Electroweak penguin measurements and prospects at Belle II

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On behalf of the Belle II Collaboration

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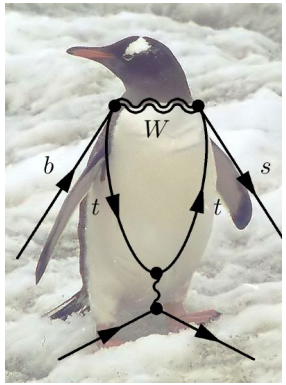
Outline

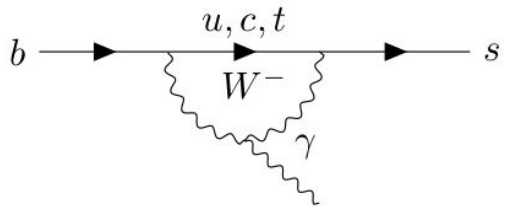
- Motivation
- Belle II status
- Electroweak *B* decays
- Radiative *B* decays
- Summary

Motivation

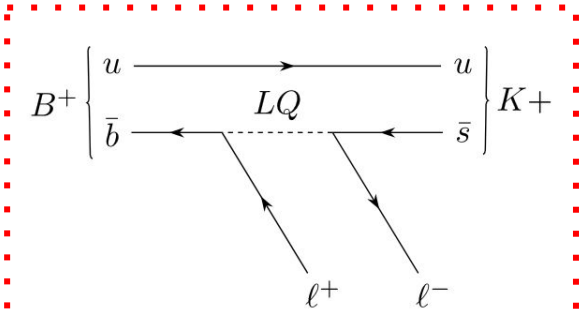
- FCNC transition $b \to s(d)$ is forbidden at tree level in the Standard Model and proceeds via electroweak loop diagrams.
- New physics effects can contribute in the loop or mediate the process at tree level.



