Recent Results from CLEO

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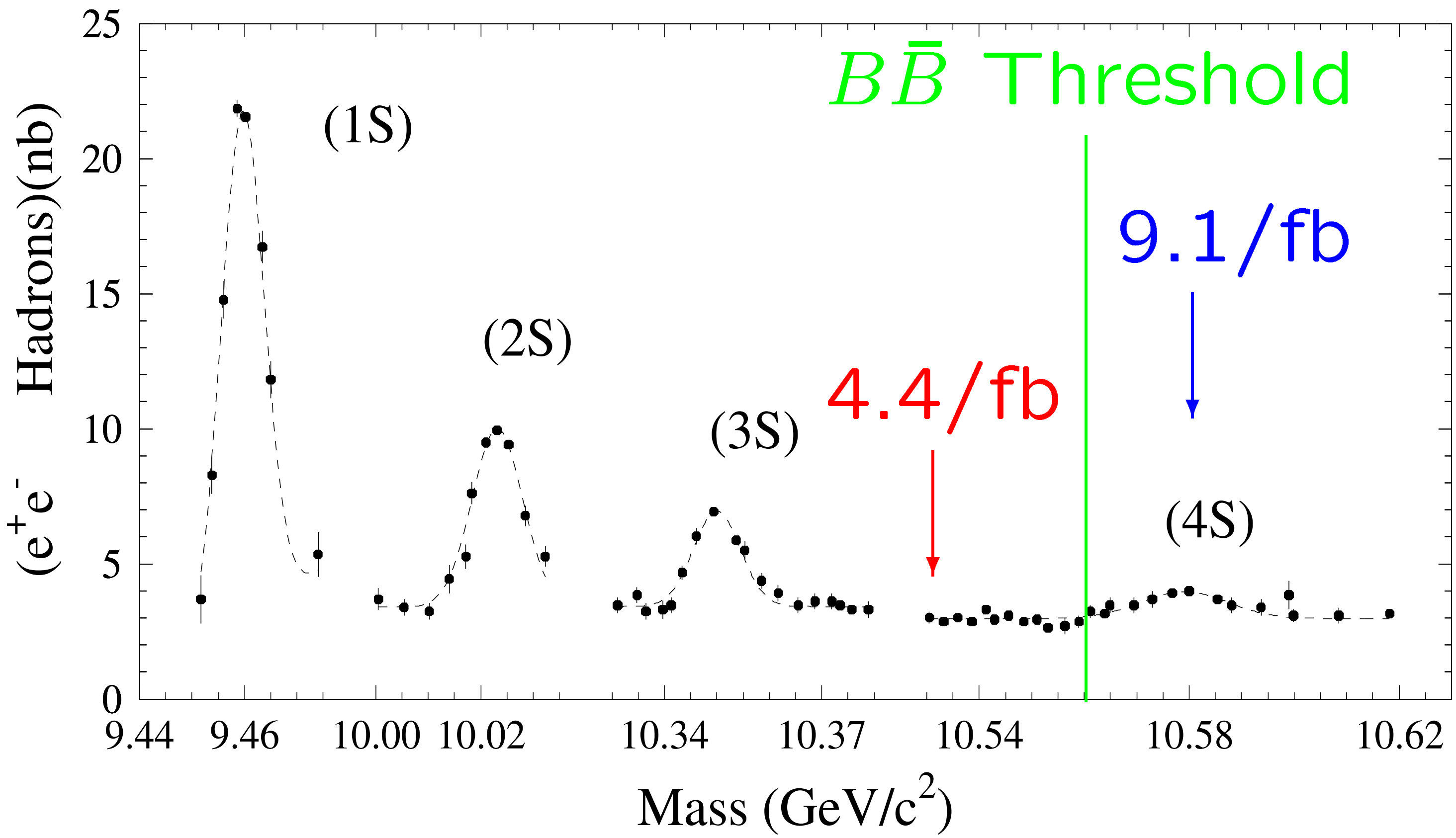
(CLEO Collaboration)

May 31 – June 6, 2001 at ICFP2001

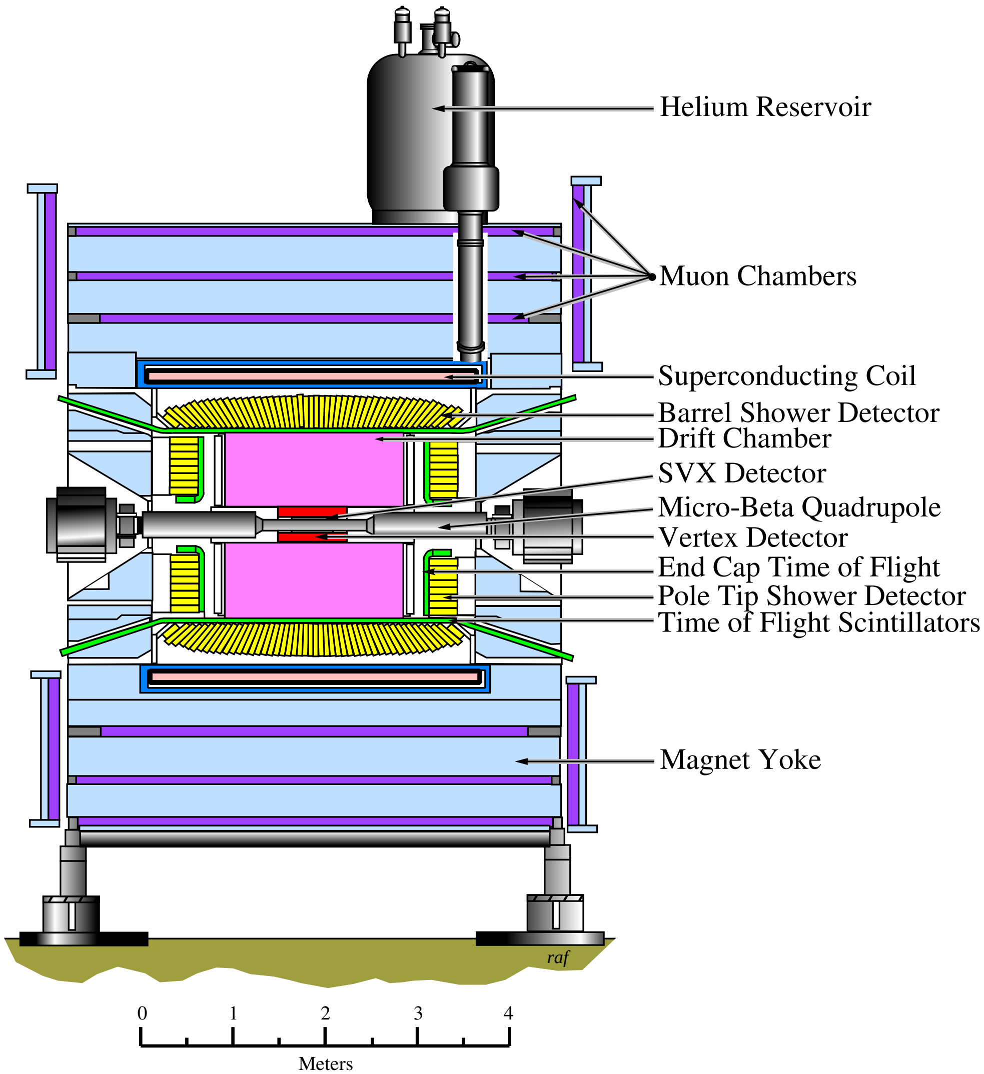
- CESR and CLEO
- Recent Results from CLEO:
  - $B \to PP$, PV, VV, $\phi K^{(*)}$, $l^+ l^- K^{(*)}$, $b \to s\gamma$
  - CP **Violation in** B **Decays**
  - CP **Violation in** D^0 **Decays**
- Summary and Future Outlook

Cornell Electron-positron Storage Ring



- **Total CLEO II, II.V integrated luminosity: $\sim$ 14 fb^{-1}:**
  - **9.1 fb^{-1} on** $\Upsilon(4S)$ **N(**$B\overline{B}$ **)**$= 9.7 \times 10^6$
  - **4.4 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

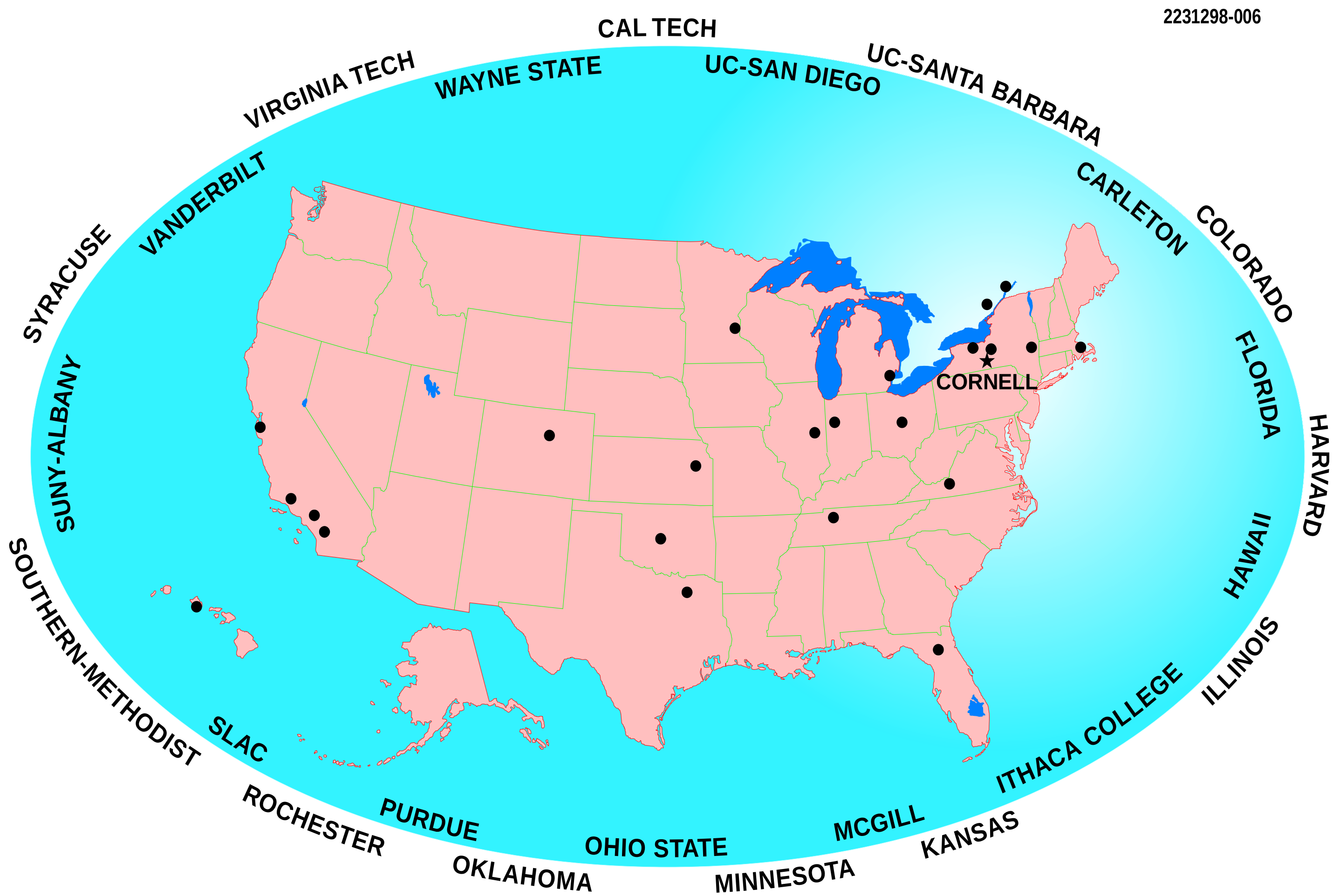
CLEO II.V

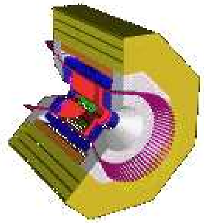
- Nov.'95 – Feb.'99
- N($B\overline{B}$)= 6.4×10^6
- 3-layer Si vertex detector

