Baryogensis Related Topics at Belle II

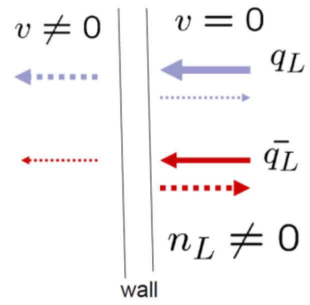
Akimasa Ishikawa
(KEK)

Baryogensis Related Topics at Belle II

- EW Baryogenesis
  - B decays : $b \rightarrow s\gamma$ and $B \rightarrow \tau\nu$
  - Tau decays : EDM
- Leptogenesis
  - Sterile neutrino searches at GeV scale
- B-mesogenesis
  - B meson decaying into dark matter having baryon number
    - Not related to Higgs

- Suehara-san asked to give the topics on B decays
  - Tau will be covered at next meeting?

EW Baryogenesis and B physics



- Sakharov's three conditions and EW Baryogensis
  1. B violation ← sphaleron
  2. C and CP violations ← CPV in Higgs sector
  3. Out of thermal equilibrium ← 1st order phase transition of the Higgs field

- B Physics
  - Sensitive to BSM Higgs due to its heaviness
    - Especially to 2HDM type-II
    - Branching Fraction measurements → Extended Higgs sector → 3. Non thermal equilibrium
    - New CPV Searches → CPV in Higgs sector → 2. C and CP violations

2HDM and B decays

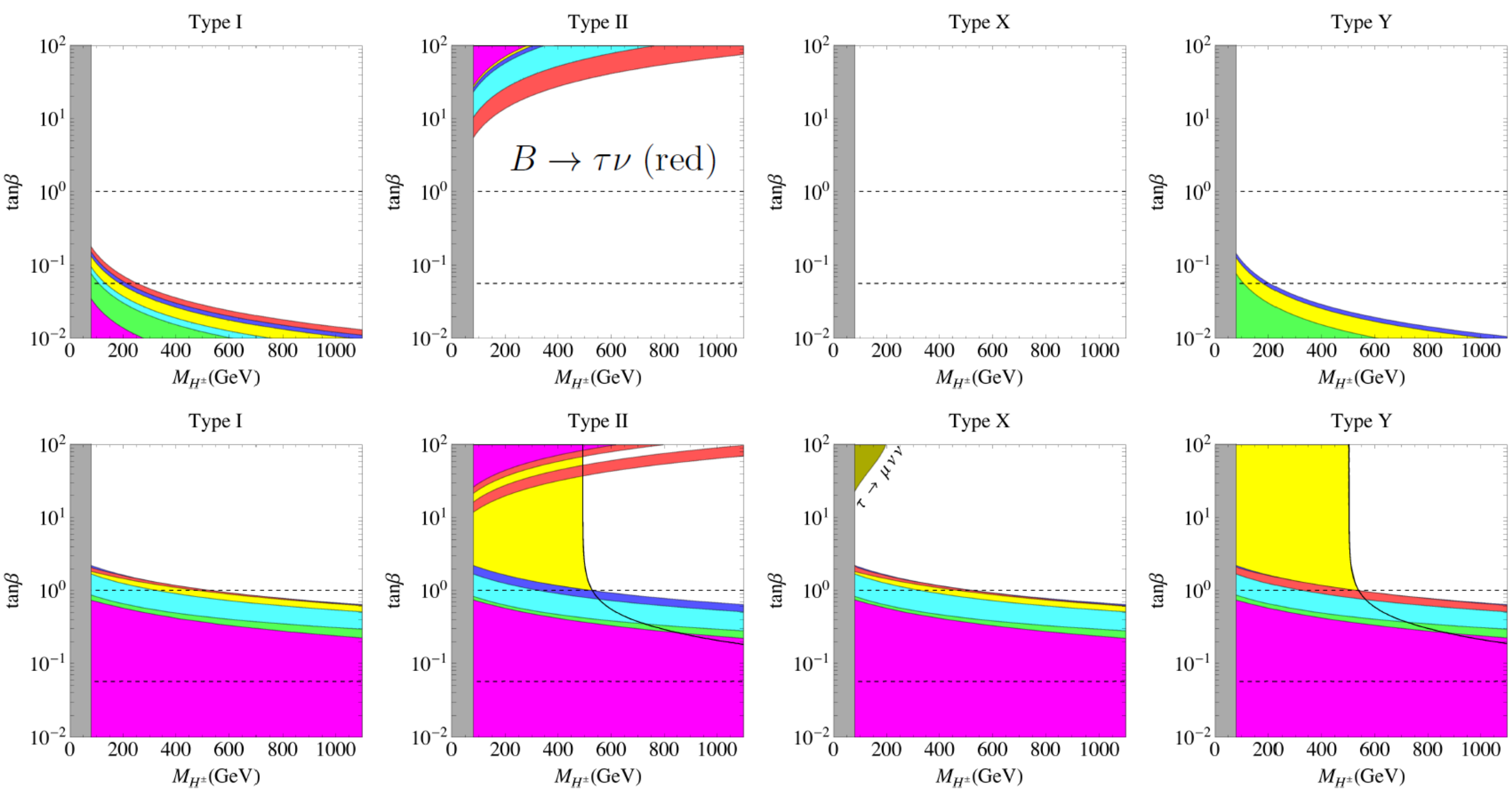
- B^0 Mixing, $b \to s\gamma$, $B \to \tau\nu$

