Electroweak Rare B Decays

10th March 2010

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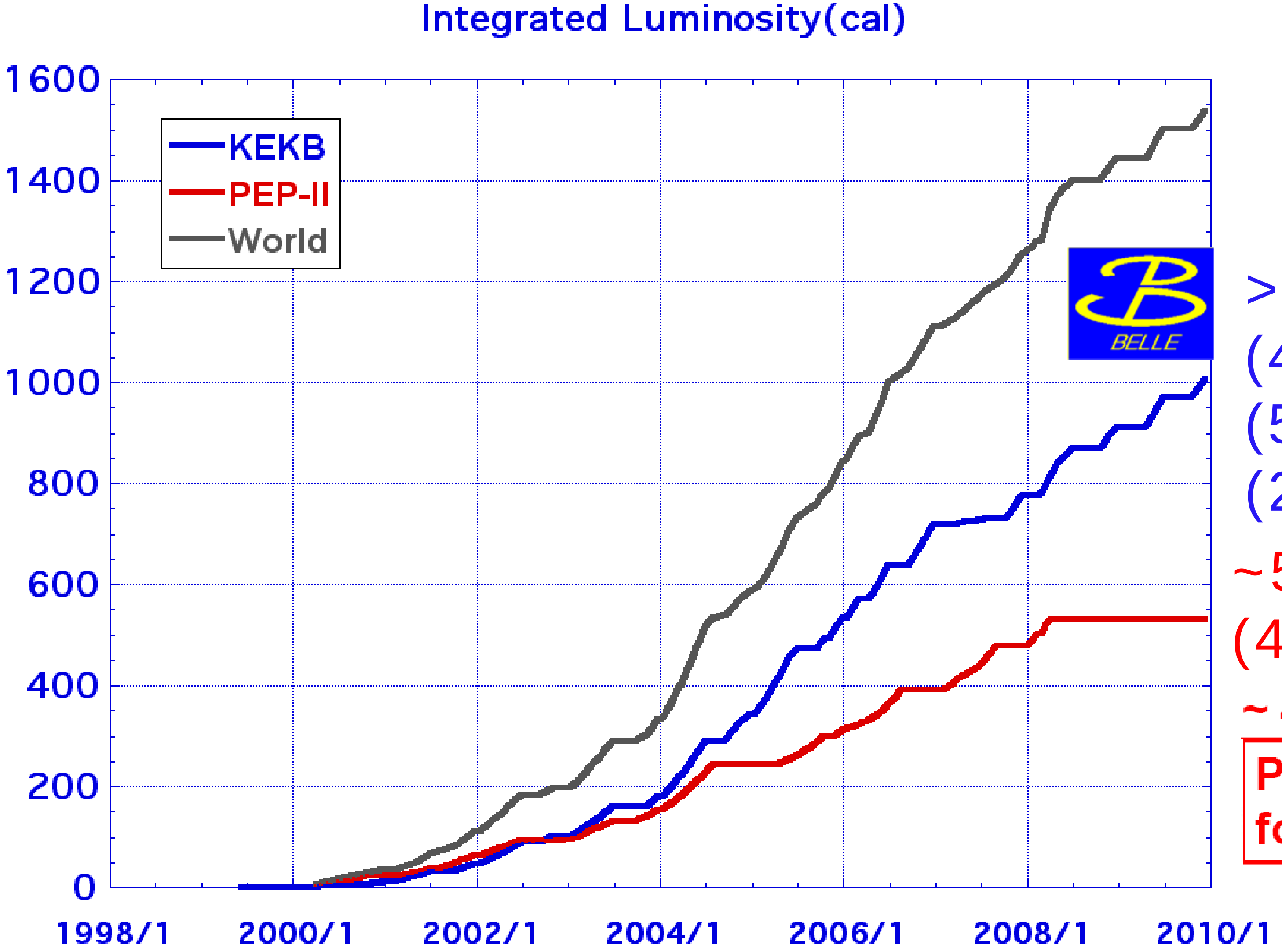
Luminosity at B factories



~770M BB

KEKB for Belle

> 1000 fb^{-1}
(4S:710 fb^{-1})
(5S:120 fb^{-1})
(2S: 24 fb^{-1})

~553 fb^{-1}
(4S: 433 fb^{-1})

~ 470M BB

PEP-II for BaBar

Contents

- Introduction
- Exclusive b → s ll (B → K* ll)
  - B.F. and lepton flavor ratio(R_{K*})
  - K* longitudinal polarization(F_L) ,
    lepton forward-backward asymmetry(A_{FB}), and
    Isospin asymmetry(A_I)
  - Xsll
  - K$\nu\nu$ upper limit
- b → s γ
  - B.F. of inclusive b → s γ
- Summary

Exclusive b → s ll (B → K* ll)

Flavor Changing Neutral Current (FCNC)

Forbidden at tree level in Standard Model (SM)

Loop-induced FCNC is possible

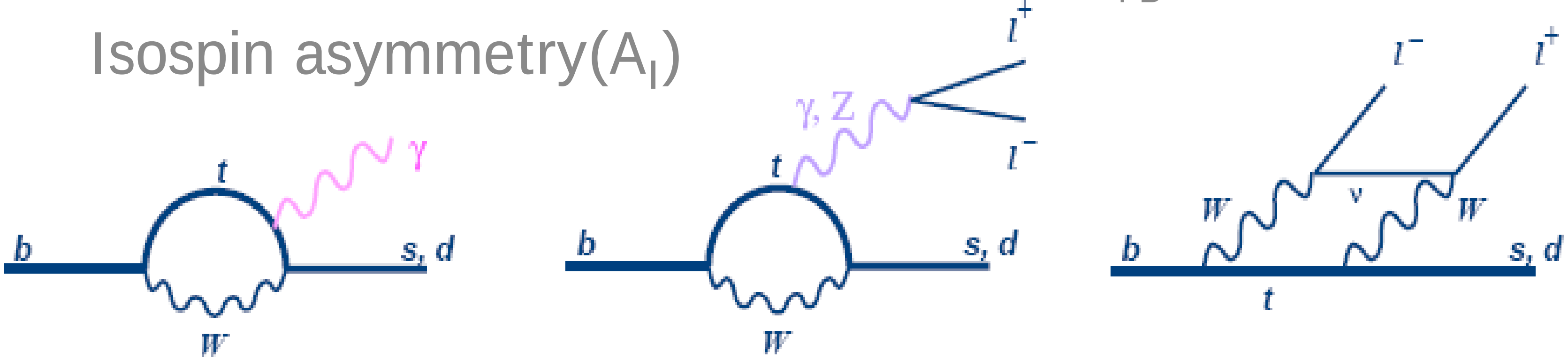
Radiative and Electroweak penguin B decays are sensitive to physics beyond the SM

B.F and lepton flavor ratio(R_{K*})

K* longitudinal polarization(F_L) and

lepton forward-backward asymmetry(A_{FB})

Isospin asymmetry(A_I)



Wilson coefficients and B → K*l⁺l⁻

- Wilson coefficients
  - C_7 : from electromagnetic penguin diagram
    (size is determined from b → s γ, but sign is from b → s l^+l^-)
  - C_9 : from vector electroweak
  - C_{10} : from axial vector electroweak
- Differential branching fraction (B.F.) and
  Forward-backward asymmetry (A_{FB}) in B → $K^*l^+l^-$

$$\frac{dA_{FB}}{dq^2} \propto -\Re e[\tilde{C}_9\tilde{C}_{10}VA_1 + \frac{M_B m_b}{q^2}\tilde{C}_7\tilde{C}_{10}(VT_2\cdot(1-\frac{m_{K^*}}{M_B}) + A_1T_1\cdot(1+\frac{m_{K^*}}{M_B}))]$$

  - B.F., A_{FB}, F_L... can be interpreted in terms of Wilson coefficients

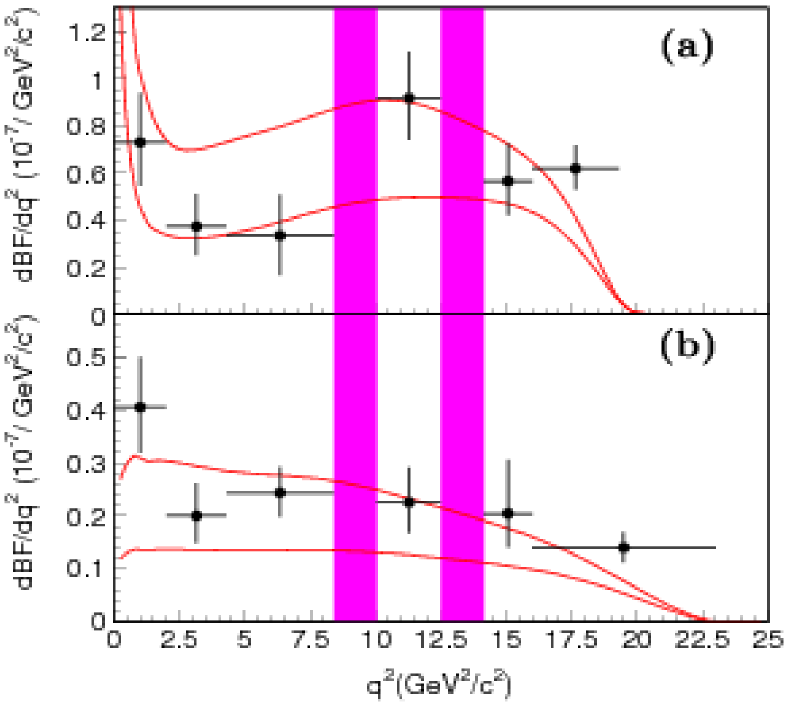
$K^{(*)}l^+l^-$ Branching Fractions

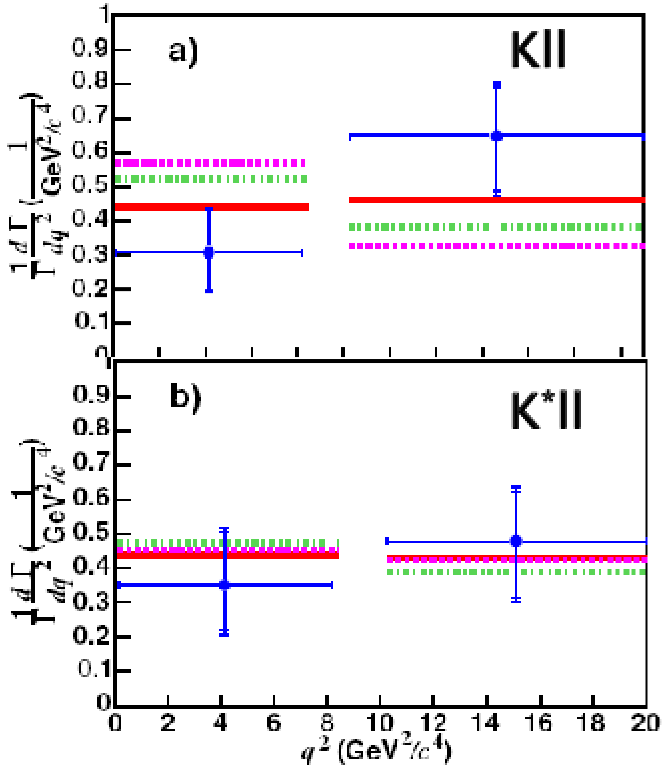
657M BB
PRL **103**, 171801 (2009)

