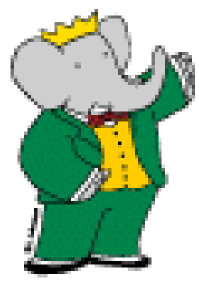
Measurements of Branching Fractions and Asymmetries in Radiative Penguin Decays of B Mesons



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Representing the BABAR Collaboration

DPF 2004
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$B \to K^{(*)} l^+l^-$ Exclusive Branching Fractions [PRL 91, 221802 (2003)]

$B \to X_s\, l^+l^-$ Inclusive BF and A_{CP} [PRL 93, 081802 (2004)]

$B \to X_s\, \gamma$ Inclusive Direct A_{CP} [PRL 93, 021804 (2004)]

$B \to K^*\, \gamma$ Exclusive Direct A_{CP} [hep-ex/0407003, sub to PRL]

$B \to K^*\gamma$, $K^* \to K^0_S\, \pi^0$ Time-Dependent A_{CP} [hep-ex/0405082, sub to PRL]

Motivation

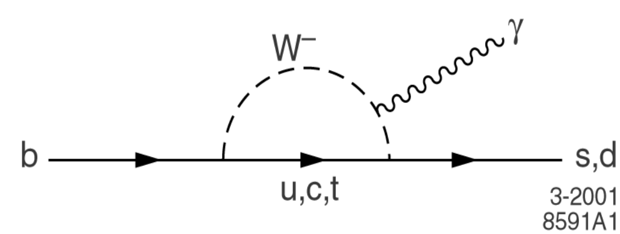
- Radiative Penguins in the SM
  - Rare FCNC decays

    Hurth *et al.*, hep-ph/0312260
    $BF(B \to X_s\, \gamma) = (3.61 \pm 0.49)\; 10^{-4}$

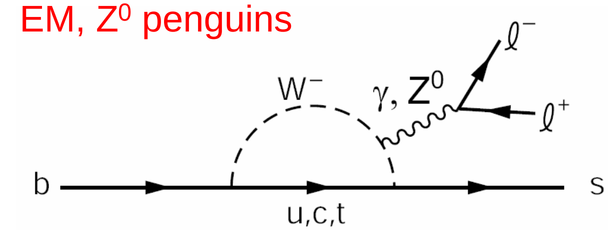
    Ali *et al.*, PRD 66, 034002 (2002)
    $BF(B \to X_s\, e^+e^-) = (6.89 \pm 1.01)\; 10^{-6}$
    $BF(B \to X_s\, \mu^+\mu^-) = (4.15 \pm 0.70)\; 10^{-6}$

  - Inclusive BF has less theoretical uncertainty than exclusive BF
  - Theoretical errors largely cancel A_{cp}
  - SM predicts small or no A_{cp}

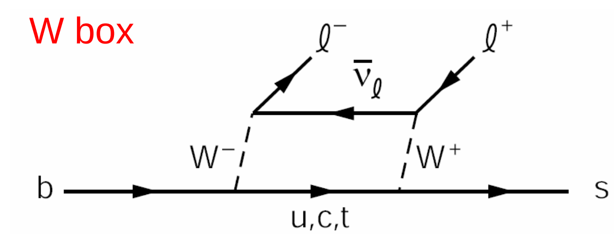
    $A_{CP}(B \to X_s\, \gamma) = 0.0044 \pm 0.0024$
    $A_{CP}(B \to X_s\, l^+l^-) = 0.0019 \pm 0.0019$



EM, Z^0 penguins



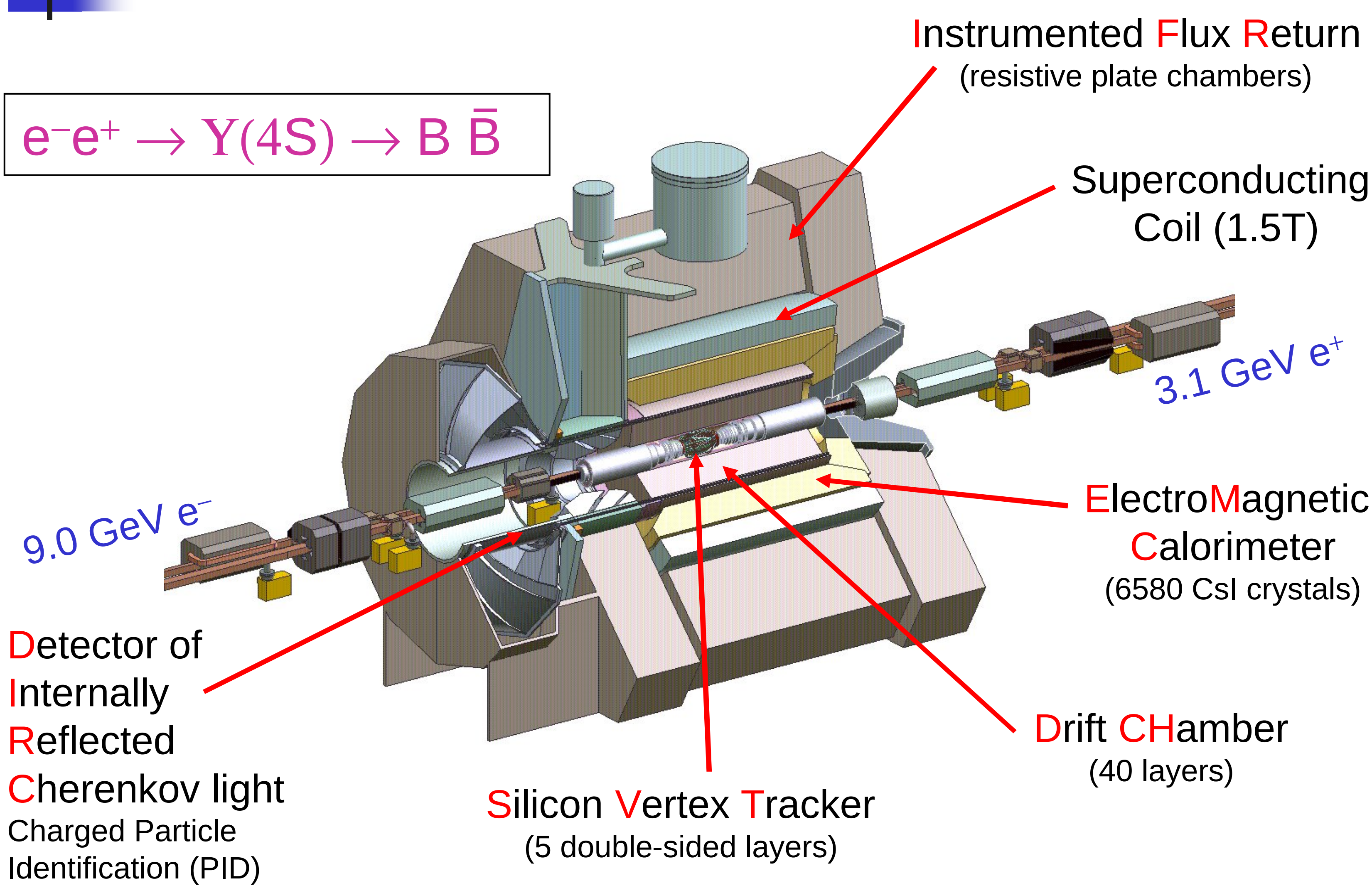
W box



- New Physics could enter loops: enhance BF, introduce significant A_{cp}, change decay distributions

