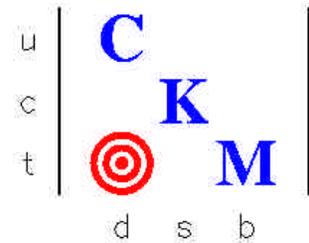


# Charged Kaons at the Main-Injector

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

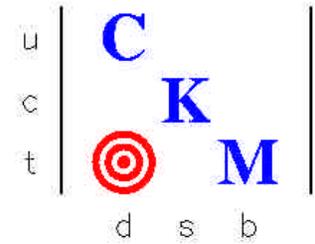
*Peter Cooper, Fermilab March 26th, 2003*

*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 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$



## Experimental challenge

- $\text{Br}[K^+ \rightarrow \pi^+ \nu \bar{\nu}] = 8 \pm 3 \times 10^{-11}$  (Standard Model)
- 2 clean events seen in BNL787 ( $\text{Br} = 16^{+18}_{-8} \times 10^{-11}$ ) 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

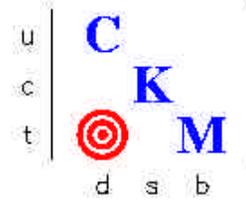
## This is beyond the decay at rest technique

- BNL787+CKM join forces: **E949** [complete at rest] ® **CKM** [in flight]

## CKM's goals

- 100 signal events at  $\text{Br} = 1 \times 10^{-10}$  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  
 $K^+ \rightarrow \pi^+ D D$  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. Kobilaric, H. Nguyen, E. Ramberg,  
R. S. Tschirhart, H. D. White, J. Y. Wu  
Fermi National Accelerator Laboratory, Batavia, IL, USA

C. Bricchi, V. Durovov, A. V. Inyakin, V. Kuschetsov, A. Kushnirenko,  
L. C. Landsberg, V. Malchanov, V. Obratsov, 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. Dolotov, S. Laptov, A. Polunin, A. Pastusik, R. Sirodeev  
Institute of Nuclear Research, Troitsk, Russia

J. Engelfried, A. Morales  
Instituto de Física, Universidad Autónoma de San Luis Potosí, 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

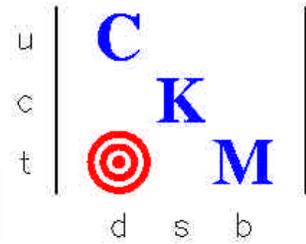
C.M. Jenkins  
University of South Alabama, Mobile, Alabama 36688

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

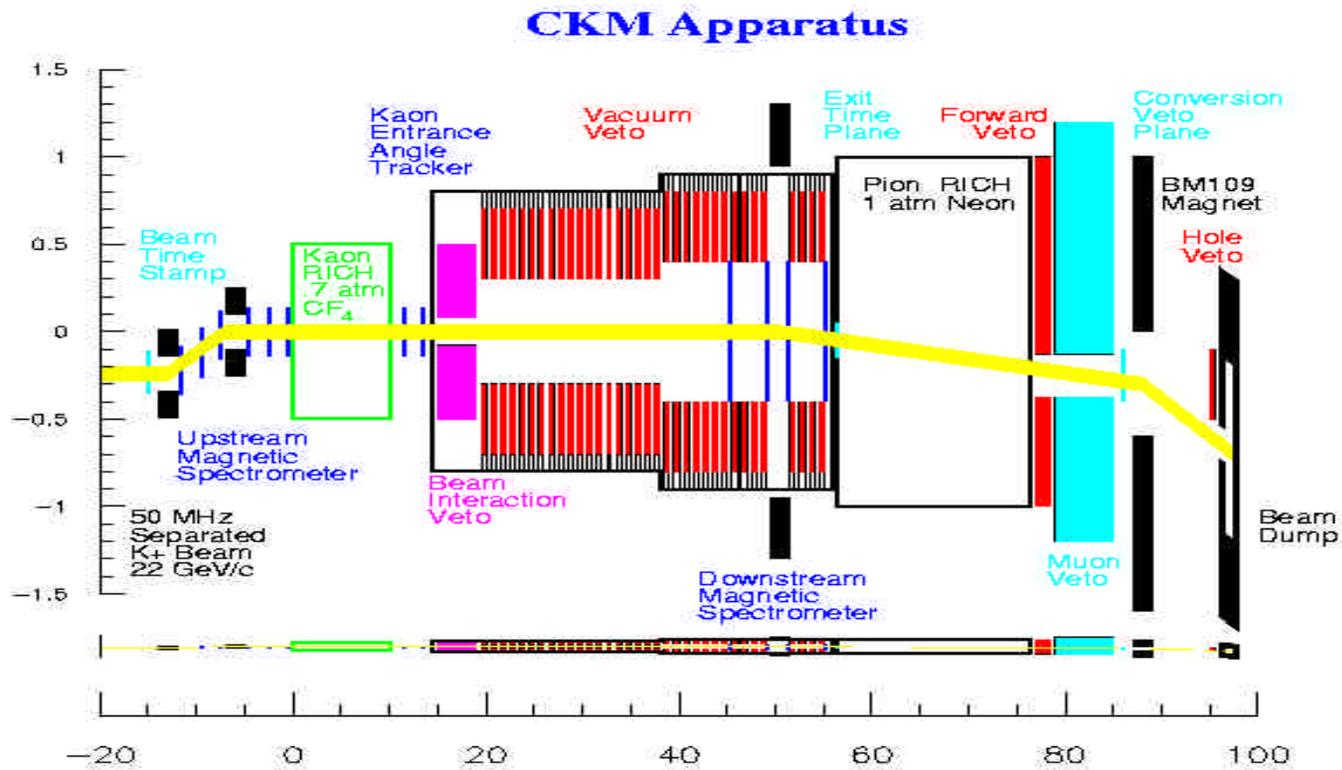
C. Dulac, L. Lu, K. Nelson, C. Niculescu  
University of Virginia, Charlottesville, Virginia 22901