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

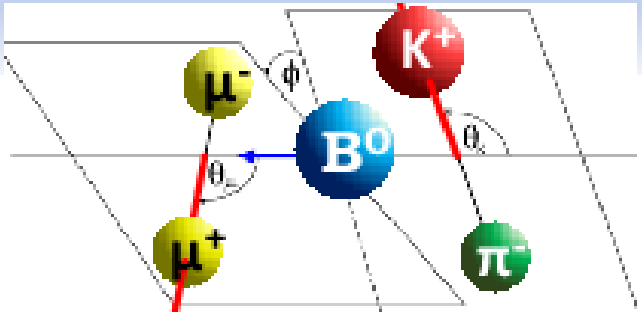
: SM expectation w/ min. & max. form factors from[Ali et al. PRD 66, 034002 (2002)]

Lines are SM predictions w/ various form factor models.

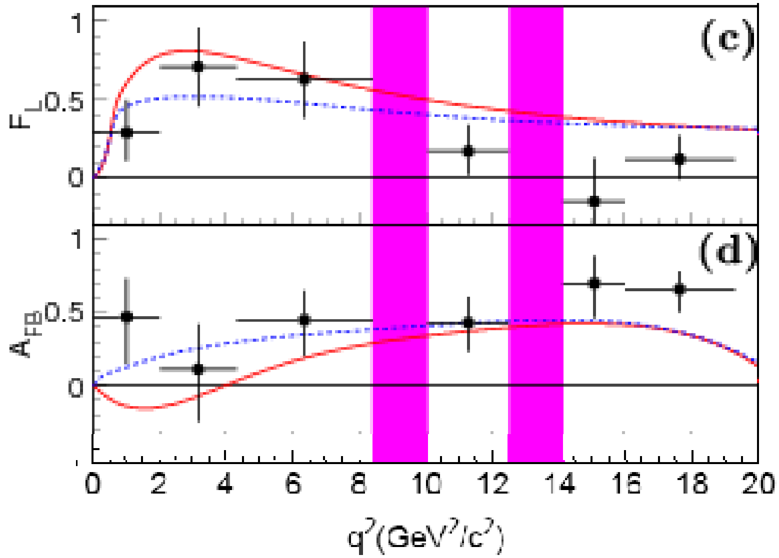
F_L and A_{FB} for K*ll

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

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



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

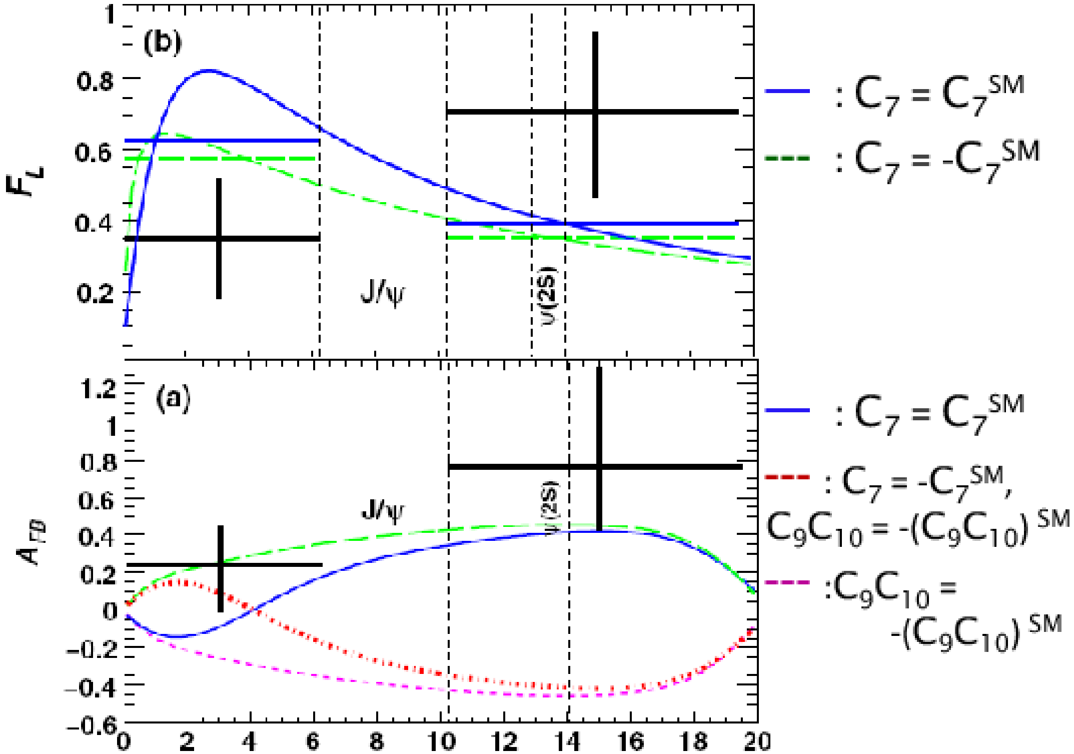


: J/ψ (ψ') veto regions

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

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

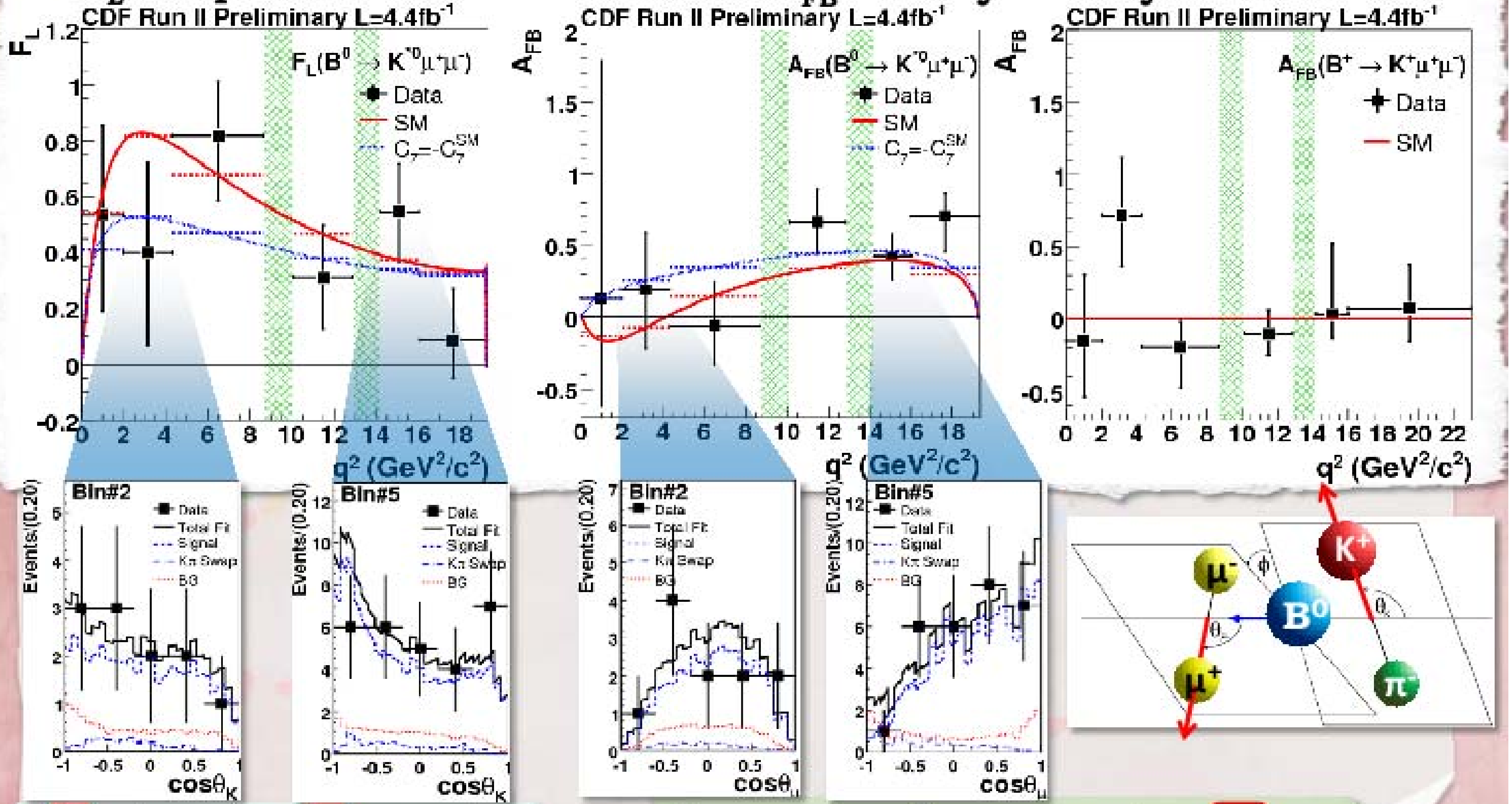
383M BB
PR **D79**, 031102 (2009)



$A_{FB}(B \to K^{(*)}\mu\mu)$

F_L: K* polarization

A_{FB}: FB asymmetry



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

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

F_L=1 for Kμμ

$B \to X_s ll$ analysis

"Semi-inclusive" reconstruction : sum of 36 exclusive modes

- X_s: charged K /K^0_s + ≦ 4 π (≦1 π^0), ll: e^+e^- /$\mu^+\mu^-$

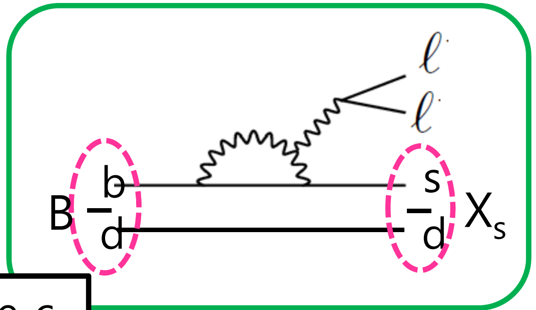
$B^0 \to K^+\pi^-l^+l^-$
- $K^+\pi^-\pi^0l^+l^-$
- $K^+\pi^-\pi^+\pi^-l^+l^-$
- $K^+\pi^-\pi^+\pi^-\pi^0l^+l^-$

