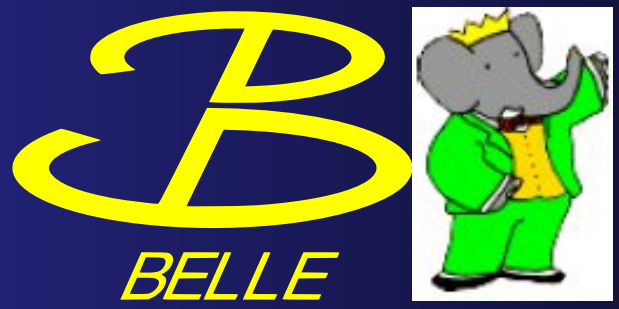


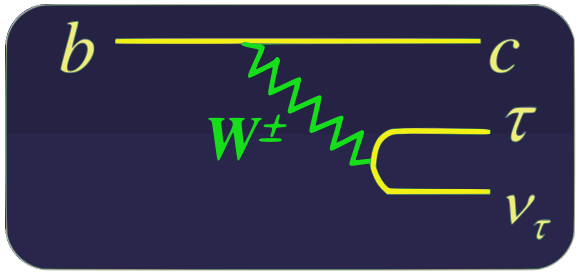
Experimental status of $B \to D^{(*)}\tau\nu$

Outline

1. Motivation
2. B-factories
3. Multi-neutrino B decays – experimental techniques
4. results
5. Summary and outlook

Motivation

Semitauonic B decays

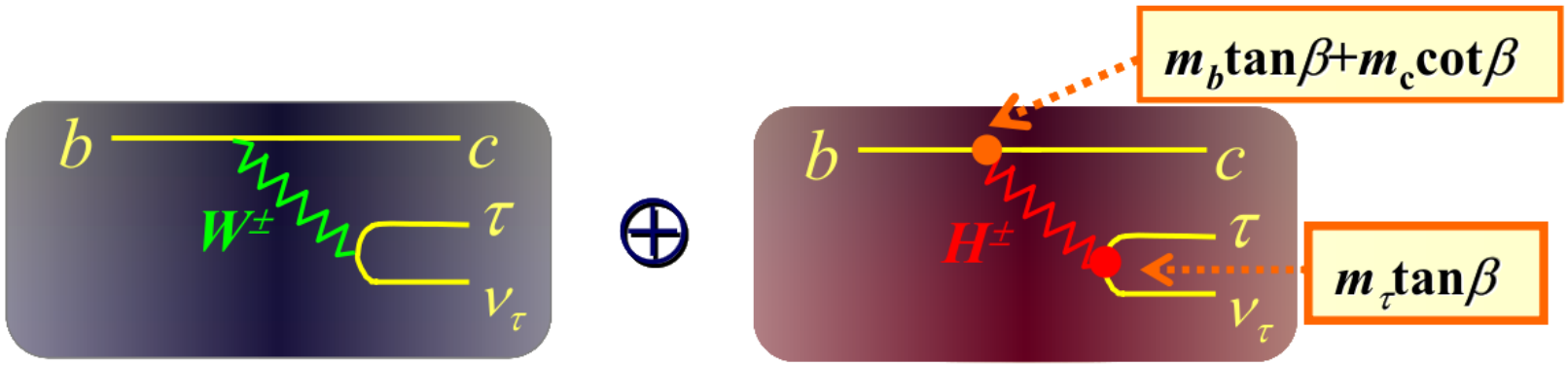


$B \to D^{(*)} \tau \nu_\tau$

- form-factors that cannot be accessed in other semileptonic B decays

- poorly known – experimentally difficult
- not observed exclusively before B-factories
  - Inclusive $\mathcal{B}(B \to c\tau^+\nu_\tau) = (2.48 \pm 0.26)\%$ from LEP (PDG 2007)

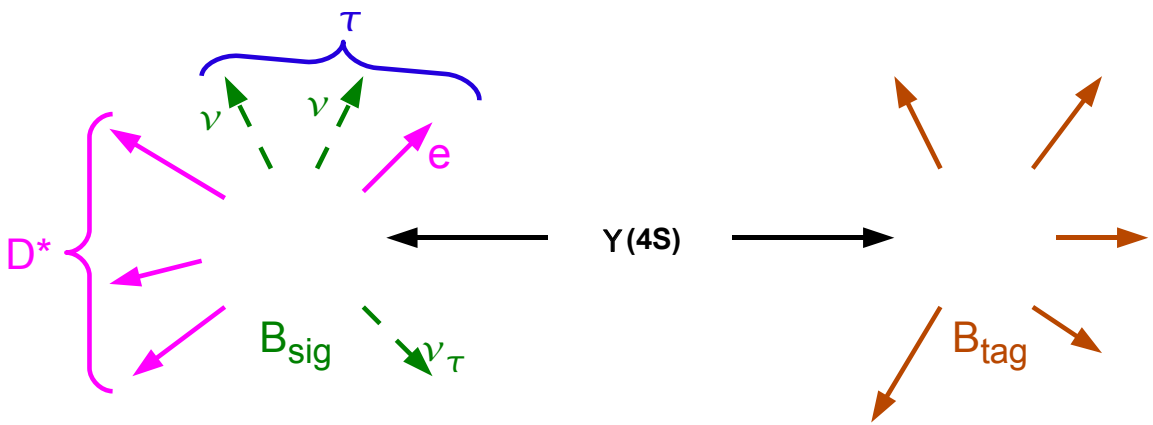
- sensitive to extended Higgs sector; complementary to and competitive with $B \to \tau\nu$



- different theory uncertainties from $B \to \tau^+\nu_\tau$:
  - free from f_B and $|V_{ub}|$, depends on the $B \to \overline{D}^{(*)}\tau^+\nu_\tau$ form-factors
  - $|V_{cb}|$ (known better than $|V_{ub}|$) cancels out in the ratio $R = \frac{\mathcal{B}(B\to D\tau\nu)}{\mathcal{B}(B\to Dl\nu)}$
- 3-body decay $\Rightarrow$ more observables (*e.g.* q^2-distribution, τ polarization, D^* polarization) – possible $\mathcal{O}(1)$ effects
- Hbu and Hbc vertices complementary to Htb searches at the LHC
  - H - b - u measured in $B \to \tau^+\nu_\tau$
  - H - b - c measured in $B \to \overline{D}^{(*)}\tau^+\nu_\tau$
  - H - b - t direct production at LHC

Experimental techniques

Signal decay with multiple (2 or 3) neutrinos can be observed using kinematic constraints available only at B-factories. To ensure that we have missing 4-momentum consistent with multi-neutrino hypothesis we take the advantage of exclusive $B\overline{B}$ production.



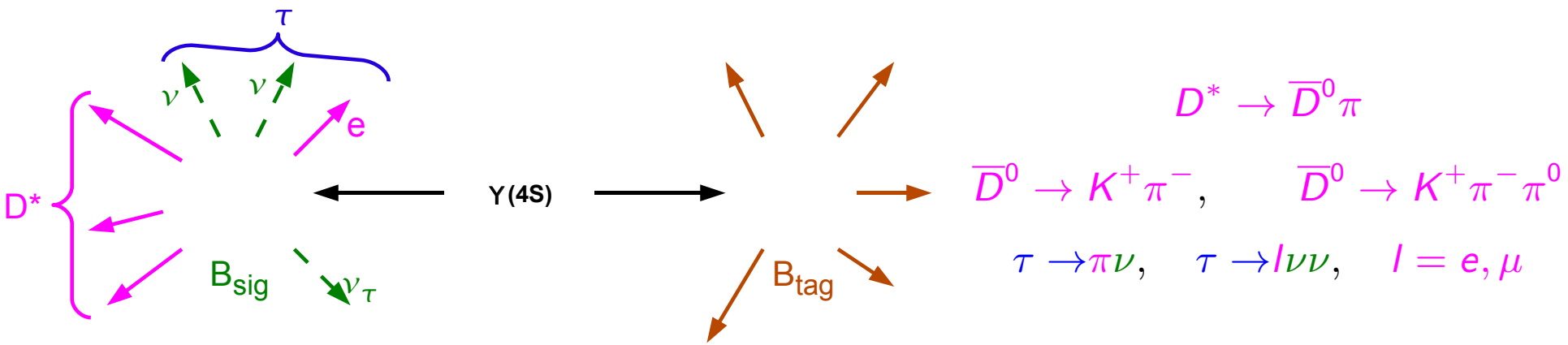
two ways of reconstructing B_{tag}

1. reconstruct B_{tag} (in exclusive mode) and check whether remaining particles are consistent with B_{sig} ("exclusive" B_{tag} reconstruction)
2. select B_{sig} candidate and check whether remaining particles are consistent with B decay ("inclusive" B_{tag} reconstruction)

