Karlsruhe Institute of Technology

Sensitivity study of the measurement of the branching fraction of $B^+ \to \tau^+ \nu$ decays at the Belle II experiment

Thomas Keck on behalf of the Belle II collaboration | 21.04.2017

INSTITUT OF EXPERIMENTAL NUCLEAR PHYSICS (IEKP)

1. Theory

- $B^+ \to \ell^+ \nu$ in the SM
- $B^+ \to \ell^+ \nu$ in the Type-II 2HDM

2. Measurement

- Signal Side Selection
- Tag Side Reconstruction
- Branching Fraction Extraction

3. Results

- E_{ECL} - Fit
- Uncertainties

4. Summary

1. Theory

- $B^+ \to \ell^+ \nu$ in the SM
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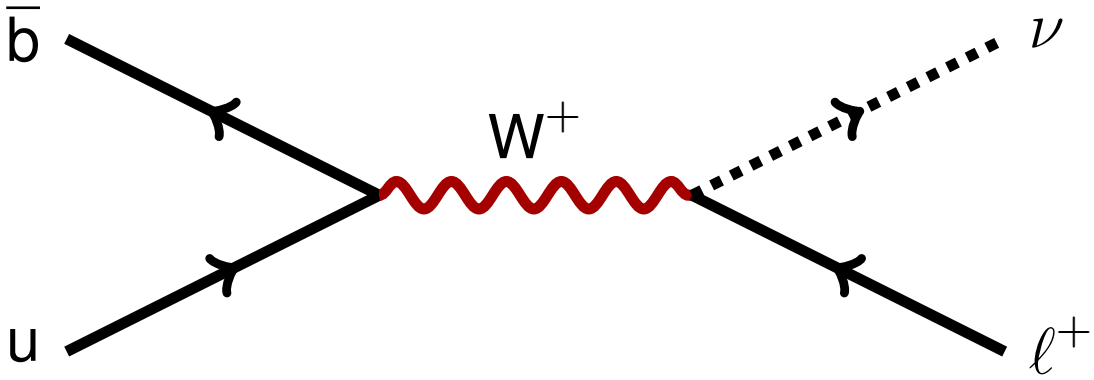
$B^+ \to \ell^+ \nu$



$$\mathcal{B}\left(B^+ \to \ell^+ \nu\right)_{\mathrm{SM}} = \frac{G_F^2 M_B M_\ell^2}{8\pi}\left(1 - \frac{M_\ell^2}{M_B^2}\right)^2 f_B{}^2 |V_{ub}|^2 \tau_B$$

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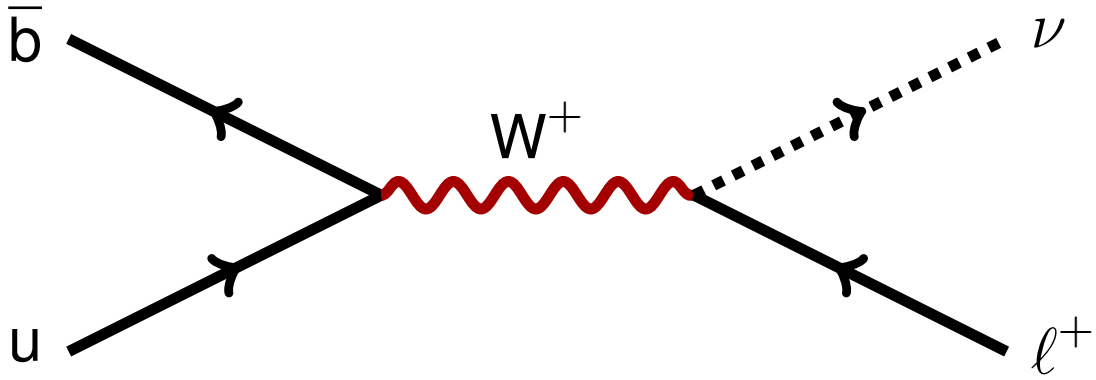

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	Value	Relative uncertainty
G_F	11.7 TeV	$5 \cdot 10^{-7}$
m_B	5.28 GeV	$3 \cdot 10^{-5}$
m_τ	1.78 GeV	$7 \cdot 10^{-5}$
τ_B	1.64 ps	$2 \cdot 10^{-3}$

	Value	Relative uncertainty
f_B	187.1 MeV	$2 \cdot 10^{-2}$
$\lvert V_{ub}\rvert_{\mathrm{inc}}$	$4.49 \cdot 10^{-3}$	$5 \cdot 10^{-2}$
$\lvert V_{ub}\rvert_{\mathrm{exc}}$	$3.72 \cdot 10^{-3}$	$5 \cdot 10^{-2}$
$\lvert V_{ub}\rvert_{\mathrm{avg}}$	$4.09 \cdot 10^{-3}$	$1 \cdot 10^{-1}$

