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

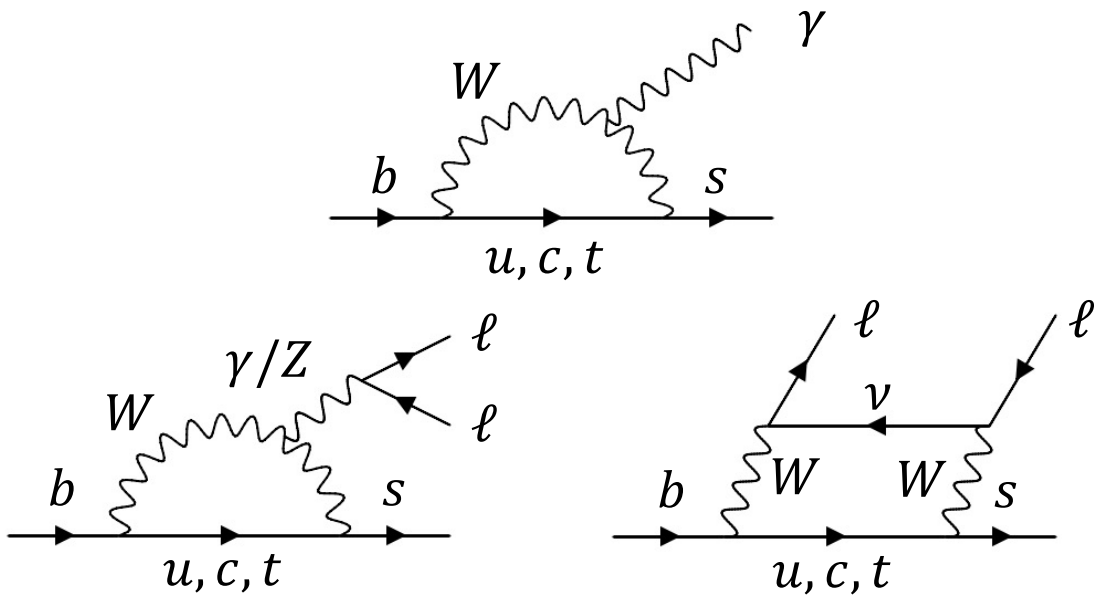
Yo Sato on behalf of Belle II collaboration

KEK

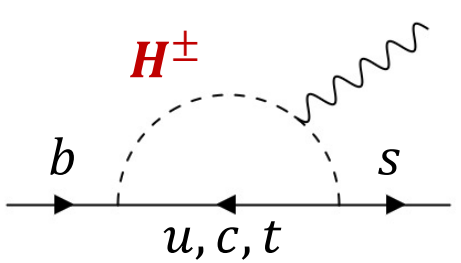
SUSY 2021, 23-28 August 2021

Introduction

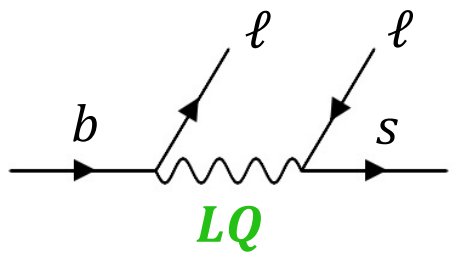
Radiative and Electroweak Penguin decays in SM



