NP constraint by rare decays at the B factories

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On behalf of the Belle collaboration

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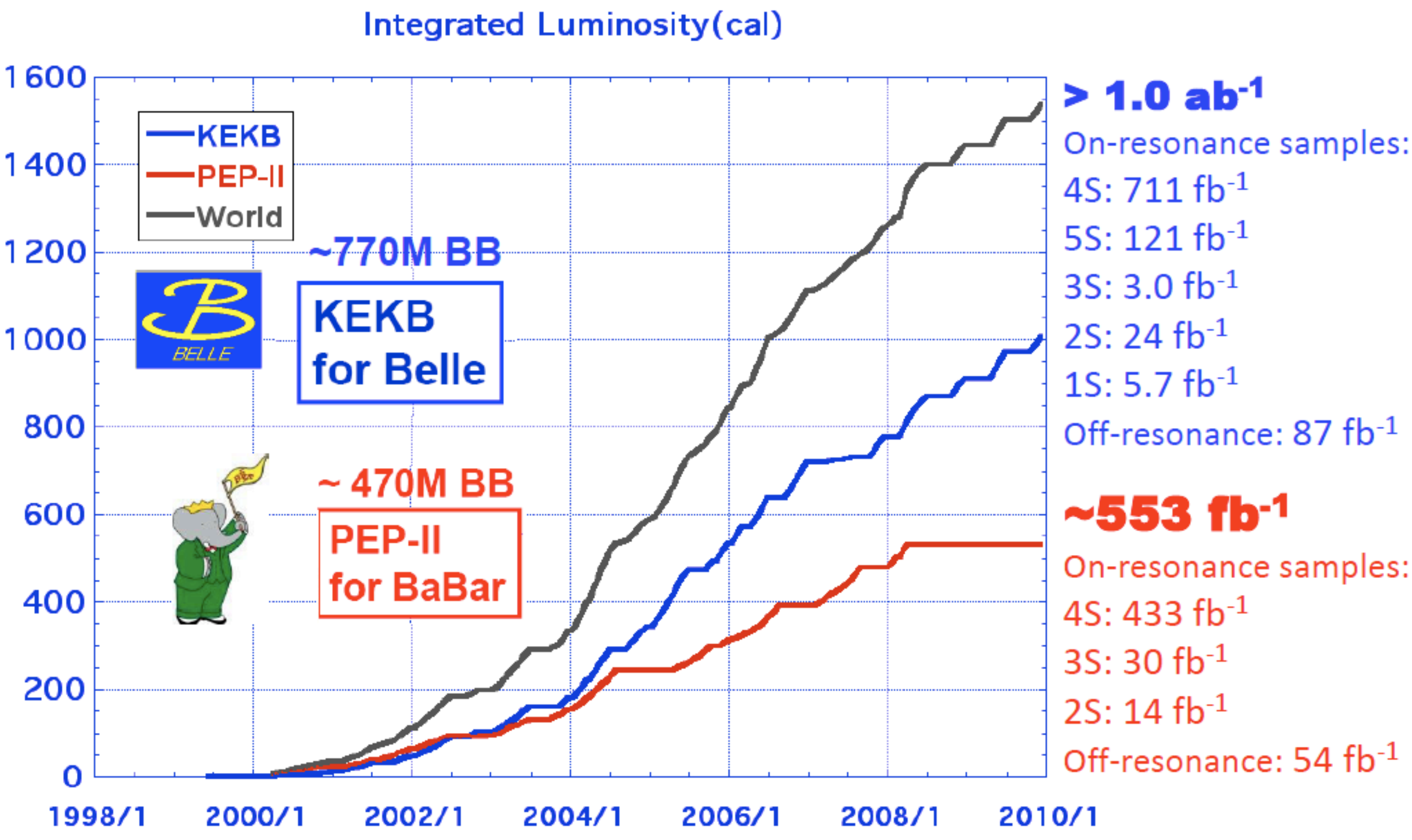
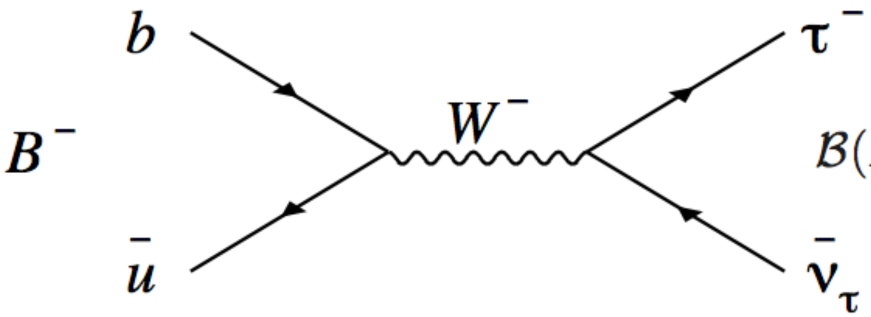
Belle and Babar's datasets



$B \rightarrow \tau\nu$

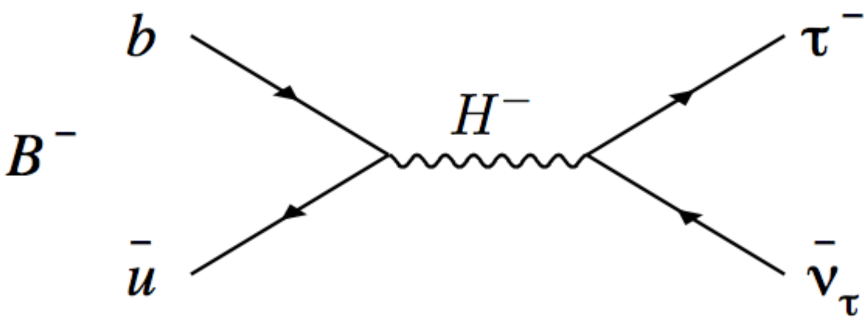
B → τν in the Standard Model



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

- Theoretically clean in the SM
  - pure leptonic decay, thus small hadronic effects
  - Br(B → τν) = (1.20 ± 0.25) x 10^{-4}
  - Assuming $|V_{ub}|$ = (4.32 ± 0.33) x 10^{-3} [HFAG summer 2008] and
  - f_B = 190 ± 13 MeV [HPQCD arXiv:0902.1815]

Sensitive to the charged Higgs H^+



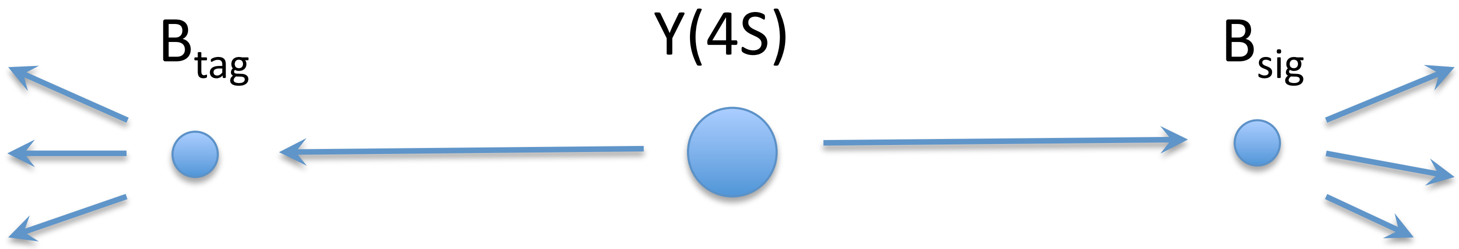
$$\mathcal{B}(B^- \to \tau^- \bar{\nu}) = \mathcal{B}_{\rm SM} \times r_H$$

$$r_H = \left(1 - \tan^2\beta \frac{m_{B^-}^2}{m_{H^-}^2}\right)^2$$

W.S.Hou, PRD 48, 2342 (1993)

- Type II Higgs doublet model
- Amplitude of the charged Higgs diagram proportional to $m_b m_\tau \tan^2\beta$
- Enhancement for large tan β or small m_{H+}

Measurement of $B \rightarrow \tau\nu$



Reconstruction of B_{tag}

- Reconstruct either hadronic or semileptonic decays of B_{tag}
- Remove the corresponding particles from the event to reduce combinatorial background

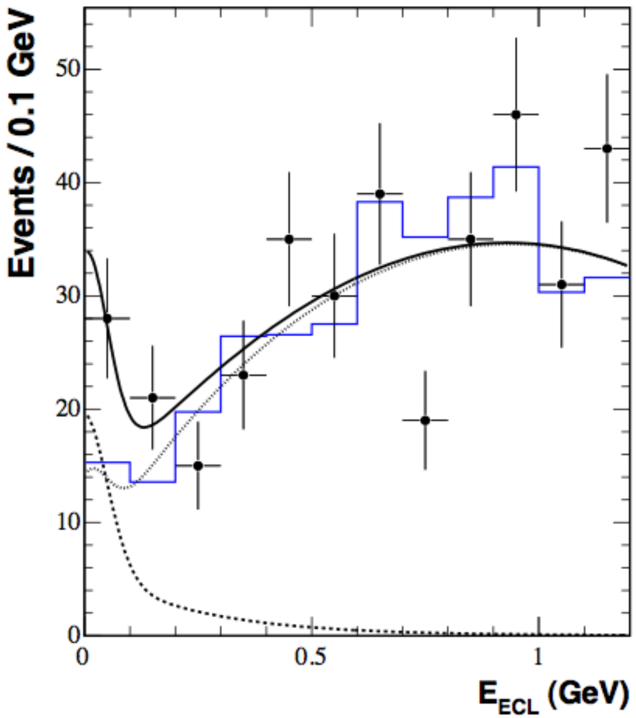
Reconstruction of B_{sig}

- Challenging even in tagged events: two neutrinos for hadronic ($\tau \rightarrow \pi\nu$), three for leptonic ($\tau \rightarrow \mu\nu\nu$) τ decay mode in the final state
- Extract signal from remaining energy distribution (signal peak at zero)

