Image credit: KEK

Leptonic and Semi-leptonic Decays at the Belle II Experiment

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THE UNIVERSITY OF SYDNEY

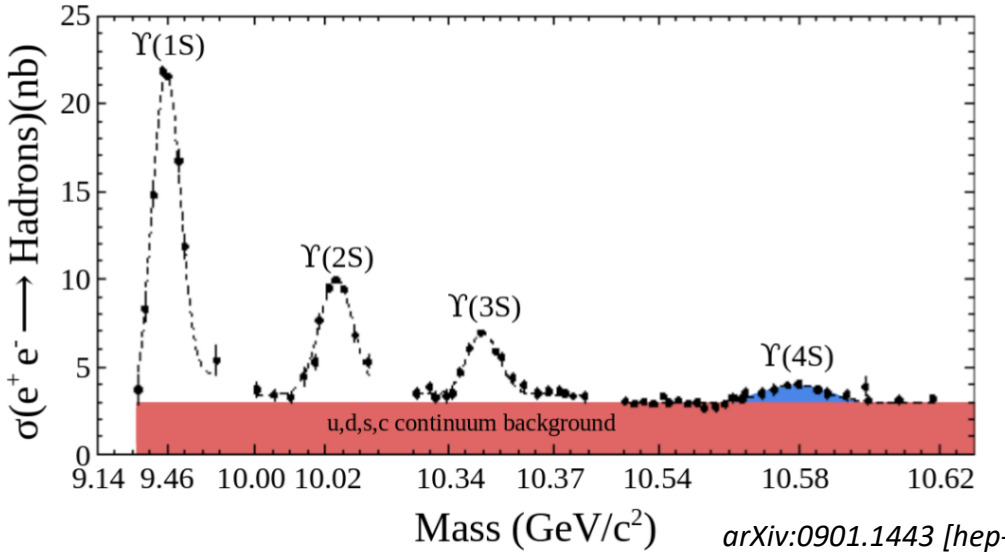
Belle II

Overview

- The Belle II Experiment
- Prospects and motivation for (semi-)leptonic decays at Belle II
- Analysis strategies and software
- Recent physics results

The Belle II Experiment

- Successor to Belle - first observation of CP-violation in neutral *B*-mesons, along with BaBar in Stanford. *arXiv:hep-ex/0107061*
- SuperKEKB accelerator collides asymmetric beams of 4.0 GeV positrons e^+ and 7.0 GeV electrons e^-
- Center-of-mass energy of collision at *Y(4S)* ($b\bar{b}$) resonance → produces a pair of B-mesons > 96% of the time. *Chin.Phys.C,40,100001*
- Primary aim is to measure the branching fractions of rare decays in the search for new physics
- First collisions April 2018!

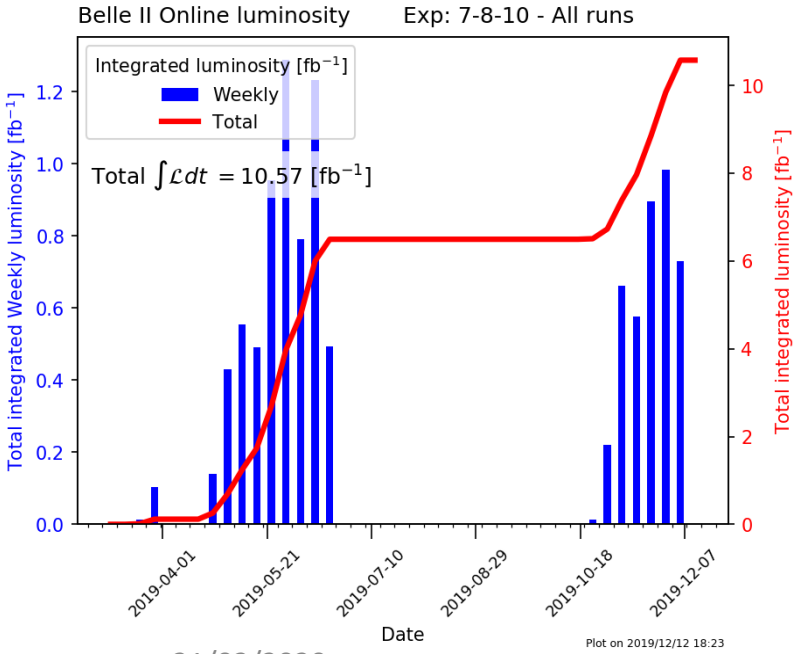


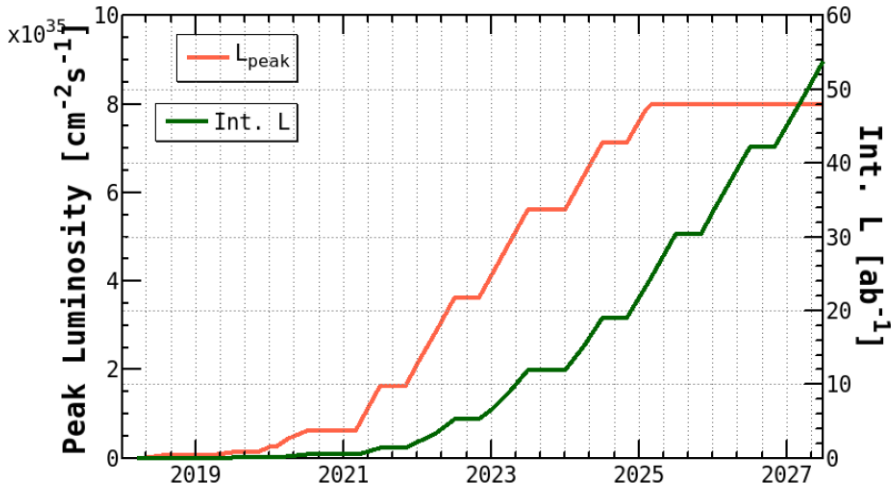
arXiv:0901.1443 [hep-ex]

