EW Penguin Decays at Belle

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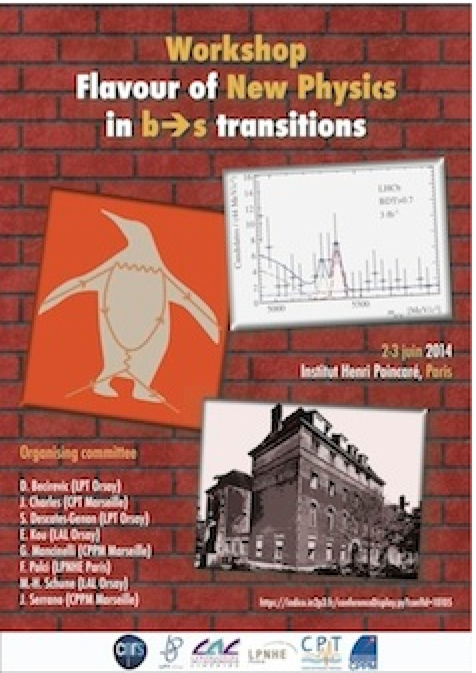


What is required for Belle (II) after LHCb (Personal View)

- LHCb is very powerful for all charged final states ($B \rightarrow K^+\pi^-\mu\mu$), and those with a hard photon ($B \rightarrow K^*\gamma$, $K\pi\pi\gamma$)
- LHCb will continue the analyses with larger stastistics

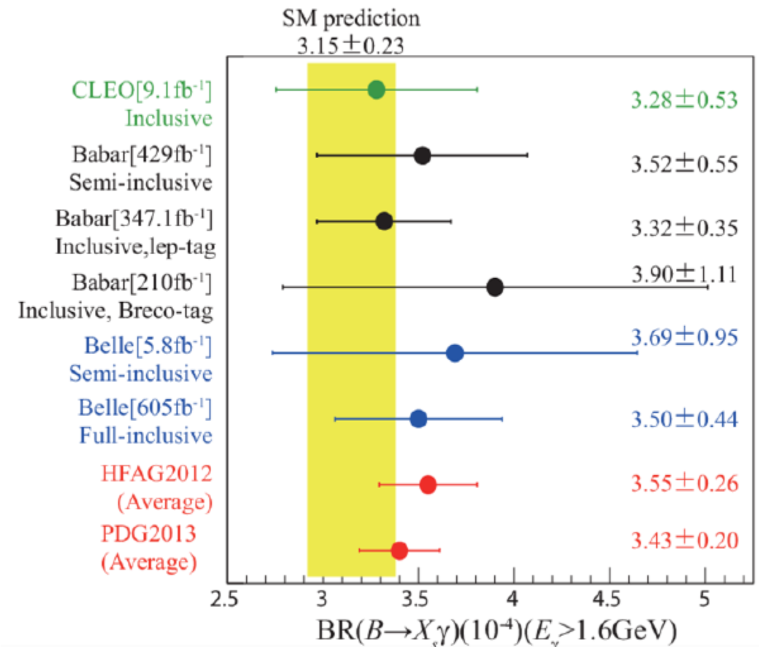
- What Belle (II) can do more than LHCb are
  - Modes with π^0 and Ks
    - Isospin Violation etc.
  - Inclusive Measurements
    - $B \rightarrow X_{s,d}\gamma$, $B \rightarrow X_s l^+ l^-$
  - Lepton Flavor Universality
    - $e/\mu/\tau/\nu$
  - Phonic mode
    - $B_{d,s} \rightarrow \gamma\gamma$

Contents

Recent Results

BF(B→Xsγ)

- A SM prediction very precise
  - $(3.15 \pm 0.23) \times 10^{-4}$ Misiak et al.
- Precision of current WA comparable to the prediction
  - $(3.55 \pm 0.26) \times 10^{-4}$ HFAG2012
  - $(3.40 \pm 0.21) \times 10^{-4}$ PDG2013
- All the measurements are larger?
  - NP in C_7?
  - But within the error



BF(B→Xsγ) with Semi-Inclusive Technique

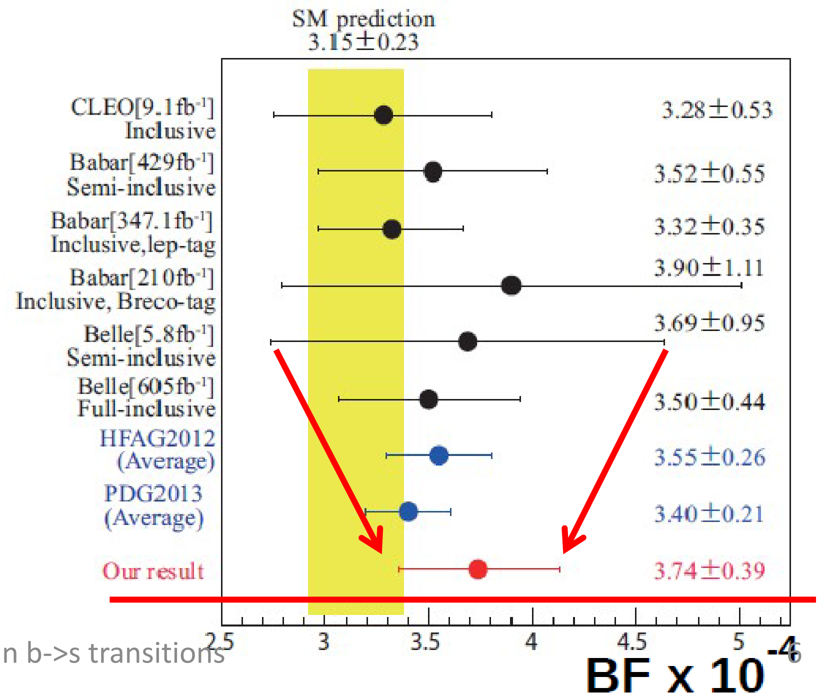
- 38 X_S decay modes are reconstructed and combined with γ.
  - Extract signal yield in each M_{Xs} bin and give the BF

$$B(B\to X_s\gamma) = (3.51\pm0.17\pm0.33)\times10^{-4}\ (M_{Xs}<2.8\ \mathrm{GeV}/c^2)$$

- Extrapolated to E_γ > 1.6GeV

$$B(B\to X_s\gamma)=(3.74\pm0.18\pm0.35)\times10^{-4}\ (E_\gamma>1.6\ \mathrm{GeV})$$

