Belle and Belle II

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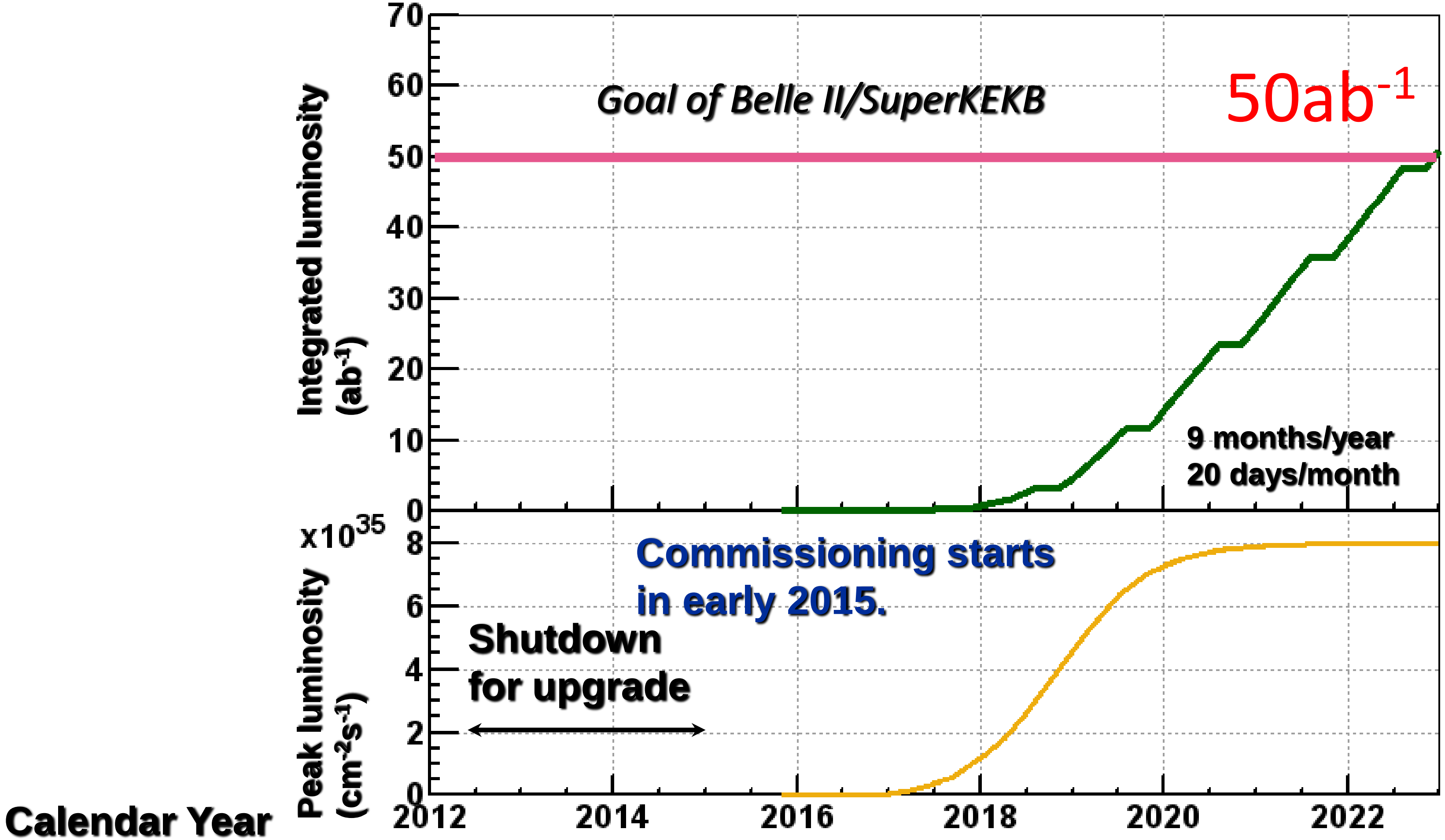
Belle II Schedule

- Start from Oct 2016
  - But not on Υ(4S) but on Υ(nS) since PID detector (TOP) is not fully ready
- $50ab^{-1}$ by the end of 2022



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1. $b \rightarrow sll$
2. Other EWP measurements
3. What is missing ?
4. Measurements improve LHCb results and Theory predictions