\* Spokesman: P.S. Cooper, [pscooper@fnal.gov](mailto:pscooper@fnal.gov), (630) 840-2629  
Web Address: [www.fnal.gov/projects/ckm/Welcome.html](http://www.fnal.gov/projects/ckm/Welcome.html)

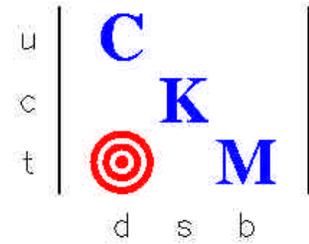
# CKM – A high rate decay-in-flight spectrometer to measure $\text{Br}[K^+ \rightarrow \pi^+ \nu \bar{\nu}]$



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



# Experimental Technique



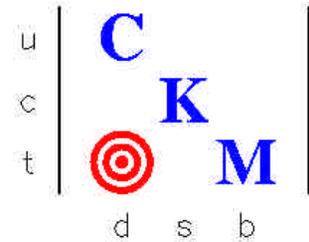
## ○ High Flux Separated $K^+$ Beam

- 30 MHz  $K^+$ , 6 MHz decay in the acceptance.
- $5 \times 10^{12}$  120 GeV proton /sec in slow spill from the Main Injector to produce the required  $K^+$  beam ( $\sim 15\%$  of design intensity)
- Debunched proton beam required ( $\sim 10\%$  53MHz ok).

