Status of γ/ϕ_3 measurement @ Belle + Belle II

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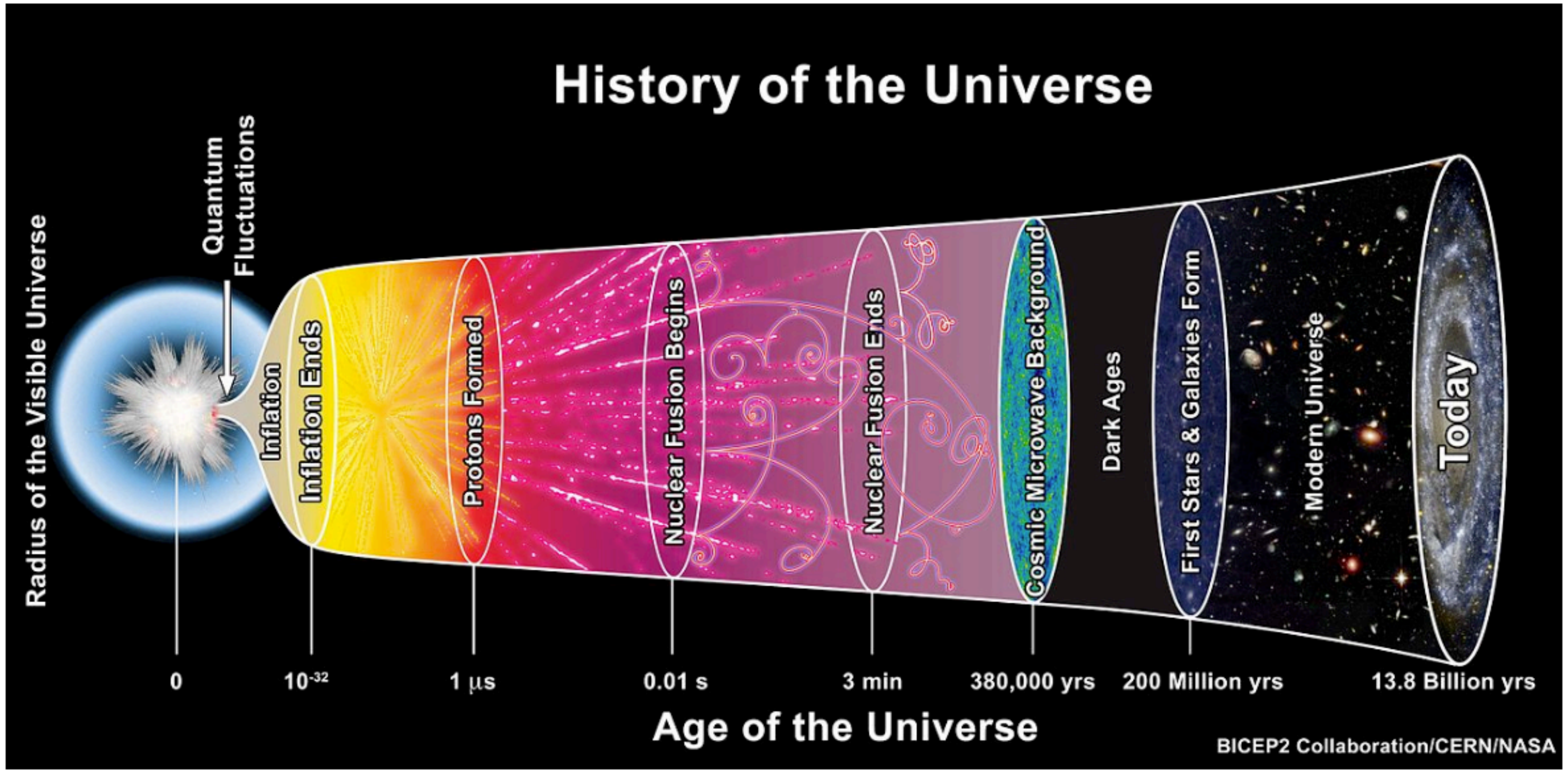
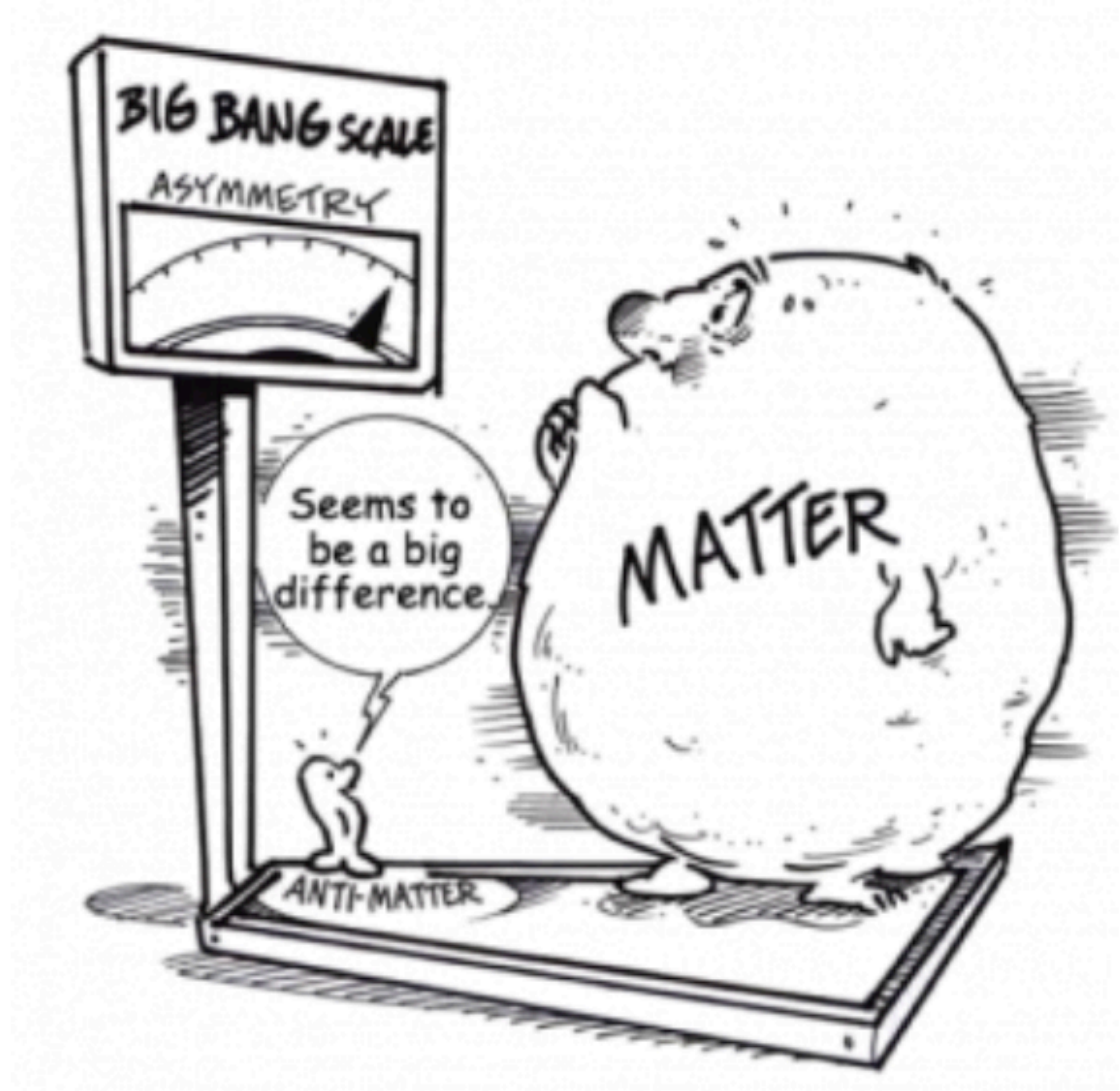
KEK, IPNS
2023.08.31 @ USTC

Outline

- **Why CPV is interesting and what is CKM matrix**
- About γ/ϕ_3
- SuperKEKB and Belle II
- All γ/ϕ_3 results from Belle and Belle II
- Discussion and outlook

Matter-antimatter asymmetry





- Same anti-matter and matter in the initial period.

- But now we observe much more matter than anti-matter!

$$\frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}} \sim 10^{-10}$$

Matter-antimatter asymmetry, CP violation

- In 1967, Andrei Sakharov proposed three conditions for the matter-antimatter asymmetry:
  - Baryon number violation
  - **C and CP violation**
  - Interactions out of thermal equilibrium

- So we shall understand **CP violation (CPV)**!

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- In 1964, first CPV observation in Kaon system
- In 2001, CPV observed in B system
- In 2019, direct CPV observed in D system by LHCb
- Standard Model (SM) can describe these CPV by a phase in Cabibbo-Kobayashi-Maskawa (CKM) matrix.

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- SM only gives $\sim 10^{-17}$,

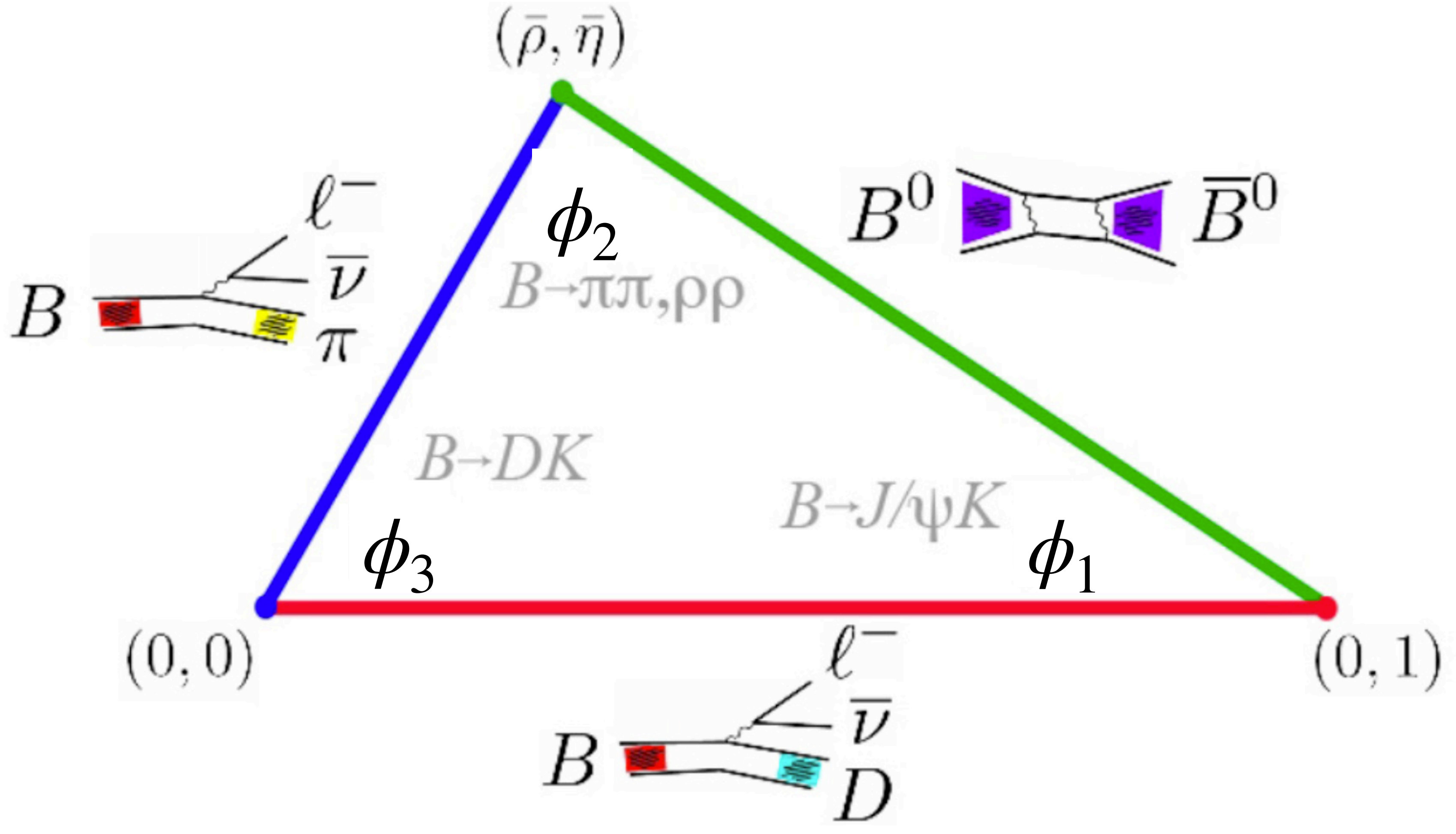
$$\frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}} \sim 10^{-10}$$

- need extra sources of CPV. Hint of NP?