BABAR/PEP-II B Factory

$e^-e^+ \rightarrow \Upsilon(4S) \rightarrow B\,\bar{B}$



Leptonic Penguin Overview

	$B \to K^{(*)} l^+l^-$	$B \to X_s l^+l^-$; Inclusive
Data sample	113.1 fb^{-1}	81.9 fb^{-1}
Full reconstruction of $B \to X_s l^+l^-$ candidates ($l^+l^- = e^+e^-$ or $\mu^+\mu^-$)	4 X_s topologies: K^+, $K^0_s \to \pi^+\pi^-$, $K^{*0} \to K^+\pi^-$, $K^{*+} \to K^0_s\pi^+$	10 X_s topologies (~50% of BF): K^+, $K^+\pi^0$, $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+$, K^0_s, $K^0_s\pi^0$, $K^0_s\pi^+$, $K^0_s\pi^+\pi^0$, $K^0_s\pi^+\pi^-$ with $K^0_s \to \pi^+\pi^-$
	$0.7 < m(K\pi) < 1.1$ GeV	$m(X_s) < 1.8$ GeV
Leptons	tight PID requirements for e (μ), bremsstrahlung photon recovery for e^+e^-, veto e^+e^- pairs from photon conversions	
Signal Extraction	maximum likelihood fit to kinematic variables	
Non-peaking bkg	(1) B bkg from events with 2 semi-leptonic decays (2) continuum	
Peaking bkg	(1) $B \to J/\psi\ (\psi') X_s$ with $J/\psi\ (\psi') \to l^+l^-$ (2) $B \to X_s\ \pi^+\pi^-$ from $B \to D^{(*)} n\pi\ (n \ge 1)$ with $\pi^+\pi^- \to l^+l^-$ mis-ID	

BF($B \to K^{(*)} l^+l^-$) results

- Fit Components
  - (1) signal
  - (2) peaking bkg
  - (3) combinatorial bkg
  - (4) $B \to K^{(*)} l^+l^-$ decays with a added(lost) pion
- BF($B \to K l^+l^-$): 2D fit: m_{ES}, ΔE
- BF($B \to K^* l^+l^-$)
  - 3D fit: m_{ES}, ΔE, $m(K\pi)$
  - Pole at low $m(e^+e^-)$ enhances the rate in the e^+e^- channel, constrain:

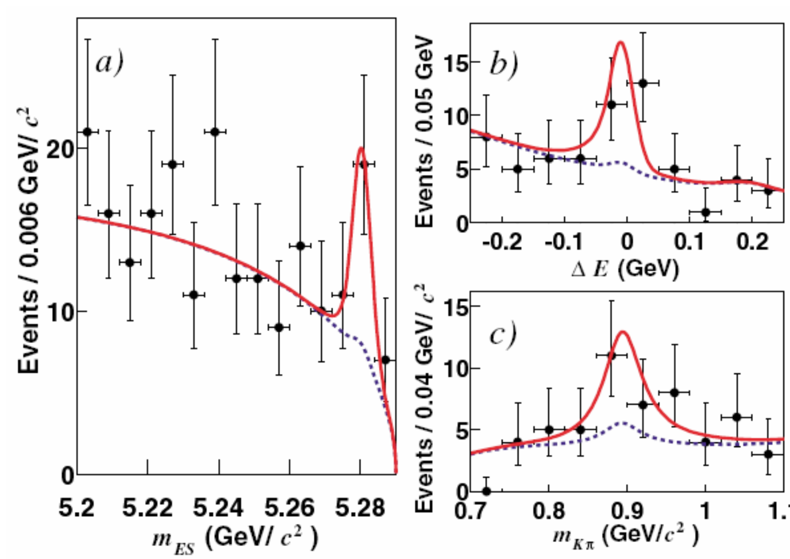
    $\Gamma_{B \to K^* ee} / \Gamma_{B \to K^* \mu\mu} = 1.33$

    Ali *et al.*, PRD 66, 034002 (2002)

- Fit variables
  - $m_{ES} = (E^2_{beam} - p^2_B)^{1/2}$
  - $\Delta E = E_B - E_{beam}$
  - $m(K\pi)$

BF($B \to K l^+l^-$) = $(0.65 \pm ^{0.14}_{0.13} \pm 0.04)\ 10^{-6}$
BF($B \to K^* l^+l^-$) = $(0.88 \pm 0.330.29 \pm 0.10)\ 10^{-6}$
[PRL 91, 221802 (2003)]

(red) full fit, (blue) all bkg components



Fit for BF($B \to K^* l^+l^-$)

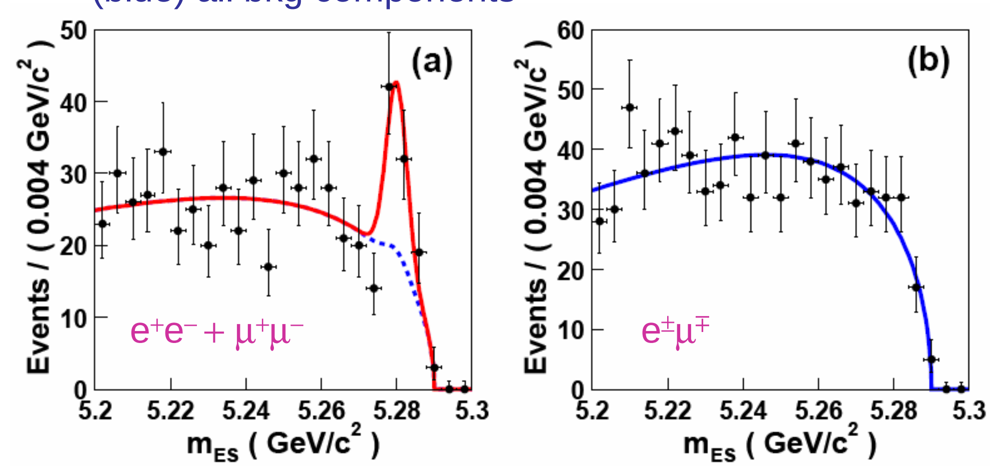
BF($B \to X_s\, l^+l^-$) result

- Maximum likelihood fit in m_{ES}
  - Fit components:
    - (1) signal
    - (2) peaking bkg
    - (3) combinatorial bkg

Mode	Signal yield ± (stat)	Efficiency [%]
$B \to X_s\, e^+e^-$	29.2 ± 8.3	2.74
$B \to X_s\, \mu^+\mu^-$	11.2 ± 6.2	1.26

(red) full fit
(blue) all bkg components

(blue) fit



$$BF(B \to X_s\, l^+l^-) = (5.6 \pm 1.5 \pm 0.6 \pm 1.1)\, 10^{-6}$$
[PRL 93, 081802 (2004)]

Experimental syst:
Detector model, fit syst, etc.

