B leptonic decays

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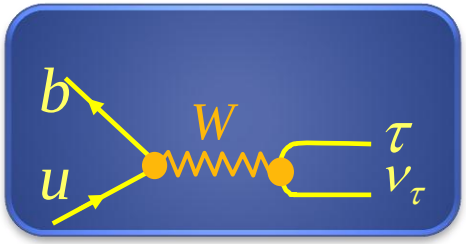
Flavor Physics and CP Violation

20-25 May 2012

- $B \to l\nu$
- $B \to ll, \nu\nu$

$B^+ \rightarrow l^+ \nu$ Introduction

- $B \rightarrow l\nu$ decay proceed through W boson annihilation in the Standard Model



- Decay rate simply related to B meson decay constant f_B and $|V_{ub}|$

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

- Taking $|V_{ub}|$ value from $b \rightarrow u l \nu$ measurements, $B \rightarrow l\nu$ can be used for direct measurement of f_B
- Due to the helicity suppression $B \rightarrow \tau\nu$ has the largest branching fraction

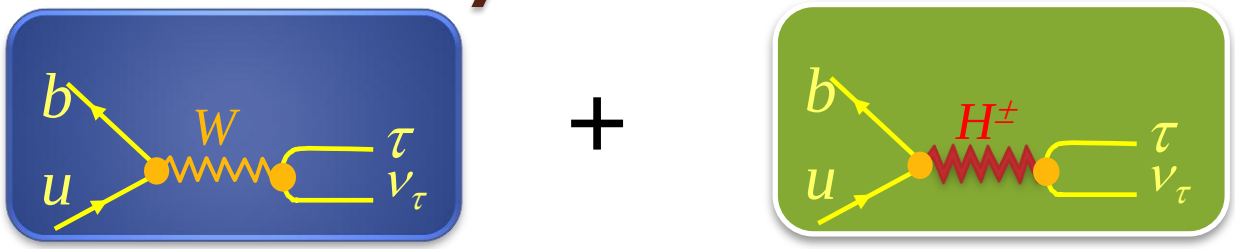
  Using f_B = 190 ± 13 MeV [HPQCD Collaboration, PRD80, 014503]

  and $|V_{ub}| = (3.89 \pm 0.44) \times 10^{-3}$ [PDG2011]

  SM Expected $Br(B \rightarrow \tau\nu) = (0.96 \pm 0.25) \times 10^{-4}$

  → Measurable at B factories: Belle and BaBar

$B^+ \to l^+ \nu$ beyond the SM



- $B \to l\nu$ decays are sensitive to Charged Higgs contribution

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H$$

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

Type II 2HDM

[Wei-Shu Hou Phys. Rev. D48, 2342 (1993)]

$$r_H = \left(1 - \frac{\tan^2\beta}{1 + \tilde{\epsilon}_0 \tan\beta} \frac{m_B^2}{m_{H^\pm}^2}\right)^2$$

SUSY

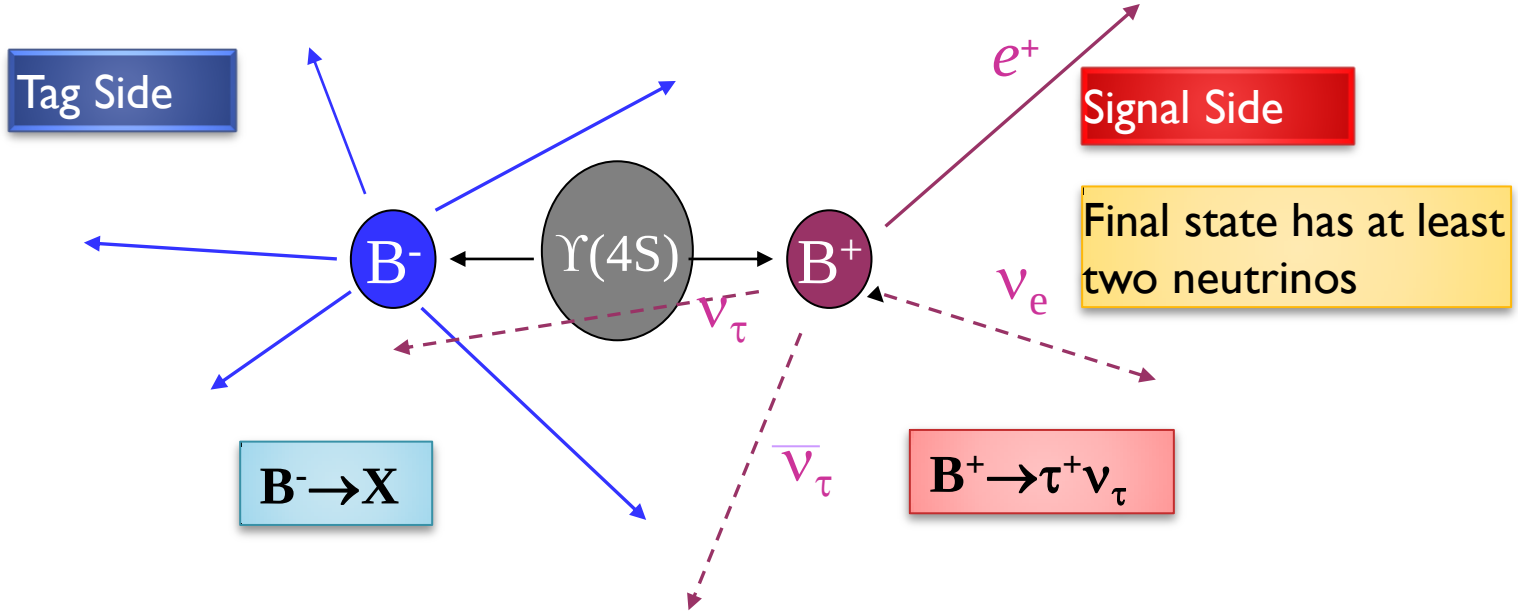
[A.G. Akeroyd and S.Recksiegel J. Phys. G29, 2311 2003)]

