(Preparing for) Measurement of the UT angle ϕ_3 at Belle II

BEAUTY 2020

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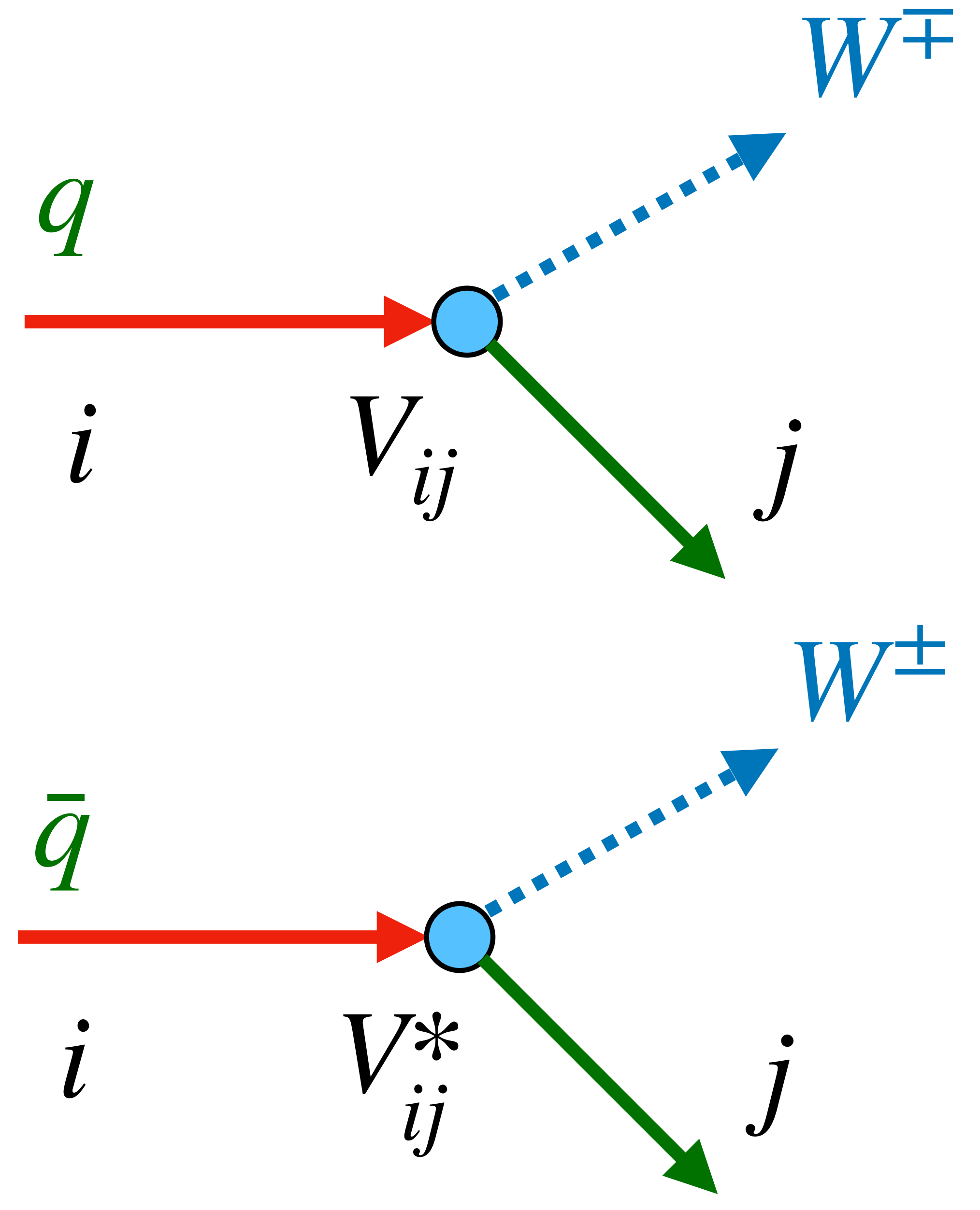
on behalf of Belle II Collaboration

Introduction

CKM Quark Mixing

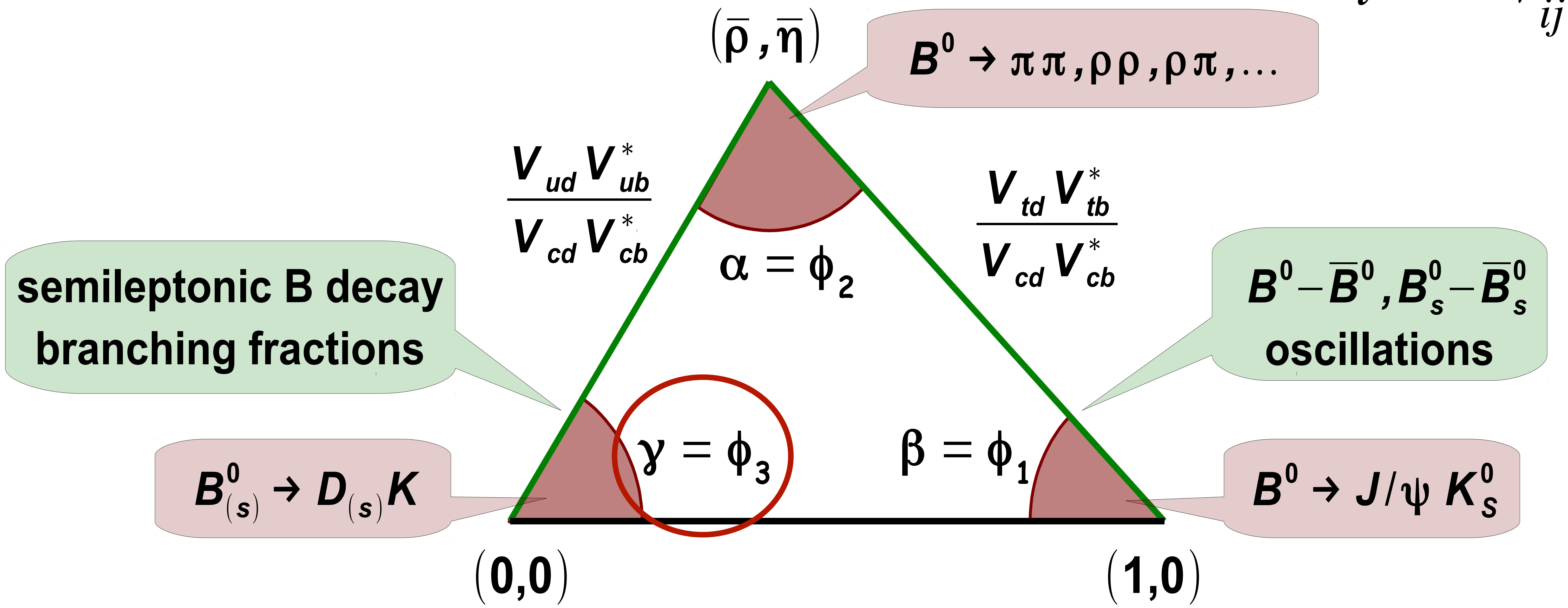
- V_{CKM} contains coupling constants of weak interaction and complex phase



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

Unitarity $\Rightarrow$ 6 triangle relations in the complex plane, e.g.

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



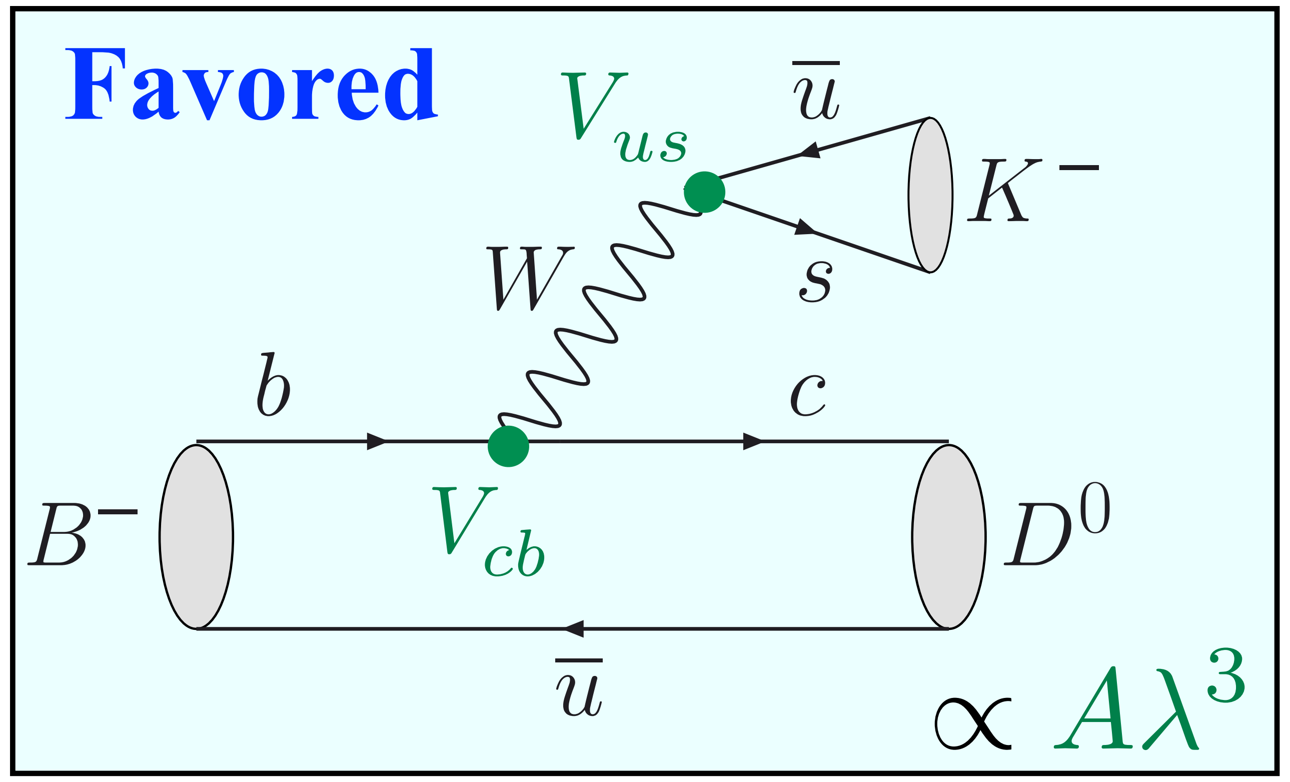
Measurement of φ3 (phase of |Vub| in $B \rightarrow$ Charm)

