Measurement of time-dependent CP violation in $B^0 \to J/\psi\, K_s$ decays using early Belle II data

B. Oberhof*
*LNF-INFN, Italy
on behalf of the Belle II Collaboration

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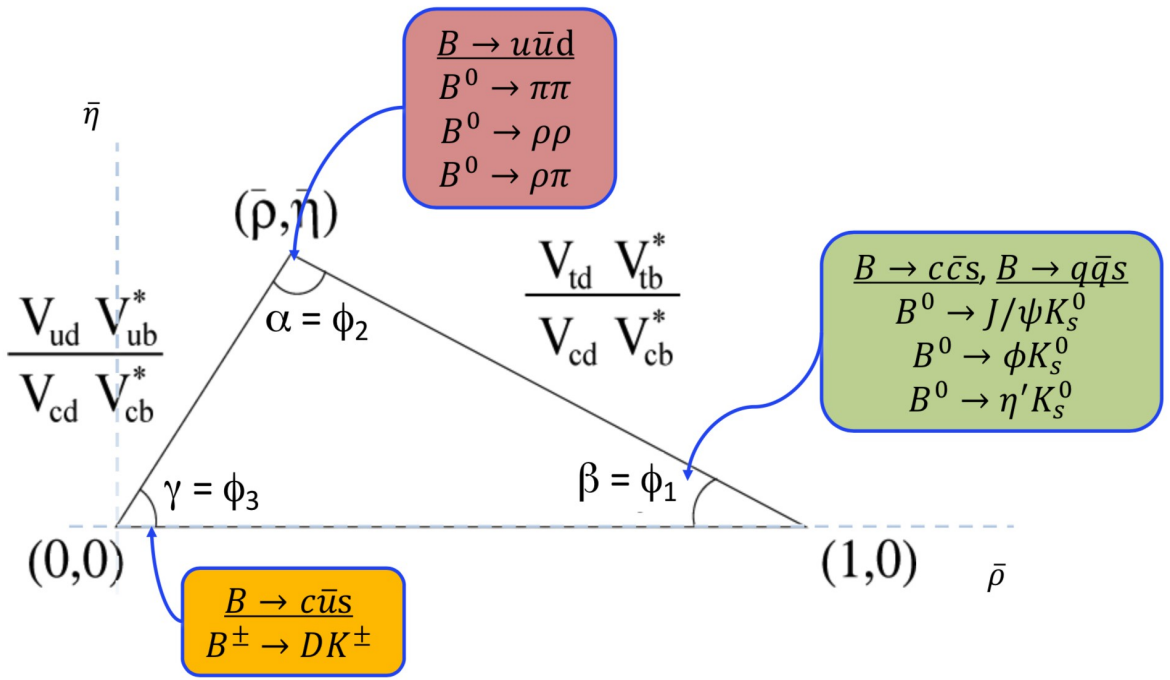
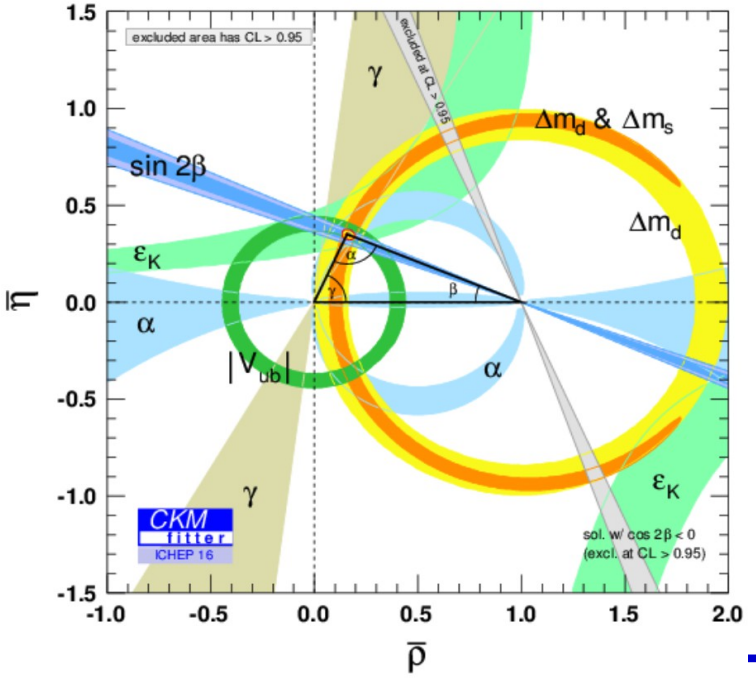
Unitarity Triangle from B Decays

