Rare B Decays

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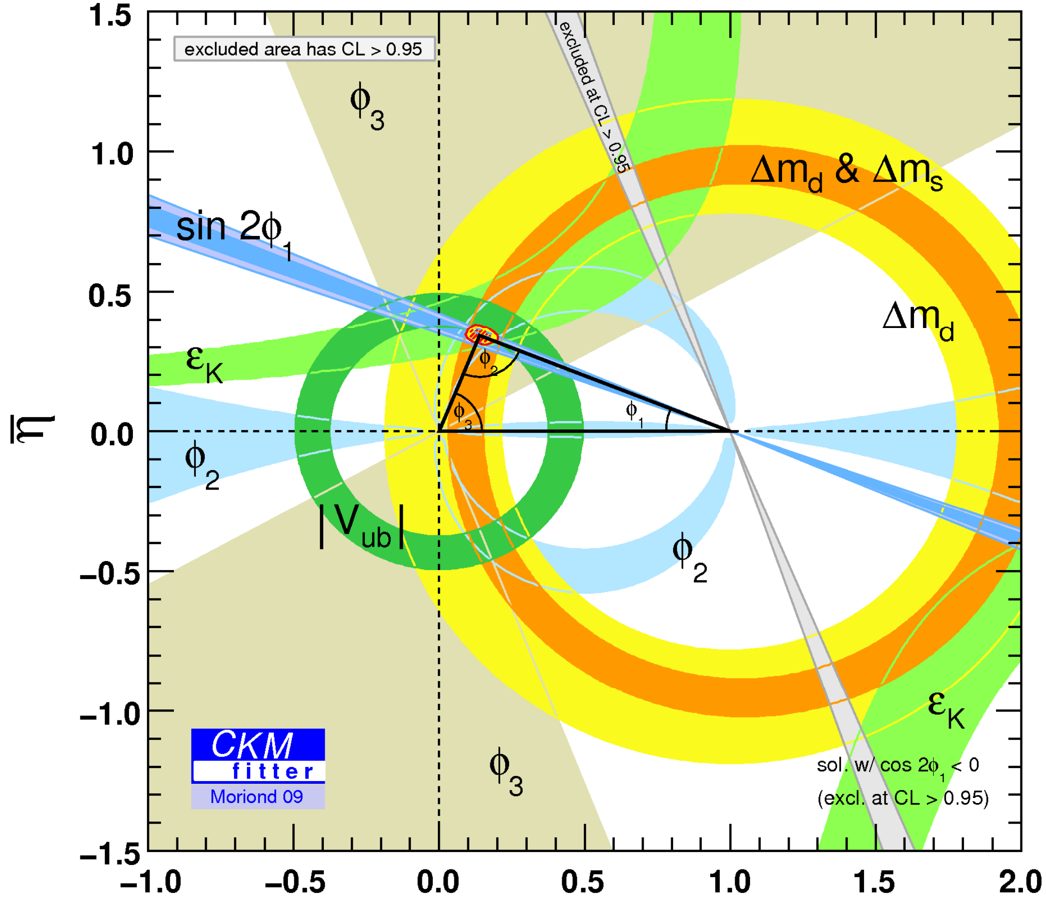
Nagoya University

August 21, 2009
Lepton-Photon 2009

Success of the B-factories



Similar plot by the UT-fit group

2008 Nobel Prize in Physics

M. Kobayashi

T. Maskawa

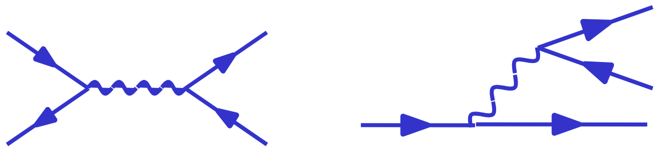
Still room for modifications by NP.
Rare B decays are powerful tools !

Talk Outline

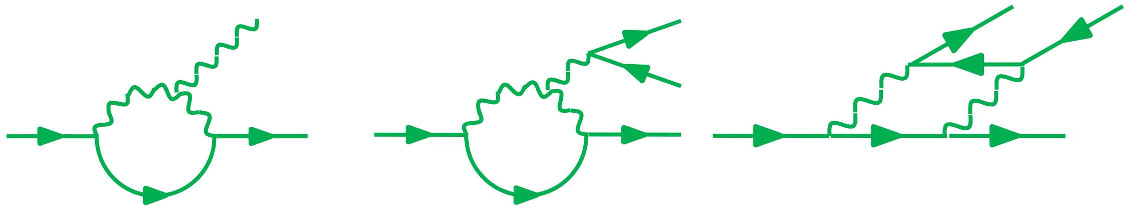
There are many places to look for NP in rare B decays.

Review the present status of NP search in

- $B \to l\nu$, $\tau\nu$, $D\tau\nu$

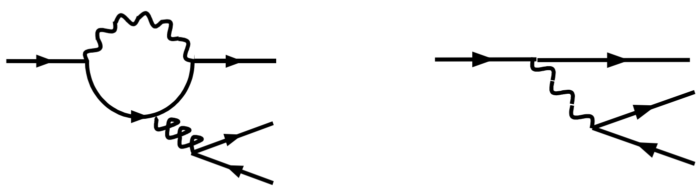


- $b \to s\gamma$
- $b \to sll$



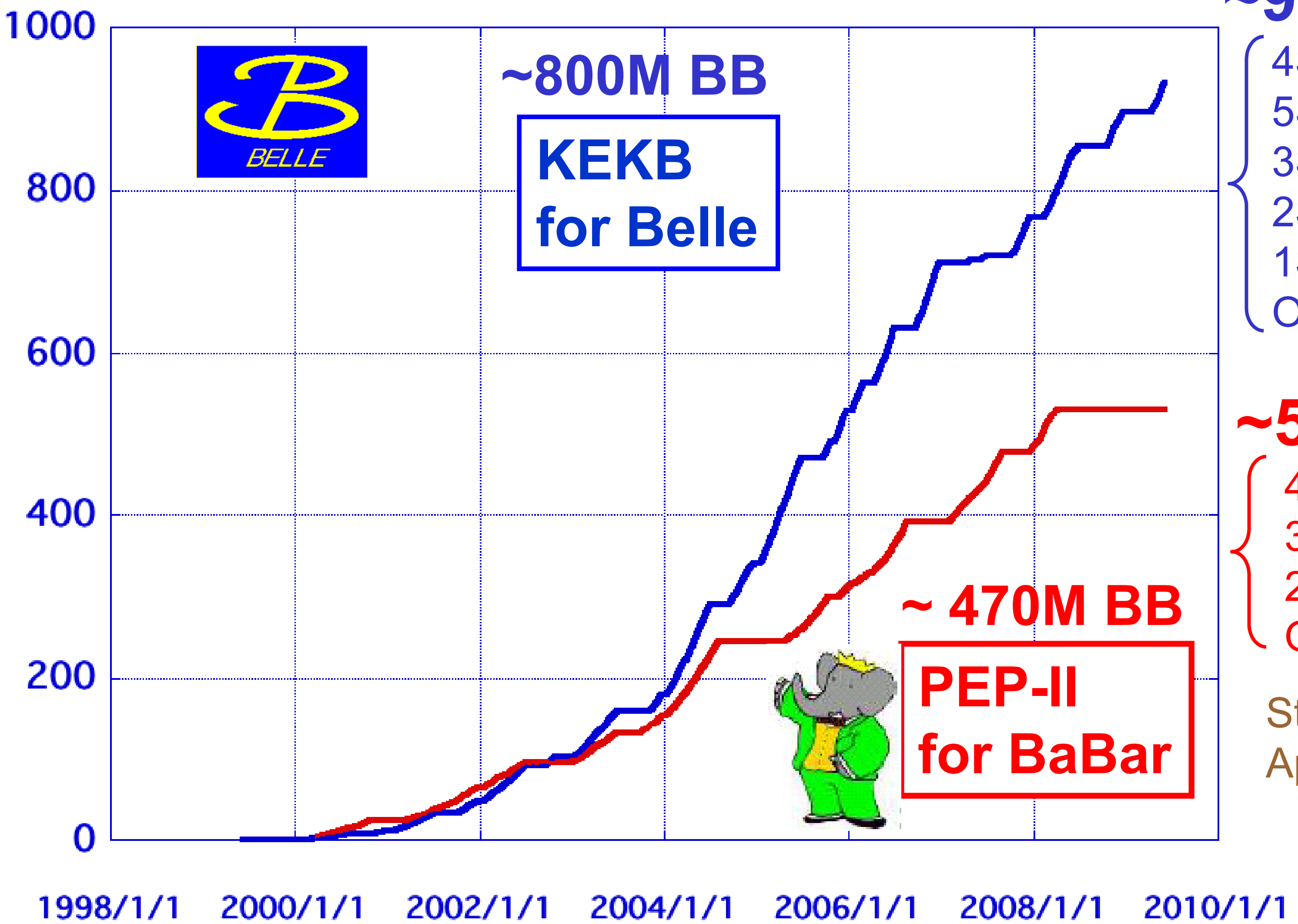
- $B_{s,d} \to ll$

- $b \to sg + b \to uq\bar{q}$



Results are from

Luminosity at the B-factories



~950 fb^{-1}

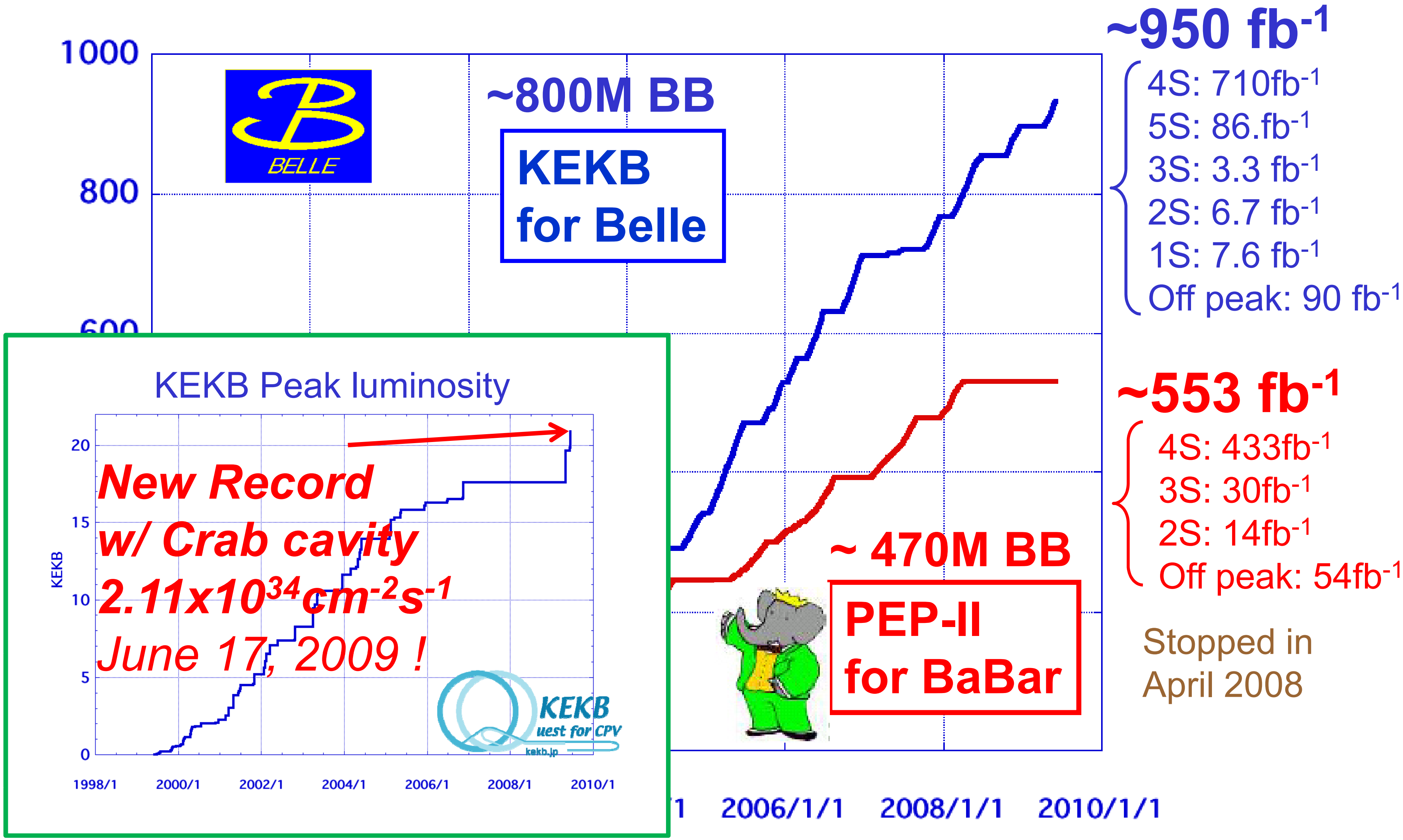
- 4S: 710fb^{-1}
- 5S: 86.fb^{-1}
- 3S: 3.3 fb^{-1}
- 2S: 6.7 fb^{-1}
- 1S: 7.6 fb^{-1}
- Off peak: 90 fb^{-1}

~553 fb^{-1}

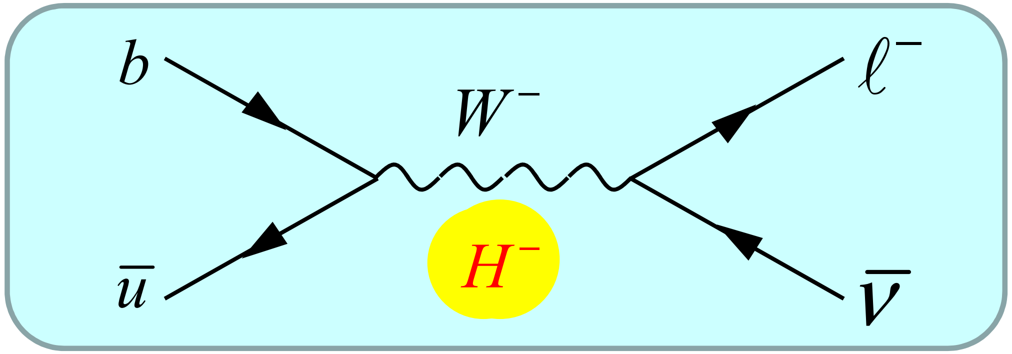
- 4S: 433fb^{-1}
- 3S: 30fb^{-1}
- 2S: 14fb^{-1}
- Off peak: 54fb^{-1}

Stopped in April 2008

Luminosity at the B-factories



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



- 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

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

$\sim 10^{-11}$ $\sim 10^{-7}$

Determination of $f_B|V_{ub}|$

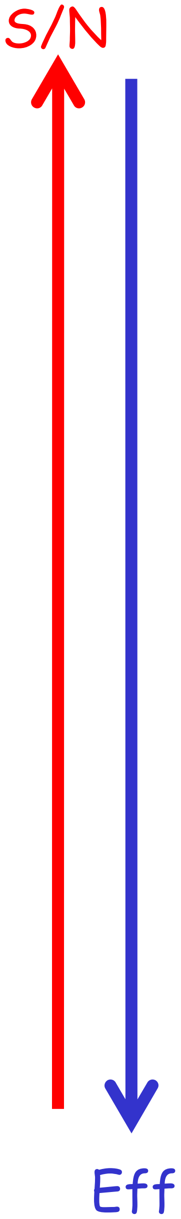
$f_B = 190 \pm 13\ MeV$ HPQCD, 0902.1815v2

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

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

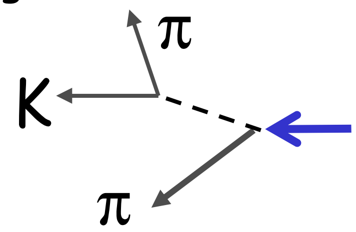
Sensitive also to NP (charged Higgs)

Analysis for $B \to l\nu$



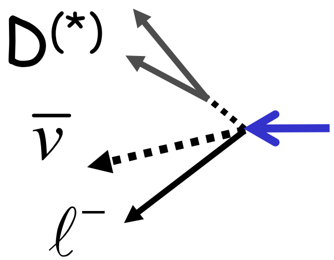
Hadronic tags

$B_{tag} \to D^{(*)}\pi/\rho$ etc.



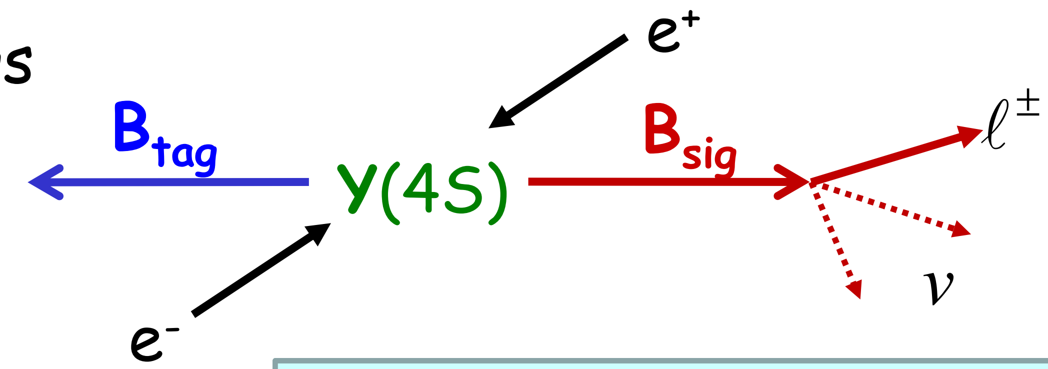
Semileptonic tags

$B_{tag} \to D^{(*)} l \nu$ etc.



