Belle Hot Topics

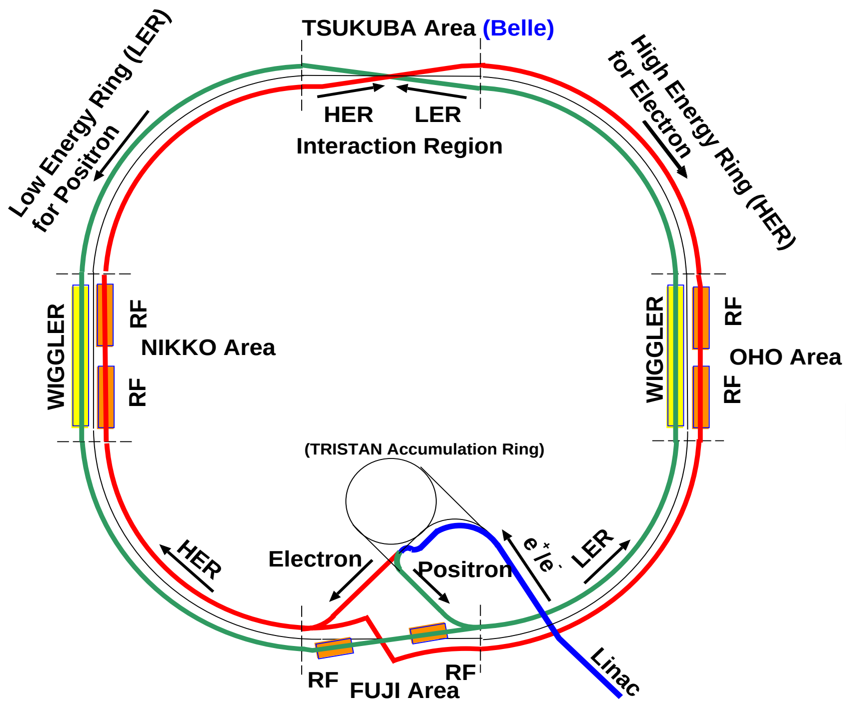
Nagoya University
Koji Ikado
(for the Belle Collaboration)

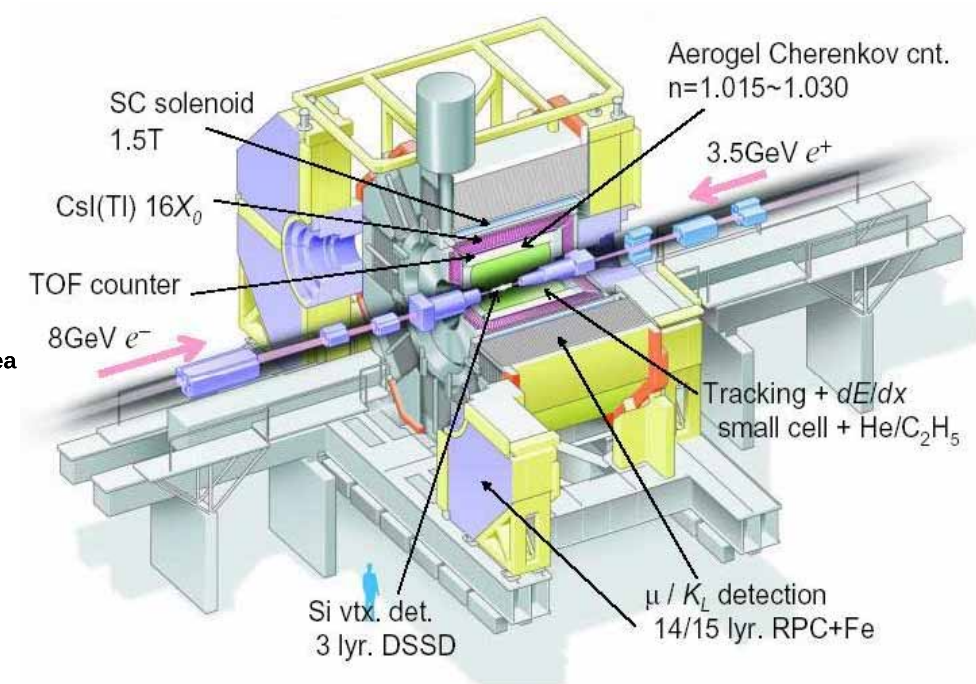
Flavor Physics and CP Violation Conference (FPCP2006)
Apr. 9, 2006

Outline

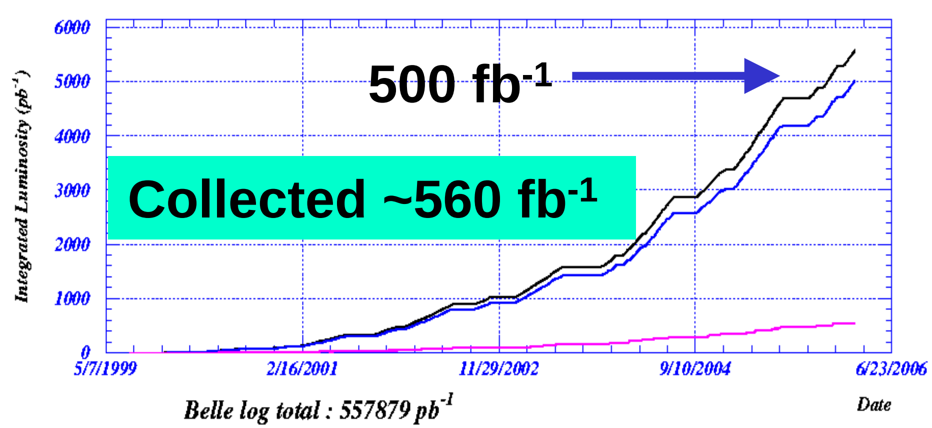
- Search for the Purely Leptonic Decay $B \rightarrow \tau\nu$
- Results from the Υ(5S) Engineering Run
- Summary

KEKB & Belle





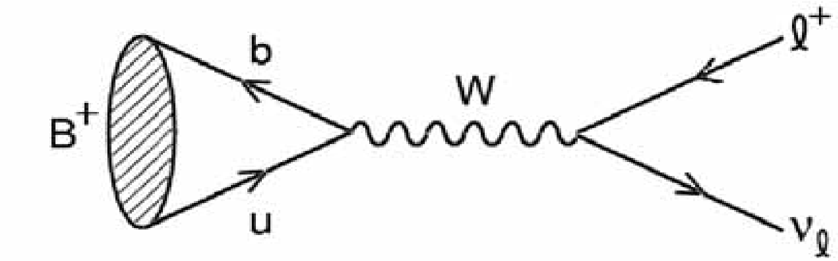
- Asymmetric-energy e^+e^- collider
  - 8GeV – 3.5 GeV
  - High Luminosity
    - L ~ 1.5 x 10^{34}



Search for the Purely Leptonic Decay $B \to \tau\nu$

B→τν and B Meson Decay Constant f_B

- Leptonic decay proceeding through W boson annihilation in the Standard Model



- Decay rate simply related to B meson decay constant f_B

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

Helicity suppressed by light lepton mass : τν is favored over eν and μν

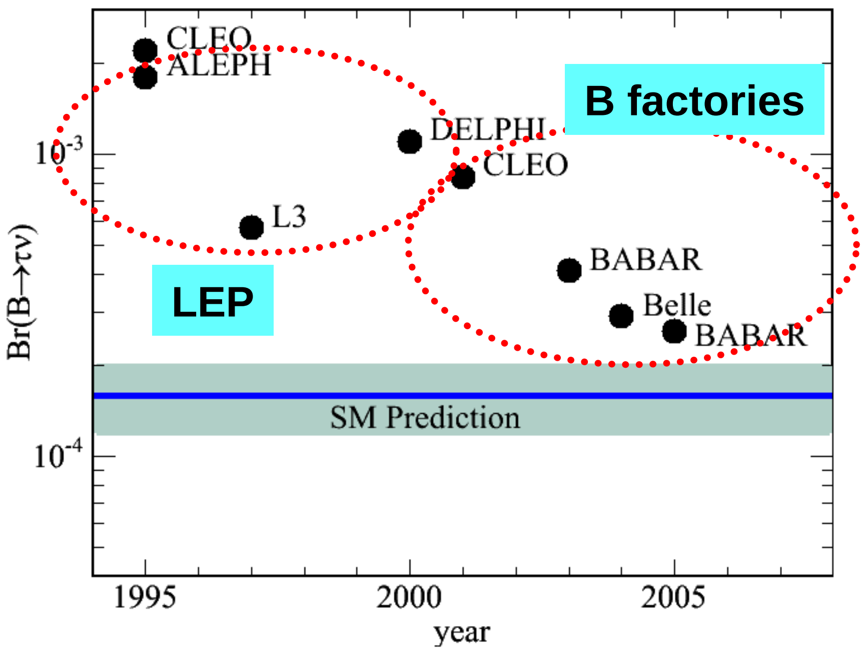
- Clean experimental method of measuring B meson decay constant f_B
- Physics beyond the SM could enhance the branching fraction through the introduction of a charged Higgs boson

$B \to \tau\nu$ and B Meson Decay Constant f_B (cont.)

- Search for $B \to \tau\nu$ is important for both of SM and physics beyond the SM

Experimentally challenging due to the presence of additional neutrinos from τ decay

- $B \to \tau\nu$ search history

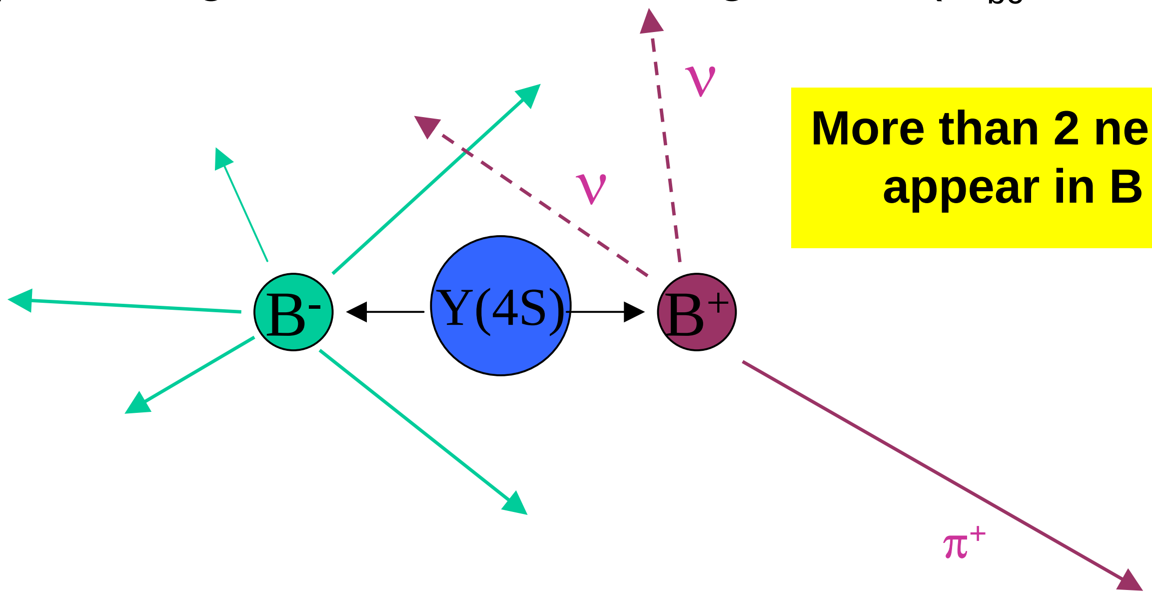


Experimental limit on B($B \to \tau\nu$) is getting close to the prediction

The story has a happy ending ?

