Review of Radiative Penguin Measurements

Mikihiko Nakao (KEK, IPNS)
mikihiko.nakao@kek.jp

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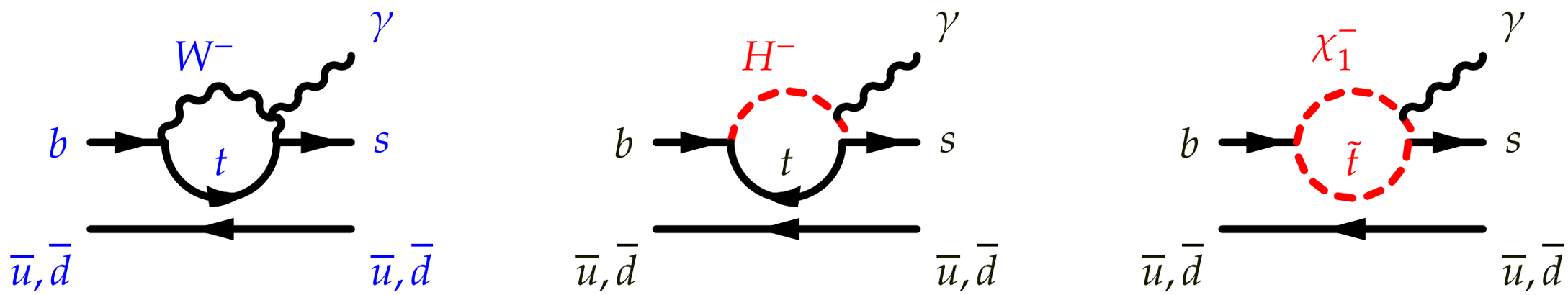
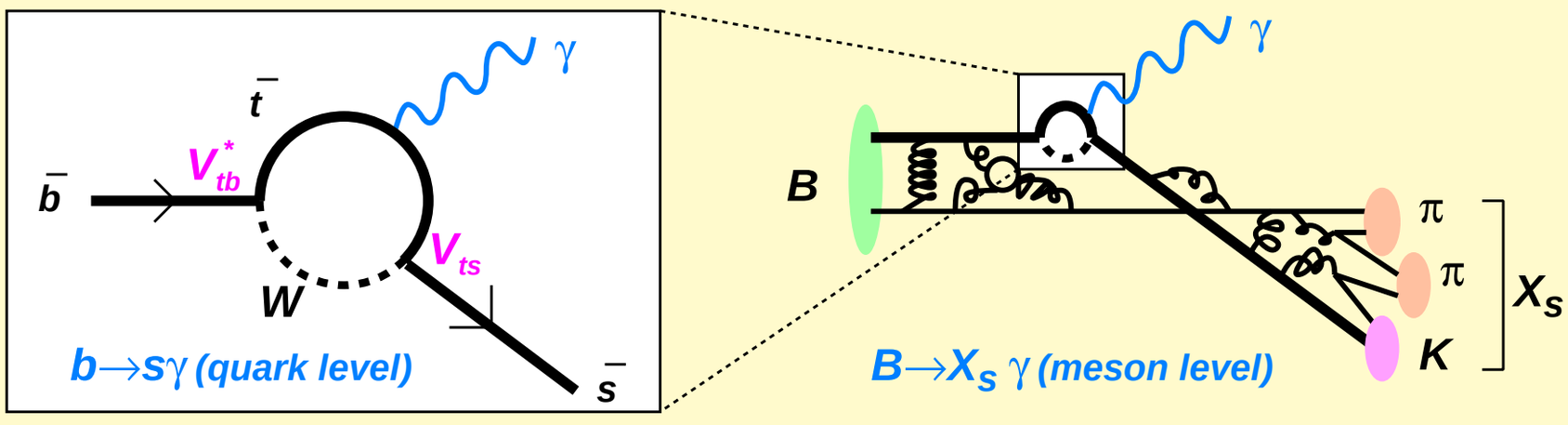
Rencontres de Moriond EW 2009

Radiative ($b \to s\gamma$ and $b \to d\gamma$) and electroweak ($b \to s\ell^+\ell^-$) penguin B decays are sensitive to physics beyond the SM



Photons(leptons) are good probes of the short distance loop process (especially in inclusive measurements)



Also sensitive to the non-perturbative B decays properties

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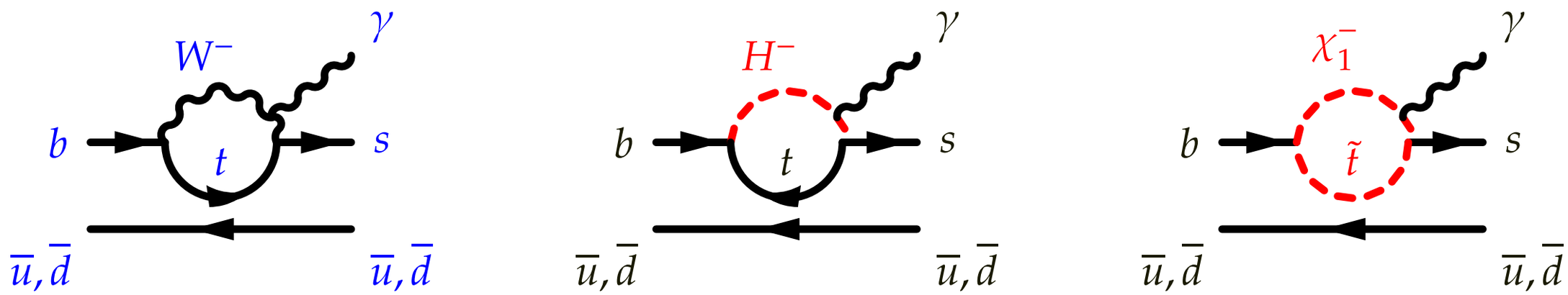
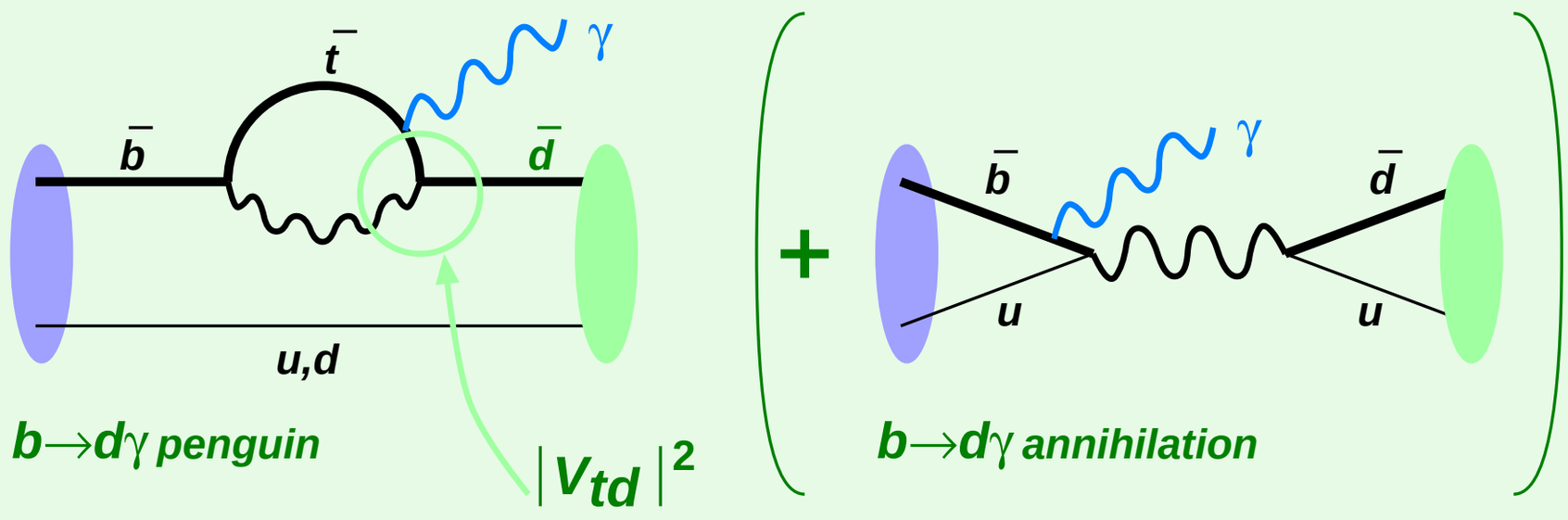


Photons(leptons) are good probes of the short distance

$b \to d$ transition is sensitive to $|V_{td}/V_{ts}|$ and the effect from the spectator quark (annihilation)



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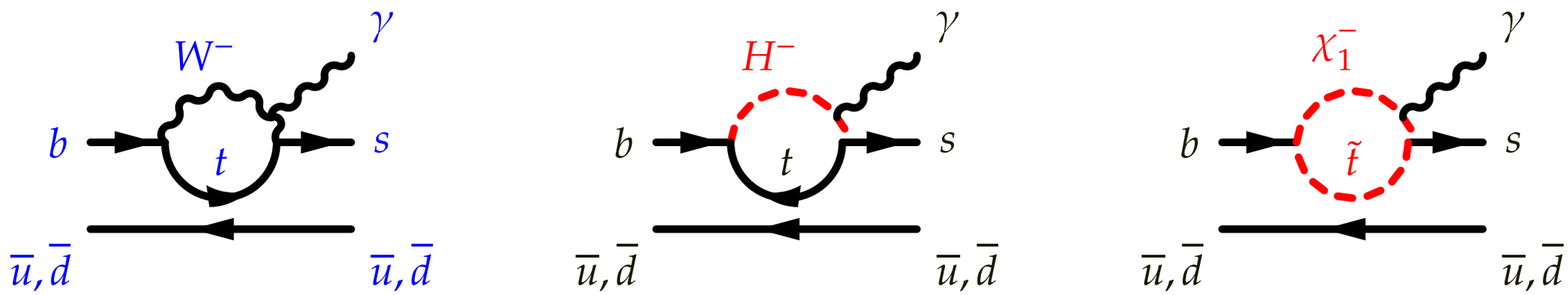
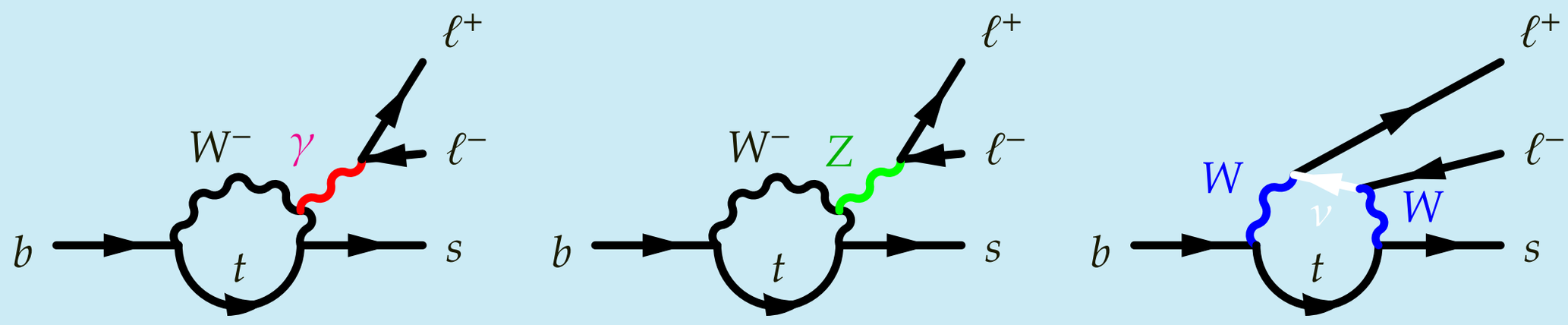


Photons(leptons) are good probes of the short distance

$b \to s$ transition is sensitive to W_L/W_R and the effect from

$b \to s\ell^+\ell^-$ involves diagrams with Z and W, and rich set of observables to distinguish type of new physics



Non-SM effects to each diagram may differ from SM

Penguin B decays at B-factories

$b \to s\gamma$:	large $\mathcal{B}$ ☺ , limited observables (2-body kinematics)
$b \to s\ell^+\ell^-$:	small $\mathcal{B}$, rich observables ☺ (3-body kinematics)
$b \to d\gamma$:	small $\mathcal{B}$, huge $b \to s\gamma$ background, $\lvert V_{td}/V_{ts}\rvert$ ☺

Large dataset made it possible to study penguin B decays!

- CsI calorimeter (photon measurement) is the key detector
  typically <2% photon energy resolution for $b \to s\gamma / b \to d\gamma$
- Exclusive final state: $M_{\rm bc}(M_{ES})$ and ΔE variables
  Inclusive: clean environment, sum of exclusives with π^0s
- Dataset
  - 384 M or 465 M $B\overline{B}$ for BaBar results (color-code=green)
  - 657 M $B\overline{B}$ for Belle results (color-code=blue)

(Topics in this talk covers subset of the latest results in the last 12 months)

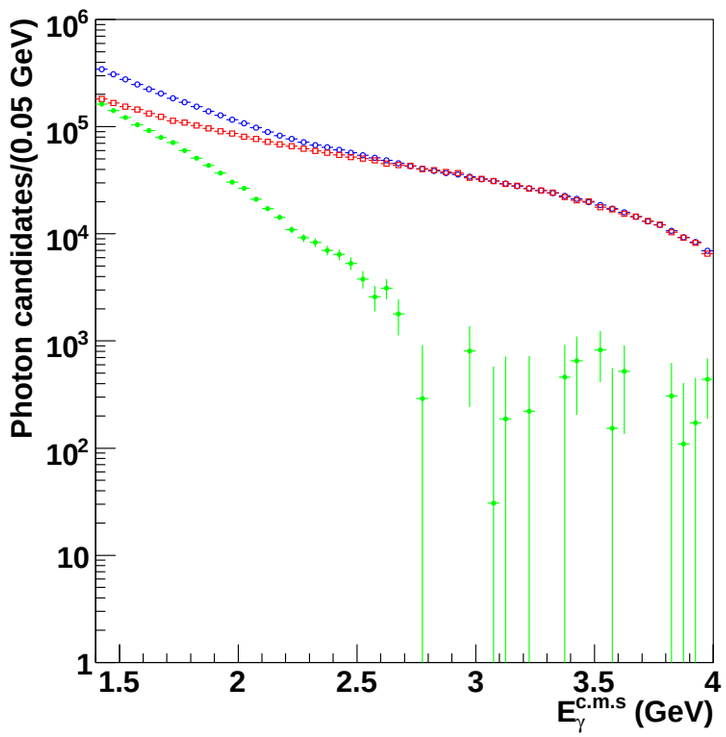
$b \to s\gamma$

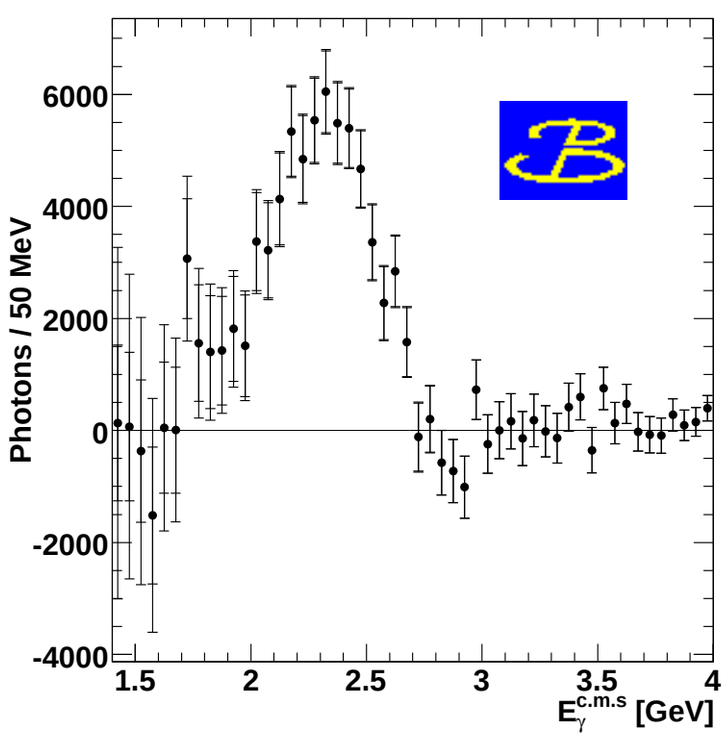
Inclusive branching fraction

Isospin and direct CP asymmetry

Time-dependent CP asymmetry

Inclusive $B \to X_s\gamma$





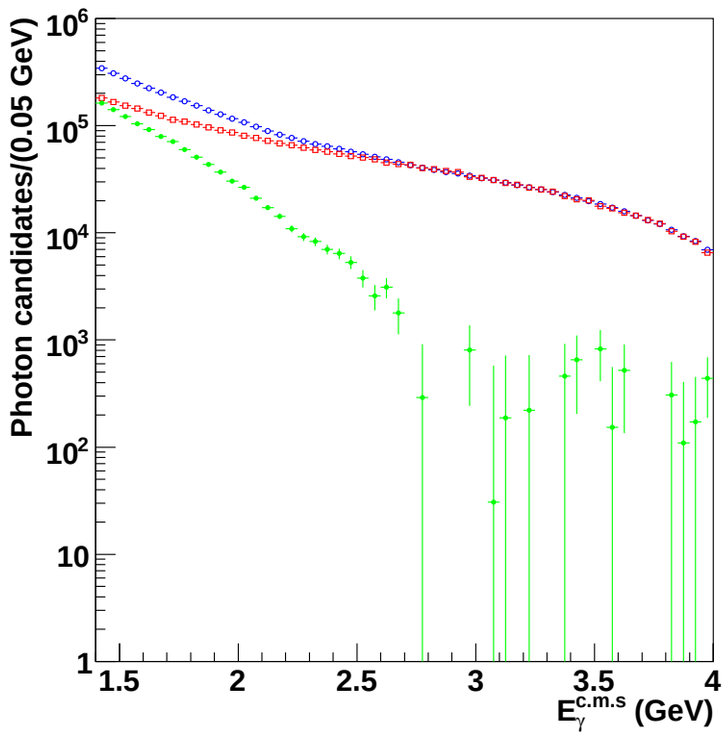
- Fully inclusive photon spectrum
  $\Rightarrow$ subtraction of huge backgrounds
  $e^+e^- \to q\bar{q}$ continuum (off-resonance data),
  $B \to \pi^0 X, \eta X$ (measured spectrum),
  others (small, MC)
- Total $\mathcal{B}$ — integrated spectrum
  lower E_γ cut reduces extrapolation error
- E_γ spectrum to nonpert. HQ params:
  (otherwise monochromatic E_γ; in B frame)
  mean & width $\Rightarrow (m_b,\ \mu_\pi^2) \Rightarrow V_{cb}$ & V_{ub}

E_γ cut down to 1.7 GeV for the first time

$\mathcal{B}(B \to X_s\gamma) = (3.31 \pm 0.19 \pm 0.37 \pm 0.01) \times 10^{-4}$

(Belle arXiv:0804.1580, 657M$B\bar{B}$, first reported in Moriond'08)

Inclusive $B \to X_s\gamma$



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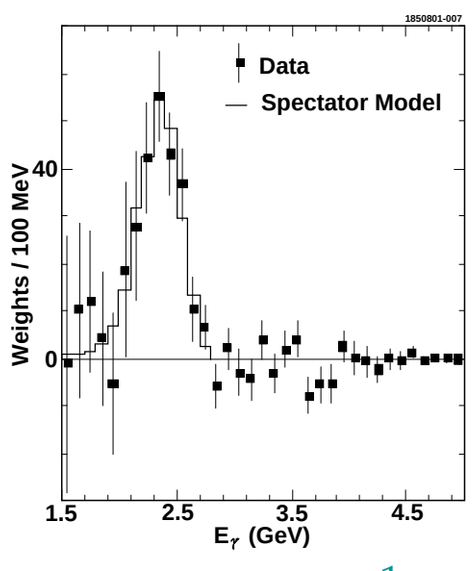
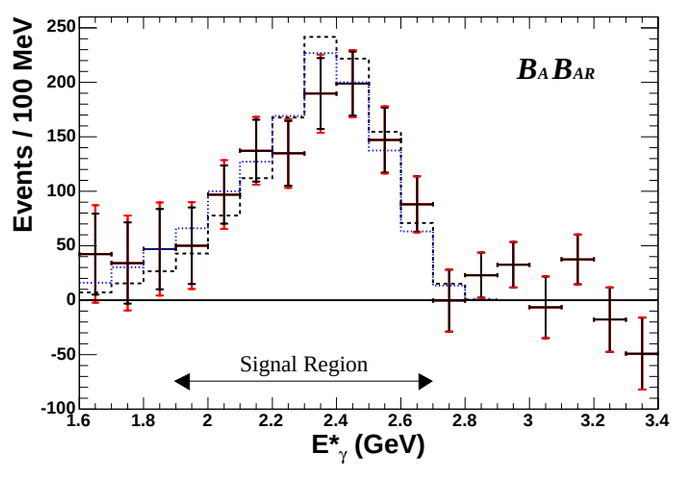
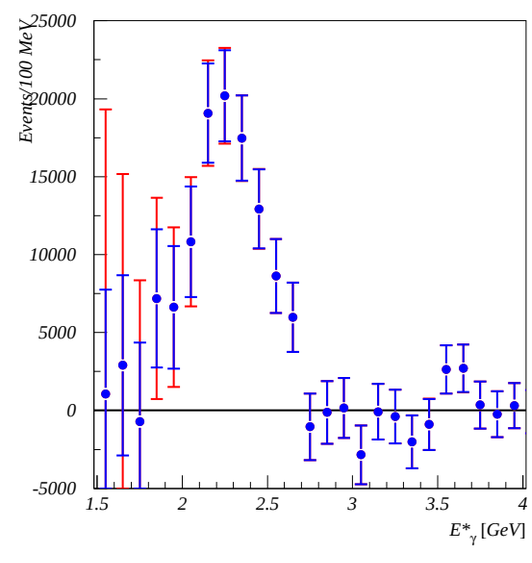
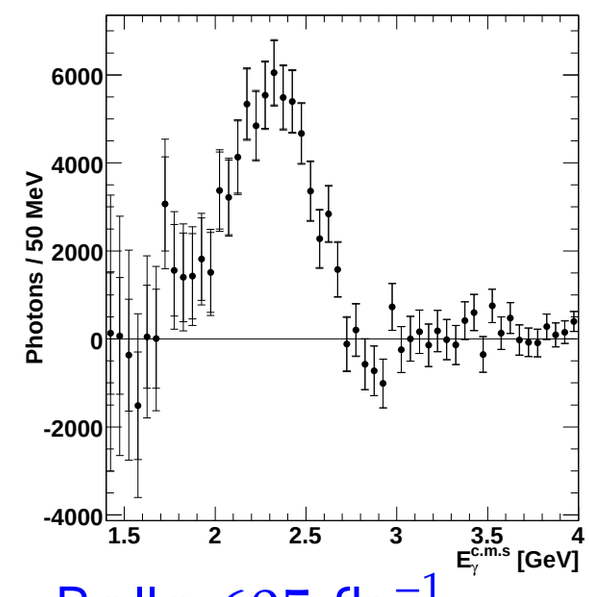








