Charged Kaons at the Main-Injector

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

Peter Cooper, Fermilab *March 26th, 2003*

P5 Review.

I. Experimental Technique.

II. Activities of the Last Year and Now.

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

IV. The Road Ahead…

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

u
c
t
C K M
d s b

- Experimental challenge
  - Br[$K^+ \rightarrow \pi^+ \nu \bar{\nu}$] = $8 \pm 3 \times 10^{-11}$ (Standard Model)
  - 2 clean events seen in BNL787 (Br = $16^{+18}_{-8} \times 10^{-11}$) in decay at rest
  - 6 MHz K decays to see 100 events in 2 years
  - Need to control background to 10^{-11} of all K^+ decays + interactions
- This is beyond the decay at rest technique
  - BNL787+CKM join forces: **E949** [complete at rest] → **CKM** [in flight]
- **CKM**'s goals
  - 100 signal events at Br=1×10^{-10} with <10 background in 2 years of data.
  - Hole cards: ~140 additional events below the $K_{\pi 2}$ peak; background TBD. Form factor if this works!

CKM Collaboration

- Groups from 4 national laboratories and 6 universities.
- 48 people today including 7 postdocs + students
- Roots in BNL787/E949, BNL871, CDF, HyperCP, KTeV, IHEP-Istra, Selex
- 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. B. 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. Shapkin, O. G. Tchikilev, D. Vavilov, O. Yushchenko
Institute of High Energy Physics, Serpukhov, Russia

V. Duk, 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. Nielsen, 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

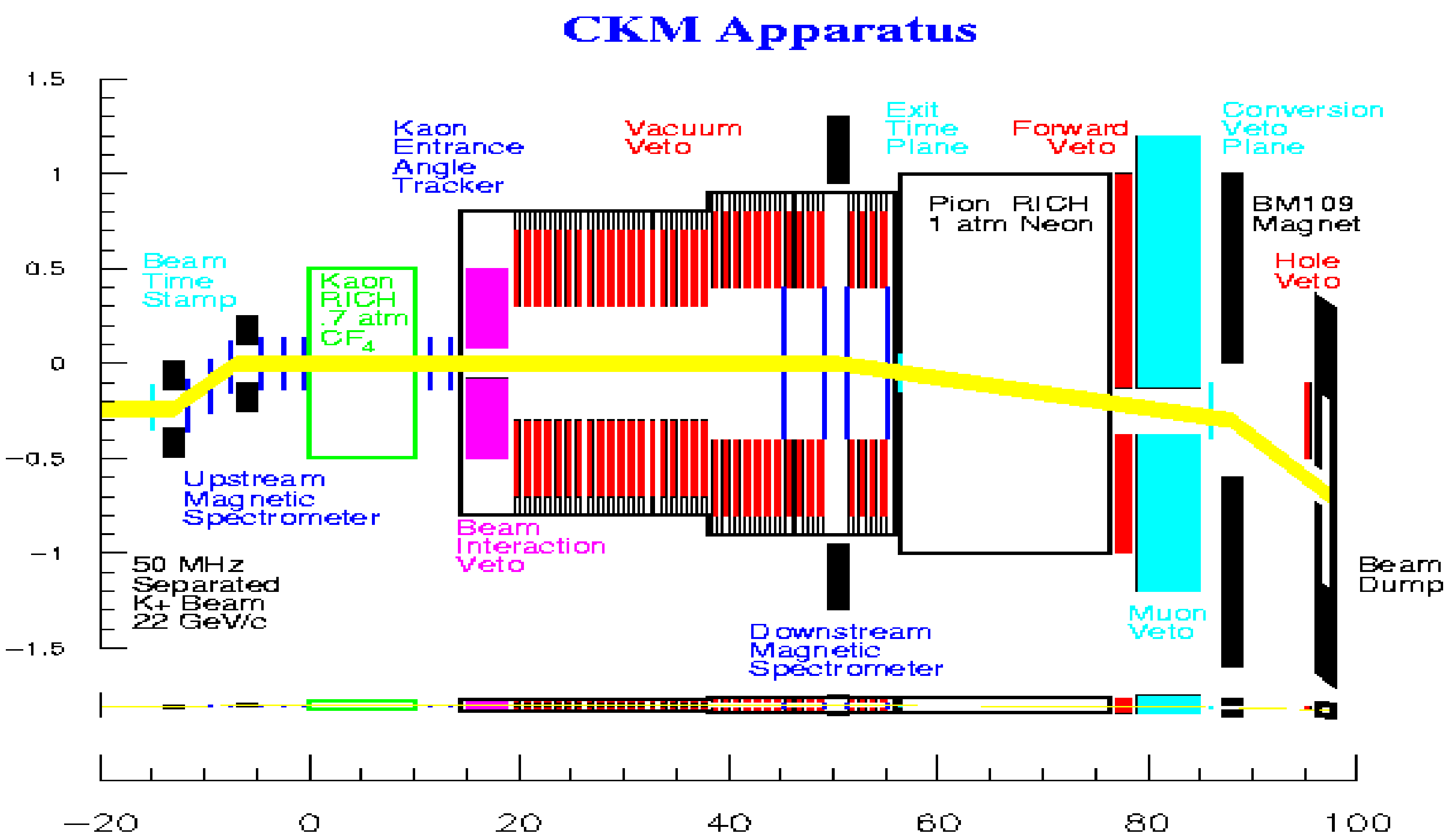
K. Lang
University of Texas at Austin, Austin, Texas 78712

