Results Related to Anomalies at Belle II

Martin Angelsmark on behalf of the Belle II Collaboration

DIS2022: WG3 - Electroweak Physics and Beyond the Standard Model

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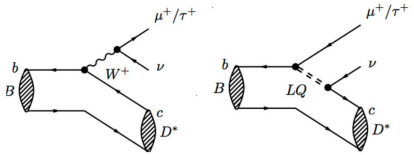
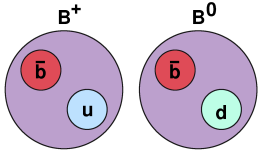
B-meson Anomalies

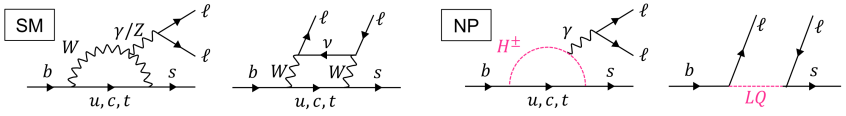
Semileptonic decays:





Electroweak penguin decays:

- Sensitive to new physics contributing to Flavor Changing Neutral Current



Examples of anomalies:

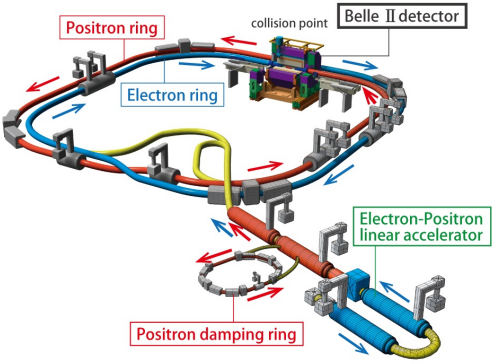
- Rates
- Angular distributions

Experimental observations of anomalies

- B-factories: BaBar, Belle
- LHCb

Belle II

- Located at superKEKB (Tsukuba, Japan)
- e^+e^- collider at $\Upsilon(4S)$ (10.58 GeV)



Belle II

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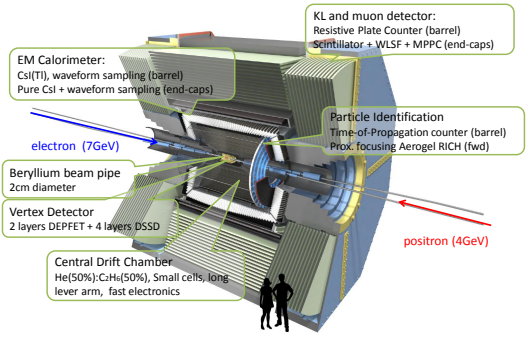
- e^+e^- collider at $\Upsilon(4S)$ (10.58 GeV)
- $\Upsilon(4S) \to B\overline{B}$
- Clean $B\overline{B}$ events
- Initial state well known

Collected > 350 fb^{-1}
10 year goal: 50 ab^{-1}
World record instantaneous luminosity:
$3.8 \cdot 10^{34}$ cm^{-2}s^{-1}

[BELLE2-REPORT-2016-001]

Belle II Detector



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Sometimes no $\Upsilon(4S)$ is produced:

- $e^+e^- \to q\overline{q}$ (continuum)
- Largest background component

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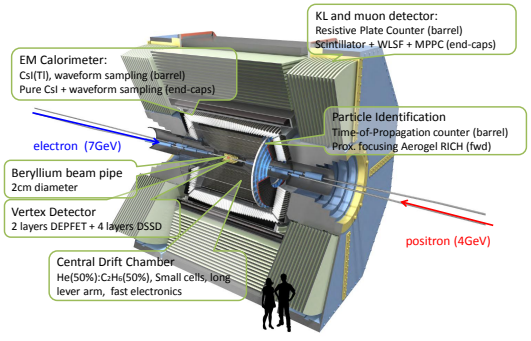

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[BELLE2-REPORT-2016-001]

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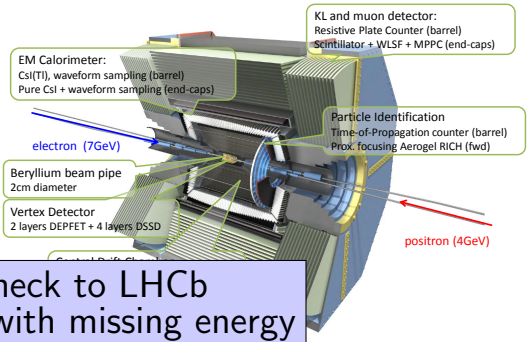