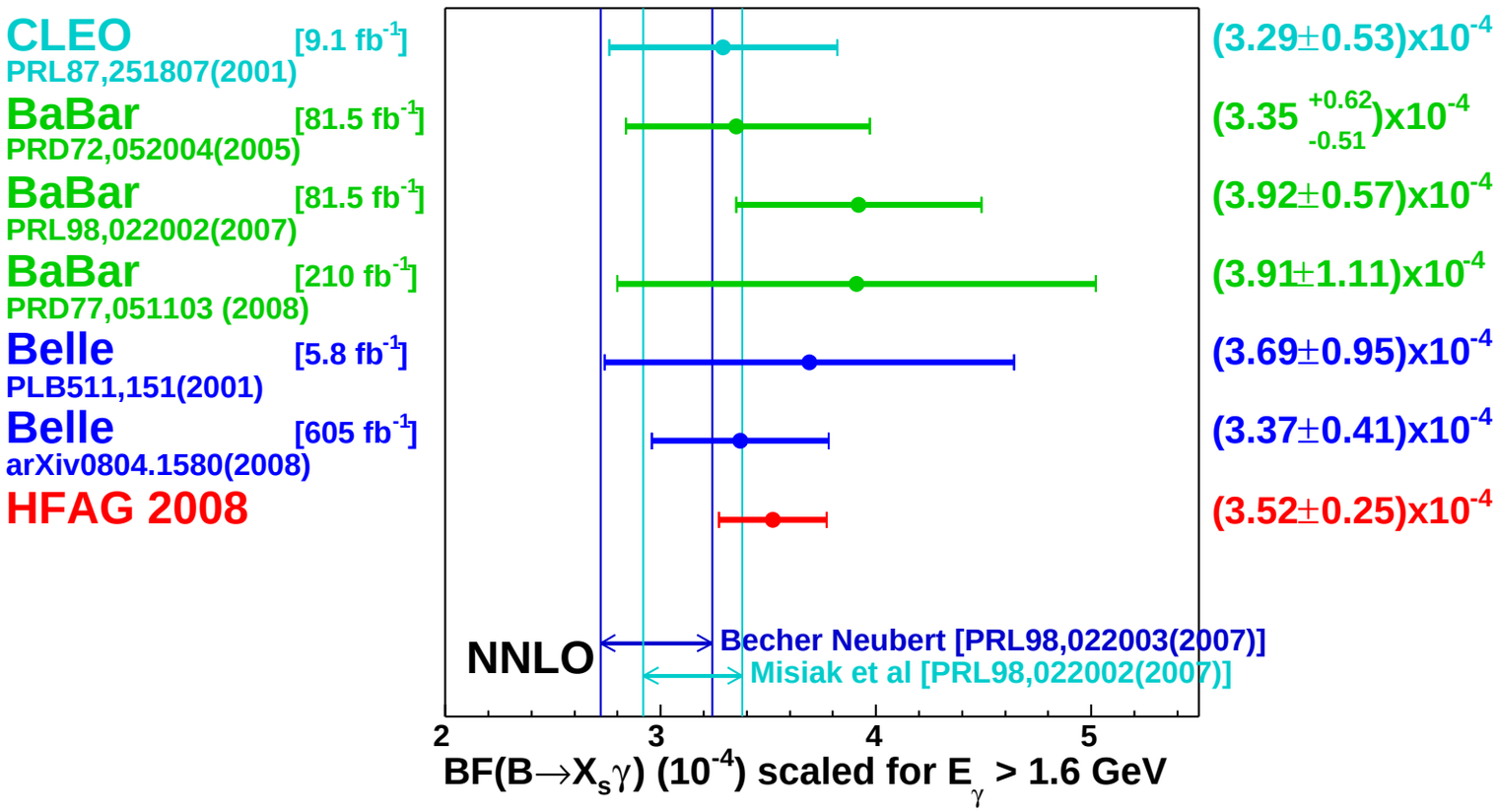
CLEO 9.1 fb^{-1} — $E_\gamma > 2.0$ GeV

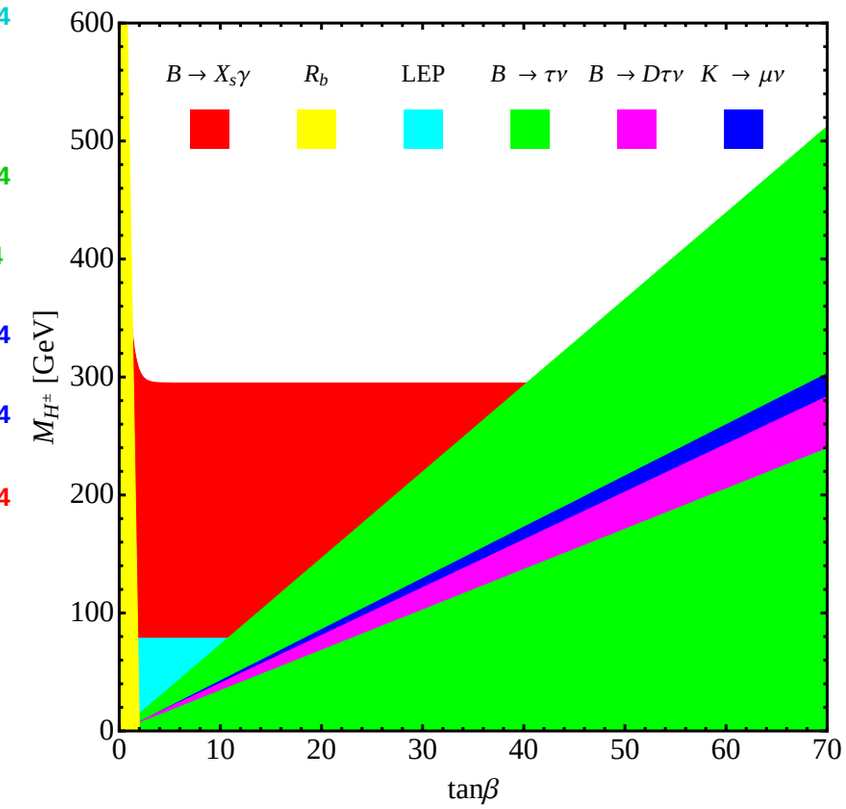
BaBar 81.5 fb^{-1} — $E_\gamma > 1.9$ GeV

Belle 140 fb^{-1} — $E_\gamma > 1.8$ GeV

Belle 605 fb^{-1} — $E_\gamma > 1.7$ GeV

The more data, the lower the E_γ cut





HFAG average: $\mathcal{B}(B \to X_s\gamma)_{E_\gamma>1.6\,\text{GeV}} = (3.52 \pm 0.25) \times 10^{-4}$

(scaling down to 1.6 GeV may be controvertial — motivation to lower E_γ)

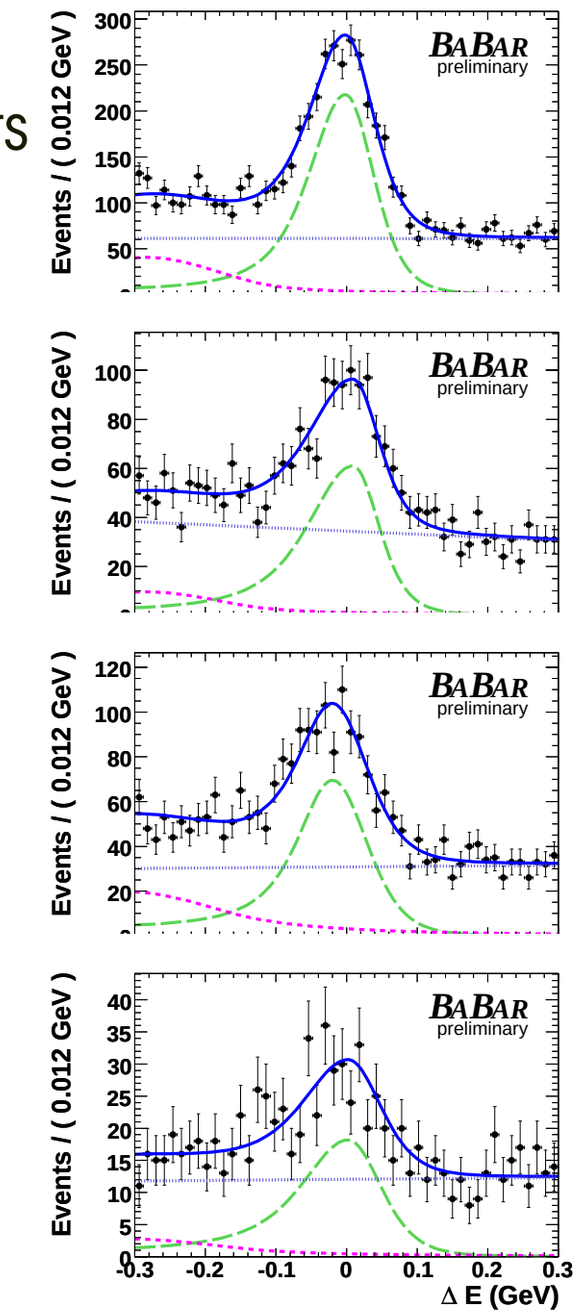
- Agreement with latest NNLO calculation
- Strong constraints on generic 2HDM charged Higgs
  (MSSM charged Higgs case is more complicated due to possible destructive interference)
- Also strong constraints on various new physics scenarios
  (but bigger room than before as data $\mathcal{B}$ is now higher than SM)

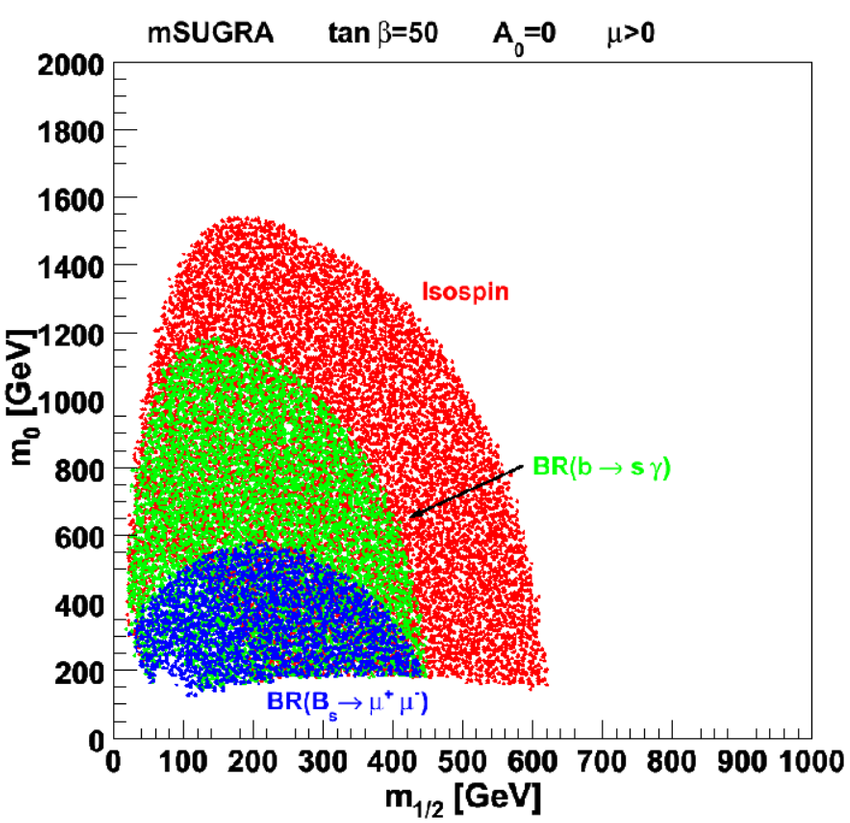
Direct CP asymmetry and isospin asymmetry

- Exclusive mode: $B \to K^*\gamma$ — high precision results

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.58 \pm 0.10 \pm 0.16) \times 10^{-5}$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.73 \pm 0.15 \pm 0.17) \times 10^{-5}$$
$$A_{CP}(B \to K^*\gamma) = -0.009 \pm 0.017 \pm 0.011$$
$$\Delta_{0-}(B \to K^*\gamma) = 0.029 \pm 0.019 \pm 0.016 \pm 0.018$$

(BaBar arXiv:0808.1915, 383M)





Direct CP asymmetry

$$A_{CP} = \frac{\Gamma(\overline{B} \to \overline{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\overline{B} \to \overline{K}^*\gamma) + \Gamma(B \to K^*\gamma)}$$

Isospin asymmetry

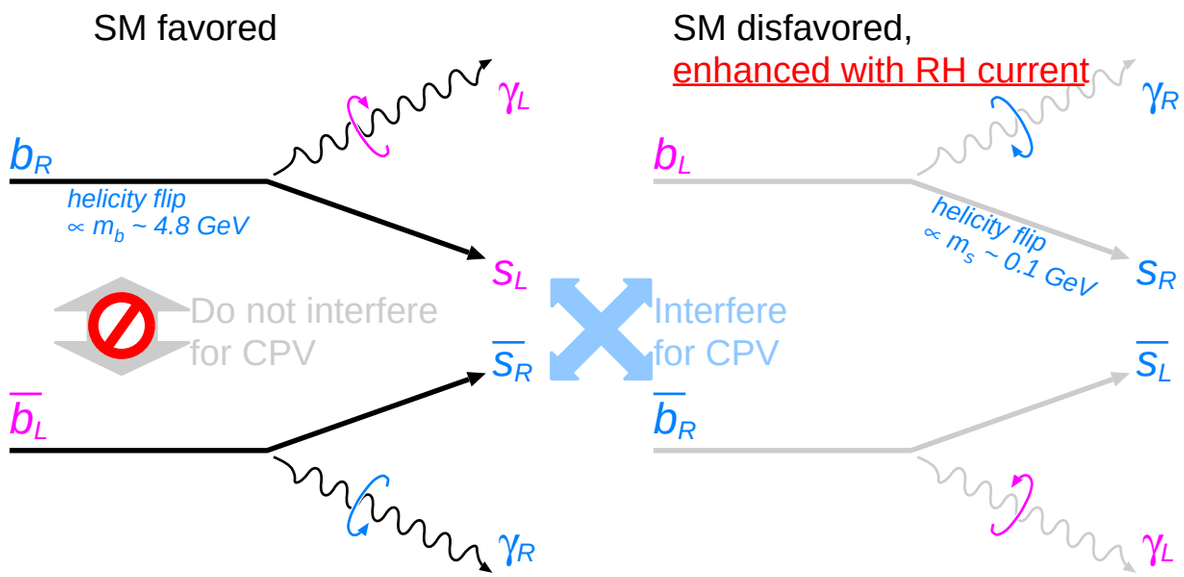
$$\Delta_{0-} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)}$$

Asymmetries are useful to constrain new physics: e.g. mSUGRA $m_{1/2}$-m_0 space from Δ_{0-} (Mahmourdi arXiv:0710.3791, implemented in SuperISO program)

Time-dependent CP asymmetry in $B \to K_S^0 \pi^0 \gamma$

TCPV: $\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}[1 \pm \mathcal{S}\sin(\Delta m \Delta t) \mp \mathcal{C}\cos(\Delta m \Delta t)]$

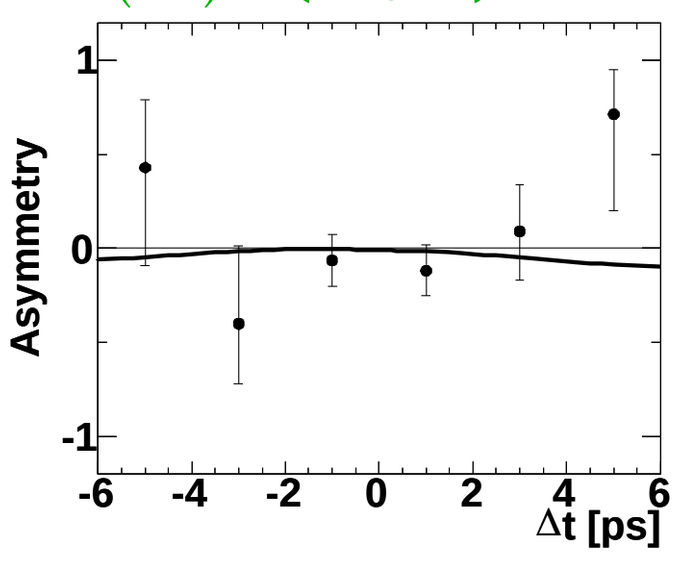
(Δt: vertex displacement between extrapoated K_S^0 vertex and tag-B vertex)

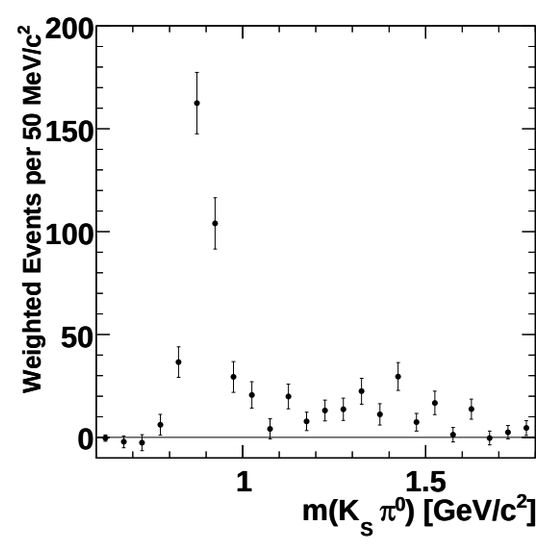


- TCPV suppressed by $(m_s/2m_b)$ (otherwise $\sim \sin 2\phi_1$)
- Sensitive to right-handed non-SM current, relaxes suppression $\Rightarrow$ non-zero $\mathcal{S}$

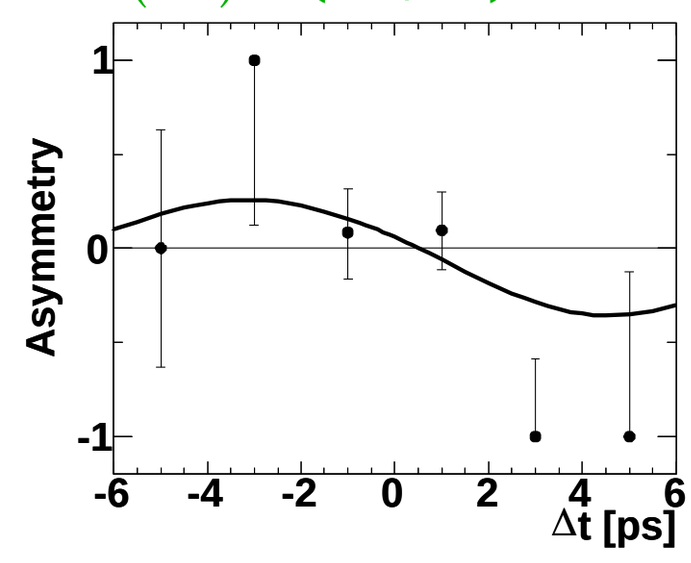
(BaBar PRD78,071102(2008), 467M)

$M(K\pi)$ in (0.8,1.0) GeV





$M(K\pi)$ in (1.1,1.8) GeV



$\mathcal{S}_{K^*\gamma} = -0.03 \pm 0.29 \pm 0.03$

$\mathcal{C}_{K^*\gamma} = -0.14 \pm 0.16 \pm 0.03$

$\mathcal{S}_{K_S^0\pi^0} = -0.78 \pm 0.59 \pm 0.09$

$\mathcal{C}_{K_S^0\pi^0} = -0.36 \pm 0.33 \pm 0.04$

Time-dependent CP asymmetry in $B \to K_S^0 \pi^0 \gamma$

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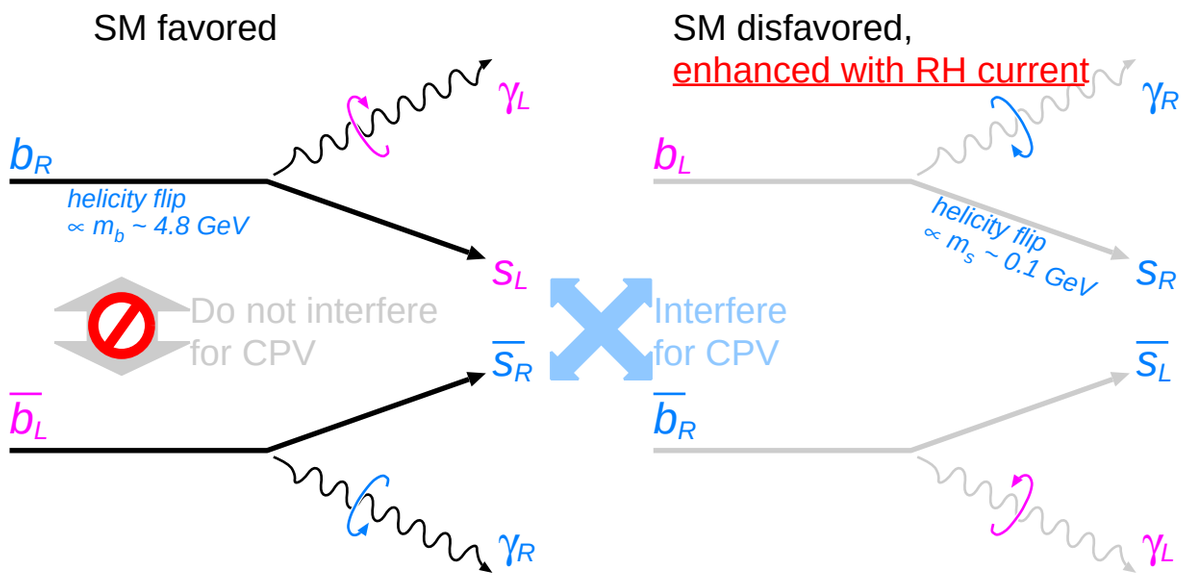

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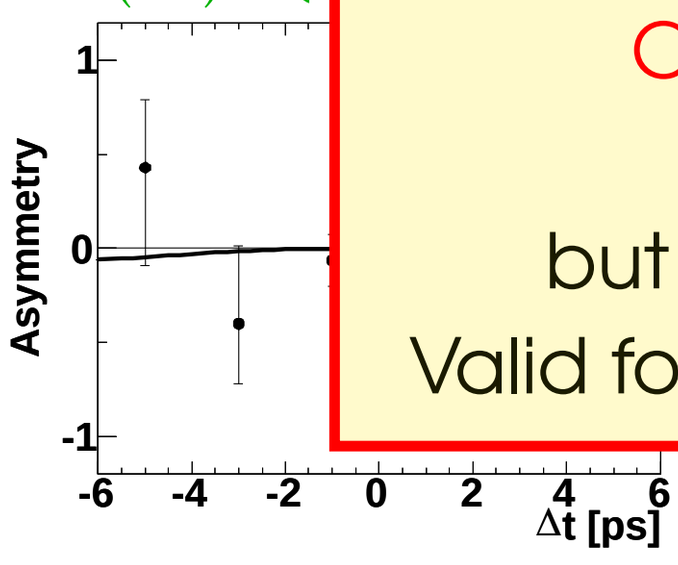
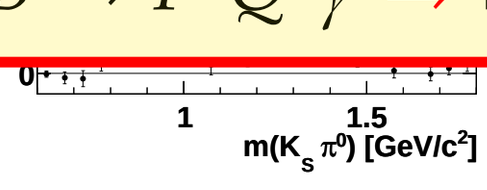
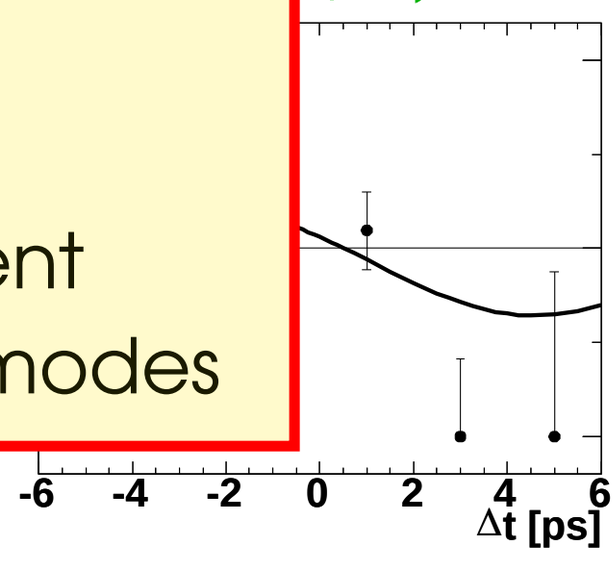
$M(K\pi)$ in (0.8,1.0) GeV