PRL 97, 251802 (2006)

First evidence – hadronic tag

449M BB



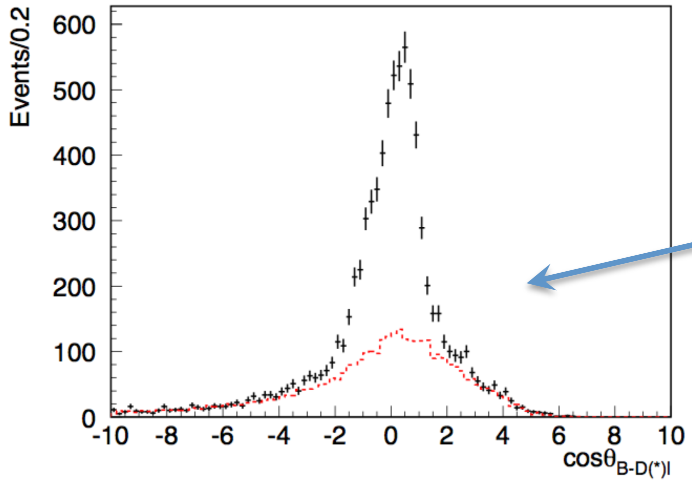
- Hadronic tag
- Two leptonic ($e\nu\nu$, $\mu\nu\nu$) and three hadronic ($\pi\nu$, $2\pi\nu$, $3\pi\nu$) τ modes
- $17.2^{+5.3}_{-4.7}$ signal events
- 3.5 sigma significance (including systematics)

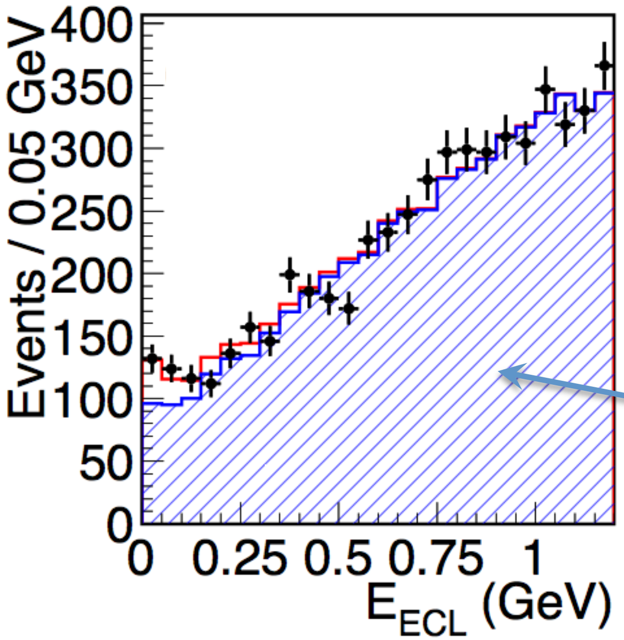
$Br(B \to \tau\nu) = (1.79^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)) \times 10^{-4}$

657M BB

Semileptonic tag

arXiv:1006.4201
submitted to PRD





- Tag-side
  - $B^+ \to D^{*0} l^+ \nu$ or $B^+ \to D^0 l^+ \nu$
  - $D^{*0} \to D^0 \pi^0, D^0 \gamma$
  - $D^0 \to K^- \pi^+, K^- \pi^+ \pi^0, K^- \pi^+ \pi^- \pi^+$
- Signal-side
  - $\tau^+ \to e^+ \nu\nu, \mu^+ \nu\nu, \pi^+ \nu$
- Signal E_{ECL} shape calibrated with double semileptonic tagged events
- 143^{+36}_{-35} signal events, 3.6 sigma significance (including systematics)

$Br(B \to \tau\nu) = (1.54^{+0.38}_{-0.37}(stat)^{+0.29}_{-0.31}(syst)) \times 10^{-4}$

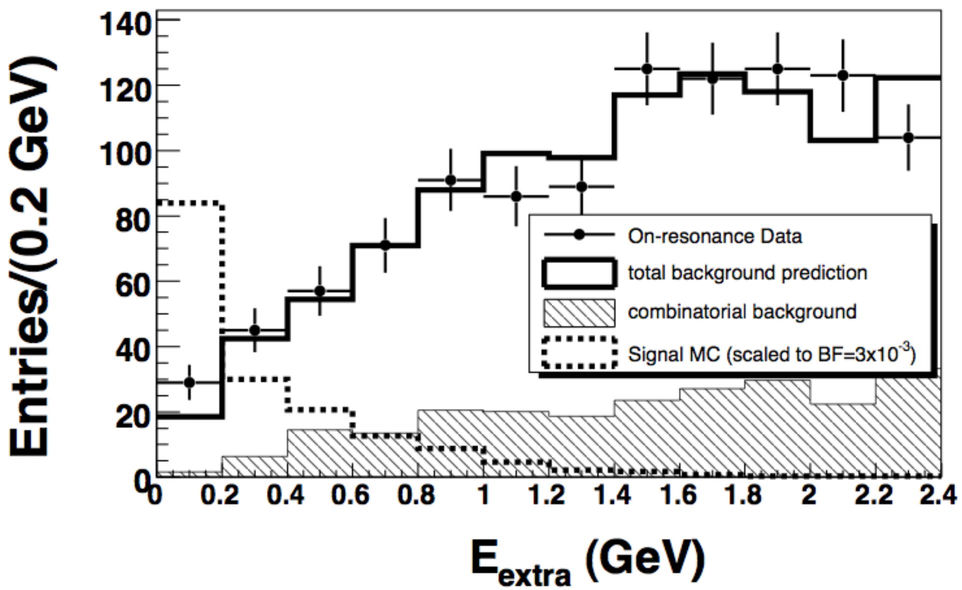
PRD 77, 011107(2008)
PRD 81, 051101 (2010)

BaBar's results

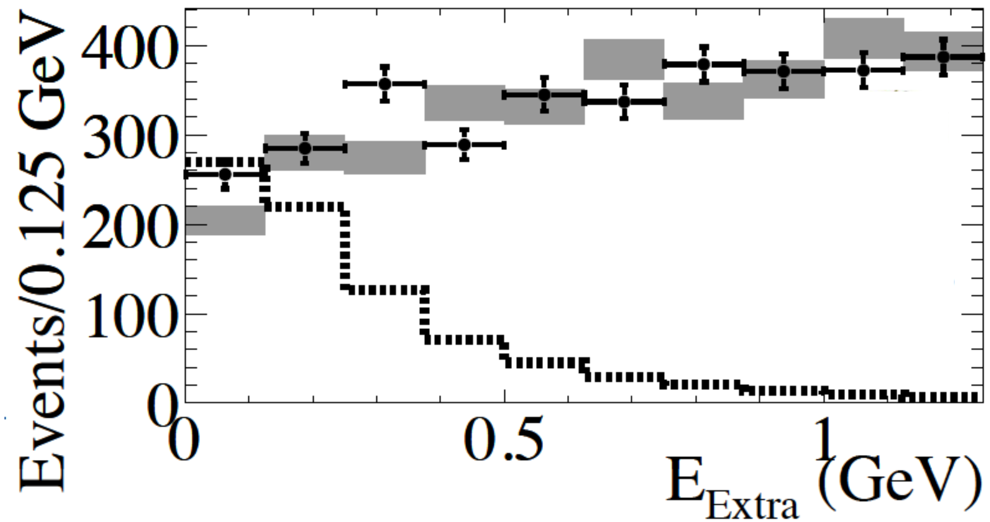
383M BB

459M BB

Hadronic tag



Semileptonic tag



- 2.2 sigma excess
- Br(B → τν) = $(1.8^{+0.9}_{-0.8}$(stat) ± 0.4(bkgrd) ± 0.2(syst)) x 10^{-4}

- 2.4 sigma excess
- Br(B → τν) = (1.7 ± 0.8(stat) ± 0.2(syst)) x 10^{-4}

Constraints on NP

Naïve world average:
$Br(B \to \tau\nu) = (1.73 \pm 0.35) \times 10^{-4}$

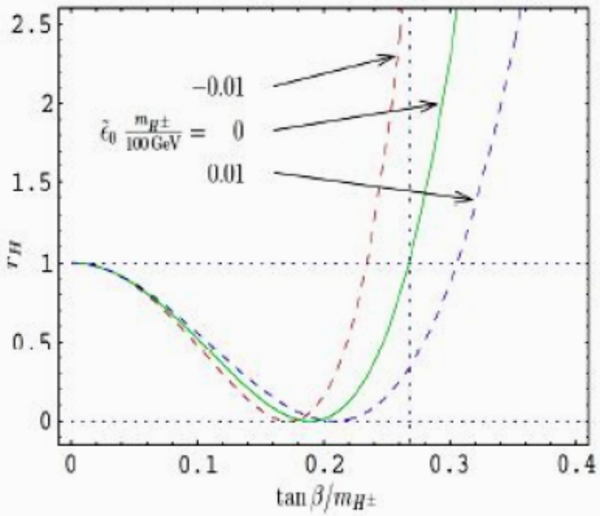
SM value:
$Br(B \to \tau\nu) = (1.20 \pm 0.25) \times 10^{-4}$

