Inclusive $B \to X_u l \nu$ at Belle II

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on behalf of the Belle II Collaboration

Karlsruhe Institute of Technology

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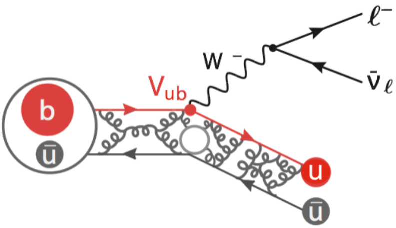
18 September 2018



- $|V_{ub}| = \sqrt{\frac{\Delta \mathcal{B}}{\tau_B \Delta \Gamma}}$

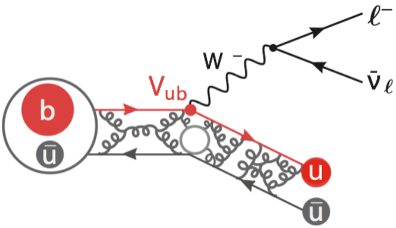
Exclusive V_{ub}

- $\bar{B} \to \pi l \bar{\nu}$
- Needs input from non-perturbative methods, i.e. lattice QCD.

Inclusive V_{ub}

- $\bar{B} \to X_u l \bar{\nu}$
- Total decay rate determined from the Heavy Quark Expansion (HQE).

$B \to X_u l \nu$ and $|V_{ub}|$



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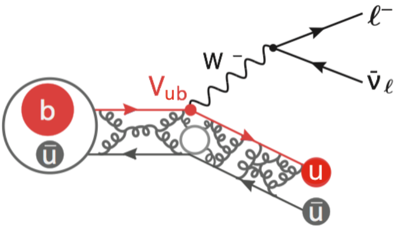

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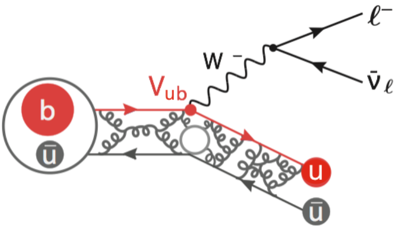

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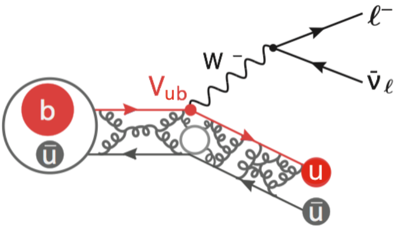

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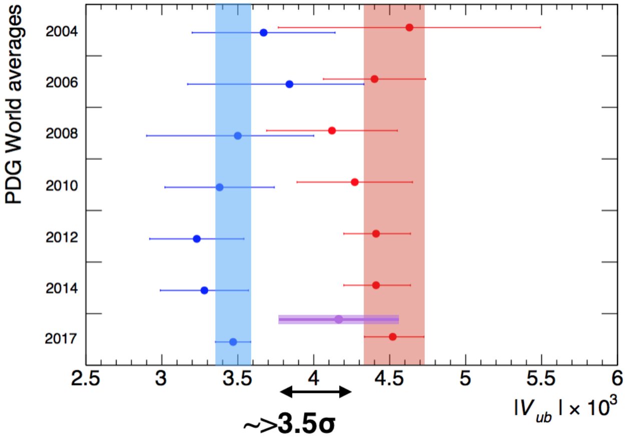
Current status



Exclusive

$\bar{B} \to \pi l \bar{\nu}$, $\bar{B} \to D^* l \bar{\nu}$,
$\Lambda_b \to p \mu \nu_\mu$

Inclusive

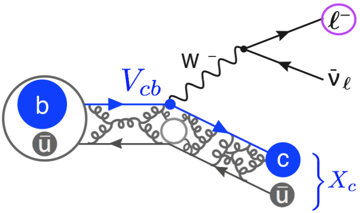
$\bar{B} \to X_u l \bar{\nu}$

Leptonic

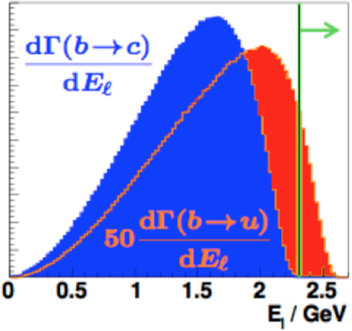
$\bar{B} \to \tau \nu_\tau$

Why is it hard to measure V_{ub}?

