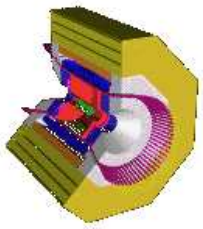


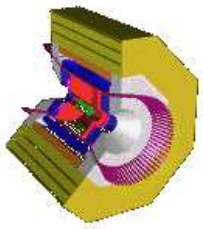
Results on B to charmonia decays from CLEO

Yongsheng Gao
Southern Methodist University
CLEO Collaboration

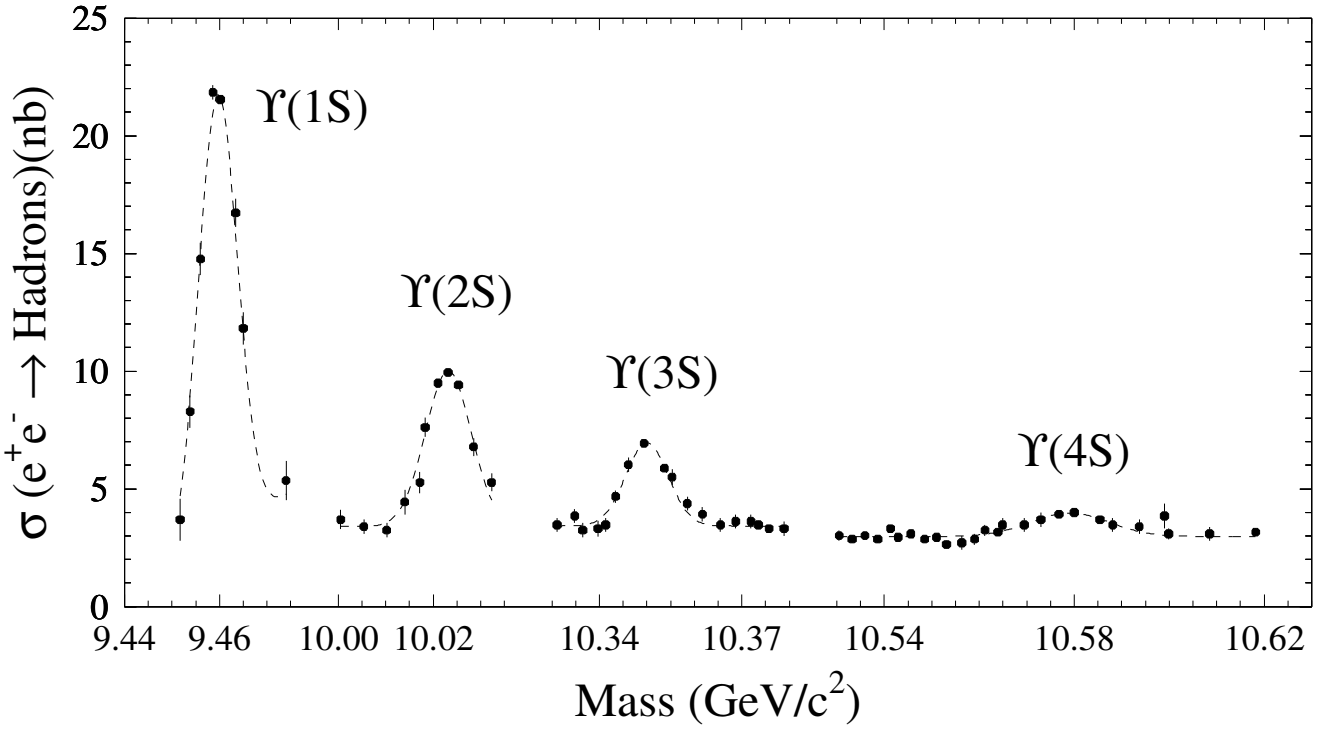
August 2000 at DPF2000

Outline

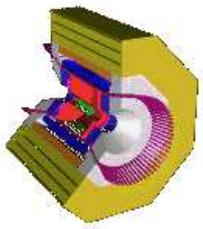
- CESR and CLEO
- Results on $B^0 \to J/\psi\, K^0_S$, $\chi_{c1}\, K^0_S$, and $J/\psi\, \pi^0$
- Search for direct CP violation in $B^\pm \to J/\psi\, K^\pm$ and $B^\pm \to \psi(2S)\, K^\pm$
- Observation of $B \to J/\psi\, \phi\, K$, $\eta_c\, K$
- Study of χ_{c1}, χ_{c2} production in B decays
- Measurement of $f_{+-}/f_{00} \equiv \mathcal{B}[\Upsilon(4S) \to B^+B^-]/\mathcal{B}[\Upsilon(4S) \to B^0\overline{B}^0]$