Mixing and **chirality suppressed** decays

I will talk on the $b \to s\gamma$ and $B \to \tau\nu$ which is only possible at Belle II

tree

loop

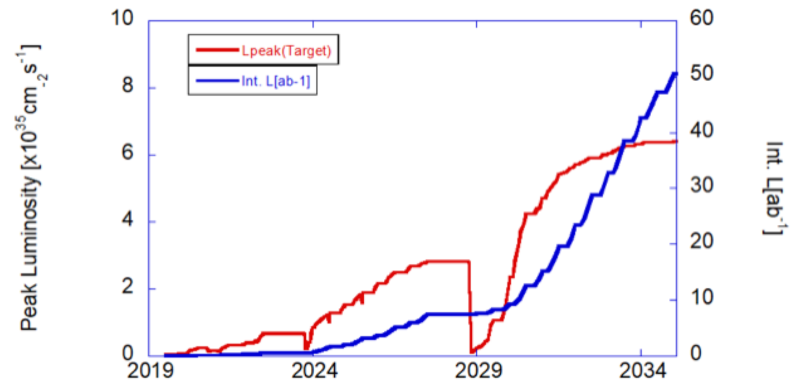


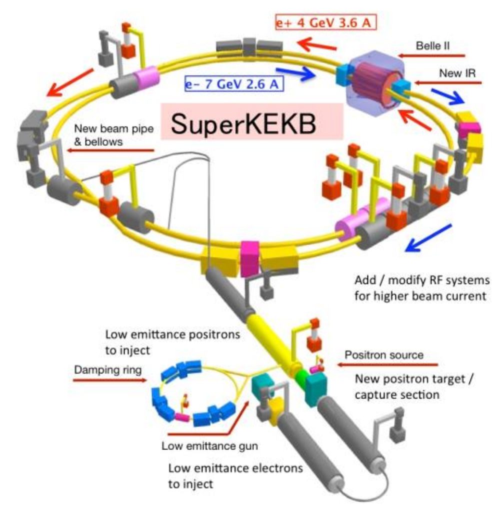
$B_s^0 \to \mu^+\mu^-$ (red), $B_d^0 \to \mu^+\mu^-$ (magenta), $\bar{B} \to X_s\gamma$ (yellow), ΔM_s (blue) ΔM_d (cyan)

Belle II @ SuperKEKB

- Highest luminosity collider experiment
  - $L=6.5\times10^{35}\ cm^{-2}s^{-1}$
  - E_{CM}=10.58GeV on Υ(4S)
    - Just above the BB threshold to produce B meson pairs efficiently
    - Can go higher, Υ(5S) and above
  - Energy-asymmetric collisions
    - 7.0GeV x 4.0GeV
    - To boost B mesons to measure time dependent CPV
  - $50ab^{-1}$ will be accumulated around 2034
    - Containing 1×10^{11} B mesons, 1.5×10^{11} charm hadrons, and 0.9×10^{11} τ
    - Processes with cross sections of O(1)ab are reachable
- Physics
  - Flavor physics : B, D and τ
    - Including HVP with radiative return for muon g-2
  - Light dark matter and new particle searches
  - And more