Inclusive tags

4-vector sum of PID tracks
(except for signal tracks)

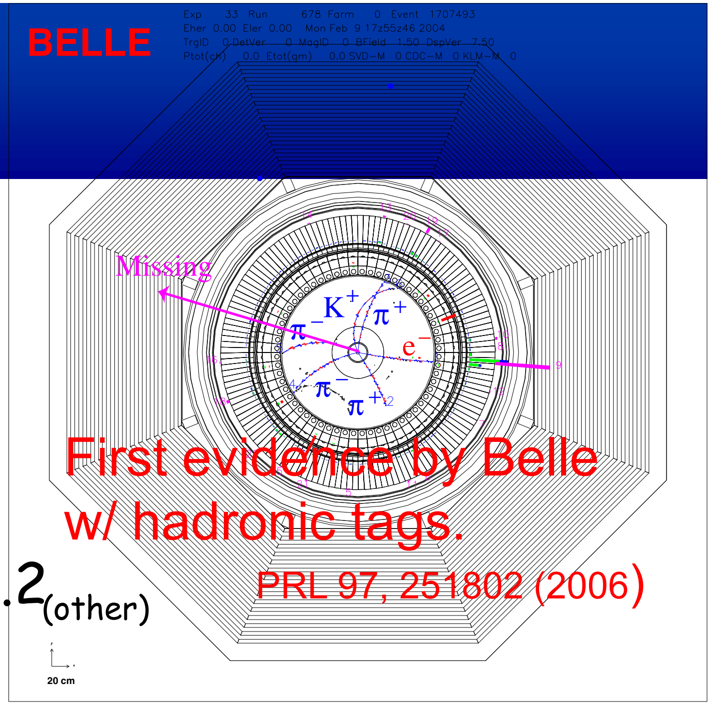


Tagging side

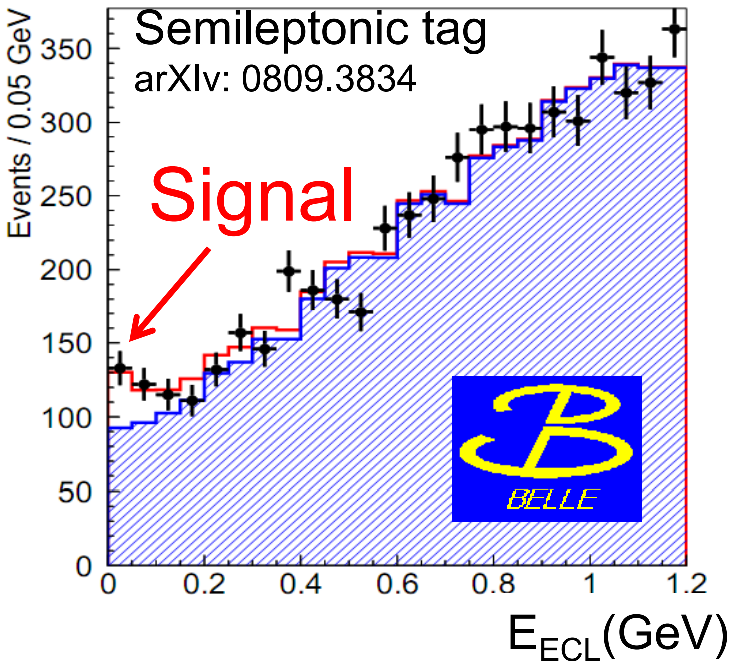
Reconstruct the recoil B to tag
- B production
- B flavor/charge
- B momentum

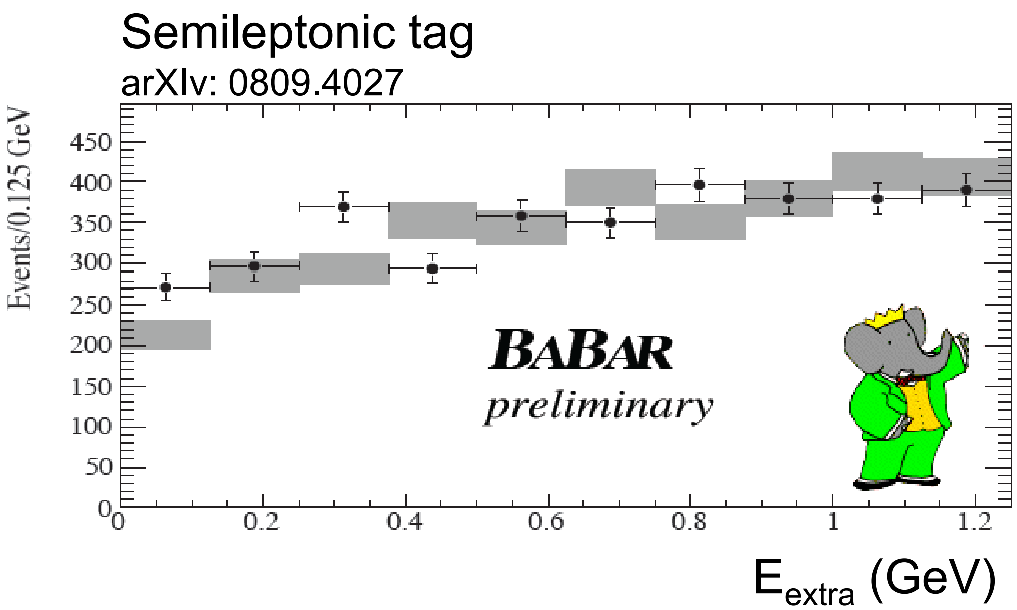
Signal side: $B_{sig} \to l\,\nu$
- Detect charged track(s)
- Missing energy (mass) due to ν's
- No extra activities in EM calorimeter ($E_{ECL(extra)}$)

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



	Branching fraction (10^{-4})
Belle	
• 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)	$1.8 \pm 0.8 \pm 01$





Constraint on Charged Higgs

Naïve world average

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

⟺

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

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

Effect of Charged Higgs

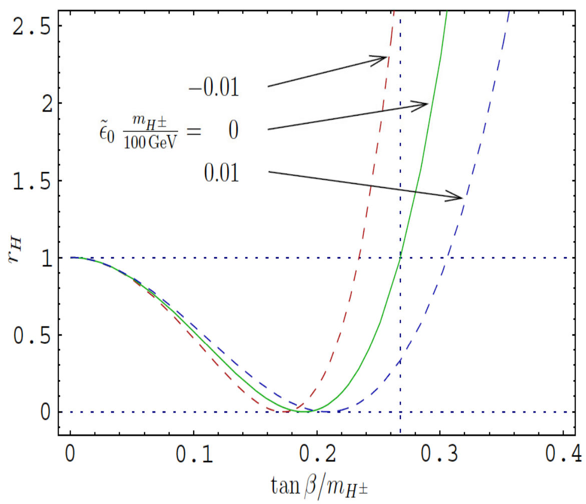
W. Hou, Phys. Rev. D48, 2342 (1993)

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

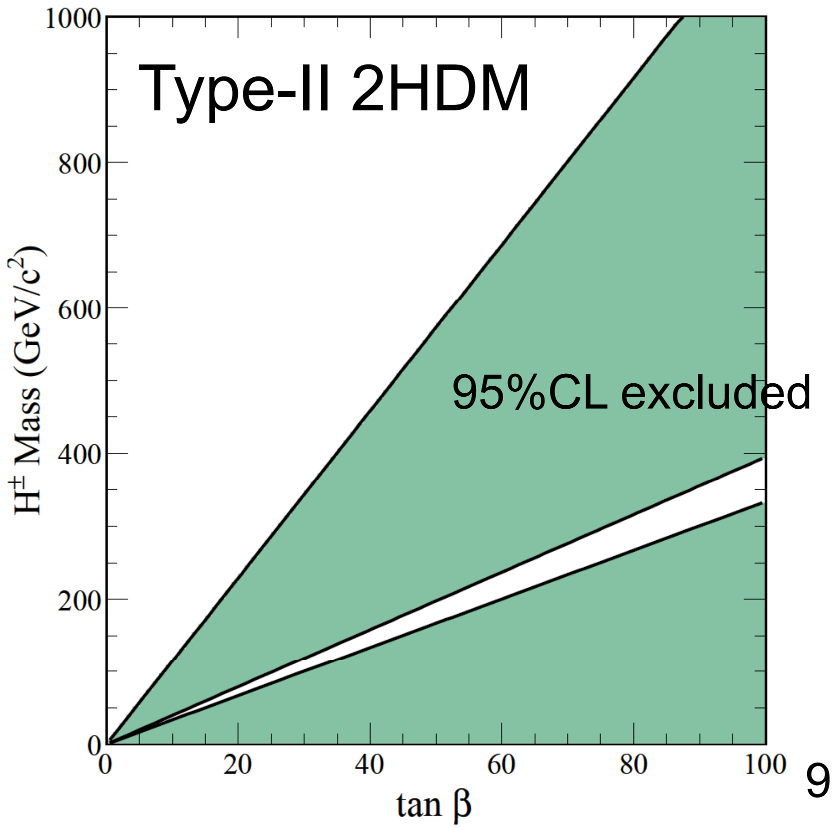
$$r_H = \left(1 - \frac{m_B^2 \tan\beta^2}{m_H^2} \frac{1}{1 + \varepsilon_0 \tan\beta} \right)^2$$

$$\tan\beta = \frac{v_u}{v_d}$$

SUSY Loop correction
$\varepsilon_0 = 0$ for Type-II 2HDM



Constraint on charged Higgs



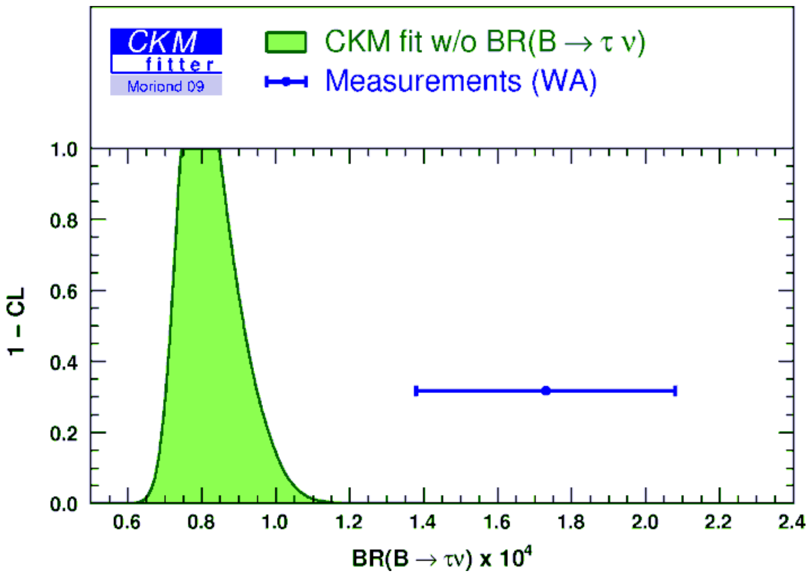
Comparison to CKM fit

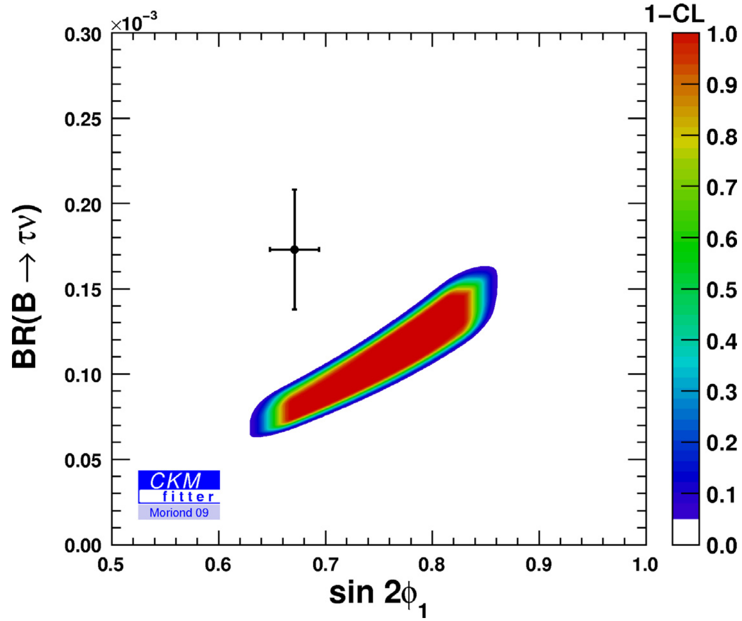
Naïve world average

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

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

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

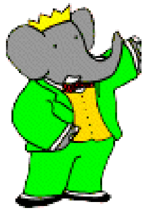




The measured Br is 2.4 σ higher than the value predicted by the CKM fit.

$B \to e/\mu\nu(\gamma)$ by BaBar

- $B \to e/\mu\nu$ w/ inclusive tag



468 M BB PRD79, 091101(R)

Inclusively reconstruct B_{tag}
4-momentum vector sum
for the rest of the event .

$$Br(B \to \mu\nu) < 1.0 \times 10^{-6}$$
$$Br(B \to e\nu) < 1.9 \times 10^{-6}$$

@90%CL

- $B \to e/\mu\nu\gamma$ w/ hadronic tag.

465 M BB Submitted to PRL, arXiv:0907.1681

Not helicity suppressed.

Form factor dependence (f_A, f_V)

Hadronic tag.

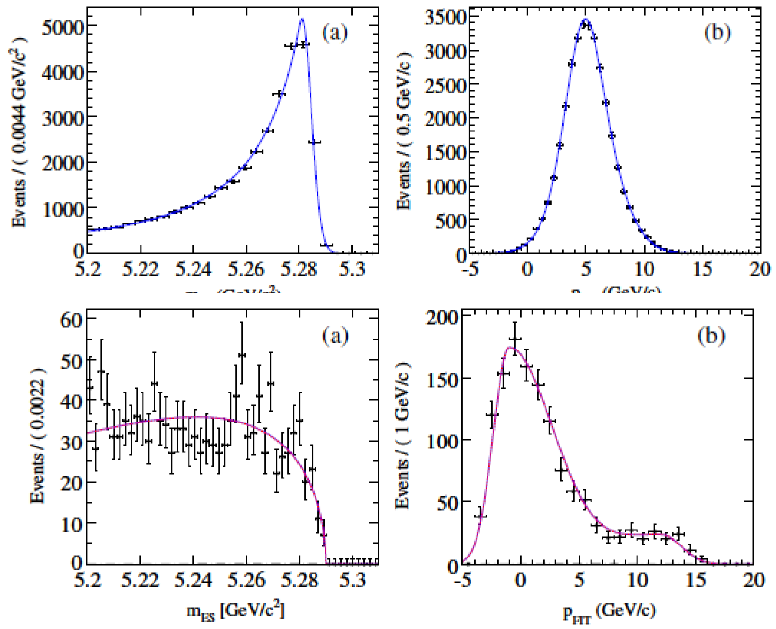
→ Model independent search.

$$Br(B \to \mu\nu\gamma) < 24 \times 10^{-6}$$
$$Br(B \to e\nu\gamma) < 17 \times 10^{-6}$$

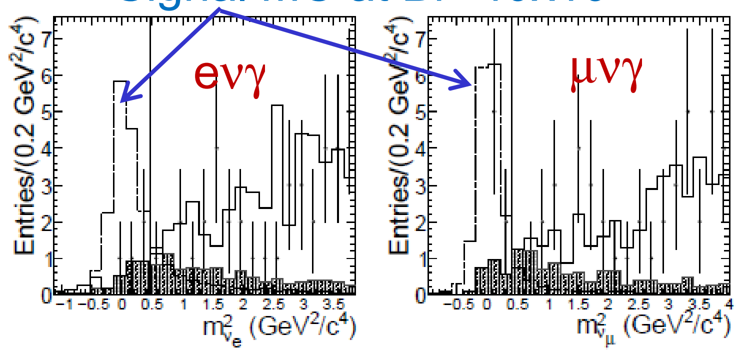
@90%CL

Dirstributions for $\mu\nu$ mode
Signal MC(top) / Data (bottom)

m_{ES} (GeV/c^2) P_{FIT}(GeV/c)

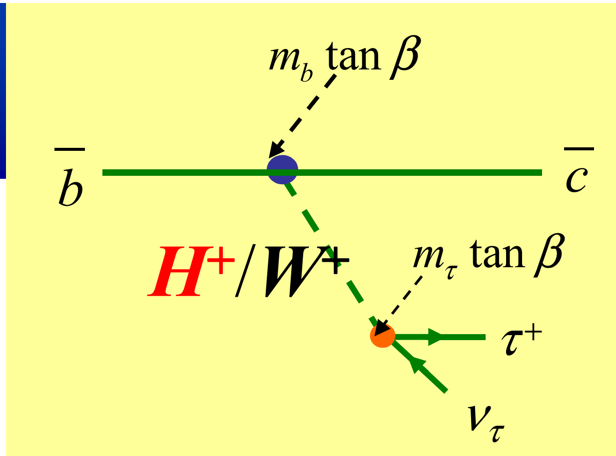


Signal MC at Br=40×10^{-6}



M_ν^2 (GeV^2/c^4)

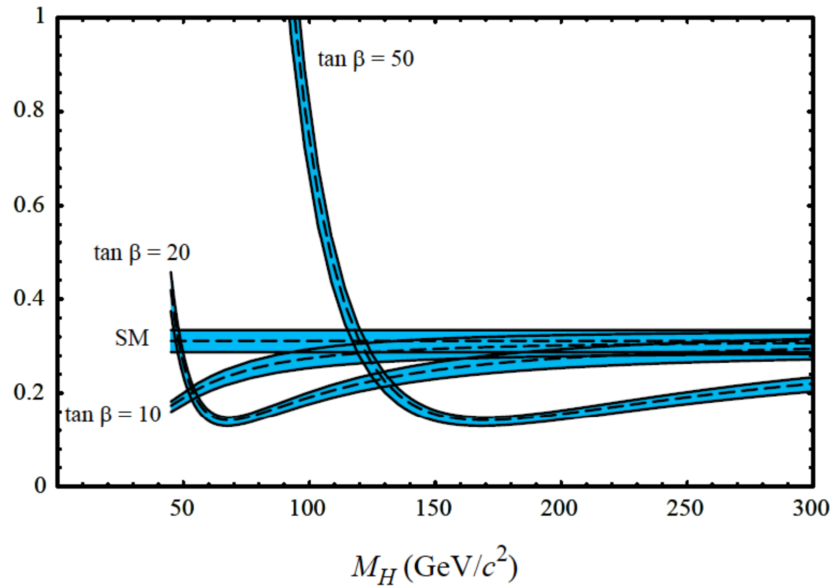
$B \to D\ \tau\ \nu$



B→D τ ν is also sensitive to H⁺, and complementary to B→τν.

