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

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Flavor Physics and CP Violation 2010
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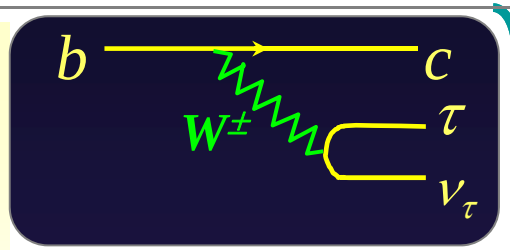
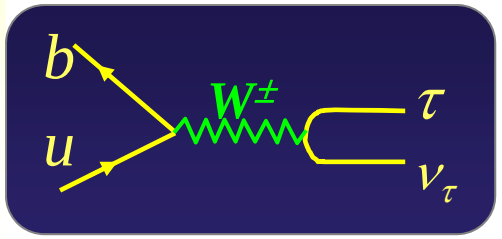
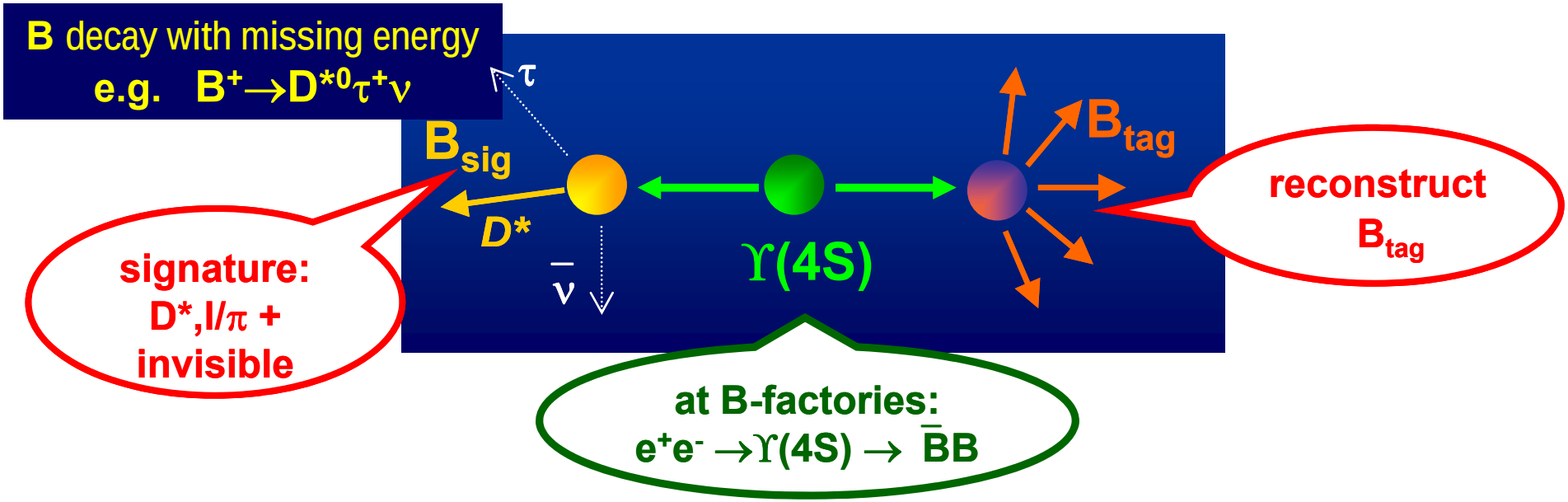
Motivation

	expected decay rates	examples of SM amplitudes	
$B \to D^{(*)}\tau^+\nu_\tau$	$\mathcal{O}(10^{-3}\text{-}10^{-2})$		Small hadronic effects; theoretically clean.
$B^+ \to \tau^+\nu_\tau$	$\mathcal{O}(10^{-4})$		**Sensitive** to New Physics

poorly known: multiple ν's in final states $\Rightarrow$ experimentaly difficult !

Experimental Techniques



B_{tag} reconstruction:

- $B\bar{B}$ event
- identify particles belonging to B_{sig}
- kinematical constraints on B_{sig}

$$\vec{p}_{sig} = -\vec{p}_{tag}$$

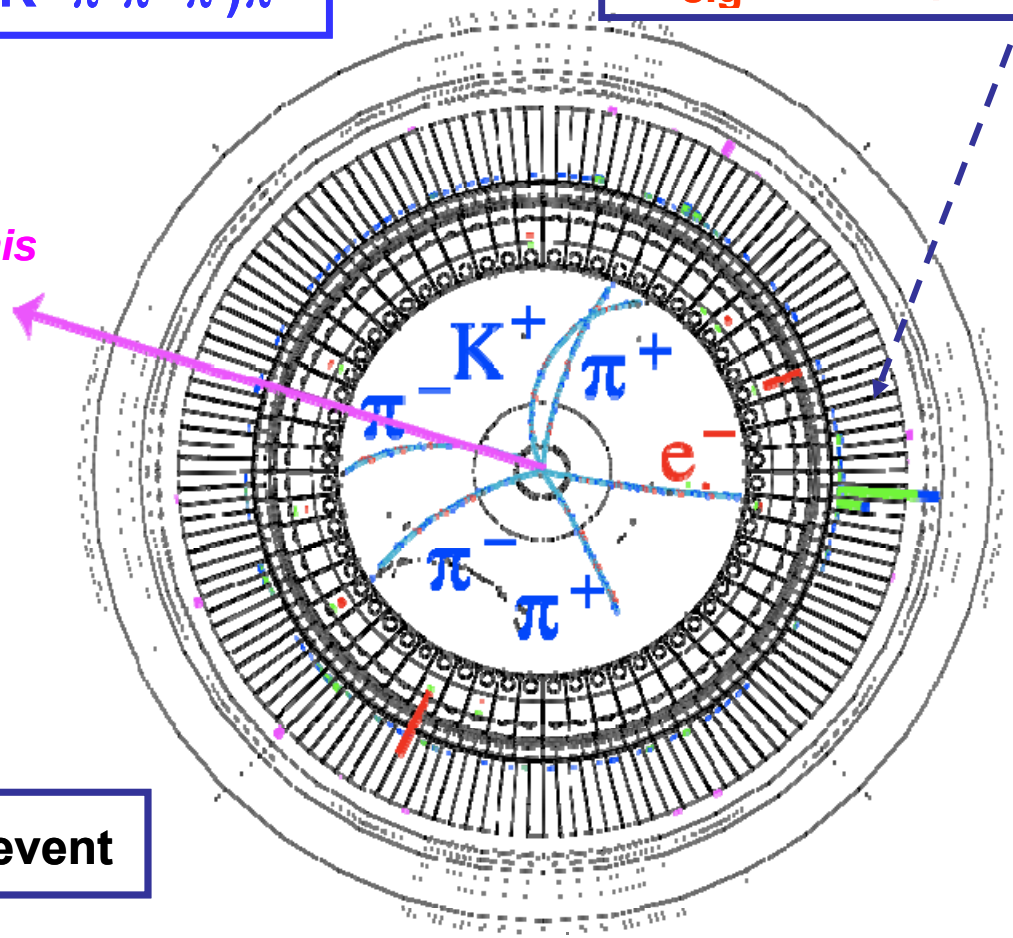
Two methods of B_{tag} reconstruction:

- Select B_{sig} candiate and check whether remaining particles consistent with B decay ("inclusive" B_{tag} reconstruction)
- Reconstruct B_{tag} (in exclusive mode) and check whether remaining particles consistent with B_{sig} ("exclusive" B_{tag} reconstruction)

$B \to \tau \nu_\tau$ event at B-factories

$B^+_{tag} \to \bar{D}^0(\to K^+ \pi^- \pi^+ \pi^-)\pi^+$

$B^-_{sig} \to \tau^- (\to e^- \nu\nu)\nu_\tau$

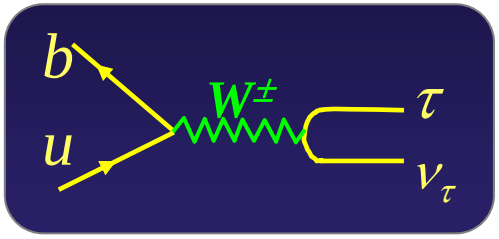


BELLE

Belle candidate event

$B \to \tau \nu_\tau$

purely leptonic B decay:
W-mediated annihilation



theoretically very clean, SM BF:

$$BF(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$BF(B^+ \to \tau^+ \nu_\tau) = (1.20 \pm 0.25) \times 10^{-4}$$

B decay constant

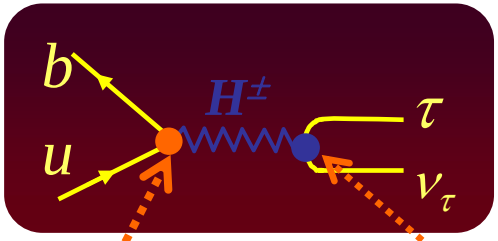
Decay rate simply related to B meson decay constant f_B and |Vub|