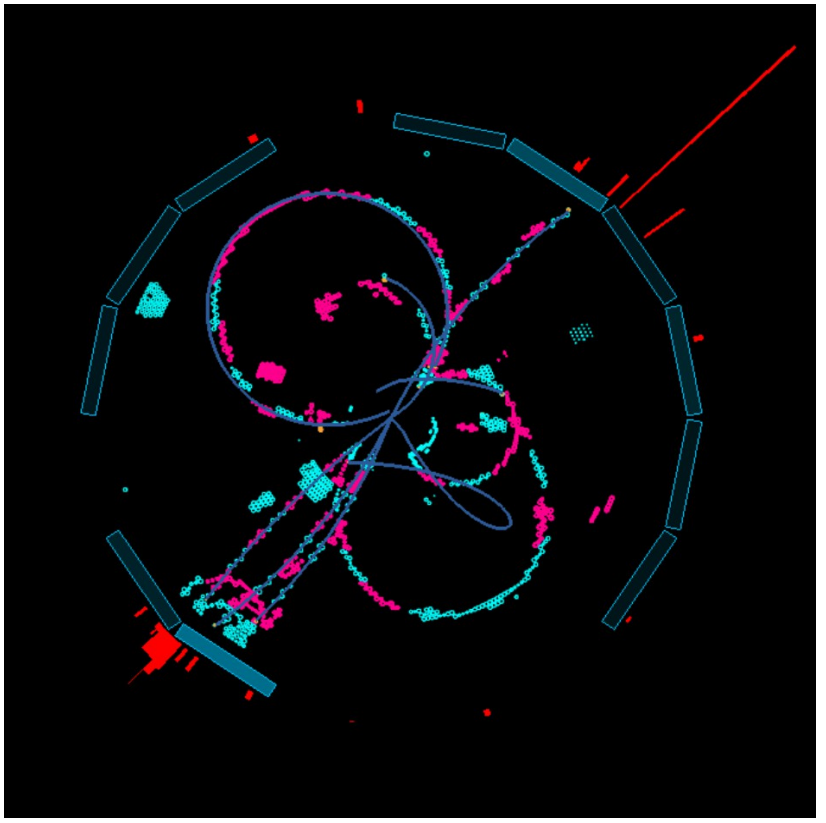
- Quark interactions are described by the CKM unitary matrix V_{CKM}
- Off-diagonal elements of $V^{\dagger}V=I$ can be represented by triangles in complex plane
  - Sides ~ Amplitudes ~ Branching fractions
  - Angles ~ Phases ~ CPV
- Most common triangle from $\Sigma_i V_{id} V_{ib}^{*}$, i=u,c,t (be aware that $\varphi_1 = \beta$, $\varphi_2 = \alpha$, $\varphi_3 = \gamma$!)
- All angles can be accessed at B-factories → BaBar (SLAC) and Belle (KEK) together with LHCb (CERN) → precise determination of unitarity triangle





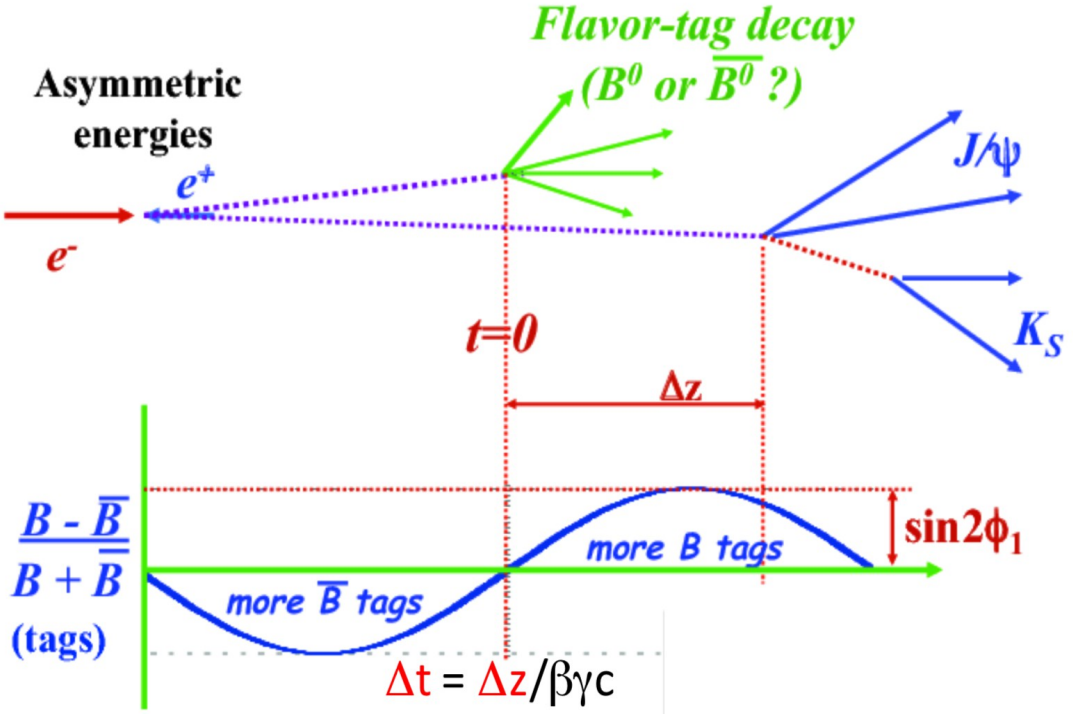
Belle → Belle II

- Belle II is an upgrade of the Belle detector designed to improve performance, especially in spite of the harsh SuperKEKB machine conditions, in particular:
  - much higher background environment w.r.t. KEKB (40x higher luminosity)
  - reduced CM boost w.r.t. Belle
- New Vertex detector:
  - 2 layers of pixels
  - 4 DSSD layers with extended coverage
- EM calorimeter:
  - new electronics with waveform readout
- Particle-ID:
  - new TOP + ARICH (FWD)
- Drift chamber:
  - smaller cell size, longer lever arm
- K_L & muons:
  - Inner (barrel) and FWD RPCs replaced with scintillators



