Rare Decays at B Factories

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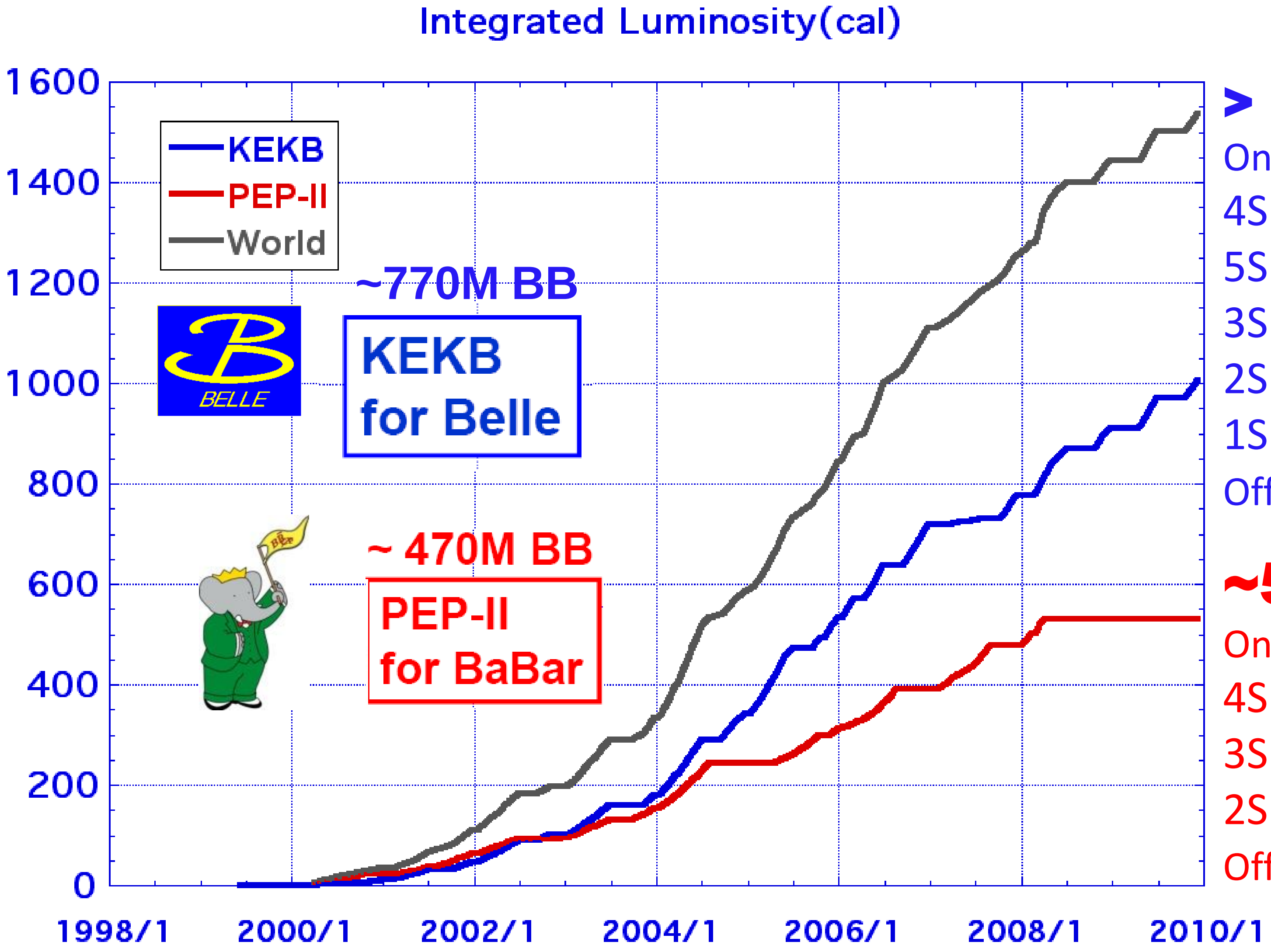
Luminosity at the B Factories



~770M BB

KEKB for Belle

~ 470M BB

PEP-II for BaBar

> 1.0 ab^{-1}

On-resonance samples:

4S: 711 fb^{-1}

5S: 121 fb^{-1}

3S: 3.0 fb^{-1}

2S: 24 fb^{-1}

1S: 5.7 fb^{-1}

Off-resonance: 87 fb^{-1}

~553 fb^{-1}

On-resonance samples:

4S: 433 fb^{-1}

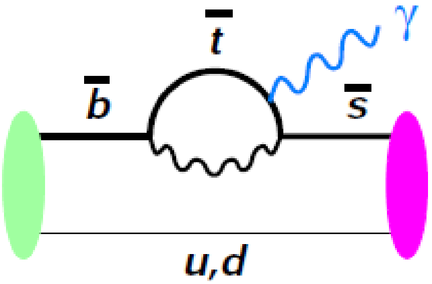
3S: 30 fb^{-1}

2S: 14 fb^{-1}

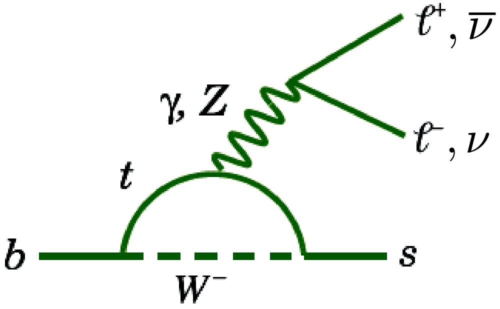
Off-resonance: 54 fb^{-1}

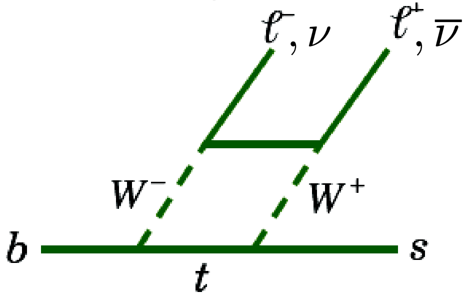
Rare Decays, Loops and Penguins

- Flavor changing neutral current (FCNC) processes are forbidden at tree level ➔ loops make them sensitive to potential contributions from new physics.
  - Radiative penguins, e.g., $b \to s\gamma$:

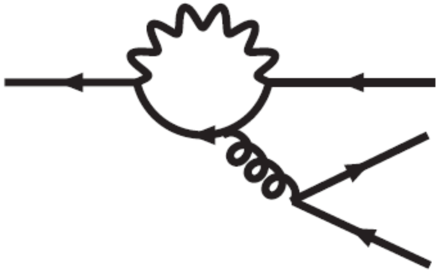


  - Electroweak penguins or box diagrams, e.g., $b \to s\ell\ell$,$b \to s\nu\bar{\nu}$:



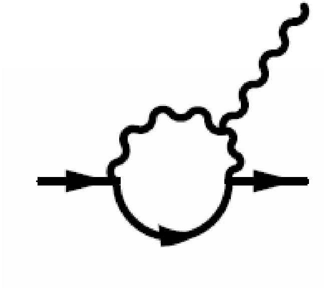


  - Hadronic penguins, e.g., $b \to sg$:

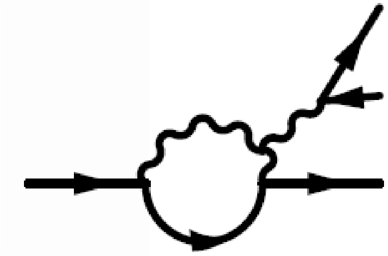


Outline

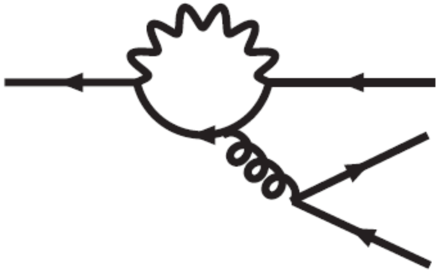
- Radiative penguins: $b \rightarrow s\gamma$
  - Exclusive:
    - $B \rightarrow K\eta^{(\prime)}\gamma$
    - $B \rightarrow K\phi\gamma$
    - $B \rightarrow K^{*}\gamma$
  - Inclusive



- Electroweak penguins: $b \rightarrow s\ell^{+}\ell^{-}, b \rightarrow s\nu\overline{\nu}$
  - Exclusive:
    - $B \rightarrow K^{(*)}\ell\ell$
    - $B \rightarrow K\nu\overline{\nu}$
  - Inclusive

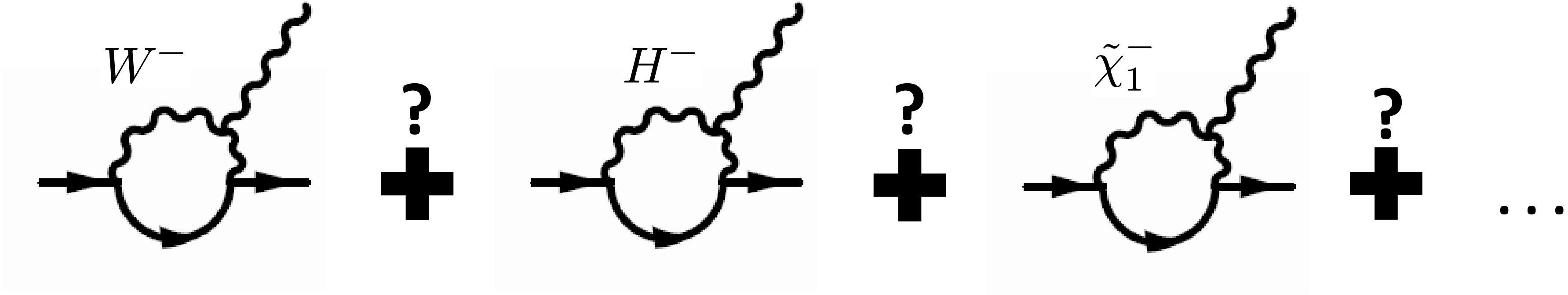


- Hadronic penguins: $b \rightarrow sg, b \rightarrow sq\overline{q}$
  - Exclusive:
    - $B \rightarrow \eta^{(\prime)}K^{(*)}$
    - $B \rightarrow \eta^{\prime}\rho$
    - $B \rightarrow \eta^{\prime}f_0$
  - Inclusive: $B \rightarrow X_s\eta^{(\prime)}$



Radiative Penguins: $b \to s\gamma$

- Extensions of the Standard Model can have particles that contribute in the loops…



- Search for beyond SM contributions in:
  - Branching fractions
    - Inclusive measurements ➔ more experimental uncertainty, smaller theoretical uncertainties.
    - Exclusive measurements ➔ smaller experimental uncertainty, larger theoretical uncertainties (hadronic uncertainties).
  - CP asymmetries
  - Isospin asymmetries

Exclusive $B \to K^*(892)\gamma$

383M BB
PRL **103**, 211802 (2009)

- Branching fractions:

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.47 \pm 0.10 \pm 0.16) \times 10^{-5}$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.22 \pm 0.14 \pm 0.16) \times 10^{-5}$$

- CP asymmetry:

$$\mathcal{A} = \frac{\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)}$$

Measured:

$$\mathcal{A} = -0.003 \pm 0.017 \pm 0.007$$
$$-0.033 < \mathcal{A} < 0.028$$ (90% CL)

SM:
~1%

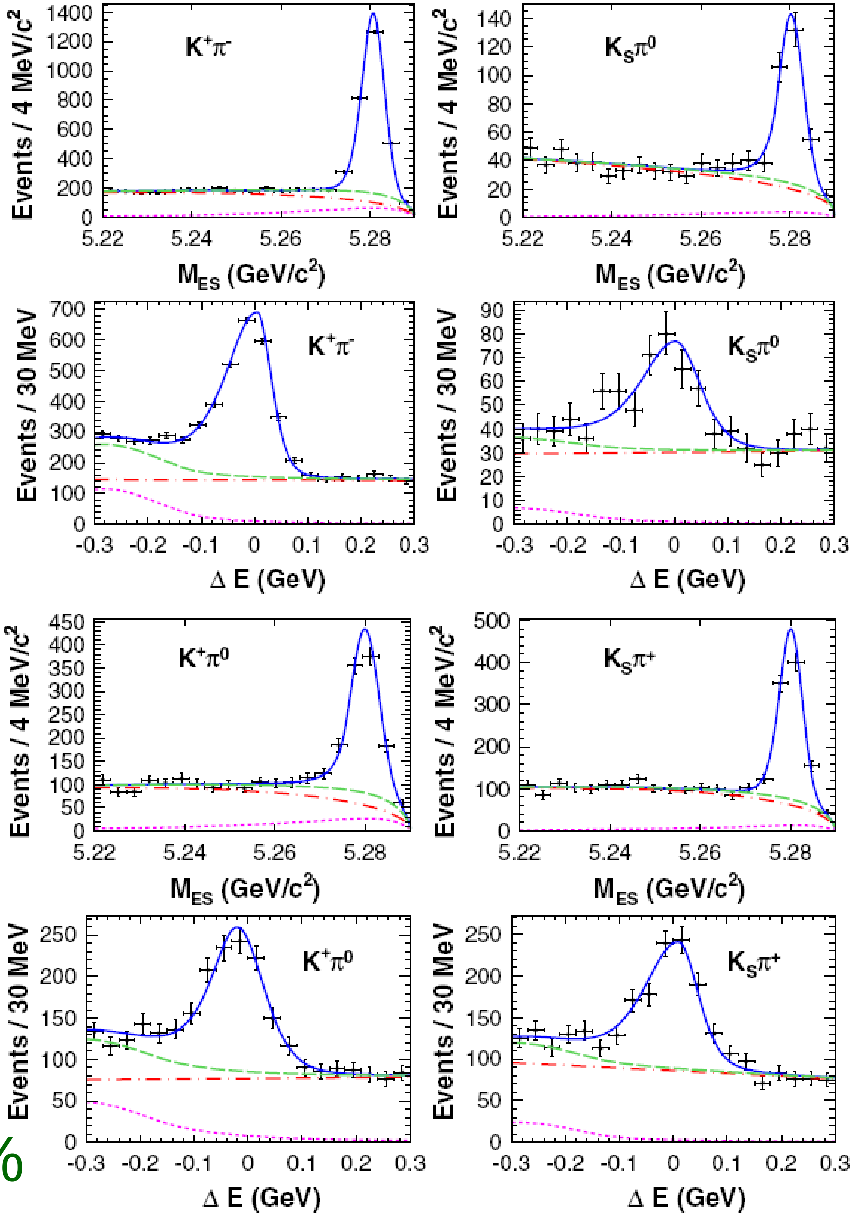
- Isospin asymmetry:

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

Measured:

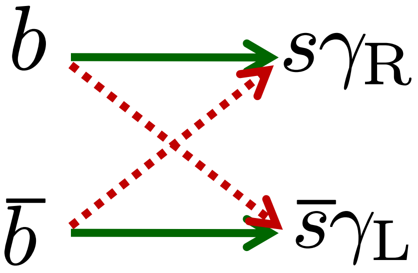
$$\Delta_{0-} = 0.066 \pm 0.021 \pm 0.022$$
$$0.017 < \Delta_{0-} < 0.116$$ (90% CL)

SM:
2-10%



$b \rightarrow s\gamma$ & Right Handed Currents

- In SM, photon polarizations in $b \rightarrow s\gamma$ depend on *b* flavor:



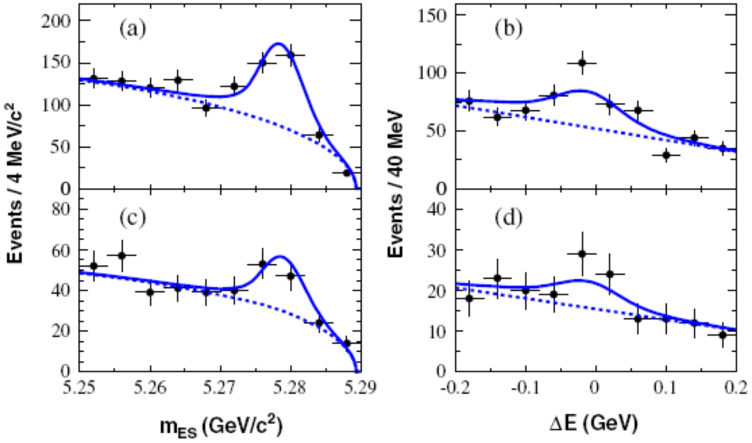
🟩 : **Allowed**

🟥 : **Suppressed by m_s / m_b**

- Presence of mixing-induced CP violation would indicate the presence of right handed currents and clear hints of new physics.
  - This type of new physics does not require a new phase.