NP contributions



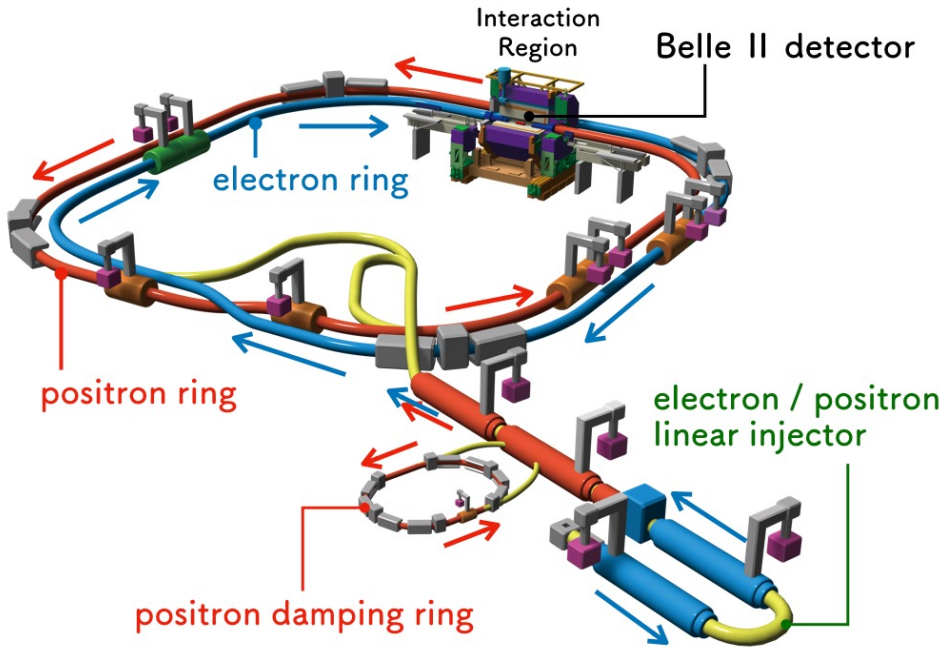
e.g.
Charged Higgs

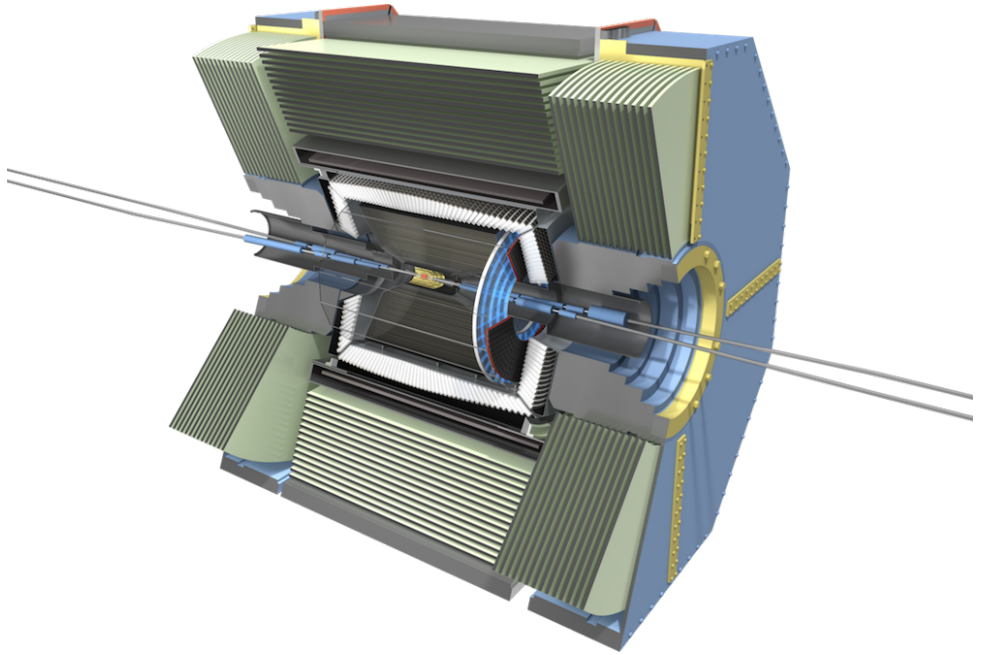


e.g.
Leptoquark

- Radiative and Electroweak penguin decays are flavor-changing neutral current (FCNC), which proceeds via one-loop diagrams in the standard model (SM) and thus suppressed.
- New physics (NP) can appear in the loop or mediate FCNC at tree level.

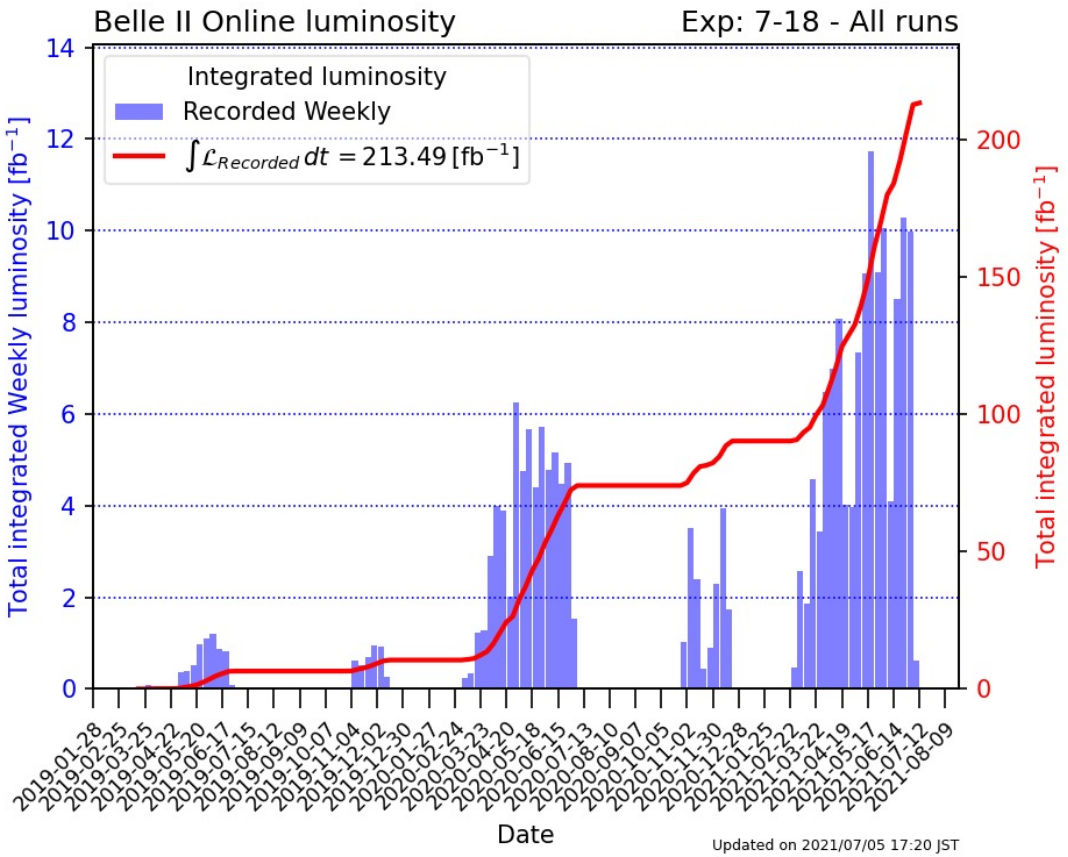
SuperKEKB and Belle II experiment





- Asymmetric e^-(7 GeV) e^+(4 GeV) collider.
- CM-energy is at $\Upsilon(4S)$ resonance, 10.58 GeV → Produce $B\bar{B}$-pair efficiently.
- Precise study of b, c, τ to search NP in the clean experimental environment.