CLEO III

- 2000 – 2001
- New SVX, DR and RICH

CLEO Collaboration





Success and Limitation of the SM

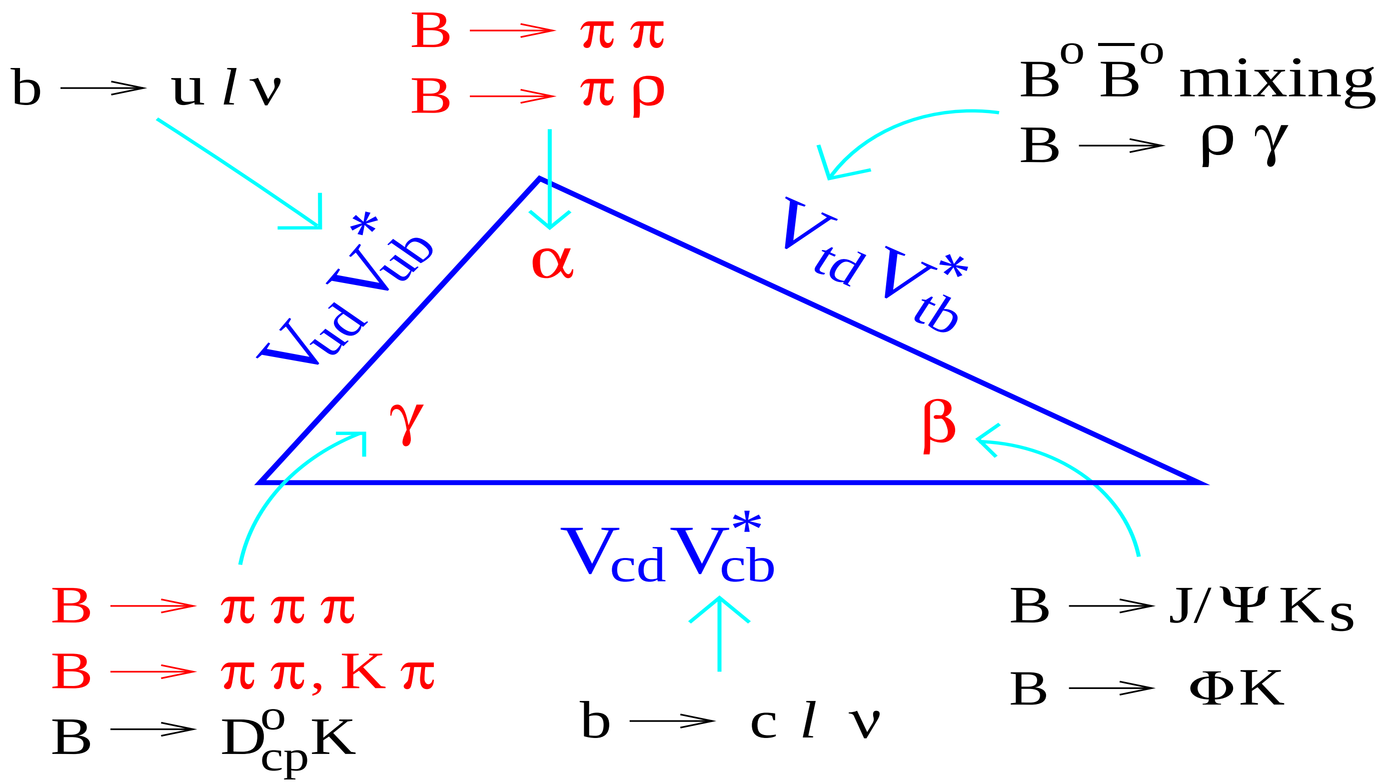
- **"Replication" problem**
- **Free parameters**
- **Matter-antimatter asymmetry**

Test the SM and Search for New Physics

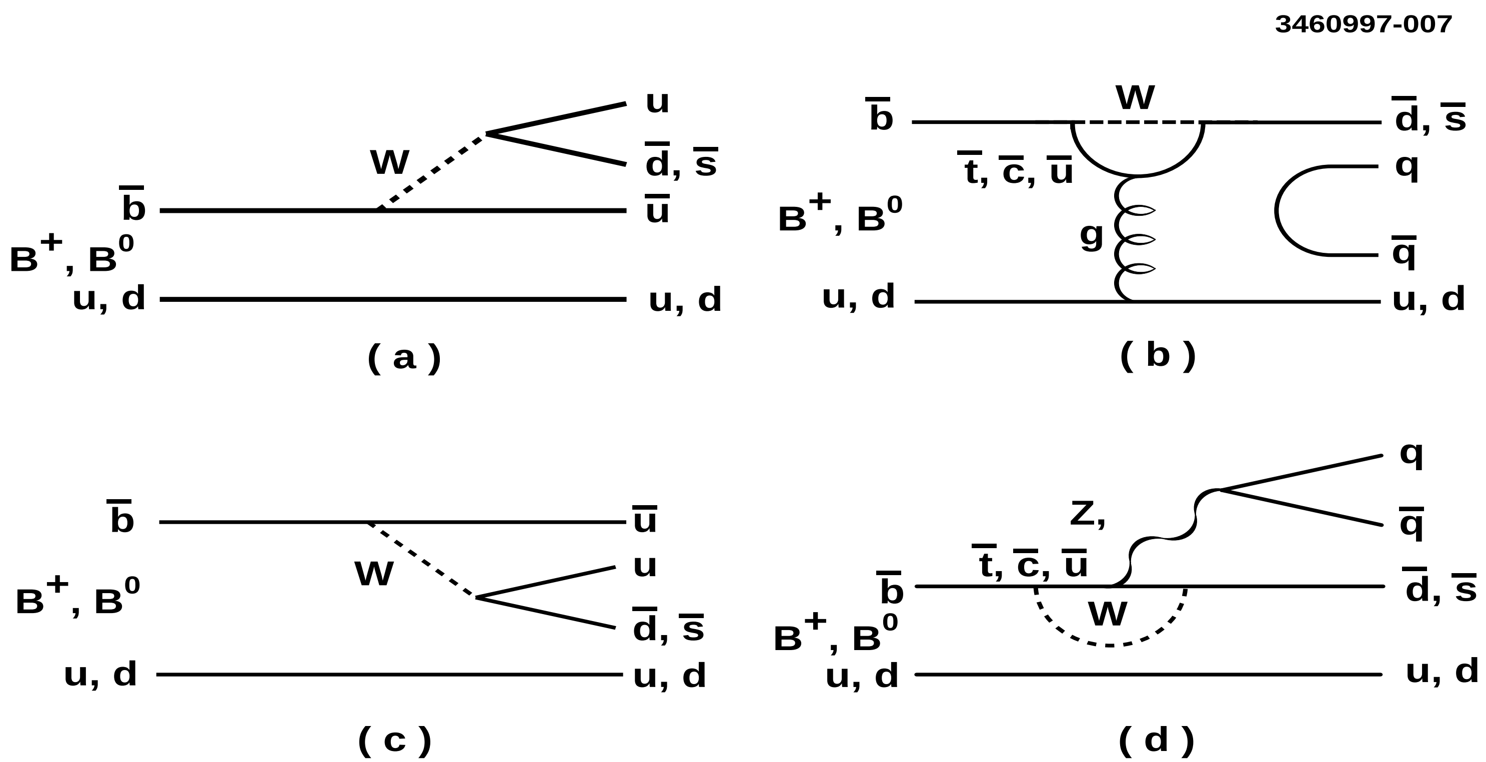
- **New particles search (LEP, Tevatron, LHC etc)**
- **Neutrino physics (Super-K, Minos etc)**
- CP **violation study (B-factories etc)**

Test the SM and Search for New Physics

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



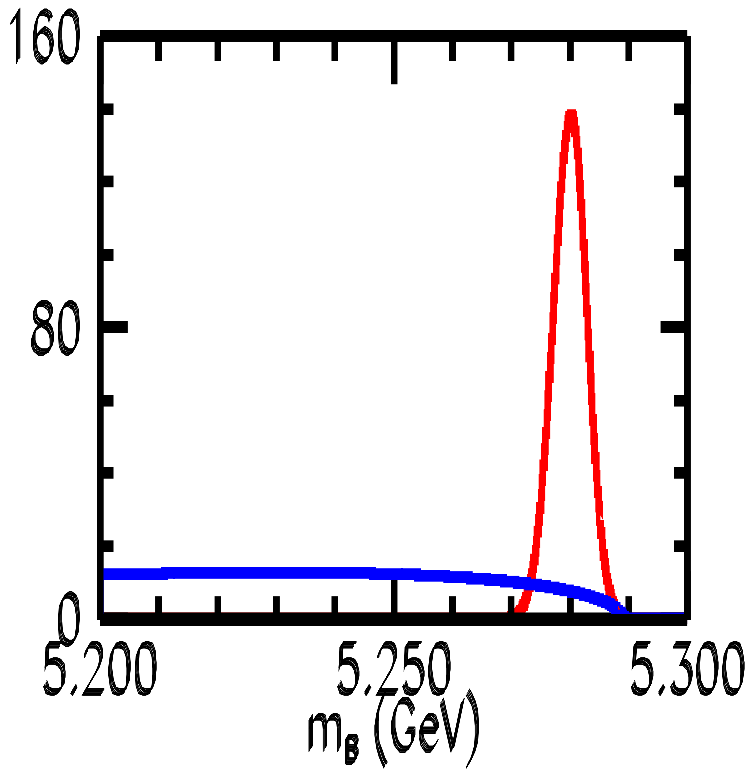
Why Rare B Decays?