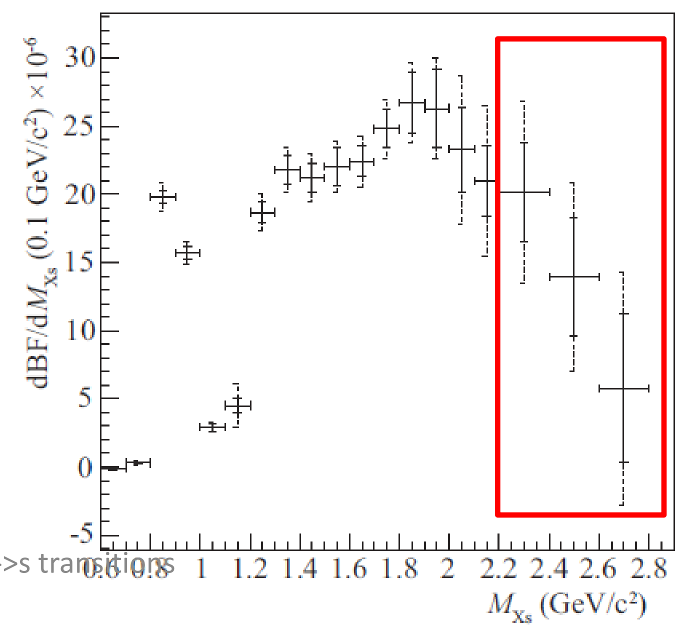
- Measurement with the 2nd smallest error : 0.39
  - The best is fully inclusive analysis by Babar : 0.35
- If we take fractional error, the best measurement.
  - δBF/BF = 10.4%



Breakdown of the Systematic Error

- Largest source is fragmentation model
  - in high M_{Xs} region
  - Determined from data
  - can be reduced by additional data set
- The second is Mbc PDF
  - in high M_{Xs} region
  - Dominated by uncertainty in BBbar background.
  - Which is determined by data driven method so additional data set helps to reduce the error but not so much, I guess

Systematic Uncertainties(%)	
B counting	1.4
Detector Response	3.0
Background Rejection	3.4
M_{bc} PDF	5.1
Fragmentation model	6.7
Missing mode	1.6
Total	**9.3**



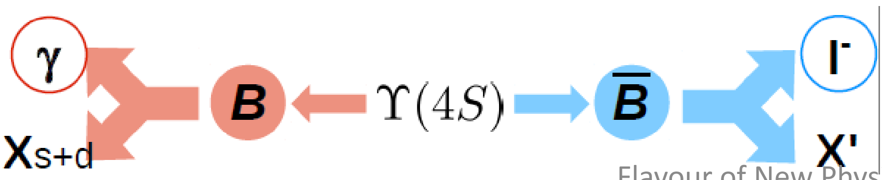
CP Asymmetry in B→$X_{s,d}\gamma$

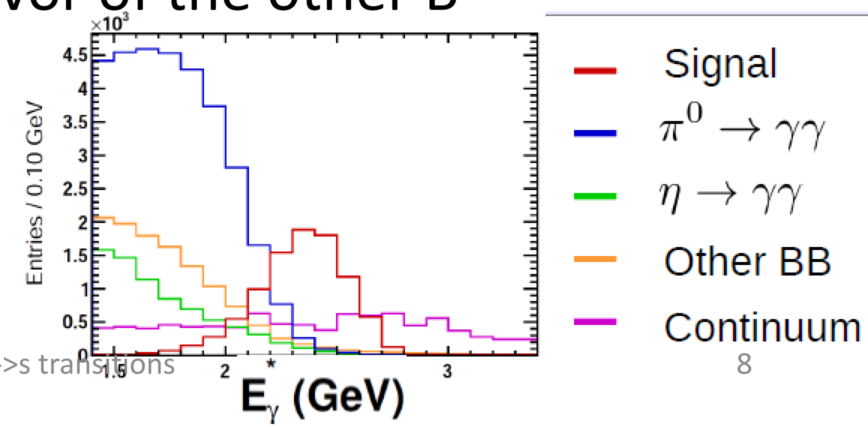
- Theoretical prediction is very precise thanks to unitarity.
  - If deviated from 0, clear new physics signal

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

PRL 106, 141801 (2011)

- Inclusively reconstruct photon with 1.7 < E_γ < 2.8GeV
  - Veto for asymmetric decays of $\pi^0(\eta)\rightarrow\gamma\gamma$
- High momentum lepton to tag flavor of the other B
  - Correction of mixing applied