C. Dukes, L. Lu, K. Nelson, C. Niculescu
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

CKM – A high rate decay-in-flight spectrometer to measure Br[$K^+ \rightarrow \pi^+ \nu \bar{\nu}$]

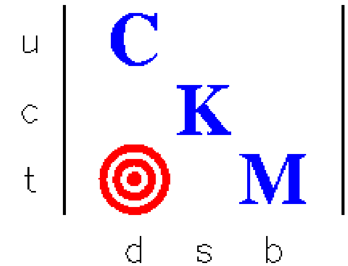
- High Flux (30 MHz) separated K^+ beam at 22 Gev/c.
- Redundant high rate detectors and veto systems.



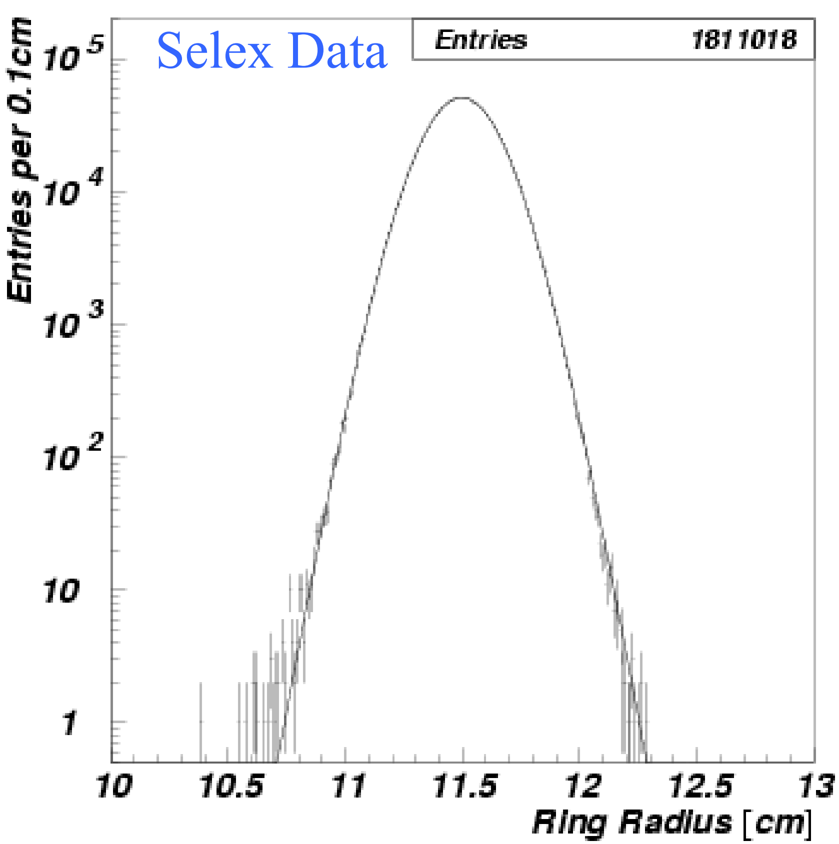
Experimental Technique

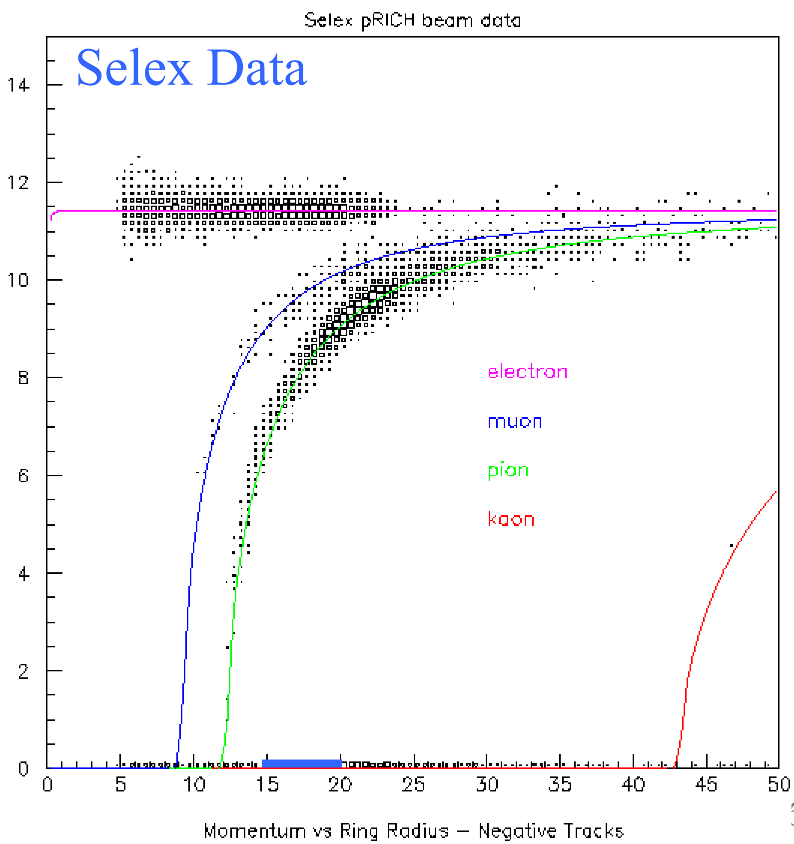
- High Flux Separated K^+ Beam
  - 30 MHz K^+, 6 MHz decay in the acceptance.
  - 5×10^{12} 120 GeV proton /sec in slow spill from the Main Injector to produce the required K^+ beam (~15% of design intensity)
  - Debunched proton beam required (~10% 53MHz ok).
- Apparatus
  - Decay in flight spectrometer with both velocity (RICH) and momentum (magnetic) spectrometer for 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.

