Technical Progress of the CKM Experiment

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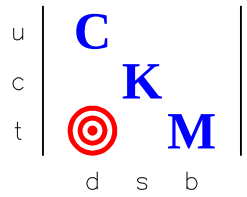
on behalf of the CKM Collaboration

Fermilab PAC
March 28, 2003



Charged Kaons at the Main Injector

March 29, 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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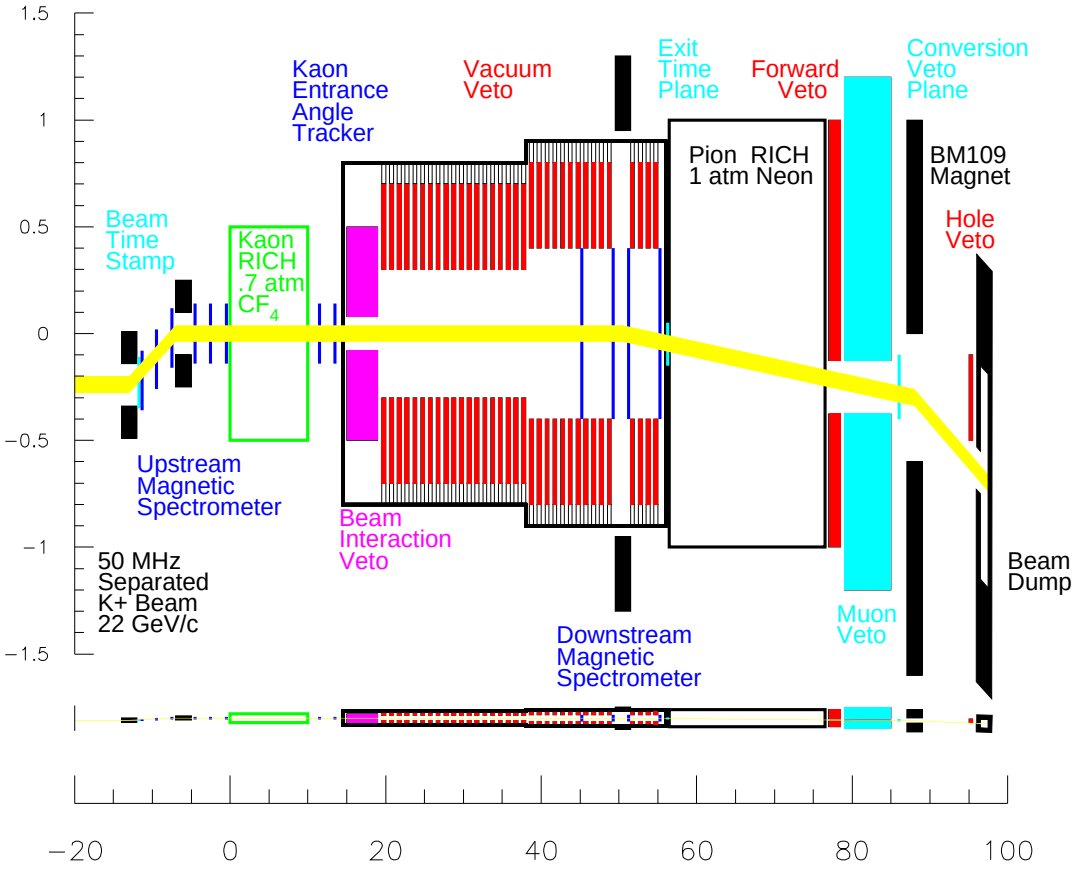
- Groups from 4 national labs and 6 universities
- 48 people now; 7 postdocs + students.
  Will grow by $\sim 2\times$ (U. Colorado joined).
- Roots in BNL787/949, CDF, IHEP-Istra, KTeV, HyperCP, SELEX :
  Substantial experience in rare K decays.

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

- Theoretical errors are small and robustly estimated (~8%).
- Experimental Challenge:
  - Br $\left[K^+ \to \pi^+ \nu\overline{\nu}\right] = 8 \pm 3 \times 10^{-11}$ (SM)
  - BNL-E787 w/ 2 clean events $\Rightarrow$ Br $= 16^{+18}_{-8} \times 10^{-11}$
  - Need 6 MHz K decays to collect 100 events in 2 years.
  - Need to control background to 10^{-11} of all K^+ decays & interactions.
- CKM's experimental goal:
  - 100 signal events (at Br $= 1 \times 10^{-10}$) with < 10 background in 2 years.
  - other physics: form factor, $V_{\rm us}$ & $V_{\rm ud}$ unitarity test, *LFV* search, χPT tests, *CPT* and *T*-odd tests.

The CKM Apparatus



- 22 GeV/c enriched K^+ beam: decay in flight.
- 30 MHz K^+ $\Rightarrow$ very-high rate, low-mass detectors.
- Philosophy: Make redundant measurements with proven technologies.