Signal model syst:
BF($B \to K(*)$ l+l-), Fermi motion dominates

CP-violation asymmetry $A_{CP}(B \to X_s l^+l^-)$

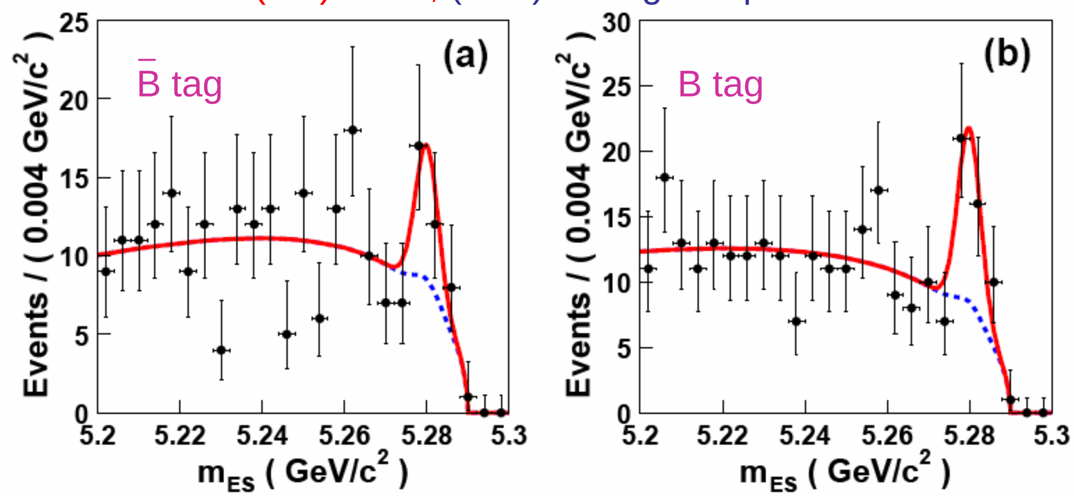
- Use 7 self-tagging modes for $A_{CP} = \{N(\bar{B}) - N(B)\} / \{N(\bar{B}) + N(B)\}$

- Fits to B, $\bar{B}$ samples

	$B \to X_s l^+l^-$
$N(\bar{B}) \pm$ (stat)	14.7 ± 6.5
$N(B) \pm$ (stat)	22.9 ± 7.4
$A_{CP} \pm$ (stat)	-0.22 ± 0.26

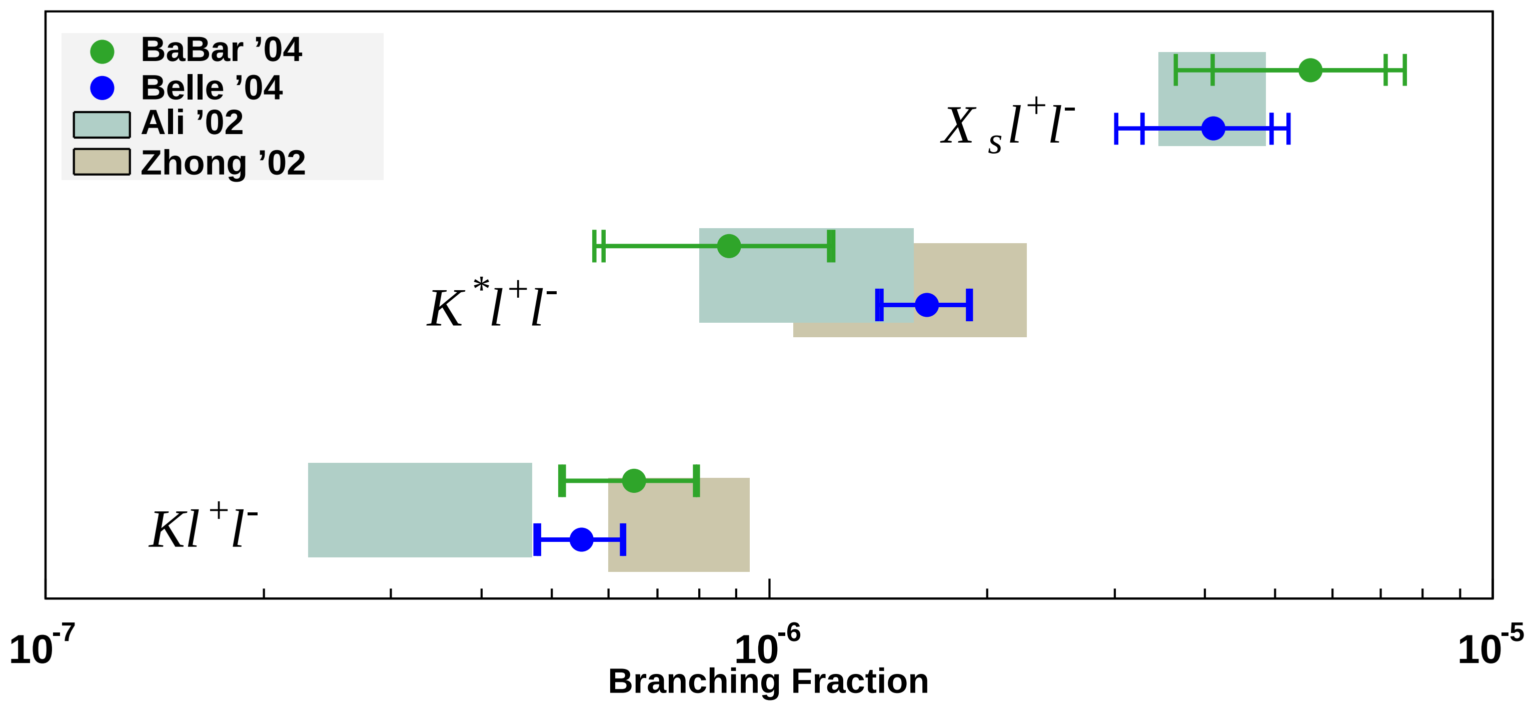
- Use A_{CP} stat error from $J/\psi + \psi'$ control sample as syst error

(red) full fit, (blue) all bkg components



$A_{CP} = -0.22 \pm 0.26 \pm 0.02$
[PRL 93, 081802 (2004)]