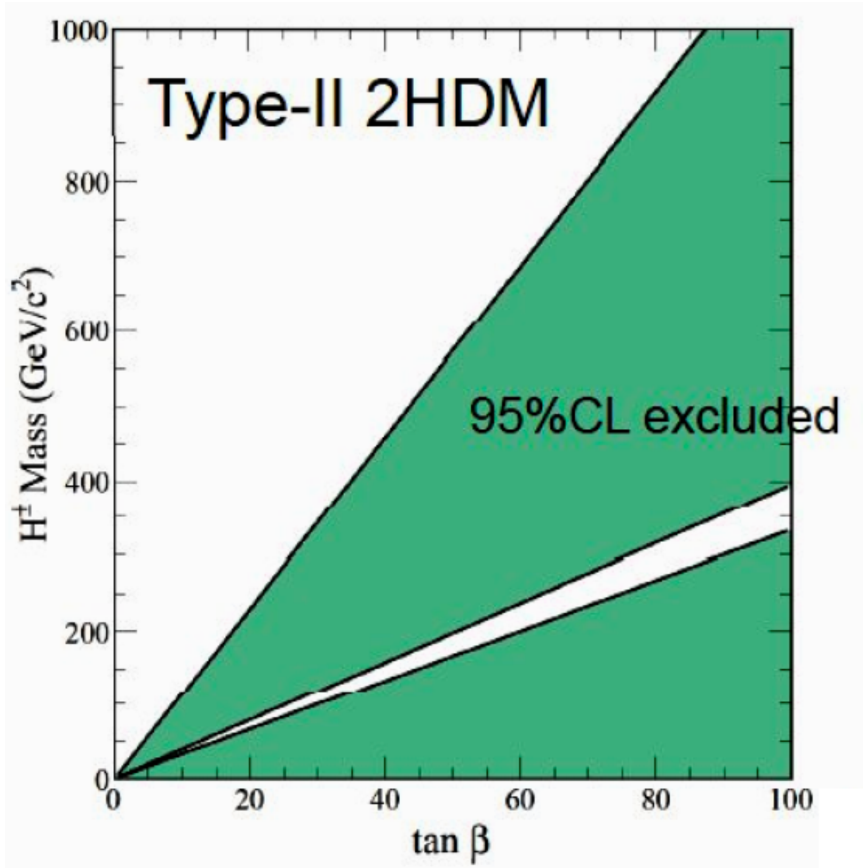
$$Br = Br_{SM} \times r_H,$$

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

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

SUSY Loop correction
ε_0=0 for Type-II 2HDM

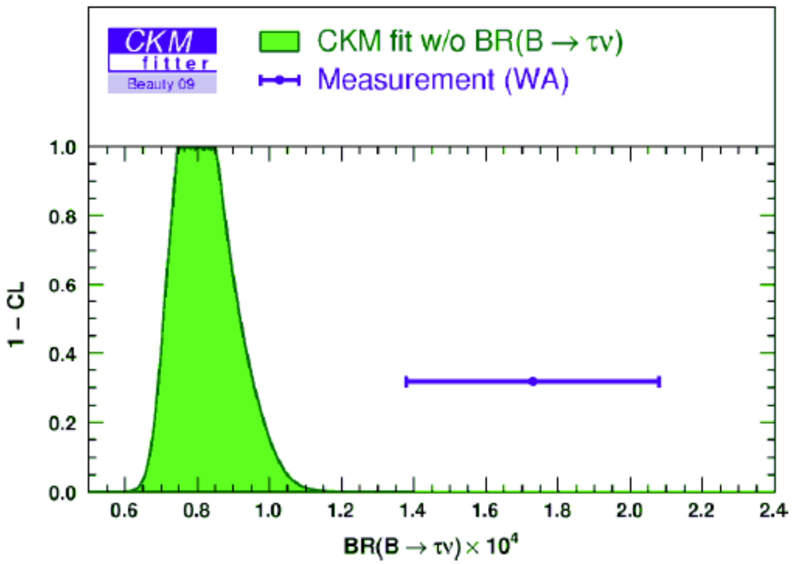


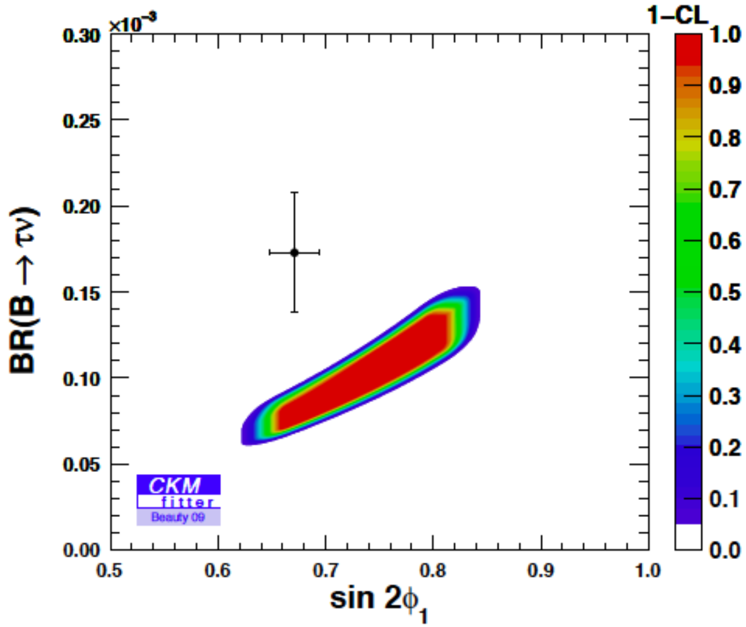


Constraints on NP (2)

Naïve world average:
$Br(B \to \tau\nu) = (1.73 \pm 0.35) \times 10^{-4}$

CKM fitter, Beauty 2009:
$Br(B \to \tau\nu) = (0.786^{+0.179}_{-0.083}) \times 10^{-4}$

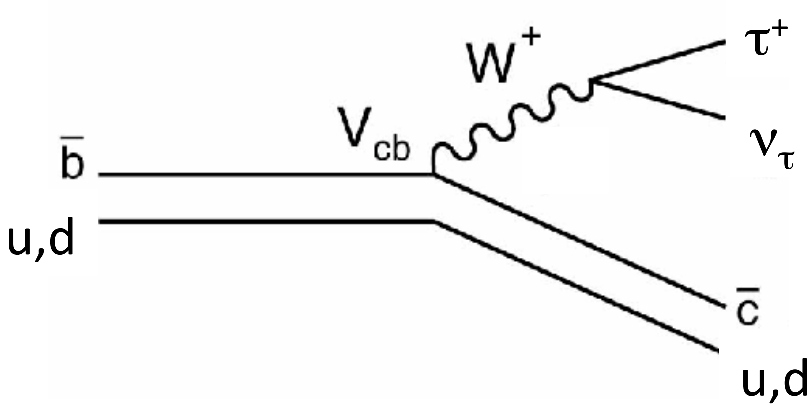


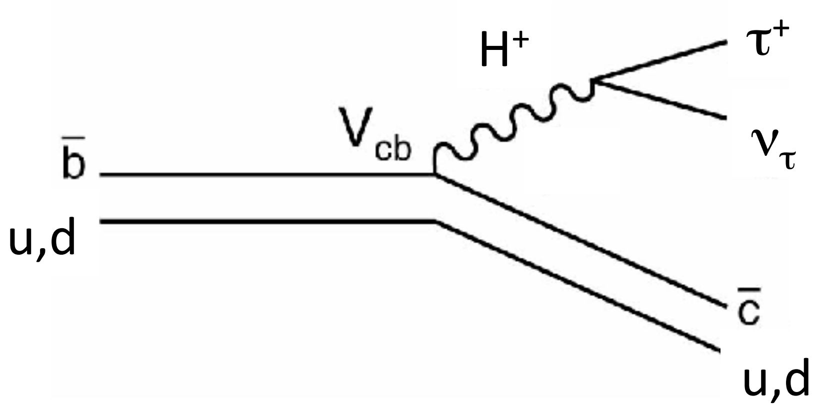


- 2.4 sigma difference between $B \to \tau\nu$ measurement and CKM fitter value (excluding $B \to \tau\nu$)

$B \to D^{(*)}\tau\nu$

Also sensitive to H^+

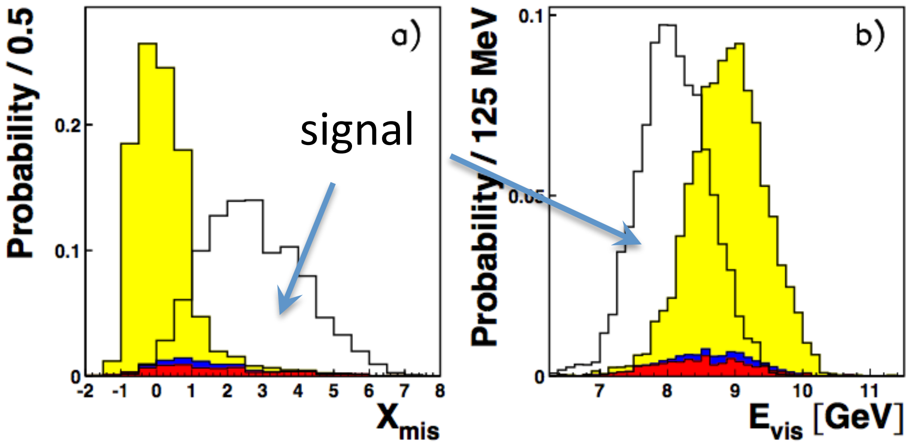




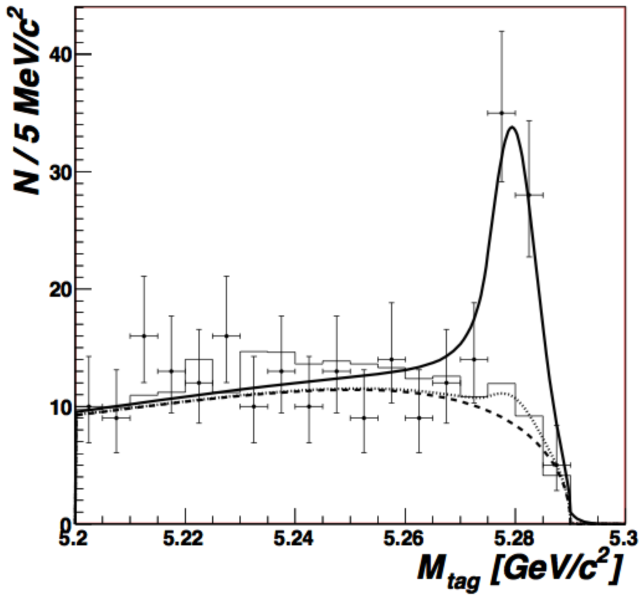
- Different theory uncertainties
  - No dependence of the decay constant f_B
  - $|V_{cb}|$ cancels in the ratio $Br(B \to D^{(*)}\tau\nu)/Br(B \to D^{(*)}l\nu)$
- More observables
  - q^2-distribution, τ polarization, D^* polarization

