B decays to τ at Belle

OUTLINE

- motivation
- experimental techniques
- results
- summary

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

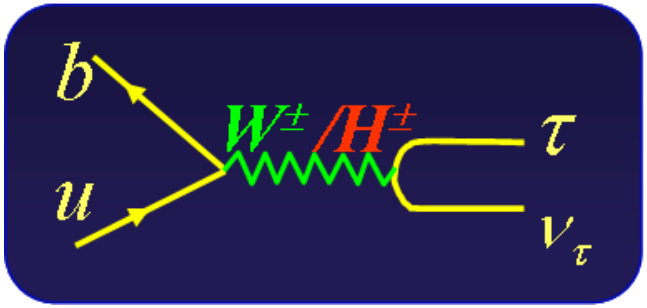
$B \to \bar{D}^{(*)} \tau^+ \nu_\tau$

New

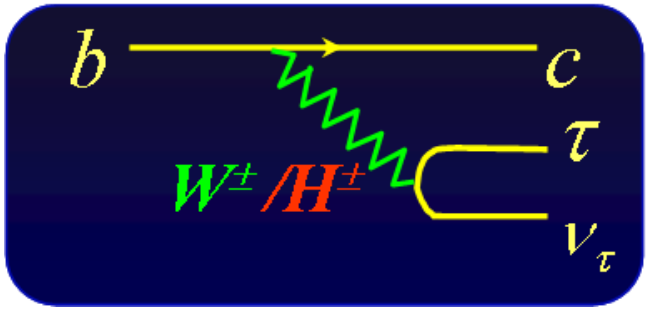
Maria Różańska
for the Belle Collaboration

Motivation

$B^+ \rightarrow \tau^+ \nu_\tau$



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



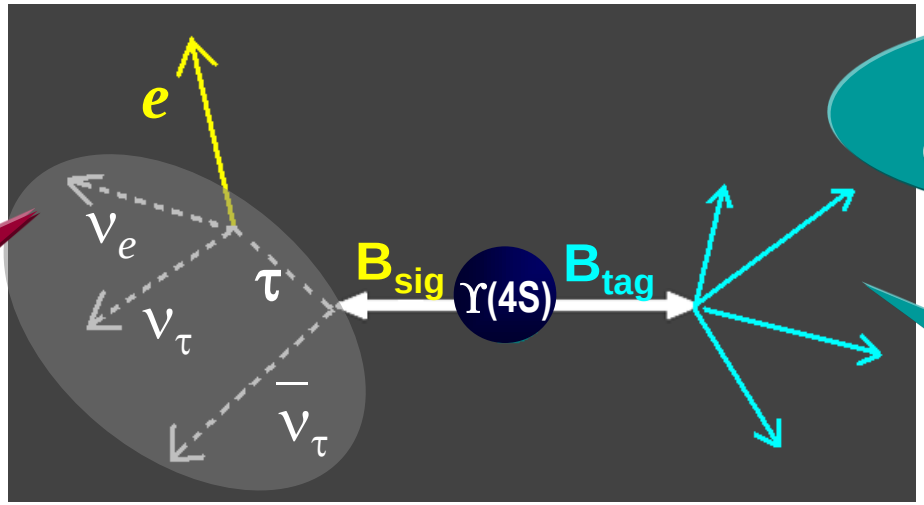
- sensistive to new physics, *e.g.* extended Higgs sector – NP at tree level;
- learn about standard model:

  e.g. *B-decay constant f_B,* *form-factors that cannot be accessed in other semileptonic B decays;*

- experimentally challenging – still poorly known ; *multiple ν's in final states*

Experimental techniques

e.g. $B \to \tau \nu_\tau$, $\tau \to e \nu_e \nu_\tau$



at B-factories:
$e^+e^- \to \Upsilon(4S) \to B\bar{B}$

signature:
$e + p_{mis}$

reconstruct B_{tag}

B_{tag} reconstruction:

- $B\bar{B}$ event
- assignment of secondaries to B_{sig}
- kinematical constraints on B_{sig}

Methods of B_{tag} reconstruction:

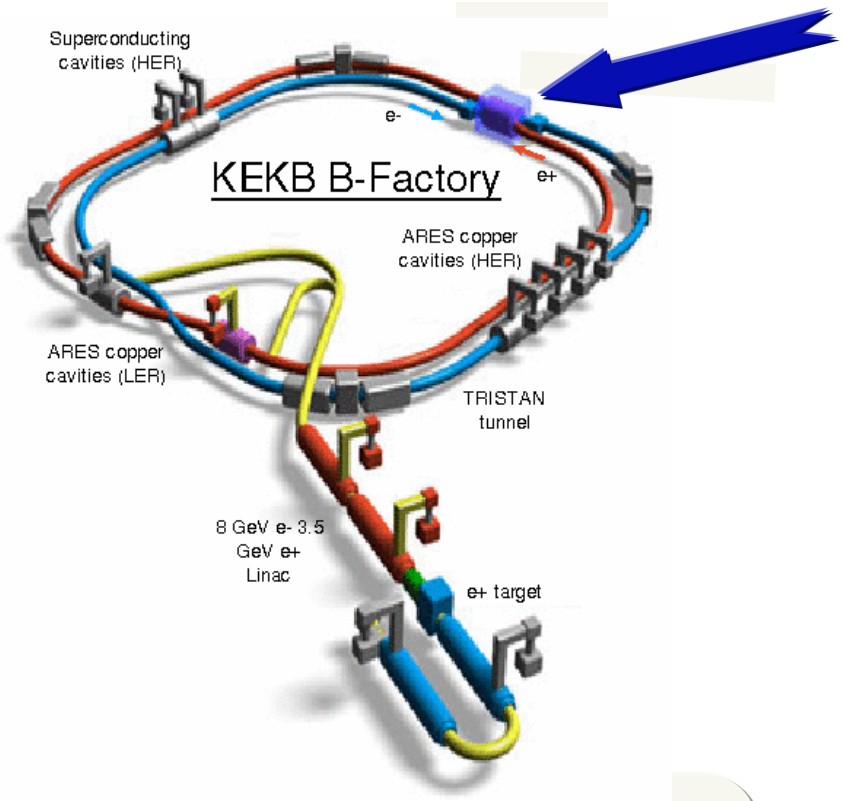
- ***"exclusive"***

reconstruct B_{tag} (in exclusive mode) and check whether remaining particles consistent with B_{sig}