Exclusive $B \to K\eta\gamma$

465M BB
PRD **79**, 011102 (2009)



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

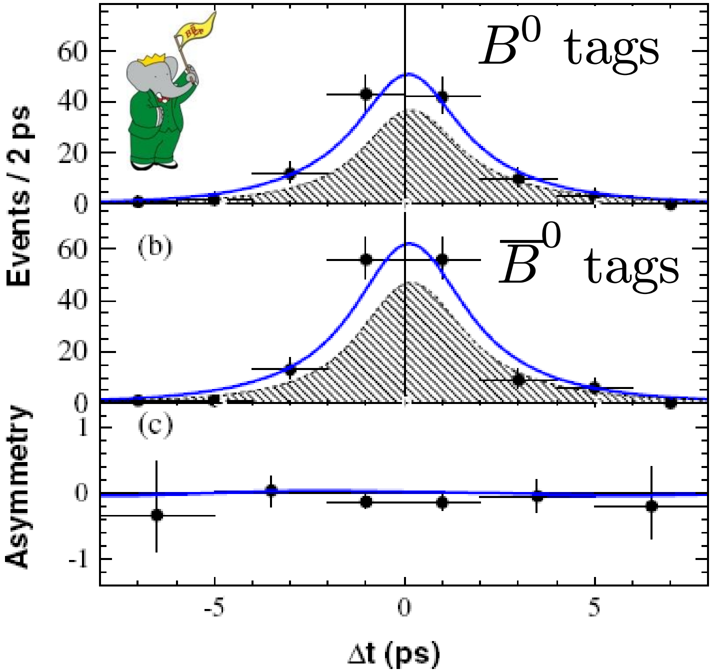
$$A_{\mathrm{CP}} = (-9.0^{+10.4}_{-9.8} \pm 1.4) \times 10^{-2}$$

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

First time dependent CPV search in this mode:

$$S = -0.18^{+0.49}_{-0.46} \pm 0.12$$

$$C = -0.32^{+0.40}_{-0.39} \pm 0.07$$



Similar mode, $B^0 \to K^0_S\rho^0\gamma$ measured at Belle w/ 657 M BB [PRL **101**, 251601 (2008)]:

$$S(B^0 \to K^0_S\rho^0\gamma) = 0.11 \pm 0.33^{+0.05}_{-0.09}$$

$$C(B^0 \to K^0_S\rho^0\gamma) = -0.05 \pm 0.18 \pm 0.06$$

In both cases, analyses need improved statistics.
Potentially promising for Super B factories!

Exclusive $B \to K\eta'\gamma$, $B \to K\phi\gamma$

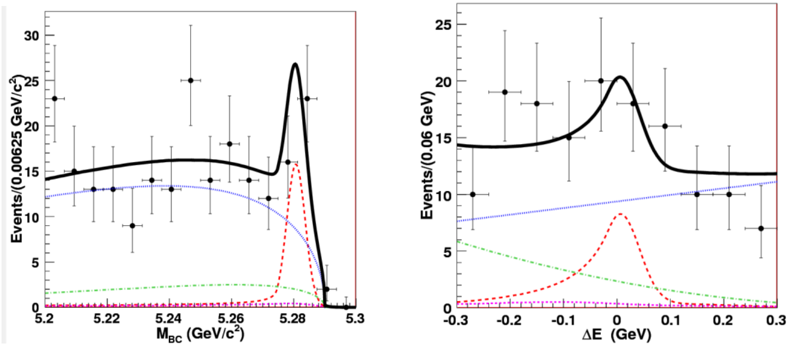
$B \to K\eta'\gamma$

657M BB
arXiv: 0810.0804, Submitted to PRD(RC)

$$\mathcal{B}(B^0 \to K^0\eta'\gamma) \leq 6.4 \times 10^{-6} \text{ (90\% CL)}$$

$$\mathcal{B}(B^+ \to K^+\eta'\gamma) = (3.6 \pm 1.2 \pm 0.4) \times 10^{-6}$$

First evidence w/ 3.3σ significance



$B \to K\phi\gamma$

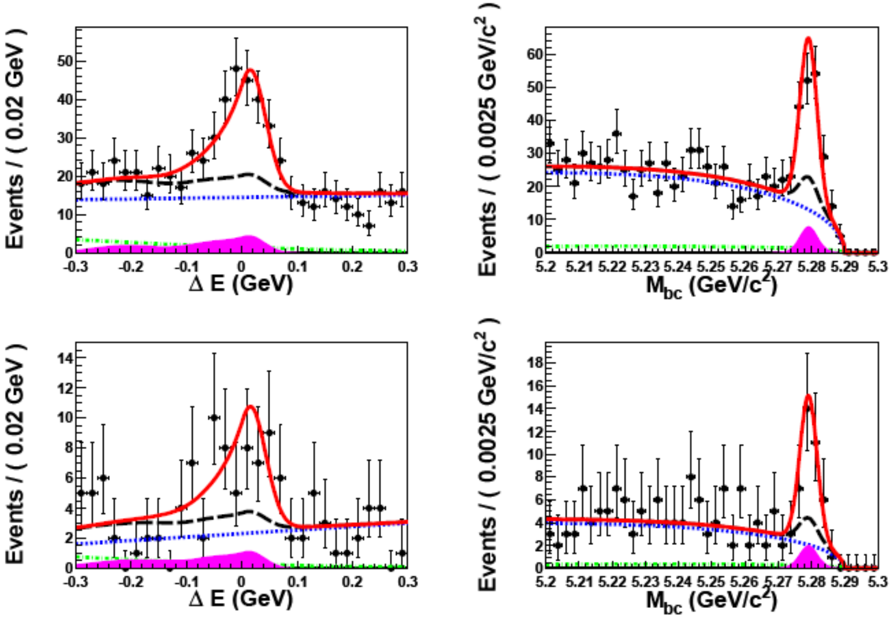
772M BB
Preliminary, arXiv: 0911.1779

$$\mathcal{B}(B^+ \to \phi K^+\gamma) = (2.34 \pm 0.29 \pm 0.23) \times 10^{-6}$$

$$\mathcal{B}(B^0 \to \phi K^0\gamma) = (2.66 \pm 0.60 \pm 0.32) \times 10^{-6}$$

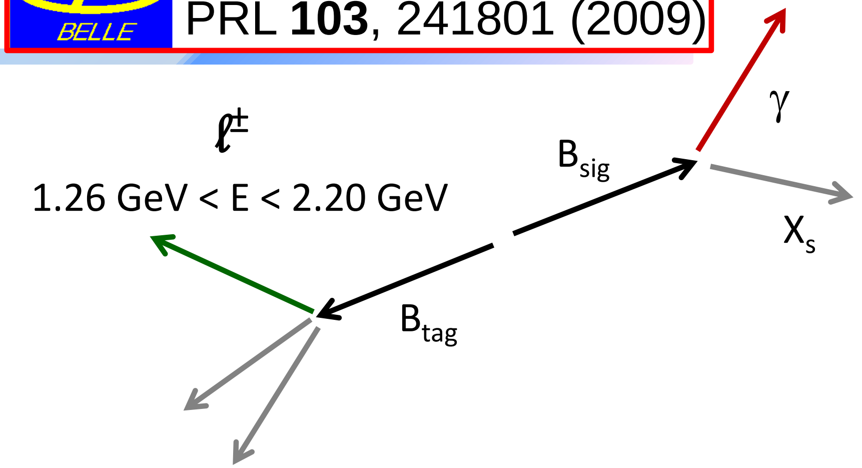
First observation w/ 5.4σ significance

Time dependent analysis ongoing…

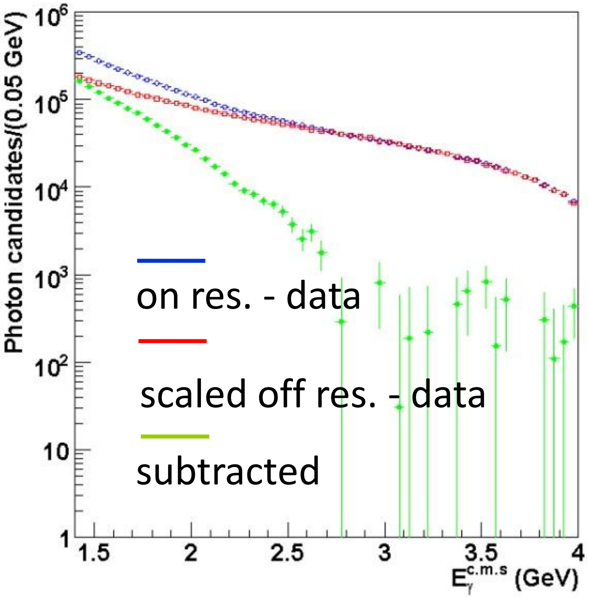


Inclusive $b \to s\gamma$

657M BB
PRL **103**, 241801 (2009)

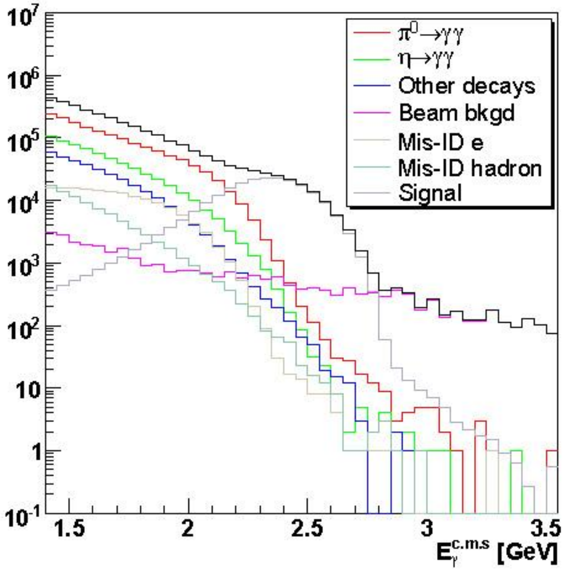


- Fully inclusive measurement (only the γ w/ E^{CM} > 1.4 GeV is reconstructed):
  - Divided into two streams:
    - MAIN - without lepton tag
    - LT – w/ lepton tag, reduces qq background
  - A data sample of 68 fb^{-1} taken below $\Upsilon(4S)$ is used to subtract $e^+ e^- \to qq$ backgrounds from 605 fb^{-1} on-resonance sample.



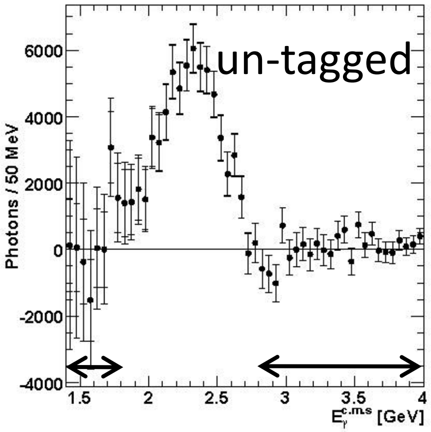
Left: photon energy distributions in data for on resonance, off resonance, and continuum subtracted samples.

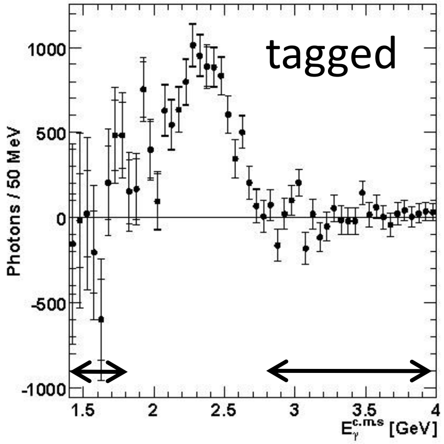
Right: photon energy signal / background distributions. π^0 and η backgrounds dominate

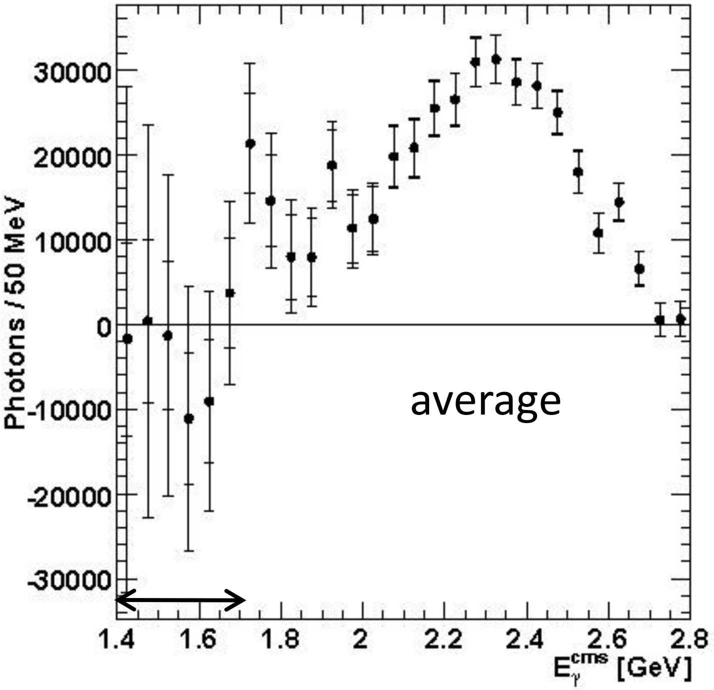


Inclusive $b \to s\gamma$

⟷ : control regions (no yield expected)







- Untagged and tagged spectra are combined:
  - Corrected for selection efficiency.
  - Including statistical correlations between tagged/untagged spectra.

