TOHOKU UNIVERSITY

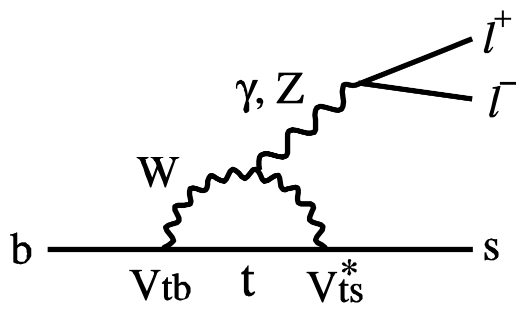
Radiative and EW Penguin Decays at Belle and Belle II

Akimasa Ishikawa
(Tohoku University)

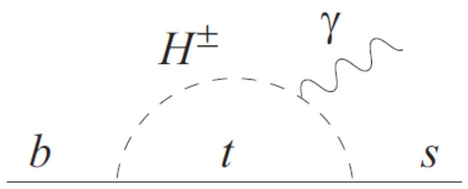
Flavour Physics with High-Luminosity Experiments
at MIAPP

Radiative and EW Penguin Decays

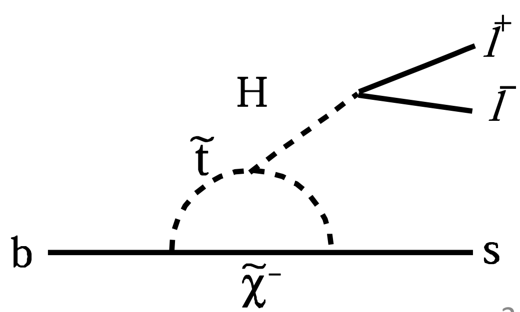
- Proceed via one loop diagrams in the SM



- New physics can enter in the loop or can contribute even at tree level.



- These decays are theoretically and experimentally clean due to final states having color singlet leptons or photon



- Very sensitive to new physics

Wilson Coefficients

- These decays are expressed by real Wilson Coefficients in the SM
  - $b \to s\gamma$: C_7
  - $b \to sll$: C_7, C_9 and C_{10}
- In the new physics models,
  - coefficients deviated from the SM values
  - scalar coefficients (C_S and C_P)
  - right handed counter parts (C_i')
  - All could have imaginary parts
- Observables of radiative and EW penguin decays in and beyond the SM can be parameterized by the Wilson coefficients.

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

$$\begin{aligned}
\mathcal{O}_1 &= (\bar{s}_\alpha \gamma_\mu L c_\beta)(\bar{c}_\beta \gamma^\mu L b_\alpha), \\
\mathcal{O}_2 &= (\bar{s}_\alpha \gamma_\mu L c_\alpha)(\bar{c}_\beta \gamma^\mu L b_\beta), \\
\mathcal{O}_3 &= (\bar{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu L q_\beta), \\
\mathcal{O}_4 &= (\bar{s}_\alpha \gamma_\mu L c_\beta) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu L q_\alpha), \\
\mathcal{O}_5 &= (\bar{s}_\alpha \gamma_\mu L b_\alpha) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu R q_\beta), \\
\mathcal{O}_6 &= (\bar{s}_\alpha \gamma_\mu L c_\beta) \sum_{q=u,d,s,c,b} (\bar{q}_\beta \gamma^\mu R q_\alpha), \\
\mathcal{O}_7 &= \frac{e}{16\pi^2} \bar{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) b_\alpha F^{\mu\nu}, \\
\mathcal{O}_8 &= \frac{g}{16\pi^2} \bar{s}_\alpha \sigma_{\mu\nu} (m_s L + m_b R) T^a_{\alpha\beta} b_\beta G^{a\mu\nu}, \\
\mathcal{O}_9 &= \frac{e^2}{16\pi} \bar{s}_\alpha \gamma^\mu L b_\alpha \bar{\ell} \gamma_\mu \ell, \\
\mathcal{O}_{10} &= \frac{e^2}{16\pi} \bar{s}_\alpha \gamma^\mu L b_\alpha \bar{\ell} \gamma_\mu \gamma_5 \ell,
\end{aligned}$$

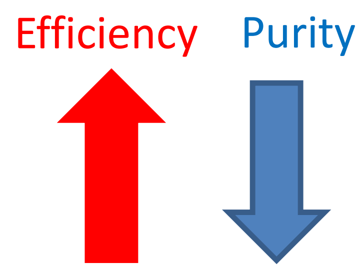
Contents

- Radiative Decays
  - BF and Asymmetries in Inclusive $b \rightarrow s\gamma$ ($b \rightarrow s+d\gamma$)
  - TCPV in $B^0 \rightarrow K^{*0}\gamma$
- EW Penguin Decays
  - BF and A_{FB} in Inclusive $b \rightarrow sll$
  - Lepton Flavor Universality (LFU) in $b \rightarrow sll$

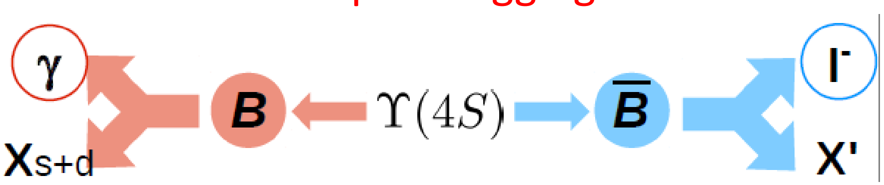
Radiative Decays

Reconstruction of B→Xs γ

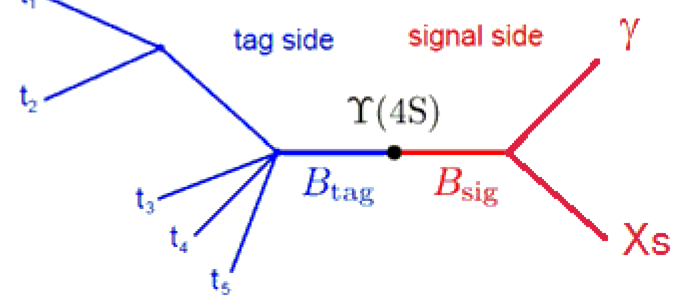
- Two methods to reconstruct B→Xsγ
  - Sum of exclusive method
    - Xs is reconstructed from many exclusive decays, K$n\pi$, 3K$m\pi$, K$\eta m\pi$ etc (n>1, m>=1).
    - can single out b→s (b→d)
    - Flavor and isospin known
  - Fully inclusive photon method
    - Measure sum of b→s and b→d
    - To know the flavor and/or isospin, tagging with the other B is needed
- Three tagging methods for inclusive analysis
    - Lepton tagging → flavor
    - Semileptonic B tagging → flavor and isospin
    - Hadronic B tagging → momentum, flavor and isospin



Lepton tagging

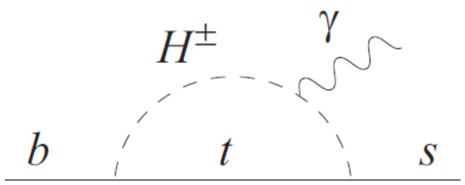


Hadronic B tagging



BF(B→Xs γ)

- Sensitive to $|C_7|$ (or $C_7^2 + C_7'^2$)
- In the new physics model
  - Charged higgs in 2HDM type-II
    - Constructive to SM amplitude
    - Almost no tanβ dependence
  - SUSY
    - Constructive or destructive to SM
    - Depending on SUSY parameters
- Very precise prediction is available.
  - 6.8% precision