Sensitive to
Charged Higgs

providing f_B is known

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

$f_B = 190 \pm 13$MeV, HPQCD arXiv:0902.1815



$m_b \tan\beta + m_c \cot\beta$ $m_\tau \tan\beta$

Decay amplitude $\propto m_b m_\tau \tan^2\beta$

$H^\pm$ effects to branching fraction:

$$BF(B^+ \to \tau^+ \nu_\tau) = BF(B^+ \to \tau^+ \nu_\tau)_{SM} \times r_H$$

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

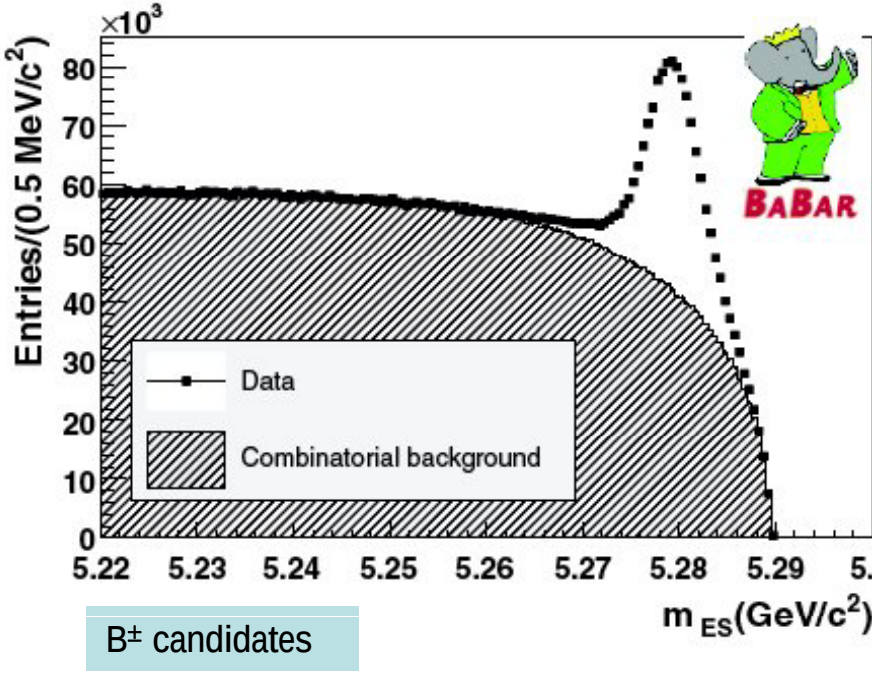
W. S. Hou, PR D 48, 2342 (1993)

$B \to \tau\nu$ - tag side

Reconstruct B_{tag} (in exclusive mode)

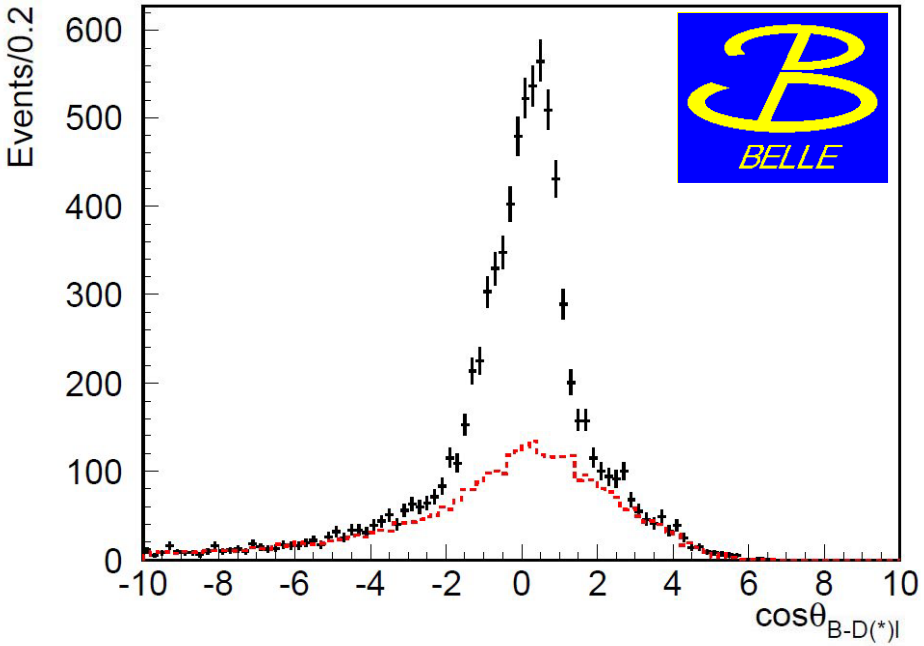
Reconstruct B_{tag} in hadronic mode:

$$\Delta E = \Sigma E_i - E_{beam}$$
$$M_{ES} = \sqrt{E^2_{beam} - (\Sigma \mathbf{p}_i)^2}$$



B± candidates

Reconstruct B_{tag} in semileptonic mode $B \to D^{*0} l \nu$:



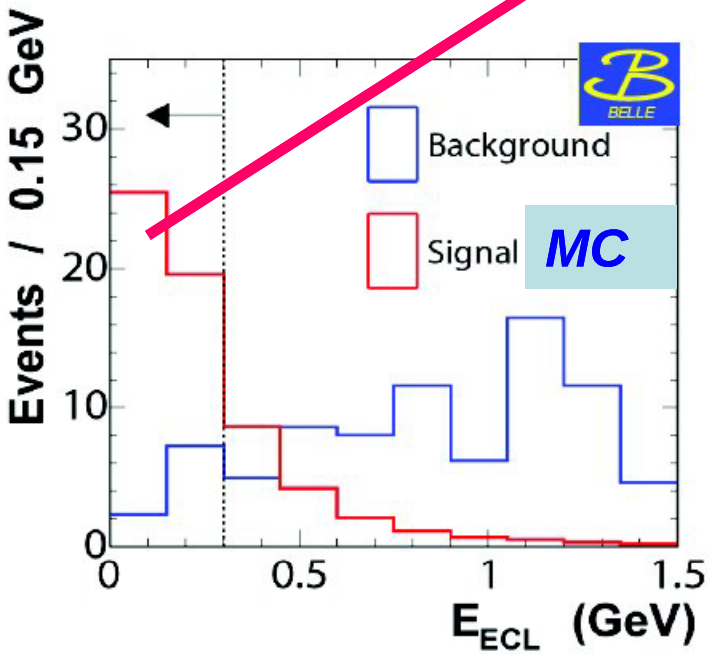
$B \to \tau\nu$ - signal side

signal side signature:

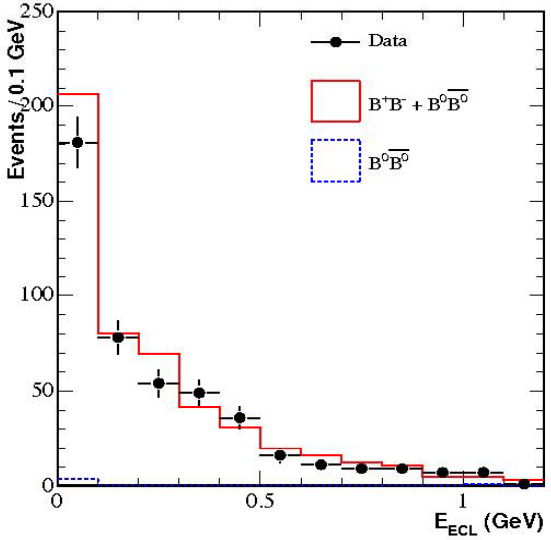
X + *nothing*

X= $\rho^{\pm}, \pi^{\pm}, (3\pi)^{\pm}, e^{\pm}, \mu^{\pm}$

E_{ECL}: residual energy in calorimeter
for signal: $E_{ECL} \approx 0$



validate E_{ECL} simulation using
$B \to D^{*0} l \nu$ control sample



$B \to \tau \nu_\tau$ - results

449 M $B\bar{B}$

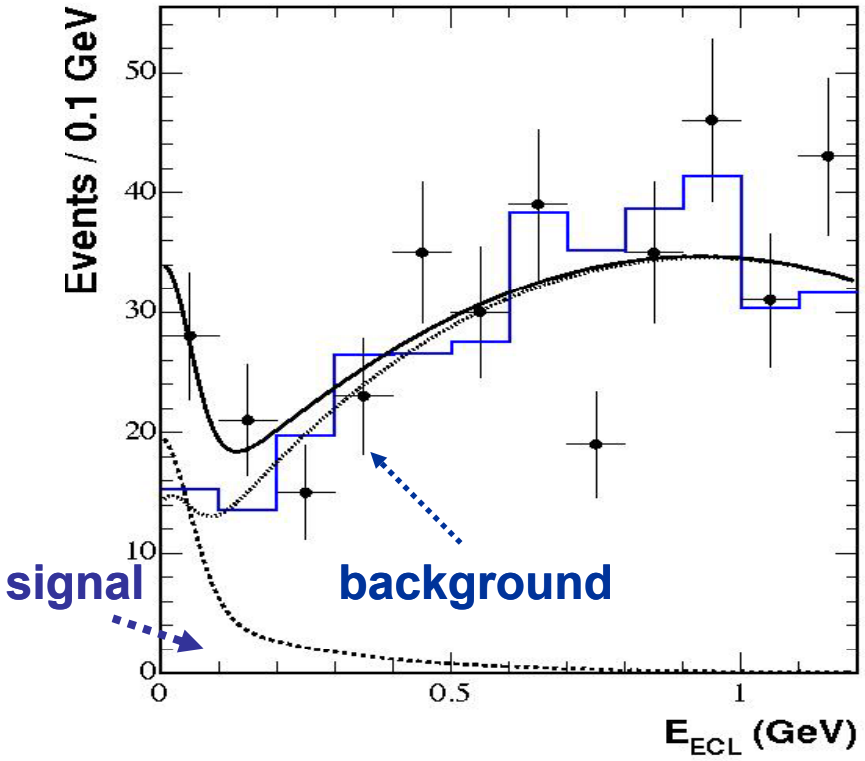
PRL 97, 251802 (2006)

visible products of τ decay

Hadronic tag

$h = \rho^{\pm}, \pi^{\pm}, (3\pi)^{\pm}$, $l = e^{\pm}, \mu^{\pm}$

81% of all modes



Find $17.2^{+5.3}_{-4.7}$ signal events from a fit to a sample of 54 events.

