Measurement of the CKM angle ϕ_3 at Belle II

BEAUTY 2020

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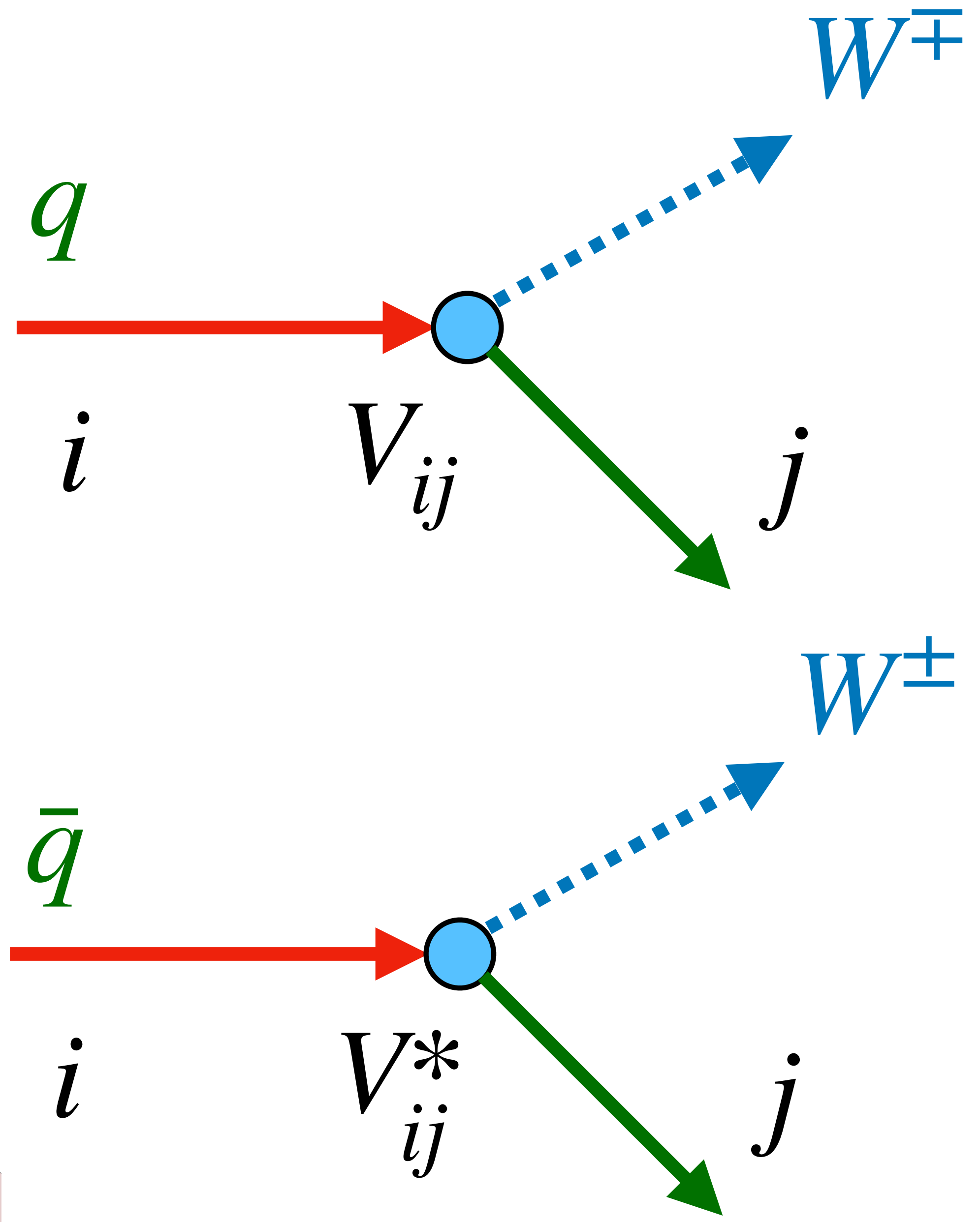
on behalf of Belle II Collaboration

Introduction

CKM Quark Mixing

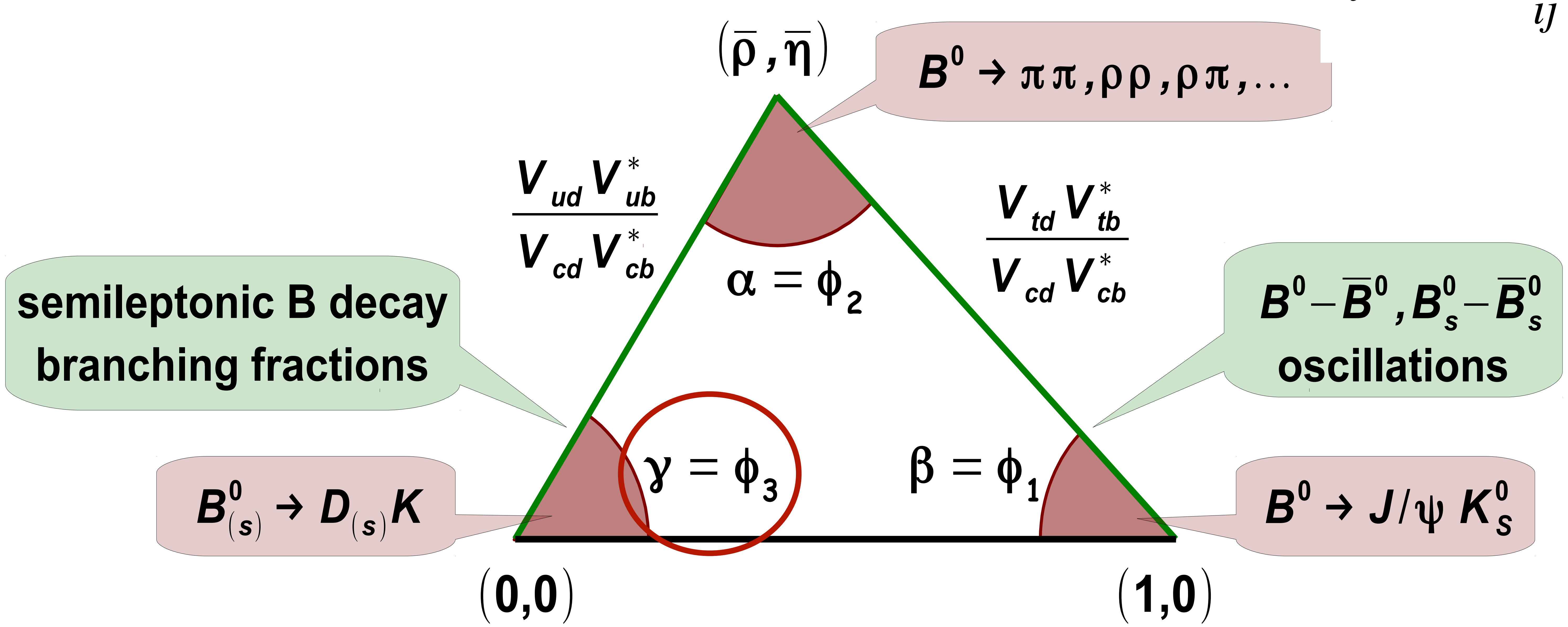
- V_{CKM} contains coupling constants of weak interaction and complex phase



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - \imath\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-\imath\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Unitarity ⇒ 6 triangle relations in the complex plane, e.g.

$$V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td}$$



Measurement of φ3 (phase of |V_{ub}| in $B \to$ Charm)

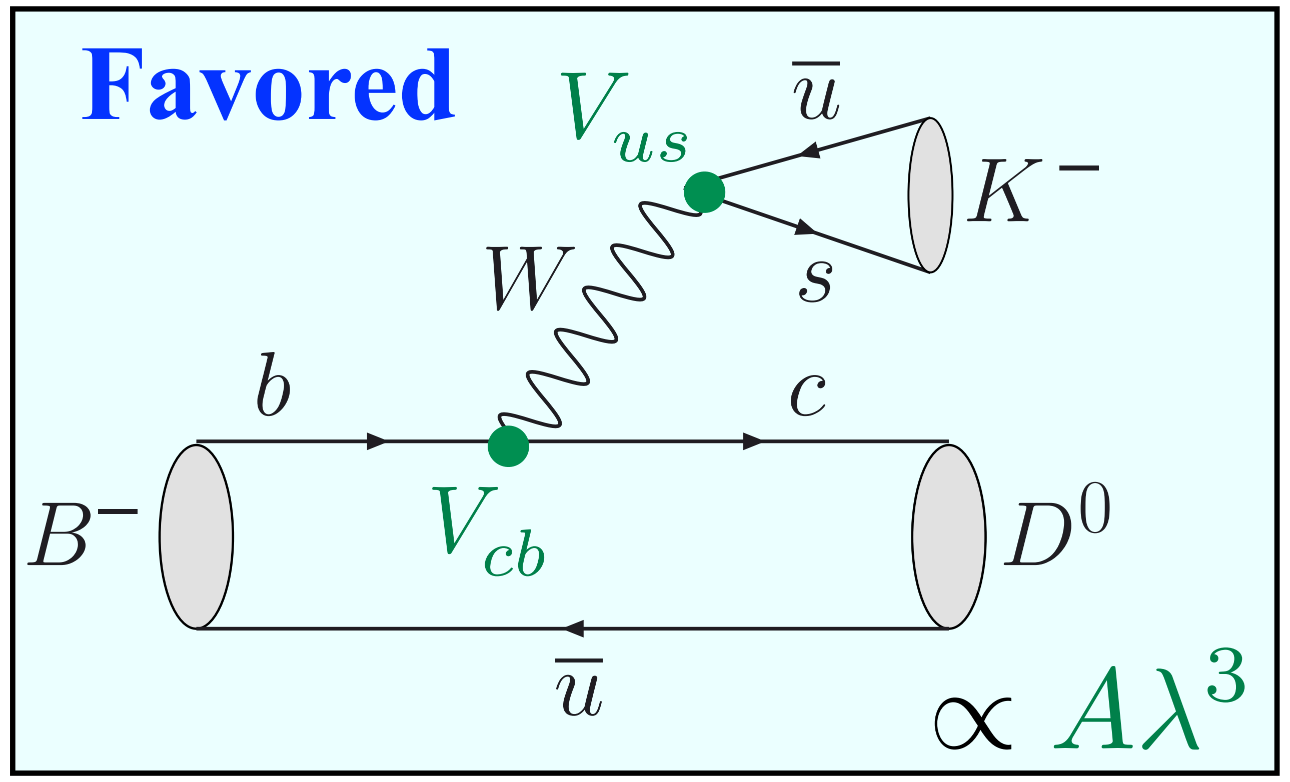
- The weak phase $\phi_3 \equiv \arg\frac{i\eta}{\rho}$ … can b measured in $B^{\pm} \to D^{(*)}K^{(*)\pm}$ decays by the interference between two amplitudes if both $B^- \to D^0K^-$ and $B^- \to \bar{D}^0K^-$ decay via tree level.

