Recent BaBar results on CP violation in B-meson decays

Marcin Chrząszcz[1]
on behalf of the BaBar collaboration

[1] University of Zurich

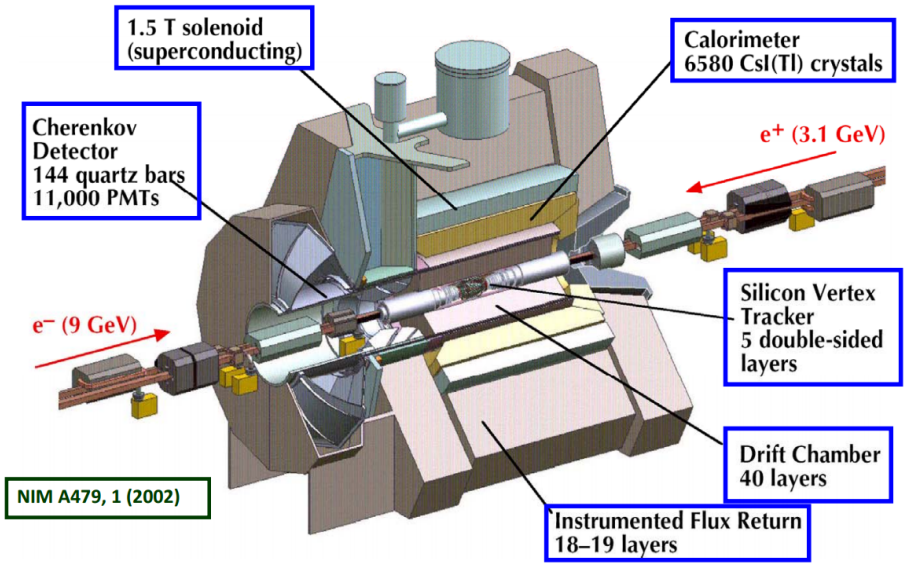
Deep-Inelastic Scattering 2015

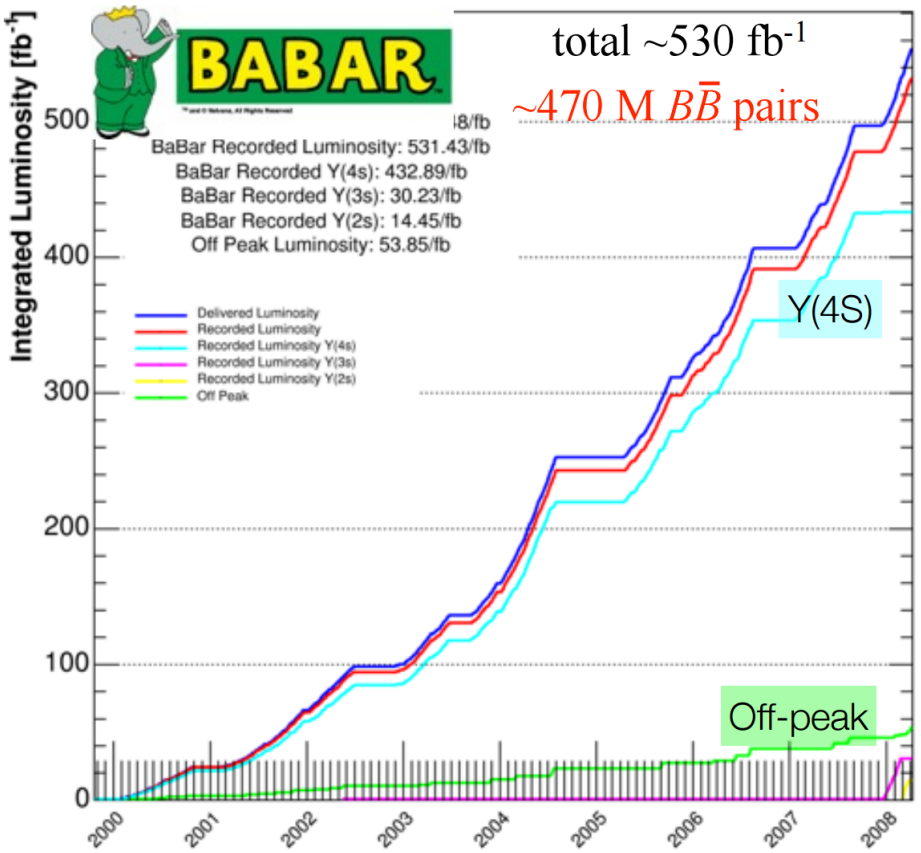
University of Zurich[UZH]