$M(K\pi)$ in (1.1,1.8) GeV



Consistent with SM, $\delta\mathcal{S} \sim 0.3$

(also in previous Belle data)

but hardly constrains RH current

Valid for any $B \to P^0 Q^0 \gamma \Rightarrow$ more modes

$\mathcal{S}_{K^*\gamma} = -0.03 \pm 0.29 \pm 0.03$

$\mathcal{C}_{K^*\gamma} = -0.14 \pm 0.16 \pm 0.03$

$\mathcal{S}_{K_S^0\pi^0} = -0.78 \pm 0.59 \pm 0.09$

$\mathcal{C}_{K_S^0\pi^0} = -0.36 \pm 0.33 \pm 0.04$

TCPV in $B \to K_S^0 \eta\gamma$

TCPV can be measured in $B^0 \to K_S^0 \eta\gamma$

(BaBar PRD78,112001(2008), 465M)

$M(K\eta) < 3.25$ GeV

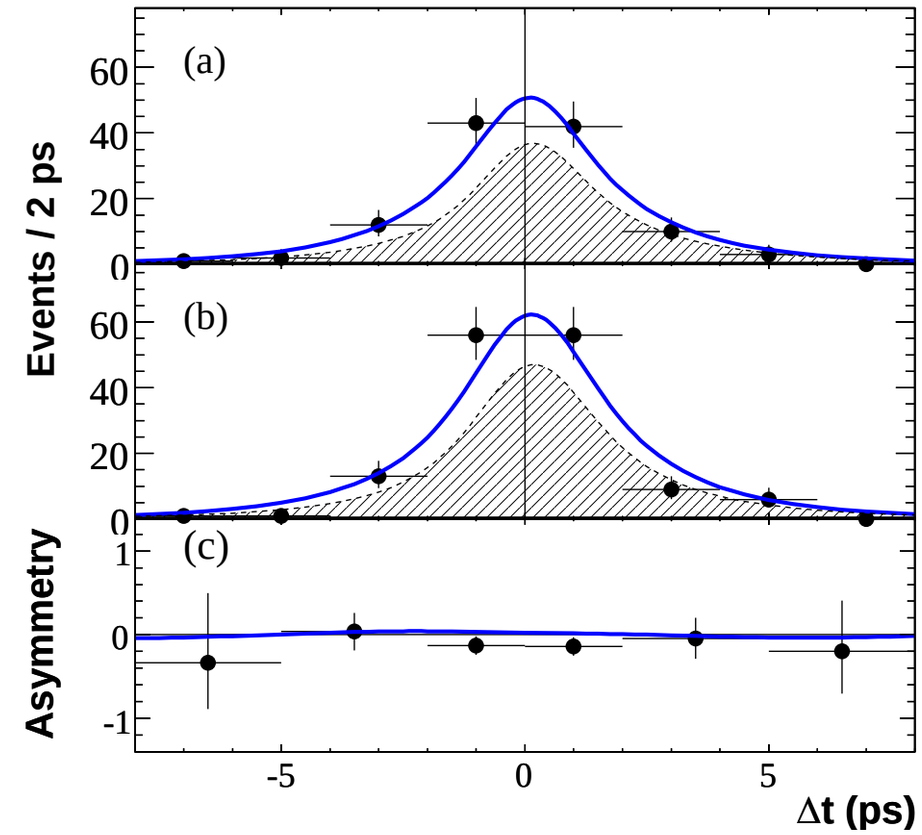
$$\mathcal{S}_{K_S^0\eta\gamma} = -0.18\,^{+0.49}_{-0.46} \pm 0.12$$

$$\mathcal{C}_{K_S^0\eta\gamma} = -0.32\,^{+0.40}_{-0.39} \pm 0.07$$

$$\mathcal{B}(B^0 \to K^0\eta\gamma) = (7.1\,^{+2.1}_{-2.0} \pm 0.4) \times 10^{-6}$$

$$\mathcal{B}(B^+ \to K^+\eta\gamma) = (7.7 \pm 1.0 \pm 0.4) \times 10^{-6}$$

$$A_{CP}(K^+\eta\gamma) = (-9.0\,^{+10.4}_{-9.8} \pm 1.4) \times 10^{-2}$$



Or in $B^0 \to K_S^0 \eta'\gamma$? — but η' mode seems to be much smaller than η

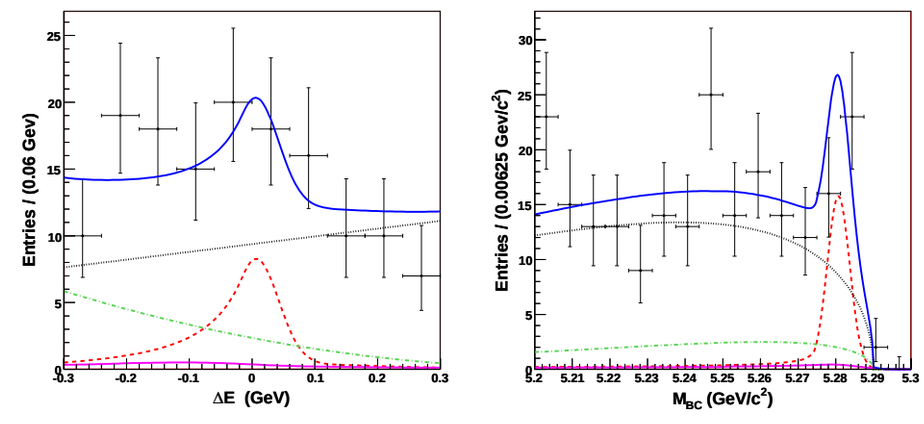
(similar to $B \to \eta^{(\prime)} K^*$, opposite to $B \to \eta^{(\prime)} K$)

(Belle arXiv:0810.0804, 657M)

$M(K\eta') < 3.4$ GeV

$$\mathcal{B}(B \to K^+\eta'\gamma) = (3.2\,^{+1.2}_{-1.1} \pm 0.3) \times 10^{-6}$$

$$\mathcal{B}(B \to K^0\eta'\gamma) < 6.3 \times 10^{-6} \text{ (90\% CL)}$$



3.3σ, First evidence

TCPV in $B \to K_S^0 \rho^0 \gamma$

- Relatively large $\mathcal{B}(B \to K_S^0 \rho^0 \gamma)$
  ($B \to K_1(1270)\gamma$ is dominant)
- Vertex from $\rho^0 \to \pi^+\pi^-$ (no K_S^0 vertex needed)

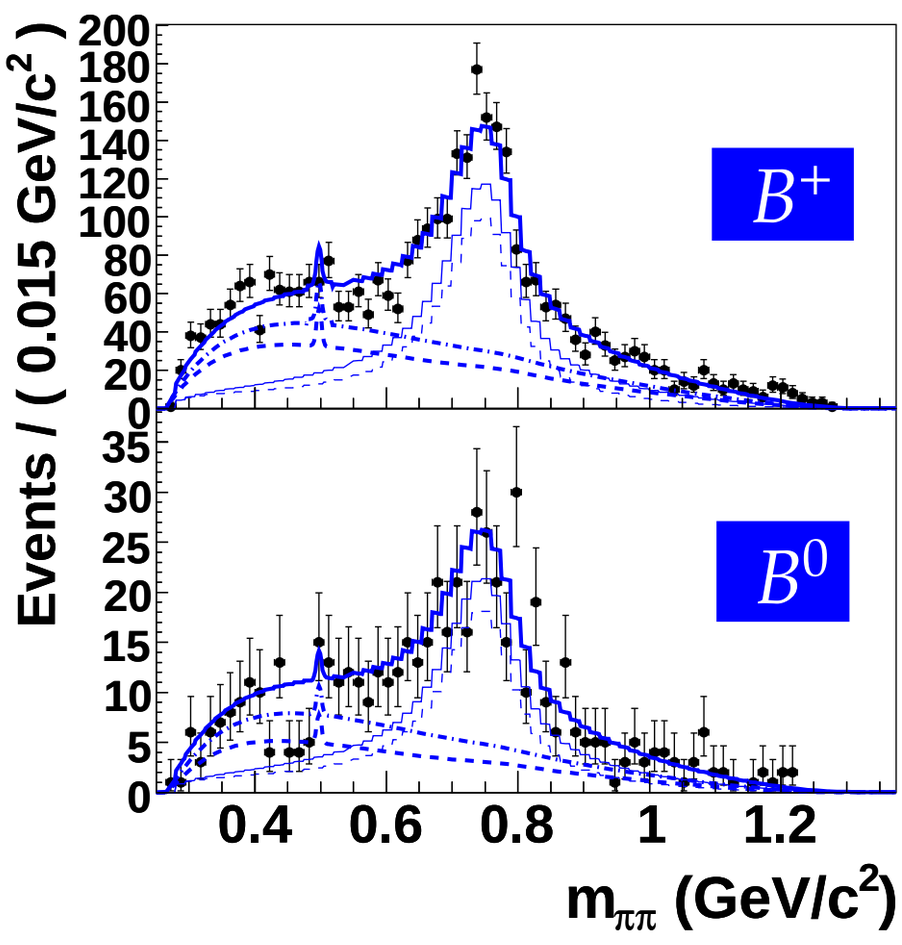
Sensitivity competitive to $B \to K_S^0 \pi^0 \gamma$

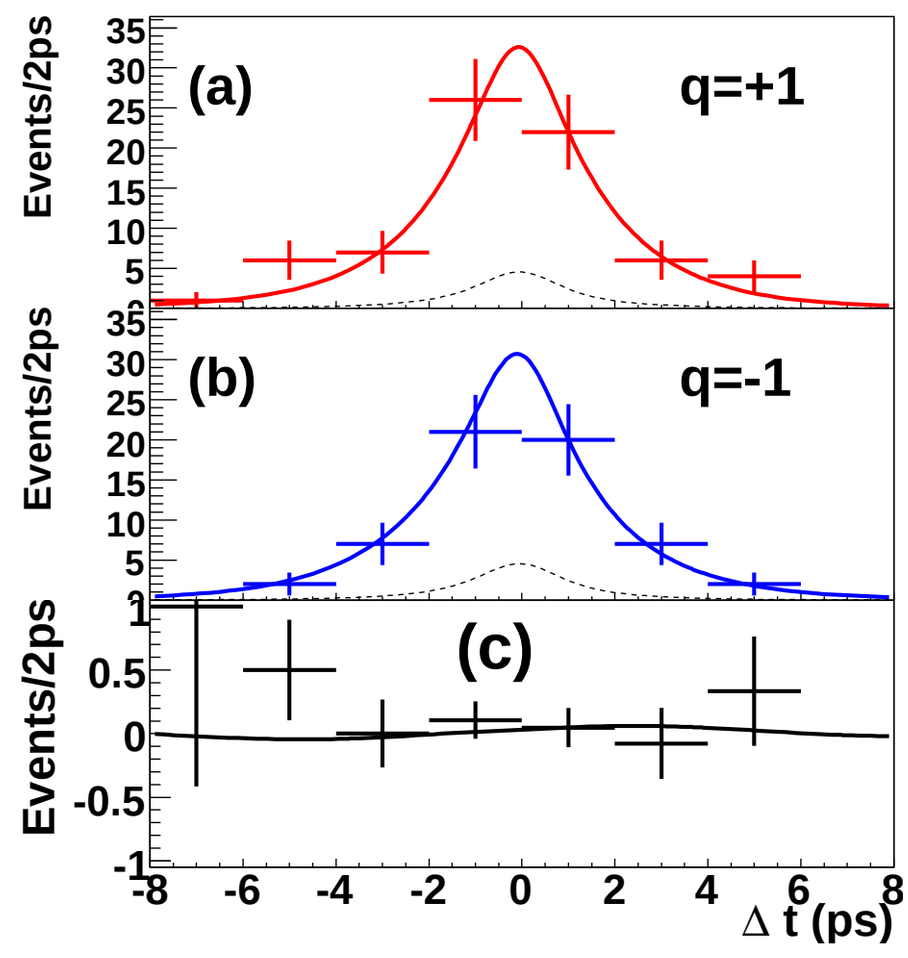
Dilution due to $\mathcal{B}(B \to K^*\pi\gamma)$ is small: $\mathcal{D} = 0.83\,^{+0.19}_{-0.03}$
(measured in $B^+ \to K^+\pi^+\pi^-\gamma$)

$S_{K_S^0\rho^0\gamma} = +0.11 \pm 0.33\,^{+0.05}_{-0.09}$

$A_{K_S^0\pi^+\pi^-\gamma} = +0.05 \pm 0.18 \pm 0.06$

(Belle PRL101,251601(2008), 657M$B\overline{B}$)





$b \to d\gamma$

$|V_{td}/V_{ts}|$

Isospin asymmetry $\Delta(\rho\gamma)$

$b \to d\gamma$ and $|V_{td}/V_{ts}|$

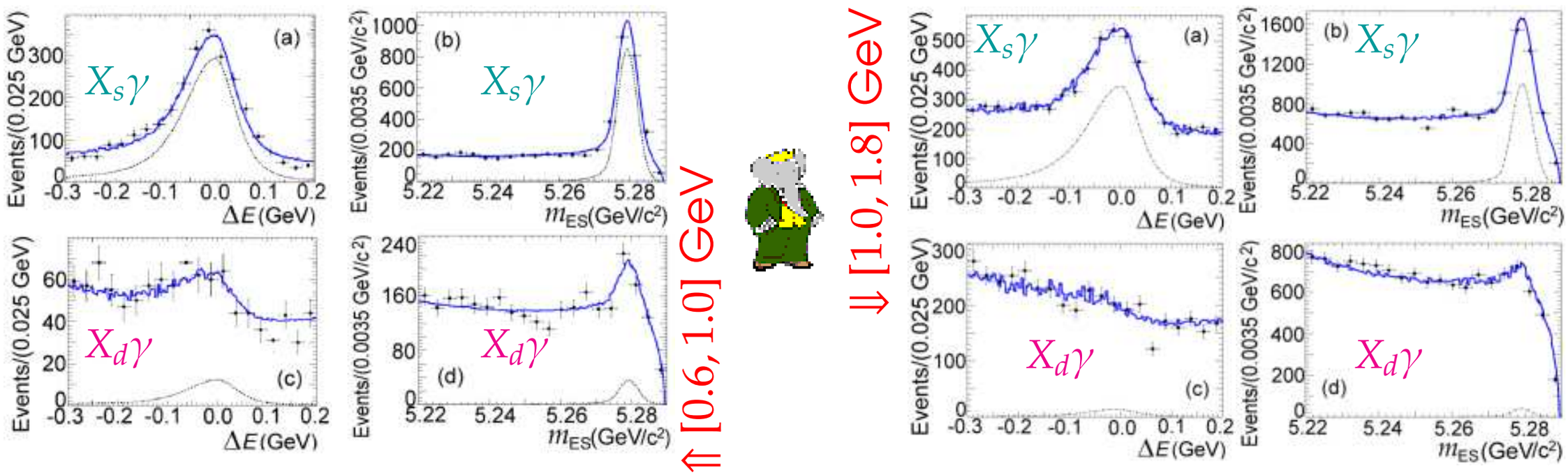
Semi-inclusive $b \to d\gamma$ (and $b \to s\gamma$) by summing up exclusive modes in $M(X_{s/d})$: $[0.6, 1.8]$ GeV (BaBar arXiv:0807.4975, submitted to PRL)

$B \to X_d\gamma$: $\pi^+\pi^-\gamma, \pi^+\pi^0\gamma, \pi^+\pi^-\pi^0\gamma, \pi^+\pi^-\pi^+\gamma, \pi^+\pi^-\pi^+\pi^-\gamma, \pi^+\pi^-\pi^+\pi^0\gamma, \pi^+\eta\gamma$

$B \to X_s\gamma$: $K^+\pi^-\gamma, K^+\pi^0\gamma, K^+\pi^-\pi^0\gamma, K^+\pi^-\pi^+\gamma, K^+\pi^-\pi^+\pi^-\gamma, K^+\pi^-\pi^+\pi^0\gamma, K^+\eta\gamma$

$\mathcal{B}(B \to X_d\gamma)_{[0.6,1.8]\mathrm{GeV}} = (7.2 \pm 2.7 \pm 2.3) \times 10^{-6}$ ➡ $|V_{td}/V_{ts}| = 0.177 \pm 0.043$

~2× correction for missings with JETSET, otherwise free from theory errors



Exclusive $B \to (\rho, \omega)\gamma$ ($B \to \rho\gamma$ and $B \to \omega\gamma$ combined)

$\mathcal{B} = (11.4 \pm 2.0\,^{+1.0}_{-1.2}) \times 10^{-7}$ $|V_{td}/V_{ts}| = 0.195\,^{+0.020}_{-0.019} \pm 0.015$ Belle PRL101,111801(2008)

$\mathcal{B} = (16.3\,^{+3.0}_{-2.8} \pm 1.6) \times 10^{-7}$ $|V_{td}/V_{ts}| = 0.233\,^{+0.025}_{-0.024}\,^{+0.022}_{-0.021}$ BaBar PRD78,112001(2008)

$b \to d\gamma$ and $|V_{td}/V_{ts}|$

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$B \to X_s\gamma$: $K^+\pi^-\gamma, K^+\pi^0\gamma, K^+\pi^-\pi^0\gamma, K^+\pi^-\pi^+\gamma, K^+\pi^-\pi^+\pi^-\gamma, K^+\pi^-\pi^+\pi^0\gamma, K^+\eta\gamma$

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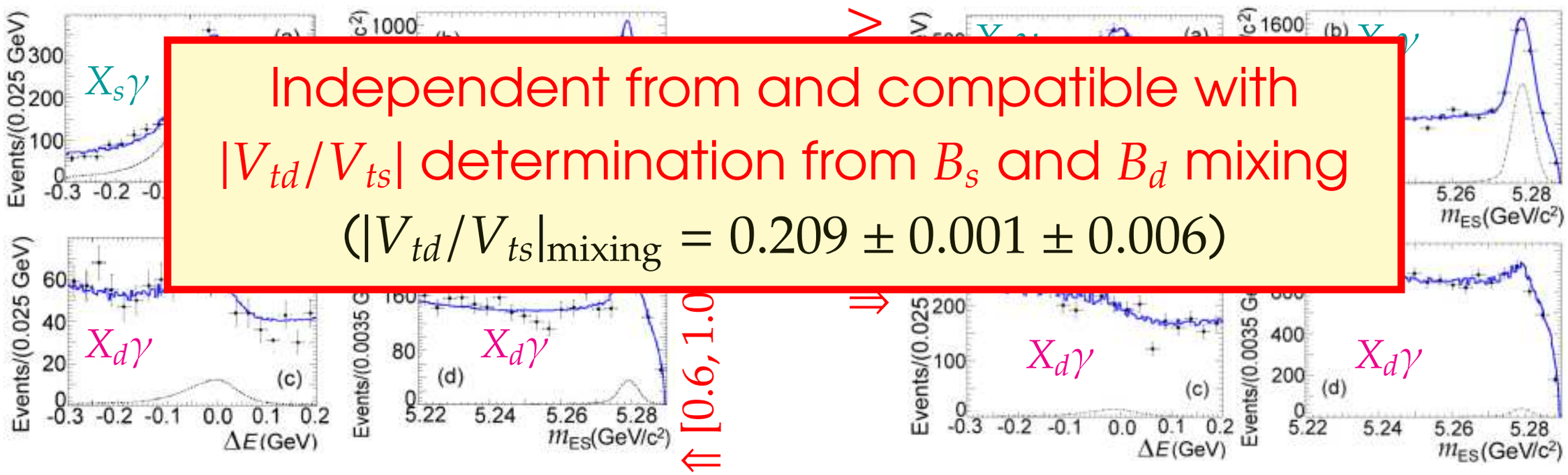


Independent from and compatible with $|V_{td}/V_{ts}|$ determination from B_s and B_d mixing

$(|V_{td}/V_{ts}|_{\mathrm{mixing}} = 0.209 \pm 0.001 \pm 0.006)$

Exclusive $B \to (\rho, \omega)\gamma$ ($B \to \rho\gamma$ and $B \to \omega\gamma$ combined)

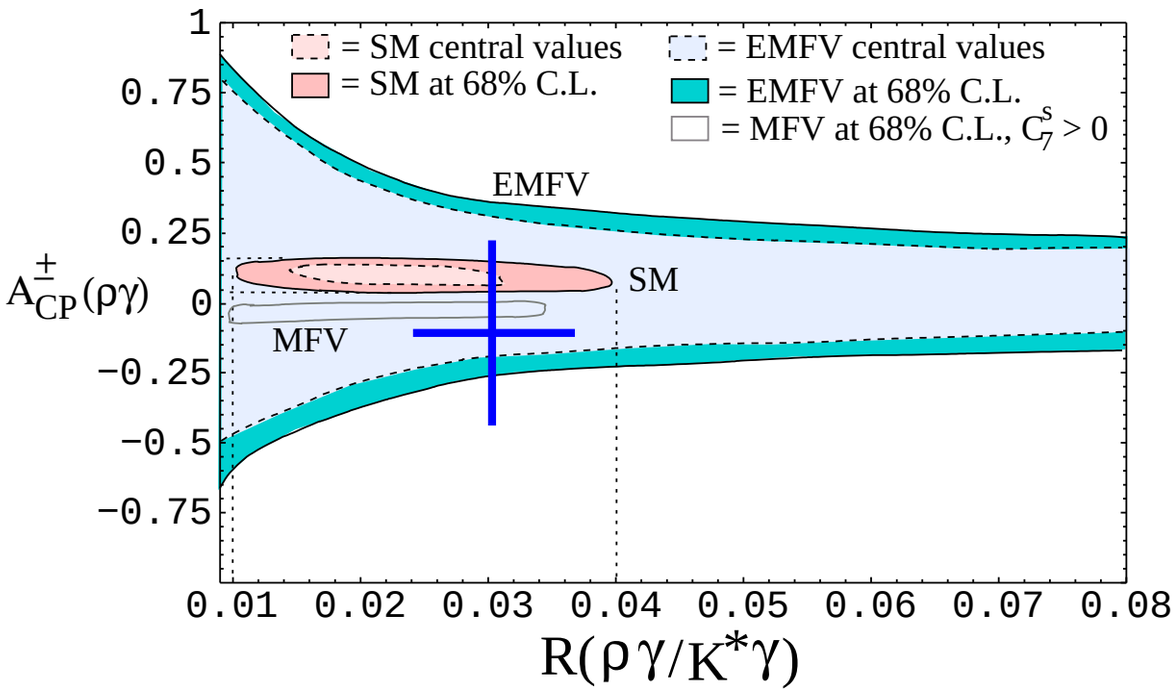
$\mathcal{B} = (11.4 \pm 2.0\,^{+1.0}_{-1.2}) \times 10^{-7}$ $|V_{td}/V_{ts}| = 0.195\,^{+0.020}_{-0.019} \pm 0.015$ Belle PRL101,111801(2008)

$\mathcal{B} = (16.3\,^{+3.0}_{-2.8} \pm 1.6) \times 10^{-7}$ $|V_{td}/V_{ts}| = 0.233\,^{+0.025}_{-0.024}\,^{+0.022}_{-0.021}$ BaBar PRD78,112001(2008)