$B \to \overline{D}^{(*)}\tau^+\nu_\tau$ with inclusive B_{tag} reconstruction

- B_{sig} clean signature *e.g.* $D^{*-}e^+$
- reconstruct B_{tag} inclusively: $M_{\text{tag}} = \sqrt{E_{\text{beam}}^2 - \left(\sum_{i \notin \text{sig}} \vec{p}_i\right)^2}$

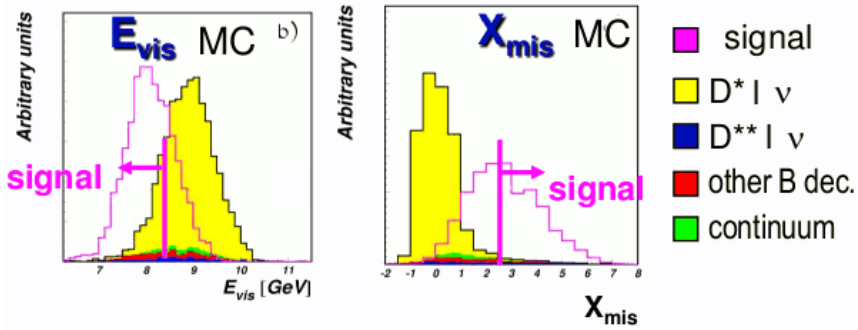
B_{sig} decay chains that combine a high reconstruction efficiency with a low background level are chosen



background suppression

- visible energy E_{vis}
- $X_{\text{mis}} = \frac{E_{\text{mis}} - |\vec{p}_{D^*} + \vec{p}_{l/\pi}|}{|\vec{p}_B|}$

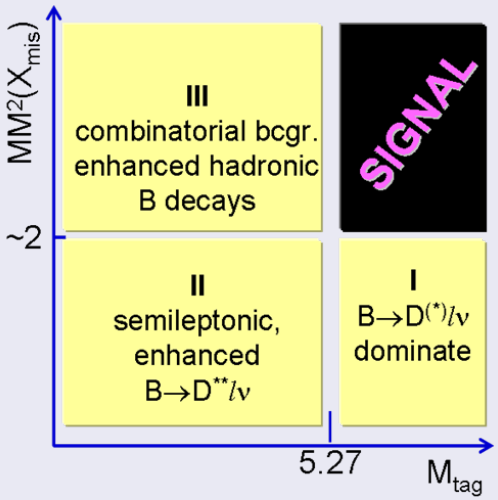
  similar to M_{mis} but M_{tag} independent.



$B \to \overline{D}^{(*)}\tau^+\nu_\tau$ background calibration

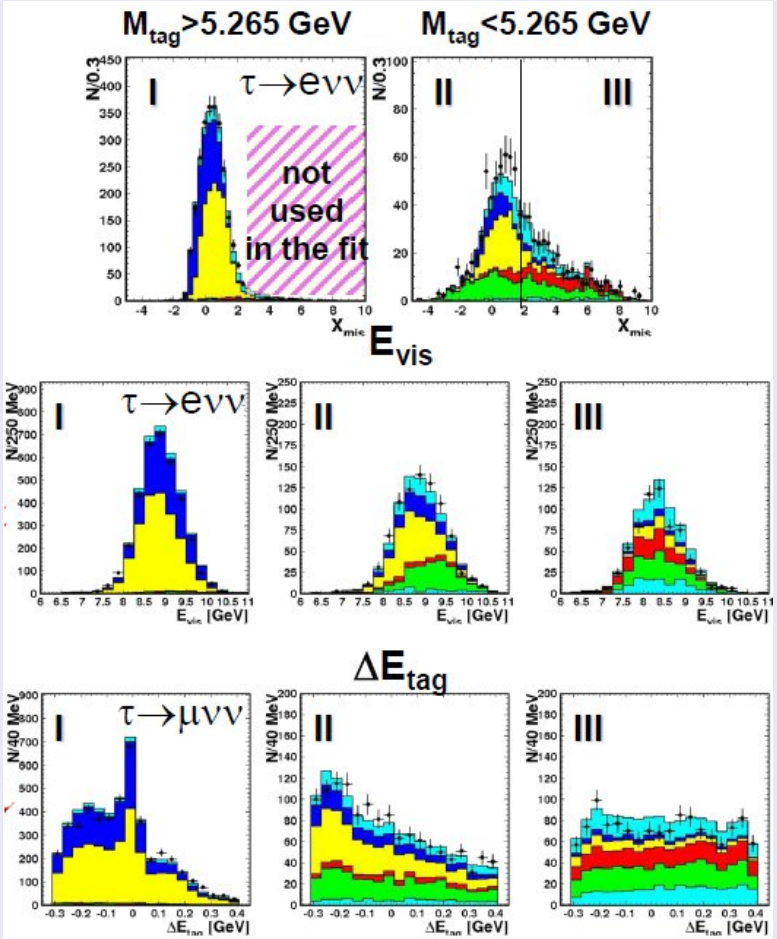
Fit scale factors for the background components: using experimental distributions in side-bands

M_{tag} vs. X_{mis} plane



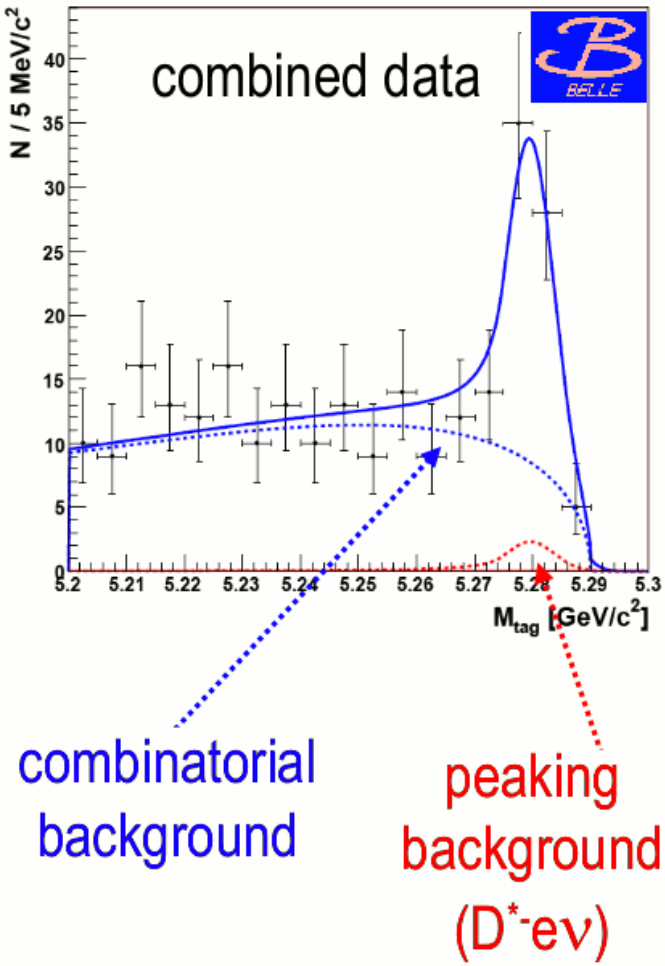
- Fits were performed for several observables (X_{mis}, E_{vis}, ΔE_{tag}, M_{D^0}, ...).
- Fitted scale factors for semileptonic decays are consistent with recent PDG values.

e.g. $B^+ \to \overline{D}^0\tau^+\nu_\tau$, $\overline{D}^0 \to K^+\pi^-\pi^0$



FIRST OBSERVATION[1]

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



signal yield in 535M $B\overline{B}$

$N_S = 60^{+12}_{-11}$ $\quad 6.7\sigma$ (5.2σ with syst.)