All numerical values are extracted from: C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)

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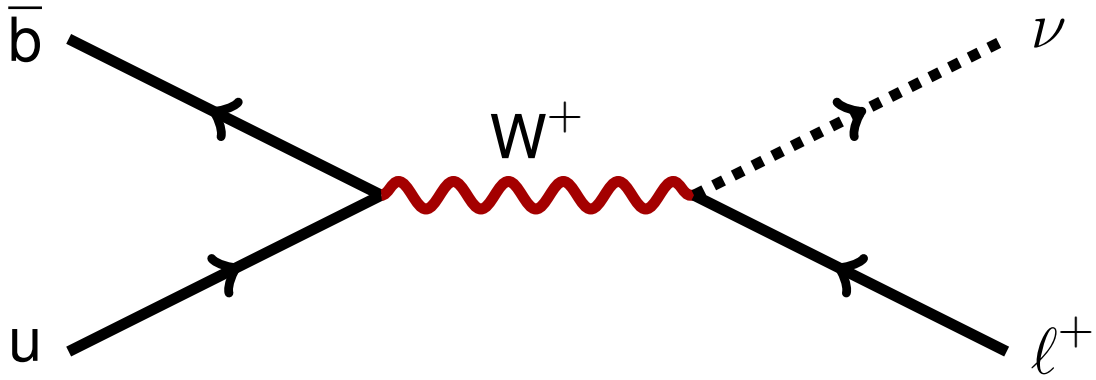

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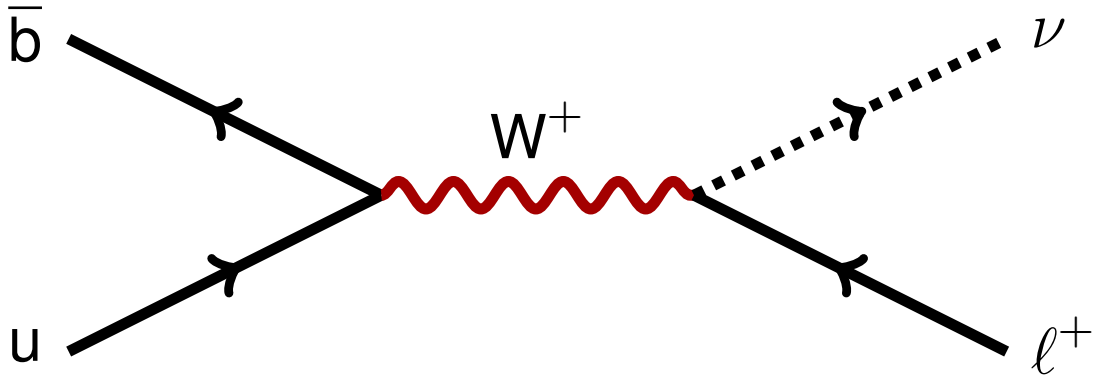

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	SM Prediction	PDG 2016
$\mathcal{B}\left(B^+ \to e^+ \nu_e\right)$	$(1.09 \pm 0.21) \cdot 10^{-11}$	$< 9.8 \cdot 10^{-7}$ CL=90%
$\mathcal{B}\left(B^+ \to \mu^+ \nu_\mu\right)$	$(4.65 \pm 0.91) \cdot 10^{-7}$	$< 1.0 \cdot 10^{-6}$ CL=90%
$\mathcal{B}\left(B^+ \to \tau^+ \nu_\tau\right)$	$(1.03 \pm 0.2) \cdot 10^{-4}$	$(1.06 \pm 0.20) \cdot 10^{-4}$

