Searches for CP Violation and New Physics at CLEO

B

Bounds on CP Asymmetry in $b \to s\gamma$ Decays

Exclusive Penguins and CP Asymmetry

CP Asymmetries in Dileptons from $B^0\bar{B}^0$

Search for CP Violation in $B^\pm \to J/\psi K^\pm$ and $B^\pm \to \psi(2S) K^\pm$

CP Asymmetries in Charmless Hadronic B Decays

τ

Search for CP Violation in τ Decays

D

CP Violation in D^0 Decays to Pairs of Pseudoscalar Mesons

New Fits to D^0 Proper Time and y Measurement

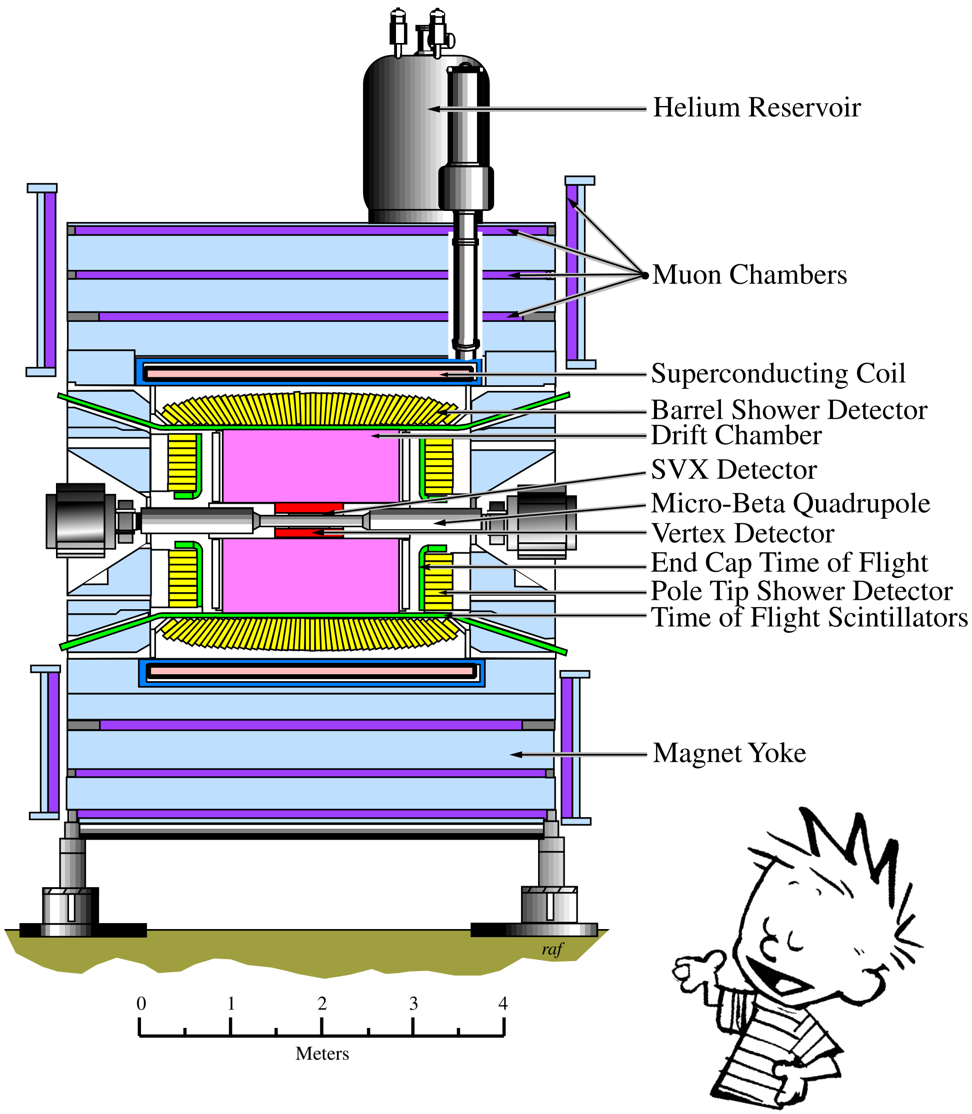
First Measurement of "wrong-sign" $D^0 \to K^+\pi^-\pi^0$ Rate

New Results on FCNC Decays $B \to K^{(*)} l^+ l^-$

http://www.phyast.pitt.edu/~savinov

On behalf of CLEO Collaboration

CLEO II / II.V Detector



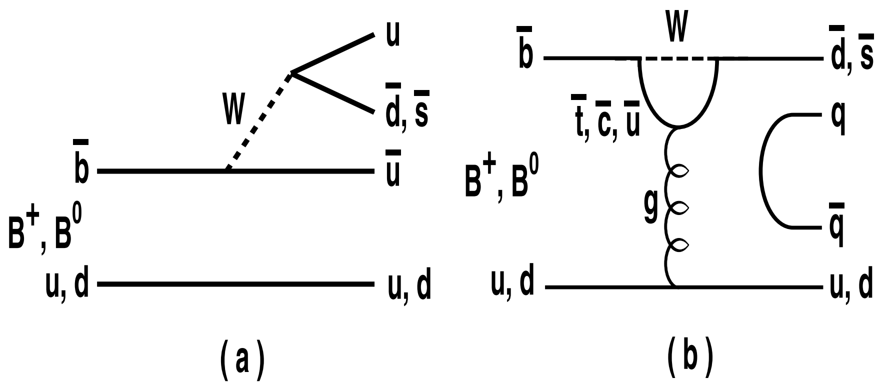
Performance of the Detector

- Electromagnetic Calorimeter (96% 4π)
  - 7800 CsI crystals, each $\approx 16\ \chi_0$ long
  - $\sigma_E/E \approx 2\%$ at 5 GeV, 5% at 200 MeV
- Tracking (PT/SVX, VD, DR; 95% 4π)
  - $\sigma_p/p = \sqrt{(0.0059)^2 + (0.0016p(\mathrm{GeV/c}))^2}$
- Muon System (85% 4π, $|p_\mu| \geq 1.0$ GeV/c)
- Particle Identification
  - Specific ionization energy losses ($dEdx$)
  - Time-of-flight (TOF) scintillator
- Trigger
  - L0: (VD and TOF) or (CsI)
  - L1 and L2: VD, DR, CsI, TOF
  - L3: beam-gas rejection (software)

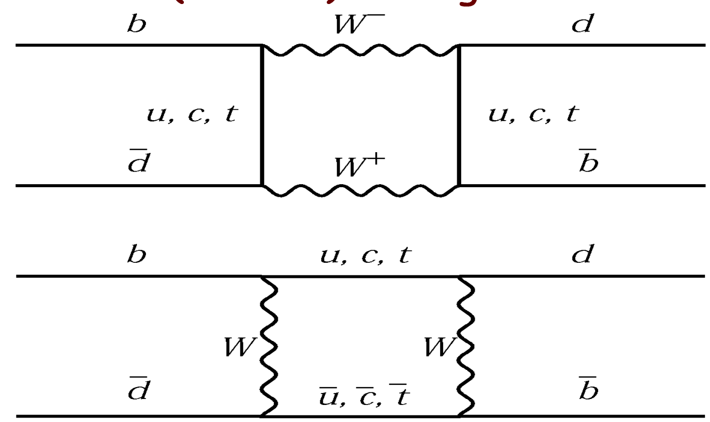
$\hookrightarrow$ General purpose e^+e^- detector

Describing Possible New Physics in Term of Loops, Boxes and Mixing

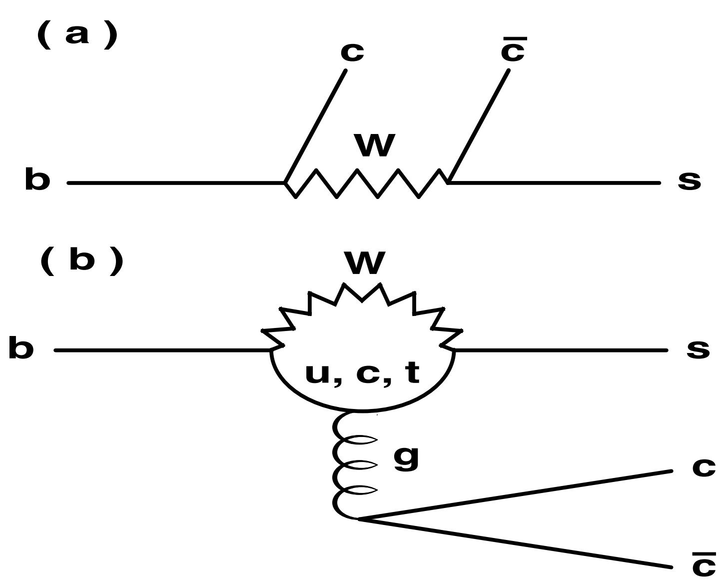
- CP Violation in Charmless B Decays



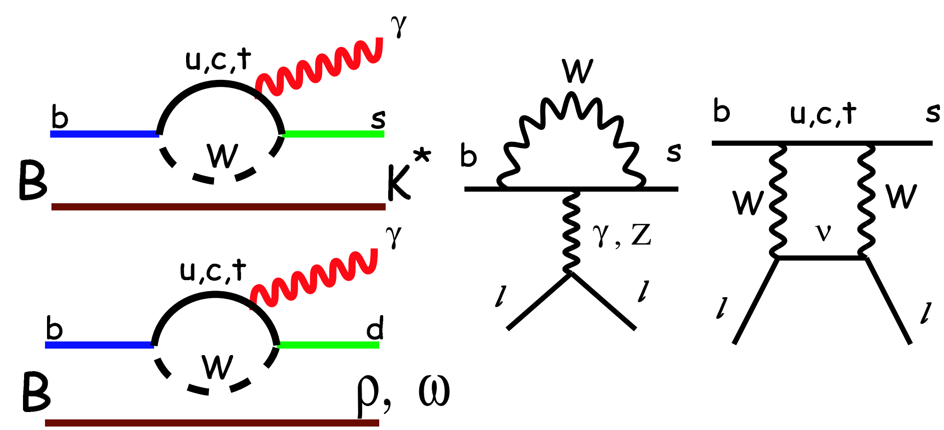
- BB (and DD) Mixing



- Absence of SM CP Violation in B J/ψK



- Flavor Changing Neutral Currents
  - SM: only effective FCNC
  - New Physics: replace W by H