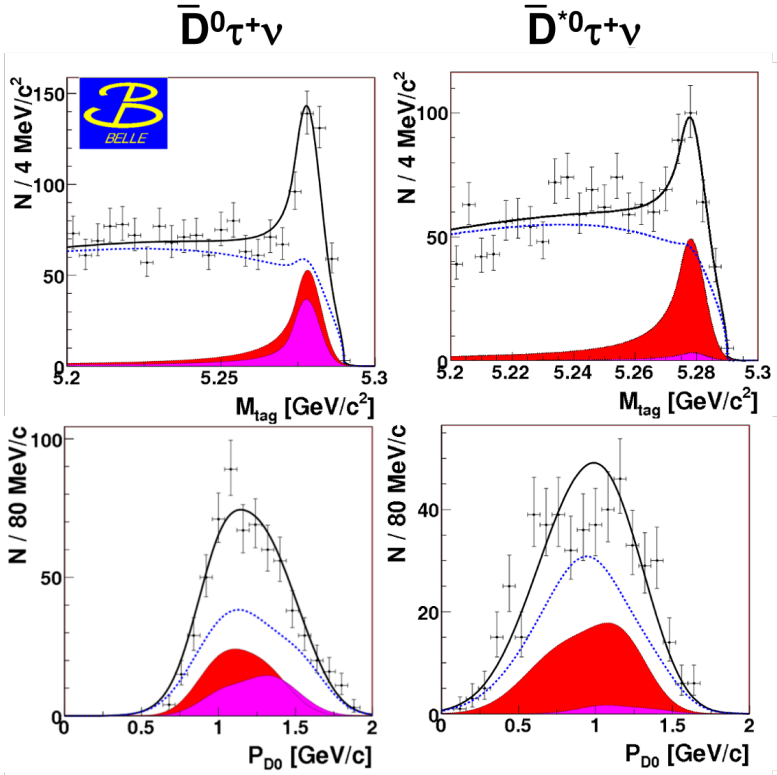
from a combined maximum likelihood fit (with a single BF) to M_{tag} distributions for all sub-decay modes

At large X_{mis} most of background contributions behave like combinatorial bckg while the signal is visible as a well reconstructed B_{tag}.

[1] A. Matyja et al. (The Belle Collaboration) PRL **99**, 191807 (2007)

Belle: $B^+ \to \overline{D}^{(*)0}\tau^+\nu_\tau$

- simultaneous extraction of signals in $B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$ and $B^+ \to \overline{D}^{0}\tau^+\nu_\tau$ taking into account $\overline{D}^{*0} \leftrightarrow \overline{D}^{0}$ cross-feeds
- signal extraction from fit to 2-dim distributions in $M_{\rm tag}$ and P_{D^0} (momentum of D^0 in $\Upsilon(4S)$ rest frame)
- simultaneous fit to 13 decay chains with floating 2 signal BFs and 13 background normalizations



$N(\overline{D}^{*0}\tau^+\nu_\tau) = 446^{+58}_{-56}$ **8.1σ**

$BF(B^+ \to \overline{D}^{*0}\tau^+\nu_\tau) = (\mathbf{2.12}^{+0.28}_{-0.27} \pm 0.29) \times 10^{-2}$

$N(\overline{D}^{0}\tau^+\nu_\tau) = 146^{+42}_{-41}$ **3.5σ** **first evidence**

$BF(B^+ \to \overline{D}^{0}\tau^+\nu_\tau) = (\mathbf{0.77}^{+0.22}_{-0.22} \pm 0.12) \times 10^{-2}$

based on 675M $B\overline{B}$

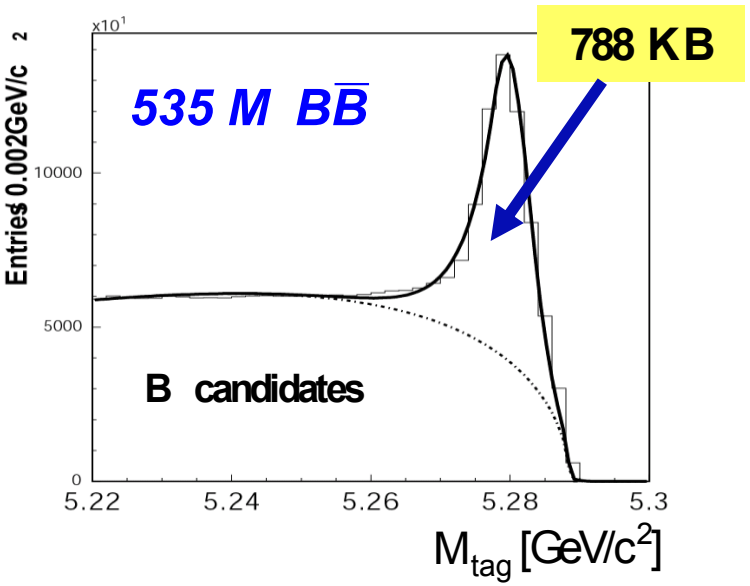
[2]

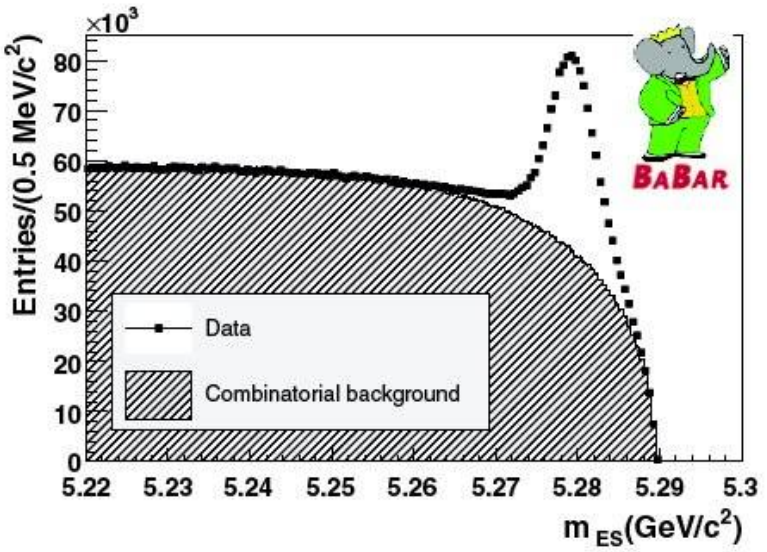
[2] A. Bozek, et al. (The Belle Collaboration)hep-ex/1005.2302, submitted to PRL

$B \to \overline{D}^{(*)}\tau^+\nu_\tau$ with exclusive B_{tag} reconstruction

- reconstruct B_{tag} exclusively in hadronic mods (low efficiency)
  - $B \to \overline{D}^{(*)}\pi/\rho/a_1/D_{(s)}^{(*)}$ Belle
  - $B \to \overline{D}^{(*)} + Y^+(n \times \pi^\pm, \pi^o, K^\pm, K^0)$ BaBar (1114 final states)
- then B_{sig} is reconstructed *e.g.* $D^{*-}e^+$

B_{sig} decay chains are reconstructed in many hadronic modes (11 final states) thanks to a low background level after B_{tag} cut.