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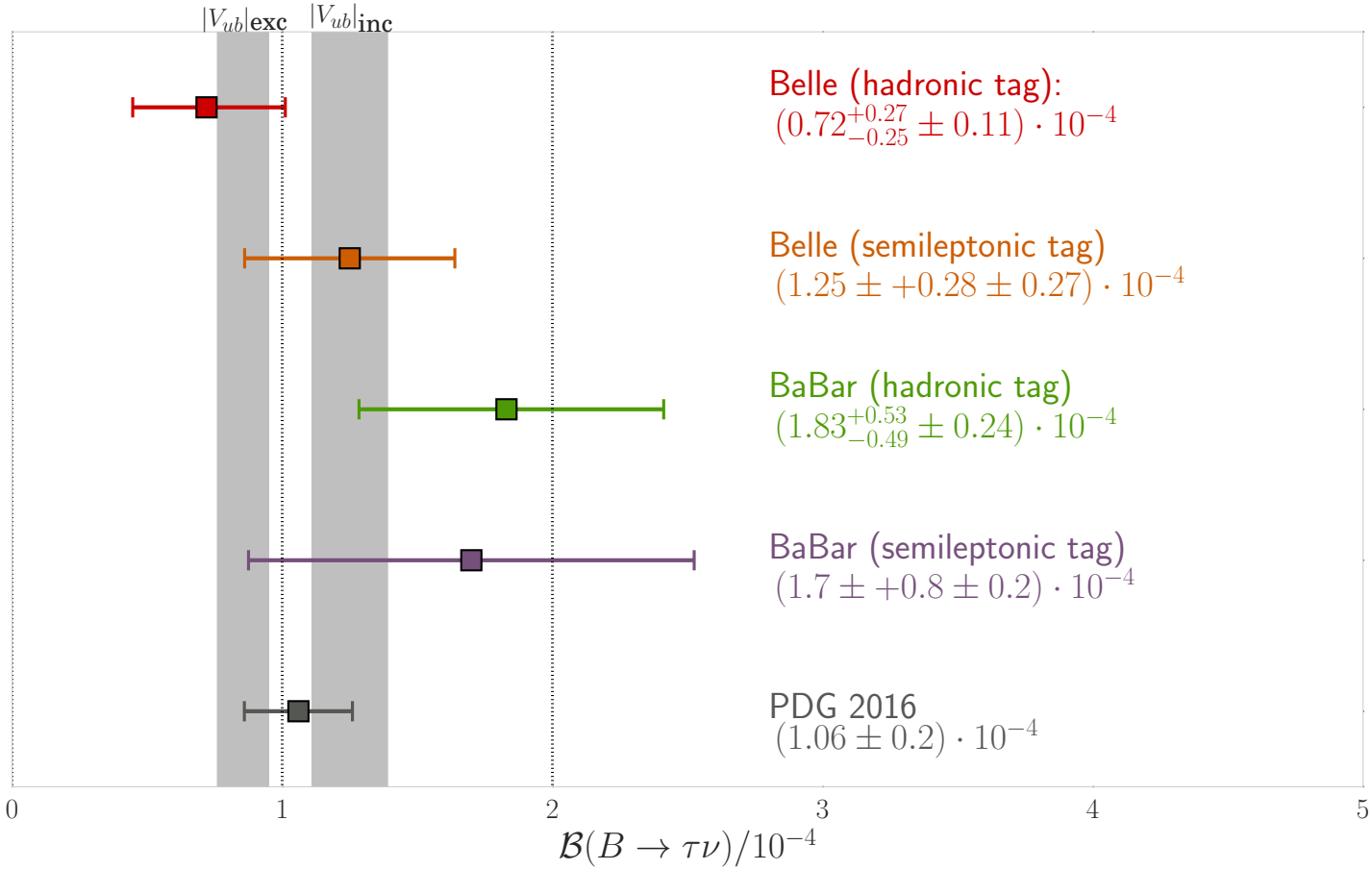
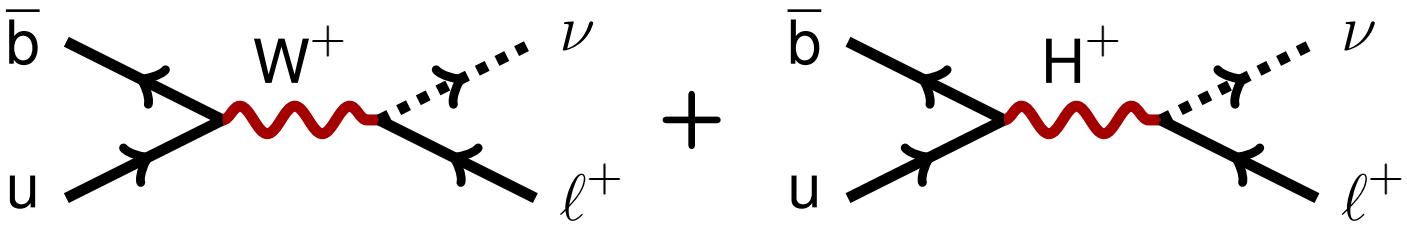
$B^+ \to \tau^+ \nu_\tau$: Current status



Theoretical prediction and experimental measurement are compatible.

