

Belle II status and prospects for semileptonic decay

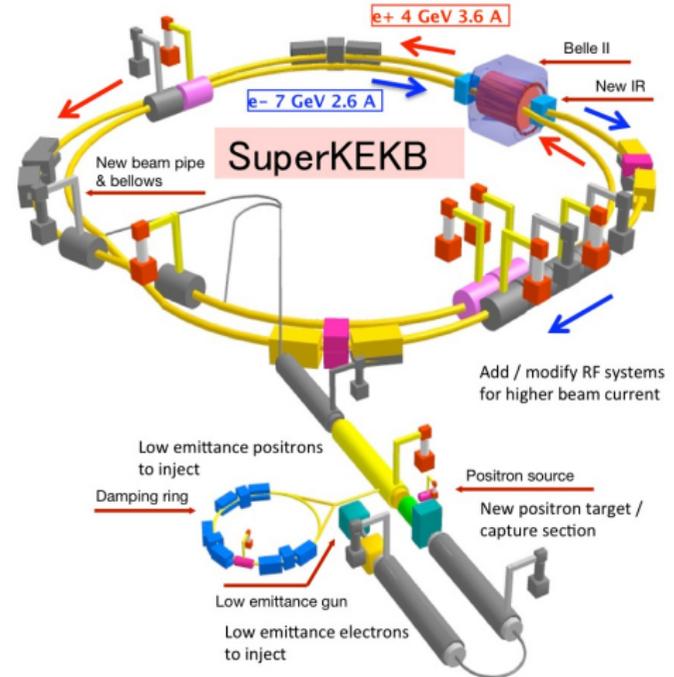
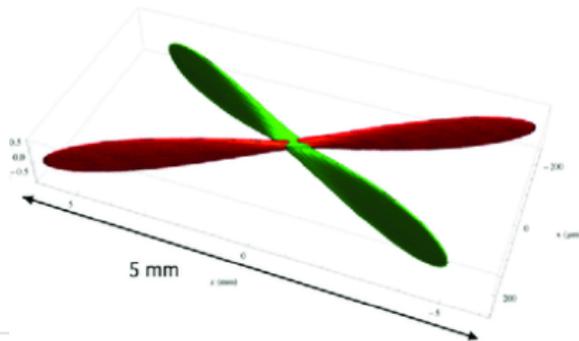
On behalf of the Belle II Collaboration for HQL2021

Moritz Bauer | 15. September 2021



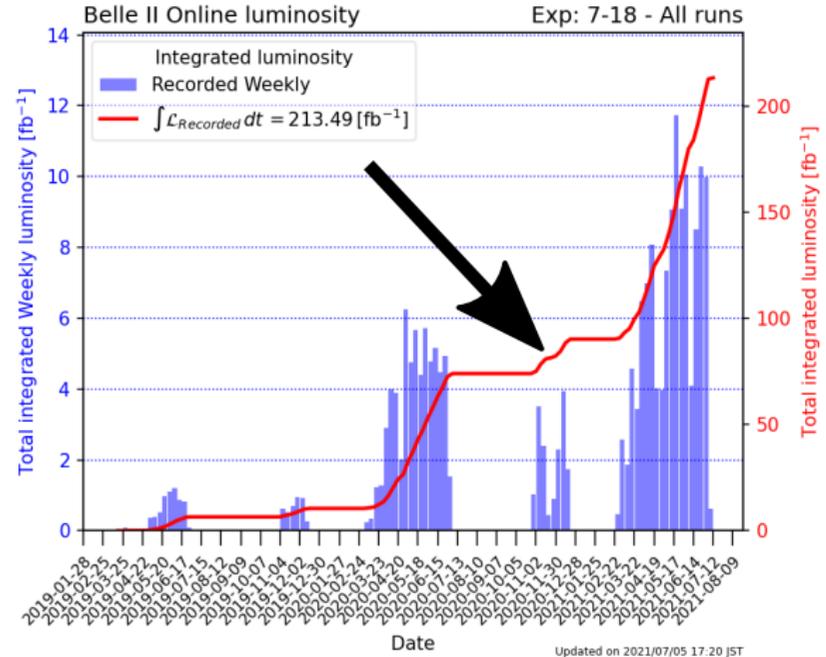
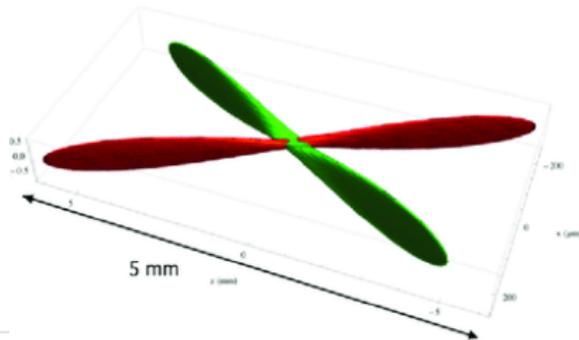
World record luminosity: SuperKEKB accelerator

- e^+e^- collider with $\sqrt{s} \approx 10.6$ GeV ($\Upsilon(4S)$ resonance)
- Peak luminosity (June 22): $3.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (+50% vs. KEKB)
 - In part thanks to nano-beam scheme.

