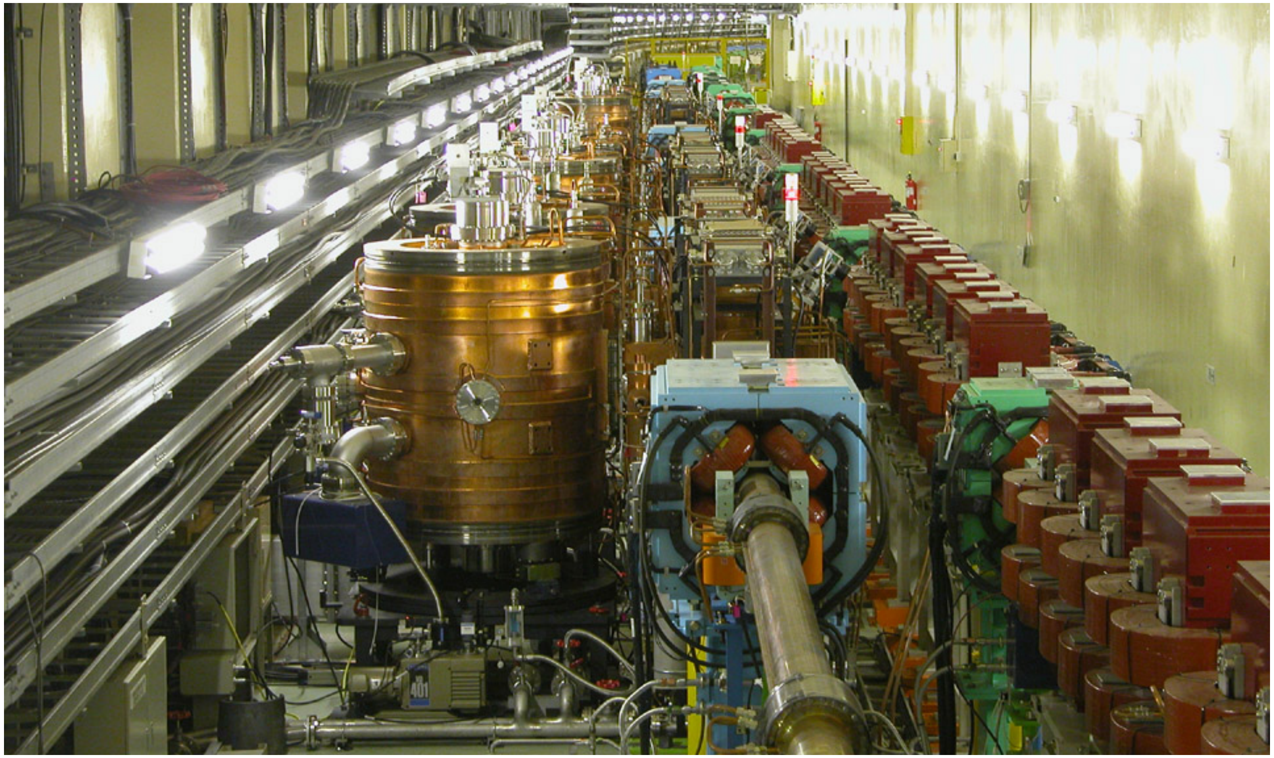


Rare b Decays at

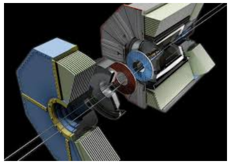
Belle II

Alan Schwartz
University of Cincinnati, USA

Snowmass 2021:
Rare Processes and Precision Measurements Frontier Town Hall Meeting

via Zoom: 2 October 2020

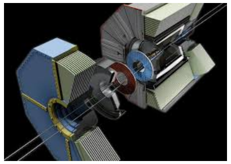
- *overview*
- *charmless hadronic: indirect CPV*
- *charmless hadronic: direct CPV*
- *inclusive leptonic decays*
- *inclusive radiative decays*
- *exclusive radiative decays*



Motivation

Why an e^+e^- flavor factory experiment?

- *A flavor factory searches for NP by measuring phases, CP asymmetries, inclusive decay processes, rare leptonic decays, absolute branching fractions. There is a wide range of observables with which to confront theory.*
- *Low backgrounds, high trigger efficiency, excellent γ and π^0 recontruction (and thus η, η', ρ+, etc. reconstruction), high flavor-tagging efficiency with low dilution, many control samples to study systematics*
- *Negligible trigger bias, and good kinematic resolutions, Dalitz plots analyses are straightforward. Absolute branching fractions can be measured. Missing energy and missing mass analyses are straightforward.*
- *Systematics quite different from those at LHCb. If true NP is seen by one of the experiments, confirmation by the other would be important.*



Belle II “golden modes”

“The Belle II Physics Book"
E. Kou et al., PTEP 2019, 123C01 (2019)
[arXiv:1808.10567]

B physics:

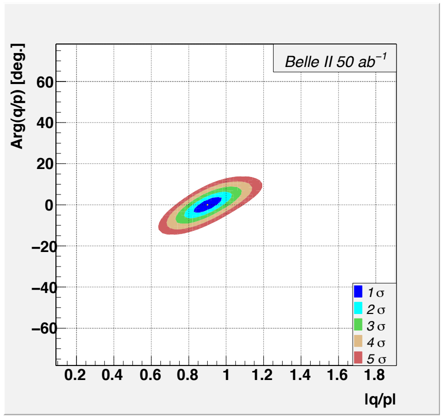
(● discussed here)

[see also talk by A. Gaz, “CKM Measurements and CPV”]

Observables	Expected exp. uncertainty	Facility (2025)
UT angles & sides		
ϕ_1 [°]	0.4	Belle II
ϕ_2 [°]	1.0	Belle II
ϕ_3 [°]	1.0	LHCb/Belle II
$\|V_{cb}\|$ incl.	1%	Belle II
$\|V_{cb}\|$ excl.	1.5%	Belle II
$\|V_{ub}\|$ incl.	3%	Belle II
$\|V_{ub}\|$ excl.	2%	Belle II/LHCb
CPV		
$S(B \to \phi K^0)$	0.02	Belle II
$S(B \to \eta' K^0)$	0.01	Belle II
● $\mathcal{A}(B \to K^0 \pi^0)[10^{-2}]$	4	Belle II
● $\mathcal{A}(B \to K^+ \pi^-)$ $[10^{-2}]$	0.20	LHCb/Belle II
(Semi-)leptonic		
● $\mathcal{B}(B \to \tau \nu)$ $[10^{-6}]$	3%	Belle II
$\mathcal{B}(B \to \mu \nu)$ $[10^{-6}]$	7%	Belle II
$R(B \to D \tau \nu)$	3%	Belle II
$R(B \to D^* \tau \nu)$	2%	Belle II/LHCb
Radiative & EW Penguins		
● $\mathcal{B}(B \to X_s \gamma)$	4%	Belle II
● $A_{CP}(B \to X_{s,d} \gamma)$ $[10^{-2}]$	0.005	Belle II
$S(B \to K_S^0 \pi^0 \gamma)$	0.03	Belle II
$S(B \to \rho \gamma)$	0.07	Belle II
$\mathcal{B}(B_s \to \gamma \gamma)$ $[10^{-6}]$	0.3	Belle II
● $\mathcal{B}(B \to K^* \nu \overline{\nu})$ $[10^{-6}]$	15%	Belle II
● $\mathcal{B}(B \to K \nu \overline{\nu})$ $[10^{-6}]$	20%	Belle II
$R(B \to K^* \ell \ell)$	0.03	Belle II/LHCb

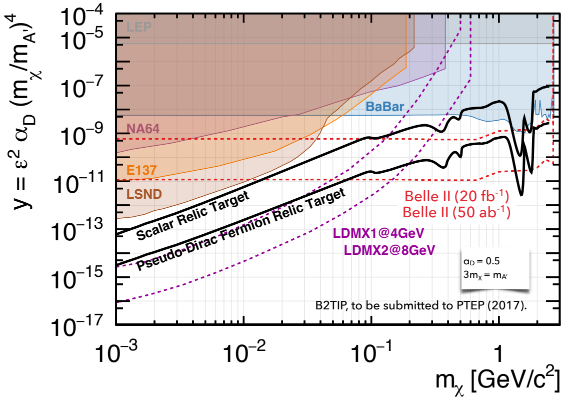
Charm physics:

[see talk by J. Bennett]



Dark Photon/Sector:

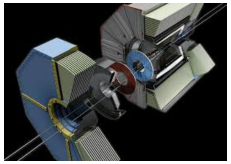
[see talk by K. Flood]