- ***"inclusive"***

select B_{sig} candidate and check whether remaining particles consistent with B decay

KEKB / Belle

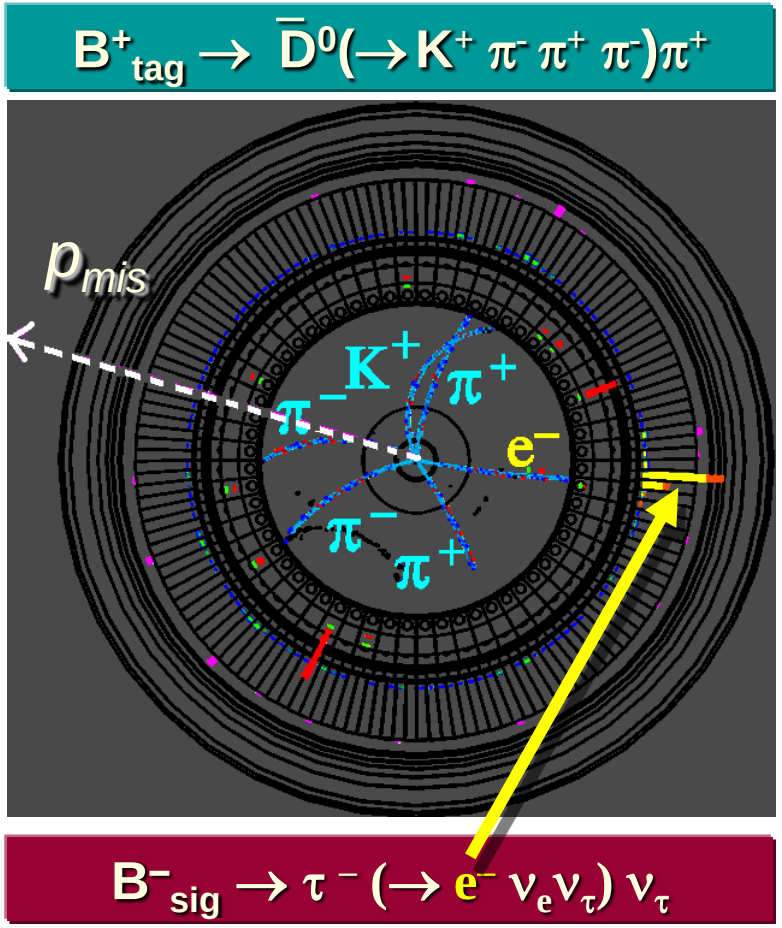


8 GeV e^- × 3.5 GeV e^+

$L_{peak} = 2.11 \times 10^{34}$

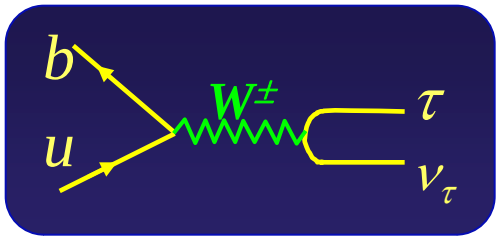
$L_{int} = 1\ ab^{-1}$; 700 fb^{-1} @ $\Upsilon(4S)$

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



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

SM: W-mediated annihilation



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

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

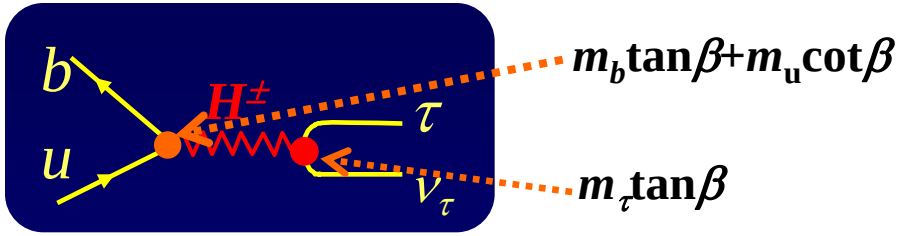
$$BF(B \to \tau\nu)_{SM} = [1.2 \pm 0.25] \times 10^{-4}$$

most accessible purely leptonic B decay

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

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

- Sensitive to charged Higgs:



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

- CP Violation may be sensitive to "unparticle" physics

R. Zwicky, Phys.Rev.D **77,** 036004(2008),
C.-S. Huang and X.-H. Wu, Phys.Rev.D **77**, 075014(2008)

results

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

reconstruct B_{tag} in exclusive modes

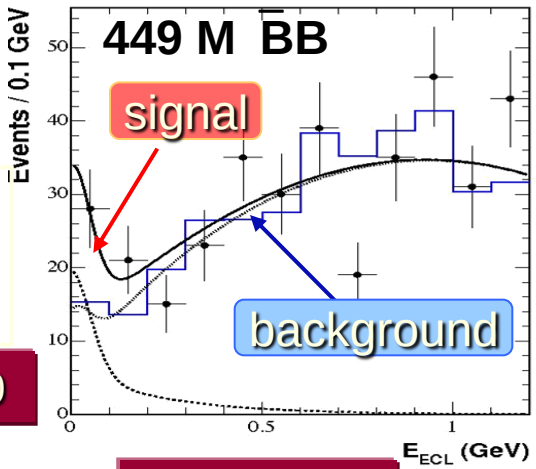
hadronic tags

first evidence

PRL **97**, 251802 (2006)

