambda^3)$	$s \to d$ $(\sim\lambda^5)$
$\Delta F=2$ box	ΔM_{Bs}, $A_{CP}(B_s \to \psi\phi)$	ΔM_{Bd}, $A_{CP}(B_d \to \psi K)$	ΔM_K, ε_K
$\Delta F=1$ 4-quark box	$B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to \pi\pi$, $B_d \to \rho\pi$, ...	ε'/ε, $K \to 3\pi$, ...
gluon penguin	$B_d \to X_s \gamma$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d \gamma$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
γ penguin	$B_d \to X_s l^+ l^-$, $B_d \to X_s \gamma$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to X_d \gamma$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
Z^0 penguin	$B_d \to X_s l^+ l^-$, $B_s \to \mu\mu$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to \mu\mu$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, $K \to \pi\nu\nu$, $K \to \mu\mu$, ...
H^0 penguin	$B_s \to \mu\mu$	$B_d \to \mu\mu$	

The most clean and most rare entries of the table !

Reach in SUSY Space

Buras et.al. have studied the discovery reach in MSSM SUSY space, and demonstrates that $K \rightarrow \pi\nu\nu$ is particularly incisive.

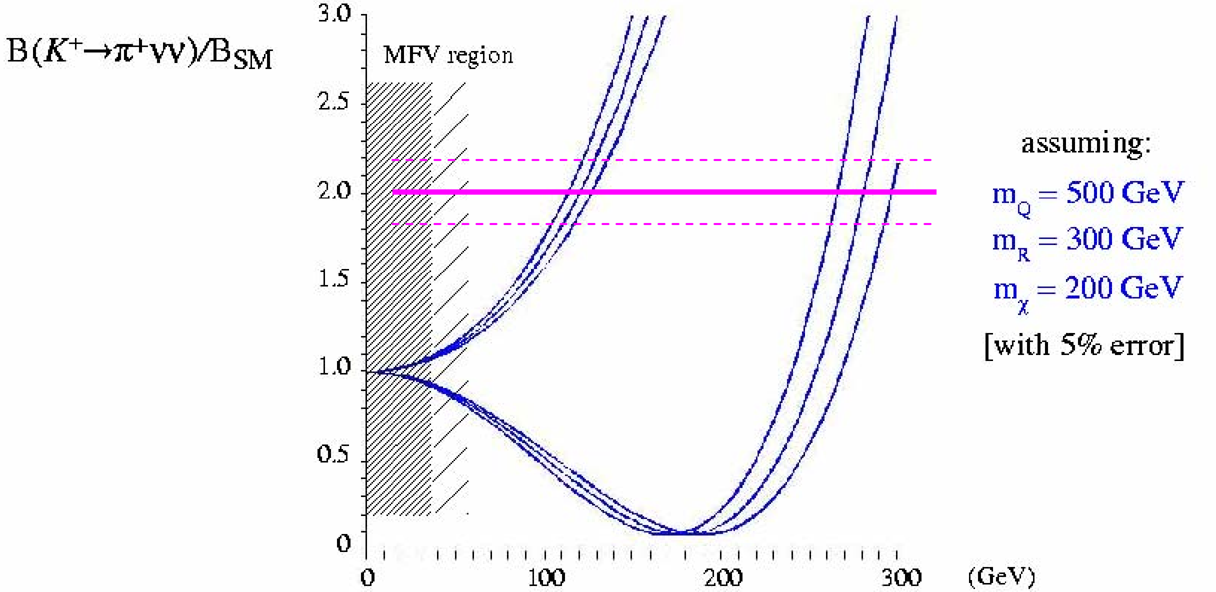


Flavor Physics in 2012 (Isidori)

u c t / d s b — K^+

A possible realistic scenario in 2012:

- LHC has seen NP ! It looks like low-energy SUSY
- Squark and chargino masses are measured with good accuracy, but we are still far from a complete determination of all the soft-breaking terms



$\sqrt{\left|\mathrm{Re}\left(A^U_{13} A^U_{32}\right)\right|}$ ← Off-diag SUSY breaking terms (typically not accessible @ LHC)

Kaon Physics Milestones of the Past Year.