Type-II Two Higgs Doublet Model



$$\mathcal{B}\left(\mathrm{B}^+ \to \ell^+\nu\right)_{\mathrm{2HDM}} = \mathcal{B}\left(\mathrm{B}^+ \to \ell^+\nu\right)_{\mathrm{SM}} \cdot \left(1 - \frac{M_{\mathrm{B}}^2 \tan^2\beta}{M_{\mathrm{H}^+}^2}\right)^2$$

Already tightly constrained by weak radiative B meson decays

$$M_{\mathrm{H}^+} > 580\ \mathrm{GeV}$$

Steinhauser, https://arxiv.org/pdf/1702.04571.pdf

2. Measurement

- Signal Side Selection
- Tag Side Reconstruction
- Branching Fraction Extraction

Signal Side $B^+_{sig} \to \tau^+ \nu_\tau$

- Five τ decay channels covering a total branching fraction of 80.8%
- Distinct selection criteria reducing background by factor 10
- Due to crossfeed 97% of the signal events are selected

$\tau^+ \to e^+ \nu_e \overline{\nu}_\tau$

- $\mathcal{B} = 17.8\%$
- electron-id
- $\epsilon = 0.73$

$\tau^+ \to \mu^+ \nu_\mu \overline{\nu}_\tau$

- $\mathcal{B} = 17.4\%$
- muon-id
- $\epsilon = 0.59$

$\tau^+ \to \pi^+ \overline{\nu}_\tau$

- $\mathcal{B} = 10.8\%$
- Two-body decay
- $\epsilon = 0.87$

$\tau^+ \to \rho^+ (\to \pi^+ \pi^0 (\to \gamma\gamma))\, \overline{\nu}_\tau$

- $\mathcal{B} = 25.5\%$
- Intermediate resonances
- $\epsilon = 0.75$

$\tau^+ \to a_1^+ (\to \pi^+ \pi^+ \pi^-)\, \overline{\nu}_\tau$

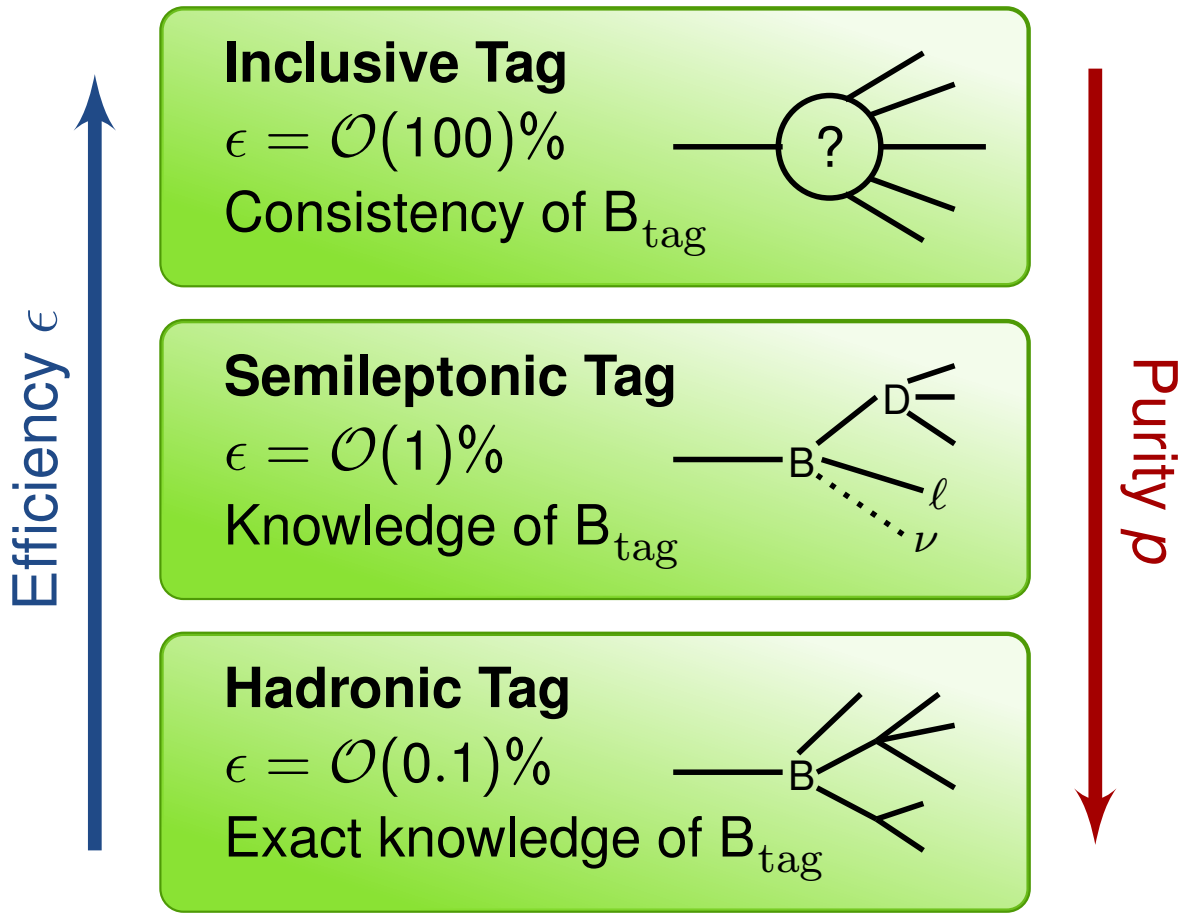
- $\mathcal{B} = 9.3\%$
- 3-prong decay
- $\epsilon = 0.85$

