Status Report of the CKM Experiment

Ken Nelson - University of Virginia

on behalf of the CKM Collaboration

Fermilab User's Meeting
June 3, 2003

The CKM Collaboration

- Groups from 4 national labs and 6 universities.
- 48 people now; 7 postdocs + students.
  – Anticipate growth by $\sim 2\times$ after final approval.
- Roots in BNL787/949, CDF, IHEP-Istra, KTeV, HyperCP, SELEX
- Substantial experience in rare K decays.

Charged Kaons at the Main Injector

March 29, 2003

A Proposal for a Precision Measurement of the Decay $K^+ \to \pi^+\nu\overline{\nu}$ and Other Rare K^+ Processes at Fermilab Using the Main Injector

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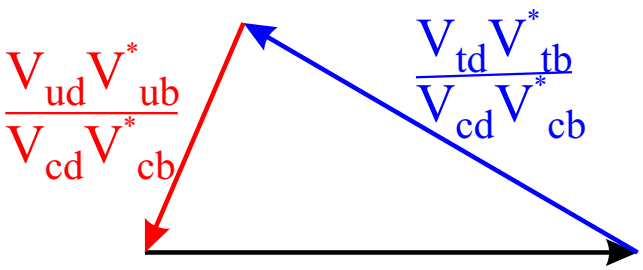
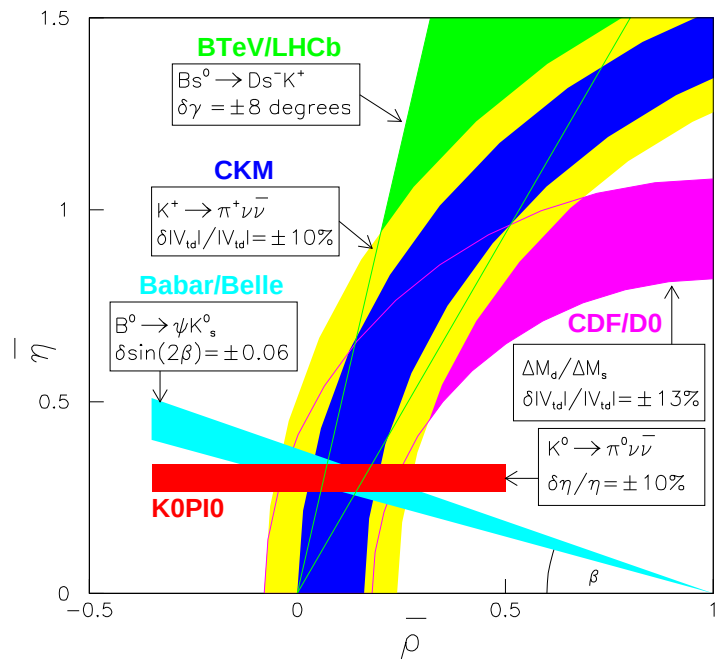
Testing the SM: Are all CP violating phenomena described by the CKM matrix parameters ρ and η ?

B Unitarity Triangle



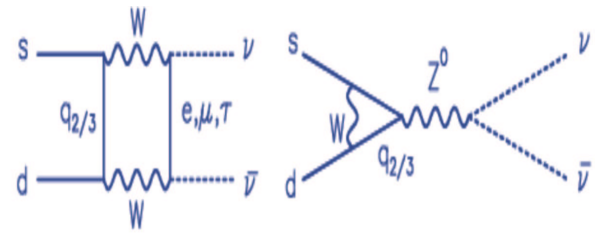


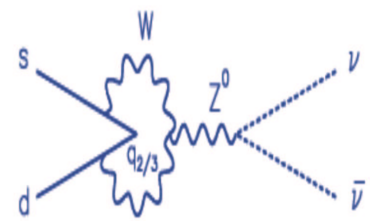
- Precision B and K experiments provide independant measurements of ρ and η.

- Beyond–SM physics (*e.g.* SUSY) can affect B and K systems differently; particularly in FCNC interactions.

Measuring $|V_{\text{td}}|$ through $B(K^+ \to \pi^+ \nu\overline{\nu})$

- Decay is determined by loop processes in the Standard Model.
- Can be calculated in SM with confidence (8–5%).
- Hadronic uncertainties removed by normalizing to $K^+ \to \pi^\circ e^+ \nu$





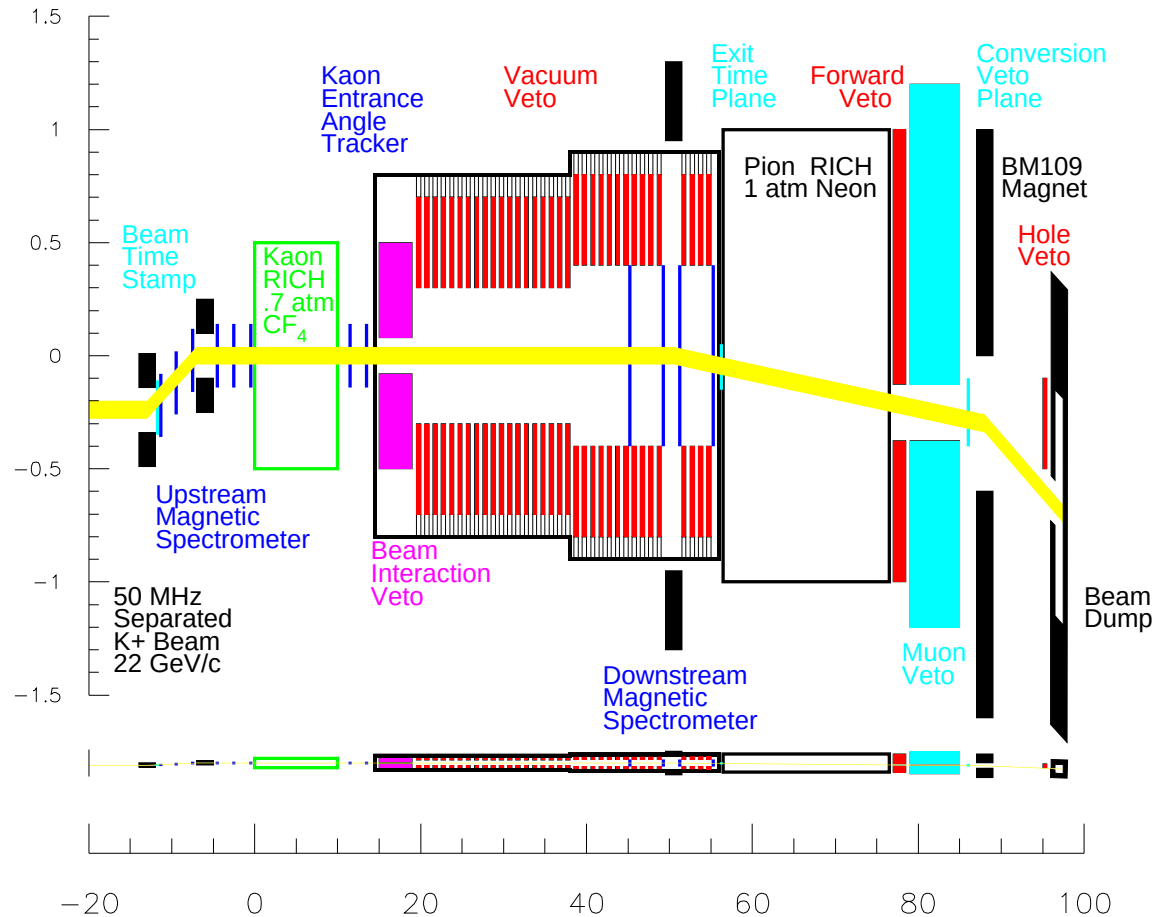
$\Rightarrow$ Sensitivity for new physics at the EW scale and beyond.