- Theory is "pristine" in these approaches $\delta\phi_3/\phi_3 \sim 10^{-7}$. [J. Brod, J. Zupan,arxiv:1308.5663].

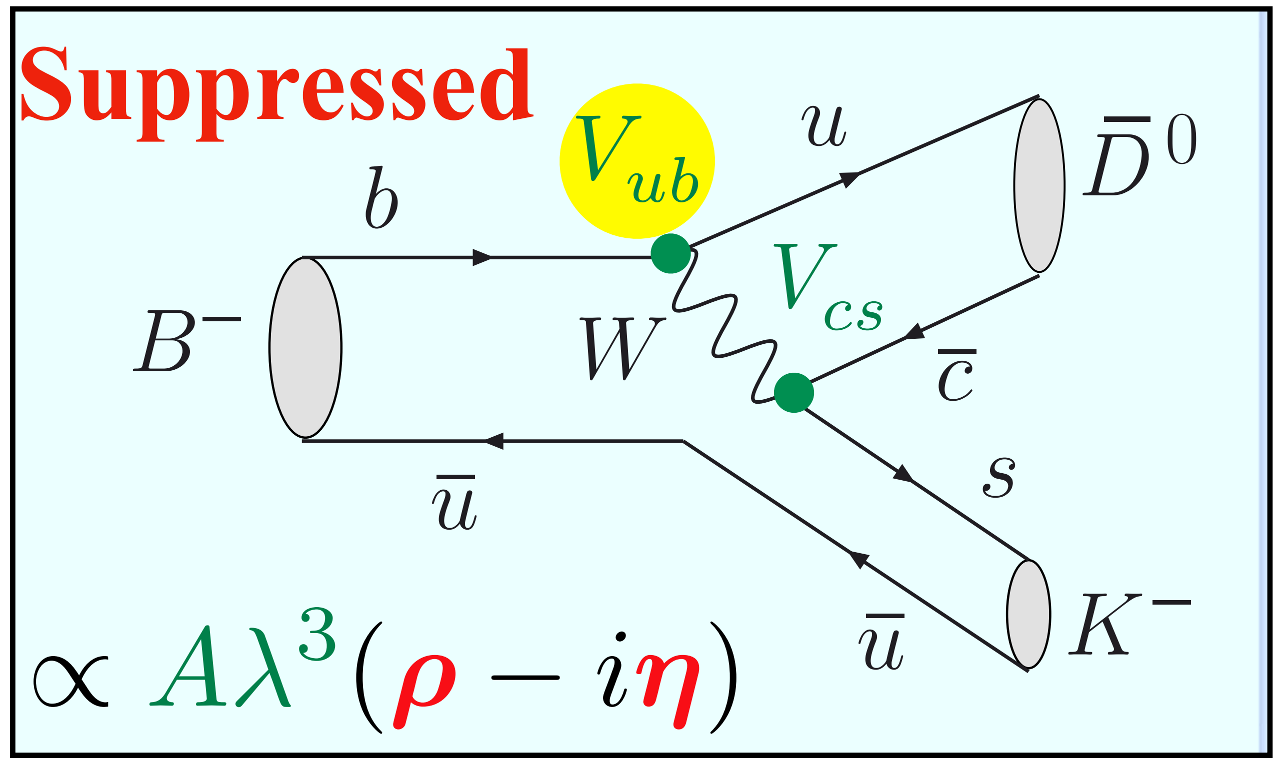
$$\frac{\mathcal{A}^{\text{suppr.}}(B^- \to \overline{D^0}K^-)}{\mathcal{A}^{\text{favor.}}(B^- \to D^0K^-)} = r_B e^{i(\delta_B - \phi_3)}$$

δ_B strong CP conserving phase

Three techniques to measure ϕ_3 used rare decays of the form $B^{\pm} \to D^{(*)}K^{(*)\pm}$



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



$B^- \to \bar{D}^0K^-$

Measurement of φ3 (phase of $|V_{ub}|$ in $B \to$ Charm)

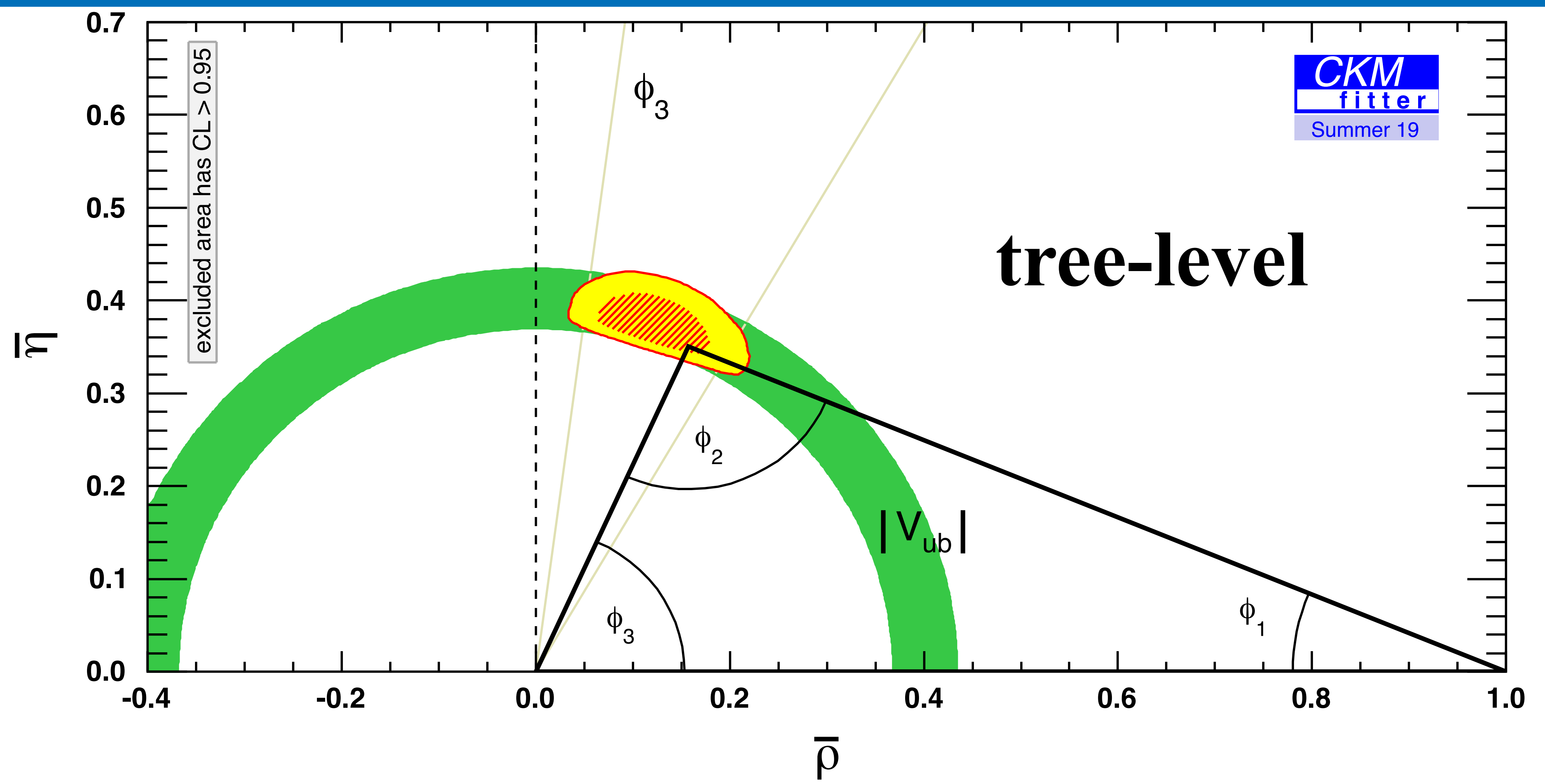
Three techniques to measure ϕ_3 used rare decays of the form $B^{\pm} \to D^{(*)}K^{(*)\pm}$