CPV and isospin asymmetry in $B \to \rho\gamma$

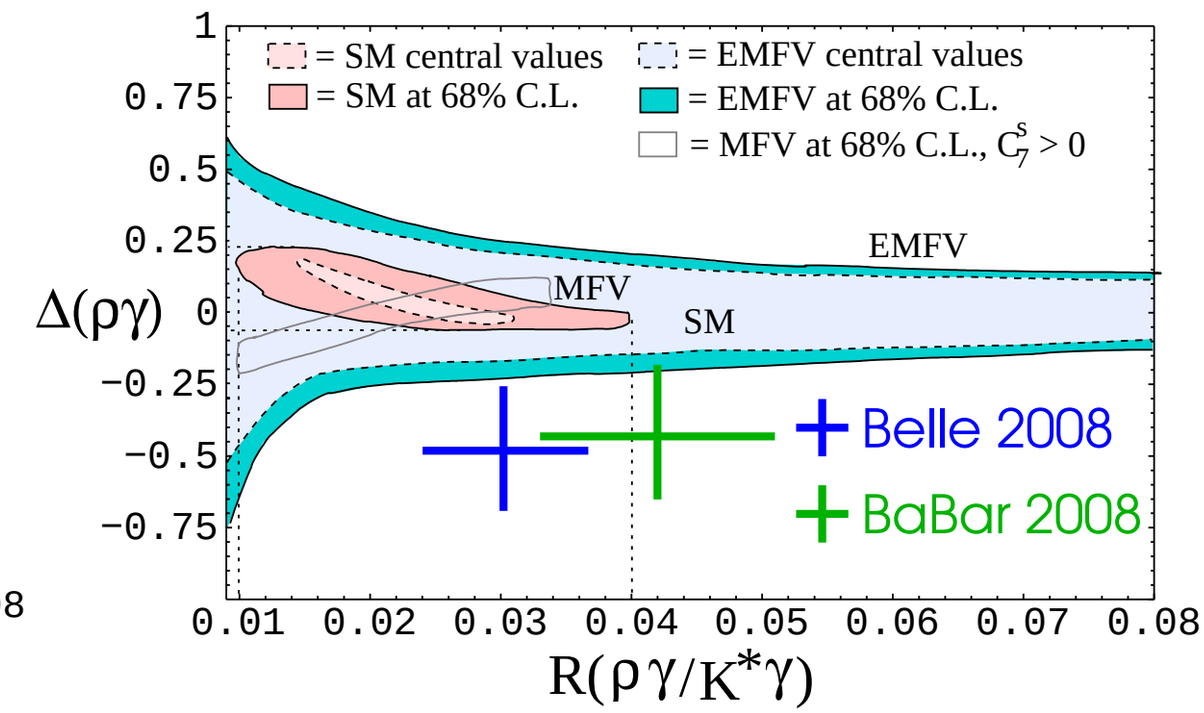
Direct CP asymmetry

$$A_{CP} = \frac{\mathcal{B}(B^- \to \rho^-\gamma) - \mathcal{B}(B^+ \to \rho^+\gamma)}{\mathcal{B}(B^- \to \rho^-\gamma) + \mathcal{B}(B^+ \to \rho^+\gamma)}$$



Isospin asymmetry

$$\Delta(\rho\gamma) = \frac{\Gamma(B^+ \to \rho^+\gamma)}{2\Gamma(B^0 \to \rho^0\gamma)} - 1$$



	Belle	BaBar
$R(\rho\gamma/K^*\gamma)$	$0.0302^{+0.0060}_{-0.0055}{}^{+0.0026}_{-0.0028}$	0.042 ± 0.009
$A_{CP}(\rho^+\gamma)$	$-0.11 \pm 0.32 \pm 0.09$	—
$\Delta(\rho\gamma)$	$-0.48^{+0.21}_{-0.19}{}^{+0.08}_{-0.09}$	$-0.43^{+0.25}_{-0.22} \pm 0.10$

Large Δ_ρ could be sign of new physics (Ali-Lunghi EPJC26, 195(2002)), or O(10%) Δ_ρ may be explained by non-perturbative charming penguin (C. Kim *et al.*, PRD78,054024(2008))

$b \to s\ell^+\ell^-$

F_L and forward-backward asymmetry

Isospin asymmetry

Branching fraction and other measurements

Wilson coeffients and $B \to K^* \ell^+ \ell^-$

- Wilson coefficients to identify type of new physics

C_7	for magnetic penguin operator $[\frac{e}{8\pi^2} m_b \bar{s}_i \sigma^{\mu\nu}(1+\gamma_5) b_i F_{\mu\nu}]$
(size is determined from $b \to s\gamma$, but sign is from $b \to s\ell^+\ell^-$)	
C_9	for vector electroweak operator $[(\bar{b}s)_{V-A}(\bar{\ell}\ell)_V]$
C_{10}	for axial-vector electroweak operator $[(\bar{b}s)_{V-A}(\bar{\ell}\ell)_A]$

- Foward-backward asymmetry ($A_{\rm FB}$) and Wilson coefficients

$$A_{\rm FB}(q^2) = -C_{10}^{\rm eff}\xi(q^2)\left[Re(C_9^{\rm eff})F_1 + \frac{1}{q^2}C_7^{\rm eff}F_2\right]$$

(similar to γ-Z interference at high energy)

- Angular distributions to extract FB asymmetries

K^* logitudinal polarization F_L from kaon angle θ_K

$$\frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

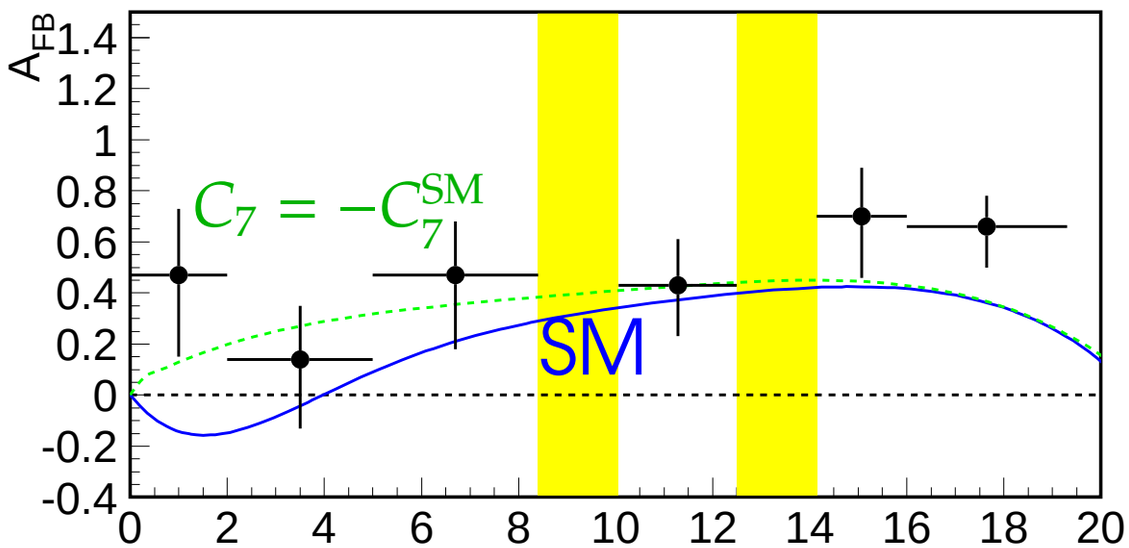
Forward-backward asymmetry $A_{\rm FB}$ from lepton angle θ_ℓ

$$\frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{\rm FB}\cos\theta_\ell$$

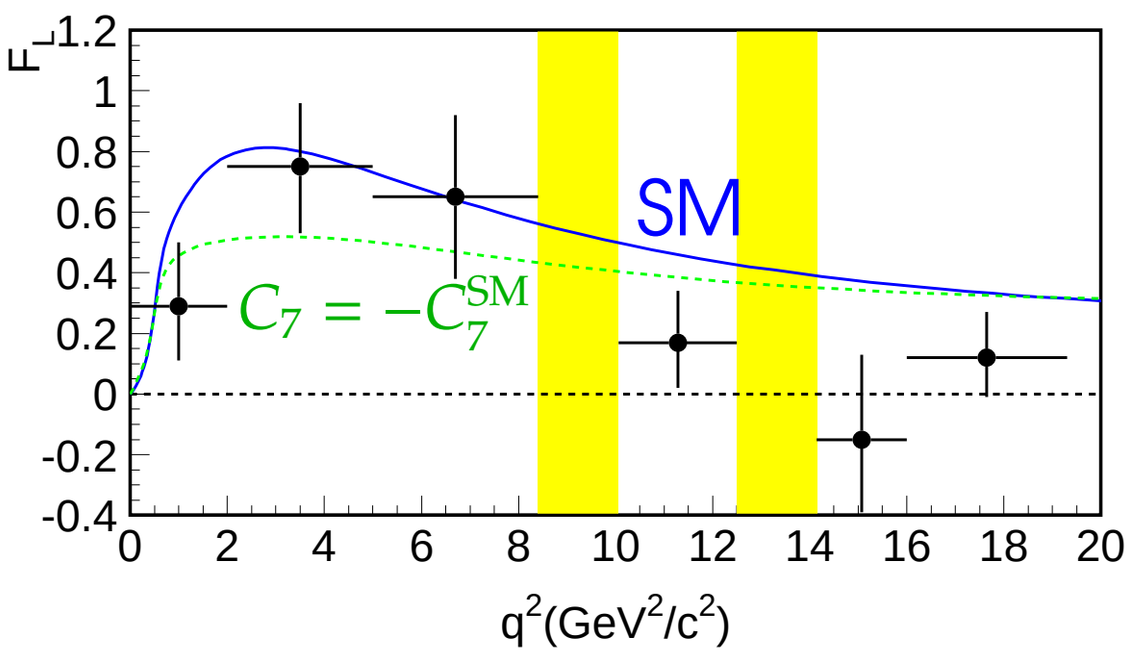
F_L and A_{FB}

Belle

A_{FB} (Belle arXiv:0810.0335, 657M $B\overline{B}$)

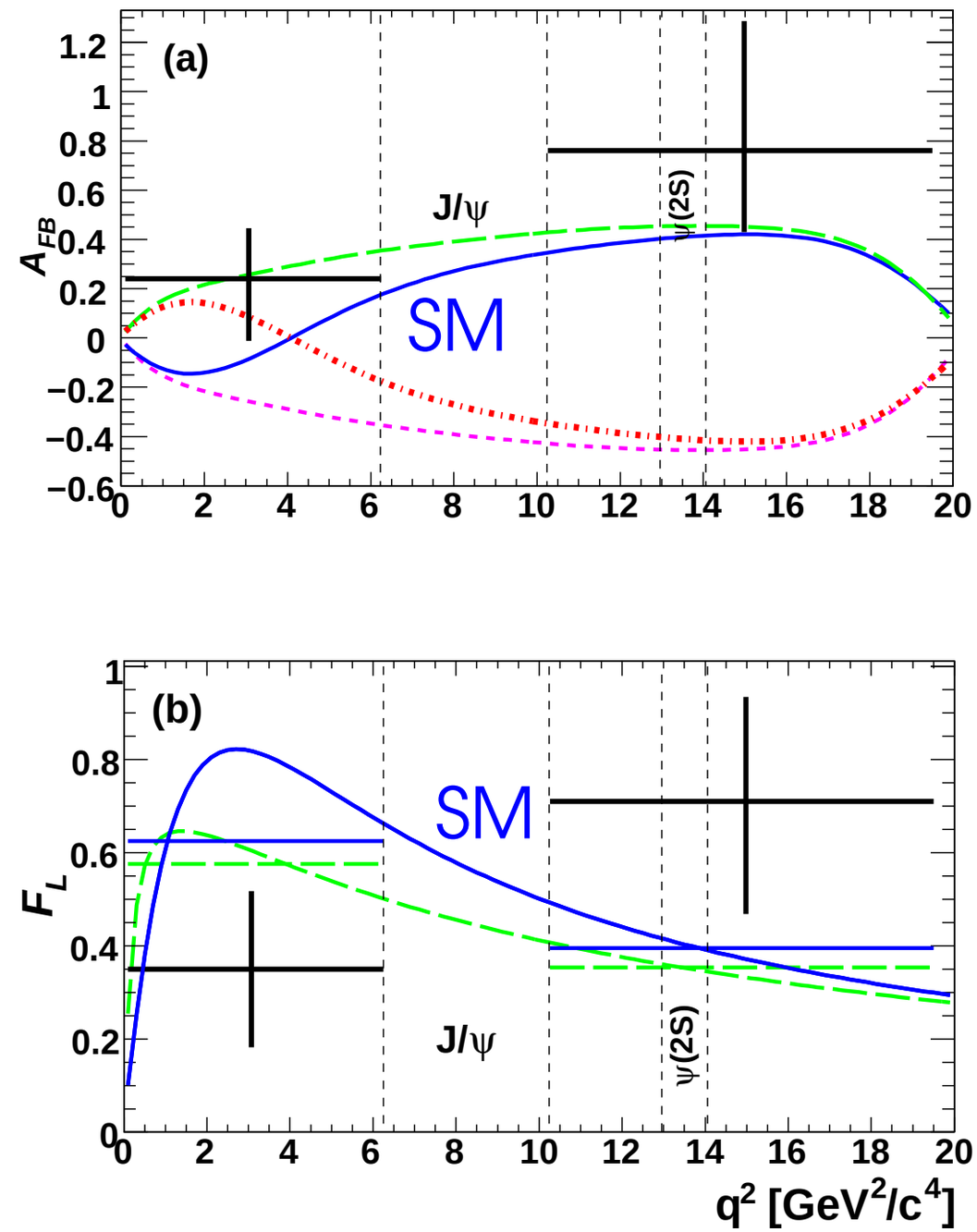


F_L



BaBar

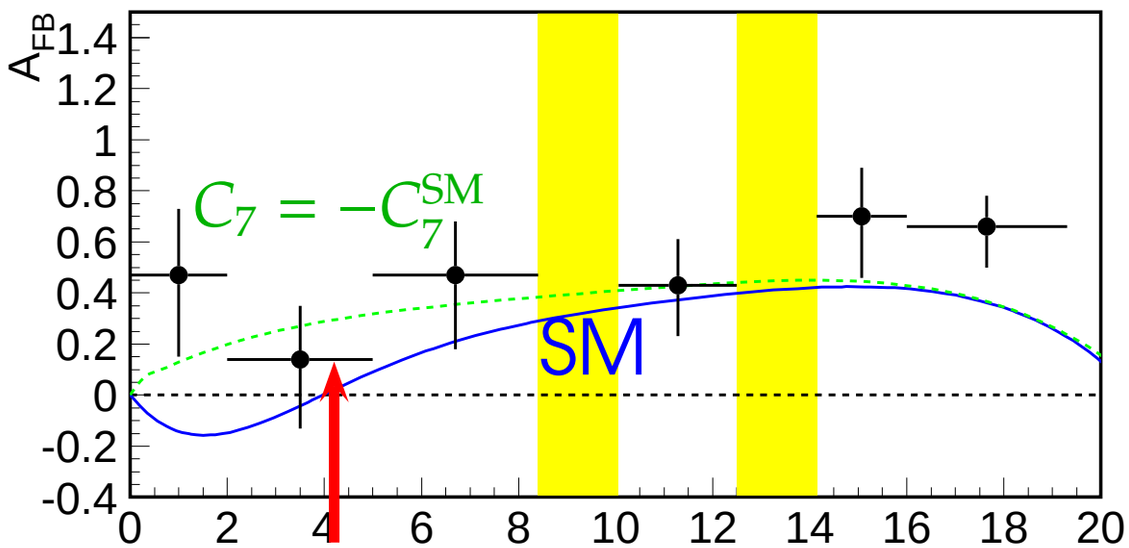
(BaBar arXiv:0804.4412, 384M $B\overline{B}$)



F_L and $A_{\rm FB}$

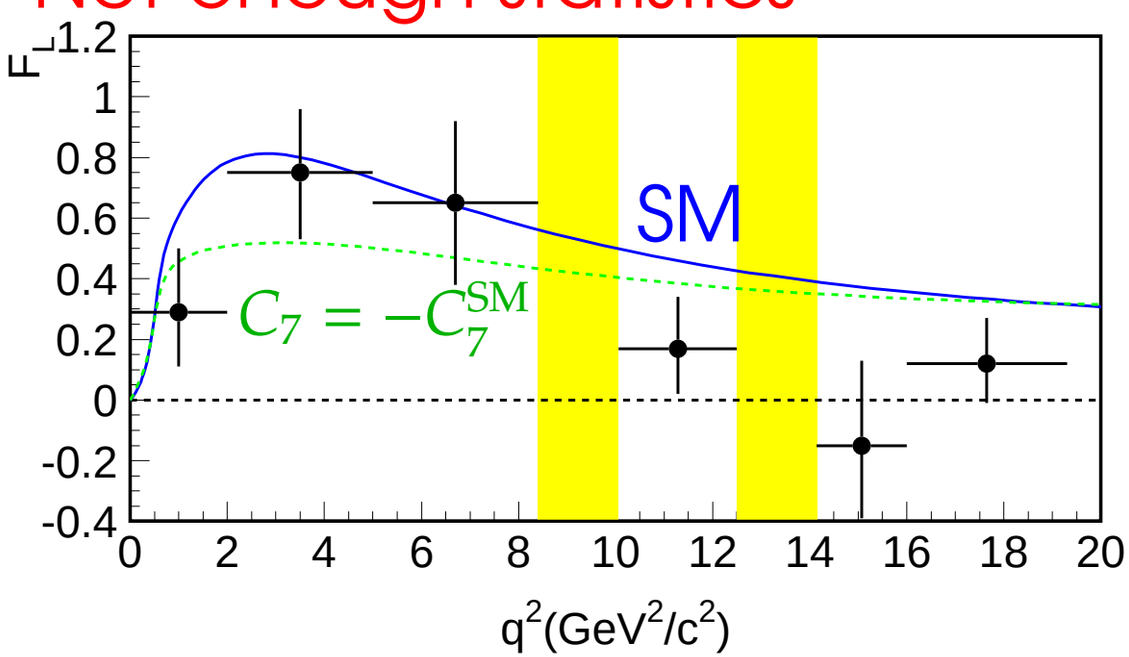
Belle

$A_{\rm FB}$ (Belle arXiv:0810.0335, 657M $B\overline{B}$)



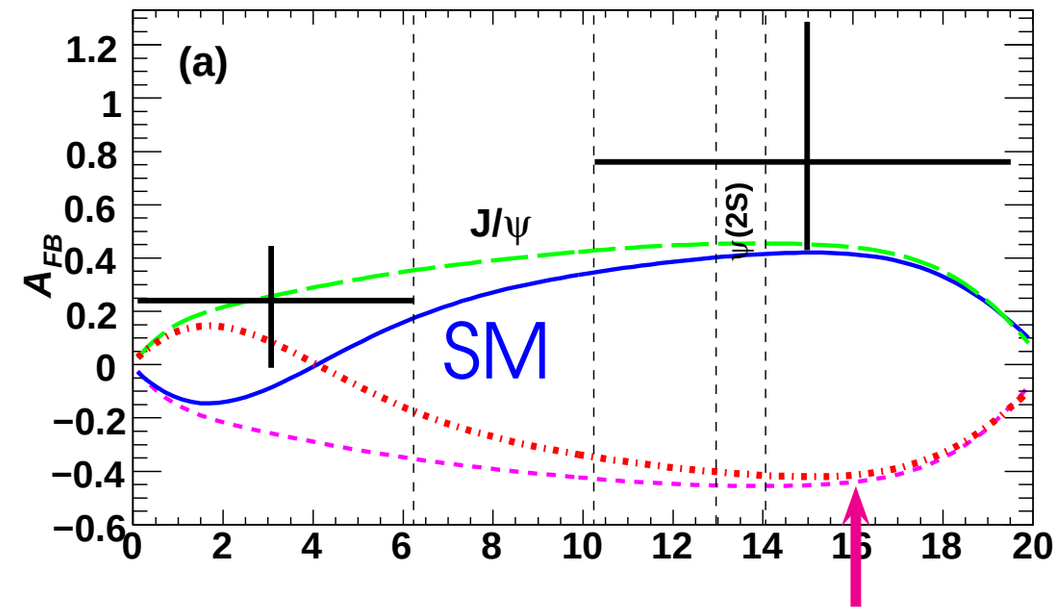
No crossing (Opposite sign C_7)?

