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

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(On behalf Belle II collaboration)

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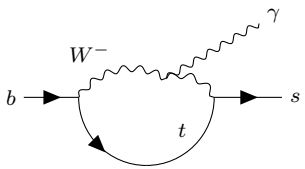
Overview

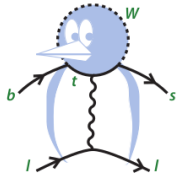
1. Motivation
2. Belle II operation status
3. Radiative penguin B decays
4. Electroweak penguin B decays
5. Conclusion

BSM searches via rare B decays

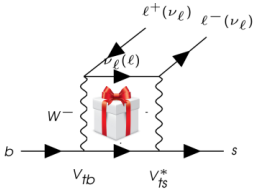
- $b \to s(d)$ is an FCNC transition which is not allowed at tree level in the standard model (SM)
  - $\to$ loop and CKM suppressed
- BSM particles can appear in loop, change branching fractions and/or other observables



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

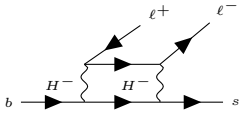


$b \to s\ell\ell$ (EW penguin)



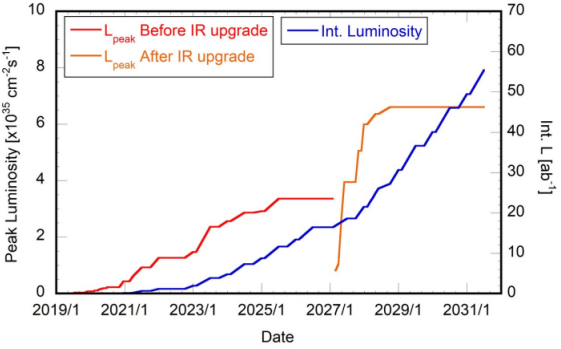
$b \to s\ell\ell$ (box diagram)

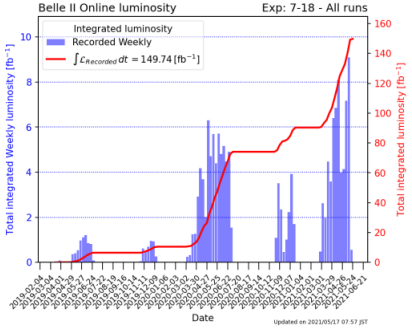
SM allowed processes



A possible BSM process

Belle II operation



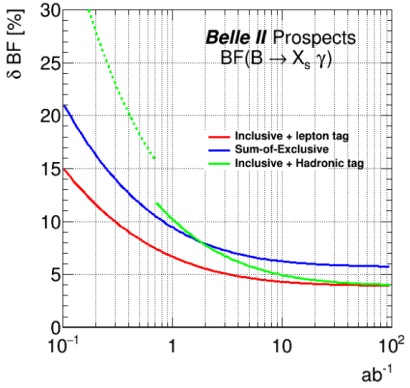


- Collected 0.5 fb^{-1} in 2018
- Recorded about 55 fb^{-1} since 2019
- Analyses performed on upto 8.7fb^{-1} of data
- Goal: integrate upto 50 ab^{-1} by 2029

Inclusive branching fraction measurement

- Theoretically more reliable than exclusive
  - $\mathcal{B}^{\mathrm{SM}}(B \to X_s\gamma) = (3.36 \pm 0.23) \times 10^{-4}$ for $E_\gamma > 1.6$ GeV (PRL 114 (2015) 22)
- In effective field theory it puts a strong constraint on the Wilson coefficient C_7
- Measurements (eg. arxiv:1608.02344) are consistent with SM and limited by systematic uncertainty

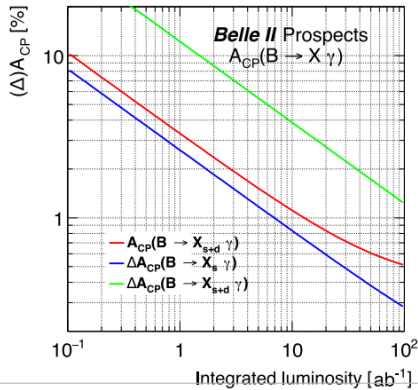
- Goal for Belle II
  - Fully inclusive - reduce systematics by better modelling of neutral hadrons faking photons
  - Sum-of-exclusive - increase the number of modes to reduce the systematic from X_s hadronization
  - Hadronic tagging method - increased purity so that the $E_\gamma^{\mathrm{threshold}}$ can be reduced



