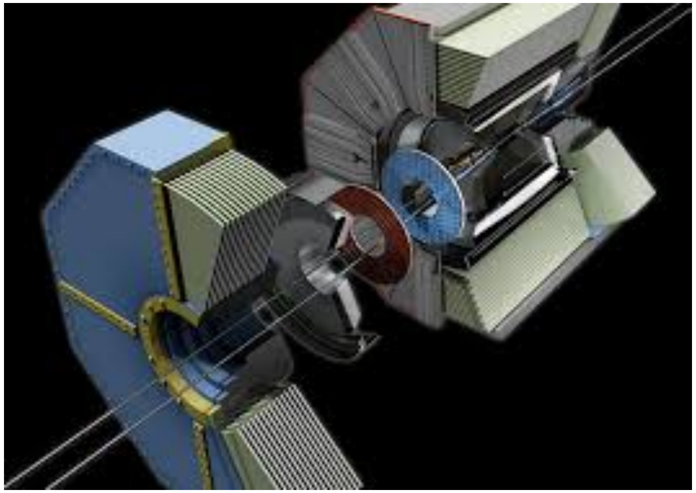


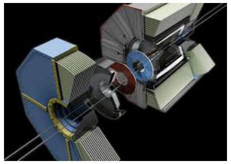
Physics Prospects for Belle II

Alan Schwartz
University of Cincinnati, USA

American Physical Society April Meeting

Denver, Colorado
14 April 2019

- *overview*
- *measurement of angles*
- *measurement of sides ($|V_{ub}|$)*
- *searches for new physics [$R(D^{(*)})$...]*
- *status and schedule*



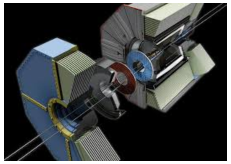
Motivation

Why a flavor factory?

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.

Why an e^+e^- Machine?

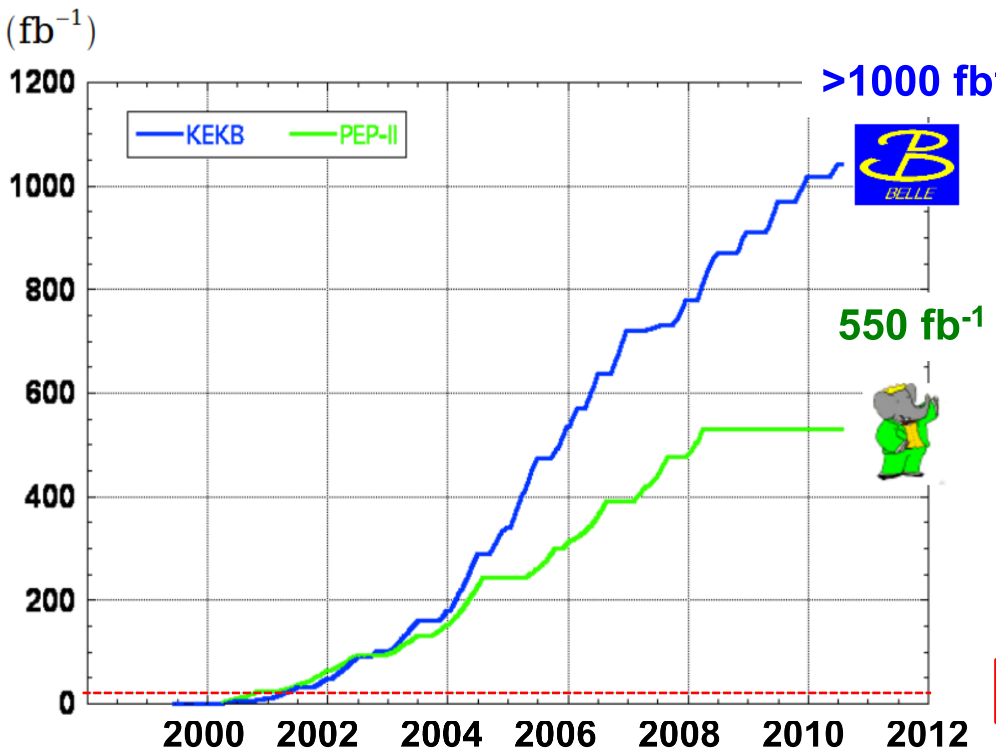
- *Low backgrounds, high trigger efficiency, excellent γ and π^0 recontruction (and thus η, η', ρ+, etc. reconstruction), high flavor-tagging efficiency with low dilution, many control samples to study systematics*
- *Due to low backgrounds, negligible trigger bias, and good kinematic resolutions, Dalitz 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.*



History

The Belle + BaBar Era:

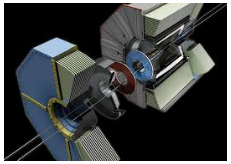
*The “B Factory” experiments Belle and BaBar ran for ~10 years (2000-2010) and were huge successes: **1108 papers** published to date, many discoveries (CPV in $B^0 \to J/\psi K^0$, direct CPV in $B^0 \to \pi^+\pi^-$, D^0-D^0bar mixing, X(3872), D_{sJ}(2317), etc.), **a Nobel Prize** (Kobayashi and Maskawa, 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*



Belle II physics: “golden modes”

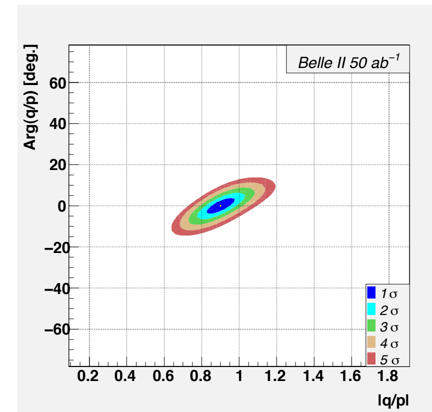
The Belle II Physics Book, arXiv:1808.10567, to appear in Prog. Theor. Exp. Physics

B physics:

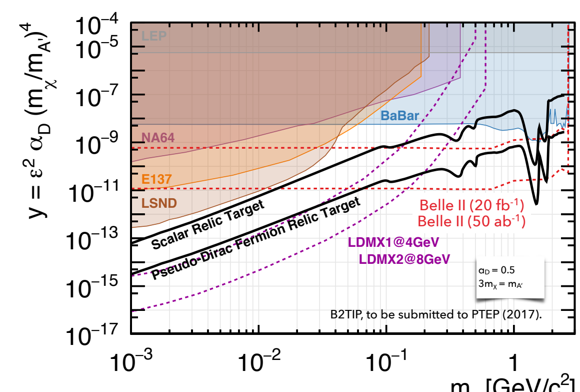
(● covered here)

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
$\lvert V_{cb}\rvert$ incl.	1%	Belle II
$\lvert V_{cb}\rvert$ excl.	1.5%	Belle II
$\lvert V_{ub}\rvert$ incl.	3%	Belle II
● $\lvert V_{ub}\rvert$ 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:

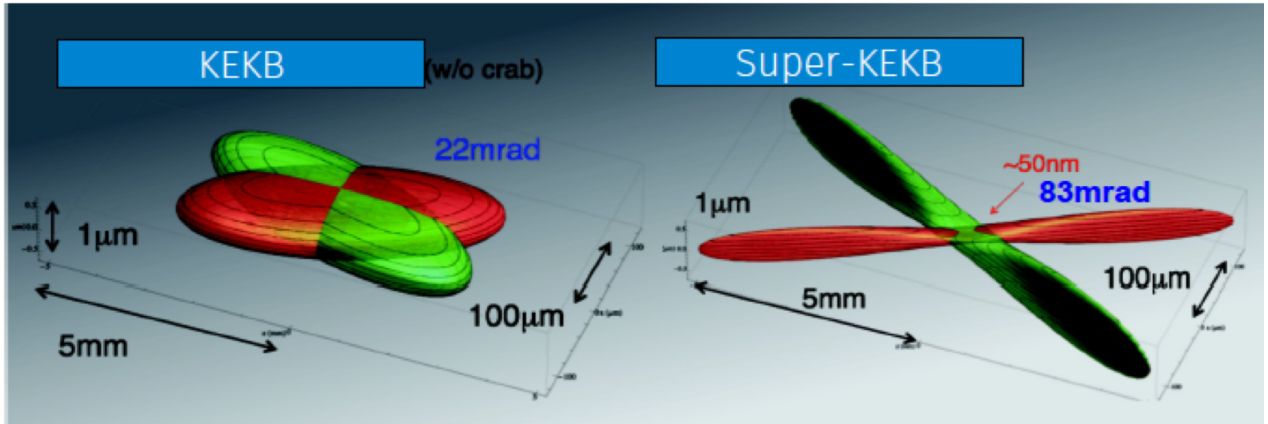


Dark Photon/Sector:



Tau physics
Quarkonium-like
B_s physics at Υ(5S)

How to get 40x instantaneous luminosity?