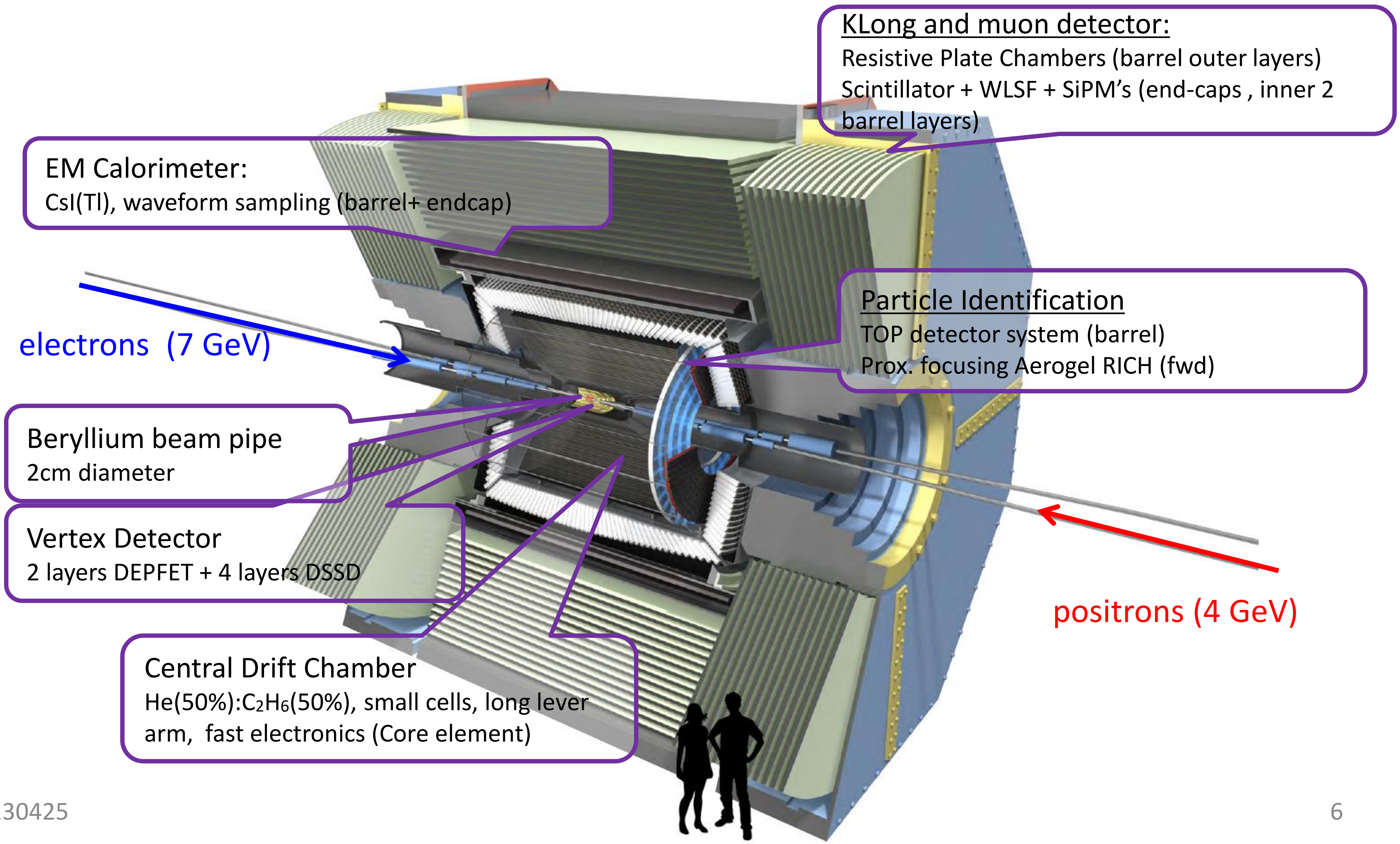
Luminosity Projection





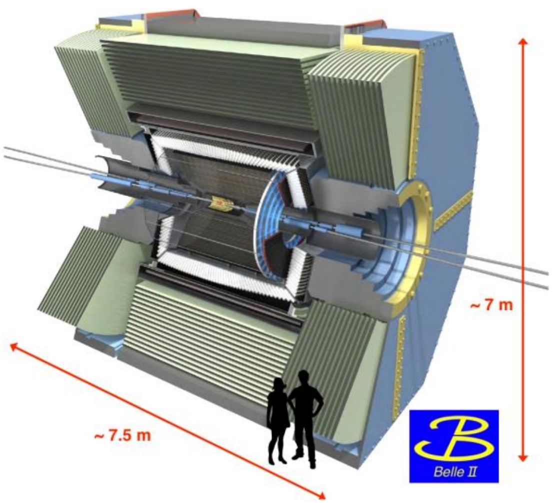
Belle II Detector

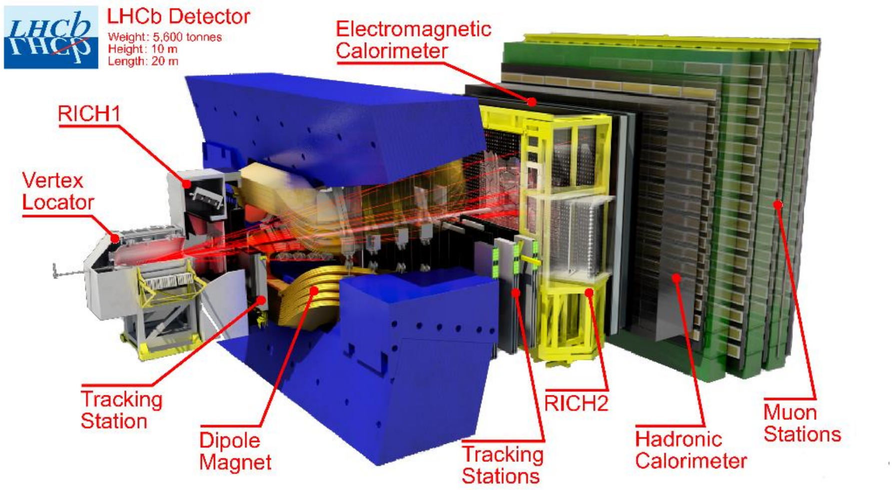
- Significant detector improvements
  - Better and Larger VXD ➔ Time dependent CPV, especially with long lived Ks.
  - Trigger improvement ➔ single photon final state etc.



Belle II Cons and Pros (VS LHCb)

- Cons.
  - Statistics of b hadrons!! (1nb VS 144μb)
    - We will only have 10^{11} B mesons with $50ab^{-1}$ on Υ(4S) and 5×10^{8} B_s with $5ab^{-1}$ on Υ(5S)
  - No large samples of b baryon and B_c
    - Production of these hadrons are not yet established around Υ(nS).
  - Proper time resolution is worse and B meson is not so boosted.
    - Background suppression with B vertex is not so easy
    - Bs mixing (Δm_s) can not be measured (while $\Delta\Gamma_s$ can be measured).



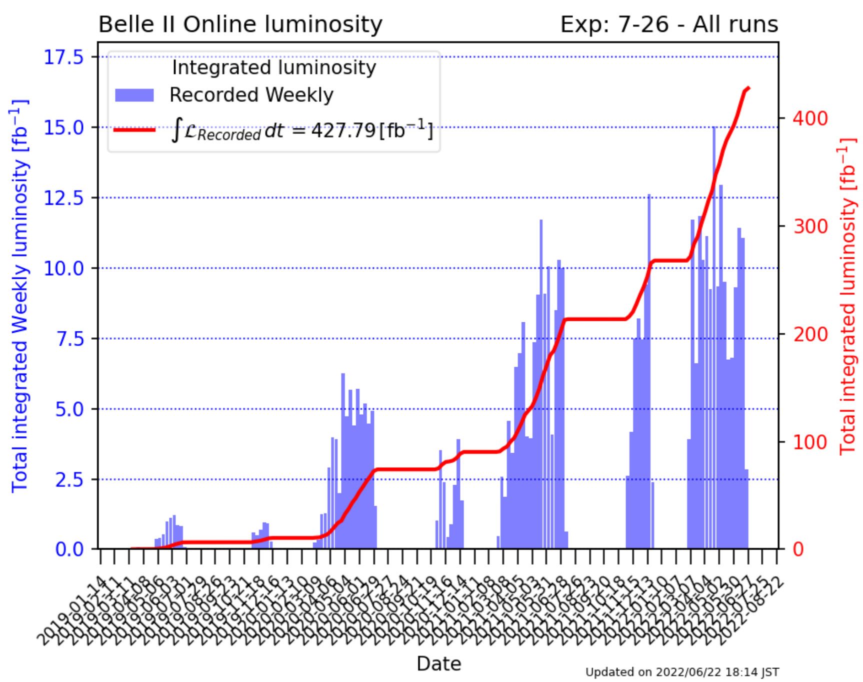


Belle II Cons and Pros (VS LHCb)

- Pros.
  - Smaller background cross section (O(1)nb VS O(10)mb)
    - ~3.4nb for ee→qq, ~1nb for ee→Υ(4S)→BB
  - Almost 100% trigger efficiency for BB events.
    - Main trigger : ntrack >= 3 || ECL energy sum >1GeV || ECL nCluster >=4
    - 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 ➔ $B \to D(*)\tau\nu$, $B \to \tau\nu$, $B \to K^{(*)}\nu\nu$, $B \to K\tau\tau$, $B \to \nu\nu$ or DM
  - Detection of electron
    - Detection efficiency of electron is almost the same as that of muon ➔ test of LFU (R_K anomaly gone since careless LHCb analysis was improved to normal one)
    - Easy to recover bremsstrahlung photon
  - Detection of neutrals
    - γ, π^0 and Ks can be reconstructed efficiently ➔ sum-of-exclusive approach $B \to Xsl^+l^-$, $B \to \pi^0\pi^0$, $B_{(s)} \to \gamma\gamma$
    - Better energy resolution of hard γ ➔ $B \to \rho\gamma$ with good PID device to suppress $B \to K^*\gamma$