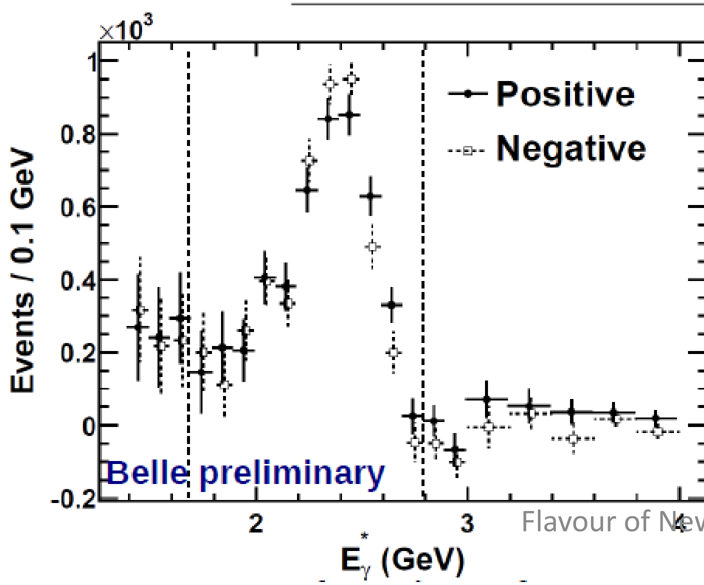


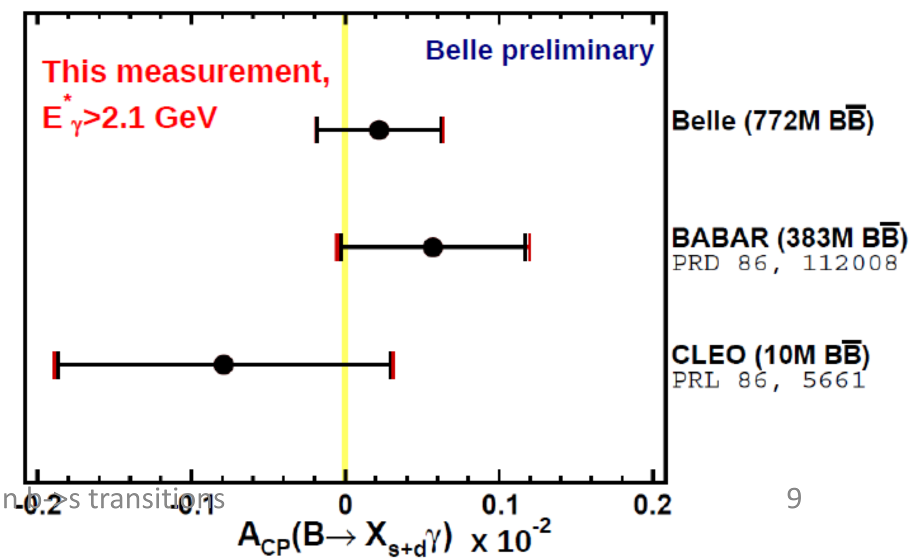


Result for $A_{CP}(B \to X_{s,d}\gamma)$

- The world best measurement
- Consistent with null
- Still statistical error dominates → Belle II

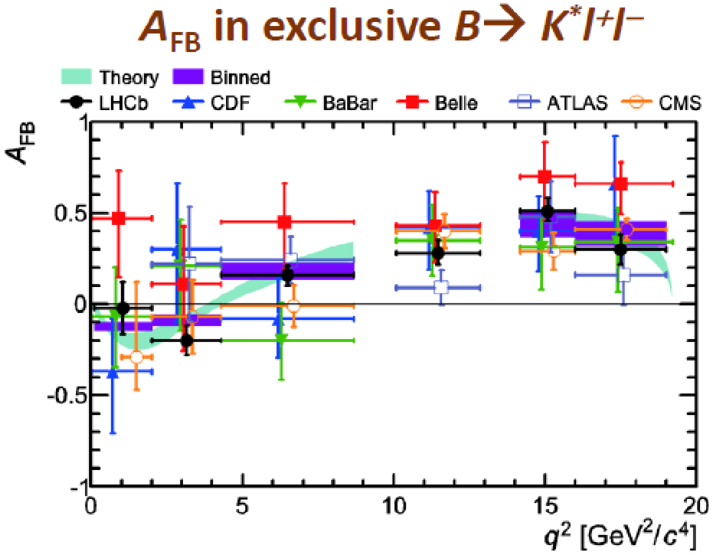
E^*_γ(thresh.)	$A^{\rm meas}_{\rm CP}(\times 10^2)$	$A_{\rm det}(\times 10^2)$	$A_{\rm bkg}(\times 10^2)$	$A^{\rm corrected}_{\rm CP}(\times 10^2)$
1.7 GeV	1.3 ± 3.2	0.1 ± 0.2	-0.4 ± 2.5	$1.3 \pm 4.4 \pm 3.5$
1.8 GeV	2.0 ± 3.1	0.1 ± 0.2	-0.3 ± 1.9	$2.4 \pm 4.3 \pm 2.6$
1.9 GeV	0.9 ± 2.9	0.1 ± 0.2	-0.2 ± 1.3	$1.0 \pm 4.1 \pm 1.9$
2.0 GeV	1.6 ± 2.8	0.1 ± 0.2	-0.2 ± 0.9	$2.1 \pm 4.0 \pm 1.2$
2.1 GeV	1.6 ± 2.9	0.1 ± 0.2	-0.1 ± 0.5	$2.2 \pm 4.0 \pm 0.8$
2.2 GeV	1.1 ± 2.9	0.1 ± 0.2	-0.1 ± 0.3	$1.5 \pm 4.0 \pm 0.5$





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

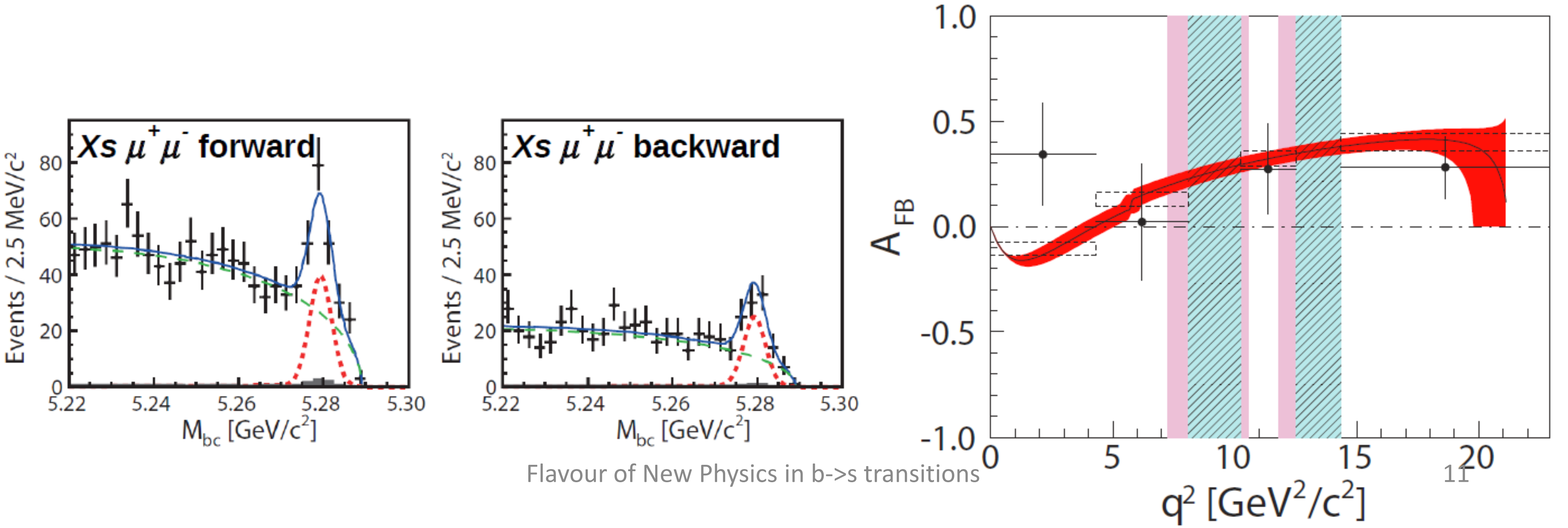
- A_{FB} in exclusive decays is measured by many experiments but A_{FB} in inclusive decays is not.
- No FF uncertainty in inclusive decays
- Precise prediction possible but experimentally hard to measure



$$A_{FB} \propto -\mathrm{Re}\left[\left(2C_7^{eff} + \frac{q^2}{m_b^2} C_9^{eff}\right) C_{10}\right]$$