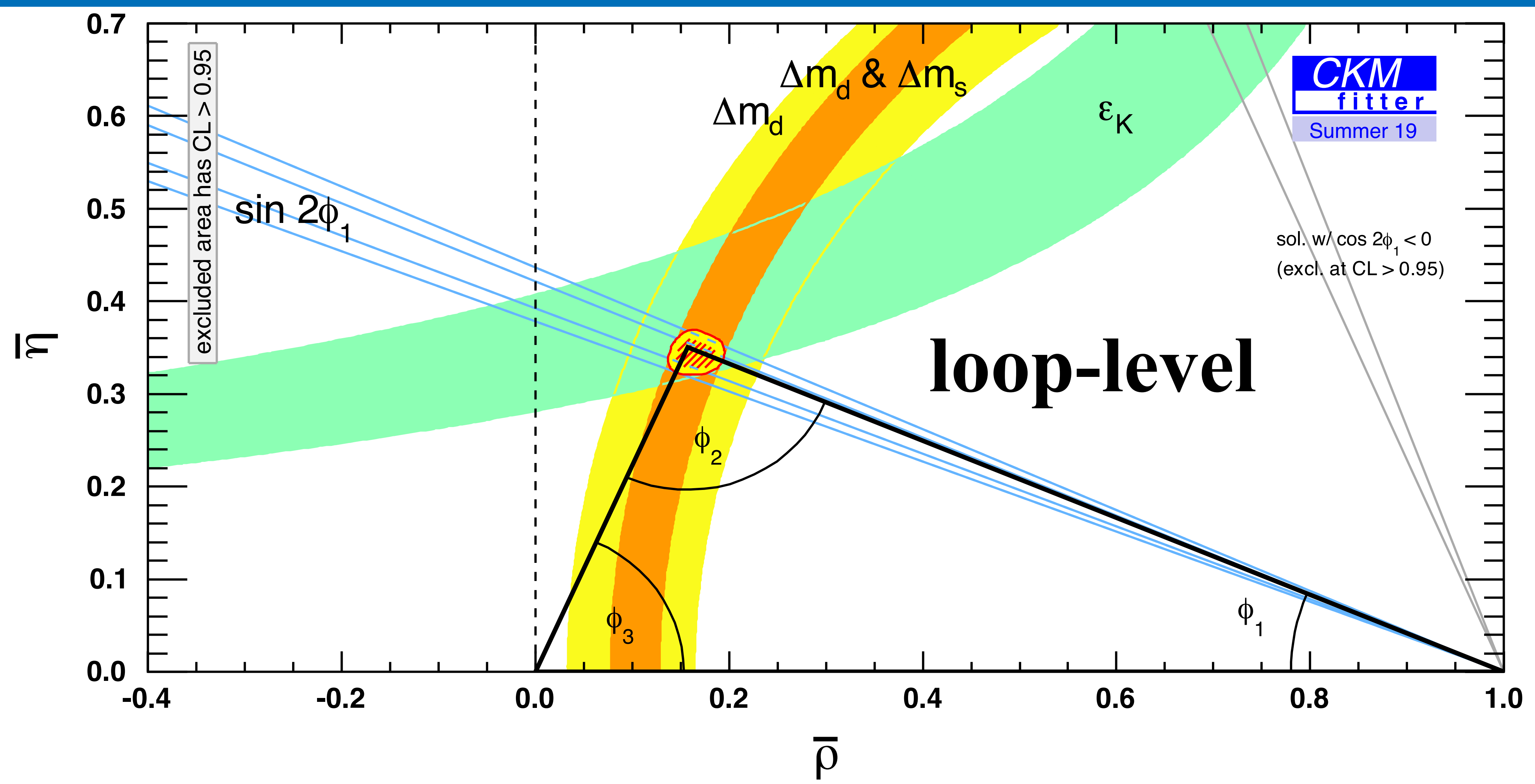
- **GLW method**
  - Interference with CP eigenstates
  - Final state of D^0 = CP eigen states such as $K^+K^-, \pi^+\pi^-, K_S\pi^0$ **[Phys. Lett. B 253, 483]**
- **ADS method**
  - Interference with flavor specific
  - Final state of D^0 = doubly-Cabibbo suppressed D decays such $K\pi, K\pi\pi^0$ **[Phys. Rev. Lett. 78, 3257]**
- **BPGGSZ**
  - Self conjugate of D decays using Dalitz plot
  - Final state of D^0 = three body decays such as $D \to K_S\pi^+\pi^-, K_SK^+K^-$ **[Phys. Rev. D 68, 054018]**

ϕ_3 is extracted by combining information from all measurements

- Belle II has strength in measuring neutral e.g. K_S,→very efficient in K_S reconstruction → allowing to stay competitive in these measurements despite a smaller number of B's available.

Current Precision of CKM Matrix





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

$$\beta \equiv \phi_1 = (22.2 \pm 0.7)^\circ$$

$$\alpha \equiv \phi_2 = (84.9^{+5.1}_{-4.5})^\circ$$

$$\gamma \equiv \phi_3 = (71.1^{+4.6}_{-5.3})^\circ$$

CKM Fitter [ckmfitter.in2p3.fr/]

$$\beta \equiv \phi_1 = (22.51^{+0.55}_{-0.40})^\circ$$

$$\alpha \equiv \phi_2 = (91.6^{+1.7}_{-1.1})^\circ$$

$$\gamma \equiv \phi_3 = (65.81^{+0.99}_{-1.66})^\circ$$

φ_3 is measured in tree decays together with $|V_{ub}|$ provides a SM reference for new physics searches !!!

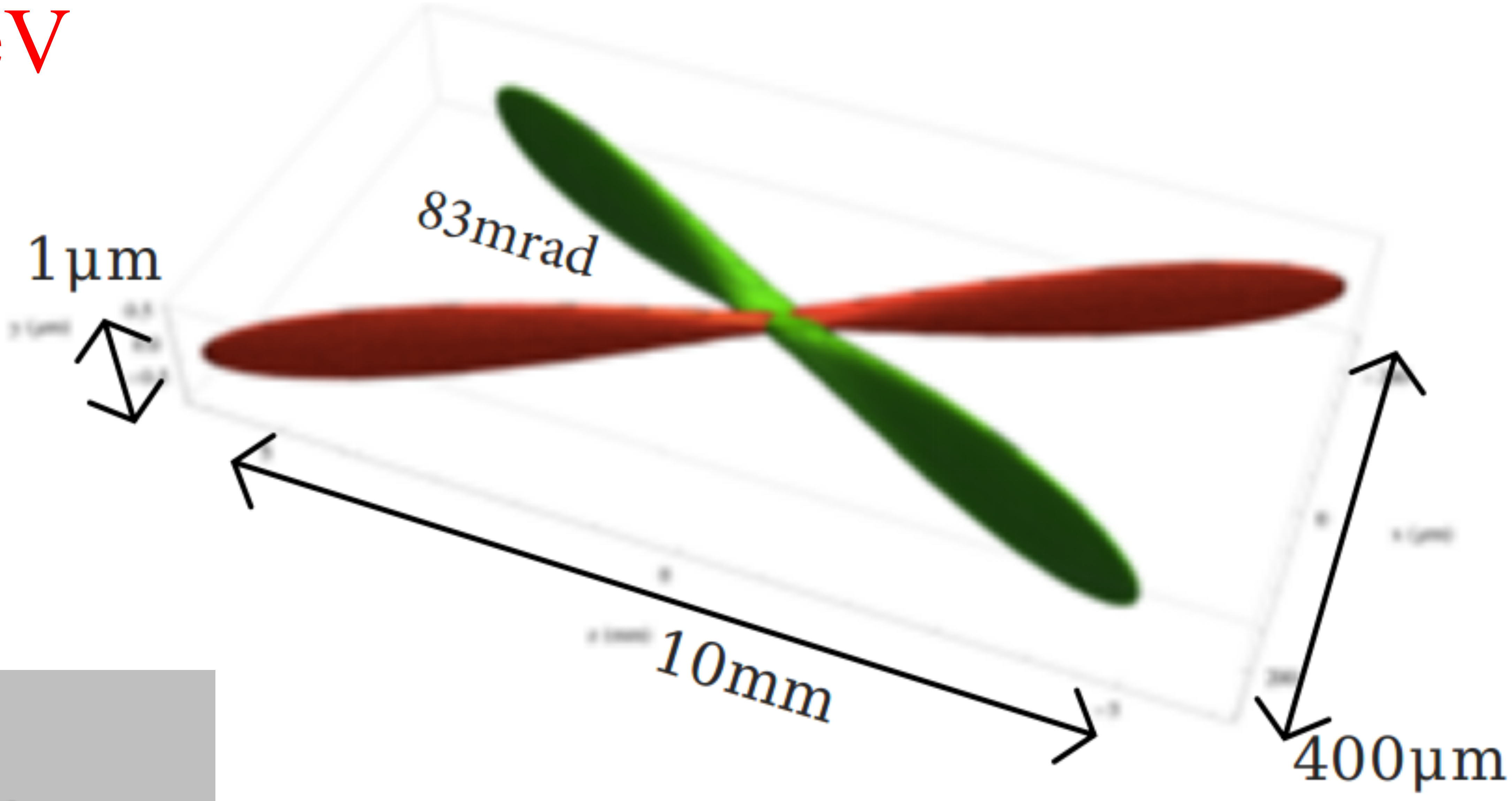
SuperKEKB and Belle II

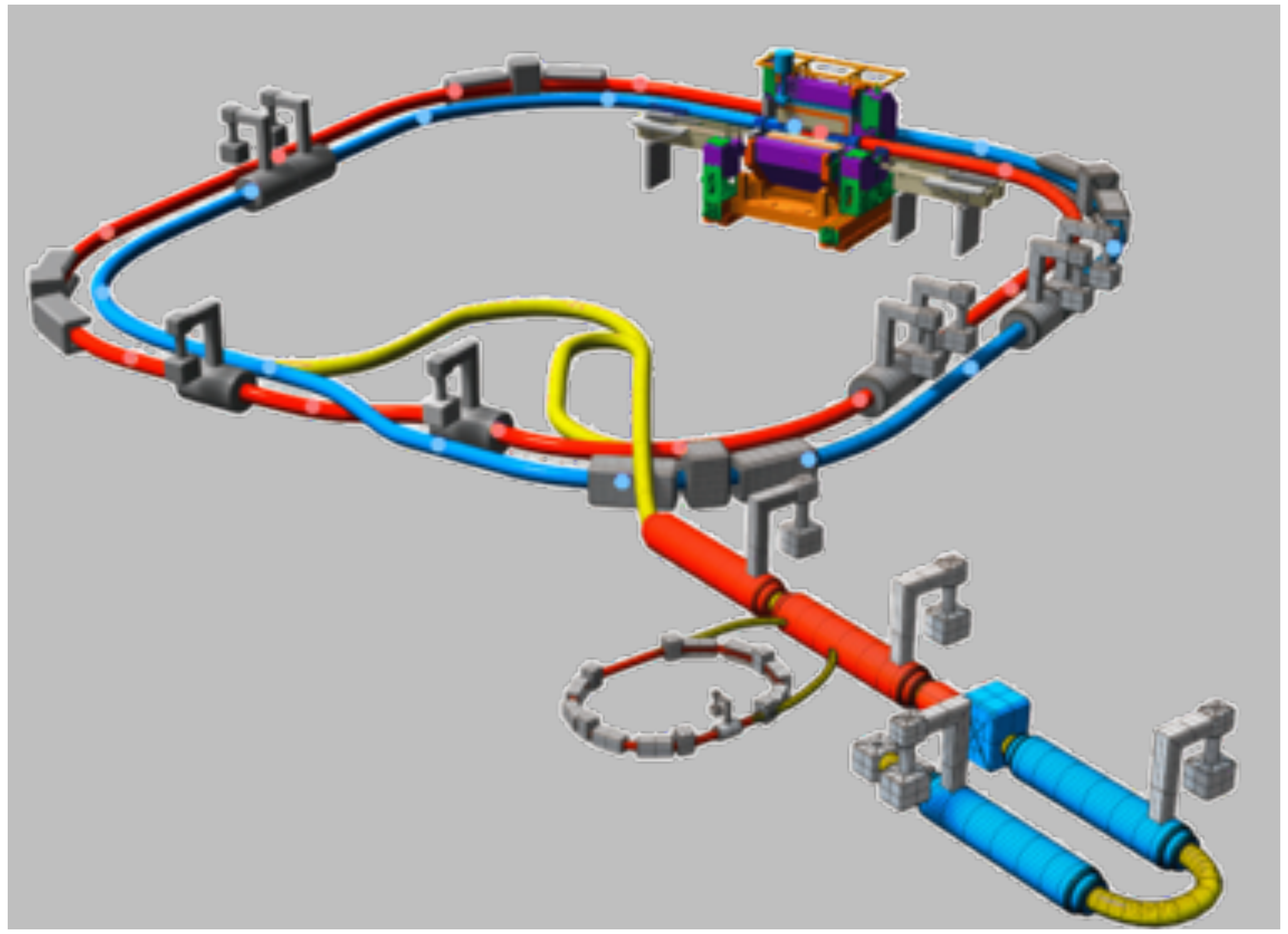
SuperKEKB Accelerator

Assymetric B-factory with e^- at 7 GeV and e^+ at 4 GeV

$$Y = \sigma \times \mathcal{L} \text{ where } \mathcal{L} \propto \frac{\text{Beam current}}{\text{Beam size}}$$

events cross-section luminosity $[s^{-1}]$ $[cm^2]$ $[cm^{-2}s^{-1}]$





- Beam current $\times 2$
- $\mathscr{L}^{peak}_{KEKB} = 2.1 \times 10^{34}/cm^2s$
- $\mathscr{L}^{peak}_{SuperKEKB} = 6.5 \times 10^{34}/cm^2s$