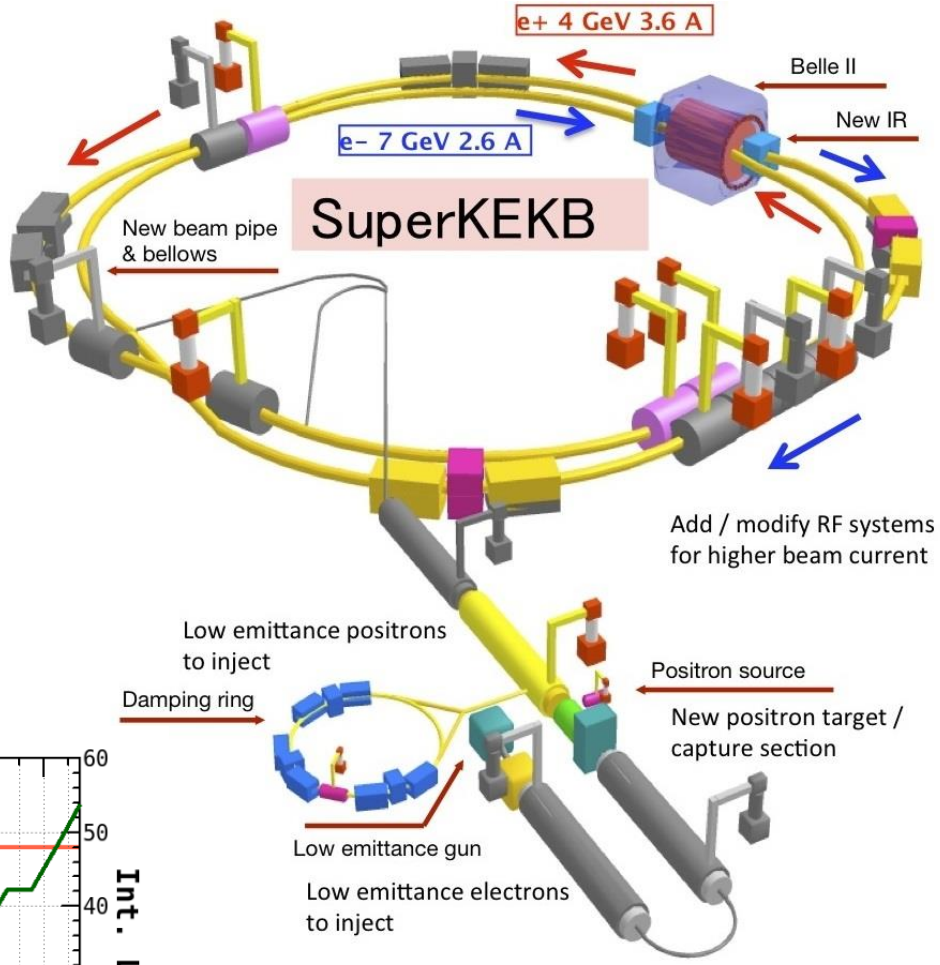
Phys. Rev. Accel. Beams 19, 121001

SuperKEKB

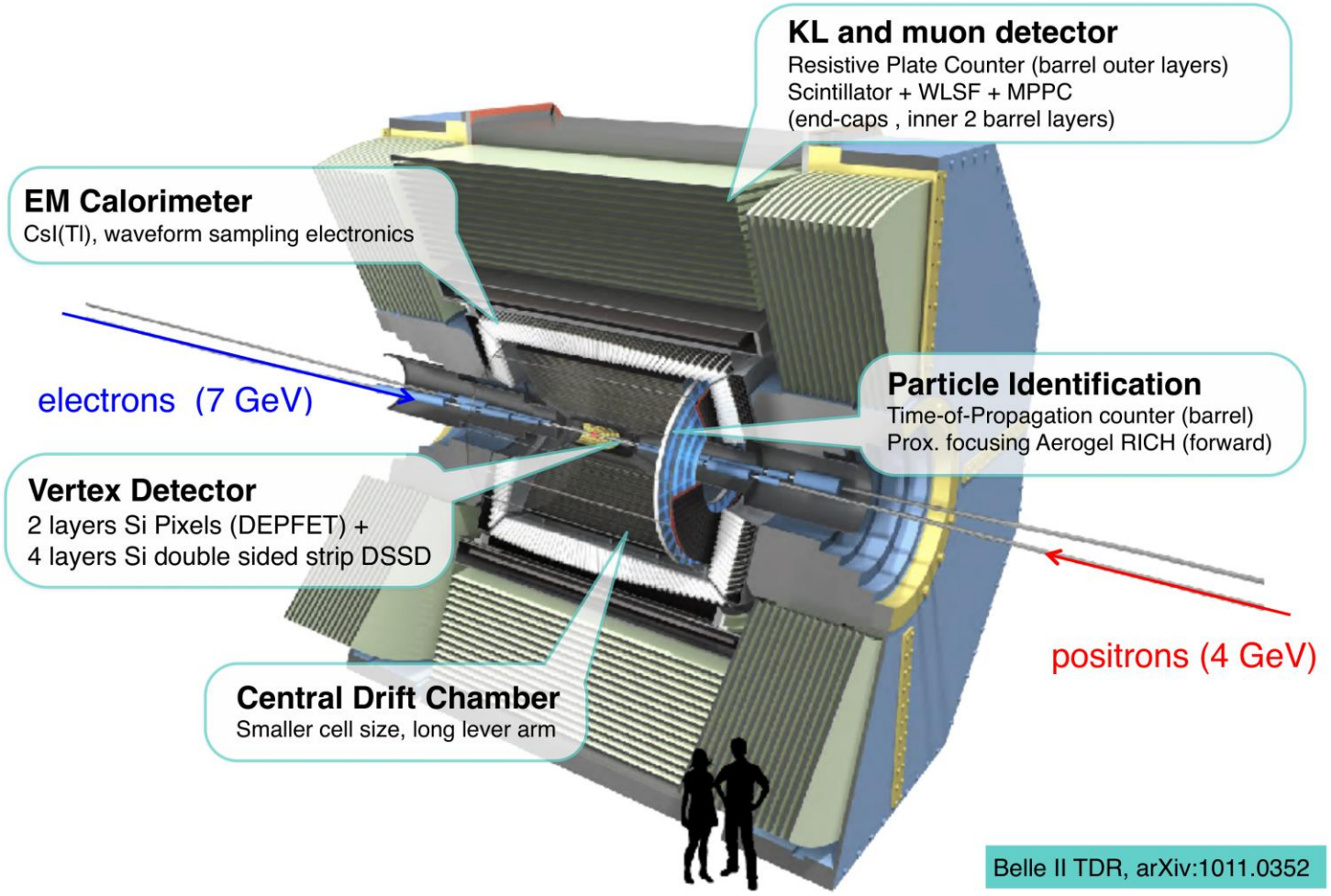
- Collected over 10 fb^{-1} of data so far – equivalent to more than 10 million $B\bar{B}$ pairs
- Target total integrated luminosity of 50 ab^{-1} – 50 times larger than Belle