E_{ECL} residual energy in calorimeter

for signal $E_{ECL} \approx 0$



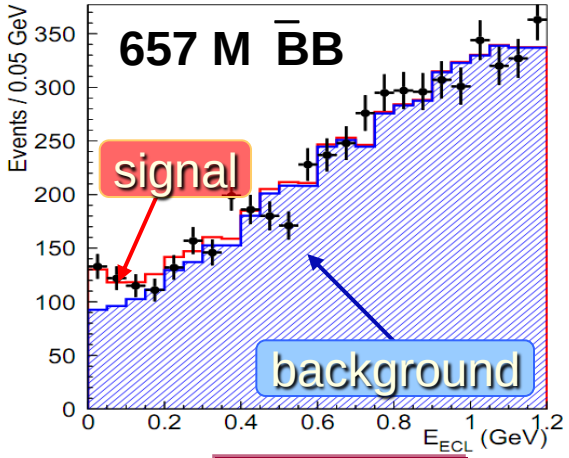
3.5σ $N_{sig} = 17.2^{+5.3}_{-4.7}$

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

semileptonic tags

preliminary

arXiv: 0809.3834, BELLE-CONF-0840



3.8σ $N_{sig} = 154^{+36}_{-35}$

$$BF(B \to \tau\nu) = [\mathbf{1.65}^{+0.38}_{-0.37}(stat)^{+0.35}_{-0.37}(syst)] \times 10^{-4}$$

other measurements:

BaBar:

$$BF(B \to \tau\nu) = [\mathbf{1.8}^{+0.9}_{-0.8}(stat) \pm 0.4 \pm 0.2] \times 10^{-4}$$

PRD **77**, 011107 (2008)

$$BF(B \to \tau\nu) = [\mathbf{1.8}^{+0.9}_{-0.8}(stat) \pm 0.8 \pm 0.1] \times 10^{-4}$$

arXiv:809.4027

predictions:

SM+LQCD:

$$BF(B \to \tau\nu)_{SM} = [\mathbf{1.2} \pm 0.25] \times 10^{-4}$$

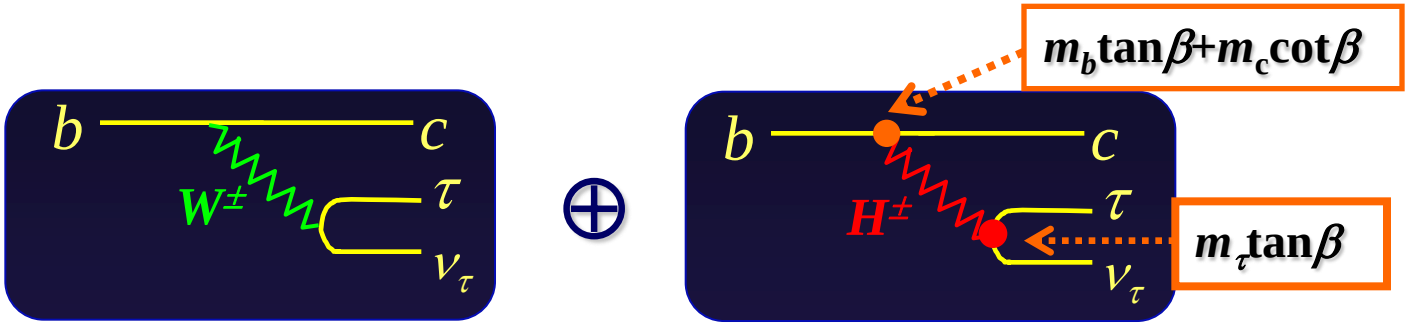
CKM fitter

$$BF(B \to \tau\nu)_{CKM} = [\mathbf{0.80}^{+0.16}_{-0.11}] \times 10^{-4}$$

output of the CKM fit without $B \to \tau\nu$ measurement

http://ckmfitter.in2p3.fr/plots_Beauty09/

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



sensitive to $H^\pm$ and complementary to $B^+ \to \tau^+\nu$

- different theory uncertainties:
  - free from f_B, depends on the $B \to D^{(*)}\tau\nu_\tau$ formfactors;
  - $|V_{cb}|$ cancels out in the ratio $R = \frac{BF(B \to D\tau\nu)}{BF(B \to Dl\nu)}$
- 3-body decay $\Rightarrow$ more observables,
  e.g. q^2-distribution, τ polarization, D* polarization
- universality between: H-b-t vertex (direct production at LHC),
  H-b-u ($B \to \tau\nu_\tau$) and
  H-b-c ($B \to D\tau\nu_\tau$)

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

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

"inclusive" reconstruction of B_{tag}

• select signal candidate:

select decay chains that combine a high reconstruction efficiency with a low background level

$\bar{D}^{(*)}$ decay modes

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

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

τ decay modes

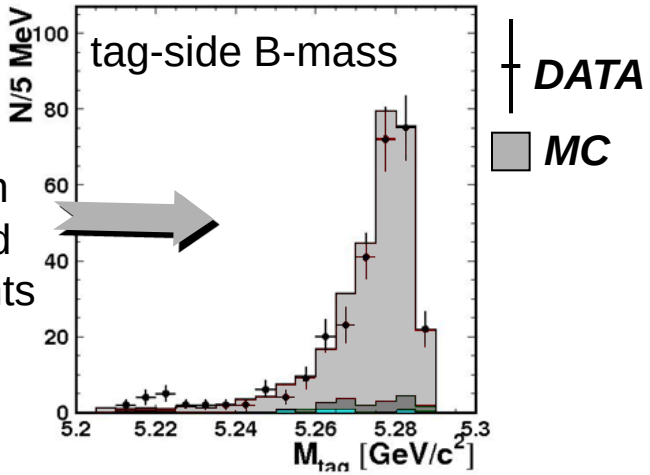
$\tau^+ \to e^+\nu\nu,\ \mu^+\nu\nu,\ \pi^+\nu$

• reconstruct B_{tag} from remaining particles

$$M_{tag} = \sqrt{E_{beam}^2 - (\sum \vec{p}_i)^2}, \quad \Delta E_{tag} = \sum E_i - E_{beam}$$

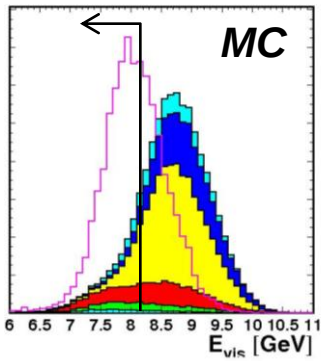
$-0.30\ \text{GeV} < \Delta E_{tag} < 0.05\ \text{GeV}$