Tau physics *[see talk by S. Banerjee]*

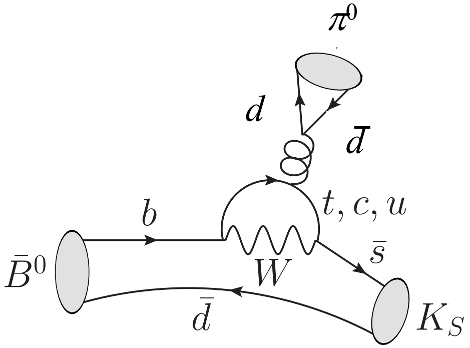
Quarkonium *[see talk by B. Fulsom]*

B_s physics at Υ(5S)



Searching for NP via $B^0 \to \pi^0 K_S$

"The Belle II Physics Book"
PTEP 2019, 123C01 (2019)
[arXiv:1808.10567]

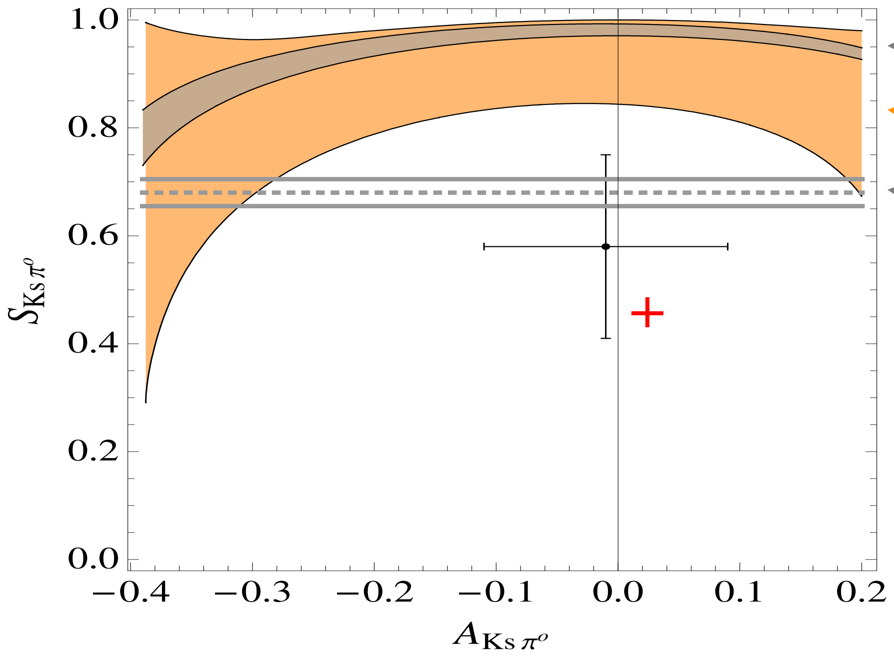


$$A_{CP} = A\cos(\Delta M \Delta t) + S\sin(\Delta M \Delta t)$$

	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$K_S^0\pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

Isospin symmetry:

$\mathcal{B}(B^0 \to \pi^0 K_S)$, $\mathcal{B}(B^0 \to \pi^+ K^-)$, $\mathcal{B}(B^+ \to \pi^0 K^+)$, $\mathcal{B}(B^+ \to \pi^+ K_S)$ constrain A_{CP} of $B^0 \to \pi^0 K_S$



*Belle II 50 ab^{-1} **indirect** constraint*

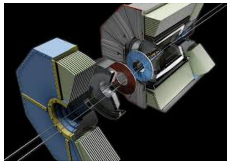
Preferred region based on current branching fractions

$b \to ccs$ WA

Current WA

*Belle II 50 ab^{-1} **direct** measurement*

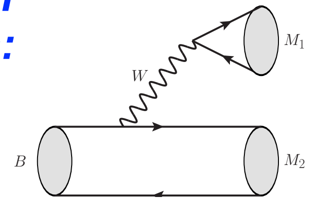
Details:
Fleischer et al., EPJC 78, 943 (2018), arXiv:1806.08783;
Fleischer et al., PRD 78, 111501 (2008), arXiv:0806.2900;
Gronau and Rosner, PLB 666, 467 (2008), arXiv:0807.3080.



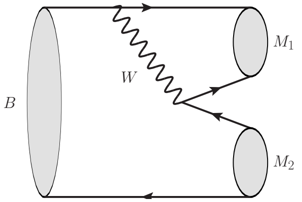
Direct CPV in $B^0 \to \pi K$

"The Belle II Physics Book"
PTEP 2019, 123C01 (2019)
[arXiv:1808.10567]

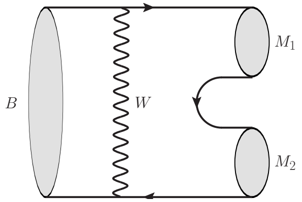
Topological amplitudes:



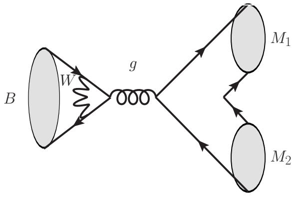
$T = \alpha_1$



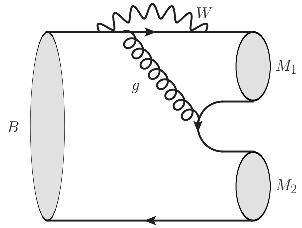
$C = \alpha_2$



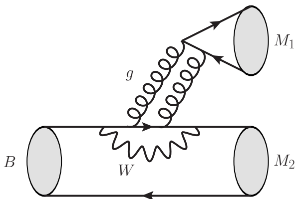
$E = \beta_2$



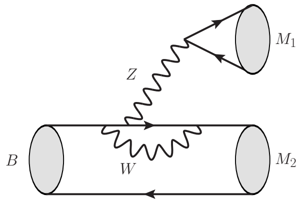
$PA = \beta_4$



$P = \alpha_4 + \beta_3$



$S = \alpha_3$



$P_{EW} = \alpha_{3,EW}$

QCD Factorization:

$$\mathcal{A}_{B^-\to\pi^-\bar{K}^0} = \lambda_p\, A_{\pi\bar{K}}\Big[\hat{\alpha}_4^p - \tfrac{1}{2}\alpha^p_{4,\mathrm{EW}}\Big]\,,$$

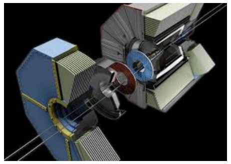
$$\boxed{\begin{aligned}\sqrt{2}\,\mathcal{A}_{B^-\to\pi^0K^-} &= \lambda_p\, A_{\pi\bar{K}}\Big[\delta_{pu}\,\alpha_1 + \hat{\alpha}_4^p + \alpha^p_{4,\mathrm{EW}}\Big] + \lambda_p\, A_{\bar{K}\pi}\Big[\delta_{pu}\,\alpha_2 + \tfrac{3}{2}\alpha^p_{3,\mathrm{EW}}\Big]\,,\\ \mathcal{A}_{\bar{B}^0\to\pi^+K^-} &= \lambda_p\, A_{\pi\bar{K}}\Big[\delta_{pu}\,\alpha_1 + \hat{\alpha}_4^p + \alpha^p_{4,\mathrm{EW}}\Big],\end{aligned}}$$

$$\sqrt{2}\,\mathcal{A}_{\bar{B}^0\to\pi^0\bar{K}^0} = \lambda_p\, A_{\pi\bar{K}}\Big[-\hat{\alpha}_4^p + \tfrac{1}{2}\alpha^p_{4,\mathrm{EW}}\Big] + \lambda_p\, A_{\bar{K}\pi}\Big[\delta_{pu}\,\alpha_2 + \tfrac{3}{2}\alpha^p_{3,\mathrm{EW}}\Big]\,,$$

Assuming α_2 and $\alpha_{3,EW}$ small, $A_{CP}(B^- \to \pi^0 K^-) = A_{CP}(B^0 \to \pi^+ K^-)$

Data: $A_{CP}(B^- \to \pi^0 K^-) - A_{CP}(B^0 \to \pi^+ K^-) = (12.2 \pm 2.2)\%$ "the K-π puzzle"

Exciting possibility: $\alpha_{3,EW}$ has NP **Current thinking:** α_2 is enhanced by perturbative corrections
Still a problem: such an enhancement doesn't affect strong phase difference between α_2 and α_1 (to NNLO)



Search for NP via $B^0 \to \pi K$

“The Belle II Physics Book"
PTEP 2019, 123C01 (2019)
[arXiv:1808.10567]

Theory:

