Prospects of $b \rightarrow sl^+l^-$ and related modes at Belle II

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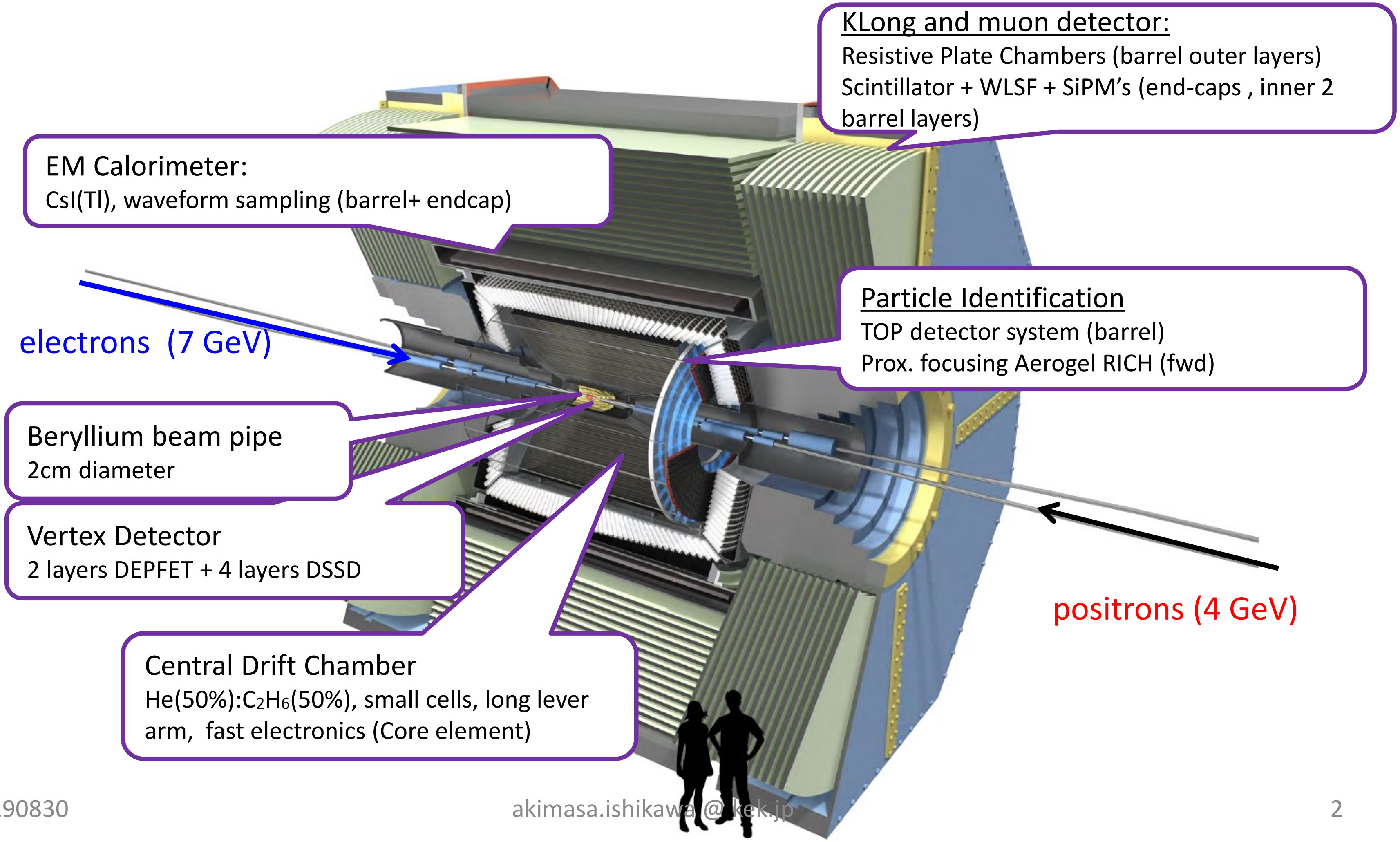
The numbers are basically taken from Belle II Physics Book

Belle II Detector

- Two significant detector improvements for Radiative and EWP B decays
  - Better PID ➔ Kaon ID for B→$\rho\gamma(l^+l^-)$, B→$X_d\gamma(l^+l^-)$, low momentum lepton ID for b→sll
  - Better and Larger VXD ➔ TCPV in B→$Ks\pi^0\gamma$, B meson tagging for b→$s\nu\nu$



Belle II Cons and Pros (VS LHCb)

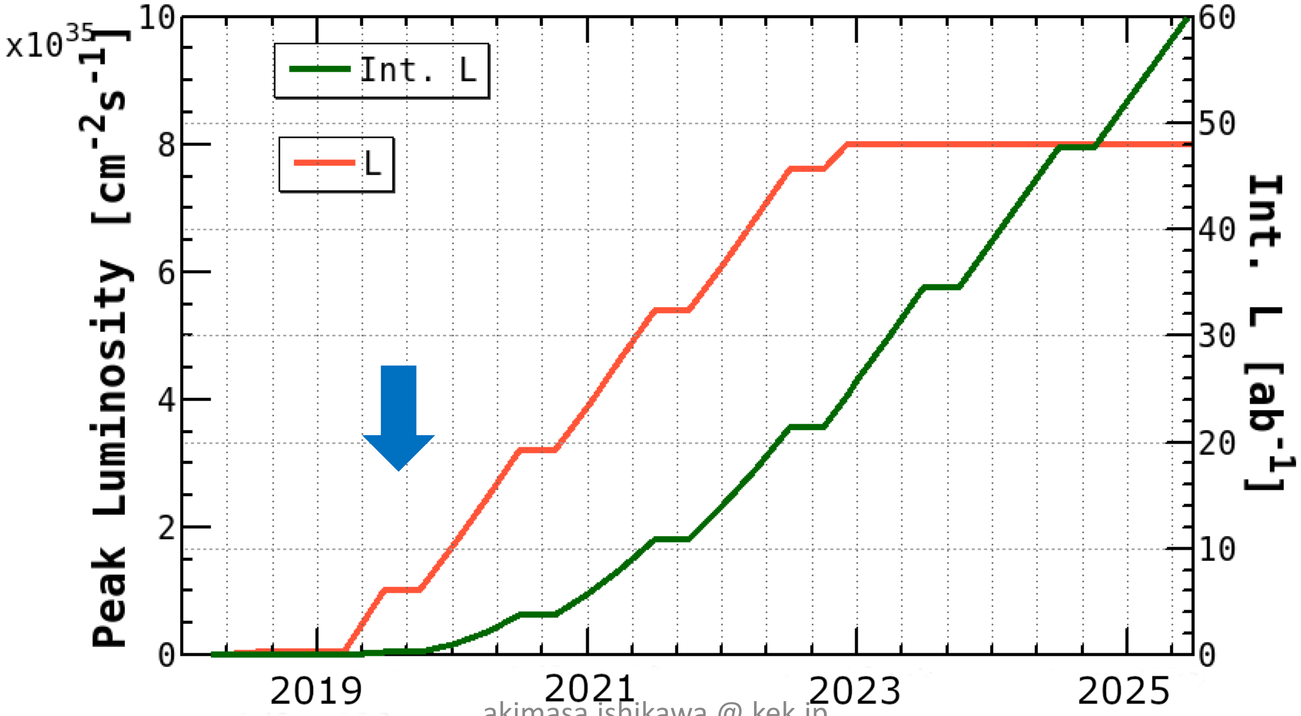
- Cons.
  - Statistics of b hadrons!!
    - We will only have 10^{11} B mesons with $50ab^{-1}$ on Y(4S) and $5x10^{8}$ B_s with $5ab^{-1}$ on Y(5S)
  - No larger samples of b baryon and B_c
    - Production of these hadrons are not yet established around Y(nS).
  - Proper time resolution is worse and B meson is not so boosted.
    - Background suppression with B vertex is not so easy ➔ fully inclusive b→sll??
    - Bs mixing (Δm_s) can not be measured (while $\Delta\Gamma_s$ can be measured).

Belle II Cons and Pros (VS LHCb)

- Pros.
  - Smaller background cross section : ~3.4nb for ee→qq, ~1nb for ee→Y(4S)→BB
  - Almost 100% trigger efficiency for Y(4S)→BB events.
    - Main trigger : 3-track-trigger || ECL high energy trigger.
    - Absolute BF measurement possible.
  - High hermeticity 4π x 94%
    - High reconstruction efficiency of O(1)~O(10)%.
    - Full reconstruction possible (Reconstruction of the other B meson)
    - More than one missing neutrino modes can be also searched for ➔ $B \to K^{(*)}\nu\nu$, $B \to K\tau\tau$, $B \to \nu\nu$
  - Detection of electron
    - Detection efficiency of electron is almost the same as that for muon ➔ test of LFU
  - Detection of neutrals
    - γ, π^0 and Ks can be reconstructed efficiently ➔ sum-of-exclusive approach, $B_{(s)} \to \gamma\gamma$
    - Better energy resolution of hard γ ➔ $B \to \rho\gamma$ with good PID devise

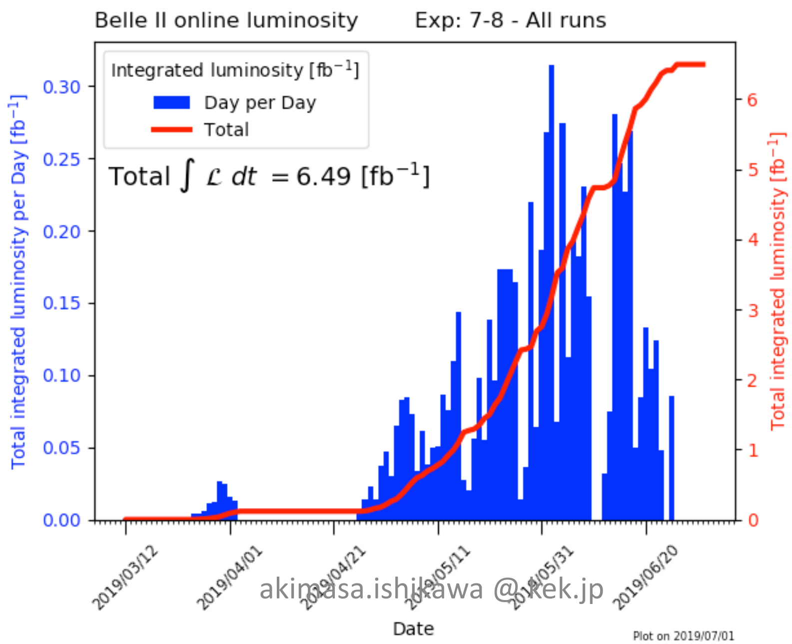
Luminosity Projection

- 50ab^{-1} by 2027
  - Discussion of upgrade aiming for 250ab^{-1} started.
  - Strongly related to the ILC plan
- In this talk, 50ab^{-1} is assumed.



