Charged Kaons at the Main-Injector

R. Tschirhart, Fermilab *March 15th, 2003*

URA Visiting Committee

I. Physics and Experimental Technique.

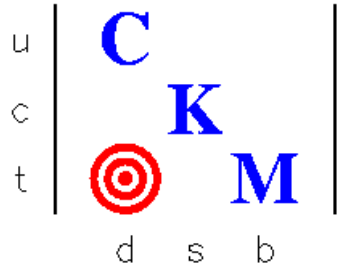
II. Activities of the Last Year.

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

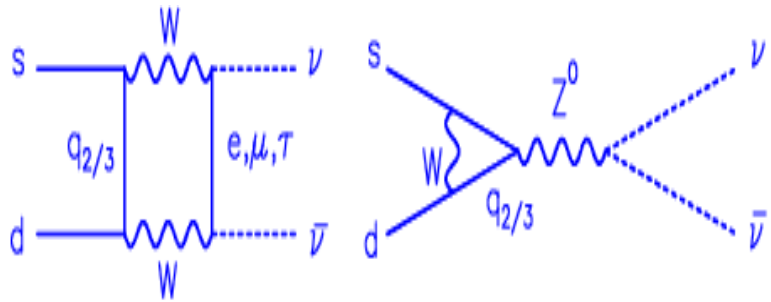
IV. The Road Ahead…

Primary Physics Goal:

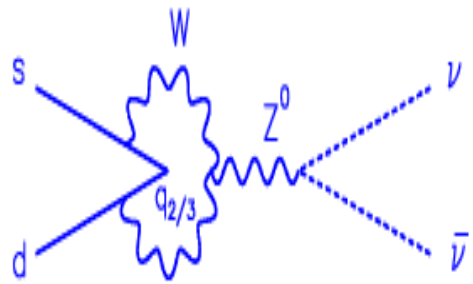
Precision Measurement of $K^+ \to \pi^+ \nu \bar{\nu}$.



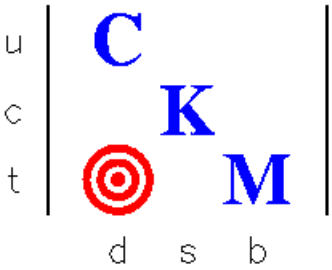
This decay is determined by loop processes to high order in the SM, and hence has a reach for *new physics at the EW scale and beyond*.



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.

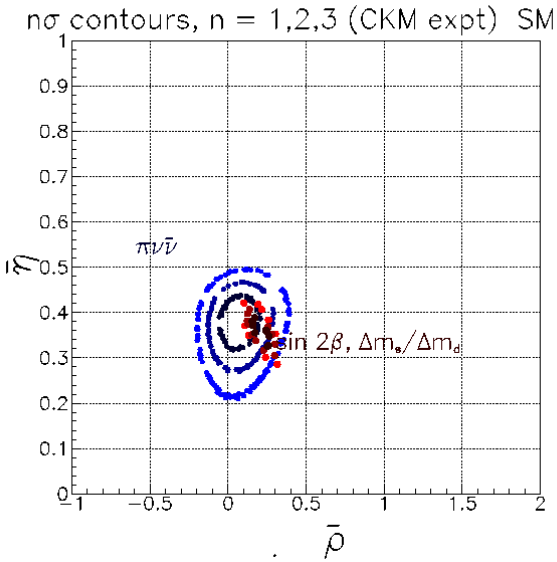


Challenging the Standard Model of CP-Violation with Golden Modes; Consider the Quartet:

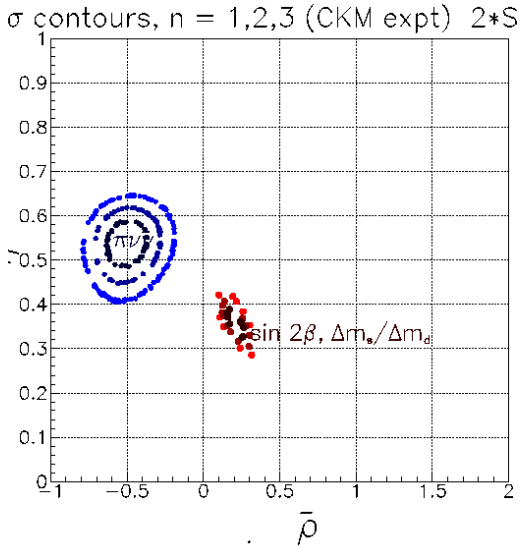


$\sin(2\beta)$, $K^0 \to \pi^0 \nu \bar{\nu}$, $K^+ \to \pi^+ \nu \bar{\nu}$, $\Delta m_d / \Delta m_s$ in B_d^0 and B_s^0 Decays

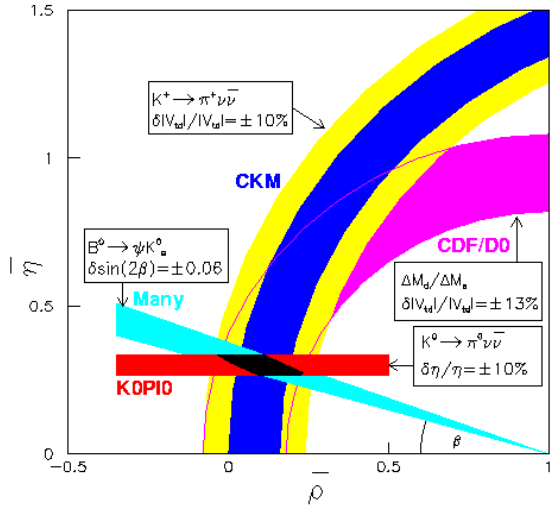
$\Gamma(\pi\nu\nu)$ = SM



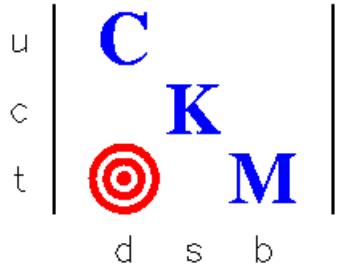
$\Gamma(\pi\nu\nu)$ = 2xSM



expected sensitivities



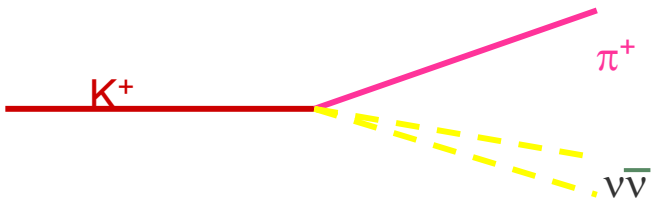
Measuring $|V_{td}|$ with $K^+ \to \pi^+ \nu \bar{\nu}$