- r_H factor common to all $B \to l\nu$ modes

  → Important to measure all $B \to l\nu$ modes

B→lν Analysis Concepts

Possible only in B factory



Tag B pair event by reconstructing one B meson

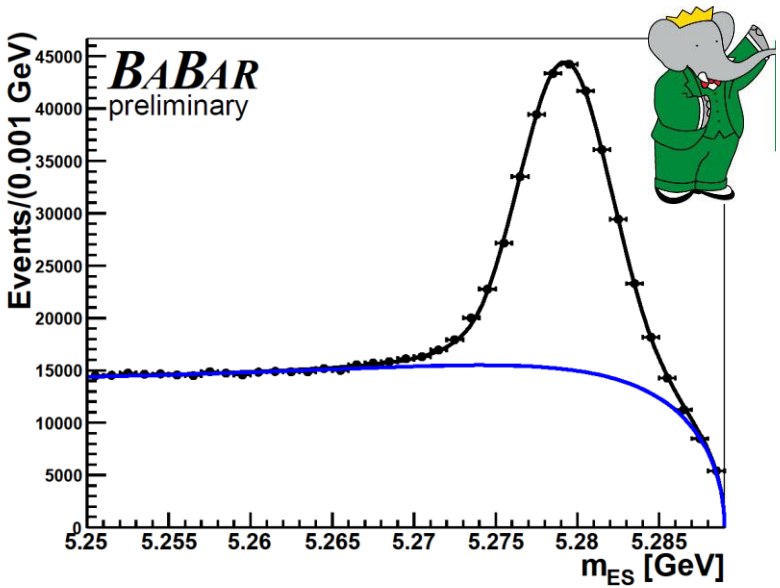
→ Provide pure single B event

Require **no** particle remains after removing products of tagging B and the particle(s) from signal decays

Tagging Methods

Hadronic Tag

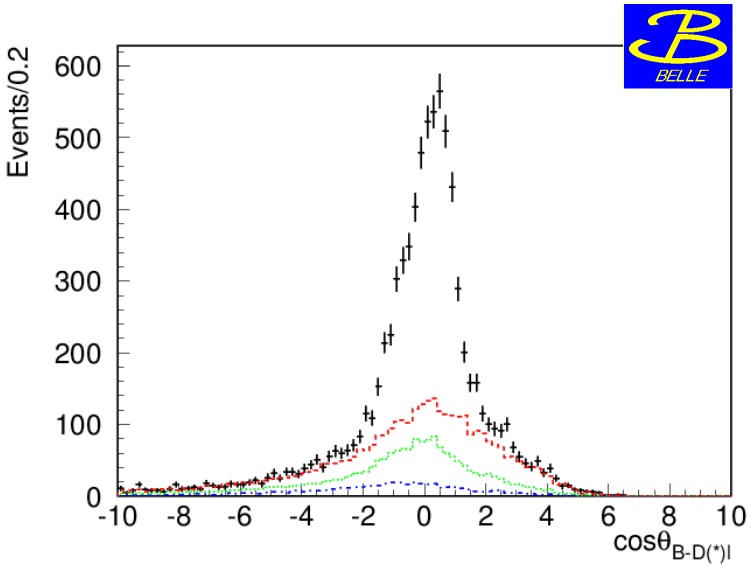
- Fully reconstruct in B→DX hadronic decays
- Tagging efficiency ~ 0.2 %
- P_{Bsig} measured
- Less background



$$m_{ES} = \sqrt{E_{beam}^2 - p_B^2}$$

Semileptonic Tag

- Reconstruct B→D$^{(*)}$lν
  - $E_B = E_{beam}$
  - Undetected neutrino mass ~ 0
- Tagging efficiency ~ 1%
- No P_{Bsig} measurement
- More background

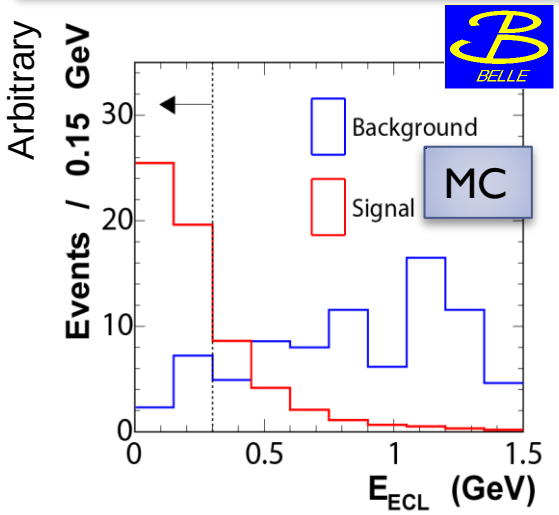


$$\cos\theta_{B,D^{(*)}\ell} = \frac{2E_{\rm beam}^{\rm cms}E_{D^{(*)}\ell}^{\rm cms} - m_B^2 - M_{D^{(*)}\ell}^2}{2P_B^{\rm cms}\cdot P_{D^{(*)}\ell}^{\rm cms}}$$

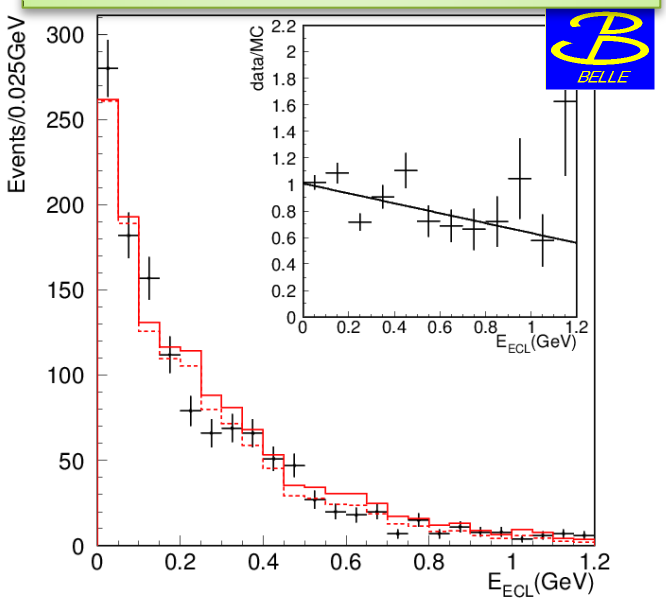
B→τν Signal side selection

- Recostruct signal candidate particles
  - B→τν,
  - τ→ lν$\bar{\nu}$, πν, ρν
- Require no particles remain in the event
  - No charged tracks, π^0
  - Extra energy in the EM calorimeter ~ 0
    - split-off showers created by Btag and Bsig particles
    - beam background hits

