Leptonic & semileptonic B decays at Belle

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Outline

Semileptonic B decays:

$$B \to h\ell\nu_\ell \quad (\ell = e, \mu)$$

$$(B^0 \to \pi^+\ell\nu, B^+ \to \pi^0\ell\nu, B^0 \to \rho^+\ell\nu, B^+ \to \rho^0\ell\nu, B^+ \to \omega\ell\nu, B^+ \to \eta^{(\prime)}\ell\nu)$$

Leptonic B decays:

$$B^+ \to \ell^+\nu_\ell \left\{ \begin{array}{c} B^+ \to e^+\nu_e,\ B^+ \to \mu^+\nu_\mu \\ B^+ \to \tau^+\nu_\tau \end{array} \right\}$$

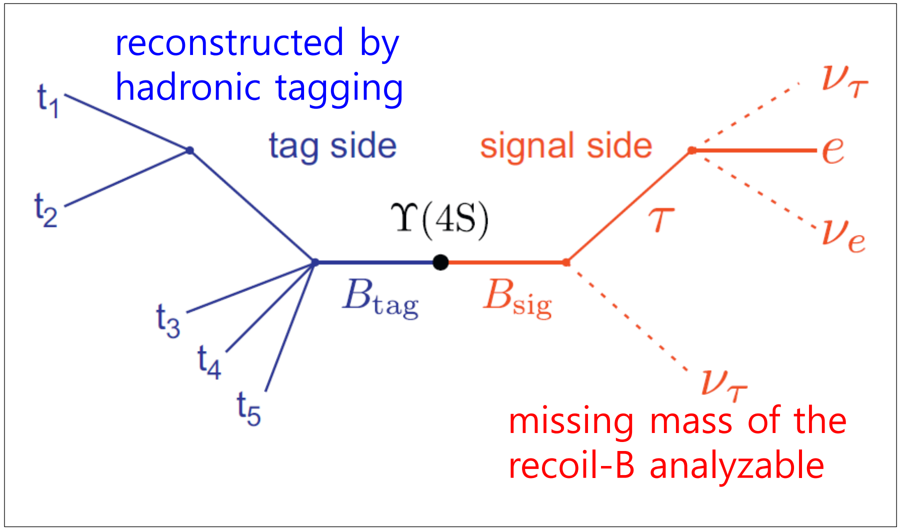
We fully reconstructed a *B*-meson in order to handle the invisible neutrinos

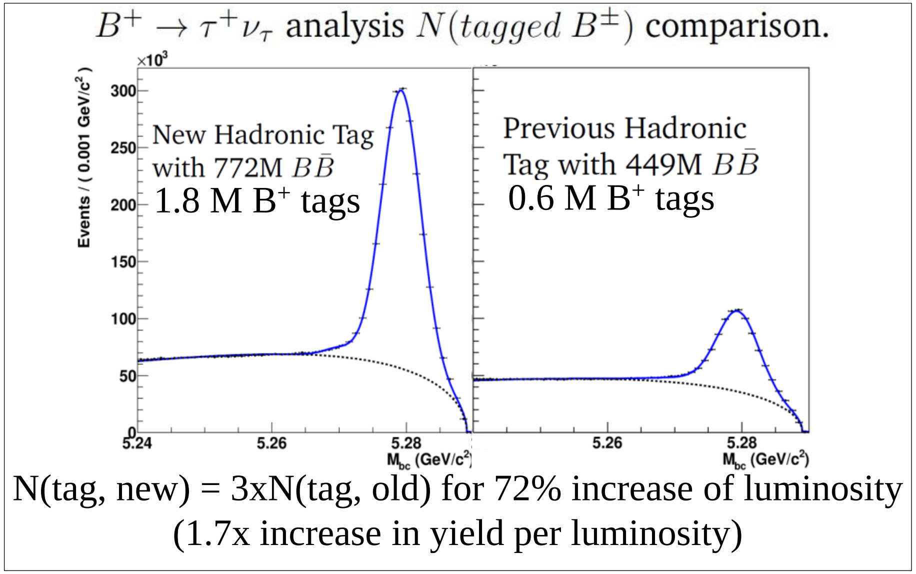
Hadronic Tagging Method

HADRONIC TAGGING

Complete tagging of a B in Y(4S)->BB

→ Constrain the charge, flavor, 4-momentum of the recoil-B
→ Results in very high-purity (but with low efficiency)
→ Good continuum (e^+e^- → u,d,s,c) suppression
→ Reconstructs rare modes with neutrinos





N(tag, new) = 3xN(tag, old) for 72% increase of luminosity
(1.7x increase in yield per luminosity)

Reprocessed Data: improved detection efficiency for low p_T tracks and neutral particles
Modified Hadronic Tag: Neurobayes algorithm + Addition of more B/D tagging modes
→ increased statistics, better sensitivity

Measurements of $|V_{ub}|$ from Exclusive $B \to h\ell\nu$

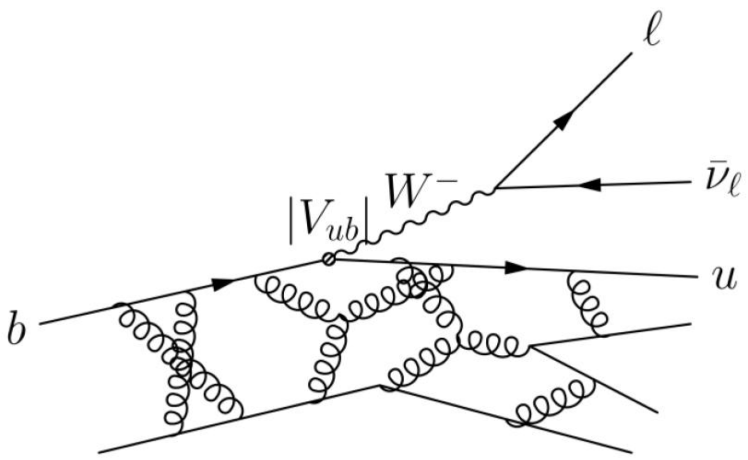
($h = \pi^+, \pi^0, \rho^+, \rho^0, \omega, \eta, \eta'$, Lepton includes e and μ)

- Precision measurement of the $B \to X_u \ell \nu$ branching fraction
- With increased and reprocessed data and new hadronic tagging

With exclusive $B \to \pi \ell^+ \nu_\ell$, for instance, $|V_{ub}|$ can be extracted from the differential decay rate

$$\frac{d\Gamma(B \to \pi \ell^+ \nu_\ell)}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} |p_\pi|^3 |f_+(q^2)|^2$$

Theory input is needed to determine the form factor $f_+(q^2)$.



$B \to \pi \ell \nu$

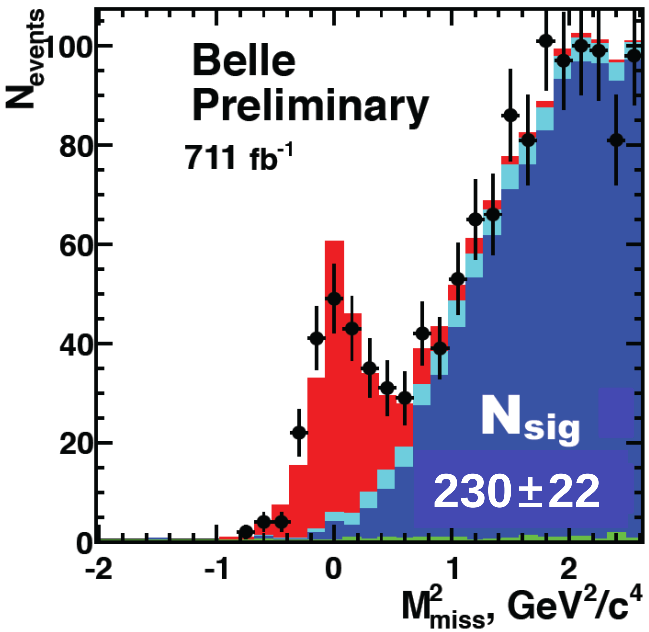
- Full $\Upsilon(4S)$ data used ($N(B\bar{B})$ = 772M / 711fb^{-1})
- Signal yield extracted from maximum-likelihood fit to M^2_{miss}

$$M^2_{miss} = (E_{CM} - E_{B_{tag}} - E_{B_{sig}})^2 - (P_{B_{tag}} - P_{B_{sig}})^2$$

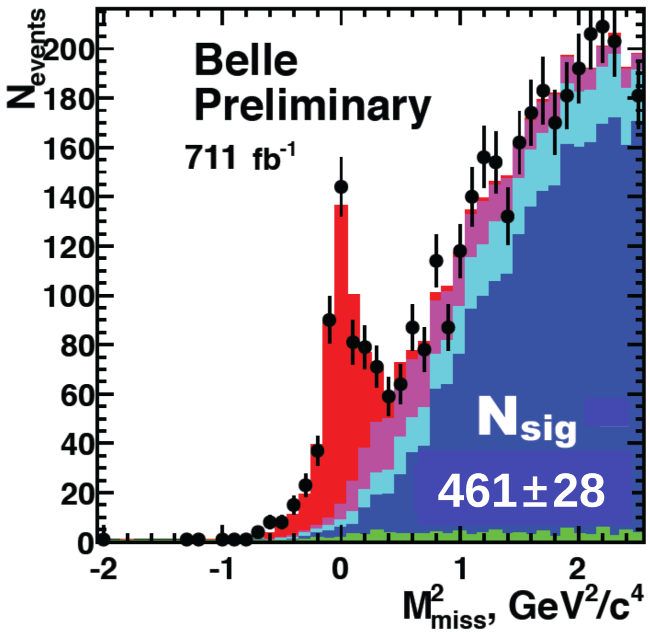
E and $P_{B_{tag}}$: Energy and momentum of the tagged-B
E and $P_{B_{sig}}$: Energy and momentum of signal side B particles

The cleanest measurement of these modes!

$B^+ \to \pi^0 \ell^+ \nu$



$B^0 \to \pi^- \ell^+ \nu$

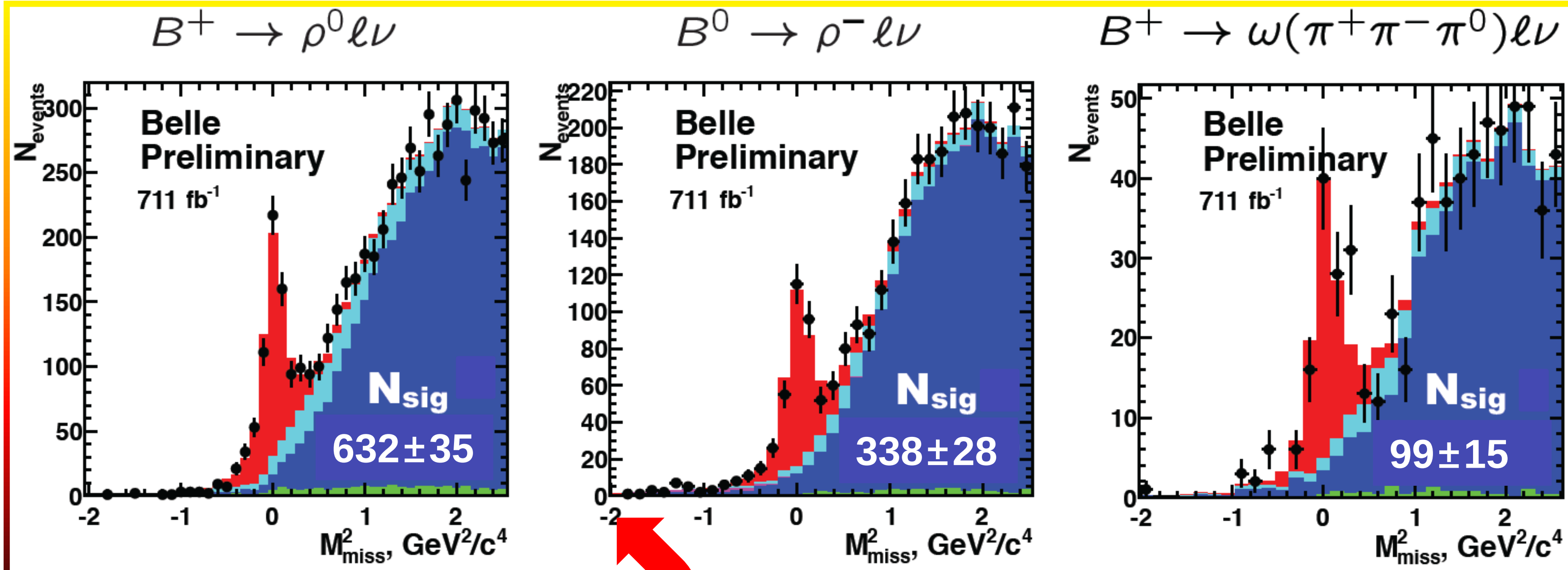


signal
B --> ρ l ν
other X_u l ν
B --> X_c l ν
continuum

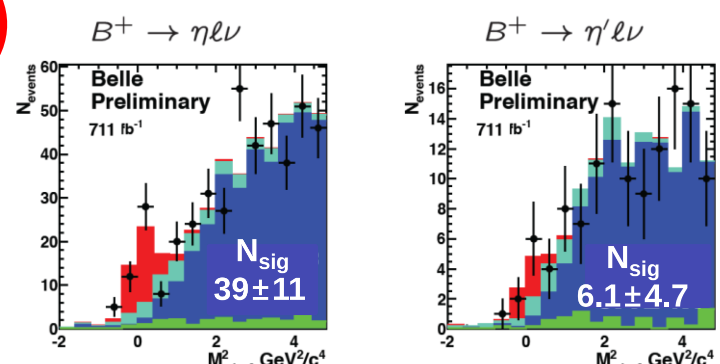
stat. error only for N_{sig}

Major systematic uncertainty from hadronic tag efficiency ~ 5.0%

Other $B \to h\ell\nu$



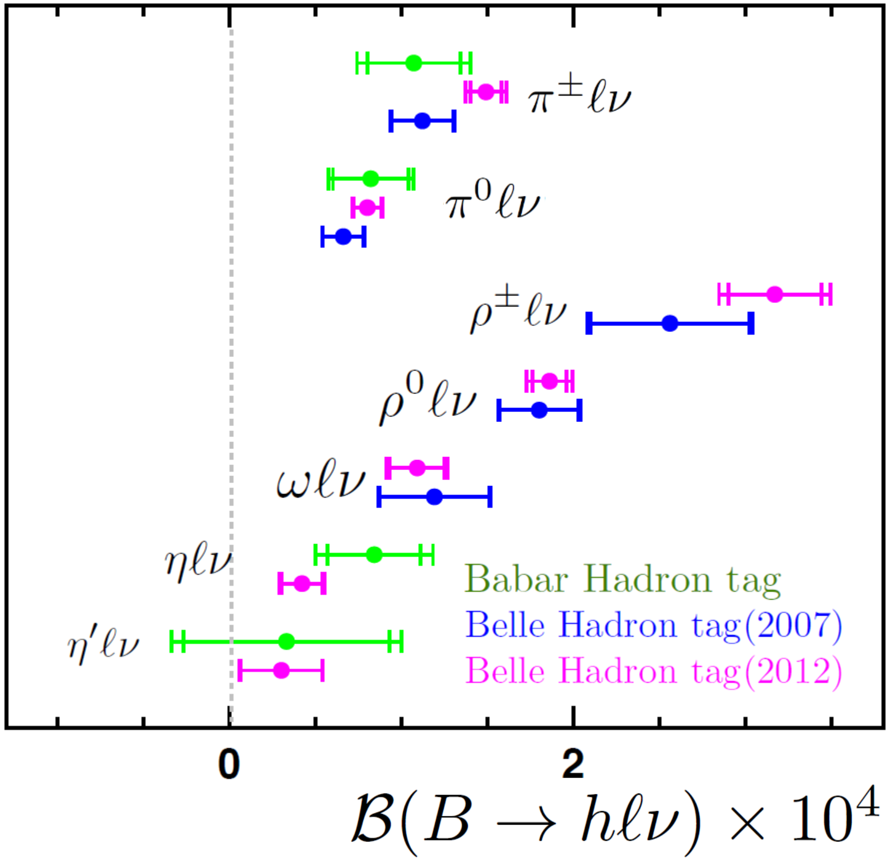
Great achievements in CLEAN SIGNAL EXTRACTION of $B \to \rho \ell \nu$ and $B \to \omega \ell \nu$!