Inclusive direct CP violation

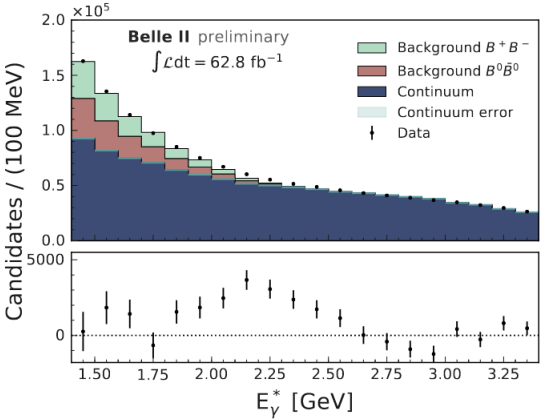
- $A_{CP}^{X_{s+d}\gamma} = \frac{\Gamma(\bar{B}\to X_{s+d}\gamma)-\Gamma(B\to X_{s+d}\gamma)}{\Gamma(\bar{B}\to X_{s+d}\gamma)+\Gamma(B\to X_{s+d}\gamma)} \sim \mathcal{O}(\Lambda_{QCD}/m_b)$
  - → Deviation from zero indicates BSM physics (PRL 106 (2011) 141801)
  - → $A_{CP}^{X_{s+d}\gamma} = (2.2 \pm 3.9\ (\text{stat}) \pm 0.9\ (\text{syst}))\%$ (arxiv:1608.02344)
- $\Delta A_{CP}(B \to X_s\gamma) = A_{CP}(B^+ \to X_s^+\gamma) - A_{CP}(B^0 \to X_s^0\gamma) \propto Im(C_{8g}/c_{7\gamma})$ → zero in SM
  - → $\Delta A_{CP} = (3.69 \pm 2.65\ (\text{stat}) \pm 0.76\ (\text{syst}))\%$ (PRD 99 (2019) 3)

- Goal for Belle II
  - Reduce statistical uncertainty
  - 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 → Room for improvement using more realistic peaking background study



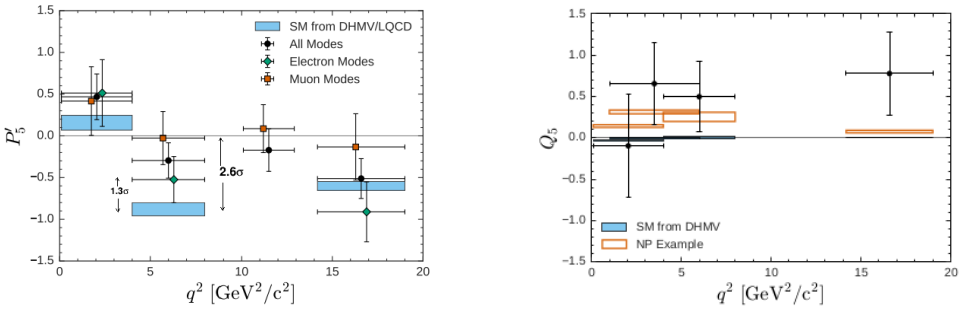
Inclusive photon spectrum from $b \to (s, d)\gamma$ transition

- Monochromatic (smeared) photon energy from the two-body decay $b \to s\gamma$.
- High energy photon $E^*_\gamma > 1.4$ GeV
- The γ 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.



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 $Q_i = P_i^\mu - P_i^e$



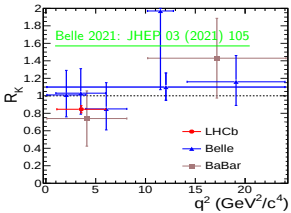
Distribution of P'_5 (left) and Q'_5(right) in Belle measurement

- 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)

Lepton flavor universality test

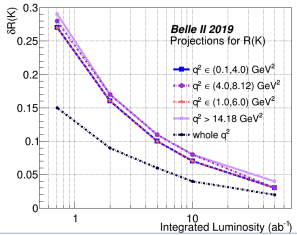
$$R_H[q_0^2, q_1^2] = \frac{\int_{q_0^2}^{q_1^2} dq^2 \frac{d\Gamma(B \to H\mu^+\mu^-)}{dq^2}}{\int_{q_0^2}^{q_1^2} dq^2 \frac{d\Gamma(B \to He^+e^-)}{dq^2}}$$