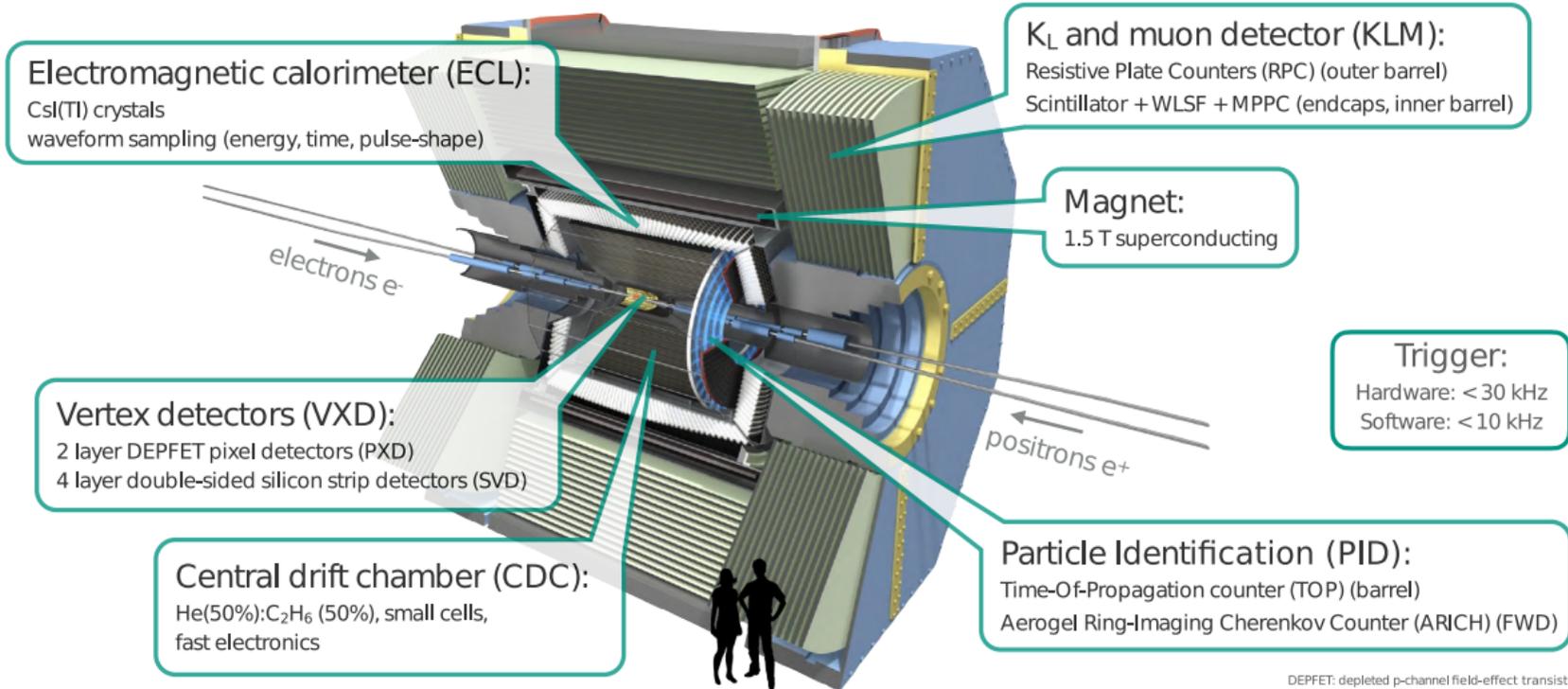


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 - In part thanks to nano-beam scheme.
- Current recorded dataset: $\approx 213 \text{ fb}^{-1}$
 - Aiming for 50x of Belle's dataset (50 ab^{-1})
 - Newest published analyses use $\approx 70 \text{ fb}^{-1}$.



The Belle II detector



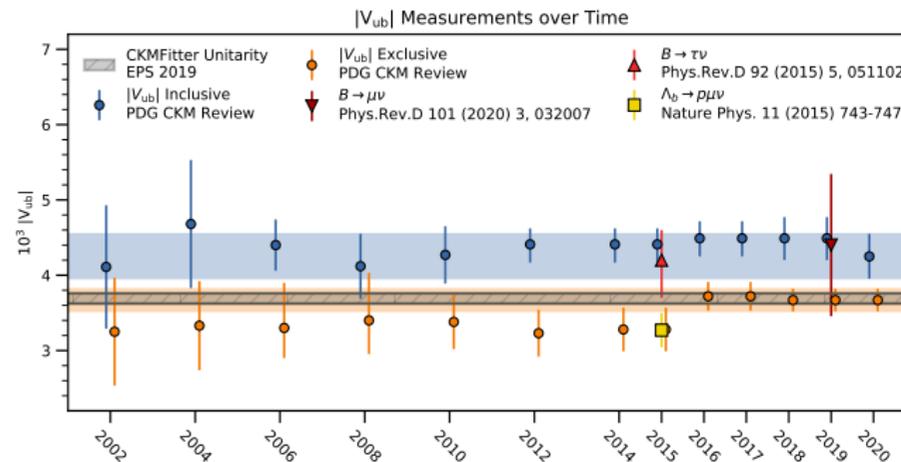
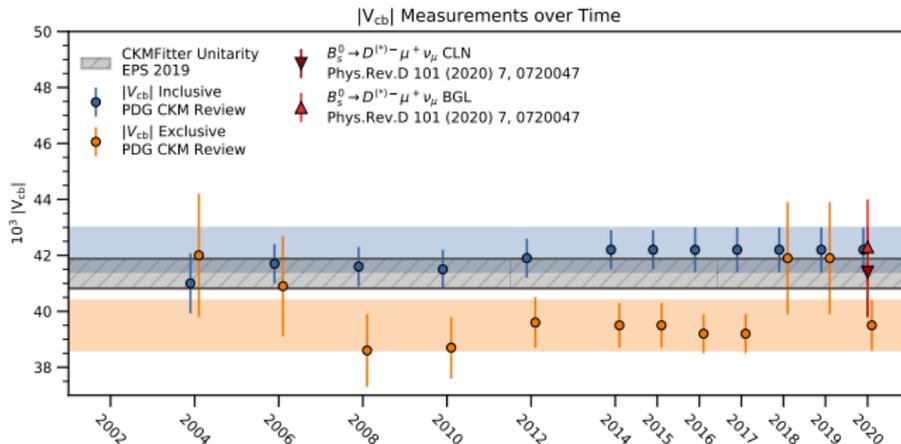
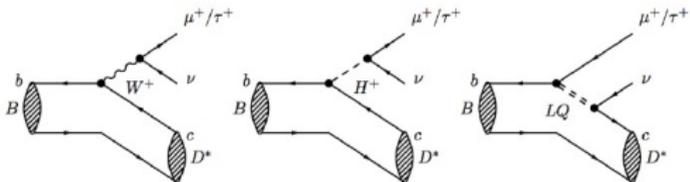
DEPFET: depleted p-channel field-effect transistor
 WLSF: wavelength-shifting fiber
 MPPC: multi-pixel photon counter

Semileptonic decays

- Tension ($\approx 3.3\sigma$) between
 - incl. (all $B \rightarrow X\ell\bar{\nu}_\ell$) and
 - excl. (one $b \rightarrow x$ process)

measurements of $|V_{ub}|/|V_{cb}|$.

- $|V_{cb}|$ sensitive to charged Higgs in 2HD models or leptoquarks.