- KPLUS/NA48 R&D effort on ultra-high rate tracking.
- First run at KEK $K_L \rightarrow \pi^0 \nu\nu$ experiment went well.
- KTeV V_{us} result---Fermilab Result of the Year.
- NA48/3 LOI presentation to SPSC received well.
- NA48/2: New physics results from their charged beam.
  - $\pi\pi$ scattering length from $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$
  - CP Asymmetry in $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

Flavor Physics Challenges of the Last Year

- The end of BaBar/RunII programs are defined.
- BTeV is cancelled.
- The RSVP/KOPIO experiment faces major cost growth.

After decades of investment quark flavor physics in US may end this decade.

Updates to the Timeline

- KOPIO & JPARC $K_L \rightarrow \pi^0 \nu\nu$ running in 2011, results in 2015+.
- B_s mixing results from RunII/LHCb by 2010 at sensitivities at or beyond the SM.
- NA48/3 running in 2009, results ~2012.

Time competitive results from Fermilab?

Claiming the Sensitivity Frontier for Fermilab.

- Why not join CERN to make this measurement?

  "*CERN should remain in the future a major laboratory for kaon physics at the sensitivity frontier.*" – SPSC Villiars-report Feb 28,2005

  We have an invitation to join NA48/3 at CERN, which we are prepared to accept.

- We know how to make this measurement, and it is well suited to Fermilab's existing accelerator facilities.

  K*plus* requires ~10% of the total MI proton resources, and has a realizable future if the physics mandates it. CERN does not have this reach.

NA48/3's Plan.

- Recent K^+ running went well, producing physics.
- LOI was well received, proposal is in preparation for submission in Spring 2005.
- CERN is supportive of SPS running in 2009-2012.
- Issues/Concerns:

  External fraction (most) of $10M USD M&S for experiment.

  Collaboration strength/size. Required scale is about 100 scientists (eg. NA48/KTeV)

A Case for a Physics R&D Program

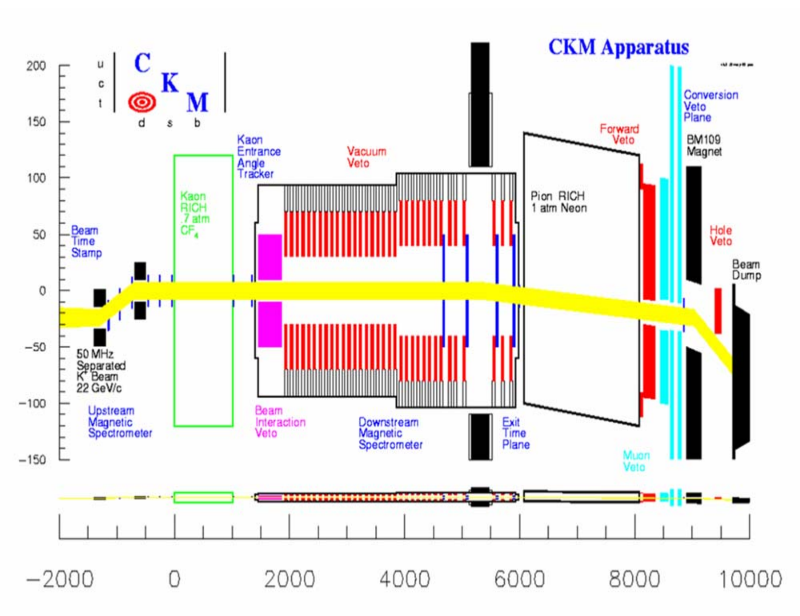
- Validate estimates of physics and instrumental backgrounds.
- Demonstration of serious interest from Fermilab and DOE.
  - Enables growth of collaboration.
  - Decides the issue of where we work (Fermilab/CERN)
- Allows us to maintain competitiveness with CERN as the national review unfolds.

