B^+ leptonic decays: review and prospects

Youngjoon Kwon

Yonsei University
Seoul, Korea

Hints for New Physics in Heavy Flavor @ KMI, Nagoya

Outline

- Motivations and features
  - * To tag, or not to tag
- $B^+ \to \tau^+ \nu$
- $B^+ \to \ell^+ \nu(\gamma)$
- Prospects (Belle II)

Features of $B^+ \to \ell^+\nu$

SM predictions

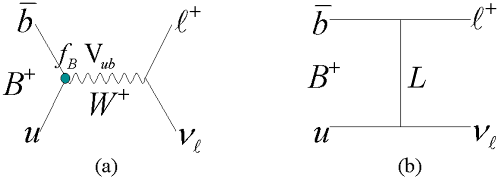
$$\Gamma(B^+ \to \ell^+\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

- $\mathcal{B}(B^+ \to \tau^+\nu) \sim 10^{-4}$
- $\mathcal{B}(B^+ \to \mu^+\nu) \sim \mathcal{B}(B^+ \to \tau^+\nu)/300$
- $\mathcal{B}(B^+ \to e^+\nu) \sim \mathcal{B}(B^+ \to \tau^+\nu)/10^7$

Experimental features

- $B^+ \to \tau^+\nu$ large BF, but multiple ν's
- $B^+ \to \ell^+\nu$ $(\ell \neq \tau)$ $E_\ell \sim M_B/2$, but small BF

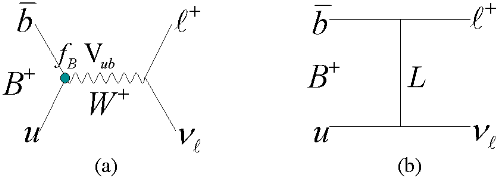
Motivations for $B^+ \to \ell^+\nu$



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

- very clean place to measure $f_B|V_{ub}|$
  and/or search for new physics (e.g. H^+, LQ)

Motivations for $B^+ \to \ell^+\nu$

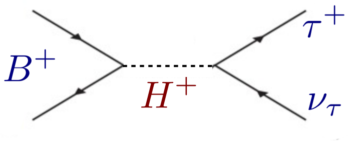


$$\Gamma(B^+ \to \ell^+\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

- very clean place to measure $f_B|V_{ub}|$
  and/or search for new physics (e.g. H^+, LQ)

- ultimate test of **LUV**
  $\Gamma(B^+ \to \ell^+\nu)/\Gamma(B^+ \to \tau^+\nu) = f(m_\ell^2, m_\tau^2)$,
  and all other parameters cancel!

$B^+ \to \tau^+\nu$ by new physics, e.g. H^+



- $B^+ \to \tau^+\nu$ can be affected by new physics effects
  For instance, H^+ of 2-Higgs doublet model (type II)

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

where $r_H = \left[1 - (m_B^2/m_H^2)\tan^2\beta\right]^2$

W.S. Hou, PRD 48, 2342 (1993)

$B^+ \to \tau^+\nu$ for new physics

Two useful (*for NP*) ratios

$$R_{\rm ps} = \frac{\tau_{B^0}}{\tau_{B^+}} \frac{\mathcal{B}(B^+ \to \tau^+\nu)}{\mathcal{B}(B^0 \to \pi^-\ell^+\nu)}$$

$$R_{\rm pl} = \frac{\mathcal{B}(B^+ \to \tau^+\nu)}{\mathcal{B}(B^+ \to \mu^+\nu)}$$

$$R_{\rm ps}^{\rm NP} = (0.539 \pm 0.043)\left|1 + r_{\rm NP}^{\tau}\right|^2,$$

$$R_{\rm pl}^{\rm NP} = \frac{m_\tau^2}{m_\mu^2} \frac{(1 - m_\tau^2/m_B^2)^2}{(1 - m_\mu^2/m_B^2)^2}\left|1 + r_{\rm NP}^{\tau}\right|^2 \simeq 222.37\left|1 + r_{\rm NP}^{\tau}\right|^2$$

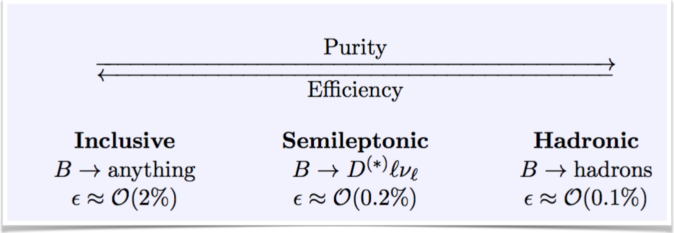
Tanaka & Watanabe,
PTEP (2017), 1608.05207

To tag, or not to tag

- Why bother?
  - * $B^+ \to \tau^+\nu$ has multiple ν's in the final state
  - * need extra kinematic constraints to improve sensitivity
  - * exploit $\Upsilon(4S)$ producing $B\bar{B}$ and nothing else

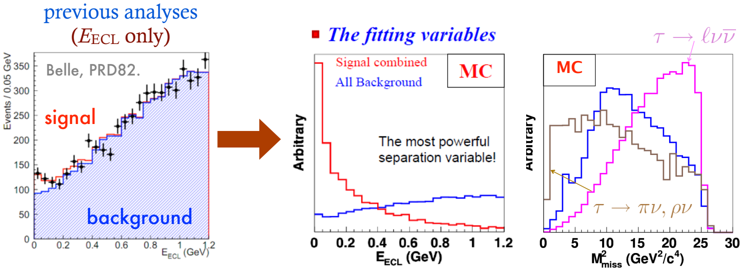
$$e^+e^- \to \Upsilon(4S) \to B_{\text{sig}}\overline{B}_{\text{tag}}$$

- How to tag?
  - * "**hadronic tagging**" – full reconstruction of the decay chain of B_{tag}
  - * "**semileptonic tagging**" – use $B^+ \to \overline{D}^{(*)}\ell^+\nu$