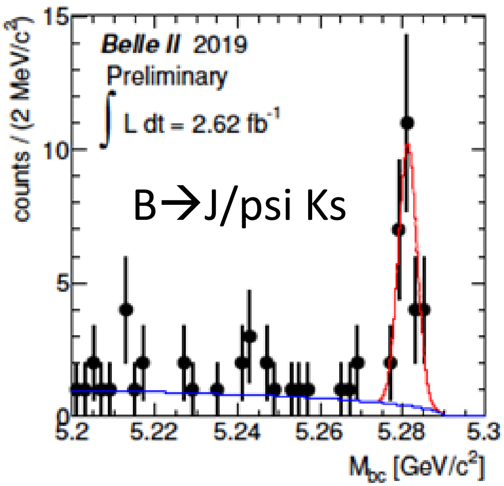
Belle II by summer 2019

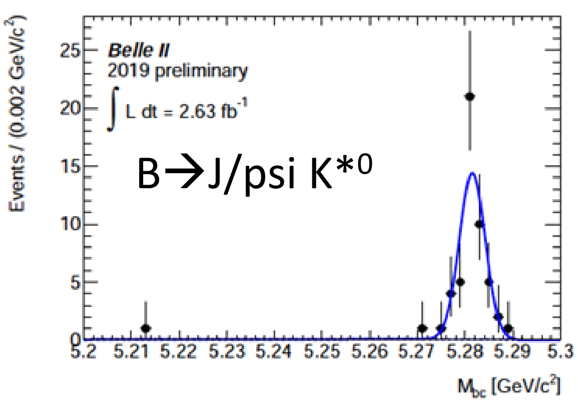
- We started data taking with almost full Belle II detector
  - 2^{nd} Pixel layer was partially installed.
- Reached 1.2x 10^{34} $cm^{-2}s^{-1}$ (1/2 of KEKB) luminosity while background is higher due to vacuum level in LER beam pipe. Need scrubbing.
- 6.5fb^{-1} data (1/100 of Belle) were accumulated by this summer.
  - 2.6fb^{-1} data was analyzed for summer conferences.

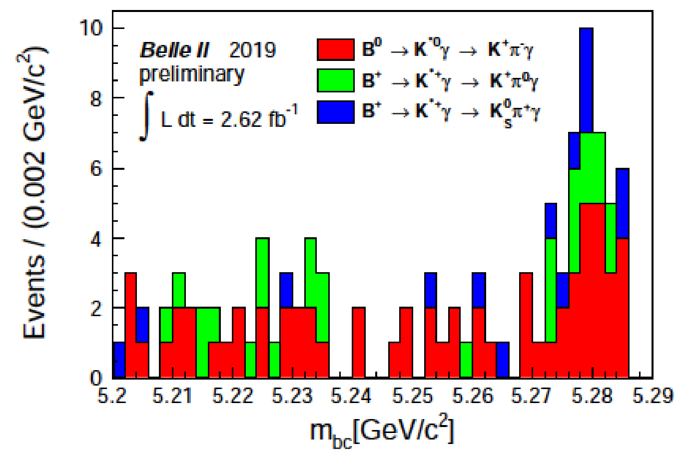


Rediscoveries of B decays

- With 2.6fb^{-1}
  - We observed B→J/psi K(*) which are used for calibration of b→sl+l-
  - We rediscovered the penguin mode B→K*γ.







Prospects of b→sl$^+$l$^-$

- We assume LFU except for LFU violating observables
  - We can combine electron and muon modes
  - Our selection efficiencies for electron and muon modes are almost the same.

- Contents
  - Inclusive B→Xsll
  - Exclusive B→K(*)ll
  - LFU Violation

Inclusive B→Xsl+l-

- So far, Belle and Babar performed sum-of-exclusive method which can control background level with reasonable signal efficiency.

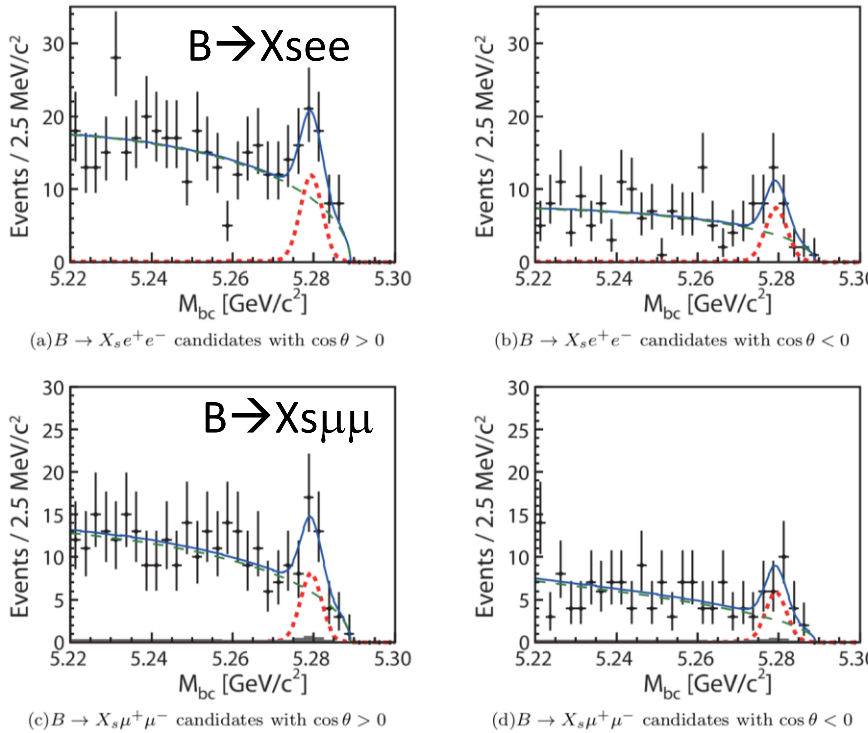
- There is a possibility to use fully inclusive dilepton method by tagging the other B which should have no uncertainties related to Xs, e.g. fragmentation and M_{Xs} cut.
- But a detailed study, especially on background suppression, is needed.
  - And also statistics is needed since the tagging efficiency is O(1)% even at Belle II

- In this talk, I only mention about sum-of-exclusive analysis with MXs cut at 2.1GeV.

Reconstruction of B→Xsl+l-

- Dilepton
  - Electron selected from dE/dx in CDC and ECL
  - Muon from KLM
  - We might be able to use TOP and ARICH for low momentum region which improve efficiency for low q^2 region
- Xs
  - is reconstructed from K*n*π (0<=*n*<=4).
  - We can add three kaon modes and η modes (two pi0 modes?)
- Backgrounds
  - Dominated by B→Xlν and B→Ylν
    - Second largest is ee→cc but event shape information can suppress the background.
  - Can be suppressed with missing energy and vertex information.

Y. Sato, Phys.Rev. D93 032008 (2016)



(a) $B \to X_s e^+ e^-$ candidates with $\cos\theta > 0$

(b) $B \to X_s e^+ e^-$ candidates with $\cos\theta < 0$

(c) $B \to X_s \mu^+ \mu^-$ candidates with $\cos\theta > 0$

(d) $B \to X_s \mu^+ \mu^-$ candidates with $\cos\theta < 0$

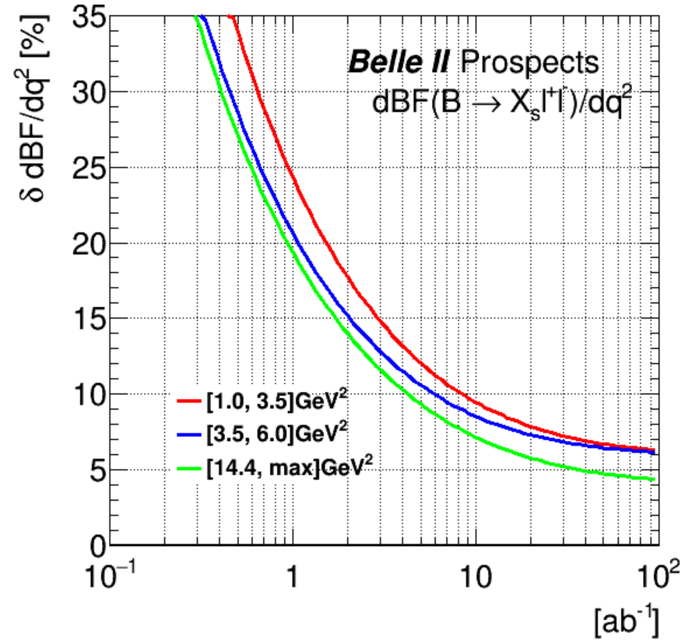
Forward event backward event

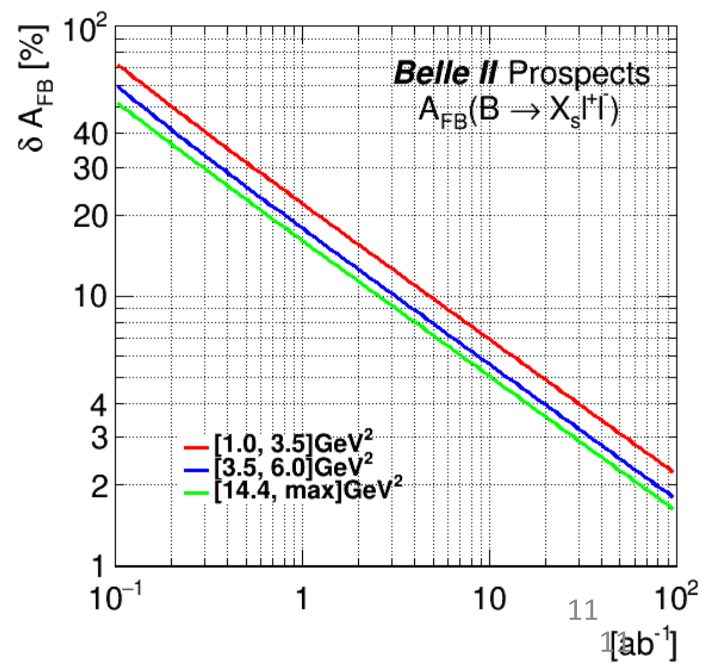
[1,6]GeV^2

BF and A_{FB} in $B \to X_s l^+ l^-$

- The uncertainty of BF is dominated by systematic one with ~15ab^{-1}.
  - Largest one is due to fragmentation modeling which could be improved by adding decay modes and data driven PYTHIA tuning.
  - We can use finner binning of 1GeV^2 with 50ab^{-1} or can go higher M_{Xs} cut of ~2.5GeV.
- A_{FB} is still statistically dominated thanks to the ratio observable.
  - We can also measure CP difference (or asymmetry) of Forward-backward asymmetry