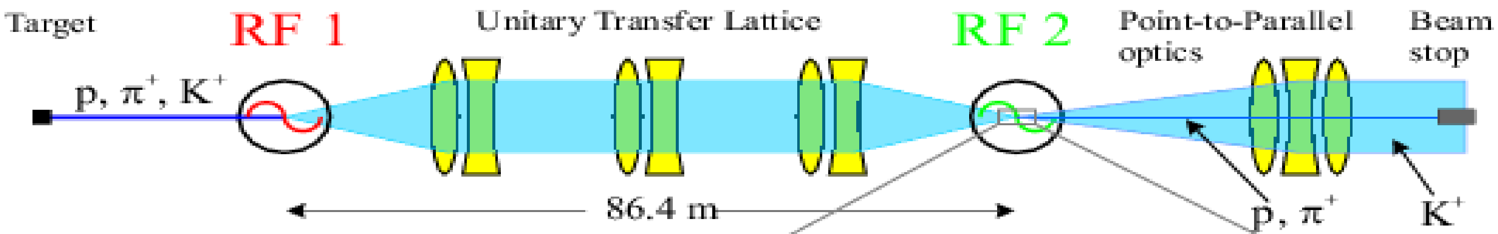




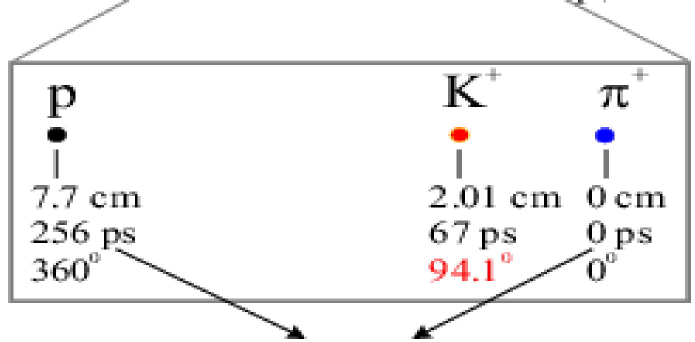
Prototypes in 2002/4

- 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 1GeV photons.
  - Demonstrate that the torrent of data can be dealt with.
- 2003 – prototypes in Fermilab Test beam
  - High rate low mass MWPC K^+ tracker
  - Beam time stamp (scintillating fibers) prototype demonstration
  - Ultra-low mass π^+ tracker – rate, resolution and gas studies
  - PMT RICH prototype to study gases and high rate operation
- 2004
  - First full SCRF module – test in A0 test beam
  - DAQ system prototype