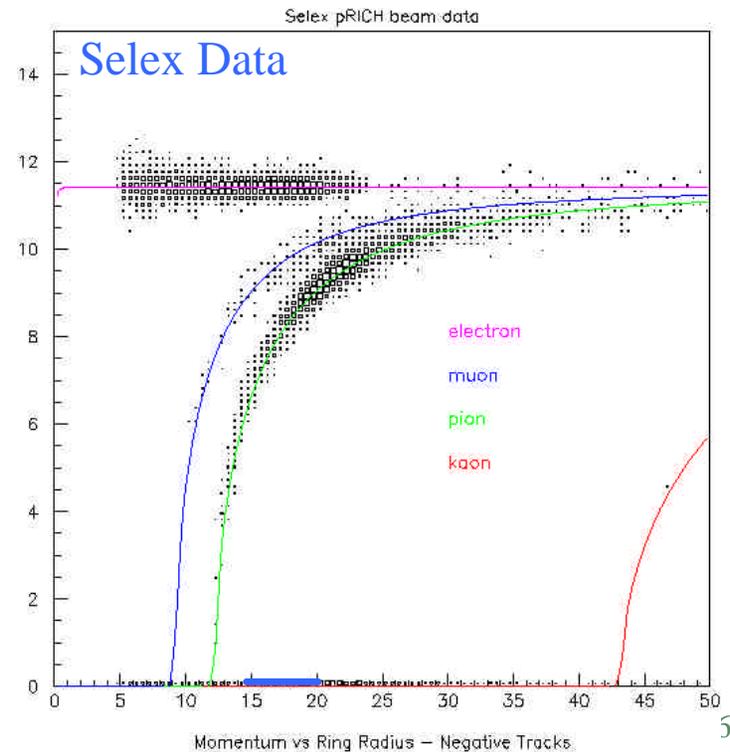
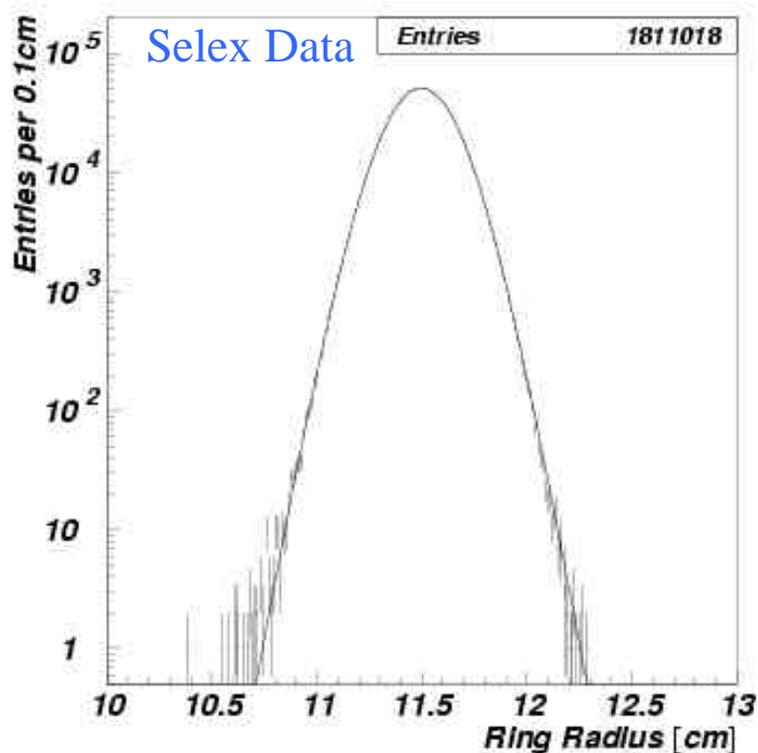
## ○ Apparatus

- Decay in flight spectrometer with both velocity (RICH) and momentum (magnetic) spectrometer for both  $K^+$  and  $\pi^+$ .
- Significant requirements on photon vetos
- All detector technologies used are well established
- **Redundancy** is critical to **measure** all backgrounds

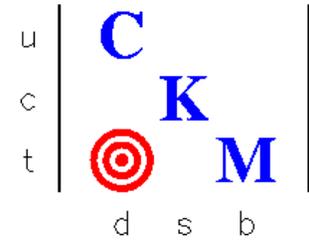
# Ring Imaging Cherenkov Counters



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

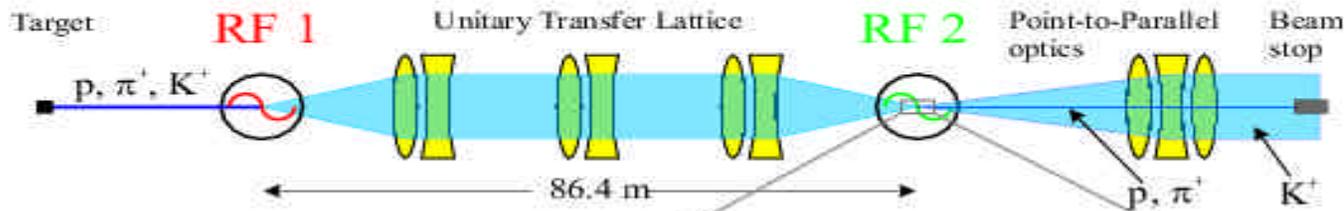


# Prototypes in 2002/4



- 2002
  - Super-conducting RF required for high duty factor separated  $K^+$  beam.
  - Demonstrate ultra-low mass  $\pi^+$  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  $\pi^+$  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