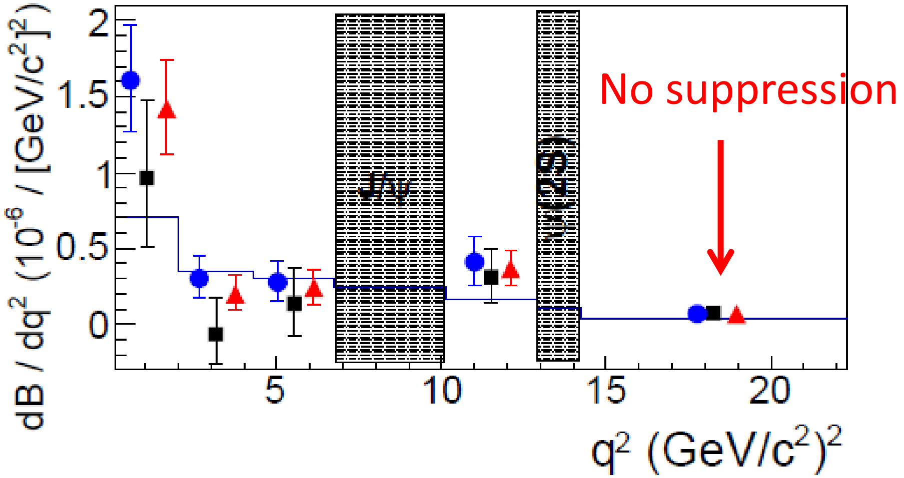
$b \to s l^+ l^-$

- LHCb will do almost everything in exclusive all charged final states with dimuon
  - $B \to K^{*0}(K^+\pi^-)\mu\mu$
  - $B \to K^+\mu\mu$
  - We can not have comparable sensitivities for these measurements.
- What e^+e^- B-factory can do more than or equal to LHCb are
  - Ks and π^0 detection
    - Semi-inclusive Measurements : $B \to X_s ll$
    - Isospin Asymmetry : $B \to K^{*0}(K^+\pi^-)ll$ VS $B \to K^{*+}(K^+\pi^0, K_s\pi^+)ll$
  - Sensitivity of electron modes are almost same as muon modes
    - Lepton Flavor Universality : $B \to K\, ee$ VS $B \to K\, \mu\mu$
  - Tau with hadronic tagging??
    - $B \to K^{(*)}\tau\tau$

Not guaranteed
Order of probability

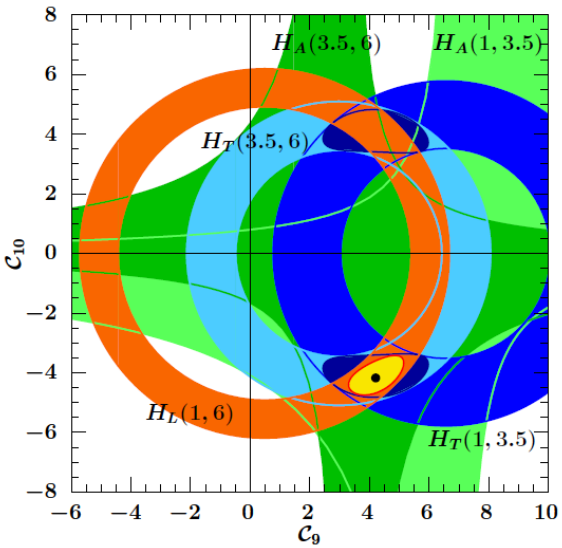
Near Future b→sll Measurements1

- B→Xsll
  1. BF and dBF/dq²
     - Recently Babar published final result.
  2. Ratio of BFs of B→Xsee to B→Xsμμ
     - Sensitive to A^0 in NMSSM at large tanβ
  3. CP and Isospin Asymmetries
  4. Angular decomposition
     - Longitudinal : H_L
     - transverse : H_T, H_A



