BaBar Results on

$B \to X_s \gamma$

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Outline

I. $b \to s\gamma$ motivation

II. Inclusive $B \to X_s\gamma$ (with lepton tag)

   i. Branching fraction
   ii. Spectrum and moments
   iii. A_{CP}

Publication imminent

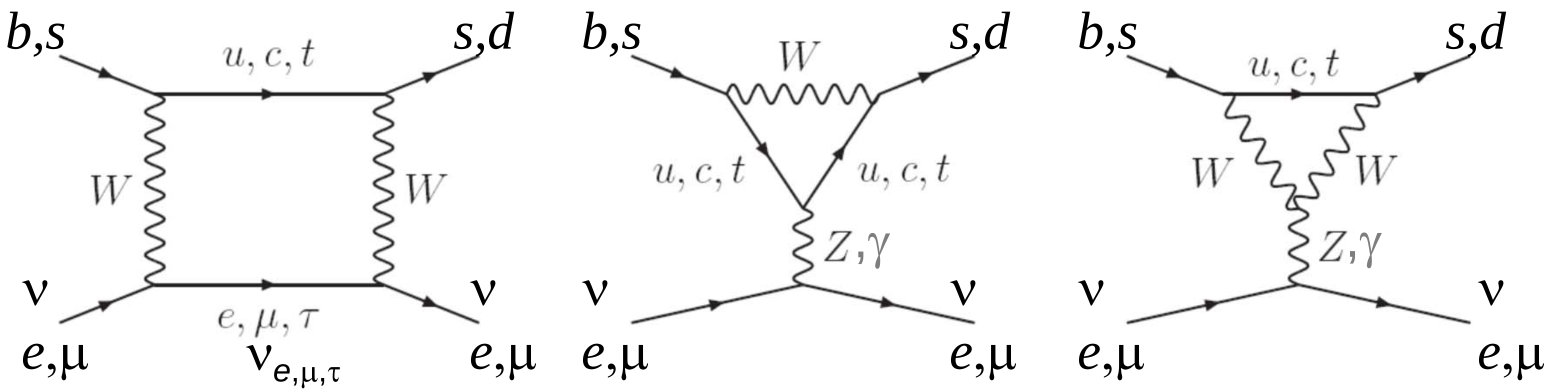
III. Semi-inclusive $B \to X_s\gamma$

   i. Branching fraction
   ii. Spectrum

Published this month

IV. Summary/Conclusions

Flavor Changing Neutral Currents



Responsible for rare decays in Standard Model

e.g.,

$B \to X_s \gamma$

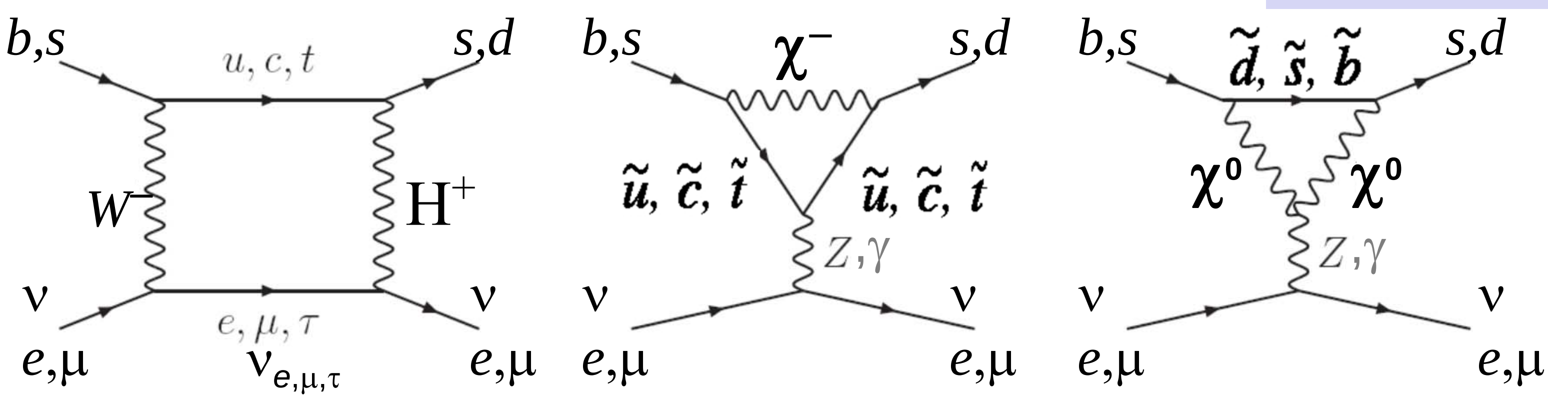
$B \to X_s \ell^+ \ell^- \ (\ell = e \text{ or } \mu)$

$B_s \to \mu^+ \mu^-$

$K_L^0 \to \mu^+ \mu^-$

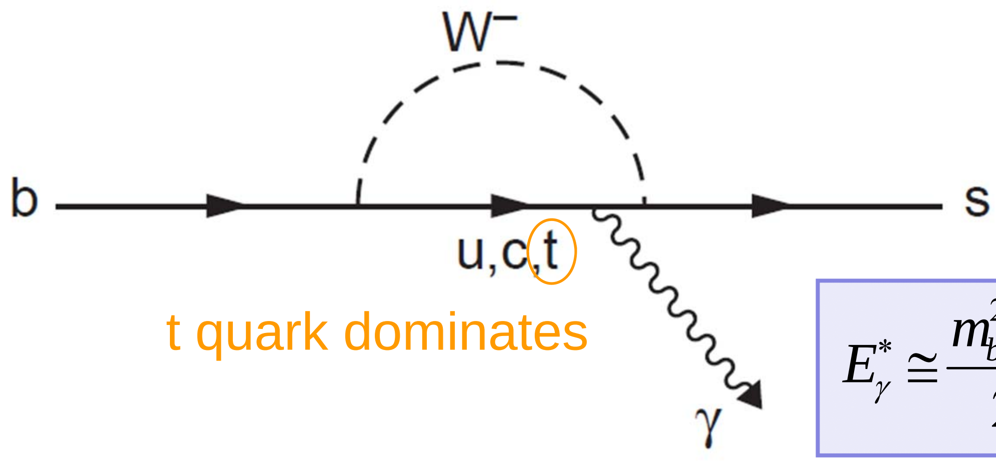
$K^+ \to \pi^+ \nu \bar{\nu}$

$K_L^0 \to \pi^0 \nu \bar{\nu}$



Sensitive to new (high-mass) particles in loops.