The Belle II Detector



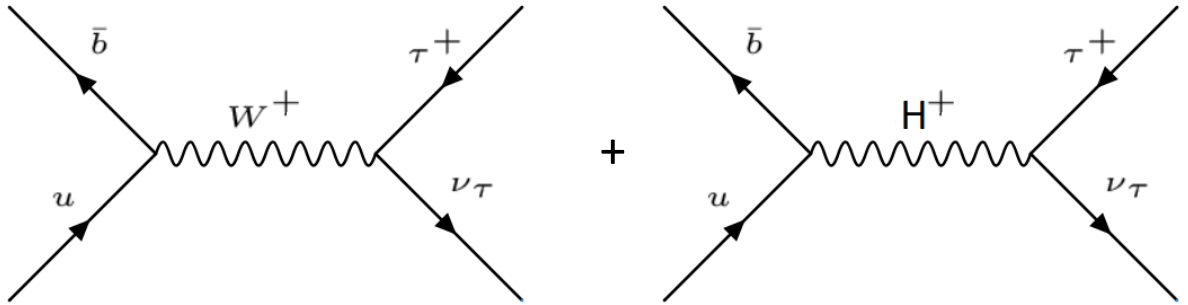
Why Study (Semi-)Leptonic Decays at Belle II?

Probe rare decays with sensitivity to new physics:

e.g. $B \to \tau\nu$

A charged Higgs proposed by the Two Higgs Doublet Model (2HDM) could mediate the decay instead of a W boson.

Interference between the two processes would cause a deviation in the branching fraction from SM predictions.



e.g. Tension in $B \to X_c\tau\nu$ measurements

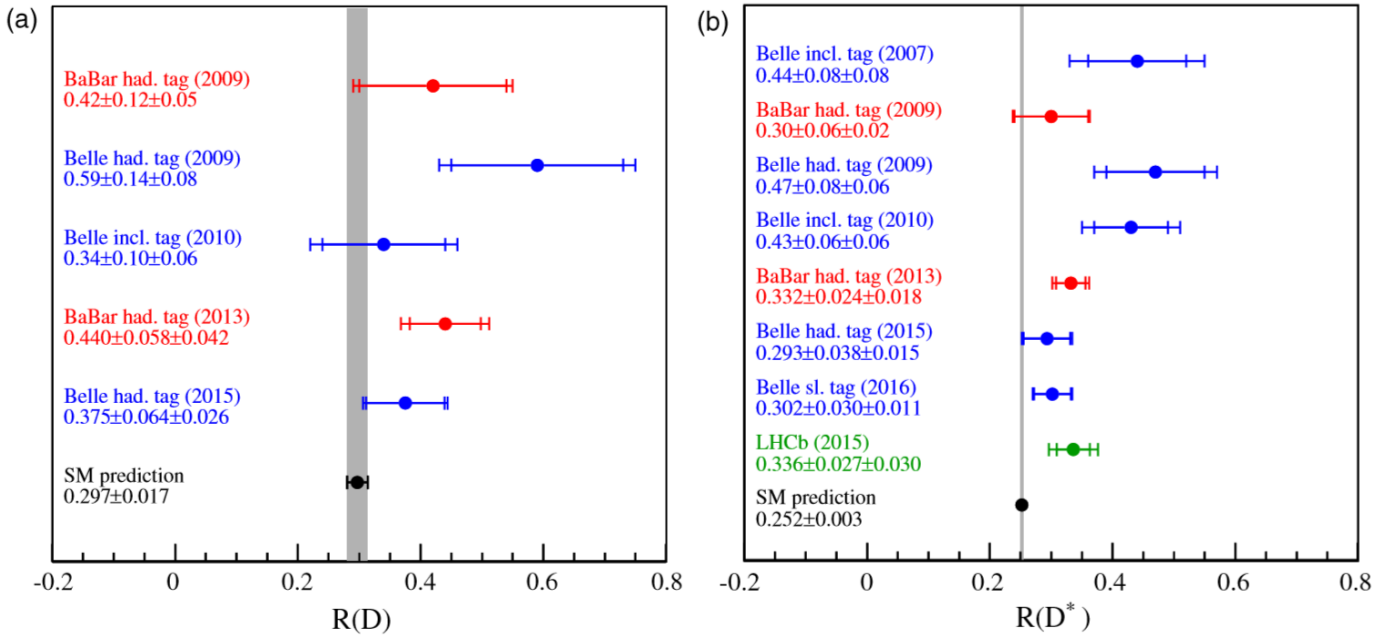
Most recent combined results from Belle and BaBar show a deviation from the SM of 1.9σ and 3.3σ for *R(D)* and *R(D*)*

