Results and Prospects of Radiative and Electroweak Penguin Decays at Belle II

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(On behalf of the Belle II Collaboration)

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Overview

1. Motivation

2. Belle II status

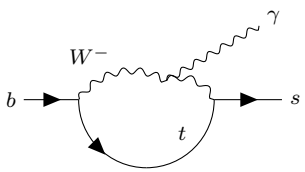
3. Radiative penguin B decays

4. Electroweak penguin B decays
   4.1. $b \to s\ell^+\ell^-$
   4.2. $b \to s\nu\bar{\nu}$ (will be covered by Cyrille Praz)

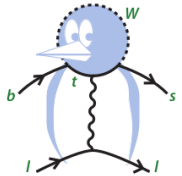
5. Conclusions

BSM searches via rare B decays

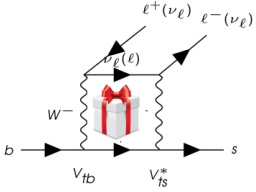
- $b \to s(d)$ is an FCNC transition that is not allowed at tree level in the Standard Model (SM)
  $\to$ loop and CKM suppressed
- BSM model allowing FCNC at tree level or new particles appearing in loop can change branching fractions and/or other observables



$b \to s\gamma$ (radiative penguin)

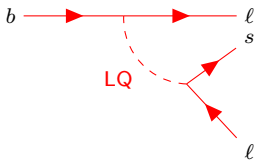


$b \to s\ell\ell$ (EW penguin)



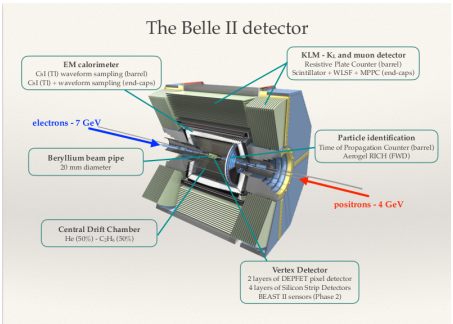
$b \to s\ell\ell$ (box diagram)

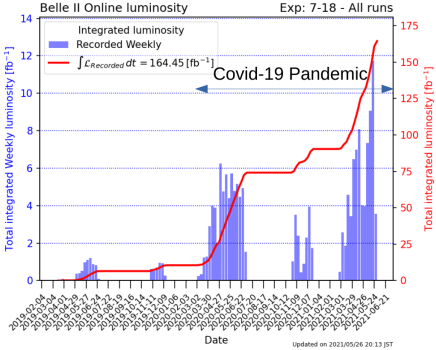
SM allowed processes



A possible BSM process

Belle II operation[1]





- Goal: integrate upto 50 ab^{-1} by 2031
- Collected $\sim$170 fb^{-1} since 2018
- Belle II has achieved highest instantaneous luminosity ever (2.4×10^{34}cm^{-2}s^{-1})
- Analysis (shown here) are performed in 62.8 fb^{-1} dataset

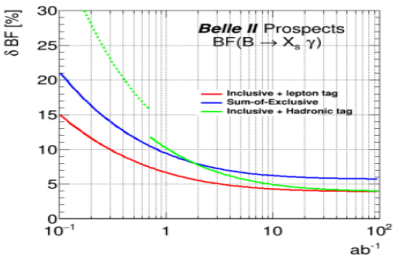
[1]For more information about Belle II status see Christoph Schwanda's talk

Inclusive measurements

Key obsevables

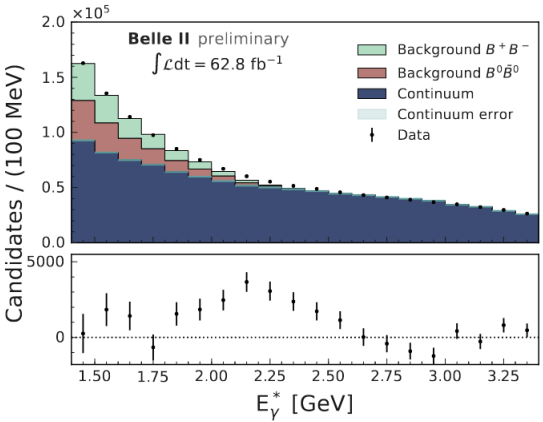
- $\mathcal{B}(B \to X_s\gamma)$
- $A_{CP}^{X_{s+d}\gamma} = \frac{\Gamma(\bar{B}\to X_{s+d}\gamma)-\Gamma(B\to X_{s+\bar{d}}\gamma)}{\Gamma(\bar{B}\to X_{s+d}\gamma)+\Gamma(B\to X_{s+\bar{d}}\gamma)} \sim \mathcal{O}(\Lambda_{QCD}/m_b)$
- $\Delta A_{CP}(B \to X_s\gamma) = A_{CP}(B^+ \to X_s^+\gamma) - A_{CP}(B^0 \to X_s^0\gamma) \propto Im(C_{8g}/c_{7\gamma}) \to$ zero in SM