CKM is similar in size and scope to KTEV

Progress Since Approval

Technical Progress:

- Prototype 13–cell superconducting RF cavity built and under test.
- Construction of prototype upstream chamber in progress.
- Construction of prototype beam time stamp fiber array in progress.
- Technical design of Beam Interaction Veto.
- Prototype vacuum veto sector built and tested in beam.
- Prototype straw chamber tested in vacuum.
- Inherited Magnet, CsI (for FVS) and Muon detectors from KTeV.
- Front-end electronics prototypes in testing.
- DAQ/Trigger design, simulation and prototyping.

Other:

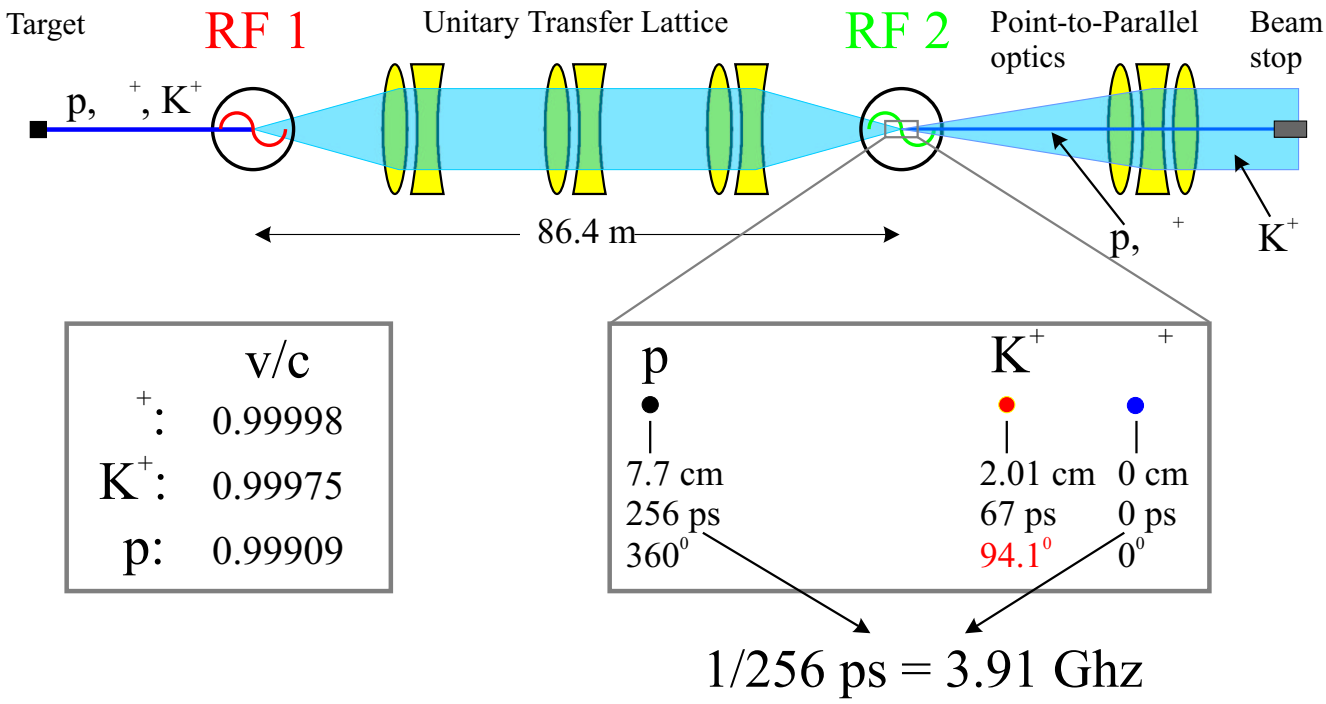
- experiment has been sited
- Internal Lab (Temple) Review