April 20, 2015

BaBar Detector

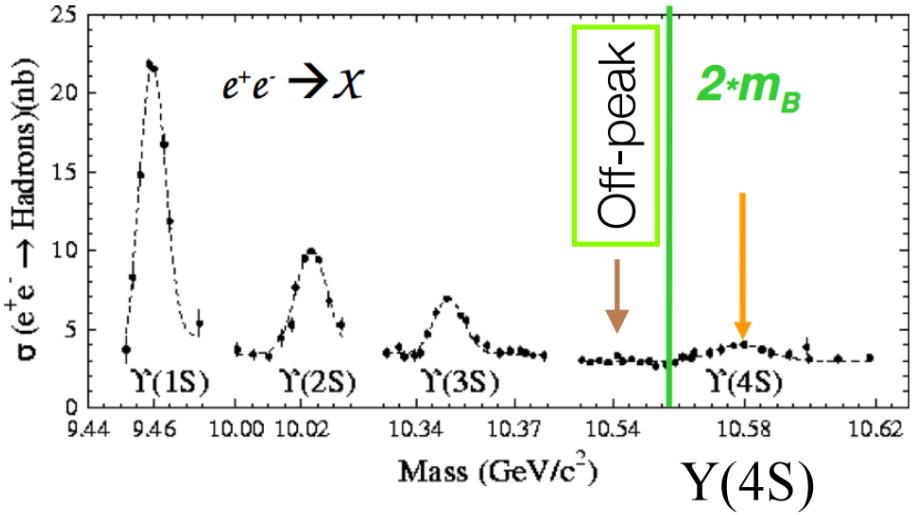
- PEP-II, an asymmetric $e^- e^+$ collider.
- Operating mostly at $\Upsilon(4S)$ threshold.



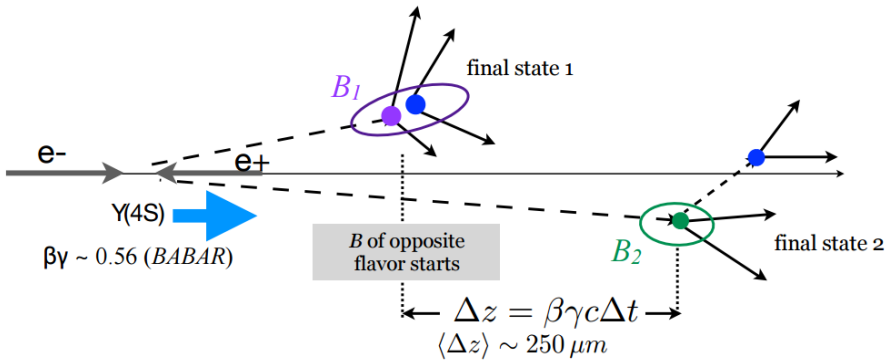


University of Zurich[UZH]

B factories



- B mesons produced in a clean environment.
- Just above the $m(\mathrm{BB})$ threshold.



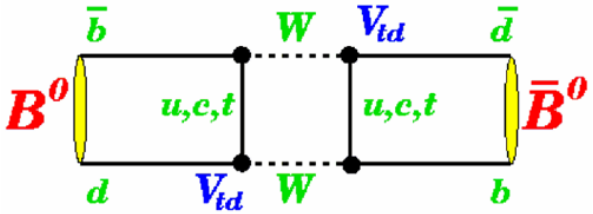
University of Zurich[UZH]

$B^0\overline{B}^0$ mixing

- Neutral mesons couple to their anti particles via weak interactions.