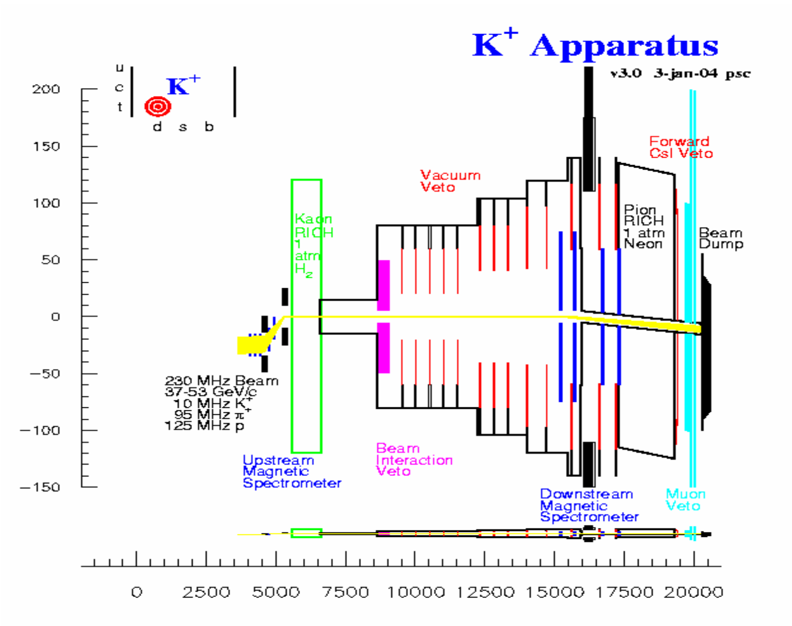
Experimental Technique

- Experimental Challenge: Br=1x10^{-10} !
- High Flux Un-separated 37-53 GeV/c Beam - 4% K^+
  - Proton / π^+ : 120 / 100, 230 MHz total, 1x1 cm^2, 0.1x0.1 mRad^2
  - 10 MHz K^+, 1.7 MHz decay in the acceptance.
  - 5 x10^{12} 120 GeV proton /sec in slow spill from the Main Injector to produce the required K^+ beam
  - 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 π^+.
  - Significant requirements on photon and muon vetoes
  - All detector technologies used are well established
  - **Redundancy** is critical to measure all backgrounds

Apparatus

- Decay in flight
- Redundant high rate detectors and veto systems.
- separated K+ beam at 22 GeV/c. Un-separated + beam at 37-53 GeV