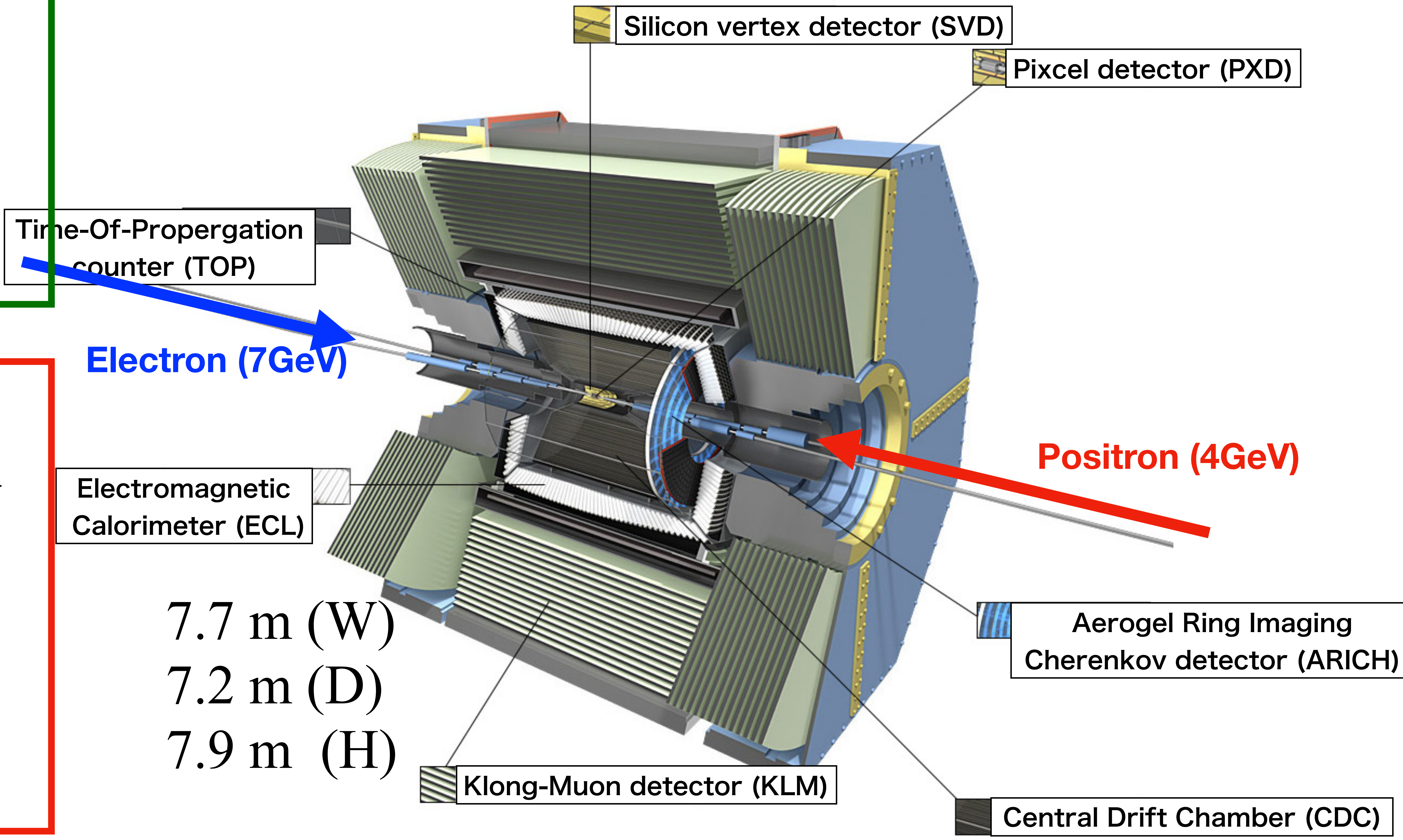
Belle II Detector and Status (1)

Improvement

- Improved tracking and vertexing
- Better particle identification
- Better calorimeter resolution

Challenges

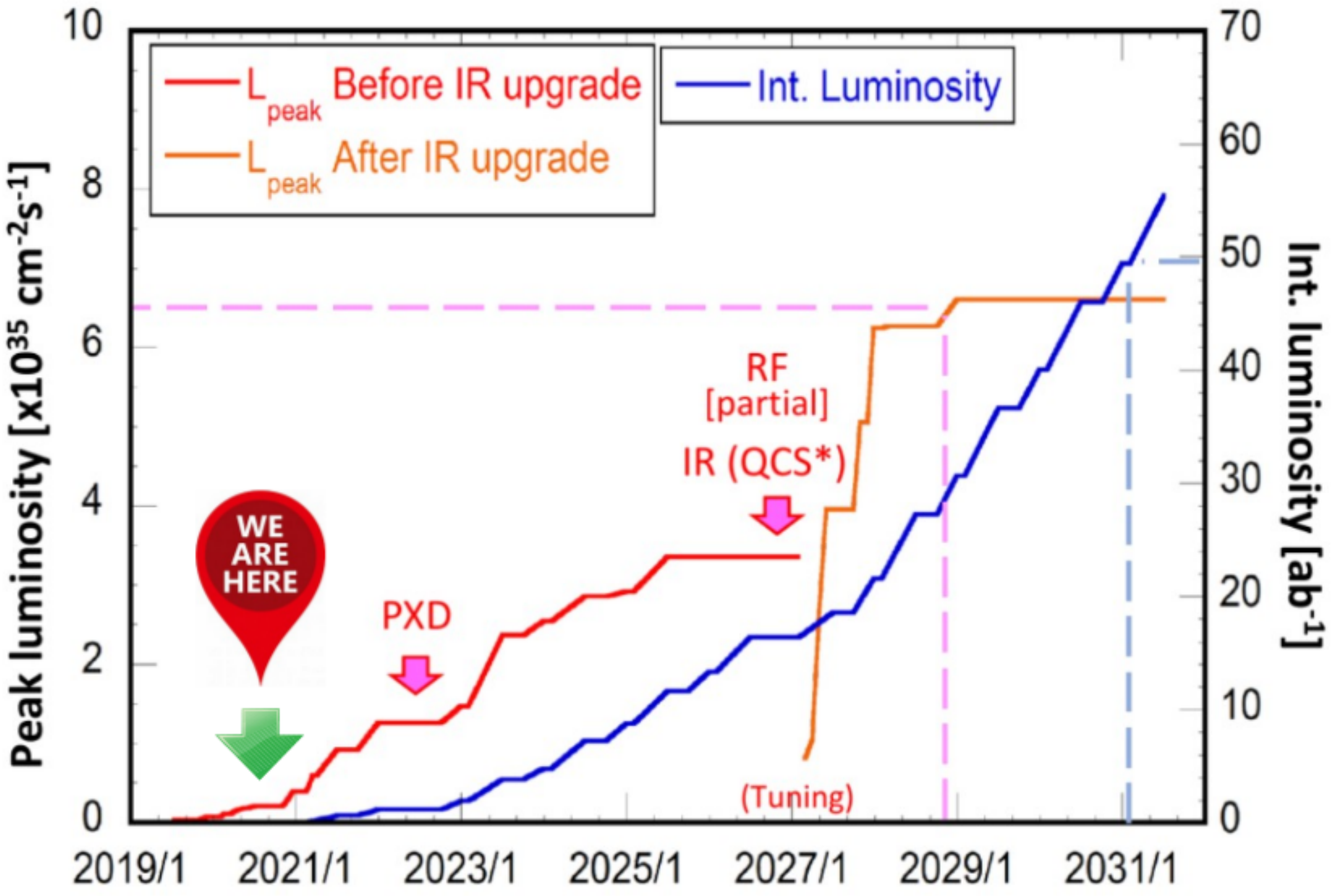
- Larger trigger rate 500 Hz → 30KHz
- Larger background, 10 ~ 20 beam background
- Performance improved



Projection towards 50 ab^{-1}

Plan to collect 50 ab^{-1} of collisions at and near $\Upsilon(4S)$ successor to Belle at KEKB (1.05 ab^{-1})

- Belle II data-taking is ongoing, sub-detectors performance have been confirmed
- B physics traditional channels such as $B \to J/\psi K_S$ result presented on ICHEP2020.
- $B \to \pi^+\pi^-$ hopefully soon after