Leptonic BF Consistent with SM



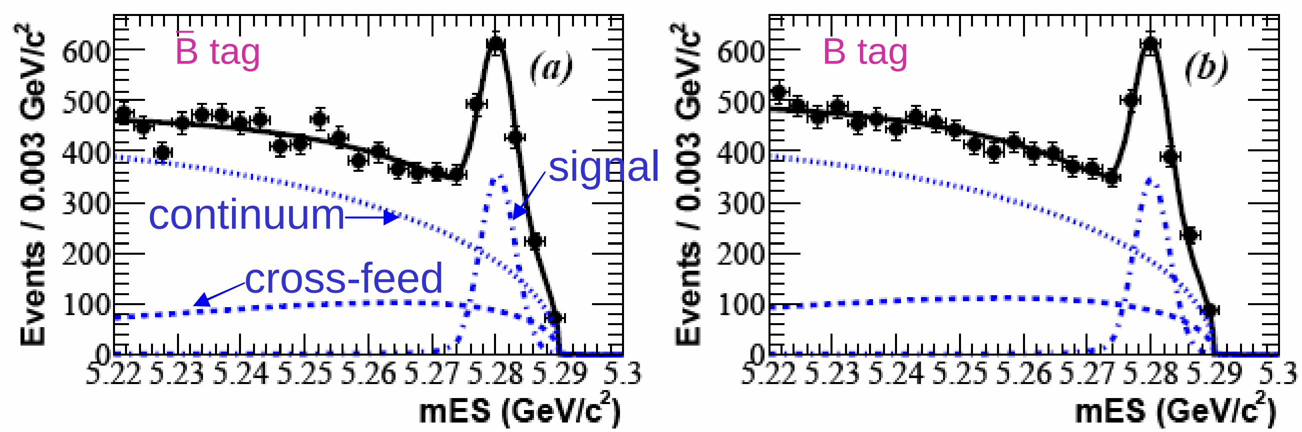
Photonic Penguin A_{CP}

	$B \to K^* \gamma$	$B \to X_s \gamma$ "Sum over exclusive modes"
Data sample	82 fb^{-1}	82 fb^{-1}
Full reconstruction of $B \to X_s \gamma$ Candidates	4 X_s topologies: $K^{*+} \to K^+\pi^0$, $K^{*+} \to K^0{}_s\pi^+$, $K^{*0} \to K^+\pi^-$, $K^{*0} \to K^0{}_s\pi^0$ with $K^0{}_s \to \pi^+\pi^-$	12 X_s topologies: $K^+\pi^0$, $K^+\pi^-\pi^+$, $K^+\pi^0\pi^0$, $K^+\pi^-\pi^+\pi^0$, $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^0\pi^0$, $K^+\pi^-\pi^+\pi^-$, $K^0{}_s\pi^+$, $K^0{}_s\pi^+\pi^0$, $K^0{}_s\pi^+\pi^0\pi^0$, $K^0{}_s\pi^+\pi^-\pi^+$
	$0.8 < m(K\pi) < 1.0$ GeV	0.6 GeV $< m(X_s) <$ 2.3 GeV
Photon Energy	1.5 GeV $< E_{\gamma,CM} <$ 3.5 GeV	$E_{\gamma,CM} >$ 1.8 GeV
π^0,η veto	combine γ with other photon candidates remove those with $m_{\gamma\gamma}$ consistent with π^0 or η	
Backgrounds	(1) B bkg from $B \to X_s \gamma$ (2) Continuum	(1) Cross-feed from misreconstructed X_s (2) B bkg from events with high energy γ (3) Continuum

CP-violation asymmetry $A_{CP}(B \to X_s \gamma)$

- One dimensional fit to m_{ES}

(black) full fit, (blue) components



–	$B \to X_s \gamma$
N(B) ± (stat)	787 ± 54
N(B) ± (stat)	769 ± 54
A_{CP} ± (stat)	0.025 ± 0.050

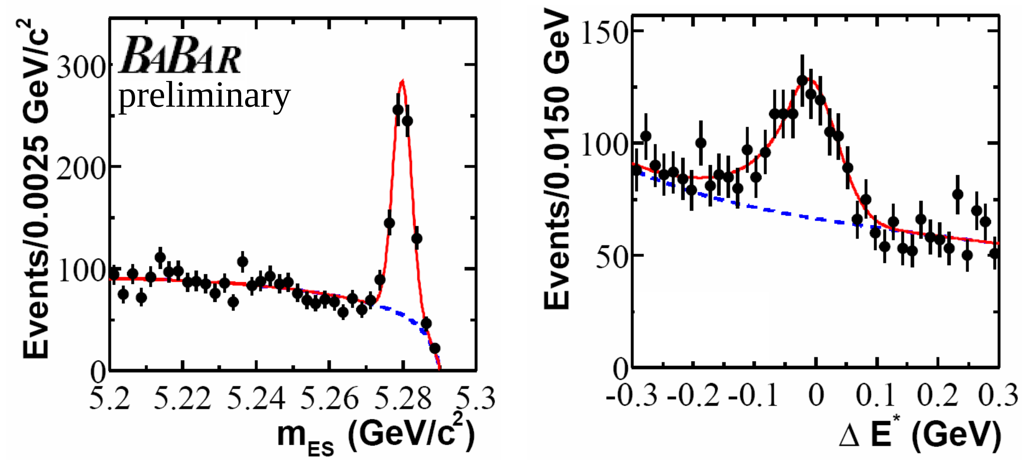
$A_{CP}(B \to X_s \gamma) = 0.025 \pm 0.050 \pm 0.015$
[PRL 93 (2004) 021804]

New physics models allow $A_{CP}(B \to X_s \gamma)$ up to 10%.

Direct CP-violation asymmetry $A_{CP}(B \to K^* \gamma)$

- 2D unbinned maximum likelihood fit in m_{ES} and ΔE
  - Fit components:
    - (1) signal
    - (2) B bkg
    - (3) continuum bkg
  - Details of BF in talk tomorrow by Johannes Bauer