Independent check to LHCb
Sensitive to modes with missing energy

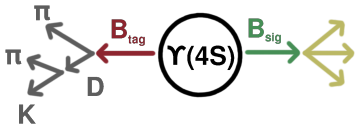
B-meson Tagging

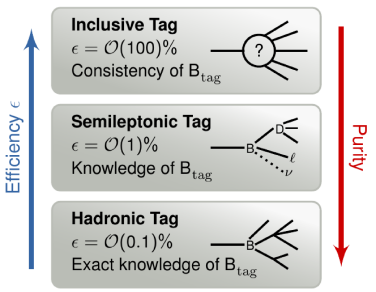
Reconstruct one of the B-meson

- Tag-side – Other B is our signal
- Used to reconstruct invisible particles in our signal

Three methods:

- Inclusive tagging
- Semileptonic tagging
- Hadronic tagging





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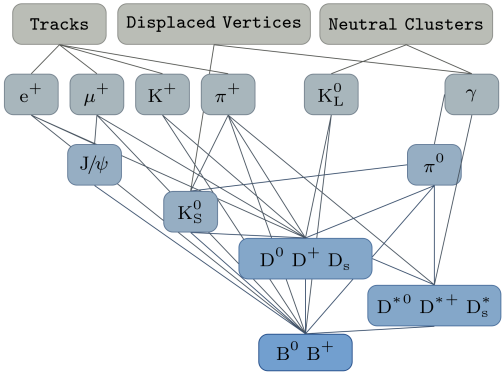
Full Event Interpreter (FEI) [arXiv:1807.08680]:

- Uses $>$ 200 BDTs
- Reconstructs 10,000 B-decay chains



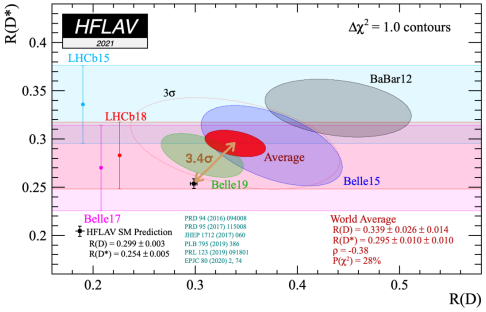
Lepton Flavor Universality in $B \to D^{(*)}\ell\nu_\ell$

$B \to D^{(*)}\tau\nu_\tau$ used to probe LFU

Standard Model Prediction

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\nu_\ell)} = 0.300(0.252) \pm \mathcal{O}(10^{-3}) \qquad , \ell = e, \mu$$

[HFLAV average]

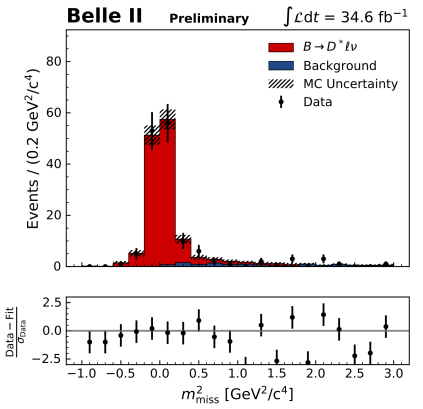


Discrepancy w.r.t. combined average (BaBar, Belle, LHCb):

- $R(D)$: 1.4σ
- $R(D^*)$: 2.9σ
- Combined: 3.4σ

$B \to D^{(*)}\ell\nu_\ell$ at Belle II

[arXiv:2008.10299]



Multiple neutrinos in final state

- Hadronic tagging

Feed down from D^{**} poorly understood

- Tagged measurement of $B \to D^{**}\ell\nu_\ell$ planned

First tagged Belle II results of $\overline{B^0} \to D^{*+}\ell^-\overline{\nu_\ell}$:

- 34 fb^{-1} Belle II data
- Signal: Fit of M^2_{miss}
- $\mathcal{B}(\overline{B^0} \to D^{*+}\ell^-\overline{\nu_\ell}) =$
  $(4.51 \pm 0.41_{stat} \pm 0.27_{syst} \pm 0.45_{\pi_s})\%$

Missing mass squared: $M^2_{miss} = (p_{e^+e^-} - p_{B_{tag}} - p_{D^*} - p_\ell)^2$

Lepton Flavor Universality in $B \to K^{(*)}\ell\ell$

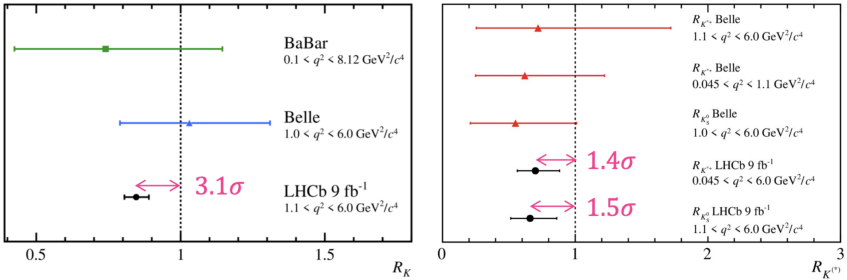
$B \to K^{(*)}\ell\ell$ used to probe LFU