RevModPhys.88.035008

$$R(D) = \frac{\Gamma(B \to D\tau\bar{\nu})}{\Gamma(B \to D\ell\bar{\nu})} = 0.297 \pm 0.017,$$

$$R(D^*) = \frac{\Gamma(B \to D^*\tau\bar{\nu})}{\Gamma(B \to D^*\ell\bar{\nu})} = 0.252 \pm 0.003.$$

SM Prediction

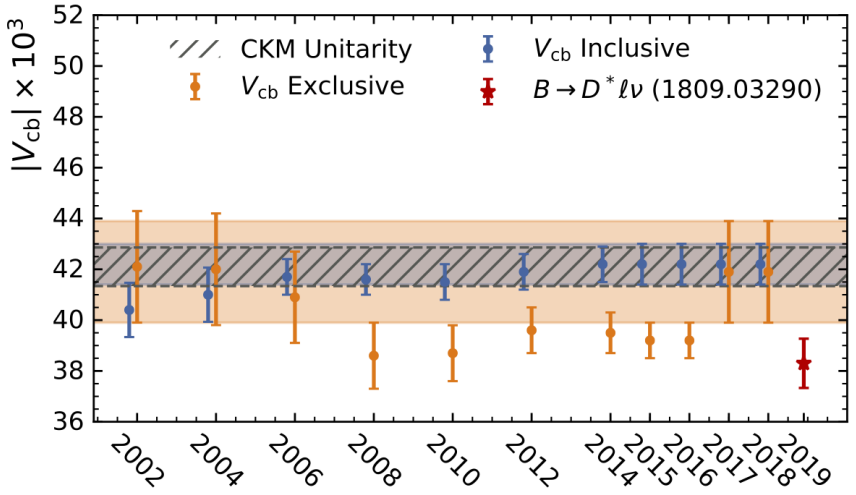


Why Study (Semi-)Leptonic Decays at Belle II?

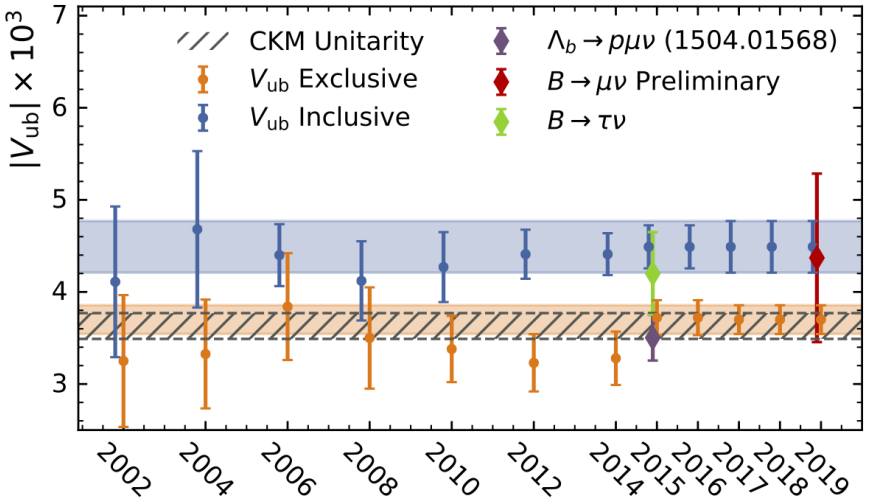
Precision measurements of Standard Model Parameters:

e.g. extracting $|V_{ub}|$ from an exclusive analysis of B → πlν (my thesis topic)

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{pmatrix}$$



Credit: Markus Prim

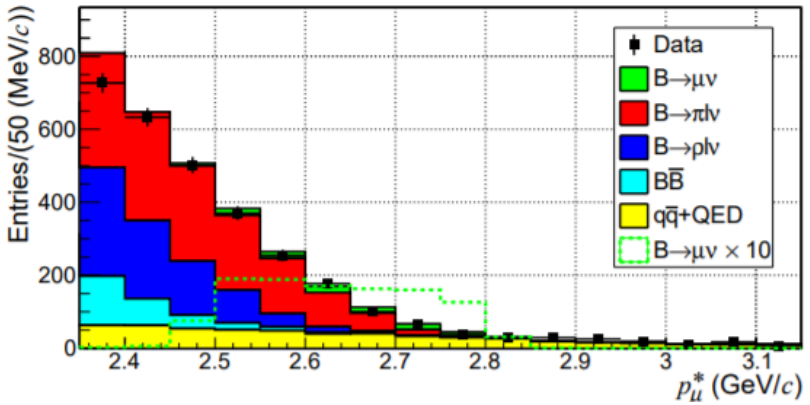


Credit: Markus Prim

Discovery of rare decays:

e.g. B → μν

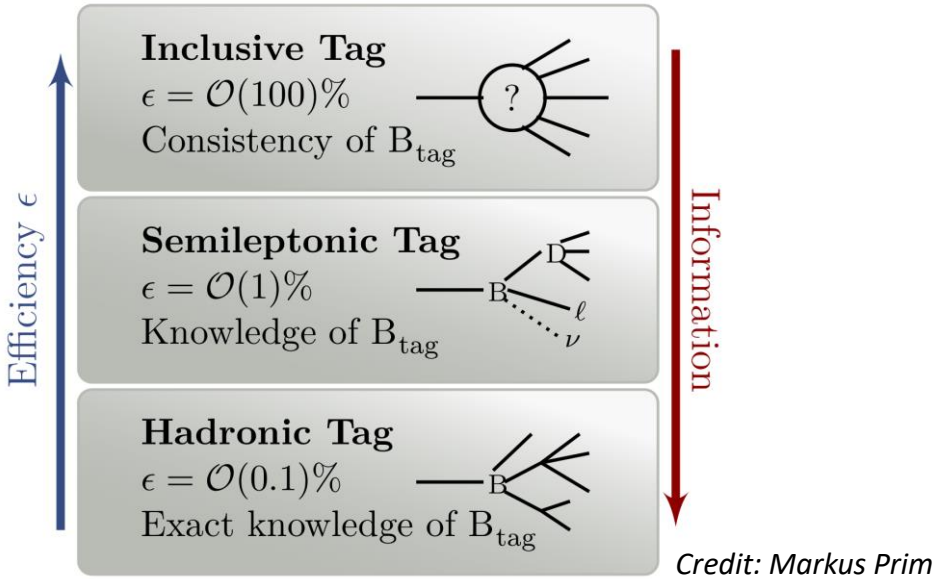
Recent Belle result found a 2.4σ excess above background, with a branching fraction of $\mathcal{B}(B^- \to \mu^- \bar{\nu}_\mu) = (6.46 \pm 2.22 \pm 1.60) \times 10^{-7}$ and an upper limit of 10.7×10^{-7} at a 90% confidence interval. *Phys. Rev. Lett. 121, 031801*



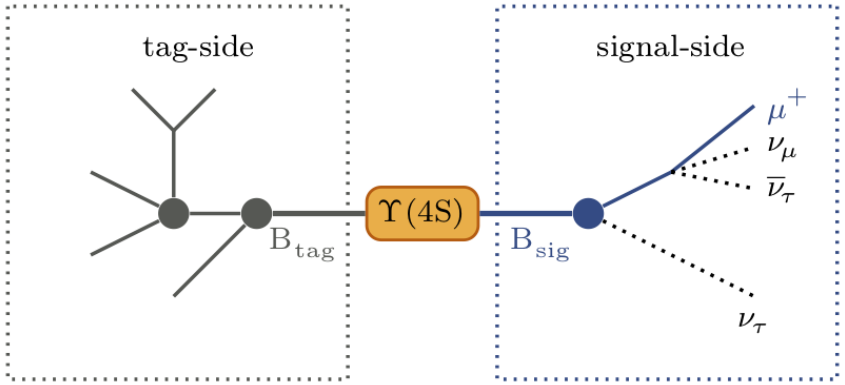
Belle → Belle II

711 fb^{-1} → 50 ab^{-1}

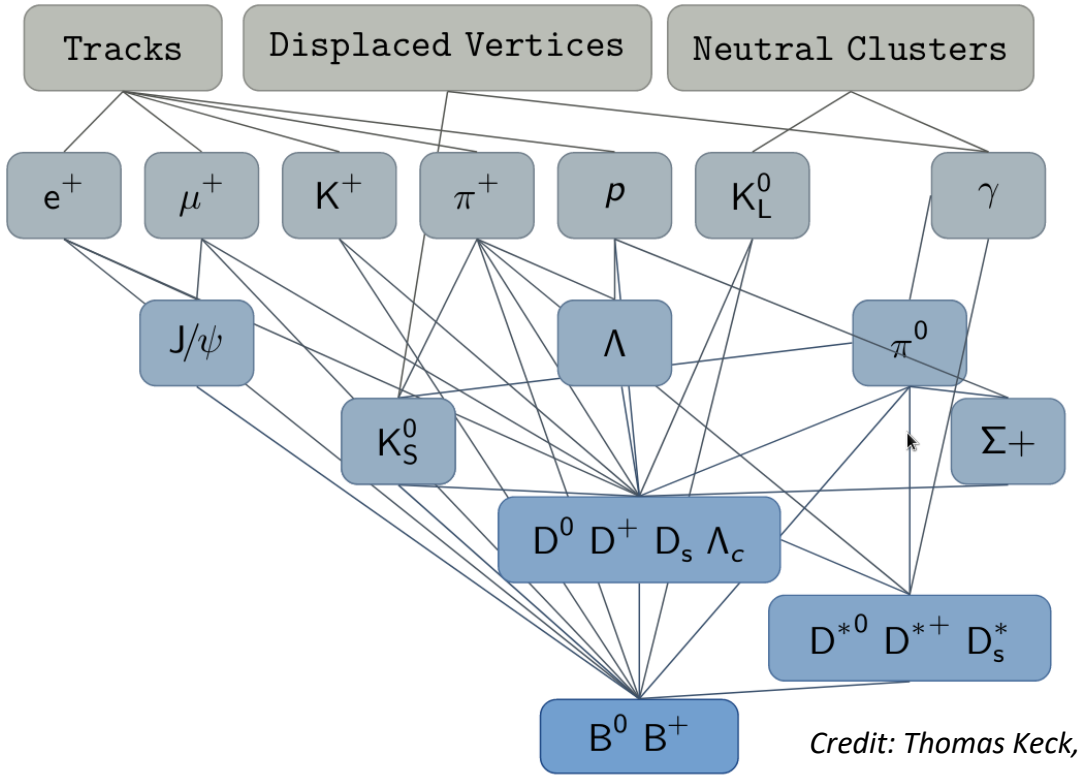
Analysing (Semi-)Leptonic Decays at Belle II