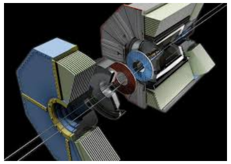
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

factor 20 factor 2-3

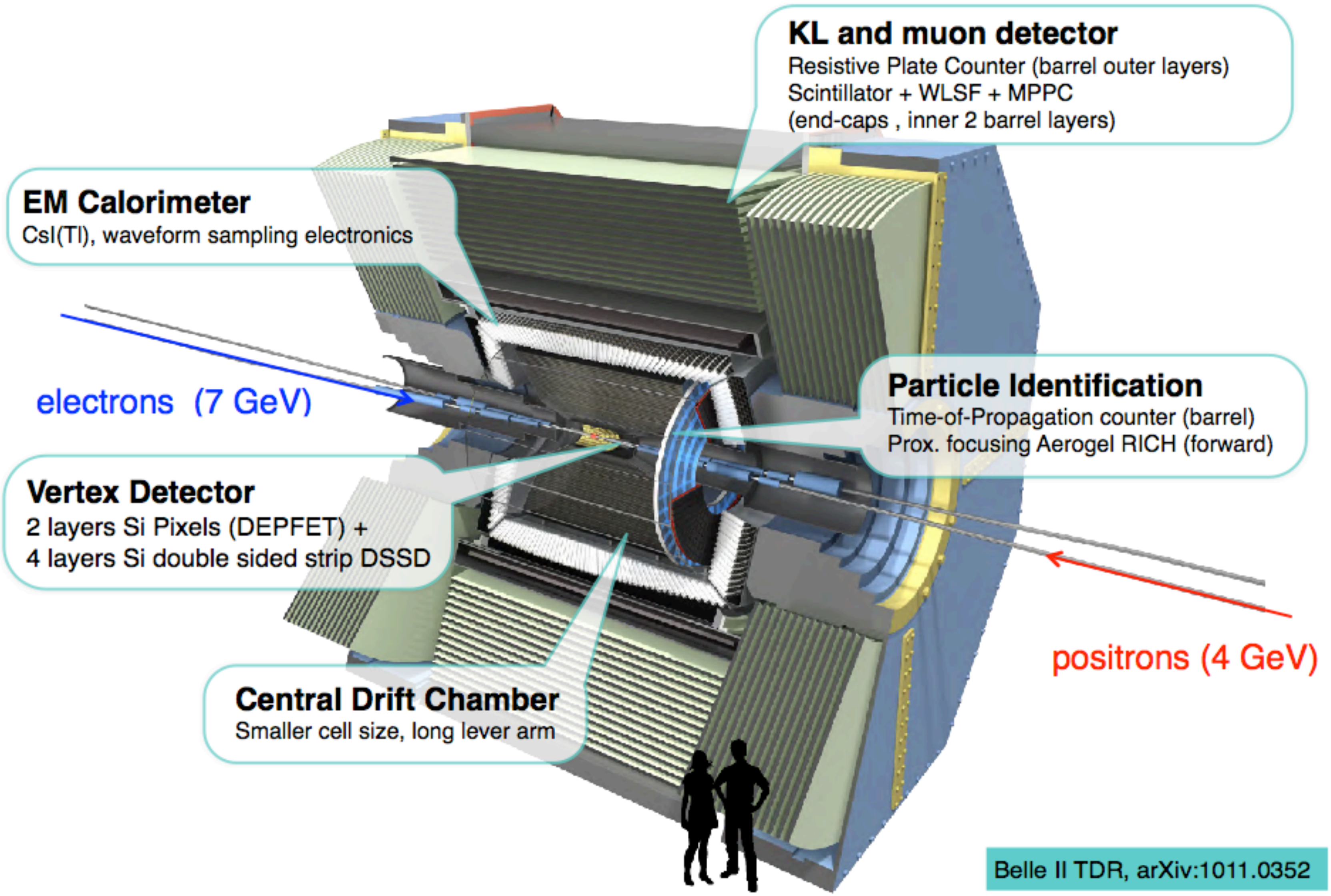
beam size:
100 μm(H) x 2 μm(V)
→ 10 μm(H) x 59 nm(V)

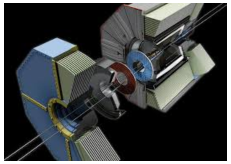
Belle-II Goal:
40 x Belle = 8 x 10^{35}

Final focus quadrupole being inserted:



The Belle II Detector





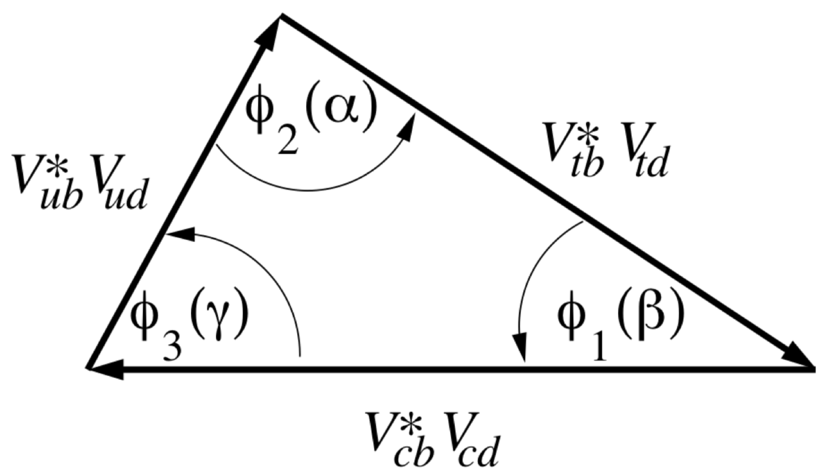
Unitarity triangle – determining the angles

$$V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0$$

The internal angles of this triangle are phase differences that can be measured via various strategies:

Belle/BaBar **LHCb**

- $B \to \pi^+\pi^- / \pi^+\pi^0 / \pi^0\pi^0$
- $B \to \rho^+\rho^- / \rho^+\rho^0 / \rho^0\rho^0$
- $B^0 \to \rho\,\pi$
- $B^0 \to a_1(\rho\pi)^+\,\pi^-$

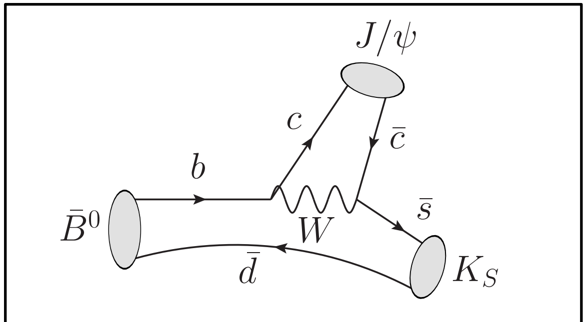


- $B^- \to D^{(*)}{}_{CP}\,K^{(*)-}$
- $B^0 \to D_{CP}\,K^{*0}$
- $B^- \to D^{(*)}(K^+\pi^-)\,K^{(*)-}$
- $B^- \to D^{(*)0}\,\pi^-$
- $B^- \to D^{(*)}(K_S\,\pi^+\pi^-)\,K^{(*)-}$
- $B^- \to D(\pi^0\pi^+\pi^-)\,K^-$
- $B^- \to D(K_S\,K^+\pi^-)\,K^-$

- $B^0 \to J/\psi\,K_S$
- $B^0 \to J/\psi\,K_L$
- $B^0 \to \psi'\,K_S$
- $B^0 \to \chi_c\,K_S$
- $B^0 \to \eta_c\,K_S$
- $B^0 \to D^{(*)}{}_{CP}\,h^0$
- $B^0 \to (\phi/\eta'/\pi^0/f^0)K^0$
- $B^0 \to (K_S K_S/\rho^0/\omega)K_S$

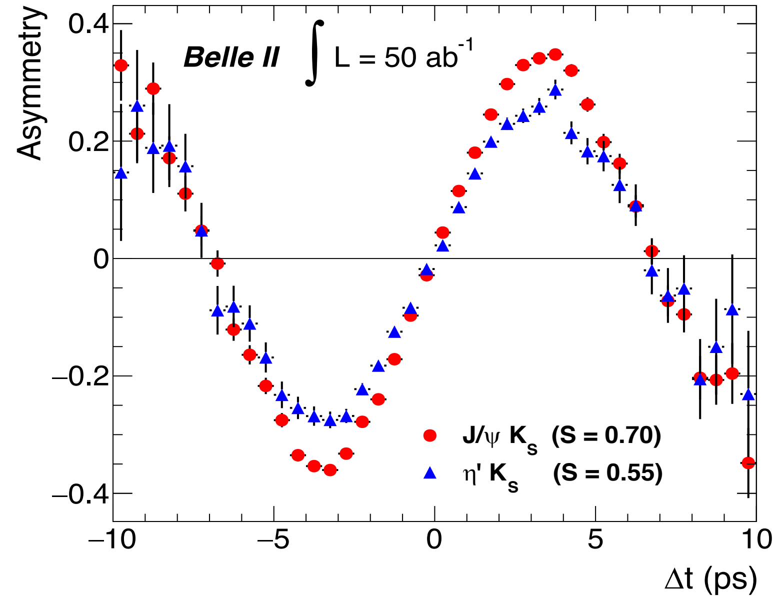
Determining ϕ_1 (β)

$B^0 \to J/\psi\, K_S$ *(the "Golden" mode):*



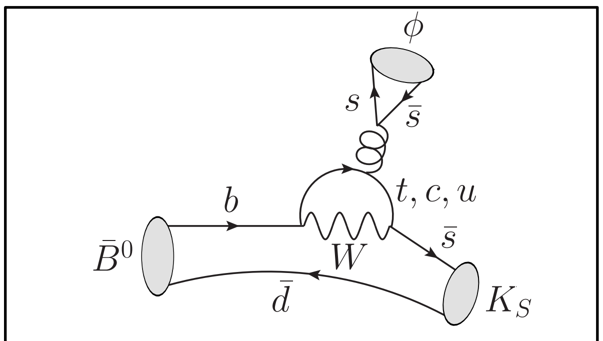
$$\mathcal{A}_{c\bar{c}s} \;=\; V^*_{cb}V_{cs}T + V^*_{ub}V_{us}P$$

expected 50 ab-1 uncertainty: $\delta\phi_1$ = 0.4°
(this is less than the current theory error of 1-2°)



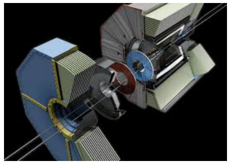
$$A_{CP} \;=\; A\cos(\Delta M\Delta t) + S\sin(\Delta M\Delta t)$$

$B^0 \to \phi\, K_S, \eta' K_S, \omega K_S, \pi^0 K_S$ *("penguin" modes):*



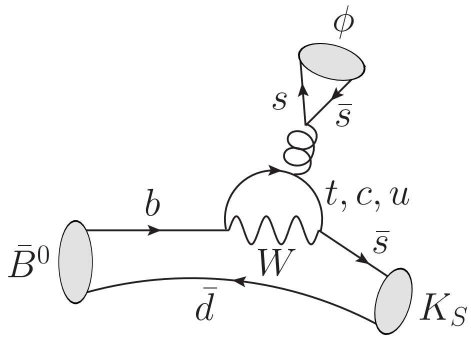
$$\mathcal{A}_{q\bar{q}s} \;=\; V^*_{cb}V_{cs}P + V^*_{ub}V_{us}T'$$