All B_{sig} channels contain at least 2 undetectable neutrinos!

Tag Side B_{tag}: Overview

Reconstruct tag-side to recover information about signal-side:

- Consistency of conserved quantities
- **Four-momentum**
- Flavour
- Event-type
- Decay time difference Δt
- **ECL cluster & Track assignment**



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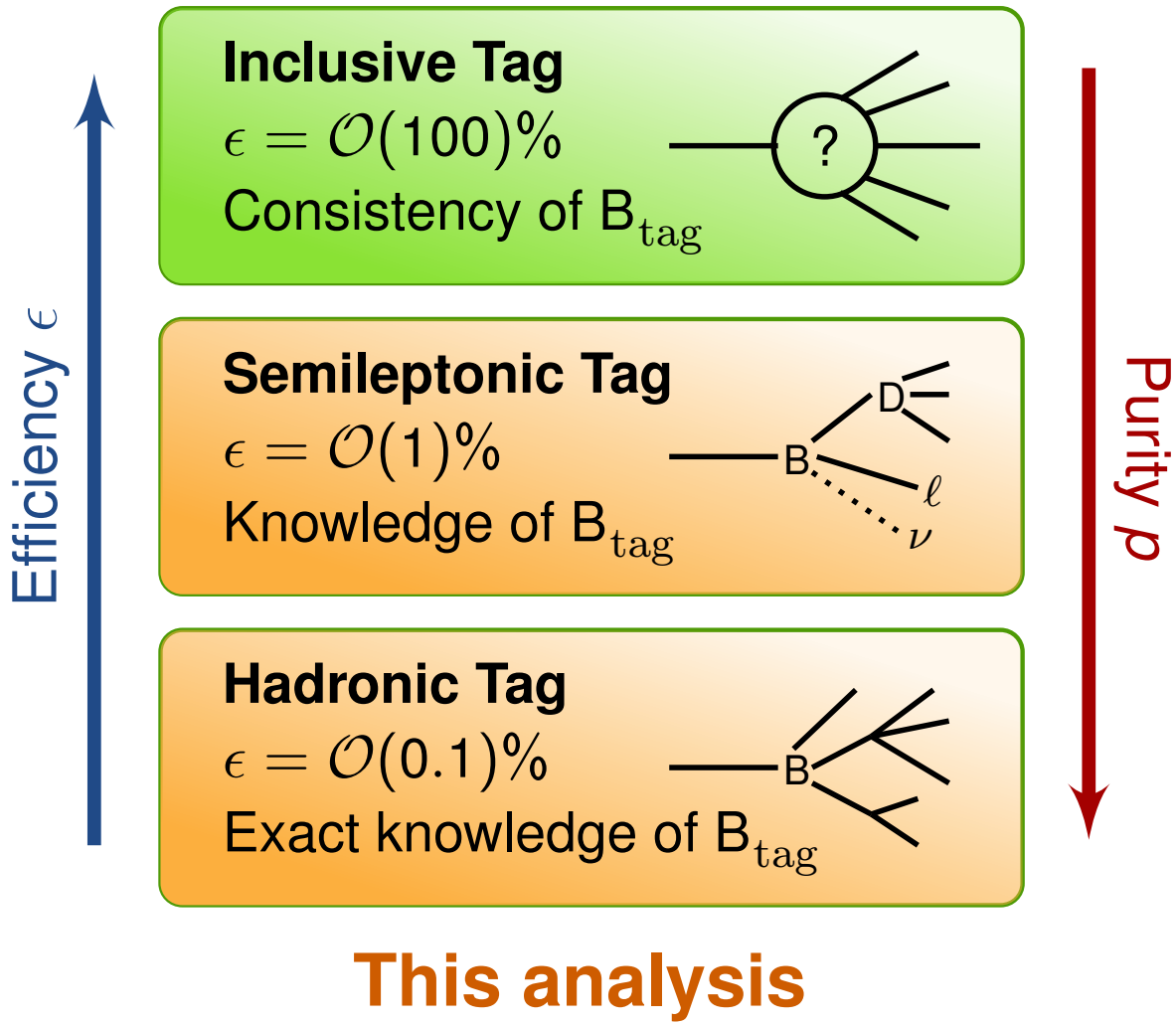