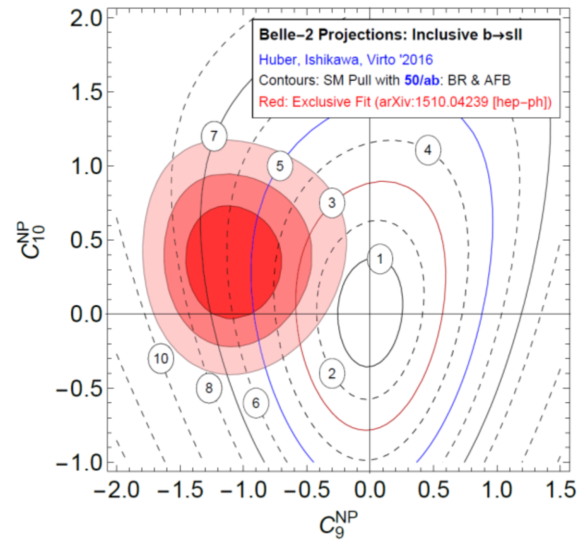
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B \to X_s \ell^+ \ell^-)$ ([1.0, 3.5] GeV^2)	29%	13%	6.6%
$\mathrm{Br}(B \to X_s \ell^+ \ell^-)$ ([3.5, 6.0] GeV^2)	24%	11%	6.4%
$\mathrm{Br}(B \to X_s \ell^+ \ell^-)$ ($>$ 14.4 GeV^2)	23%	10%	4.7%
$A_{CP}(B \to X_s \ell^+ \ell^-)$ ([1.0, 3.5] GeV^2)	26%	9.7 %	3.1 %
$A_{CP}(B \to X_s \ell^+ \ell^-)$ ([3.5, 6.0] GeV^2)	21%	7.9 %	2.6 %
$A_{CP}(B \to X_s \ell^+ \ell^-)$ ($>$ 14.4 GeV^2)	21%	8.1 %	2.6 %
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ([1.0, 3.5] GeV^2)	26%	9.7%	3.1%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ([3.5, 6.0] GeV^2)	21%	7.9%	2.6%
$A_{FB}(B \to X_s \ell^+ \ell^-)$ ($>$ 14.4 GeV^2)	19%	7.3%	2.4%
$\Delta_{CP}(A_{FB})$ ([1.0, 3.5] GeV^2)	52%	19%	6.1%
$\Delta_{CP}(A_{FB})$ ([3.5, 6.0] GeV^2)	42%	16%	5.2%
$\Delta_{CP}(A_{FB})$ ($>$ 14.4 GeV^2)	38%	15%	4.8%





Constraints on Wilson Coefficients

Huber, Ishikawa, Virto, Belle II Physics Book



- With BF and A_{FB}
  - We can test the anomaly in exclusive decays with inclusive decays

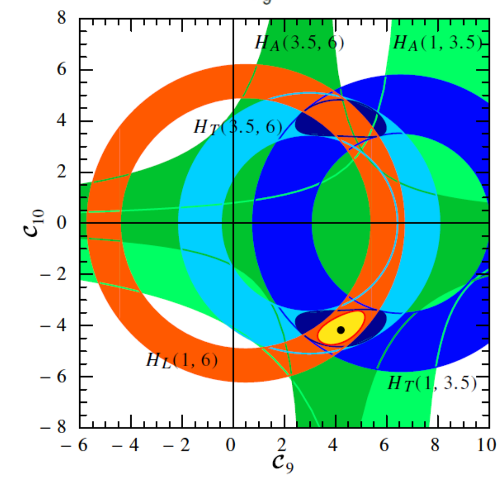
- Helicity decomposition gives third observables
  - H_T, H_L, H_A

$$\frac{d^2\Gamma}{dq^2\,dz} = \frac{3}{8}\big[(1+z^2)H_T(q^2) + 2zH_A(q^2) + 2(1-z^2)H_L(q^2)\big] .$$

$$\frac{d\Gamma}{dq^2} = H_T(q^2) + H_L(q^2) ,$$

$$\frac{dA_{FB}}{dq^2} = \frac{3}{4}H_A(q^2) .$$

$$z = \cos\theta$$



Lee, Ligeti Stewart and Tackmann, PRD 75, 034016 (2007)

Exclusive $B \to K^{(*)} l^+ l^-$

- Reconstruction of exclusive decays is very straight forward and well established at Belle.
  - Of course, improvement is possible at Belle II.
- BF and q^2 distributions are already systematic dominant at LHCb
  - But we can test the deficit of muon modes observed by LHCb.
  - And recheck the higher charmonium contributions for $q^2 > 14.4 GeV^2$
- Isospin violation might be good topic again in the light of new Belle measurements of $A_I(B \to Kl+l-)$ (which is consistent with LHCb)

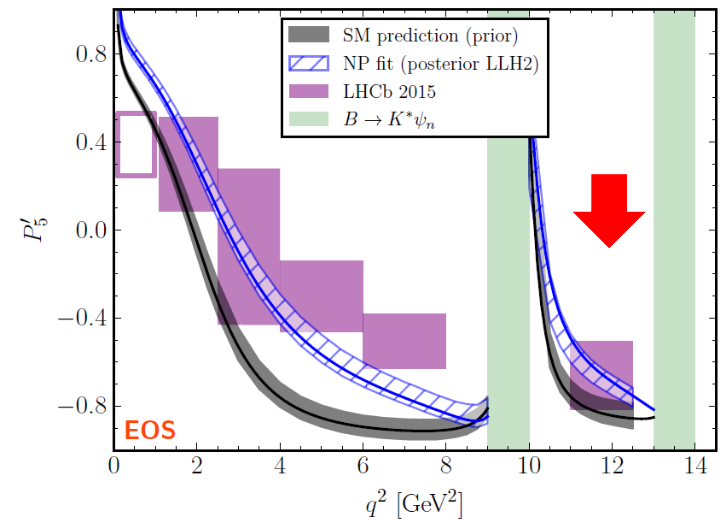
- Angular analysis is very important topic at Belle II
  - LHCb will observe a deviation of P_5' from an SM prediction by DHMV with data already in hand??

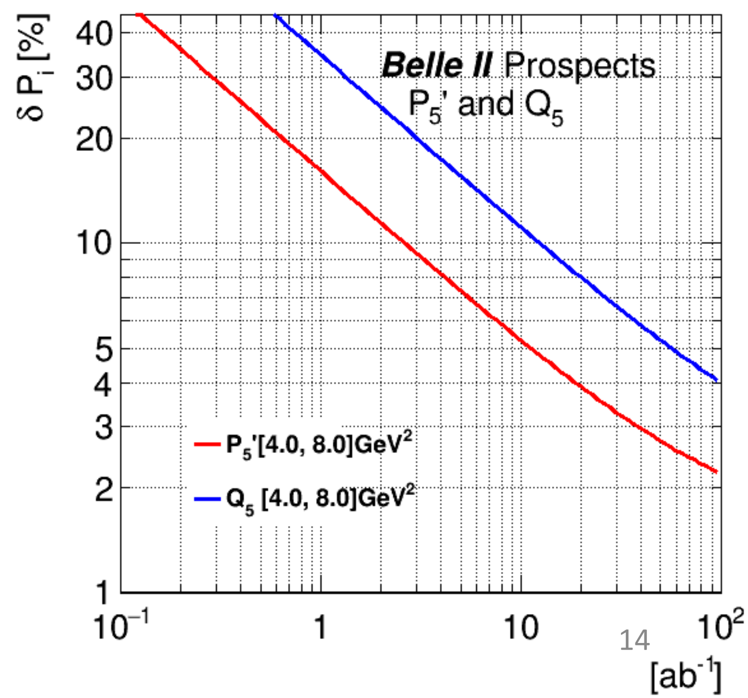
P_5'

- Statistically dominated even with 50ab^{-1}
  - Belle II can confirm or deny LHCb anomaly in P_5' with
  - With 50ab^{-1}, the uncertainty is about 20% worse than LHCb with 50fb^{-1}
  - We can also measure P_5' etc in the q^2 bin in between J/psi and psi', [11,12.5]GeV^2
    - Sorry no projections

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
P_5' ([1.0, 2.5] GeV^2)	0.47	0.17	0.054
P_5' ([2.5, 4.0] GeV^2)	0.42	0.15	0.049
P_5' ([4.0, 6.0] GeV^2)	0.34	0.12	0.040
P_5' (> 14.2 GeV^2)	0.23	0.088	0.027

Bobeth, Chrzaszcz, van Dyk, Virto





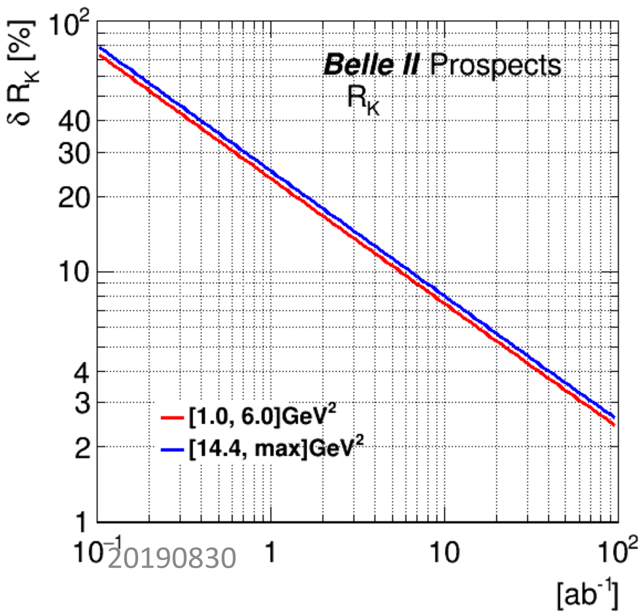
LFU Violation

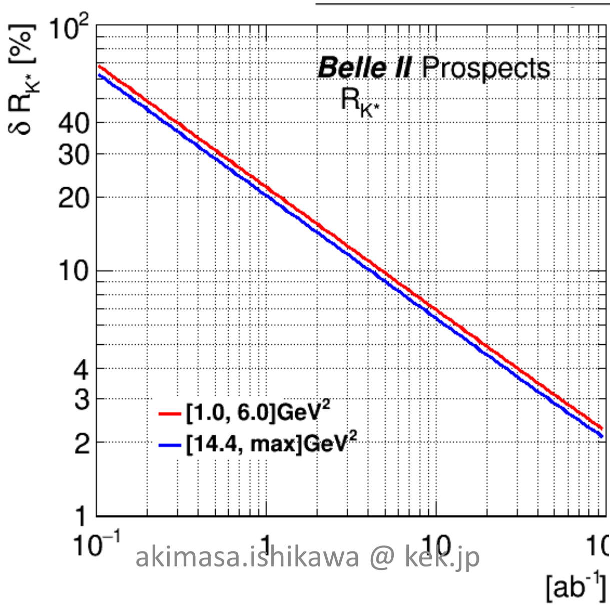
- LHCb reported anomalies in the rate, $R_{K(*)}$.
- Belle and Babar also measured the $R_{K(*)}$ while consistent with both SM and central values by LHCb due to large uncertainties.
  - Recent updates by Belle should be covered by Simon
- Belle also measured angular observables for the first time, $Q_5 = P_5'^{e} - P_5'^{\mu}$
- Belle will measure the R_{Xs} with inclusive decays
- Belle II will measure everything, rate and angular observables

