CKM P921: Measurement of $K^+ \to \pi^+ \upsilon\bar{\upsilon}$

"the key question…is that of the technical feasibility of making a low-background measurement…with a sample of 100 events"

- **Introduction, Physics, Separated Beam:** **Leo Bellantoni**
- **Principle of the measurement, Charged particle tracking, Simulation:** **Jurgen Engelfried**
- **Summary of backgrounds, Veto systems:** **Vladimir Molchanov**
- **Background measurement, Conclusion:** **Peter Cooper**

Physics Advisory Committee
20-21 April, 2001

Charged Kaons at the Main Injector

April 2, 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

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

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

G. Britvich, A. V. Inyakin, V. Kurshetsov, L. G. Landsberg,V. Molchanov,
V. Obraztsov, S. I. Petrenko, V. Polyakov, V. I. Rykalin, A. Soldatov,
M. M. Shapkin, O. G. Tchikilev, 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, R. Gustafson, M. Longo, H. Park
University of Michigan, Ann Arbor, Michigan 48109

K. Lang
University of Texas at Austin, Austin, Texas 78712

C. Dukes, R. Godang, L. Lu, K. Nelson
University of Virgina, Charlottesville, VA 22901

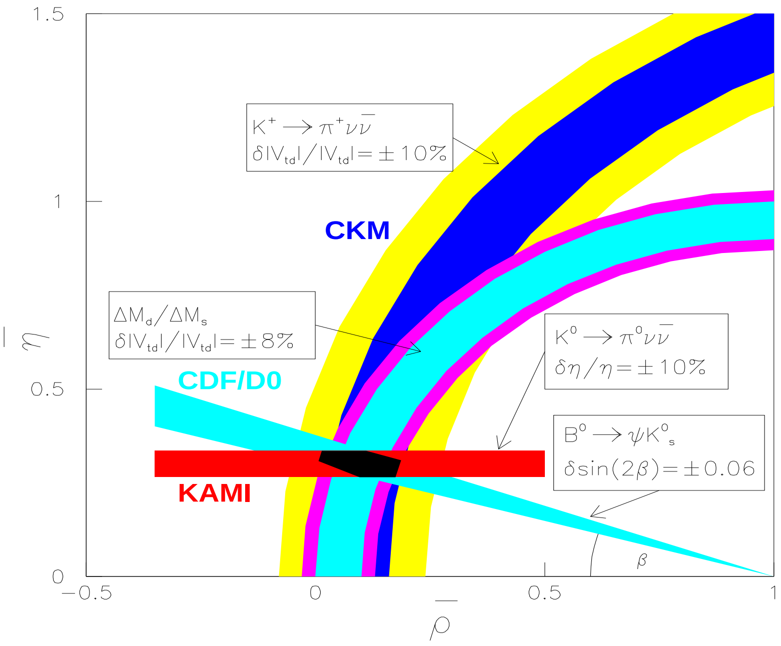
† Visitor from the Institute for Nuclear Research, Troitsk, Russia

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

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

The Physics

A well understood mode.



$$Br\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = \frac{R_+ \left|V_{cb}\right|^4 F\left(x_t\right)^2}{\sigma}\left[\left(\bar{\rho} - \rho_0\right)^2 + \left(\sigma\bar{\eta}\right)^2\right]$$

where $R_+ = 0.901\left(\frac{3\alpha^2}{2\pi^2 \sin^4 \vartheta_W}\right) Br\left(K^+ \to \pi^+ e^+ \nu\right)$

$$\sigma = \left(1 - \lambda^2/2\right)^{-2} \qquad \rho_0 = 1.40 \pm 0.07\,(+0.02)$$

$$F\left(x_t\right) = 1.53 \pm 0.05$$

(Buchalla & Buras, Falk *et. al.*)

The Physics

BNL787 has 1 clean event with 0.08±0.03 event background

$$\Rightarrow \; Br\left(K^{+} \rightarrow \pi^{+}\nu\bar{\nu}\right) = 1.5^{+3.4}_{-1.2} \times 10^{-10}$$

based on ~1/2 their data.