657M BB
PRL **103**, 241801 (2009)

$$\mathcal{B}(B \to X_s\gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$$

$$1.7\ \mathrm{GeV} < E_\gamma < 2.8\ \mathrm{GeV}$$

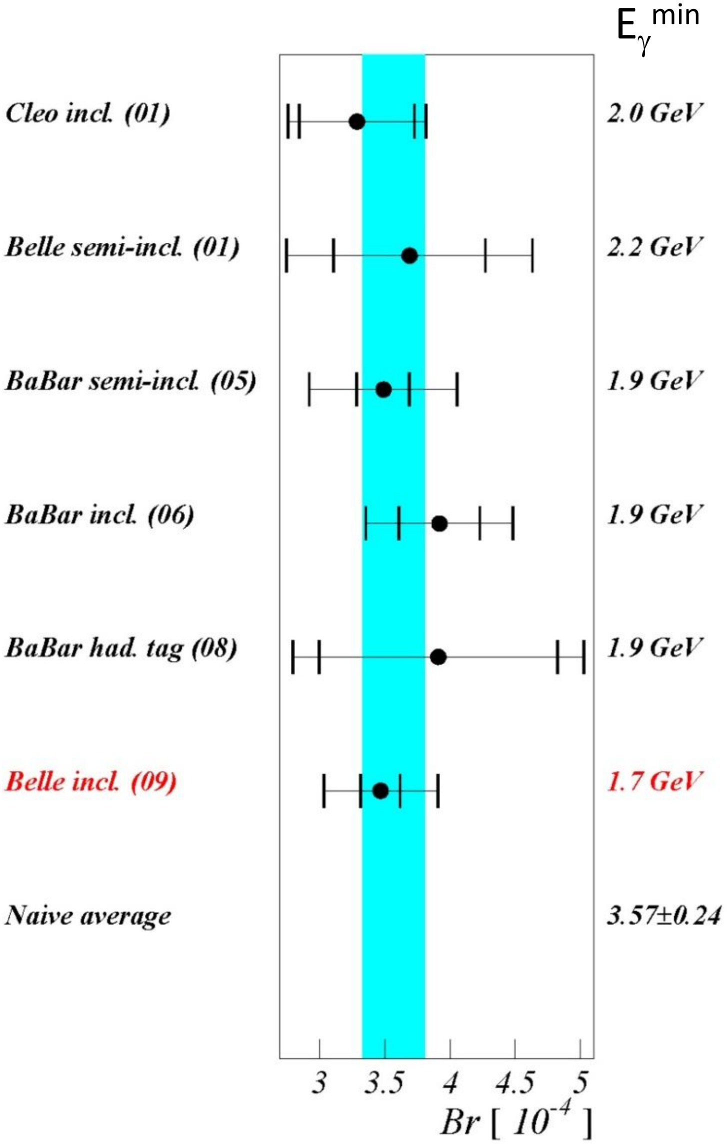
Inclusive $b \to s\gamma$

657M BB
PRL **103**, 241801 (2009)

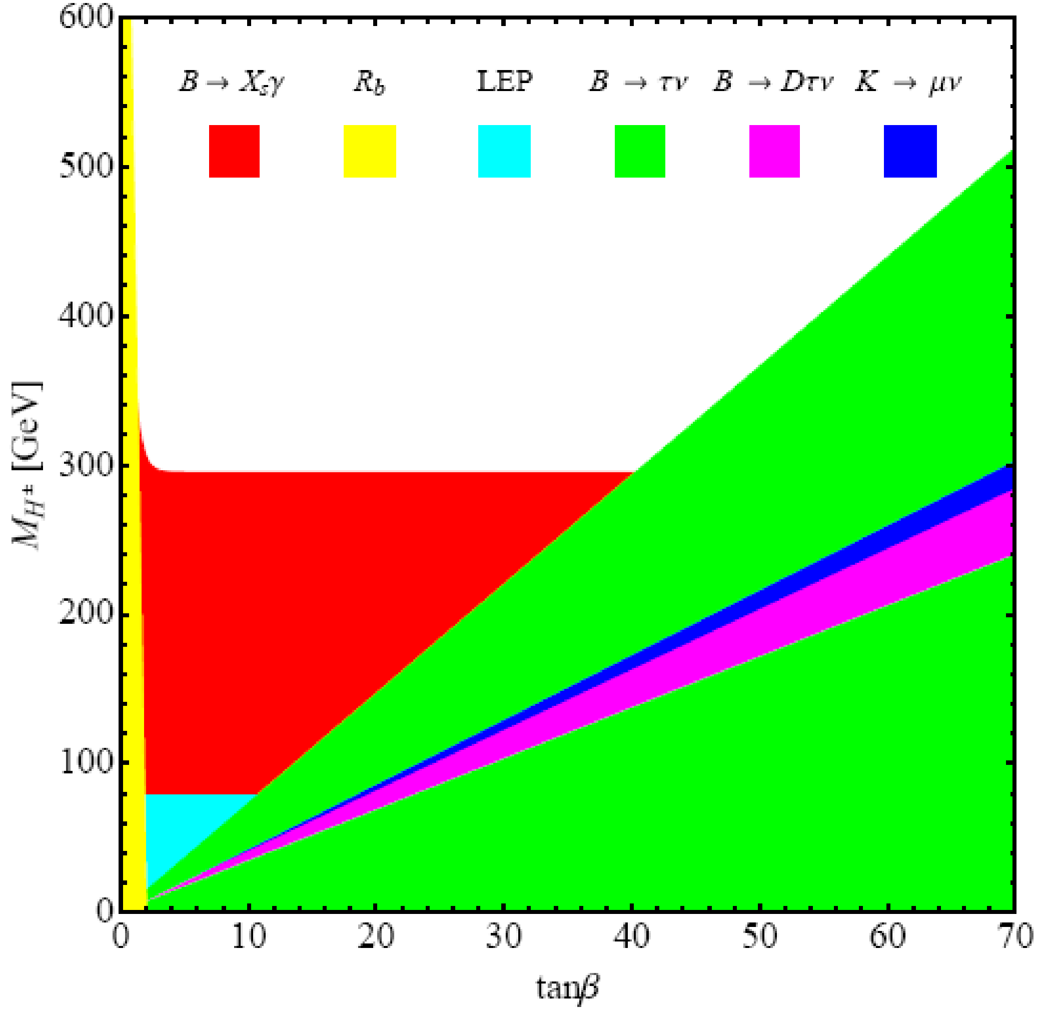
$$\mathcal{B}(B \to X_s\gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$$
$$1.7\ \mathrm{GeV} < E_\gamma < 2.8\ \mathrm{GeV}$$

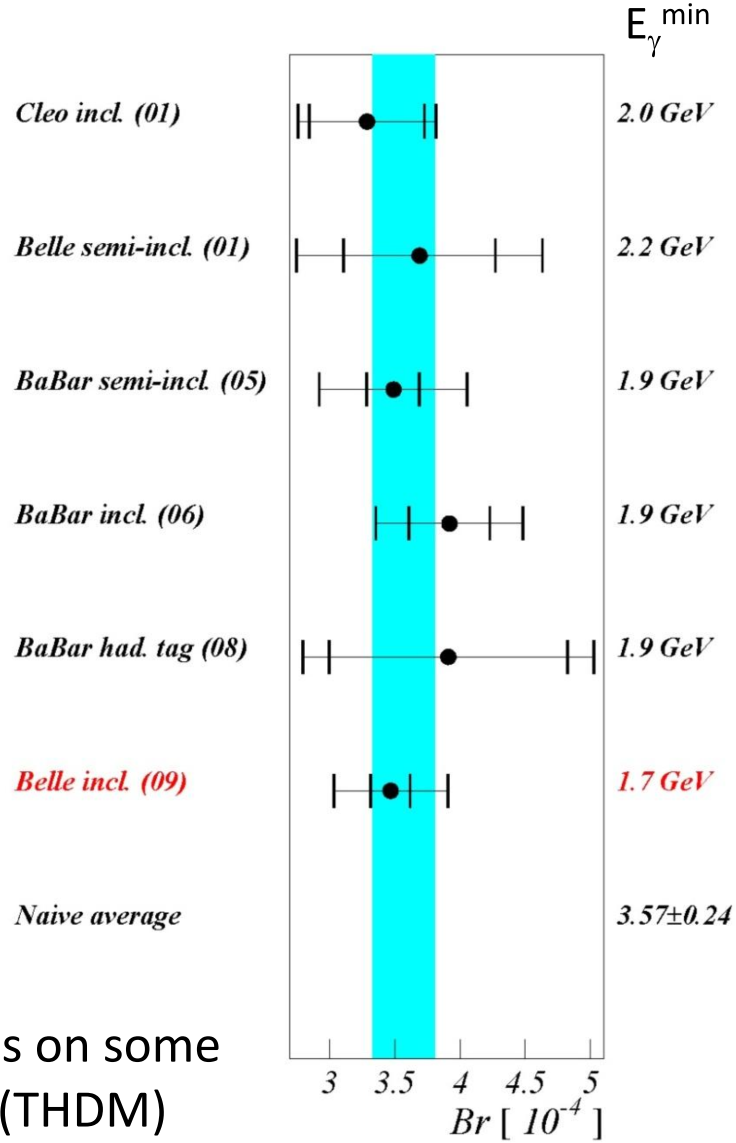
Consistent with NNLO SM calculations
[Misiak et al., PRL **98**, 022002 (2007)]:

$$\mathcal{B}_{SM}(B \to X_s\gamma; E_\gamma > 1.6GeV) = (3.15 \pm 0.23) \times 10^{-4}$$



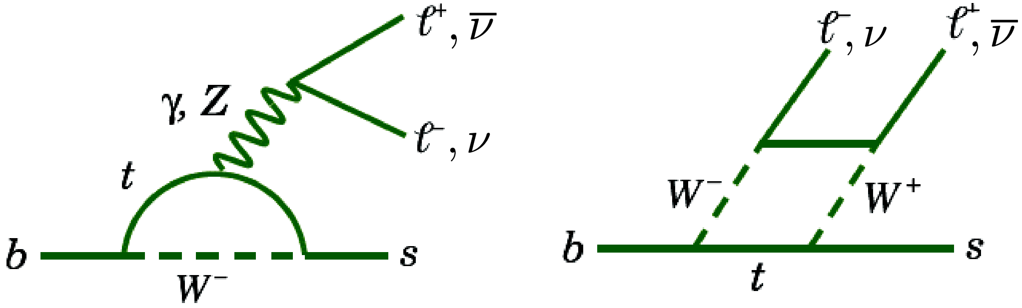
Limits from $b \to s\gamma$





$b \to s\,\gamma$ measurements can place strong constraints on some NP models: e.g., type II two-Higgs doublet models (THDM) [Ulrich Haisch, arXiv:0805.2141]

Electroweak Penguins $b \to s\ell\ell, b \to s\nu\overline{\nu}$



- Observables:
  - – Branching fractions
    - Large theoretical form factor uncertainties
  - – Longitudinal polarization fraction (F_L)

$$\frac{d\Gamma}{d\cos\theta_{K^*}} = \frac{3}{2}F_L\cos^2\theta_{K^*} + \frac{3}{4}(1-F_L)(\sin^2\theta_{K^*})$$

  - – Forward backward asymmetry (A_{FB})

$$\frac{d\Gamma}{d\cos\theta_{B\ell}} = \frac{3}{4}F_L\sin^2\theta_{B\ell} + \frac{3}{8}(1-F_L)(1+\cos^2\theta_{B\ell}) + A_{FB}\cos\theta_{B\ell}$$

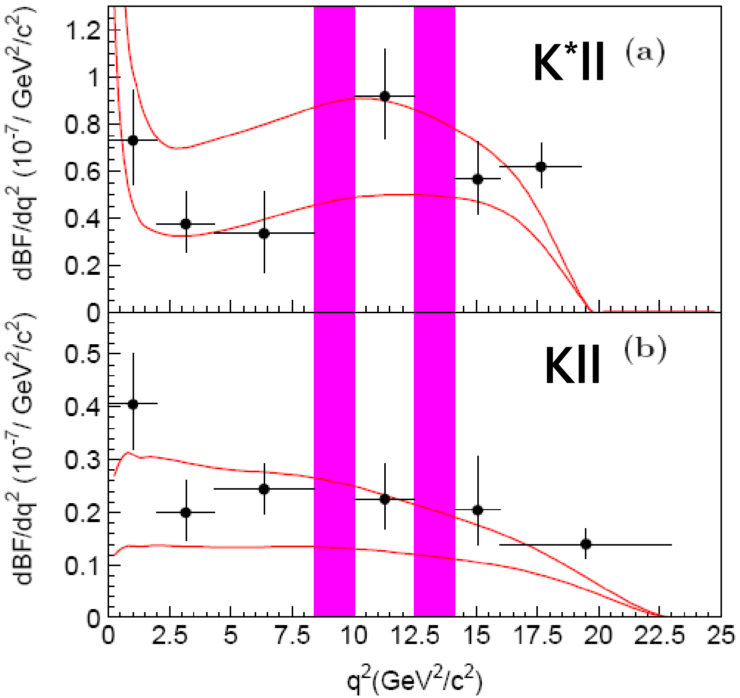
Branching Fractions for $B \to K^{(*)}\ell\ell$

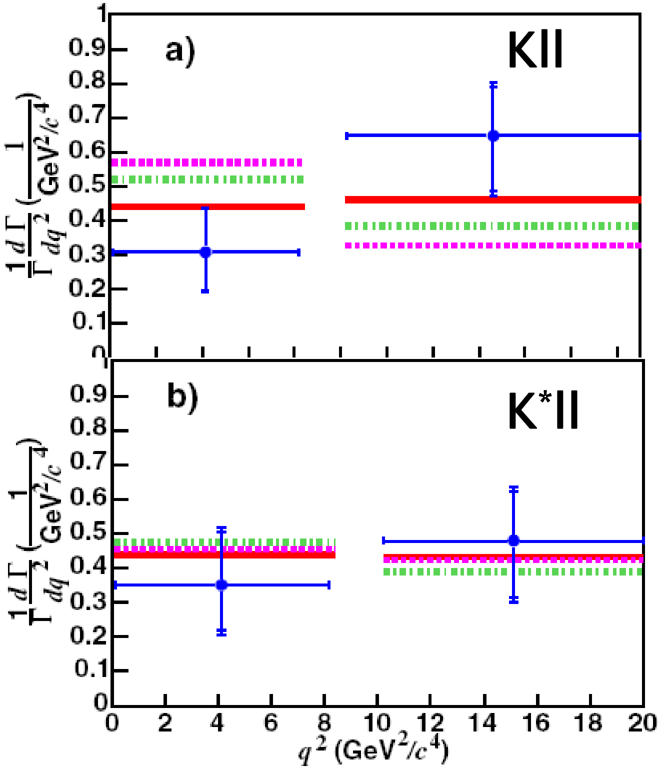
657M BB
PRL **103**, 171801 (2009)

383M BB
PR **D73**, 092001 (2009)

$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (10.7^{+1.1}_{-1.0} \pm 0.9) \times 10^{-7}$$
$$\mathcal{B}(B \to K\ell^+\ell^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}$$

$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (7.8^{+1.9}_{-1.7} \pm 1.1) \times 10^{-7}$$
$$\mathcal{B}(B \to K\ell^+\ell^-) = (3.4 \pm 0.7 \pm 0.2) \times 10^{-7}$$





🟪 : J/ψ (ψ') veto regions

— : SM expectation w/ min. & max. form factors from[Ali et al. PRD 66, 034002 (2002)]

Lines are SM predictions w/ various form factor models.

F_L, and A_{FB} for $B \to K^*\ell\ell$

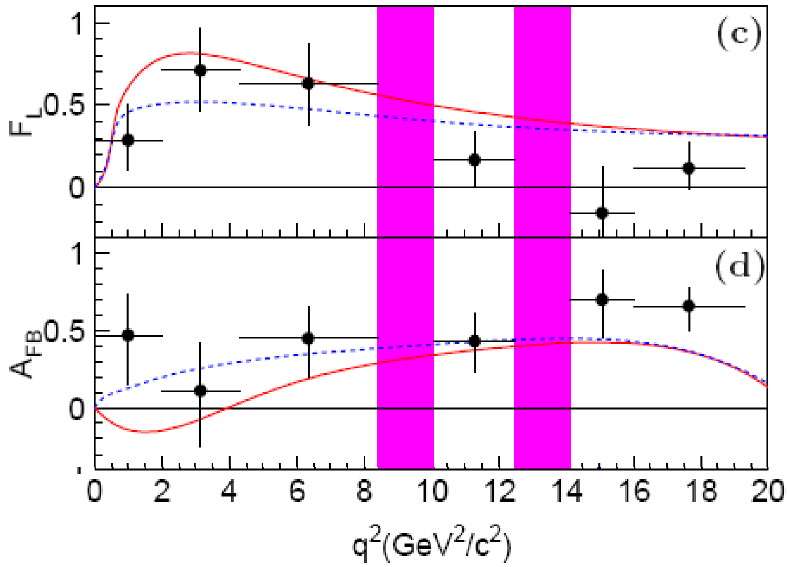
$$\frac{d\Gamma}{d\cos\theta_{K^*}} = \frac{3}{2}F_L\cos^2\theta_{K^*} + \frac{3}{4}(1-F_L)(\sin^2\theta_{K^*})$$

$$\frac{d\Gamma}{d\cos\theta_{B\ell}} = \frac{3}{4}F_L\sin^2\theta_{B\ell} + \frac{3}{8}(1-F_L)(1+\cos^2\theta_{B\ell}) + A_{FB}\cos\theta_{B\ell}$$

Wrong sign C_7 ??