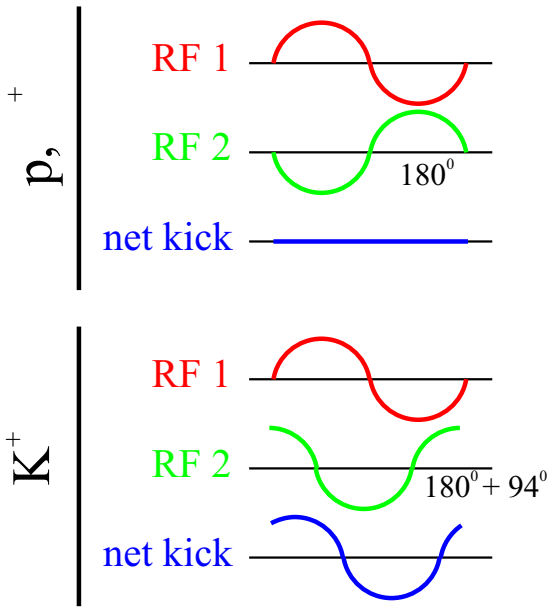
Beamline

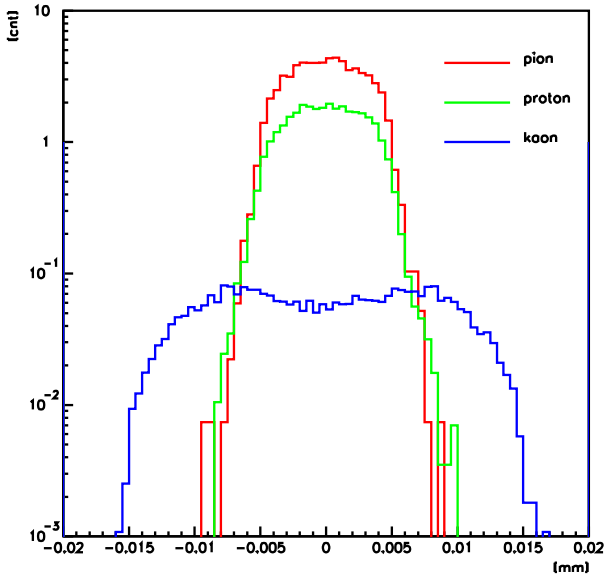
- KTeV experience:
  - Neutral K beam tails controlled and understood at the 10^{-4} level.
  - Detector rates predicted by GEANT and validated by measurement.
  - Same people designed the CKM beam line.

Extrapolation of the rate of "out-of-time" hits in KTeV
$\Rightarrow$ negligible low energy n background in CKM.

Enriching the Kaon Content of the Beam



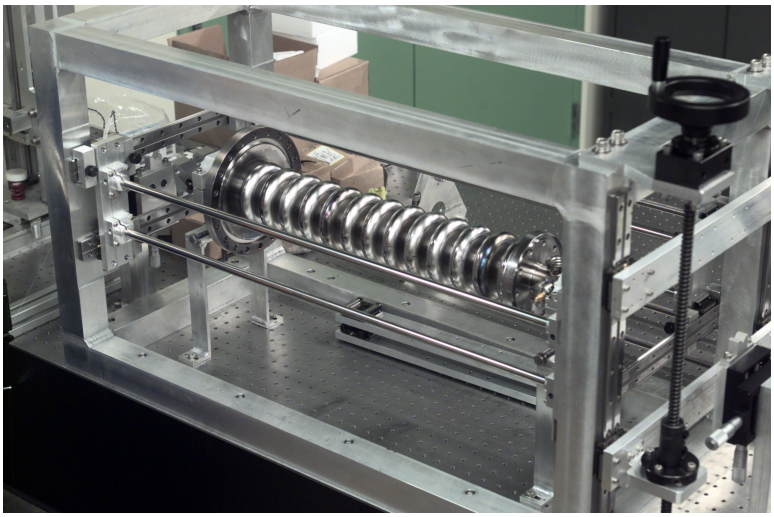




Superconducting RF Separated Beam

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

- Design requires 12 structures of 13–cell cavities
  – First prototype built and under test.