PRL 84, 3768 (2000)

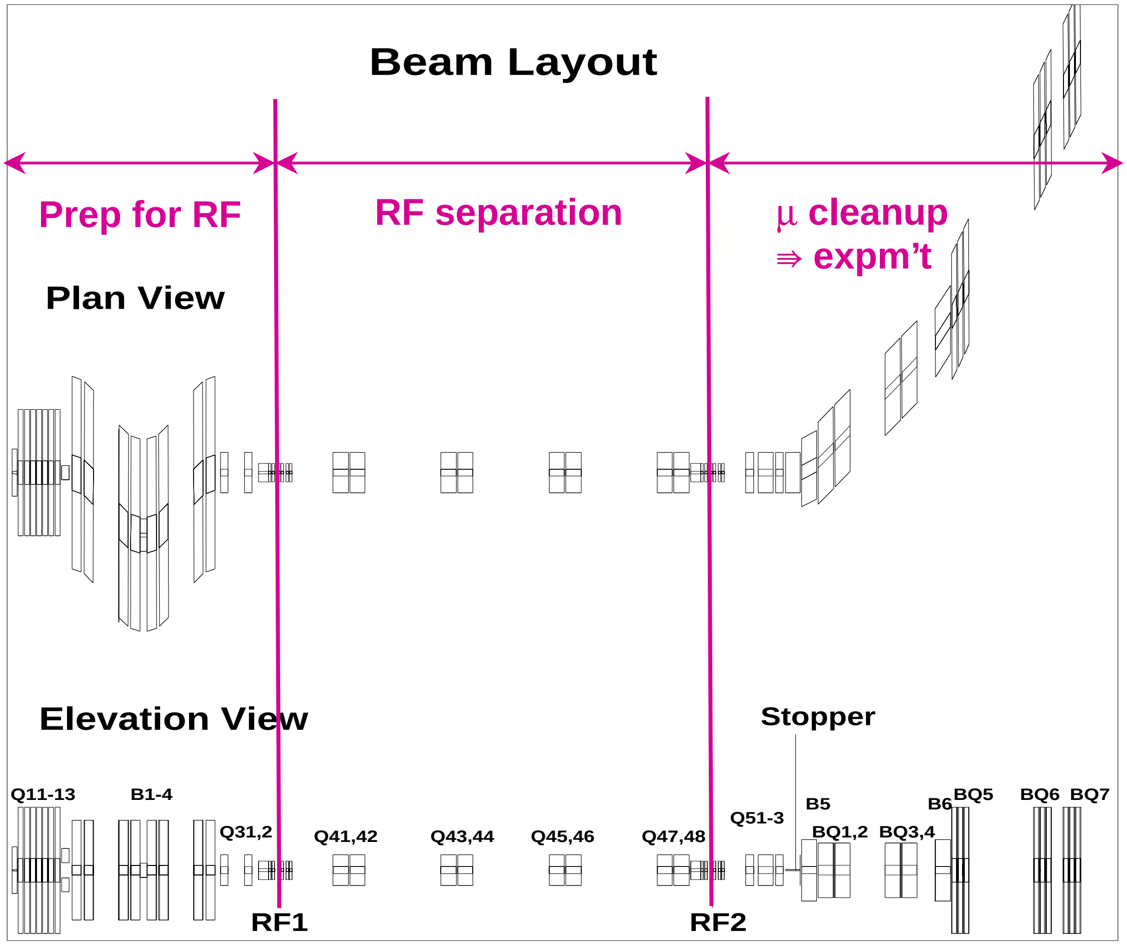
An upgrade, E949, projects a 5-10 event sample and is taking an engineering run now. They are slated to start data taking in June.

Joint collaboration between E949 and CKM – 11 people from BNL, IHEP, FNAL.

RF separated K^+ beam

Experimental Requirements:

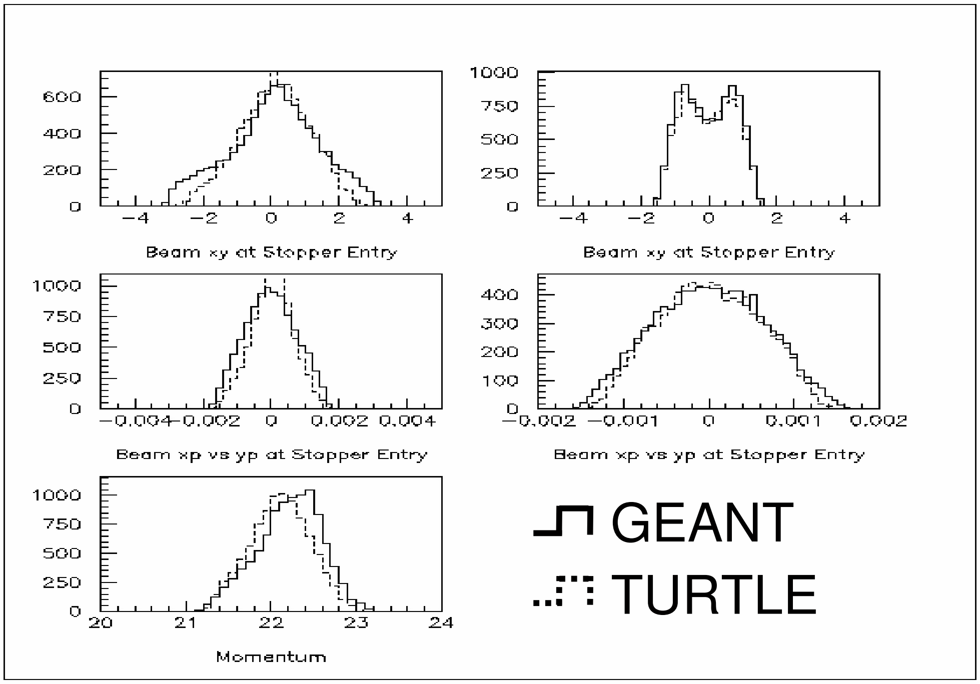
- 30MHz K^+ rate @ Kaon RICH
- <50MHz total charged particle rate
- Debunched beam
- 22GeV momentum (± 2%)


Beam Layout
Prep for RF
RF separation
μ cleanup
⇒ expm't
Plan View
Elevation View
Stopper
Q11-13
B1-4
Q31,2
Q41,42
Q43,44
Q45,46
Q47,48
Q51-3
B5
BQ1,2
BQ3,4
B6
BQ5
BQ6
BQ7
RF1
RF2

RF separated K$^+$ beam

The beamline has been simulated in both GEANT and TURTLE, giving similar results

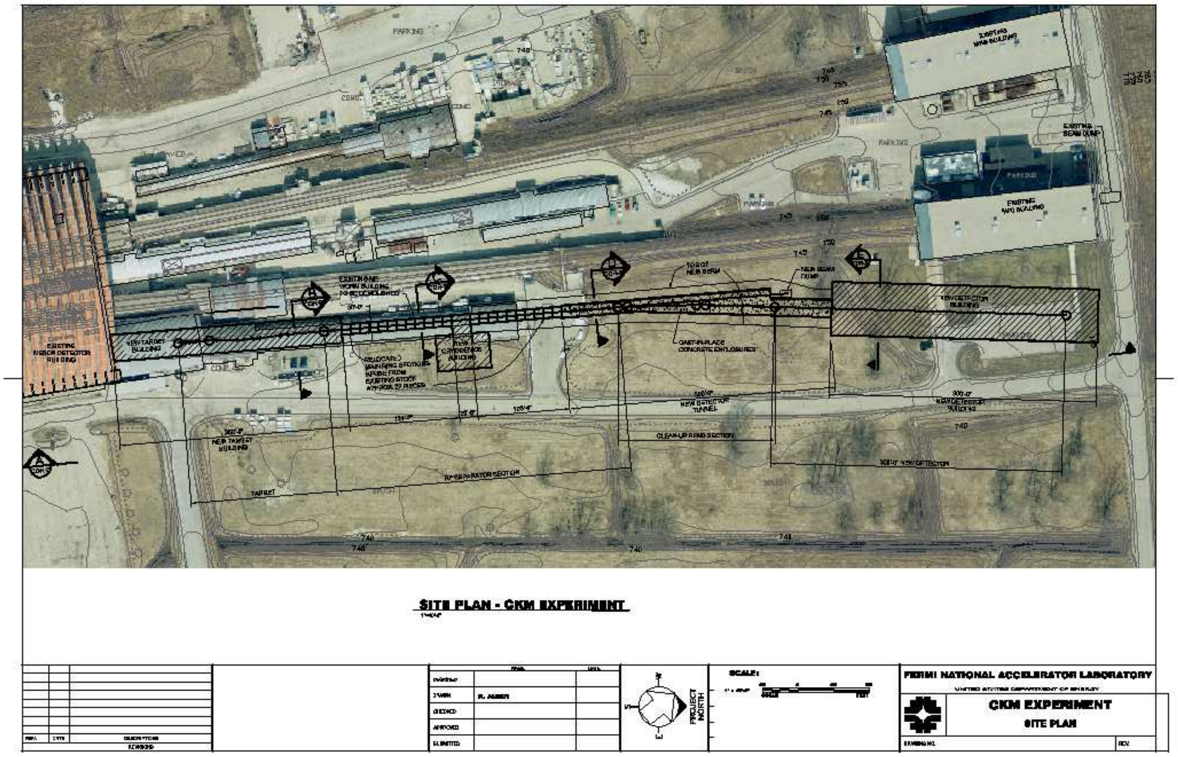
Phase space of beam at stopper



The design exceeds the requirements:

	Spec	**GEANT**	**TURTLE**
K$^+$ rate	33 MHz @ end beamline ⇒	4.1 x10^{12} ppp	3.9 x10^{12} ppp
Hadronic purity	>70%	81%	82%
Muons		7.4 MHz	-NA-
Total Charged	<50 MHz	48 MHz	

Site selection study


PARKING
EXISTING NWA BUILDING
EXISTING BEAM DUMP
EXISTING NPO BUILDING
EXISTING NEW MUON BUILDING TO BE DEMOLISHED
TOP OF NEW BERM
NEW BEAM DUMP
NEW DETECTOR BUILDING
EXISTING NEBOR DETECTOR BUILDING
NEW TARGET BUILDING
RELOCATED MAIN RING SHIELDING FROM EXISTING STOCK
NEW CRYOGENICS BUILDING
CAST-IN-PLACE CONCRETE ENCLOSURES
NEW DETECTOR TUNNEL
NEW DETECTOR BUILDING
CLEAN-UP RF SECTION
NEW DETECTOR
NEW TARGET BUILDING
RF SEPARATOR SECTION
TARGET
740
SITE PLAN - CKM EXPERIMENT
DRAWN
CHECKED
APPROVED
SUBMITTED
PROJECT NORTH
SCALE:
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
CKM EXPERIMENT
SITE PLAN
DRAWING NO.
REV.

One alternative shown…

RF separated K^+ beam

The beamline design assumes SCRF systems capable of 30 MeV total $P_\perp$ kick

We have been working with the Beams Division to carry out the necessary R&D

D.E.Edwards, R. Wanzenberg
DESY

T.W.Koeth, G.B.Thompson
Physics Department, Rutgers University

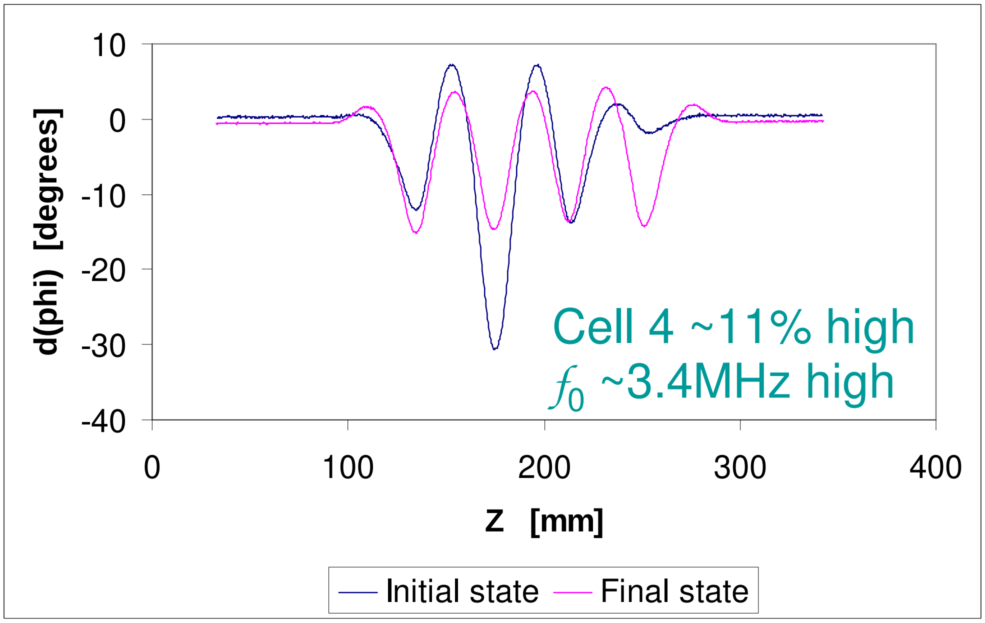
J. Doornbos
TRIUMF

T.Berenc, M.Champion, R.Coleman,
C. Deibele, J.E.Dey,D.Edwards, H.Edwards,
M.Foley, J.Fuerst, W.Hartung, T.Jurgens,
T.Kobilarcik, K.Koepke, M.Kuchnir, M.MacAshan,
C.Milsténe, G.Romanov, S.Tarasov, A.Rowe,
Y.Terechkine, H.B.White, L.Bellantoni
Fermilab