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

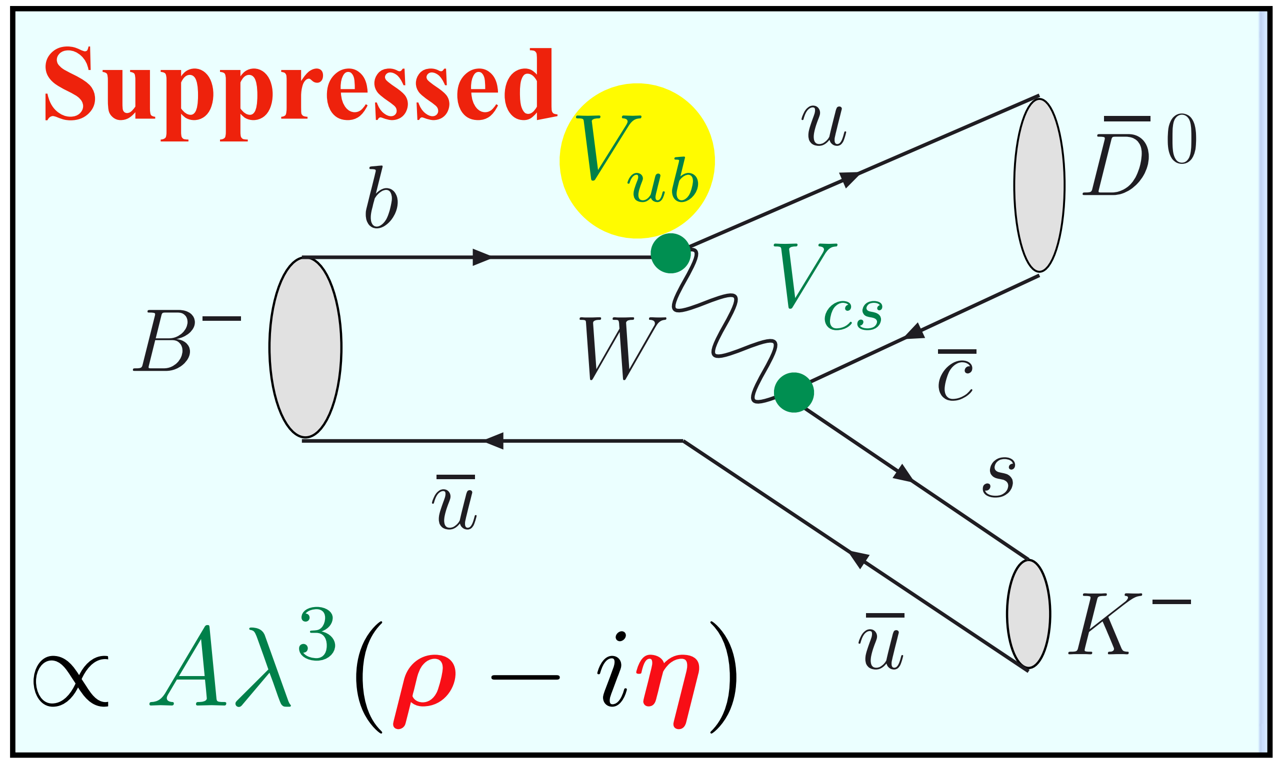
- Theory is "pristine" in these approaches $\Rightarrow \delta\phi_3/\phi_3 \sim 10^{-7}$. [J. Brod, J. Zupan, JHEP 1401 (2014) 051]

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

δ_B strong CP conserving phase



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



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

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

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 eigenstates 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]

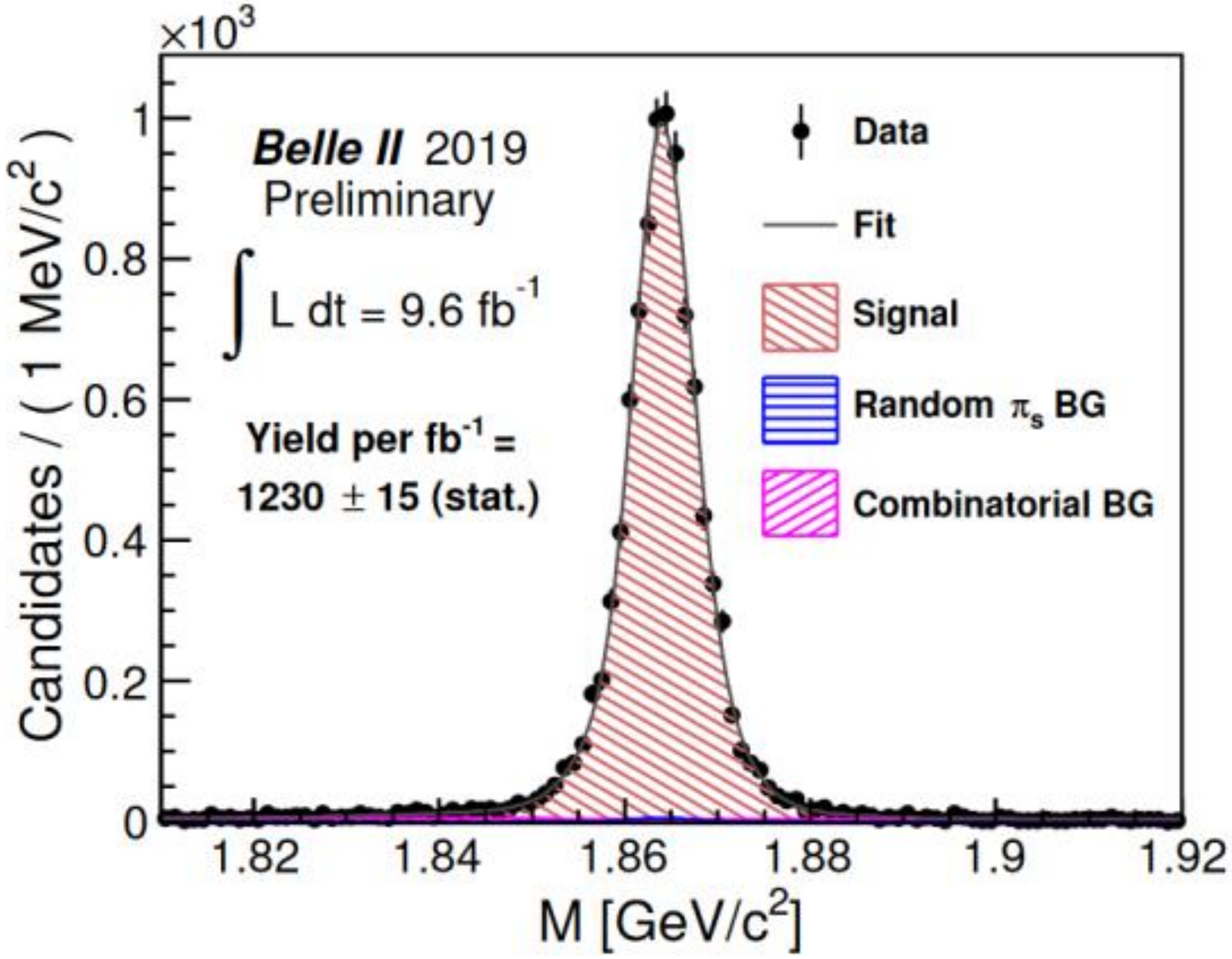
ϕ_3 is extracted by combining information from all measurements

- Belle II (will) stay competitive in all these measurements → strength in measuring neutral e.g. K_S (present in the final states in all methods)

