CKM measurements and CPV in b decays at Belle II

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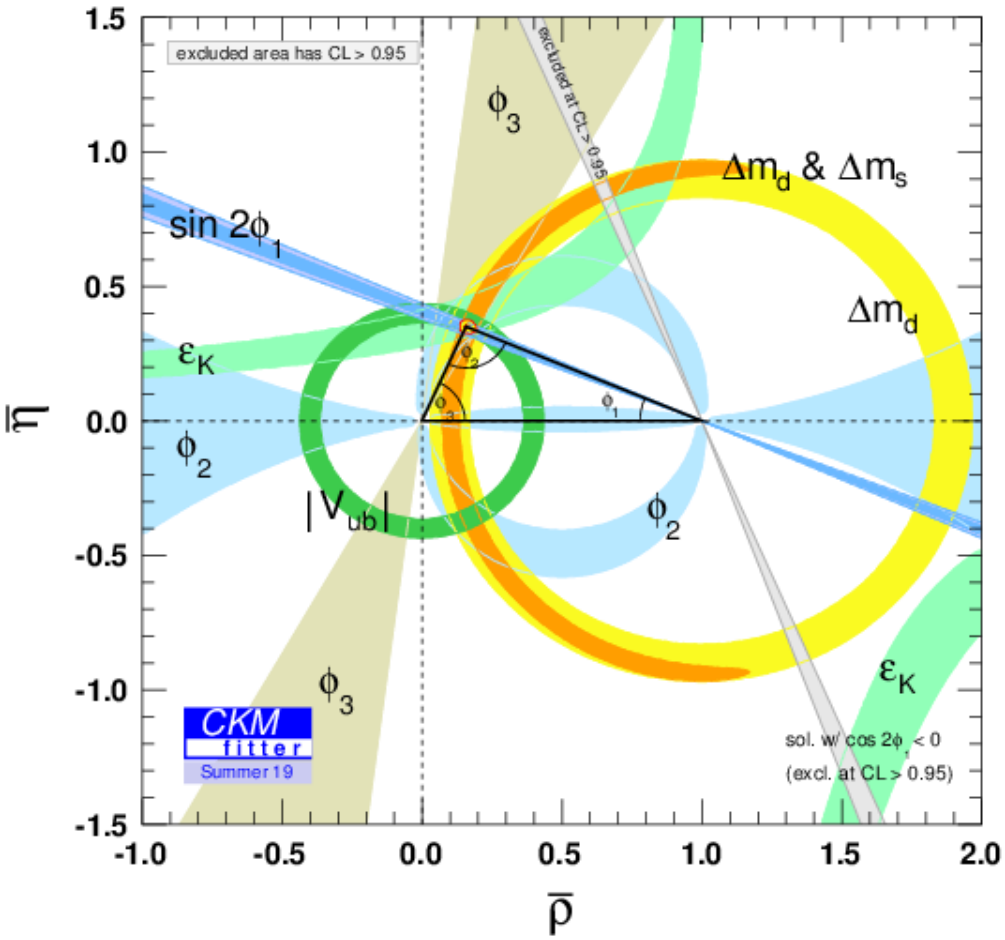
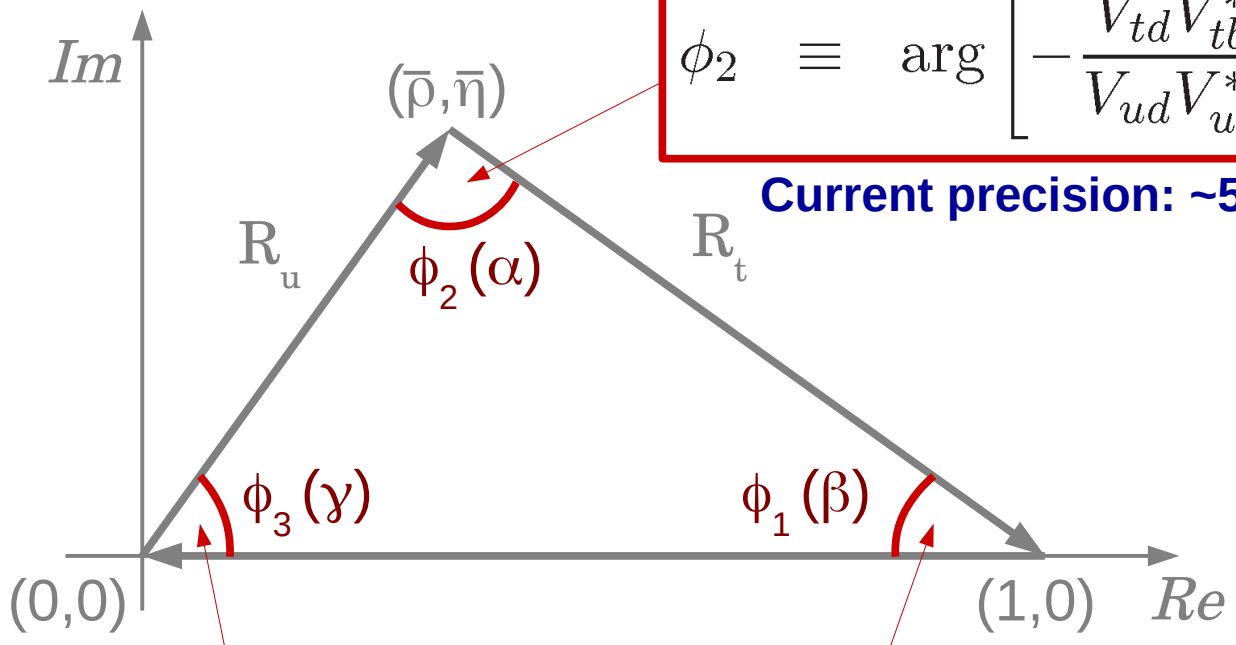
The CKM UT fit today