4.6σ stat. significance $\Rightarrow$ 3.5σ (syst. included)

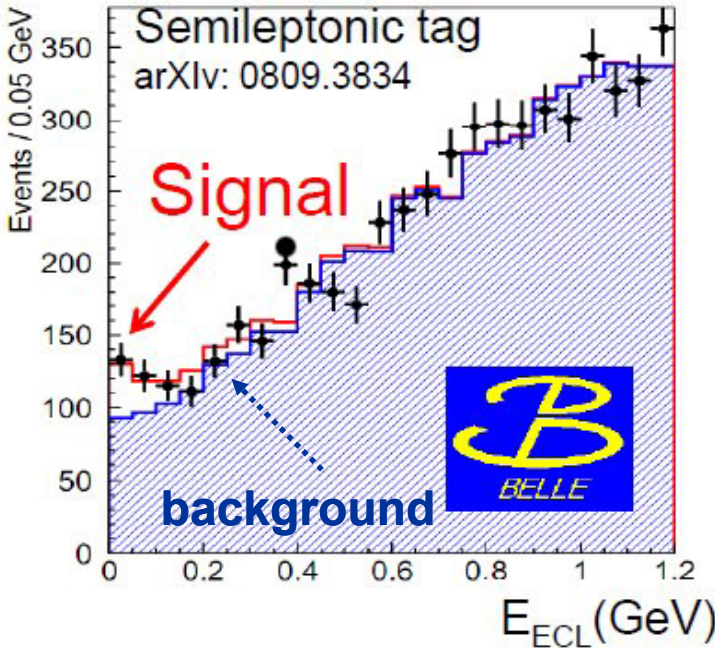
FIRST EVIDENCE

$B \to \tau \nu_\tau$ - results

657 M $B\bar{B}$

hep-ex/0809.3834

Preliminary



D(*)l ν tag

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

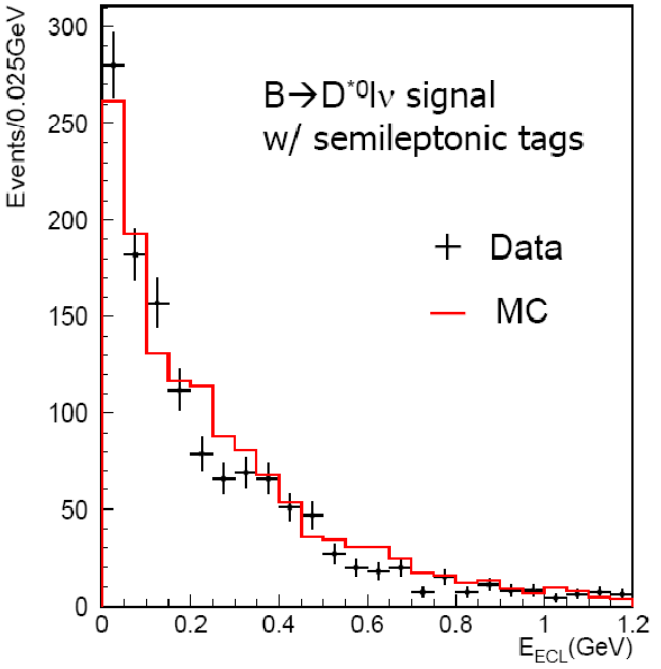
$D^{*0} \to D^0 \pi^0$, $D^0 \gamma$

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

visible products of τ decay

h = $\pi^\pm$, l = $e^\pm$, $\mu^\pm$

$B \to D^{*0} l \nu$ control sample



$N_{sig} = 154^{+36}_{-35}$ (stat) $^{+20}_{-22}$ (syst)

$\Rightarrow \mathcal{B}(B \to \tau\nu) = (1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-4}$

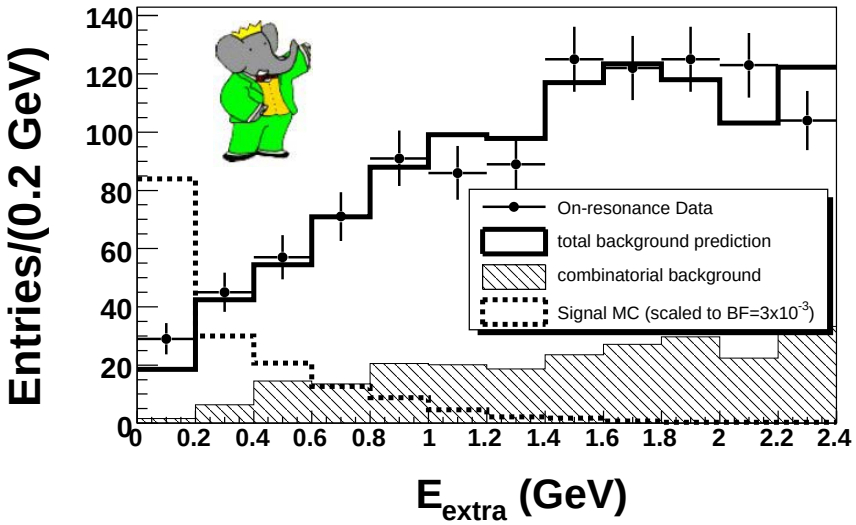
3.8σ

Obtained $Br(B^- \to D^{*0} l \nu) = 6.0 \pm 0.2$ (stat) %

$B \to \tau \nu_\tau$ - results

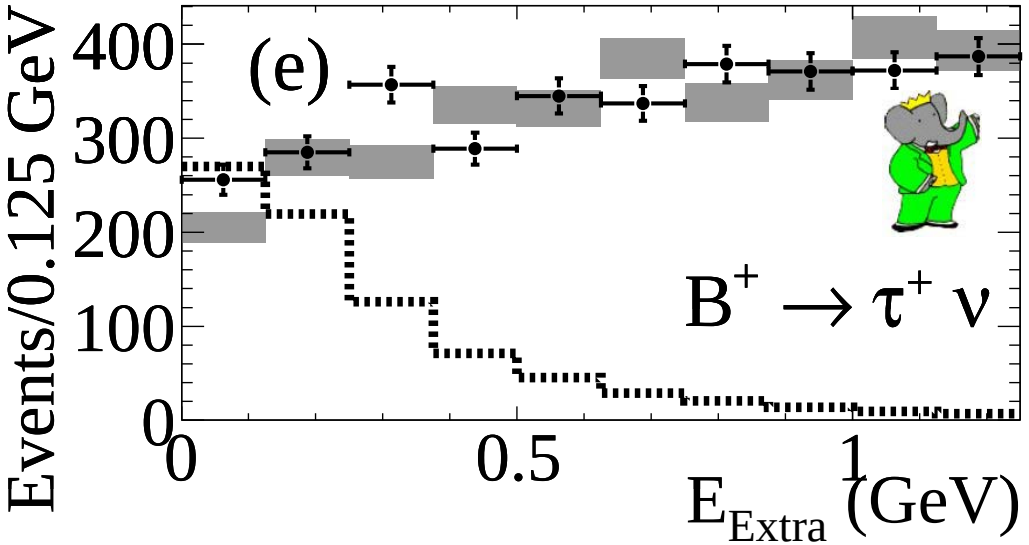
Hadronic tag

PRD-RC 77, 011107 (2008)



Semileptonic tag

PRD-RC 81, 051101 (2010)



Hadronic tag (383MBB) $\mathcal{B}(B \to \tau\nu) = (1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2) \times 10^{-2}$

Semileptonic tag (459MBB) $\mathcal{B}(B \to \tau\nu) = (1.7 \pm 0.8 \pm 0.2) \times 10^{-2}$

Hadronic tag (449MBB) $\mathcal{B}(B \to \tau\nu) = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-2}$

Semileptonic tag (657MBB) $\mathcal{B}(B \to \tau\nu) = (1.65^{+0.38+0.35}_{-0.37-0.37}) \times 10^{-2}$

$B \to \tau \nu_\tau$ - results

Naïve world average

$$Br(\tau\nu) = [1.73 \pm 0.35] \times 10^{-4} \quad \Leftrightarrow \quad Br_{SM}(\tau\nu) = [1.20 \pm 0.25] \times 10^{-4}$$

Based on f_B from HPQCD and |Vub| from HFAG (BLNP,ICHEP08)

Effect of Charged Higgs

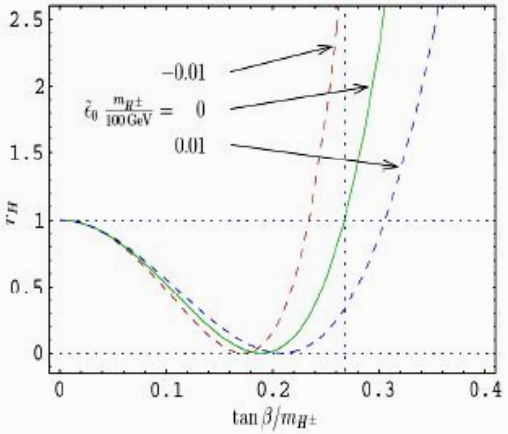
W. Hou, Phys. Rev. D48, 2342 (1993)