$b \to s\gamma$ in the Standard Model



The first penguin – 1993 CLEO observation of $B \to K^{*}\gamma$

$$E_\gamma^* \cong \frac{m_b^2 - m_s^2}{2m_b} \approx \frac{m_b}{2}$$

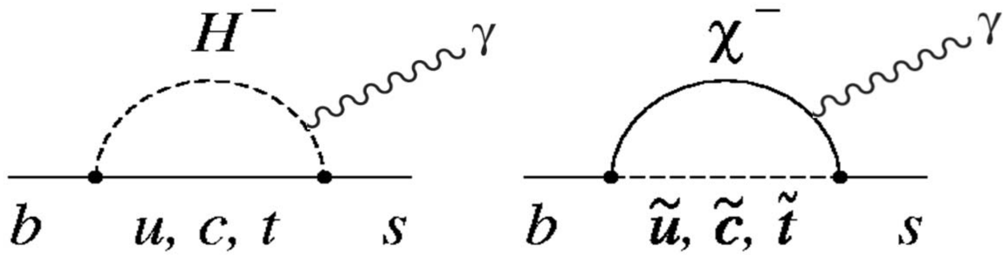
- Heavy-quark hadron duality $\Rightarrow$ $B(B \to X_s\gamma) \cong B(b \to s\gamma)$
- Theoretically clean prediction in the Standard Model
  - Next-to-next-leading order (NNLO) calculation (E_γ > 1.6 GeV)

$$B(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

Misiak et al., PRL 98, 022002(2007)

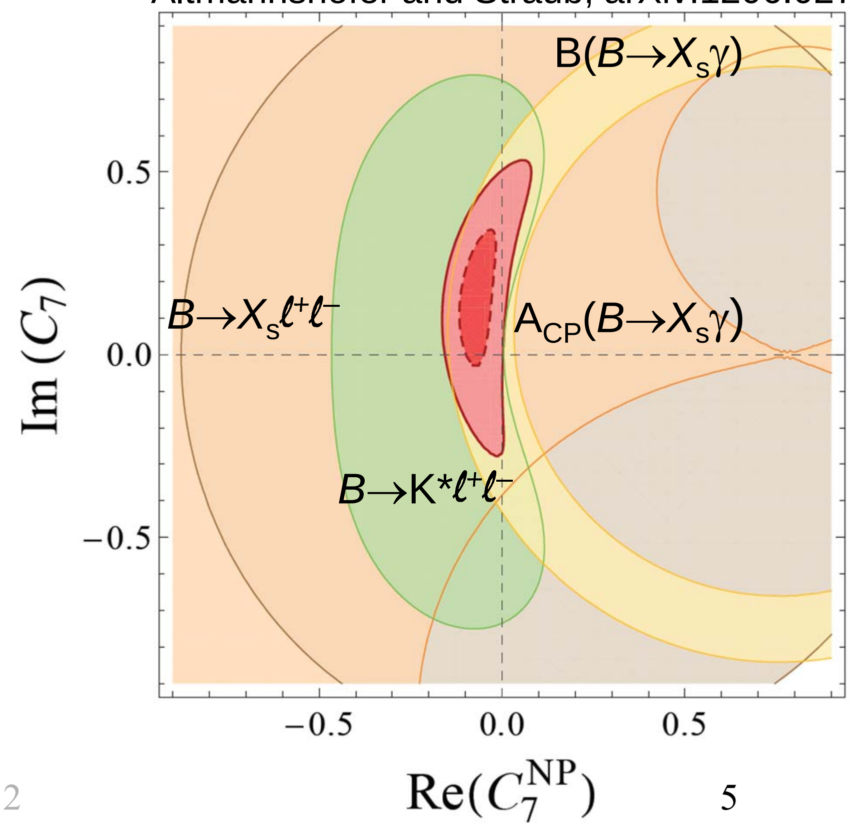
  - Small (7%) SM theory uncertainty $\Rightarrow$ constraint on New Physics
- E_γ spectrum reflects b quark's mass, Fermi motion and gluon brem
  - Input to shape function parameters for $|V_{ub}|$ from $b \to u l^- \nu$ endpoint and used in extraction of $|V_{cb}|$ from $b \to c l^- \nu$