- Achieved $Q_\circ$ about 60% of spec

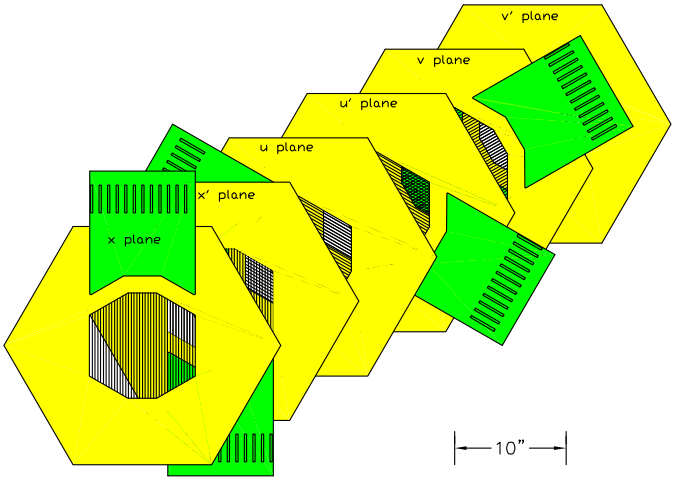
- Suspects identified

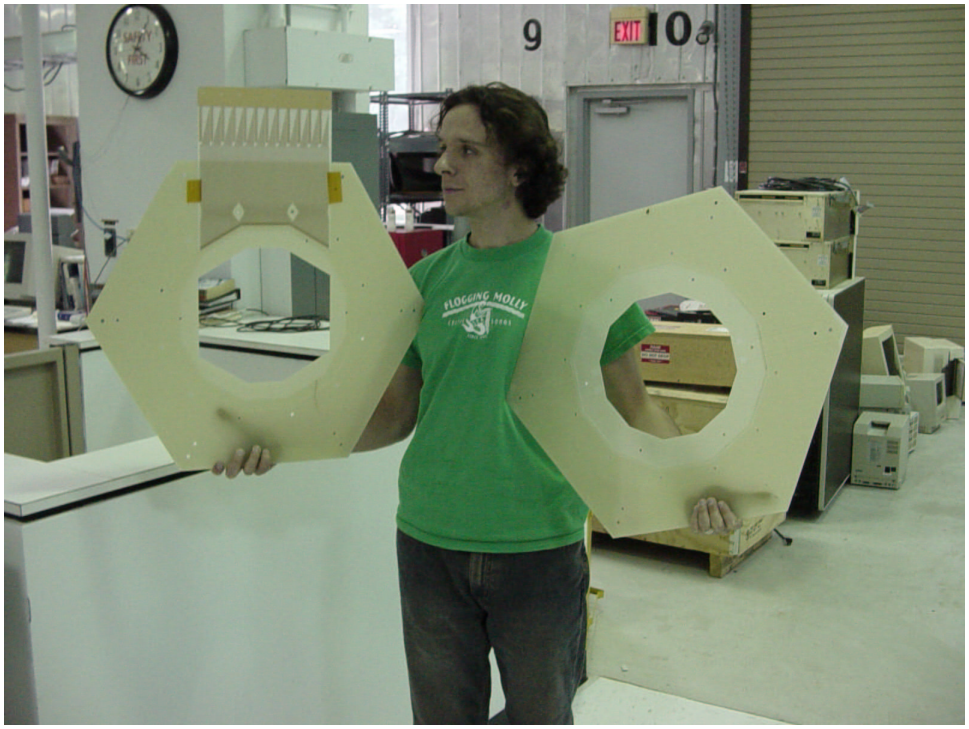
A production protoype RF station (2 × 13-cells) planned for 2004.

K–Tracker (UMS, KEAT)

Specifications:

- Rate capability $0.5 - 1.0\,\mathrm{MHz/cm^2}$
- $\sim 20\,\mathrm{cm}$ diameter aperture.
- $0.8\,\mathrm{mm}$ pitch anode planes interleaved w/ cathode foil planes.

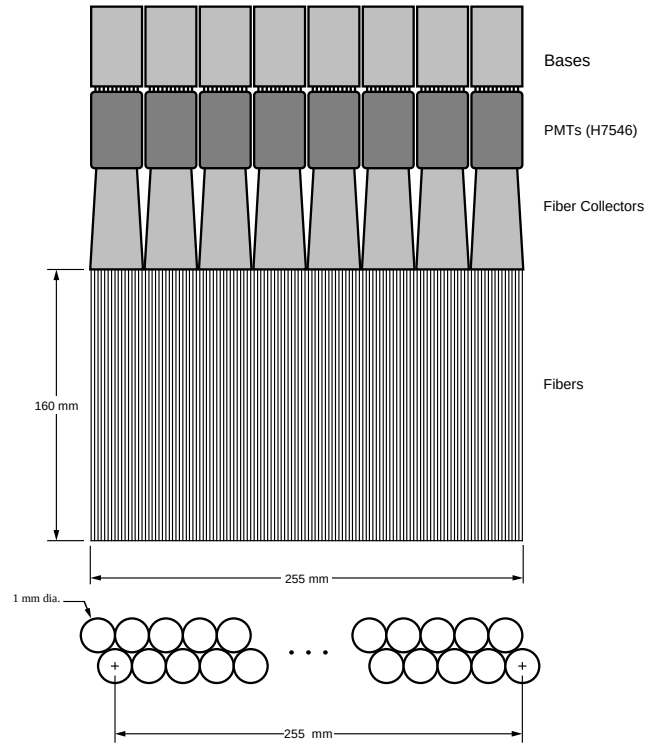


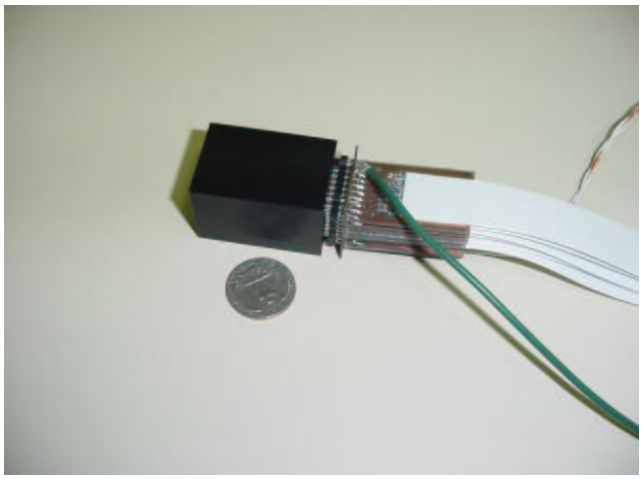


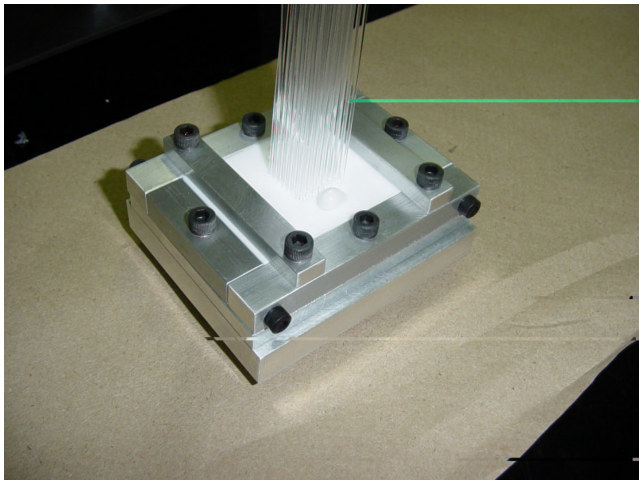
- Will perform high-rate beam test in fall 2003.

