TOHOKU UNIVERSITY

BELLE Belle II

Belle II Prospects for EW Penguin Decays (Except R_K)

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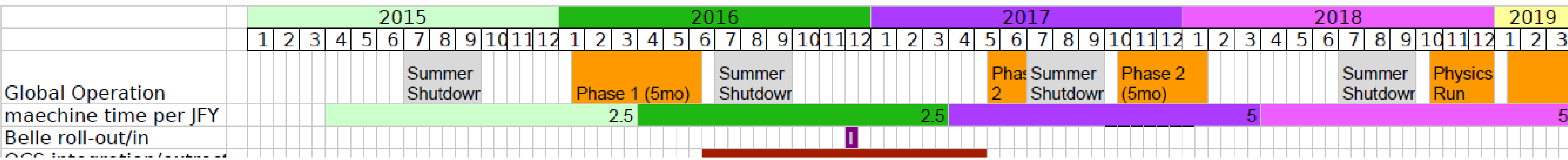
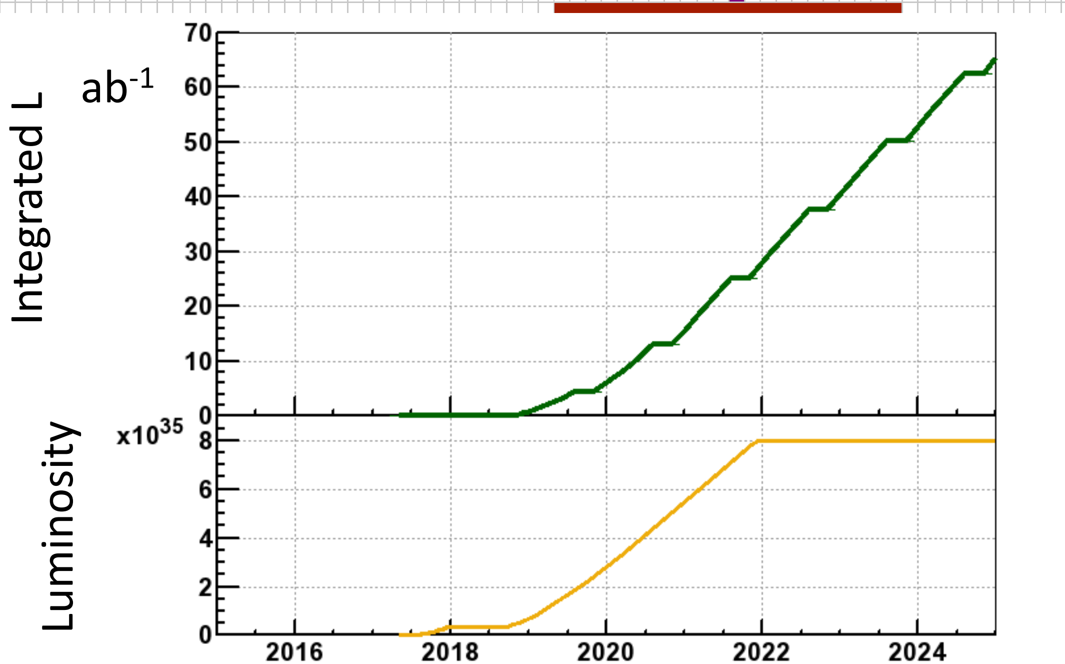
Belle II Schedule

- Beam commissioning
  - starts in Jan 2016 with BEAST II detector without Belle II detector
  - With BEAST II with Belle II but without VTX detector on Y(1-3S) in May 2017
- Data taking with full Belle II on Y(4S) in Oct 2018
- Accumulate 50ab^{-1} in 2024

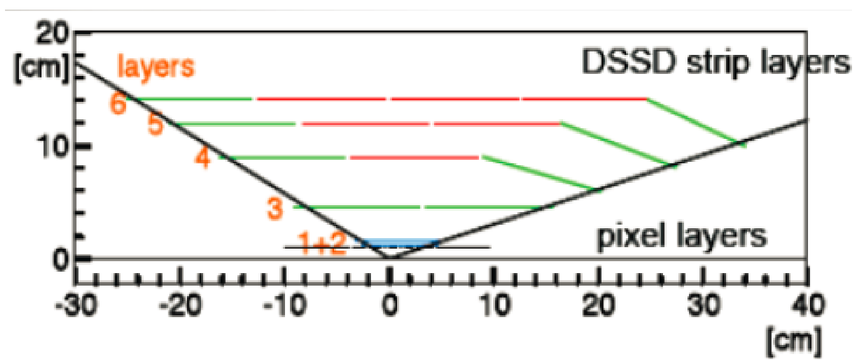


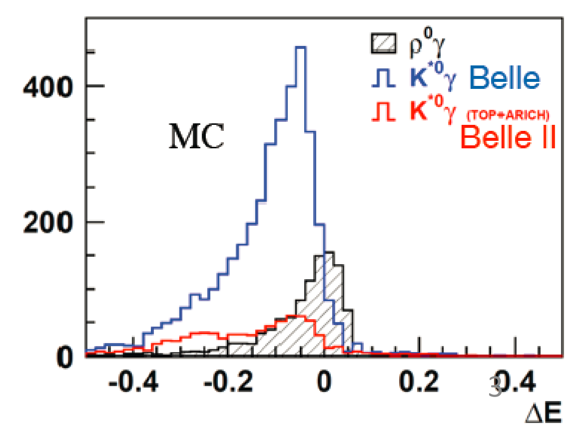


Belle II Detector Improvements

- Particle Identification
  - Kaon ID with TOP and ARICH is much better than Belle
    - ~10 times smaller $B \rightarrow K^*\gamma$ background to $B \rightarrow \rho\gamma$ in the acceptane
  - Low momentum muon ID can be identified by TOP and ARICH
  - Electron ID also improve with TOP and ARICH?
- Ks for Time dependent analysis
  - Radius of 2nd Outer most VTX detector **2** times larger 6cm → 11.5cm
    - For Ks vertexing, 2 VTX hits needed.
    - ~30% more $B \rightarrow K_S\pi^0\gamma$ for time dependent CPV