Status of SuperKEKB and Belle II



- New world record of luminosity :
  - L = 3.1x10^{34} cm^{-2} sec^{-1}
  - 12 fb^{-1}/week, 40.3 fb^{-1}/month

  (KEKB : 2.1x10^{34} cm^{-2} sec^{-1}, 8 fb^{-1}/week, 29.4fb^{-1}/month)

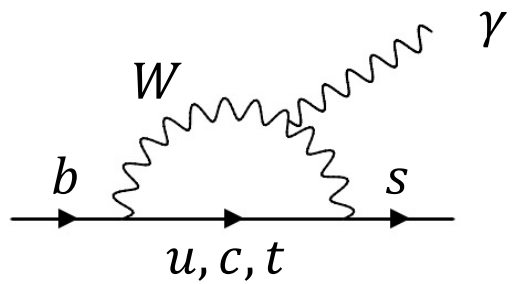
- Total integrated luminosity : 213 fb^{-1}
  - >120 fb^{-1} in Feb-June 2021
  - *Today's results* :

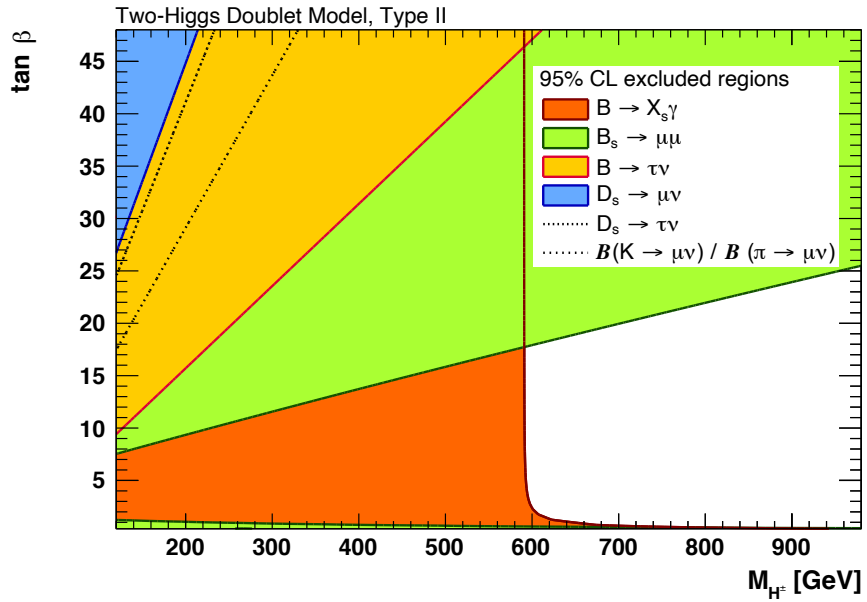
    62.8 fb^{-1} at $\Upsilon(4S)$ + 9 fb^{-1} at off-resonance

    (off-resonance = 60 MeV below the $\Upsilon(4S)$)

Radiative Penguin Decays $b \to s\gamma$

- Relatively large branching fraction, $O(10^{-5})$
- Great sensitivity to new heavy particle which can enter the loop.
  - Strong constraint on the Charged Higgs is obtained from $\mathrm{Br}(B \to X_s\gamma)$:
    $M_{H^\pm} < 590$ GeV (Type II, 2HDM)
    Eur.Phys.J.C 78 (2018) 8, 675





Contents

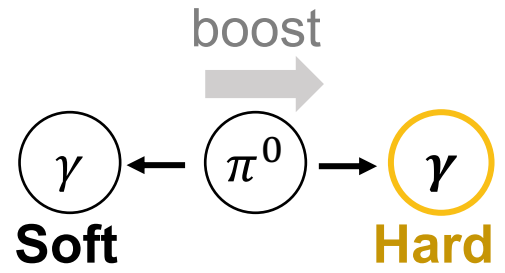
- Measurement of branching fractions of $B \to K^*\gamma$
  BELLE2-CONF-PH-2021-014
- Observation of $B \to X_s\gamma$
  BELLE2-NOTE-PL-2021-004

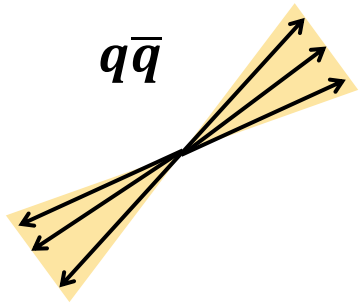
Measurement of branching fractions of $B \to K^*\gamma$

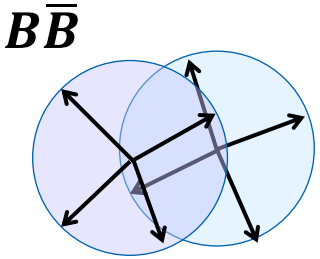
- The cleanest exclusive mode in $b \to s\gamma$ modes.
- All final states are explicitly reconstructed,
  - K^* : $K^+\pi^-, K_S^0\pi^0, K^+\pi^0, K_S^0\pi^+$ ($K_S^0 \to \pi^+\pi^-, \pi^0 \to \gamma\gamma$), $0.817 < M_{K^*} < 0.967$ GeV (~3σ)
  - γ : Cluster of the electromagnetic calorimeter (ECL), $2.25 < E_\gamma^{\mathrm{CM-frame}} < 2.85$ GeV

Dominant background

- $q\bar{q}$ ($q = u, d, s, c$) events with γ from π^0, η decay
  - π^0, η veto using kinematic information of combination of hard-/soft-photon.
  - Suppressed with MVA using event-shape variables.