RF separated K^+ beam

Task 1: Develop a robust design for the RF fields in the cavity

- Demountable Al models
- Extensive finite-element modeling
- Warm-tuned 5-cell cavity
- Multipacting calculation
- Lorentz force calculation
- Higher Order Mode prediction



Cell 4 ~11% high

f_0 ~3.4MHz high

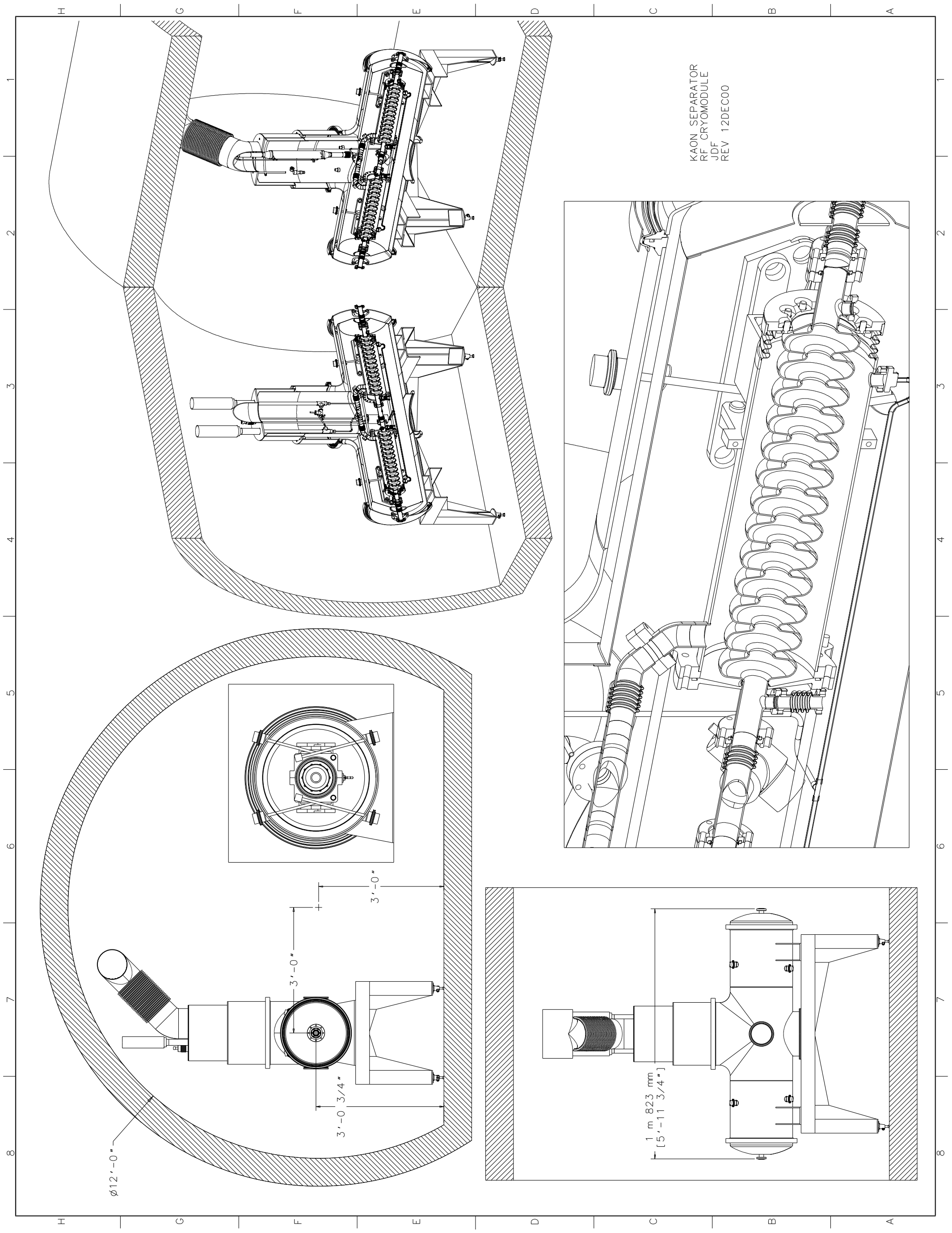
RF separated K^+ beam

Task 2: Engineer and build 13 cell cavities & cryostat

- Half-cell deep drawing, e-beam welding, technology proven on 1, 5 cell structures
- Design and manufacture of cryostat under way
- Cold tuner design started
- Design of side port coupler under way
- High power RF supply, control system