- The Experimental Challenge
  - SM: $B(K^+ \to \pi^+ \nu\bar{\nu}) = (8 \pm 3) \times 10^{-11}$
  - Need 100 sig with < 10 bkgnd to match theory error.
  - With $\sim$1% acceptance require 10^7 decays/s to see 100 in a year.
  - Need to control background to 10^{-11} of all K^+ decays.
- The discovery program at BNL787
  - Two clean events seen $\Rightarrow B(K^+ \to \pi^+ \nu\bar{\nu}) = 16^{+18}_{-8} \times 10^{-11}$
  - demonstrated control over backgrounds to 2×10^{-11}.
  - fundamentally rate limited by $\pi \to \mu \to e$ and AGS protons.
- Evolution to a precision measurement
  - CKM employs isochronous detector elements $\Rightarrow$ high rates.
  - Only $\sim$15% of the MI capacity/pulse needed.

CKM Goal: 100 signal events ($<$ 10 background) in two years of data

The CKM Apparatus

- 50 MHz 22 GeV/c enriched K^+ beam $\sim$ 6 MHz decay in acceptance.
- Redundant measurement of K^+ and π^+ momenta.
- Redundant veto instrumentation.
- High rate detectors and minimal material.

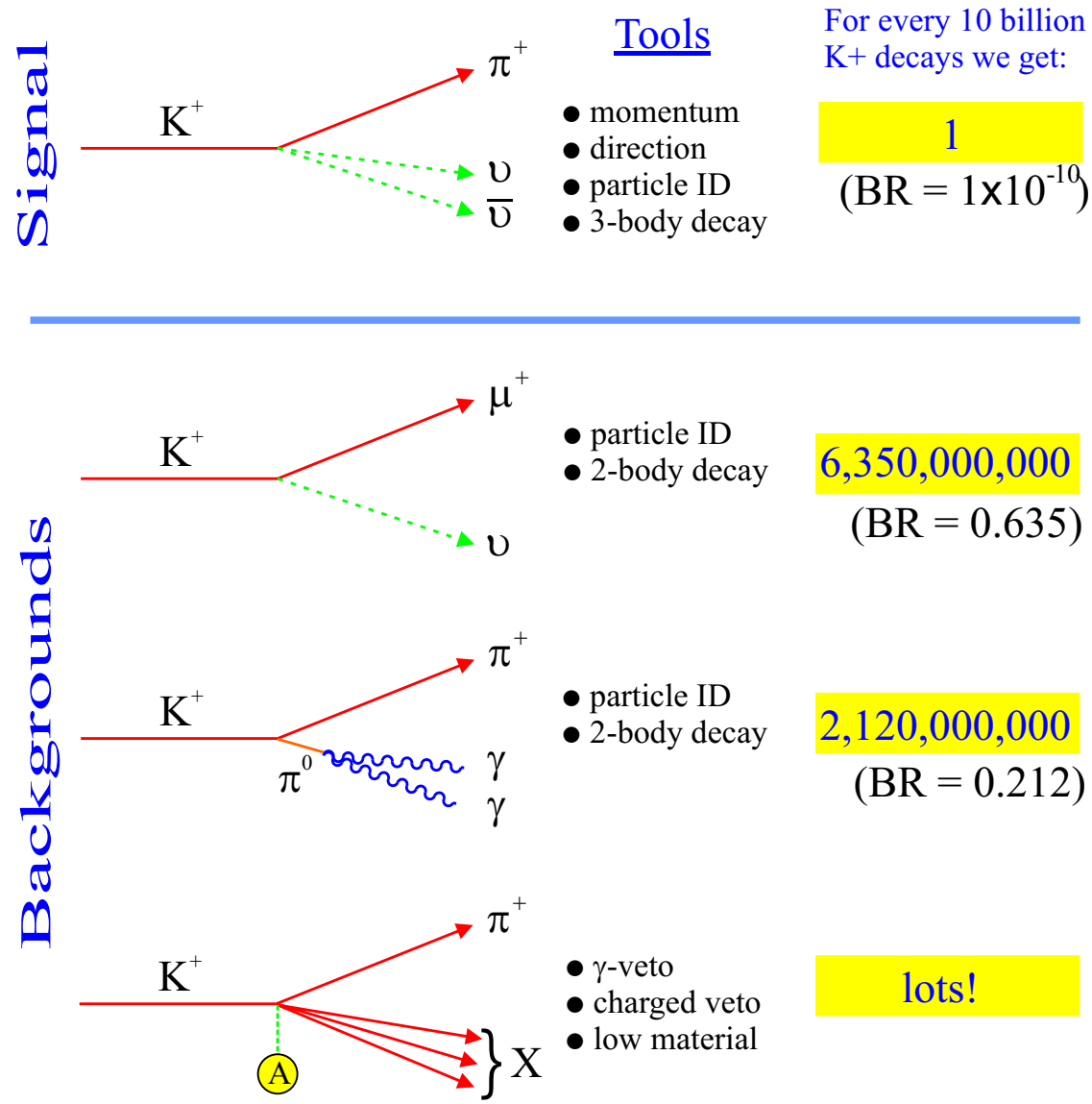


Redundancy critial to measure all backgrounds

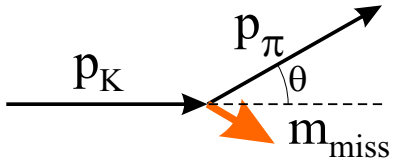
Backgrounds....