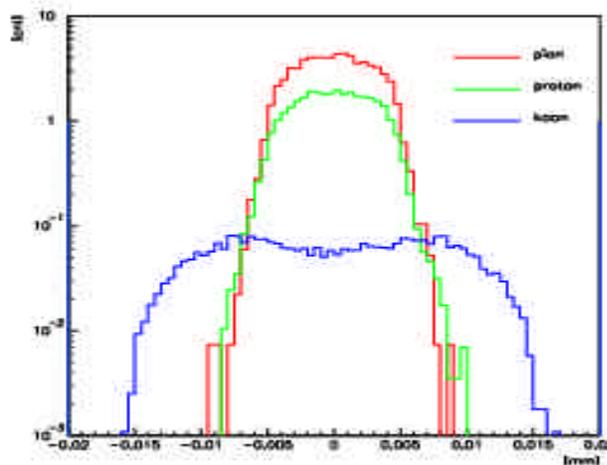
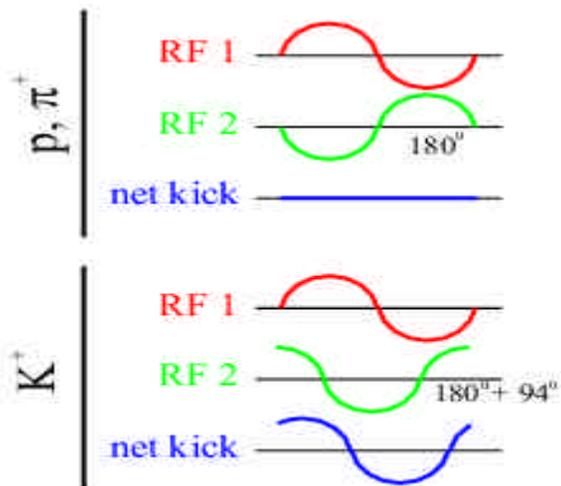
# Enriching the Kaon Content of the Beam



	$v/c$
$\pi^+$	0.99998
$K^+$	0.99975
$p$	0.99909

$p$	$K^+$	$\pi^+$
7.7 cm	2.01 cm	0 cm
256 ps	67 ps	0 ps
$360^\circ$	$94.1^\circ$	$0^\circ$

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

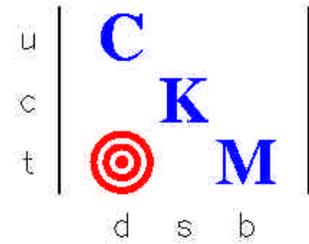


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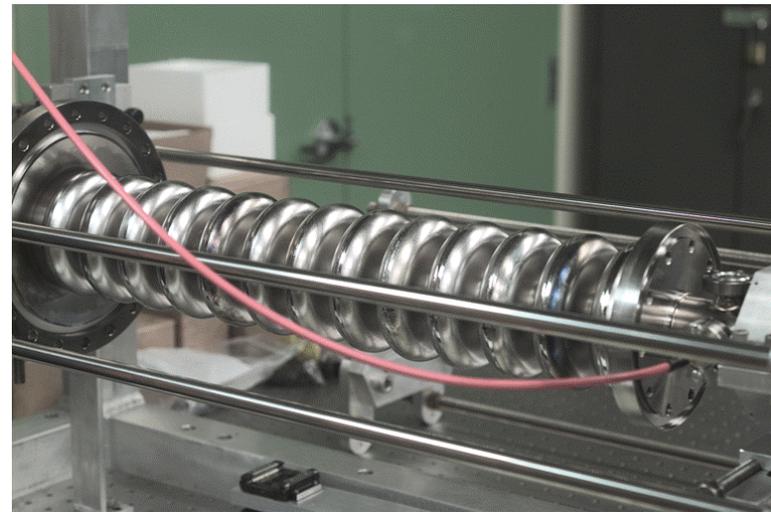
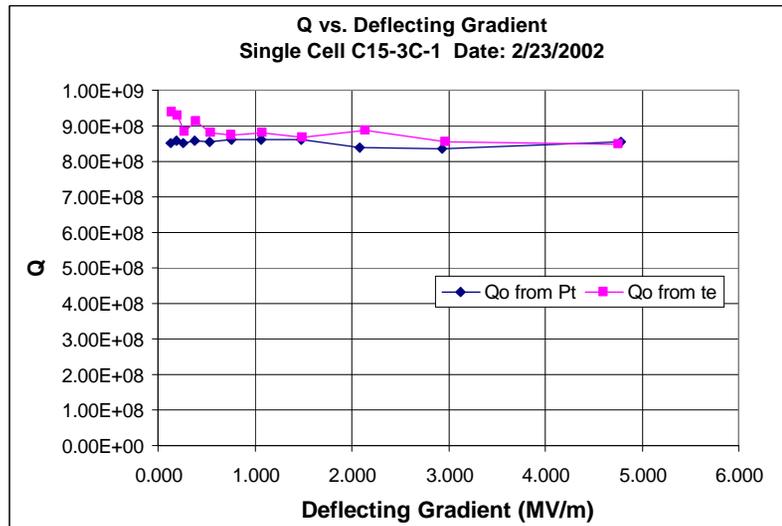
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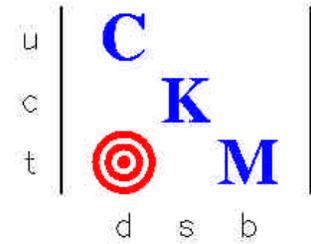
# SCRF Separated BEAM