(red) full fit, (blue) all bkg components

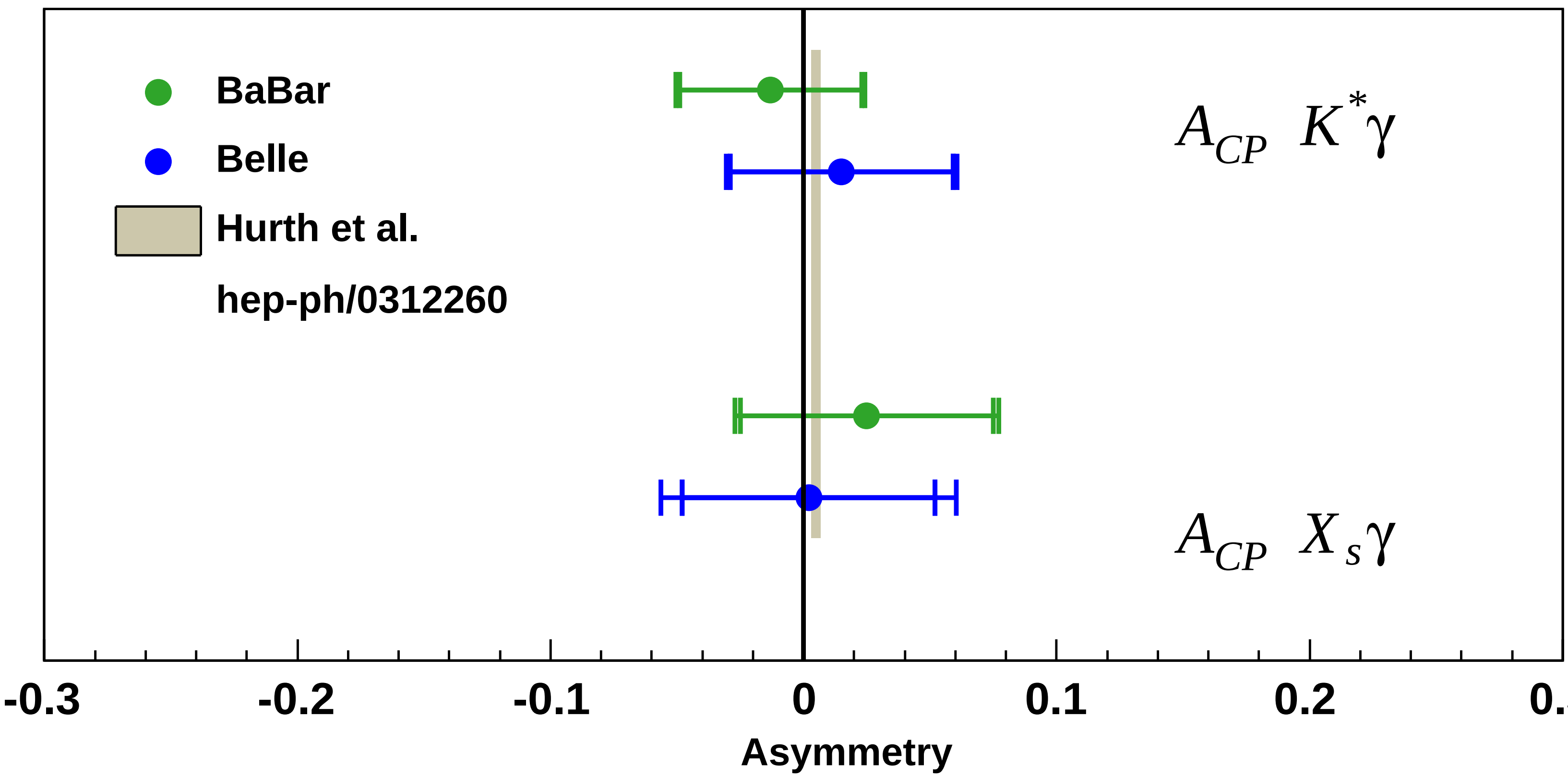


Example fit: $B^0 \to K^{*0} \gamma$, $K^{*0} \to K^+\pi^-$

Mode	$A_{CP} \pm$ (stat) $\pm$ (sys) preliminary
$K^{*0} \to K^+ \pi^-$	$-0.069 \pm 0.046 \pm 0.011$
$K^{*+} \to K^+ \pi^0$	$0.084 \pm 0.075 \pm 0.007$
$K^{*+} \to K^0_S \pi^+$	$0.061 \pm 0.092 \pm 0.007$

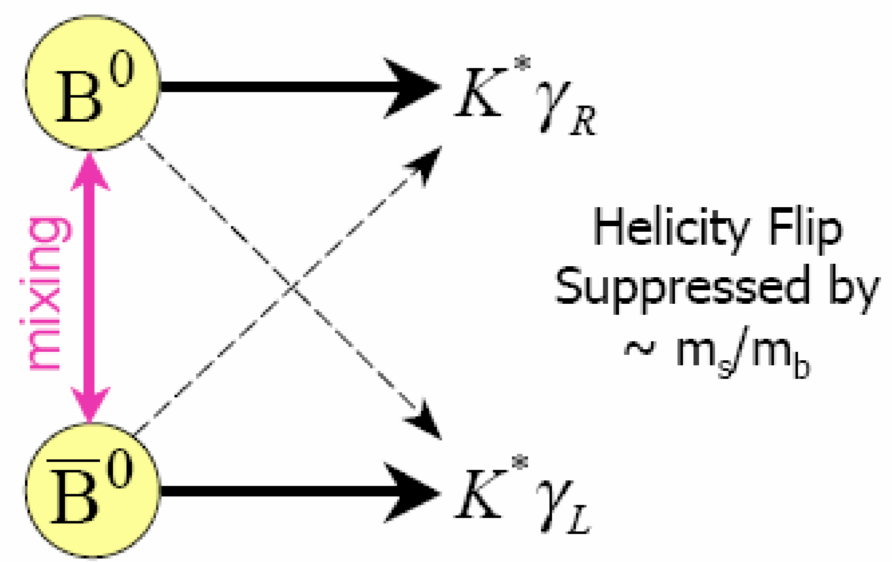
$A_{CP}(B \to K^* \gamma) = -0.013 \pm 0.036 \pm 0.010$
preliminary
[hep-ex/0407003, submitted to PRL]

Photonic A_{CP} Consistent with SM



Time-Dependent CP Asymmetry in $B \to K^*\gamma$ (113 fb^{-1})

- $B^0 \to K^{*0}\gamma$, $K^{*0} \to K^0_S \pi^0$



- Dominant γ polarization in SM
  - $B^0 \to (K^0_S\pi^0)\,\gamma_R$, $\bar{B}^0 \to (K^0_S\pi^0)\,\gamma_L$
  - Final state interference requires suppressed helicity flip
  - Interference significant in some new physics scenarios

- Asymmetry parameterization:

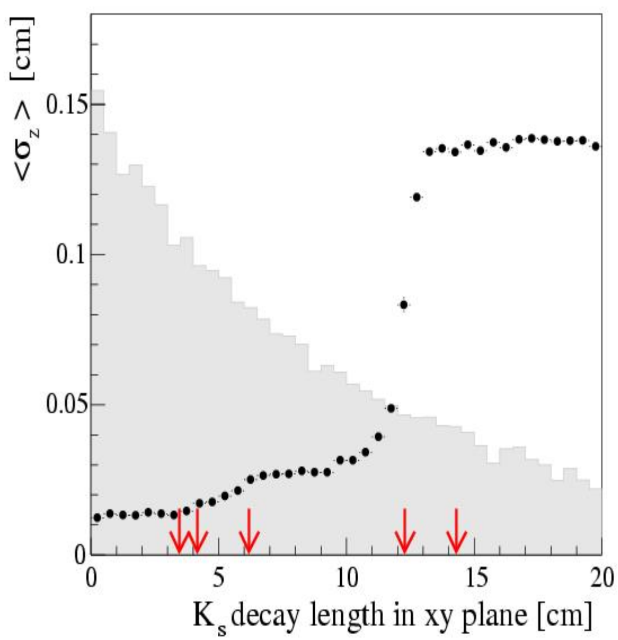
$$P^{B^0}_{\bar{B}^0}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\left[1 \pm \left(S\sin(\Delta t \Delta m_d) - C\cos(\Delta t \Delta m_d)\right)\right]$$