Babar: $B \to \overline{D265}^{(*)}\tau^+\nu_\tau$

- 238M $B\overline{B}$
- Exclusive hadronic tags
- Signal characterized by large MM^2
- Simultanious extraction of $D\tau\nu/D^*\tau\nu$
- Extracted from the fit was the ratio $R = \frac{\mathcal{B}(B\to D\tau\nu)}{\mathcal{B}(B\to Dl\nu)}$
- Also measure decay distributions for the first time

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

[3] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **100**, 021801 (2008); Phys. Rev. D. **79**, 092002 (2009)

Babar: $B \to \overline{D}^{(*)}\tau^+\nu_\tau$

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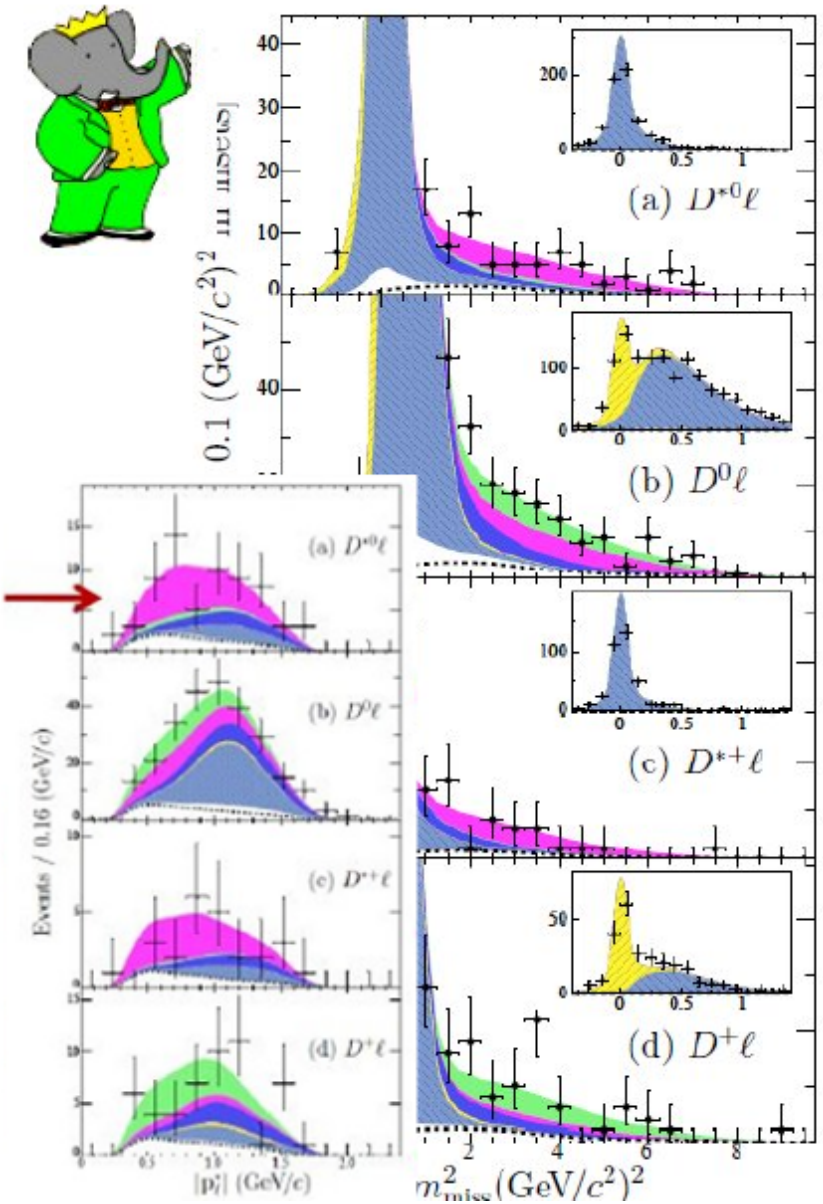
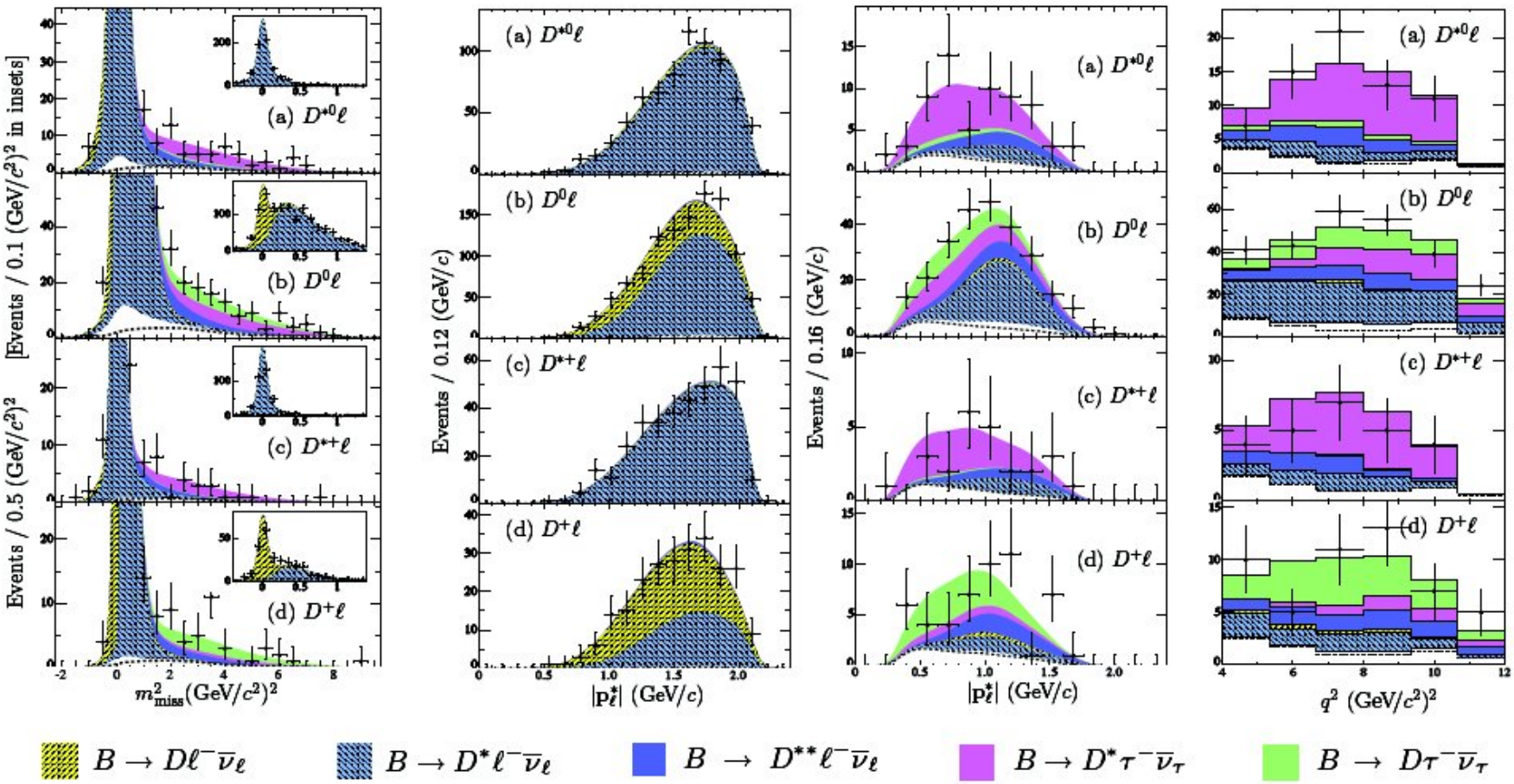


[4] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **100**, 021801 (2008); Phys. Rev. D. **79**, 092002 (2009)

