



Hot topics from Belle

B decays to τ

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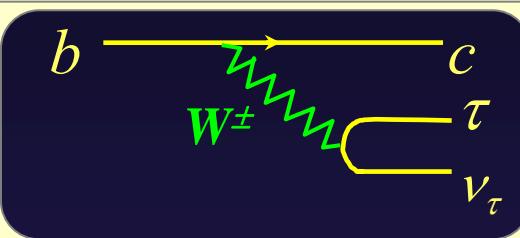
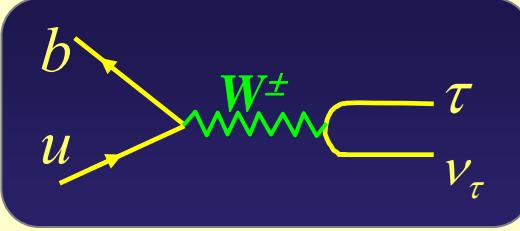
7-14 March 2009

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

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

Summary

Motivation

expected decay rates	examples of SM amplitudes	
$B^0 \rightarrow D^* - \tau^+ \nu_\tau$	$\mathcal{O}(10^{-2})$	
$B^+ \rightarrow \tau^+ \nu_\tau$	$\mathcal{O}(10^{-4})$	

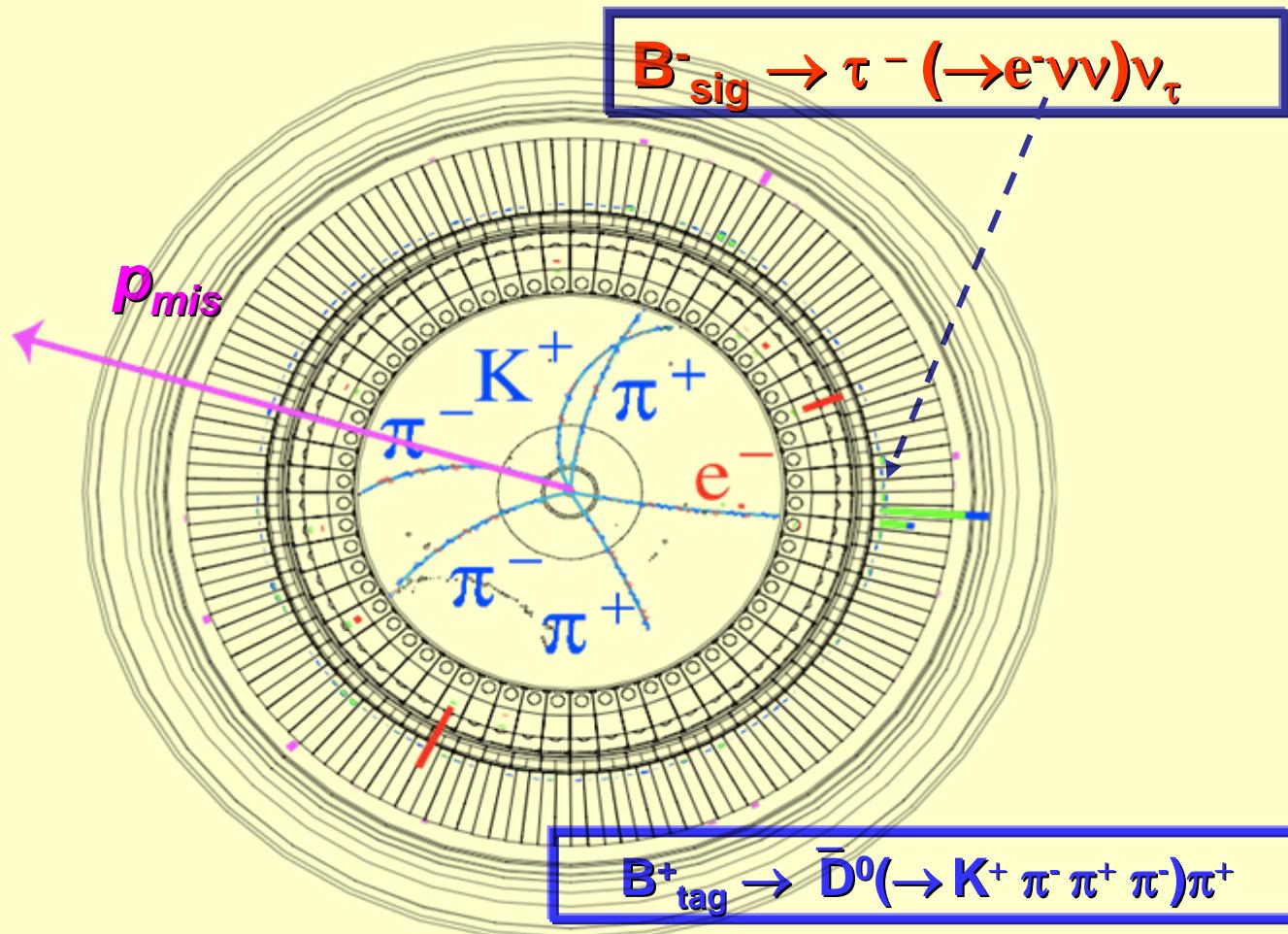
Small hadronic effects;
theoretically clean.

Sensitive to New
Physics

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

Belle event reconstructions

$$e^+ e^- \rightarrow \gamma(4S) \rightarrow \bar{B}B$$

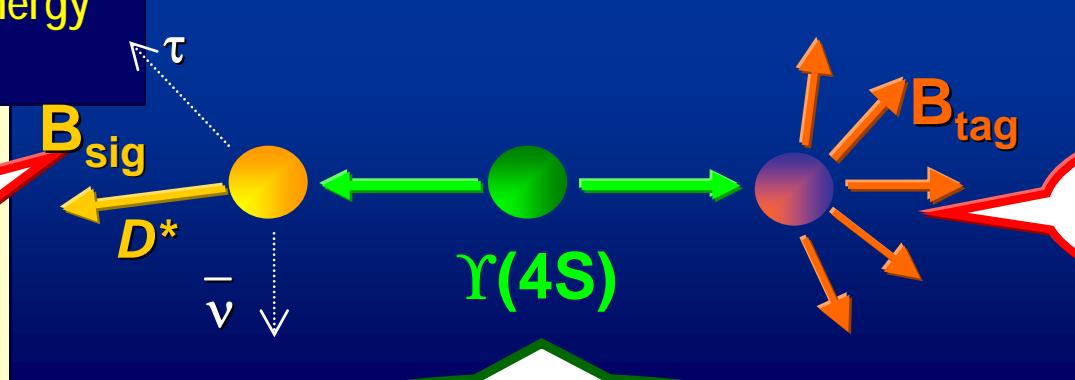


Experimental Techniques

B decay with missing energy

$$\text{e.g. } B^+ \rightarrow D^{*0} \tau \bar{\nu}$$

signature:
 D^* , l/h +
invisible



reconstruct
 B_{tag}

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

B_{tag} reconstruction:

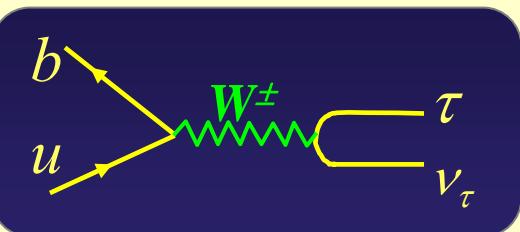
- $B\bar{B}$ event
- which particles belong to B_{sig}
- kinematical constraints on B_{sig}

Two ways of B_{tag} reconstruction:

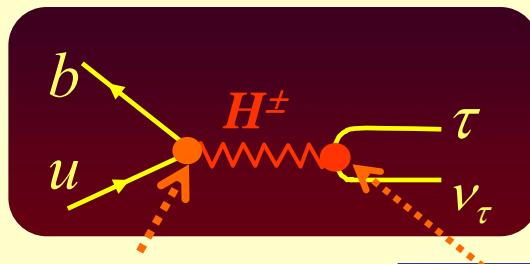
- Reconstruct B_{tag} (in exclusive mode) and check whether remaining particles consistent with B_{sig} ("exclusive" B_{tag} reconstruction)
- Select B_{sig} candidate and check whether remaining particles consistent with B decay ("inclusive" B_{tag} reconstruction)

B $\rightarrow\tau\nu_\tau$

purely leptonic B decay: W-mediated annihilation



Sensitive to Charged Higgs



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

$$m_\tau \tan\beta$$

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

H $^\pm$ effects on the branching fraction:

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

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

providing f_B is known

B \rightarrow $\tau\nu$ - method

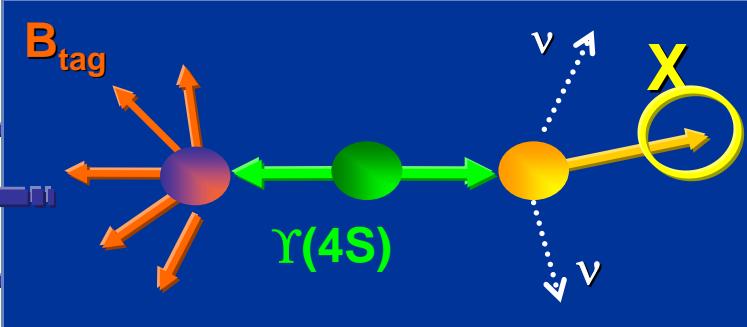


Reconstruct B_{tag} in hadronic mode:

$$B^+ \rightarrow \bar{D}^{(*)0}\pi^+/\rho^+/a_1^+/D_s^{(*)+}$$

$$\Delta E = \sum E_i - E_{\text{beam}}$$

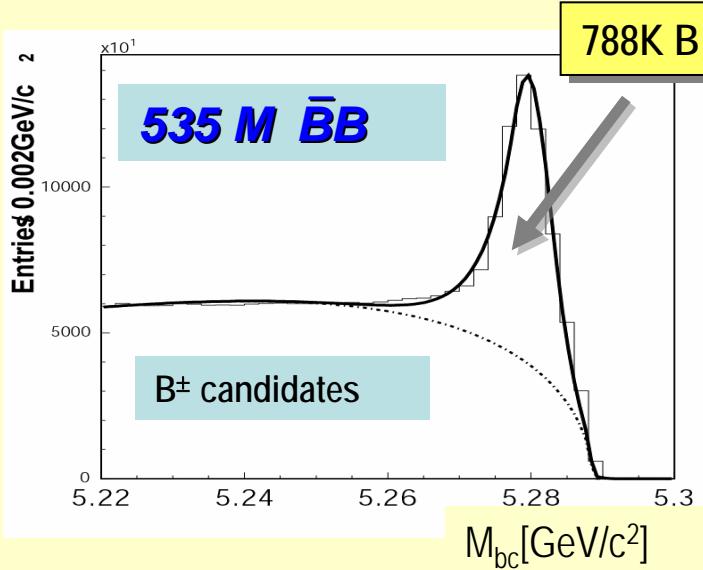
$$M_{bc/\text{tag}} = \sqrt{E_{\text{beam}}^2 - (\sum \mathbf{p}_i)^2}$$