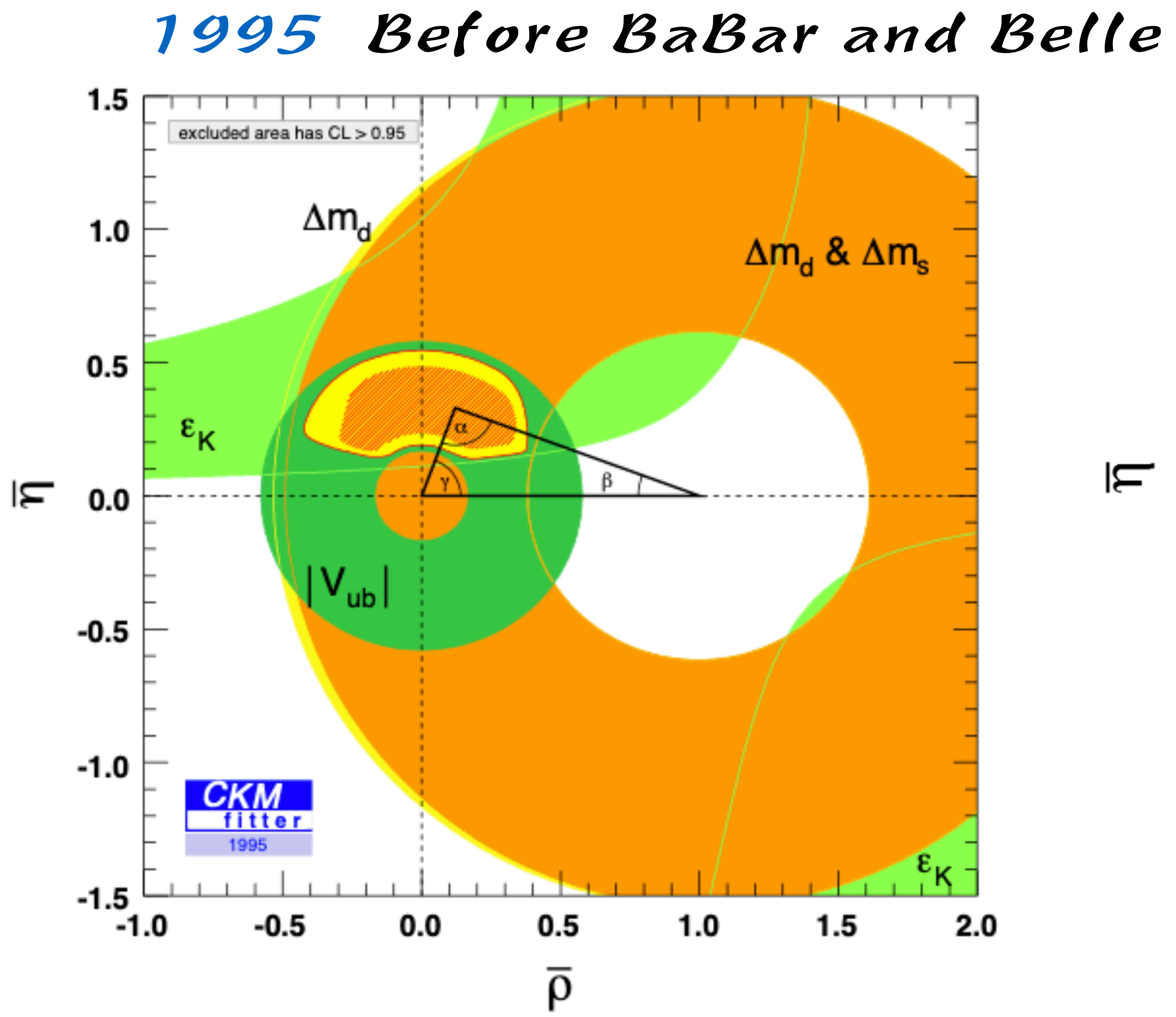
CKM matrix and the unitary triangle

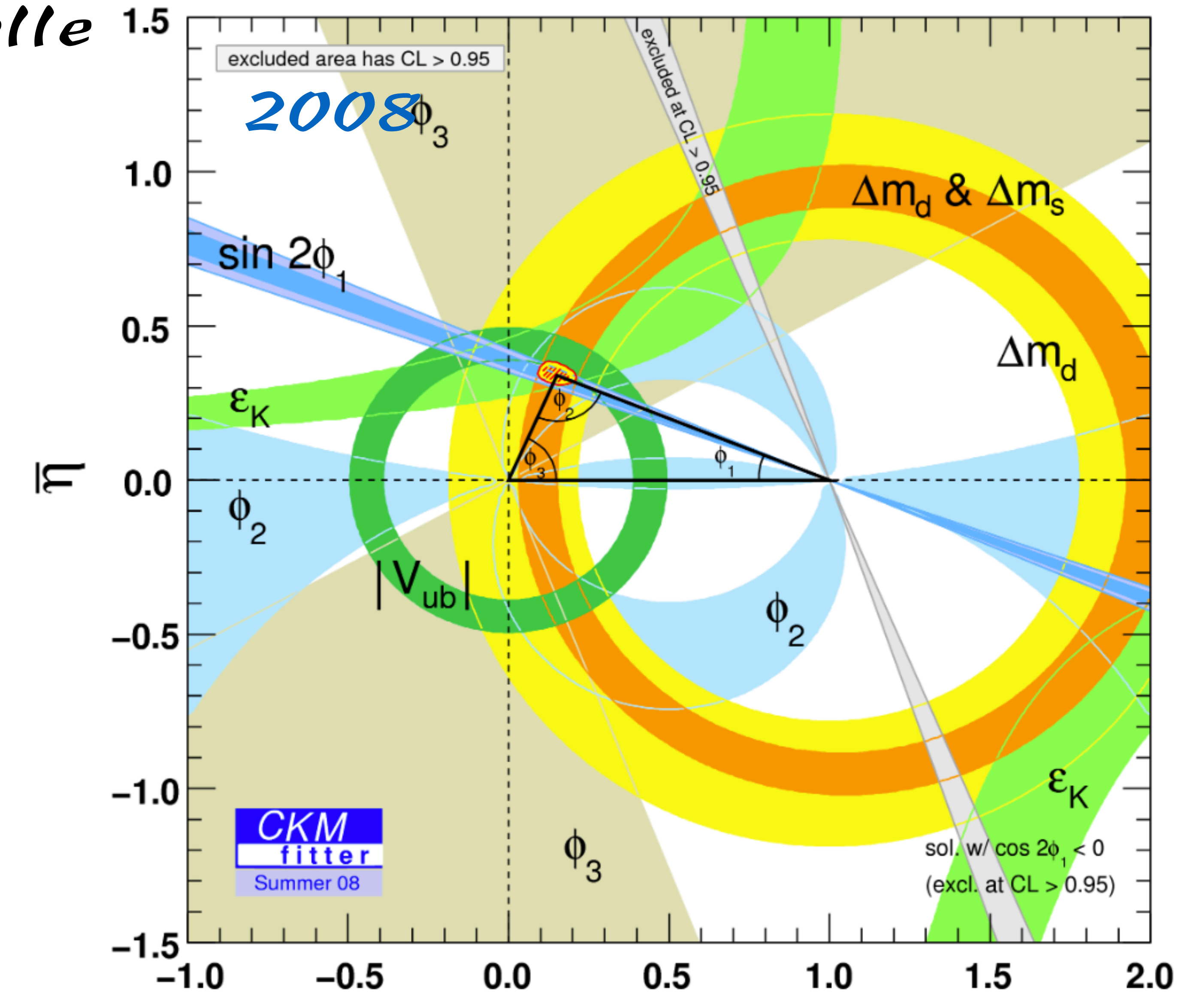
$$\begin{pmatrix} u \\ c \\ t \end{pmatrix} \leftarrow W^{\pm} \rightarrow \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

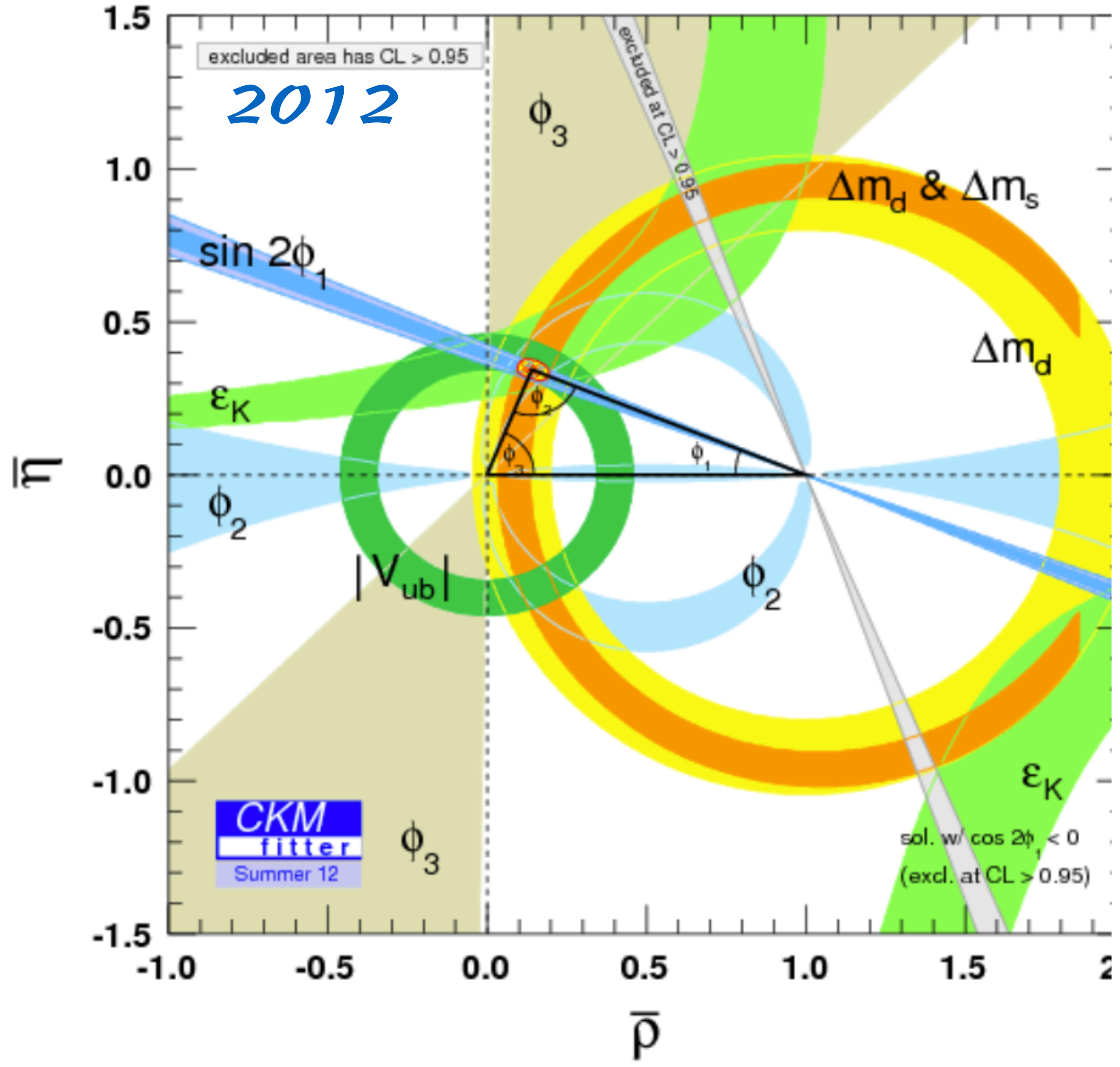
- CKM matrix connects *u*- and *d*-type quarks via weak force
- In SM, CKM matrix is unitary: four free parameter, one of them is the complex phase, the only one source of CPV in quark sector in SM!
- One way to examine this CKM matrix: examine the unitarity: $\Sigma_i V_{ik} V^*_{il} = \Sigma_i V_{ki} V^*_{li} = \delta_{kl}$
- One "popular" case: $V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$