Bounds on CP Asymmetry in b → sγ Decays

$$\mathcal{A}_{CP} \equiv \frac{\Gamma(b \to s\gamma) - \Gamma(\bar{b} \to \bar{s}\gamma)}{\Gamma(b \to s\gamma) + \Gamma(\bar{b} \to \bar{s}\gamma)} \qquad \Gamma(b \to s\gamma) = \frac{\alpha G_F^2 m_b^5}{32\pi^4}|c_7(m_B)|^2 |V_{tb}V_{ts}^*|^2$$

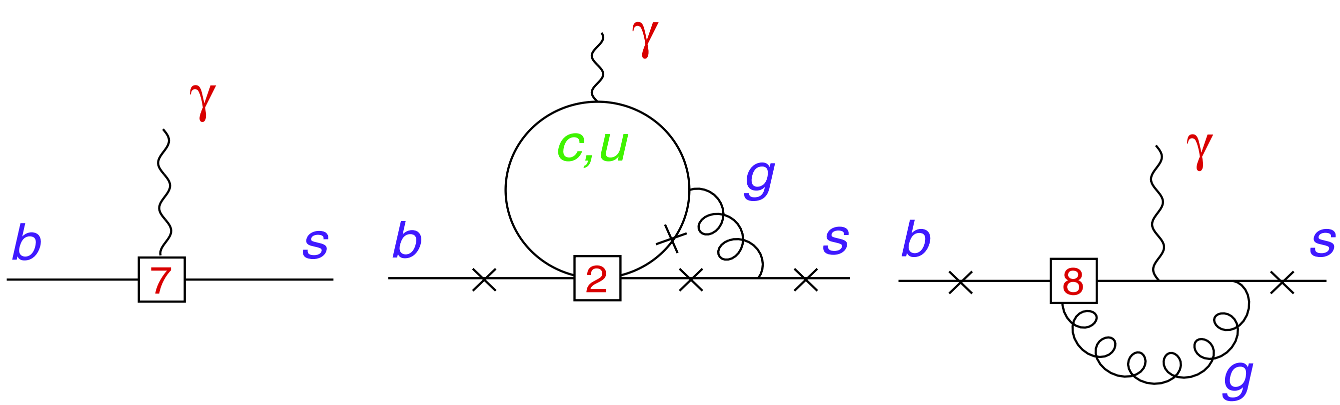
c_7 is Wilson coefficient for $b \to s\gamma$ in the effective weak Hamiltonian.

Sensitivity to new physics (J.L. Hewett and J.D. Wells, Phys. Rev. D 55, (1997) 5549):

- 2HDM (required for SUSY) and 3HDM extensions of the SM
- Fourth generation, anomalous $W\gamma$ coupling

Direct CP violation from interferences between c_2–c_7 and c_7–c_8,

where c_7: $b \to s\gamma$, c_8: $b \to sg$, c_2: four-fermion interaction.



$A_{CP} \sim \alpha_s(m_b)$

SM: $A_{CP}(b \to s\gamma) \approx 0.5\%$. Non-SM: 10%–50%? (Kagan and Neubert, PRD 58 (98) 094012)

Bounds on CP Asymmetry in $b \to s\gamma$ Decays: Experiment

High energy photon: $2.2 < E_\gamma < 2.7$ GeV

Flavor tagging: either lepton or self-tag (pseudo reconstruction)

Substantial background from continuum processes

Utilizing all available background-suppression variables

Subtraction of remaining (after neural net cut) continuum

NOT needed: good knowledge of efficiency (cancels in ratio)

Tagging is correct 89% (using lepton) and 90% (using PR)

Systematics: mistag rate, ON-OFF and BB subtractions, particle ID and particle detection biases (small)

$$\mathcal{A}_{CP} = (-0.079 \pm 0.108 \pm 0.022)(1.0 \pm 0.030)$$

To be published in PRL
hep-ex/0010075

Exclusive Penguins and CP Asymmetry

The Technique

- Use only self-tagging channels
- K–π misidentification is taken care of

$$A_{CP} \equiv \frac{1}{1-2\omega} \frac{\mathcal{B}(\bar{B} \to \overline{K^*}\gamma) - \mathcal{B}(B \to K^*\gamma)}{\mathcal{B}(\bar{B} \to \overline{K^*}\gamma) + \mathcal{B}(B \to K^*\gamma)}$$

Misidentification rate $\omega \approx 3.5\%$

- Background asymmetry: $+0.01 \pm 0.06$
- Systematics is small:
  - Detector asymmetries: $< 1.5\%$
  - Cross-feed among K^* decay modes: 1.0%

$A_{CP}(B \to K^*\gamma) = +0.08 \pm 0.13$ (PRL 84 (2000) 5283)