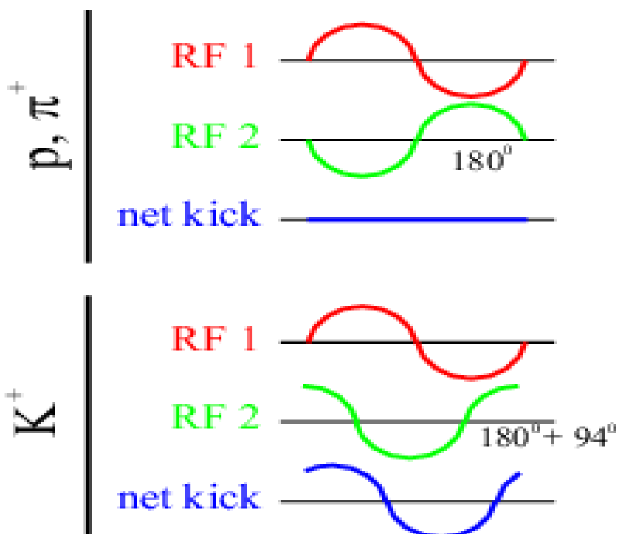
Enriching the Kaon Content of the Beam

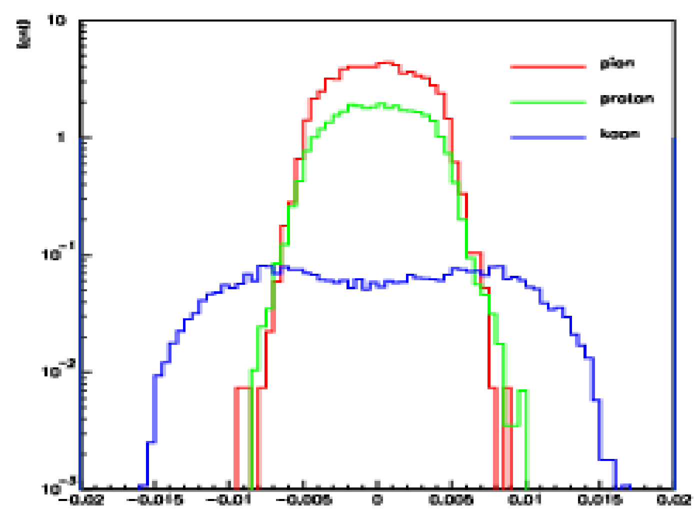


	v/c
π^+:	0.99998
K^+:	0.99975
p:	0.99909



$$1/256 \text{ ps} = 3.91 \text{ Ghz}$$

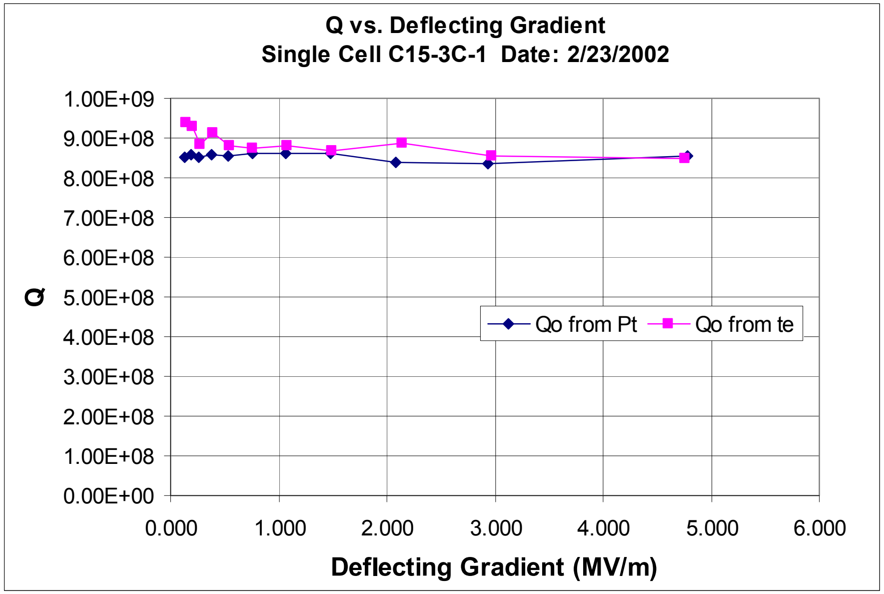


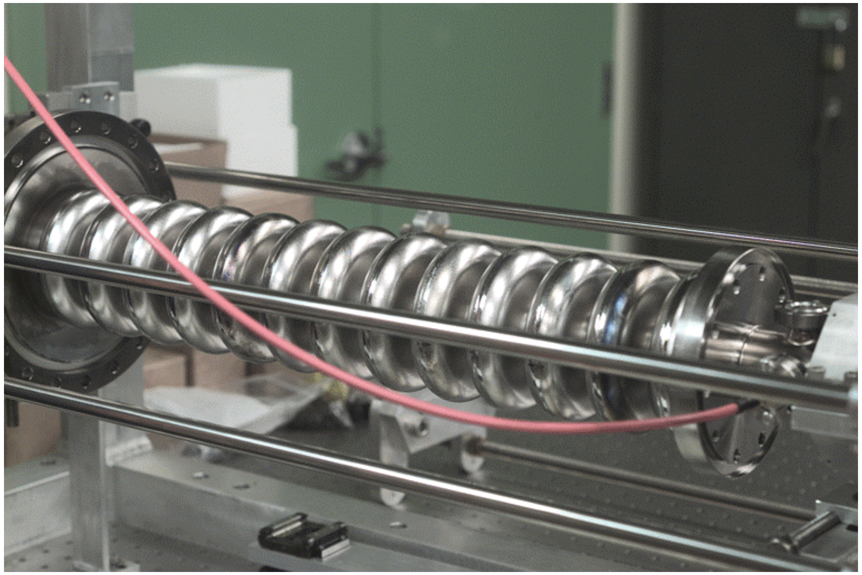


SCRF Separated BEAM

- Require 5 MeV/m deflecting gradient at 3.9 GHz
  Have achieved this in prototype 1 and 3 cell cavities

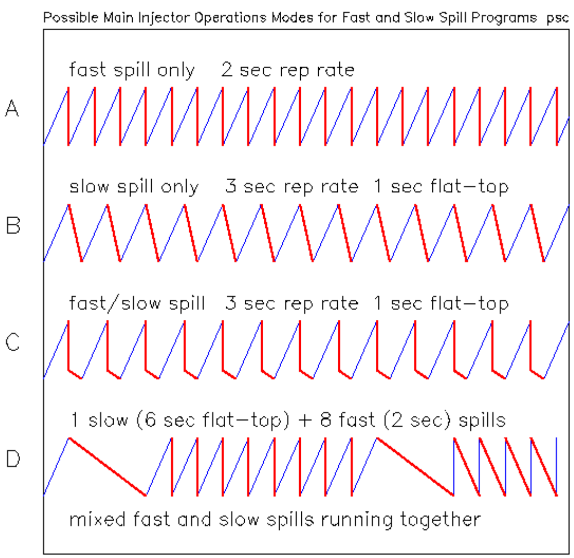
- Design requires 12 Structures of 13-cell cavities
  1st prototype built and under test