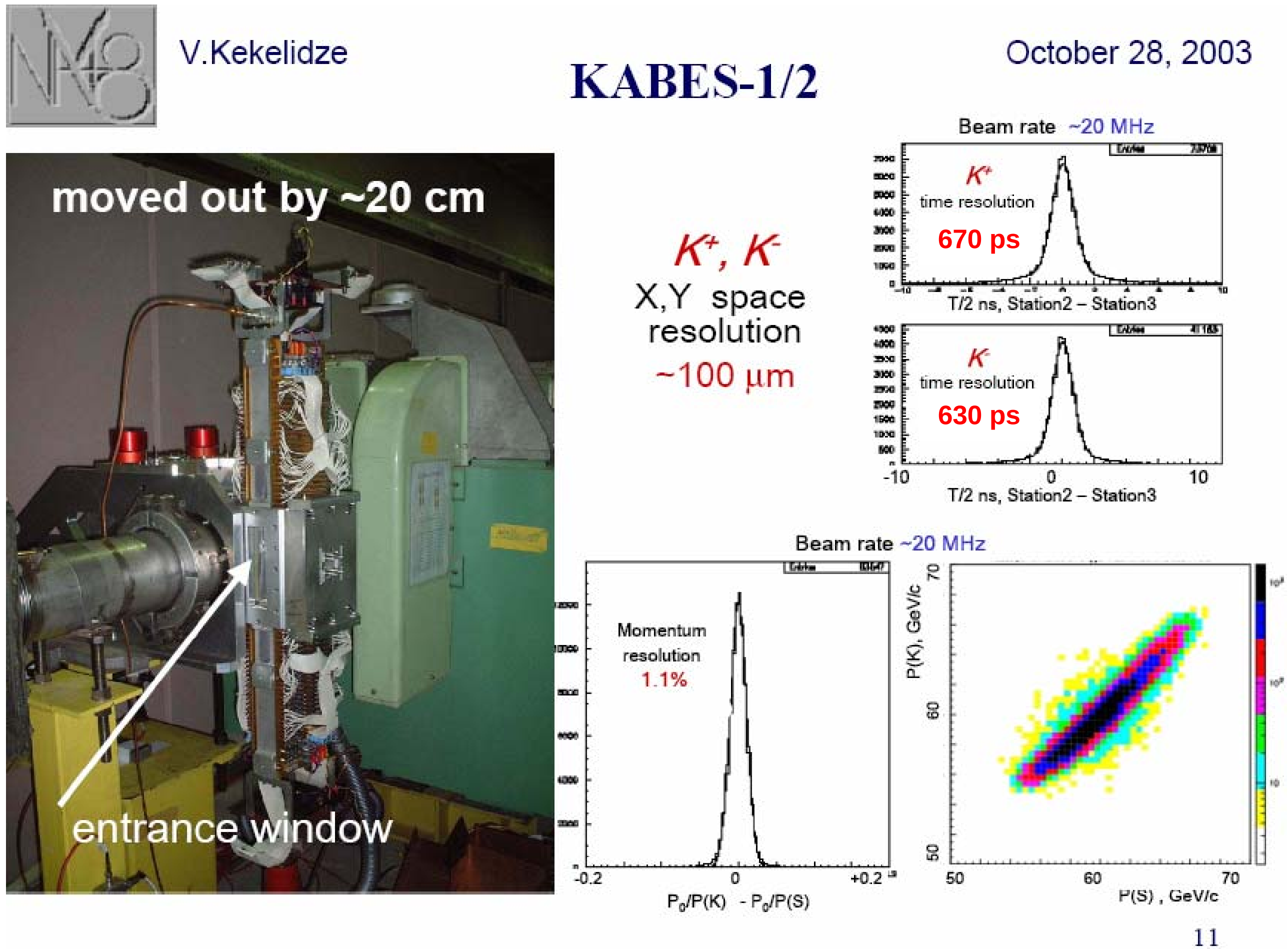




Changes to the apparatus

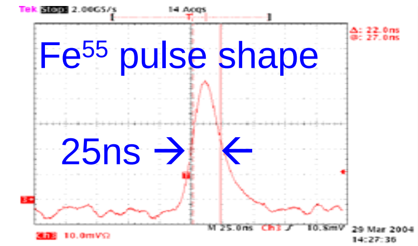
- o Beamline — existing NM2 beamline and NM3-4 detector hall (KTeV)
  - 120 GeV proton transport re-etablished
  - Target station can be modified – designed for required intensity
- o Kaon RICH — 10 $\rightarrow$ 12m, radiator gas to H_2 at 0.9 atm – only sees beam Kaons
- o DMS — same strawtube in vacuum design as CKM, hole for 10cm beampipe
- o Pion RICH
  - Same basic design as CKM (1atm Ne, 3000 1/2in PMTs)
  - Optics modified to accommodate beampipe down the middle.
- o Photon Vetoes
  - 85% of π^0's have at least 1 photon hitting CsI $1-\varepsilon \sim 3\times10^{-6}$ for E>1 GeV
  - VVS - 5 existing Pb-scint rings from KTeV + 9 new ones of CKM design
  - Photon energy threshold >60 MeV, >1.5 MIP in CsI.
- o Muon Vetoes — combined KTeV MVS + descoped CKM design
- o UMS — replace CKM MWPC's with μMegas of KABES design

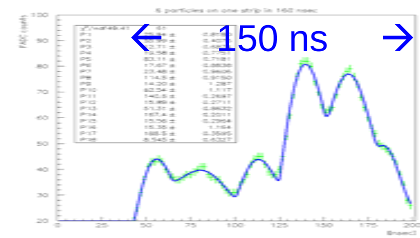
NA48 KABES data



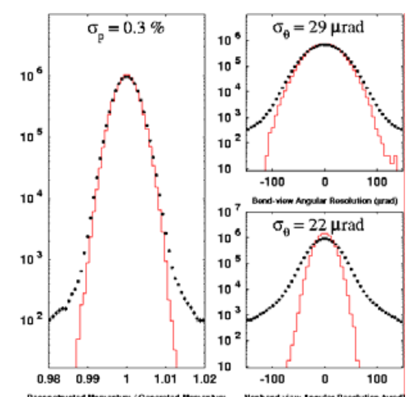
KABES for K*plus*

- o 25µm KABES data in NA48/2 at up to 11 MHz/mm
  - Detectors operated with no hardware problems
  - Inadequate redundancy to track in NA48 system
  - NA48/2 operated at 0.8 MHz/mm
  - **K*plus*** requires 2-3 (6) MHz/mm
- o Full **K*plus*** system designed and simulated at 250 MHz
  - Response functions from NA48/2 data
  - MCS, accidentals and pattern recognition effects included
  - Resolutions and backgrounds are under control
  - Work on pattern recognition continues