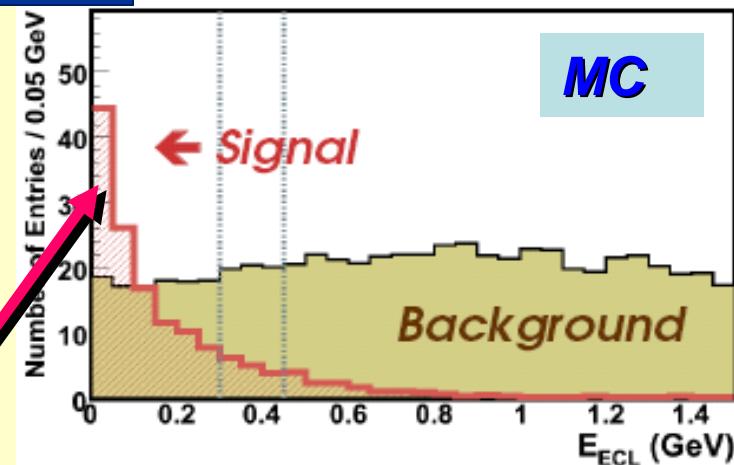
$$X = \rho^\pm, \pi^\pm, (3\pi)^\pm, e^\pm, \mu^\pm$$

signal signature:

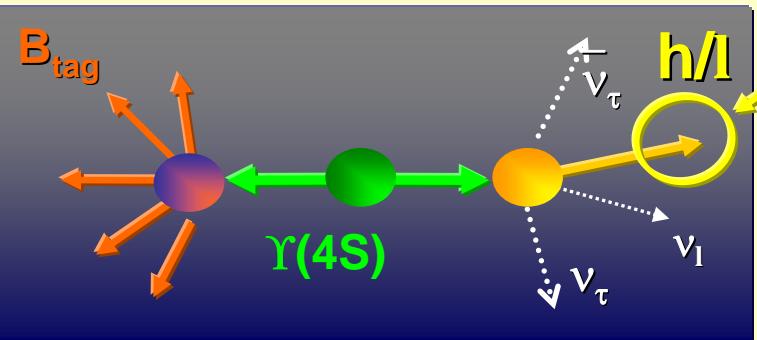
X + nothing



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



$B \rightarrow \tau \nu_\tau$ - analysis



visible products of τ decay

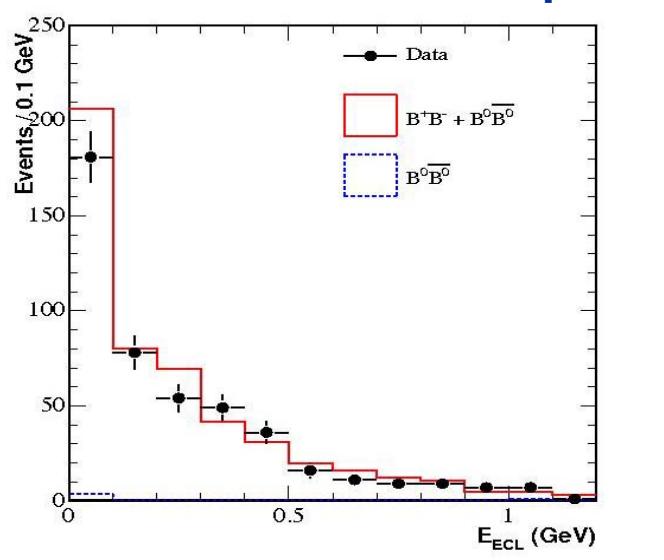
$$h = \rho^\pm, \pi^\pm, (3\pi)^\pm, l = e^\pm, \mu^\pm$$

81% of all modes

449 M $\bar{B}B$

PRL 97, 251802
(2006)

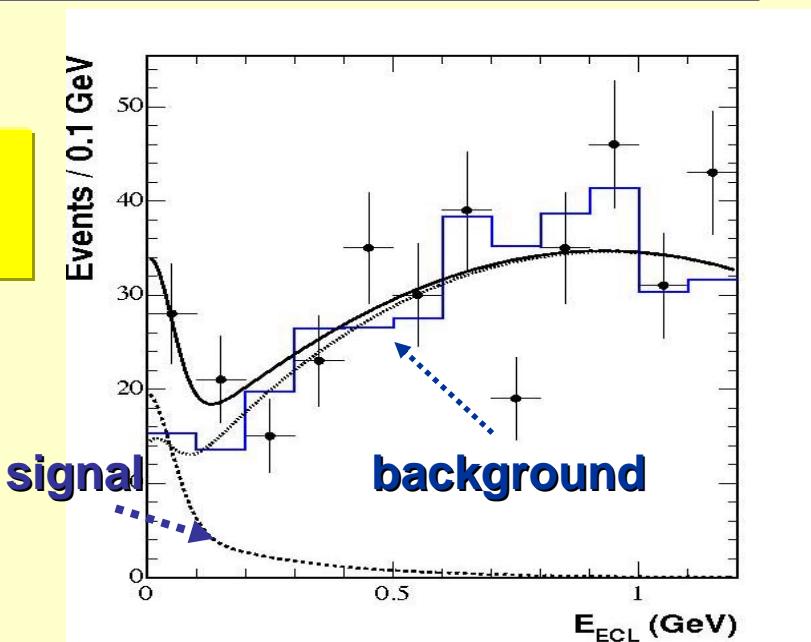
validate E_{ECL} simulation using
 $B \rightarrow D^{*0} l \nu$ control sample



FIRST
EVIDENCE

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

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



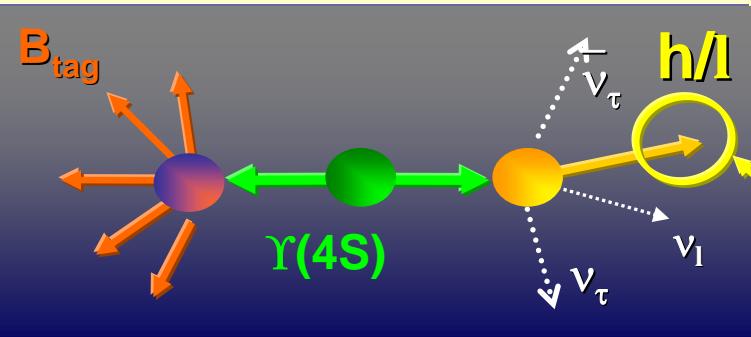
$B \rightarrow \tau \nu_\tau$ - analysis



657 M $\bar{B}B$

arXiv: 0809.3834

NEW with 3.8σ



D($^*\!\!D$) $\bar{l}\nu$ Semileptonic tag

visible products of τ decay

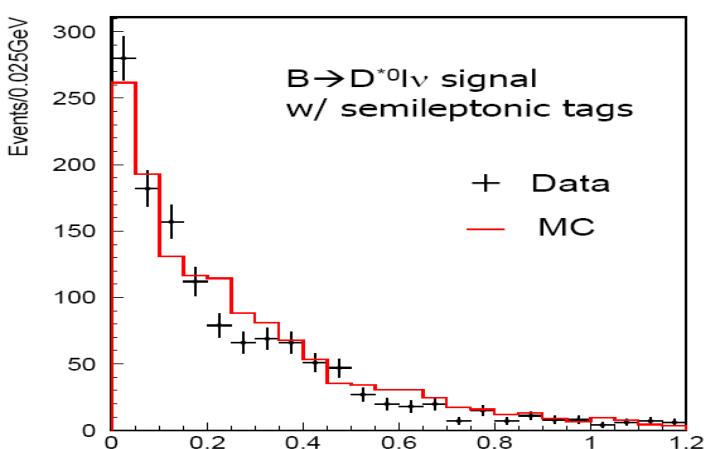
$$h = \pi^\pm, l = e^\pm, \mu^\pm$$

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

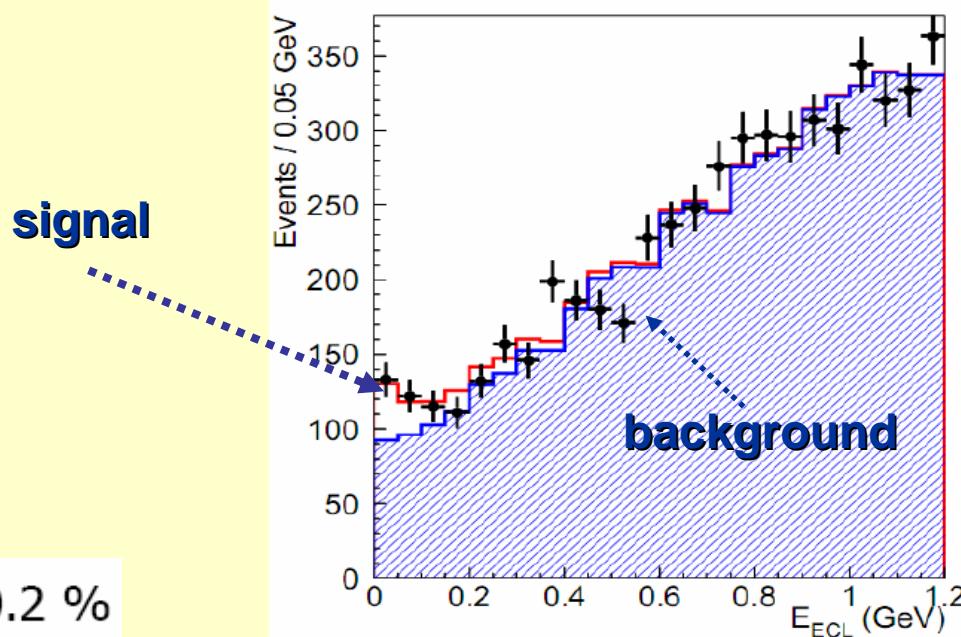
$$N_{\text{sig}} = 154^{+36}_{-35} \text{ (stat)}^{+20}_{-22} \text{ (syst)}$$

$$\Rightarrow BF(B^+ \rightarrow \tau^+ \nu_\tau) = (1.65^{+0.38}_{-0.37} \text{ (stat)}^{+0.35}_{-0.37} \text{ (syst)}) \times 10^{-4}$$