- Relatively large Br ~0.8%
- Different theory systematics:
  - free from V_{ub} and f_B uncertainties.
  - depends on the B→D form factors,

$$R(D) = \frac{Br(B \to D\tau\nu)}{Br(B \to D\ell\nu)}$$

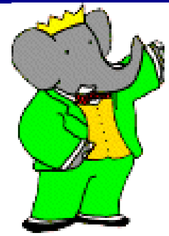


- Three-body decay permits the study of decay distributions which discriminate between W^+ and H^+ exchange. U. Nierste, S. Trine, S.Westhoff PRD78, 015006 (2008).
- Universality between H-b-c, (Dτν), H-b-u (τν), H-b-t (LHC) can be tested.

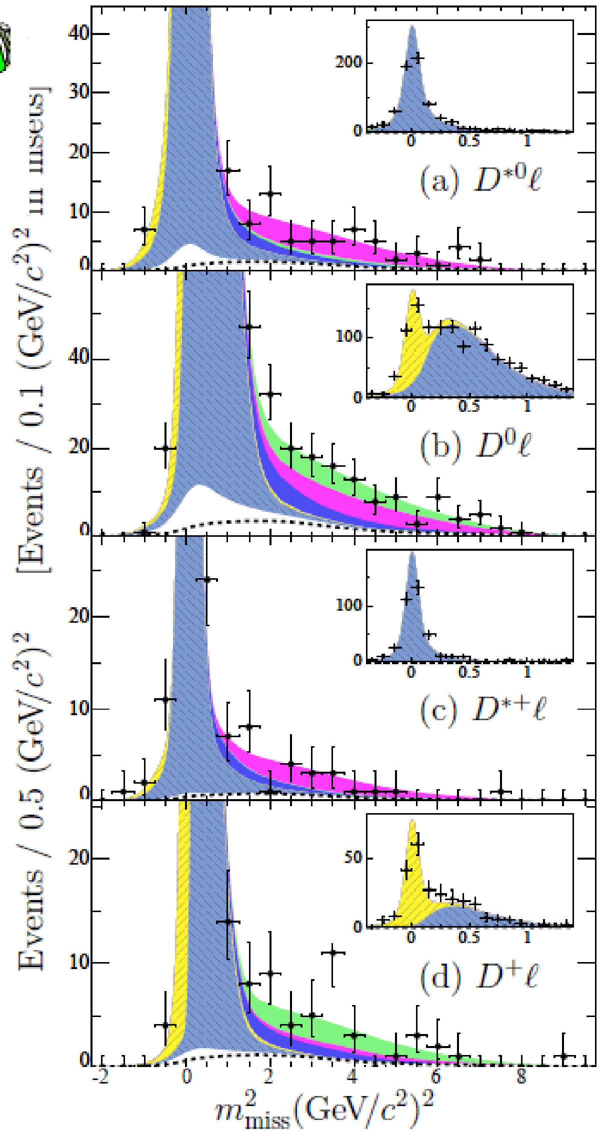
arXiv:0906.1652 (hep-ph/)
A. Cornell, A. Deandrea, N. Gaur, H. Itoh, M. Klasen, Y. Okada

B→D τ ν by BaBar

PRL100, 021801 (2008)
+arXiv: 0902.2660



- 238M BB
- Hadronic tags.
- Signal characterized by large MM².
- Simultaneous extraction of Dτν/D*τν.
- Also measure decay distributions for the first time.



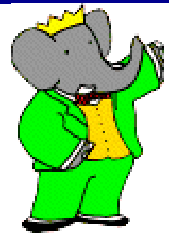
	R(%)	Ns	Signif.
D^0 τ ν	31.4±17.0±4.9	35.6±19.4	1.8(1.8)
D^+ τ ν	48.9±16.5±6.9	23.3±7.8	3.3(3.6)
D^{*0} τ ν	34.6±7.3±3.4	92.2±19.6	5.3(5.8)
D^{*+} τ ν	20.7±9.5±0.8	15.5.2±7.2	2.7(2.7)

D^0 τ ν + D^+ τ ν: 3.6 (4.9) σ

First evidence for B→D τν

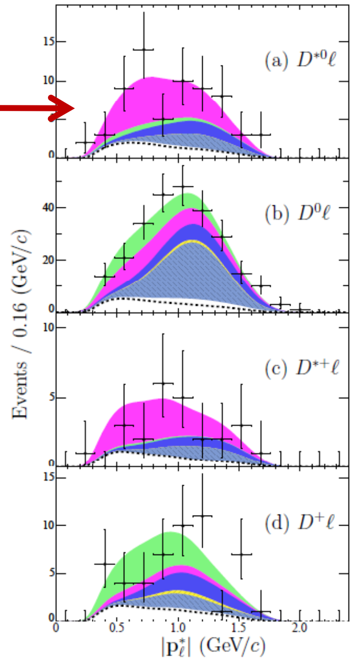
B→D τ ν by BaBar

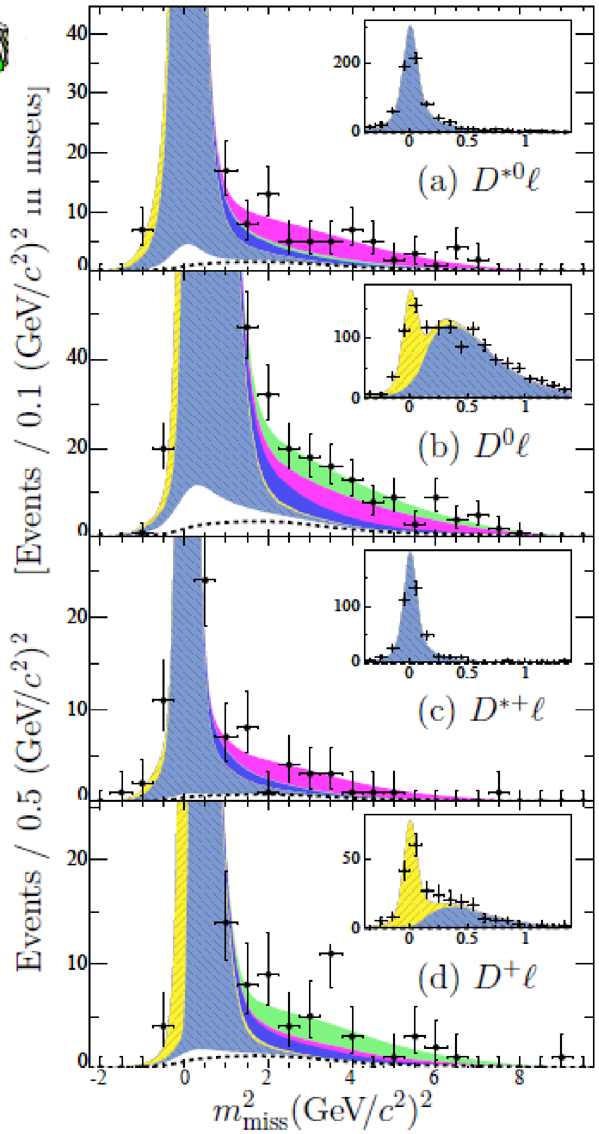
PRL100, 021801 (2008)
+arXiv: 0902.2660



- 238M BB
- Hadronic tags.
- Signal characterized by large MM^2.
- Simultaneous extraction of D$\tau\nu$/D*$\tau\nu$.
- Also measure decay distributions for the first time.

P_{lep} distributions→





	R(%)	Ns
$D^0\,\tau\,\nu$	31.4±17.0±4.9	35.6±19.4
$D^+\,\tau\,\nu$	48.9±16.5±6.9	23.3±7.8
$D^{*0}\,\tau\,\nu$	34.6±7.3±3.4	92.2±19.6
$D^{*+}\,\tau\,\nu$	20.7±9.5±0.8	15.5.2±7.

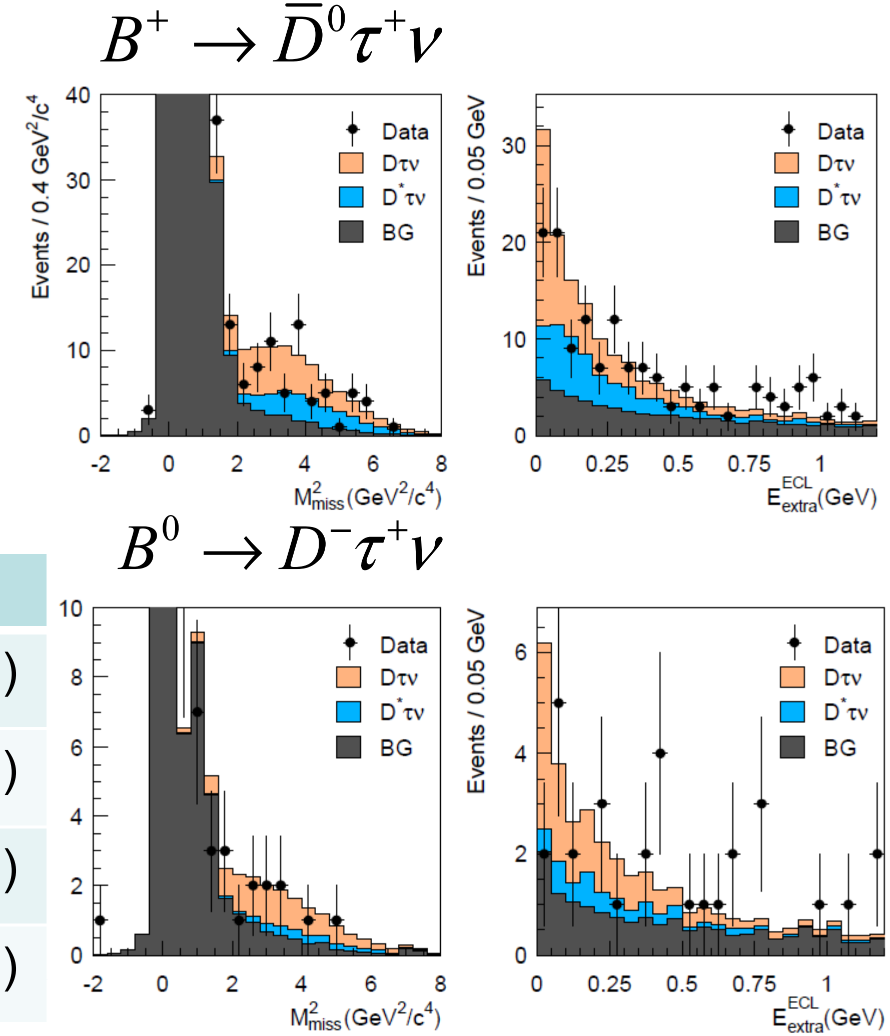
First evidence for B→D τν

$B \to D \tau \nu$ w/ by Belle

First observation of $B \to D^* \tau \nu$ w/ inclusive tag
PRL99, 191807 (2007),

- 657M BB
- Hadronic tags.
- Extract signals in (MM^2, E_{ECL}) distribution.
- Simultaneous extraction of $D\tau\nu/D^*\tau\nu$.

	R(%)	Ns	Signif.
$D^0 \tau \nu$	$70.2^{+18.9}_{-18.0}{}^{+11.0}_{-9.1}$	$98.6^{+26.3}_{-25.0}$	3.8(4.4)
$D^+ \tau \nu$	$47.6^{+21.6}_{-19.3}{}^{+6.3}_{-5.4}$	$17.2^{+7.7}_{-6.9}$	2.6(2.8)
$D^{*0} \tau \nu$	$46.8^{+10.6}_{-10.2}{}^{+6.2}_{-7.2}$	$99.8^{+22.2}_{-22.3}$	3.9(5.2)
$D^{*+} \tau \nu$	$48.1^{+14.0}_{-12.3}{}^{+5.8}_{-4.1}$	$25.0^{+7.2}_{-6.3}$	4.7(5.9)



Dτν signal

D*τν cross talk

B→Dτν: BaBar+Belle

My Naïve Average

- Belle $R(D) = [60 \pm 14(stat) \pm 8(syst)]\%$
- BaBar $R(D) = [41.6 \pm 11.7(stat) \pm 5.2(syst)]\%$
- Belle+BaBar $R(D) = [49 \pm 10]\%$

$$R(D) = \frac{Br(B \to D\tau\nu)}{Br(B \to D\ell\nu)}$$

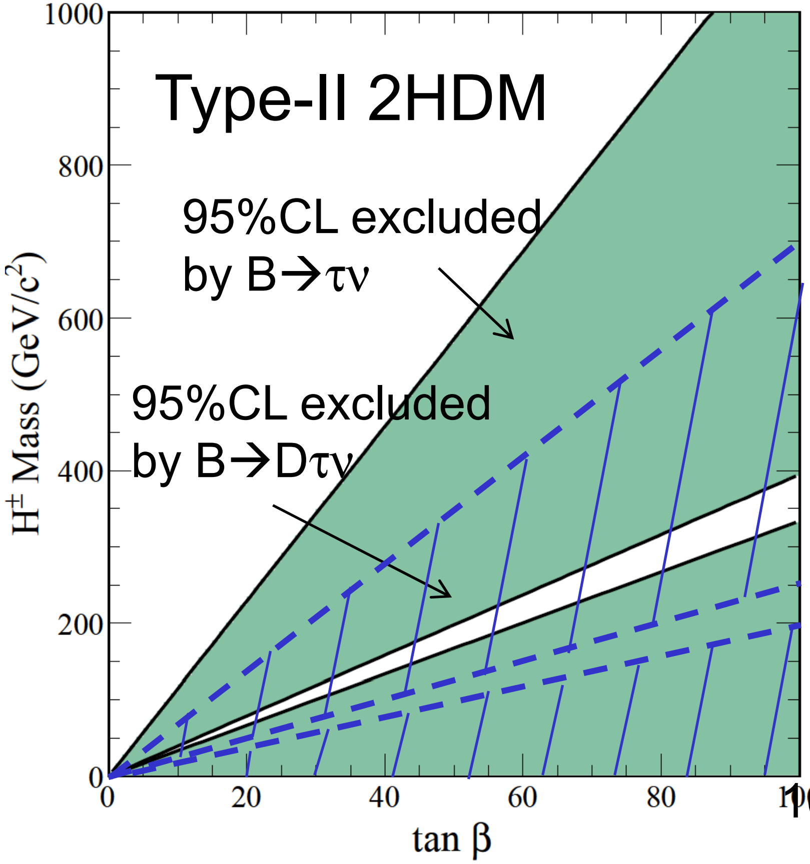
Constraint on Charged Higgs

form factors

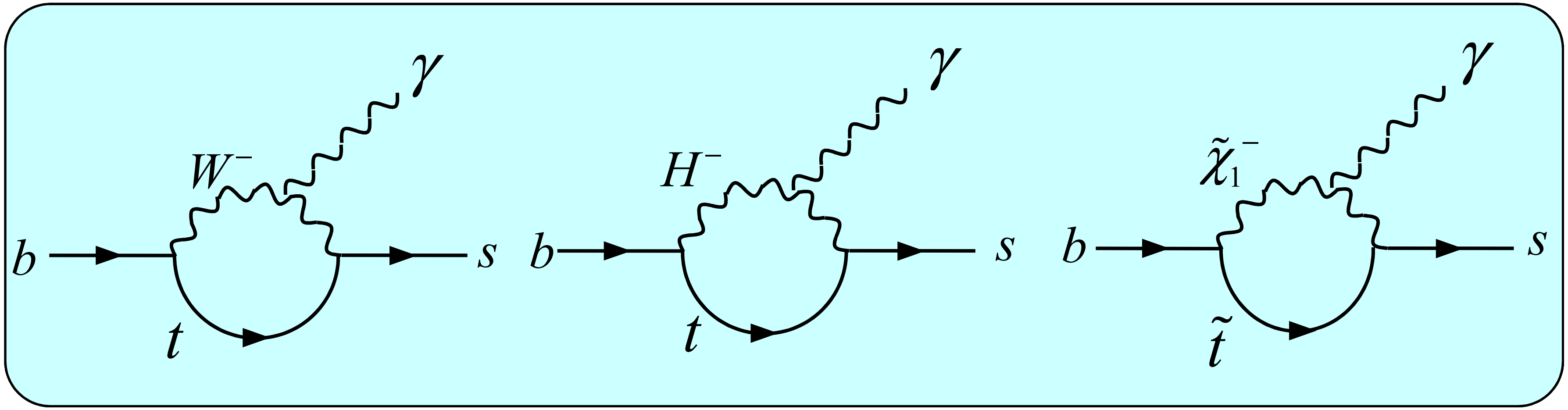
$$Br(B \to D\tau\nu) = G_F^2 \tau_B |V_{cb}|^2 f(F_V, F_S, g_S)$$

$$g_S = \frac{m_B^2}{m_H^2} \tan^2\beta \quad \text{(Type-II 2HDM)}$$

H. Itoh, S. Komine and Y. Okada,
PTP 114, 179 (2005), hep-ph/0503124.
D l ν form factor reported by BaBar;
arXiv: 0807.4978, 0809.0828



$b \to s\gamma$



- Flavor changing neutral current process (FCNC).
  Most powerful mode to constrain new physics.