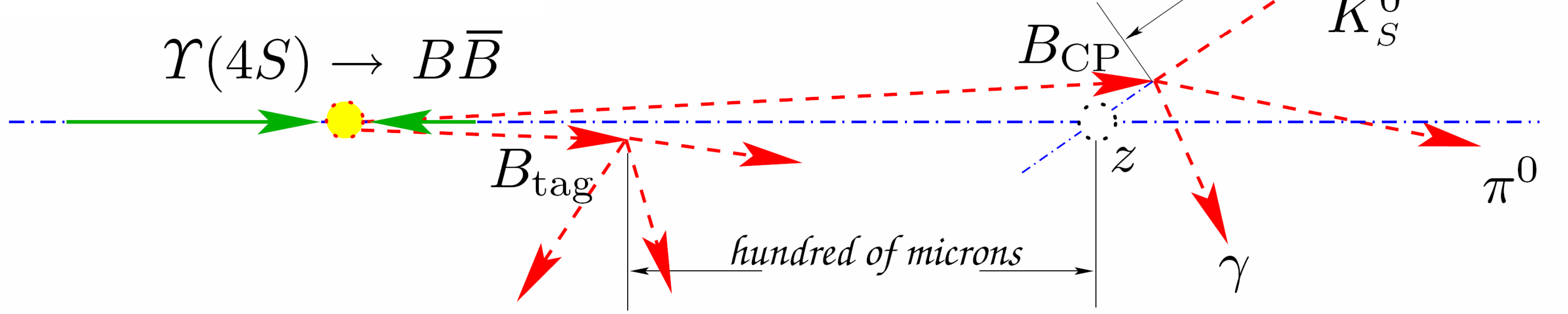
Δt: proper decay time difference
Δm_d: B mixing frequency
S: magnitude of mixing A_{CP}
C: magnitude of direct A_{CP}

Standard Model:
$C = -A_{CP} \approx -1\%$
$S \approx 2(m_s/m_b)\sin 2\beta \approx 4\%$

Time-Dependent CP Asymmetry in $B \to K^*\gamma$ (113 fb^{-1})

- Measure proper decay time difference Δt
  - $\Delta t = t_{signal} - t_{tag}$
  - Computed from the longitudinal decay vertex separation (Δz) and the known boost
- Requires novel beam-constrained vertexing:
  - Intersection of K_S trajectory and beam-line
  - Usable resolution for K_S decaying inside SVT
  - Validated with $B^0 \to J/\psi\ K_S$ events





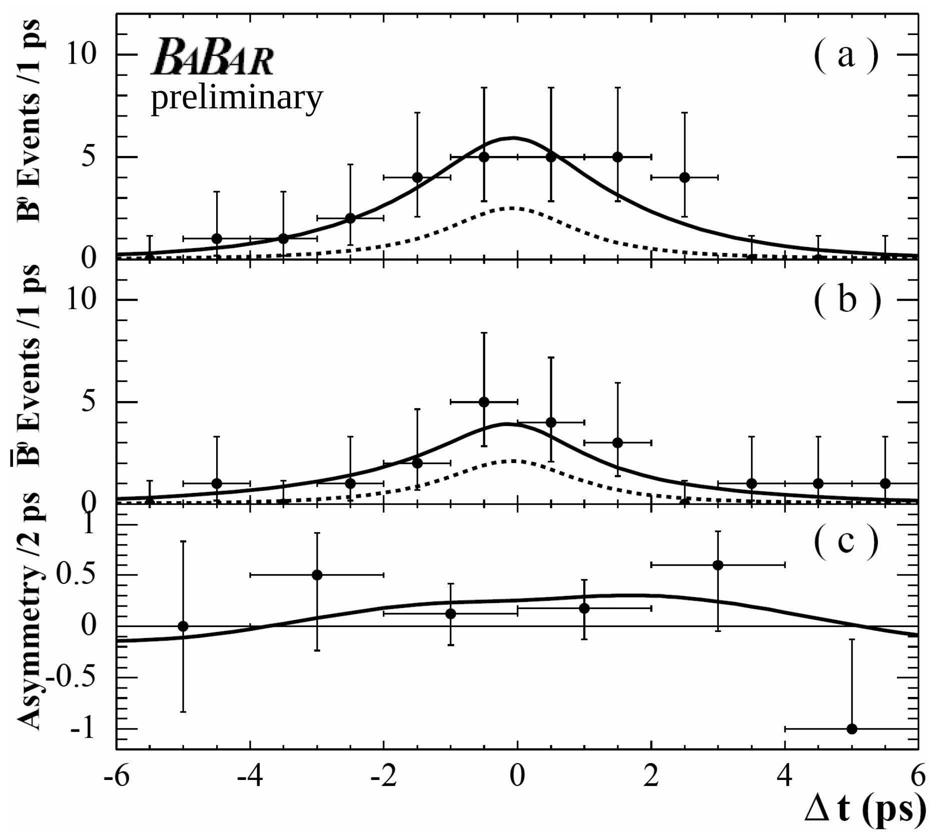
Time-Dependent CP Asymmetry in $B \to K^*\gamma$ (113 fb^{-1})

- 5 dimensional likelihood fit
  (m_{ES}, ΔE, Fisher, m_{K^*}, Δt)
- 3 fit components
  - signal
  - continuum
  - $B\bar{B}$ background
- $K^*\gamma$ signal yield = 105 ± 14 events

S = +0.25 ± 0.63 ± 0.14

C = -0.57 ± 0.32 ± 0.09

submitted to PRL, hep-ex/0405082



- Consistent with SM

For fixed C = 0, S = 0.25 ± 0.65 ± 0.14

First ever measurement of time-dependent CP asymmetries in radiative penguins!

Conclusions

- Presented Five Radiative Penguin measurements:
  - $B \to K^{(*)} l^+l^-$ Exclusive Branching Fractions
    [PRL 91, 221802 (2003)]
  - $B \to X_s l^+l^-$ Inclusive BF and A_{CP}
    [PRL 93, 081802 (2004)]
  - $B \to X_s \gamma$ Inclusive Direct A_{CP}
    [PRL 93, 021804 (2004)]
  - $B \to K^* \gamma$ Exclusive Direct A_{CP}
    [hep-ex/0407003, submitted to PRL]
  - $B \to K^*\gamma$, $K^* \to K^0_S \pi^0$ Time-Dependent A_{CP}
    [hep-ex/0405082, submitted to PRL]
- ***BaBar*** results consistent with SM
- Updating measurements with 205 fb^{-1}

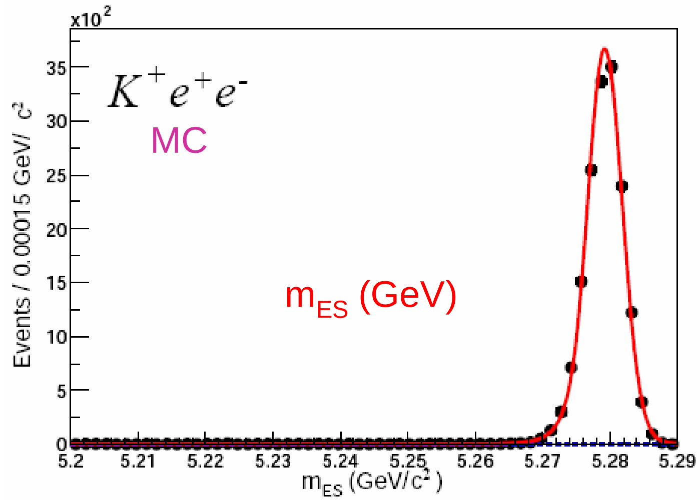
Acknowledgements

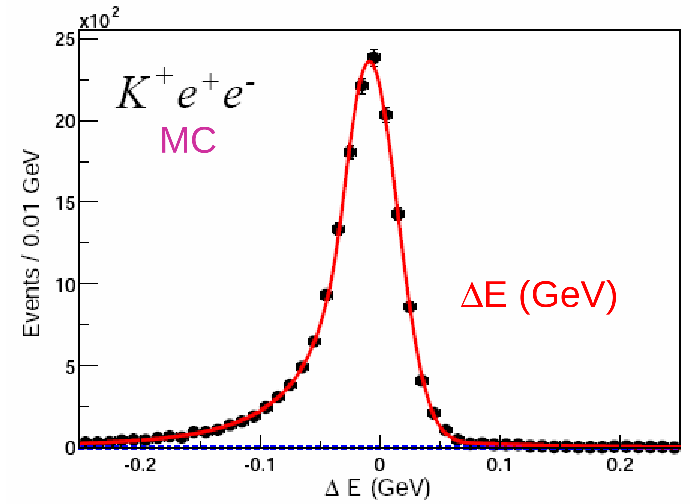
The presenter would like to thank Jeffrey Berryhill (University of California, Santa Barbara) and Hermann Staengle (University of Massachusetts) for their assistance in preparing this talk.

