Flavor Physics at FNAL

Fermilab Annual Users Meeting
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Outline

- Kaon Decays
  - $K_L \to \pi^0 e^+ e^-$
  - $\pi^0 \to e^+ e^- e^+ e^-$
  - Improvement in V_{us}
- Baryon CP Asymmetries
- Charm Decays
  - Advances in Three Body Decays, K-matrix formalism
  - Semileptonic Decays
  - Excited D states
  - New Four-, Five-, and Six-body decays
  - Charm Pentaquarks
- Beauty Physics at FNAL

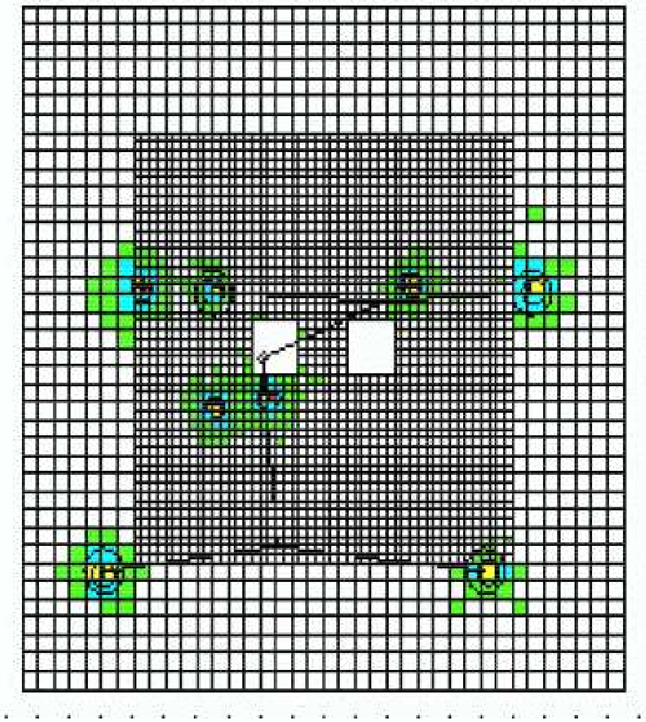
Apologize for leaving out results there is still considerable activity in flavor physics from fixed target community.

$K \to \pi l\bar{l}$ at Fermilab

- $K \to \pi l\bar{l}$ is a Flavor Changing Neutral Current that is highly suppressed in the Standard Model opening a window for new physics to peek through. e.g. SUSY, extra dimensions, etc.
- $K^+ \to \pi^+\nu\bar{\nu}$: A clean measure of $|V_{td}|$ and a sensitive probe of all anomalous $s \to d$ transitions. See Erik Ramberg's talk yesterday.
- $K_L \to \pi^0 e^+e^-$: K_L is mostly CP-odd (K_2), with a small admixture of εK_1. Expected rate of $K_L \to \pi^0 ee$ is a coherent sum of CP violating amplitude $K_2 \to \pi^0 ee$ and CP conserving amplitude $\varepsilon K_1 \to \pi^0 ee$. NA48 discovered $K_S \to \pi^0 ee$ this year with a BR of 6×10^{-9} which fixes the $K_1 \to \pi^0 ee$ amplitude.
- $K_L \to \pi^0 ee$ is now expected to be $\approx 3 \times 10^{-11}$. Reasonable extensions of SM (Buras et al) raise this rate to $\approx 10 \times 10^{-11}$
- The CP violating component (K_2) is a clean test (η) of CP violation in Standard Model. KTeV limit on $K_L \to \pi^0 e^+e^-$ from combined data sets is BR $< 28 \times 10^{-11}$ @ (90%CL). $3 \times$ Buras estimate.