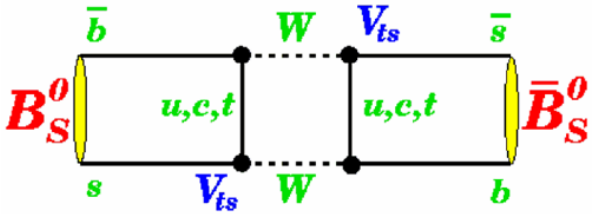
- $B^0 \Leftrightarrow \overline{B}^0$, $B_s^0 \Leftrightarrow \overline{B}_s^0$, $K \Leftrightarrow \overline{K}^0$.
- We can writhe the weak eigenstates as:

$$|B_{L/H}\rangle = \frac{1}{\sqrt{p^2+q^2}}(p\,|B^0\rangle \pm q\,|\overline{B}^0\rangle)$$



- Then the CP asymmetry can can be written as:

$$A_{CP} = \frac{\mathcal{P}(\overline{B}^0 \to B^0) - \mathcal{P}(B^0 \to \overline{B}^0)}{\mathcal{P}(\overline{B}^0 \to B^0) + \mathcal{P}(B^0 \to \overline{B}^0)} \approx 2(1 - |\frac{q}{p}|)$$

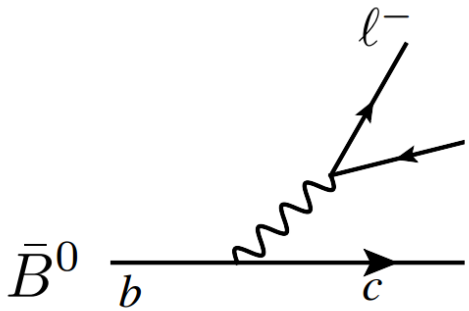


  - $\Upsilon(4S)$ has an anti-symmetric state:
    $\frac{1}{\sqrt{2}}(B^0(t_1)\overline{B}^0(t_2) - \overline{B}^0(t_1)B^0(t_2))$
  - One B is a specific flavour state tags the other one.

University of Zurich[UZH]

Inclusive dilepton measurement

- B mesons decay in $\sim 10\%$ semileptonicaly.
- Charge of lepton determines the B meson flavour.
- If one observes same sign leptons $\rightarrow$ mixing occurred:
  - $\ell^-\ell^+$: no mixing
  - $\ell^-\ell^-$: $B^0 \rightarrow \overline{B}^0$.
  - $\ell^+\ell^+$: $\overline{B}^0 \rightarrow B^0$.



- Writing down the mixing provabilities (time integrated):

$$\mathcal{P}^{\pm\pm} \propto (1 \pm A_{CP})\chi_d$$

$$\mathcal{P}^{\pm\mp} \propto (1 - \chi_d)$$

University of Zurich[UZH]

Detector effects

- Detector is not a perfect device $\rightarrow$ Introduced charge asymmetries a_{ℓ_j} for each ℓ_j.
- $\Upsilon(4S)$ also goes to B^+B^-. Contribution: $r_B = N_{B^+B^-}/N_{B^0\overline{B}0}$.
- Time integrated probability gets modified:

$$\mathcal{P}^{\pm\pm} \propto (1 \pm a_{\ell_1} \pm a_{\ell_2} \pm A_{CP})\chi_d$$
$$\mathcal{P}^{\pm\mp} \propto (1 - \chi_d + r_B)(1 \pm a_{\ell_1} \mp a_{\ell_2})$$

- Summing over all events in $\ell_1\ell_2 \in \{ee, e\mu, \mu e, \mu\mu\}$ categories:

$$N^{\pm\pm}_{\ell_1\ell_2} = 1/2 N^0_{\ell_1\ell_2}(1 \pm a_{\ell_1} \pm a_{\ell_2} \pm A_{CP})\chi_d^{\ell_1\ell_2}$$
$$N^{\pm\mp}_{\ell_1\ell_2} = 1/2 N^0_{\ell_1\ell_2}(1 - \chi_d^{\ell_1\ell_2} + r_B)(1 \pm a_{\ell_1} \mp a_{\ell_2})$$

- We got 16 observables, and 13 unknowns. a_{ℓ_j} highly correlated.
- Adding events containing only single electron for a_e constrain.
- 17 observables as input to χ^2 fit, extracting: A_{CP}, 4 signal yields 4 efficiency asymmetries, 4 mixing probabilities.