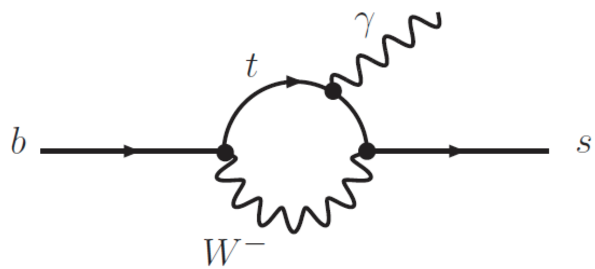
Belle II Operation

- Physics run since 2019
- Stop in June 2022 for Long Shutdown1 to install PXD layer2
- World records
  - $L = 4.7 \times 10^{34}\ cm^{-2}\ s^{-1}$ ($47\ nb^{-1}/s$)
- $428 fb^{-1}$ has been accumulated so far (Belle $1040 fb^{-1}$).

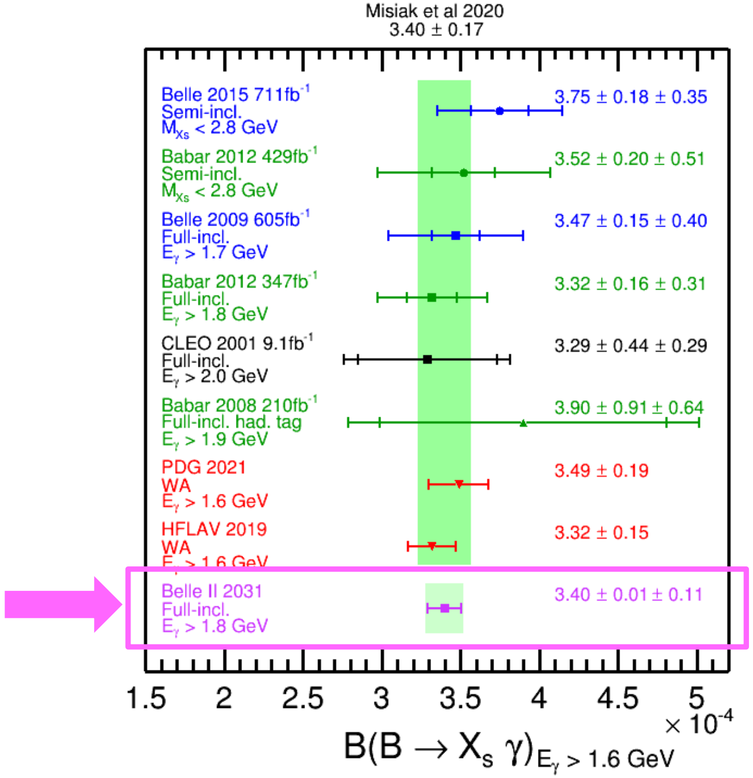


b→sγ

- EW penguin

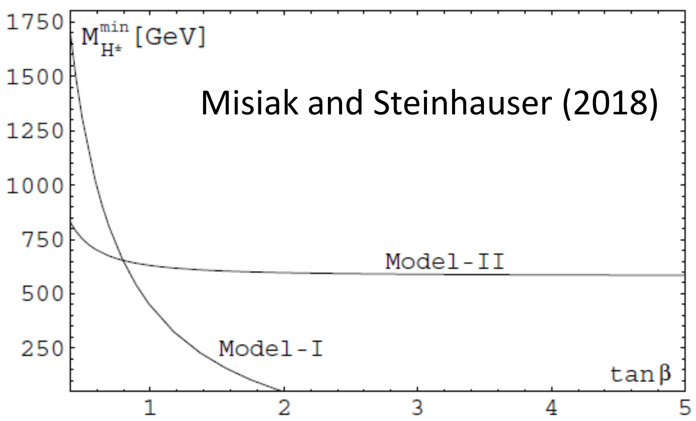


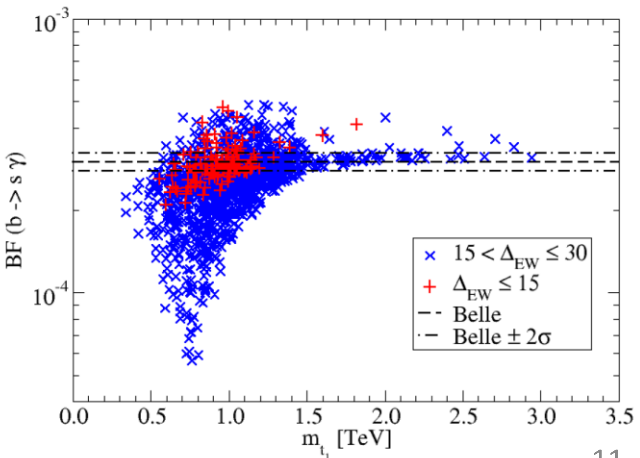
$BF(B \to X_s\gamma)$



- Exp and theory are in good agreement
  - Exp ~5% (systematic dominant)
    - Improvement at Belle II possible
  - Thoery ~5% M. Misiak et al, 2002.01548