Electroweak penguin

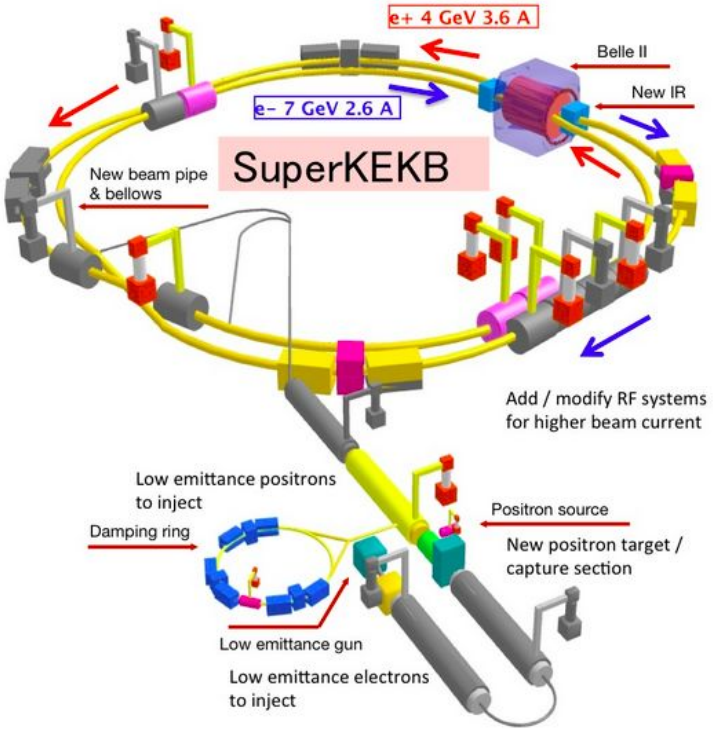


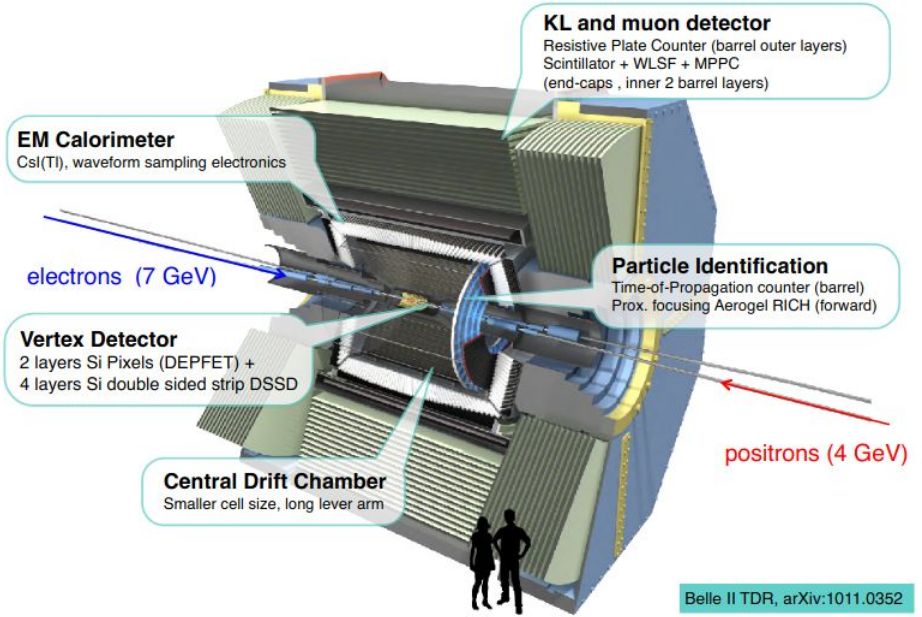
$b \to s\gamma$ loop



New physics contribution

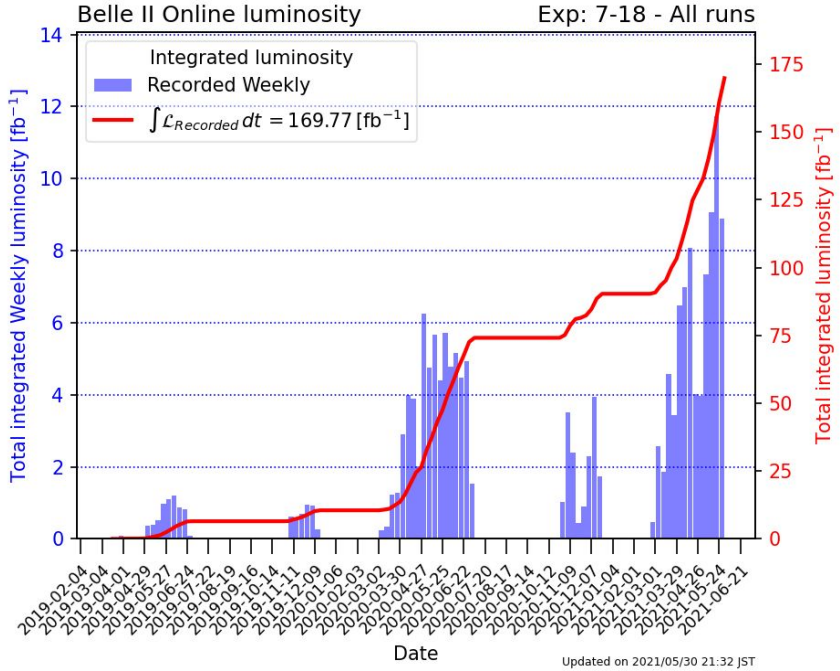
Belle II and SuperKEKB





Belle II status

- Reached a record peak luminosity of $2.9 \times 10^{34}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- Luminosity goal: $6.5 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- Collected $\approx 170\ \mathrm{fb}^{-1}$ data since 2018, ultimate goal to collect $50\ \mathrm{ab}^{-1}$



Electroweak B decays (semi-leptonic)