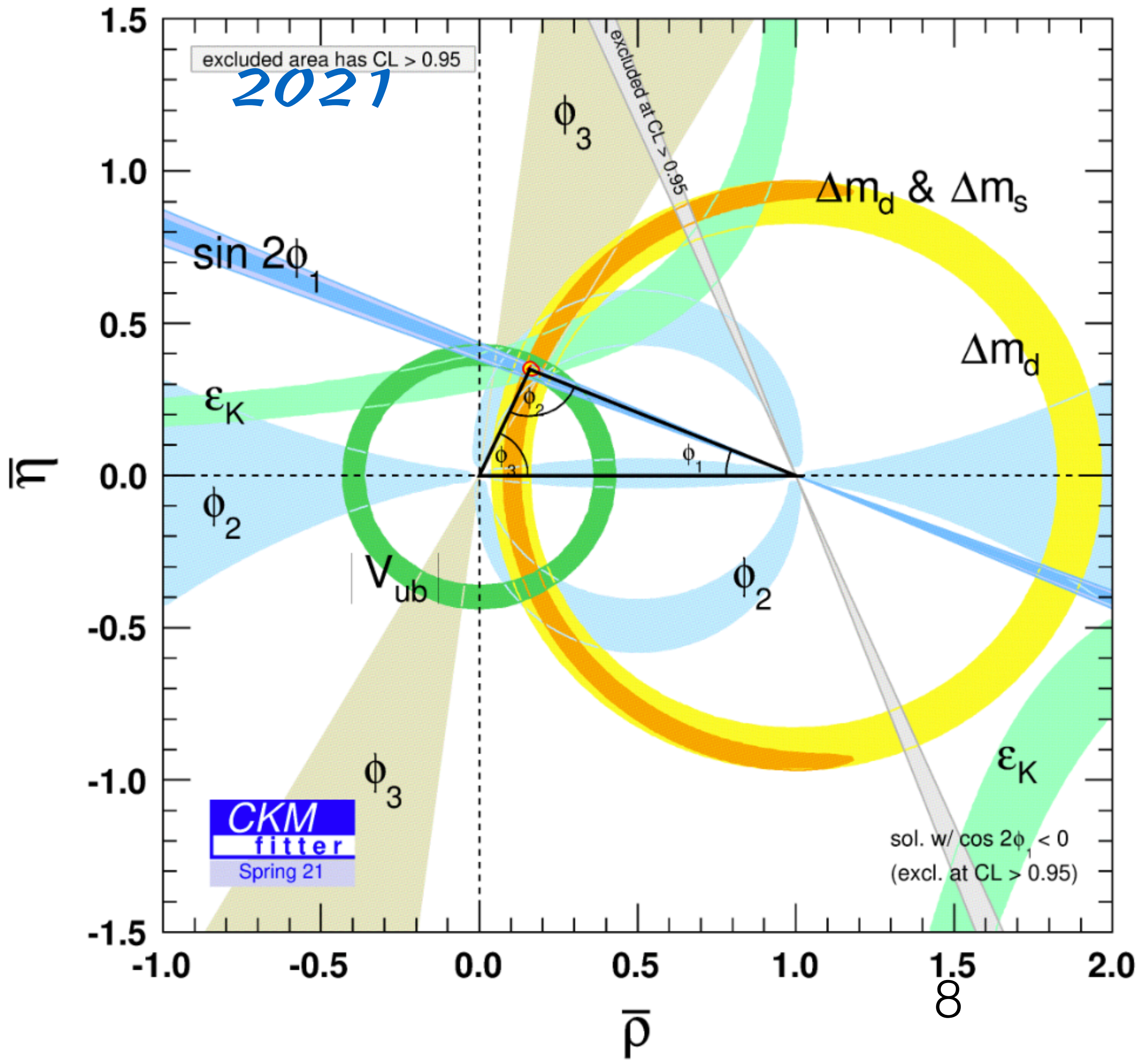


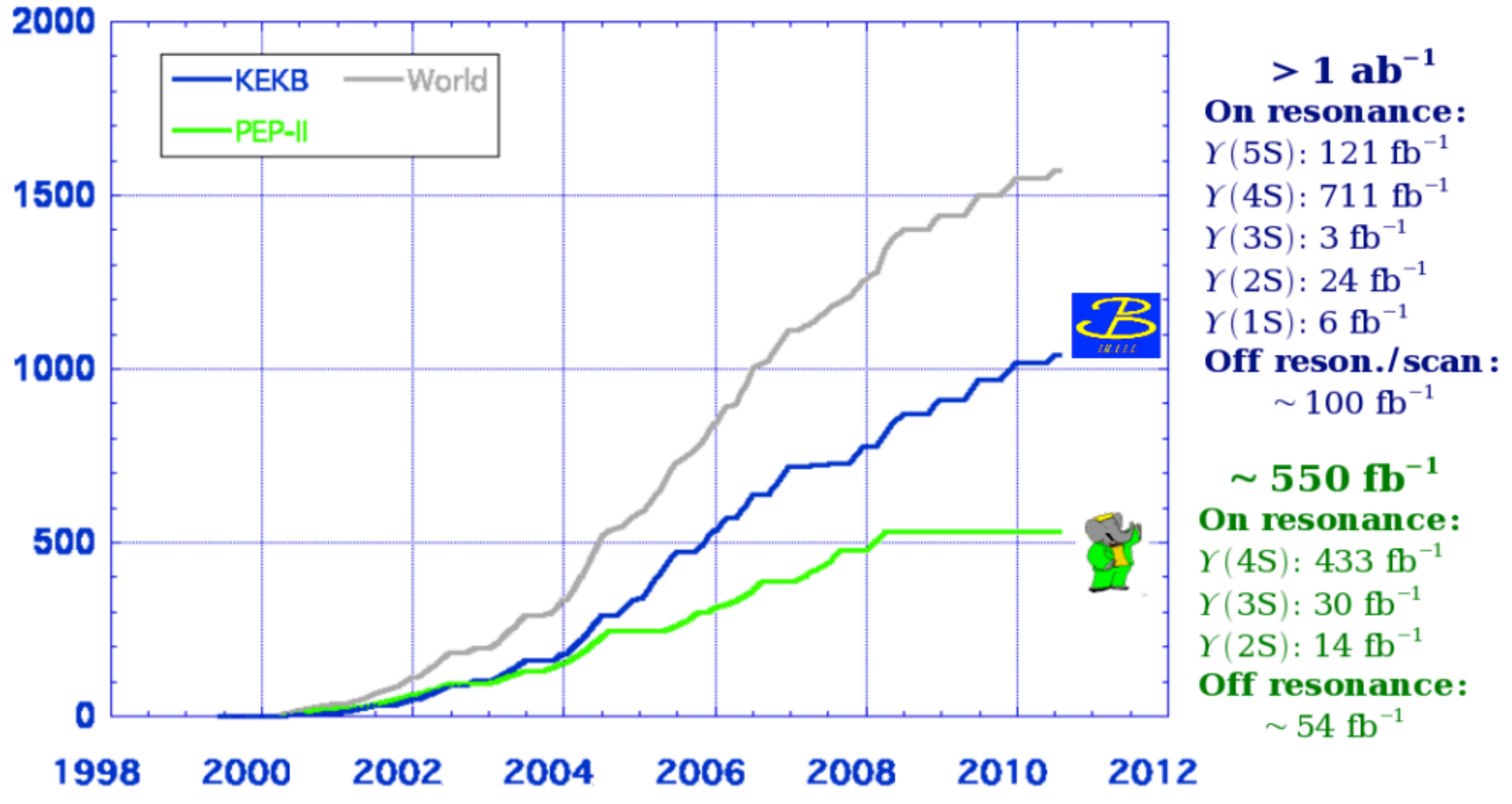
Is the triangle closed? (Hint of New Physics?)











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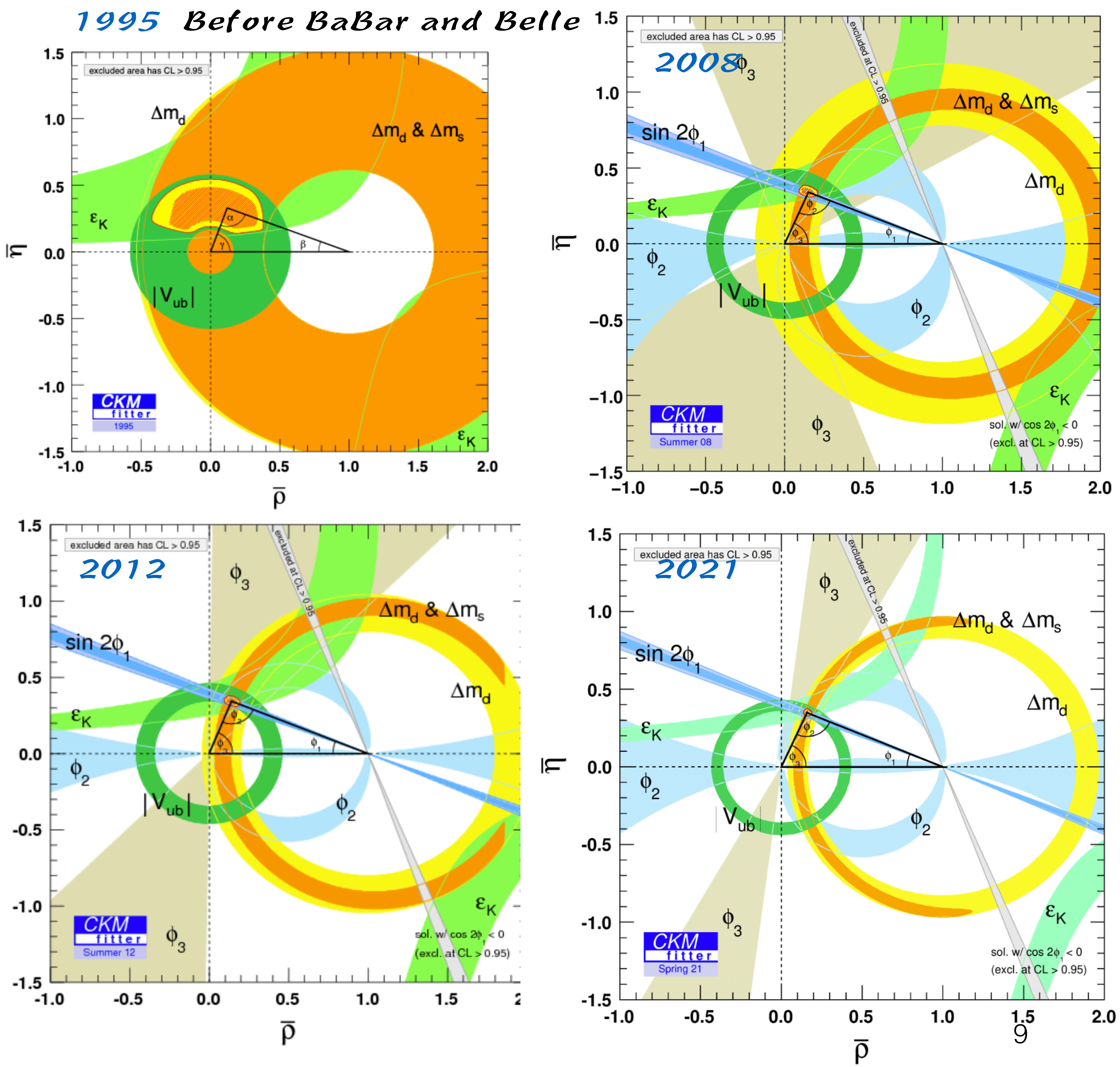

- With results from BaBar, Belle, and LHCb's Run1,2 data, the triangle is still closed.
- $\phi_1 = \beta = \arg(-\frac{V_{cd}V^*_{cb}}{V_{td}V^*_{tb}})$, $(22.2 \pm 0.7)^\circ$
- $\phi_2 = \alpha = \arg(-\frac{V_{td}V^*_{tb}}{V_{ud}V^*_{ub}})$,$(85.2^{+4.8}_{-4.3})^\circ$
- $\phi_3 = \gamma = \arg(-\frac{V_{ud}V^*_{ub}}{V_{cd}V^*_{cb}})$,$(66.2^{+3.4}_{-3.6})^\circ$

HFLAV

- With much more data from LHCb and Belle II, we could shrink the uncertainty, test this triangle and look for hints from new physics.

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About ϕ_3

$$V_{CKM} = \begin{matrix} \\ u \\ c \\ t \end{matrix} \begin{matrix} d & s & b \\ \left(\begin{matrix} 1-\frac{1}{2}\lambda^2 \\ -\lambda \\ A\lambda^3(1-\rho-i\eta) \end{matrix} \right. & \begin{matrix} \lambda \\ 1-\frac{1}{2}\lambda^2-i\eta A^2\lambda^4 \\ -A\lambda^2 \end{matrix} & \left. \begin{matrix} A\lambda^3(\rho-i\eta+\frac{i}{2}\eta\lambda^2) \\ A\lambda^2(1+i\eta\lambda^2) \\ 1 \end{matrix} \right) \end{matrix} + \mathcal{O}(\lambda^6)\ (\sim 10^{-4})$$

Wolfenstein expansion in powers of the Cabibbo angle, λ, up to λ^5

Zero phase in V_{ud}, V_{cd}

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

About ϕ_3

$$
V_{CKM} = \begin{matrix} \\ u \\ c \\ t \end{matrix}
\overset{\begin{matrix} d & s & b \end{matrix}}{\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta + \frac{i}{2}\eta\lambda^2) \\ -\lambda & 1-\frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 & A\lambda^2(1+i\eta\lambda^2) \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}} + \mathcal{O}(\lambda^6)\ (\sim 10^{-4})
$$

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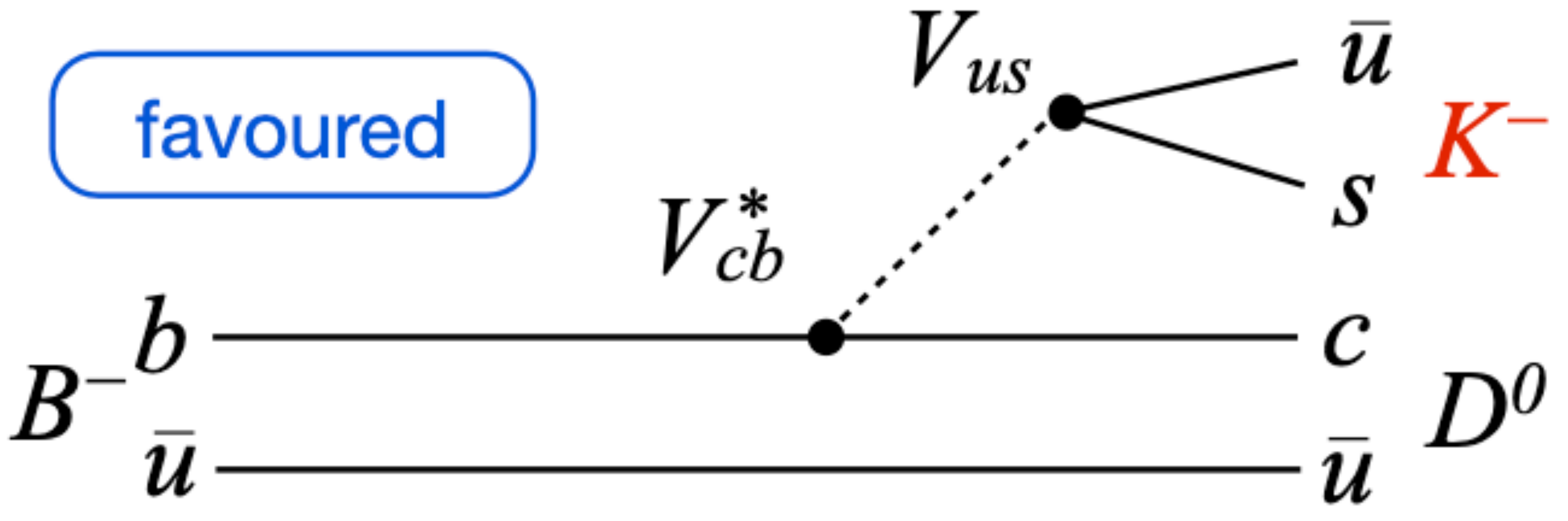
favoured