CPV at B-factories

- $B^0\overline{B}^0$ mixing and decay amplitudes interfere → time-dependent CP asymmetry
- Need to measure the difference in decay time Δt, hence the decay vertex
- $B^0\overline{B}^0$ are produced threshold → Y(4S) → $B^0\overline{B}^0$ pairs at rest in the CM frame
- Asymmetric beam energies e^+ = 4, e^- = 7 GeV



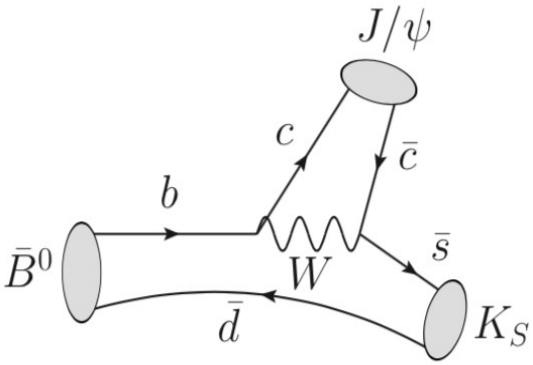
$$\Delta t = \frac{\Delta z}{\beta \gamma c}$$

$$a_{f_{cp}}(\Delta t) \equiv \frac{\Gamma_{\bar{B}\to f_{cp}}(\Delta t) - \Gamma_{B\to f_{cp}}(\Delta t)}{\Gamma_{\bar{B}\to f_{cp}}(\Delta t) + \Gamma_{B\to f_{cp}}(\Delta t)} = S\sin(\Delta M \Delta t) - C\cos(\Delta M \Delta t)$$

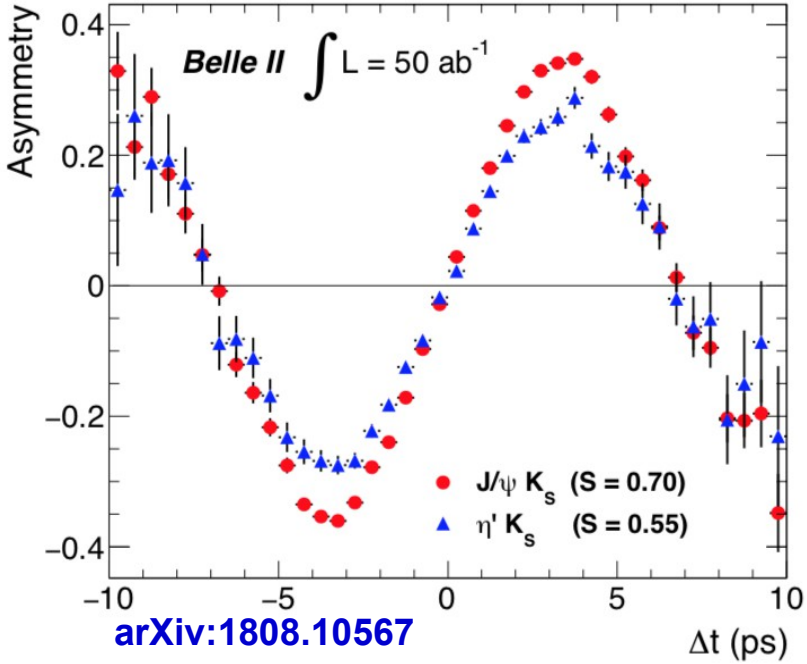
$\sin(2\varphi_1)$ in $b \to c\bar{c}s$

- Tree dominated modes, golden channel $B \to J/\psi\, K_S$
  - Theoretically clean process, $S = -\xi_f \sin(2\varphi_1)$, $C \sim 0$
  - Clean experimental signature: 4 tracks
- Recent theoretical improvements in the calculation of penguin pollution **arXiv:1503.00859**
- Resolution on Δt dominated by the resolution of the tagging B vertex fit
- Thanks to the huge Belle II dataset comparison with other final states could help disentangle new physics effects

→ key ingredients:
vertex fit, flavor tagging



$S \simeq \sin(2\beta)$



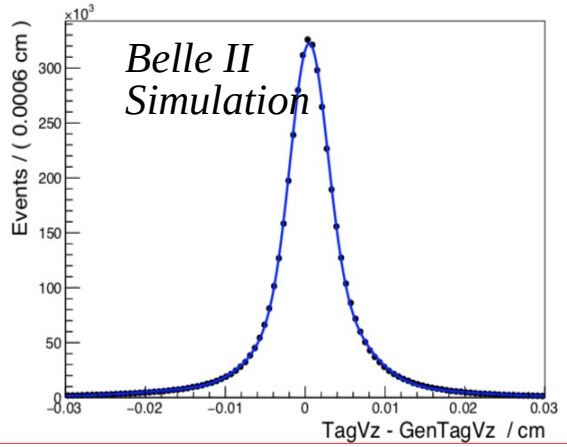
arXiv:1808.10567

Vertex resolution

- Thanks to the new vertex detector (DSSD + pixels) and the update of the fitting strategy (RAVE) we achieve a better vertex resolution w.r.t. Belle in spite of reduced CM boost! (βγ=0.28 vs 0.45)