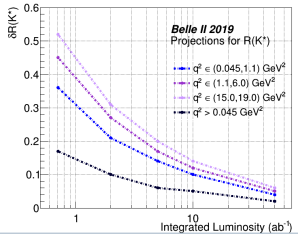
- In SM gauge bosons couple equally to different lepton flavours
- Precise prediction of R_H ratios in SM



Advantage for Belle II

- 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

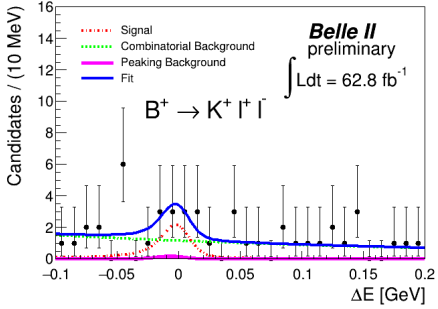


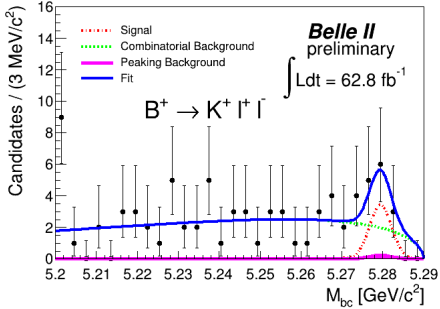


If 2.7σ deviation is real, Belle II should be able to make a 5σ discovery with $\approx$20 ab^{-1}

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

- First $b \to s\ell^+\ell^-$ decay observed in 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 and vertex related variables.





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

- Theoretically cleaner w.r.t $b \to s\ell^+\ell^-$
  - No photon mediated (Q_7) contribution
  - BF allows to extract form factors to high accuracy
- Clean observable: K^* longitudinal polarisation fraction (F_L).
  - $F_L^{\text{SM}} = 0.47 \pm 0.03$
  - Sensitive to BSM right-handed-current $\to Q_R^\nu$ (JHEP 04 (2009) 022)
- Interesting in dark matter context (JHEP 03 (2012) 090)

$\Rightarrow$ Measurement in Belle (PRD 87, 111103) and BaBar (PRD 82, 112002) provided UL on the BF

Belle II prospects

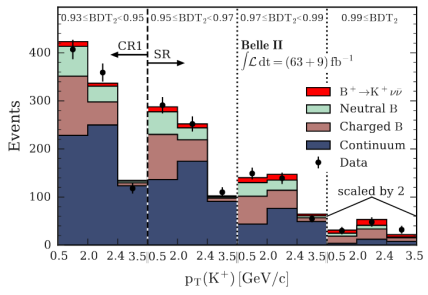
- Expect to observe $B \to K^*\nu\bar{\nu}$ decays with ≈ 5 ab^{-1}
- 10% BF measurement possible with 50 ab^{-1}
- Sensitivity on F_L with 50 ab^{-1} is about 0.08 for both $K^{*0/+}\nu\bar{\nu}$

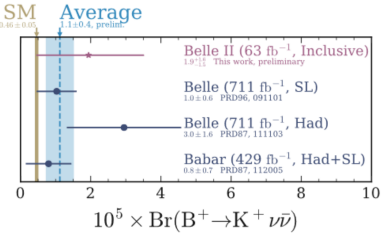
$B^+ \to K^+ \nu\bar{\nu}$ decays at Belle II

- Inclusive tagging approach : nested statistical-learning discriminators exploits efficiently topology allowing for sizeable signal (4%) while controlling large backgrounds.

Results

- Measured signal strength $\mu = 4.2^{+2.9+1.8}_{-2.9-1.6}$
- Consistent with the bkg-only hypothesis at 1.3 σ level
- Observed (expected) UL @90% CL 4.1×10^{-5} (2.6×10^{-5})
- $\mathcal{B}(B \to K^+ \nu\bar{\nu}) = 1.9^{+1.3+0.8}_{-1.3-0.7} \times 10^{-5}$





Sensitivity with just 63 fb^{-1} data is already close to previous searches with significantly large data-set.

Conclusion

- Clean environment at Belle II grants access to unique observables in rare B decays
- 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}