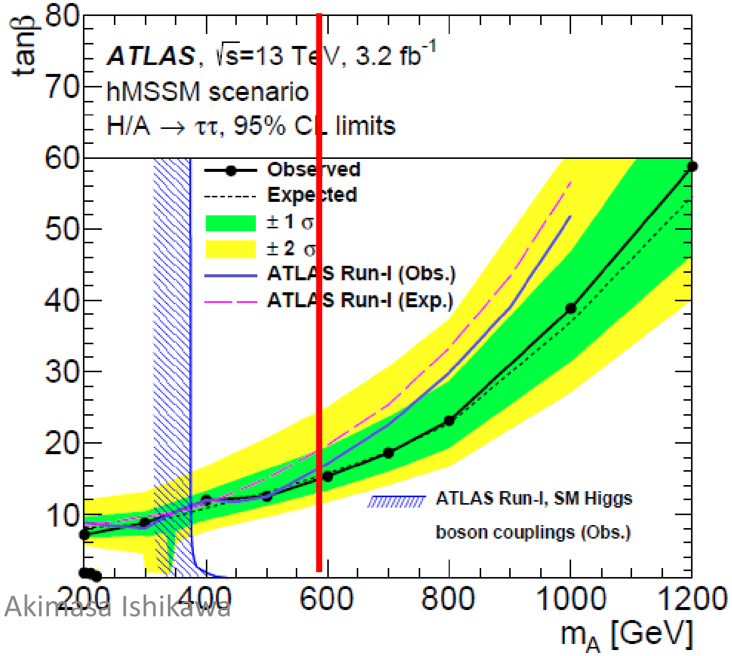


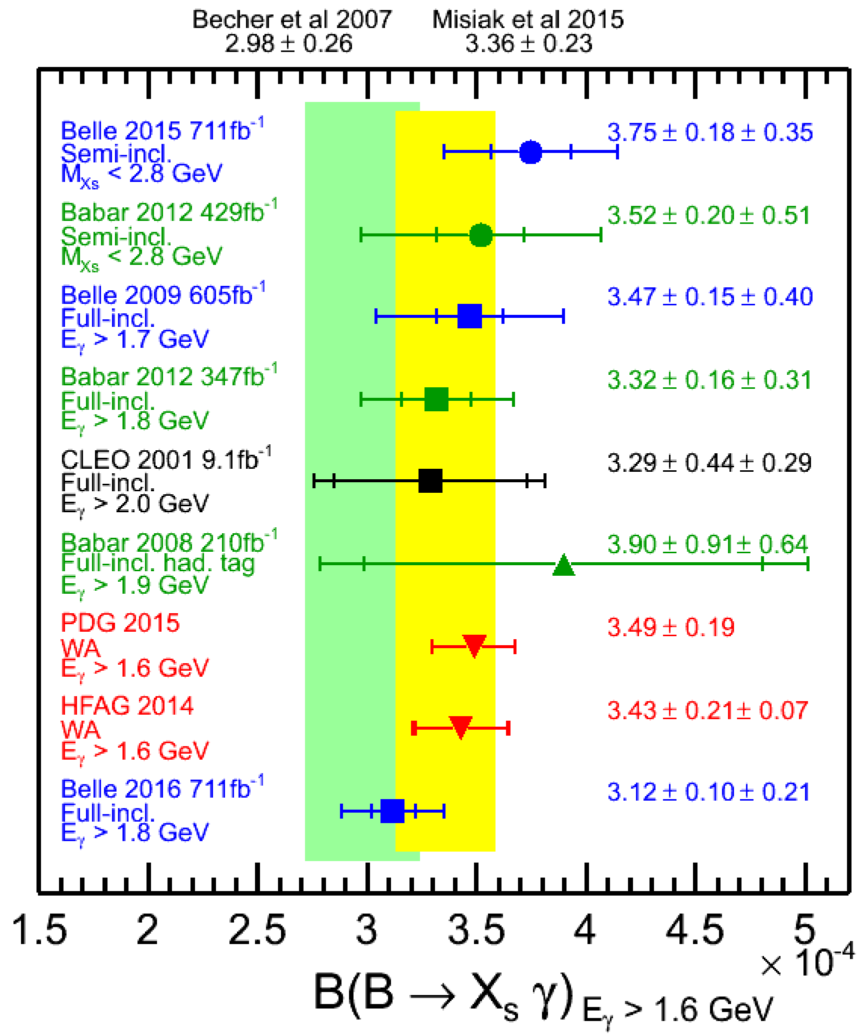
$$\mathcal{B}_{s\gamma}^{\rm SM} = (3.36 \pm 0.23) \times 10^{-4}$$

M. Misiak et al, Phys. Rev. Lett. 114, 221801 (2015)

Measurement of BF(B→Xs γ)

- Exp. and theory are consistent.
  - Strong limit on NP.
- The newest Belle result with fully inclusive method is only 7.3% uncertainty.
  - Charged Higgs mass > 580 GeV at 95% CL
    - Based on CKM fitter
    - moderate tanβ (~7) region can be excluded
      - LHC is very hard to set the limit.
  - Already systematic dominant.





BF(B→Xsγ) at Belle II

- Mission at Belle II is to reduce the systematic uncertainty with huge data.
- Large uncertainties for inclusive analysis for E_γ>1.8GeV are
  - Other backgrounds (hadron, radiative meson decays, electron, etc) 3.7%
    - Hadronic interaction to Caloriemeter will be able to be calibrated and modeled in MC.
  - Stat. error 3.2%
  - Efficiency modeling with HQE parameters 2.5%
    - Now, conservatively taken. Precision of HQE parameters, m_b and μ_π^2 , will be better.
  - Eta background 2.2%
    - eta spectrum can be measured precisely.
- Conservatively estimated, 3.9% total error will be reachable with 50/ab which is comparable to uncertainty due to nonpertubartive effect (which is very hard to reduce) in theory.

> Individual contributions to the total uncertainty are of nonperturbative ($\pm 5\%$), higher-order ($\pm 3\%$), interpolation ($\pm 3\%$), and parametric ($\pm 2\%$) origin. They are combined

M. Misiak et al, Phys. Rev. Lett. 114, 221801 (2015)

- We can also measure the BF with E_γ>1.6GeV (w/o extrapolation).

$A_{CP}(B \to X_{s+d}\,\gamma)$ and $\Delta A_{CP}(B \to X_s\,\gamma)$

- Prediction of $A_{CP}(B \to X_s\,\gamma)$ in SM has larger uncertainty than previously expected due to resolved photon.
- However, A_{CP} for sum of $b \to s\gamma$ and $b \to d\gamma$ is predicted as negligibly small thanks to Unitarity of CKM matrix.

Channel	A_{CP}(SM)
$B \to X_s\gamma$	[-0.6% , +2.8%]
$B \to X_d\gamma$	[-62% ,+14%]
$B \to X_{s+d}\gamma$	0

- Further, difference of $A_{CP}(B \to X_s\,\gamma)$ btw charged and neutral B mesons ($\Delta A_{CP}(B \to X_s\,\gamma)$) is sensitive to phase in C_7 or C_8.
  - In the SM , phases in C_7 and C_8 are zero → $\Delta A_{CP} = 0$.

$$\Delta\mathcal{A}_{X_s\gamma} \equiv \mathcal{A}_{X_s^-\gamma} - \mathcal{A}_{X_s^0\gamma} \approx 4\pi^2\alpha_s\,\frac{\tilde{\Lambda}_{78}}{m_b}\,\mathrm{Im}\,\frac{C_{8g}}{C_{7\gamma}}$$

$$\approx 12\% \times \frac{\tilde{\Lambda}_{78}}{100\ \mathrm{MeV}}\,\frac{r_8}{r_7}\,\sin(\theta_8 - \theta_7)$$

- If either is deviated from null, clear NP signal!

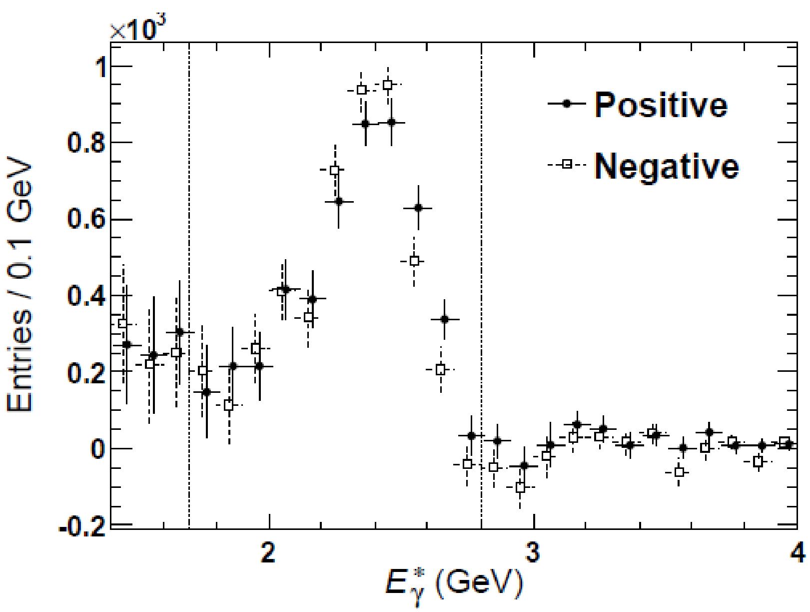
M. Benzke et al, PRL 106, 141801 (2011)

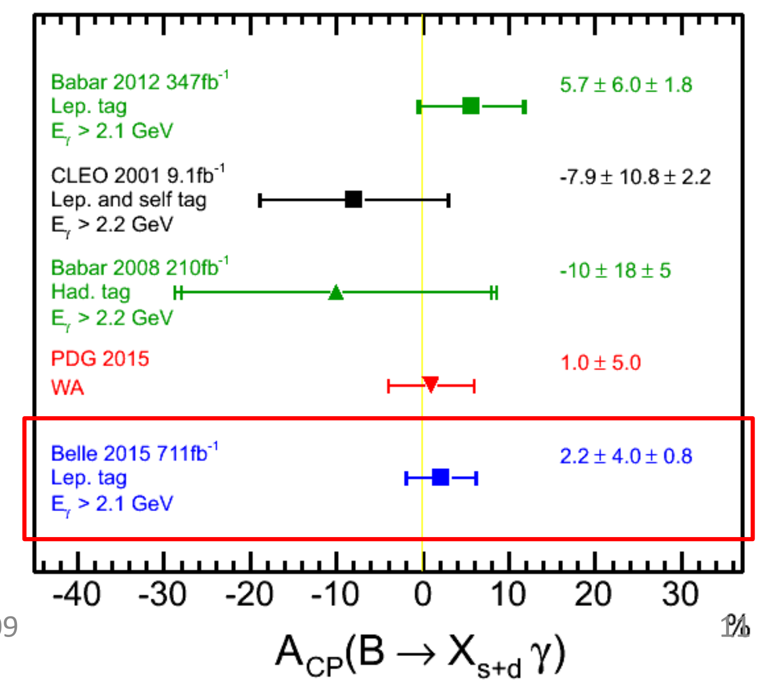
T. Hurth, E. Lunghi and W. Porod, Nucl. Phys. B 704, 56 (2005).