Observables: Branching fraction (Br), Isospin asymmetry(Δ_{0-})
Direct CPV (A_{CP}),
Mixing induced time-dep.CPV (S)

- Photon spectrum is an ideal tool to determine HQE parameters. ⇒ $|V_{cb}|$, $|V_{ub}|$

New B→K*(892)γ by BaBar

- 383 M BB

x5 more data than the previous results.

- Branching fractions

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

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

- Direct CPV

~1% in SM

$$A_{CP}(B \to K^*\gamma) = -0.003 \pm 0.017 \pm 0.007$$

$$-0.033 < A_{CP}(B \to K^*\gamma) < 0.028$$ 90%CL

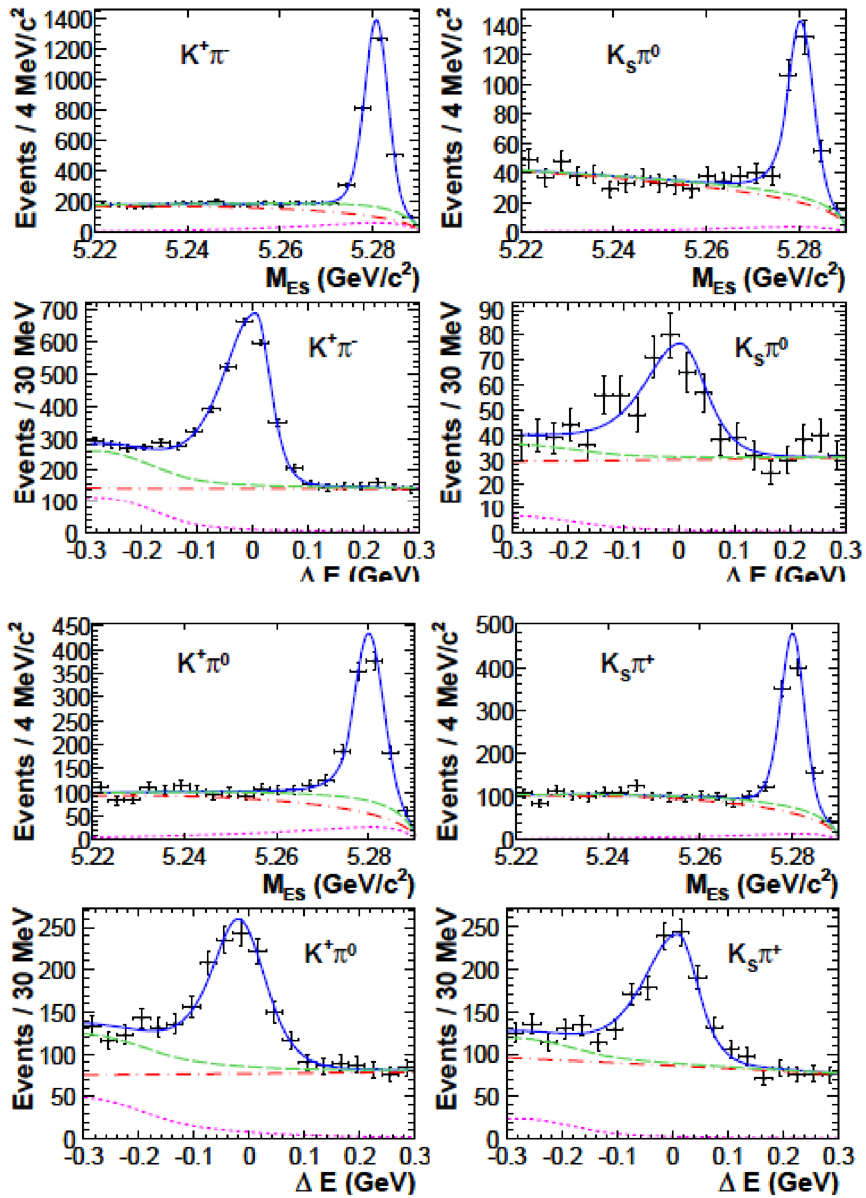
- Isospin asymmetry

$$\Delta_{0-}(B \to K^*\gamma) = 0.066 \pm 0.021 \pm 0.022$$

$$-0.017 < \Delta_{0-}(B \to K^*\gamma) < 0.116$$ 90%CL

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

2-10 % in SM

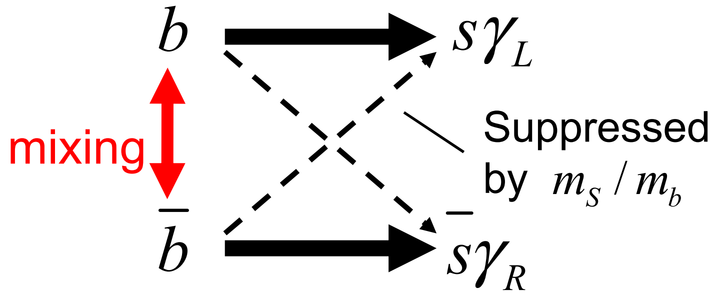


Submitted to PRL, arXIv: 0906.2177

Search for Right-handed Currents

Mixing-induced CPV (time-dependent).

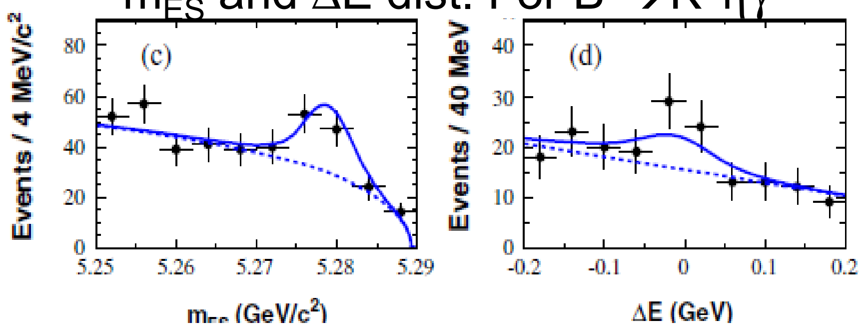
- In SM, photon polarization is b flavor specific.
- Sensitive to non-SM right-handed currents.



B→Kηγ

BaBar 465 MBB
PRD79, 011102(R) (2009)

m$_{ES}$ and ΔE dist. For $B^0 \to K^0 \eta\gamma$



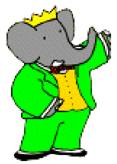
$$Br(B^0 \to K_S^0 \eta\gamma) = (7.1\,^{+2.1}_{-2.0} \pm 0.4) \times 10^{-6}$$

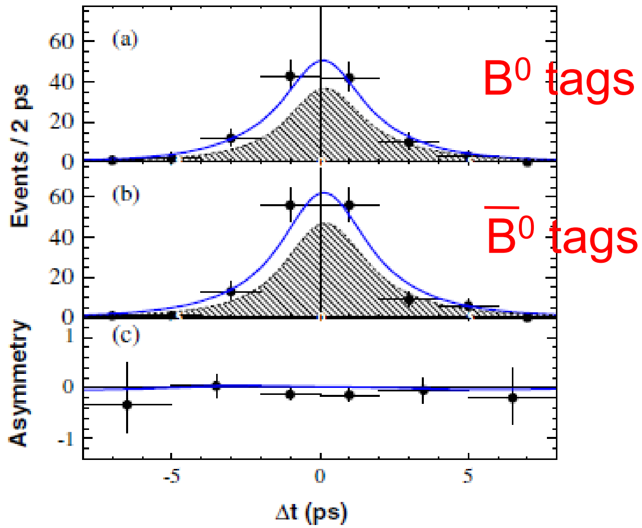
$$Br(B^+ \to K^+ \eta\gamma) = (7.7 \pm 1.0 \pm 0.4) \times 10^{-6}$$

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

$$S_{K_S\eta\gamma} = -0.18^{+0.49}_{-0.46} \pm 0.12$$

$$C_{K_S\eta\gamma} = -0.32^{+0.40}_{-0.39} \pm 0.07$$





The 1st time-dep. CPV measurement for this mode.

$B \to K\eta'\gamma / K\phi\gamma$

B→Kη'γ

Belle 657 MBB

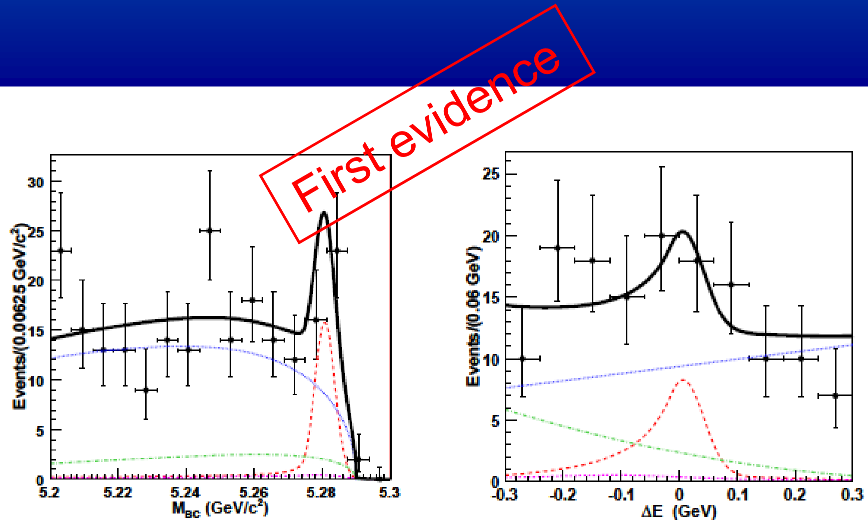
Submitted to PRD(RC), arXiv:0810.0804

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

3.3 σ

$$Br(B^0 \to K^0\eta'\gamma) \le 6.4\times 10^{-6}$$

90%CL



B→K φ γ

Belle 772 MBB

Preliminary

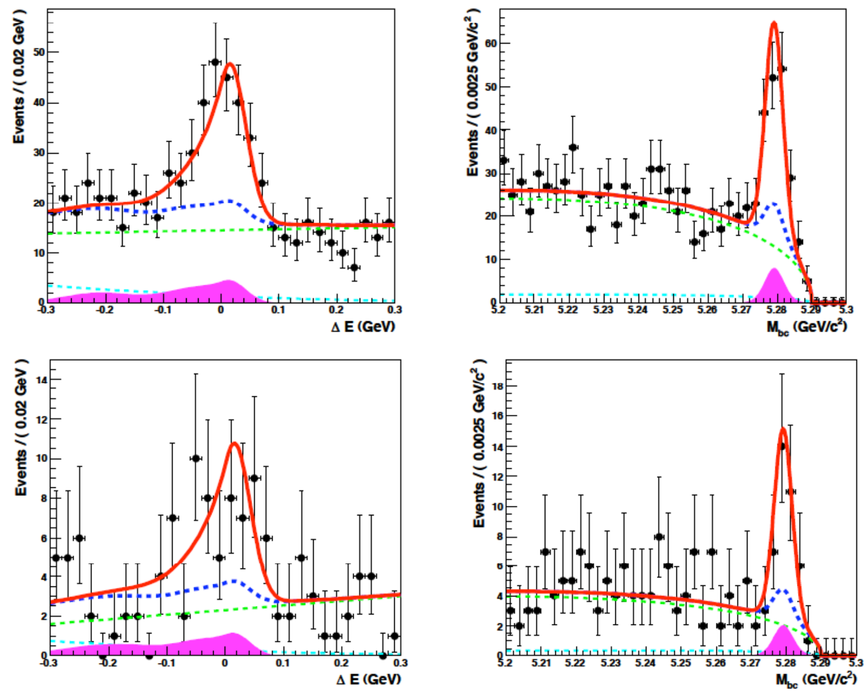
$$Br(B^+ \to K^+\phi\gamma) = (2.34 \pm 0.29 \pm 0.23)\times 10^{-6}$$

$Ns = 136 \pm 17$ 10.5 σ (stat. only)

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

$Ns = 35 \pm 8$ 5.8 σ (stat. only)

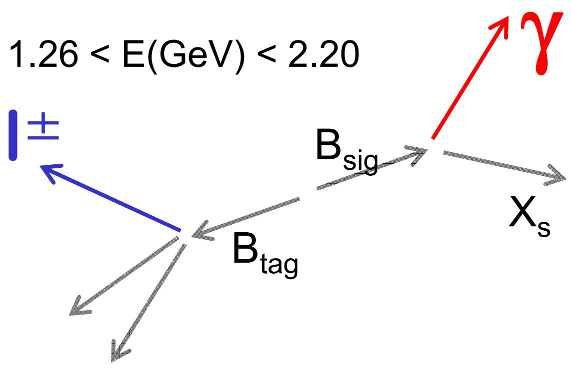
⇨ Will be used for time-dep. CPV



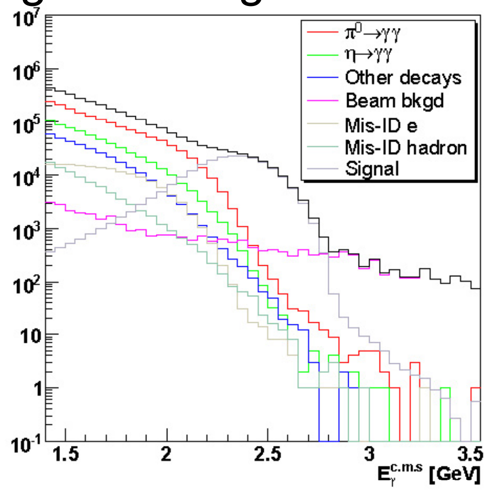
New B→Xs γ by Belle

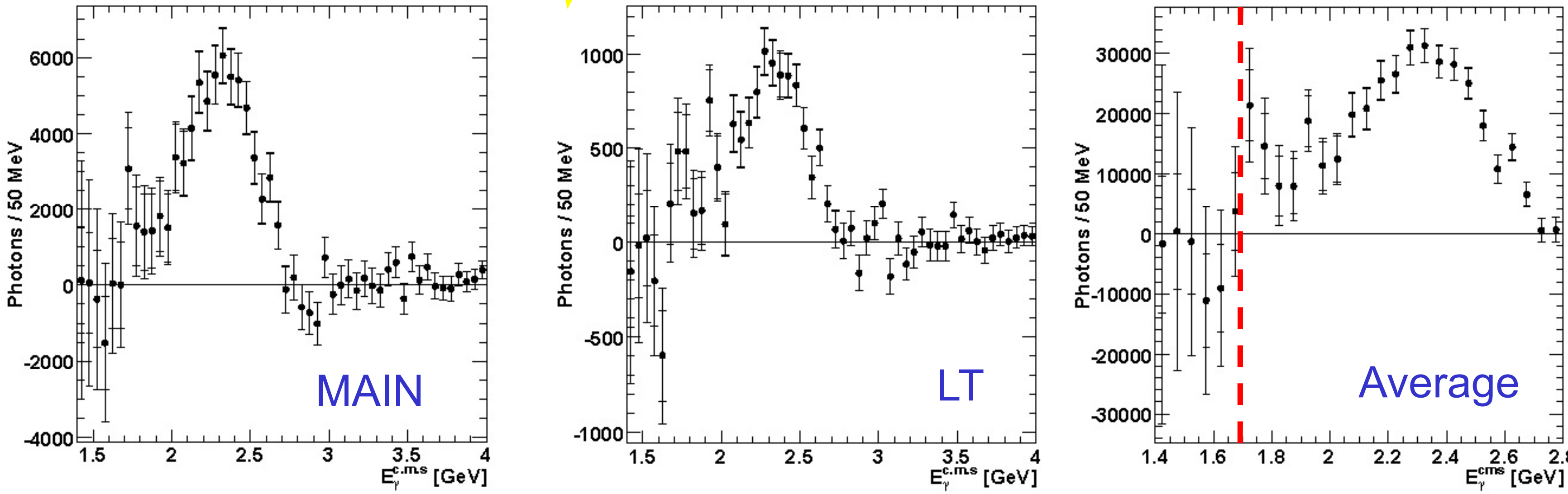
- 657M BB ($605fb^{-1}$)
- $E\gamma^{th}$ = 1.7 GeV
  - cover 97% of the decay.
- Two streams;
  - w/o tag (MAIN)
  - w/ lepton tag (LT) New !