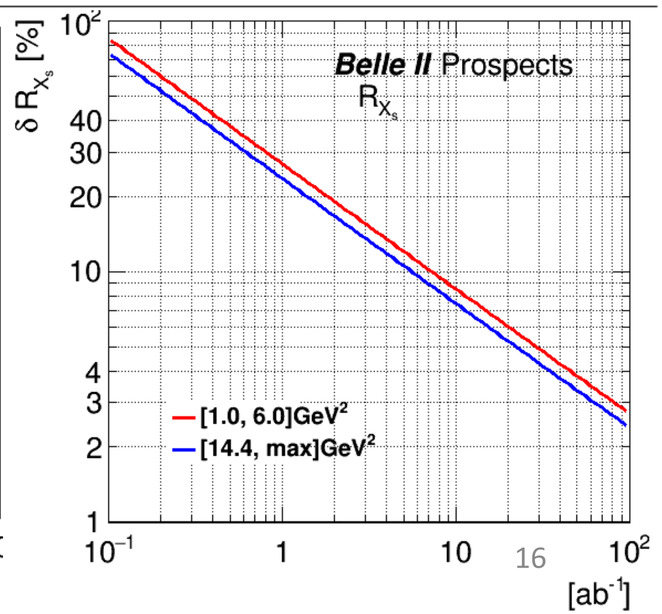
R_K, R_{K^*} and R_{Xs}

- Belle II is an ideal place to measure the R
  - Bremsstralung recovery not difficult
  - Dominant systematics from lepton ID ~0.4%.
  - Statistically dominated even with 50/ab
- About 20/ab (2022) is needed to observe the NP in $R_{K(*)}$ if central values unchange
- ~3% for both high and low q^2 with 50/ab
  - Assuming SM values
  - eID improvement with TOP and ARICH not included

Observables	Belle $0.71\,\mathrm{ab}^{-1}$	Belle II $5\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
R_K ($[1.0, 6.0]\,\mathrm{GeV}^2$)	28%	11%	3.6%
R_K ($> 14.4\,\mathrm{GeV}^2$)	30%	12%	3.6%
R_{K^*} ($[1.0, 6.0]\,\mathrm{GeV}^2$)	26%	10%	3.2%
R_{K^*} ($> 14.4\,\mathrm{GeV}^2$)	24%	9.2%	2.8%
R_{X_s} ($[1.0, 6.0]\,\mathrm{GeV}^2$)	32%	12%	4.0%
R_{X_s} ($> 14.4\,\mathrm{GeV}^2$)	28%	11%	3.4%

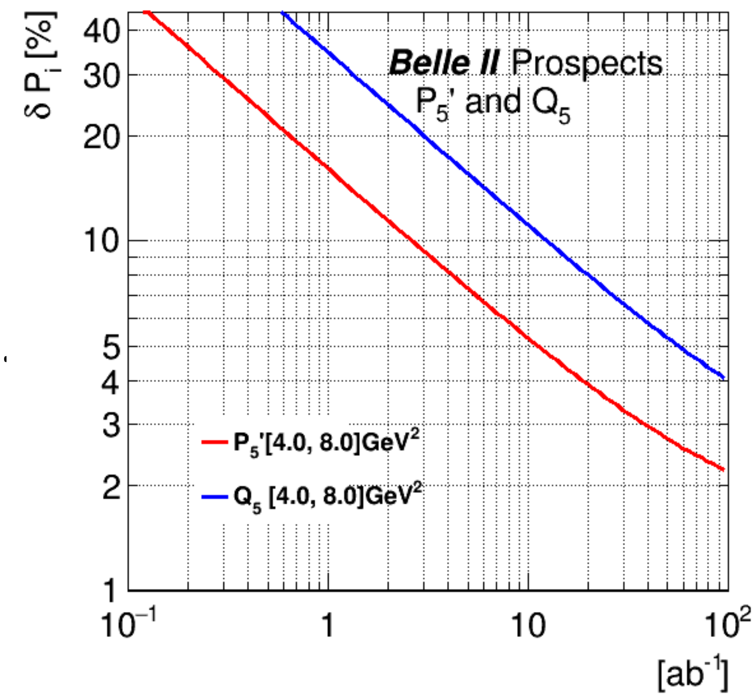


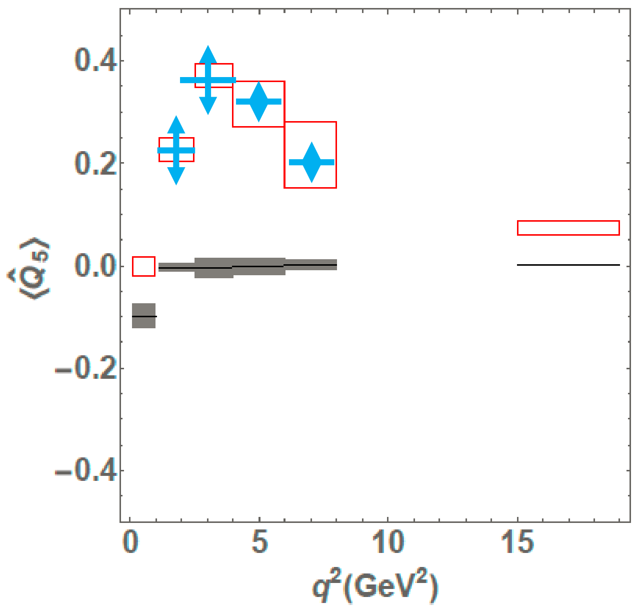




$Q_5 = P_5'^{e} - P_5'^{\mu}$

- $Q_5 = P_5'^{e} - P_5'^{\mu}$
  - 5.3% with 50/ab
  - Can resolve the NP effect in $C_{9\mu}$
- We can also measure A_{FB} difference between electron and muon modes with inclusive decays.





Belle II 50ab^{-1}

SM : gray

NP : red

$$C_{9\mu}^{\mathrm{NP}} = -1.11$$

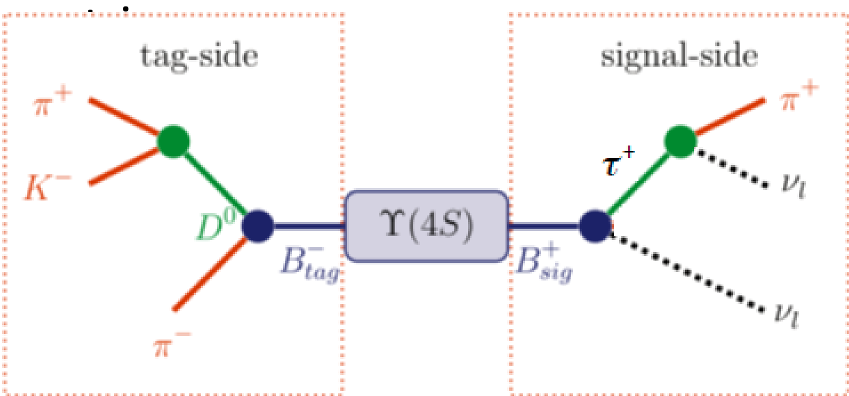
Capdevila, Descotes-Genon, Matias and Virto 1605.03156

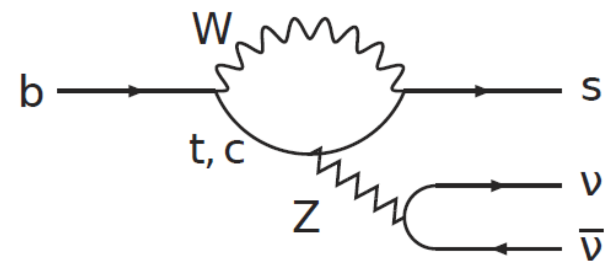
Overlaid Belle II sensitivity

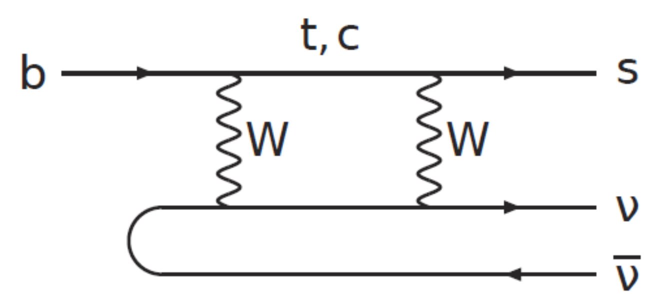
$B \rightarrow K^{(*)}\nu\nu$

$B \to K^{(*)}\nu\nu$

- If C_9 is deviated from the SM value, vector current in $b \to s\nu\nu$ might be also affected in some BSM models?
- If so, at Belle II, we can test the deviation with $B \to K(*)\nu\nu$
- The BF is cleanly predicted in the SM.
  - F_L also
- Experimentally, we need to tag the other B meson due to final states having multiple







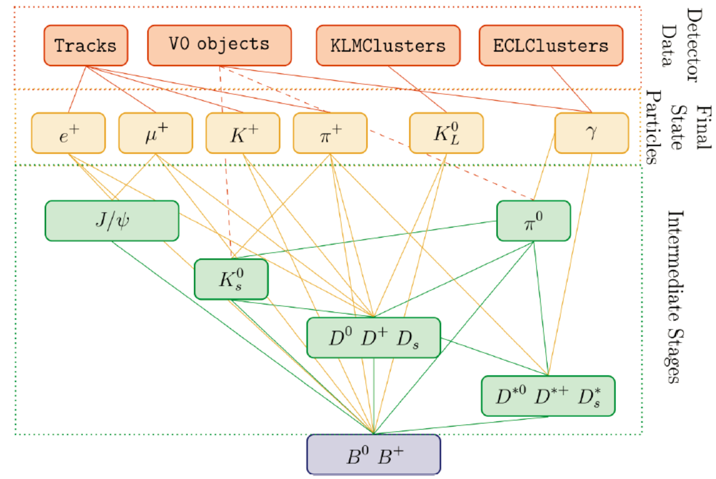
A. Buras, et al. JHEP 02 184 (2015)