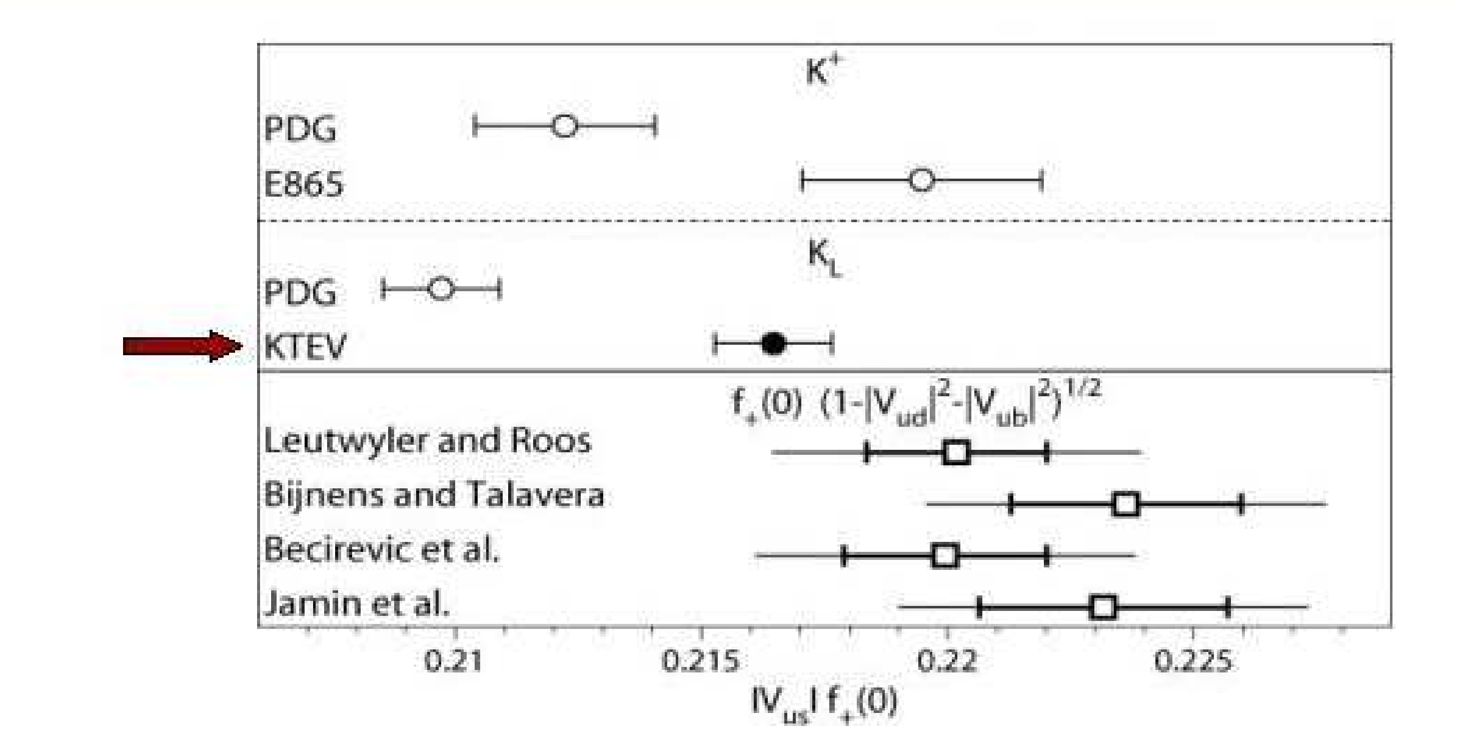
$\pi^0 \to e^+e^-e^+e^-$ from KTeV

- This impressive double dalitz decay was last measured in 1962 by Samios et al based on 146 events.
- KTeV observes 30,000 events by tagging with $K_L \to 3\pi^0$, enabling precision studies of form factor and rate.



8-cluster $K_L \to 3\pi^0, (\pi^0 \to 4e)$ event reconstructed with CsI calorimeter.

A New Determination of $|V_{us}|$ from KTeV



Submitted for publication on June 1:

- A Determination of the CKM Parameter $|V_{us}|$, hep-ex/0406001
- Measurements of K_L Branching Fractions and the CP Violation Parameter $|\eta_{+-}|$, hep-ex/0406002
- Measurements of Semileptonic K_L Decay Form Factors, hep-ex/0406003

June 4 Wine and Cheese Talk by Ed Blucher

Recent Results from HyperCP(E871)

- The CP asymmetry in the decay $\Xi \to \Lambda\pi$ is given by:

$$A_\Xi = \frac{\alpha_\Xi + \alpha_{\overline{\Xi}}}{\alpha_\Xi - \alpha_{\overline{\Xi}}} \approx -tan(\delta_P - \delta_S) sin(\phi_P - \phi_S)$$

  where α_Ξ is the decay parameter, δ_S and δ_P are the strong phase shifts of $\Lambda\pi$, ϕ_S and ϕ_P are the CP-violating phases.
- Need to calculate the phases δ and ϕ, to predict A_Ξ.
- Can determine the strong phase-shift difference by measuring:

$$\frac{\beta_\Xi}{\alpha_\Xi} \approx tan(\delta_P - \delta_S)$$

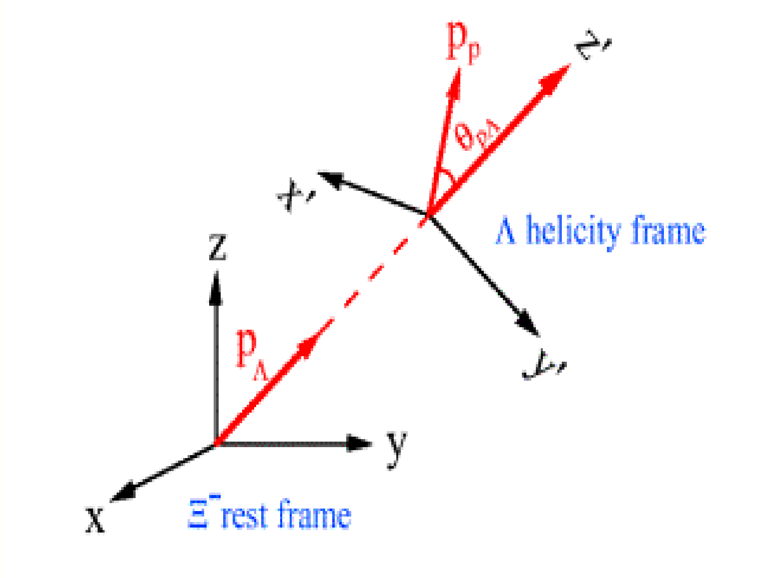
- Based on $\sim$ 132 million polarized $\Xi^- \to \Lambda\pi^-$, obtained

$$\delta_P - \delta_S = (4.6 \pm 1.4 \pm 1.2)^o$$

  indicating CP-odd effect is small in $\Xi \to \Lambda\pi$ decay.