Channel	WA (2017) $\sigma(S)$	WA (2017) $\sigma(A)$	5 ab^{-1} $\sigma(S)$	5 ab^{-1} $\sigma(A)$	50 ab^{-1} $\sigma(S)$	50 ab^{-1} $\sigma(A)$
$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
ωK^0_S	0.21	0.14	0.08	0.06	0.024	0.020
$K^0_S\pi^0\gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K^0_S\pi^0$	0.17	0.10	0.09	0.06	0.028	0.018



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

The Belle II Physics Book, arXiv:1808.10567

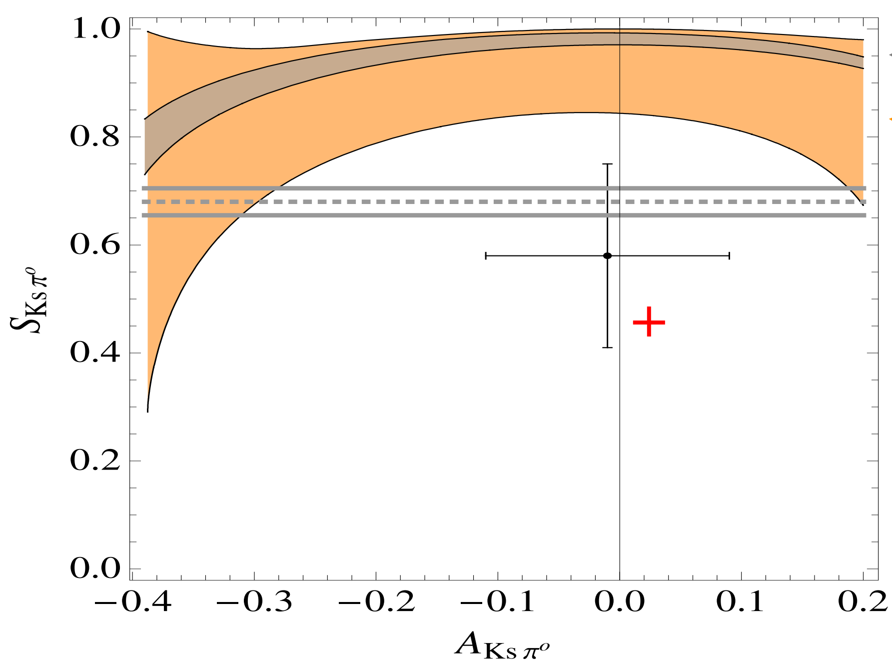


$$A_{CP} = A\cos(\Delta M \Delta t) + S\sin(\Delta M \Delta t)$$

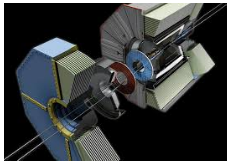
	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$K^0_S\pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

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 $B^0 \to \pi^0 K_S$



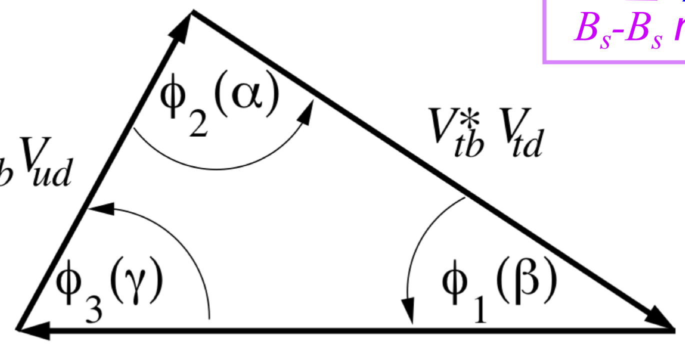
Also: Fleischer et al., arXiv:1806.08783



Determining sides of the Unitarity Triangle

Belle
LHCb

$B^0 \to \rho^0 \gamma$
B_s-$\bar{B}_s$ mixing



Jubb et al., Nucl. Phys. B 915, 431 (2017)
Artuso et al., RMP 88, 045002 (2016)
Lenz, Nierste, arXiv:1102.4274 (2011)
FNAL/MILC, PRD 93, 113016 (2016)
FLAG, EPJC 77, 112 (2017)

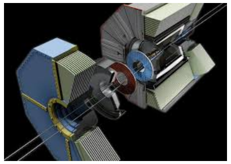
$B^0 \to \pi \ell^+ \nu$
$B^0 \to X_u \ell \nu$
$B^+ \to \tau^+ \nu$
$\Lambda_b \to p \ell \nu$

Bourrely et al., PRD 79, 013008 (2009)
FLAG, arXiv:1607.00299 (2016)
Bharucha, JHEP 05, 092 (2012)
Detmold et al., PRD 92, 034503 (2015)
Faustov and Galkin, PRD 94, 073008 (2016)

Lange et al. (BLNP), PRD 72, 073006 (2005)
Andersen, Gardi (DGE), JHEP 601, 97 (2006)
Gambino et al. (GGOU), JHEP 10, 058 (2007)
Aglietti et al. (ADFR), EPJ C59 (2009)
Bauer et al. (BLL), PRD 64, 113004 (2001)

$B^0 \to D^{(*)} \ell \nu$
$B^0 \to X_c \ell \nu$ (ℓ energy, hadron mass moments)
$B^0 \to X_s \gamma$ (γ energy moments)

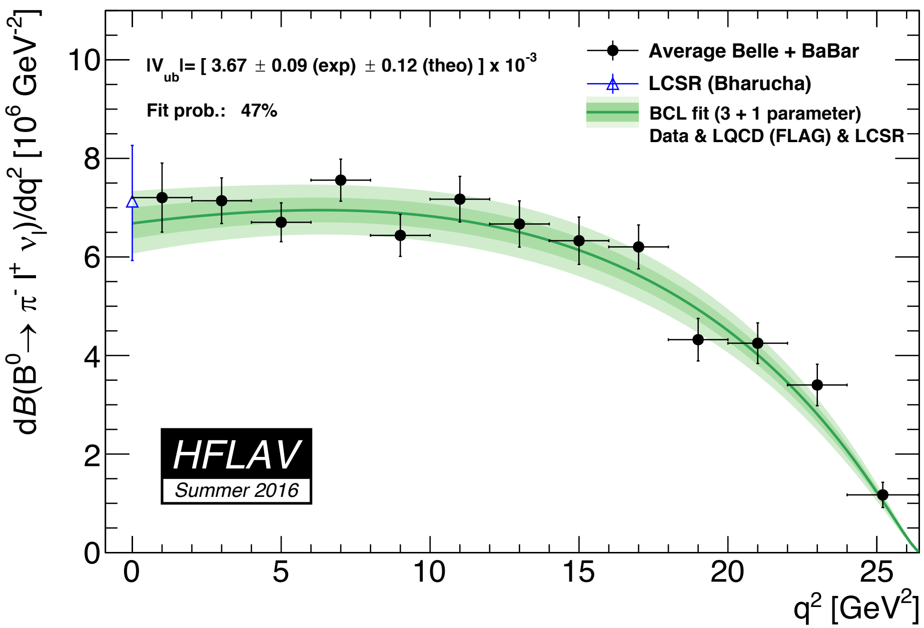
Caprini et al., Nucl. Phys. B530, 153 (1998)
FNAL/MILC, PRD 89, 114504 (2014)
FNAL/MILC, PRD 92, 034506 (2015)
Benson et al., Nucl. Phys. B665, 367 (2003)
Gambino, Uraltsev, EPJ C34, 181 (2004)
Gambino, JHEP 09, 055 (2011)
Alberti et al., PRL 114, 061802 (2015)
Bauer, Ligeti, et al., PRD 70, 094017 (2004)
Gambino and Schwanda, PRD 89, 014002 (2014)



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

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

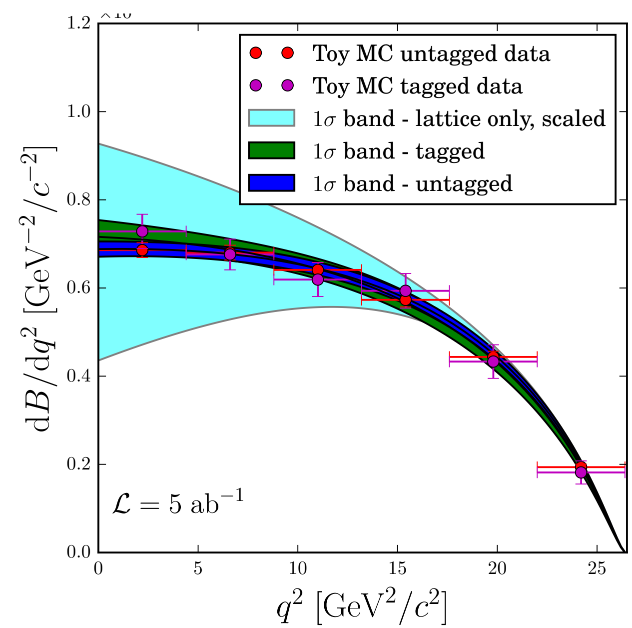
Use BCL parametrization of form factor, fit q^2 spectrum for BCL parameters and $|V_{ub}|$

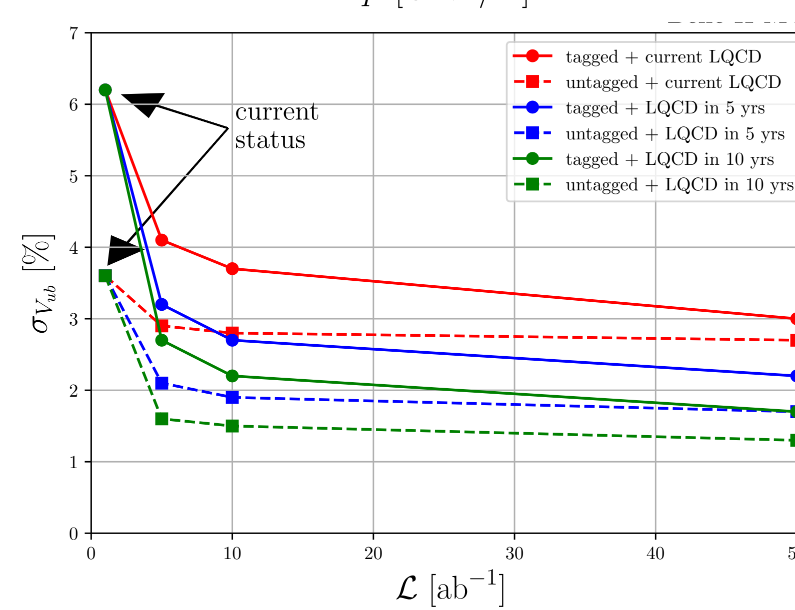


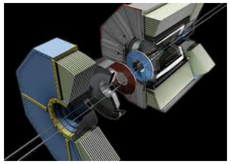
$|V_{ub}| = (3.67 \pm 0.09_{exp} \pm 0.12_{th}) \times 10^{-3}$