Belle 1





Belle II

- What only Belle II can do, or Belle II can do more than LHCb are
  - Ks and π^0 reconstructions
    - Isospin analysis
    - A_{UD}($B \rightarrow K\pi\pi\gamma$) with π^0
  - Inclusive analyses
    - $B \rightarrow Xs\gamma$
    - $B \rightarrow Xd\gamma$
    - $B \rightarrow Xsl^+l^-$
  - Electron/Tau/Neutrino modes (tau and neutrino by B recon tag)
    - Lepton Universality, LFV
    - $B_d \rightarrow \tau\tau$, $Bs \rightarrow \tau\tau$
    - $B \rightarrow K\mu\mu$/$B \rightarrow Kee$/$B \rightarrow K\tau\tau$/$B \rightarrow K\nu\nu$
  - Photonic modes
    - $B_d \rightarrow \gamma\gamma$, $Bs \rightarrow \gamma\gamma$
  - Ks vertexing and Flavor tagging
    - TCPV in $B \rightarrow Ks\pi^0\gamma$ and $B \rightarrow \rho^0\gamma$

Contents

1. $b \rightarrow sll$ and $B \rightarrow K^{(*)}\nu\nu$
2. Radiative Decays

$b \rightarrow s l^+ l^-$

- LHCb will do almost everything in exclusive all charged final states with dimuon
  - $B \rightarrow K^{*0}(K^+\pi^-)\mu\mu$
  - $B \rightarrow K^+\mu\mu$
  - We can not have comparable sensitivities for these measurements.
    - But anyway we will look into these.

- Belle II targets should be other important decay modes/observables

BF(B→Xsll)

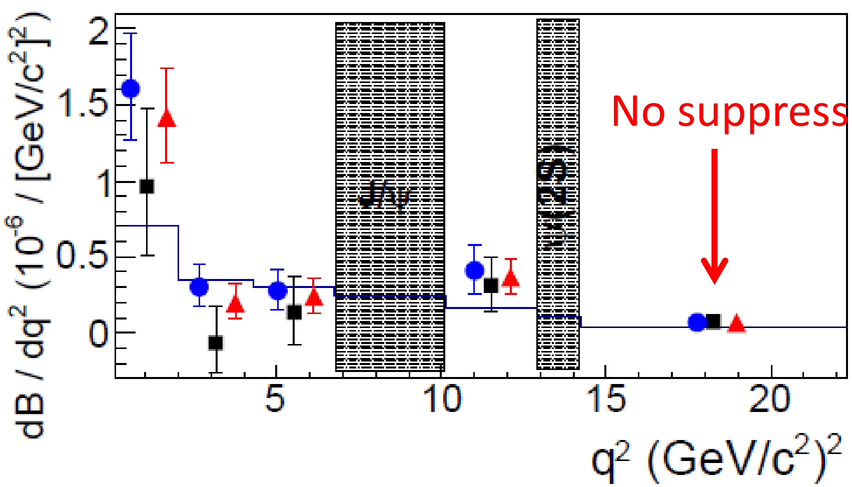
Huber, Hurth, Lunghi

- Inclusive b→sll is theoretically clean
- BF(B→Xsll) sensitive to C_9 and C_{10}
  - Babar published with full data ~400fb-1
  - If C_9 is smaller, high q^2 region should be suppressed but it's not.

Babar: $BR(B \to X_s \ell\ell) =$

$(0.57\ (+0.16-0.15)_{stat}(+0.03-0.02)_{syst})\,10^{-6}$

2σ higher than SM $\quad q^2 > 14.2 GeV^2$



Only 6% theo uncertainty in low q^2.

Low-q^2 $(1GeV^2 < q^2 < 6GeV^2)$

$BR(B \to X_s ee) = (1.67 \pm 0.10)\,10^{-6}$

$BR(B \to X_s \mu\mu) = (1.62 \pm 0.09)\,10^{-6}$

High-q^2, Theory: $q^2 > 14.4 GeV^2$,

$BR(B \to X_s ee) = (0.220 \pm 0.070)\,10^{-6}$

$BR(B \to X_s \mu\mu) = (0.253 \pm 0.070)\,10^{-6}$

Uncertainties at Belle and Belle II

Unofficial numbers
Please not refer in your paper

M_{Xs} cut = 2.0GeV

Stat + syst	**711fb^{-1}**	**5ab^{-1}**	**50ab^{-1}**
B(B→Xsl+l-)	8% + 9%	3% + 7%	---
N(B→Xsl+l-) events	400events	2800events	28000events
B(B→Xsl+l-) in $1<q^2<6GeV^2$	12% + 15%	5% + 9%	---
B(B→Xsl+l-) in $q^2>14.4GeV^2$	10% + 15%	4% + 8%	---

- Systematic dominant even at 5ab^{-1} with the same analysis
  - Next page
- High q^2 region is easier to reduce syst errors since efficiency in q^2 VS cos(theta)is almost flat and high M_{Xs} events are suppressed.
- With 50ab^{-1},
  - Reduce systematic error
  - try higher M_{Xs} cut (uncertainty from shape function reduced)
  - try fully inclusive with hadronic tagging?