HyperCP(E871) cont.

- To determine A_Ξ, need to determine α_Ξ with $\Xi^- \to \Lambda\pi^-$ and $\alpha_{\overline{\Xi}}$ with $\overline{\Xi}^+ \to \overline{\Lambda}\pi^+$ decays.
- For the decay sequence $\Xi \to \Lambda\pi$, $\Lambda \to p\pi$, in the helicity frame, the decay distribution is given by:



$$\frac{dN_p}{dcos\theta_{p\Lambda}} = \frac{N_0}{2}\left(1 + \alpha_\Lambda\alpha_\Xi\, cos\theta_{p\Lambda}\right)$$

Define CP-asymmetry parameter:

$$A_{\Xi\Lambda} = \frac{\alpha_\Xi\alpha_\Lambda + \alpha_{\overline{\Xi}}\alpha_{\overline{\Lambda}}}{\alpha_\Xi\alpha_\Lambda - \alpha_{\overline{\Xi}}\alpha_{\overline{\Lambda}}} \approx A_\Xi + A_\Lambda$$

- Based on 42 million $\overline{\Xi}$ and 118 million Ξ^- decays, 10% of the total, by measuring the difference $(\alpha_\Xi\alpha_\Lambda - \alpha_{\overline{\Xi}}\alpha_{\overline{\Lambda}})$ directly, obtained

$$A_{\Xi\Lambda} = [0.0 \pm 5.1(\text{stat}) \pm 4.2(\text{syst})] \times 10^{-4}$$

HyperCP(E871) Ω^- Parity Result

Based on about 5 million $\Omega^- \to \Lambda K^-$ decays, obtained

$\alpha_\Omega \alpha_\Lambda$ **= [1.29**$\pm$ **0.11(stat)** $\pm$ **0.06(syst)]** $\times 10^{-2}$

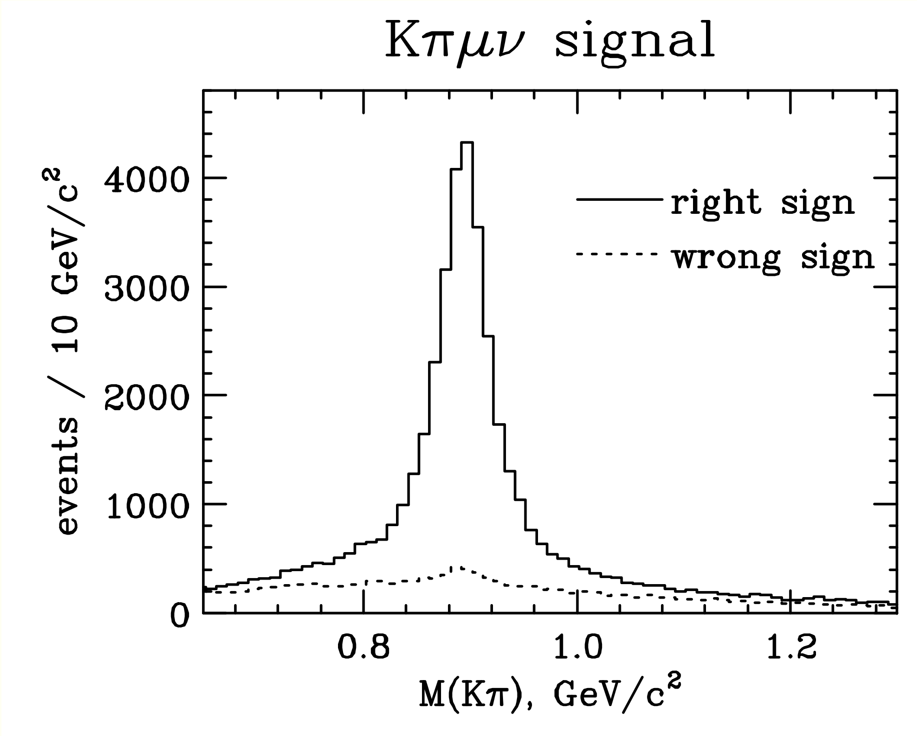
α_Ω **= [2.00**$\pm$ **0.17(stat)** $\pm$ **0.10(syst)]** $\times 10^{-2}$

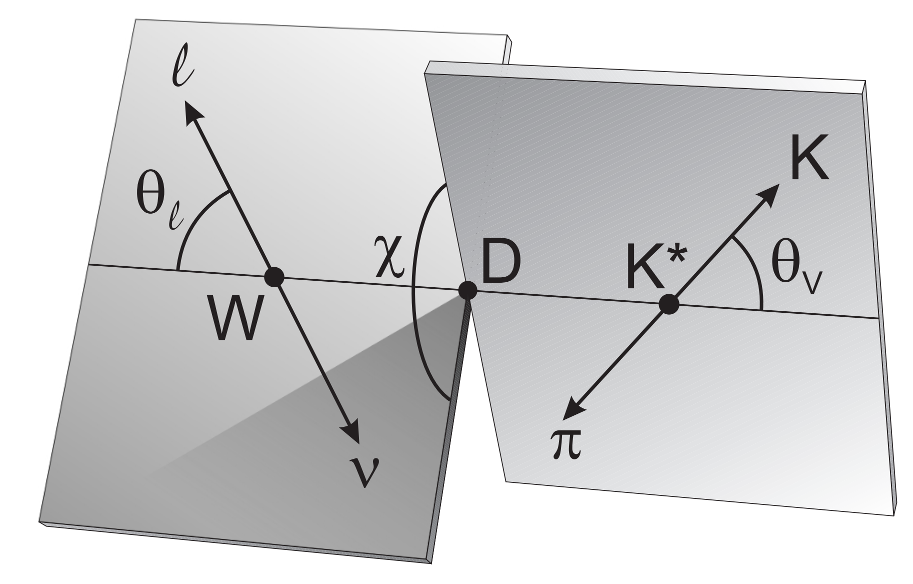
shows for the first time that parity is violated in this decay.