New Physics in $b \to s\gamma$

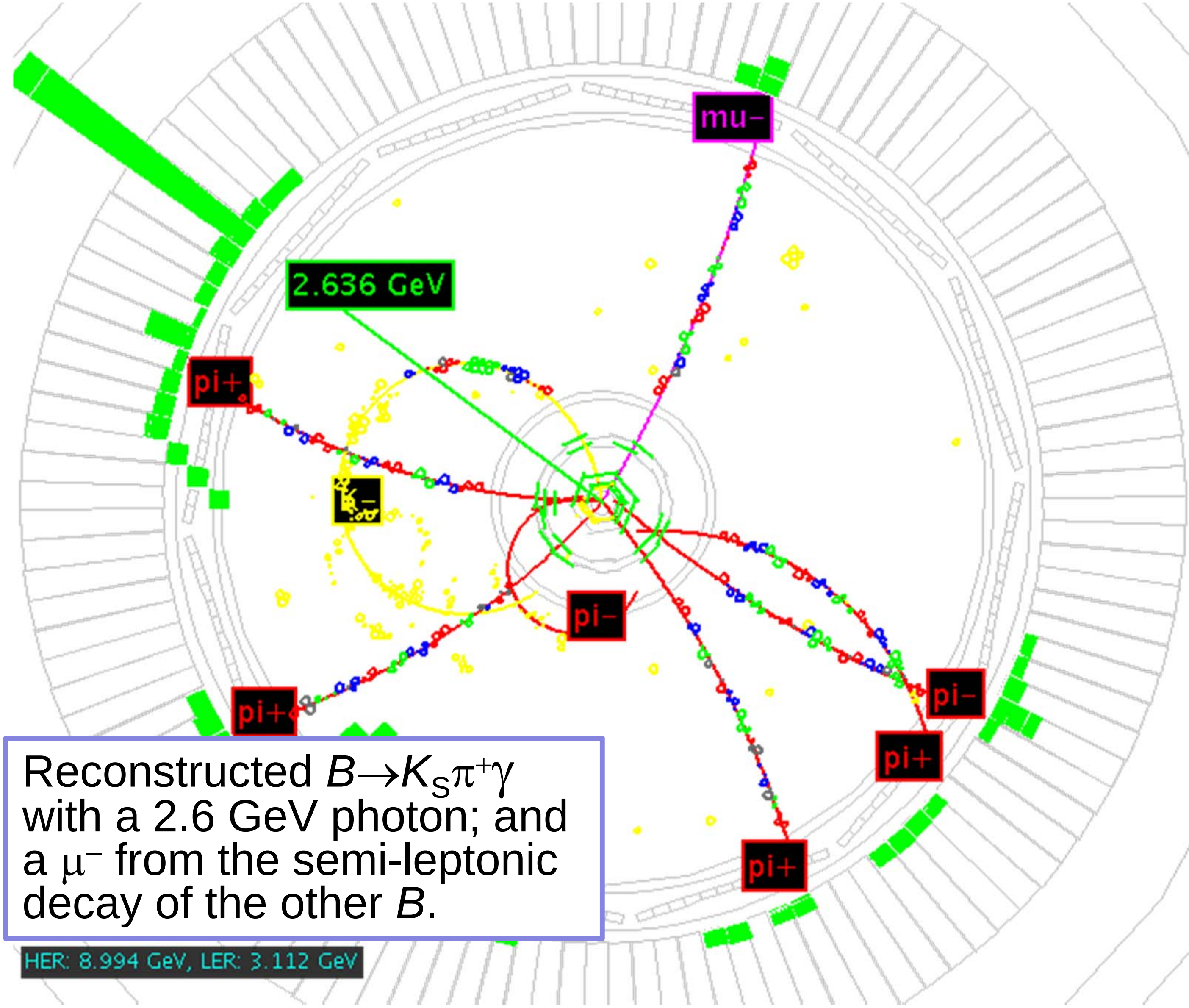


- Sensitive to new heavy particles in the loops
  - charged Higgs, superpartners, etc
- Leading-order and next-to-leading order calculations for many models
- Experiment vs theory BF ⇒ strong constraints on New Physics

Altmannshofer and Straub, arXiv:1206.0273



BaBar Event Display



Reconstructed $B \rightarrow K_S \pi^+ \gamma$ with a 2.6 GeV photon; and a μ^- from the semi-leptonic decay of the other *B*.

Experimental Issues for $B \to X_s\gamma$

- Two experimental techniques
  - Not statistics limited for branching fraction measurement

- Fully Inclusive
  - Only look at the γ from the signal B decay
    - ➢ Photon energy is smeared by the calorimeter resolution ($\sigma/E \sim 2.6\%$)
    - ➢ $B \to X_d\gamma$ is not distinguishable (i.e., it's included); $|V_{td}/V_{ts}|^2 \cong 0.04$
  - Suppress B decay background with E_γ min cut (a compromise between experimental versus theoretical uncertainties); $E_\gamma > 1.8$ GeV
  - Continuum rejection via event shape **and** either lepton tag or reconstructing the other B

- "Semi-inclusive" (sum of exclusive modes)
  - Reconstruct many final states (38 in *BABAR*)
  - Dominant systematic from the missing fraction ($\approx$45%)

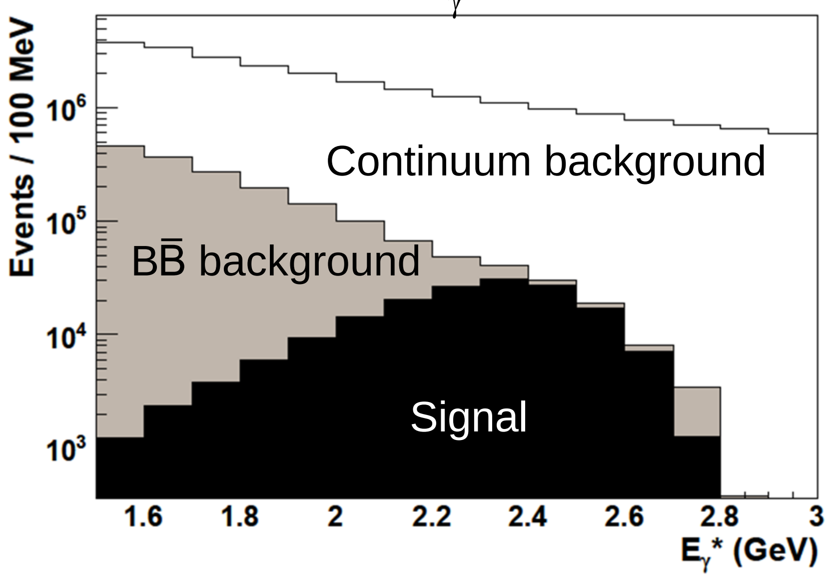
Fully Inclusive $B \to X_s \gamma$ with lepton tag

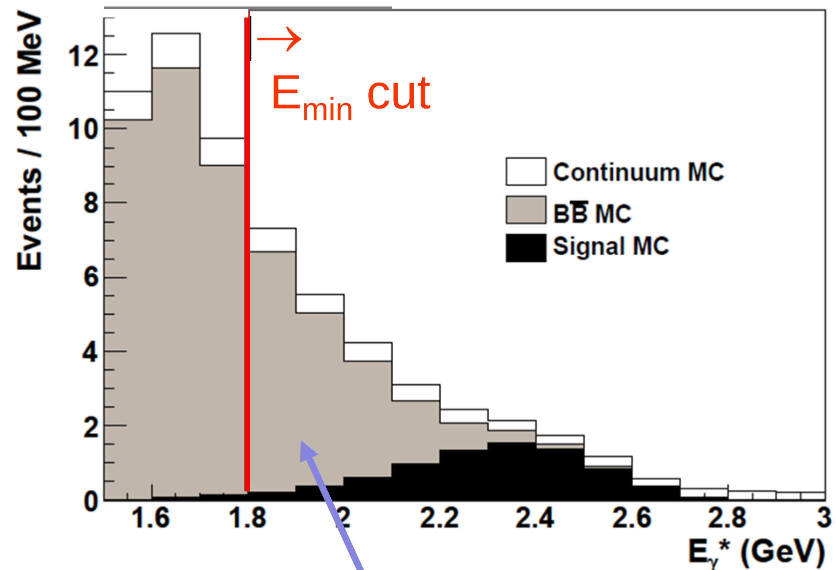
347 fb^{-1}

Lepton tag ($p_{e,\mu}$>1.05 GeV/c) and event shape NN's

(background rejection ~10^{-5}
for 2.6% signal efficiency)