- Prospects for Belle II: A_{CP} and ΔA_{CP}
  - Systematic uncertainty due to detector asymmetry could be reduced using control samples
  - More measurements at Belle II of A_{CP} in rare charmless decays, that can fake the inclusive signal $\to$ Room for improvement using more realistic peaking background study
- Prospects for Belle II: $\mathcal{B}(B \to X_s\gamma)$
  - Fully inclusive - reduce systematics by better modeling of neutral hadrons faking photons
  - Sum-of-exclusive - increase the number of modes to reduce systematic from X_s hadronization
  - Hadronic tagging method - increased purity so that the $E_\gamma^{\text{threshold}}$ can be reduced



Inclusive photon spectrum from $b \to (s, d)\gamma$ transition

- Monochromatic (smeared) photon energy from the two-body decay $b \to s\gamma$
- High energy photon with $E^*_\gamma > 1.4$ GeV
- It should not be arising from a π^0 decay
- Continuum suppression with event shape variables
- Data driven (from off-resonance and side-bands) scaling of MC



Lepton flavor universality test

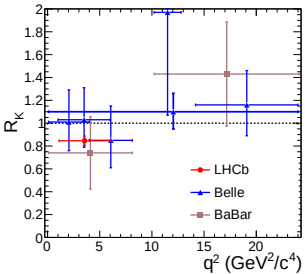
$$R_H[q_0^2, q_1^2] = \frac{\int_{q_0^2}^{q_1^2} dq^2 \frac{d\Gamma(B\to H\mu^+\mu^-)}{dq^2}}{\int_{q_0^2}^{q_1^2} dq^2 \frac{d\Gamma(B\to He^+e^-)}{dq^2}}$$

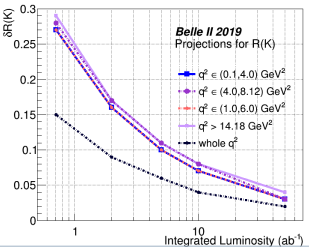
$Q_i = P_i^\mu - P_i^e$ (def of P_i: JHEP 05 (2013) 137)

- In SM gauge bosons couple equally to different lepton flavours
- Precise prediction of R_H ratios in SM
- Belle R_K measurement: JHEP 03 (2021) 105 , Angular analysis $B \to K^*\ell^+\ell^-$: PRL 118, 111801

Advantage for Belle II over hadronic machine

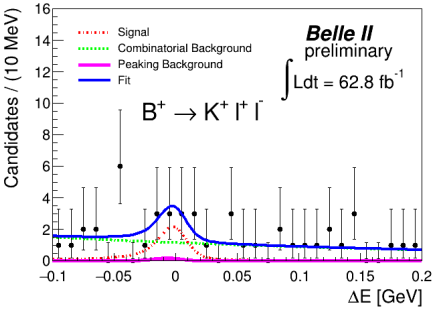
- Electron and muon modes have similar efficiency
- Both low and high q^2 regions will be measured
- All $R_{K^{(*)}}$ and R_{X_s} are possible at Belle II

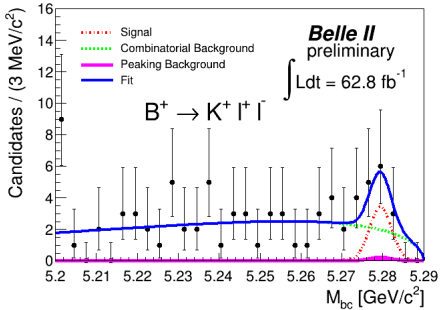




Observation of $B^+ \to K^+\ell^+\ell^-$ signal

- First $b \to s\ell^+\ell^-$ decay observed at Belle II
- $B^+ \to \psi(nS)K^+$ where $n = 1, 2$, events are rejected by applying optimized veto on di-lepton invariant mass
- BDT classifier used to suppress background trained with event shape, vertex related variables and missing energy.