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

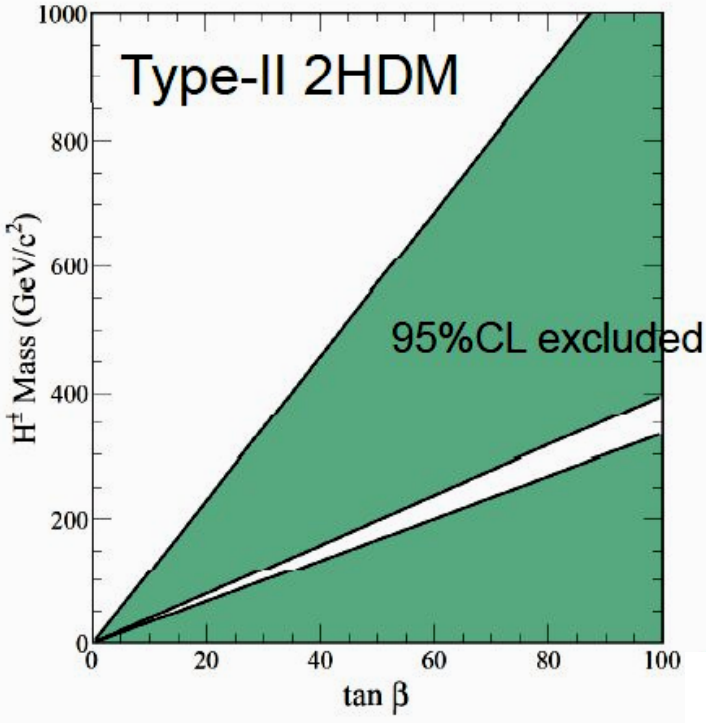
$$r_H = \left(1 - \frac{m_B^2 \tan\beta^2}{m_H^2} \frac{1}{1 + \varepsilon_0 \tan\beta}\right)^2$$

$$\tan\beta = \frac{v_u}{v},$$

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



Constraint on charged Higgs



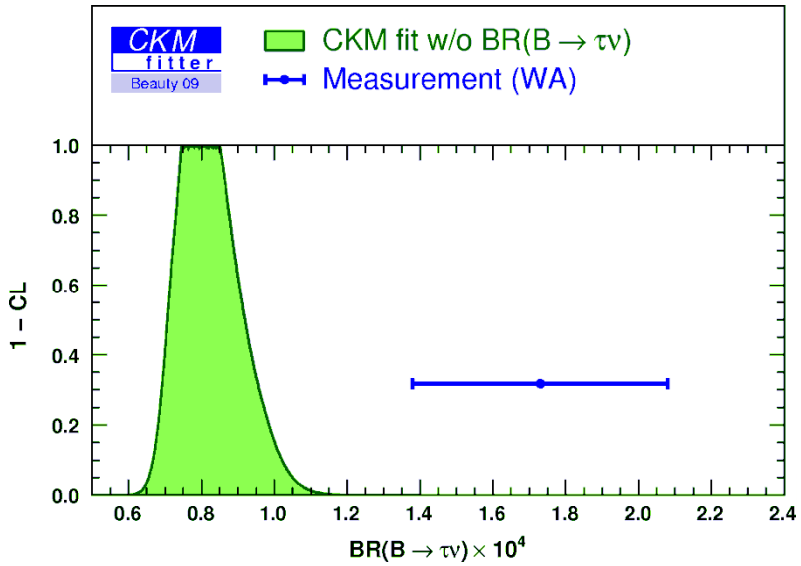
$B \to \tau \nu_\tau$ - results

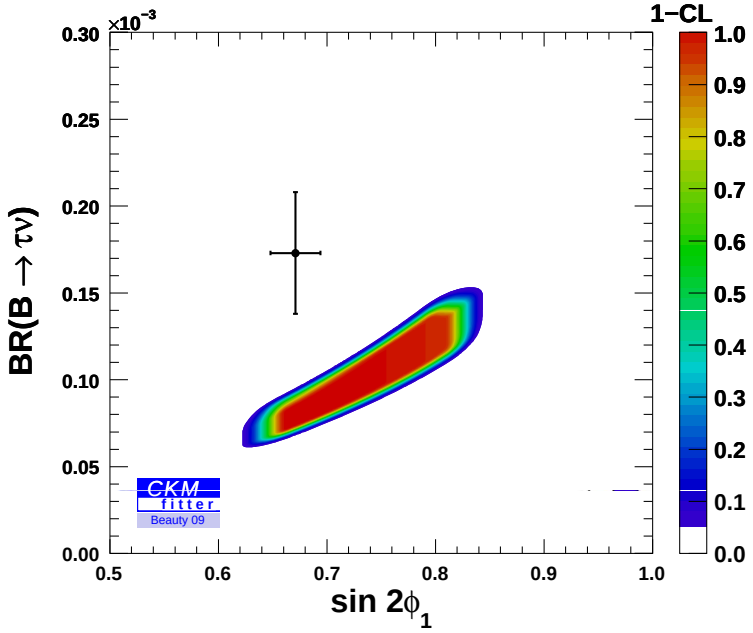
Naïve world average

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

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

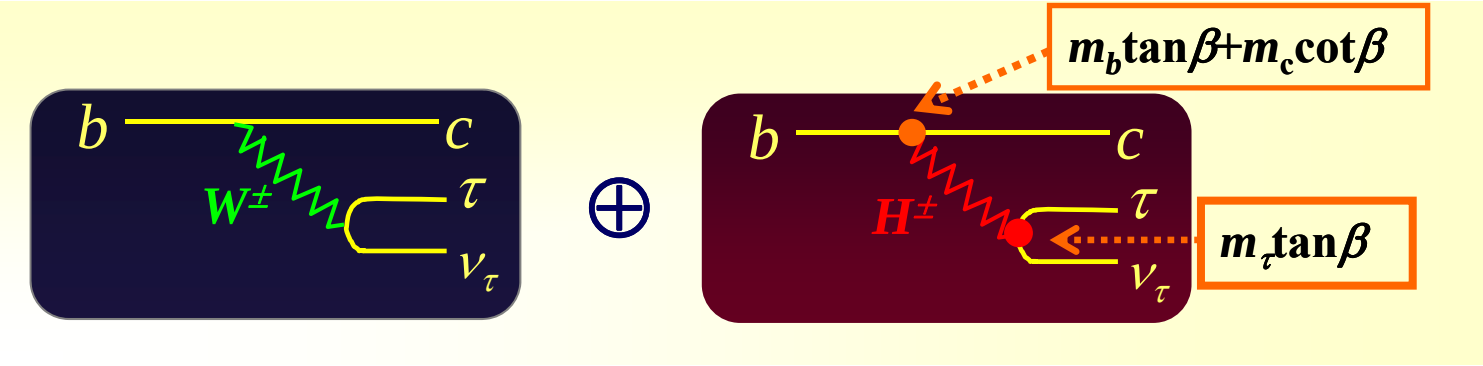
Output of a CKM fit without including $B \to \tau \nu_\tau$ in the fit (CKM fitter, Beauty 09)





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

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



✓Alternative theory uncertainties:

- free from f_B, depends on the $B \to D^{(*)} \tau \nu_\tau$ formfactors;
- $|V_{cb}|$ cancels out in the ratio $R = BF(B \to D \tau \nu_\tau) / BF(B \to D l \nu_l)$

✓ 3-body decay $\Rightarrow$ more observables;
q^2-distribution, τ polarization, D* polarization; possible $\mathcal{O}(1)$ effects from NP

inclusive $BF(b \to c \tau \nu_\tau) = (2.48 \pm 0.26)\%$ from LEP — PDG 2007

A. Cornell et al., arXiv:0906.1652 [hep-ph]

Universality between : H-b-u vertex measured in $B \to \tau \nu_\tau$
H-b-c vertex measured in $B \to D \tau \nu_\tau$
H-b-t vertex measured in direct production by LHC.

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

clean signature

$D^{*-} e^+ + p_{mis}$

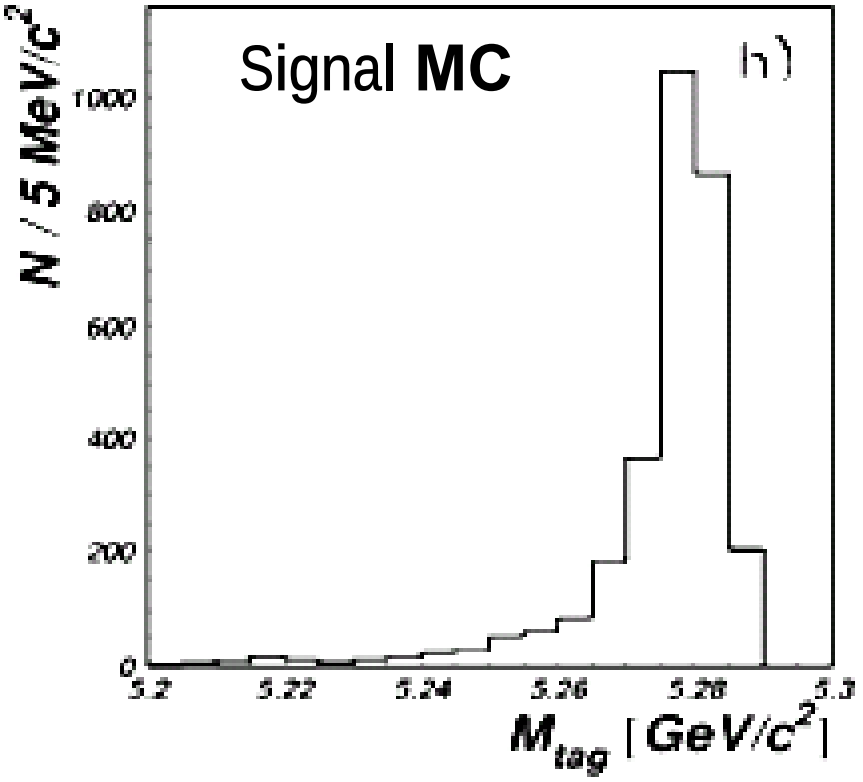
reconstruct B_{tag} inclusively

$\Delta E_{tag} = \Sigma E_i - E_{beam}$

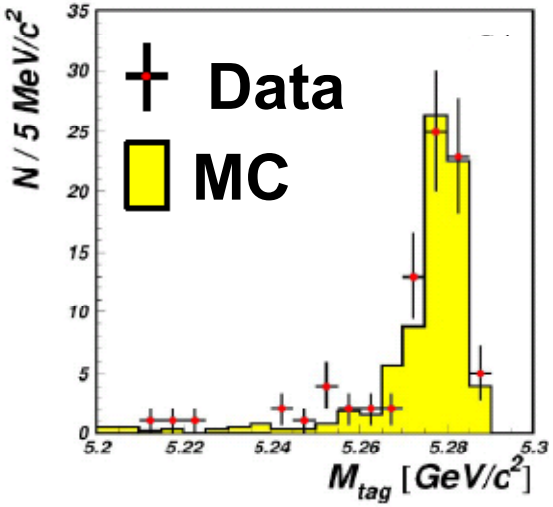
$M_{tag} = \sqrt{E^2_{beam} - (\Sigma \mathbf{p}_i)^2}$

verify B_{tag} reconstruction

Control sample : $B^0_{sig} \to D^{*-} \pi^+$



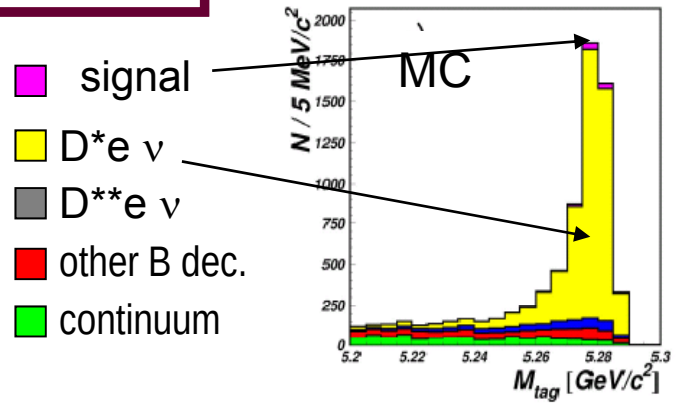
apply all the tag-side selection criteria