BELLE
657M BB
PRL **103**, 171801 (2009)

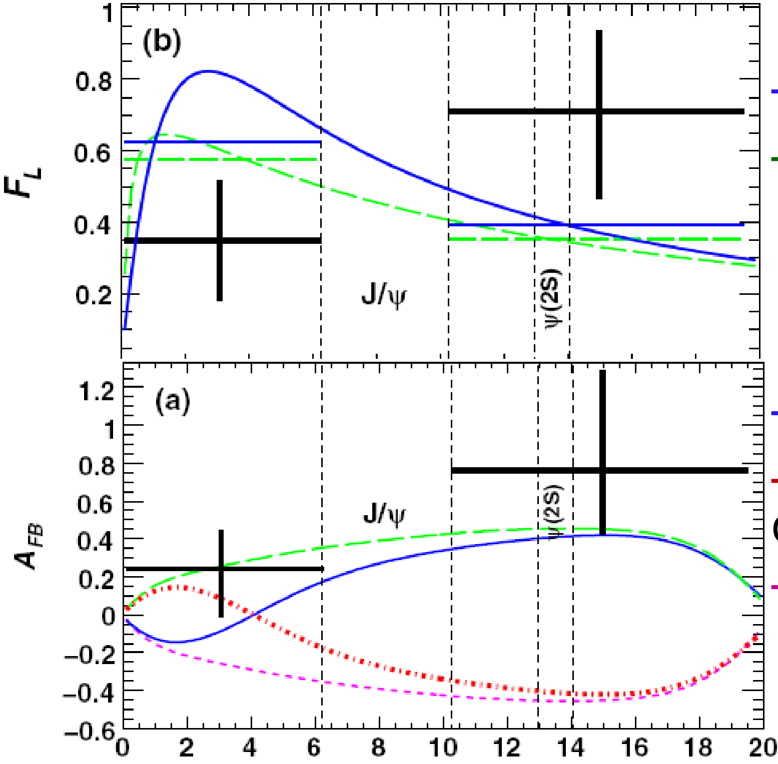
383M BB
PR **D79**, 031102 (2009)



🟪 : J/ψ (ψ') veto regions

: SM expectation ($C_7 = C_7^{SM}$)

: Sign-flipped C_7 ($C_7 = -C_7^{SM}$)



: $C_7 = C_7^{SM}$

: $C_7 = -C_7^{SM}$

: $C_7 = C_7^{SM}$

: $C_7 = -C_7^{SM}$, $C_9C_{10} = -(C_9C_{10})^{SM}$

: $C_9C_{10} = -(C_9C_{10})^{SM}$

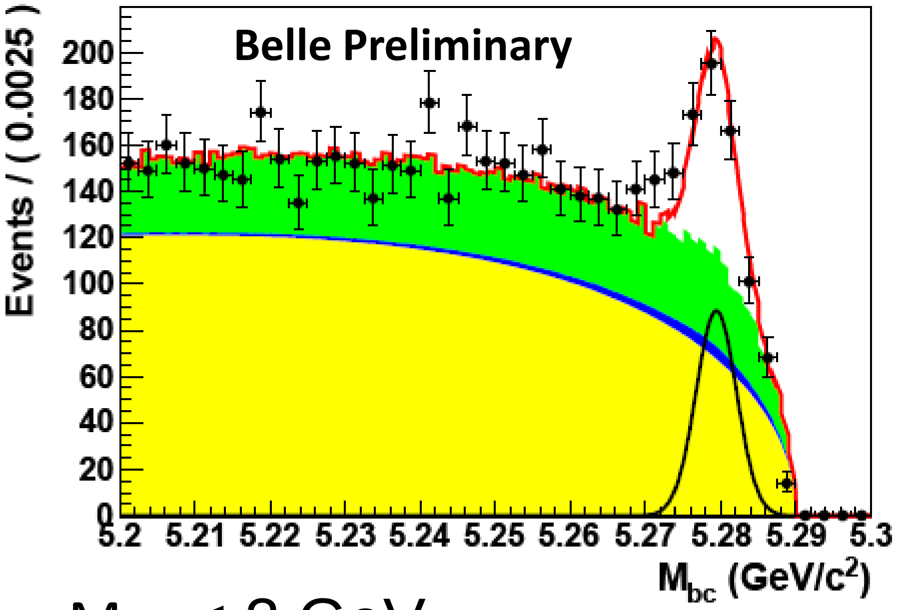
Inclusive $B \to X_s \ell\ell$

- Opposite sign C_7 would enhance branching fraction of $B \to X_s \ell\ell$

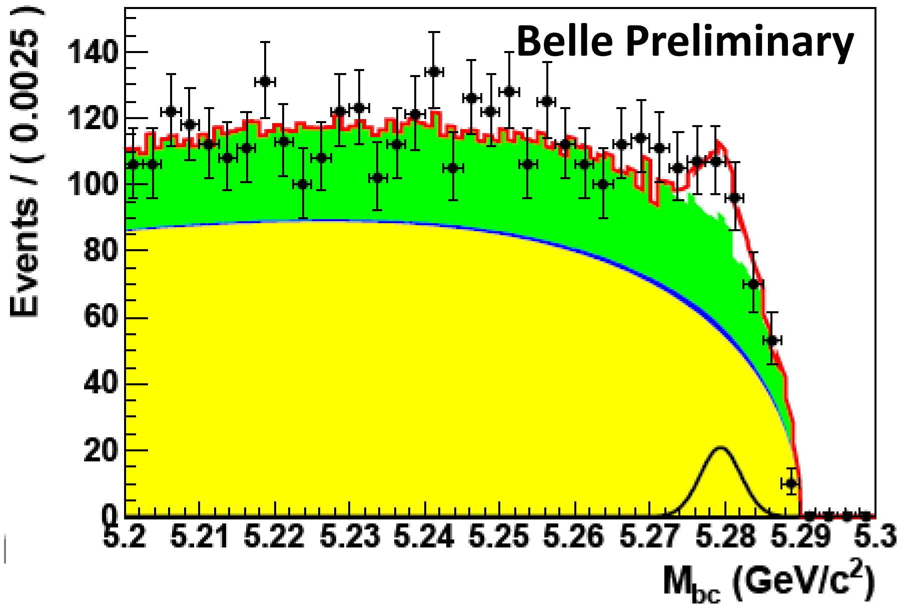
BELLE

657M BB
Preliminary

- Modest form factor uncertainties relative to $K^{(*)}\ell\ell$
- Belle update with sum-of-exclusive technique, , $X_s = K + n\pi$,*n* = 0-4



$M_{Xs} < 2$ GeV 10σ significance



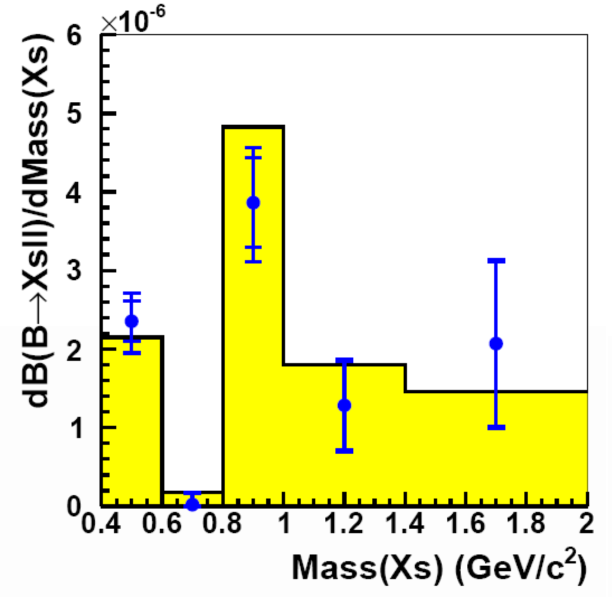
1 GeV < $M_{Xs} < 2$ GeV 3σ significance

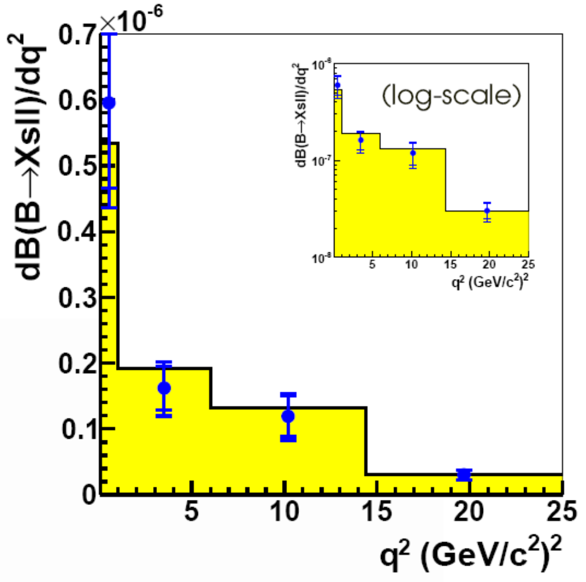
Large backgrounds:

Combinatorial from continuum & semileptonic B decays

Leakage after J/ψ and ψ' vetoes, mis-id in $X_s\ \pi^+\ \pi^-$, other ψ states, $X_s\ l\nu$

Branching Fraction for $B \to X_s\ell\ell$

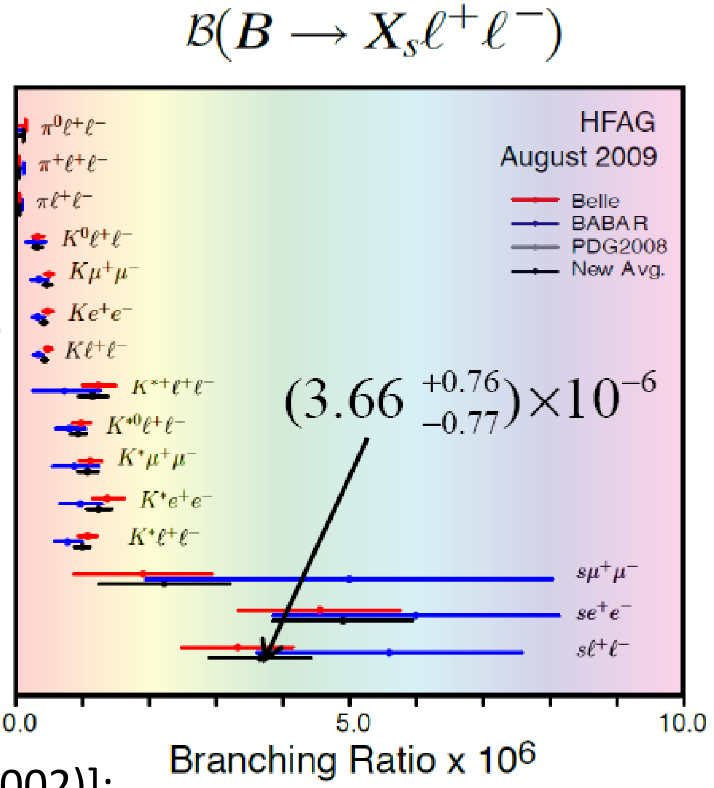




657M BB
Preliminary

$$\mathcal{B}(B \to X_s\ell\ell) = (3.33 \pm 0.80^{+0.19}_{-0.24}) \times 10^{-6}$$

*Total branching fraction is for $q^2 > 0.2$ (GeV/c2)^2 & extrapolated to entire M_{Xs} region



Standard model prediction [Ali et al. PRD 66, 034002 (2002)]:

$$\mathcal{B}_{\rm SM}(B \to X_s\ell\ell) = (4.2 \pm 0.7) \times 10^{-6}$$

No enhancement ➔ opposite sign C_7 is **not** favored by the inclusive measurement.

Searches for $B \to K\nu\bar{\nu}$

- Previous best upper limits (90% CL):
  - BaBar, semileptonic tagging:

$$\mathrm{B}(B^+ \to K^+\nu\bar{\nu}) < 4.5\times10^{-5}$$

351M BB
arXiv: 0911.1988

  - Belle, using full hadronic reconstruction of one B:

$$\mathrm{B}(B^+ \to K^+\nu\bar{\nu}) < 1.4\times10^{-5}$$

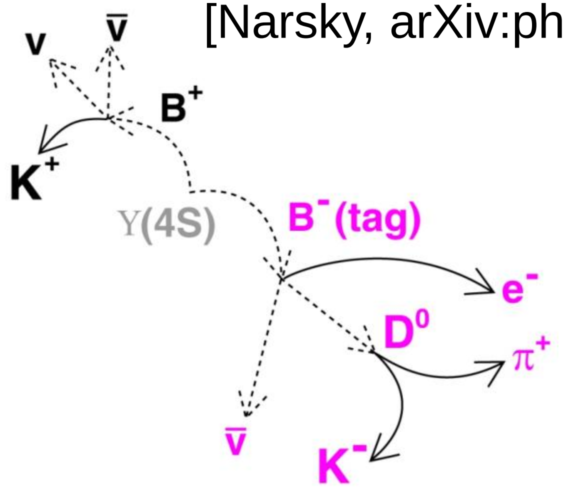
$$\mathrm{B}(B^0 \to K^0\nu\bar{\nu}) < 16\times10^{-5}$$

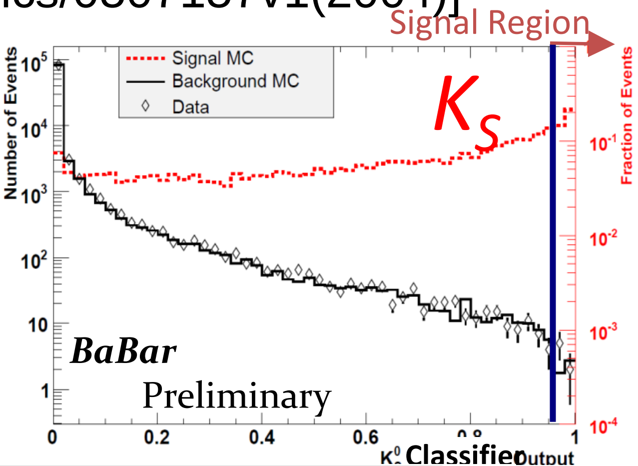
535M BB
PRL **99**, 221802 (2007)

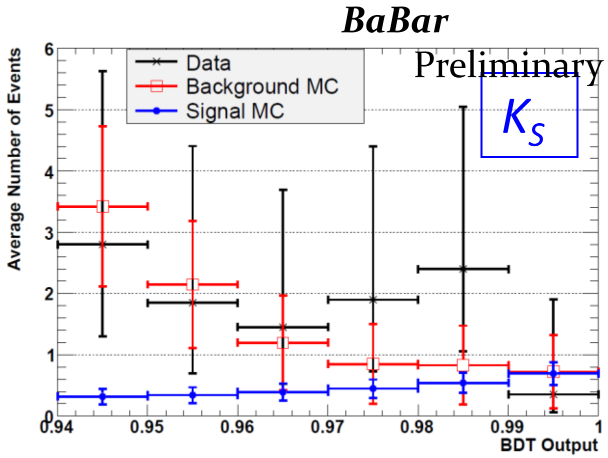
New BaBar $B \to K\nu\overline{\nu}$ w/ semileptonic tagging

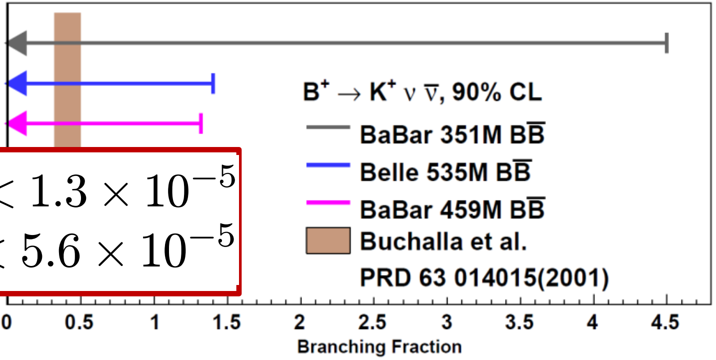
- Method:
  - Tag one B using $D^{(*)}\ell\nu$ (~1% efficiency)
  - Look for a lone K (K_S plots shown, K^+ in backup)
  - Multivariate technique (bagged decision tree) to select events [Narsky, arXiv:physics/0507157v1(2004)]

