Measurement of γ (ϕ_3) and first results on CP violation at Belle II

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Outline

- Introduction
- SuperKEKB and Belle II
- Prospects for ϕ_3
- Prospects for ϕ_1
- Summary

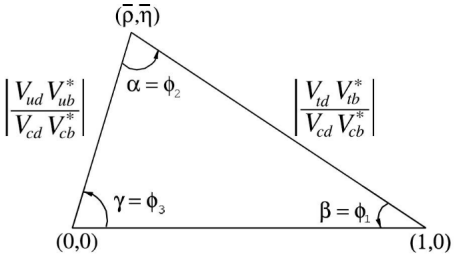
Introduction

Measuring SM *CP* violation ⇒ Measure complex phase of CKM elements.

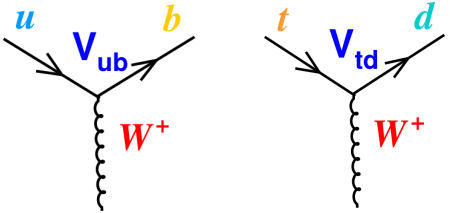
$$V_{ij} \approx \begin{array}{c} \\ u \\ c \\ t \end{array} \begin{array}{c} \begin{array}{ccc} d & s & b \end{array} \\ \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ -\lambda^3 & -\lambda^2 & 1 \end{pmatrix} \end{array}$$

Unitarity condition

$(1^{st} \leftrightarrows 3^{rd})$



$\lambda \approx 0.22$: Cabbibo angle



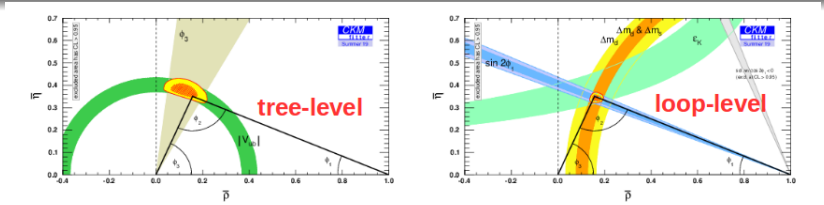
This talk is focused on:

$$\phi_1/\beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

$$\phi_3/\gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

ϕ_2: see Eldar Ganiev's talk.

CKM: Current status



World average (HFLAV)
[hflav.web.cern.ch/]

$$\beta \equiv \phi_1 = (22.2 \pm 0.7)^\circ$$
$$\alpha \equiv \phi_2 = (84.9^{+5.1}_{-4.5})^\circ$$
$$\gamma \equiv \phi_3 = (71.1^{+4.6}_{-5.3})^\circ$$

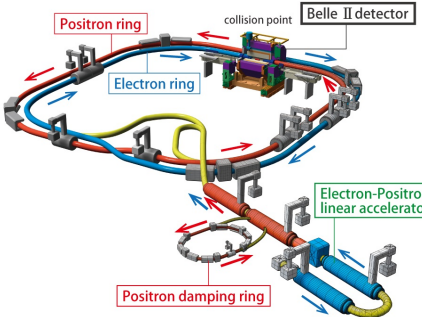
Global fit (CKM fitter)
[ckmfitter.in2p3.fr/]

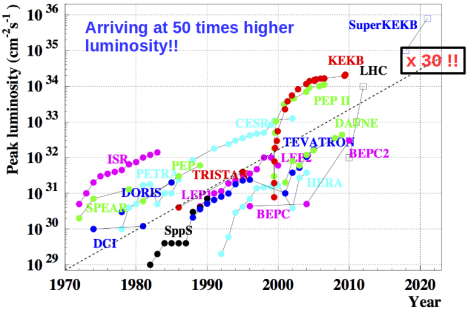
$$\beta \equiv \phi_1 = (22.51^{+0.55}_{-0.40})^\circ$$
$$\alpha \equiv \phi_2 = (91.6^{+1.7}_{-1.1})^\circ$$
$$\gamma \equiv \phi_3 = (65.81^{+0.99}_{-1.66})^\circ$$

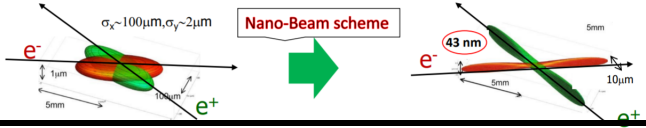
- **New physics (NP) prospects:**
  - ϕ_1: **comparison of TD-asymmetry in tree- and loop-dominated processes.**
  - ϕ_3: **test of direct vs indirect disagreement (requires improvement of precision in direct measurement).**