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



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



Constraint on Charged Higgs

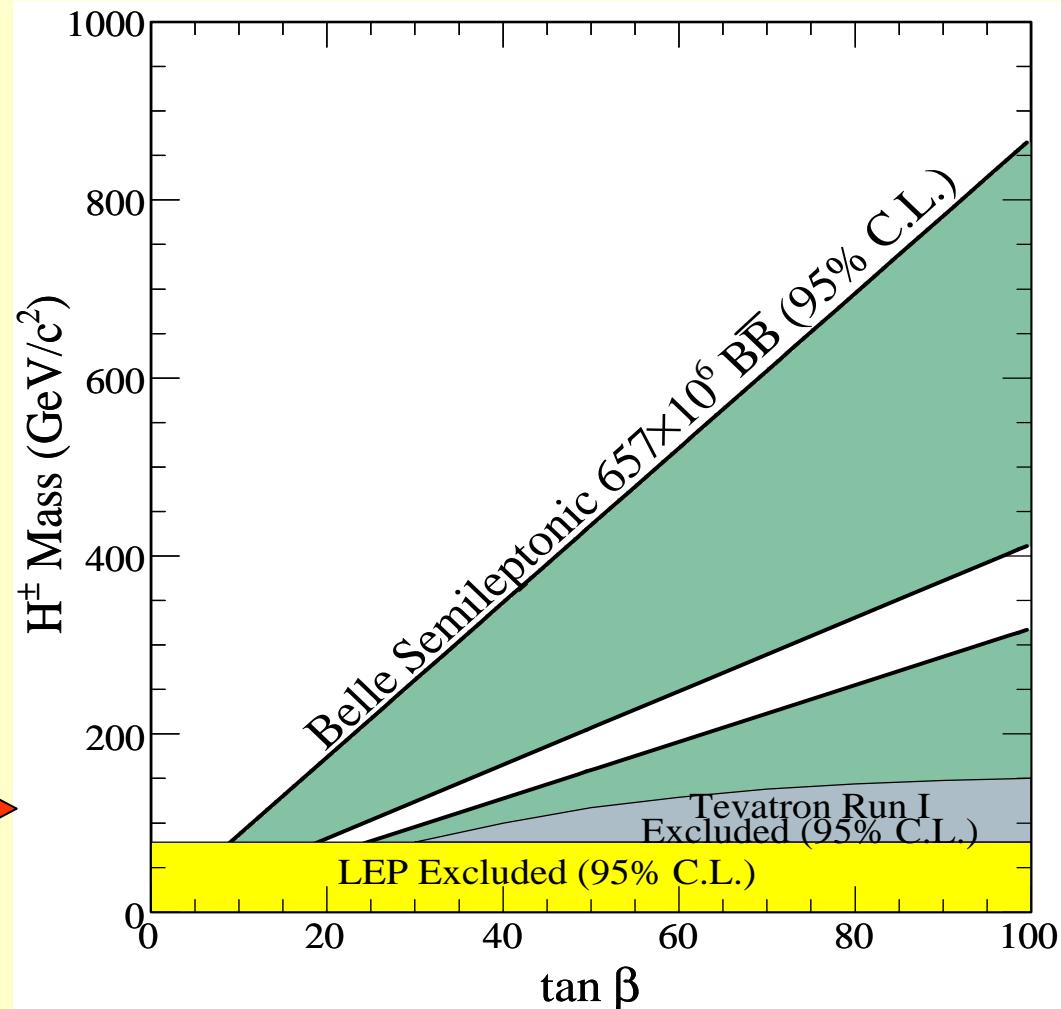
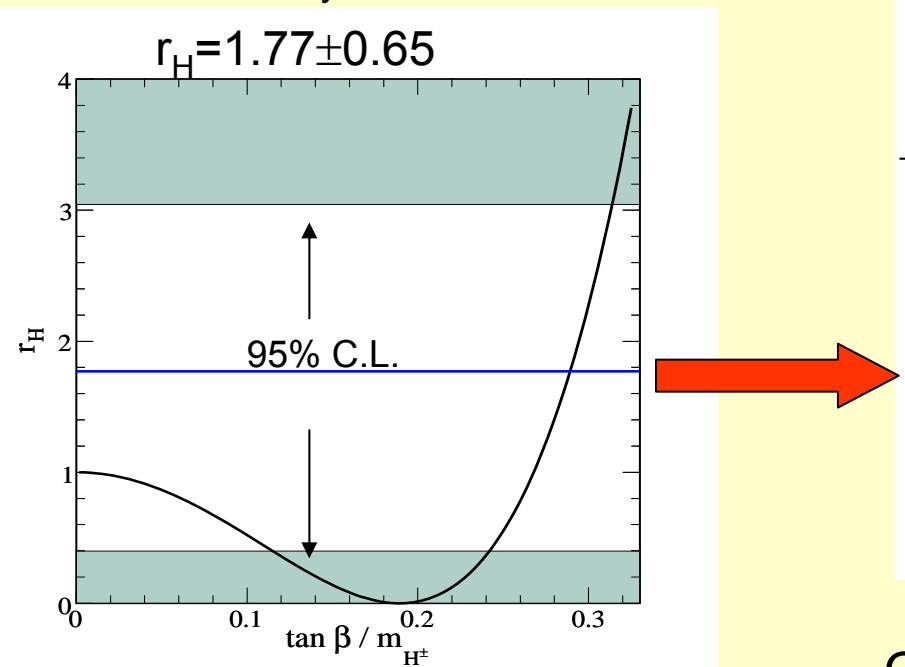


$$r_H = \left(1 - \frac{m_B^2}{m_H^2} \tan^2 \beta\right)^2$$

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

$$\mathcal{B}(B \rightarrow \tau \nu)_{SM} = (0.93^{+0.12}_{-0.11}) \times 10^{-4}$$

SM expectation from other experimental constraints by CKMfitter



Complementarity to hadron colliders

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

Semileptonic vs purely leptonic

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

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

$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ with longitudinally polarized D^* are also sensitive to new physics²

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

Hbc and Hbu vertices complementary with Htb searches at LHC



$B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ - inclusive B tag rec

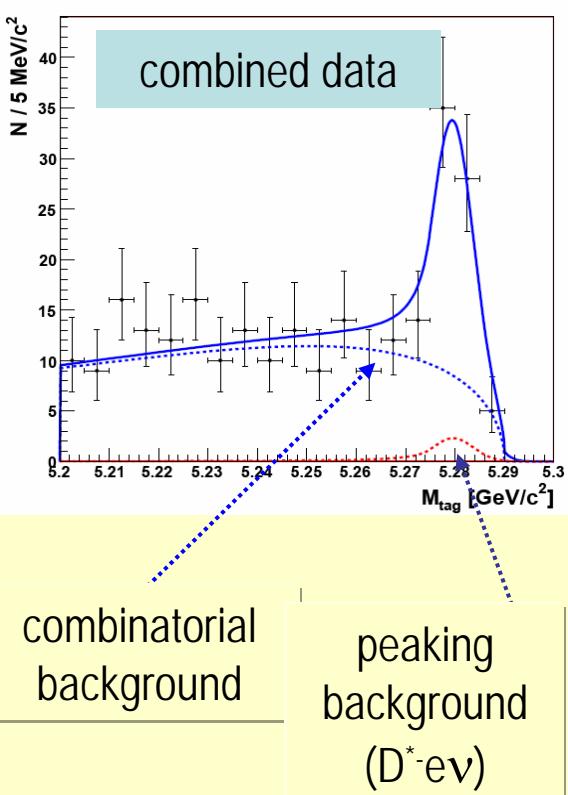


FIRST OBSERVATION - 2007

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

535 M $\bar{B}B$

PRL 99, 191807
(2007)

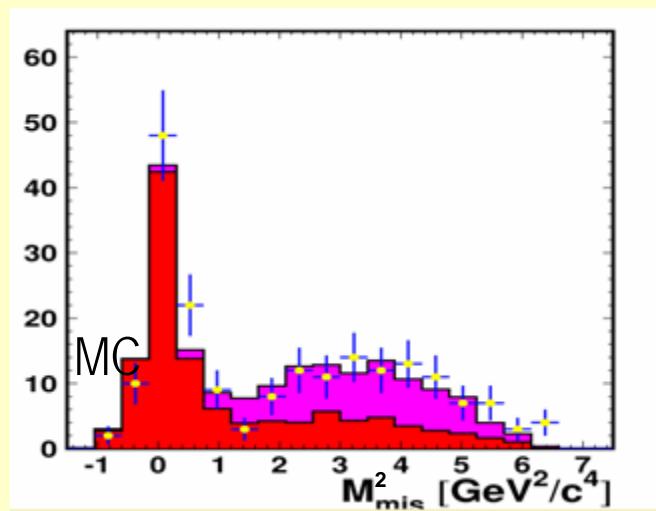


SIGNAL YIELD $N_s = 60^{+12}_{-11}$ 6.7σ (5.2 σ with syst.)

$$M_{mis}^2 = (E_b - E_{D^{(*)}} - E_{l/h})^2 - (-\vec{p}_{tag} - \vec{p}_{D^{(*)}} - \vec{p}_{l/h})^2$$

M_{mis}^2

- + DATA
- [signal
- [bckgr.



$B \rightarrow D^{(*)}\tau^+\nu_\tau$ - exclusive B tag rec



- B_{tag} reconstructed exclusively in hardonic modes
- B_{sig} the following decay chains are considered

$D^{(*)}$ decay modes

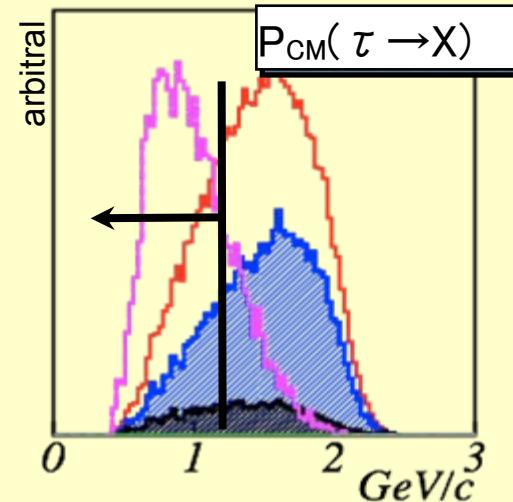
$$\begin{aligned}
 \bar{D}^0 &\rightarrow K^+\pi^-, K^+\pi^-\pi^0, K + \pi^-\pi^+ + \pi^-\pi^0 \\
 &\quad K_S^0\pi^0, K_S^+\pi^-\pi^+, K_S^0\pi^-\pi^+\pi^0. \\
 D^- &\rightarrow K^+\pi^-\pi^-, K^+\pi^-\pi^-\pi^0, K_S^0\pi^-. \\
 D^{*+} &\rightarrow D^0\pi^+, D^+\pi^0 \\
 D^{*0} &\rightarrow D^0\pi^0, D^+\gamma
 \end{aligned}$$

τ decay modes: $\tau \rightarrow e\nu\nu, \mu\nu\nu$

Analysis Strategy:

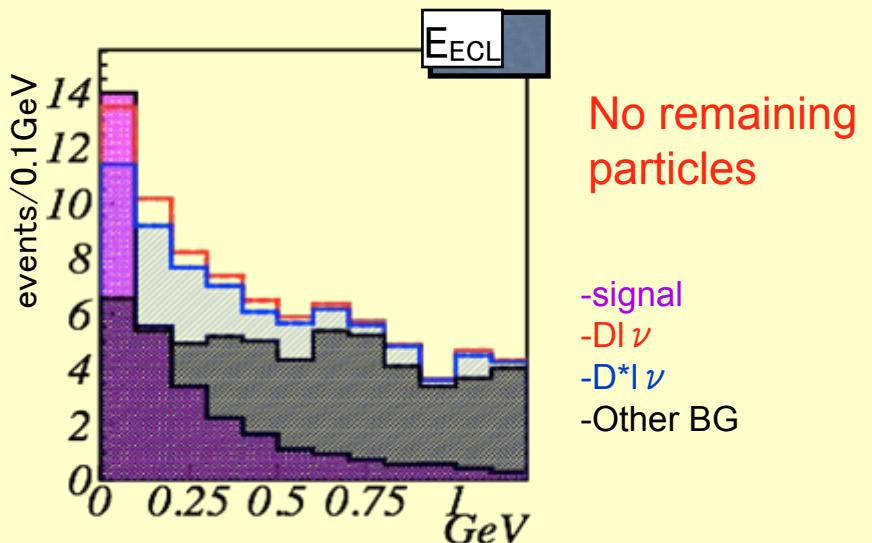
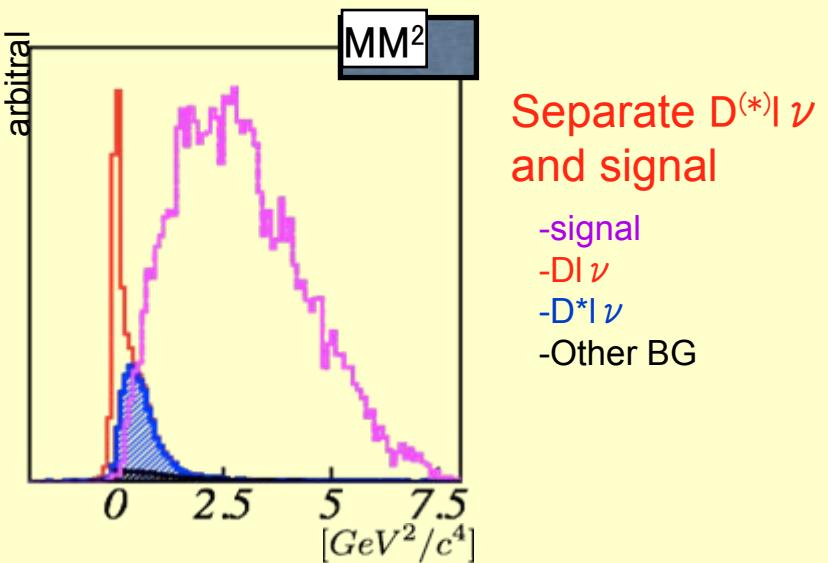
Reconstruct $B \rightarrow D^{(*)}\ell\nu$, $B \rightarrow D^{(*)}\tau\nu$ to obtain $R(D) \equiv \frac{\mathcal{B}(B \rightarrow D\tau\nu)}{\mathcal{B}(B \rightarrow D\ell\nu)}$