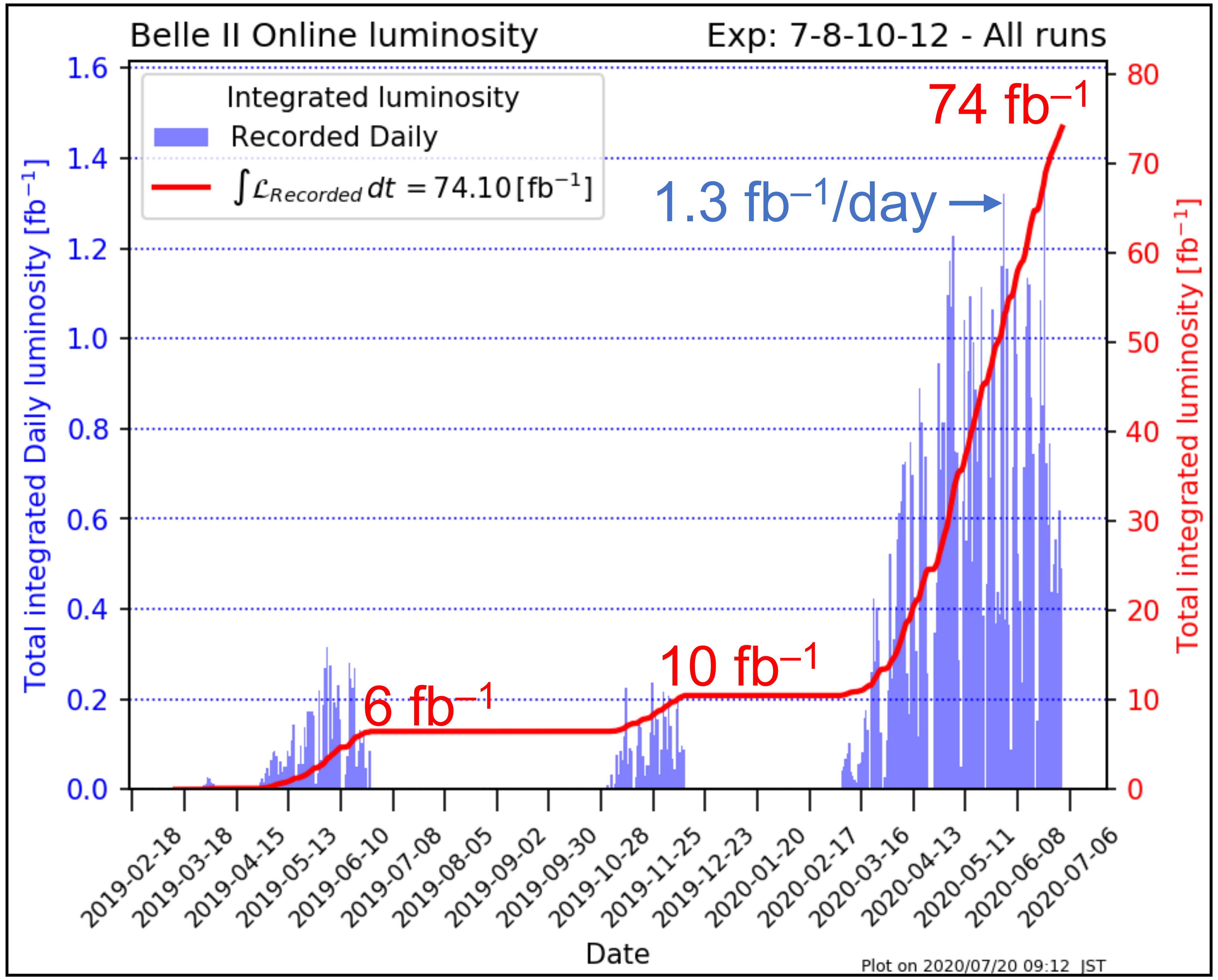


Belle II Detector and Status (3)

Integrated Luminosity

- Belle II data taking efficiency has been improved to 84%.

World Record by SuperKEKB on June 15th 202:
$\mathscr{L} = 2.4 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$



~1 ab⁻¹ before long shutdown in 2022 to surpass BaBar and Belle → Belle II will join in with the hunting for New Physics in earnest.

ICHEP2020 dataset
34.6(3.2) fb⁻¹ on-(off-)resonance

Measurement of ϕ_3

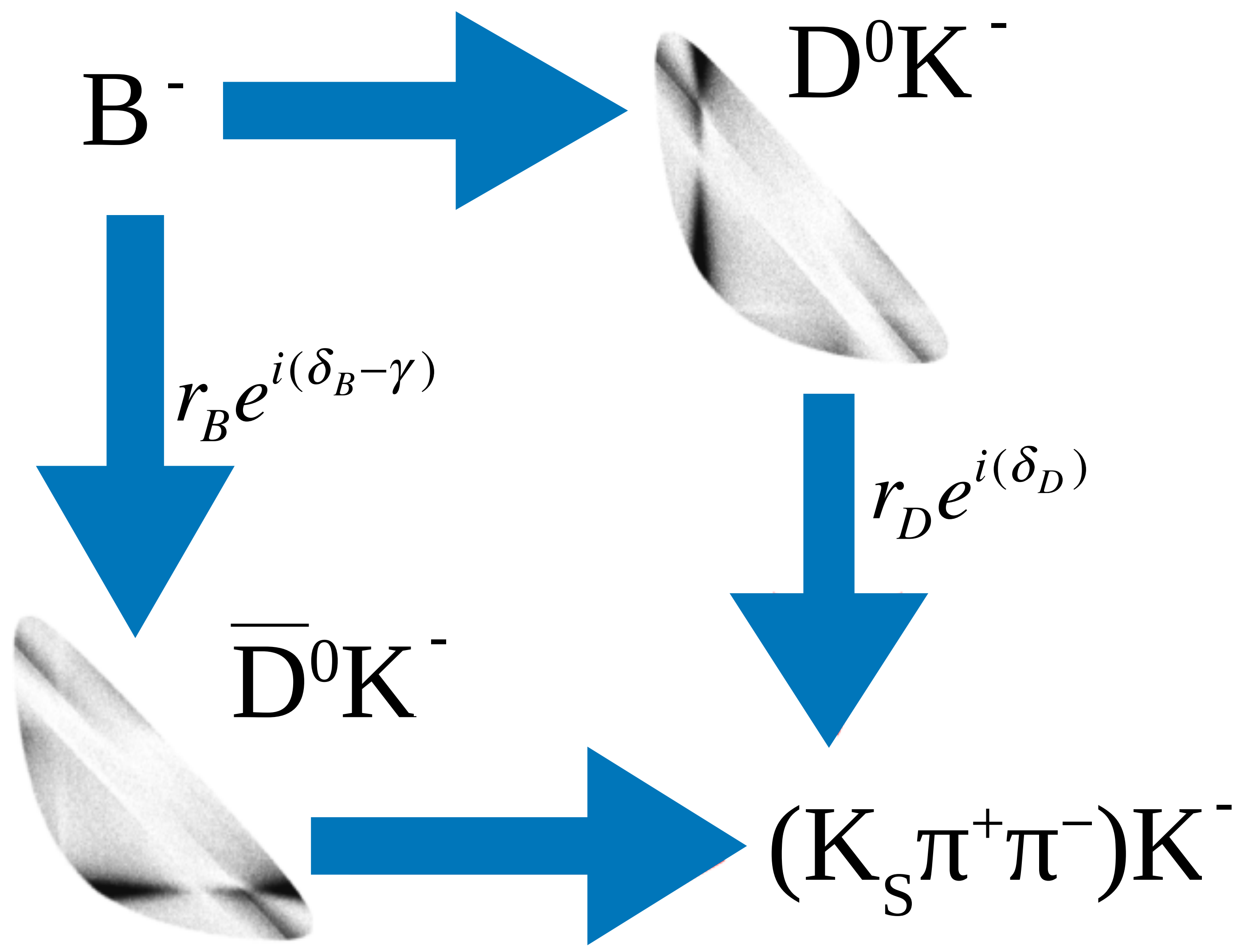
Measurement of φ3 at Belle II

- Determination of φ3 ⇒ dominated by Dalitz-plot (BPGGSZ) analysis at Belle/Belle II.
  - $B^\pm \to D(\to K_S^0\pi^+\pi^-)K^\pm \to$ the most sensitive single analysis.

Each point on the Dalitz plot has different r_D and δ_D.

$$r_D = \left|\frac{A(D^0 \to f)}{A(\bar{D}^0 \to f)}\right|$$

$\delta_D =$ strong phase difference



- Model dependent BPGGSZ method
  - r_D and δ_D is determined via amplitude model
  - Large systematic uncertainty (i.e. 8.9°) due to large amplitude
- Model independent BPGGSZ method
  - Use quantum coherence in $e^+e^- \to \gamma^* \to D\bar{D}$ (CLEO-c, BESIII) to measure amplitude-averaged strong phase differences c_i, s_i.

$$c_i = \langle \cos\Delta\delta_D \rangle, \; s_i = \langle \sin\Delta\delta_D \rangle$$

Belle II prospects for φ3 (1)