Mode	$\mathcal{B}$ $[10^{-6}]$
$B^+ \to K^+\nu\bar{\nu}$	$3.98 \pm 0.43 \pm 0.19$
$B^0 \to K^0_S\nu\bar{\nu}$	$1.85 \pm 0.20 \pm 0.09$
$B^+ \to K^{*+}\nu\bar{\nu}$	$9.91 \pm 0.93 \pm 0.54$
$B^0 \to K^{*0}\nu\bar{\nu}$	$9.19 \pm 0.86 \pm 0.50$

$F_L^{\rm SM} = 0.47 \pm 0.03$

Improvement of Tagging

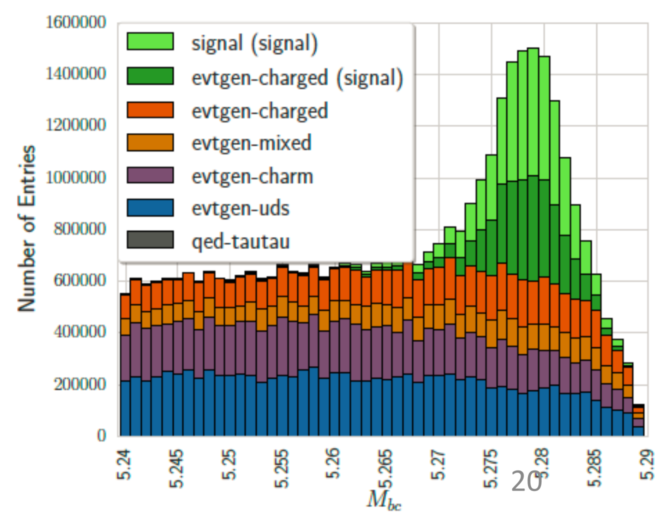
- Full Event Interpretation (FEI)
  - Tagging method using multivariate technique
    - Hierarchical reconstruction
  - More tagging modes than Belle 1
  - Both hadronic decays and semileptonic decays can be used
- About 2 times better tagging efficiency than Belle 1.



Improvement of Algorithm

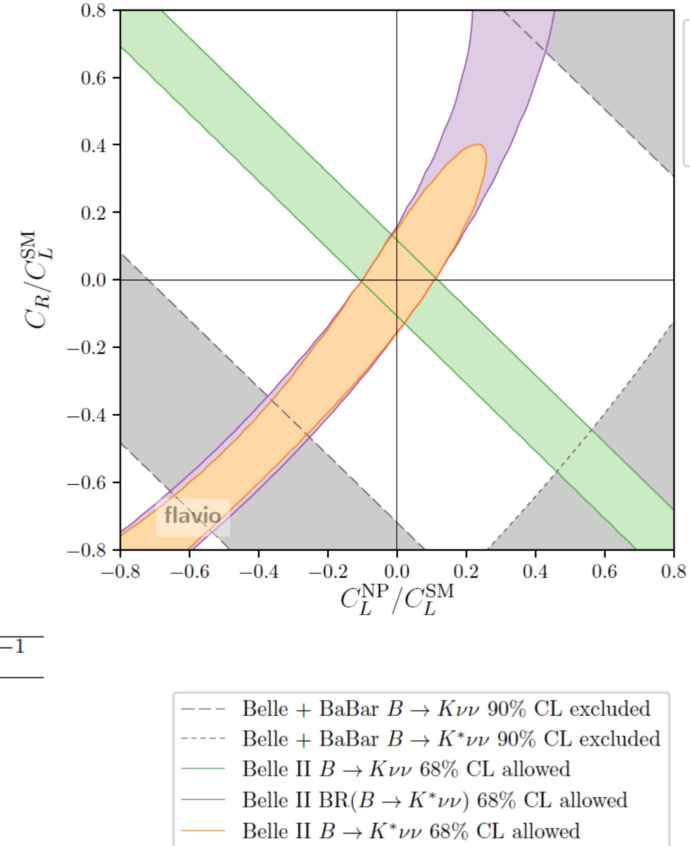
Improvement of Detector and Increase of Background effects

Tag	FR[4] @ 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 %



Measurements of B→K$^{(*)}\nu\nu$

D. Straub, Belle II Physics Book
Inputs from Al and E. Manoni



- We can observe the B→K$^{(*)}\nu\nu$ at early stage (several ab^{-1}) of Belle II, and the sensitivity of the BF is 10% level with 50ab^{-1}.
- We can measure the $F_L(K^*)$, which is less sensitive to form factor uncertainties than BF, with 20% precision with 50ab^{-1}

$$\mathcal{O}_L = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu)$$

$$\mathcal{O}_R = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_R b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu)$$

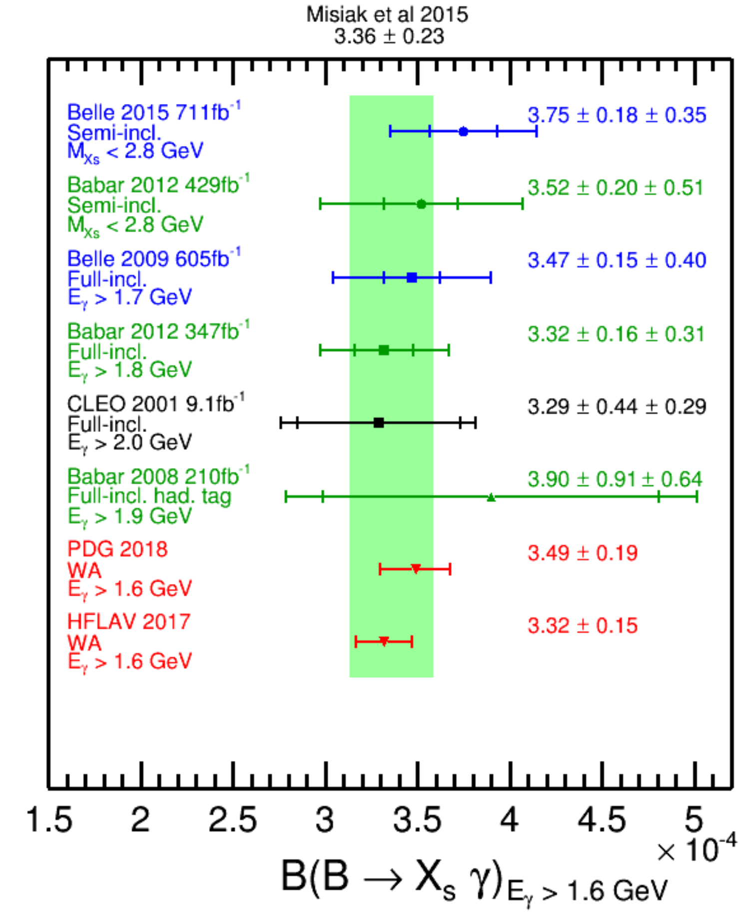
Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B^+ \to K^+\nu\bar{\nu})$	$< 450\%$	30%	11%
$\mathrm{Br}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 180\%$	26%	9.6%
$\mathrm{Br}(B^+ \to K^{*+}\nu\bar{\nu})$	$< 420\%$	25%	9.3%
$F_L(B^0 \to K^{*0}\nu\bar{\nu})$	–	–	0.079
$F_L(B^+ \to K^{*+}\nu\bar{\nu})$	–	–	0.077
$\mathrm{Br}(B^0 \to \nu\bar{\nu}) \times 10^6$	< 14	< 5.0	< 1.5
$\mathrm{Br}(B_s \to \nu\bar{\nu}) \times 10^5$	< 9.7	< 1.1	–

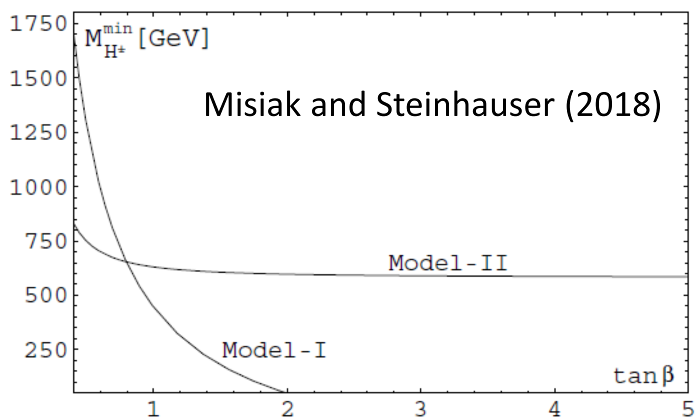
b→sγ

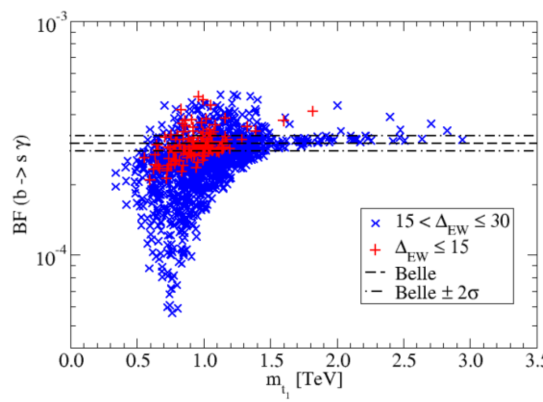
BF($B \to X_s \gamma$)

- Exp and theory are in a good agreement
  - The uncertainties are almost comparable
  - Exp WA ~5% : already systematic dominant
  - Theory ~7%
- Strong constraint on new physics
  - Constraint on $|C_7|^2 + |C_7'|^2$
  - Charged Higgs in 2HDM type-II
    - > 580GeV Misiak and Steinhauser (2018)
  - stop in natural SUSY

Baer, Bager, Nagata and Savoy (2017)