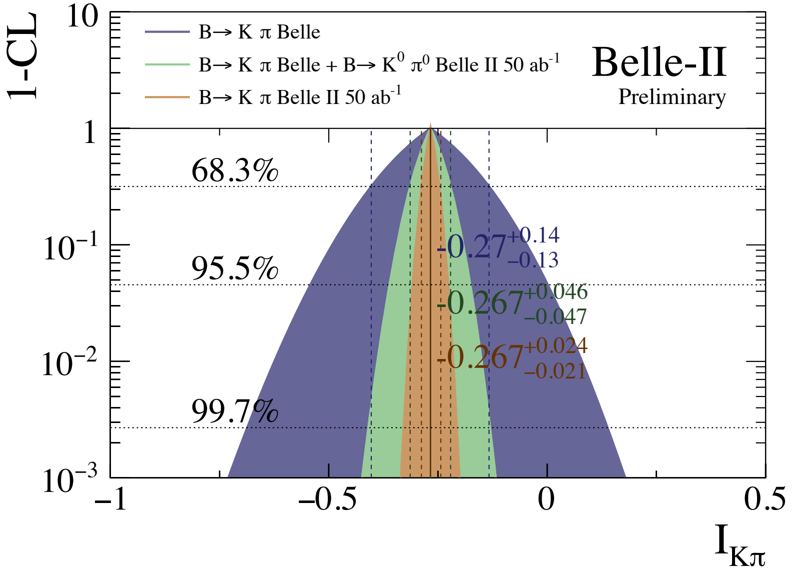
$$\boxed{\begin{aligned} I_{K\pi} &= A_{CP}^{K^+\pi^-}\Gamma(K^+\pi^-) + A_{CP}^{K^0\pi^+}\Gamma(K^0\pi^+) - 2A_{CP}^{K^+\pi^0}\Gamma(K^+\pi^0) - 2A_{CP}^{K^0\pi^0}\Gamma(K^0\pi^0) \\ &= A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)} \end{aligned}}$$

	NLO	NNLO	NNLO + LD	Exp (WA)	Exp (Belle II)
$\pi^-\bar{K}^0$	$0.71\,^{+0.13}_{-0.14}\,^{+0.21}_{-0.19}$	$0.77\,^{+0.14}_{-0.15}\,^{+0.23}_{-0.22}$	$0.10\,^{+0.02}_{-0.02}\,^{+1.24}_{-0.27}$	-1.7 ± 1.6	Belle input
π^0K^-	$9.42\,^{+1.77}_{-1.76}\,^{+1.87}_{-1.88}$	$10.18\,^{+1.91}_{-1.90}\,^{+2.03}_{-2.62}$	$-1.17\,^{+0.22}_{-0.22}\,^{+20.00}_{-6.62}$	4.0 ± 2.1	
π^+K^-	$7.25\,^{+1.36}_{-1.36}\,^{+2.13}_{-2.58}$	$8.08\,^{+1.52}_{-1.51}\,^{+2.52}_{-2.65}$	$-3.23\,^{+0.61}_{-0.61}\,^{+19.17}_{-3.36}$	-8.2 ± 0.6	
$\pi^0\bar{K}^0$	$-4.27\,^{+0.83}_{-0.77}\,^{+1.48}_{-2.23}$	$-4.33\,^{+0.84}_{-0.78}\,^{+3.29}_{-2.32}$	$-1.41\,^{+0.27}_{-0.25}\,^{+5.54}_{-6.10}$	1 ± 10	-14 ± 13
ΔA_{CP}	$2.17\,^{+0.40}_{-0.40}\,^{+1.39}_{-0.74}$	$2.10\,^{+0.39}_{-0.39}\,^{+1.40}_{-2.86}$	$2.07\,^{+0.39}_{-0.39}\,^{+2.76}_{-4.55}$	12.2 ± 2.2	
$I_{K\pi}$	$-1.15\,^{+0.21}_{-0.22}\,^{+0.55}_{-0.84}$	$-0.88\,^{+0.16}_{-0.17}\,^{+1.31}_{-0.91}$	$-0.48\,^{+0.09}_{-0.09}\,^{+1.09}_{-1.15}$	-14 ± 11	$-27 \pm 14(7)(3)$

Experiment:

$\mathcal{B}(10^{-6})$		
Mode	BaBar	Belle
$K^+\pi^-$	$19.1 \pm 0.6 \pm 0.6$	$20.0 \pm 0.34 \pm 0.60$
$K^+\pi^0$	$13.6 \pm 0.6 \pm 0.7$	$12.62 \pm 0.31 \pm 0.56$
$K^0\pi^+$	$23.9 \pm 1.1 \pm 1.0$	$23.97 \pm 0.53 \pm 0.71$
$K^0\pi^0$	$10.1 \pm 0.6 \pm 0.4$	$9.68 \pm 0.46 \pm 0.50$

A_{CP}			
Mode	BaBar	Belle	LHCb
$K^+\pi^-$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$-0.069 \pm 0.014 \pm 0.007$	$-0.080 \pm 0.007 \pm 0.003$
$K^+\pi^0$	$0.030 \pm 0.039 \pm 0.010$	$0.043 \pm 0.024 \pm 0.002$	
$K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$	$-0.011 \pm 0.021 \pm 0.006$	$-0.022 \pm 0.025 \pm 0.010$
$K^0\pi^0$	$-0.13 \pm 0.13 \pm 0.03$	$0.14 \pm 0.13 \pm 0.06$	

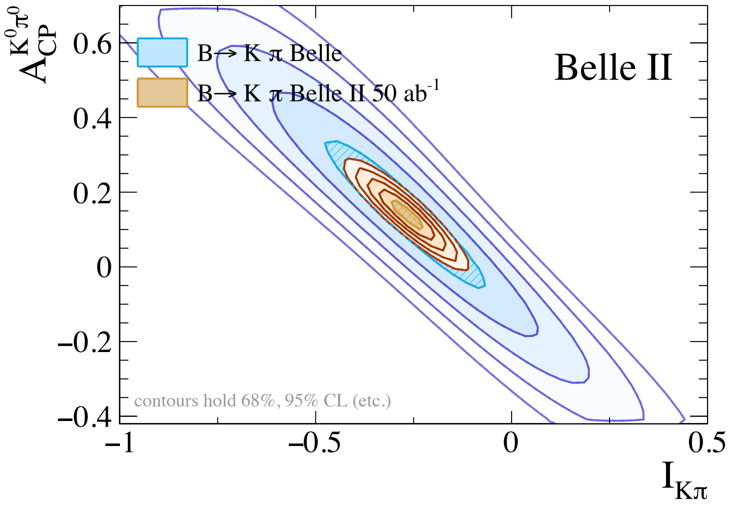


Search for NP via $B^0 \to \pi/\rho\, K^{(*)}$

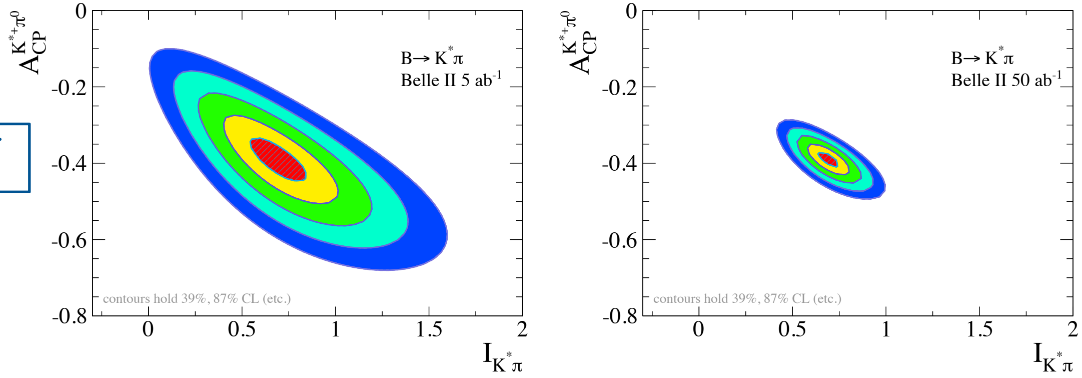
"The Belle II Physics Book"
PTEP 2019, 123C01 (2019)
[arXiv:1808.10567]

$$I_{K\pi} = A_{CP}^{K^+\pi^-}\Gamma(K^+\pi^-) + A_{CP}^{K^0\pi^+}\Gamma(K^0\pi^+) - 2A_{CP}^{K^+\pi^0}\Gamma(K^+\pi^0) - 2A_{CP}^{K^0\pi^0}\Gamma(K^0\pi^0)$$