Main background:
Semileptonic B decays ($D^{(*)}\ell\nu$)
 e, μ with lower momentum



D τ ν Signal extraction

Extract signal from 2D fit in missing mass squared (MM^2) and extra calorimeter Energy(E_{ECL})

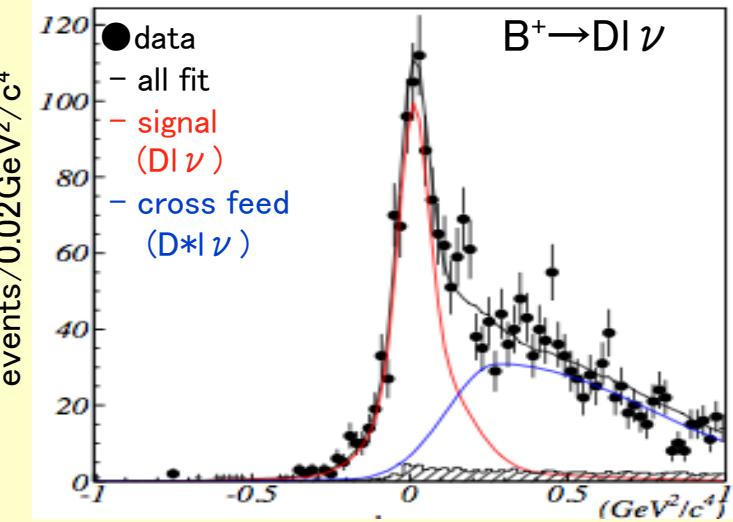


$B^{+}/0 \rightarrow D^{(*)} l \nu$ Reconstruction

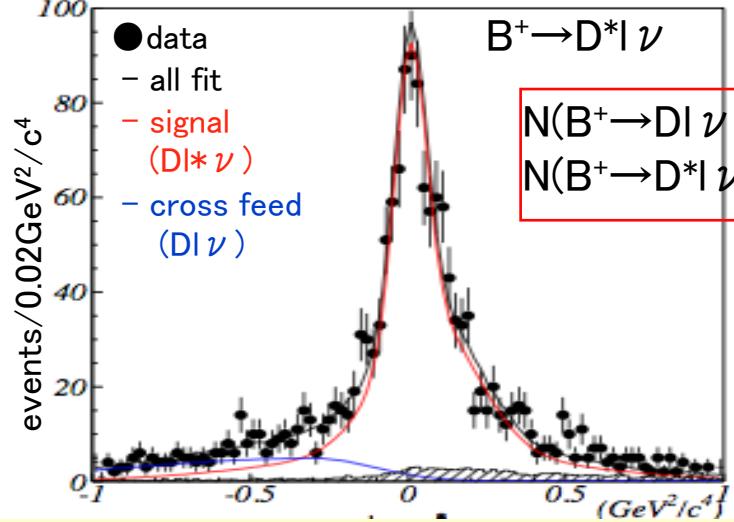


657 M $\bar{B}B$

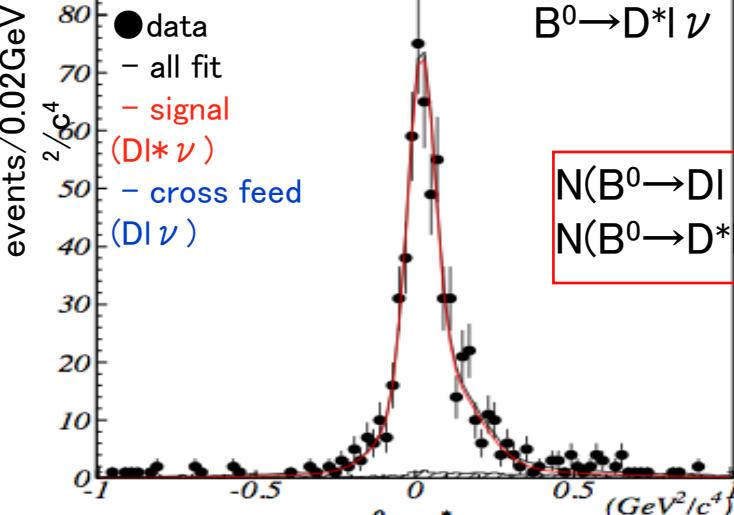
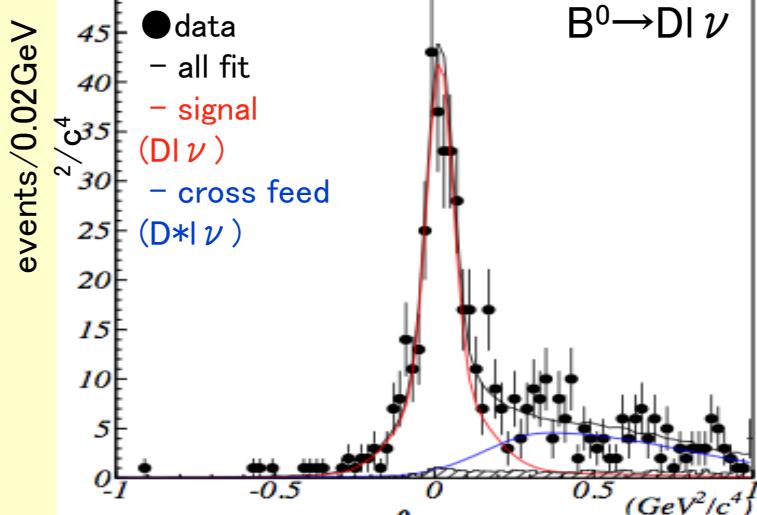
MM² distributions



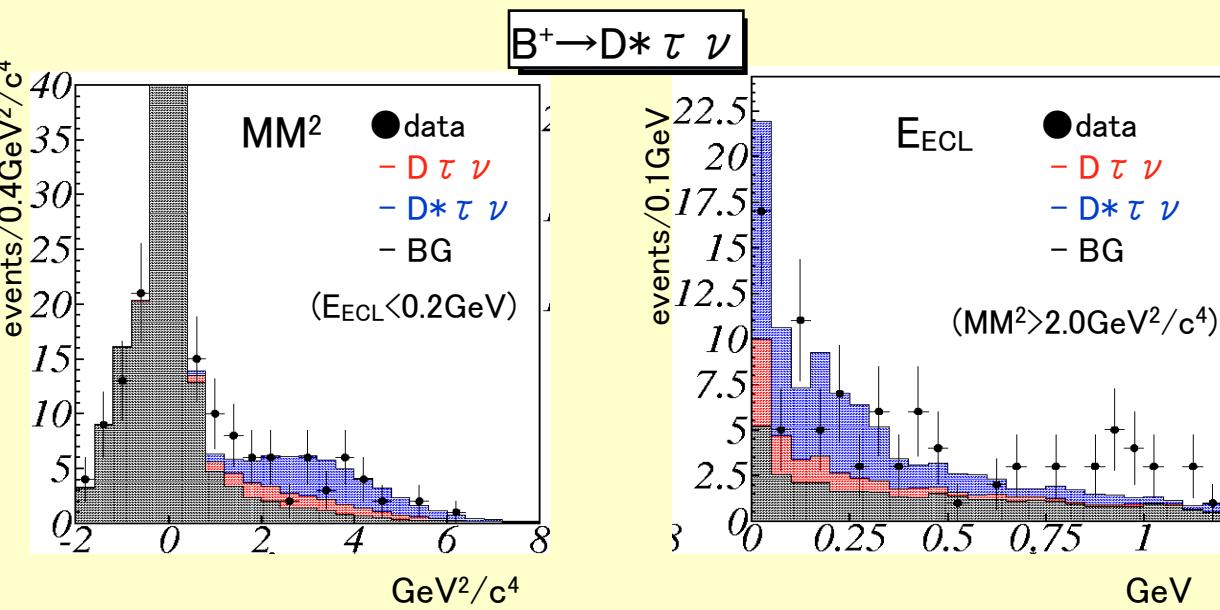
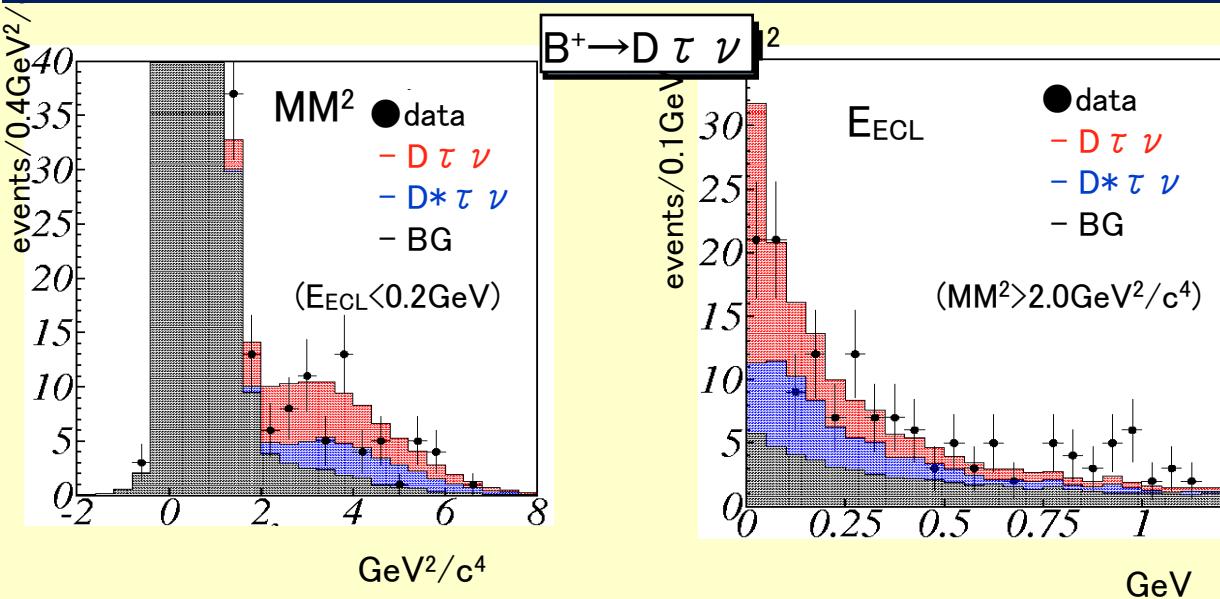
P cut