- Overall, the SM is in pretty good shape!
- The first generation of B-factories proved the correctness of the CKM paradigm in explaining Flavor Physics;
- There are some small (< 3σ) tensions among the different constraints…
- … they might go away, or points towards New Physics!



The angles



$$\phi_2 \equiv \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]$$

Current precision: ~5°

$$\phi_3 \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

Current precision: ~4°

$$\phi_1 \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

Current precision: ~0.7°

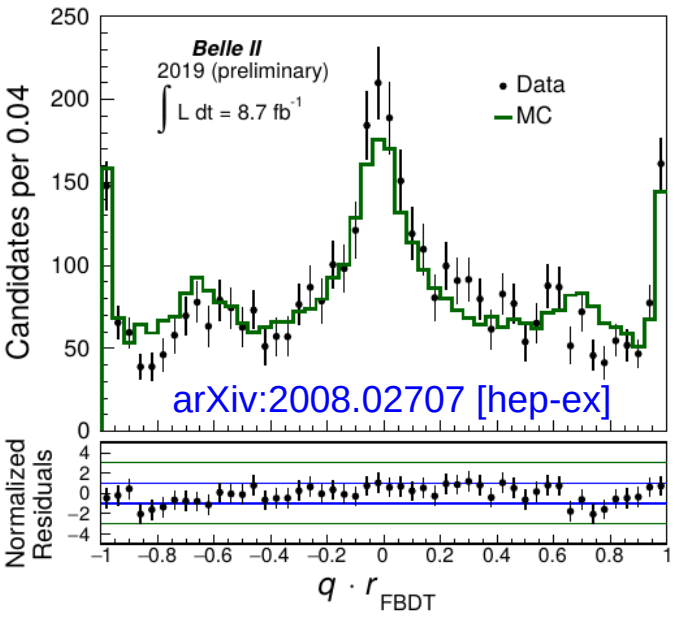
Measurement of ϕ_1 (β)

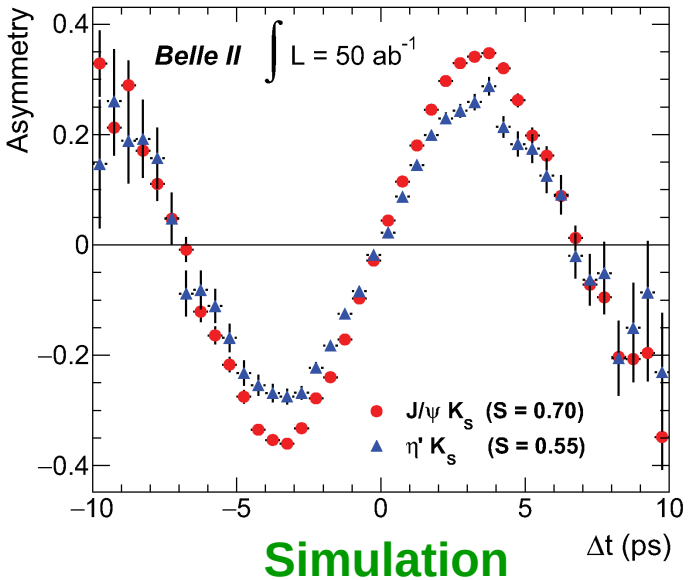
- Most precise measurement from time-dependent analysis of $B \to J/\psi\, K^0$;
- Exploiting large B Flavor Tagging efficiency: $Q = (33.8 \pm 3.6 \pm 1.6)\%$ (preliminary);
- At 50 ab^{-1}, the measurement will most likely be dominated by systematic uncertainties (dominant contributions from vertex detector alignment and DCS decays on tag side);

HFLAV average: $\sin(2\phi_1) = 0.699 \pm 0.017$

Belle II (50 ab^{-1}): $\sin(2\phi_1) = 0.xxx \pm 0.005$

- Belle II will have unique sensitivity on penguin amplitude dominated channels (e.g. $B \to \eta' K^0$, ϕK^0, $K^0_S \pi^0$, …), that are potentially sensitive to New Physics.