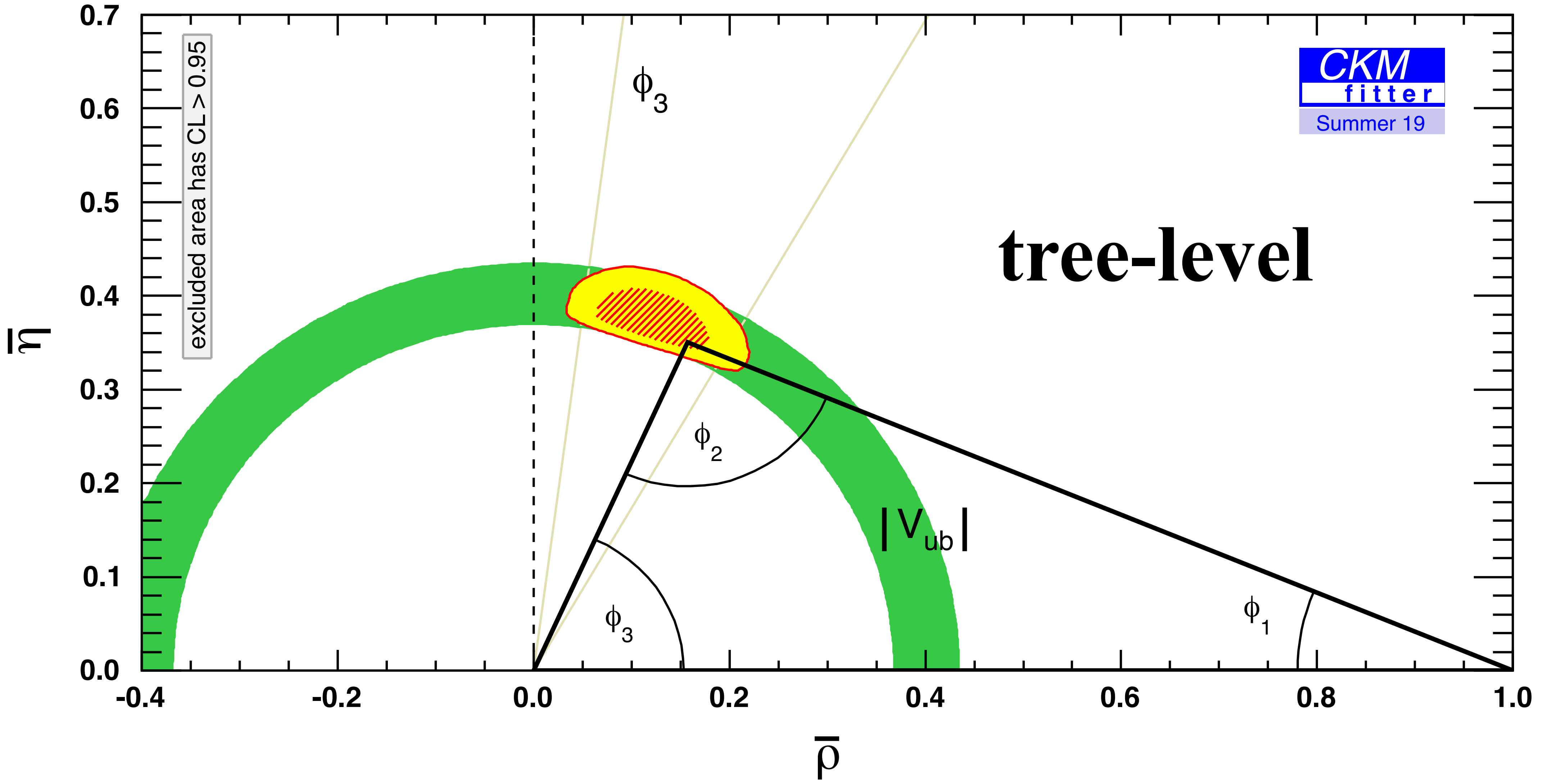
Measurement of φ3 (phase of |V_{ub}| in $B \to$ Charm)

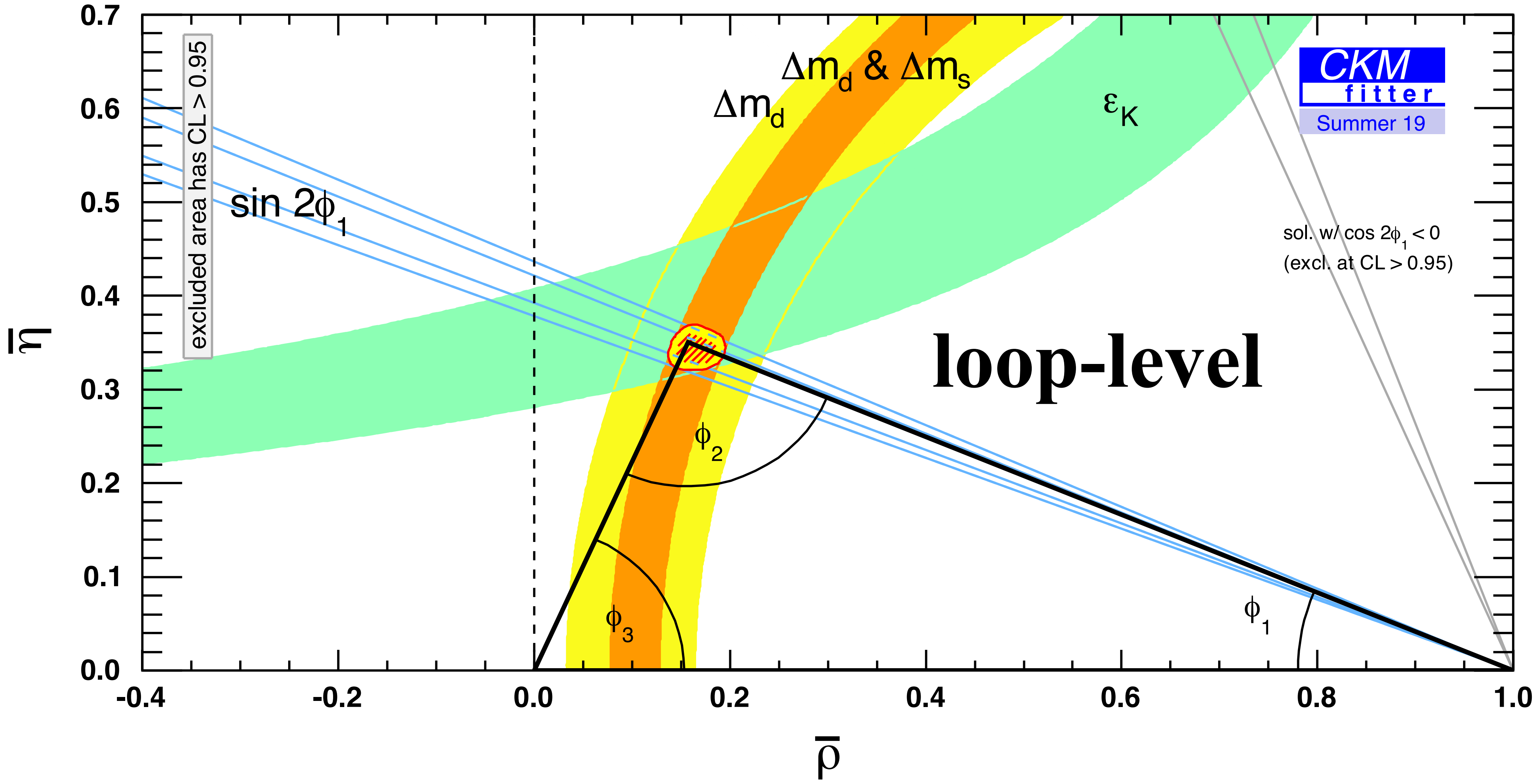
- Belle II (will) stay competitive in all these measurements → strength in measuring neutral e.g. K_S (present in the final states in all methods)

- Belle II is very efficient in K_S^0 reconstruction despite a smaller number of Bs available as compared to LHCb.
- Rediscovery of D^0 channel ($D^0 \to K_s\pi^+\pi^-$): Self-conjugate channel with K_S in it, mixing parameters could easily be disentangled from strong phase. Please see Guanda Gong's Talk for more detail.



Current Precision of CKM Matrix





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

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

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

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

CKM Fitter
[ckmfitter.in2p3.fr/]

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

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

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

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

New Physics in φ_3

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

- The traditional way: compare φ_3 from tree-level decays with the one from penguin-dominated processes.
- Recent studies show that new physics contributions to tree-level Wilson coefficients C_1 and C_2 of $\mathcal{O}(40\%)$ and $\mathcal{O}(20\%)$ are not excluded. [10.1007/JHEP06(2014)040, 10.1103/PhysRevD.92.033002]
- Shifts in φ_3 of the order of $\pm 4°$ can not be eliminated [10.1103/PhysRevD.92.033002].
- Strong motivation to 1° precision.