$B \to \tau\nu$ Analysis Concepts

- B decays with missing neutrinos lack the kinematic constraints which are used to separate signal events from backgrounds (M_{bc} and ΔE)



More than 2 neutrinos appear in $B \to \tau\nu$ decay

- Reconstruct the decay of the non-signal B (tagging), then look for the signal decay in whatever is left over

Tagging side :
Fully reconstruct hadronic modes

Signal side :
Reconstruct particles from τ decay

Features with Fully Reconstructed B Tag

- Merit : Offline B meson Beam
  - **B momentum is available**

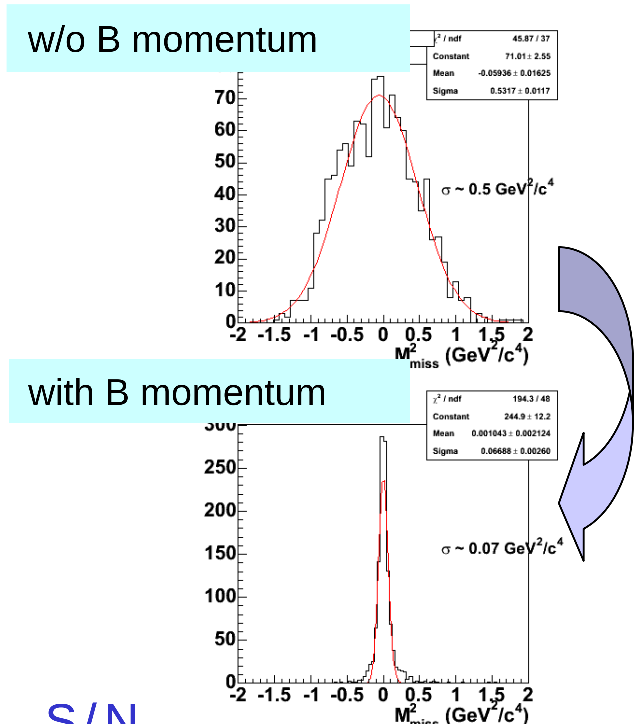
    -Resolution of M_{miss}^2 can be significantly improved.

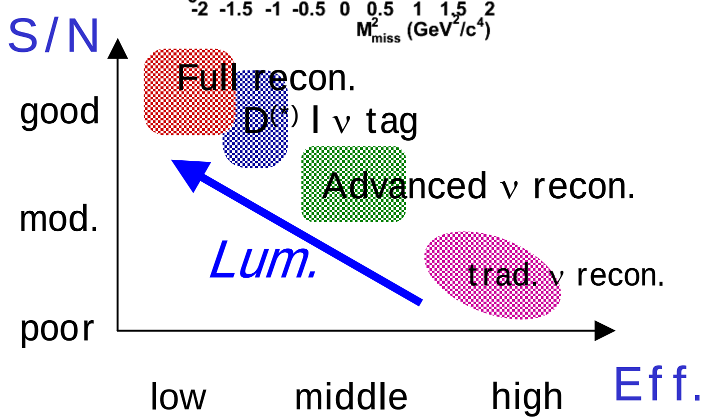
    -separate similar semileptonic decays

    → reduce background significantly
  - **B-flavor is also available**

    -We can treat charged & neutral B separately
- Demerit : Low statistics
  - Efficiency : 0.2 - 0.3%
  - However, we can rely on KEKB, providing World record luminosity

M_{miss}^2 for $B^- \to D^0 \mu^- \nu$ (MC)





Fully Reconstructed B's with 447 M $B\bar{B}$

$$B^+ \to \bar{D}^{(*)0} + \pi^+ / \rho^+ / a_1^+ / D_S^{(*)+}$$
$$\bar{D}^{*0} \to \bar{D}^0\pi^0 / \bar{D}^0\gamma \qquad D_S^{*+} \to D_s^+\gamma$$

$$B^0 \to D^{(*)-} + \pi^+ / \rho^+ / a_1^+ / D_S^{(*)+}$$
$$D^{*-} \to \bar{D}^0\pi^- / D^-\pi^0 \qquad D_S^{*+} \to D_s^+\gamma$$

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

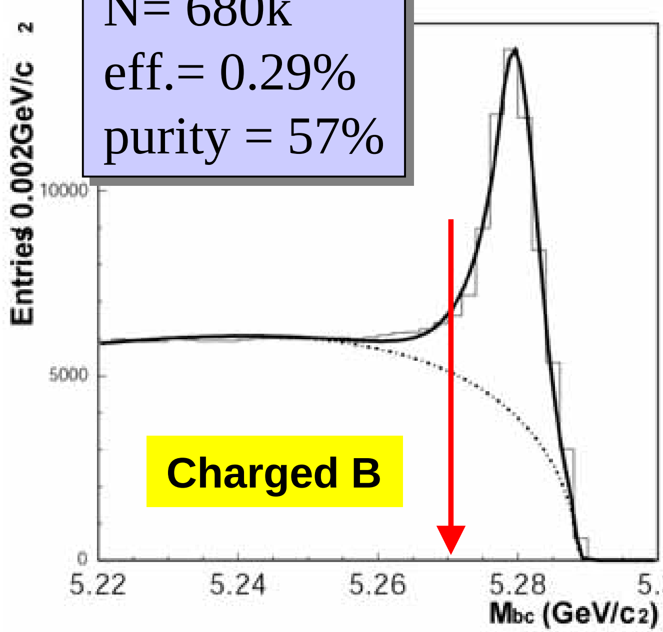
$D^- \to$ 6 modes

$D_s^+ \to$ 2 modes

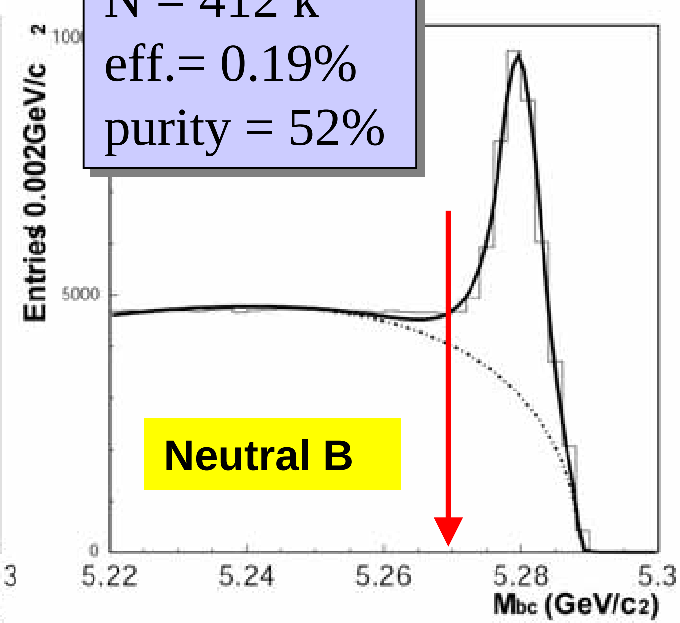
~ 180 channels used

- Beam constrained mass

N= 680k
eff.= 0.29%
purity = 57%



N = 412 k
eff.= 0.19%
purity = 52%



m ~ 5.28 GeV/c²

σ~ 3 MeV/c² due to σ(E_{beam})

~10% for feed-across between B^+ and B^0

Signal region : $-0.08 < \Delta E < 0.06$ GeV, $M_{bc} > 5.27$ GeV/c²

Signal Selection

- τ lepton is identified in the 5 decay modes

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

81% of all τ decay modes

$\tau^- \to \mu^-\nu\bar{\nu}$	$\tau^- \to e^-\nu\bar{\nu}$	$\tau^- \to \pi^-\nu$	$\tau^- \to \pi^-\pi^0\nu$	$\tau^- \to \pi^-\pi^+\pi^-\nu$
1 signal-side track				3 signal-side tracks
No signal-side π^0			1 signal-side π^0	No signal-side π^0
$E_{ECL} < 0.2$ GeV			$E_{ECL} < 0.3$ GeV	
$P^*_{\ell^-} > 0.3$ GeV		$P^*_{\pi^-} > 0.8$ GeV	$P^*_{\pi\pi} > 1.2$ GeV	$P^*_{3\pi} > 1.8$ GeV
$P^*_{miss} > 0.2$ GeV		$P^*_{miss} > 1.0$ GeV	$P^*_{miss} > 1.2$ GeV	$P^*_{miss} > 1.8$ GeV
			$\lvert M_\rho - M_{\pi\pi}\rvert < 0.15$ GeV	$\lvert M_\rho - M_{\pi\ \pi^-}\rvert < 0.15$ GeV
				$\lvert M_a - M_{3\pi}\rvert < 0.3$ GeV
$-0.86 < \cos\theta^*_{miss} < 0.95$				