$B^+ \to \tau^+\nu$ (Belle, had) – signal extraction

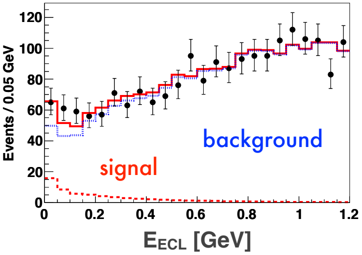
- Signal τ modes: $\tau^+ \to e^+\nu_e\overline{\nu}_\tau,\ \mu^+\nu_\mu\overline{\nu}_\tau,\ \pi^+\overline{\nu}_\tau,\ \rho^+\overline{\nu}_\tau$
- π^0, K_L^0 veto – demand no trace of π^0, K_L^0 after reconstructing B_{tag} and B_{sig}
  - K_L^0 gives $\sim 5\%$ improvement in the expected sensitivity
- 2D fitting to E_{ECL} & M^2_{miss}
  - improve sensitivity by $\sim 20\%$; more robust against peaking backgs. in E_{ECL}



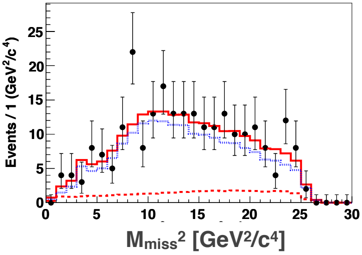
E_{ECL} = residual energy in the EM calorimeter (ECL) that has not been attributed to either B_{sig} or B_{tag}

$B^+ \to \tau^+\nu$ (Belle, had) – Result

- Simultaneous fit to different τ decay modes
  Figures below shown for the sum of different τ decay modes



(Projection for all M_{miss}^2 region.)

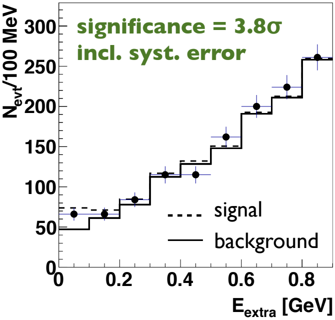


(Projection for E_{ECL} < 0.2 GeV)

- Signal yield: $62^{+23}_{-22} \pm 6$ significance = 3.0σ incl. systematic error
  Major sources of systematic error are: background PDF (8.8%), K_L^0 efficiency (7.3%), and B_{tag} efficiency (7.1%).
- $\mathcal{B}(B^+ \to \tau^+\nu) = \left(0.72^{+0.27}_{-0.25} \pm 0.11\right) \times 10^{-4}$ PRL 110, 131801 (2013)

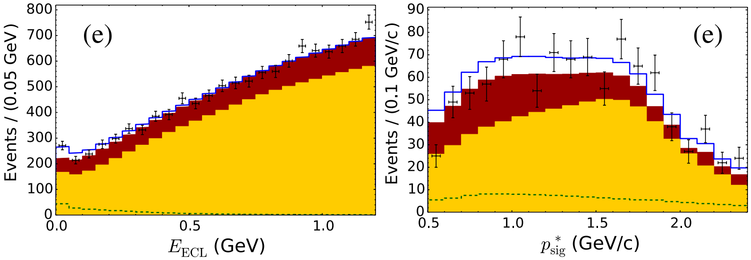
$B^+ \to \tau^+\nu$ (BABAR, had) – Result

- Hadronic B-tagging analysis with $N_{B\bar{B}} = 468 \times 10^6$
- Signal τ modes: $\tau^+ \to e^+\nu_e\overline{\nu}_\tau,\ \mu^+\nu_\mu\overline{\nu}_\tau,\ \pi^+\overline{\nu}_\tau,\ \rho^+\overline{\nu}_\tau$
- Signal extraction via $E_{\rm extra}$ $(= E_{\rm ECL})$
  $N_{\rm sig} = 62.1 \pm 17.3$
  from simultaneous fit to the four τ modes
- $\mathcal{B}(B^+ \to \tau^+\nu) = (1.83^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4}$
- Major systematic uncertainties are from
  background PDF's (10%), B-tag efficiency (5%), etc.



PRD 88, 031102(R) (2013)

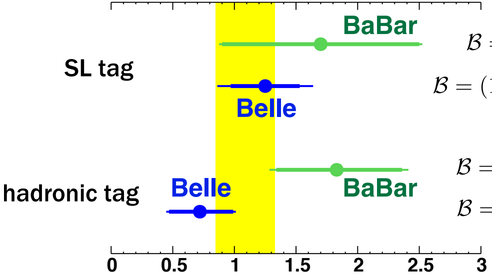
$B^+ \to \tau^+\nu$ (Belle, SL-tag)



- tagged by $B^- \to D^{(*)0}\ell^-\overline{\nu}$
- Signal extraction by 2D-fitting $(E_{\mathrm{ECL}}, p^*_{\mathrm{sig}})$
  $N_{\mathrm{sig}} = 222 \pm 50$ events
- $\mathcal{B}(B^+ \to \tau^+\nu) = (1.25 \pm 0.28 \pm 0.27) \times 10^{-4}$
  4.6σ significance by combining had-tag and SL-tag analyses of Belle

PRD 92, 051102(R) (2015)

$B^+ \to \tau^+\nu$ Summary



$\mathcal{B} = (1.7 \pm 0.8 \pm 0.2) \times 10^{-4}$

$\mathcal{B} = (1.25 \pm 0.28 \pm 0.27) \times 10^{-4}$

$\mathcal{B} = (1.83^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4}$

$\mathcal{B} = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$

Belle combined: $\mathcal{B}(B^+ \to \tau^+\nu) = (0.91 \pm 0.22) \times 10^{-4}$

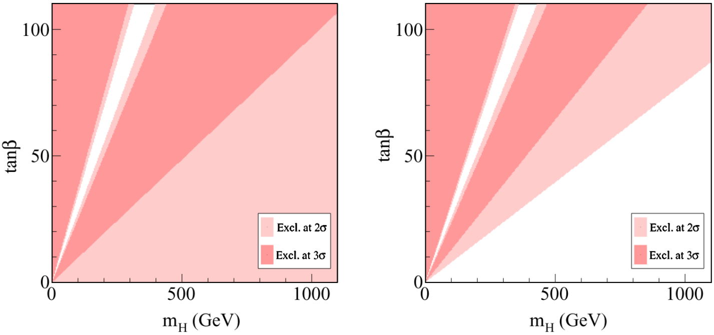
BABAR combined: $\mathcal{B}(B^+ \to \tau^+\nu) = (1.79 \pm 0.48) \times 10^{-4}$