Babar full data

Bin	Range	$B \to X_s \ell^+ \ell^-$
q_0^2	$1.0 < q^2 < 6.0$	$1.60^{+0.41}_{-0.39}{}^{+0.17}_{-0.13} \pm 0.18$

PRD 72, 092005 (2005)

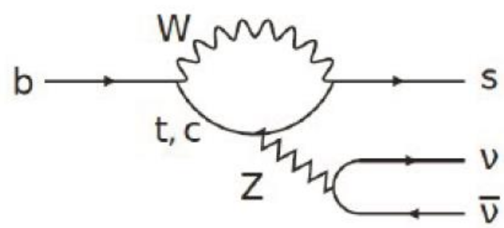
Breakdown of Syst Error

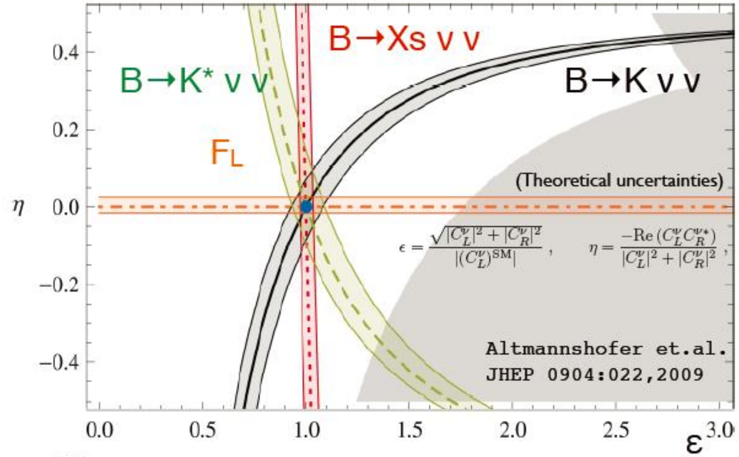
- Dominated by
  - BG shape
    - Reducible
  - Exclusive Fraction
    - LHCb already gives much better BF
  - Hadronization
    - reducible

Source	$X_s\, e^+e^-$	$X_s\, \mu^+\mu^-$
Signal shape	±1.4	±0.5
BG shape	±7.8	±4.7
Peaking background statistics	±0.9	±0.6
Peaking background PID error	< 0.1	±0.5
Peaking background shape	±4.3	±2.1
Cross-feed events	±4.1	±2.2
Signal yield total	±9.9	±5.7
Tracking efficiency	±3.5	±3.5
Lepton identification efficiency	±4.1	±5.9
Kaon identification efficiency	±0.8	±0.8
$\pi^\pm$ identification efficiency	±0.6	±0.5
K^0_S efficiency	±0.7	±0.8
π^0 efficiency	±0.3	±0.3
$\mathcal{R}$ requirement efficiency	±5.4	±4.5
Fermi motion model	$^{+6.5}_{-2.4}$	$^{+6.1}_{-2.3}$
$\mathcal{B}(B \to K\ell^+\ell^-)$	±9.9	±10.5
$\mathcal{B}(B \to K^*\ell^+\ell^-)$	±7.0	±7.8
K^*–X_s transition	±4.5	±4.7
Hadronization	±8.5	±8.2
Missing modes	±4.5	±4.4
Monte Carlo statistics	±1.6	±1.5
Efficiency total	$^{+19.0}_{-18.1}$	$^{+19.7}_{-18.9}$
$B\bar{B}$ counting	±0.5	±0.5
Total	$^{+21.5}_{-20.6}$	$^{+20.5}_{-19.7}$

Jared Yamaoka

Prospective: Di-Neutrino

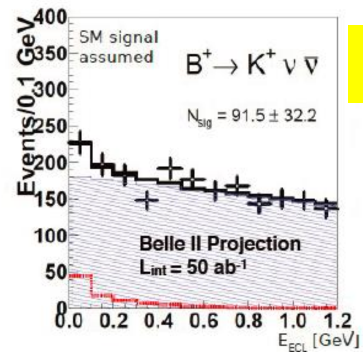




- $BF(B^+ \to K^+ \nu \nu) = (4.4 \pm 0.7)10^{-6}$
  [Buchalla, NPPS 209, 137]
- $BF(B^+ \to K^{*+} \nu \nu) = (6.8^{+1.0}_{-1.1})10^{-6}$
  [Altmannshofer, JHEP 0904, 022]

Ultimate test of Belle II

Further improvements to consider: tag efficiency, calorimeter timing, better K_L ID



Scaling from Belle results

N_{sig} at Belle II ~90±30 based on Belle 2013 (hadronic tag only)

Recent SM prediction for B→K*^{0}νν become larger
Hadronic B tagging efficiency with 6-layer VTX much (twice?) improved.
slow pion tracking is very important
Semi-leptonic B tagging also usable.
➔ Observation possible!

$$Br(B^0 \to K^{*0} \nu\bar{\nu})_{SM} = (9.19 \pm 0.86 \pm 0.50) \cdot 10^{-6}$$

Buras et al 1409.4557

Others not done at Belle (No sensitivity estimated)