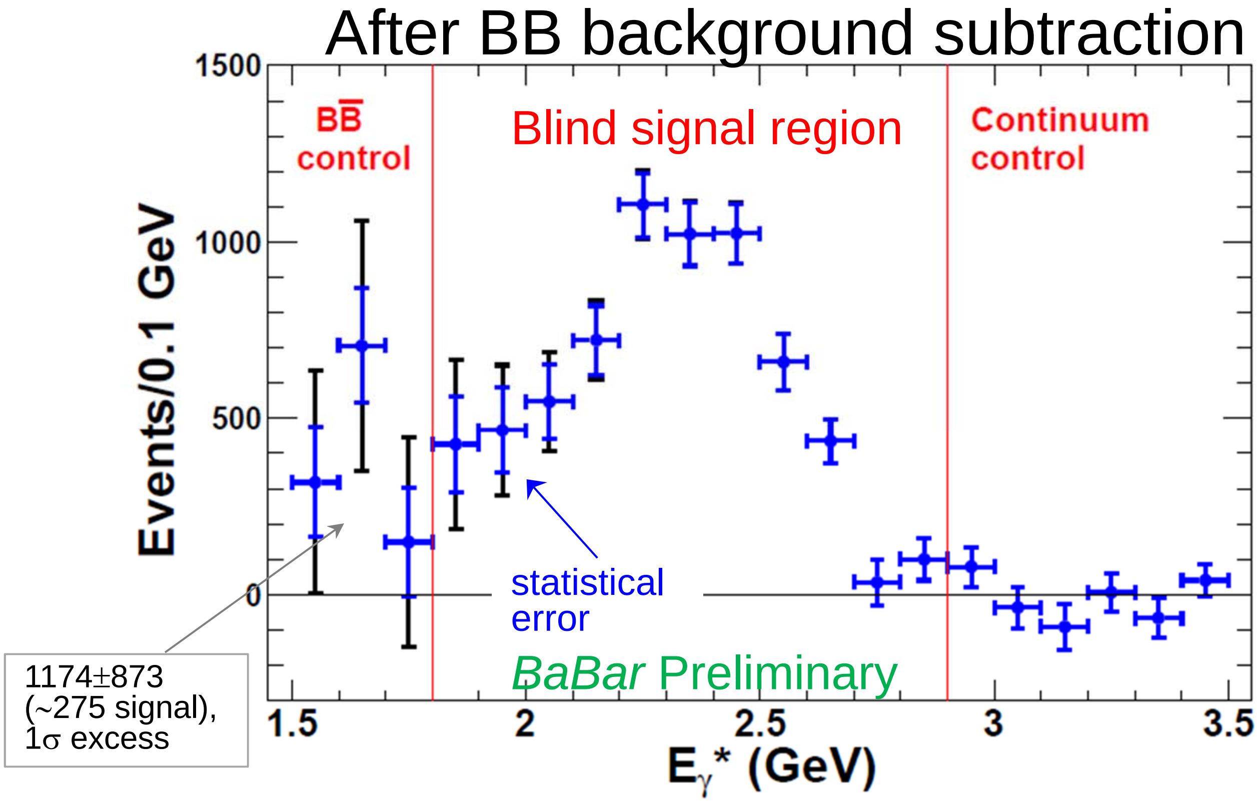
1.53 GeV < E_γ^*< 3.5 GeV





Remaining $B\bar{B}$ background is subtracted using MC corrected with data control samples. Details in arXiv:1207.5772. Publication imminent (PR D).

Inclusive $B \to X_s\gamma$ Branching Fraction



- Blind analysis
- Signal efficiency based on HFAG parameters for spectrum
- Corrected for EMC and Doppler smearing of photon energy.
- Correct for $b \to d\gamma$ using $1/(1+|V_{td}/V_{ts}|^2)=0.958\pm0.003$
- Evaluate statistical, systematic (mostly $B\bar{B}$ subtraction), and model (spectrum) errors

BaBar Preliminary

Energy Range	$\mathcal{B}(B \to X_{s+d}\gamma)$ (10^{-4})	$\mathcal{B}(B \to X_s\gamma)$ (10^{-4})
1.8 to 2.8 GeV	$3.347 \pm 0.158 \pm 0.301 \pm 0.080$	$3.207 \pm 0.151 \pm 0.288 \pm 0.077$
1.9 to 2.8 GeV	$3.126 \pm 0.141 \pm 0.203 \pm 0.059$	$2.995 \pm 0.135 \pm 0.194 \pm 0.057$
2.0 to 2.8 GeV	$2.925 \pm 0.128 \pm 0.146 \pm 0.045$	$2.802 \pm 0.122 \pm 0.140 \pm 0.043$

arXiv:1207.5772
Publication imminent (PR D)

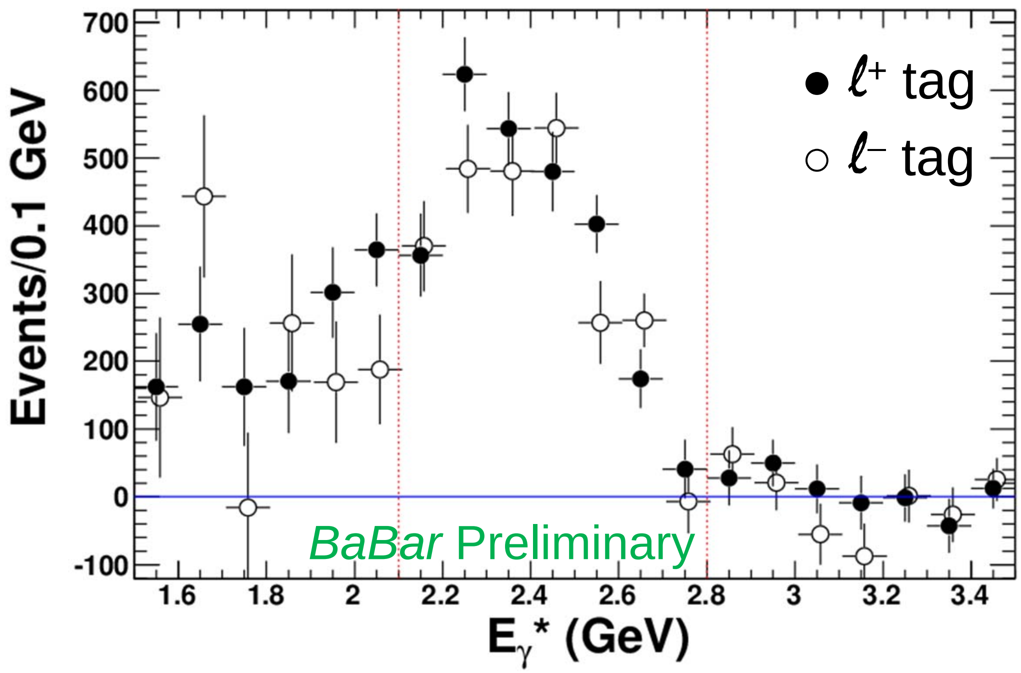
Direct CP Violation (A_{CP}) in $B \to X_{s+d}\gamma$

