Charged Kaons at the Main-Injector

R. Tschirhart, Fermilab *March 19th, 2003*

Fermilab DOE Review.

I. Physics and Experimental Technique.

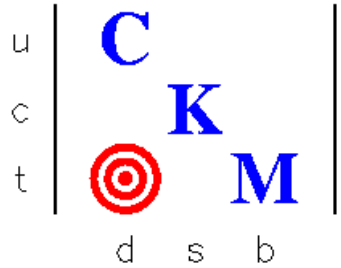
II. Activities of the Last Year.

III. Summary of the Recent Internal Lab (Temple) Review.

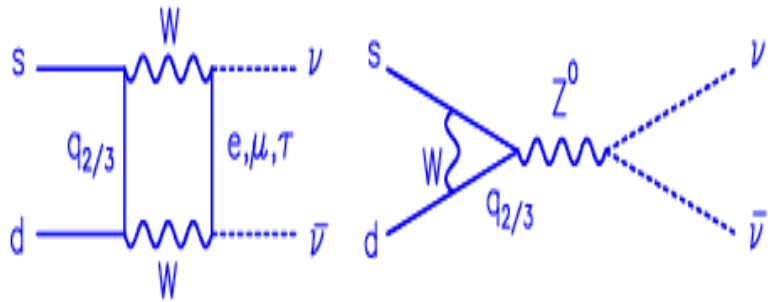
IV. The Road Ahead…

Primary Physics Goal:

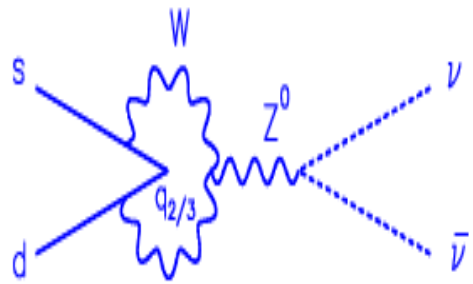
Precision Measurement of $K^+ \to \pi^+ \nu \bar{\nu}$.



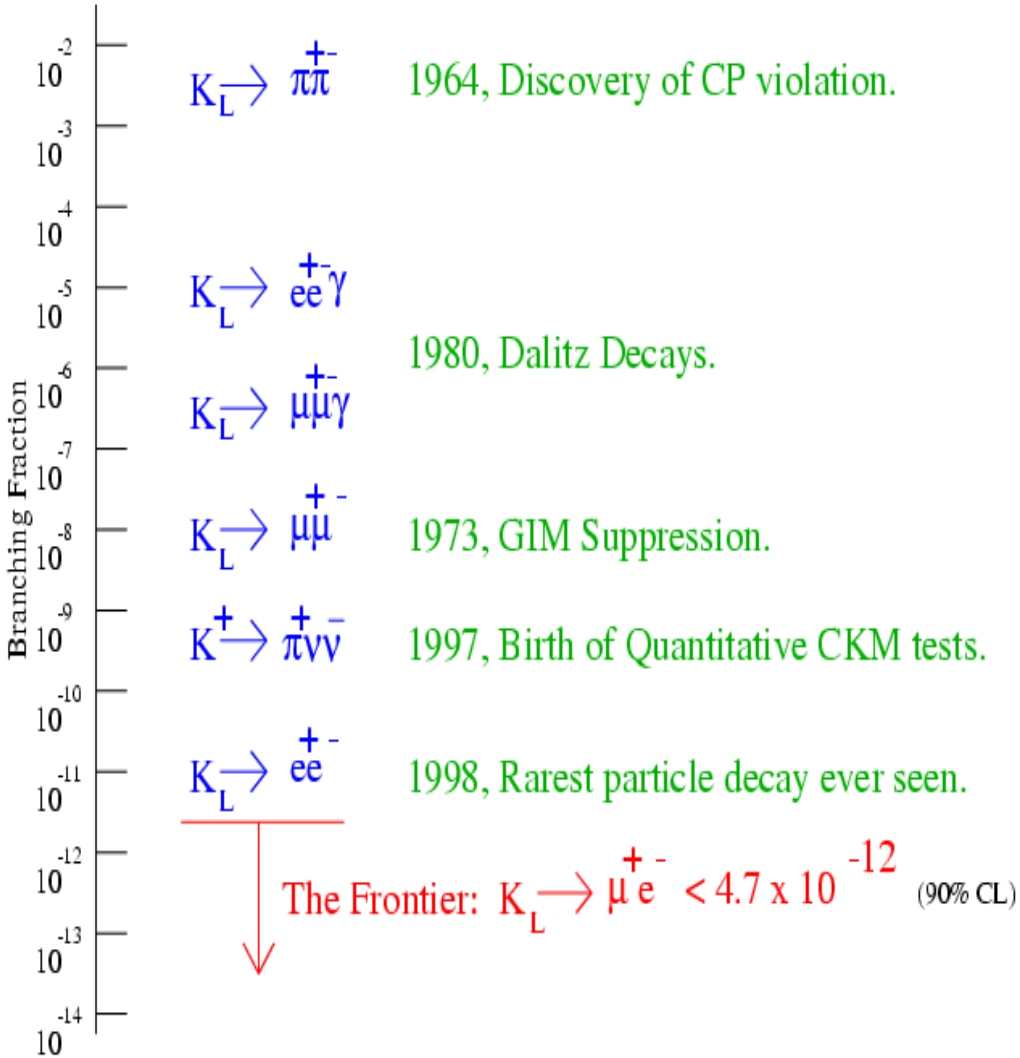
This decay is determined by loop processes to high order in the SM, and hence has a reach for *new physics at the EW scale and beyond*.

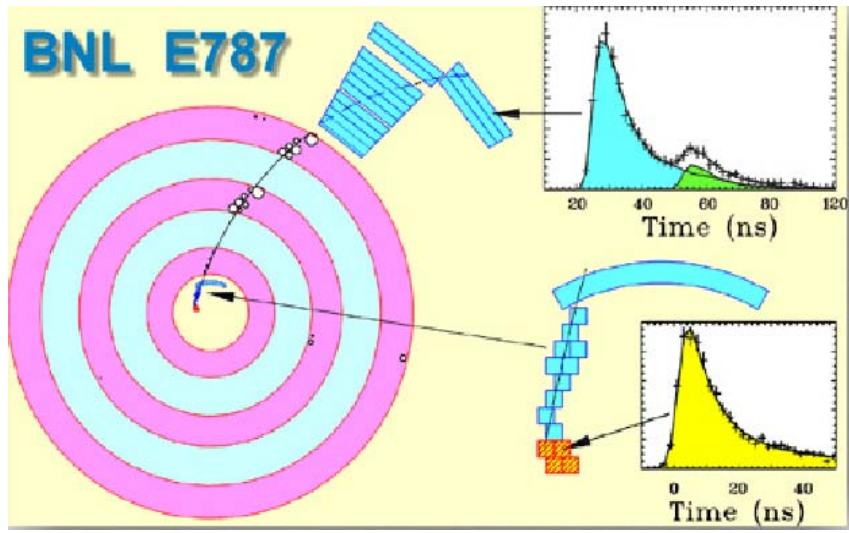


The SM rate can be calculated with a high degree of confidence, and hence any deviation in the measured rate is a signal for new physics.



Evolution of the Frontier...

