Belle実験での$B\to\tau\nu$測定

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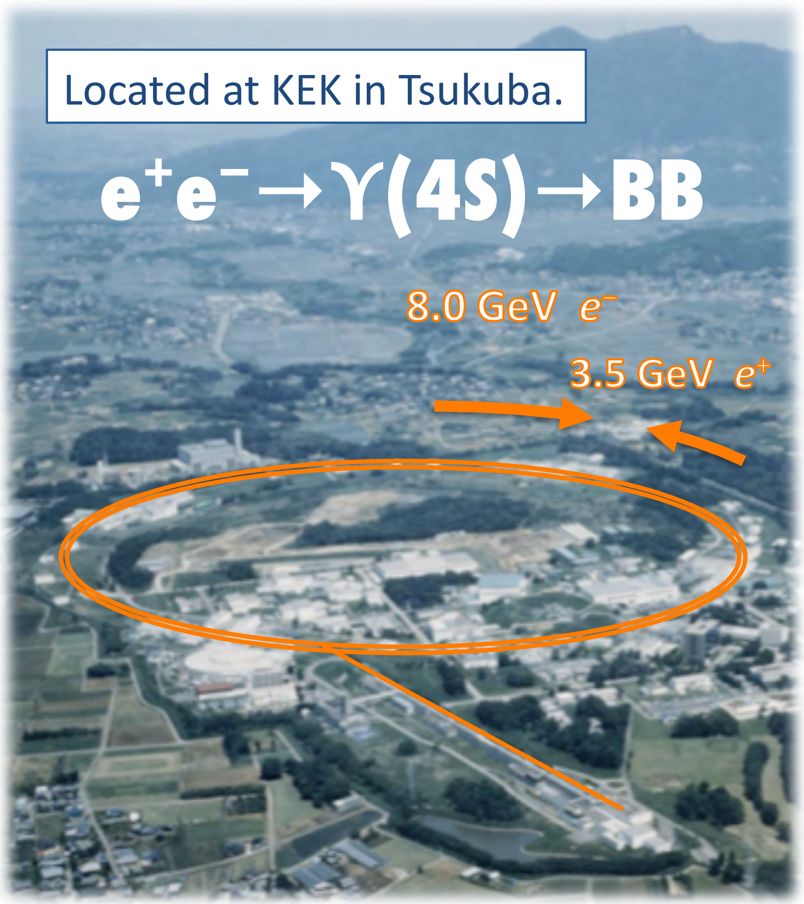
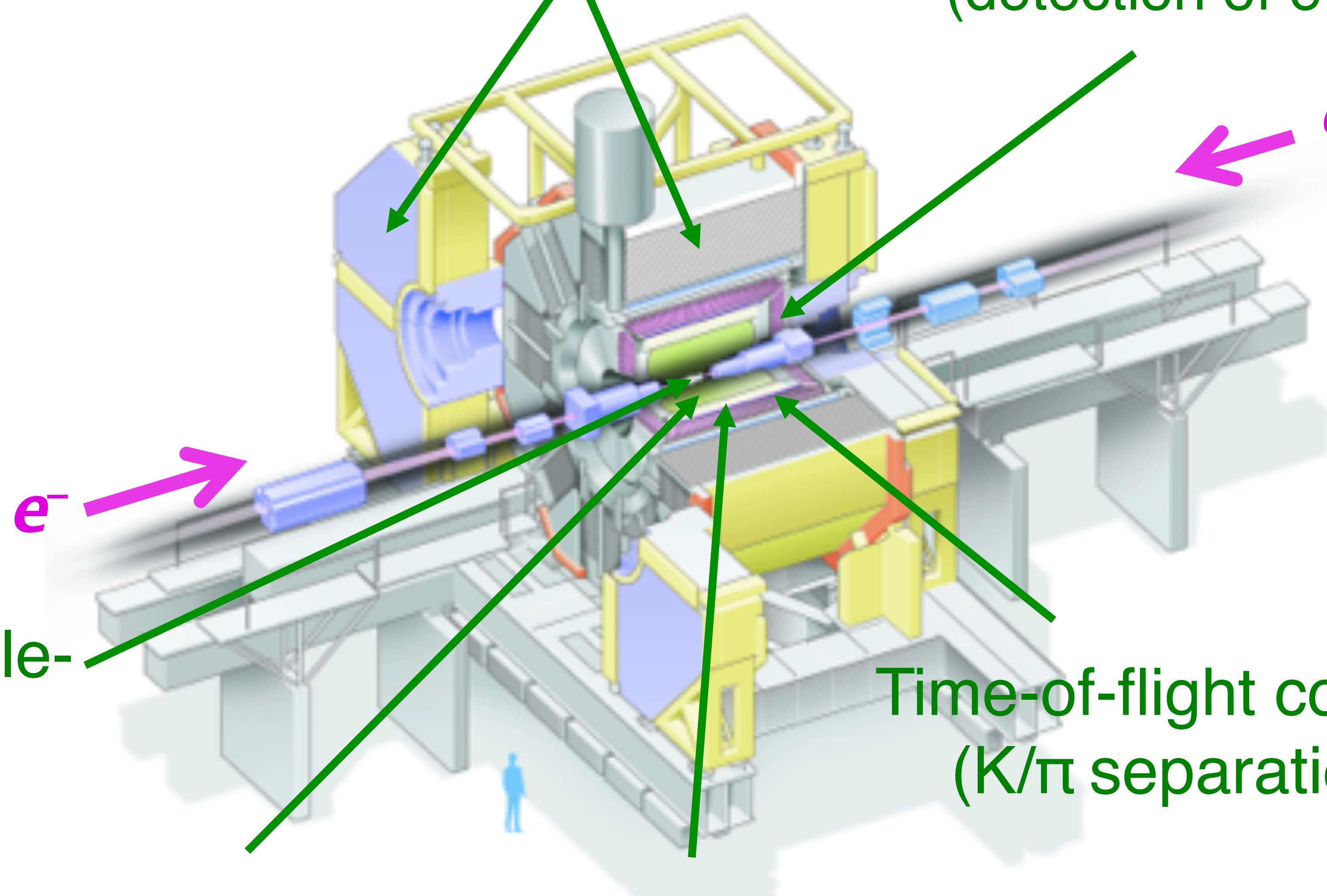
２０１２年　７月７日

KEKB collider and Belle detector





Resistive plate chamber + Fe
(detection of μ and K_L)

CsI(Tl) calorimeter
(detection of $e^{\pm}$ and γ)

Four layers of double-sided-silicon-strip
(vertexing)

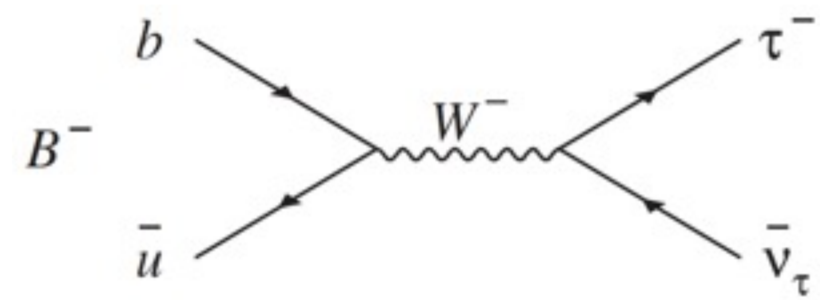
Time-of-flight counter
(K/π separation)

Drift chamber
(tracking and dE/dx)

Aerogel Cherenkov counter
(K/π separation)

Introduction for $B \to \tau\nu$

- In the SM, annihilation process mediated by $W^{\pm}$.



- Branching fraction proportional to $f_B^2|V_{ub}|^2$.

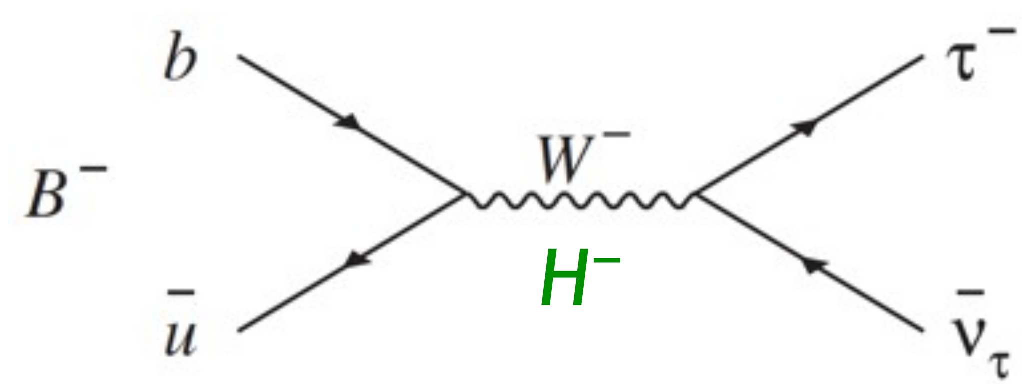
$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

  - f_B: B meson decay constant. (190 ± 13) MeV from HPQCD.
    PRD80, 014503 (2009)
  - V_{ub}: CKM matrix element. $(4.15 \pm 0.49) \times 10^{-3}$ from PDG.
    From $b \to u l \nu$ transitions.

- Expected branching fraction = $(1.10 \pm 0.30) \times 10^{-4}$.

Effect of charged Higgs for B→τν

- Branching fraction of B→τν could be affected by charged Higgs.



- An example of the modifications is:

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

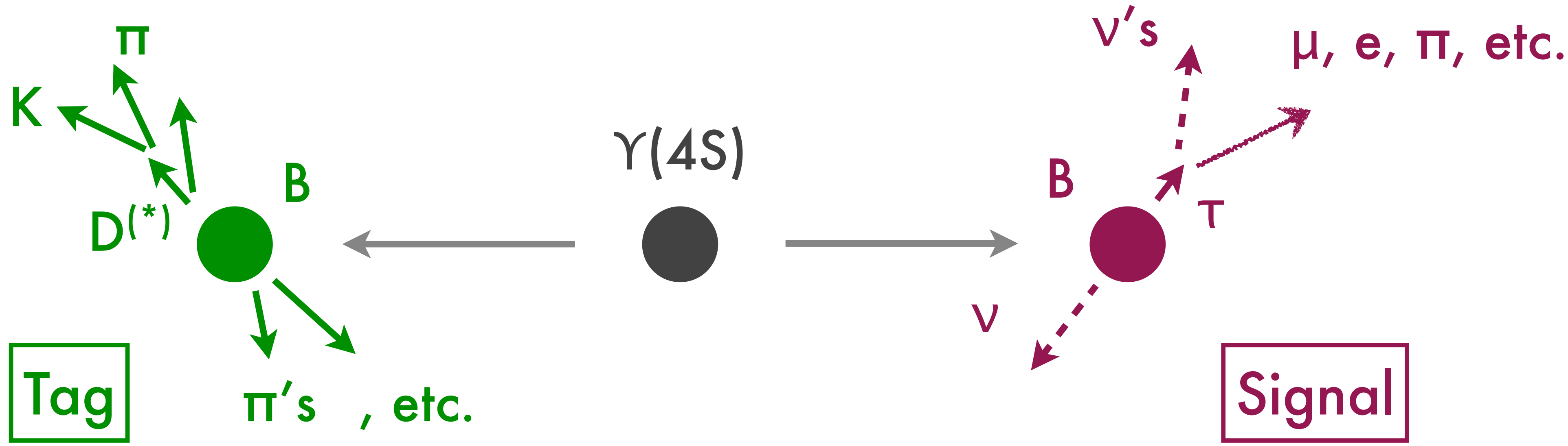
where

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

Type II of two Higgs doublet model,
W. S. Hou, PRD48, 2342 (1993)

Methods for analyzing $B \to \tau\nu$

Exploit that a B meson pair is generated by $e^+e^- \to \Upsilon(4S) \to BB$.



- Two independent tags are used.
  - Hadronic tag: tag B in hadoronic decays $B \to D^{(*)}\pi$, etc.
  - Semileptonic tag: tag B in semileptonic decays $B \to D^{(*)}l\nu$.
- Signal extraction using extra energy in electromagnetic calorimeter, which corresponds to detected energy for neutrinos (~0 for signal).

First evidence for B→τν

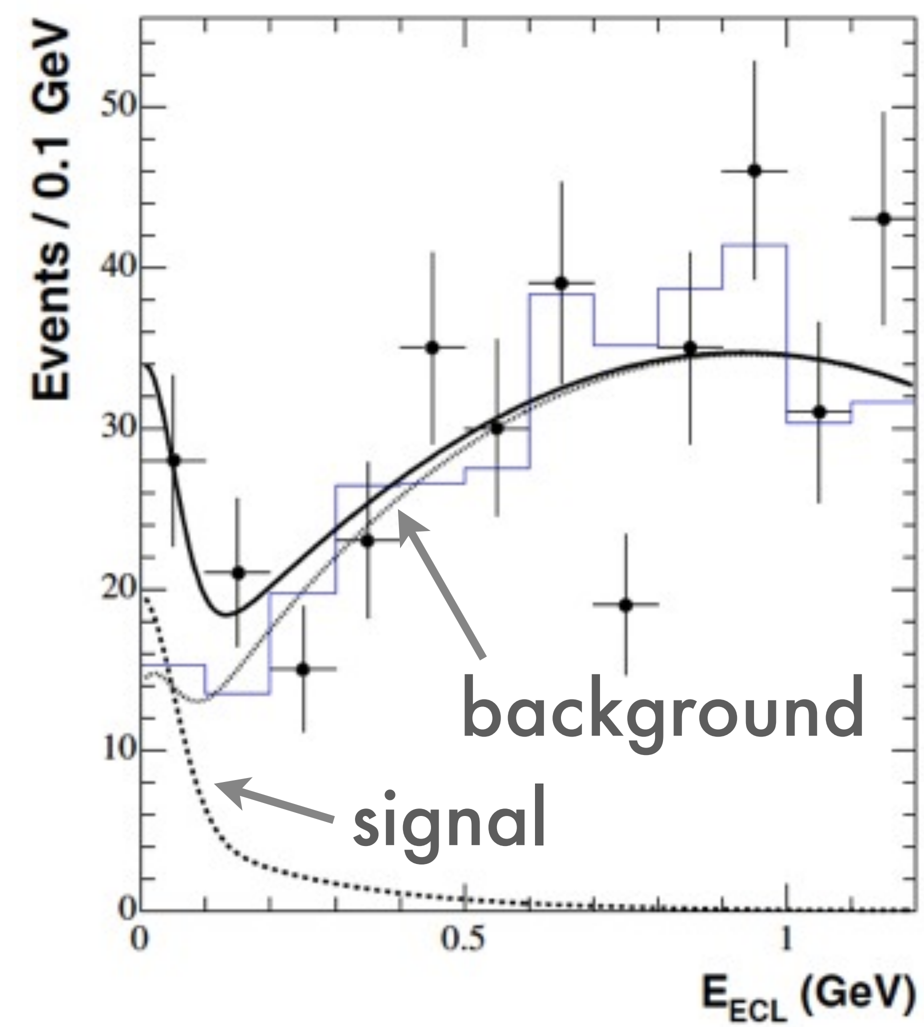
- First evidence for B→τν signal obtained by Belle using hadronic tag for 449M BB data (3.5σ).

60% of full data

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

Syst. from BG PDF, tag efficiency, etc.

τ decay	N_{obs}	N_s	N_b	$\mathcal{B}(10^{-4})$	Σ
$\mu^- \bar{\nu}_\mu \nu_\tau$	13	$5.6^{+3.1}_{-2.8}$	$8.8^{+1.1}_{-1.1}$	$2.57^{+1.38}_{-1.27}$	2.2σ
$e^- \bar{\nu}_e \nu_\tau$	12	$4.1^{+3.3}_{-2.6}$	$9.0^{+1.1}_{-1.1}$	$1.50^{+1.20}_{-0.95}$	1.4σ
$\pi^- \nu_\tau$	9	$3.8^{+2.7}_{-2.1}$	$3.9^{+0.8}_{-0.8}$	$1.30^{+0.89}_{-0.70}$	2.0σ
$\pi^- \pi^0 \nu_\tau$	11	$5.4^{+3.9}_{-3.3}$	$5.4^{+1.6}_{-1.6}$	$4.54^{+3.26}_{-2.74}$	1.5σ
$\pi^- \pi^+ \pi^- \nu_\tau$	9	$3.0^{+3.5}_{-2.5}$	$4.8^{+1.4}_{-1.4}$	$6.42^{+7.58}_{-5.42}$	1.0σ



Fitted by smooth PDFs.