World avg: $\mathcal{B}(B^+ \to \tau^+\nu) = (1.06 \pm 0.19) \times 10^{-4}$ HFLAV (2017)

- Belle vs. BABAR – consistent within $\sim 1.7\sigma$
- The average is consistent with SM

$B^+ \to \tau^+\nu$ constraints on charged Higgs

- With 2-Higgs doublet model (type II),
  $\mathcal{B}(B^+ \to \tau^+\nu) = \mathcal{B}_{\rm SM}(B^+ \to \tau^+\nu) \times \left[1 - (m_B^2/m_H^2)\tan^2\beta\right]^2$



Plots are from PRD 88, 031102(R) (2013), by *BABAR*, based on *BABAR*'s combined $\mathcal{B}(B^+ \to \tau^+\nu)$.

Search for $B^+ \to \ell^+ \nu$

- (*experimental*) very clean
  - * just a mono-energetic charged lepton and nothing else
- (*theoretical*) very small branching fraction compared to $B^+ \to \tau^+ \nu$
  - * helicity suppression: $\Gamma \propto m_\ell^2$
- Tagged vs. Untagged for $B^+ \to \ell^+ \nu$,
  - * tagging is not really necessary $\because$ mono-energetic ℓ^+ in the final state
  - * Nonetheless, analyses with tagging have also been tried

$\Gamma(B^+ \to e^+\nu_e)/\Gamma_{total}$

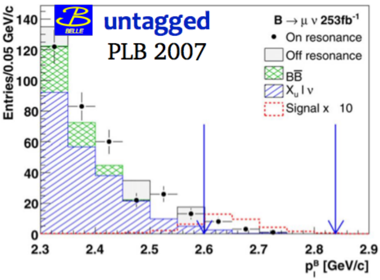
VALUE (10^{-6})	CL%		DOCUMENT ID		TECN	COMMENT	
< 0.98	90	1	SATOYAMA	2007	BELL	$e^+ e^- \to \Upsilon(4S)$	untagged
*** We do not use the following data for averages, fits, limits, etc ***							
<3.5	90	2	YOOK	2015	BELL	$e^+ e^- \to \Upsilon(4S)$	had tag
<8	90	1	AUBERT	2010E	BABR	$e^+ e^- \to \Upsilon(4S)$	SL tag
<1.9	90	1	AUBERT	2009V	BABR	$e^+ e^- \to \Upsilon(4S)$	untagged
<5.2	90	1	AUBERT	2008AD	BABR	$e^+ e^- \to \Upsilon(4S)$	had tag

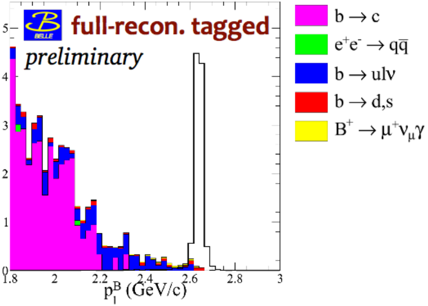
$\Gamma(B^+ \to \mu^+\nu_\mu)/\Gamma_{total}$

	VALUE (10^{-6})	CL%		DOCUMENT ID		TECN	COMMENT
untagged	**< 1.0**	90	1	AUBERT	2009V	BABR	$e^+ e^- \to \Upsilon(4S)$
	*** We do not use the following data for averages, fits, limits, etc ***						
had tag	<2.7	90	2	YOOK	2015	BELL	$e^+ e^- \to \Upsilon(4S)$
SL tag	<11	90	1	AUBERT	2010E	BABR	$e^+ e^- \to \Upsilon(4S)$
had tag	<5.6	90	1	AUBERT	2008AD	BABR	$e^+ e^- \to \Upsilon(4S)$
untagged	<1.7	90	1	SATOYAMA	2007	BELL	$e^+ e^- \to \Upsilon(4S)$

Why then bother with 'tagged' for $B^+ \to \ell^+\nu$?

- The signal lepton candidate's momentum in B_{sig} rest frame. -





- much better resolution of p_ℓ^B with the full-recon. tagging
- But, does it make a case for 'full-recon-tagged' analysis of $B^+ \to \ell^+\nu$?

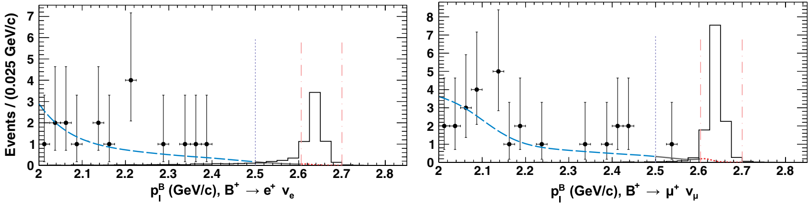
Why then bother with 'tagged' for $B^+ \to \ell^+\nu$?

- Note: $\mathcal{B}_{\rm SM}(B^+ \to e^+\nu) \sim 10^{-11}$ and $\mathcal{B}_{\rm SM}(B^+ \to \mu^+\nu) \sim 3\times 10^{-7}$

  $\Rightarrow$ Any signal for $B^+ \to e^+\nu$ at the Belle sensitivity is way beyond the SM
- In that case, are we *sure* what we see is *really* $B^+ \to e^+\nu$?

