Missing energy and electroweak penguin modes in (early) Belle II data

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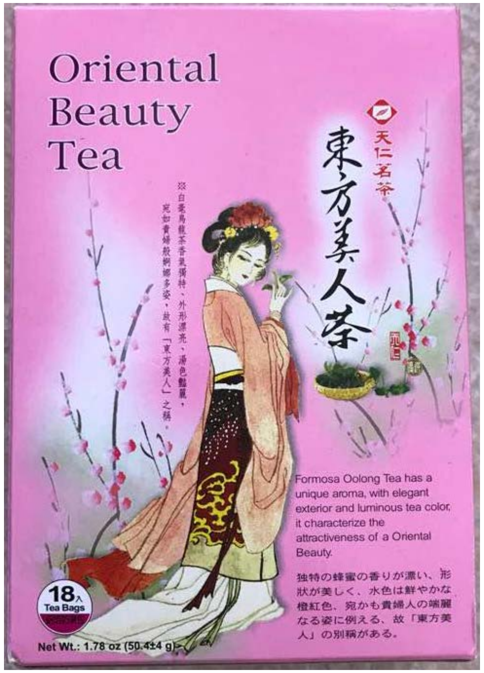
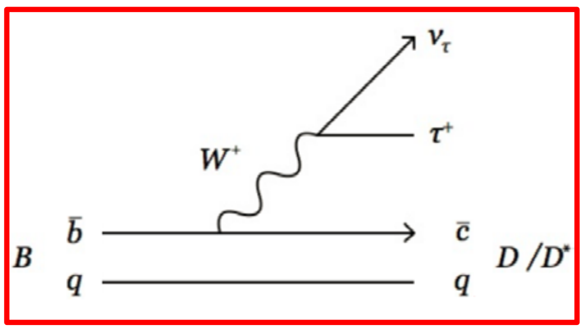
(KEK)



Two Anomalies in B decays

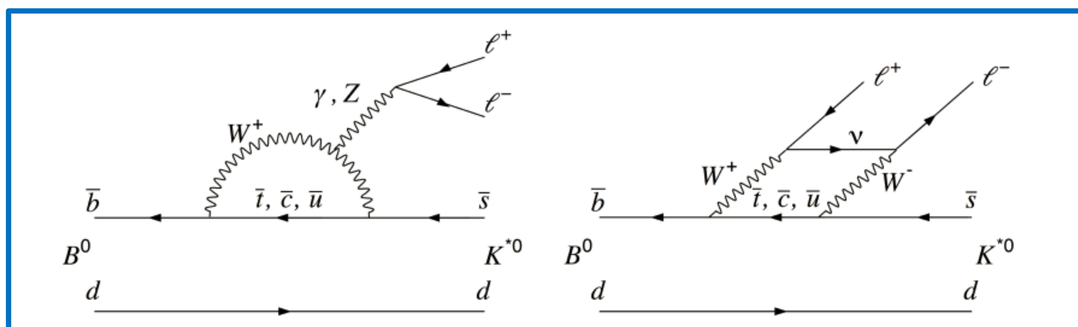
- Two anomalies are found in missing energy mode and electroweak penguin mode
  - $b \rightarrow c\tau\nu$ claimed by Babar, Belle and LHCb.
  - $b \rightarrow s l^+ l^-$ claimed by LHCb
- These two modes are important guidelines for Belle II physics program

Missing energy signature $b \rightarrow c\tau\nu$



Tree
BF~O(10^{-2})

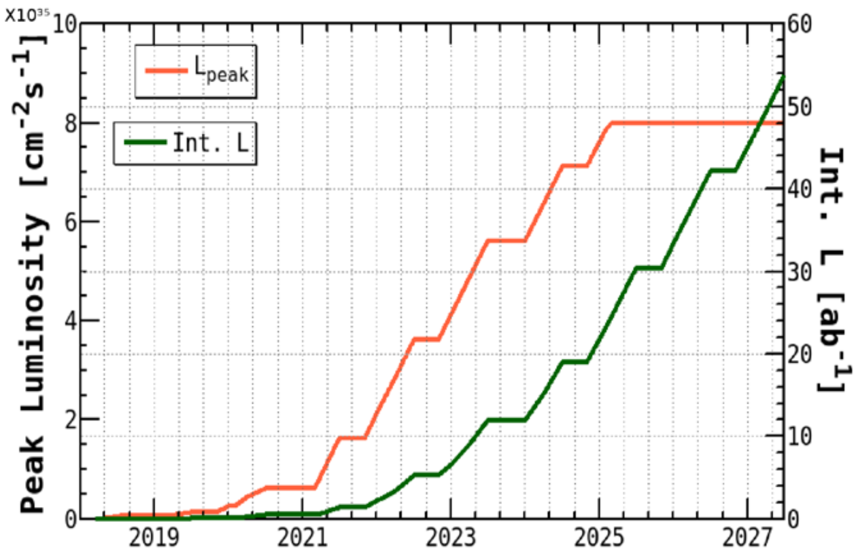
electroweak penguin mode $b \rightarrow s l^+ l^-$



Loop
BF~O(10^{-6})

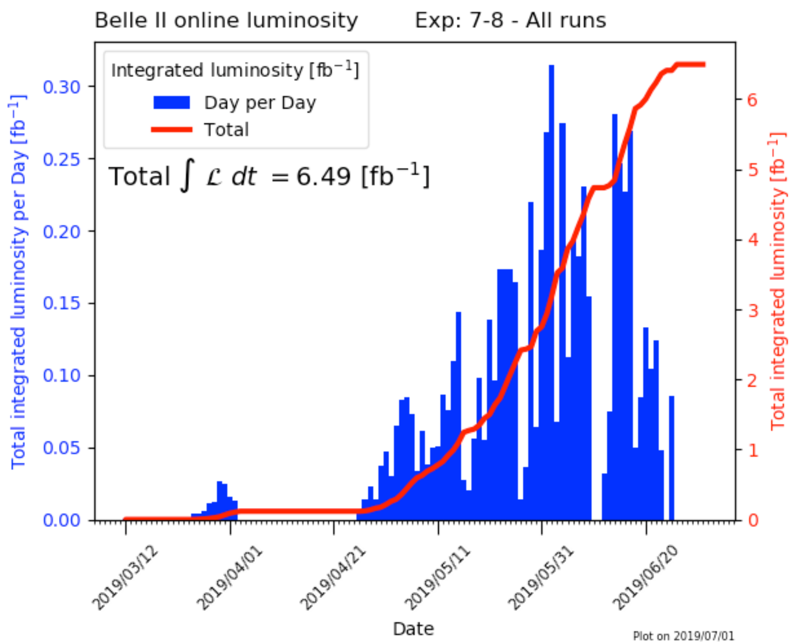
Belle II @ SuperKEKB

- Highest luminosity collider experiment
  - $L=8x10^{35}$ $cm^{-2}s^{-1}$
  - E_{CM}=10.58GeV on Υ(4S)
  - Energy-asymmetric collisions 7.0GeV x 4.0GeV
    - To boost B mesons to measure time dependent CPV
  - $50ab^{-1}$ will be accumulated by 2027
    - Contain $1x10^{11}$ B mesons, $1.4x10^{11}$ charm hadrons, and $0.9x10^{11}$ τ



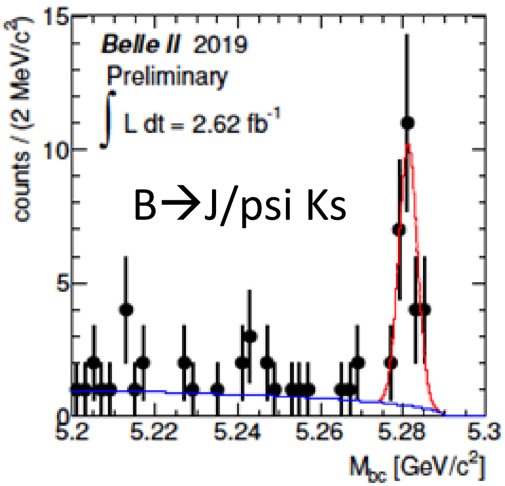
Belle II by summer 2019

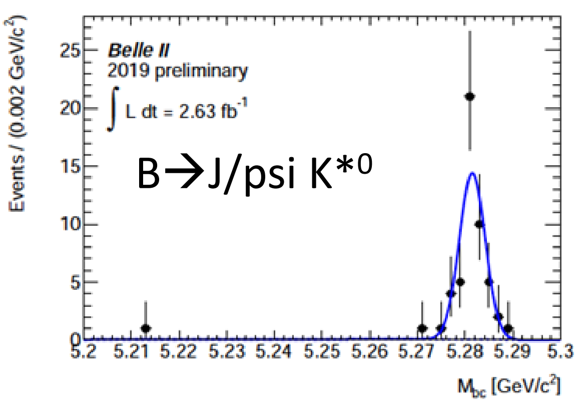
- We started data taking with almost full Belle II detector
  - 2nd Pixel layer was partially installed.
- Reached 1.2x 10^{34} $cm^{-2}s^{-1}$ (1/2 of KEKB) luminosity while background is higher due to vacuum level in LER beam pipe. Need scrubbing.
- 6.5fb^{-1} data (1/100 of Belle) were accumulated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

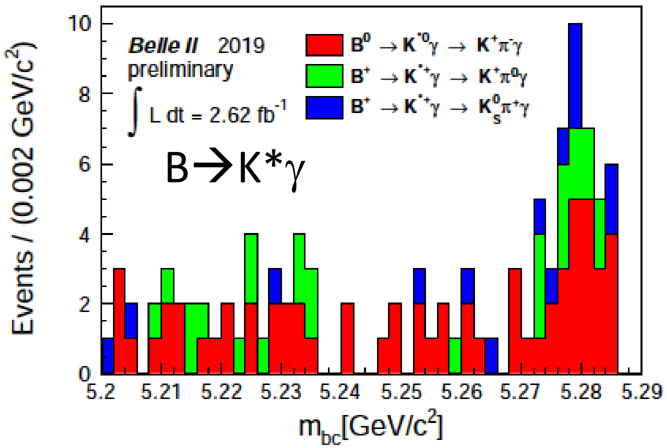


Rediscoveries of B decays

- 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.

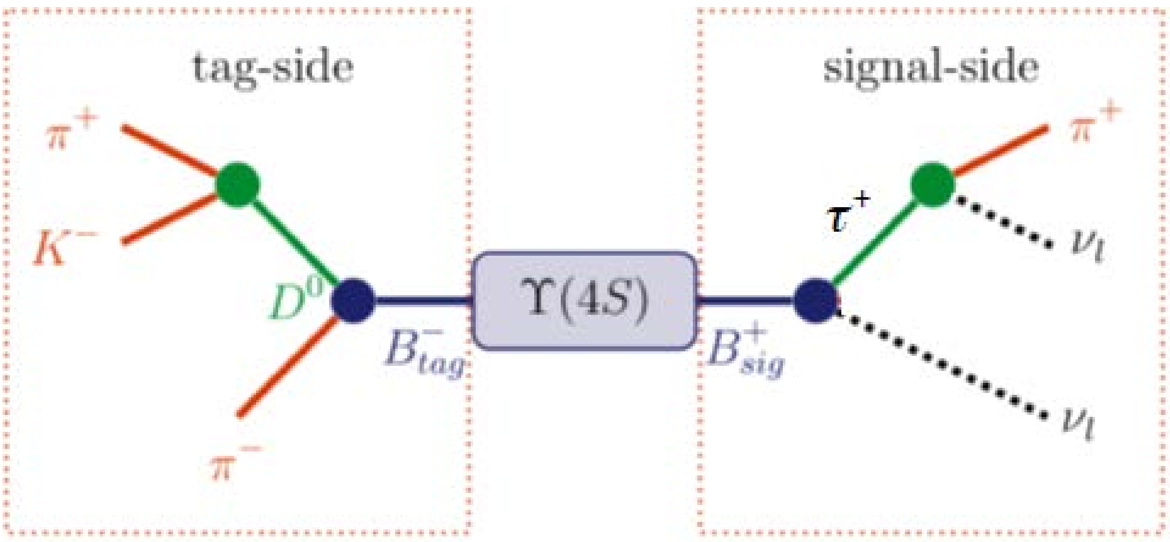






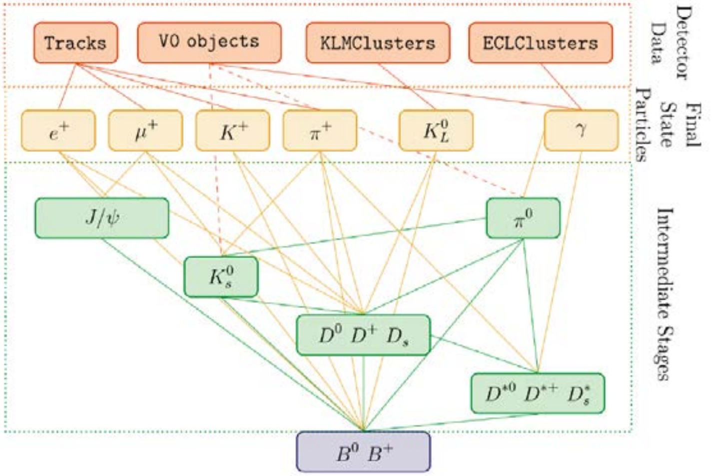
B Decays with Multiple ν

- We need to tag the other B meson due to final states having multiple neutrinos.
- Three tagging methods
  - Inclusive tag
  - Hadronic B tag
  - Semileptonic B tag