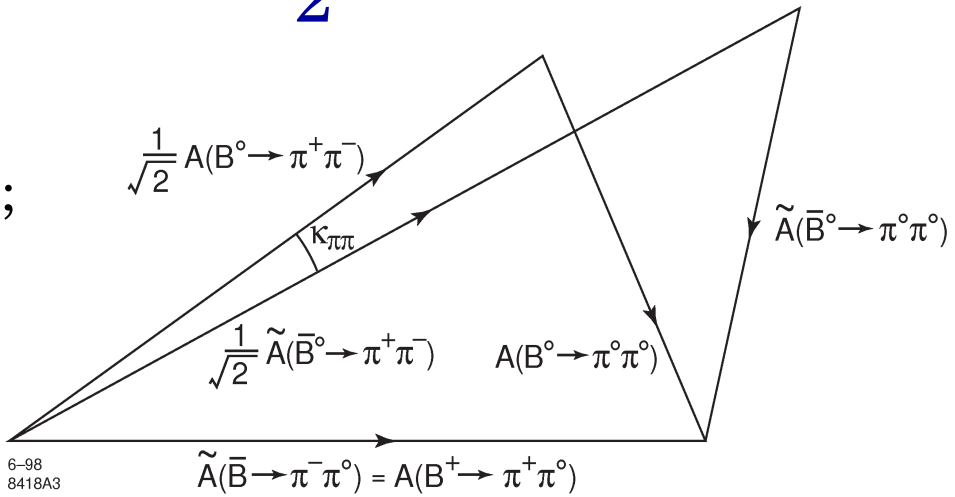


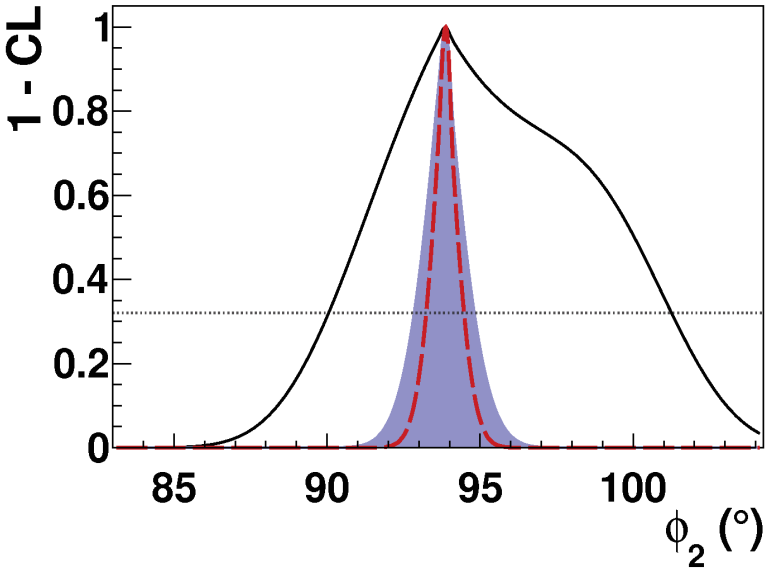
Simulation (dream scenario)

Target precision: ~0.2°

Measurement of ϕ_2 (α)

- ϕ_2 is determined through an isospin analysis of the $B \to \pi\pi$ or $B \to \rho\rho$ systems;
- π^0's are unavoidable, Belle II will have the edge on LHCb on most of the modes;
- Unique to Belle II: time dependent $B^0 \to \pi^0\pi^0$ analysis, exploiting π^0 Dalitz decays and photon conversions;
- We expect ~270 signal events @50 ab^{-1}, with an uncertainty of ~0.30 on the TD asymmetry (S^{00});
- This will eliminate spurious solutions and improve the precision.





Target precision: ~0.6° (all modes combined)

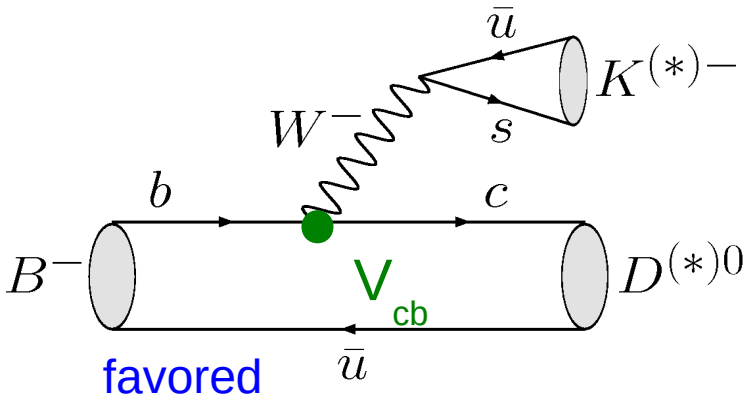
Solid black line: current sensitivity;