University of Zurich[UZH]

Systematics

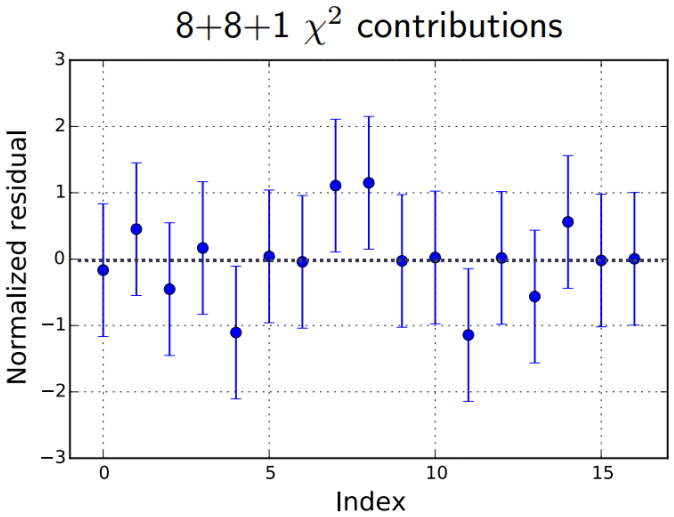
Source	(10^{-3})
Generic MC bias correction	1.04
MC branching fractions	0.43
Fake lepton corrections in dilepton	0.77
Fake e correction in single electron	0.65
Neutral/charged B difference	0.74
Direct-/cascade e asymmetry difference	0.44
Direct-/cascade μ asymmetry difference	0.34
Background-to-signal ratios	0.68
Random forest cut efficiency	0.08
Total	1.90

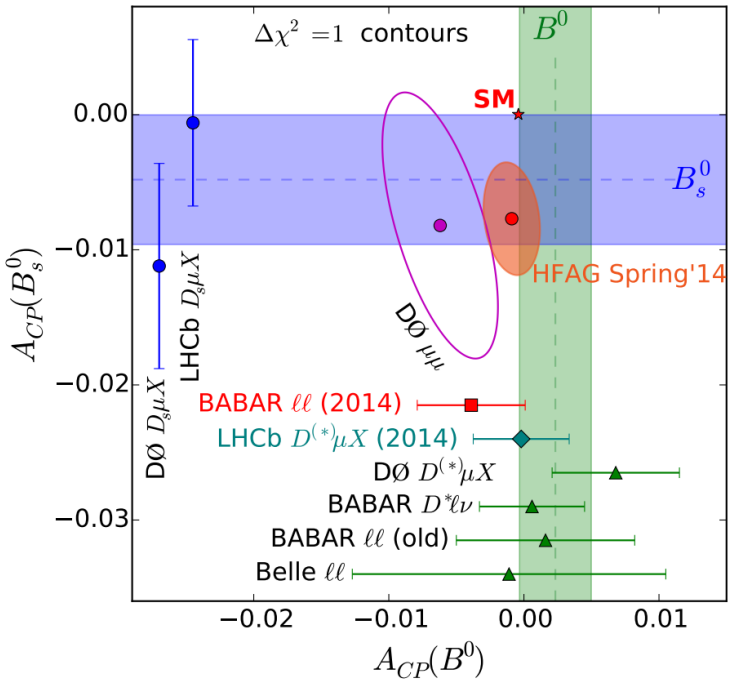
- Dominant systematic from bias in MC.
- Secondly the MC/data corrections to PID.
- Difference in charge asymmetry between B^0 and average of B^0 and $B^{\pm}$.

University of Zurich[UZH]

Fit results

$A_{CP} = (-3.9 \pm 3.5) \times 10^{-3}$		BABAR PRL 114, 081801 (2015)	
N^0_{ee}	$N^0_{e\mu}$	$N^0_{\mu e}$	$N^0_{\mu\mu}$
430875 ± 515	365343 ± 429	458200 ± 480	268077 ± 381
χ_d^{ee}	$\chi_d^{e\mu}$	$\chi_d^{\mu e}$	$\chi_d^{\mu\mu}$
0.2248 ± 0.0006	0.1769 ± 0.0006	0.1754 ± 0.0005	0.2032 ± 0.0007
a^{e1}	a^{e2}	$a^{\mu 1}$	$a^{\mu 2}$
0.0034 ± 0.0006	0.0030 ± 0.006	-0.0056 ± 0.0011	-0.0065 ± 0.0011





- Result $A_{CP} = (-3.9 \pm 3.5 \pm 1.9) \times 10^{-3}$ in agreement with SM.

Flavour-changing neutral current

- CKM structure in SM allows only the charged interactions to change flavour.
- One can escape the CKM structure and produce b $\longrightarrow$ s and b $\longrightarrow$ d only at loop level.
  - This kind of processes are suppressed by the GIM in SM $\longrightarrow$ Rare decays.
- LHCb already sees a 3.7 σ deviation in the angular observables in $B^0 \longrightarrow K^* \mu^- \mu^+$. See my talk from yesterday: LINK.
- Here we present CP observables in $b \longrightarrow s\gamma$ and $b \longrightarrow s\ell\ell$ decays.