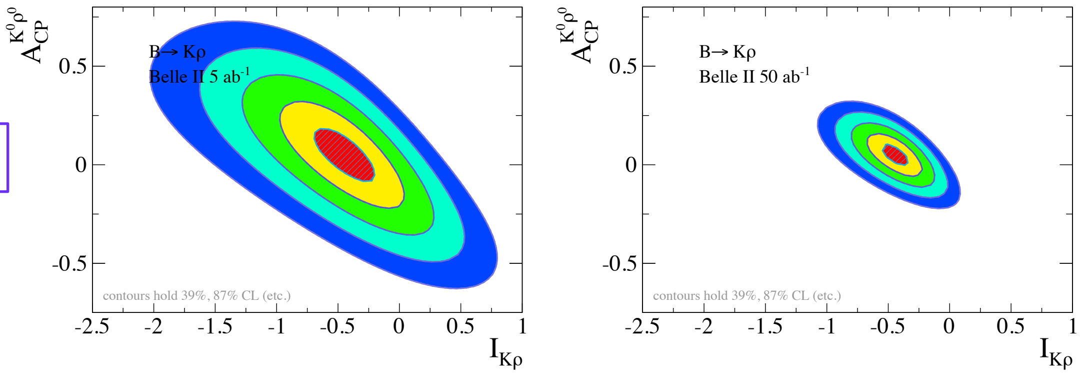
$B^0 \to \pi K$



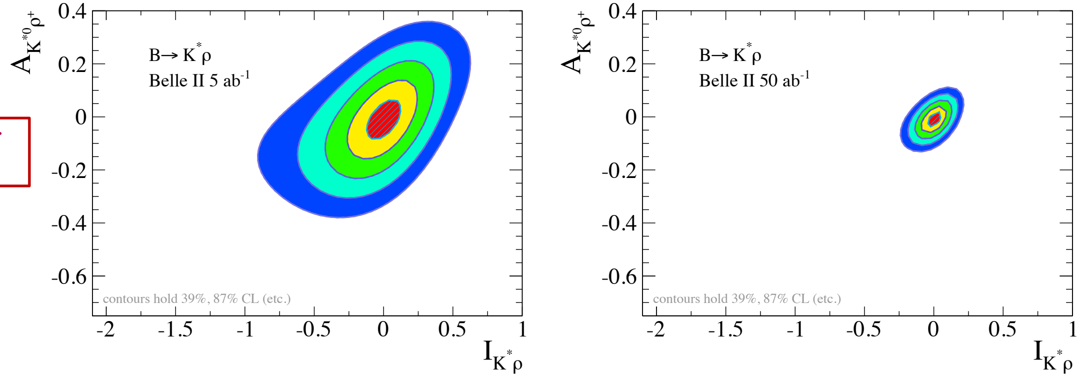
$B^0 \to \pi K^*$

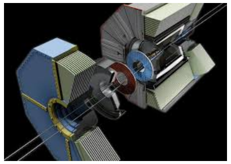


$B^0 \to \rho K$



$B^0 \to \rho K^*$





Inclusive $B \to X_{(s,d)}\ell^+\ell^-$ decays

"The Belle II Physics Book"
PTEP 2019, 123C01 (2019)
[arXiv:1808.10567]

Inclusive decays were measured at Belle/BaBar using a sum-of-exclusives method: e.g., $X_s = Kn(\pi)$ with $n \leq 4$ and max 1 π^0. This can be improved at Belle II:

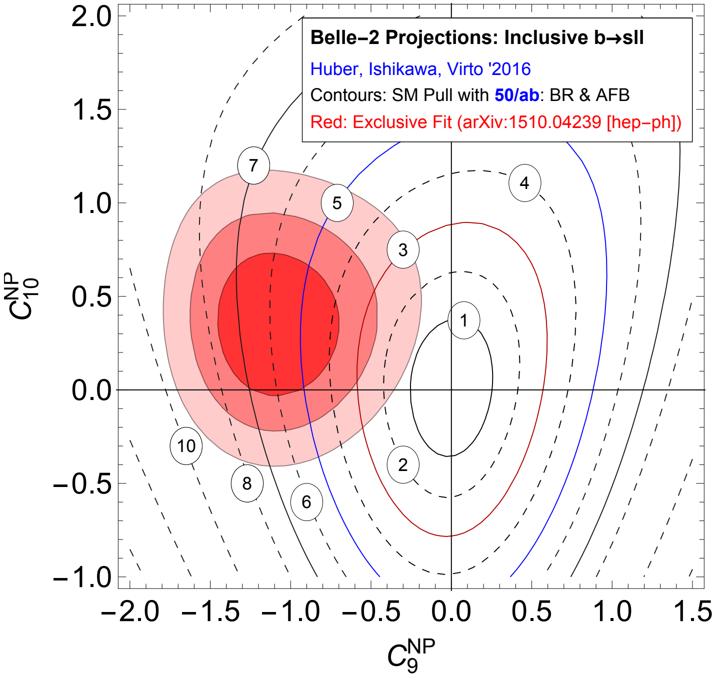
- *3 K modes can be included;*
- *more π^+ can possibly be included;*
- *another π^0 can possibly be included;*
- *improved full reconstruction on tagging side (with neural network)*
  should make true inclusive analysis feasible (under study)

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B \to X_s\ell^+\ell^-)$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	29%	13%	6.6%
$B(B \to X_s\ell^+\ell^-)$ $(3.5 < q^2 < 6.0\ \mathrm{GeV}^2)$	24%	11%	6.4%
$B(B \to X_s\ell^+\ell^-)$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	23%	10%	4.7%
$A_{CP}(B \to X_s\ell^+\ell^-)$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	26%	9.7 %	3.1 %
$A_{CP}(B \to X_s\ell^+\ell^-)$ $(3.5 < q^2 < 6.0\ \mathrm{GeV}^2)$	21%	7.9 %	2.6 %
$A_{CP}(B \to X_s\ell^+\ell^-)$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	21%	8.1 %	2.6 %
$A_{FB}(B \to X_s\ell^+\ell^-)$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	26%	9.7%	3.1%
$A_{FB}(B \to X_s\ell^+\ell^-)$ $(3.5 < q^2 < 6.0\ \mathrm{GeV}^2)$	21%	7.9%	2.6%
$A_{FB}(B \to X_s\ell^+\ell^-)$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	19%	7.3%	2.4%
$\Delta_{CP}(A_{FB})$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	52%	19%	6.1%
$\Delta_{CP}(A_{FB})$ $(3.5 < q^2 < 6.0\ \mathrm{GeV}^2)$	42%	16%	5.2%
$\Delta_{CP}(A_{FB})$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	38%	15%	4.8%

$[\Delta_{CP}(A_{FB}) = A_{FB}(B\text{-bar}) - A_{FB}(B)\ ]$

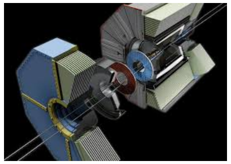
Note: *A_{FB} provides stringent constraint on C_9, C_{10}*

Belle II 50 ab^{-1} exclusion contours
(BR and A_{FB} of inclusive $b \to s\ell\ell$) :

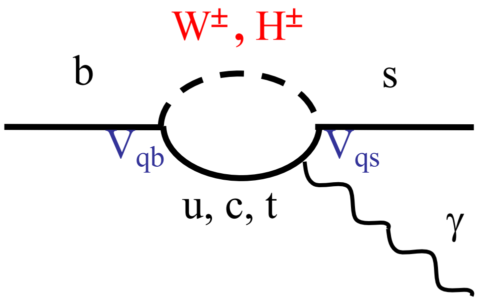


ⓝ σ pull to SM fit if true values

Exclusive decays fit:
Descotes-Genon et al., JHEP 06 (2016)092
Aebischer et al., EPJC 80 (2020) 252



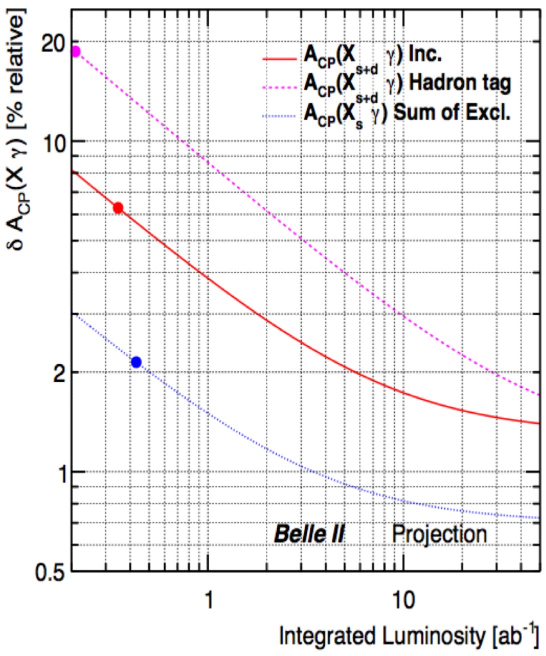
Inclusive $B \rightarrow X_{(s,d)}\gamma$ radiative decays