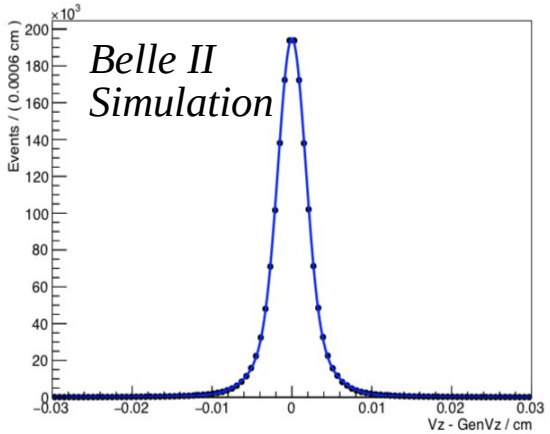
$$\langle \Delta l \rangle_{\text{Belle}} \sim 200\ \mu\text{m}$$
$$\langle \Delta l \rangle_{\text{Belle II}} \sim 130\ \mu\text{m}$$

Δz resolution Tag-side



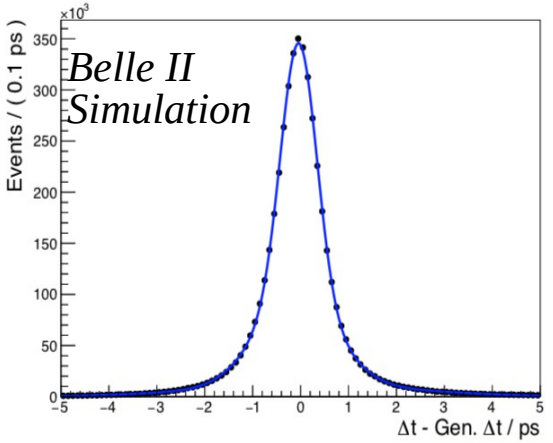
	Belle	Belle II
Bias	$29\mu m$	$6\mu m$
Resolution	$89\mu m$	$53\mu m$