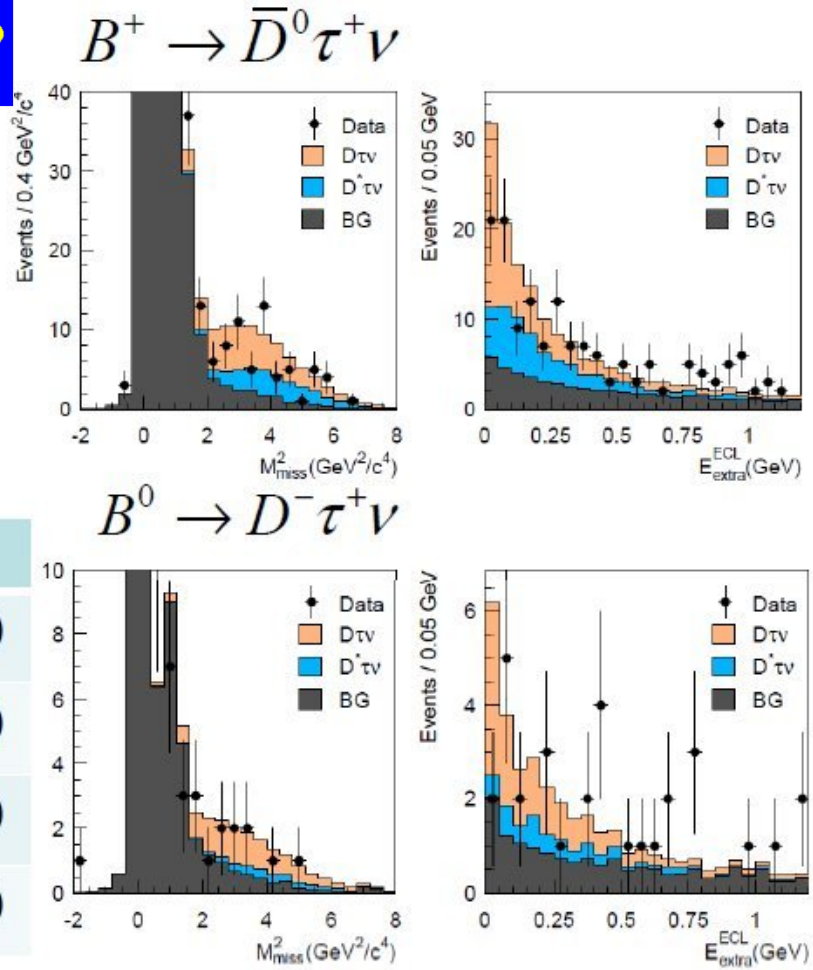
Babar: $B \to \overline{D}^{(*)}\tau^+\nu_\tau$



$$\mathcal{B}(B \to \overline{D}\tau^+\nu) = (0.86 \pm 0.24 \pm 0.11 \pm 0.06)\% \quad (3.6\sigma)$$
$$\mathcal{B}(B \to \overline{D}^*\tau^+\nu) = (1.62 \pm 0.31 \pm 0.10 \pm 0.05)\% \quad (6.2\sigma)$$

First measurement of kinematic distributions: q^2, $|P_l^*|$

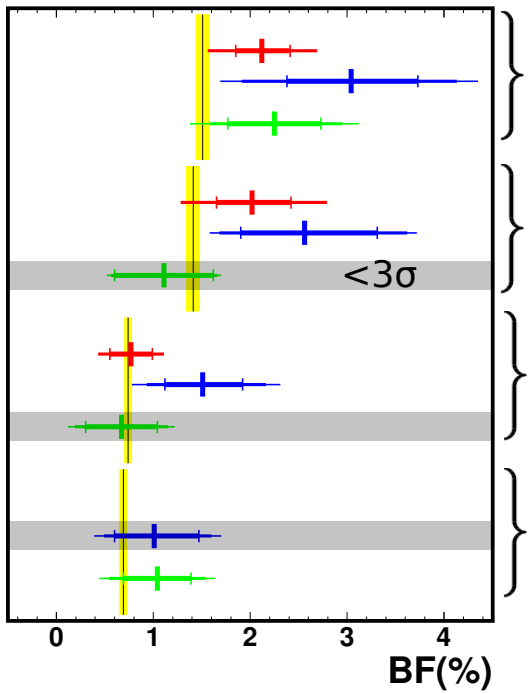
- 657M BB
- Hadronic tags.
- Extract signals in (MM^2, E_{ECL}) distribution.
- Simultaneous extraction of $D\tau\nu/D^*\tau\nu$.



	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)

[5] Belle Preliminary, I. Adachi, et al. (The Belle Collaboration)hep-ex/0910.4301

$B \to \overline{D}^{(*)}\tau^+\nu_\tau$ summary



$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$

$[2.12^{+0.28}_{-0.27} \pm 0.29]\%$ 8.1σ

$[3.04^{+0.69\ +0.40}_{-0.66\ -0.47}]\%$ 3.9σ

$[2.25 \pm 0.48 \pm 0.22]\%$ 5.3σ

$B^0 \to D^{*-}\tau^+\nu_\tau$

$[2.02^{+0.40}_{-0.37} \pm 0.37]\%$ 5.2σ

$[2.56^{+0.75\ +0.31}_{-0.66\ -0.22}]\%$ 4.7σ

$[1.11 \pm 0.51 \pm 0.04]\%$ 2.7σ

$B^+ \to \overline{D}^0\tau^+\nu_\tau$

$[0.77 \pm 0.22 \pm 0.12]\%$ 3.5σ

$[1.51^{+0.41\ +0.24}_{-0.39\ -0.19}]\%$ 3.8σ

$[0.67 \pm 0.37 \pm 0.11]\%$ 1.8σ

$B^0 \to D^-\tau^+\nu_\tau$

$[1.01^{+0.46\ +0.13}_{-0.41\ -0.11}]\%$ 2.6σ

$[1.04 \pm 0.35 \pm 0.15]\%$ 3.3σ

– Belle inclusive B_{tag}[6]

– Belle exclusive B_{tag}[7]

– BaBar exclusive B_{tag}[8]

Standard Model[9]

- results are above SM predictions (similarly to $B \to \tau\nu$)
- inclusive reconstruction gives the smallest statistical errors

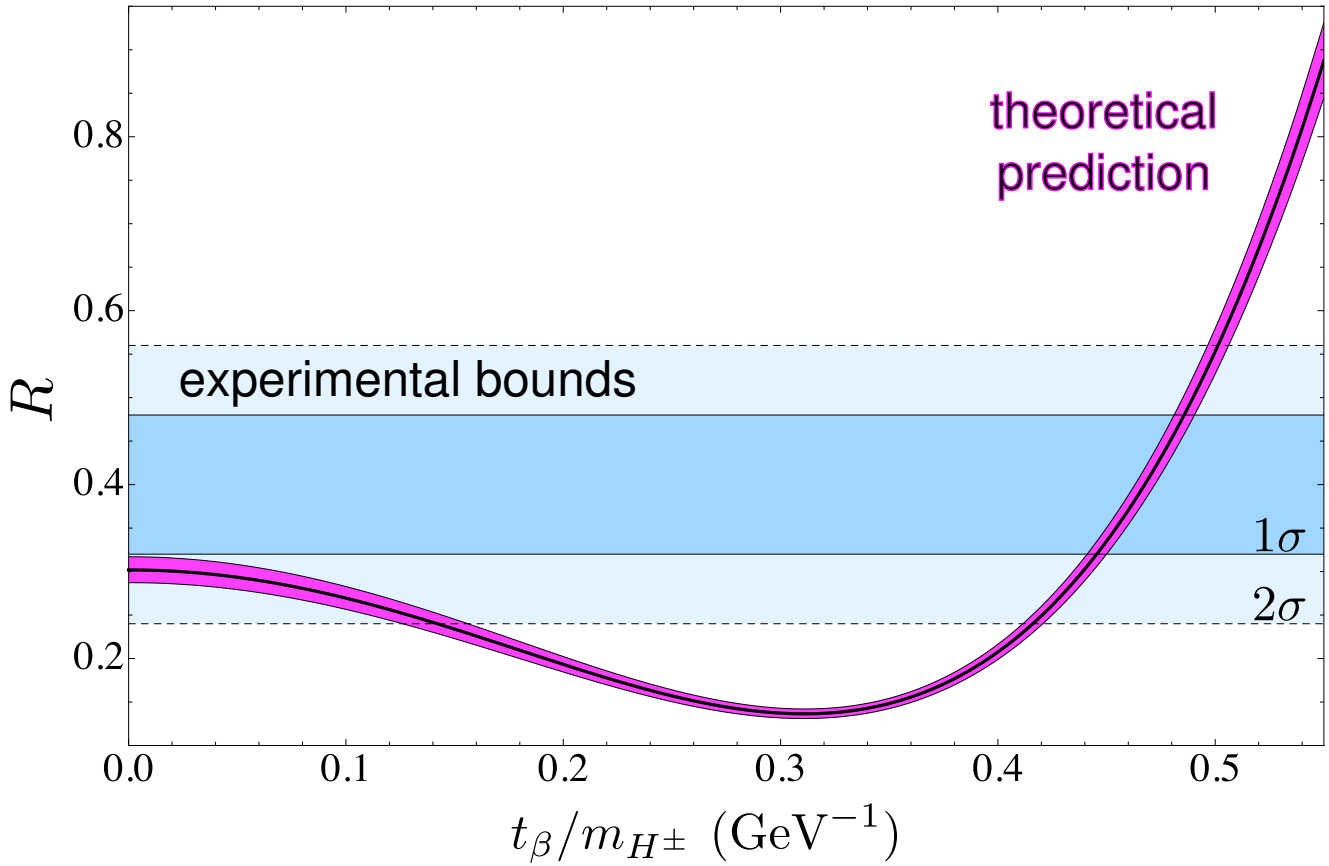
[6] The Belle Collaboration PRL **99**, 191807 (2007) and hep-ex/1005.2302