$K^{*0} \to K^+\pi^-, K^0\pi^0$

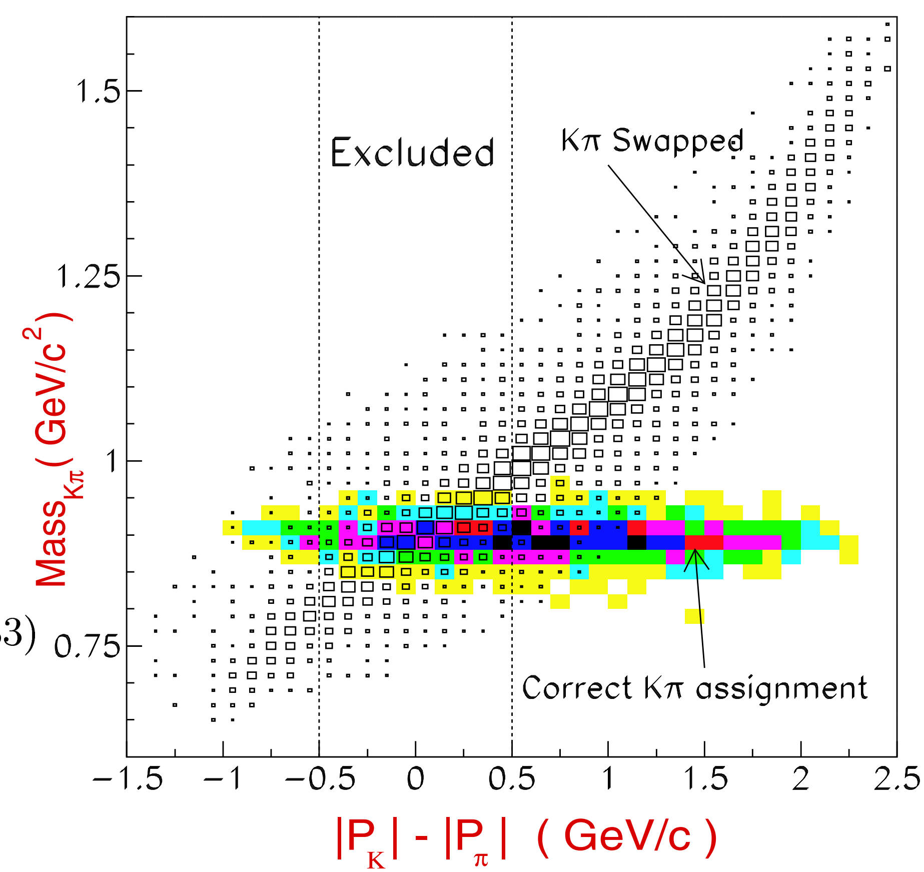
$88.3^{+12.2}_{-11.5}$ K^{*0}

$K^{*+} \to K^+\pi^0, K^0\pi^+$

$36.7^{+8.3}_{-7.6}$ K^{*+}

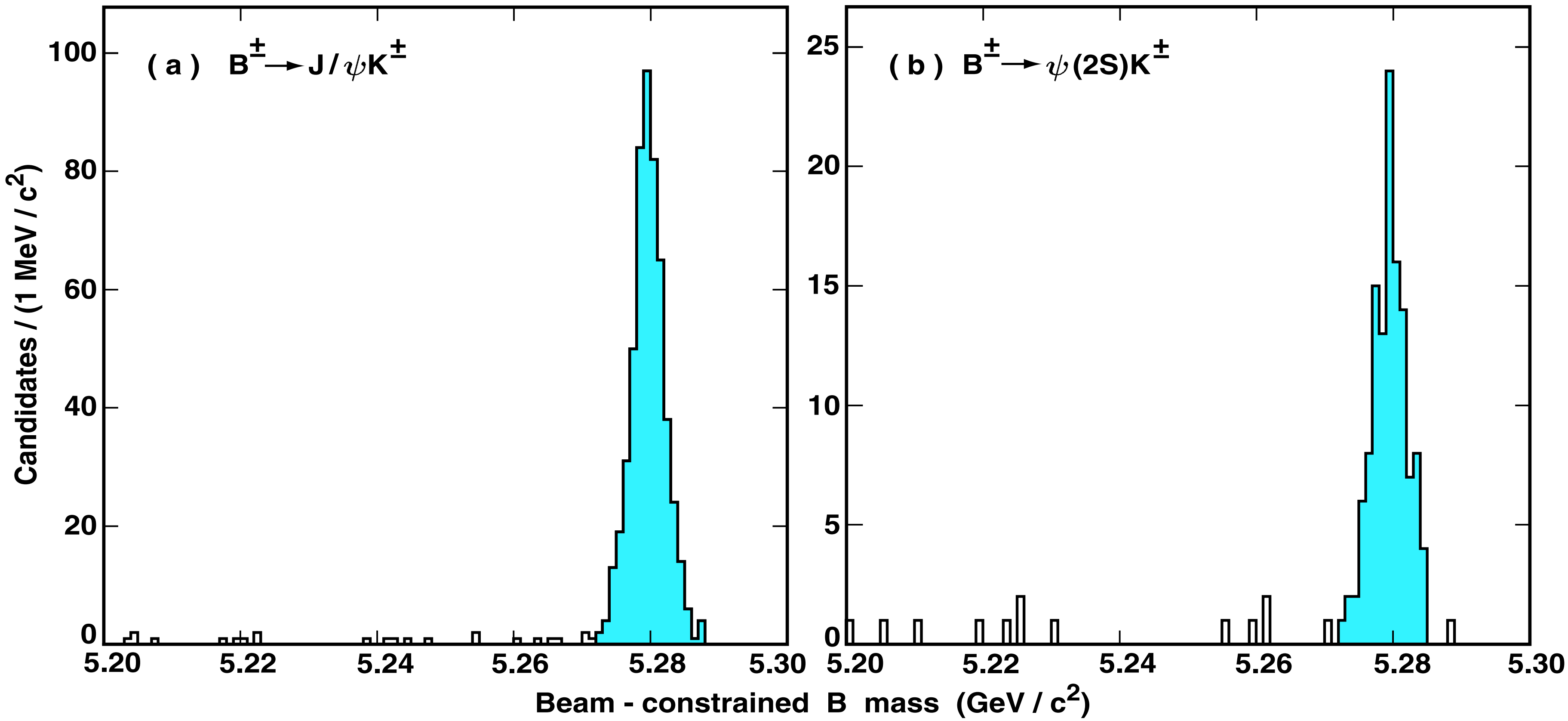
62%-efficient K–π separation:

Simulation of K*0(892) --> K+ π- decays



Search for CP Violation in $B^{\pm} \to J/\psi K^{\pm}$ and $B^{\pm} \to \psi(2S) K^{\pm}$

G. Wu and A. Soni, Report BNL-HET-99/40, hep-ph/9911419; K. Kiers, A. Soni and G. Wu, Phys. Rev. D **59**, 096001 (1999).



$A_{CP}(B^{\pm} \to J/\psi K^{\pm}) = (+1.8 \pm 4.3[\text{stat}] \pm 0.4[\text{syst}])\%$

$A_{CP}(B^{\pm} \to \psi(2S) K^{\pm}) = (+2.0 \pm 9.1[\text{stat}] \pm 1.0[\text{syst}])\%$

PRL 84 (2000) 5940

Bounds on CP Asymmetry in Dileptons from $B^0\bar{B}^0$ Decays

$$a_{\ell\ell} \equiv \frac{N(\ell^+\ell^+)-N(\ell^-\ell^-)}{N(\ell^+\ell^+)+N(\ell^-\ell^-)} \approx \frac{4\mathcal{R}e(\epsilon_B)}{1+|\epsilon_B|^2}$$

Mass eigenstates: $\left[(1+\epsilon_B)B^0 \pm (1-\epsilon_B)\bar{B}^0\right] / \sqrt{2(1+|\epsilon_B|^2)}$

$$a_{\ell\ell} = (+0.013 \pm 0.050 \pm 0.005)(1.00 \pm 0.10)$$

A_{CP} from hadronic reconstruction (PLB 490 (2000) 36): $+0.017 \pm 0.070 \pm 0.014$

Weighted average of two CLEO measurements: $\frac{Re(\epsilon_B)}{1+|\epsilon_B|^2} = +0.0035 \pm 0.0103 \pm 0.0015$

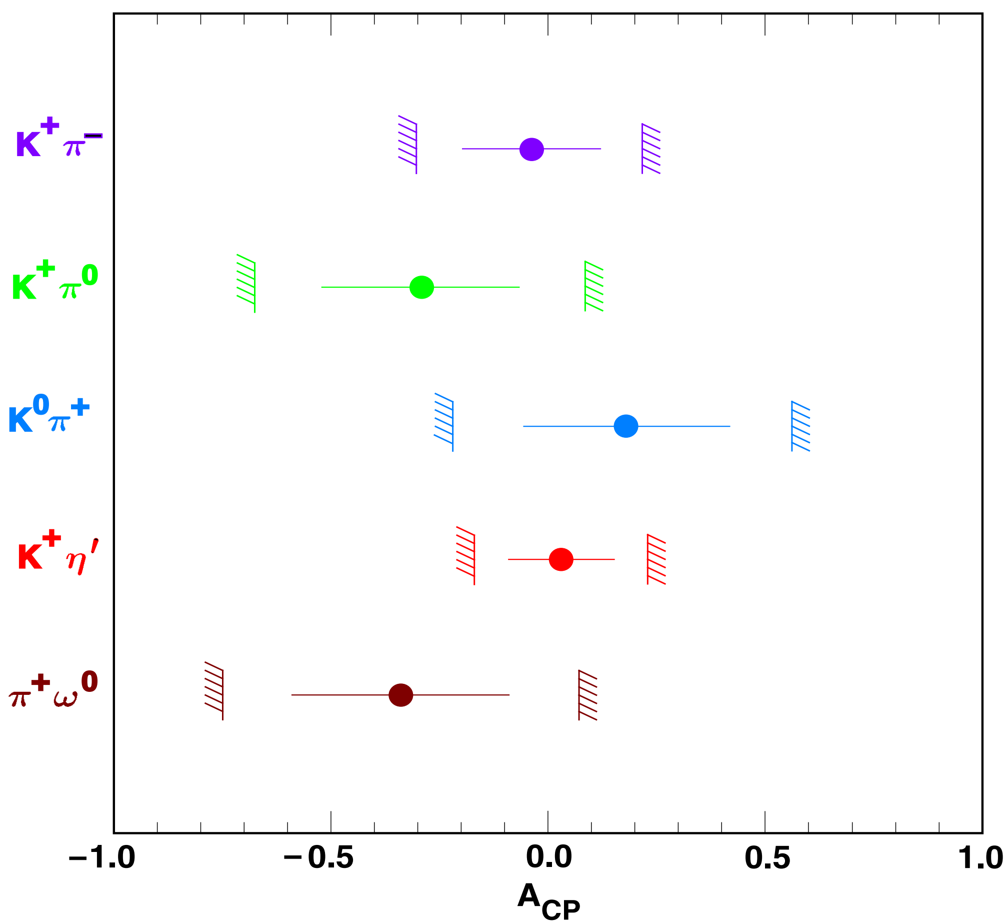
PRL 86(2001) 5000

CDF (PRD 55 (1997) 2546): $+0.025 \pm 0.062 \pm 0.032$

OPAL (Z. Phys. C 76 (1997) 401): $+0.002 \pm 0.007 \pm 0.003$

CP Asymmetries in Charmless Hadronic B Decays

Ali et al. (PRD 59 (1999) 014005): $A_{CP} < 0.1$



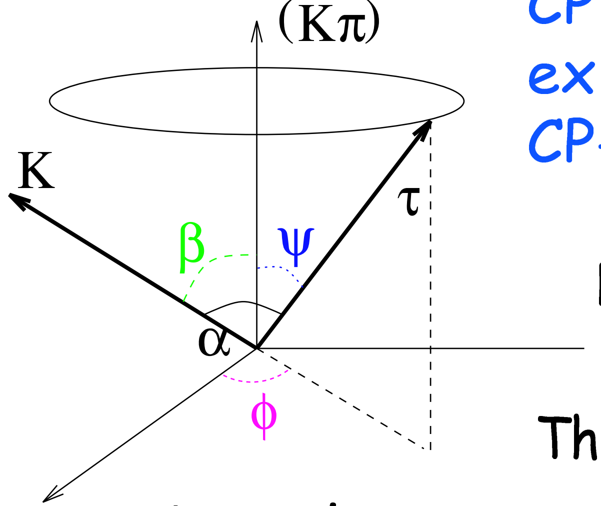
Self tagging employed

Mode	$\mathcal{A}_{CP}$
$K^{\pm}\pi^{\mp}$	-0.04 ± 0.16
$K^{\pm}\pi^{0}$	-0.29 ± 0.23
$K^{0}_{S}\pi^{\pm}$	$+0.18 \pm 0.24$
$K^{\pm}\eta'$	$+0.03 \pm 0.12$
$\omega\pi^{\pm}$	-0.34 ± 0.25

(systematics not shown)

PRL 85 (2000) 525

First CLEO Search for CPV in $\tau \to K_s \pi^- \nu$ Decays



CPV would be possible if scalar coupling existed for τ with CP-odd phase θ_{CP} and CP-even phase δ_{strong} (w.r.t. vector W coupling)