PRL 99, 191807 (2007)

First observation $B^0 \to D^{*-}\tau^+\nu$



$$X_{\rm mis} \equiv (E_{\rm mis} - |\mathbf{p}_{D^*} + \mathbf{p}_{e/\pi}|)/\sqrt{E_{\rm beam}^2 - m_{B^0}^2}$$



- Reconstruct signal side first
  - $D^{*+} \to D^0\pi^+$
  - $D^0 \to K^-\pi^+, K^-\pi^+\pi^0$
  - $\tau^+ \to e^+\nu\nu, \pi^+\nu$
- Inclusively reconstruct tag side
  - $P_{tag} = \Sigma P_i$, $E_{tag} = \Sigma E_i$
- Background suppression with E_{mis}, X_{mis} and E_{vis}
- 60^{+12}_{-11} signal events with 5.2σ significance

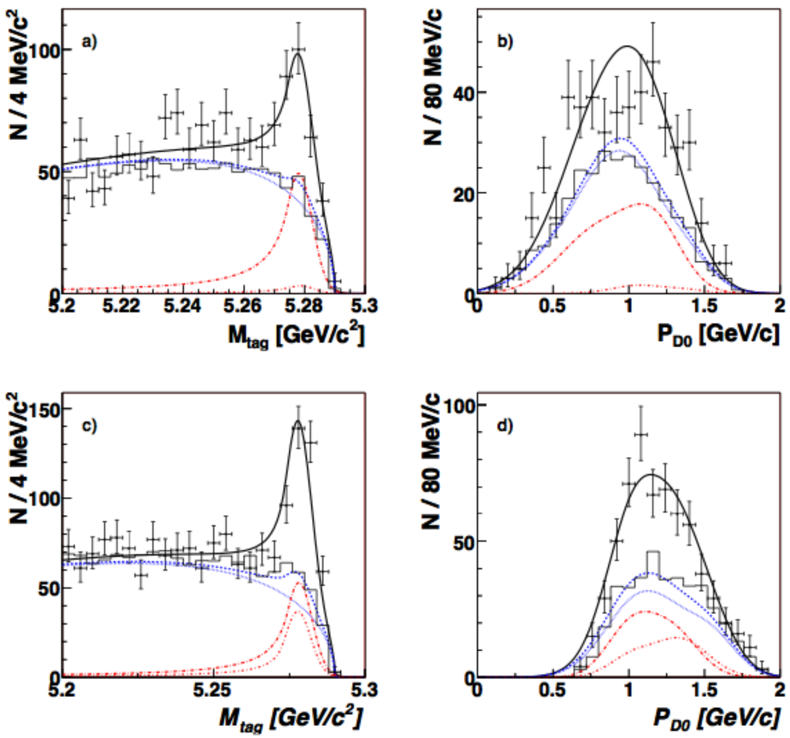
$Br(B^0 \to D^{*-}\tau^+\nu) =$
$(2.02^{+0.40}_{-0.37}(stat) \pm 0.37(syst))\%$

657M BB

arXiv:1005.2302
submitted to PRL

Extension to B^+ decays

- Signal side
  - $D^{*0} \to D^0\pi^0$, $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$
  - $\tau^+ \to e^+\nu\nu$, $\mu^+\nu\nu$, $\pi^+\nu$
- Strong D^{*0}/D^0 crossfeed → simultaneous measurement of $D^{*0}\tau\nu$ and $D^0\tau\nu$ by fitting M_{tag} vs. P_{D0}



$Br(B^+ \to D^{*0}\tau^+\nu) = (2.12^{+0.28}_{-0.27}(stat) \pm 0.29(syst))\%$

446^{+58}_{-56} events (8.1σ significance)

$Br(B^+ \to D^0\tau^+\nu) = (0.77 \pm 0.22(stat) \pm 0.12(syst))\%$

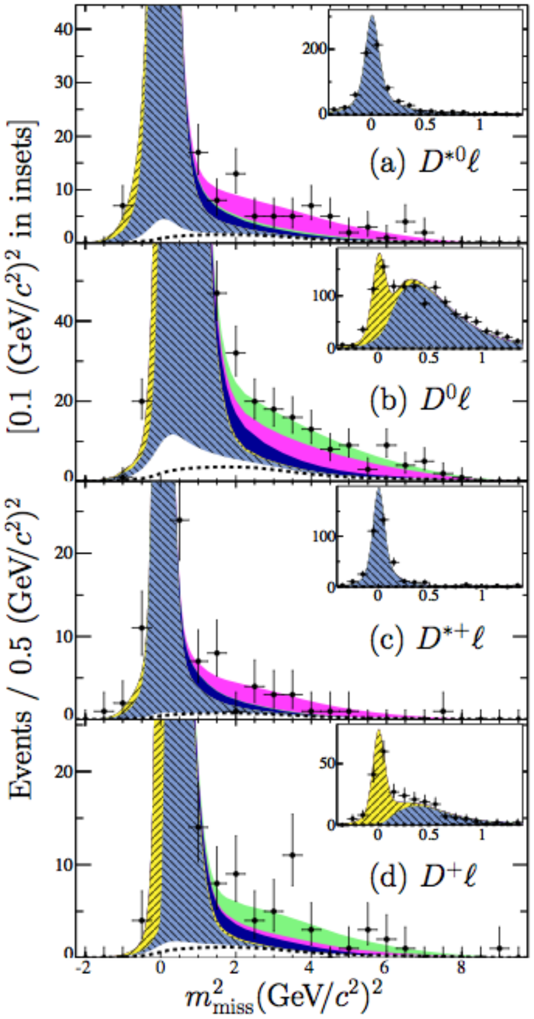
146^{+42}_{-41} events (3.5σ significance)

First evidence

232M BB

PRL 100, 021801 (2008)
PRD 79, 092002 (2009)

BaBar hadronic tag



Signal shown in light green resp. magenta

- First reconstruct hadronic decay of the other B
- Reconstruct $D^{*0}l$, $D^{0}l$, $D^{*+}l$ and $D^{+}l$ pairs on the signal side
- Simultaneous fit to the missing mass sqaured distribution

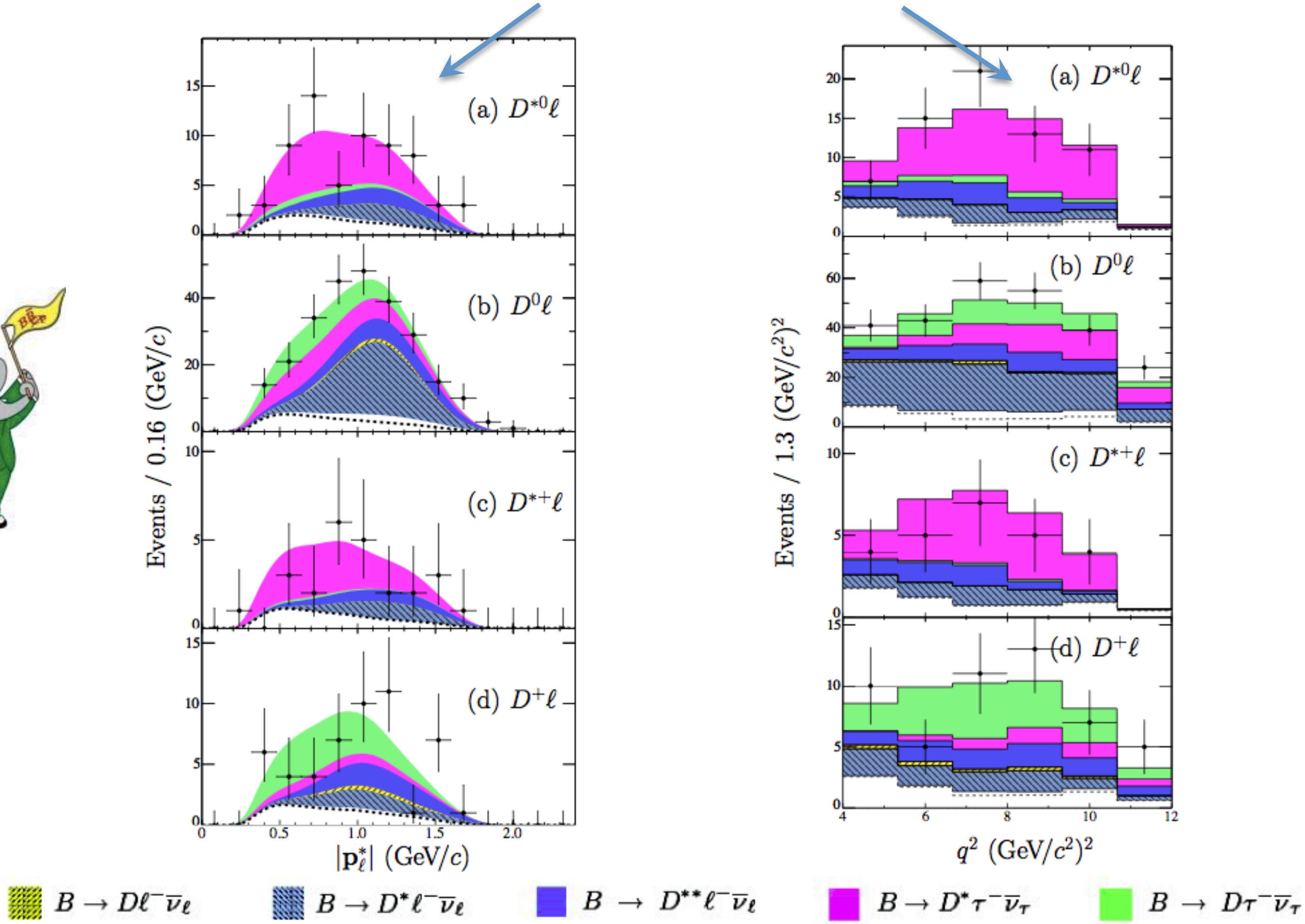
$Br(B^+ \to D^0 \tau^+ \nu)$ =
(0.67 ± 0.37(stat) ± 0.11(syst) ± 0.07(norm))%
35.6 ± 19.4 events (1.8σ significance)