    - Also improvements possible
- Constraints
  - H+ in 2HDM type-II : M_H >800GeV
  - Stop in Natural SUSY

Baer, Bager and Nagata (2017)





BF($B \rightarrow X_s\gamma$) in 2034

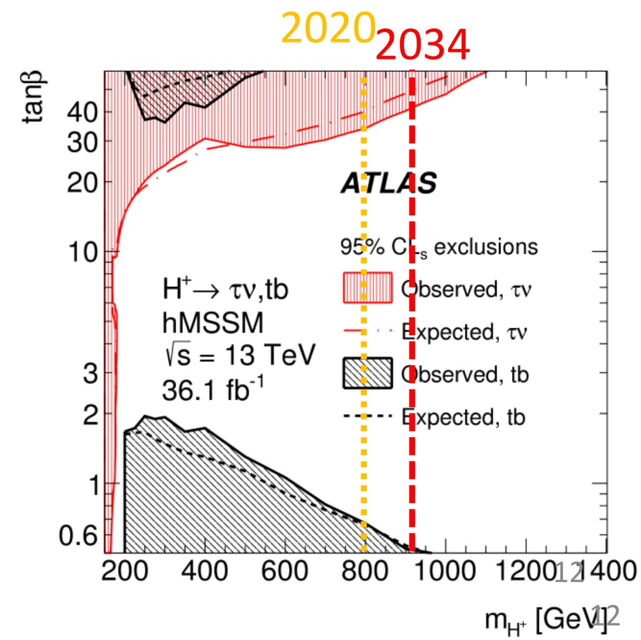
- Exp : Already systematic dominant
  - But large Belle II data can reduce the uncertainty to ~3%
  - We have already reduced the photon selection syst from 2% to 1%
- Theory
  - Part of Non-perturbative can be reduced by data driven way
  - Other uncertainties also reducible
  - 3.5% in 2025

Private communication with M.Misiak

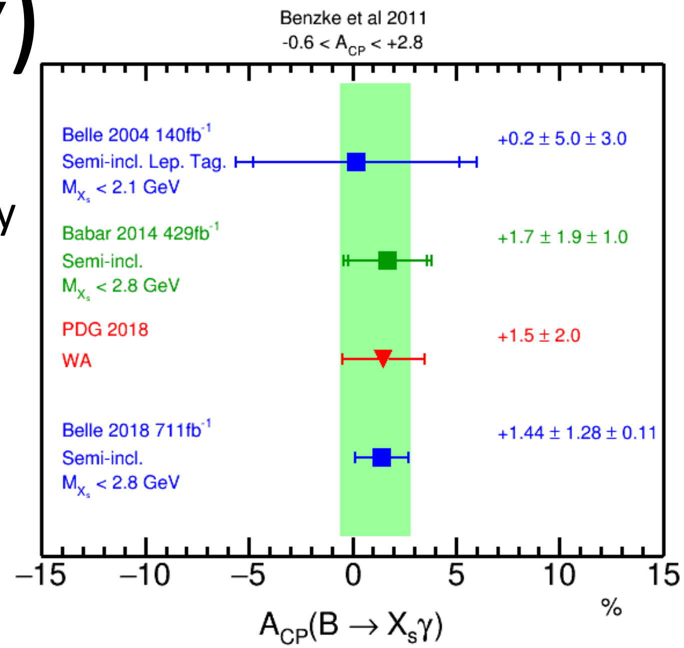
Source	Belle	Belle II
Photon selection	2.0	1.0