Define $A_{CP} = \dfrac{N^+(\cos\beta\cos\psi) - N^-(\cos\beta\cos\psi)}{N^+(\cos\beta\cos\psi) + N^-(\cos\beta\cos\psi)}$

Then $A_{CP} = K|F_p||F_s|g \sin\delta_{strong} \sin\theta_{cp} \cos\beta\cos\psi$

g is scalar to vector coupling strength in units of $G_F/2\sqrt{2}$

The direction of τ is not known, however, analysis is possible in terms of angles β and ψ

Effectively, $\theta_{CP} = \pi/2$ assumed

Used $K_s \pi^- \nu$ channel (signal and sideband of $K_s \to \pi^+\pi^-$ invariant mass)

	$A_{observed}(\cos\beta\cos\psi < 0)$	$A_{observed}(\cos\beta\cos\psi > 0)$
Signal	0.058 ± 0.023	0.024 ± 0.021
Sideband	0.049 ± 0.030	0.034 ± 0.033

$A^{subtracted}_{observed}(\cos\beta\cos\psi < 0) = 0.009 \pm 0.038$

$A^{subtracted}_{observed}(\cos\beta\cos\psi > 0) = -0.010 \pm 0.039$

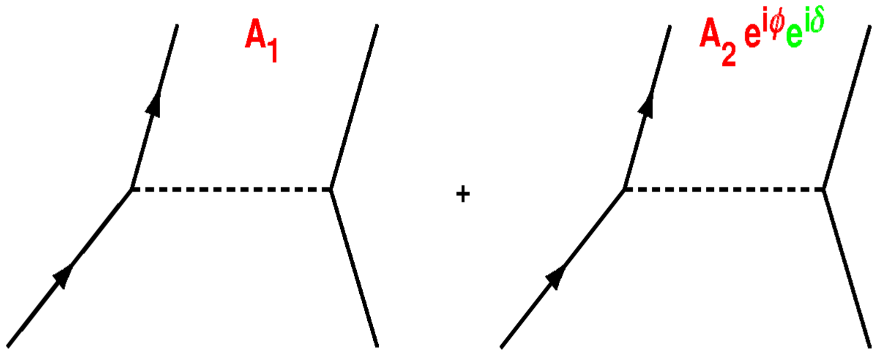
$-1.7 < g \sin\theta_{CP} < 0.6$

PRL 81 (1998) 3823

New CLEO Search for CPV in τ Decays to $\pi^-\pi^0\nu$: hep-ex/0104009

Measuring Imaginary Part of the τ Scalar Coupling

Achieving maximum sensitivity: utilize the fact that τ pairs are produced coherently and use optimal variable (D.Atwood, A.Soni, PRD 45(1992)2405)



$$\xi = \frac{\text{CP-odd term } P_{odd}}{\text{CP-even term } P_{even}}$$

$$|A|^2 = (A_1 + A_2 e^{i\phi} e^{i\delta})(A_1 + A_2 e^{-i\phi} e^{-i\delta})$$

$$= \underbrace{A_1^2 + A_2^2 + 2A_1A_2\cos\phi\cos\delta}_{\text{CP-even term } P_{even}} - \underbrace{2A_1A_2\sin\phi\sin\delta}_{\text{CP-odd term } P_{odd}}$$

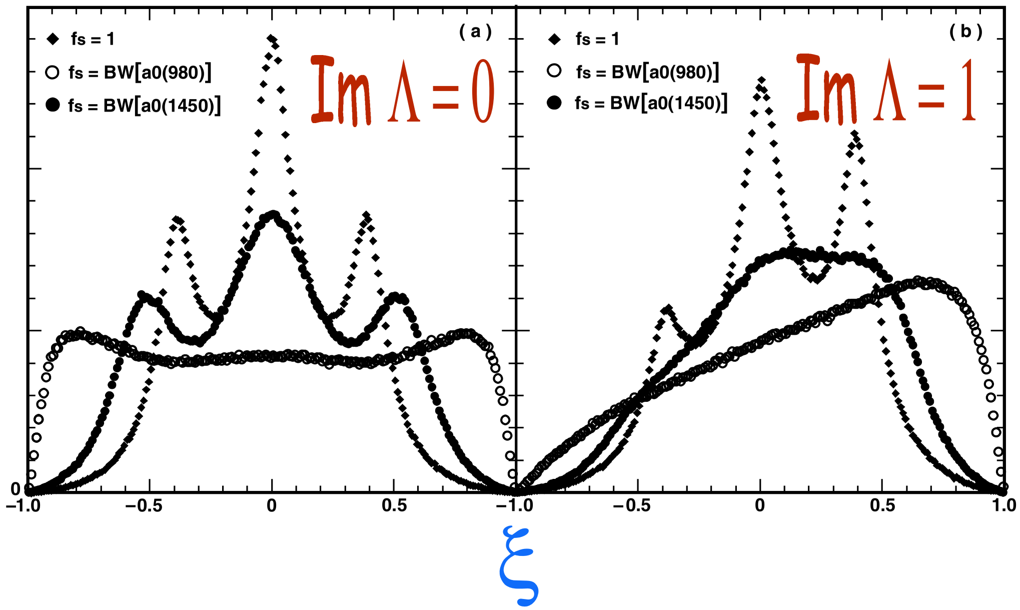
Measure $<\xi> = c \; \text{Im}\,\Lambda$, where this holds to first order for small $\text{Im}\,\Lambda$

Find c from toy MC experiments

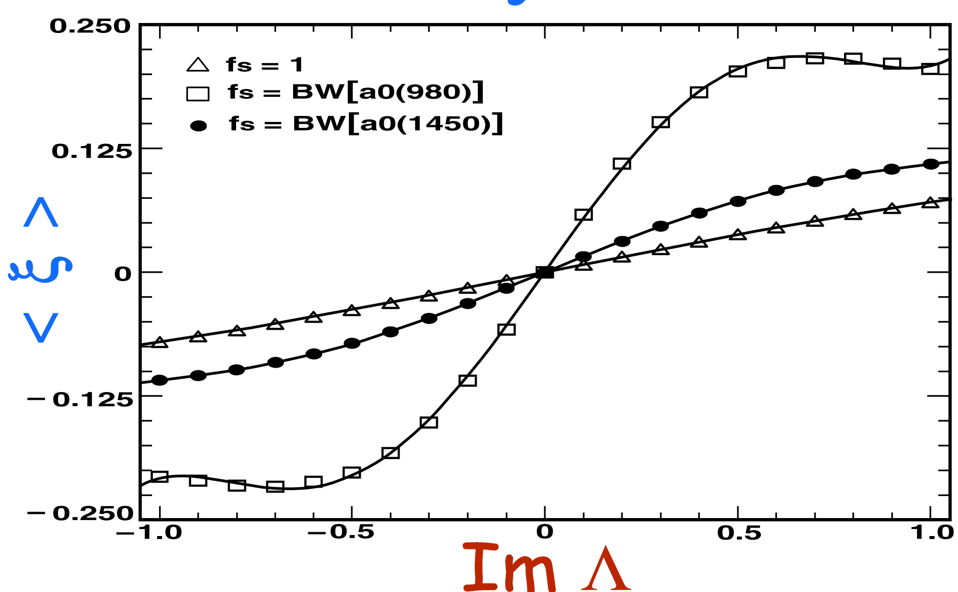
Prove absence of bias!

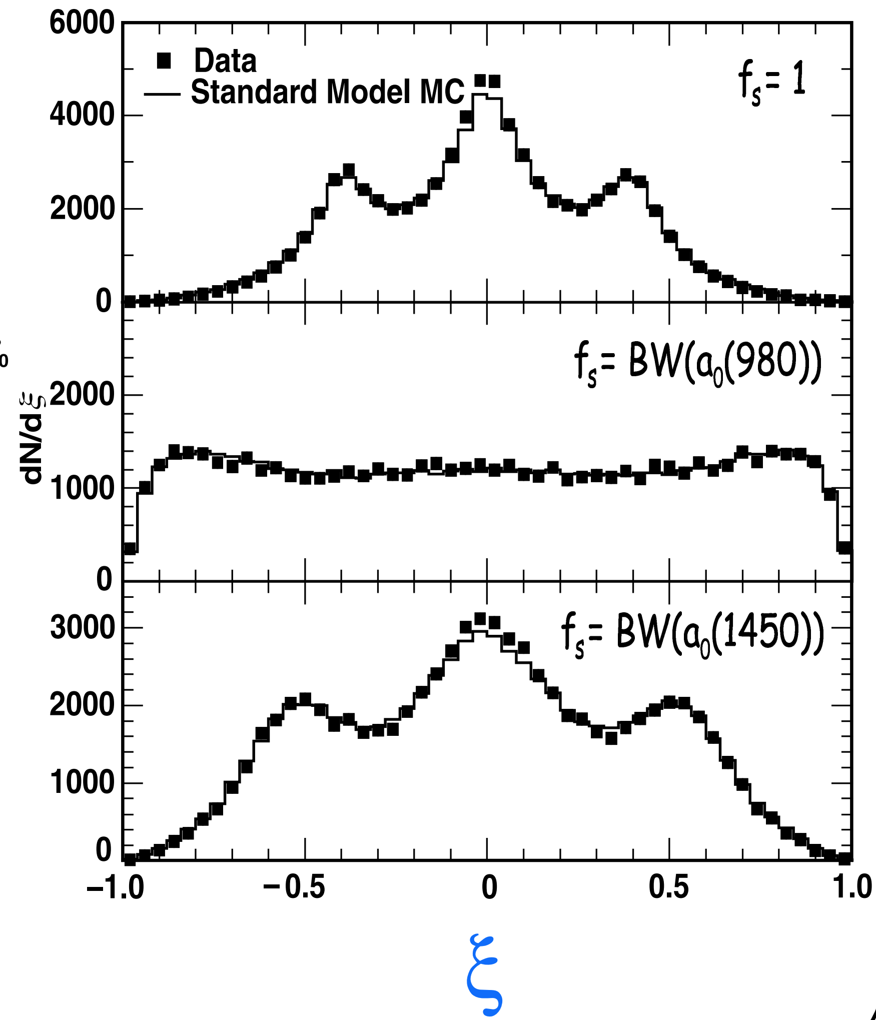
This procedure represents the data using SM and New Physics-based matrix element!

