Electroweak and Radiative Penguin Transitions from B Factories

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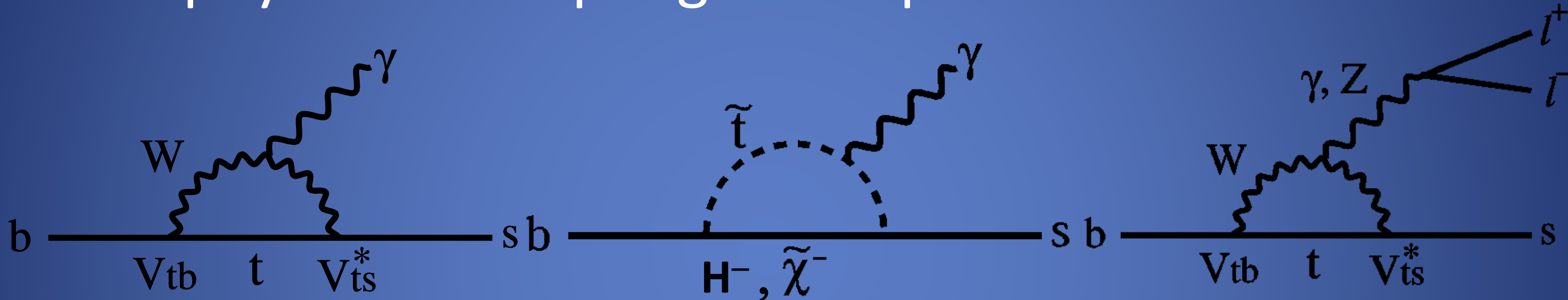
Introduction

- Electroweak and radiative B decays are sensitive to new physics in the penguin loop.



  – Small SM branching fraction ($\mathcal{B}$)
  – More precise theoretical predictions
  – Many observables: $\mathcal{B}$, A_{cp}, A_{FB}, P_5', iso-spin asym. …
- In this talk :

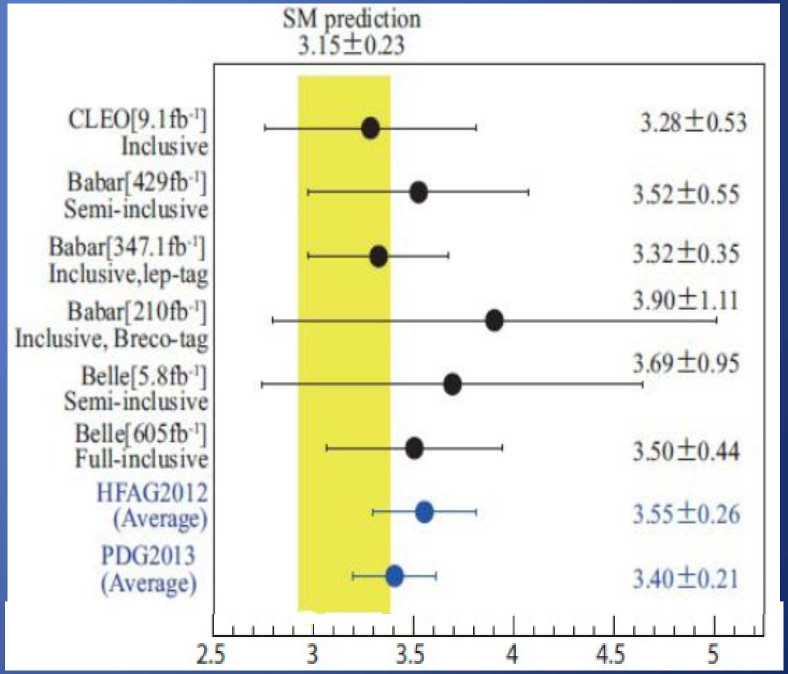
  1. $\mathcal{B}$ ($B \rightarrow X_s \gamma$) ; 2. A_{cp} ($B \rightarrow X_{s(+d)} \gamma$); 3. $B \rightarrow X_s l^+ l^-$: A_{FB}, $\mathcal{B}$, A_{CP}

$B \to X_s \gamma$, Measurements & Prediction

- NNLO calculation: $\mathcal{B}$ ($B \to X_s \gamma$) = $(3.15 \pm 0.23) \times 10^{-4}$ with $E_\gamma > 1.6$ GeV. Misiak et al., PRL 98, 022002 (2007)

- Experimental measurements
  - Require minimum E^*_γ
  - Inclusive approach
    1. Subtraction with off-resonance data
    2. Lepton tags or full reconstruct the other B
  - Semi-Inclusive approach

    Reconstruct many X_s states.

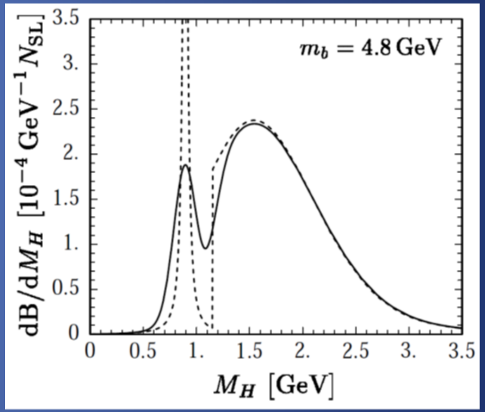


$B \to X_s \gamma$, semi-inclusive

- Data sample: 711 fb^{-1} (772 $B\bar{B}$ pairs)
- Signal reconstruction:

  1. $1.8 < E^*_\gamma < 3.4$ GeV; veto π^0 and η
  2. X_s = $1K^\pm$ (K_S) + up to 4 π ($\leq 2\pi^0$)
     $1K^\pm$ (K_S) + η + up to 2π
     3K with at most $1K_S$ + up to 1π

     $0.6 < M_{Xs} < 2.8$ GeV/c^2 $\Rightarrow$ 38 states

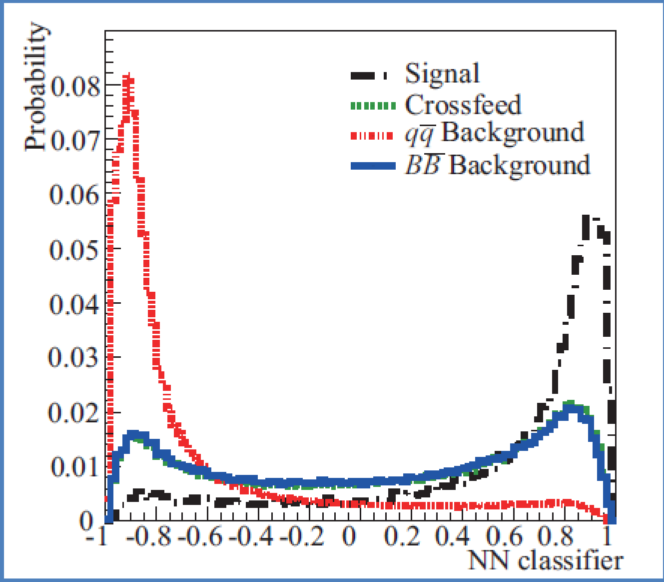


- Signal Model: $\begin{cases} M_{Xs} < 1.15 \text{ GeV}/c^2 \Rightarrow B \to K^*(892) \\ M_{Xs} > 1.15 \text{ GeV}/c^2 \Rightarrow \text{Kagan-Neubert+JETSET} \end{cases}$

  Generate with $\begin{cases} M_b = 4.44 \text{ GeV}/c^2 \\ \mu_\pi^2 = 0.750 \text{ GeV}^2 \end{cases}$

$B \to X_s\, \gamma$, Analysis

- Veto D decays, $B \to D^{(*)}\,(K\pi\pi)\,\rho$
- Continuum suppression is achieved by combining shape variables, tagging and $\Delta E = E^*_B - E^*_{beam}$ into Neural Network after the ΔE cut.

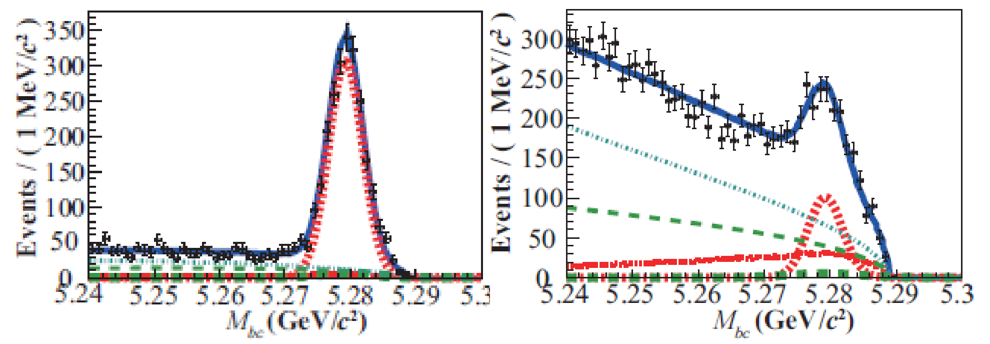


- Choose the best candidate based on NN value.
- Fit on M_{bc} in 19 M_{Xs} bins.