1.26 < E(GeV) < 2.20



signal /background dist.





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

$$1.7 < E_\gamma(GeV) < 2.8$$

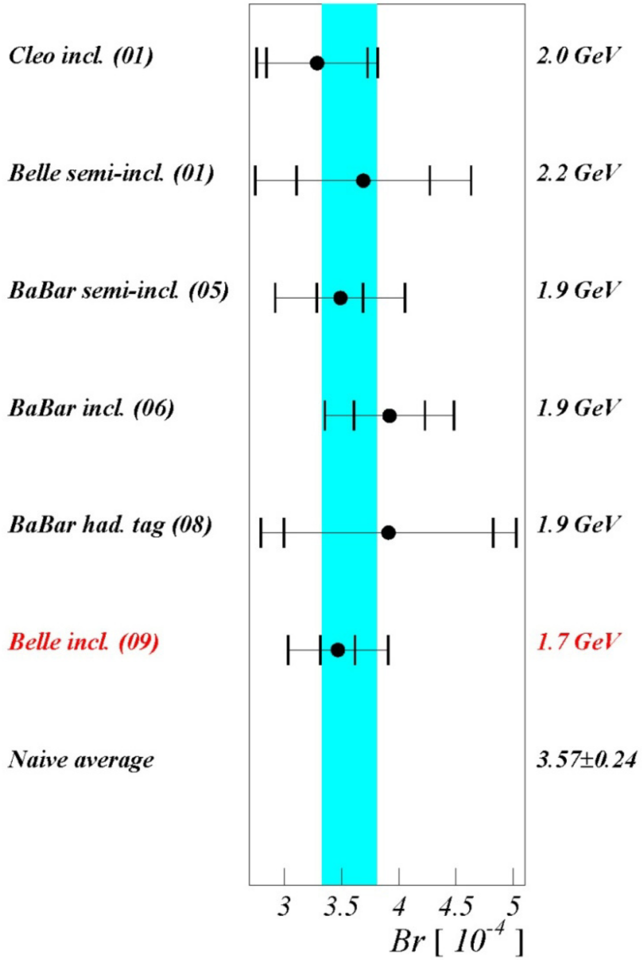
arXiv: 0907.1384, submitted to PRL.

$B \to X_s\gamma$: New average

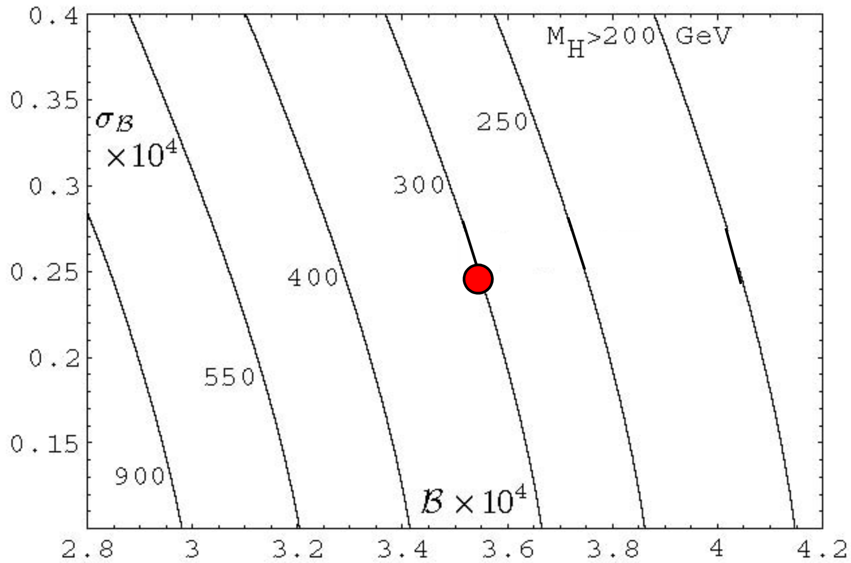
$E_\gamma > 1.6 GeV$

NNLO calculation by
M. Misiak et al. PRL98, 022003(2007)

$Br(B \to X_s\gamma) = (3.57 \pm 0.24)\times 10^{-4}$ ⟺ $Br_{SM}(B \to X_s\gamma) = (3.15 \pm 0.23)\times 10^{-4}$



Constraints on type-II 2HDM

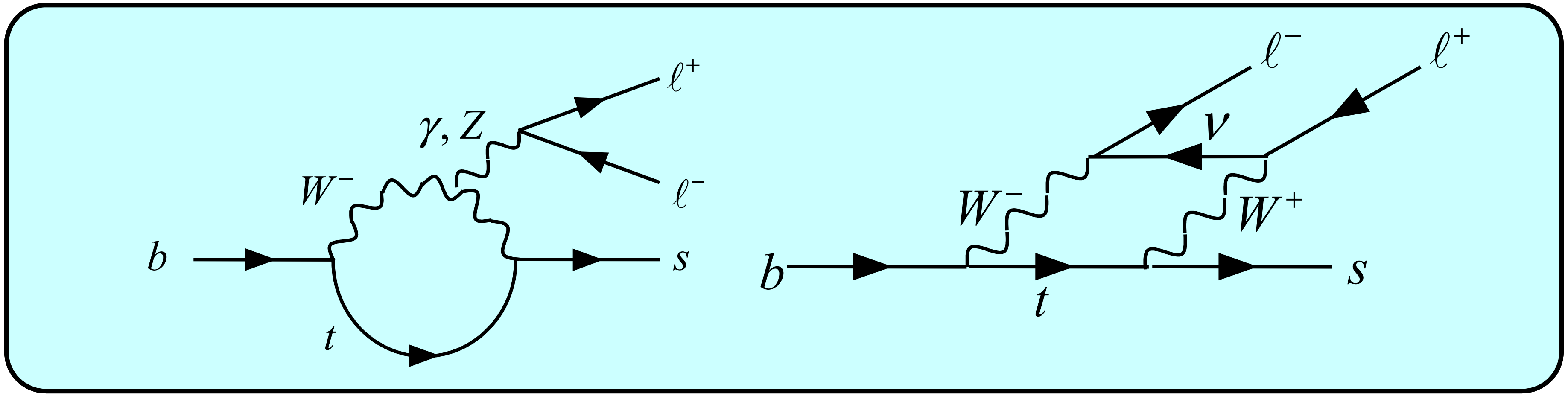


$M_{H^\pm} \geq 300 GeV$ @95%C.L.

Consistent w/ B→τν results.

Complementary to direct search at hadron colliders.

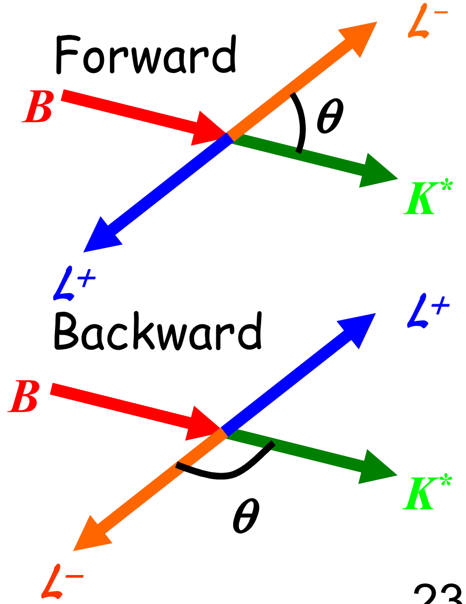
$b \to sll$



- Many places where NP can contribute
- Many observables, distributions.
  - Branching fractions, q^2 distribution
  - K* polarization (F_L)
  - Forward-Backward asymmetry (A_{FB})
  - Isospin asymmetry (A_I)
  - Lepton universality (R)

  etc.

A_{FB} by γ-Z interference



$B \to K^{(*)}ll$: Exclusive

- Belle: 657 M BB, submitted to PRL, arXiv: 0904.0770

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

$$Br(B \to K \ell\ell) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7}$$

- BaBar: 384M BB, PRD79, 031102(R) (2009)
  PRD73, 092001(2009)

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

$$Br(B \to K \ell\ell) = (3.4 \pm 0.7 \pm 0.2) \times 10^{-7}$$

- CDF: 924pb-1, PRD79, 011104 (2009)

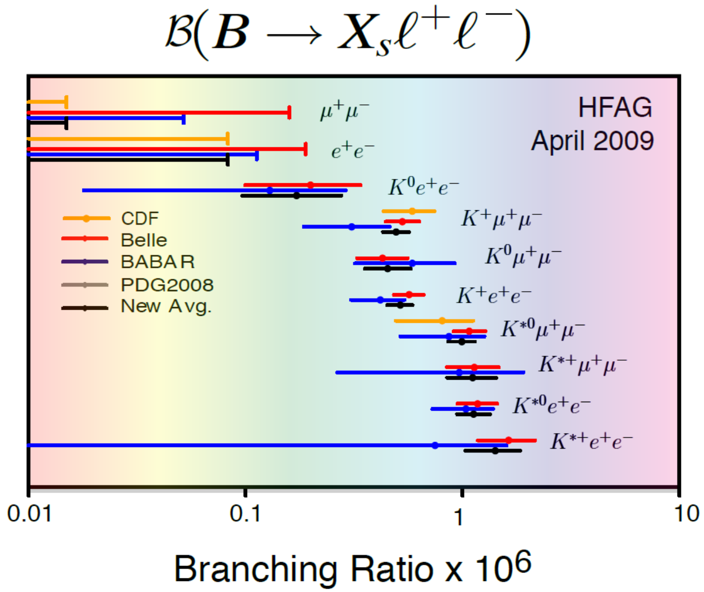
$$Br(B \to K^* \mu\mu) = (8.1 \pm 3.0 \pm 1.0) \times 10^{-7}$$

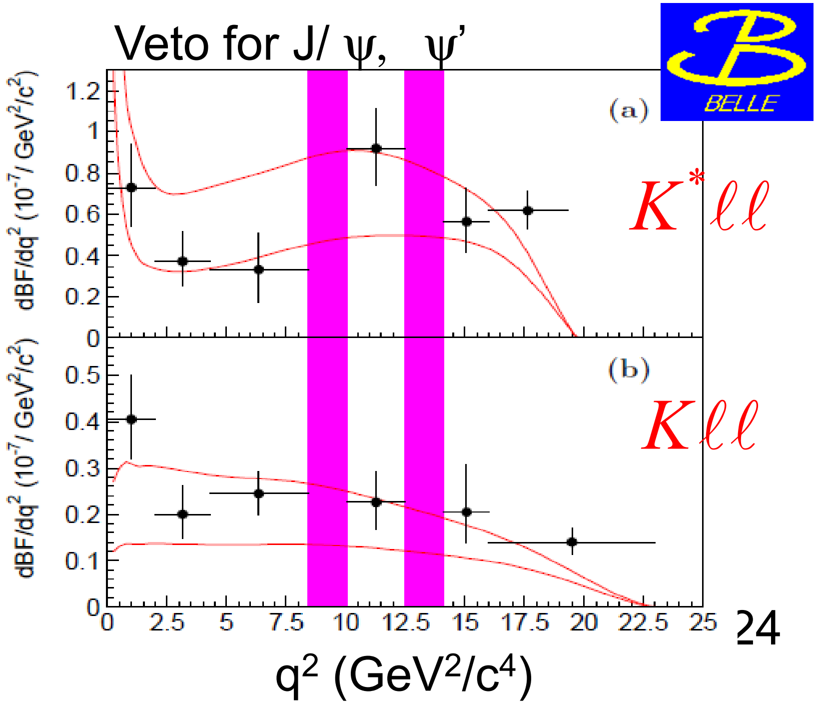
$$Br(B \to K \mu\mu) = (5.9 \pm 1.5 \pm 0.4) \times 10^{-7}$$

HFAG Average (2009 Winter)

$$Br(B \to K^* \ell\ell) = (10.0 \pm 1.1) \times 10^{-7}$$

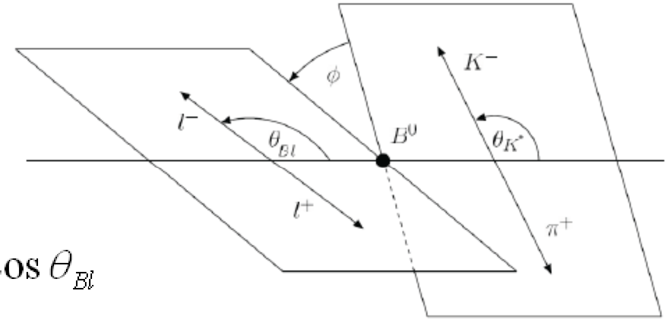
$$Br(B \to K \ell\ell) = (4.3 \pm 0.4) \times 10^{-7}$$





q² distribution in Belle 657 MBB → Red lines show theoretical predictions with max. and min. allowed form factors.

$B \to K^*ll$: FB Asymmetry

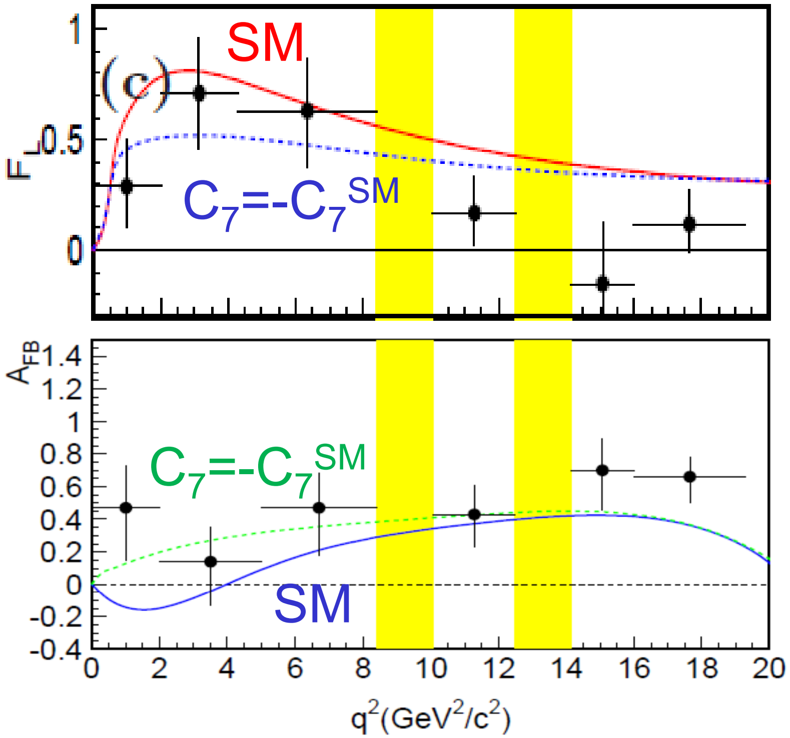


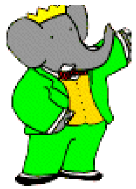
A_{FB} extracted from fits to

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

657 M BB,

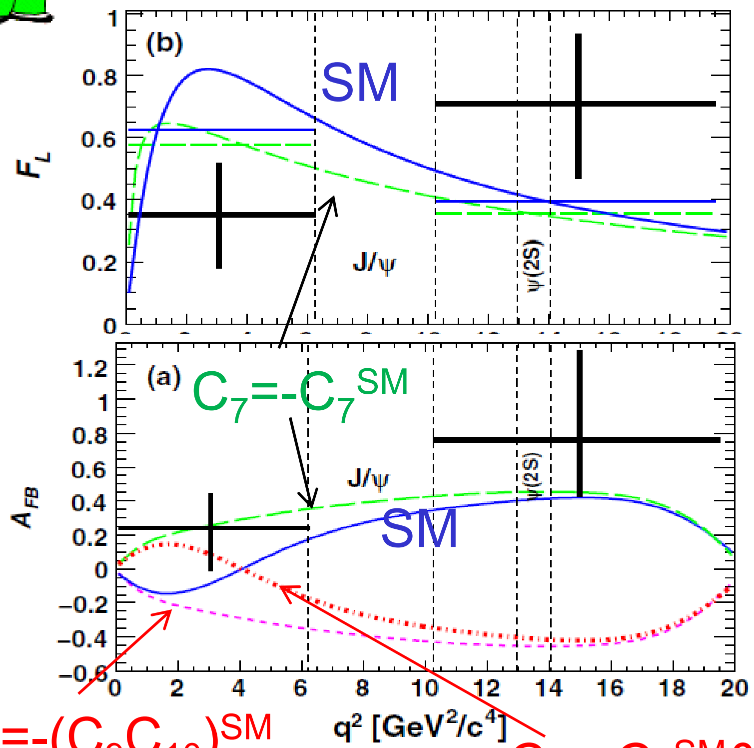
submitted to PRL, arXiv: 0904.0770





384M BB,

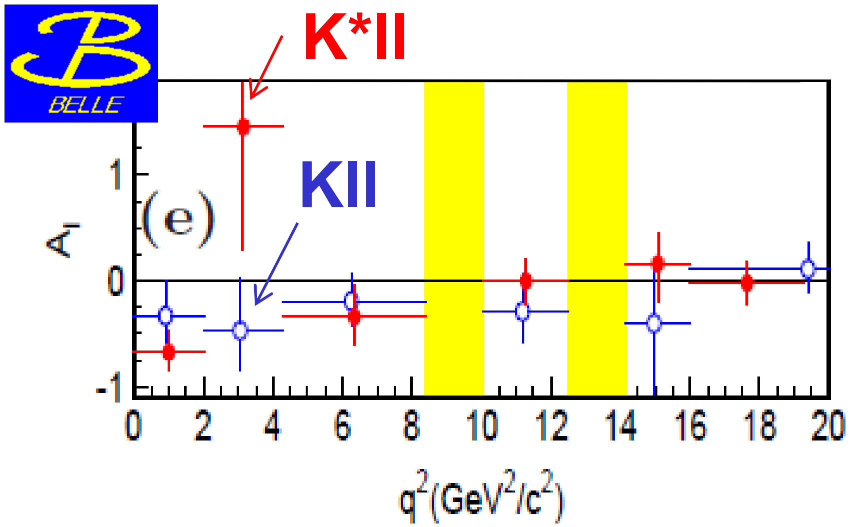
PRD79, 031102(R) (2009)