F_L Not enough statistics

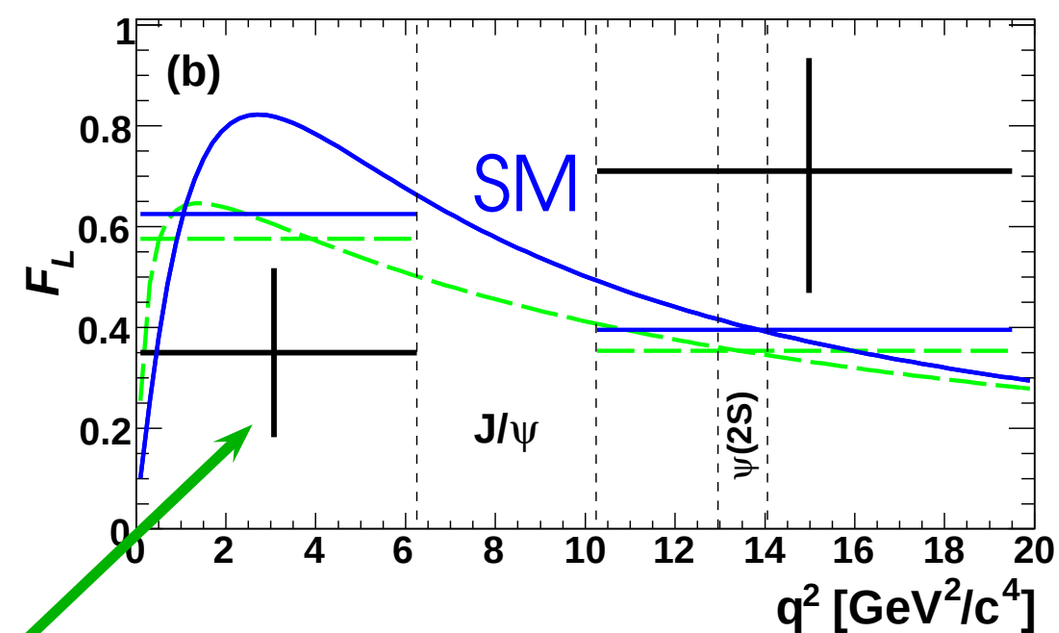


BaBar

(BaBar arXiv:0804.4412, 384M $B\overline{B}$)



Opposite sign C_9C_{10} is disfavored

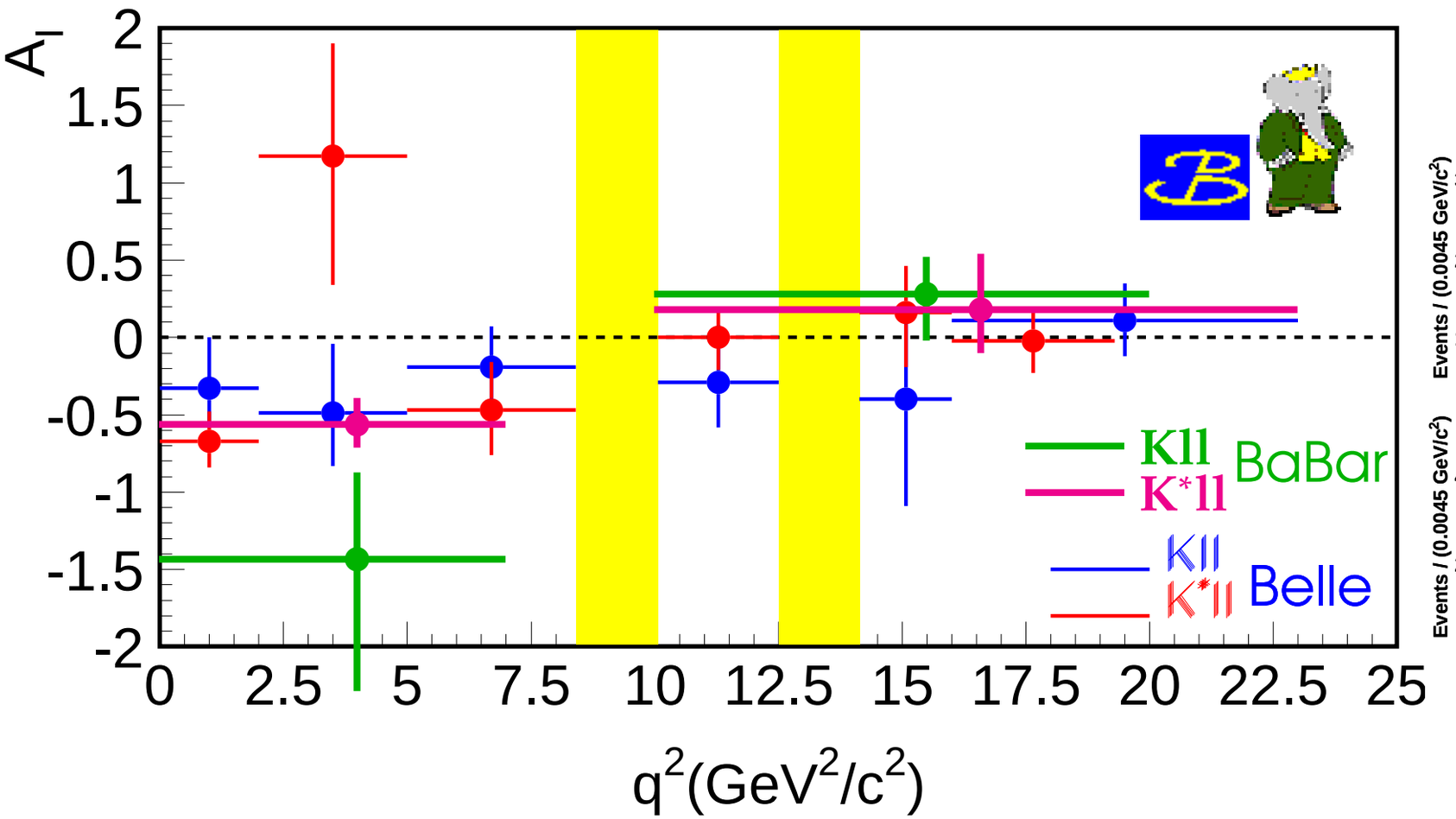


Anomaly? not in Belle

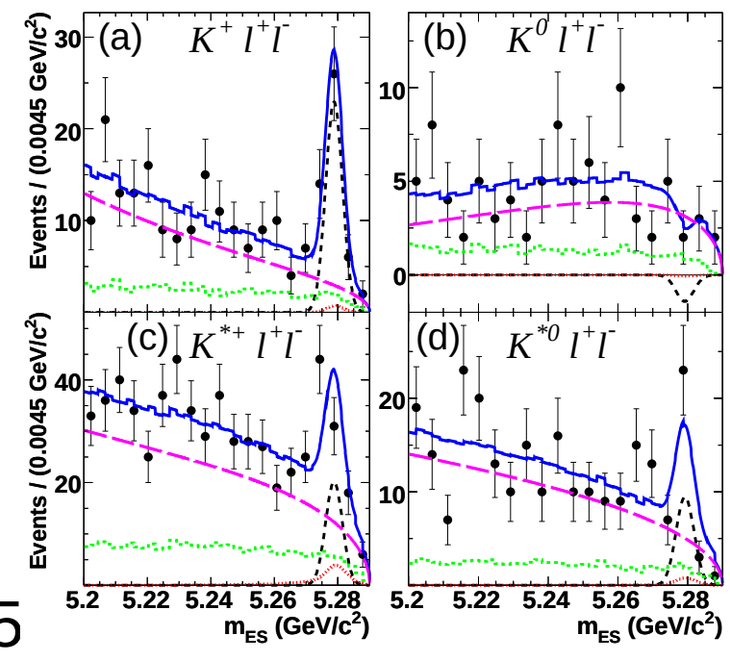
Isospin asymmetry in $B \to K^* \ell^+ \ell^-$

$$A_I^{K^{(*)}} = \frac{\Gamma(B^0 \to K^{(*)0}\ell^+\ell^-) - \Gamma(B^\pm \to K^{(*)+}\ell^+\ell^-)}{\Gamma(B^0 \to K^{(*)0}\ell^+\ell^-) + \Gamma(B^\pm \to K^{(*)+}\ell^+\ell^-)}$$

(Belle arXiv:0810.0335,657M $B\overline{B}$, BaBar arXiv:0807.4119,384M $B\overline{B}$)



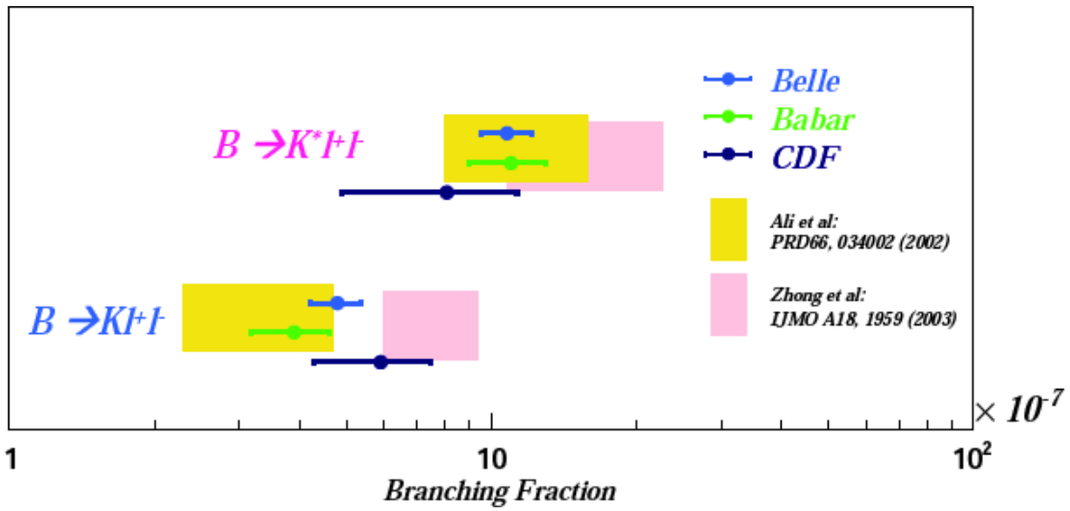
BaBar

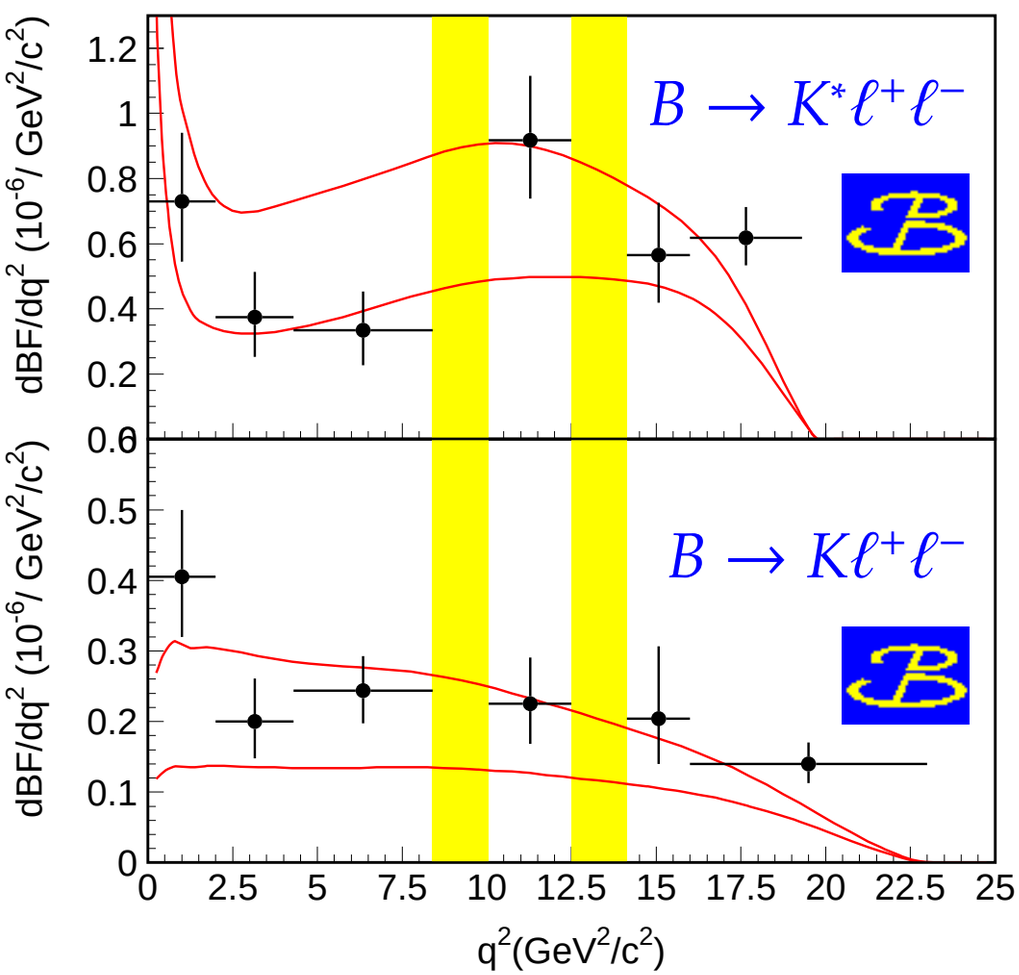


Clear deficit of neutral $B^0 \to K^{(*)0}\ell^+\ell^-$ at low q^2 at BaBar?

Belle's data is consistent with null isospin asymmetry

Branching fraction and lepton flavor ratio





- $\mathcal{B} \sim 10^{-6}$ or less
  also measured by CDF
  (CDF PRD79,011104(2009), 924 pb^{-1})
- Differential BF
  sensitive to Wilson coefficients
  (but suffer from form-factor uncertainty)
- Lepton flavor ratio: sensitive to SUSY neutral Higgs at large $\tan\beta$

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$

	Belle	BaBar
R_K	$1.03 \pm 0.19 \pm 0.06$	$0.96\,^{+0.44}_{-0.34} \pm 0.05$
R_{K^*}	$0.83 \pm 0.17 \pm 0.05$	$1.10\,^{+0.42}_{-0.32} \pm 0.07$

($R^{\rm SM}_{K^*} = 0.75$ due to photon pole)

Inclusive $B \to X_s\ell^+\ell^-$ are yet to be updated
(Last results were 152 M (Belle) / 88 M (BaBar))

Summary

Summary

- Radiative and electroweak penguin decays $b \to s\gamma$, $b \to d\gamma$ and $b \to s\ell^+\ell^-$ are almost fully explored by Belle and BaBar
- Consistent with the SM, but may not be a perfect fit
  - Inclusive $B \to X_s\gamma$
  - Time-dependent CP asymmetry in $B \to K_S^0\pi^0\gamma, K_S^0\rho^0\gamma, \ldots$
  - Isospin asymmetry in $B \to \rho\gamma$
  - Forward-backward asymmetry in $B \to K^*\ell^+\ell^-$

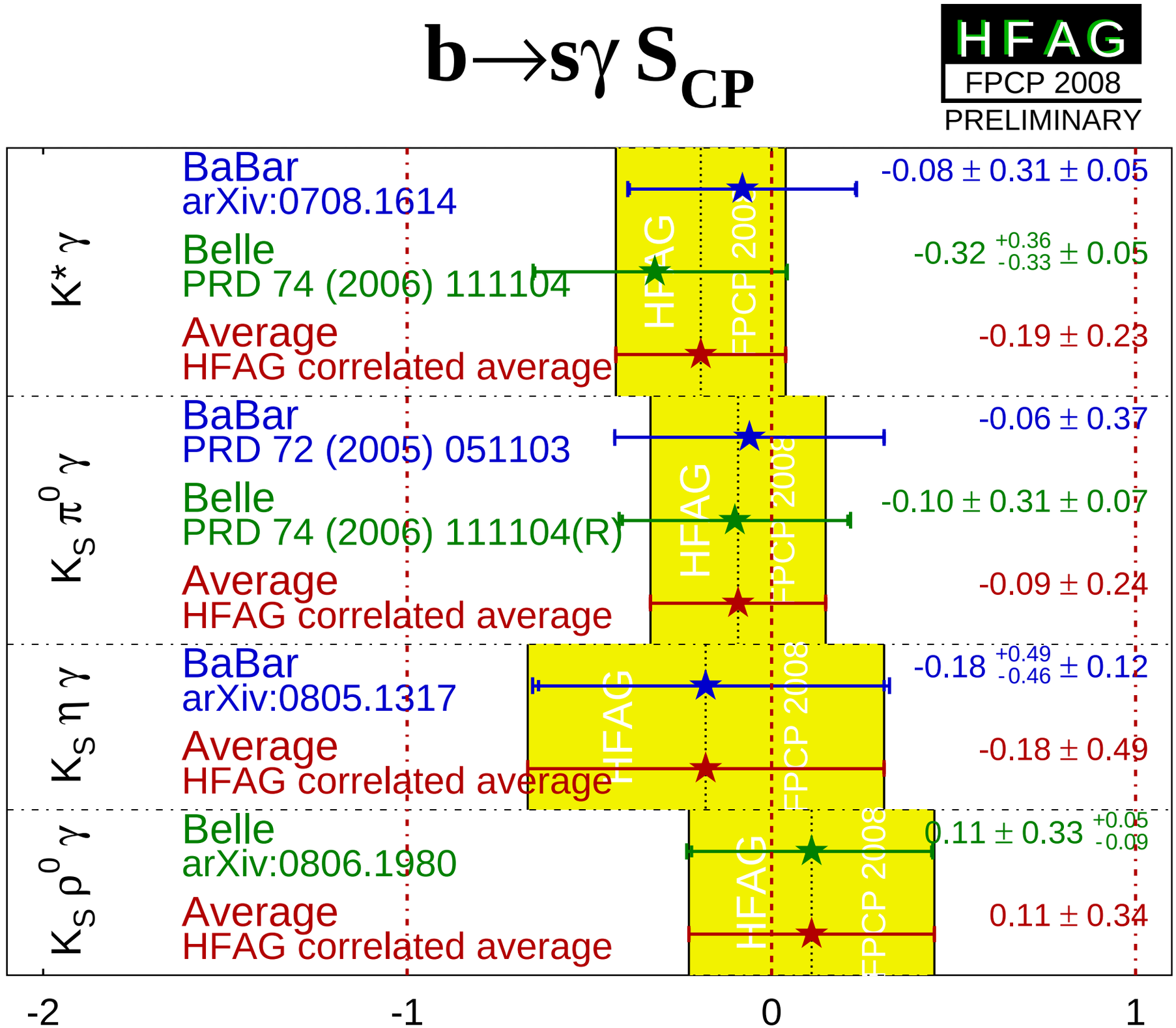
  would be extremely interesting to test with more data

$B \to K^*\ell^+\ell^-$ will be studied at LHCb, but others are not...

Definitely demanding for the next generation B factory!

Backup

$b \to s\gamma$ S_{CP}



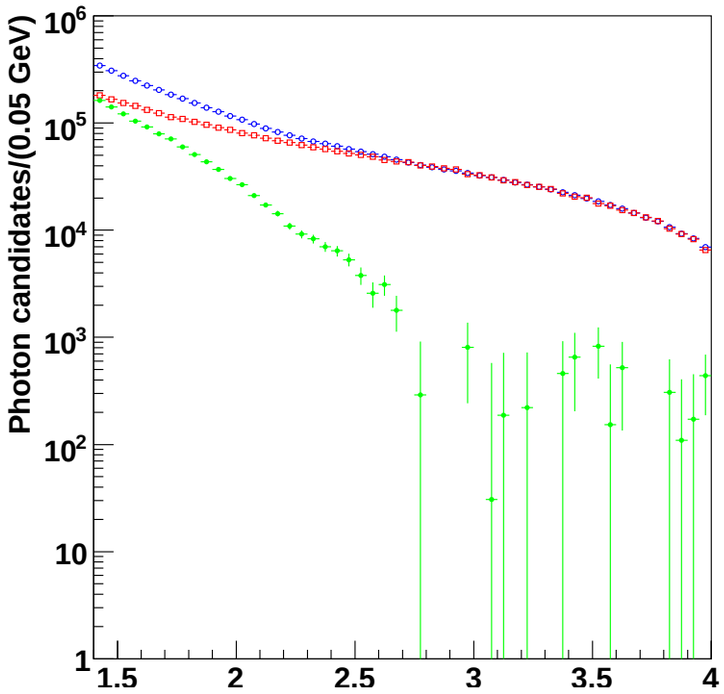
(Plot has to be updated for the latest BaBar result on $B \to K^*\gamma$ and $B \to K_S^0\pi^0\gamma$)

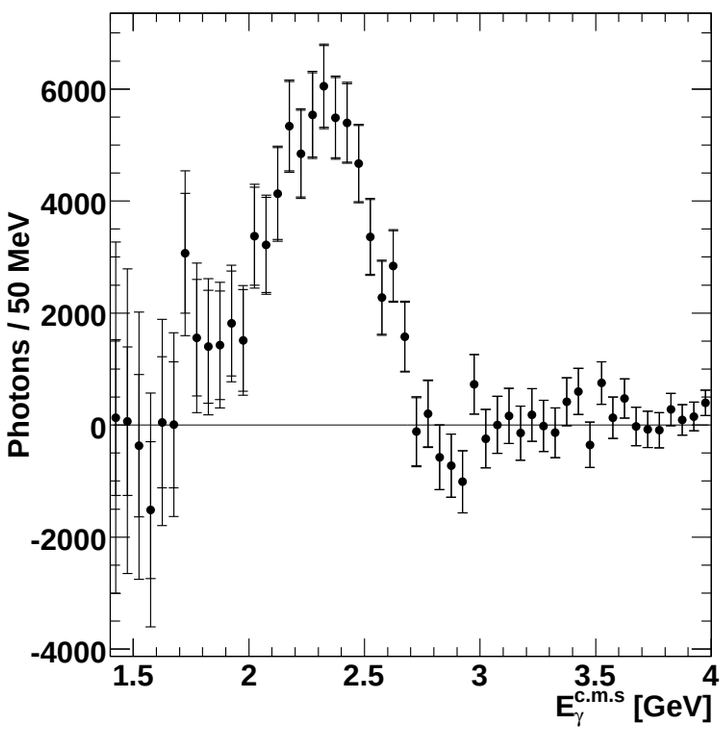
All consistent with no RH current within current sensitivity

References

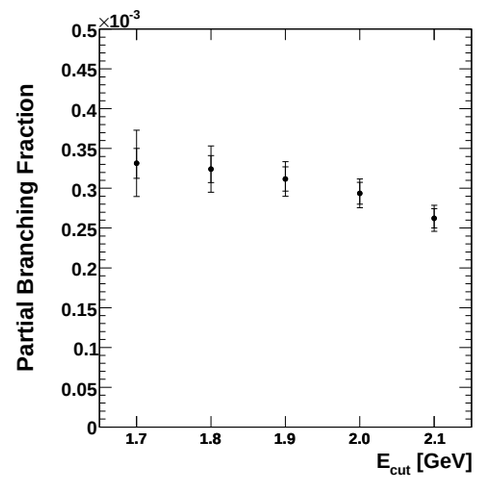
Belle $B \to X_s\gamma$ (657M$B\bar{B}$)

Belle Collaboration, K. Abe *et al.*, arXiv:0804.1580v1 (hep-ex)

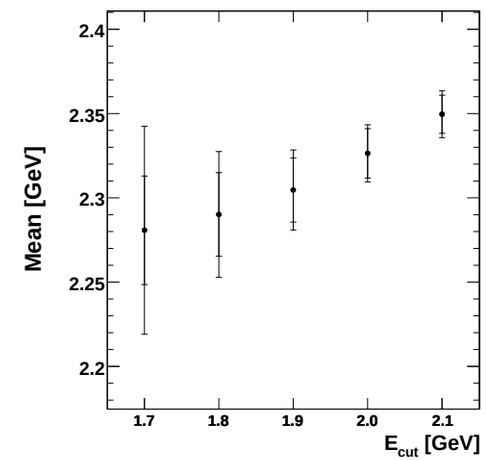




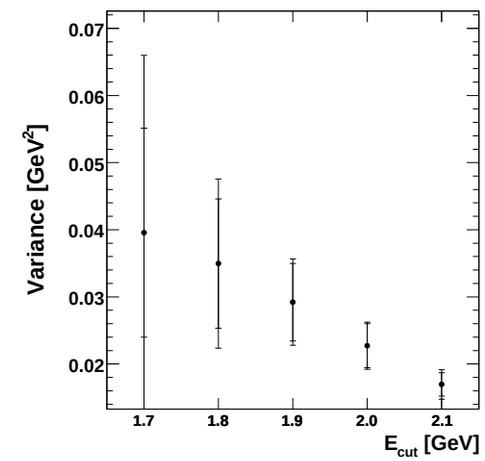
$\mathcal{B}$



Mean



Variance



For $E_\gamma > 1.7$ GeV in B rest frame:

$$\mathcal{B}(B \to X_s\gamma) = (3.31 \pm 0.19 \pm 0.37 \pm 0.01) \times 10^{-4}$$

$$\langle E_\gamma \rangle = (2.281 \pm 0.032 \pm 0.053 \pm 0.002)\ \text{GeV}$$

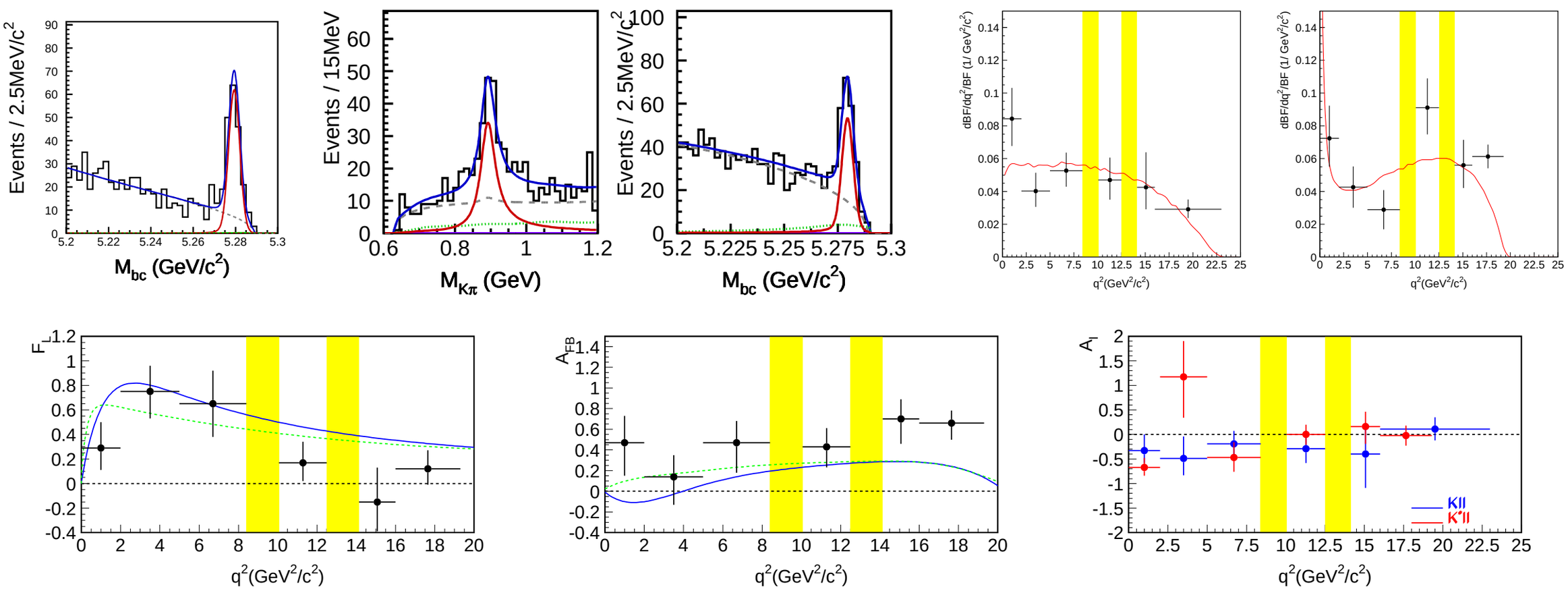
$$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 = (0.0396 \pm 0.0156 \pm 0.0214 \pm 0.0012)\ \text{GeV}^2$$