Improvement of Tagging

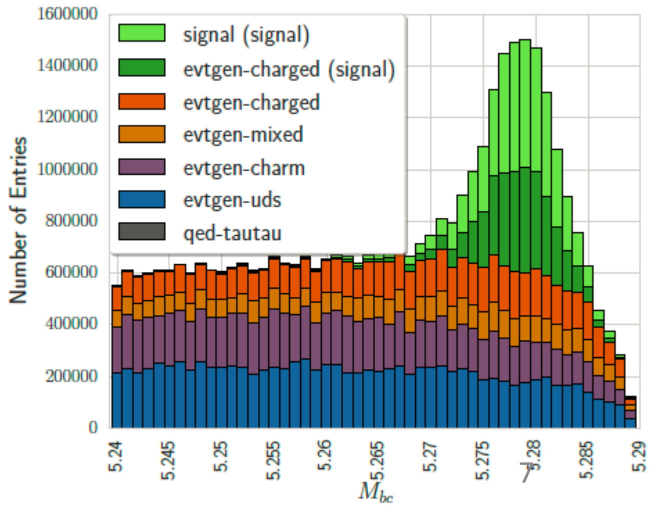
- Full Event Interpretation (FEI)
  - Tagging method using multivariate technique
    - Hierarchical reconstruction
  - More tagging modes than Belle 1
  - Both hadronic decays and semileptonic decays can be used
- About 2 times better tagging efficiency than Belle 1 (FR).



Improvement of Algorithm

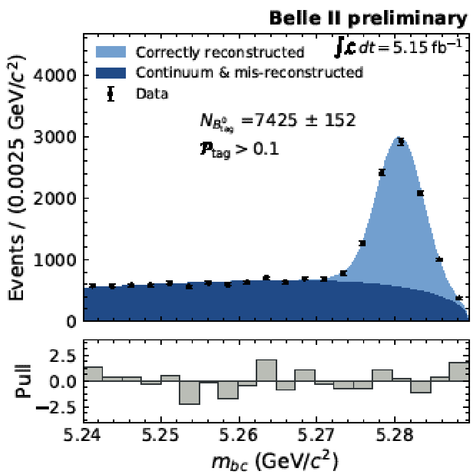
Improvement of Detector and Increase of Background effects

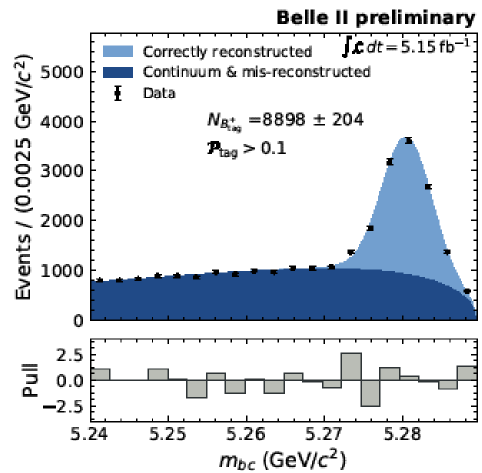
Tag	FR[4] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %



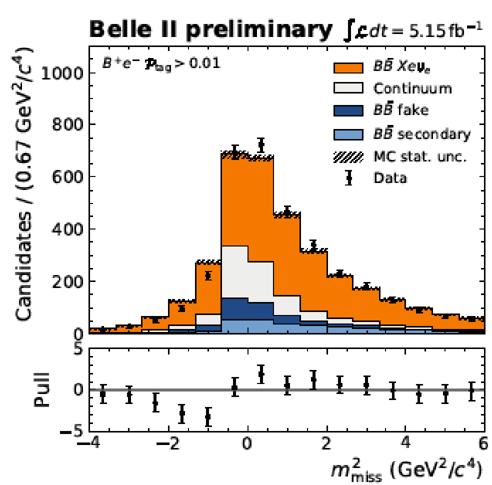
FEI with real data

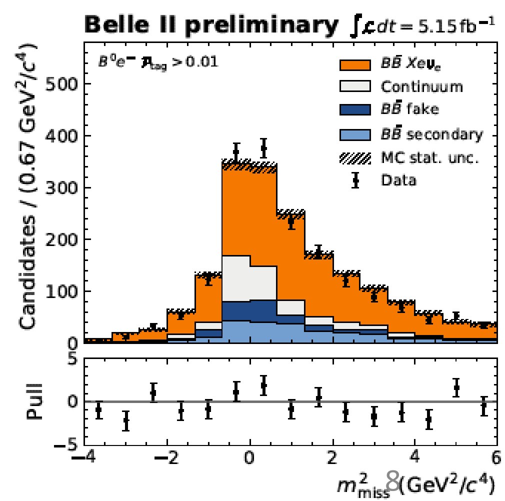
- FEI successfully reconstructed hadronic B decays





- Missing mass distributions for B→Xe$^+\nu$ with the tagged B meson
  - Can be used for |Vcb| measurement and extraction of HQE parameters





Contents

- Missing energy
  - B→D(*)τν
  - B→τν, μν

b→sνν

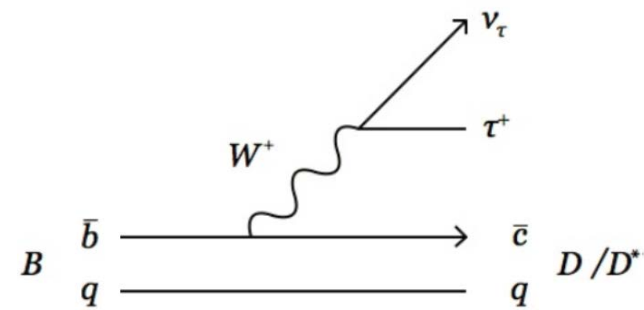
- EWP
  - b→sl+l-
  - b→sγ

B→D(*)$\tau\nu$

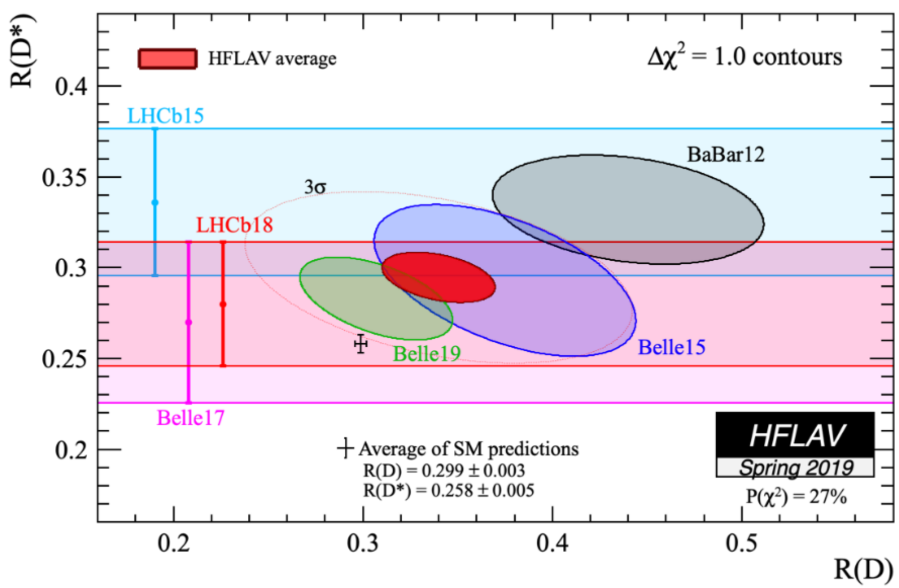
B→D(*)τν

- A hint of LFUV are found in b→cτν
  - claimed by LHCb, Babar and Belle. ~3.1σ
  - ~15% deviation from the SM predictions

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^- \bar{\nu}_\ell)} \quad (\ell = e, \mu)$$



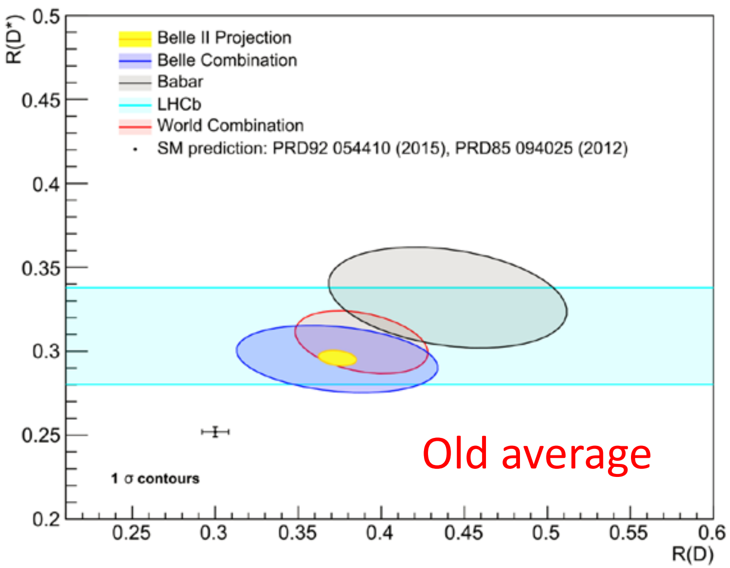
- Leptoquarks, flavorful W' and/or exotic Higgs could explain the deviation



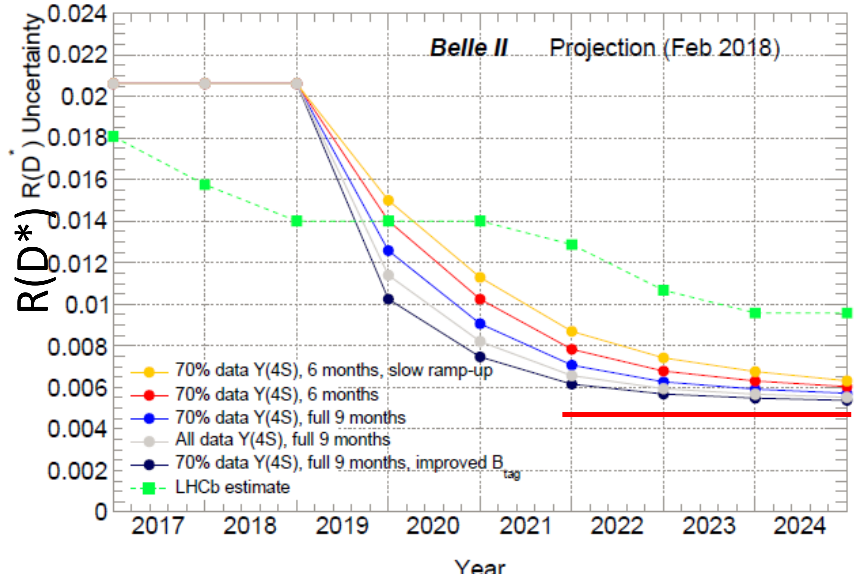
Prospects on R(D$^{(*)}$)

- We could observe 5σ deviation in R(D) VS R(D*) in 2022 if central value unchanged
  - Sensitivity of R(D*) is 0.006 in 2027.