Semileptonic Problems in Charm

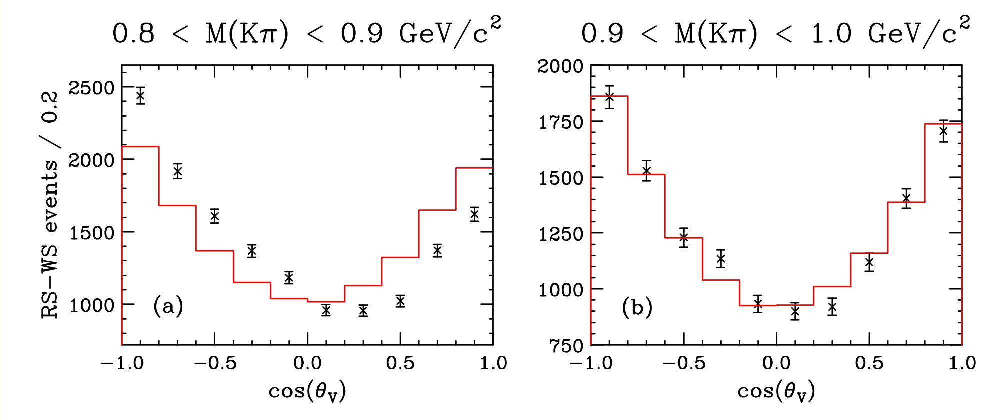
- Only external spectator diagram involved.
- Factorization is possible between hadronic and leptonic current.
- Should be easy to understand, but ......
  - Ratio of pseudoscalar to vector rates has been uncertain experimentally. FOCUS now measures $(D^+ \to \overline{K^{*0}}\mu^+\nu)/(D^+ \to \overline{K^0}\mu^+\nu) = 0.594 \pm 0.043 \pm 0.033$ and demonstrates that the current World Average branching ratios for $D^+ \to \overline{K^0}(\mu^+, e^+)\nu_{\mu,e}$ are low.
  - S-wave interference found in $D^+ \to \overline{K^{*0}}\mu^+\nu$
  - Form factor disagreement between $D^+ \to \overline{K^{*0}}\mu^+\nu$ and $D_s^+ \to \phi\mu^+\nu$
  - New questions on K^{*0} mass and width