L. Pesantez et al (Belle Collaboration) PRL 114, 151601 (2015)

Measurement of $A_{CP}(B \to X_{s+d}\gamma)$ at Belle

- If deviated from 0, clear new physics signal.
- Inclusively reconstruct photon with $1.7 < E_\gamma < 2.8$GeV
- High momentum lepton to tag flavor of the other B
  - Correction of mixing applied
- Belle performed world best measurement
  - Even better than PDG 2015!



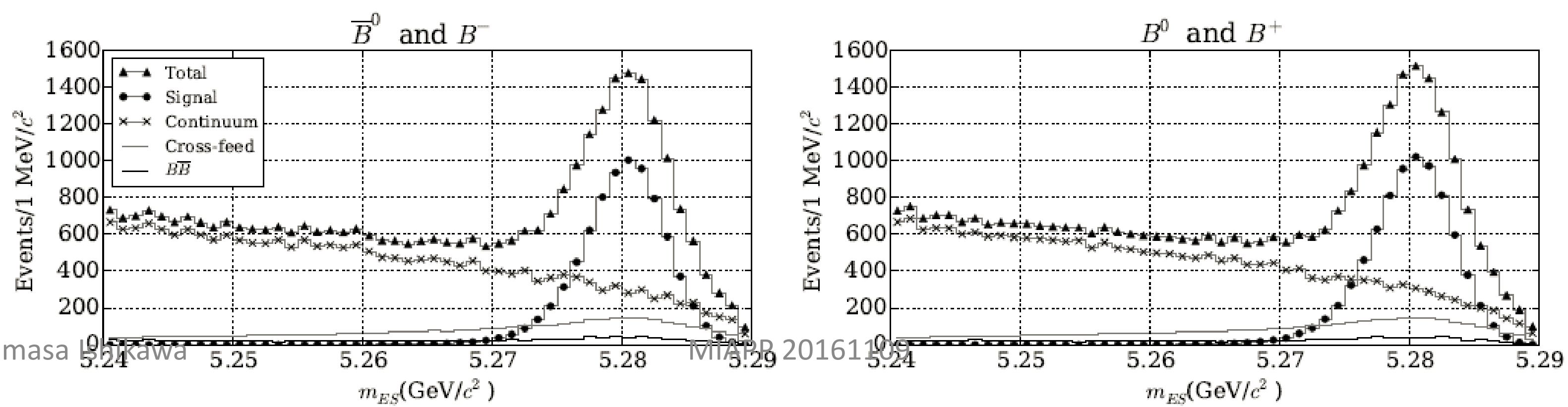


Measurement of $\Delta A_{CP}(B \rightarrow X_s \gamma)$ at Babar

- Only measured by Babar.
  - Belle analysis is on-going.
- Sum-of-exclusive with 38 decay modes.
  - Only self-tagged modes were used.

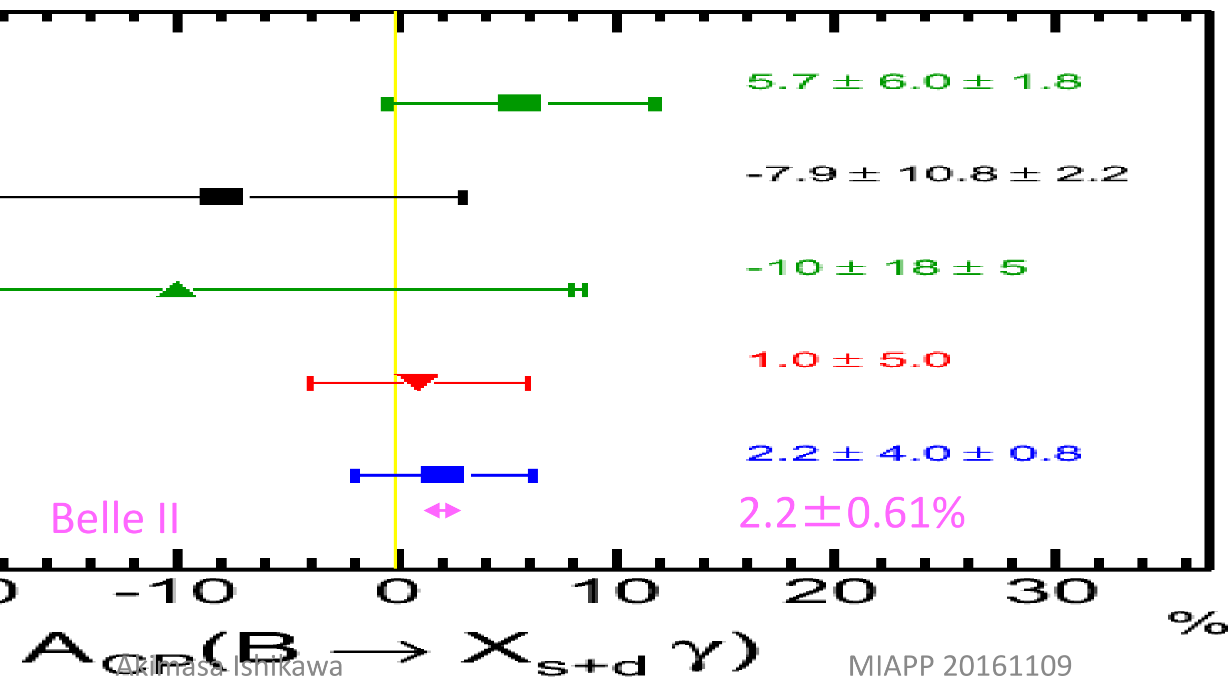
$$\Delta A_{X_s\gamma} = +(5.0 \pm 3.9 \pm 1.5)\%$$

- Quoted systematic error is conservative.
  - According to the paper and corresponding PhD thesis, very conservatively took quadratic sum of uncertainties of A_{CP} for charged and neutral B even part of the systematic errors cancel out.
    - Ex. Detector asymmetry



$A_{CP}(B \rightarrow X_{s+d}\gamma)$ and $\Delta A_{CP}(B \rightarrow X_s \gamma)$ at Belle II

- In asymmetry (difference) measurements, most of systematic error cancel out, so both are still statistically dominated at Belle II with 50/ab.
  - Uncertainty in A_{CP} to be $\pm 0.61\%$ → 3.4σ if the central value not change
  - Uncertainty in ΔA_{CP} to be $\pm 0.37\%$ → 13.5σ if the central value not change



Babar

$$\Delta A_{X_s\gamma} = +(5.0 \pm 3.9 \pm 1.5)\%$$

Belle II

5.0±0.37%

Photon Polarization in $b \to s\gamma$

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

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

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

- 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
  - Time dependent CPV in $B \to f_{CP}\gamma$ ← Golden modes
  - A_{UD} in $B \to K_1(K\pi\pi)\gamma$
  - Very low q^2 analysis in $B \to K^*ee$
  - Photon conversion

This topic was already given by Luigi, but I would repeat this since this measurement is really important

Time Dependent CPV in $B^0 \rightarrow K^{*0}\gamma$

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

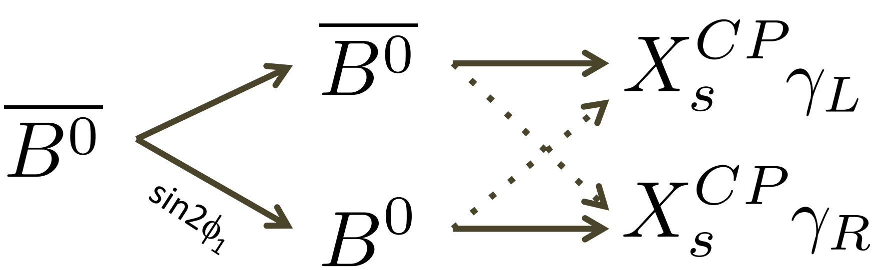
$$|S_{CP}| \approx \frac{2m_s}{m_b}\sin 2\phi_1 \sim \text{a few \%}$$

In the B2TiP program, prediction of S is converged to be small (not as large as 0.1). How about $B^0 \rightarrow K_S\pi^0\gamma$ case (not from K*)?