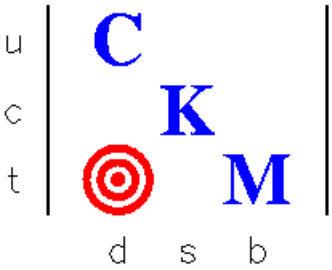




$B(K^+ \to \pi^+\nu\bar{\nu}) = (16^{+18}_{-8}) \times 10^{-11}$

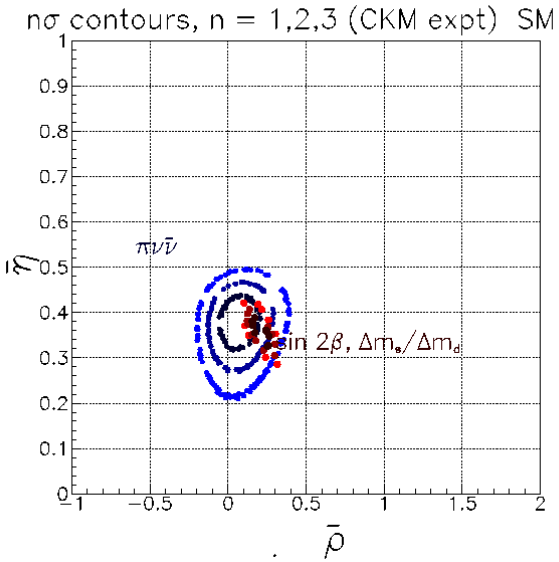
SM: $(8^{+3}_{-3}) \times 10^{-11}$

Challenging the Standard Model of CP-Violation with Golden Modes; Consider the Quartet:

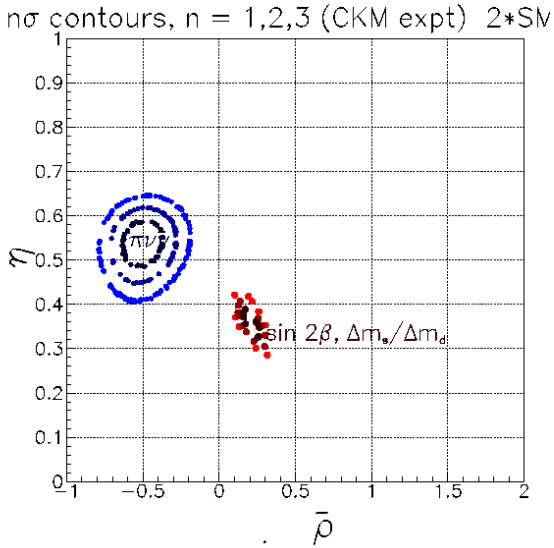


$\sin(2\beta)$, $K^0 \to \pi^0 \nu \bar{\nu}$, $K^+ \to \pi^+ \nu \bar{\nu}$, $\Delta m_d / \Delta m_s$ in B_d^0 and B_s^0 Decays

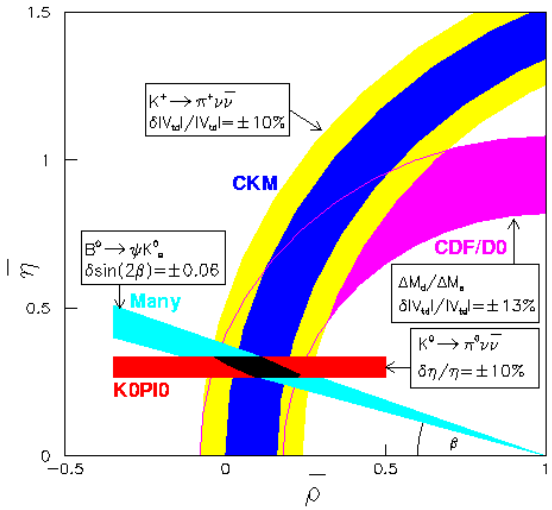
$\Gamma(\pi\nu\nu)$ = SM



$\Gamma(\pi\nu\nu)$ = 2xSM

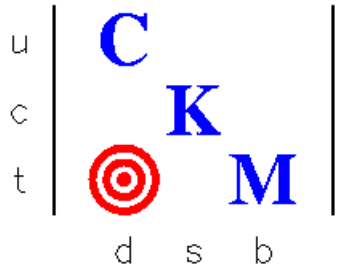


expected sensitivities



CKM Fitter Results, D. Jaffe (BNL).

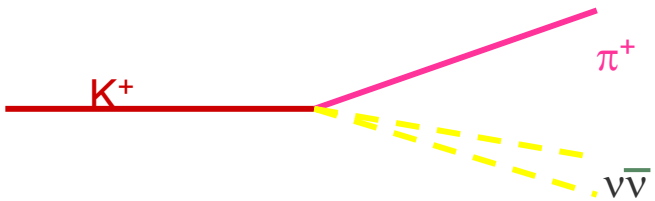
Measuring $|V_{td}|$ with $K^+ \to \pi^+ \nu \bar{\nu}$



- $K^+ \to \pi^+ \nu\bar{\nu}$ is the best way to measure $|V_{td}|$
  - Theoretical uncertainties are small (m_{charm}) and robustly estimated. (~8%)
  - Structure of K^+ controlled by measurement, NO final state interactions.
  - Need 100 signal events with <10 background (6%) to match theory error.
- Experimental Challenge
  - Br[$K^+ \to \pi^+ \nu\bar{\nu}$] = $8 \pm 3 \times 10^{-11}$ (Standard Model)
  - 2 clean events seen in BNL787 (Br = $16\ ^{+18}_{-8} \times 10^{-11}$)
- The tyranny of tiny decay rates
  - 100 events / 10^{-10} (Br) / 1% (acc) = 10^{14} K decays must be studied
  - 10^7 sec/year ➔ 10^7 K decay /sec to see 100 in 1 year
  - Need to control background to 10^{-11} of all K^+ decays

Backgrounds

What We Want:



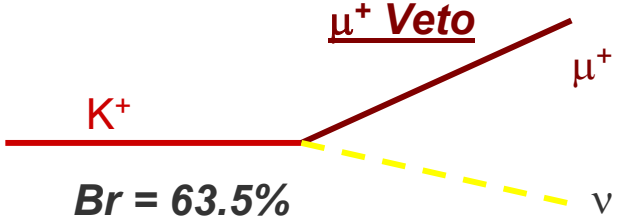
Br = ~1 x 10^{-10}

Kinematics

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

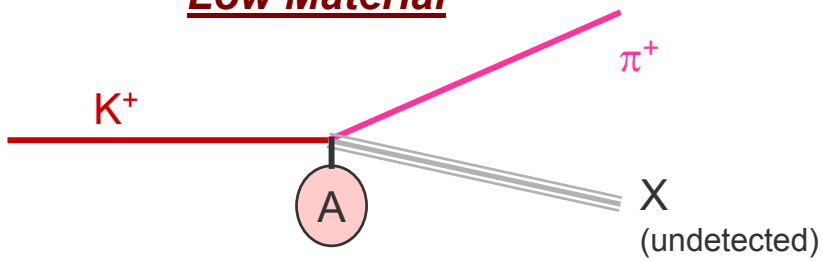
What We'll Get:

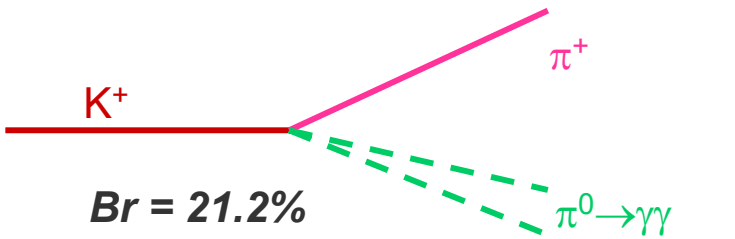
μ^+ Veto



Br = 63.5%
Also $K^+ \rightarrow \mu^+ \nu\gamma$

Charged Veto
Low Material





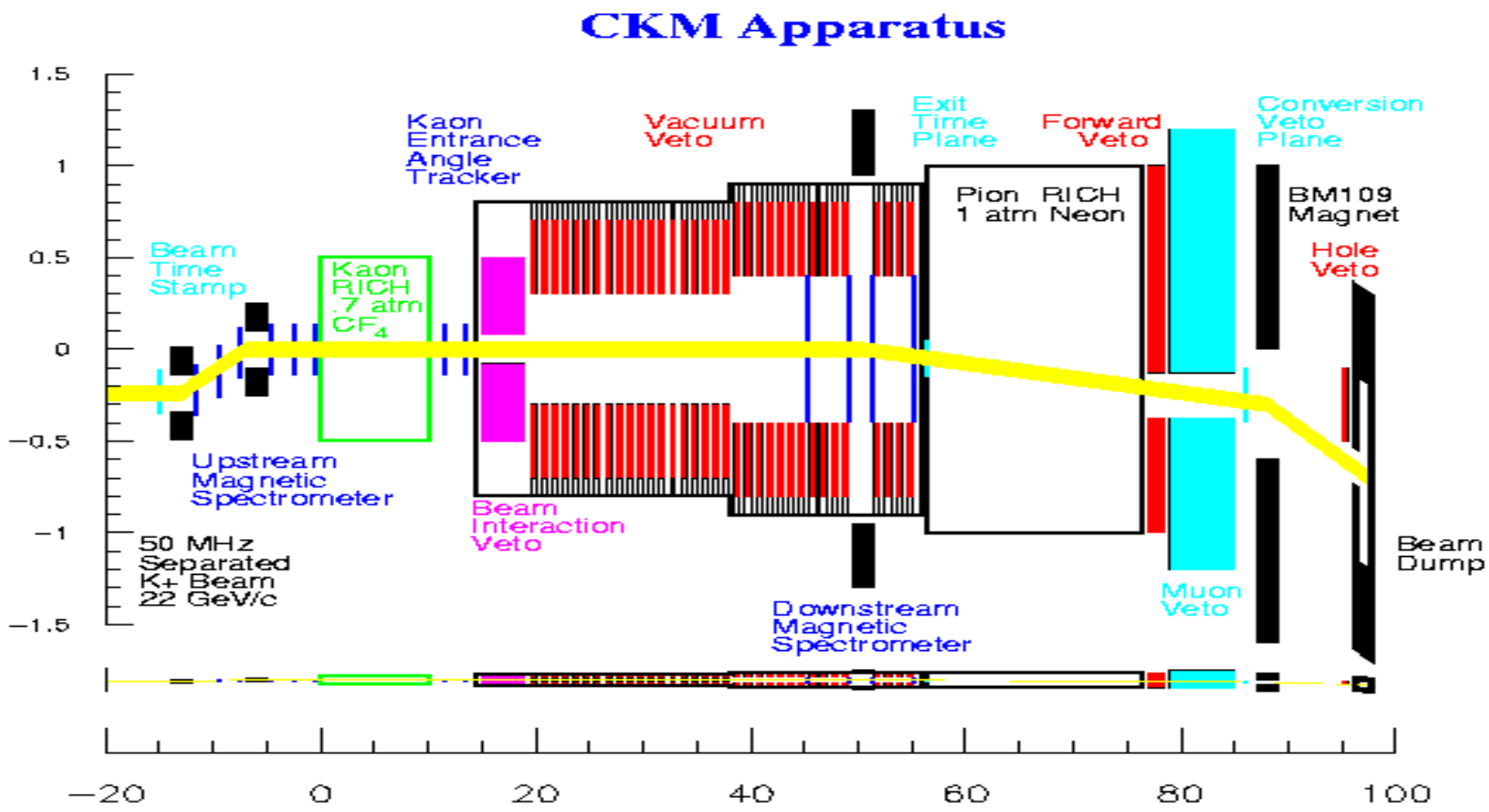
Br = 21.2%

γ Veto

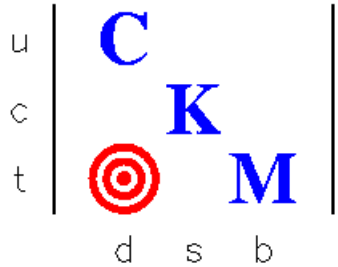
(undetected)

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

- Decay in flight in a separated K^+ beam at 22 Gev/c.
- Redundant high rate detectors and veto systems.



Experimental Technique

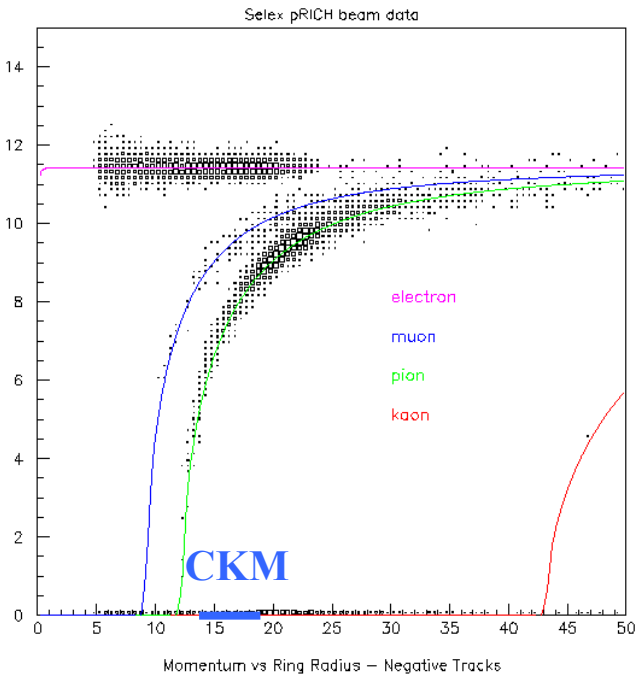


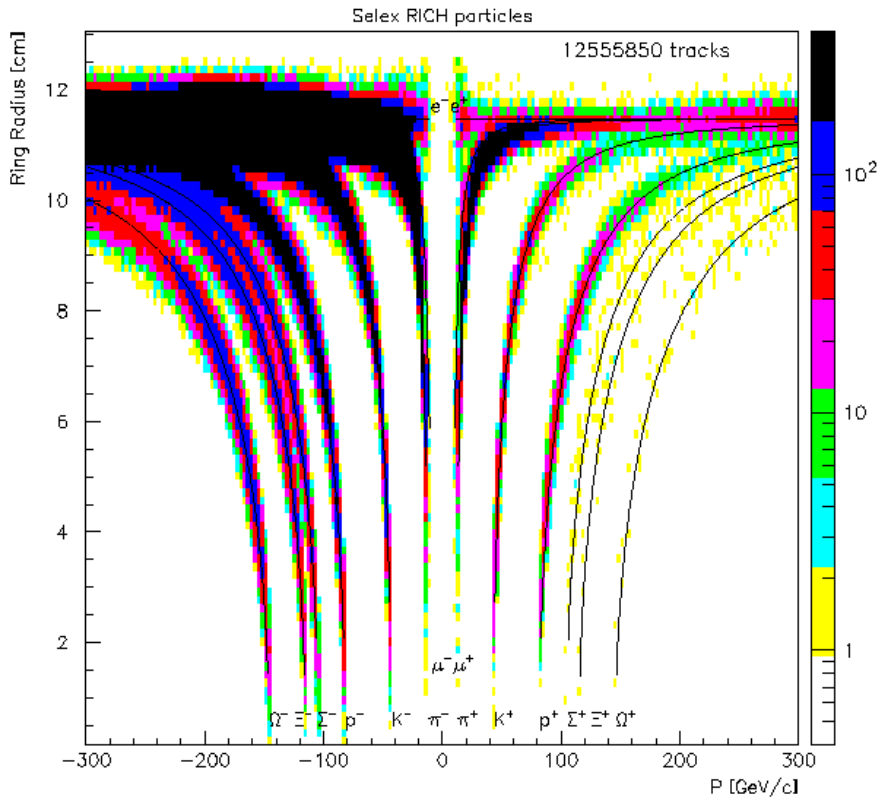
- High Flux Separated K^+ Beam
  - 30 MHz K^+, 6 MHz decay in the acceptance.
  - 5 x10^{12} 120 GeV proton /sec in slow spill from the Main Injector to produce the required K^+ beam (17% of design intensity)
  - Debunched proton beam required