$$M_{bc} = \sqrt{E^2_{beam} - P^2_B}$$

Signal, $q\bar{q}$, Non-peaking $B\bar{B}$, Cross-feed, Peaking $B\bar{B}$

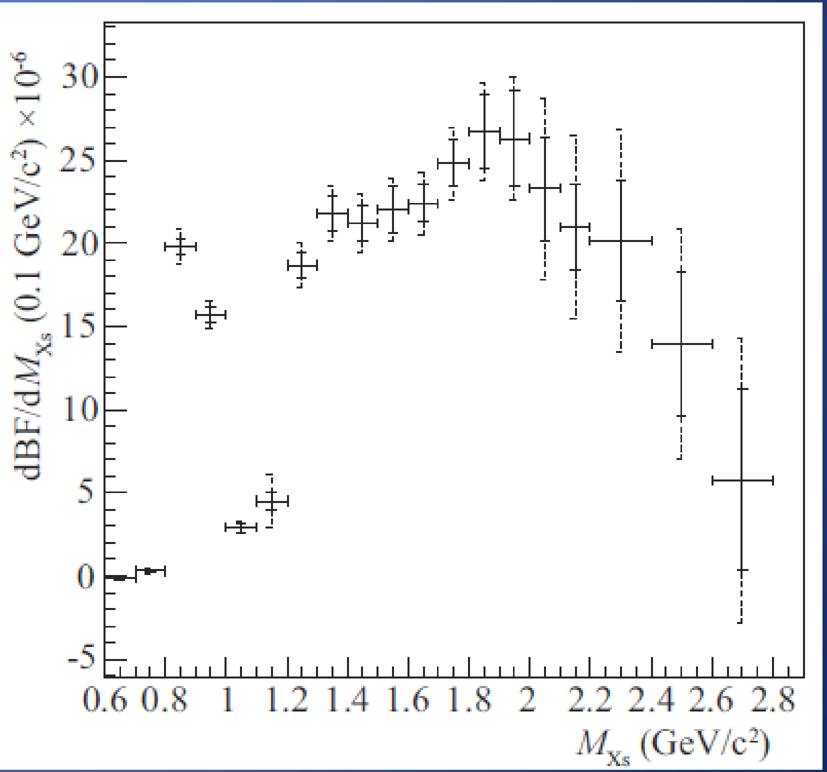
$0.8 < M_{Xs} < 0.9$ $\quad$ $1.9 < M_{Xs} < 2.0$



$B \to X_s \gamma$, Preliminary results

- With $0.6 < M_{Xs} < 2.8$ GeV/c^2 ($E_\gamma^* > 1.8$ GeV)
  $\mathcal{B}(B \to X_s \gamma) = (3.51 \pm 0.17 \pm 0.33) \times 10^{-4}$

- Calibrate the Xs fragmentation model by comparing the 10 fractions of final states in data and MC.

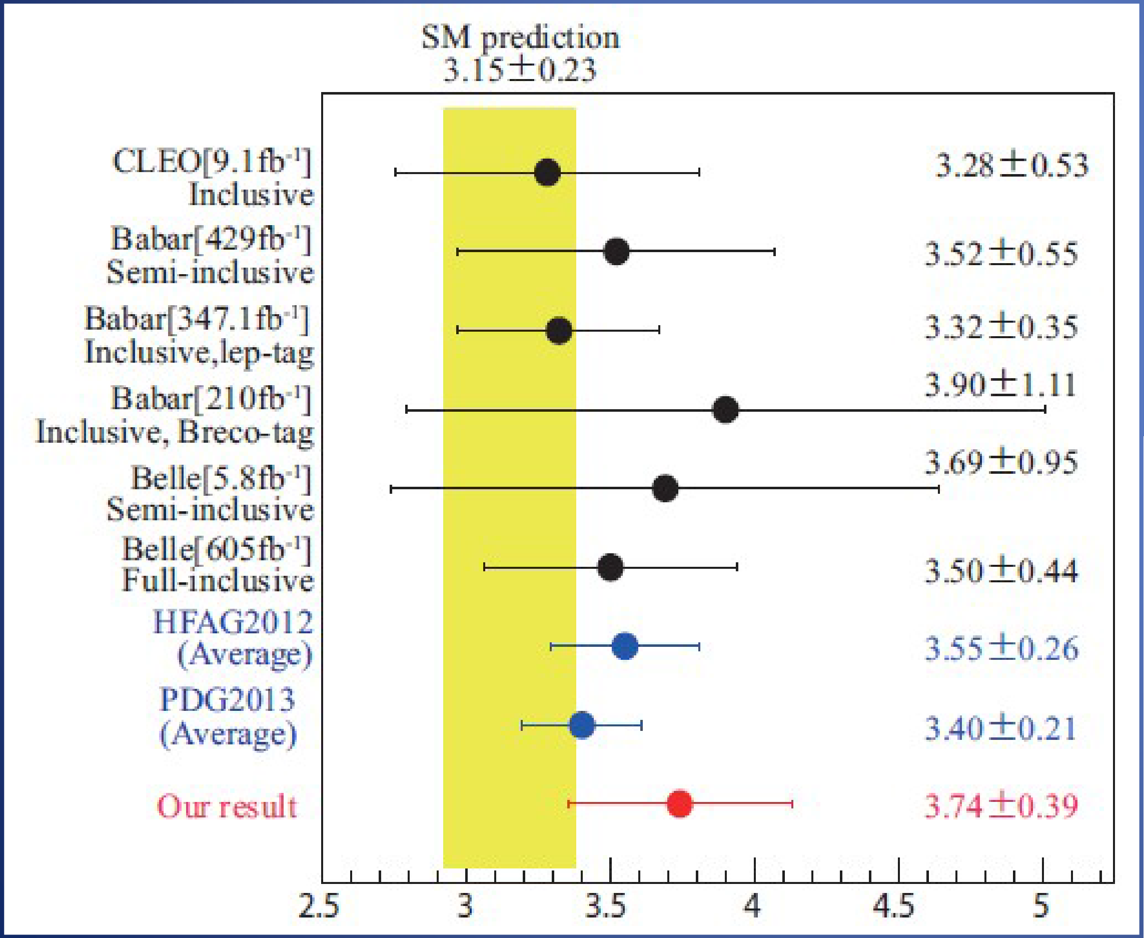


Source	Systematic uncertainty (%)
$B\overline{B}$ counting	1.37
Detector response	2.98
Background rejection	3.38
M_{bc} PDF	5.06
Hadronization model	6.66
Missing mode	1.59
Total	9.3

$\mathcal{B}$ ($B \to X_s \gamma$), comparison

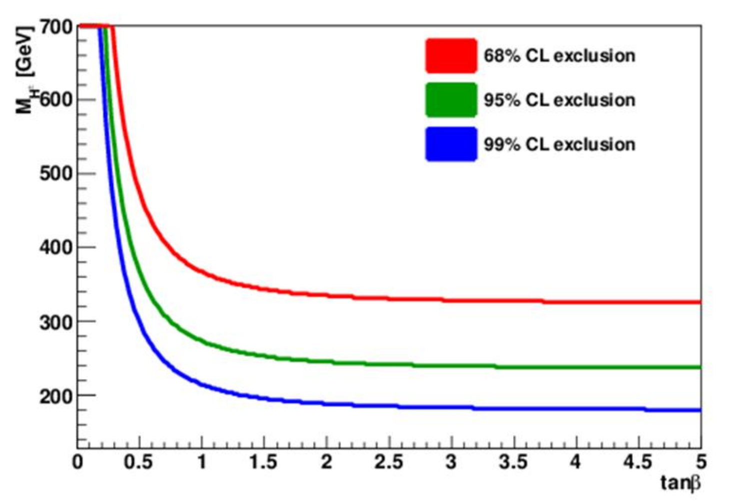
Extrapolation to $E_\gamma^* > 1.6$ GeV and compare with theory

$\mathcal{B}(B \to X_s \gamma) = (3.74 \pm 0.18 \pm 0.35) \times 10^{-4}$



- Best semi-inclusive result

Charged Higgs Mass VS tanβ
Only from this result



Direct CP Asymmetry in $B \rightarrow X_{s/d}\,\gamma$

- Small A_{CP} in SM.

$$A_{CP} = \frac{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}{\Gamma(\bar{B} \rightarrow \bar{f}) + \Gamma(B \rightarrow f)} \quad (f = X_{s,d}\,\gamma)$$

$$A^q_{CP} = \frac{\Delta\Gamma^q}{2\Gamma^q_{avg}},\ q = d, s$$

$$\Delta\Gamma^q \propto \mathrm{Im}\,(V_{uq}\, V^*_{ub} V_{cq}\, V^*_{cb})$$

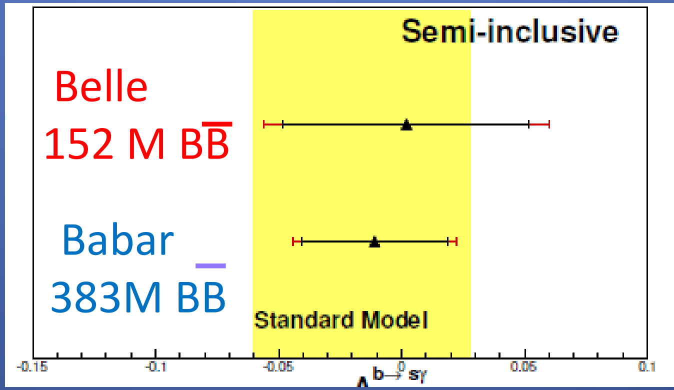
Due to unitarity of CKM matrix, $\Delta\Gamma^s = -\Delta\Gamma^d$

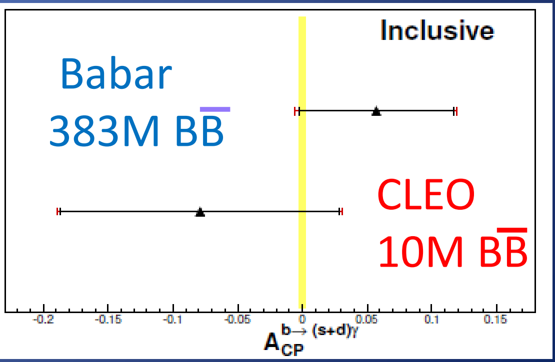
	A_{CP} (SM)
$B \rightarrow X_s\,\gamma$	$-0.6\% - 2.8\%$
$B \rightarrow X_d\,\gamma$	$-62\% - 14\%$
$B \rightarrow X_{s+d}\,\gamma$	~ 0