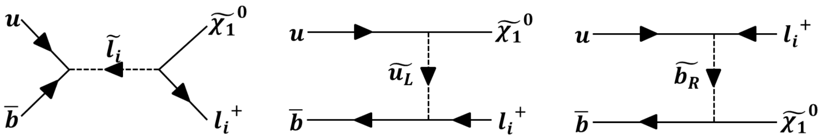
  What about $B^0 \to e^+\tau^-$? How about $B^+ \to e^+X^0$ where X^0 is any unknown particle from NP?
- With full-recon., we can use p_ℓ^B to discern many such cases
- Belle analysis with hadronic B-tagging

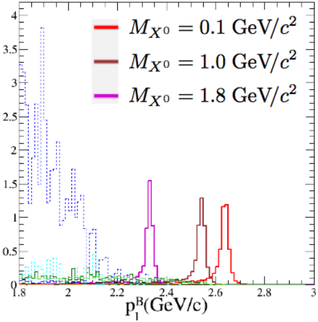
PRD 91, 052016 (2015)



Mode	ϵ_s [%]	$N_{\rm obs}$	$N_{\rm exp}^{\rm bkg}$	$\mathcal{B}$ (in 10^{-6})
$B^+ \to e^+\nu_e$	0.086 ± 0.007	0	0.10 ± 0.04	**< 3.5**
$B^+ \to \mu^+\nu_\mu$	0.102 ± 0.008	0	$0.26^{+0.09}_{-0.08}$	**< 2.7**

$B^+ \to \ell^+ X^0$ (Belle)

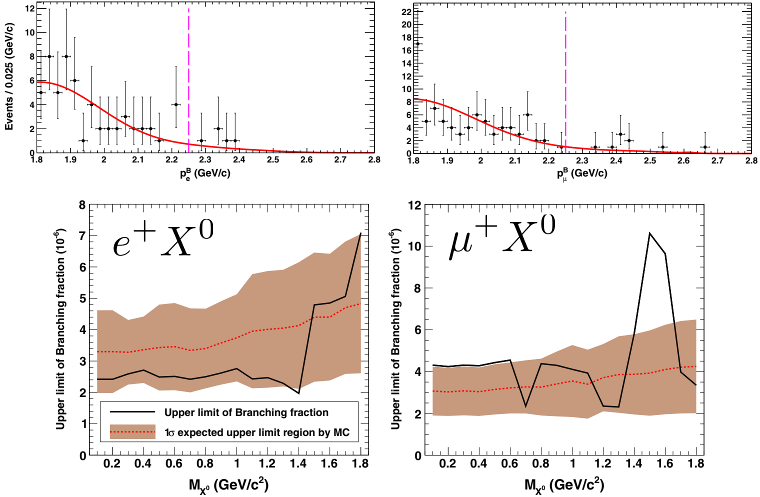




- Search for massive neutral invisible fermion "X^0"

  a heavy neutrino, or an LSP in RPV models, or whatever
- Very similar experimental signature to $B^+ \to \ell^+ \nu$
- But, p_ℓ^B gives a handle on M_X

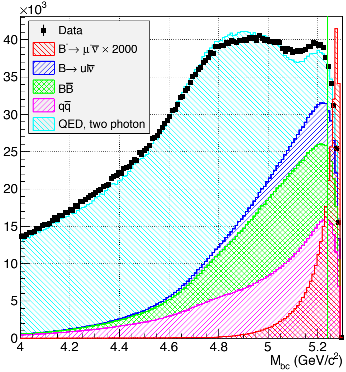
$B^+ \to \ell^+ X^0$ (Belle)

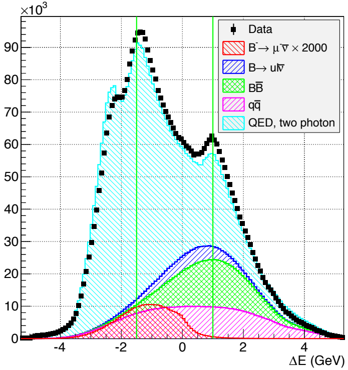


PRD 94, 012003 (2016)

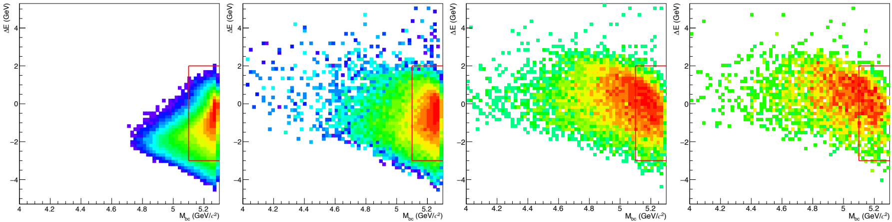
untagged $B^+ \to \mu^+\nu$ Belle (2018)

- all particles except for the μ^+ are to come from the other B, but its decay chain is not explicitly reconstructed (*hence, untagged*)
- require $M_{\mathrm{bc}} > 5.1$ and $-3.0 < \Delta E < +2.0$

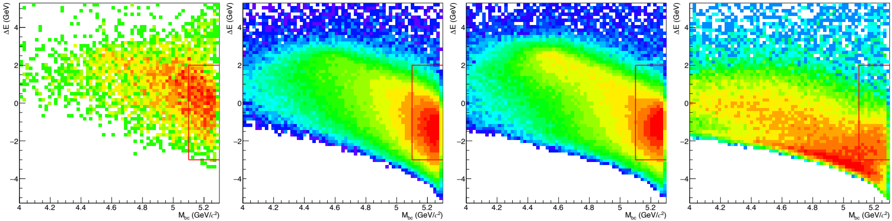




untagged $B^+ \to \mu^+\nu$ Belle (2018)



(a) $B \to \mu\bar{\nu}_\mu$ (b) $B \to \pi\ell\nu$ (c) $B \to \rho\ell\nu$ (d) $B \to X_u\ell\nu$



(e) $B\bar{B}$ (f) $c\bar{c}$ (g) $u\bar{u}$, $d\bar{d}$, $s\bar{s}$ (h) $e^+e^- \to \tau^+\tau^-$

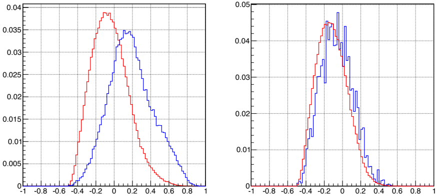
untagged $B^+ \to \mu^+\nu$ Belle (2018)