Measurement of $B^+ \to \eta^{(\prime)}\ell\nu$ modes

signal
other X_u l ν
B --> X_c l ν
continuum

Branching Ratios of the $B \to h\ell\nu$



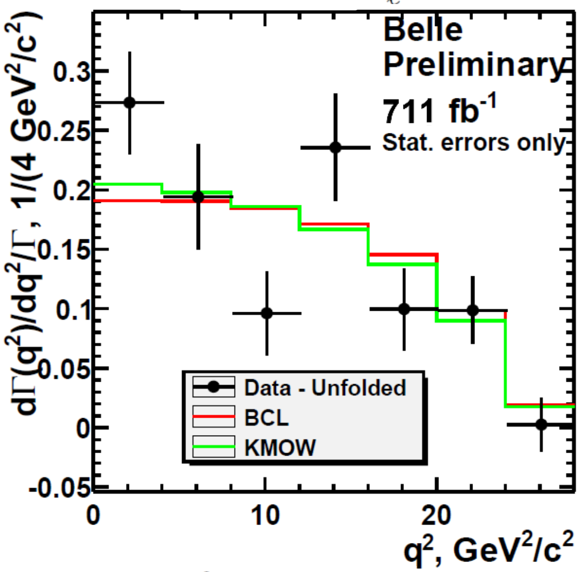
$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_l) = (1.49 \pm 0.09 \pm 0.07) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_l) = (0.80 \pm 0.08 \pm 0.04) \times 10^{-4}$$
$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu_l) = (3.17 \pm 0.27 \pm 0.18) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu_l) = (1.86 \pm 0.10 \pm 0.09) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \omega \ell^+ \nu_l) = (1.09 \pm 0.16 \pm 0.08) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \eta \ell^+ \nu_l) = (0.42 \pm 0.12 \pm 0.05) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \eta' \ell^+ \nu_l) < 0.57 \times 10^{-4} \ @ \ 90\% CL.$$

[Belle Preliminary Results]

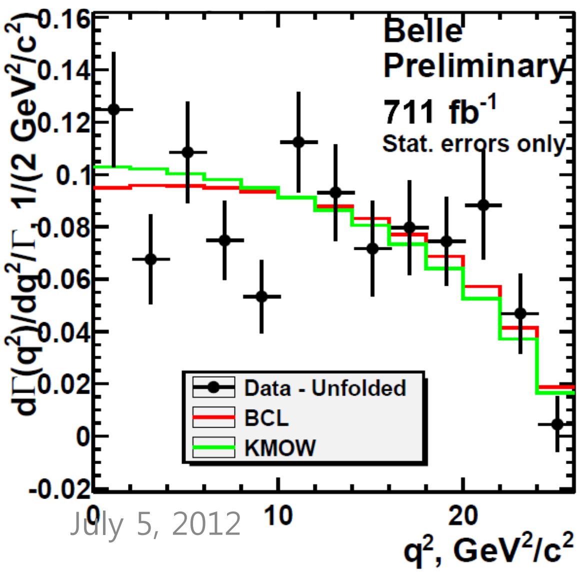
→ **Significantly improved branching ratios compared to the past results.**

Values of $|V_{ub}|$ from $\mathcal{B}(B \to \pi\ell\nu)$

$B^+ \to \pi^0 \ell \bar{\nu}_\ell$



$B^0 \to \pi^+ \ell \bar{\nu}_\ell$



($|V_{ub}|$(CKM fitter 2012) $= [3.14^{+0.21}_{-0.10}] \times 10^{-3}$)

Belle preliminary

$X_u l\nu$	Theory	q^2[GeV^2]	$\lvert V_{ub}\rvert$x10^3
$\pi^0 l\nu$	KMOW[1]	<12	$3.30 \pm 0.22 \pm 0.09^{+0.35}_{-0.30}$
	Ball/Zwicky[2]	<16	$3.62 \pm 0.20 \pm 0.10^{+0.60}_{-0.40}$
	FNAL[3]	>16	$3.30 \pm 0.30 \pm 0.09^{+0.36}_{-0.30}$
	HPQCD[4]	>16	$3.45 \pm 0.31 \pm 0.09^{+0.58}_{-0.38}$
$\pi^+ l\nu$	KMOW[1]	<12	$3.38 \pm 0.14 \pm 0.09^{+0.36}_{-0.32}$
	Ball/Zwicky[2]	<16	$3.57 \pm 0.13 \pm 0.09^{+0.59}_{-0.39}$
	FNAL[3]	>16	$3.69 \pm 0.22 \pm 0.09^{+0.41}_{-0.34}$
	HPQCD[4]	>16	$3.86 \pm 0.23 \pm 0.10^{+0.66}_{-0.44}$

Statistical

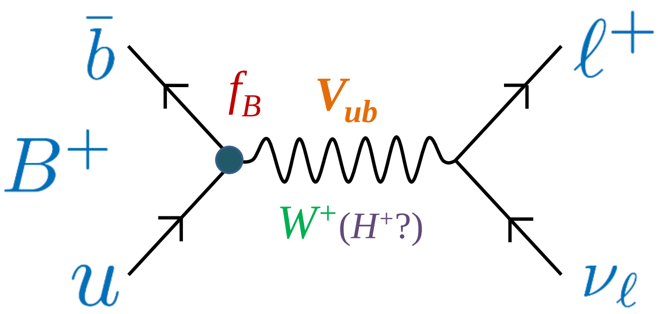
Experimental Systematic

Theoretical

[1] PRD 83 (2011) 094031
[2] PRD 71 (2005) 014015 } LCSR
[3] PRD 79 (2009) 054507
[4] PRD 73 (2006) 074502 } Lattice QCD

Calculation of $|V_{ub}|$ from different theory input for each q^2 range.

$B^+ \to \ell^+ \nu_\ell$



A Clean Process for the Measurement of f_B, $|V_{ub}|^2$

Helicity Suppression:
Branching fraction proportional to m_ℓ^2

<standard model calculation>

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

D.Silverman and H.Yao, Phys. Rev. D. 38, 214 (1998).

$$\mathcal{B}(B \to e\nu)_{SM} \sim 10^{-11}$$
$$\mathcal{B}(B \to \mu\nu)_{SM} \sim 3.5 \times 10^{-7}$$
$$\mathcal{B}(B \to \tau\nu)_{SM} \sim 10^{-4}$$

Deviation from Standard Model can indicate New Physics such as 2HDM(type2) or lepto-quark.

2HDM(type2)

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell)_{2HDM} = \mathcal{B}(B^+ \to \ell^+ \nu_\ell)_{SM} \times \left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

W. Hou, Phys. Rev. D. 48, 2342 (1993).

$B^+ \to \ell^+ \nu_\ell \; (\ell = e, \mu)$

previous results of B→lnu

(Loose Tagging)

$\mathcal{B}(B^+ \to e^+ \nu_e) < 9.8 \times 10^{-7}$ 90%C.L. 253fb^{-1}

N. Satoyama *et al.* (Belle Collaboration), arXiv:hep-ex/0611045 v2 (2007).

$\mathcal{B}(B^+ \to \mu^+ \nu_\mu) < 1.0 \times 10^{-6}$ 90%C.L. 426fb^{-1}

B. Aubert *et al.* (Babar Collaboration), arXiv:hep-ex/0903.1220 v2 (2009).

(Hadronic Tagging)

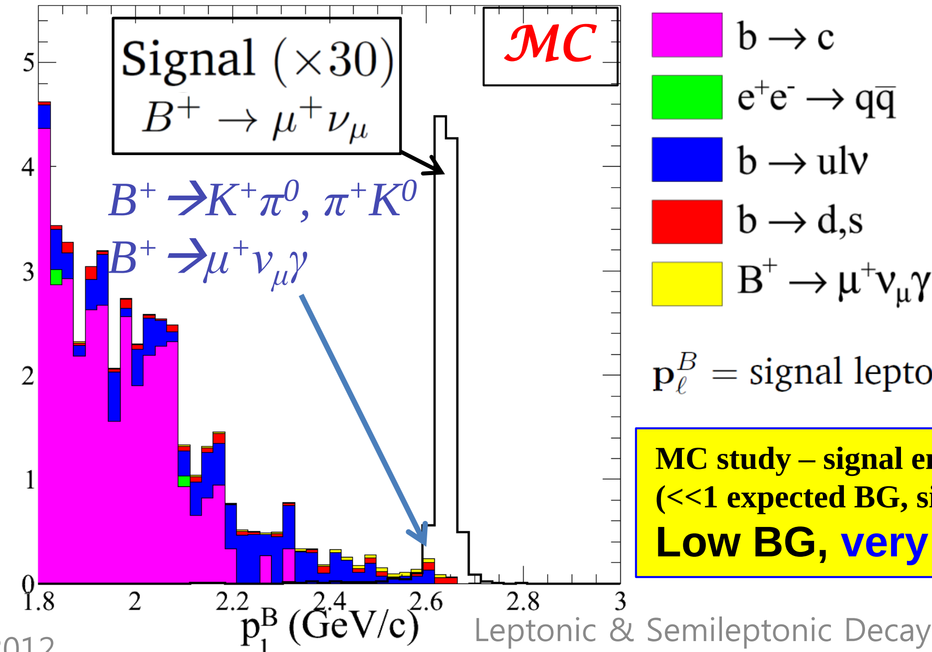
$\mathcal{B}(B^+ \to e^+ \nu_e) < 5.2 \times 10^{-6}$

$\mathcal{B}(B^+ \to \mu^+ \nu_\mu) < 5.6 \times 10^{-6}$ 90%C.L. 342fb^{-1}

B. Aubert *et al.* (Babar Collaboration), arXiv:hep-ex/0807.4187 v1 (2008).

Uses full $\Upsilon(4S)$ data (711fb^{-1})/Hadronic Tagging/Blind Analysis

Strategy: Fit the sideband of $\mathbf{p}_\ell^B$ ($2.0 \sim 2.5$GeV) to extrapolate the background into the signal region ($2.6 < \mathbf{p}_\ell^B < 2.7$(GeV/$c$)).

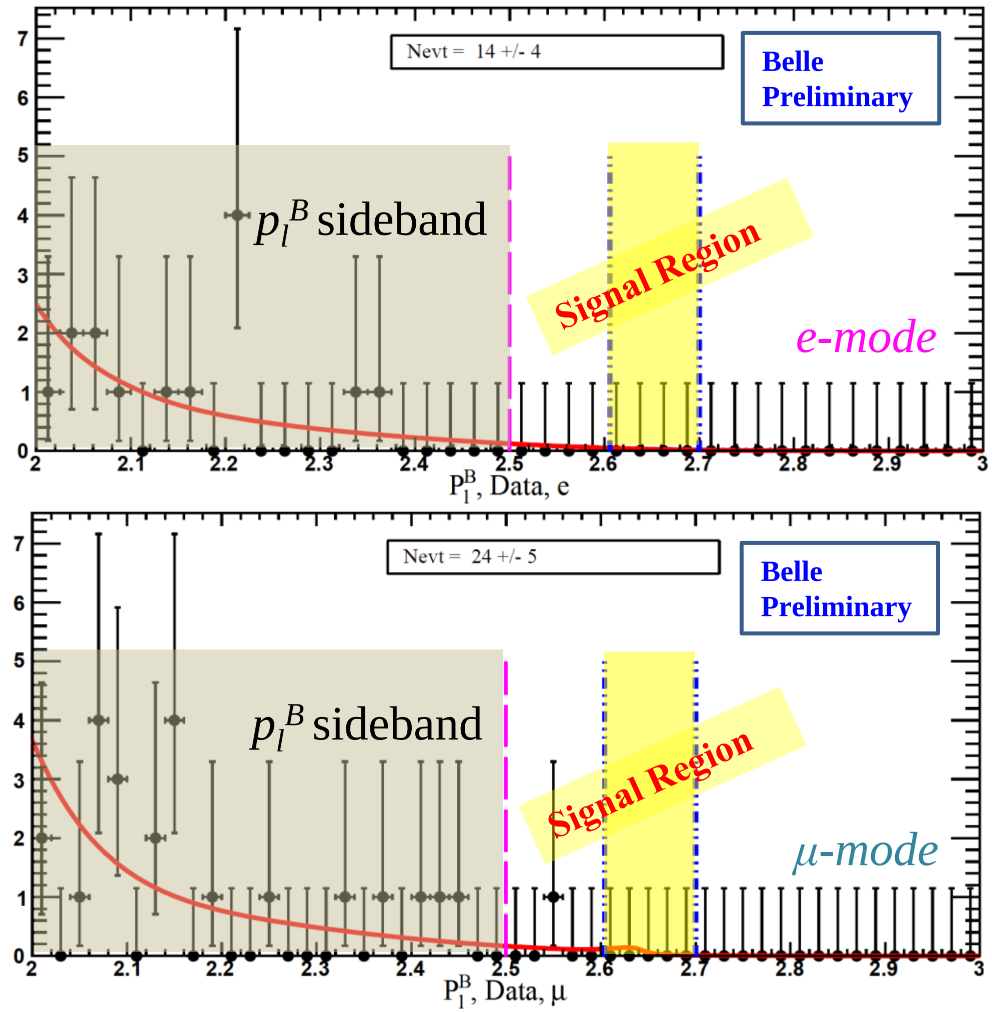


P_l^B: the signal lepton's momentum in the signal-B rest frame.

$\mathbf{p}_\ell^B$ = signal lepton momentum in signal-B rest frame

MC study – signal enhanced plot for muon mode
(<<1 expected BG, signal for both e, mu)
Low BG, very clean signal distribution

$B^+ \to \ell^+ \nu_\ell \ (\ell = e, \mu)$



Data Unblind!

Upper Limit calculated by POLE (Feldman-Cousins method)

$\mathcal{B}(B \to e\nu) < 3.5 \times 10^{-6} (90\% C.L.)$

$\mathcal{B}(B \to \mu\nu) < 2.5 \times 10^{-6} (90\% C.L.)$

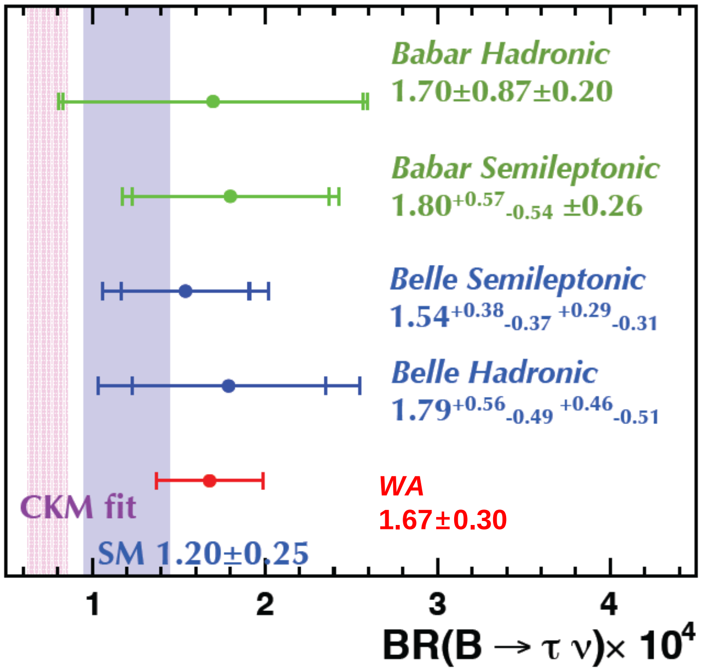
$N_{\text{expected BG}}$	$0.11^{+0.75}_{-0.06}$	$0.33^{+0.10}_{-0.08}$
ϵ_{signal}	$[9.1 \pm 1.5] \times 10^{-4}$	$[1.15 \pm 0.18] \times 10^{-3}$
$N_{\text{data observed}}$	0	0

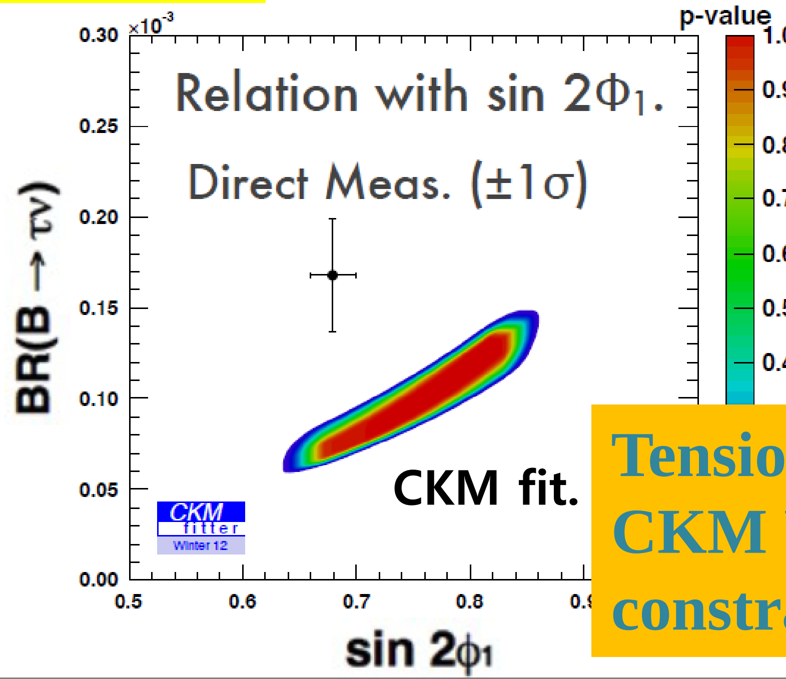
Most of the signal efficiency error from signal shape uncertainty estimated with $B^+ \to \bar{D}^0 \pi^+$ control samples

$$BF = \frac{Yield}{N(B\bar{B}) * \epsilon_{sig}}$$

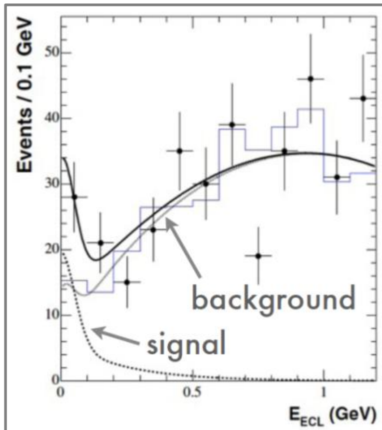
$B^+ \to \tau^+ \nu_\tau$

Current results on $B \to \tau\nu$





Tension with the CKM UT constraints?