459M BB
Preliminary

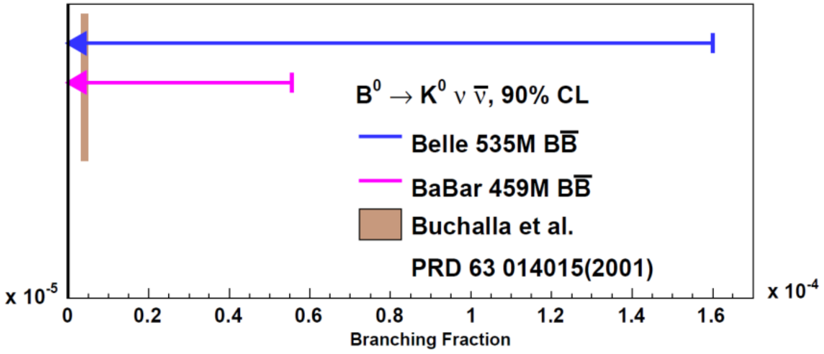






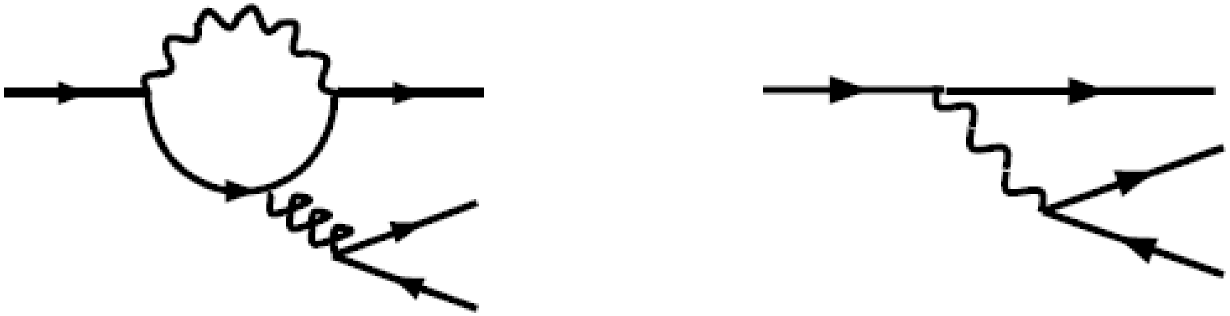


$$\mathcal{B}(B^+ \to K^+\nu\overline{\nu}) < 1.3\times10^{-5}$$
$$\mathcal{B}(B^0 \to K^0\nu\overline{\nu}) < 5.6\times10^{-5}$$



SM Prediction [Buchalla, PRD 63, 014015 (2001)]: $\mathrm{B}(B \to K\nu\overline{\nu}) = (3.8^{+1.2}_{-0.6})\times10^{-6}$

Hadronic Penguins

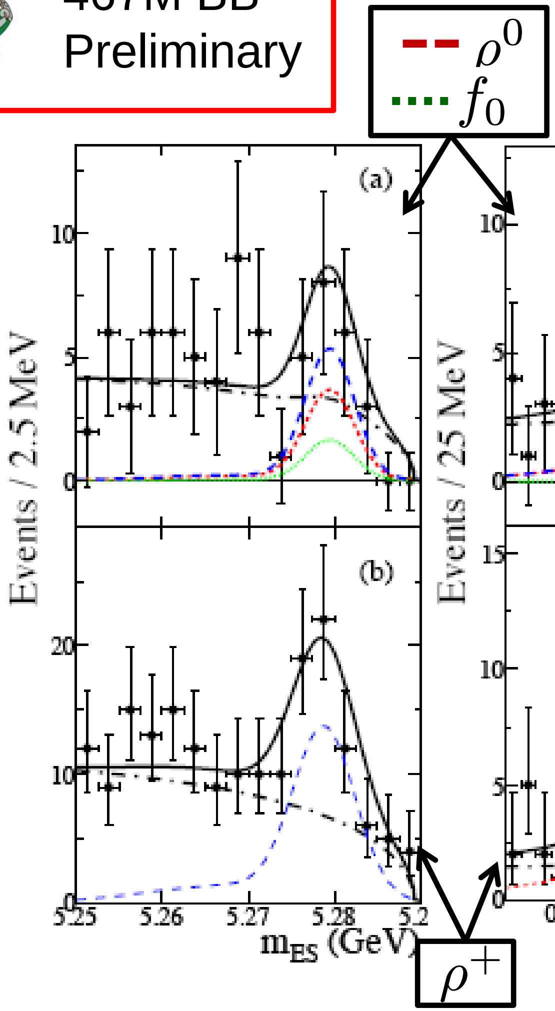


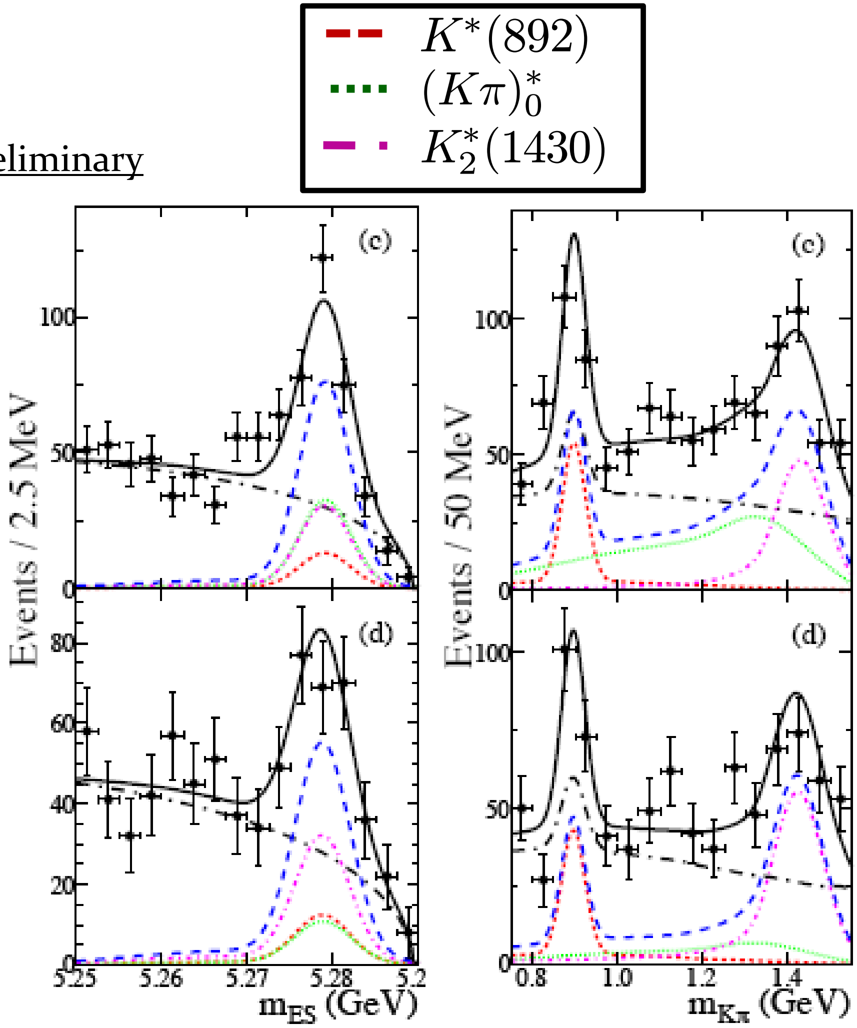
- Final states with η and η' particularly interesting:
  - Interference patterns in dominant amplitudes
  - Sensitive to flavor singlet contributions
- Branching fractions:
  - A history of unexpected or unexpectedly large signals

Exclusive $B \to \eta'(\rho, f_0, K^*(892), K^*(1430))$

467M BB
Preliminary

BaBar Preliminary





Observation of $\eta'\rho^+, \eta' K_2^*(1430)^{(0,+)}$ **!** **Evidence for** $\eta' K^{*(0,+)}$ **!**

Exclusive $B \to \eta'(\rho, f_0, K^*(892), K^*(1430))$

467M BB
Preliminary

BaBar Preliminary

Mode	Y (events)	Y_0 (events)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ U.L. (10^{-6})	$\mathcal{A}_{ch}$
$\eta'\rho^0$	37±15	9±5	23.4	17.5	2.0	$1.5 \pm 0.8 \pm 0.3$	2.8	–
$\eta' f_0$	8±8	4±2	25.9	17.5	0.5	$0.2^{+0.4}_{-0.3} \pm 0.1$	0.9	–
$\eta'\rho^+$	128±22	15±8	14.3	17.5	5.8	$9.7^{+1.9}_{-1.8} \pm 1.1$	–	$0.26 \pm 0.17 \pm 0.02$
$\eta' K^{*0}$					4.0	$3.1^{+0.9}_{-0.8} \pm 0.3$	4.4	$0.02 \pm 0.23 \pm 0.02$
$\eta' K^{*+}$					3.8	$4.8^{+1.6}_{-1.4} \pm 0.8$	7.2	$-0.26 \pm 0.27 \pm 0.02$
$\eta'(K\pi)^{*0}_0$					5.6	$7.4^{+1.5}_{-1.4} \pm 0.6$	–	$-0.19 \pm 0.17 \pm 0.02$
$\eta'(K\pi)^{*+}_0$					2.9	$6.0^{+2.2}_{-2.0} \pm 0.9$	9.3	$0.06 \pm 0.20 \pm 0.02$
$\eta' K^*_2(1430)^0$					5.3	$13.7^{+3.0}_{-2.9} \pm 1.2$	–	$0.14 \pm 0.18 \pm 0.02$
$\eta' K^*_2(1430)^+$					7.2	$28.0^{+4.6}_{-4.3} \pm 2.6$	–	$0.15 \pm 0.13 \pm 0.02$

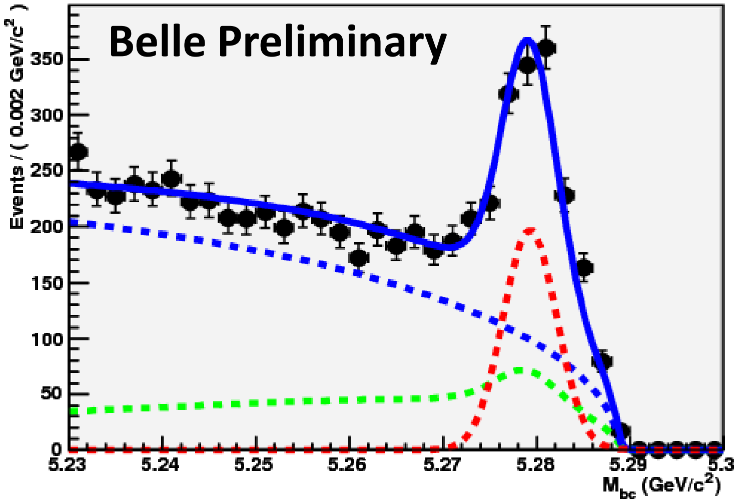
- No significant direct CP asymmetry in any modes.
- Results for $\eta'\rho^+$ generally favor pQCD and QCDF predictions over SCET
- Unexpected enhancements of $K_2^*(1430)$ over $K^*(892)$

Inclusive $B \to X_s \eta$

657M BB
Preliminary, arXiv: 0910.4751

- Sum of exclusive modes: $\boldsymbol{B \to X_s \eta}\ (p_\eta^{cm} > 2.0\ \mathrm{GeV/c})$

$$\eta \to \gamma\gamma$$
$$X_s \to \boldsymbol{K n\pi}\ (\boldsymbol{n} \leq 4,\ \boldsymbol{n_{\pi^0}} \leq 1)$$



----- : signal

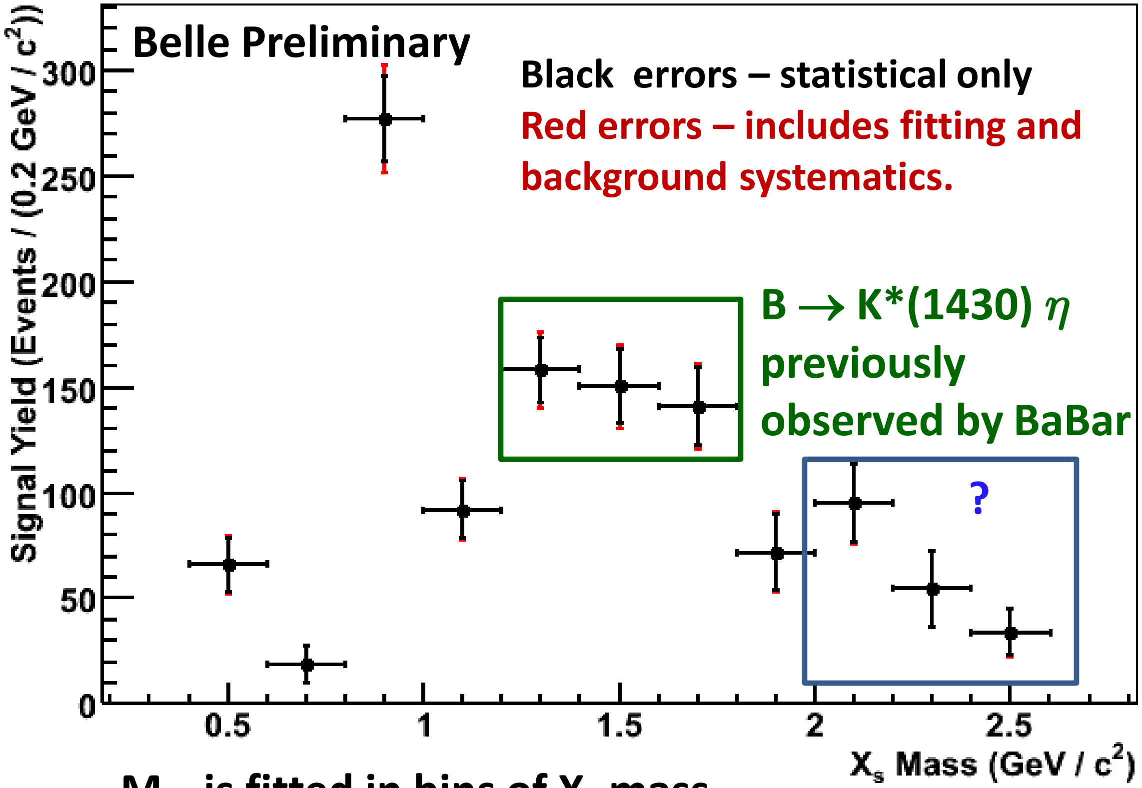
----- : BB background

----- : combinatorial background

Signal yield (M_{X_s} > 1.0 GeV/c²) =

$$749 \pm 48 \pm 7$$

<u>17.6σ statistical significance</u>



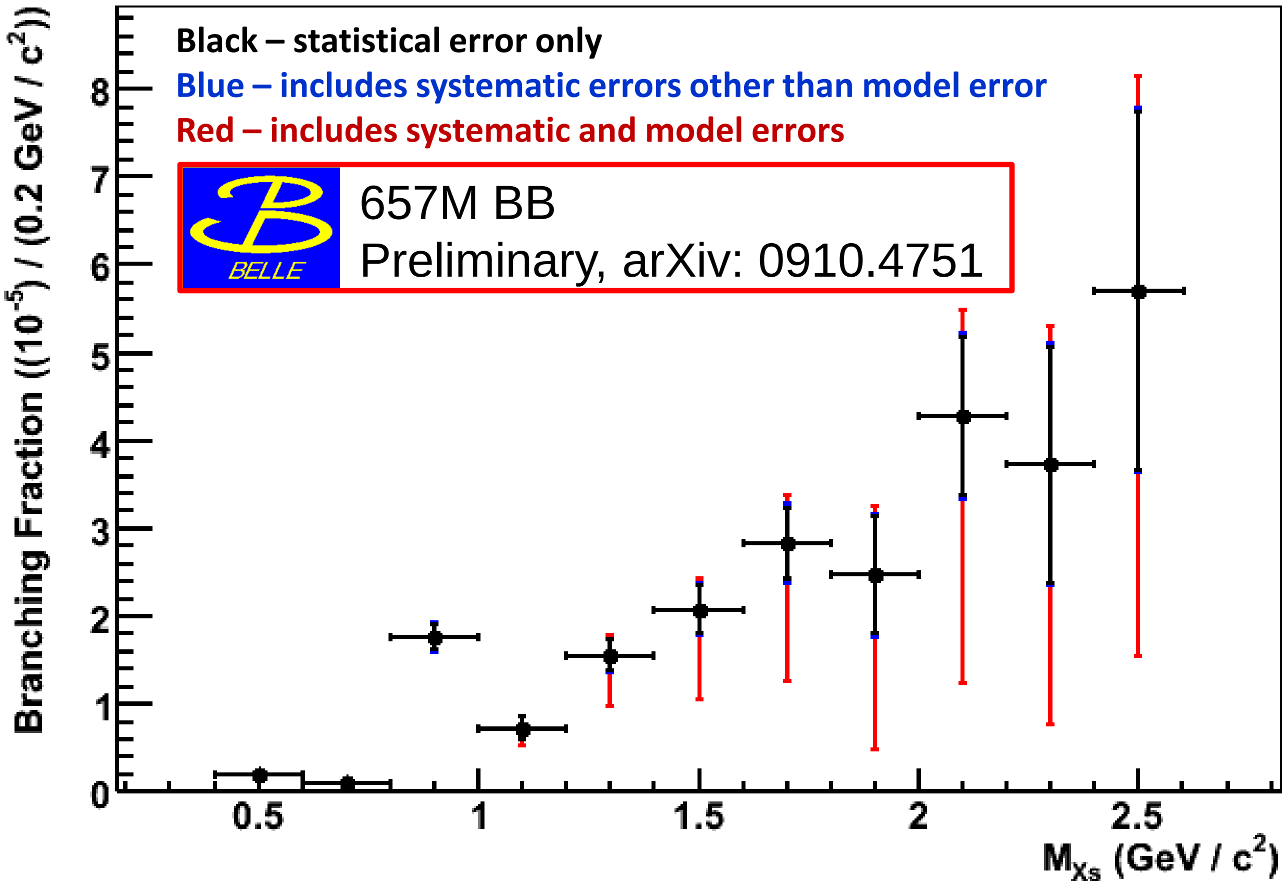
Black errors – statistical only

Red errors – includes fitting and background systematics.