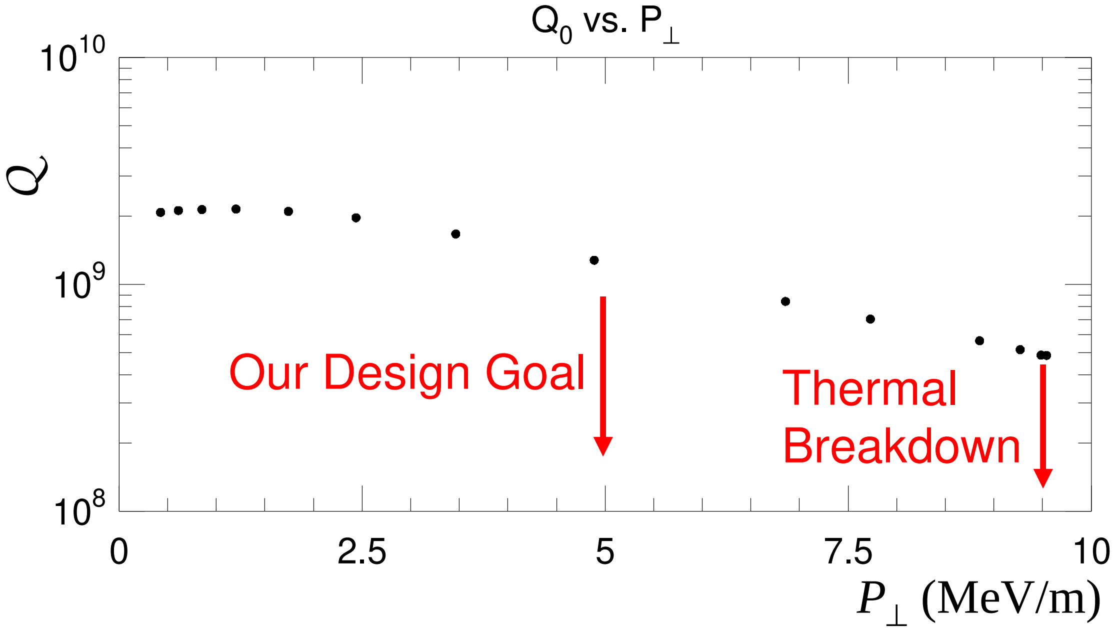
Goal is to test a complete cryomodule in 2002 and test it in a beam during 2003.

RF separated K^+ beam


KAON SEPARATOR
RF CRYOMODULE
JDF
REV 12DEC00
3'-0"
3'-0"
3'-0 3/4"
Ø12'-0"
1 m 823 mm
[5'-11 3/4"]
H
G
F
E
D
C
B
A
1
2
3
4
5
6
7
8

RF separated K^+ beam

Task 3: Assimilate the QC & surface processing technology of other labs to obtain required field strengths



Our most recent 1-cell test result

Expressed as B_{MAX} on inner Nb surface:

This result:	104mT
Our design @ 5MeV/m:	77mT
TESLA @25 MeV/m:	110mT
TESLA @35 MeV/m:	160mT

RF separated K^+ beam

The SCRF project was externally reviewed in Oct. 1998 by M.Tigner, D.Chan, P.Kneisel, D.McGuiness, H.Padamsee, A.Tollestrup.

"The proposed rf separator system is technically feasible…"

Next review early May

Following slide are spares

The Physics

Plot shows ±10% uncertainty in $|V_{td}|$ as yellow lines; blue band is ±5% ~ 1/√100 over 2 for $Br \sim |V_{td}|^2$. This leaves ±8.7% for systematic uncertainties.

At Lake Louise 1999, Buras said

$$\frac{\sigma(|V_{td}|)}{|V_{td}|} = \left[\pm 0.04_{\mu_c}\right] \oplus \left[\pm 0.7 \frac{\sigma(\overline{m}_c)}{\overline{m}_c}\right] \oplus \left[\pm \frac{\sigma(|V_{td}|)}{|V_{td}|}\right] \oplus \left[\pm 0.65 \frac{\sigma(Br(K^+ \to \pi\upsilon\upsilon))}{Br(K^+ \to \pi\upsilon\upsilon)}\right]$$