$$A_{CP} = \frac{\Gamma(B \to X_{s+d}\gamma) - \Gamma(\bar{B} \to X_{\bar{s}+\bar{d}}\gamma)}{\Gamma(B \to X_{s+d}\gamma) + \Gamma(\bar{B} \to X_{\bar{s}+\bar{d}}\gamma)} \cong 0$$

A strong SM prediction, so a good NP test.

Remains valid despite long-distance dominance for X_s only;
Benzke, Lee, Neubert, Paz, PRL **106** 141801 (2011)

Events separated by charge of lepton



- Blind analysis
- Dilution correction accounts for B^0-$\bar{B}^0$ mixing (+mistags)
- Energy range chosen to minimize total (stat+syst) error.
- Optimized region $2.1 < E_\gamma^* < 2.8$ GeV

BaBar Preliminary

$A_{CP} = 0.057 \pm 0.060 \pm 0.018$

arXiv:1207.5772
Publication imminent (PR D)

Unfolded Spectrum and Moments

Unfolding procedure corrects for detector acceptance, selection efficiency, energy resolution,

and for CM motion of the *B.*

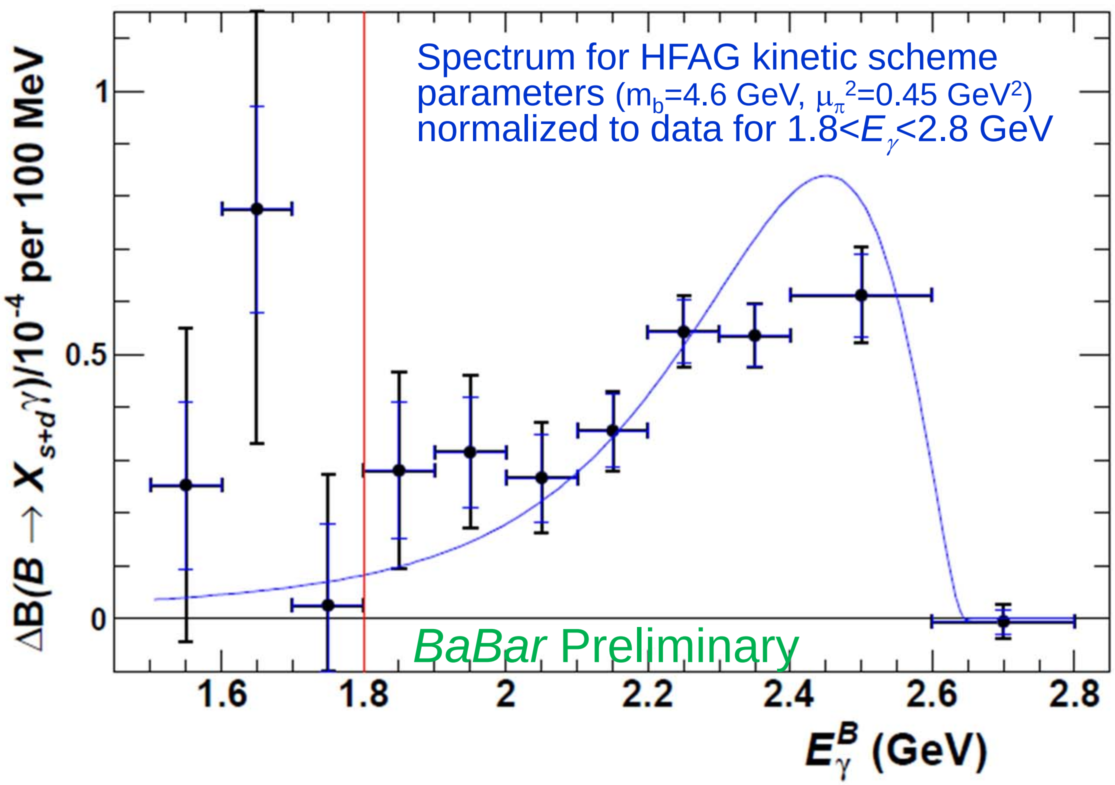
Moments measured

$$E_1 = \langle E_\gamma \rangle$$

$$E_2 = \langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle$$

$$E_3 = \langle (E_\gamma - \langle E_\gamma \rangle)^3 \rangle$$

Useful for determining heavy quark parameters.



E_γ^B Range (GeV)	E_1 (GeV)	E_2 (GeV^2)
1.8 to 2.8	$2.267 \pm 0.019 \pm 0.032 \pm 0.003$	$0.0484 \pm 0.0053 \pm 0.0077 \pm 0.0005$
1.9 to 2.8	$2.304 \pm 0.014 \pm 0.017 \pm 0.004$	$0.0362 \pm 0.0033 \pm 0.0033 \pm 0.0005$
2.0 to 2.8	$2.342 \pm 0.010 \pm 0.008 \pm 0.005$	$0.0251 \pm 0.0021 \pm 0.0013 \pm 0.0009$

arXiv:1207.5772
Publication imminent (PR D)