* E_{ECL} = Extra energy in ECL

$N(B\bar{B}) = 449\text{M}$

$\mathcal{B} = [1.79^{+0.56}_{-0.49}(\text{stat})^{+0.46}_{-0.51}(\text{syst})] \times 10^{-4}$

(3.5σ) PRL 97, 251802 (2006)

Past hadronic tag analysis from Belle with 1-D fit to E_{ECL}

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

- Major differences from 2006 analysis
  - Reprocessing of full Belle data set (2011)
    - → Improved detection efficiencies of low p_T tracks and neutral particles
  - Added 322M more $B\bar{B}$ data in addition to previous 449M
  - New sophisticated hadronic tagging algorithm
    - → Based on neural net & Bayesian interpretation
    - → More *B* / *D* decay modes included for the tag
  - Signal extraction by 2D fit to (E_{ECL}, $M_{miss}{}^2$)
    - → Improved handling of peaking backgrounds

Definition of variables

$$M^2_{miss} = (E_{CM} - E_{B_{tag}} - E_{B_{sig}})^2 - (P_{B_{tag}} - P_{B_{sig}})^2$$

E and $P_{B_{tag}}$: Energy and momentum of the tagged-B

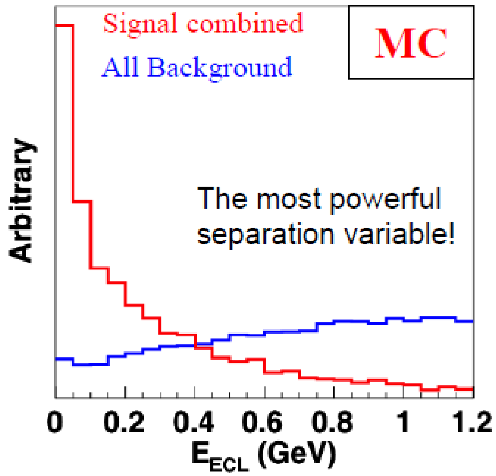
E and $P_{B_{sig}}$: Energy and momentum of signal side B particles

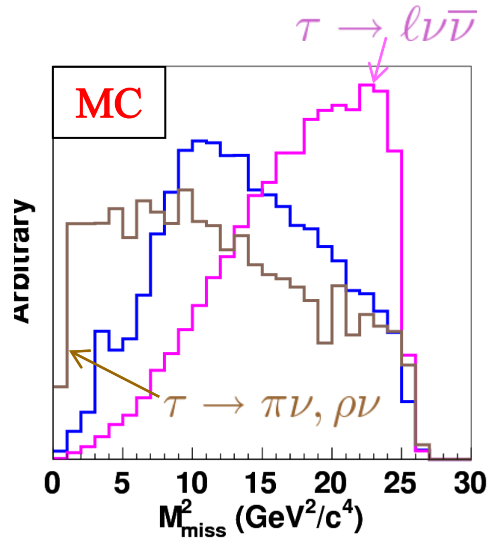
E_{ECL} = Extra energy in ECL aside from those contributed via tagged-B and signal-B constituents

τ-decays used
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$
$\tau^- \to \pi^- \nu_\tau$
$\tau^- \to \rho^- \nu_\tau$

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

- ***The fitting variables***





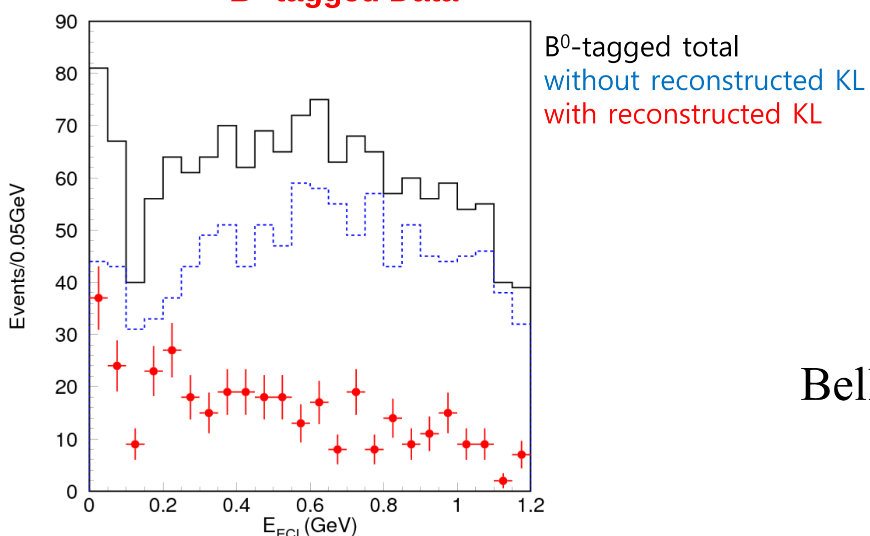
Using these variables for 2D histogram PDF fitting.

Improves the signal significance by about 20%

Use of 2-D fitting will reduce the sensitivity to peaking backgrounds in E_{ECL}.

Peaking background **enhanced** sample

B^0-tagged Data



Background rejection using the K_L is introduced

→ Effective to reduce the peaking background

Improves the signal significance by about 5%

Belle full data + improvement of analysis

⇩

Expected signal significance : 6.3σ for Br($B \to \tau\nu$)=1.65×10^{-4}

Validation of Analysis
Validated with Data

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

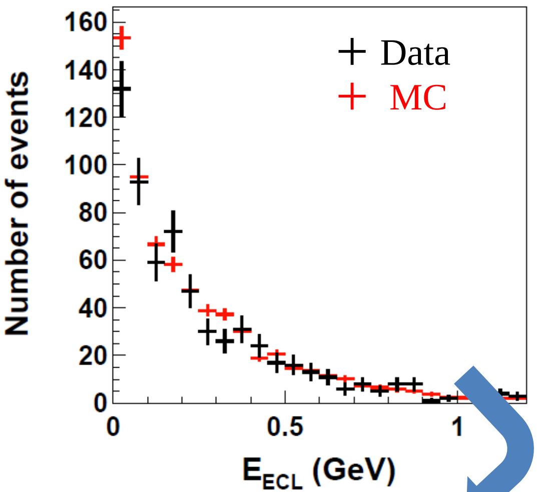
1. Sophisticated B tagging algorithm
2. Background rejection using K_L

Reconstruction efficiencies calibrated with Data

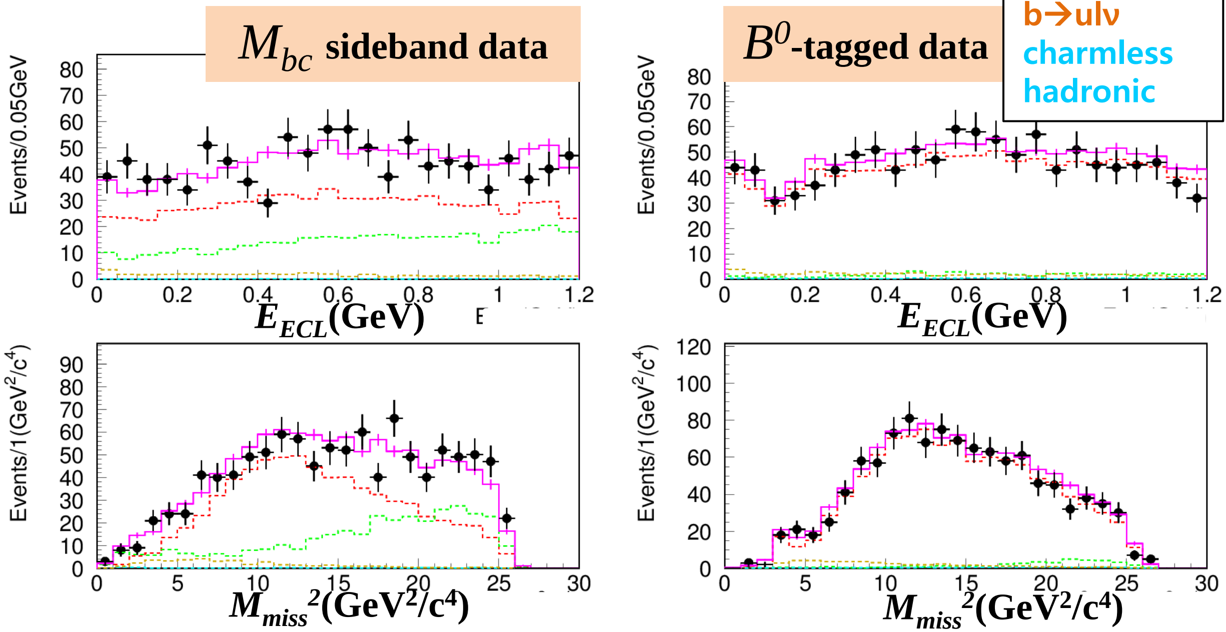
3. E_{ECL} and M_{miss}^2 signal/BG shape of MC →

Confirmed with Control Samples

Reconstruct
$B \to D^{(*)}\ell\nu$ as the signal



$\mathcal{B}(B^- \to D^{*0}\ell^-\bar{\nu}_\ell) = [5.60 \pm 0.22(stat) \pm 0.28(syst)]\%$
Consistent with the PDG world average: (5.68±0.19)%

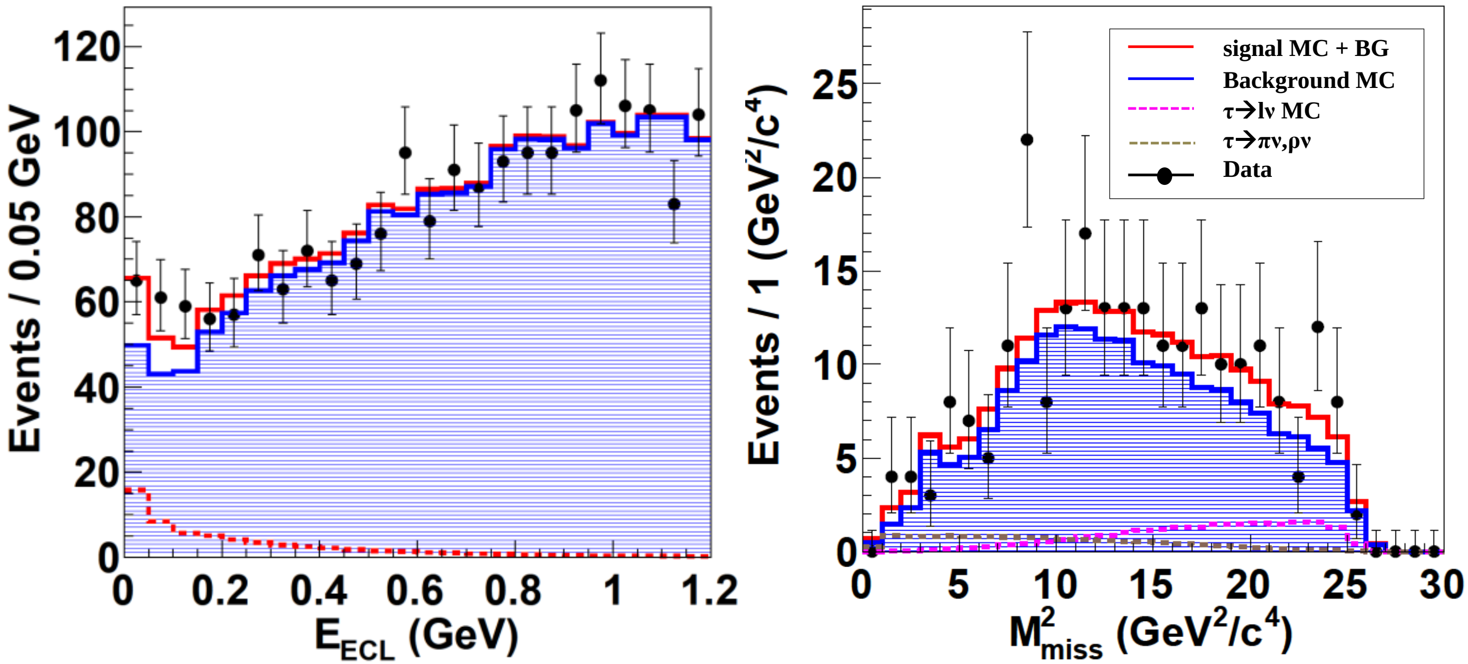


Data-MC consistency is also confirmed with E_{ECL} sideband and wrong charge combination events.

Unblind the Data !

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

2D ML fit to E_{ECL}-M_{miss}^2 Fit to Data Results.



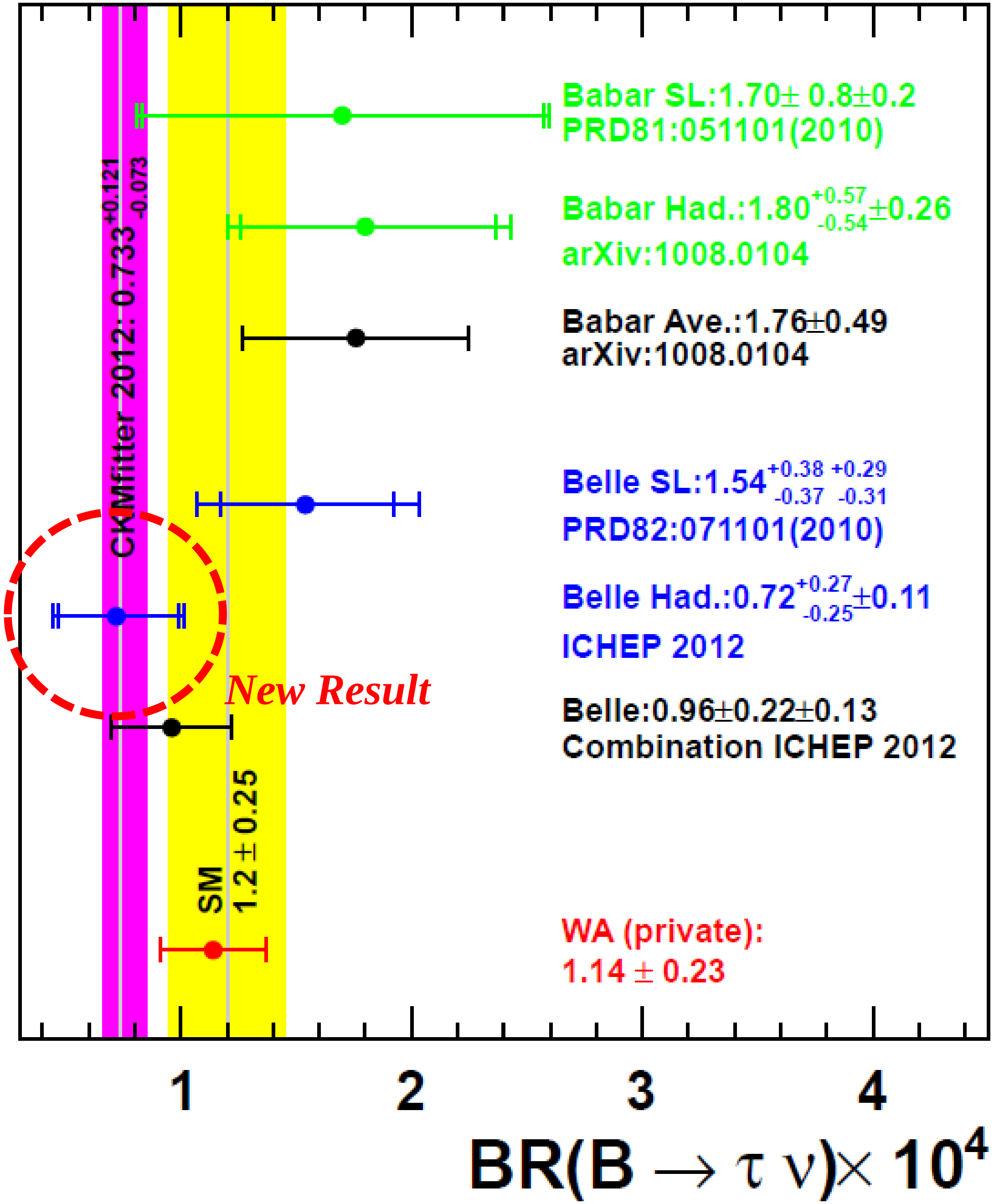
[Fit Projection for E_{ECL} and M_{miss}^2]

$$N_{signal} = 62.3^{+23.1}_{-21.7}$$

$$\mathcal{B}(B \to \tau\nu) = (0.72^{+0.27}_{-0.25}(\text{stat.}) \pm 0.11(\text{syst.})) \times 10^{-4}$$

Previous hadronic tag result at Belle $\mathcal{B} = [1.79^{+0.56}_{-0.49}(\text{stat})^{+0.46}_{-0.51}(\text{syst})] \times 10^{-4}$ ⟶ 1.9σ difference

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



Summary

- With reprocessed data and improved hadronic tagging of B, Belle extends its sensitivity to semileptonic and leptonic decays.

