
# BELLE II PHYSICS PERSPECTIVES: $B \rightarrow K^{(*)}\nu\nu$

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Belle II

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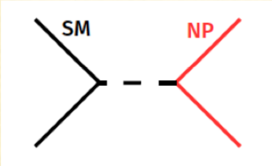
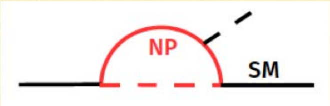
# Belle II and New physics searches (I)

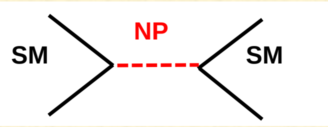
Search for new physics (NP)

- Energy frontier: direct production of new particles - limited by beam energy (LHC - ATLAS, CMS)




- Intensity frontier: new virtual particles in loops/trees transitions, deviation from SM expectations (B factories, LHCb)



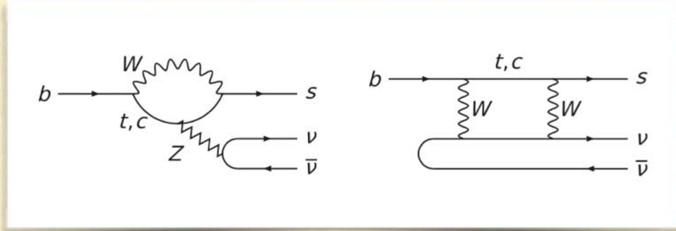



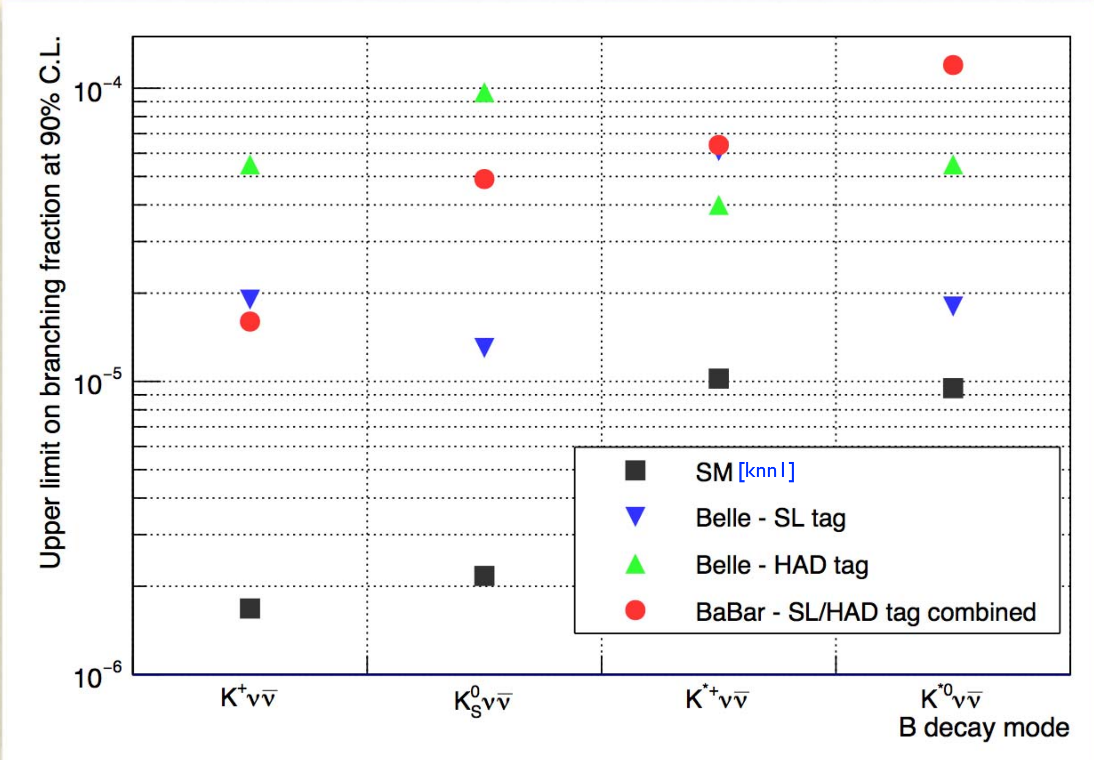

- $B \to K^{(*)}\upsilon\upsilon$ and LHCb/Belle2 interplay:
  - Belle II measurement only
  - from latest B2TiP studies, we foresee to have 10% uncertainties on the branching ratio with full statistics

| Observable | Expected th. accuracy | Expected exp. uncertainty | Facility |
|---|---|---|---|
| CKM matrix | | | |
| $\|V_{us}\|$ $[K \to \pi \ell \nu]$ | ** | 0.1% | $K$-factory |
| $\|V_{cb}\|$ $[B \to X_c \ell \nu]$ | ** | 1% | Belle II |
| $\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$ | * | 4% | Belle II |
| $\sin(2\phi_1)$ $[c\bar{c}K^0_S$ | *** | $8 \cdot 10^{-3}$ | Belle II/LHCb |
| $\phi_2$ | | 1.5° | Belle II |
| $\phi_3$ | *** | 3° | LHCb |