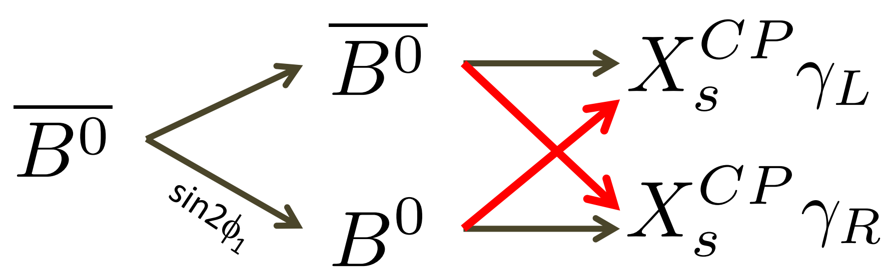
- If right-handed new physics contributes to the decay, larger CPV is possible

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

- LHCb can also measure photon polarization in $B_s \rightarrow \phi\gamma$ from $A^{\Delta\Gamma}$
  - Recently paper was published but it seems vertexing with $\phi \rightarrow KK$ is hard due to collinear kaons and the sensitivity is not good.



dotted : helicity flip



red : helicity flip + NP

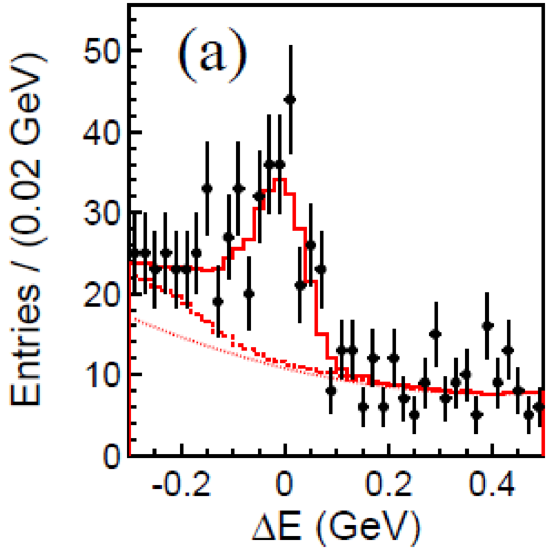
Measurement of S($B^0 \rightarrow K^{*0}\gamma$)

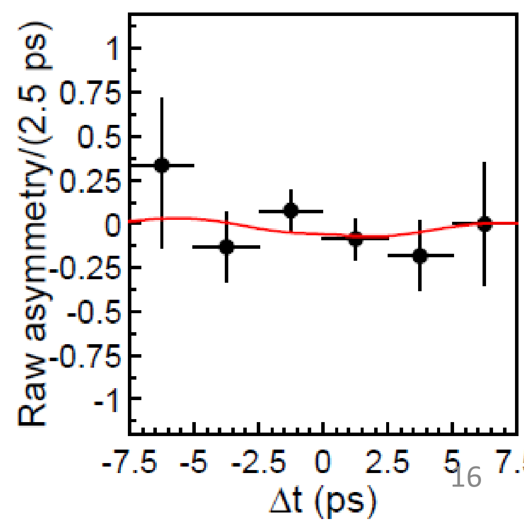
- Both Belle and Babar performed the analysis with 535M and 467M BB pairs.

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

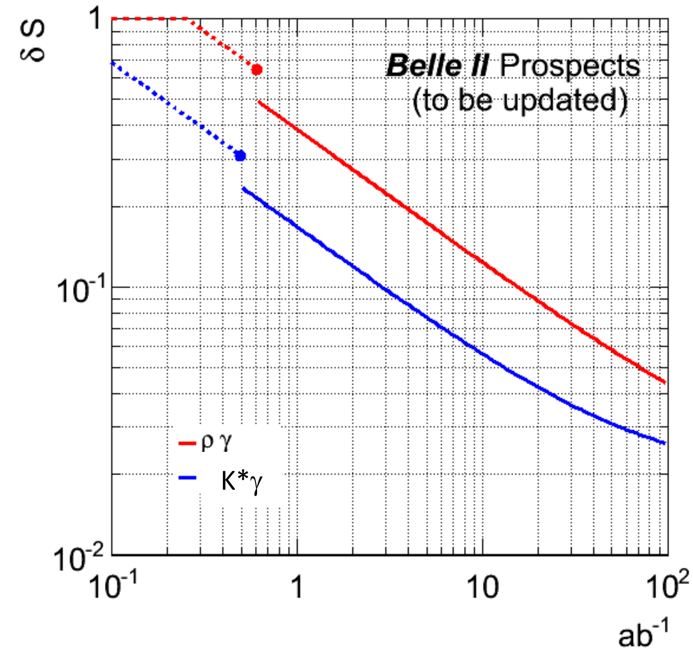
$$S_{K^{*}\gamma} = -0.03 \pm 0.29\ (\text{stat}) \pm 0.03\ (\text{syst}) \quad \text{(Babar)}$$

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



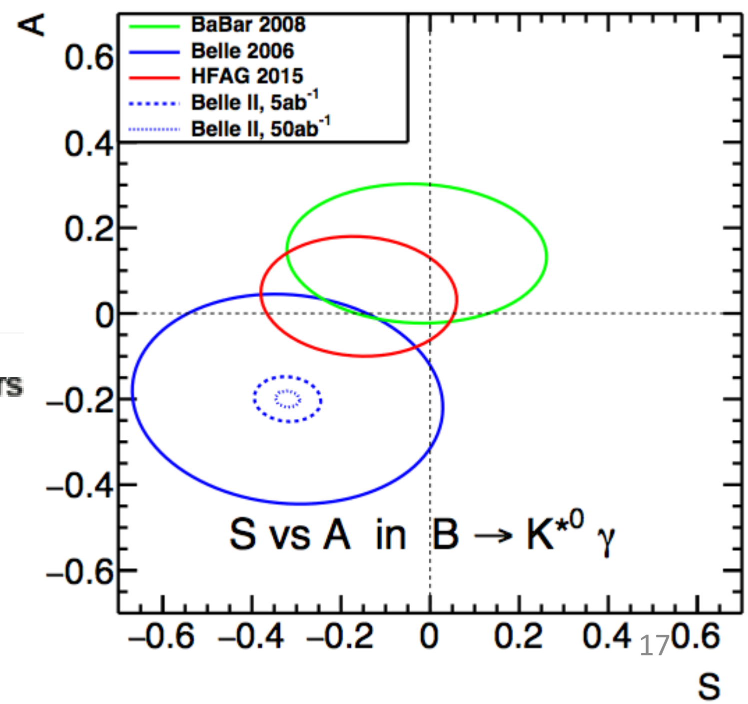


$S(B^0 \rightarrow K^{*0}\gamma)$ at Belle II

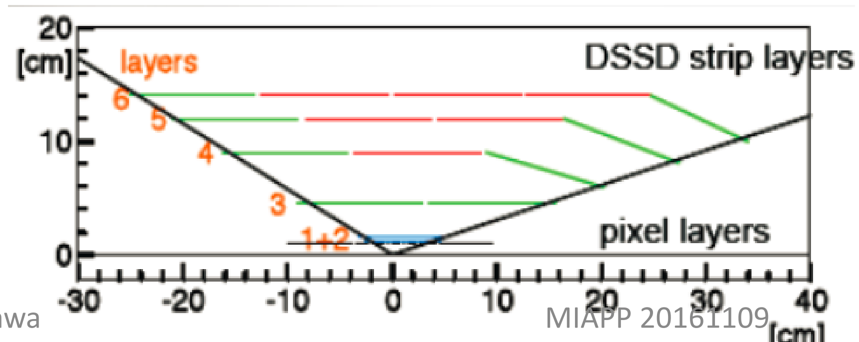


- Belle II vertex detector becomes larger
  - R of second outmost layer is 11.5cm (was 6cm)
  - 30% more Ks with vertex hits available.
- Effective tagging efficiency is 13% better
  - This is old estimation. Current one is much better!
- We can reach 0.03 uncertainty on S.
  - Still statistically dominated

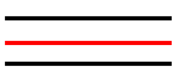
Mode	5 ab^{-1}	50 ab^{-1}
$K^*\gamma$	0.09	0.030
$\rho^0\gamma$	0.19	0.064