    (~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 vetos
  - All detector technologies used are well established
  - Redundancy is critical to measure all backgrounds

Ring Imaging Cherenkov Counters

- High rate high resolution
- Matched to momentum resolution
- Based on successful Selex RICH
- Photo-detectors are individual PMTs





CKM Collaboration

- Groups from 4 national laboratories and 6 universities.
- 48 people today including 7 postdocs + students
- Roots in KTeV, Selex, HyperCP, CDF, BNL787/E949, BNL871, IHEP-Istra
- Substantial experience in rare and ultra rare kaon decay experiments
- Collaboration will double with time

Temple Review
Charged Kaons at the Main Injector

February 24-25, 2003

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*, T. R. Kobilarcik, H. Nguyen, E. Ramberg, R. S. Tschirhart, H. D. White, J. Y. Wu
Fermi National Accelerator Laboratory, Batavia, IL, USA

G. Britvich, V. Burtovoy, A. V. Inyakin, V. Kurshetsov, A. Kushnirenko, L. G. Landsberg, V. Molchanov, V. Obraztsov, S. I. Petrenko, V. I. Rykalin, A. Soldatov, M. M. Shaplin, O. G. Tchikilev, D. Vavilov, O. Yushchenko
Institute of High Energy Physics, Serpukhov, Russia

V. Bolotov, S. Laptev, A. Polarush, A. Pastsiak, R. Sirodeev
Institute of Nuclear Research, Troisk, Russia

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

A. R. Barker, H. Huang, R. Niclasen, M. Wilking
University of Colorado, Boulder, Colorado, 80309

M. Campbell, R. Gustafson, M. Longo, H. Park
University of Michigan, Ann Arbor, Michigan 48109

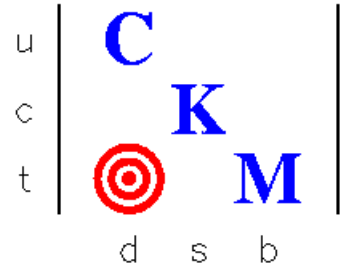
C.M. Jenkins
University of South Alabama, Mobile, Alabama 36688

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

C. Dukes, L. Lu, K. Nelson, C. Nicolescu
University of Virgina, Charlottesville, Virgina 22901

* Spokesman: P.S. Cooper, pcooper@fnal.gov, (630) 840-2629
Web Address: www.fnal.gov/projects/ckm/Welcome.html

Scope & Timeline:



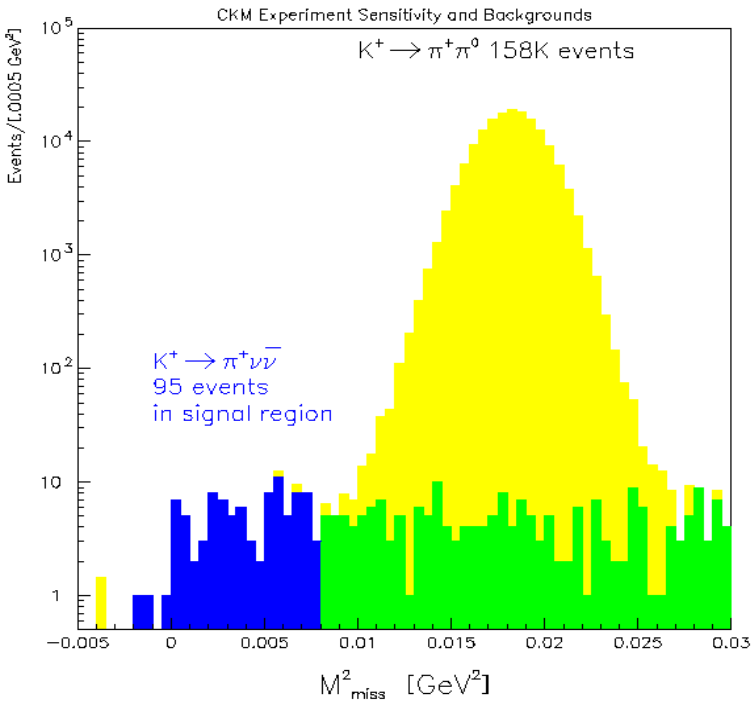
- CKM LOI in 1996
  - 1st proposal 1998 (unconsidered)
  - 2nd proposal considered and approved 2001 (Stage-I)
  - Prototypes and testbeam work completed in FY03
  - Temple Review, February 2003.
  - SCRF production prototype in FY04

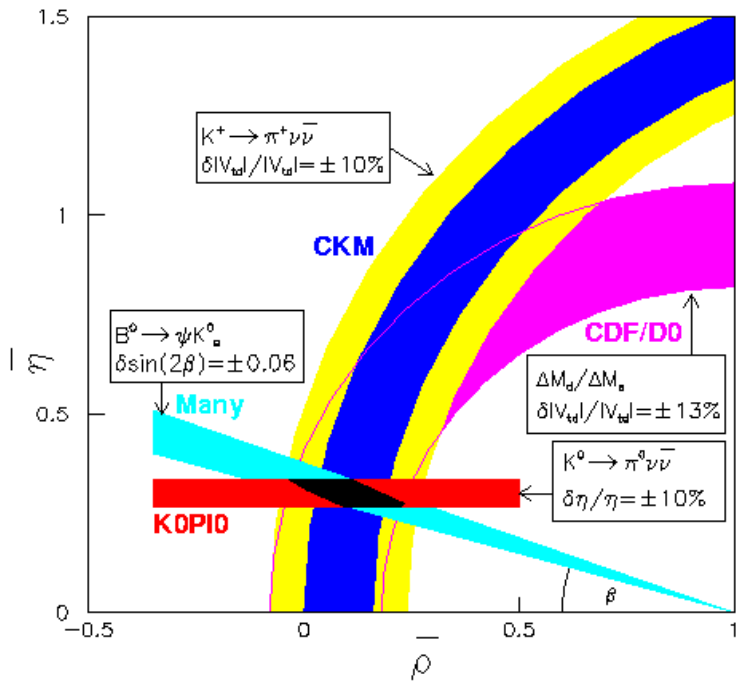
- Scope of project is very similar to KTeV

- We require a ~3 year funding profile to built the beam and detector
  - 1 year of commissioning – some overlap with construction is possible
  - 2 years of data taking

When it all works

- 95 signal events with <10 background events
- In 2 years of data taking
- Together with others a critical test of Standard Model CP violation