| CPV | | | |
| $S(B_s \to \psi\phi)$ | ** | 0.01 | LHCb |
| $S(B_s \to \phi\phi)$ | ** | 0.05 | LHCb |
| $S(B_d \to \phi K)$ | *** | 0.05 | Belle II/LHCb |
| $S(B_d \to \eta' K)$ | *** | 0.02 | Belle II |
| $S(B_d \to K^*(\to K^0_S \pi^0)\gamma))$ | *** | 0.03 | Belle II |
| $S(B_s \to \phi\gamma))$ | *** | 0.05 | LHCb |
| $S(B_d \to \rho\gamma))$ | | 0.15 | Belle II |
| $A^d_{SL}$ | *** | 0.001 | LHCb |
| $A^s_{SL}$ | *** | 0.001 | LHCb |
| $A_{CP}(B_d \to s\gamma)$ | * | 0.005 | Belle II |
| rare decays | | | |
| $\mathcal{B}(B \to \tau\nu)$ | ** | 3% | Belle II |
| $\mathcal{B}(B \to D\tau\nu)$ | | 3% | Belle II |
| $\mathcal{B}(B_d \to \mu\nu)$ | ** | 6% | Belle II |
| $\mathcal{B}(B_s \to \mu\mu)$ | *** | 10% | LHCb |
| zero of $A_{FB}(B \to K^*\mu\mu)$ | ** | 0.05 | LHCb |
| $\mathcal{B}(B \to K^{(*)}\nu\nu)$ | *** | 30% | Belle II |
| $\mathcal{B}(B \to s\gamma)$ | | 4% | Belle II |
| $\mathcal{B}(B_s \to \gamma\gamma)$ | | $0.25 \cdot 10^{-6}$ | Belle II (with 5 $ab^{-1}$) |
| $\mathcal{B}(K \to \pi\nu\nu)$ | ** | 10% | $K$-factory |
| $\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$ | *** | 0.1% | $K$-factory |
| charm and $\tau$ | | | |
| $\mathcal{B}(\tau \to \mu\gamma)$ | *** | $3 \cdot 10^{-9}$ | Belle II |
| $\|q/p\|_D$ | *** | 0.03 | Belle II |
| $arg(q/p)_D$ | *** | 1.5° | Belle II |