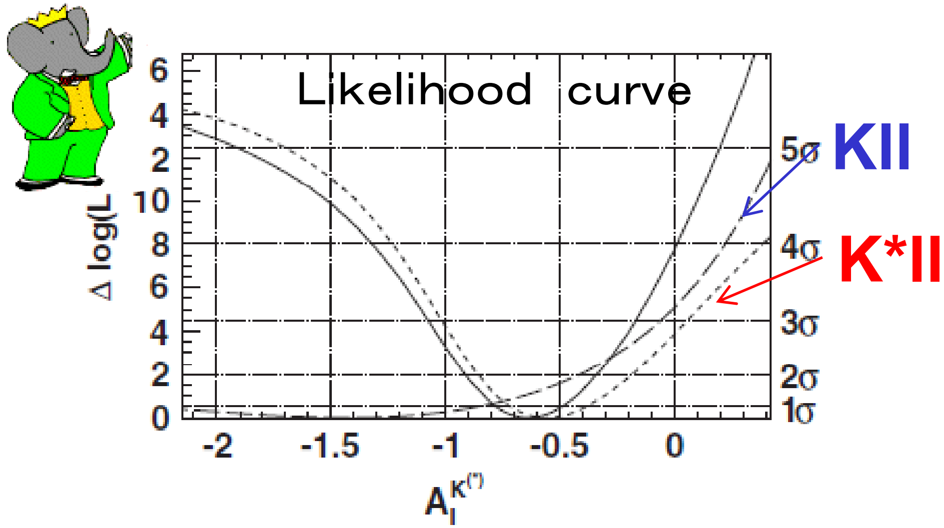


A_{FB} exceeds SM ?

$B \to K^{(*)}ll$: Isospin Asymmetry

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





$q^2 < 8.68\ GeV^2/c^2$		$q^2 = 0.1 - 7.02\ GeV^2/c^2$	
$A_I(K^*\ell\ell) = -0.29^{+0.16}_{-0.16} \pm 0.03$	1.40σ	$A_I(K^*\ell\ell) = -0.56^{+0.17}_{-0.15} \pm 0.03$	2.7σ
$A_I(K\ell\ell) = -0.31^{+0.17}_{-0.14} \pm 0.05$	1.75σ	$A_I(K\ell\ell) = -1.43^{+0.56}_{-0.85} \pm 0.05$	3.2σ
$A_I(K^{(*)}\ell\ell) = -0.30^{+0.12}_{-0.11} \pm 0.04$	2.24σ	$A_I(K^{(*)}\ell\ell) = -0.64^{+0.15}_{-0.14} \pm 0.03$	3.9σ

A_I deviates from zero at low-q^2 ?

New $B \to X_s ll$ by Belle

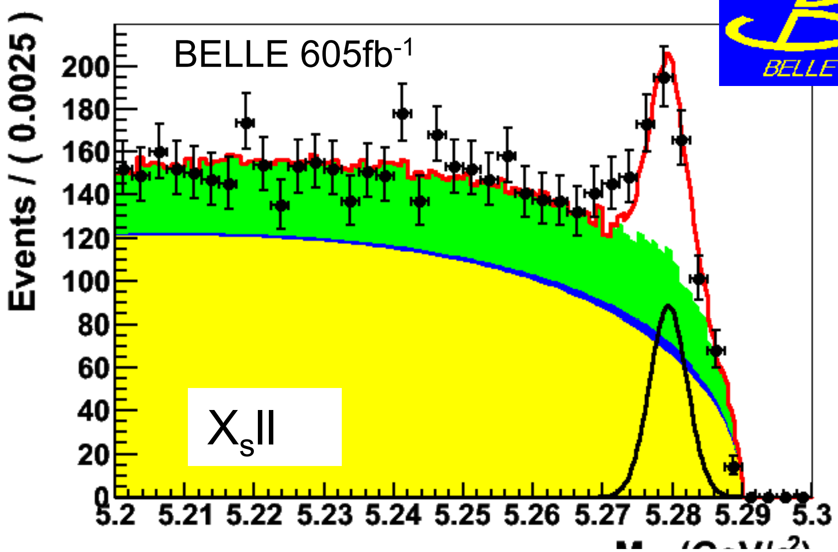
- 657MBB
- X_s reconstructed by:
  1 K^+/K_S^0 + up to 4 π's ($N_{\pi 0} \leq 1$)
- Improved background rejection and peaking background from
  - Higher charmonium resonances
  - Semileptonic decays

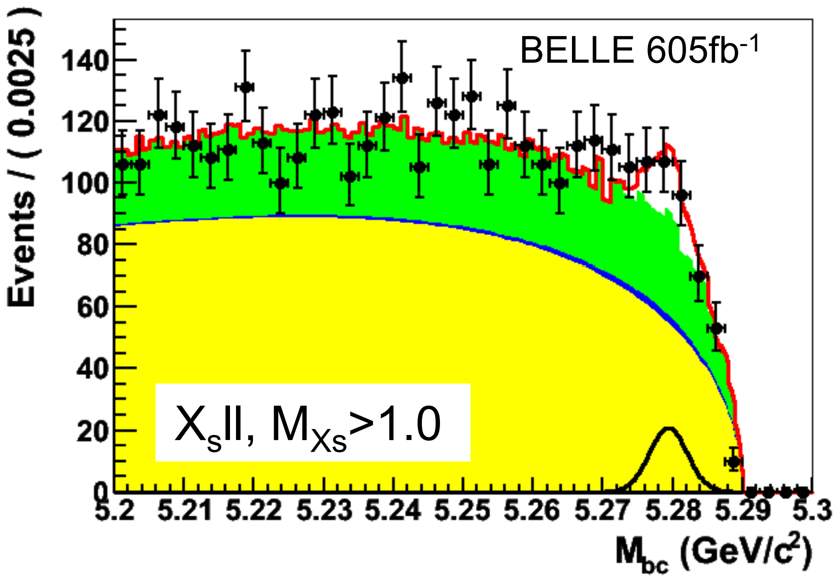
x4 data than the previous result.

Mode	N_{sig}	Signif.
Xs $e^+ e^-$	121.6±19.3±2.0	7.0
Xs $\mu^+ \mu^-$	118.5±17.3±1.5	7.9
Xs $l^+ l^-$	238.3±26.4±2.3	10.1

For M_{Xs}>1.0GeV/c^2

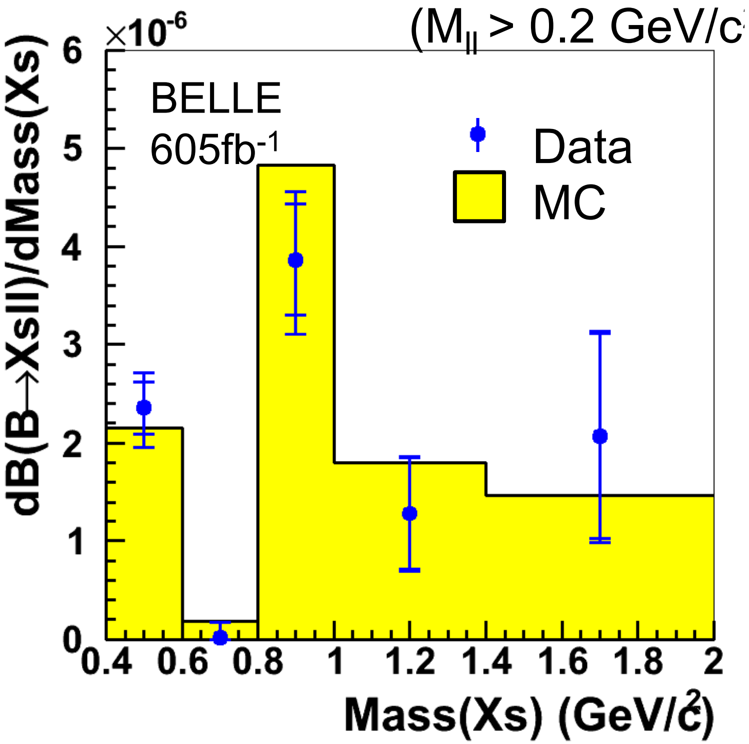
Mode	N_{sig}	Signif.
Xs $l^+ l^-$	56.2±19.6±0.5	3.0

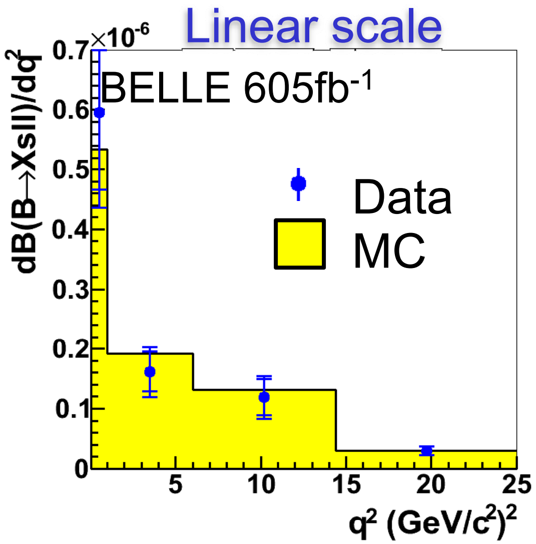


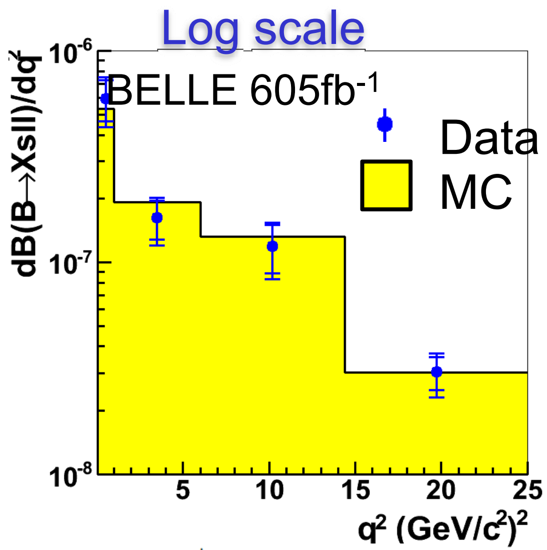


Detailed property of $B \to X_s ll$

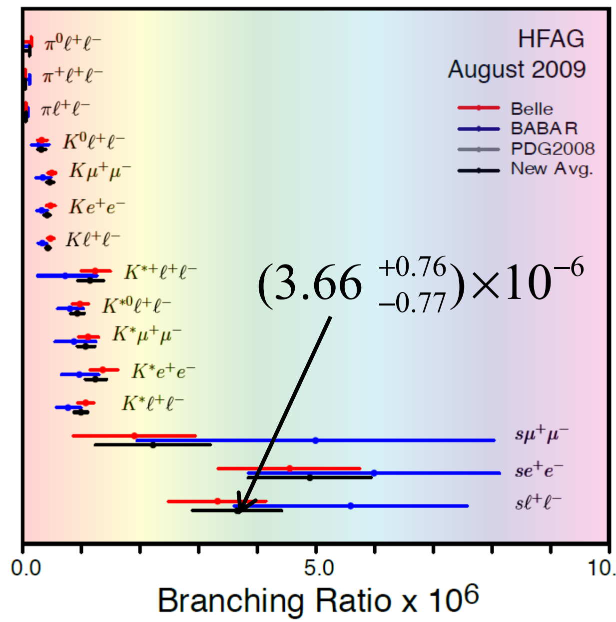
Δ(stat.) much larger than Δ(syst.)







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



For entire MXs region

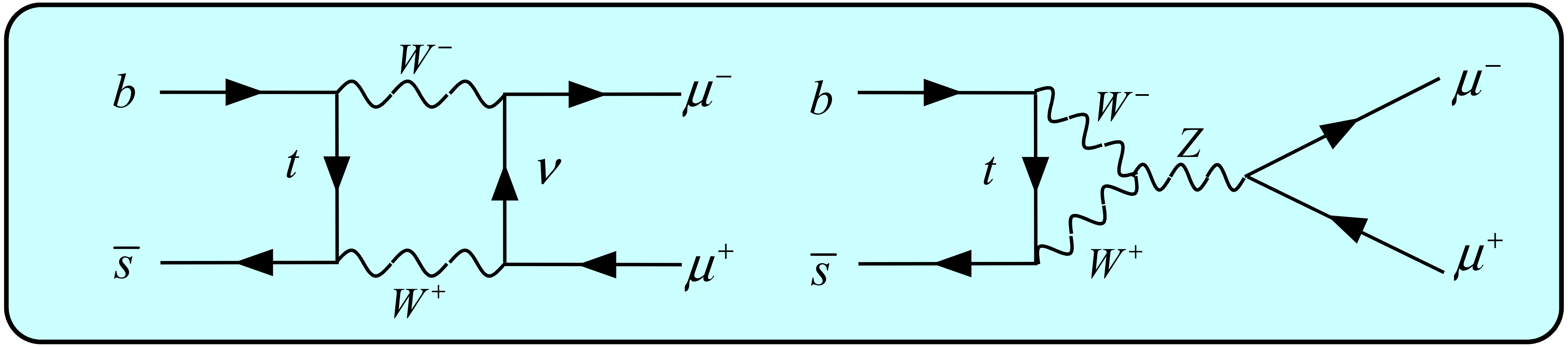
$$Br(B \to X_s ee) = (4.56 \pm 1.15^{+0.33}_{-0.40}) \times 10^{-6}$$

$$Br(B \to X_s \mu\mu) = (1.91 \pm 1.02^{+0.16}_{-0.18}) \times 10^{-6}$$

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

Note: Measured Br (M(XS):0.2-2.0 GeV/c^2) x [1.10±0.002] --- based on signal MC

$B_S / B_d \to \mu\mu$



- SM prediction: $Br(B_S \to \mu\mu) = (3.6 \pm 0.3) \times 10^{-9}$

  $Br(B_d \to \mu\mu) = (1.1 \pm 0.1) \times 10^{-10}$

  A.J.Buras arXiv:0904.4917

- Possible enhancements in many new physics models.
- In SUSY, several orders of magnitude at large tan β,

  In MSSM: ~$\tan^6\beta$

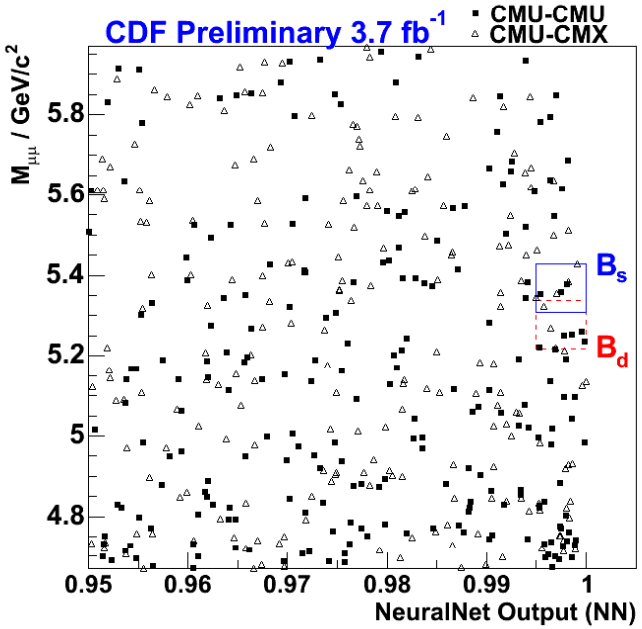
- Current best limits at 90%(95%)CL

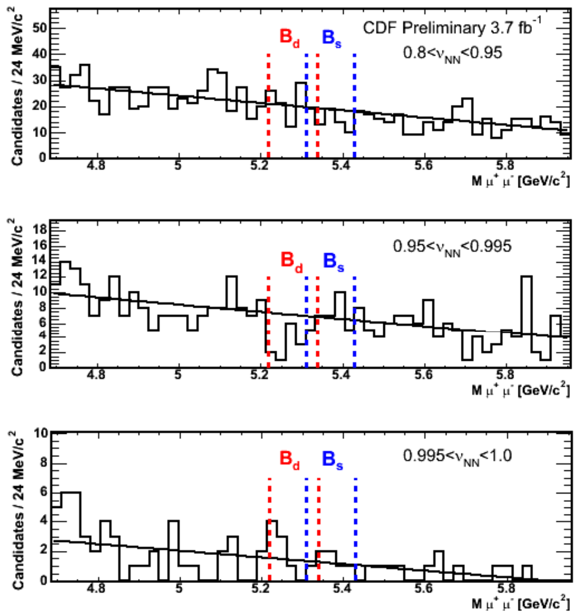
$X10^{-8}$	**Bd**	**Bs**
CDF ($2fb^{-1}$)	1.5(1.8)	4.7(5.8)
D0 ($2fb^{-1}$)	-	7.5(9.3)

$B_S / B_d \to \mu\mu$: Updates from CDF

- 3.7 fb-1
- Analysis technique is identical to that for 2fb^{-1}
  - Muons in CMU-CMU / CMU-CMX triggers.
  - Neural network (NN) to separate signal from background.