$B^+ \to K^+l^+l^-$
- $K^+\pi^0l^+l^-$
- $K^+\pi^+\pi^-l^+l^-$
- $K^+\pi^+\pi^-\pi^0l^+l^-$
- $K^+\pi^+\pi^-\pi^+\pi^-l^+l^-$

$B^0 \to K^0_sl^+l^-$
- $K^0_s\pi^0l^+l^-$
- $K^0_s\pi^+\pi^-l^+l^-$
- $K^0_s\pi^+\pi^-\pi^0l^+l^-$
- $K^0_s\pi^+\pi^-\pi^+\pi^-l^+l^-$

$B^+ \to K^0_s\pi^+l^+l^-$
- $K^0_s\pi^+\pi^0l^+l^-$
- $K^0_s\pi^+\pi^-\pi^+l^+l^-$
- $K^0_s\pi^+\pi^-\pi^+\pi^0l^+l^-$

+ charge c onjugate



~60% coverage of all X_s state

~80% coverage assuming K_L=K_S

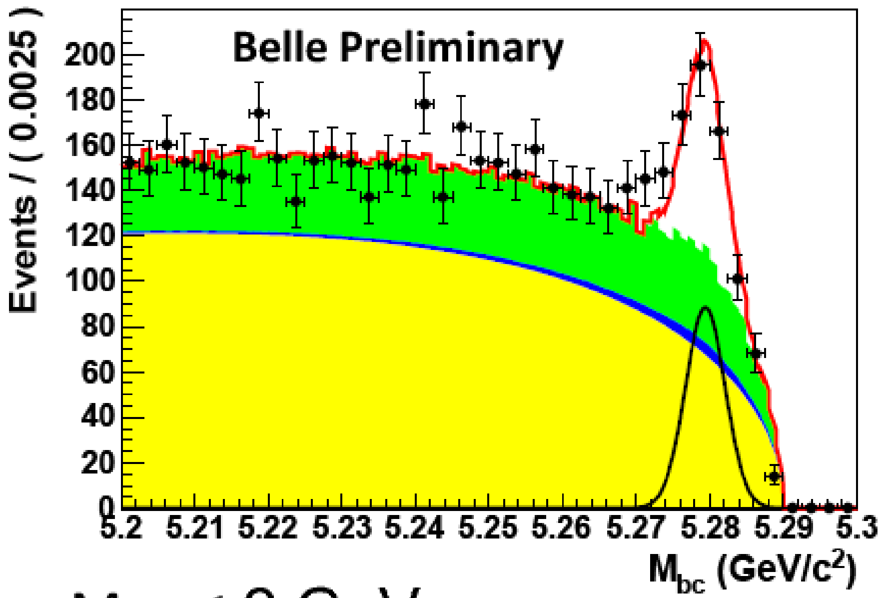
Compared to the exclusive analysis ($B \to K^{(*)}ll$), inclusive mode is theoretically clean, but experimentally hard.

B→$X_s$ll analysis

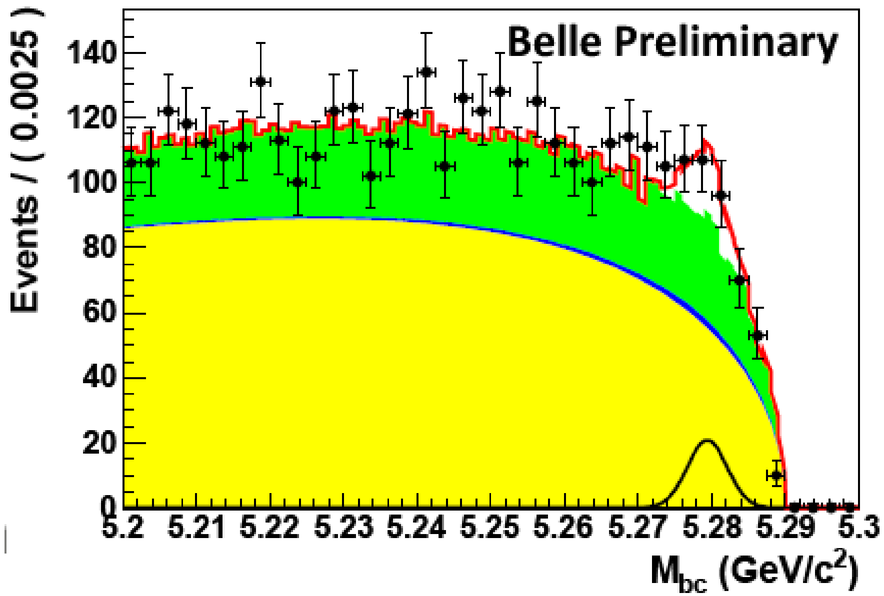
- Opposite sign C_7 would enhance branching fraction of $B \to X_s \ell\ell$

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

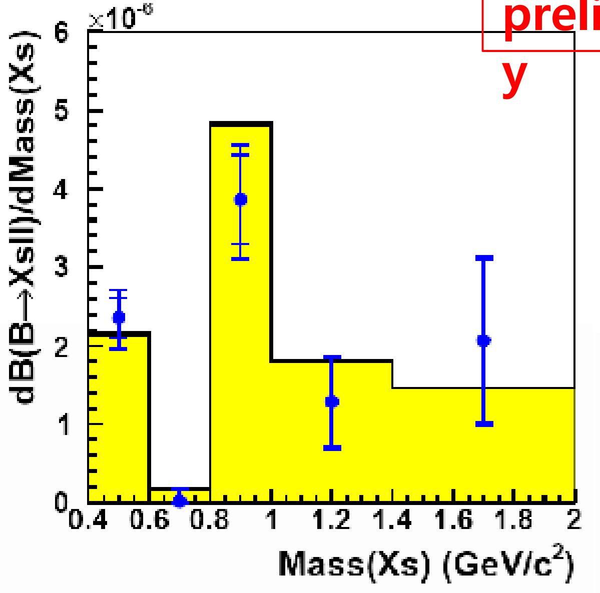
Large backgrounds:

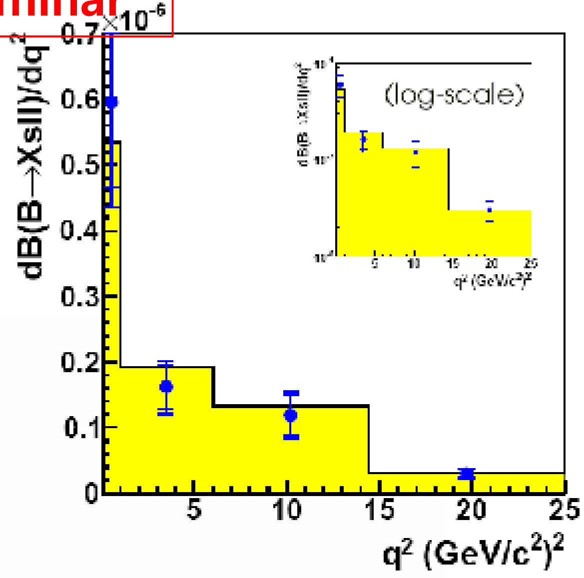
Combinatorial from continuum & semileptonic B decays

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

B->$X_s$ll Branching Ratio

preliminary





657M BB
Preliminary

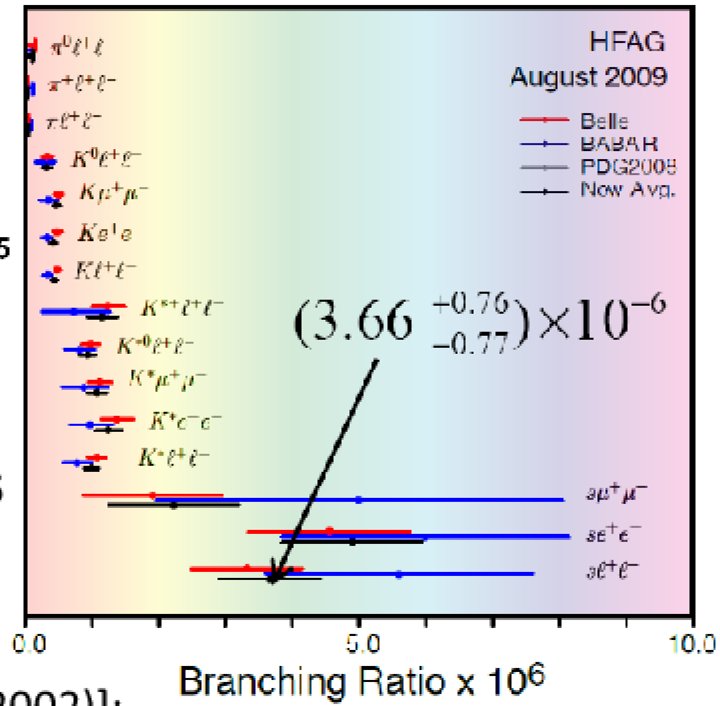
$$\mathcal{B}(B \to X_s \ell\ell) = (3.33 \pm 0.80^{+0.19}_{-0.24}) \times 10^{-6}$$

*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)]:

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

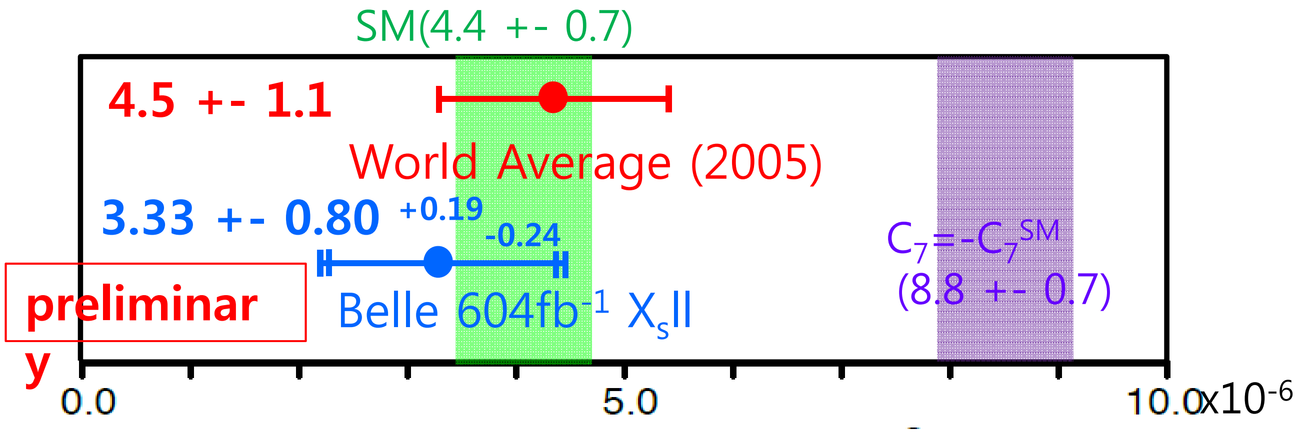
$\mathcal{B}(B \to X_s \ell^+ \ell^-)$



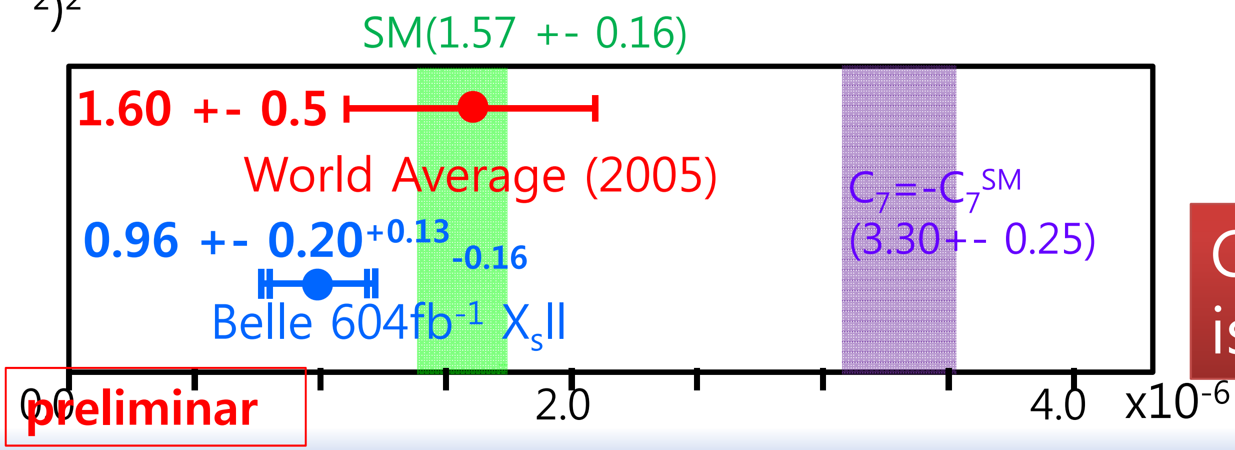
$C_7 = C_7^{SM}$ v.s. $C_7 = -C_7^{SM}$

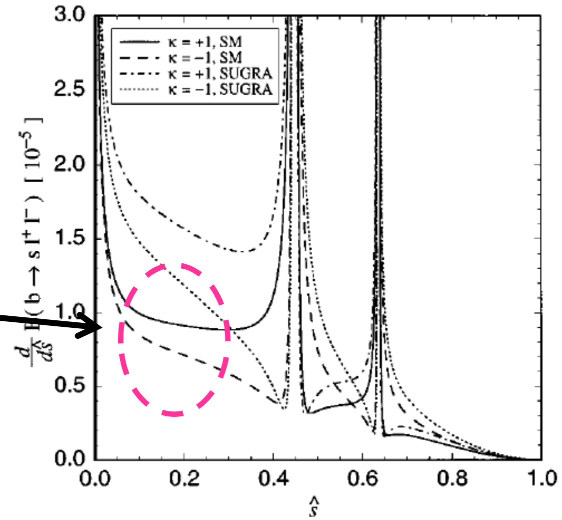
$|C_7|$: determined from $B \to X_s \gamma$

Xsll Branching fraction



Xsll Branching fraction for $M(l^+l^-)^2$= 1-6(GeV/c^2)^2





C_7 sign flipped case is unlikely

Theory calculations(NNLO): Gambino(2005)

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)

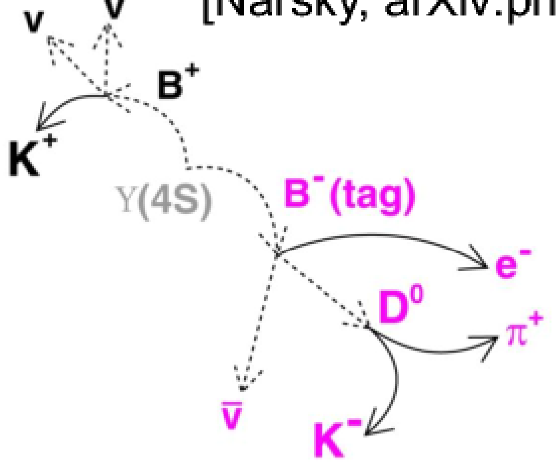
SM prediction:

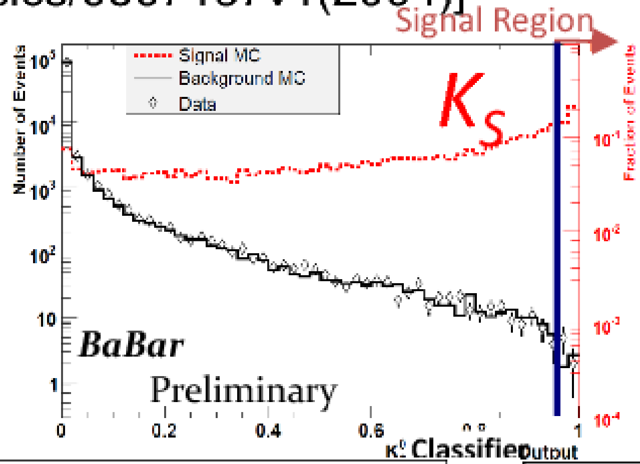
$Br(K\nu\nu)=(4.5+-0.7)10^{-6}$ W.Altmannshofer, A.Buras *et al.* JHEP 0904, 022 (2009)
$Br(K\nu\nu)=(3.8^{+1.2}_{-0.6})10^{-6}$ G.Buchalla, G.Hiller and G.Isidori PRD 63,014015 (2000)

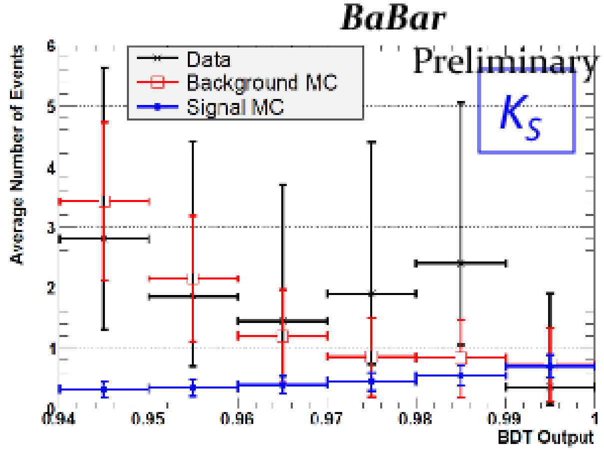
B->$K\nu\bar{\nu}$ with Semileptonic Tagging

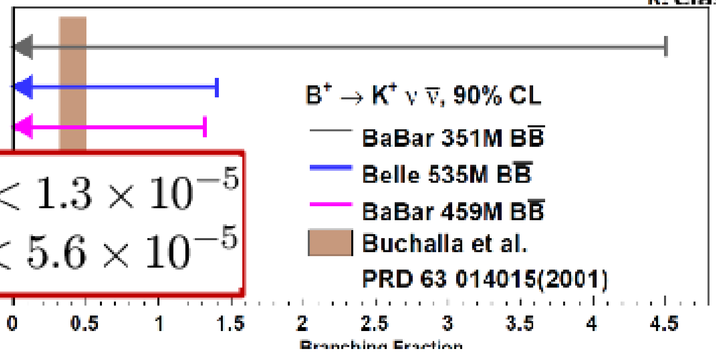
- Method:
  - Tag one B using $D^{(*)}\ell\nu$ (~1% efficiency)
  - Look for a lone K (K_s plots shown, K^+ in backup)
  - Multivariate technique (bagged decision tree) to select events [Narsky, arXiv:physics/0507157v1(2004)]

459M BB
Preliminary

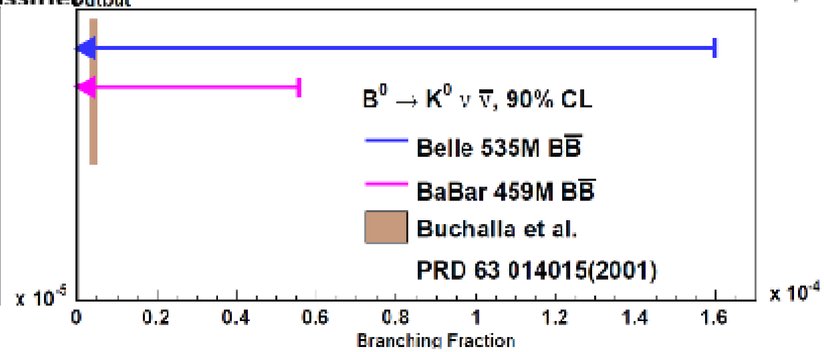








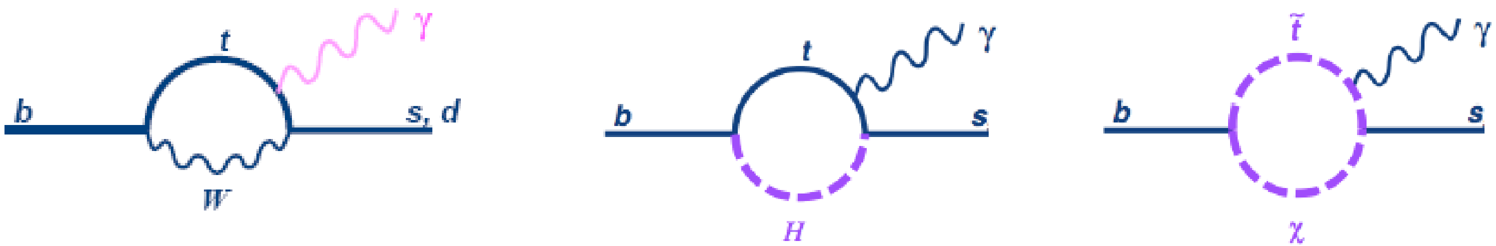
$$\mathcal{B}(B^+ \to K^+\nu\overline{\nu}) < 1.3 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K^0\nu\overline{\nu}) < 5.6 \times 10^{-5}$$