PRL 97, 251802 (2006)

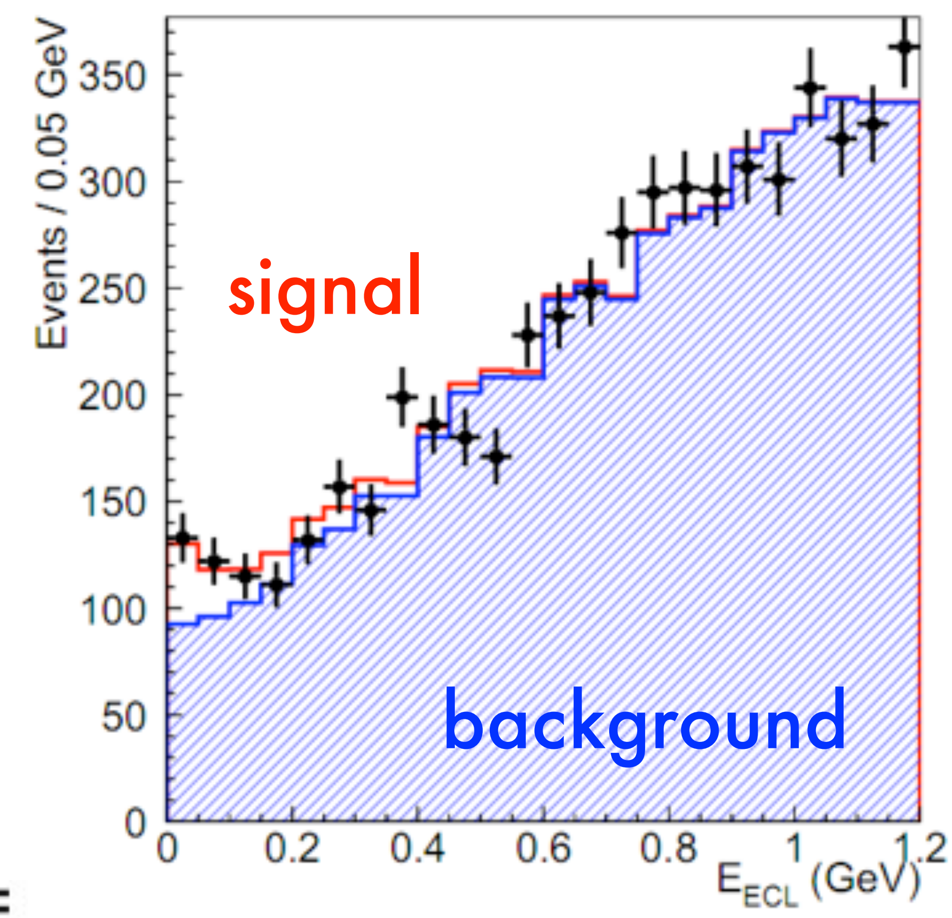
$B \to \tau\nu$ by semileptonic tag

- Using 657 M BB (85% of full data).
- Evidence of signal (3.6σ).
- Precision better than hadronic-tag result.

$$\mathcal{B} = [1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4}$$

Syst. from BG PDF, tag efficiency, etc.

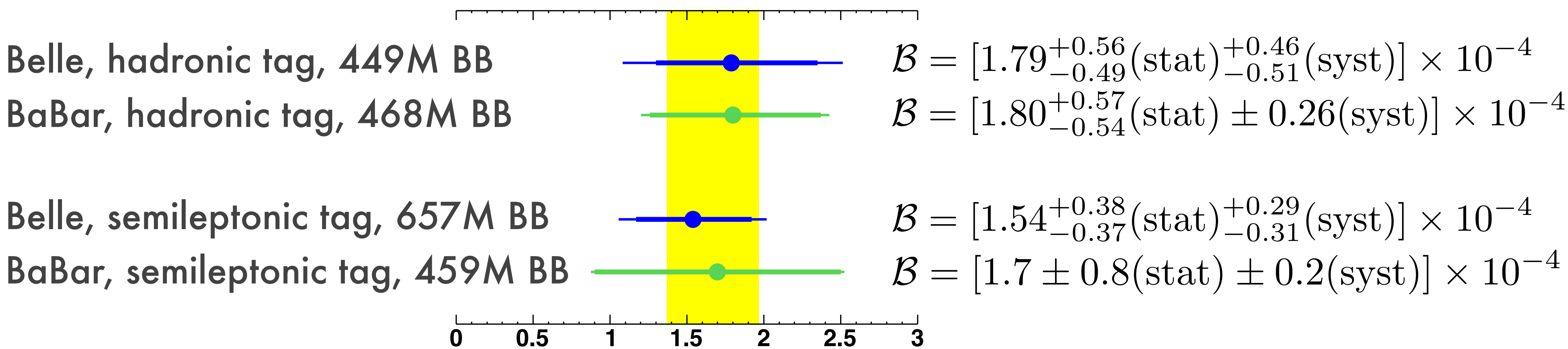
Decay mode	Signal yield	ε, 10^{-4}	$\mathcal{B}$, 10^{-4}
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	73^{+23}_{-22}	5.9	$1.90^{+0.59+0.33}_{-0.57-0.35}$
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	12^{+18}_{-17}	3.7	$0.50^{+0.76+0.18}_{-0.72-0.21}$
$\tau^- \to \pi^- \nu_\tau$	55^{+21}_{-20}	4.7	$1.80^{+0.69+0.36}_{-0.66-0.37}$
Combined	143^{+36}_{-35}	14.3	$1.54^{+0.38+0.29}_{-0.37-0.31}$



Fitted by histogram PDFs.

PRD 82, 071101(R) (2010)

Summary for B→τν as of winter 2012



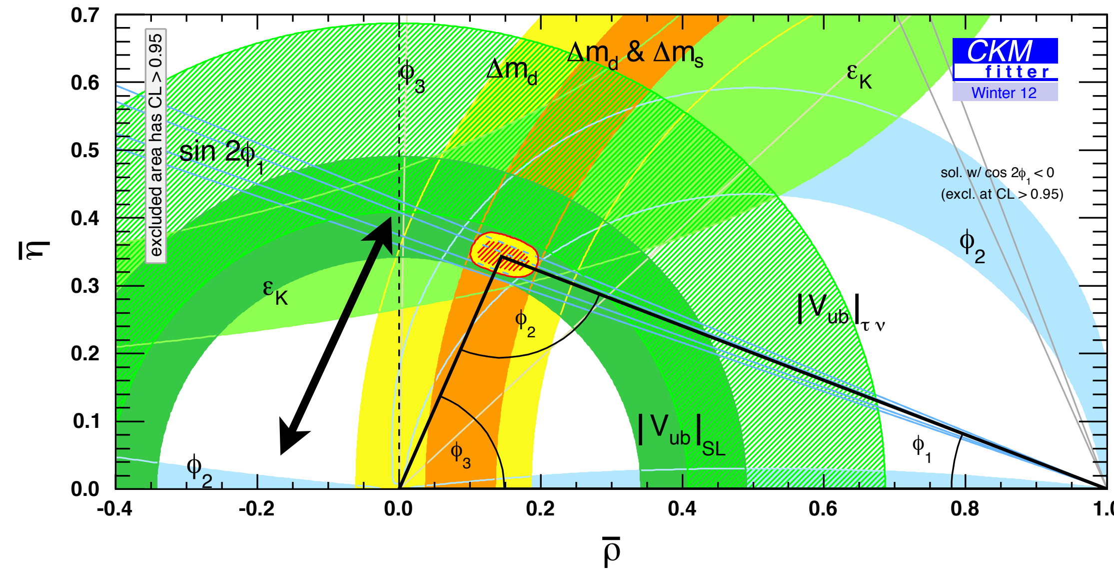
HFAG average: $\mathcal{B} = (1.67 \pm 0.30) \times 10^{-4}$

- BaBar also obtained results for hadronic and semileptonic tags.
- The results are in good agreement while all results are slightly higher than a SM expectation: $(1.10 \pm 0.30) \times 10^{-4}$.

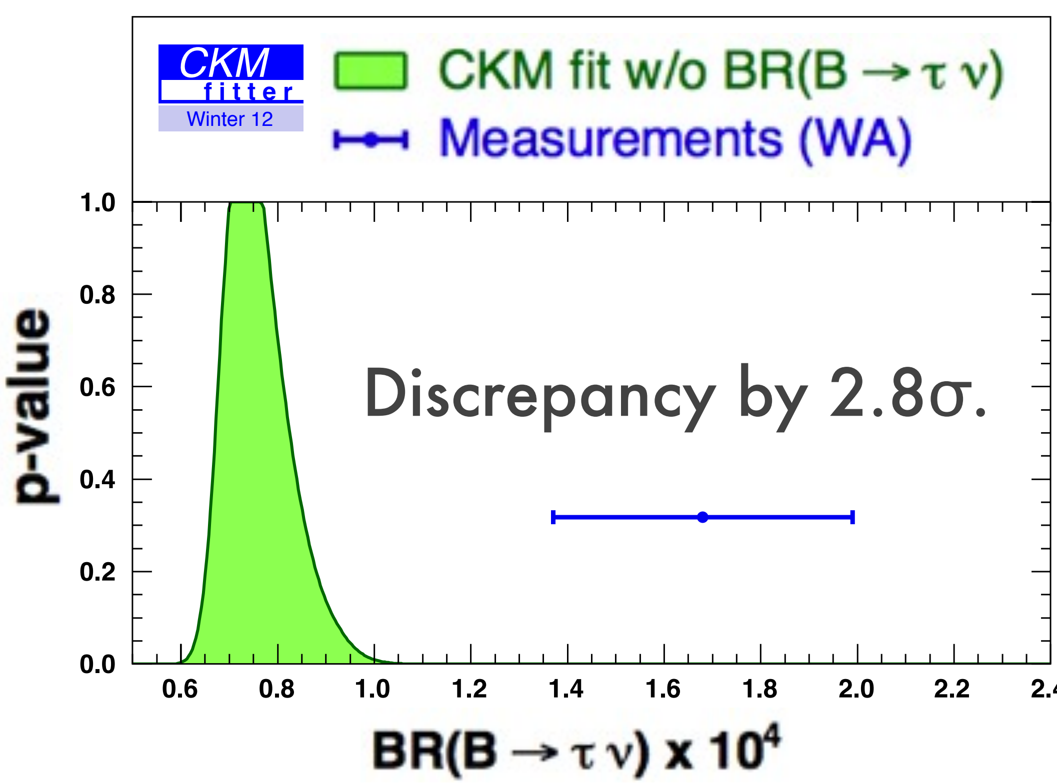
Tension with CKM-fit prediction

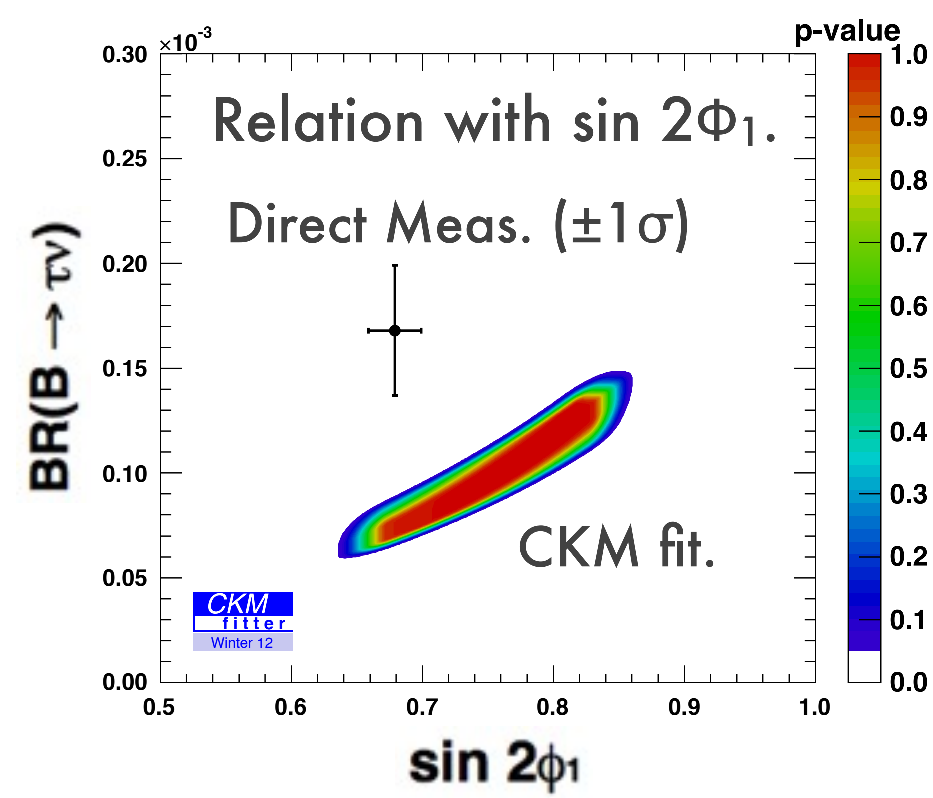
$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$|V_{ub}|$ can be obtained from a global CKM fit.

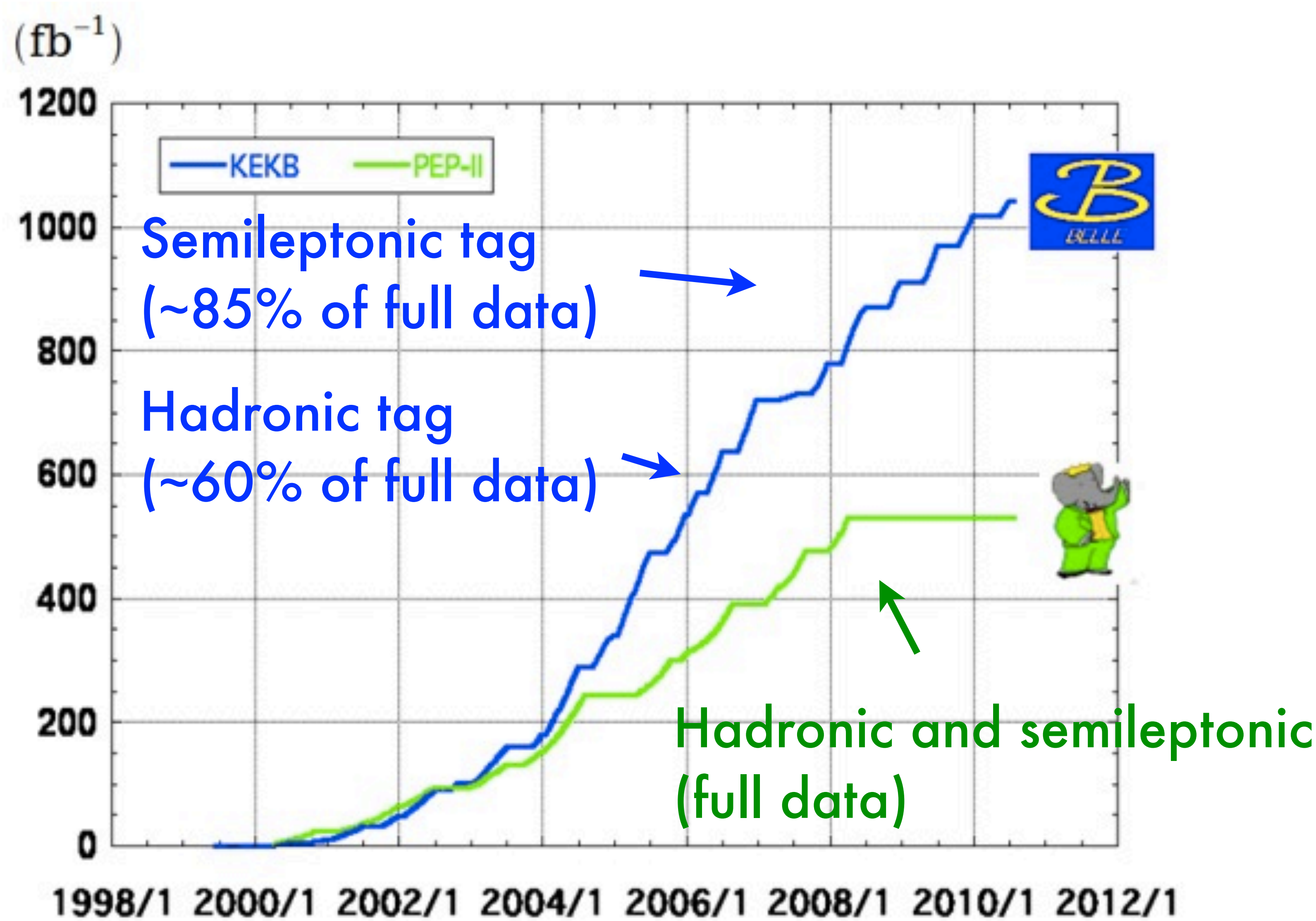


Using this $|V_{ub}|$, we obtain a tension with a significance of 2.8σ.