Δz resolution $J/\psi \to \mu\mu$



	Belle	Belle II
Bias	$0.2\mu m$	$2\mu m$
Resolution	$43\mu m$	$26\mu m$

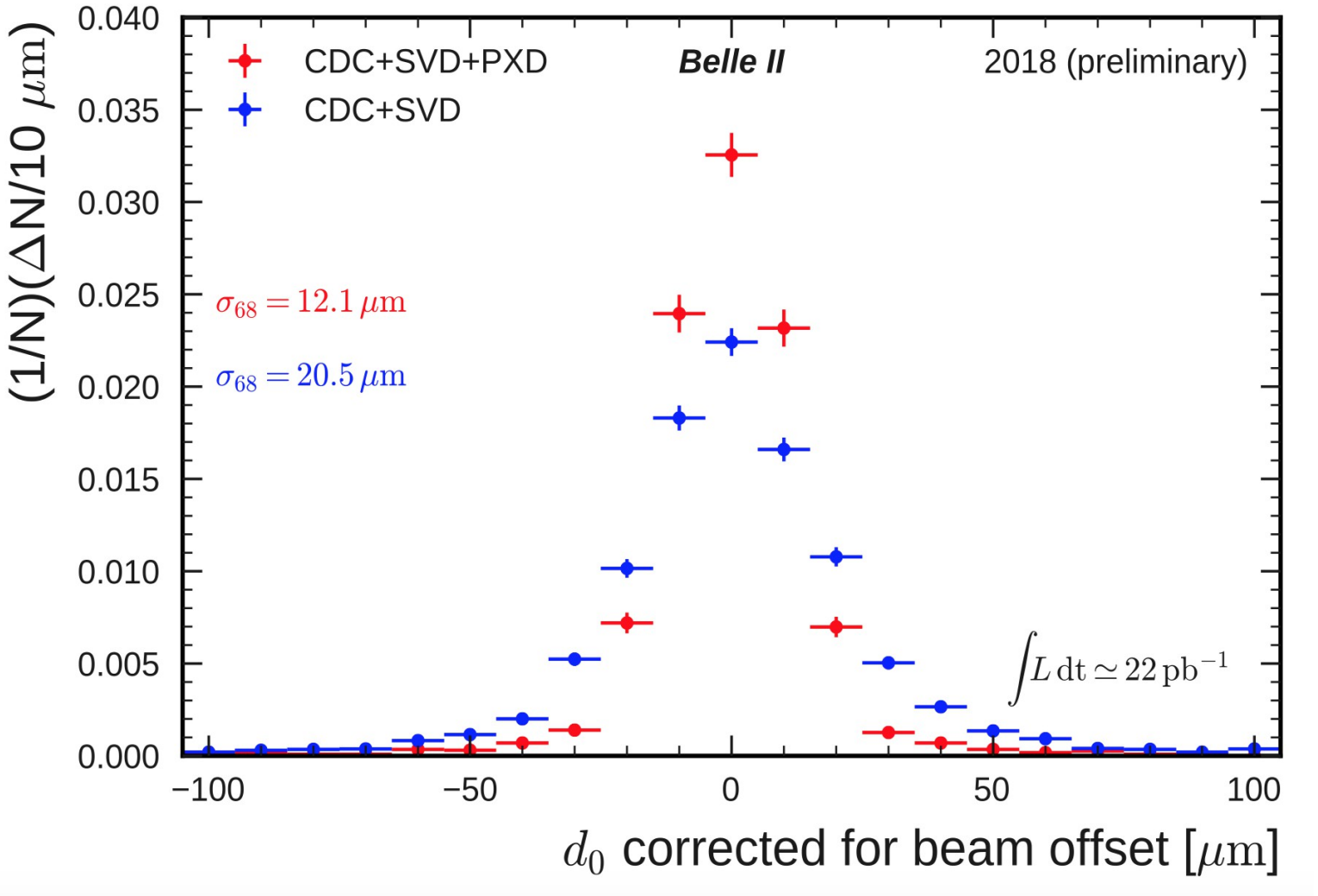
Δt resolution



	Belle	Belle II
Bias	0.2 *ps*	-0.03 *ps*
Resolution	0.92 *ps*	0.77 *ps*

Vertex resolution

- Belle II resolution on the transverse impact parameter with full vertex detector (red) and without pixel layers (blue)



Flavor tagging

- Charged leptons, kaons, pions and Λs from the unreconstructed B^0 (rest of event) are used to determine its flavor
- New algorithms have been developed for Belle II, using more variables and different MVA discriminators which benefit also of the improved PID system
- The new algorithm has already been tested on Belle data

$$\overline{B}^0 \to D^{*+}\ \overline{\nu}_\ell\ \ell^-$$
$$\hookrightarrow D^0\ \pi^+$$
$$\hookrightarrow X\ K^-$$

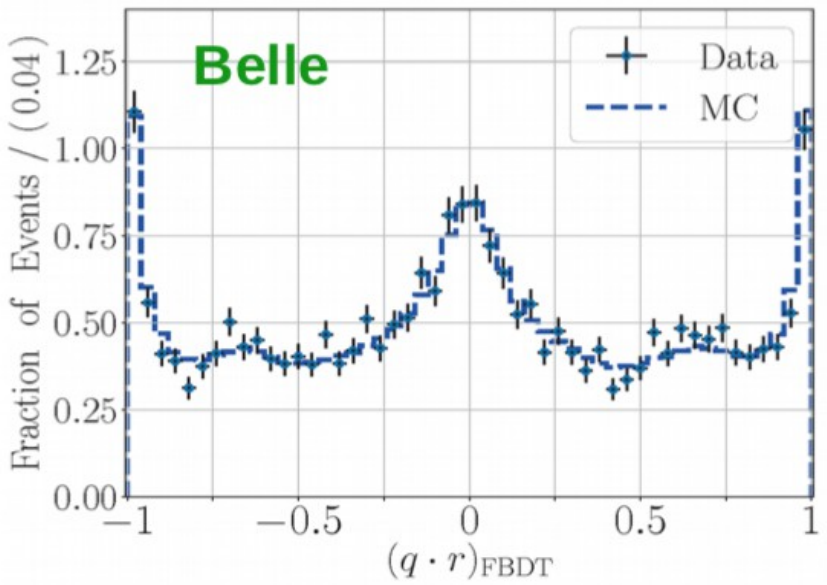
$$\overline{B}^0 \to D^+\ \pi^-\ (K^-)$$
$$\hookrightarrow K^0\ \nu_\ell\ \ell^+$$

$$\overline{B}^0 \to \Lambda_c^+\ X^-$$
$$\hookrightarrow \Lambda\ \pi^+$$
$$\hookrightarrow p\ \pi^-$$

$$\varepsilon_{eff} = \sum_i \varepsilon_i (1 - 2w_i)^2$$

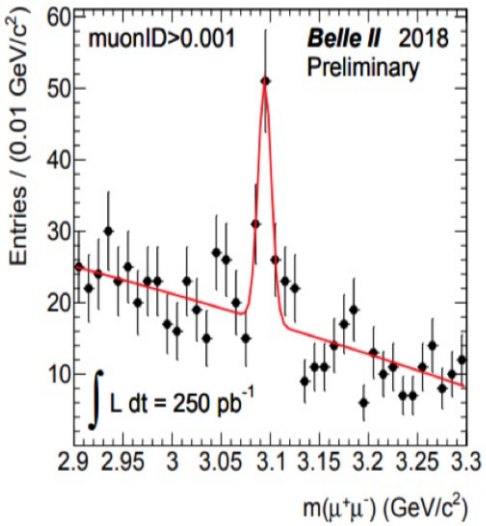
- ε_{eff}: effective tagging efficiency
- ε_i: efficiency of category i
- w_i: mis-tagging probability of category i