	5 ab^{-1}	50 ab^{-1}
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$



1year delay, Blue one is nominal scenario

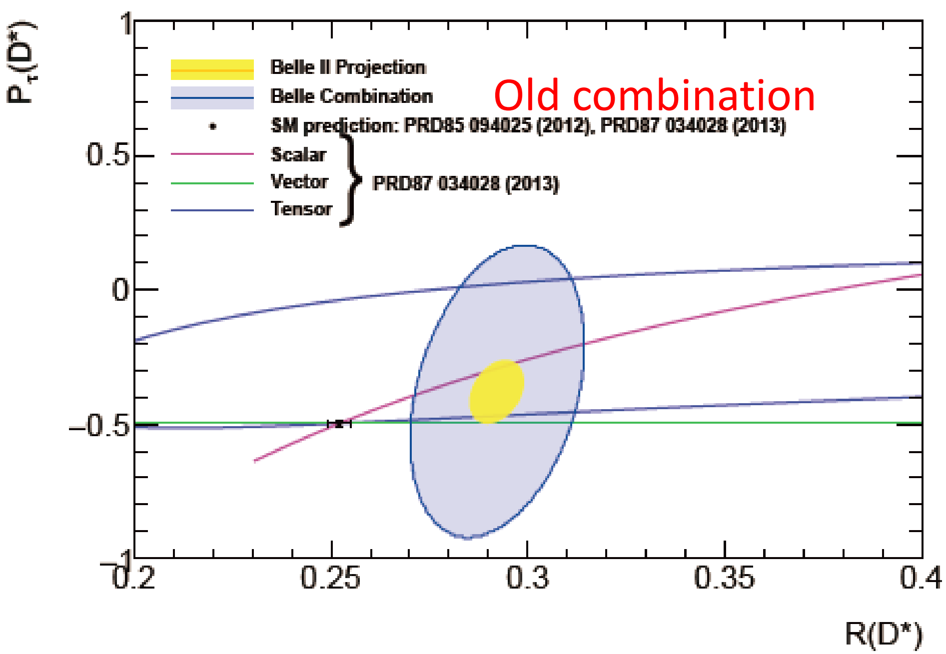


Current theory uncertainty
LD QED??

Polarizations

- Polarizations of tau and D* are also sensitive to NP
- Together with R(D) and R(D*), model discrimination can be performed
  - Scalar, vector or tensor couplings

E. Kou et al. 1808.10567



	5 ab^{-1}	50 ab^{-1}
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$

B→$\tau\nu$, $\mu\nu$

B→τν

- BF(B→τν) in SM
  - Helicity suppression : Amp ∝ m_τ

$$\mathcal{B}(B\to\ell\nu)=\frac{G_F^2 m_B}{8\pi}m_\ell^2\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 f_B^2|V_{ub}|^2\tau_B$$

- BF(B→τν) in 2HDM type-II — W. S. Hou, PRD48, 2342 (1993)
  - No helicity suppression with Higgs exchange
  - Higgs coupling ∝ m_τ

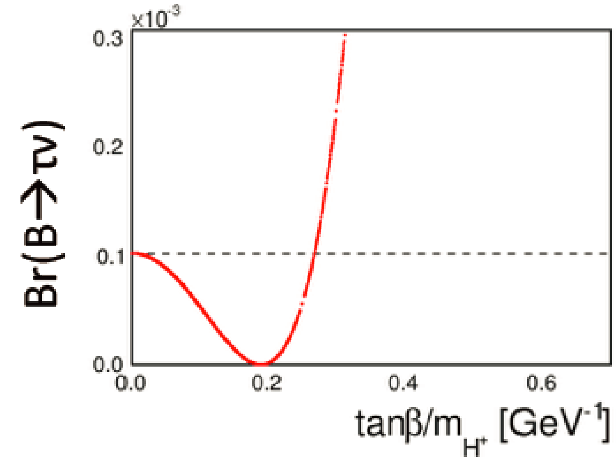
$$\mathcal{B}(B\to\tau\nu)=\mathcal{B}(B\to\tau\nu)_{\text{SM}}\times r_H$$

$$r_H=\left(1-\frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

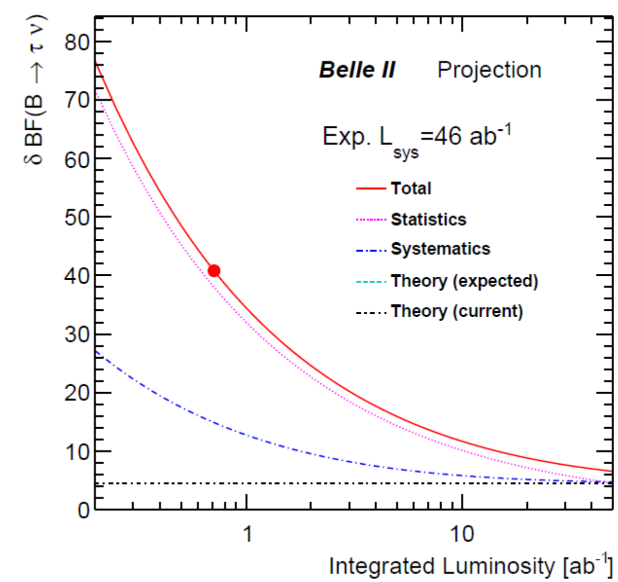
  - BF only dependent on r_H (function of $\tan\beta/m_H$)
- Belle II
  - Tagging efficiency twice than Belle
  - Observation with ~1ab^{-1}
  - With 50ab^{-1}, about 4% precision can be achieved

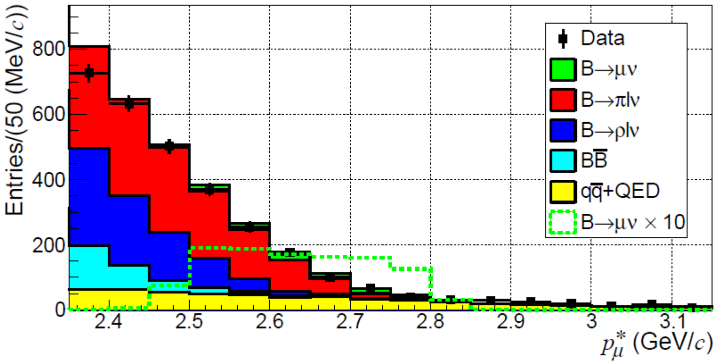
Interpretation later

	Integrated Luminosity (ab^{-1})	1	5	50
hadronic tag	statistical uncertainty (%)	29	13	4
	systematic uncertainty (%)	13	7	5
	total uncertainty (%)	32	15	6
semileptonic tag	statistical uncertainty (%)	19	8	3
	systematic uncertainty (%)	18	9	5
	total uncertainty (%)	26	12	5



ℓ	$\mathcal{B}_{\text{SM}}$
τ	$(7.71\pm0.62)\times10^{-5}$
μ	$(3.46\pm0.28)\times10^{-7}$
e	$(0.811\pm0.065)\times10^{-11}$





B→μν

- B→μν can be searched with inclusive tagging
  - Observation of B→μν with 5ab^{-1}
  - 7% precision with full data
  - Test of LFU possible with B→τν

Result (this) $(5.3 \pm 2.0 \pm 0.9) \times 10^{-7}$ @ $2.8\,\sigma$

Belle Moriond 2019

$$R_{\rm pl} = \frac{\mathcal{B}(B^- \to \tau^- \bar\nu_\tau)}{\mathcal{B}(B^- \to \mu^- \bar\nu_\mu)}$$

$$R_{\rm pl}^{\rm NP} = \frac{m_\tau^2}{m_\mu^2}\frac{(1-m_\tau^2/m_B^2)^2}{(1-m_\mu^2/m_B^2)^2}\left|1+r_{\rm NP}^\tau\right|^2 \simeq 222.37\left|1+r_{\rm NP}^\tau\right|^2$$

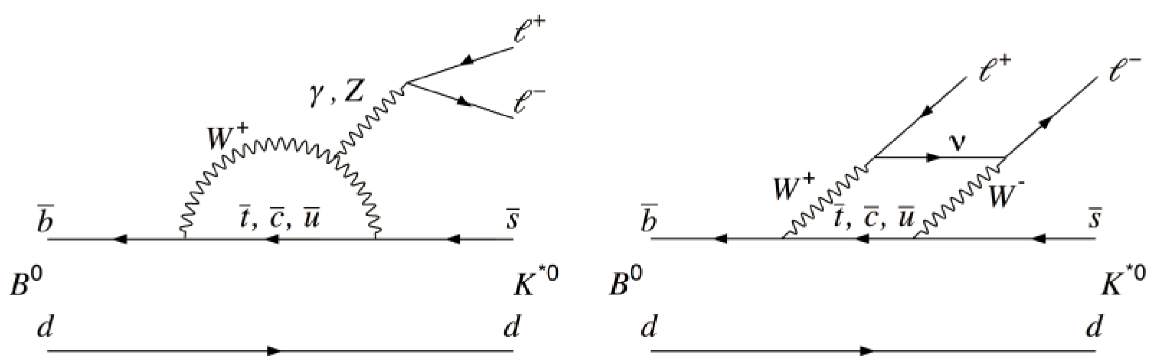
ℓ	$\mathcal{B}_{\rm SM}$
τ	$(7.71 \pm 0.62) \times 10^{-5}$
μ	$(3.46 \pm 0.28) \times 10^{-7}$
e	$(0.811 \pm 0.065) \times 10^{-11}$

Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$91(1 \pm 24\%)$	9%	4%
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%

Luminosity	$R_{\rm ps}$	$r_{\rm NP}^\tau$
5 ab^{-1}	$[-0.22, 0.20]$	$[-0.42, 0.29]$
50 ab^{-1}	$[-0.11, 0.12]$	$[-0.12, 0.11]$

$b \rightarrow sl^+l^-$

- Angular analysis in B→K*l+l-
- B→Xsl+l-
- LFU Violation



Wilson Coefficients in b→s processes

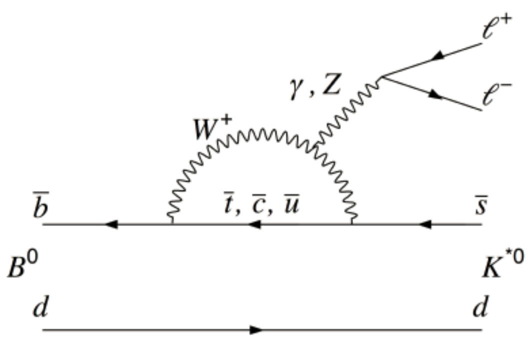
- In the SM
  - b→sγ : C_7
  - b→sll : C_7, C_9 and C_{10}
  - $C_7 \sim -0.3$, $C_9 \sim 4$, $C_{10} \sim -4$
- If NP contributes,
  - Deviation from the SM values
  - Lepton flavor dependent $C_{9e} \neq C_{9\mu}$
  - New coefficients appear
    - $\mathrm{Im}(C_i)$, C_i', C_S , C_P , C_T and C_{T5}

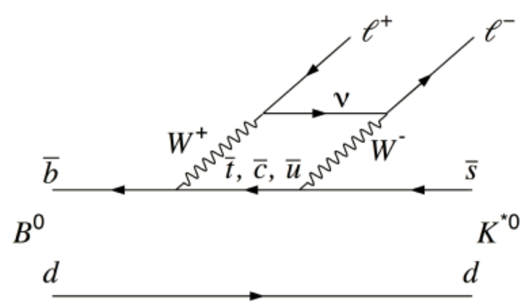
$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$$