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



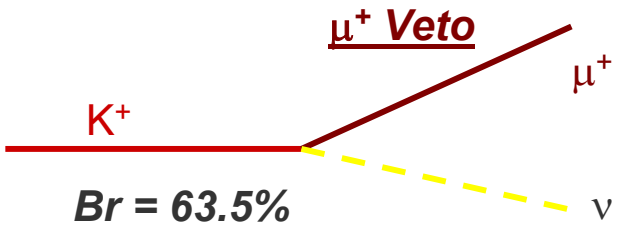
Br = ~1 x 10^{-10}

Kinematics

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

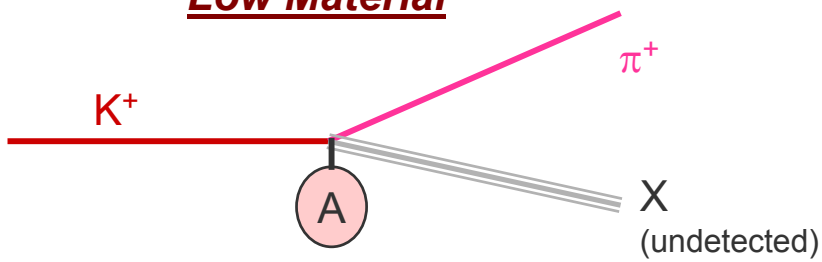
What We'll Get:

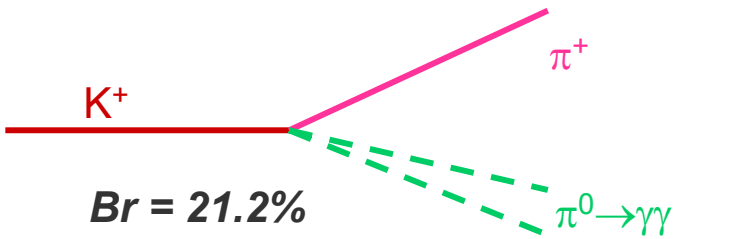
μ^+ Veto



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

Charged Veto
Low Material



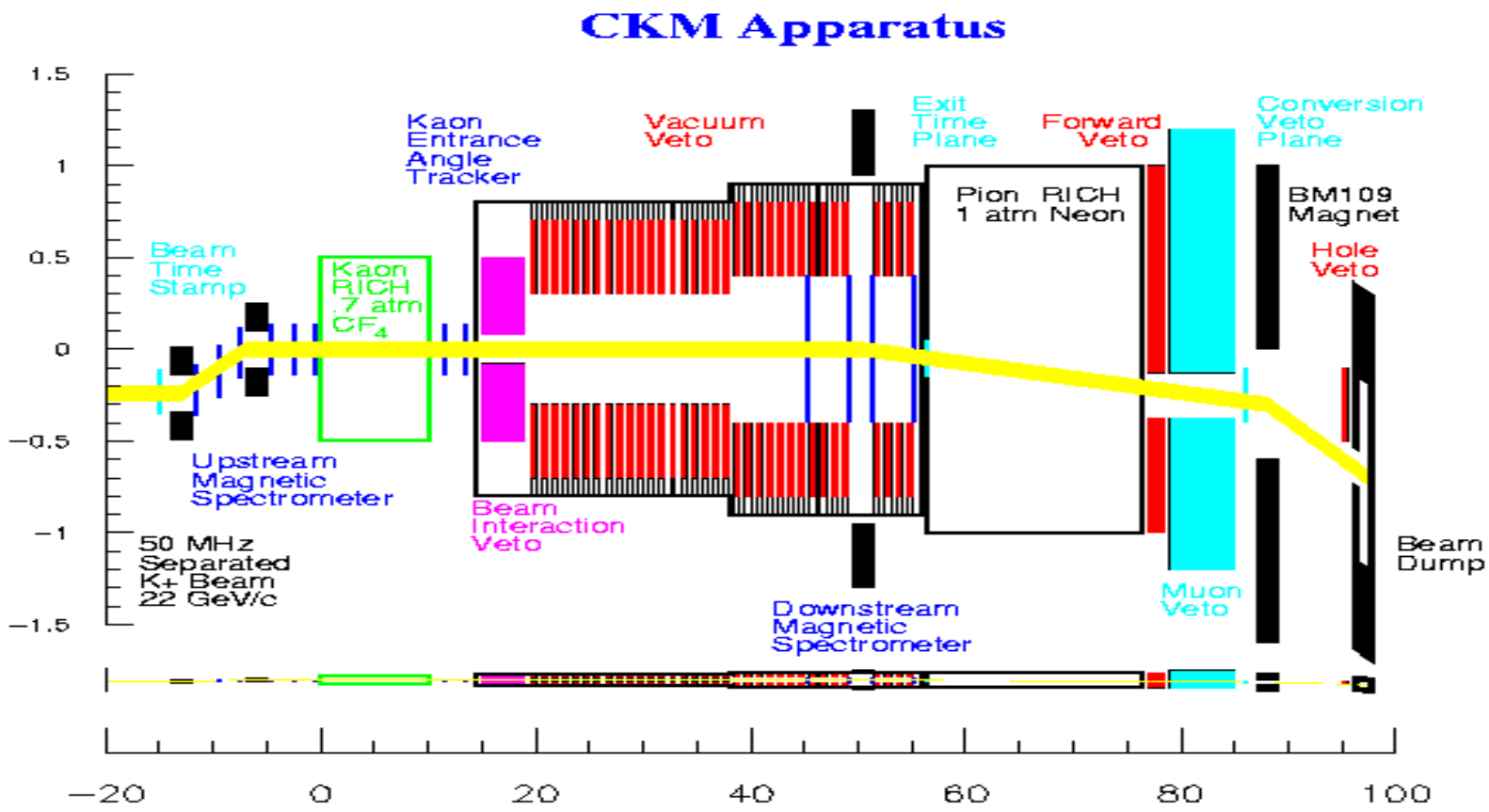


Br = 21.2%

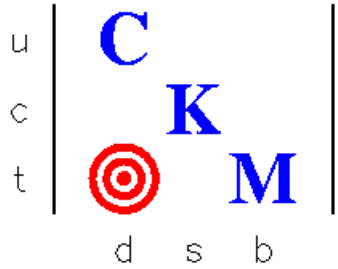
γ Veto

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 /1 sec 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