Beam Time Stamp

- Tag candidate UMS tracks with $\sim$ 1 ns resolution
- Must handle rate of $\sim 1\,\mathrm{MHz/cm^2}$
- Similar detectors downstream: ETP, CVP

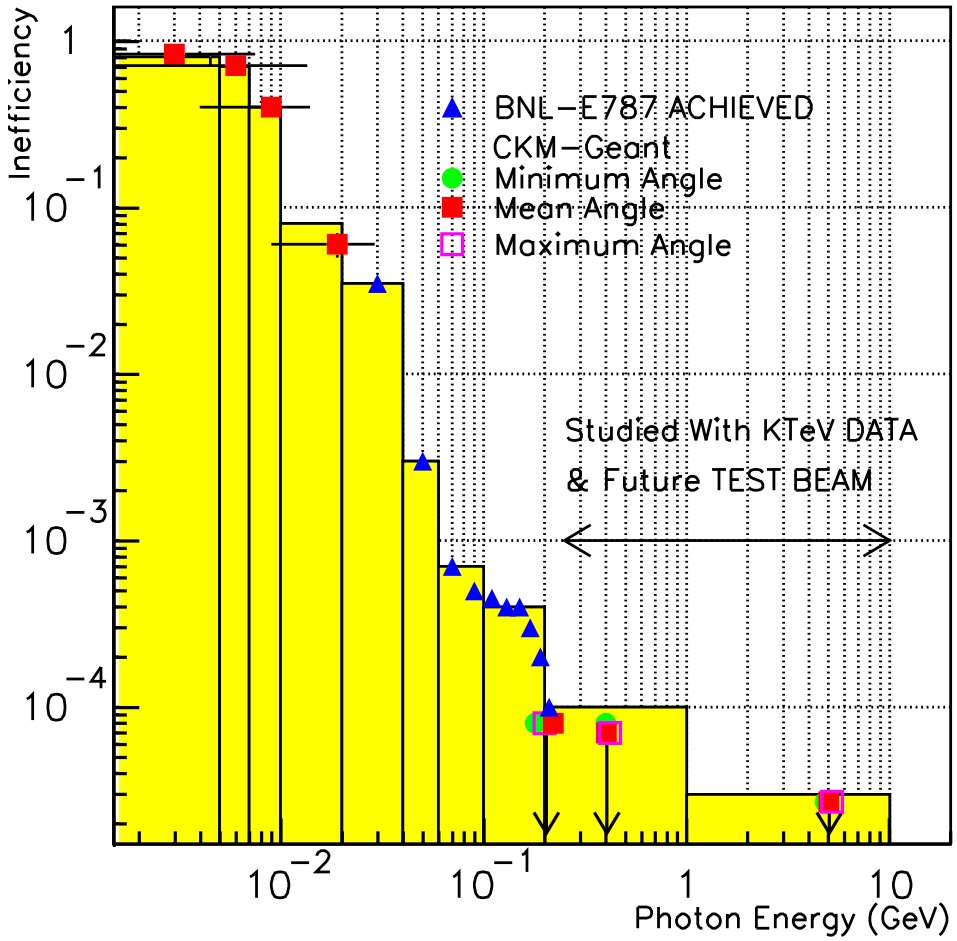






Will perform high-rate beam test in fall 2003

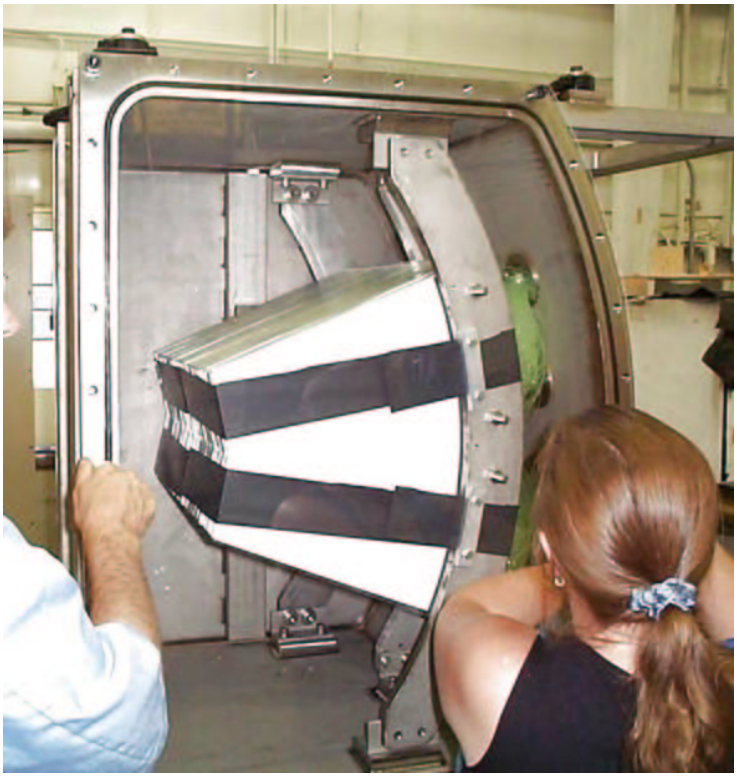