SuperKEKB accelerator

- **SuperKEKB**: 4 GeV e^+ and 7 GeV e^- asymmetric collider at KEK.
- A 30-fold increase in instantaneous luminosity over Belle, $\mathcal{L} = \mathbf{6x10^{35}}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

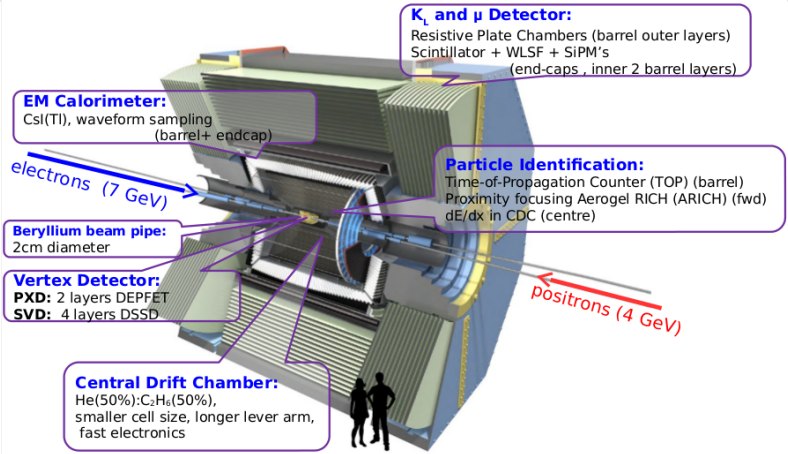






20× smaller beam spot and 1.5× increase in beam current ⇒ 30× Lumi

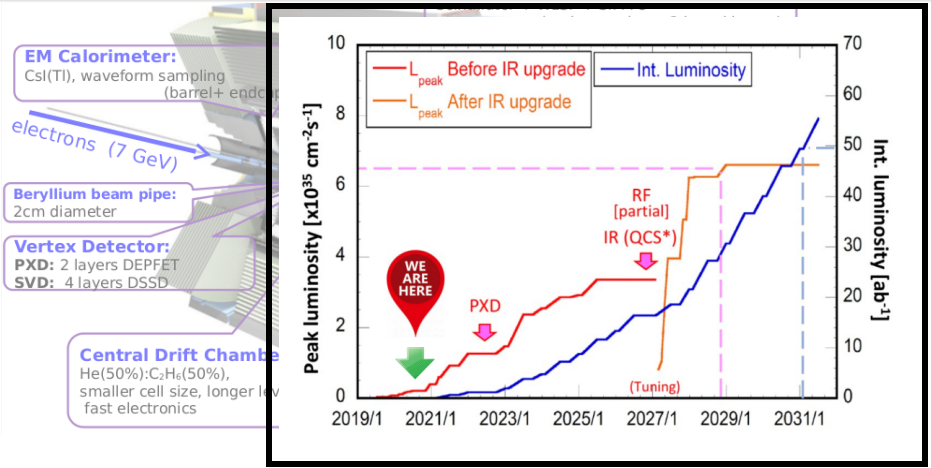
Belle II detector and status



- Improved tracking, vertexing.
- Better particle identification.
- Better calorimeter resolution.

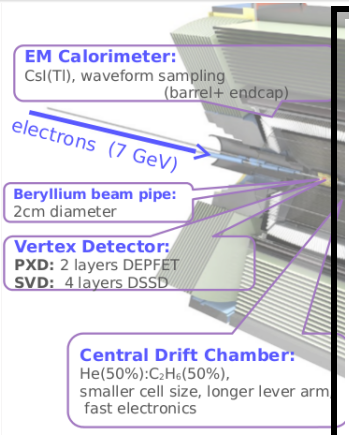
- Challenge:
  - Higher beam background
  - Higher trigger rate

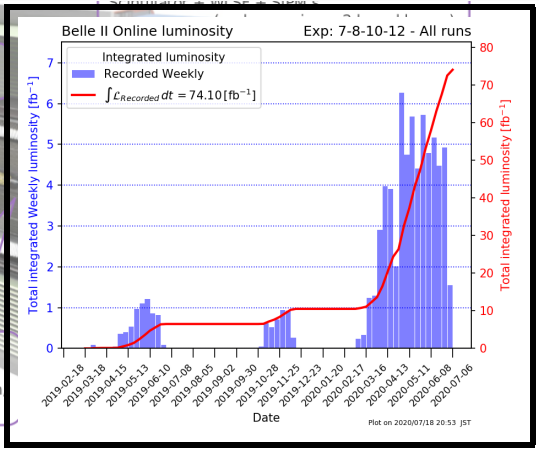
Belle II detector and status



- Improved tracking, vertexing.
- Better particle identification. More details in K.Matsuoka's talk.
- Better calorimeter resolution.