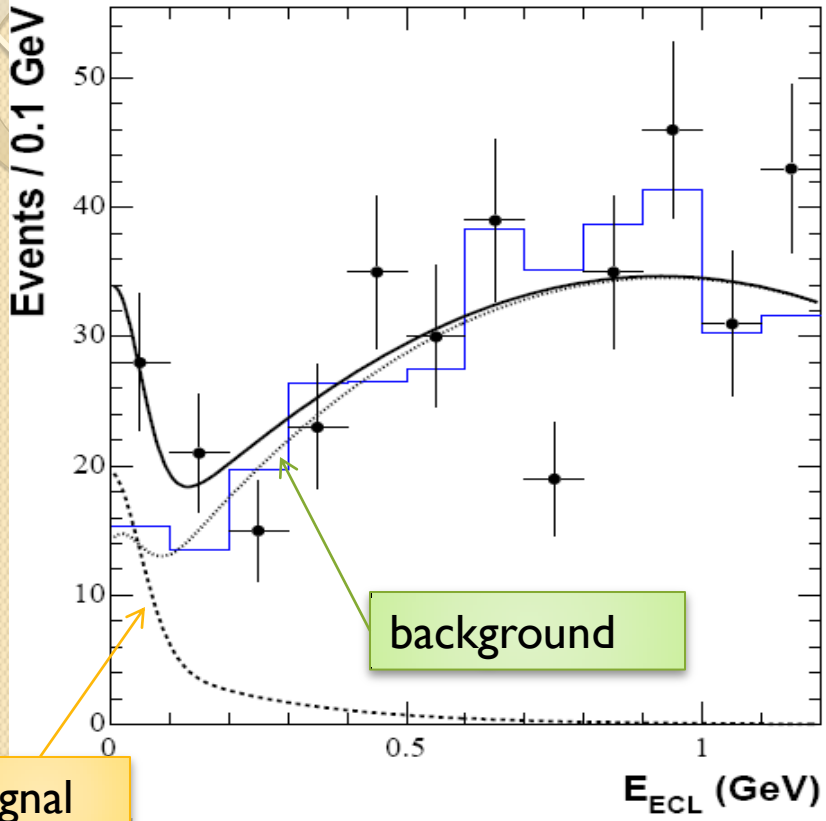
Most powerful discriminant variable:
Extra calorimeter energy E_{ECL}



Calibrate EECL simulation using B→D*⁰lν control sample



Belle Hadronic Tag B→τν Result



$$N_{\rm sig} = 17.2^{+5.3}_{-4.7}$$

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

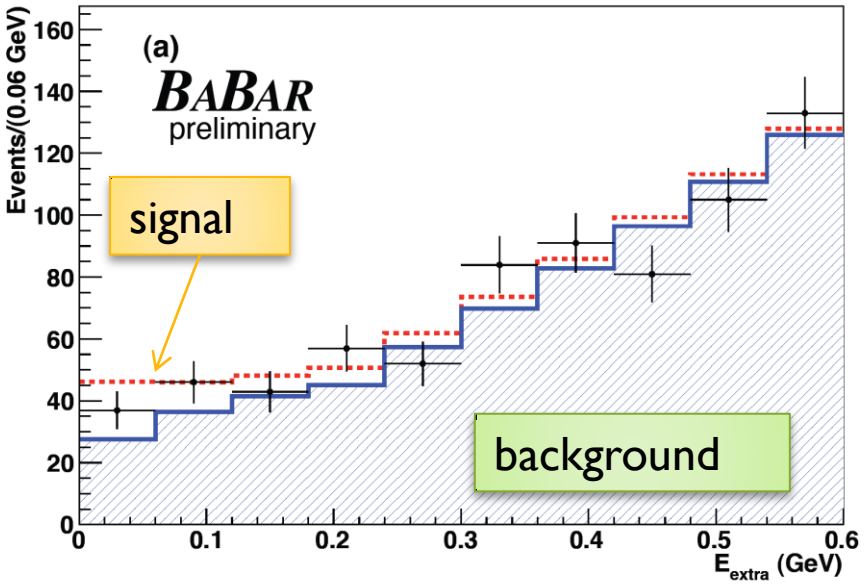
[PRL 97, 251802 (2006)]

449 M $B\bar{B}$

3.5σ First evidence

	$N_{\rm obs}$	$N_{\rm s}$	$N_{\rm b}$	Σ
$\mu^-\bar{\nu}_\mu\nu_\tau$	13	$5.6^{+3.1}_{-2.8}$	$8.8^{+0.1}_{-0.1}$	2.2σ
$e^-\bar{\nu}_e\nu_\tau$	12	$4.1^{+3.3}_{-2.6}$	$9.0^{+0.1}_{-0.1}$	1.4σ
$\pi^-\nu_\tau$	9	$3.8^{+2.7}_{-2.1}$	$3.9^{+0.1}_{-0.1}$	2.0σ
$\pi^-\pi^0\nu_\tau$	11	$5.4^{+3.9}_{-3.3}$	$5.4^{+0.6}_{-0.6}$	1.5σ
$\pi^-\pi^+\pi^-\nu_\tau$	9	$3.0^{+3.5}_{-2.5}$	$4.8^{+0.4}_{-0.4}$	1.0σ
Combined	54	$17.2^{+5.3}_{-4.7}$	$32.0^{+0.7}_{-0.7}$	3.5σ

BaBar Hadronic Tag B→τν Result



$$\mathcal{B}(B \to \tau\nu) = [1.80^{+0.57}_{-0.54}(stat) \pm 0.26(syst)] \times 10^{-4}$$

Preliminary [arxiv:1008.0104]