Main Injector Operation And Proton Economics

- Need 6×10^{19} debunched 120 GeV slow spill protons (7% MINOS)
- Best plan seems to be mixed fast and slow spill cycles
- Allocation of protons then purely is a program planning decision
- Debunching of slow spill should require <100 msec
- Calculations and studies are required to demonstrate long spill, de-bunching, loses, shielding requirements, …



	Spill Mode	Cycle Time [sec]	Flat top [sec]	Protons /Hour [x1E15] Pbar	Neutrino	SY120	Total
A	Fast Only	1.9	0	15.2	47.4	-	62.5
B	Slow Only	2.9	1	-	-	41.0	41.0
C	Combined	2.9	1	9.9	24.8	6.2	41.0
D	Mixed Fast	1.9 / 7.9	0 / 6				
	Fast cycles / Slow cycle						
	5	17.4	6	8.3	25.9	6.2	40.3
	6	19.3	6	9.0	28.0	5.6	42.5
	7	21.2	6	9.5	29.7	5.1	44.3
	8	**23.1**	**6**	**10.0**	**31.2**	**4.7**	**45.8**
	9	25	6	10.4	32.4	4.3	47.1
	10	26.9	6	10.7	33.5	4.0	48.2
	11	28.8	6	11.0	34.4	3.8	49.1
	12	30.7	6	11.3	35.2	3.5	50.0

Straws in Vacuum:
Old Wine, New Bottle.

- Mechanical properties extensively studied.

  (Fermi-Pub 02-241-E)
- Prototype operating in vacuum.
- Proven Principle.

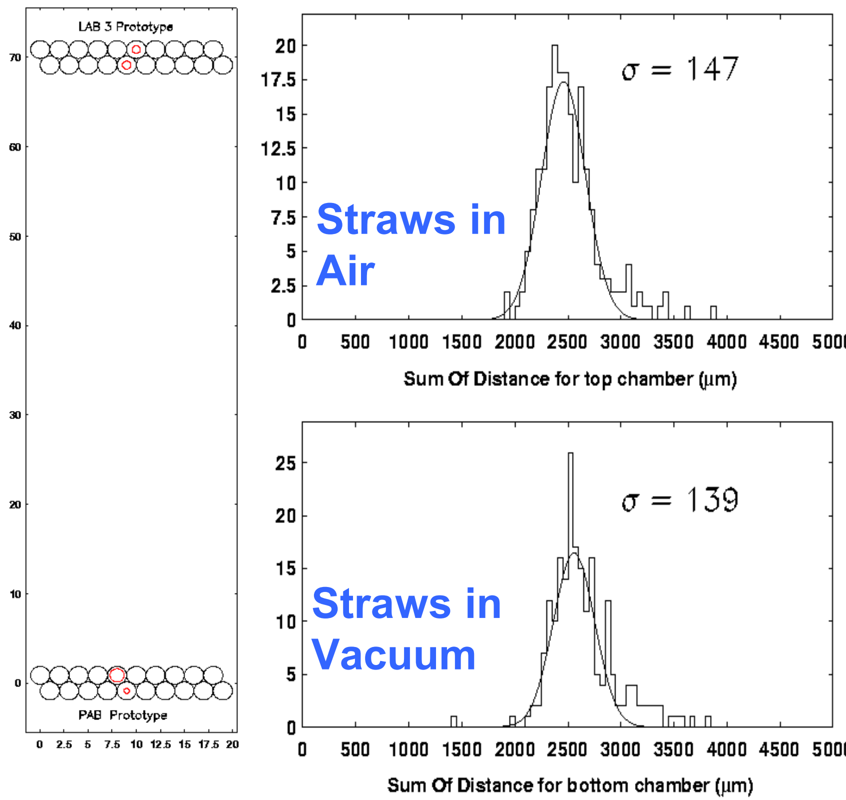
  (BNL 871)

  Now ready for detailed engineering.