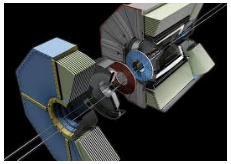
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B \to X_s\gamma)^{\text{lep-tag}}_{\text{inc}}$	5.3%	3.9%	3.2%
$\mathrm{Br}(B \to X_s\gamma)^{\text{had-tag}}_{\text{inc}}$	13%	7.0%	4.2%
$\mathrm{Br}(B \to X_s\gamma)_{\text{sum-of-ex}}$	10.5%	7.3%	5.7%
$\Delta_{0+}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.1%	0.81%	0.63%
$\Delta_{0+}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	9.0%	2.6%	0.85%
$A_{\text{CP}}(B \to X_s\gamma)_{\text{sum-of-ex}}$	1.3%	0.52%	0.19%
$A_{\text{CP}}(B^0 \to X_s^0\gamma)_{\text{sum-of-ex}}$	1.8%	0.72%	0.26%
$A_{\text{CP}}(B^+ \to X_s^+\gamma)_{\text{sum-of-ex}}$	1.8%	0.69%	0.25%
$A_{\text{CP}}(B \to X_{s+d}\gamma)^{\text{lep-tag}}_{\text{inc}}$	4.0%	1.5%	0.48%
$A_{\text{CP}}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	8.0%	2.2%	0.70%
$\Delta A_{\text{CP}}(B \to X_s\gamma)_{\text{sum-of-ex}}$	2.5%	0.98%	0.30%
$\Delta A_{\text{CP}}(B \to X_{s+d}\gamma)^{\text{had-tag}}_{\text{inc}}$	16%	4.3%	1.3%
$\mathrm{Br}(B \to X_d\gamma)_{\text{sum-of-ex}}$	30%	20%	14%
$\Delta_{0+}(B \to X_d\gamma)_{\text{sum-of-ex}}$	30%	11%	3.6%
$A_{\text{CP}}(B^+ \to X^+_{u\bar{d}}\gamma)_{\text{sum-of-ex}}$	42%	16%	5.1%
$A_{\text{CP}}(B^0 \to X^0_{d\bar{d}}\gamma)_{\text{sum-of-ex}}$	84%	32%	10%
$A_{\text{CP}}(B \to X_d\gamma)_{\text{sum-of-ex}}$	38%	14%	4.6%
$\Delta A_{\text{CP}}(B \to X_d\gamma)_{\text{sum-of-ex}}$	93%	36%	11%

un-measured

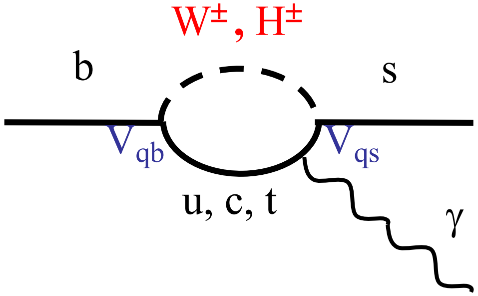
[$\Delta A_{\text{CP}} = A_{\text{CP}}(B^+) - A_{\text{CP}}(B^0) \propto \mathrm{Im}(C_8/C_7)$]



Note: *experimental error from background subtraction grows as E_γ is lower; theoretical errors grow as E_γ is higher. Both A_{CP} (residual photon contribution) and isospin asymmetry Δ_{0+} (S_{78}) reduce theoretical uncertainties in the inclusive BF*



Exclusive B→Vγ radiative decays



Observables	Belle 0.71 ab^{-1} (0.12 ab^{-1})	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\Delta_{0+}(B \to K^*\gamma)$	2.0%	0.70%	0.53%
$A_{\rm CP}(B^0 \to K^{*0}\gamma)$	1.7%	0.58%	0.21%
$A_{\rm CP}(B^+ \to K^{*+}\gamma)$	2.4%	0.81%	0.29%
$\Delta A_{\rm CP}(B \to K^*\gamma)$	2.9%	0.98%	0.36%
$S_{K^{*0}\gamma}$	0.29	0.090	0.030
$\text{Br}(B^0 \to \rho^0\gamma)$	24%	7.6%	4.5%
$\text{Br}(B^+ \to \rho^+\gamma)$	30%	9.6%	5.0%
$\text{Br}(B^0 \to \omega\gamma)$	50%	14%	5.8%
$\Delta_{0+}(B \to \rho\gamma)$	18%	5.4%	1.9%
$A_{\rm CP}(B^0 \to \rho^0\gamma)$	44%	12%	3.8%
$A_{\rm CP}(B^+ \to \rho^+\gamma)$	30%	9.6%	3.0%
$A_{\rm CP}(B^0 \to \omega\gamma)$	91%	23%	7.7%
$\Delta A_{\rm CP}(B \to \rho\gamma)$	53%	16%	4.8%
$S_{\rho^0\gamma}$	0.63	0.19	0.064
$\lvert V_{td}/V_{ts}\rvert_{\rho/K^*}$	12%	8.2%	7.6%
$\text{Br}(B_s^0 \to \phi\gamma)$	23%	6.5%	–
$\text{Br}(B^0 \to K^{*0}\gamma)/\text{Br}(B_s^0 \to \phi\gamma)$	23%	6.7%	–
$\text{Br}(B_s^0 \to K^{*0}\gamma)$	–	15%	–
$A_{\rm CP}(B_s^0 \to K^{*0}\gamma)$	–	15%	–
$\text{Br}(B_s^0 \to K^{*0}\gamma)/\text{Br}(B_s^0 \to \phi\gamma)$	–	15%	–
$\text{Br}(B^0 \to K^{*0}\gamma)/\text{Br}(B_s^0 \to K^{*0}\gamma)$	–	15%	–

systematics limited: f_{+-}/f_{00}

statistics limited

statistics limited

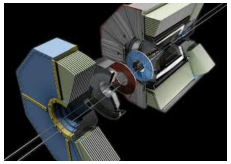
Theory:

$\Delta_{0+}(K^*\gamma) = (4.9 \pm 2.6)\%$
$A_{CP}(K^*\gamma) = (0.3 \pm 0.1)\%$
[constrains $\text{Im}(C_7)$]

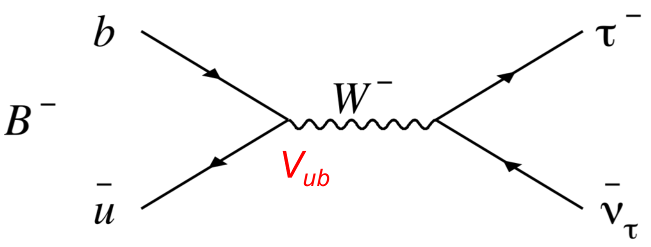
$\Delta_{0+}(\rho\gamma) = (5.2 \pm 2.8)\%$

Lyon and Zwicky, PRD D88, 094004 (2013)

Paul and Straub, JHEP 04, 027 (2017)



$|V_{ub}|$ via $B^+ \to \tau^+ \nu$



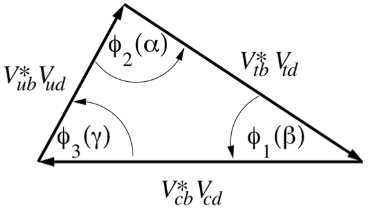
Belle + BaBar average:

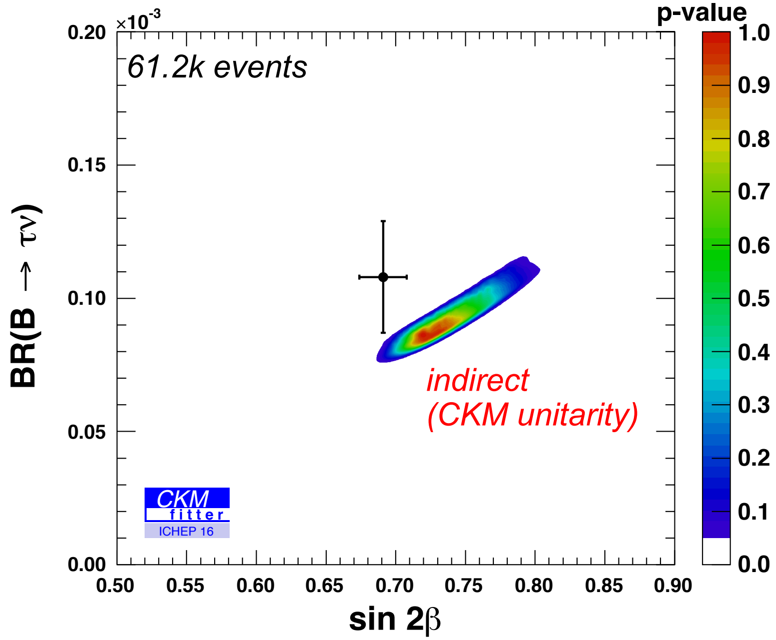
$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.06 \pm 0.20) \times 10^{-4}$