CMU: |h|<0.6
CMX: |h|=0.6-1.0





Updated limits (3.7fb^{-1}): @ 95%CL

$$Br(B_S \to \mu\mu) < 4.3\times10^{-8}$$

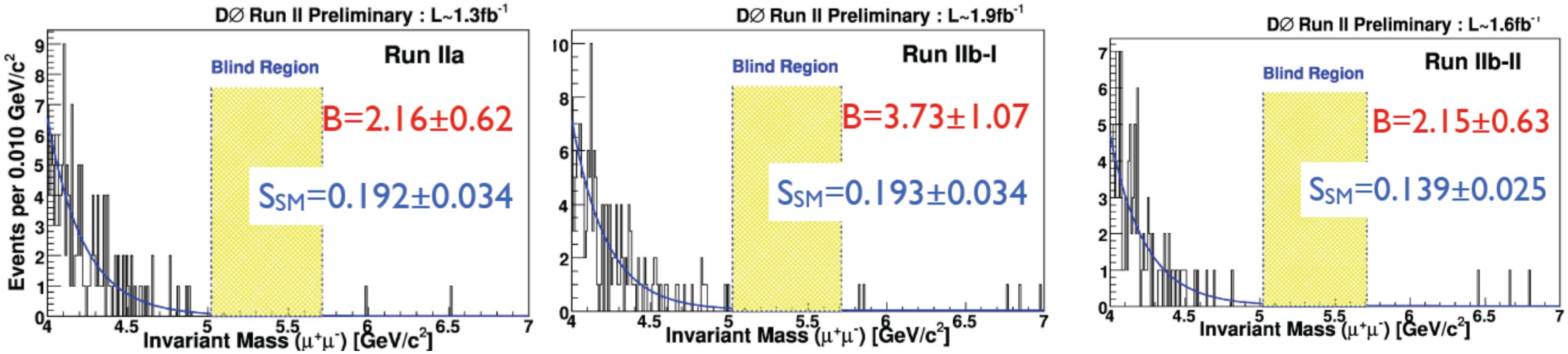
$$Br(B_d \to \mu\mu) < 7.6\times10^{-9}$$

$B_S / B_d \rightarrow \mu\mu$: Updates from D0

Analysis of $B_s \rightarrow \mu\mu$ using $5fb^{-1}$ data.

- Use BDT (boosted decision tree)
- Divide data into 3 periods:
  - Run-IIa ($1.3fb^{-1}$)
  - Run-Iib-I ($1.9fb^{-1}$): + SMT layer0
  - Run-Iib-II($1.6fb^{-1}$): + tighter trigger

Background estimation
- Combinatorial
- $B \rightarrow hh$



Signal box is still blinded.

Expected upper limit assuming no signal

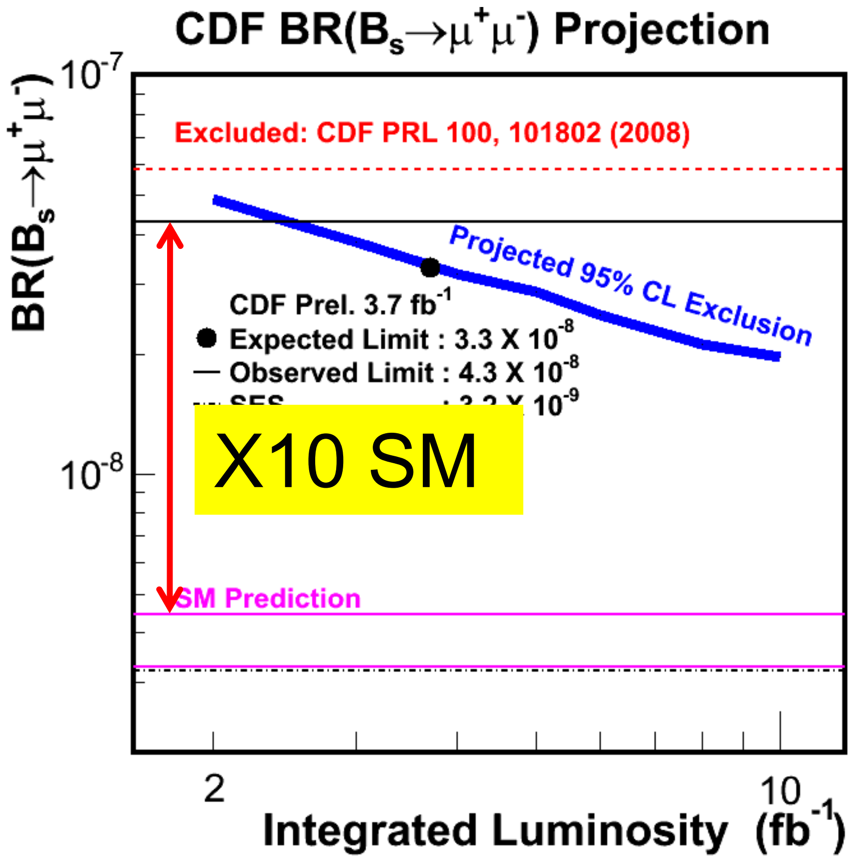
$$Br(B_S \rightarrow \mu\mu) < 4.7(5.8)\times 10^{-8}$$ @95(90)%CL

Still trying to improve the analysis

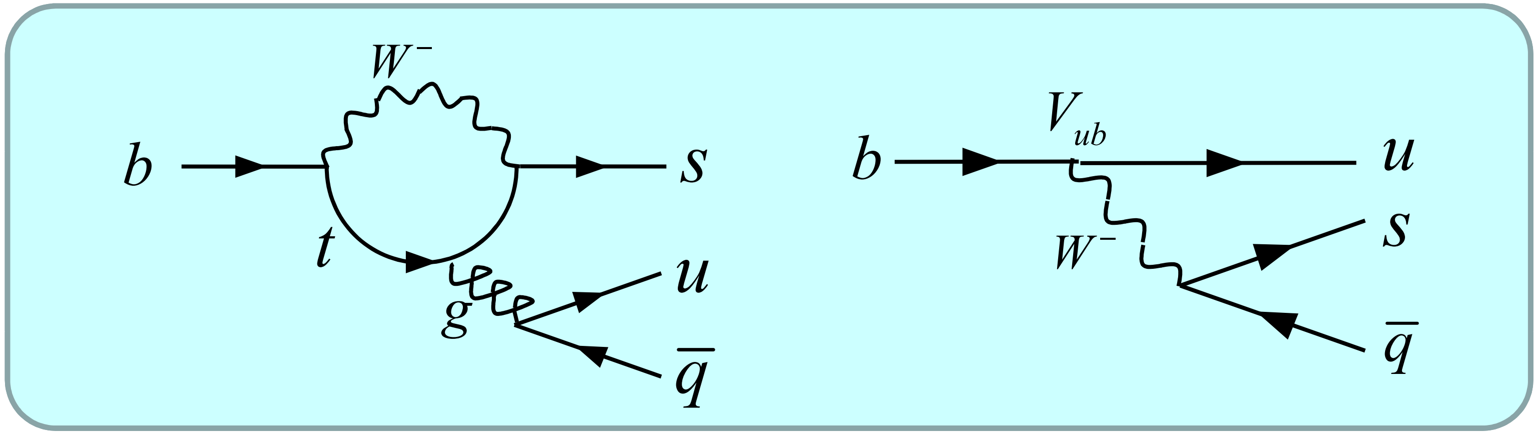
$B_S / B_d \to \mu\mu$:

- Tevatron limits have reached x10 above the SM prediction.
- More data
  - $6fb^{-1}$ in hand
  - x2 more data by the end of Run-II
- + Improvement in the analysis.

Will provide significantly tighter constraints on NP parameter space



Charmless Hadronic Decays

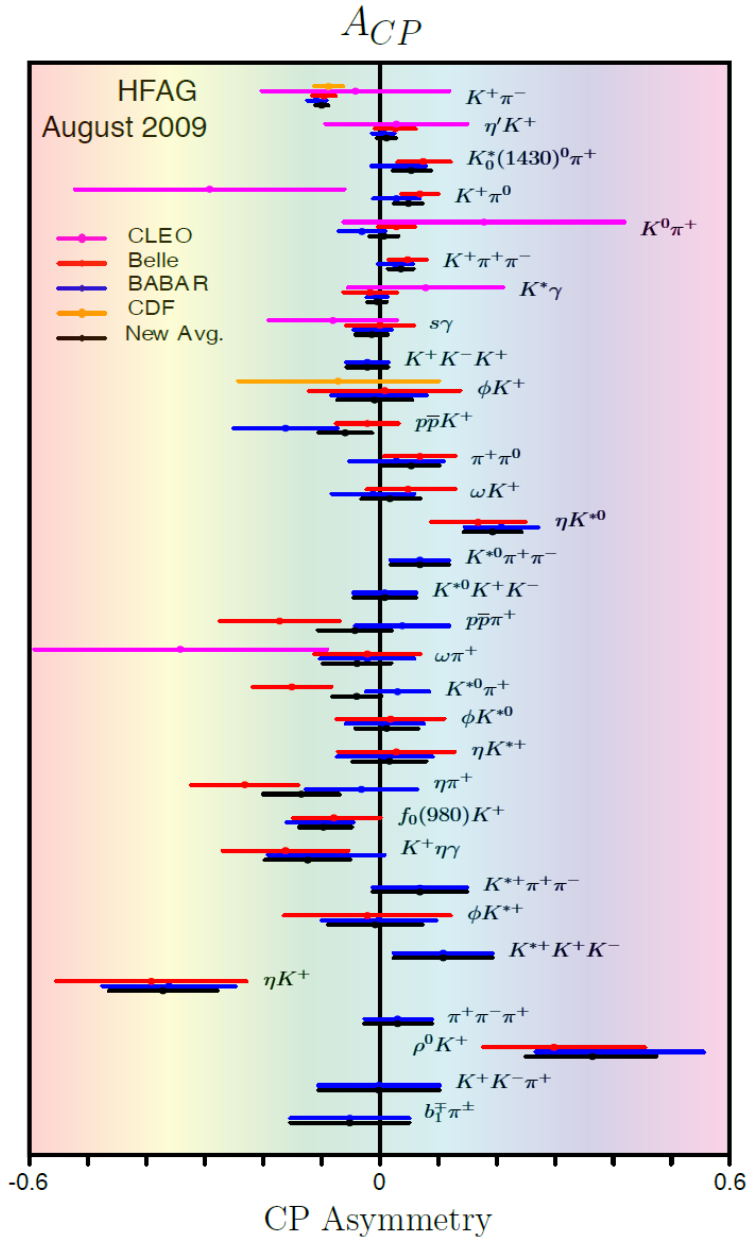


- Direct CP violation due to interference between b→sg penguin and b→u tree diagrams.

$$A_{CP} = \frac{\Gamma(\bar{B}^0 \to K\pi) - \Gamma(B^0 \to K\pi)}{\Gamma(\bar{B}^0 \to K\pi) + \Gamma(B^0 \to K\pi)} \propto \sin\phi_3 \sin(\delta_P - \delta_T)$$

- Two Known puzzles
  - A_{CP} puzzle in $K\pi$ decays
  - Polarization in B→VV modes.

Direct CP Violation



Direct CP Violation

$\Delta A_{K\pi}$ puzzle

$$\Delta A_{K\pi} = A_{K^+\pi^0} - A_{K^+\pi^-} = +0.144 \pm 0.029$$

- They occur via the same diagrams at leading order.
- Interpretation with SM & non-SM
- $K^0\pi^0$ data useful (check isospin relation)

- Observation (>5σ)

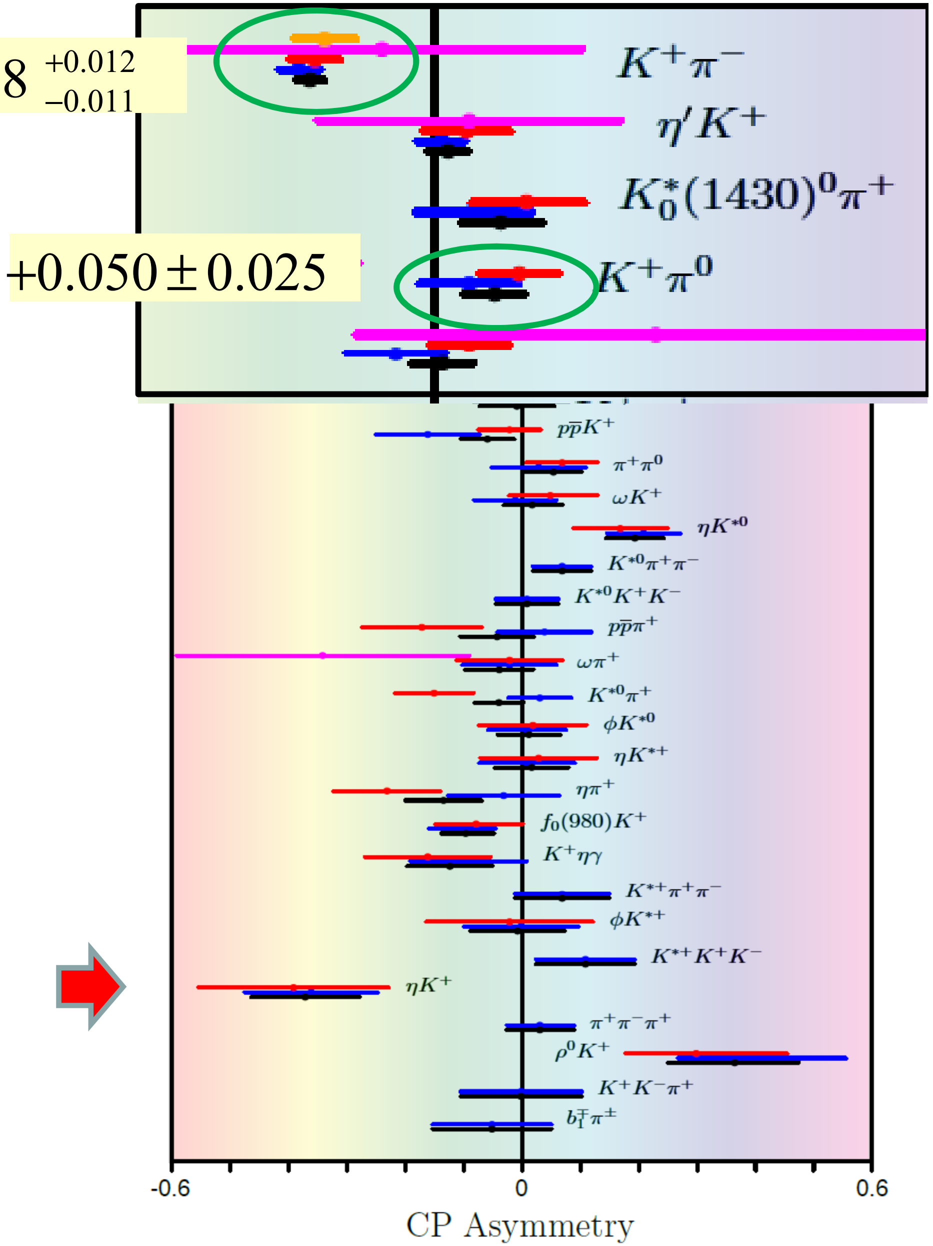
  $$B^0 \to K^+\pi^-, B^0 \to \pi^+\pi^-$$