- Many recent results on exclusive semileptonic decays (clean measurements of $B \to \pi l \nu$, $B \to \rho l \nu$, and related modes). $\frac{d\Gamma(B\to\pi l\nu)}{dq^2}$ is used to extract $|V_{ub}|$.

- New results for ICHEP2012 on purely leptonic modes: $B \to l \nu$ ($l = e, \mu$) and $B \to \tau \nu$

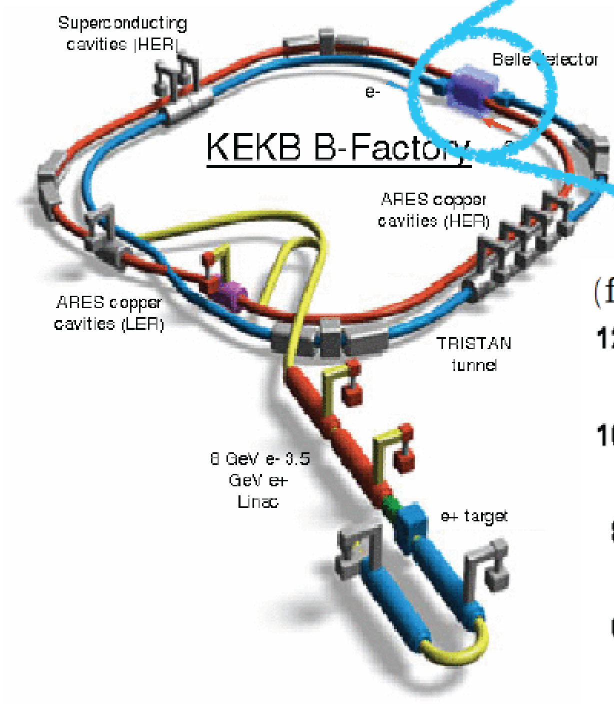
- $B \to \mu \nu$: The best constraint to date using hadronic tags.

- Un-blinded new $B \to \tau \nu$ result with hadronic tags. New result will move the world average much closer to the result from the CKM unitarity triangle fit.

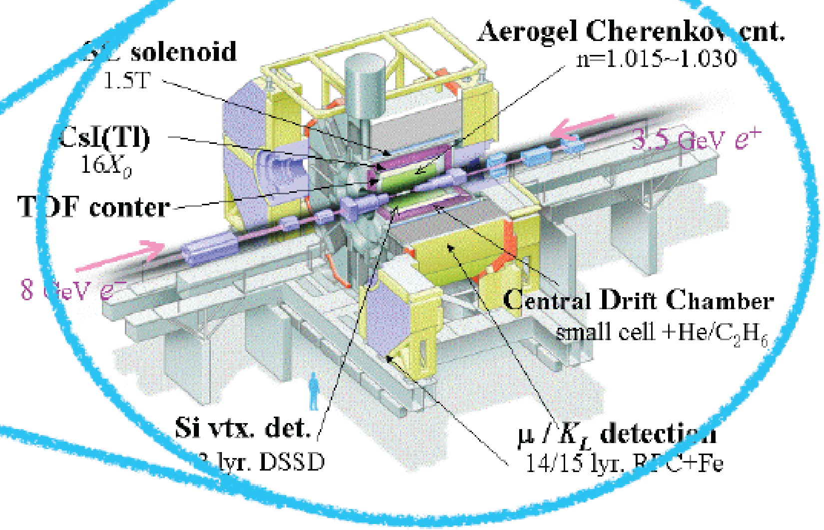
BACK-UP SLIDES

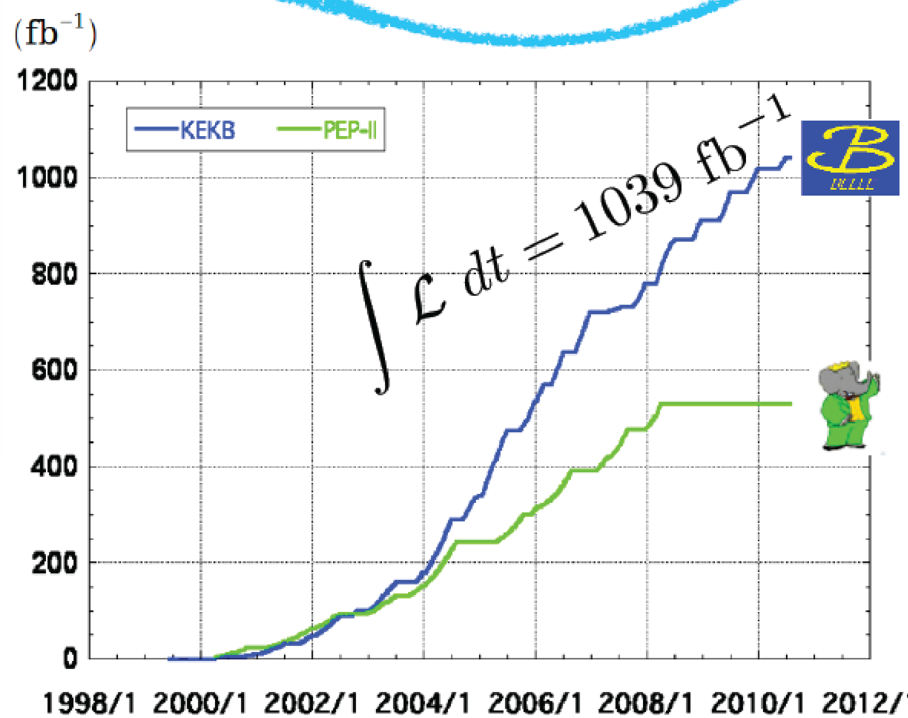
16 countries
68 institutes
~400 members

$$\mathcal{L}_{\text{peak}} = 21.1\ \text{nb}^{-1}\text{s}^{-1}$$



Belle Detector





> 1 ab^{-1}

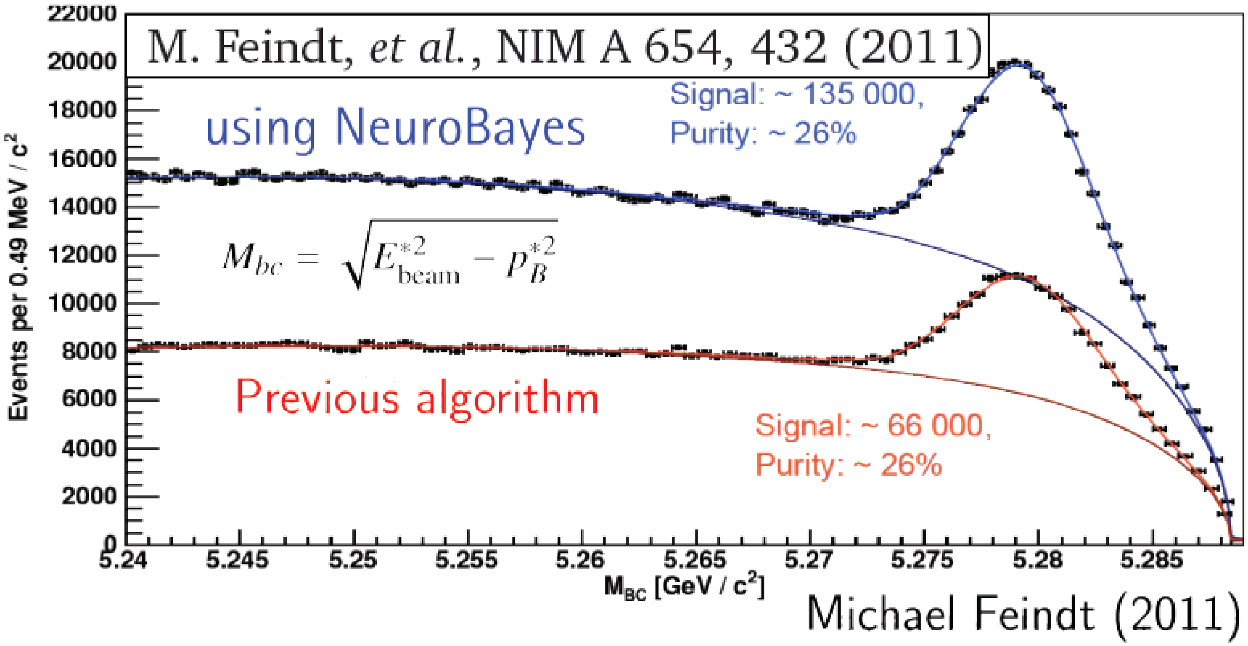
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Hadronic Tagging Method

Same purity level, more signal BB



Signal Event Selection

$B^+ \to \ell^+ \nu_\ell \; (\ell = e, \mu)$

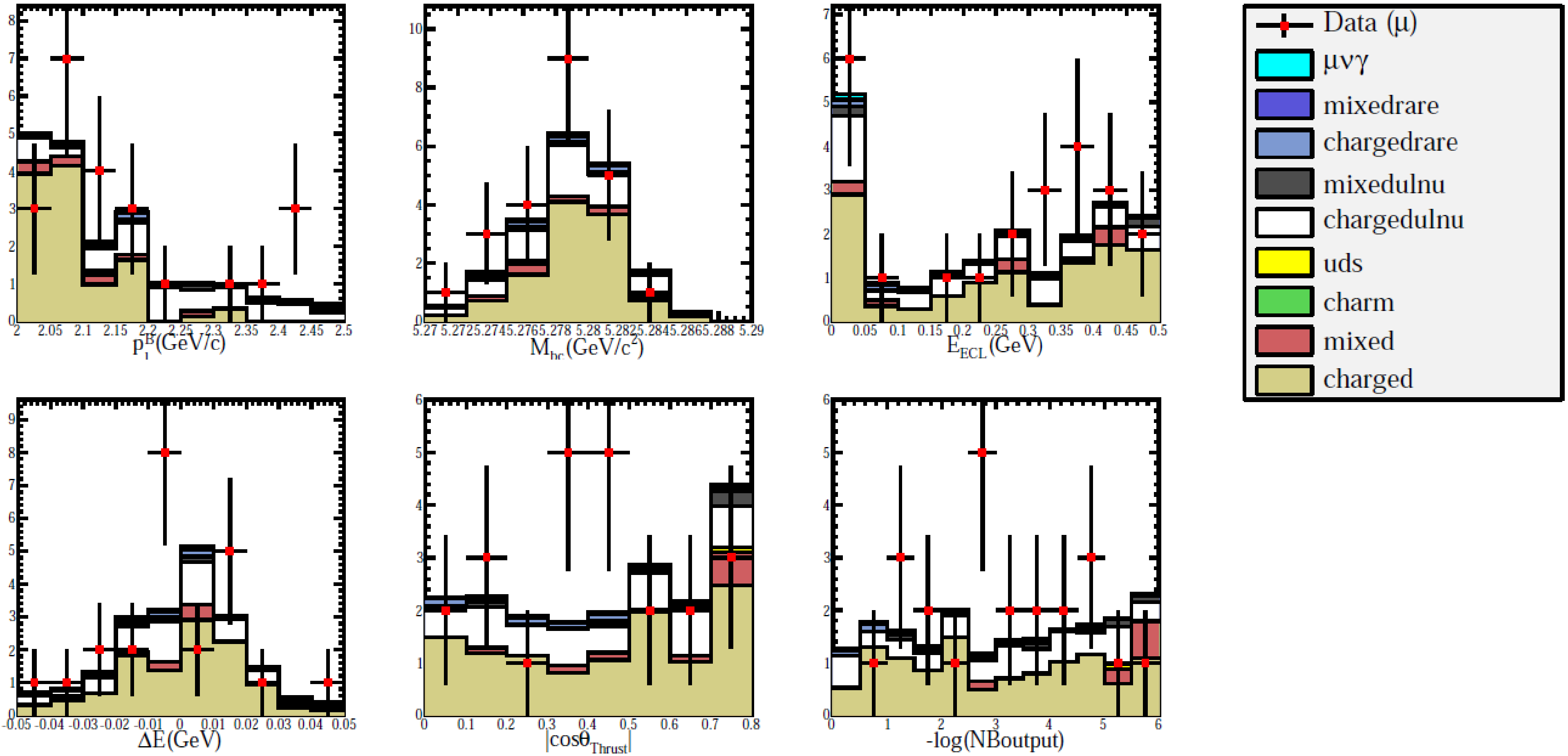
e: electron probability > 0.9 for e-mode study
μ: muon probability > 0.9, $\chi^2 > 0$ for μ-mode study
$\Downarrow$
$dr < 0.05cm$, $dz < 1.5cm$
$|\Delta E^{tag}| < 0.05GeV$: quality of the tagged-$B$ reconstruction
$ln(NBoutput) > -6$: consistancy with $N(B\bar{B})^{tag}$ count condition

[Continuum Suppression]
For e-mode search: $|\cos\theta_{thrust}| < 0.9$
For μ-mode search: $|\cos\theta_{thrust}| < 0.8$ to suppress fake π, K's

$M_{\rm bc}^{tag} > 5.27$ GeV $\quad E_{ECL} < 0.5$ GeV

$2.6 < \mathbf{p}_\ell^B < 2.7$ GeV: this variable is planned to be optimized.
However for the MC study we assume the cut described.

Background MC Validation $B^+ \to \ell^+ \nu_\ell \; (\ell = e, \mu)$

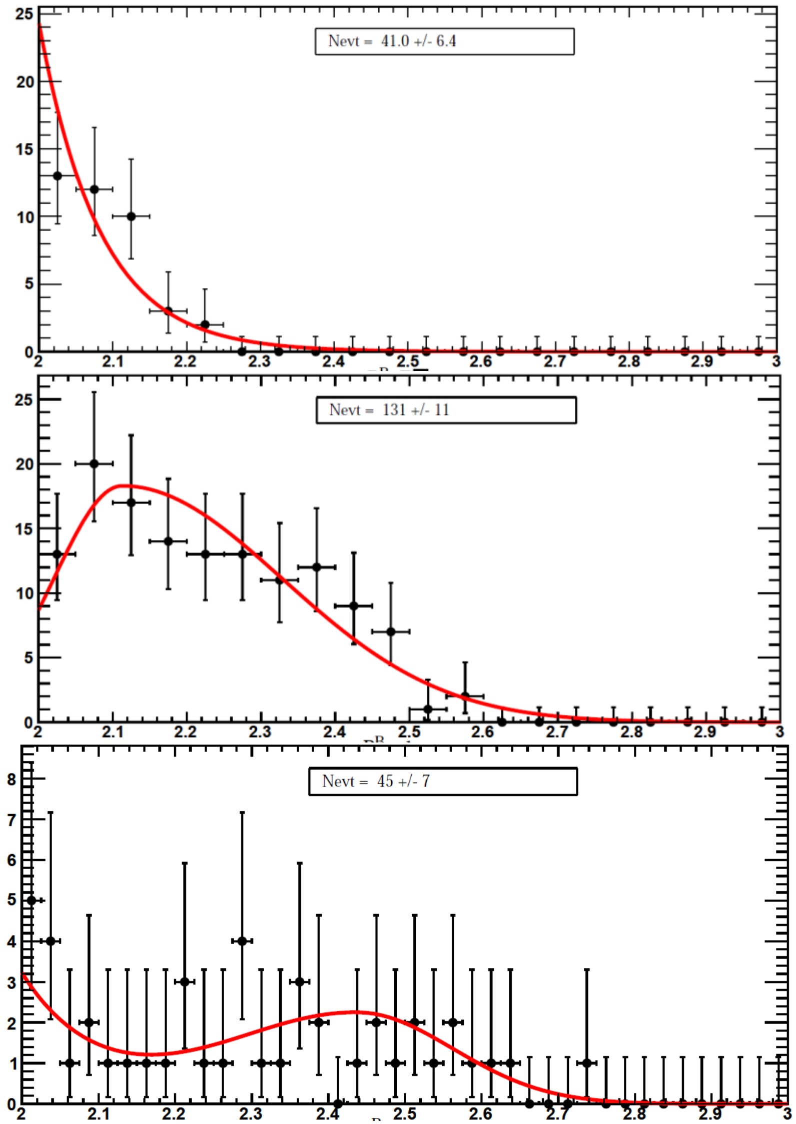


comparison of data and MC at p_l^B sideband region: 2.0< p_l^B <2.5 (GeV/c)