University of Zurich[UZH]

Flavour-changing neutral current

- CKM structure in SM allows only the charged interactions to change flavour.
- One can escape the CKM structure and produce b $\longrightarrow$ s and b $\longrightarrow$ d only at loop level.
  - This kind of processes are suppressed by the GIM in SM $\longrightarrow$ Rare decays.
- LHCb already sees a 3.7 σ deviation in the angular observables in $B^0 \longrightarrow K^* \mu^- \mu^+$. See my talk LINK.
- Here we present CP observables in $b \longrightarrow s\gamma$ and $b \longrightarrow s\ell\ell$ decays.

University of Zurich[UZH]

CP asymmetries in $B \to X_s\gamma$

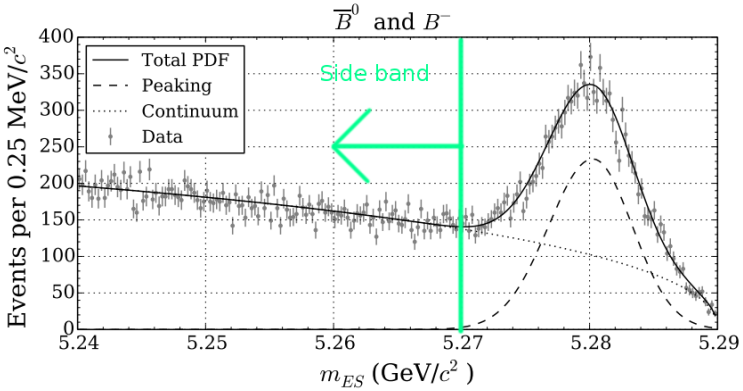
- Fully inclusive approach impossible.
- Instead use semi-inclusive (sum of exclusive modes).
- 16 modes used (marked with $*$)
- Additional requirements:

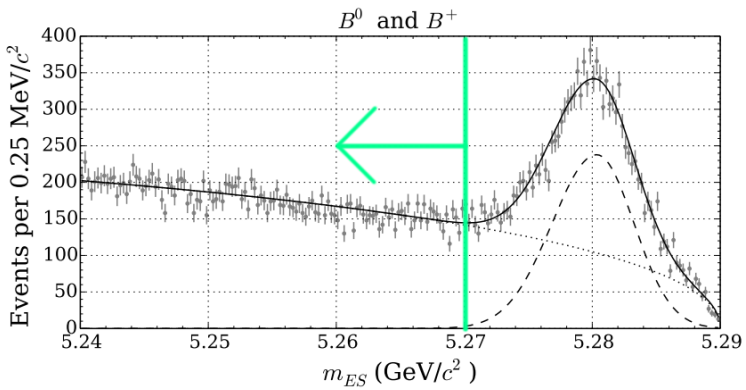
- PRD 90, 092001 (2014)
- Requirements:
  - $m(X_s) \in (0.6, 2.0)$ GeV
    - Indirect cut on $E_\gamma > 2.3$ GeV
  - $|\Delta E| < 0.15$ GeV
  - MVA based approach to get ride of $q\bar{q}$ background.

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

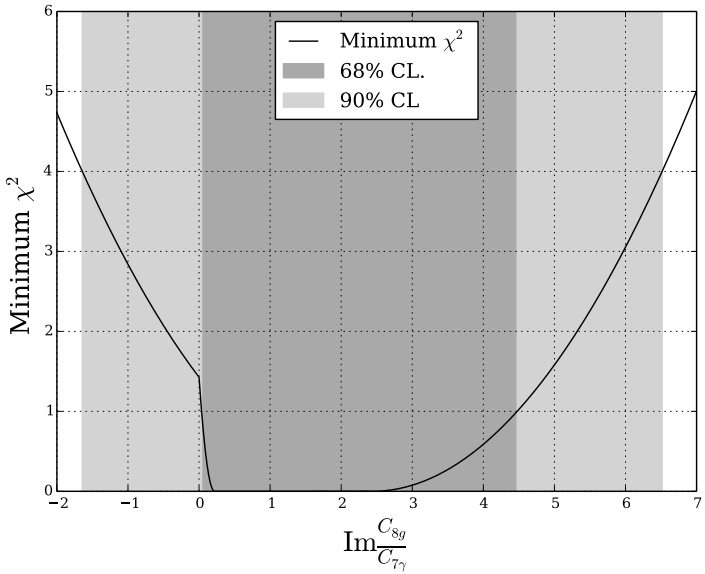
Asymmetry extraction

- Asymmetry for fitted yields needs to be corrected as in previous analysis detector asymmetries.
- Asymmetry extracted from side-bands.
  - (-1.4 ± 0.7) %.