[7] The Belle Colaboration hep-ex/0910.4301

[8] The BaBar Colaboration PRL **100**, 021801 (2008)

[9] C.-H. Chen and C.-Q. Geng, JHEP **0610**, 053 (2006)

experimental bounds on $\tan\beta/m_H$ in type-II 2HDM from averaged Belle and BaBar measurements[10] of $R = \frac{\mathcal{B}(B\to D\tau\nu_\tau)}{\mathcal{B}(B\to Dl\nu_l)} = 0.40 \pm 0.08$

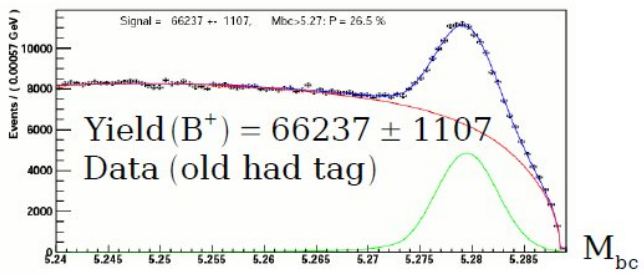


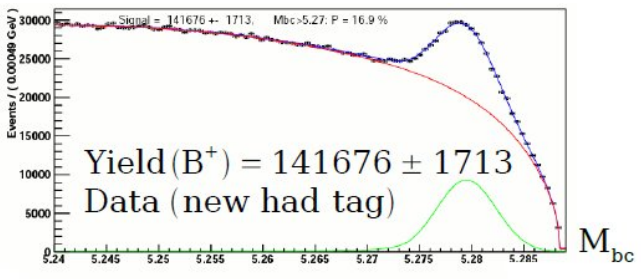
[10] M. Tanaka, R. Watanabe, arXiv:1005.4306

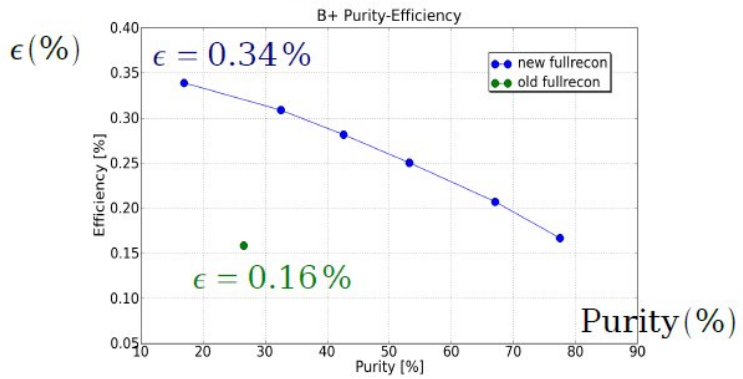
What is comming next?

Belle

- reprocessed data sample with improved tracking efficiency
- none of the results shown use full data sample yet
- hadronic tag efficiency improved: effective luminosity improved by factor x2







Super B factories !

Summary and outlook

- B-factories are a good environment for studies of both tauonic and semitauonic B decays
- Recent measurements by Belle of $B^+ \to \bar{D}^{(*)0}\tau\nu_\tau$ with inclusive reconstruction
  $\mathcal{B}(B^+ \to \bar{D}^{*0}\tau^+\nu_\tau) = (2.12^{+0.28}_{-0.27}(\mathrm{stat}) \pm 0.29(\mathrm{syst}))\%$ and
  $\mathcal{B}(B^+ \to \bar{D}^{0}\tau^+\nu_\tau) = (0.77 \pm 0.22(\mathrm{stat}) \pm 0.12(\mathrm{syst}))\%$
- measurements of semitauonic-B decays are now well established and provide constraints on charged Higgs sector that can compete with direct searches
- measured BFs are consistent within experimental uncertainties with expectations of the SM, but there is still room for new physics
- New results from Belle are comming (full luminosity, new tracking and improved tagging: $\approx \times 2$ in effective luminosity)
- The most interesting measurements will be polarizations.
- Interesting prospects for future Super B-factories

$B \to \overline{D}^{(*)}\tau^+\nu_\tau$ average

Naive averages were calculated:

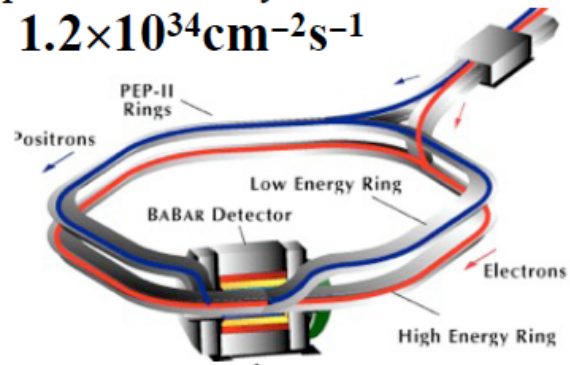
- $\mathcal{B}(B^+ \to \overline{D}^{*0}\tau^+\nu_\tau) = (2.36 \pm 0.27)\%$
- $\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau) = (1.70 \pm 0.34)\%$
- $\mathcal{B}(B^+ \to \overline{D}^{0}\tau^+\nu_\tau) = (0.89 \pm 0.20)\%$
- $\mathcal{B}(B^0 \to D^{-}\tau^+\nu_\tau) = (1.03 \pm 0.30)\%$

- Belle inclusive and exclusive tag measurement has negligible overlap ($\approx 0.3\%$).
- Averages include all mean values also one with marginal significance ($< 3\sigma$). In case we took into account only significant results changes are:
  - $\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau) = (2.24 \pm 0.46)\%$ (Belle only)
  - $\mathcal{B}(B^+ \to \overline{D}^{0}\tau^+\nu_\tau) = (1.03 \pm 0.23)\%$ (Belle only)
  - $\mathcal{B}(B^0 \to D^{-}\tau^+\nu_\tau) = (1.04 \pm 0.35 \pm 0.15)\%$ (Babar only)