$A_{FB}(B \rightarrow X_s l^+ l^-)$ with Semi-Inclusive Technique

- Reconstruct 36 decay modes
- 20 self-tag decay modes used to measure A_{FB}
- The result is consistent with a SM precition within error.
- Still statistically dominated → Belle II



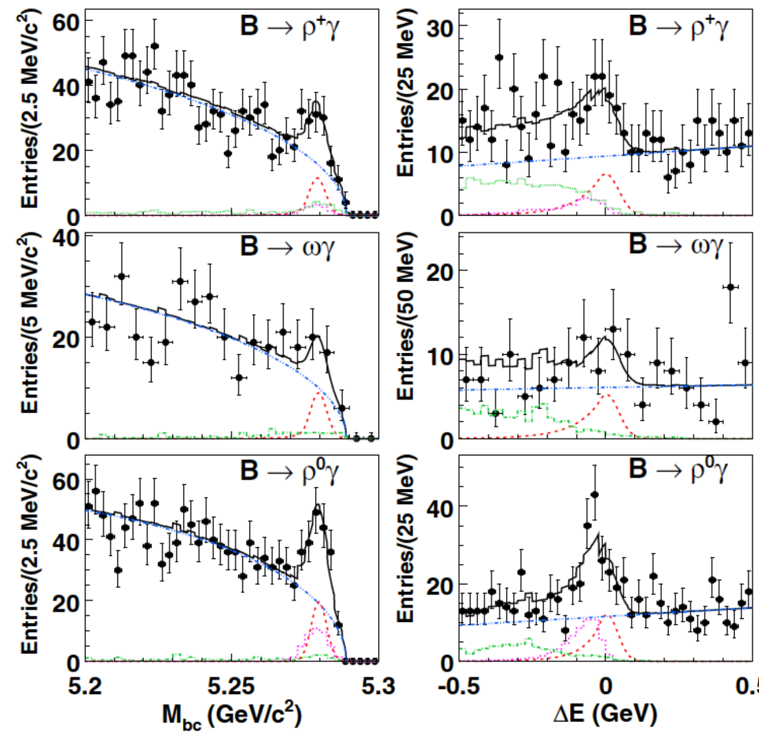
$b \to d$

$B \to (\rho,\omega)\gamma$: $|V_{td}/V_{ts}|$, A_{CP} and Δ_ρ

- $|Vtd/Vts|$ can be measured from the ratio of BF of $B\to(\rho,\omega)\gamma$ and $B\to K^*\gamma$
  - Consistent with the SM
- Direct CPV in $B\to\rho^+\gamma$ consistent with null
- Δ_ρ Isospin Violation large?

$$\Delta_\rho = \frac{\Gamma(B^- \to \rho^-\gamma)}{2\Gamma(\overline{B}^0 \to \rho^0\gamma)} - 1$$

  - 2~3σ deviation
  - $+4^{+14}_{-7}$ % Ali, Lunghi
  - -10 ± 6 % Lyon, Zwicky
  - -5.4 ± 3.9 % if $\phi_3 = 60$deg Ball, Jones, Zwicky
  - -4.6 ± 7 % Beneke, Feldmann, Seidel



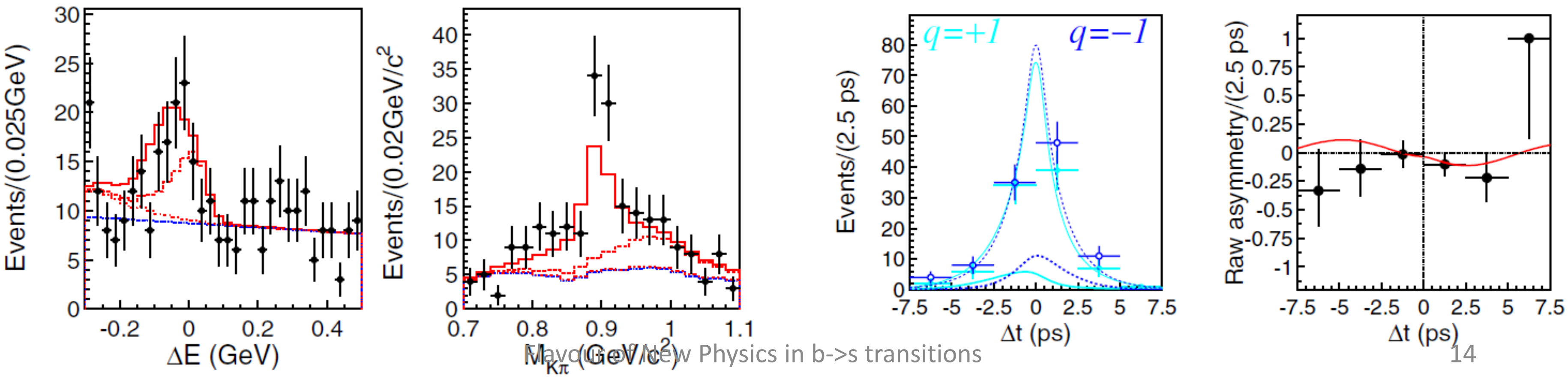
	$|Vtd/Vts|$	$A_{CP}(B^+\to\rho^+\gamma)$	Δ_ρ
Babar 423fb^{-1}	$0.233^{+0.025+0.022}_{-0.024-0.021}$	n.a.	$-0.43^{+0.25}_{-0.22}\pm0.10$
Belle 605fb^{-1}	$0.195^{+0.020}_{-0.019}\pm0.015$	$0.11\pm0.32\pm0.09$	$-0.48^{+0.21+0.08}_{-0.19-0.09}$
Average	n.a.	0.11 ± 0.33	$-0.46^{+0.17}_{-0.16}$