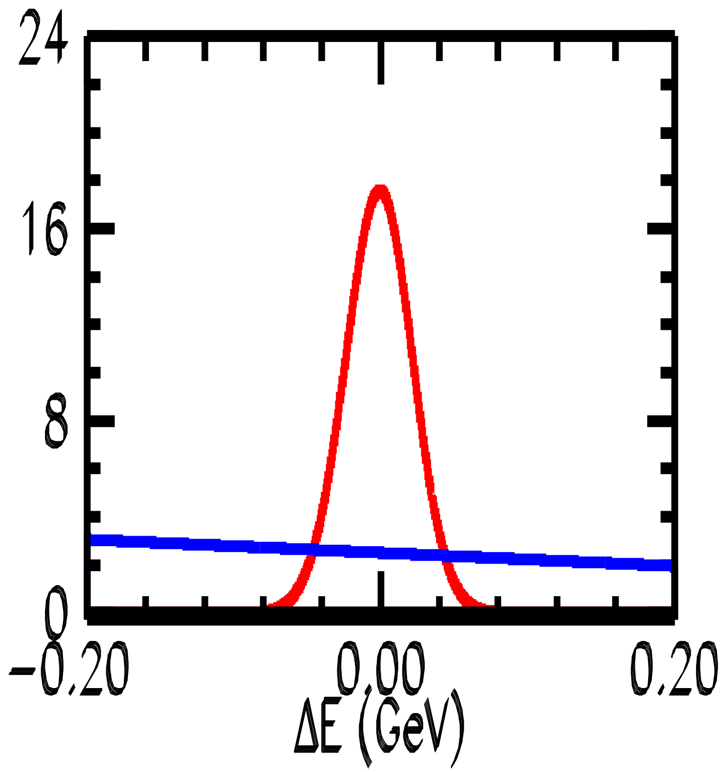


- **Unitarity triangle (angles α and γ, CKM elements V_{ub}, ...)**
- **Sensitive to physics beyond the Standard Model**

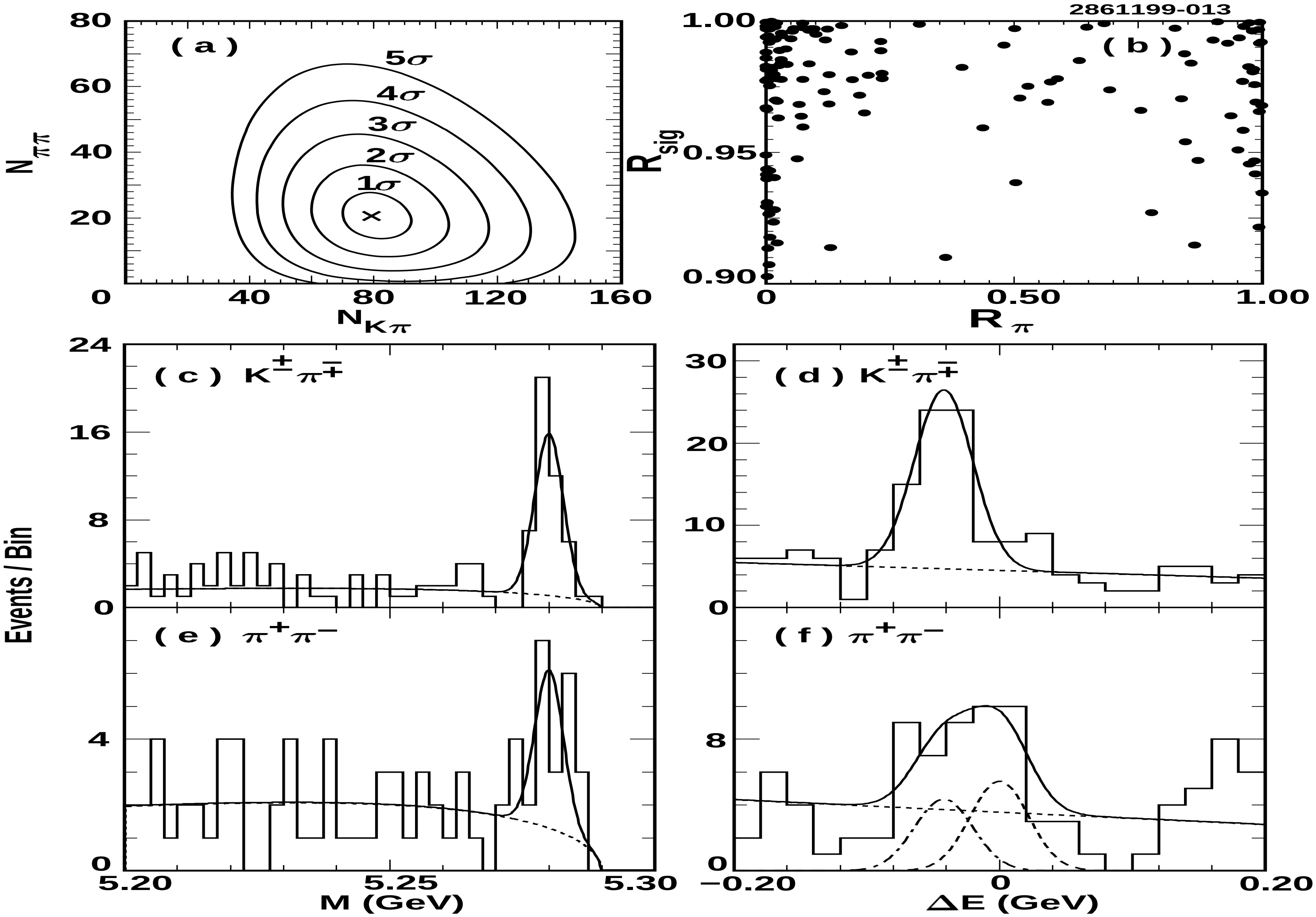
CLEO Analysis Technique

- $M_B = \sqrt{E_{beam}^2 - p_{\rm cand}^2}$ $(\sigma_M \approx 2.5 - 3.4\, MeV/c^2)$
- $\Delta E = E_{\rm cand} - E_{beam}$ $(\sigma \approx 20 - 60\, MeV)$





$B \to \pi\pi$, $K\pi$ and KK Results



$B \to \pi\pi$, $K\pi$ and KK Results

Mode	N_{sig}	Sig.	Efficiency	$BR \times 10^6$
$\pi^+\pi^-$	$20.0^{+7.6}_{-6.5}$	4.2σ	48%	$4.3^{+1.6}_{-1.4} \pm 0.5$
$\pi^\pm\pi^0$	$21.3^{+9.7}_{-8.5}$	3.2σ	39%	< 12.7 (90%C.L.)
$\pi^0\pi^0$	$6.2^{+4.8}_{-3.7}$	2.0σ	29%	< 5.7 (90%C.L.)
$K^\pm\pi^\mp$	$80.2^{+11.8}_{-11.0}$	11.7σ	48%	$17.2^{+2.5}_{-2.4} \pm 1.2$
$K^\pm\pi^0$	$42.1^{+10.9}_{-9.9}$	6.1σ	38%	$11.6^{+3.0+1.4}_{-2.7-1.3}$
$K^0\pi^\pm$	$25.2^{+6.4}_{-5.6}$	7.6σ	14%	$18.2^{+4.6}_{-4.0} \pm 1.6$
$K^0\pi^0$	$16.1^{+5.9}_{-5.0}$	4.9σ	11%	$14.6^{+5.9+2.4}_{-5.1-3.3}$
K^+K^-	$0.7^{+3.4}_{-0.7}$	0.0σ	48%	< 1.9 (90%C.L.)
$K^\pm K^0$	$1.4^{+2.4}_{-1.3}$	1.1σ	14%	< 5.1 (90%C.L.)
$K^0\bar{K}^0$	0	0.0σ	5%	< 17 (90%C.L.)

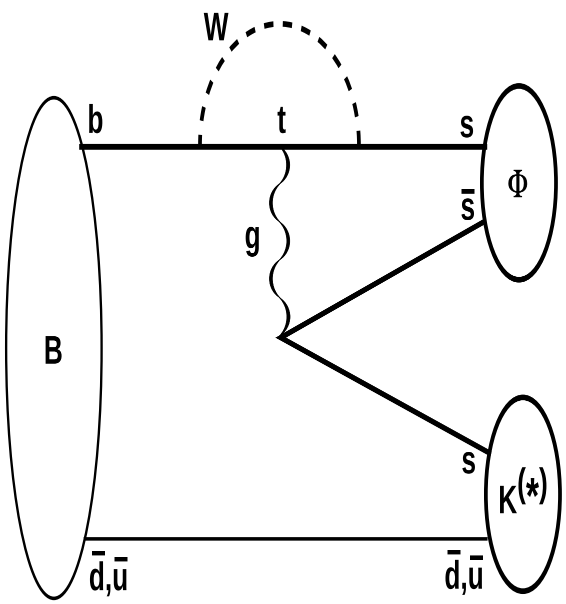
- **Published in Phys. Rev. Lett. 85, 515 (2000)**
- **hep-ex/0103040, CLNS 01/1718, submitted to PRL**

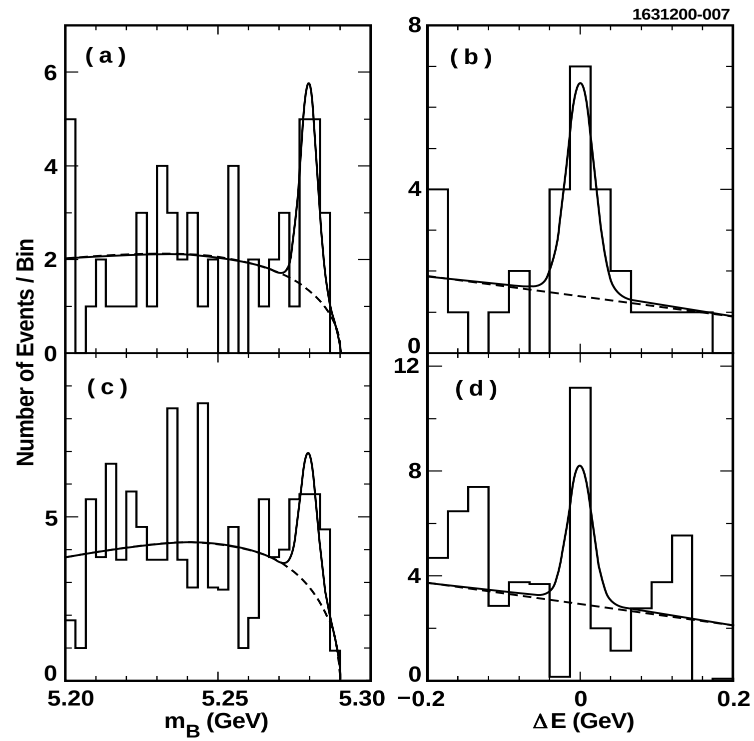
$B \to PV$ and VV Results

Decay Mode	$BR \times 10^6$	Theoretical Prediction $\times 10^6$
$\pi^\pm\rho^0$	$10.4^{+3.3}_{-3.4} \pm 2.1$	$0.4 - 13.0$
$\pi^\pm\rho^\mp$	$27.6^{+8.4}_{-7.4} \pm 4.2$	$12 - 93$
$\pi^0\rho^0$	< 5.5	$0.0 - 2.5$
$K^\pm\rho^0$	< 17	$0.0 - 6.1$
$\pi^\pm K^{*0}$	< 16	$3.4 - 13.0$
$K^\pm K^{*0}$	< 5.3	$0.2 - 1.0$
$\rho^0\rho^0$	< 4.6 (5.9)	$0.54 - 2.5$
$K^{*0}\rho^0$	< 13 (19)	$0.7 - 6.2$
$K^{*0}\bar{K}^{*0}$	< 8.7 (10)	$0.28 - 0.96$