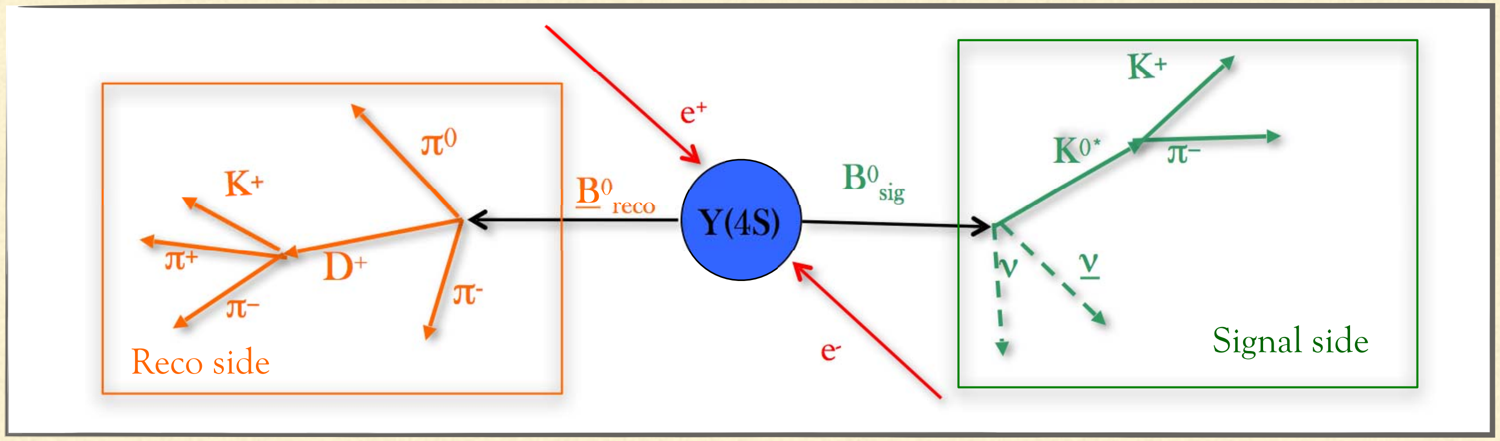
# $B \to K^{(*)}\nu\nu$ : theoretical and experimental status

- Flavour changing neutral current, prohibited at tree level in the SM
    - NP contribution (from new mediators or sources of missing energy) may be comparable to SM ones
    - free of uncertain long-distant hadronic effects, theoretically clean
    - Experimental searches from BaBar and Belle on both HAD and SL recoil[knn2]
        - no signal evidence, UL less than 1 order of magnitude away from SM predictions for K* channels



# B meson decays with missing energy: how to




(Why *a Belle-II measurement only*)

- Clean event environment and well defined initial state.
- Good and efficient reconstruction of decays with neutrals
- Full solid angle detector, lower boost wrt Belle/BaBar ⟷ higher detector hermeticity

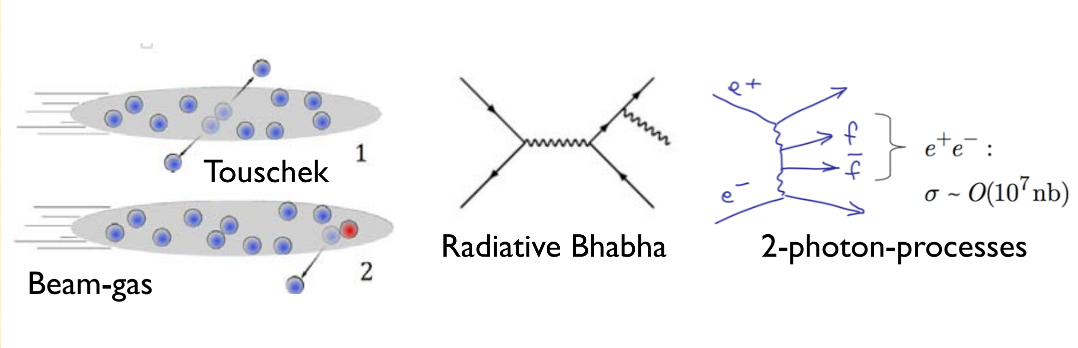
→ Ideal environment to search for decays with missing energy in the final state

- Full Event interpretation reconstruction algorithm:
  - Multivariate technique to reconstruct the B-tag side through both semileptonic (SL) and hadronic (HAD)
  - Signal specific training technique.