What we want

What we'll get

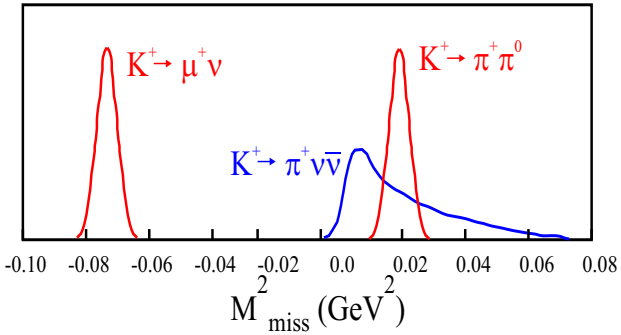


Eliminating Backgrounds



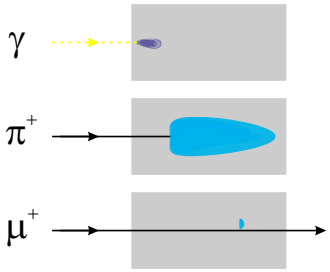
- Major backgrounds, $K_{\pi 2}$, $K_{\mu 2}$, have well defined missing masses.

- Redundant measurements with Magnetic (tracking) and Velocity (RICH) Spectrometers.



- Measuring how particles interact in dense matter

- Veto systems instrumented redundantly



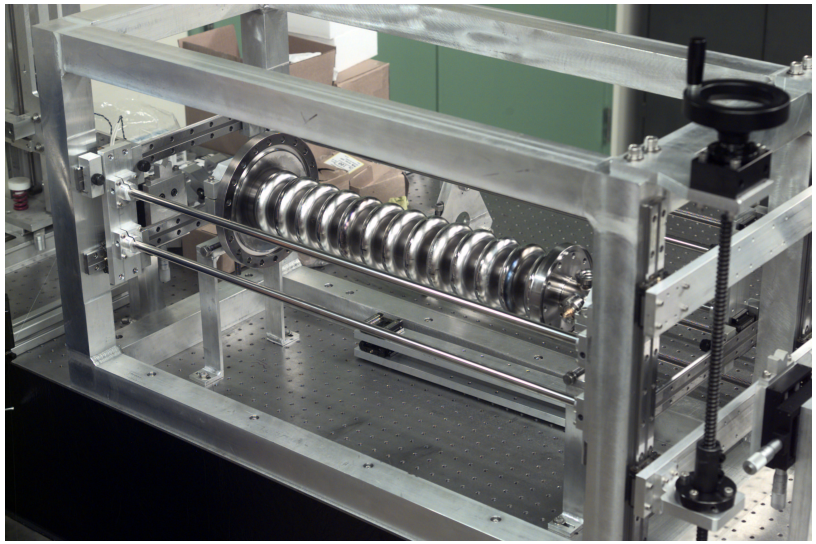
SCRF – Superconducting RF Separated Beam

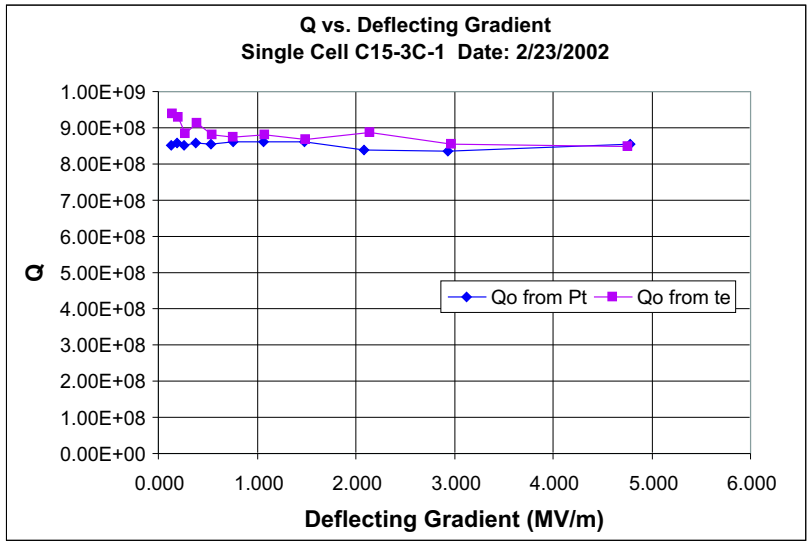
- Require 5 MeV/m transverse deflecting gradient.
  – Have achieved in prototype 1 and 3 cell cavities.

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

- R&D on-going at FNAL (with help from Cornell, JLab, TRIUMF, DESY).

- Production prototype of 2 $\times$ 13 cells is planned for 2004.