429 fb^{-1}

Semi-inclusive $B \to X_s\gamma$

- Reconstruct 38 modes
- Signal selection and π^0 rejection using random forest classifiers
- Fits to extract signal yields in 18 X_s-mass bins in range $0.6<m_{Xs}<2.8$ GeV
- Determine photon energy from

$$E_\gamma^B = \frac{m_B^2 - m_{X_s}^2}{2m_B}$$

- Estimate missing fraction from JETSET studies

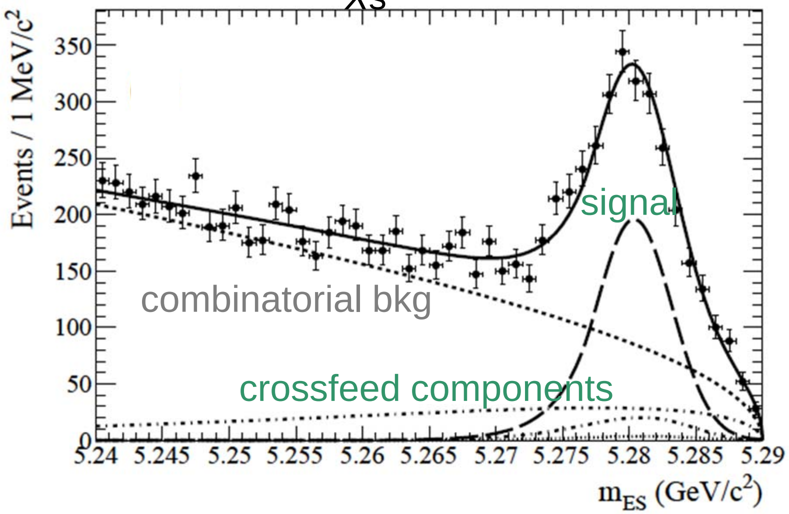
1	$K_S\pi^+$	20	$K_S\pi^+\pi^-\pi^+\pi^-$
2	$K^+\pi^0$	21	$K^+\pi^+\pi^-\pi^-\pi^0$
3	$K^+\pi^-$	22	$K_S\pi^+\pi^-\pi^0\pi^0$
4	$K_S\pi^0$	23	$K^+\eta$
5	$K^+\pi^+\pi^-$	24	$K_S\eta$
6	$K_S\pi^+\pi^0$	25	$K_S\eta\pi^+$
7	$K^+\pi^0\pi^0$	26	$K^+\eta\pi^0$
8	$K_S\pi^+\pi^-$	27	$K^+\eta\pi^-$
9	$K^+\pi^-\pi^0$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

For A_{CP} study, will measure

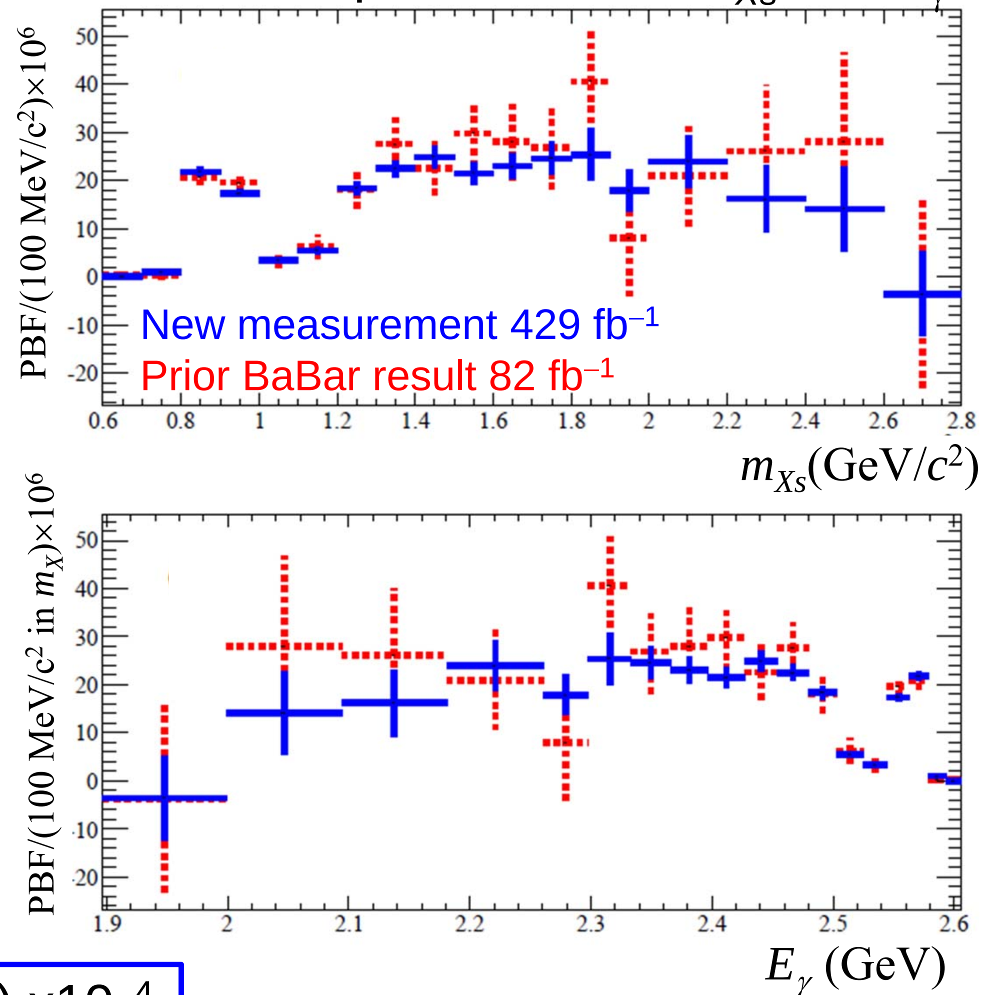
$$\Delta\mathcal{A}_{X_s\gamma} \equiv \mathcal{A}_{X_s^-\gamma} - \mathcal{A}_{X_s^0\gamma}$$

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

$1.4 < m_{Xs} < 1.5$ GeV



Measured partial BFs vs M_{Xs} and E_γ



- Fits in 18 X_s mass bins
- Crossfeed shape and fraction from MC
- Signal+crossfeed yield and combinatorial background shape from fits to data
- BF from spectrum (E_γ>1.9 GeV)