G. Hiller
Phys. Rev. D70 (2004) 034018,

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

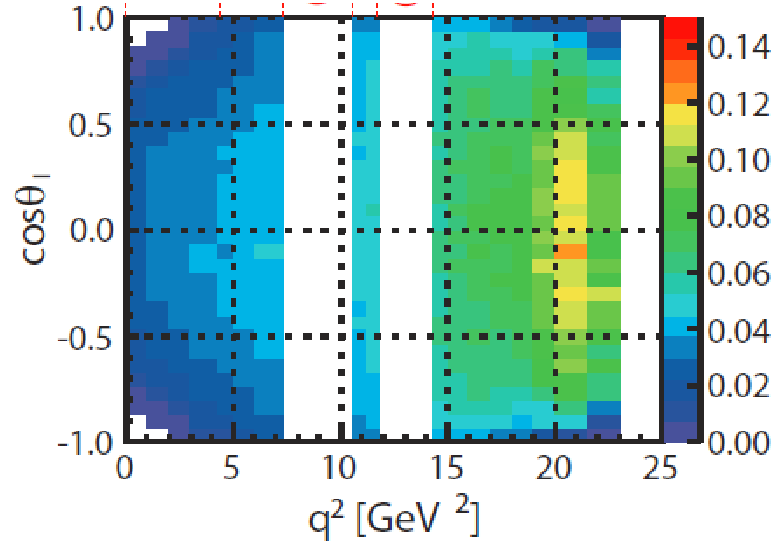


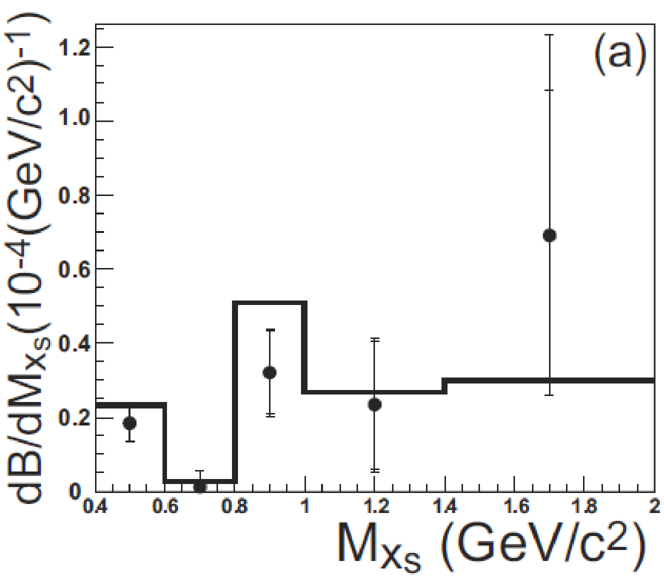
K.S.M. Lee et al, Phys. Rev. D 75, 034016

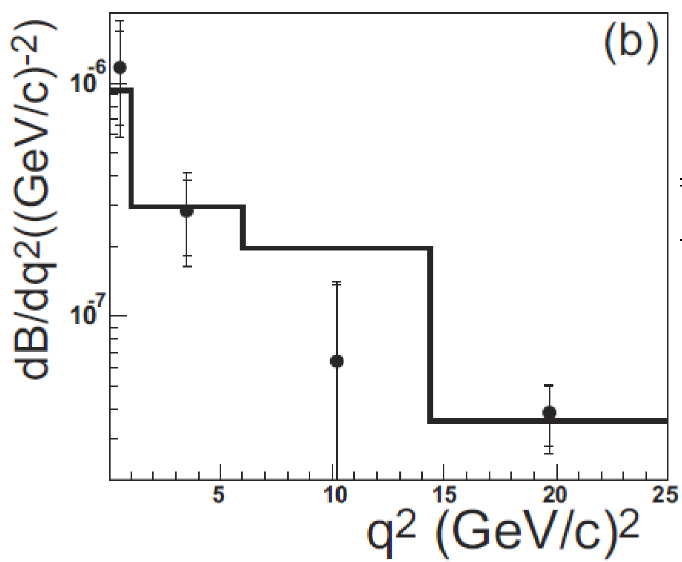
$B \rightarrow X_s l^+ l^-$ with $140 fb^{-1}$

- Selections
  - 18 hadronic modes cover 78% of Xs decays
  - $p_{lab}^{e} > 0.4$GeV
  - $p_{lab}^{\mu} > 0.8$GeV
  - $M_{Xs} < 2.0$GeV

Efficiency in Electron modes
For A_{FB} analysis



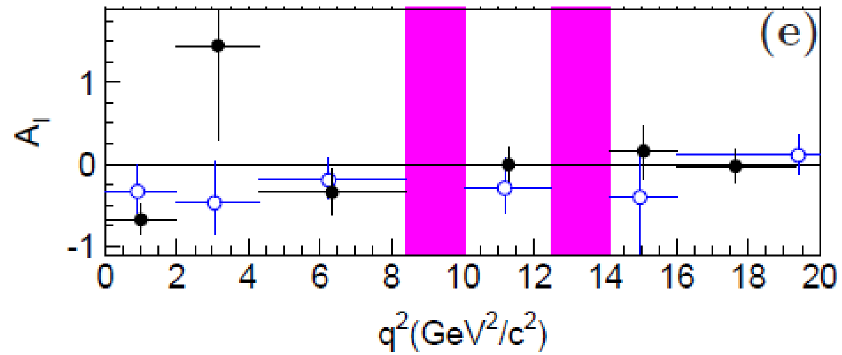




q^2 in $(\mathrm{GeV}/c)^2$	$\mathcal{B}$ $(\times 10^{-7})$
$[0.04, 1.0]$	$11.34 \pm 4.83^{+4.60}_{-2.71}$
$[1.0, 6.0]$	$14.93 \pm 5.04^{+4.11}_{-3.21}$
$[6.0, 14.4]$	$7.32 \pm 6.14^{+1.84}_{-1.91}$
$[14.4, 25.0]$	$4.18 \pm 1.17^{+0.61}_{-0.68}$

Not guaranteed
Order of probability

Near Future b→sll Measurements2



- B→Kll and K*ll
  1. BF and dBF/dq^2
     - But this is just cross check of LHCb results with smaller statistics.