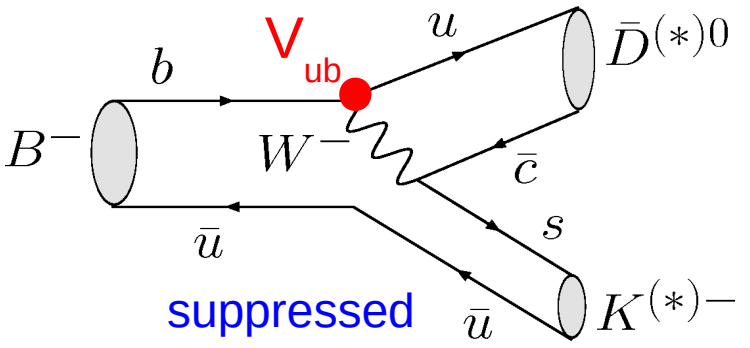
Filled area: extrapolation of Belle results to Belle II luminosity;

Dashed line: same as above, but adding S^{00}.

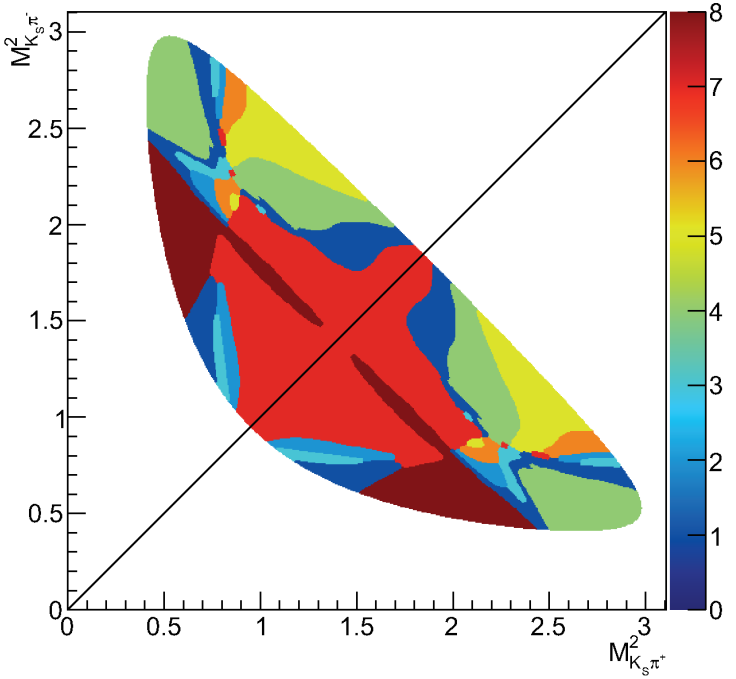
Measurement of ϕ_3 (γ)

- The most sensitive method exploitz V_{cb}/V_{ub} interference in $B^+ \to D^0/\overline{D}^0 K^+$;





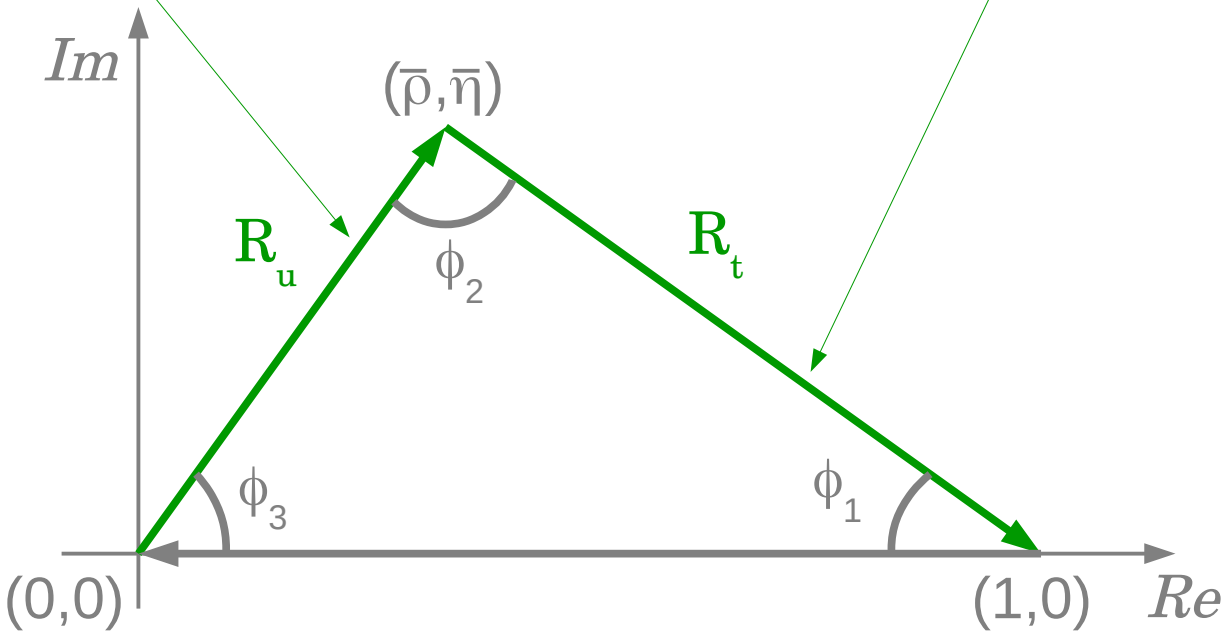
- Only tree level amplitudes, fundamental input for the CKM fit;
- Competition with LHCb will be hard… ;
- We need to focus on keeping the systematic uncertainties from the Dalitz Plot modeling low, e.g. by using the binned Dalitz Plot;
- Considering also final states with K_S's and π^0's.