- $B \to K^*ee$ at low q^2
  - Recently LHCb published very interesting result.
  - At Belle we have ~10 events for $0.14 < M_{ee} < 1$GeV
    - We can remove $M_{ee}<0.14$GeV cut
- $B \to K^{(*)}\tau\tau$
  - will be searched.
  - Even with improved tagging efficiency, observation is not easy
    - BF < 10^{-6}, ~10^{11} B mesons, tagging efficiency <1%
- Time dependent angular analysis in $B \to K^{*0}ll$ ($K^{*0} \to K_S\pi^0$)
- LFV modes, $B \to K\mu\tau$

If lepton flavor is violated,
$B \to D\tau\nu$, R_K, $B \to K\mu\tau$ and $B \to Ke\mu$

G. L. Glashow

Radiative Decays

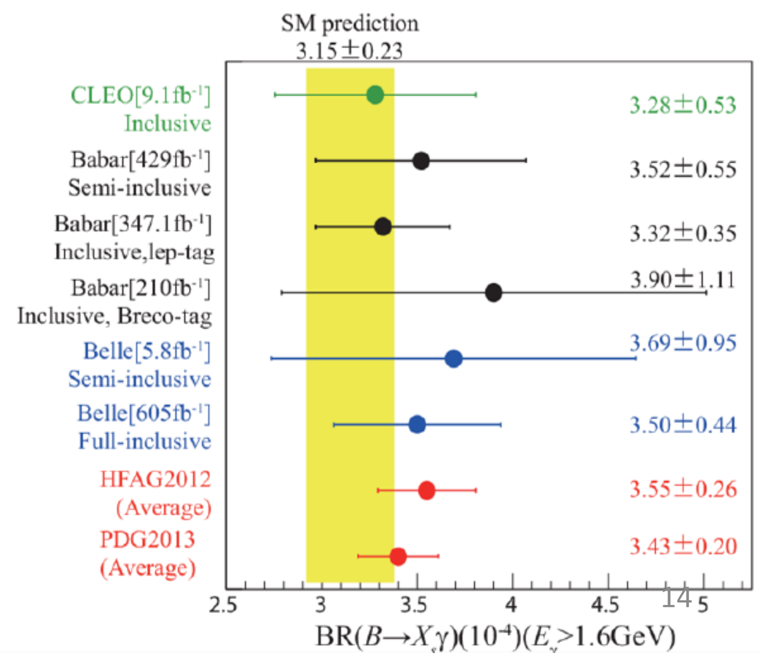
Inclusive $b \to s\gamma$

- Three reconstruction methods
  - Each method has own pros and cons.
  - Access to different observables
    - Ex. $A_{CP}(b \to s\gamma)$ VS $A_{CP}(b \to s,d\gamma)$

Recon method	Flavor	Isospin	$b \to d\gamma$	observables
Semi-inclusive Xs + γ	yes	yes	no	BF, dBF/dE, $A_{CP}(b \to s\gamma)$, A_I, $\Delta A_{CP}(b \to s\gamma)$
Fully inclusive γ (with lepton tag)	No (yes, mixing dilution)	No (no)	Yes (Yes)	BF, dBF/dE (BF, dBF/dE, $A_{CP}(b \to s,d\gamma)$)
Fully inclusive γ with B recon tag	Yes, mixing dilution	yes	yes	BF, dBF/dE, $A_{CP}(b \to s,d\gamma)$, A_I, $\Delta A_{CP}(b \to s,d\gamma)$

BF(b→sγ)

- Constrain on $|C_7|$
- SM prediction precise (in Belle era)
  - $(3.36 \pm 0.23) \times 10^{-4}$ Misiak et al.
- Precision of current WA comparable to the prediction HFAG2012
  - $(3.55 \pm 0.26) \times 10^{-4}$
  - $(3.40 \pm 0.21) \times 10^{-4}$
  - Error dominated by systematic ones

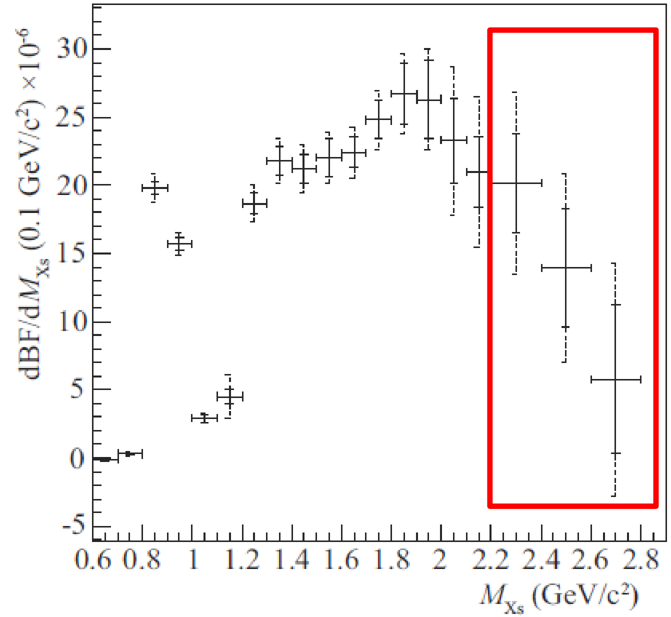


Breakdown of the Systematic Error

Semi-Inclusive

- 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
  - To be 4%?
- Precision to be~7%

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**



Breakdown of the Systematic Error

Fully Inclusive

- Largest source is continuum subtraction
  - Scaled by luminosity
- The second is other B backgrounds than π^0X and ηX
  - in low E_γ region
  - To reduce the systematic error, need to understand other B background
  - Hard to reduce
  - Down to ~5%?
  - Will dominate the total error
- Precision to be ~6%
- A theorists suggested to use only high Eγ region and rely on theory to extrapolate to Eγ=1.6GeV.
  - If 1.9GeV is OK, already 5% syst error.