Benzke et al., PRL 106, 141801 (2011)

Hurth et al., Nucl. Phys. 704, 56-74 (2005)

- Clean Probe for new physics
- Previous results





$A_{CP}(B \to X_s \gamma)$, Semi-inclusive

- Data sample: 429 $fb^{-1} \Rightarrow 471 \times 10^6$ $B\bar{B}$ pairs
- Flavour specific X_s states: 10 for B^+ and 6 for B^0
- Require $1.6 < E_\gamma^* < 3.0$ GeV
- Best candidate: $\Delta E/\sigma_E$, M_{Xs}, FWM, thrust, P_{π^0}
- Reject continuum : shape variables & π^0 score
- Possible asymmetry bias:
  - Asymmetry due to $\varepsilon(K\pm) \Rightarrow D^{*+} \to D^0 \pi^+$, $D^0 \to K^- \pi^+$
  - Peaking BB background $\Rightarrow$ MC

$A_{CP}(B \to X_s\,\gamma)$ and ΔA_{CP}, Preliminary

- With BaBar full data sample,

arXiv: 1406.0534

$$A_{CP}(B \to X_s\,\gamma) = (+1.7 \pm 1.9 \pm 1.0)\% \Leftarrow \text{Most precise}$$

$$\Delta A(X_s\gamma) = A_{CP}(X_s^{\pm}\gamma) - A_{CP}(X_s^{0}\gamma) = (+5.0 \pm 3.9 \pm 1.5)\%$$

- $\Delta A(X_s\,\gamma)$ is related to C_{8g} and $C_{7\gamma}$,

$$\Delta A(X_s\gamma) = 4\pi^2 \alpha_s \frac{\bar{\Lambda}_{78}}{m_b} \mathrm{Im}(C_{8g}/C_{7\gamma}) \approx 0.12 \frac{\bar{\Lambda}_{78}}{100\ \mathrm{MeV}} \mathrm{Im}(C_{8g}/C_{7\gamma})$$

Interference amplitude: $\bar{\Lambda}_{78}$; $17 < \bar{\Lambda}_{78} < 190$ MeV

In SM, C_{8g} and $C_{7\gamma}$ are real. $\Rightarrow \Delta A = 0$

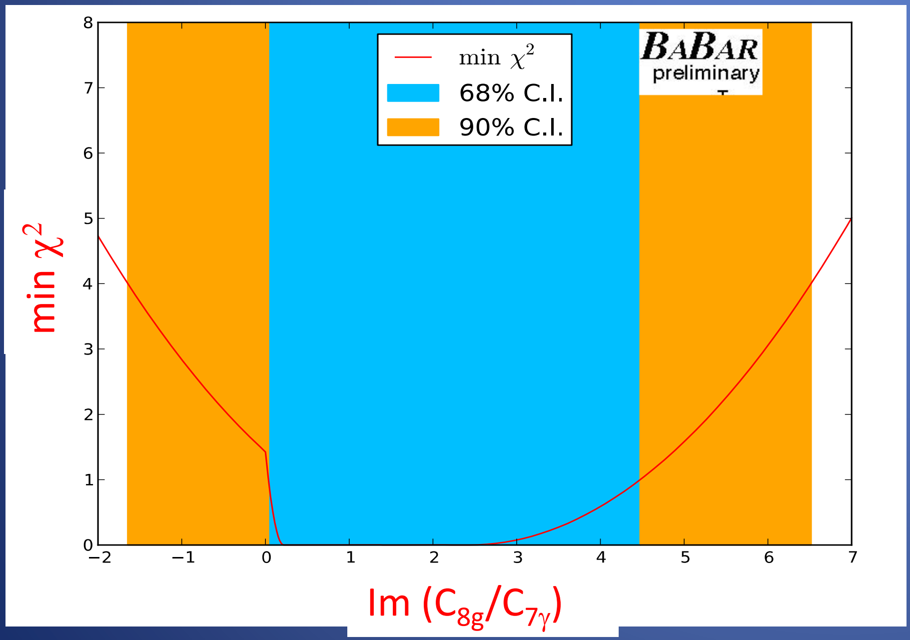
Benzke et al., PRL 106, 141801 (2011)

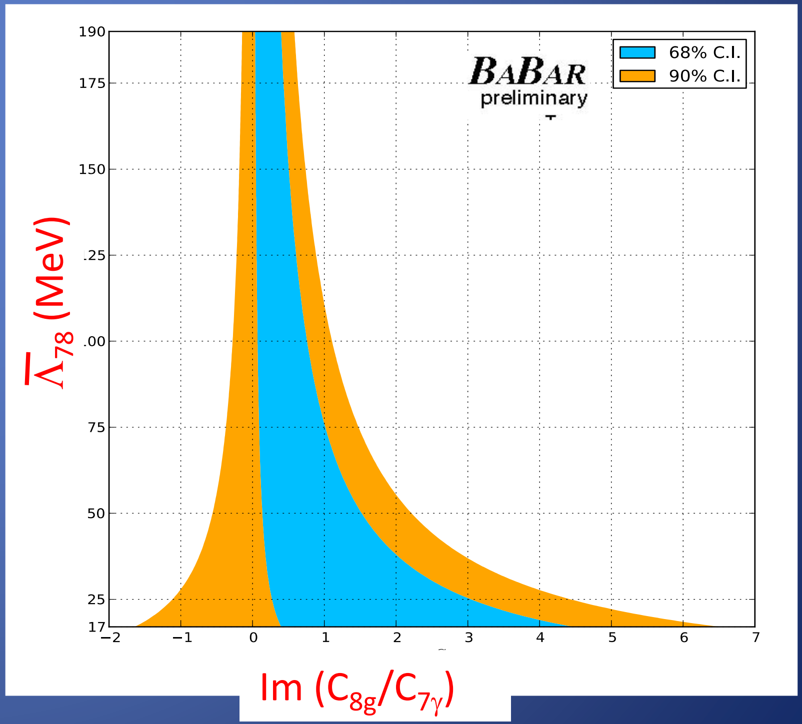
Implication on $\mathrm{Im}(C_{8g}/C_{7\gamma})$

$$\text{Minimum } \chi^2 = \frac{\min\limits_{\bar{\Lambda}_{78}} [\, (\Delta A_{Th} - \Delta A_{Exp})^2]}{\sigma^2}$$

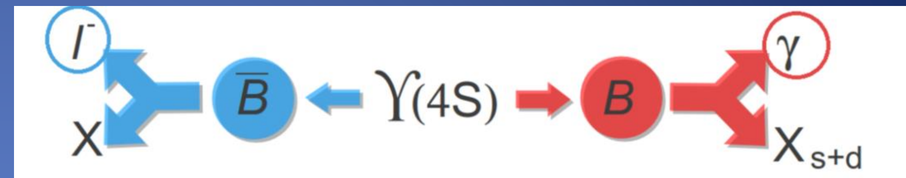
$-1.64 < \mathrm{Im}(C_{8g}/C_{7\gamma}) < 6.52$ @90% CL

arXiv:1406.0534

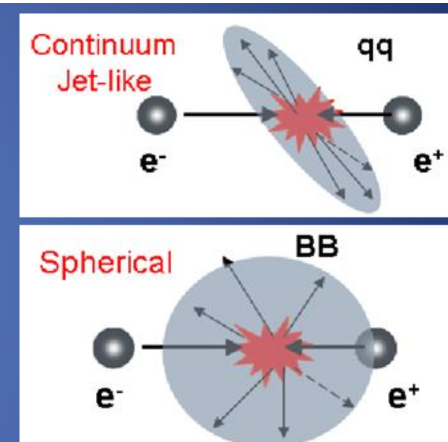


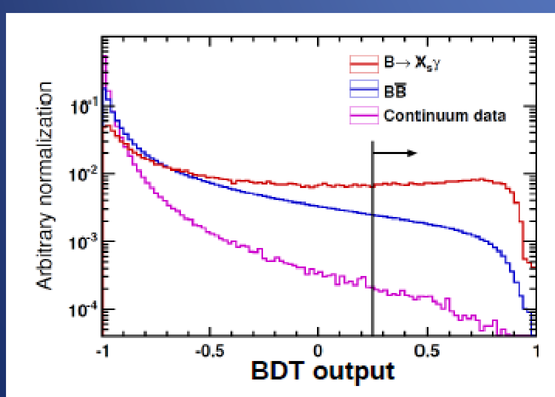


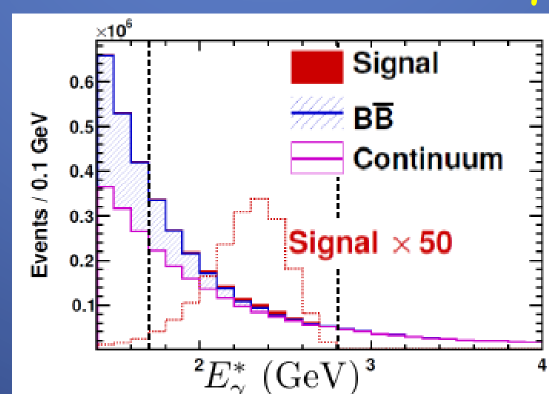
$B \to X_{s+d}\,\gamma$, Analysis method



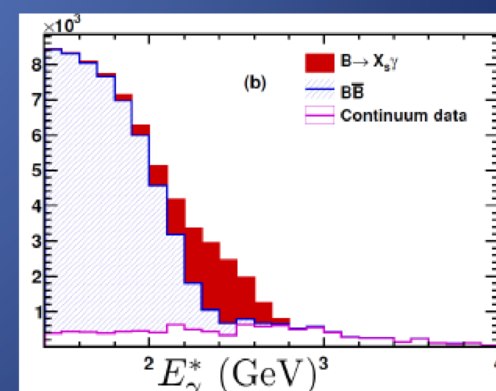
- $1.7 < E^*_\gamma < 2.8$ GeV
- Veto γ from $\pi^0\ (\eta) \to \gamma\gamma$.
- Veto pile-up γ based on timing info.
- Tag leptons with $1.10 < P^*_\ell < 2.25$ GeV/c
- Suppress the continuum using BDT.
  - Topological variables: Thrust, Modified FWM
  - Kinematic variables: M^2_{miss}, E_T
  - Isolation and calorimeter variables for γ.