600fb^{-1}

  2. Ratio of BFs of B→Xsee to B→Xsμμ
  3. CP and Isospin Asymmetries
  4. ? Full angular analysis
  5. ? Very low q^2 region (<1GeV^2) in K*ee for a measurement of virtual photon helicity

$$R_{K^*} = 0.83 \pm 0.17 \pm 0.08 \,,$$
$$R_K = 1.03 \pm 0.19 \pm 0.06 \,.$$

Y. Grossman and D. Pirjol, J. High Energy Phys. 06 (2000) 029

- C_7'
- Lower q^2 region, larger events and larger sensitivity.
  – Muon modes in low q^2 is not high sensitivity.
- Cut on $q^2 > (140MeV)^2$ to suppress pi0 Dalitz decay background
  – 10events with 600fb^{-1}
- Other analyses, TCPV in K*γ and A_{UD} in Kππγ, can search for right handed current

Uncertainties at Belle and Belle II

Unofficial numbers
Please not refer in your paper

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

- 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 $50ab^{-1}$, we should try other method than semi-inclusive, or try higher M_{Xs} cut
  - Fully inclusive?

Babar full data

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

Belle II Sensitivities to b→sll Measurements

mode	5 ab^{-1}	50 ab^{-1}
$R_K(B \to K\ell^+\ell^-)$	0.07	0.02
$\overline{A}_{FB}(B \to K^*\ell^+\ell^-)$		
C_9 from $\overline{A}_{FB}(B \to K^*\ell^+\ell^-)$	0.11	0.04
C_{10} from $\overline{A}_{FB}(B \to K^*\ell^+\ell^-)$	0.13	0.04
$\hat{s}_0$ from $\overline{A}_{FB}(B \to K^*\ell^+\ell^-)$	13%	5%

- C_9 and C_{10} sensitivities are assumed that no theoretical uncertainties and whole q^2 region except J/psi and psi' can be used.
- B→K*l+l-
  - 1800events for 5ab^{-1}
  - 18000events for 50ab^{-1}

R_K=BF(B→Kee)/BF(B→Kmm)

Extrapolation from Belle
Need to update with Belle II software

Other EWP Measurements

- $b \rightarrow (s,d)\gamma$
  - Branching fraction of inclusive and exclusive decays
  - Time dependent CPV in $B \rightarrow K^{*0}(K_S\pi^0)\gamma$, $\rho^0\gamma$, $\omega^0\gamma$
    - Search for right handed current
  - CP and isospin Asymmetries
- $b \rightarrow s\nu\nu$
  - BF of $B \rightarrow K^{(*)}\nu\nu$ with hadronic tagging
  - 25% enchancement in U. Haisch's model
    - Error of BF due to uncertainties in exp and theo should be less than 5%

$$(4.4 \pm 1.5) \times 10^{-6} \text{ for } B^+ \to K^+\nu\bar{\nu}$$
$$(6.8 \pm 2.0) \times 10^{-6} \text{ for } B^+ \to K^{*+}\nu\bar{\nu}$$

- $b \rightarrow dl^+l^-$
  - Search for $B \rightarrow \pi^0 l^+l^-$, $B \rightarrow \rho^+ l^+l^-$
  - If found, Isospin and CPV
- Bs, B $\rightarrow \gamma\gamma$
- Bs, B $\rightarrow \tau\tau$

Belle II Sensitivities for EWP Measurements

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 $S_{K_S^0\pi^0\gamma}$	0.1	0.03
$\mathcal{B}(B \to X_d\gamma)$	24%	
Mixing induced $S_{\rho^0\gamma}$	0.4	0.15

- B→Kνν observation with 5~10ab^{-1} →20% stat uncertainty (improvements of tracking and tagging method assumed)
  - Assuming the BFs

    $(4.4 \pm 1.5) \times 10^{-6}$ for $B^+ \to K^+\nu\bar{\nu}$

  - With 50ab^{-1}, 7%~10% stat uncertainty?
- Bs → γγ
  - Can be observed with ~600fb^{-1}

    BF(B_s → γγ) = (0.3−1.0) × 10^{-6}

Extrapolation from Belle
Need to update with Belle II software

What is missing?

- If you propose something to measure/search but not done at Belle (and Babar), please let me know.

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Measurements Improve LHCb results and Theory Predictions

- Normalization modes used at LHCb
  - BF(B→J/psi K), BF(B→J/psi K*)
  - f_{+-}/f_{00} is the key measurement for these
    - f_{+-} = BF(Y(4S) → B^+B^-)
- Test of form factors
  - Semileptonic decays, dBF/dq^2 (B → (π,ρ,ω, $\pi\pi$) l ν)
    - |Vub| Inclusive VS exclusive problem?
  - Tensor FF at q^2=0, BF(B→K*γ), BF(Bs →$\phi\gamma$)
- BFs of B→K(*) + resonances which decay to dilepton measured with other modes
  - B→$K^{(*)}$ psi(3770), psi(3770)→DD (and other higher charmonium)
  - B→$K^{(*)}$ phi, phi→KK
  - B→$K^{(*)}$ ρ, ρ→$\pi\pi$
  - B→$K^{(*)}$ ω, ω→$\pi\pi\pi^0$
  - B→$K^{(*)}$ eta, eta→$\pi\pi\pi^0$, $\gamma\gamma$