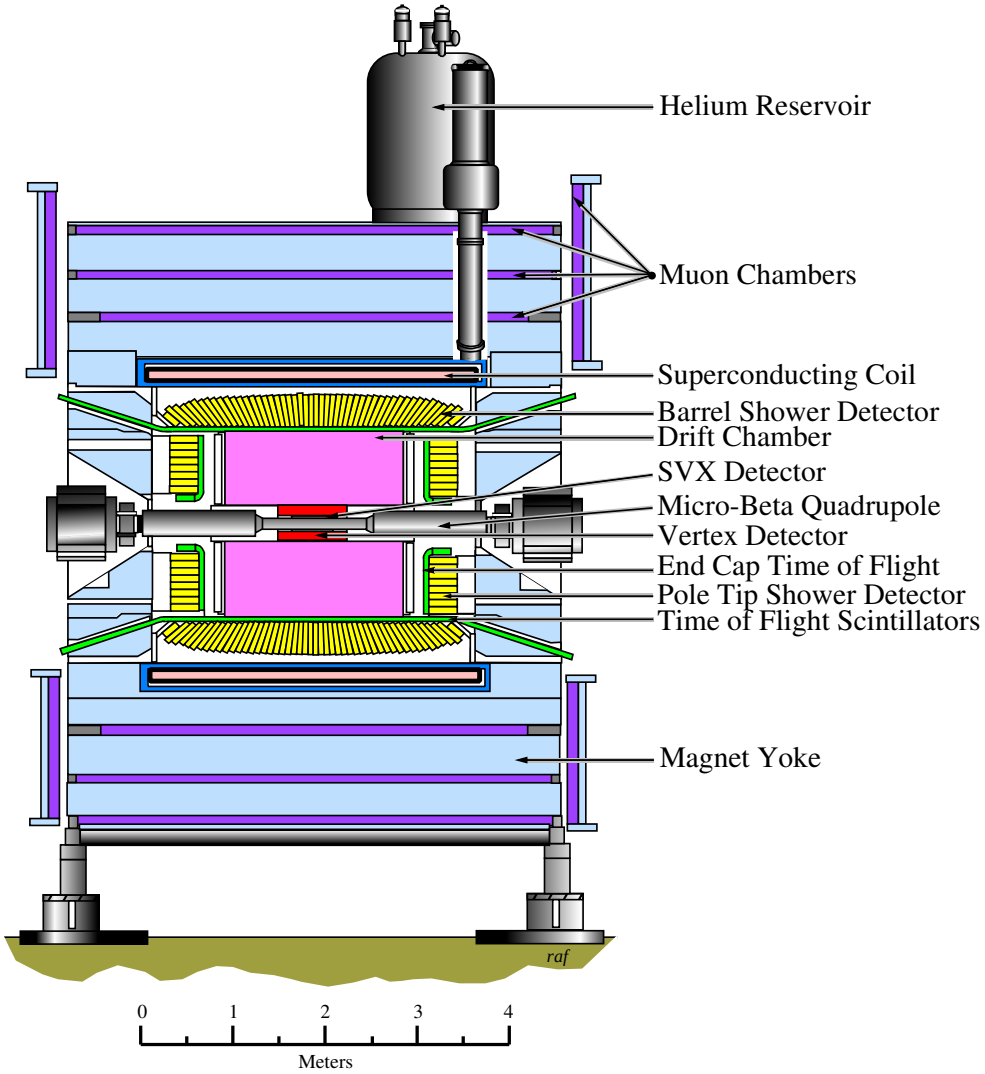
Cornell Electron-positron Storage Ring



- Symmetric e^+e^- machine operating at the $\Upsilon(4S)$
- Total intergrated luminosity: ~ 14 fb^{-1}:
  - 9.2 fb^{-1} on $\Upsilon(4S)$ N($B\overline{B}$)$= 9.7 \times 10^6$
  - 4.6 fb^{-1} below $B\overline{B}$ threshold



CLEO Detector



CLEO II

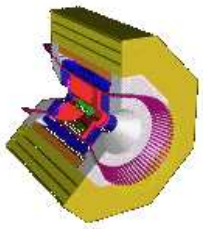
- Oct.'89 – Apr.'95
- N($B\overline{B}$)= 3.3×10^6
- 6-layer straw tube