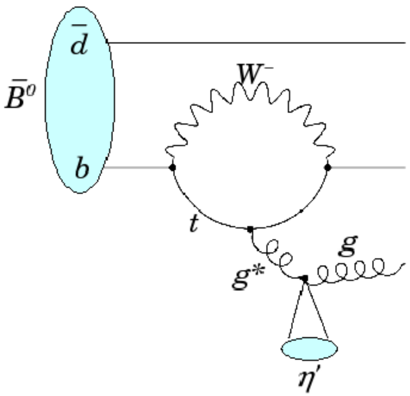
B → K*(1430) η previously observed by BaBar

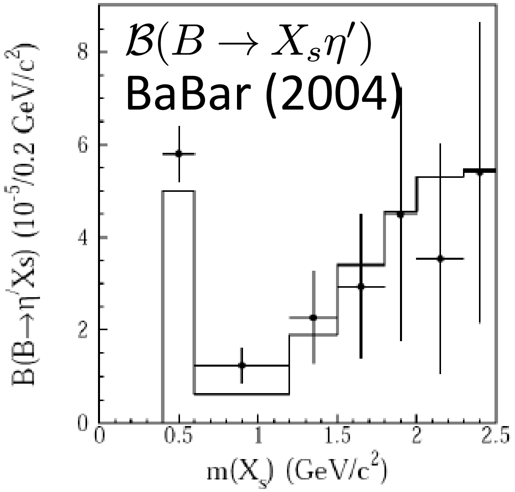
M$_{bc}$ is fitted in bins of X$_s$ mass.

$B \to X_s\eta$ Branching Fraction



$B \to X_s\eta'$, QCD anomaly?





Belle partial branching fraction for X_s mass range 0.4 – 2.6 GeV/c^2 :

$$\boxed{\mathcal{B}(B \to X_s\eta)^* = (25.5 \pm 2.7(stat) \pm 1.6(sys)^{+3.8}_{-14.1}(model)) \times 10^{-5}}$$

*assuming JETSET hadronization.

PDG average for $\mathcal{B}(B \to X_s\eta')$:
$(42.0 \pm 9.0) \times 10^{-5}$

➔ Signals beyond the known K*(892,1430) contributions in both Xs η and Xs η' modes

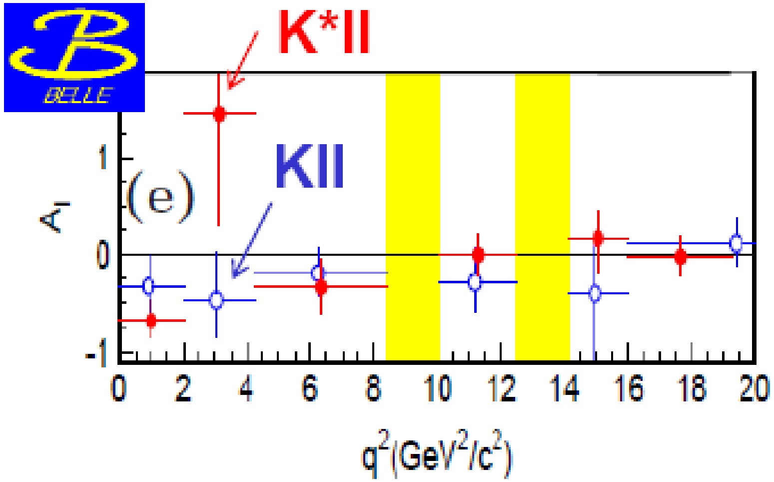
Conclusion

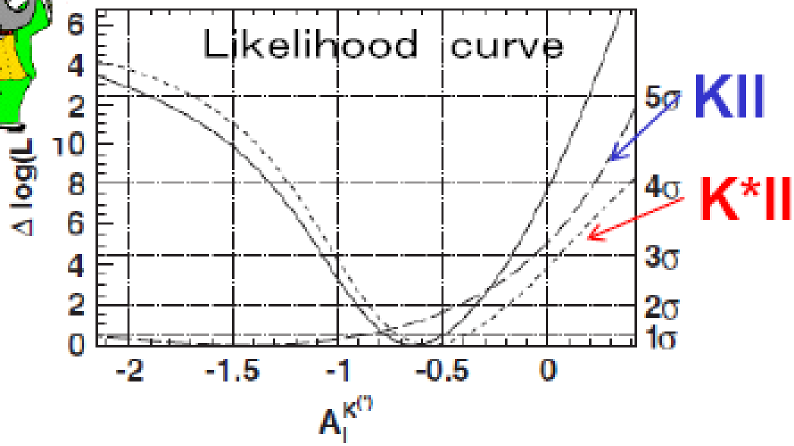
- Rare B decays provide a valuable tool to test Standard Model predictions.
- Both Belle and BaBar have accumulated a large set of data with which to study these decays…
  - We can look forward to many final results using the entirety of the Belle and BaBar data sets…
  - …but many modes require significantly improved statistics:
    - Super B factories may reveal and elucidate the nature of new physics!
      - ➔ More on SuperKEKB in Bostjan's talk on Friday.

Backup Slides

B→K$^{(*)}$ll: Isospin Asymmetry

$$A_I \equiv \frac{(\tau_{B^+}/\tau_{B^0}) \times \mathcal{B}(K^{(*)0}\ell^+\ell^-) - \mathcal{B}(K^{(*)\pm}\ell^+\ell^-)}{(\tau_{B^+}/\tau_{B^0}) \times \mathcal{B}(K^{(*)0}\ell^+\ell^-) + \mathcal{B}(K^{(*)\pm}\ell^+\ell^-)}$$





$q^2 < 8.68\ GeV^2/c^2$

$A_I(K^*\ell\ell) = -0.29^{+0.16}_{-0.16} \pm 0.03$ 1.40σ

$A_I(K\ell\ell) = -0.31^{+0.17}_{-0.14} \pm 0.05$ 1.75σ

$A_I(K^{(*)}\ell\ell) = -0.30^{+0.12}_{-0.11} \pm 0.04$ 2.24σ

$q^2 = 0.1 - 7.02\ GeV^2/c^2$

$A_I(K^*\ell\ell) = -0.56^{+0.17}_{-0.15} \pm 0.03$ 2.7σ

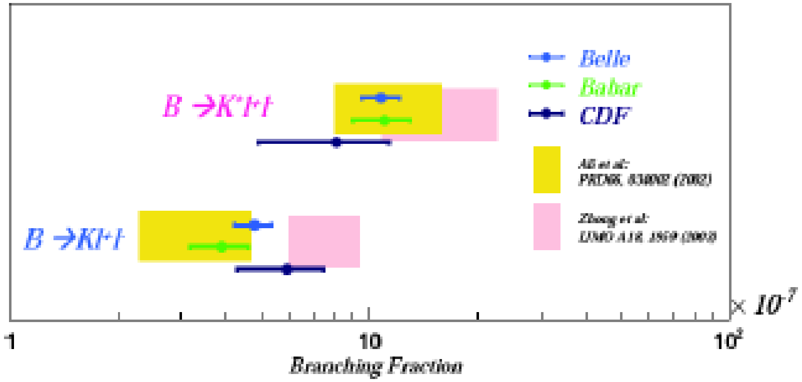
$A_I(K\ell\ell) = -1.43^{+0.56}_{-0.85} \pm 0.05$ 3.2σ

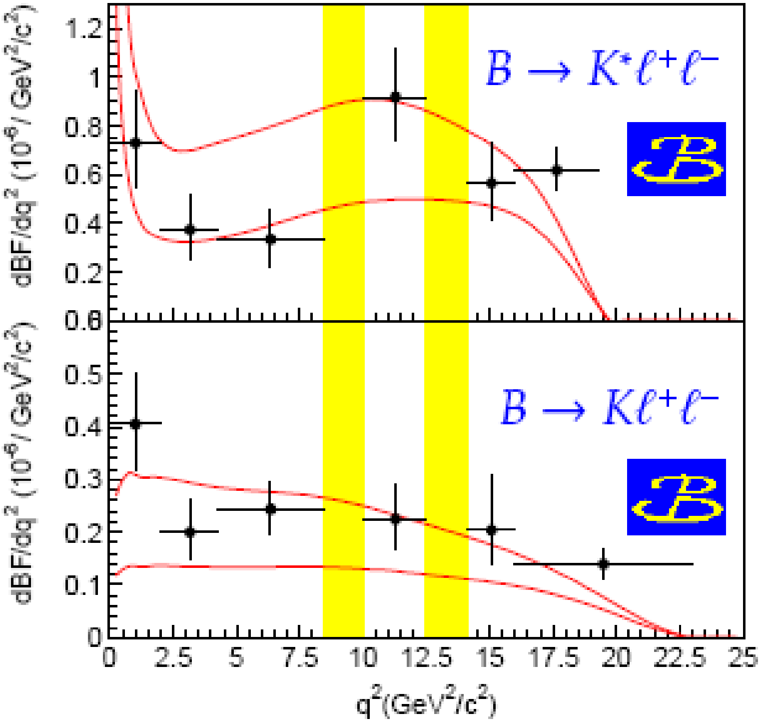
$A_I(K^{(*)}\ell\ell) = -0.64^{+0.15}_{-0.14} \pm 0.03$ 3.9σ

A_I deviates from zero at low-q^2 ?

***Slide from T. Iijima, Lepton-Photon 2009**

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))

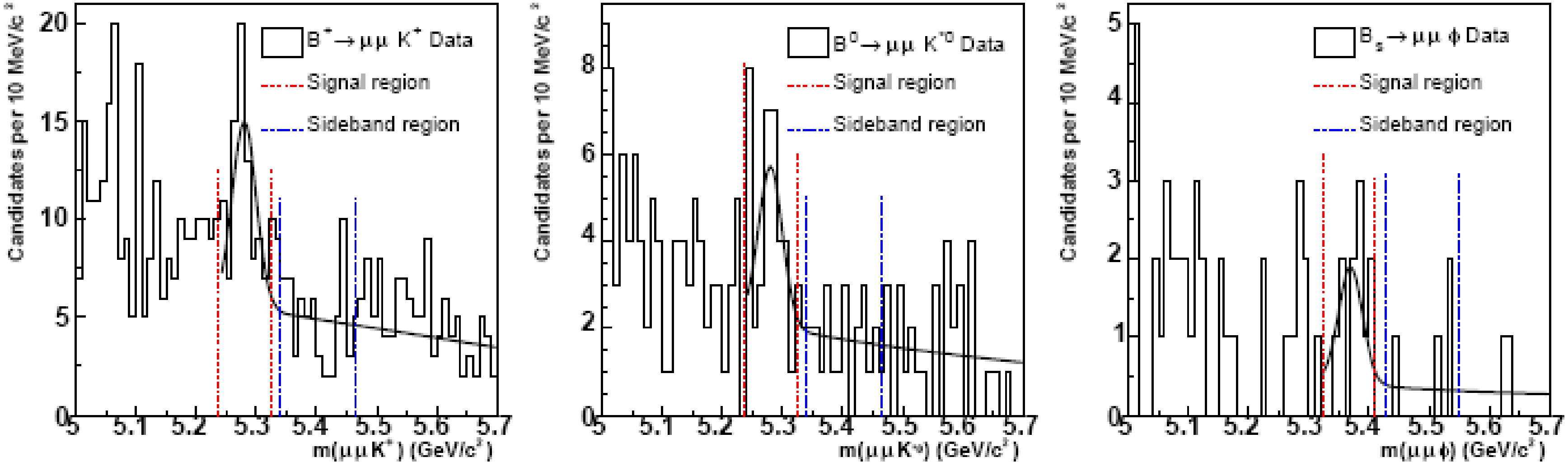
CDF $B \to K^{(*)}\ell^+\ell^-$ (924 pb^{-1})

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

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

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

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



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

- Forward-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)

- 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 $[(\bar{b}s)_{V-A}(\bar{\ell}\ell)_A]$

- Angular distributions to extract FB asymmetries

K^* longitudinal polarization F_L from kaon angle θ_K

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

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

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

$B \to X_s \ell^+ \ell^-$ and Wilson coefficients

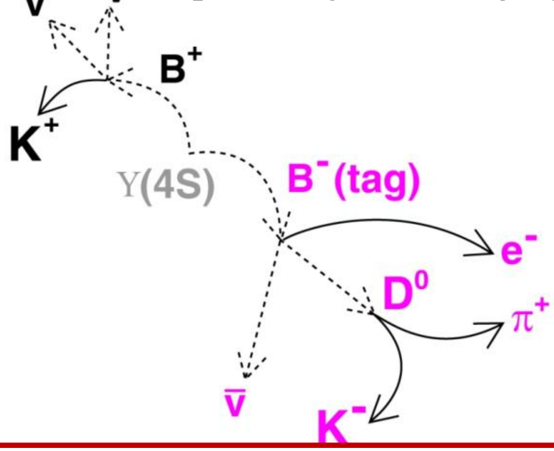
$$\frac{d\Gamma(b \to s\ell^+\ell^-)}{dq^2} = \left(\frac{\alpha_{\rm em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3}(1-q^2)^2$$
$$\times\left[(1+2q^2)\left(|C_9^{\rm eff}|^2 + |C_{10}^{\rm eff}|^2\right) + 4\left(1+\frac{2}{q^2}\right)|C_7^{\rm eff}|^2 + 12{\rm Re}\left(C_7^{\rm eff} C_9^{\rm eff}\right)\right] + \text{corr.}$$

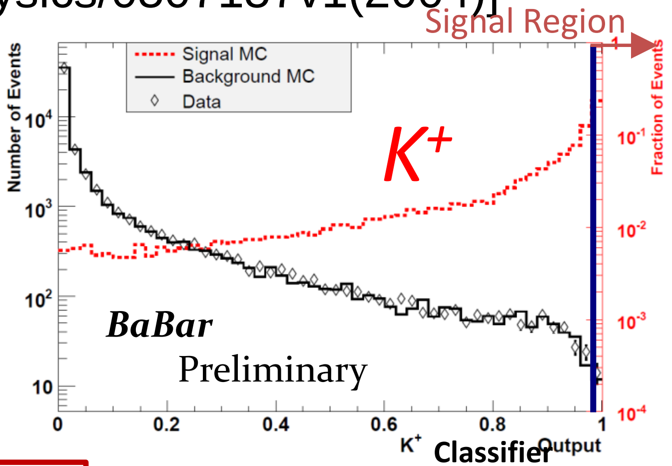
- Inclusive differential branching fraction is sensitive to Wilson coefficients (no form factor uncertainties of $B \to K^*\ell^+\ell^-$)
- Opposite-sign C_7 makes the branching fraction larger
  (in SM, $C_7 < 0$ and $C_9 > 0$)
- Fully inclusive measurement is not feasible so far, sum-of-exclusive technique has been used by Belle/BaBar