- all particles except for the μ^+ are to come from the other B, but its decay chain is not explicitly reconstructed (*hence, untagged*)
- require $M_{\rm bc} > 5.1$ and $-3.0 < \Delta E < +2.0$
- In the B^+ rest frame, $p_\mu = 2.64$ GeV (*sharp!*), but in the CM frame, $2.45 < p^*_\mu < 2.85$ GeV
- Use p^*_μ and neural net (NN) for signal extraction (2D fit)

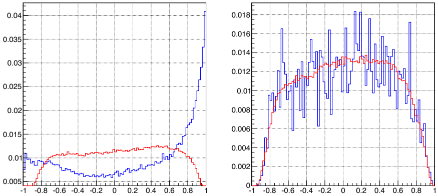
NN variables

- $R_1^{\mu o}/R_0^{\mu o}$, $R_2^{\mu o}/R_0^{\mu o}$, $R_3^{\mu o}/R_0^{\mu o}$ – where $R_i^{\mu o} = \sum_j$ in the cm frame, $\vec{p}_j$ is in the cm frame and j the muon, and $P_i(x)$ is the $i^{\rm th}$ Legendre polynor 17b, 17c.
- R_1^{oo}/R_0^{oo} – where $R_i^{oo} = \sum_k \sum_j |\vec{p}_k||\vec{p}_j|P_i(\cos\theta_{kj})$,
- $R_1^{\rm KFW} = \sum_k \sum_{j>k} |\vec{p}_k||\vec{p}_j|P_i(\cos\theta_{kj})$, the first Kaku cm frame, see Fig. 17e.
- $\cos(\theta_{\rm miss})$ – angle of missing momentum in the
- $\sqrt{\sqrt{\sqrt{\Delta Z^2}}}$ – distance between reconstructed z- transformation tries to make the strongly peak the neural net catch the small difference betw shown in Fig. 17g. The square root function se discriminating variable away from zero.
- $\dfrac{\vec{n}_{\rm t} \cdot \vec{p}_\mu}{|\vec{n}_{\rm t}||\vec{p}_\mu|}$ – angle between thrust and muon
- $s = 1 - \vec{n}_{\rm t}^2$ – sphericity, see Fig. 17i
- ΔE – difference between the sum of energ signal muon and expected energy of B me
- $\dfrac{\vec{n}_{\rm t}^{\rm ECL} \cdot \vec{p}_\mu}{|\vec{n}_{\rm t}^{\rm ECL}||\vec{p}_\mu|}$ – where the thrust vector $\vec{n}_{\rm t}^{\rm ECL}$ i and calculated in the lab frame, $\vec{p}_\mu$ is in th
- $(q_\mu + q_{\rm tag}) \times q_\mu$ – charge balance, see Fig.
- $\dfrac{\vec{p}_\mu \cdot \vec{p}_{B_{\rm tag}}}{|\vec{p}_\mu||\vec{p}_{B_{\rm tag}}|}$ – angle between muon and tag r
- $\cos\theta_\mu$ – muon angle in the cm frame, see F

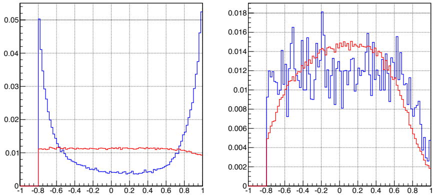
NN variables



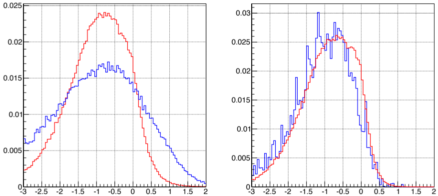
(b) $R_2^{\mu o}/R_0^{\mu o}$



(f) $\cos(\theta_{\mathrm{miss}})$

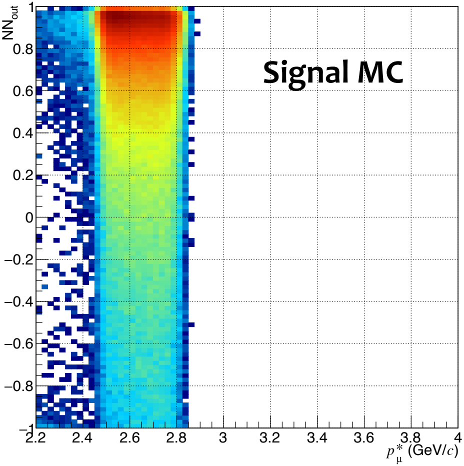


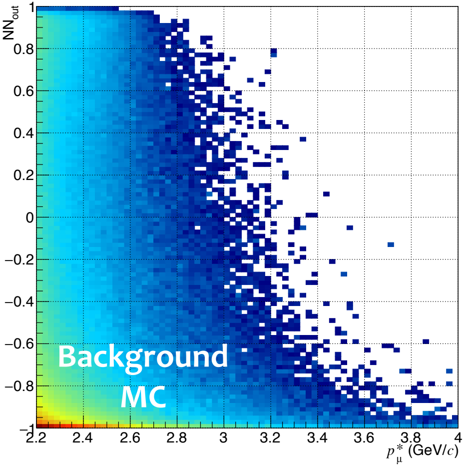
(h) $\dfrac{\vec{n}_{\mathrm{t}} \cdot \vec{p}_{\mu}}{|\vec{n}_{\mathrm{t}}||\vec{p}_{\mu}|}$



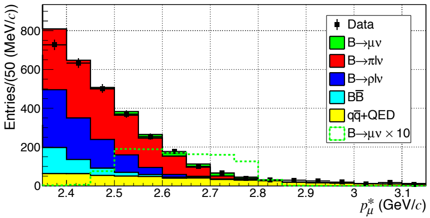
(j) ΔE (GeV)