CLEO II.V

- Nov.'95 – Feb.'99
- N($B\overline{B}$)= 6.4×10^6
- 3-layer Si vertex detector

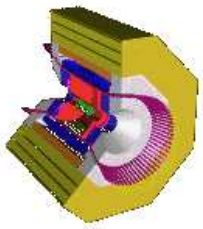
CLEO III

- 2000 –
- New SVX, DR and RICH

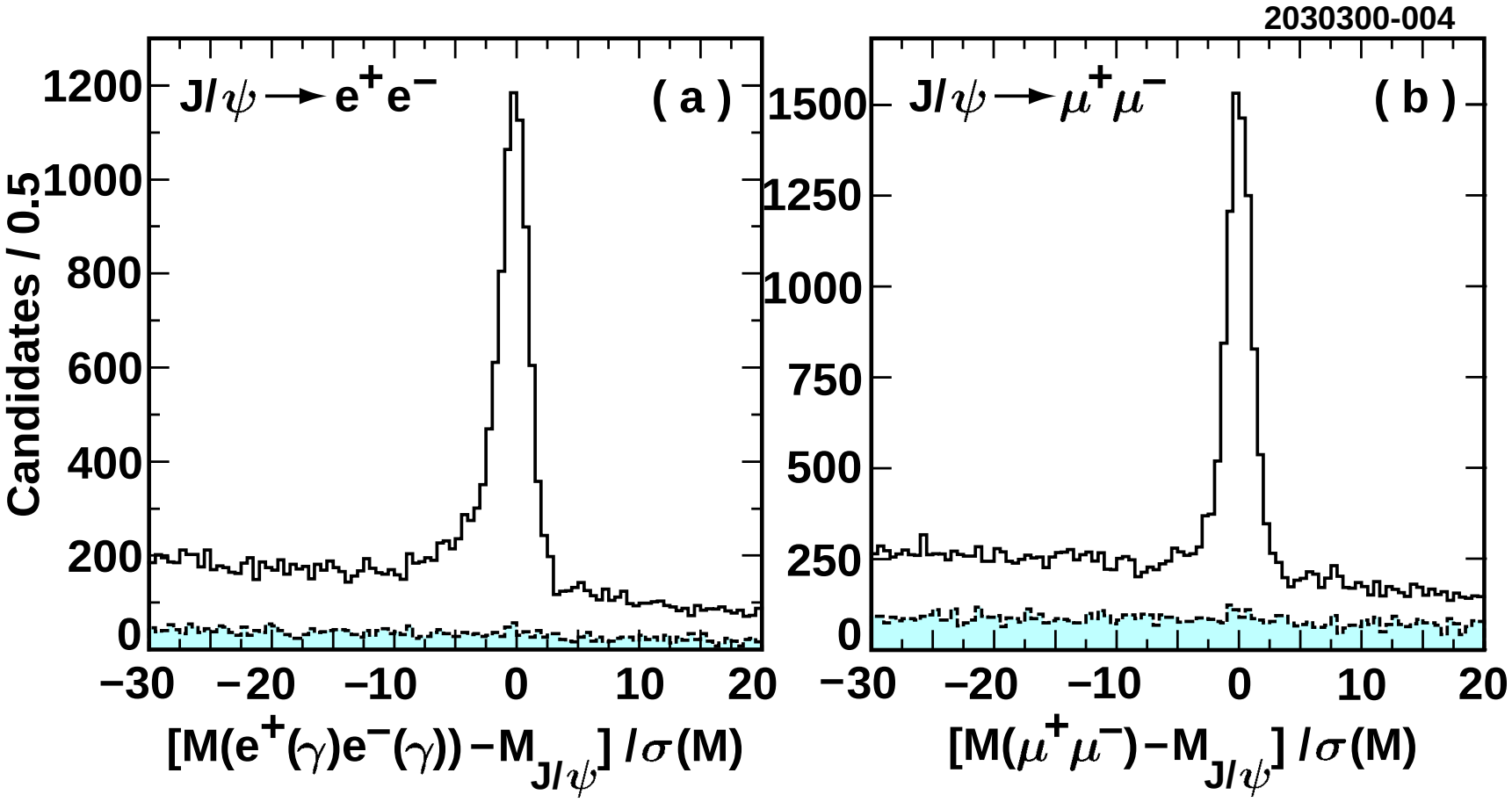


B^0 decays for $\sin 2\beta$ measurements

- $B^0 \to J/\psi K^0_S$ where $K^0_S \to \pi^+\pi^-$
  - Golden decay mode for $\sin 2\beta$ measurement
- $B^0 \to J/\psi K^0_S$ where $K^0_S \to \pi^0\pi^0$
  - Add $\sim 15\%$ more statistics in $\sin 2\beta$ measurement
- $B^0 \to \chi_{c1} K^0_S$
  - Exactly like $J/\psi K^0_S$ for $\sin 2\beta$ measurement
- $B^0 \to J/\psi \pi^0$
  - Tree-Penguin interference
  - May allow resolution of the β and $\beta + \pi$ ambiguity
  - Grossman and Quinn, hep-ph/9705356

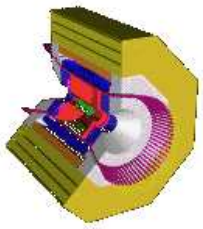


$J/\psi \to \ell^+\ell^-$ signal

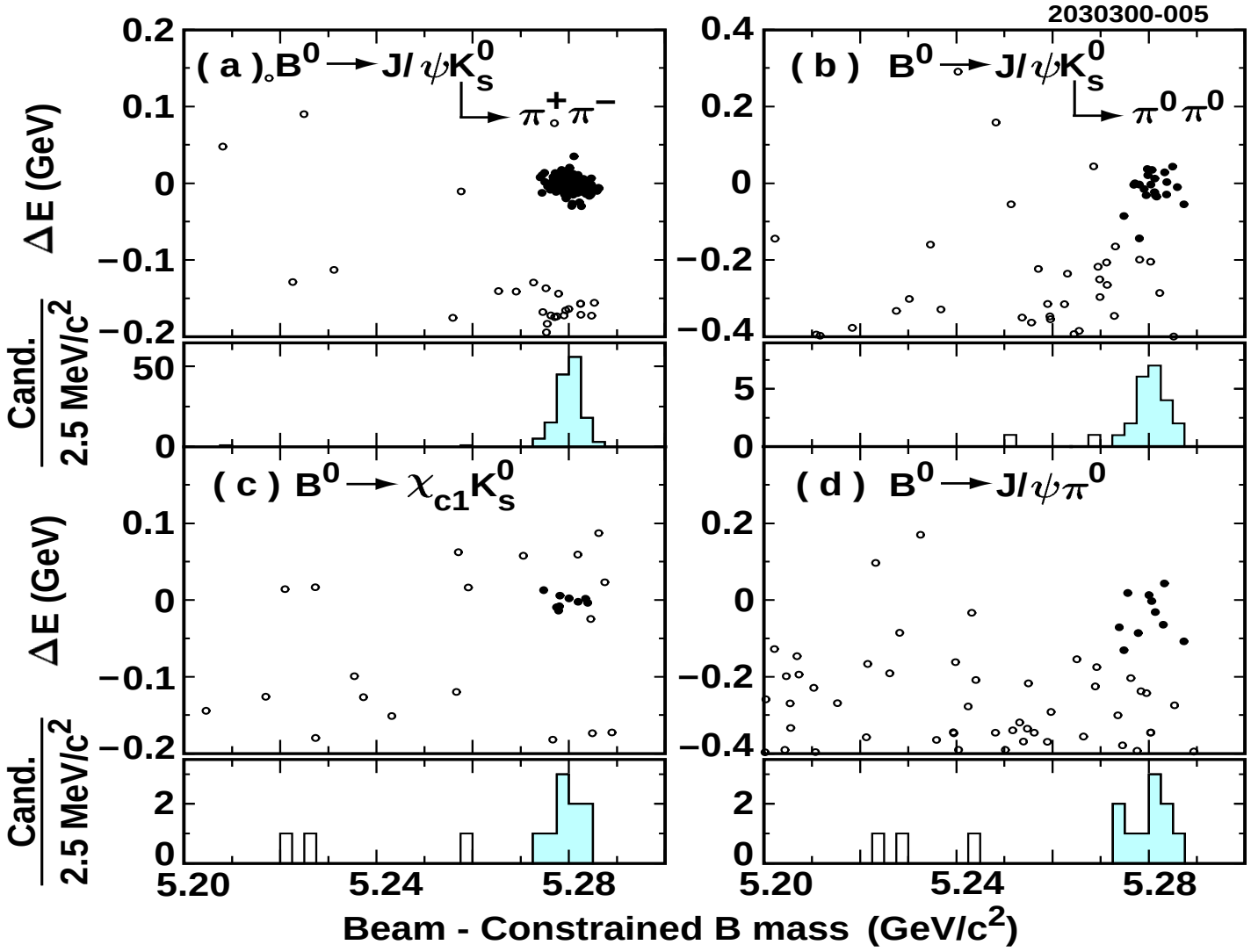


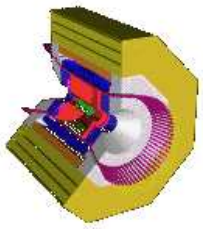
Bremsstrahlung photons from $J/\psi \to e^+e^-$ are detected in CsI calorimeter and used in invariant mass calculation