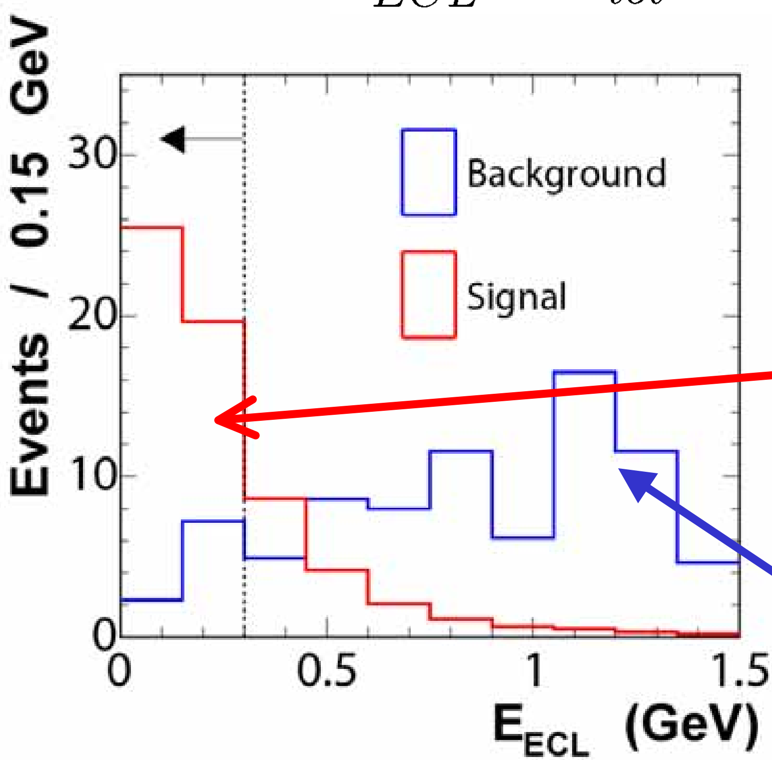
Total efficiency with τ decay branching fraction : 32.92 ±0.12%

All the selection criteria have been optimized to achieve the highest sensitivity

Signal Selection

- Extra neutral energy in calorimeter E_{ECL}
  - Most powerful variable for separating signal and background
  - Total calorimeter energy from the neutral clusters which are not associated with the tag B

$$E_{ECL} = E_{tot} - E_{rec.\ B} \quad (-E_{\pi^-} \text{ for } \pi^-\pi^0\nu)$$



Minimum energy threshold
- **Barrel : 50 MeV**
- **Forward(Backward) endcap : 100(150) MeV**

Zero or small value of E_{ECL} arising only from beam background

Higher E_{ECL} due to additional neutral clusters

B^+B^- is dominant in background

Signal Selection

- Extra neutral energy E_{ECL} Validation

-Double tagged sample, B_{tag} is fully reconstructed and B_{sig} is semileptonic mode

$B^+ \to D^{(*)0} X^+$ **(fully reconstruction)**

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

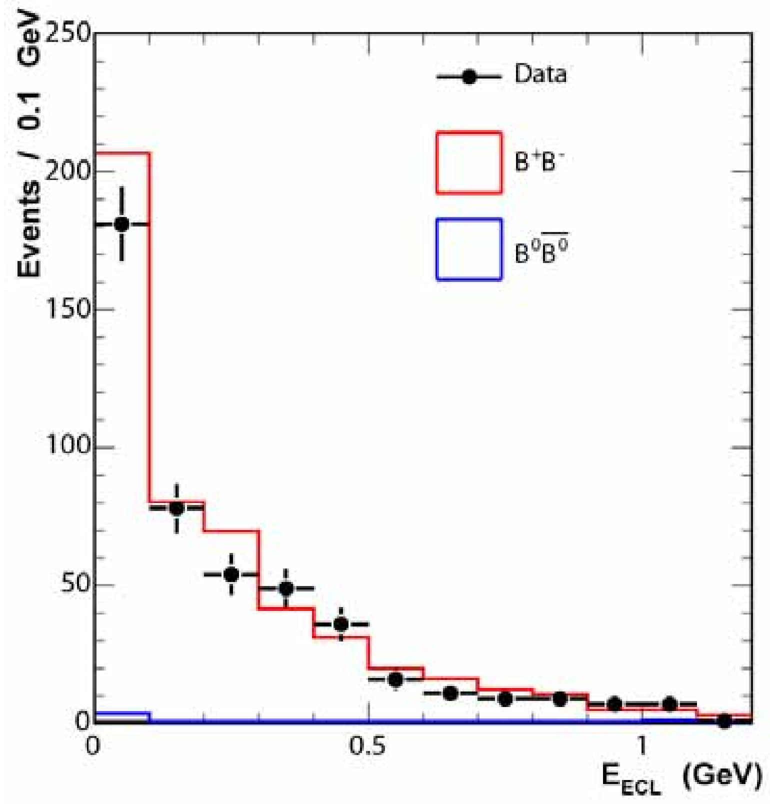
$\quad \hookrightarrow D^0 \pi^0$

$\quad\quad \hookrightarrow K^- \pi^+$

$\quad\quad\quad K^- \pi^+ \pi^- \pi^+$

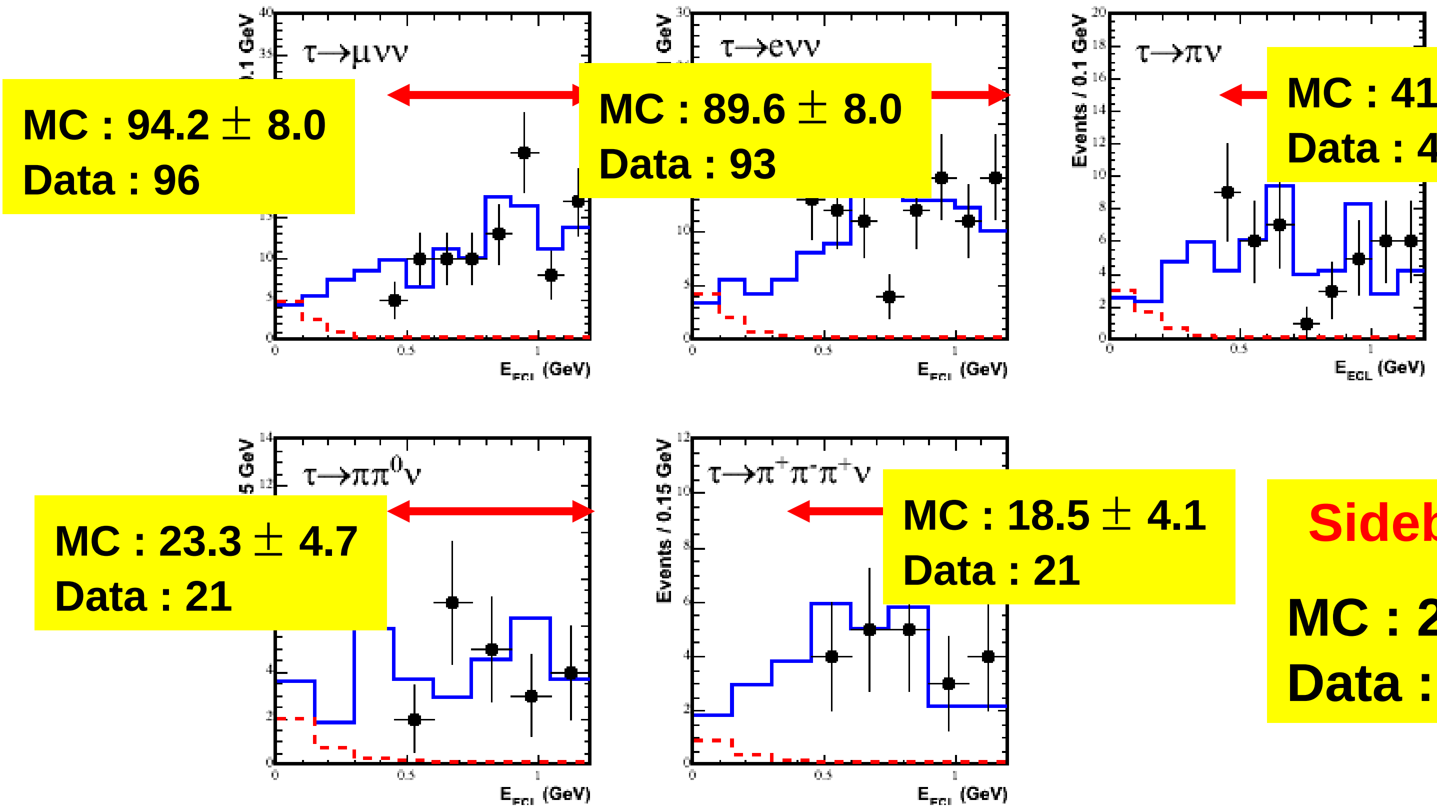
B^+B^-	494 ± 18
B^0B^0	7.9 ± 2.2
Total	502 ± 18
Data	458

Purity ～ 90%



Validate with double tagged events

Background Estimation



Sideband Total

MC : 267 $\pm$ 14

Data : 274

Large MC samples for $e^+e^- \rightarrow BB$**, qq,** $X_u l\nu$**,** $X_u \tau\nu$**,** $\tau^+\tau^-$ **, and rare B decays are used (including beam-background)**

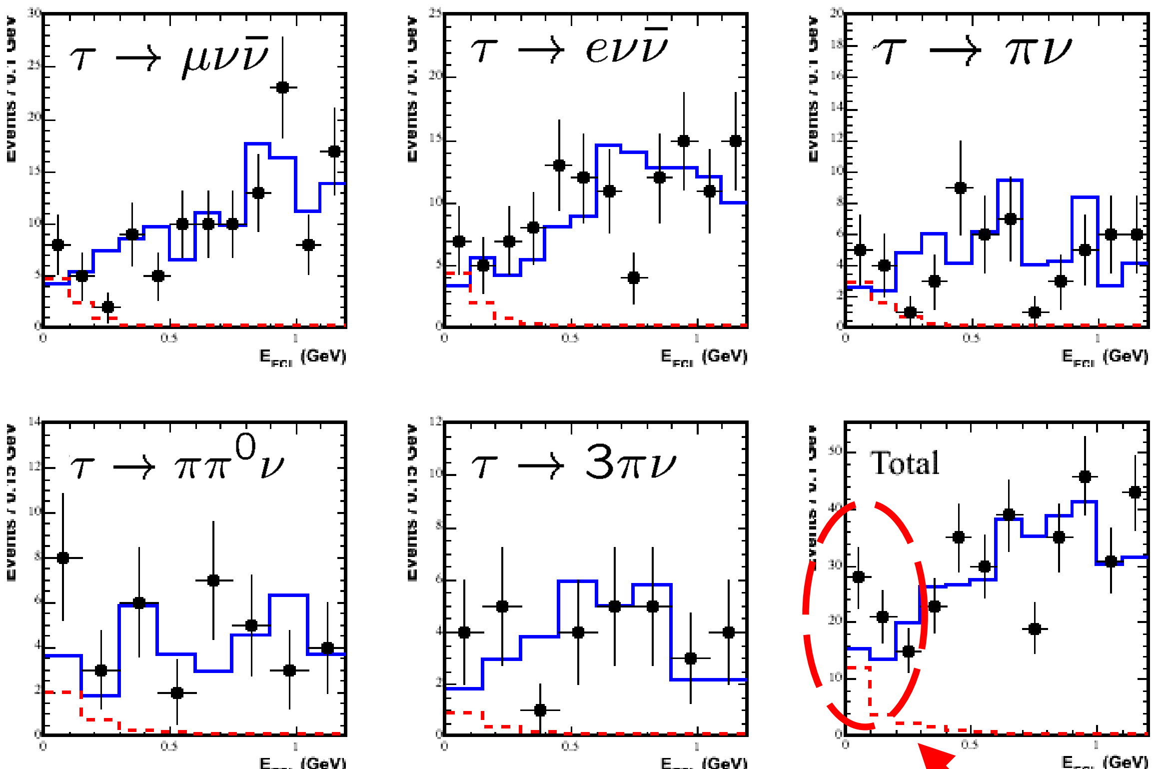
Good agreement between data and MC in sideband region
→ Validity of background MC simulation