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]*

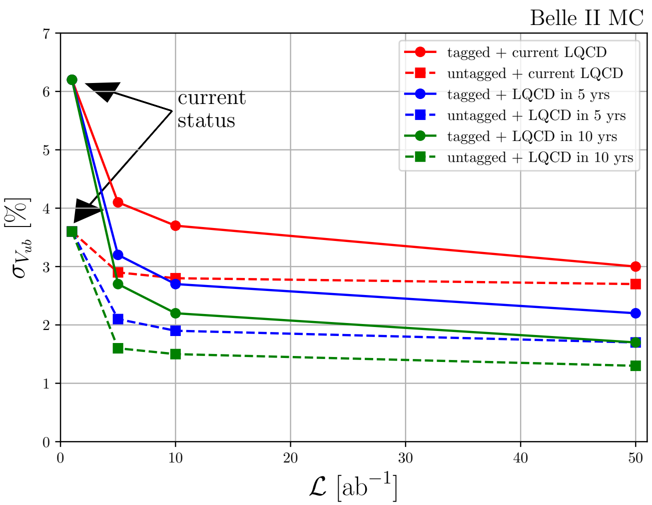
Belle II 5 ab^{-1} $B \to \pi l \nu$

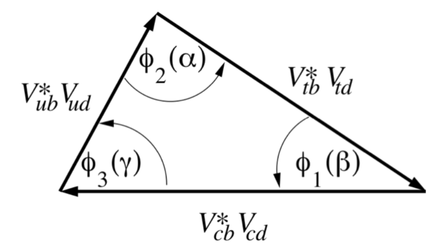






$|V_{ub}|$ via exclusive $B \to \pi l \nu$

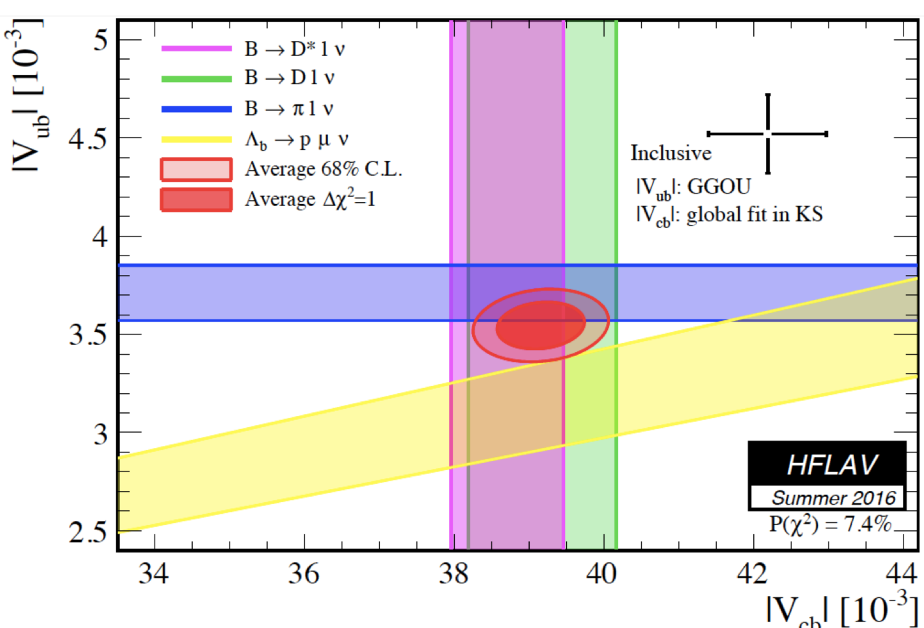


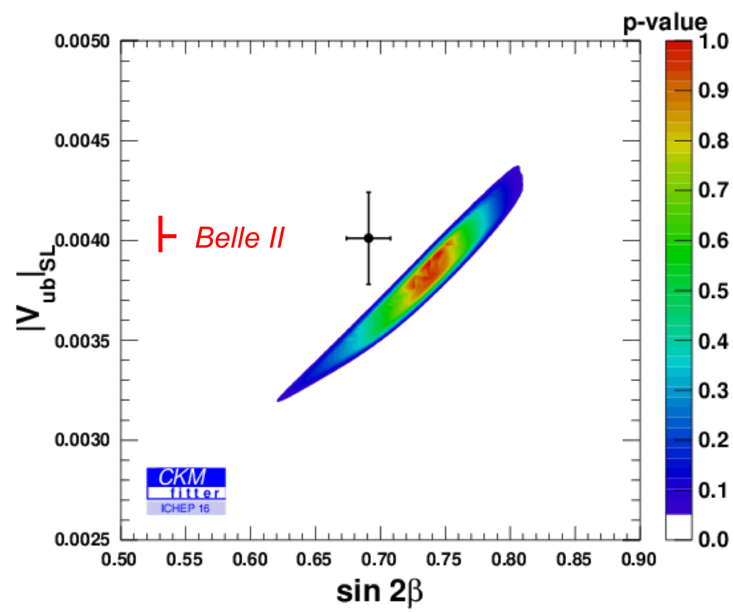


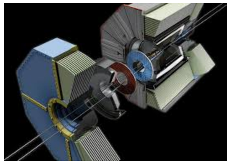
Should help resolve 2 "tensions" (discrepancies):

Exclusive $|V_{ub}|$ vs. inclusive $|V_{ub}|$

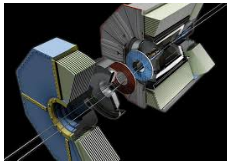
Consistency with ϕ_1 (β)



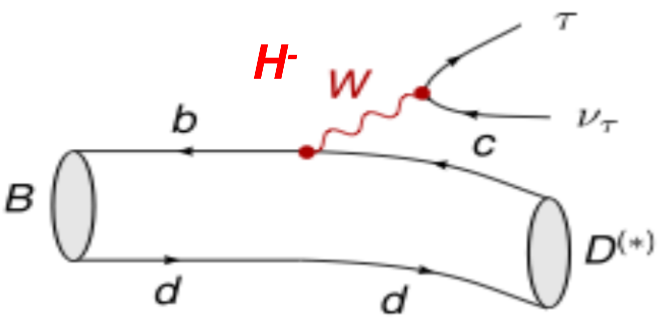




Searches for New Physics



$B \to D^{(*)} \tau \nu$

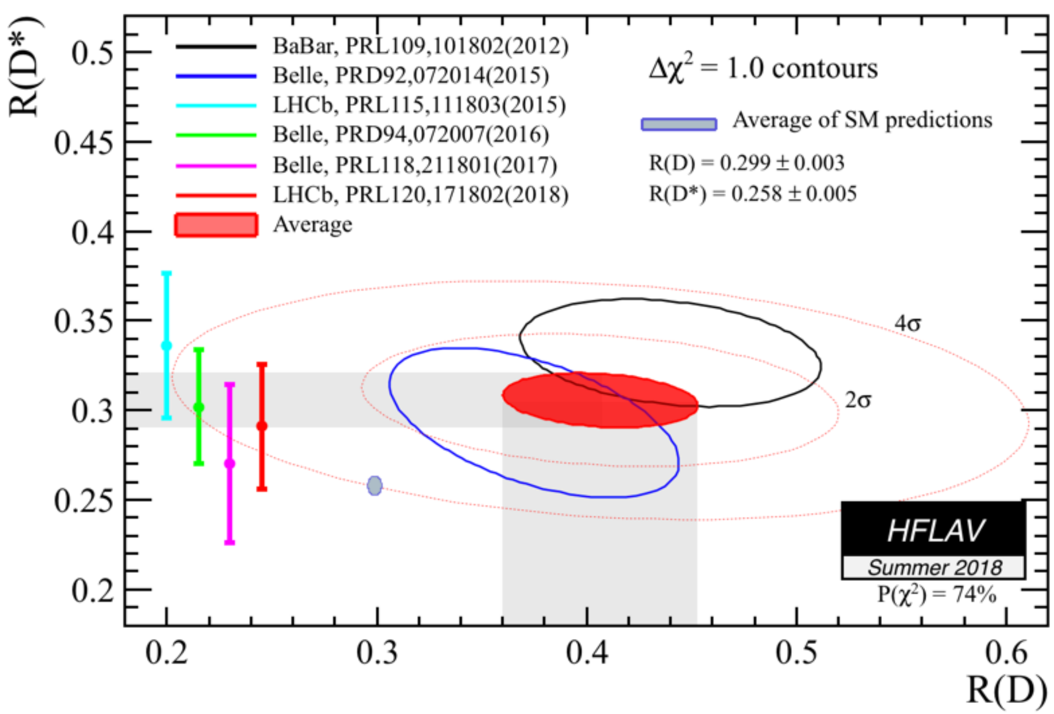


$B \to D^{(*)} \tau \nu$ can also receive contribution from a charged Higgs, changing the rate, q^2 distribution, etc.