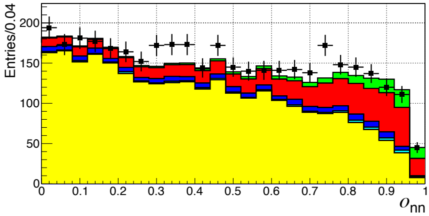
2D distributions (MC) for signal fit





untagged $B^+ \to \mu^+\nu$ Belle (2018) Result





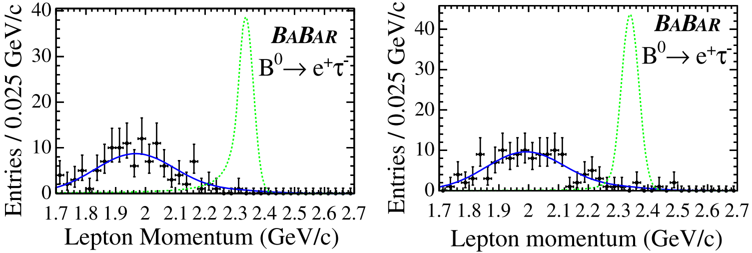
- $B \to \pi\ell\nu$, $\rho\ell\nu$, studied in detail by FF variation
- measure $R \equiv N_{B\to\mu\nu}/N_{B\to\pi\ell\nu}$ for (partial) cancellation of syst. error
- most significant (2.4σ), and consistent with SM

$$\mathcal{B}(B^+ \to \mu^+\nu) = (6.46 \pm 2.22 \pm 1.60) \times 10^{-7}$$
$$\in [2.9, 10.7] \times 10^{-7} \text{ @ 90\% C.L.}$$

Belle, PRL 121, 031801 (2018)

$B^0 \to \ell^\pm \tau^\mp$ (BABAR)

PRD 77, 091104(R) (2008)



- In a hadronic B-tagging analysis very similar to $B^+ \to \ell^+\nu$, BABAR also searched for $B^0 \to \ell^\pm\tau^\mp$.
- Background suppression using m_{ES} and E_{extra}
- Signal extraction by unbinned max. likelihood fit to p_ℓ^B

$$\mathcal{B}(B^0 \to e^\pm\tau^\mp) < 2.8 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to \mu^\pm\tau^\mp) < 2.2 \times 10^{-5}$$

$B^+ \to \ell^+\nu\gamma$

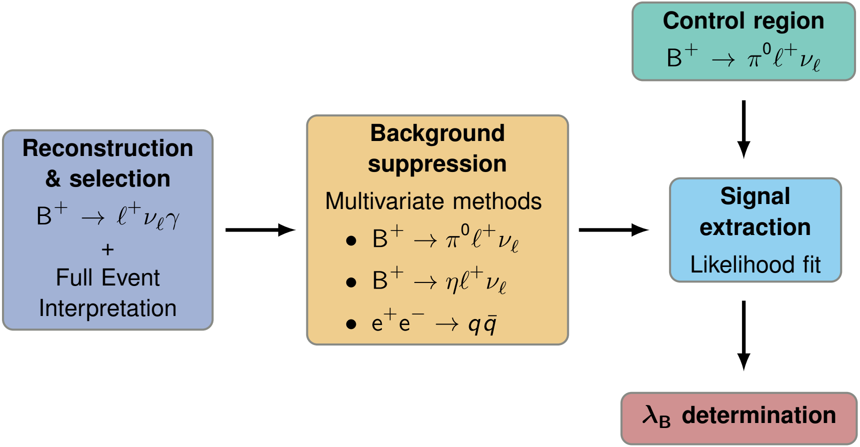
- Helicity suppression (of $B^+ \to \ell^+\nu$) is avoided by γ.

$$\frac{d\Gamma(B^+ \to \ell^+\nu\gamma)}{dE_\gamma} = \frac{\alpha_{\rm em} G_{\rm F}^2 |V_{ub}|^2}{6\pi^2} m_B E_\gamma^3 \left(1 - \frac{2E_\gamma}{m_B}\right) \left(\left|F_{\rm V}\right|^2 + \left|F_{\rm A} + \frac{e_\ell f_B}{E_\gamma}\right|^2 \right)$$

$$F_{\rm V}(E_\gamma),\ F_{\rm V}(E_\gamma) \sim \frac{e_u f_B m_B}{2E_\gamma \lambda_B} + \cdots$$

- λ_B is needed for QCDF to calculate, e.g., charmless hadronic B decays
- SM expectation: $\mathcal{B}(B^+ \to \ell^+\nu\gamma) \sim \mathcal{O}(10^{-6})$
  - * Calculation is reliable only for $E_\gamma > 1$ GeV
- Previous Belle (2015): $\Delta\mathcal{B}(B^+ \to \ell^+\nu\gamma) < 3.5 \times 10^{-6}$
- Updated results from Belle (2018) with 'FEI' algorithm
  - * a new B-tagging algorithm developed for Belle II

$B^+ \to \ell^+\nu\gamma$ Belle (2018) analysis strategy

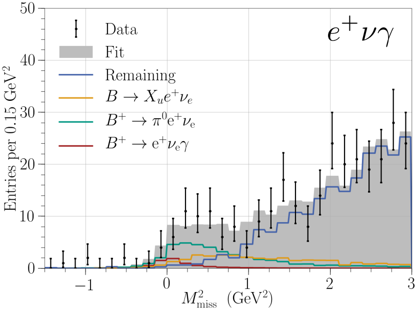


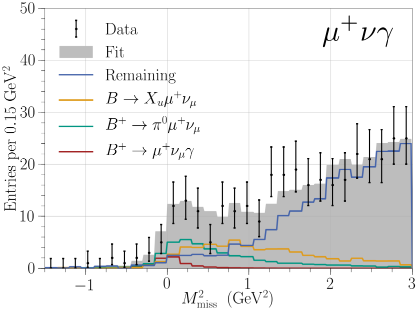
from M. Gelb talk at CKM2018

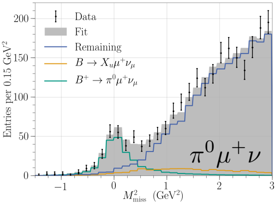
$B^+ \to \ell^+\nu\gamma$ Belle (2018) features

- Measure $B^+ \to \pi^0\ell^+\nu$ separately ("*control sample*"), to constrain the peaking background
- Two parameters
  - $\Delta\mathcal{B}(B^+ \to \ell^+\nu\gamma)_{E_\gamma > 1.0\mathrm{GeV}}$
  - $R_\pi = \Delta\mathcal{B}(B^+ \to \ell^+\nu\gamma)_{E_\gamma > 1.0\mathrm{GeV}} / \mathcal{B}(B^+ \to \pi^0\ell^+\nu)$
    $\Rightarrow$ This allows to extract λ_B independent of $|V_{ub}|$, and some systematics cancel in the ratio R_π.