468 M $B\bar{B}$

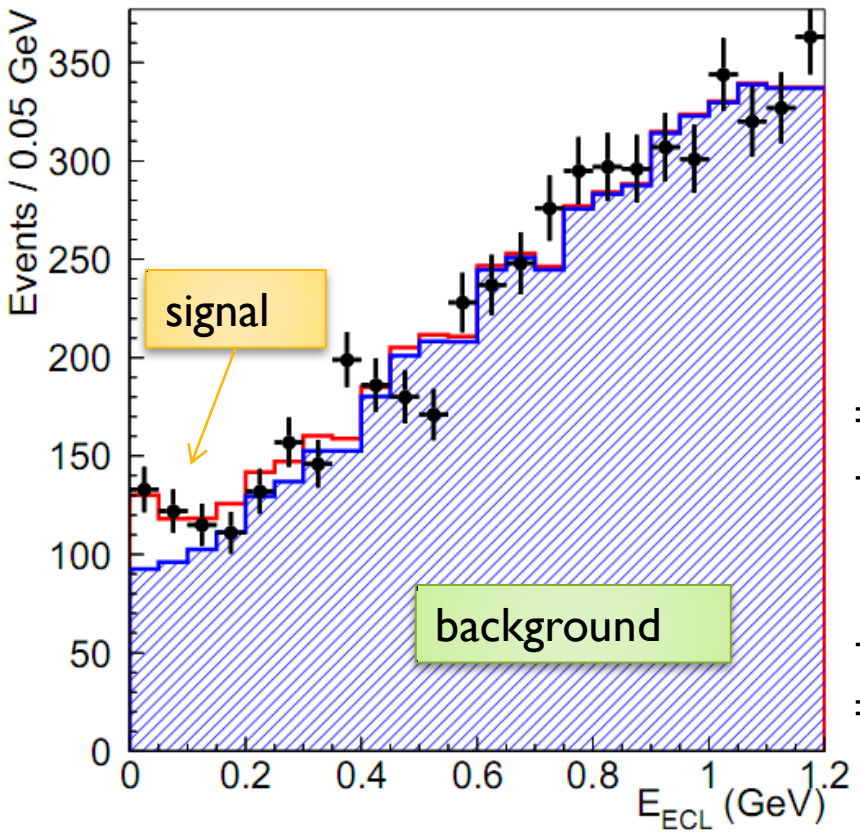
3.3 σ significance

Decay Mode	$\epsilon \times 10^{-4}$	Branching Fraction $(\times 10^{-4})$	Significance σ
$\tau^+ \to e^+\nu\bar{\nu}$	2.73	$0.39^{+0.89}_{-0.79}$	0.5
$\tau^+ \to \mu^+\nu\bar{\nu}$	2.92	$1.23^{+0.89}_{-0.80}$	1.6
$\tau^+ \to \pi^+\nu$	1.55	$4.0^{+1.5}_{-1.3}$	3.3
$\tau^+ \to \rho^+\nu$	0.85	$4.3^{+2.2}_{-1.9}$	2.6
combined	8.05	$1.80^{+0.57}_{-0.54}$	3.6

Belle Semileptonic Tag B→τν Result

Tag side

$B^- \to D^{*0}l^+\nu$, $D^0l\nu$
$D^{*0}\to D^0\pi^0$, $D^0\gamma$
$D^0\to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, $K^-\pi^+\pi^0$



$$N_{\rm sig} = 143^{+36}_{-35}(stat)$$
$$\mathcal{B}(B\to\tau\nu) = [1.54^{+0.38}_{-0.37}(stat)^{+0.29}_{-0.31}(syst)]\times 10^{-4}$$

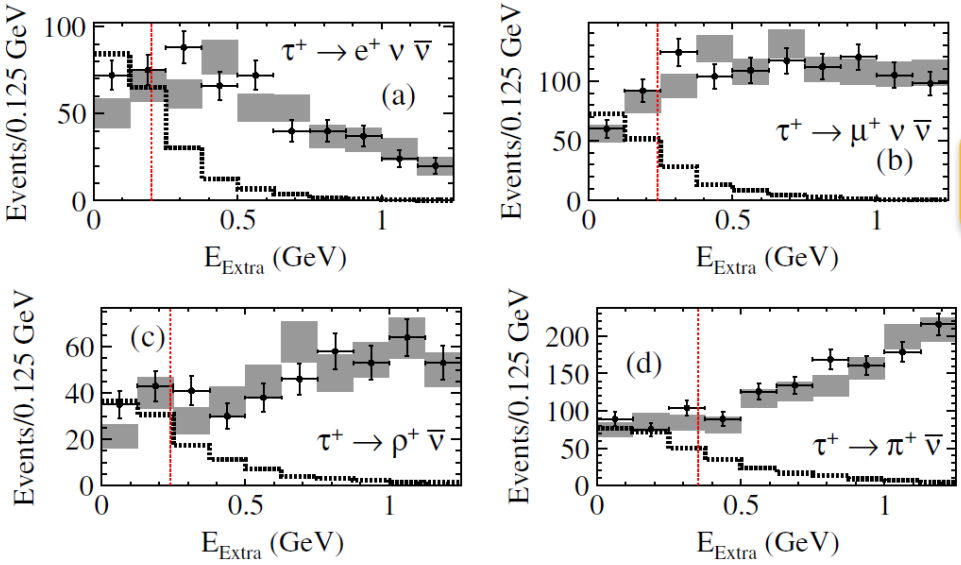
657M $B\bar{B}$

[PRD 82, 071101(R) (2010)]

3.6σ significance

Decay Mode	Signal Yield	ε, 10^{-4}	$\mathcal{B}$, 10^{-4}
$\tau^-\to e^-\bar{\nu}_e\nu_\tau$	73^{+23}_{-22}	5.9	$1.90^{+0.59+0.33}_{-0.57-0.35}$
$\tau^-\to \mu^-\bar{\nu}_\mu\nu_\tau$	12^{+18}_{-17}	3.7	$0.50^{+0.76+0.18}_{-0.72-0.21}$
$\tau^-\to \pi^-\nu_\tau$	55^{+21}_{-20}	4.7	$1.80^{+0.69+0.36}_{-0.66-0.37}$
Combined	143^{+36}_{-35}	14.3	$1.54^{+0.38+0.29}_{-0.37-0.31}$