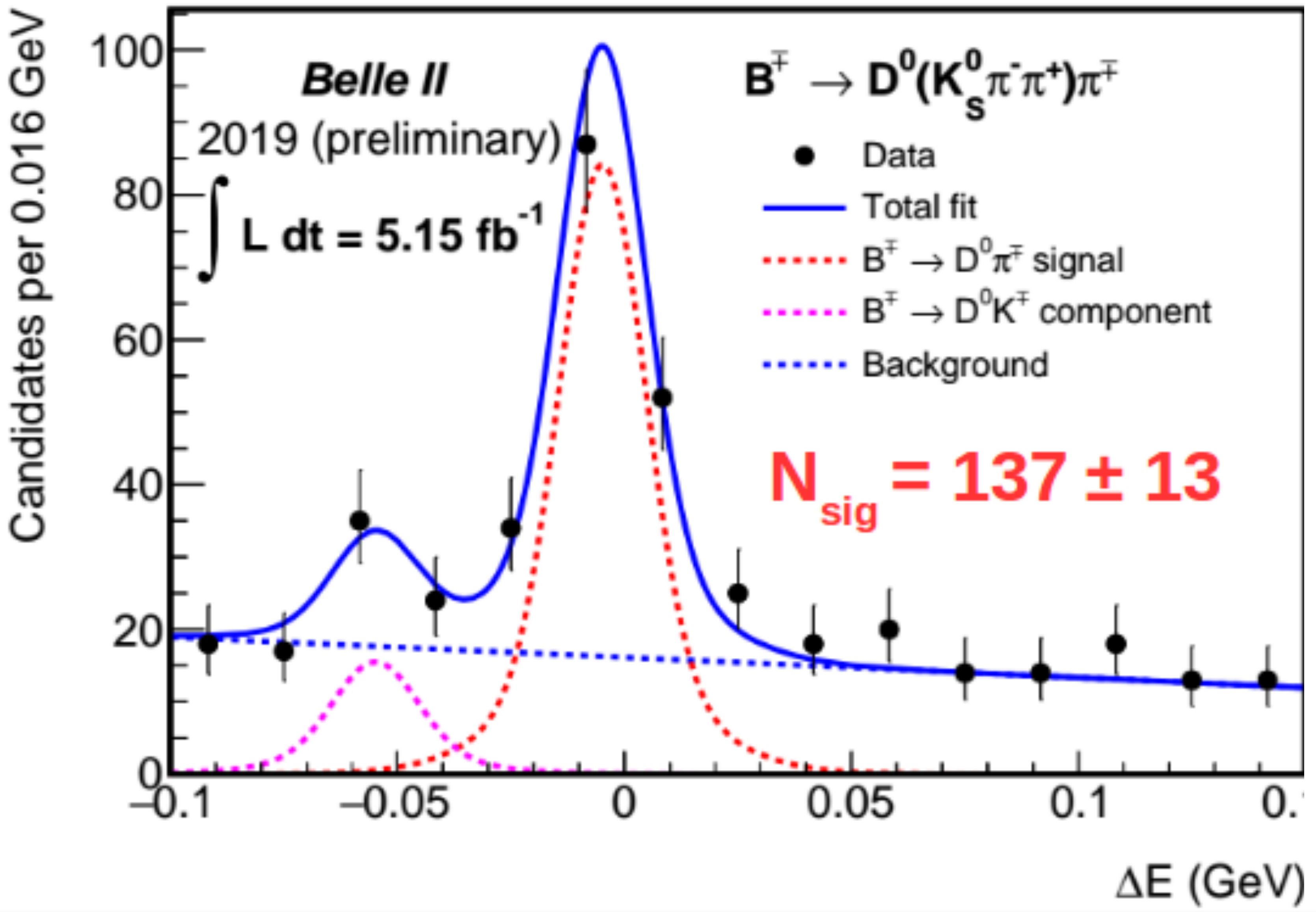
Measurement of φ3 →a dream of B factories → difficult due to color suppression. Many direct CPV techniques developed at the B factories.

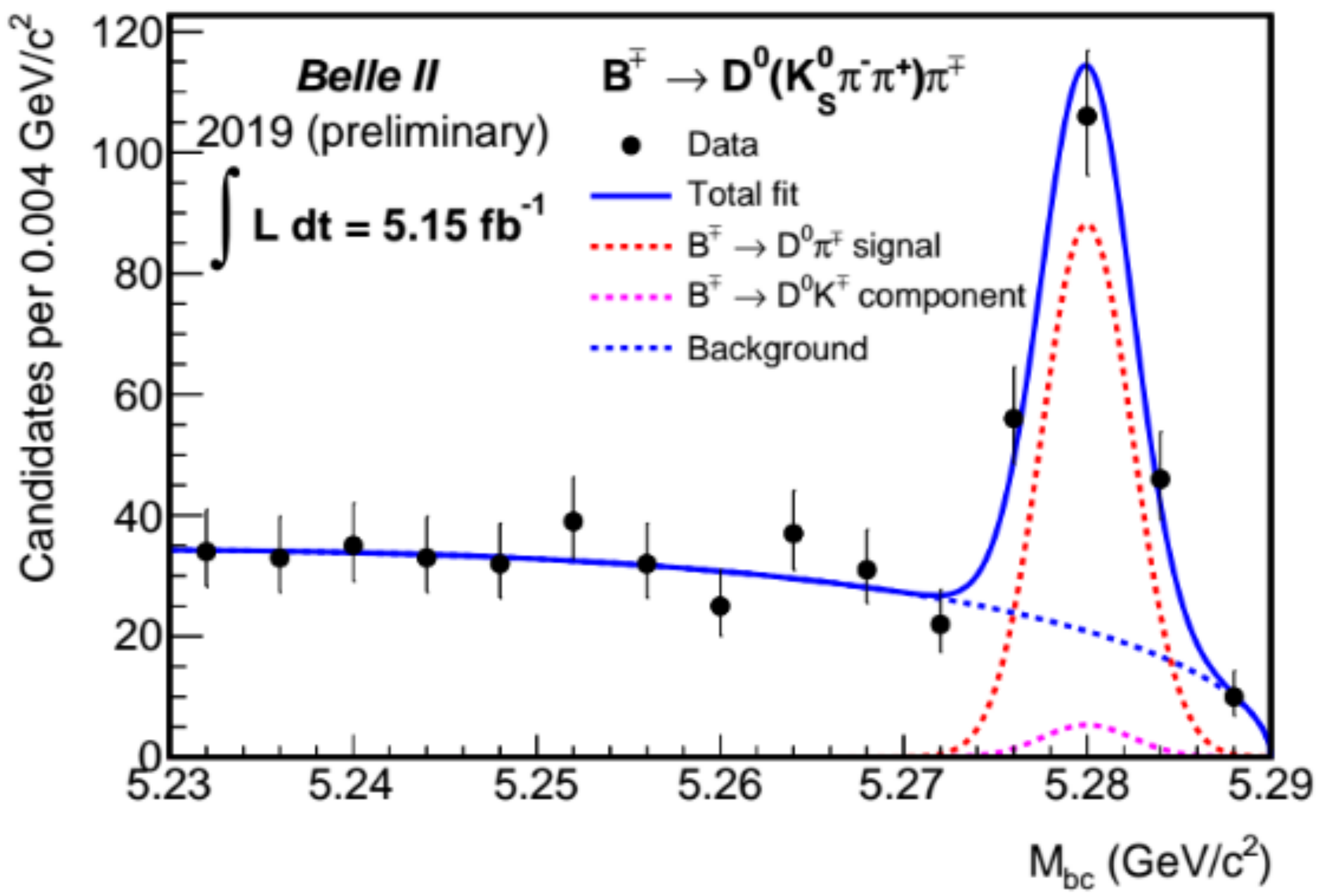
Golden mode in Belle II: $B^{\pm} \to D^0(K_S^0\pi^-\pi^+)K^{\pm}$

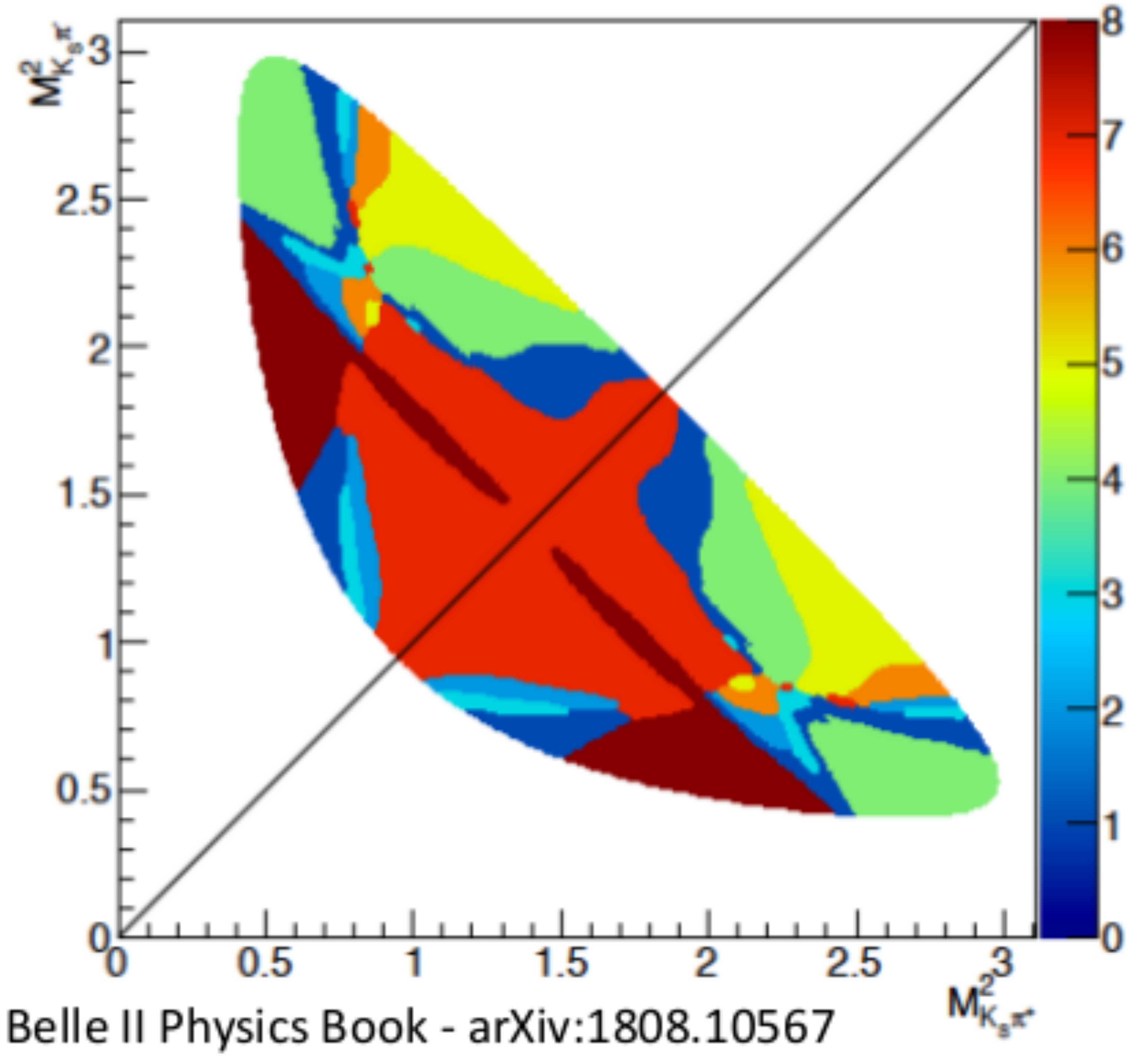
- Model - independent binned Dalitz plot approach.
- Number of events in i^{th} bin is a function of $x_{\pm}/y_{\pm}$

