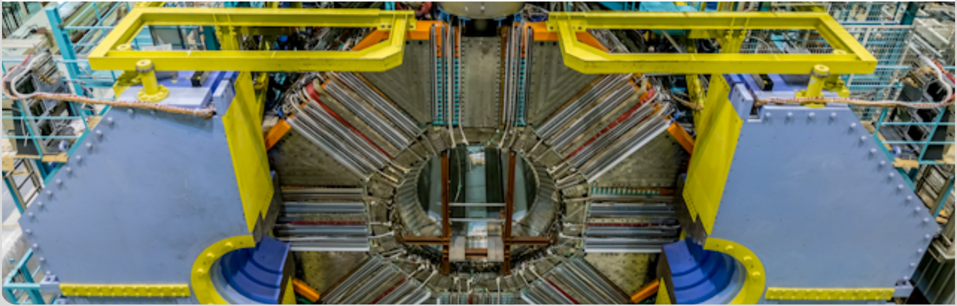
Karlsruhe Institute of Technology

Search for the rare decay $B^+ \to \ell^+ \nu_\ell \gamma$ at Belle and Belle II

XXIV Cracow EPIPHANY Conference on Advances in Heavy Flavour Physics

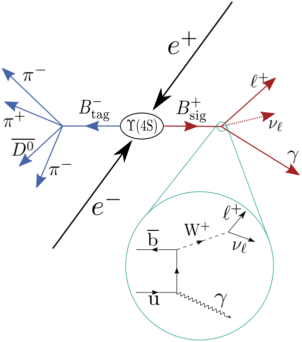
Moritz Gelb for the Belle II Collaboration | 11.01.2018

INSTITUTE OF EXPERIMENTAL PARTICLE PHYSICS (ETP)



Introduction

- B meson pair is produced at the $\Upsilon(4S)$ resonance with no additional particles
- Measurement of missing energy modes possible
- New *tagging algorithm* for Belle II developed
- Opposite B meson can now be reconstructed with higher efficiency compared to the Belle approach
- New method applied to (converted) Belle MC/data and later Belle II
- Update of the Belle hadronically tagged $B^+ \to \ell^+ \nu_\ell \gamma$ analysis[a]



[a] Phys. Rev. D 91, 112009 (2015)

The Decay $B^+ \to \ell^+ \nu_\ell \gamma$

The decay $B^+ \to \ell^+ \nu_\ell \gamma$ allows to probe the first inverse moment λ_B of the Light-Cone Distribution Amplitude (LCDA) of the B meson.

$\Rightarrow$ Important input for QCD factorization necessary for theory predictions of non-leptonic B meson decays

Belle Result (A. Heller)

Upper Limits:

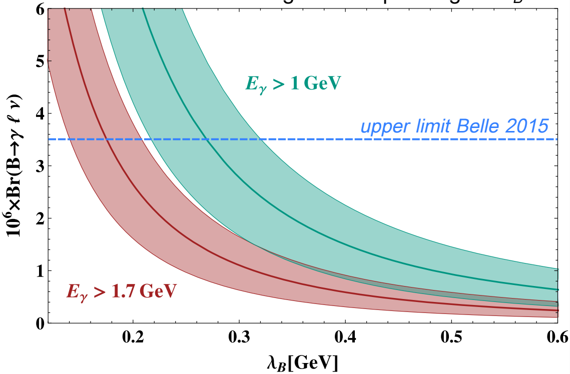
$\mathcal{B}(B^+ \to e^+ \nu_e \gamma) < 6.1 \cdot 10^{-6}$

$\mathcal{B}(B^+ \to \mu^+ \nu_\mu \gamma) < 3.4 \cdot 10^{-6}$

$\mathcal{B}(B^+ \to \ell^+ \nu_\ell \gamma) < 3.5 \cdot 10^{-6}$

$\lambda_B > 238\,\mathrm{MeV}$ (90%C.L.)

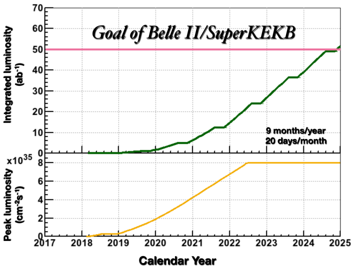
Theoretical Branching Ratio depending on λ_B

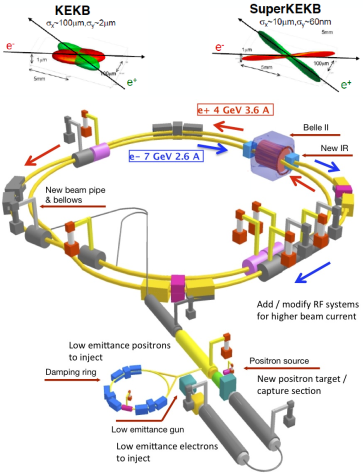


M. Beneke and J. Rohrwild (2011)

SuperKEKB Accelerator

- Asymmetric e^+e^- collider at $\Upsilon(4S)$ resonance ($E_{\mathrm{CMS}} = 10.58\,\mathrm{GeV}$)
- Nanobeam scheme