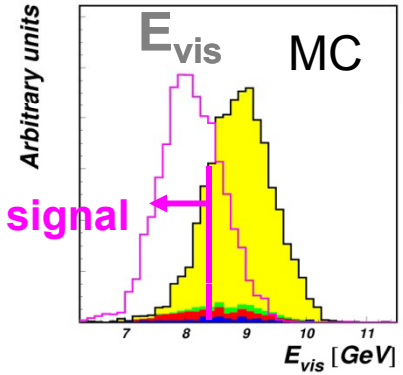


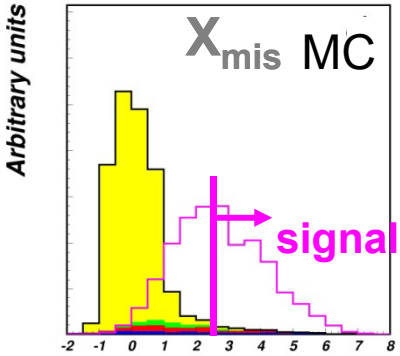
$B^0 \to D^{*-}\tau^+\nu_\tau$ - analysis

background suppression

$\tau \to e\bar{\nu}\nu$ (3ν)







exploit signal-side variables:

visible energy: E_{vis}**<8.3** GeV

X_{mis}>2.75 ★

$X_{mis} \equiv (E_{mis} - |p_{D^*} + p_{e/\pi}|)/|p_B|$

$E_{mis} \equiv E_{beam} - E_{D^*} - E_e$: **$1.9 < E_{mis} < 2.6$ GeV**

missing mass: $M_M^2 \equiv (E_{mis})^2 - (p_{sig} - p_{D^*} - p_{e/\pi})^2$

virtual W mass: $M_W^2 \equiv (E_b - E_{D^*})^2 - (p_{sig} - p_{D^*})^2$

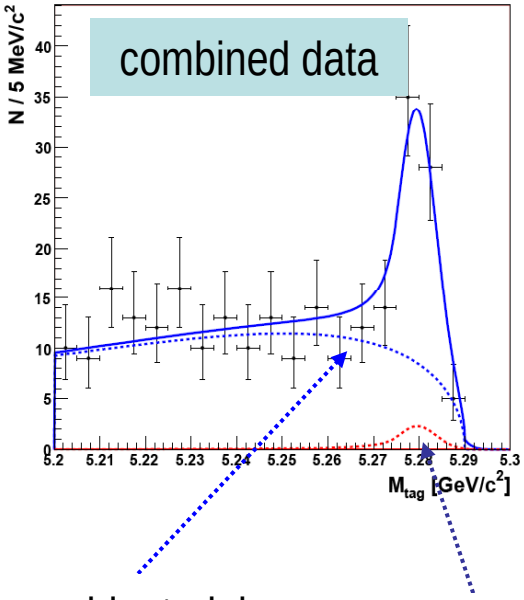
$B^0 \to D^{*-}\tau^+\nu_\tau$ - results

SIGNAL YIELD $N_s = 60^{+12}_{-11}$ **6.7σ (5.2σ with syst.)**

from a combined maximum likelihood fit (with a single *BF*) to 3 M_{tag} distributions

535 M $B\bar{B}$

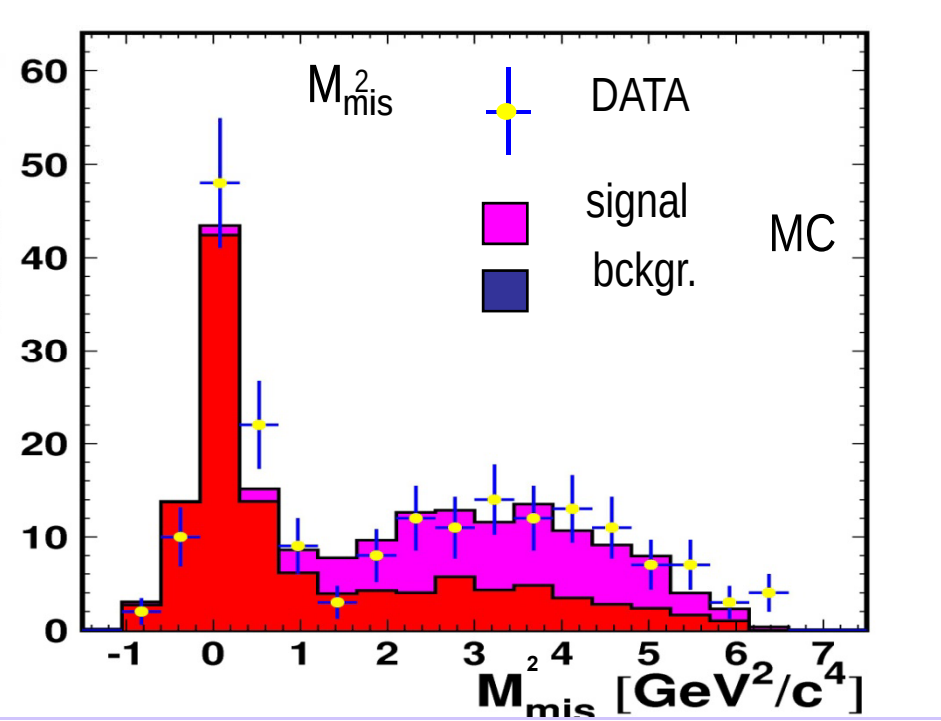
PRL 99, 191807 (2007)



FIRST OBSERVATION

$$BF(B^0 \to D^{*-}\tau^+\nu_\tau) = (2.02^{+0.40}_{-0.37}(stat) \pm 0.37(syst)) \times 10^{-2}$$

CROSS-CHECKS



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

657 M $B\bar{B}$

Extension of the same analysis for B^+ decays.

- $D^{*0} \leftrightarrow D^0$ cross-feeds $\Rightarrow$ simultaneous extraction of signals in $B^+ \to D^{*0}\tau^+\nu_\tau$ and $B^+ \to D^0\tau^+\nu_\tau$;
- signal extraction from UML fit to 2 observable M_{tag} and P_{D0} (P_{D0} = momentum of $\bar{D}^0$ in $\Upsilon(4S)$ rest frame);
- simultaneous fit to 13 decay chains with floating 2 signal BF's and 13 background normalizations;

Signal sub-decay modes:

$D^{*0} \to \bar{D}^0\pi^0$

$\tau \to e\nu\nu$, $\bar{D}^0 \to K^+\pi^-$

$\tau \to e\nu\nu$, $\bar{D}^0 \to K^+\pi^-\pi^0$

$\tau \to \pi\nu$, $\bar{D}^0 \to K^+\pi^-$

$\tau \to \mu\nu\nu$, $\bar{D}^0 \to K^+\pi^-$

$\tau \to \mu\nu\nu$, $\bar{D}^0 \to K^+\pi^-\pi^0$

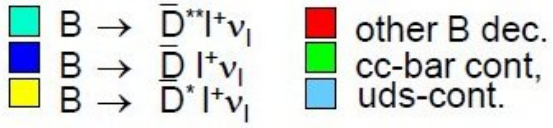
$B^+ \to D^{(*)0}\tau^+\nu_\tau$ - analysis

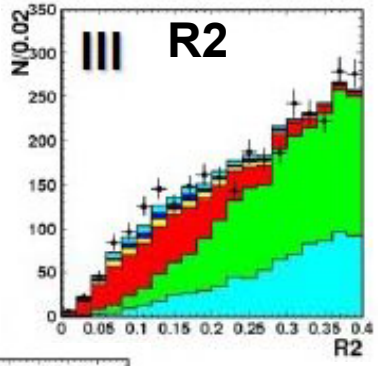
Fit scale factors for the background components:

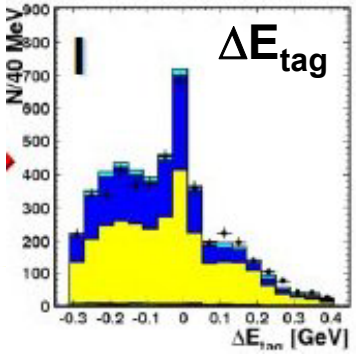
$B \to D^* l\nu$, other B decays,
$B \to D l\nu$, $\bar{c}c$-continuum,
$B \to D^{**} l\nu$, uds-continum

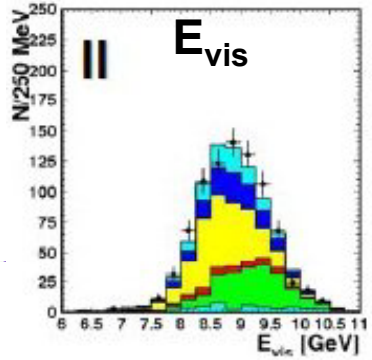
using experimental distributions in sidebands