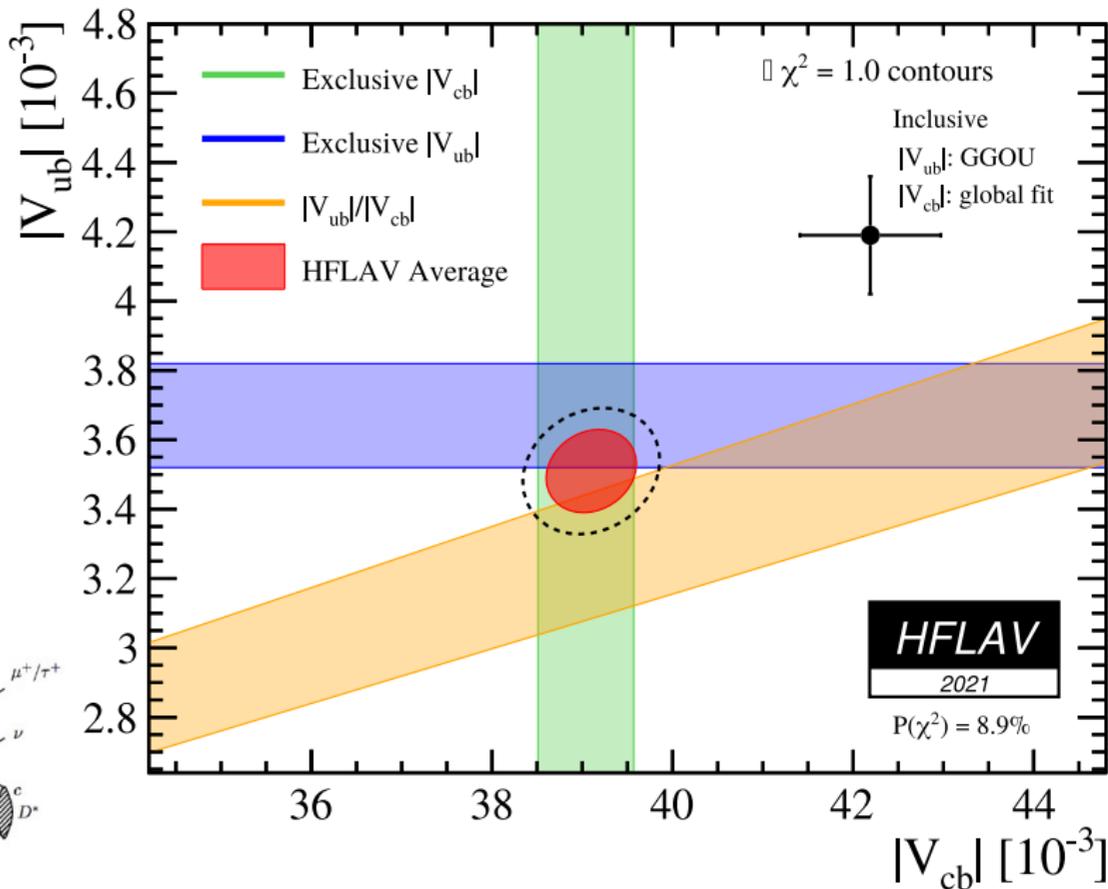
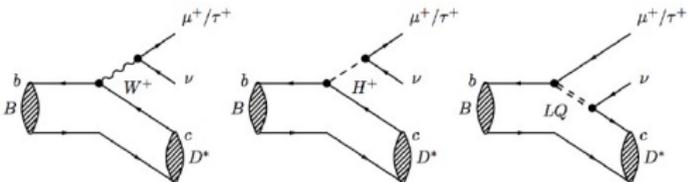


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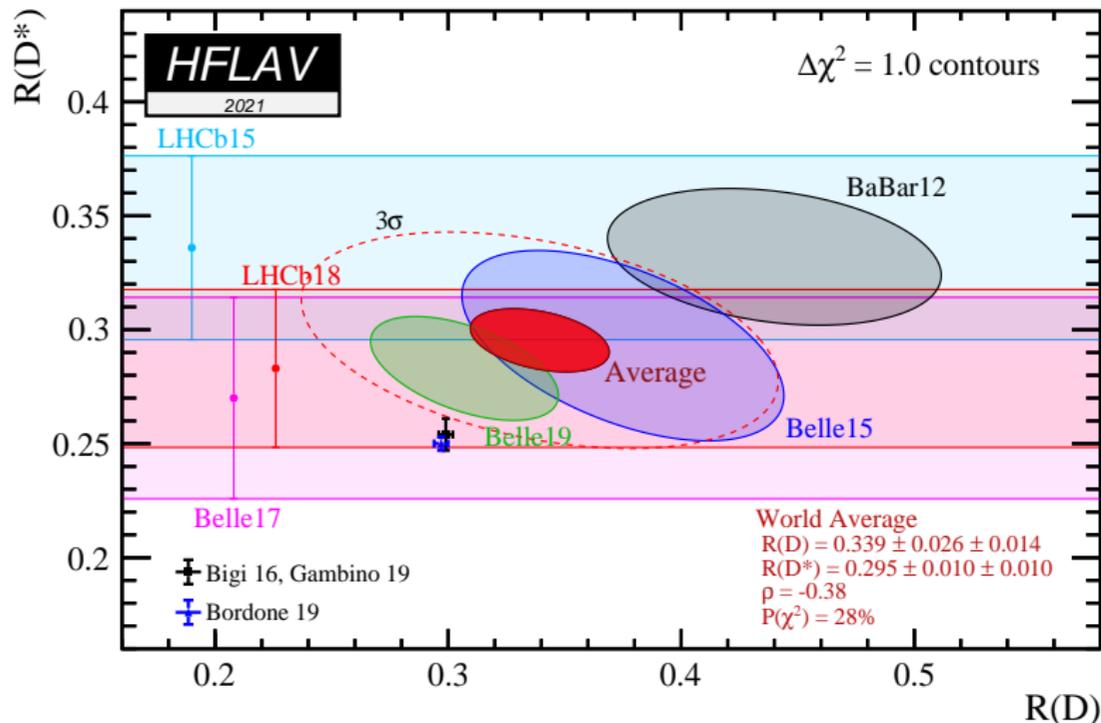
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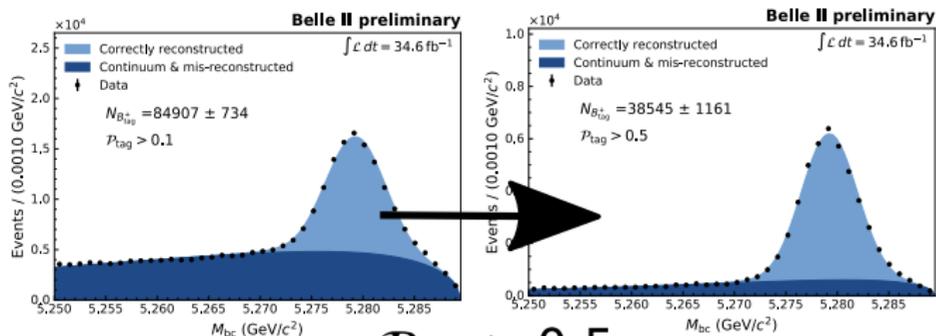
- Similar situation (combined $\approx 3.1\sigma$) for ratios

