

Probing the Standard Model with Electroweak Penguin B Decays

Sridhara Dasu

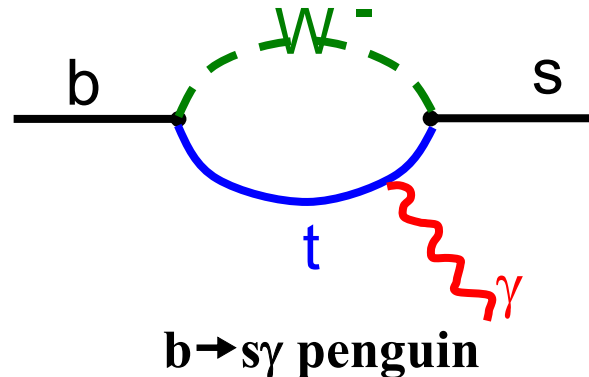
BaBar Collaboration

University of Wisconsin - Madison

Outline:

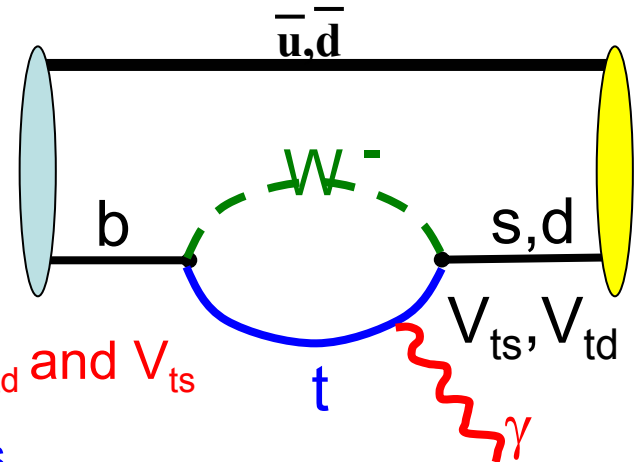
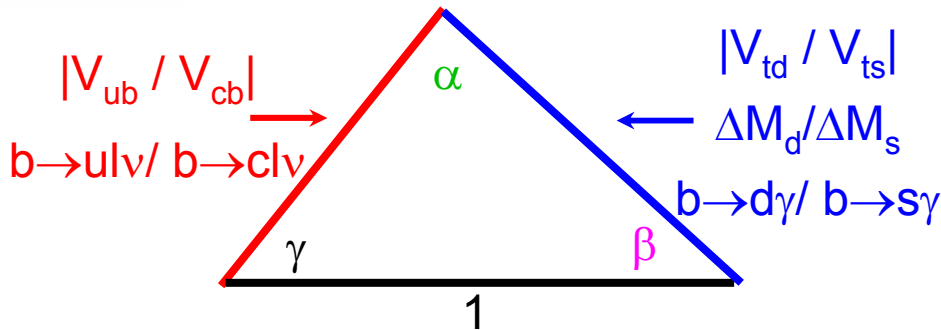
- Branching fractions
- CP Asymmetry
- Isospin breaking
- Measurement of CKM parameters
- B Decays
 - $b \rightarrow s \gamma$: $B \rightarrow K^* \gamma$, $B \rightarrow \rho \gamma$, $B \rightarrow K^*(1430) \gamma$, etc.
 - $b \rightarrow s l^+ l^-$: $B \rightarrow K l^+ l^-$, $B \rightarrow K^* l^+ l^-$

Electroweak Penguins : Sensitivity to New Physics



- Flavor changing neutral currents ($b \rightarrow s$) are small
- At tree level FCNC is prohibited in the Standard Model
- Loop level contributions (radiative penguins: strong and EM)
- EM radiative penguins are a good indirect probe of new physics as non-Standard Model contributions (H^\pm, χ^\pm, \dots) can appear in the loop
- New Physics can effect the branching fraction and/or CP and isospin breaking asymmetries

Measuring CKM Parameters

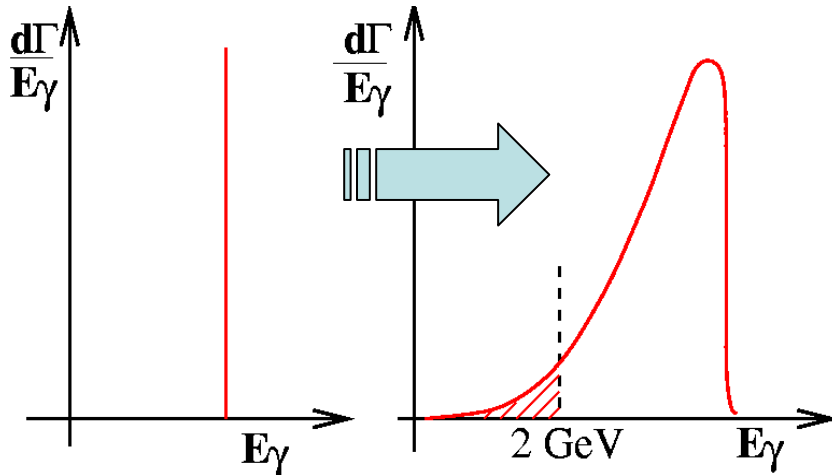


Measuring $b \rightarrow s\gamma$ and $b \rightarrow d\gamma \Rightarrow$ access to V_{td} and V_{ts}

- Theorists ideal: inclusive measurements
 - Avoid hadronic uncertainty
 - However, large experimental backgrounds
- Experimentally more accessible: exclusive measurements
 - Backgrounds much reduced
 - Must contend with large B-meson model dependence
 - Most theoretical and systematic effects cancel in the ratio of $B \rightarrow K^*\gamma$ and $B \rightarrow \rho\gamma$, $B \rightarrow \omega\gamma$

Understanding the B Meson

γ **Energy Spectrum: No monochromatic γ spectrum because of b quark motion within the B meson**



From moments analysis of γ energy spectrum \rightarrow extraction of Heavy Quark Effective Theory (HQET) parameters:

- $\bar{\Lambda}$ = energy of the light degrees of freedom in the B meson
- λ_1 = average momentum squared of the b quark in the B meson

Understanding the B meson model is important for reducing systematic uncertainty in measurement of V_{ub} from semileptonic decays.

Tackling $b \rightarrow s\gamma$, $b \rightarrow d\gamma$ Backgrounds

- Fully Inclusive Analysis

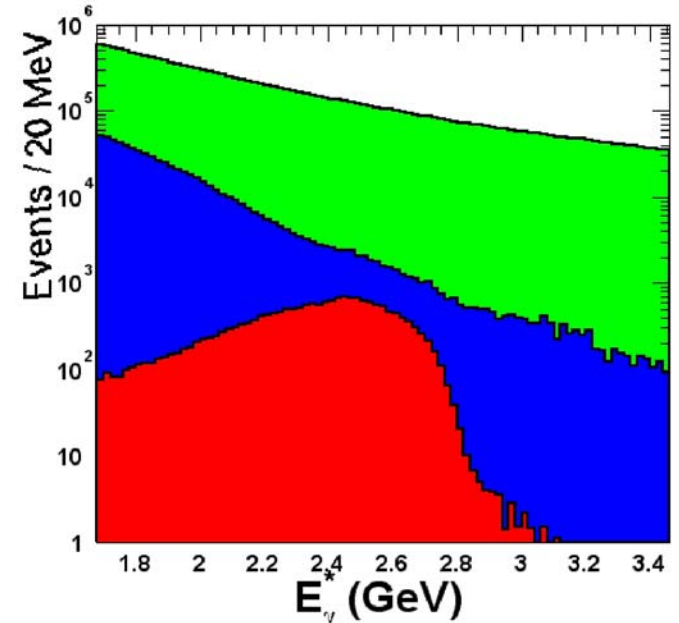
- Large continuum background
 - Event shapes, B-Tagging
 - Statistical subtraction using off resonance data
- B background (π^0 and η misidentification)
 - Strict vetos based on calorimeter energy profile

- Semi-Inclusive Analysis

- Require hadronic system with a single kaon and up to 3 pions
- B mass reconstruction

- Exclusive Analysis

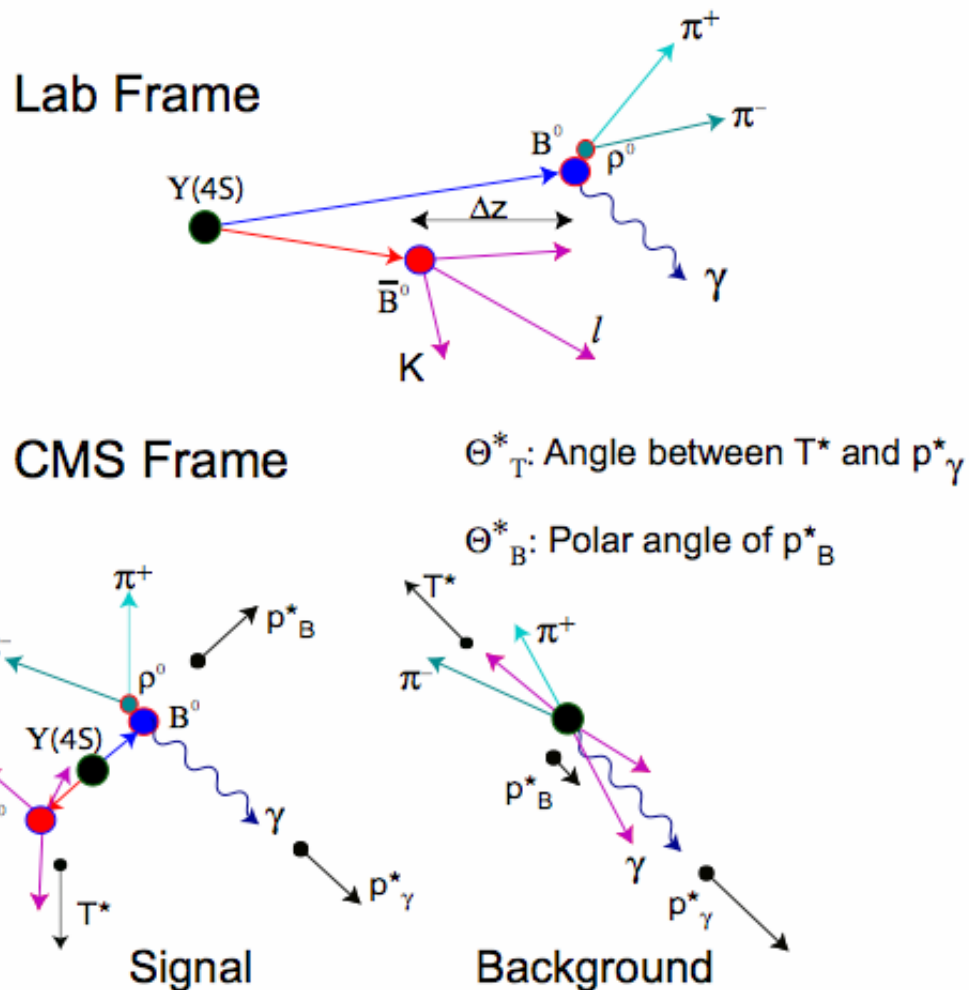
- Cuts down the background by explicitly reconstructing hadronic system and combining with g to make B candidates
 - K^* , higher K resonances, ρ , ω