Data sizes used for B→τν



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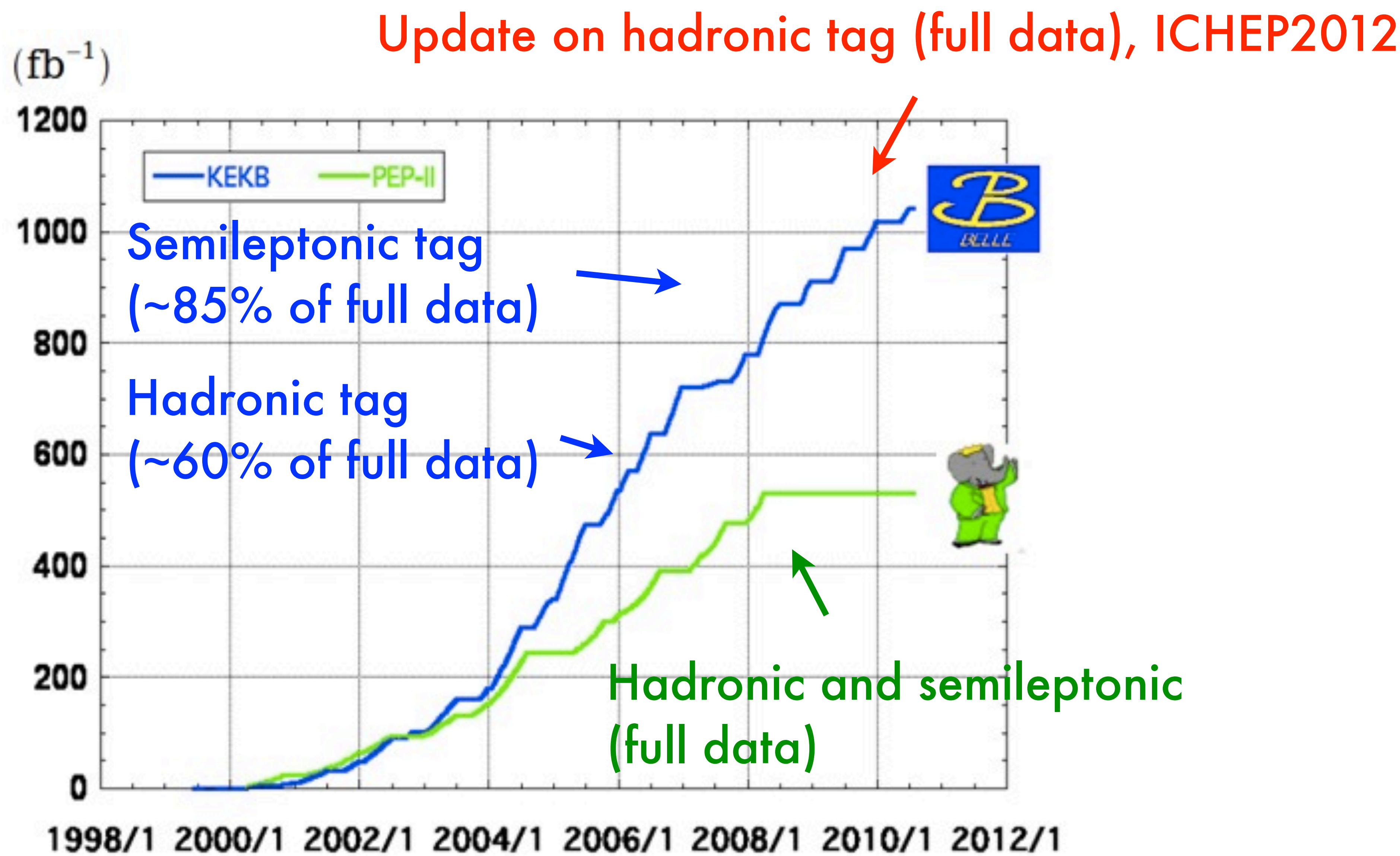


From next page, will explain about recent update on hadronic-tag analysis.

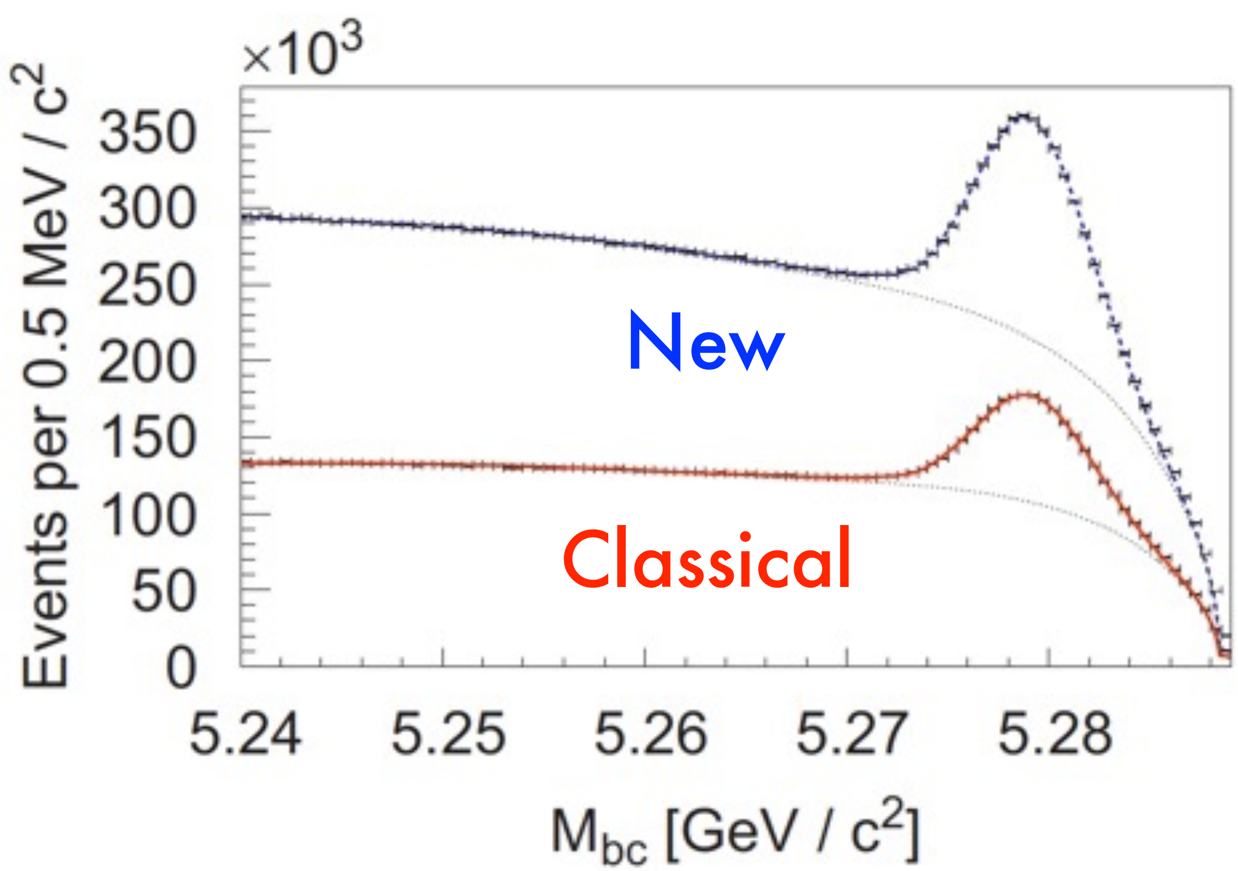
Improvements for new hadronic-tag analysis at Belle

- Data size x 1.7.
- Improved hadronic tag: efficiency x ~2.
- Improved signal extraction: sensitivity x ~25%.
- ...

Expected sensitivity: x ~2.

Improved hadronic tag

- More decay modes. NIMA 654, 432 (2011)
- Event selection by using NeuroBayes (neural network).



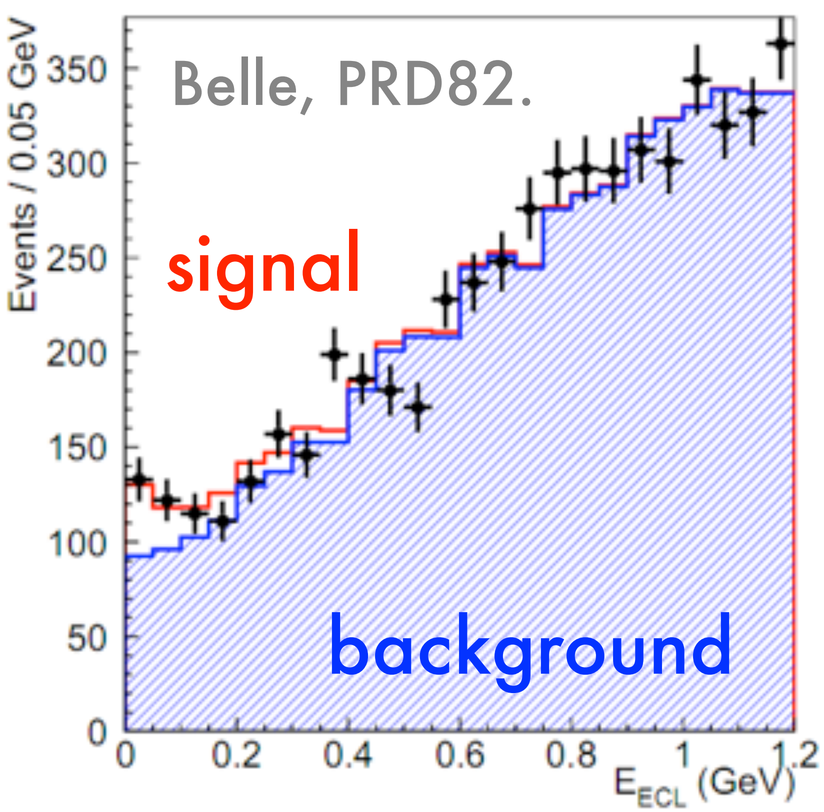
M_{bc}: mass of tagged B obtained using e^+e^- energy.

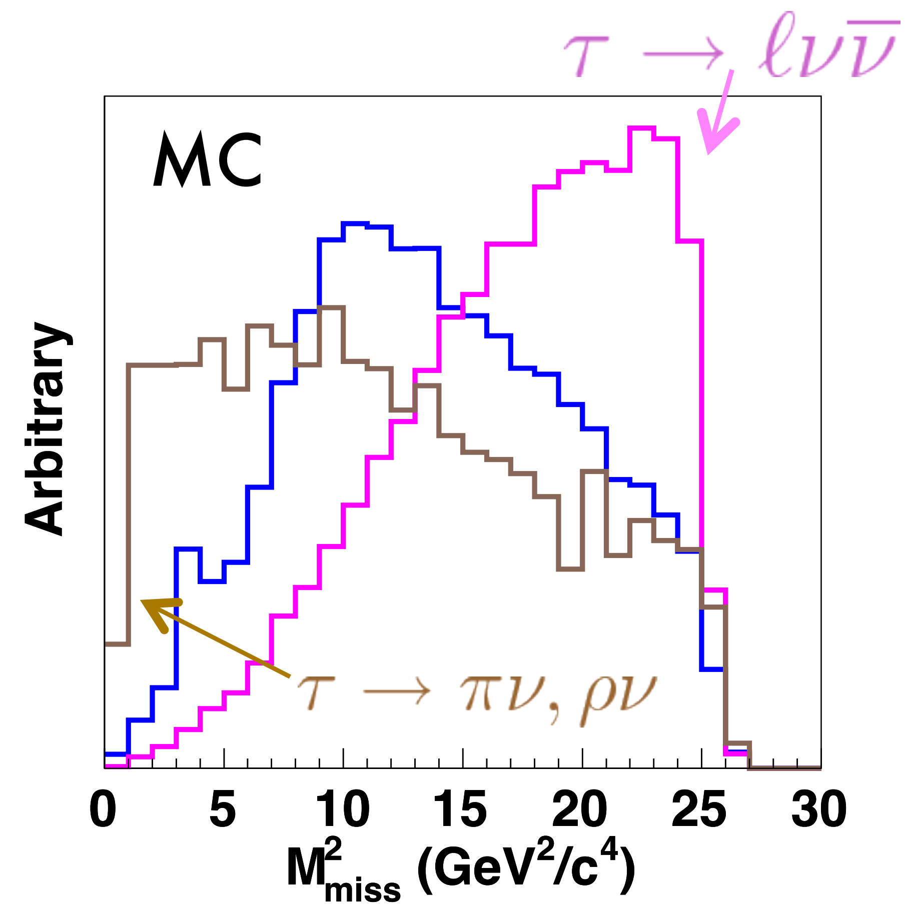
Efficiency improved by a factor of ~2 (at ~same purity).

Improvement for signal extraction

Previous analyses (including BaBar) used single variable E_{ECL} for signal extraction.

This analysis uses two variables E_{ECL} and M_{miss}^2 for the signal extraction.





E_{ECL}: extra energy detected at ECL after removing all detected particles ("detected" energy of neutrinos).

M_{miss}^2: missing mass squared in an event (mass squared for neutrinos).

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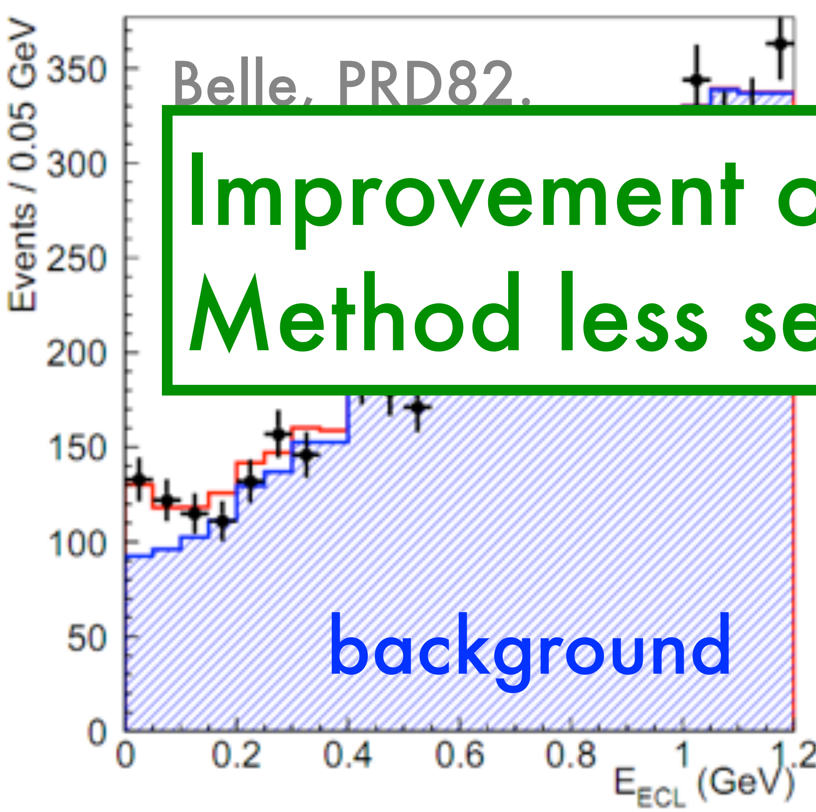
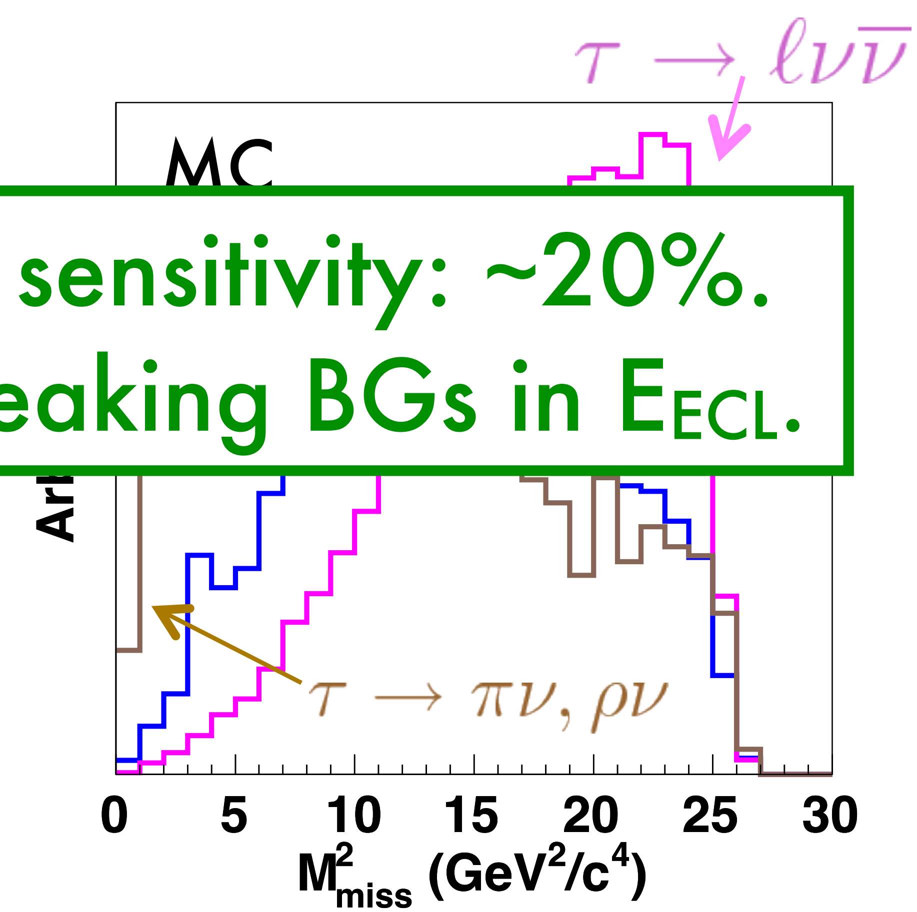




Improvement on statistical sensitivity: ~20%.
Method less sensitive to peaking BGs in E_{ECL}.