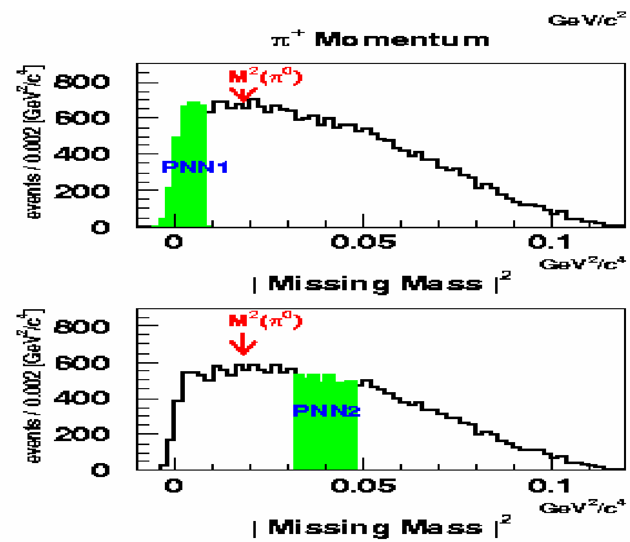
30MHz / 0.8mm strip



Acceptance

- Acceptance was re-evaluated. Decay fraction increased 13% → 16.3%
- Nearly identical sensitivity as CKM for same 120 GeV beam incident.
- PNN2 acceptance region has somewhat different cuts to control Ke4 background.
- PNN2 acceptance for CKM would scale similarly

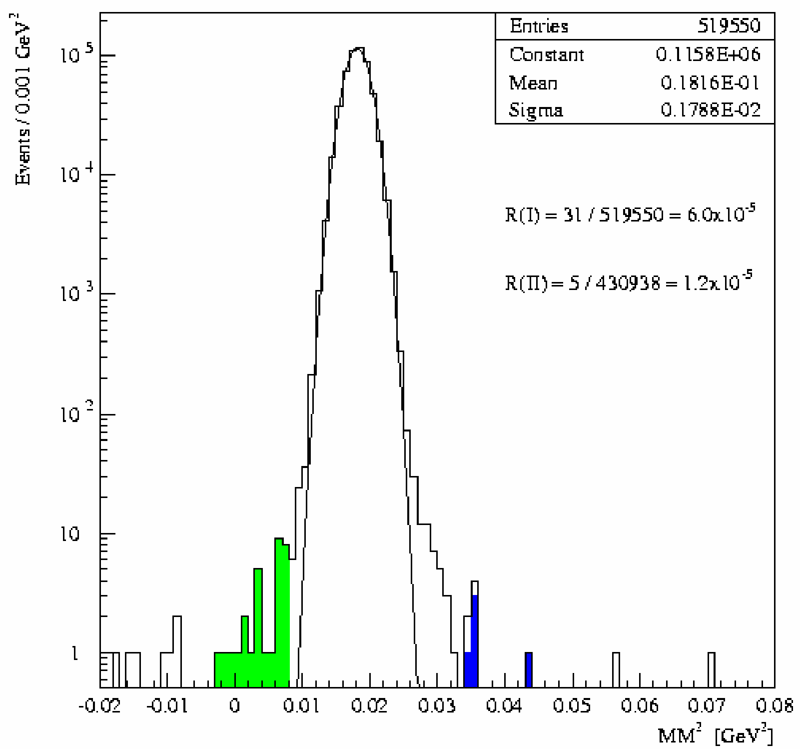
parameter	CKM	K*plus*
120 GeV/c $protons/sec$	5×10^{12}	4×10^{12}
kaon momentum	$22 - 23 GeV/c$	$37 - 53 GeV/c$
decay volume	$19 - 42m$	$90 - 150m$
K+ decay fraction	13%	16.3%
PNN1 acceptance	$\sim 1.9\%$	3.5%
PNN2 acceptance		5.0%
total	$\sim 1.9\%$	8.5%