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

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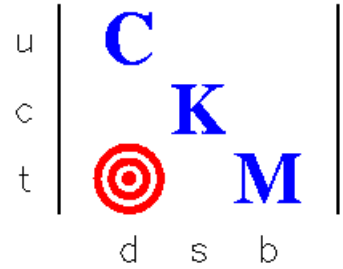
Scope & Timeline:



- 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

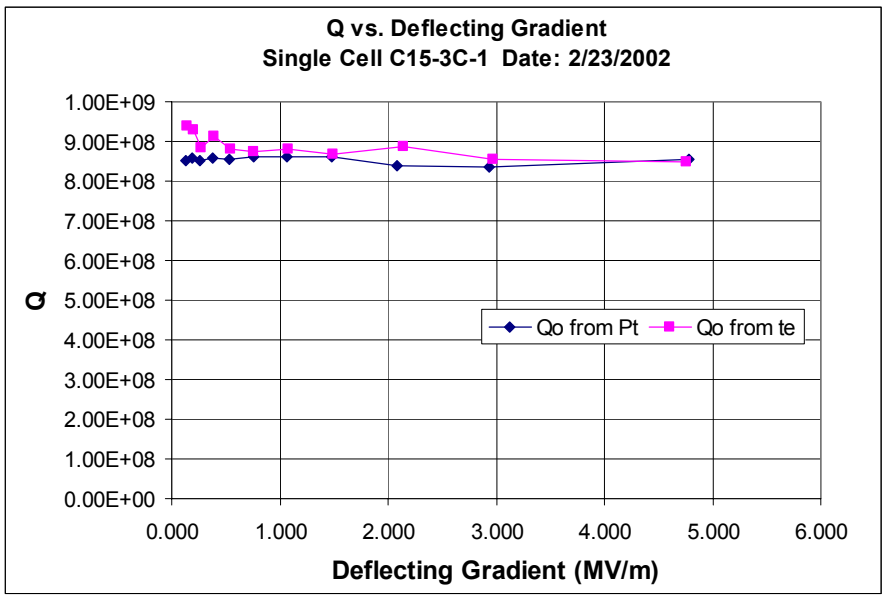
Prototype Focus in 2002.

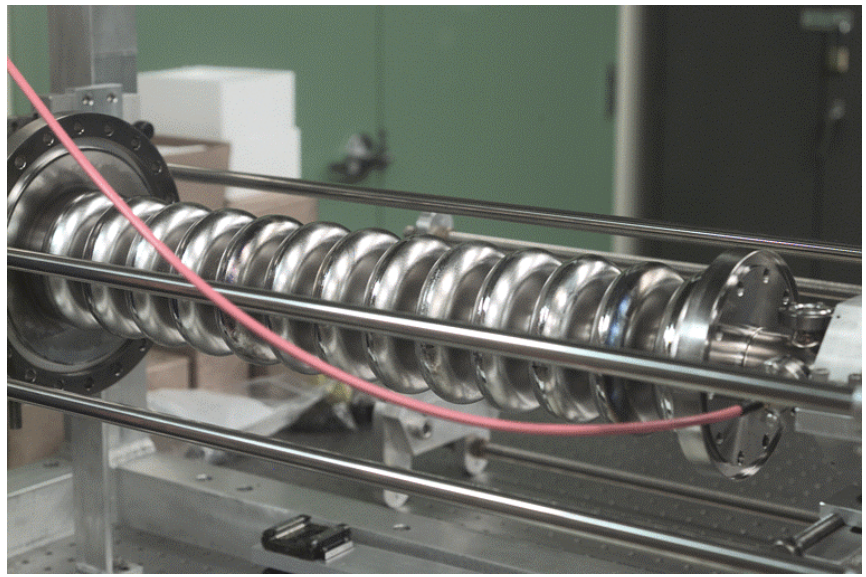
- Super-Conducting RF required for high duty-factor separated K^+ beam.
- Demonstrate Ultra-low mass π^+ tracker.
- Demonstrate Ultra-low tagging inefficiency ($\sim 10^{-5}$) for high energy photons.
- Demonstrate that the torrent of data can be dealt with.

SCRF Separated BEAM

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

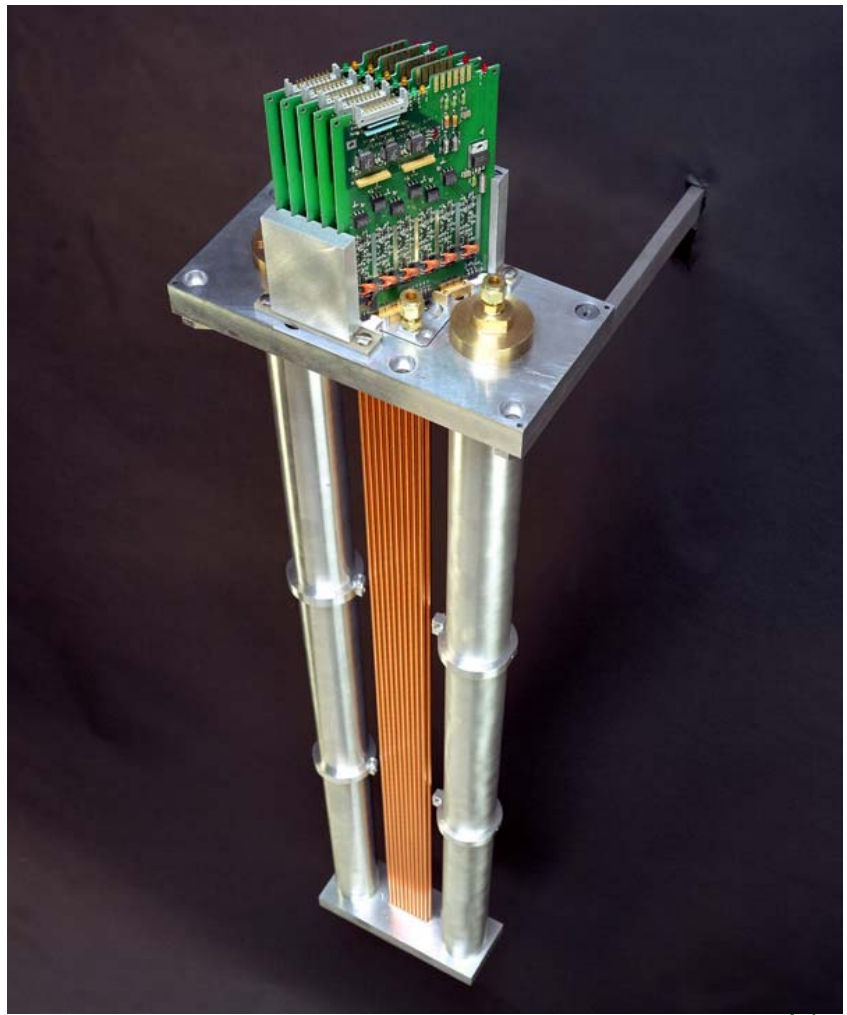
- Design requires 12 Structures of 13-cell cavities
  1st prototype built and tested