Background MC PDF Modeling

B A C K U P

$B^+ \to \ell^+ \nu_\ell \; (\ell = e, \mu)$



Electron mode

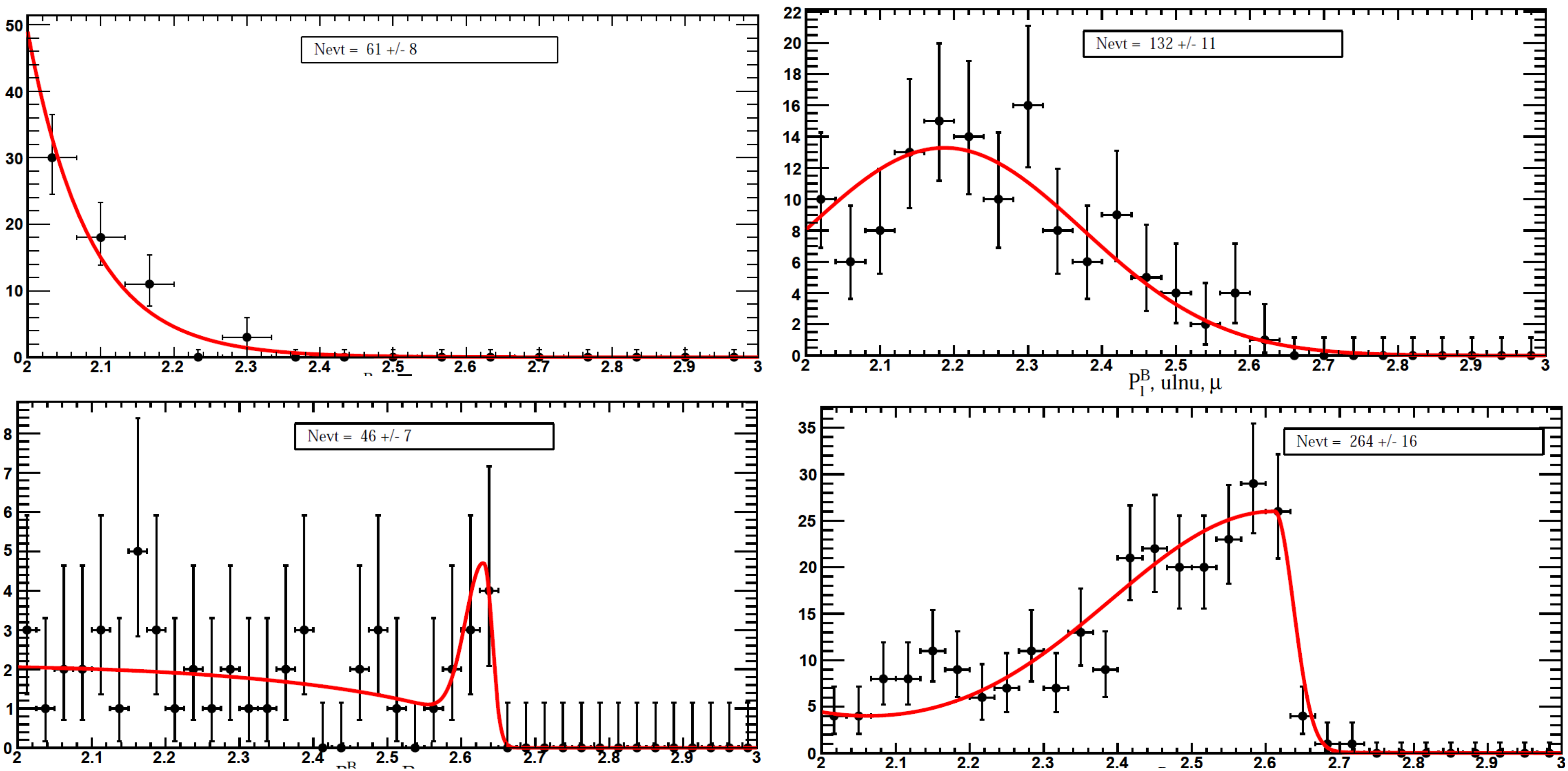
b→c (data x5)
b→ulν (data x20)
b→s,d or leptonic (data x50)

Background MC PDF Modeling

Muon mode

B A C K U P

$$B^+ \to \ell^+ \nu_\ell \; (\ell = e, \mu)$$

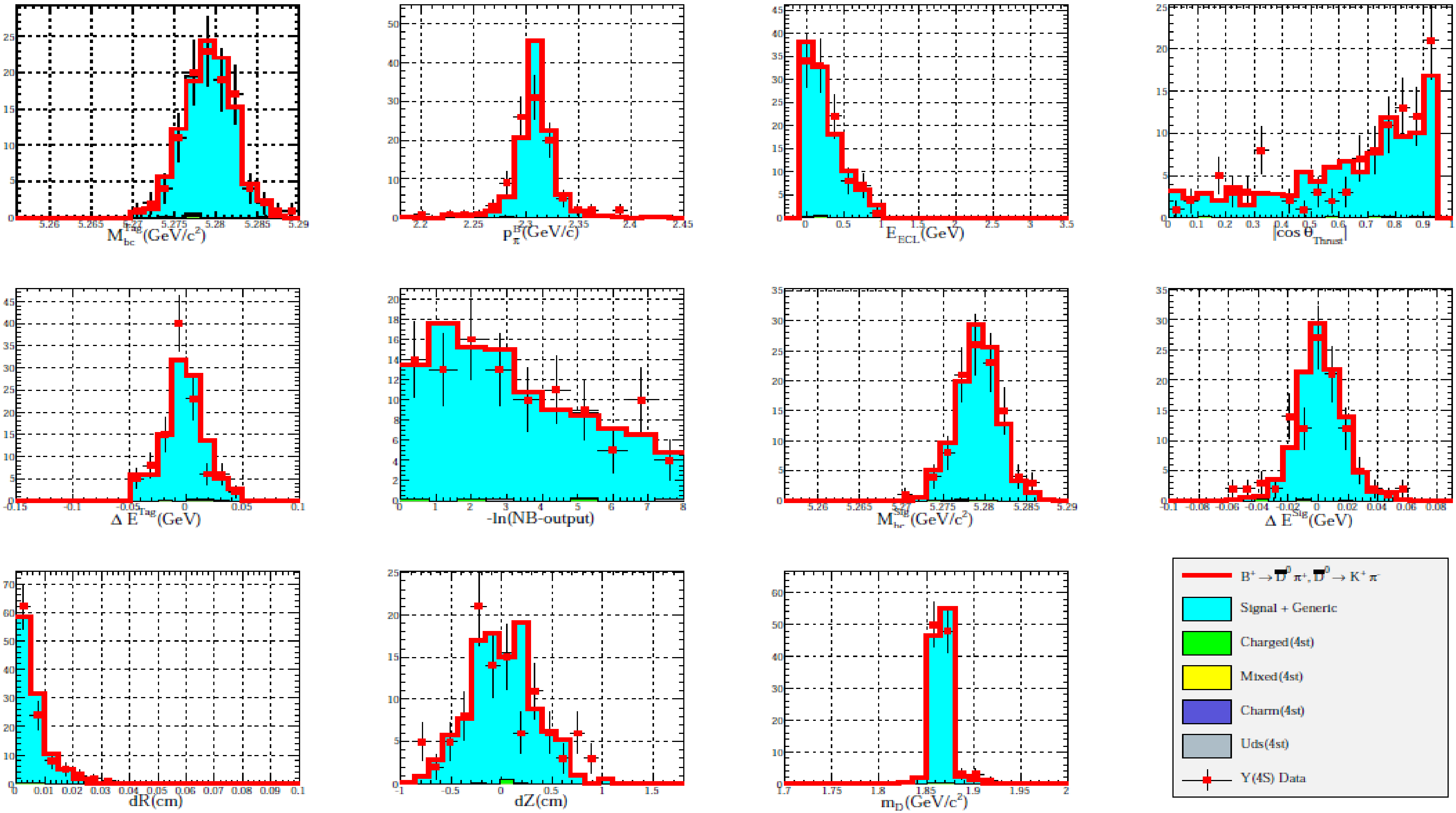


b→c (data x5)	b→ulν(data x20)
b→s,d(data x50)	b→μνγ(data x500)

Signal Shape Correction with Data

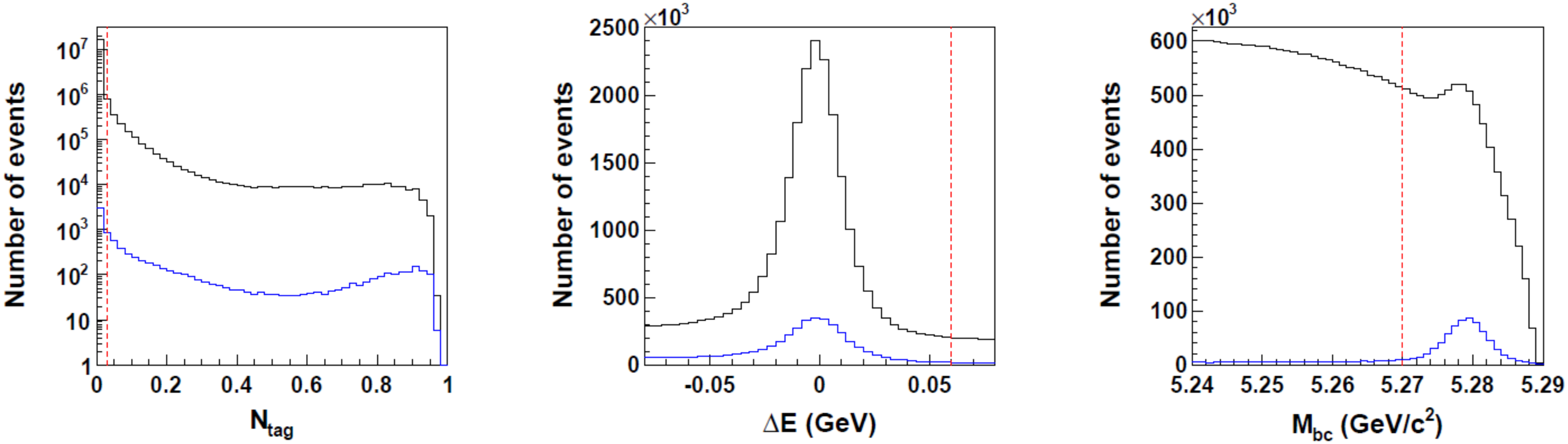
$B^+ \to \ell^+ \nu_\ell \; (\ell = e, \mu)$

with B→D⁰lν D0→K-pi+, K-pi+pi, K-pi+pi0, (D0→K-pi+ here)



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

The best B_{tag} candidate selection:
Largest N_{tag}, the Neural-network output of hadronic tagging.



Variables of the tagged-B

$$\Delta E = E_{taggedB} - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - |\vec{p}_B^{\,*}|^2}$$

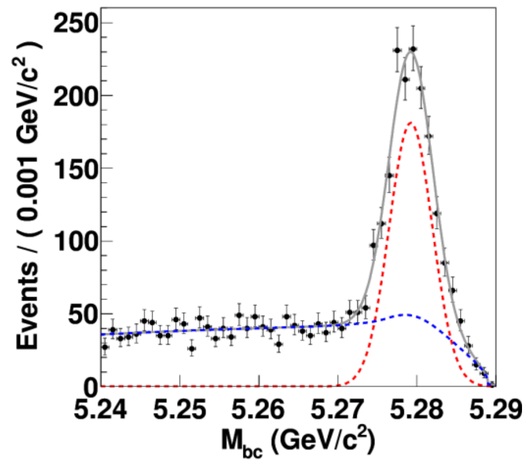
$B^+ \to \tau^+ \nu_\tau$

$\tau^- \to \mu^- \overline{\nu}_e \nu_\tau$	$\tau^- \to e^- \overline{\nu}_\mu \nu_\tau$	$\tau^- \to \pi^- \nu_\tau$	$\tau^- \to \rho^- \nu_\tau$
One signal-side track in $\lvert\Delta z\rvert < 3$ cm and $\lvert\Delta r\rvert < 0.5$ cm			
No extra track in $\lvert\Delta z\rvert < 75$ cm and $\lvert\Delta r\rvert < 15$ cm			
No signal-side π^0			One signal-side π^0
			$\lvert M_{\pi^-\pi^0} - M_{\rho^-}\rvert < 0.15$ GeV
No K_L candidate reconstructed from KLM			
$-0.86 < \cos\theta^*_{\text{miss}} < 0.95$			
$M^2_{\text{miss}} > 0.7\ (\text{GeV}/c^2)^2$			
$E_{\text{ECL}} < 1.2$ GeV			

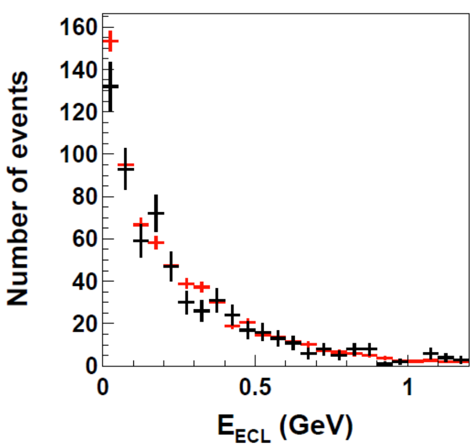
Selection criteria for the B_{sig} reconstruction.

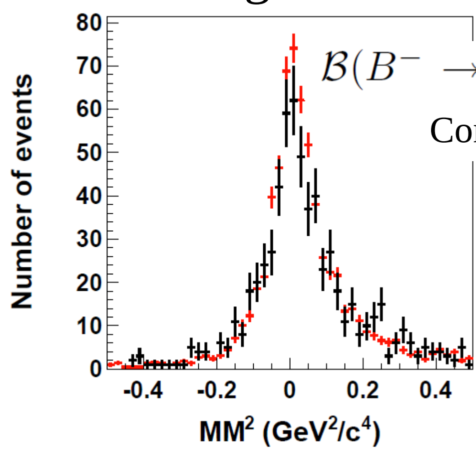
Tagging efficiency calibration
Signal E_{ECL}, M^2_{miss} Shape validation

- B tagging efficiency is calibrated with the E_{ECL} sideband data
  - Same event topology as signal.
  - MC expectations for both signal and background are corrected.



- Confirmed by reconstructing $B^- \to D^*lnu$, $D^* \to D^0p^0$, $D^0 \to Kp$ as signal





$$\mathcal{B}(B^- \to D^{*0} l^- \overline{\nu}_l) = [5.60 \pm 0.22(\mathrm{stat}) \pm 0.28(\mathrm{syst})]\ \%.$$

Consistent with the PDG world average: (5.68+/-0.19)%

M^2_{miss} (GeV^2/c^4)

B A C K U P

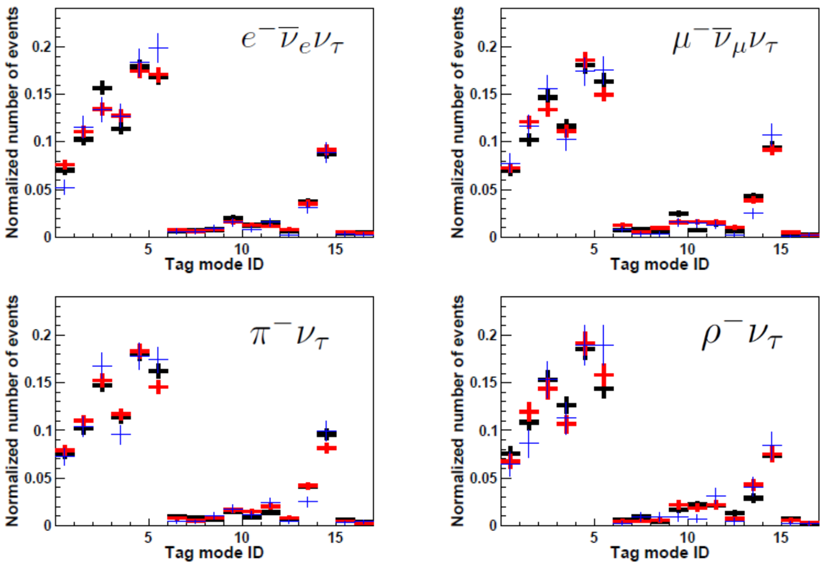
$B^+ \to \tau^+ \nu_\tau$

Tagging efficiency calibration

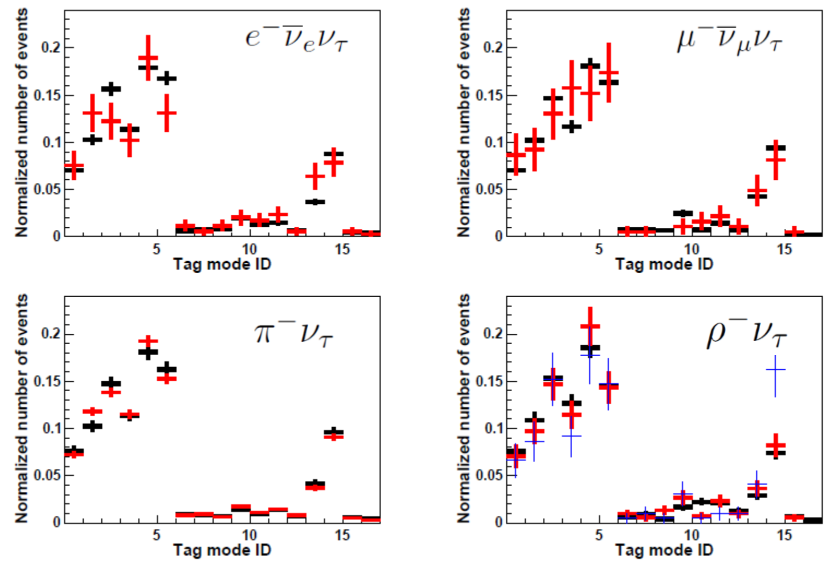
ID	0	1	2	3	4	5
Mode	$D^{*0}\pi^-$	$D^{*0}\pi^-\pi^0$	$D^{*0}\pi^-\pi^-\pi^+$	$D^0\pi^-$	$D^0\pi^-\pi^0$	$D^0\pi^-\pi^-\pi^+$