Define ratios:

$$\mathcal{R}_{D^*} \equiv \frac{\mathcal{B}(B \to D^* \tau \nu)}{\mathcal{B}(B \to D^* \ell \nu)} \qquad \mathcal{R}_D \equiv \frac{\mathcal{B}(B \to D \tau \nu)}{\mathcal{B}(B \to D \ell \nu)}$$

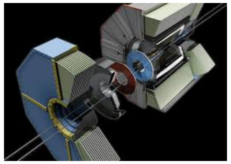
Uncertainties from form factors and V_{cb} drop out ⇒ ratios test lepton universality. Measured values are above SM prediction:



R(D) and R(D) exceed SM predictions by 2.3σ and 3.0σ respectively. As R(D)-R(D*) correlation = -0.203, two-dimensional χ^2 =17.55*

⇒ for 2 deg. of freedom, p-value = 1.57×10^{-4} (3.8σ)

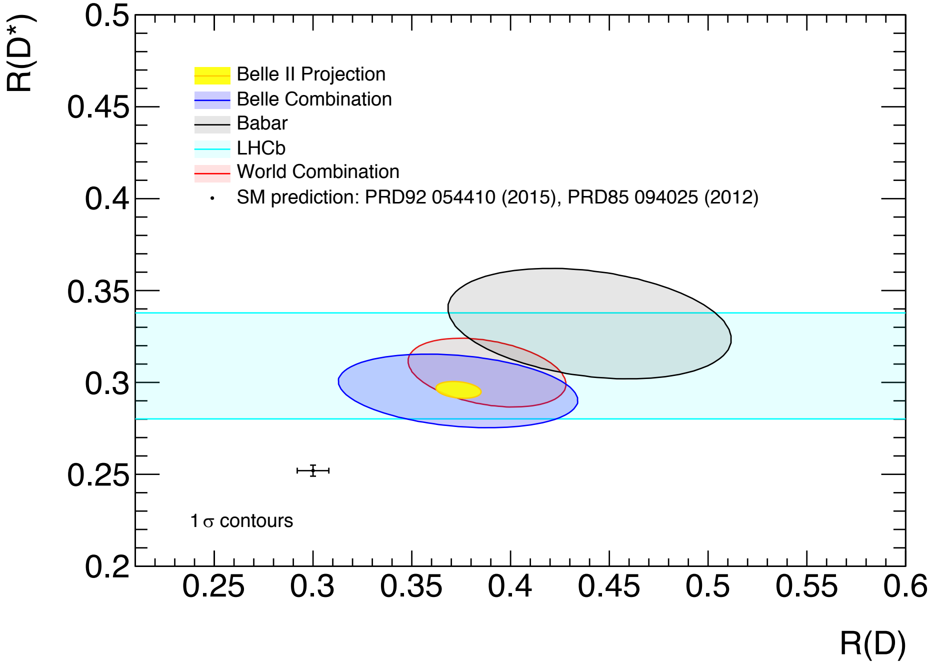
[Moriond 2019: 3.1σ]



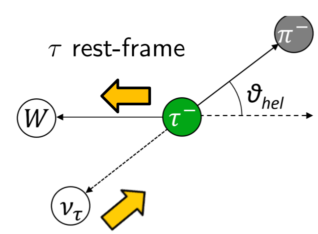
$B \to D^{(*)} \tau \nu$ @ Belle II

The Belle II Physics Book, arXiv:1808.10567

Scaling from Belle → Belle II (50 ab^{-1}):



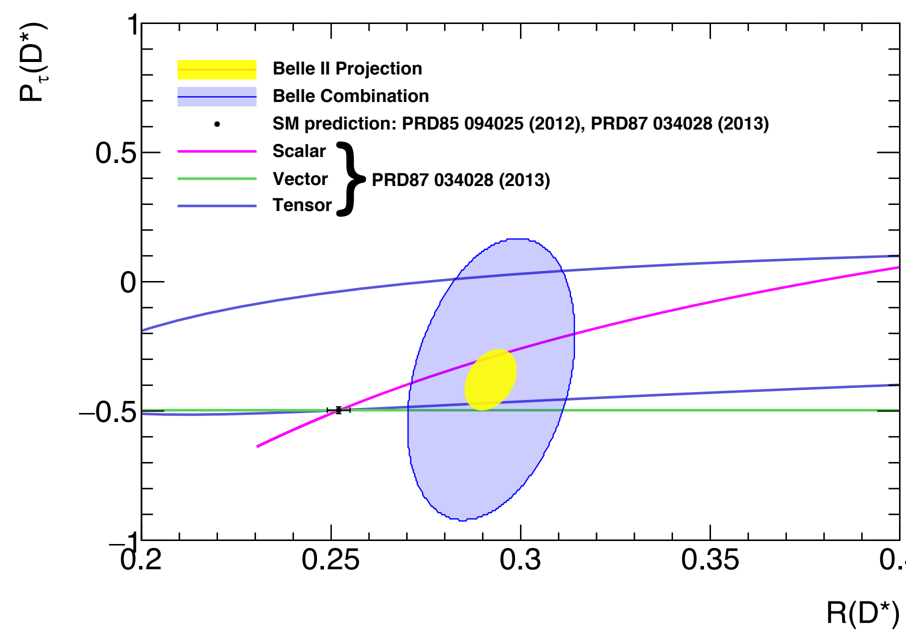
Belle II can measure the τ polarization:

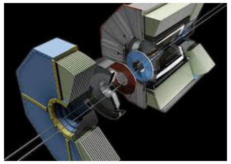


$$P_\tau \equiv \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-}$$

$$\frac{d\Gamma}{d\cos\theta_h} \propto 1 + \alpha P_\tau \cos\theta_h$$

$$\left(\begin{array}{l} \tau \to \pi\nu: \ \alpha = 1 \\ \tau \to \rho\nu: \ \alpha = 0.45 \end{array} \right)$$





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

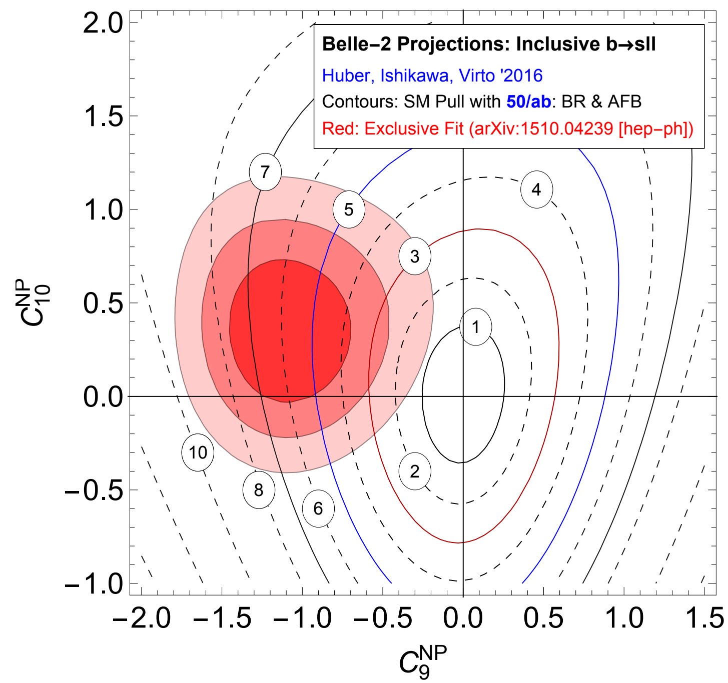
The Belle II Physics Book, arXiv:1808.10567

Inclusive decays were measured at Belle/BaBar using a sum-of-exclusives method: e.g., $X_s = Kn(\pi)$ with n<5 and max 1 π^0. This can be improved at Belle II in several ways:

- *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) may make true inclusive analysis feasible (under study)*

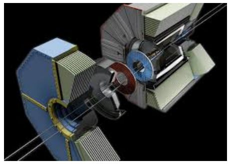
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$B(B \to X_s \ell^+\ell^-)$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	29%	13%	6.6%
$B(B \to X_s \ell^+\ell^-)$ $(3.5 < q^2 < 6.0\ \mathrm{GeV}^2)$	24%	11%	6.4%
$B(B \to X_s \ell^+\ell^-)$ $(q^2 > 14.4\ \mathrm{GeV}^2)$	23%	10%	4.7%
$A_{CP}(B \to X_s \ell^+\ell^-)$ $(1.0 < q^2 < 3.5\ \mathrm{GeV}^2)$	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%

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

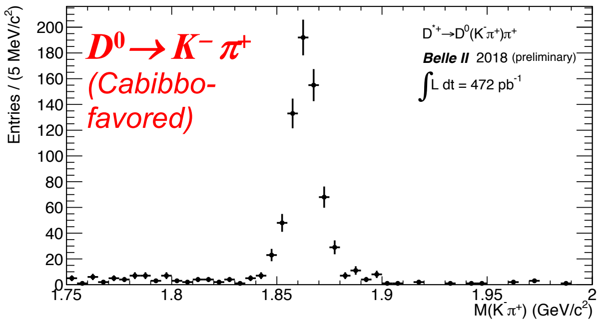


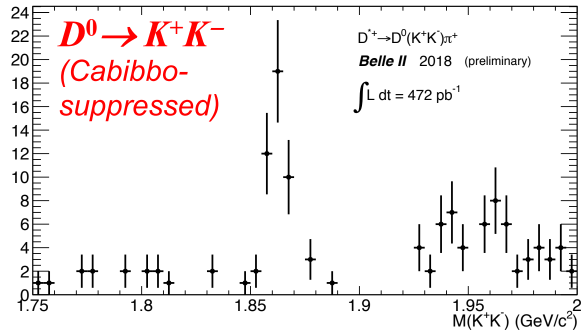
(n) σ pull to SM fit if true values

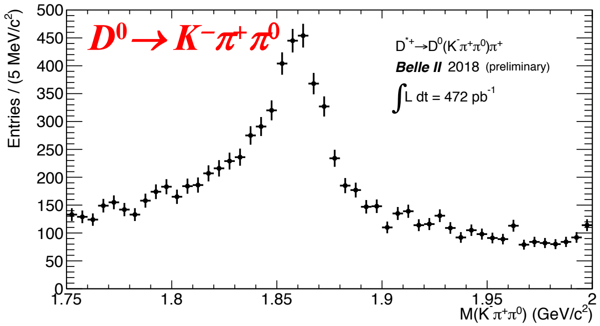
Exclusive decays fit: JHEP 06 (2016)092

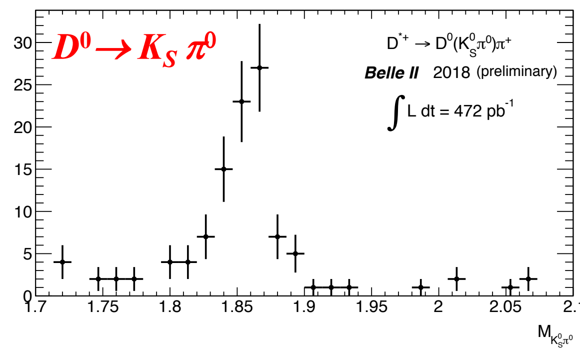


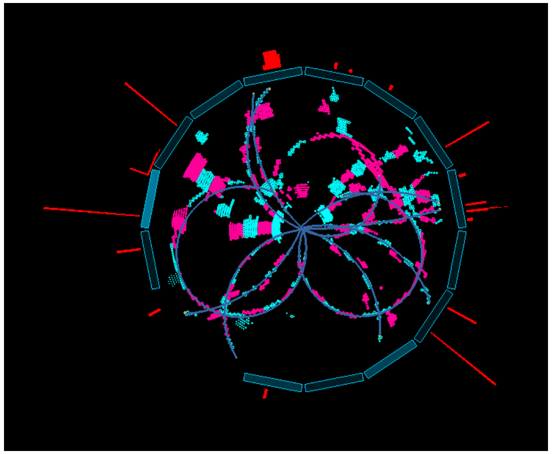
Status: detector is working (!)