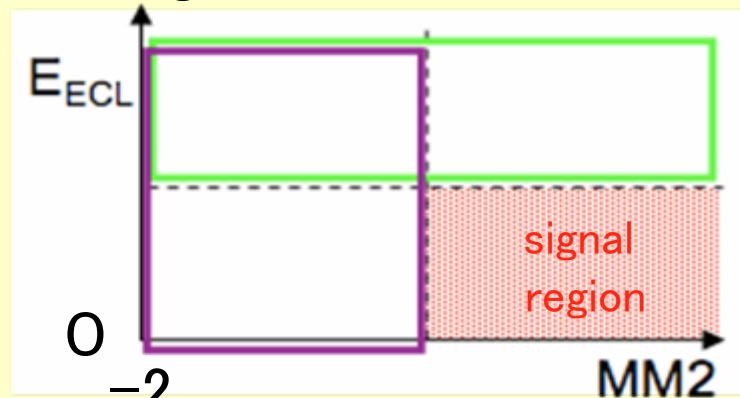
Belle preliminary



Results $B^+ \rightarrow D^{(*)} \tau \nu$



- Plots are projections in the signal enhance region



clear signal seen

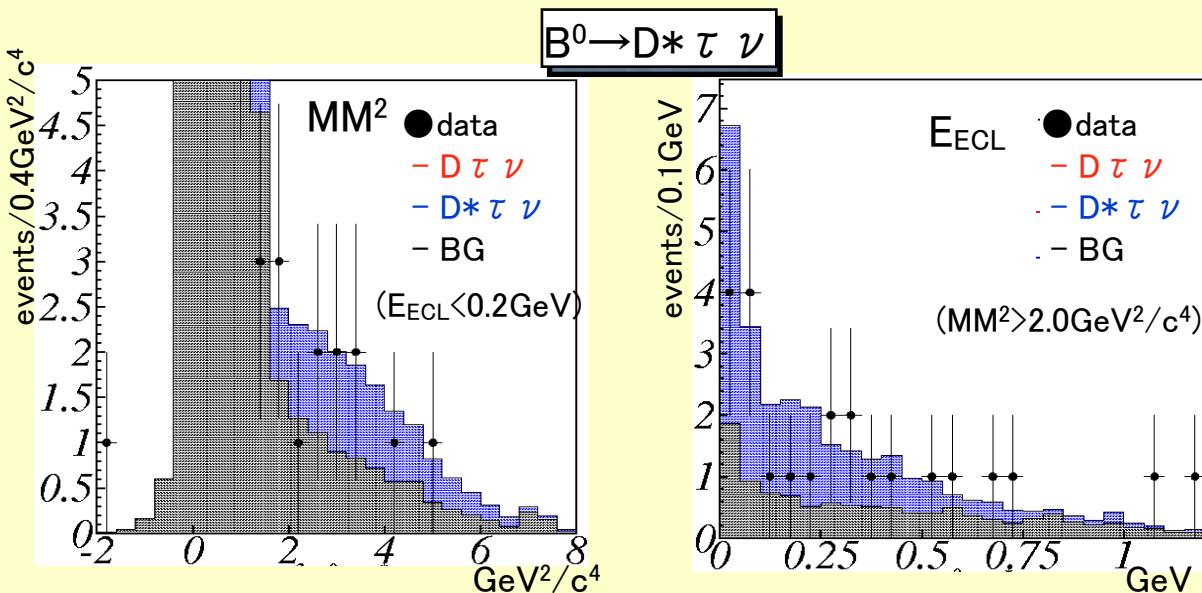
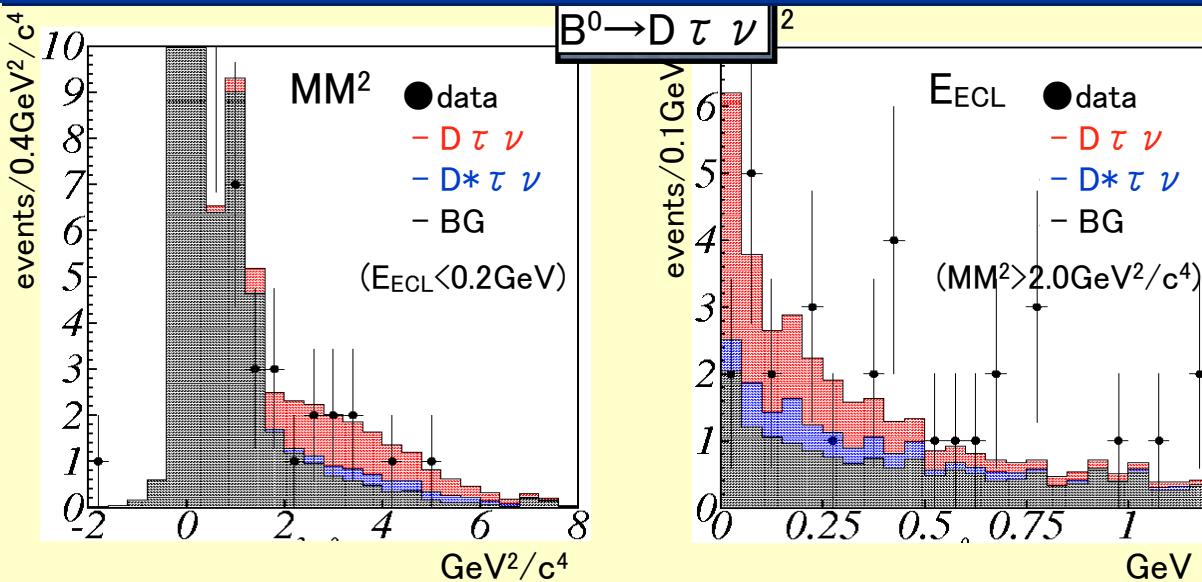
$$N_{\text{yield}} \Sigma$$

$$N_{B^+ \rightarrow D \tau \nu} = 98.6^{+26.3}_{-25.0} (3.8\sigma)$$

$$N_{B^+ \rightarrow D^* \tau \nu} = 99.8^{+22.2}_{-22.3} (3.9\sigma)$$

Belle preliminary

Results $B^0 \rightarrow D^{(*)} \tau \nu$



Plots are projection in the signal enhance region

Clear signal seen

N_{yield}

Σ

$$N_{B^0 \rightarrow D \tau \nu} = 17.2^{+7.7}_{-6.9} (2.6\sigma)$$

$$N_{B^0 \rightarrow D^* \tau \nu} = 25.0^{+7.2}_{-6.3} (4.7\sigma)$$

Belle preliminary

Determination of R(D^(*)) and BF



657 M $\bar{B}B$

$R(\bar{D}^0)$	$\equiv \mathcal{B}(B^+ \rightarrow \bar{D}^0 \tau^+ \nu) / \mathcal{B}(B^+ \rightarrow \bar{D}^0 \ell^+ \nu)$	$= 70.2^{+18.9}_{-18.0} {}^{+11.0}_{-9.1} [\%]$
$R(\bar{D}^{*0})$	$\equiv \mathcal{B}(B^+ \rightarrow \bar{D}^{*0} \tau^+ \nu) / \mathcal{B}(B^+ \rightarrow \bar{D}^{*0} \ell^+ \nu)$	$= 46.8^{+10.6}_{-10.2} {}^{+6.2}_{-7.2} [\%]$
$R(D^-)$	$\equiv \mathcal{B}(B^0 \rightarrow D^- \tau^+ \nu) / \mathcal{B}(B^0 \rightarrow D^- \ell^+ \nu)$	$= 47.6^{+21.6}_{-19.3} {}^{+6.3}_{-5.4} [\%]$
$R(D^{*-})$	$\equiv \mathcal{B}(B^0 \rightarrow D^{*-} \tau^+ \nu) / \mathcal{B}(B^0 \rightarrow D^{*-} \ell^+ \nu)$	$= 48.1^{+14.0}_{-12.3} {}^{+5.8}_{-4.1} [\%]$

Deviation from the SM
expectation

$B^+ \rightarrow D \tau^- \nu : 1.6 \sigma$
 $B^0 \rightarrow D \tau^- \nu : 0.5 \sigma$

Consistent within errors

Branching fraction

$$BF(B^+ \rightarrow D \tau^+ \nu_\tau) = 1.51^{+0.41}_{-0.39} (stat)^{+0.24}_{-0.19} (syst) \pm 0.15 (D(*) l v BR \text{ error}) [\%]$$

$$BF(B^0 \rightarrow D \tau^+ \nu_\tau) = 1.01^{+0.46}_{-0.41} (stat)^{+0.13}_{-0.11} (syst) \pm 0.10 (D(*) l v BR \text{ error}) [\%]$$

$$BF(B^+ \rightarrow D^{*0} \tau^+ \nu_\tau) = 3.04^{+0.69}_{-0.66} (stat)^{+0.40}_{-0.47} (syst) \pm 0.22 (D(*) l v BR \text{ error}) [\%]$$

$$BF(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau) = 2.56^{+0.75}_{-0.66} (stat)^{+0.31}_{-0.22} (syst) \pm 0.10 (D(*) l v BR \text{ error}) [\%]$$

Belle preliminary

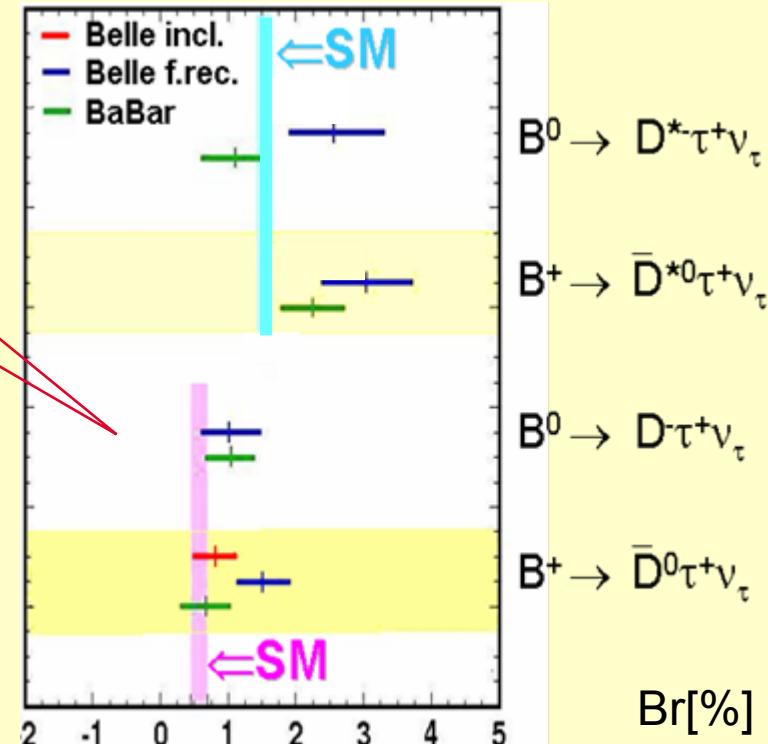
Comparison with others results

Babar full reconstruction tag :

$232 \times 10^6 B\bar{B}$

$\mathcal{B}(B^- \rightarrow D^0 \tau^- \bar{\nu}_\tau)$	$= 0.61 \pm 0.37(stat) \pm 0.11(syst) \pm 0.07[\%]$	1.8σ
$\mathcal{B}(B^- \rightarrow D^{0*} \tau^- \bar{\nu}_\tau)$	$= 2.25 \pm 0.48(stat) \pm 0.22(syst) \pm 0.17[\%]$	5.3σ
$\mathcal{B}(B^0 \rightarrow D^+ \tau^- \bar{\nu}_\tau)$	$= 1.04 \pm 0.37(stat) \pm 0.15(syst) \pm 0.10[\%]$	3.3σ
$\mathcal{B}(B^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau)$	$= 1.11 \pm 0.51(stat) \pm 0.04(syst) \pm 0.04[\%]$	2.7σ