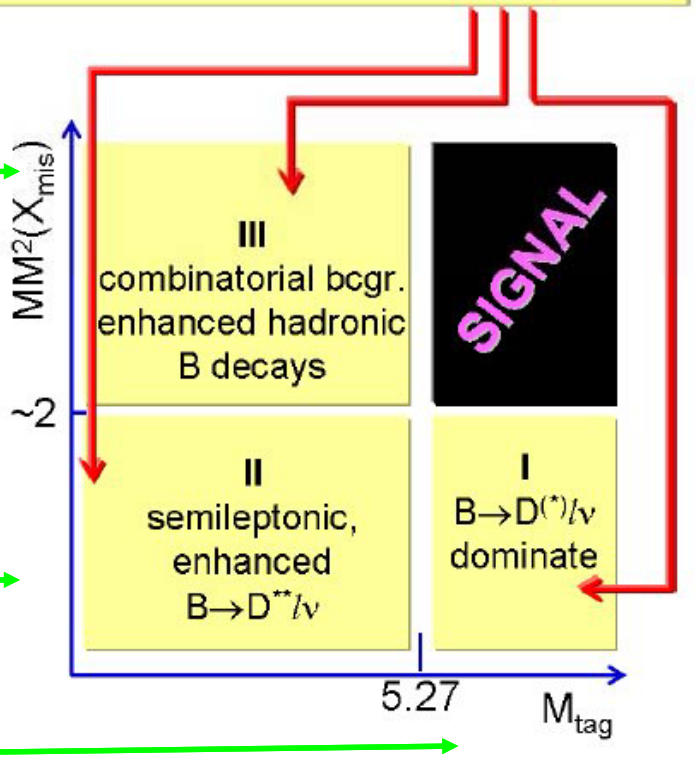
- **background calibration**







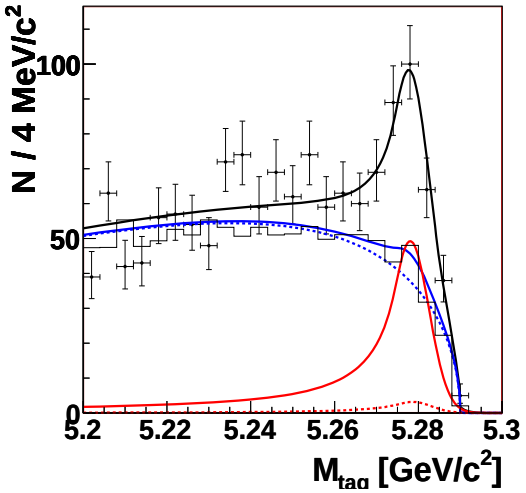


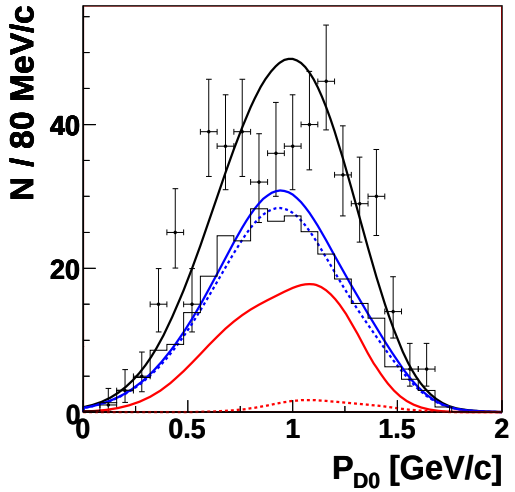


$B^+ \to D^{(*)0}\tau^+\nu_\tau$ - results

hep-ex/1005.2302
submitted to PRL

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

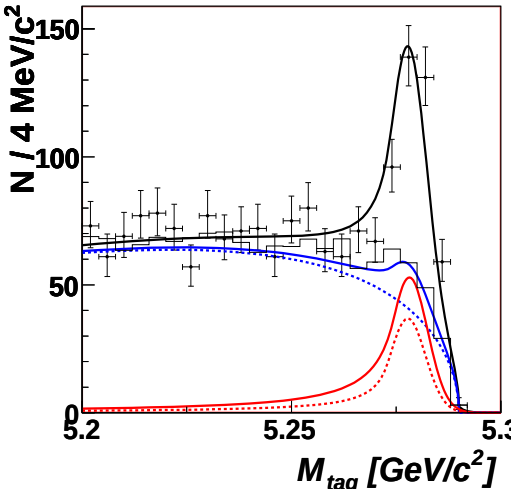


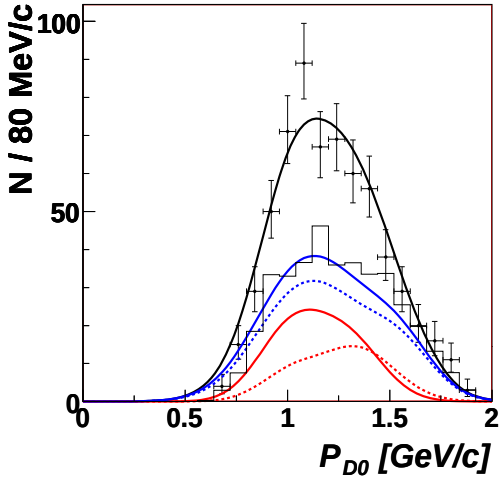


$$N(\overline{D}^{*0}\tau^+\nu_\tau) = 446^{+58}_{-56} \quad 8.1\sigma$$

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

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





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

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

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

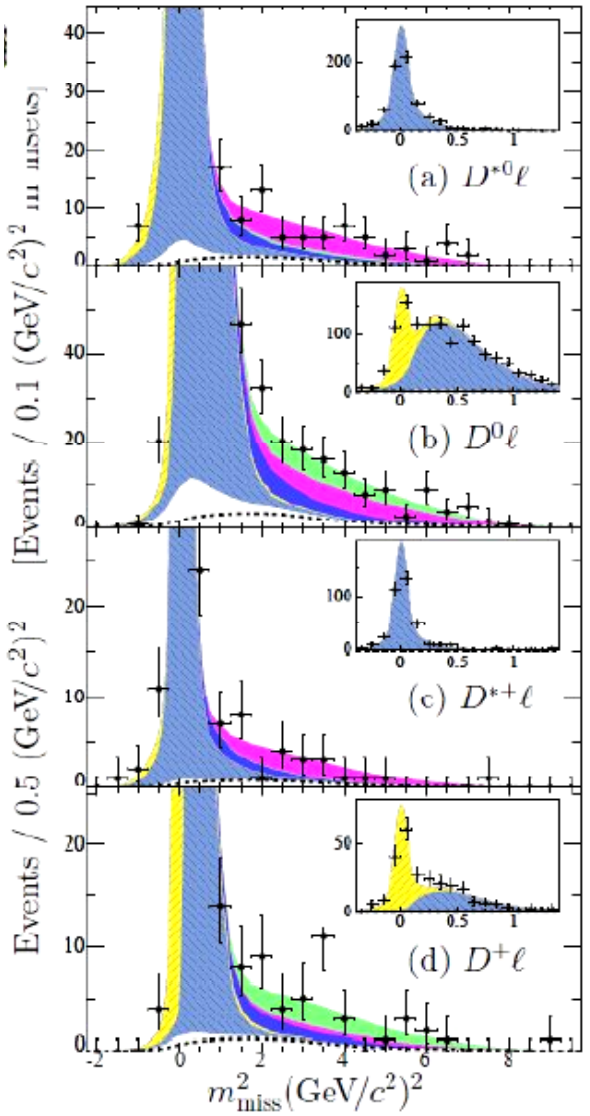
- 238M $B\bar{B}$
- Hadronic tags.
- Signal characterized by large MM^2.
- Simultaneous extraction of $D\tau\nu/D^*\tau\nu$.
- Also measure decay distributions for the first time.

PRL 100, 021801 (2008)

PRD 79, 092002 (2009)

	R(%)	Ns	Signif.
$D^0 \tau \nu$	$31.4 \pm 17.0 \pm 4.9$	35.6 ± 19.4	1.8(1.8)
$D^+ \tau \nu$	$48.9 \pm 16.5 \pm 6.9$	23.3 ± 7.8	3.3(3.6)
$D^{*0} \tau \nu$	$34.6 \pm 7.3 \pm 3.4$	92.2 ± 19.6	5.3(5.8)
$D^{*+} \tau \nu$	$20.7 \pm 9.5 \pm 0.8$	15.5 ± 7.2	2.7(2.7)

$D^0 \tau \nu + D^+ \tau \nu$: 3.6 (4.9) σ



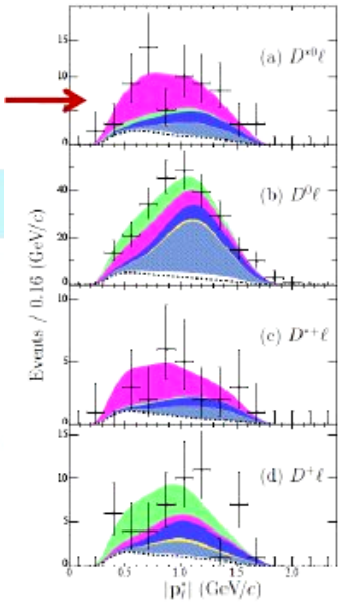
$B^+ \to D^{(*)0} \tau^+ \nu_\tau$

PRL 100, 021801 (2008)

PRD 79, 092002 (2009)