Observables

$$R_H[q_0^2, q_1^2] = \frac{\int_{q_0^2}^{q_1^2} dq^2 \frac{d\Gamma(B\to H\mu^+\mu^-)}{dq^2}}{\int_{q_0^2}^{q_1^2} dq^2 \frac{d\Gamma(B\to He^+e^-)}{dq^2}} \quad \begin{matrix}(q^2 = M_{\ell\ell}^2) \\ (\ell \Rightarrow e \text{ or } \mu)\end{matrix}$$

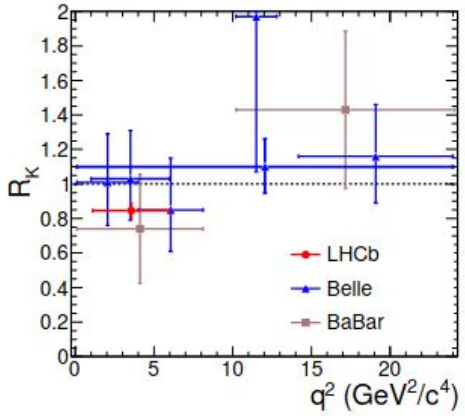
$Q_i = P_i^\mu - P_i^e$ (def of P_i : JHEP 05 (2013) 137)

Overview

- SM gauge bosons don't discriminate between different leptons, similar couplings
- R_H is a clean observable
- Belle R_K measurement: JHEP 03, 105 (2021) ,
- $B \to K^* \ell\ell$ angular analysis: PRL 118, 111801

Belle II vs hadron machines

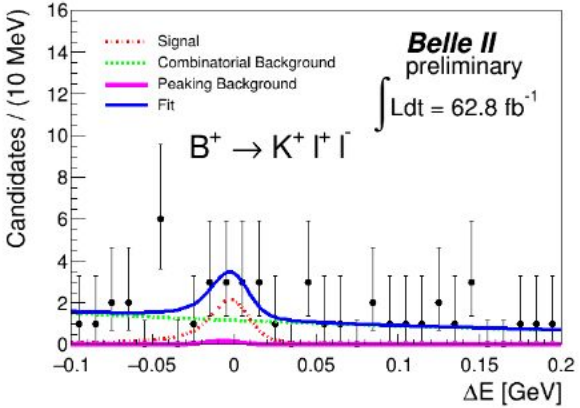
- Equal sensitivity to electron and muon modes
- Access to high and low q^2 regions
- $B \to X\gamma$, $B \to X\ell\ell$ inclusive measurements



2.7σ

Electroweak B decays (semi-leptonic)

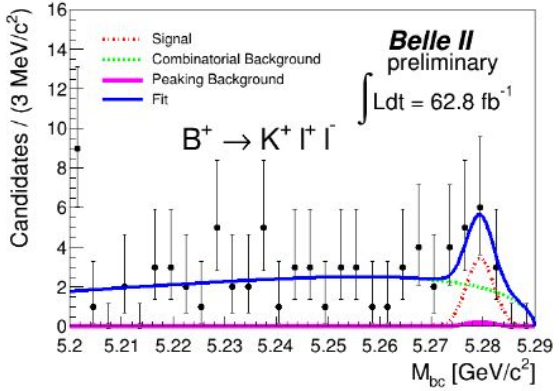
- First $b \to s\ell\ell$ decay observed at Belle II
- Reject $B^+ \to K^+\psi(\mathrm{nS})$ [where n=1,2] background with di-lepton invariant mass veto
- Employed BDT (event shape, vertex related and missing energy variables) to suppress background from light quark and inclusive *B* decays.



First observation with just 63 fb^{-1} of collision data

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

$$\Delta \mathrm{E} = E^{*}_{beam} - E^{*}_{B}$$



- $8.6^{+4.3}_{-3.9} \pm 0.4$ signal events (2.7σ significance) [errors are stat. and syst. resp.]