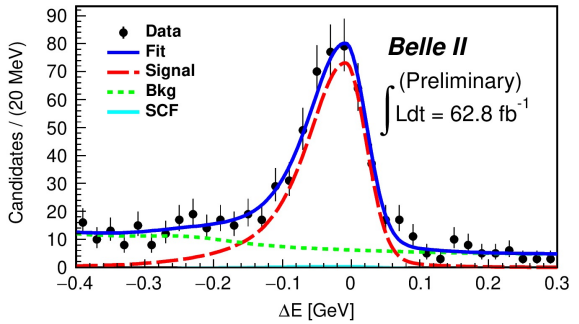




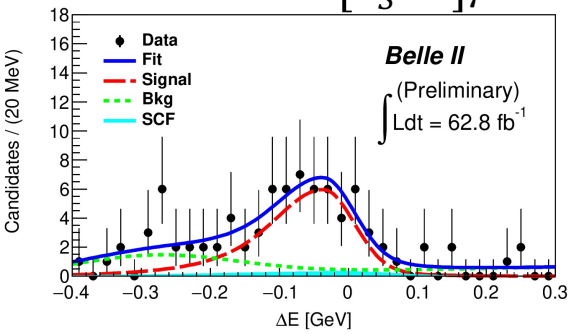
$B \to K^*\gamma$: Fit to ΔE distributions

- Signal yield is obtained from unbinned maximum likelihood (ML) fit to ΔE distribution : $\Delta E = E_B^{\mathrm{CM-frame}} - \sqrt{s}/2$
  - Signal : Cruijff function + Gaussian.
  - Self-cross-feed (SCF) : Cruijff function.
  - Background (Bkg) has two components
    - $q\bar{q}$: Chebyshev polynomial.
    - Shifted peaking $B\bar{B}$ (e.g. $B \to K\pi\pi\gamma$) : Gaussian
- The measured values are consistent with the world average values within 1σ (2σ) for neutral (charged) modes.
- Plan to upgrade for the measurement of CP- and Isospin- asymmetry.