BDT →

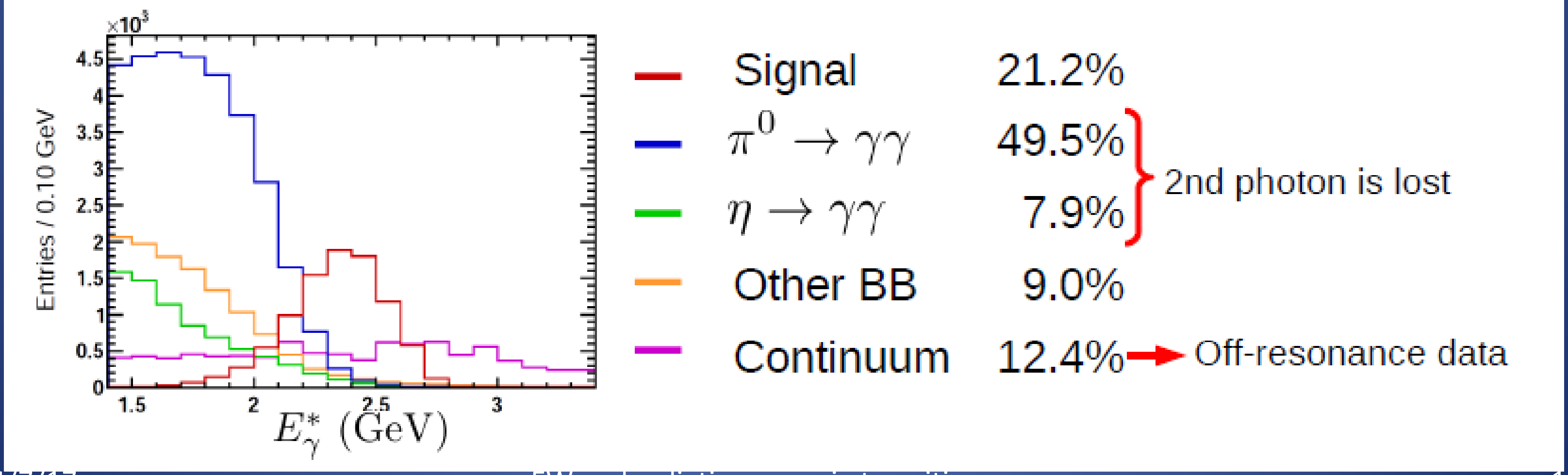


$B \to X_{s+d}\,\gamma$, Background Calibration

- Sources:
  - Continuum $\Rightarrow$ off-resonance
  - π^0 and η to $\gamma\gamma \Rightarrow$ Estimated from MC with correction factors in $P_{\pi\,(\eta)}$. Study π^0 and η veto using BDT sideband.
  - Other $B\bar{B}$ background from MC.

- Measure $\mathcal{B}(B \to X\,\pi^0/\eta)$ in data and MC

$$C = \frac{N_{ON} - \alpha_{off}\,N_{off}}{N_{MC}}$$



$B \to X_{s+d}\,\gamma$, Wrong Tag Fraction

- $W = W_{osc} + W_{sec} + W_{misID}$

  $A_{CP}^{true} = \frac{1}{1-2W} A_{CP}^{meas}$

- B-$\bar{B}$ mixing $\chi_d = 0.187$
- W_{sec} from MC.
- $D^{*+} \to D^0 (K^- \pi^+) \pi^+$ for misID

Factor	Value
ω_{misID}	0.0069 ± 0.0034
ω_{2nd}	0.0431 ± 0.0036
ω_{osc}	0.0913 ± 0.0015
ω_{total}	0.1413 ± 0.0052

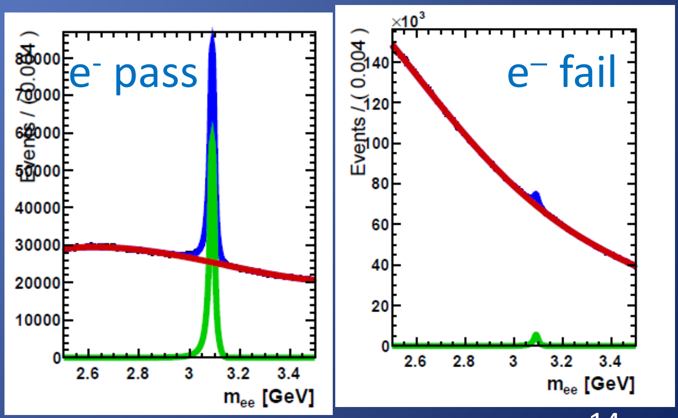
- Detector bias
  - Lepton ID

    Tag-and-probe using $J/\psi \to \ell^+\ell^-$

    $\varepsilon^{\pm} = \frac{N_{pass}}{N_{pass} + N_{fail}}$; $A_{LID} = \frac{\varepsilon^+ - \varepsilon^-}{\varepsilon^+ + \varepsilon^-}$
    $= (0.11 \pm 0.07)\%$
  - Tracking

    Partially recon. D* $\Rightarrow (-0.01 \pm 0.21)\%$
  - Asymmetry in $B\bar{B}$ background