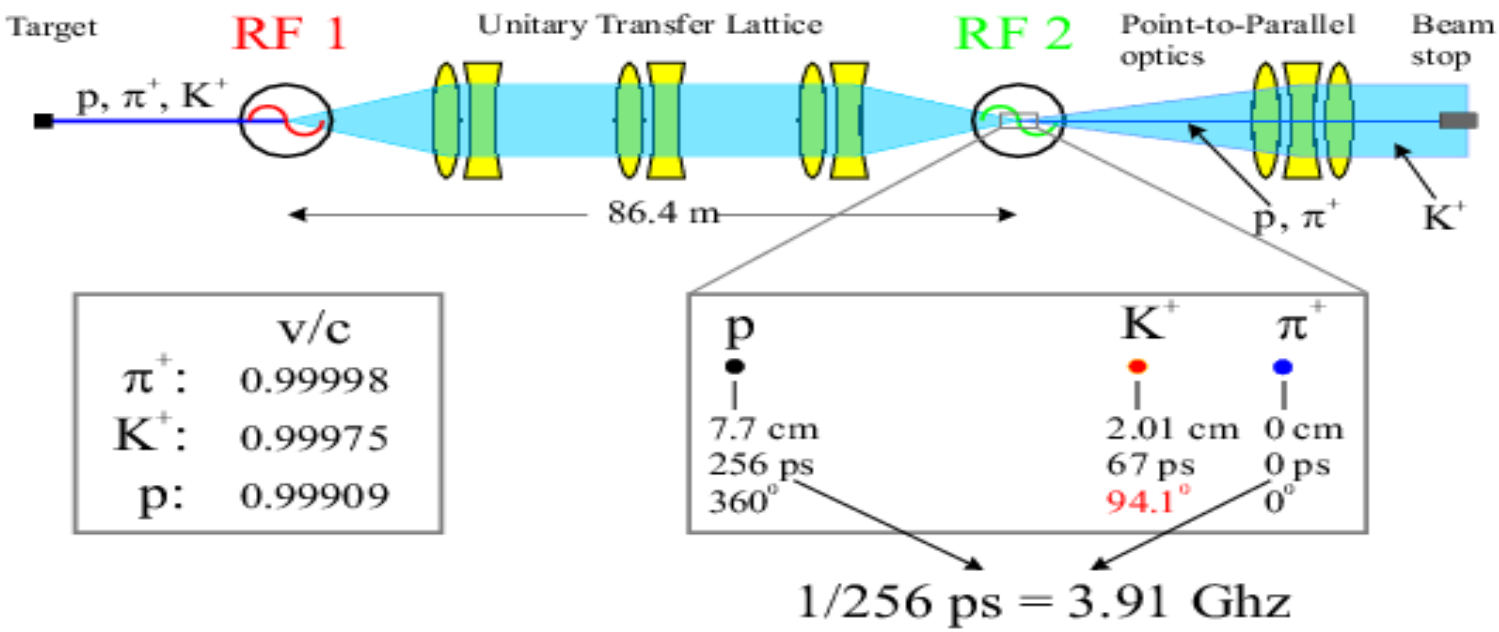


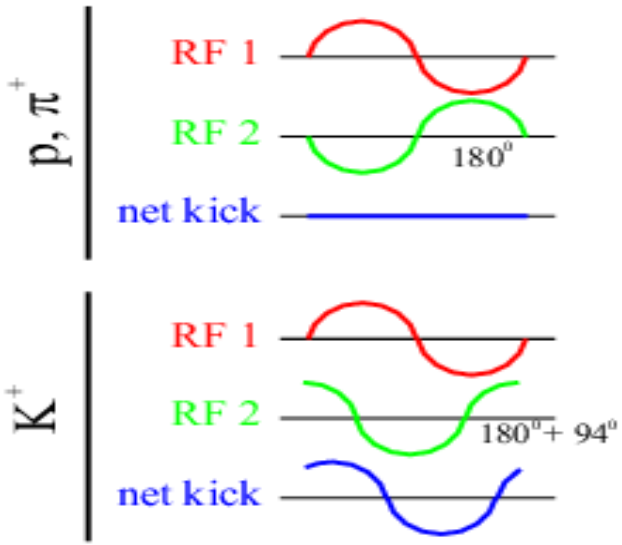


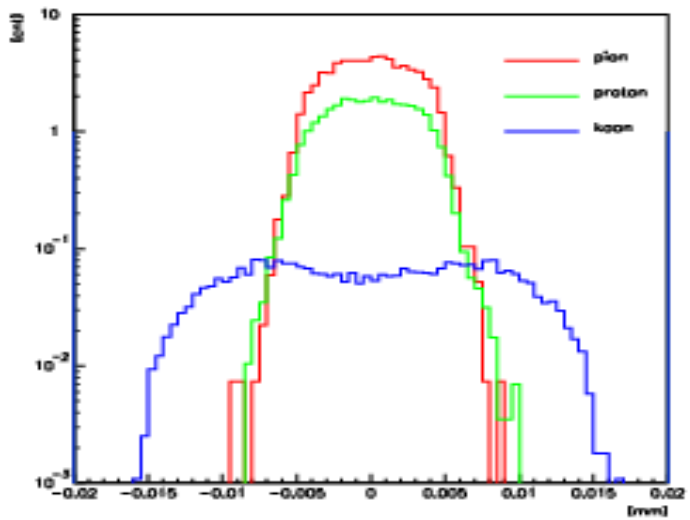
Prototype Focus in 2002.

- Super-Conducting RF required for high duty-factor separated K^+ beam.
- Demonstrate Ultra-low mass π^+ tracker.
- Demonstrate Ultra-low tagging inefficiency ($\sim 10^{-5}$) for high energy photons.
- Demonstrate that the torrent of data can be dealt with.

Enriching the Kaon Content of the Beam



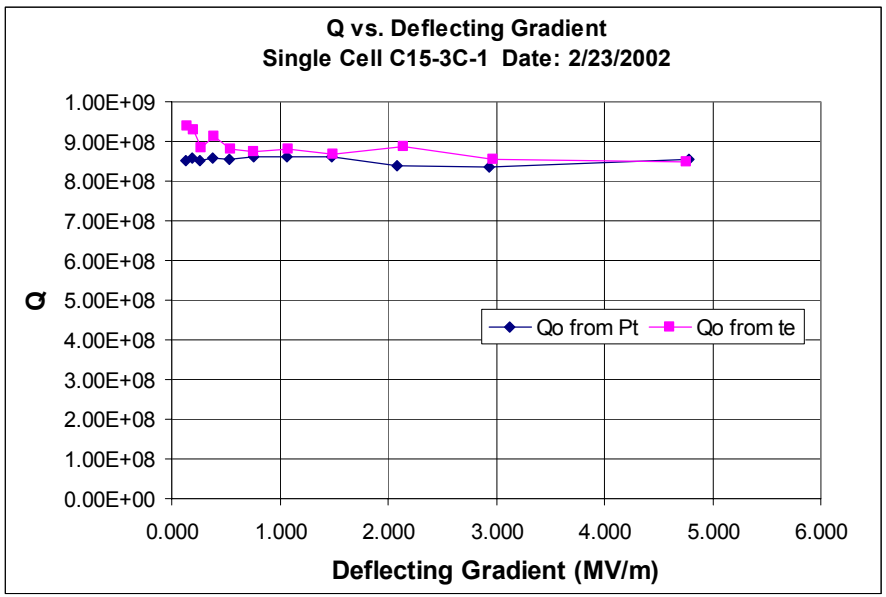


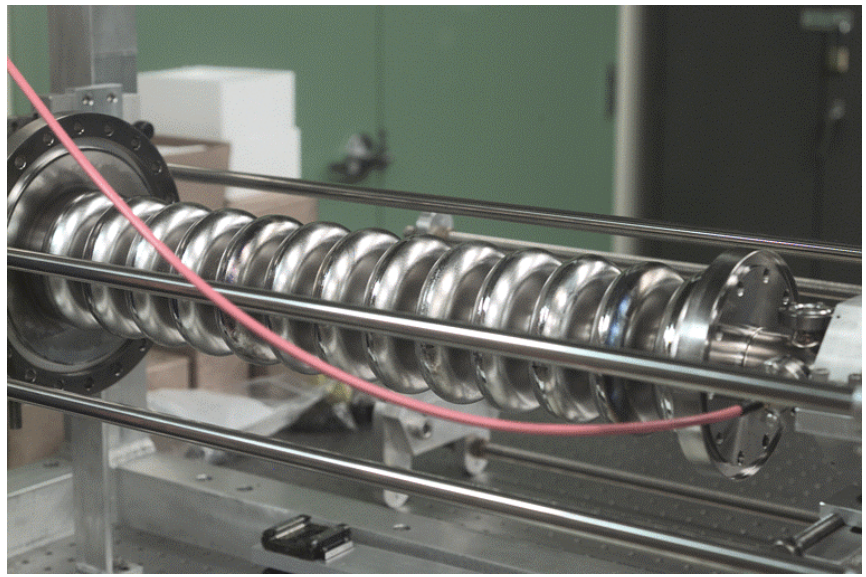


SCRF Separated BEAM

- Require 5 MeV/m deflecting gradient
  Have achieved this in prototype 1 and 3 cell cavities