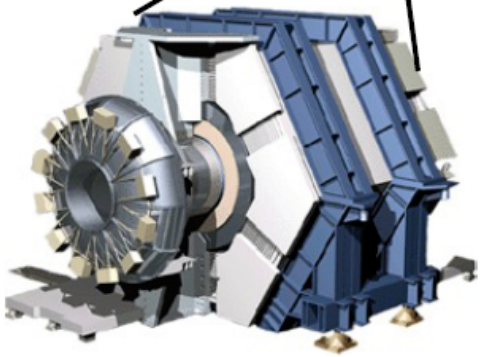
BACKUP

PEP-II at SLAC

9GeV (e^-) × 3.1GeV (e^+)
peak luminosity:
$1.2\times10^{34}cm^{-2}s^{-1}$

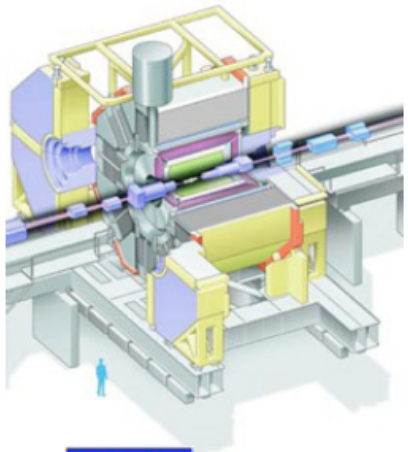


BaBar

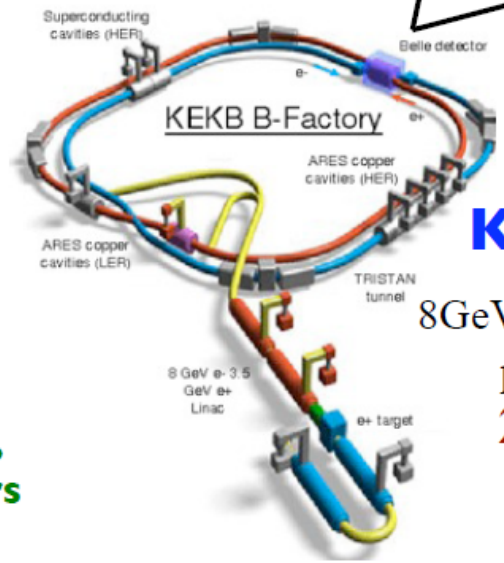


11 nations,
80 institutes,
~600 members

13 countries,
57 institutes,
~400 members



Belle



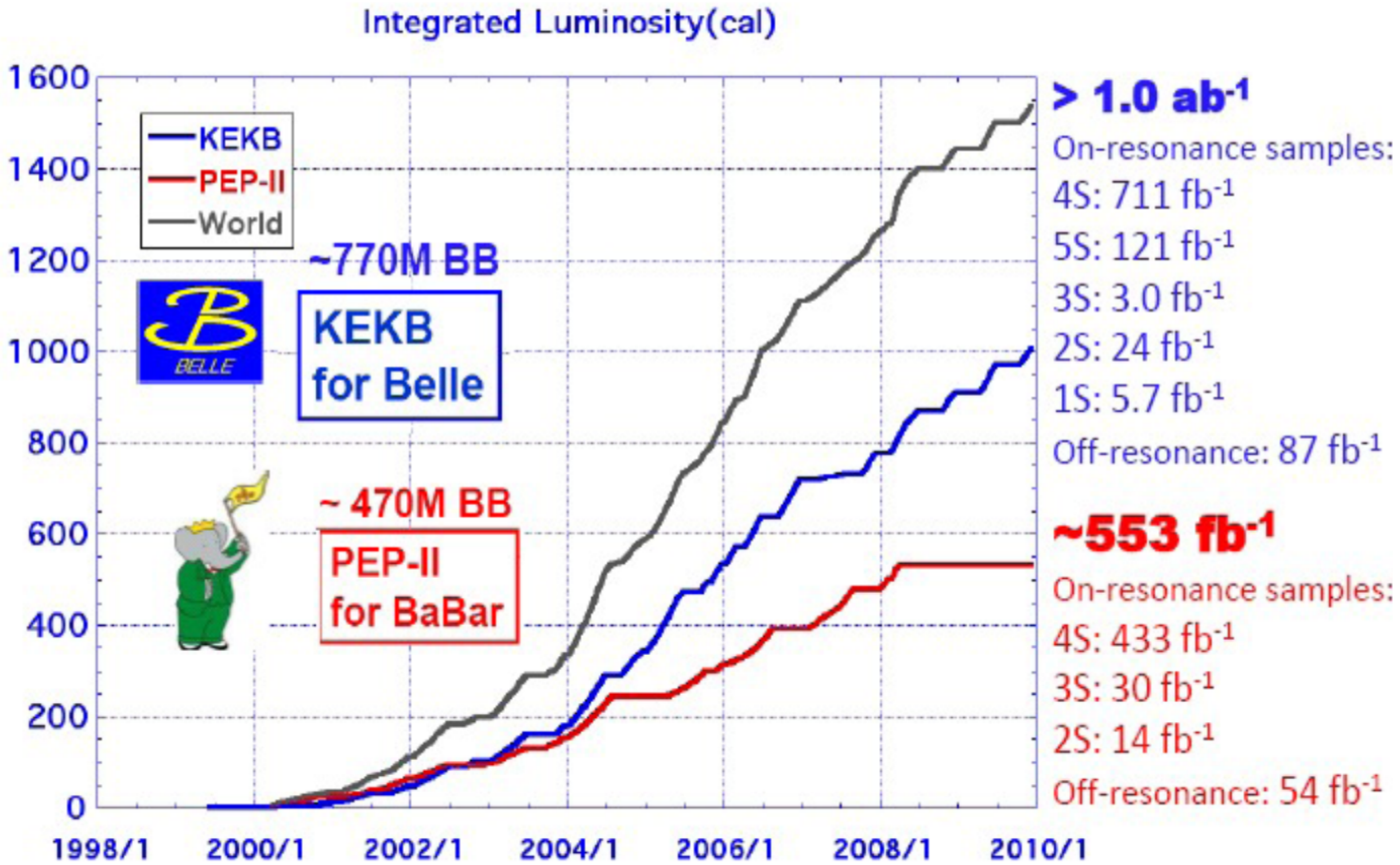
KEKB at KEK

8GeV (e^-) × 3.5GeV (e^+)
peak luminosity:
$2.1\times10^{34}cm^{-2}s^{-1}$
world record

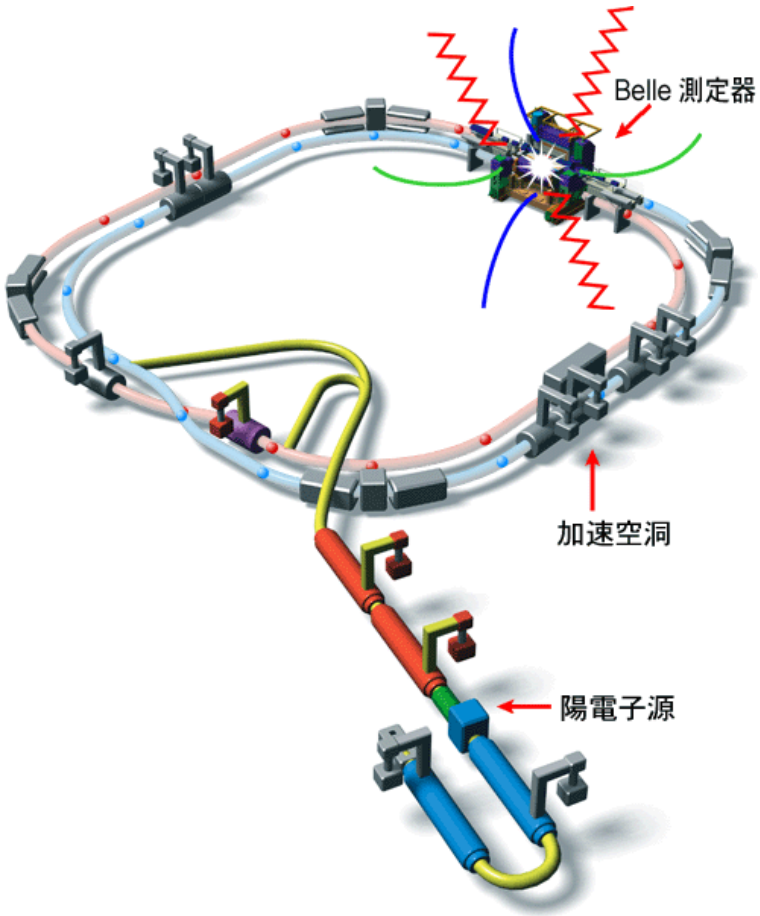
characteristics

$e^+e^- \to \Upsilon(4S) \to B\overline{B}$ clean source of exclusive B meson pairs