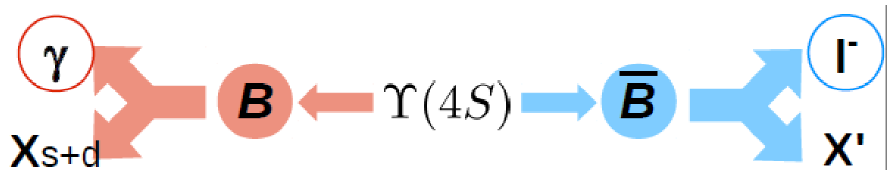
	BF($B \to X_s\gamma$) (10^{-4})			
$E^B_{\gamma\text{-Low}}$ (GeV)	1.70	1.80	1.90	2.00
Value	3.45	3.36	3.21	3.02
±statistical	0.15	0.13	0.11	0.10
±systematic	0.40	0.25	0.16	0.11
1. Continuum	0.26	0.16	0.10	0.07
2. Selection	0.15	0.12	0.10	0.08
3. π^0/η	0.07	0.05	0.04	0.02
4. Other B	0.25	0.14	0.06	0.02
5. Beam bkgd.	0.03	0.02	0.02	0.01
6. Unfolding	0.01	0.01	0.02	0.02
7. Model	0.01	0.01	0.00	0.01
8. Resolution	0.05	0.03	0.01	0.00
9. γ Detection	0.03	0.02	0.00	0.00
10. $B \to X_d\gamma$	0.01	0.01	0.01	0.01
11. Boost	0.01	0.01	0.02	0.02
Syst	12%	7%	5%	3.5%

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

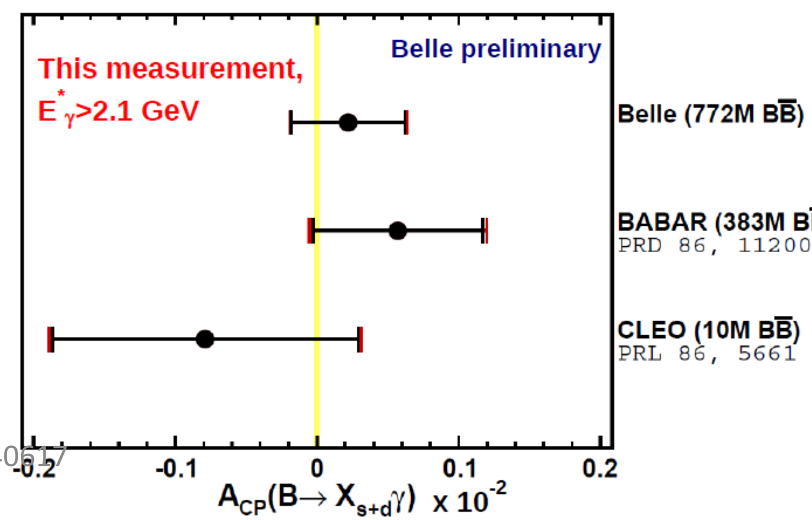
- Theoretical prediction is very precise thanks to unitarily.
  - If deviated from 0, clear new physics signal
  - Precision of $A_{CP}(B \to Xs\gamma)$ is already comparable to theory

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

PRL 106, 141801 (2011)