$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu_\tau)}{\mathcal{B}(B \rightarrow D^{(*)} \ell \nu_\ell)}$$



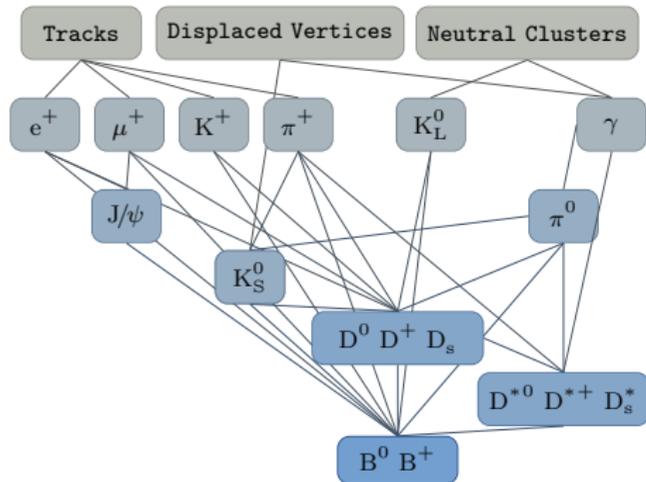
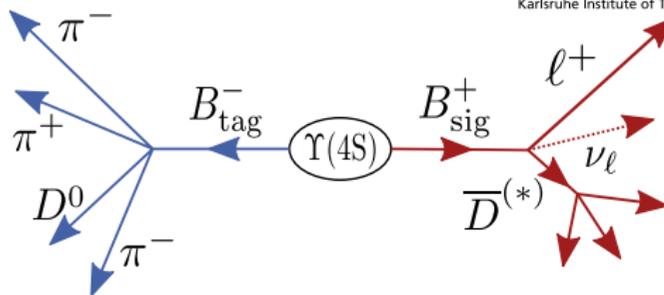
Experimental techniques

- e^-e^+ collisions “clean” compared to pp.
- Tagging: Use 2nd B (B_{tag}) e.g. with Full Event Interpretation (FEI). Keck, T. et al. *Comput Softw Big Sci* 3, 6



$P_{\text{tag}} > 0.5$ [arXiv:2008.06096](https://arxiv.org/abs/2008.06096)

- Alternative: Untagged with potentially all events.
 - Exclusive analyses can combine all non-signal events into “inclusive tag”.
 - Smaller systematic uncertainties can compete already (see $B^+ \rightarrow K^+ \nu \bar{\nu}$; arXiv:2104.04754).



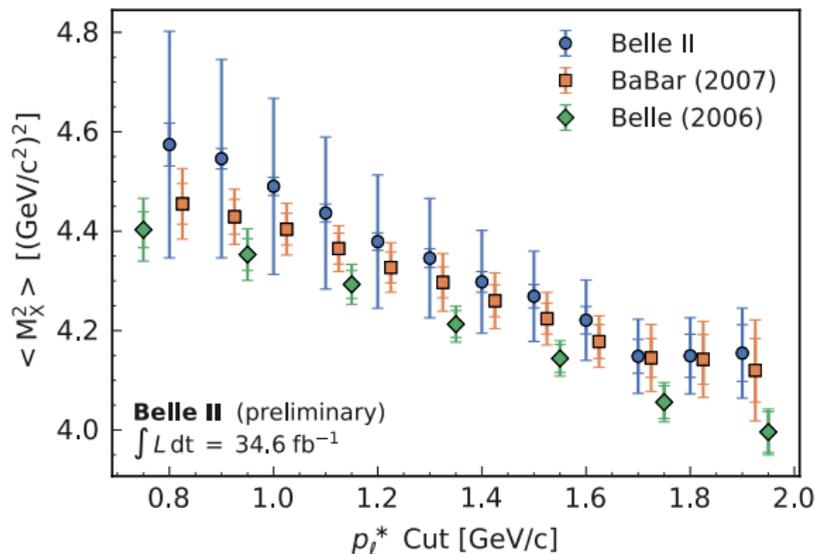
Tagged inclusive $B \rightarrow X_c \ell \nu$

arXiv:2009.04493

- Measurement of first six mass moments $\langle M_X^n \rangle$ of the hadronic system.

- Background is subtracted with weight $\omega_i(M_X)$.
- To avoid unfolding, calibration between true and reconstructed mass is needed.
- Main systematic uncertainty from X_c composition.
- Next: $|V_{cb}|$ from q^2 moments (novel approach!).

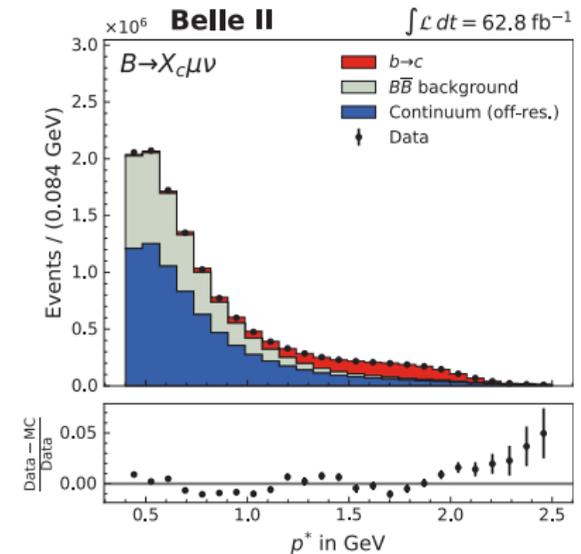
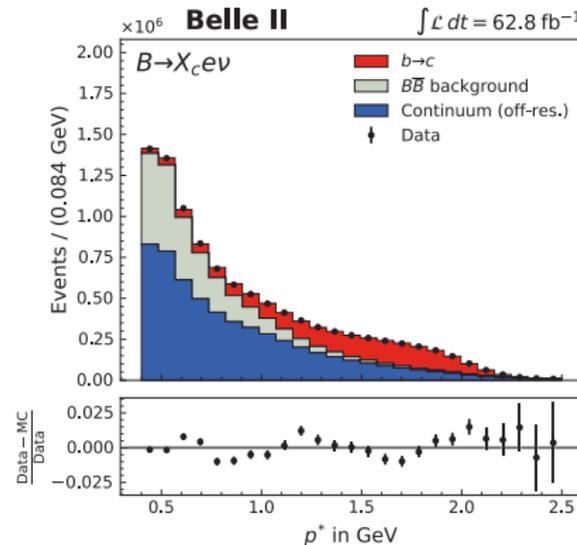
Momentum transfer squared: $q^2 = (p_B - p_X)^2$



Untagged inclusive $B \rightarrow X_c \ell \nu$

- Only signature: single (well identified) lepton.
 - Use missing mass/momentum and event charge to reject events with >1 neutrino.