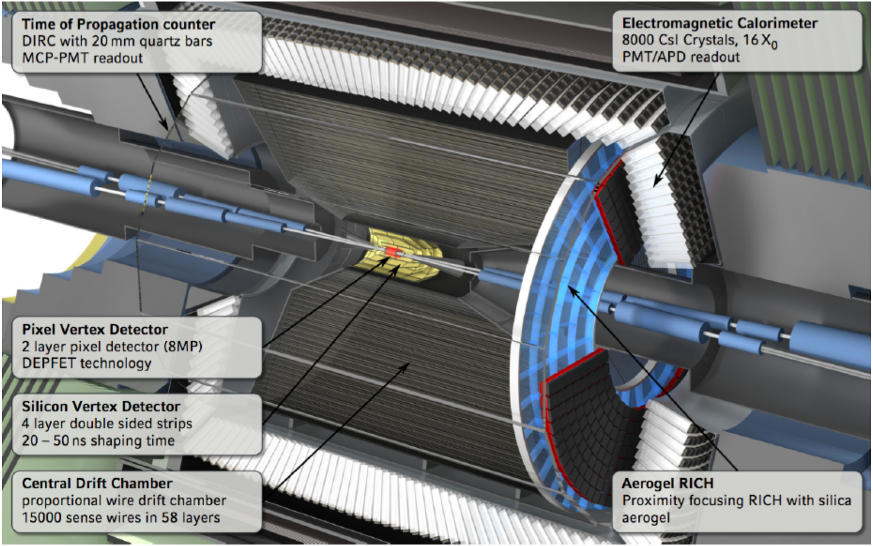




Goal: 40x $\mathcal{L}_{\mathrm{peak}}$ and 50x $\mathcal{L}_{\mathrm{int}}$ compared to KEKB

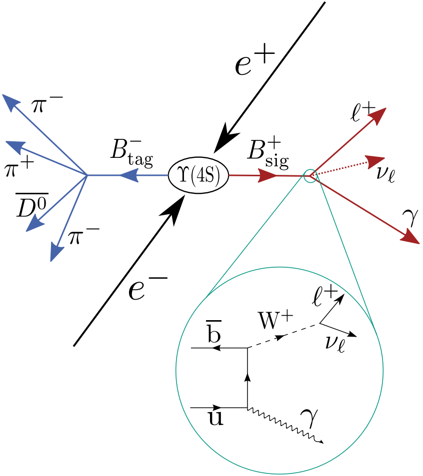
See also talk on Wednesday:
"Belle 2 Prospects for CP-Violation Measurements"
by Chiara La Licata

Belle II Detector



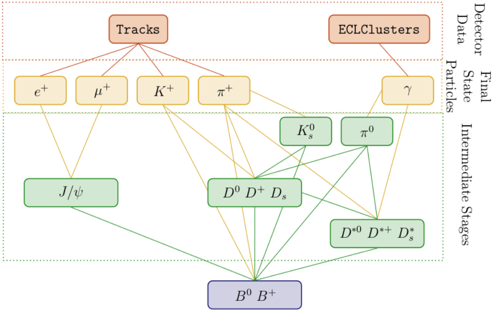
Analysis Procedure

- Identification of signal lepton and photon
- Isolation of the remaining particles
- Application of the Full Event Interpretation (FEI) for B-tagging
- Recombination of the initial $\Upsilon(4S)$



The Tagging Algorithm: 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** $\rightarrow$ trained on specific event topology
- Each B_{tag} candidate has an assigned probability P_{FEI}



Source: T.Keck (KIT)

Tagging ϵ 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.

Ref. T. Keck: `https://ekp-invenio.physik.uni-karlsruhe.de/record/48602/files/EKP-2015-00001.pdf`

Calibration of the Tagging Algorithm

Why calibration?

Correct for difference in tagging efficiency on data and MC caused by:

- Hadronic branching ratios
- Dynamics of hadronic decays
- Detector simulation
- ...

Procedure[1]

1) Reconstruct B_{sig} in well-known calibration channel
2) Apply tagging algorithm
3) Extract the number of events on MC and data via a fit on M^2_{miss}
4) Calculate the correction factor for calibration channel:

$$\epsilon = \frac{N_{\mathrm{Data}}}{N_{\mathrm{MC}}}$$

The correction factor ϵ incorporates all corrections on the tag-side B_{tag}!