Extra Calorimeter Energy in Data

- Observed events compared with background expected

414 fb^{-1}

After finalizing the signal selection criteria, the signal region is examined



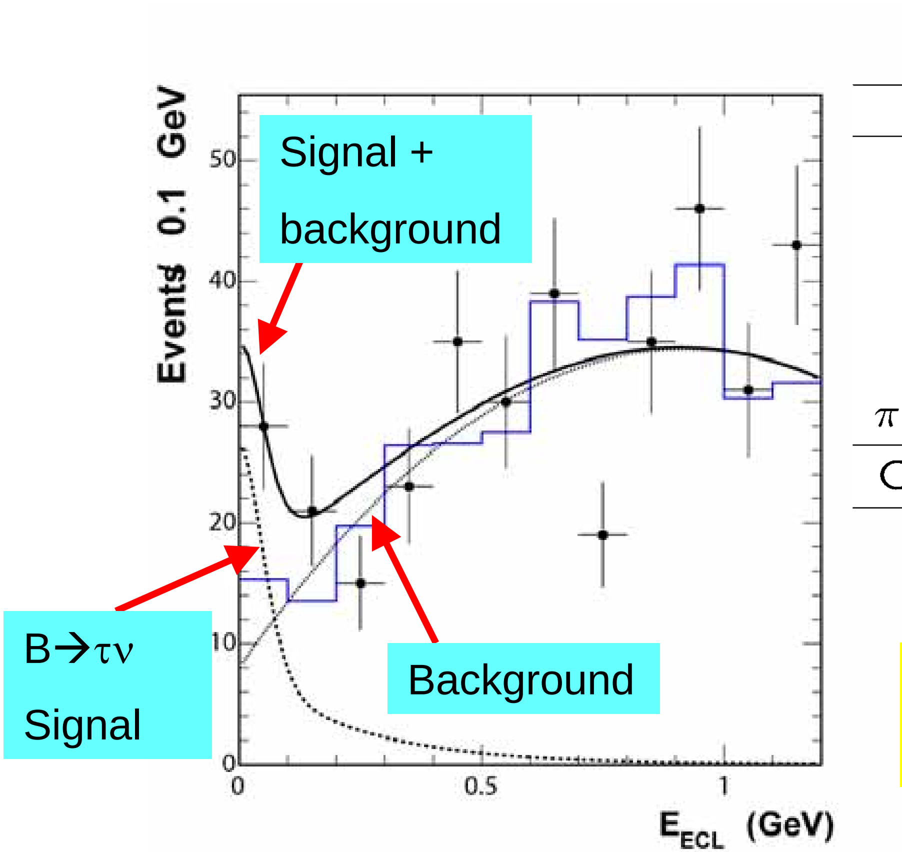
Number of data in signal region

	BG	Data
$\mu^-\nu\bar{\nu}$	9.4 ± 2.6	13
$e^-\nu\bar{\nu}$	8.6 ± 2.3	12
$\pi^-\nu$	4.7 ± 1.7	9
$\pi^-\pi^0\nu$	5.9 ± 1.9	11
$\pi^-\pi^+\pi^-\nu$	4.2 ± 1.6	9
Total	32.8 ± 4.6	54

Observe excess in signal region

Fit Results

- Unbinned Likelihood fit to the obtained E_{ECL} distributions



	N_{obs}	N_s	N_b	Σ
$\mu^- \bar{\nu}_\mu \nu_\tau$	13	$5.4^{+3.2}_{-2.2}$	$9.1^{+0.2}_{-0.1}$	2.3σ
$e^- \bar{\nu}_e \nu_\tau$	12	$3.9^{+3.5}_{-2.5}$	$9.2^{+0.2}_{-0.2}$	1.5σ
$\pi^- \nu_\tau$	9	$3.4^{+2.6}_{-1.6}$	$4.0^{+0.2}_{-0.1}$	1.9σ
$\pi^- \pi^0 \nu_\tau$	11	$6.2^{+3.9}_{-2.7}$	$4.2^{+0.3}_{-0.3}$	2.6σ
$\pi^- \pi^+ \pi^- \nu_\tau$	9	$3.1^{+3.1}_{-2.6}$	$3.7^{+0.3}_{-0.2}$	1.2σ
Combined	54	$21.2^{+6.7}_{-5.7}$	$30.2^{+0.5}_{-0.4}$	4.2σ

Σ : Significance with systematics

Background yield is consistent with the expectation from the MC simulation

Signal shape : Gauss + exponential
Background shape : second-order polynomial

Observe $21.2^{+6.7}_{-5.7}$ events with a significance of 4.2σ

Systematic Uncertainty

- Signal selection efficiencies

Source	$\mu^-\nu\bar{\nu}(\%)$	$e^-\nu\bar{\nu}(\%)$	$\pi^-\nu(\%)$	$\pi^-\pi^0\nu(\%)$	$\pi^+\pi^-\pi^+\nu(\%)$
Tracking	1.0	1.0	1.0	1.0	3.0
τ decay BR	0.3	0.3	1.0	0.6	1.1
MC statistics	0.6	0.6	0.7	1.0	2.0
Lepton ID	2.1	2.1	-	-	-
π^0 reconstruction	-	-	-	3	-
$\pi^\pm$ ID	-	-	2.0	2.0	6.0

- Tag reconstruction efficiency : 10.5%

  Difference of yields between data and MC in the $B^- \rightarrow D^{*0} l^- \nu$ control sample

- Number of BB : 1%
- Signal yield : $^{+12\%}_{-10\%}$

  signal shape ambiguity estimated by varying the signal PDF parameters

  BG shape : changing PDF

- Total systematic uncertainty $^{+17\%}_{-15\%}$

$B \to \tau\nu$ Branching Fraction

- Branching fractions are calculated by

$$\mathcal{B} = \frac{N_s}{2 \cdot \varepsilon^{\text{sel}} \cdot \varepsilon^{\text{tag}} \cdot N_{BB}}$$

- All τ decay modes combined

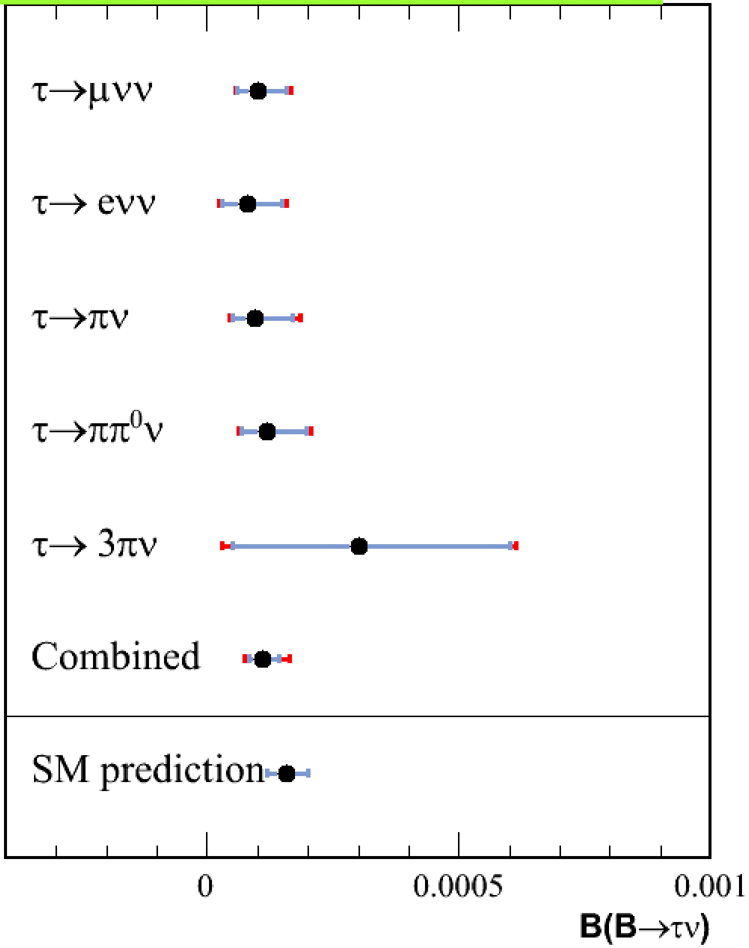
$$\mathcal{B}(B \to \tau\nu) =$$

$$(1.06^{+0.34}_{-0.28}(\text{stat})^{+0.18}_{-0.16}(\text{syst})) \times 10^{-4}$$

SM : $B(B \to \tau\nu) = (1.59 \pm 0.40) \times 10^{-4}$

Result is consistent with SM prediction within error

Extracted branching fraction for each τ decay mode



f_B Extraction

- Product of B meson decay constant f_B and CKM matrix element $|V_{ub}|$

$$f_B \cdot |V_{ub}| = (7.73^{+1.24}_{-1.02}(\mathrm{stat})^{+0.66}_{-0.58}(\mathrm{syst})) \times 10^{-4}\ \mathrm{GeV}$$

G_F	1.16639×10^{-5}	GeV^{-2}
τ_B	$(1.643 \pm 0.010) \times 10^{-12}$	s
m_B	5.279	GeV
m_τ	1.77699	GeV

- Using $|V_{ub}| = (4.38 \pm 0.33) \times 10^{-3}$ from HFAG

$$f_B = 0.176^{+0.028}_{-0.023}(\mathrm{stat})^{+0.020}_{-0.018}(\mathrm{syst})\ \mathrm{GeV}$$

$f_B = 0.216 \pm 0.022$ GeV (HPQCD)

Phys. Rev. Lett. 95, 212001 (2005)