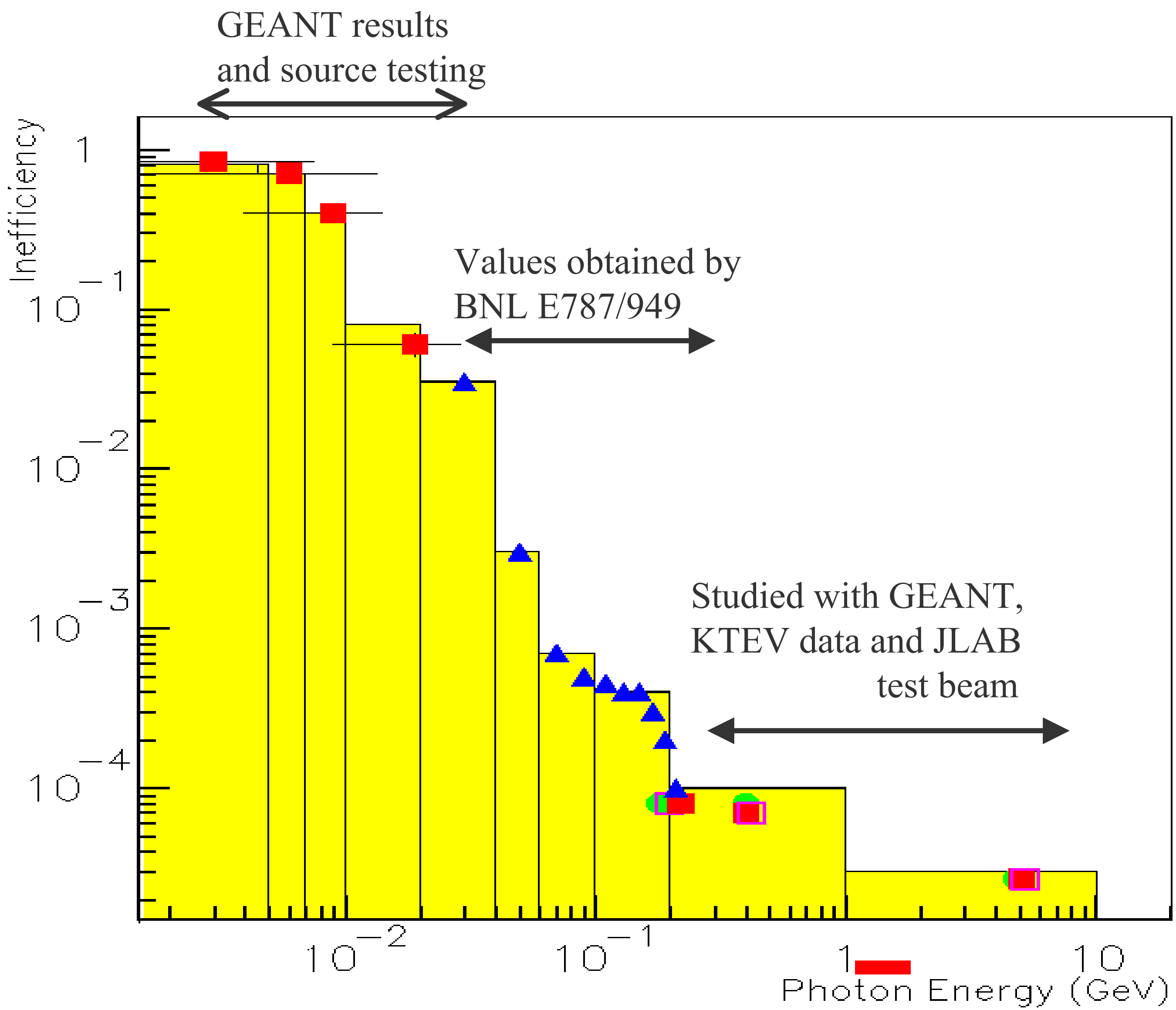
Strawtubes in a Vacuum

- Prototype built after BNL871design
  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)