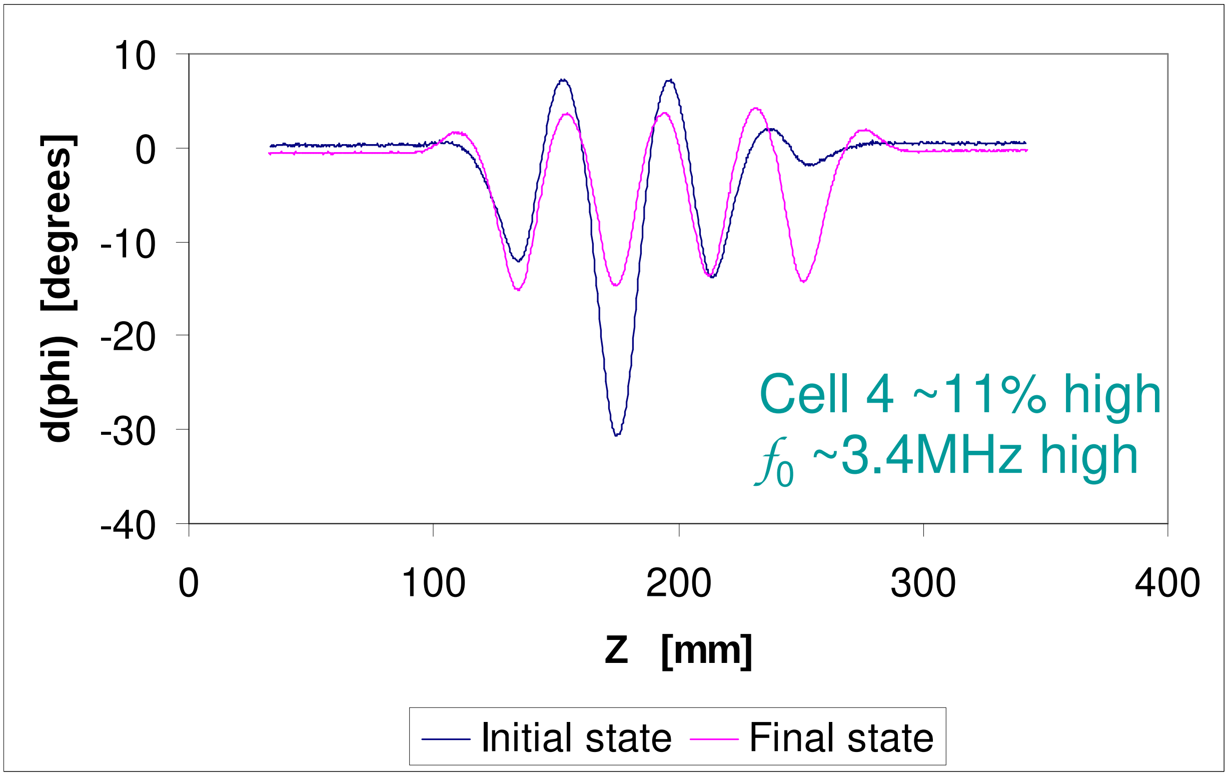
to which should be added small terms for m_t, α_s, and $|V_{ub}|/|V_{cd}|$. For $\sigma(m_c)/m_c = 0.1 / 1.3$ and $\sigma(V_{td})/V_{td} = \pm 0.0016 / 0.0410$, a 10% measurement of $Br\ (K^+ \to \pi^+ \upsilon\upsilon)$ gives $|V_{td}|$ to ±11%

5 cell cavity

Bead pull tests for cell-to-cell uniformity

$$\delta f / f = 3/8 \, (\delta v/\mathcal{U}) \, (\mu_0 H^2 - 2\varepsilon_0 E^2)$$

Measure frequency shift due to bead in cavity by measuring phase shift around resonance