BaBar Semileptonic Tag B→τν Result



$$\mathcal{B}(B \to \tau\nu) = [1.7 \pm 0.8(stat) \pm 0.2(syst)] \times 10^{-4}$$

459M $B\bar{B}$

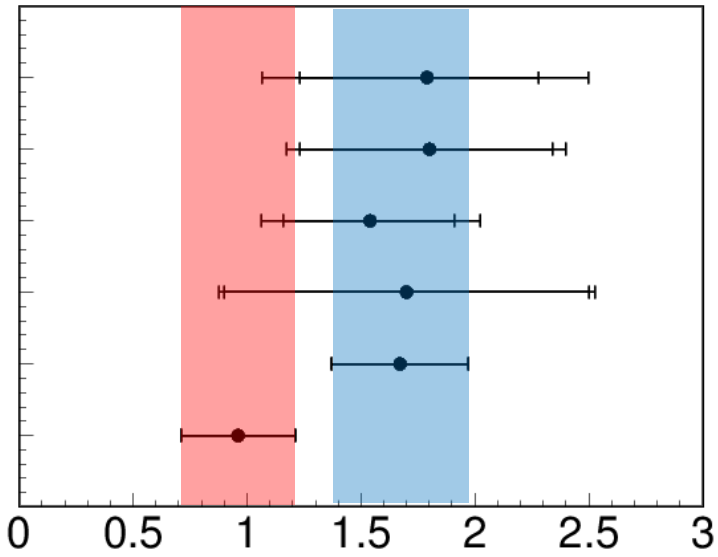
[PRD 81, 051101(R) (2010)]

2.3 σ significance

Expected signal × 10

Mode	$\mathcal{N}_{bg}^{data}$	N_{obs}	Branching fraction ($\times 10^{-4}$)
$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$	81 ± 12	121	(3.6 ± 1.4)
$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$	135 ± 13	148	$(1.3^{+1.8}_{-1.6})$
$\tau^+ \to \rho^+ \bar{\nu}_\tau$	59 ± 9	71	$(2.1^{+2.0}_{-1.8})$
$\tau^+ \to \pi^+ \bar{\nu}_\tau$	234 ± 19	243	$(0.6^{+1.4}_{-1.2})$
$B^+ \to \tau^+ \nu_\tau$	509 ± 30	583	$(1.7 \pm 0.8 \pm 0.2)$