Inclusive EM cluster spectrum
(includes γ and misidentified hadrons)

Signal & Background Topology

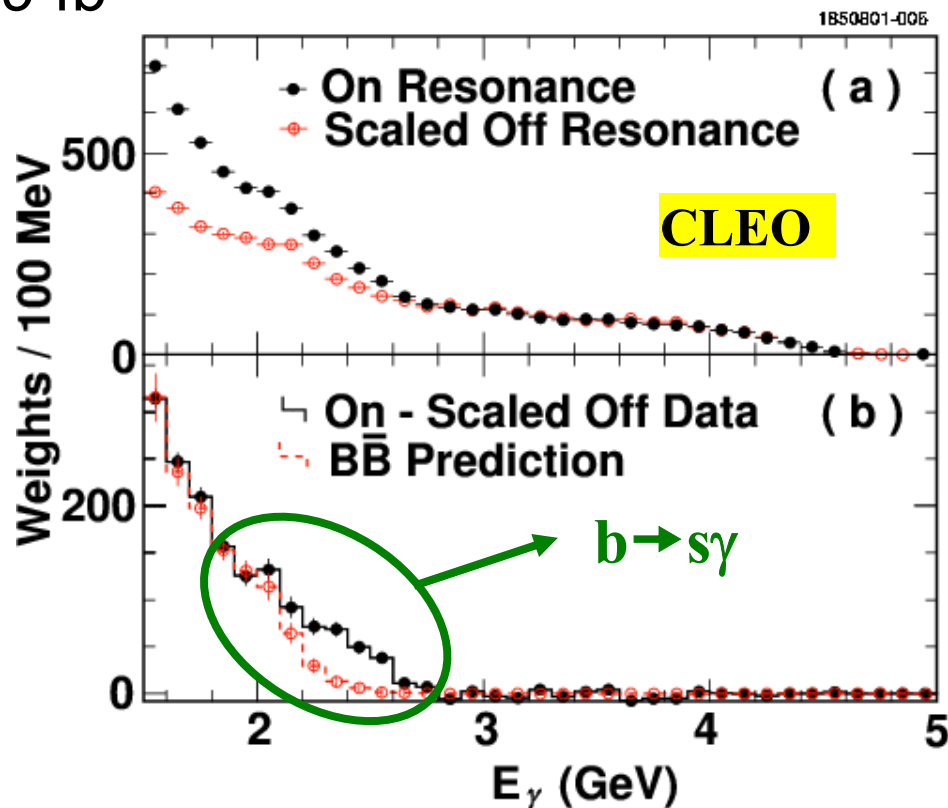
- At BaBar & Belle Bs are boosted
 - Large Δz identifies B
- In CMS frame
 - Signal events are spherical
 - Continuum is jet like
 - Thrust, sphericity,...
 - Angles about γ direction
 - Net flavor of the event
- Multivariate analysis
 - Individual variables offer limited separation of signal from background
 - Newer analysis, especially, $b \rightarrow d, \gamma$, use sophisticated techniques



Suppressing $b \rightarrow s\gamma$ background Using Off-resonance Data

Identify γ and suppress background exploiting large off-resonance data set + other techniques (CLEO)

$\sim 9 \text{ fb}^{-1}$



Experimentally hard to suppress BB background at low γ energy

Lower energy cut on the γ energy in all the experimental measurements \rightarrow model dependence

Eg. $E_\gamma > 2 \text{ GeV}$ corresponds to $\sim 90\%$ of the whole spectrum



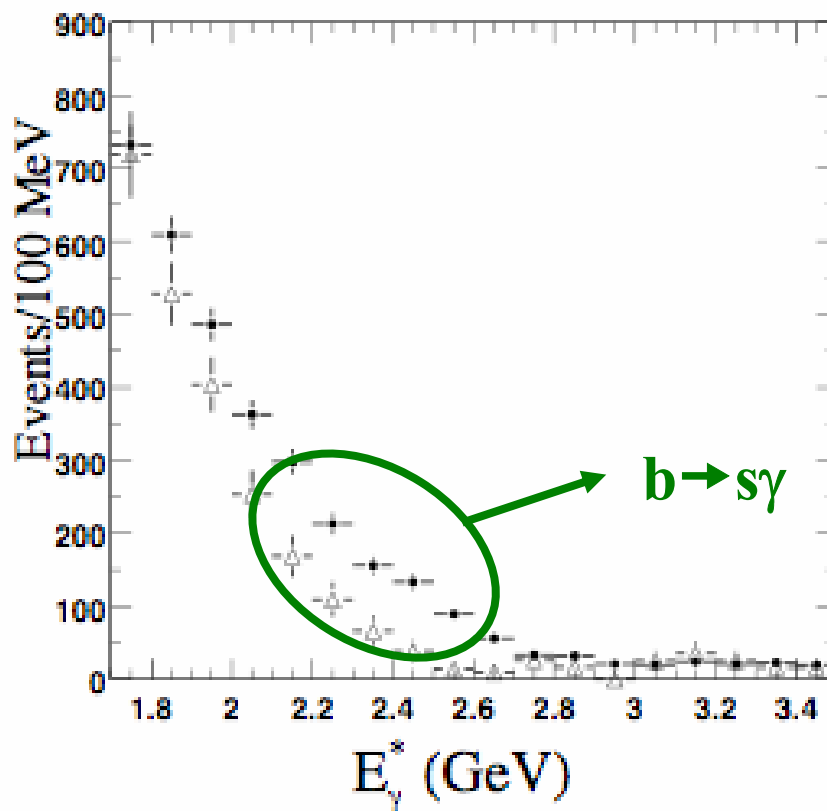
Suppressing $b \rightarrow s\gamma$ background by tagging lepton from the other B

Preliminary result presented at ICHEP 2002:

BABAR

55 fb^{-1}

Lepton
tagged

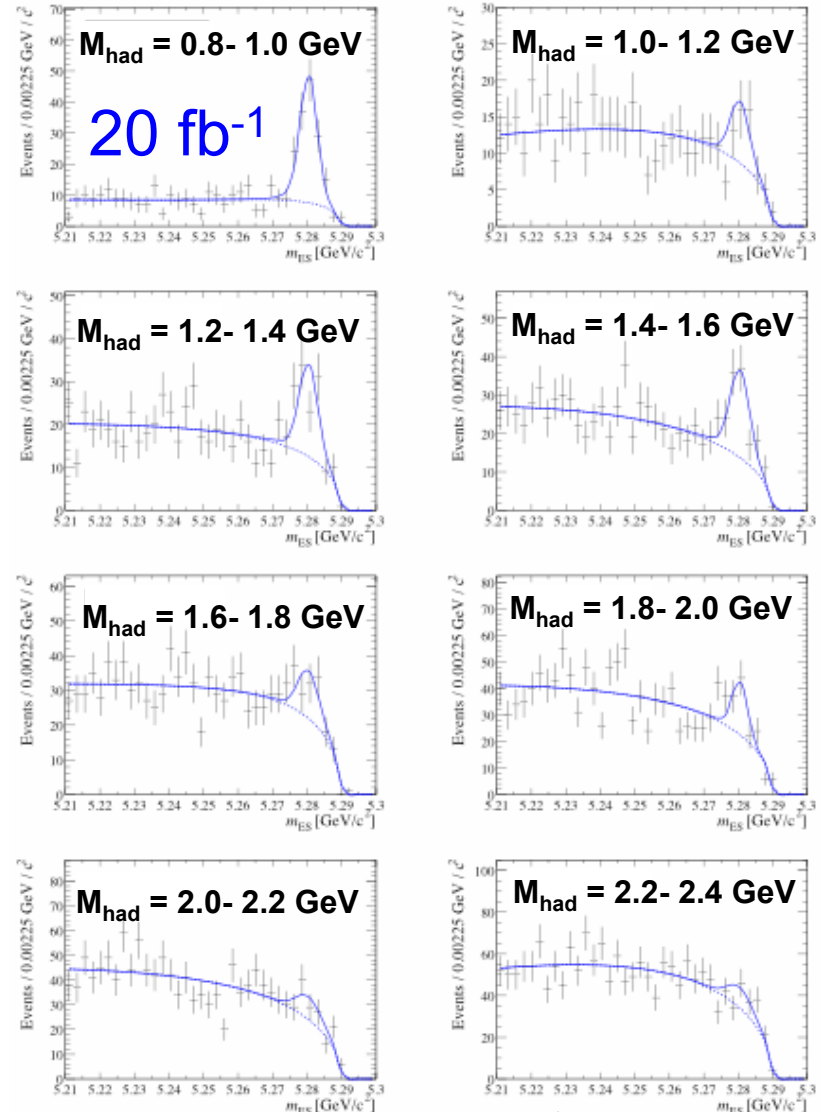


$\Delta = B\bar{B} +$
Continuum
Backgrounds

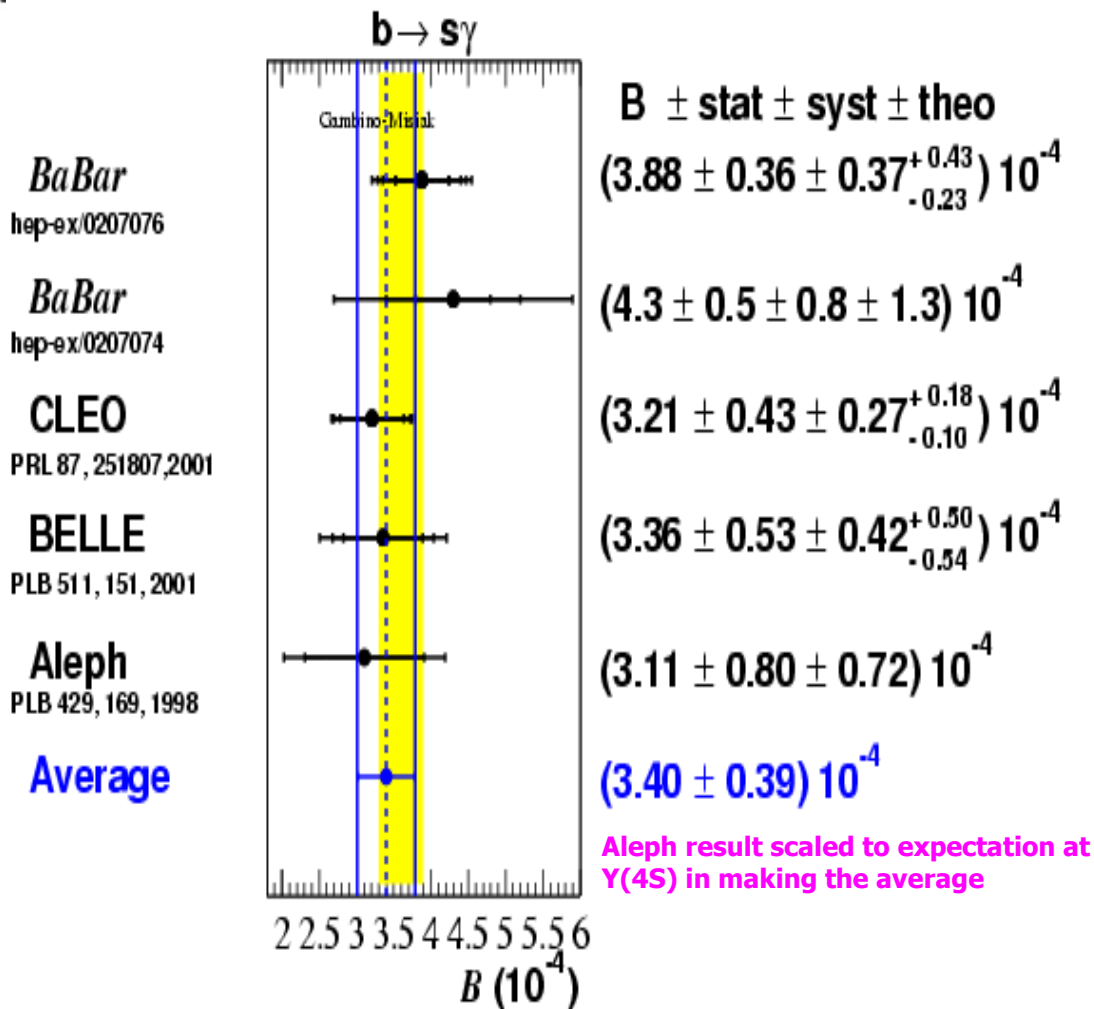
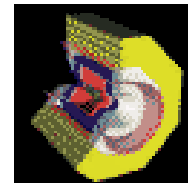
Suppressing $b \rightarrow s\gamma$ background by summing up exclusively reconstructed B mesons

Two body decay $\Rightarrow E_\gamma = \frac{M_b^2 - M_{had}^2}{2M_b}$

- **Reconstruct 12 hadronic modes**
 - Require K^\pm or K_s and up to 3 pions ($n_{\pi^0} \leq 1$)
 - Extract signal from m_{es} , ΔE fits in bins of hadronic mass M_{had}
- **Advantages**
 - M_{had} has better resolution than E_γ
 - M_{had} spectrum can be used for improving V_{ub} measurement
- **Difficulties**
 - Multiple candidates
 - Selected best with least ΔE
 - Larger background for high multiplicity states
 - Missing mode correction model



$b \rightarrow s\gamma$ Branching Fraction



Theoretical prediction for $B(b \rightarrow s\gamma (E_\gamma > 1.6 \text{ GeV})) = (3.60 \pm 0.30) \cdot 10^{-4}$
 Gambino, Misiak
 hep-ph/010434

No consistent treatment of the theoretical errors among the experiments

Average made assuming only theoretical errors correlated

Experimental results consistent with the SM \rightarrow limits on new physics contributions (Ellis et al., hep

Unofficial averages made using L.Lyons *et al.*, NIM A270, 110, 1988

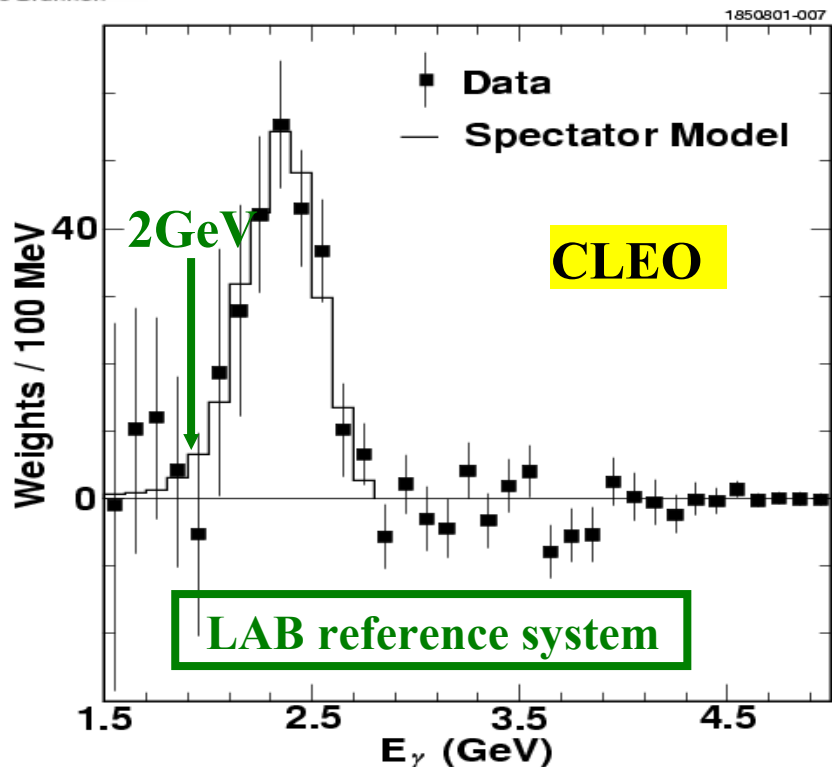
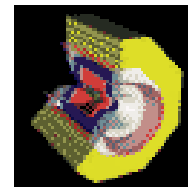


Direct CP asymmetry in $b \rightarrow s\gamma$

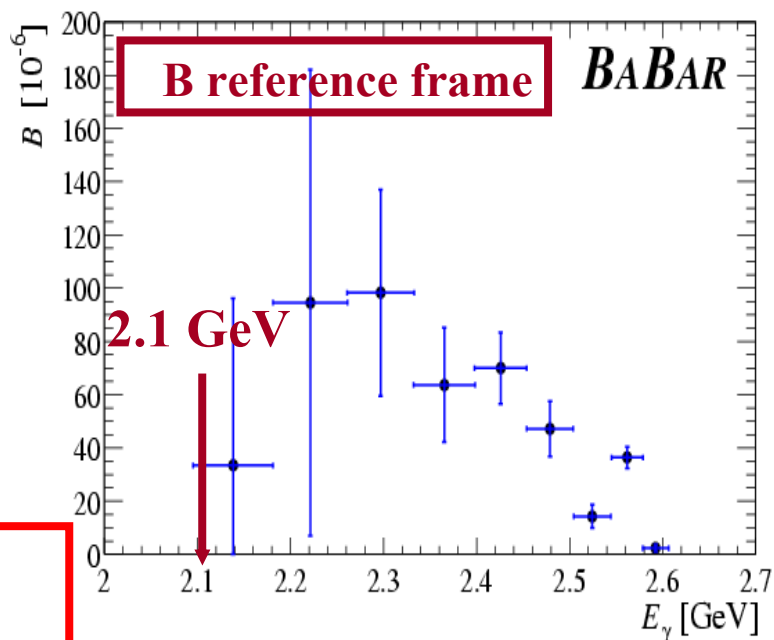
$$A_{\text{CP}} = \frac{B(b \rightarrow s\gamma) - B(\bar{b} \rightarrow \bar{s}\gamma)}{B(b \rightarrow s\gamma) + B(\bar{b} \rightarrow \bar{s}\gamma)}$$

- Only a measurement from CLEO, using inclusive and exclusive final states (PRL 86, 5661, 2001), 9.1 fb^{-1}
- Inclusive final states: need to flavor tag the other B
- Exclusive final states: self-tagging
- No distinction between $b \rightarrow s\gamma$ and $b \rightarrow d\gamma$
 $A_{\text{CP}} = 0.965 * A_{\text{CP}}(b \rightarrow s\gamma) + 0.02 * A_{\text{CP}}(b \rightarrow d\gamma) = (-0.079 \pm 0.108 \pm 0.22) \cdot (1.0 \pm 0.030)$
- Asymmetry is consistent with zero within rather large errors.