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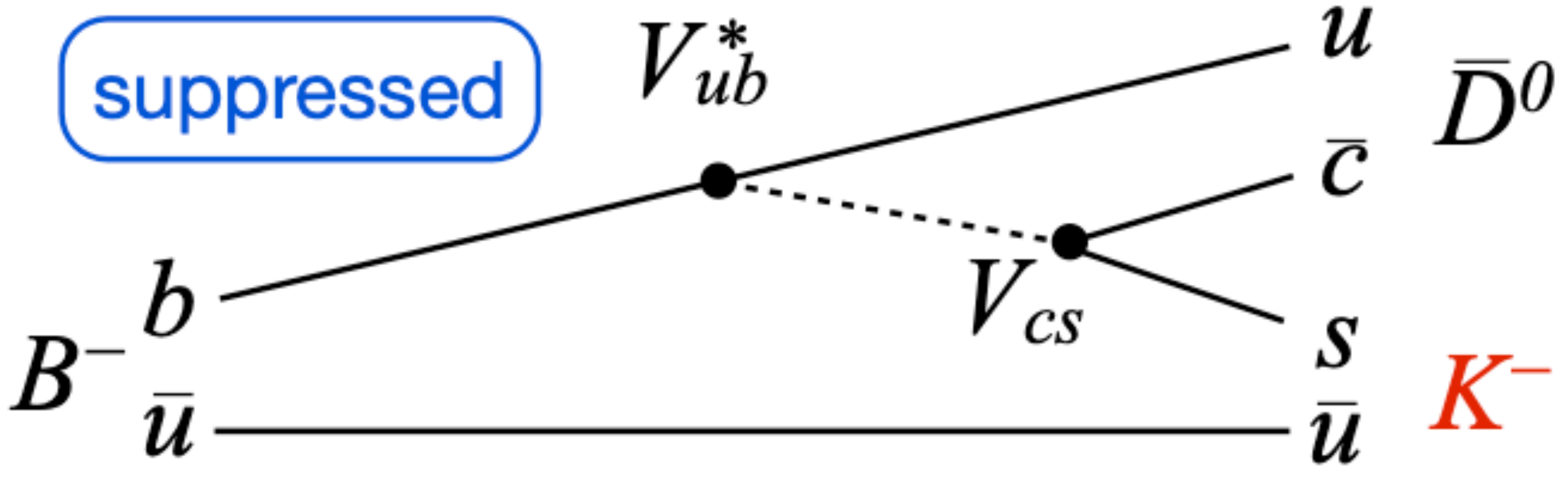


relative amplitude:

$$
\left|\frac{V_{cs}V_{ub}^*}{V_{us}V_{cb}^*}\right| f_{col} = r_B \approx 0.1
$$

relative strong phase:

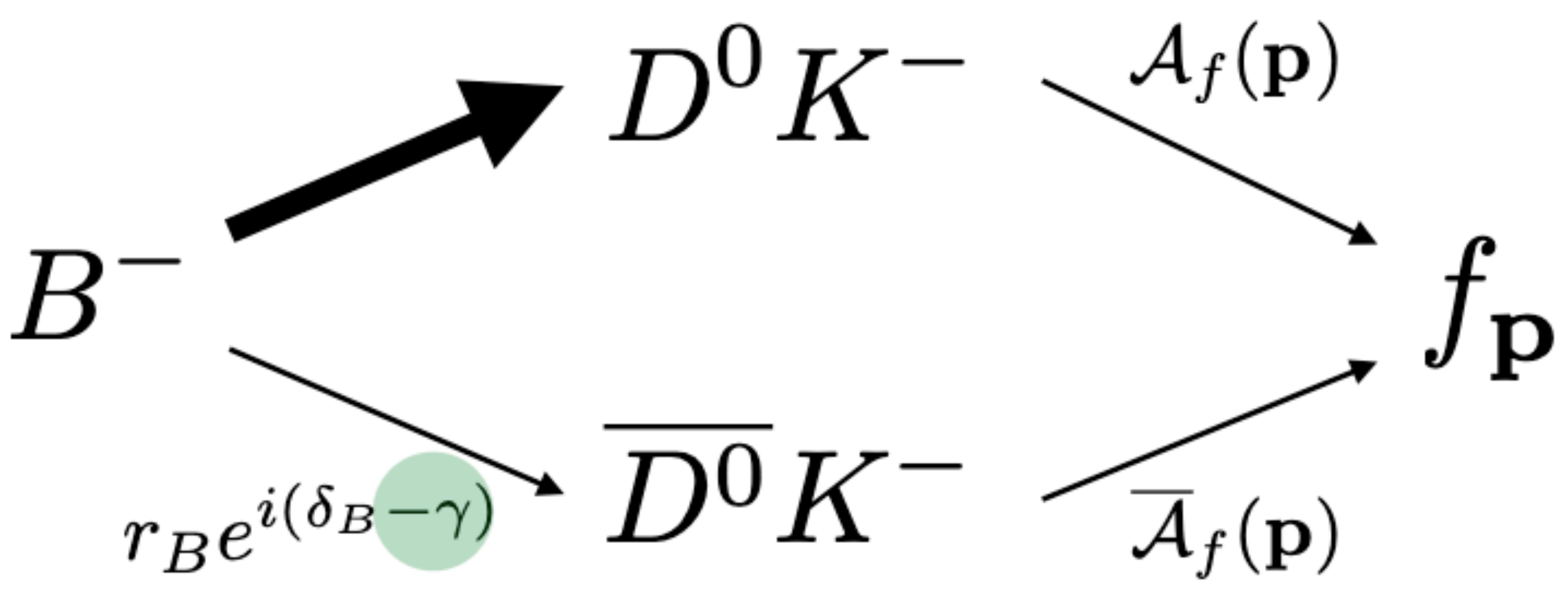
$$
= \delta_B
$$

weak phase difference:

$$
\arg\left(-\frac{V_{cs}\ V_{ub}^*}{V_{us}\ V_{cb}^*}\right) = \arg\left(-\frac{V_{ub}^*}{V_{cb}^*}\right) = \phi_3
$$

$* \ r_B(D\pi^-) = (0.0049 \pm 0.0006)$

About ϕ_3



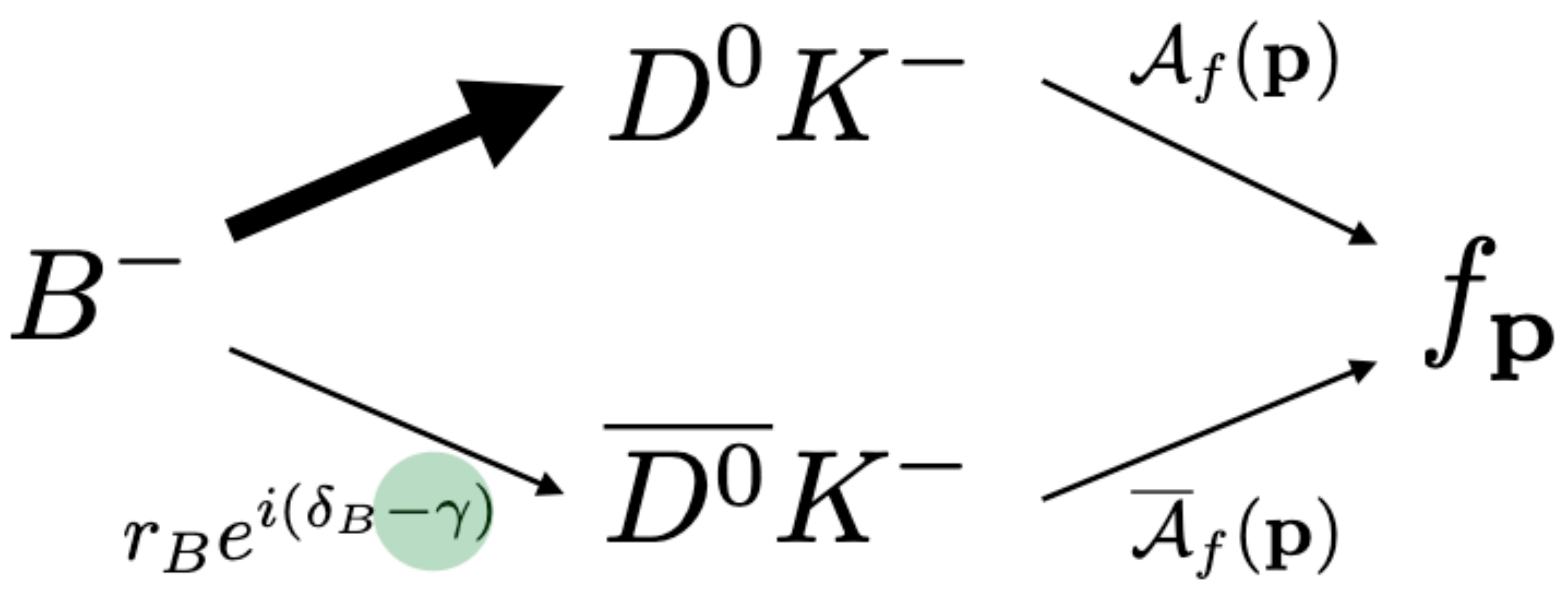
Current W.A.: [HFLAV]

- $\phi_3 = (66.2^{+3.4}_{-3.6})^\circ$
- $r_B(DK^-) = (0.0994 \pm 0.0026)$
- $\delta_B(DK^-) = (127.7^{+3.6}_{-3.9})^\circ$
- $r_B(D\pi^-) = (0.0049 \pm 0.0006)$
- $\delta_B(D\pi^-) = (294^{+9.7}_{-11})^\circ$

- Also need measure r_B, δ_B at same time.
- Need consider the D decays, e.g. strong-phase difference.
  - CLEO-c and BESIII provides model-independent external inputs.

- Depends on the D decay final states, different methods:
  - **BPGGSZ**: self conjugated multi-body decays, e.g. $K^0_S\pi^+\pi^-, K^0_S\pi^+\pi^-\pi^0, \pi^+\pi^-\pi^+\pi^-$
  - **GLW**: CP eigenstates, e.g. $K^0_S\pi^0, K^+K^-$
  - **ADS**: CF and DCS decays, e.g. $K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^\pm\pi^\mp$
  - **GLS**: SCS decays, e.g. $K^0_S K^\mp\pi^\pm$

About ϕ_3



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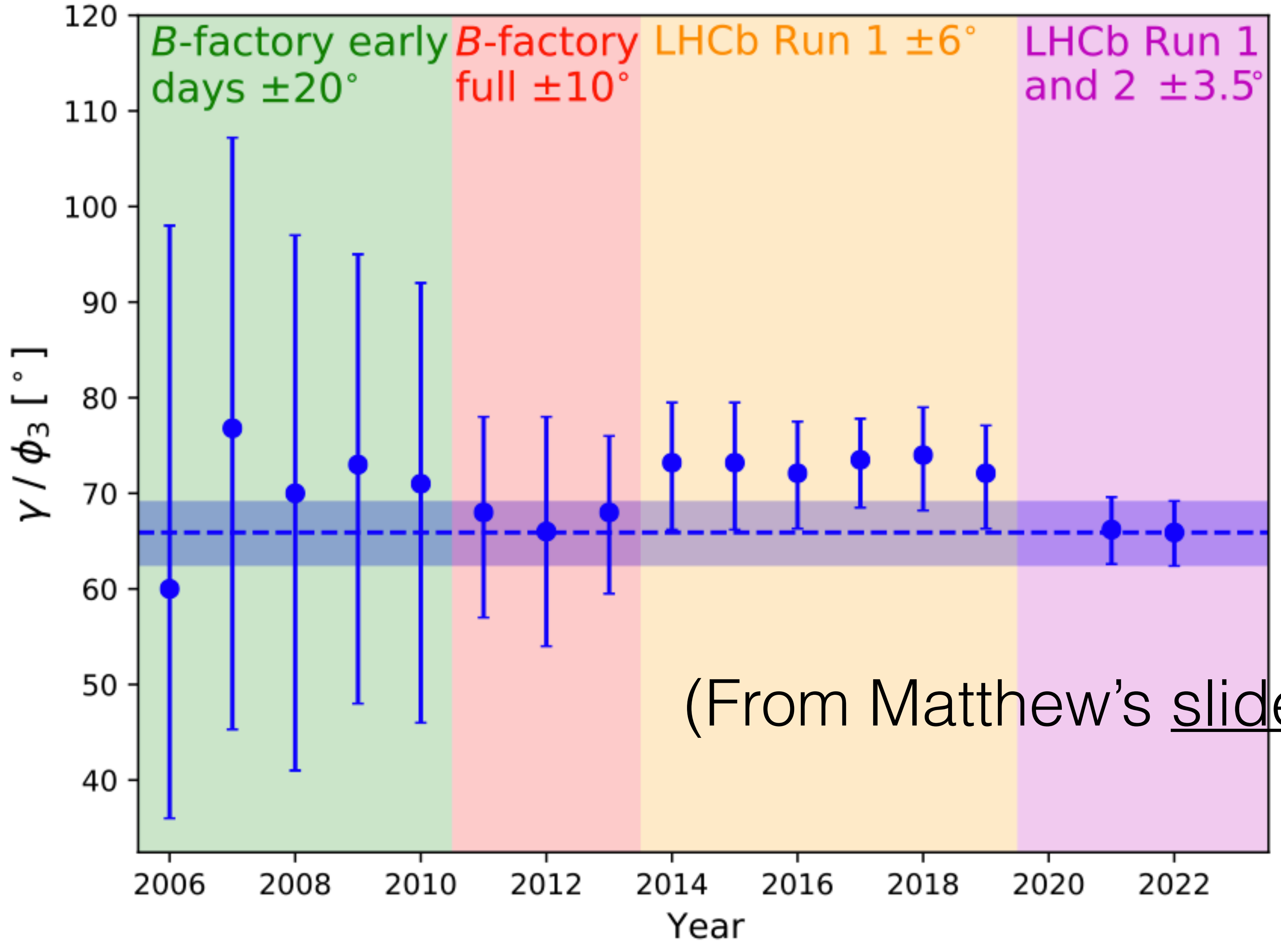