b → s γ

B.F. of inclusive b → s γ

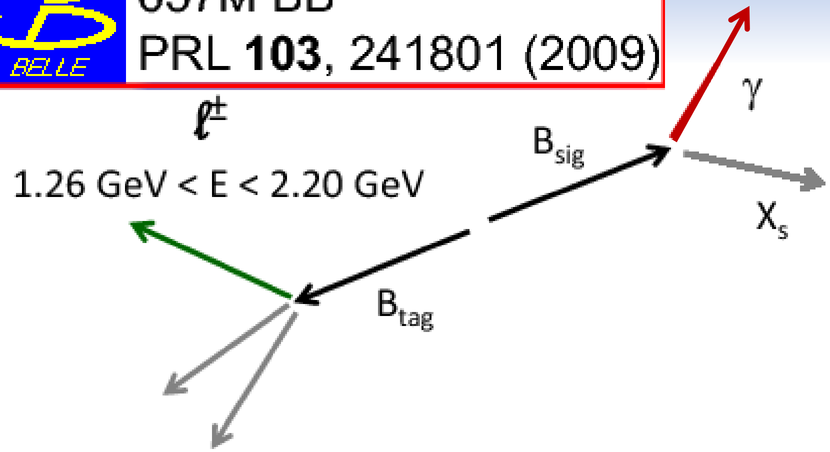
Xs mass distribution

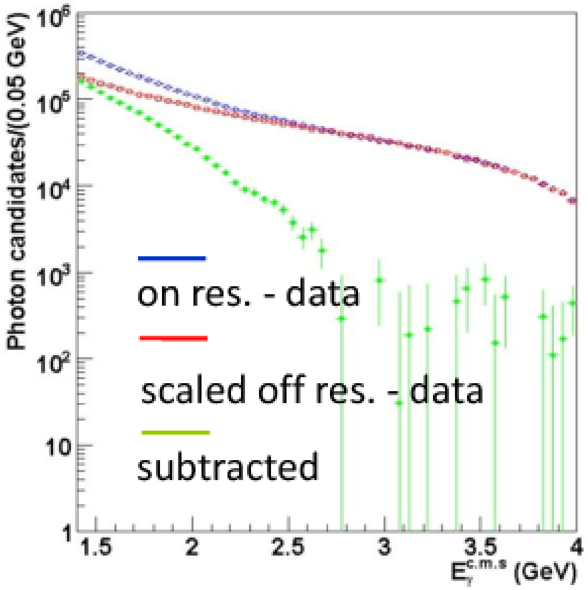


Inclusive b->sγ

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

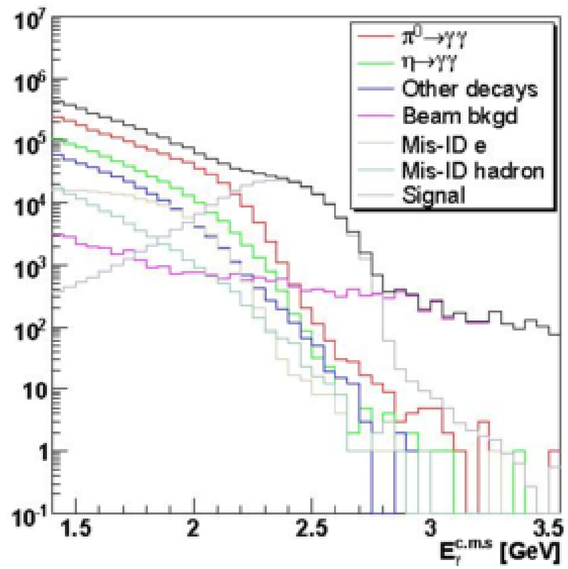
- Fully inclusive measurement (only the γ w/ E^{CM} > 1.4 GeV is reconstructed):
  - Divided into two streams:
    - MAIN - without lepton tag
    - LT – w/ lepton tag, reduces qq background
  - A data sample of 68 fb^{-1} taken below $\Upsilon(4S)$ is used to subtract $e^+ e^- \rightarrow qq$ backgrounds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



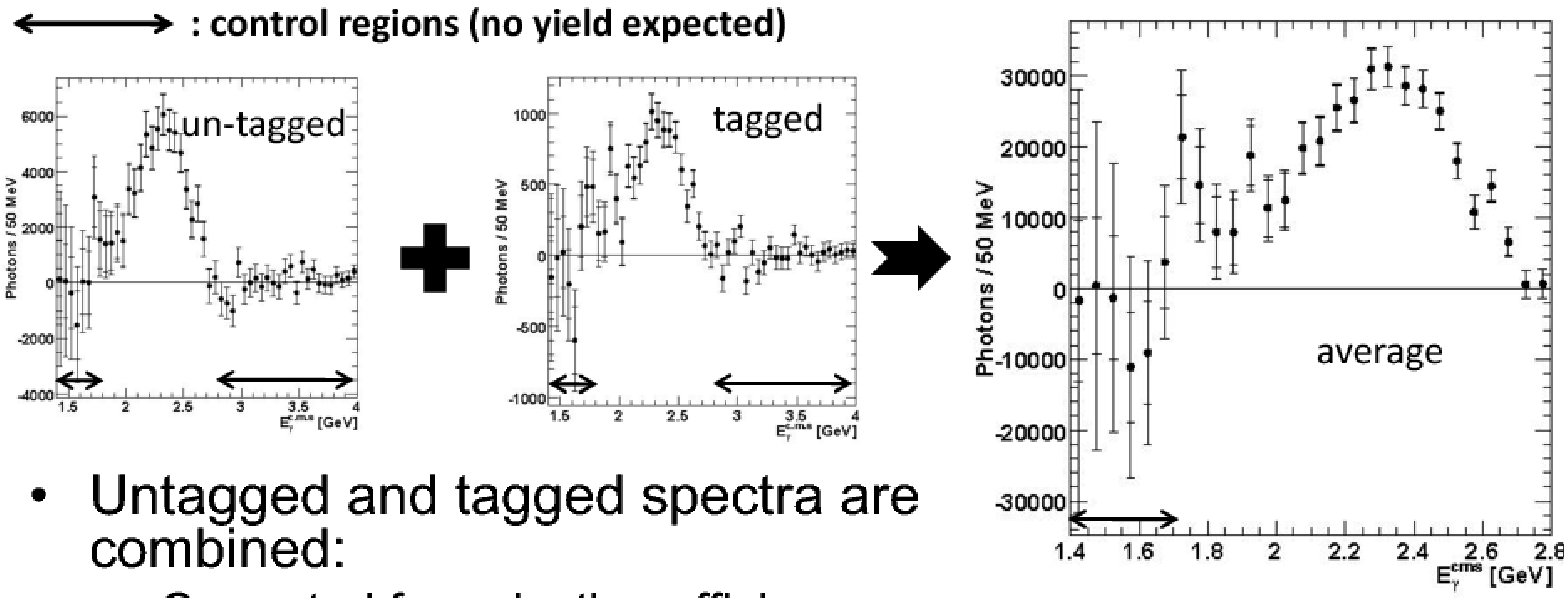


<u>Left</u>: photon energy distributions in data for on resonance, off resonance, and continuum subtracted samples.