Required Vacuum Veto Inefficiencies



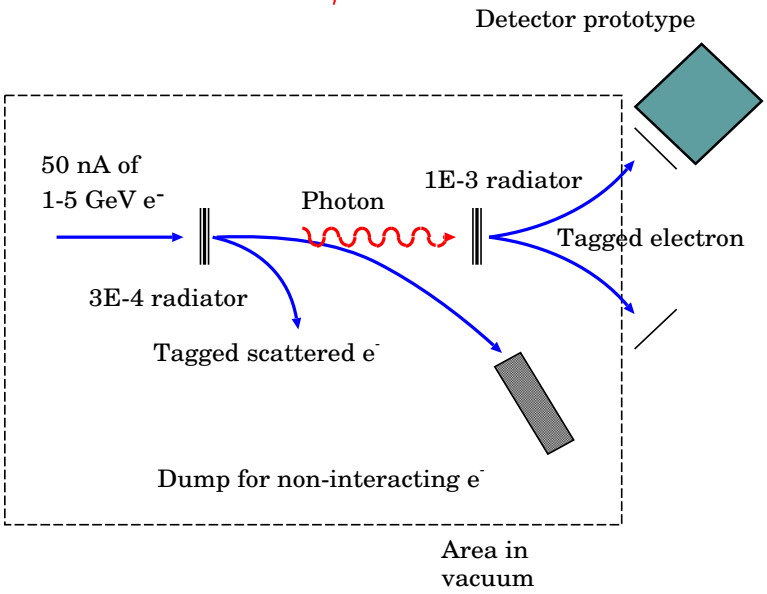
CKM-Geant simulation of low and high E_γ regions now validated with data.

Photon Veto Technology

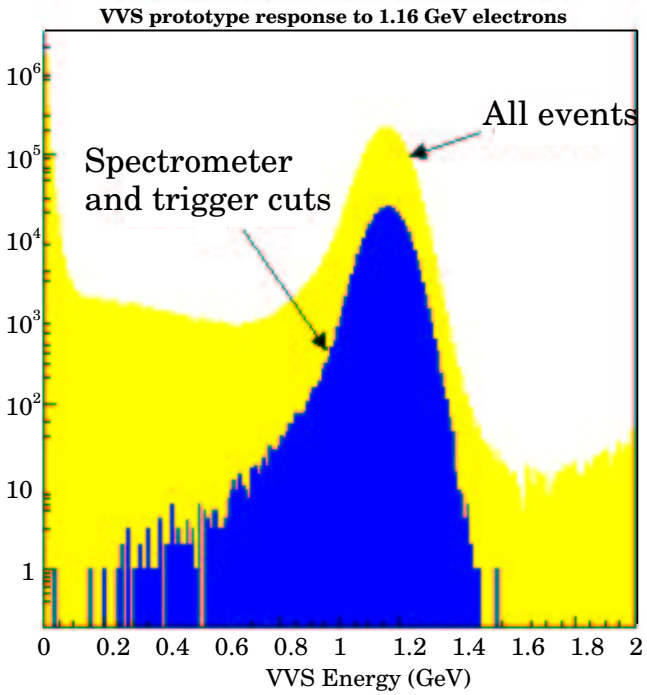
- 0.3% VVS prototype built.
- Instrumented with ADC's and TDC's (1MeV threshold).
- Tested at JLAB in an e^- beam.