Straws in Vacuum: Old Wine, New Bottle.

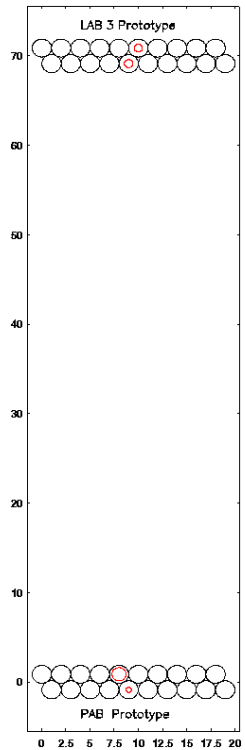
- Mechanical properties extensively studied. (Fermi-Pub 02-241-E)
- Prototype operating in vacuum.
- Proven Principle. Now ready for detailed engineering.

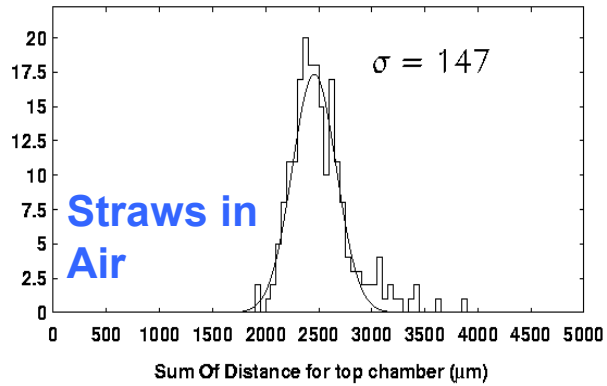


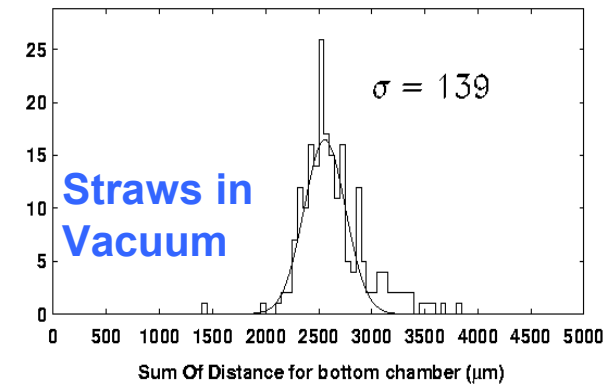
Strawtubes in a Vacuum

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

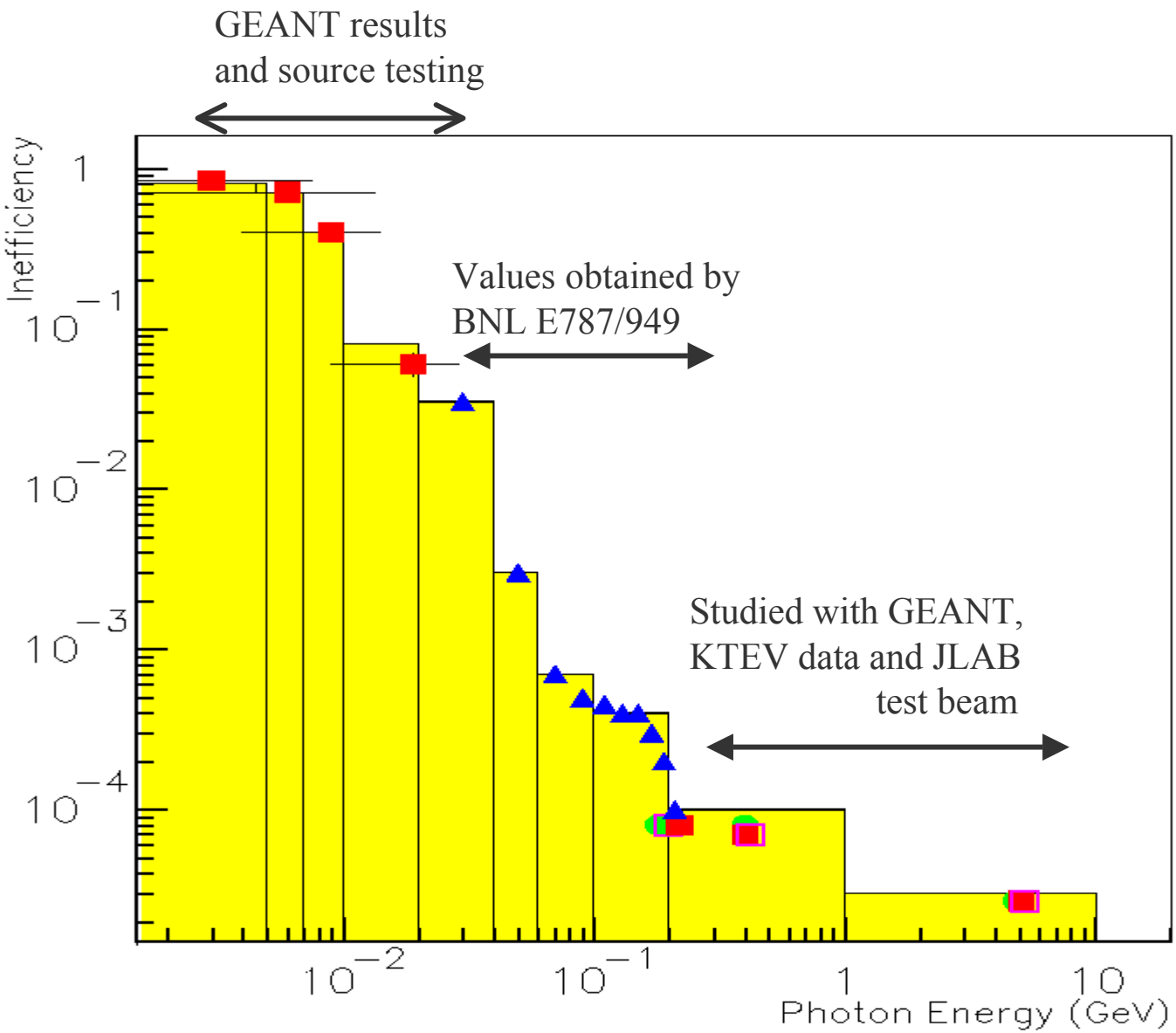
Tested in vacuum with cosmics
- Successful operation
- Negligible leak rate
- Wrong gas ($ArCO_2$ for safety)