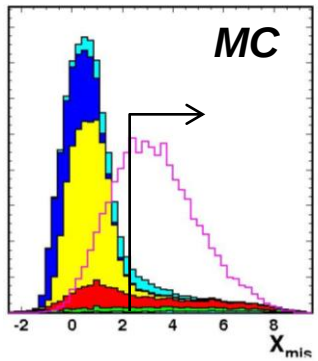
validation with double tagged $B \to D^{*0}\pi$ events



• suppress background *most powerful variables:*

E_{vis} visible energy





- signal
- $B \to D^{**} l\nu$
- $B \to D\, l\nu$
- $B \to D^*\, l\nu$
- other B dec.
- continuum

e.g. $B^+ \to D^0\tau^+(\to e^+\nu\nu)\nu$

$\mathbf{X_{mis}} = [(E_{beam}-E_{sig}) - |\mathbf{p}_{sig}|]/|\mathbf{p}_B|$

similar to missing mass:

$M^2_{mis} = (E_{beam}-E_{sig})^2 - (\mathbf{p}_B - \mathbf{p}_{sig})^2$

E_{sig}, $\mathbf{p}_{sig}$ – reconstructed energy and momentum on the signal side

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

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

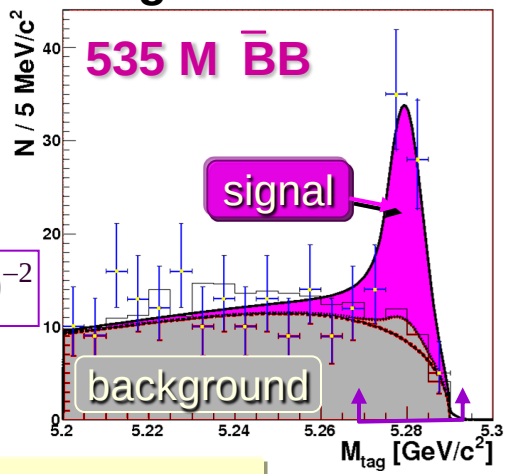
SIGNAL YIELD *from unbinned maximum likelihood (UML) fit to M_{tag}*

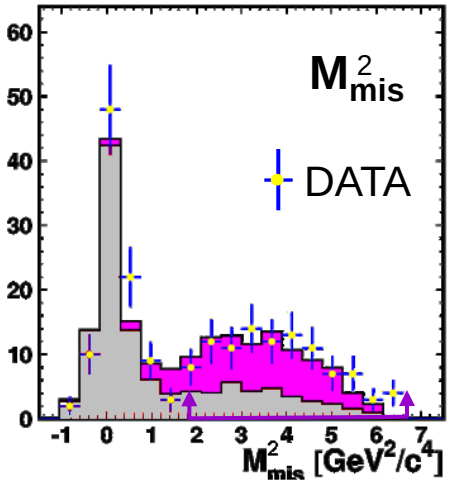
$N_{sig} = 60^{+12}_{-11}$ **5.2σ**

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

first observation PRL **99**, 191807 (2007)

tag side B mass





At large M^2_{mis} flat M_{tag} distribution for most background components.