B→J/psi K^+ at Belle

$$\mathcal{B}(B^+ \to J/\psi K^+) = \frac{N_{\rm sig}}{2\epsilon N_{BB} f_{+-}}$$

- We measured A_{CP}(B→J/psi K^+) at Belle with full data.
- About 40k events are reconstructed with S/N >> 1, so statistical error of the signal yield (Nsig) should about 0.5%, and the systematic error is less than 1%.
- Systematic errors in effciency (ε) is about 1%, and could be improved at Belle II
- But the problem is uncertainty of number of B^+ mesons produced.
  - N_{BB} f_{+-}
    - N_{BB} could be measured with less than 1% using better event shape variables

$$\mathcal{B}(B^+ \to J/\psi K^+) = \frac{N_{\rm sig}}{\epsilon N_{BB}}$$

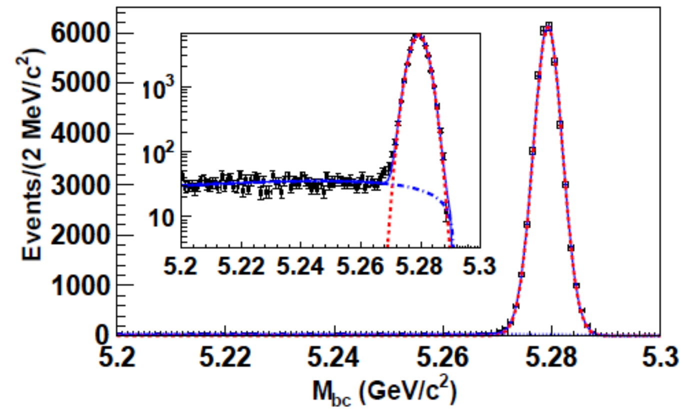

FIG. 2: (color online). $M_{\rm bc}$ distribution of $B^+ \to J/\psi K^+$ candidates summed over all bins and for both B charge states (inset plot is on a semilog scale). The blue solid, blue dot-dashed, and red dashed curves are the total fit, the background and the signal components, respectively.

$\Gamma(J/\psi(1S)K^+)/\Gamma_{\rm total}$

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
10.28± 0.31 OUR FIT					
10.24± 0.35 OUR AVERAGE					
8.1 ± 1.3 ±0.7		[1] AUBERT	06E	BABR	$e^+e^- \to \Upsilon(4S)$
10.61± 0.15±0.48		[2] AUBERT	05J	BABR	$e^+e^- \to \Upsilon(4S)$
10.4 ± 1.1 ±0.1		[3] AUBERT,B	05L	BABR	$e^+e^- \to \Upsilon(4S)$
10.1 ± 0.2 ±0.7		[2] ABE	03B	BELL	$e^+e^- \to \Upsilon(4S)$
10.2 ± 0.8 ±0.7		[2] JESSOP	97	CLE2	$e^+e^- \to \Upsilon(4S)$
9.3 ± 3.1 ±0.1		[4] BORTOLETTO	92	CLEO	$e^+e^- \to \Upsilon(4S)$
8.1 ± 3.5 ±0.1	6	[5] ALBRECHT	90J	ARG	$e^+e^- \to \Upsilon(4S)$

f_{+-}/f_{00}

- The error is about 2.5%. Need to reduce the error.
- Further problem, the measurement used J/psi $K^{(*)}$ assuming Isospin symmetry. Other methods should be used.

$\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ Γ_2/Γ_4

VALUE	DOCUMENT ID		TECN	COMMENT
1.055±0.025 OUR EVALUATION				
1.006±0.036±0.031	[6] AUBERT	04F	BABR	$\Upsilon(4S) \to B\overline{B} \to J/\psi K$
1.01 ±0.03 ±0.09	[6] HASTINGS	03	BELL	$\Upsilon(4S) \to B\overline{B} \to$ dileptons
1.058±0.084±0.136	[7] ATHAR	02	CLEO	$\Upsilon(4S) \to B\overline{B} \to D^* \ell \nu$
1.10 ±0.06 ±0.05	[8] AUBERT	02	BABR	$\Upsilon(4S) \to B\overline{B} \to (c\overline{c})K^*$
1.04 ±0.07 ±0.04	[9] ALEXANDER	01	CLEO	$\Upsilon(4S) \to B\overline{B} \to J/\psi K^*$

- Babar measured f_{00} with the ratio of single semileptonic decays (B→D*lν, B→anything) and double semileptonic decays. Belle (II) and Babar can improve the measurements
  - If we assume f_{00}+ f_{+-} = 1, uncertainty of f_{+-} could be 1% level.
  - f_{+-} can be measured with the same technique.

$\Gamma(B^0\overline{B}^0)/\Gamma_{total}$ Γ_4/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.487±0.006 OUR EVALUATION	Assuming B($\Upsilon(4S) \to B\overline{B}$) = 1			
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.487±0.010±0.008	[5] AUBERT,B	05H	BABR	$\Upsilon(4S) \to \overline{B}B \to D^* \ell \nu_\ell$

- Uncertainty of BF(B→J/psi K^+) could be ~2% (but more than 1%).