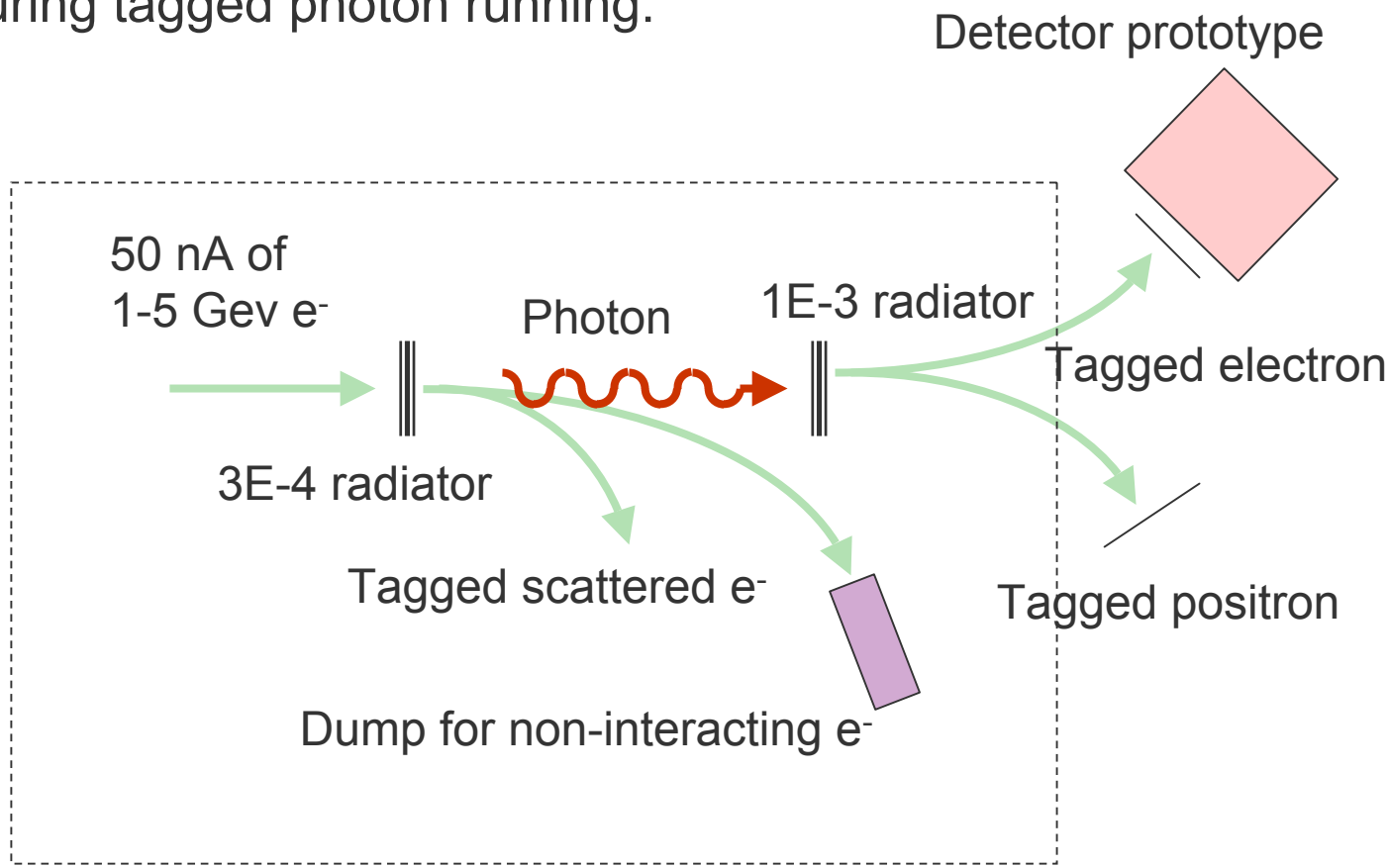


Photon Veto Inefficiency Now *Measured* .



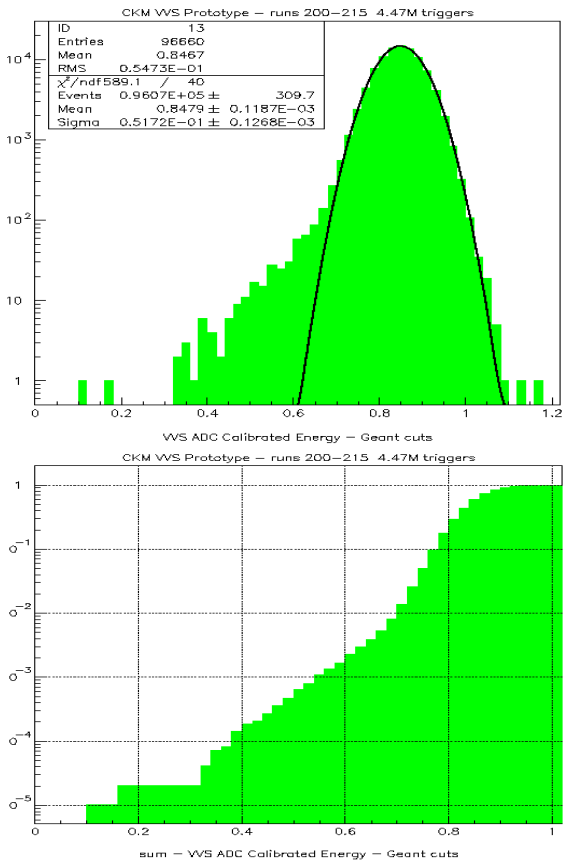
Efficiency to tag 500-1500 MeV electromagnetic showers probed to unprecedented levels @ JLab