- **Published in Phys. Rev. Lett. 85, 2881 (2000)**
- **hep-ex/0101029, CLNS 00/1705, submitted to PRL**

Observation of $B \to \phi K^{(*)}$



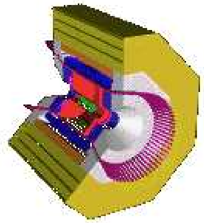


- **Clean signature for gluonic penguin**
- **Sensitive to $\mathbf{V}_{ts}$**

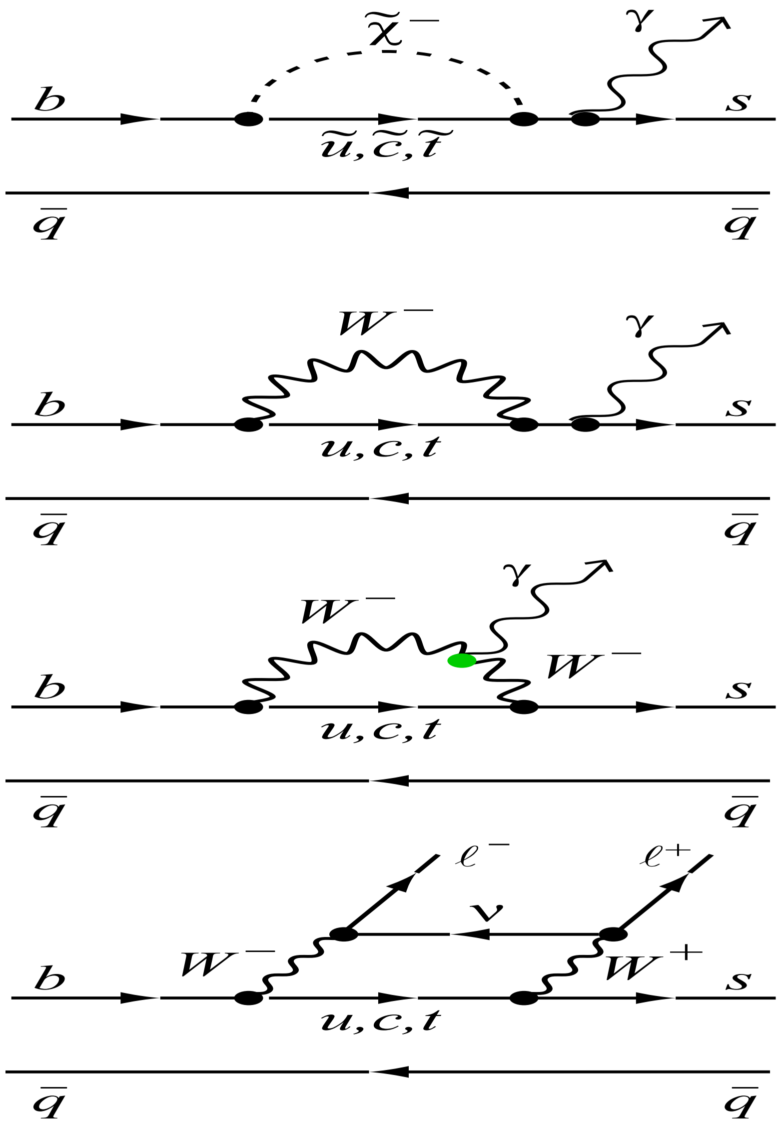
Observation of $B \to \phi K^{(*)}$

Mode	N_{sig}	Sig.	Efficiency	$BR \times 10^6$
$\phi K^{\pm}$	$14.2^{+5.5}_{-4.5}$	5.4σ	54%	$5.5^{+2.1}_{-1.8} \pm 0.6$
ϕK^0	$4.2^{+2.9}_{-2.1}$	2.9σ	48%	< 12.3 (90%C.L.)
ϕK Combined		6.1σ		$5.5^{+1.8}_{-1.5} \pm 0.7$
$\phi K^{*0}(K^-\pi^+)$	$12.1^{+5.3}_{-4.3}$	4.5σ	38%	$9.9^{+4.3}_{-3.5} \pm 1.6$
$\phi K^{*0}(K^0\pi^0)$	$5.1^{+3.9}_{-2.8}$	2.7σ	20%	$46.3^{+35.7+5.9}_{-26.0-6.6}$
ϕK^{*0} Combined		5.1σ		$11.5^{+4.5+1.8}_{-3.7-1.7}$
$\phi K^{*\pm}(K^{\pm}\pi^0)$	$3.8^{+4.1}_{-2.8}$	1.5σ	25%	$9.3^{+10.1+1.7}_{-7.0-1.5}$
$\phi K^{*\pm}(K^0\pi^{\pm})$	$4.0^{+3.1}_{-2.2}$	2.7σ	32%	$11.4^{+9.0}_{-6.3} \pm 1.8$
$\phi K^{*\pm}$ Combined		3.1σ		$10.6^{+6.4+1.8}_{-4.9-1.6}$
ϕK^* Combined		5.9σ		$11.2^{+3.6+1.8}_{-3.1-1.7}$

- **hep-ex/0101032, to be published by PRL**

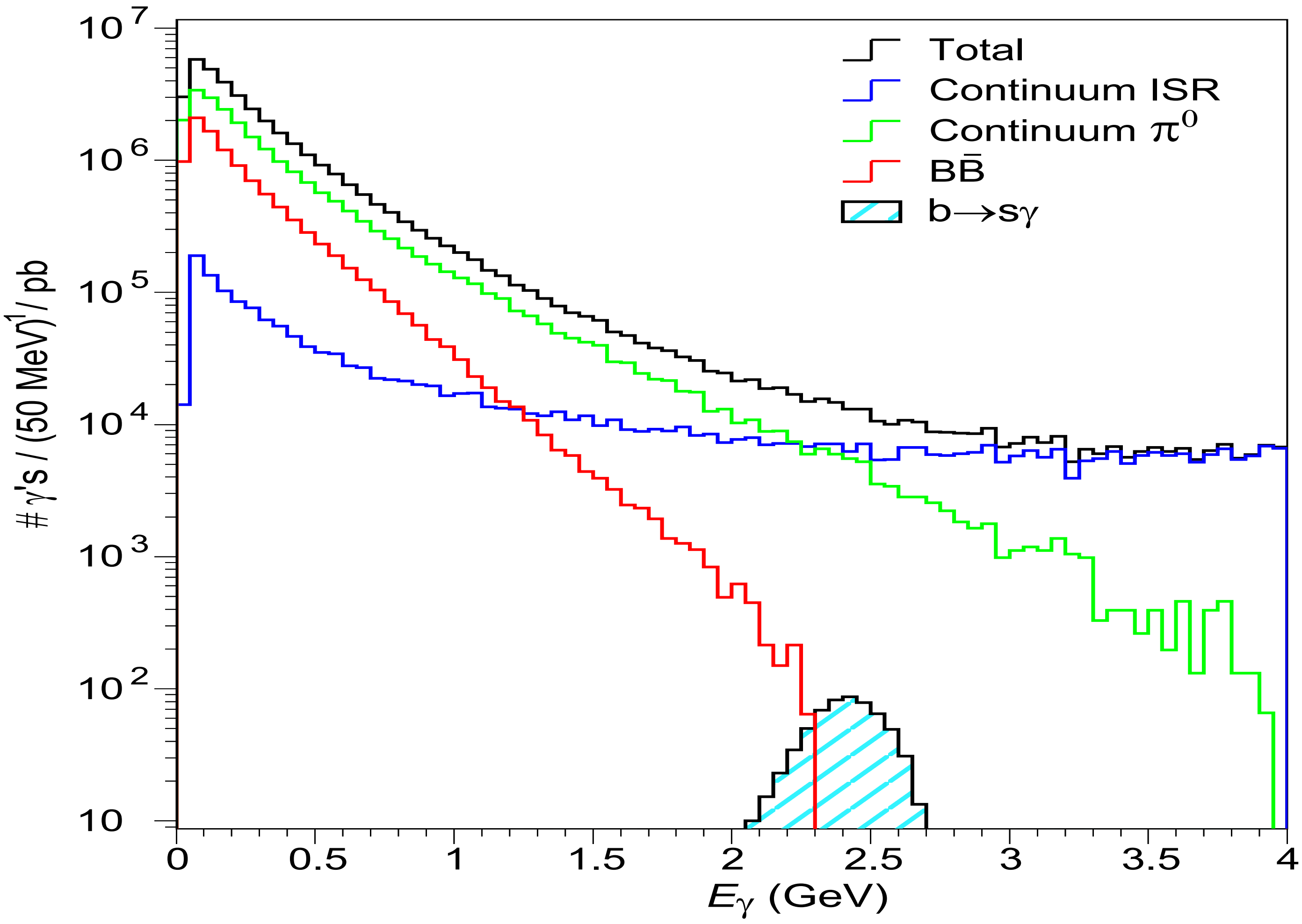


$b \to s\gamma$



- **EW penguin** $\mathbf{V}^*_{ts}\mathbf{V}_{tb}$
- **SM prediction:** $\mathcal{B}(b \to s\gamma) = (\mathbf{3.28} \pm \mathbf{0.33}) \times \mathbf{10}^{-4}$
- **Sensitive to New Physics beyond SM**