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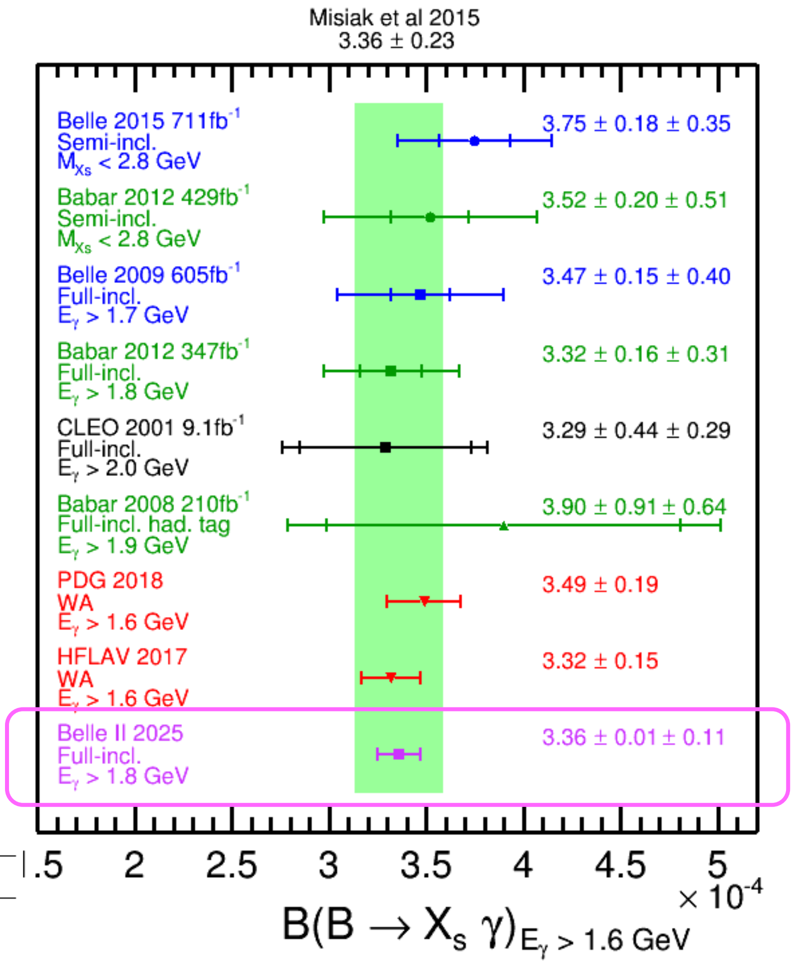
BF($B \to X_s\gamma$) in Belle II Era

- Exp : Already systematic dominant
  - But large Belle II data can reduce the uncertainty to ~3% (WA ~2.6%)
    - Photon detection etc.
- Theory
  - Part of Non-perturbative uncertainties : data driven reduction possible
    - Isospin asymmetry
    - Photon energy spectrum
    - HQE parameters from $b \to c l \nu$ and $b \to s\gamma$ moments
  - Other uncertainties also reducible
  - 3.5% in 2025

Private communication with M. Misiak



Some people say that BF($B \to X_s\gamma$) is already uncertainty limited at B-factories but it is not true!

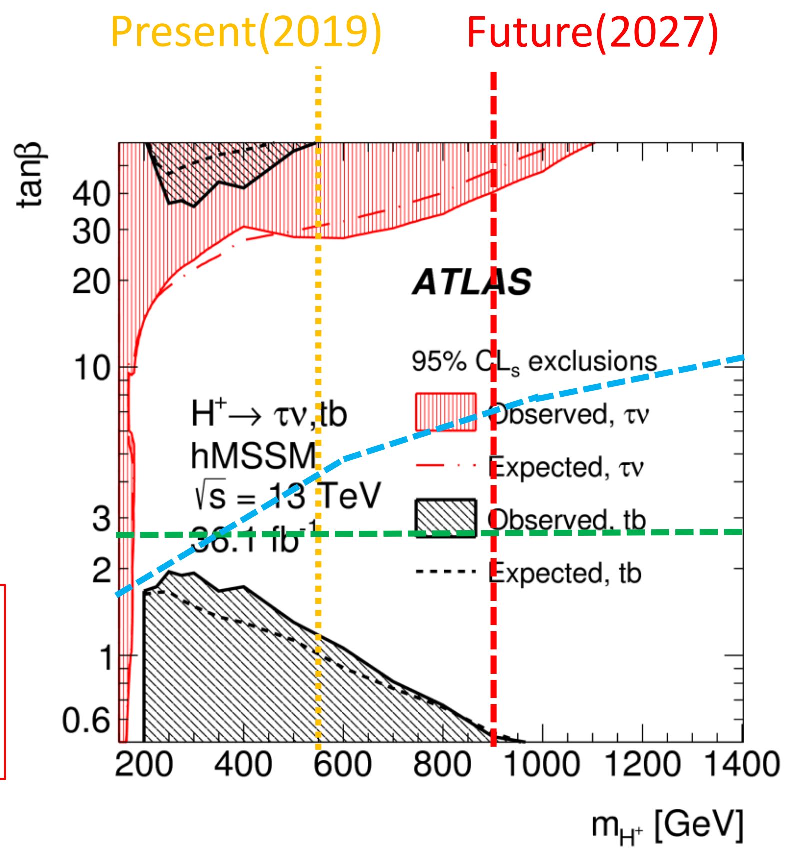
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B \to X_s\gamma)^{\text{lep-tag}}_{\text{inc}}$	5.3%	3.9%	3.2%
$\mathrm{Br}(B \to X_s\gamma)^{\text{had-tag}}_{\text{inc}}$	13%	7.0%	4.2%
$\mathrm{Br}(B \to X_s\gamma)_{\text{sum-of-ex}}$	10.5%	7.3%	5.7%
$\Delta_{0+}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.4%	0.94%	0.69%
$\Delta_{0+}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	9.0%	2.6%	0.85%

Belle II Physics book 1808.10567

Limit on Charged Higgs

- R_b at LEP
  - tanβ >~2.5
- BF(B→Xs γ)
  - M_H > 580GeV
  - →>~900GeV in 2027
- BF(B→τν) in 2027
  - Tanβ/M_H ~< 0.008/GeV (~4% on BF)
- And BF(Bs→μμ) at LHC

Ishikawa's private estimation



Before ILC measures Higgs couplings, B physics observables might give the strongest constraint on 2HDM type-II at moderate tanβ

$\Delta A_{CP}(B \to X_s\gamma)$

- $A_{CP}(B \to X_s\gamma)$ is sensitive to CPV in NP but theoretical uncertainty already dominant

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{X}_s\gamma) - \Gamma(B \to X_s\gamma)}{\Gamma(\bar{B} \to \bar{X}_s\gamma) + \Gamma(B \to X_s\gamma)}$$

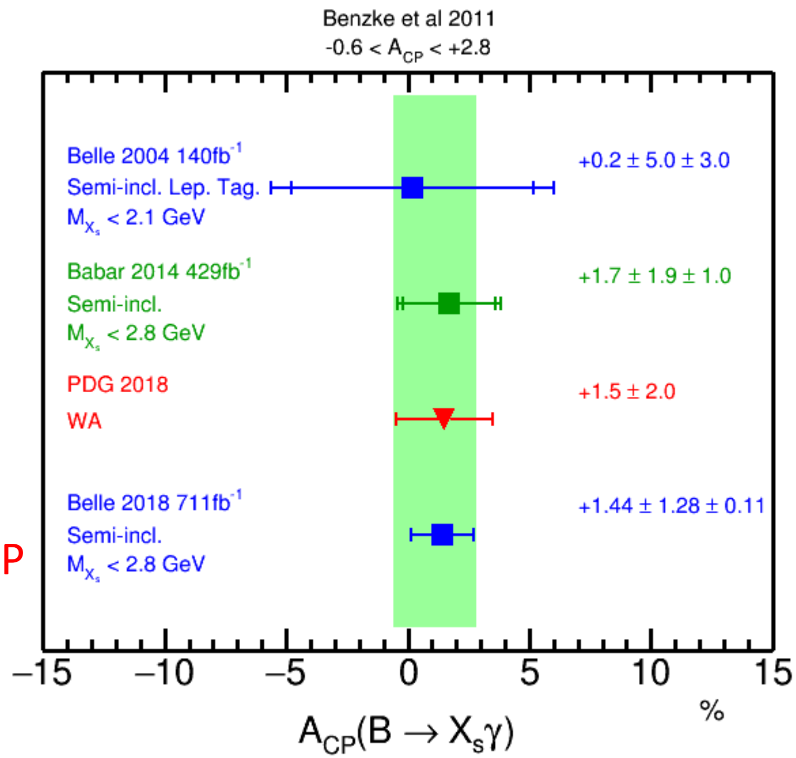
- New observable ΔA_{CP} is null in SM and sensitive to NP

$$\begin{aligned}\Delta A_{CP} &= A_{CP}(B^+ \to X_s^+\gamma) - A_{CP}(B^0 \to X_s^0\gamma) \\ &= 4\pi^2\alpha_s \frac{\tilde{\Lambda}_{78}}{m_b}\mathrm{Im}\left(\frac{C_8}{C_7}\right), \\ &\approx 0.12\left(\frac{\tilde{\Lambda}_{78}}{100\ \mathrm{MeV}}\right)\mathrm{Im}\left(\frac{C_8}{C_7}\right),\end{aligned}$$

M. Benzke, S. J. Lee, M. Neubert, G. Paz, JHEP 08 (2010) 099

  - Ex. SUSY with flavor violating trilinear couplings

M. Endo, T. Goto, T. Kitahara, S. Mishima, D. Ueda and K. Yamamoto, JHEP 04 (2018) 019.



Recent estimation gives larger uncertainty Gunawardana and Paz 1908.02812

- Belle measured the observable in 2018

$$\Delta A_{CP} = [+3.69 \pm 2.65(\mathrm{stat.}) \pm 0.76(\mathrm{syst.})]\%$$

Watanuki, Ishikawa et al, PRD 99, 032012 (2019)

Shun Watanuki is now at LAL

ΔA_{CP} at Belle II

- The latest Belle result

$$\Delta A_{CP} = [+3.69 \pm 2.65(\text{stat.}) \pm 0.76(\text{syst.})]\%$$

  - We found the systematic uncertainty is much smaller then statistical one
  - And also most of the systematic uncertainties are reducible

- At Belle II, we can reduce the uncertainty to 0.3% level
  - If current central value holds, the deviation is about 12σ from zero
  - Strong constraints on $\text{Im}(C_8/C_7)$
    - Theoretical improvement on $\sim\Lambda_{78}$ is desirable.