New CLEO Search for CPV in τ Decays: Check for Biases



No CPV $\longrightarrow$ $<\xi> = 0$





New CLEO Search for CPV in τ Decays: the Results

This analysis done in the framework of 3HDM (see Y. Grossman, NPB 426 (1994) 355):

$$A_H \sim \bar{u}(\nu)(1-\gamma_5)u(\tau) \underbrace{\frac{m_\tau}{m^2_{Higgs}}[m_u Z^* X - m_d Z^* Y]}_{\Lambda} \underbrace{f_s}_{|f_s|e^{i\delta_s}} M$$

$$\Lambda = \frac{m_\tau}{m^2_{Higgs}}[m_u Z^* X - m_d Z^* Y]$$

Using (most conservative) $f_s = 1$, we obtain 90% CL interval on CP violating parameter:

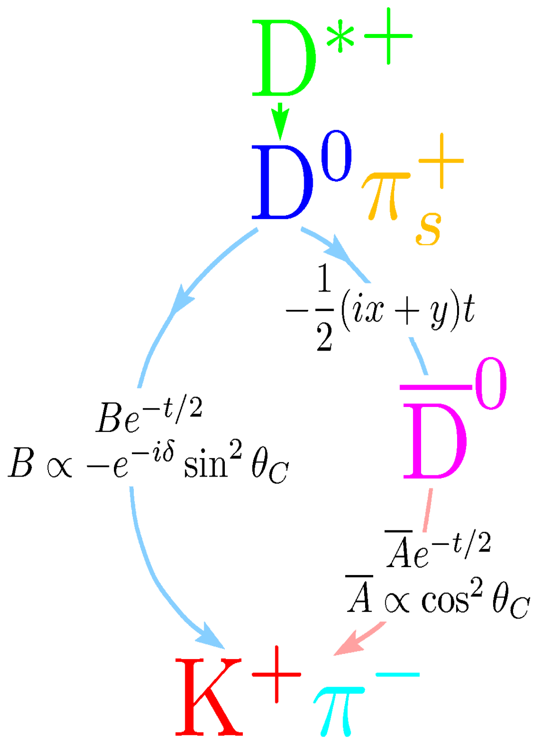
$$-0.046 < \mathrm{Im}\ \Lambda < 0.022$$

The results of the analysis in the framework of pseudo helicity are consistent with this result

To come: $K_s \pi^- \nu$ analysis using optimal variable

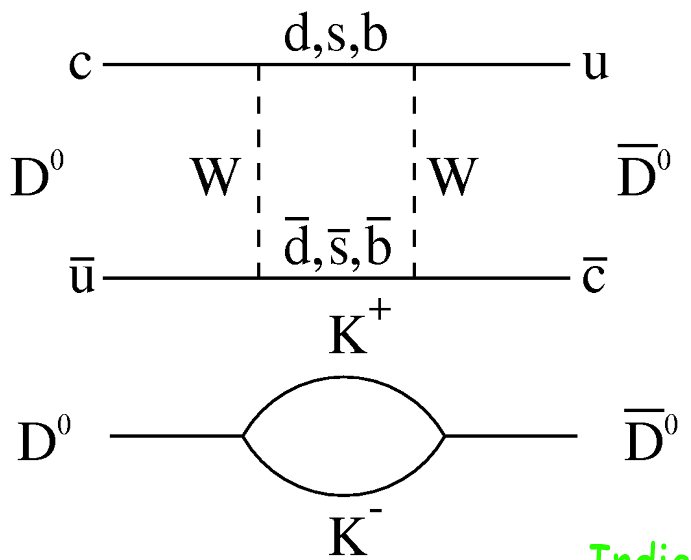
hep-ex/0104009

Mixing in $D\bar{D}$ System, D Production Mechanism and Decays



$$\frac{\partial}{\partial t}\begin{pmatrix} D^0 \\ \overline{D^0} \end{pmatrix} = \begin{bmatrix} -iM - \Gamma/2 & -iM_{12} - \Gamma_{12}/2 \\ -iM_{12}^{*} - \Gamma_{12}^{*}/2 & -iM - \Gamma/2 \end{bmatrix} \begin{pmatrix} D^0 \\ \overline{D^0} \end{pmatrix}$$

$$\Delta\Gamma = \Gamma_2 - \Gamma_1$$
$$\Gamma = \frac{\Gamma_1+\Gamma_2}{2}$$



$$x \equiv \frac{2M_{12}}{\Gamma} \rightarrow x = \frac{\Delta M}{\Gamma}$$
$$y \equiv \frac{\Gamma_{12}}{\Gamma} \rightarrow y = \frac{\Delta\Gamma}{2\Gamma}$$

$$y_{CP} = \frac{\Gamma_2}{\Gamma} - 1$$

$$r_{\rm ws}(t) = |[\frac{B}{\overline{A}} - \frac{1}{2}(ix+y)t]e^{-t/2}|^2$$
$$= [R_D + \sqrt{R_D}(y\cos\delta - x\sin\delta)t + \frac{1}{4}(x^2+y^2)t^2]e^{-t}$$
$$= [R_D + \sqrt{R_D}\; y' \; t + \frac{1}{4}(x'^2+y'^2)t^2]e^{-t}$$

Indication of large strong phase:

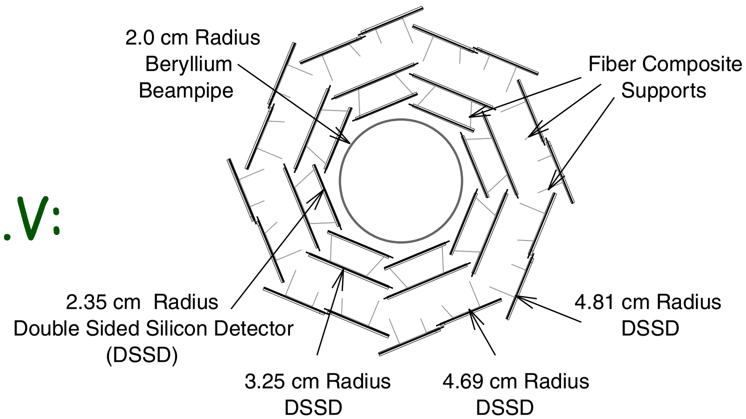
$$R = \frac{D^0 \rightarrow K^+K^-}{D^0 \rightarrow \pi^+\pi^-} = 2.80 \pm 0.20$$

$$R_{\rm WS} = \int_0^\infty r(t)dt = R_D + \sqrt{R_D}\, y' + \frac{1}{2}(x'^2 + y'^2)$$

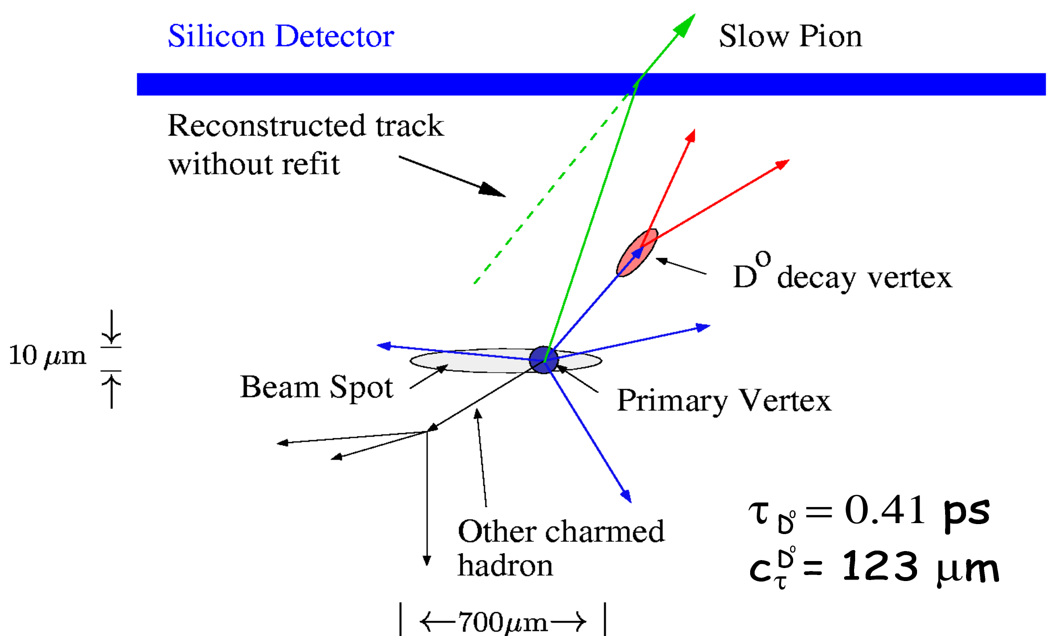
What we measure
Interpretation Framework
How we interpret our results