Measurements Improve LHCb results and Theory Predictions

- Normalization modes used at LHCb
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  - f_{+-}/f_{00} is the key measurement for these
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  - B→$K^{(*)}$ eta, eta→$\pi\pi\pi^0$, γγ

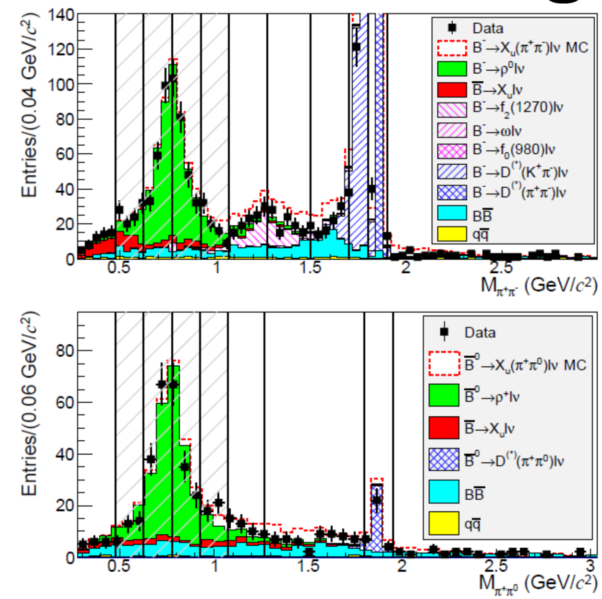
PRD 88, 032005 (2013)

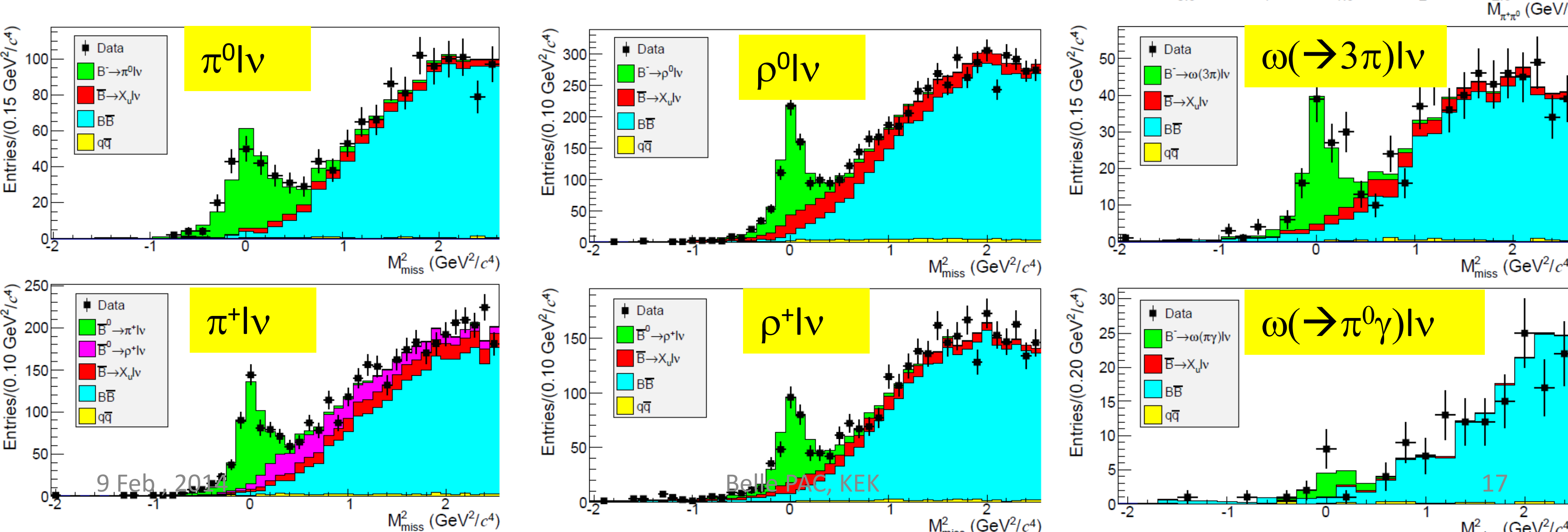
Exclusive B→(π^+,π^0,ρ^+,ρ^0,ω)lν with hadronic tag

- We can test FFs using exclusive b→ulν
- 6 final states are analyzed simultaneously
- missing mass consistent with 0

$$M^2_{\mathrm{miss}} = [p(\mathrm{Beam}) - (p(B_{\mathrm{tag}}) + p(\mathrm{visible}))]^2$$

- Also $m_{\pi\pi}$ spectrum measured
- Extract FFs assuming |Vub|
  - Or shape of FFs can be determined.





Uncertainty in $|V_{ub}|$ from exclusive $B \rightarrow X_u l\nu$

- $\delta|V_{ub}|$ from exp. is less than 10% with single measurement, and smaller than FFs → can use to test FFs.