B→τν results and Charged Higgs constraint

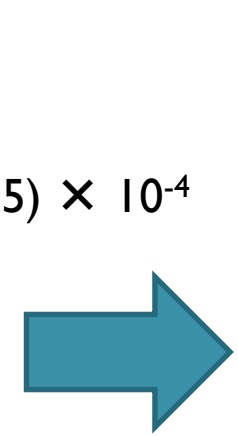


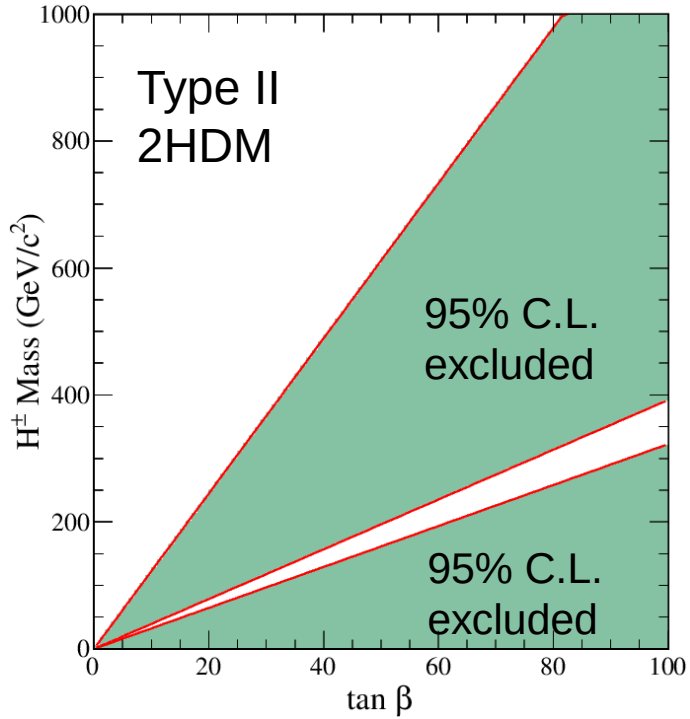
- Using HFAG average

$(1.67 \pm 0.30) \times 10^{-4}$ and

SM expectation $(0.96 \pm 0.25) \times 10^{-4}$

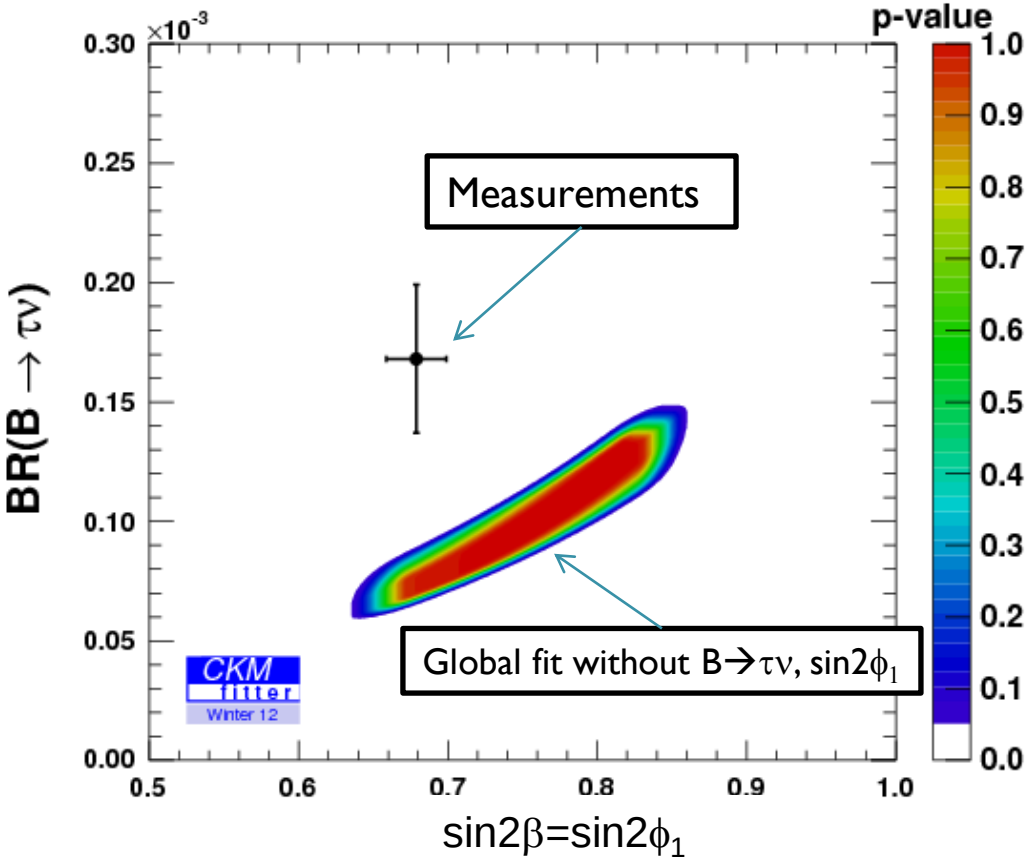
$r_H = 1.74 \pm 0.55$





Comparison with the CKM global fit

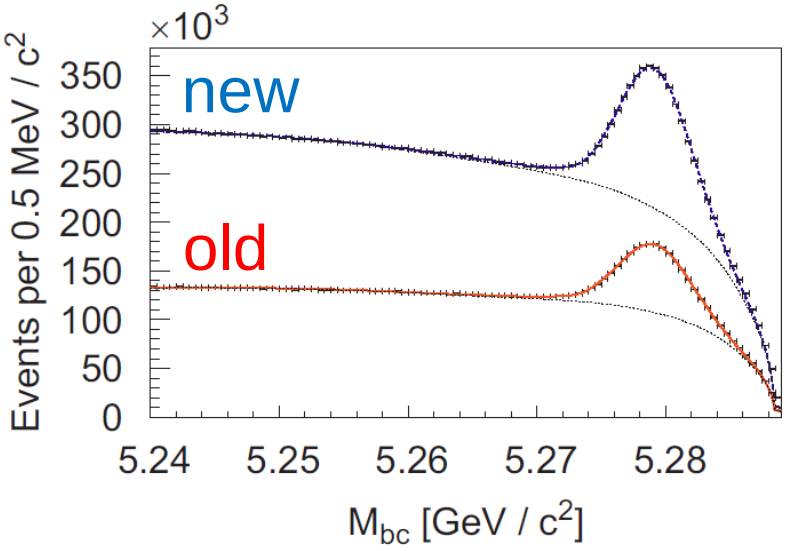
- "Tension" observed in $B \to \tau\nu$ - $\sin 2\phi_1$ relation
- f_B uncertainty is canceled by Δm_d
- $|V_{ub}|$ uncertainty cannot explain the tension



Improved $B \to \tau\nu$ measurement is crucial

Analysis Improvement at Belle

- Improved Full-reconstruction Tagging [NIM A654, 432(2011)]
  - More decay modes
  - Sophisticated event selection by NeuroBayes (neural net)
  - >2 statistical gain over previous tag



3.5 M B reconstructed in 772 M $B\bar{B}$ data

→ **tag efficiency ~ 0.45 %**

Significant improvement using full Belle data (772 M $B\bar{B}$) with the new fullrecon-tag is expected.

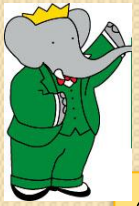
B→μν , eν inclusive tag

- Signal signature
  - Monochromatic lepton in the signal side
  - Remaining particles (tag-side) is consistent with B decay

$\mathcal{B}(B^+ \to \mu^+\nu) < 1.7\times10^{-6}$ at 90% C.L.
$\mathcal{B}(B^+ \to e^+\nu) < 1.0\times10^{-6}$ at 90% C.L.

277 M $B\bar{B}$

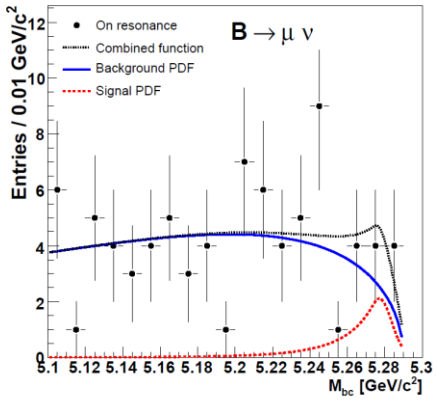
[PLB 647, 67 (2007)]

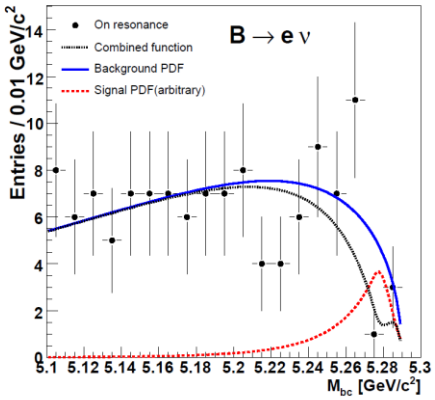


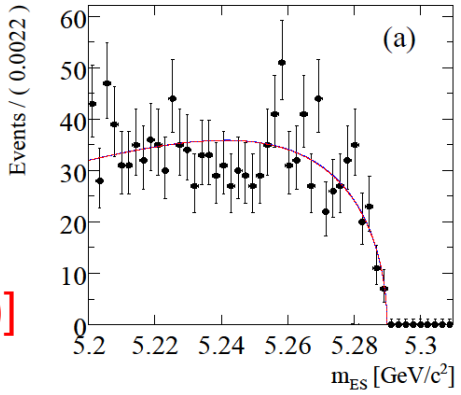
$\mathcal{B}(B^+ \to \mu^+\nu) < 1.0\times10^{-6}$ at 90% C.L.
$\mathcal{B}(B^+ \to e^+\nu) < 1.9\times10^{-6}$ at 90% C.L.