- Signal extraction in p_{lep}^* , from 0.4 GeV to 2.5 GeV.
- BF result: $(9.75 \pm 0.03_{stat} \pm 0.47_{sys})\%$
- Dominant sys. uncert. from $B \rightarrow X_c \ell \nu$ composition.
- Next: $|V_{cb}|$ from q^2 moments



Tagged exclusive $\bar{B}^0 \rightarrow D^{*+} (\rightarrow D^0 \pi_s) \ell \nu$

arXiv:2008.10299

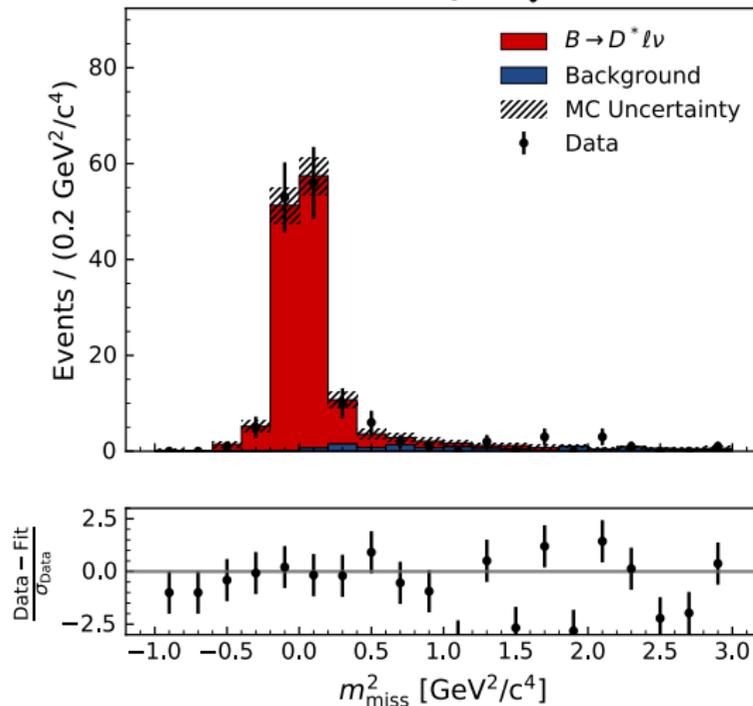
- Little background with $m_{D^*}, m_D, p_l^* > 1 \text{ GeV}$ and extra track cuts.

- Signal extraction in M_{miss}^2 .

$$M_{miss}^2 = (p_{e^+e^-} - p_{B_{tag}} - p_{D^*} - p_\ell)^2$$

- BF: $(4.51 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_s})\%$
 - In agreement with world average but not competitive yet.
- Main systematic: “slow” pion from D^* and MC modelling.

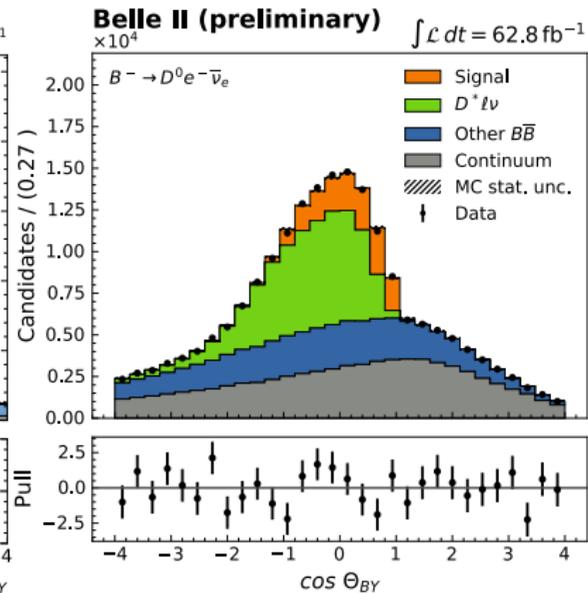
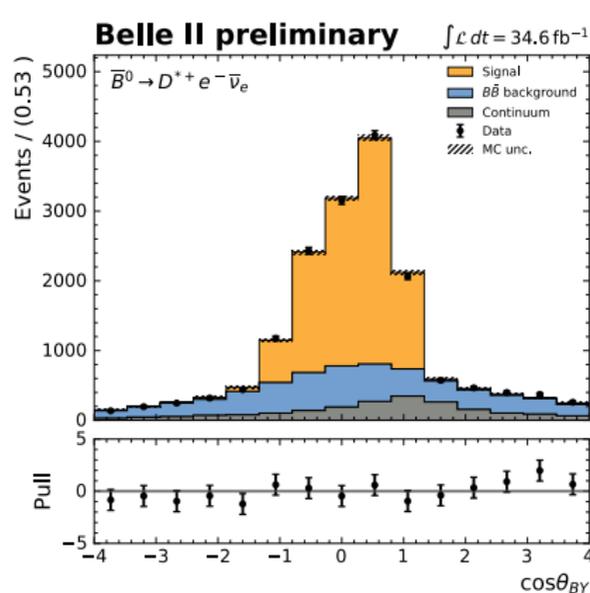
Belle II Preliminary $\int \mathcal{L} dt = 34.6 \text{ fb}^{-1}$