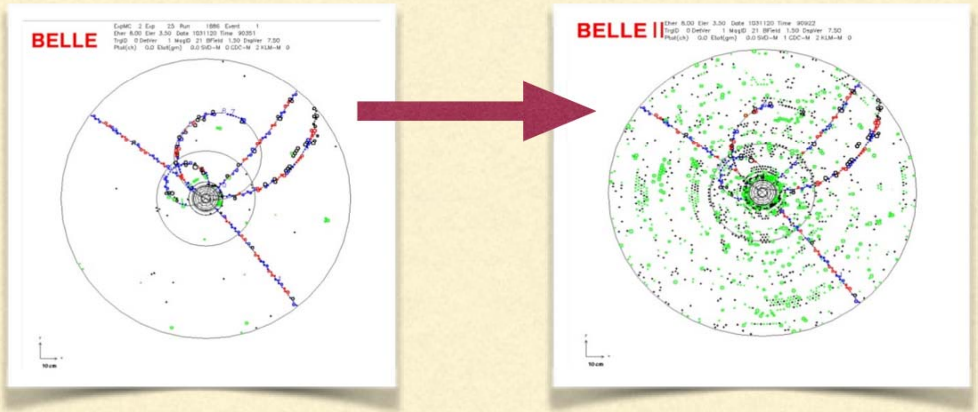
→ x2 in both HAD and SL reconstruction efficiency wrt Belle

# B→K(*)νν: robustness against machine background (I)

- From Belle to Belle II: Factor x40 luminosity → higher data samples + higher rate and radiation damage to detectors from "machine background processes"




- Upgrade of Belle detector and reconstruction algorithm in order to keep same or better performances wrt Belle in higher radiation environment




- REMARK: the study shown in the next slides have been performed with the second-to-last Belle II MonteCarlo production campaign (MC8)
  - study with MC9 (3x machine bkg wrt MC8) will be repeated

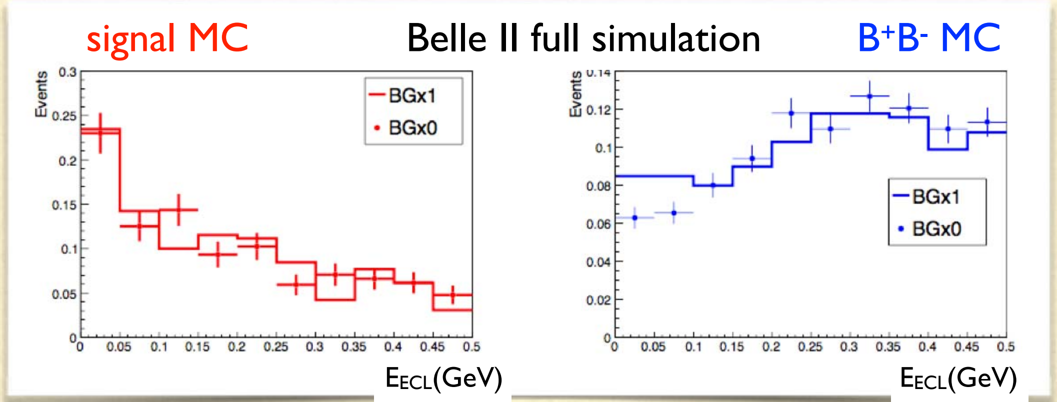
# $B \to K^{(*)}\nu\nu$: robustness against machine background (II)

- Analysis on Belle II Full simulation using hadronic B reconstruction using $K^{*+} \to K\pi^0$ to establish machine background impact