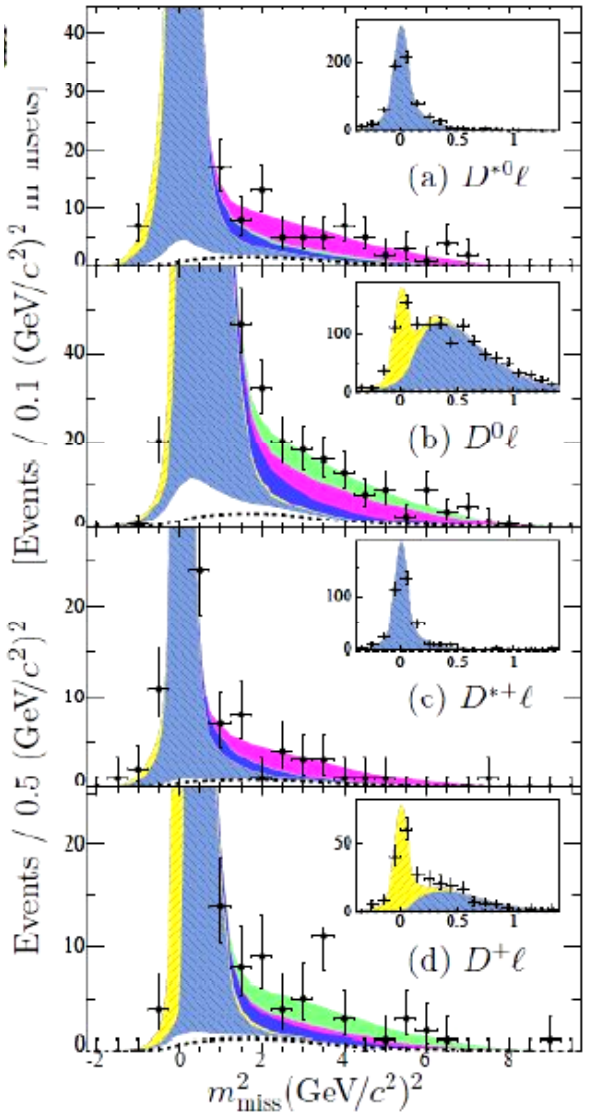
- 238M $B\bar{B}$
- Hadronic tags.
- Signal characterized by large MM^2.
- Simultaneous extraction of $D\tau\nu/D^*\tau\nu$.
- Also measure decay distributions for the first time.

P_{lep} distributions →

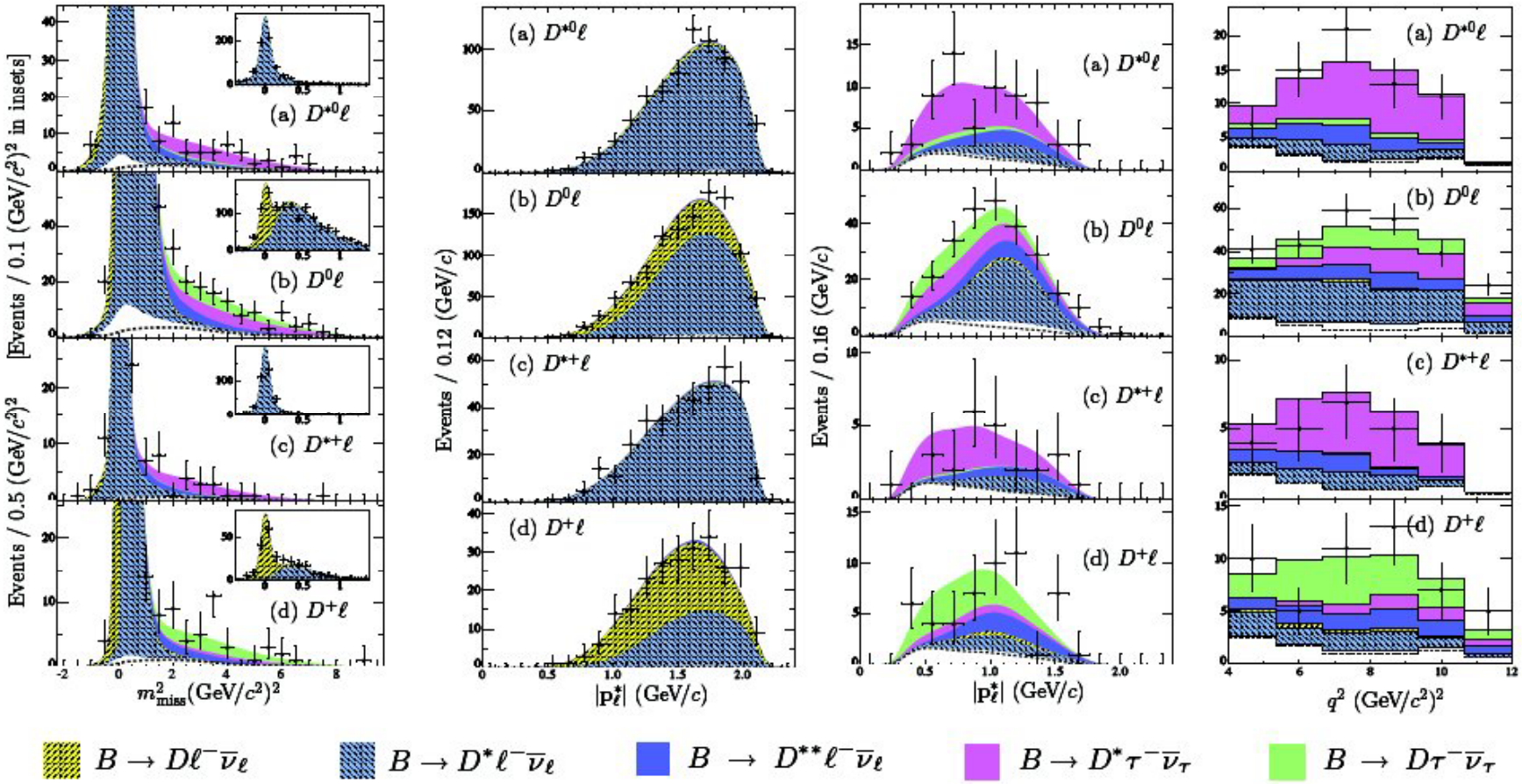


	R(%)	Ns
$D^0 \tau \nu$	$31.4 \pm 17.0 \pm 4.9$	35.6 ± 19.4
$D^+ \tau \nu$	$48.9 \pm 16.5 \pm 6.9$	23.3 ± 7.8
$D^{*0} \tau \nu$	$34.6 \pm 7.3 \pm 3.4$	92.2 ± 19.6
$D^{*+} \tau \nu$	$20.7 \pm 9.5 \pm 0.8$	15.5 ± 7.2

$D^0 \tau \nu + D^+ \tau \nu$: 3.6 (4.9) σ



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



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

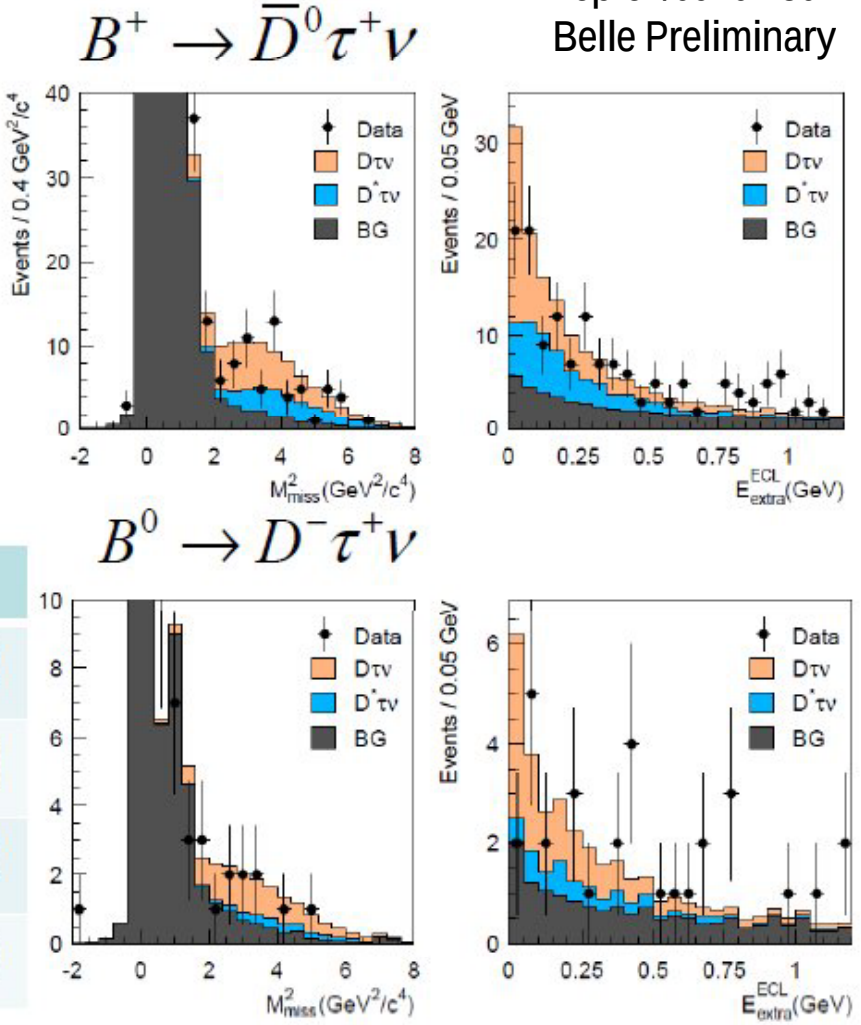
$$\mathcal{B}(B \to \overline{D}^*\tau^+\nu) = (1.62 \pm 0.31 \pm 0.10 \pm 0.05)\% \quad (6.2\sigma)$$