Electroweak B decays (missing energy)

Observables

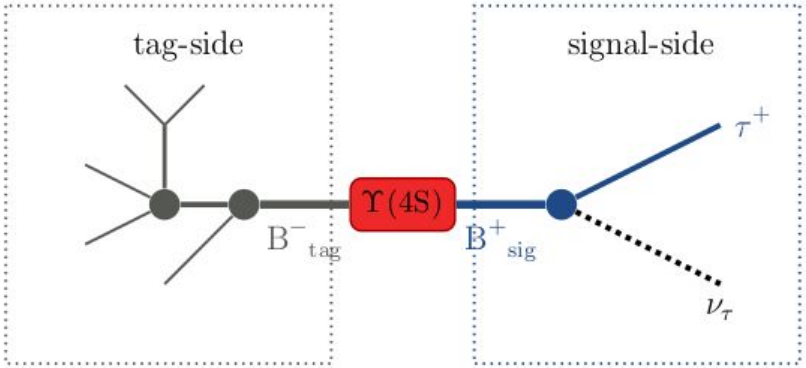
Branching fraction: $\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})$
Longitudinal polarisation fraction (F_L) of K^*
$F_L^{SM} = 0.47 \pm 0.03$

	UL @ 90% CL (10^{-5})	Ref
$B^+ \to K^+ \nu\nu$	1.6	BaBar, HAD+SL TAG, 429 fb^{-1}
$B^+ \to K^{*+} \nu\nu$	4.0	Belle, HAD TAG, 711 fb-1
$B^0 \to K^0 \nu\nu$	2.6	Belle, SL TAG, 711 fb-1
$B^0 \to K^{*0} \nu\nu$	1.8	Belle, SL TAG, 711 fb-1

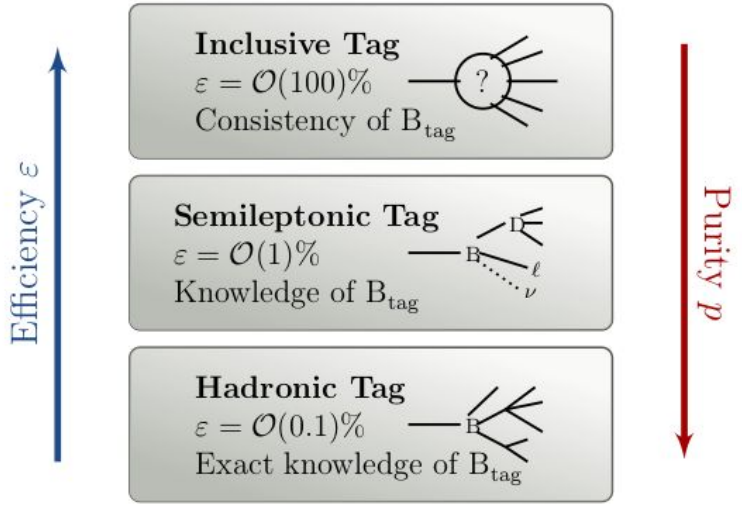
Overview

- Sensitive to BSM (JHEP 04, 022 (2019))
- Portal to dark matter search (JHEP 03, 090 (2012))
- Belle (PRD 87, 111103) and BaBar (PRD 82, 112002) measurements provided UL on the BF

Electroweak B decays (missing energy)