Time Dependent CPV in $B^0 \rightarrow \rho^0\gamma$

- Only Belle had measured time dependent CPV in $B^0 \rightarrow \rho^0\gamma$
- 48±14 signal events are used for fits.
  - Though signal yield is smaller than $B^0 \rightarrow K_S\pi^0\gamma$, fraction of events used for time dependent fit is larger thanks to easier vertex reconstruction with $\rho^0 \rightarrow \pi^+\pi^-$
- The results are consistent with null asymmetry

$$S_{CP} = -0.83 \pm 0.65 \pm 0.18$$

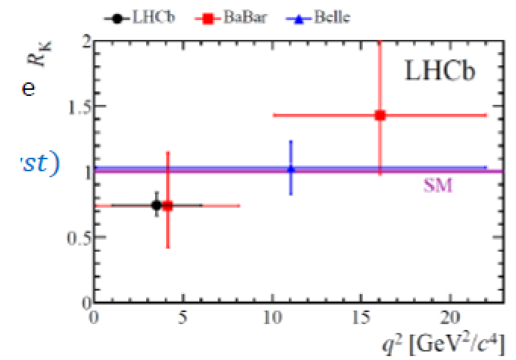
$$A_{CP} = -0.44 \pm 0.49 \pm 0.14$$



Plan/Personal Hope

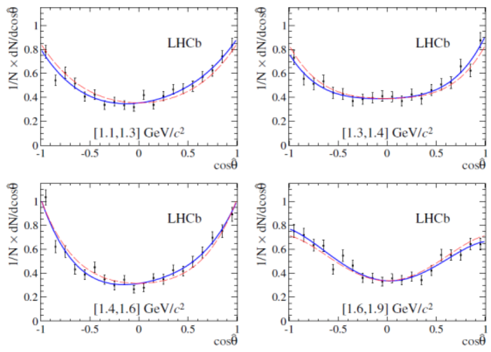
Not so far future?

A. Shires



- BF, A_{FB}, F_L, A_{CP}, A_I, $R_{K(*)}$ in $B \to K^{(*)} l^+ l^-$
  - Most of the observable are not competitive to LHCb but anyway
    - $R_K = 0.745^{+0.090}_{-0.074}(stat) \pm 0.036(syst)$

A.Puig



- A_{UD} and A_{CP} in $B \to K\pi\pi\gamma$
  - modes with π^0 give ~4.7times larger A_{UD} for $K_1(1400)$ than modes w/o

- Search for $B \to \gamma\gamma$, $Bs \to \gamma\gamma$
  - Not so easy at LHCb

- BF($B \to X_s l^+ l^-$) with semi-inclusive reconstruction Method
  - C_9^{NP} ?

Before Belle II?

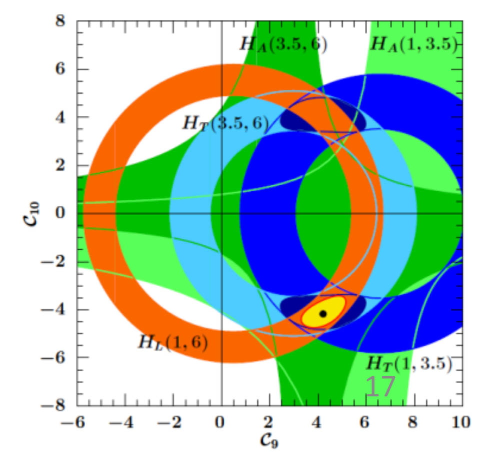
- Time dependent CPV param. S_{CP}, A_{CP}, and A_I (Δ_{0-}) in $B \to K^*\gamma$
  - $78\text{fb}^{-1} \to 711\text{fb}^{-1}$ for A_{CP} and A_I
- BF, $|Vtd/Vts|$, S_{CP}, A_{CP}, A_I (Δ_ρ), δ_{aI} in $B \to (\rho,\omega)\gamma$
  - A_I (Δ_ρ) 2~3 sigma deviation

$$\delta_{a_I} \equiv 1 - \frac{\bar{a}_I(\rho\gamma)}{\bar{a}_I(K^*\gamma)} R_{\rho K^*}$$

- BF($B \to X_{s,d}\gamma$) with fully inclusive reconstruction Method

$$R_{\rho K^*} \equiv \sqrt{\frac{\bar{\Gamma}(B \to \rho\gamma)}{\bar{\Gamma}(B \to K^*\gamma)}} \left|\frac{V_{ts}}{V_{td}}\right|$$

- BF($B \to X_{s,d}\gamma$) with hadronic tagging Method
  - Also A_{CP} and A_I ?
- A_{CP}, ΔA_{CP}, A_I ($B \to X_s\gamma$) with semi-inclusive Method
- Helicity decomposition of $B \to Xsl^+l^-$
  - C_9^{NP}?



Someone Try?

- Limit on C_8 from BF(b→c)

  $bsg : |C_8| \lesssim 5|C_8|_{\rm SM}$

  – Can reduce factor three on limit on BF??

$\Gamma(\overline{b} \to \overline{s}\,\text{gluon})/\Gamma_{\text{total}}$ Γ_{79}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<0.068	90		[1] COAN	98	CLE2	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.08		2	[2] ALBRECHT	95D	ARG	$e^+e^- \to \Upsilon(4S)$

[1] COAN 98 uses D-ℓ correlation.

$$\mathcal{B}(b \to c) + \mathcal{B}(b \to sg) \sim 1$$

$$\begin{aligned}
\mathcal{B}(b \to c) = \mathcal{B}(B \to D^0 or \overline{D}^0) \\
+ \mathcal{B}(B \to D^+ or D^-) \\
+ \mathcal{B}(B \to D_s^+ or D_s^-) \\
+ \mathcal{B}(B \to \Lambda_c^+ or \Lambda_c^-) \\
+ \mathcal{B}(B \to c\bar{c}) \\
- \mathcal{B}(B \to D_s D X or D D X)
\end{aligned}$$

Any Others?