- Evidence (>3σ)

  $$B^0 \to \eta K^{*0}, B^+ \to \eta K^+$$

  $$B^0 \to \rho^+\pi^-, B^+ \to \rho^0 K^+$$

  $$B^+ \to D^{(*)0} K^+$$

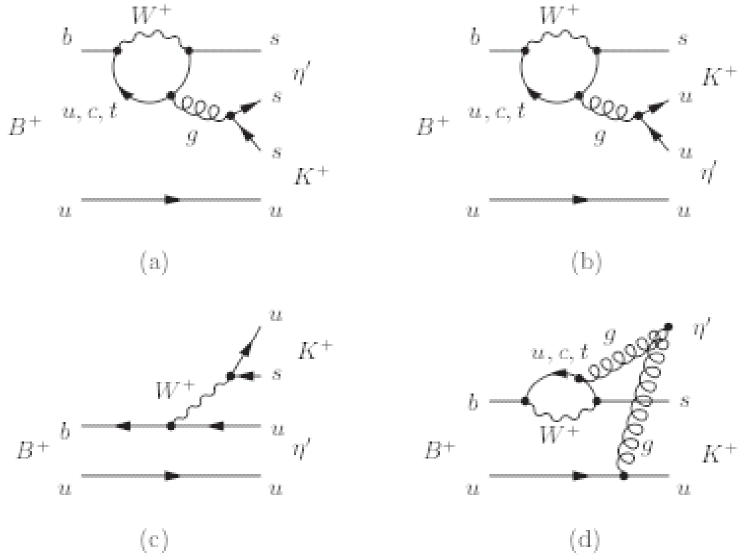


Modes including η, η'

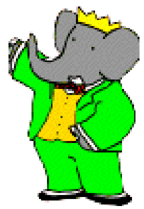
- Br(η'K) >> Br(ηK)

  -- 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



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

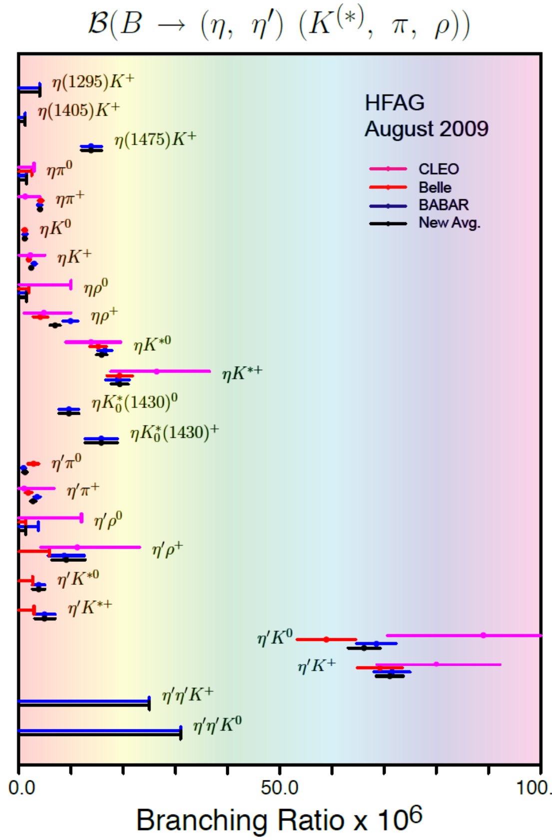
  $A_{CP}(B^+ \to \eta K^+) = -0.36 \pm 0.11 \pm 0.03$

- Evidence for three decay modes.

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

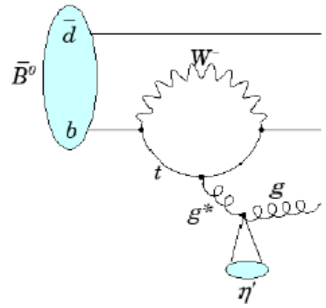
  $Br(B^0 \to \eta \omega) = (0.94\ ^{+0.35}_{-0.30} \pm 0.19) \times 10^{-6}$

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



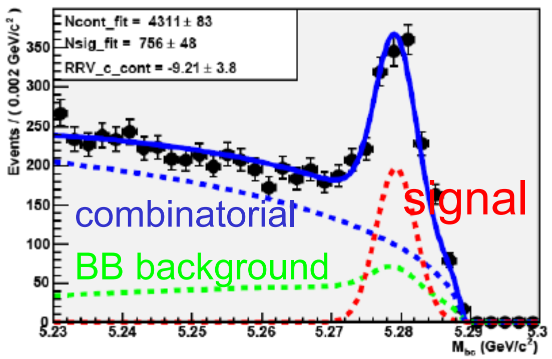
$B \to X_s \eta$ by Belle

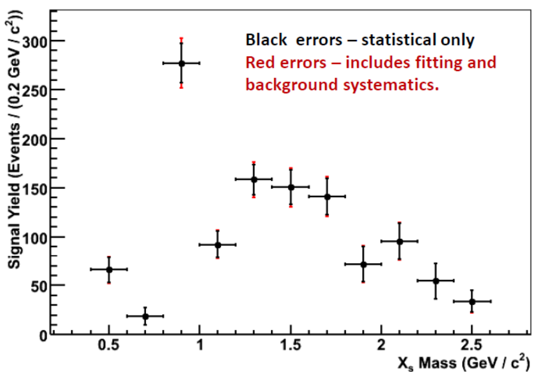
$B \to X_s\eta'$, QCD anomaly?



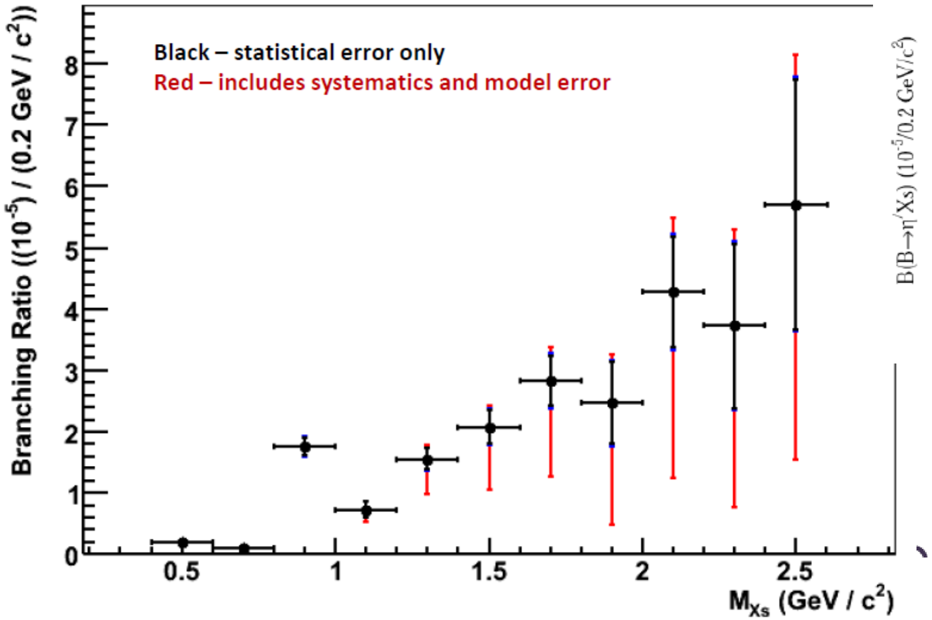
- 657MBB
- X_s η reconstruction

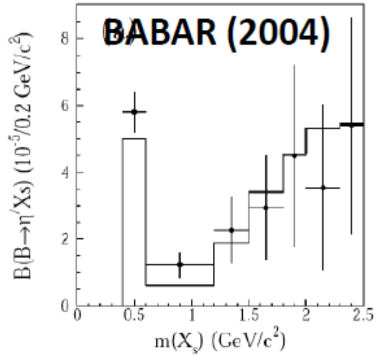
$$B \to X_s\eta(p_\eta^{CM} > 2.0GeV/c)$$
$$\eta \to \gamma\gamma$$
$$X_s \to Kn\pi(n \le 4, n_{\pi^0} \le 1)$$





Ns (Xs mass >1.0GeV/c²)
= 749±48±7 17.6σ





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

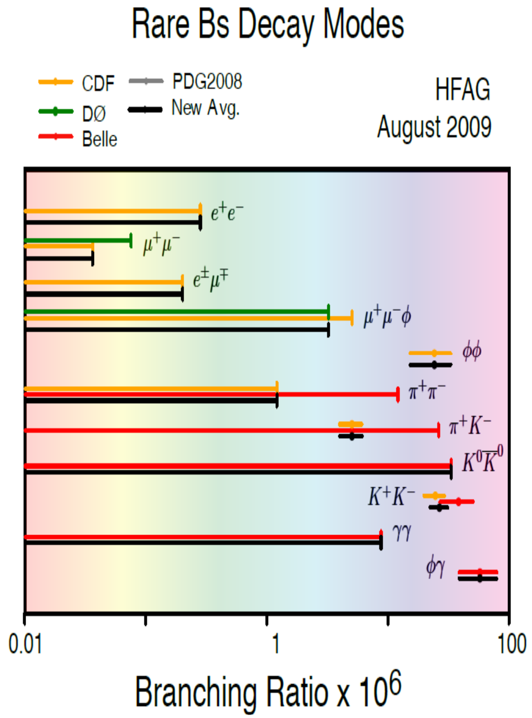
Partial Br for M(Xs) =0.4-2.6 GeV/c²

$$Br(B \to X_S\eta)^* = (25.5 \pm 2.7 \pm 1.6^{+3.8}_{-14.1}) \times 10^{-5}$$

* Assuming JETSET hadronization model error

B_s Charmless Decays

- Charmless decays of the B_s meson will exhibit equally rich phenomena.

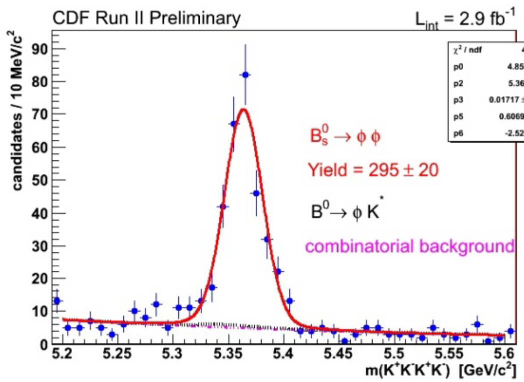


CDF 2.9 fb^{-1}

$$Br(B_S \to \phi\phi) / Br(B_S \to J/\psi\, \phi) = (1.78 \pm 0.14 \pm 0.20)\times 10^{-2}$$

$$Br(B_S \to \phi\phi) = (24.0 \pm 2.1 \pm 2.7 \pm 8.2)\times 10^{-6}$$

BR error

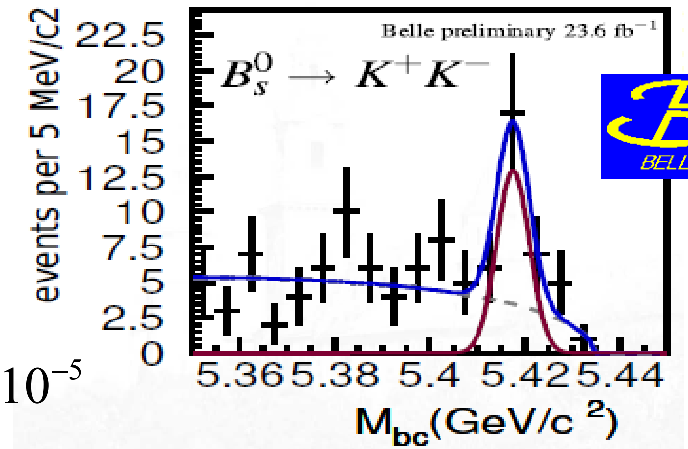


Belle 23.6fb^{-1} on Y(5S)

$$Br(B_S \to K^+K^-) = (3.8\,^{+1.0}_{-0.9} \pm 0.7)\times 10^{-5}$$

cf) CDF $(3.3 \pm 0.6 \pm 0.7)\times 10^{-5}$

PRL97, 211802



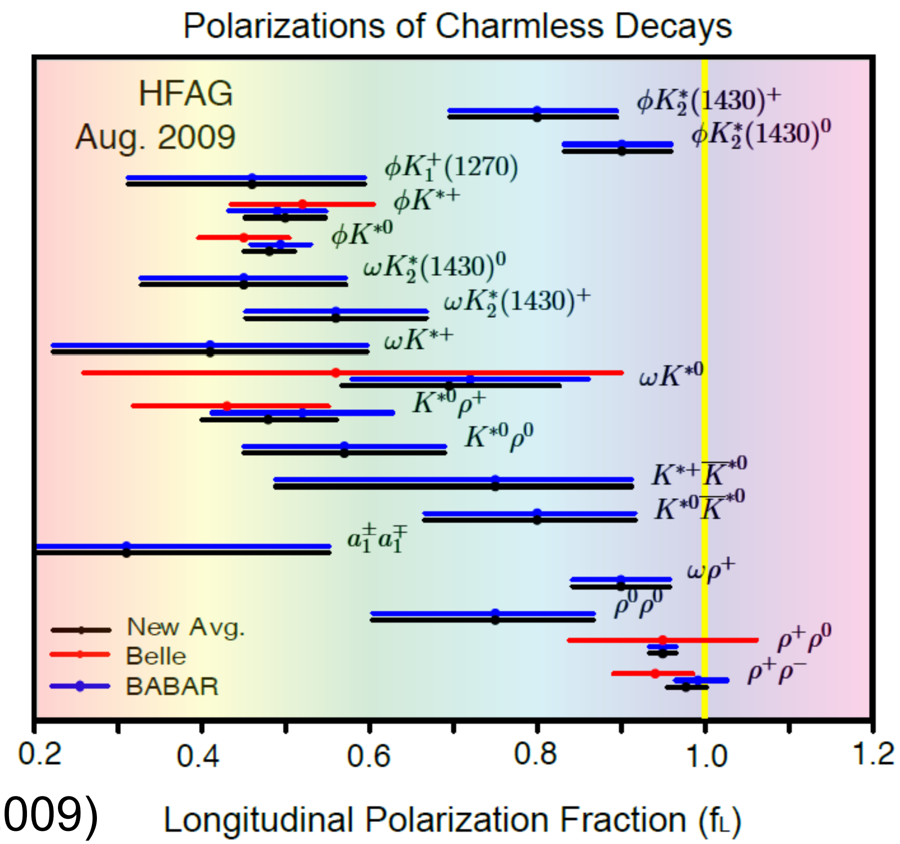
~90fb^{-1} at Y(5S) on hand.

B→VV modes

- Naïve expectation is f_L~1 in B→VV decays.

  f_L: longitudinal polarization fraction

- However, $f_L(\phi K^*)$ ~0.5 penguin
- $F_L(\rho\rho)$~1.0 tree
- $F_L(\phi K_2^*(1430))$ close to 1



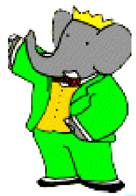
BaBar: 465MBB PRD79, 052005(2009)

VV $f_L(\omega K^{*+}) = 0.41 \pm 0.18 \pm 0.05$

$f_L(\omega\rho^+) = 0.90 \pm 0.05 \pm 0.03$

VT $f_L(\omega K_2^*(1430)^0) = 0.45 \pm 0.12 \pm 0.02$

$f_L(\omega K_2^*(1430)^+) = 0.56 \pm 0.10 \pm 0.04$



Can be explained within SM ?, or is NP required ?

b→d $Br(\overline{K}^{*0}K^{*+}) = (1.2 \pm 0.5 \pm 0.1)\times 10^{-6}$

$f_L(\overline{K}^{*0}K^{*+}) = 0.75^{+0.16}_{-0.26} \pm 0.03$

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Summary

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- There are some hints and puzzles.

Large Br($B \rightarrow \tau\nu$) ?	$\leftrightarrow$	tension between $\lvert V_{ub} \rvert$ - $\sin 2\phi_1$?
Large A_{FB}(K*ll) ?		Deviation of A_I(K*ll) in low q^2 ?
A_{CP} ($K\pi$) puzzle ?		Polarization puzzle in $B \rightarrow VV$?

- $B_s/B_d \rightarrow \mu\mu$ at Tevatron will be at critical corner in coming years.
- We need much more luminosity to clearly see the effects of new physics; O(0.1) correction to SM.

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Next generation
Super B factories + LHCb

Let's prepare for an exciting future in B physics!