Standard Model Prediction

$$R(K^{(*)}) = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} = 1 \pm \mathcal{O}(10^{-2})$$

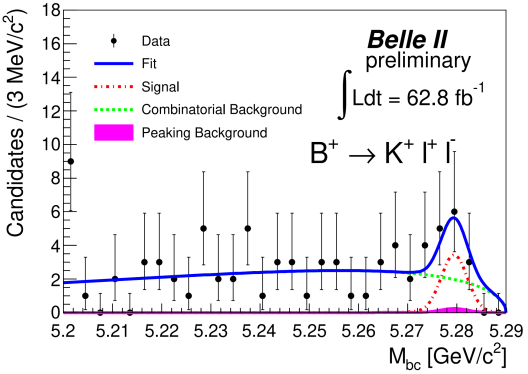
Discrepancy observed by LHCb

[arXiv:2103.11769], [arXiv:2110.09501]



$B \to K^{(*)}\ell\ell$ at Belle II

[BELLE2-NOTE-PL-2021-005]



$R(K^{(*)})$ at Belle II:

- Equivalent reconstruction for electrons and muons
- 5-10 ab^{-1} needed for independent check

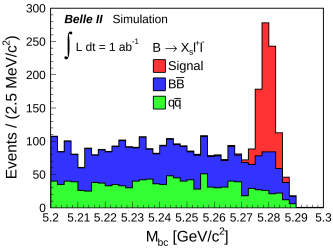
Preliminary 2021 results on $B^+ \to K^+\ell\ell$:

- 63 fb^{-1} Belle II data
- Signal: CrystalBall fit on M_{bc}
- 2.7σ significance on signal

Beam-constrained mass: $M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$

$B \to X_s \ell\ell$ at Belle II

[arXiv:2012.15394], [arXiv:1709.10308]



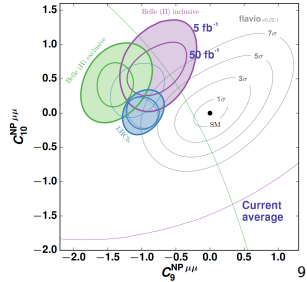
Measurement of $R(X_s) = \frac{\mathcal{B}(B \to X_s \mu^+ \mu^-)}{\mathcal{B}(B \to X_s e^+ e^-)}$ also in progress

Two methods available:

- Sum-of-exclusive modes
- Fully inclusive using tagging

Expected sensitivity:

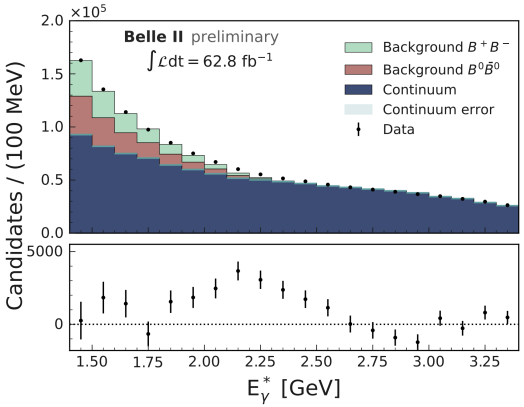
Observables	Belle (0.71 ab^{-1})	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})
R_{X_s} ($[1.0, 6.0]$ GeV$^2/c^4$)	32%	12%	4.0%
R_{X_s} ($[> 14.4]$ GeV$^2/c^4$)	28%	11%	3.4%



Angular analysis of $B \to X_s \ell\ell$ will improve constraints on Wilson coefficient C9 and C10

First Results of $B \to X_s\gamma$

[BELLE2-NOTE-PL-2021-004]



Belle II has better photon resolution compared to BaBar and Belle

Untagged analysis using 63 fb^{-1}:

- Only reconstruct high energy γ
- $B\overline{B}$ background from simulation
- Continuum from off-resonance

Observed evidence for inclusive $B \to X_s\gamma$ signal

Tagged analyses also in development

$B \to K^+\nu\overline{\nu}$ at Belle II

Standard Model Prediction

$\mathcal{B}(B \to K^+\nu\overline{\nu}) = (4.6 \pm 0.5) \cdot 10^{-6}$

Experimental upper limit:
$\mathcal{B}(B \to K^+\nu\overline{\nu}) < (1.6 \pm 0.5) \cdot 10^{-5}$