Experimental Technique, Assumptions and Relevant Quantities

SVX at CLEO II.V:



$(Q \equiv M(D^0_{\rm cand}\pi^+_S) - M(D^0_{\rm cand}) - M_\pi)$



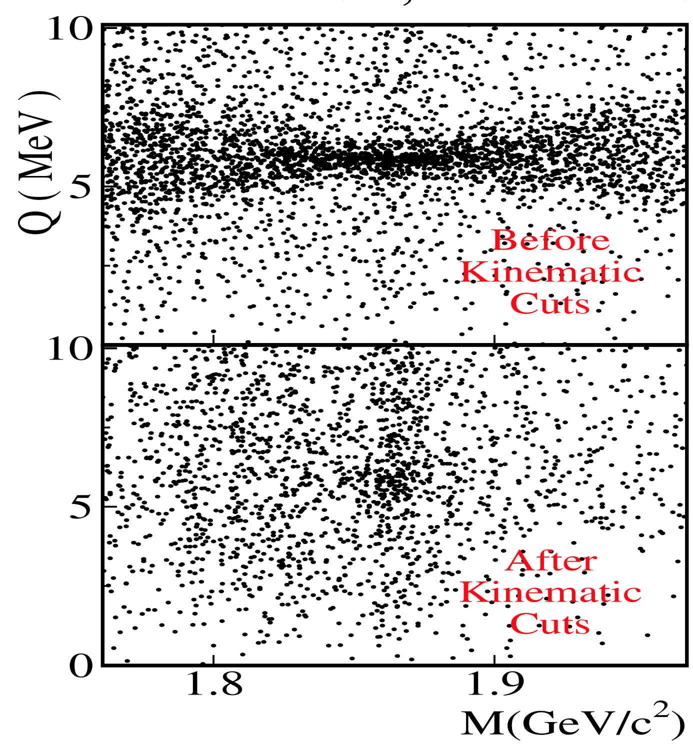
$\tau_{D^0} = 0.41$ ps

$c\tau_{D^0} = 123$ μm

Slow pion tagging technique

$$D^{*+} \to D^0 + \pi^+$$
$$D^{*-} \to \bar{D}^0 + \pi^-$$

$D^{*+} \to D^0\pi^+,\ D^0 \to K^+\pi^-$



CP Violation in D^0 Decays to Pairs of Pseudoscalar Mesons

$$A = \frac{\Gamma\left(D^0 \to f\right) - \Gamma\left(\overline{D^0} \to f\right)}{\Gamma\left(D^0 \to f\right) + \Gamma\left(\overline{D^0} \to f\right)}$$

$$A^f = \frac{\Gamma\left(D^{\star +} \to \pi_s^+ f\right) - \Gamma\left(D^{\star -} \to \pi_s^- f\right)}{\Gamma\left(D^{\star +} \to \pi_s^+ f\right) + \Gamma\left(D^{\star -} \to \pi_s^- f\right)}$$

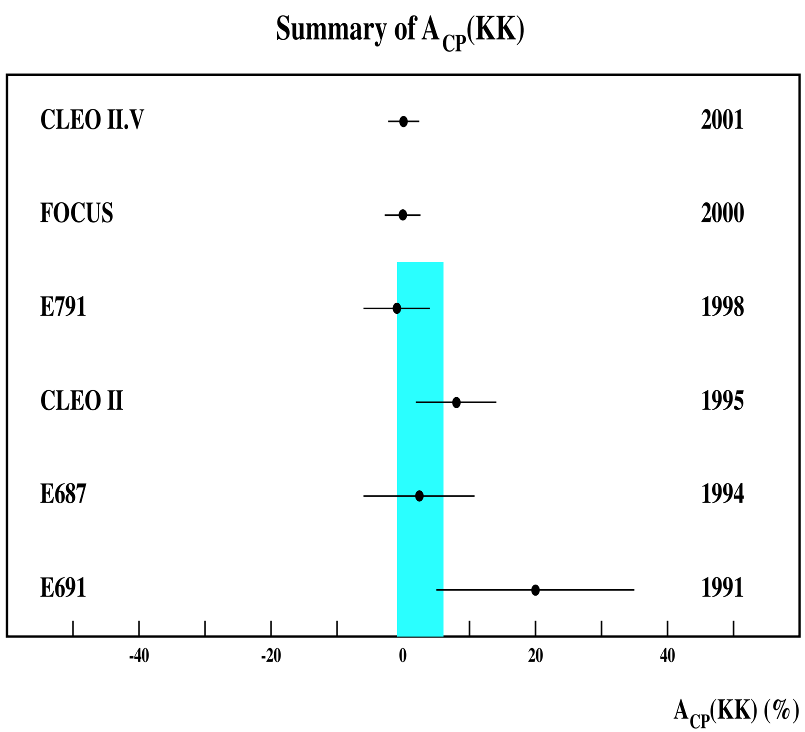
PRD 63 (2000) 071101 (R)

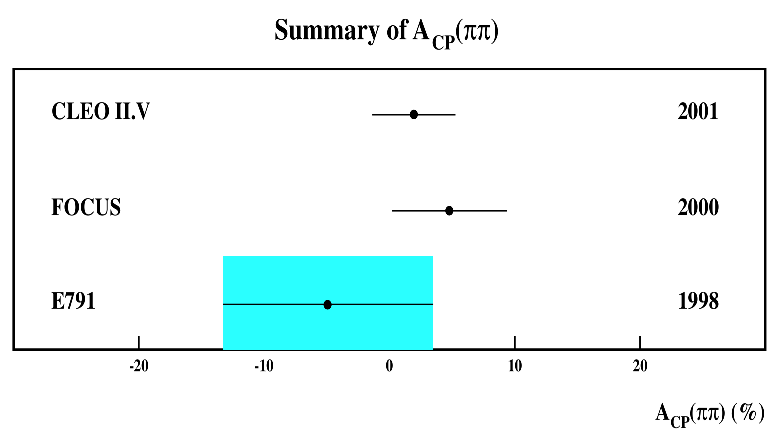
hep-ex/0105002

$A_{CP}(K_S\pi^0) = (+0.1 \pm 1.3)\%$

$A_{CP}(\pi^0\pi^0) = (+0.1 \pm 4.8)\%$

$A_{CP}(K_S K_S) = (-23 \pm 19)\%$





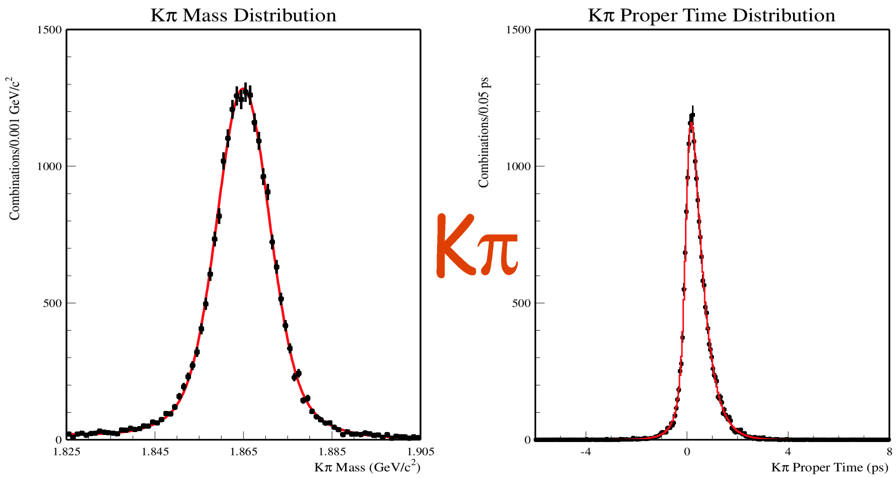
New Fits to D^0 Proper Time and y Measurement

Time evolution of CP eigenstate: $R(t) \sim e^{-\Gamma(1-\eta_{CP} y_{CP})t}$

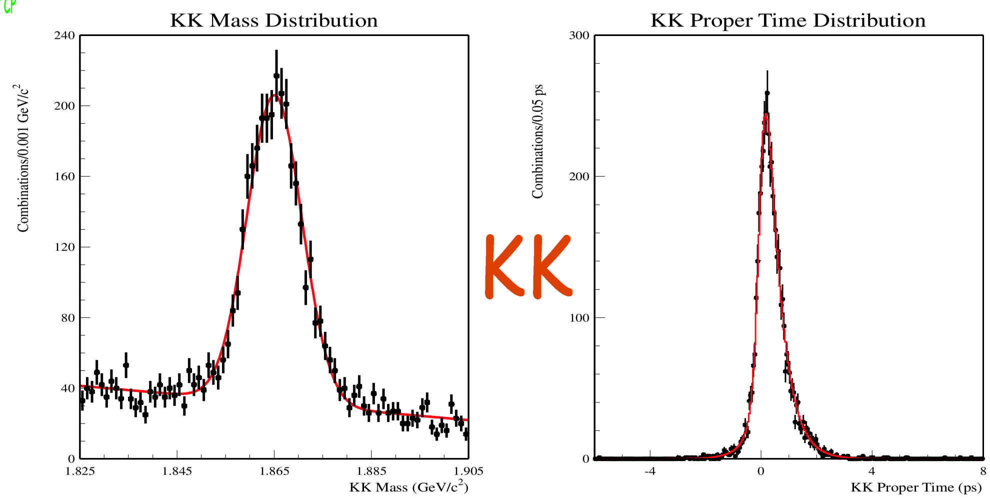
Time evolution of a mixed CP state: $R(t) \sim e^{-\Gamma t}$