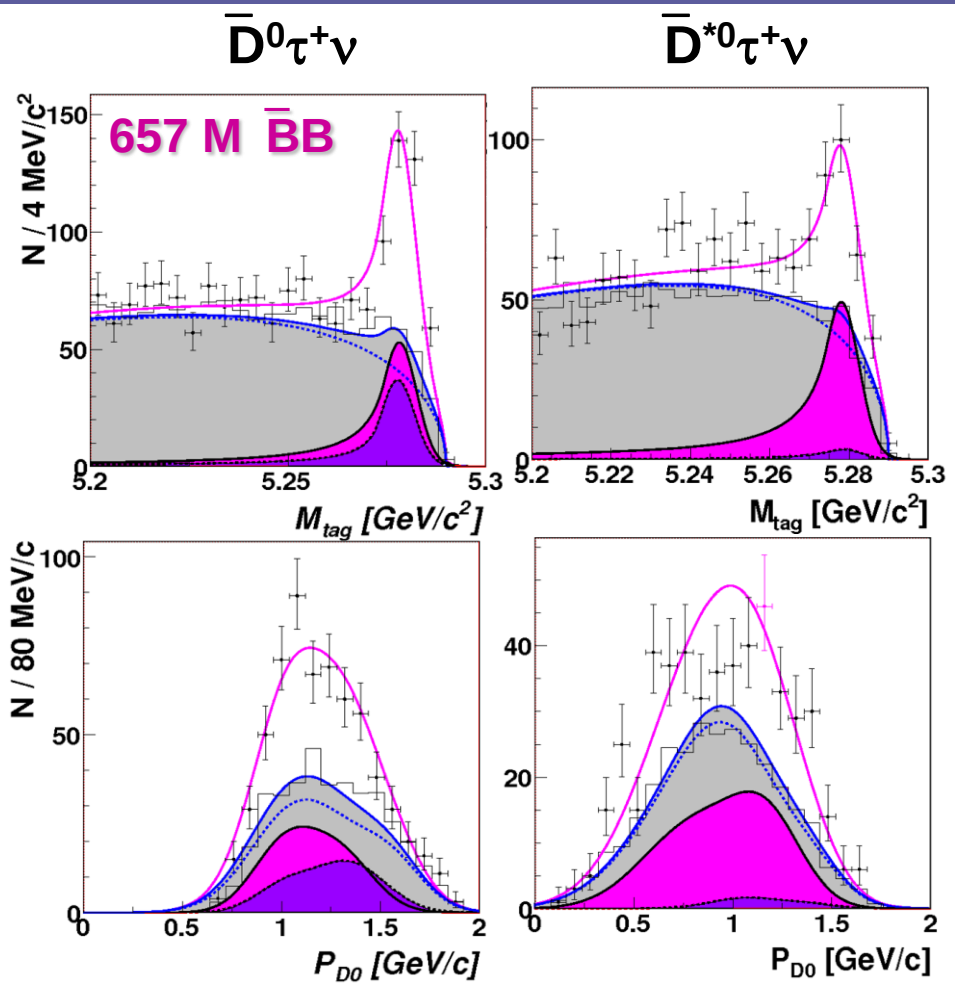
New

Extension of the analysis to $B^+ \to \bar{D}^{(*)0}\tau^+\nu_\tau$

657 M $\bar{B}B$

- $\bar{D}^{*0} \leftrightarrow \bar{D}^0$ cross-feeds $\Rightarrow$ simultaneous extraction of signals in $B^+ \to \bar{D}^{*0}\tau^+\nu_\tau$ and $B^+ \to \bar{D}^0\tau^+\nu_\tau$ modes;
- signal extraction from UML fit to 2-dim distributions in M_{tag} and P_{D^0}
  (P_{D^0} = *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; $\bar{D}^0 \to K^+\pi^-$, $\tau^+ \to e^+, \mu^+, \pi^+$ $\bar{D}^* \to \bar{D}^0\pi^0$, π^0- fully reconstr. or 1 γ missing
  $\bar{D}^0 \to K^+\pi^-\pi^0$, $\tau^+ \to e^+, \mu^+$ $\bar{D}^* \to \bar{D}^0\pi^0$, π^0- fully reconstructed

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



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

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

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

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

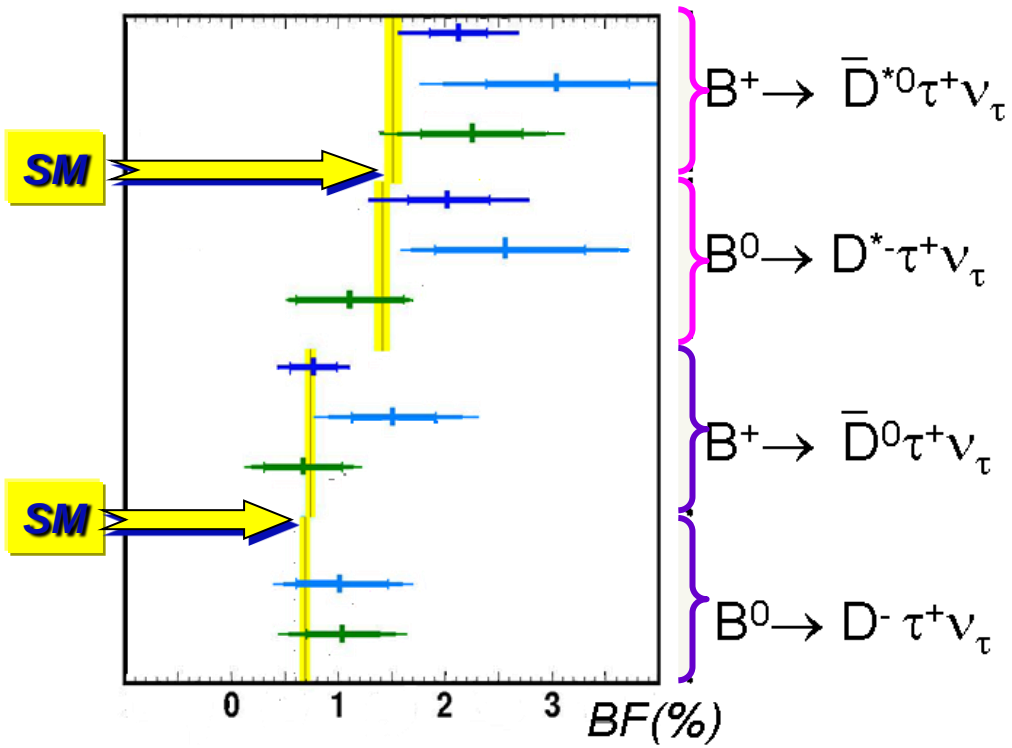
BaBar:

$Br(B^+ \to \bar{D}^{*0}\tau^+\nu_\tau) = [\mathbf{2.25} \pm 0.48(stat) \pm 0.22(syst) \pm 0.17(norm)] \times 10^{-2}$ **5.3σ**

$Br(B^+ \to \bar{D}^0\tau^+\nu_\tau) = [\mathbf{0.67} \pm 0.37(stat) \pm 0.11(syst) \pm 0.07(norm)] \times 10^{-2}$ **1.8σ**

BaBar PRL **100**, 021801(2008)

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



syst. *stat.*

”inclusive” B_{tag} reconstruction — this analysis($B^+ \to \bar{D}^{(*)0}\tau^+\nu$) and PRL **99**, 191807(2007) ($B^0 \to \bar{D}^{*-}\tau^+\nu$)

”exclusive” B_{tag} reconstruction — Belle preliminary, arXiv:0910.4301 [hep-ex]

BaBar PRL **100**, 021801(2008)

SM — C.-H. Chen and C.-Q. Geng, JHEP **0610**, 053 (2006)

Constraints on theoretical models

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

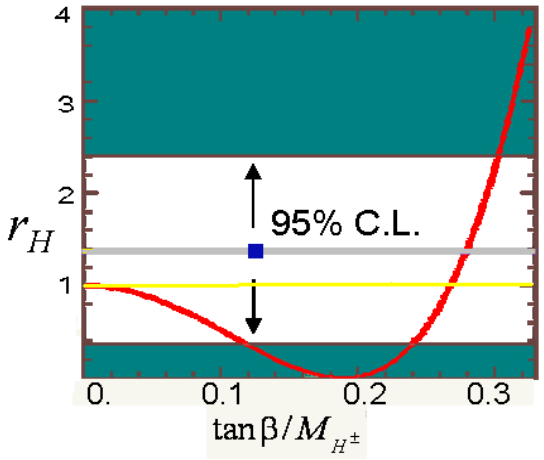
Effects of charged Higgs on *BF*: $BF(B^+ \to \tau^+ \nu_\tau) = BF(B^+ \to \tau^+ \nu_\tau)_{SM} \times r_H$