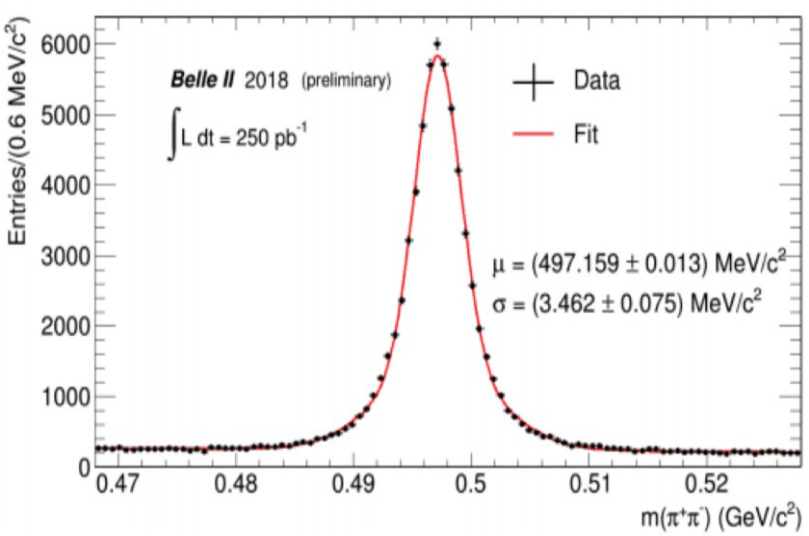
Old FT - Belle data:	ε_{eff} = (30.1	± 0.4) %
New FT - Belle data:	ε_{eff} = (33.6	± 0.5) %
New FT - Belle MC:	ε_{eff} = (34.18	± 0.03)%
New FT - Belle II MC:	ε_{eff} = (37.16	± 0.03)%

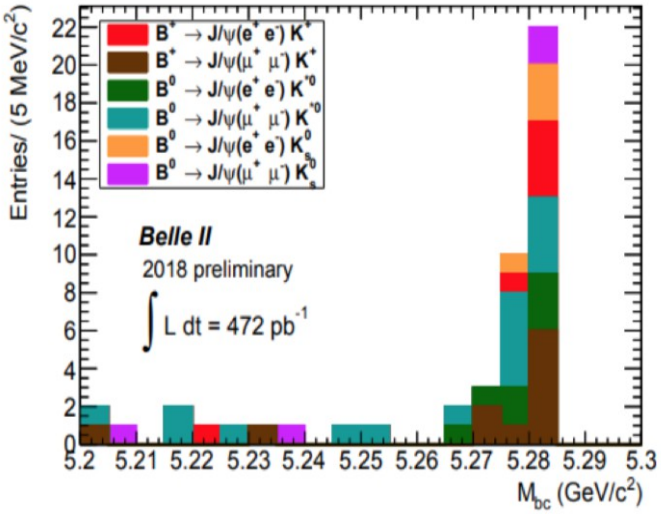


First data

- First collisions of SuperKEKB during commissioning run from April to July 2018 (Phase2): total data sample collected corresponding to about 500 pb^{-1} → first “rediscoveries”:







- Phase3 has started in March 2019 with full vertex detector → data analysis is ongoing (about 6 fb^{-1} to date)
- Hard work on understanding the detector → physics performance is constantly improving

Belle vs Belle II

- Comparison of sensitivities for the measurement of $S \simeq \sin(2\beta)$ in Belle and Belle II using full dataset (1 and 50 ab^{-1} respectively):

	Belle (1 ab^{-1})		
Sample	Value	Stat. ($\times 10^{-3}$)	Syst. ($\times 10^{-3}$)
$B \to J/\psi K_S$	+0.67	29	13
$b \to c\bar{c}s$	+0.667	23	12

PRL 108 171802

Statistically limited!

Worst case scenario, same systematics as Belle

	Belle II (50 ab^{-1})				
Sample	Stat. ($\times 10^{-3}$)	Syst. (1) ($\times 10^{-3}$)		Syst. (2) ($\times 10^{-3}$)	
		Red.	Non-red.	Red.	Non-red.
$B \to J/\psi K_S$	3.5	1.2	8.3	1.2	4.4
$b \to c\bar{c}s$	2.7	2.6	7.0	2.6	3.6