    Data in $E_{\gamma}^{*} < 1.7$ GeV $\Rightarrow (-0.14 \pm 0.78)\%$

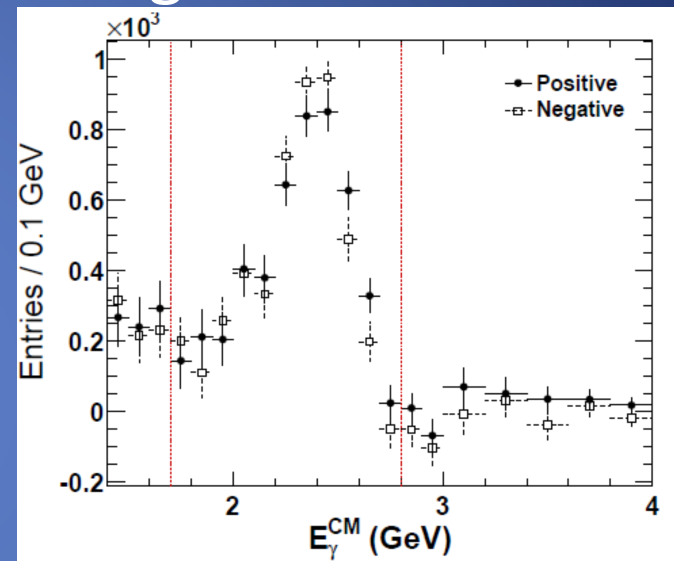


$A_{CP}(B \to X_{s+d}\,\gamma)$, Preliminary

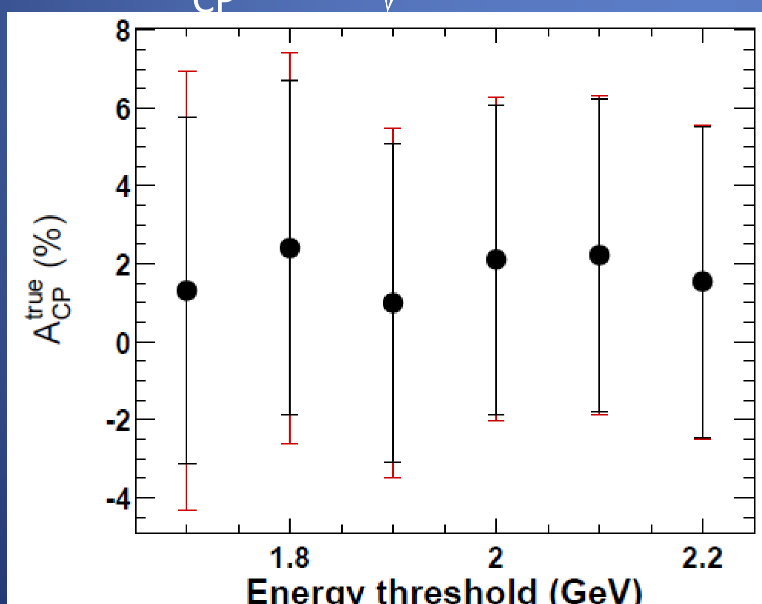
- 770 M $B\bar{B}$ pairs

$$A_{CP}^{obs} = \frac{N_+ - N_-}{N_+ + N_-}$$

Background subtracted



A_{CP}^{true} in E_γ threshold



$A_{CP}^{true}(E_\gamma^{CM} > 1.7) = 1.32 \pm 4.43 \pm 3.49$

$A_{CP}^{true}(E_\gamma^{CM} > 1.8) = 2.41 \pm 4.28 \pm 2.63$

$A_{CP}^{true}(E_\gamma^{CM} > 1.9) = 1.00 \pm 4.09 \pm 1.87$

$A_{CP}^{true}(E_\gamma^{CM} > 2.0) = 2.11 \pm 3.96 \pm 1.24$

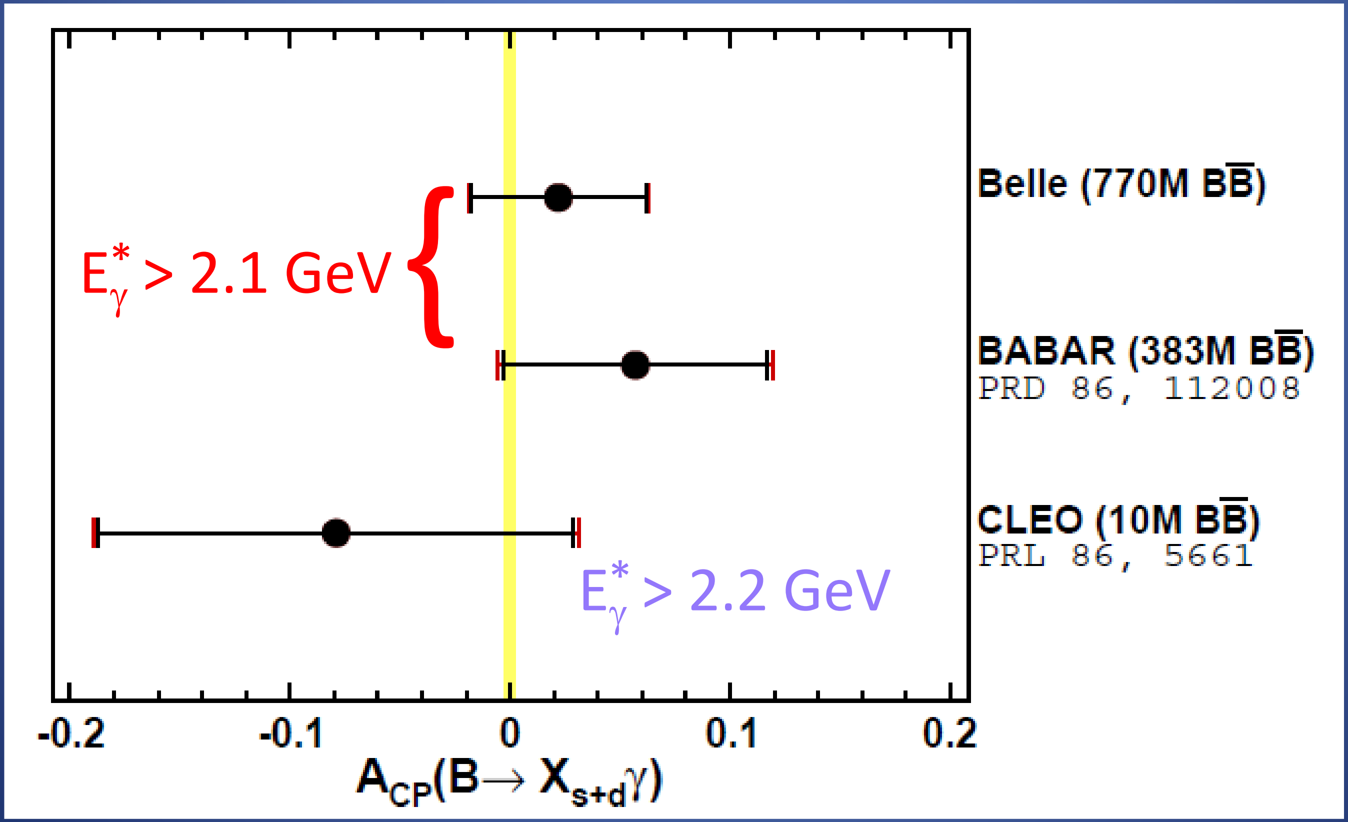
$A_{CP}^{true}(E_\gamma^{CM} > 2.1) = 2.23 \pm 4.02 \pm 0.78$

$A_{CP}^{true}(E_\gamma^{CM} > 2.2) = 1.55 \pm 3.99 \pm 0.52$

Comparison with other results

- Most precise measurement.
  Statistical uncertainty dominant

$A_{CP}(B \to X_{s+d}\, \gamma) = (2.23 \pm 4.02 \pm 0.78)\%$

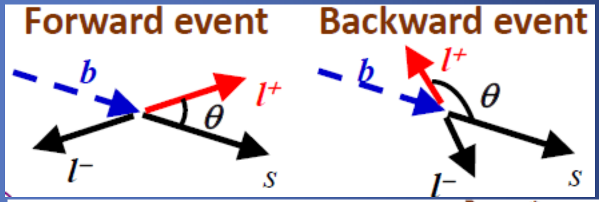


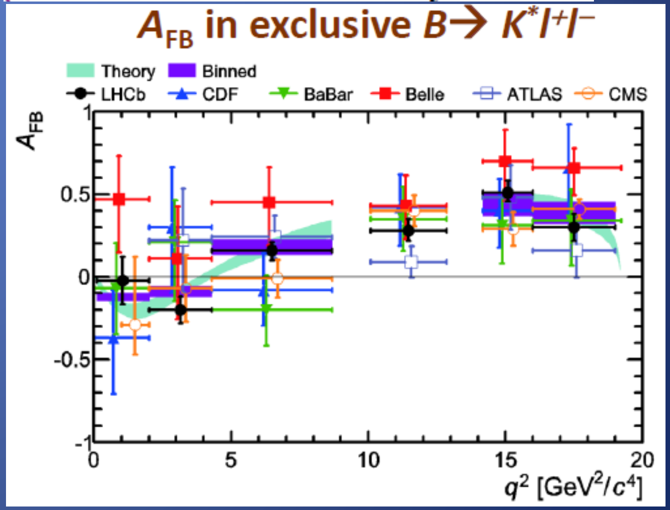
$B \to X_s \ell^+\ell^-$

- The $X_s \ell^+\ell^-$ decay can be expressed with C_7, C_9 & C_{10}.
- probe new physics with observables as a function of q^2 ($M^2_{\ell\ell}$): BF, A_{CP}, A_{FB}, A_{iso}, f_L … other variables
- $A_{FB} = \dfrac{N(\cos\theta>0) - N(\cos\theta<0)}{N(\cos\theta>0) + N(\cos\theta<0)}$

$$\propto -\mathrm{Re}\left[\left(2C_7^{eff} + \frac{q^2}{M_b^2} C_9^{eff}\right) C_{10}\right]$$

- A_{FB} in $B \to K^* \ell^+\ell^-$ has been measured by many experiments.
- Less theoretical uncertainty in inclusive $B \to X_s \ell^+\ell^-$.





$B \to X_s \ell^+ \ell^-$, semi-inclusive

- 18 states for X_s, 1 $K^\pm$ (K_S) + up to 4 π (at most 1 π^0). Only 10 flavor specific states are used for A_{FB}. ($M_{Xs} < 2.0$ GeV/c^2)
- Veto J/ψ (ψ')$\to \ell^+ \ell^-$. $\Rightarrow$ wider veto range for e^+e^-.
- Suppress background using Neural Bayes (23 variables).
  - Semi-leptonic B decays
    - Lepton vertex separation
    - Missing mass
    - Visible energy
  - Continuum
    - Shape variables
- Peaking backgrounds $\Rightarrow$

  $\Rightarrow$ Included in the fit

1. Leakage from $B \to J/\psi(\psi')\, X_s$ veto.
   ⇨ Estimated using MC
2. Double miss ID from $B \to D^{(*)}\, n\pi$.
3. Swapped mis ID in $B \to J/\psi(\psi')\, X_s$
   ⇨ Estimated using data

$B \to X_s \ell^+ \ell^-$, Signal Extraction

- Divide data into 4 q^2 regions to perform a fit.
- Correct A_{FB}^{raw} to A_{FB}^{true}.

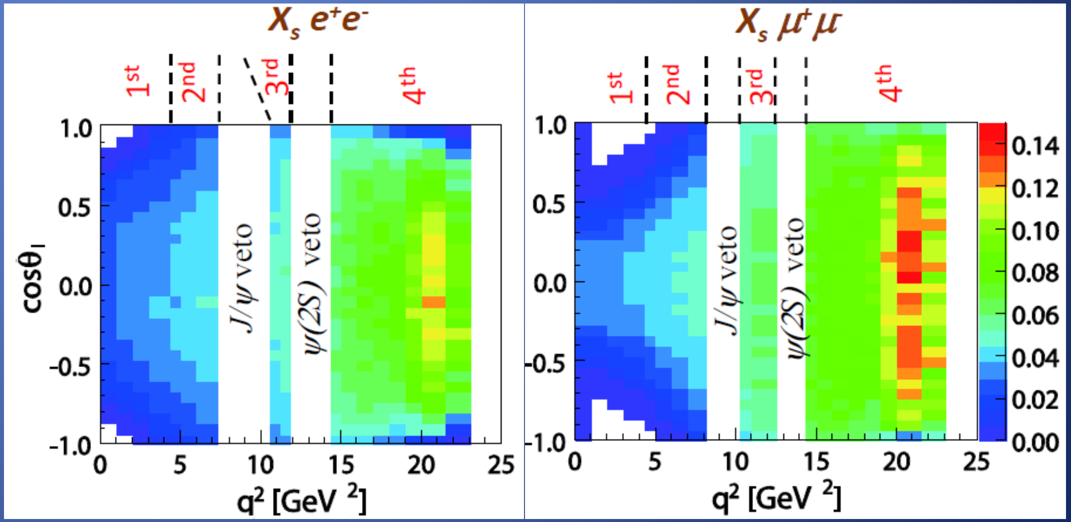
$$A_{FB}^{true} = \alpha^{\mu\mu} \times A_{FB}^{raw,\,\mu\mu}$$
$$= \alpha^{ee} \times \beta \times A_{FB}^{raw,\,ee}$$

α: scale factor due to rec. efficiency

β: correction due to different $J/\psi(\psi')$ veto range.