$B^+ \to \ell^+ \nu \gamma$ Belle (2018) results



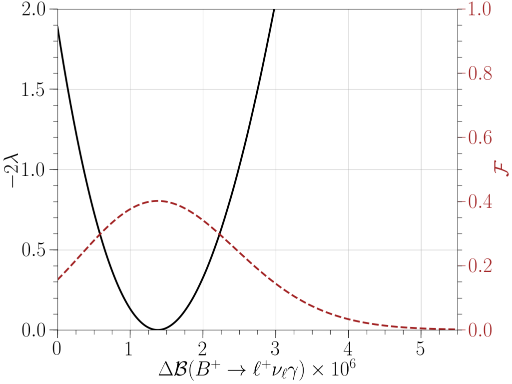




ℓ	$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_\ell)$ (10^{-5})	σ	$\Delta\mathcal{B}(B^+ \to \ell^+ \nu_\ell \gamma)$ (10^{-6})	σ
e	$8.3^{+0.9}_{-0.8} \pm 0.9$	8.0	$1.7^{+1.6}_{-1.4} \pm 0.7$	1.1
μ	$7.5^{+0.8}_{-0.8} \pm 0.6$	9.6	$1.0^{+1.4}_{-1.0} \pm 0.4$	0.8
e, μ	$7.9^{+0.6}_{-0.6} \pm 0.6$	12.6	$1.4^{+1.0}_{-1.0} \pm 0.4$	1.4

Preliminary, *submitted to PRD, 1810.12976*

$B^+ \to \ell^+ \nu \gamma$ Belle (2018) upper limits



Bayesian limit

$$0.9 = \frac{\int_0^{\mathrm{UL}} \mathcal{F}(\Delta\mathcal{B}) d\Delta\mathcal{B}}{\int_0^{\infty} \mathcal{F}(\Delta\mathcal{B}) d\Delta\mathcal{B}}$$

ℓ	BaBar	Belle (2015)	Belle (2018)
e	-	< 6.1	< 4.3
μ	-	< 3.4	< 3.4
e, μ	< 14	< 3.5	< 3.0

Preliminary, *submitted to PRD, 1810.12976*

$B^+ \to \ell^+\nu\gamma$ Belle (2018) for λ_B

$$R_\pi^{\text{meas}} = (1.7 \pm 1.4) \times 10^{-2}$$

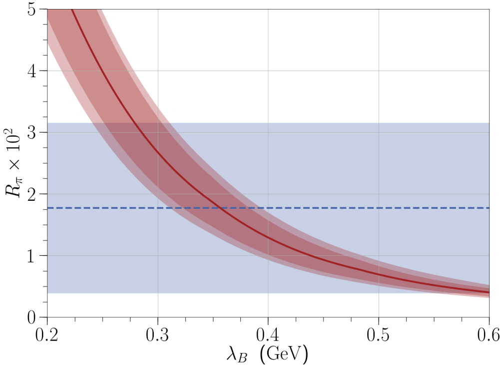
$$R_\pi = \frac{\Delta\Gamma(\lambda_B)}{\Gamma(B^+ \to \pi^0 \ell^+ \nu)}$$

Use theory to determine interval for λ_B

- Beneke, Braun, Ji, Wei, JHEP 1807, 154 (2018)
- HFLAV, EPJC 77, 895 (2017)

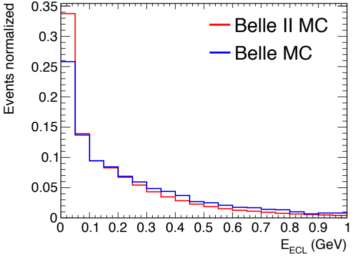
Two one-sided limits

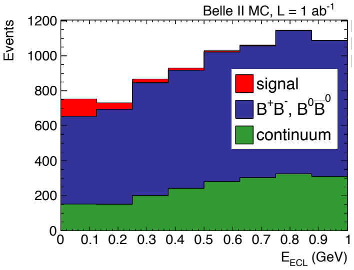
λ_B > 0.24 GeV and λ_B < 0.68 GeV



Preliminary, *submitted to PRD, 1810.12976*

$B^+ \to \tau^+\nu$ Prospects for Belle II





- $E_{\rm ECL}$ is crucial for $B^+ \to \tau^+\nu$ study
  - In Belle II, beam background is much higher
  - But such backgrounds can be rejected by tighter selection based on ECL cluster's energy, timing, shape, etc.
- Expected precision at 1 $\rm ab^{-1} \sim 29\%$ (stat.)
- Major systematic sources (bkg. PDF, K_L^0 veto eff., $B_{\rm tag}$ eff., etc.) can be improved with more data

	Integrated Luminosity ($\rm ab^{-1}$)	1	5	50
hadronic tag	statistical uncertainty (%)	29	13	4
	systematic uncertainty (%)	13	7	5
	total uncertainty (%)	32	15	6
semileptonic tag	statistical uncertainty (%)	19	8	3
	systematic uncertainty (%)	18	9	5
	total uncertainty (%)	26	12	5

$B^+ \to \tau^+\nu$ Prospects for Belle II

Two useful (*for NP*) ratios

$$R_{\rm ps} = \frac{\tau_{B^0}}{\tau_{B^+}} \frac{\mathcal{B}(B^+ \to \tau^+\nu)}{\mathcal{B}(B^0 \to \pi^-\ell^+\nu)}$$

$$R_{\rm pl} = \frac{\mathcal{B}(B^+ \to \tau^+\nu)}{\mathcal{B}(B^+ \to \mu^+\nu)}$$

$$R_{\rm ps}^{\rm NP} = (0.539 \pm 0.043)\left|1 + r_{\rm NP}^{\tau}\right|^2,$$

$$R_{\rm pl}^{\rm NP} = \frac{m_\tau^2}{m_\mu^2}\frac{(1 - m_\tau^2/m_B^2)^2}{(1 - m_\mu^2/m_B^2)^2}\left|1 + r_{\rm NP}^{\tau}\right|^2 \simeq 222.37\left|1 + r_{\rm NP}^{\tau}\right|^2$$