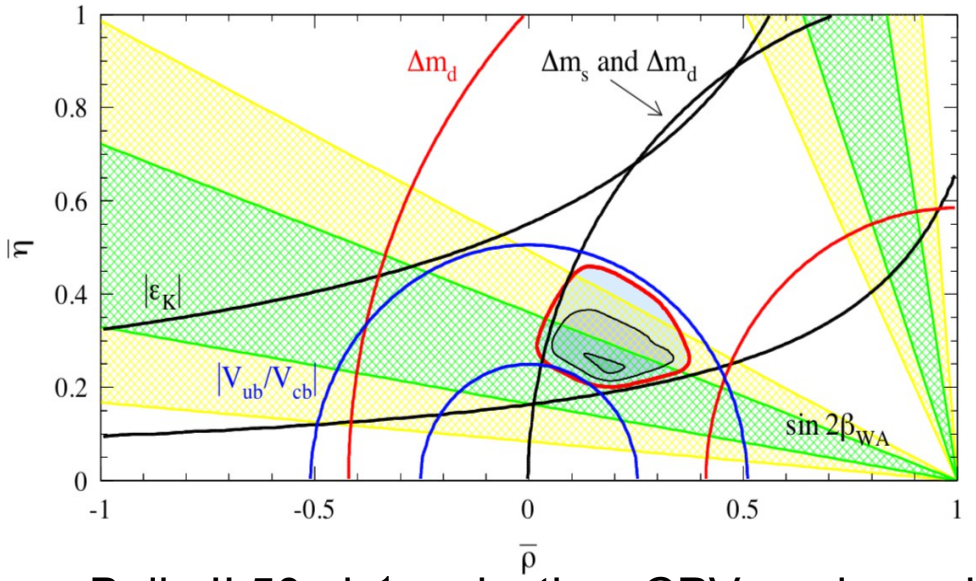
arXiv:1808.10567

With expected improvement due to better vertexing

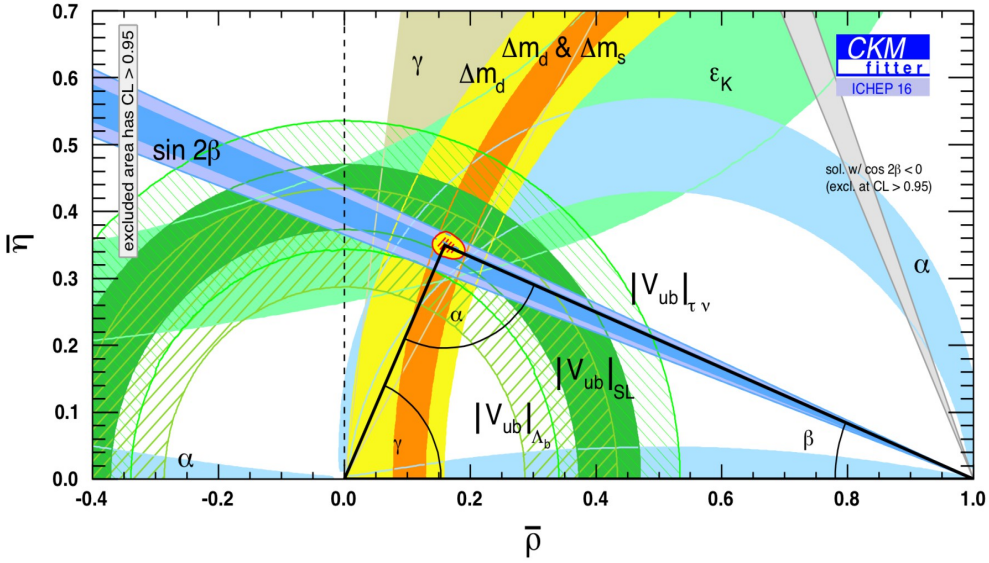
Pictorial Outlook

Before B-factories

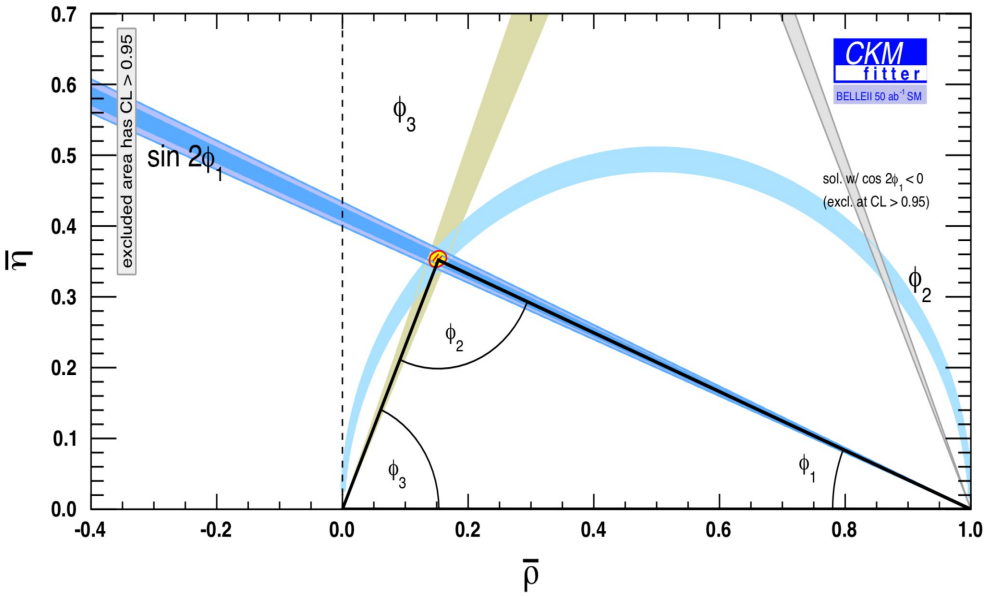
Eur.Phys.J.C21:225-259,2001



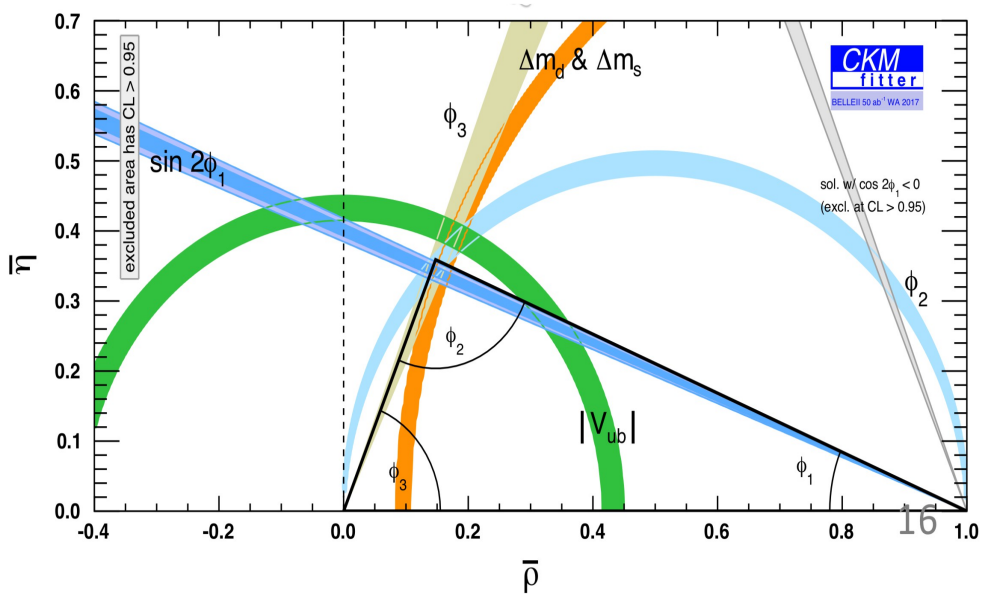
After B-factories



Belle II 50 ab^{-1} projection, CPV modes only



Belle II 50 ab^{-1} projection, all constraints



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Summary