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

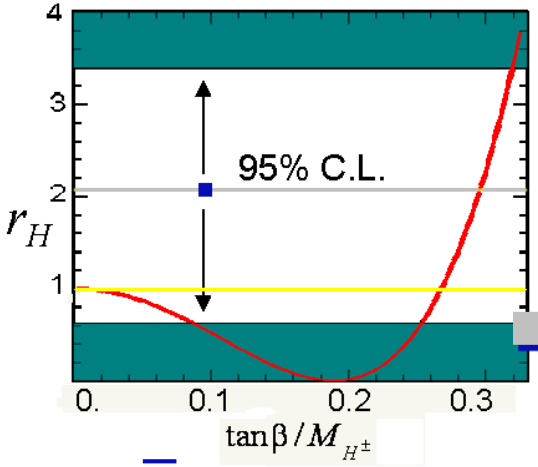
W. S. Hou, PR D **48**, 2342 (1993)

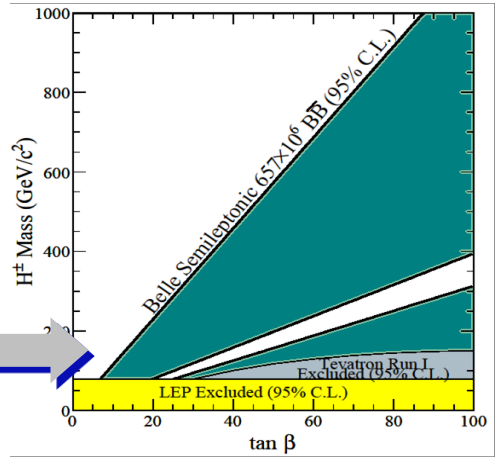
$B^+ \to \tau^+ \nu_\tau$
SL-tags

r_H=1.38±0.52 (LQCD)



r_H=2.07±0.74 (CKM)

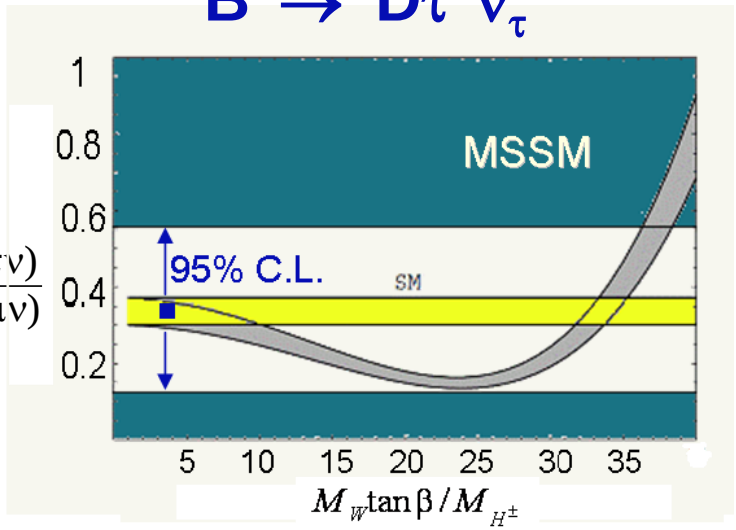




$B \to \bar{D}\tau^+\nu_\tau$

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

$R = \frac{BF(B \to D\tau\nu)}{BF(B \to D\mu\nu)}$



T. Miura, M. Tanaka, arXiv: hep-ph/0109244

SUMMARY

- high luminosity B-factories made possible studies of B meson decays to final states with τ-leptons;
- measurements of (semi)tauonic-B decays are now well established and provide constraints on charged Higgs sector that are competitive with direct searches;
- measured BF's are consistent within experimental uncertainties with expectations of the SM but:
  - large BF($B \to \tau\nu$)?
  - large BF($B \to D^{*}\tau\nu$)??

interesting prospects for Belle-II @ SuperKEKB

BACKUP

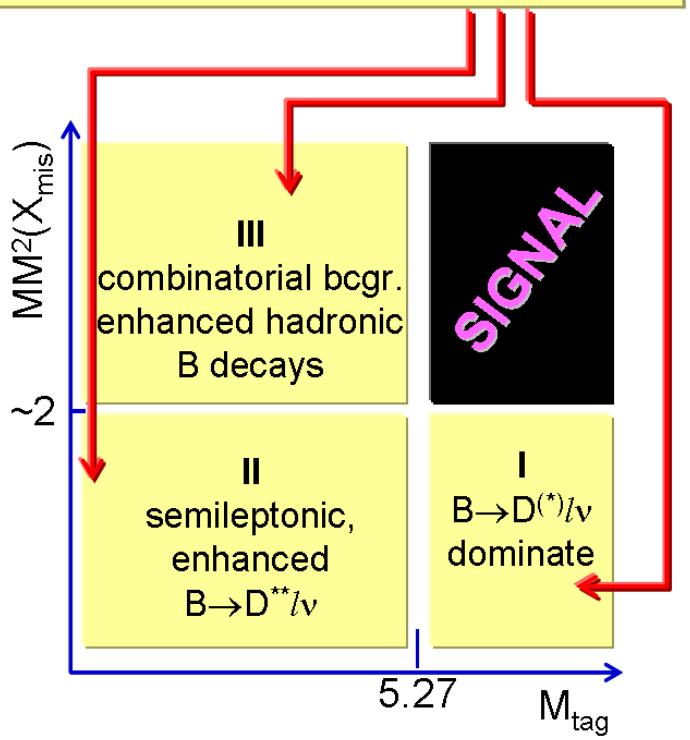
Main steps of the analysis

- preselection
- B_{tag} selection
- **background calibration**
- signal selection criteria from MC
- check side-bands
- check signal-box and extract the signal
- cross-checks and systematics

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 experimentall distributions in side-bands.