- Results:
  - $A_{CP}(\mathrm{B}^+ \to X_s^+\gamma) = (4.23 \pm 2.93 \pm 0.95)\%$
  - $A_{CP}(\mathrm{B}^0 \to X_s^0\gamma) = (-0.74 \pm 2.57 \pm 1.10)\%$
  - Average:
  - $A_{CP} = (1.7 \pm 1.9 \pm 1.0)$ %
  - SM: $A_{CP} \sim 0 \leftrightarrow Im(C_8) \sim 0$



CP asymmetries in $B \to X_s \ell\ell$

- Very important channel for NP searches.
- Significant deviation found by LHCb.
- CP observables are very clean predictions in SM and almost QCD free.
- Similar "semi-include" modes:

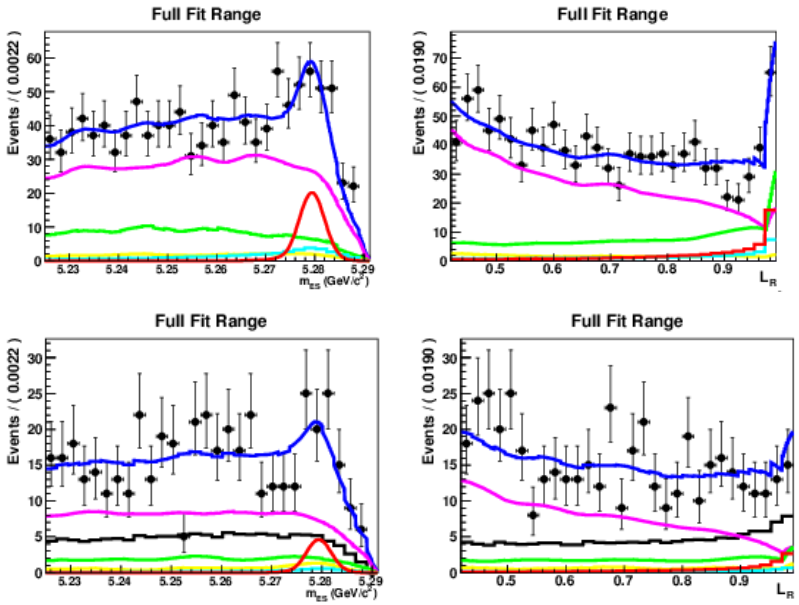
$$X_s = \{K^+,\ K^+\pi^0,\ K^+\pi^-,\ K^+\pi^-\pi^0,$$
$$K^+\pi^-\pi^+,\ K_s,\ K_s\pi^+,\ K_s\pi^+\pi^0,\ K_s\pi^+\pi^-\}$$

- Look for two leptons flavours: $\ell\ell = \{ee, \mu\mu\}$
- Additional requirements:
  - Require: $m(X_s) < 1.8$ GeV
  - $\Delta E \in [-0.1(-0.05), 0.05]$ for $\ell\ell = ee$ $(\mu\mu)$

Differential branching fraction

- PRL 112 (2014) 211802
- J/ψ, ($\psi(2S)$) veto:
  $6.8 - 10.1$ ($12.9 - 14.2$) GeV
- Suppress $q\bar{q}$ background with a BDT.
- Perform a simultaneous fit to m_{ES} and

$$L_R = \frac{\mathcal{P}_S}{\mathcal{P}_S + \mathcal{P}_B}$$



CP & BR asymmetries results

q^2 [GeV^2]	A_{CP}
$1.0 < q^2 < 6.0$	$-0.06 \pm 0.22 \pm 0.01$
$0.1 < q^2 < 2.0$	$-0.13 \pm 0.18 \pm 0.01$
$2.0 < q^2 < 4.3$	$0.42\ ^{+0.50}_{-0.42} \pm 0.01$
$4.3 < q^2 < 6.8$	$-0.45^{+0.44}_{-0.57} \pm 0.01$
$10.1 < q^2 < 14.2$	$0.19\ ^{+0.18}_{-0.17} \pm 0.01$