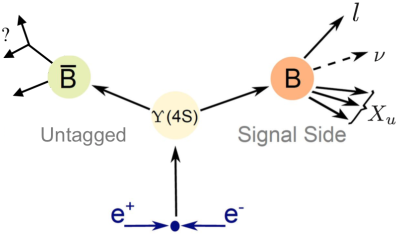
Dominant background: $\bar{B} \to X_c l \nu$



$\hookrightarrow$ $\mathcal{O}(100)$ times more abundant than signal!

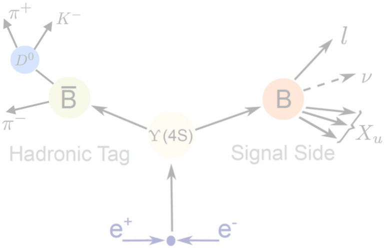


Analysis strategy



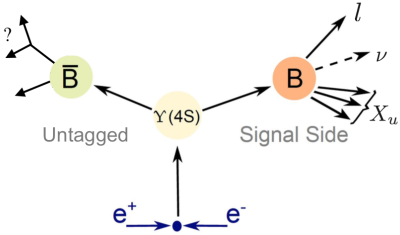
Inclusive tagging

- Use the initial event information and the reconstructed visible momenta to constrain the neutrino momentum.



Hadronic tagging

- Use the information from the B-tag side to reconstruct the neutrino momentum.
- Low efficiency, but high purity.



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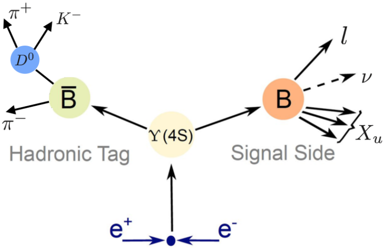

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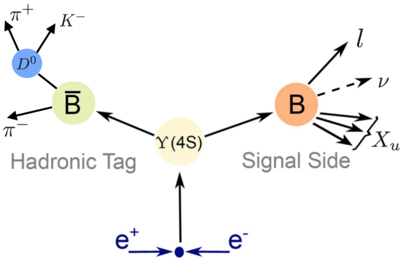
Typical selection



Signal lepton

Select one lepton with $p_{l^*} > 1$ GeV.

Missing mass

$MM^2 = m_\nu^2 = p_\nu^2 = (p_{\Upsilon(4s)} - p_{B_{tag}} - p_X - p_l)^2$

$B \to D^* l \nu$ vetoes

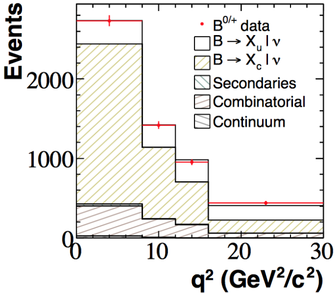
- Partially reconstruct D^* with slow pions.
- $E_{D^*} \approx m_{D^*} \times E_\pi / \Delta m$
- $MM^2_{veto} = (p_{B_{sig}} - p_{D^*} - p_l)^2$

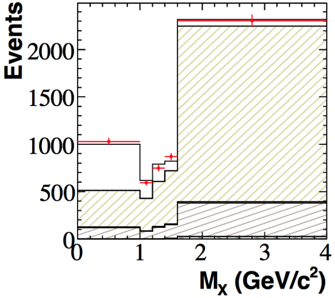
Alternative: separation with MVA

Most recent Belle analysis

- Separates $B \to X_u l \nu$ from $B \to X_c l \nu$ with Boosted Decision Trees.
- Makes use of 17 different kinematic variables as feature inputs.
- Accesses $\approx 90\%$ of the $B \to X_u l \nu$ phase space!
- Minimises shape function dependance.