Statistical errors only



SUMMARY



Rich program of $B \rightarrow E_{\text{mis}}$ studies is being pursued in Belle

$B \rightarrow \tau v$

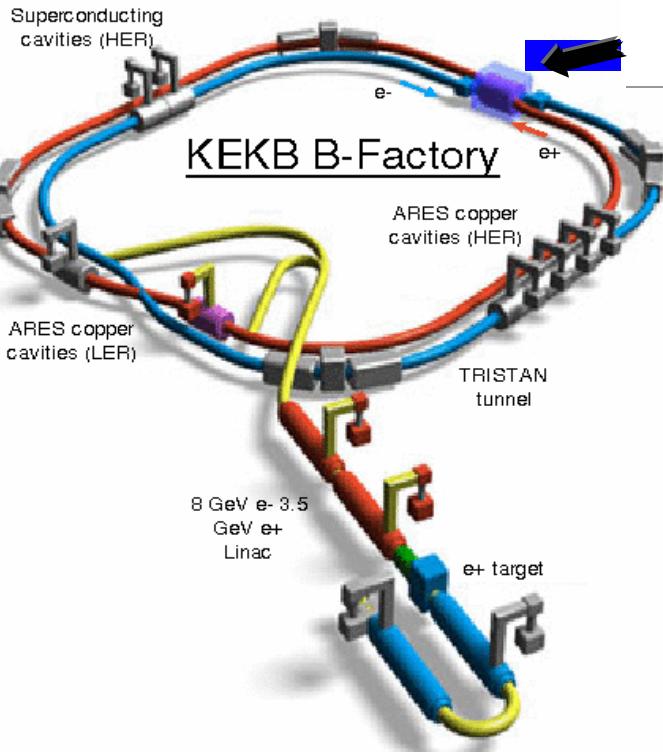
- first evidence (3.5σ) of purely leptonic B decay (hadronic tag)
- new result with semileptonic tag (3.8σ)
- constraints on H^\pm competitive with direct searches

$B \rightarrow D^*(*) \tau v$

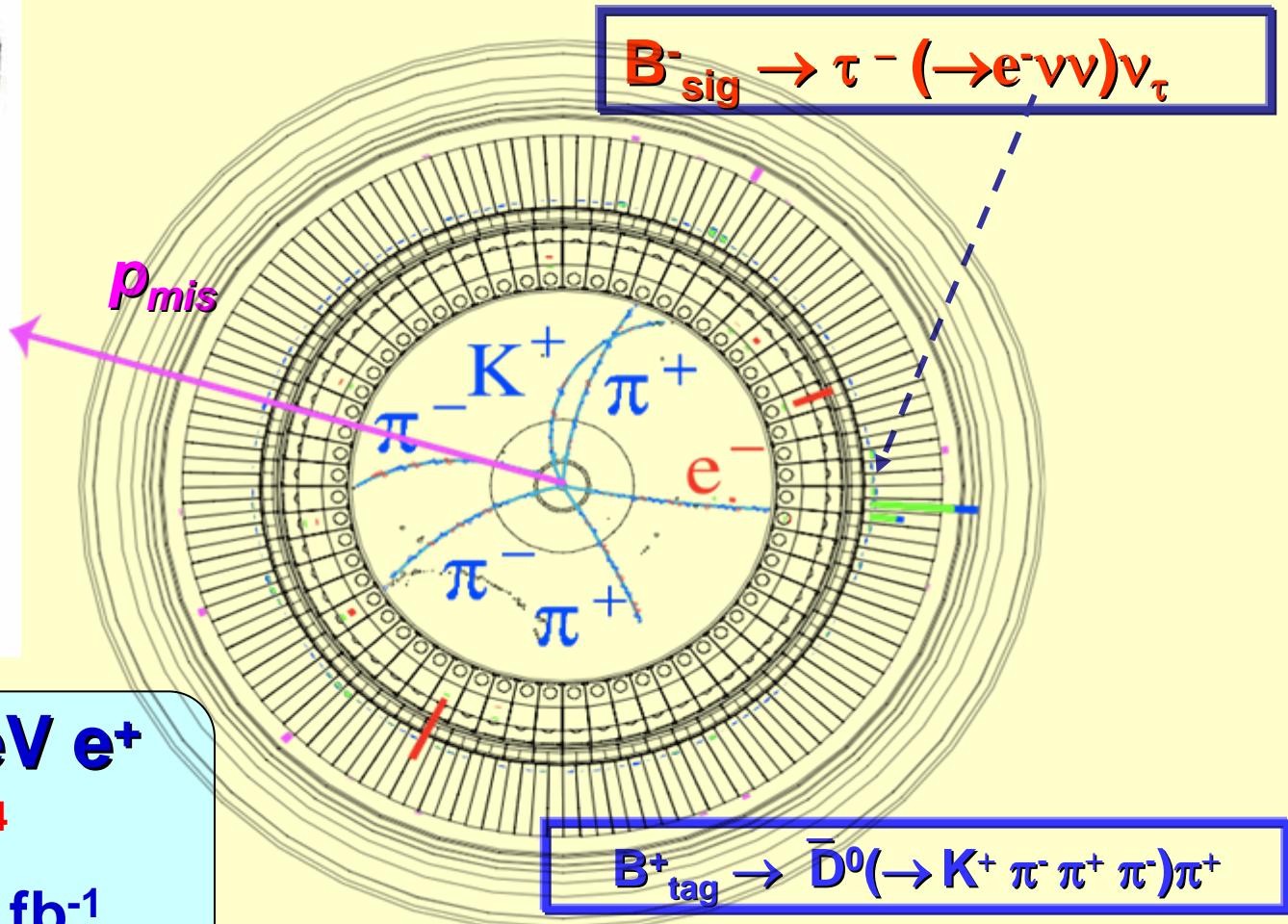
- new results with "exclusive" B_{tag} reconstruction method are presented.
- observation (5.2σ) of inclusive B decay in the $B^0 \rightarrow D^* \tau v_\tau$ mode Belle and $B^- \rightarrow D^{*0} \tau v_\tau$ mode for Babar.