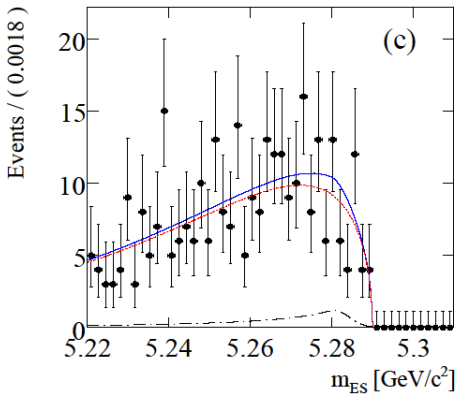
468 M $B\bar{B}$

[PRD 79, 091101(R) (2009)]







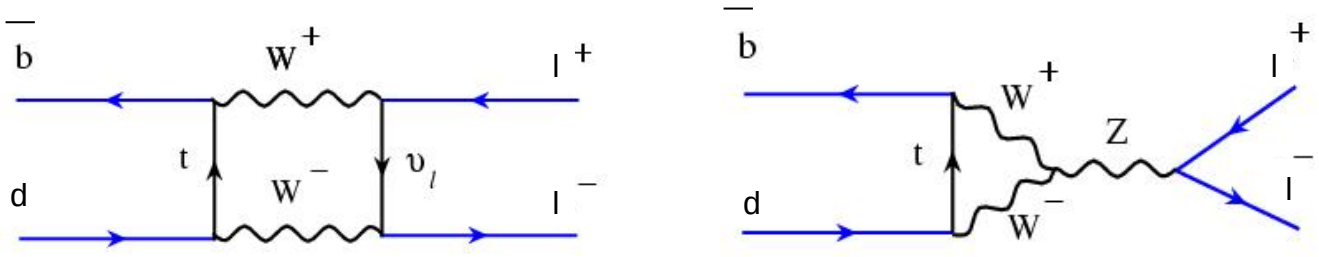


SM expectation :
B(B→μν) ~ 5 x 10^{-7}
B(B→eν) ~ 1 x 10^{-11}

Belle full data analysis is on going

B→ll, $\nu\bar{\nu}$ Introduction

- Neutral B meson decay to l^+l^- via box or penguin annihilation



- Branching fractions are highly suppressed in SM

$$B(B^0 \to e^+e^-) \sim 10^{-15}$$
$$B(B^0 \to \mu^+\mu^-) \sim 10^{-10}$$
$$B(B^0 \to \tau^+\tau^-) \sim 10^{-7}$$
$$B(B^0 \to \nu\,\nu) \sim 0$$

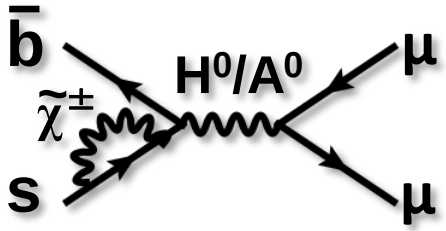
$Br \propto (m_l/m_B)^2$

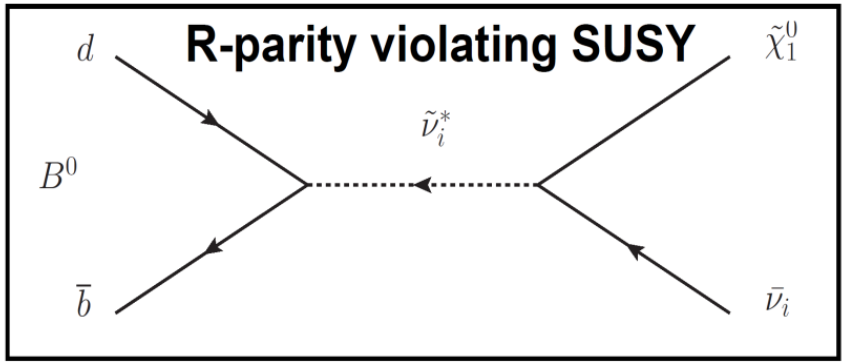
- B→νν and ττ are only possible in B factories.
- Hadron collider (LHC, Tevatron) experiments have better sensitivity for B→ee, μμ thanks to the large production cross section

→ Talks by C. Guoming and S. Nicola for B^0→μμ and B_S→μμ

B→ll beyond the SM

- Br may be enhanced by New physics contribution

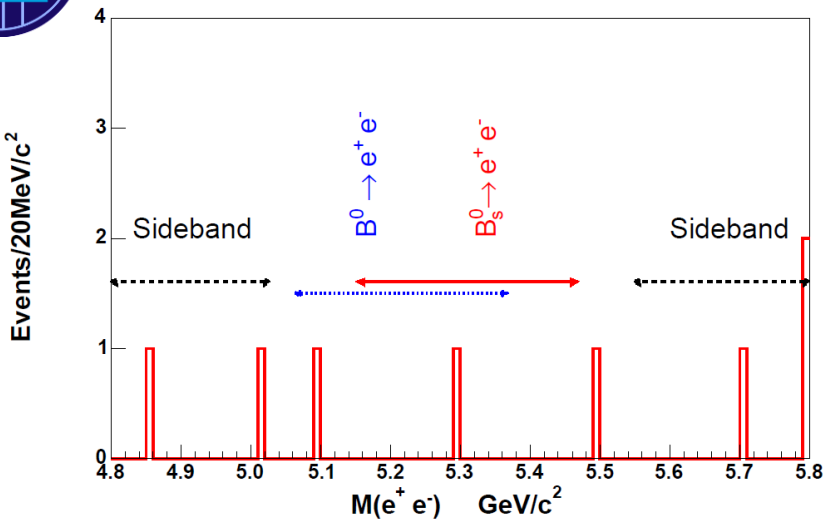




- To test the NP model, important to measure
  - B^0 and B_S ,
  - ee μμ, ττ ,
  - invisible decays