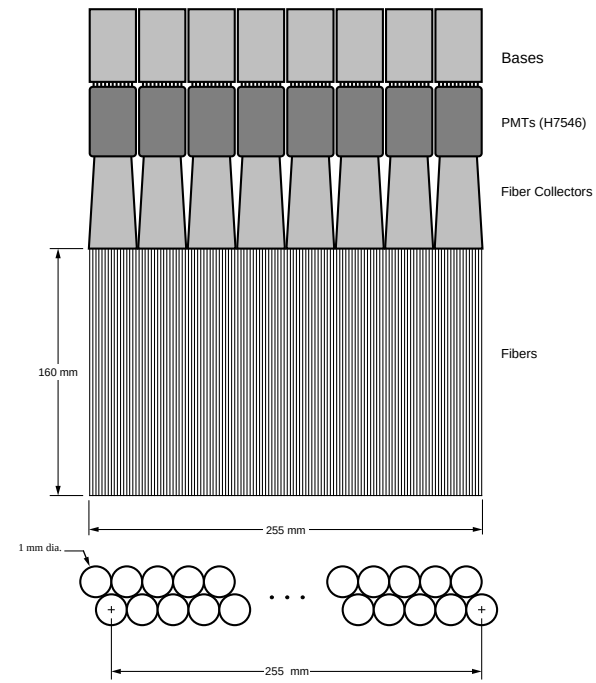




Upstream Magnetic Spectrometer: UMS

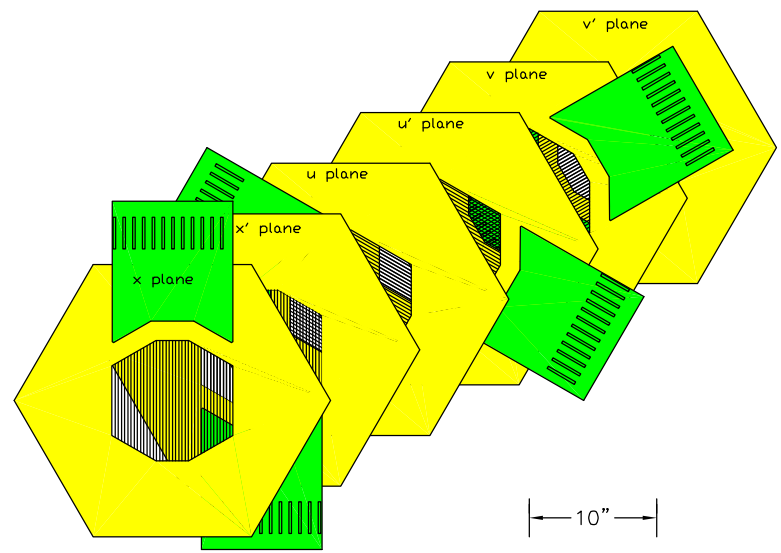
Beam Time Stamp:

- Tag K^+ with ~ 1 ns resolution
  e.g. resolve ambiguities in trackers
- Two-layer scintillating fiber (1 mm dia.) array readout by multianode PMT.
- beam flux $\sim 1\,\mathrm{MHz/cm^2}$
- similar detectors downstream: ETP, CVP.



UMS trackers:

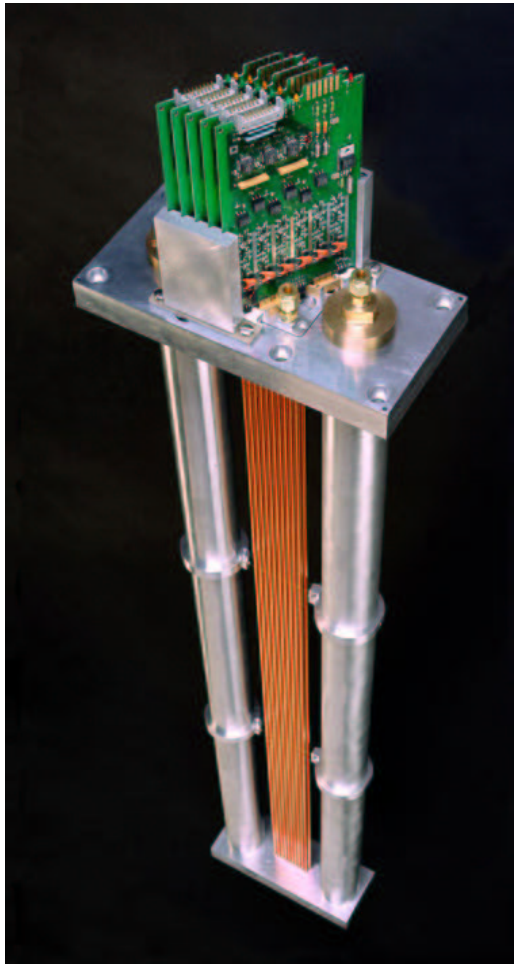
- 6 PWCs (36 planes)
- High rate capability: 0.8 mm pitch.
- Minimal material: $0.7 \times 10^{-2}\lambda_I$, $1.6 \times 10^{-2} X_\circ$
- Based on HyperCP wire chambers



Same design for KEAT
Kaon Entrance Angle Tracker

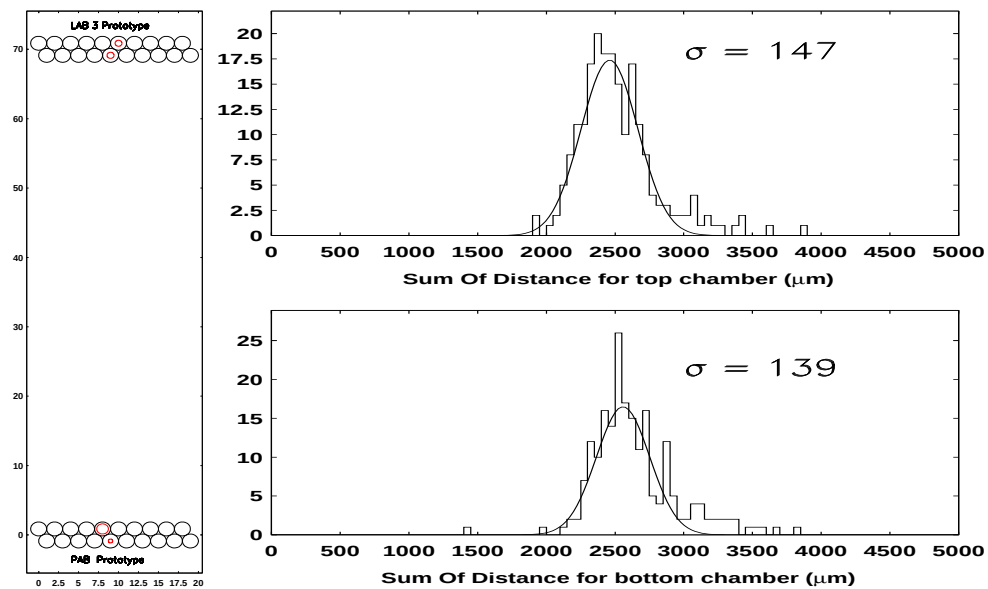
Downstream Magnetic Spectrometer: DMS

- Straw based tracker, following BNL871 design
- Modest rate 120 kHz (beam region dead)
- Four Stations, 29 planes, 4060 straws.
- 5 mm diameter, 1 m long with 30 μm kapton walls.
- Minimal material – preserving vacuum: $P = 10^{-6}$torr
- Mechanical properties extensively studied: (Fermi-PUB 02-241-E)



Cosmic-ray Test of Strawtubes in Vacuum

- Top doublet in air
  Bottom in 0.5Torr vac.
- $< 150\,\mu m$ resolution
  98% efficiency.
- mechanical distortion and
  gas diffusion negligible
- Wrong (but safe) gas; A-CO_2