E_{ECL}: extra energy detected at ECL after removing all detected particles ("detected" energy of neutrinos).

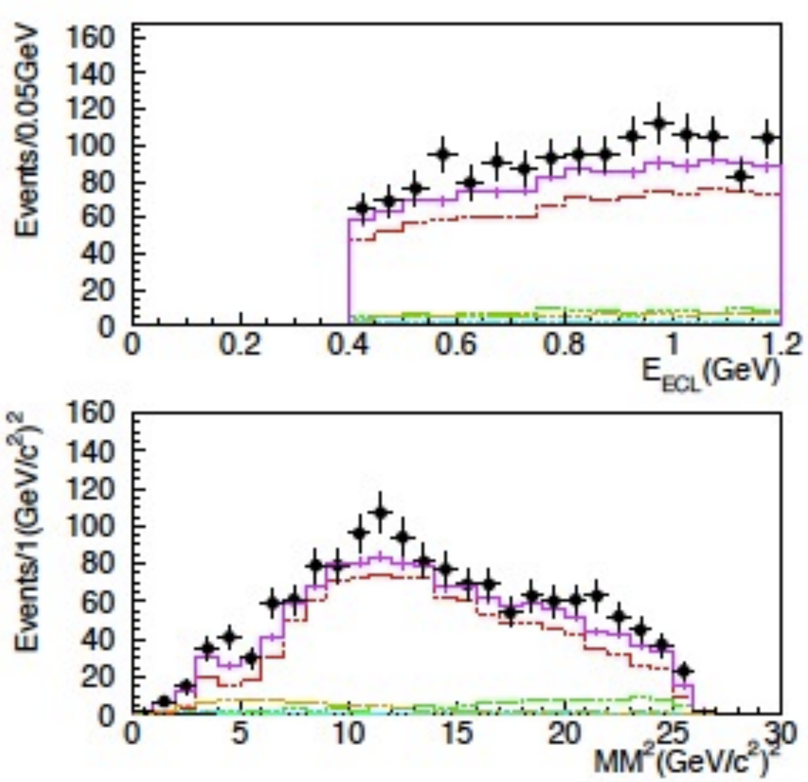
M_{miss}^2: missing mass squared in an event (mass squared for neutrinos).

Another improvement: K_L veto

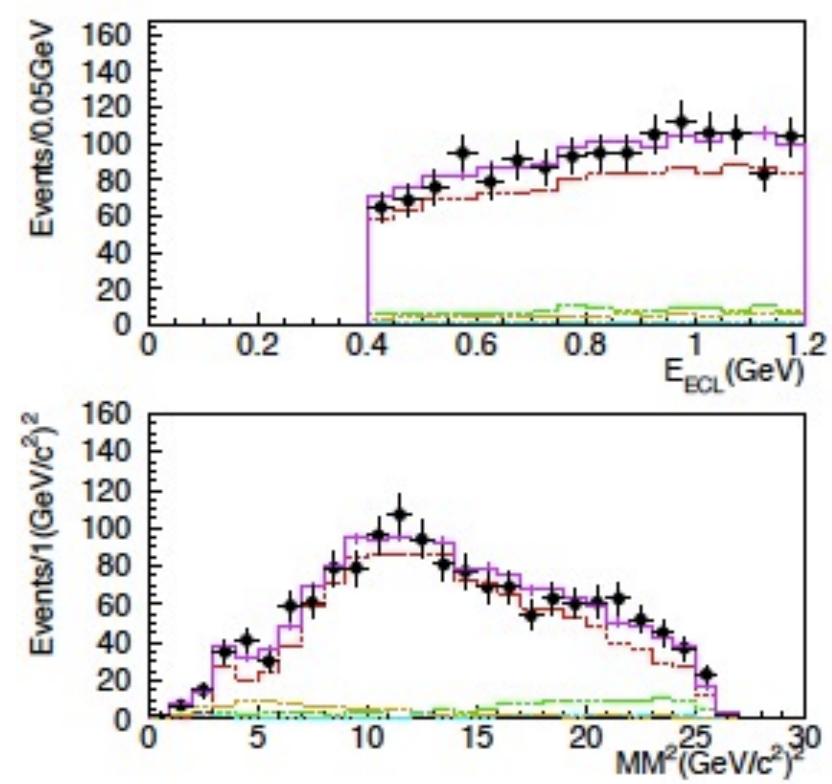
- If a K_L exists, we reject the events.
- Efficiency difference in data and MC calibrated by $D^0 \to \phi K_S$, $\phi \to K_S K_L$ (normalized by $\phi \to K^+ K^-$).
- Validity checked using $B^0 \to D^{*-}\pi^+$, $D^{*-} \to D\pi^-$, $D \to K_L \pi^0$.

Check done also for $B \to \tau\nu$ BG in E_{ECL} sideband data.

w/ K_L veto, w/o K_L veto efficiency correction



w/ K_L veto, w/ K_L veto efficiency correction



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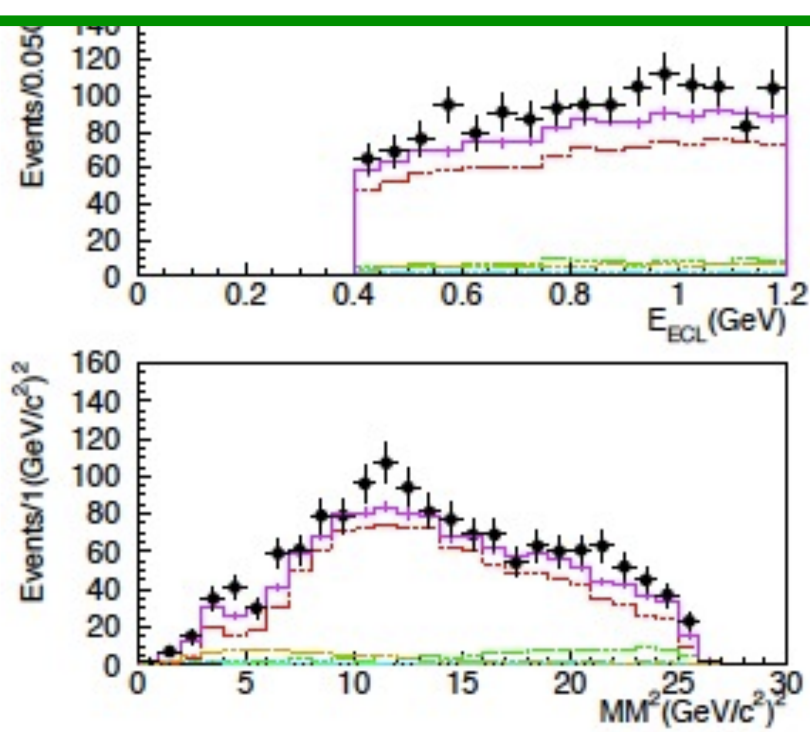
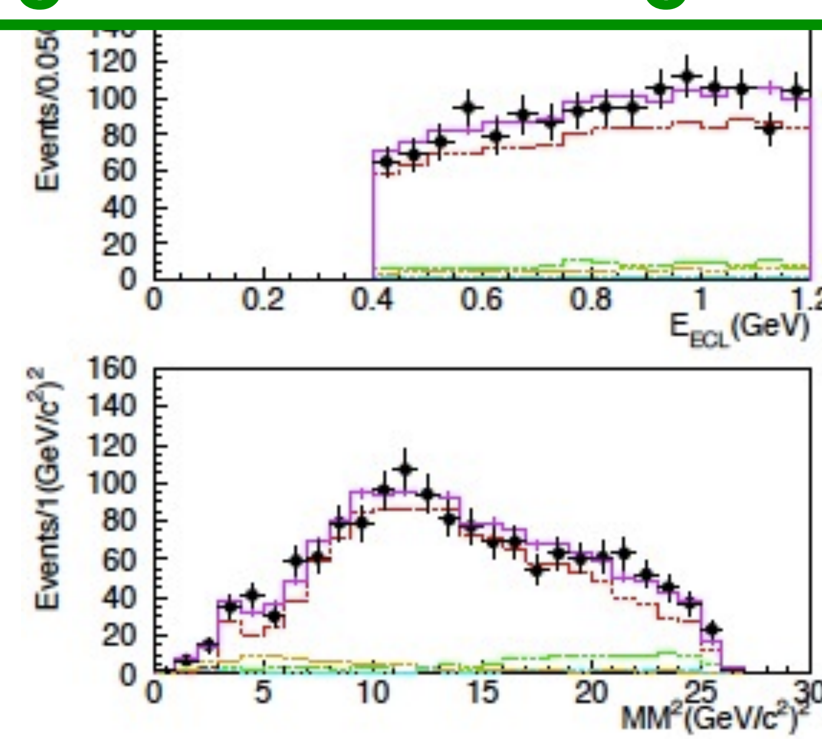
- Validity checked using $B^0 \to D^{*-}\pi^+$, $D^{*-} \to D\pi^-$, $D \to K_L \pi^0$.

Che

w/ ... ction

Improvement on statistical sensitivity: ~5%.
Method less sensitive to peaking BGs including K_L.





Efficiency and expected signal yield

- Efficiencies and expected signal yields are listed depending on signal τ decays following to B→τν.

Preliminary

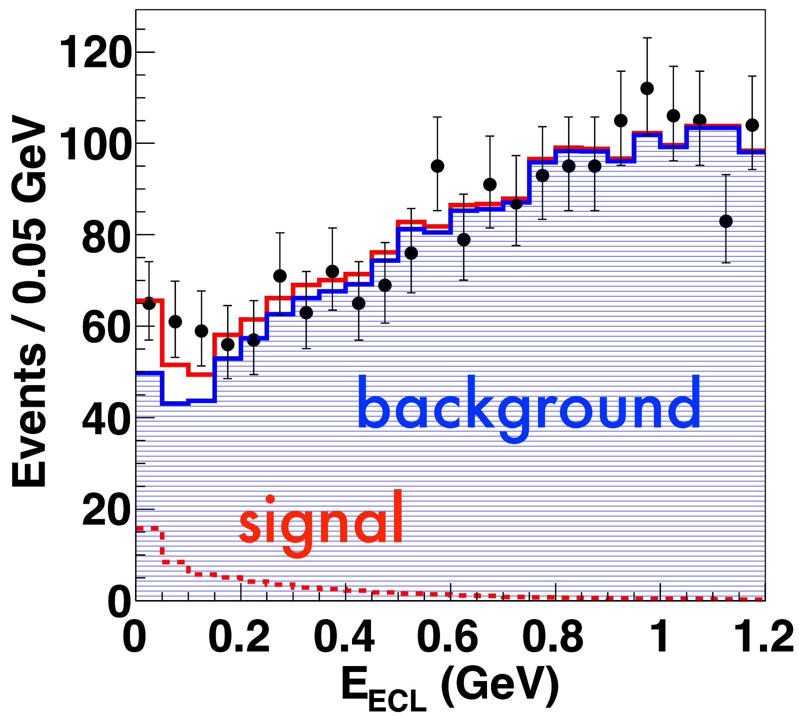
Mode	ϵ	Number of signal
$\tau^- \to e^- \overline{\nu}_e \nu_\tau$	2.45×10^{-4}	31.2
$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$	1.70×10^{-4}	21.6
$\tau^- \to \pi^- \nu_\tau$, true $\tau^- \to \pi^- \nu_\tau$	1.76×10^{-4}	22.4
$\tau^- \to \pi^- \nu_\tau$, $\tau^- \to \ell^- \nu_\tau \overline{\nu_\ell}$ cross feed	1.95×10^{-4}	24.8
$\tau^- \to \pi^- \nu_\tau$, $\tau^- \to \rho^- \nu_\tau$ and other cross feeds	1.86×10^{-4}	23.7
$\tau^- \to \rho^- \nu_\tau$	1.51×10^{-4}	19.2
Total	11.22×10^{-4}	142.9

Cross feeds taken as signal (ratios of efficiencies fixed in the fit).

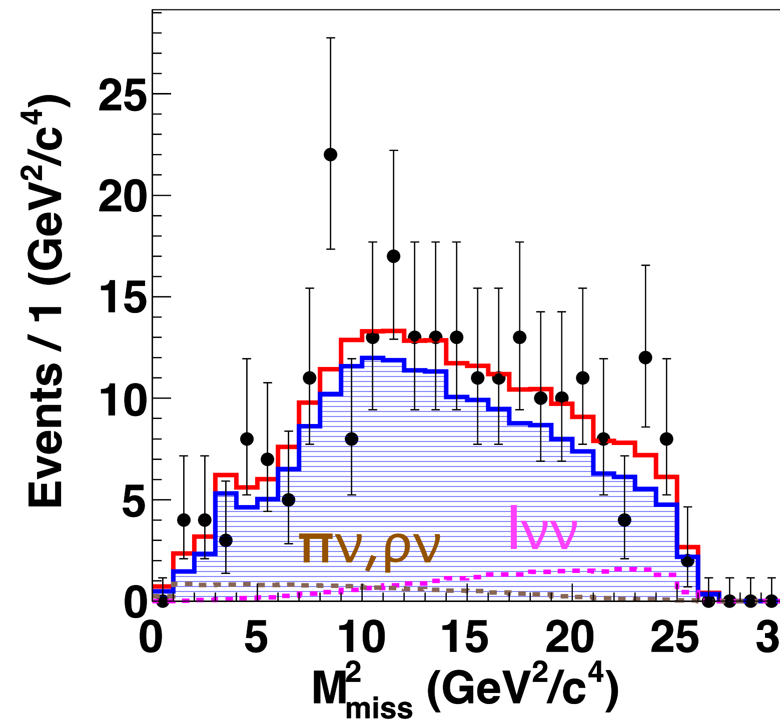
- Expected signal yields obtained for BR(B→τν) = 1.65 x 10^{-4}.
- Corresponding expected statistical significance is 6.7σ!

Box opened.

Preliminary



E_{ECL} in all M_{miss}^2 region.



M_{miss}^2 in E_{ECL} < 0.2 GeV.

- Signal yield: $62.3^{+23.1}_{-21.7}$.
- BR($B \rightarrow \tau\nu$)= $[0.72^{+0.27}_{-0.25}] \times 10^{-4}$. 3.2σ (stat only)

(Only statistical errors are shown.)