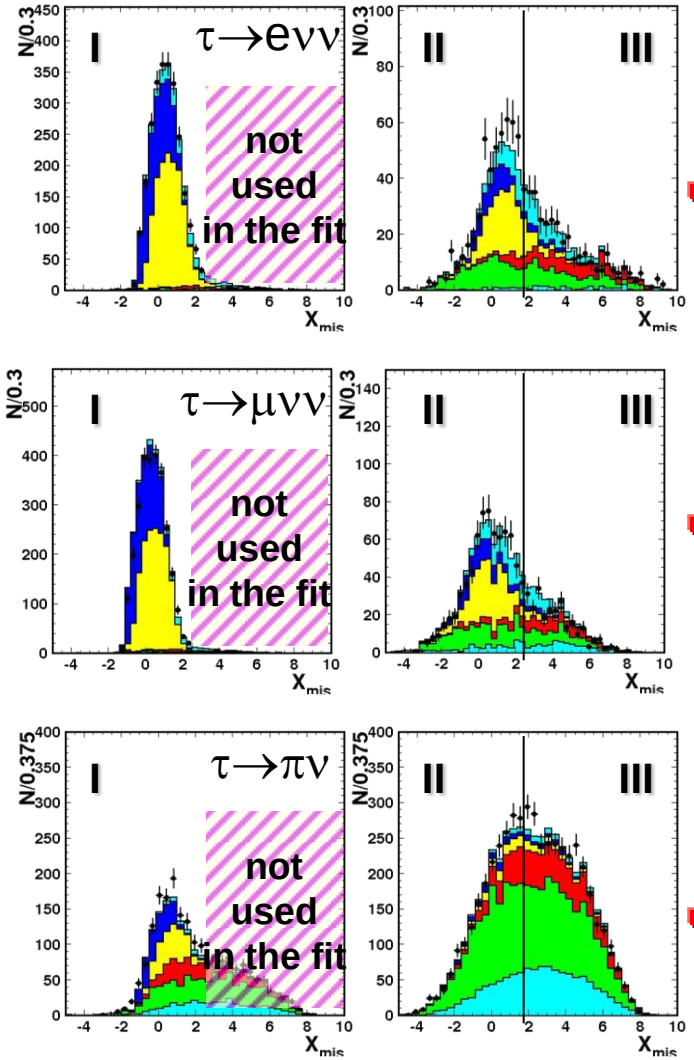


Background calibration

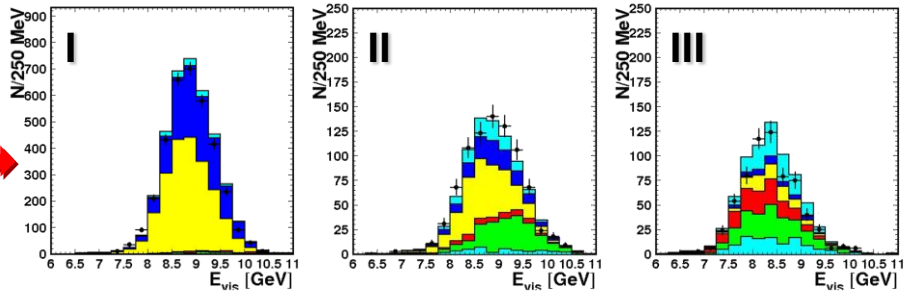
$B^+ \to \bar{D}^0\tau^+\nu_\tau$

$B \to \bar{D}^{**}l^+\nu_l$
$B \to \bar{D}\, l^+\nu_l$
$B \to \bar{D}^*\, l^+\nu_l$
other B dec.
cc-bar cont,
uds-cont.

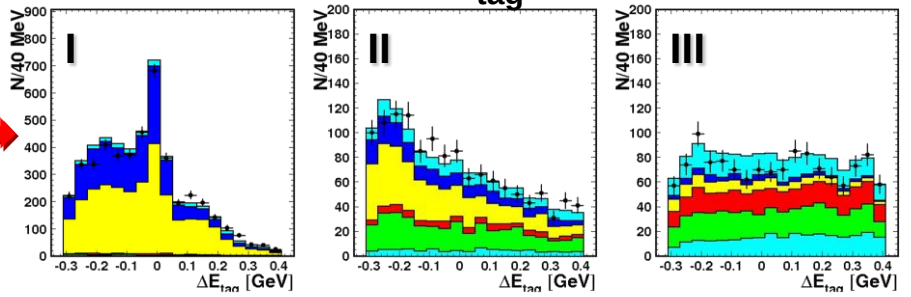
M_{tag}>5.265 GeV M_{tag}<5.265 GeV



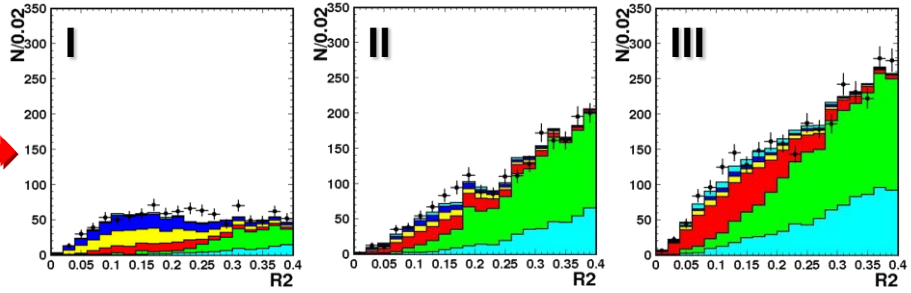
E_{vis}



ΔE_{tag}



R_2



scale factors

0.53	0.53	0.53
0.90	0.90	0.90
0.80	0.80	0.80
1.04	1.04	0.99
1.07	1.07	2.02
1.05	1.05	0.58

$B \rightarrow D^{(*)}\tau\nu$ Semileptonic TagSystematic Errors of Yield

B_{tag}-reconstruction	±12.9	±12.8
BG shape	±3.3	±2.7
signal PDF shape	±2.5	±6.0
Signal selection	+1.3/-1.4	+4.2/-4.4
Total	+13.9	-15.2

method

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

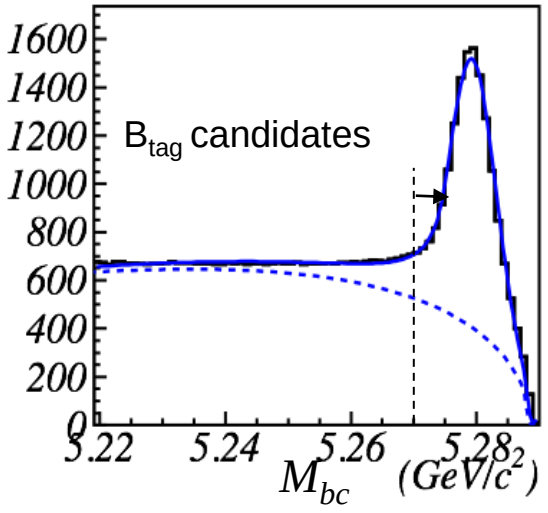
reconstruct B_{tag} in exclusive modes

- **full reconstruction in a hadronic mode**

$$B^- \to D^{(*)0}\pi^-/\rho^-/a_1^-/D_s^{(*)-}$$

$$M_{bc} = \sqrt{E_{beam}^2 - (\sum \vec{p}_i)^2}, \quad \Delta E = \sum E_i - E_{beam}$$