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

Belle II Physics book 1808.10567



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



- $A_{CP}(B \to X_s\gamma)$ is sensitive to CPV in NP but theory 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 CPV in extended Higgs sector

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

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

- Belle measured the observable in 2018
  - Found dominant syst error can be reducible → Belle II further improve the measurement

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

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

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

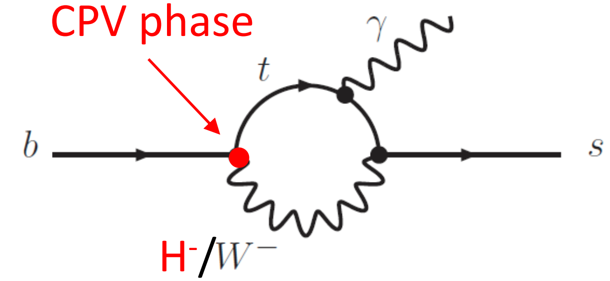
Belle II Physics book 1808.10567

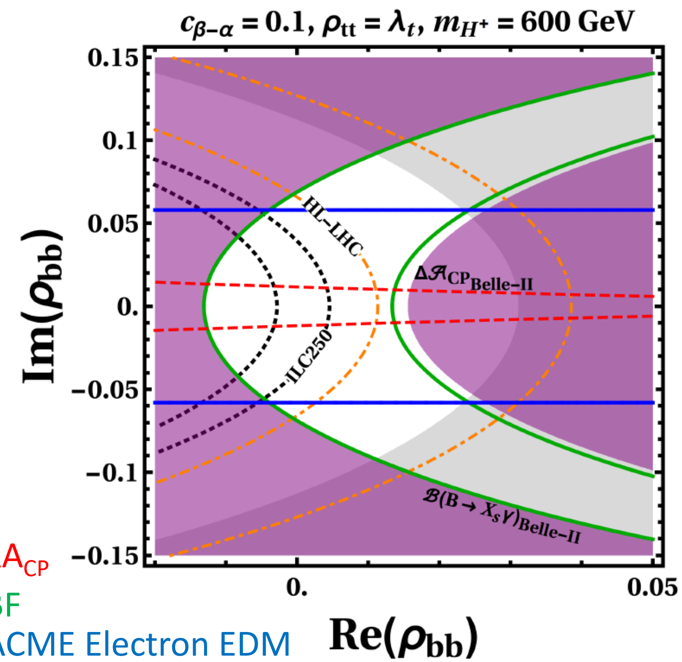
ΔA_{CP}(B→Xsγ) and EW Baryogensis

- 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 EW Baryogensis is possible
- ΔA_{CP} is sensitive to phase in ρ
- Combining H→bb coupling measurements at HL-LHC/ILC, additional bottom Yukawa and phase can be searched
  - If found it→ Higgs self coupling measurments at ILC500

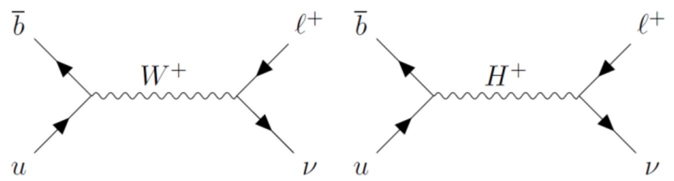




B→$\tau\nu$ ($\mu\nu$)

B→τν(μν) in SM and 2HDM

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

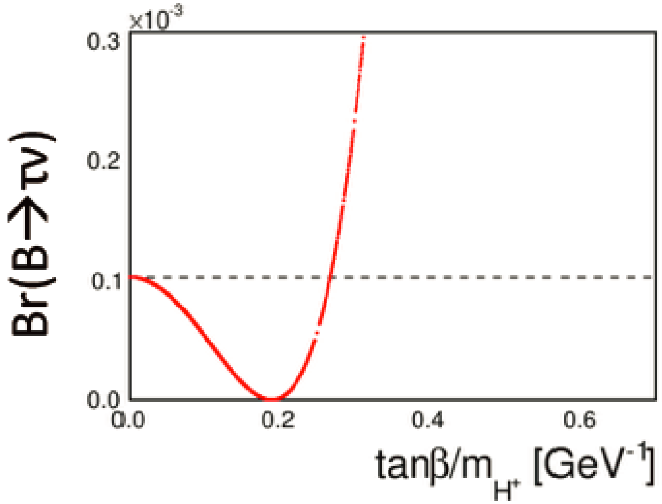


$$\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B}{8\pi} m_\ell^2 (1 - \frac{m_\ell^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$