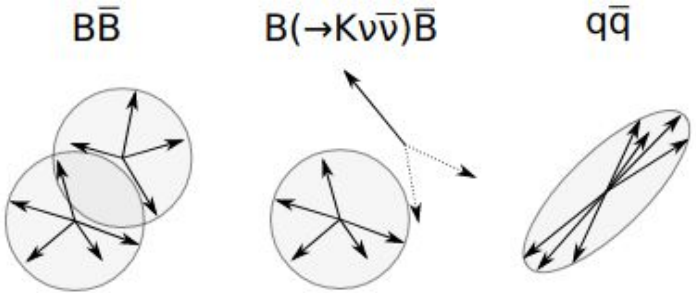
Tagging approach

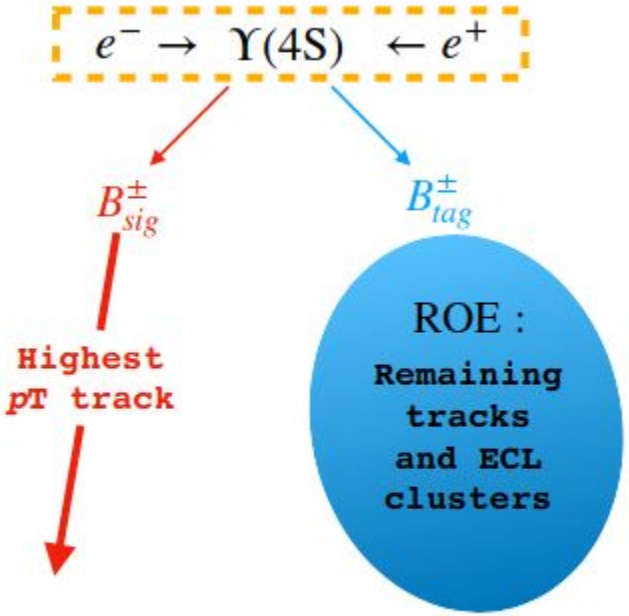


- Previous searches for $\mathcal{B}(B \to K\nu\bar{\nu})$ adopted a tagging technique where the tag-side *B* meson was explicitly reconstructed
- Hadronic tag: $\epsilon(\text{tag}) \times \epsilon(\text{sig}) \approx 0.04\%$
  Semi-leptonic tag: $\epsilon(\text{tag}) \times \epsilon(\text{sig}) \approx 0.2\%$

Electroweak B decays (missing energy)

- Reconstruct the track with highest p_T and at least one hit in the PXD as the signal candidate.
- Inclusive reconstruction of remaining tracks as cluster as rest of event (ROE)
- Identification of signal using topological features of decay

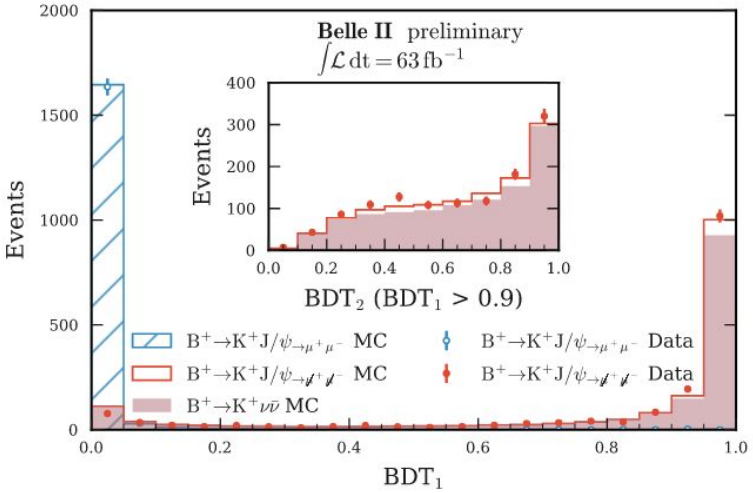




Inclusive tagging approach

Electroweak B decays (missing energy)

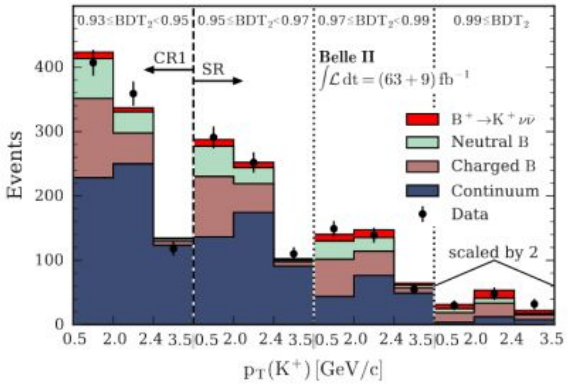
- First results for $\mathcal{B}(B \to K\nu\bar{\nu})$ at Belle II employing inclusive tag approach
- Use of nested statistical-learning discriminators exploiting the event topology
- Sizeable signal selection efficiency (4%) while controlling large backgrounds.