Phys. Rev. Lett. 104.2, 021801 (2010)





A look at systematics

Source	Error on $\mathcal{B}$ (irreducible limit)
$\mathcal{B}(D^{(*)}\ell\nu)$	1.2 (0.6)
Form factors $(D^{(*)}\ell\nu)$	1.2 (0.6)
Form factors & $\mathcal{B}(D^{(**)}\ell\nu)$	0.2
$B \to X_u\ell\nu(\mathrm{SF})$	3.6 (1.8)
$B \to X_u\ell\nu(g \to s\bar{s})$	1.5
$\mathcal{B}(B \to \pi/\rho/\omega\ell\nu)$	2.3
$\mathcal{B}(B \to \eta^{(\prime)}\ell\nu)$	3.2
$\mathcal{B}(B \to X_u\ell\nu)$ unmeasured/fragmentation	2.9 (1.5)
Continuum & Combinatorial	1.8
Secondaries, Fakes & Fit	1.0
PID& Reconstruction	3.1
BDT/Normalisation	3.1 (2.0)
Total	8.1
(Total reducible)	7.4
(Total irreducible)	3.2

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MC hybrid mix

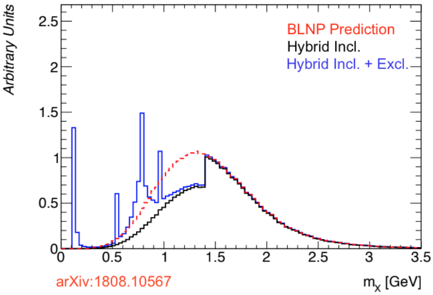
- Consists of inclusive and resonant contributions.

Room for improvement:

- Resonant contributions ($X_u = \pi,\ \rho,\ \eta,\ \omega$) only account for 20% of the total rate.

Belle II to the rescue!

- Larger data set will aid to constrain uncertainties on signal modelling.



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. . . more systematics

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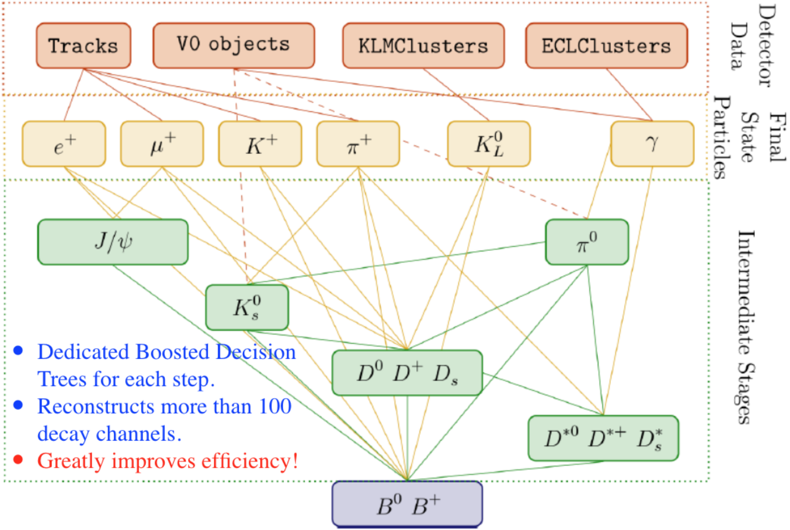
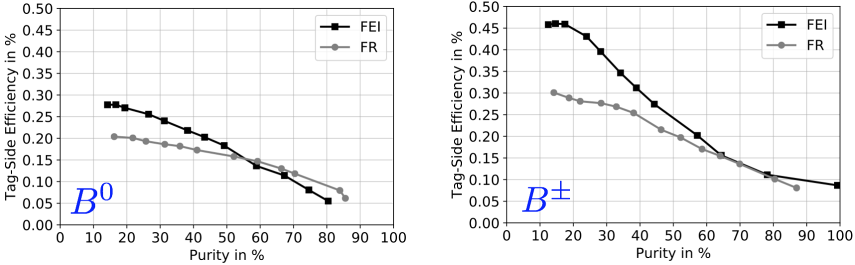
Introducing the Full Event Interpretation!