ID	6	7	8	9	10	11
Mode	$D^{*0}D_s^{*-}$	$D^{*0}D_s^-$	$D^0D_s^{*-}$	$D^0D_s^-$	$J/\psi K^-$	$J/\psi K^-\pi^+\pi^-$

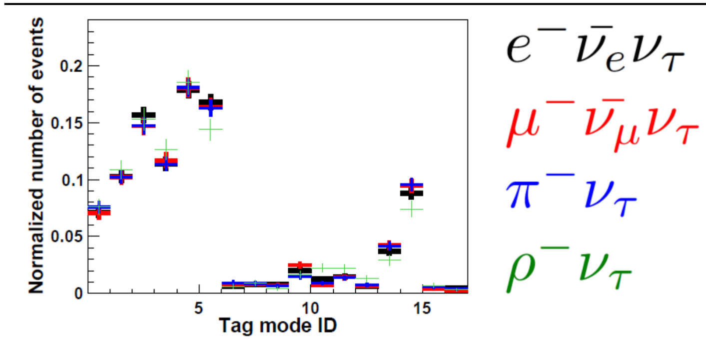
ID	12	13	14	15	16
Mode	D^0K^-	$D^+\pi^-\pi^-$	$D^{*0}\pi^-\pi^-\pi^+\pi^0$	$J/\psi K^-\pi^0$	$J/\psi K_S\pi^-$



Signal MC
EECL sideband generic MC
EECL signal region generic MC



Correctly reconstructed
Cross-feeds
Self-cross-feeds



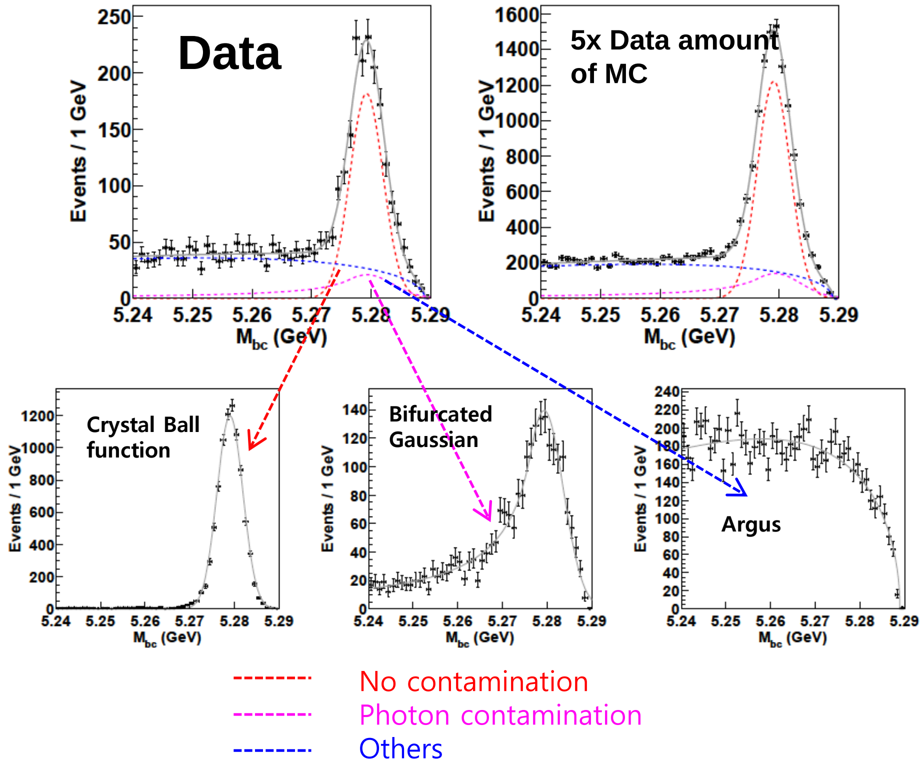
Comparison of the tagged-B mode ratio
→Good MC/Data agreement
→Common scale applicable

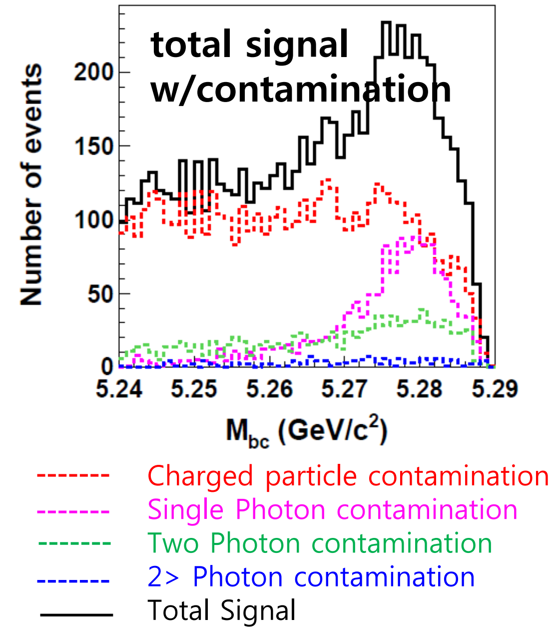
E_{ECL} sideband region: $0.4 < E_{ECL} < 1.2\text{GeV}$

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

Tagging efficiency calibration

E_{ECL} sideband region





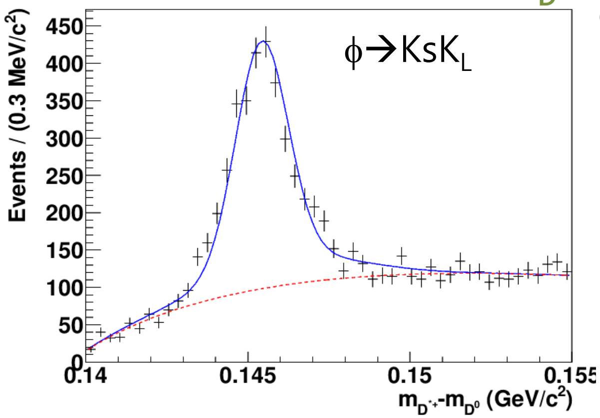
Group ID	Modes	Correction factor
A	$D^{*0}\pi^-,\ D^0\pi^-,\ D^0K^-$	1.07 ± 0.07
B	$D^{*0}\pi^-\pi^0,\ D^0\pi^-\pi^0$	0.79 ± 0.07
C	$D^{*0}\pi^-\pi^-\pi^+,\ D^0\pi^-\pi^-\pi^+,\ D^+\pi^-\pi^-,\ D^{*0}\pi^-\pi^-\pi^+\pi^0$	0.50 ± 0.04
D	$D^{*0}D_s^{*-},\ D^{*0}D_s^-,\ D^0D_s^{*-},\ D^0D_s^-,$ $J/\psi K^-,\ J/\psi K^-\pi^+\pi^-,\ J/\psi K^-\pi^0,\ J/\psi K_S\pi^-$	0.96 ± 0.12

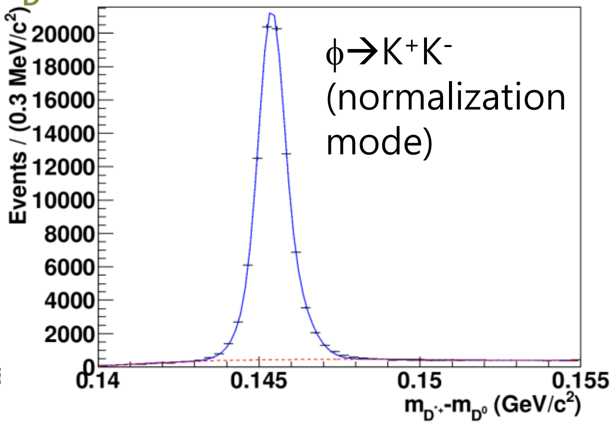
K_L efficiency calibration

- It is essential to estimate the K_L reconstruction efficiency with KLM in **data**.
  - The dominant component is the low momentum K_L from D decays in the background of $B \to \tau\nu$.
- The K_L efficiency in data is calibrated using $D^{*+} \to D^0 \pi^+$, $D^0 \to \varphi K_s$, $\varphi \to K_s$ K_L decays

Typical K_L efficiency at 1GeV/c ~ 11%

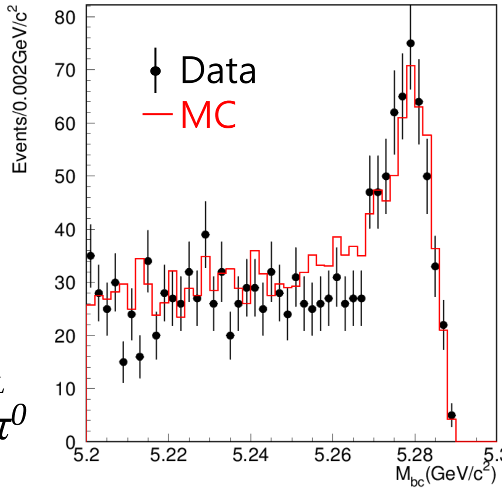
Reconstructed m_{D*}-m_D distribution in data



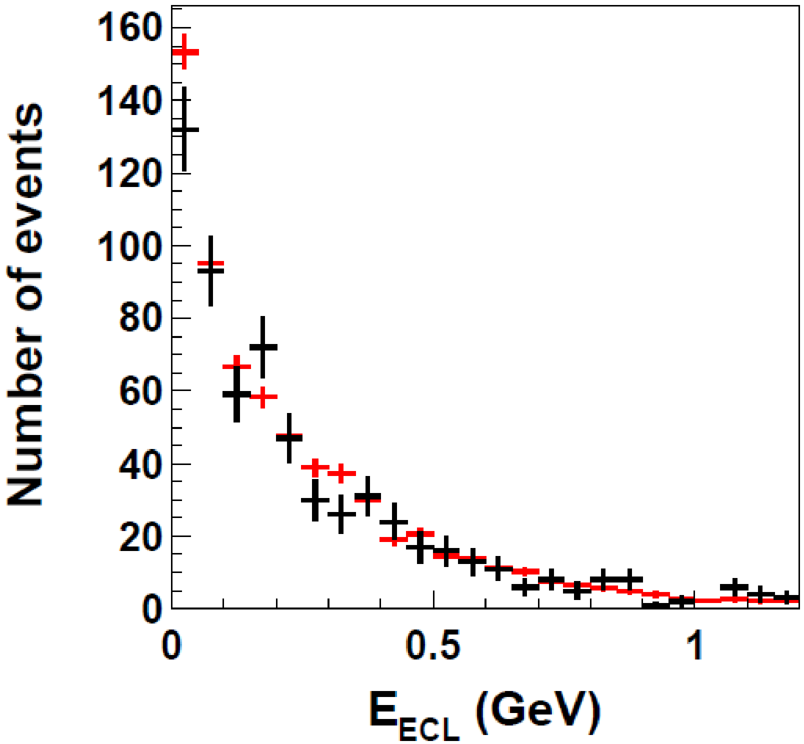


Estimated K_L reconstruction efficiency confirmed with the B decay including K_L

$B^0 \to D^{*+}\pi^-$, $D^* \to D^0\pi^+$, $D^0 \to K_L\, \pi^0$



K_L rejection efficiency correction



Efficiency of K_L^0 Rejection

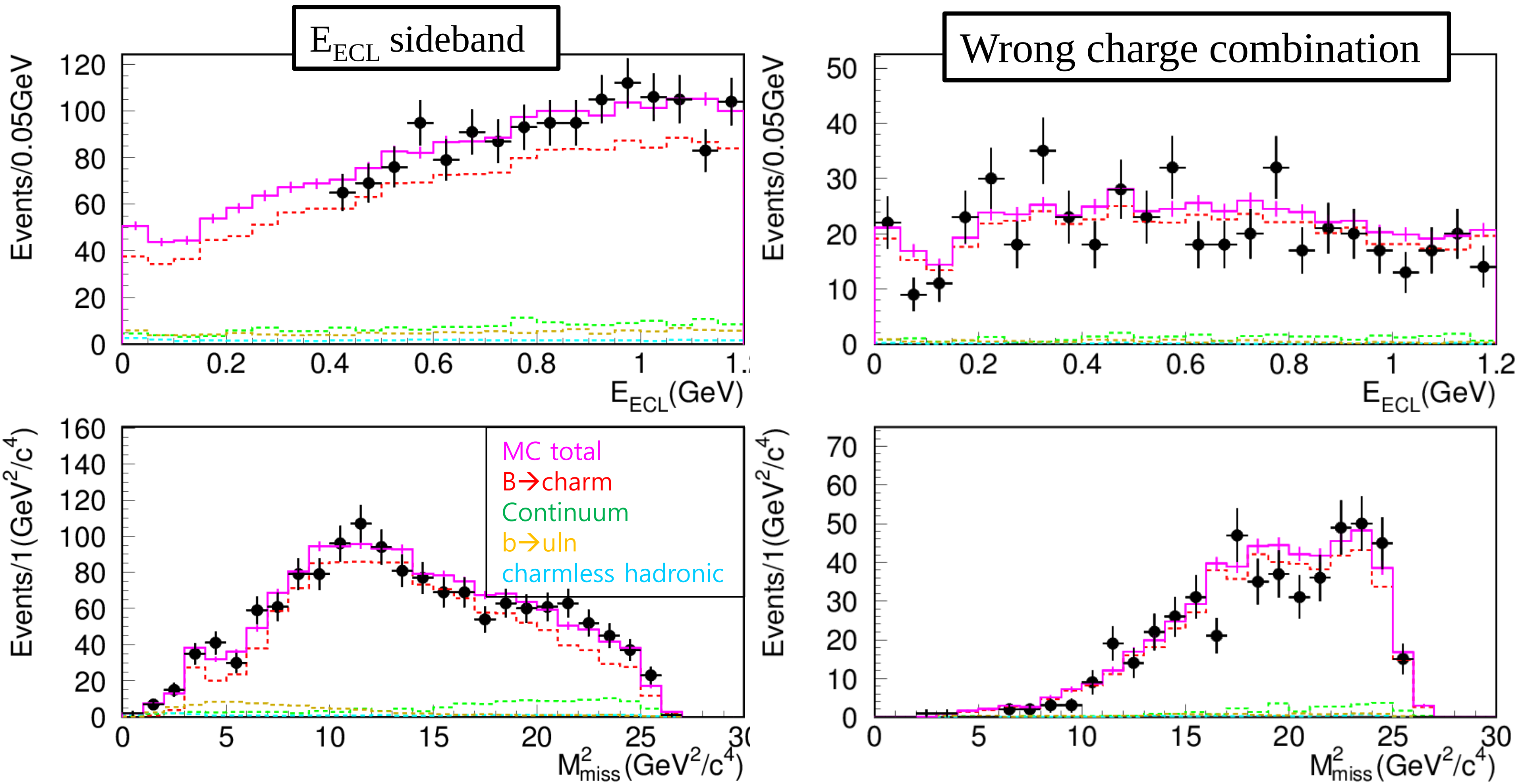
Data: 0.860 ± 0.013

MC: 0.824 ± 0.005

Data/MC: 1.04 ± 0.02

Background MC Validation

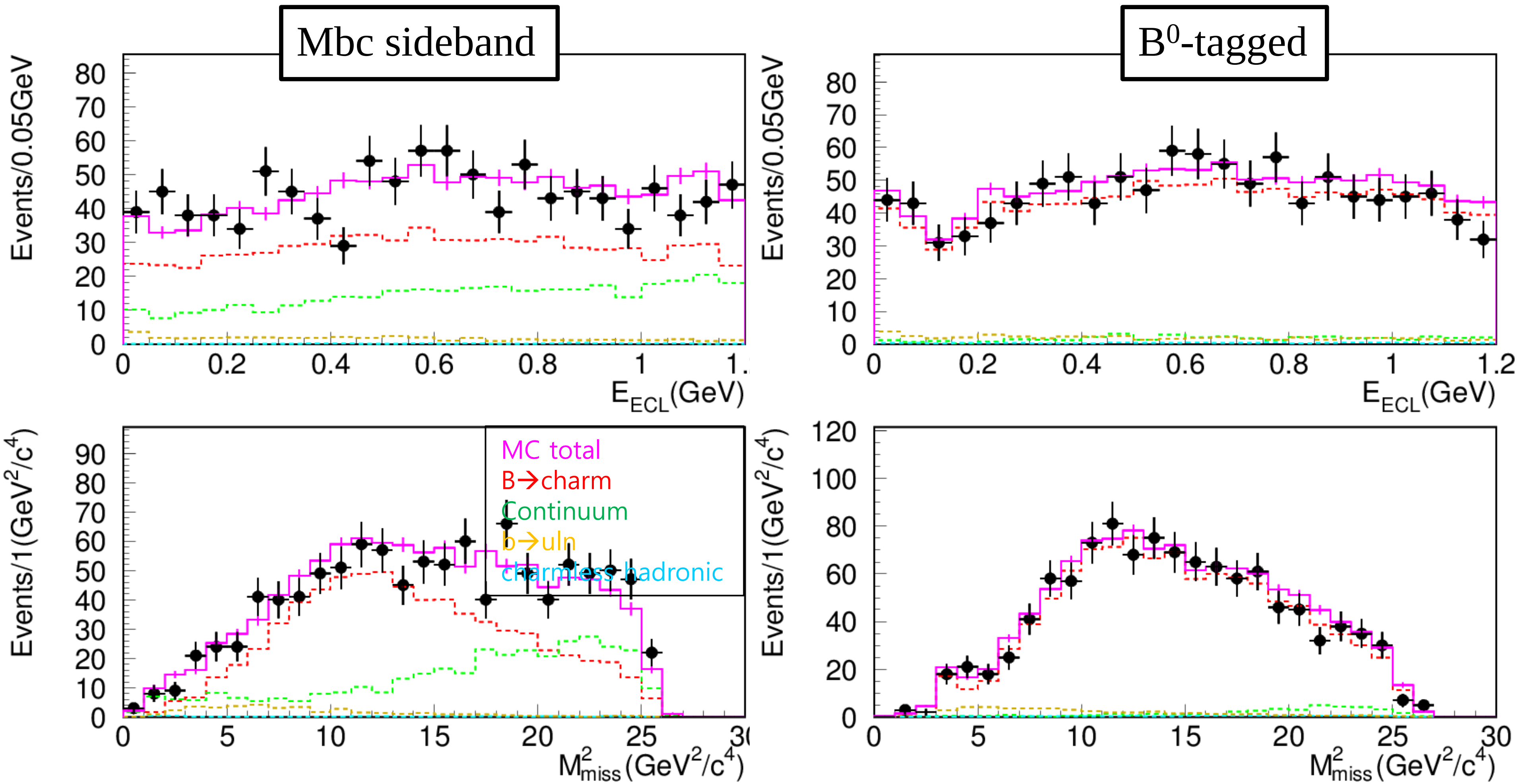
$B^+ \to \tau^+ \nu_\tau$



The MC E_{ECL} and M_{miss}^2 distributions are confirmed by the BG control samples.