- BF(B→τν) in 2HDM type-II
  - No helicity suppression with Higgs exchange
  - Higgs coupling ∝ m_τ

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

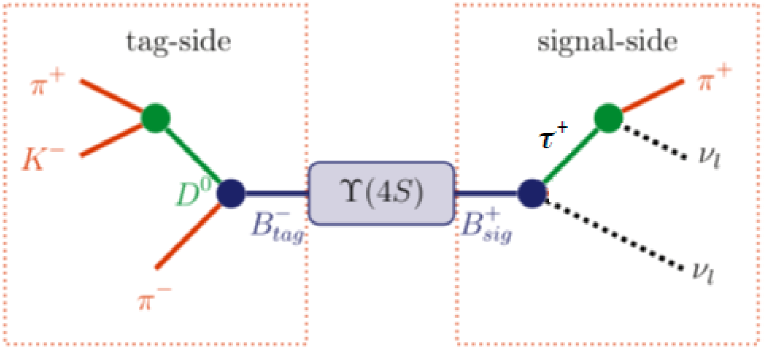
$$r_H = (1 - \frac{m_B^2}{m_H^2} \tan^2\beta)^2$$



  - BF only dependent on r_H (function of $\tan\beta/m_H$)
  - Flavor independent so the same can be applied to B→μν

$\mathcal{B}(B\to\tau\nu)$ and $\mathcal{B}(B\to\mu\nu)$

- Precision of BF($B\to\tau\nu$) at Belle II
  - 2x better tagging efficiency (the other B recon)
  - 4% precision on B ($B\to\tau\nu$) with 50ab^{-1}

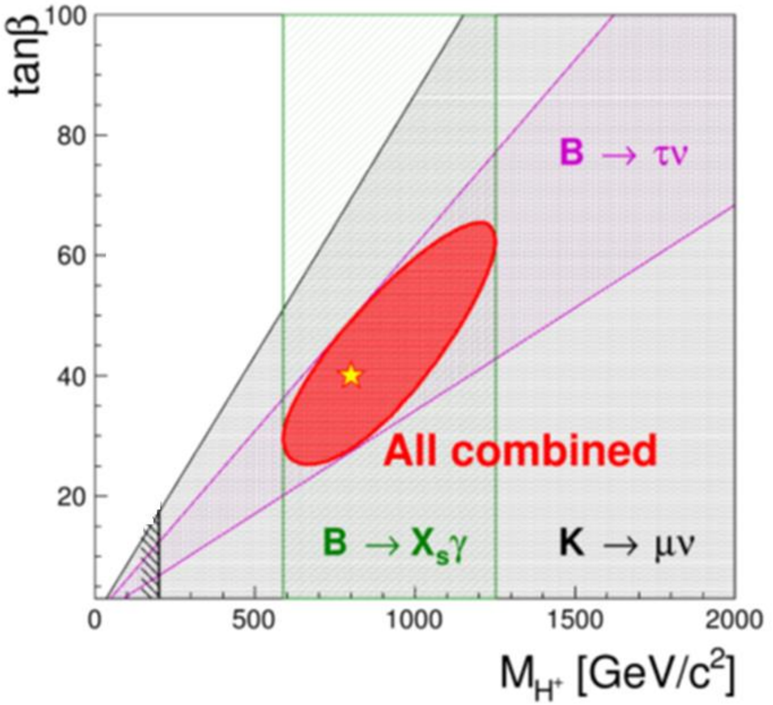


	Integrated Luminosity (ab^{-1})	1	5	50
hadronic tag	statistical uncertainty (%)	29	13	4
	systematic uncertainty (%)	13	7	5
	total uncertainty (%)	32	15	6
semileptonic tag	statistical uncertainty (%)	19	8	3
	systematic uncertainty (%)	18	9	5
	total uncertainty (%)	26	12	5

- BF($B\to\mu\nu$)
  - 12% with 50ab^{-1} (dominated by statistical uncertainty)

A Scenario of Evidence for Charged Higgs

- $B \to X_s\gamma$: $\tan\beta$ independent
- $B \to \tau\nu$: $\tan\beta/m_H$ = const.
- With 50/ab, M_{H+}=800GeV and $\tan\beta$=40 can be found.



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Summary

- B meson is a good tool to search for extended Higgs sector and its CPV
  - Hence, EW Baryogenesis
- The branching fractions of $b \rightarrow s\gamma$ and $B \rightarrow \tau\nu$ and and difference of CPV in $b \rightarrow s\gamma$ can test the EW baryogenesis via bottom transport
  - Only Belle II can measure the decays
- Stay tuned

backup