This analysis

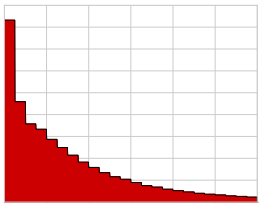
Tag Side B_{tag}: Result

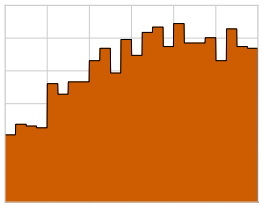
Maximum reconstruction efficiency

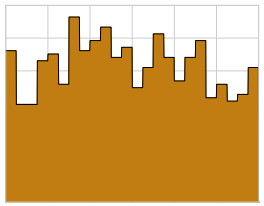
Tag	FR @ Belle	FEI @ Belle	FEI @ Belle II
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

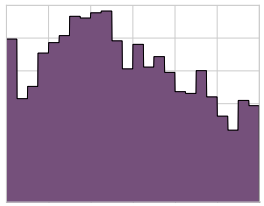
Branching Fraction Extraction

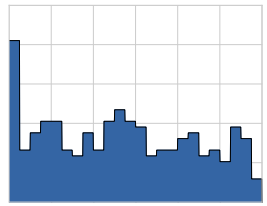
1. Determine E_{ECL} shapes of individual components on MC and off-resonance data


Signal


Charged


Mixed


Charm


UDS

2. Extended Unbinned Maximum Likelihood Fit on Data

$$P(E_{\mathrm{ECL}}) = \left(N_{\mathrm{sig}} P_{\mathrm{sig}}(E_{\mathrm{ECL}}) + N_{\mathrm{bkg}} \sum_i c_{\mathrm{i}} P_{\mathrm{bkg,i}}(E_{\mathrm{ECL}}) \right)$$

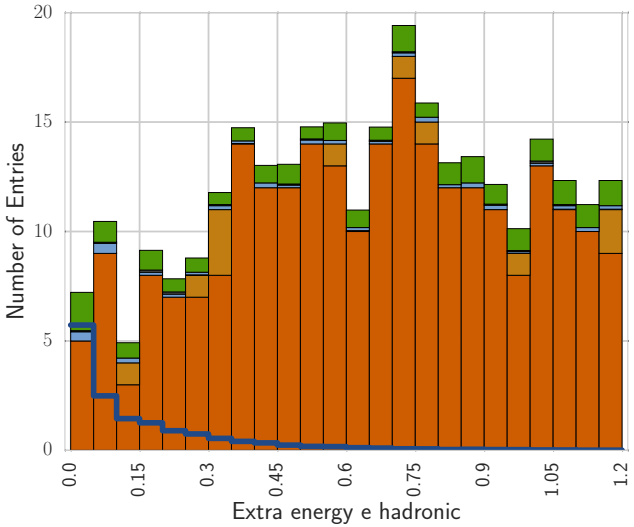
3. Calculation of branching fraction

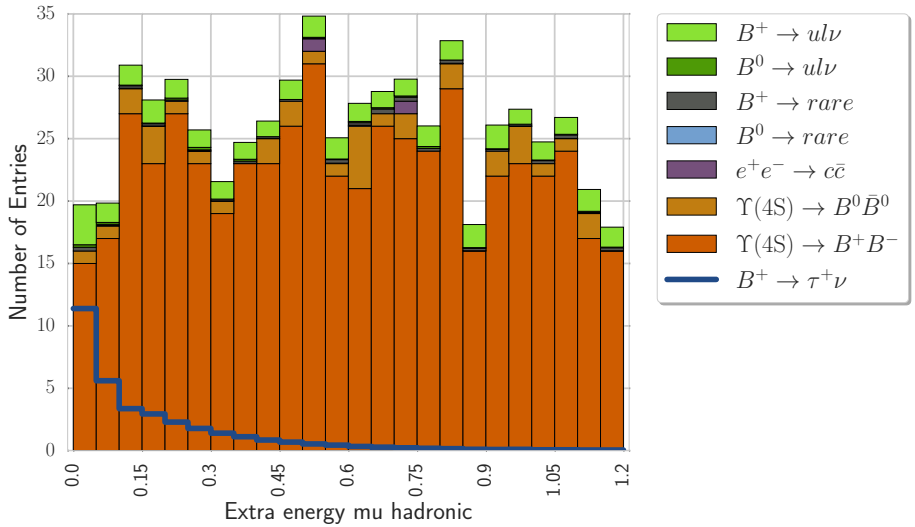
$$\mathcal{B}(\mathrm{B} \to \tau \nu_\tau) = \frac{N_{\mathrm{sig}}}{N_{\mathrm{B\overline{B}}} \cdot \epsilon}$$