SuperKEKB and Belle II

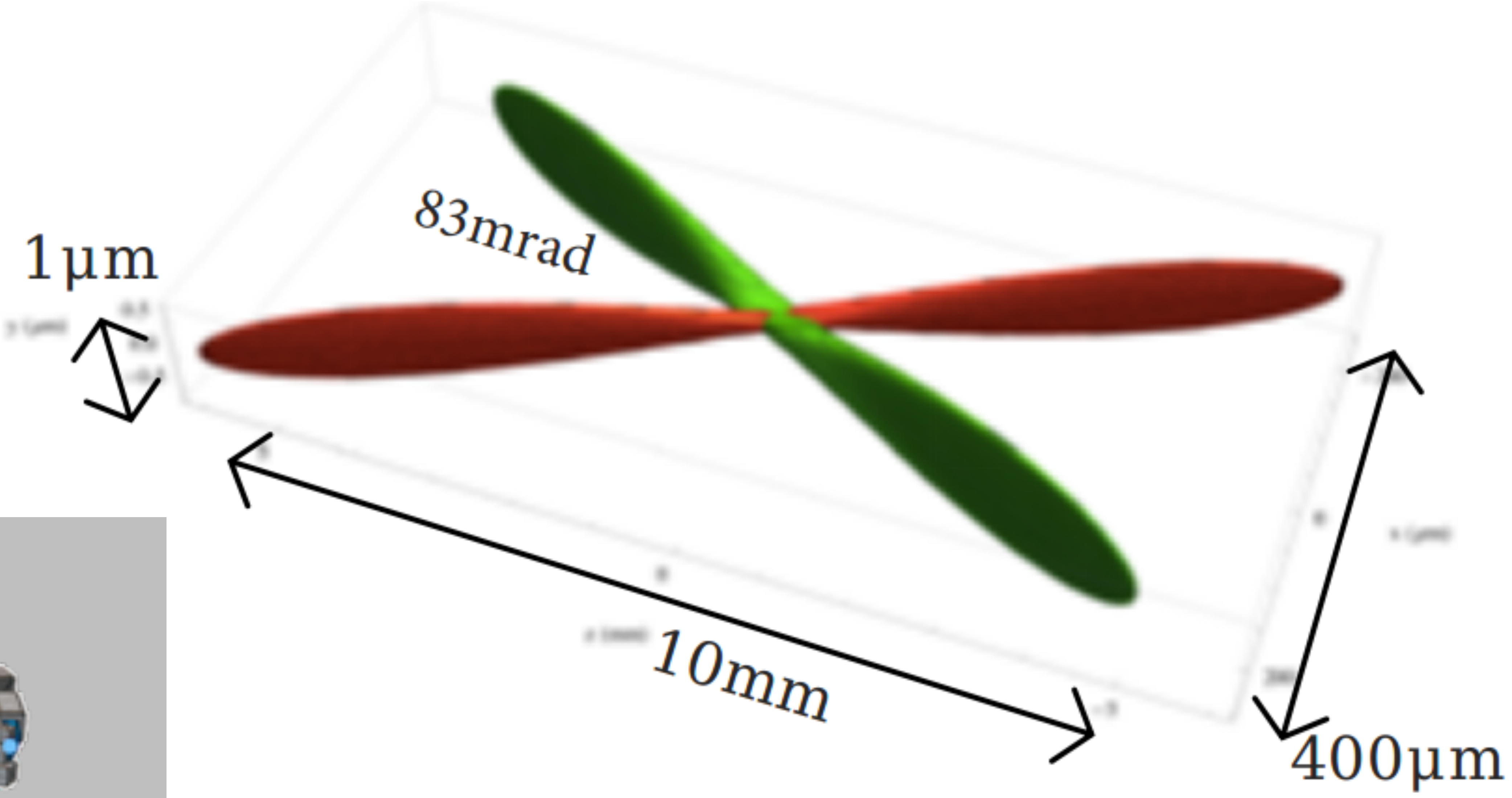
SuperKEKB Accelerator

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

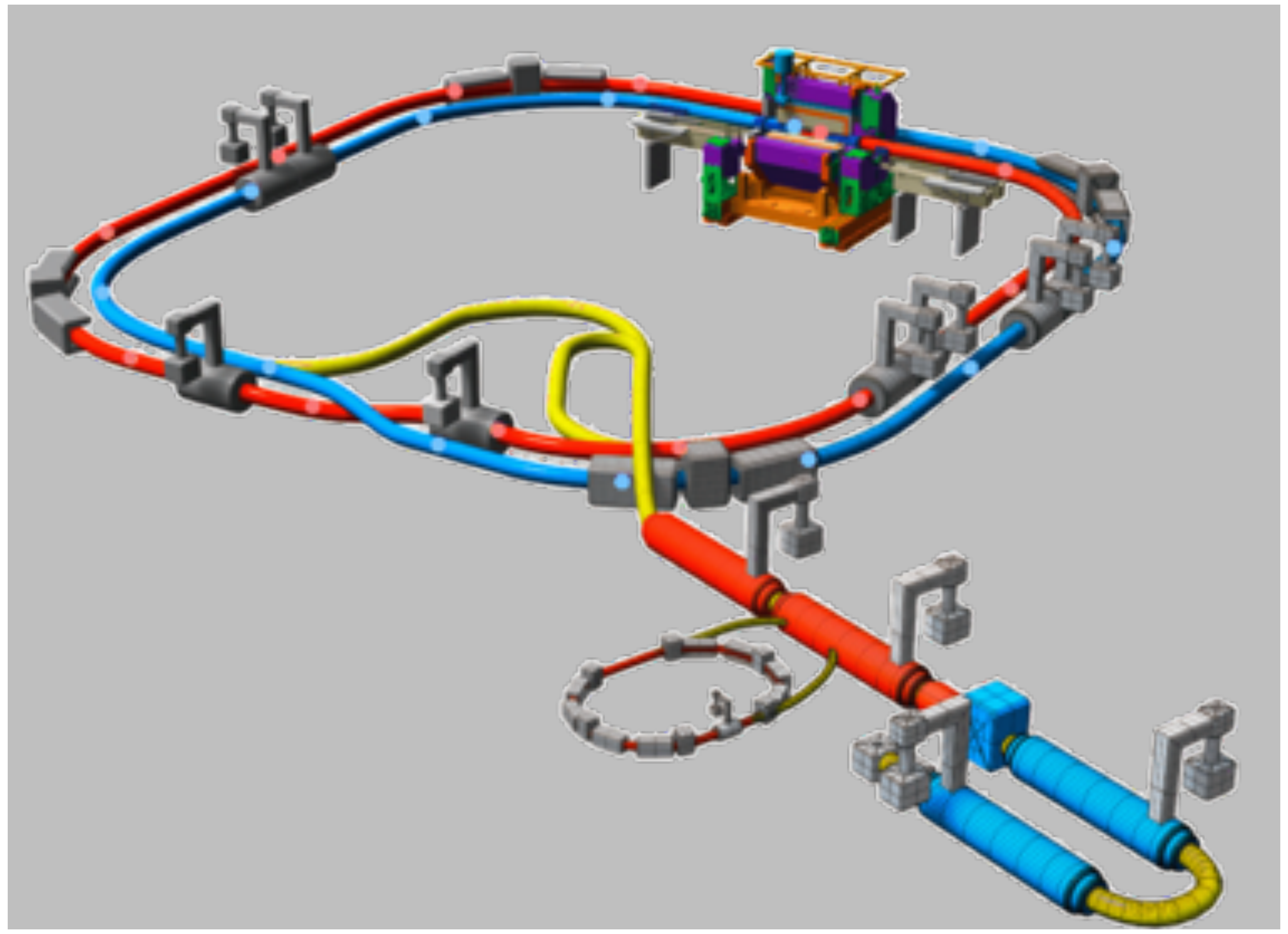
Beam size ↓ 20 times
Beam current ↑ 2 times

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

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



- $\mathcal{L}^{peak}_{KEKB} = 2.1 \times 10^{34}/cm^2s$
- $\mathcal{L}^{peak}_{SuperKEKB} = 6.5 \times 10^{35}/cm^2s$



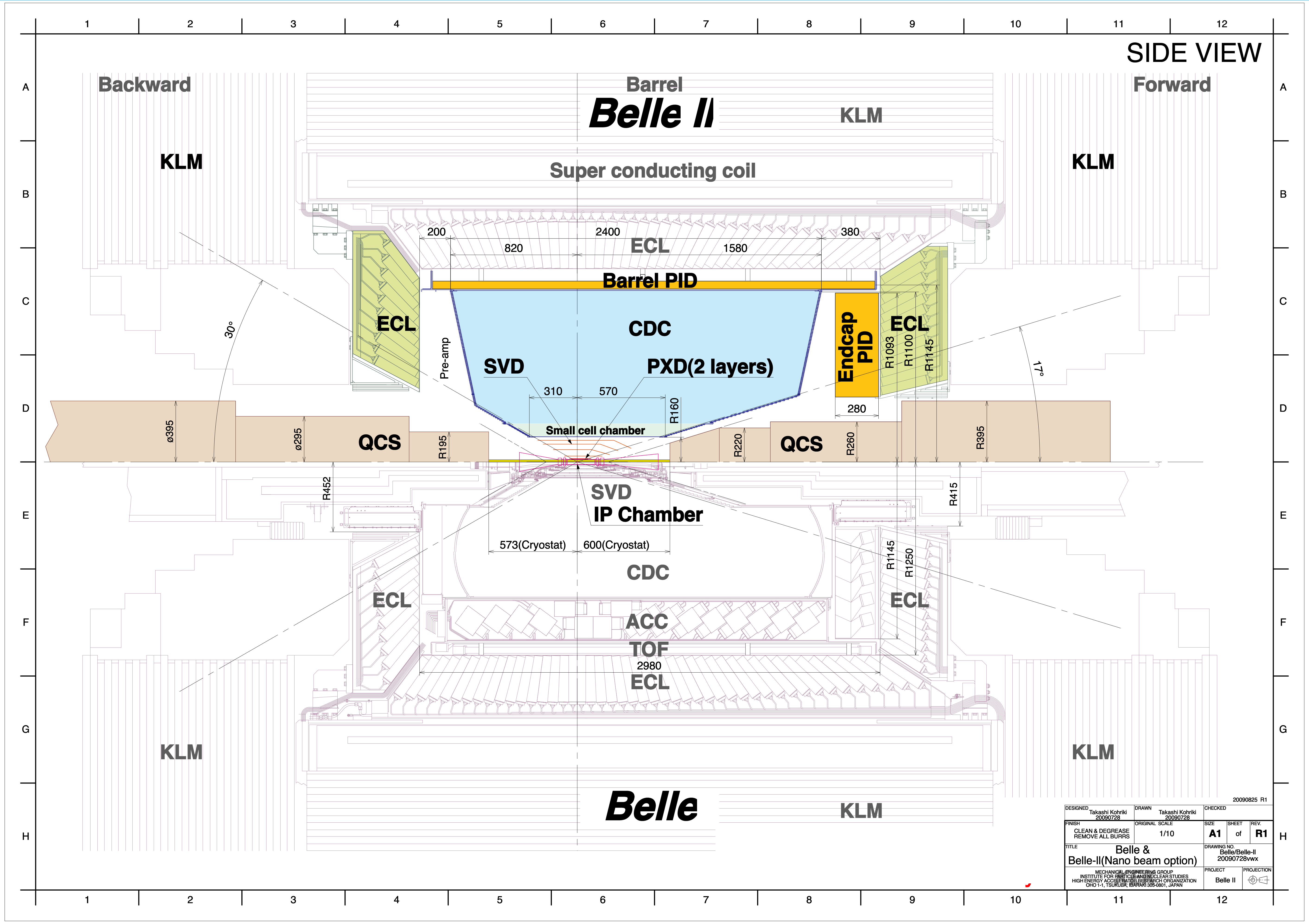
Belle II Detector and Status (1)