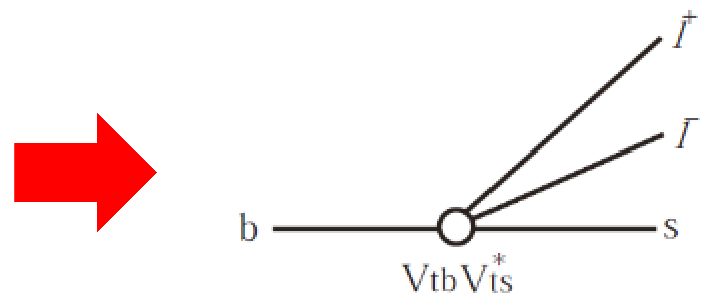
$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu},$$

$$\mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell),$$

$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$





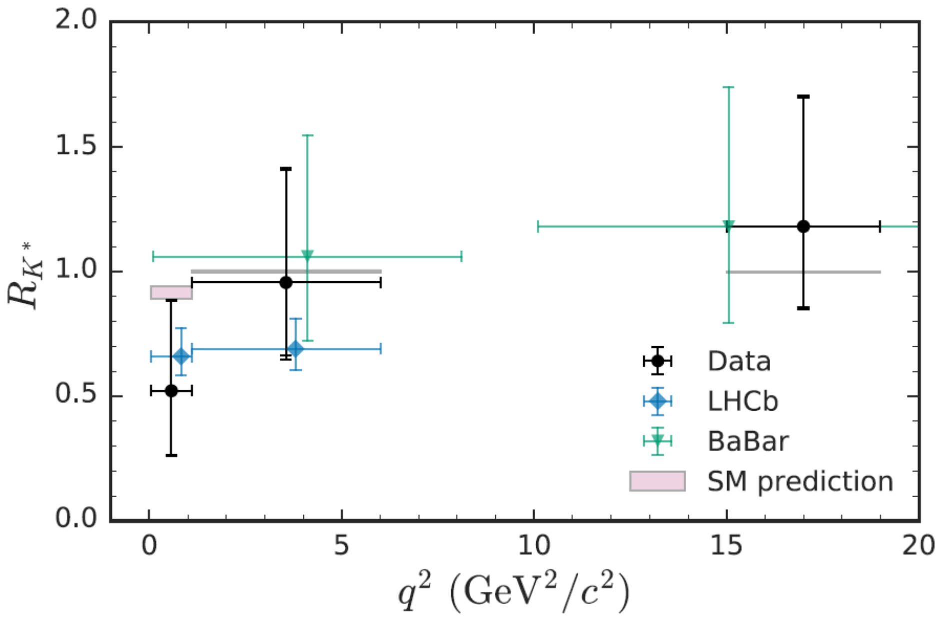


Anomalies in b→sl+l-

- Claimed by LHCb
  - LFU violation
    - Theoretically clean
    - Naïve combination of R_K and R_{K*} ~4σ
    - ~30% deviation from the SM

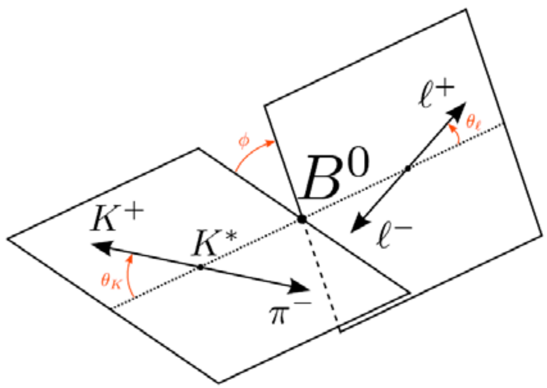
$$R_H = \frac{\mathcal{B}(B \to H\mu^+\mu^-)}{\mathcal{B}(B \to He^+e^-)}$$

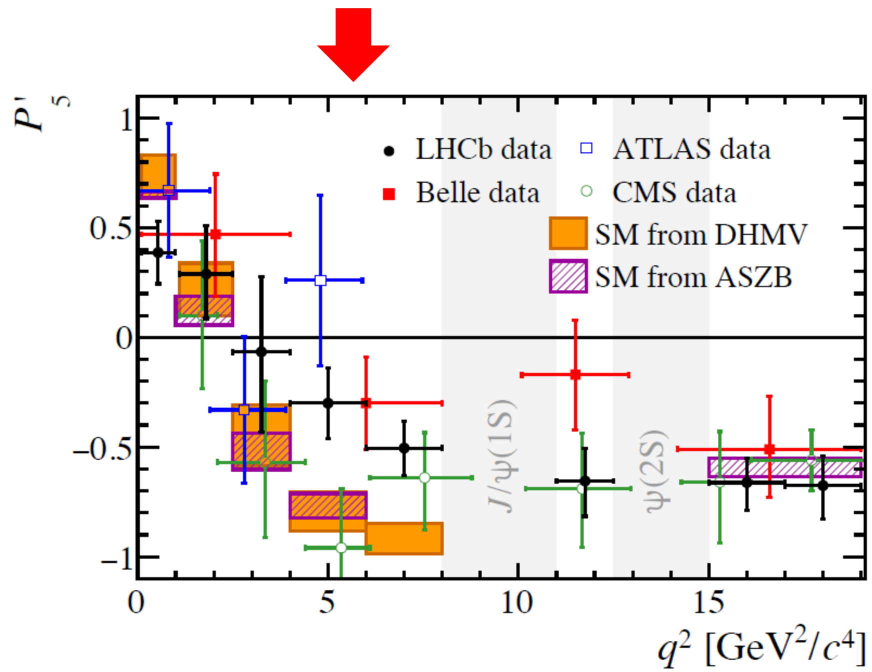
$$H = K, K^*, X_s, \ldots$$



Anomalies in b→sl+l-

- Claimed by LHCb
  - Angular Observable P_5'
    - Theoretically dirty (charm loop)
    - About ~4σ deviation q^2=[4,8]GeV2
    - ~50% deviation





$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$

$$- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi$$

$$+ S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$

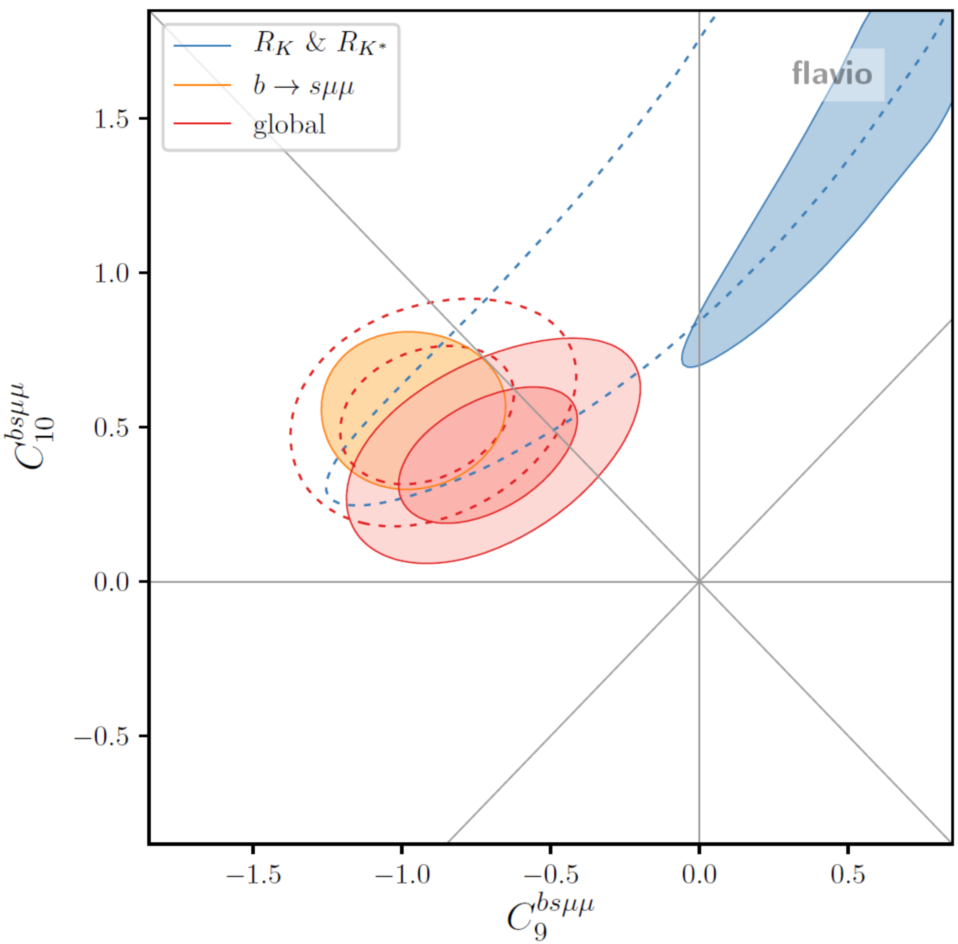
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big],$$

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$

Global Fit to b→s

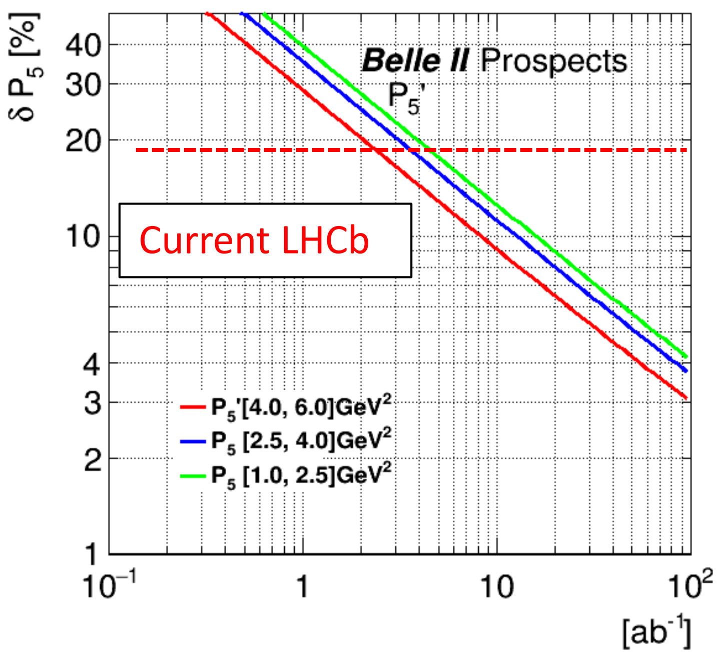
- NP effect in C_9^μ

D. Straub@MoriondEW2019



P_5' in B→K*l+l-

- LHCb can observe the deviation with data already in hand.
- In 2022, Belle II can reach current LHCb sensitivity
  - Belle II can confirm or deny LHCb anomaly in P_5' with
- Statistically dominated even with $50ab^{-1}$
  - With $50ab^{-1}$, the sensitivity is competitive to LHCb with $50fb^{-1}$

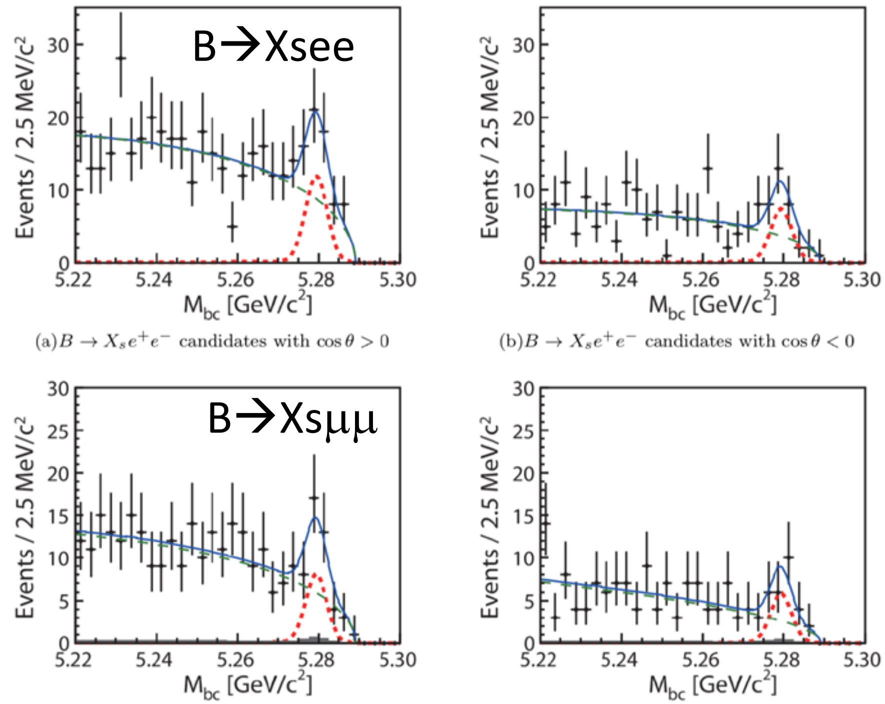


Observables	Belle $0.71\,ab^{-1}$	Belle II $5\,ab^{-1}$	Belle II $50\,ab^{-1}$
P_5' ($[1.0, 2.5]\,GeV^2$)	0.47	0.17	0.054
P_5' ($[2.5, 4.0]\,GeV^2$)	0.42	0.15	0.049
P_5' ($[4.0, 6.0]\,GeV^2$)	0.34	0.12	0.040
P_5' ($> 14.2\,GeV^2$)	0.23	0.088	0.027

Reconstruction of B→Xsl+l-

- We will use sum-of-exclusive method
  - Xs is reconstructed from K$n\pi$ (0<=n<=4).
    - We can add three kaon modes and η modes (two pi0 modes?)
  - then combined with dilepton
- Reconstruction efficiencies for electron and muon modes are almost similar
  - Good for LFU test
- Backgrounds
  - Dominated by B→Xlν and B→Ylν
    - Can be suppressed with missing energy and vertex information.
  - Second largest is ee→cc
    - event shape information can suppress the background so much.
- We could also use fully inclusive dilepton but need dedicated simulation study.