- Validation using $B \to KJ/\psi[\to \mu^+\mu^-]$
- Ignore $\mu^+\mu^-$ and modify K^+ 4-momentum using generator level info of K^+ from $B \to K^+\nu\bar{\nu}$
- Validation channel now mimics signal!
- Excellent Data/MC agreement between the BDTs of signal and control channel

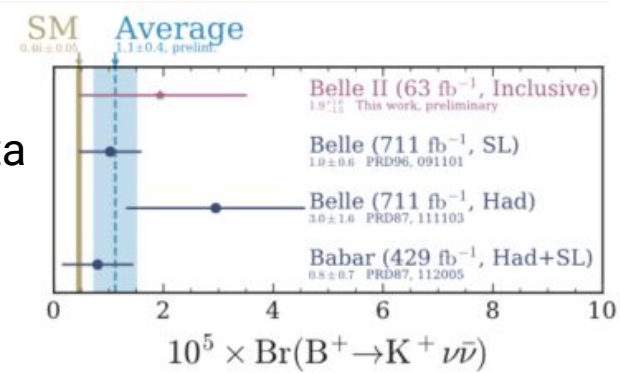
Electroweak B decays (missing energy)

- Signal strength: $\mu = 4.2^{+2.9+1.8}_{-2.9-1.6}$ [errors are stat. and syst. resp.]
- Consistent with the bkg-only (SM) hypothesis at CL 1.3σ (1σ)
- Observed (expected) UL @90% CL: $4.1 \times 10^{-5} (2.6 \times 10^{-5})$ arXiv:2105.05754



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

Submitted to journal



$$\mathcal{B}(B \to K^+ \nu\bar{\nu}) = 1.9^{+1.3+0.8}_{-1.3-0.7} \times 10^{-5}$$

Electroweak B decays (missing energy)

Prospects for Belle II

- Expected to observe $B \to K^* \nu\bar{\nu}$ with 5 ab^{-1} collision data
- Sensitivity on branching fraction will be about 10% with $50\ \mathrm{ab}^{-1}$ data
- Possible to determine F_L with a sensitivity of 0.08 with $50\ \mathrm{ab}^{-1}$ data
- Work in progress to improve the inclusive tag method and employ the same strategy for other modes like $B \to K^* \nu\bar{\nu}$

Radiative electroweak B decays

Observables

Branching fraction: $\mathcal{B}(B \to X_s\gamma)$, $\mathcal{B}(B \to X_{s+d}\gamma)$

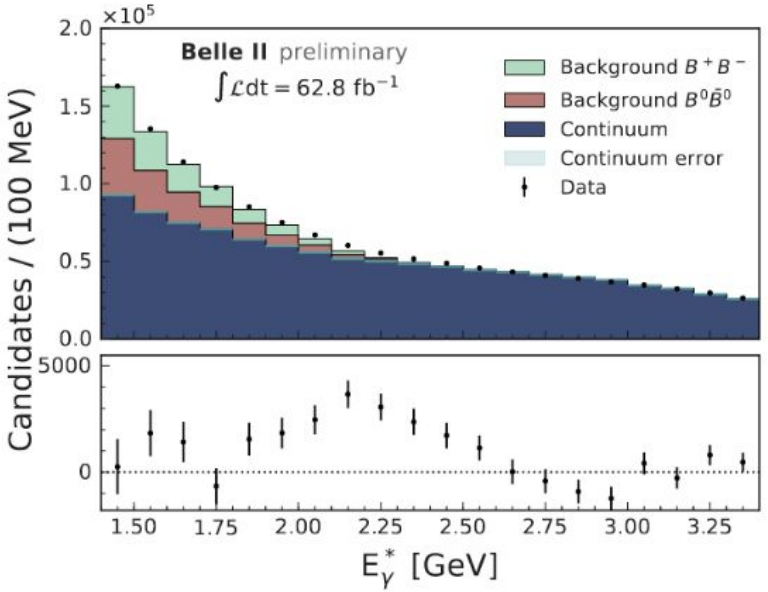
$$A_{\rm CP}^{X_{s+d}\gamma} = \frac{\Gamma(\bar{B}\to X_{s+d}\gamma)-\Gamma(B\to \bar{X}_{s+d}\gamma)}{\Gamma(\bar{B}\to X_{s+d}\gamma)+\Gamma(B\to \bar{X}_{s+d}\gamma)}, \quad \Delta A_{\rm CP} = A_{\rm CP}(B^+ \to X_s^+\gamma) - A_{\rm CP}(B^0 \to X_s^0\gamma)$$