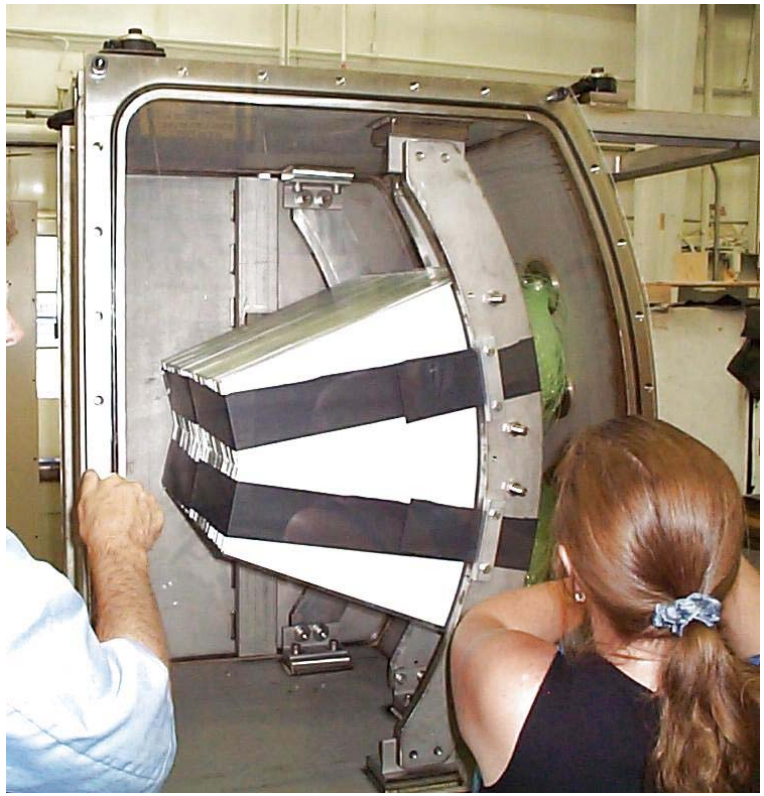
General Schematic of JLab Hall-B beamline during tagged photon running:



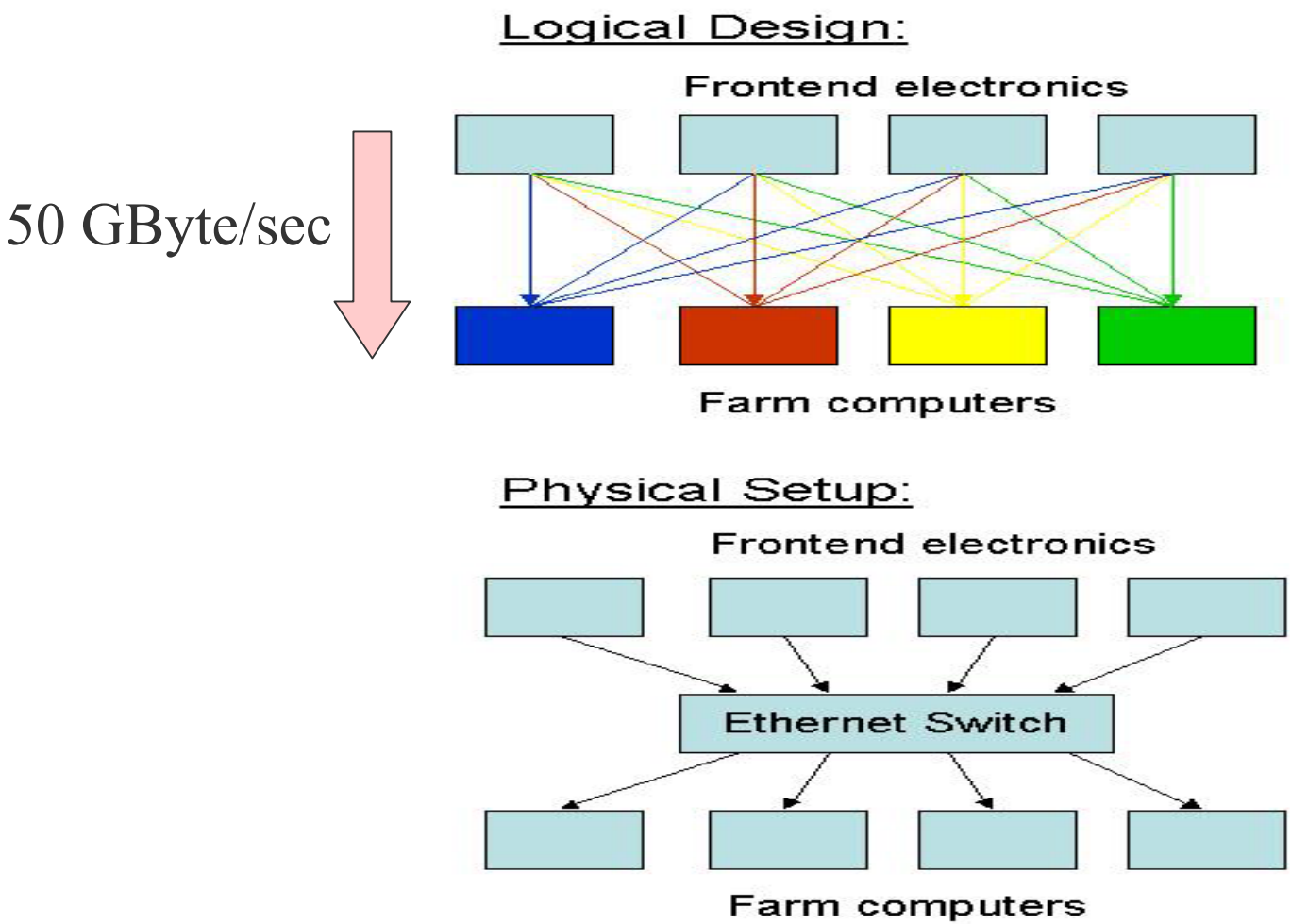
Photon Veto Inefficiency and Technology

- 0.3% VVS Prototype built
- Tested at JLAB in an e^- beam
- Achieved $<1x10^{-5}$ 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.