$B \to K^+\nu\bar{\nu}$ at Belle II

[arXiv:2104.12624]

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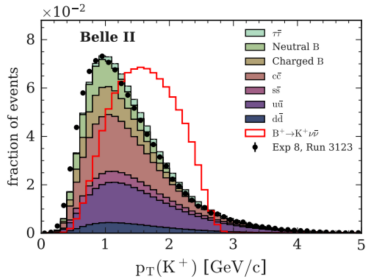
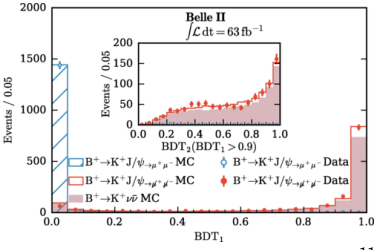
Novel method using inclusive tagging:

- Highest p_T track = Signal Kaon
- Use 2 BDTs to separate signal from background
  - Use event topology to separate from background
  - Also uses kinematics and vertex information

  Test sample $B^+ \to K^+(J/\psi \to \mu^+\mu^-)$
  - di-muon veto → signal like
- SM signal efficiency $\approx 4.3\%$





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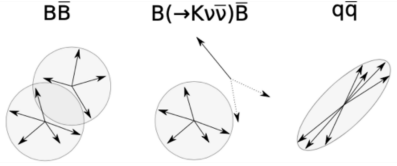
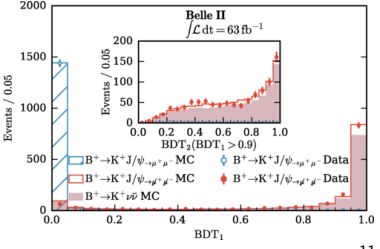
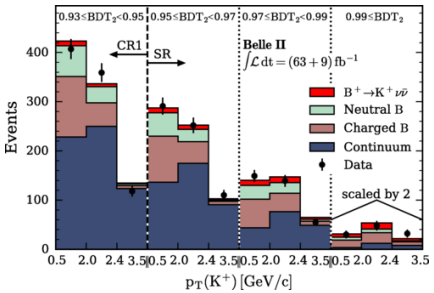


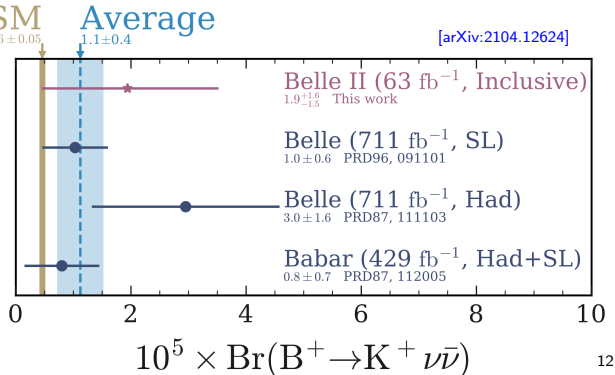


First $B \to K^+\nu\bar{\nu}$ Results

First results using 63 fb^{-1}:

- Yield is investigated in control region ($0.93 \leq BDT_2 < 0.95$) and 3 signal regions
- $\mathcal{B}(B \to K^+\nu\bar{\nu}) = 1.9^{+1.6}_{+1.5} \cdot 10^{-5}$
- With a Belle II upper limit at 90% CL: $\mathcal{B}(B \to K^+\nu\bar{\nu}) < 4.1 \cdot 10^{-5}$
- Comparable to Belle Hadronic tagged result at a factor 10 less data





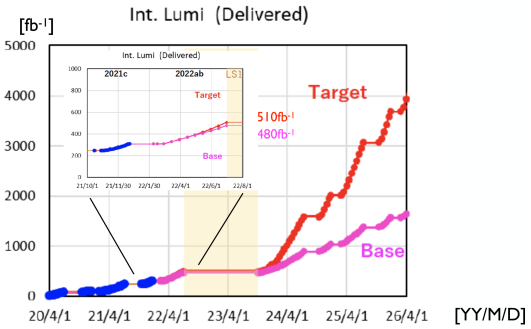
Summary

Studies of B-meson anomalies is ongoing

- LFU in $b \to c\ell\ell$ and $b \to s\ell\ell$
- C9 and C10 constraints using $b \to s\ell\ell$
- Inclusive analyses (less dependent on theoretical modelling)
- B decays with multiple invisible particles

The results shown only used 63 fb^{-1}

- More than 350 fb^{-1} now available
- 50 ab^{-1} planned



Thank you for listening!