Belle II



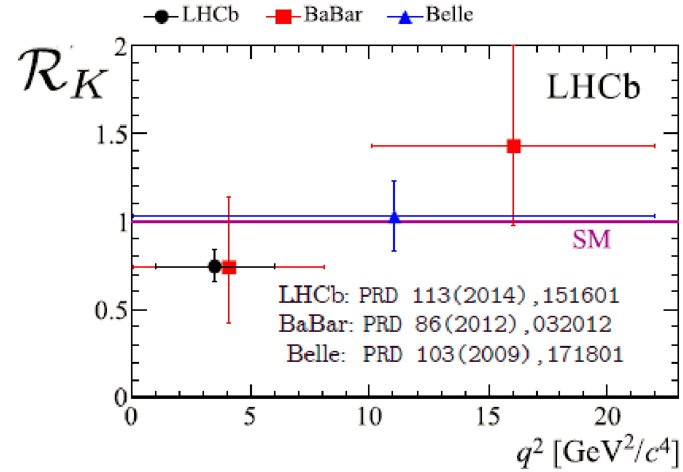
Belle 1

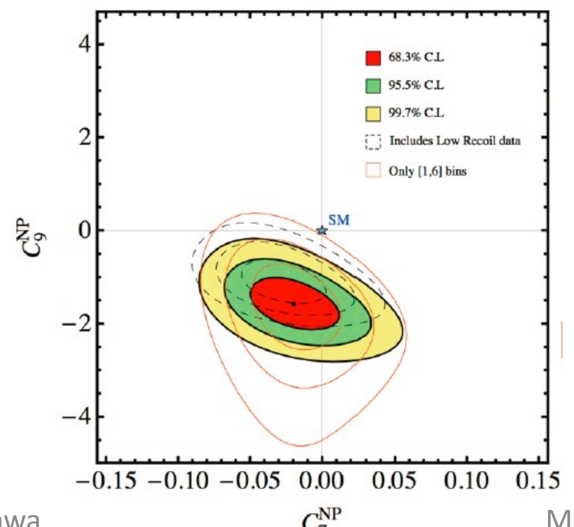


EW Penguin Decays

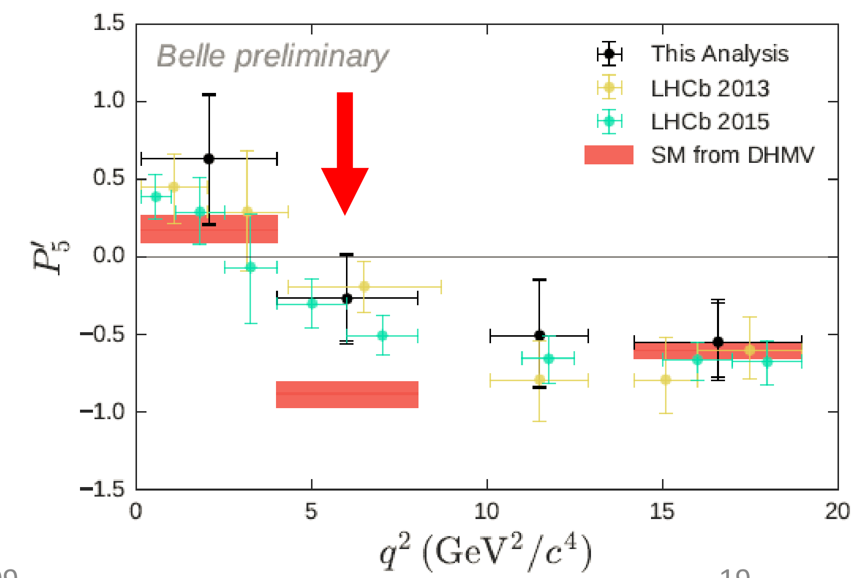
b→sl+l-

- b→sl+l- decay is sensitive to Wilson coefficients C_7, C_9 and C_{10}
- LHCb reported two anomalies in this process
  - LFU violation in $B^+ \to K^+ l^+ l^-$: 2.6σ
  - P5’ in $B^0 \to K^{*0} l^+ l^-$: ~4σ (adding Belle result)
    - Charm loop????
- Global fit to b→s processes shows deviation of C_9
  - $C_9^{NP} \sim -1$ is the best fit result.





S.Descotes-Genon et al, PRD 88 074002 (2013)



(b)Result for P_5'

What Belle can do for b→sl+l-?

- LHCb dominates measurements with exclusive dimuon final states
- Belle can do better for
  - Inclusive analysis
    - Reconstruction of neutrals Ks and π^0 needed for sum-of-exclusive analysis.
    - Fully inclusive dilepton analysis????
  - LFU test
    - Electron modes
      - Radiative photon correctly included at LHCb?
    - (Search for tau modes)
      - BF ~< O(10^{-5}) at 95%CL at Belle II

Measurement of BF(B→Xsl+l-)

- Clean prediction is available
  - NNLO in QCD, NLO in QED
  - Experimental cut on M_{Xs}<2.0GeV introduce only 5% additional theory error due to subleading shape function (T. Hurth@Barcelona2016)
- Babar with full data while Belle with 140/fb (1/5 of full data)
  - With sum-of-exclusive method
    - M_{Xs} < 2.0GeV
  - Still statistically dominated.
  - Belle analysis for final result is on-going
- Belle and Babar results on BF at high q^2 region is slightly larger.

$\mathcal{B}(\bar{B} \to X_s \ell^+ \ell^-)^{\rm exp}_{\rm low}$ [1,6]GeV^2

$$(1.493 \pm 0.504^{+0.411}_{-0.321}) \times 10^{-6} \quad (\text{Belle}, \ell\ell)$$
$$(1.93^{+0.47+0.21}_{-0.45-0.16} \pm 0.18) \times 10^{-6} \quad (\text{BaBar}, ee)$$
$$(0.66^{+0.82+0.30}_{-0.76-0.24} \pm 0.18) \times 10^{-6} \quad (\text{BaBar}, \mu\mu)$$
$$(1.6^{+0.41+0.17}_{-0.39-0.13} \pm 0.18) \times 10^{-6} \quad (\text{BaBar}, \ell\ell)$$

$(1.67 \pm 0.10) \cdot 10^{-6}$ ee
$(1.62 \pm 0.09) \cdot 10^{-6}$ μμ (HHL prediction)

$\mathcal{B}(\bar{B} \to X_s \ell^+ \ell^-)^{\rm exp}_{\rm high}$ [14.4,]GeV^2

$$(0.418 \pm 0.117^{+0.061}_{-0.068}) \times 10^{-6} \quad (\text{Belle}, \ell\ell)$$
$$(0.56^{+0.19+0.03}_{-0.18-0.03} \pm 0.00) \times 10^{-6} \quad (\text{BaBar}, ee)$$
$$(0.60^{+0.31+0.05}_{-0.29-0.04} \pm 0.00) \times 10^{-6} \quad (\text{BaBar}, \mu\mu)$$
$$(0.57^{+0.16+0.03}_{-0.15-0.02} \pm 0.00) \times 10^{-6} \quad (\text{BaBar}, \ell\ell)\,.$$

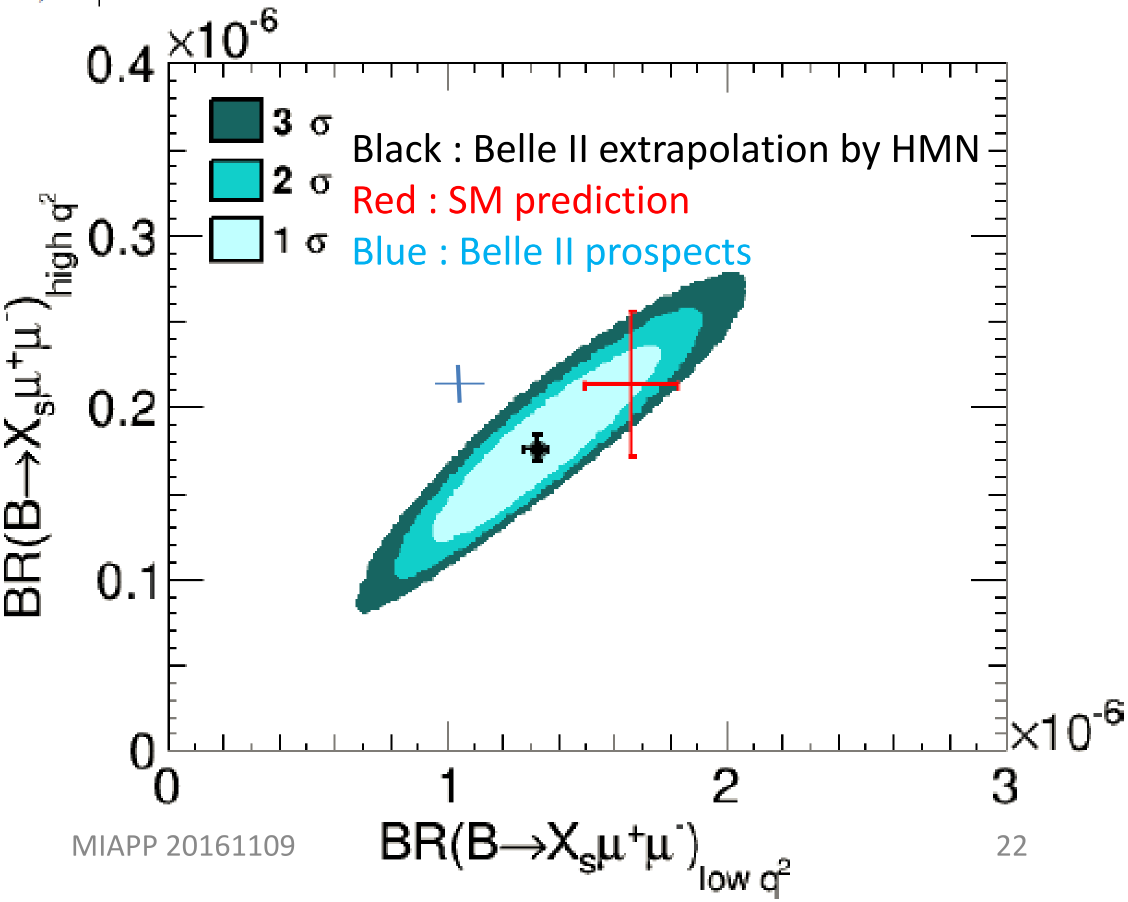
$(2.20 \pm 0.70) \cdot 10^{-7}$ ee
$(2.53 \pm 0.70) \cdot 10^{-7}$ μμ (HHL prediction)