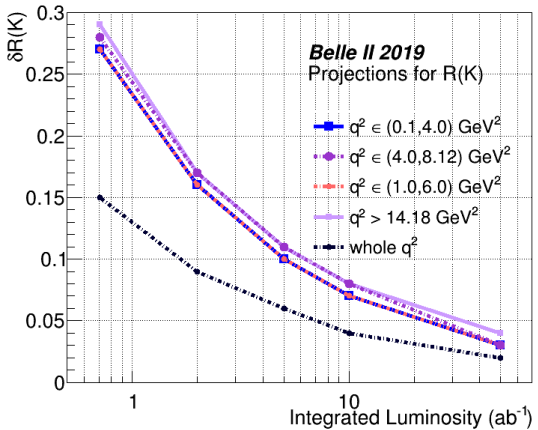
- Signal yield: $8.6^{+4.3}_{-3.9} \pm 0.4$ (statistical and systematic uncertainty).
- Signal significance: 2.7 standard deviations

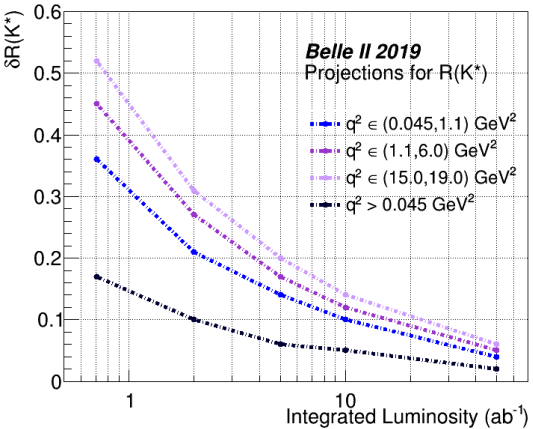
Conclusions

- Clean environment at Belle II grants access to unique observables (R_{x_s}, Q_5) in rare B decays
- Similar sensitivity of electron and muon mode of a decay makes lepton flavour test more reliable
- Improved detector and analysis methods at Belle II leads to better sensitivity
- Results using early data demonstrates the expected performances of all the sub-detectors
- Belle II is running well in this Covid-19 pandemic towards its ultimate goal to record 50 ab^{-1}


BACKUP SLIDES

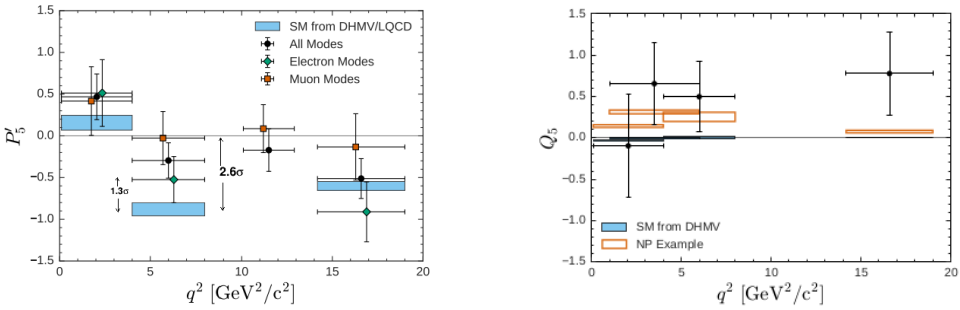
The Belle II sensitivities to $R_{K^{(*)}}$





Angular analysis: $B \to K^* \ell^+ \ell^-$

- Angular observables $P'_{i=4,5,6,8}$ are suggested to be theoretically robust (JHEP 05 (2013) 137)
- Sensitive to Wilson coefficients C_7, C_9 and C_{10}
- Lepton flavour universality (LFU) test with $Q_i = P_i^\mu - P_i^e$



Distribution of P'_5 (left) and Q'_5(right) in Belle measurement

- Belle measurement (PRL 118, 111801) uncertainty is statistically dominated
- Sensitivity to P'_5 with full Belle II data in the 4-8 GeV^2/c^2 bin will be around 0.04 (PTEP 2020(2020) 2)

The Belle II sensitivities to P_5' angular observables