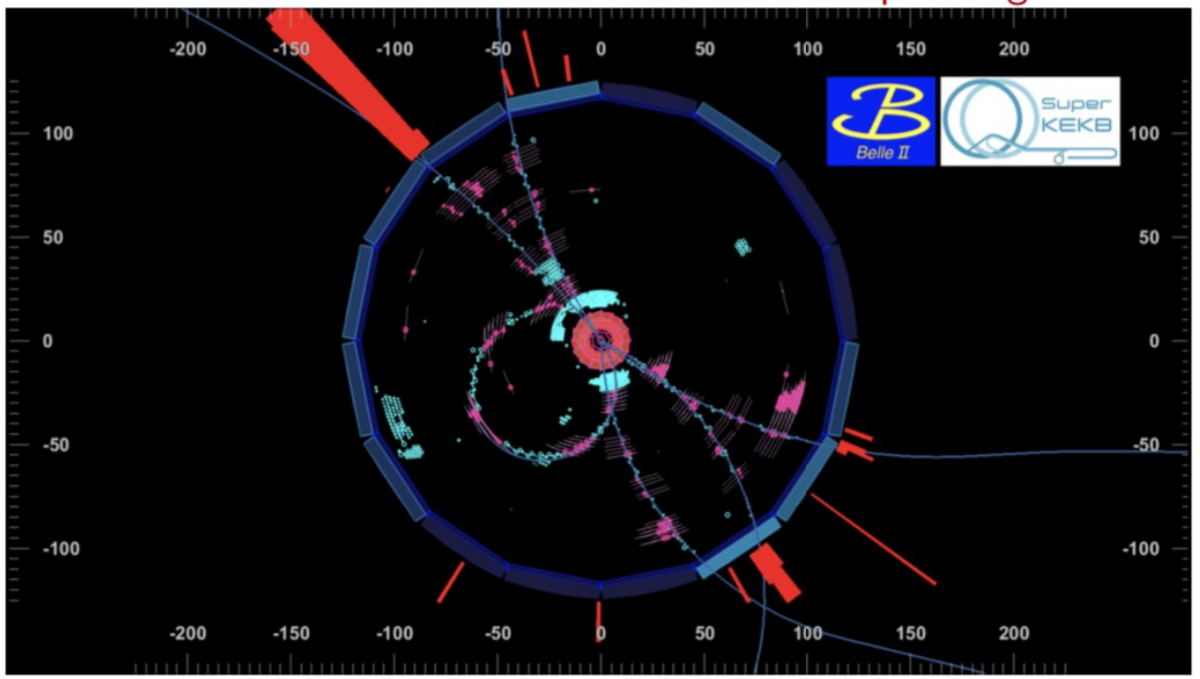
- Belle and BaBar have been very successful in testing the CKM paradigm
- Belle II and SuperKEKB represent a new generation B-factory
- The huge dataset along with improved detector performance will allow

to test CKM mechanism at 1% level

- $\sin(2\varphi_1)$: precision better than 1% using $c\bar{c}s$ modes

Second "First" SuperKEKB collision on March 11^{th}

Phase III - Full detector installed and operating



B-factories are back in the game

Thanks for your attention!