$Br(B^+ \to D^{*0} \tau^+ \nu)$ =
(2.25 ± 0.48(stat) ± 0.22(syst) ± 0.17(norm))%
92.2 ± 19.6 events (5.3σ significance)

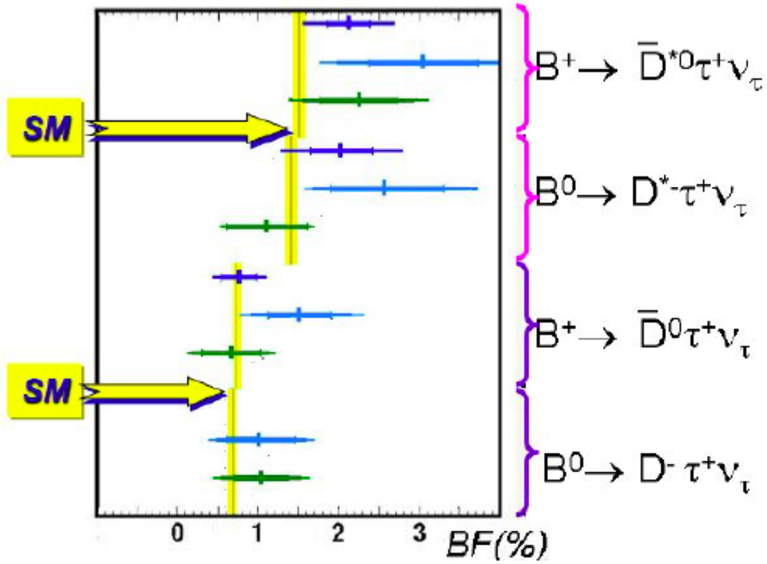
$Br(B^0 \to D^- \tau^+ \nu)$ = First evidence
(1.04 ± 0.35(stat) ± 0.15(syst) ± 0.10(norm))%
23.3 ± 7.8 events (3.3σ significance)

$Br(B^0 \to D^{*-} \tau^+ \nu)$ =
(1.11 ± 0.51(stat) ± 0.04(syst) ± 0.04(norm)%
15.5 ± 7.2 events (2.7σ significance)

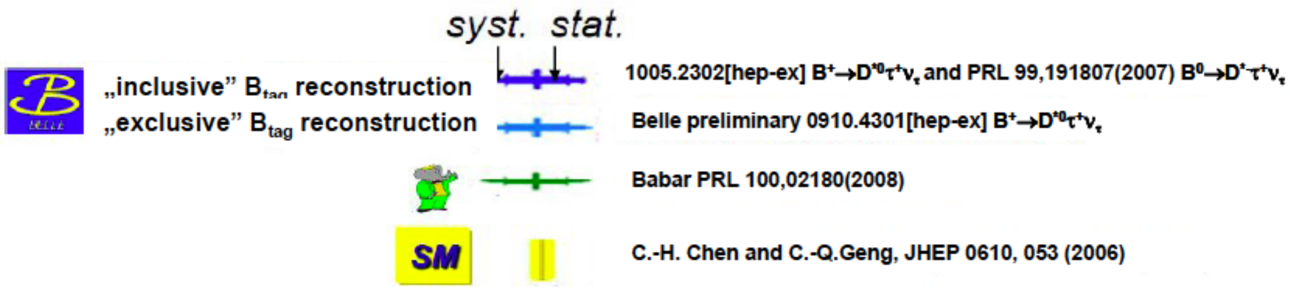
Lepton momentum and q^2 distributions



- Kinematic distributions in the signal region $m^2_{miss} > 1$ GeV^2



Overlap between „inclusive" and „exclusive" B_{tag} reconstruction Belle analysis is negligible (~.2%)



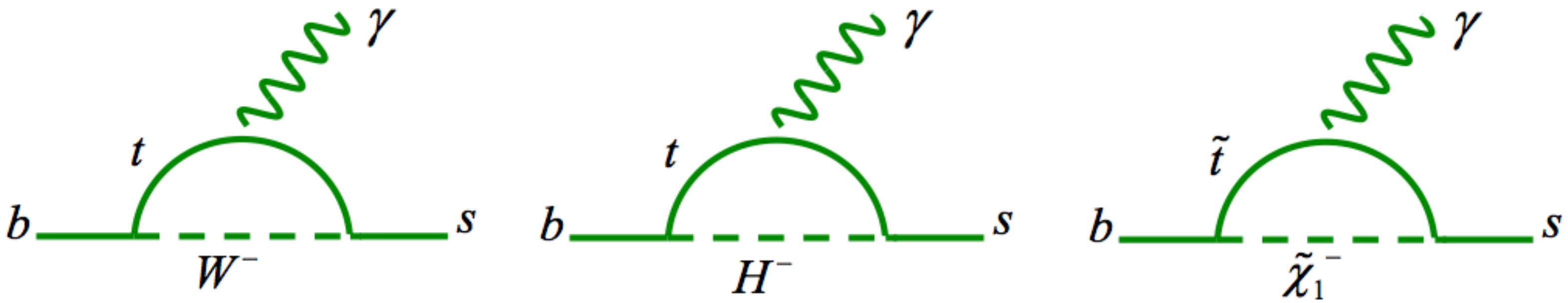
- q^2 or other kinematic distributions are expected to give better sensitivity to the charged Higgs than the rate alone

$b \to s\gamma$ decays

NP sensitivity

- Flavor changing neutral currents (FCNC)
  - Forbidden at tree level in the SM
  - New, heavy particles likely to appear at loop level
- Rich program
  - Branching fraction and moments
  - (Time-dependent) CP asymmetry
  - Isospin asymmetry

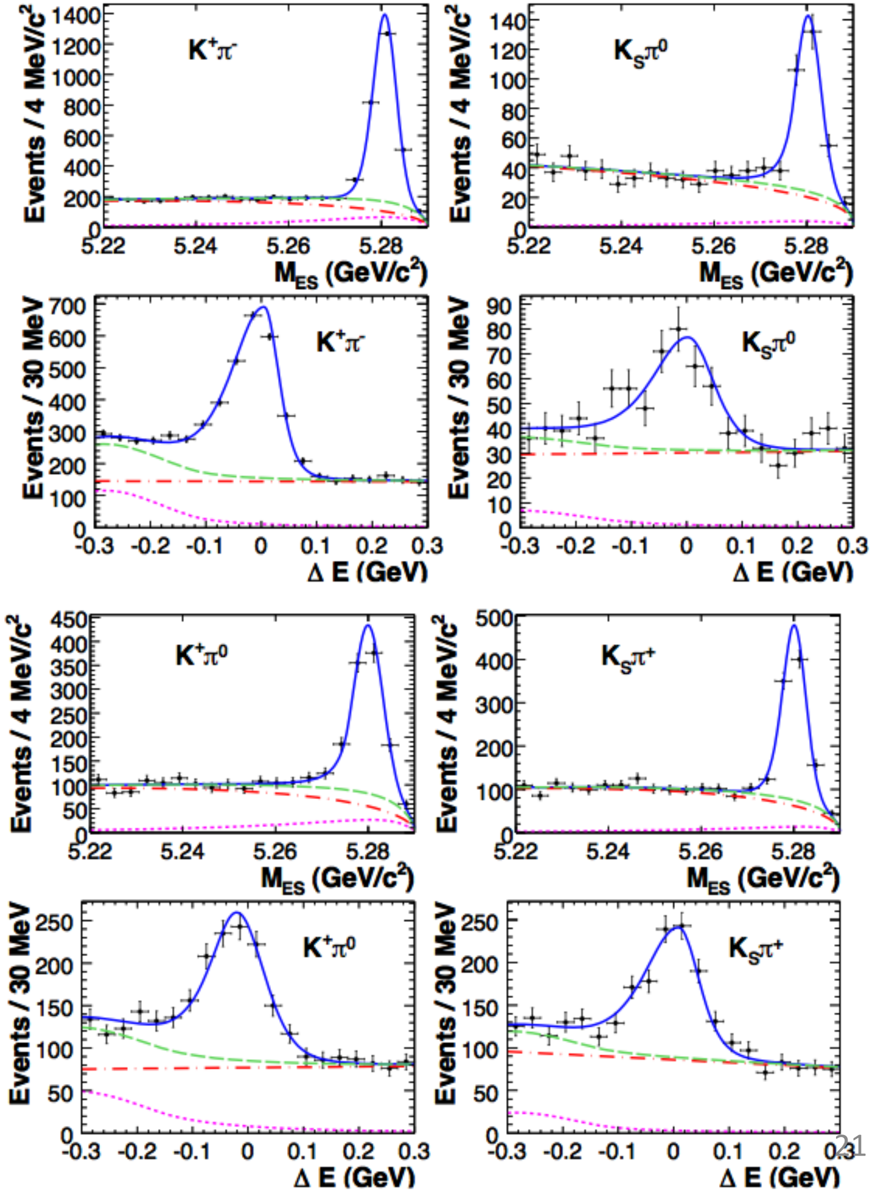
$$\Delta_{0-} = \frac{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$