- Fully Inclusive with lepton tag



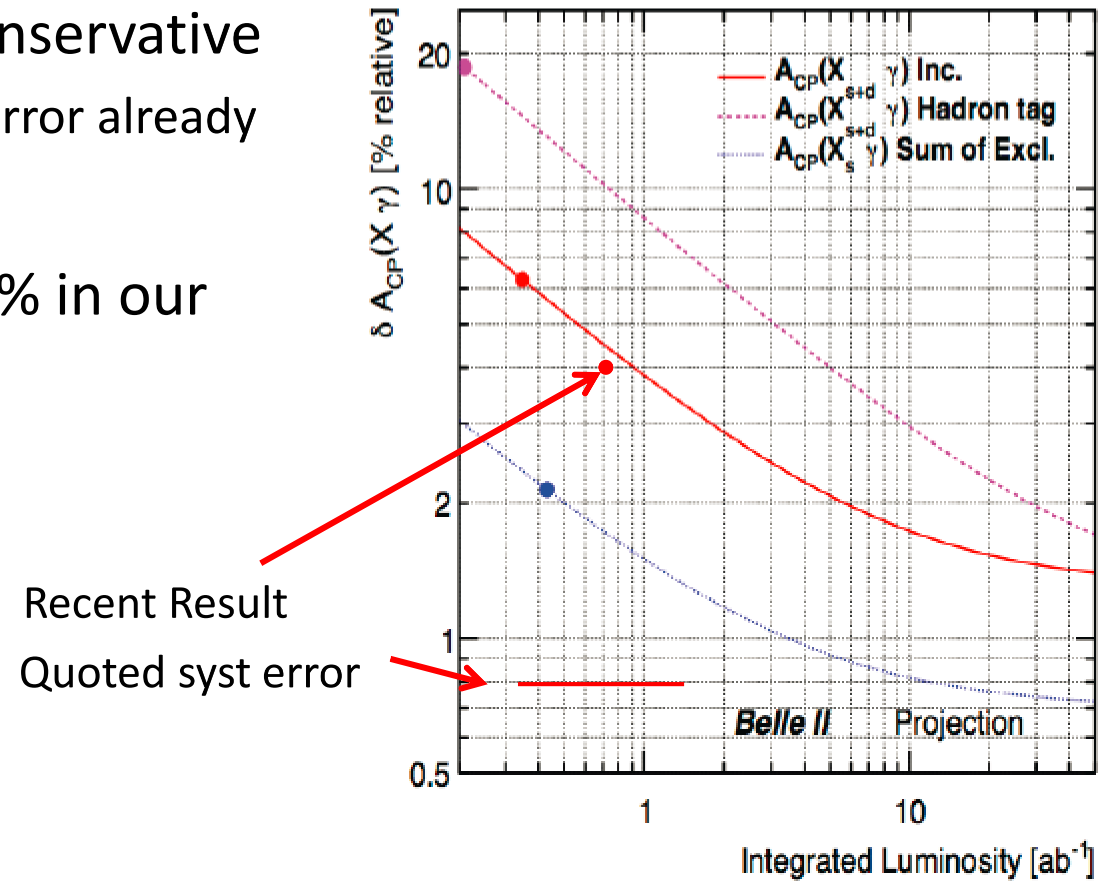
Still statistical error dominated

E^*_γ(thresh.)	$A^{meas}_{CP}(\times 10^2)$	$A_{det}(\times 10^2)$	$A_{bkg}(\times 10^2)$	$A^{corrected}_{CP}(\times 10^2)$
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	$1.5 \pm 4.0 \pm 0.5$

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

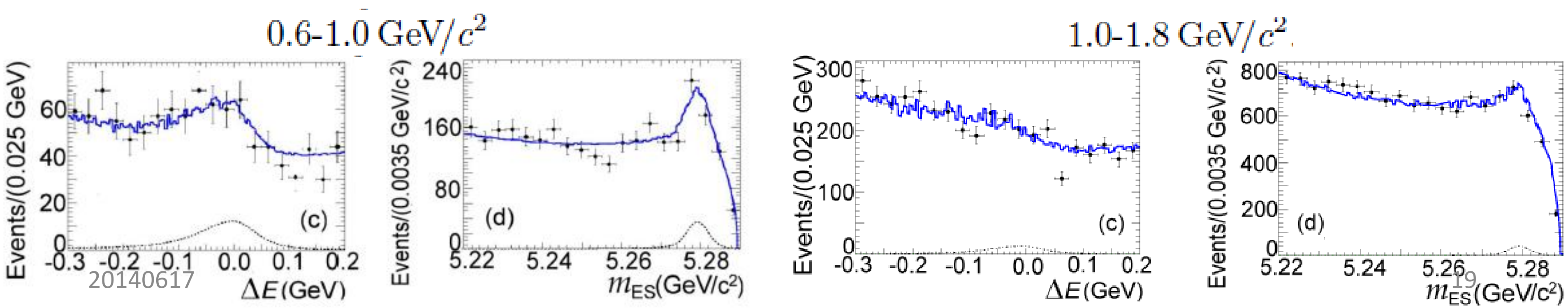
- Systematic error assumed in this figure is somewhat conservative
  - We quoted 0.8% syst error already

- Total error around 0.5% in our scope



BF($B \to X_d\gamma$)

- Semi-Inclusive approach to reduce $B \to Xs\gamma$ backgrounds
- Naïve estimation from the Babar measurement gives $B \to X_d\gamma$ can be observed (20% stat error) with a few /ab with M_{Xd} < 1.8GeV cut.
- Additional data set could be used
  - to extend M_{Xd} region to reduce the extrapolation uncertainty to $E\gamma$>1.6GeV.



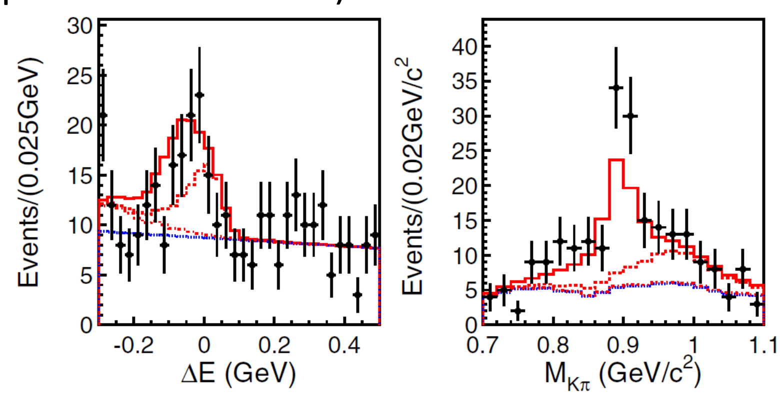
Photon Polarization in b→s,d γ

- In the SM, photon is polarized left handed predominantly
  - $O(m_{s,d}/m_b)$ right handed component.
    - Charm loop contribution???
- If new physics has right handed current, right handed polarization appears
- 4 methods to measure
  - TCPV in B→$f_{CP}\gamma$
  - A_{UD} in B→$K\pi\pi\gamma$
    - Modes with pi0 is 4.7 times larger A_{UD} for $K_1(1400)$
  - Photon conversion in B→$K^*\gamma$
  - Very low q^2 in B→K*e+e-

(Last three methods:) Not measured yet even at Belle !