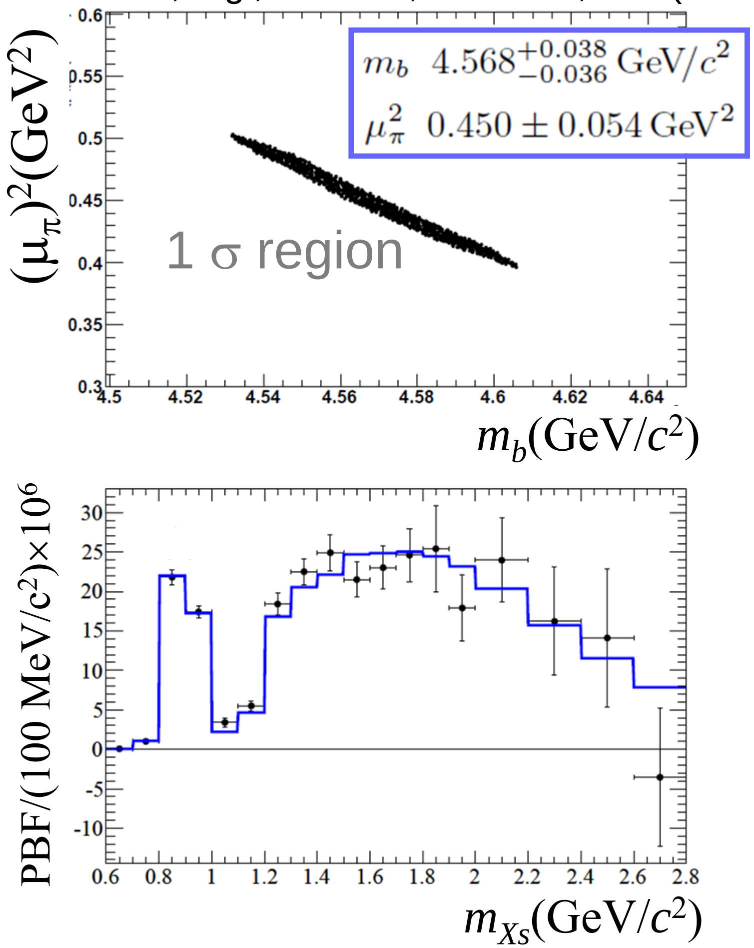
$$B(B\to X_s\gamma)=(3.29\pm0.19\pm0.48)\times10^{-4}$$

Phys. Rev. D **86**, 052012 (2012)
arXiv:1207.2520

Spectrum Fits and Moments

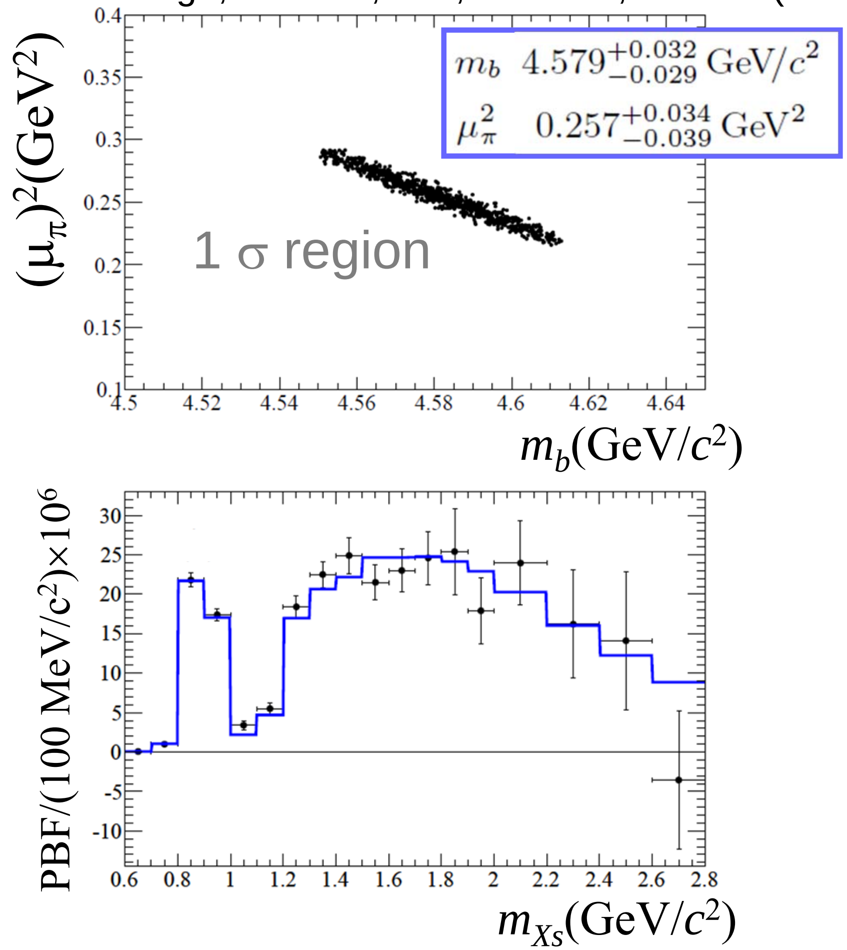
Kinetic model

Benson, Bigi, Uraltsev, NP B**710**, 271 (2005)



Shape function model

Lange, Neubert, Paz, PR D **72**, 073006 (2005)