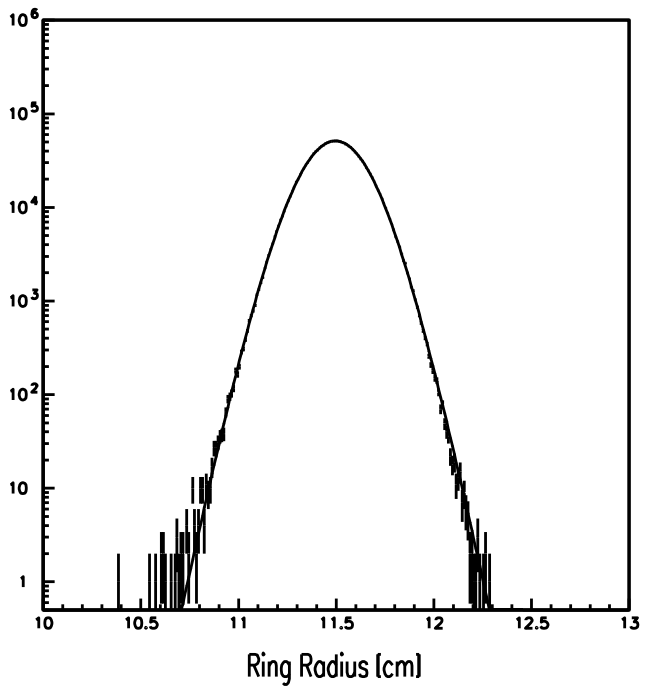


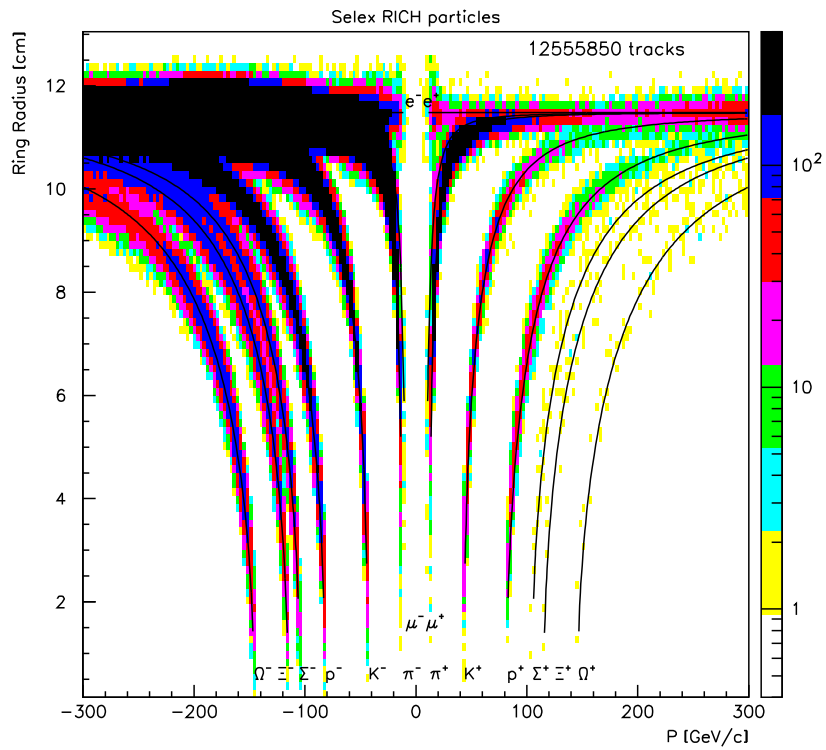
Velocity Spectrometers: KRICH, πRICH

- Provide independent measurement of K^+ and π^+ momenta .
  – M_{miss} resolution matched to magnetic spectrometer.

- High rate capability – photodetectors are individual PMTs.