Backup slides

Background suppression (1)

- Fully reco'd signal B peaks in $m_{ES} = (E^2_{beam} - p^2_B)^{1/2}$ and $\Delta E = E_B - E_{beam}$





- Non-peaking backgrounds are suppressed with multivariate techniques
  - Combinatorial continuum $e^+e^- \rightarrow q\bar{q}$ (q = u,d,s,c) background: rejection of "jetty" events with event shape variables
  - Combinatorial B background from events with 2 semi-leptonic decays: rejection based on missing energy in event, B direction, B and l^+l^- vertex probabilities

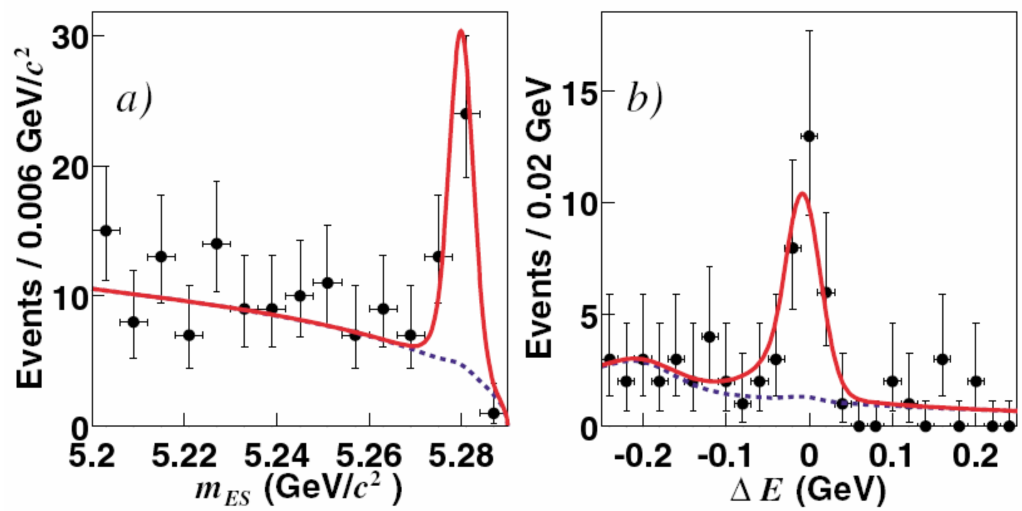
BF($B \to K l^+l^-$) result

- 2D unbinned maximum likelihood fit in $m_{ES} = (E^2_{beam} - p^2_B)^{1/2}$ and $\Delta E = E_B - E_{beam}$

  - Fit components:
    (1) signal
    (2) peaking bkg
    (3) combinatorial bkg
    (4) $B \to K^* l^+l^-$ decays with a lost pion

Mode	Signal yield ± (stat)	Efficiency [%]
$B^+ \to K^+ e^+e^-$	$24.7 \pm^{5.9}_{5.2}$	19.2
$B^+ \to K^+ \mu^+\mu^-$	$0.7 \pm^{2.0}_{1.2}$	8.5
$B^0 \to K^0 e^+e^-$	$-1.8 \pm^{2.0}_{1.4}$	20.1
$B^0 \to K^0 \mu^+\mu^-$	$5.9 \pm^{3.0}_{2.3}$	8.6

(red) full fit, (blue) all bkg components



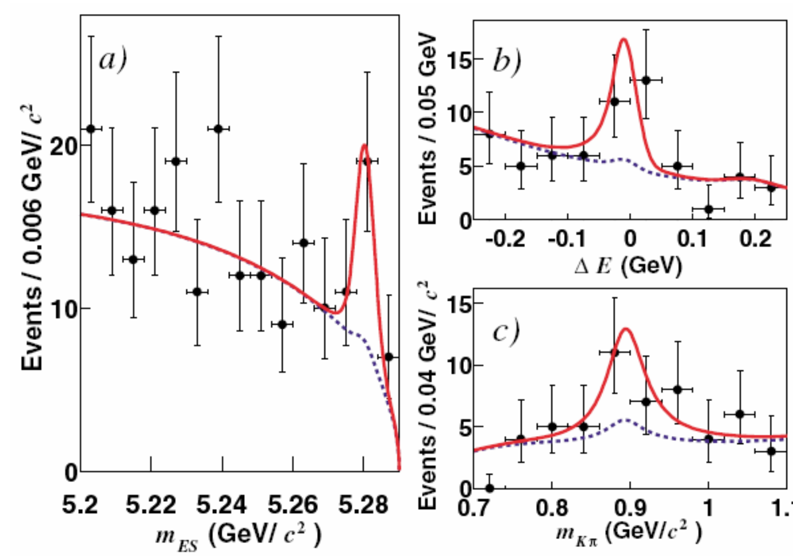
BF($B \to K l^+l^-$) = $(0.65 \pm^{0.14}_{0.13} \pm 0.04)\ 10^{-6}$ [PRL 91, 221802 (2003)]

- Ali *et al.*, PRD 66, 034002 (2002)
  BF($B \to K l^+l^-$) = $(0.35 \pm 0.12)\ 10^{-6}$

BF($B \to K^* l^+l^-$) result

- 3D unbinned maximum likelihood fit in m_{ES}, ΔE, $m(K\pi)$
  - Since pole at low $m(e^+e^-)$ enhances the rate in the e^+e^- channel, constrain:
    $\Gamma_{B \to K^* ee} / \Gamma_{B \to K^* \mu\mu} = 1.33$
    Ali *et al.*, PRD 66, 034002 (2002)