Systematic uncertainties

Preliminary

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

Syst. for signal yield

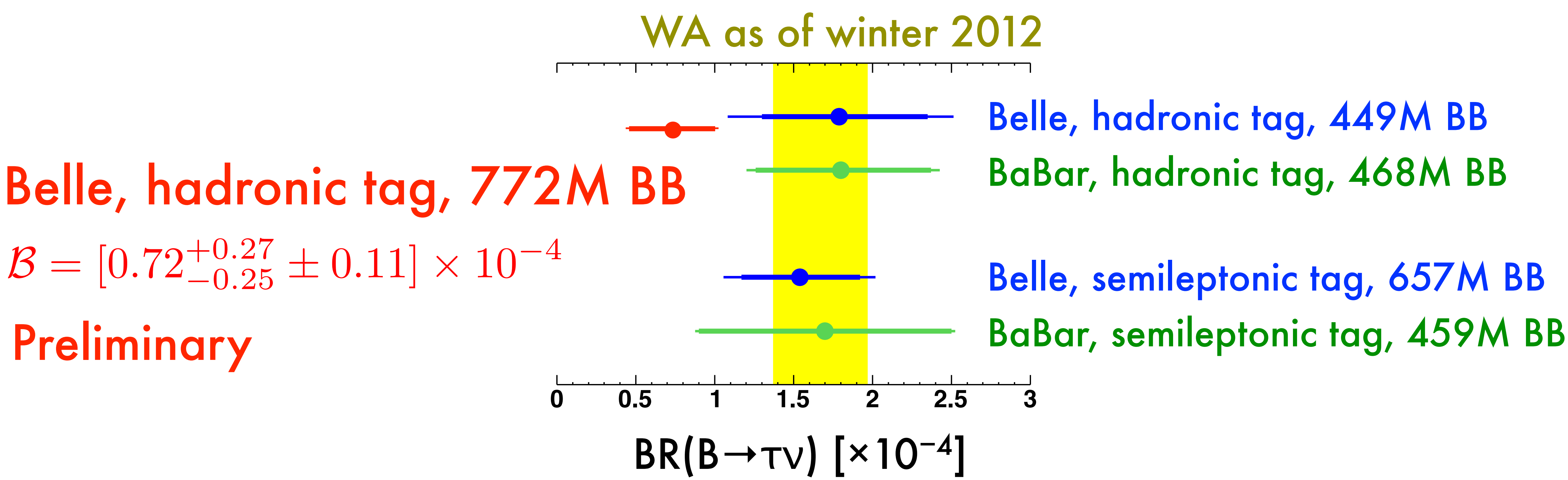
source	error
PDF Histogram MC Statistics	$^{+5.6}_{-5.0}$
Signal $E_{\rm ECL}$ Shape	$^{+0.6}_{-2.4}$
PHOTOS radiative correction	$^{+0.0}_{-0.6}$
Peaking BG, generic B	± 1.3
Peaking BG, rare B	± 1.9
Peaking BG, $b \to u \ell \nu$	± 0.4
Efficiency ratio, MC stat	$^{+0.1}_{-0.2}$
τ branching fraction	$^{+0.2}_{-0.0}$
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	$^{+6.2}_{-6.5}$

Syst. for branching fraction

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

Significance for signal yield: 3.0σ (including syst)

Comparison of the results for $B \to \tau\nu$

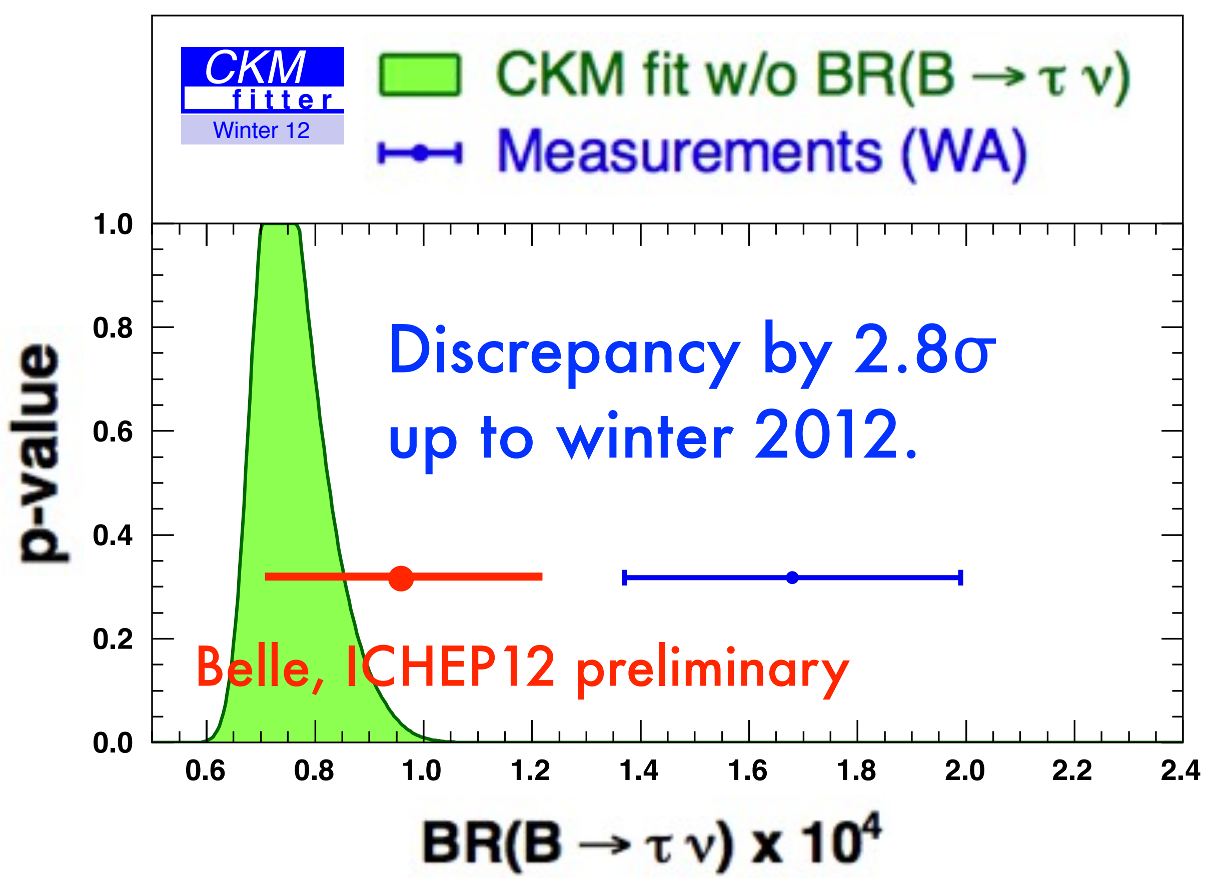


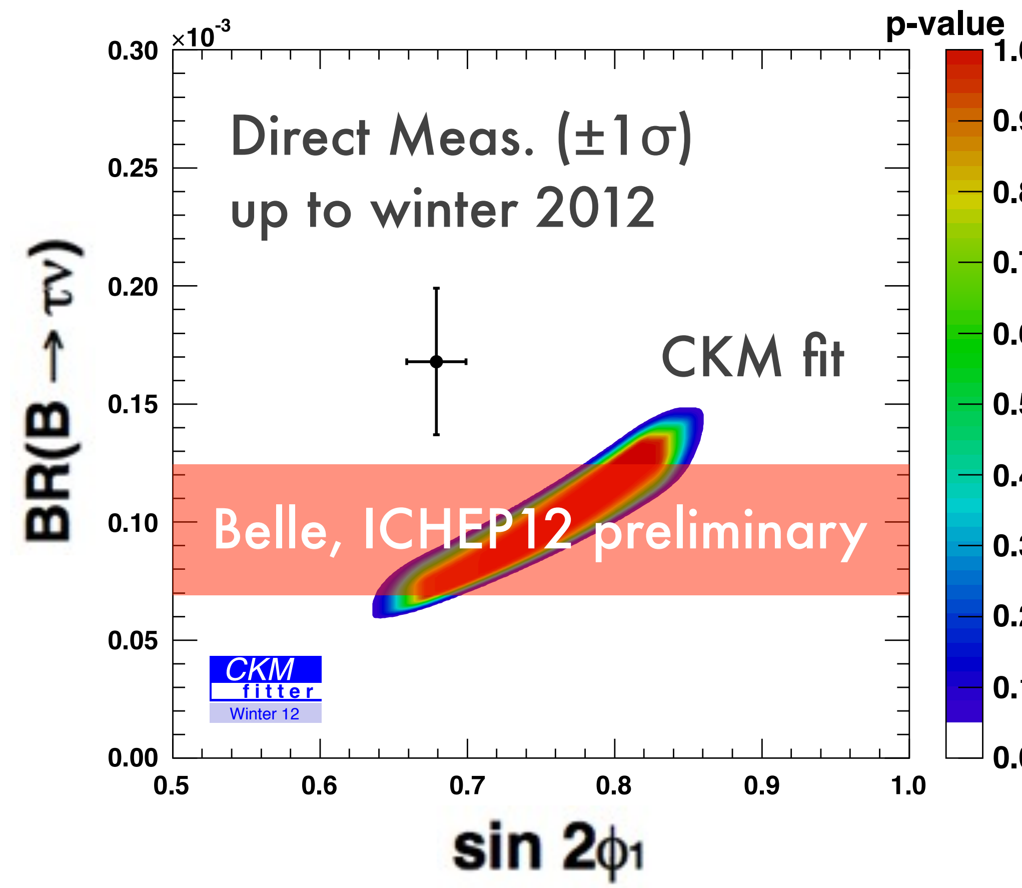
New result lower than the previous results.

Preliminary

Combining the results for hadronic and semileptonic tags of Belle, we obtain $B(B \to \tau\nu) = (0.96 \pm 0.26) \times 10^{-4}$.

Comparison of the result with CKM-fit prediction





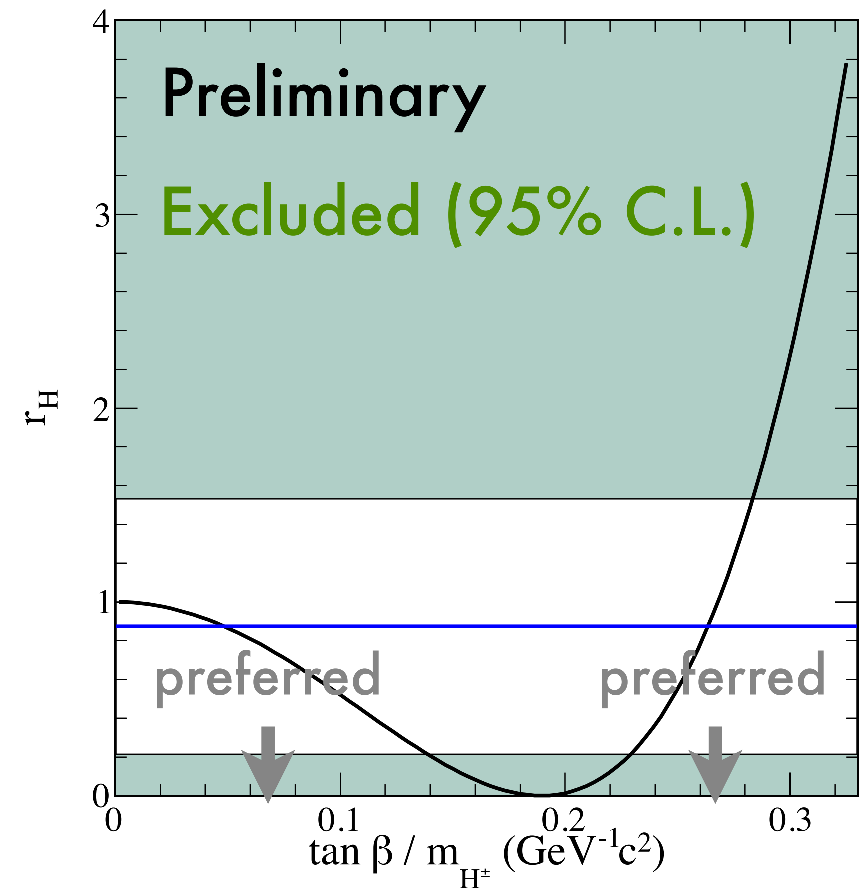
New result is in good agreement with CKM-fit prediction.

Constraint on Type II 2HDM

From B(B→τν) = (0.96±0.26)x10^{-4},
we constrain r_H for Type II of 2HDM.

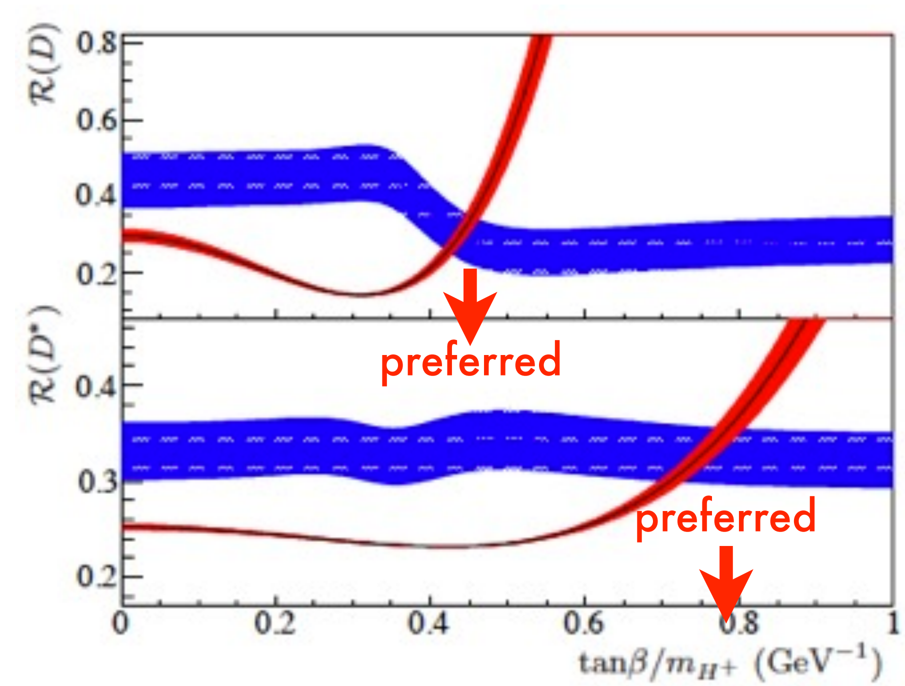
$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\rm SM} \times r_H$$

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



Do not agree with recent results on B→$D^{(*)}$τν from BaBar...

arXiv:1205.5442



Type II disfavored...?
Would need more statistics.

Summary

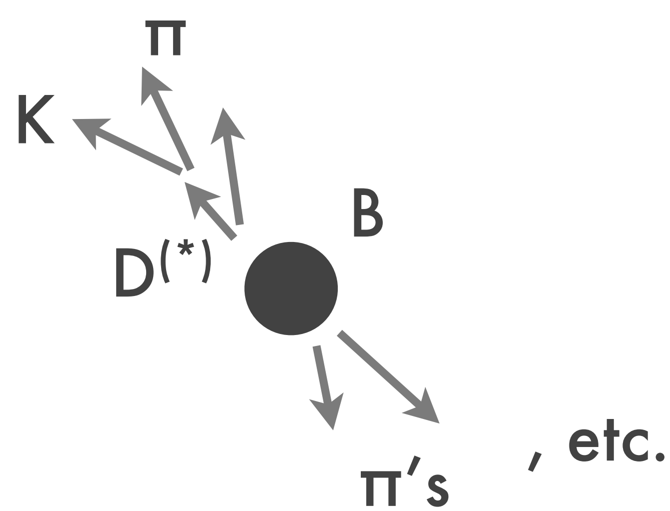
- Recent update on $B \to \tau\nu$ at Belle.
  - Sensitivity x ~2 by data increase, improved hadronic tag, improved signal extraction, etc.
  - Result consistent with SM expectations.

- Relation between $B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$: interesting topic at super B factories.
  - Note: error still dominated by the statistical error. (Also most of the systematics related to data size.)

Backup slides

Event selection

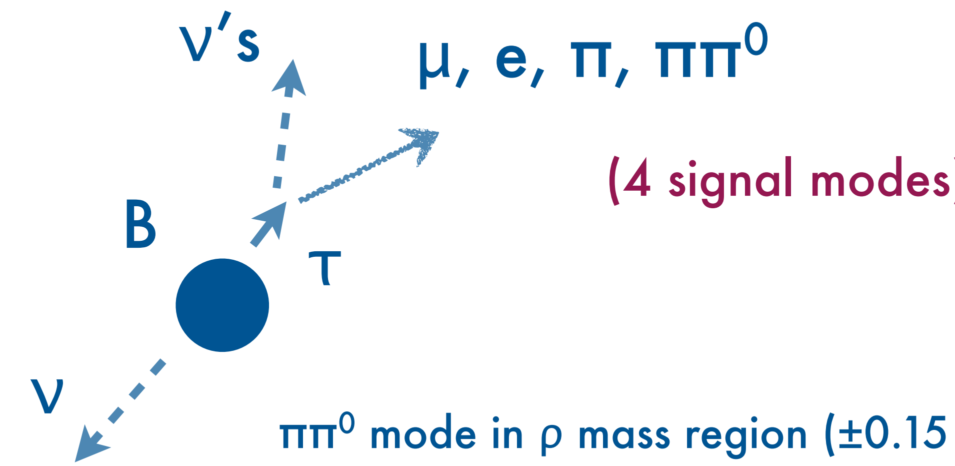
Tag side



Hadronic tag:

- -0.08 GeV $< \Delta E <$ 0.06 GeV
- 5.27 GeV/c^2 $< M_{bc} <$ 5.29 GeV/c^2
- Tag quality (neural net) > 0.03

Signal side



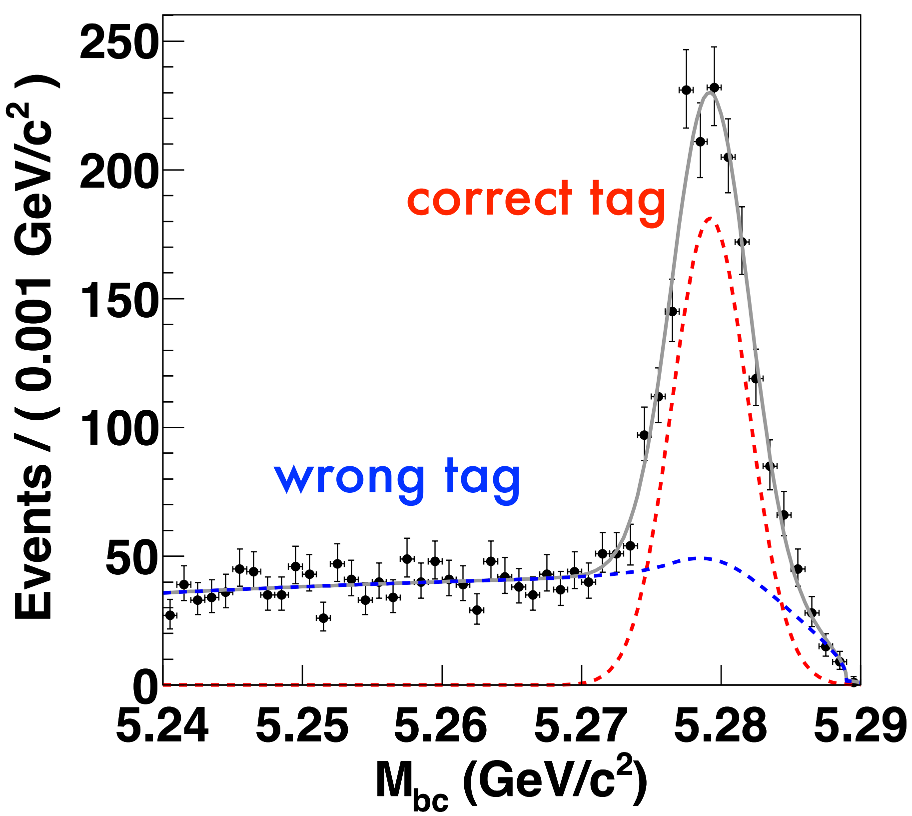
$\pi\pi^0$ mode in ρ mass region (±0.15 GeV)

- Charged particle:
  - $e^\pm$, $\mu^\pm$, or $\pi^\pm$ with $|\Delta r| <$ 0.5 cm and $|\Delta z| <$ 3 cm.
- π^0:
  - 0.1178 GeV/c^2 $< M_\pi <$ 0.1502 GeV/c^2
  - $E_{\gamma,\text{ forward}} >$ 0.05-0.15 GeV depending on angle.
- No extra tracks in $|\Delta r| <$ 15 cm and $|\Delta z| <$ 75 cm.
- No extra π^0's.
- No K_L.
- $-0.86 <$ cosine of missing 3-momentum in e^+e^- frame < 0.95.