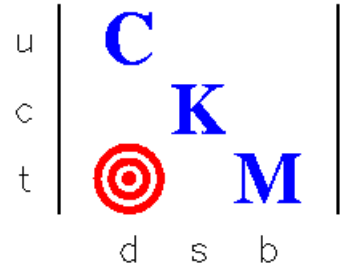
- Commodity processsors and switches are leading (Performance/Cost) .

- 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.

The Road Ahead…



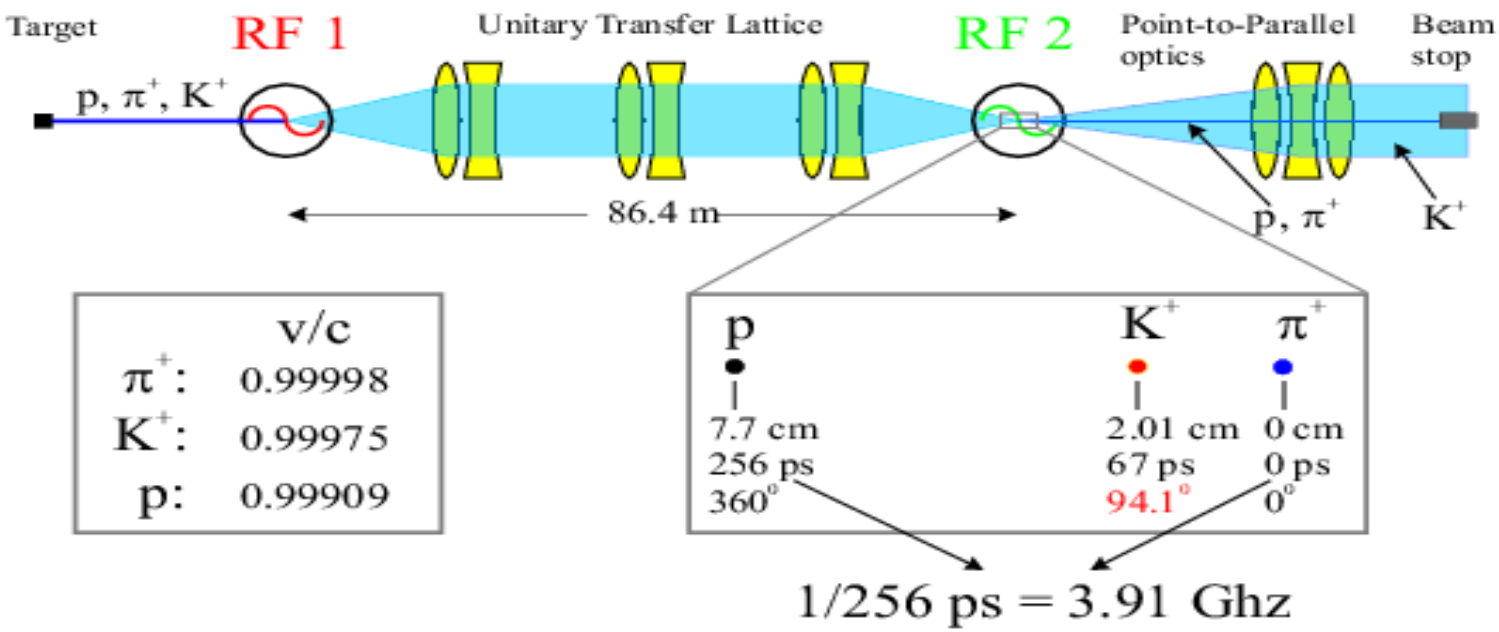
- Fermilab is providing engineering now to develop an accurate cost estimate for the civil construction and conventional beamline. Review in October 2003.

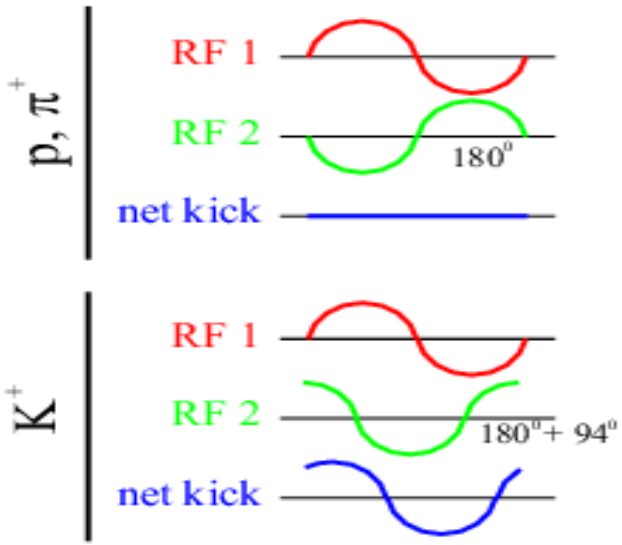
- Goal to *the Goal*: Lehman Baseline in 2004.

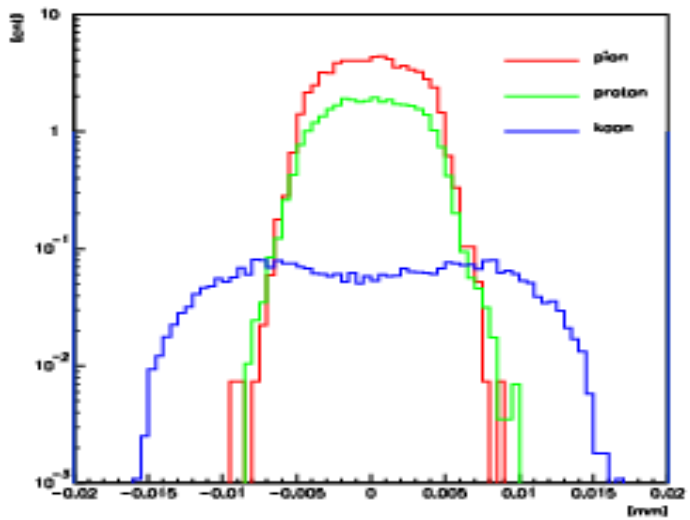
- *The Goal*: Open a new and clear window to the high mass world.