Credit: Markus Prim



Credit: Thomas Keck, Moritz Gelb



Credit: Thomas Keck, William Sutcliffe

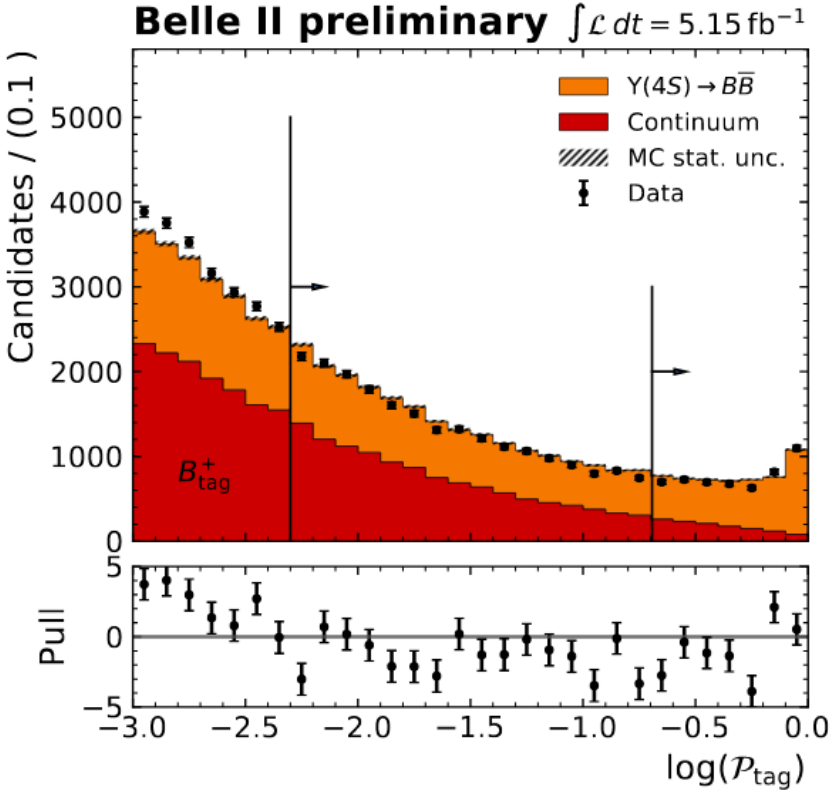
Full Event Interpretation (FEI)

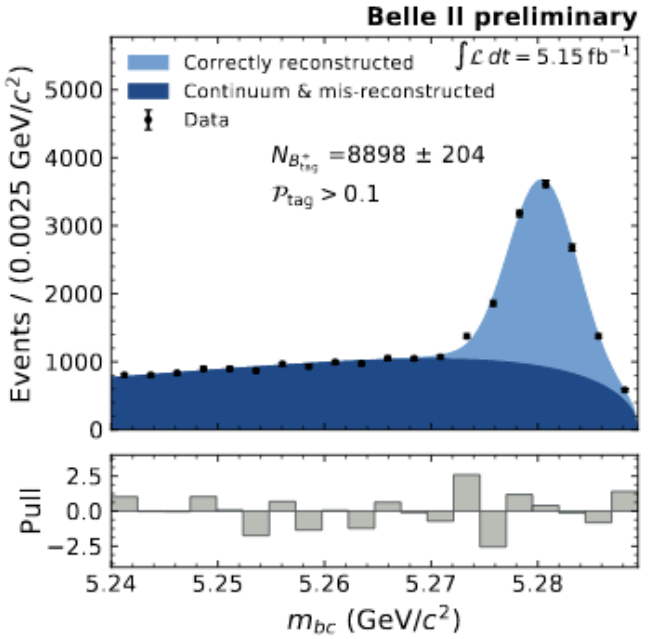
FEI Performance on Early Data

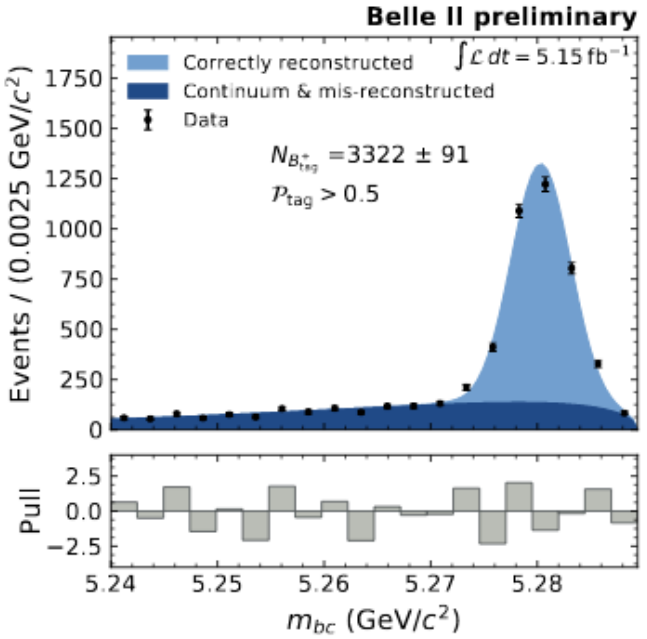
William Sutcliffe, BELLE2-NOTE-PL-2019-030

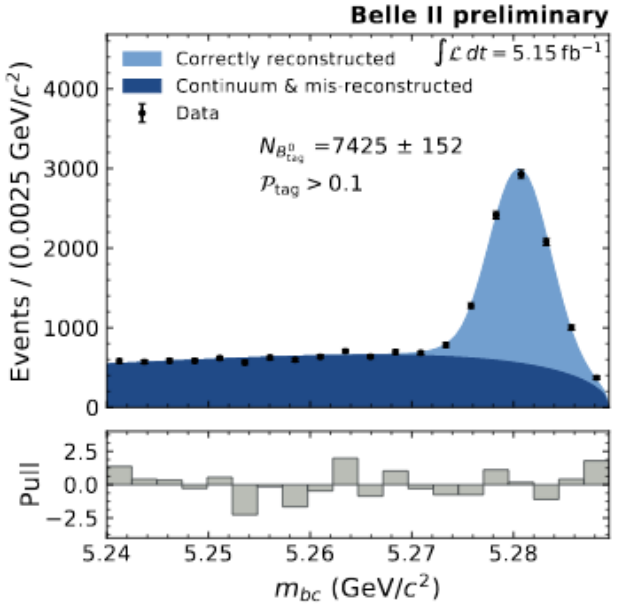
(+ cross-check by myself)