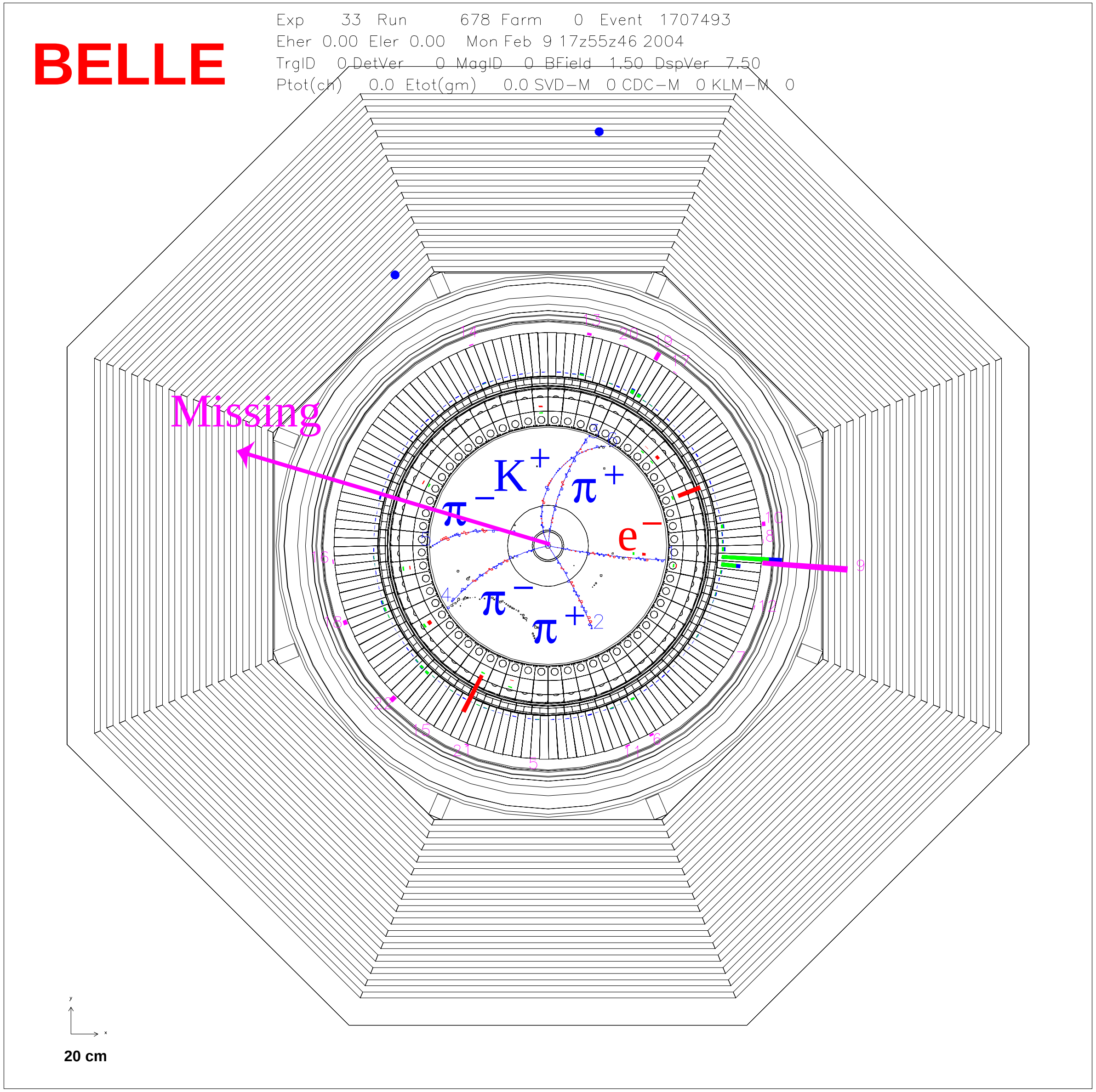
$B \rightarrow \tau\nu$ Candidate Event

$B^+ \rightarrow \overline{D^0}\,\pi^+$

↳ $K^+\,\pi^-\,\pi^+\,\pi^-$

$B^- \rightarrow \tau^-\,\nu$

↳ $e^-\nu\nu$

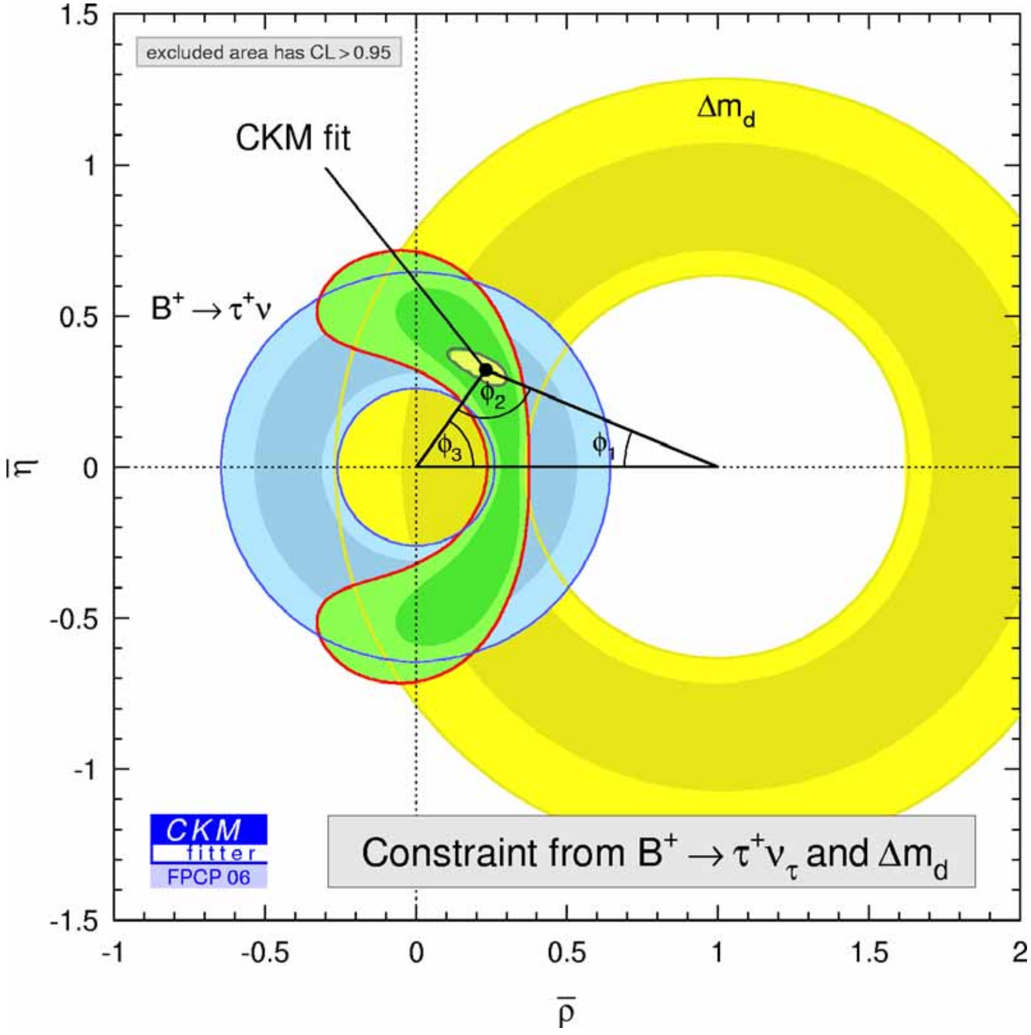


Constraints on Physics Parameters

- CKM parameters

-Constraint in the (ρ,η) plane from the $B \rightarrow \tau\nu$ branching fraction and Δm_d

$$\frac{\mathcal{B}(B \rightarrow \tau\nu)}{\Delta m_d} = \frac{|V_{ub}|^2}{|V_{td}|^2} = \frac{1}{[1-(\lambda^2/2)^2]} \frac{\bar{\rho}^2+\bar{\eta}^2}{(1-\bar{\rho})^2+\bar{\eta}^2}$$



Constraints on Physics Parameters

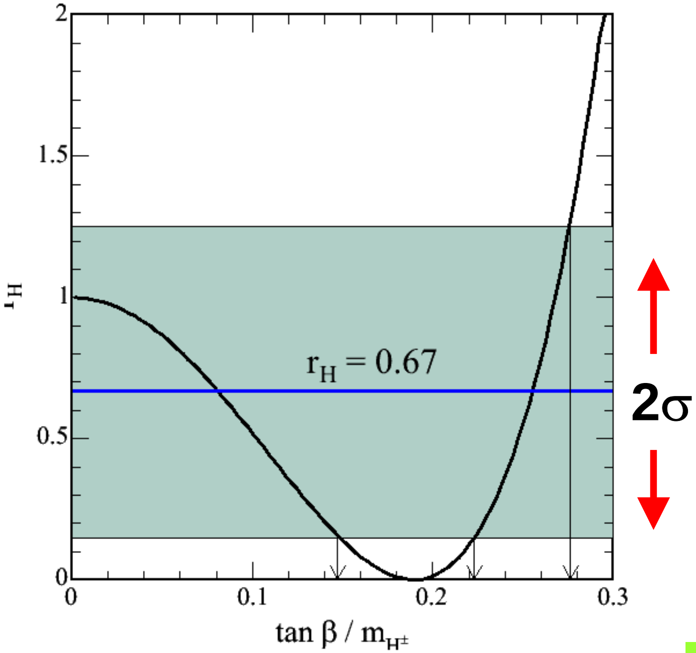
- Constraint on Charged Higgs

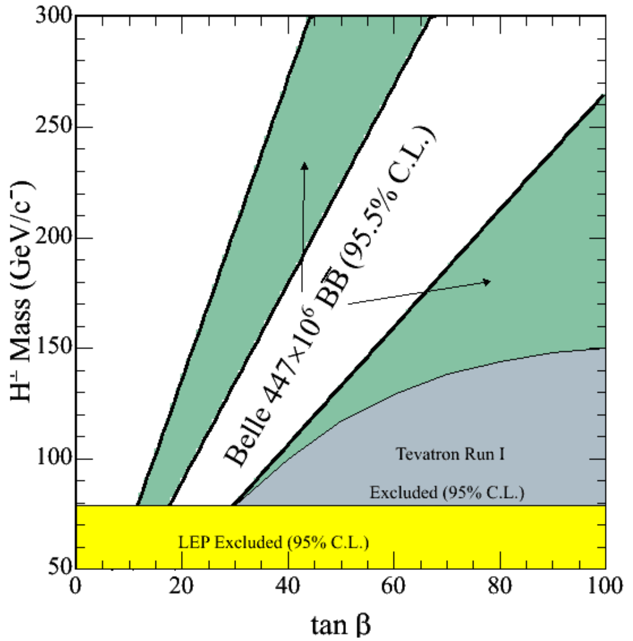
$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H$$