Target precision: ~1.5°

The sides

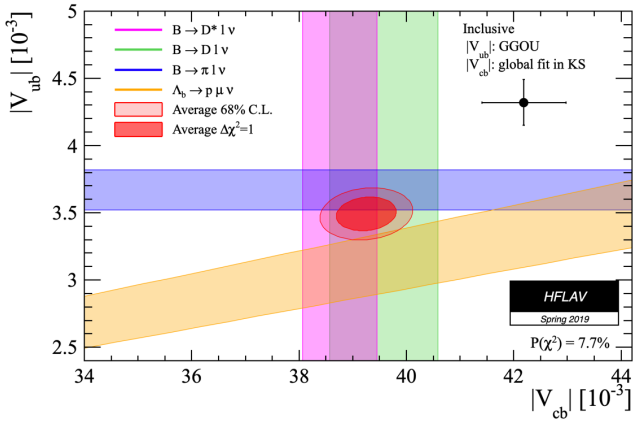
$$R_u \equiv \left| \frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right| \qquad R_t \equiv \left| \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} \right|$$

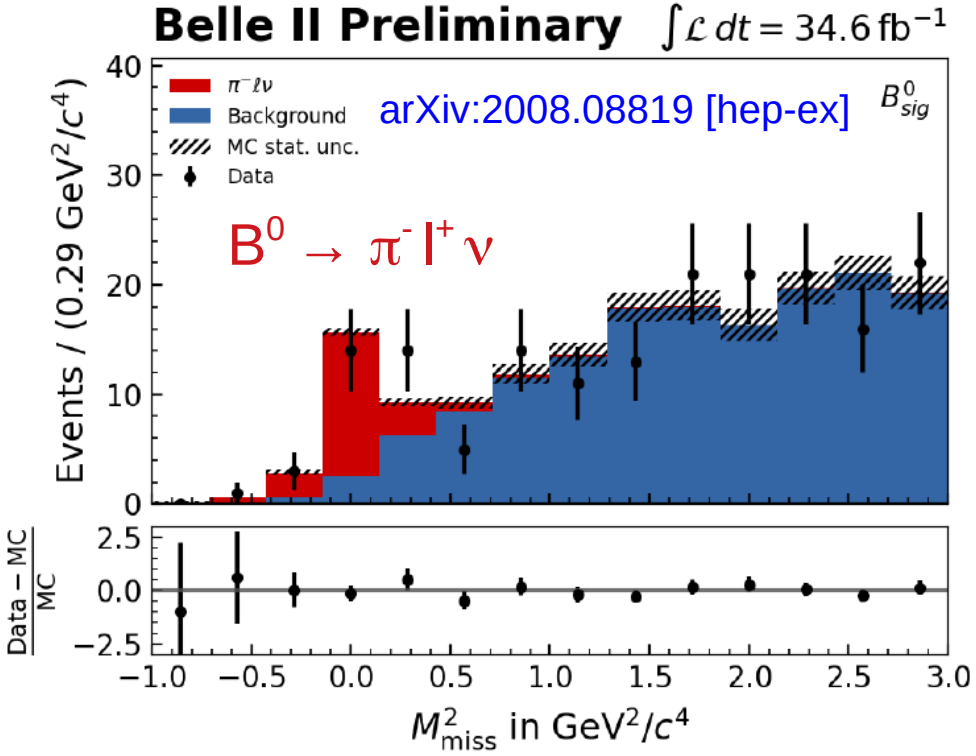


- R_t is determined by the B_d and B_s oscillations (currently dominated by LHCb);
- Huge progress expected on R_u, thanks to better precision on $|V_{ub}|$.

Measurement of $|V_{ub}|$ at Belle II

- Current precision on $|V_{ub}| \sim 5\text{-}6\%$;
- The progress will be driven by the exclusive measurements, thanks to the huge progress in Lattice QCD;
- Hopefully we will also shed light on the inclusive vs exclusive "V_{xb} puzzle":





Expected errors: (Experiment ⊕ Theory)

	Belle (0.8 ab^{-1})	Belle II (50 ab^{-1})
$\|V_{ub}\|$ exclusive (tagged)	$(3.8 \oplus 7.0)\%$	$(1.2 \oplus 0.9)\%$
$\|V_{ub}\|$ exclusive (untagged)	$(2.7 \oplus 7.0)\%$	$(0.9 \oplus 0.9)\%$
$\|V_{ub}\|$ inclusive	$(6.0 \oplus 2.5\text{-}4.5)\%$	$(1.7 \oplus 2.5\text{-}4.5)\%$