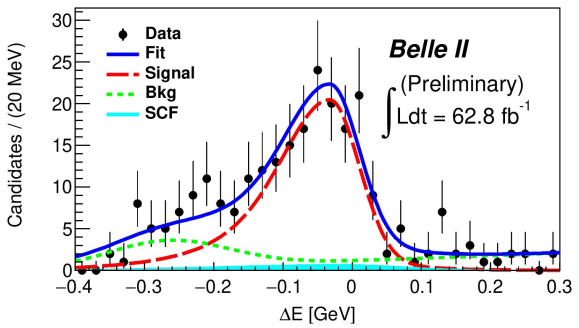
$B^0 \to K^{*0}[K^+\pi^-]\gamma$



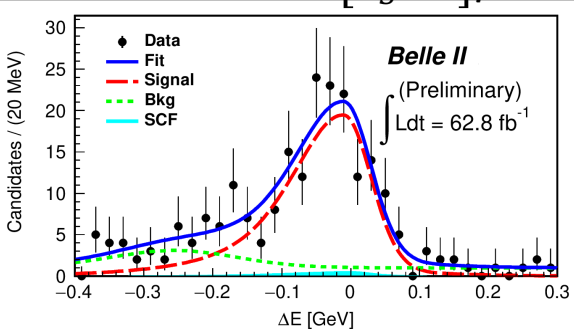
$B^0 \to K^{*0}[K_S^0\pi^0]\gamma$



$B^+ \to K^{*+}[K^+\pi^0]\gamma$



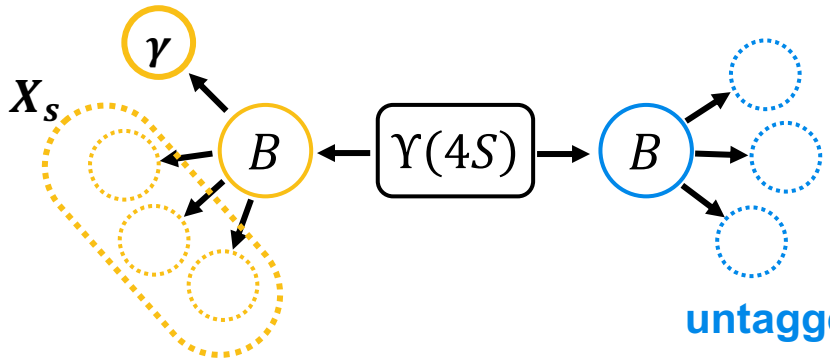
$B^+ \to K^{*+}[K_S^0\pi^+]\gamma$

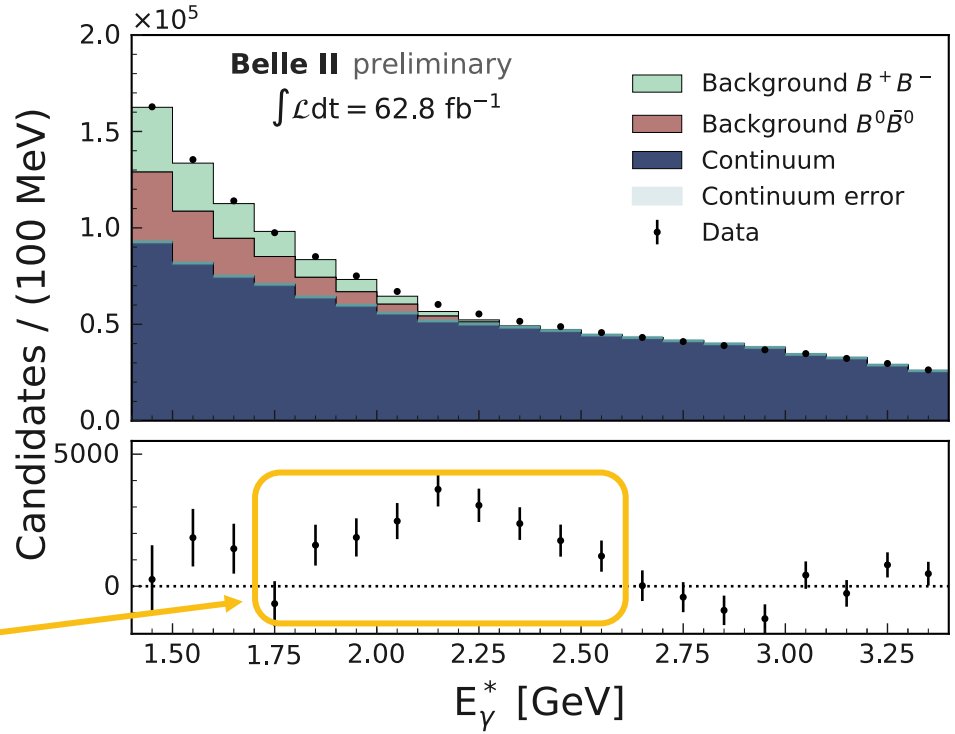


Mode	Br (fit) x10^{-5}	Br (PDG) x10^{-5}
$B^0 \to K^{*0}[K^+\pi^-]\gamma$	$4.5 \pm 0.3(\mathrm{stat}) \pm 0.2(\mathrm{syst})$	4.18 ± 0.25
$B^0 \to K^{*0}[K_S^0\pi^0]\gamma$	$4.4 \pm 0.9(\mathrm{stat}) \pm 0.6(\mathrm{syst})$	
$B^+ \to K^{*+}[K^+\pi^0]\gamma$	$5.0 \pm 0.5(\mathrm{stat}) \pm 0.4(\mathrm{syst})$	3.92 ± 0.22
$B^+ \to K^{*+}[K_S^0\pi^+]\gamma$	$5.4 \pm 0.6(\mathrm{stat}) \pm 0.4(\mathrm{syst})$	

Observation of $B \to X_s\gamma$ with untagged method

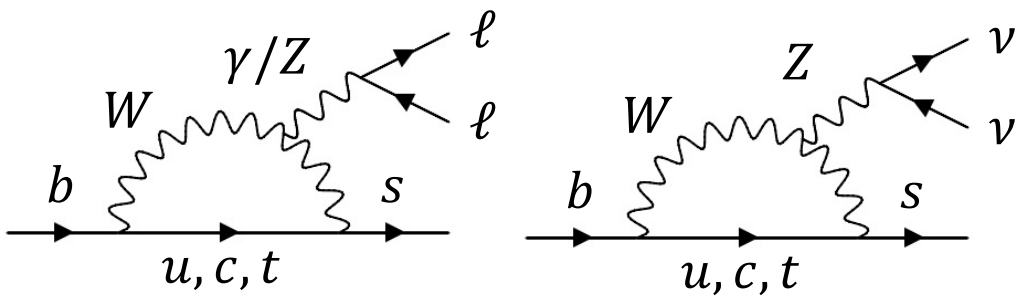
- Reconstruct only γ in the signal side B-meson.
- *Untagged method* : No explicit reconstruction of other side B-meson.
  - Higher efficiency & lower purity than tagging method.
  - **Subtract expected background contributions.**
- Photon energy spectrum is used to extract signal component after the background suppression.
  - Monochromatic spectrum is expected for signal.
  - Continuum ($q\bar{q}$) is estimated from data of off-resonance.
  - $B\bar{B}$ is estimated from simulation.
- Excess is clearly visible in the expected region.