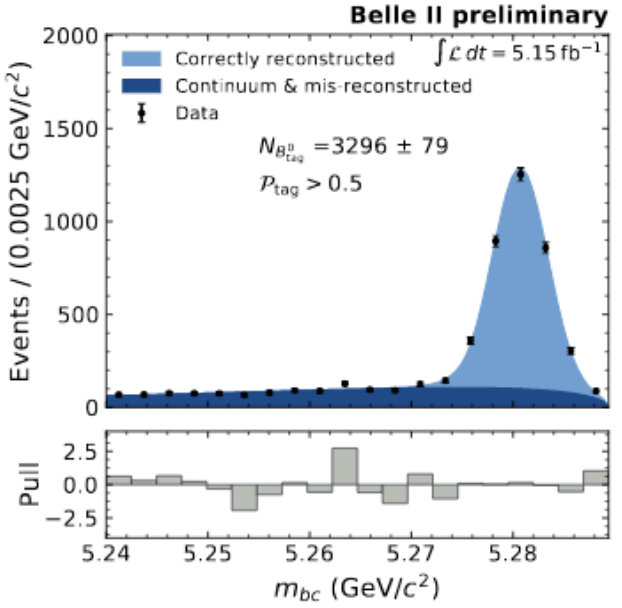
$$M_{bc} = \sqrt{E^2_{beam} - \vec{p}^2_{\mathrm{B}}}$$











$B_{sig} \to X e \nu_e$ with Hadronic FEI Tagging

William Sutcliffe, BELLE2-NOTE-PL-2019-030

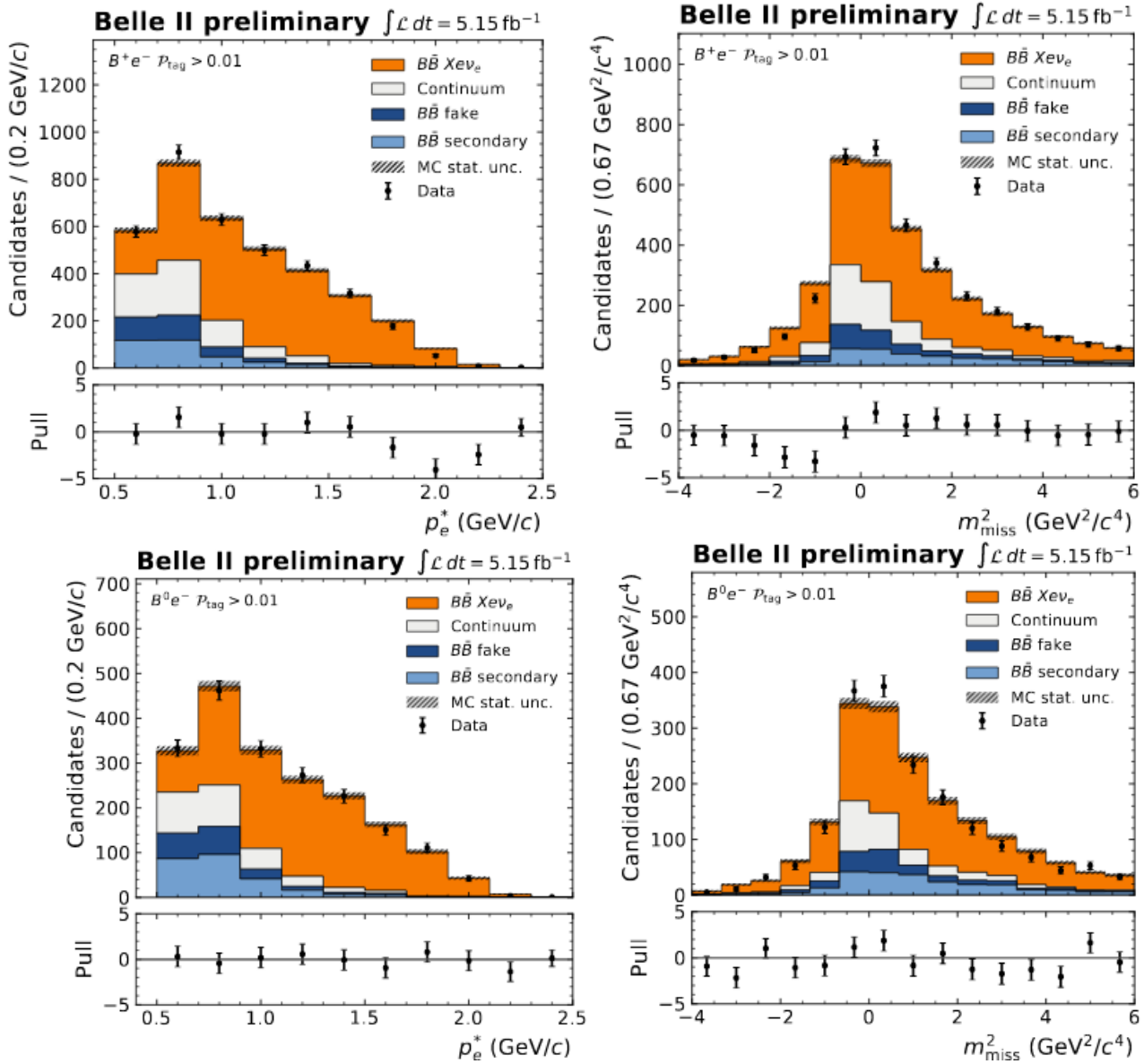
(+ cross-check by myself)

Reconstruction of an inclusive semi-leptonic signal side recoiling against a hadronic tag.