efficiency~0.2%



- **partial reconstruction in a semileptonic mode**

$$B^- \to D^{(*)0} l^- \nu_l, \; l = e, \mu$$

$$\cos\theta_{(B^-, D^{(*)}l)} = \frac{2E_{beam}E_{D^{(*)}_l} - M_B^2 - M_{D^{(*)}_l}^2}{2P_B P_{D^{(*)}_l}}$$

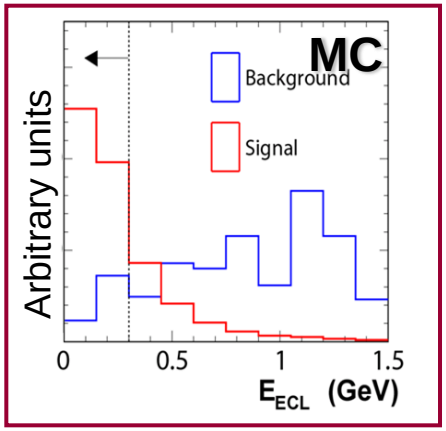
efficiency ~0.7%;
larger background
complementary sample

signal side: $\tau^+ \to e^+\nu\nu,\ \mu^+\nu\nu,\ \pi^+\nu,\ \rho^+\nu,\ (3\pi)^+\nu$

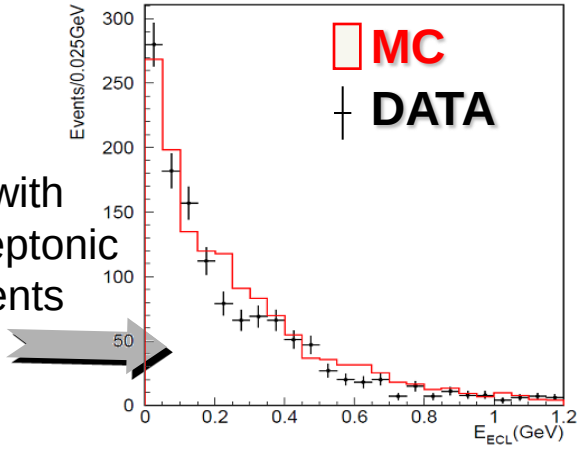
signal signature: no particle left after removing B_{tag} and B_{sig} daughters

E_{ECL}: residual energy in calorimeter

for signal $E_{ECL} \approx 0$



validation with double semileptonic tagged events

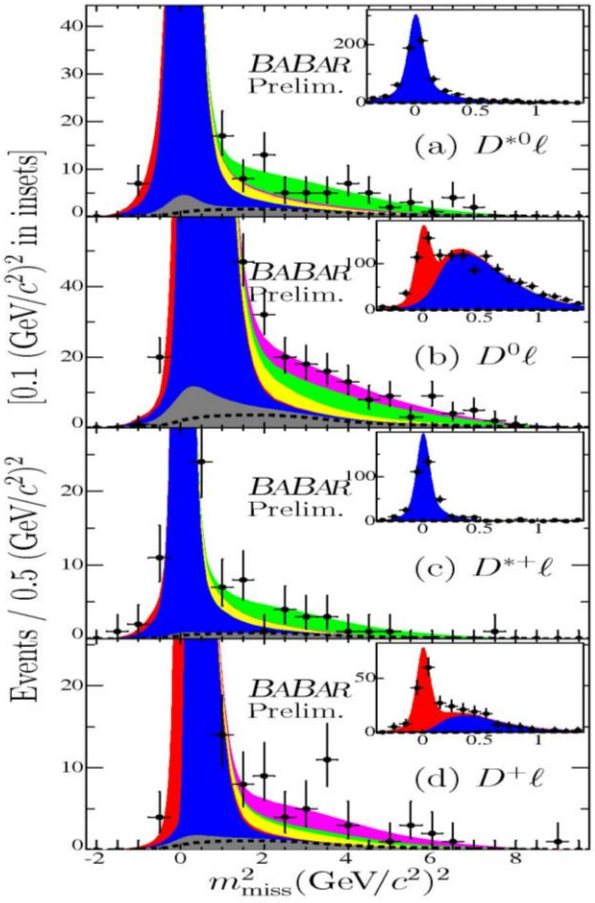


B→τν Semileptonic TagSystematic Errors of Yield

BG PDF shape	+18.1 −17.2
Signal PDF shape	+3.1 −3.2
Br of peaking BG	+6.4 −13.0
Rare B,b→ulν,τ pair BG	+5.9 −5.9
Efficiency ratio	+0.5 −0.6
Total	+20.3 −22.3

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

hep-ex/0707.2758



$BF(B^- \to D^0 \tau\nu) = (0.63 \pm 0.38 \pm 0.10 \pm 0.06)\%$,

$BF(B^- \to D^{*0} \tau\nu) = (2.35 \pm 0.49 \pm 0.22 \pm 0.18)\%$,

$BF(B^0 \to D^- \tau\nu) = (1.03 \pm 0.35 \pm 0.14 \pm 0.10)\%$,

$BF(B^0 \to D^{*-} \tau\nu) = (1.15 \pm 0.53 \pm 0.04 \pm 0.04)\%$

Combined B^- and B^0 :

$BF(B \to D \tau\nu) = (0.90 \pm 0.26 \pm 0.11 \pm 0.06)\%$ (3.5σ),

$BF(B^- \to D^* \tau\nu) = (1.81 \pm 0.33 \pm 0.11 \pm 0.06)\%$ (6.2σ)