- Simple cut-and-count analysis, signal efficiency and bkg yield estimanted in extra neutral energy signal region
- nominal machine bkg (BGx1) and machine bkg-free (BGx0) simulated samples analysed

- Negligible impact of machine background both in terms of variables shape and signal significance

MC8 campaign




- Detector performances and reconstruction proves to be robust against machine background

# $B \to K^{(*)}\nu\nu$ : perspectives @ Belle II (I)

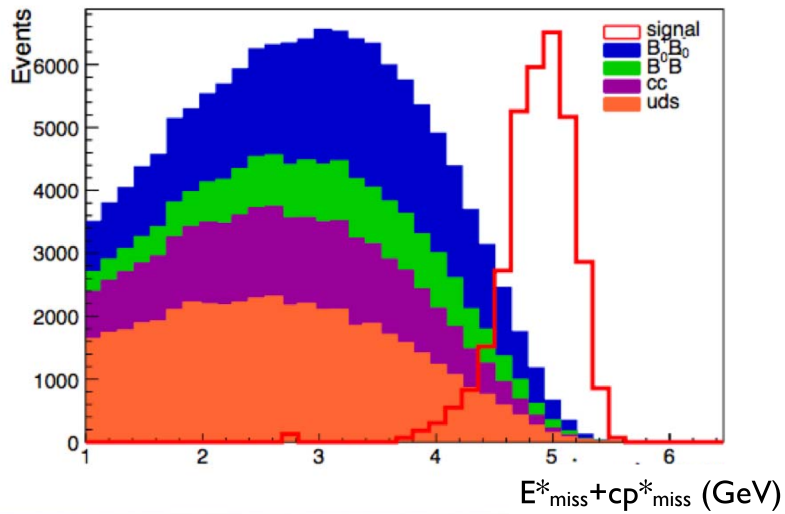
- Extrapolation on full Belle II statistics on Belle HAD and SL analyses, assuming two times better $B_{tag}$ reconstruction efficiency:
  - observation with about 18 $ab^{-1}$
  - precision on the branching fraction at 50 $ab^{-1}$, assuming SM central value:

| | stat only | total |
|---|---|---|
| $B^+ \to K^+\nu\nu$ | 9,5% | 10,7% |
| $B^+ \to K^{*+}\nu\nu$ | 7,9% | 9,3% |
| $B^+ \to K^{*0}\nu\nu$ | 8,2% | 9,6% |

- Fraction of longitudinally polarized K* may be measured, ~20% precision with full statistics
  - may help in disentangling different New Physics scenarios[knn3]

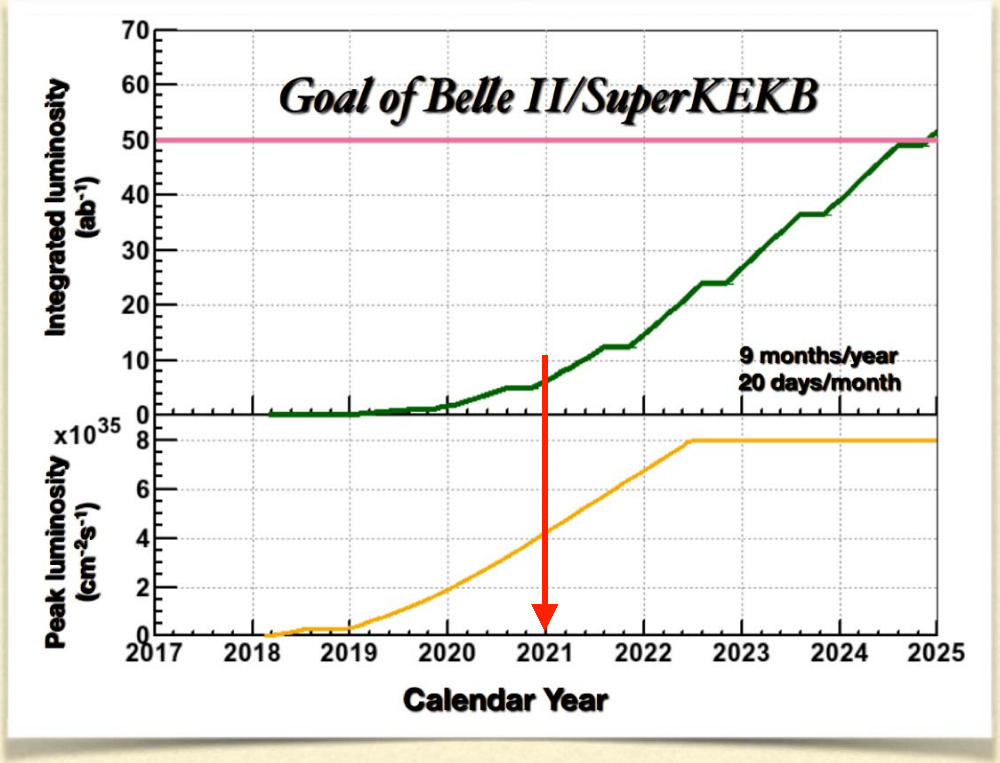
- Robustness against machine background proved, predicted precision can be exceeded by improving analysis strategy