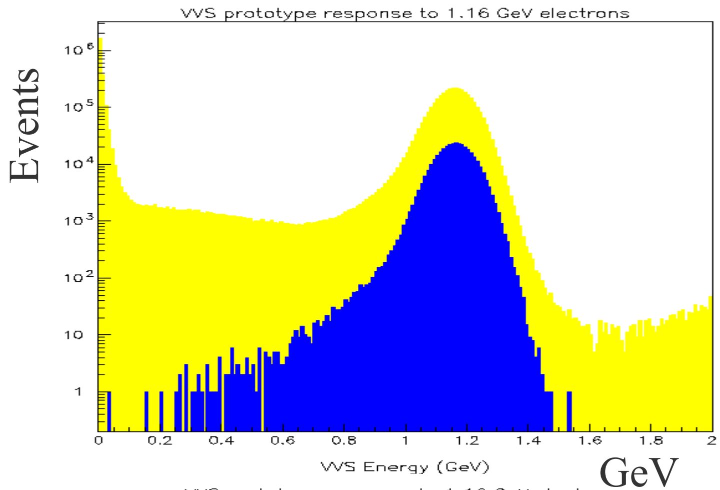


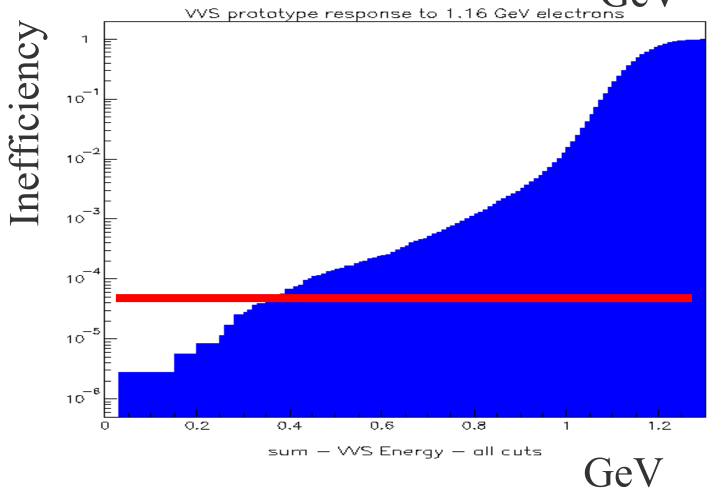
Photon Veto Inefficiency *Measured*

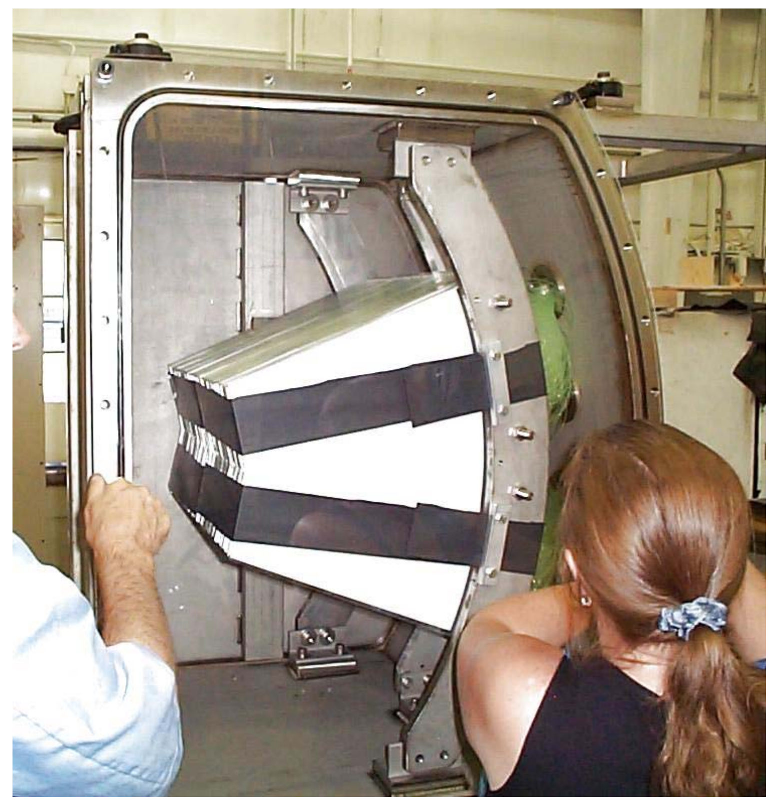


Photon Veto Inefficiency and Technology

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

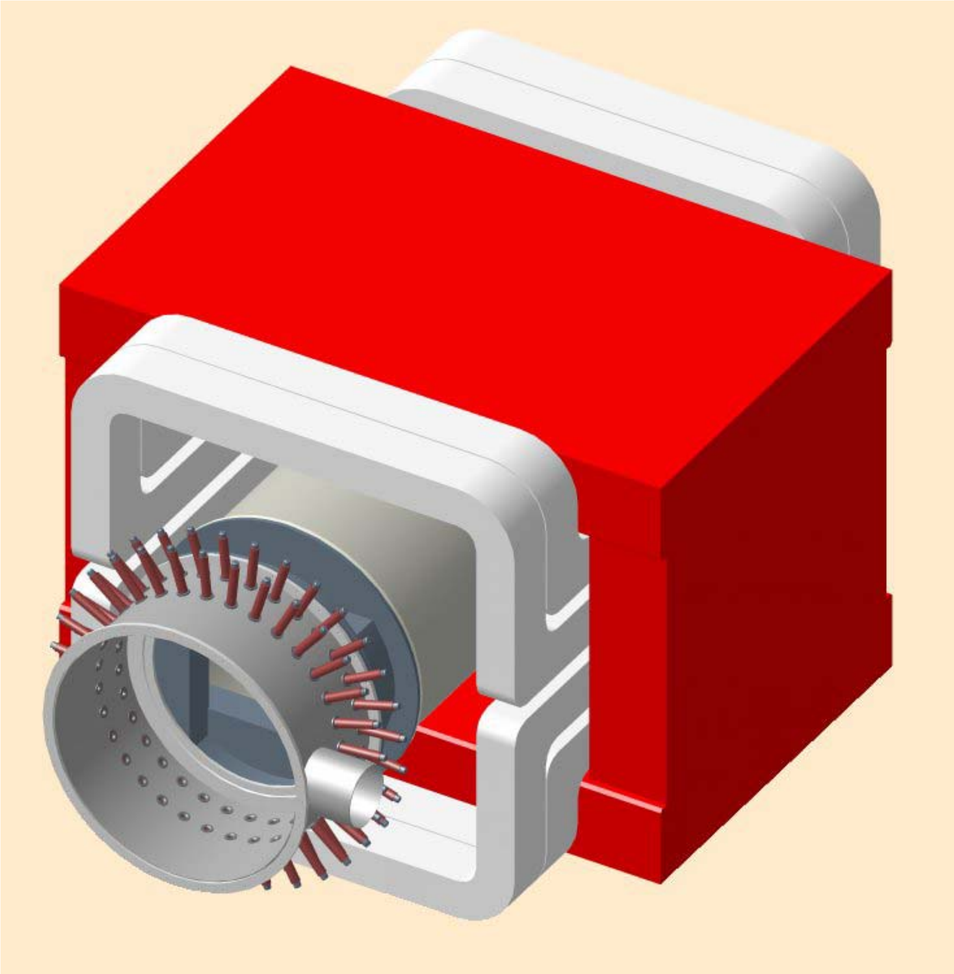






Engineering & System Design

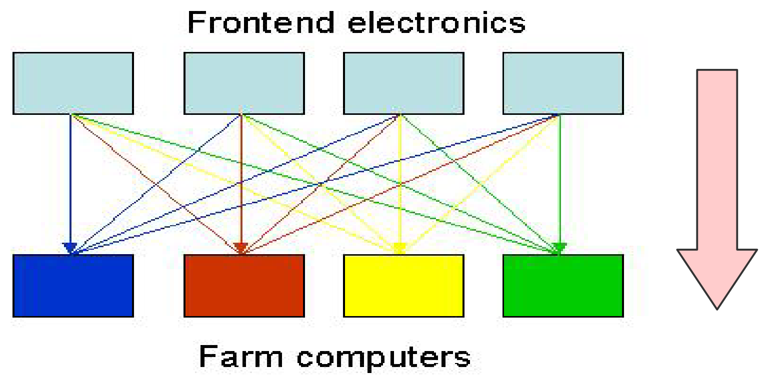
- Full mechanical design for vacuum veto system done
- Injection molded scintillator demonstrated. Production mold ordered.
- Planning whole ring (3%) production prototype.
- System engineering of whole detector underway.