Cell 4 ~11% high

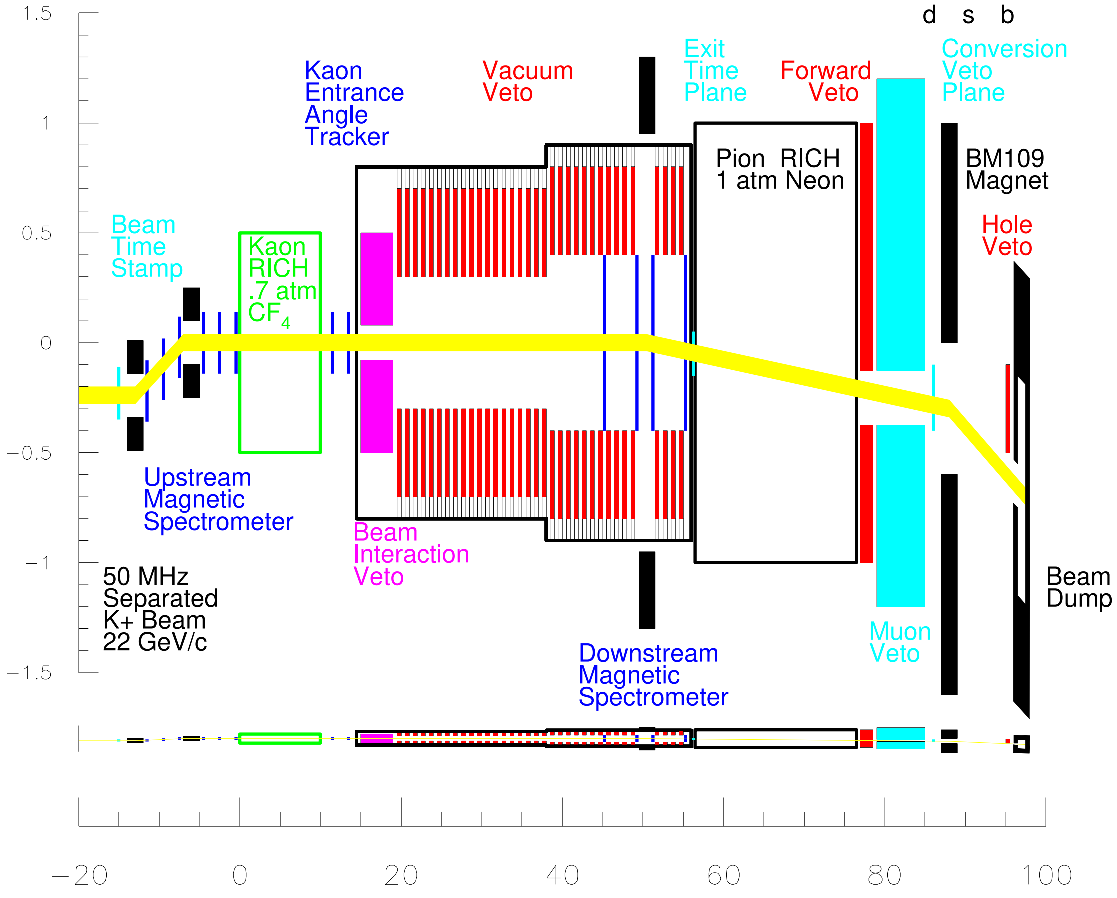
f_0 ~3.4MHz high

RF separated K^+ beam

Frequency	3.9 GHz
Mode	TM_{110} , π intercell phase advance
Equator radius	47.18 mm
Iris radius	15.00 mm
Iris curvature	5.50 mm
Cell length	38.40 mm
Cells / cavity	13
Total cavity length	660.0 mm
(R/Q)'	$351\Omega/$ m $= 701\Omega/$cell
$V_\perp/$ m	5 MeV/ m
E_{MAX}	18.5 MeV/ m
B_{MAX}	77 mT
Intercell coupling	Inductive, mixed to TE_{110}
$(f_{\pi/13} - f_\pi)/f_{7\pi/13}$	4.3%
$f_{12\pi/13} - f_\pi$	1.0 MHz
Polarization split	$10 \sim 40$ MHz
Tuning range	± 1 MHz
Q_{Cu}, room temp	14×10^3
Q_{Nb}, room temp	$Q_{Cu}/2.89$
$G = Q \times R_{surf}$	228Ω
R_{surf}, 2K	$110n\Omega$
Stored Energy	0.73 J/m
Dissipated Power	8.5 W/m
$Q_{external}$	6×10^7
Beam tube mode	TE_{11}
Evanescent length	10.9 mm
Beam tube cutoff freq.	5.86 GHz

CKM: $K^+ \to \pi^+ \nu \bar{\nu}$

CKM Apparatus


1.5
1
0.5
0
−0.5
−1
−1.5
Beam Time Stamp
Kaon RICH .7 atm CF_4
Kaon Entrance Angle Tracker
Vacuum Veto
Exit Time Plane
Forward Veto
Conversion Veto Plane
Pion RICH 1 atm Neon
BM109 Magnet
Hole Veto
Upstream Magnetic Spectrometer
Beam Interaction Veto
50 MHz Separated K+ Beam 22 GeV/c
Downstream Magnetic Spectrometer
Muon Veto
Beam Dump
−20
0
20
40
60
80
100