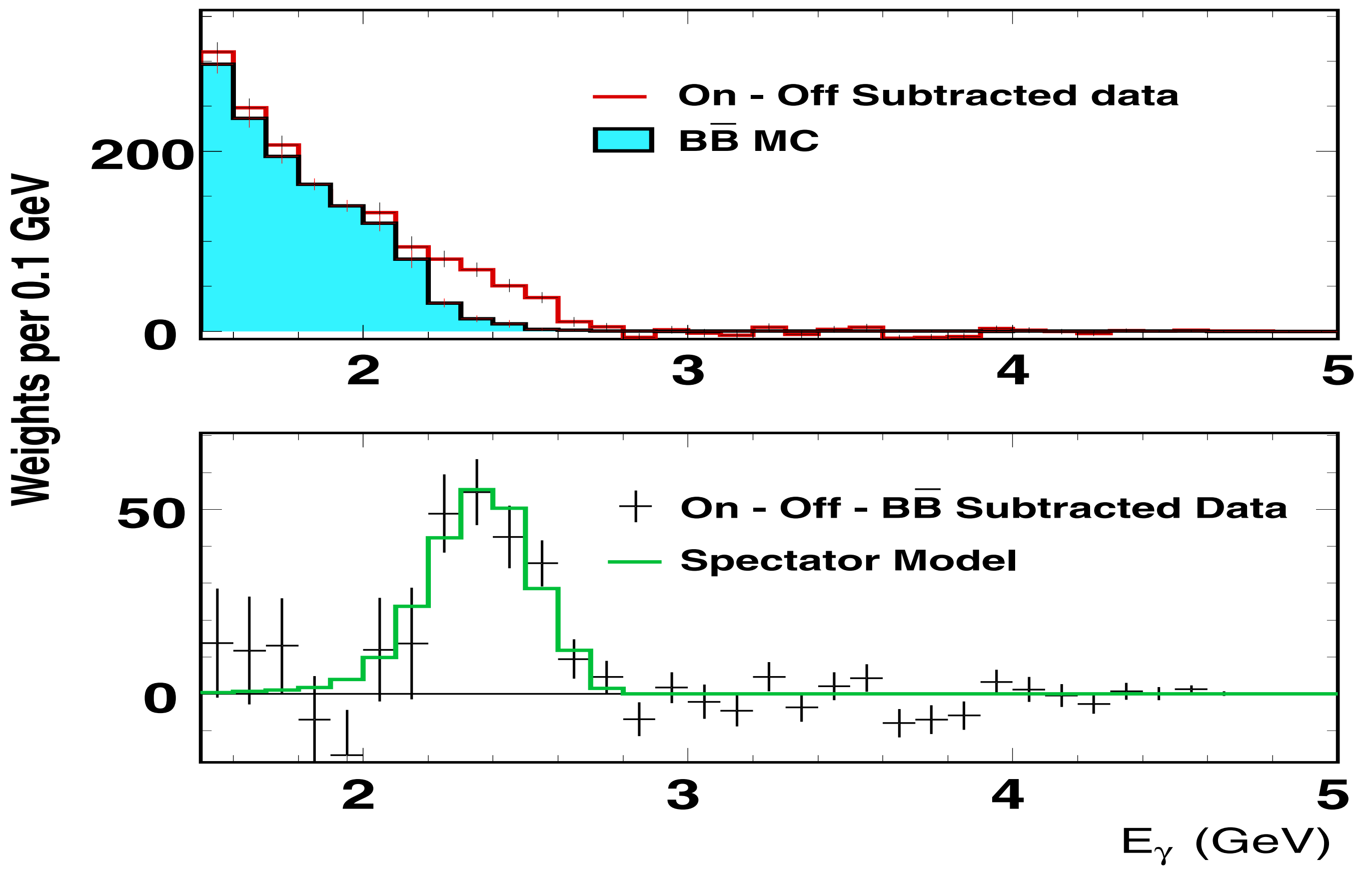
Experimental challenge in measuring $b \to s\gamma$



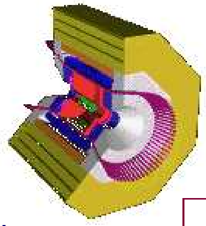
Analysis Strategy in measuring $b \to s\gamma$

- **Select photon candidate:** **2.0GeV $<$ E$_\gamma$ $<$ 2.7GeV**
- **Suppression of Continuum background:**
  - **"pseudo reconstruction"**
  - **"lepton tag"**
  - **Event shape variables (neural net)**
- **Subtract backgrounds from π^0, η, and other B decays**

$b \to s\gamma$ Results



- $\mathcal{B}(b \to s\gamma) = (2.85 \pm 0.35 \pm 0.22) \times 10^{-4}$
- **SM prediction:** $\mathcal{B}(b \to s\gamma) = (3.28 \pm 0.33) \times 10^{-4}$



Exclusive FCNC Processes: $B \rightarrow l^+ l^- K^{(*)}$

- **Suppressed in SM:** **BR $\sim$ (10^{-6} to 10^{-7})**
- **Sensitive to Physics beyond SM:** **SUSY etc**

Current Results on FCNC

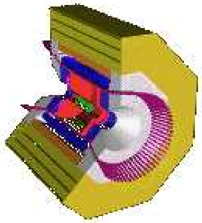
Results	$B\overline{B}$ (10^6)	$B \rightarrow e^+e^-K^\pm$	$B \rightarrow \mu^+\mu^-K^\pm$	$B \rightarrow e^+e^-K^{*0}$	$B \rightarrow \mu^+\mu^-K^{*0}$
CLEO 98	3.3	$< 11.0\times10^{-6}$	$< 9.7\times10^{-6}$	$< 15.0\times10^{-6}$	$< 10.0\times10^{-6}$
CDF 99	88 pb^{-1}		$< 5.2\times10^{-6}$		$< 4.0\times10^{-6}$
BaBar 00	3.7	$< 12.5\times10^{-6}$	$< 8.3\times10^{-6}$	$< 24.1\times10^{-6}$	$< 24.5\times10^{-6}$
Belle 01	11.1	$< 2.43\times10^{-6}$	$< 3.96\times10^{-6}$	$< 11.1\times10^{-6}$	$< 10.5\times10^{-6}$

Strategy in Searching for FCNC Processes

- **Select Lepton candidates**
- **Select Kaon candidate from pion backgrounds**
- **Suppress Physics Backgrounds:**
  - $B \to J/\psi K^{(*)}$ **where** $J/\psi \to e^+e^-$ **or** $\mu^+\mu^-$
  - $B \to \psi(2S)K^{(*)}$ **where** $\psi(2S) \to e^+e^-$ **or** $\mu^+\mu^-$
- **Suppress Continuum and other B backgrounds:**
  - **Event Shape variable, Missing Energy, etc**

CLEO Exclusive FCNC Results

Decay Mode	Efficiency	Evts Obsved	BR UL (90% CL)
$B \to K^0 e^+ e^-$	**4.8%**	**1**	$< \mathbf{8.5} \times 10^{-6}$
$B \to K^0 \mu^+ \mu^-$	**3.3%**	**0**	$< \mathbf{7.2} \times 10^{-6}$
$B \to K^\pm e^+ e^-$	**15.6%**	**1**	$< \mathbf{2.4} \times 10^{-6}$
$B \to K^\pm \mu^+ \mu^-$	**8.4%**	**1**	$< \mathbf{4.5} \times 10^{-6}$
$B \to K l^+ l^-$	**32.2%**	**3**	$< \mathbf{1.9} \times 10^{-6}$
$B \to K^{*\pm}(K^0 \pi^\pm) e^+ e^-$	**2.0%**	**0**	$< \mathbf{11.9} \times 10^{-6}$
$B \to K^{*\pm}(K^0 \pi^\pm) \mu^+ \mu^-$	**1.2%**	**0**	$< \mathbf{20.1} \times 10^{-6}$
$B \to K^{*\pm}(K^\pm \pi^0) e^+ e^-$	**1.4%**	**3**	$< \mathbf{46.4} \times 10^{-6}$
$B \to K^{*\pm}(K^\pm \pi^0) \mu^+ \mu^-$	**0.7%**	**0**	$< \mathbf{34.2} \times 10^{-6}$
$B \to K^{*0}(K^\pm \pi^\mp) e^+ e^-$	**8.0%**	**1**	$< \mathbf{4.8} \times 10^{-6}$
$B \to K^{*0}(K^\pm \pi^\mp) \mu^+ \mu^-$	**3.9%**	**0**	$< \mathbf{6.2} \times 10^{-6}$
$B \to K^{*0}(K^0 \pi^0) e^+ e^-$	**0.6%**	**0**	$< \mathbf{43.0} \times 10^{-6}$
$B \to K^{*0}(K^0 \pi^0) \mu^+ \mu^-$	**0.2%**	**0**	$< \mathbf{145.23} \times 10^{-6}$
$B \to K^* l^+ l^-$	**18.0%**	**4**	$< \mathbf{3.8} \times 10^{-6}$



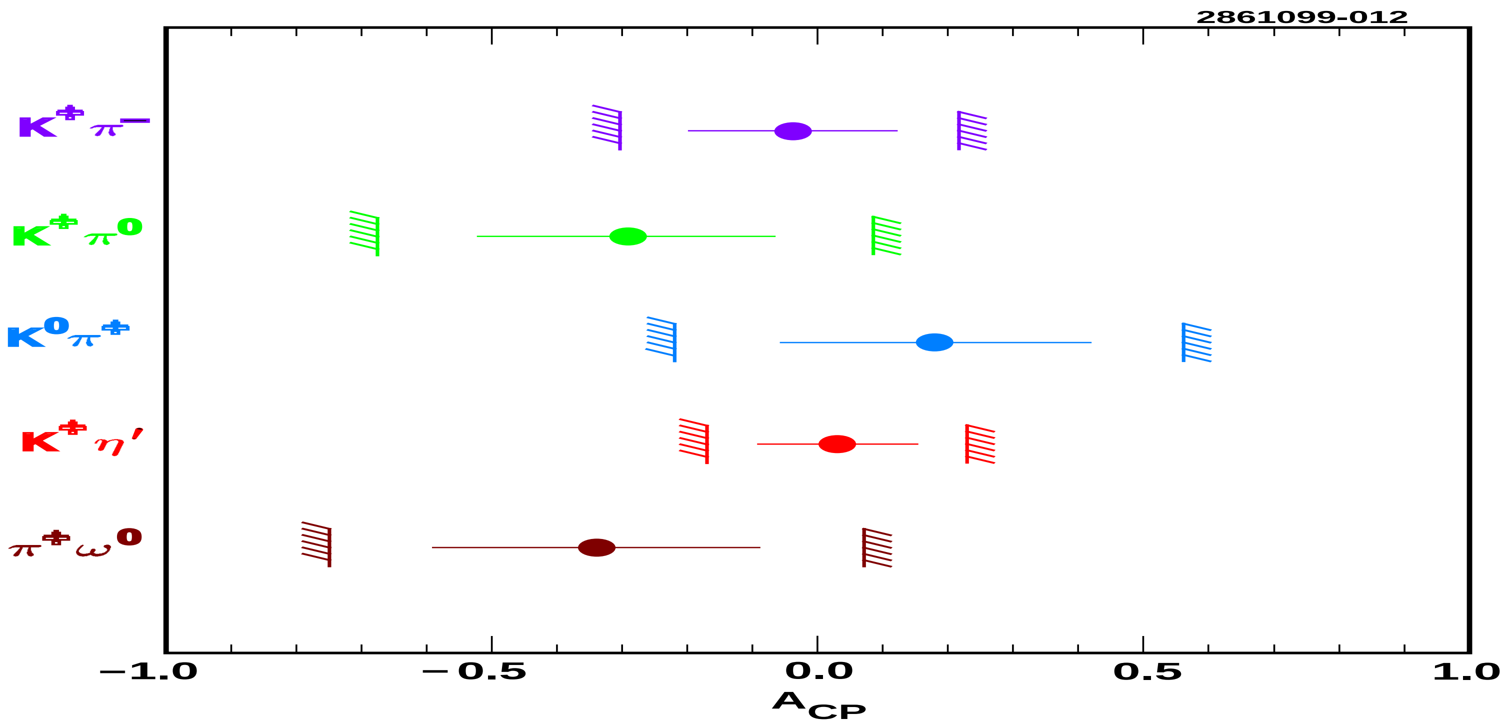
CP Asymmetries in $b \to s\gamma$

- **Measure the asymmetry:** $\mathcal{A}_{CP} \equiv \frac{\Gamma(b\to s\gamma)-\Gamma(\bar{b}\to\bar{s}\gamma)}{\Gamma(b\to s\gamma)+\Gamma(\bar{b}\to\bar{s}\gamma)}$
- **Standard Model Prediction:** $\mathcal{A}_{CP} < \mathbf{1.0\%}$
- **Non Standard Model Prediction:** $\mathcal{A}_{CP} \approx \mathbf{(10-40)\%}$
- **Analysis strategy:**
  - **2.2GeV $<$ E$_\gamma$ $<$ 2.7GeV**
  - **Flavor Tag by “pseudo reconstruction” and “lepton tag”**
  - **Mistake rates, On-off subtraction, particle detection biases**
- $\mathcal{A}_{CP} = \mathbf{(-0.079 \pm 0.108 \pm 0.022)(1.0 \pm 0.030)}$

$$-0.27 < \mathcal{A}_{CP} < +0.10 \quad \text{at } 90\% \text{ C.L.}$$

CP Asymmetries in other B Decays

- Search for CP violation in self tagging decays
- Measure the asymmetry: $\mathcal{A}_{CP} \equiv \frac{\mathcal{B}(\bar{B}\to\bar{f})-\mathcal{B}(B\to f)}{\mathcal{B}(\bar{B}\to\bar{f})+\mathcal{B}(B\to f)}$
- Prediction: $\mathcal{A}_{CP} \approx \pm\, 0.1\%$ (Ali, Kramer, Lu, PRD 59, 014005 (1999))