T. Huber, T. Hurth and E. Lunghi JHEP 1506 (2015) 176

Prospects for BF(B→Xsl+l-)

Observables	Belle 0.7 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B \to X_s \ell^+ \ell^-)$ $(1 < q^2 < 6\ \mathrm{GeV}^2)$	20%	10%	6.2%
$B(B \to X_s \ell^+ \ell^-)$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	17%	8.0%	4.3%

- Systematic error dominated with 50/ab for both low and high q^2
  - Stat error <2%
- Experimental uncertainty is slightly worse than extrapolation by HML while better than theoretical uncertainty.
  - → we can extend M_{Xs}

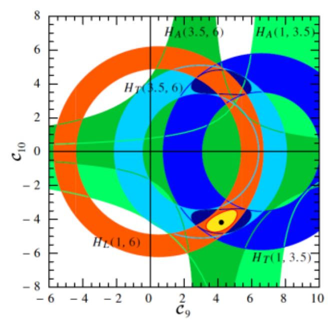


Measurement of Normalized $A_{FB}(B \rightarrow Xsl^+l^-)$

- A_{FB} (and other angular observables) in exclusive $B \rightarrow K^*l^+l^-$ decays were measured by many experiments while A_{FB} in inclusive decays was only done by Belle

- Different systematic uncertainties in inclusive decays from those in exclusive decays.
  - Important tool for independent check of C_9 deviation

- Helicity decomposition is also important but not measured yet
  - H_T, H_L, H_A
  - $A_{FB} = 3H_A / 4(H_T + H_L)$



K. S. M. Lee et al., PRD 75, 034016 (2007)

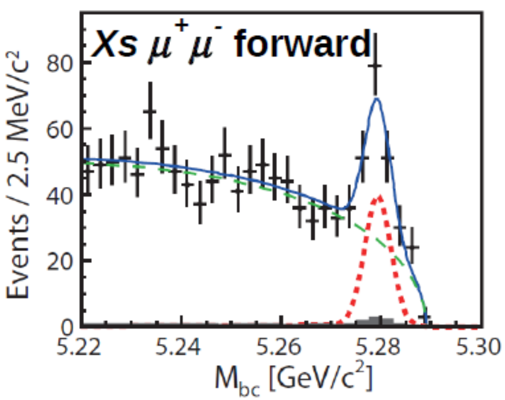
711fb^{-1}

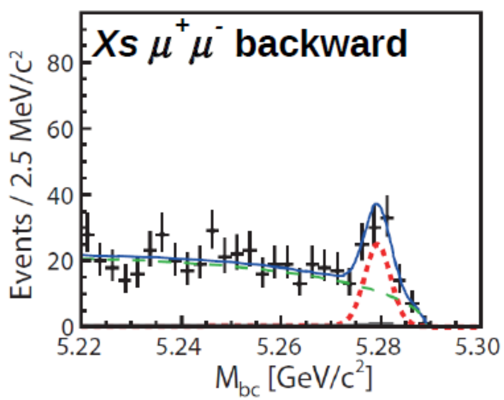
Measurement of $A_{FB}(B \rightarrow X_s l^+ l^-)$

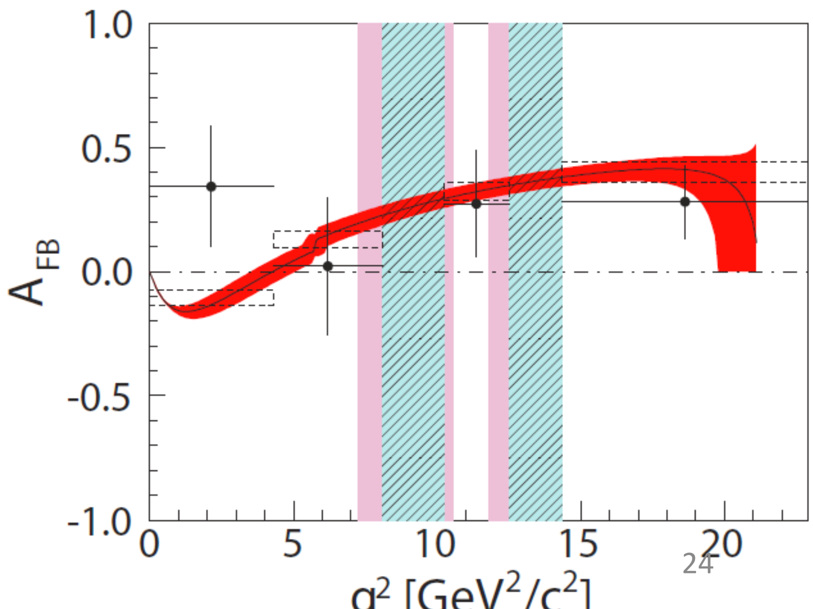
- With Sum-of-exclusive
  - Reconstruct 36 decay modes
  - MXs<2.0GeV
- 20 self-tag decay modes used to measure normalized A_{FB}

$$\mathcal{A}_{\rm FB}(q^2_{\rm min}, q^2_{\rm max}) = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} dq^2 \int_{-1}^{1} d\cos\theta \, {\rm sgn}(\cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta}}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} dq^2 \int_{-1}^{1} d\cos\theta \frac{d^2\Gamma}{dq^2 d\cos\theta}}$$

- The result is consistent with a SM prediction within large error.