$y_{CP} = \Delta\Gamma / 2\Gamma$

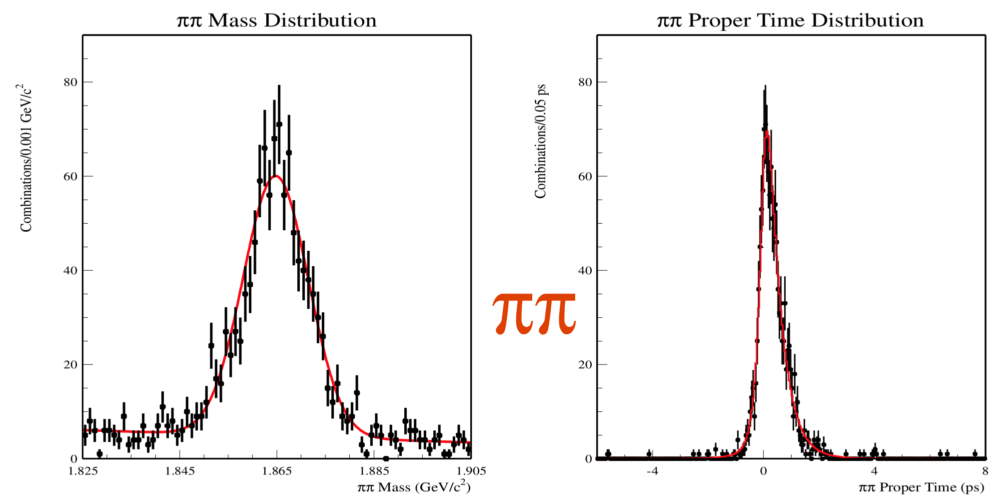
η_{CP} – CP eigenvalue



Kπ



KK



ππ

$$y_{KK} = -0.019 \pm 0.029(\text{stat}) \pm 0.016(\text{syst})$$

$$y_{\pi\pi} = 0.005 \pm 0.043(\text{stat}) \pm 0.018(\text{syst})$$

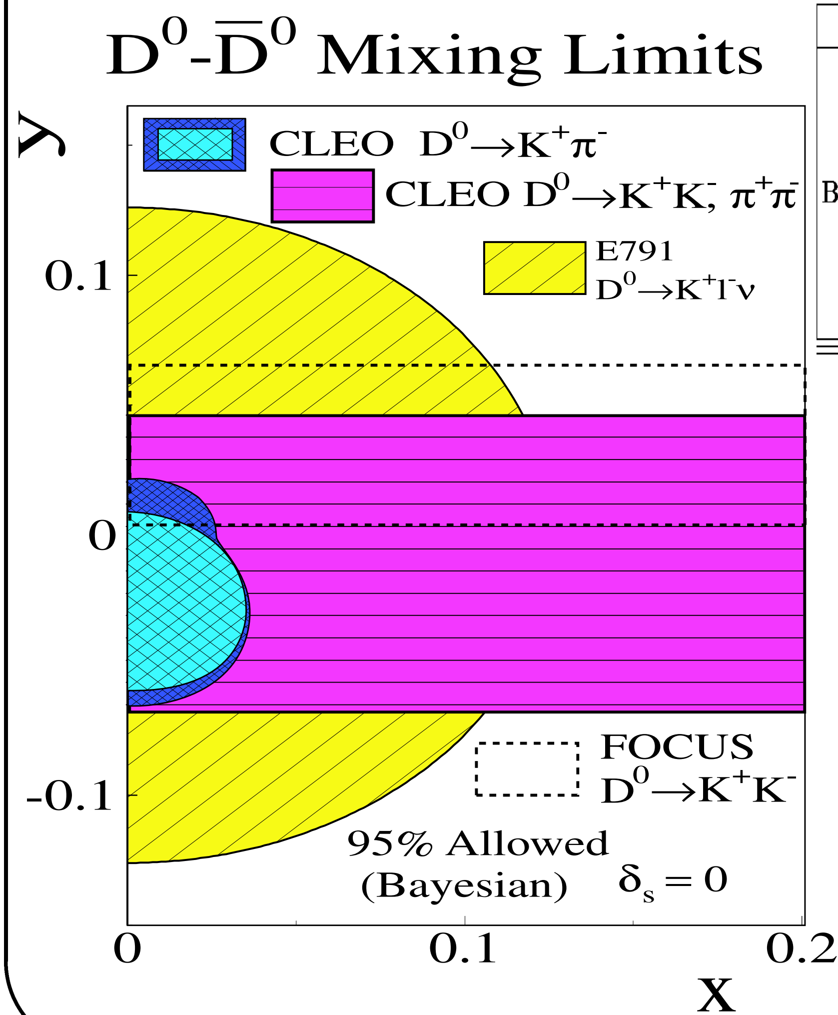
$$y_{CP} = -0.011 \pm 0.025(\text{stat}) \pm 0.014(\text{syst})$$

CLEO CONF 01-1: preliminary results

http://www.lns.cornell.edu/public/CONF/2001/

New Fits to D^0 Proper Time and y Measurement (cont.)

$$y_{CP} = -0.011 \pm 0.025(\text{stat}) \pm 0.014(\text{syst})$$



Parameter	$K\pi$	KK	$\pi\pi$
Number of Signal	20272 ± 178	2463 ± 65	930 ± 37
τ_{sig} (ps)	0.4046 ± 0.0036	0.411 ± 0.012	0.401 ± 0.017
Background Frac (%)	8.8 ± 0.2	50.7 ± 0.7	29.1 ± 1.3
Background Life Frac (%)	81.0 ± 4.8	85.7 ± 2.9	32.2 ± 7.5
τ_{back} (ps)	0.376 ± 0.030	0.436 ± 0.020	0.56 ± 0.15
f_{mis} %	3.8 ± 0.9	Fixed	Fixed
σ_{mis} (ps)	0.590 ± 0.079	Fixed	Fixed

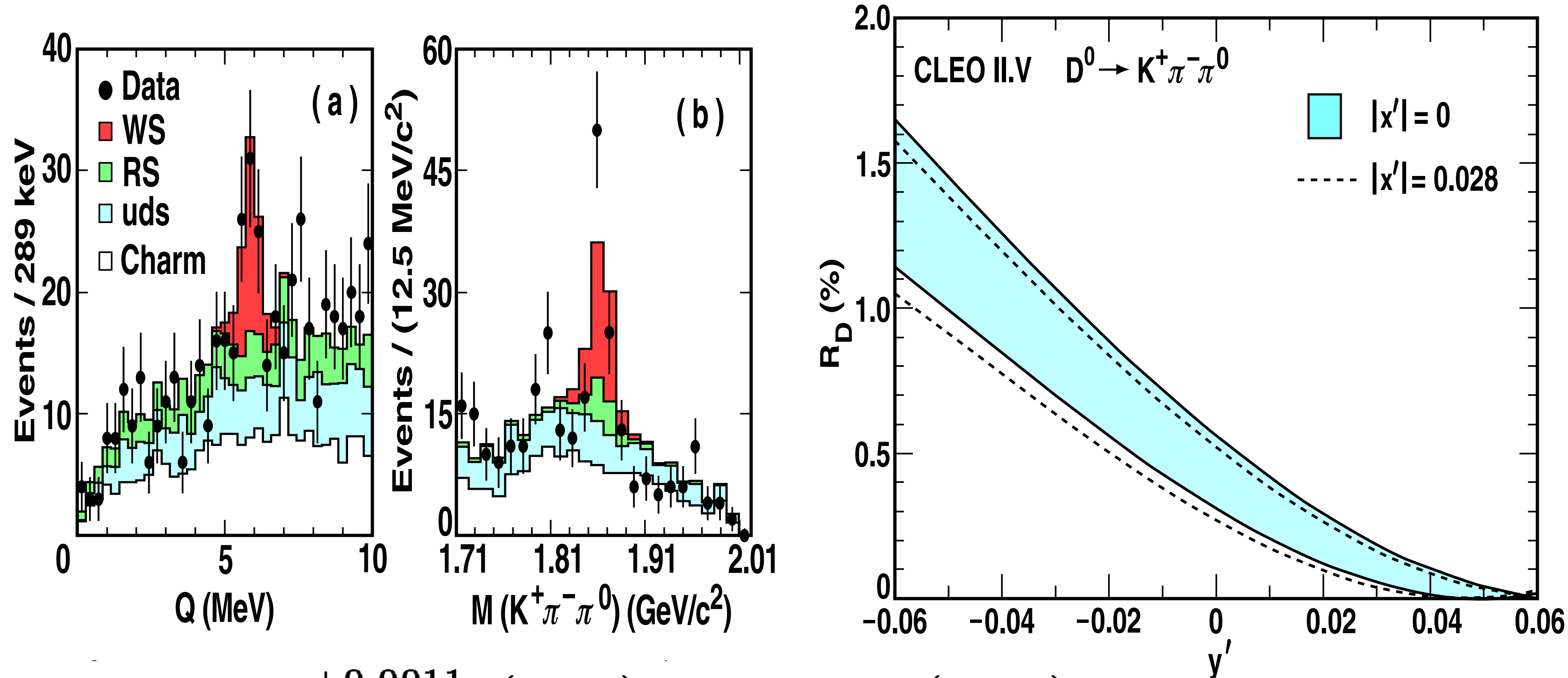
Sources of systematics

Stat. uncertainty in (MC) studies of small corrections
Description of background contributions
Uncertainty in proper time resolution function
Fit procedure uncertainties