383M BB

PRL 103, 211802 (2009)

Exclusive: B → K*(892)γ



- 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

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

SM prediction: ~1% (Nucl. Phys. B 434, 39 (1995))

- Isospin asymmetry

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

SM prediction: 2~10%

(PRD 72, 014013 (2005), Phys. Lett. B 539, 227(2002))

465M BB

PRL 103, 211802 (2009)

Exclusive: B → Kηγ

- Branching Fractions

$$\mathcal{B}(B^+ \to \eta K^+ \gamma) = (7.7 \pm 1.0 \pm 0.4) \times 10^{-6}$$
$$\mathcal{B}(B^0 \to \eta K^0 \gamma) = (7.1^{+2.1}_{-2.0} \pm 0.4) \times 10^{-6}$$

- Integrated charge asymmetry

$$\mathcal{A}_{ch} = (-9.0^{+10.4}_{-9.8} \pm 1.4) \times 10^{-2}$$

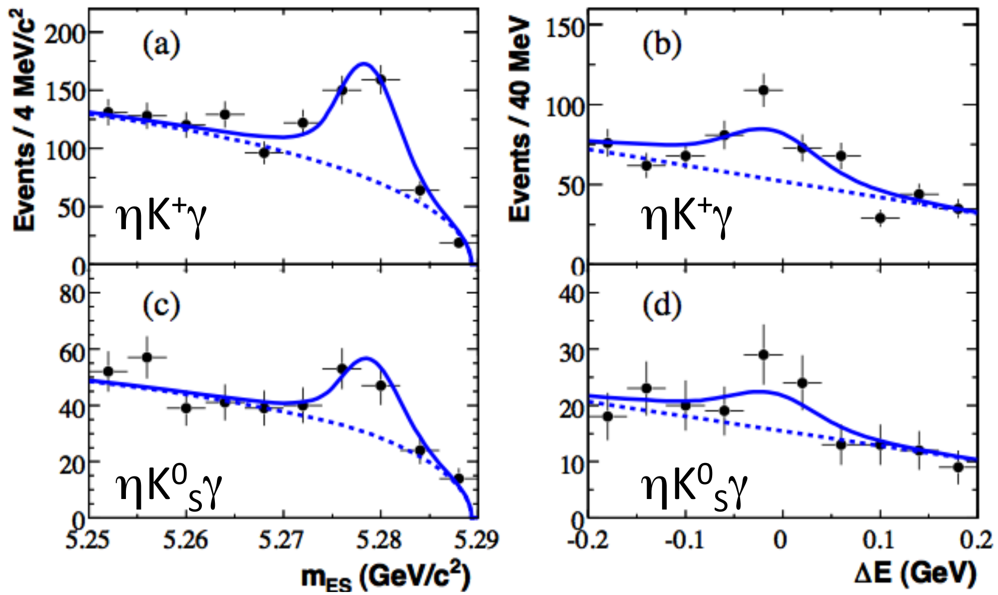
- Time-dependent CPV

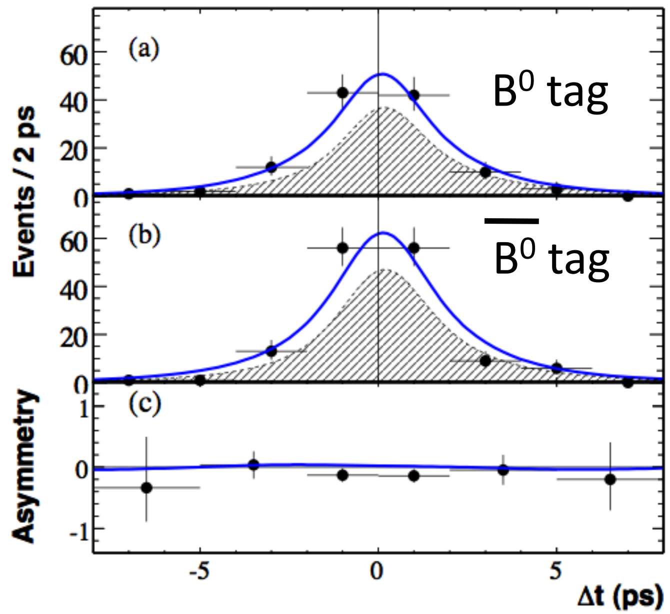
First result for this mode

$$S = -0.18^{+0.49}_{-0.46} \pm 0.12$$
$$C = -0.32^{+0.40}_{-0.39} \pm 0.07$$

cf. $B^0 \to K_s^0 \rho^0 \gamma$ (Belle 657M BB)
$S = 0.11$ +- $0.35\ ^{+0.05}_{-0.09}$
$C = -0.05$ +- 0.18 +- 0.06

PRL 101, 251601 (2008)





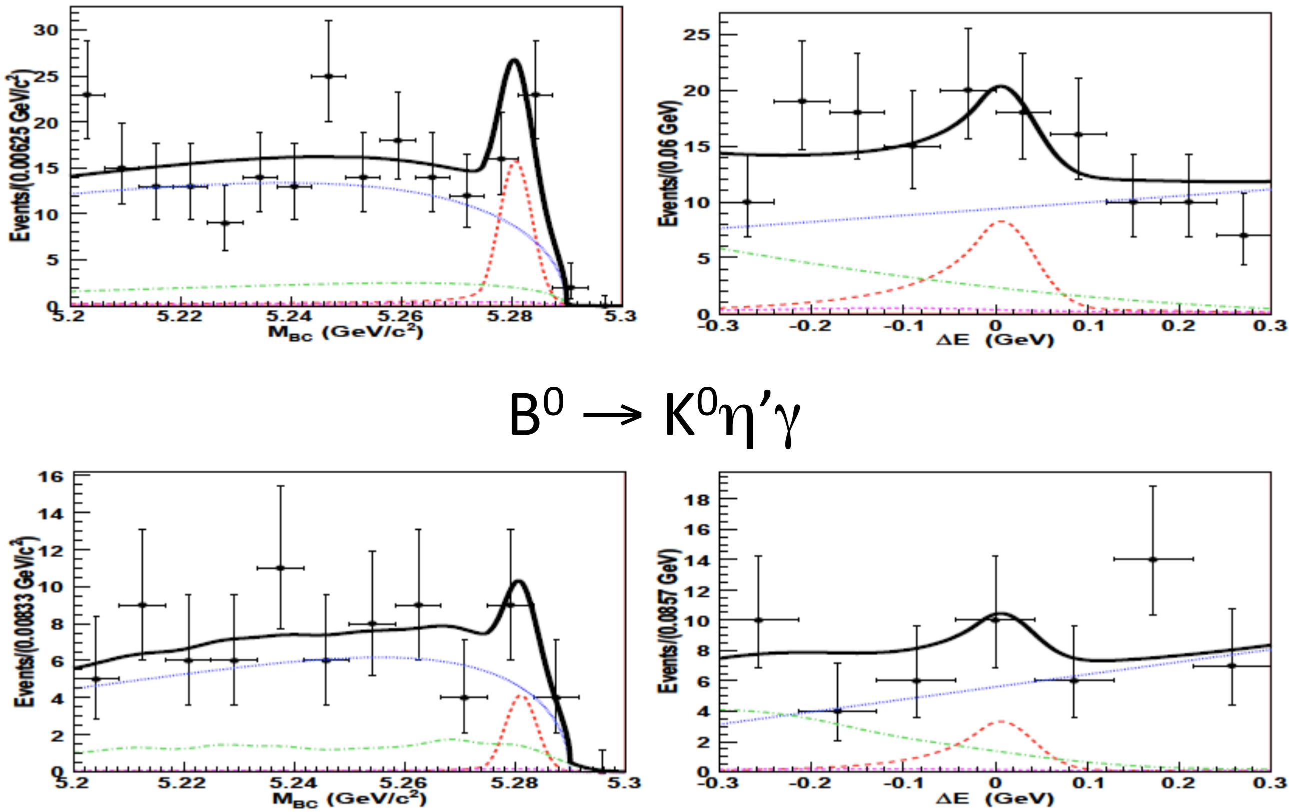
Exclusive: $B \to K\eta'\gamma$

arXiv:0810.0804
submitted to PRD

657M BB

$B^+ \to K^+\eta'\gamma$

$B^0 \to K^0\eta'\gamma$



$$\mathcal{B}(B^+ \to K^+\eta'\gamma) = (3.6 \pm 1.2 \pm 0.4) \times 10^{-6}$$
$$\mathcal{B}(B^0 \to K^0\eta'\gamma) \le 6.4 \times 10^{-6} \ (90\% \text{ CL})$$