Belle II full simulation with machine background (signal with arbitrary normalisation)



# $B \to K^{(*)}\nu\nu$ : perspectives @ Belle II (II)

- Perspectives with 2018-2021 data:
  - expected luminosity as a function of time:
  - 5-10 $ab^{-1}$ collected by 2021




- With 5 $ab^{-1}$ statistics:
  - ~ 25% precision on branching fraction, both for charged and neutral K* channels
  - ~ 4 $\sigma$ statistical significance

- With 10 $ab^{-1}$ statistics, improved analysis strategy and machine background robustness, 5 $\sigma$ discovery MAY be approached

# Summary

- Belle II unique or very competitive environment to study B decays with missing energy, sensitive to indirect NP effects
- x40 luminosity (and much higher machine background) wrt first generation B-factories
- Belle II full simulation studies proved the detector performances and the reconstruction algorithms to be robust against simulated machine background
  - measurements on machine background rates and spectra during phase I (2016) and phase II (starting Nov. 2018) operation phases
- Improvements in analysis strategy and larger data sample will allow to approach SM prediction ($B \to K^{(*)}\upsilon\upsilon$)
- 2021 perspectives:
  - with current estimations, 3 $\sigma$ evidence accomplished with less than 5 $ab^{-1}$
  - ~ 25% precision on BF measurement with 5 $ab^{-1}$
  - 4 to 5 $\sigma$ significance with 10 $ab^{-1}$, machine bkg robustness and some analysis improvements

# References

[knn1] BELLE2-MEMO-2016-007, Buras et al. JHEP 1502 (2015) 184

[knn2] Belle collaboration, arXiv:1702.03224; Belle collaboration, Phys.Rev. D87 (2013) no.11, 111103; BaBar collaboration, Phys.Rev. D87 (2013) no.11, 112005

[knn3] W. Altmannshofer et al. JHEP 0904 (2009) 022

# BACK-UP SLIDES

# FEI performances

Table 5: Tag-side efficiency: Number of correctly reconstructed tag-side $B$ mesons divided by the total number of $\Upsilon(4S)$ events. The presented efficiencies depend on the used BASF2 release (7.2), MC campaign (MC 7) and FEI training configuration.

| Tag | $FR^2$ @ Belle | FEI @ Belle MC | FEI @ Belle II MC |
|---|---|---|---|
| Hadronic $B^+$ | 0.28 % | 0.49 % | 0.61 % |
| Semileptonic $B^+$ | 0.67 % | 1.42 % | 1.45 % |
| Hadronic $B^+0$ | 0.18 % | 0.33% | 0.34 % |
| Semileptonic $B^0$ | 0.63 % | 1.33% | 1.25 % |