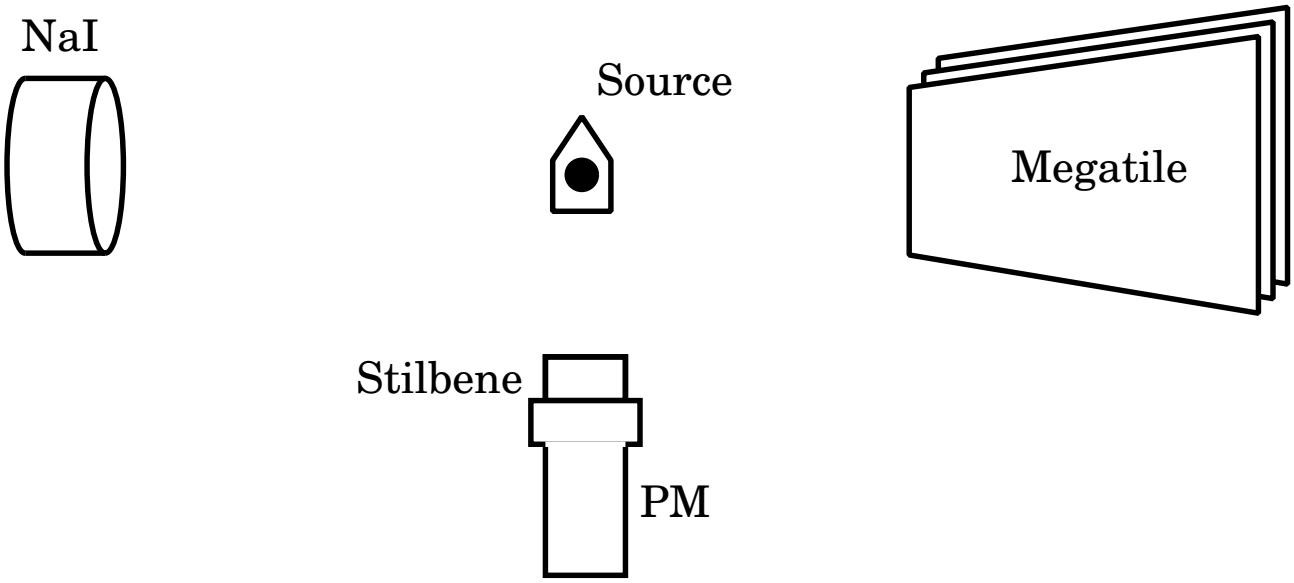
Measuring High E_γ Inefficiency at JLAB



- Achieved $< 5 \times 10^{-6}$ inefficiency at 1 GeV
- *require* $< 3 \times 10^{-5}$



Measuring Low Energy Inefficiency at IHEP



orientation of the prototype corresponds to 90°

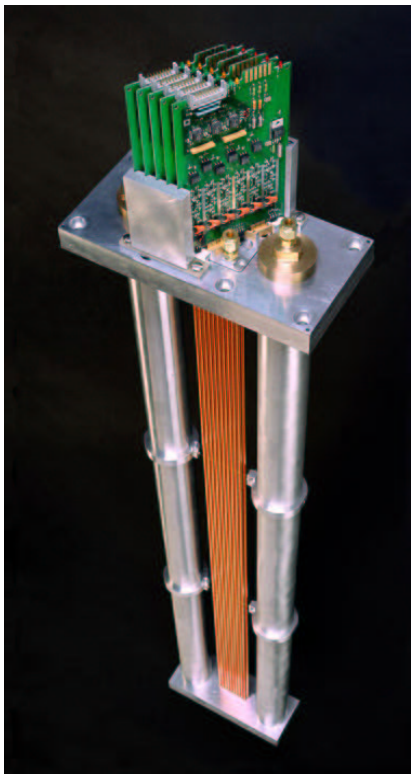
Sources:

$$^{60}\text{Co} \rightarrow \gamma(1.17\,\text{MeV}) + \gamma(1.33\,\text{MeV})$$
$$\text{Pu} + \text{Be} \rightarrow n + \gamma(4.44\,\text{MeV})$$

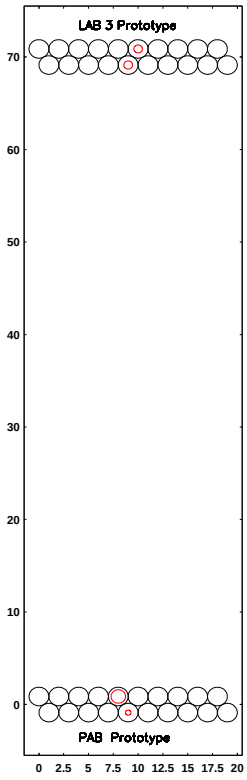
- measured inefficiency $< 60\%$; study on-going.
- inefficency spec of $< 40\%$ at 4 MeV appears achievable.

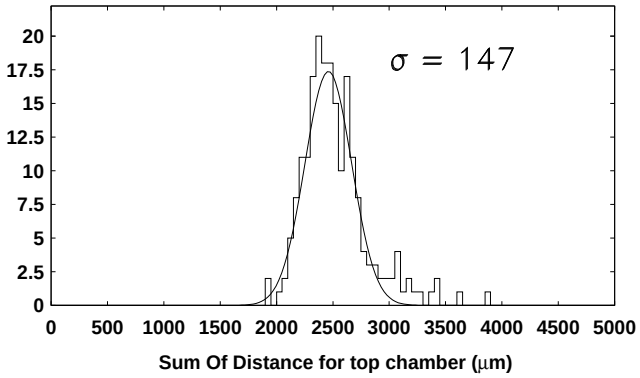
DMS: Straws in Vacuum

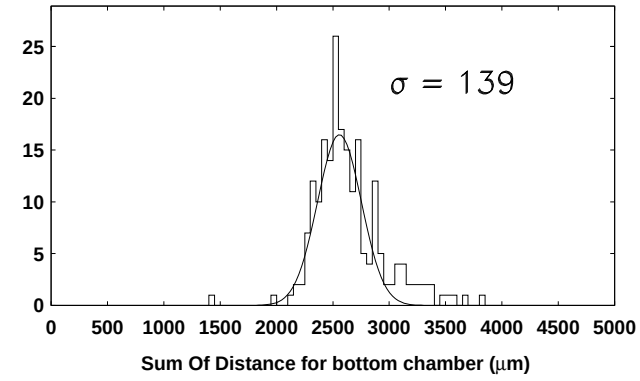
- Follows BNL871 design
- Each view consists of a doublet layer.
- 5 mm diam., 1 m long straws having 30 μm kapton walls.
- expected rate 120 kHz
- operation in vacuum
  - mechanical tolerance maintained
  - diffusion rate negligible