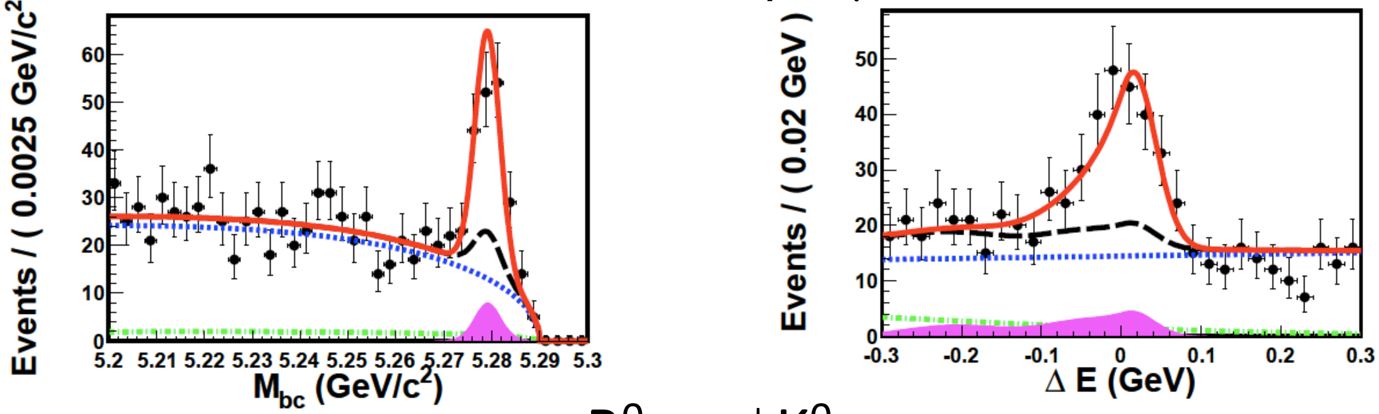
First evidence with 3.3 σ significance

772M BB

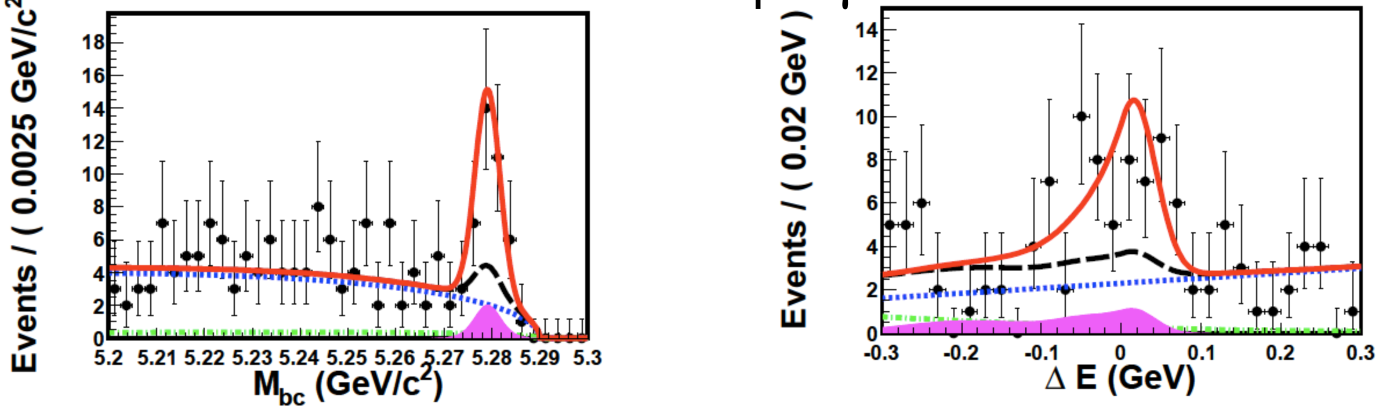
arXiv:0911.1779
preliminary

Exclusive: $B \to K\phi\gamma$

$B^+ \to \phi K^+\gamma$



$B^0 \to \phi K^0\gamma$



- TCPV study ongoing

$$\mathcal{B}(B^+ \to \phi K^+\gamma) = (2.34 \pm 0.29 \pm 0.23) \times 10^{-6}$$
$$\mathcal{B}(B^0 \to \phi K^0\gamma) = (2.66 \pm 0.60 \pm 0.32) \times 10^{-6}$$

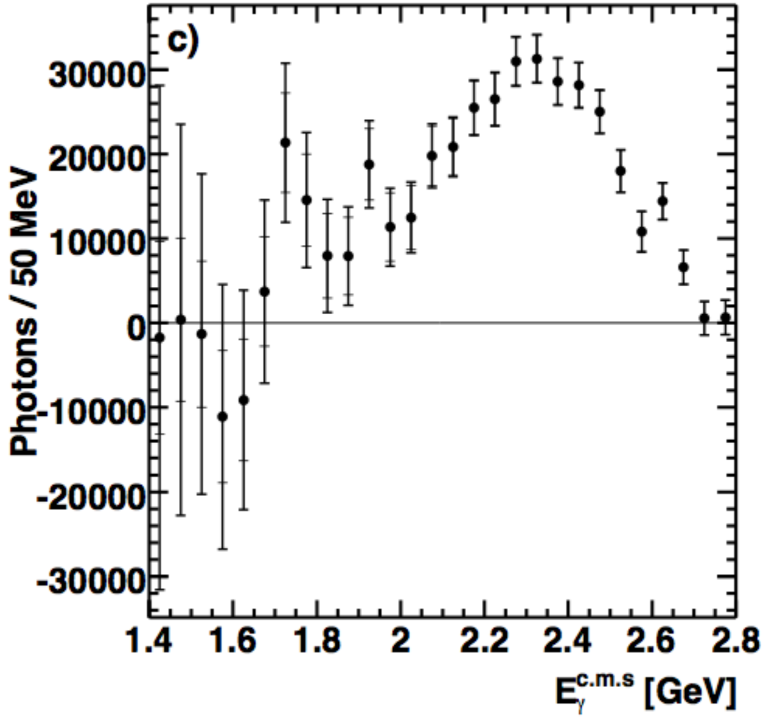
First observation with 5.4 σ significance

657M BB

PRL 103, 241801 (2009)

$B \rightarrow X_s\gamma$ inclusive

- Two sub-samples
  - untagged, lepton tagged
- Photon energy cut
  - pushed down to 1.7 GeV
- BF, first and second moments are measured



→ Consistent with NNLO SM calculation

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

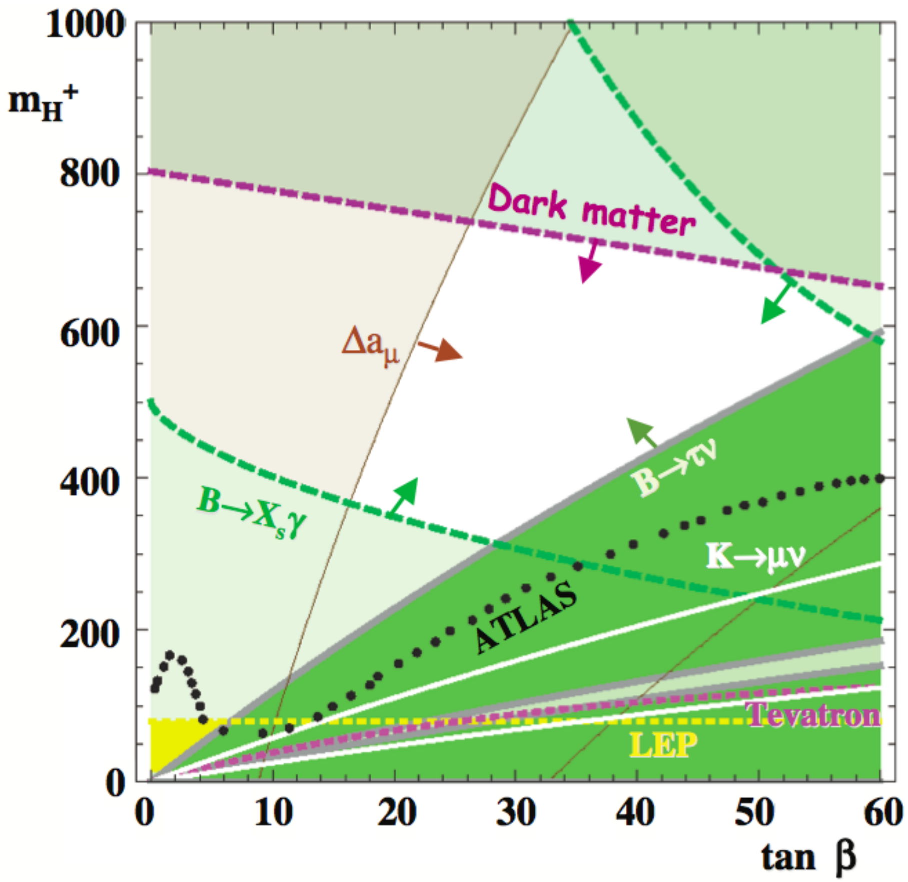
$$\mathcal{B}(\bar{B} \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4} \quad \text{for } E_\gamma > 1.6\ \mathrm{GeV}$$

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

Constraints on NP

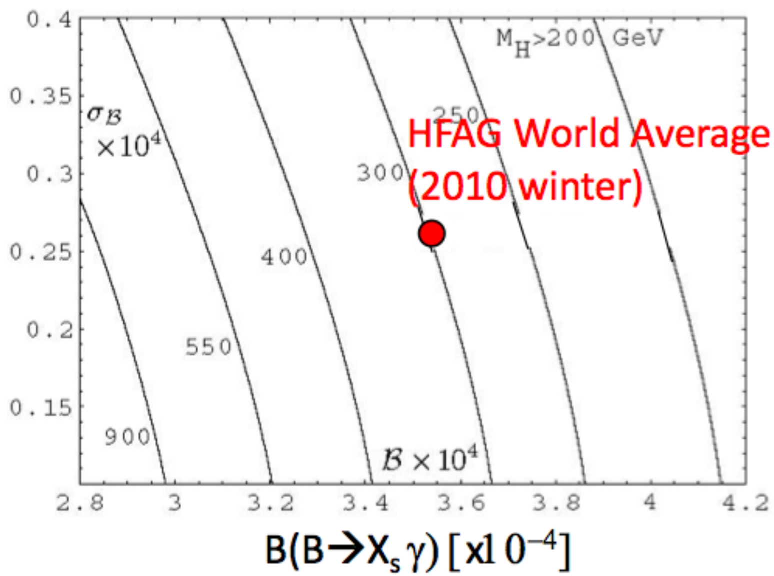
- $B \to X_s\gamma$ puts strong constraints on NP models