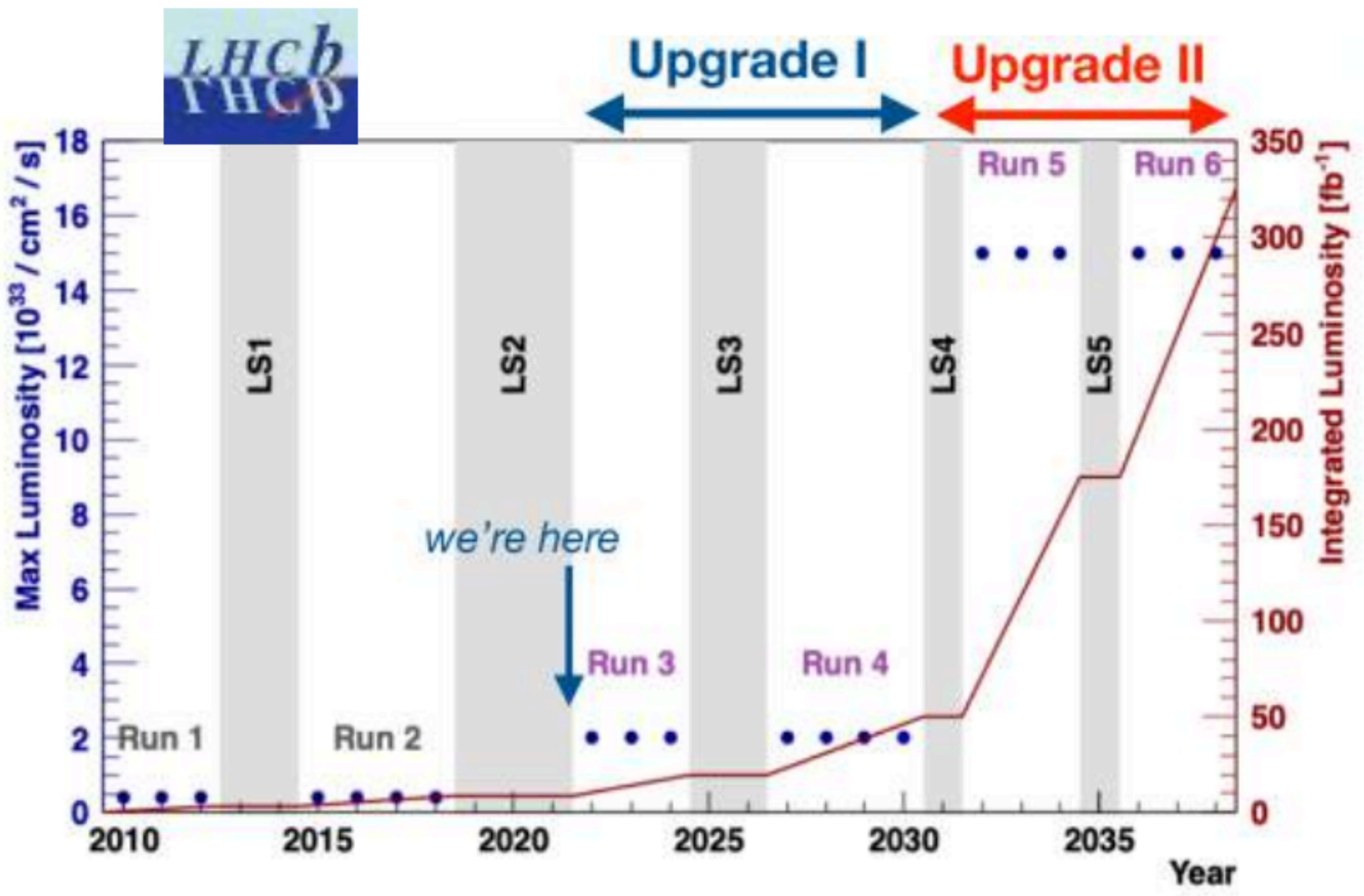
(From Matthew's slides)

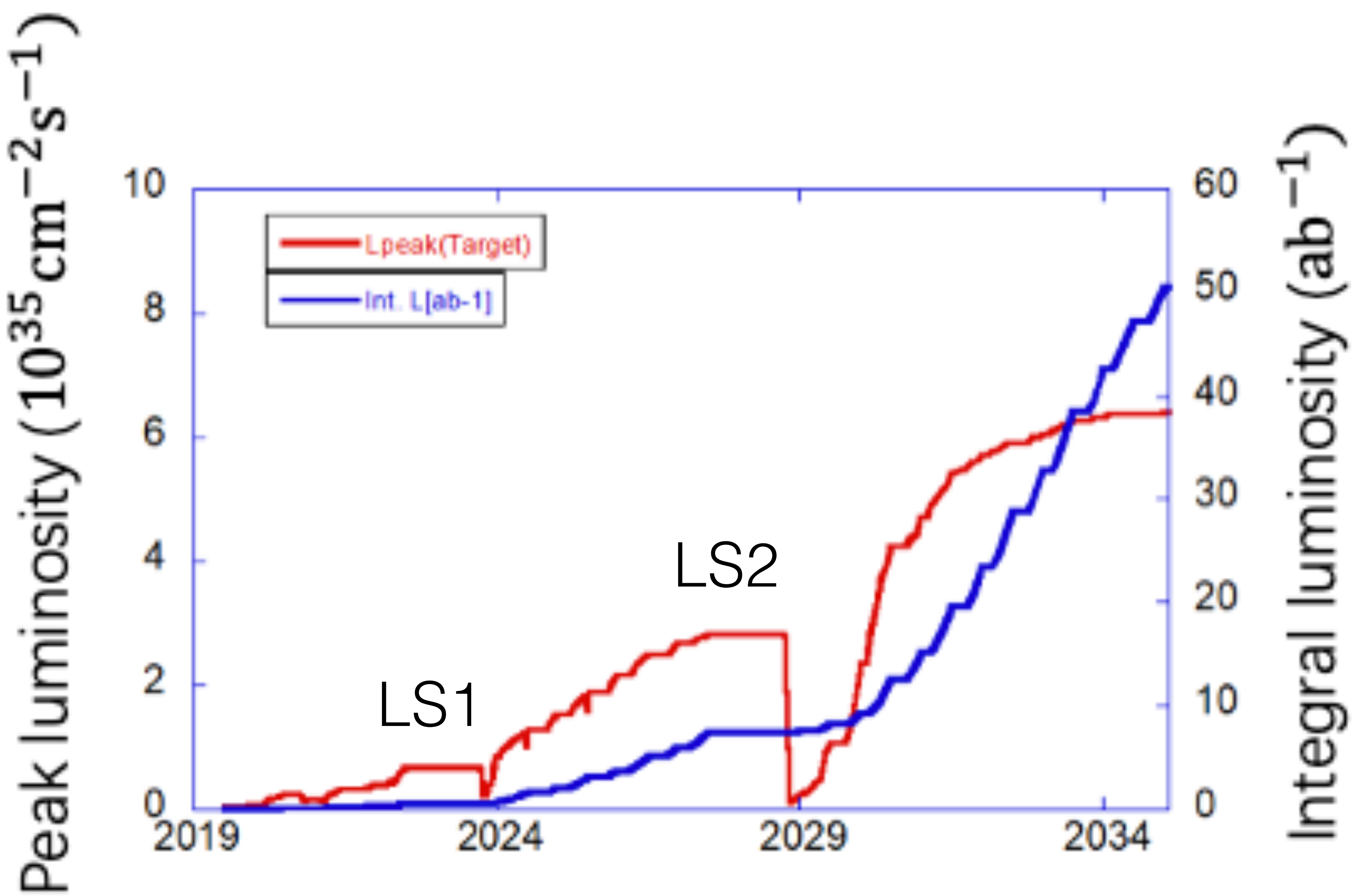
- Now the w.a. of ϕ_3 is dominated by LHCb.

About ϕ_3

- Theoretically clean, non-tree SM contribute ~10^{-7} [arXiv:1308.5663]
- Current W.A.: $\phi_3 = (66.2^{+3.4}_{-3.6})^{\circ}$[HFLAV], statistically uncertainty dominated.
- More B data in the next decades
  - LHCb expect 1.5° by end of Run 3 (~ 22 fb^{-1}), <1° by end of Run 4 (~ 50 fb^{-1}), ~ 0.4° in Phase II upgrade (~ 300 fb^{-1}).[arXiv:1709.10308, CERN-LHCC-2017-003]
  - Belle II expect 1.5° with $50\ \mathrm{ab}^{-1}$ [2020 snowmass].

—> In the future, ϕ_3 can be a "**candle**" of SM.





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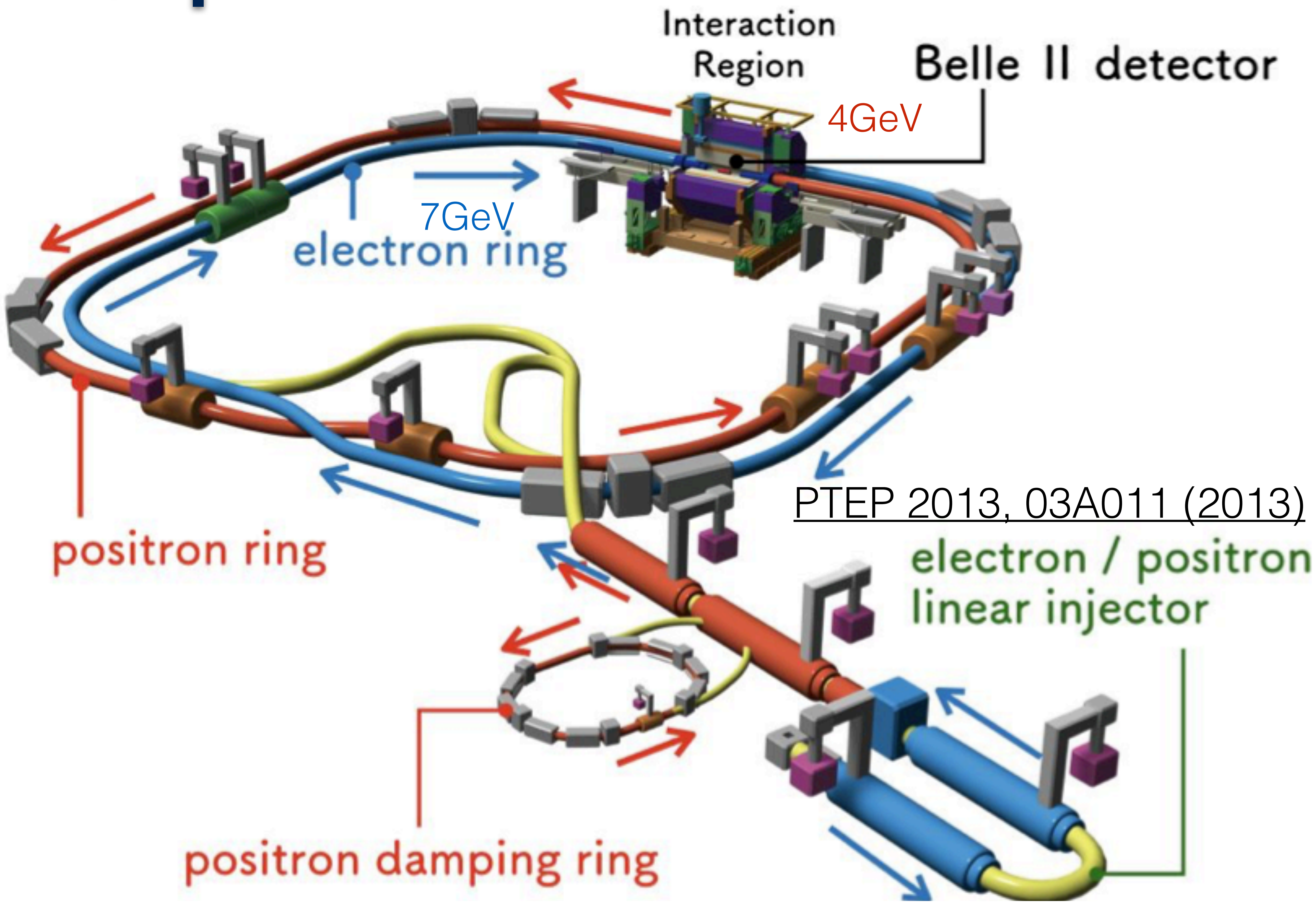
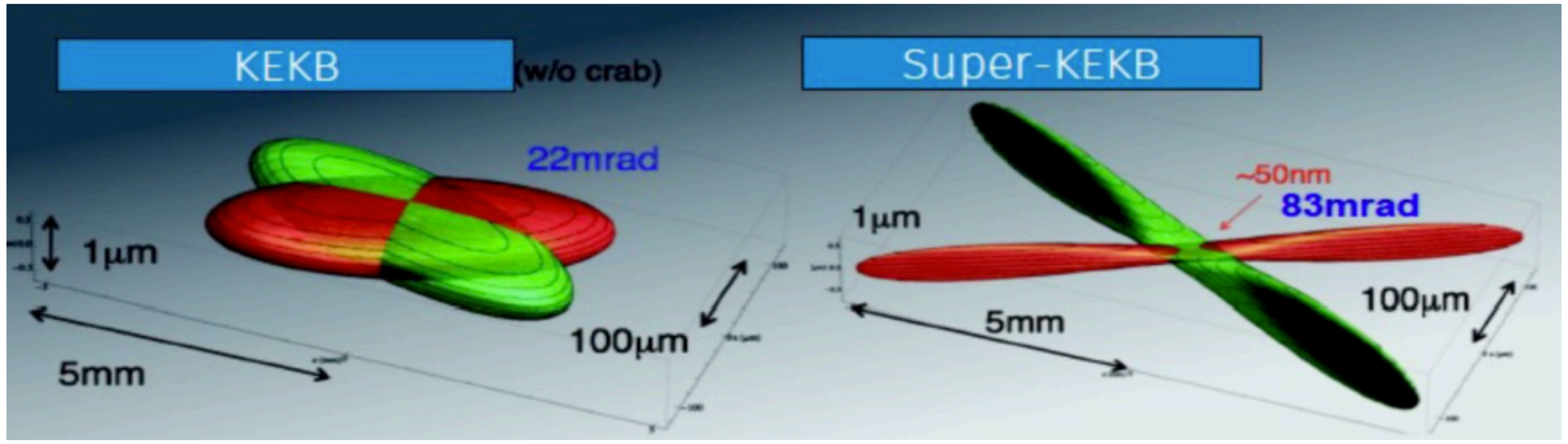
SuperKEKB