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2 \rightarrow r_H = 0.67^{+0.29}_{-0.26}$$

$$\mathcal{B}(B \to \tau\nu) = (1.06^{+0.34}_{-0.28}(\mathrm{stat})^{+0.18}_{-0.16}(\mathrm{syst})) \times 10^{-4}$$

$$\mathrm{SM} : \mathcal{B}(B \to \tau\nu) = (1.59 \pm 0.40) \times 10^{-4}$$

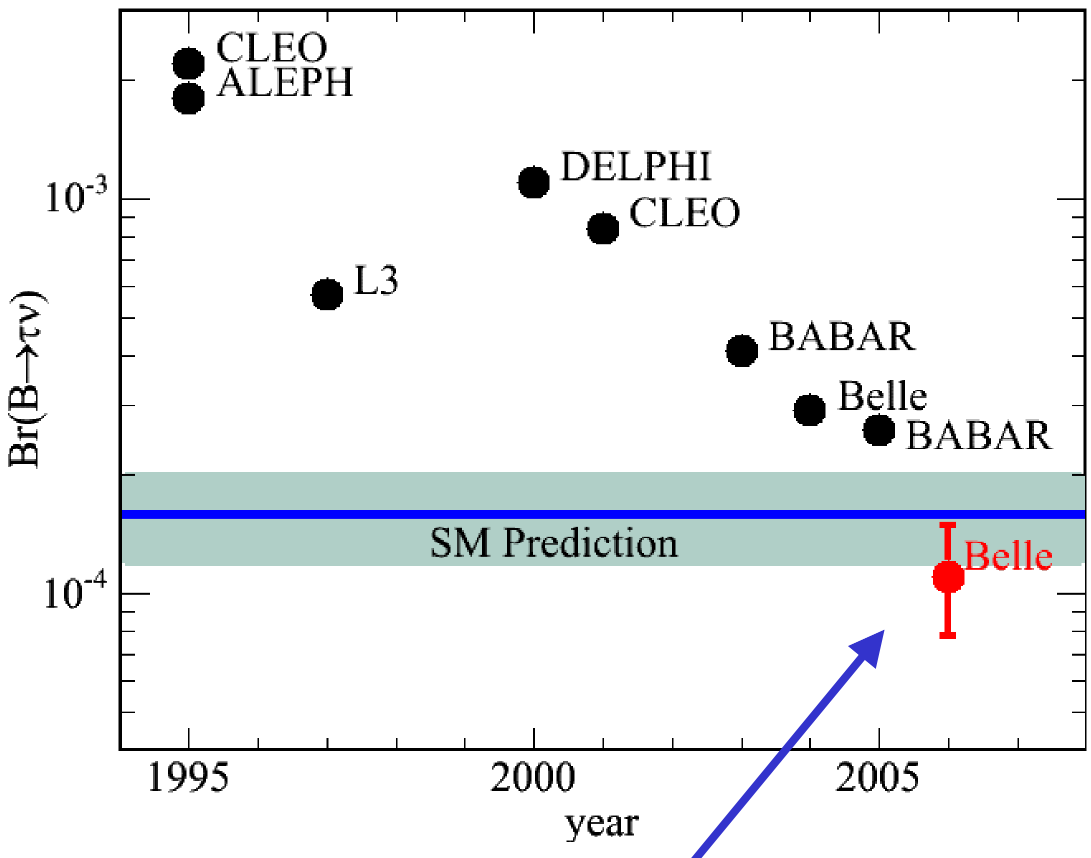




95.5%C.L. exclusion boundaries

$B \to \tau\nu$ Search History

- Branching fraction upper limits obtained from various experiments



First evidence of the purely leptonic decay $B \to \tau\nu$

Results from the Υ(5S) Engineering Run

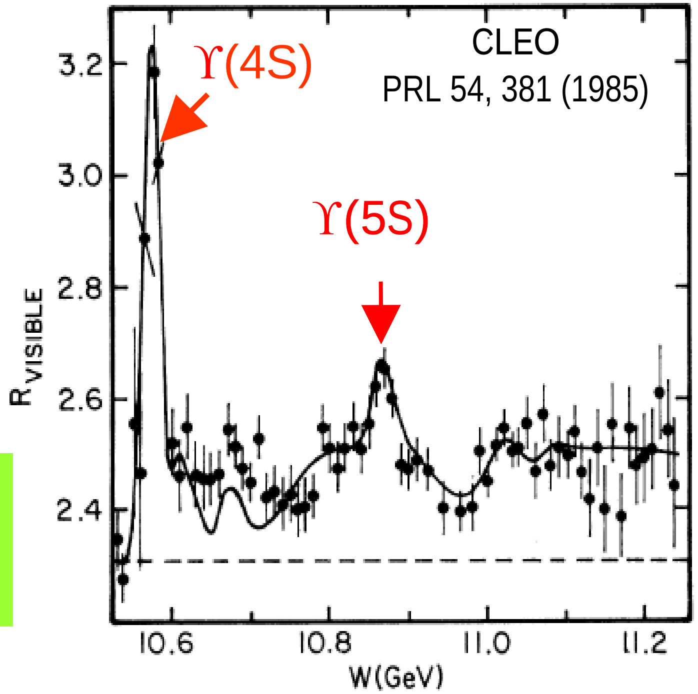
B Factory Running at Υ(5S)

- Provide the possibility to study Bs decays

$e^+e^- \rightarrow \Upsilon(5S) \rightarrow B\bar{B}, B^*\bar{B}, B^*\bar{B}^*, B\bar{B}\pi, B\bar{B}\pi\pi, B_s\bar{B}_s, B_s^*\bar{B}_s, B_s^*\bar{B}_s^*$

- e^+e^- collider has advantages over hadronic machines
-CLEO has observed B_s signals from $0.42 fb^{-1}$ Υ(5S) data [PRL96 022002(2006)]

- Υ(5S) Engineering Run performed at KEKB/Belle
  - Achieved high luminosity as Υ(4S) run L_{peak}=13.9/nb/sec
  - L_{int}=1.86 fb^{-1} has been taken during 3 days runs (June 21-23, 2005)

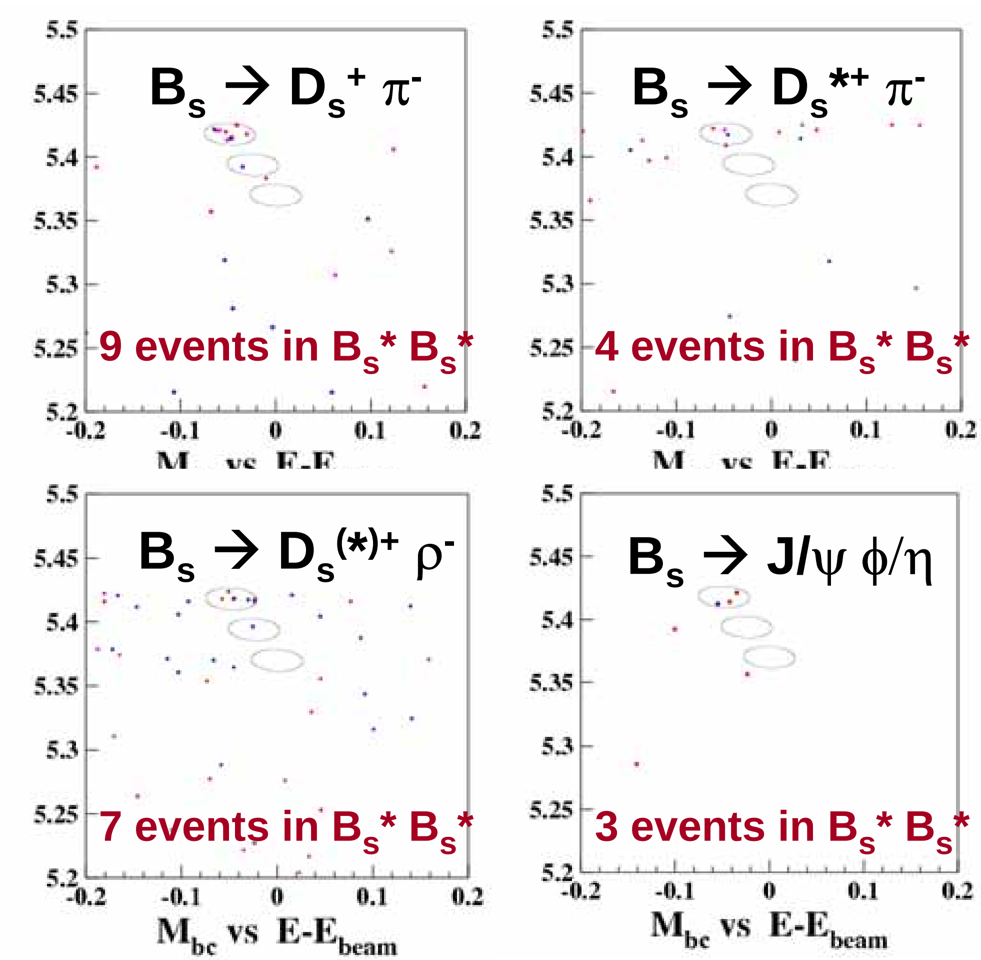


e^+ and e^- beam energies were increased by 2.7% (same Lorentz boost **β γ** = 0.425) to move from Υ(4S) to Υ(5S)

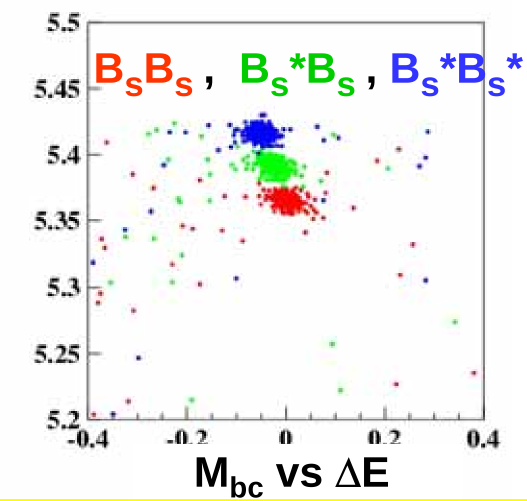
No modifications for Belle detector, trigger system or software