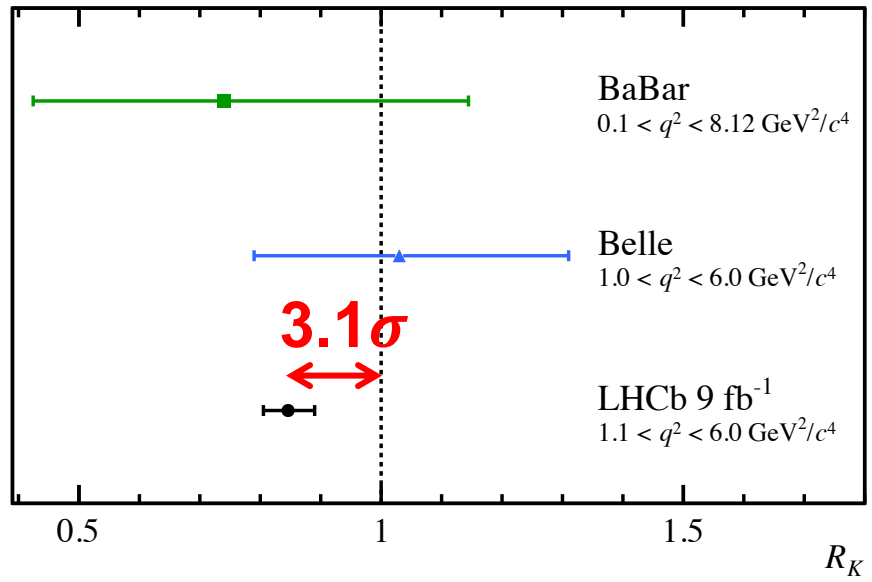




Electroweak Penguin Decays $b \to s\ell^+\ell^-$, $b \to s\nu\bar{\nu}$

- *Lepton Flavor Universality (LFU)* violation in $b \to s\ell^+\ell^-$ is drawing attention recently.
  - Evidence of LFU violation on $B^+ \to K^+\ell^+\ell^-$ from LHCb. arXiv:2103.11769
- Shed further light on the anomalies by independent measurements on $b \to s\ell^+\ell^-$ and search for $b \to s\nu\bar{\nu}$.
  - $b \to s\nu\bar{\nu}$ provide complementary prove of NP that explain $b \to s\ell^+\ell^-$ anomalies. arXiv:2103.16558





Contents

- Study of $B^+ \to K^+\ell^+\ell^-$ BELLE2-NOTE-PL-2021-014
- Search for $B^+ \to K^+\nu\bar{\nu}$ using an inclusive tagging arXiv:2104.12624

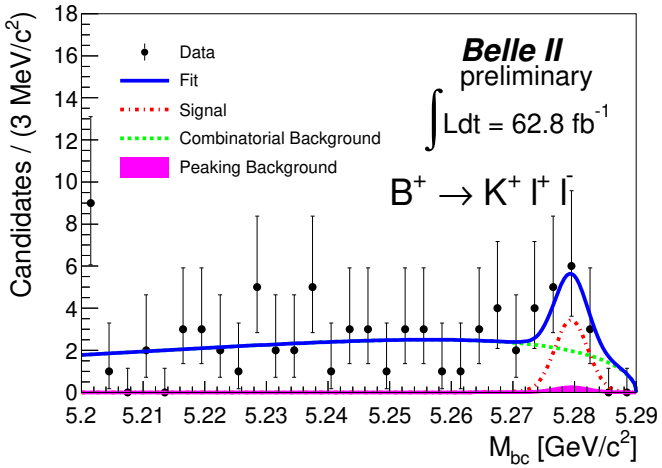
Study of $B^+ \to K^+\ell^+\ell^-$

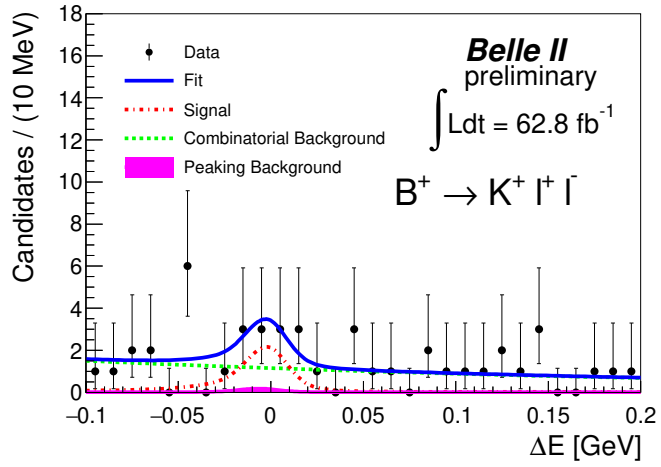
- $B^+ \to K^+\ell^+\ell^-$ is reconstructed from both electron and muon modes.
  - Electron can be reconstructed at similar level of muon at Belle II.
- Background is suppressed with MVA using event shape, vertex information...

- 2D unbinned ML fit, $(M_{\mathrm{bc}}, \Delta E)$:

$$M_{\mathrm{bc}} = \sqrt{s/4 - \left|p_B^{\mathrm{CM-frame}}\right|^2}$$

- Signal yield : $8.6^{+4.3}_{-3.9} \pm 0.4$





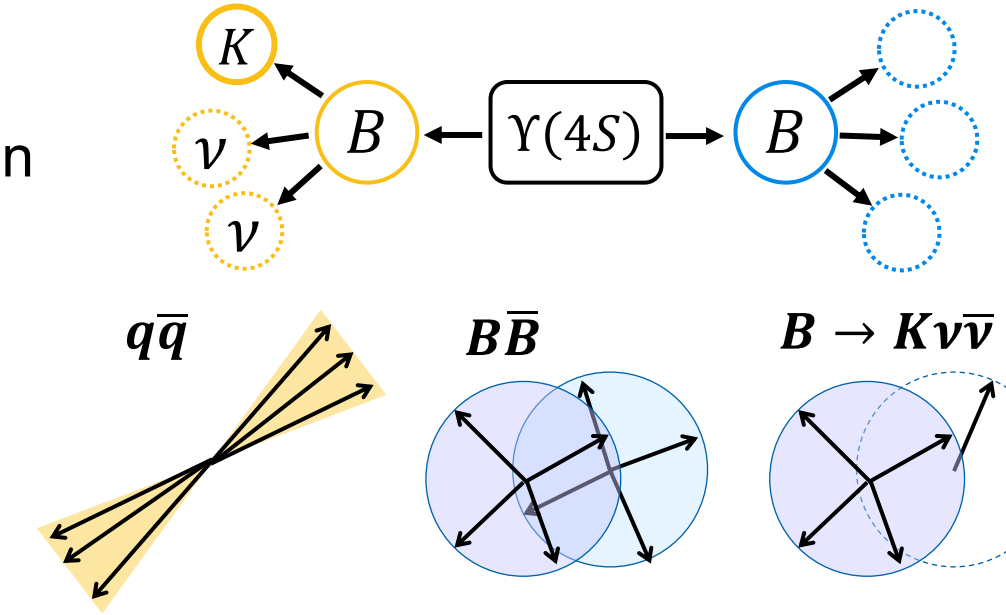
Measurement of important observables is planed using more upcoming data!

Search for $B^+ \to K^+\nu\bar{\nu}$ with an inclusive tagging

- Two undetectable neutrinos in the final state.
- $b \to s\nu\bar{\nu}$ decays are not observed yet.
  - SM : $Br(B^+ \to K^+\nu\bar{\nu}) = (4.6 \pm 0.5)\times10^{-6}$ Prog.Part.Nucl.Phys. 92 (2017) 50-91
  - Upper limit on $Br(B^+ \to K^+\nu\bar{\nu})$: <1.6×10^{-5} (BaBar 429 fb^{-1}, Phys.Rev.D 87 (2013) 11, 112005)
    - Previous measurements are performed by reconstructing the other side B-meson.

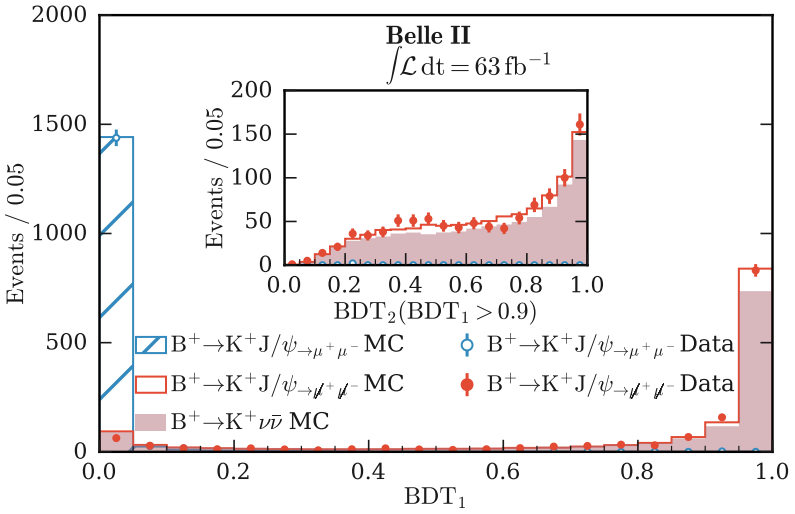
- *Inclusive tagging method* :
  No explicit reconstruction of other side B-meson
  - Higher efficiency & lower purity.
  - **Exploit distinct kinematics of signal event.**

  This method has not been used for this process!

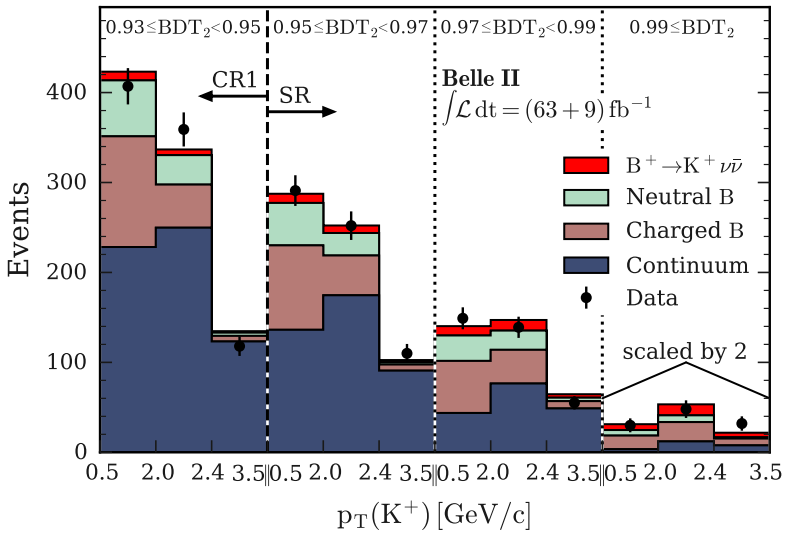


$B^+ \to K^+ \nu\bar{\nu}$: Analysis procedure

- Select highest p_T track as signal Kaon, $K^{\pm}$
- Train MVA (BDT) to suppress backgrounds using event shape, missing energy, ΔE of the other side B-meson…
  - Two BDT-classifiers are trained, BDT_1 and BDT_2.
  - Select events with BDT_1>0.9 and then train BDT_2.
- BDT performance is validated using data of control mode $B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$.
- Signal strength is extracted by binned ML fit on the 2D ($p_T(K^+)$, BDT_2) histogram.
  - Continuum components are constrained using off-resonance data.