Overview

- Belle measurement of $A_{\rm CP}$ and $\Delta A_{\rm CP}$ for $B \to X_s\gamma$: PRD 99, 032012
- $A_{\rm CP}$ measurement for $B \to X_{s+d}\gamma$ with lepton tag: PRL 114, 151601

Radiative electroweak B decays

- Presence of monochromatic (smeared) photon from $b \to s\gamma$ two-body decay.
- Select high energy photon $E^*_\gamma > 1.4$ GeV
- Photon should not be arising from π^0 decay
- BDT based continuum suppression with event shape variables
- Data driven scaling of MC (off-resonance and side-bands)

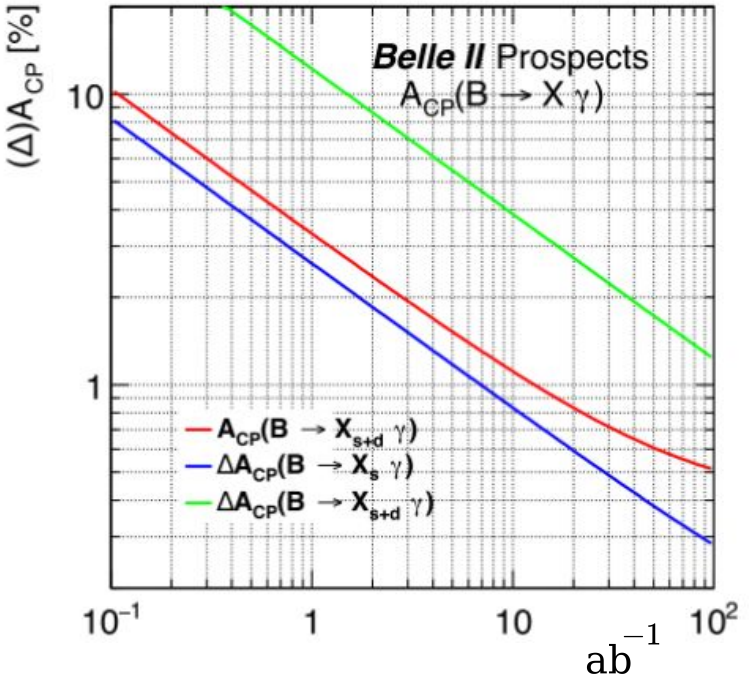


Spectrum of selected candidates overlaid with various background contributions.

Radiative electroweak B decays

Prospects for Belle II

- Fully inclusive measurements: reduce systematics by better modeling of neutral hadrons faking photons
- Sum-of-exclusive measurements: increase the number of modes to reduce systematic from X_s hadronization
- Hadronic tagging method to increase purity and reduce E_γ threshold



Summary

- Clean environment at Belle II grants access to unique observables (R_{X_s}, Q_5) in rare B decays
- Improved detector and analysis methods, better sensitivity.
- Opportunity to probe neutral as well as charged final states.
- Belle II is collecting data despite the Covid-19 pandemic thanks to our collaboration, inching towards the ultimate goal to record $50\ \mathrm{ab}^{-1}$ collision data.