Vector Semileptonic Decays



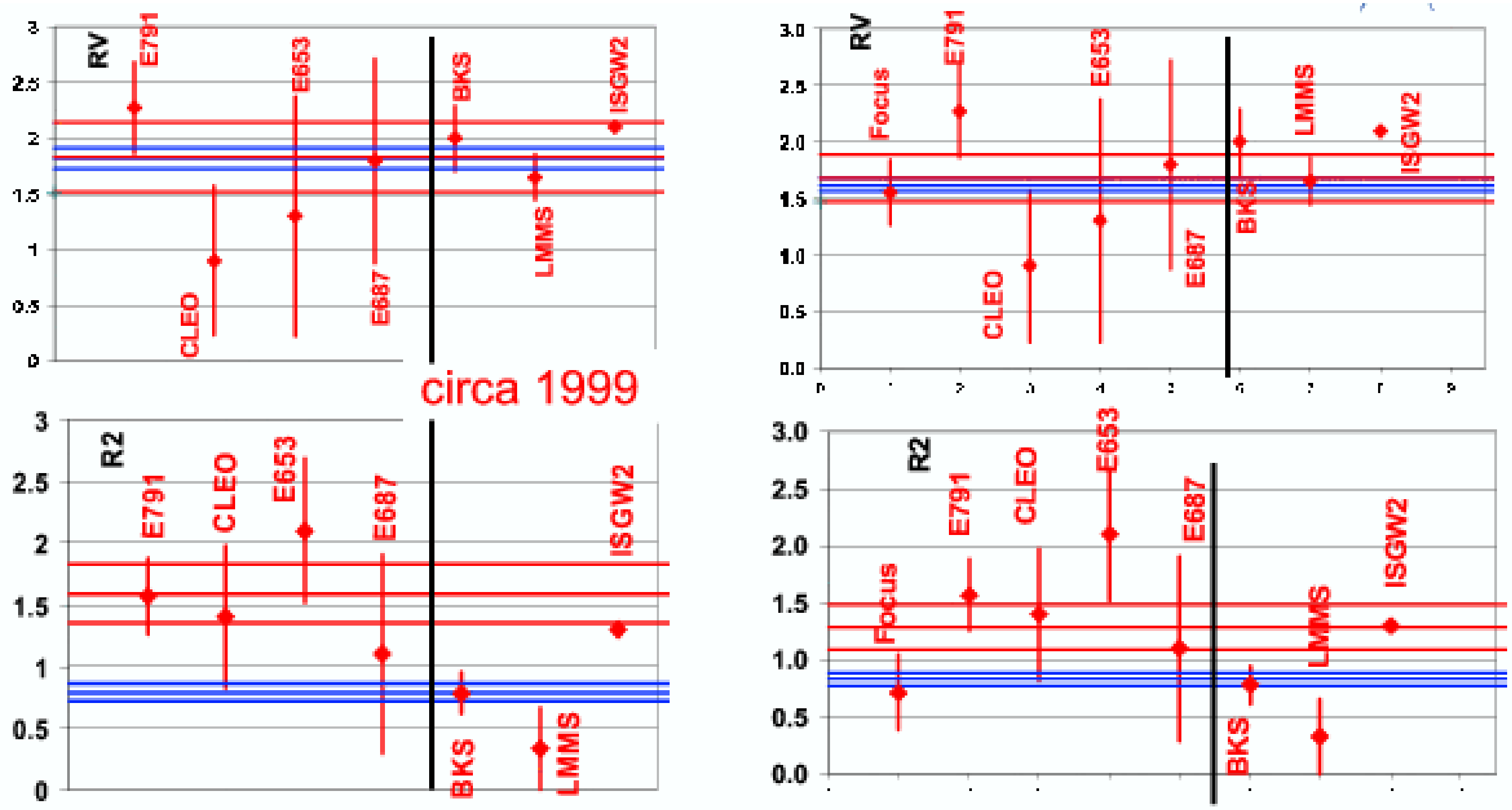


- Four body decay requires five variables; 3 angles, $M_{K\pi}$, q^2



- Huge asymmetry in $\cos(\theta_v)$ below the K^* pole led to the discovery of s-wave interference

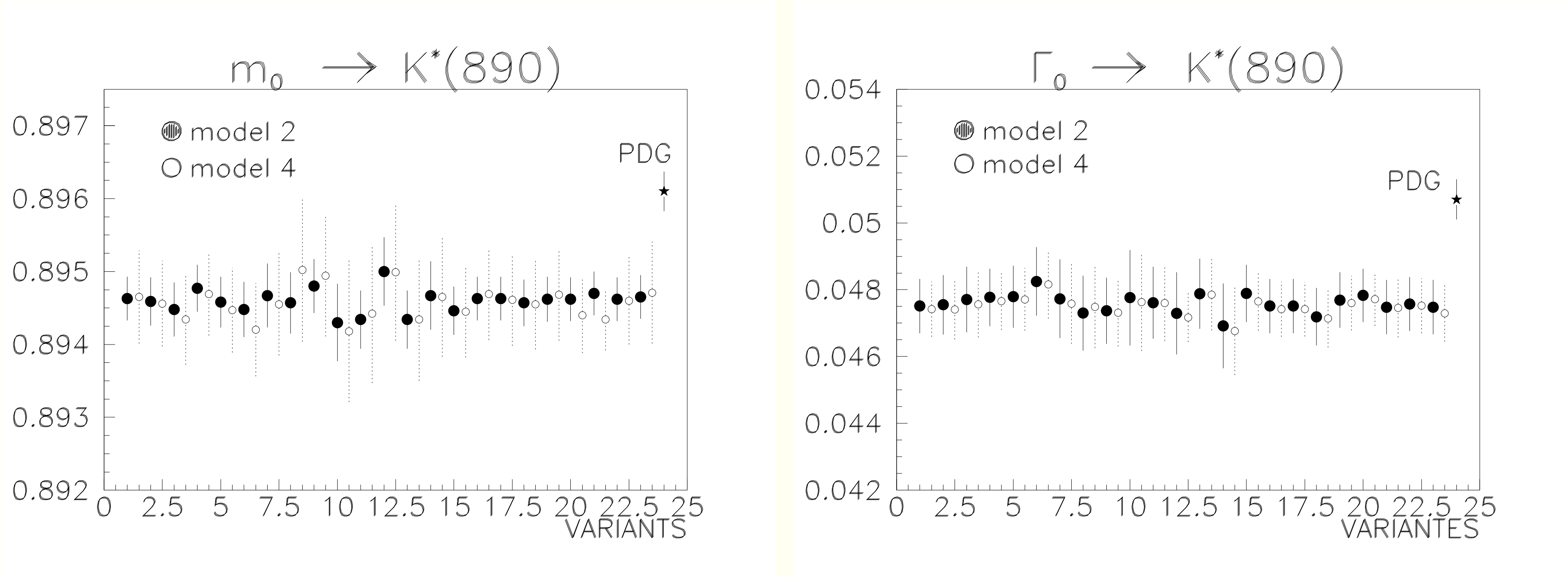
$D_s^+ \to \phi\mu^+\nu$ Form Factors



Theoretically the **Ds→φlν** form factor should be within 10% of **D →K*lν** . The rV values were consistent but r2 for **Ds→φlν** was ≈ 2⊗ higher than **D →K*lν** .

But the (2004) FOCUS measurement has consistent r2 values as well!

$K^{*0}(892)$ Information, cont.