Observables	Belle $0.71\,\text{ab}^{-1}$	Belle II $5\,\text{ab}^{-1}$	Belle II $50\,\text{ab}^{-1}$
$\Delta A_{CP}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.7%	0.98%	0.30%

Photon Polarization in $b \rightarrow s\gamma$

- In the SM, photon is predominantly left-handed $b \rightarrow s_L \gamma_L$.
  - Right-handed is suppressed by $O(m_s/m_b)$

$$\mathcal{O}_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{s}_{\alpha L} \sigma^{\mu\nu} b_{\alpha R} F_{\mu\nu}$$ Left handed

$$\mathcal{O}'_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{s}_{\alpha R} \sigma^{\mu\nu} b_{\alpha L} F_{\mu\nu}$$ Right handed

- If new physics has right-handed current, fraction of right-handed polarized photon could be larger than SM.
  - Ex. LRSM, SUSY
- There are four methods to measure photon polarization on Υ(4S)
  - Time dependent CPV in $B \rightarrow f_{CP}\gamma$ ← Golden modes at Belle II
  - A_{UD} in $B \rightarrow K_1(K\pi\pi)\gamma$
  - Very low q^2 analysis in $B \rightarrow K^*ee$
  - Photon conversion

Measurement of $S(B^0 \rightarrow K^{*0}\gamma)$

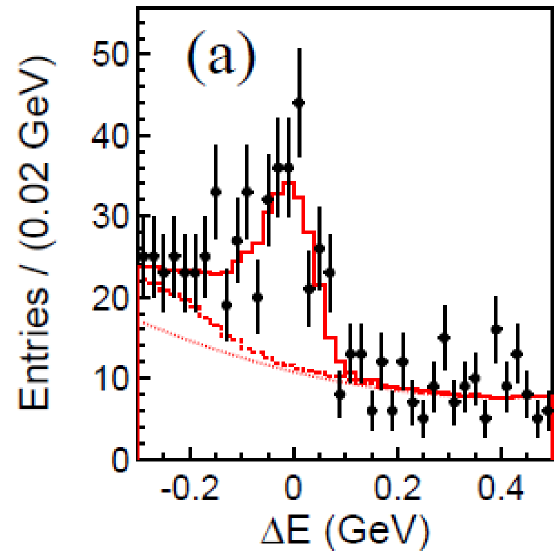
$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \{1 + q\,[\mathcal{S}\sin(\Delta m_d \Delta t) + \mathcal{A}\cos(\Delta m_d \Delta t)]\}$$

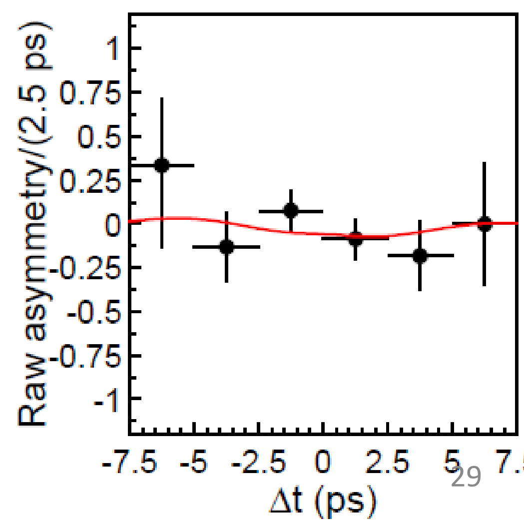
- Both Belle and Babar performed the analysis with 535M and 467M BB pairs.

$$S_{K^{*0}\gamma} = -0.32^{+0.36}_{-0.33} \pm 0.05 \quad \text{(Belle)}$$

$$S_{K^{*}\gamma} = -0.03 \pm 0.29\ (\mathrm{stat}) \pm 0.03\ (\mathrm{syst}) \quad \text{(Babar)}$$

- Belle result is slightly worse than Babar's since # of Ks with vertex detector hits, which can be used for TCPV analysis, are smaller due to smaller vertex detector.



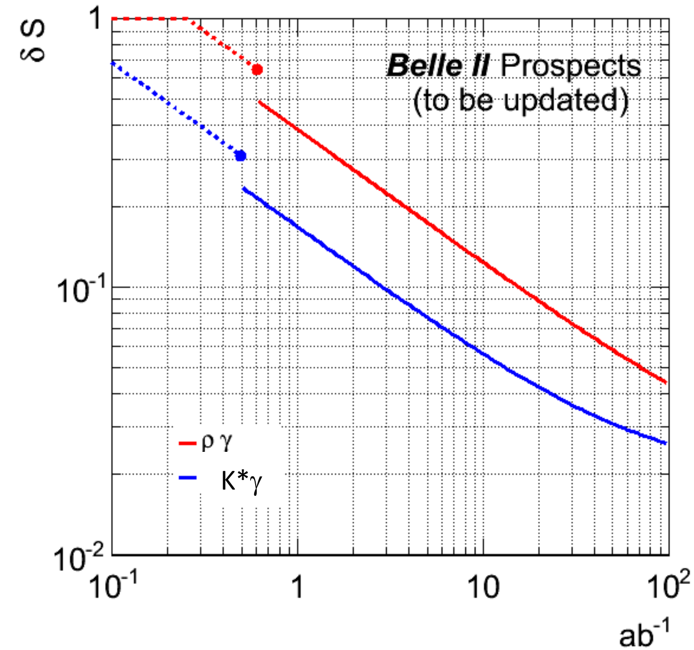


$S(B^0 \rightarrow K^{*0}\gamma)$ at Belle II

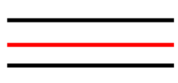
- Belle II vertex detector becomes larger
  - R of second outmost layer is 11.5cm (was 6cm)
  - 30% more Ks with vertex hits available.
- Effective tagging efficiency is ~20% better
- We can reach 0.03 uncertainty on S.
  - Still statistically dominated

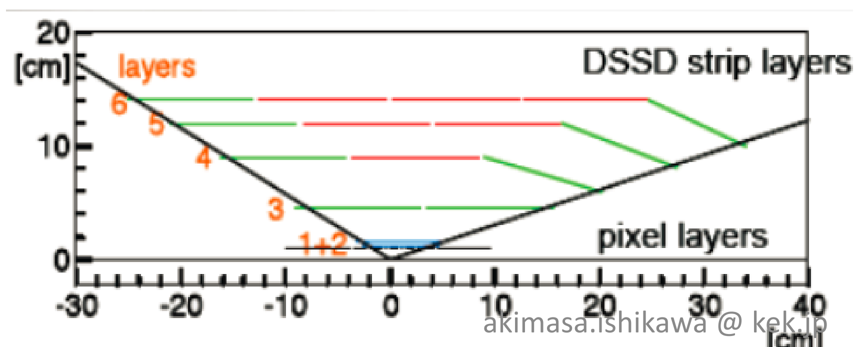
Mode	$5\ \mathrm{ab}^{-1}$	$50\ \mathrm{ab}^{-1}$
$K^*\gamma$	0.09	0.030
$\rho^0\gamma$	0.19	0.064

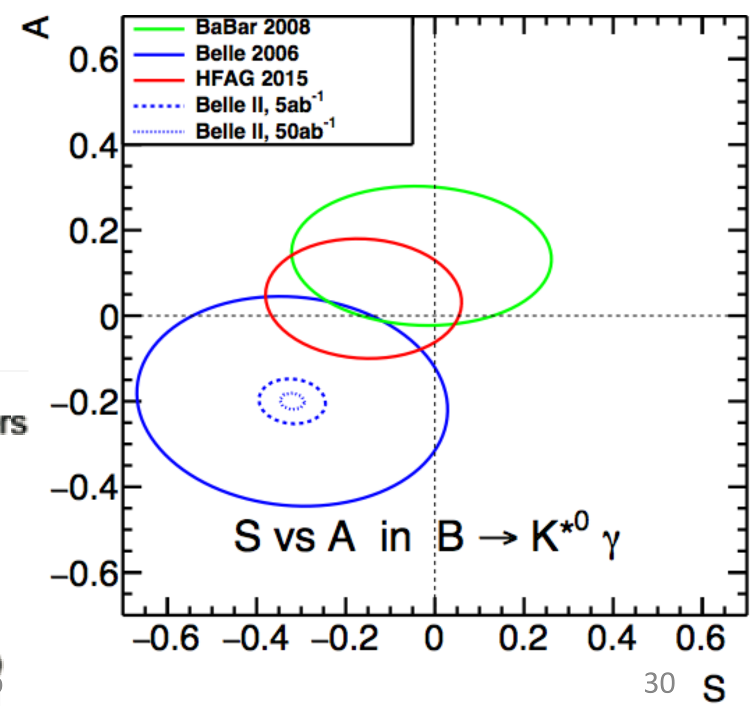
Belle II



Belle 1







16σ deviation from (0,0)

Photon Polarization

- We can constrain on C_7' from $S_{K^*\gamma}$ and angular observables in $B \rightarrow K^*ee$ at low q^2 region, $A_T^{(2)}$ and $A_T^{(Im)}$
  - Belle II
  - LHCb (additional observables $S_{\phi\gamma}$ and $A^{\Delta}_{\phi\gamma}$)
- Adding $S(B \rightarrow K_1(K\pi\pi)\,\gamma)$ is one of the keys to improve the sensitivity
  - Both experimentally and theoretically

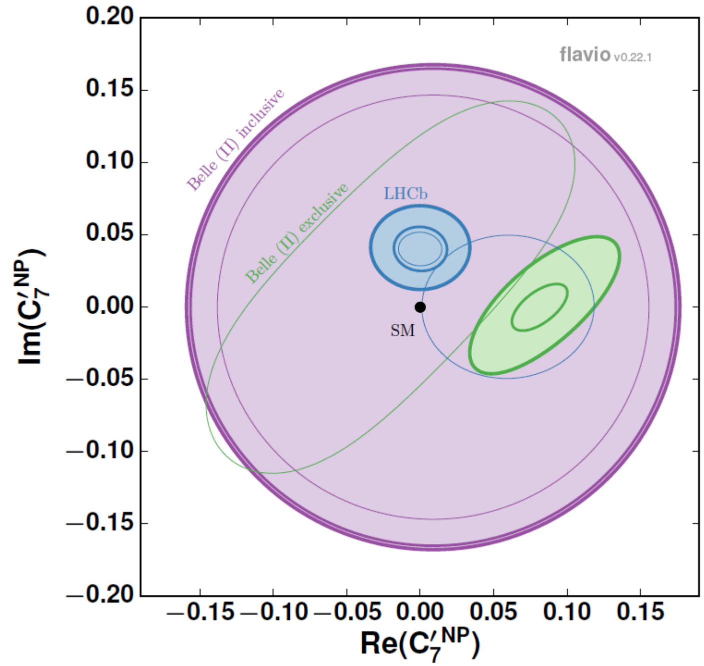
Gratrex and Zwicky (2018)

Akar, Ben-Haim, Hebinger, Kou and Yu (2018)

Observables	Belle $0.71\,\mathrm{ab}^{-1}$ $(0.12\,\mathrm{ab}^{-1})$	Belle II $5\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
$S_{K^{*0}\gamma}$	0.29	0.090	0.030
$S_{\rho^0\gamma}$	0.63	0.19	0.064

Observables	Belle $0.71\,\mathrm{ab}^{-1}$	Belle II $5\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
$A_T^{(2)}$ ($[0.002, 1.12]\ \mathrm{GeV}^2$)	–	0.21	0.066
A_T^{Im} ($[0.002, 1.12]\ \mathrm{GeV}^2$)	–	0.20	0.064

Straub, Belle II Physics book



LHCb have additional observables

Summary

- Belle II has started data taking aiming for $50ab^{-1}$ by 2027.
  - We rediscovered B→K*γ
- We can perform inclusive analyses and lepton flavor dependent angular analyses.
  - B→Xsl+l-
  - Q_5
- Other related modes are also important
  - B→K(*)$\nu\nu$
  - b→sγ