Y. Sato (Belle Collaboration), 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 $\cos\theta < 0$

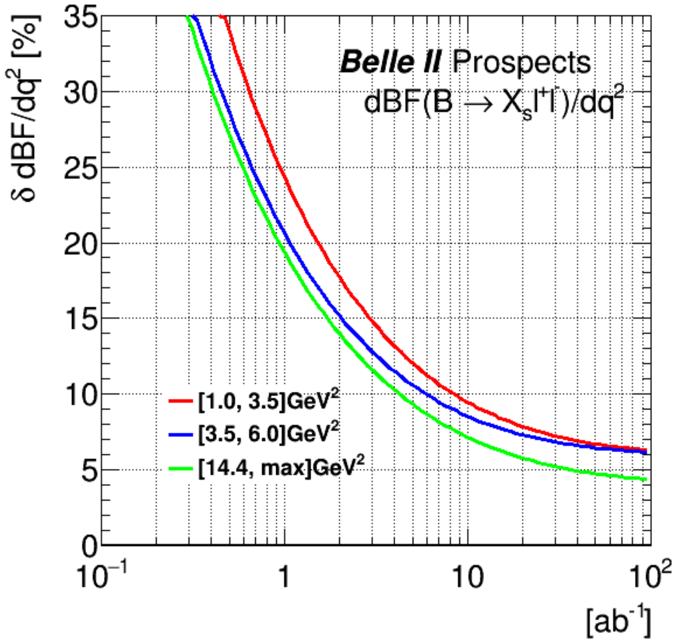
Forward event backward event

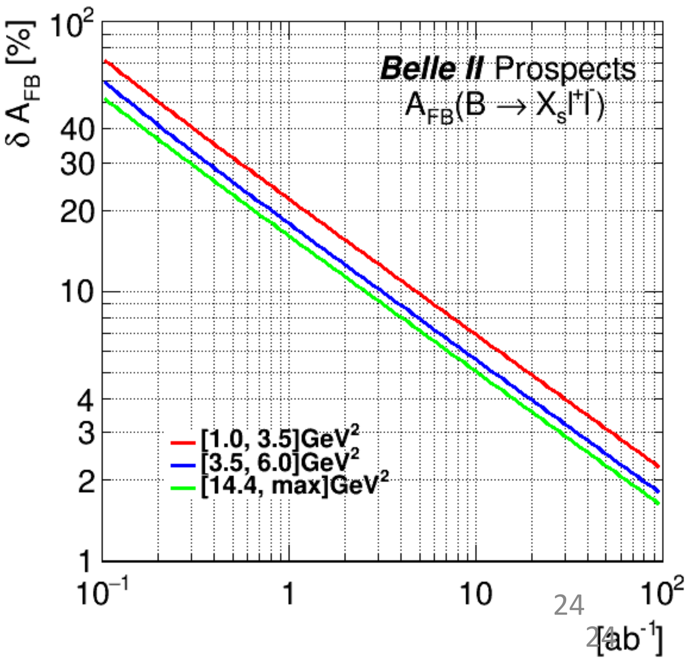
[1,6]GeV^2

BF and A_{FB} in B→Xsl+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%
$A_{\mathrm{CP}}(B \to X_s \ell^+\ell^-)$ ([1.0, 3.5] GeV^2)	26%	9.7 %	3.1 %
$A_{\mathrm{CP}}(B \to X_s \ell^+\ell^-)$ ([3.5, 6.0] GeV^2)	21%	7.9 %	2.6 %
$A_{\mathrm{CP}}(B \to X_s \ell^+\ell^-)$ (> 14.4 GeV^2)	21%	8.1 %	2.6 %
$A_{\mathrm{FB}}(B \to X_s \ell^+\ell^-)$ ([1.0, 3.5] GeV^2)	26%	9.7%	3.1%
$A_{\mathrm{FB}}(B \to X_s \ell^+\ell^-)$ ([3.5, 6.0] GeV^2)	21%	7.9%	2.6%
$A_{\mathrm{FB}}(B \to X_s \ell^+\ell^-)$ (> 14.4 GeV^2)	19%	7.3%	2.4%
$\Delta_{\mathrm{CP}}(A_{\mathrm{FB}})$ ([1.0, 3.5] GeV^2)	52%	19%	6.1%
$\Delta_{\mathrm{CP}}(A_{\mathrm{FB}})$ ([3.5, 6.0] GeV^2)	42%	16%	5.2%
$\Delta_{\mathrm{CP}}(A_{\mathrm{FB}})$ (> 14.4 GeV^2)	38%	15%	4.8%





LFU Violation

- In the SM, LFU holds.
  - Well tested

- While LHCb reported anomalies in the rate, $R_{K(*)}$.
  - Belle and Babar also measured the $R_{K(*)}$
    - consistent with both SM and central values by LHCb due to large uncertainties.
- Belle also measured angular observables for the first time, $Q_5 = P_5'^{e} - P_5'^{\mu}$
  - Consistent with both SM and a NP model inspired by $R_{K(*)}$ anomalies

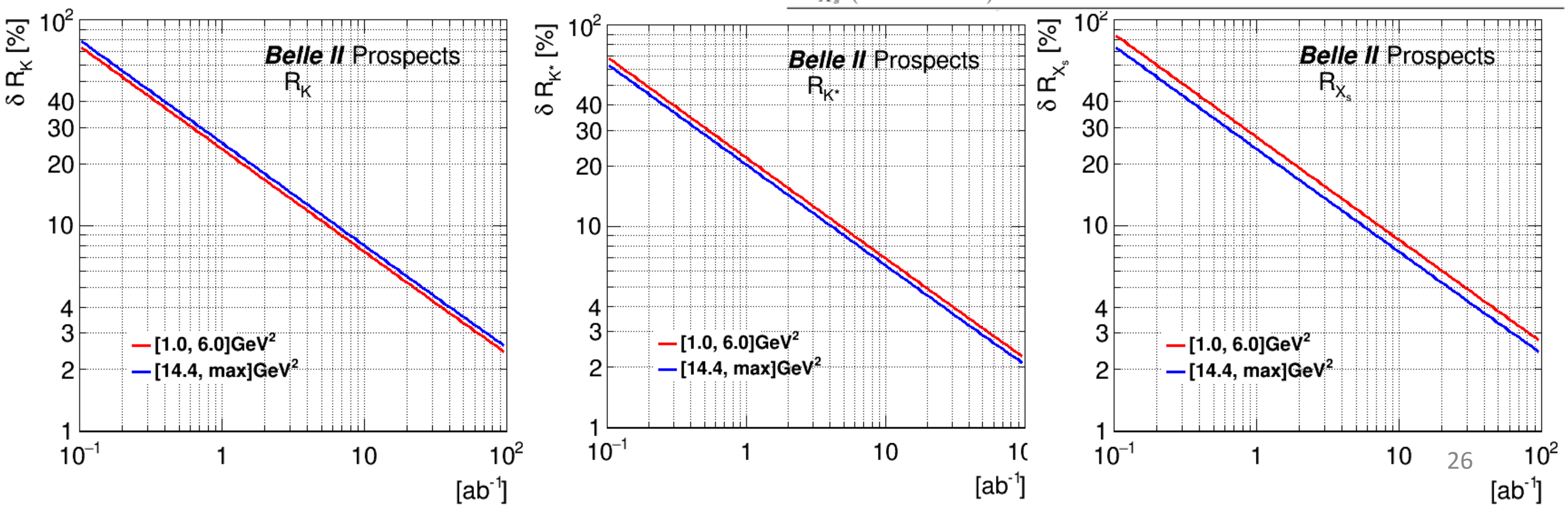
- Belle will measure the R_{Xs} with inclusive decays

- Belle II can measure everything, rate and angular observables

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

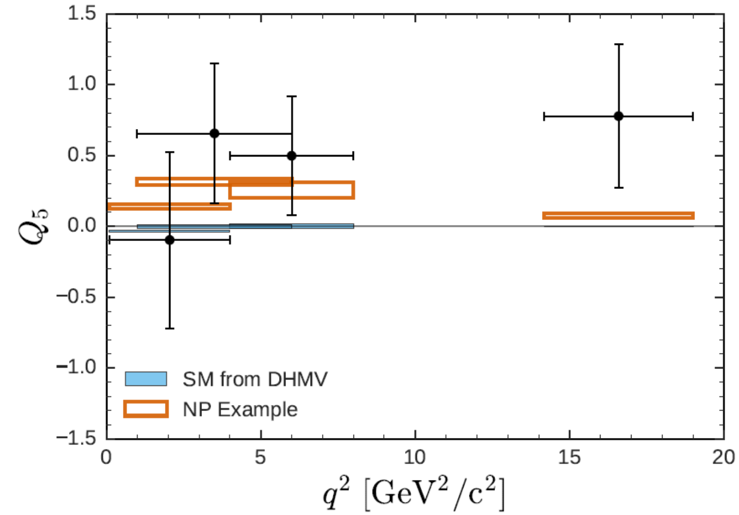
- Belle II is an ideal place to measure the R
  - Bremsstralung recovery not difficult
  - Dominant systematics from lepton ID ~0.4%.
  - Statistically dominated even with 50/ab
- About 20/ab (2022) is needed to observe the NP in $R_{K(*)}$ if central values unchange
- ~3% for both high and low q^2 with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

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

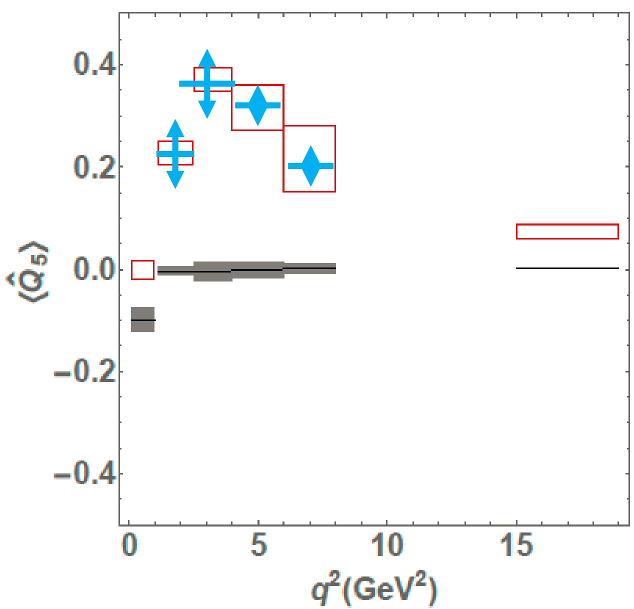


S. Wehle, Belle Collaboration, Phys.Rev.Lett. 118 (2017) no.11, 111801

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



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



Belle II 50ab^{-1}

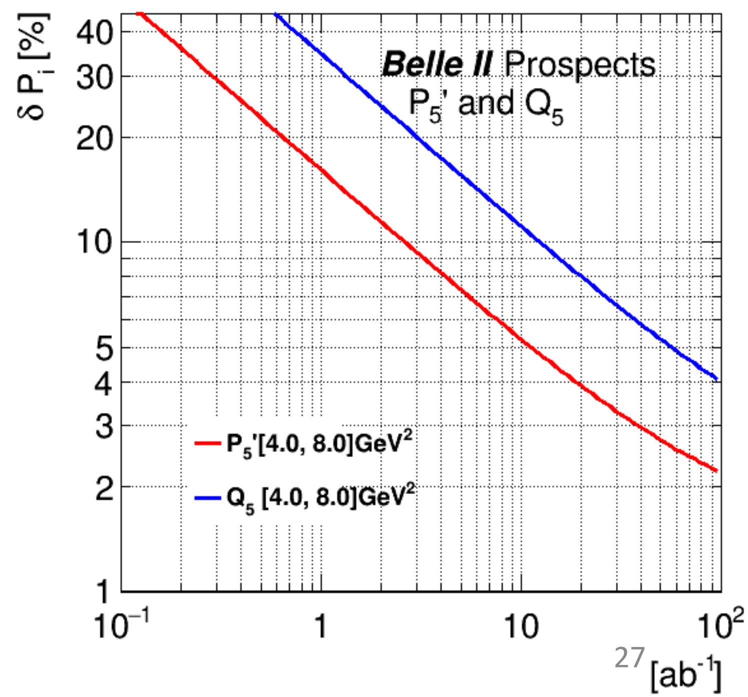
SM : gray

NP : red

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

Capdevila, Descotes-Genon, Matias and Virto 1605.03156

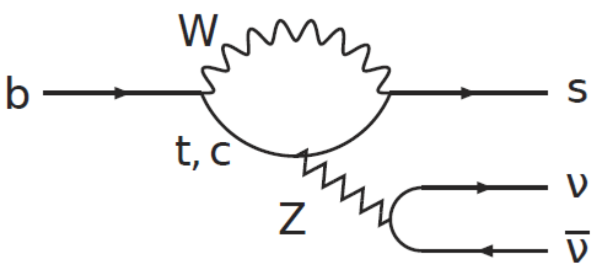
Overlaid Belle II sensitivity



B→K(*)$\nu\nu$

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

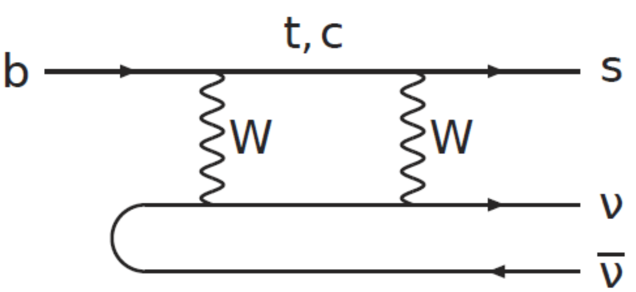
- If C_9 is deviated from the SM value, vector current in $b \to s\nu\nu$ might be also affected in some BSM models?
- If so, at Belle II, we can test the deviation with $B \to K(*)\nu\nu$
- The BF is cleanly predicted in the SM.
  - F_L also