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



Inclusive b->sγ



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

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

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

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

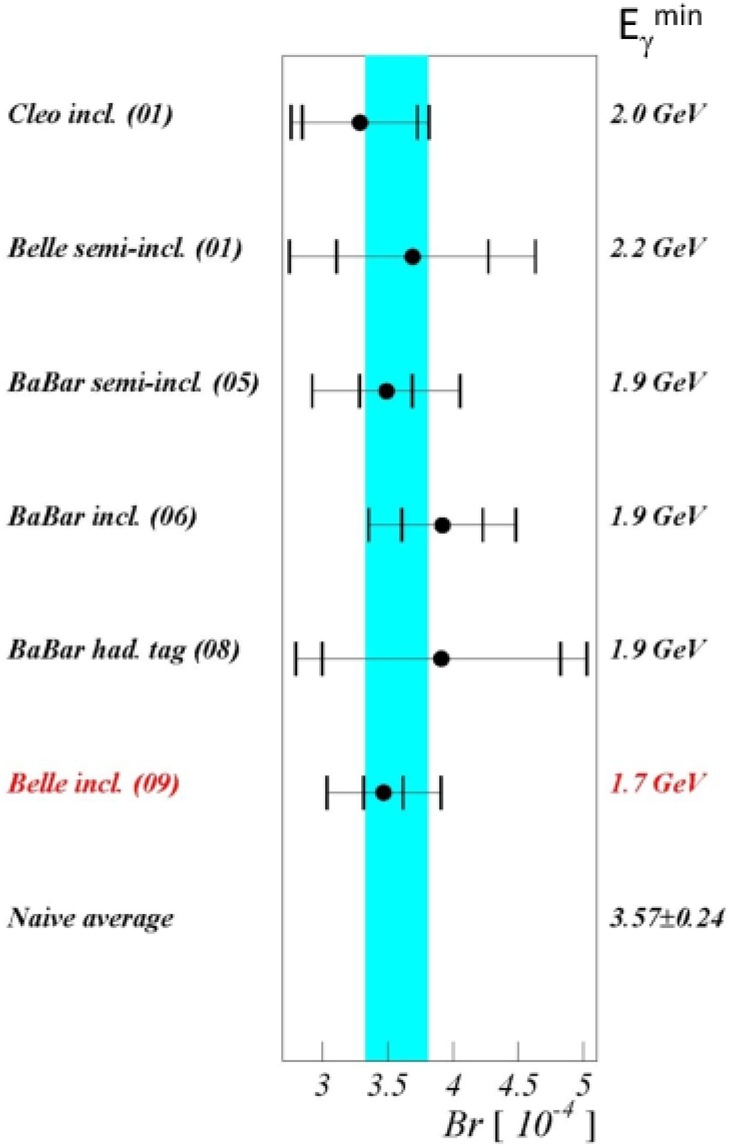
Inclusive b->sγ

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

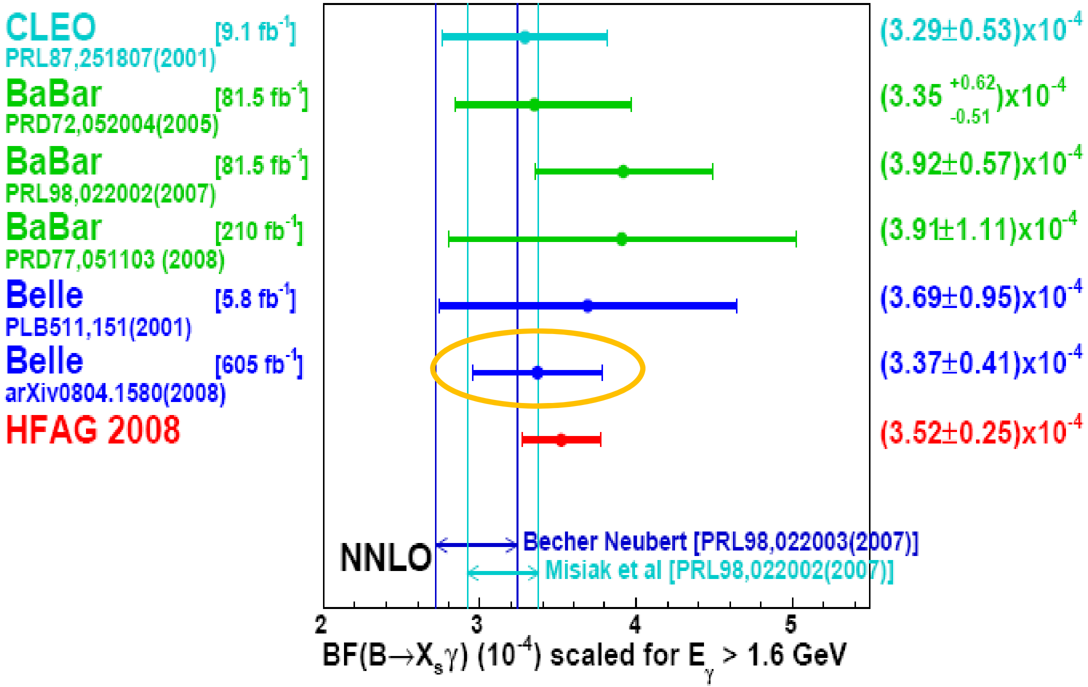
$$\mathcal{B}(B \to X_s\gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$$
$$1.7\ \text{GeV} < E_\gamma < 2.8\ \text{GeV}$$

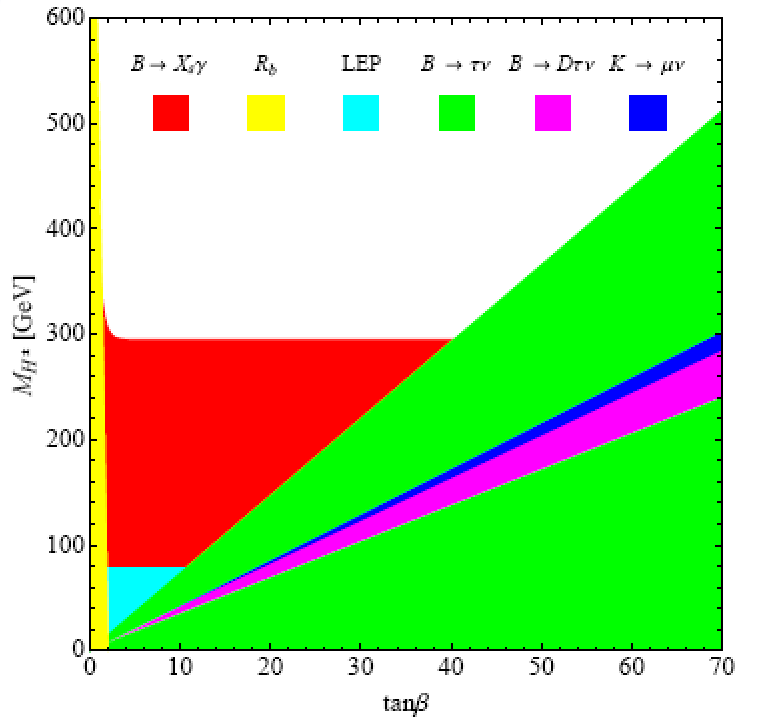
Consistent with NNLO SM calculations
[Misiak et al., PRL **98**, 022002 (2007)]:

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



Inclusive b → s γ





Ulrich Haisch, arXiv:0805.2141v2 [hep-ph]

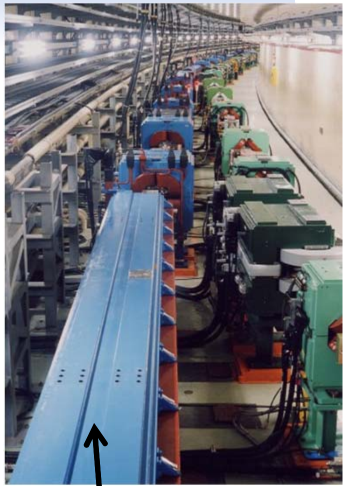
HFAG average $B.F(B \to X_s\gamma)_{E\gamma > 1.6\ GeV} = (3.52 \pm 0.25) \times 10^{-4}$

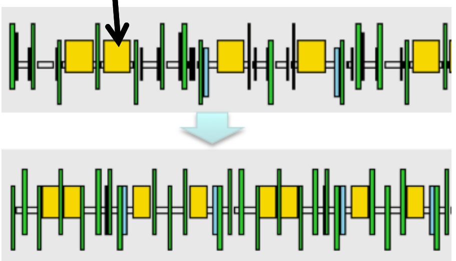
- Agreement with SM (latest NNLO calculation)
- Strong constraints on generic 2HDM charged Higgs

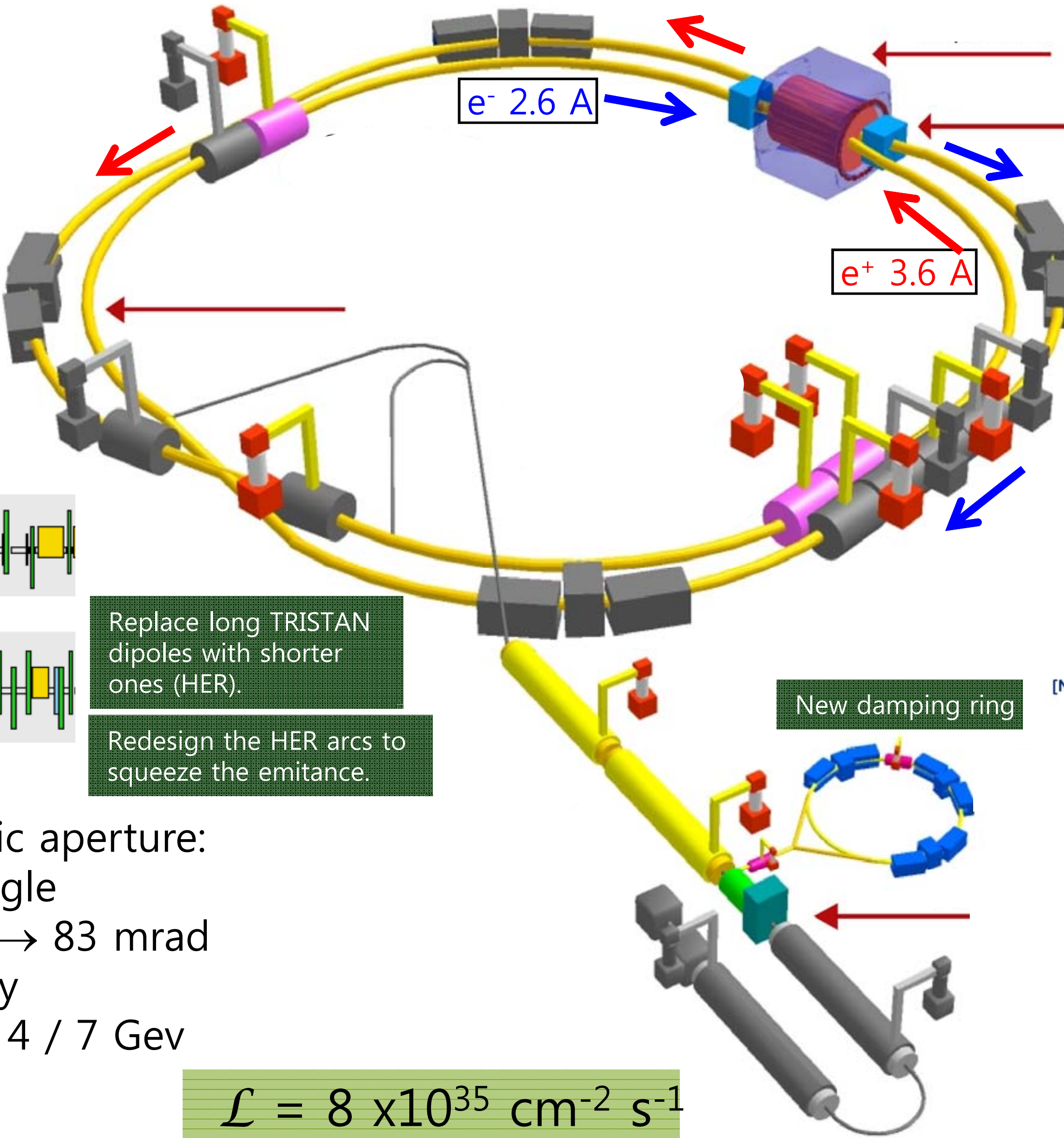
Conclusion

- Rare EW B decays provide a valuable tool to test Standard Model predictions.
- Both Belle and BaBar have accumulated a large set of data with which these decays were studied...
  - We can look forward to many results using the entirety of the Belle and BaBar data sets...
  - ...but many modes require significantly improved statistics:
    - LHCb
    - Super B factories

SuperKEKB



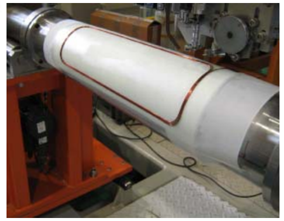




Belle II

New IR

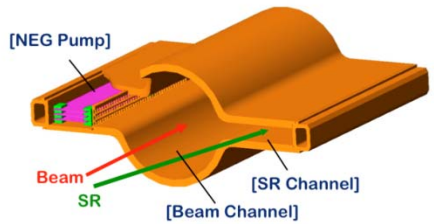
New Superconducting / permanent final focusing quads near the IP



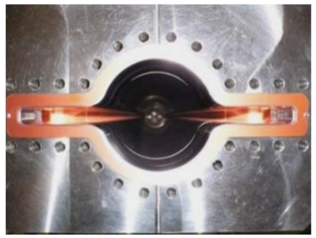
Replace long TRISTAN dipoles with shorter ones (HER).