(red) full fit, (blue) all bkg components

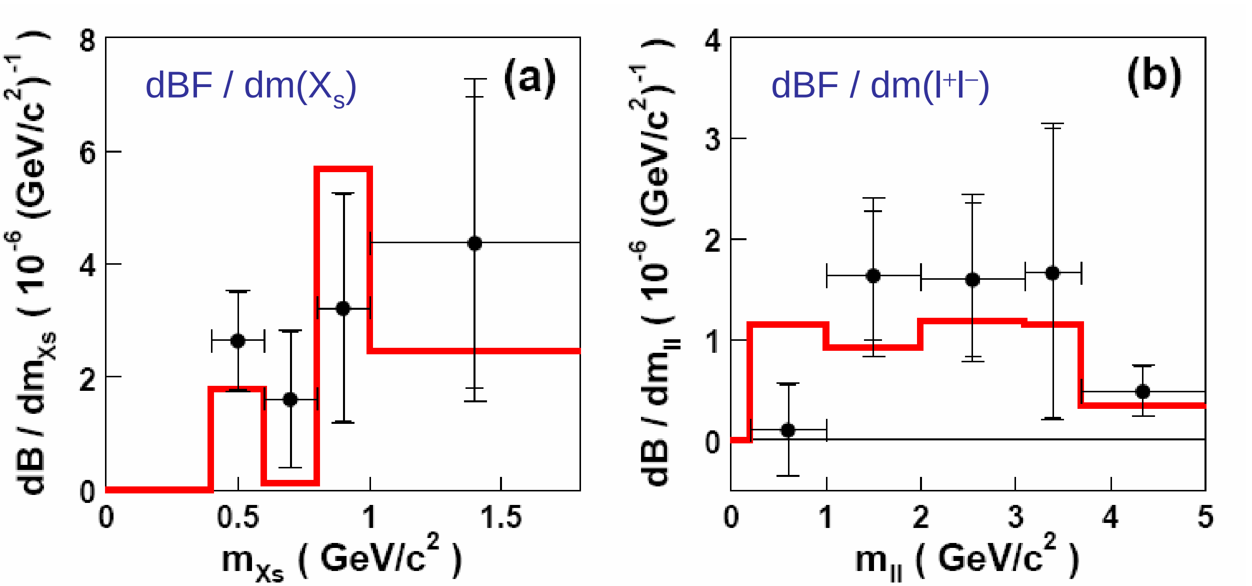


Mode	Signal yield $\pm$ (stat)	Efficiency [%]
$B^0 \to K^{*0} e^+e^-$	$12.4 \pm^{6.3}_{5.2}$	13.6
$B^0 \to K^{*0} \mu^+\mu^-$	$4.5 \pm^{4.1}_{3.0}$	6.4
$B^+ \to K^{*+} e^+e^-$	$0.6 \pm^{3.8}_{2.5}$	10.2
$B^+ \to K^{*+} \mu^+\mu^-$	$4.2 \pm^{3.5}_{2.4}$	4.8

BF($B \to K^* l^+l^-$) = $(0.88 \pm^{0.33}_{0.29} \pm 0.10)\ 10^{-6}$
[PRL 91, 221802 (2003)]

- Ali *et al.*, PRD 66, 034002 (2002)
  BF($B \to K^* l^+l^-$) = $(1.19 \pm 0.39)\ 10^{-6}$

Partial BF results in bins of $m(l^+l^-)$ and $m(X_s)$

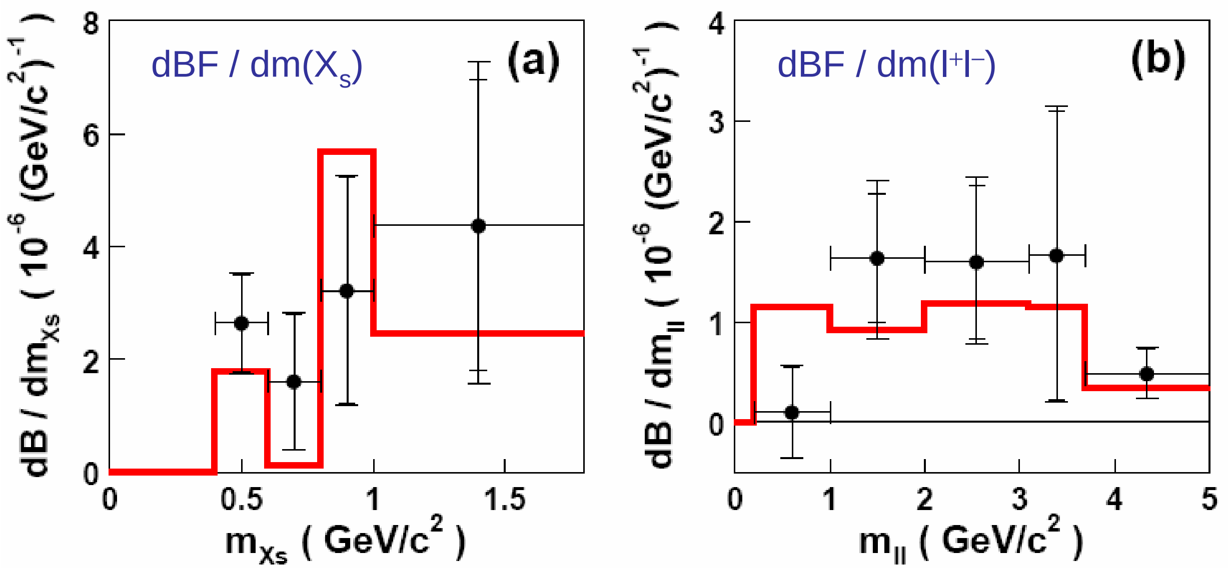


	$BF(B \to X_s\, l^+l^-)$ $[10^{-6}]$ hep-ex/0404006 (2004)	$BF(B \to X_s\, l^+l^-)$ $[10^{-6}]$ Ghinculov *et al.*, NPB685, 351 (2004)
$1 < m(l^+l^-) < 2.45$ GeV	$1.8 \pm 0.7 \pm 0.5$	1.63 ± 0.20
$3.8 < m(l^+l^-) < 5$ GeV	$0.50 \pm 0.25 \pm ^{0.08}_{0.07}$	0.40 ± 0.08

Partial BF results in bins of $m(l^+l^-)$ and $m(X_s)$

$m(l^+l^-)$ [GeV]	BF ± (stat) ± (syst) [10^{-6}]
0.2 – 1.0	$0.08 \pm 0.36 \pm ^{0.07}_{0.04}$
1.0 – 2.0	$1.6 \pm 0.6 \pm 0.5$
2.0 – J/ψ	$1.8 \pm 0.8 \pm 0.4$
J/ψ – ψ'	$1.0 \pm 0.8 \pm 0.2$
ψ' – 5.0	$0.64 \pm 0.32 \pm ^{0.12}_{0.09}$

$m(X_s)$ [GeV]	BF ± (stat) ± (syst) [10^{-6}]
0.4 – 0.6	$0.53 \pm 0.17 \pm 0.04$
0.6 – 0.8	$0.32 \pm 0.24 \pm 0.04$
0.8 – 1.0	$0.64 \pm 0.40 \pm 0.08$
1.0 – 1.8	$3.5 \pm 2.1 \pm ^{1.1}_{0.9}$



	$BF(B \to X_s l^+l^-)$ [10^{-6}] hep-ex/0404006 (2004)	$BF(B \to X_s l^+l^-)$ [10^{-6}] Ghinculov *et al.*, NPB685, 351 (2004)
$1 < m(l^+l^-) < 2.45$ GeV	$1.8 \pm 0.7 \pm 0.5$	1.63 ± 0.20
$3.8 < m(l^+l^-) < 5$ GeV	$0.50 \pm 0.25 \pm ^{0.08}_{0.07}$	0.40 ± 0.08