using $f_B = (190.0 \pm 1.3)$ MeV *(FLAG 2019, arXiv:1902.08191)*

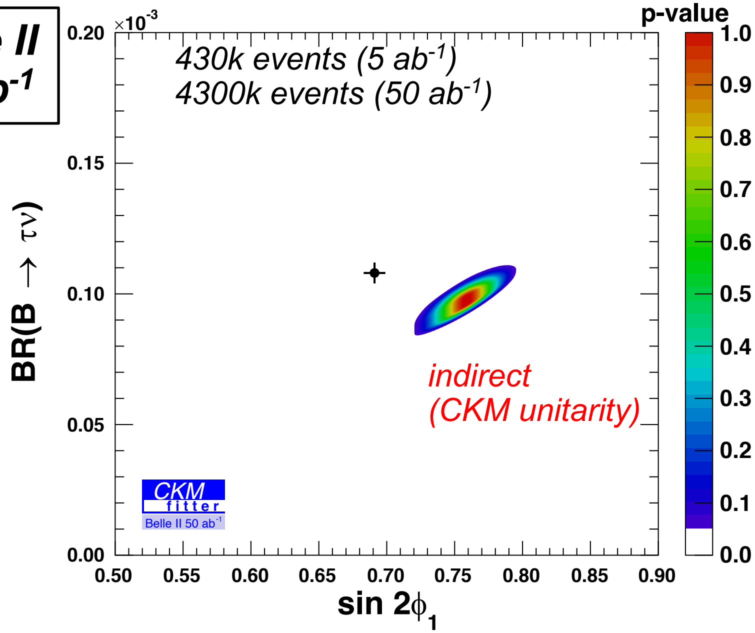
⇒ $|V_{ub}| = (4.05 \pm 0.37) \times 10^{-3}$

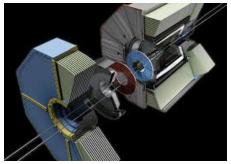
There is rough agreement between $|V_{ub}|$ measured in $\mathcal{B}(B^+ \to \tau^+ \nu)$ and ϕ_1 (β) and ϕ_2 (α):





Belle II
50 ab^{-1}



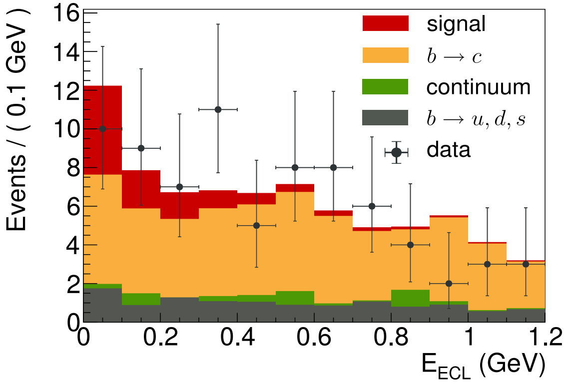


$B \to h \nu\nu$ $(h = \pi^+, \pi^0, \rho^+, \rho^0, K^+, K_S, K^{*0}, K^{*+})$

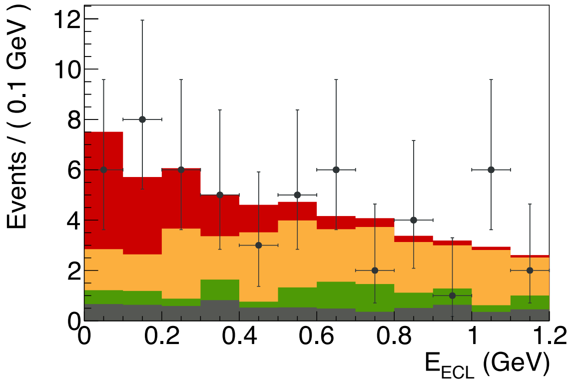
711 fb^{-1} Grygier et al. (Belle), PRD 96, 091101 (2017)

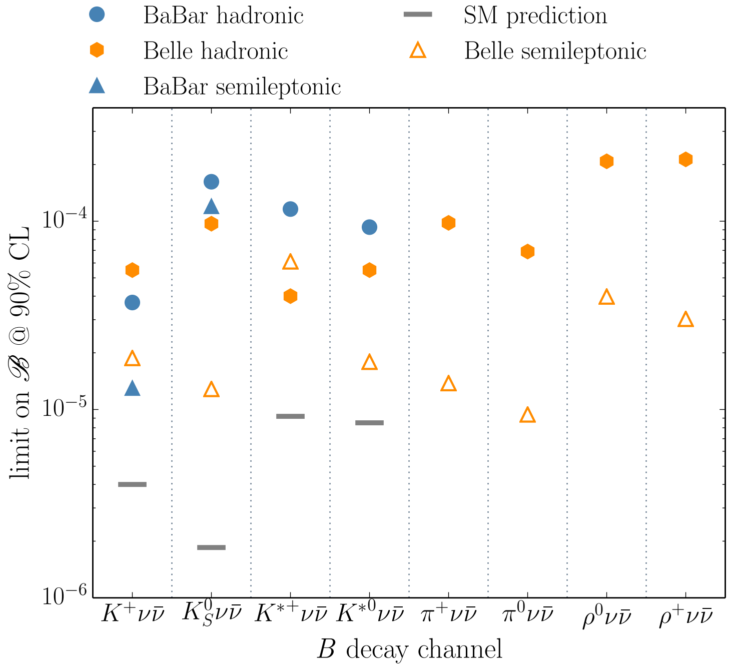
- **Semileptonic tag:** use Neural Network (NN) to identify $B \to D^{(*)} l \nu$ decay on tagging side. Including D^0 and D^+ modes, there are 108 different decay channels considered.
- Require only relevant tracks on signal side: no extra tracks, extra π^0's, or K_L's.
- Suppress continuum background (uu, dd, ss, cc) with a second NN based on Fox-Wolfram moments, event topology
- Reject backgrounds with a third NN based on 17-31 kinematic variables
- Fit E_{ECL} (unassociated energy in the calorimeter) distribution for signal

ρ^0



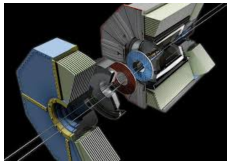
K^{*+}





- no signals observed. most limits are the world's best
- limits are a factor of 2.7 (K^*) – 3.9 (K) above SM prediction

⇒ Belle II should get to SM level



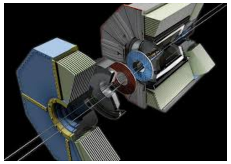
Summary

- *Belle II is now ~fully constructed and installed. The only missing element is the second layer of the PXD (to be installed in 2020/2021). The experiment has finished 3 limited running periods, thus far accumulating ~70 fb^{-1} of data.*

- *Detector is working: seeing clean signals for D and B decays. Many first physics signals shown at ICHEP 2020.*

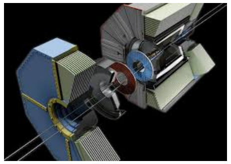
- *Accelerator commissioning is proceeding, but there are challenges (as expected) for this new machine: background is higher than expected, dominated by beam gas. β_y^* is slowly being reduced. Both instantaneous luminosity and specific luminosity already higher than Belle and BaBar.*

- *Physics potential is large: there is much better vertexing (and thus decay time resolution) and better particle ID than in Belle; full reconstruction on tag side is notably improved over Belle/BaBar; and factor of 50x statistics.*