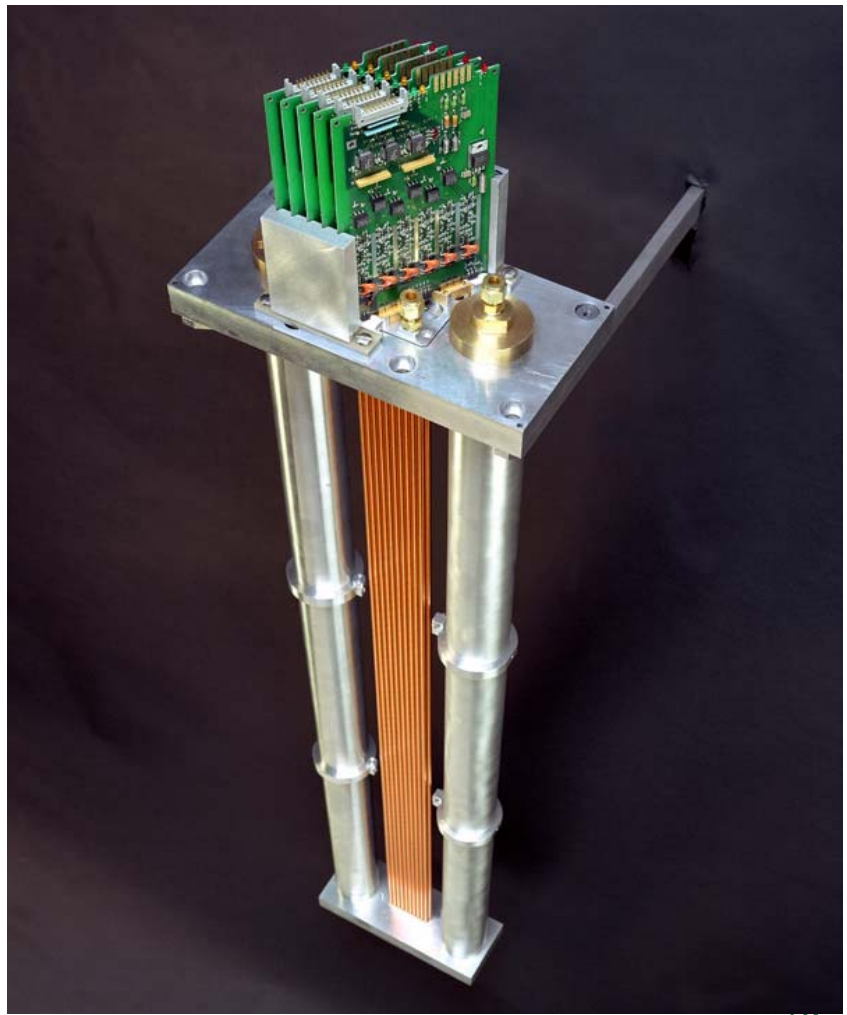
- Design requires 12 Structures of 13-cell cavities
  1st prototype built and tested





Straws in Vacuum: Old Wine, New Bottle.

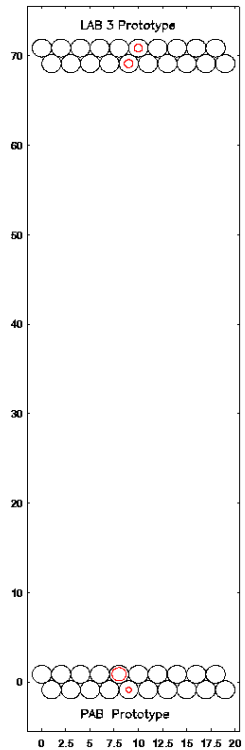
- Mechanical properties extensively studied. (Fermi-Pub 02-241-E)
- Prototype operating in vacuum.
- Proven Principle. Now ready for detailed engineering.

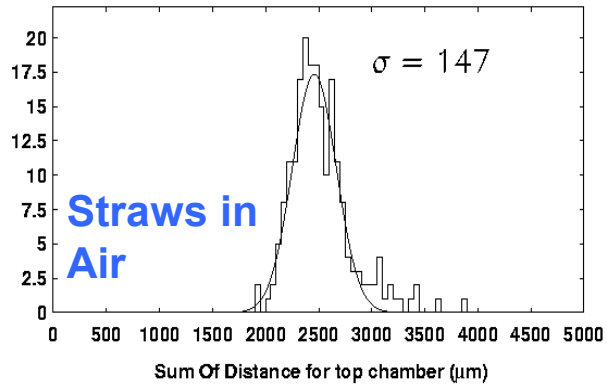


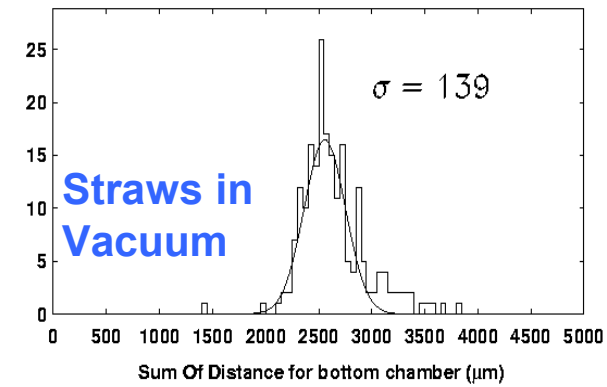
Strawtubes in a Vacuum

Prototype built after BNL871 design
- All chamber specs achieved
- 100 μm resolution, 98% efficiency

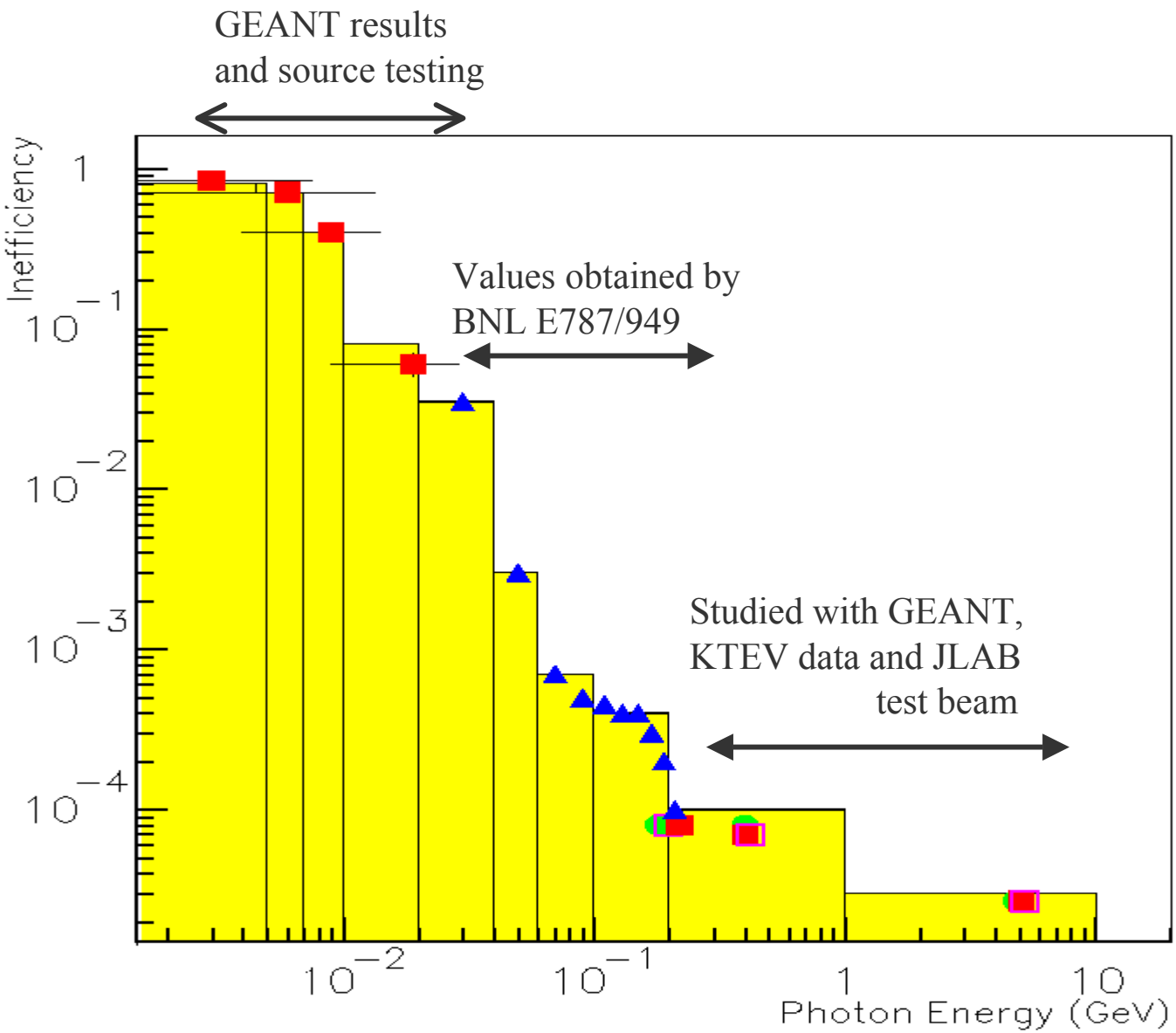
Tested in vacuum with cosmics
- Successful operation
- Negligible leak rate
- Wrong gas ($ArCO_2$ for safety)