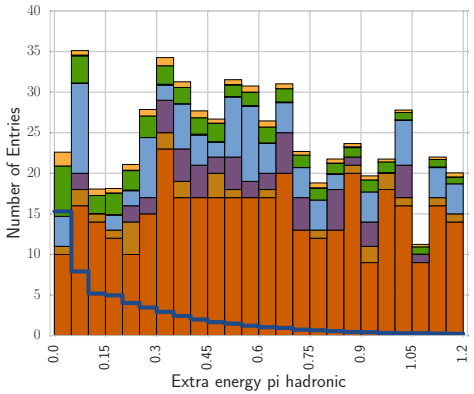
3. Results

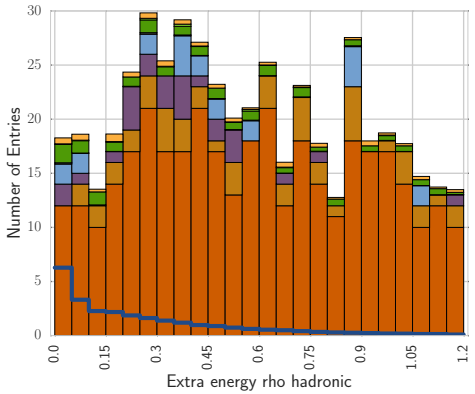
- E_{ECL} - Fit
- Uncertainties

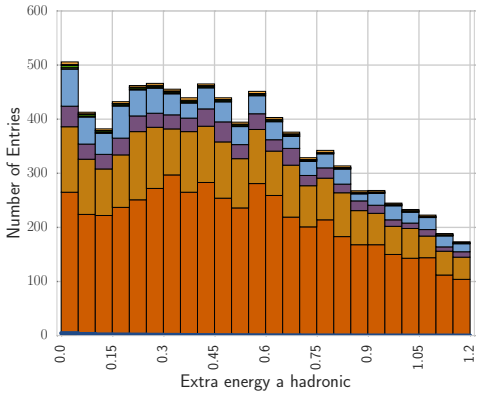
Belle MC (Hadronic)