Background MC Validation

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



The MC E_{ECL} and M_{miss}^2 distributions are confirmed by the BG control samples.

Corrections for data/MC differences

- Hadronic Tag efficiency correction
- K_L^0 rejection efficiency correction
- Branching fraction of peaking background modes, event by event correction

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

Systematic Uncertainties

source	error (%)
Signal Yield	11.2
$N_{B\overline{B}}$	1.3
Reconstruction efficiency	
MC statistics	0.4
Br. of τ	0.6
PID efficiency	1.0
π^0 efficiency	0.4
Tracking	0.3
K_L^0 veto	7.3
Tagging efficiency	8.5
Total	15.9

[Multiplicative uncertainties]

source	error
PDF Histogram MC Statistics	$^{+5.6}_{-5.0}$
Signal E_{ECL} Shape	$^{+0.6}_{-2.4}$
PHOTOS radiative correction	$^{+0.0}_{-0.6}$
Peaking BG, generic B	±1.3
Peaking BG, rare B	±1.9
Peaking BG, $b \to u\ell\nu$	±0.4
Efficiency ratio, MC stat	$^{+0.1}_{-0.2}$
τ branching fraction	$^{+0.2}_{-0.0}$
π^0 efficiency	±0.3
PID efficiency	$^{+0.5}_{-0.6}$
K_L^0 veto efficiency	$^{+0.5}_{-2.2}$
Tagging Efficiency in BG	±0.1
Total	$^{+6.2}_{-6.5}$

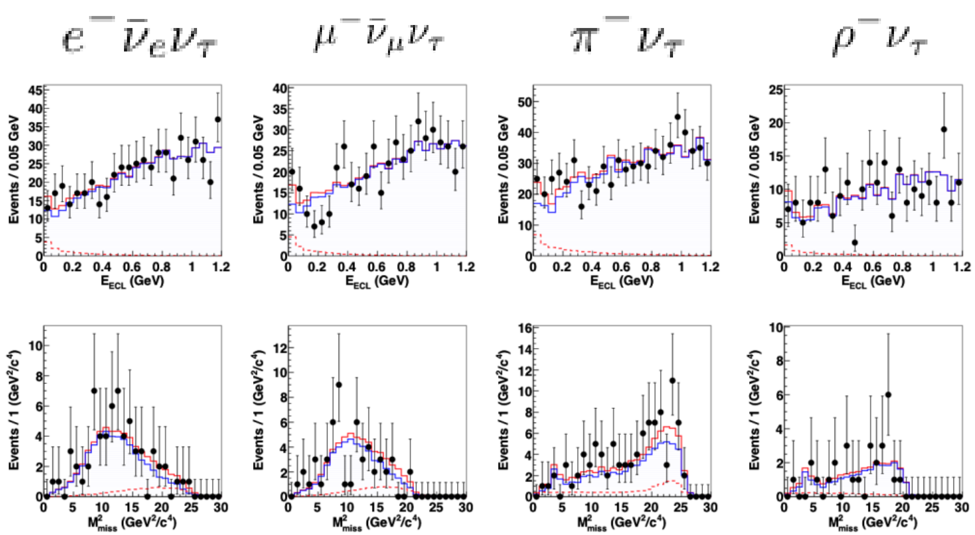
[Additive uncertainties]

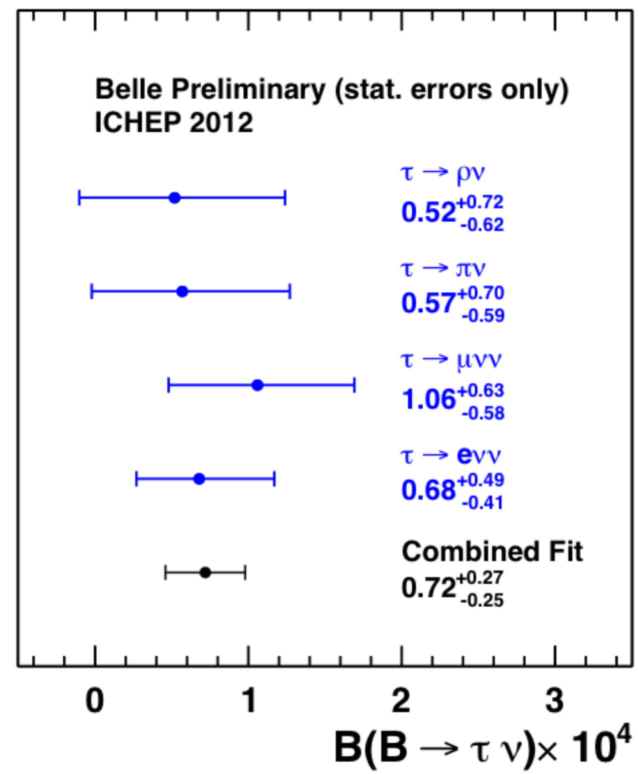
$B^+ \to \tau^+ \nu_\tau$

Fit Consistency Check

In the fit for signal yield extraction, ratio between τν components is fixed.
Result of simultaneous fit floating each yield of τν components

Mode	Number of signal	Efficiency
$e^- \overline{\nu}_e \nu_\tau$	$15.5^{+11.2}_{-9.4}$	2.98×10^{-4}
$\mu^- \overline{\nu}_\mu \nu_\tau$	$25.6^{+15.1}_{-13.8}$	3.12×10^{-4}
$\pi^- \nu_\tau$	$7.8^{+9.5}_{-7.9}$	1.76×10^{-4}
$\rho^- \nu_\tau$	$13.6^{+18.7}_{-16.1}$	3.37×10^{-4}



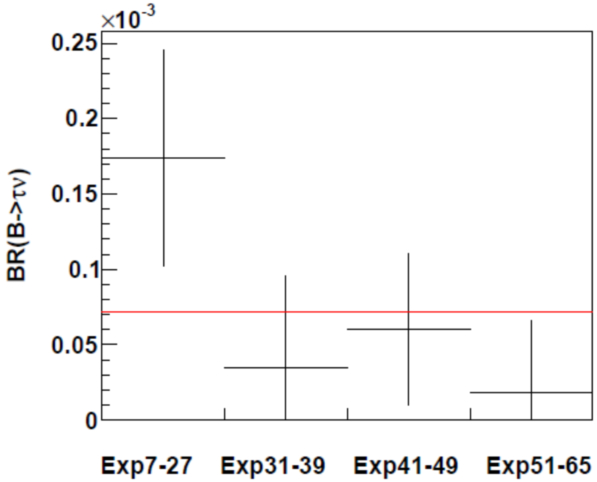


Consistent results obtained.

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

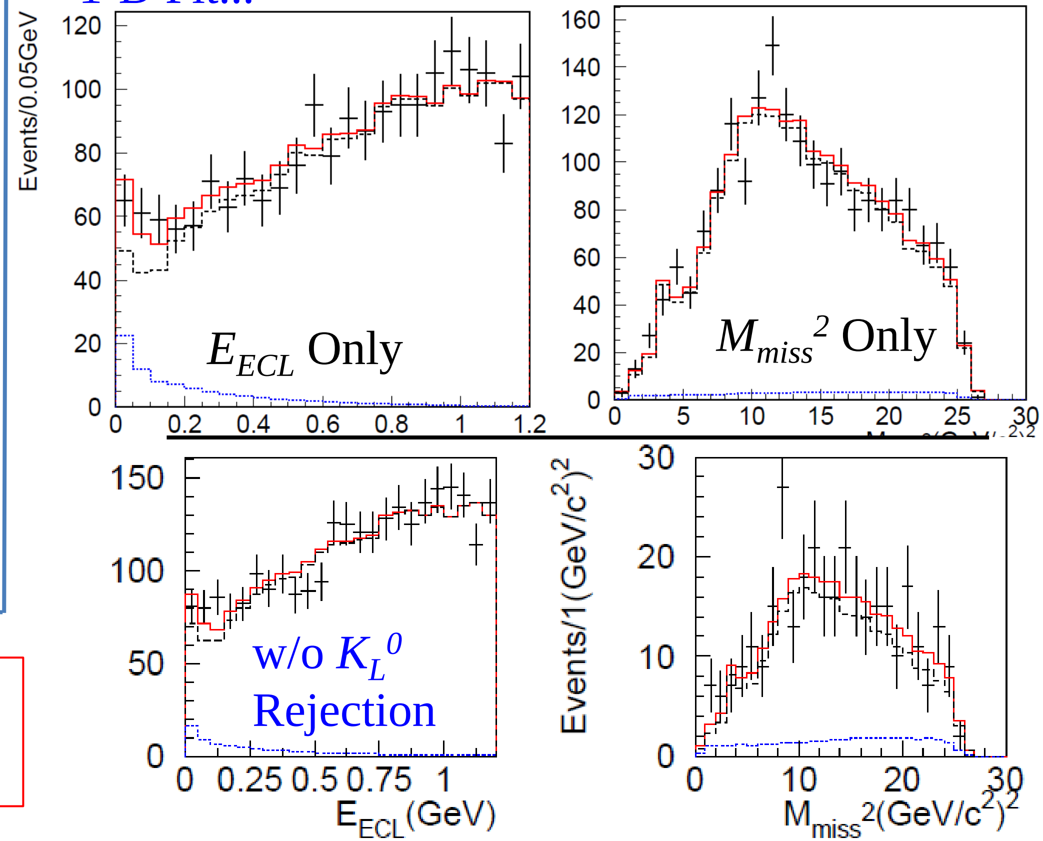
Fit Consistency Check

Comparison with different data range



Comparison with 1-D fit(E_{ECL},M_{miss}^2) and no K_L^0 Rejection

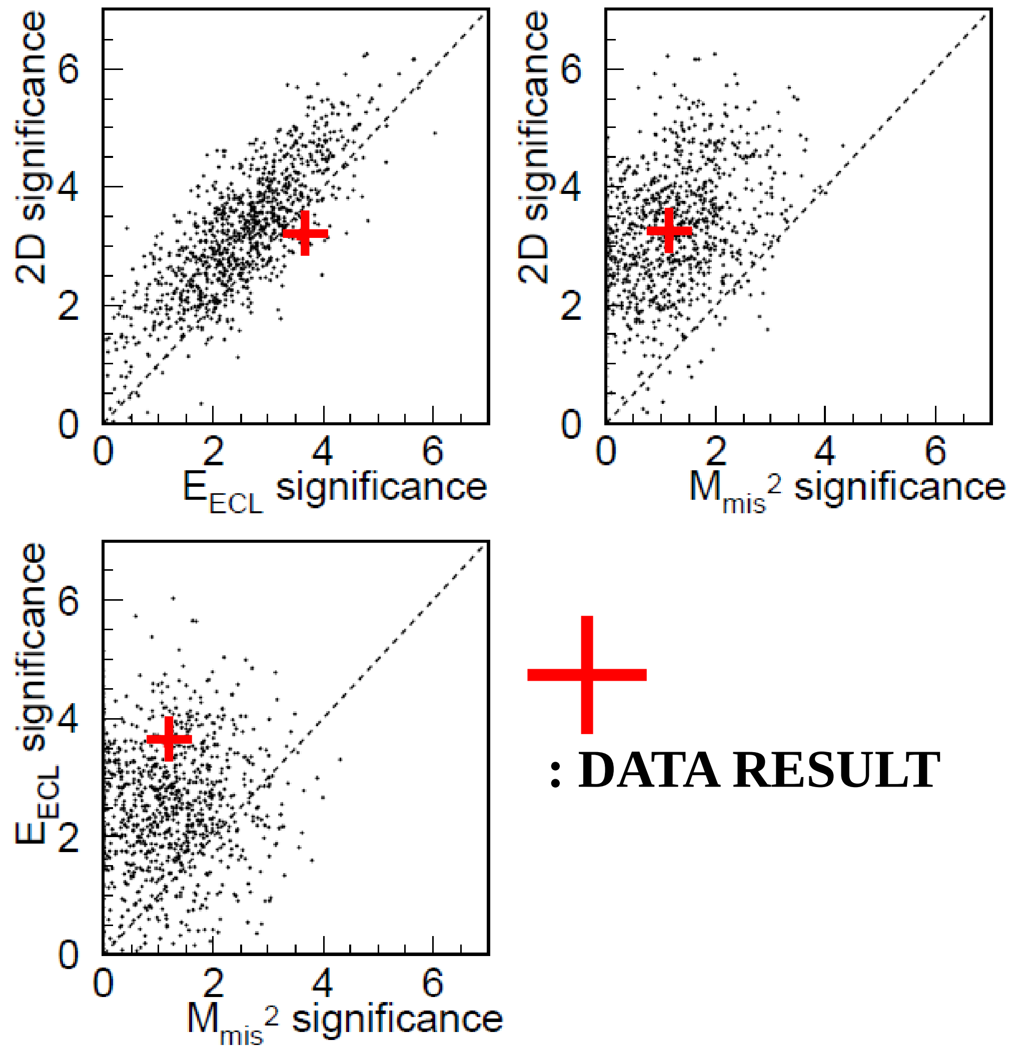
1-D Fit...



Method/sample	Number of signal	Signal Eff.	Br. ($\times 10^{-4}$)	Significance (stat. only)
Nominal 2D fit	$62.3^{+23.1}_{-21.7}$	1.12×10^{-3}	$0.72^{+0.27}_{-0.25}$	3.16
$E_{\rm ECL}$ only	$87.1^{+27.5}_{-26.4}$	ditto	$1.03^{+0.32}_{-0.30}$	3.57
$M^2_{\rm miss}$ only	$67.9^{+62.0}_{-58.8}$	ditto	$0.78^{+0.72}_{-0.68}$	1.16
without K_L^0 veto	$65.3^{+26.5}_{-25.0}$	1.29×10^{-3}	$0.65^{+0.27}_{-0.25}$	2.81

Fit Consistency Check

Comparison with 1-D fit(E_{ECL},$M_{miss}{}^2$) and no $K_L{}^0$ Rejection



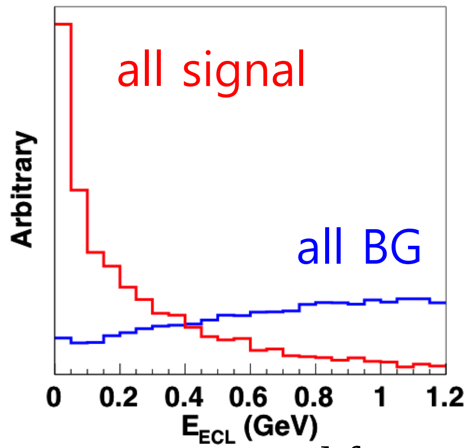
Toy MC pseudo experiments generated from the yields of signal and BGs obtained from fit to the data.