Buras, Girrbach-Noe, Niehoff and Straub, JHEP 02 184 (2015)

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

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



Measurements of B→K$^{(*)}\nu\nu$

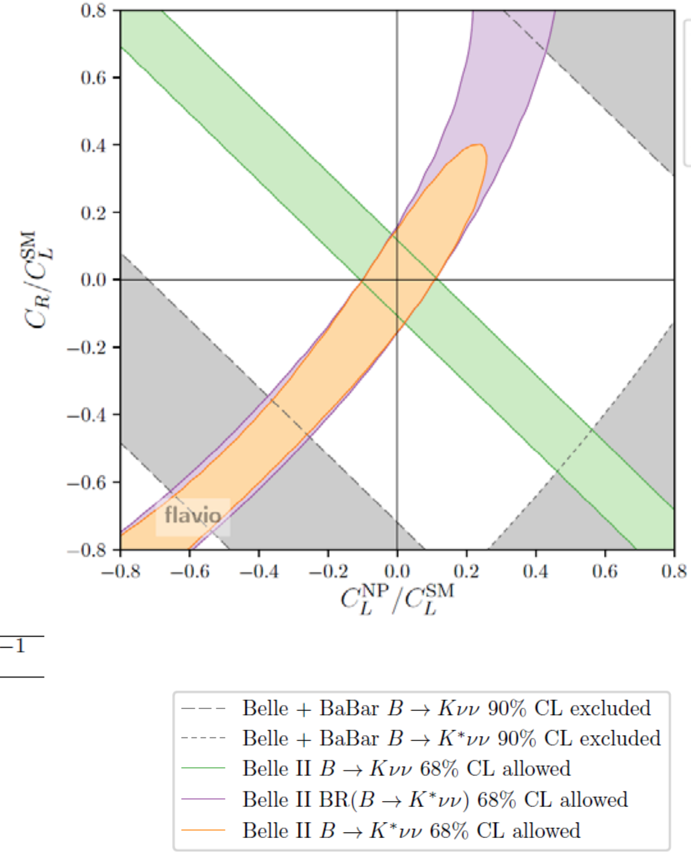
- We can observe the B→K$^{(*)}\nu\nu$ at early stage (several ab^{-1}) of Belle II, and the sensitivity of the BF is 10% level with 50ab^{-1}.
- We can measure the $F_L(K^*)$, which is less sensitive to form factor uncertainties than BF, with 20% precision with 50ab^{-1}

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

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

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	–

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

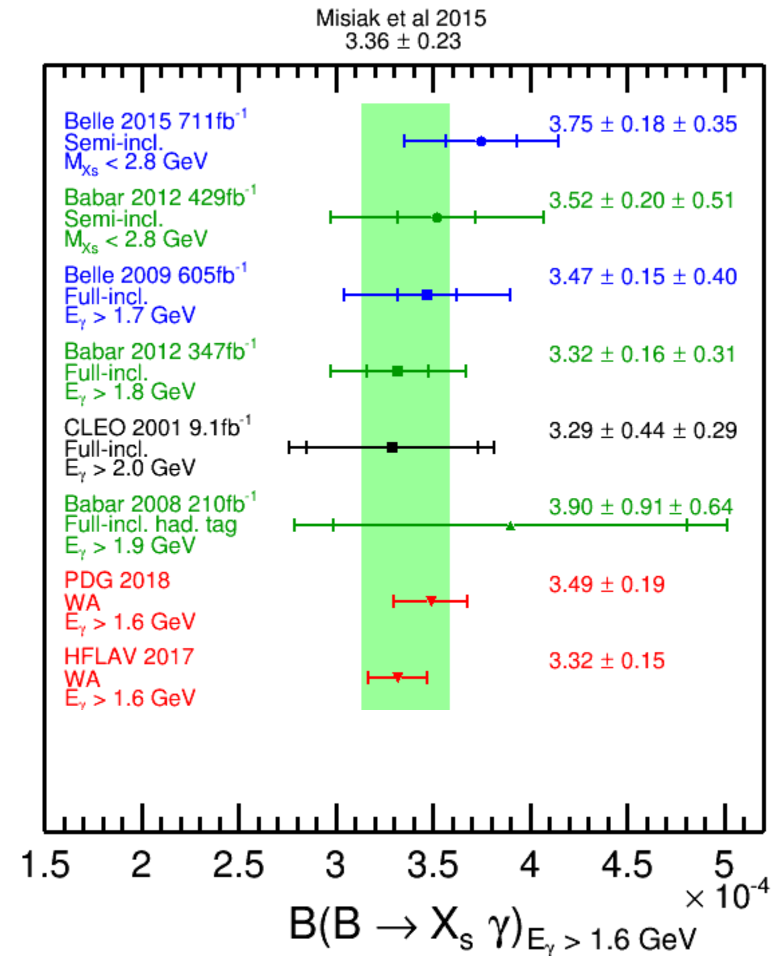


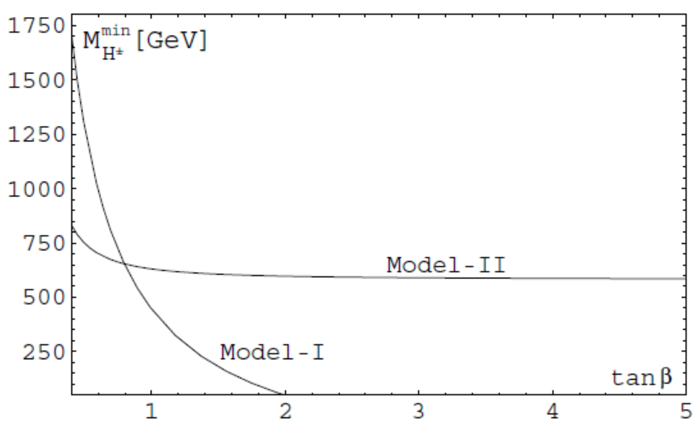
$b \rightarrow s\gamma$

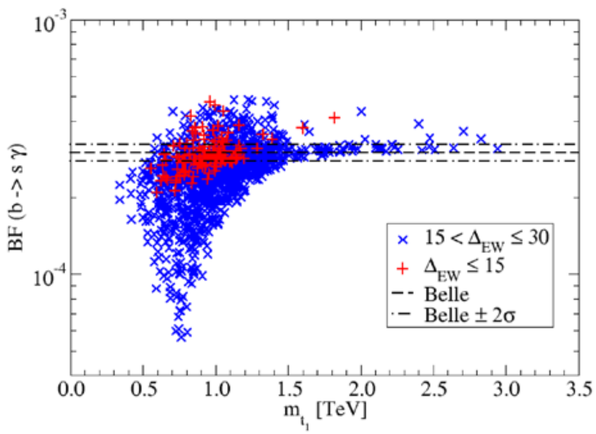
$BF(B \to X_s \gamma)$

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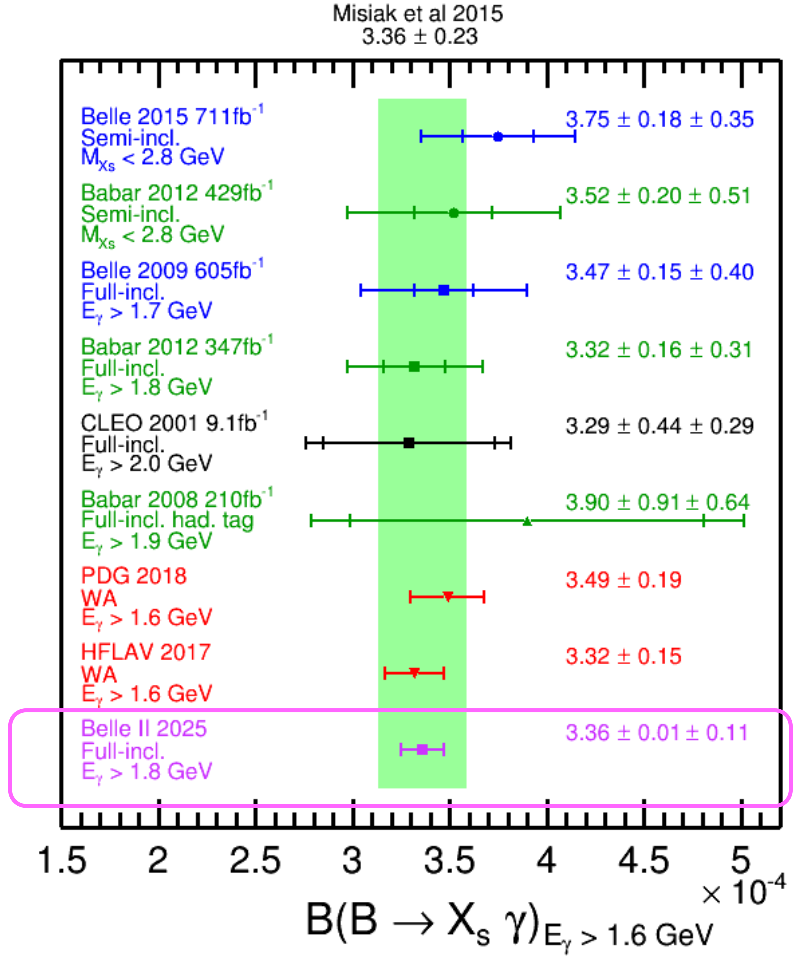
BF($B \to X_s\gamma$) in Belle II Era

- 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 (5%) : data driven reduction possible
    - Isospin asymmetry

      Watanuki, Ishikawa et al (Belle), PRD 99, 032012 (2019)
      Gunawardana and Paz 1908.02812
    - 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%

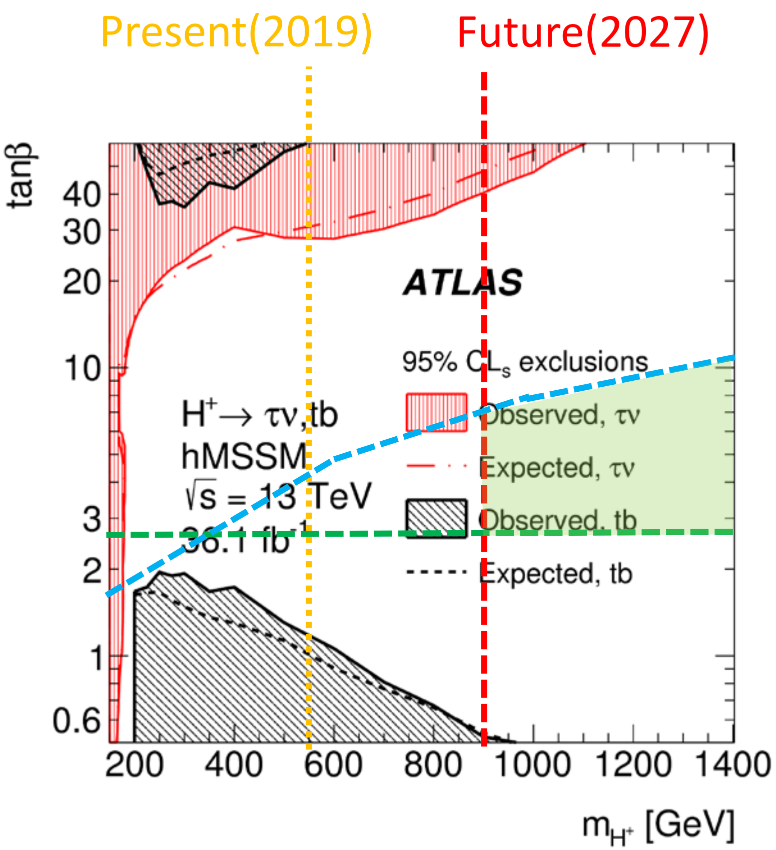
Belle II Physics book 1808.10567

Limit on Charged Higgs

- R_b at LEP
  - $\tan\beta$ >~2.5
- BF(B→Xs γ)
  - M_H > 580GeV
  - →>~900GeV in 2027
- BF(B→$\tau\nu$) in 2027
  - $\tan\beta/M_H$ < 0.008/GeV (4% on BF)
  - If $\tan\beta$=60 → M_H>7.5TeV
- And BF(Bs→$\mu\mu$) at LHC
  - $\propto\tan^6\beta$ in SUSY!!
- Allowed region in 2017