Derive α using MC with various sets of C_7, C_9, C_{10}

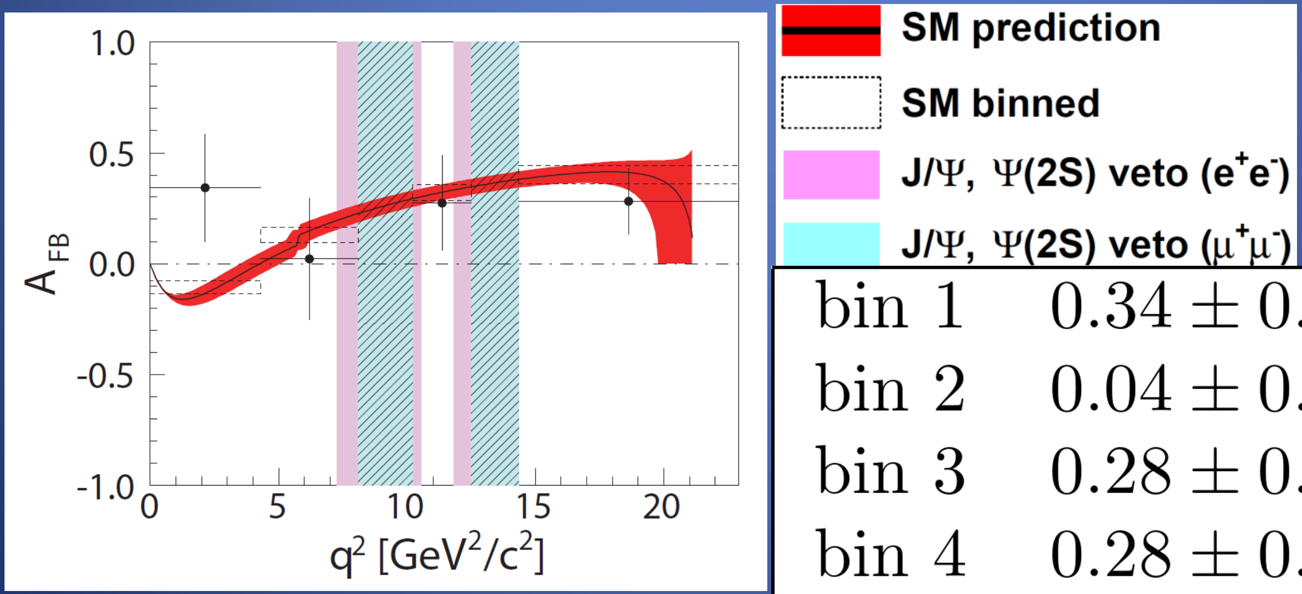
Rec. Eff.



$A_{FB}(B \to X_s \ell^+\ell^-)$, Results

- The measured A_{FB} values are consistent with the SM.
  - The deviation of the 1st bin is 1.8 σ.
  - Exclude $A_{FB}<0$ at $q^2 > 10.2\ GeV^2/c^2$ at 2.3 σ.

arXiv: 1402.7134; submitted to PRL



	A_{FB}
bin 1	$0.34 \pm 0.24 \pm 0.02$
bin 2	$0.04 \pm 0.31 \pm 0.05$
bin 3	$0.28 \pm 0.21 \pm 0.01$
bin 4	$0.28 \pm 0.15 \pm 0.01$

$B \to X_s \ell^+ \ell^-$, semi-inclusive

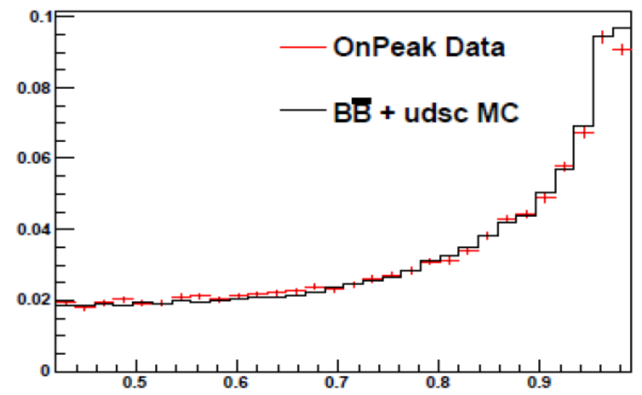
- Reconstruct 10 X_s states with 1K (K^0_S) + 0–2 π ($\geq 1\ \pi^0$) for branching fraction and 7 self tagged states for A_{CP}.
  This 10 X_s states correspond to 70% of inclusive rate with $M_{Xs} < 1.8$ GeV/c^2.
- Extract the missing states and the states with $M_{Xs} > 1.8$ GeV/c^2 using JETSET fragmentation and theory predictions.
- Kinematic requirements:

$M_{ES} > 5.225$ GeV/c^2 ; $-0.1 < \Delta E < 0.05$ GeV for $X_s ee$;
$|\Delta E| < 0.05$ GeV for $X_s \mu\mu$

$B \to X_s \ell^+\ell^-$, Analysis Strategy

- Use likelihood ratio defined from BDT output to distinguish signals and backgrounds.
- Veto J/ψ and ψ'.
- Measure $d\mathcal{B}(B \to X_s \ell^+\ell^-)/dq^2$ in 6 q^2 & 4 M_{X_s} bins.
- Measure $A_{CP}(B \to X_s \ell^+\ell^-)$ in 5 q^2 bins.

Likelihood ratio on J/ψ sample



- Data sample: 471×10^6 $B\bar{B}$ pairs

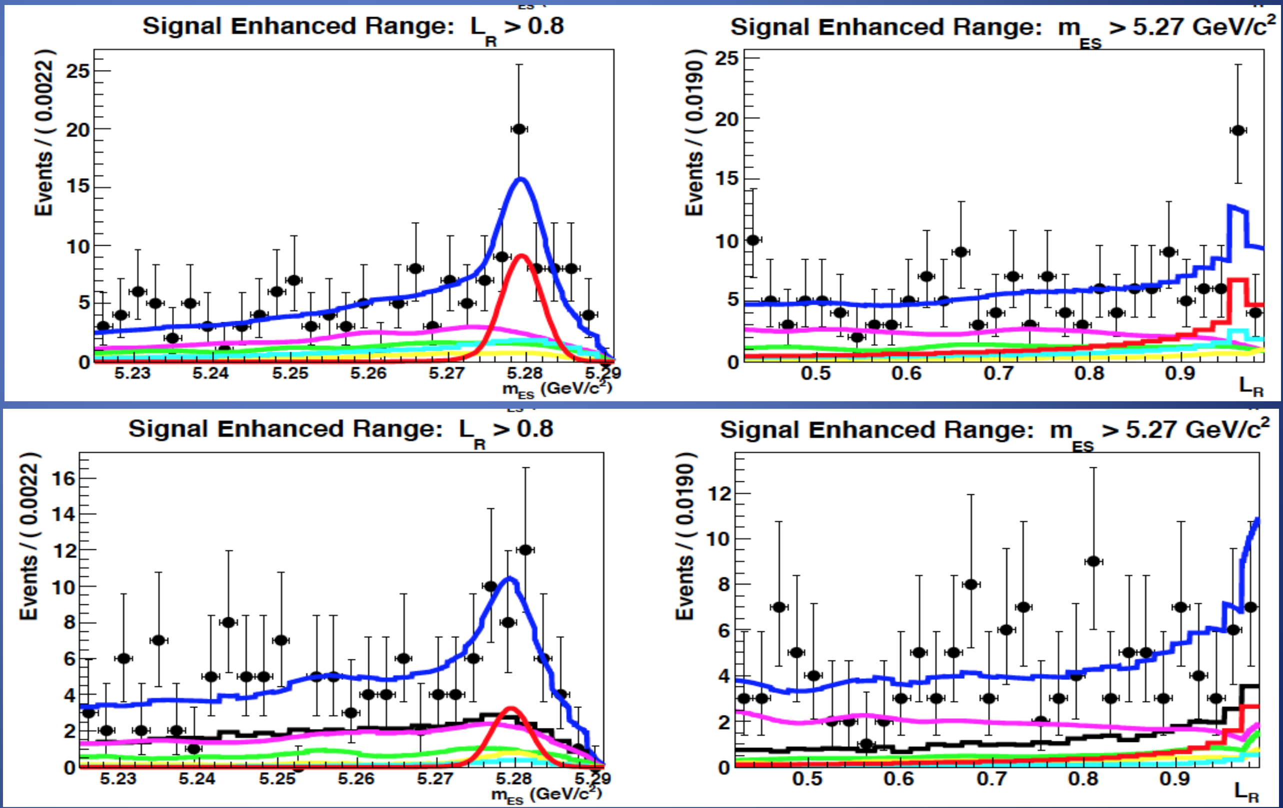
q^2 bin	$m^2_{\ell\ell}$ (GeV^2/c^4)	$m_{\ell\ell}$ (GeV/c^2)
0	1.0 – 6.0	1.00 – 2.45
1	0.1 – 2.0	0.32 – 1.41
2	2.0 – 4.3	1.41 – 2.07
3	4.3 – 8.1	2.07 – 2.60
4	10.1 – 12.9	3.18 – 3.59
5	$14.2 - (M_B - M^*_K)^2$	$3.77 - (M_B - M^*_K)$

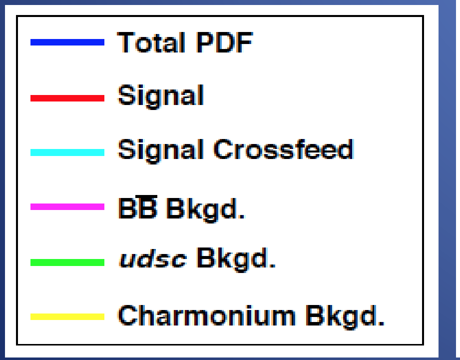
B→$X_s \ell^+\ell^-$, Signal Extraction

- Extract signals from 2D ML fit on M_{ES} and LR

5^{th} q bin for X_s ee

1^{st} q bin for X_s $\mu\mu$





$\mathcal{B}(B\to X_s\,\ell^+\ell^-)$, Results

Phys.Rev.Lett. 112, 211802 (2014)