Extra

Extra Slides

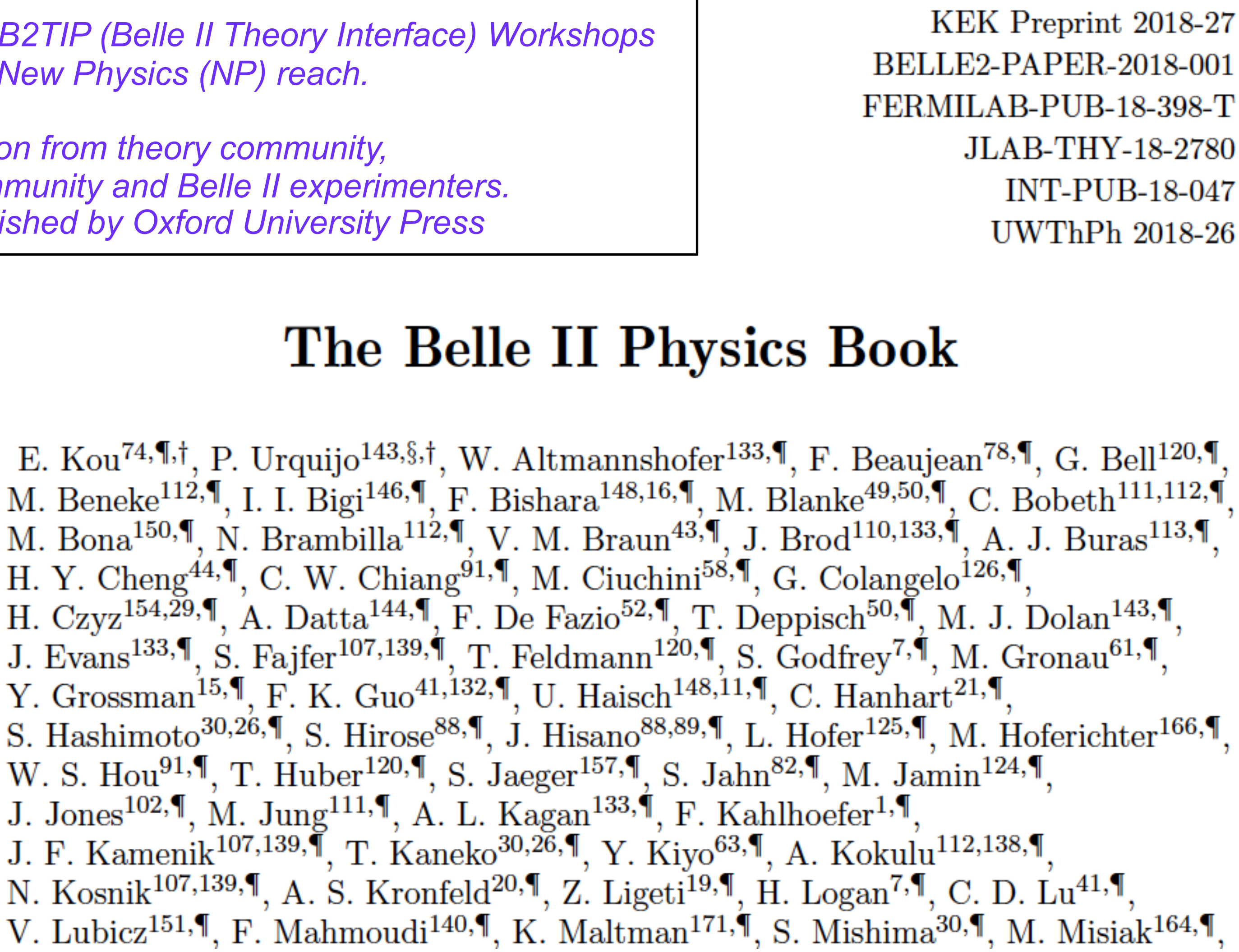


Physics potential

E. Kou et al., Prog. Theor. Exp. Phys. 2019, 123C01 (2019) [arxiv.org/abs/1808.10567]

Outcome of the B2TIP (Belle II Theory Interface) Workshops
Emphasis is on New Physics (NP) reach.

Good participation from theory community,
lattice QCD community and Belle II experimenters.
689 pages, published by Oxford University Press



KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

The Belle II Physics Book

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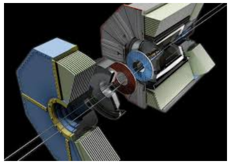
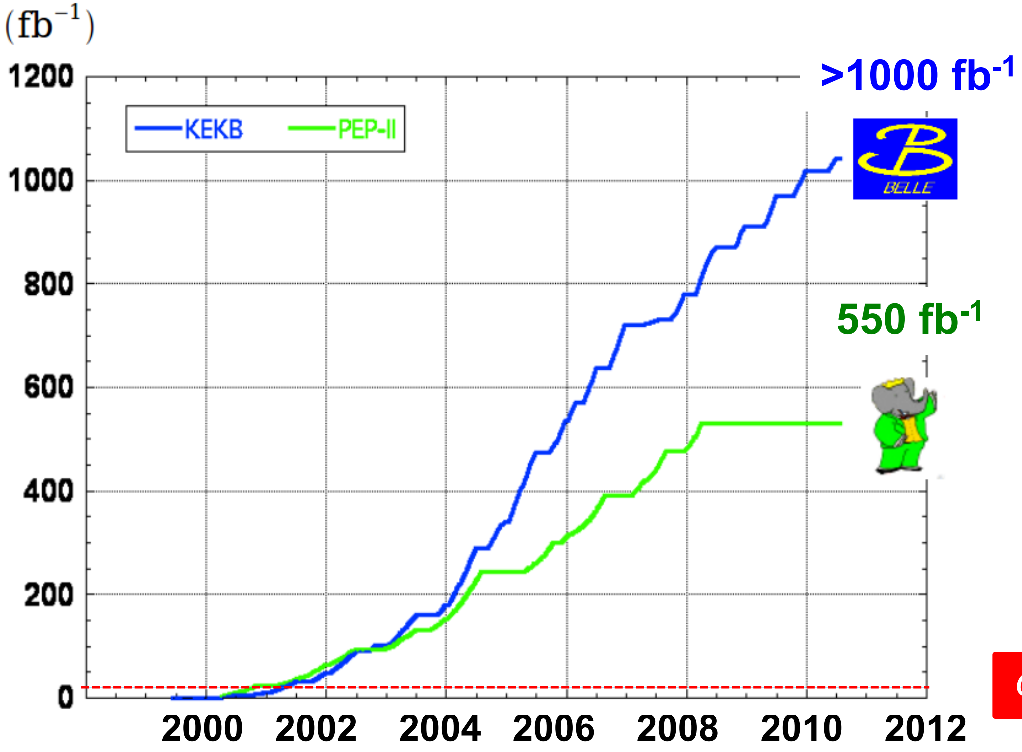


History

The Belle + BaBar Era:

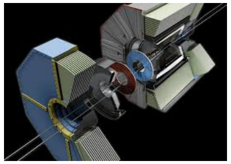
The "B Factory" experiments Belle and BaBar ran for ~10 years (2000-2010): 556 (Belle) + 595 (BaBar) = 1151 physics papers published, many discoveries (CPV in $B^0 \to J/\psi K^0$, direct CPV in $B^0 \to \pi^+\pi^-$, D^0-D^0bar mixing, X(3872), D_{sJ}(2317), etc.), ***a Nobel Prize*** *(Kobayashi and Maskawa, 2008)*