PTEP 2013, 03A011 (2013)

Machine parameters as of June 8th 2022, with the design values in ( )

Papameter	LER	HER	unit
Beam current	1321 (3600)	1099 (2600)	mA
# of bunches	2249 (2500)		
Bunch current	0.587	0.489	mA
β_x^*/β_y^*	80/1.0 (32/0.27)	60/1.0 (25/0.30)	mm
Beam-Beam Parameter ξ_y	0.0407 (0.088)	0.0279 (0.081)	
σ_y^*	0.215 (0.048)	0.215 (0.062)	μm
tunes (x/y)	44.525/46.589	45.532/43.573	
Specific luminosity($\times10^{31}$)	7.21		$cm^{-2}s^{-1}/mA^2$
Luminosity($\times10^{34}$)	4.65 (60)		



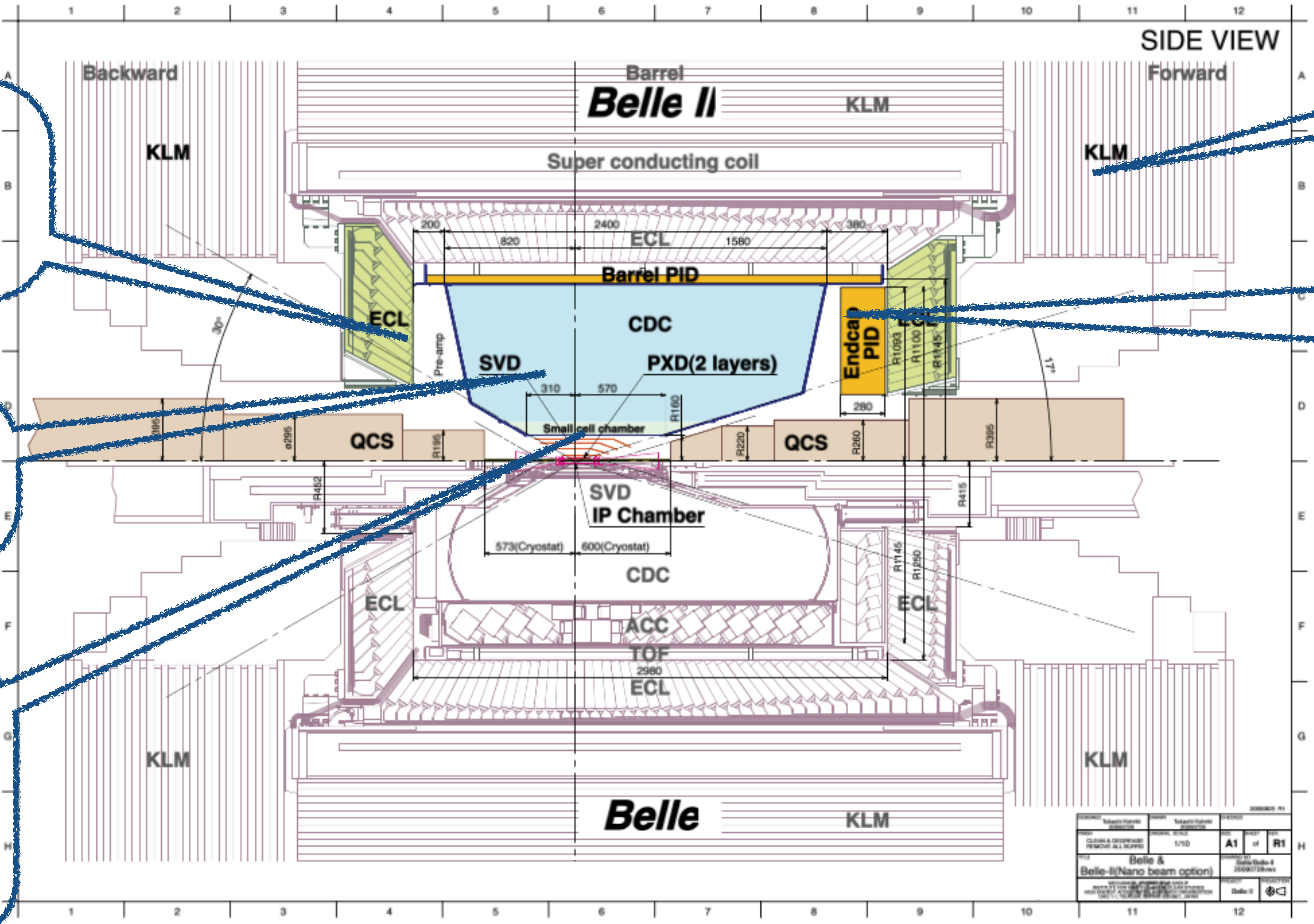
- Asymmetric e^+e^- collider at KEK
- Design instant luminosity: $6.5 \times 10^{35} cm^{-2}s^{-1}$
- Nano-beam collision, crab waist scheme
- Instant luminosity record of $4.7 \times 10^{34} cm^{-2}s^{-1}$ (x2 of KEKB's peak luminosity)

Belle and Belle II detector

ECL
CsI(Tl)+waveform sampling
Energy resolution: 1.6~4%

CDC
Track efficiency: ~99%
dE/dx resolution: 5%
Pt resolution: 0.4%

VXD
Inner 2 layers: pixel detector (PXD)
Outer 4 layers: strip sensor (SVD)
Vertex resolution: 15 μm

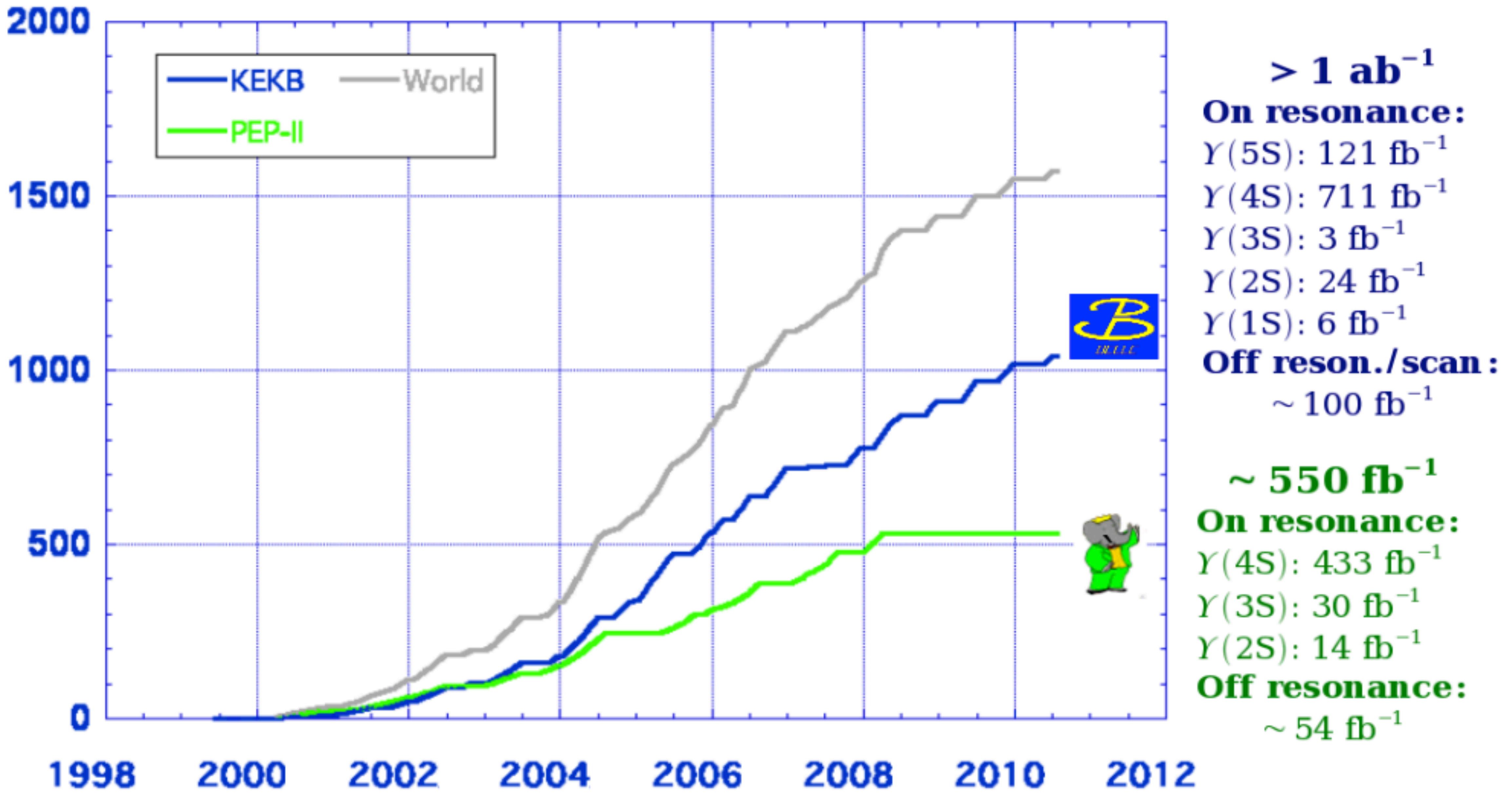


KLM
Outer barrel: Resistive Plate Counter (RPC)
Endcap/inner barrel: Scintillator

PID
Barrel: Time-Of-Propagation counters(TOP)
Endcap: ARICH

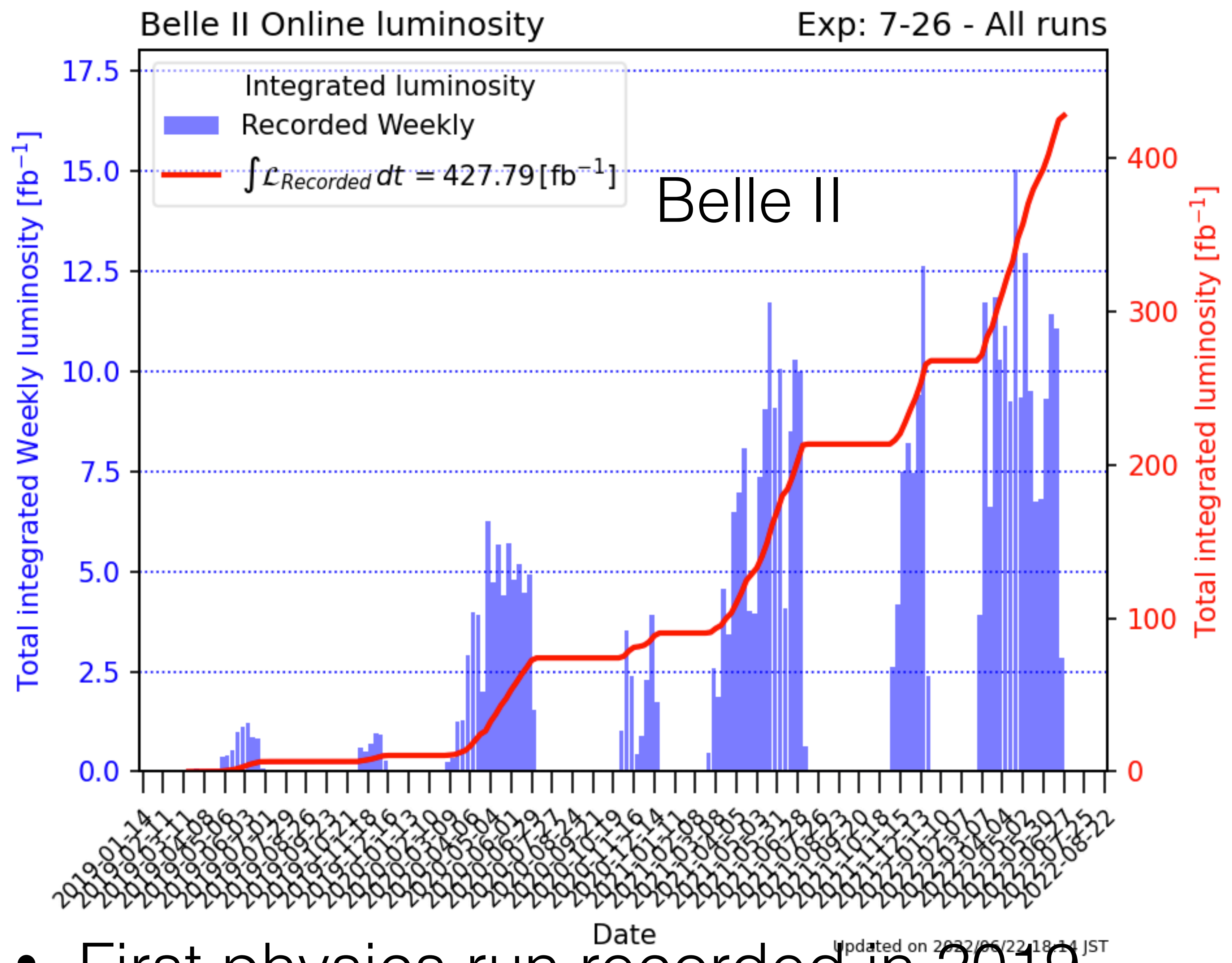
- Not just Belle “too”.
- A brand new detector.
- Only re-use magnet, calorimeter crystals.