$\epsilon(J/\psi \to e^+e^-)$ increases by 25% without adding more back ground



Observation of $B^0 \to J/\psi K^0_S(\pi^0\pi^0)$, $\chi_{c1}K^0$ and $J/\psi\pi^0$

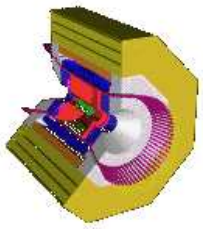




Observation of $B^0 \to J/\psi K^0_S(\pi^0\pi^0)$, $\chi_{c1}K^0$ and $J/\psi\pi^0$

	Decay mode	Signal	Background	Efficiency (%)	$\mathcal{B}$ ($\times 10^{-4}$)
	$B^0 \to J/\psi\, K^0$				$9.5 \pm 0.8 \pm 0.6$
Update	$K^0_S \to \pi^+\pi^-$	142	0.3 ± 0.2	37.0 ± 2.3	$9.8 \pm 0.8 \pm 0.7$
New	$K^0_S \to \pi^0\pi^0$	22	1.1 ± 0.3	13.9 ± 1.1	$8.4^{+2.1}_{-1.9} \pm 0.7$
New	$B^0 \to \chi_{c1}\, K^0$	9	0.9 ± 0.3	19.2 ± 1.3	$3.9^{+1.9}_{-1.3} \pm 0.4$
New	$B^0 \to J/\psi\, \pi^0$	10	1.0 ± 0.5	31.4 ± 2.2	$0.25^{+0.11}_{-0.09} \pm 0.02$

Results can be found in hep-ex/0004032

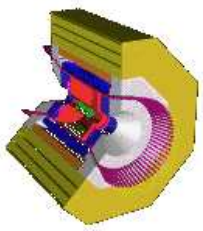


Search for direct CP violation in $B^{\pm} \to \psi^{(\prime)} K^{\pm}$

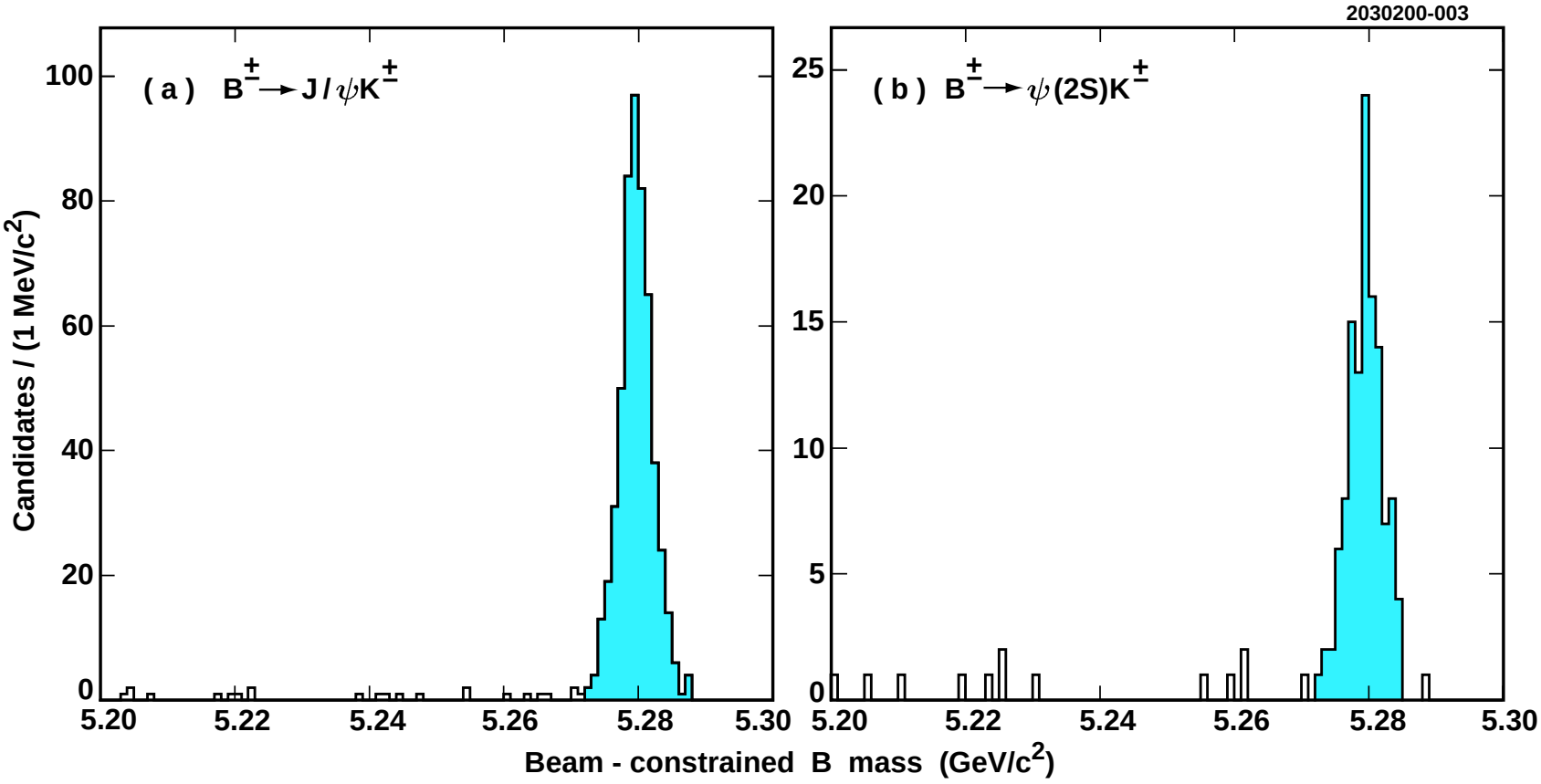
$$\mathcal{A}_{CP} \equiv \frac{\mathcal{B}(B^- \to \psi^{(\prime)} K^-) - \mathcal{B}(B^+ \to \psi^{(\prime)} K^+)}{\mathcal{B}(B^- \to \psi^{(\prime)} K^-) + \mathcal{B}(B^+ \to \psi^{(\prime)} K^+)} = \frac{b - \overline{b}}{b + \overline{b}}$$