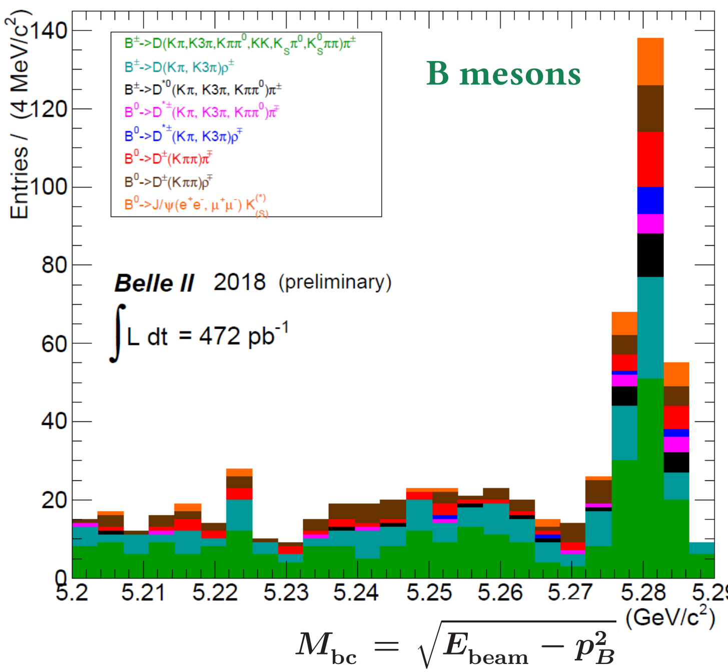


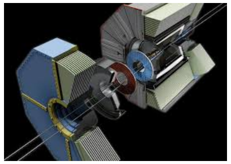






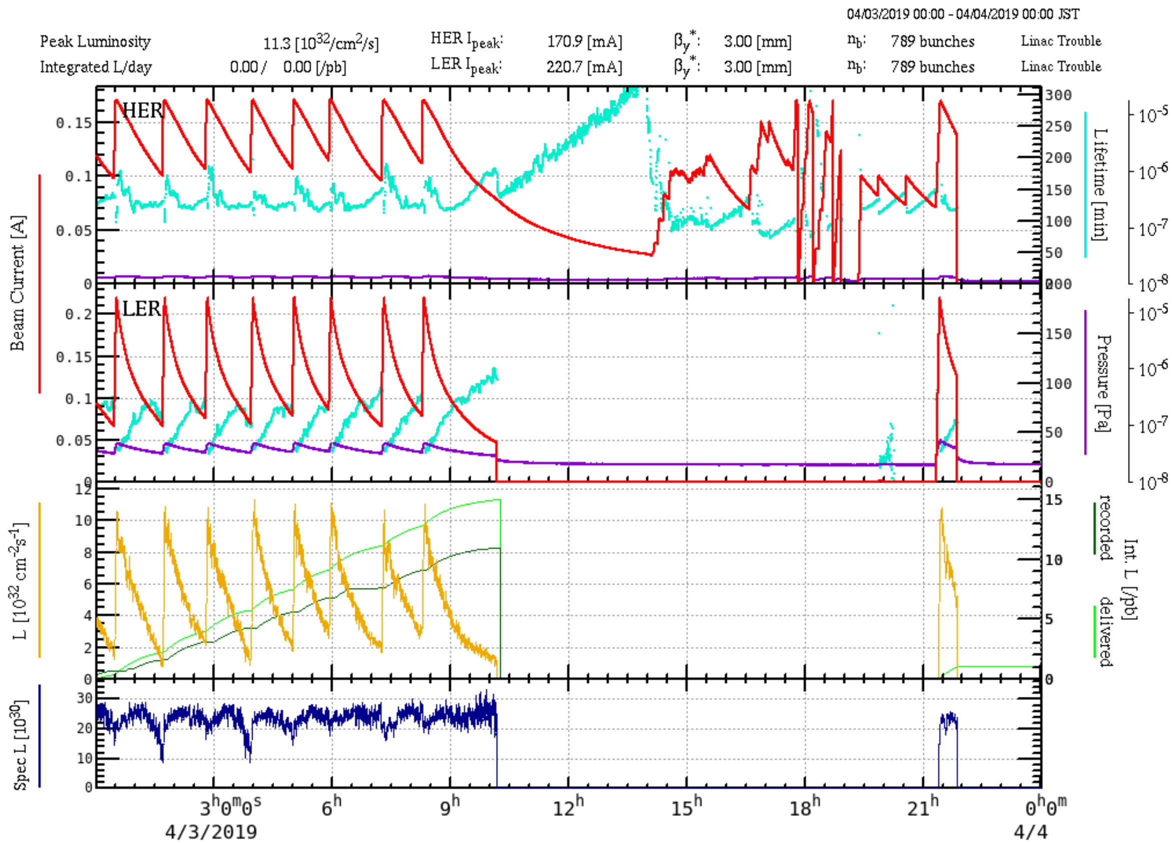
$B^+ \rightarrow D^0 \pi^+$
$B^+ \rightarrow D^0 \rho^+$
$B^+ \rightarrow D^{*0} \pi^+$
$B^0 \rightarrow D^{*+} \pi^-$
$B^0 \rightarrow D^{*+} \rho^-$
$B^0 \rightarrow D^+ \pi^-$
$B^0 \rightarrow D^+ \rho^-$
$B^0 \rightarrow J/\psi\, K_S$



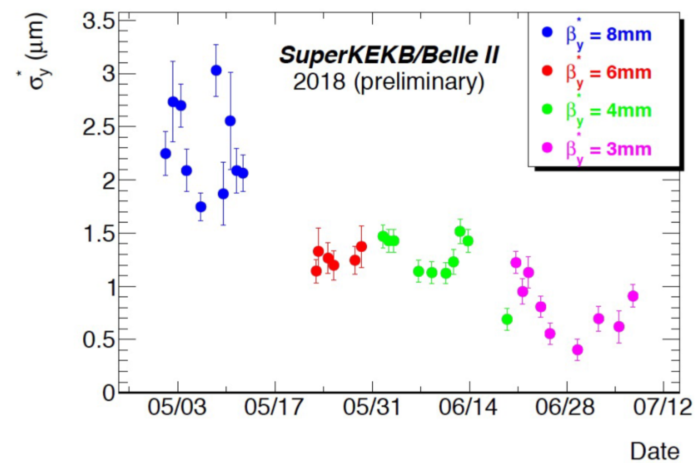


Status: accelerator is totally new, growing pains

Ramping up beam currents:

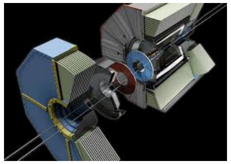


Squeezing the beams:



Achieved:

- L_{peak} = 5.55 x 10^{33} cm^2/s
- Belle II recorded ~ 500 pb^{-1}
- Confirmed the nano-beam scheme
- Reduced β_y^* to 3 mm, σ_y^* ~ 400 nm (Final target β_y^* = 0.3 mm)

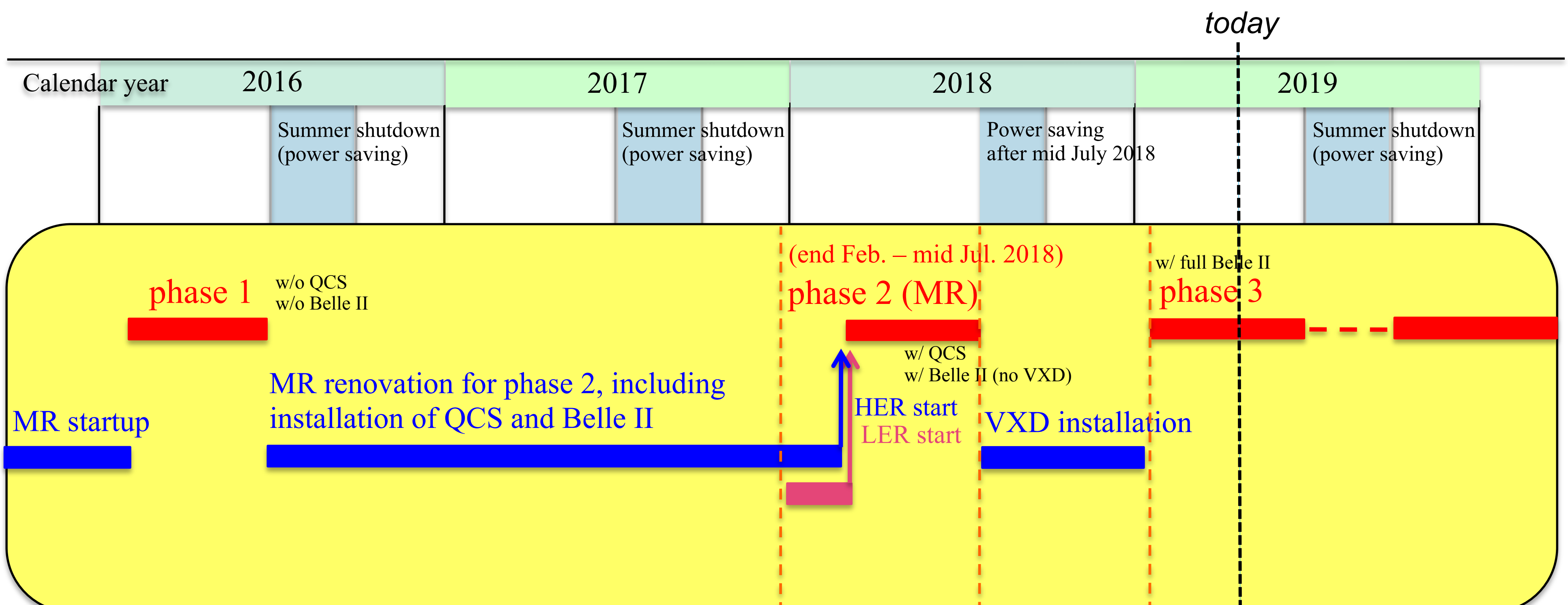


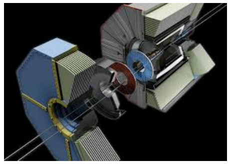
Summary

- *Belle II is now (essentially) fully constructed and installed. The experiment is beginning its first physics run ("Phase III") run (April-July). This will fully commission the detector, and there will be early physics (e.g., $D^0 \to \gamma\gamma$, dark photon search, etc.)*