CP Asymmetries in other B Decays

Decay Mode	$N_{\rm sig}$	$\mathcal{A}_{CP}$	Prediction
$B \to K^{\pm}\pi^{\mp}$	80^{+12}_{-11}	-0.04 ± 0.16	$(+0.037, +0.106)$
$B \to K^{\pm}\pi^{0}$	$42.1^{+10.9}_{-9.9}$	-0.29 ± 0.23	$(+0.026, +0.092)$
$B \to K_s^0\pi^{\pm}$	$25.2^{+6.4}_{-5.6}$	$+0.18 \pm 0.24$	$+0.015$
$B \to K^{\pm}\eta'$	100^{+13}_{-12}	$+0.03 \pm 0.12$	$(+0.020, +0.061)$
$B \to \omega\pi^{\pm}$	$28.5^{+8.2}_{-7.3}$	-0.34 ± 0.25	$(-0.120, +0.024)$
$B \to J/\psi K^{\pm}$	534	$+0.018 \pm 0.043$	< 0.04
$B \to \psi(2S)K^{\pm}$	120	$+0.020 \pm 0.092$	< 0.04

- **Published in Phys. Rev. Lett. 84, 5940 (2000)**
- **Published in Phys. Rev. Lett. 85, 525 (2000)**

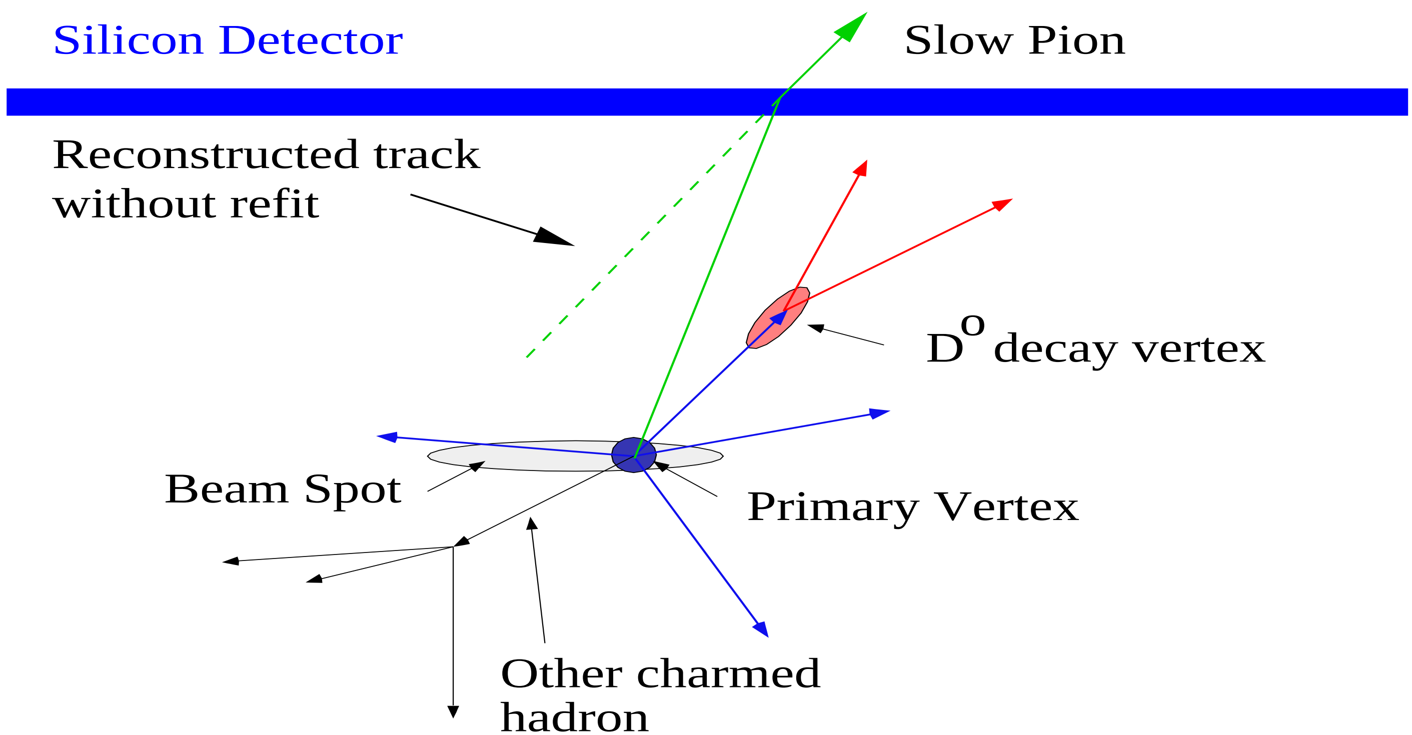
Search for CP Violation in D^0 Decay

Possible CP violation in Cabibbo Suppressed D^0 decays:

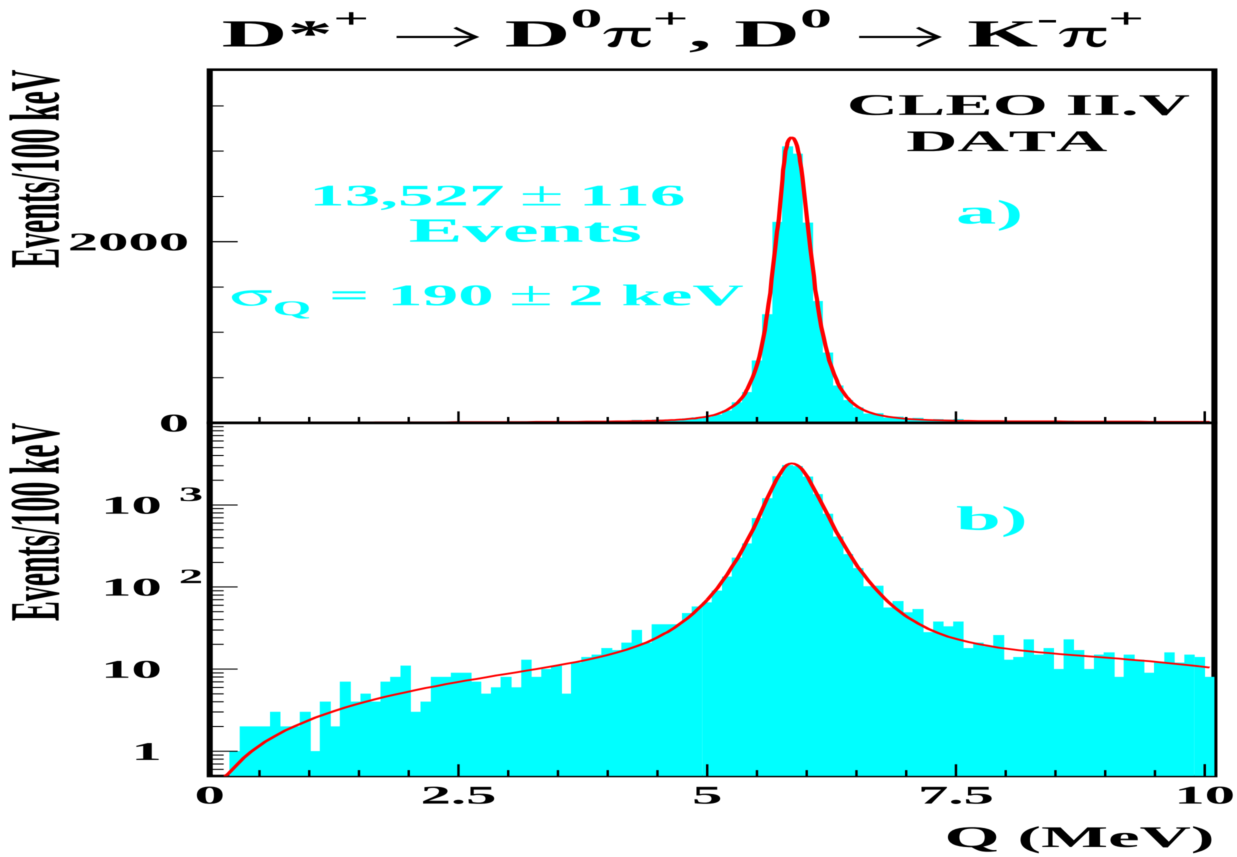
- **At least two paths (tree, exchange, penguin)**
- **Same final state with different CP-odd, CP-even phases**
- **Sensitive to New Physics:**
  - **Standard Model Expection:** $\mathcal{A}_{CP}$ $\mathcal{O}(0.1\%)$
  - **New Physics can enter in the loops**

Experimental Technique

- **Decay chain:** $D^{*+} \rightarrow D^0 \pi_s^+$
- **Use SLOW π_s^+ to tag D^0 flavor at production**
- **Refit slow pion:** $Q \equiv M(D^0_{cand}\pi_S^+) - M(D^0_{cand}) - M_\pi$