- $1<q^2<6$ GeV/c^2

$$\mathcal{B}(B\to X_s\mu^+\mu^-)=(0.66^{+0.82+0.30}_{-0.76-0.24}\pm0.07)\times10^{-6}$$

$$\mathcal{B}(B\to X_s e^+e^-)=(1.93^{+0.47+0.21}_{-0.45-0.16}\pm0.18)\times10^{-6}$$

$$\mathcal{B}(B\to X_s\ell^+\ell^-)=(1.60^{+0.41+0.17}_{-0.39-0.13}\pm0.18)\times10^{-6}$$

Consistent with the SM

SM ⇨

$$\mathcal{B}(B\to X_s\mu^+\mu^-)=(1.59\pm0.11)\times10^{-6}$$

$$\mathcal{B}(B\to X_s e^+e^-)=(1.64\pm0.11)\times10^{-6}$$

- $q^2>14.2$ GeV/c^2

$$\mathcal{B}(B\to X_s\mu^+\mu^-)=(0.60^{+0.31+0.05}_{-0.29-0.04}\pm0.00)\times10^{-6}$$

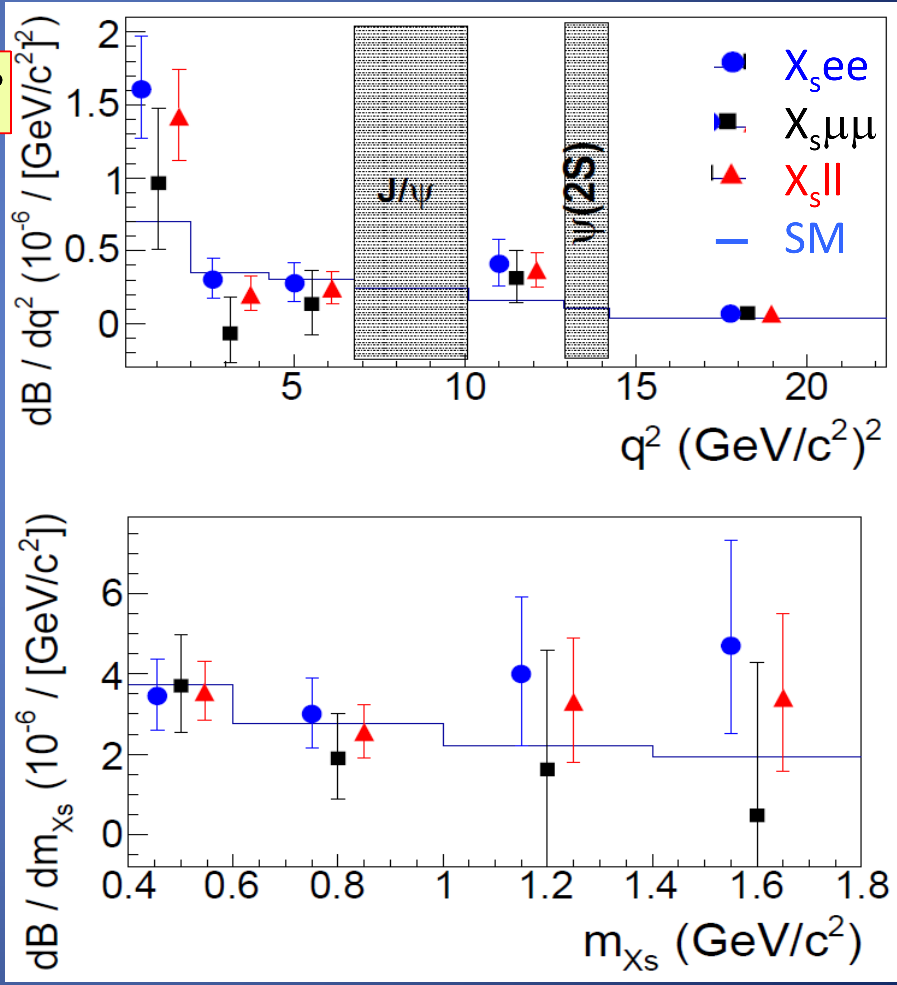
$$\mathcal{B}(B\to X_s e^+e^-)=(0.56^{+0.19+0.03}_{-0.18-0.03}\pm0.00)\times10^{-6}$$

$$\mathcal{B}(B\to X_s\ell^+\ell^-)=(0.57^{+0.16+0.03}_{-0.15-0.02}\pm0.00)\times10^{-6}$$

Consistent with the SM at ~1σ

SM ⇨

$$\mathcal{B}(B\to X_s\mu^+\mu^-)=(0.25^{+0.07}_{-0.06})\times10^{-6}$$



$A_{CP}(B \rightarrow X_s \ell^+\ell^-)$, Results

- Over the full q^2 range,

$A_{CP}(B \rightarrow X_s \ell^+\ell^-) = 0.04 \pm 0.11 \pm 0.01$

Consistent with 0, as expected with the SM.

- A_{CP} in each q^2 is also consistent with 0

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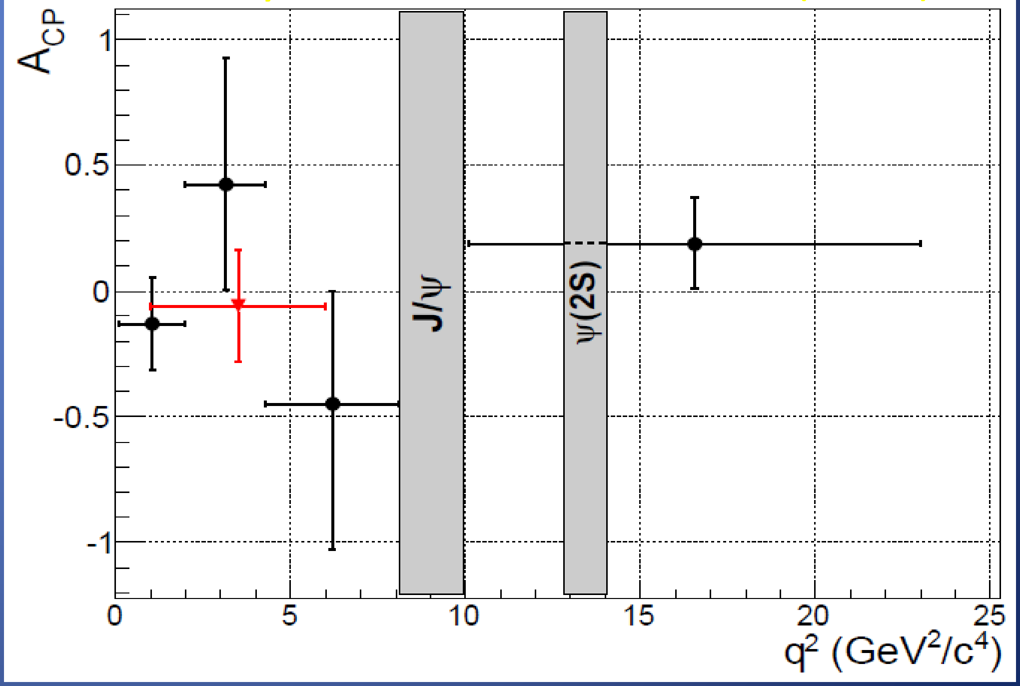


Summary

- Several $B \rightarrow X_s \gamma(\ell\ell)$ measurements are reported.
  - Most precise semi-inclusive $\mathcal{B}(B \rightarrow X_s \gamma)$ from Belle
  - Most precise $A_{CP}(B \rightarrow X_s \gamma)$ from BaBar

    First $\Delta A_{CP}(B \rightarrow X_s \gamma)$ and constraint on $\mathrm{Im}(C_{8g}/C_{7\gamma})$
  - Most precise $A_{CP}(B \rightarrow X_{s+d} \gamma)$ from Belle
  - First $A_{FB}(B \rightarrow X_s \ell^+\ell^-)$ from Belle
  - First $\mathcal{B}(B \rightarrow X_s \ell^+\ell^-)$ and $A_{CP}(B \rightarrow X_s \ell^+\ell^-)$ from BaBar
- Expect precision measurements in Belle II.

  Full hadronic tag for inclusive analysis.

BACK UP

$B \to X_s \gamma$, Semi-inclusive

38 X_s states correspond to 70% of total.

Mode ID	Final State	Mode ID	Final State
1	$K^+\pi^-$	20	$K^0_S\pi^+\pi^0\pi^0$
2	$K^0_S\pi^+$	21	$K^+\pi^+\pi^-\pi^0\pi^0$
3	$K^+\pi^0$	22	$K^0_S\pi^+\pi^-\pi^0\pi^0$
4	$K^0_S\pi^0$	23	$K^+\eta$
5	$K^+\pi^+\pi^-$	24	$K^0_S\eta$
6	$K^0_S\pi^+\pi^-$	25	$K^+\eta\pi^-$
7	$K^+\pi^+\pi^0$	26	$K^0_S\eta\pi^+$
8	$K^0_S\pi^+\pi^0$	27	$K^+\eta\pi^0$
9	$K^+\pi^+\pi^-\pi^-$	28	$K^0_S\eta\pi^0$
10	$K^0_S\pi^+\pi^+\pi^-$	29	$K^+\eta\pi^+\pi^-$
11	$K^+\pi^+\pi^-\pi^0$	30	$K^0_S\eta\pi^+\pi^-$
12	$K^0_S\pi^+\pi^-\pi^0$	31	$K^+\eta\pi^-\pi^0$
13	$K^+\pi^+\pi^+\pi^-\pi^-$	32	$K^0_S\eta\pi^+\pi^0$
14	$K^0_S\pi^+\pi^+\pi^-\pi^-$	33	$K^+K^+K^-$
15	$K^+\pi^+\pi^-\pi^-\pi^0$	34	$K^+K^-K^0_S$
16	$K^0_S\pi^+\pi^+\pi^-\pi^0$	35	$K^+K^+K^-\pi^-$
17	$K^+\pi^0\pi^0$	36	$K^+K^-K^0_S\pi^+$
18	$K^0_S\pi^0\pi^0$	37	$K^+K^+K^-\pi^0$
19	$K^+\pi^-\pi^0\pi^0$	38	$K^+K^+K^0_S\pi^0$

$B \to X_s\, \ell^+\ell^-$, semi-inclusive

TABLE I. The 18 hadronic final states used to reconstruct X_s. The 8 final states enclosed in parentheses are not used for the measurement of $A_{\rm FB}$.