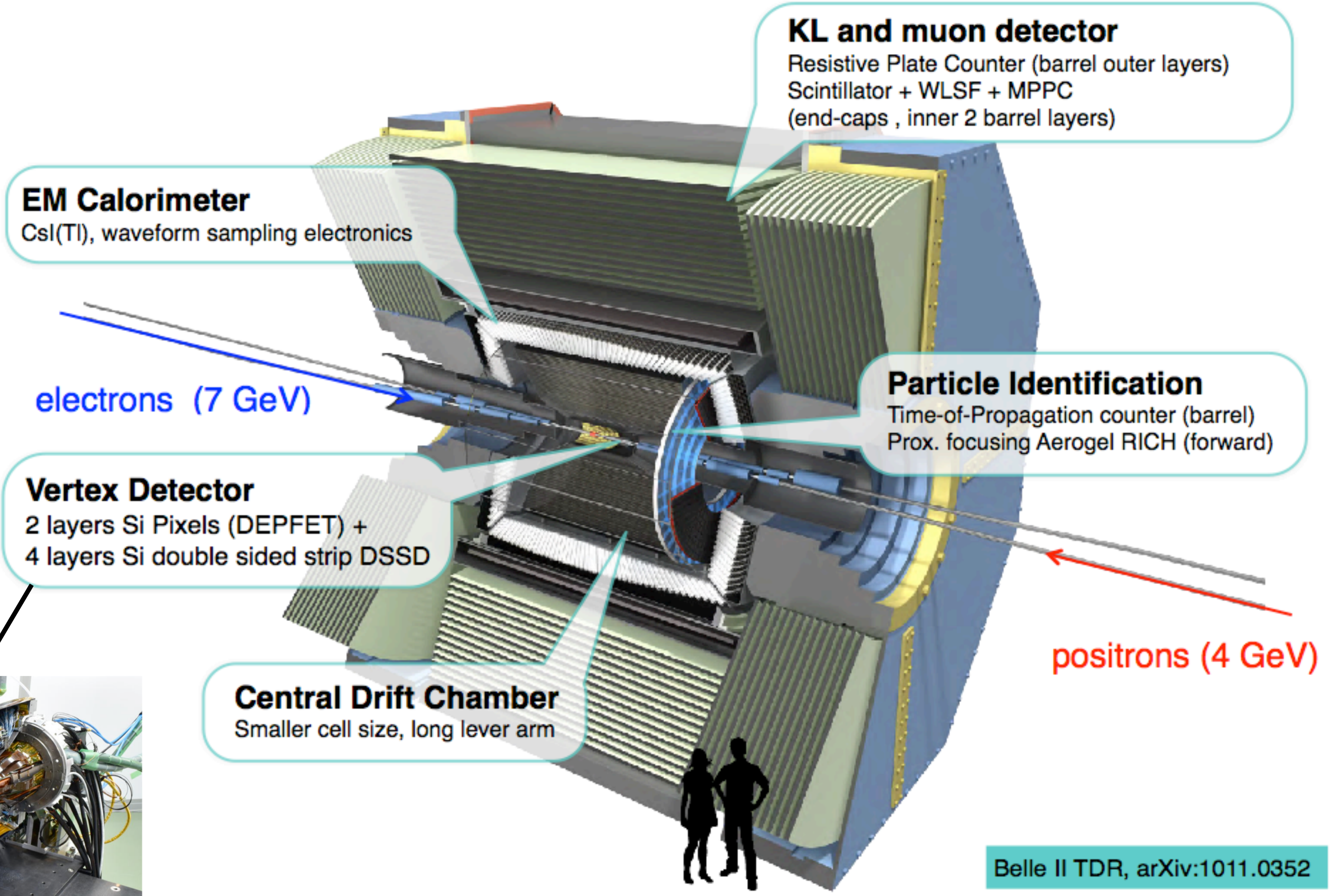
CLEO 11 fb⁻¹

Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

Belle II *is a significant upgrade of Belle: new accelerator, new detector, new electronics, new DAQ, new trigger.* ***Goal:*** *50 ab^{-1} of data*



The Belle II Detector



KL and muon detector
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC
(end-caps , inner 2 barrel layers)

EM Calorimeter
CsI(Tl), waveform sampling electronics

electrons (7 GeV)

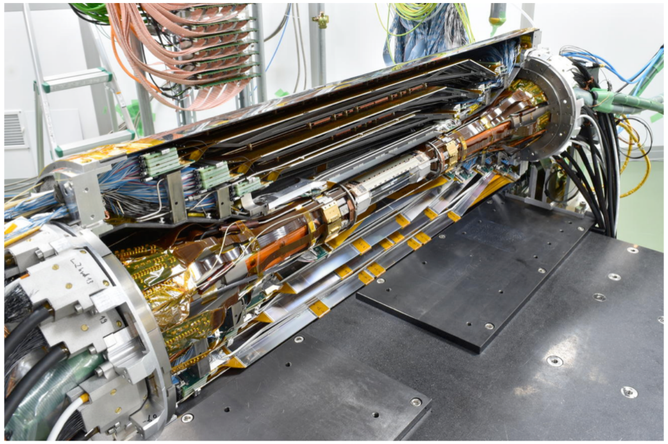
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

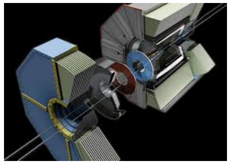
Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD

positrons (4 GeV)

Central Drift Chamber
Smaller cell size, long lever arm

Belle II TDR, arXiv:1011.0352

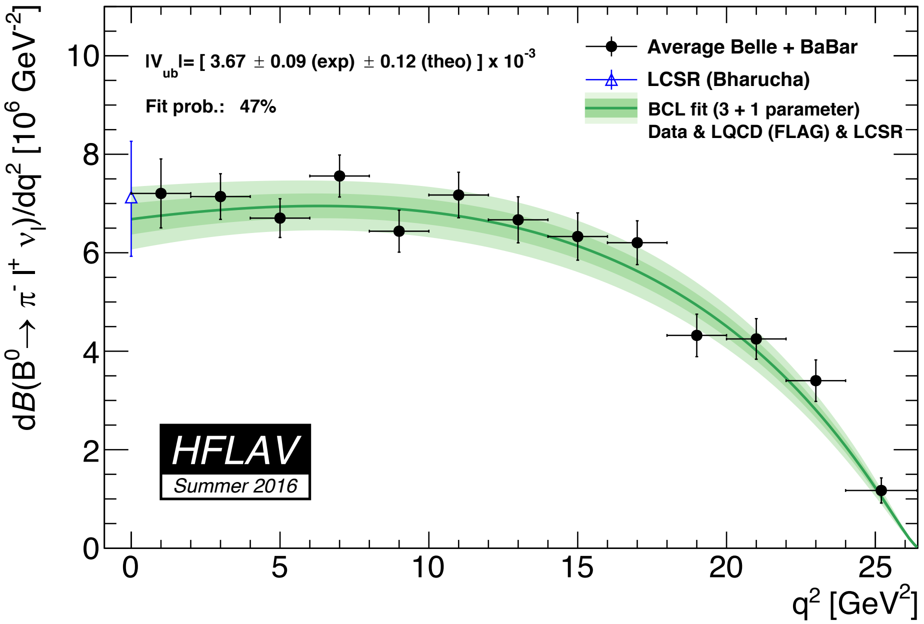




$|V_{ub}|$ via exclusive $B\to\pi l\nu$

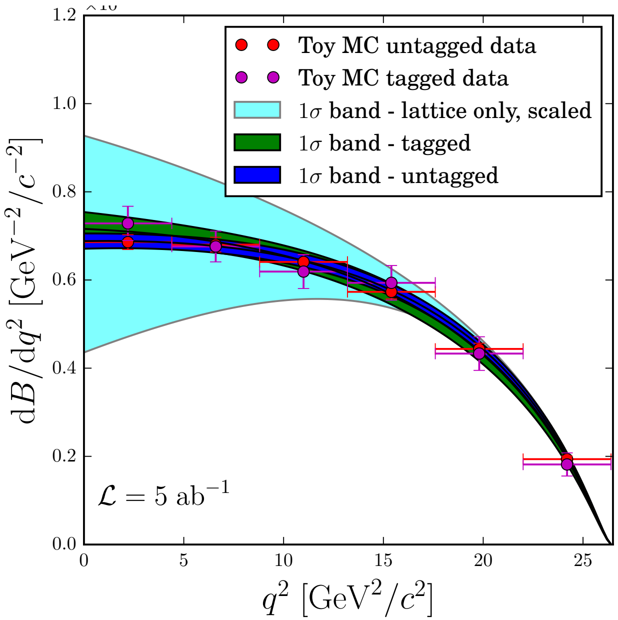
$$\boxed{\frac{d\Gamma(B\to P\ell^+\nu)}{dq^2} = \frac{G_F^2}{24\pi^3}|f^+(q^2)|^2|V_{ub}|^2 p^{*3}}$$

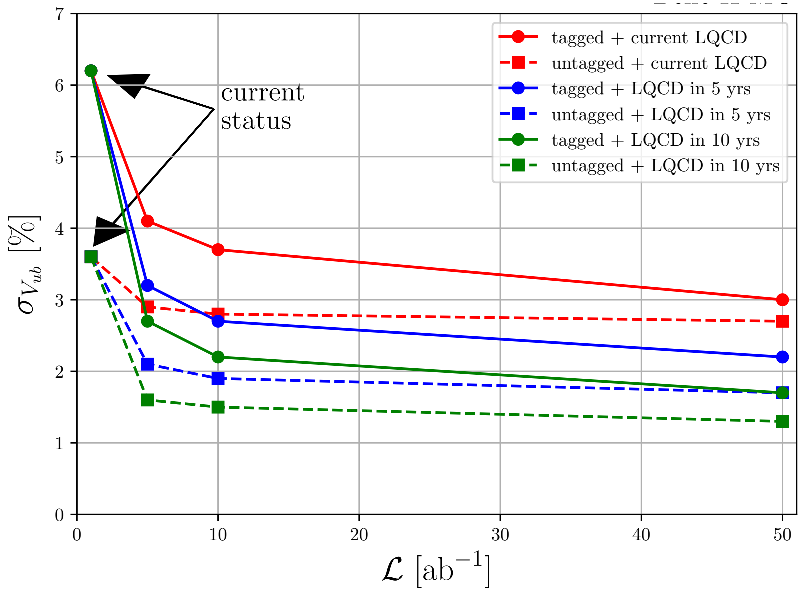
Use BCL parametrization of form factor, fit q^2 spectrum for BCL parameters and $|V_{ub}|$



$|V_{ub}| = (3.67 \pm 0.09_{exp} \pm 0.12_{th}) \times 10^{-3}$

Belle II 5 ab^{-1} $B\to\pi l\nu$





BCL: *Bourrely, Caprini, Lellouch, PRD 79, 013008 (2009)*
Lattice: *Aoki et al., (FLAG), EPJC 77, 112, (2017)*
LCSR: *Bharucha, JHEP 05, 092, (2012)*
HFLAV: *EPJC 77 (2017) 895 [arXiv:1612.07233]*