Signal extraction by extra energy E_{ECL} and M_{miss}^2.

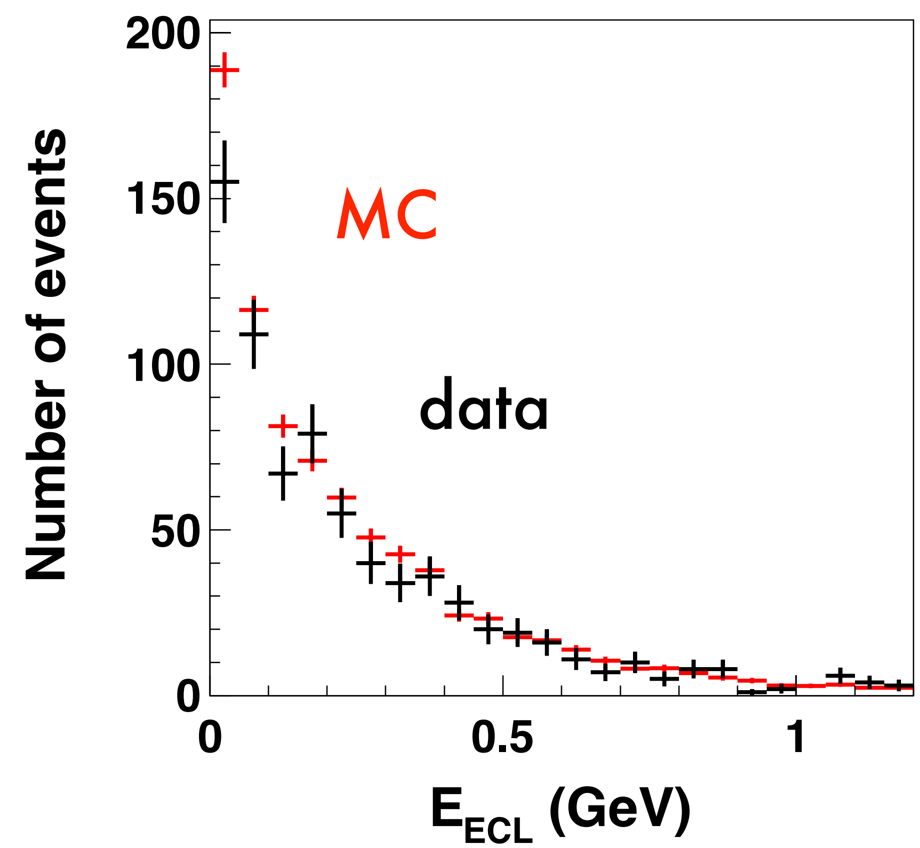
Tag efficiency correction

Efficiency correction by fitting M_{bc} for E_{ECL} sideband data.



After applying selection for the signal side.

Validity of tag efficiency correction using $B \to D^{(*)} l \nu$ control sample.

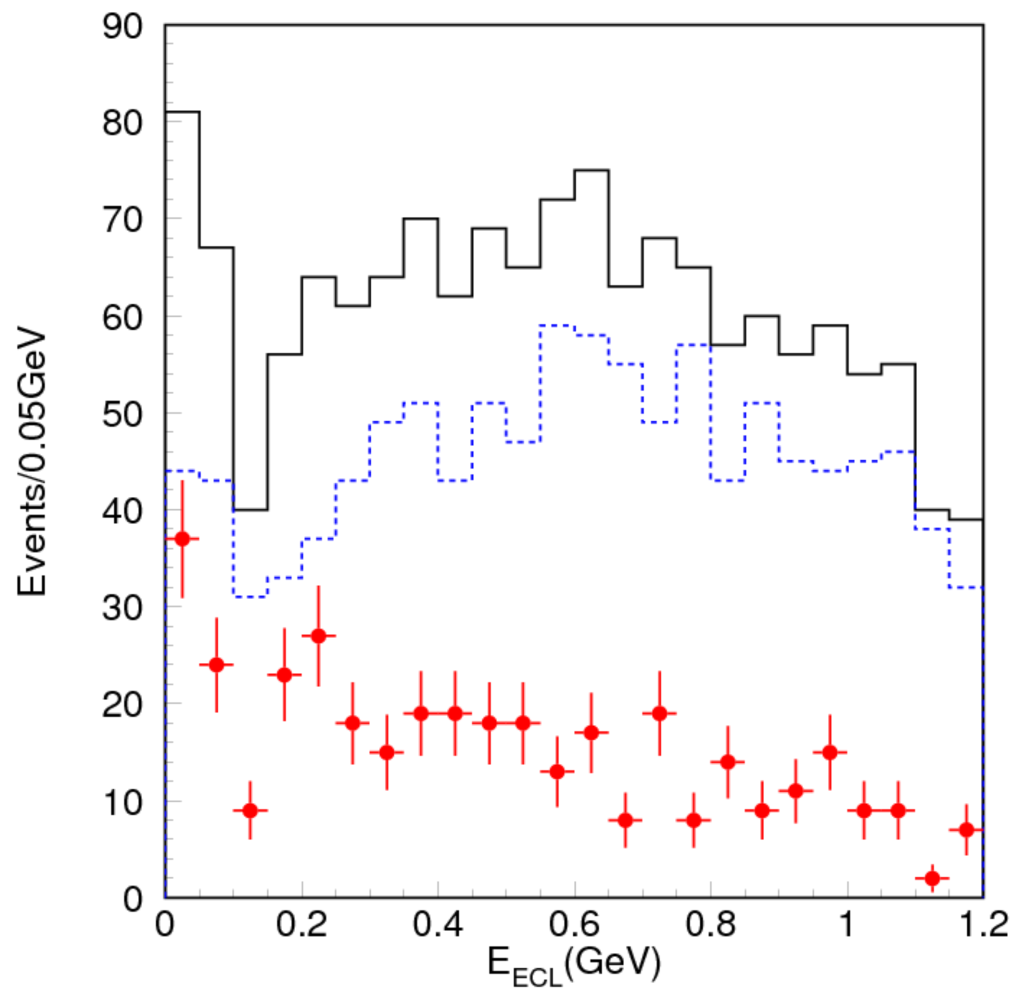


$$\mathcal{B}(B^- \to D^{*0} l^- \overline{\nu}_l) = [5.60 \pm 0.22(\text{stat}) \pm 0.28(\text{syst})]\ \%$$

PDG: $\mathcal{B}(B^- \to D^{*0} l^- \overline{\nu}_l) = (5.68 \pm 0.19)\ \%$

K_L veto

- Background rejection using K_L is introduced.
- Effective to reduce peaking backgrounds.
- Improves the statistical significance about 5%.

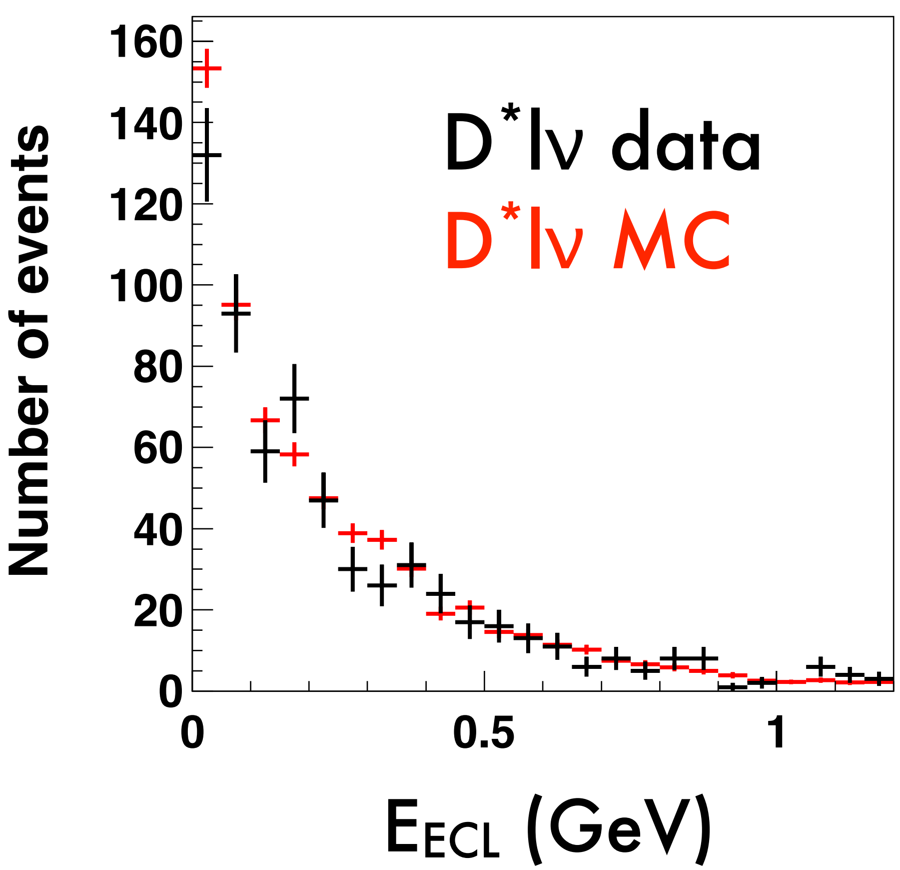


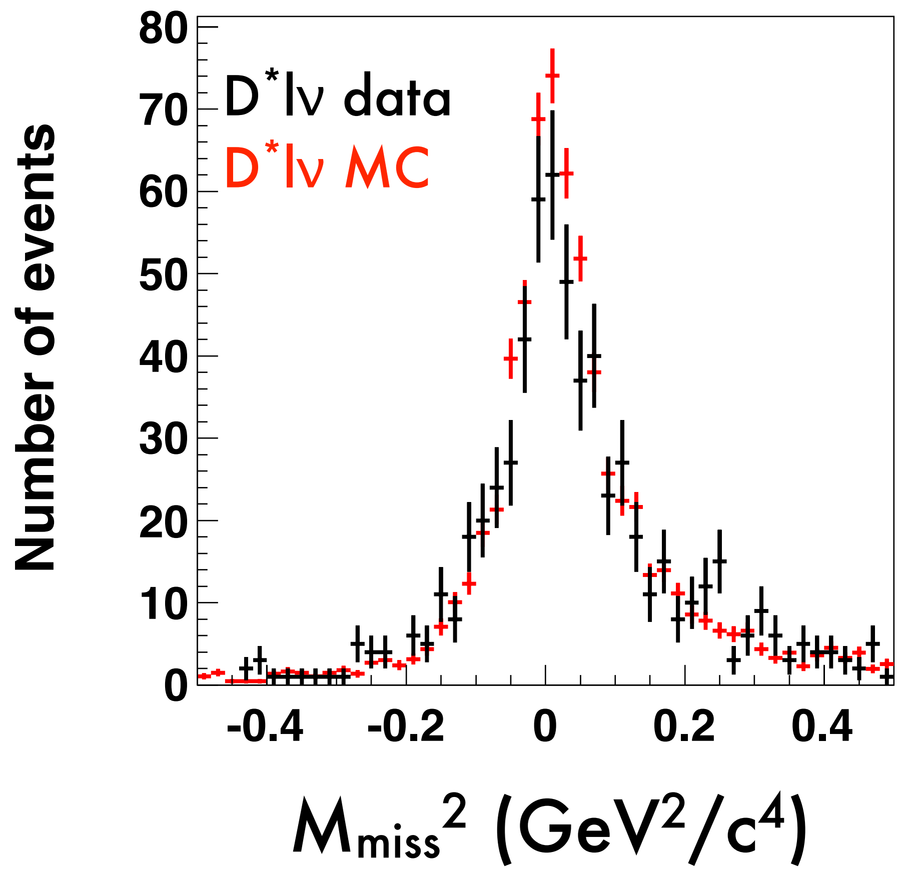
B^0-tagged total
without reconstructed K_L
with reconstructed K_L

Signal PDFs for E_{ECL} and M_{miss}^2

Signal PDF for E_{ECL} is calibrated using $D^*l\nu$ control sample.

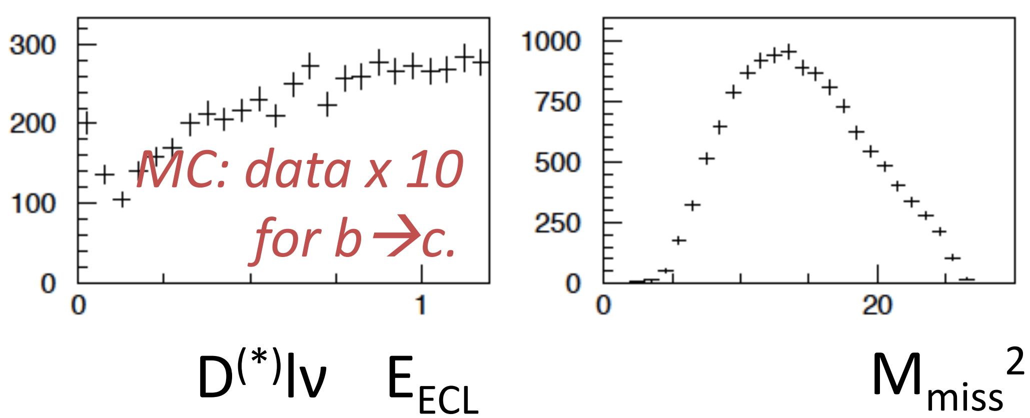
Signal PDF for M_{miss}^2 is affected by momentum resolutions.
Since M_{miss}^2 for $B \rightarrow \tau\nu$ has wide distribution, do not apply correction.