Q resolution after refit

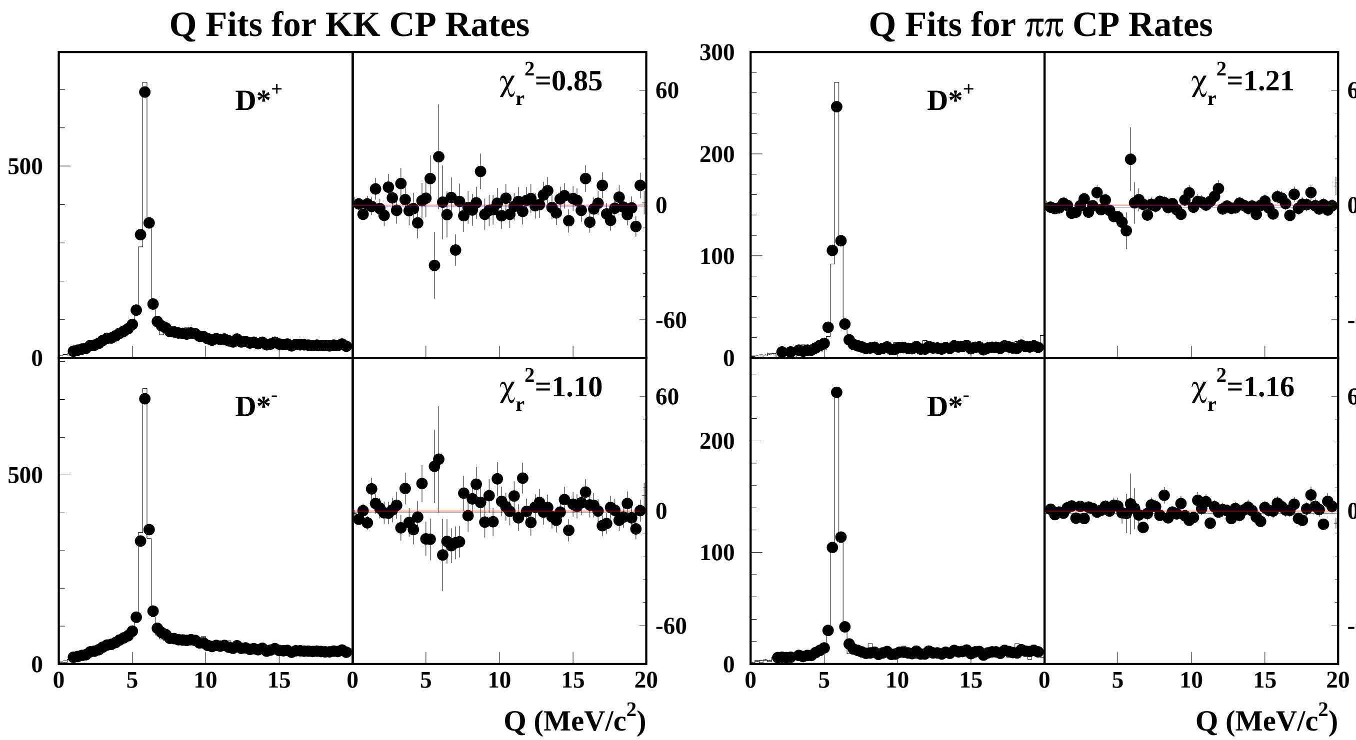


- **Same technique we measured** $\Gamma(D^{\star +}) = 96 \pm 4 \pm 22$ **MeV**

CP Violation in $D^0 \to K^+K^-, \pi^+\pi^-$

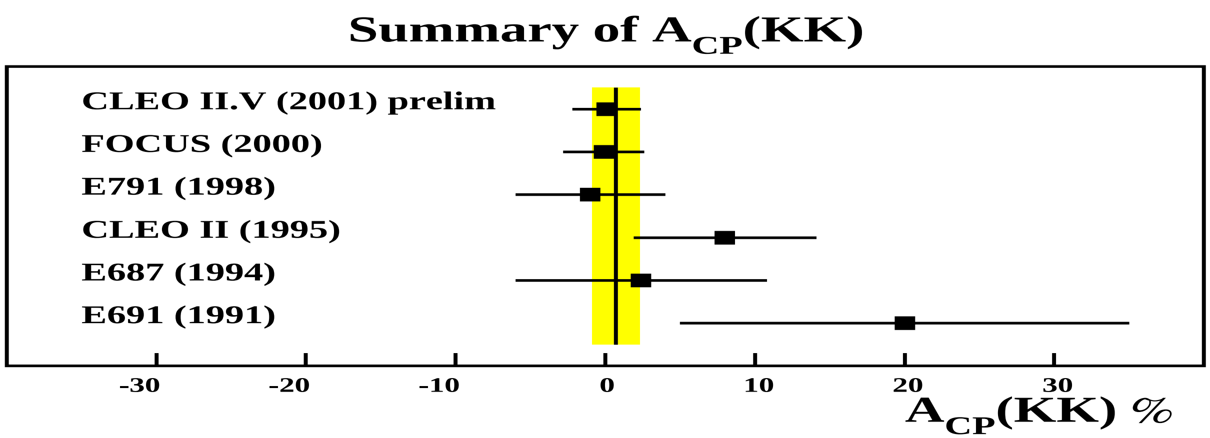
- **Select** $D^0 \to K^+K^-(\pi^+\pi^-)$
- **Use slow pion tag from** $D^{*+} \to D^0\pi_S^+$
- **Fit** Q **distribution to obtain yields**
- **Measure** CP **asymmetry** $A_{CP}(KK)$
- $A_{CP}(KK) = \frac{\Gamma(D^0 \to K^+K^-) - \Gamma(\overline{D^0} \to K^+K^-)}{\Gamma(D^0 \to K^+K^-) + \Gamma(\overline{D^0} \to K^+K^-)}$

CP Violation in $D^0 \to K^+K^-, \pi^+\pi^-$

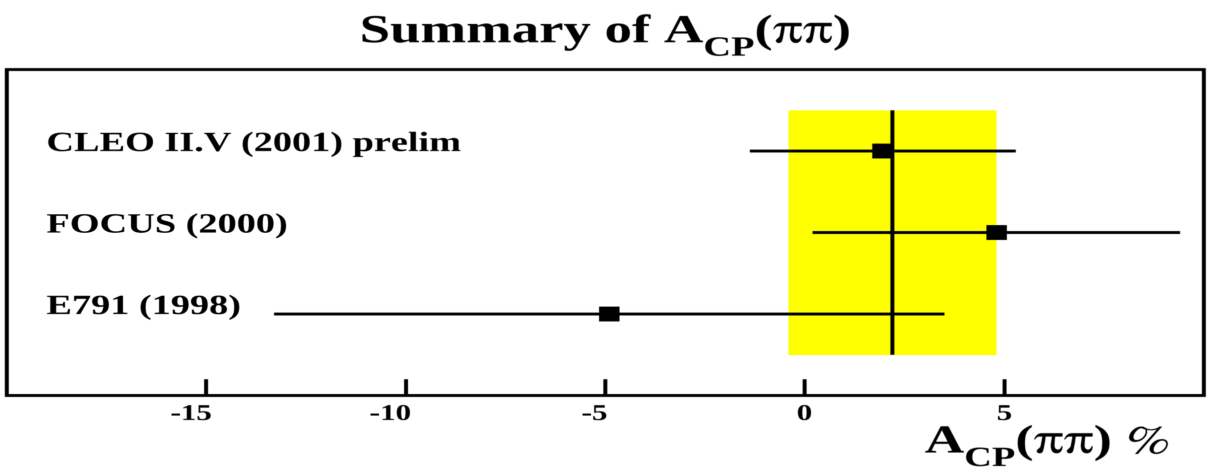


- 1512 ± 47 $D^0 \to K^+K^-$ **events** $\quad$ 579 ± 26 $D^0 \to \pi^+\pi^-$ **events**
- 1511 ± 47 $\overline{D^0} \to K^+K^-$ **events** $\quad$ 557 ± 26 $\overline{D^0} \to \pi^+\pi^-$ **events**