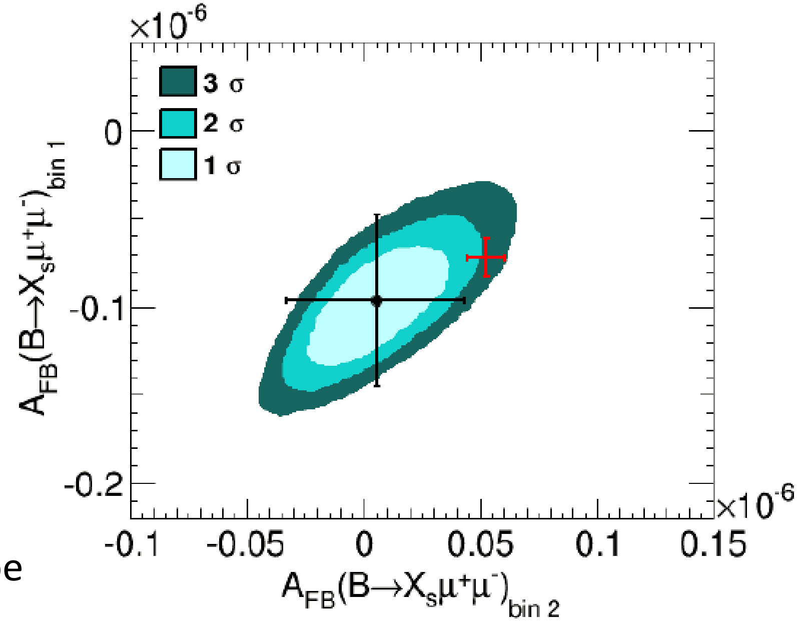






$A_{FB}(B \to X_s l^+ l^-)$ at Belle II

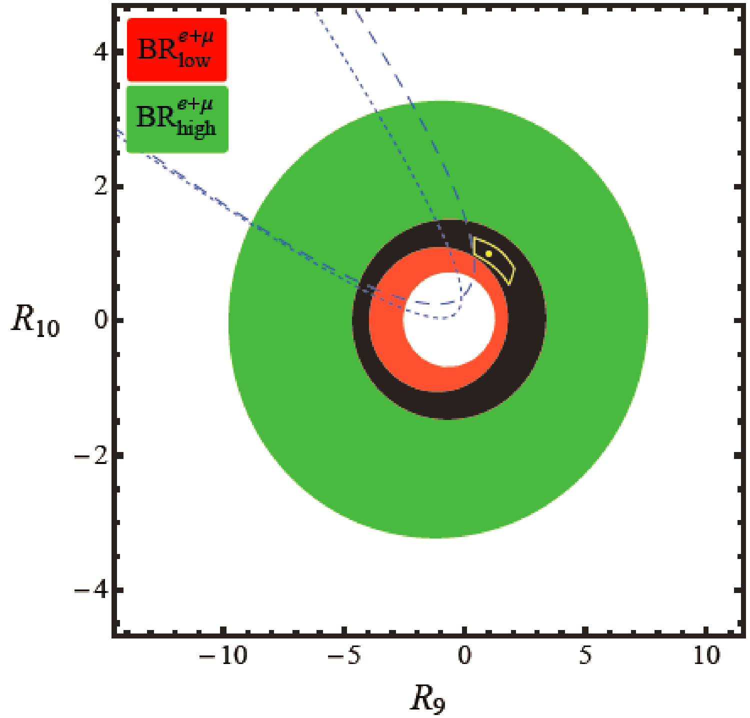
- Naïve estimation.
  - Systematic error (<1%) is smaller than statistical error with 50/ab
    - 3.1% for bin1 [1, 3.5]GeV^2
    - 2.9% for bin2 [3.5, 6]GeV^2
  - I would compare the results again with HMN but they gave unnormalized A_{FB}
    - Since a part of experimental systematic error cancels out, prediction of normalized A_{FB} would be also preferable.
  - The results at Belle II are still larger than theoretical uncertainties.



Hurth, Mahmoudi, Neshatpour JHEP 1412 (2014) 053

Wilson Coefficients from inclusive b→sll

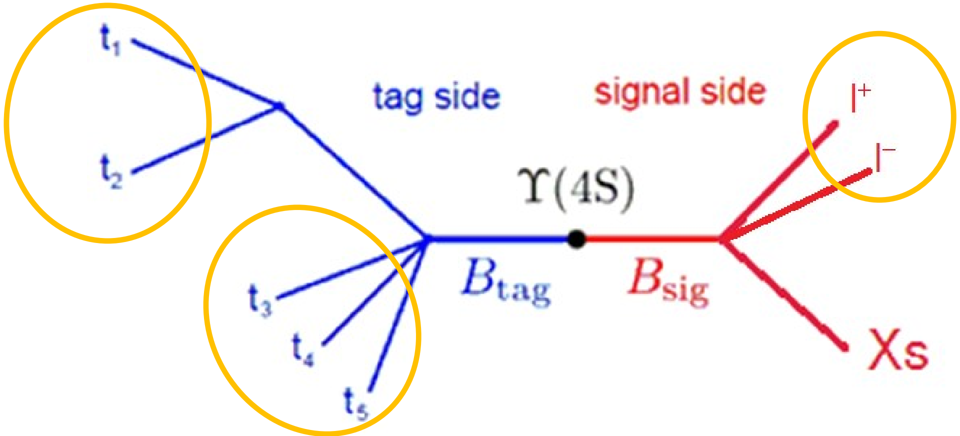
- This includes measurement of helicity decomposition
  - Belle II projections : Yellow
  - We should make the plot and compare with exclusive one



T. Huber, T. Hurth and E. Lunghi JHEP 1506 (2015) 176

Inclusive dilepton with Hadronic B tagging

- To avoid the uncertainty due to subleading shape function, theorists prefer not to apply M_{Xs} selection
- One possible way is that the other B meson is tagged with hadronic decays, and then looking at only dilepton
  - With this method, we expect a few 100 signal events with 50/ab.
  - While we need to suppress $b \rightarrow c l^- \nu$, $c \rightarrow s l^+ \nu$ background whose BF is about 1% (2500 times larger than signal)
    - Vertexing of dilepton might help
    - Lepton from $c \rightarrow s l^+ \nu$ is soft so high q^2 region might have better S/N (while low q2 region is much more interesting.)
- Anyway we need the simulation study.



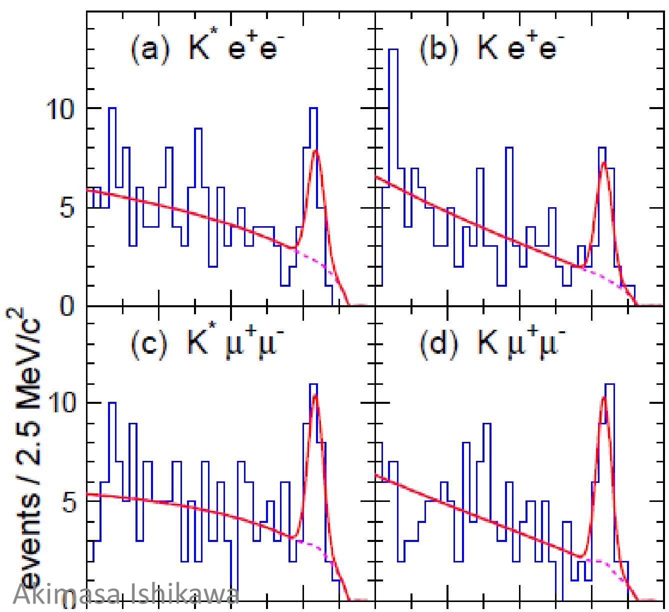
R_K, R_{K*} and R_{Xs}

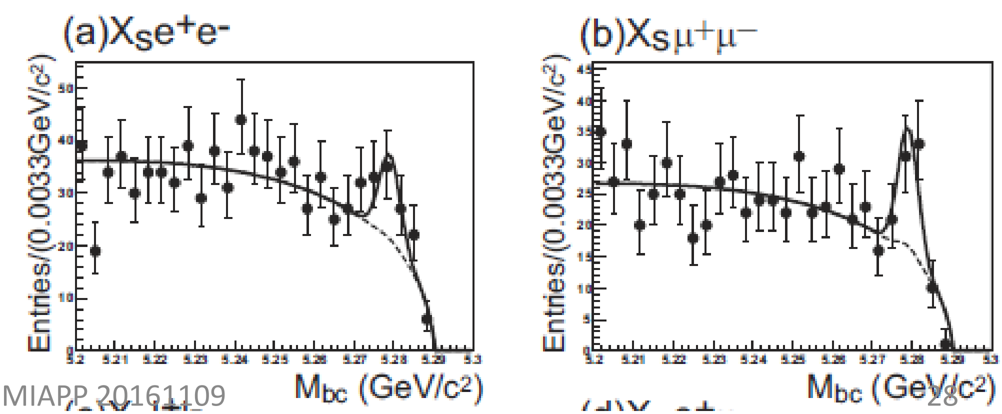
- R_K is very clean observable in the SM

$$R_K = \frac{\mathcal{B}(\bar{B} \to \bar{K}\mu\mu)}{\mathcal{B}(\bar{B} \to \bar{K}ee)} = 1.0003 \pm 0.0001$$

C. Bobeth, G. Hiller and G. Piranishvili, JHEP 0712, 040 (2007)

- At Belle, efficiencies for muon and electron modes are almost same, and both can be extracted Mbc distributions which are very similar.
- By taking the ratio, almost all errors cancel out
  - Except lepton ID systematics





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

- $R_{K(*)}$ Reported with 605fb^{-1} for full q^2 range PRL 103, 171801 (2009)

$$R_{K^*} = 0.83 \pm 0.17 \pm 0.08, \qquad R_{K^*}^{SM} = 0.75$$

$$R_K = 1.03 \pm 0.19 \pm 0.06. \qquad R_K^{SM} = 1$$

- No measurement on R_{Xs} yet but can be obtained from BF analysis with 140fb^{-1} PRD 72, 092005 (2005)
  - $R_{Xs} = 1.0 \pm 0.4$

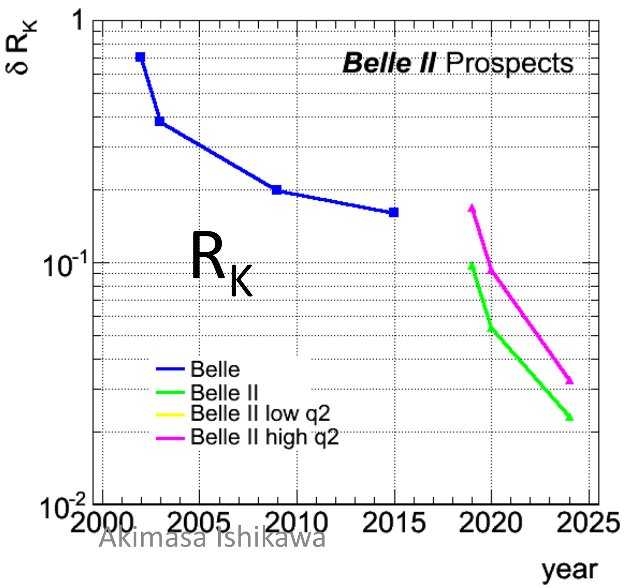
Mode	N_{sig}	Significance	ϵ (%)	$\mathcal{B}$ ($\times 10^{-6}$)
$X_s e^+ e^-$	$31.8 \pm 10.2 \pm 3.1$	3.2	$2.59 \pm 0.20^{+0.45}_{-0.42}$	$4.04 \pm 1.30^{+0.87}_{-0.83}$
$X_s \mu^+ \mu^-$	$36.3 \pm 9.3 \pm 2.1$	4.4	$2.89 \pm 0.24^{+0.52}_{-0.49}$	$4.13 \pm 1.05^{+0.85}_{-0.81}$
$X_s \ell^+ \ell^-$	$68.4 \pm 13.8 \pm 5.0$	5.4	$2.74 \pm 0.22^{+0.48}_{-0.45}$	$4.11 \pm 0.83^{+0.85}_{-0.81}$