- At CLEO, $\mathcal{A}_{CP}(\psi K^{\pm})$ can be measured with 4% precision
- In Standard Model $\mathcal{A}_{CP}(\psi K^{\pm}) << 4\%$
- $\mathcal{A}_{CP} = \frac{-2A_1 A_2 \sin(\delta_1 - \delta_2)_{\text{strong}} \sin(\phi_1 - \phi_2)_{\text{weak}}}{A_1^2 + A_2^2 + 2A_1 A_2 \cos(\delta_1 - \delta_2) \cos(\phi_1 - \phi_2)}$
- Large $\mathcal{A}_{CP}(\psi K^{\pm})$ indicates NEW physics beyond the SM

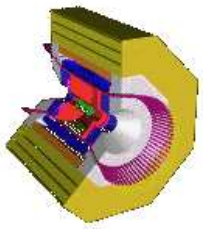
- Two-Higgs doublet model with special status for top quark
- Kiers, Soni, and Wu, hep-ph/9911419
- $\mathcal{A}_{CP}(\psi K^{\pm})$ could be $\mathcal{O}(10\%)$



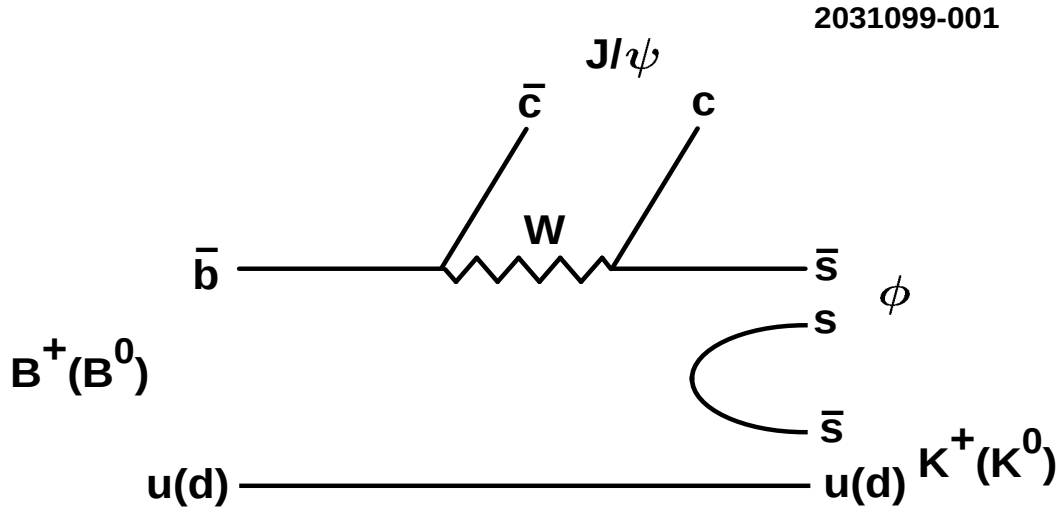
Search for direct CP violation in $B^{\pm} \to \psi^{(\prime)} K^{\pm}$



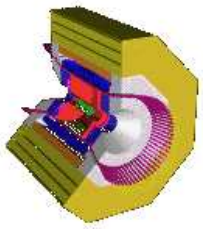
Mode	$N(B^{\pm})$	$N(B^-)$	$N(B^+)$	$\frac{N(B^-)-N(B^+)}{N(B^-)+N(B^+)}$	$\mathcal{A}_{CP}$
$B^{\pm} \to J/\psi\, K^{\pm}$	534	271	263	$(+1.5 \pm 4.3)\%$	$(+1.8 \pm 4.3 \pm 0.4)\%$
$B^{\pm} \to \psi(2S)\, K^{\pm}$	120	61	59	$(+1.7 \pm 9.1)\%$	$(+2.0 \pm 9.1 \pm 1.0)\%$