Belle II detector and status





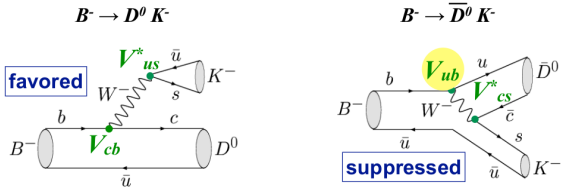
- Improved tracking, vertexing.
- Better particle identification.
- Better calorimeter resolution.

World Record by SuperKEKB on June 15$^{\text{th}}$ 2020:
$\mathcal{L} = 2.4x10^{34}\text{cm}^{-2}\text{s}^{-1}$

Extraction of ϕ_3

- Only CKM angle accessible at tree level.
- Very precise theoretical prediction $\delta\phi_3/\phi_3 \sim 10^{-7}$ [J. Brod, J. Zupan, arxiv:1308.5663].
- ϕ_3 **is the phase between** $b \to u$ **and** $b \to c$ **transition:**

$$\frac{\mathcal{A}^{\text{suppr.}}(B^- \to \overline{D^0}K^-)}{\mathcal{A}^{\text{favor.}}(B^- \to D^0K^-)} = r_B e^{i(\delta_B - \phi_3)}$$



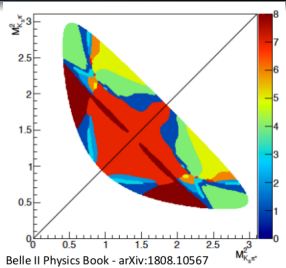
- Measured via the interference between $B^- \to D^0K^-$ and $B^- \to \overline{D}^0K^-$ with various D^0 channels.
  - **GLW method**: *CP* eigenstates: $K^-K^+, \pi^-\pi^+, K^0_S\pi^0$ *[Phys. Lett. B* **253***, 483]*
  - **ADS method**: DCS modes: $K^+\pi^-, K\pi\pi^0$ *[Phys. Rev. Lett.* **78***, 3257]*
  - **BPGGSZ method**: self-conjugate multibody final states: $K^0_S\pi^-\pi^+$, $K^0_S\pi^-\pi^+\pi^0, K^0_SK^-K^+$ *[Phys. Rev. D* **68***, 054018]*

Belle II prospects for ϕ_3

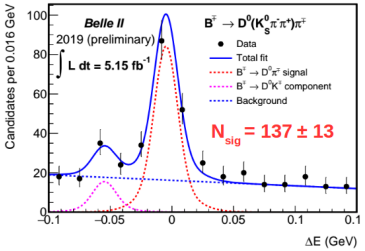
- Golden mode in Belle II: $B^{\pm} \to D^0(K^0_S\pi^-\pi^+)K^{\pm}$
  - Model-independent binned Dalitz plot approach.
  - Number of events in i^{th} bin is a function of $x_{\pm}/y_{\pm}$:

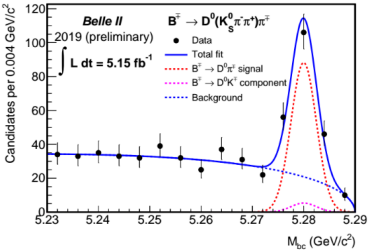
$$N_i^{\pm} = h_B[K_{\pm i} + r_B^2 K_{\mp i} + \sqrt{K_i K_{-i}}(x_{\pm}c_i \pm y_{\pm}s_i)]$$

$$(x_{\pm}, y_{\pm}) = r_B(\cos(\pm\phi_3 + \delta_B), \sin(\pm\phi_3 + \delta_B))$$