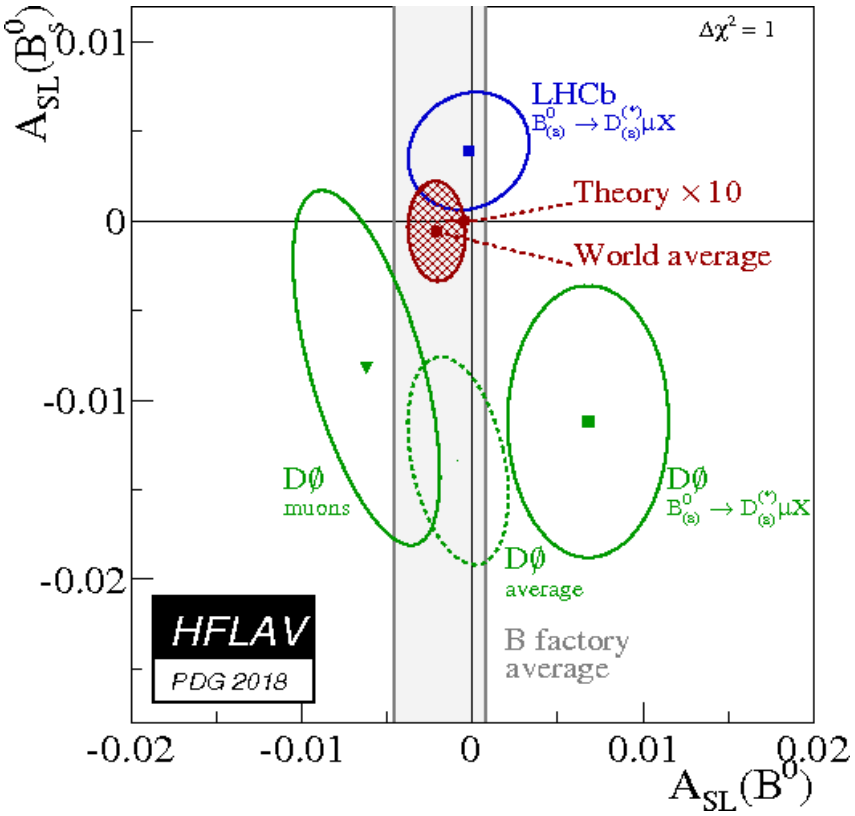
CPV in $B\bar{B}$ mixing

- Last kind of CP violation yet to be observed in B's;
- For the B_d, A_{SL} is predicted to be ~5 x 10^{-4}, almost one order of magnitude smaller than current sensitivity:

$$A_{SL} = \frac{N(\ell^+\ell^+) - N(\ell^-\ell^-)}{N(\ell^+\ell^+) + N(\ell^-\ell^-)}$$

	A^d_{SL}:
BaBar (ll):	(-0.39 ± 0.35 ± 0.19)%
BaBar (D*lν):	(0.06 ± 0.17 ± 0.35)%
D0 (DμX):	(0.68 ± 0.45 ± 0.14)%
LHCb (DμX):	(-0.02 ± 0.19 ± 0.30)%

	A^s_{SL}:
D0 (D_sμX):	(-1.12 ± 0.74 ± 0.17)%
LHCb (D_sμX):	(0.39 ± 0.26 ± 0.20)%



- With a dataset ~100 bigger than BaBar's, we might have a chance to observe it.

Conclusions

- CKM Physics is a big part of Belle II's program;
- We expect very significant progress from Belle II on:
  - all CKM UT angles (especially on ϕ_2 and ϕ_1);
  - modes with (π^0, η, η', …)'s in the final state;
  - $|V_{ub}|$ from exclusive decays;
  - CP violation in $B\bar{B}$ mixing;
- All this will not come for free: reducing systematic uncertainties will be the name of the game;

- The sensitivity studies shown today are taken from:

The Belle II Physics Book

E. Kou et al., PTEP 2019, 123C01 (2019), arXiv:1808.10567 [hep-ex]

Backup Slides

ϕ_1 precision

Time-dependent CP-violation parameter

Direct CP-violation parameter

	No improvement	Vertex improvement	Leptonic categories
$S_{c\bar{c}s}$ (50 ab^{-1})			
stat.	0.0027	0.0027	0.0048
syst. reducible	0.0026	0.0026	0.0026
syst. irreducible	0.0070	0.0036	0.0035
$A_{c\bar{c}s}$ (50 ab^{-1})			
stat.	0.0019	0.0019	0.0033
syst. reducible	0.0014	0.0014	0.0014
syst. irreducible	0.0106	0.0087	0.0035