Improvement

- Improved tracking and vertexing [see Thibaud Humair's Talk]
- Better particle identification
- Better calorimeter resolution

Challenges

- Larger trigger rate 500 Hz → 30KHz
- Larger background, beam background
- Performance improvement

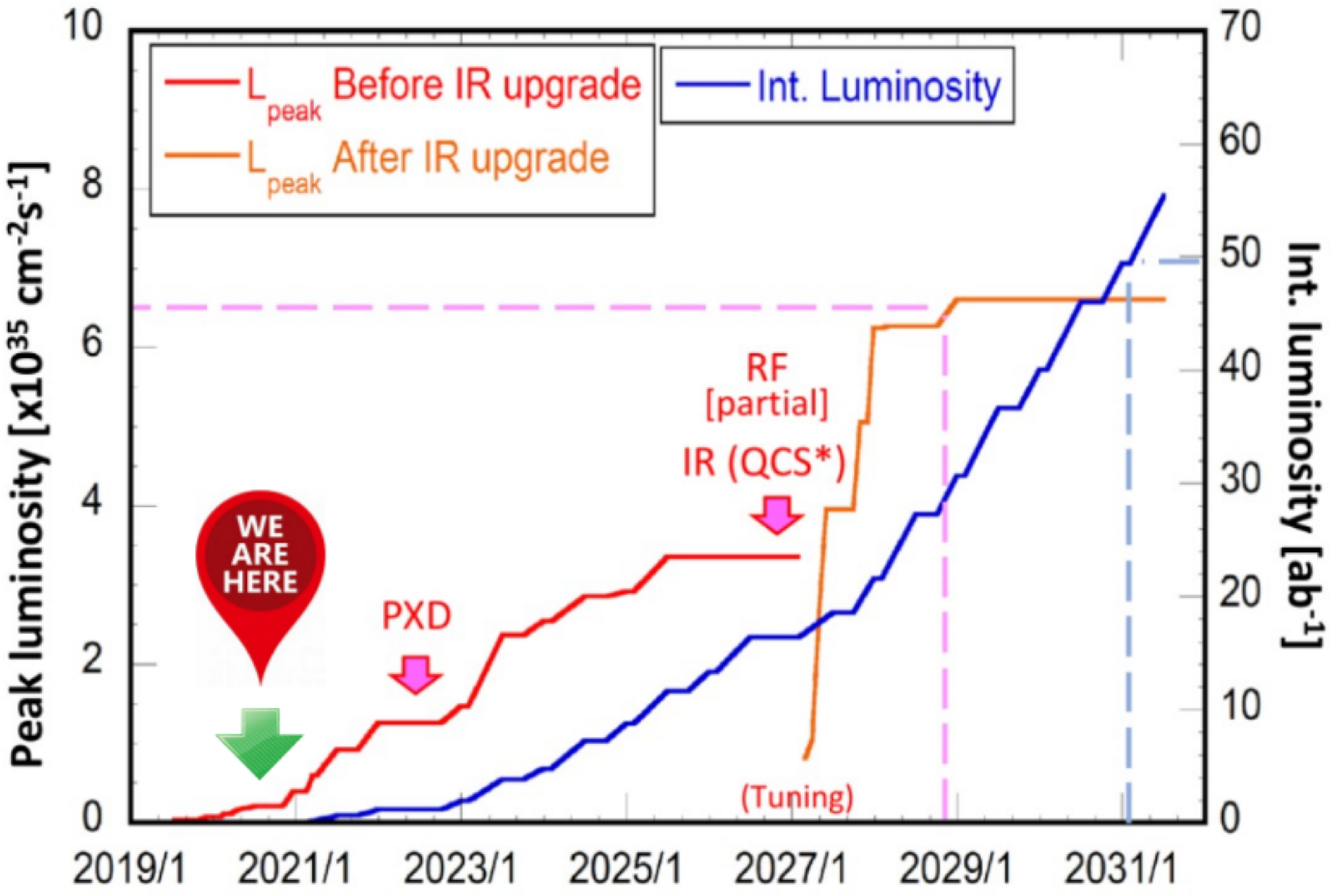


Upgraded Belle II spectrometer (top half) as compared to the present Belle detector (bottom half).

Projection towards 50 ab^{-1}

- Belle II data-taking is ongoing, many sub-detectors at design performance already, other improving steadily
- B physics traditional channels such as $B \rightarrow J/\psi K_S$ result presented on ICHEP2020.
- $B \rightarrow \pi^+\pi^-$ B.F measurement shown at ICHEP2020

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



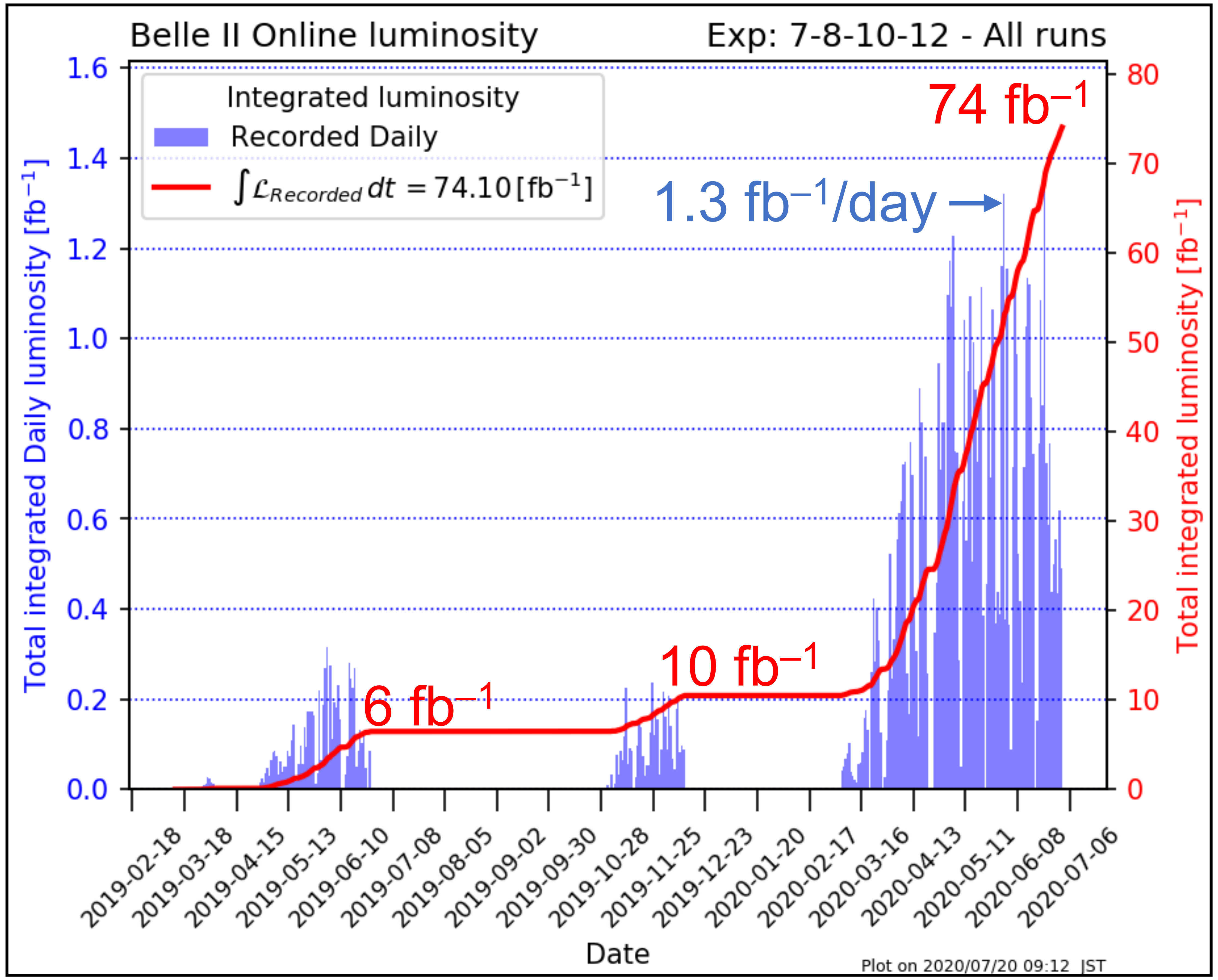
Belle II Detector and Status (3)

Integrated Luminosity

- Belle II data taking efficiency has been improved.