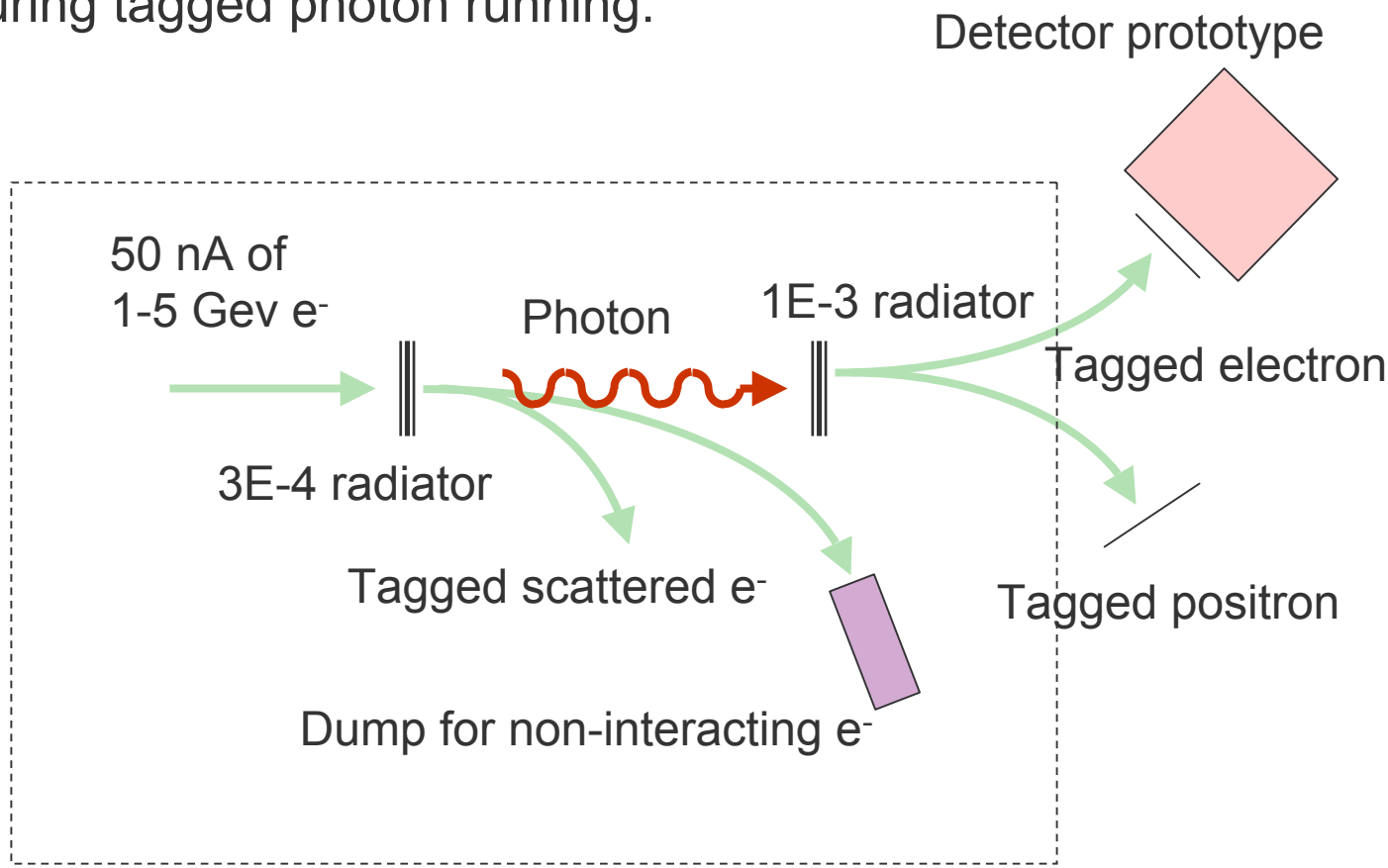


Photon Veto Inefficiency Now *Measured* .



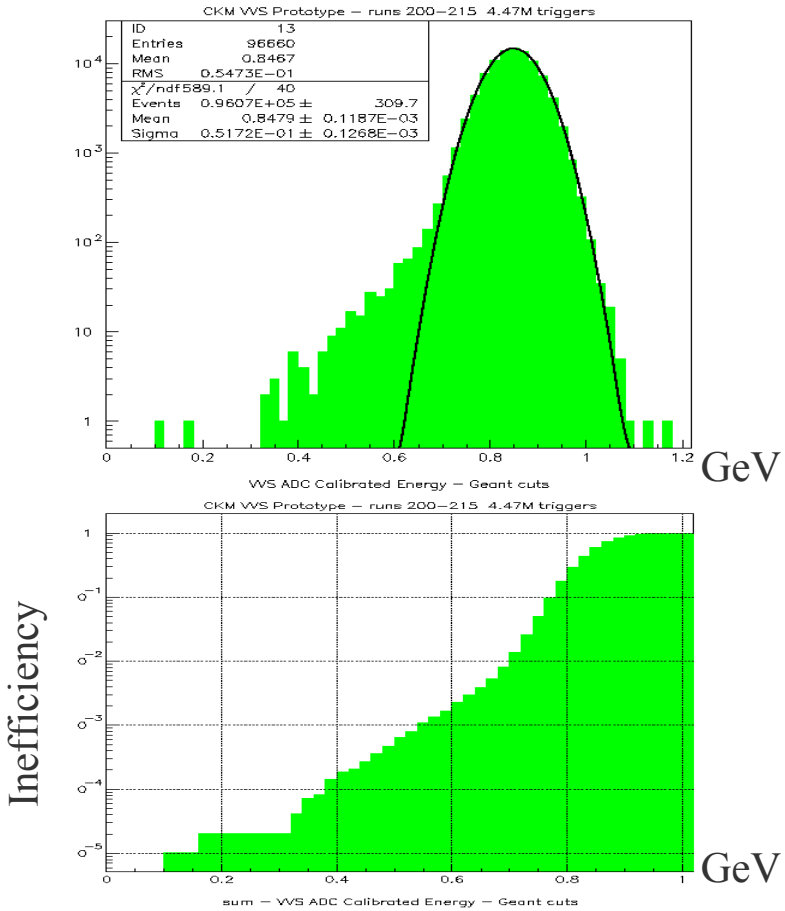
Efficiency to tag 500-1500 MeV electromagnetic showers probed to unprecedented levels @ JLab