Belle $B \to K^{(*)}\ell^+\ell^-$ (657M$B\bar{B}$)

Belle Collaboration, I. Adachi *et al.*, arXiv:0810.0335v1 (hep-ex), to be updated soon

	$B \to K\ell^+\ell^-$	$B \to K^*\ell^+\ell^-$
$\mathcal{B}$	$(4.8\,^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}$	$(10.8\,^{+1.1}_{-1.0} \pm 0.09) \times 10^{-7}$
A_{CP}	$-0.04 \pm 0.10 \pm 0.02$	$-0.10 \pm 0.10 \pm 0.02$
$1/R_{K^{(*)}}$	$0.97 \pm 0.18 \pm 0.06$	$1.21 \pm 0.25 \pm 0.08$

(R_K definition here is $e^+e^-/\mu^+\mu^-$ as opposed to usual defs)



(SM curve for $A_{\rm FB}$ in arXiv has to be updated)

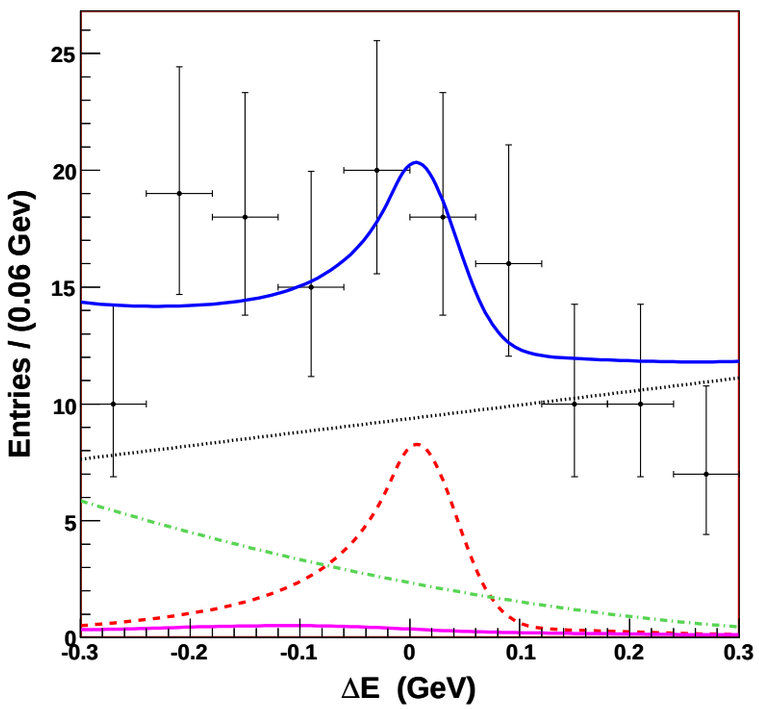
Belle $B \to K\eta'\gamma$ (657M$B\overline{B}$)

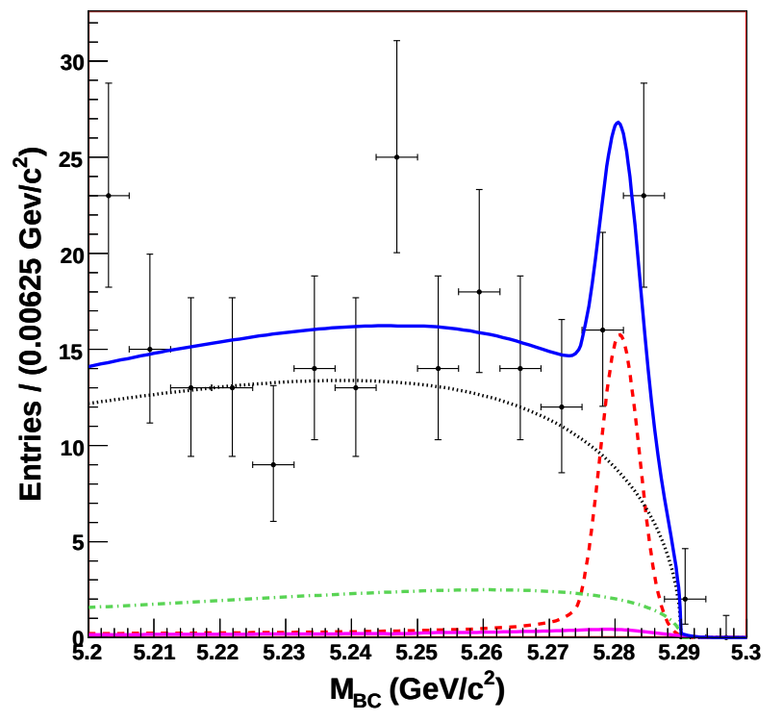
Belle Collaboration, I. Adachi *et al.*, arXiv:0810.0804v1 (hep-ex)

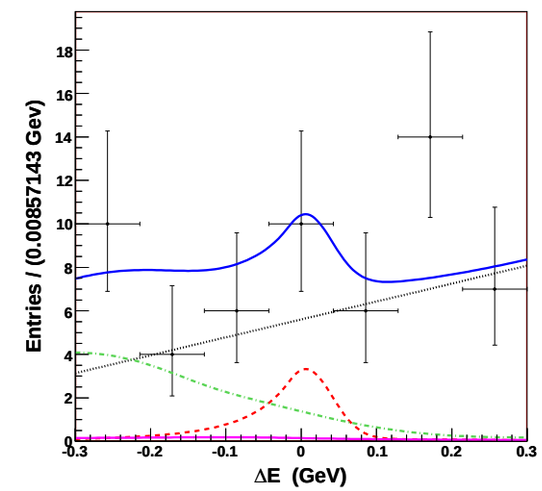
In $M(K\eta') < 3.4$ GeV:

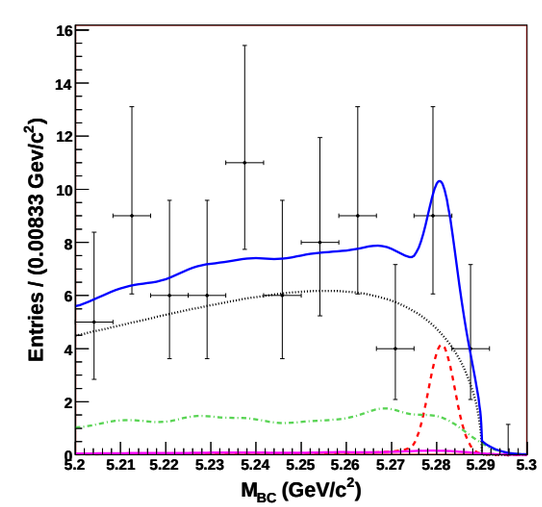
$\mathcal{B}(B \to K^+\eta'\gamma) = (3.2\,^{+1.2}_{-1.1} \pm 0.3) \times 10^{-6}$ (3.3σ)

$\mathcal{B}(B \to K^0\eta'\gamma) < 6.3 \times 10^{-6}$ (90% CL)









First evidence

η' mode is much smaller than η

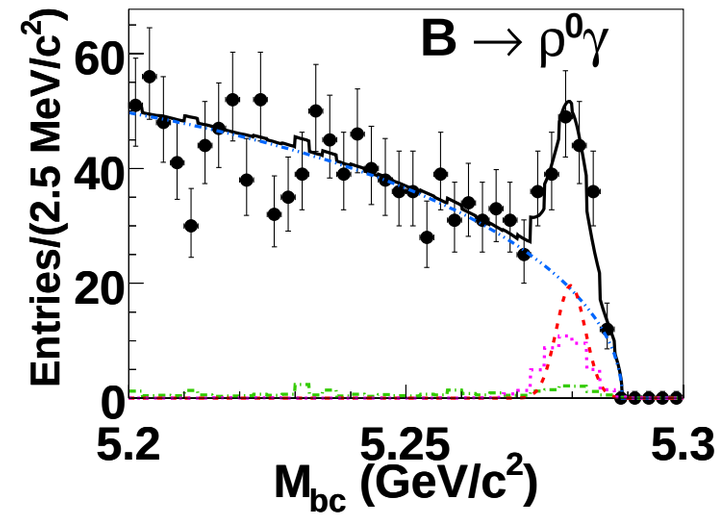
(similar to $B \to \eta^{(\prime)}K^*$, opposite to $B \to \eta^{(\prime)}K$)

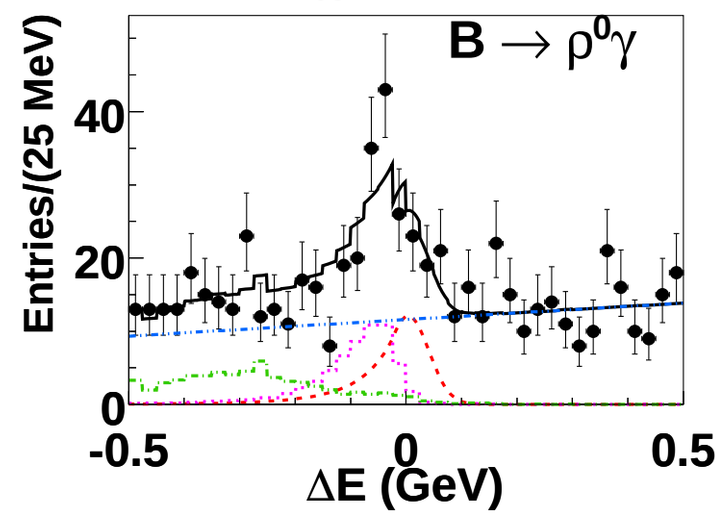
Belle $B \to \rho\gamma, \omega\gamma$ (657M$B\bar{B}$)

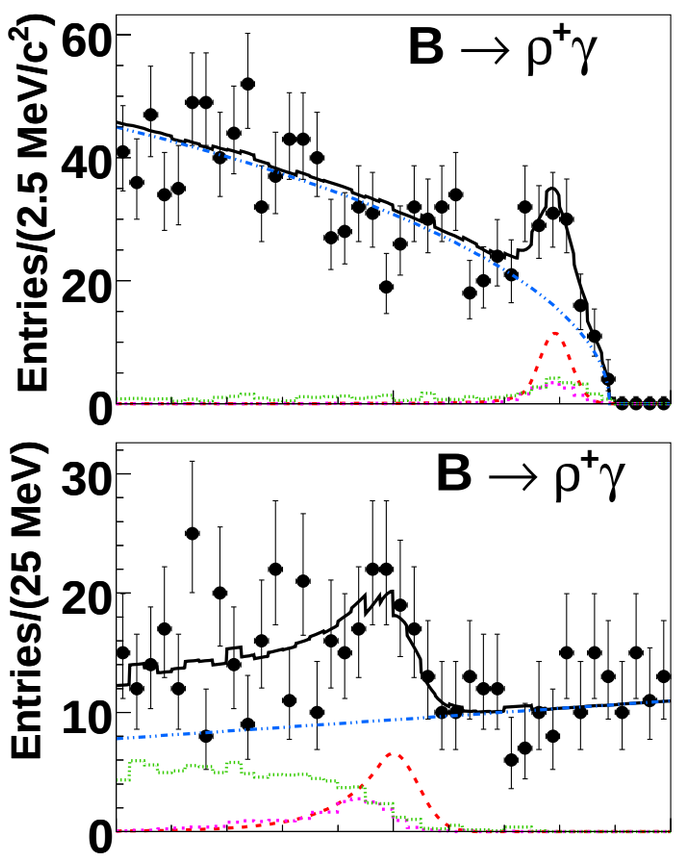
Belle Collaboration, N. Taniguchi *et al.*, Phys. Rev. Lett. **101**, 111801 (2008)

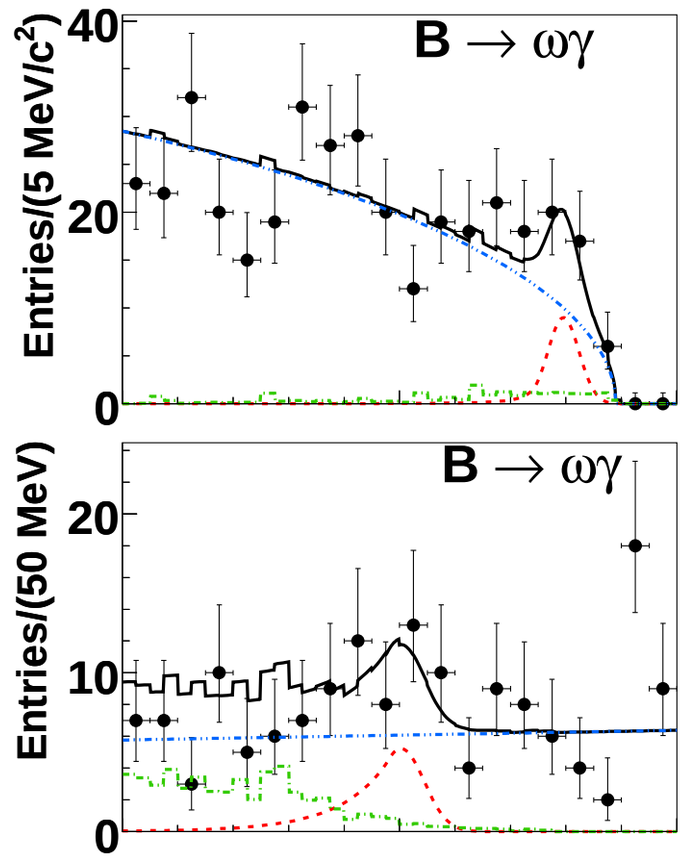
$$\mathcal{B}(B^+ \to \rho^+\gamma) = (8.7\,^{+2.9}_{-2.7}\,^{+0.9}_{-1.1}) \times 10^{-7}$$
$$\mathcal{B}(B^0 \to \rho^0\gamma) = (7.8\,^{+1.7}_{-1.6}\,^{+0.9}_{-1.0}) \times 10^{-7}$$
$$\mathcal{B}(B^0 \to \omega\gamma) = (4.0\,^{+1.9}_{-1.7} \pm 1.3) \times 10^{-7}$$
$$\mathcal{B}(B \to \rho\gamma) = (12.1\,^{+2.4}_{-2.2} \pm 1.2) \times 10^{-7}$$
$$\mathcal{B}(B \to (\rho,\omega)\gamma) = (11.4 \pm 2.0\,^{+1.0}_{-1.2}) \times 10^{-7}$$
$$\Delta_\rho = -0.48\,^{+0.21}_{-0.19}\,^{+0.08}_{-0.09}$$

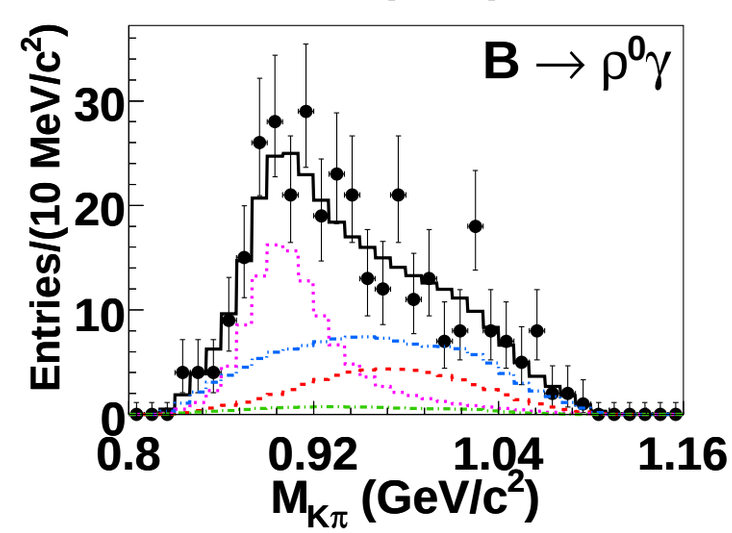
($R^{+/0} = 1$ is assumed)





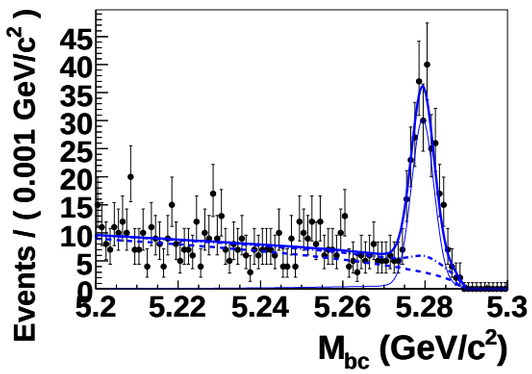






Belle TCPV $B \to K\rho\gamma$ (657M$B\overline{B}$)

Belle Collaboration, J. Li *et al.*, Phys. Rev. Lett. **101**, 251601 (2008)



212 ± 17 events

$M_{K\pi\pi} < 1.8$ GeV

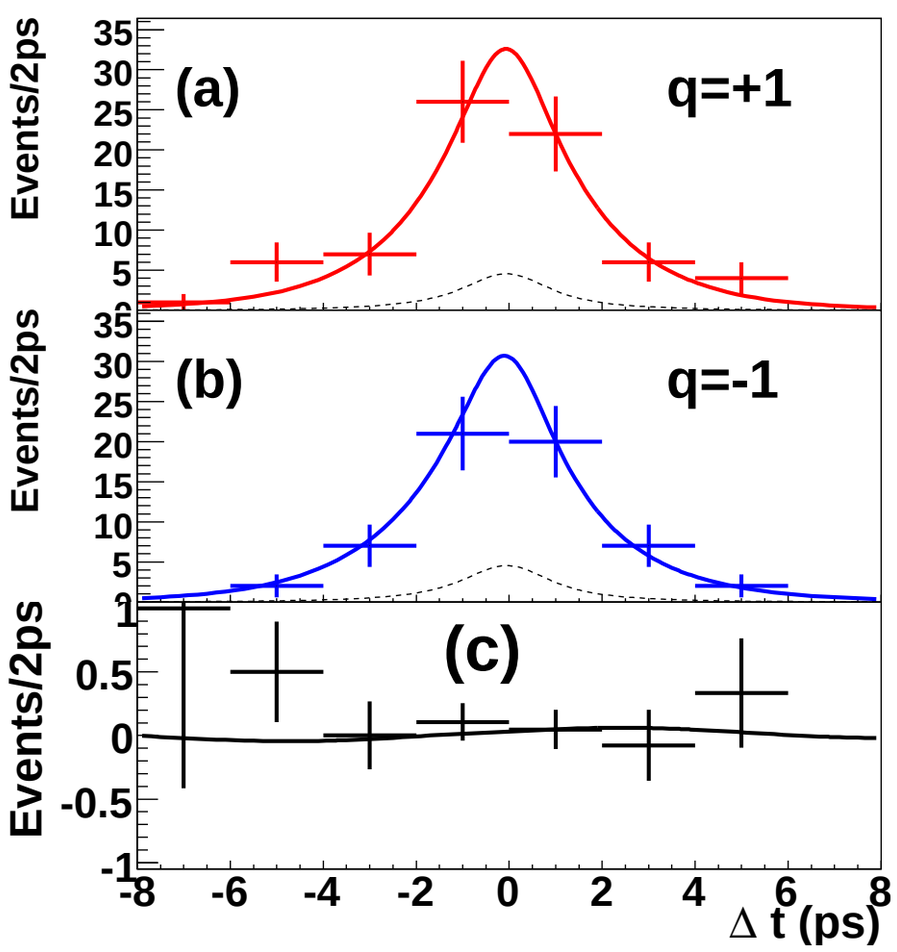
$M_{\pi\pi}[0.6, 0.9]$ GeV:

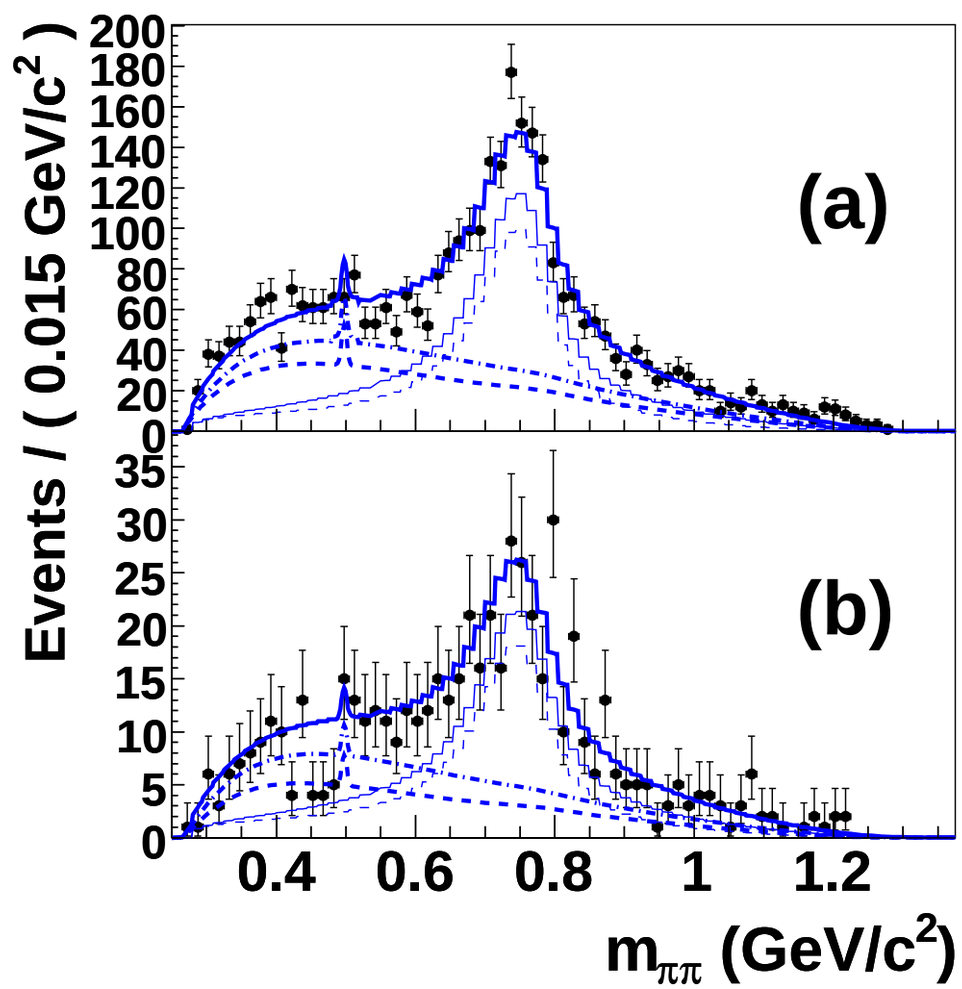
	$K_S^0\rho^0\gamma$	$K^*\pi\gamma$	interf $K\rho/K^*\pi$	interf $K^*/\overline{K}^*$
1^+	151.0	35.1	7.5	4.4
1^-	11.3	8.0	4.9	1.3
K_2^*	2.2	6.1	2.0	4.5
total	164.4	49.2	14.5	10.2

$$\mathcal{D} = 0.83^{+0.19}_{-0.03}$$

$$S_{K_S^0\rho^0\gamma} = +0.11 \pm 0.33^{+0.05}_{-0.09}$$

$$A_{K_S^0\pi^+\pi^-\gamma} = +0.05 \pm 0.18 \pm 0.06$$



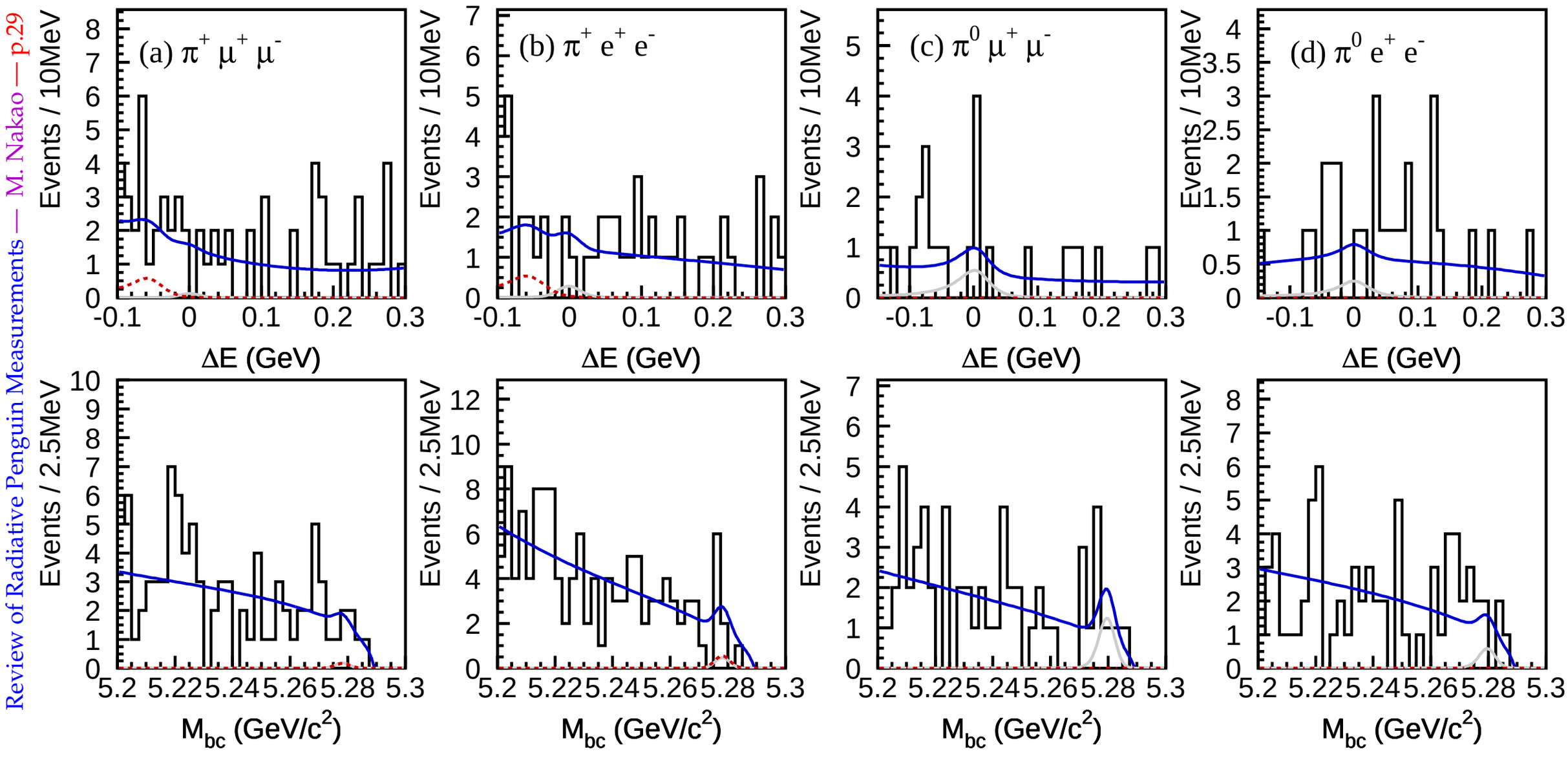


Belle $B \to \pi\ell^+\ell^-$ (657M$B\overline{B}$)

Belle Collaboration, J. T. Wei *et al.*, Phys. Rev. D **78**, 011101(R) (2008)

$$\mathcal{B}(B \to \pi\ell^+\ell^-) < 6.2 \times 10^{-8}$$

	$\pi\mu^+\mu^-$	πe^+e^-	$\pi\ell^+\ell^-$
B^+	$<6.9 \times 10^{-8}$	$<8.0 \times 10^{-8}$	$<22.7 \times 10^{-8}$
B^0	$<18.4 \times 10^{-8}$	$<4.9 \times 10^{-8}$	$<15.4 \times 10^{-8}$



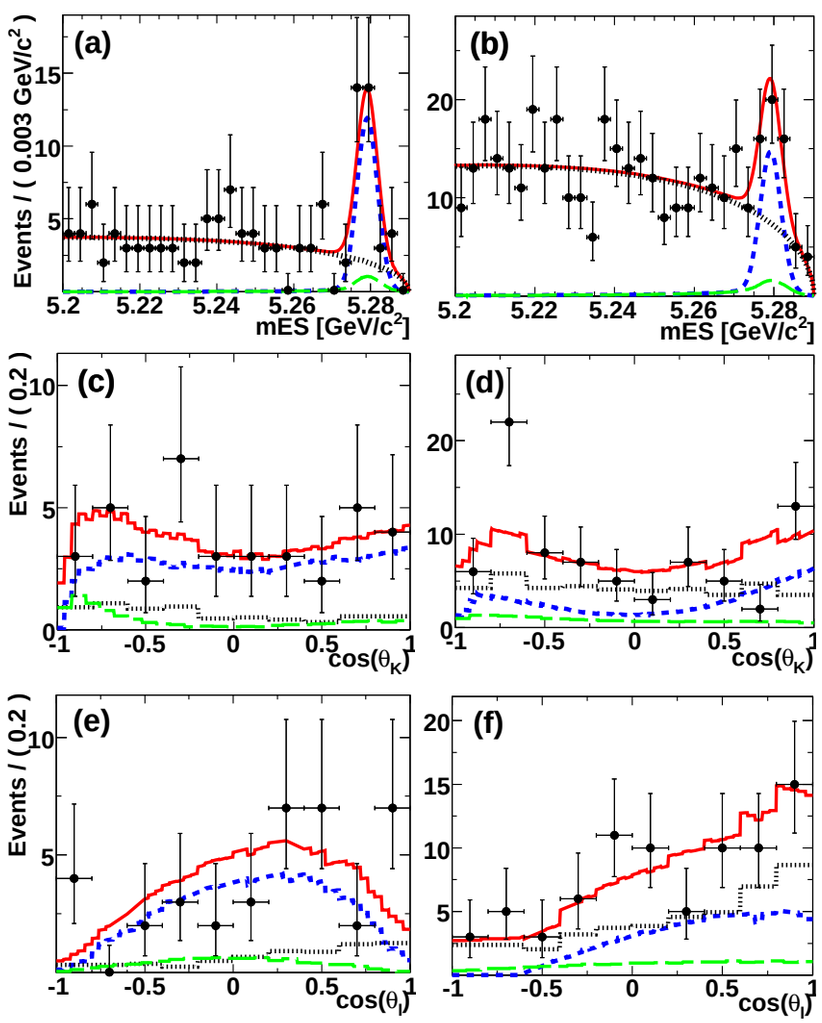
BaBar $B \to K^* \ell^+ \ell^-$ angular distributions (384M$B\overline{B}$)

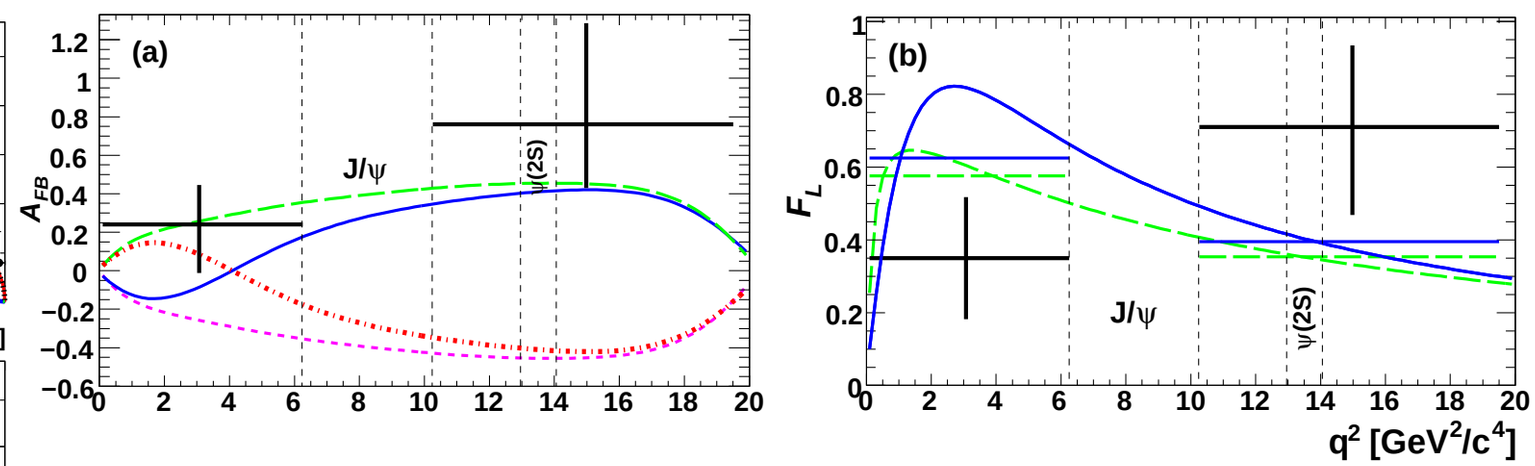
BaBar Collaboration, B. Aubert *et al.*, arXiv:0804.4412v2 (hep-ex)

Kaon angle θ_K and lepton angle θ_ℓ

$$\frac{3}{2} F_L \cos^2\theta_K + \frac{3}{4}(1 - F_L)(1 - \cos^2\theta_K)$$

$$\frac{3}{4} F_L (1 - \cos^2\theta_\ell) + \frac{3}{8}(1 - F_L)(1 + \cos^2\theta_\ell) + A_{\rm FB} \cos\theta_\ell$$





	$M_{\ell^+\ell^-} < 2.5$ GeV	$M_{\ell^+\ell^-} > 3.2$ GeV
$A_{\rm FB}$	$0.24\,^{+0.18}_{-0.23} \pm 0.05$	$0.76\,^{+0.52}_{-0.32} \pm 0.07$
F_L	$0.35 \pm 0.16 \pm 0.04$	$0.71\,^{+0.20}_{-0.22} \pm 0.04$

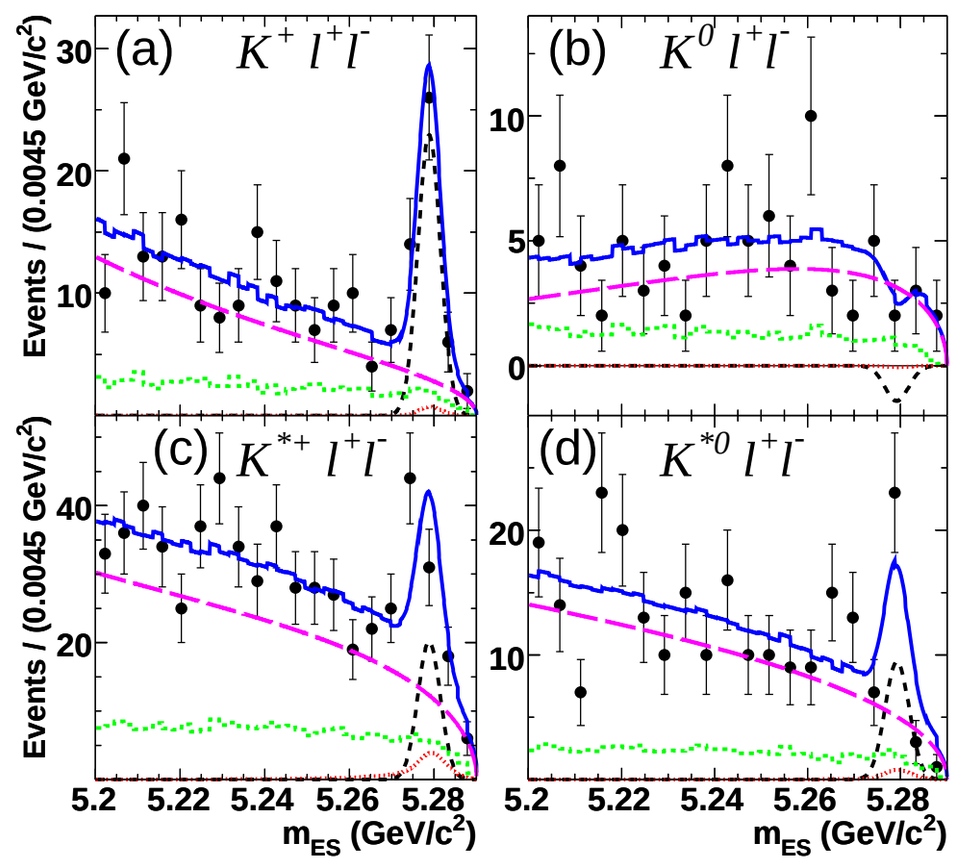
Limit on $C_{10}^{\rm eff NP} \leq 7 \Leftrightarrow C_{10}^{\rm eff SM} = -4.13$ (Altmannshofer *et al.*, arXiv:0811.1214)

BaBar $B \to K^{(*)}\ell^+\ell^-$ asymmetries (384M$B\overline{B}$)

BaBar Collaboration, B. Aubert *et al.*, arXiv:0807.4119v1 (hep-ex)

$$R_{K^{(*)}} = \mathcal{B}(B \to K^{(*)}\mu^+\mu^-)/\mathcal{B}(B \to K^{(*)}e^+e^-)$$
$$A_{CP}^{K^{(*)}} = [\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) - \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)]/[\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) + \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)]$$
$$A_I^{K^{(*)}} = [\Gamma(B^0 \to K^{(*)0}\ell^+\ell^-) - \Gamma(B^\pm \to K^{(*)+}\ell^+\ell^-)]/[\Gamma(B^0 \to K^{(*)0}\ell^+\ell^-) + \Gamma(B^\pm \to K^{(*)+}\ell^+\ell^-)]$$

	$B \to K\ell^+\ell^-$	$B \to K^*\ell^+\ell^-$
$R_{K^{(*)}}$	$0.96\,^{+0.44}_{-0.34} \pm 0.05$	$1.10\,^{+0.42}_{-0.32} \pm 0.07$
($q^2 > 0.1$ GeV)		$1.37\,^{+0.53}_{-0.40} \pm 0.09$
A_{CP}	$-0.18 \pm 0.18 \pm 0.01$	$0.01\,^{+0.16}_{-0.15} \pm 0.01$
(low q^2)	$-0.18 \pm 0.19 \pm 0.01$	$0.01\,^{+0.21}_{-0.20} \pm 0.01$
(high q^2)	$-0.09\,^{+0.36}_{-0.39} \pm 0.02$	$0.09 \pm 0.21 \pm 0.02$
A_I	$-0.37\,^{+0.27}_{-0.34} \pm 0.04$	$-0.12\,^{+0.18}_{-0.16} \pm 0.04$
(low q^2)	$-1.43\,^{+0.56}_{-0.85} \pm 0.05$	$-0.56\,^{+0.17}_{-0.15} \pm 0.03$
(high q^2)	$0.28\,^{+0.24}_{-0.30} \pm 0.03$	$0.18\,^{+0.36}_{-0.28} \pm 0.04$



low q^2: [0.1, 7.02] GeV^2, high q^2: > 10.24 GeV^2 with $\psi(2S)$ veto

$A_I \neq 0$ at low q^2? — 3.2σ for $B \to K\ell^+\ell^-$ 2.7σ for $B \to K^*\ell^+\ell^-$ 3.9σ for $B \to K^{(*)}\ell^+\ell^-$

SM: A_I in +6 – 13% (Feldman-Matias, JHEP 0301, 074 (2003))

BaBar $B \to X_d\gamma$ (383M$B\overline{B}$)

BaBar Collaboration, B. Aubert *et al.*, arXiv:0807.4975v2 (hep-ex)

$B \to X_d\gamma$: $\pi^+\pi^-\gamma, \pi^+\pi^0\gamma, \pi^+\pi^-\pi^0\gamma, \pi^+\pi^-\pi^+\gamma, \pi^+\pi^-\pi^+\pi^-\gamma, \pi^+\pi^-\pi^+\pi^0\gamma, \pi^+\eta\gamma$

$B \to X_s\gamma$: $K^+\pi^-\gamma, K^+\pi^0\gamma, K^+\pi^-\pi^0\gamma, K^+\pi^-\pi^+\gamma, K^+\pi^-\pi^+\pi^-\gamma, K^+\pi^-\pi^+\pi^0\gamma, K^+\eta\gamma$

in $M(X_{s/d})$: $[0.6, 1.8]$ GeV

$$\mathcal{B}(B \to X_d\gamma)_{[0.6,1.8]\mathrm{GeV}} = (7.2 \pm 2.7 \pm 2.3) \times 10^{-6}$$

(correction for full phase space)

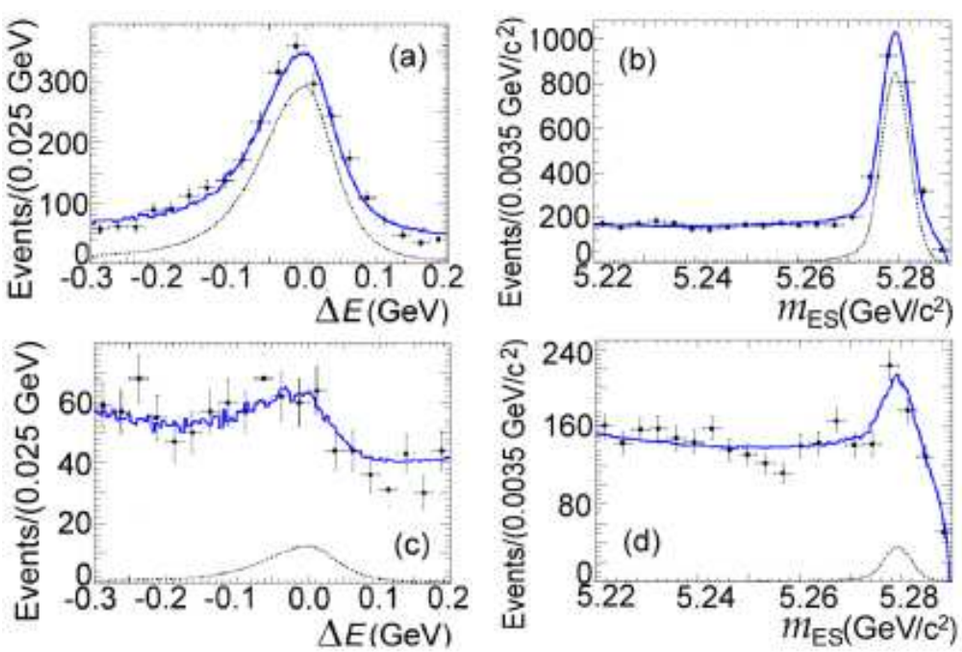
$$\mathcal{B}(B \to X_d\gamma)_{\mathrm{corr}} = (1.4 \pm 0.5 \pm 0.4 \pm 0.1) \times 10^{-5}$$

$$\mathcal{B}(B \to X_s\gamma)_{\mathrm{corr}} = (4.3 \pm 0.3 \pm 0.7 \pm 0.2) \times 10^{-6}$$

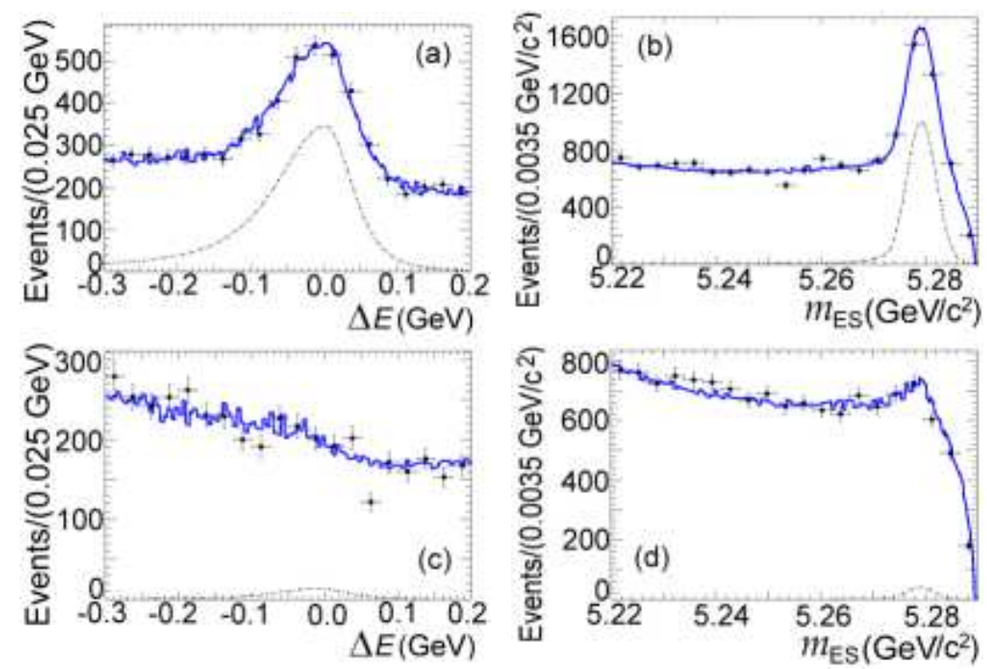
ratio:

$$0.033 \pm 0.013 \pm 0.009$$

$$|V_{td}/V_{ts}| = 0.177 \pm 0.043$$



[0.6, 1.0] GeV



[1.0, 1.8] GeV

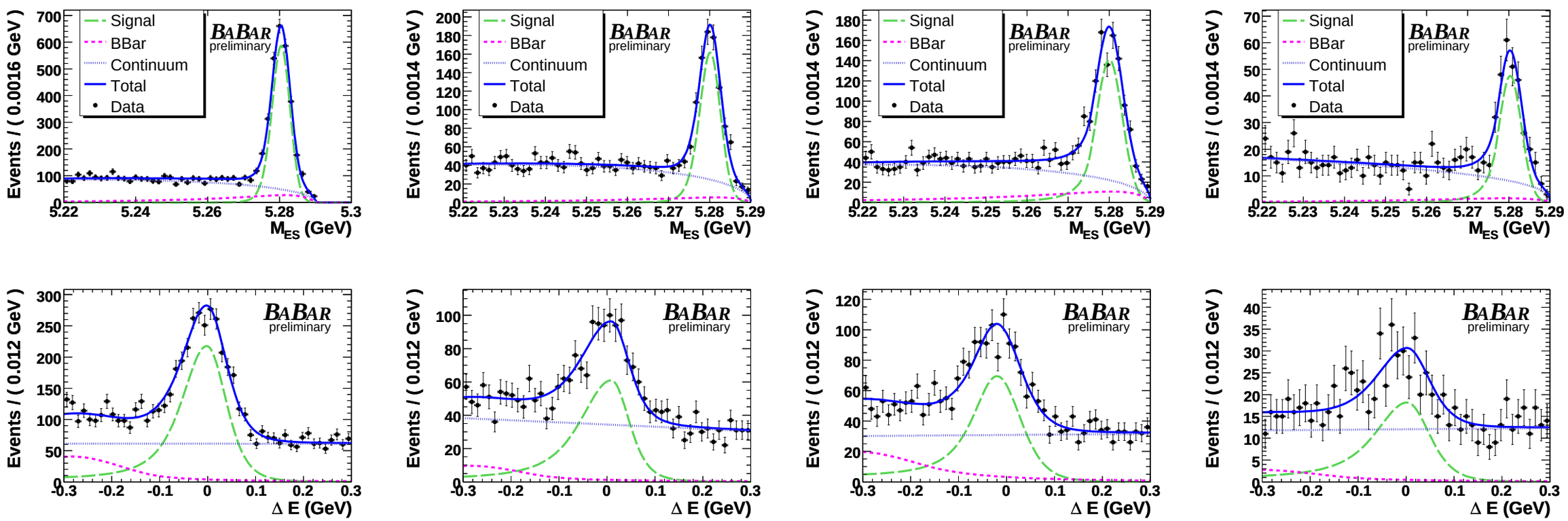
BaBar $B \to K^*\gamma$ (383M$B\bar{B}$)