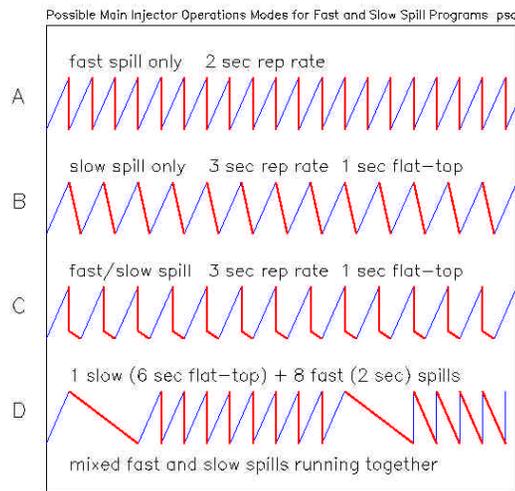
- Require 5 MeV/m deflecting gradient at 3.9 GHz  
Have achieved this in prototype 1 and 3 cell cavities
- Design requires 12 Structures of 13-cell cavities  
1<sup>st</sup> prototype built and under test



# Main Injector Operation And Proton Economics

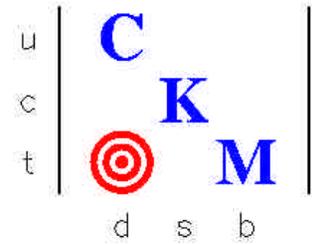


- Need  $6 \times 10^{19}$  debunched 120 GeV slow spill protons (7% MINOS)
- Best plan seems to be mixed fast and slow spill cycles
- Allocation of protons then purely is a program planning decision
- Debunching of slow spill should require  $< 100$  msec
- Calculations and studies are required to demonstrate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



	Spill Mode	Cycle Time [sec]	Flat top [sec]	Protons /Hour [ x1E15 ]			Total
				Pbar	Neutrino	SY120	
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
	<b>8</b>	<b>23.1</b>	<b>6</b>	<b>10.0</b>	<b>31.2</b>	<b>4.7</b>	<b>45.8</b>
	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

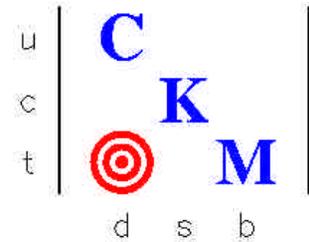
# Straws in Vacuum: Old Wine, New Bottle.



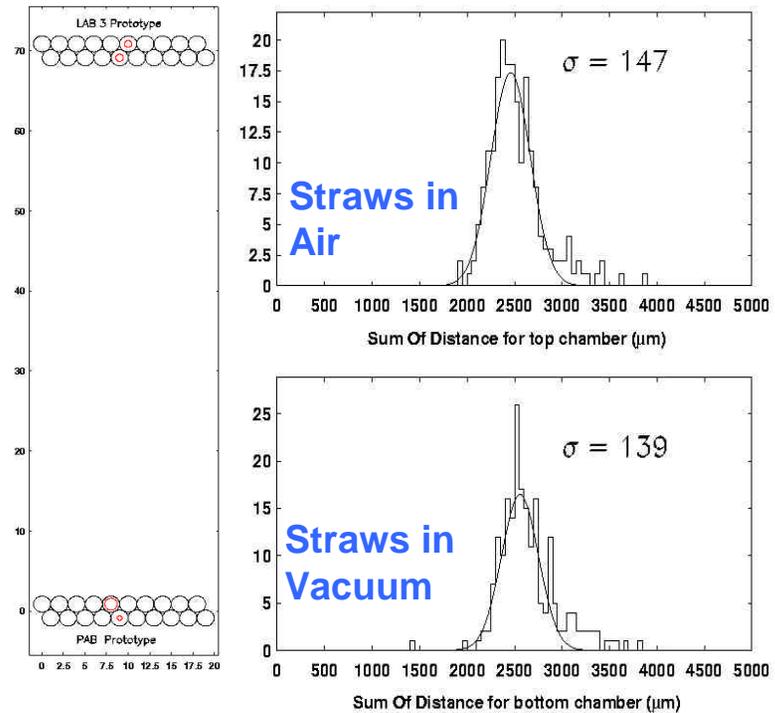
- Mechanical properties extensively studied.  
(Fermi-Pub 02-241-E)
- Prototype operating in vacuum.
- Proven Principle.  
(BNL 871)  
Now ready for detailed engineering.