Backgrounds

- Backgrounds assessed with dedicated GEANT simulations
- Accidental backgrounds from beam interactions are still small even though ***Kplus*** is 10x more sensitive to these than CKM.
- Kπ2 remains the dominant PNN1 background
- Ke4 is dominant background in PNN2

Background Process	EBR (in units of 10^{-12}) Region I	Region II
$K^+ \to \mu^+\nu$	< 1	—
$K^+ \to \pi^+\pi^0$	9.5	1.1
$K^+ \to \pi^+\pi^0\gamma$	—	4.4
$K^+ \to \pi^+\pi^-e^+\nu$	—	25
Other K^+ decays	$\ll 1$	< 1
Accidentals in the UMS	2.0	0.3
Accidentals in the UMS and kaon RICH	1.0	0.4
Total	13	31



Physics Yield
Comparison with CKM

o Beam Assumptions

- 39 weeks / year; 120 Hours/week
- debunched slow spill - 6 sec every 27 sec
  running with fast spill program assumed
- 10 MHz K^+
- additional efficiency factors of 60%
- Branching ratio of $1x10^{-10}$

Yields	3 years	
	Signal	Background
Region I	**35**	**4.6**
Region II	**52**	**16**
Total	**87**	**21**

o Comparison of K*plus* to CKM

- 60% K^+ / 50 MHz → 4% K^+ / 230 MHz — K – non K Accidentals "seem" small
- K flux 30 MHz → 10 MHz — DS rates and accidental drop
- photon vetos threshold >3 MeV → >60 MeV — much easier to veto >7 GeV π^0's
- PNN2 region doubles acceptance for both — CKM /**K*plus*** = x2 sensitivity/year

K*plus* Leaves more room for affordable adaptation provided x10 K + accidental beam interactions are really in control.

K*plus* R&D Project

Goals

- Full characterization of the charged kaon beamline
    - Long flat-top debunched Main-Injector beam operations (ongoing)
    - kaon yield, beam content and purity
    - Detailed characterization of the beam size and tails
- Characterization of KABES operation in a full rate environment
- Characterization of the kaon RICH system in a full rate environment
- **Measurement of actual scattering and interaction backgrounds**
    - Multiple Coulomb scattering
    - Signal like pions from beam detector and beam gas hadronic interactions
- Measure photon veto performance using $K^+ \rightarrow \pi^+\pi^0$ in a limited decay volume.
- Quantification of existing muon veto performance using $K^+ \rightarrow \mu^+\nu$.

Requirements

- Restore primary beamline to KTeV hall, Convert secondary beamline to charged
- Re-commission KTeV detectors: Vacuum, Photon Vetos, DC's, CsI, μ vetoes
- Add new KABES and Kaon RICH systems in KTeV beam enclosure