CLEO CONF 01-1: preliminary results
http://www.lns.cornell.edu/public/CONF/2001/

First Measurement of "Wrong-Sign" $D^0 \to K^+\pi^-\pi^0$ Rate

$$R \equiv \frac{\Gamma(D^0 \to K^+\pi^-\pi^0)}{\Gamma(\overline{D^0} \to K^+\pi^-\pi^0)} = R_D + \sqrt{R_D}y' + \frac{1}{2}(x'^2 + y'^2)$$



$$R = 0.0043^{+0.0011}_{-0.0010}\ (\text{stat}) \pm 0.0007\ (\text{syst})$$

hep-ex/0105002

Assume no mixing: $R_D = (1.7 \pm 0.4\ (\text{stat}) \pm 0.3\ (\text{syst})) \cdot \tan^4 \theta_C$

New Results on FCNC Decays $B \to K^{(*)} l^+ l^-$

Sensitive to New Physics (i.e. phenomena that not in the Standard Model)

Is better than $K^* \gamma$: at large dilepton mass no hadronic uncertainties

Selection criteria optimized for discovery and best upper limits (took average)

Fisher discriminant techique employed to suppress backgrounds

Blind analysis

Making best of what we know about CLEO

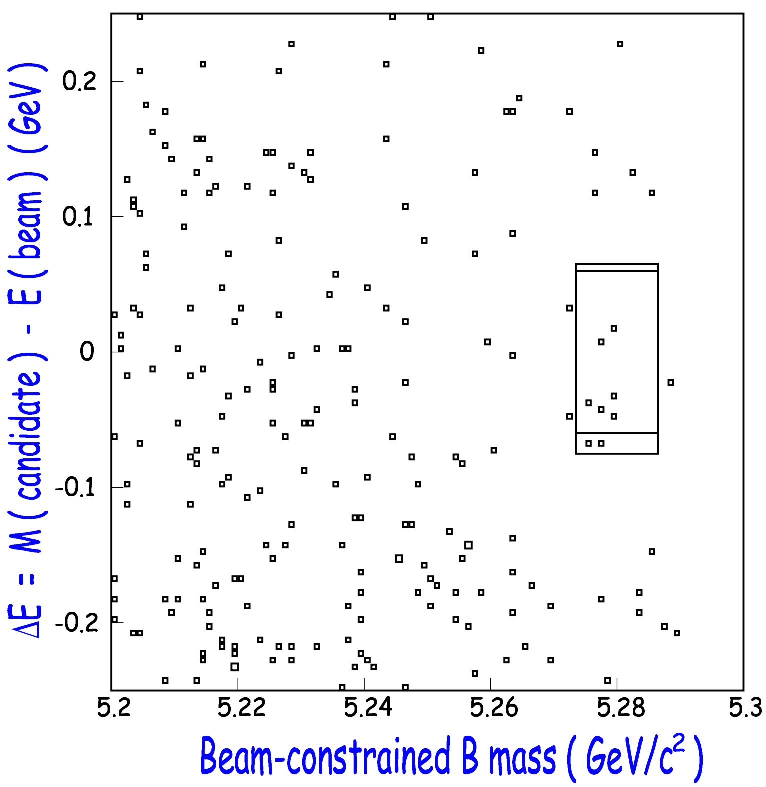
To suppress virtual $K^* \gamma$ $M(l^+ l^-) > 500\ MeV/c^2$

Efficiency-weighted sum for best limit

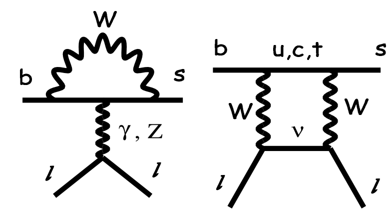
mode	$\mathcal{F}$ cut	observed events	background	efficiency	$\mathcal{B}$ lim.$\times 10^6$
$K^0 e^+ e^-$	0.938	1	0.096	0.053	7.6
$K^0 \mu^+ \mu^-$	0.925	0	0.207	0.031	7.8
$K^+ e^+ e^-$	0.925	1	0.947	0.161	2.3
$K^+ \mu^+ \mu^-$	0.850	1	0.737	0.111	3.4
$K \ell^+ \ell^-$		3	1.99 $\pm$0.35	0.356	1.54
$K^0 \pi^+ e^+ e^-$	0.925	0	0.349	0.019	12.8
$K^0 \pi^+ \mu^+ \mu^-$	0.900	0	0.268	0.015	15.6
$K^+ \pi^0 e^+ e^-$	0.800	3	0.268	0.015	46.0
$K^+ \pi^0 \mu^+ \mu^-$	0.750	0	0.490	0.008	29.3
$K^+ \pi^- e^+ e^-$	0.925	1	0.966	0.073	5.0
$K^+ \pi^- \mu^+ \mu^-$	0.875	0	1.241	0.053	4.6
$K^0 \pi^0 e^+ e^-$	0.900	0	0.113	0.007	35.8
$K^0 \pi^0 \mu^+ \mu^-$	0.750	0	0.101	0.002	117.3
$K^* \ell^+ \ell^-$		4	3.80$\pm$0.57	0.192	2.88
Sum		7	5.79$\pm$0.83	0.548	1.38

MC based on work of Ali et al. (PRD 61(2000) 074024)

New Results on FCNC Decays $B \to K^{(*)} l^+ l^-$



Major sources of background are real dileptons:
1) J/ψ and ψ(2S)
2) dileptons from continuum
3) dileptons from BB decays



Solutions: 1) vetoes, 2) Fisher discriminant and 3) missing energy (semileptonic decays)

Internal and external bremsstrahlung recovery employed

Signal boxes shown (shifted by 5 MeV for electrons)

Almost no model dependence in efficiency

FCNC Decays $B \to K^{(*)} l^+ l^-$:
(90% CL upper limits, preliminary)

$\mathcal{B}(B \to K\ell^+\ell^-) < 1.7 \times 10^{-6}$

$\mathcal{B}(B \to K^*(892)\ell^+\ell^-)_{m_{\ell\ell}>0.5\mathrm{GeV}} < 3.2 \times 10^{-6}$

$0.65\mathcal{B}(B \to K\ell^+\ell^-) + 0.35\mathcal{B}(B \to K^*(892)\ell^+\ell^-)_{m_{\ell\ell}>0.5\mathrm{GeV}} < 1.5 \times 10^{-6}$

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50% above SM prediction!

Conclusions

B

$b \to s\gamma$: $\mathcal{A}_{CP} = (-0.079 \pm 0.108 \pm 0.022)(1.0 \pm 0.030)$, $\mathcal{A}_{CP}$ lies between -0.27 and 0.030)

$A_{CP}(B \to K^*\gamma) = +0.08 \pm 0.13$

Mode	$\mathcal{A}_{CP}$
$K^\pm\pi^\mp$	-0.04 ± 0.16
$K^\pm\pi^0$	-0.29 ± 0.23
$K^0_S\pi^\pm$	$+0.18 \pm 0.24$
$K^\pm\eta'$	$+0.03 \pm 0.12$
$\omega\pi^\pm$	-0.34 ± 0.25

$A_{CP}(B^\pm \to J/\psi K^\pm) = (+1.8 \pm 4.3[\text{stat}] \pm 0.4[\text{syst}])\%$
$A_{CP}(B^\pm \to \psi(2S) K^\pm) = (+2.0 \pm 9.1[\text{stat}] \pm 1.0[\text{syst}])\%$

Dileptons from $B^0\bar{B}^0$: $Re(\epsilon_B)/(1+|\epsilon_B|^2) = +0.0035 \pm 0.0103 \pm 0.0015$

τ

Imaginary part of the τ scalar coupling (at 90% CL): $-0.046 < \text{Im}\ \Lambda < 0.022$

D

A_{CP} in D^0 Decays:

$(K^0_S\pi^0) = (+0.1 \pm 1.3\ (\text{stat}+\text{syst}))\%$
$(\pi^0\pi^0) = (+0.1 \pm 4.8\ (\text{stat}+\text{syst}))\%$
$(K^0_S K^0_S) = (-23 \pm 19\ (\text{stat}+\text{syst}))\%$
$(K^+K^-) = 0.0005 \pm 0.0218\ (\text{stat}) \pm 0.0084\ (\text{syst})$
$(\pi^+\pi^-) = 0.0195 \pm 0.0322\ (\text{stat}) \pm 0.0084\ (\text{syst})$

"Wrong-sign" $D^0 \to K^+\pi^-\pi^0$ Rate:

$R_{WS} = (0.43^{+0.11}_{-0.10}\ (\text{stat.}) \pm 0.07\ (\text{syst.}))\%$

y from D^0 Proper Time Measurement: $-0.011 \pm 0.025\ (\text{stat}) \pm 0.014\ (\text{syst})$

FCNC Decays $B \to K^{(*)} l^+ l^-$:

$\mathcal{B}(B \to K\ell^+\ell^-) < 1.7 \times 10^{-6}$
$\mathcal{B}(B \to K^*(892)\ell^+\ell^-)_{m_{\ell\ell}>0.5\text{GeV}} < 3.2 \times 10^{-6}$
$0.65\mathcal{B}(B \to K\ell^+\ell^-) + 0.35\mathcal{B}(B \to K^*(892)\ell^+\ell^-)_{m_{\ell\ell}>0.5\text{GeV}} < 1.5 \times 10^{-6}$