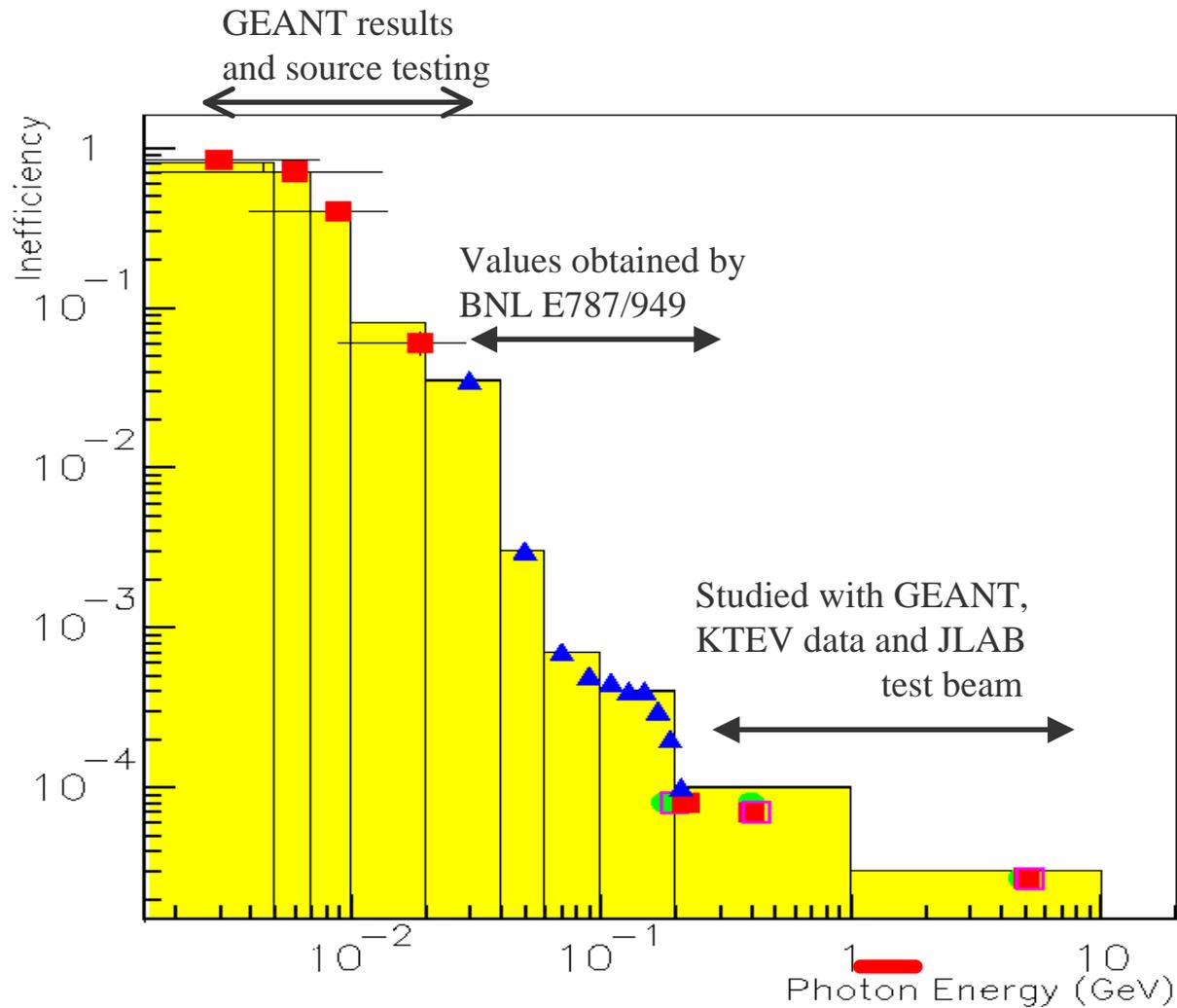
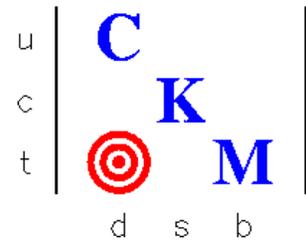
# Strawtubes in a Vacuum