- Based on SELEX RICH

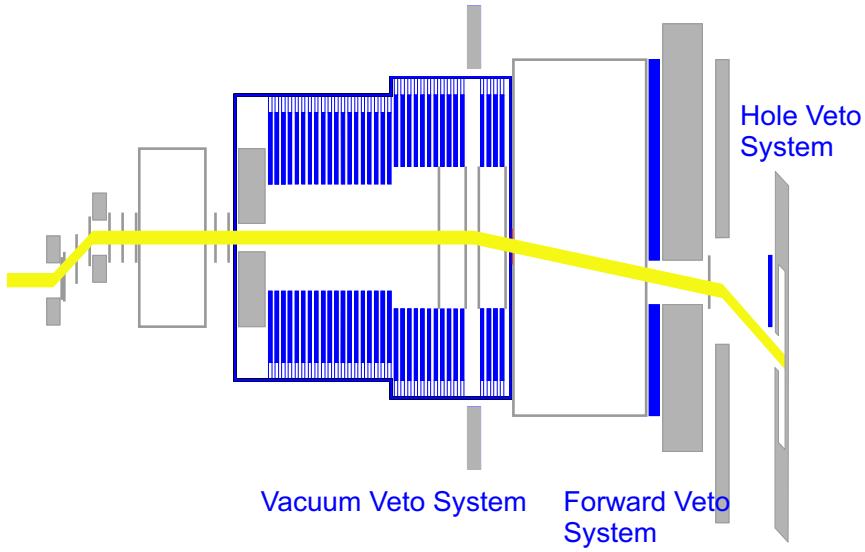




Photon Veto Systems

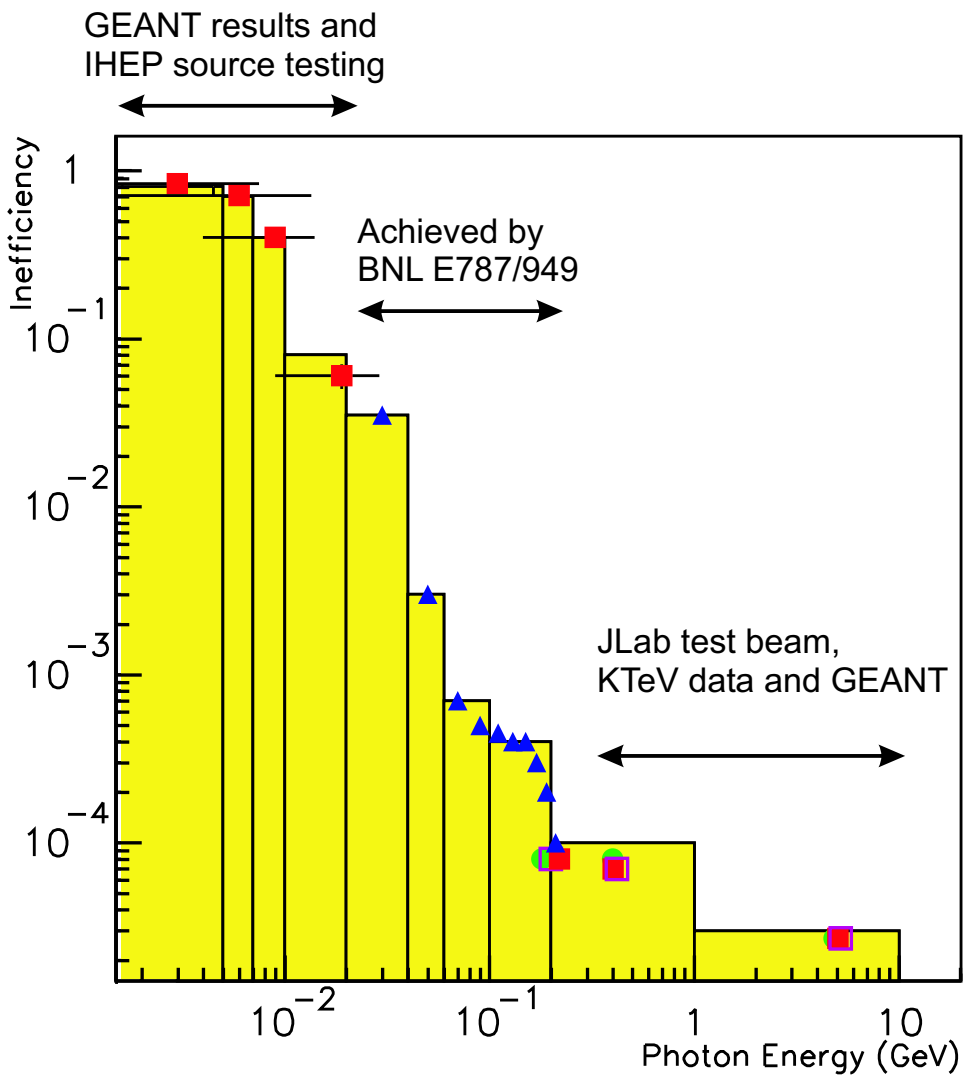
Photon detectors:

1. Vacuum Veto System (VVS):
   – 5 mm Scintillator/1 mm Pb.
2. Forward Veto System (FVS):
   – CsI (KTeV).
3. Hole Veto System (HVS):
   – Shashlik
4. Conversion Veto Plane (CVP):
   – Scintillating fibers.



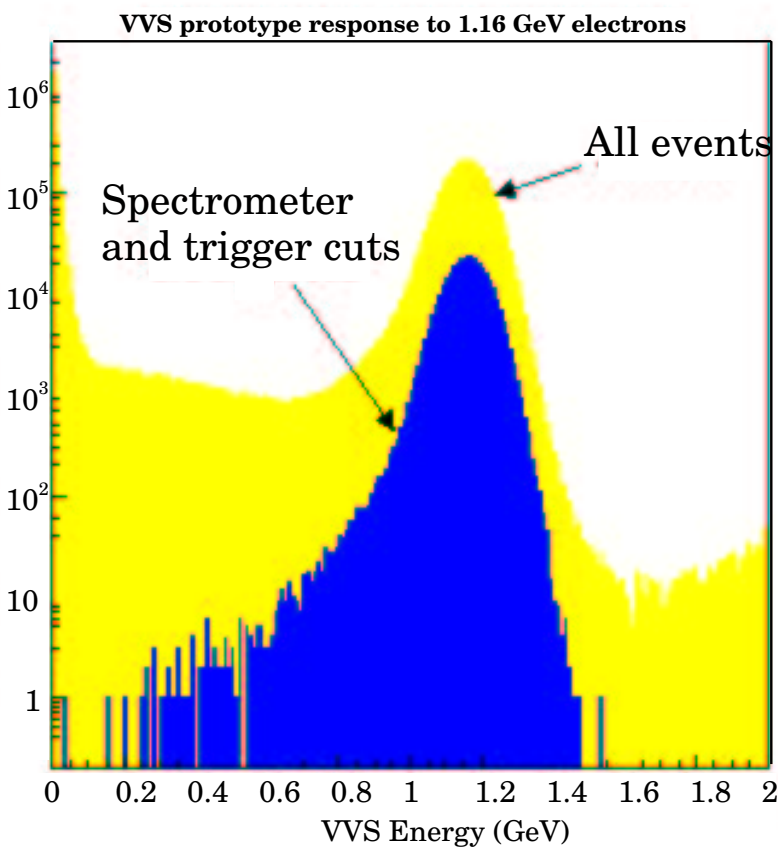
Background dominated by high energy inefficiency of VVS

Required VVS Inefficiency: now measured



Photon Veto Inefficiency and Technology

- 0.3% VVS prototype built and tested in a tagged e^- beam at JLAB.
- Achieved $< 5 \times 10^{-6}$ inefficiency at 1 GeV, (require $< 3 \times 10^{-5}$)
- outgassing into vaccum is within spec.

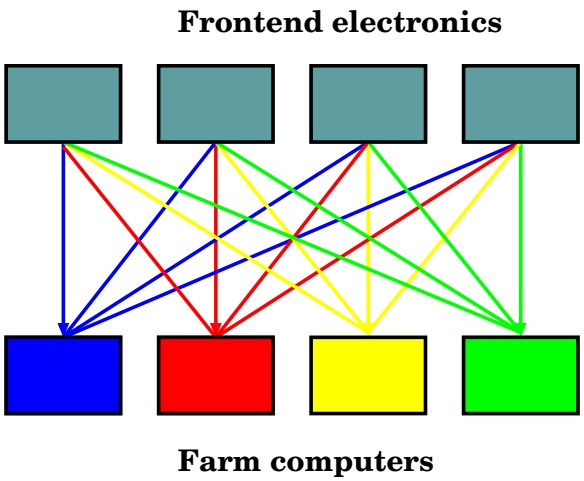


Software Trigger & DAQ

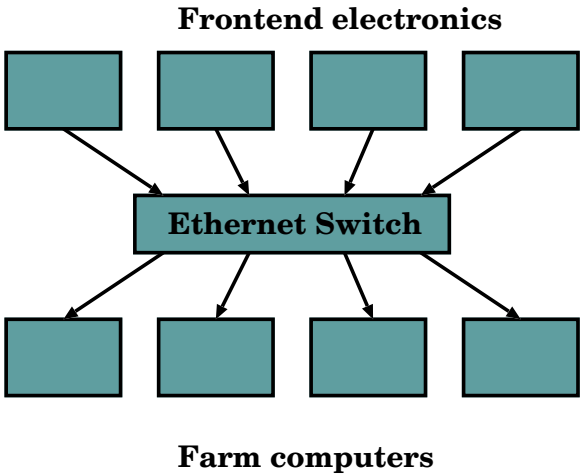
Conceptual design exists

- Front-end electronics continuously send (50 GB/s) zero–suppressed data to computer farm which executes various "levels" of filtering (Trigger).
- Data flow simulated (full GEANT – all hits)
- Switching and L1 Trigger demonstrated using current commodity equipment.