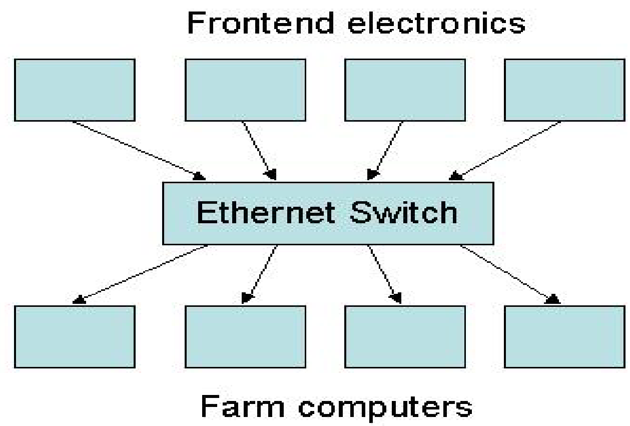
Trigger & DAQ:
Can we go "Triggerless"?
Yes! How Do We Build This?

- Our research community no longer drives the relevant standards.
  (cf. **Best Buy, Circuit City**)
- Commodity processsors and switches are leading (Performance/Cost) .
- Conceptual Design exists
  - Data simulated (full GEANT - all hits)
  - Switching and L1 trigger demonstrated.
- Endorsed by Temple review.

Logical Design: 50 GByte/sec

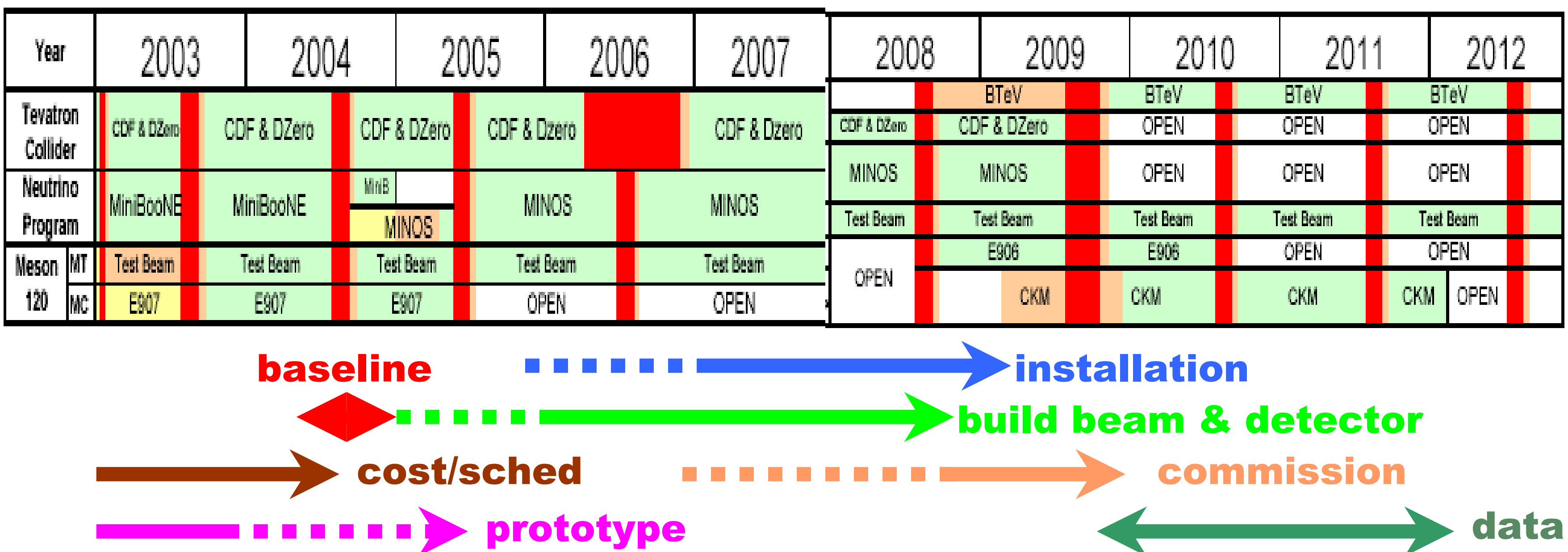


Physical Setup:



Scope & Timeline

- CKM LOI in 1996
  - 1st proposal 1998 – approved as R&D proposal (E905)
  - 2nd proposal considered and approved 2001 (Stage-I) (E921)
  - 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 build the beam & detector



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 a baseline cost estimate. Active work on:
  - Detector Systems.
  - Civil construction and conventional beamline.
  - Cost / schedule.
- Goal to *the Goal*: Lehman Baseline in 2004.
- *The Goal*: CP Violation as a new and clear window to the high mass world.

- We hope you concur. We believe you should .

When it all works

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