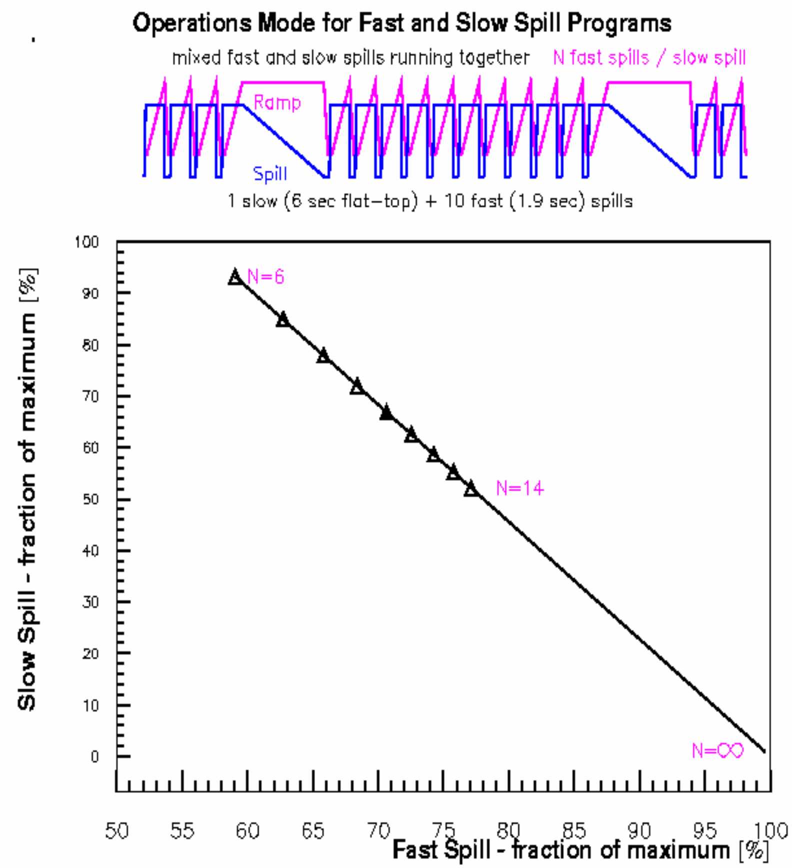
Requests

- Scientific approval to advance K*plus* for consideration by the national review process.
- Prompt institution of the K*plus* R&D project to re-establish at Fermilab the capability for a world competitive program of kaon physics.
- Recognition that for a 3 year period beginning around 2009 K*plus* will require 30% of the Main Injector timeline for debunched - slow extracted spill. Advancement of K*plus* is a commitment on the part of Fermilab to provide the proton beam required to yield a measurement on a competitive timescale.

Extra Slides

Proton Economics

- We require debunched protons from the Main Injector (10% 53MHz ripple is OK).
- Separate fast (neutrino) and slow spill Main Injector cycles make these different modes of operation independent by timesharing
- N=10 fast cycles / slow cycle gives both fast and slow spill 2/3 of the maximum available to either. This requires 30% of the MI timeline
- Setting N in this model is a program planning decision.



Kaon sensitivity in MFV (Isidori)

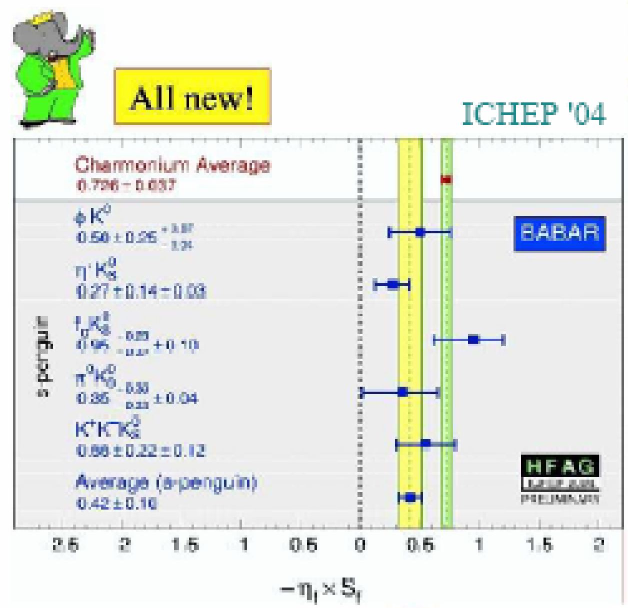
More about non-MFV models:

- Rare K decays particularly sensitive to new sources of flavour-symm. Breaking
  [⇔ λ^5 suppression]

↓

If a 10% deviation from SM is clearly established in time-dependent CPV asymmetries in B decays →