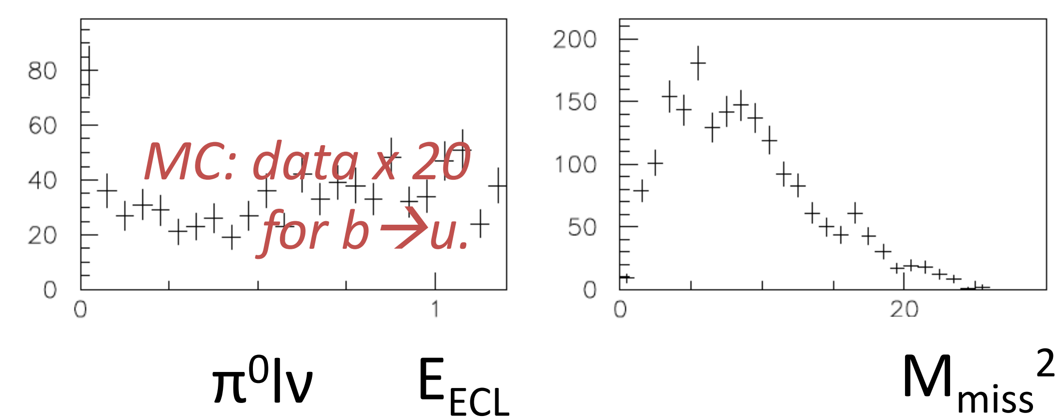




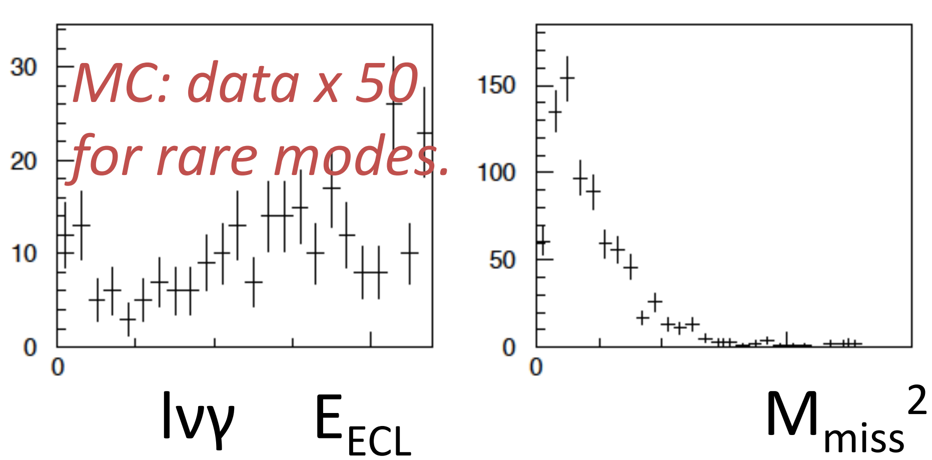
Peaking backgrounds

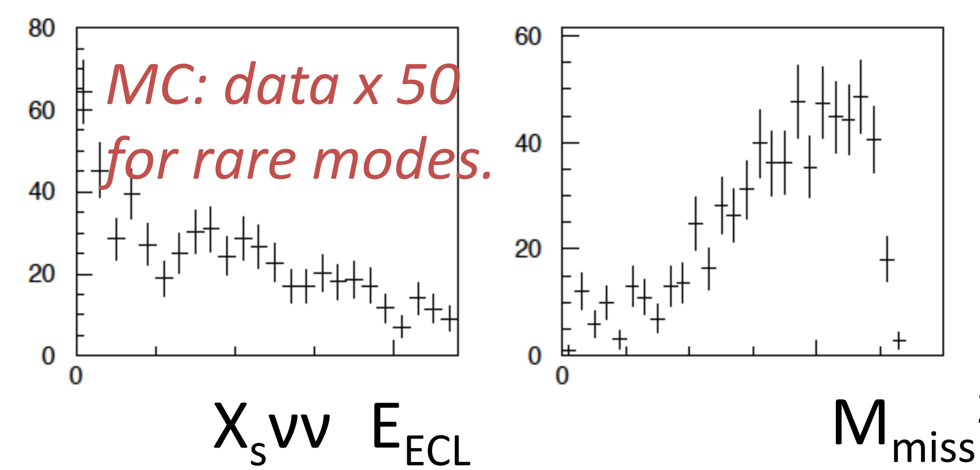
- At least one of E_{ECL} and M_{miss}^2 distributions have difference from signal. Result is less sensitive to peaking backgrounds.
- If BR is known, error of BR and MC statistics in Syst.





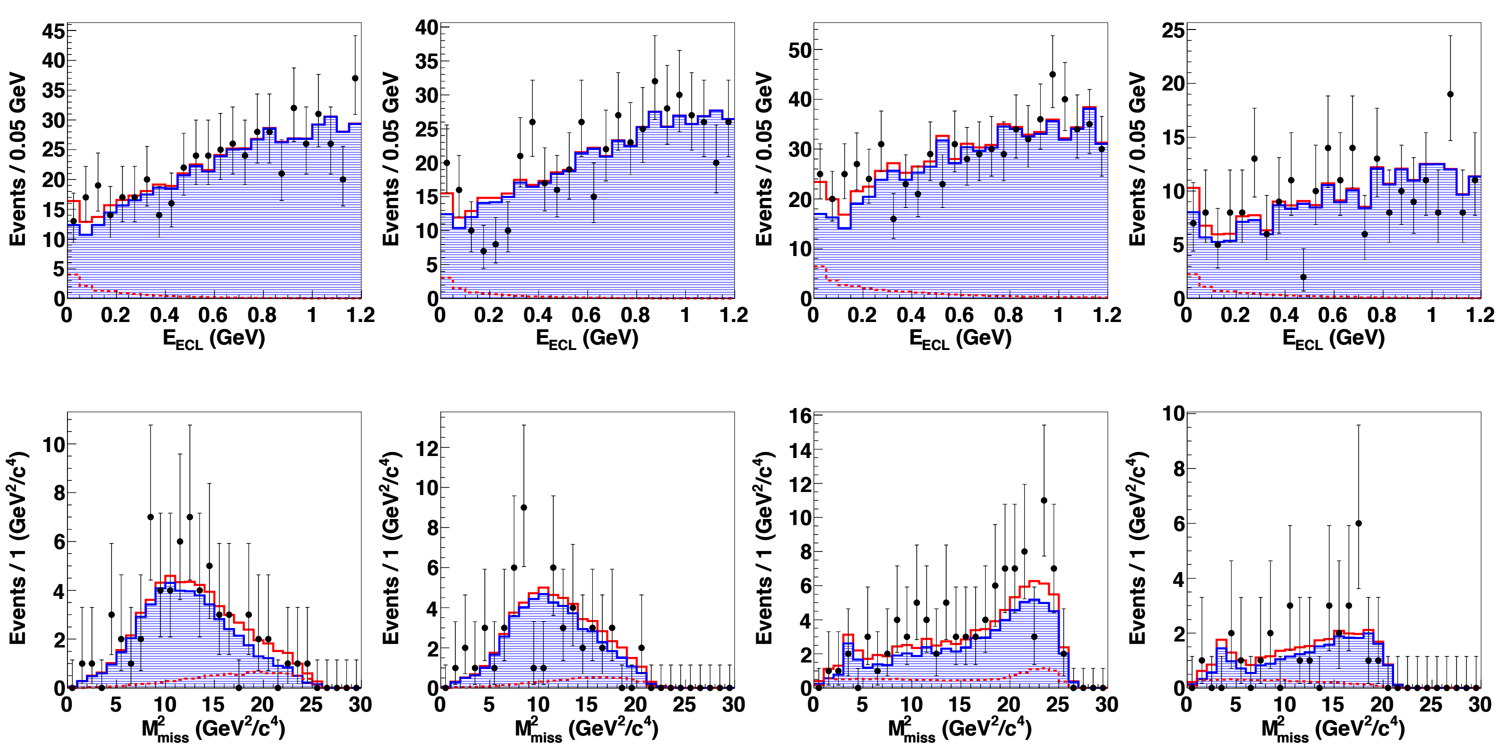
- If BR is not known, assume SM value in the nominal fit. SM value ±50% and MC statistics in Syst.

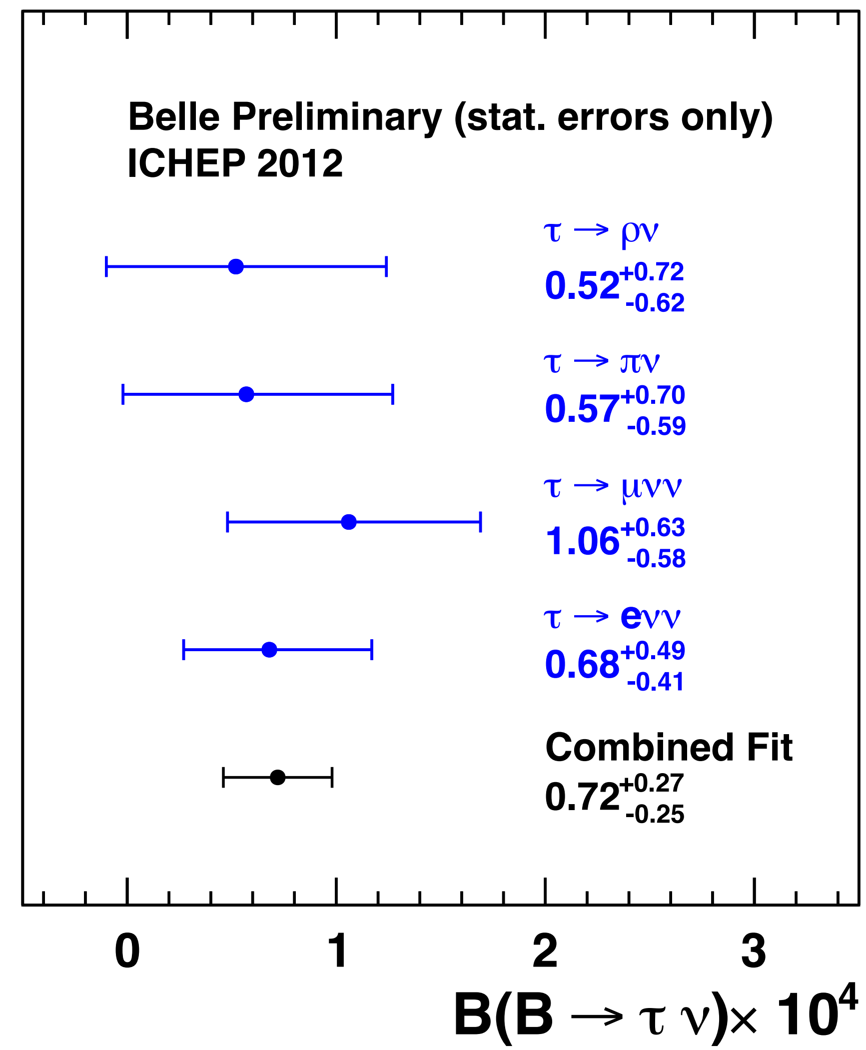




- In the nominal fit, ratios for different τ modes are fixed.
- Here we test a fit by floating yields for the four τ modes.

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}





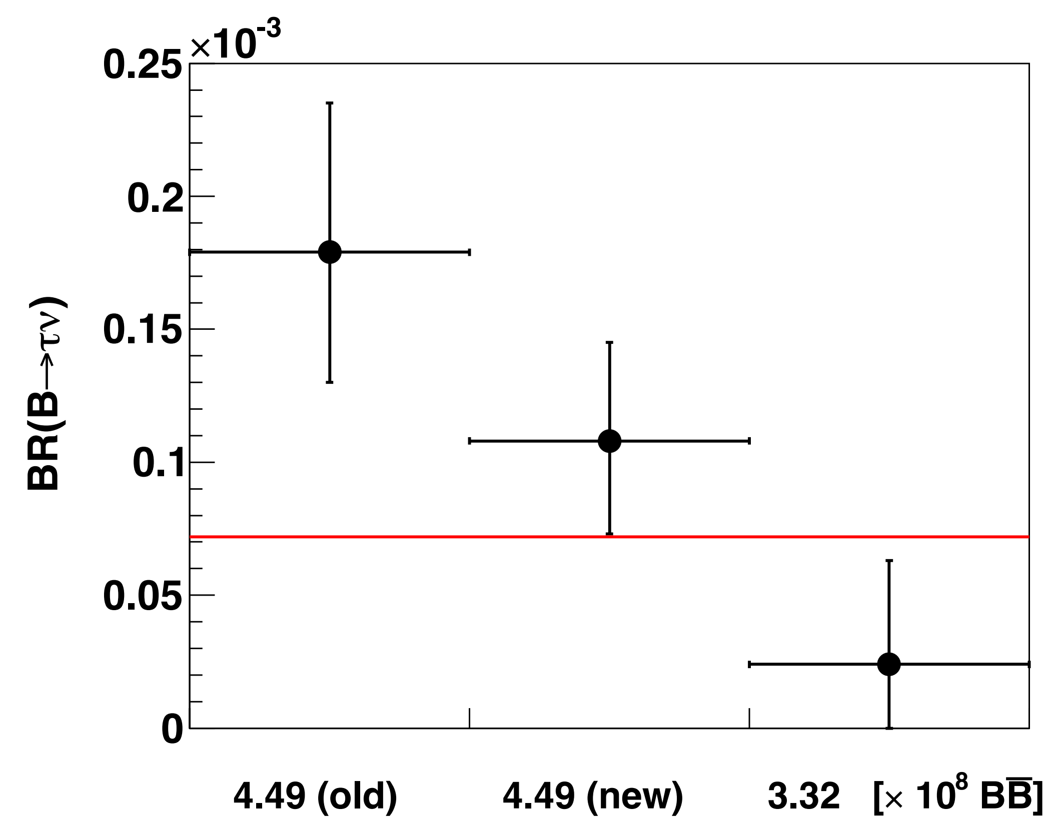
Consistent results obtained.

Comparison with the previous hadronic-tag result

	PRL 97 (2006)	This analysis	
Tag	Hadronic tag	Hadronic tag (new)	
Number of $B\overline{B}$ events ($\times 10^8$)	4.49	4.49	3.22
Efficiency ($\times 10^{-4}$)	3.0	11.2	11.2
Signal yield	$24.1^{+7.6}_{-6.6}$	$54.1^{+18.8}_{-17.4}$	$8.6^{+14.0}_{-12.4}$
$\mathcal{B}(B^- \to \tau^- \overline{\nu}_\tau)$ ($\times 10^{-4}$)	$1.79^{+0.56}_{-0.49}$	$1.08^{+0.37}_{-0.35}$	$0.24^{+0.39}_{-0.34}$

- New analysis based on improved tag, loose event selection, and reprocessed data.
- Most of the data after the selection are independent from old analysis.
- Assuming that all the events in old analysis are included in new analysis, the remaining data sample in $N_{BB} = 4.49 \times 10^8$ provides BR ~ $(0.6 \pm 0.4) \times 10^{-4}$ (1.9σ from old result).

*conservative.



Combining results of hadronic and semileptonic tags

Simultaneously fit the events of hadronic and semileptonic tags using single floated BR($B\to\tau\nu$).

Correlated and uncorrelated Syst. taken into account.

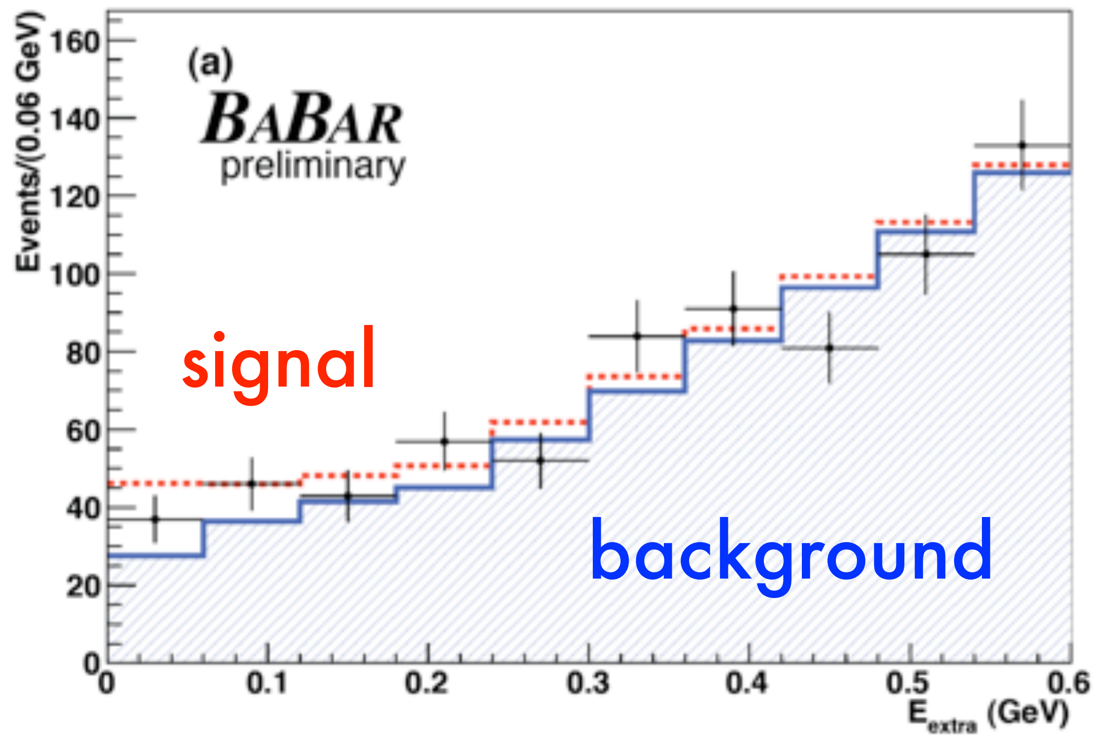
source	error (%)
Hadronic tag	
PDF MC statistics	$^{+4.4}_{-3.9}$
E_{ECL} shape correction	$^{+0.7}_{-3.2}$
Eff. MC stat	± 0.3
Eff. π^0	$^{+0.3}_{-0.4}$
K_L^0 efficiency correction	$^{+0.4}_{-4.9}$
BG, B tag efficiency	$^{+2.8}_{-2.7}$
Signal, B tag efficiency	$^{+7.0}_{-6.4}$
Semileptonic tag	
PDF MC statistics	$^{+5.5}_{-5.2}$
Continuum scaling factor	± 1.5
E_{ECL} shape correction	$^{+0.4}_{-0.3}$
Eff. MC stat	± 0.2
Signal, B tag efficiency	$^{+2.5}_{-3.2}$
Peaking BG, τ pair	± 0.5
Correlated	
Peaking BG, generic B	$^{+4.1}_{-3.4}$
Peaking BG, rare B	$^{+2.9}_{-2.8}$
Peaking BG, ulnu B	$^{+0.5}_{-0.7}$
Br. of τ	$^{+0.5}_{-0.4}$
PID efficiency	± 0.9
Tracking	± 0.5
PHOTOS radiative correction	$^{+0.2}_{-0.0}$
Number of $B\overline{B}$	± 1.4
Total	± 13

B→τν by hadronic tag from BaBar

- Using 468 M BB.
- Evidence of signal (3.3σ).

$$\mathcal{B} = [1.80^{+0.57}_{-0.54}(\mathrm{stat}) \pm 0.26(\mathrm{syst})] \times 10^{-4}$$

Syst. from BG PDF, tag efficiency, etc.