CP Violation in $D^0 \to K^+K^-, \pi^+\pi^-$



CLEO II.V $A_{CP}(K^+K^-) = (0.1 \pm 2.2 \pm 0.8)\%$

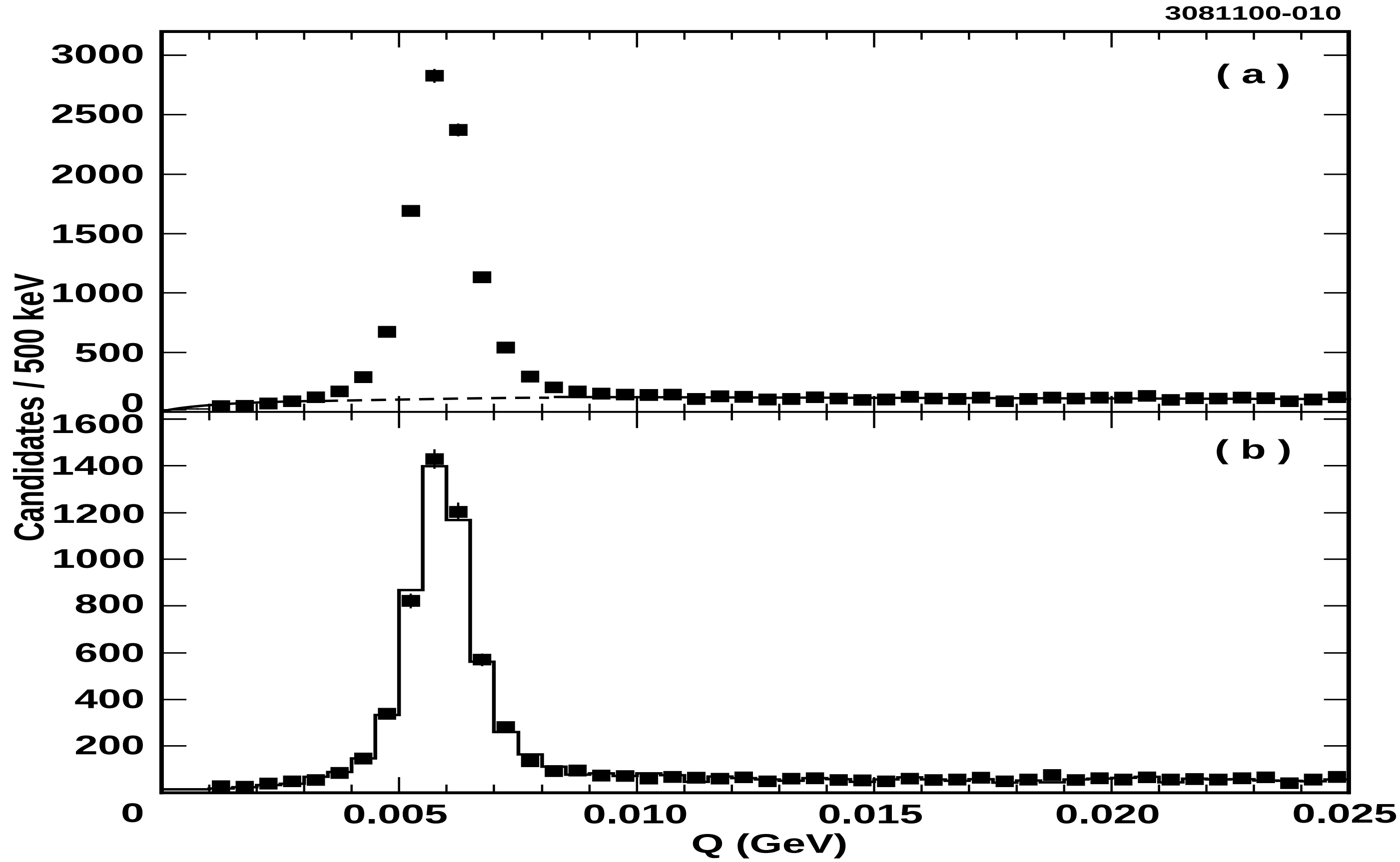


CLEO II.V $A_{CP}(\pi^+\pi^-) = (2.0 \pm 3.2 \pm 0.8)\%$

CP Violation in $D^0 \to K_s\pi^0$, $\pi^0\pi^0$ and K_sK_s

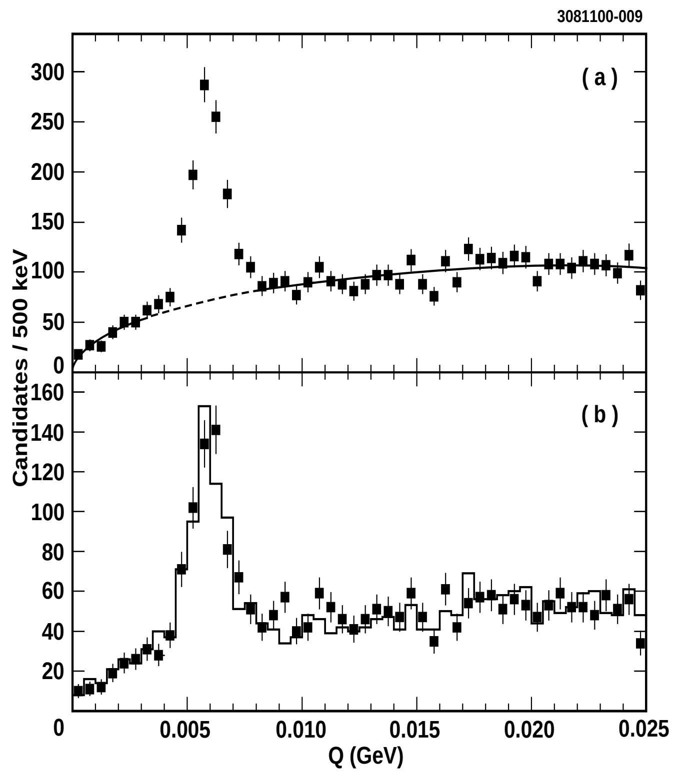
- **Similar techniques, use slow pion tag**
- **Poor resolution on D^0 projection**
- **No slow π refit**
- **Use full CLEO II + II.V data**
- **Measure CP asymmetries $A_{CP}(K_s^0\pi^0)$, $A_{CP}(\pi^0\pi^0)$, $A_{CP}(K_s^0K_s^0)$**
- $\mathbf{A}_{CP}(K_S^0\pi^0) = \frac{\Gamma(D^0\to K_S^0\pi^0)-\Gamma(\overline{D^0}\to K_S^0\pi^0)}{\Gamma(D^0\to K_S^0\pi^0)+\Gamma(\overline{D^0}\to K_S^0\pi^0)} = \frac{N(D^0\to K_S^0\pi^0)-N(\overline{D^0}\to K_S^0\pi^0)}{N(D\to K_S^0\pi^0)}$

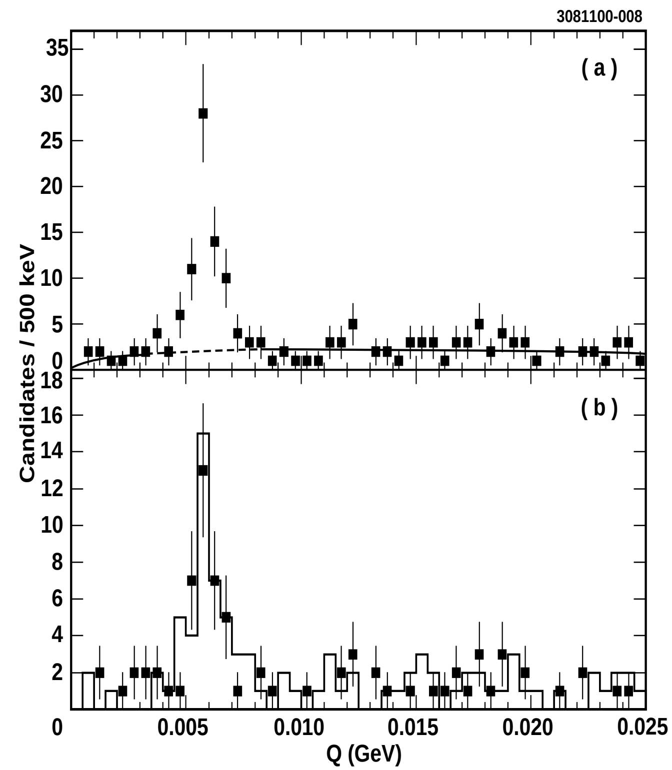
CP Violation in $D^0 \to K_s^0\pi^0$



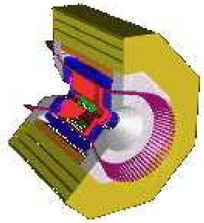
- **9099 $\pm$ 153 Events,** $A_{CP}(K_S\pi^0) = (+0.1 \pm 1.3)\%$

CP Violation in $D^0 \to \pi^0\pi^0$, K_sK_s





- 810 ± 89 Events, $A_{CP}(\pi^0\pi^0) = (+0.1 \pm 4.8)\%$
- 65 ± 14 Events, $A_{CP}(K_sK_s) = (-23 \pm 19)\%$

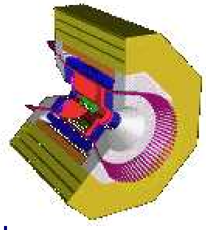


CLEO II + II.V data (13.5 fb^{-1})

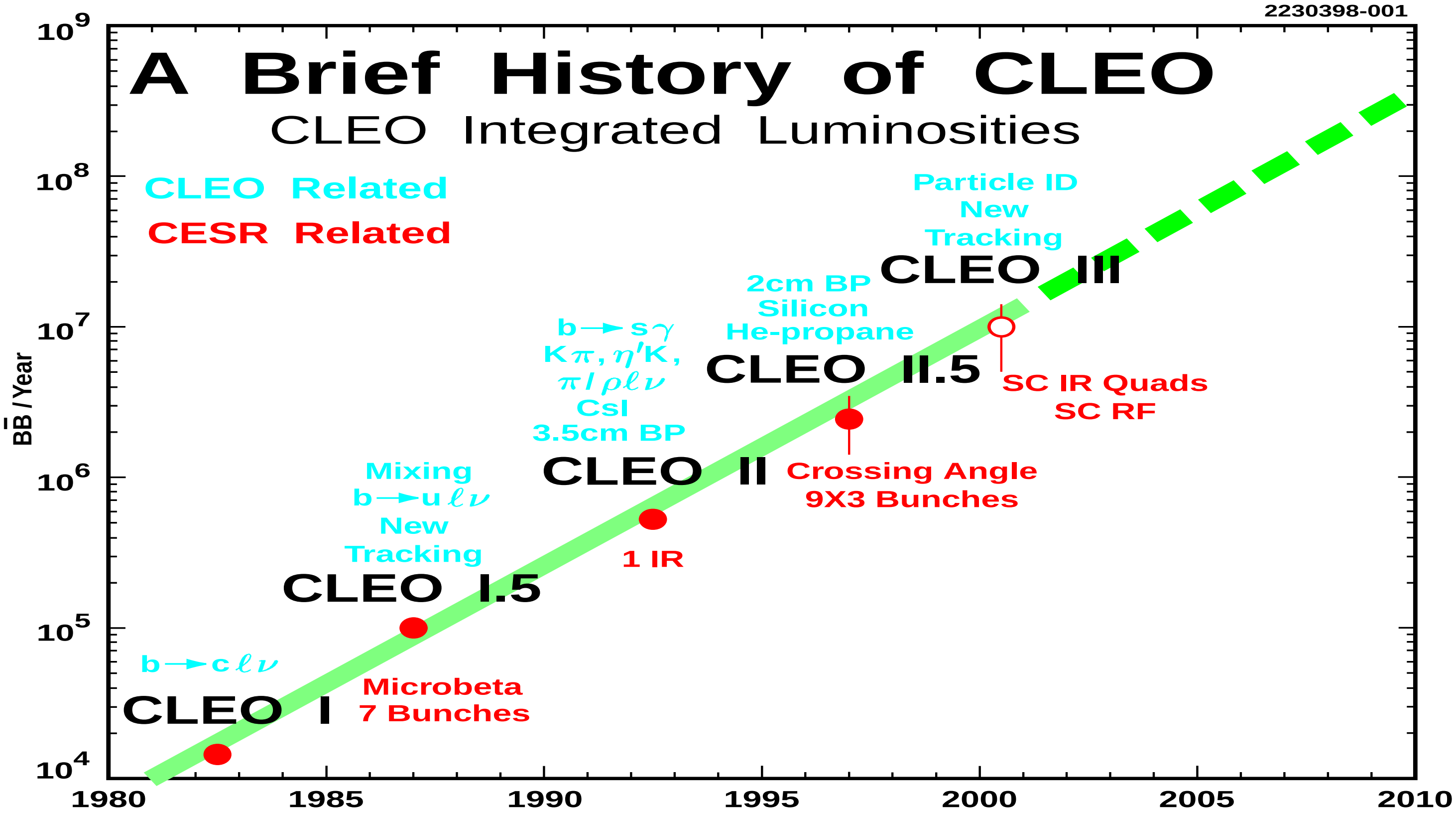
- **Rare B decays:** $B \to PP$, PV, VV, $\phi K^{(*)}$, $l^+l^-K^{(*)}$; $b \to s\gamma$
- CP **Violation in** B **Decays**
- CP **Violation in Charm Decays**
- **Observation of** $B \to D^*\pi\pi\pi\pi$
- $D^0 - \overline{D^0}$ **Mixing**
- CP **Violation in Tau Decays**
- **Measurement of CKM Elements** V_{ub} **and** V_{cb}

CLEO III data $(\sim 10 \text{ fb}^{-1})$

- **Physics Results expected in July**



The past/present/future of CESR/CLEO



The CLEO-C Proposal

- **Modify CESR/CLEO for High Lumi. @ 3 – 4 GeV**
- **CLEO-C WORKSHOP: May 5 – 7, 2001 at Cornell Univ.**
- **Expected CESR performance:**
  - **Luminosity: (1 – 4) × 10^{32} cm^{-2}s^{-1}**
  - **Intergrated Luminosity: (1 – 4) fb^{-1}/year**
- **Expected data sample (start early 2003):**
  - 2×10^9 J/ψ/**fb**$^{-1}$,   **10^7** ψ''/**fb**$^{-1}$, 5×10^5 $D_s\overline{D_s}$/**fb**$^{-1}$
- **Physics can be achieved:**
  - **Precision decay constants, absolute BR ......**
  - **Test of QCD (Glueball, Hybrids) ......**
  - **Mixing, CP violation in charm, τ decays ......**