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

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







Belle II Physics Book - arXiv:1808.10567

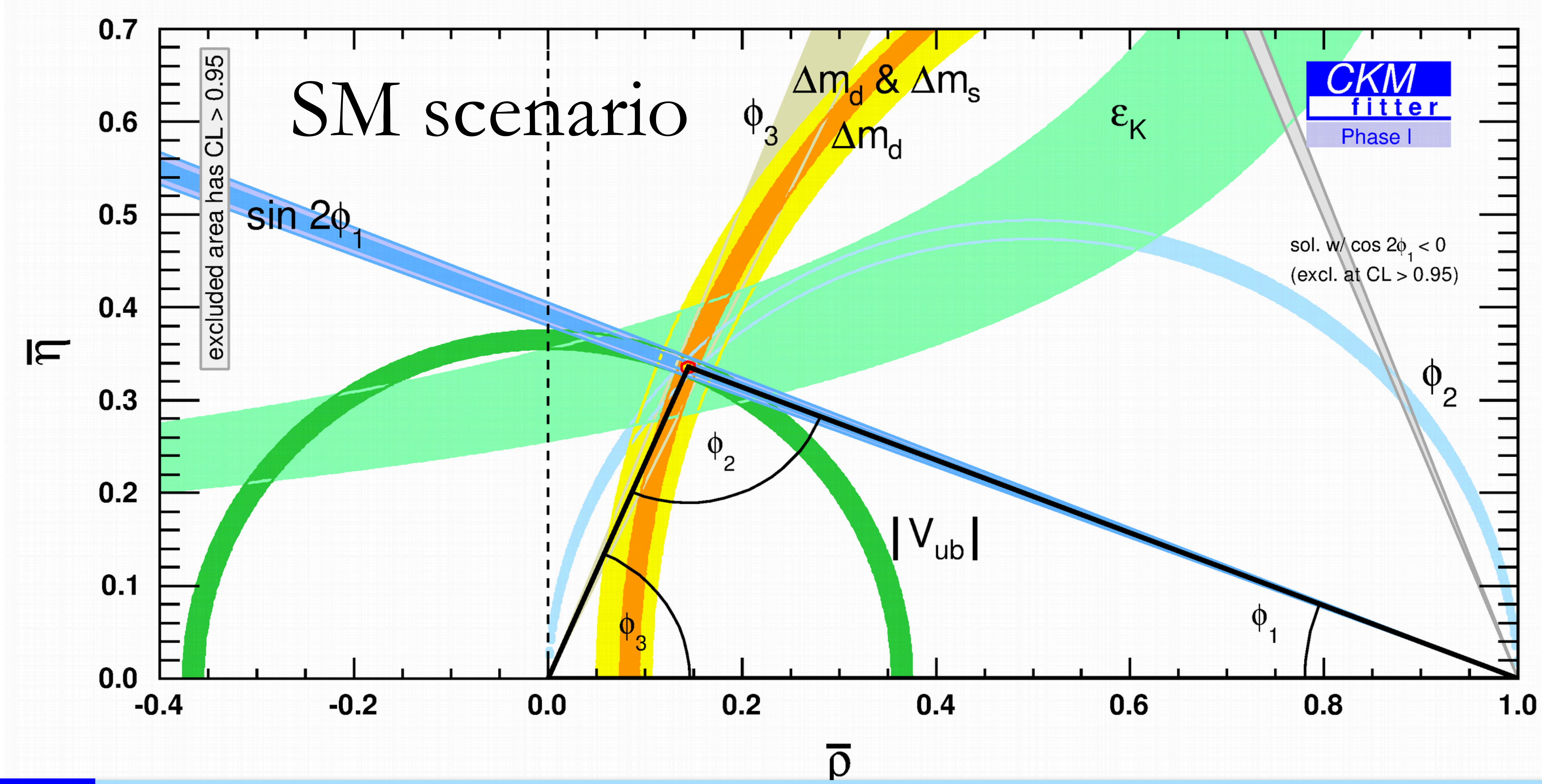
Precise strong phase measurement needed to match Belle II statistical precision: expected from 20 fb^{-1} BESIII data set

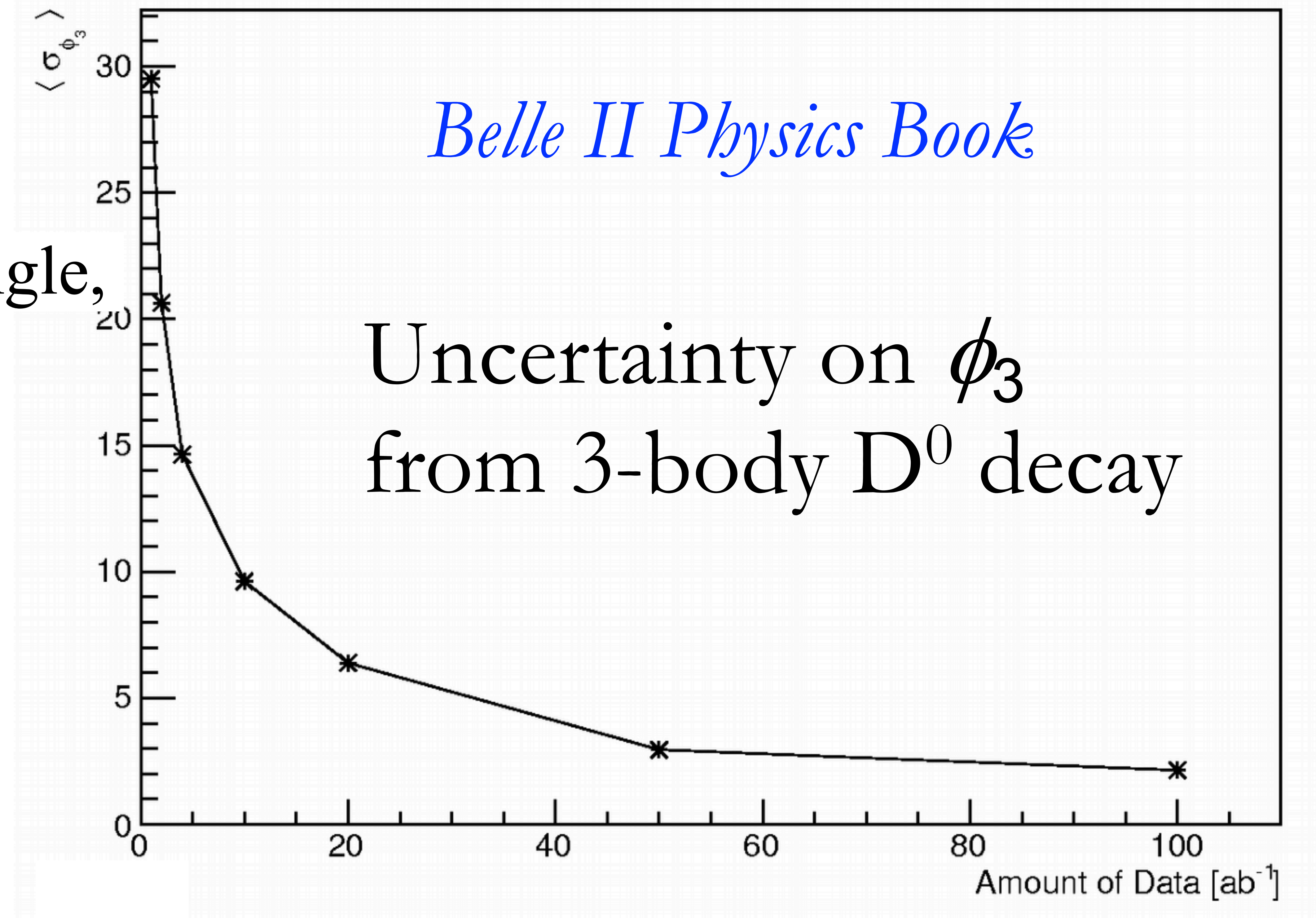
Belle II prospects for φ3 (2)

Improving precision: Model independent approach and strong phase measurements from BESIII.

Belle II will also deliver a high precision measurement of the angle, exploiting the Dalitz analysis of $K_S^0\pi^0, K_S^0\pi\pi^0\ldots$

For seen φ3 precision of 1.5°





UT in a decade

Assumptions:

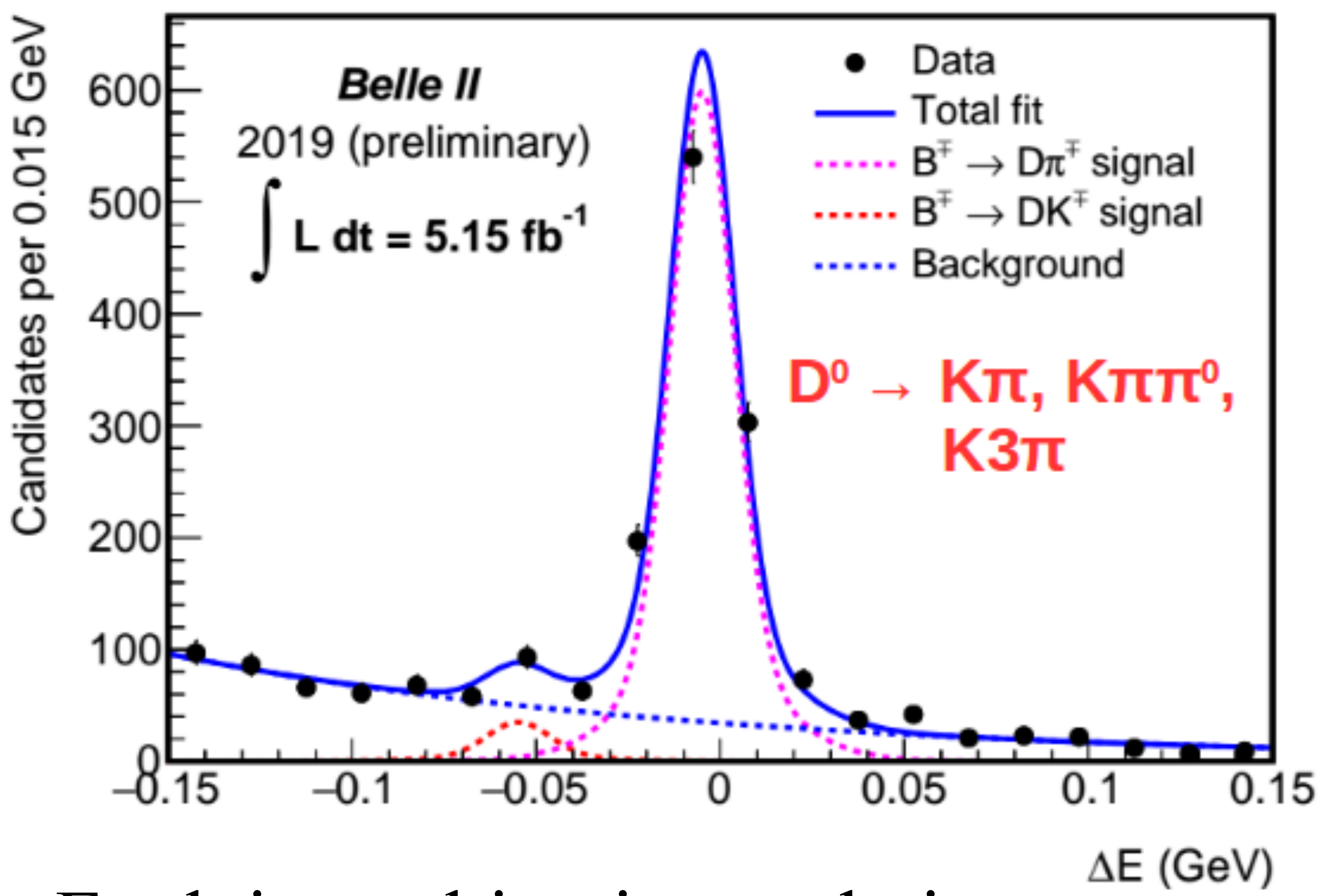
Belle II: 50 ab^{-1}

LHCb: 23 fb^{-1}

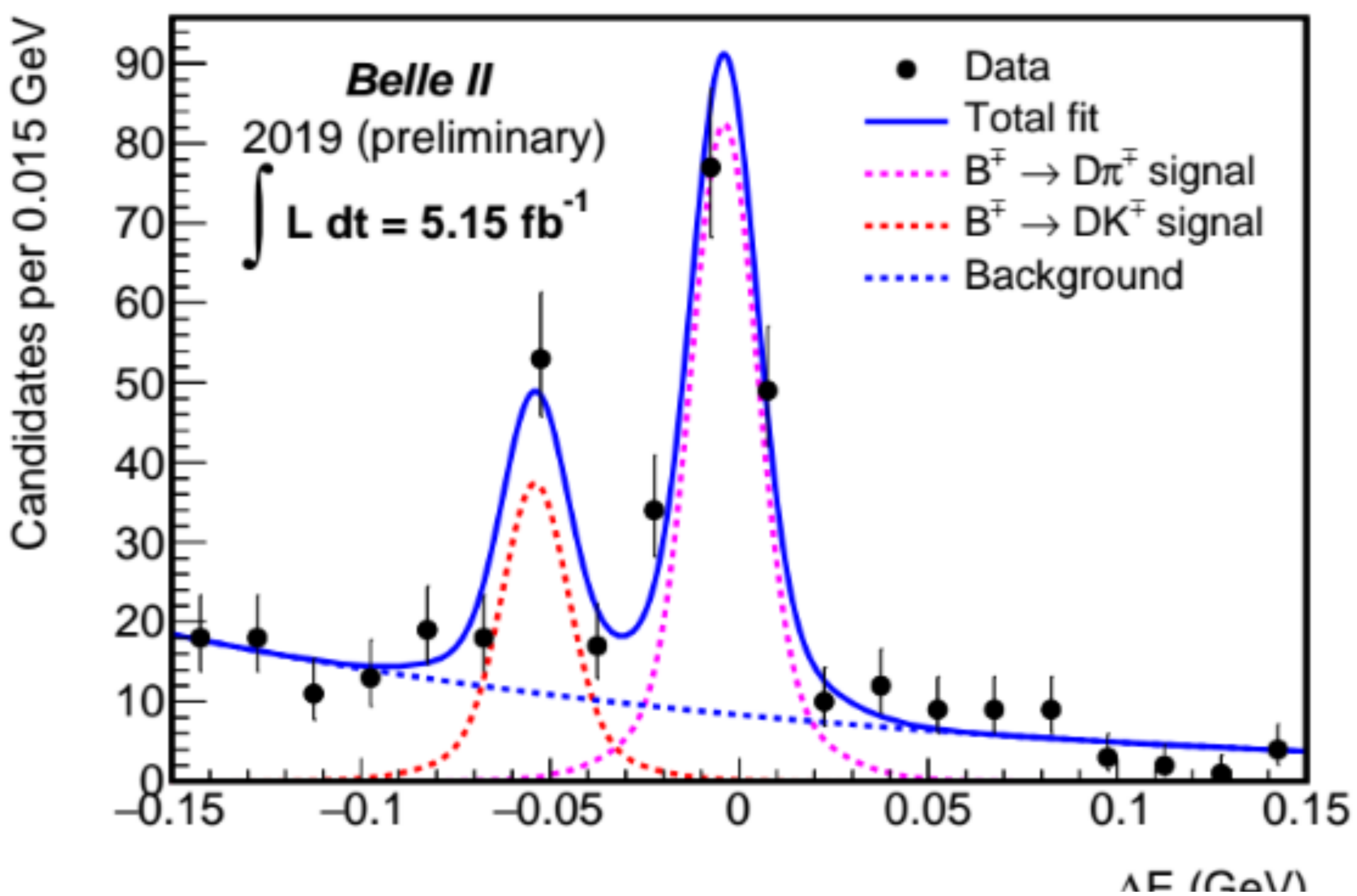
Rediscovery of $B \rightarrow DK$ Measurement at Belle II

- More sensitive to φ_3 than B → Dπ because of its higher r_B value.
- Rediscovery of B → DK with more than 5σ evidence.

Without PID Cut



With PID Cut



$$\Delta E \equiv E_B^* - \sqrt{s}/2$$

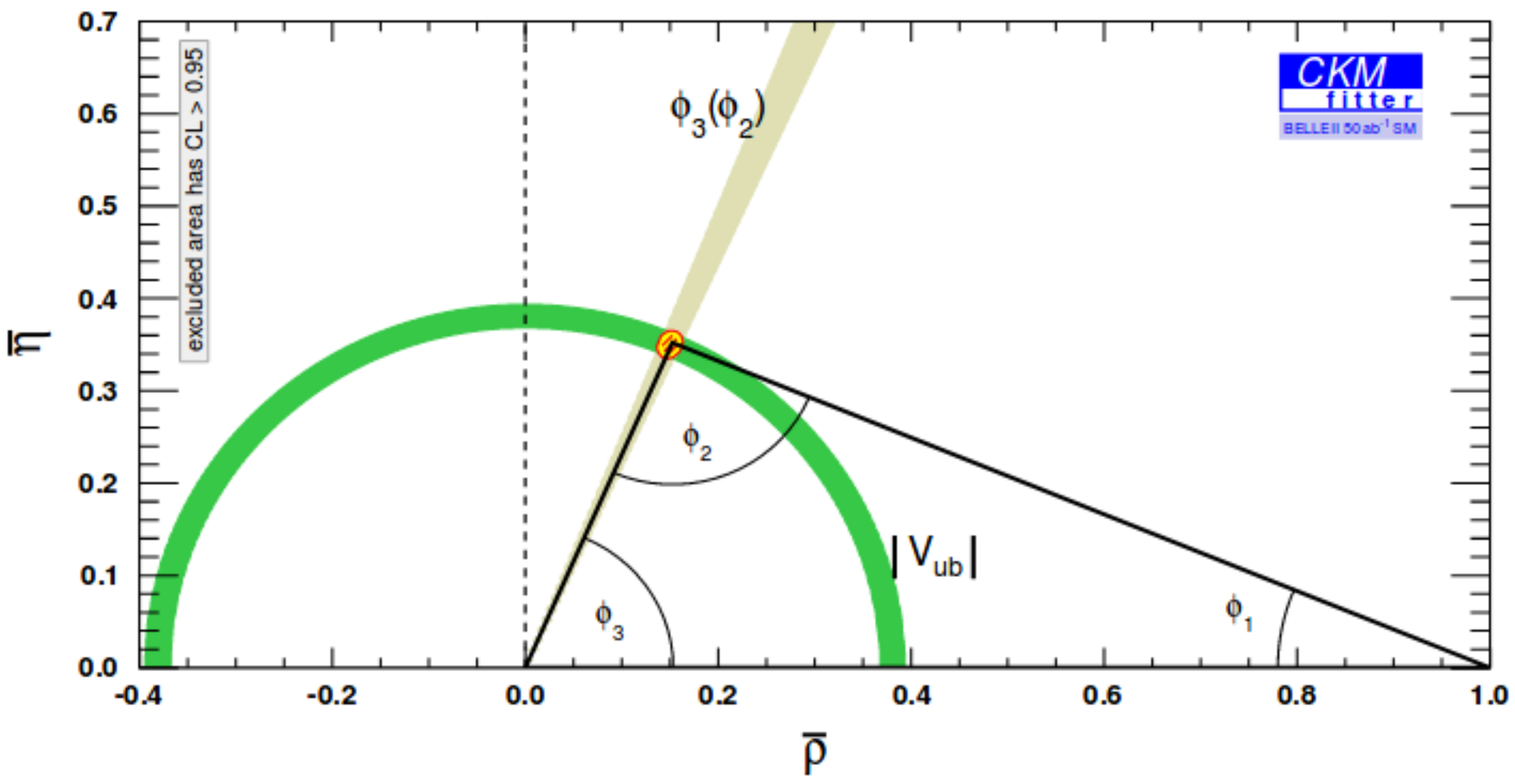
- Exploits multivariate techniques to suppress continuum background and good particle identification performances of Belle II.
- Observation of the golden 3-body decay as well

Conclusion

Future Prospects Belle II and Beyond

- Expect Belle II and LHCb upgrade to match each other's performance!
- $\delta(\varphi 3) < 1.6^{\circ}$ with 50 ab^{-1} data set.

- Modes that are good to measure at Belle II
  - $D^{*0} \rightarrow D^0\pi^0, D^0\gamma$
  - $D^0 \rightarrow K_S^0\pi^0, K_S^0\pi\pi\pi^0$
- with Belle II strength
  - High statistics
  - Better neutral reconstruction
  - Better continuum suppression



Fit extrapolated to 50 ab^{-1} for a SM-like scenario from Belle II physics book (10.1093/ptep/ptz106)

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

Summary

- Belle II aims to provide 50 ab^{-1} at $\Upsilon(4S)$ within its runtime (Belle: ~1 ab^{-1}).
- Measurements of the Belle II will test CKM unitarity with 1% precision.
- Significant improvement of $|V_{ub}|$ and φ_3 at Belle II .
- φ_3 precision better than φ_3 <1.6° (combined all approaches).
- Most relevant contribution using CKM physics is to probe new physics.

The world is waiting for our results!!!


Thank you
BEAUTY 2020
online