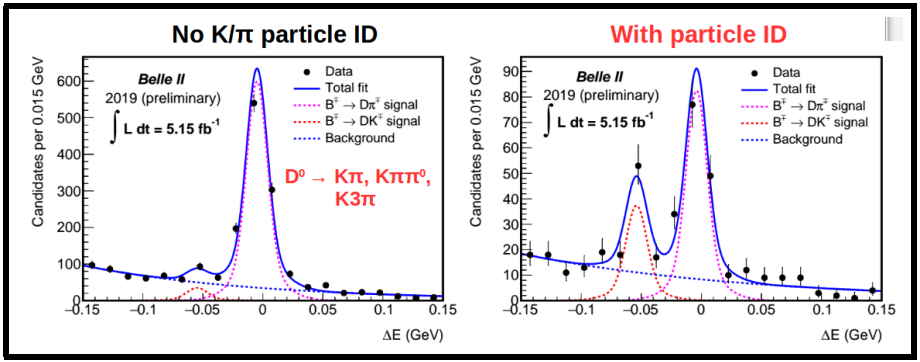
- Precise strong phase measurement needed to match Belle II stat. precision: expected from **20 fb^{-1}** BESIII data set.





$B \to DK$ @Belle II

- More sensitive to ϕ_3 than $B \to D\pi$ because of its higher r_B value.
- **Rediscovery of B → DK with more than 5σ evidence using the continuum suppression tool and particle identification technique of Belle II.**



- Total 53 ± 9 signal candidates are obtained with a 1D maximum likelihood fit to the ΔE.

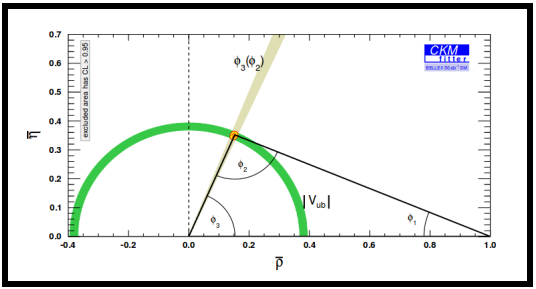
Future prospects

- Expect Belle II and LHCb upgrade to match each other's performance!
- $\delta(\phi_3) < 1.6^\circ$ with 50 ab^{-1} data set.

- Modes that are good for Belle II:
  - $D^* \to D^0\pi^0, D^0\gamma$
  - $D^0 \to K^0_S\pi^0$, $K^0_S\pi\pi\pi^0$...

    [P. K Resmi, J. High Energy Phys. **10**, *178 (2019)]*
- Belle II strength:
  - Increasing statistics
  - **Good neutral reconstruction**
  - Better K/π separation
  - Better continuum suppression

Figure: Fit extrapolated to 50 ab^{-1} for a SM-like scenario



Belle II Physics book: arXiv:1808.10567

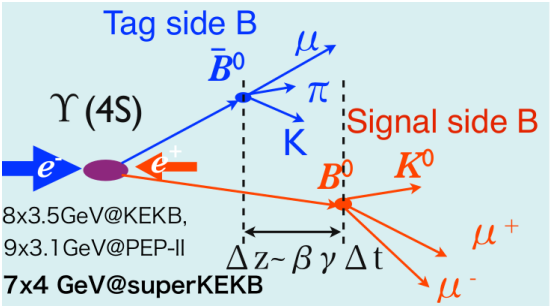
- LHCb will clearly have more precise results in fully-charged final states.

CPV at Belle II

- Decay rate of B^0 meson to CP eigen-states:

$$\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} [1 + q\,(\mathcal{A}_{CP} \cos \Delta m_d \Delta t + \mathcal{S}_{CP} \sin \Delta m_d \Delta t)]$$

- **Key element:** Vertex position measurement, B meson flavor tagging.



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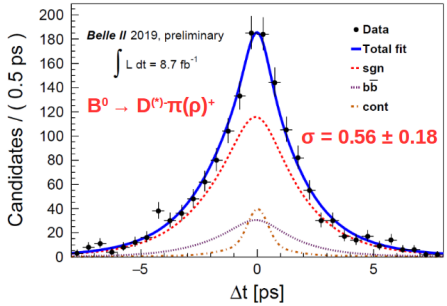
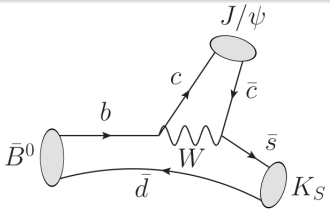


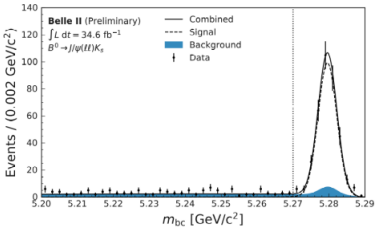
see Cyrille Praz's talk.