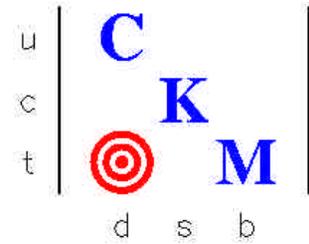
- Prototype built after BNL871 design  
All chamber specs achieved  
100  $\mu\text{m}$  resolution  
98% efficiency
- Tested in vacuum with cosmics  
Successful operation  
Negligible leak rate  
Wrong gas (ArCO<sub>2</sub> for safety)



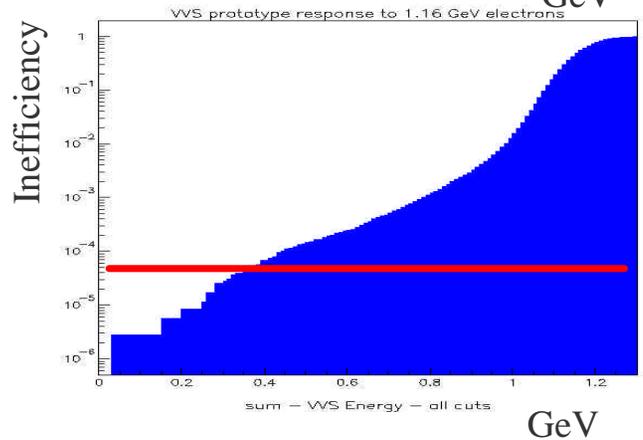
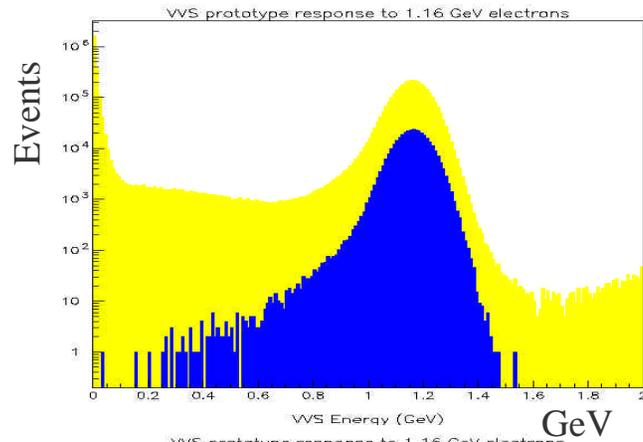
# Photon Veto Inefficiency *Measured*



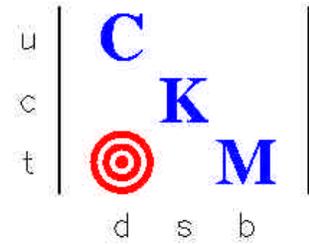
# Photon Veto Inefficiency and Technology



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



# Engineering & System Design



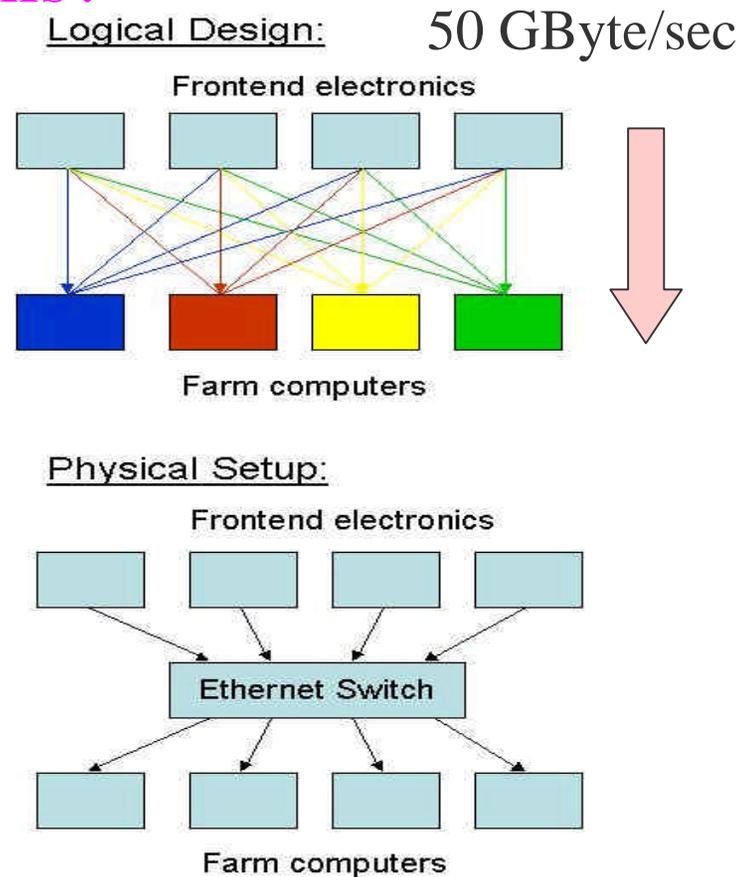
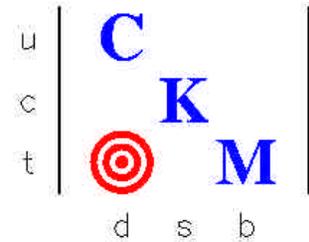
- Full mechanical design for vacuum veto system done
- Injection molded scintillator demonstrated. Production mold ordered.
- Planning whole ring (3%) production prototype.
- System engineering of whole detector underway.