World Record by SuperKEKB on June 15th 2020:
$\mathscr{L} = 2.4 \times 10^{34} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

$\sim$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.



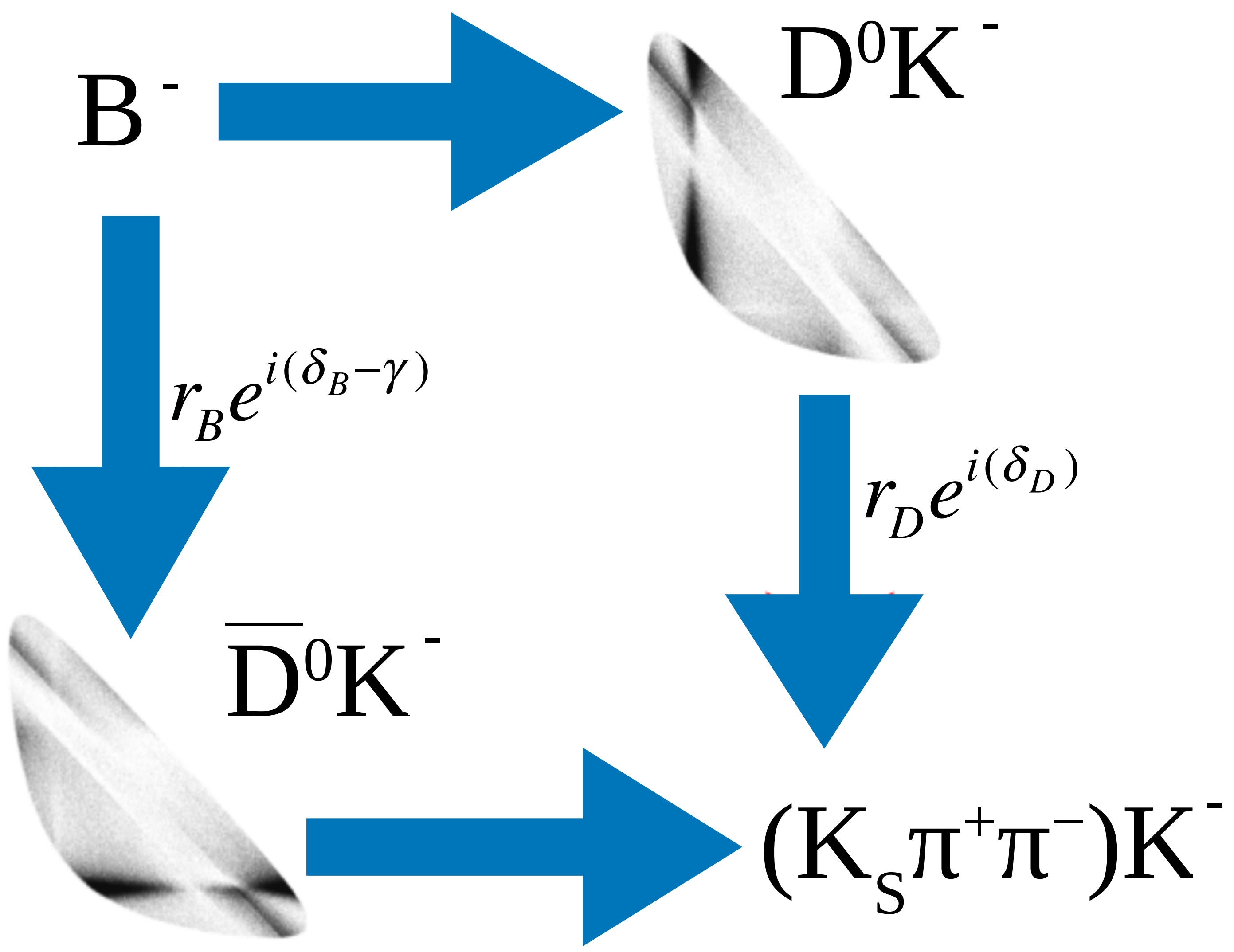
Data available till date : 34.6(3.2) fb^{-1} on-(off-)resonance

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.



$$r_D = \left|\frac{A(D^0 \to f)}{A(\bar{D}^0 \to f)}\right|; \delta_D = \text{ strong phase difference}$$

- 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.

$$c_i = < \cos\Delta\delta_D > , s_i = < \sin\Delta\delta_D >$$

Belle II prospects for φ3 (1)

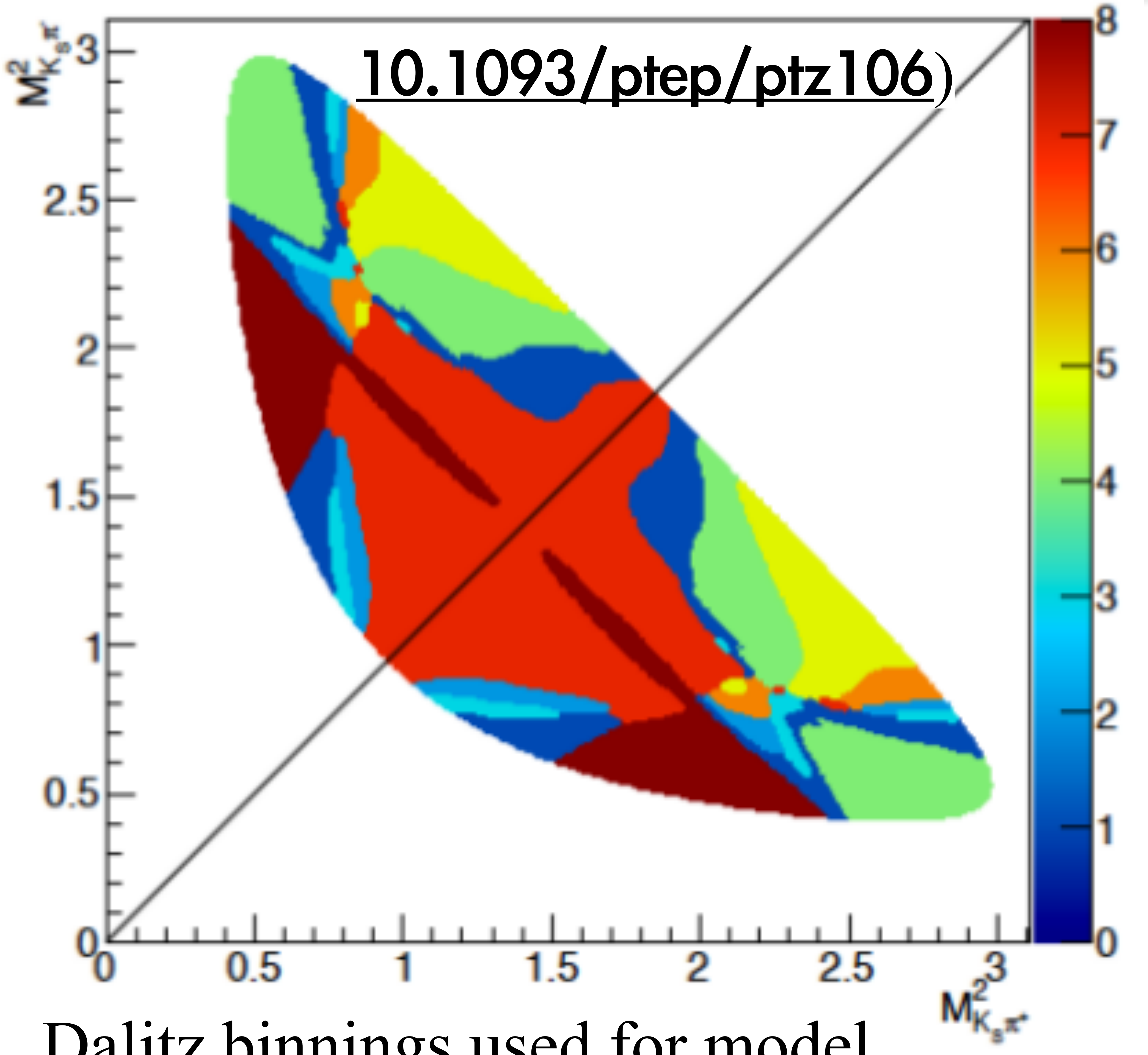
- Measurement of φ3 → a dream of B factories → difficult due to color suppression.