- If your favorites are missing, or you have suggestions, please let me know.
  - akimasa@epx.phys.tohoku.ac.jp
- Roman suggested me to measure

$$\delta_{a_I} \equiv 1 - \frac{\bar{a}_I(\rho\gamma)}{\bar{a}_I(K^*\gamma)} R_{\rho K^*}$$

$$R_{\rho K^*} \equiv \sqrt{\frac{\bar{\Gamma}(B \to \rho\gamma)}{\bar{\Gamma}(B \to K^*\gamma)}} \left| \frac{V_{ts}}{V_{td}} \right|$$

  - This is in our list

Belle II Prospects

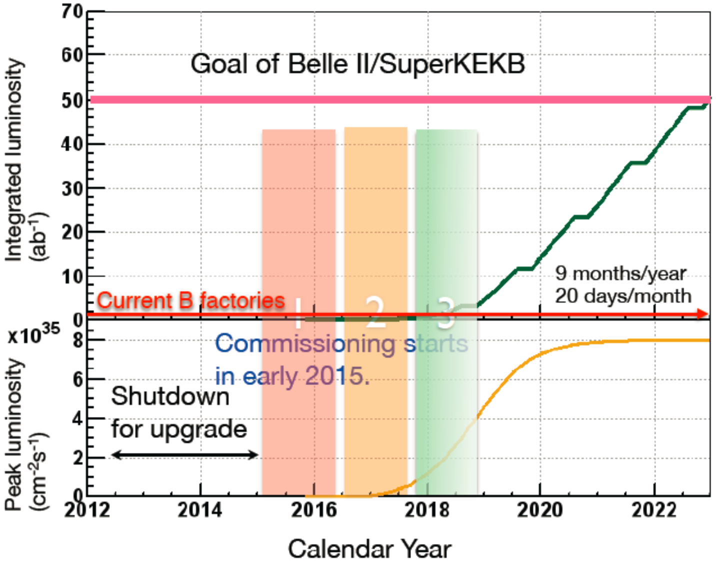
Now we are trying to update the Belle II sensitivities with full simulation.

The numbers to be shown are conservative for some case.

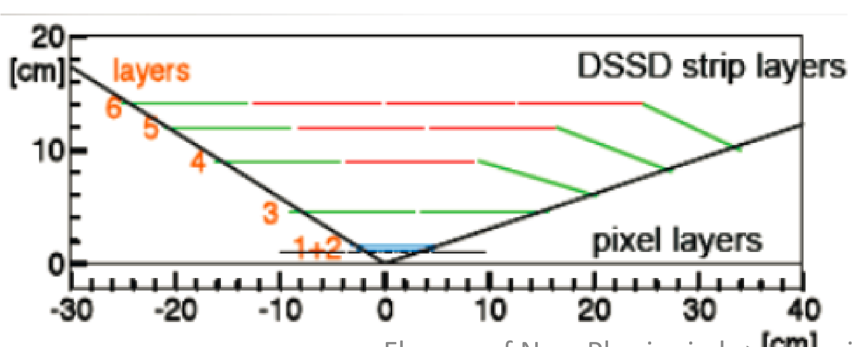
And some numbers are still missing…

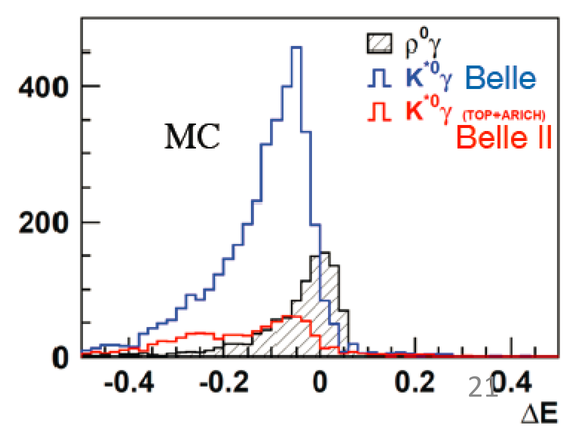
Some Important numbers for EWP

- Integrated Luminosity **50** times larger
  - Stat error reduced by 1/7
- Radius of 2nd Outer most VTX detector **2** times larger 6cm → 11.5cm
  - For Ks vertexing, 2 VTX hits needed.
  - **~30% more Ks$\pi^0\gamma$** for time dependent CPV
- Better PID device gives **~10** times smaller K*γ background to $\rho\gamma$



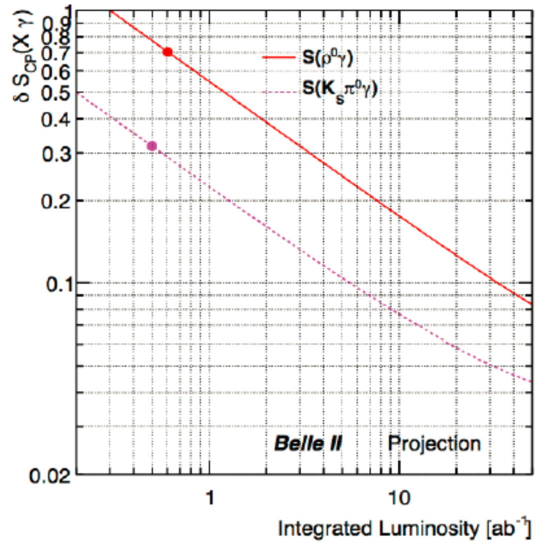
Belle 1



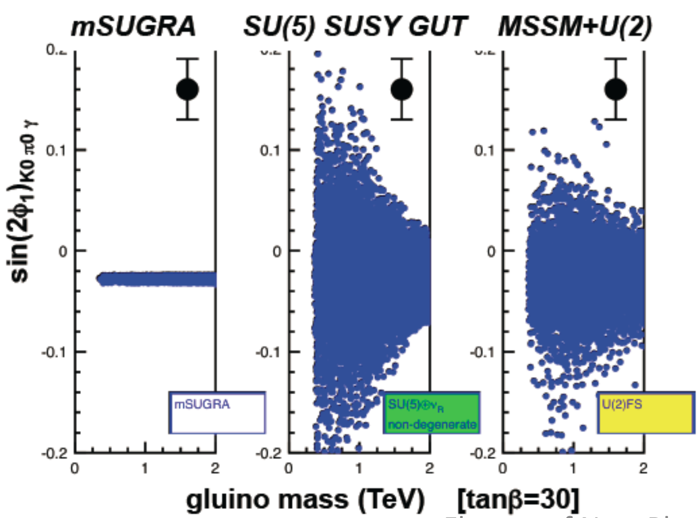


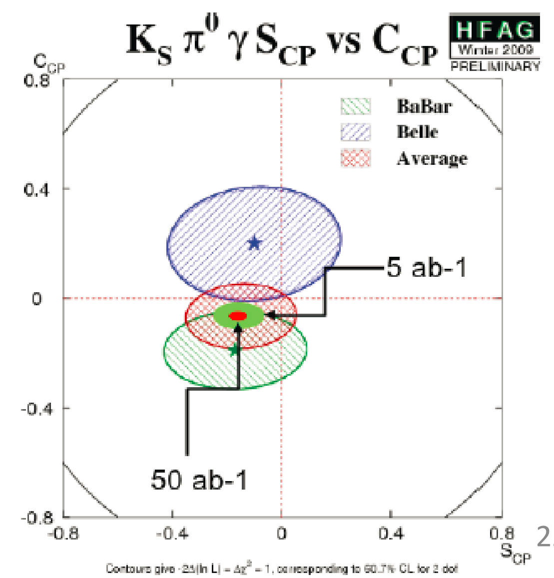
Time Dependent CPV in B→(K*,ρ)γ

- The left figures are just extrapolation of Belle numbers.
  - Very conservative scenario
  - No improvement assumed
  - B→ωγ also be measured