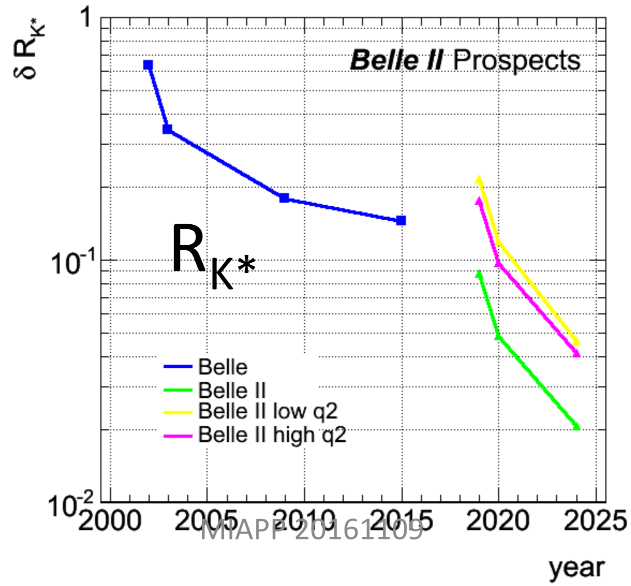
- We can measure both low (1-6GeV^2) and high q^2 (>14.4GeV^2)region
- Ultimately, almost all systematics cancel except lepton ID systematics

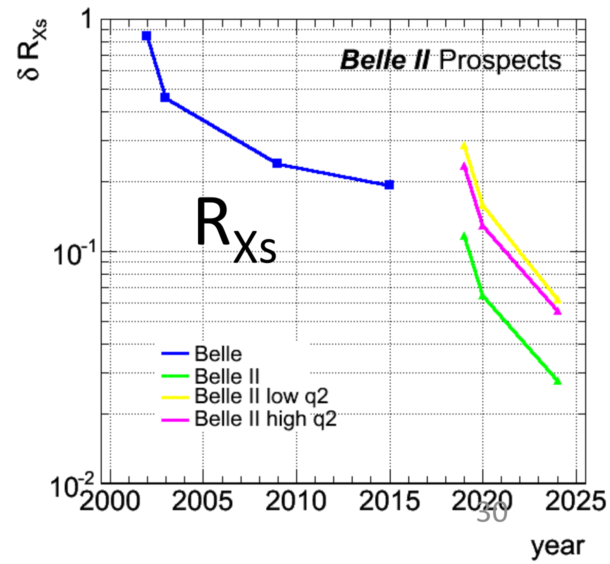
Prospects for R_K ,R_{K*} and R_{Xs}

- Even with $50ab^{-1}$, still statistically dominated.
  - Lepton ID systematics is about ±0.4% at Belle II.

Observables	Belle 0.7 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
R_{X_s} $(1 < q^2 < 6\ \mathrm{GeV}^2)$	32%	12%	4.0%
R_{X_s} $(q^2 > 14.4\ \mathrm{GeV}^2)$	28%	11%	3.4%
R_K $(1 < q^2 < 6\ \mathrm{GeV}^2)$	28%	11%	3.6%
R_K $(q^2 > 14.4\ \mathrm{GeV}^2)$	30%	12%	3.6%
R_{K^*} $(1 < q^2 < 6\ \mathrm{GeV}^2)$	38%	15%	4.6%
R_{K^*} $(q^2 > 14.4\ \mathrm{GeV}^2)$	24%	9.2%	3.4%

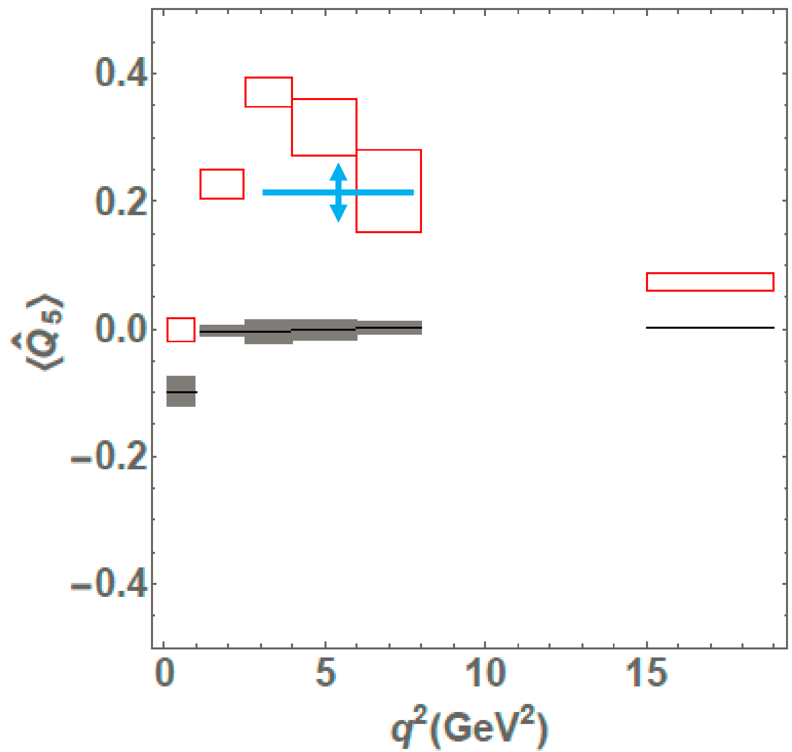






Q_5

- If P_5' is deviated from the SM, next will be LFU Violation of P_5', defined as $Q_5 = P_5'^{\mu} - P_5'^{e}$
- No experiments measure this observable yet
- Now we are estimating the uncertainty at Belle II.
  - Hope this will be included to B2TiP
- My naïve estimation is
  - 0.04 for [4,8]GeV^2
  - We can observe the NP with $C_{9\mu}^{NP} = -1.11$



SM : gray
NP : red

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

B. Capdevila et al, JHEP 10 (2016) 075

Summary

- With the better detector Belle II and higher luminosity machine SuperKEKB, we can deeply search for NP with Radiative and EW Penguin decays

- But there are many observables which are still statistically dominated.

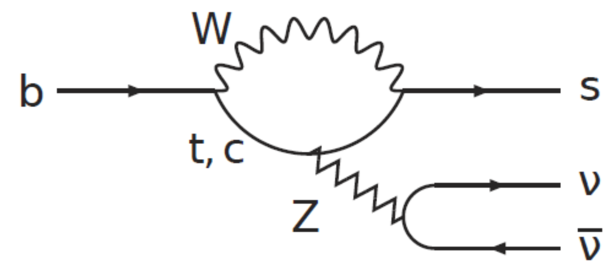
- LHCb upgrade is planned in HL-LHC era (not approved yet).
  - 22/fb → 50/fb
- Hope Belle II/SuperKEKB also upgrade
  - Crab waist scheme planed at Italian SuperB, which is not adopted by SuperKEKB, can increase the luminosity about 3 time???
  - 50/ab → 150/ab???

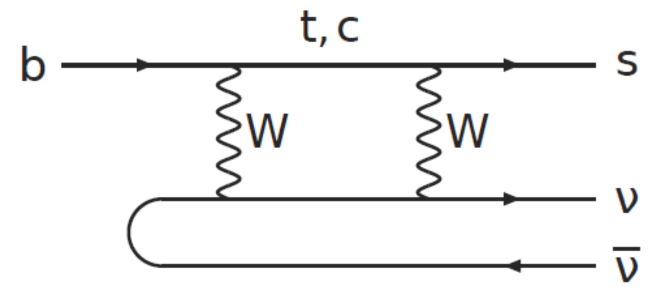
backup

Search for B→hνν

- If C_9 is deviated from the SM value, vector current in b→sνν could be also affected in some BSM models?

- Proceeds via penguin or box diagrams
- Theoretically very clean.
  - No charm loop as in b→sl⁺l⁻
- Experimentally, need to tag the other B meson due to final states having multiple neutrinos.
- Hadronic B decays are used for tag side.





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

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

Current Situation

- Babar : upper limit on B→$K^+\nu\nu$: 3 times larger
- Belle : upper limit on B→$K^*\nu\nu$: 5 times larger
- At Belle II, we can observe the decays
  - Now we are estimating the sensitivities.