- Dedicated Boosted Decision Trees for each step.
- Reconstructs more than 100 decay channels.
- Greatly improves efficiency!

Estimated improved hadronic tagging



	Method	Efficiency	Purity
Belle	Cut-based	0.1%	0.25%
Belle FR	Neurobayes	0.2%	0.25%
Belle II FEI	BDTs	0.5%	0.25%

arXiv:1807.08680v3

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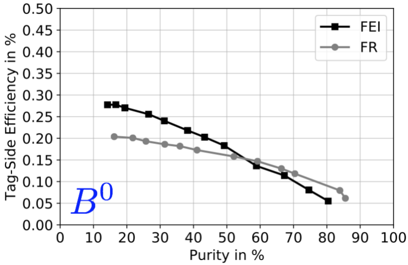

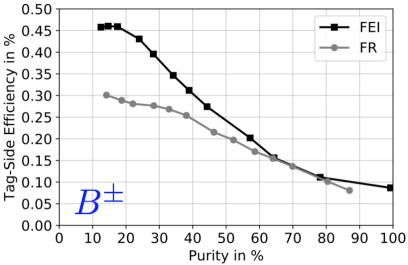

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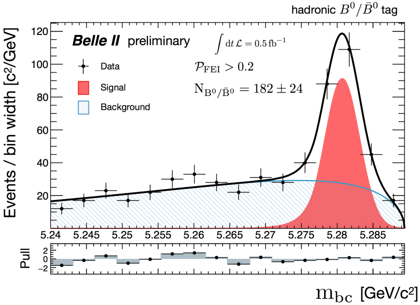
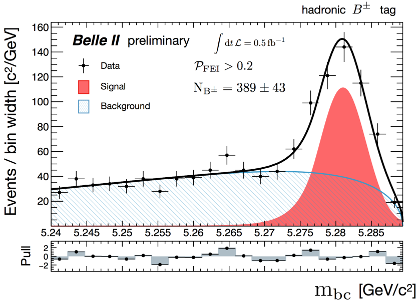
Phase II FEI performance

Phase II at Belle II

- Commissioning run from Feb 2018 to July 2018.
- First e^+e^- collisions during April 2018.





- $N = 182 \pm 24$ neutral and $N = 389 \pm 43$ charged candidates.

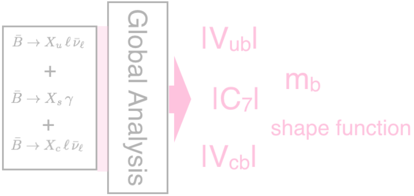
Expected performance at Belle II

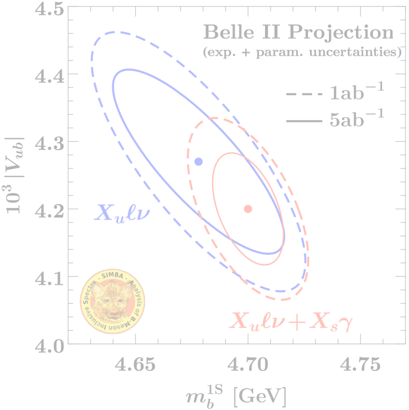
Approximate shape function

$$\hat{F}(p_b) = \left(\sum_n c_n f_n(p_b)\right)^2$$

As done by:

SIMBA & NNV_{ub}





Relative error: 2-3%

NNVub: Phys. Rev. D 94, 014031 (2016) and SIMBA: arXiv:1303.0958

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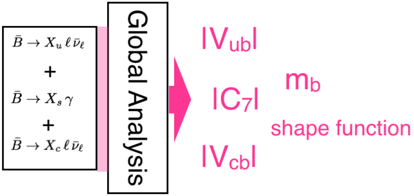

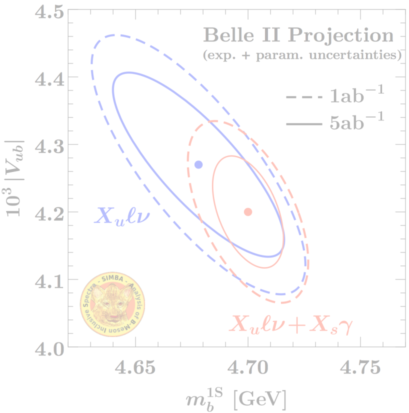

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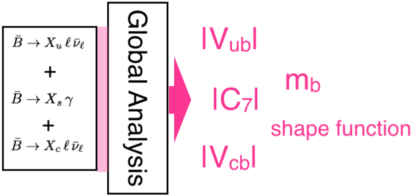

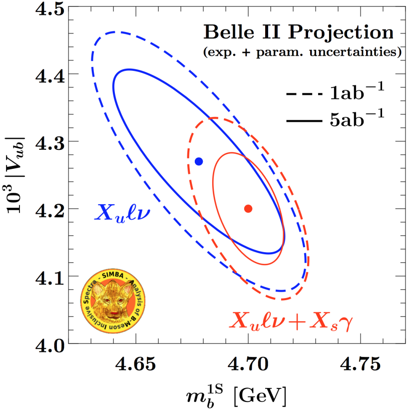

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Summary

Measuring $|V_{ub}|$ is crucial to the current exclusive vs. inclusive problem.

Difficult to measure in tiny pockets of phase space where background is suppressed, which then become sensitive to the shape function.

Precision of measurements can be improved at the Belle II experiment with much higher luminosity, better and smarter reconstruction algorithms and state-of-the-art theory models.

Additionally, global data-driven fits would yield a model independent measurement of $|V_{ub}|$, which improve precision of measurements by reducing model uncertainties from the shape function.

Back up slides

Back up!

Very specific numbers for finicky questions

	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ exclusive (had. tagged)					
711 fb^{-1}	3.0	(2.3, 1.0)	3.8	7.0	8.0
5 ab^{-1}	1.1	(0.9, 1.0)	1.8	1.7	3.2
50 ab^{-1}	0.4	(0.3, 1.0)	1.2	0.9	1.7
$\lvert V_{ub}\rvert$ exclusive (untagged)					
605 fb^{-1}	1.4	(2.1, 0.8)	2.7	7.0	7.5
5 ab^{-1}	1.0	(0.8, 0.8)	1.2	1.7	2.1
50 ab^{-1}	0.3	(0.3, 0.8)	0.9	0.9	1.3
$\lvert V_{ub}\rvert$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.7, 1.6)	6.0	2.5−4.5	6.5−7.5
5 ab^{-1}	1.1	(1.3, 1.6)	2.3	2.5−4.5	3.4−5.1
50 ab^{-1}	0.4	(0.4, 1.6)	1.7	2.5−4.5	3.0−4.8
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (had. tagged)					
711 fb^{-1}	18.0	(7.1, 2.2)	19.5	2.5	19.6
5 ab^{-1}	6.5	(2.7, 2.2)	7.3	1.5	7.5
50 ab^{-1}	2.1	(0.8, 2.2)	3.1	1.0	3.2
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (SL tagged)					
711 fb^{-1}	11.3	(10.4, 1.9)	15.4	2.5	15.6
5 ab^{-1}	4.2	(4.4, 1.9)	6.1	1.5	6.3
50 ab^{-1}	1.3	(2.3, 1.9)	2.6	1.0	2.8