γ energy spectrum in $b \rightarrow s\gamma$



Inclusive analyses need to boost γ from LAB frame to B frame.
 Exclusive analyses from M_{X_s}
 $\rightarrow E_\gamma$ in B frame



CLEO (PRL 87, 251807, 2001)

$E_\gamma > 2.0$ GeV

$\langle E_\gamma \rangle = 2.346 \pm 0.032 \pm 0.011$ GeV

$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 = 0.0226 \pm 0.0066 \pm 0.0020$

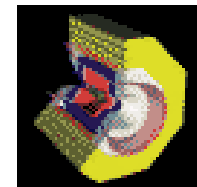
GeV²

BaBar (hep-ex/0207074)

$E_\gamma > 2.1$ GeV

$\langle E_\gamma \rangle = 2.35 \pm 0.04 \pm 0.04$ GeV

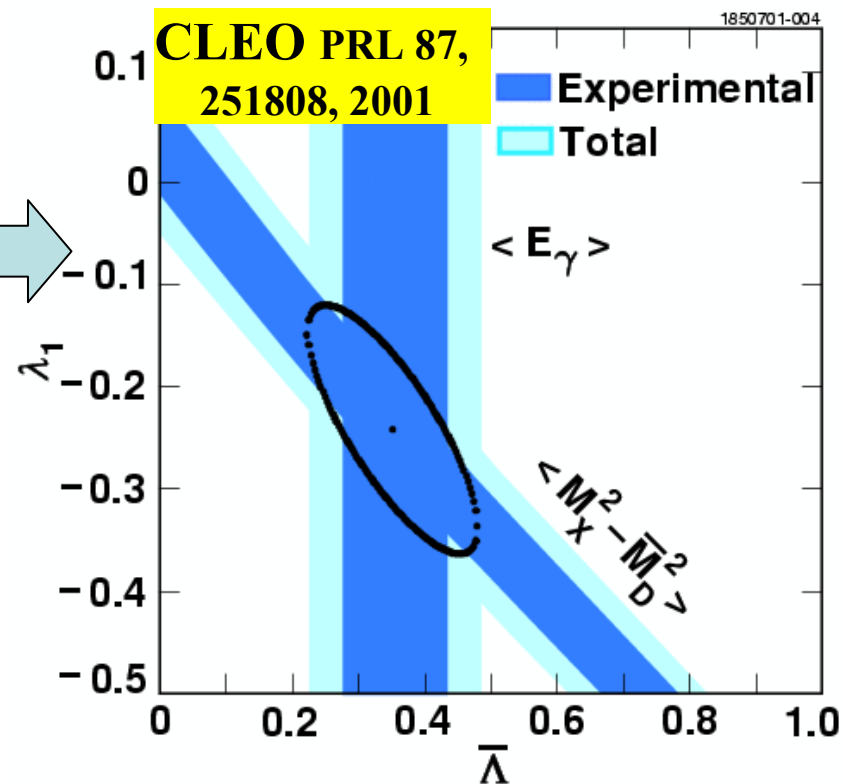
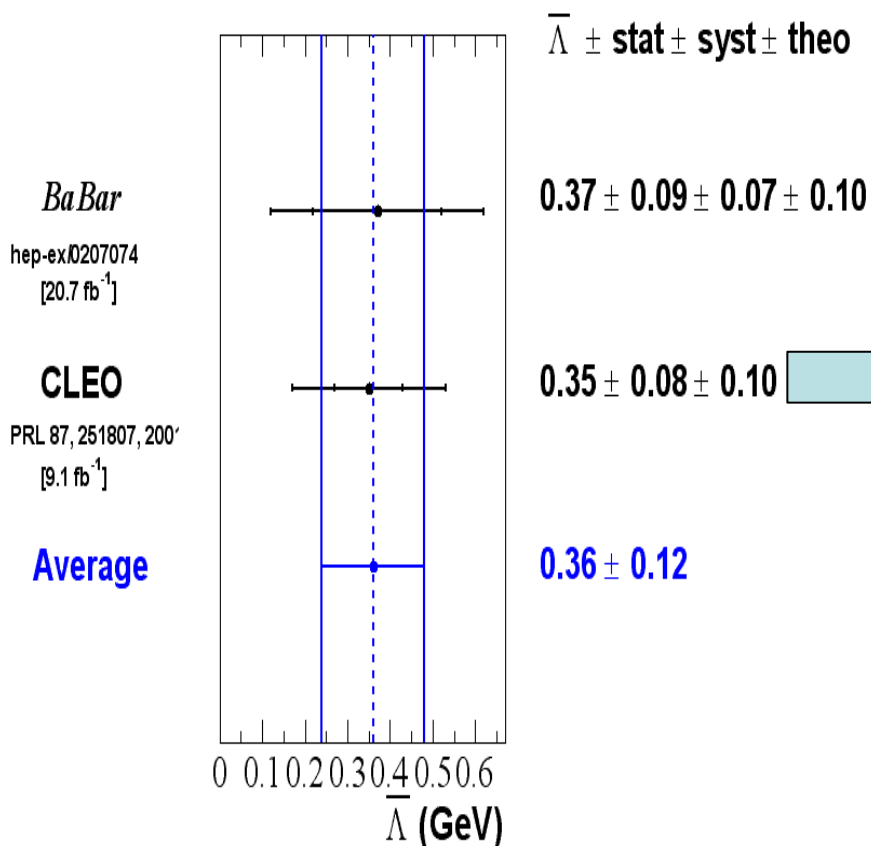
B Meson parameters from $b \rightarrow s \gamma$



$\bar{\Lambda}$ from first E_γ moment
(Ligeti et al. PRD 60, 034019, 1999):

Using the hadronic mass moments in inclusive semileptonic B decays

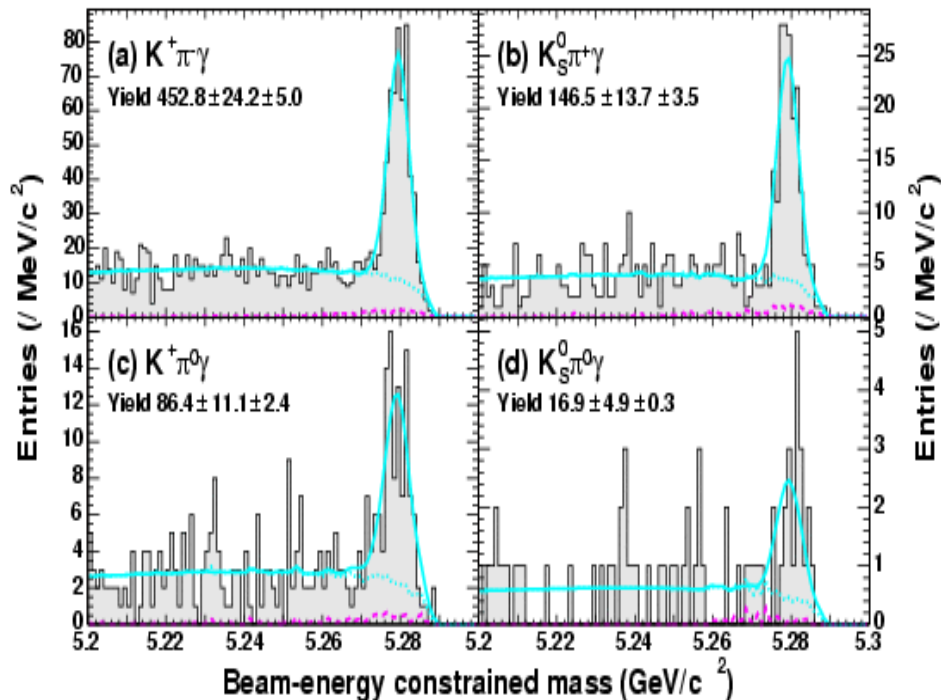
$$\lambda_1 = -0.24 \pm 0.11 \text{ GeV}^2$$



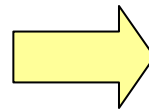


Exclusive Decay: $B \rightarrow K^* \gamma$

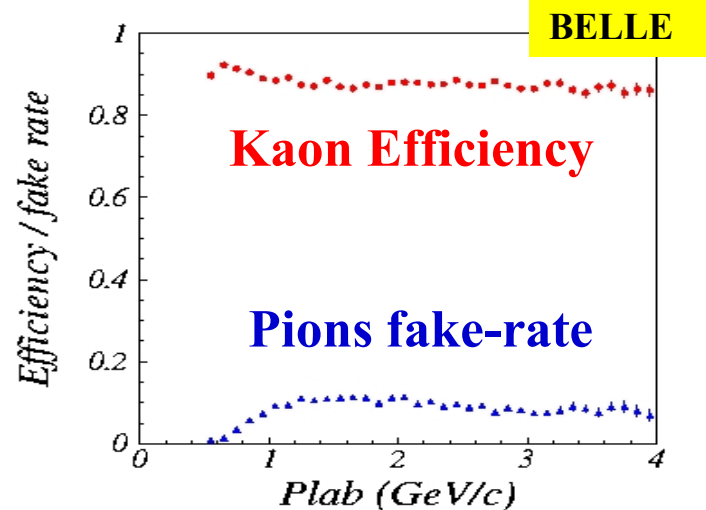
$B \rightarrow K^*(892) \gamma$ – BELLE



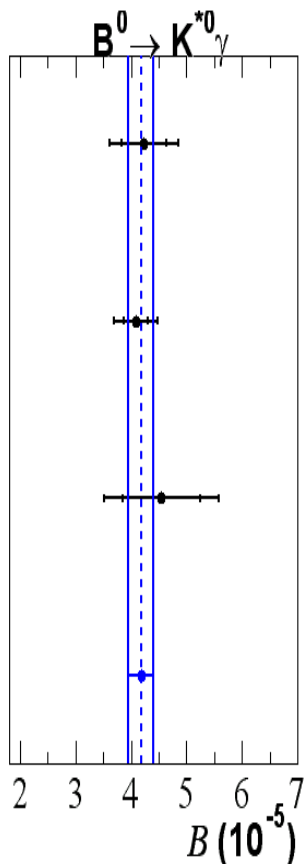
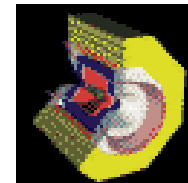
Kaon ID is important to reduce background