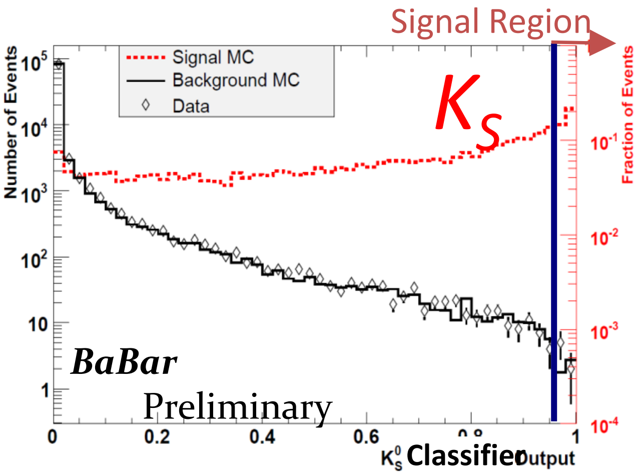
New BaBar $B \to K\nu\bar{\nu}$ w/ semileptonic tagging

459M BB
Preliminary

- Method:
  - Tag one B using $D^{(*)}\ell\nu$ (~1% efficiency)
  - Look for a lone K
  - Multivariate technique (bagged decision tree) to select events [Narsky, arXiv:physics/0507157v1(2004)]



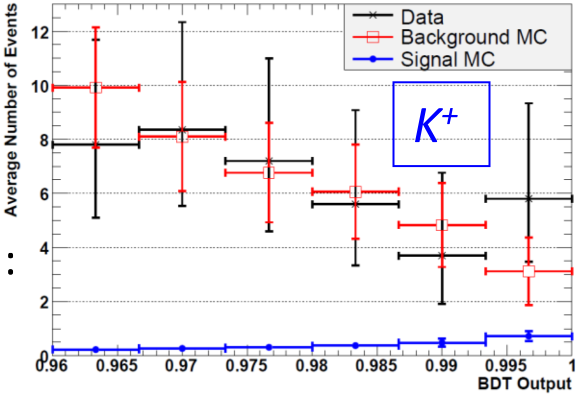


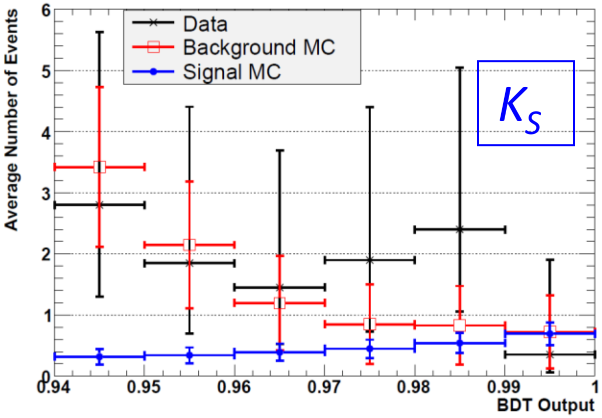


$$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) < 1.3 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K^0\nu\bar{\nu}) < 5.6 \times 10^{-5}$$

SM Prediction:
[Buchalla, PRD 63, 014015 (2001)]:

$$B(B \to K\nu\bar{\nu}) = (3.8^{+1.2}_{-0.6}) \times 10^{-6}$$

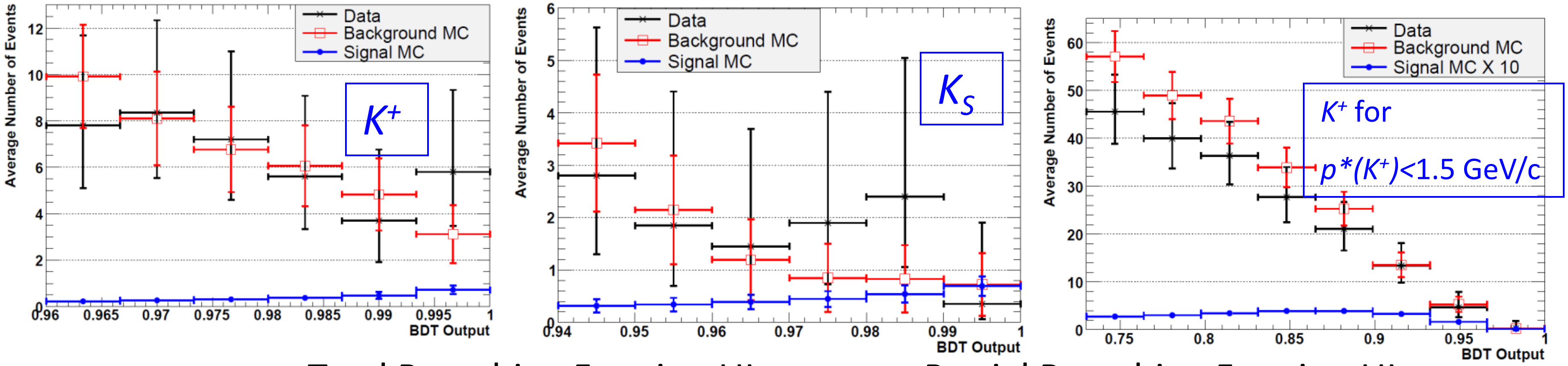




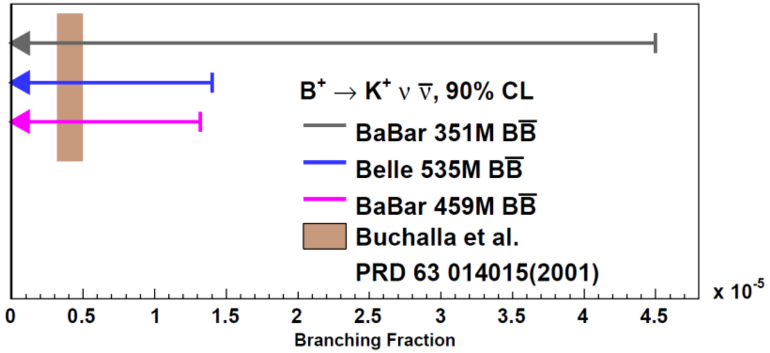
Upper limits on $B \to K\nu\bar{\nu}$

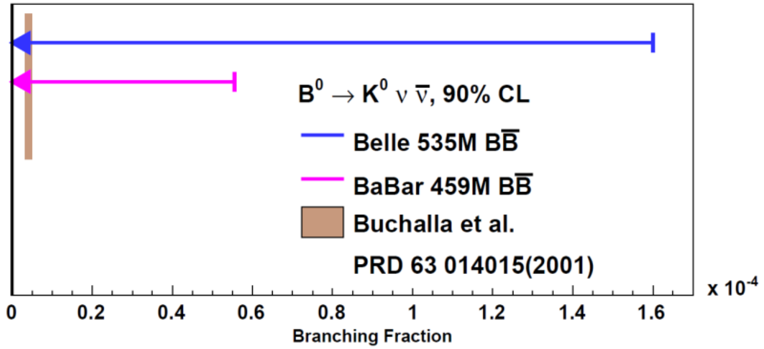
459M BB
Preliminary

Decision tree outputs in signal region:



	Total Branching Fraction ULs			Partial Branching Fraction ULs	
CL	K^+	K^0	K^+ & K^0	For $p^*(K^+)$<1.5 GeV/c	For $p^*(K^+)$>1.5 GeV/c
90%	1.3×10^{-5}	5.6×10^{-5}	1.4×10^{-5}	3.1×10^{-5}	0.89×10^{-5}
95%	1.6×10^{-5}	6.7×10^{-5}	1.7×10^{-5}	4.6×10^{-5}	1.1×10^{-5}





SM Prediction [Buchalla, PRD 63, 014015 (2001)]:

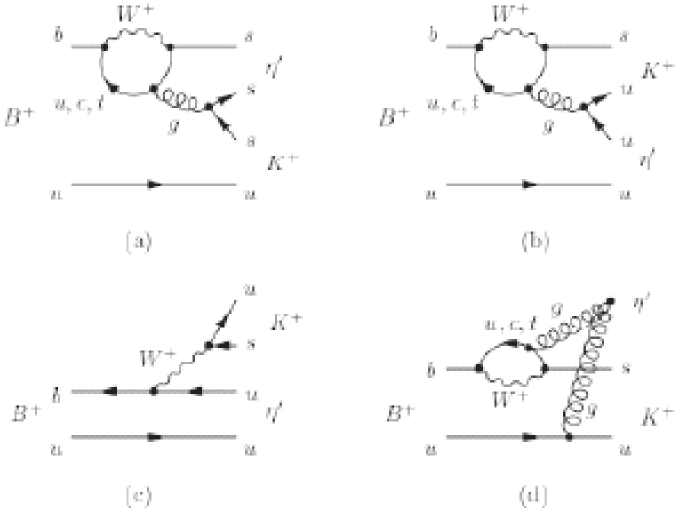
$$\mathrm{B}(B \to K\nu\bar{\nu}) = (3.8^{+1.2}_{-0.6})\times 10^{-6}$$

Modes including η, η'

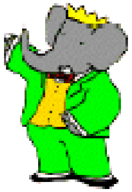
- Br(η'K) >> Br(ηK)

  -- a long-standing issue
- A_{CP}(ηK)>A_{CP}(η'K)?
- Input to SU(3)-based calculation for

  $\Delta S = S_{c\bar{c}s} - S_{\eta' K,\phi K}$



BaBar: 467 M BB



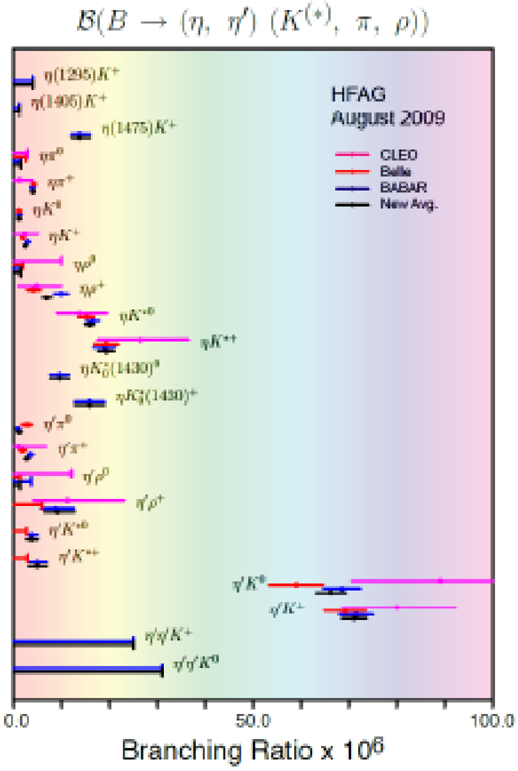
- $A_{CP}(B^+ \to \eta K^+)$

  $A_{CP}(B^+ \to \eta K^+) = -0.36 \pm 0.11 \pm 0.03$
- Evidence for three decay modes.

  $Br(B^0 \to \eta K^0) = (1.15\,^{+0.43}_{-0.38} \pm 0.09) \times 10^{-6}$

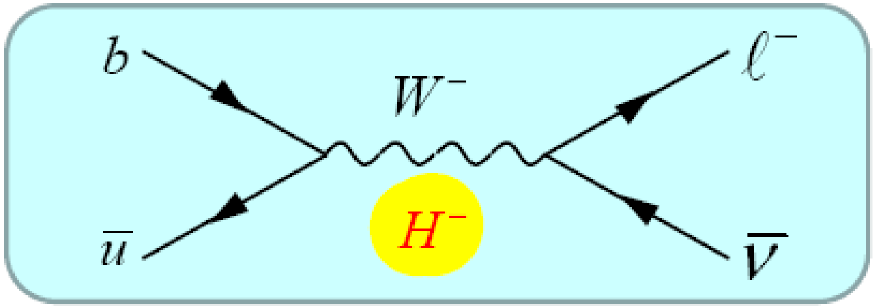
  $Br(B^0 \to \eta \omega) = (0.94\,^{+0.35}_{-0.30} + 0.19) \times 10^{-6}$

  $Br(B^0 \to \eta' \omega) = (1.01\,^{+0.46}_{-0.38} \pm 0.09) \times 10^{-6}$



***Slide from T. Iijima, Lepton-Photon 2009**

$B^- \to l^- \overline{\nu}$



- Within SM, proceed via W annihilation.

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Helicity suppression

$Br(B \to e\,\nu) \ll Br(B \to \mu\,\nu) \ll Br(B \to \tau\,\nu)$

~10^{-11} ~10^{-7}

Determination of $f_B|V_{ub}|$

$f_B = 190 \pm 13\ MeV$ HPQCD, 0902.1815v2

$|V_{ub}| = (4.32 \pm 0.16 \pm 0.29) \times 10^{-3}$ HFAG ICHEP08

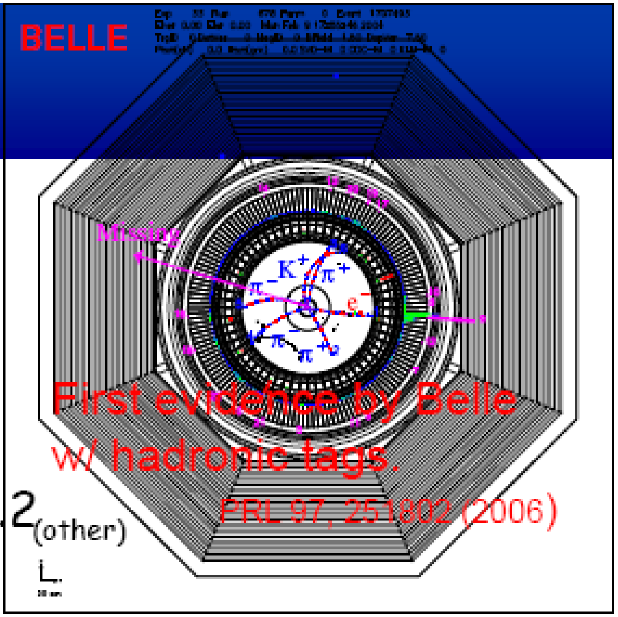
$\Rightarrow Br_{SM}(\tau\nu) = (1.20 \pm 0.25) \times 10^{-4}$

Sensitive also to NP (charged Higgs)

***Slide from T. Iijima, Lepton-Photon 2009**

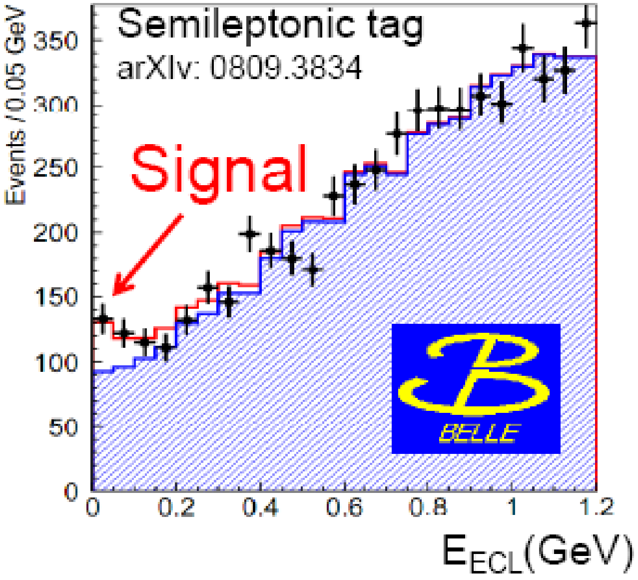
$B^{-} \rightarrow \tau^{-} \bar{\nu}$

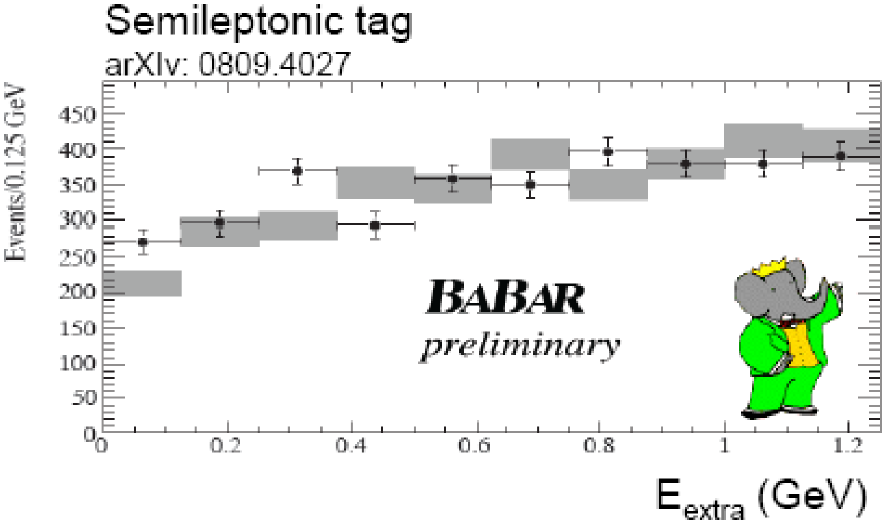
Belle	Branching fraction (10^{-4})
• Hadronic tag (449MBB)	$1.79\,^{+0.56}_{-0.49}\,^{+0.46}_{-0.51}$
• Semileptonic tag (657MBB)	$1.65\,^{+0.38}_{-0.37}\,^{+0.35}_{-0.37}$
BaBar	
• Hadronic tag (383MBB)	$1.8\,^{+0.9}_{-0.8} \pm 0.4_{(bkg)} \pm 0.2_{(other)}$
• Semileptonic tag (459MBB)	$1.8 \pm 0.8 \pm 01$



First evidence by Belle w/ hadronic tags.