Looking forward to Super B-factory

Backups



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

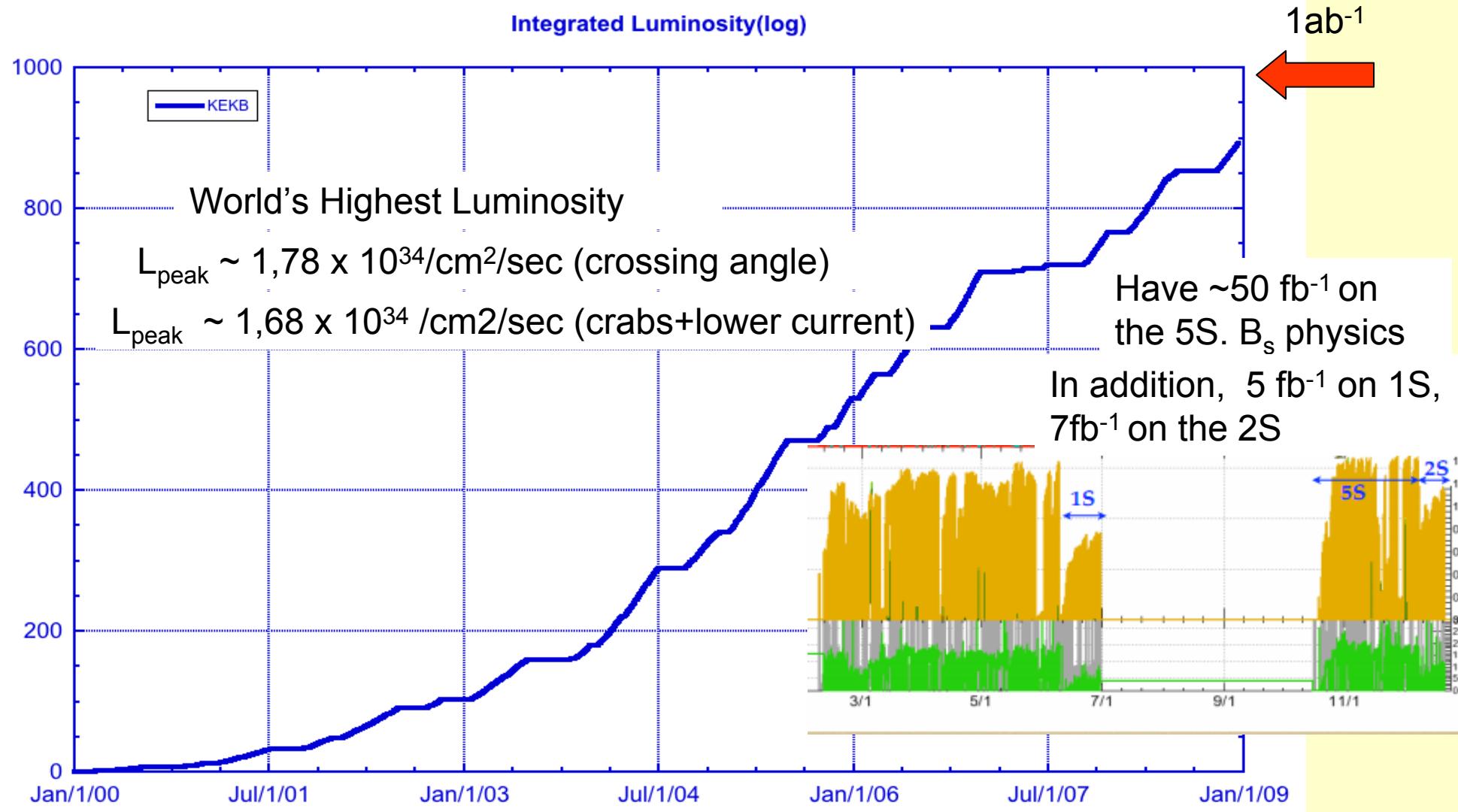


8 GeV $e^- \times 3.5$ GeV e^+

$L_{\text{peak}} = 1.78 \times 10^{34}$

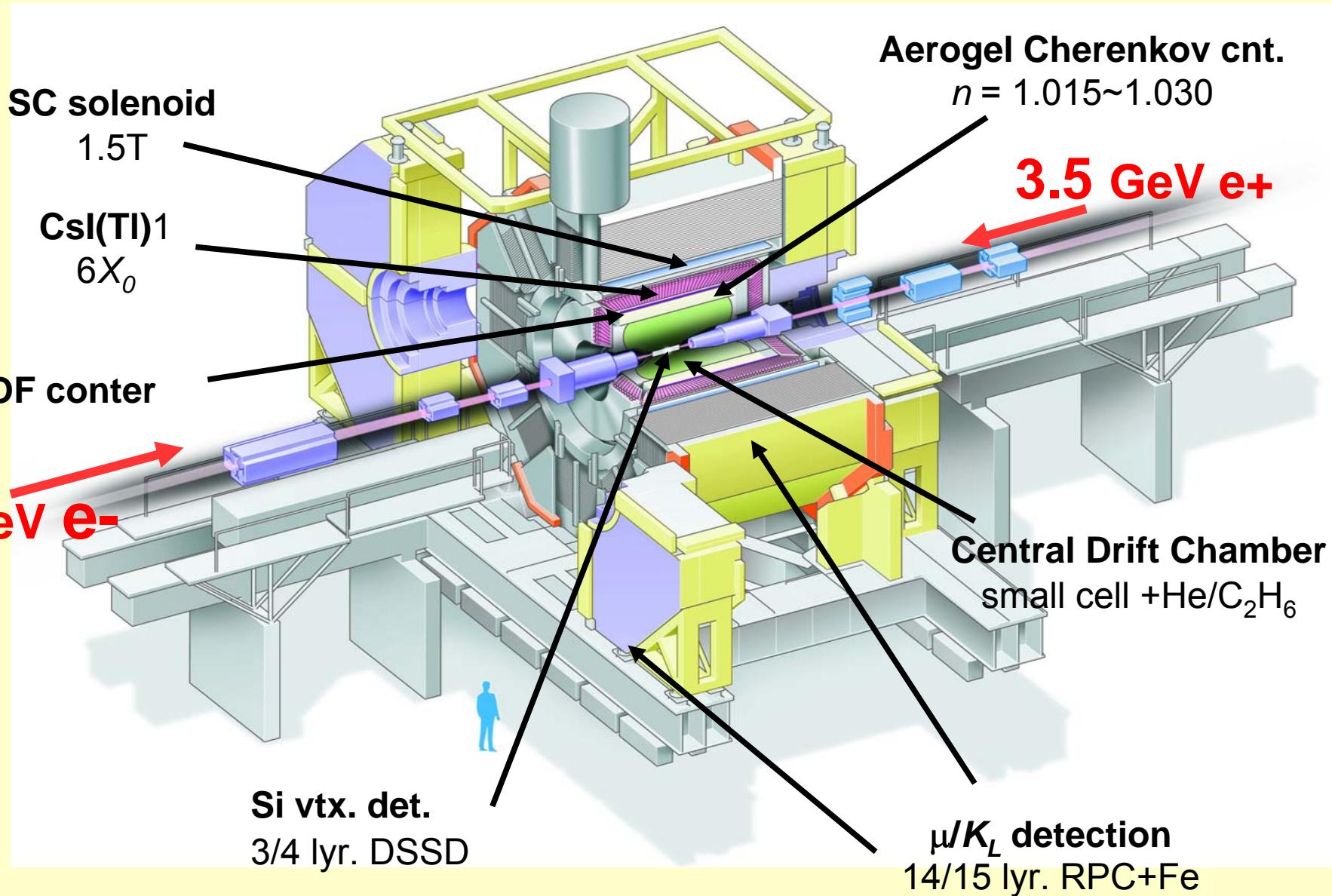
Integ. Lum. $\sim 850 \text{ fb}^{-1}$

Status of KEKB and Belle:



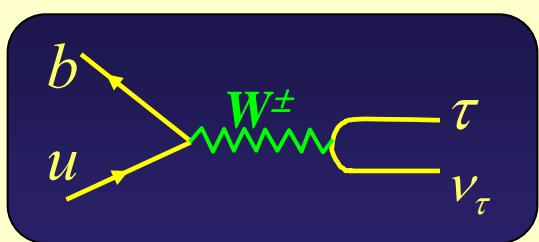
KEKB/Belle will resume in April/09 and run through the fall09

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



B \rightarrow $\tau\nu_\tau$

purely leptonic B decay: W-mediated annihilation



theoretically very clean, SM BF:

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

$$BF(B^+ \rightarrow \tau^+ \nu_\tau) = (1.59 \pm 0.40) \times 10^{-4}$$

$f_B = 0.216 \pm 0.022$ GeV from LQCD

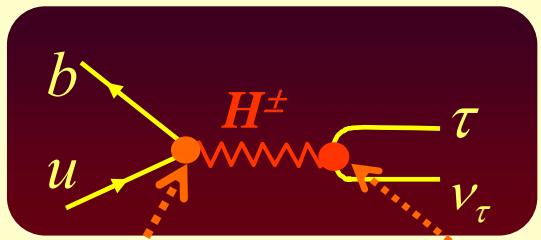
B decay constant

HPQCD Collab., PRL 95, 212001 (2005)

Sensitive to Higgs

Charged

providing f_B is known



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

$$m_\tau \tan\beta$$

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

H $^\pm$ effects to branching fraction:

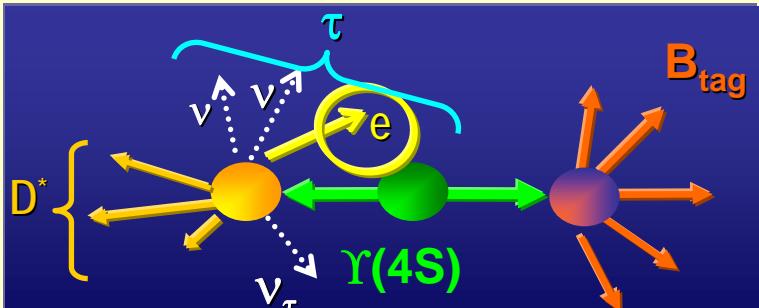
$$BF(B^+ \rightarrow \tau^+ \nu_\tau) = BF(B^+ \rightarrow \tau^+ \nu_\tau)_{SM} \times r_H$$

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

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

$B^0 \rightarrow D^* \tau^+ \nu_\tau$ - method

clean signature
 $D^* e^+ + p_{\text{mis}}$



Signal sub-decay modes:

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

$\tau \rightarrow \mu \nu \nu$ not used;
 ID inefficient for soft leptons) (μ^-)

reconstruct B_{tag} inclusively

$$\Delta E_{\text{tag}} = \sum E_i - E_{\text{beam}}$$

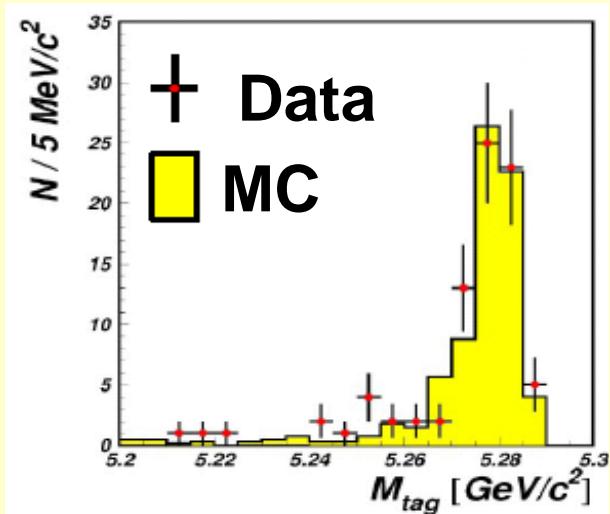
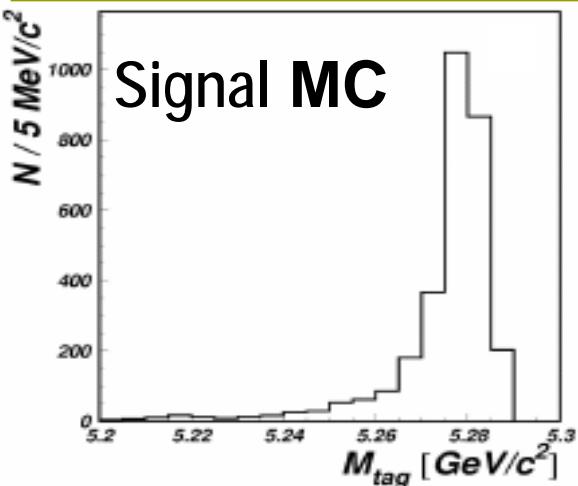
$$M_{\text{tag}} = \sqrt{E_{\text{beam}}^2 - (\sum \mathbf{p}_i)^2}$$

$\Sigma Q = 0,$
 extra leptons,
 $\sum N_{\bar{p}p} = 0$
 $-0.25 \text{ GeV} < \Delta E_{\text{tag}} < 0.05 \text{ GeV}$

verify B_{tag} reconstruction

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

apply all the tag-side selection criteria



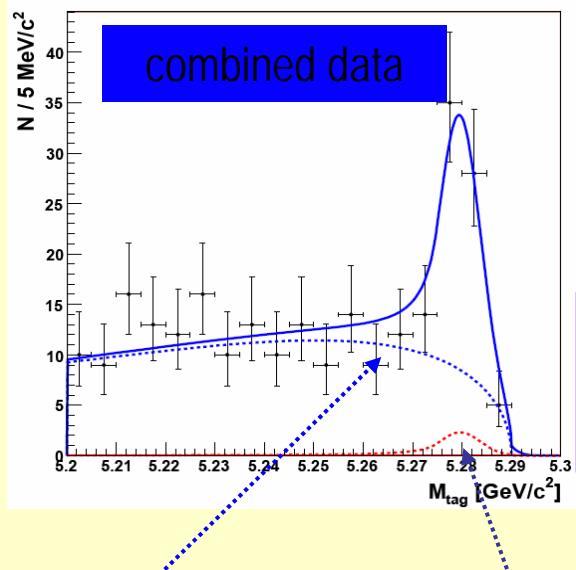
$B^0 \rightarrow D^* -\tau^+ \nu_\tau$ - inclusive B tag rec

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

535 M $\bar{B}B$

PRL 99, 191807
(2007)

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



combinatorial
background

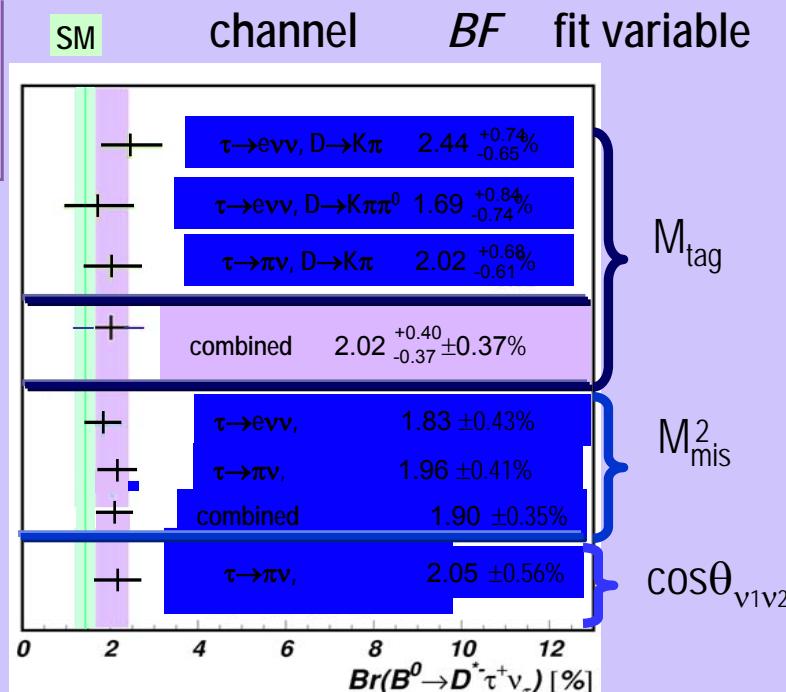
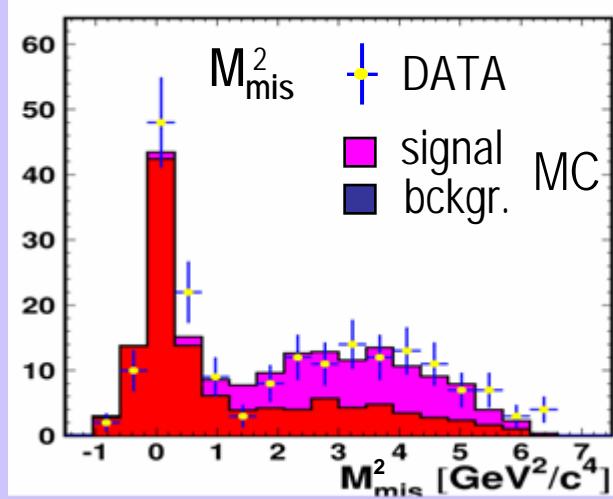
peaking
background
($D^* - e\nu$)