- First observation of $B \rightarrow K^*(892) \gamma$ and $B \rightarrow K_2^*(1430) \gamma$ by CLEO (1993 and 2000).
- Much higher statistics now. Results close to being systematics limited.
- Measurements of Branching Fractions, CP asymmetries and isospin asymmetry between B^0 and B^\pm decay widths



B → K*γ results



B ± stat ± syst

$(4.23 \pm 0.40 \pm 0.22) 10^{-5}$

BaBar

PRL 88, 101805, 2002
[20.7 fb⁻¹]

BaBar

PRL 88, 101805, 2002
[20.7 fb⁻¹]

BELLE

BELLE-CONF-0239
[78 fb⁻¹]

CLEO

PRL 84, 5283, 2000
[9.2 fb⁻¹]

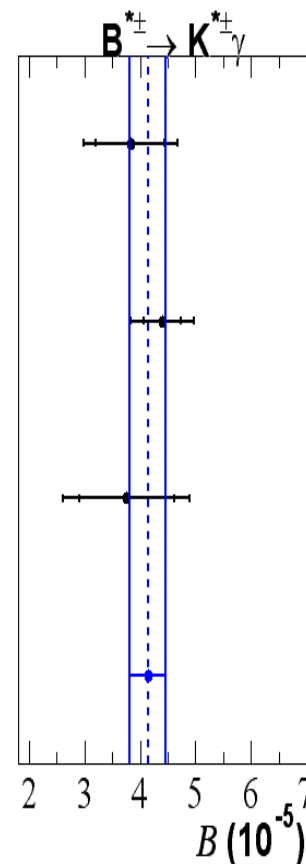
Average

$(4.09 \pm 0.21 \pm 0.19) 10^{-5}$

New

$(4.55 \pm 0.70 \pm 0.34) 10^{-5}$

$(4.18 \pm 0.23) 10^{-5}$



B ± stat ± syst

$(3.83 \pm 0.62 \pm 0.22) 10^{-5}$

BaBar

PRL 88, 101805, 2002
[20.7 fb⁻¹]

BaBar

PRL 88, 101805, 2002
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BELLE

BELLE-CONF-0239
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[9.2 fb⁻¹]

Average

BELLE

BELLE-CONF-0239
[78 fb⁻¹]

CLEO

PRL 84, 5283, 2000
[9.2 fb⁻¹]

Average

$(4.40 \pm 0.33 \pm 0.24) 10^{-5}$

New

$(3.76 \pm 0.86 \pm 0.28) 10^{-5}$

$(4.14 \pm 0.33) 10^{-5}$

BELLE isospin asymmetry:

$r = \tau_{B^{\pm}} / \tau_{B^0} = 1.083 \pm 0.017$

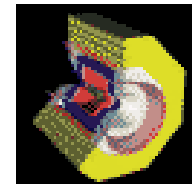
$\Delta_{0\pm} = \frac{rB(B^0 \rightarrow K^{*0} \gamma) - B(B^{\pm} \rightarrow K^{*\pm} \gamma)}{rB(B^0 \rightarrow K^{*0} \gamma) + B(B^{\pm} \rightarrow K^{*\pm} \gamma)}$

$= +0.003 \pm 0.045 \pm 0.018$

New

Isospin breaking (Kagan & Neubert hep-ph/0110078) can test Wilson coefficients (C₆/C₇)

Direct CP asymmetry



$$A_{CP} = \frac{B(\bar{B} \rightarrow \bar{K}^* \gamma) - B(B \rightarrow K^* \gamma)}{B(\bar{B} \rightarrow \bar{K}^* \gamma) + B(B \rightarrow K^* \gamma)}$$

$$A_{CP} \pm \text{stat} \pm \text{syst}$$

$$-0.044 \pm 0.076 \pm 0.012$$

$$-0.001 \pm 0.044 \pm 0.008$$

New

$$0.08 \pm 0.13 \pm 0.03$$

$$-0.005 \pm 0.037$$

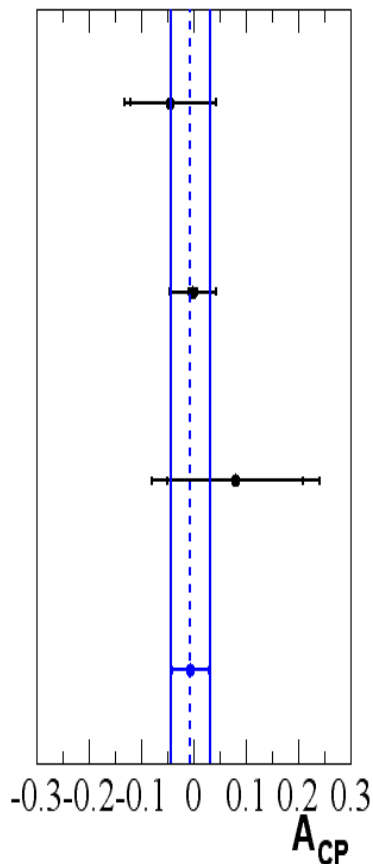
- Few percent accuracy!
- Statistics limited
- Systematic uncertainty
 - Mainly due to particle identification asymmetry
 - Background asymmetry.
 - Other systematic errors present in Branching Fraction cancel in A_{CP}

BaBar
PRL 88, 101805, 2002
[20.7 fb⁻¹]

BELLE
BELLE-CONF-0239
[78 fb⁻¹]

CLEO
PRL 84, 5283, 2000
[9.2 fb⁻¹]

Average



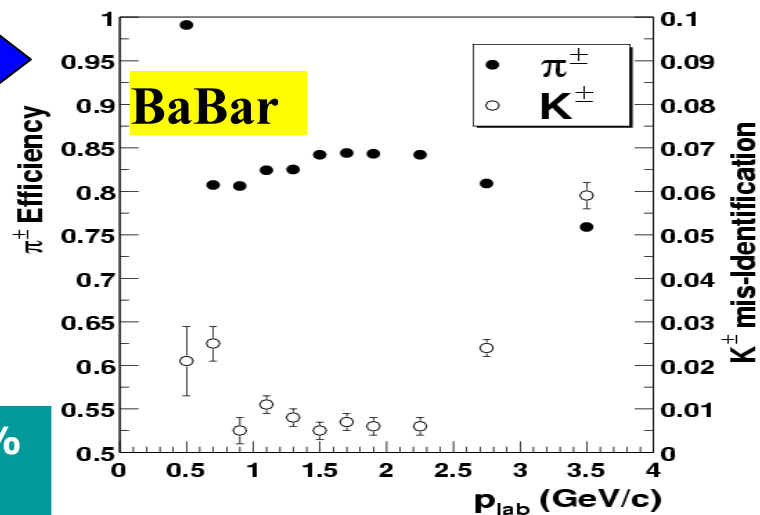
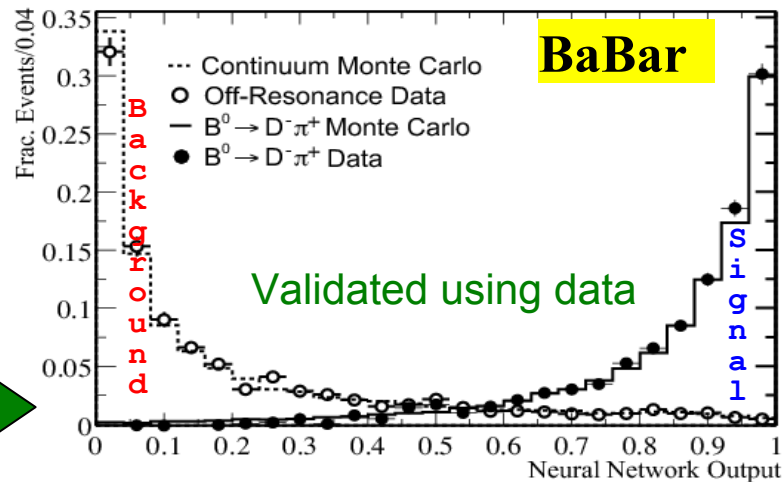
$-0.070 < A_{CP} < 0.053 @ 90\% CL$

Improved BG reduction for $B \rightarrow \rho/\omega \gamma$

Challenges :