PRL 97, 251802 (2006)





***Slide from T. Iijima, Lepton-Photon 2009**

Constraint on Charged Higgs

Naïve world average

$$Br(\tau\nu) = [1.73 \pm 0.35] \times 10^{-4} \quad \Leftrightarrow \quad Br_{SM}(\tau\nu) = [1.20 \pm 0.25] \times 10^{-4}$$

Based on fB from HPQCD and $|V_{ub}|$ from HFAG (BLNP, ICHEP08)

Effect of Charged Higgs

W. Hou, Phys. Rev. D48, 2342 (1993)

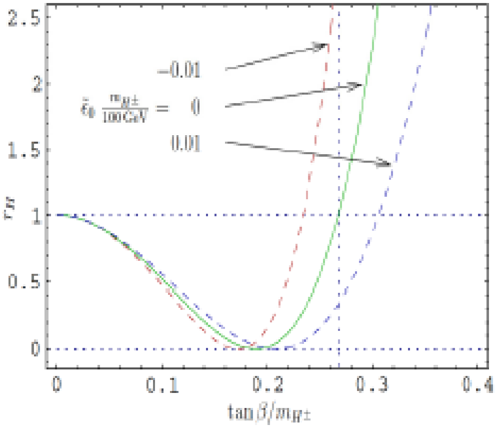
$$Br = Br_{SM} \times r_H,$$

$$r_H = \left(1 - \frac{m_B^2 \tan\beta^2}{m_H^2} \frac{1}{1+\varepsilon_0 \tan\beta}\right)^2$$

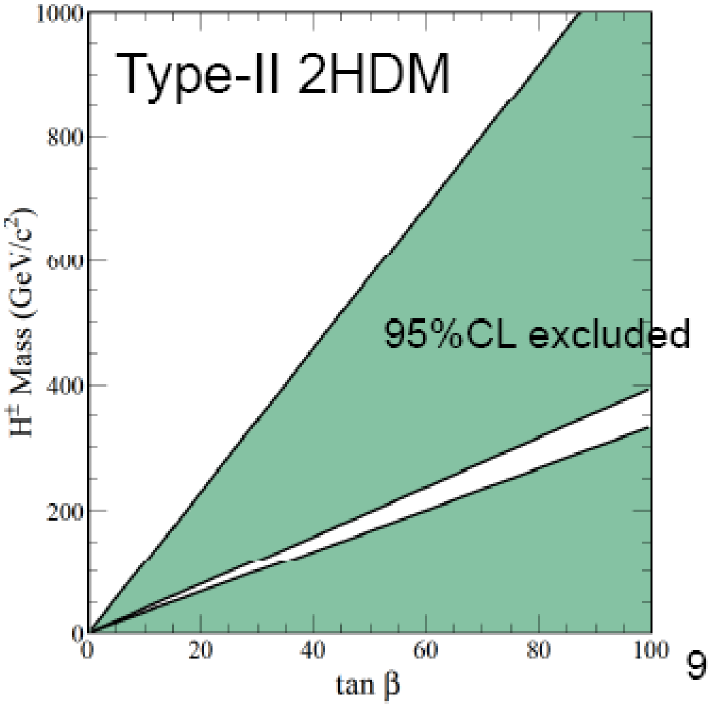
$$\tan\beta = \frac{v_u}{v_{,}}$$

SUSY Loop correction

ε_0=0 for Type-II 2HDM



Constraint on charged Higgs



***Slide from T. Iijima, Lepton-Photon 2009**

Comparison to CKM fit

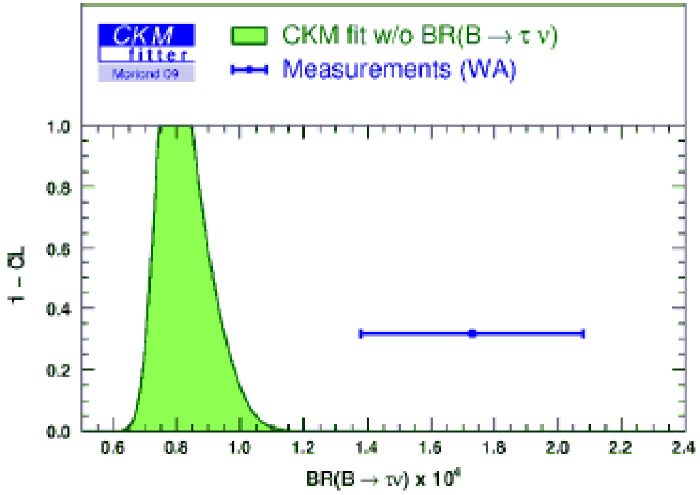
Naïve world average

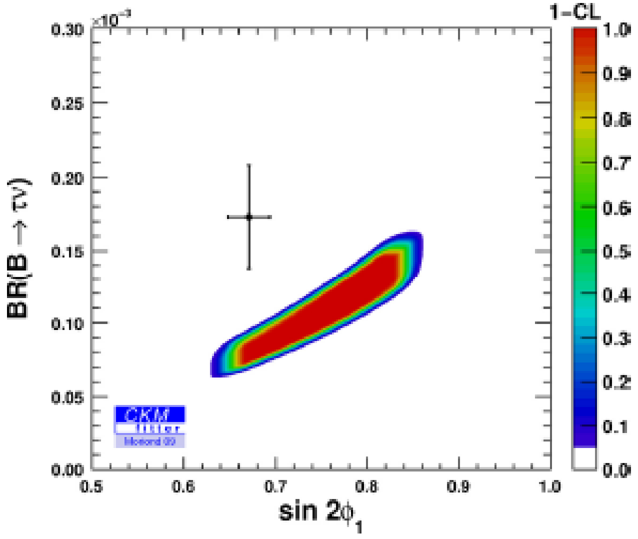
$$Br(\tau\nu) = [1.73 \pm 0.35] \times 10^{-4}$$

↕

$$Br(\tau\nu)_{CKM\ fit} = \left[0.786\ ^{+0.179}_{-0.083}\right] \times 10^{-4}$$

Output of a CKM fit without including B→τν in the fit (CKM fitter, ICHEP08)

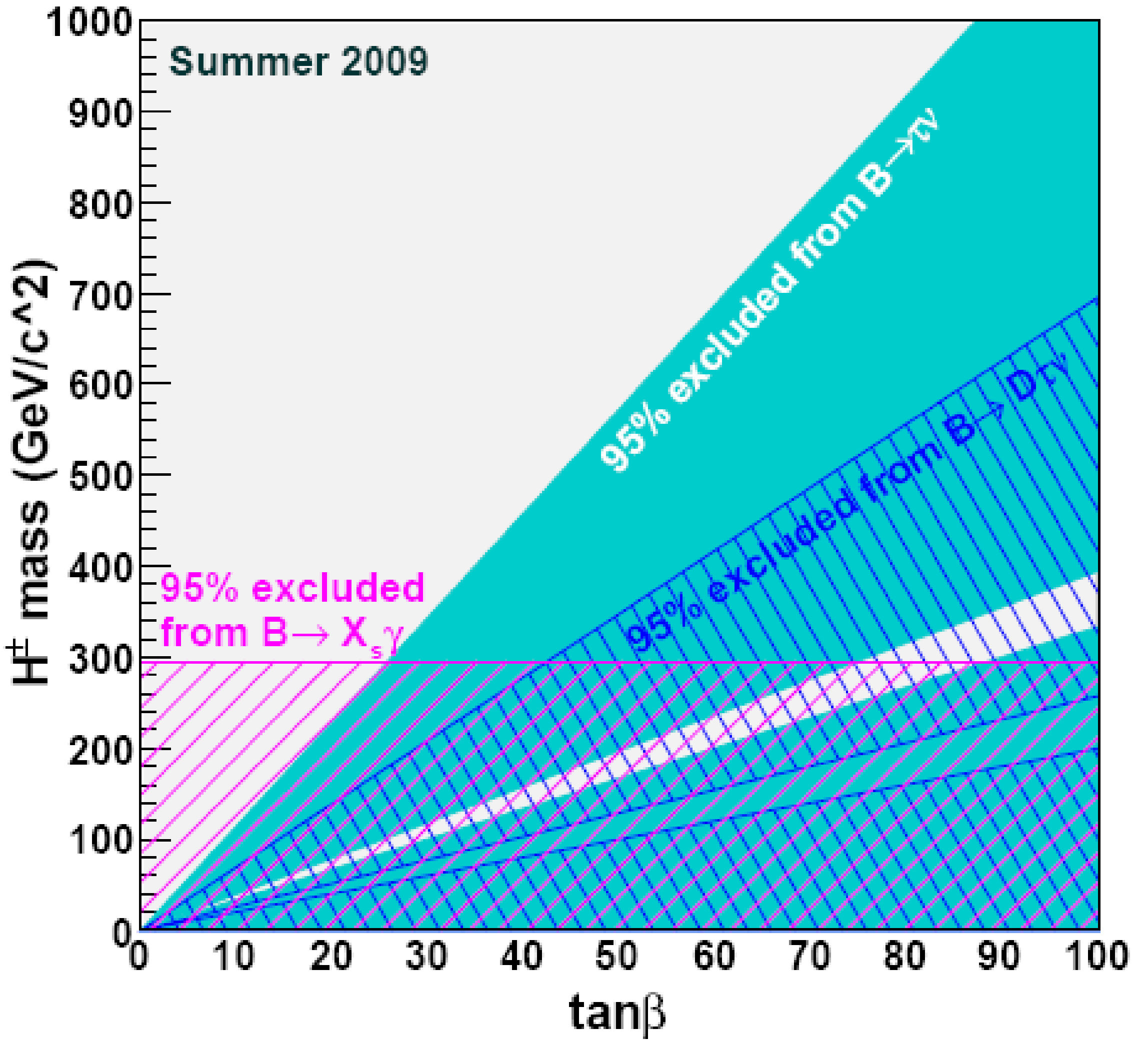




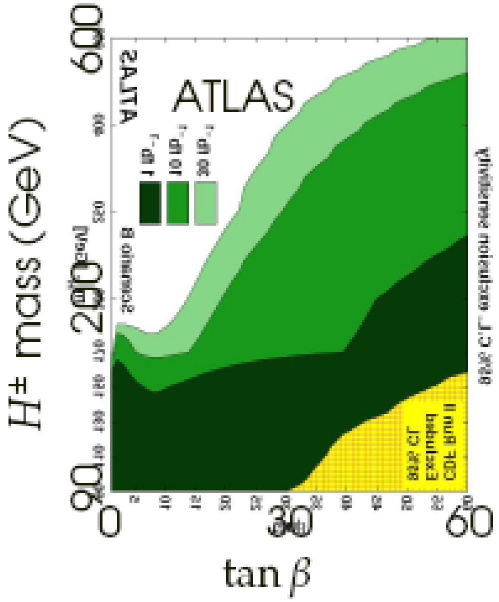
The measured Br is 2.4 σ higher than the value predicted by the CKM fit.

***Slide from T. Iijima, Lepton-Photon 2009**

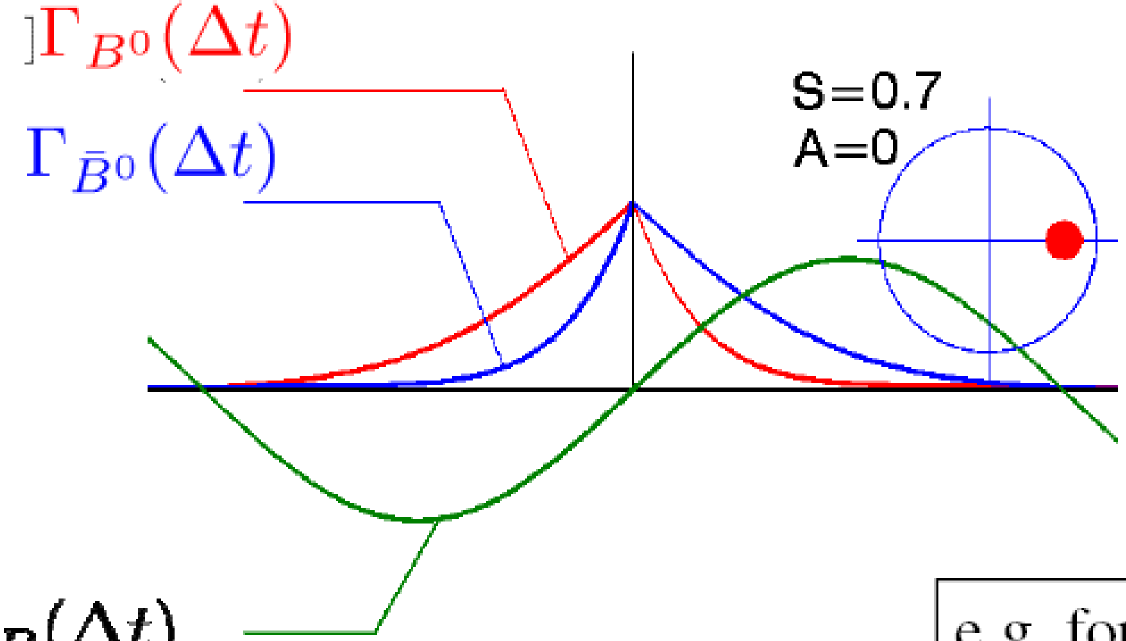
Combined charged Higgs bound from B-factories



completely covering expected exclusion region by ATLAS



Time Dependent CPV in B^0 decays



$$A_{CP}(\Delta t)$$

$$\equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)}$$

$$= S \sin \Delta m \Delta t + A \cos \Delta m \Delta t$$

Mixing-induced CPV

Direct CPV

e.g. for B→J/ψ Ks
$\mathcal{S} = -\xi_{CP}\sin 2\phi_1 = +\sin 2\phi_1$
$\mathcal{A} \sim 0$

(ξ_{CP} : CP eigenvalue ±1)

N.B. Time integrated mixing-induced asymmetries vanish