↓



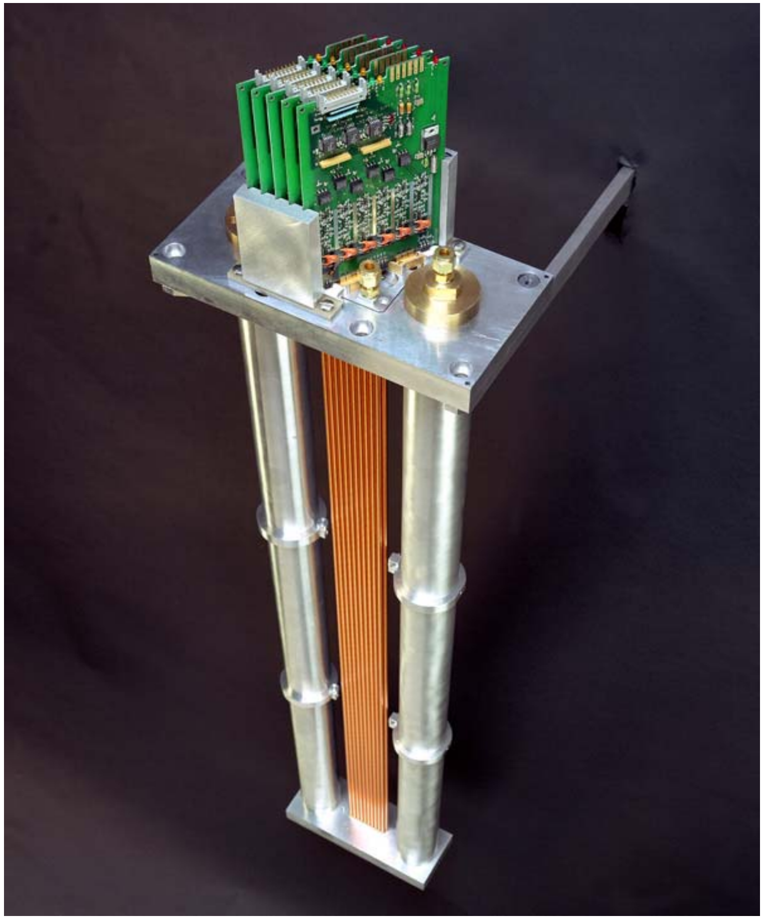
2.7σ from s-penguin to sin2β ($c\bar{c}$)

- high chances to find O(1) non-SM effects in rare K decays

- clean electroweak processes [such as $K \to \pi \nu \nu$] are crucial to identify the nature of the effect [time-dependent CP asymmetries usually not clean beyond SM]

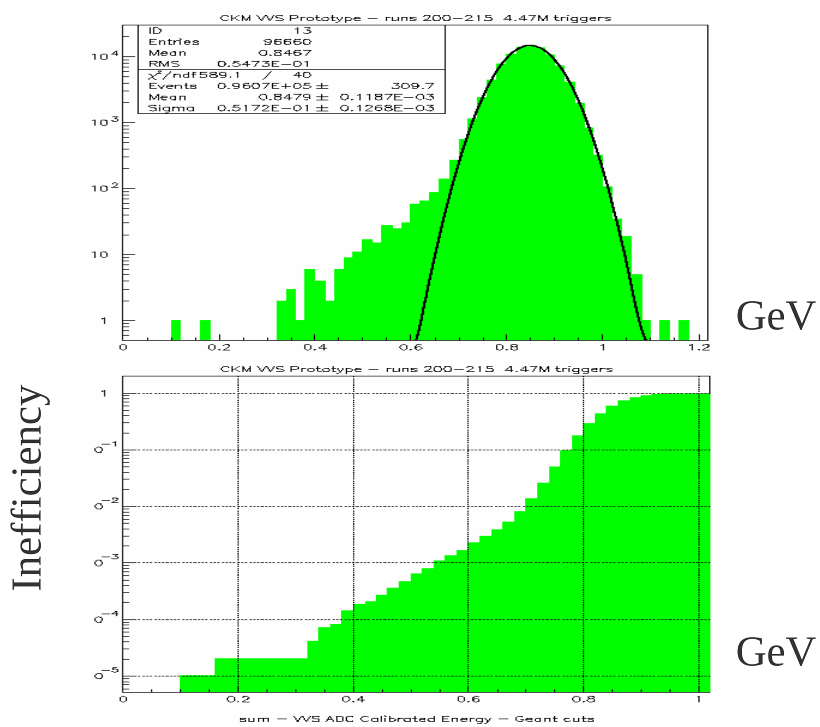
Straws in Vacuum: Old Wine, New Bottle.

- Mechanical properties extensively studied. (Fermi-Pub 02-241-E)
- Prototype operating in vacuum.
- Proven Principle. Now ready for detailed engineering.



Photon Veto Inefficiency and Technology

- 0.3% VVS Prototype built
- Tested at JLAB in an e^- beam
- Achieved $<1\text{x}10^{-5}$ ($3\text{x}10^{-6}$) veto inefficiency at 1 GeV (required $3\text{x}10^{-5}$)



KABES μMEGAS from NA48