Untagged exclusive $B \rightarrow D^{(*)} \ell \nu$

arXiv:2008.07198

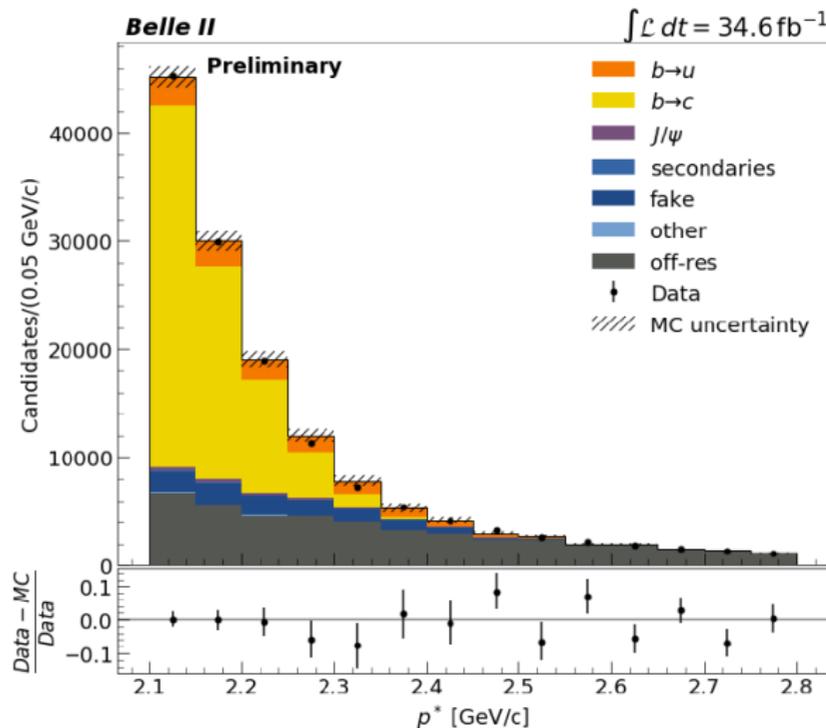
- Signal extraction in $\cos(\theta_{BY})$, the angle between $D^0 \ell$ system and B meson from beam 4-momentum.
- BF (D):
 $(2.29 \pm 0.05_{\text{stat}} \pm 0.08_{\text{sys}})\%$
 - Consistent (and competitive!) with world average.
 - Next: $|V_{cb}|$ from partial BF in bins of q^2 .



Untagged inclusive $B \rightarrow X_u \ell \nu$

arXiv:2103.02629

- Signal extraction in electron momentum in center-of-mass frame p^* .
- Signature also only a single well identified lepton (like $B \rightarrow X_c \ell \nu$).
→ go to p^* endpoint (2.1 GeV to 2.8 GeV).
- $B \rightarrow X_u \ell \nu$ observed with $\approx 3\sigma$.

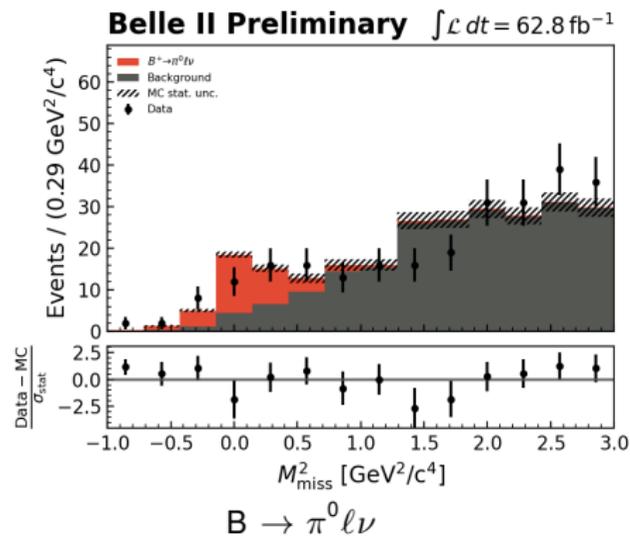
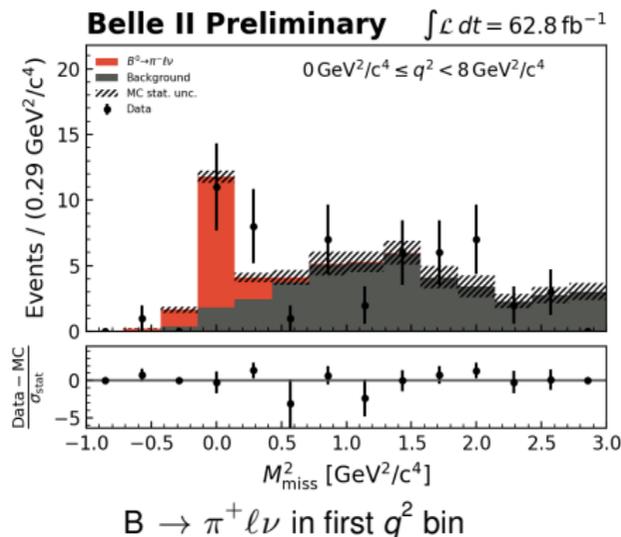


Tagged exclusive $B \rightarrow X_u \ell \nu$, $X_u = \{\pi^+, \pi^0, \rho^+, \rho^0\}$



- $\mathcal{B}(B \rightarrow \pi^0 \ell \nu) = (8.29 \pm 1.99_{\text{stat}} \pm 0.46_{\text{sys}}) \times 10^{-5}$

- $B \rightarrow \pi^{+,0} \ell \nu$ re-discovered with $> 6\sigma$.
- $\mathcal{B}(B \rightarrow \pi^+ \ell \nu)$ in bins of q^2 .
- Next: $|V_{ub}|$.
- Also first (stat. limited) results for $B \rightarrow \rho \ell \nu$.

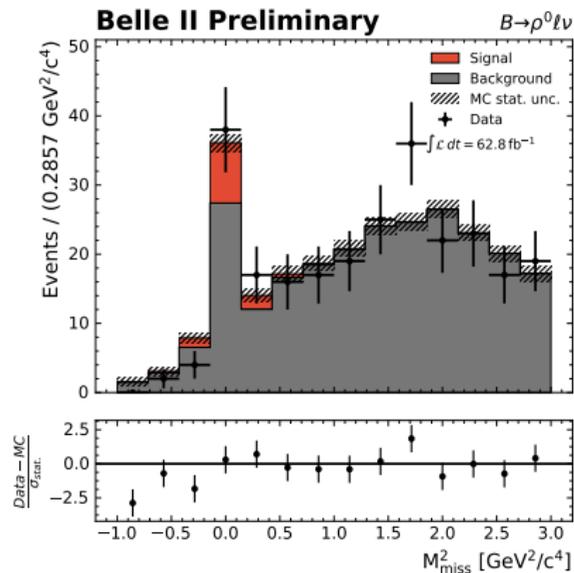
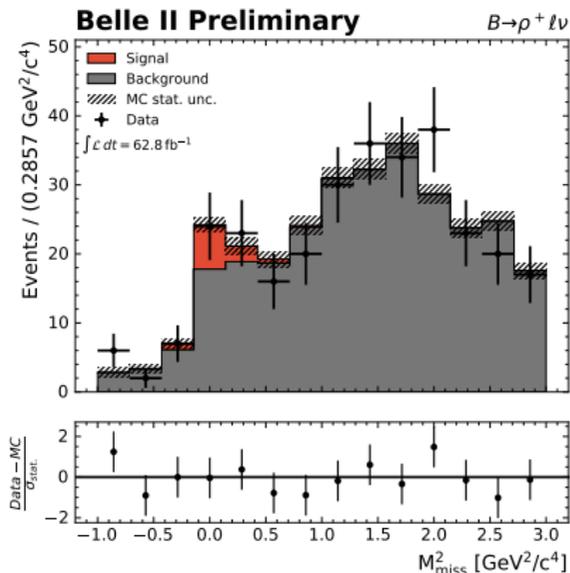


Tagged exclusive $B \rightarrow X_u l \nu$, $X_u = \{\pi^+, \pi^0, \rho^+, \rho^0\}$

NEW!