Normalized decay rate $\Delta\zeta = \int d\Gamma/|V_{ub}|^2$ is based on form factor prediction from theory.

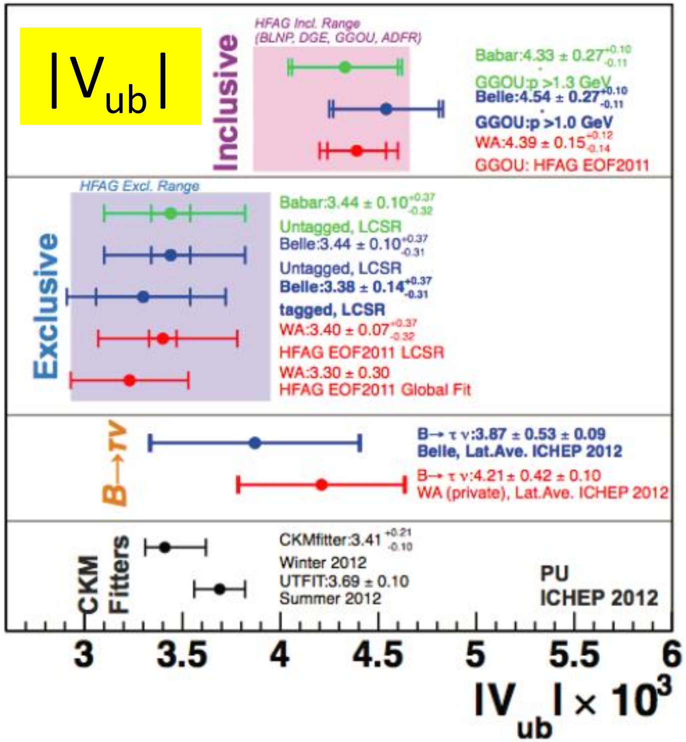
X_u	Theory	q^2 GeV/c^2	$N^{\rm fit}$	$\Delta\mathcal{B}$ 10^{-4}	$\Delta\zeta$ ps^{-1}	$\lvert V_{ub}\rvert$ 10^{-3}
π^0	LCSR1	< 12	119.6 ± 16.2	0.423 ± 0.057	$4.59^{+1.00}_{-0.85}$	$3.35 \pm 0.23 \pm 0.09^{+0.36}_{-0.31}$
	LCSR2	< 16	168.2 ± 18.9	0.588 ± 0.066	$5.44^{+1.43}_{-1.43}$	$3.63 \pm 0.20 \pm 0.10^{+0.60}_{-0.40}$
	HPQCD	> 16	58.6 ± 10.5	0.196 ± 0.035	$2.02^{+0.55}_{-0.55}$	$3.44 \pm 0.31 \pm 0.09^{+0.59}_{-0.39}$
	FNAL				$2.21^{+0.47}_{-0.42}$	$3.29 \pm 0.30 \pm 0.09^{+0.37}_{-0.30}$
π^+	LCSR1	< 12	247.2 ± 18.9	0.808 ± 0.062	$4.59^{+1.00}_{-0.85}$	$3.40 \pm 0.13 \pm 0.09^{+0.37}_{-0.32}$
	LCSR2	< 16	324.2 ± 22.6	1.057 ± 0.074	$5.44^{+1.43}_{-1.43}$	$3.58 \pm 0.12 \pm 0.09^{+0.59}_{-0.39}$
	HPQCD	> 16	141.3 ± 16.0	0.445 ± 0.050	$2.02^{+0.55}_{-0.55}$	$3.81 \pm 0.22 \pm 0.10^{+0.66}_{-0.43}$
	FNAL				$2.21^{+0.47}_{-0.42}$	$3.64 \pm 0.21 \pm 0.09^{+0.40}_{-0.33}$
ρ^0	LCSR3	< 16	476.5 ± 30.5	1.431 ± 0.091	$13.7^{+3.4}_{-3.4}$	$3.56 \pm 0.11 \pm 0.09^{+0.54}_{-0.37}$
	UKQCD	full range	621.7 ± 35.0	1.834 ± 0.103	$16.5^{+3.5}_{-2.3}$	$3.68 \pm 0.10 \pm 0.10^{+0.29}_{-0.34}$
	ISGW2				$14.1 \pm ??$	$3.98 \pm 0.11 \pm 0.10^{+?.??}_{-?.??}$
ρ^+	LCSR3	< 16	268.8 ± 25.0	2.574 ± 0.239	$13.7^{+3.4}_{-3.4}$	$3.51 \pm 0.16 \pm 0.13^{+0.53}_{-0.36}$
	UKQCD	full range	343.3 ± 28.3	3.222 ± 0.266	$16.5^{+3.5}_{-2.3}$	$3.59 \pm 0.15 \pm 0.13^{+0.28}_{-0.33}$
	ISGW2				$14.1 \pm ??$	$3.87 \pm 0.16 \pm 0.15^{+?.??}_{-?.??}$
ω	LCSR3	< 12	61.3 ± 11.4	0.611 ± 0.113	$7.88^{+1.86}_{-1.86}$	$3.08 \pm 0.29 \pm 0.11^{+0.44}_{-0.31}$
	ISGW2	full range	96.7 ± 14.5	1.069 ± 0.160	$14.1 \pm ??$	$3.03 \pm 0.23 \pm 0.11^{+?.??}_{-?.??}$