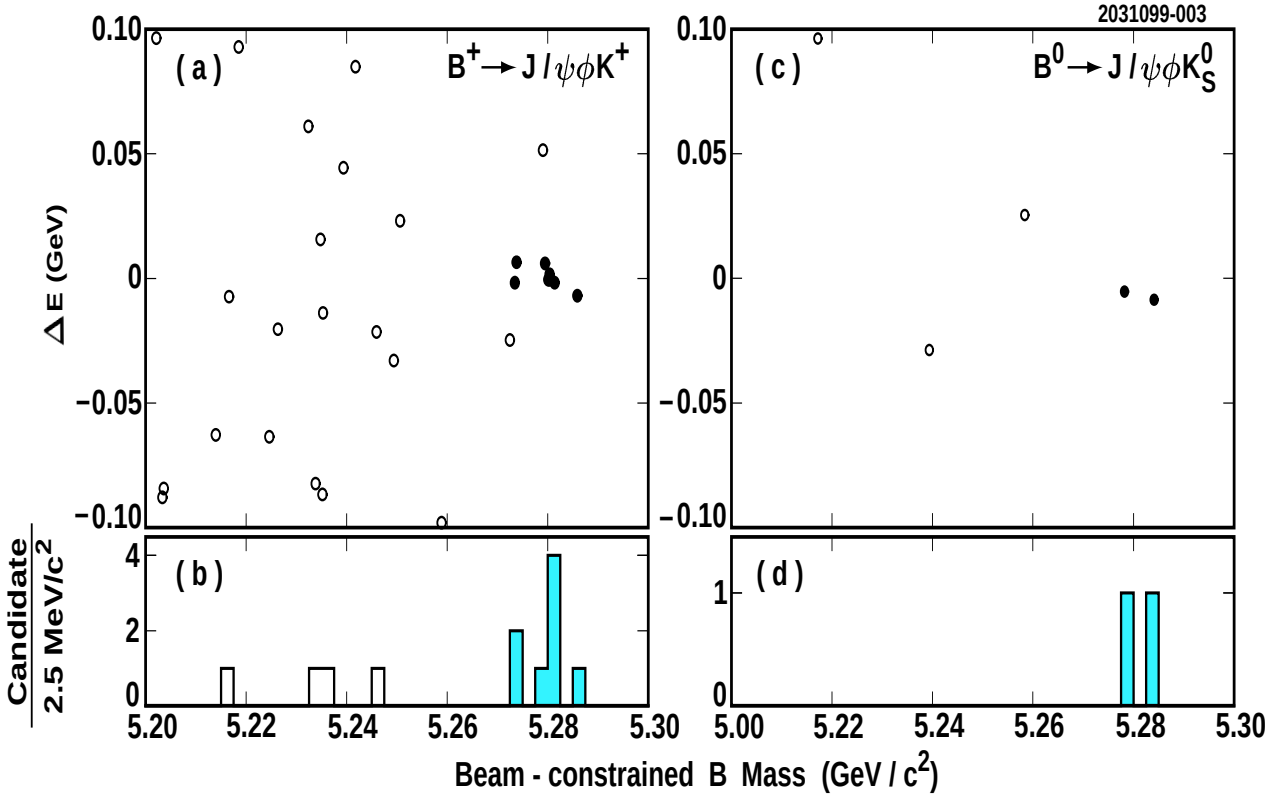
Observation of $B \to J/\psi\,\phi\,K$



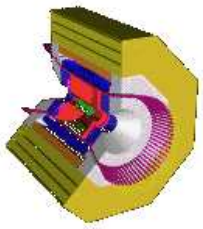
- Requires creation of an additional $s\bar{s}$ pair ($s\bar{s}$-popping)
- $s\bar{s}$-popping had been previously searched for in B decays.
  No signal had been observed.
- No known strongly decaying $J/\psi\phi$, $J/\psi K$ or ϕK resonances $\Longrightarrow$ $B \to J/\psi\,\phi\,K$ most likely genuine 3-body decay



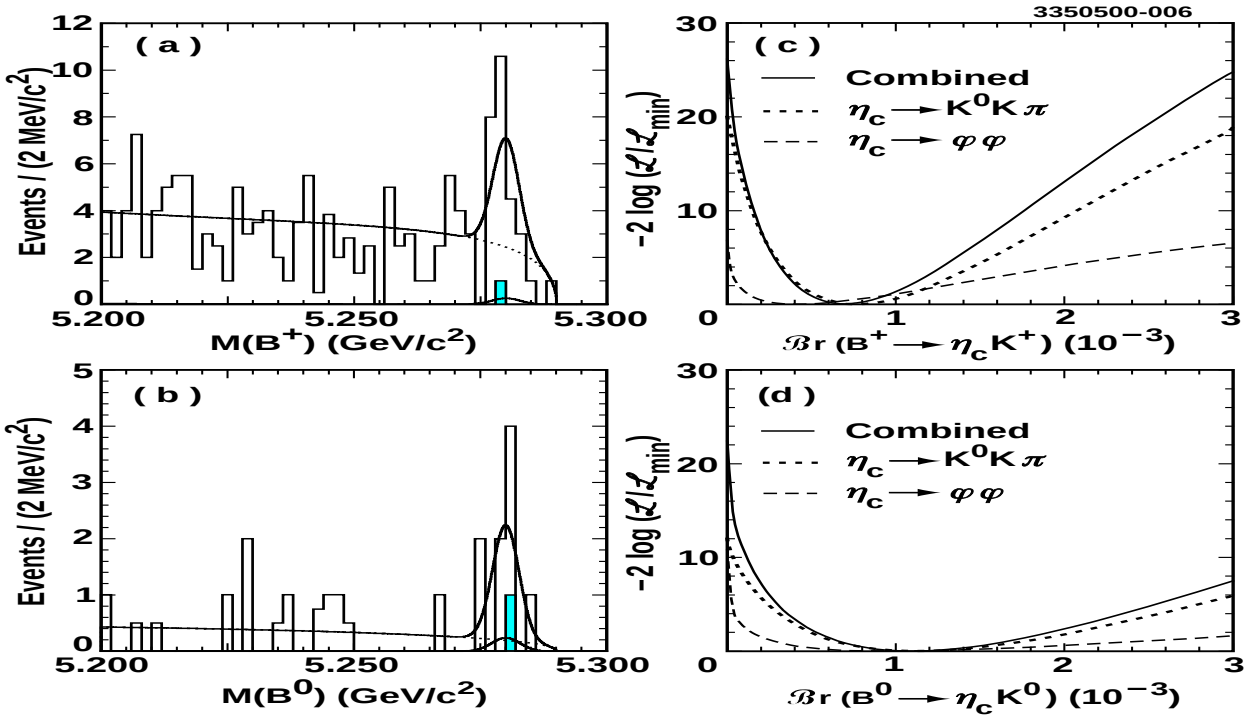
Observation of $B \to J/\psi\,\phi\,K$



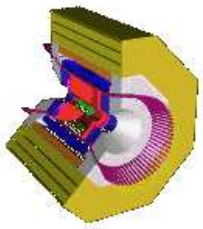
- 10 signal candidates
- 0.5 ± 0.2 expected background
- $\mathcal{B}(B \to J/\psi\,\phi\,K) = (8.8^{+3.5}_{-3.0} \pm 1.3) \times 10^{-5}$