Time Dependent CPV

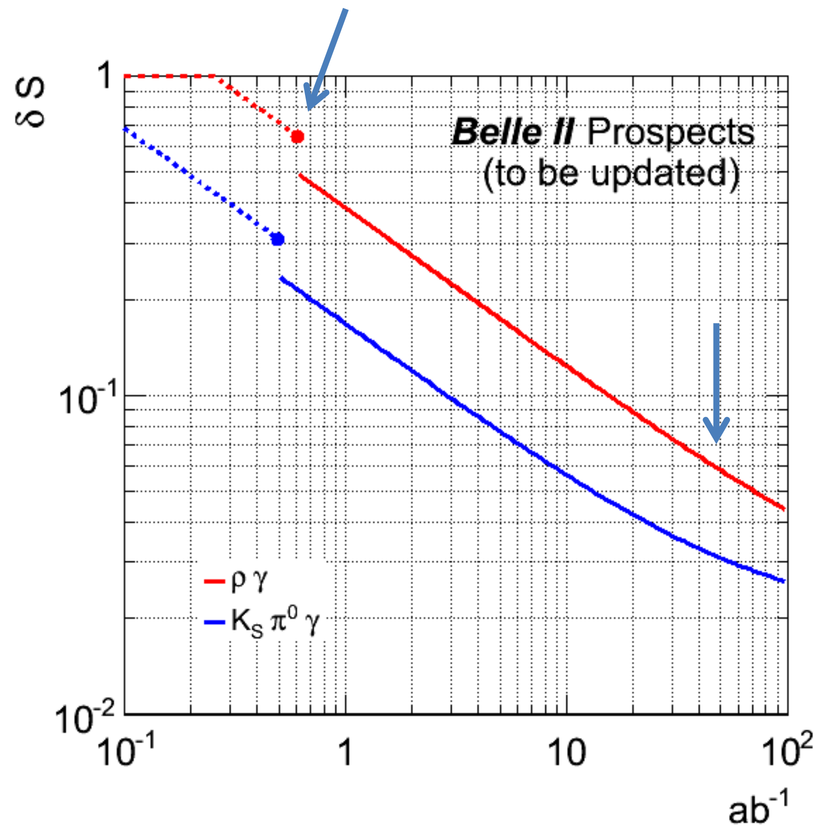
- Possible improvement
  - common
    - Improved flavor tagging thanks to better PID : 10%?
    - Background suppression with Neural Net and multi dimensional fit to extract signal : 20%?
    - (better photon resolution thanks to smaller material in front of the ECL)
  - B→Ks$\pi^0\gamma$
    - 30% more yield thanks to larger VTX detector
  - B→$\rho^0\gamma$
    - 10 times smaller K^{*0} background : 30% improved stat power
    - (better proper time resolution)



Prospects of δS

- Assuming $50ab^{-1}$ integrated lumi and 2% syst error
  - $\delta S(\rho\gamma^0) \sim 0.06$
  - $\delta S(Ks\pi^0\gamma) \sim 0.03$
- For $Ks\pi^0\gamma$, stat and syst errors are comparable
- For $\rho\gamma^0$, we need at least 4 times larger integrated luminosity (or more improved analysis) to hit syst limit

Dots show Belle results

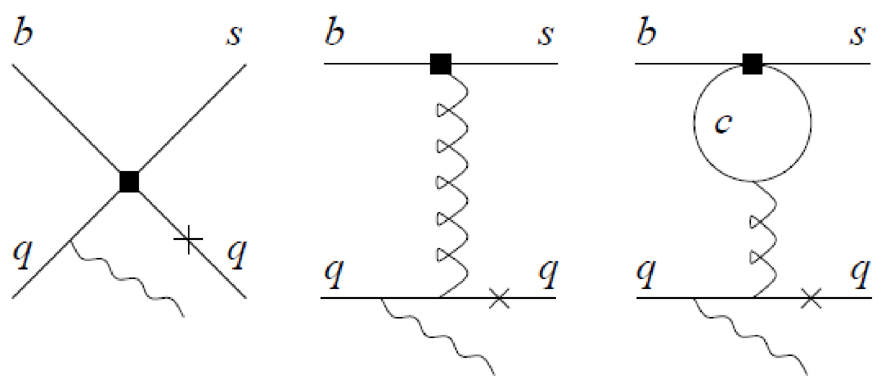


Isospin Violation

- New physics contribution changes the SM isospin breaking
  - SUSY case, the amplitude is destructive to the SM → larger Isospin V

$$\Delta_{0-} \equiv \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

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



Isospin Violation in B→K*γ

- Consistent with SM predictions : O(5%)
- Systematic error dominated even at B-factories with 347fb^{-1}.

$$\Delta_{0+} = \frac{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) - \mathcal{B}(B^+ \to K^{*+}\gamma)}{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) + \mathcal{B}(B^+ \to K^{*+}\gamma)}$$

- The dominant systematic error in exp is B^+/B^0 production ratio.