- *Accelerator commissioning is proceeding, but there are growing pains as expected: background is high, so current is kept low. β_y is slowly being reduced.*

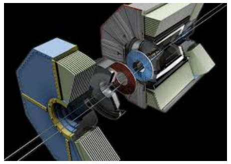
- *Physics potential is huge: there is much better vertexing, particle ID than in Belle; factor of 50x statistics; and full reconstruction on tag side is notably improved over Belle/BaBar.*



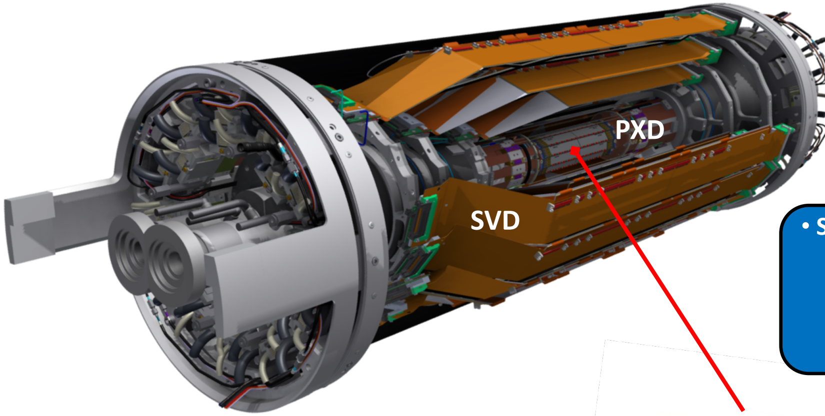


Extra

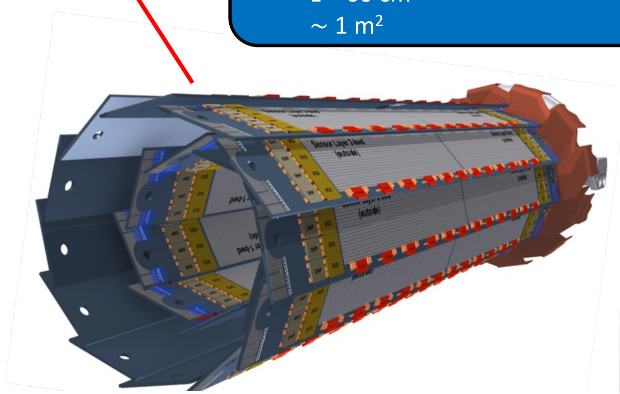
Extra Slides



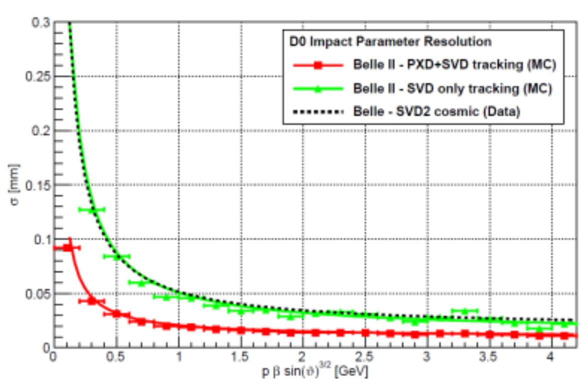
A major advance: the vertex detector



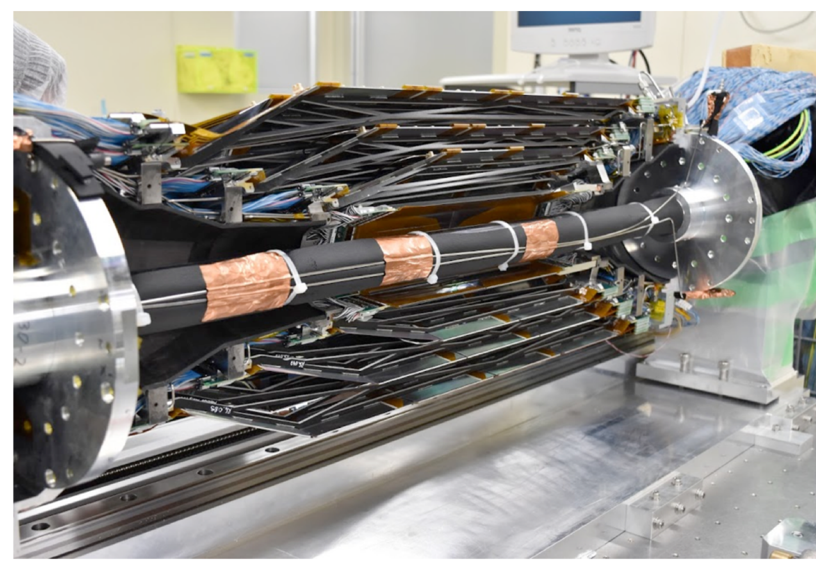
- **Silicon Vertex Detector (SVD)**
  - 4 layers of DSSD
  - r = 3.8 cm, 8.0 cm, 11.5 cm, 14 cm
  - L = 60 cm
  - $\sim$ 1 m^2



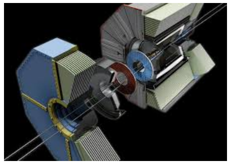
- **Pixel Detector (PXD)**
  - 2 layers of DEPFET pixels
  - r = 1.4 cm, 2.2 cm
  - L = 12 cm
  - $\sim$ 0.027 m^2



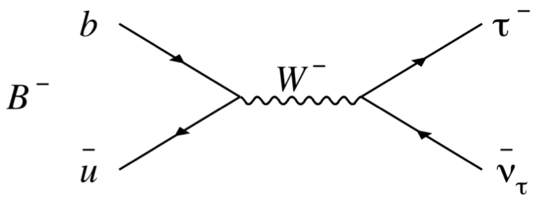
Impact parameter resolution = 15 μm



Completion of the first SVD clam-shell in Jan 2018.



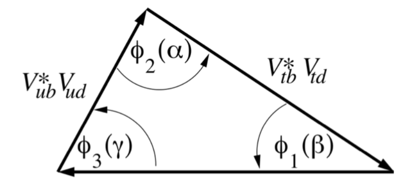
$|V_{ub}|$ via $B^+ \to \tau^+ \nu$



$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

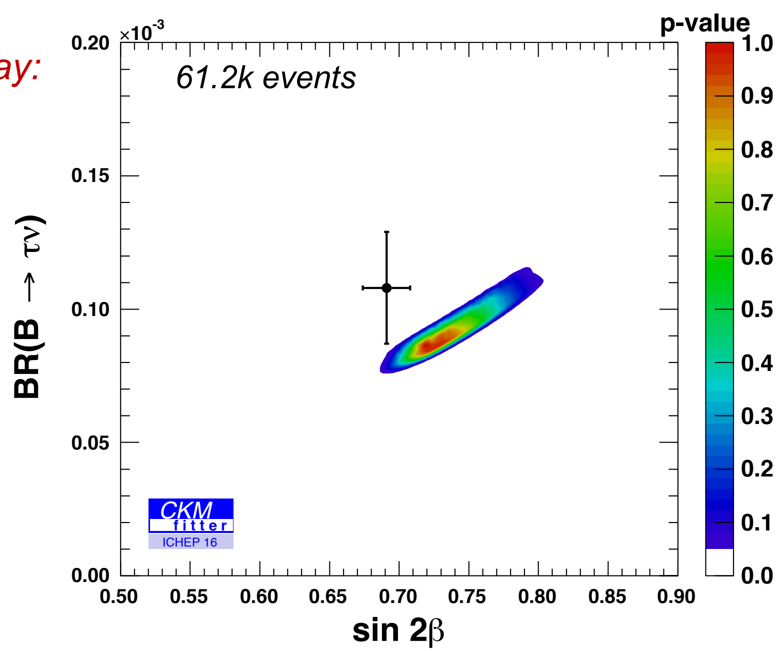
World average: $\mathcal{B}(B^+ \to \tau^+ \nu) = (1.06 \pm 0.19) \times 10^{-4}$

⇒ $|V_{ub}| = (3.55 \pm 0.12) \times 10^{-3}$ using $f_B = (185 \pm 3)$ MeV (FLAG 2017)