Redesign the HER arcs to squeeze the emitance.

New damping ring



TiN coated beam pipe with antechambers



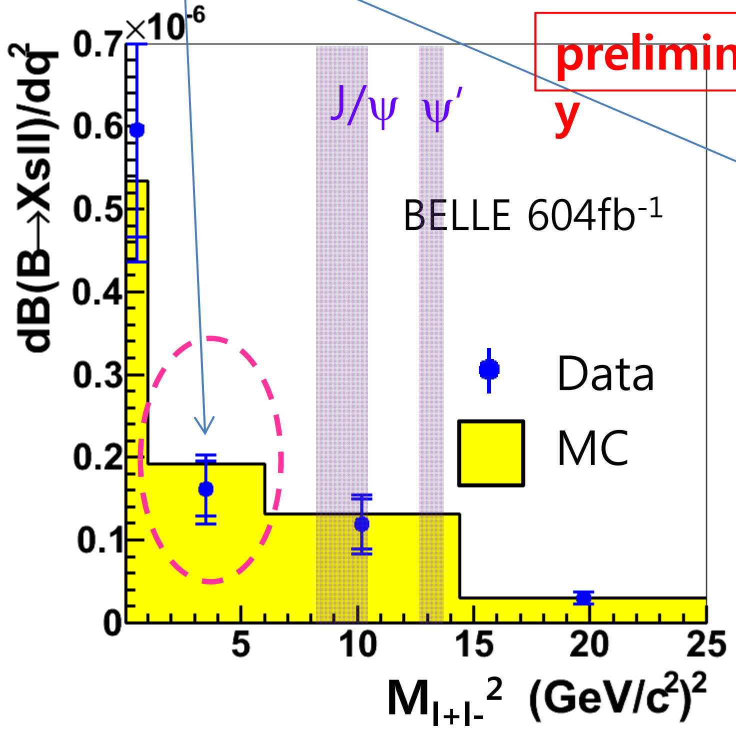
increasing dynamic aperture:
larger crossing angle
2ϕ = 22 mrad → 83 mrad
smaller asymmetry
3.5 / 8 GeV → 4 / 7 Gev
optimizing lattice:
τ_{beam} ~ 400 s
(target 600 s)

$\mathcal{L} = 8 \times 10^{35}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

Backup Slides

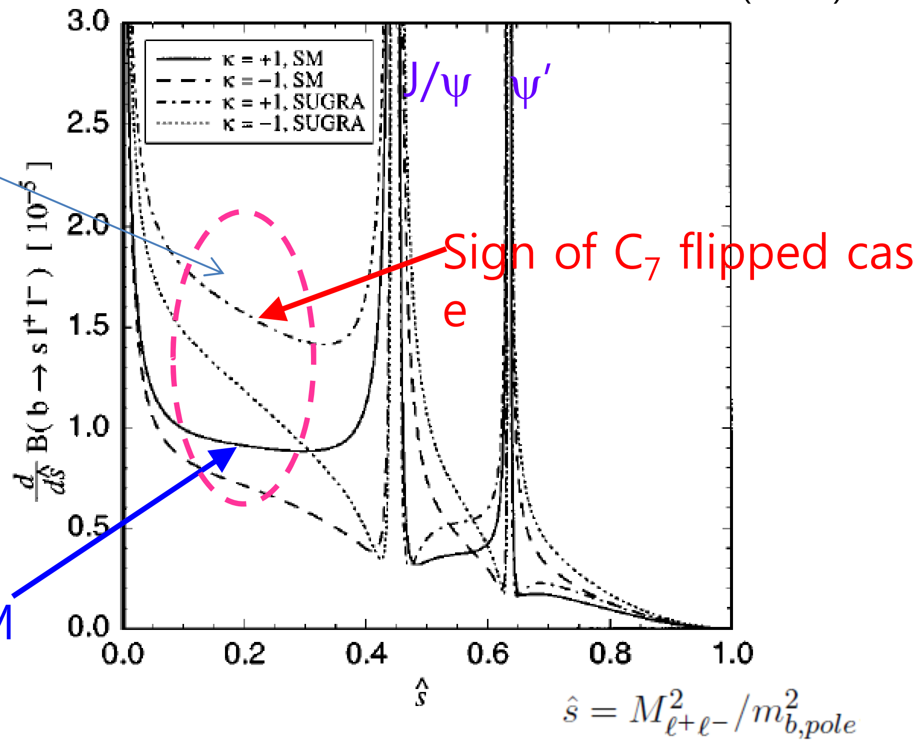
dBR($X_s$ll) / dM_{l+l-}^2

This range is sensitive to NP



(M_{Xs} < 2.0 GeV/c^2)

T.Goto et al. PRD 55 4273 (1997)



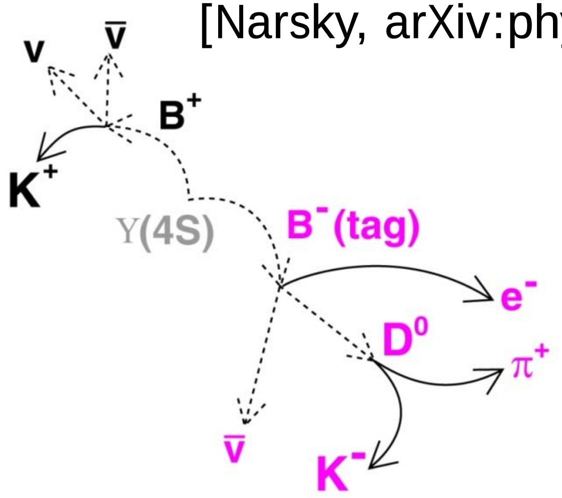
MC normalization: based on the BR measured in this analysis.

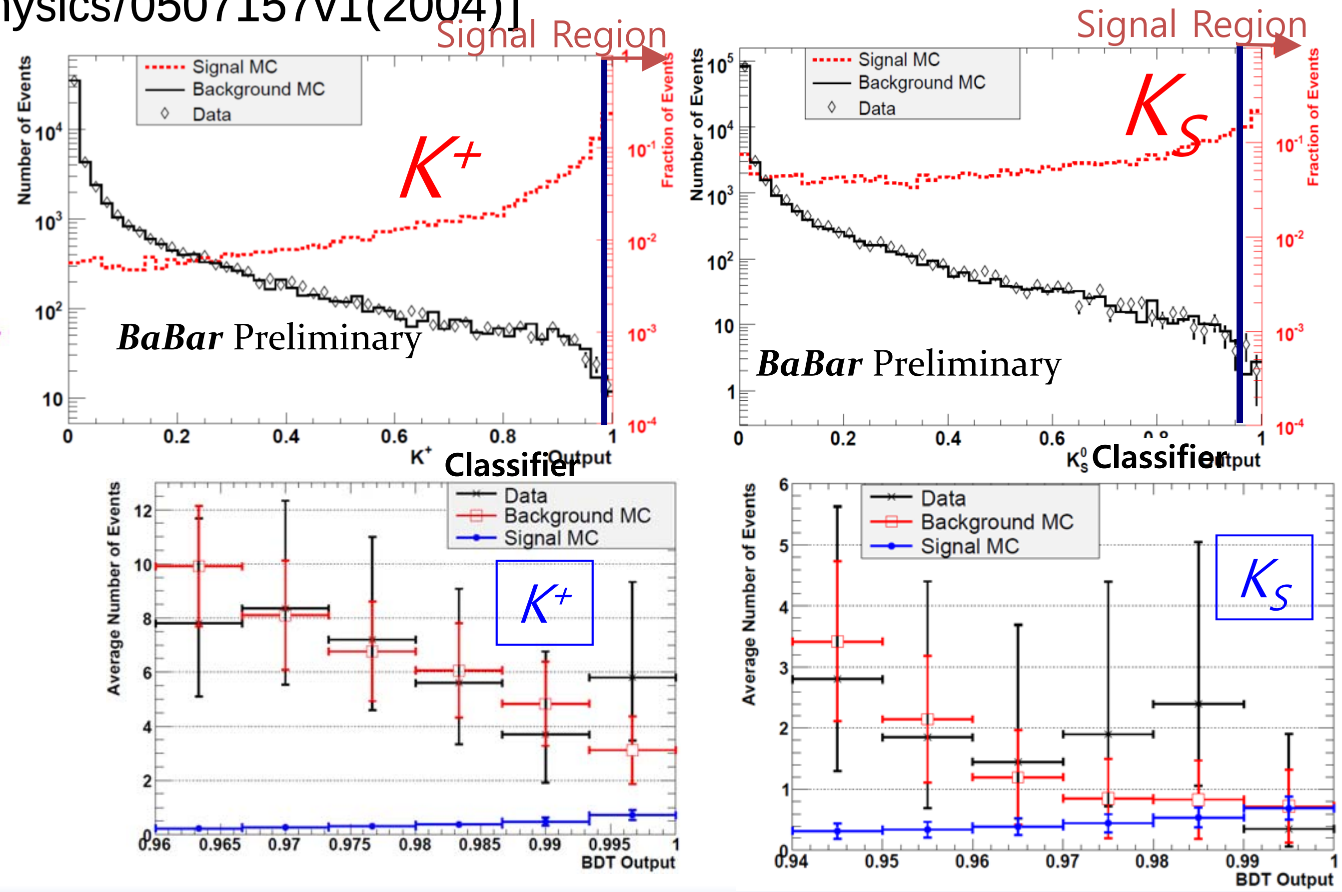
M(l$^+$l$^-$) distribution is consistent with MC expectation.