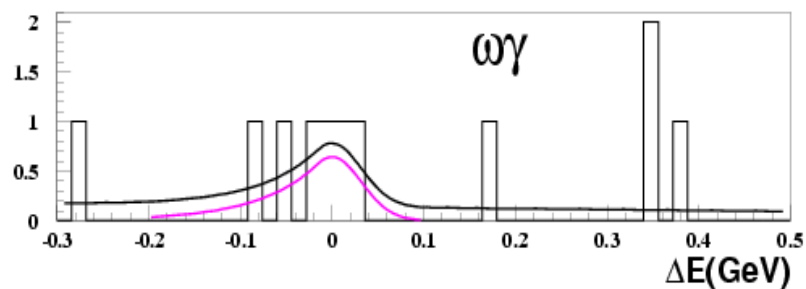
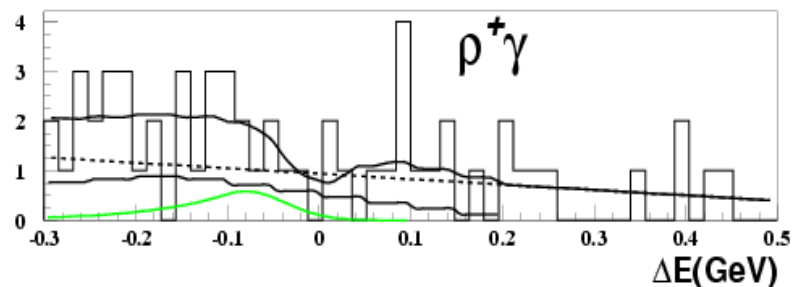
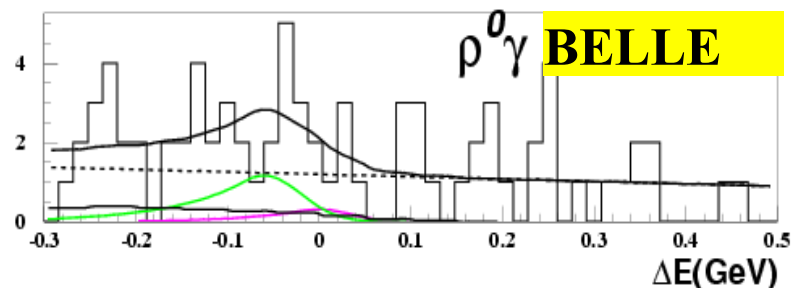
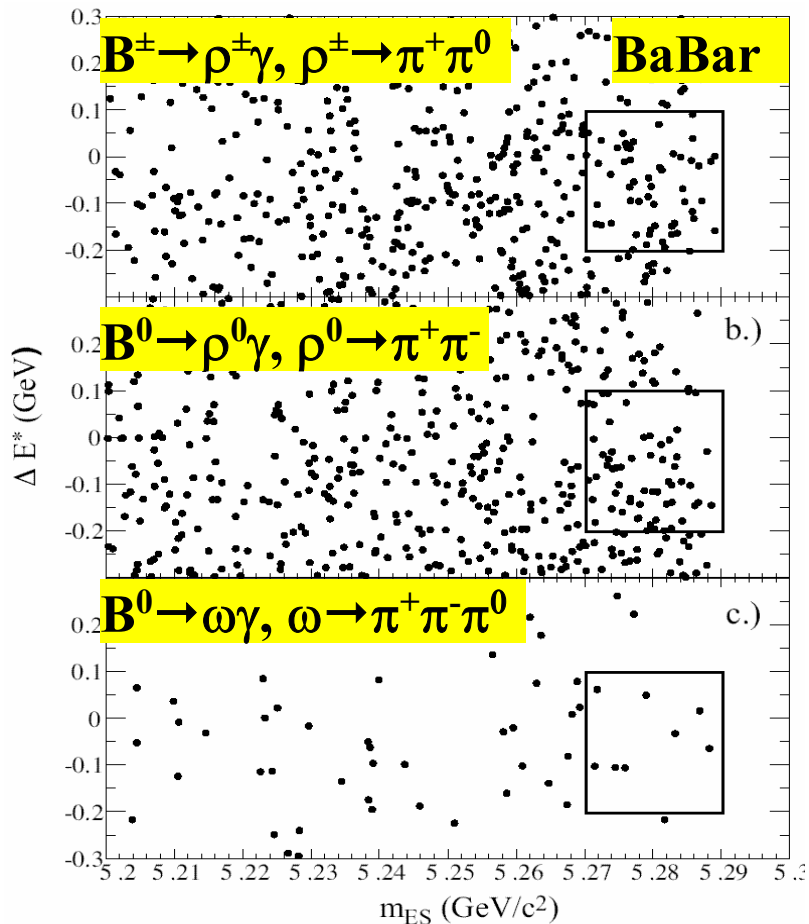
- Lower branching fraction and higher background than for $B \rightarrow K^* \gamma$. Multivariate analysis techniques used for background subtraction.
- Feed-through from $K^* \gamma$ has to be removed. Use particle identification to reduce $K \rightarrow \pi$ fake rate to $\sim 1\%$
- Irreducible background from $B \rightarrow \rho \pi^0$

$\sim 80\%$ π efficiency with $\sim 1\text{-}2\%$ K mis-ID up to ~ 3 GeV

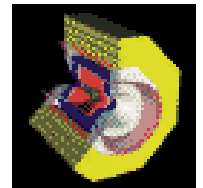


B \rightarrow ρ/ω γ

There is no evidence for signal yet:



$$B \rightarrow \rho/\omega \gamma$$



Upper limits at 90% CL on *branching ratio* are set:

	BaBar (Moriond '03)	BELLE (Moriond '03)	CLEO (PRL 84, 5283, 00)	Theory (Ali & Parkhomenko) hep-ph/0105203
	78 fb⁻¹	78 fb⁻¹	9.2 fb⁻¹	
$B(B^0 \rightarrow \rho^0 \gamma)$	$< 1.2 \cdot 10^{-6}$	$< 2.6 \cdot 10^{-6}$	$< 17 \cdot 10^{-6}$	$(0.49 \pm 0.18) \cdot 10^{-6}$
$B(B^\pm \rightarrow \rho^\pm \gamma)$	$< 2.1 \cdot 10^{-6}$	$< 2.7 \cdot 10^{-6}$	$< 13 \cdot 10^{-6}$	$(0.90 \pm 0.34) \cdot 10^{-6}$
$B(B^0 \rightarrow \omega \gamma)$	$< 1.0 \cdot 10^{-6}$	$< 4.4 \cdot 10^{-6}$	$< 9.2 \cdot 10^{-6}$	$(0.49 \pm 0.18) \cdot 10^{-6}$

CKM Parameters: $|V_{td} / V_{ts}|$

- Theoretical errors on hadronic effects mostly cancel in the ratio of exclusive modes
 - Left with $\sim 15\%$ residual uncertainty: Ali and Parmachenko
- Measurement complementary to $B_{d,s}$ mixing $\Delta M_d / \Delta M_s$
- Must first discover $b \rightarrow d \gamma$!

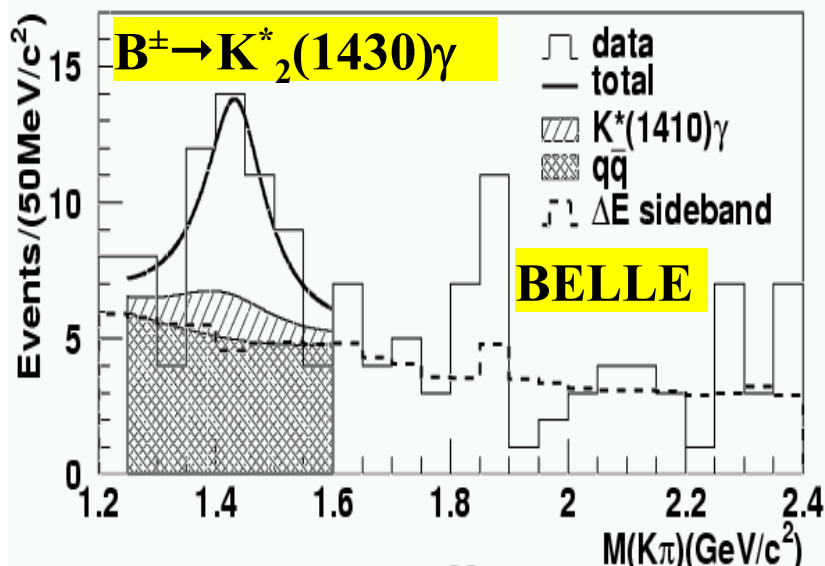
$$\frac{\text{BF}(B \rightarrow \rho \gamma)}{\text{BF}(B \rightarrow k^* \gamma)} = \left| \frac{V_{td}}{V_{ts}} \right|^2 \left(\frac{1 - \frac{m_\rho^2}{m_B^2}}{1 - \frac{m_{k^*}^2}{m_B^2}} \right) \zeta^2 [1 + \Delta R]$$

$$\zeta = 0.7 \text{ and } \Delta R = -0.25 \text{ (from Ali et al.) } \Rightarrow$$

$$\left| \frac{V_{td}}{V_{ts}} \right| < 0.36 \text{ at 90\% confidence level}$$



Understanding the hadronic spectrum: Higher K^* resonances



Ultimate goal is to track down all the resonances which contribute to the $b \rightarrow s \gamma$ spectrum!

$$B(B \rightarrow K^*_2(1430)\gamma)$$

BELLE $(1.5^{+0.6} \pm 0.1) \cdot 10^{-5}$
CLEO $(1.66^{+0.5}_{-0.53} \pm 0.13) \cdot 10^{-5}$
Average $(1.58 \pm 0.39) \cdot 10^{-5}$

90% CL limits on other resonances

- $B(B \rightarrow K_1(1270)\gamma) < 8.7 \cdot 10^{-5}$
- $B(B \rightarrow K_1(1400)\gamma) < 4.6 \cdot 10^{-5}$
- $B(B \rightarrow K^*(1410)\gamma) < 6.2 \cdot 10^{-5}$

Helicity distributions used to distinguish the resonances

**Results from BELLE (PRL 89, 231801, 2002), 29.4 fb⁻¹
and CLEO (PRL 84, 5283, 2000), 9.2 fb⁻¹**



Understanding the hadronic spectrum: Higher mass systems

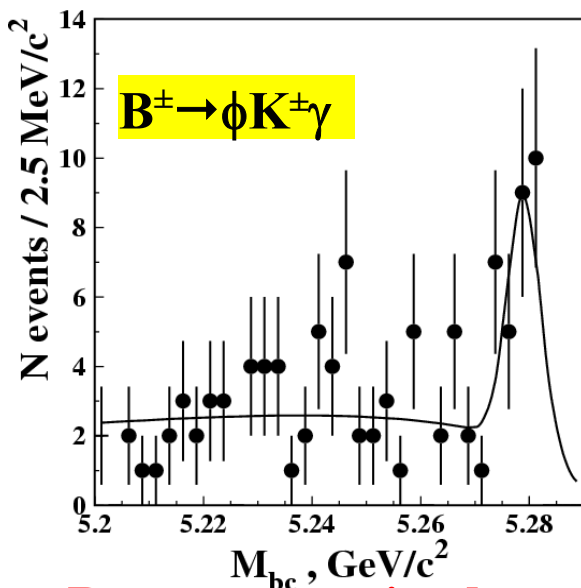
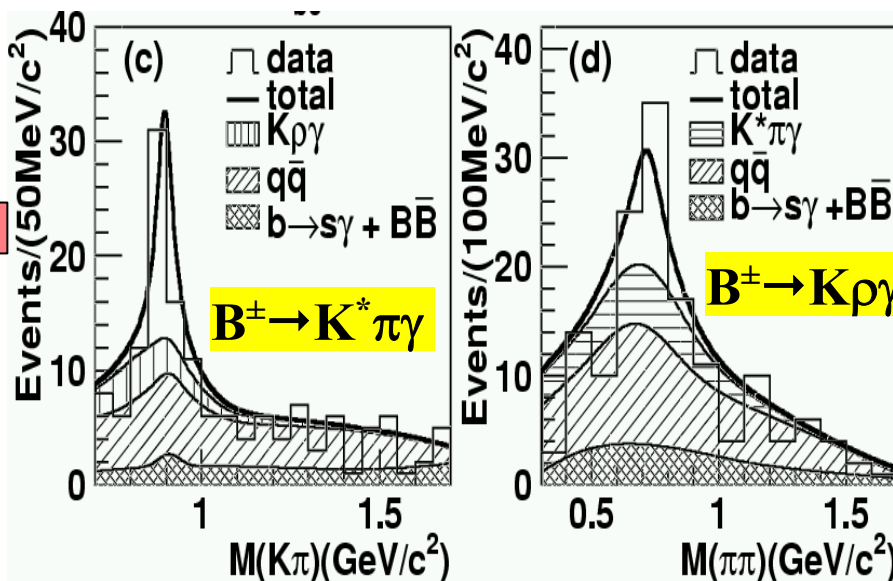
BELLE (PRL 89, 231801, 2002), 29.4 fb⁻¹