LCSR1 PRD 83 (2011) 094031 HPQCD PRD 73 (2006) 074502 LCSR2 PRD 71 (2005) 014015 FNAL PRD 79 (2009) 054507
LCSR3 PRD 71 (2005) 014029 UKQCD PLB 416 (1998) 392 ISGW2 PRD 52 (1995) 2783

Note nice agreement between $\bar{B} \to \pi\ell^-\bar{\nu}_\ell$ and $\bar{B} \to \rho\ell^-\bar{\nu}_\ell$ modes with LCSR(2,3) prediction.

|Vub| : Inclusive VS Exclusive

- ~3 sigma discripancy.
- Same tendency for Babar and Belle
- Can we trust FFs or inclusive prediction?
- This problem should be solved to understand B→light FFs.



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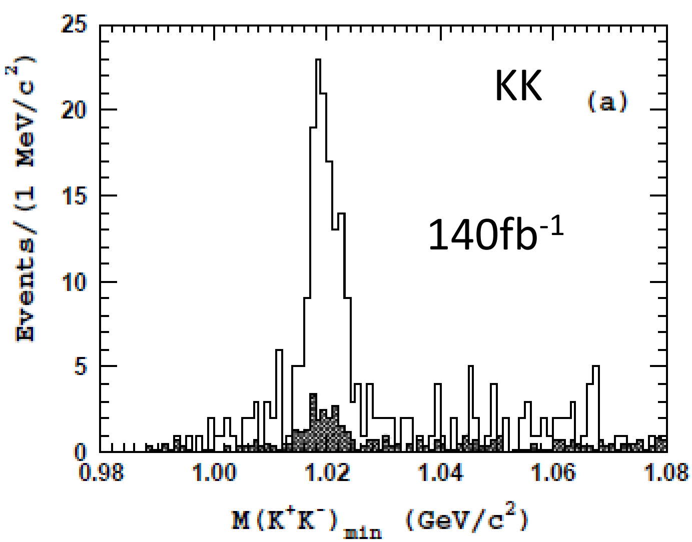
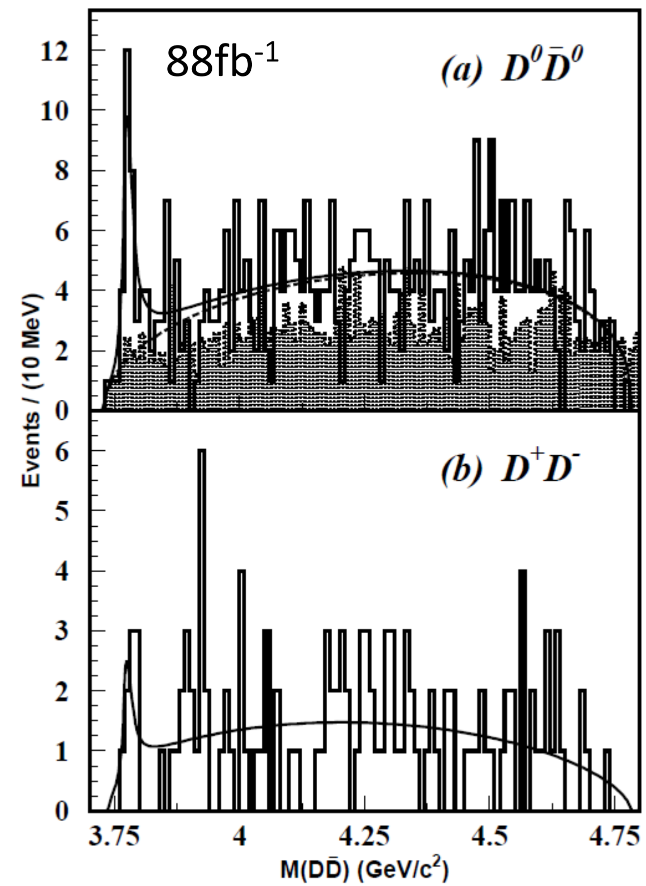
B→psi(3770)K^+, B→ϕK

- Following psi(3770)→DD, ϕ→KK Measured
- If other experiment (like BESS-III) provides the BF of higher cc→DD $n\pi$, we can measure the BF also.





Summary

- LHCb did and will do a very good job for exclusive $b \rightarrow s\mu\mu$ decays.
- We can perform the $b \rightarrow sll$ measurements not easy at LHCb
  - Ks, pi0, electron, tau?
- Other EWP modes also important.
- We can improve LHCb results and Theory predictions.