Assuming SM values

Ishikawa's private estimation

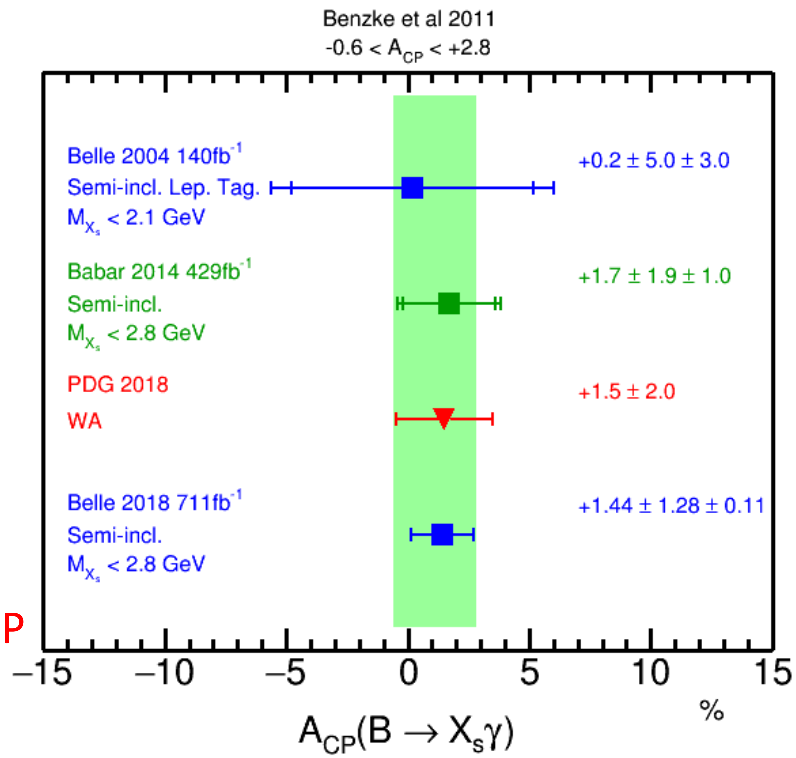


Before ILC measures Higgs couplings, B physics observables might give the strongest constraint on charged Higgs in 2HDM type-II.

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

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

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



Recent estimation gives larger uncertainty
Gunawardana and Paz 1908.02812

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

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

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

- 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 (Belle), PRD 99, 032012 (2019)

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
  - If consistent with zero, strong constraints on Im(C_8/C_7)
    - Theoretical improvement on ~Λ_{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%

- If deviation found
  - EW Baryogenesis in G2HDM — Modak and Senaha Phys.Rev. D99, 11, 115022 (2019)
  - SUSY with FV trilinear coupling — Endo, Goto, Kitahara, Mishima, Ueda and Yamamoto, JHEP 04 (2018) 019.

Summary

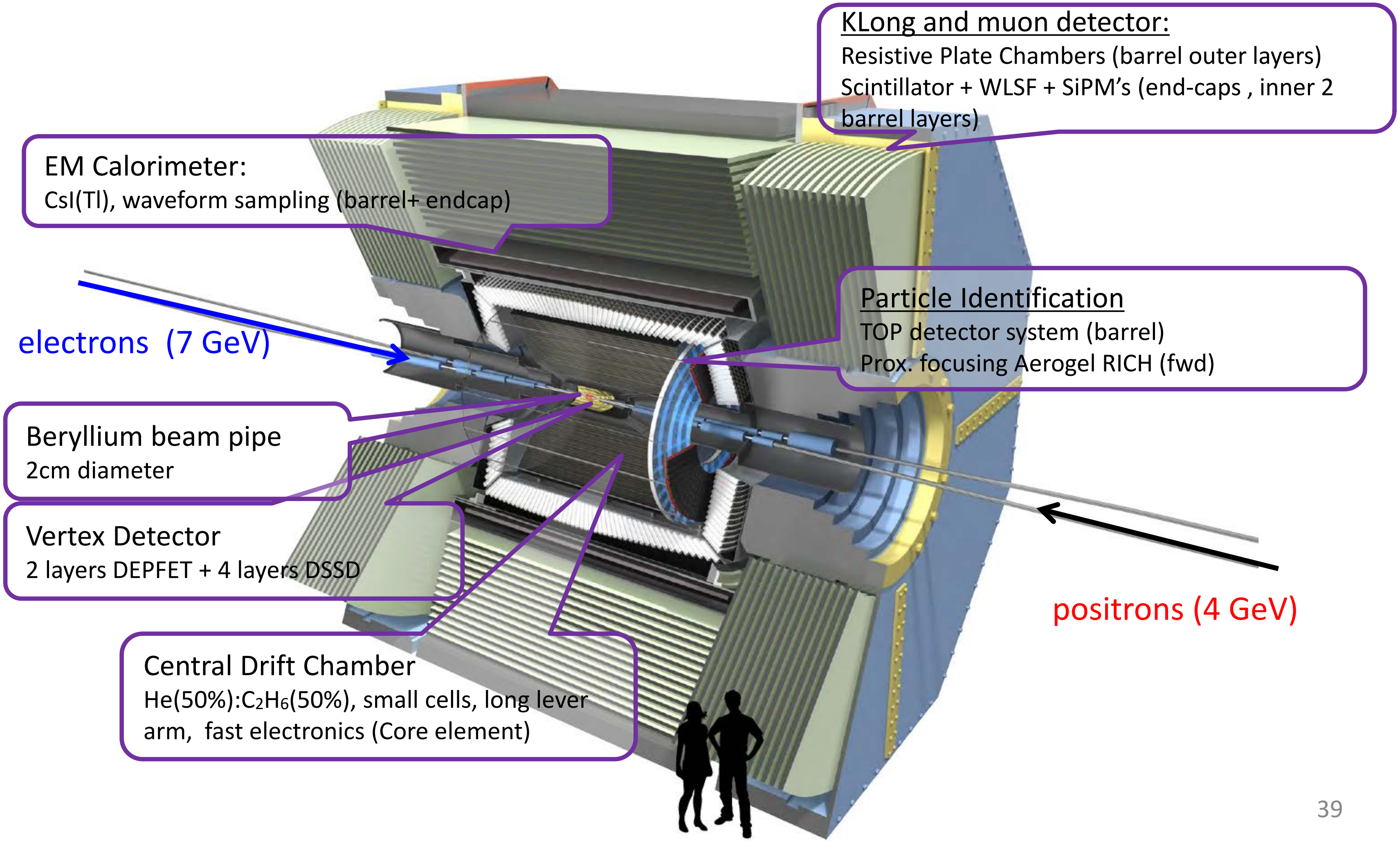
- Belle II has started data taking aiming for $50ab^{-1}$ by 2027.

- Missing energy signature is one of the keys at Belle II physics program
  - $B \to D(*)\tau\nu$
  - $B \to \tau\nu$
  - $b \to s\nu\nu$
- EW penguin and radiative B decays are very sensitive to NP in the loop
  - $b \to sl+l-$
  - $b \to s\nu\nu$
  - $b \to s\gamma$

- Stay tuned

Belle II Detector

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



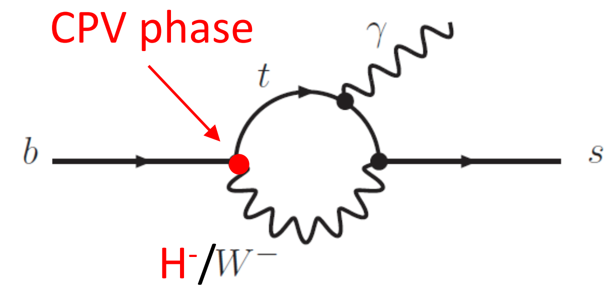
Modak and Senaha 1811.08088

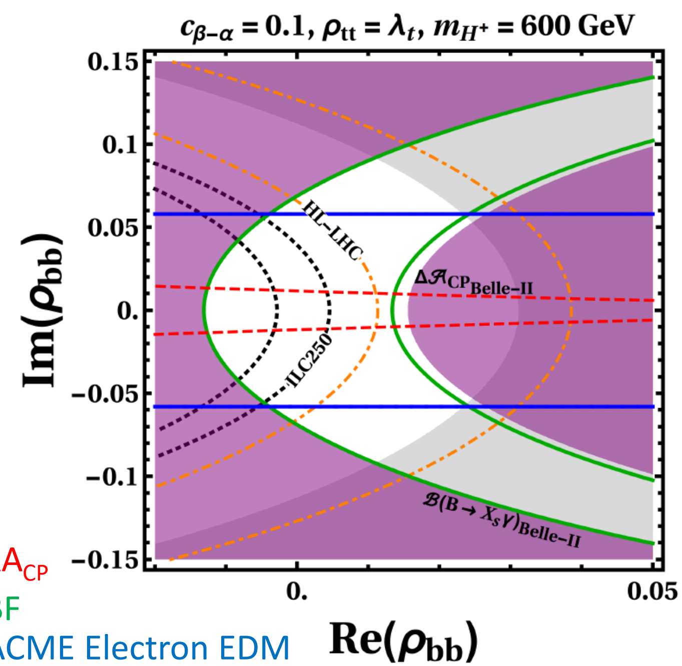
$\Delta A_{CP}(B \rightarrow Xs\gamma)$ and EW Baryogensis