Reconstructed B_s Candidates

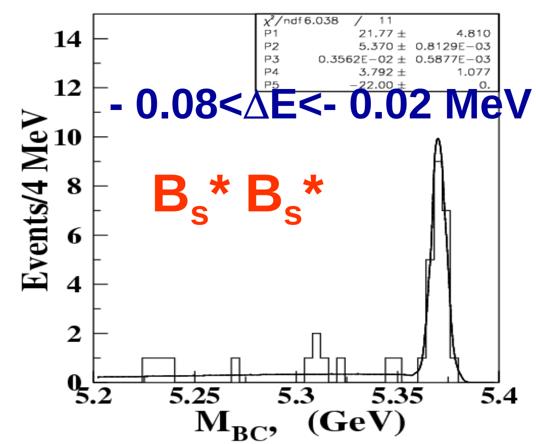
- B_s signals are identified with M_{bc} and ΔE



Clear B_s signals seen in $B_s^*B_s^*$ region



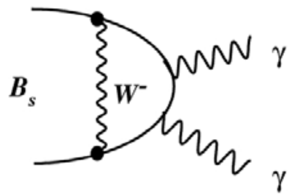
B_sB_s, $B_s^*B_s$, $B_s^*B_s^*$ signals can be separated well

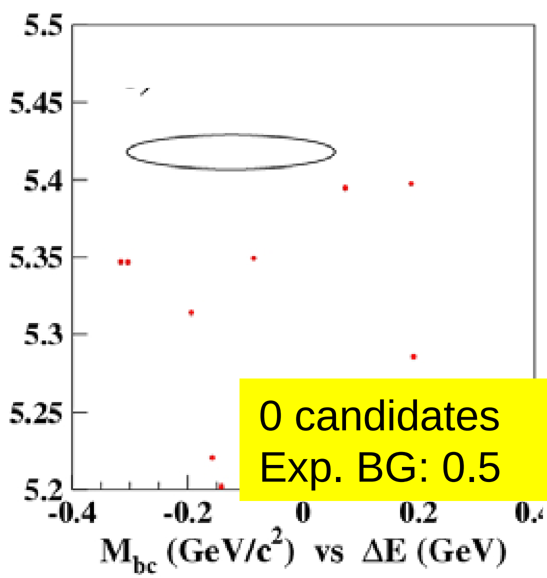


M (B_s) = 5370 ± 1 ± 3 MeV/c^2

Search for Rare B_s Decays

- $B_s \rightarrow \gamma\gamma$

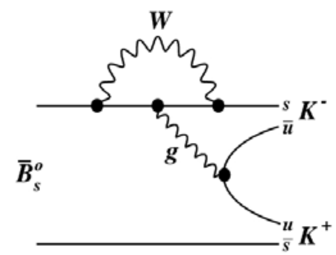


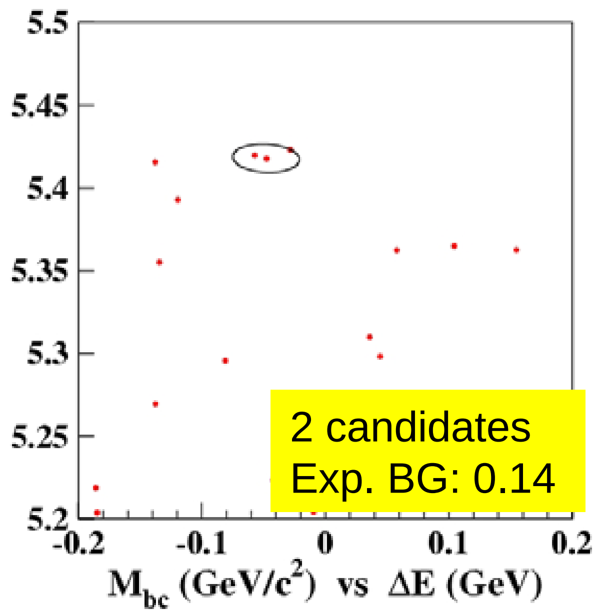


0 candidates
Exp. BG: 0.5

B($B_s \rightarrow \gamma\gamma$) < 0.56×10^{-4} (90% CL)
PDG : < 1.48×10^{-4}
SM: $0.5\text{-}1.0\times10^{-4}$

- $B_s \rightarrow K^+ K^-$

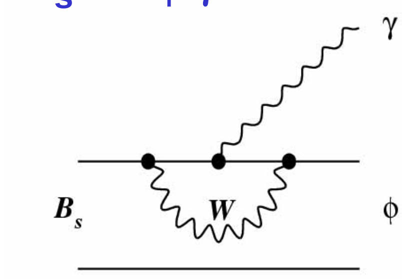


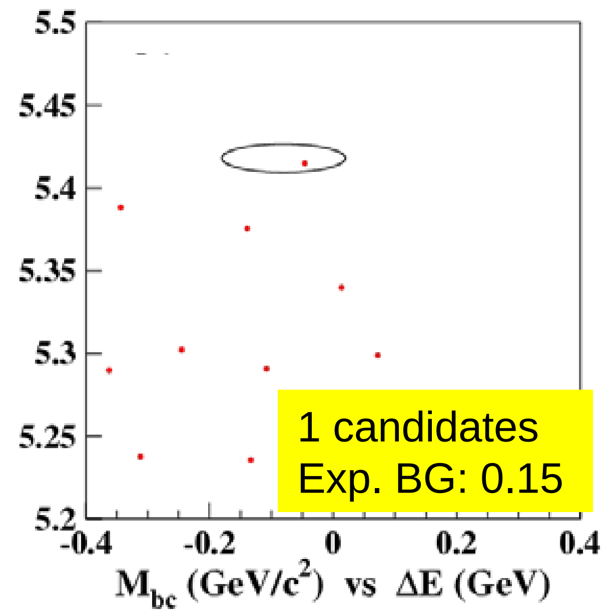


2 candidates
Exp. BG: 0.14

B($B_s \rightarrow K^+K^-$) < 3.4×10^{-4} (90% CL)
PDG : < 0.59×10^{-4}

- $B_s \rightarrow \phi\gamma$





1 candidates
Exp. BG: 0.15

B($B_s \rightarrow \phi\gamma$) < 4.1×10^{-4} (90% CL)
PDG : < 1.2×10^{-4}

Other Topics by Belle Collaborators

- ϕ_1/β from B→Charm and Charmoniumm
  - T. Hara (14:00-14:30 Sunday, Apr. 9)
- ϕ_2/α
  - C. C. Wang (16:00-16:30 Sunday, Apr. 9)
- $|V_{ub}|$ from exclusive semileptonic decays
  - K. Varvell (11:30-12:00 Tuesday, Apr. 11)
- Inclusive semileptonic decays
  - E. Barberio (14:00-14:30 Tuesday, Apr. 11)
- New physics searches at B factories
  - H. Kakuno (17:00-17:30 Tuesday, Apr. 11)
- Direct CP violation in Charmless B decays
  - Y. Chao (14:00-14:30 Wednesday, Apr. 12)
- Super B factories
  - N. Katayama (16:00-16:25 Wednesday, Apr. 12)

Summary

- Performed search for the rare leptonic B decay B $\rightarrow \tau\nu$ with 414 fb^{-1}
  - Detect the signal with a significance of 4.2σ
  - First evidence of the purely leptonic B decay
  - First direct measurement of the B meson decay constant f_B

Result is submitted to PRL

- Engineering run at Y(5S) at KEKB
  - See A. Drutskoy's talk at Moriond EW for more details

Backup Slides

$B \to \tau\nu$ and Decay Constant f_B

- Expected branching fraction

$$\mathcal{B}(B \to \tau\nu) = (1.59 \pm 0.40) \times 10^{-4}$$

$|V_{ub}|$ = (4.38 ± 0.33)×10-3 from HFAG (hep-ex/0603003)

f_B = 0.216 ± 0.022 GeV from lattice QCD

G_F	1.16639×10^{-5}	GeV^{-2}
τ_B	$(1.643 \pm 0.010) \times 10^{-12}$	s
m_B	5.279	GeV
m_τ	1.77699	GeV

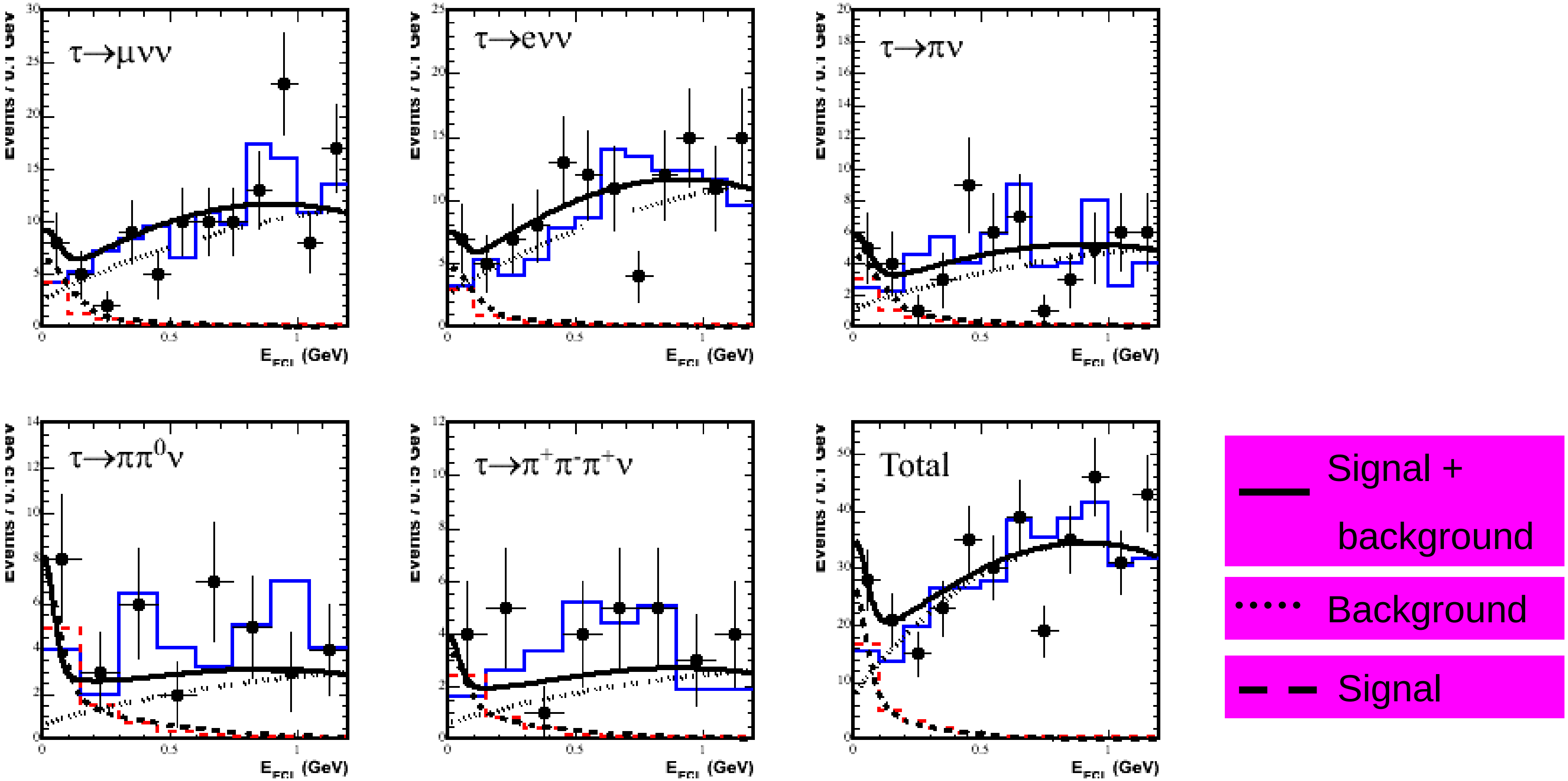
- Currently, our best knowledge of f_B comes from lattice QCD calculations with uncertainty of 10%

$$f_B = 0.216 \pm 0.022 \ \mathrm{GeV}$$

HPQCD result, Phys. Rev. Lett. 95, 212001 (2005)