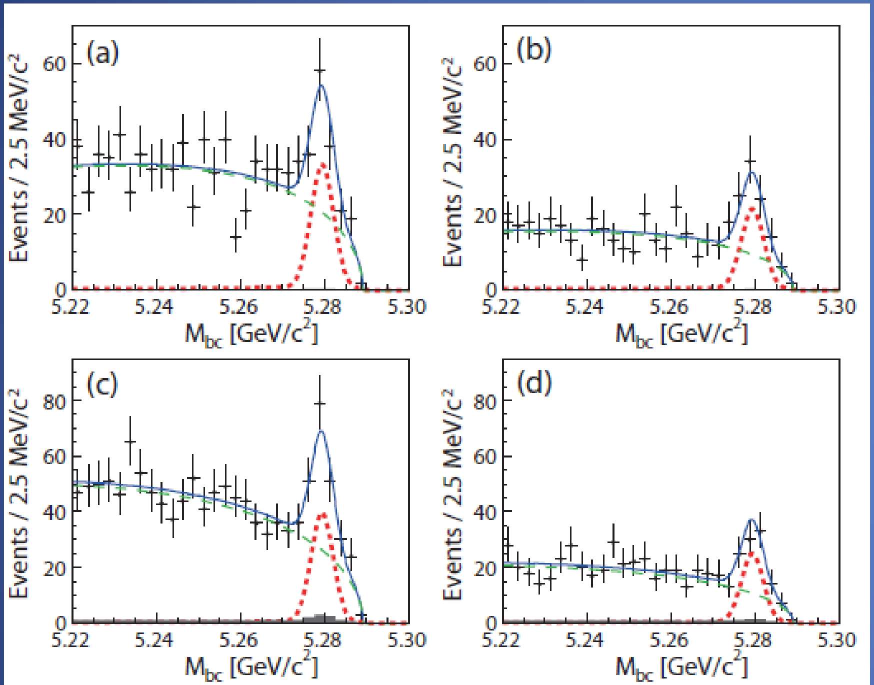
$\bar{B}^0$ decays		B^- decays	
	(K_S^0)	K^-	
$K^-\pi^+$	$(K_S^0\pi^0)$	$K^-\pi^0$	$K_S^0\pi^-$
$K^-\pi^+\pi^0$	$(K_S^0\pi^-\pi^+)$	$K^-\pi^+\pi^-$	$K_S^0\pi^-\pi^0$
$K^-\pi^+\pi^-\pi^+$	$(K_S^0\pi^-\pi^+\pi^0)$	$K^-\pi^+\pi^-\pi^0$	$K_S^0\pi^-\pi^+\pi^-$
$(K^-\pi^+\pi^-\pi^+\pi^0)$	$(K_S^0\pi^-\pi^+\pi^-\pi^+)$	$(K^-\pi^+\pi^-\pi^+\pi^-)$	$(K_S^0\pi^-\pi^+\pi^-\pi^0)$

$B \to X_s \ell^+\ell^-$, Results

forward backward

$X_s e^+e^-$

$X_s \mu^+\mu^-$



$N^{ee} = 139.9 \pm 18.6$

$N^{\mu\mu} = 160.8 \pm 20.0$

----- Signal + cross feed

- - - Combinatorial

HIST Peaking background

The dominant systematic errors are α & β and peaking bkg.

	1st bin	2nd bin	3rd bin	4th bin
q^2 range [GeV$^2/c^2$] $(B \to X_s e^+e^-)$	[0.2,4.3]	[4.3,7.3]	[10.5,11.8]	[14.3, 25.0]
q^2 range [GeV$^2/c^2$] $(B \to X_s \mu^+\mu^-)$		[4.3,8.1]	[10.2,12.5]	
$\mathcal{A}_{FB}$	$0.34 \pm 0.24 \pm 0.02$	$0.04 \pm 0.31 \pm 0.05$	$0.28 \pm 0.21 \pm 0.01$	$0.28 \pm 0.15 \pm 0.01$
$\mathcal{A}_{FB}$ (theory)	-0.11 ± 0.03	0.13 ± 0.03	0.32 ± 0.04	0.40 ± 0.04
N^{ee}_{sig}	45.6 ± 10.9	30.0 ± 9.2	25.0 ± 7.0	39.2 ± 9.6
$N^{\mu\mu}_{sig}$	43.4 ± 9.2	23.9 ± 10.4	30.7 ± 9.9	62.8 ± 10.4
α^{ee}	1.289 ± 0.004	1.139 ± 0.003	1.063 ± 0.003	1.121 ± 0.003
$\alpha^{\mu\mu}$	2.082 ± 0.010	1.375 ± 0.003	1.033 ± 0.003	1.082 ± 0.003
β	1.000	1.019 ± 0.003	1.003 ± 0.000	1.000

$B \to X_s \ell^+ \ell^-$, semi-inclusive

Bin	Range	$B \to X_s e^+ e^-$	$B \to X_s \mu^+ \mu^-$	$B \to X_s \ell^+ \ell^-$	$A_{CP\, B \to X_s \ell^+ \ell^-}$
q_0^2	$1.0 < q^2 < 6.0$	$1.93^{+0.47+0.21}_{-0.45-0.16} \pm 0.18$ (1.71)	$0.66^{+0.82+0.30}_{-0.76-0.24} \pm 0.07$ (1.78)	$1.60^{+0.41+0.17}_{-0.39-0.13} \pm 0.18$	$-0.06 \pm 0.22 \pm 0.01$
q_1^2	$0.1 < q^2 < 2.0$	$3.05^{+0.52+0.29}_{-0.49-0.21} \pm 0.35$ (1.96)	$1.83^{+0.90+0.30}_{-0.80-0.24} \pm 0.20$ (2.02)	$2.70^{+0.45+0.21}_{-0.42-0.16} \pm 0.35$	$-0.13 \pm 0.18 \pm 0.01$
q_2^2	$2.0 < q^2 < 4.3$	$0.69^{+0.31+0.11}_{-0.28-0.07} \pm 0.07$ (1.73)	$-0.15^{+0.50+0.26}_{-0.43-0.14} \pm 0.01$ (1.80)	$0.46^{+0.26+0.10}_{-0.23-0.06} \pm 0.07$	$0.42^{+0.50}_{-0.42} \pm 0.01$
q_3^2	$4.3 < q^2 < 6.8$	$0.69^{+0.31+0.13}_{-0.29-0.10} \pm 0.05$ (1.53)	$0.34^{+0.54+0.19}_{-0.50-0.15} \pm 0.03$ (1.59)	$0.60^{+0.27+0.10}_{-0.25-0.08} \pm 0.05$	$-0.45^{+0.44}_{-0.57} \pm 0.01$
q_4^2	$10.1 < q^2 < 12.9$	$1.14^{+0.42+0.22}_{-0.40-0.10} \pm 0.04$ (1.16)	$0.87^{+0.51+0.11}_{-0.47-0.08} \pm 0.03$ (1.18)	$1.02^{+0.32+0.10}_{-0.30-0.07} \pm 0.04$	
q_5^2	$14.2 < q^2$	$0.56^{+0.19+0.03}_{-0.18-0.03} \pm 0.00$ (1.02)	$0.60^{+0.31+0.05}_{-0.29-0.04} \pm 0.00$ (1.02)	$0.57^{+0.16+0.03}_{-0.15-0.02} \pm 0.00$	
q_{45}^2	$q_4^2 \cup q_5^2$	...	...	...	$0.19^{+0.18}_{-0.17} \pm 0.01$
$m_{X_s,1}$	$0.4 < m_{X_s} < 0.6$	$0.69^{+0.18+0.04}_{-0.17-0.03} \pm 0.00$ (1.00)	$0.74^{+0.25+0.04}_{-0.23-0.04} \pm 0.00$ (1.00)	$0.71^{+0.15+0.03}_{-0.14-0.03} \pm 0.00$	
$m_{X_s,2}$	$0.6 < m_{X_s} < 1.0$	$1.20^{+0.34+0.10}_{-0.33-0.07} \pm 0.00$ (1.00)	$0.76^{+0.44+0.08}_{-0.40-0.07} \pm 0.00$ (1.00)	$1.02^{+0.27+0.06}_{-0.25-0.05} \pm 0.00$	
$m_{X_s,3}$	$1.0 < m_{X_s} < 1.4$	$1.60^{+0.72+0.27}_{-0.69-0.19} \pm 0.05$ (1.18)	$0.65^{+1.16+0.27}_{-1.08-0.25} \pm 0.02$ (1.18)	$1.32^{+0.61+0.19}_{-0.58-0.15} \pm 0.05$	
$m_{X_s,4}$	$1.4 < m_{X_s} < 1.8$	$1.88^{+0.76+0.71}_{-0.73-0.47} \pm 0.12$ (1.91)	$0.19^{+1.35+0.70}_{-1.25-0.50} \pm 0.10$ (1.91)	$1.36^{+0.67+0.50}_{-0.63-0.34} \pm 0.12$	
Total	$0.1 < q^2$	$7.69^{+0.82+0.50}_{-0.77-0.33} \pm 0.50$	$4.41^{+1.31+0.57}_{-1.17-0.42} \pm 0.27$	$6.73^{+0.70+0.34}_{-0.64-0.25} \pm 0.50$	$0.04 \pm 0.11 \pm 0.01$