- 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

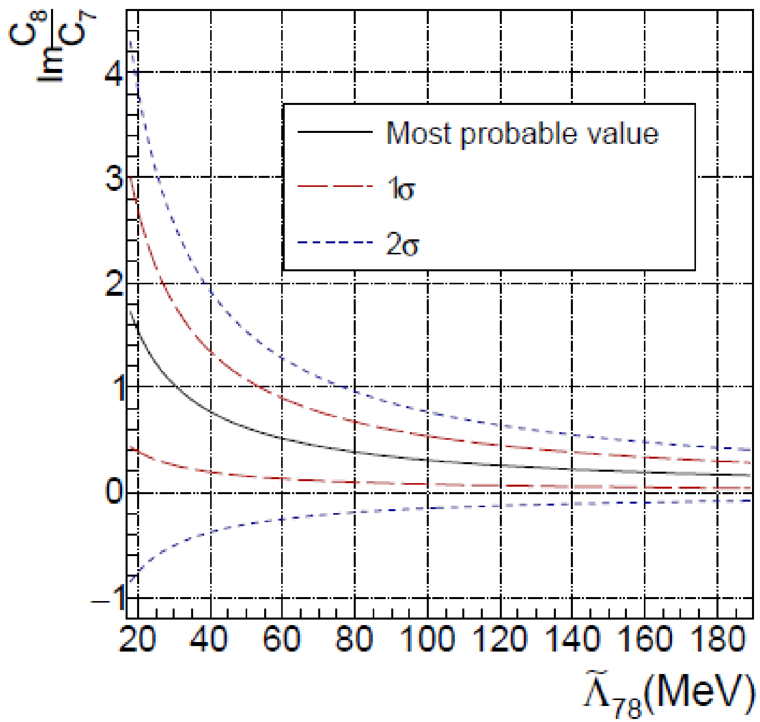




ΔA_{CP}
BF
ACME Electron EDM
HL-LHC H→bb coupling
ILC H→bb coupling

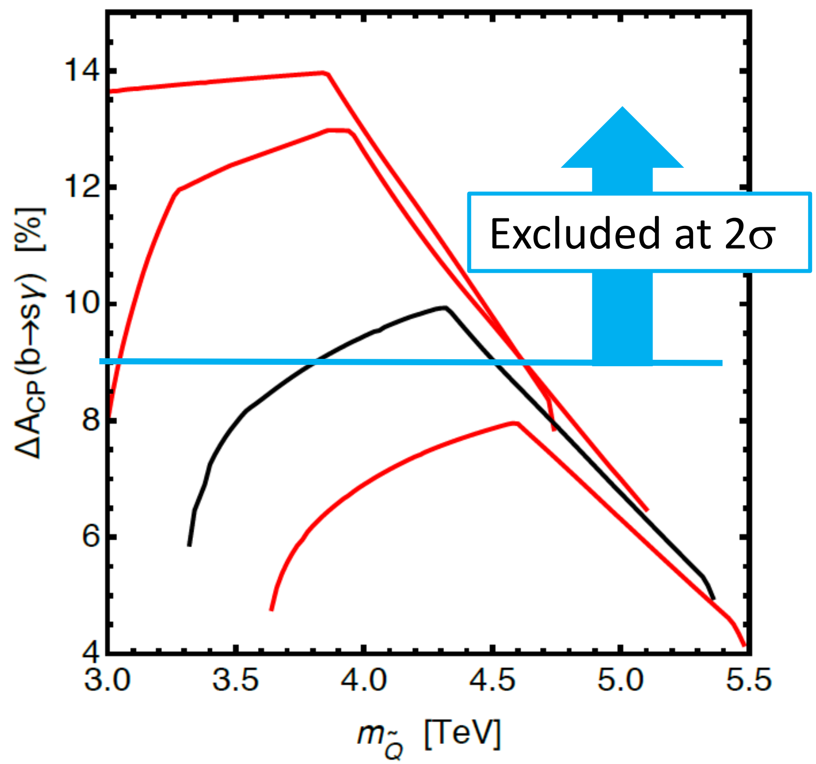
Constraint on Im(C_8/C_7) and a NP model with the Belle Result

- 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

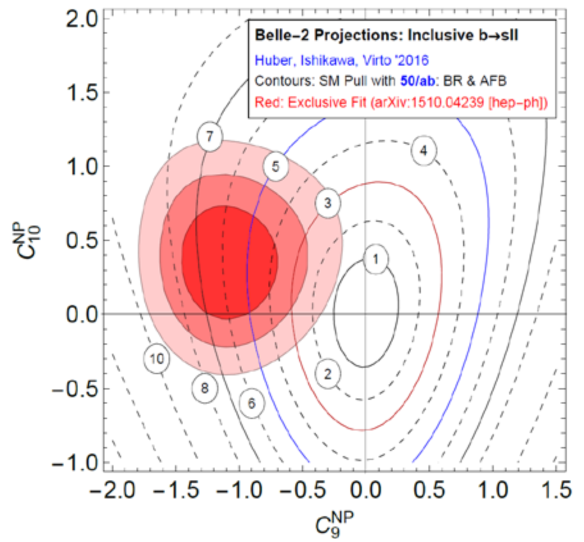
- Exclude parameter space in SUSY.
  - Gluino mediated EWP which explains ε'/ε from CPV trilinear couplings



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

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

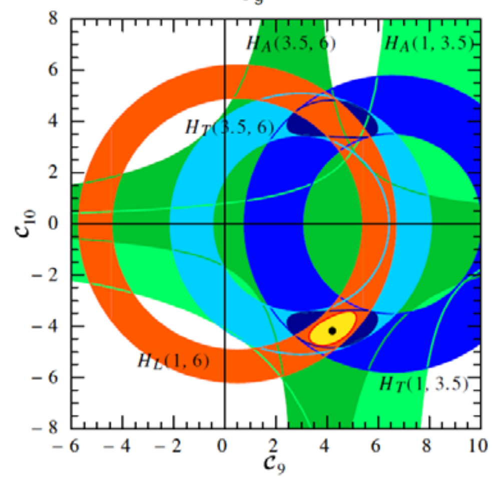
- Helicity decomposition gives third observables
  - H_T, H_L, H_A

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

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

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

$$z = \cos\theta$$



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

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 Y(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

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.

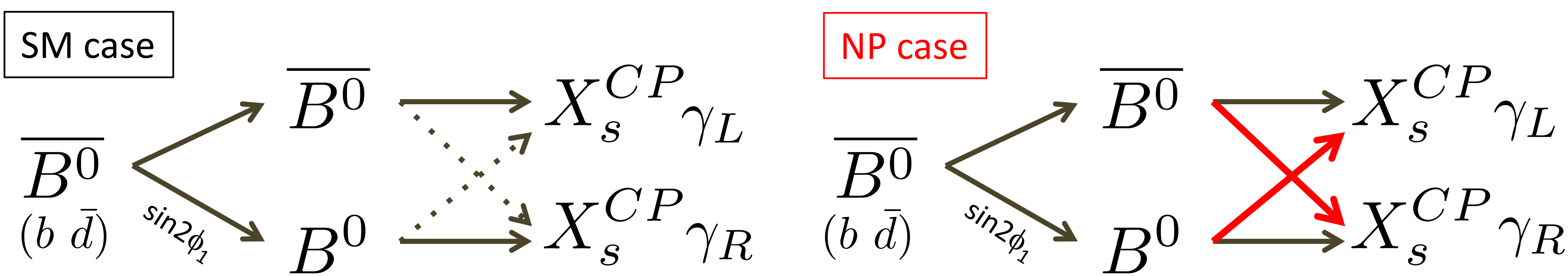
$$\left|S_{CP}\right| \approx \frac{2m_s}{m_b}\sin 2\phi_1 \quad \text{~ a few \%}$$

- 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

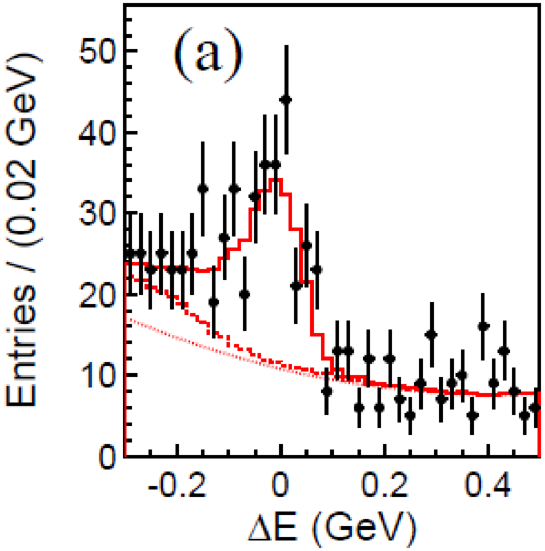
Measurement of S($B^0 \rightarrow K^{*0}\gamma$)

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

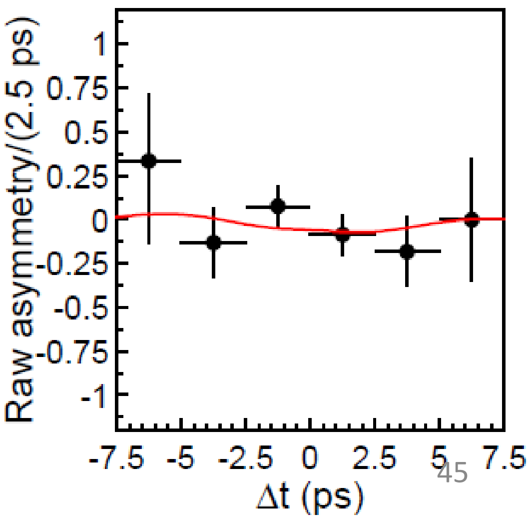
- Both Belle and Babar performed the analysis with 535M and 467M BB pairs.

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

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

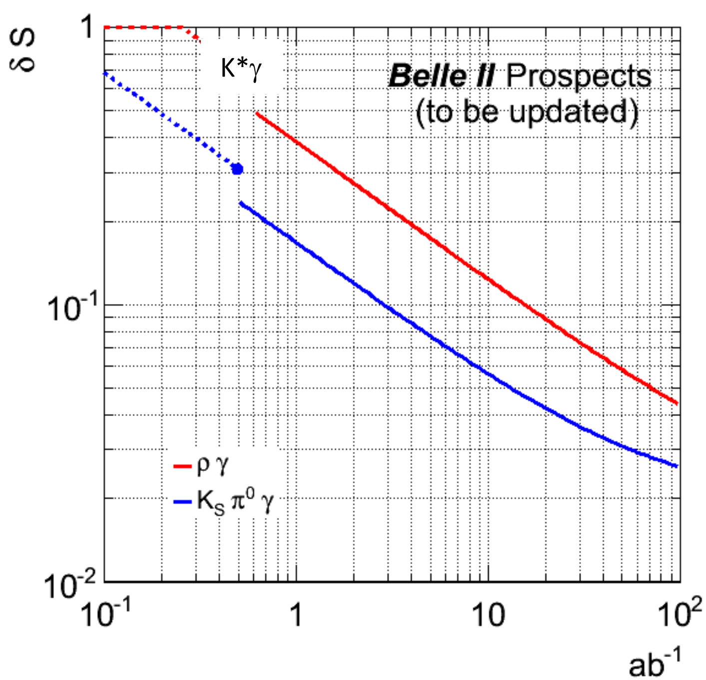


S($B^0 \rightarrow K^{*0}\gamma$) at Belle II

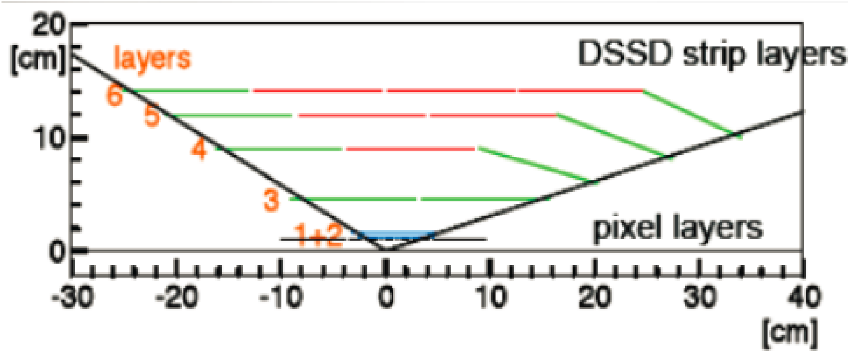
- Belle II vertex detector becomes larger
  - R of second outmost layer is 11.5cm (was 6cm)
  - 30% more Ks with vertex hits available.
- Effective tagging efficiency is ~20% better
- We can reach 0.03 uncertainty on S.
  - Still statistically dominated

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

Belle II



Belle 1



Photon Polarization

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

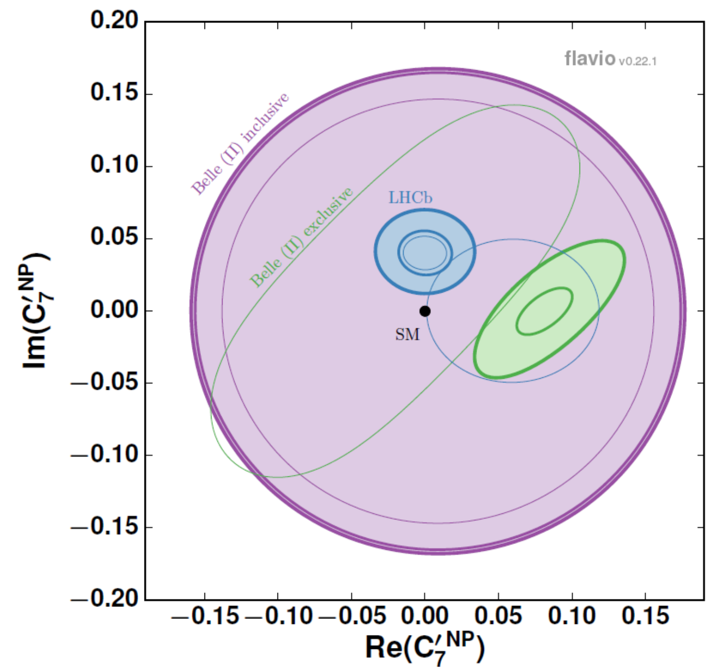
Gratrex and Zwicky (2018)

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

Belle II Physics book



LHCb have additional observables