Buchalla et al., EPJC 57, 309 (2008); arXiv:0801.1833





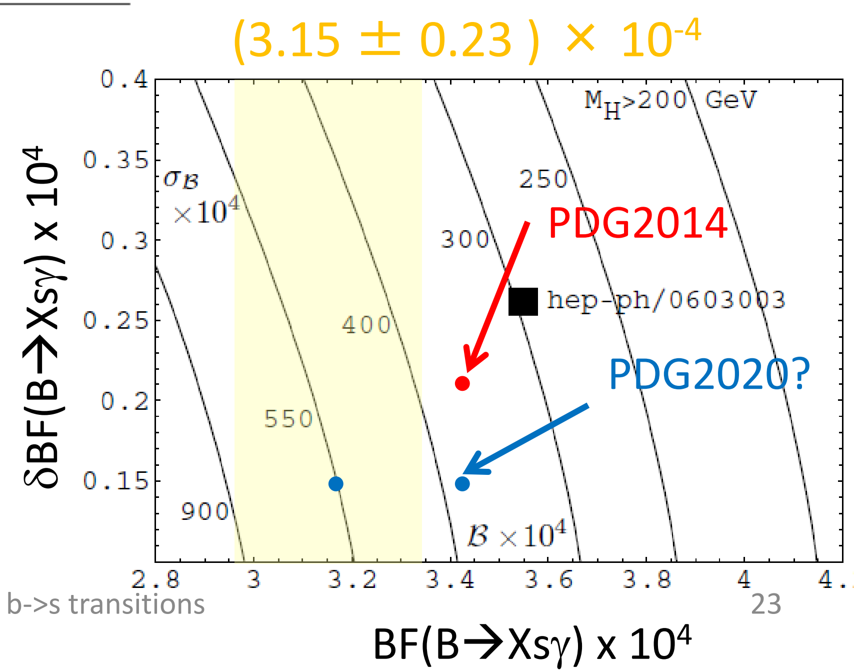
BF($B \rightarrow X_s\gamma$) and BF($B \rightarrow X_d\gamma$)

- Precision of single measurement of BF($B \rightarrow X_s\gamma$), 6%, is comparable to that of theoretical prediction ,7%.
  - The error is dominated by uncertainty in background estimation.

mode	5 ab^{-1}	50 ab^{-1}
$\mathcal{B}(B \to X_s\gamma)$	7%	6%
$A_{CP}(B \to X_s\gamma)$	$0.009 \oplus 0.006$	$0.003 \oplus 0.002 \oplus 0.003$
Mixing induced $S_{K^0_S\pi^0\gamma}$	0.1	0.03

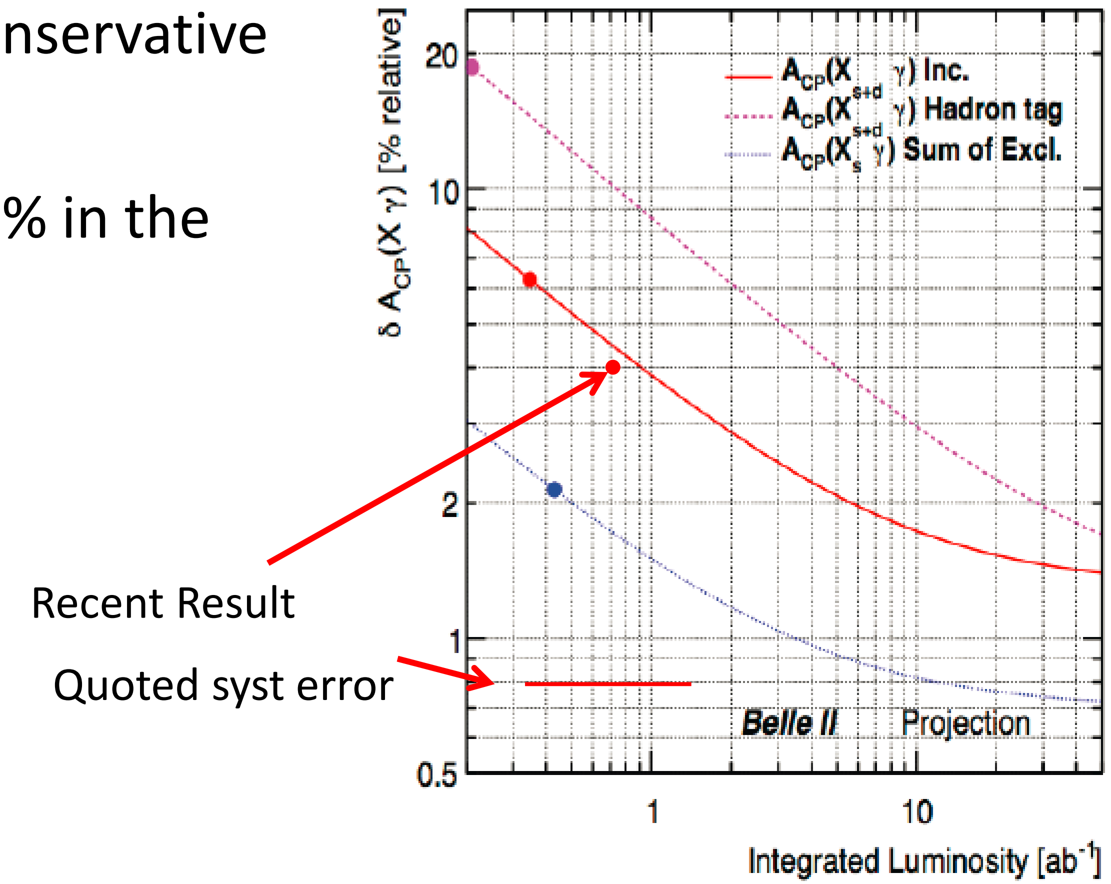
Misiak et al
Phys.Rev.Lett.98:022002,2007

- Naïve estimation gives $B \rightarrow X_d\gamma$ can be observed (20% precision) with a few /ab with M_{Xs} < 1.8GeV cut.
- Additional data set could be used to extend M_{Xs} region to reduce the extrapolation uncertainty to $E\gamma$>1.6GeV.