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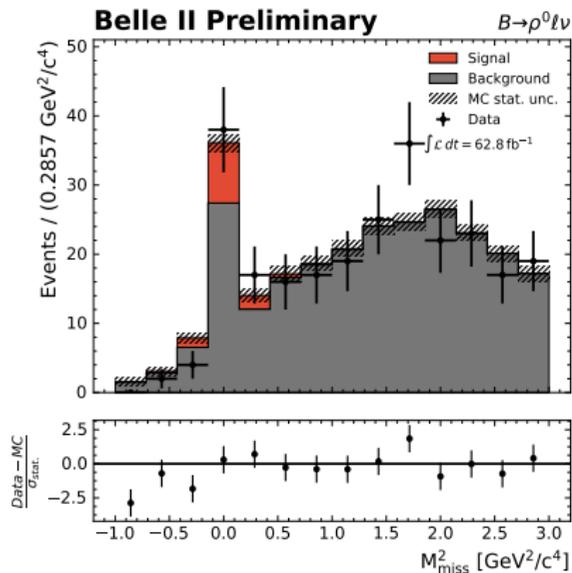
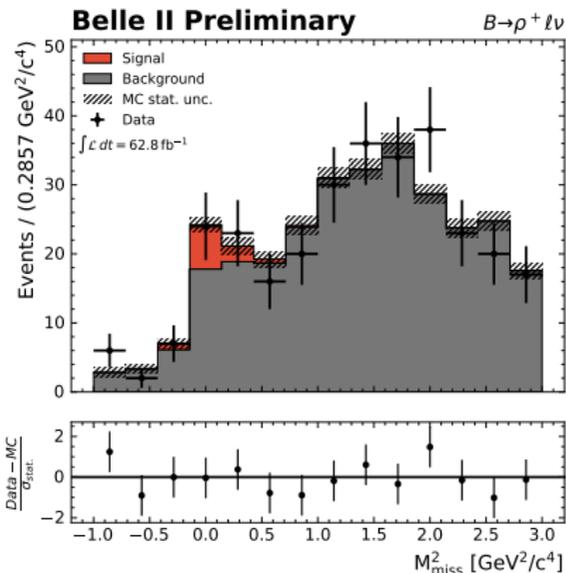


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- Also first (stat. limited) results for $B \rightarrow \rho \ell \nu$.
- Untagged excl. measurement of $|V_{ub}|$ in progress.

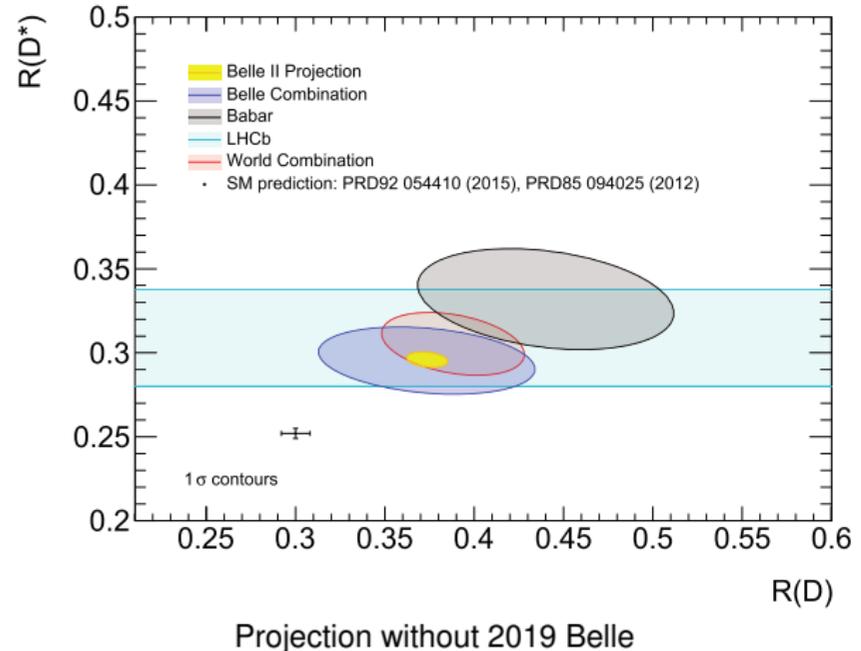


Prospects for $R(D)$ and $R(D^*)$

$$R(D^{(*)}) = \frac{\mathcal{B}(B \rightarrow D^{(*)} \tau \nu_\tau)}{\mathcal{B}(B \rightarrow D^{(*)} \ell \nu_\ell)}$$

- Theory-wise interesting because $|V_{cb}|$ & FFs partially cancel here but τ 's experimentally challenging.
- Belle II can conduct multiple indep. (un-)tagged measurements here.
 - Hadronic/SL tagged, untagged
 - Hadronic and leptonic τ decay
- Complementary to LHCb in many channels.

From Belle II physics book: [Prog Theor Exp Phys 12 \(2019\)](#)