ϕ_1 – penguin dominated modes

Mode	QCDF [32]	QCDF (scan) [32]	$SU(3)$	Data
$\pi^0 K_S^0$	$0.07^{+0.05}_{-0.04}$	$[0.02, 0.15]$	$[-0.11, 0.12]$ [36]	$-0.11^{+0.17}_{-0.17}$
$\rho^0 K_S^0$	$-0.08^{+0.08}_{-0.12}$	$[-0.29, 0.02]$		$-0.14^{+0.18}_{-0.21}$
$\eta' K_S^0$	$0.01^{+0.01}_{-0.01}$	$[0.00, 0.03]$	$(0 \pm 0.36) \times 2\cos(\phi_1)\sin\gamma$ [37]	-0.05 ± 0.06
ηK_S^0	$0.10^{+0.11}_{-0.07}$	$[-1.67, 0.27]$		—
ϕK_S^0	$0.02^{+0.01}_{-0.01}$	$[0.01, 0.05]$	$(0 \pm 0.25) \times 2\cos(\phi_1)\sin\gamma$ [37]	$0.06^{+0.11}_{-0.13}$
ωK_S^0	$0.13^{+0.08}_{-0.08}$	$[0.01, 0.21]$		$0.03^{+0.21}_{-0.21}$

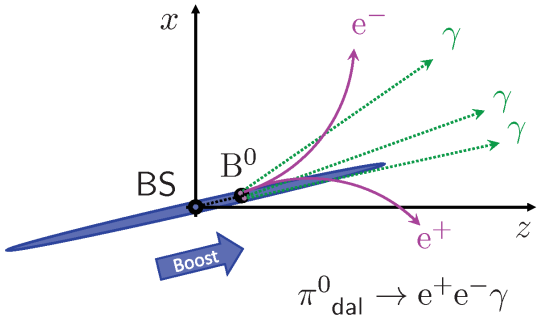
		WA (2017)		5 ab^{-1}		50 ab^{-1}	
	Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
♦	$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
★	ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
★	$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
♦	ωK_S^0	0.21	0.14	0.08	0.06	0.024	0.020
(★)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