BaBar Collaboration, B. Aubert *et al.*, arXiv:0808.1915v1 (hep-ex)

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.58 \pm 0.10 \pm 0.16) \times 10^{-5}$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.73 \pm 0.15 \pm 0.17) \times 10^{-5}$$
$$A_{CP}(B \to K^*\gamma) = -0.009 \pm 0.017 \pm 0.011$$
$$\Delta_{0-}(B \to K^*\gamma) = 0.029 \pm 0.019 \pm 0.016 \pm 0.018$$

(Δ_{0-}: isospin asymmetry with $\tau_+/\tau_0 = 1.071 \pm 0.009$, $R^{+/0} = 1.020 \pm 0.034$(HFAG))

All consistent with SM



$B^0 \to (K^+\pi^-)\gamma$ $B^+ \to (K^0_S\pi^+)\gamma$ $B^+ \to (K^+\pi^0)\gamma$ $B^0 \to (K^0_S\pi^0)\gamma$

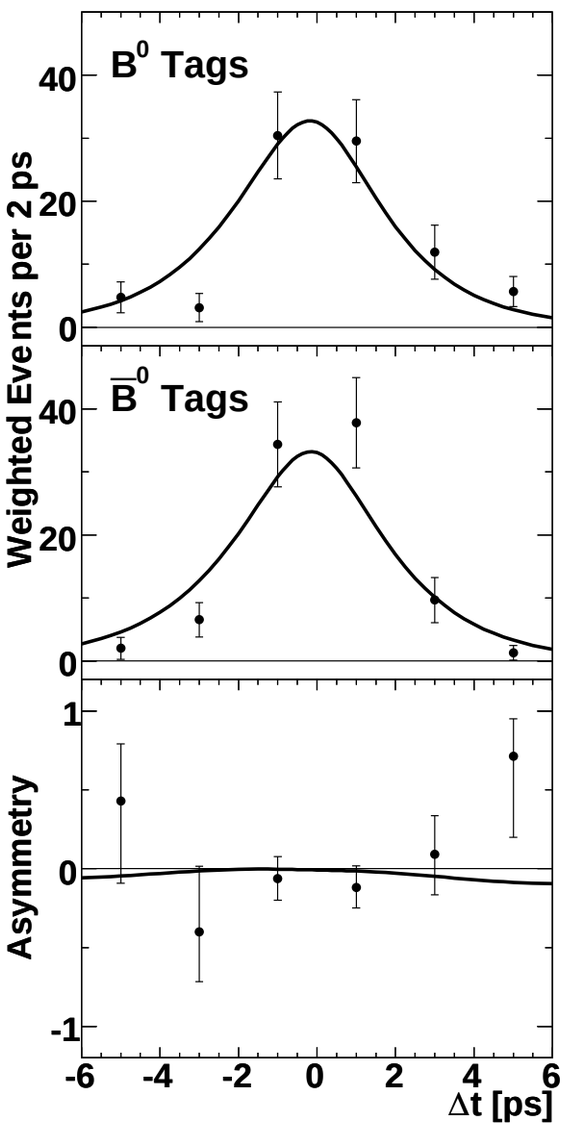
BaBar TCPV $B \to K_S^0 \pi^0 \gamma$ (467M$B\bar{B}$)

BaBar Collaboration, B. Aubert *et al.*, Phys. Rev. D **78**, 071102(R) (2008)

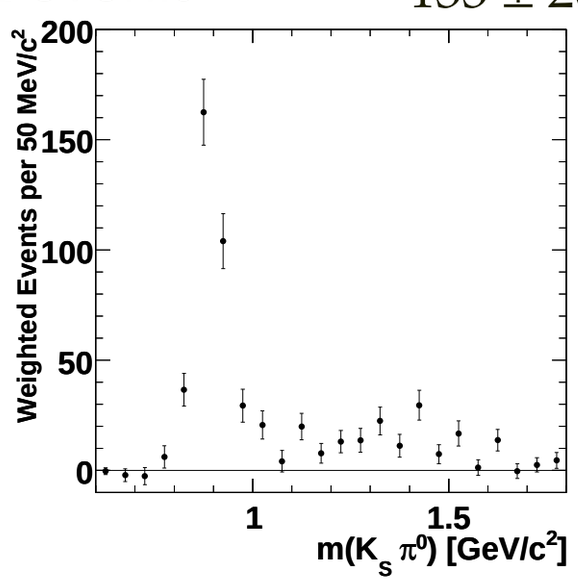
$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}[1 \pm \mathcal{S}\sin(\Delta m \Delta t) \mp \mathcal{C}\cos(\Delta m \Delta t)]$$

$$\mathcal{S}_{K^*\gamma} = -0.03 \pm 0.29 \pm 0.03$$
$$\mathcal{C}_{K^*\gamma} = -0.14 \pm 0.16 \pm 0.03$$

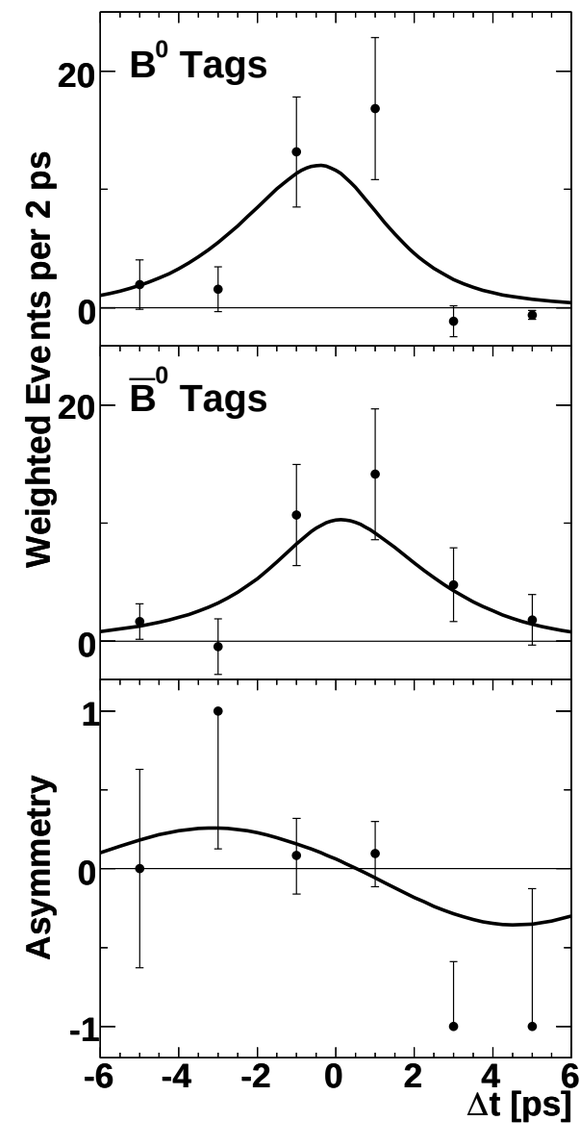
$$\mathcal{S}_{K_S^0\pi^0} = -0.78 \pm 0.59 \pm 0.09$$
$$\mathcal{C}_{K_S^0\pi^0} = -0.36 \pm 0.33 \pm 0.04$$



$m(K_S^0\pi^0)$ in
$[0.8, 1.0]$ GeV
339 ± 24 events



$m(K_S^0\pi^0)$ in
$[1.1, 1.8]$ GeV
133 ± 20 events



BaBar $B \to \rho\gamma$, $\omega\gamma$ (465M$B\overline{B}$)

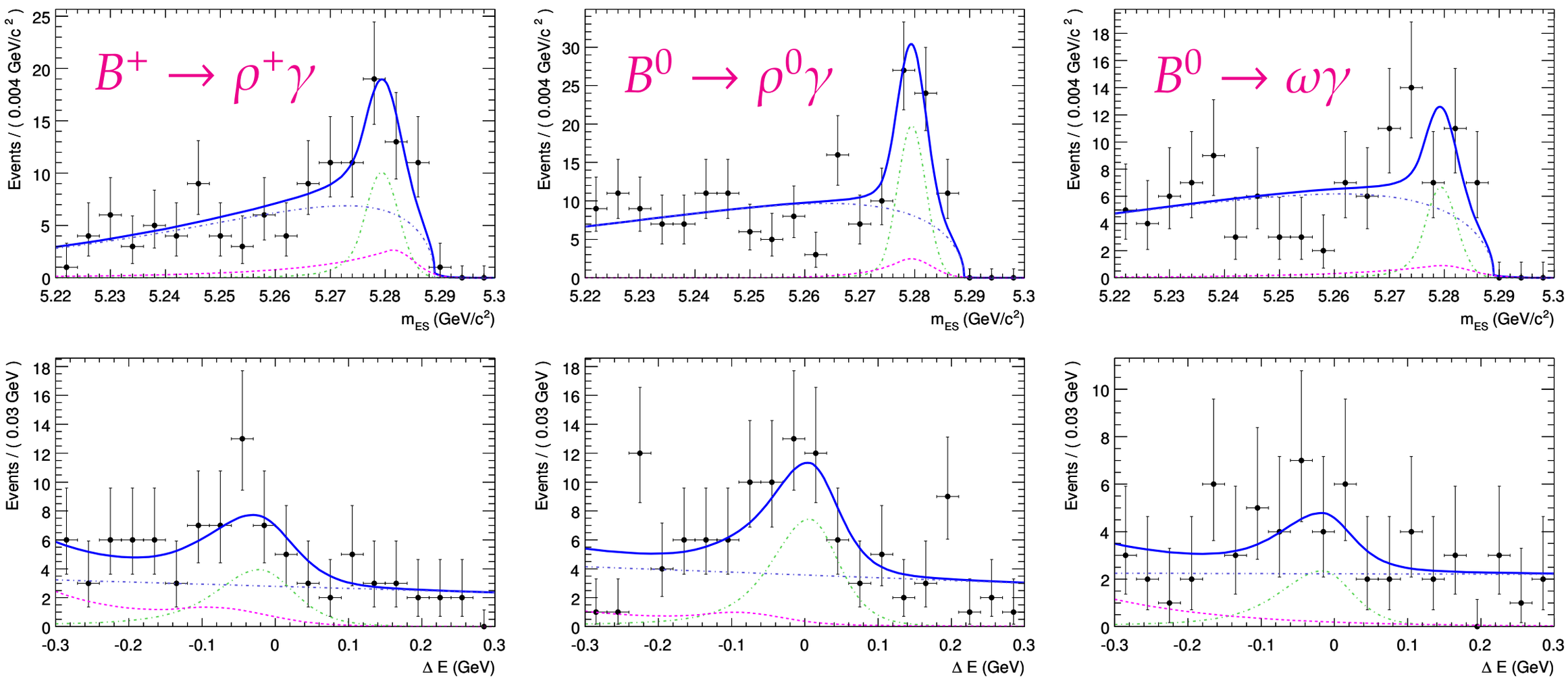
BaBar Collaboration, B. Aubert *et al.*, Phys. Rev. D **78**, 112001 (2008)

$$\mathcal{B}(B^+ \to \rho^+\gamma) = (12.0\,^{+4.2}_{-3.7} \pm 2.0) \times 10^{-7}$$
$$\mathcal{B}(B^0 \to \rho^0\gamma) = (9.7\,^{+2.4}_{-2.2} \pm 0.6) \times 10^{-7}$$
$$\mathcal{B}(B^0 \to \omega\gamma) = (5.0\,^{+2.7}_{-2.3} \pm 0.9) \times 10^{-7}$$
$$< 9 \times 10^{-7}$$
$$\mathcal{B}(B \to \rho\gamma) = (17.3\,^{+3.4}_{-3.2} \pm 1.7) \times 10^{-7}$$
$$\mathcal{B}(B \to (\rho,\omega)\gamma) = (16.3\,^{+3.0}_{-2.8} \pm 1.6) \times 10^{-7}$$

$$\Delta_\rho = -0.43\,^{+0.25}_{-0.22} \pm 0.10$$

($R^{+/0} = 1$ is assumed)

Large Δ_ρ could be sign of new physics? Or could be from non-perturbative charming penguin? (C. Kim *et al.*PRD78,054024(2008))



BaBar $B \to K\eta\gamma$ (465M$B\overline{B}$)

BaBar Collaboration, B. Aubert *et al.*, Phys. Rev. D **78**, 112001 (2008)

$M(K\eta) < 3.25$ GeV:

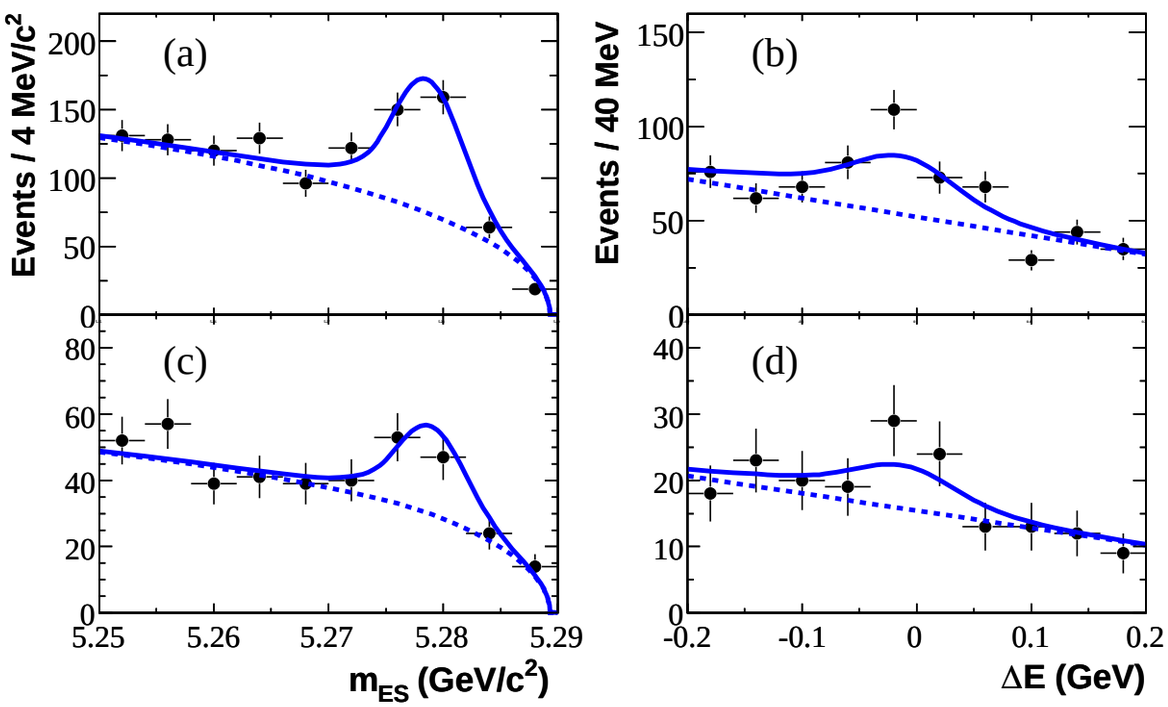
$\mathcal{B}(B^+ \to K^+\eta\gamma) = (7.7 \pm 1.0 \pm 0.4) \times 10^{-6}$

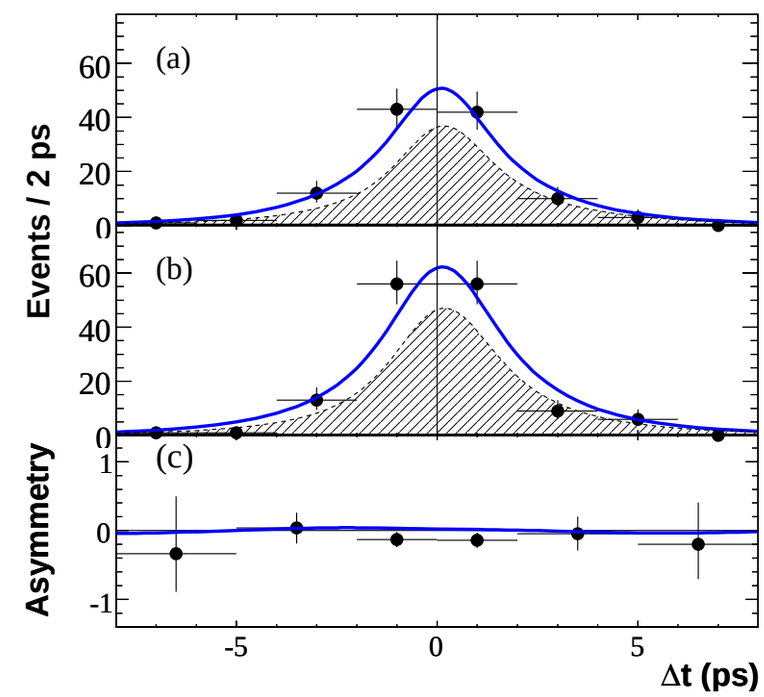
$\mathcal{B}(B^0 \to K^0\eta\gamma) = (7.1\,^{+2.1}_{-2.0} \pm 0.4) \times 10^{-6}$

$\mathcal{S}_{K^0_S\eta\gamma} = -0.18\,^{+0.49}_{-0.46} \pm 0.12$

$\mathcal{C}_{K^0_S\eta\gamma} = -0.32\,^{+0.40}_{-0.39} \pm 0.07$

$A_{CP}K^0_S\eta\gamma = (-9.0\,^{+10.4}_{-9.8} \pm 1.4) \times 10^{-2}$





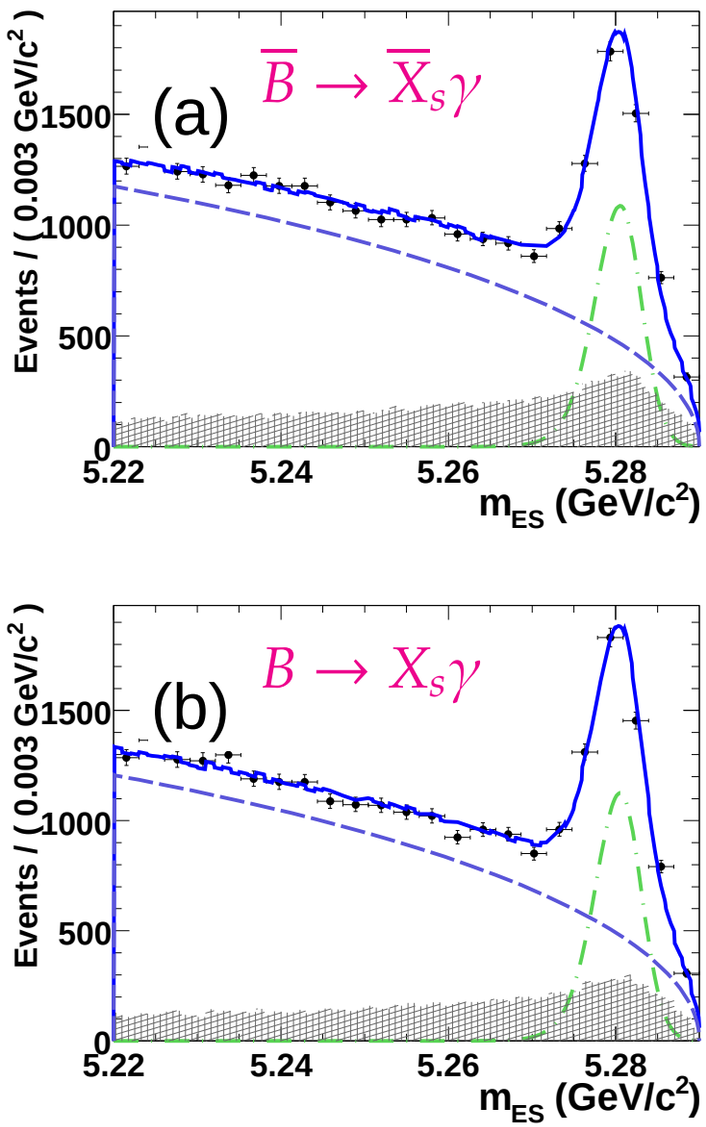
BaBar $A_{CP}(B \to X_s\gamma)$ (383M$B\overline{B}$)

BaBar Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **101**, 171804 (2008)

sum of 16 exclusive modes in $M(X_s) < 2.8$ GeV:

B^+ — $K^0_S\pi^+\gamma$, $K^+\pi^-\gamma$, $K^+\pi^-\pi^+\gamma$, $K^0_S\pi^+\pi^0\gamma$, $K^+\pi^0\pi^0\gamma$, $K^0_S\pi^+\pi^-\pi^+\gamma$, $K^+\pi^-\pi^+\pi^0\gamma$, $K^0_S\pi^+\pi^0\pi^0\gamma$, $K^+\eta\gamma$, $K^+K^-K^+\gamma$

B^0 — $K^+\pi^-\gamma$, $K^+\pi^-\pi^0\gamma$, $K^+\pi^-\pi^+\pi^-\gamma$, $K^+\pi^-\pi^0\pi^0\gamma$, $K^+\pi^-\eta\gamma$, $K^+K^-K^+\pi^-\gamma$



$$A_{CP}(B \to X_s\gamma) = -0.011 \pm 0.030 \pm 0.014$$

dilution factor: $1 - \langle D \rangle = (5.4 \pm 0.1) \times 10^{-3}$

wrong-flavor asymmetry: $\Delta D = (5 \pm 4) \times 10^{-5}$

0.6–1.1 GeV	$+0.010 \pm 0.029 \pm 0.015$
1.1–1.5 GeV	$+0.000 \pm 0.049 \pm 0.016$
1.5–2.0 GeV	$-0.047 \pm 0.077 \pm 0.014$
2.0–2.8 GeV	$-0.077 \pm 0.180 \pm 0.182$

CDF $B \to K^{(*)}\ell^+\ell^-$ (924 pb^{-1})

CDF Collaboration, T. Aaltonen *et al.*, PRD **79**, 011104 (2009)

$$\mathcal{B}(B^+ \to K^+\mu^+\mu^-) = (5.9 \pm 1.5 \pm 0.4) \times 10^{-7}$$

$$\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-) = (8.1 \pm 3.0 \pm 1.0) \times 10^{-7}$$

$$\frac{\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)}{\mathcal{B}(B \to J/\psi\phi)} < 2.6\ (2.3) \times 10^{-3}\ \text{(95(90)\% CL)}$$