Cosmic-ray Test of Strawtubes in Vacuum





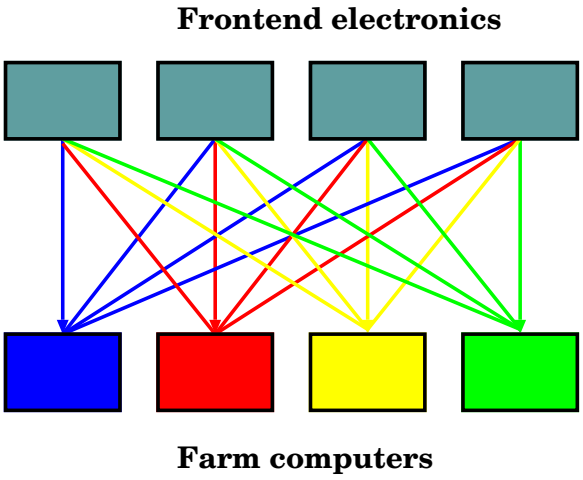


- Upper chamber in air, lower in vacuum
- All chamber specs achieved:
  - $< 150\,\mu m$ resolution and 98% efficency.
  - negligible mechanical distortion and gas diffusion
- Wrong gas (A-CO_2 for safety)

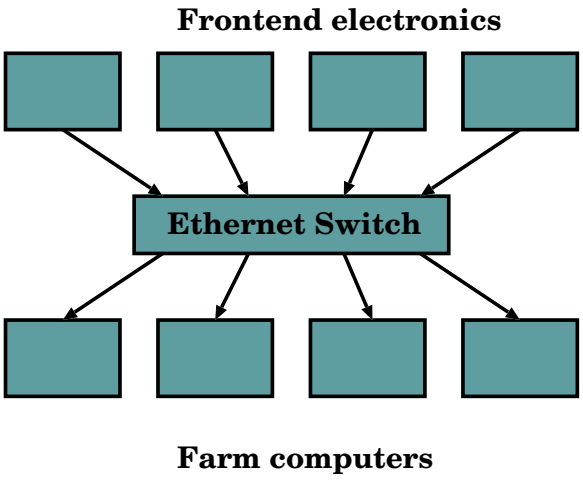
Trigger and DAQ

- A "Software-Only" trigger is feasibile.
- Front-end electronics continuosly send zero–suppressed data to a computer farm. (50 GB/s)
- Interconnection by Gigabit Ethernet network switch.
- Computers run various "levels" of triggering.

Logical Design:



Physical Design:



DAQ Simulation

- Geant based MC of events with variable random pile-up of multiple events. Includes effects of showering, multiple scattering and late energy deposits due to stopped particles,,,*etc*

- Detector & Front-end response functions include
  - drift & fiber propagation times
    $\Rightarrow$ phase shift w.r.t. clock
  - pulse shape and attenuation
  - zero suppression $\Rightarrow$ formatted data

- Network communication

- Software Trigger algorithms.

DAQ/Trigger Test Stand at Boulder

Test stand used to generate specifications for network speed and required number of CPU's in a scalable form.

Reasonable scaling of required performance to 2007:

- ~ 800-port Gigabit Ethernet Switch
- ~ 400 "10 GHz Xeon" CPU's

Front-end Electronics Developments

- ASIC or discrete circuitry using commercial components?
  - 100 MHz QIE-v*xx* (ASIC) in development
  - an implementation of the QIE concept using commercial parts is also under development
  - Amplifier-shaper-discriminator from commerical components has performance comparable to UPenn ASDQ
- Time Distribution System
- FPGA-based Time Measurement Chip under development
- Sparsified data structure defined
  - used in DAQ simulations

Outcome of the Temple Review

- Technical concerns are "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 6 mos. with engineering support provided by the lab.

Conclusions

- Active work on Detector, DAQ/Trigger systems and SCRF
  - photon veto ineff. measurements $\rightarrow$ engineering
  - High rate testbeam for K-tracker, Beam Time Stamp, KRICH and Straws in 2003
  - DAQ/Trigger design, simulation and testing
  - 13–cell SCRF cavity under testing w/ plan// towards production prototype RF station in 2004.
- This will validate technology and enable accurate cost estimates for detector, DAQ and beam.
- Fermilab is providing engineering to improve accuracy of civil construction and conventional beamline costs.

Assuming favorable P5 recommendation: plan for Lehman baseline in 2004.