★ Full study based on Belle II simulation

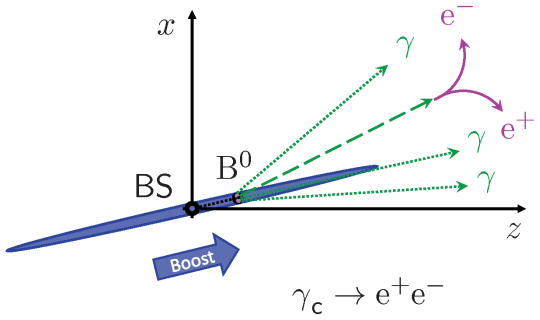
♦ Extrapolation of Belle/BaBar results

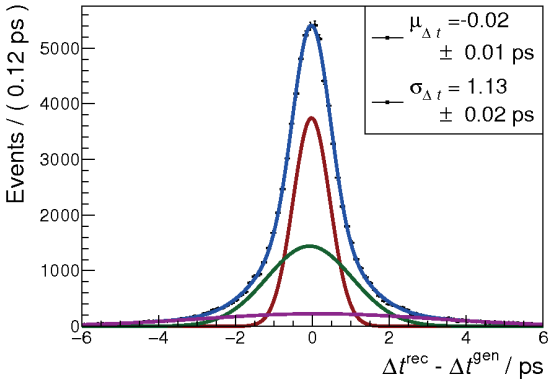
ϕ_2 from TD B → $\pi^0\pi^0$

Dalitz decays

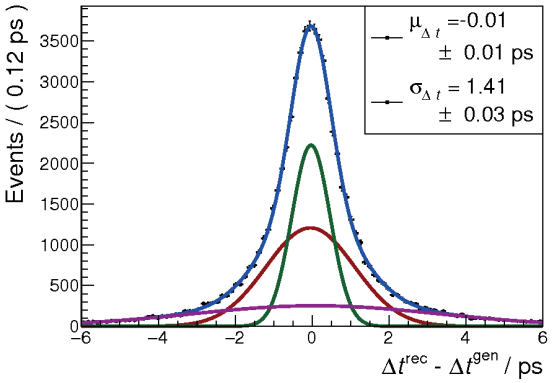


Photon conversions

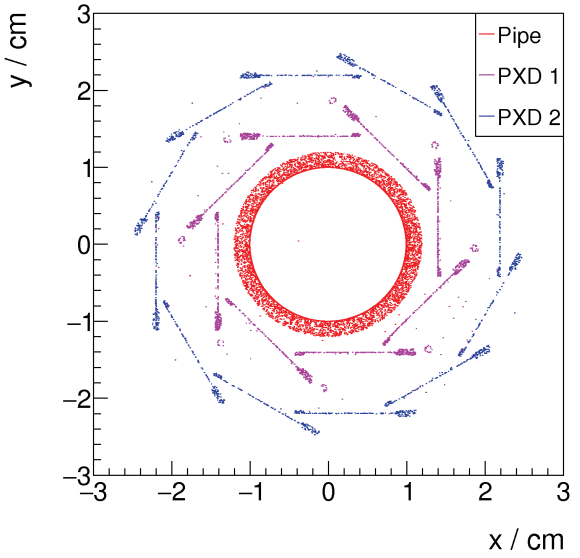




Δt_{res} ~ 1.13 ps



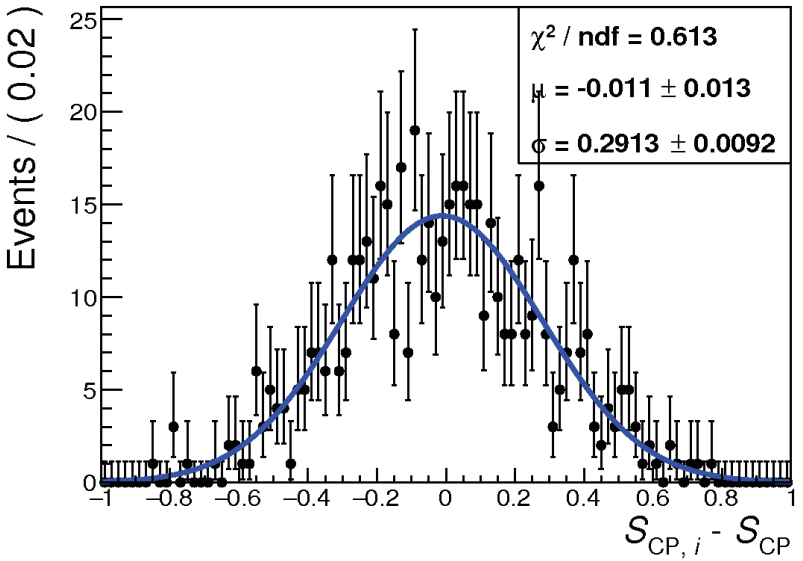
Δt_{res} ~ 1.41 ps



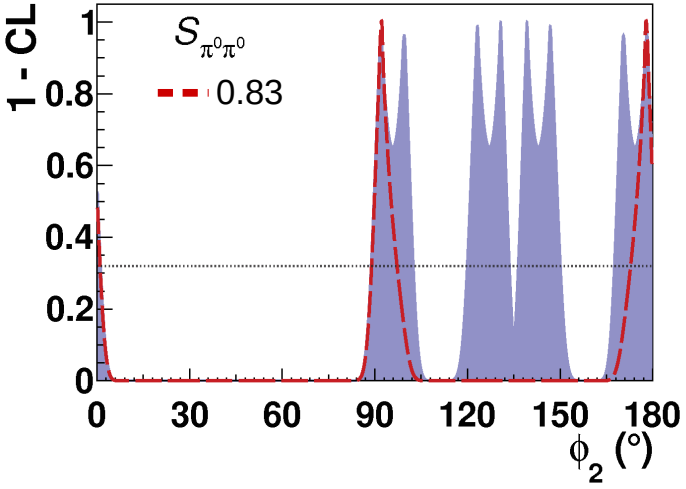
Beam pipe and PXD detector "radiography"

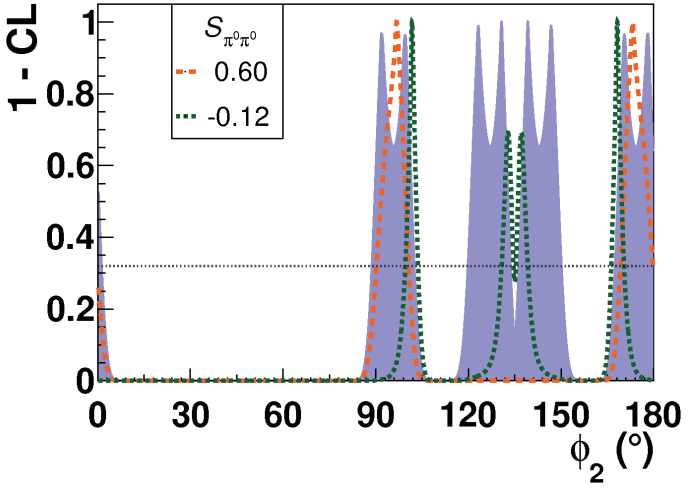
ϕ_2 from TD B → $\pi^0\pi^0$

Sensitivity on TD asymmetry (50 ab^{-1})



Impact on ϕ_2 determination





Filled area: extrapolation of Belle results to Belle II luminosity;

Dashed line: same as above, but adding S^{00}.

Reduction of ambiguity by a factor 2 or 4!

ϕ_2 combination

Channel	$\Delta\phi_2$ [°]
Current world average	$^{+4.4}_{-4.0}$
$B \to \pi\pi$	4.0
$B \to \rho\rho$	0.7
$B \to \pi\pi$ and $B \to \rho\rho$ Combined	0.6

We will also include B → ρπ, but estimating the sensitivity on ϕ_2 at this time is difficult, as the result depends on the Dalitz Plot structure of B → πππ.