Fitted by histogram PDFs.

Decay Mode	$\epsilon \times 10^{-4}$	Branching Fraction ($\times 10^{-4}$)	Significance σ
$\tau^+ \to e^+ \nu \bar{\nu}$	2.73	$0.39^{+0.89}_{-0.79}$	0.5
$\tau^+ \to \mu^+ \nu \bar{\nu}$	2.92	$1.23^{+0.89}_{-0.80}$	1.6
$\tau^+ \to \pi^+ \nu$	1.55	$4.0^{+1.5}_{-1.3}$	3.3
$\tau^+ \to \rho^+ \nu$	0.85	$4.3^{+2.2}_{-1.9}$	2.6
combined	8.05	$1.80^{+0.57}_{-0.54}$	3.6

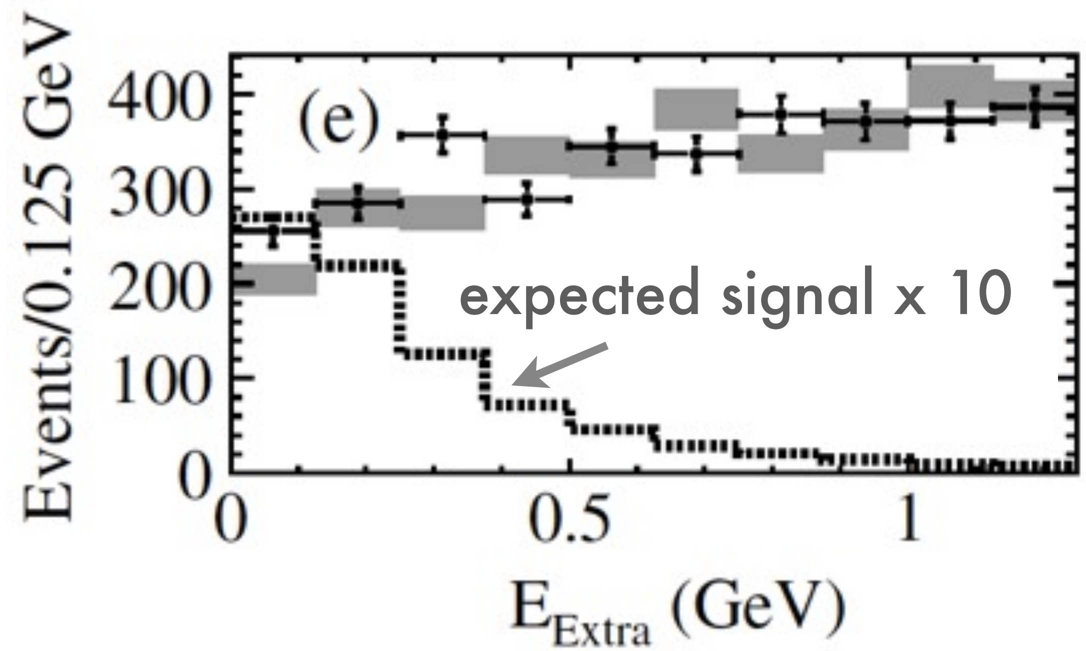
arXiv:1008.0104

B→τν by semileptonic tag from BaBar

- Using 459 M BB.
- Excess of signal (2.3σ).

$$\mathcal{B} = [1.7 \pm 0.8(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-4}$$

Syst. from BG yield, tag efficiency, etc.



Counted in signal region.
(Region depends on τ modes.)

Mode	$\mathcal{N}_{\text{bg}}^{\text{data}}$	N_{obs}	Branching fraction ($\times 10^{-4}$)
$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$	81 ± 12	121	(3.6 ± 1.4)
$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$	135 ± 13	148	$(1.3^{+1.8}_{-1.6})$
$\tau^+ \to \rho^+ \bar{\nu}_\tau$	59 ± 9	71	$(2.1^{+2.0}_{-1.8})$
$\tau^+ \to \pi^+ \bar{\nu}_\tau$	234 ± 19	243	$(0.6^{+1.4}_{-1.2})$

PRD 81, 051101 (2010)

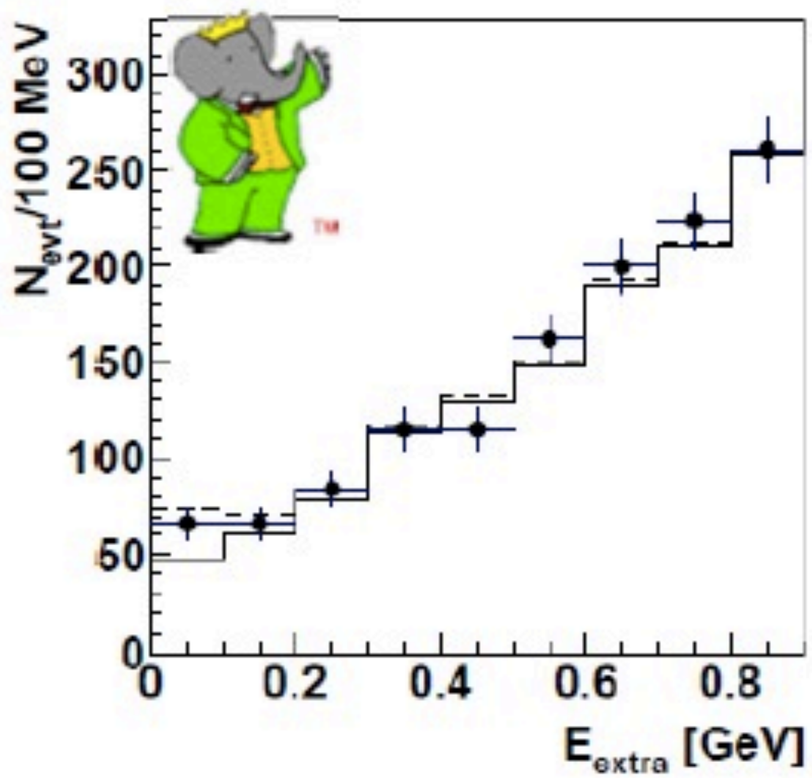
B → τν with hadronic tags at BaBar

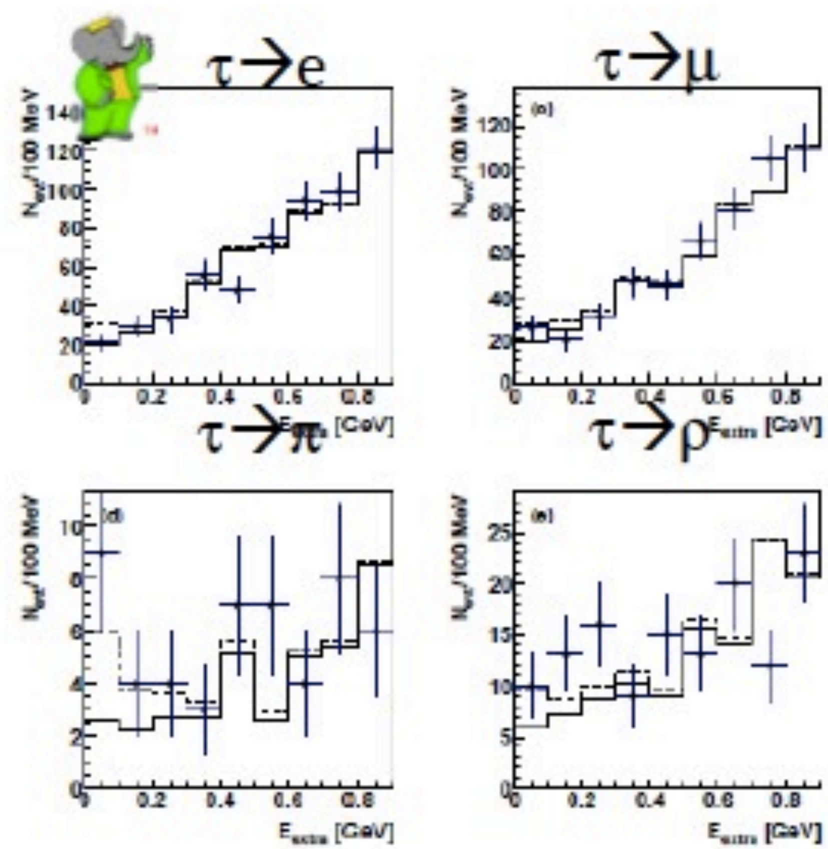
- Fit to residual energy in calorimenter simultaneously in 4 reconstructed modes (τ →eνν, τ →μνν, τ →πν, τ →ρν)
- Floating parameters: BF and 4 background yields
- Combinatorial B tag background estimated from data. B^+ background shape from MC
- Excess of events over background of 3.8 σ

arXiv:1207.0698[hep-ex]
Submitted to Phys.Rev.D (R)

MC modelling of signal E_{extra} PDF checked with double tags

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.83^{+0.53}_{-0.49}(\mathrm{stat.}) \pm 0.24(\mathrm{syst.})) \times 10^{-4}$$

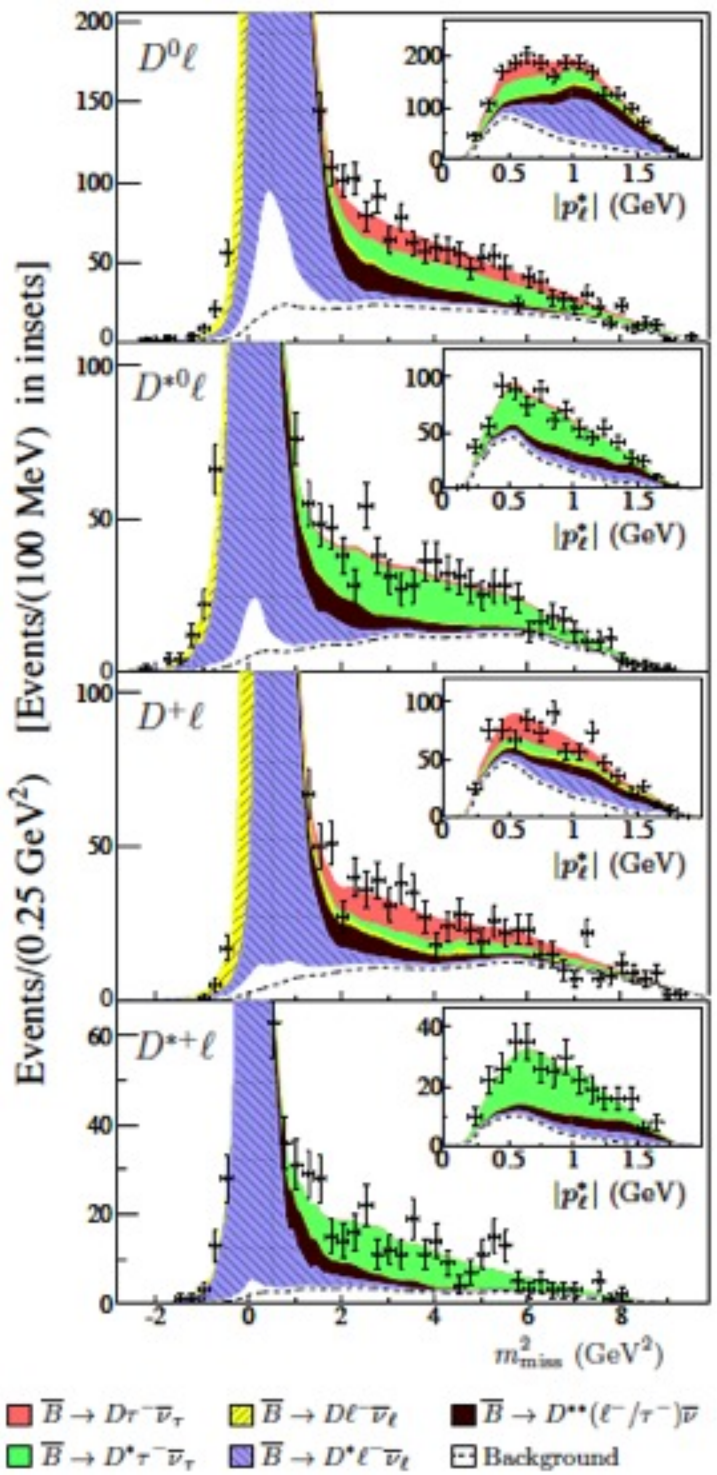


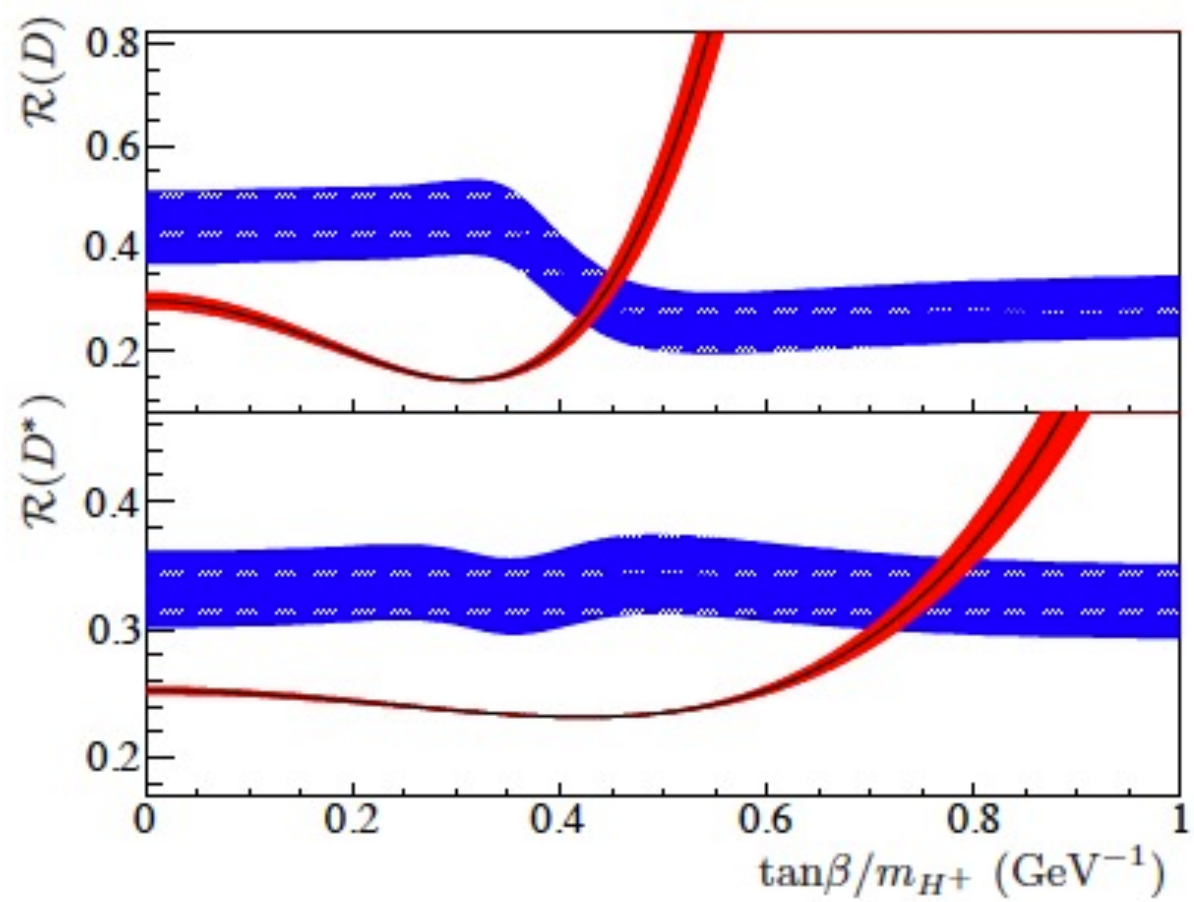


arXiv:1008.0104: $\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.80^{+0.57}_{-0.54}(\mathrm{stat.}) \pm 0.26(\mathrm{syst.})) \times 10^{-4}$

$B \to D^{(*)}\tau\nu$ from BaBar

arXiv:1205.5442





$R(D^{(*)})$: ratio btw tau and l modes.

Blue: this result, red: Type II of 2HDM.

Type II of 2HDM is excluded by 99.8%...