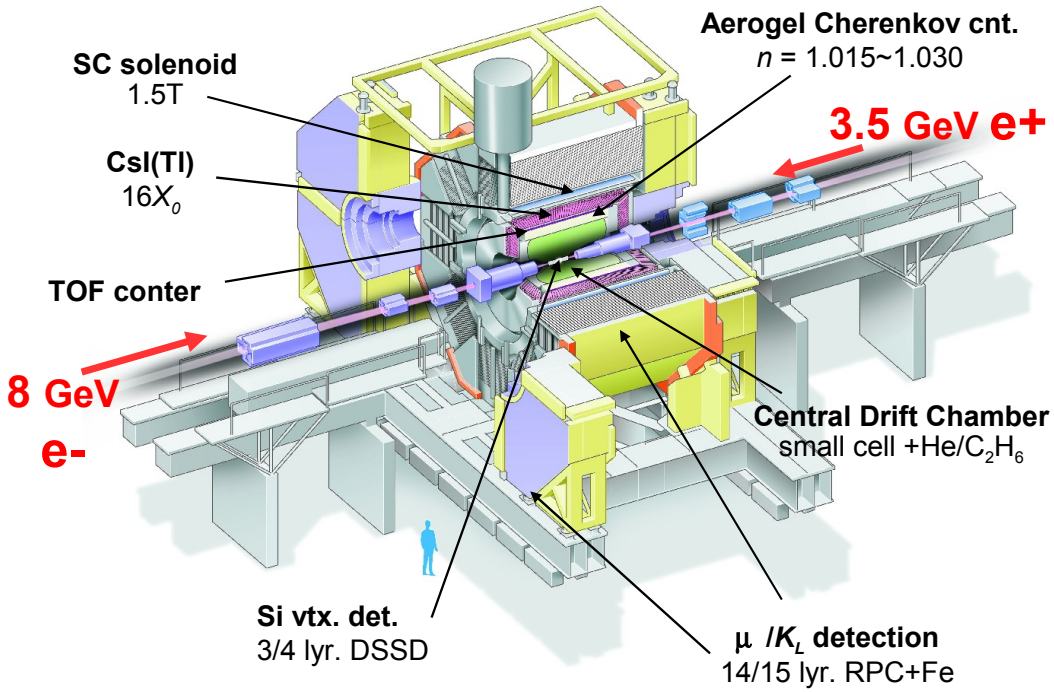
B-factory Luminosities



KEKB B-factory and Belle detector



Belle detector: multi-purpose, large-solid-angle magnetic spectrometer



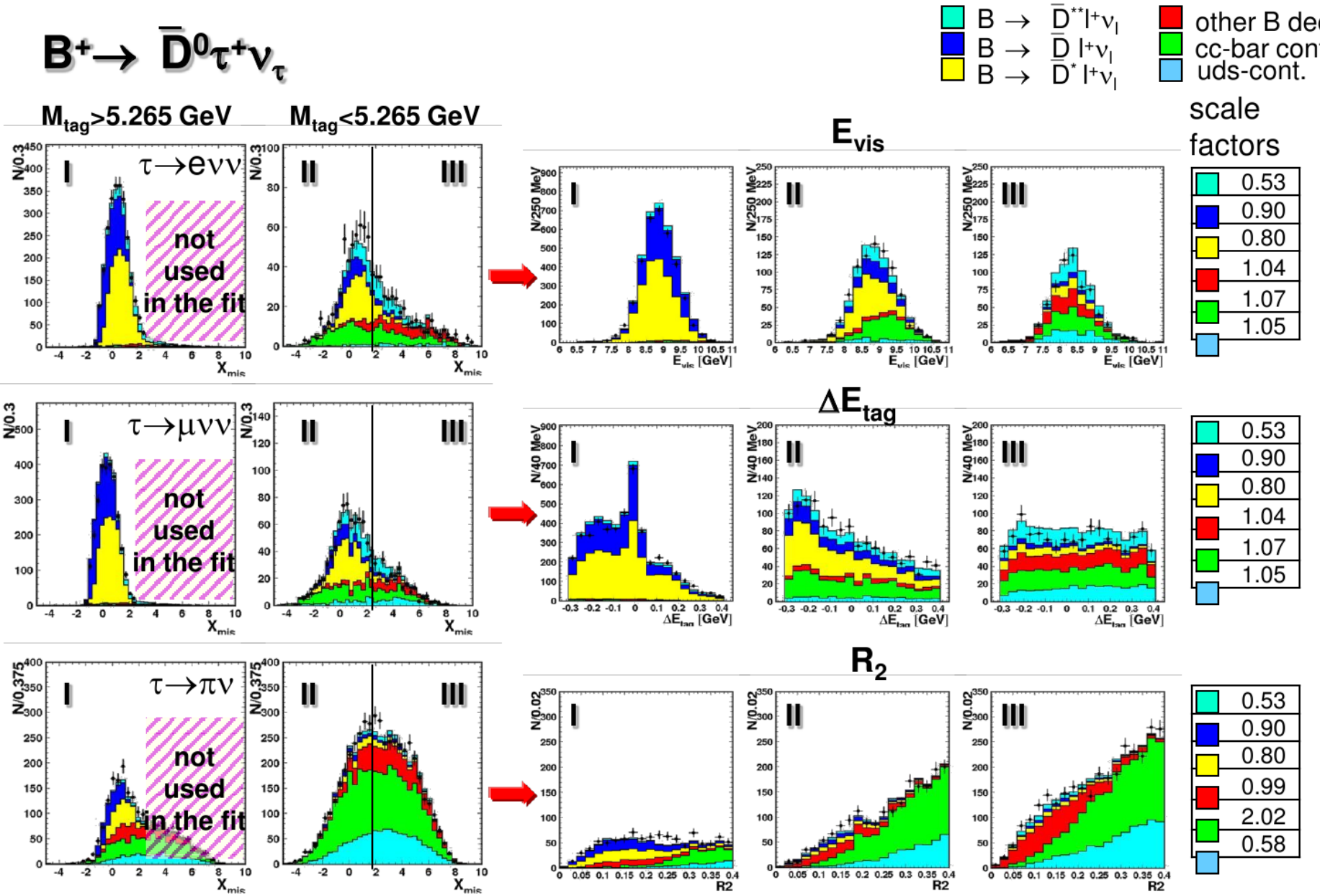
characteristics

$e^+e^- \to \Upsilon(4S) \to B\overline{B}$ clean source of exclusive B meson pairs

$\mathcal{L}_{\text{peak}} = 2.11 \times 10^{34}$ $\int \mathcal{L} > 1$ ab^{-1} 711 fb^{-1} @ $\Upsilon(4S)$

Background calibration

$B^+ \to \bar{D}^0\tau^+\nu_\tau$



Background calibration

The fitted branching fractions are consistent with the recent PDG values. Below we list the fit results for the main peaking background components together with the PDG numbers.

	fit[%]	PDG[%]
$B^0 \to D_0^{*-} l^+ \nu \times BF(D_0^{*-} \to D^0 \pi^0)$	$0.25 - .3$	0.3 ± 0.12
$B^0 \to D_1^- l^+ \nu \times BF(D_1^- \to D^{*0} \pi^-)$	$0.2 - .24$	0.28 ± 0.05
$B^0 \to D_1^{'-} l^+ \nu \times BF(D_1^{'-} \to D^{*0} \pi -)$	$0.27 - .35$	0.31 ± 0.09
$B \to D^* l \nu$	$4.6 - 5.44$	5.68 ± 0.19
$B \to D l \nu$	$1.7 - 2.2$	2.24 ± 0.11