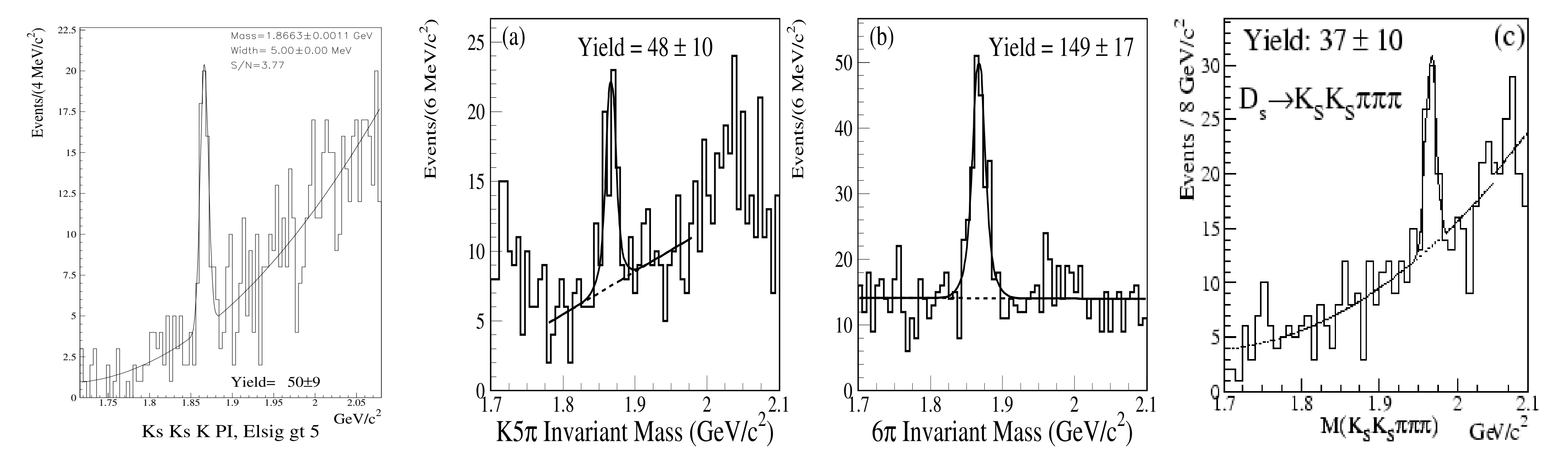


From FOCUS thesis

Parameter	PDG	FOCUS (Preliminary)
Mass K^{*0}	896.10 ± 0.27 MeV/c^2	894.52 ± 0.30 MeV/c^2
Width K^{*0}	50.7 ± 0.6 MeV/c^2	47.82 ± 0.82 MeV/c^2
Mass of K^{*-}	891.66 ± 0.26 MeV/c^2	
Width of K^{*-}	50.8 ± 0.7 MeV/c^2	

Finds an increase of about 2 MeV/c^2 in the width when the Breit-Wigner is convoluted with the resolution.

Discovery of New Charm Meson Modes



- Cabibbo Favored
  - $D^0 \to K_s K_s K^\pm \pi^\mp$
  - $D^0 \to K^- \pi^- \pi^- \pi^+ \pi^+ \pi^+$
  - $D_S^+ \to K_s K_s \pi^+ \pi^- \pi^+$
- Cabibbo Suppressed
  - $D^+ \to K^- K^+ \pi^+ \pi^- \pi^+$
  - $D^0 \to \pi^- \pi^- \pi^- \pi^+ \pi^+ \pi^+$
- 5-Body Amplitude Analyses
  - $D^0 \to K_S \pi^- \pi^+ \pi^- \pi^+$
  - $D^+ \to K^- \pi^- \pi^+ \pi^+ \pi^+$
  - $D^+ \to \pi^- \pi^- \pi^+ \pi^+ \pi^+$
  - $D_S^+ \to K^- K^+ \pi^- \pi^+ \pi^+$
- Dominance of $W^+ \to a_1$ in high multiplicity decays.

Future of Flavor Physics

Goal is to precisely measure the six CKM triangles and look for deviations that point to new physics. All six triangles can be constructed knowing only four independent angles. (Note α can be used instead of γ or β).

$$\beta = arg\left(-\frac{V_{tb}V_{td}^*}{V_{cb}V_{cd}^*}\right) \qquad \gamma = arg\left(-\frac{V_{ub}^*V_{ud}}{V_{cb}^*V_{cd}}\right)$$

$$\chi = arg\left(-\frac{V_{cs}^*V_{cb}}{V_{ts}^*V_{tb}}\right) \qquad \chi' = arg\left(-\frac{V_{ud}^*V_{us}}{V_{cd}^*V_{cs}}\right)$$

Estimated that γ and β are probably large, while χ is small ≈ 0.02 and χ' is likely to be much smaller.
Silva and Wolfenstein have pointed that sum of angles may not be sufficient and propose a SM check:

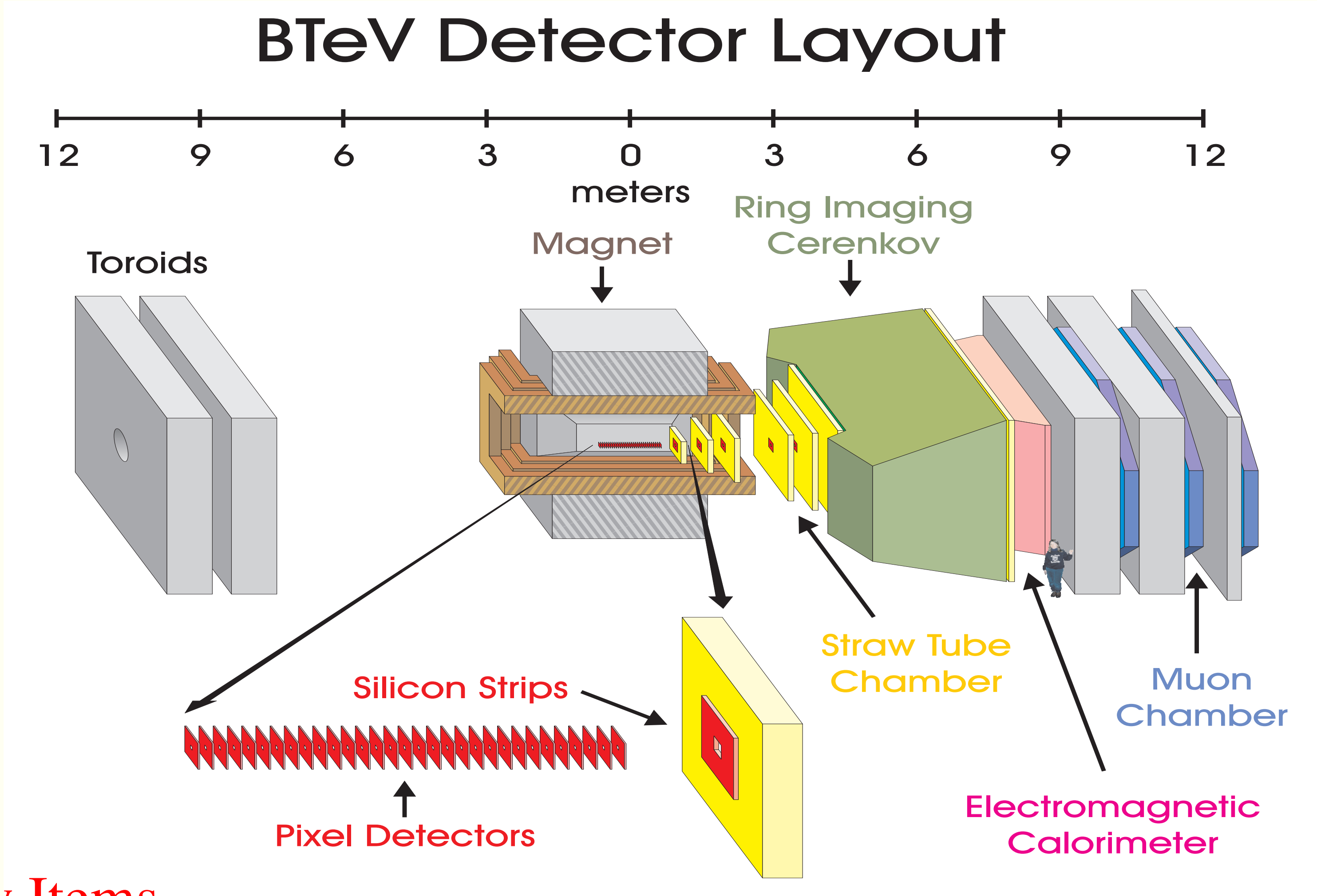
$$sin\ \chi = \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{sin\ \beta\ sin\ \gamma}{sin(\beta+\gamma)}$$

How are the CKM Angles Measured?

- Measurements of the angle β
  - Time dependent $B^0 \to J/\psi K^0$, $K^0 \to \pi l \nu$ gives cos(2β).
- Measurements of the angle α
  - Time dependent $B^0 \to \pi^+\pi^-$, but a large Penguin component.
  - $B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$
- Measurements of the angle γ
  - Time independent flavor tagged $B_s \to D_s^{\mp} K^{\pm}$.
  - Rate Differences between $B^- \to \overline{D}^0 K^-$ and $B^+ \to D^0 K^+$ in two D^0 decay modes.
- Measurements of the angle χ
  - Time independent $B_s \to J/\psi\eta$ or $B_s \to J/\psi\eta'$