$\Delta A_{CP}(B \to X_s\gamma)$ and EW Baryogensis

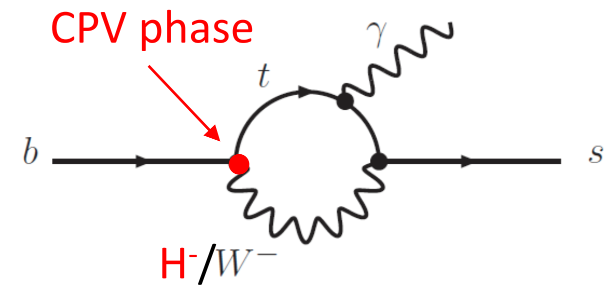
- Additional Yukawa coupling ρ appears in general 2HDM (no Z_2 symmetry)

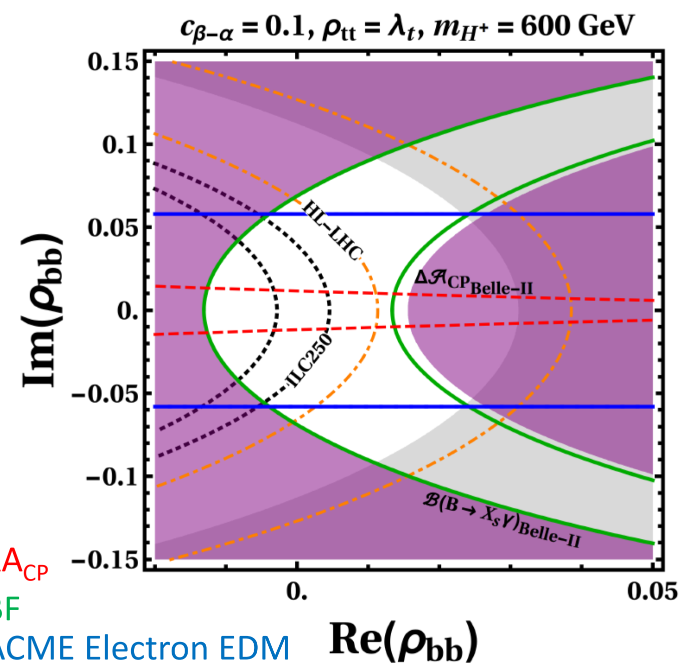
$$y^f_{hij} = \frac{\lambda^f_i}{\sqrt{2}}\delta_{ij}s_{\beta-\alpha} + \frac{\rho^f_{ij}}{\sqrt{2}}c_{\beta-\alpha},$$

$$y^f_{Hij} = \frac{\lambda^f_i}{\sqrt{2}}\delta_{ij}c_{\beta-\alpha} - \frac{\rho^f_{ij}}{\sqrt{2}}s_{\beta-\alpha},$$

$$y^f_{Aij} = \mp\frac{i\rho^f_{ij}}{\sqrt{2}},$$

- If ρ has complex phase, this could generate CPV and thus one of the conditions of EW Baryogensis is satisfied.
- ΔA_{CP} is sensitive to phase in ρ
- Combining H→bb coupling measurements at HL-LHC/ILC, additional bottom Yukawa and its phase can be searched for
  - If found it→ Higgs self coupling measurements at ILC500





ΔA_{CP}
BF
ACME Electron EDM
HL-LHC H→bb coupling
ILC H→bb coupling

Atwood, Gronau, and Soni (1997)
Atwood, Gersion, Hazumi and Soni (2005)

Time Dependent CPV in $B^0 \rightarrow K^*(K_s\pi^0)\gamma$

- Time dependent CPV in $B^0 \rightarrow K^{*0}\gamma$ is small in the SM.

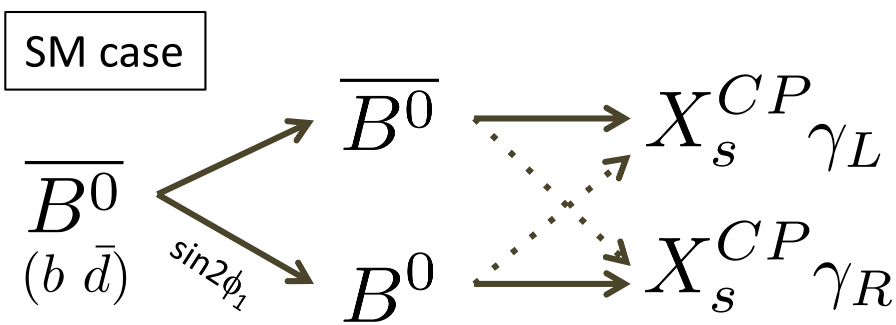
$$|S_{CP}| \approx \frac{2m_s}{m_b}\sin 2\phi_1 \quad \text{\~ a few \%}$$

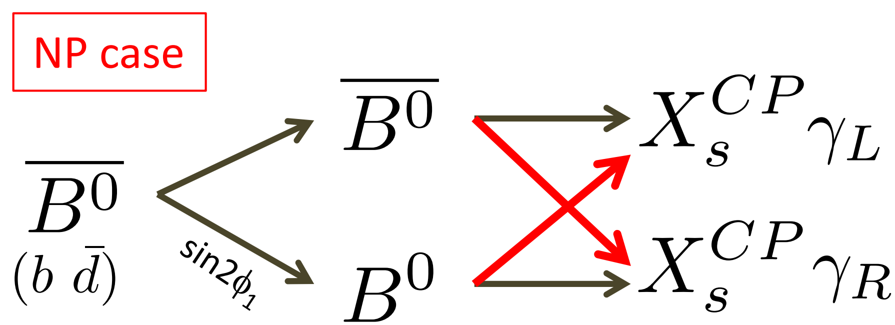
- If right-handed new physics contributes to the decay, larger CPV is possible

$$\mathcal{S} \approx \xi \frac{2\mathcal{I}m[e^{-i\phi_q}\mathcal{C}_7\mathcal{C}'_7]}{|\mathcal{C}_7|^2 + |\mathcal{C}'_7|^2}$$

- Theoretical uncertainty cancels out by taking a sum of S in exclusive $B \rightarrow K^*\gamma$ and $B \rightarrow K_1\gamma$

Gratrex and Zwicky (2018)



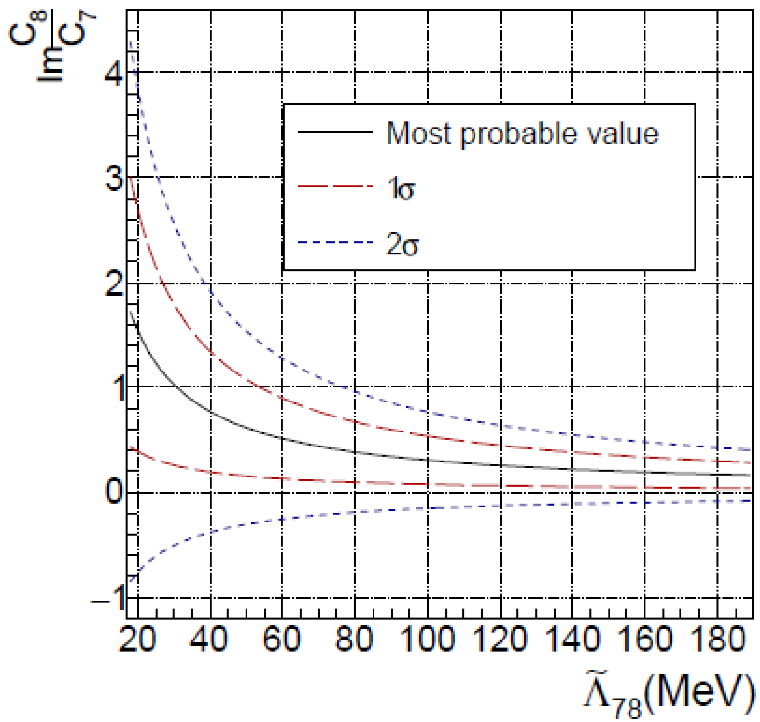


dotted : helicity flip suppressed by m_s/m_b

red : helicity flip + NP

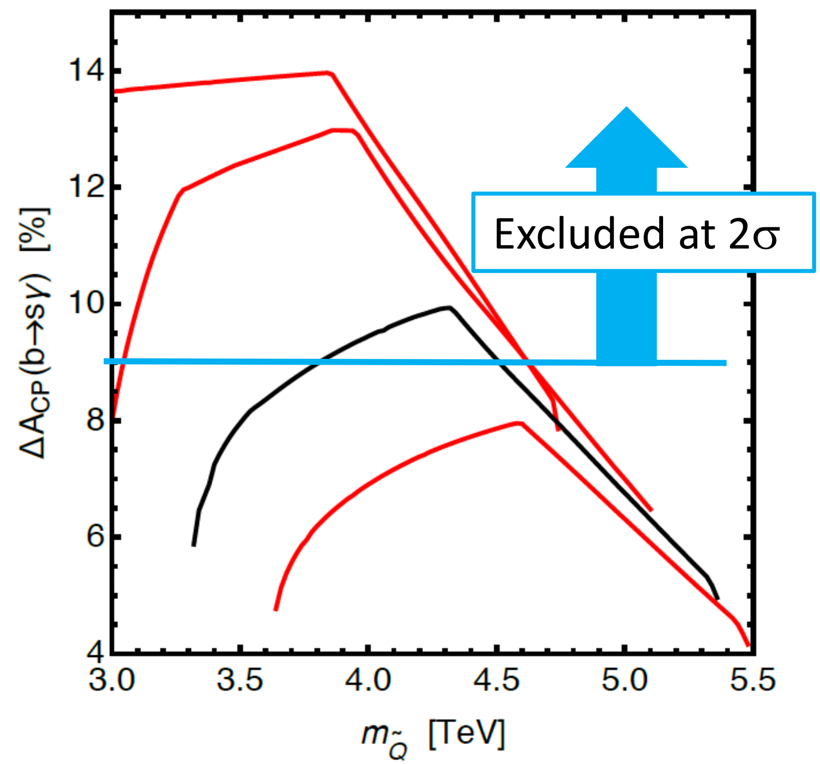
Constraint on Im(C_8/C_7) and a NP model with the Belle Result

- Belle result excludes positive region of Im(C_8/C_7) better than Babar.



$-0.17 < \mathrm{Im}(C_8/C_7) < 0.86$ for $\tilde{\Lambda}_{78} = 89$ MeV

- Exclude parameter space in SUSY.
  - Gluino mediated EWP which explains ε'/ε from CPV trilinear couplings



M. Endo, T. Goto, T. Kitahara, S. Mishima, D. Ueda and K. Yamamoto, JHEP 04 (2018) 019.