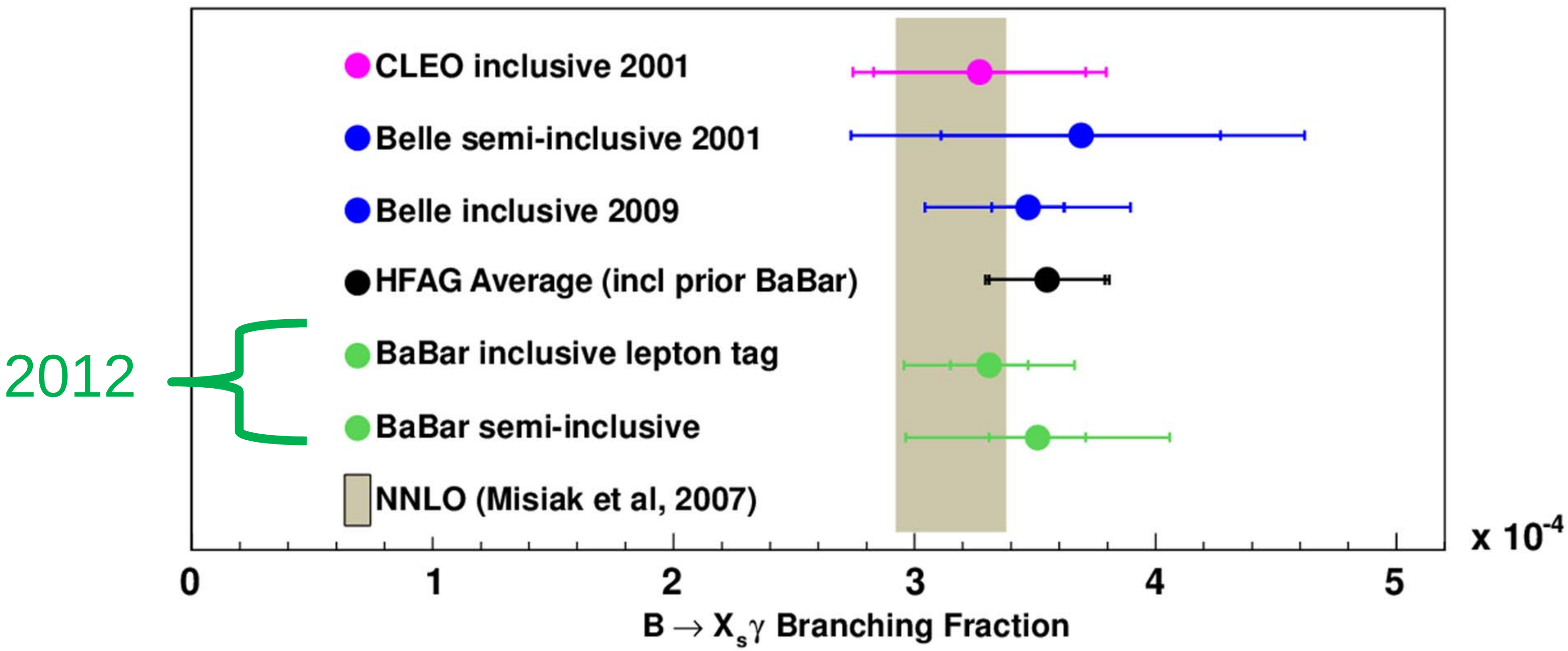


Moments of the spectrum are also measured for 1.9<E_γ<2.6 GeV and other low cutoff values of E_γ.

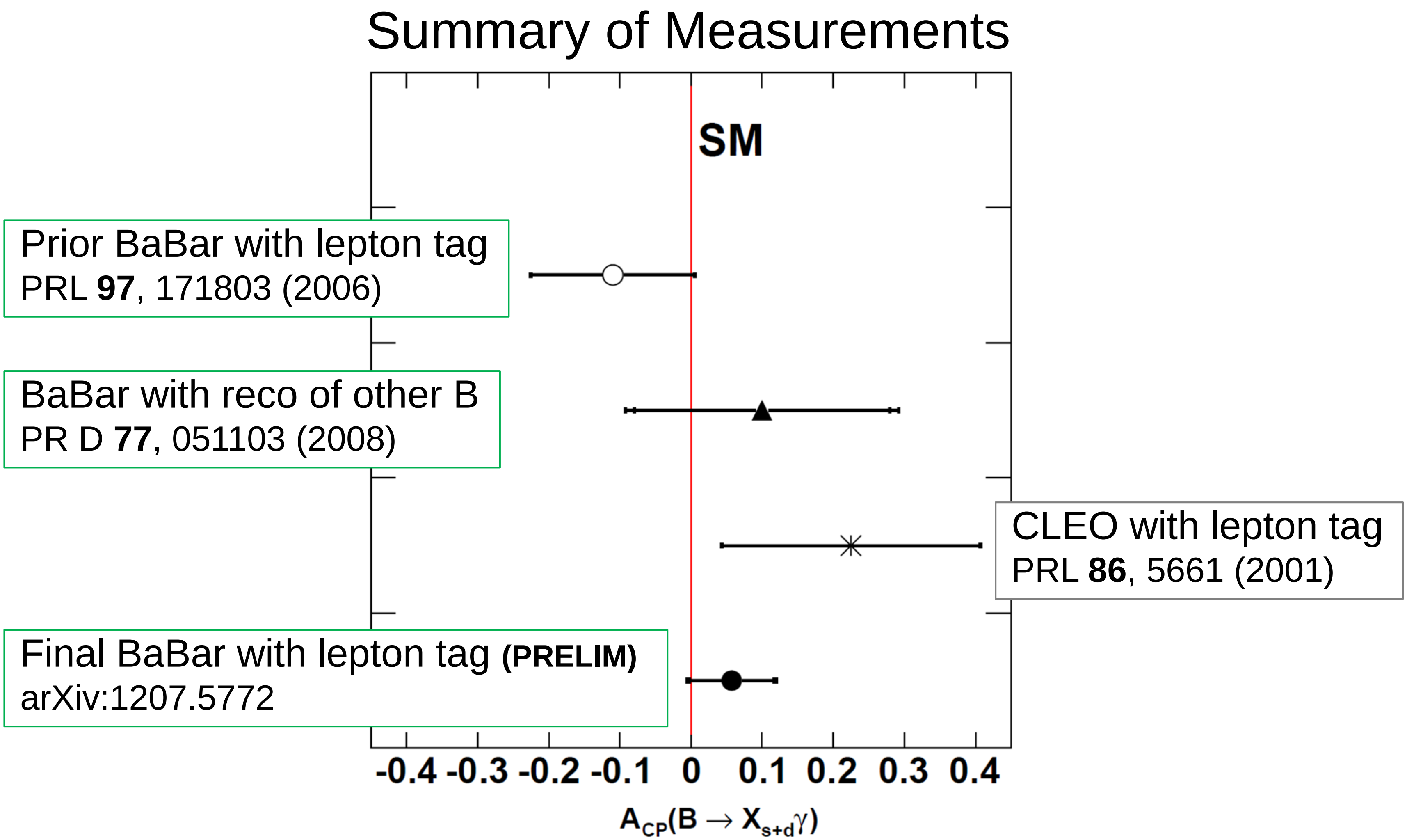
Phys. Rev. D **86**, 052012 (2012)
arXiv:1207.2520

$B \rightarrow X_s\gamma$ Branching Fraction Summary

Comparison of measurements extrapolated to E_γ>1.6 GeV by the Heavy Flavor Averaging Group.



Direct CP Violation in $B \to X_{s+d}\gamma$



Summary/Conclusions

- $B \to X_s\gamma$ is one of the theoretically cleanest FCNC modes.
  - Precision measurements provide important constraints on New Physics.
  - Spectrum provides heavy quark parameters
- *BABAR* results on $B \to X_s\gamma$
  - Inclusive (lepton tag) (preliminary until published)

    $\mathcal{B}(B\to X_s\gamma)=(3.21\pm0.15\pm0.29\pm0.08)\times10^{-4}$ ($E_\gamma > 1.8$ GeV)

    $A_{CP} = 0.057 \pm 0.060 \pm 0.018$
  - Semi-inclusive (38 modes)

    $\mathcal{B}(B\to X_s\gamma)=(3.29\pm0.19\pm0.48)\times10^{-4}$ ($E_\gamma > 1.9$ GeV)
- Results in good agreement with SM