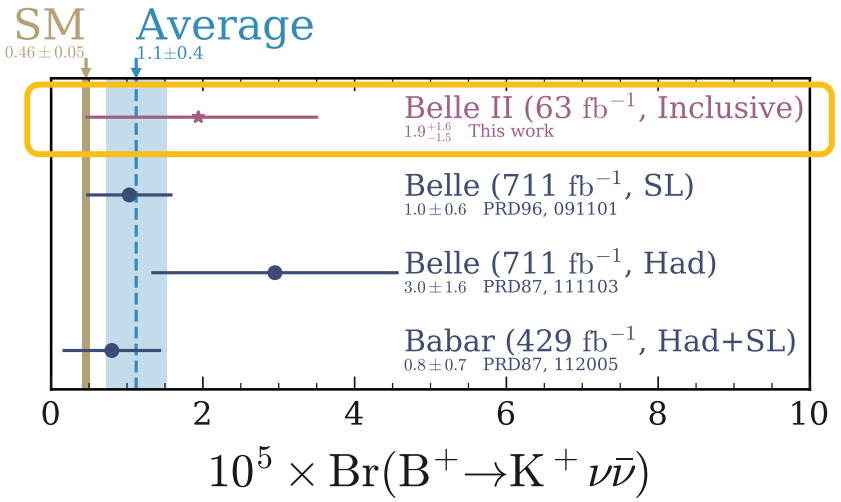


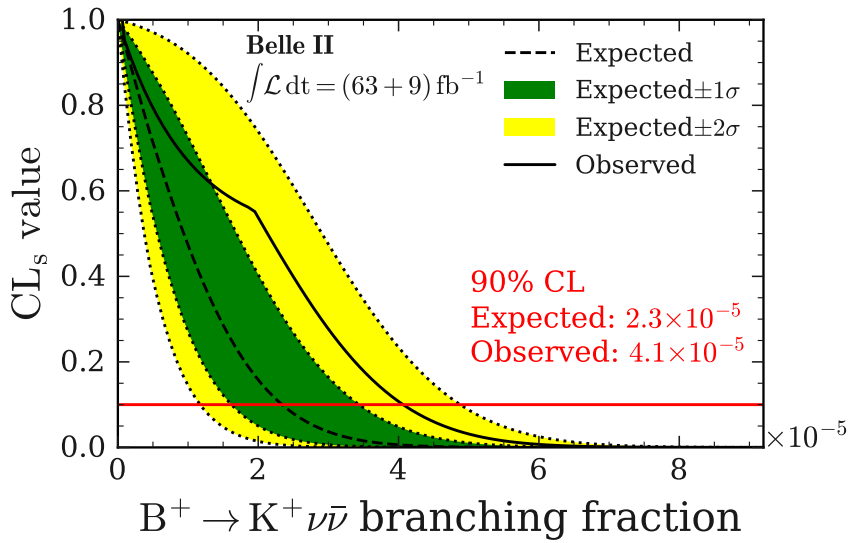
Control Region | Signal Region



$B^+ \to K^+\nu\bar{\nu}$: Results with the inclusive tagging

- Result of branching fraction is
  $Br(B^+ \to K^+\nu\bar{\nu}) = [1.9^{+1.3}_{-1.3}(\mathrm{stat})^{+0.8}_{-0.7}(\mathrm{syst})]\times10^{-5}$
  - Competitive with previous results taking into account the difference in the integrated luminosity.
- No significant signal is observed and an upper limit is set on the branching fraction.
  $Br(B^+ \to K^+\nu\bar{\nu}) = 4.1\times10^{-5}$ (90% CL)
- The capability of the inclusive tagging approach is demonstrated from the measurement.
  - Study on additional channels ($B^0 \to K^{*0}\nu\bar{\nu}, B^0 \to K^0_S\nu\bar{\nu}$) using more data is in preparation!





Summary and Outlook

- Belle II has recorded 213 fb^{-1} of data by 2021 summer.

- First results on radiative and electroweak penguin decays with (63+9) fb^{-1} demonstrate the high capabilities of the Belle II.
  - Measurement of branching fractions of $B \to K^* \gamma$. **BELLE2-CONF-PH-2021-014**
  - Observation of $B \to X_s \gamma$. **BELLE2-NOTE-PL-2021-004**
  - Study of $B^+ \to K^+ \ell^+ \ell^-$. **BELLE2-NOTE-PL-2021-014**
  - Search for $B^+ \to K^+ \nu \bar{\nu}$ with the inclusive tagging method. **arXiv:2104.12624**

- Interesting results are upcoming in near future using more data.
  - >3 times more on tape!
  - Aiming for ~400 fb^{-1} by 2022 summer (BaBar : 424 fb^{-1} at $\Upsilon(4S)$) and 50 ab^{-1} over ~10 years.