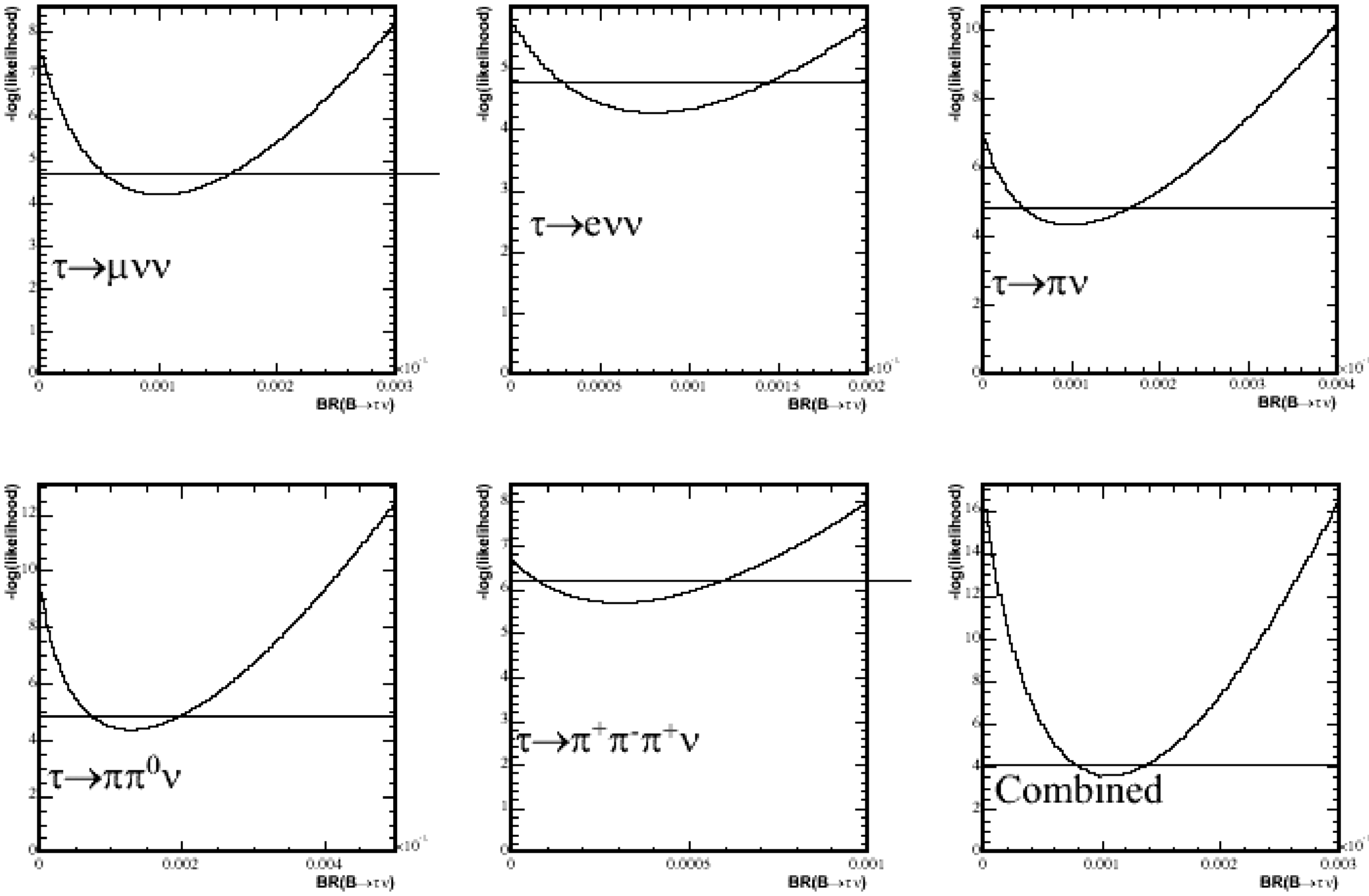
Fit Results

- Likelihood fit to the obtained E_{ECL} distributions



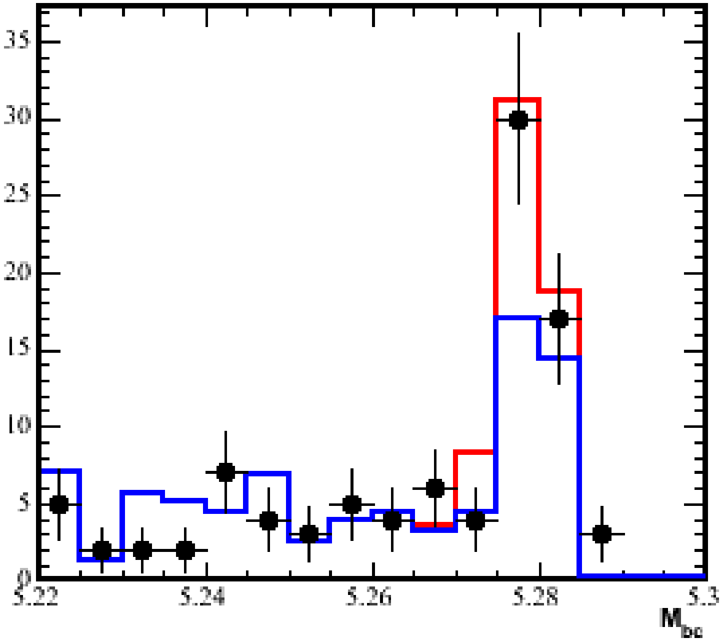
Fit Results

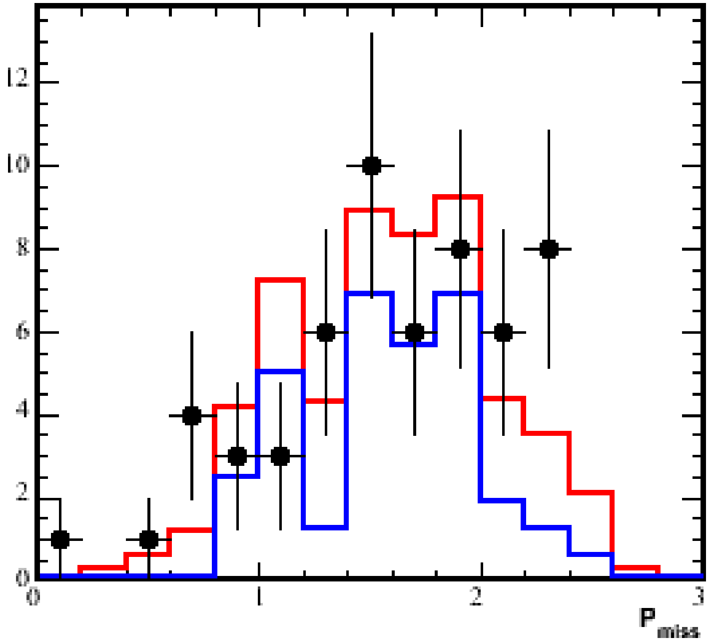
- Likelihood distributions for each τ decay



Fit Results

- M_{bc} and P_{mis} distributions





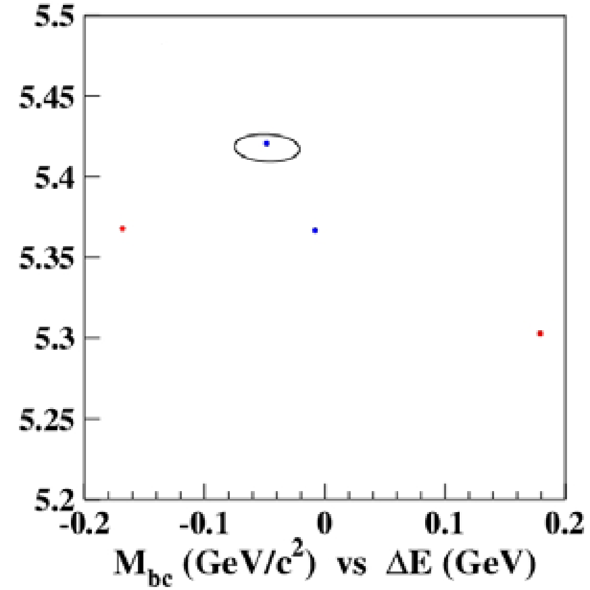
Search for $B_s \to D_s^{(*)} D_s^{(*)}$

- CP even eigenstates lead to DG/G

$$\frac{\Delta\Gamma_s}{\Gamma_s} \approx \frac{Bf(B_s\text{->}D_s^{(*)+} D_s^{(*)-})}{1\text{-} Bf(B_s\text{->}D_s^{(*)+} D_s^{(*)-}) / 2}$$

  - Can be compared with the direct measurement to test SM

Expected :~ 0.5 events in each mode.



$\mathcal{B}(B_s \to D_s^+ D_s^-)$ < 7.1 % at 90 % *CL*

$\mathcal{B}(B_s \to D_s^{*+} D_s^-)$ < 12.7 % at 90 % *CL*

$\mathcal{B}(B_s \to D_s^{*+} D_s^{*-})$ < 27.3 % at 90 % *CL*

→ 50fb^{-1} expectation: $\mathcal{B}(B_s\text{->}D_s^{(*)+} D_s^{(*)-}) = (12 \pm 3)\%$