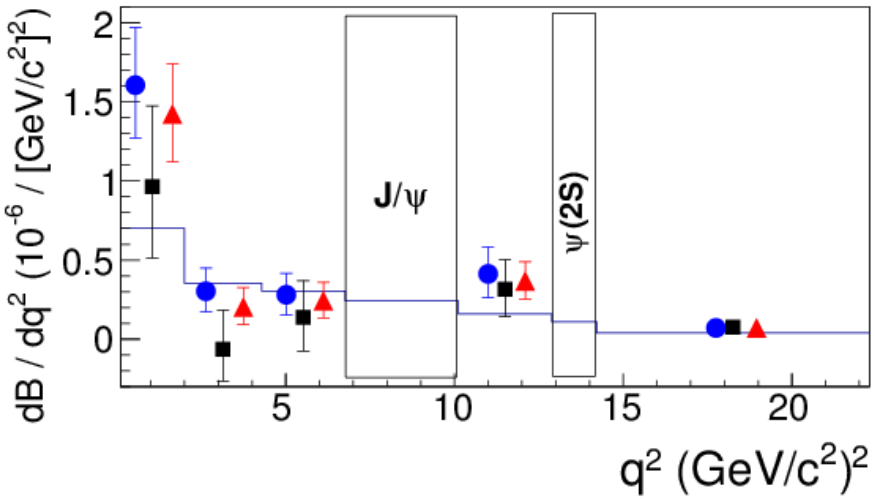
- Measured branching fractions($\times 10^{-6}$) :

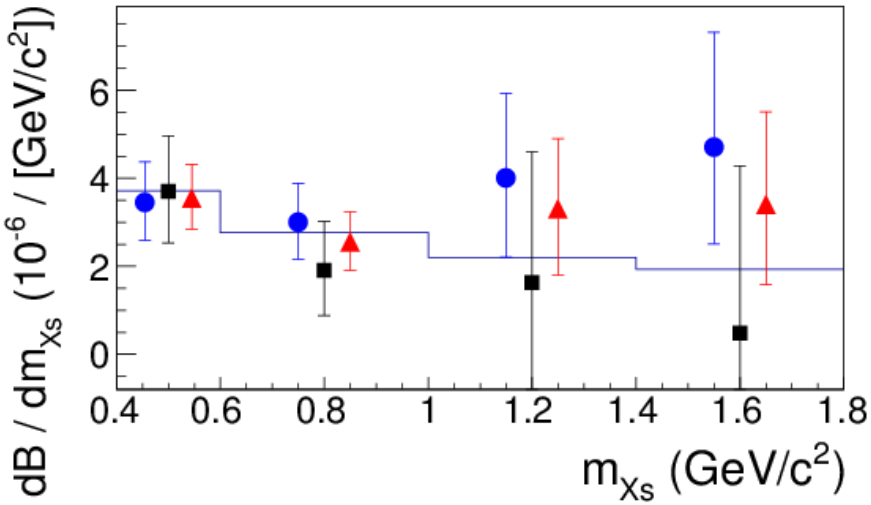
$$\mathcal{B}(\mathrm{B} \to X_s \mathrm{e}^- \mathrm{e}^+) = 7.69^{+0.82\,+0.50}_{-0.77\,-0.33} \pm 0.50$$

$$\mathcal{B}(\mathrm{B} \to X_s \mathrm{e}^- \mathrm{e}^+) = 4.41^{+1.31\,+0.57}_{-1.17\,-0.42} \pm 0.27$$

- Combined:

$$\mathcal{B}(\mathrm{B} \to X_s \ell^- \ell^+) = 6.73^{+0.70\,+0.34}_{-0.64\,-0.25} \pm 0.50$$





- In agreement with SM.

University of Zurich[UZH]

Conclusions

1. B-factories still producing new results.
2. Presented new measurements of CP violation in neutral B meson system using inclusive dileptons events.
3. BaBar continues to chase FCNC with measurement of CP asymmetries in: $b \to s\gamma$ and $b \to \ell\ell$
4. FCNC statistically limited: need future experiments.
5. All measurements consistent (for now?) with SM.

University of Zurich[UZH]