Logical Design:

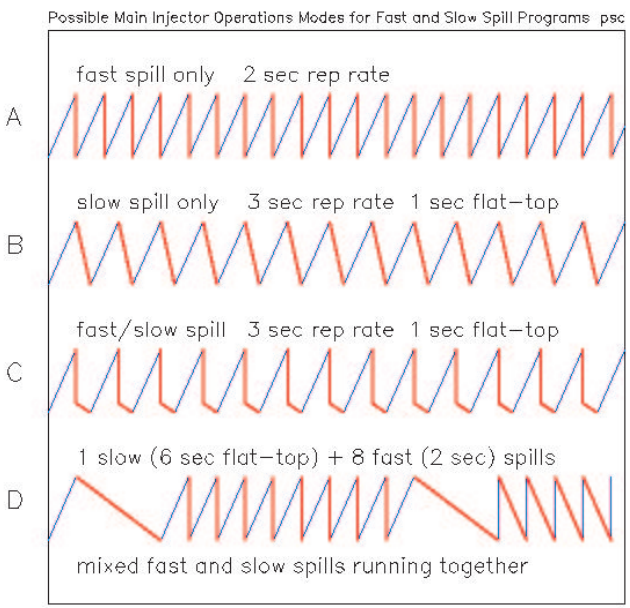


Physical Design:



Proton Economics

- Debunching requires < 100 ms.
- Need $\sim$15% of 120 GeV MI protons.
- Small proton intensity requirement immaterial: *any* Meson 120 experiment eats $\sim$30% of the Pbar or Neutrino budget because of duty factor considerations.
- Best plan seems to be a mix of fast and slow spills.

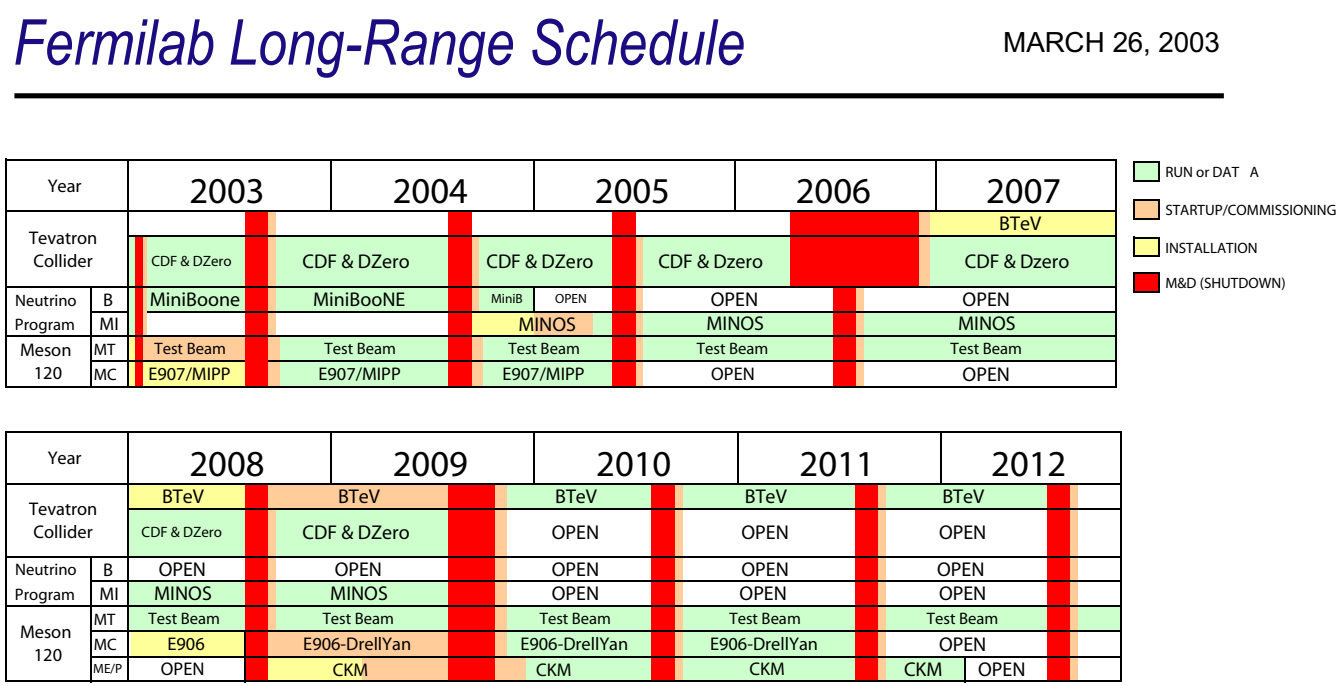


	Spill Mode	Cycle Time	Flat top	Protons /Hour [x1E15]			
		[sec]	[sec]	Pbar	Neutrino	SY120	Total
A	Fast Only	1.9	0	15.2	47.4	-	62.5
B	Slow Only	2.9	1	-	-	41.0	41.0
C	Combined	2.9	1	9.9	24.8	6.2	41.0
D	Mixed Fast	1.9 / 7.9	0 / 6				
	Fast cycles / Slow cycle						
	5	17.4	6	8.3	25.9	6.2	40.3
	6	19.3	6	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

Schedule and Scope

- 1989: Idea discussed at MI workshop in 1989
- 1996: LOI submitted in 1996.
- 1998: First proposal approved as R&D proposal.
- 2001: Second proposal considered and approved (Stage I).
- 2003: Temple review, P5 , detector prototypes and testbeam.