$B \rightarrow e^+e^-$ search at CDF II

- Isolated e^+e^- pair
- Decay vertex away from the primary vertex
- Reconstructed B trajectory points the primary vertex



$$\mathcal{B}(B_S^0 \rightarrow e^+e^-) < 2.8\times10^{-7} \text{ at } 90\% \text{ C.L.}$$
$$\mathcal{B}(B^0 \rightarrow e^+e^-) < 0.8\times10^{-7} \text{ at } 90\% \text{ C.L.}$$

$2fb^{-1}$

[PRL 102, 201801 (2009)]

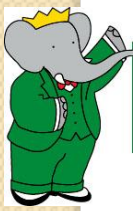
SM expectation : $B(B \rightarrow ee) \sim 10^{-15}$

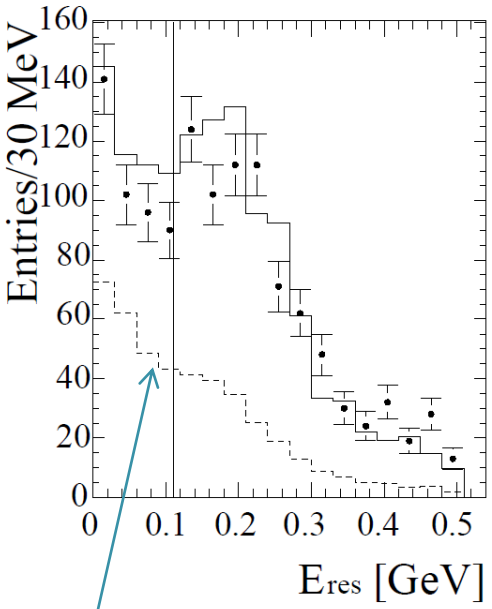
- Belle and BaBar also reports $<1.9\times10^{-7}$ and $< 1.13\times10^{-7}$ and (90% CL) for $B^0 \rightarrow e^+e^-$

B→ττ search at BaBar

- Tag side is reconstructed in hadronic decays
- Signal side is reconstructed in

  $\tau^+\tau^- \rightarrow l\nu\nu/l\nu\nu,\ l\nu\nu/\pi\nu,\ \pi\nu/\pi\nu,\ \rho\nu/\rho\nu$
- Neural net is used to separate background
- Signal is extracted using residual energy in EM calorimeter





signal (arbitrary normalization)

$\mathcal{B}(B \rightarrow \tau\tau) < 4.1\times10^{-4}$ at 90% C.L.

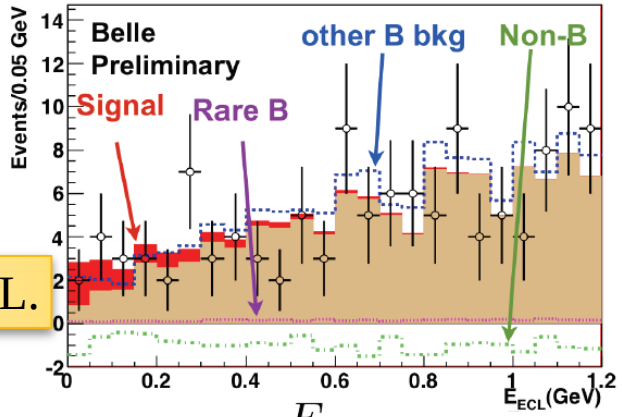
232 M $B\bar{B}$

[PRL 96, 241802 (2006)]

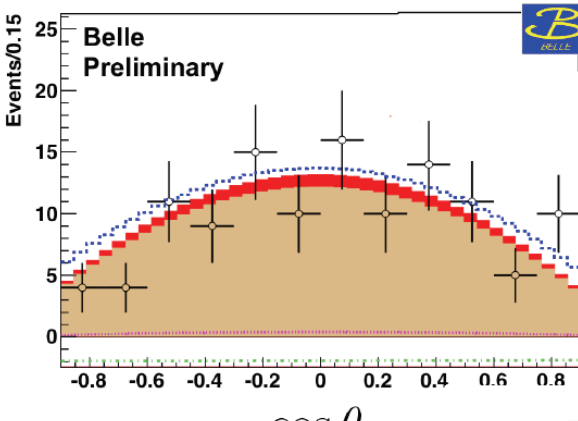
SM expectation : $B(B\rightarrow\tau\tau) \sim 1 \times 10^{-7}$

B→invisible search at B factories

- Tag-side B is reconstructed in hadronic (Belle) and Semileptonic (BaBar) decays
- No particles remains in the event



E_{ECL}

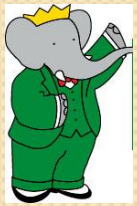


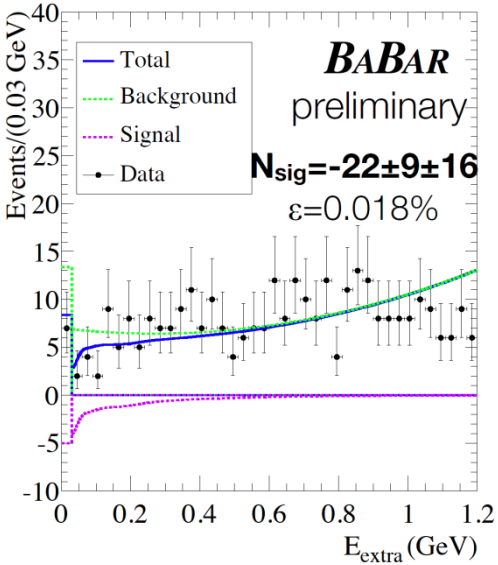
$\cos\theta_B$

$\mathcal{B}(B \to invisible) < 13\times10^{-5}$ at 90% C.L.

[Preliminary, EPS-HEP2011]

657 M $B\bar{B}$





$\mathcal{B}(B \to invisible) < 2.4\times10^{-5}$ at 90% C.L.

NEW

[Preliminary FPCP2012]

470 M $B\bar{B}$

Summary

- Leptonic B decays are very sensitive to new physics
- Some recent measurements at B factory and Hadron colliders reaches the expected the SM Br.
  - Constraining the new physics
- The results of full data set at Belle will come soon
  - Improved analysis of $B \rightarrow \tau\nu$ and $B \rightarrow l\nu$ is going on
- More interesting results will come in future from LHC and Belle II and SuperB