Prediction	Δ_{0+}
Beneke, Feldmann, Seidel	$(0.28/T_1^{K^*}(0))\,(5.8\,^{+3.3}_{-2.9}) \times 10^{-2}$
Kagan, Neubert	$(8.0^{+2.1}_{-3.2})\% \times \frac{0.3}{T_1^{B\to K^*}}$
Ball, Jones, Zwicky	$(5.4 \pm 1.4)\%$
Matsumori, Sanda, Keum	+2.7±0.8

measurement	Δ_{0+}
Babar 347fb^{-1}	$0.066 \pm 0.021 \pm 0.022$
Belle 78fb^{-1}	$+0.034 \pm 0.044(\mathrm{stat}) \pm 0.026(\mathrm{syst}) \pm 0.025(f_+/f_0)$
WA	0.052±0.026

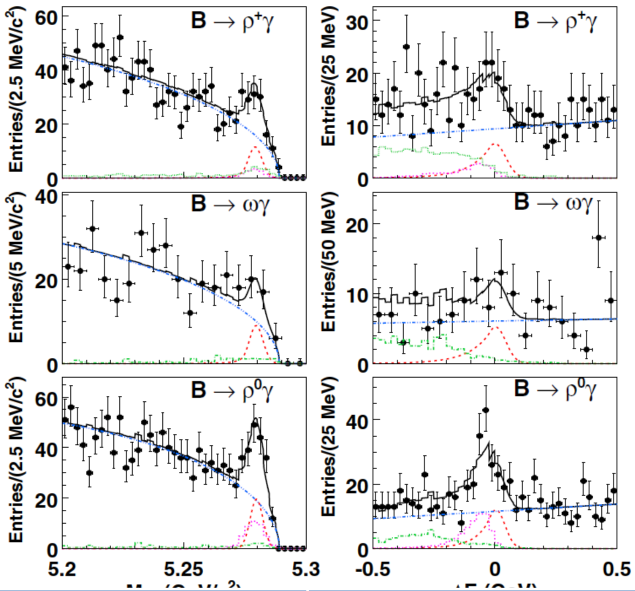
Isospin Violation in B→ργ

- Δ_ρ Isospin Violation large than prediction??

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

  – ~2.5σ deviation from theory
- The systematic error in exp is dominated by
  – Signal/BG shapes in fitting
  – Peaking BG
- Which can be reduced at Belle II

- Systematic error associated with B^+/B^0 production ratio f_{+-}/f_{00} will dominate the systematic error

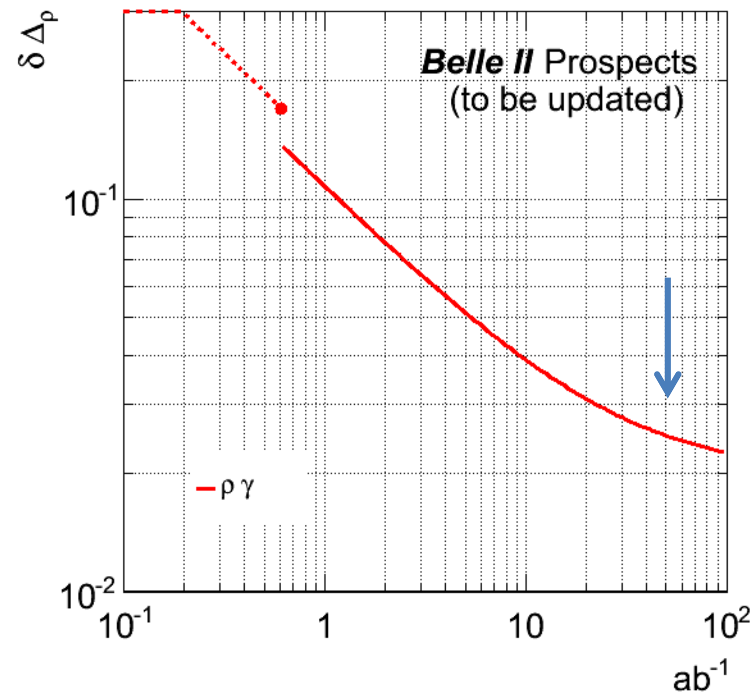


prediction	Δ_ρ[%]
Ali Lunghi	$+4^{+14}_{-7}$ %
Lyon Zwicky	-10 ± 6 %
Ball Jones Zwicky	-5.4 ± 3.9 % if ϕ_3 = 60deg
Beneke, Feldmann, Seidel	-4.6 ± 7 %

measurement	Δ_ρ
Babar 423fb^{-1}	$-0.43^{+0.25}_{-0.22}\pm0.10$
Belle 605fb^{-1}	$-0.48^{+0.21+0.08}_{-0.19-0.09}$
Average	$-0.46^{+0.17}_{-0.16}$

Prospects of $\delta\Delta_\rho$

- If the central value -0.46 is not changed, we can observe isospin violation in $B \rightarrow \rho\gamma$ with ~1.4ab^{-1}
  - The exp error is ~0.09.
  - Theoretical prediction is -5±5%→ new physics signal with ~3ab^{-1}.
  - At early stage, we can say something??
- Assuming 50ab^{-1} integrated lumi and 2.0% syst error
  - $\delta\Delta_\rho$ ~ 0.024



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Beneke, Feldmann, Seidel	– 4.6±7 %

Others

- ΔA_{CP} in B→Xs,d γ M. Benzke, S. J. Lee, M. Neubert and G. Paz, PRL 106, 141801 (2011)
  - Belle II can measure ~0.6% accuracy

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

$$17\,\mathrm{MeV} < \tilde{\Lambda}_{78} < 190\,\mathrm{MeV}$$

- A_{UD} in B→K$\pi\pi\gamma$
  - LHCb reported already
  - Modes involving π^0 gives larger sensitivity to polarization

Summary

- Belle II start data taking at Y(4S) in Oct 2018
  - Before that Y(1-3S) for quarkinum/dark photon physics
- Very exciting program for EW Penguin physics.
  - $B \rightarrow X_s ll$
  - $B \rightarrow X_s\gamma$, $X_d\gamma$
  - $B \rightarrow K\nu\nu$
- Before that we will finalize some Belle results
  - Stay tuned.