Conclusion - independent of higher statistics, one wants B_s decays

The BTeV Experiment

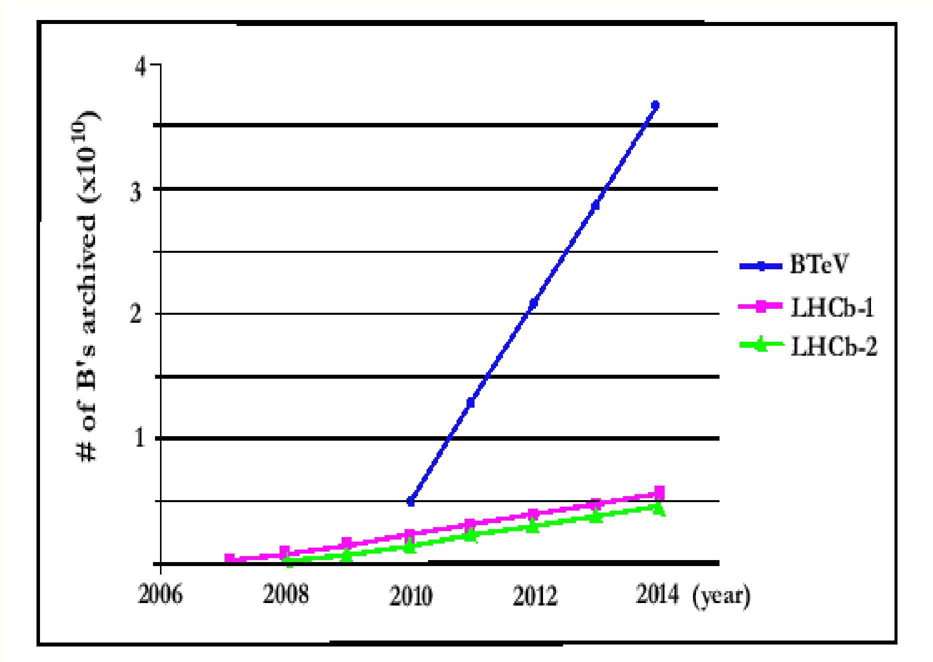


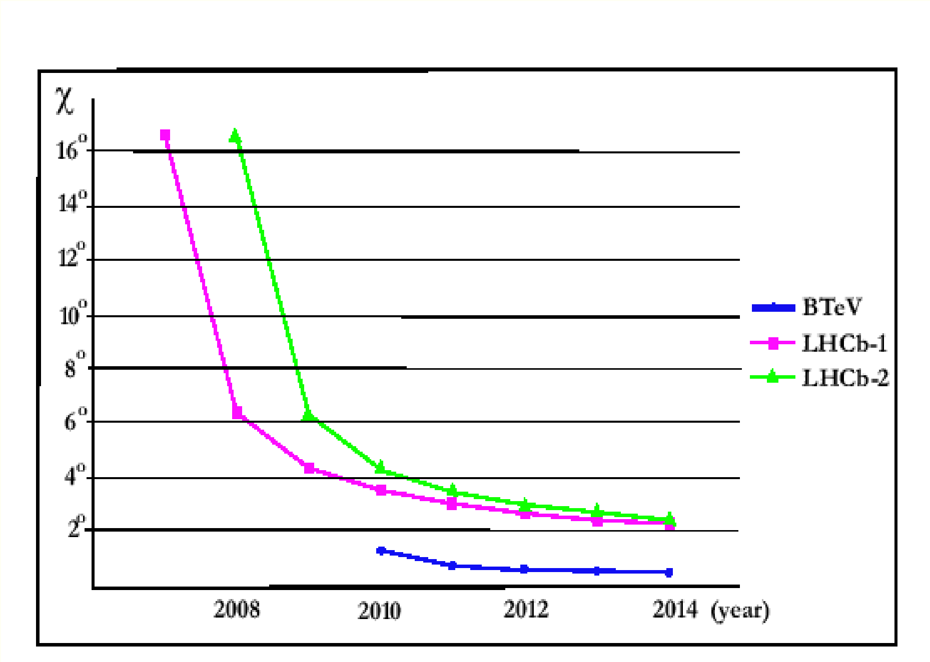
- Key Items
  - Pixel Tracking at the Vertex
  - Excellent π^0 identification
  - Fast Decay Vertex Trigger

BTeV, cont.

- BTeV Goals
  - Precise measurements of CKM parameters.
  - Structure of b states, including baryon decays and B_c decays.
  - Studies of QCD in weak decay processes probed by branching ratios, semileptonic form-factors, polarization in vector-vector decays, and Dalitz plots in three body decays.
- Isn't this already being done by Belle and BaBar?
  - No! Sit on $\Upsilon(4S)$ only get B^0 and B^-
- What about LHCb?
  - Similar b physics goals, but .....
  - Trigger-DAQ costs them a factor of 5 relative to BTeV.
  - Only get about 1/2 the running time per year as BTeV.
  - EM Calorimeter has energy resolution of $10\%/\sqrt{E} + 1.5\%$; BTeV's is $1.7\%/\sqrt{E} + 0.55\%$ and better spatial resolution.

LHCb Comparisons





- Assumptions for Estimated Yields
  - LHCb records 0.1 fb^{-1} in 2007
  - LHCb records 0.6 fb^{-1} in 2008
  - LHCb records 0.8 fb^{-1} in 2009
  - LHCb gets 0.8 fb^{-1} future years
  - BTeV installs in 2009
  - BTeV, 9 month run in 2010
- e^+e^- at 1000 fb^{-1} gets $0.1\times 10^{10} b\bar{b}$'s

- Rates factor in staged BTeV detector
- BTeV wins by factor of 10 $b\bar{b}$'s to tape and has a big advantage.

Conclusions

- Large body of data taken during past 10 years continues to produce new results, but is starting to wind down.
  - KTeV has made a significant improvement if $|V_{us}|$.
  - No CP violation yet in Hyperons, but parity violation has been observed in Ω^- decays.
  - Many new Charm Results and experimental disagreements are being resolved.
- Would be nice to continue the Kaon Program at FNAL!
- Isn't the entire HEP program neglecting baryon physics?
- Fermilab Charm Program can be carried forward in BTeV
- BTeV appears to be the leading B physics experiment in 2010 and beyond.
  - What matters is not what happens in 2008 or 2009, but ..
  - Which exp. is best able to see new physics when it arises.
  - It is time to start building the BTeV experiment!