FIRST OBSERVATION - 2007

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

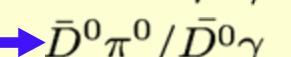
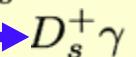
CROSS-CHEKS

- separate fits to sub-channels
- check look-back plots
- signal yield from signal-side variables

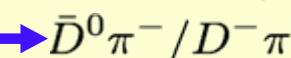
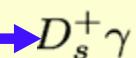


Tag side- exclusive rec.

$$B^+ \rightarrow \bar{D}^{(*)0} + \pi^+ \rho^+ / a_1^+ / D_s^{(*)}$$

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

$\bar{D}^0 \rightarrow 7$ modes

$D^- \rightarrow 6$ modes

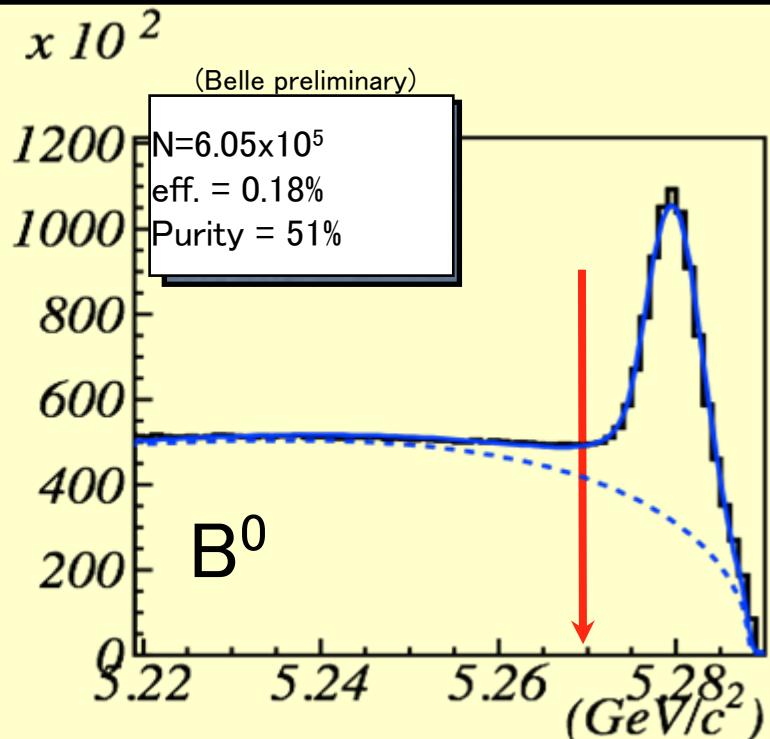
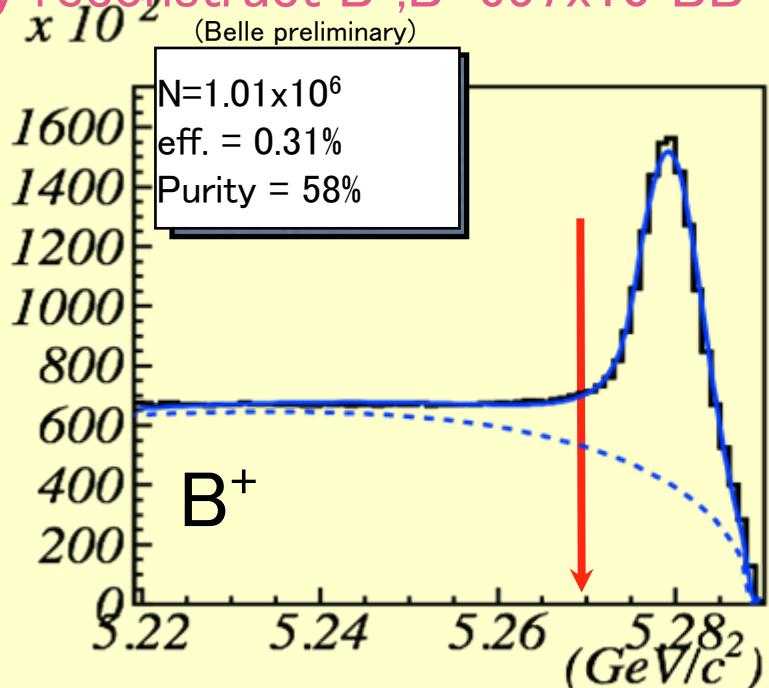
$D_s^+ \rightarrow 2$ modes

Total

$B^+ \rightarrow 147$ modes

$B^0 \rightarrow 133$ modes

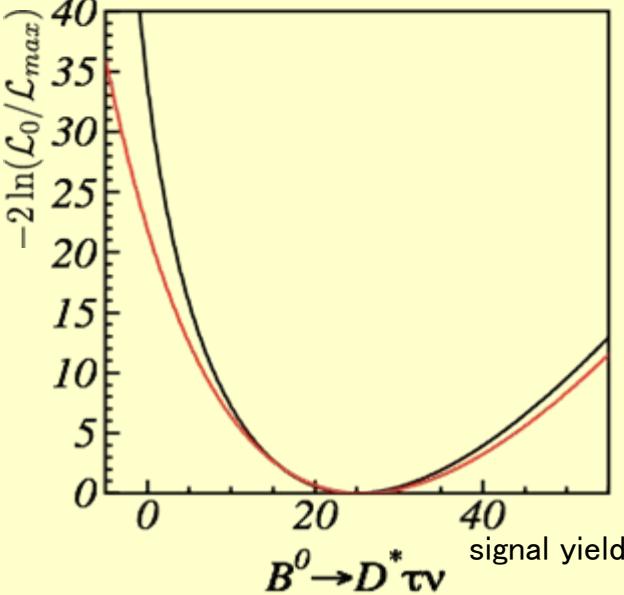
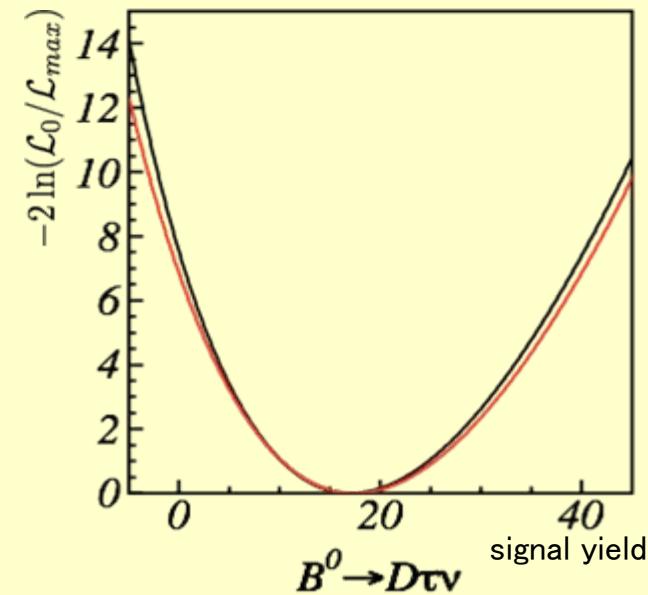
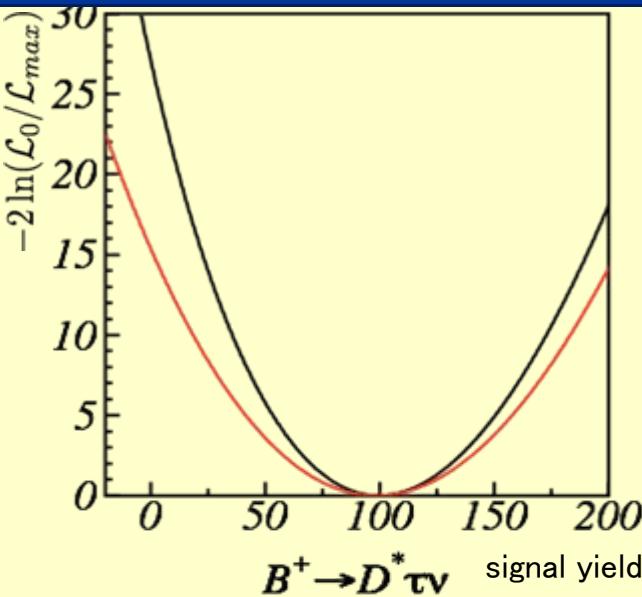
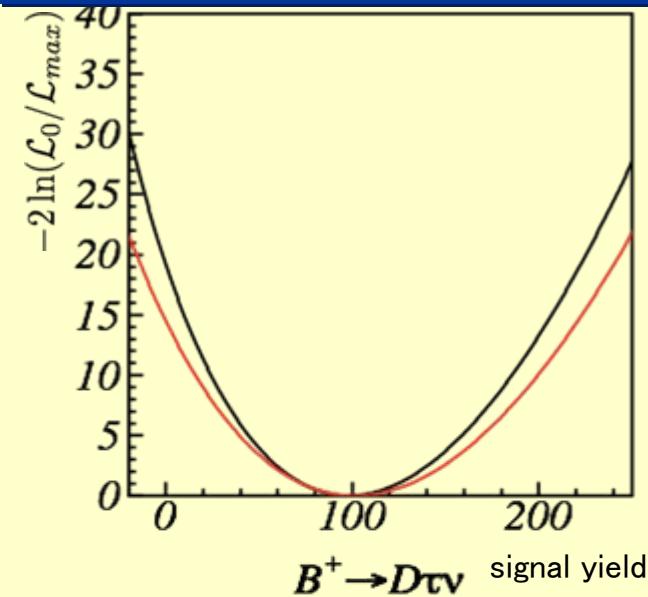
fully reconstruct B^0, B^+ 657×10^6 BB



Beam constraint Mass :

$$M_{bc} \equiv \sqrt{E_{beam}^2 - p_B^2}$$

Significance of signal yield



- Statistical error only
- Statistical + systematic

$$\Sigma = \sqrt{-2 \ln_0(\mathcal{L}_0 / \mathcal{L}_{\max})}$$

Σ_{syst}

$B^+ \rightarrow D\tau\nu : 3.8\sigma$
(First evidence)

$B^+ \rightarrow D^*\tau\nu : 3.9\sigma$

$B^0 \rightarrow D\tau\nu : 2.6\sigma$

$B^0 \rightarrow D^*\tau\nu : 4.7\sigma$

(Belle preliminary)
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Systematic error

source	$B^+ \rightarrow D \tau \nu [\%]$	$B^+ \rightarrow D^* \tau \nu [\%]$
MM ² shape	+9.1/-7.9	+10.0/-5.8
E _{ECL} shape	+10.6/-7.6	+7.0/-9.7
$Br(B \rightarrow D^{**} l \nu)$	± 0.4	+0.8/-0.0
D \rightleftharpoons D* cross feed	+7.1/-6.9	+5.1/-5.3
$Br(\tau \rightarrow l \nu \nu)$	± 0.3	± 0.3
Total	15.7/-12.9	+13.2/-15.4
source	$B^0 \rightarrow D \tau \nu [\%]$	$B^0 \rightarrow D^* \tau \nu [\%]$
MM ² shape	+6.4/-5.8	+5.8/-6.1
E _{ECL} shape	+9.0/-7.3	+9.8/-5.0
$Br(B \rightarrow D^{**} l \nu)$	+4.5/-2.6	+0.6/-0.3
D \rightleftharpoons D* cross feed	+5.8/-6.0	+3.5/-3.4
$Br(\tau \rightarrow l \nu \nu)$	± 0.3	± 0.3
Total	+13.3/-11.4	+12.0/-8.6