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

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

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

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



Dalitz binnings used for model independent analysis

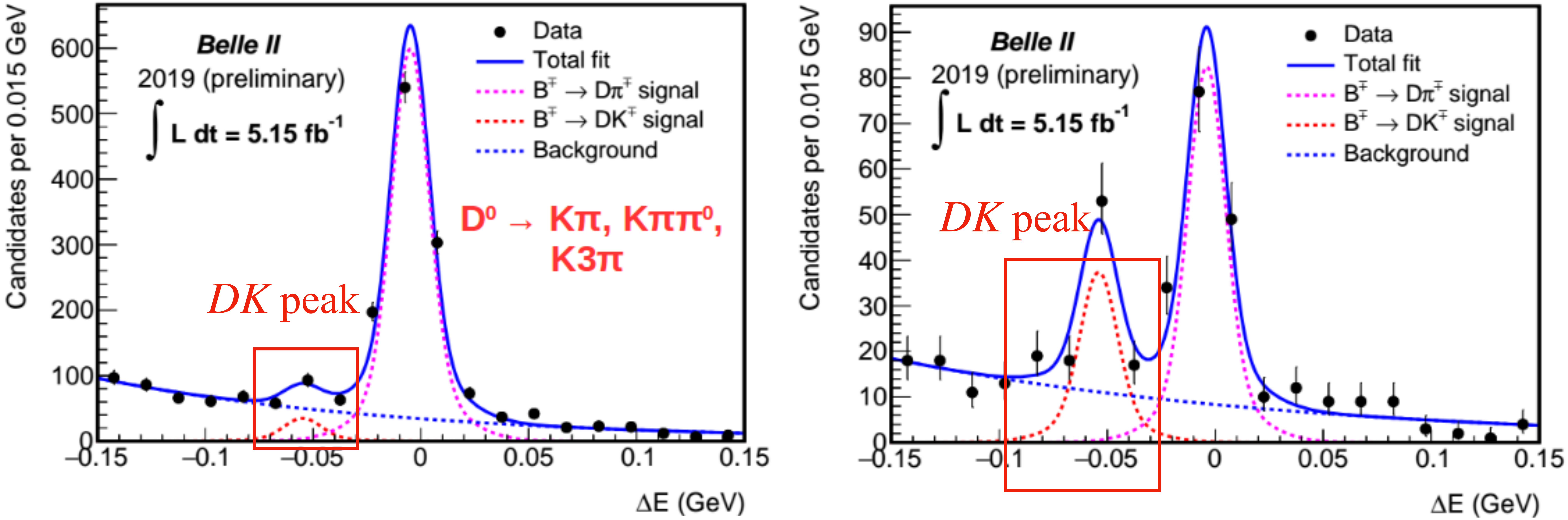
- Precise strong phase measurement (c_i, s_i) need to match Belle II statistical precision, expected to be measured from BESIII data set → 20 fb^{-1}

Rediscovery of $B \rightarrow DK$ at Belle II

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

$$\Delta E = E_B^* - E_{beam}^*$$

Without PID Cut **With PID Cut**

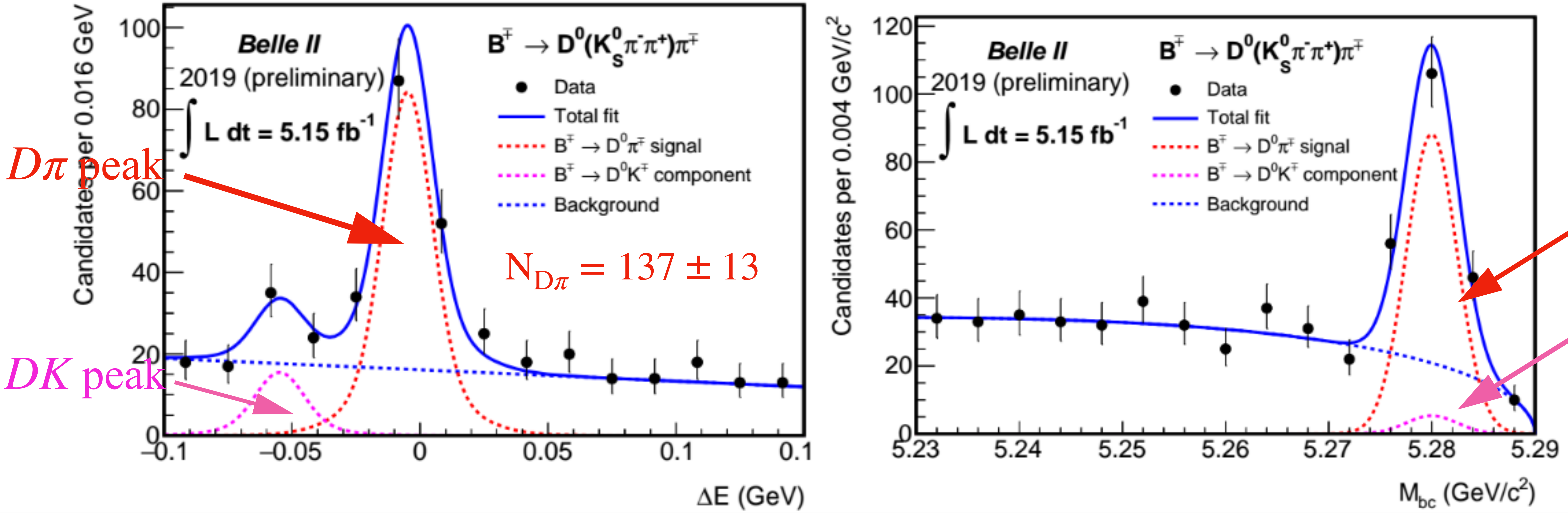


- Exploits multivariate techniques to suppress continuum background and good particle identification performances of Belle II.

Belle II prospects for φ3 (2)

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

- Limited data set (5.15 fb^{-1}) not enough to measure $B^{\pm} \rightarrow D^0(K_S^0\pi^-\pi^+)K^{\pm}$
- $B^{\pm} \rightarrow D^0(K_S^0\pi^-\pi^+)\pi^{\pm}$ can be measured → Control sample for $B^{\pm} \rightarrow D^0(K_S^0\pi^-\pi^+)K^{\pm}$
- Signal extraction from 2D unbinned maximum likelihood fit of M_{bc} and ΔE



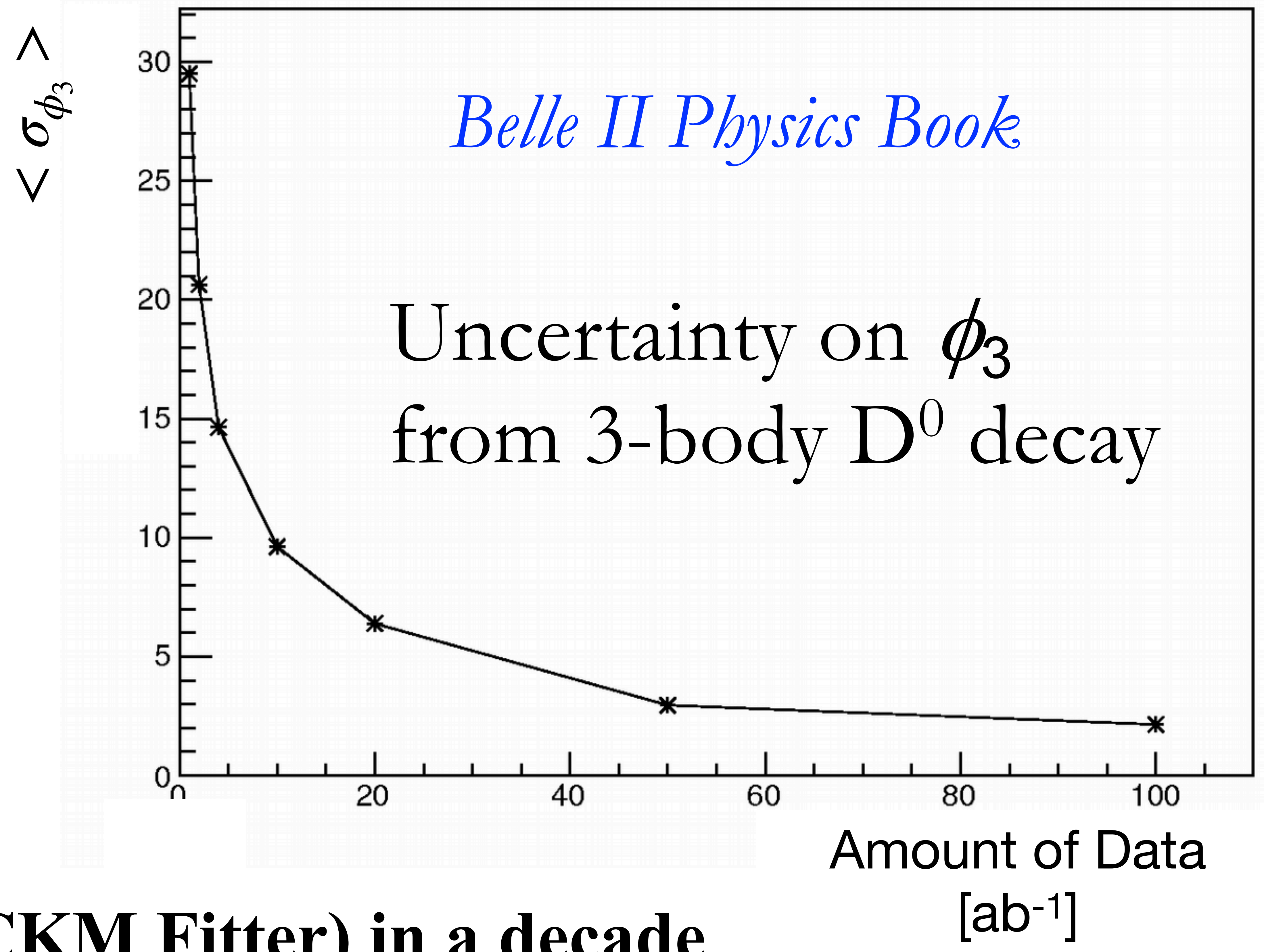
$$M_{\mathrm{bc}} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