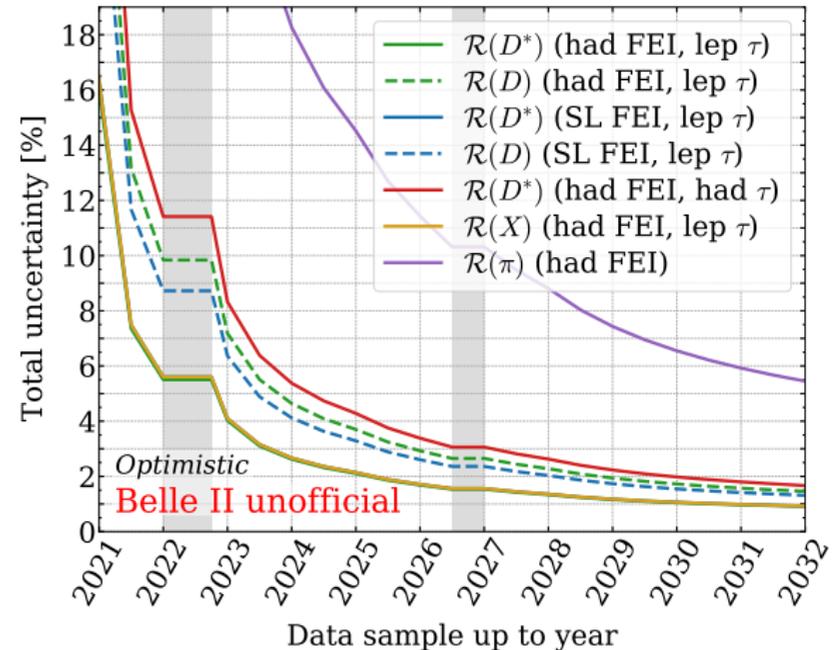


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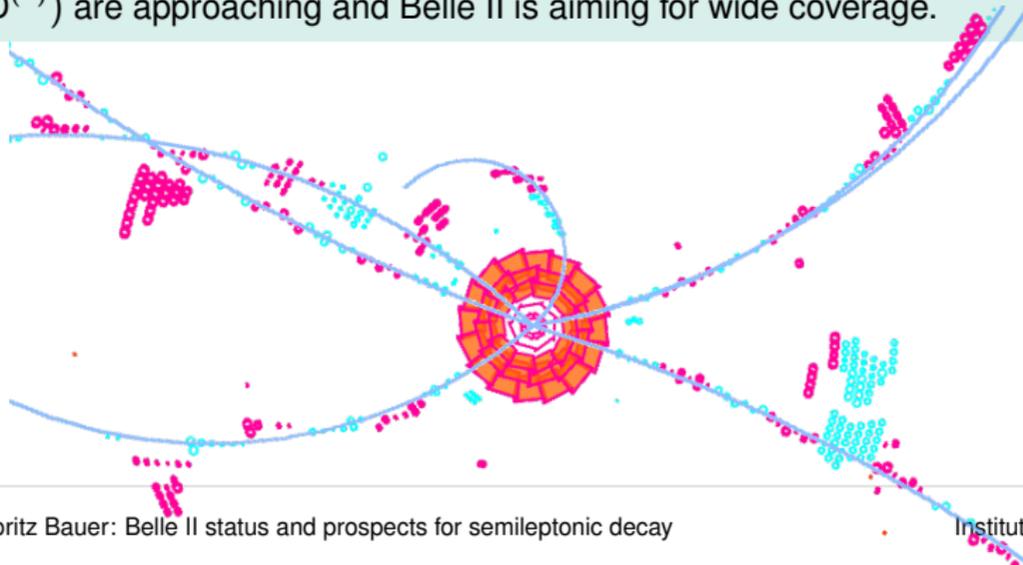
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Not Belle II official! Adapted from [arXiv:2101.08326](https://arxiv.org/abs/2101.08326)



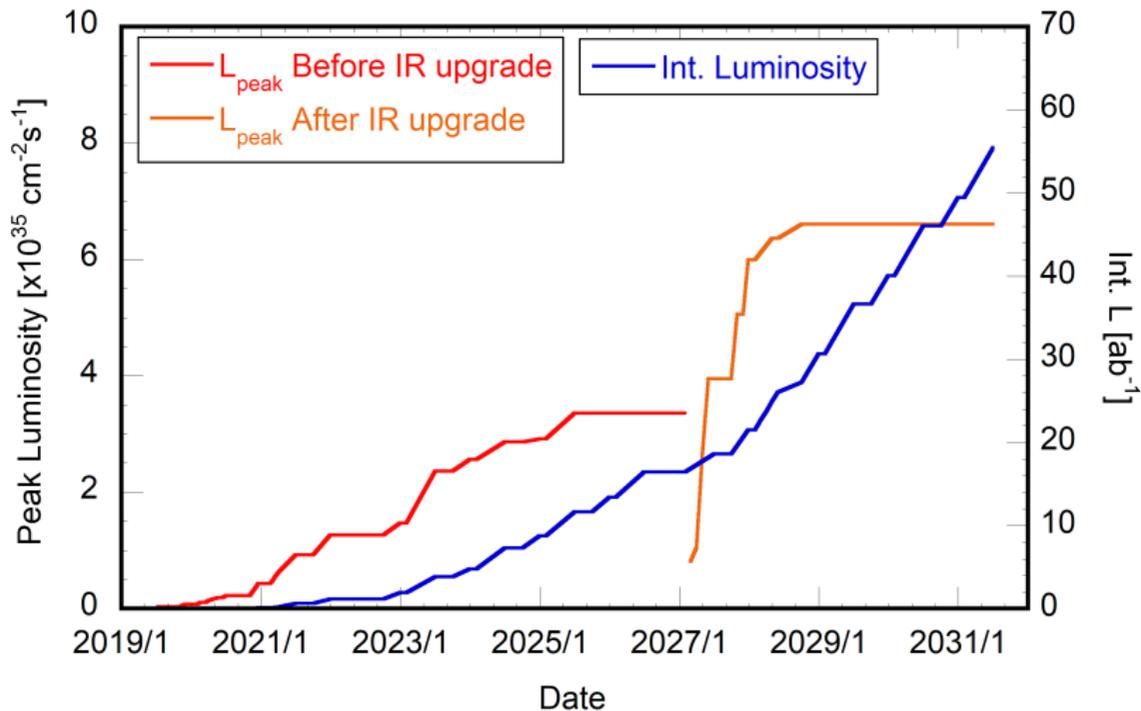
Summary

- Shown today: 6 measurements
 - Using up to 1/4 of currently recorded dataset.
 - Untagged BF measurements already competitive thanks to new techniques.
 - Tagged measurements need some more data but more competitive thanks to FEI.
- Soon, Belle II should be able to address the tension in $|V_{cb}|$ and $|V_{ub}|$ measurements.
- Results for $R(D^{(*)})$ are approaching and Belle II is aiming for wide coverage.



Backup

Luminosity projection



Tagged inclusive $B \rightarrow X_c \ell \nu$ in detail

- Measurement of first six mass moments $\langle M_X^n \rangle$ of the hadronic system [arXiv:2009.04493](https://arxiv.org/abs/2009.04493)

$$\langle M_X^n \rangle = \frac{\sum_i \omega_i(M_X) M_{X,\text{calibi}}^n}{\sum_i \omega_i(M_X)} \times C_{\text{calib}} \times C_{\text{true}}$$

- Background is subtracted with weight $\omega_i(M_X)$.
- To avoid unfolding, calibration between true and reconstructed mass is needed.
- Main systematic uncertainty from bias correction C_{true} .
- $|V_{cb}|$ from q^2 moments (novel approach!) ongoing.