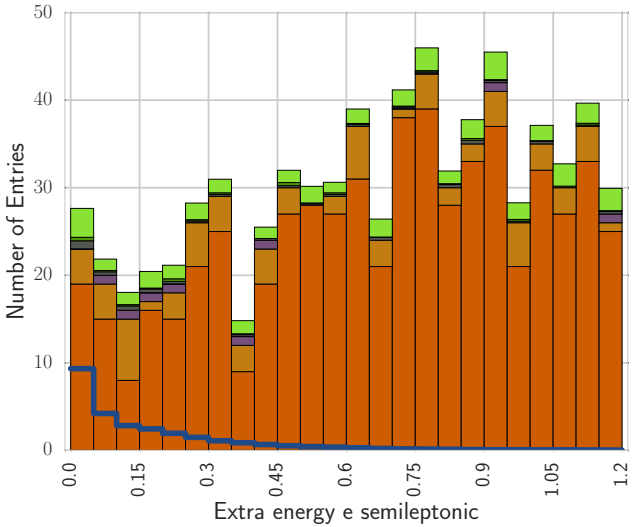


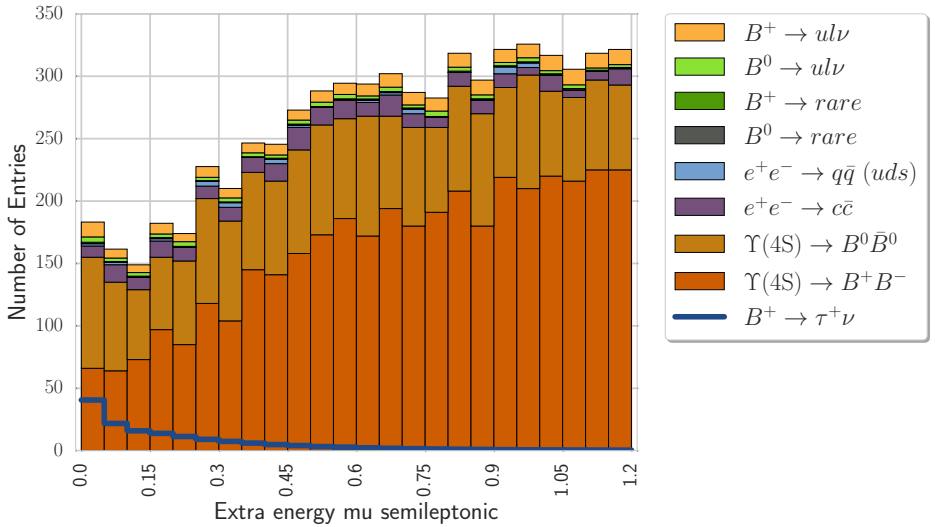


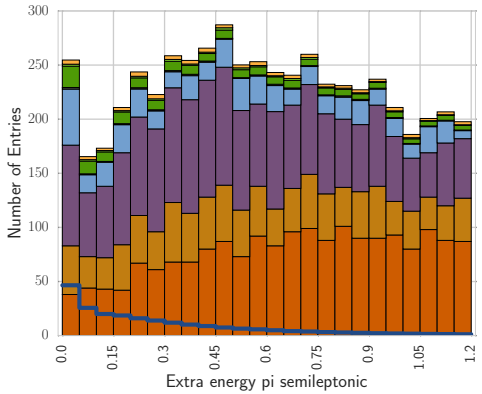


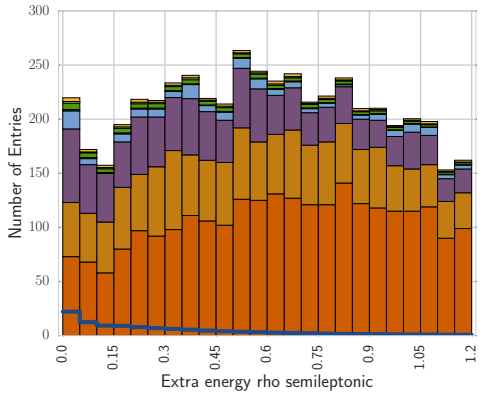


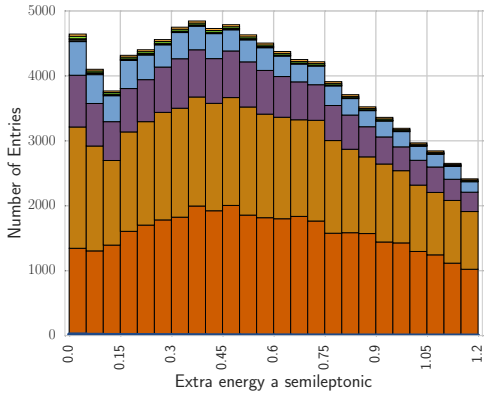
Belle MC (Semileptonic)











Belle II

First Data probably 2018: High background still challenging

Statistical uncertainties

Scenario	Luminosity in ab^{-1}	Relative Uncertainty in % Hadronic	Semileptonic	State
Belle	0.711	37.5	22.4	Measured
B2BII	0.711	29.0	21.0	MC Fit
Belle II	1	31.6	18.9	Scaled
Belle II	5	14.1	8.4	Scaled
Belle II	50	4.5	2.7	Scaled

Scaled: Belle scaled with $\frac{1}{\sqrt{N}}$

Systematic uncertainties

Source	Relative uncertainty in %		Decreases with luminosity
	Hadronic[1]	Semileptonic[2]	
PDF shapes	9.8	8.5	✓
Branching fractions	3.8	3.1	($> 3\%$)
Tag-side efficiency	7.1	12.6	✓
Continuum Description	-	14.1	✓
K_L^0	7.3	-	($> 2\%$)
Total	14.7	21.2	

Leading systematic uncertainties $>$ 2%

[1] Hara 2013 https://arxiv.org/abs/1208.4678

[2] Kronenbitter 2014 https://arxiv.org/abs/1409.5269

Summary

- Precise measurement of $B \to \tau \nu_\tau$ sheds light on V_{ub} puzzle
- Usage of new Belle Analysis Software Framework 2 on old Belle data
- Established new tag-side algorithm with increased efficiency
- Prediction of uncertainty on Belle II data is promising, but background still challenging

Backup

BASF2 (Belle Analysis Software Framework 2)