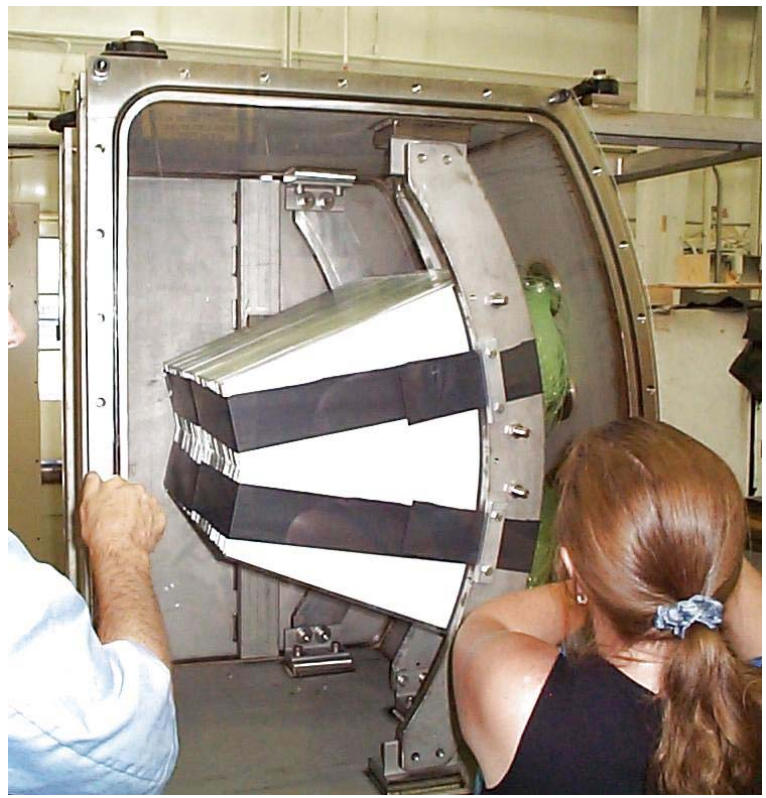
General Schematic of JLab Hall-B beamline during tagged photon running:



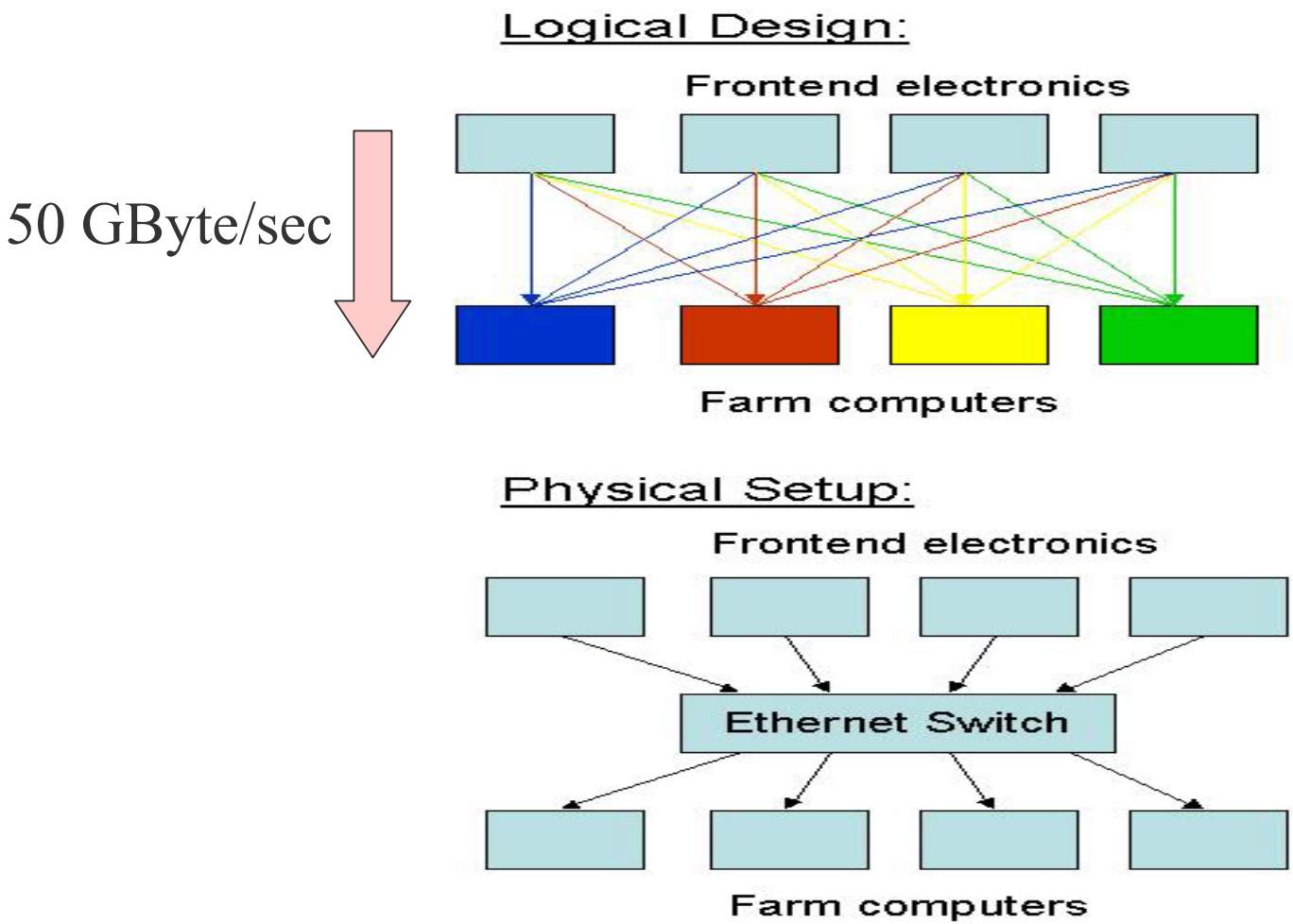
Photon Veto Inefficiency and Technology

- 0.3% VVS Prototype built
- Tested at JLAB in an e^- beam
- Achieved $<1 \times 10^{-5}$ veto inefficiency at 1 GeV





Trigger & DAQ: Can we go "Triggerless"?



Yes! How Do We Build This?? What Are the Standards?

- Our research community no longer drives the relevant standards.

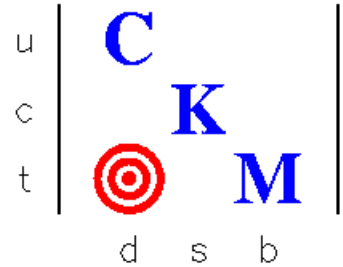
- Commodity processsors and switches are leading (Performance/Cost) .

- Conceptual Design exists, ratified by Temple review.

Temple Review Outcome

- Technical Concerns: “Much Reduced”.
- Modest cost increase (25%) advised for Detector and SCRF systems.
- Lack of engineering resources for civil construction and conventional beamline prevents the associated costs from being accurately known now. Recommendation: Work toward a review of these items in six months.

The Road Ahead…



- Fermilab is providing engineering now to develop an accurate cost estimate. Active work on:
  - Detector Systems.
  - Civil construction and conventional beamline.
  - Costing.
- Goal to *the Goal*: Lehman Baseline in 2004.
- *The Goal*: CP Violation as a new and clear window to the high mass world.