Performed for 2-D and 1-D fits

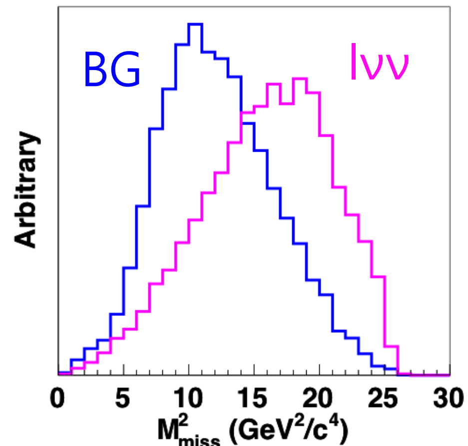
Correlations of Statistical Significance between 2-D Fit and 1-D Fits

MC distribution of E_{ECL} and M_{miss}^2

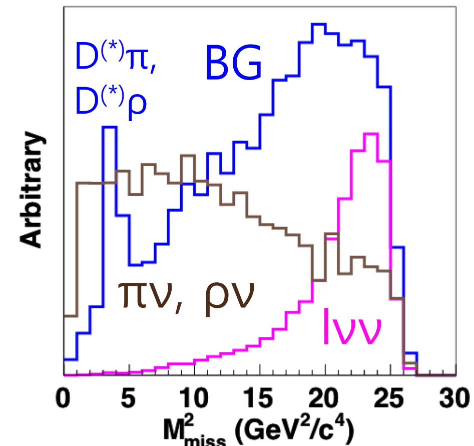
$B^+ \to \tau^+ \nu_\tau$



Reconstructed from $\tau \rightarrow l\nu\nu$, $\pi\nu$, and $\rho\nu$.



Reconstructed from $\tau \rightarrow l\nu\nu$.



Reconstructed from $\tau \rightarrow \pi\nu$ and $\rho\nu$.

E_{ECL}

Signal (red): four signal tau modes combined.

BG (blue): all expected BGs for four signal tau modes combined.

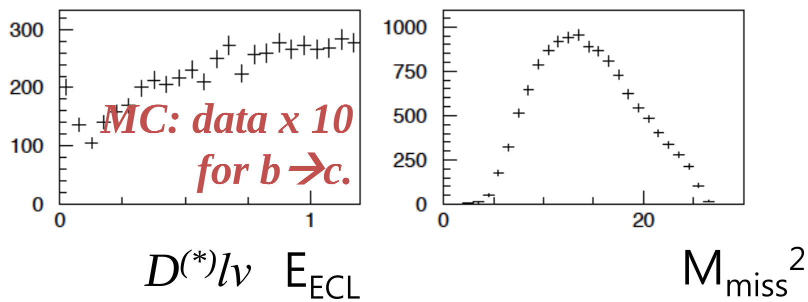
M_{miss}^2

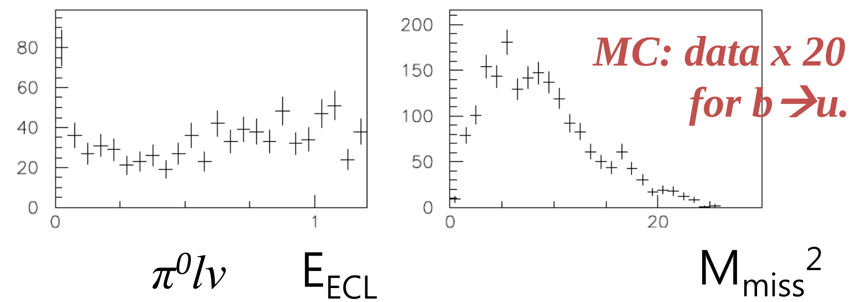
$\tau \rightarrow l\nu\nu$ signal (magenta): reconstructed as $\tau \rightarrow l\nu\nu$ (left), reconstructed as $\tau \rightarrow \pi\nu$ (right).

$\tau \rightarrow \pi\nu$, $\rho\nu$ signal (brown): reconstructed as $\tau \rightarrow \pi\nu$ and $\tau \rightarrow \rho\nu$.

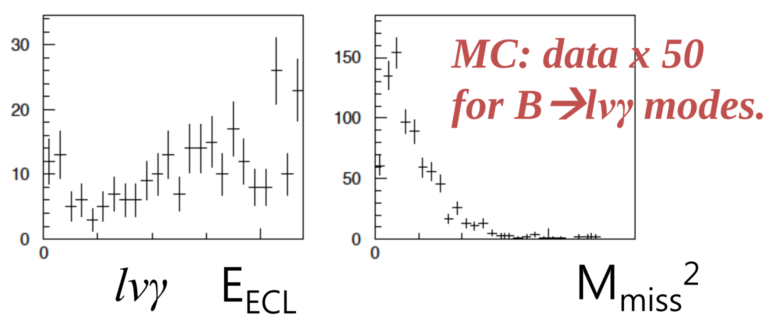
Peaking BG

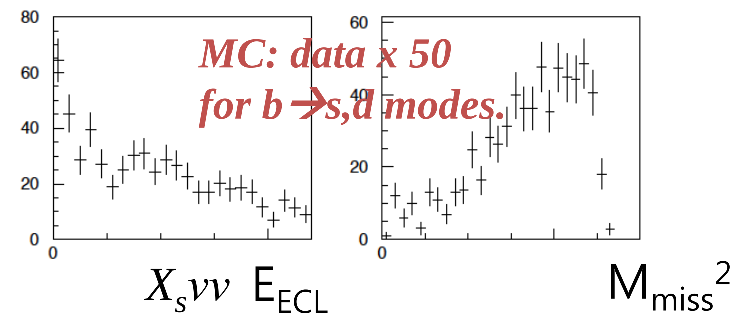
- At least one of E_{ECL} and M_{miss}^2 distributions have difference from signal. Result is less sensitive to peaking backgrounds.
- If BR is known, error of BR and MC statistics in Syst.





- If BR is not known, assume SM value in the nominal fit. SM value ±50% and MC statistics in Syst.





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

PRL 97, 251802 (2006)

Comparison with 2006 result

	PRL 97 (2006)	ICHEP 2012	
Analysis	**hadronic tag** **1D fit to E_{ECL}**	**hadronic tag(new)** **2D fit to (E_{ECL} , $M_{miss}{}^2$)**	
N(BB) (x 10^6)	**(set A)** **449**	**771**	
		(set A) 449	**(set B) 332**
Efficiency (x 10^{-4})	**3.0**	**11.2**	
N(signal yield)	$24.1^{+7.6}_{-6.6}$	$54.1^{+18.8}_{-17.4}$	$8.6^{+14.0}_{-12.4}$
Br($B^+ \to \tau^+ \nu$) (x 10^{-4})	$1.79^{+0.56}_{-0.49}$	$1.08^{+0.37}_{-0.35}$	$0.24^{+0.39}_{-0.34}$
		$0.72^{+0.27}_{-0.25}$	

1.6σ (set A' vs. set B)

2.5σ (PRL 97 (2006) vs. set B)

conservative comparison

1. Only with statistical error.
2. Assuming all the signal candidates in the old analysis become signal candidates in the new analysis.

New analysis based on improved tag, loose event selection, and re-processed data.

SET A: the data-set used in 2006

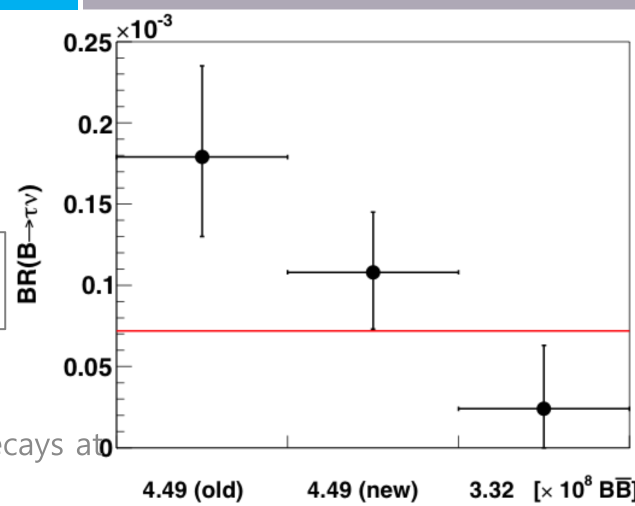
SET B: corresponds to the data-set not used in 2006

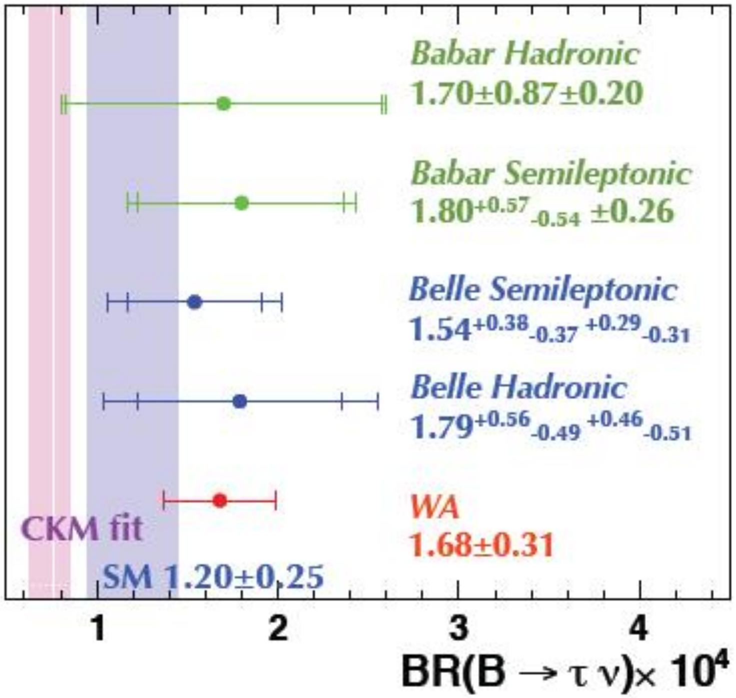
SET A': corresponds to the data-set used in 2006, but reproduced

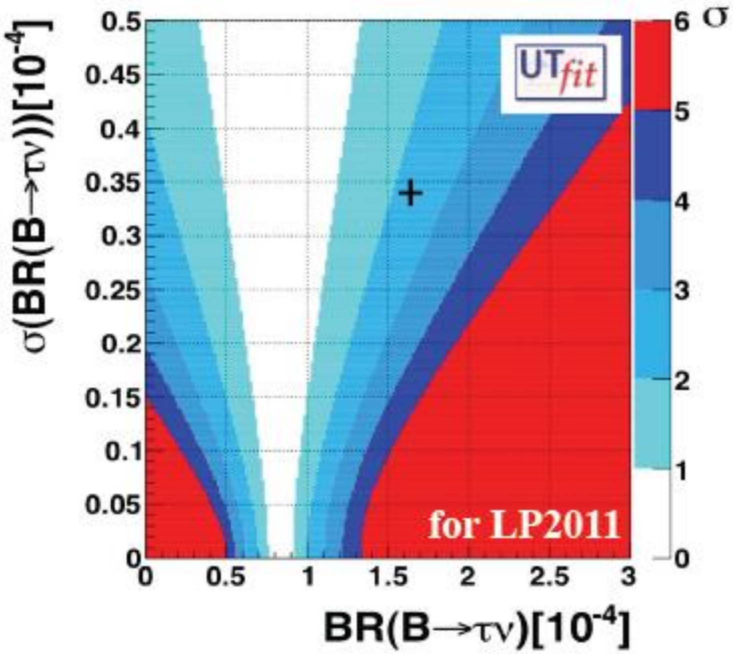
All events used for the New Analysis

Old (set A) vs. New (set B) : 2.5σ difference
New results. set A' vs. set B : 1.6σ difference
Old (set A) vs. New (set A') : 1.2σ difference

*Old result (set A) vs. New (only for non-overlapping events in the set A)
BF(non-overlapping events) = (0.6 ± 0.4)x10^-4 → 1.9 σ difference

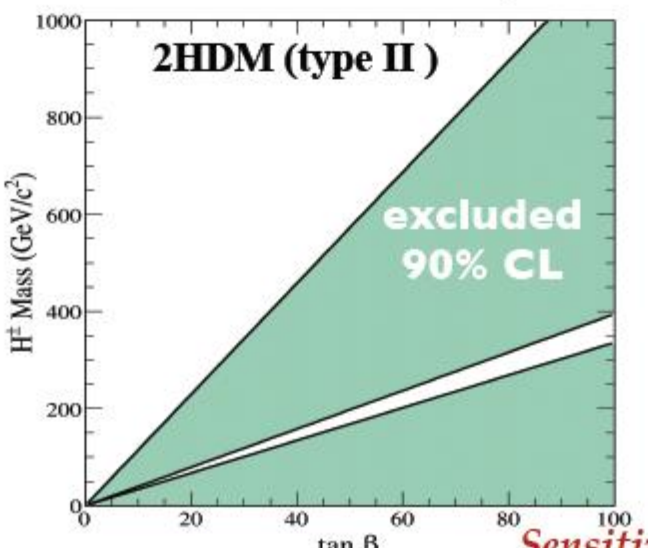






$$\mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{\rm SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2} \tan^2\beta\right)^2$$

W. Hou, PRD 48, 2342 (1993)



for this plot, we use

$B_{SM}(B^+ \to \tau^+ \nu) = (1.20 \pm 0.25) \times 10^{-4}$

using f_B (HPQCD), $|V_{ub}|$ (HFAG)

Note:

$$\mathcal{B}_{\rm SM} = 0.83 \pm 0.08 \text{ (UTfit)}$$

$$\mathcal{B}_{\rm SM} = 0.733^{+0.121}_{-0.073} \text{ (CKMfitter)}$$

Sensitivity to H⁺ is complementary to LHC direct searches

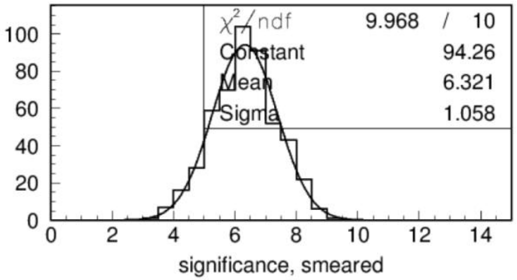
K_L^0 Rejection

OLD P14.

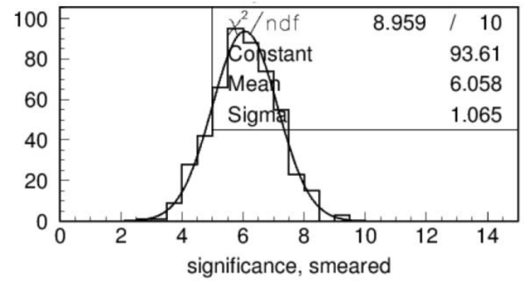
$$B^+ \to \tau^+ \nu_\tau$$

Toy Monte Carlo study with and without K_L^0 Rejection

(Input $\mathcal{B}(B^+ \to \tau\nu) = 1.65 \times 10^{-4}$ for signal MC)



<With rejection>



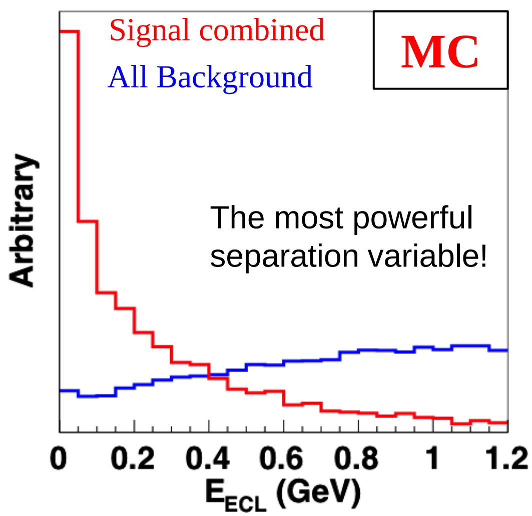
<Without rejection>

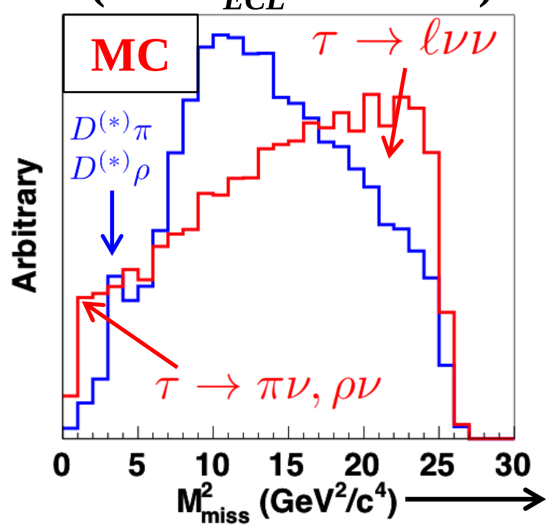
Considers... Statistical uncertainty,
Systematic uncertainties for MC PDF statistics,
K_L^0 Rejection uncertainty,
and Peaking Background uncertainty

Expected Significance = 6.32(6.06) with(without) K_L^0 Rejection

The fitting variables

(For E_{ECL}<0.2 GeV)





Using these variables for 2D histogram PDF fitting.

Use of 2-D fitting will reduce the sensitivity to peaking backgrounds in E_{ECL}.