$$\Delta E = E_B^* - E_{beam}^*$$

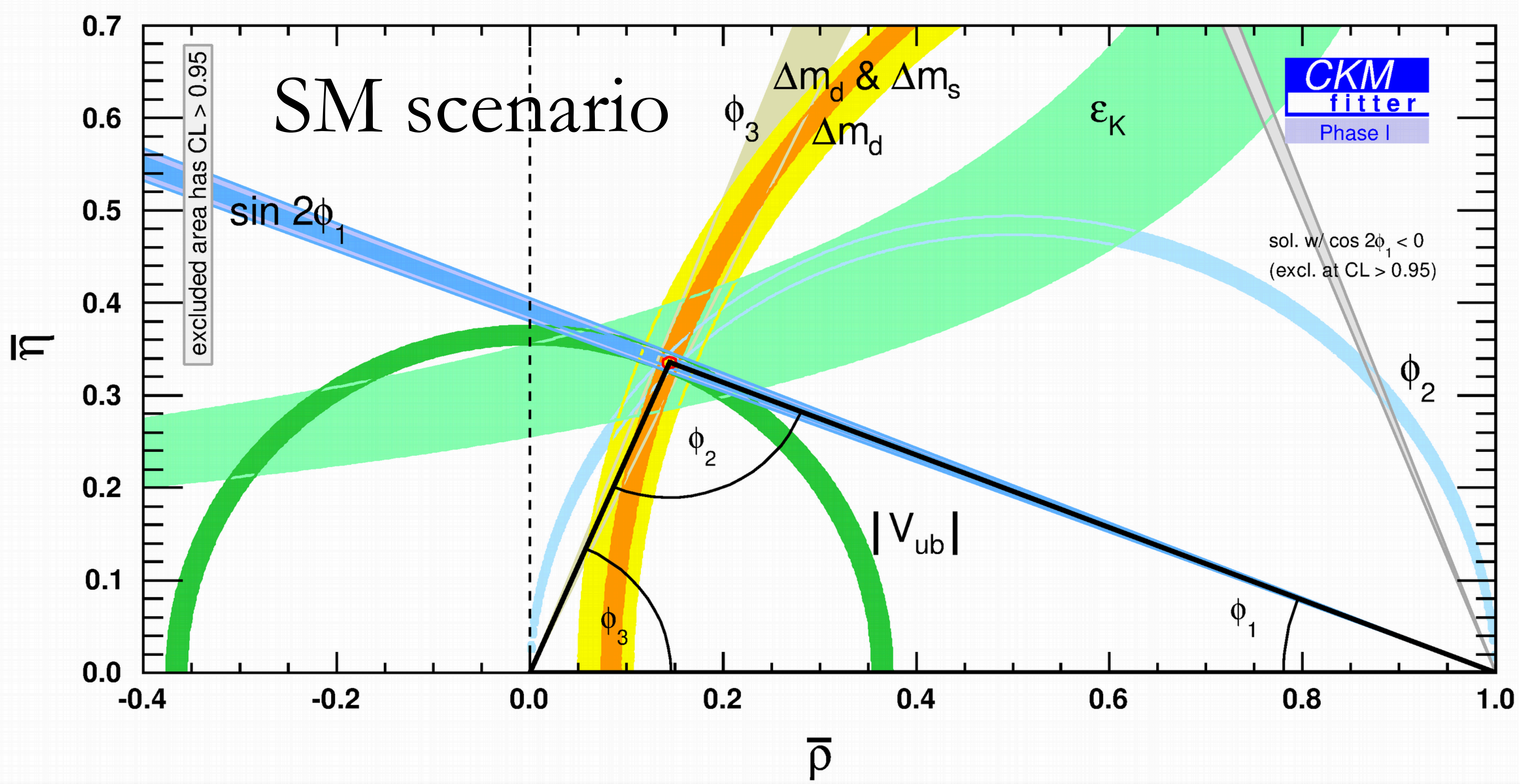
Belle II prospects for φ_3 (3)

Improving precision: Model independent approach and strong phase measurements from charm factory

- Belle II will deliver a high precision measurement of the angle, exploiting the Dalitz analysis



Foreseen φ_3 precision of ~1.5°



UT (CKM Fitter) in a decade

Assumptions:

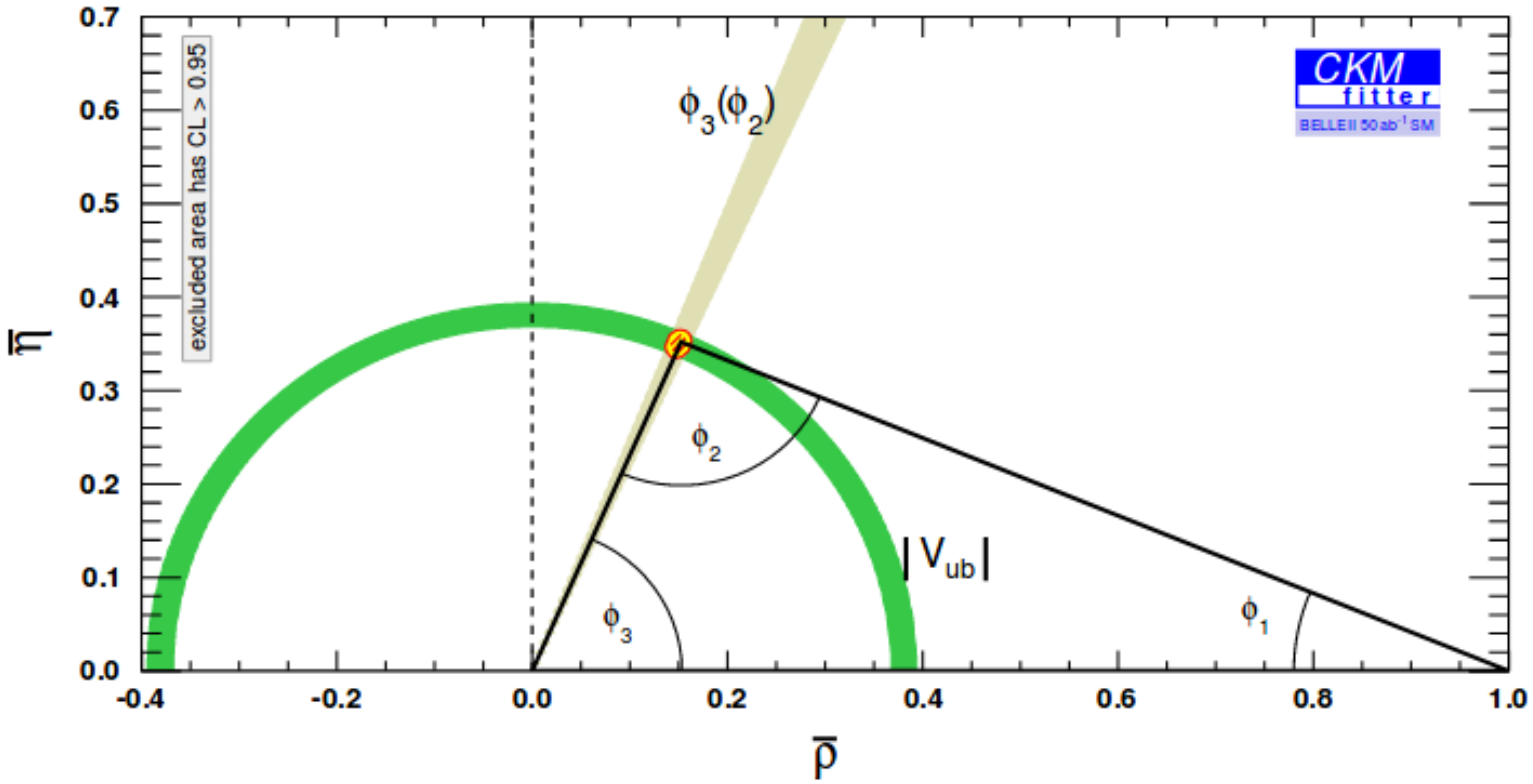
Belle II: 50 ab^{-1}

LHCb: 23 fb^{-1}

Conclusion

Future Prospects: Belle II and Beyond

- Expect Belle II and LHCb upgrade to match each other's performance!
- $\delta(\varphi3) < 1.6°$ with 50 ab^{-1} data set.
  - Modes that are good to measure at Belle II
    - $D^{*0} \to D^0\pi^0, D^0\gamma$
    - $D^0 \to K_S^0\pi^+\pi^-, K_S^0\pi^+\pi^-\pi^0$
  - 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.

More interesting results are coming.


Thank you
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online