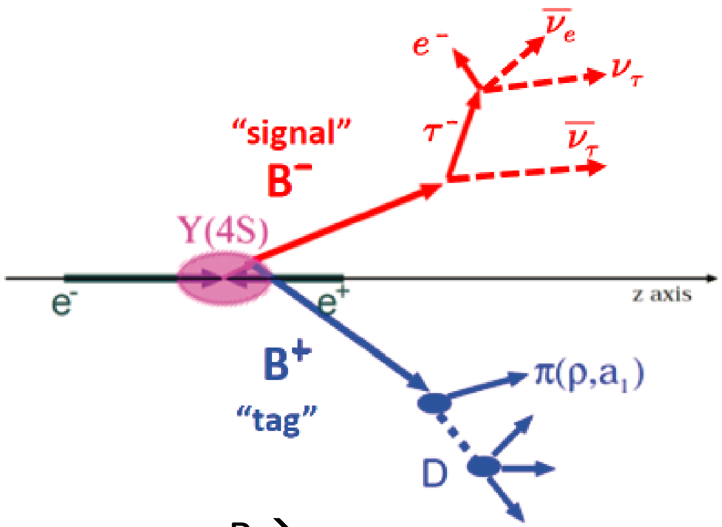


$A_{CP}(B \rightarrow X_{s,d}\gamma)$

- Systematic error assumed in this figure is somewhat conservative
- Total error around 0.5% in the scope

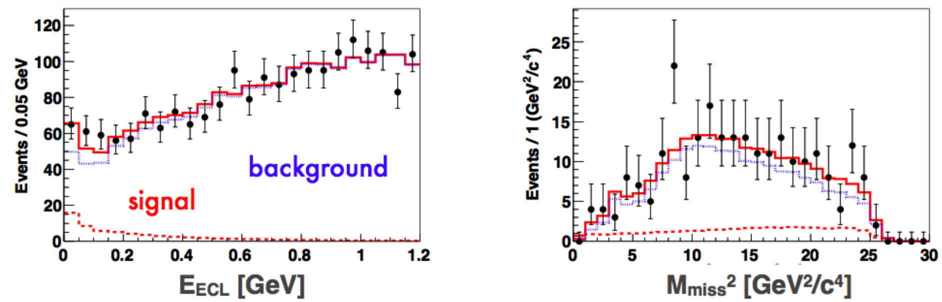


τ and ν



B→τν

- Modes involving τ and ν can be searched using hadronic/semileptonic tagging of the other B meson.
  - 0.28% and 0.18% hadronic tagging efficiency for B_u and B_d
- Search for $B_{d,s} \rightarrow \tau\tau/\nu\nu$(or invisibles)
- Measurement of $B \rightarrow K\nu\nu$
  - $B \rightarrow K\tau\tau$ also?



(Projection for all M_{miss}^2 region.) (Projection for E_{ECL} < 0.2 GeV)

- Number of B_s
  - With 120/fb^{-1}, $7\mathrm{x}10^6$ B_s pairs are produced.
  - $4\mathrm{x}10^8$ B_s pairs are expected at Belle II

Summary

- Belle had searched for new physics with b→s,d processes.
  - So far, no evidence
- Still we Belle have many important analyses on b→s,d to be done
  - If you have suggestion, please let me know.
- Belle II will further exploit EWP B decays
  - 50 times larger statistics
  - Better detector
    - Smaller systematics

b→ s γ

Mode	Observable	Belle (total 711/fb)
Inclusive γ	BF	600/fb
Inclusive γ w/ fullrec	BF, A_{CP}, Δ_{0+}	N.A
Xs γ	BF	711/fb (prelim)
	Δ_{0+}	N.A.
	A_{CP}, ΔA_{CP}	120fb
$K^*\gamma$	BF, A_{CP}, Δ_{0+}	78/fb
$K^0\pi^0$	TDCP	492/fb
$K\pi\pi\gamma$	BF	140/fb
	A_{UD}	N.A.
$K^0\rho^0$	TDCP	605/fb
$K\eta\ \gamma$	BF	250/fb
$K^0\eta$	TDCP	711/fb (prelim)
$K\eta'\ \gamma$	BF	605/fb
$K\phi\gamma$	BF, A_{CP}, TDCP	711/fb
$K\rho^0\gamma$	TDCP	605/fb
$\Lambda p\gamma$	BF, A_{CP}	410/fb

$b \rightarrow d\,\gamma$

Mode	Observable	Belle (total 711/fb)
$X_d\,\gamma$	BF, |Vtd/Vts|	N.A.
	A_{CP}	N.A.
$\rho\gamma,\omega\gamma$	BF, |Vtd/Vts|, A_{CP}, Δ_{0+}	605/fb
$\rho^0\gamma$	TDCP	605/fb
$\omega\gamma$	TDCP	N.A.

$b \rightarrow s\,l\,l$

Mode	Observable	Belle (total 711/fb)
Inclusive dilepton	BF, A_{FB}, A_{CP}	N.A.
Xs ll	BF	600/fb to be submitted (中山) 140/fb (岩崎)
	A_{FB}, A_{CP}, Δ_{0+},WC	N.A.
Kll, K*ll	BF, A_{FB}, A_{CP}, Δ_{0+}	700/fb just started (J. Yamaoka) 600/fb (J.-T. Wei)

$B \rightarrow ll, \gamma\gamma$

Mode	Belle (total 711/fb on Y(4S), 120/fb on Y(5S))
Bd $\rightarrow \gamma\gamma$	100/fb
Bs $\rightarrow \gamma\gamma$	23/fb
ee	80/fb
μe	↑
$\mu\mu$	↑
τe	N.A.
$\tau\mu$	N.A.
$\tau\tau$	N.A.