First measurem't of kinematic distributions: q^2, $|\mathbf{p}^*_\ell|$

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

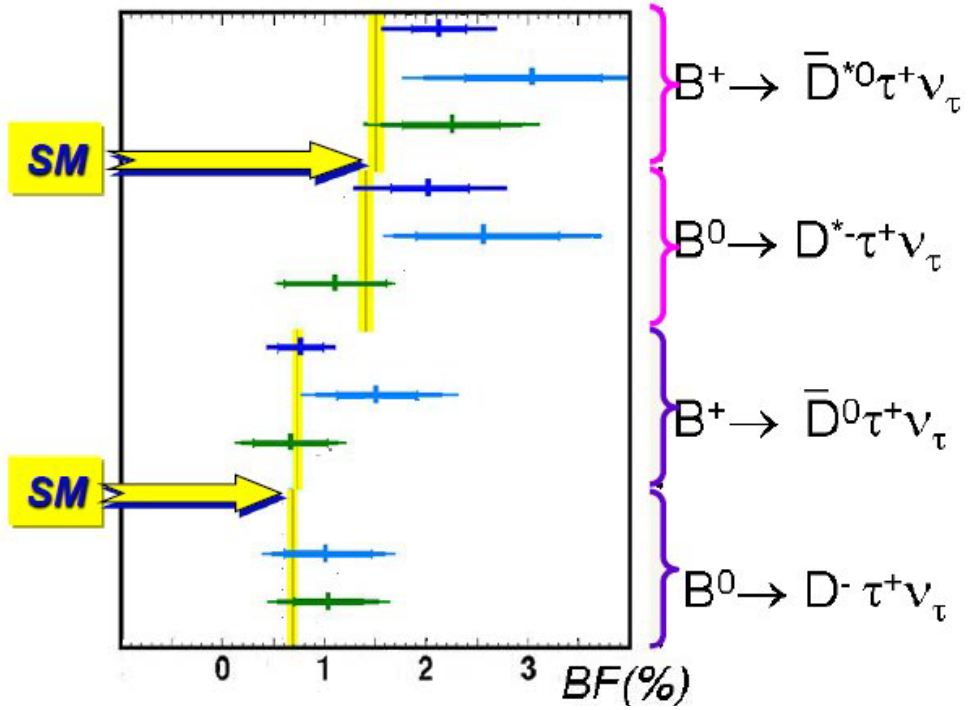
- 657M $B\bar{B}$
- Hadronic tags.
- Extract signals in (MM^2, E_{ECL}) distribution.
- Simultaneous extraction of $D\tau\nu/D^*\tau\nu$.

hep-ex/0910.4301
Belle Preliminary

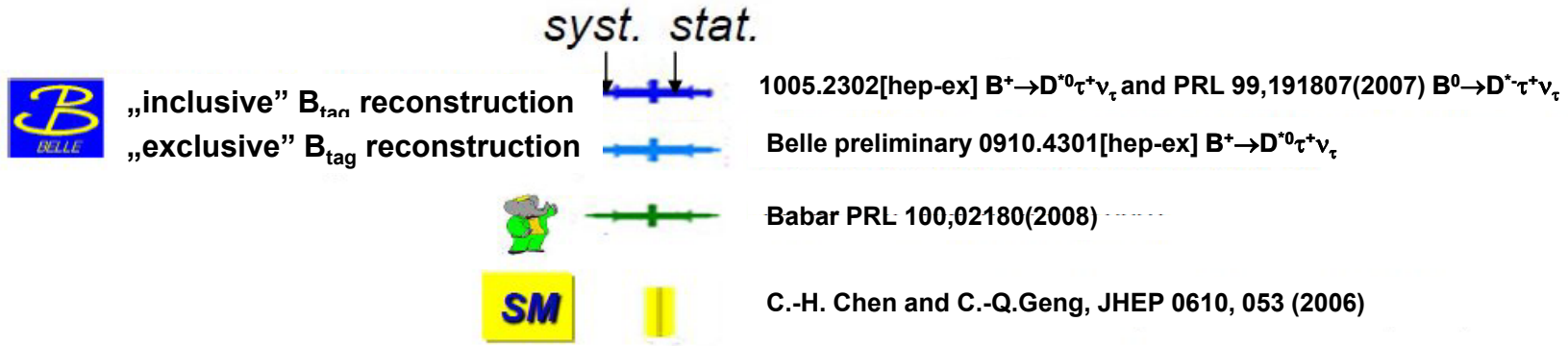


	R(%)	Ns	Signif.
$D^0\,\tau\,\nu$	$70.2^{+18.9}_{-18.0}{}^{+11.0}_{-9.1}$	$98.6^{+26.3}_{-25.0}$	3.8(4.4)
$D^+\,\tau\,\nu$	$47.6^{+21.6}_{-19.3}{}^{+6.3}_{-5.4}$	$17.2^{+7.7}_{-6.9}$	2.6(2.8)
$D^{*0}\,\tau\,\nu$	$46.8^{+10.6}_{-10.2}{}^{+6.2}_{-7.2}$	$99.8^{+22.2}_{-22.3}$	3.9(5.2)
$D^{*+}\,\tau\,\nu$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

Summary of $B^+ \to D^{(*)0}\tau^+\nu_\tau$



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



SUMMARY

Rich program of $B \to E_{mis}$ studies is being pursued in B-factories

- Measurements of (semi)tauonic-B decays are now well established and provide constraints on charged Higgs sector that are competitive with direct searches;
- high luminosity B-factories made possible studies of B meson decays to final states with τ-leptons;
- measured BF's are consistent within experimental uncertainties with expectations of the SM but:

  large BF($B \to \tau\nu$)
  large BF($B \to D^*\tau\nu$)

Looking forward for the Belle results with full data sample of 772 M $B\bar{B}$, it has been reprocessed with much improved charged particle tracking.

and to Super B-factories

BACKUP

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

Semileptonic vs purely leptonic

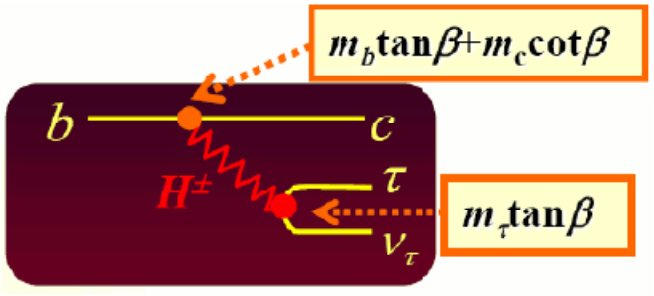
$B \to D^{(*)}\tau\nu_\tau$ has more observables (τ and D^* polarizations) than $B^+ \to \tau^+\nu_\tau$ decay

$B \to D\tau^+\nu_\tau$ are more sensitive to $H^\pm$ contribution but experimentally more challenging than $B^0 \to D^{*-}\tau^+\nu_\tau$ modes

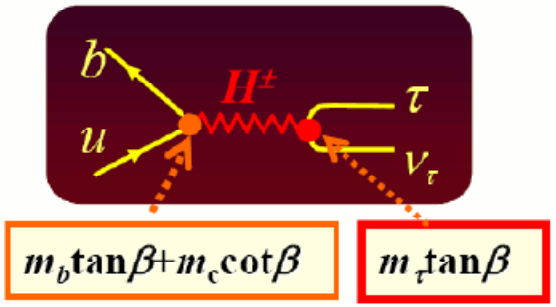
$B^0 \to D^{*-}\tau^+\nu_\tau$ with longitudinally polarized D^* are also sensitive to new physics[2]

$B^0 \to D^{*-}\tau^+\nu_\tau$ are the main background for $B \to D\tau^+\nu_\tau$

Hbc and Hbu vertices complementary with Htb searches at LHC



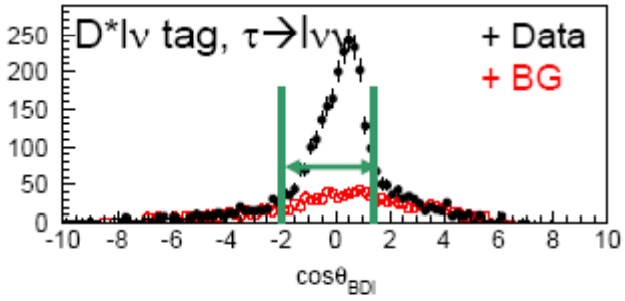
$B \to D^{(*)}\tau\nu_\tau$

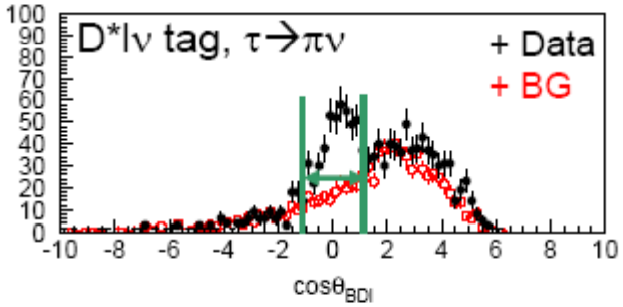


$B \to \tau\nu_\tau$ [1]

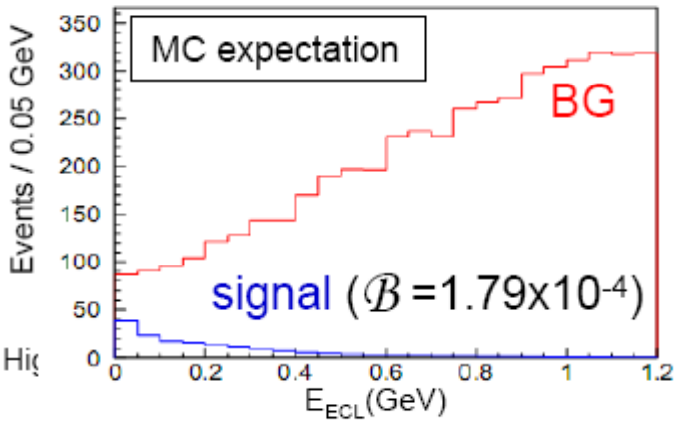
Selection Criteria

- Optimized to maximize FoM$=N_{sig}/\sqrt{N_{sig}+N_{BG}}$ in E_{ECL}<0.2 GeV
  - separately for $\tau\to l\nu\nu$ and $\pi\nu$ modes
- **Blind analysis**: E_{ECL} <0.4 GeV is masked until selection criteria are finalized
- Tagging side
  - Identified using a kinematic relation $\cos\theta_{B-D^{(*)}l}=\frac{2E_BE_{D^{(*)}l}-M_B^2-M_{D^{(*)}l}^2}{2P_BP_{D^{(*)}l}}$





- **Signal side**
  - **N_{sig} extracted from E_{ECL}**
  - **Clear Signal and BG separation expected**



$B^+ \to D^{(*)0}\tau^+\nu_\tau$ Background