Only the B_{tag} and the electron are reconstructed in the event – the neutrino escapes and all other remaining particles are assigned to the X system.

$$M^2_{miss} = (p_{beam} - p_{B_{tag}} - p_\ell - p_{\Upsilon(4S)_{ROE}})^2$$

"Re-discovery" of $B \to X e \nu_e$ in early Belle II data



Untagged Analysis of $B^0 \to D^* l\nu$

Minakshi Nayak, BELLE2-NOTE-PL-2019-008

Here, the signal-side is reconstructed from a lepton and a D^* meson with decay chain:

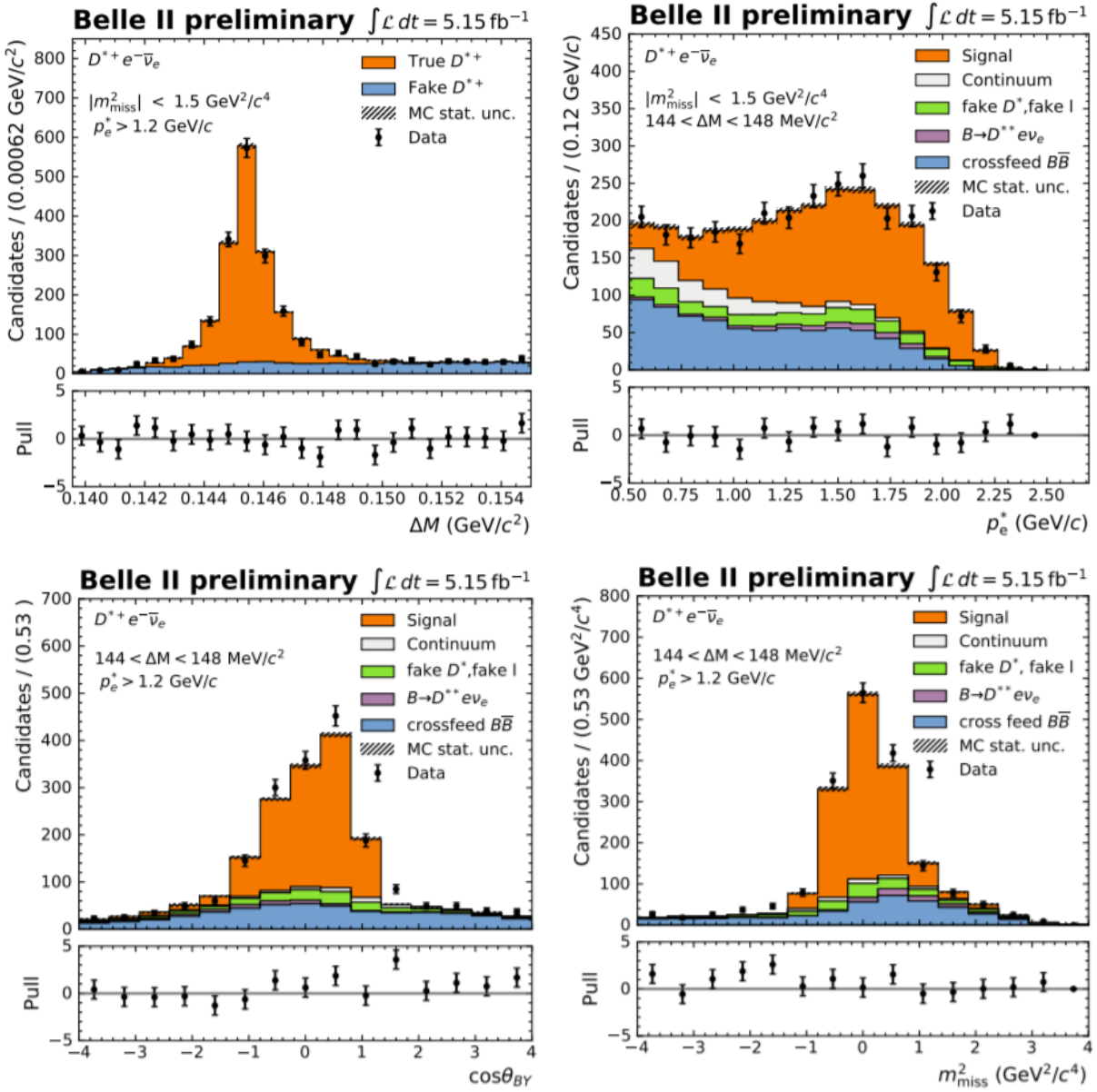
$D^{*+} \to D^0(D^0 \to K^- \pi^+)\pi^+$

O(1100) events are found for $B^0 \to D^* e\nu$, and O(1200) for $B^0 \to D^* \mu\nu$ (not pictured)

$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$$

$$m_{\mathrm{miss}}^2 = \left(\frac{P_{ee}}{2} - P_Y^*\right)^2$$

"Re-discovery" of $B^0 \to D^* l\nu$ in early Belle II data



Summary

- The Belle II Experiment is in full swing and has already collected > 10 fb^{-1} of data
- Upgrades to both the accelerator and detector from Belle aim to produce 50 times the Belle dataset at an improved performance
- Upgraded software tools are also available and currently being used for analysis
- Many prospects for the analysis of (semi-)leptonic decays, with an emphasis on the search for new physics beyond the Standard Model
- Exciting results with this early data-set have already been produced
  - stay tuned for more results in the coming years!