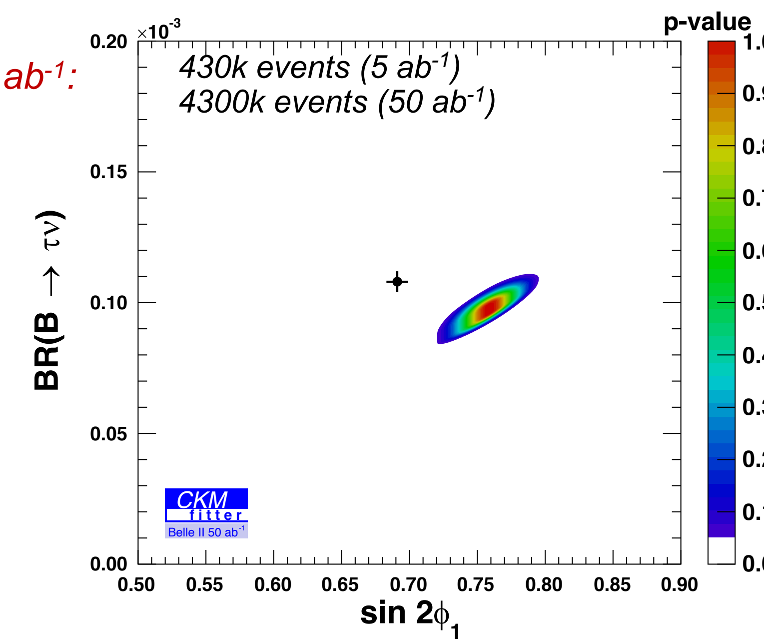


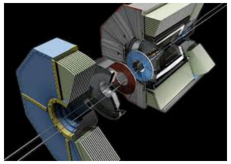
There is tension coming from $|V_{ub}|$ measured in $\mathcal{B}(B^+ \to \tau^+ \nu)$ and ϕ_1 (β) and ϕ_2 (α):

Today:



Belle II 50 ab⁻¹:





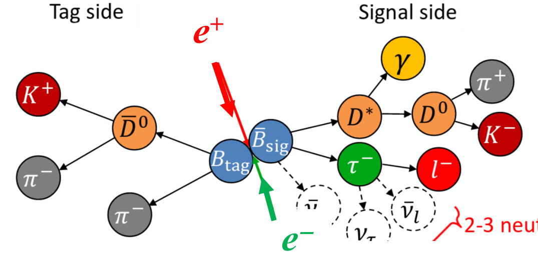
$|V_{cb}|$ from $B \to D l \nu$

711 fb^{-1}

Glattauer at al. (Belle), PRD 93, 032006 (2016)

$B \to D\ell\nu$ Reconstruction:

Divide event into 2 hemispheres: "signal" side and "flavor tag" side. Tag side is fully reconstructed (using neural net)



charged tags

$B^- \to D^{*0}\pi^-$
$B^- \to D^{*0}\pi^-\pi^0$
$B^- \to D^{*0}\pi^-\pi^+\pi^-$
$B^- \to D^{*0}\pi^-\pi^+\pi^-\pi^0$

$B^- \to D^0\pi^-$
$B^- \to D^0\pi^-\pi^0$
$B^- \to D^0\pi^-\pi^+\pi^-$

$B^- \to D^{*0}D_s^{*-}$
$B^- \to D^{*0}D_s^-$
$B^- \to D^0D_s^{*-}$
$B^- \to D^0D_s^-$

$B^- \to J/\psi\, K^-$
$B^- \to J/\psi\, K^-\pi^+\pi^-$
$B^- \to J/\psi\, K^-\pi^0$
$B^- \to J/\psi\, K_S\pi^-$

$B^- \to D^0K^-$
$B^- \to D^+\pi^-\pi^-$

neutral tags

$B^0 \to D^{*+}\pi^-$
$B^0 \to D^{*+}\pi^-\pi^0$
$B^0 \to D^{*+}\pi^-\pi^+\pi^-$
$B^0 \to D^{*+}\pi^-\pi^+\pi^-\pi^0$

$B^0 \to D^+\pi^-$
$B^0 \to D^+\pi^-\pi^0$
$B^0 \to D^+\pi^-\pi^+\pi^-$

$B^0 \to D^{*+}D_s^{*-}$
$B^0 \to D^{*+}D_s^-$
$B^0 \to D^+D_s^{*-}$
$B^0 \to D^+D_s^-$

$B^0 \to J/\psi\, K_S$
$B^0 \to J/\psi\, K^-\pi^+$
$B^0 \to J/\psi\, K_S\pi^+\pi^-$

$B^0 \to D^0\pi^0$

charged signals

$D^+ \to K^-\pi^+\pi^+$
$D^+ \to K^-\pi^+\pi^+\pi^0$
$D^+ \to K^-\pi^+\pi^+\pi^+\pi^-$
$D^+ \to K^-K^+\pi^+$

$D^+ \to K_S\pi^+$
$D^+ \to K_S\pi^+\pi^0$
$D^+ \to K_S\pi^+\pi^+\pi^-$
$D^+ \to K_S K^+$

$D^+ \to \pi^+\pi^0$
$D^+ \to \pi^+\pi^+\pi^-$

neutral signals

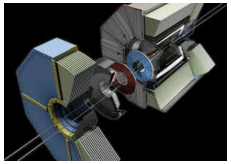
$D^0 \to K^-\pi^+$
$D^0 \to K^-\pi^+\pi^0$
$D^0 \to K^-\pi^+\pi^+\pi^-$
$D^0 \to K^-\pi^+\pi^+\pi^-\pi^0$

$D^0 \to K_S\pi^+\pi^-$
$D^0 \to K_S\pi^+\pi^-\pi^0$
$D^0 \to K_S\pi^0$

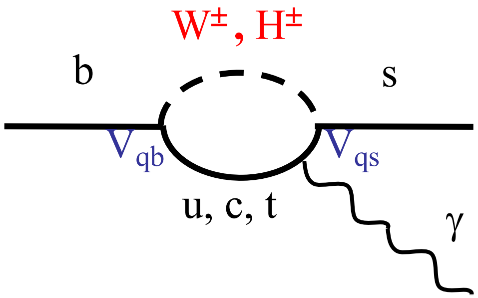
$D^0 \to K^-K^+$
$D^0 \to \pi^+\pi^-$
$D^0 \to K_SK_S$
$D^0 \to \pi^0\pi^0$
$D^0 \to K_S\pi^0\pi^0$

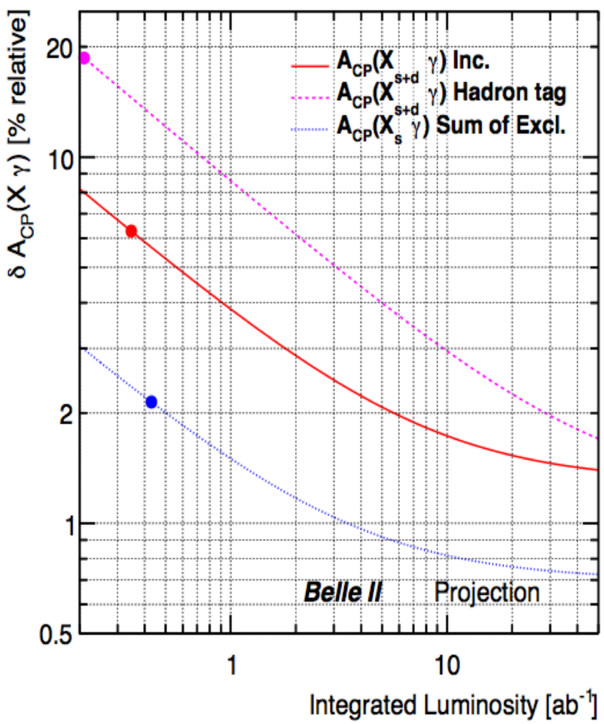
$D^0 \to \pi^+\pi^+\pi^0$

Note: over 1000 decay topologies considered.
[This is straightforward at an e^+e^- machine]



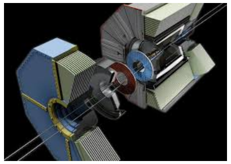
Inclusive $B \to X_{(s,d)}\gamma$ radiative decays



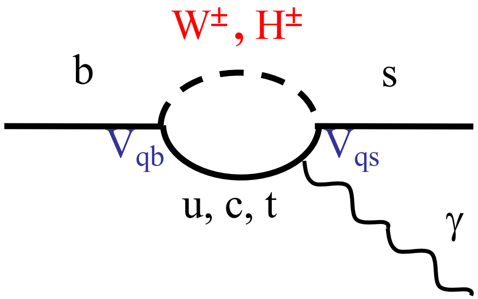


Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathrm{Br}(B \to X_s\gamma)^{\text{lep-tag}}_{\text{inc}}$	5.3%	3.9%	3.2%
$\mathrm{Br}(B \to X_s\gamma)^{\text{had-tag}}_{\text{inc}}$	13%	7.0%	4.2%
$\mathrm{Br}(B \to X_s\gamma)_{\text{sum-of-ex}}$	10.5%	7.3%	5.7%
$\Delta_{0+}(B \to X_s\gamma)_{\text{sum-of-ex}}$	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%
$A_{\text{CP}}(B^0 \to X_{d\bar{d}}^0\gamma)_{\text{sum-of-ex}}$	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%

Both A_{CP} (residual photon contribution) and isospin asymmetry Δ_{0+} (S_{78}) reduce theoretical uncertainties in the inclusive BF



Exclusive $B \rightarrow V\gamma$ 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
$\mathrm{Br}(B^0 \to \rho^0\gamma)$	24%	7.6%	4.5%
$\mathrm{Br}(B^+ \to \rho^+\gamma)$	30%	9.6%	5.0%
$\mathrm{Br}(B^0 \to \omega\gamma)$	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
$\|V_{td}/V_{ts}\|_{\rho/K^*}$	12%	8.2%	7.6%
$\mathrm{Br}(B_s^0 \to \phi\gamma)$	23%	6.5%	–
$\mathrm{Br}(B^0 \to K^{*0}\gamma)/\mathrm{Br}(B_s^0 \to \phi\gamma)$	23%	6.7%	–
$\mathrm{Br}(B_s^0 \to K^{*0}\gamma)$	–	15%	–
$A_{\rm CP}(B_s^0 \to K^{*0}\gamma)$	–	15%	–
$\mathrm{Br}(B_s^0 \to K^{*0}\gamma)/\mathrm{Br}(B_s^0 \to \phi\gamma)$	–	15%	–
$\mathrm{Br}(B^0 \to K^{*0}\gamma)/\mathrm{Br}(B_s^0 \to K^{*0}\gamma)$	–	15%	–

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

statistics limited

statistics limited

Theory:

$\Delta_{0+}(K^*\gamma) = (4.9 \pm 2.6)\%$
$A_{CP}(K^*\gamma) = (0.3 \pm 0.1)\%$

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

Lyon and Zwicky, PRD D88, 094004 (2013)

Paul and Straub, JHEP 04, 027 (2017)