$$B(B \rightarrow K^* \pi \gamma) = (3.1 \pm 1.0) \cdot 10^{-5}$$

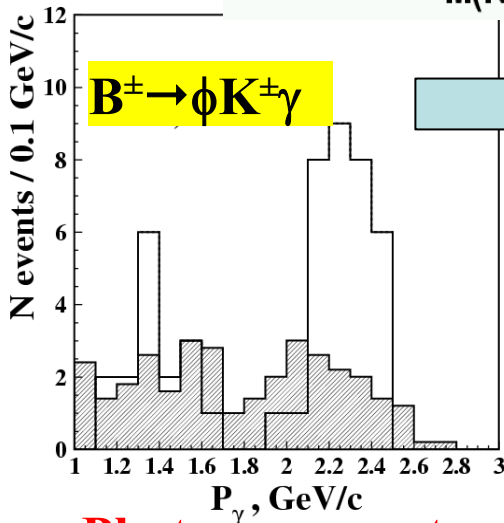
$$B(B \rightarrow K \rho \gamma) = (3.0 \pm 1.6) \cdot 10^{-5}$$

~ 1/3 B(B → X_sγ) due to

$$K^* \gamma + K^*_2(1430) \gamma + K^* \pi \gamma + K \rho \gamma$$



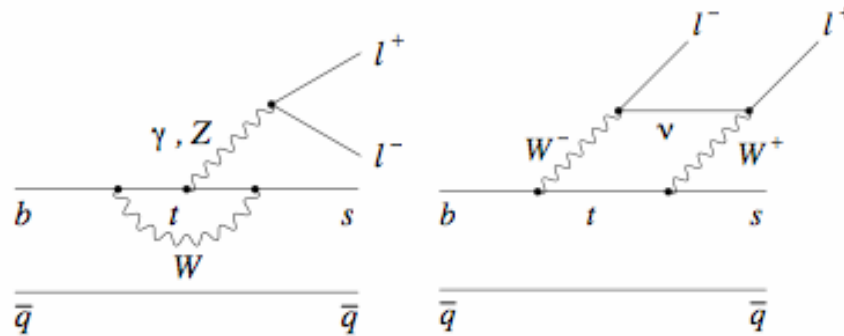
Beam-constrained mass



Photon momentum

NEW result from BELLE, 90 fb⁻¹
 $B(B^\pm \rightarrow K^\pm \phi \gamma) = (3.4 \pm 0.9 \pm 0.4) \cdot 10^{-6}$
(5.5σ significance)
 $B(B^0 \rightarrow K^0 \phi \gamma) < 8.3 \cdot 10^{-6}$
@ 90%CL

New physics sensitivity is higher for $b \rightarrow s l^+ l^-$



Exclusive decays:

$$\mathcal{B}(B \rightarrow K \ell^+ \ell^-) = (0.35 \pm 0.12) \times 10^{-6}$$

$$\mathcal{B}(B \rightarrow K^* e^+ e^-) = (1.58 \pm 0.49) \times 10^{-6}$$

$$\mathcal{B}(B \rightarrow K^* \mu^+ \mu^-) = (1.19 \pm 0.39) \times 10^{-6}$$

Inclusive rate:

$$\mathcal{B}(b \rightarrow s e^+ e^-) = (6.9 \pm 1.0) \times 10^{-6}$$

$$\mathcal{B}(b \rightarrow s \mu^+ \mu^-) = (4.2 \pm 0.7) \times 10^{-6}$$

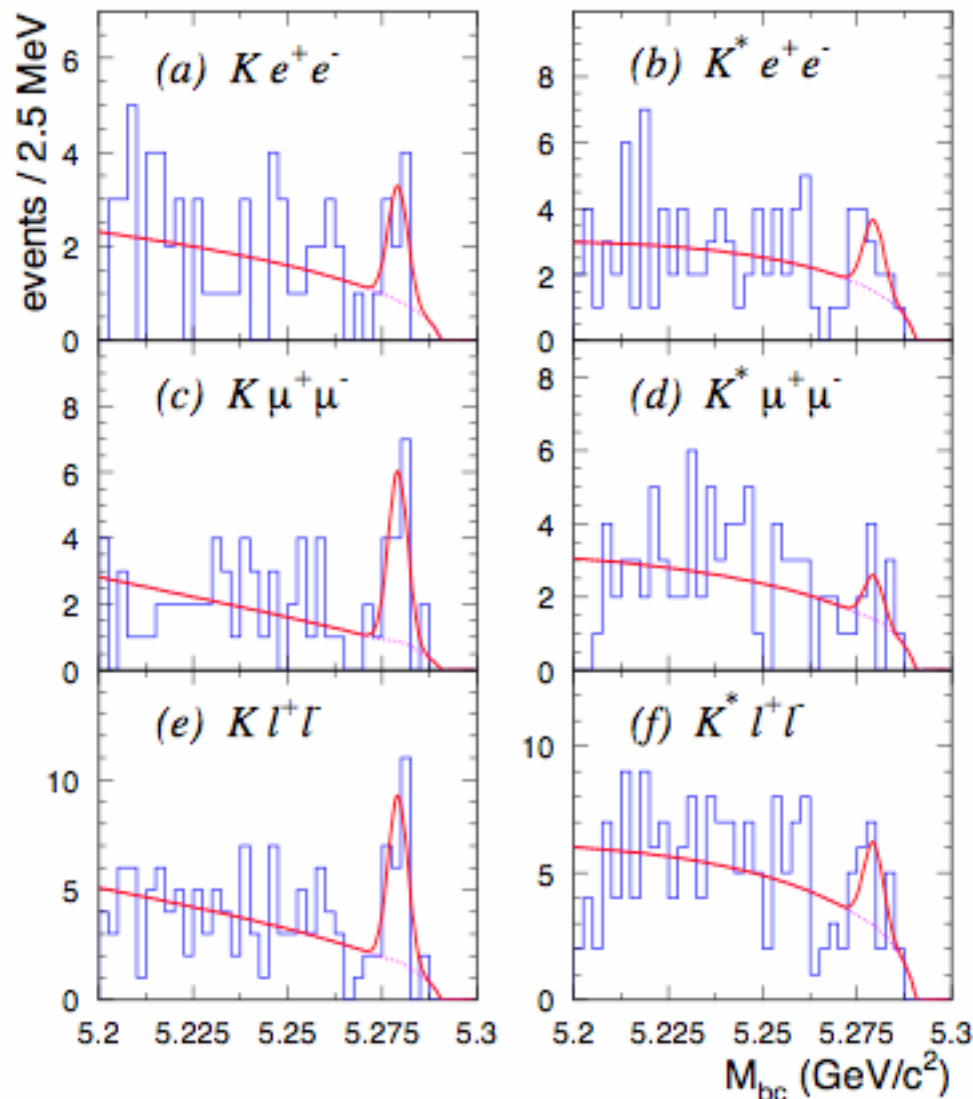
Ali, Lunghi, Greub & Hiller, hep-ph/0112300

- Lepton forward-backward asymmetry and rate dependence on $s=(q^2/m_b)^2$ can be checked.
- Scope for new physics!
- Hurth hep-ph/0212304



Exclusive decays $B \rightarrow K^{(*)} l^+ l^-$

- Belle first established signal with 29 fb^{-1}
- Has newly updated result with $60 \text{ fb}^{-1} \Rightarrow$