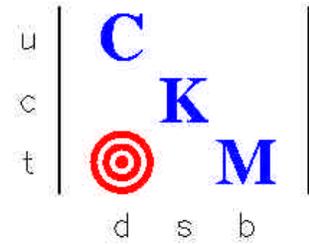
# Trigger & DAQ: Can we go “Triggerless”?

Yes! How Do We Build This?

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

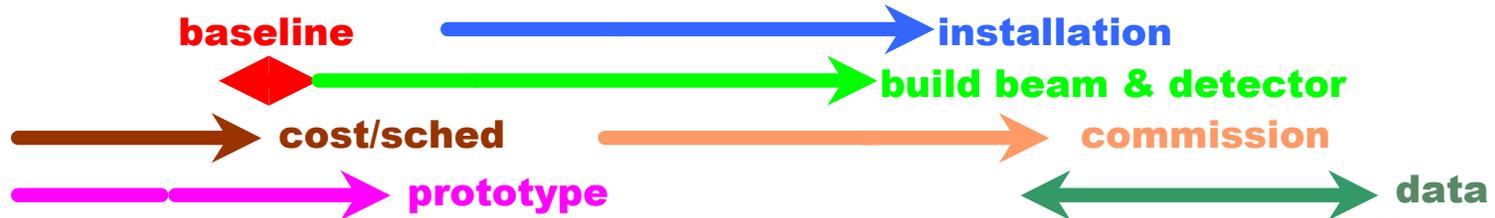


# Scope & Timeline

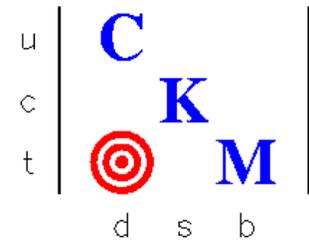


- CKM LOI in 1996
  - 1st proposal 1998 – approved as R&D proposal (E905)
  - 2nd proposal considered and approved 2001 (Stage-I) (E921)
  - Prototypes and testbeam work completed in FY03
  - Temple Review, February 2003.
  - SCRF production prototype in FY04
- Scope of project is very similar to KTeV
- We require a ~3 year funding profile to build the beam & detector

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Tevatron Collider	CDF & DZero	CDF & DZero	CDF & DZero	CDF & DZero			BTeV	BTeV	BTeV	BTeV
Neutrino Program	MiniBooNE	MiniBooNE	MiniB MINOS	MINOS	MINOS	CDF & DZero	CDF & DZero	OPEN	OPEN	OPEN
Meson 120	MT E907	Test Beam E907	Test Beam E907	Test Beam E907	Test Beam OPEN	Test Beam OPEN	Test Beam E906	Test Beam E906	Test Beam OPEN	Test Beam OPEN
							CKM	CKM	CKM	CKM OPEN

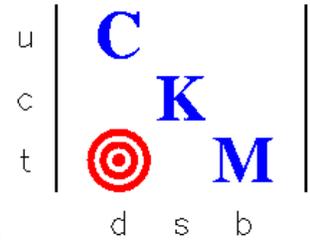


# Temple Review Outcome



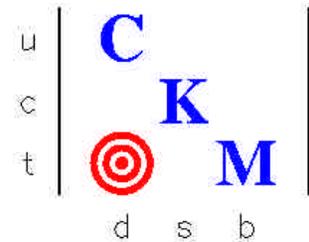
- Technical Concerns: “Much Reduced”.
- Modest cost increase (25%) advised for Detector and SCRF systems.
- Lack of engineering resources for civil construction and conventional beamline prevents the associated costs from being accurately known now.  
**Recommendation:** Work toward a review of these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