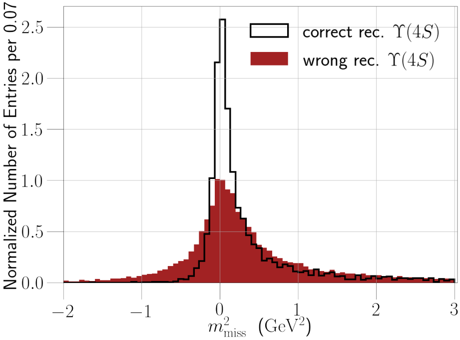
[1] More details can be found in the MsC thesis of Judith Schwab:

https://ekp-invenio.physik.uni-karlsruhe.de/record/48931/files/EKP-2017-00058.pdf

Missing Mass – M^2_{miss}

$$M^2_{\text{miss}} = (p_{B_{\text{sig}}} - p_\ell - p_\gamma)^2$$
$$= \left(\begin{pmatrix} \frac{E_{\text{CMS}}}{2c} \\ -\vec{p}_{B_{\text{tag}}} \end{pmatrix} - p_\ell - p_\gamma \right)^2$$

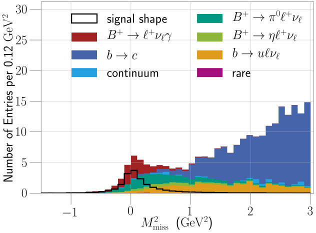
- At B-Factories the initial state of the $\Upsilon(4S)$ is well known.
- Both B mesons are produced back-to-back in the $\Upsilon(4S)$ decay.
- Momentum resolution is dominated by the photon contribution.
- Correctly reconstructed events with one neutrino peak at $M^2_{\text{miss}} = 0$.



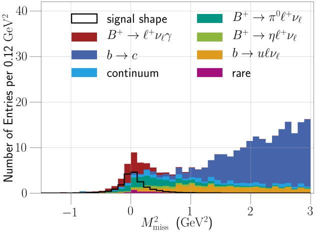
Signal MC only

Outlook

e^+ final state



μ^+ final state



Exp. Signal Yield for $\mathcal{B}(B^+ \to \ell^+\nu_\ell\gamma) = 5.0 \times 10^{-6}$

	Electron Channel $B^+ \to e^+\nu_e\gamma$	Muon Channel $B^+ \to \mu^+\nu_\mu\gamma$	Combined $B^+ \to \ell^+\nu_\ell\gamma$
Improved Analysis	17.6	18.8	36.4
Prev. Belle Analysis	8.0	8.7	16.5

Summary

- New analysis tools were developed for Belle II
- The new tagging algorithm allows for more than doubled efficiency
- Tools allow already to improve Belle analysis

Thank you!

Appendix – Calibration Results

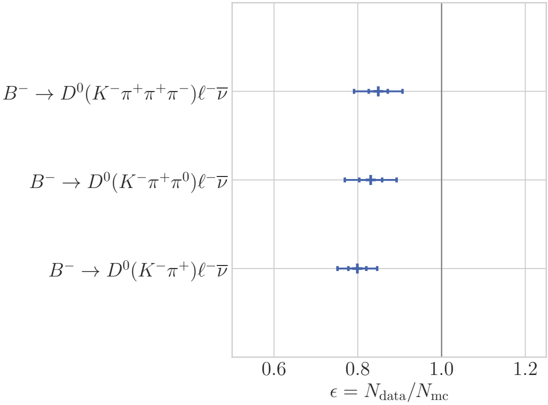


Figure: Calibration factors of the Specific FEI for the calibration channels, on data.

Average: $\boldsymbol{\epsilon = 0.825 \pm 0.014 \pm 0.049}$

Appendix – Calibration Results

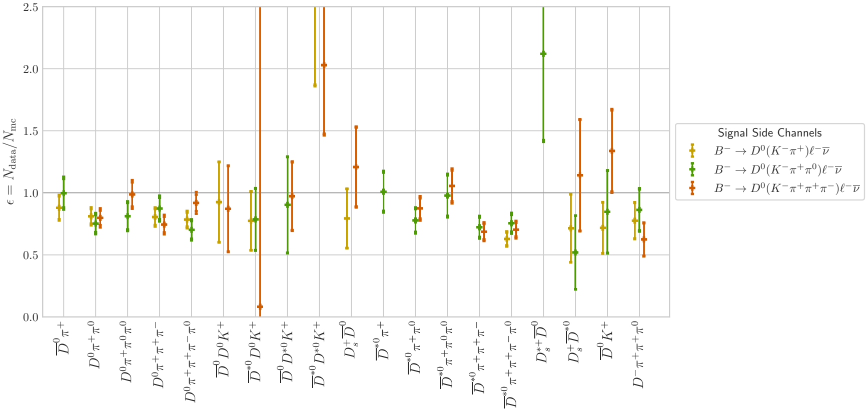


Figure: Calibration factors of the Specific FEI for the calibration channels split over the tag channels, on data.

Average: $\epsilon = \mathbf{0.825 \pm 0.014 \pm 0.049}$

Outlook for Belle II

Expected Statistical Error for $\mathcal{B}(B^+ \to \ell^+ \nu_\ell \gamma) = 5.0 \times 10^{-6}$

Belle Improv. Analysis	Belle II $5ab^{-1}$	Belle II $50ab^{-1}$
+1.2	+0.46	+0.14
-1.32	-0.50	-0.16

Systematic errors are still being evaluated.