B->K$\nu\bar{\nu}$ with 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)]

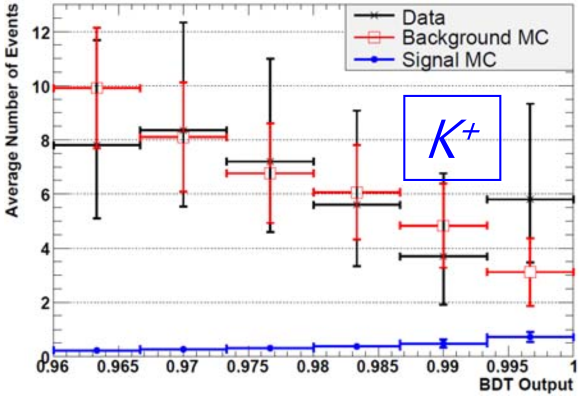


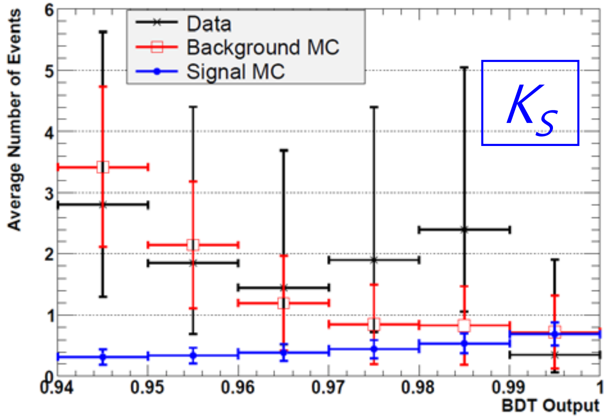


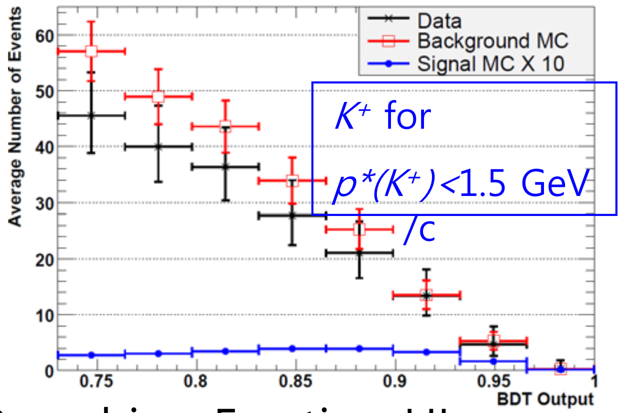
B->Kνν Upper Limits

459M BB
Preliminary

Decision tree outputs in signal regi

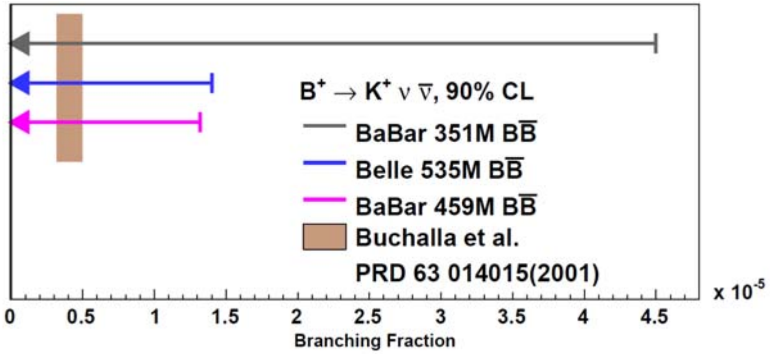


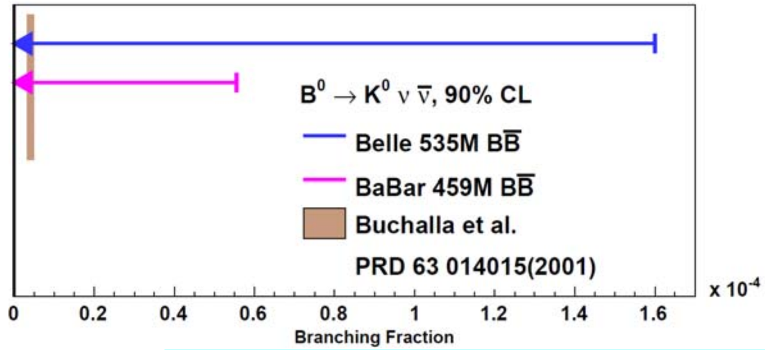




Total Branching Fraction UL | Partial Branching Fraction ULs

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

Inclusive b->sγ

Branching fractions, mean and variance of the photon energy for lower thresholds and systematic uncertainties.

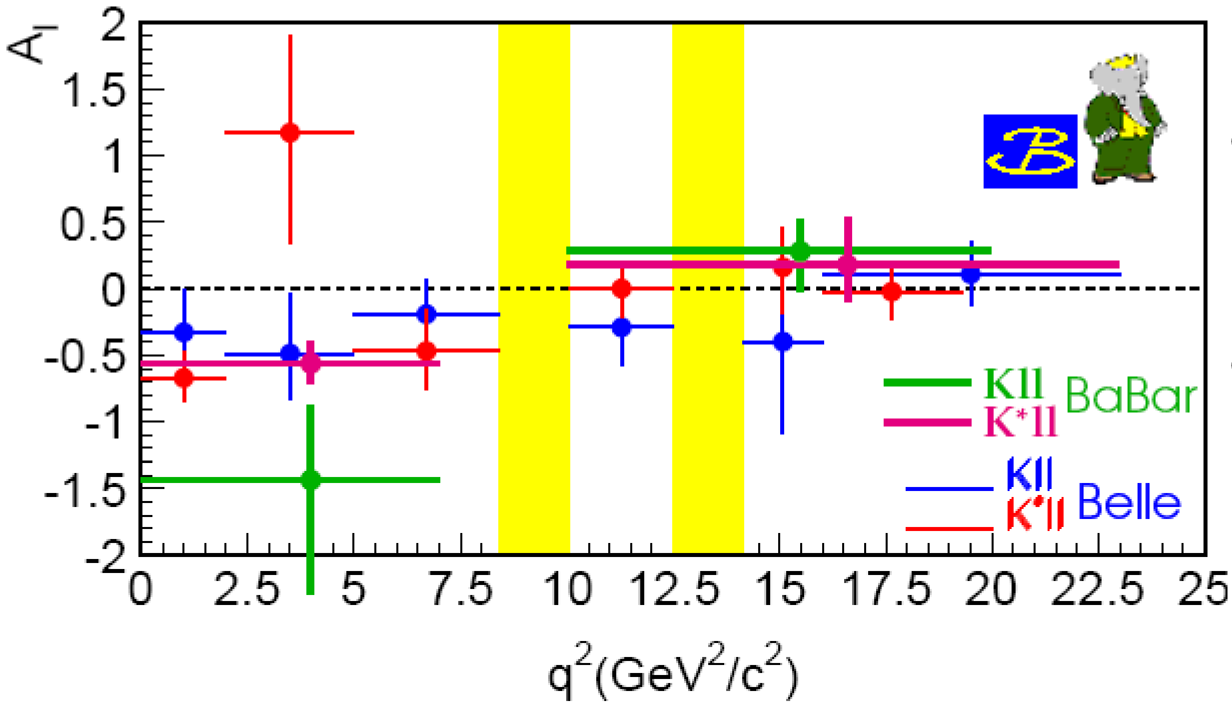
	$BF(B \to X_s\gamma)$ (10^{-4})				$\langle E_\gamma \rangle$ (GeV)				$\Delta E_\gamma^2 \equiv \langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2$ (GeV^2)			
$E^{B}_{\gamma-Low}$ [GeV]	1.70	1.80	1.90	2.00	1.70	1.80	1.90	2.00	1.70	1.80	1.90	2.00
Value	3.45	3.36	3.21	3.02	2.282	2.294	2.311	2.334	0.0428	0.0370	0.0302	0.0230
±statistical	0.15	0.13	0.11	0.10	0.015	0.011	0.009	0.007	0.0047	0.0029	0.0019	0.0014
±systematic	0.40	0.25	0.16	0.11	0.051	0.028	0.015	0.009	0.0202	0.0081	0.0030	0.0016
Systematic Uncertainties												
1. Continuum	0.26	0.16	0.10	0.07	0.033	0.018	0.009	0.004	0.0111	0.0048	0.0016	0.0005
2. Selection	0.15	0.12	0.10	0.08	0.016	0.009	0.005	0.002	0.0089	0.0029	0.0011	0.0004
3. π^0/η	0.07	0.05	0.04	0.02	0.011	0.006	0.003	0.002	0.0068	0.0022	0.0007	0.0003
4. Other B	0.25	0.14	0.06	0.02	0.033	0.017	0.007	0.002	0.0121	0.0051	0.0017	0.0004
5. Beam bkgd.	0.03	0.02	0.02	0.01	0.002	0.001	0.000	0.000	0.0006	0.0003	0.0001	0.0001
6. Unfolding	0.01	0.01	0.02	0.02	0.006	0.005	0.005	0.004	0.0008	0.0006	0.0005	0.0004
7. Model	0.01	0.01	0.00	0.01	0.002	0.001	0.000	0.001	0.0010	0.0006	0.0004	0.0004
8. Resolution	0.05	0.03	0.01	0.00	0.007	0.004	0.001	0.000	0.0026	0.0011	0.0004	0.0001
9. γ Detection	0.03	0.02	0.00	0.00	0.005	0.003	0.002	0.001	0.0015	0.0007	0.0002	0.0000
10. $B \to X_d\gamma$	0.01	0.01	0.01	0.01	0.000	0.000	0.000	0.000	0.0000	0.0000	0.0000	0.0000
11. Boost	0.01	0.01	0.02	0.02	0.002	0.002	0.004	0.005	0.0012	0.0005	0.0008	0.0009

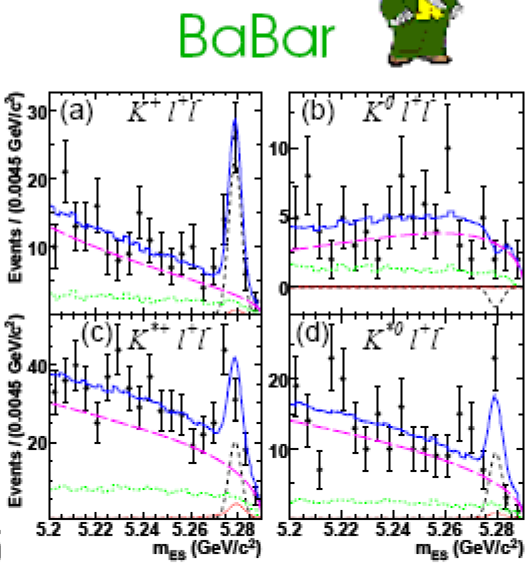
B → K*l⁺l⁻ : Isospin asymmetry

Mikihiko Nakao “Review of Radiative Penguin Measurements” at Rencontres de Moriond EW 2009

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

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





- In SM, A_I is expected to be small
- Babar found a large negative A_I in the low q^2 region