Belle and Belle II data sets



711 fb^{-1} @$\Upsilon(4S)$ from Belle

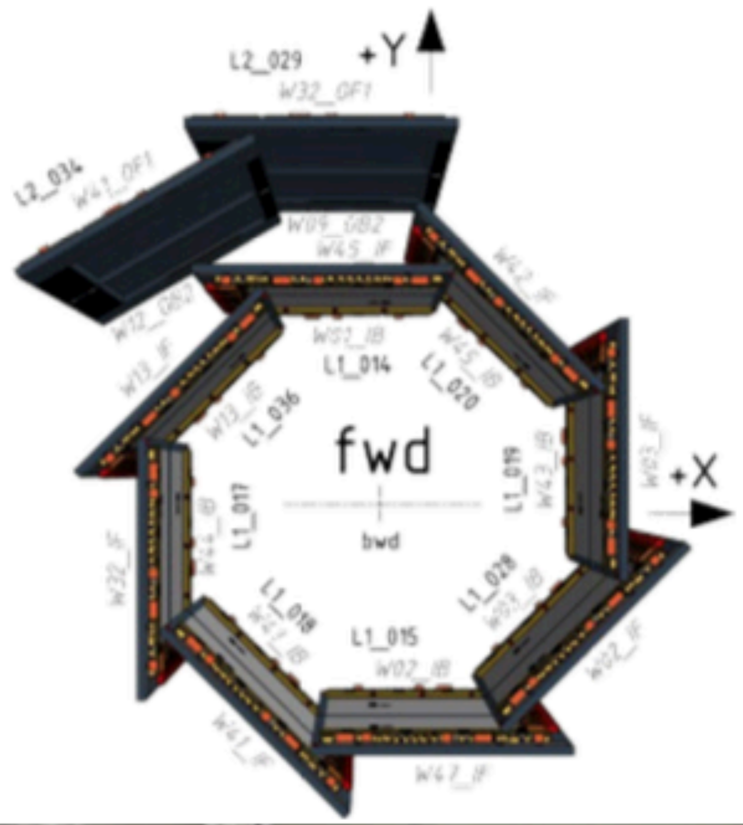
Total recorded integrated luminosity before Long Shutdown 1

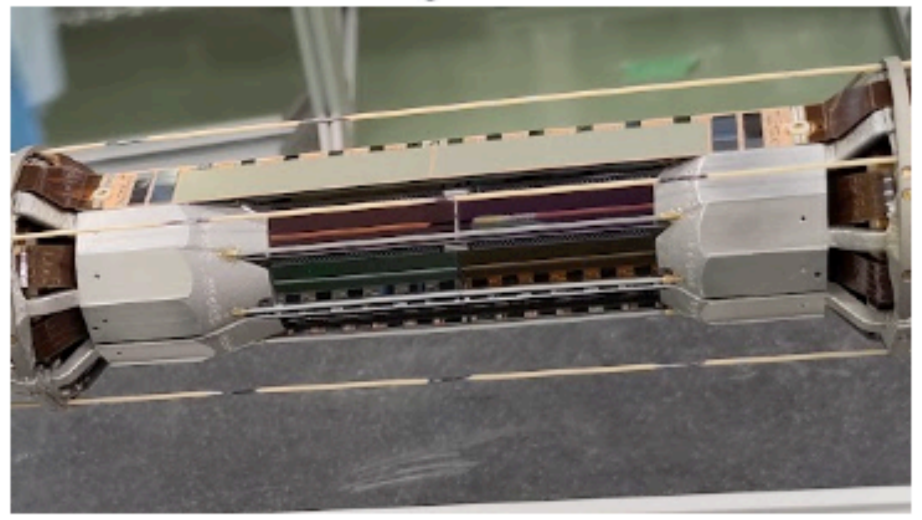


- First physics run recorded in 2019
  - **362**/fb at Y(4S) (goal: 50/ab)
  - 42/fb off-resonance, 60 MeV below Y(4S)
  - 19/fb energy scan between 10.6 to 10.8 GeV for bottomonium and exotic spectroscopy study.

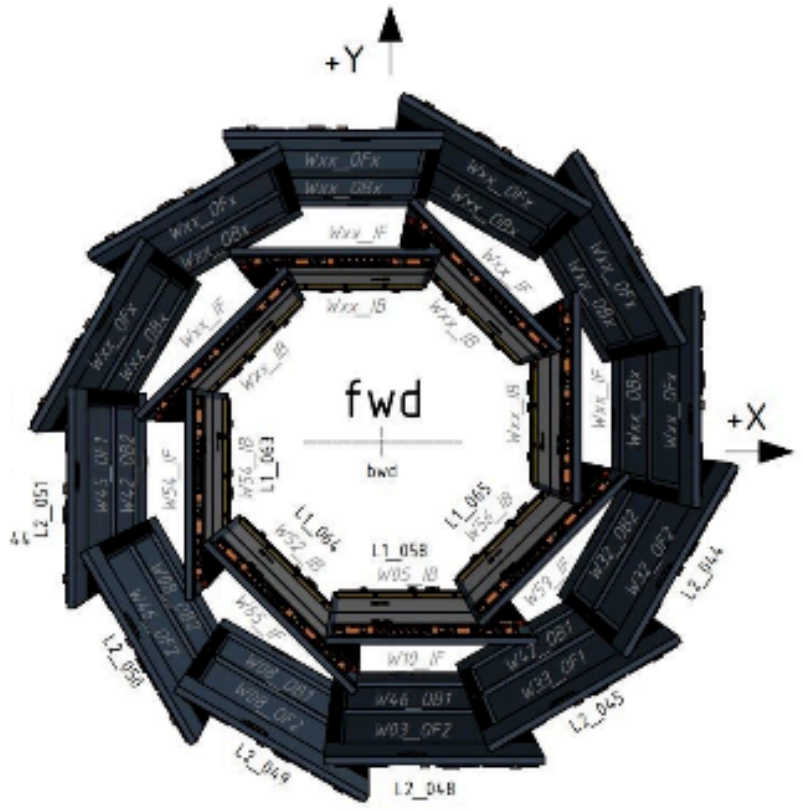
Long Shutdown 1

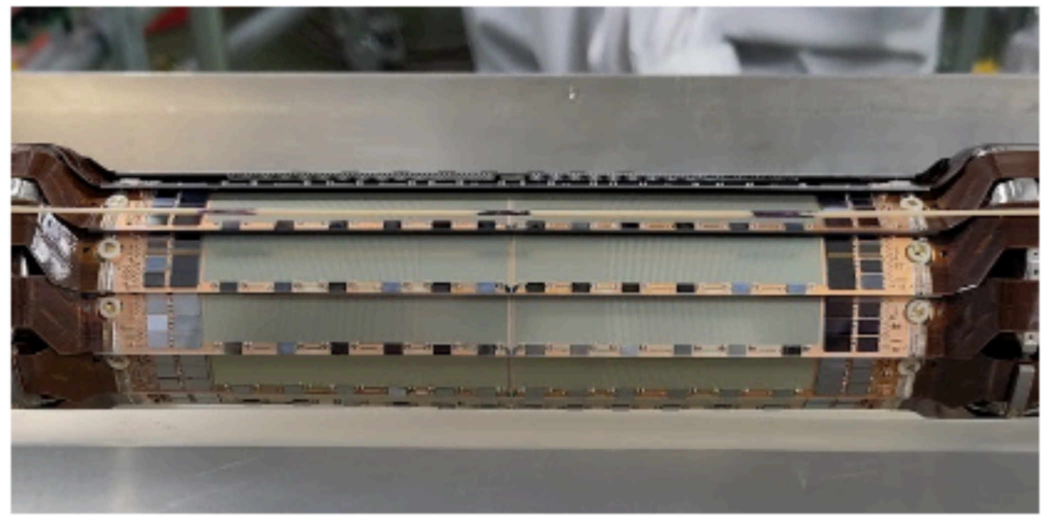
PXD1





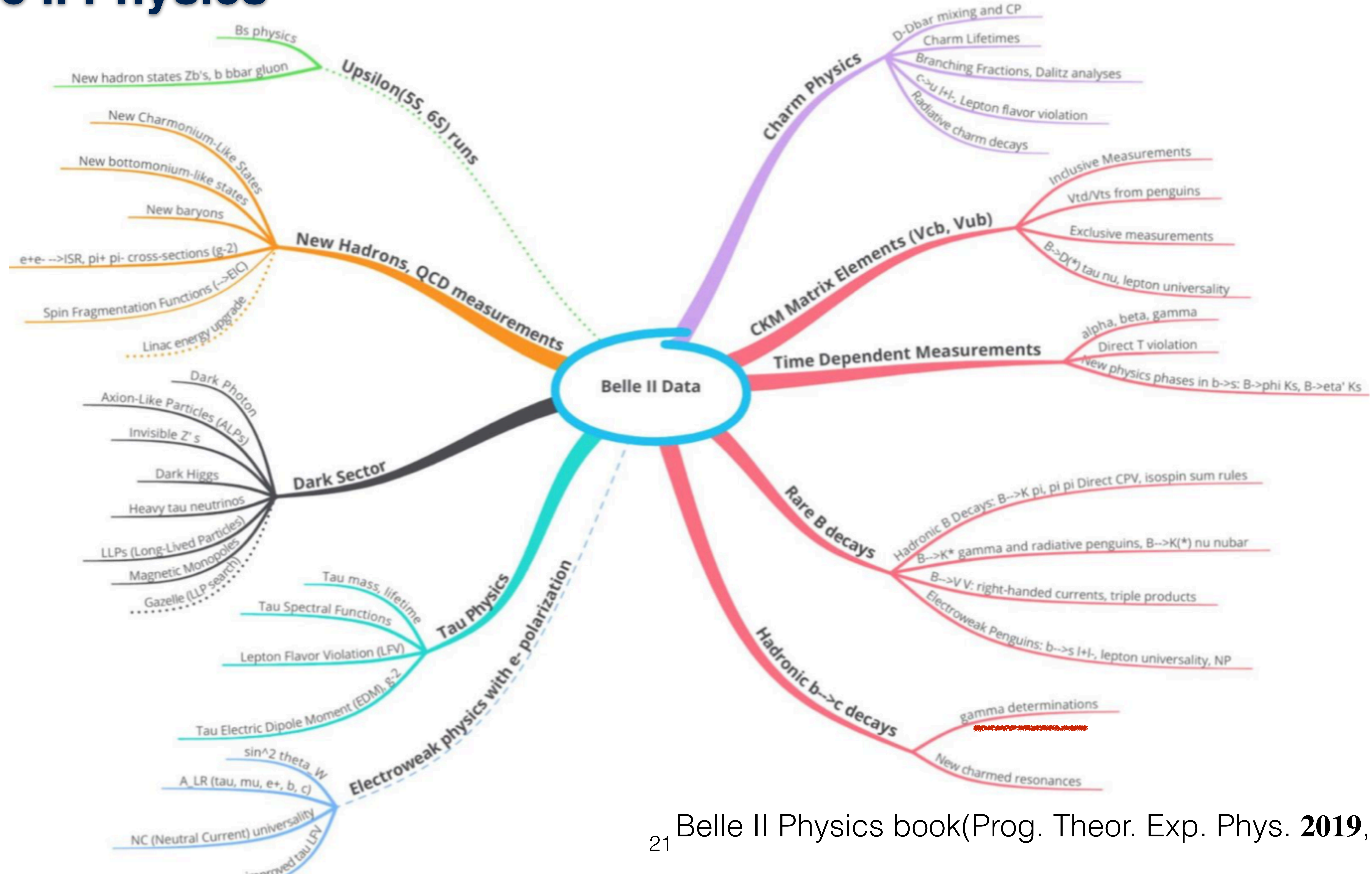
PXD2





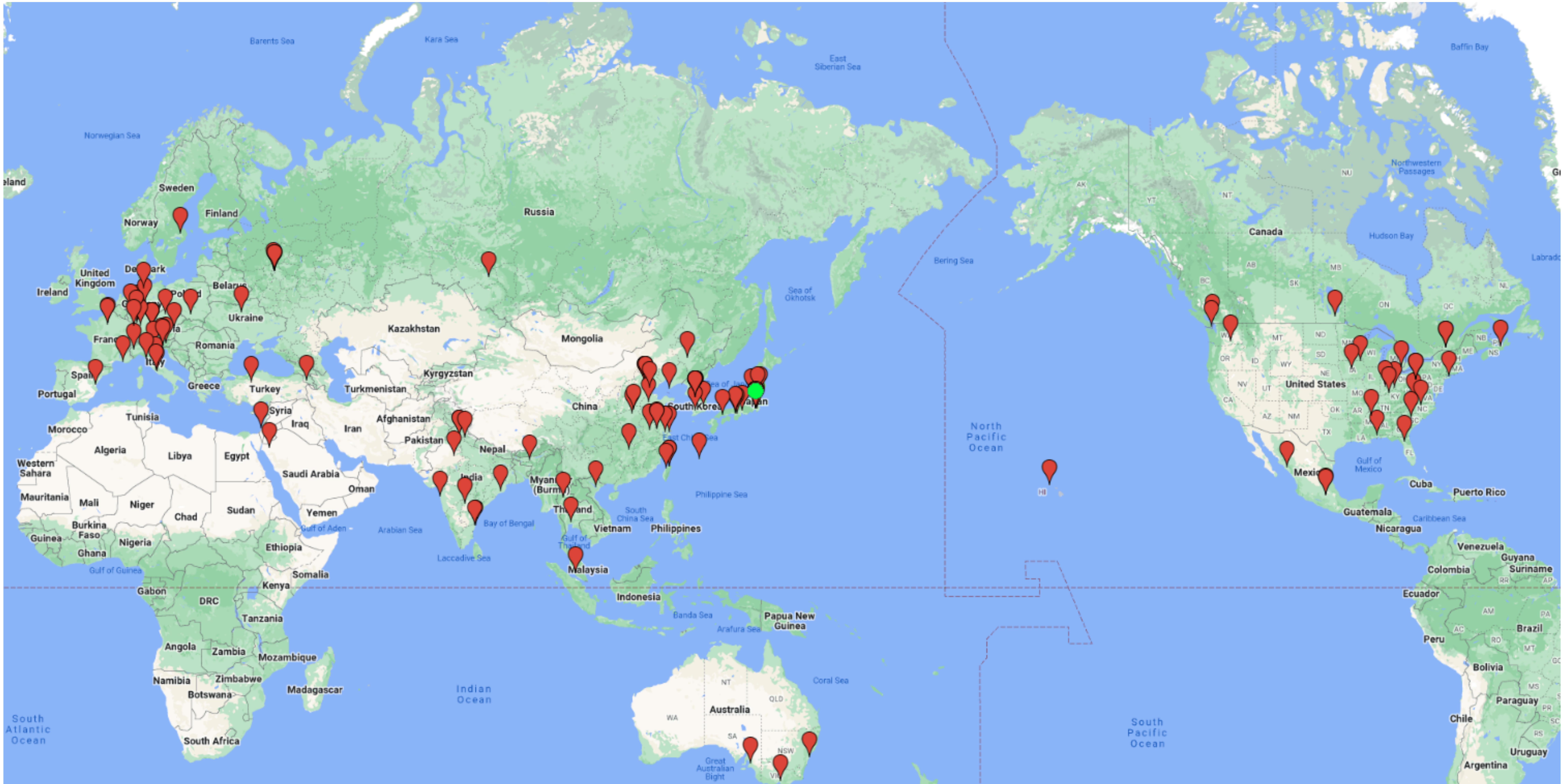
Since summer 2022 data taking, SuperKEKB and Belle II are in LS1, until fall 2023. Several improvements for accelerator complex, to reduce background and improve luminosity, and detector upgrades, such as installation of the complete two-layer vertex pixel detector.