- After TDR and Lehman baseline in 2004, will need $\sim$ 3yr for construction.
- Size and scope of the project is similar to KTeV.



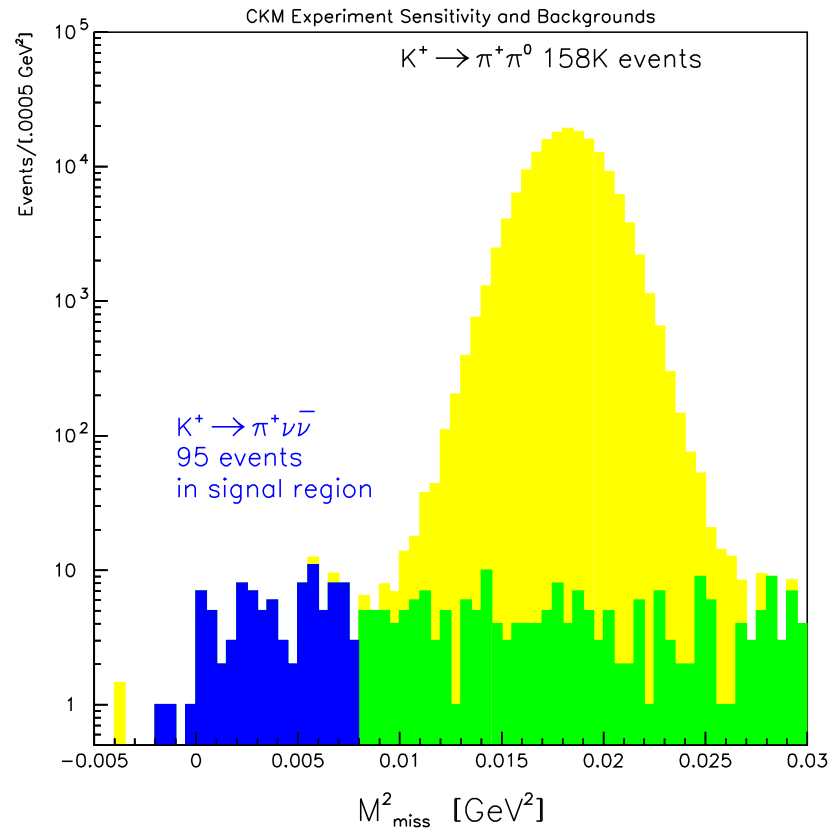
Other Physics – (some during commissioning)

- Study of the $K^+ \to \pi^+ \nu \overline{\nu}$ form factor
- Precision measurements of V_{us} (K_{e3}) and V_{ud} (π_β decay) to test unitary.
- Extend sensitivity for LFV (*e.g.* $K^+ \to \pi \mu e$ by $10 - 50 \times$).
- Precision tests of Chiral Perturbation Theory
  (*e.g.* $K^+ \to \pi^+ \ell^+ \ell^-$ & other rare K^+, π^+, π° decays.
- Plus a number of CP, $T-$odd and CPT tests.

$\sim$ 30 **PhD Theses**

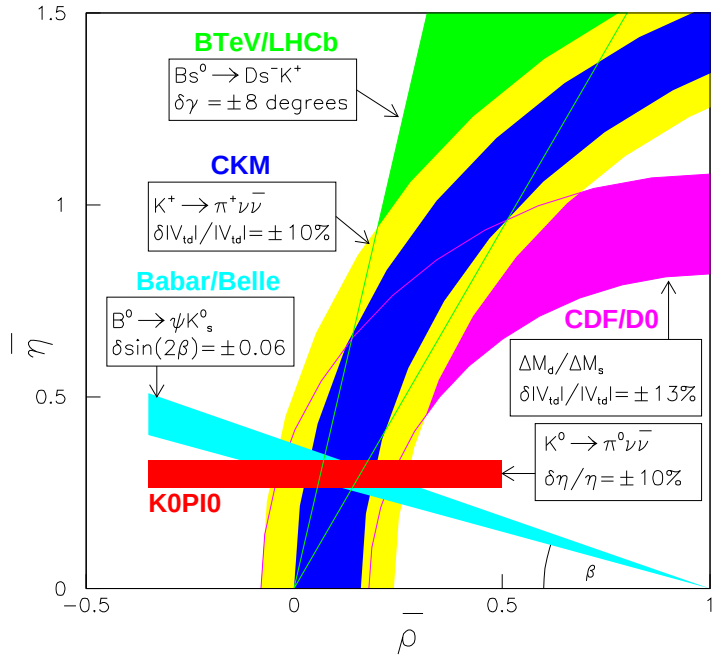
When it all works.....

95 signal events with
< 10 background events
in two years of data.

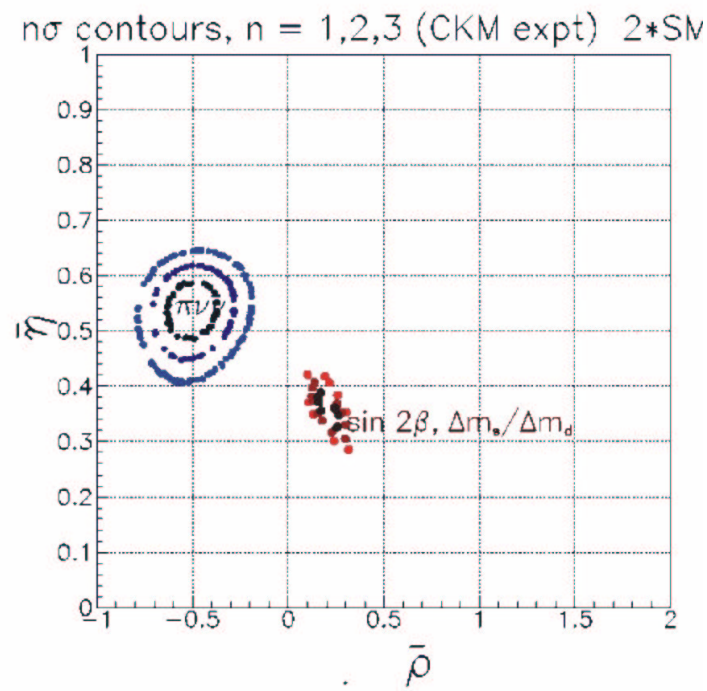


If Background above $K_{\pi 2}$ peak is manageable $\Rightarrow$ form factor.

With others; either confirm the standard model description,,,



or perhaps learn something new about CP violation



CKM Fitter: D. Jaffe