Observation of $B \to \eta_c K$



- $B^+(B^0) \to \eta_c K^+(K^0)$ where $\eta_c \to \phi\phi \to K^+K^-K^+K^-$ and $\eta_c \to K^0_S K^\pm \pi^\mp$
- Extract signal with multi-dimension maximum likelihood fit
- 5.2σ (4.8σ) significant signal
- $\mathcal{B}(B^+ \to \eta_c K^+) = (0.69^{+0.26}_{-0.21} \pm 0.08 \pm 0.20) \times 10^{-3}$
- $\mathcal{B}(B^0 \to \eta_c K^0) = (1.09^{+0.55}_{-0.42} \pm 0.12 \pm 0.31) \times 10^{-3}$



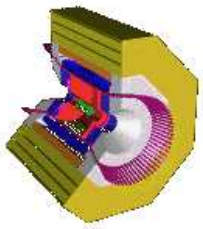
Study of χ_{c1}, χ_{c2} production in B decays

Charmonium Production:

- Heavy-Quark production
- Quarkonium bound state formation

Includive B meson decays to charmonium χ_{c2} to χ_{c1} production ratio:

- Test of the charmonium production models
- color-singlet, color-octet contributions
  - Color-singlet dominates: $\chi_{c2} : \chi_{c1} = 0 : 1$
  - Color-evaporation model: $\chi_{c2} : \chi_{c1} = 5 : 3$



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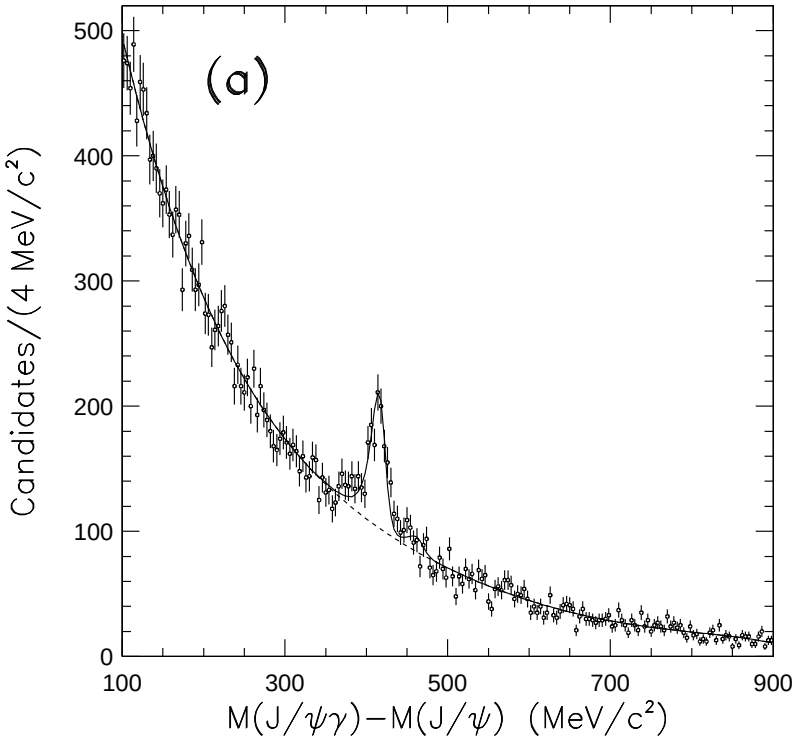
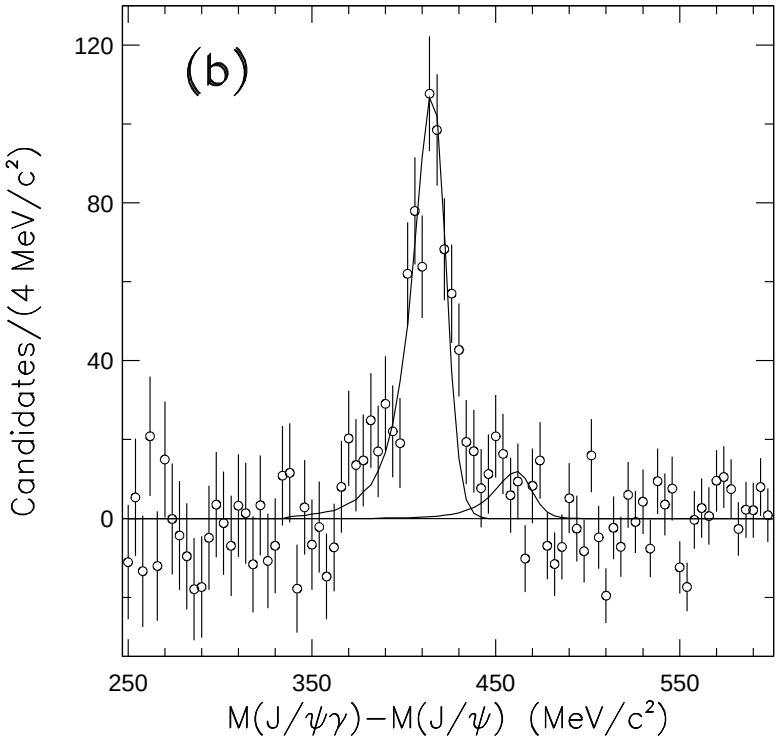
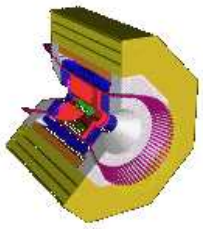


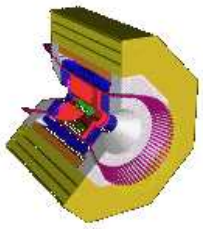




Study of χ_{c1}, χ_{c2} production in B decays

- $\mathrm{N}(B \to \chi_{c1} X) = 664 \pm 49$
- $\mathrm{N}(B \to \chi_{c2} X) = 81 \pm 39$
- Subtract feeddown from $B \to \psi(2S)X$