MSSM with minimum flavor violation



G. Eigen, arXiv:0907.4330

Two Higgs doublet type II model



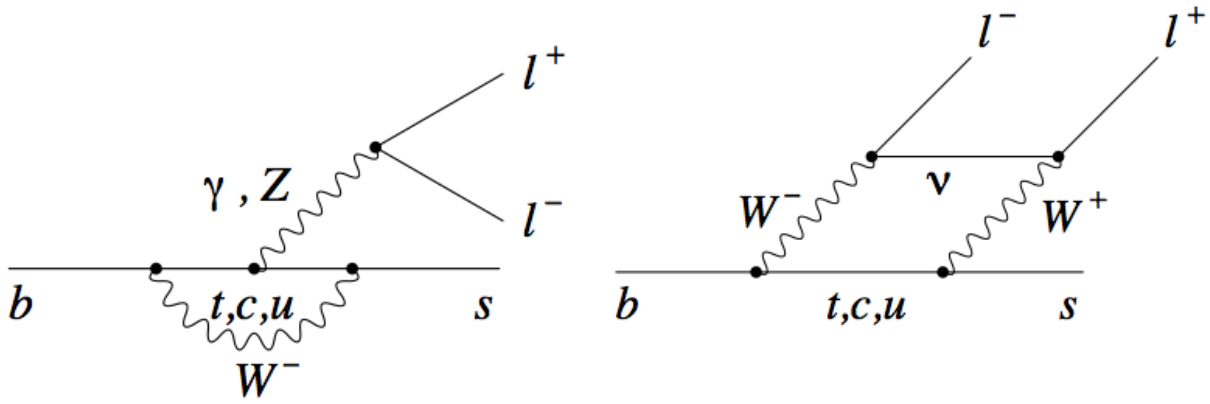
$M_{H^\pm} \geq 300 GeV$ (@95% CL)

U. Haisch, arXiv:0805.2141

$b \rightarrow s l^+ l^-$ decays

NP sensitivity

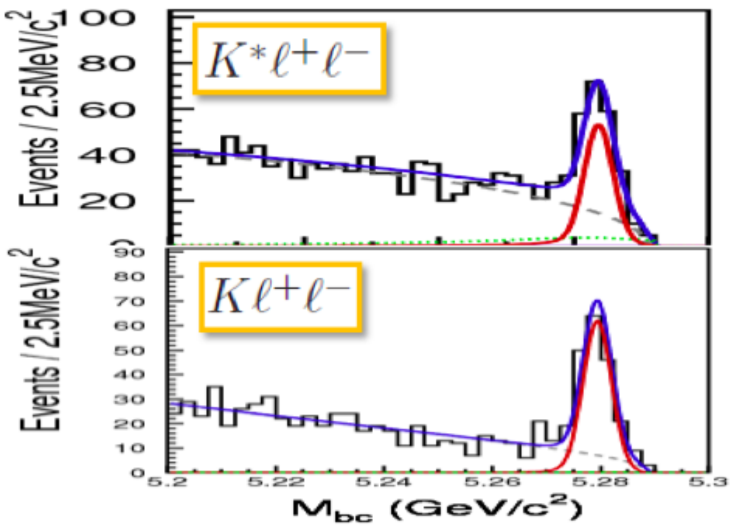
- Two orders of magnitude smaller than $b \to s\gamma$
- Electroweak penguin and W^+W^- box contribute in SM at lowest order → sensitive to the sign of C_7
- Observables
  - Branching fraction, q^2 distribution
  - K* longitudinal polarization (F_L)
  - Forward-background asymmetry (A_{FB})



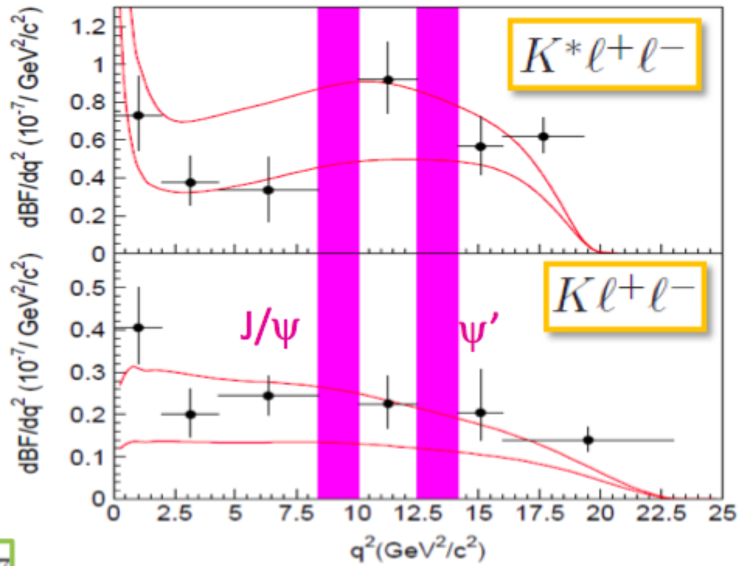
Exclusive: $B \to K^{(*)} l^+ l^-$

657M BB

PRL 103, 171801 (2009)



Differential BF



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

: SM prediction with minimum or maximum form factors

384M BB

$$\mathcal{B}(B \to K^* \ell^+ \ell^-) = (1.11^{+0.19}_{-0.18} \pm 0.07) \times 10^{-6}$$
$$\mathcal{B}(B \to K \ell^+ \ell^-) = (0.394^{+0.073}_{-0.069} \pm 0.020) \times 10^{-6}$$

PRD 79, 031102 (2009)

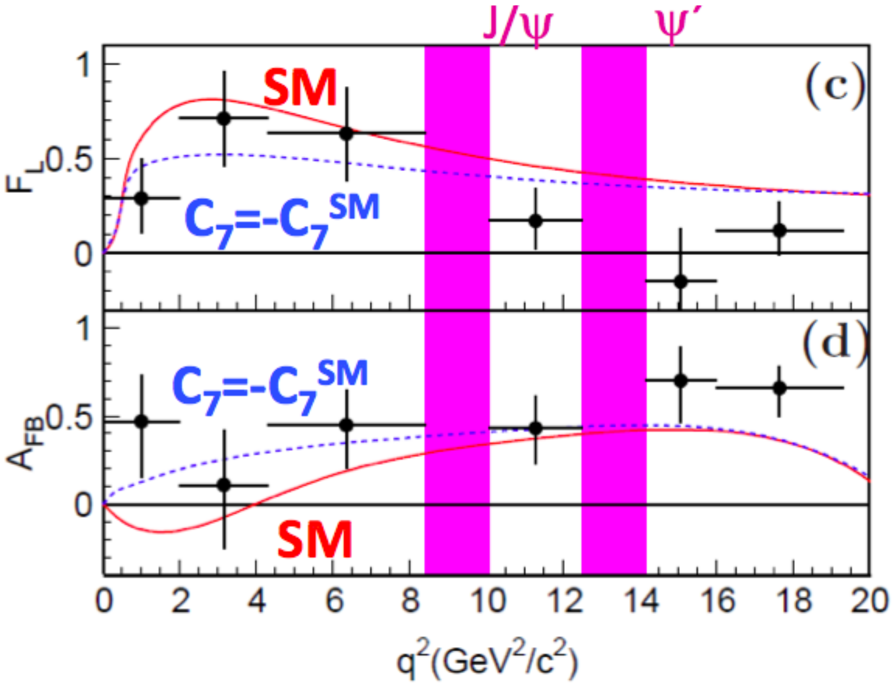
K* polarization (F_L), FB asymmetry (A_{FB})

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

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

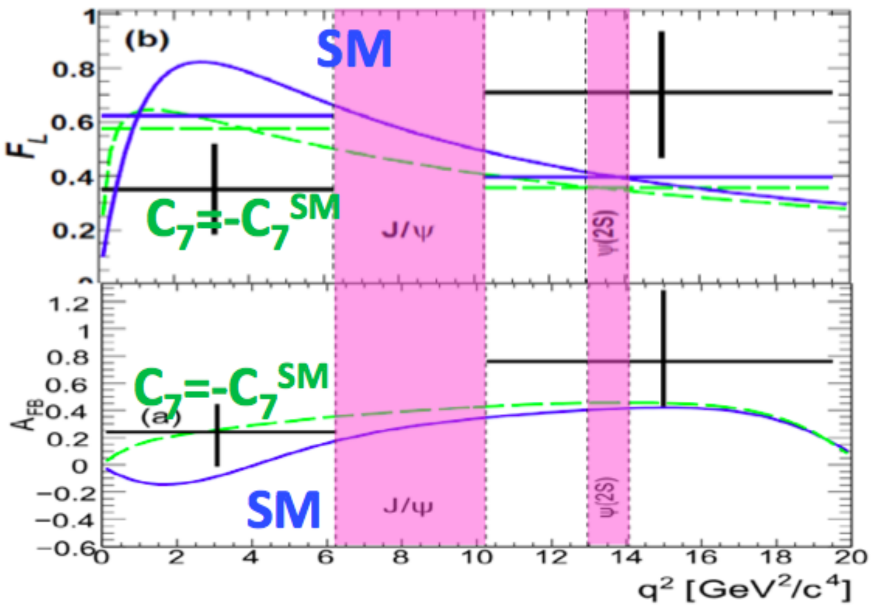
657M BB

PRL 103, 171801 (2009)



384M BB

PRD 79, 031102 (2009)



- Belle data favors sign-flipped scenario

Summary

- Tauonic and semitauonic decays
  - These decays are now well established and provide strong constraints on the charged Higgs
- FCNC decays
  - Rich opportunity to explore NP
  - Present measurements set strong constraints for NP models
- Looking forward to analyses with the full B factory dataset (Belle reprocessing), results from hadron colliders and to Super B factories