Exclusive Decays: $B \rightarrow K^{(*)} \ell^+ \ell^-$

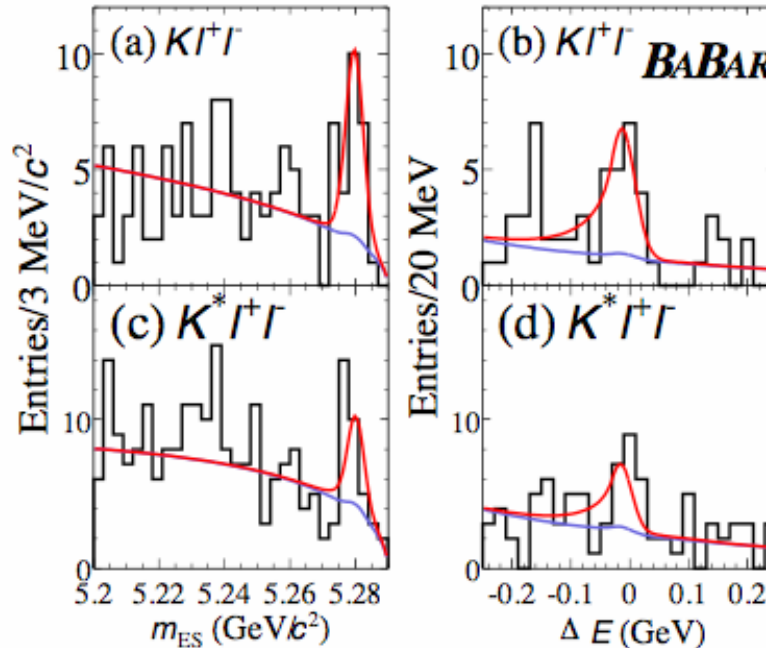
BABAR

Preliminary

78 fb^{-1}

$K\ell^+\ell^-$

4.4σ



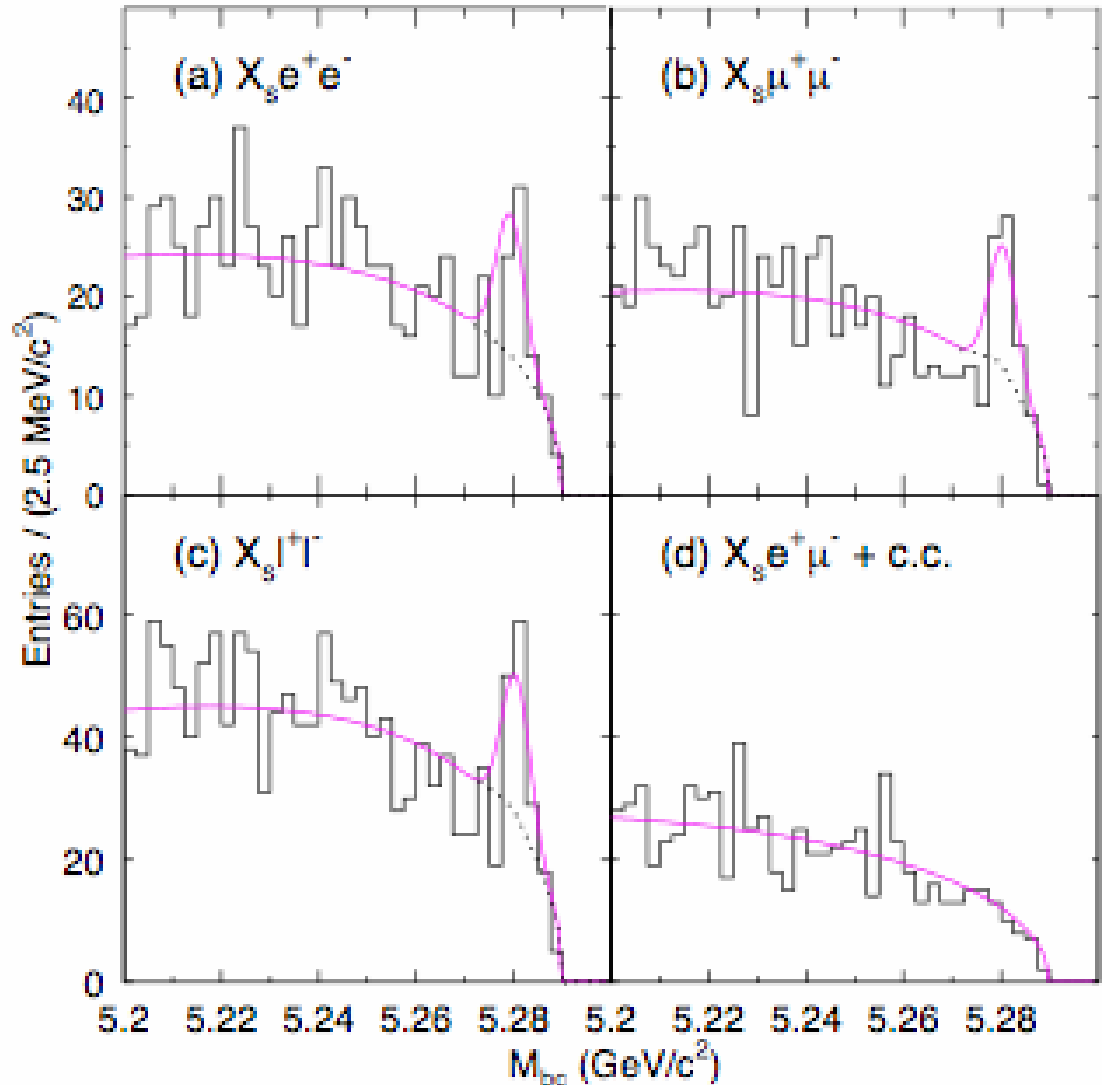
Averages of exclusive modes:

	$B \rightarrow K\ell^+\ell^- / 10^{-6}$	$B \rightarrow K^*\ell^+\ell^- / 10^{-6}$
BABAR	$0.78^{+0.24}_{-0.20} \pm 0.15$	< 3.0 (90% CL)
BELLE	$0.58^{+0.17}_{-0.15} \pm 0.06$	< 1.4 (90% CL)
Average	$0.66^{+0.15}_{-0.13} \pm 0.06$	



Inclusive decay: $b \rightarrow s l^+ l^-$

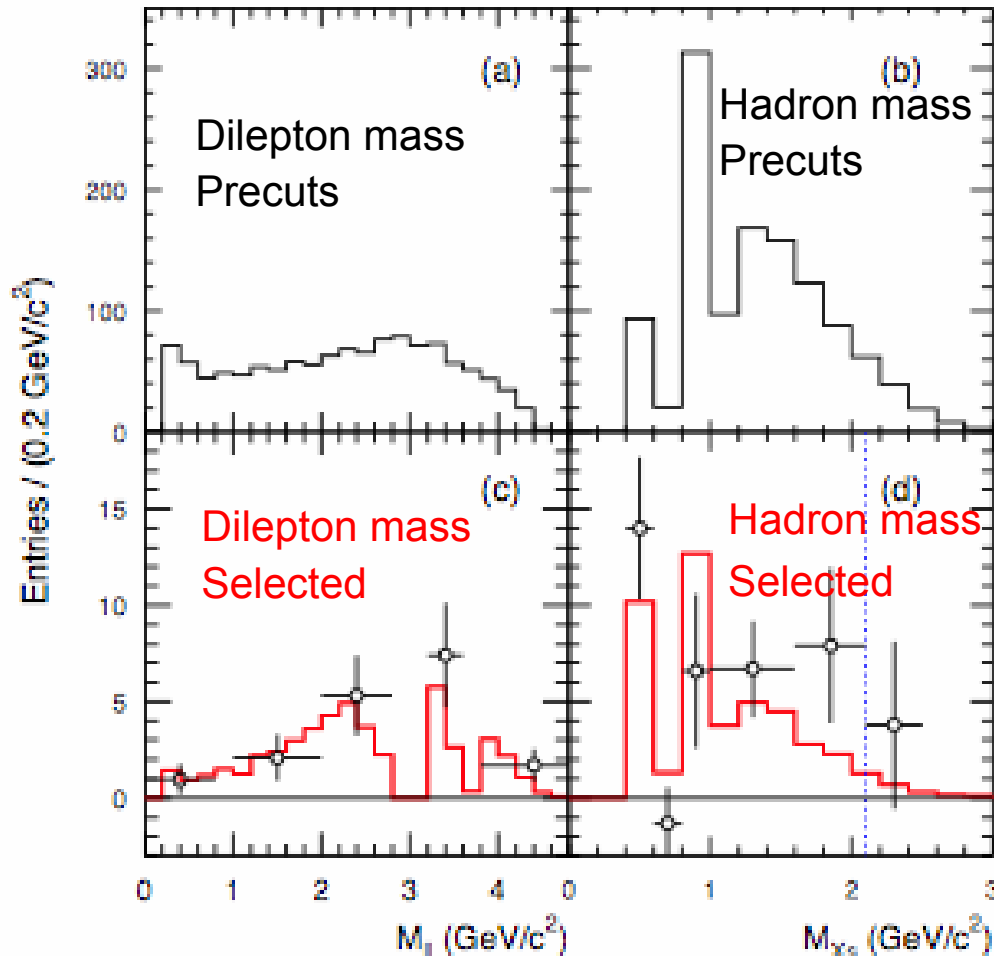
- **Semi-inclusive**
 - Use sum of exclusive modes techniques a la $b \rightarrow s \gamma$ analysis
 - Hadronic component, X_s , has one K^\pm and up to 3 π





Inclusive $b \rightarrow s l^+ l^-$ branching ratio

$$B(B \rightarrow X_s l^+ l^-) = [6.1 \pm 1.4(\text{stat})_{-1.1}^{+1.4}(\text{syst})] \times 10^{-6}$$



Prediction:

$$B(b \rightarrow s e^+ e^-) = (6.9 \pm 1.0) \times 10^{-6}$$

$$B(b \rightarrow s \mu^+ \mu^-) = (4.2 \pm 0.7) \times 10^{-6}$$

- Signal: 57.4 events, 5.5σ
- Average of e^+e^- and $\mu^+\mu^-$
- Model dependence included in systematic uncertainty

Summary

- **Precise measurements in $b \rightarrow s\gamma$**
 - **Branching Fractions (\rightarrow allows limits on new physics):**
 - **High precision results for $K^*\gamma$**
 - **Limits on other resonances and higher mass systems \rightarrow narrowing down all the $b \rightarrow s\gamma$ resonant spectrum**
 - **CP asymmetries (\rightarrow allows limits on new physics):**
 - **Best Direct CP limit in B system thus far**
 - **Indirect probe of new physics - will remain of interest for a while**
 - **Moments of X_s spectrum to understand B meson:**
 - **Measuring universal parameters important for measuring V_{ub}**
- **Still awaiting $b \rightarrow d\gamma$ discovery!**
 - ***Allows measurement of V_{td}/V_{ts} complementary to $\Delta M_d/\Delta M_s$***
- **Discovered $B \rightarrow K l^+ l^-$ (even better probe of new physics)**
 - **$K^* l^+ l^-$ and inclusive $B \rightarrow X_s l^+ l^-$ work in progress**
- **Integrated Luminosity: $\sim 130\text{-}150 \text{ fb}^{-1}$ by summer and $\sim 500 \text{ fb}^{-1}$ by 2006!**