Luminosity	$R_{\rm ps}$	$R_{\rm pl}$
$5\,{\rm ab}^{-1}$	$[-0.22, 0.20]$	$[-0.42, 0.29]$
$50\,{\rm ab}^{-1}$	$[-0.11, 0.12]$	$[-0.12, 0.11]$

Expected sensitivity @ 95% CL.
Assumed: NP contribution is real and $|r_{\rm NP}^{\tau}| < 1$

NP contributions to $B^+ \to \tau^+\nu$ with $|r_{\rm NP}| > \mathcal{O}(0.1)$ can be tested at 95% CL.

$B^+ \to \mu^+\nu$ Prospects for Belle II

- By scaling the FoM of Belle new untagged analysis (PRL 2018),

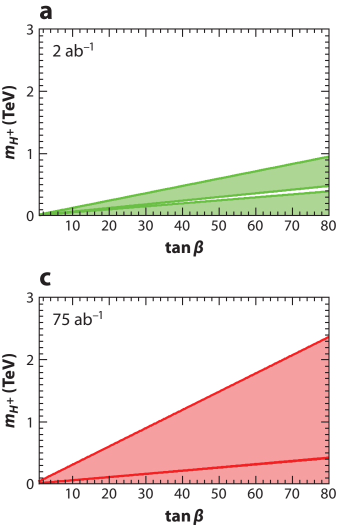
$$\mathcal{F}_{\mathrm{B2}} = \mathcal{F}_{B1} \times \sqrt{50\ \mathrm{ab}^{-1}/0.711\ \mathrm{ab}^{-1}} \sim 14.5\%$$

  corresponding to $\sim 7\%$ statistical precision

- naive expectation (Ref. B2TiP draft)
  - $B^+ \to \mu^+\nu$ can reach 5σ with $\sim 6\ \mathrm{ab}^{-1}$
  - 5% statistical precision, with full 50 ab^{-1}

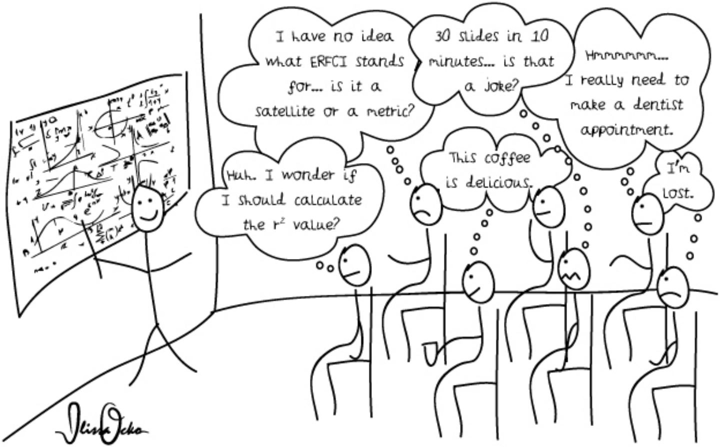
$B^+ \to \ell^+\nu$ Prospects beyond 50 ab^{-1}

from Ciuchini & Stocchi, Ann. Rev. Nucl. Part. Sci. 61 (2011) 491



Concluding Remarks

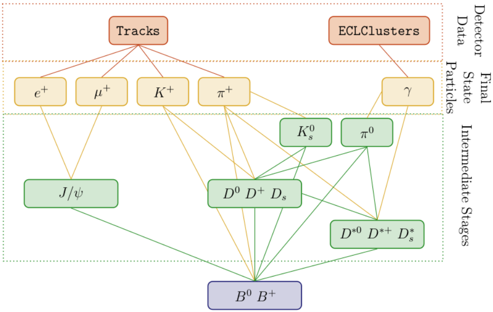
- Leptonic B decays, in particular $B^+ \to \ell^+\nu$ ($\ell = e, \mu, \tau$), provide powerful probe for new physics beyond the SM.
- $B^+ \to \tau^+\nu$ decays have been measured at nearly 5σ significance, and new physics models such as 2HDM (II) have been tested.
- With hadronic B-tagging, Belle has searched for *invisible, massive, lepton-like neutral* particle X^0 in $B^+ \to \ell^+X^0$ for the first time.
- Belle II with $\int \mathcal{L}\, dt = 50$ ab^{-1} branching fractions for both $B^+ \to \tau^+\nu$ and $B^+ \to \mu^+\nu$ are expected to be measured with precision of $\sim 5\%$.


I have no idea what ERFCI stands for... is it a satellite or a metric?
30 slides in 10 minutes... is that a joke?
Hmmmmm... I really need to make a dentist appointment.
Huh. I wonder if I should calculate the r² value?
This coffee is delicious.
I'm lost.

Thank you!

A new B-tagging: Full Event Interpretation

- Hierarchical reconstruction of B_{tag} with a network of classifiers
- Successor of the Belle Full Reconstruction (FR)
- Training and application
- **Hadronic** and semi-leptonic tag modes
- *Generic FEI:*
  1) FEI trained and applied on full event
  2) Signal selection
- ***Signal-specific FEI*** *(new):*
  1) Signal selection
  2) FEI trained and applied on **rest-of-event** → trained on specific event topology
- Each B_{tag} candidate has an assigned probability P_{FEI}



Tagging efficiency on MC

Tag	FR[1]	gen. FEI Belle	gen. FEI Belle II
Hadronic B^+	**0.28%**	**0.76%**	0.66%
SL B^+	0.67%	1.80%	1.45%
Hadronic B^0	0.18%	0.46%	0.38%
SL B^0	0.63%	2.04%	1.94%

[1] Belle Full Reconstruction algorithm.

from M. Gelb talk at CKM2018