Branching Ratio	Measured Value	95% C.L. Upper Limit
$\mathcal{B}(B \to \chi_{c1} X)$	$(4.14 \pm 0.31 \pm 0.40) \times 10^{-3}$	
$\mathcal{B}(B \to \chi_{c1}[direct] X)$	$(3.83 \pm 0.31 \pm 0.40) \times 10^{-3}$	
$\mathcal{B}(B \to \chi_{c2} X)$	$(0.98 \pm 0.48 \pm 0.15) \times 10^{-3}$	$< 2.0 \times 10^{-3}$
$\mathcal{B}(B \to \chi_{c2}[direct] X)$	$(0.71 \pm 0.48 \pm 0.16) \times 10^{-3}$	$< 1.7 \times 10^{-3}$
$\frac{\mathcal{B}(B \to \chi_{c2}[direct] X)}{\mathcal{B}(B \to \chi_{c1}[direct] X)}$	$(0.18 \pm 0.13 \pm 0.04)$	< 0.44



$\mathcal{B}[\Upsilon(4S) \to B^+B^-]/\mathcal{B}[\Upsilon(4S) \to B^0\overline{B}^0]$

$$\frac{f_{+-}}{f_{00}} \equiv \frac{\mathcal{B}[\Upsilon(4S)\to B^+B^-]}{\mathcal{B}[\Upsilon(4S)\to B^0\overline{B}^0]}$$

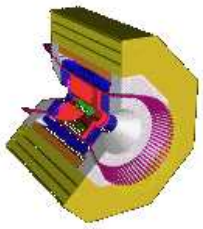
- Any comparison of B^+ and B^0 rates depends on f_{+-}/f_{00} and its uncertainty
- PDG assumes $f_{+-}/f_{00} = 1$ when listing $\Upsilon(4S)$ results
- Theoretical predictions
  - Phase space

    $\Upsilon(4S)(\text{spin-1})\to B\overline{B} \Rightarrow P\text{-wave} \Rightarrow \Gamma \propto P_B^3 \Rightarrow \frac{\delta\Gamma}{\Gamma} = 3\frac{\delta P}{P} = -3\frac{M^2}{P^2}\frac{\delta M}{M}$

    $M(B^0) - M(B^+) = 0.34 \pm 0.32$ MeV $\Rightarrow f_{+-}/f_{00} = 1.05 \pm 0.05$
  - Coulomb attraction

    B^+B^- attract $\Rightarrow$ more overlap $\Rightarrow$ higher rate $\Rightarrow f_{+-}/f_{00} \approx 1.18$ (pointlike)
  - Subtleties and corrections: B form factor, $\Upsilon(4S)$ wave function

    $\Rightarrow f_{+-}/f_{00} = 0.95 \sim 1.05$



f_{+-}/f_{00} measurements

Isospin conserving transitions:

- Semileptonic decays $\overline{b} \to \overline{c}\ell^+\nu$:

  $\Gamma(B^+ \to \overline{D}^{*0}\ell^+\nu) = \Gamma(B^0 \to \overline{D}^{*-}\ell^+\nu)$

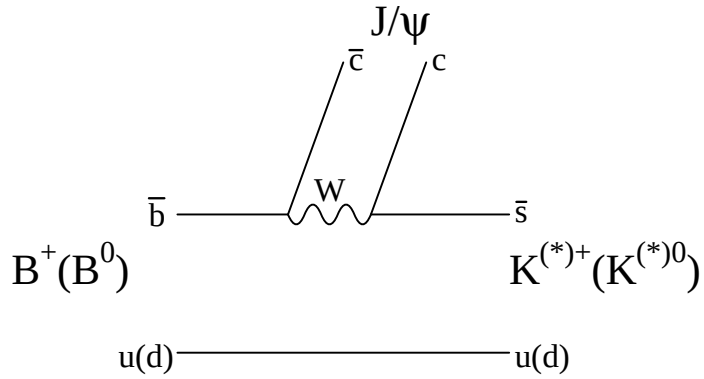
  $$\frac{f_{+-}}{f_{00}}\frac{\tau(B^+)}{\tau(B^0)} = \frac{N(B^+ \to \overline{D}^{*0}\ell^+\nu)}{N(B^0 \to \overline{D}^{*-}\ell^+\nu)} = 1.14 \pm 0.14 \pm 0.13 \text{ (CLEO'95)}$$

- $\overline{b} \to \overline{c}c\overline{s}$

  $\Gamma(B^+ \to J/\psi K^{(*)+}) = \Gamma(B^0 \to J/\psi K^{(*)0})$

  $$\frac{f_{+-}}{f_{00}}\frac{\tau(B^+)}{\tau(B^0)} = \frac{N(B^+ \to J/\psi K^{(*)+})}{N(B^0 \to J/\psi K^{(*)0})}$$

  $$\frac{f_{+-}}{f_{00}}\frac{\tau(B^+)}{\tau(B^0)} = 1.15 \pm 0.17 \pm 0.06 \text{ (CLEO'97)}$$

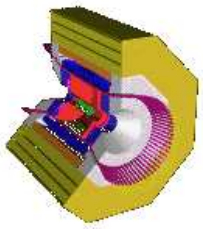


Update

$$\frac{f_{+-}}{f_{00}}\frac{\tau(B^+)}{\tau(B^0)} = 1.11 \pm 0.07 \pm 0.04 \text{ (CLEO'00)}$$

Taking new world average $\tau(B^+)/\tau(B^0) = 1.066 \pm 0.024$,

$$\frac{f_{+-}}{f_{00}} = 1.04 \pm 0.07 \pm 0.04 \text{ (CLEO'00)}$$



Summary

Results from CLEO II + II.V Data ≈ 10 million $B\overline{B}$ pairs

- Results on $B^0 \to J/\psi\, K^0_S(\pi^0\pi^0)$, $B^0 \to \chi_{c1}\, K^0_S$, and $B^0 \to J/\psi\, \pi^0$
- Search for direct CP violation in $B^\pm \to J/\psi\, K^\pm$ and $B^\pm \to \psi(2S)\, K^\pm$
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