Spare Slides.

Enriching the Kaon Content of the Beam

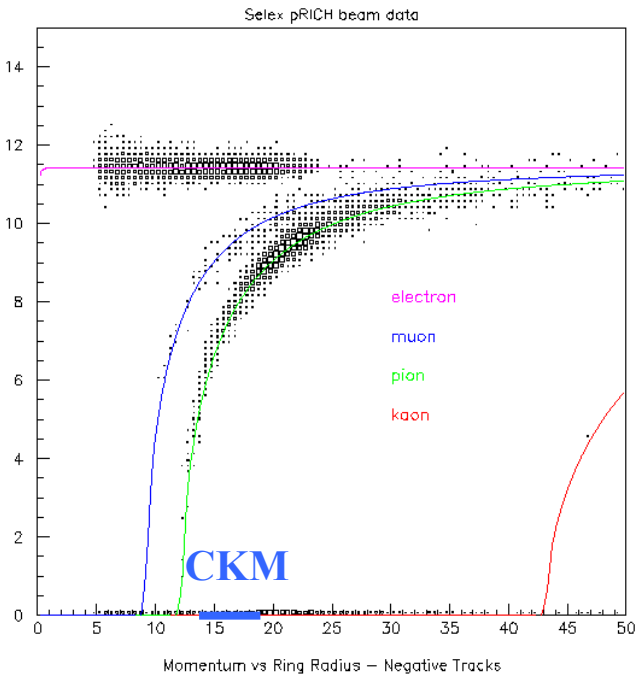


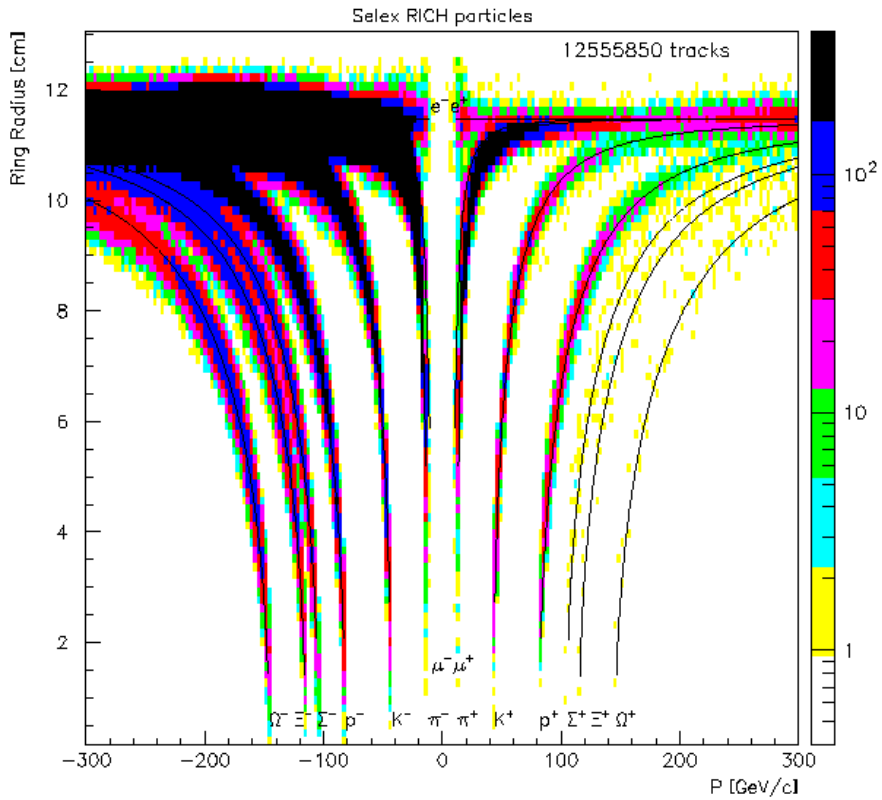




Ring Imaging Cherenkov Counters

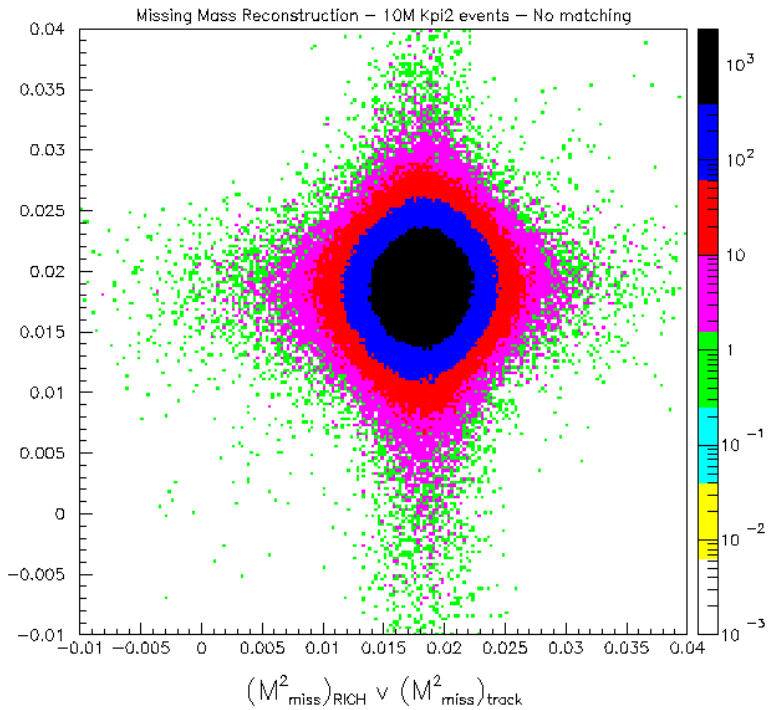
- High rate high resolution
- Matched to momentum resolution
- Based on successful Selex RICH
- Photo-detectors are individual PMTs





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
- Uncorrelated measurements
  - Backgrounds from mis measurements and be studied and quantified from the data



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