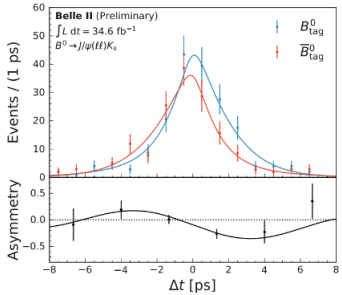
Belle II prospects for $\sin 2\phi_1$

- Most precisely measured UT parameter so far.
- Tree-dominated $b \to c\bar{c}s$ golden mode:
  $\mathbf{B^0 \to J/\psi K^0_S}$, $\Rightarrow \mathcal{A}_{CP} = 0$, $\mathcal{S}_{cp} = \sin 2\phi_1$
  - Theoretically and experimentally precise.
- Asymmetry in $\mathbf{B^0 \to J/\psi K^0_S}$



BRAND NEW





- Numbers:

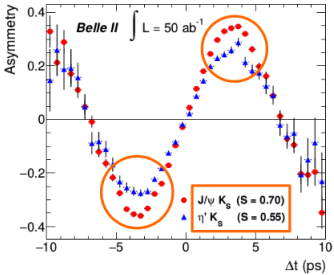
Future prospects

- Challenge both for experiment and theory: penguin pollution.
- Can be controlled experimentally: $\mathbf{B^0 \to J/\psi \pi^0}$

$\sin 2\phi_1$			
Belle II		LHCb	
5 ab^{-1}	50 ab^{-1}	8 fb^{-1}	50 fb^{-1}
0.4°	0.3°	0.6°	0.3°

- Other modes which can also contribute ($b \to q\bar{q}s$):
  $\mathbf{B^0 \to \phi K_S, \eta' K_S, \omega K_S}$...
- **Compare the time-dependent asymmetry between tree- and loop-dominated processes: NP could produce a sizable shift.**

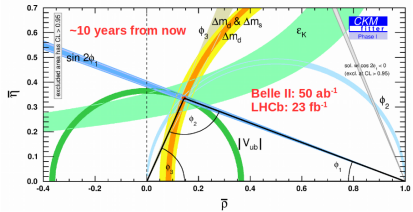
CP asymmetry projection @50ab^{-1}



Summary

- **Flavor physics at high luminosity B-factories offers good probe for testing SM and looking for NP.**

- Belle II will play a key role in particle physics.
  - Experience from Belle and Babar.
  - Good complementarity with LHCb.
  - CKM angle measurements can be improved with just 5 -10 ab^{-1} data set.
  - Huge data set of 50 ab^{-1}: several measurements will be syst. limited $\rightarrow$ lots of work ahead!



$$\delta\phi_1 \lesssim 0.1^\circ$$
$$\delta\phi_2 \lesssim 1^\circ$$
$$\delta\phi_3 \lesssim 1.6^\circ$$

- Brand new asymmetry results from $\mathbf{B^0 \rightarrow J/\psi K^0_S}$: towards $\sin 2\phi_1$
- Expected experimental performance often better w.r.t Belle despite 20x higher beam background and lower boost.
- Looking forward to the next decade of Belle II results!!

Thank you!

Belle II highlights at ICHEP 2020

- CPV and CKM: Experimental overview: **Doris Kim**
- First results and prospects for τ LFV decays: **Francesco Tenchini**
- First results on V_{ub} and V_{cb} with Belle II: **Racha Cheaib**
- Leptonic and semileptonic decays with τs at the Belle II experiment: **Marco Milesi**
- Early charmless B decay physics at Belle II: **Eldar Ganiev**
- Tau physics prospects at Belle II: **Kenji Inami**
- Charm potential at Belle II: **Giulia Casarosa**
- Results and Prospects of Radiative and EWP Decays at Belle II: **Yo Sato**
- First results from Belle II on exotic and conventional quarkonium: **Roberto Mussa**
- Dark Sector first results at Belle II: **Enrico Graziani**
- The Belle II Experiment: Status and Prospects: **Kodai Matsuoka**
- Status and Future development of the FEI Algorithm at Belle II: **William Sutcliffe**
- B lifetimes at Belle II: **Cyrille Praz**
- Track rec. eff. measurement using $e^+e^- \to \tau^+\tau^-$ events at Belle II: **Laura Zani**
- Trg eff measurement using $e^+e^- \to \tau^+\tau^-$ events at Belle II: **Petar Rados**

Stay tuned!!