Belle II Physics



Belle II Physics book(Prog. Theor. Exp. Phys. **2019**, 123C01)

Belle II Collaboration



- 26 countries and regions, 123 institutions, ~1100 collaborators

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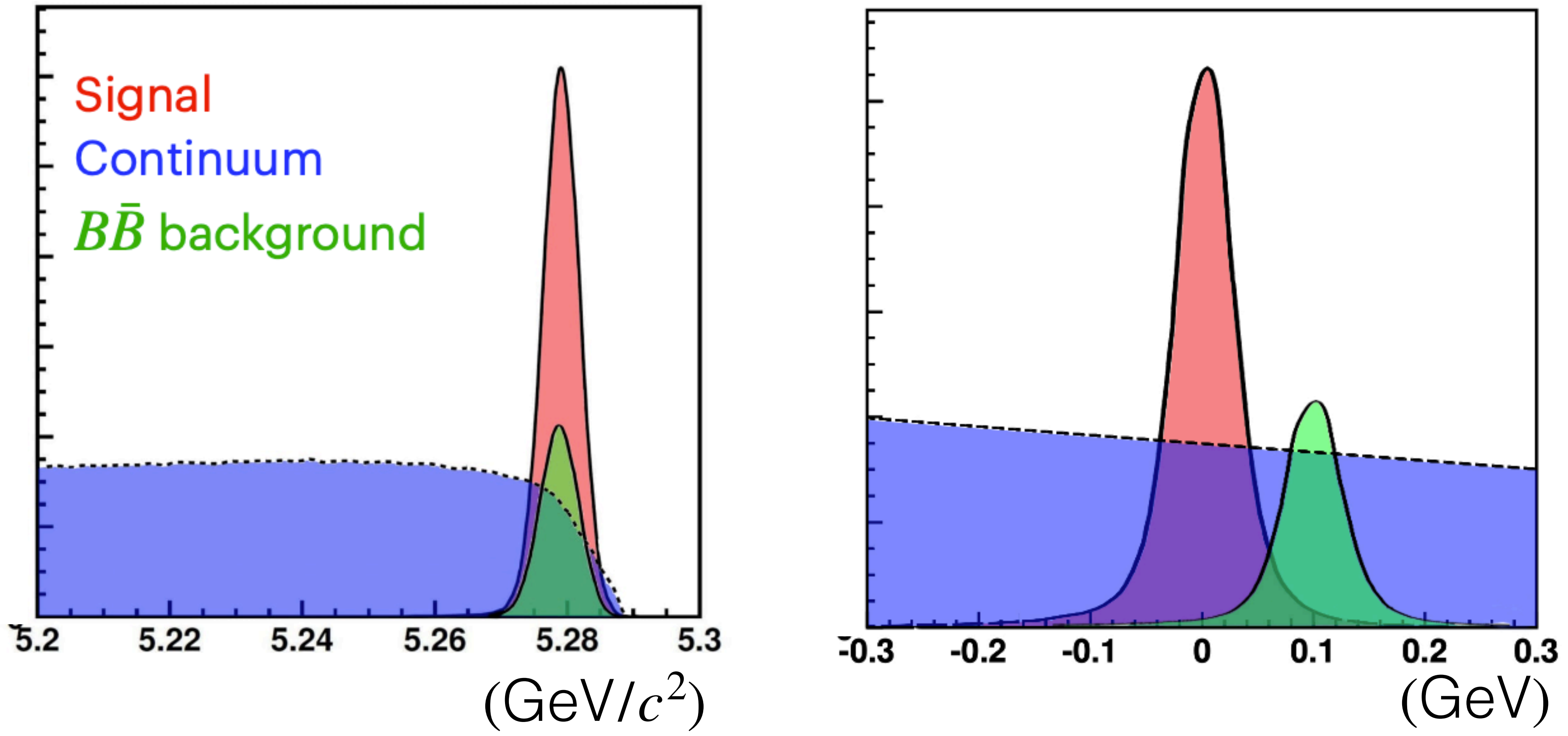
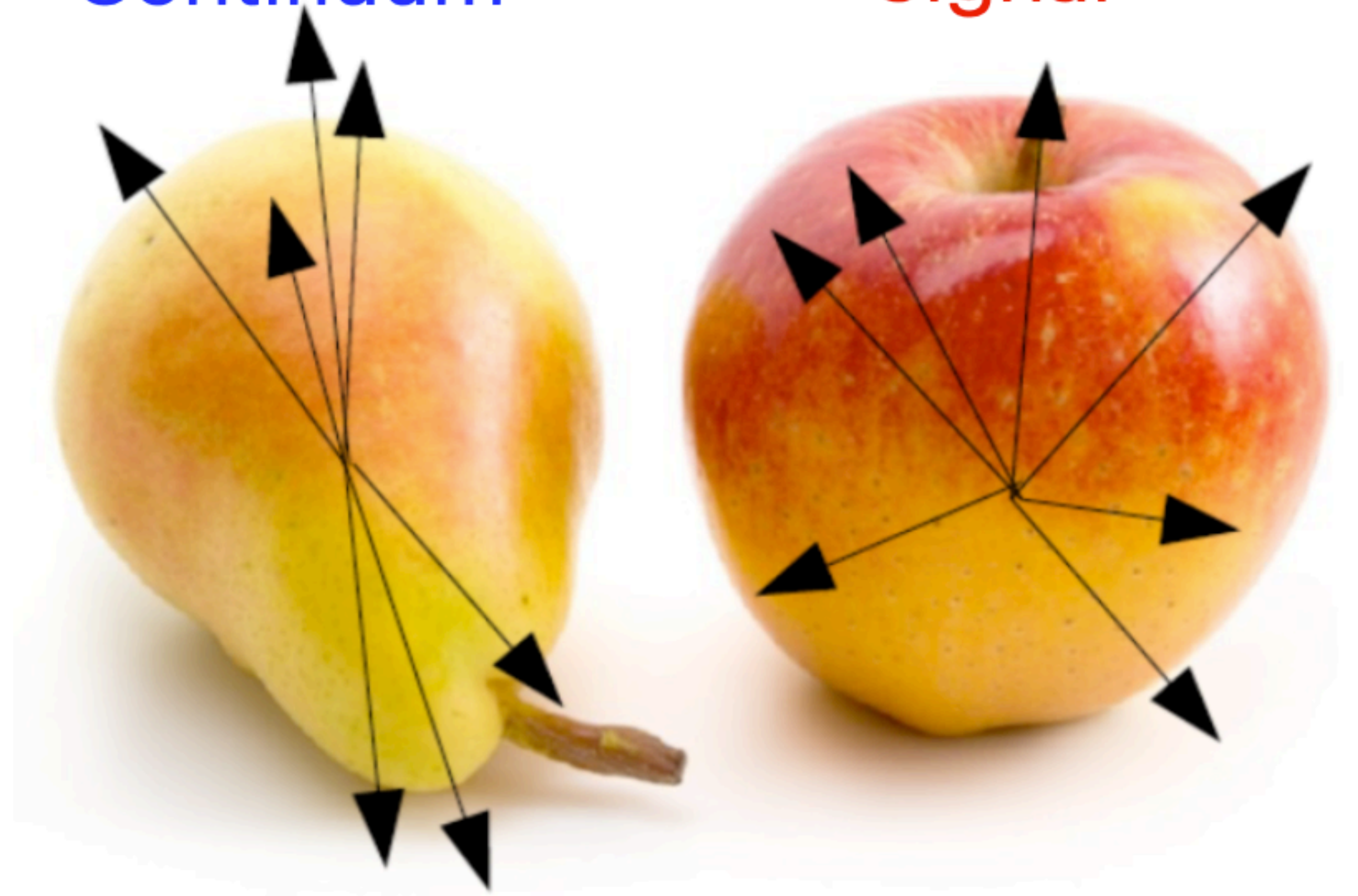
Similar analysis flow

- e^+e^- collide at $\Upsilon(4S)$, just above $B\bar{B}$ threshold: low background and well-known knowledge of initial state

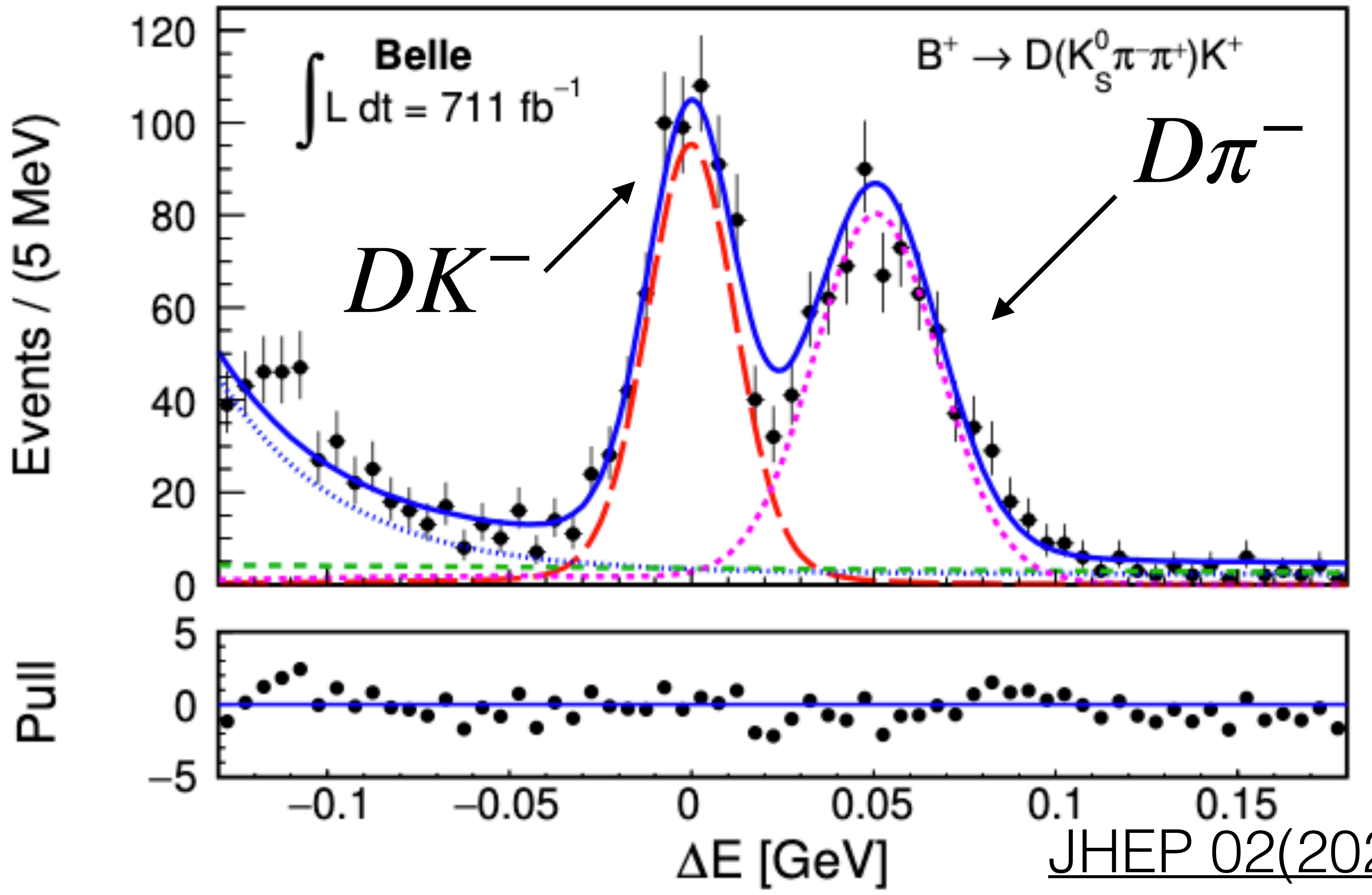


$M_{bc} = \sqrt{s/4 - p_B^{*2}}$ $\Delta E = E_B^* - \sqrt{s}/2$

- Use event shape to identify continuum background.



Extract signal on ΔE and BDT output.



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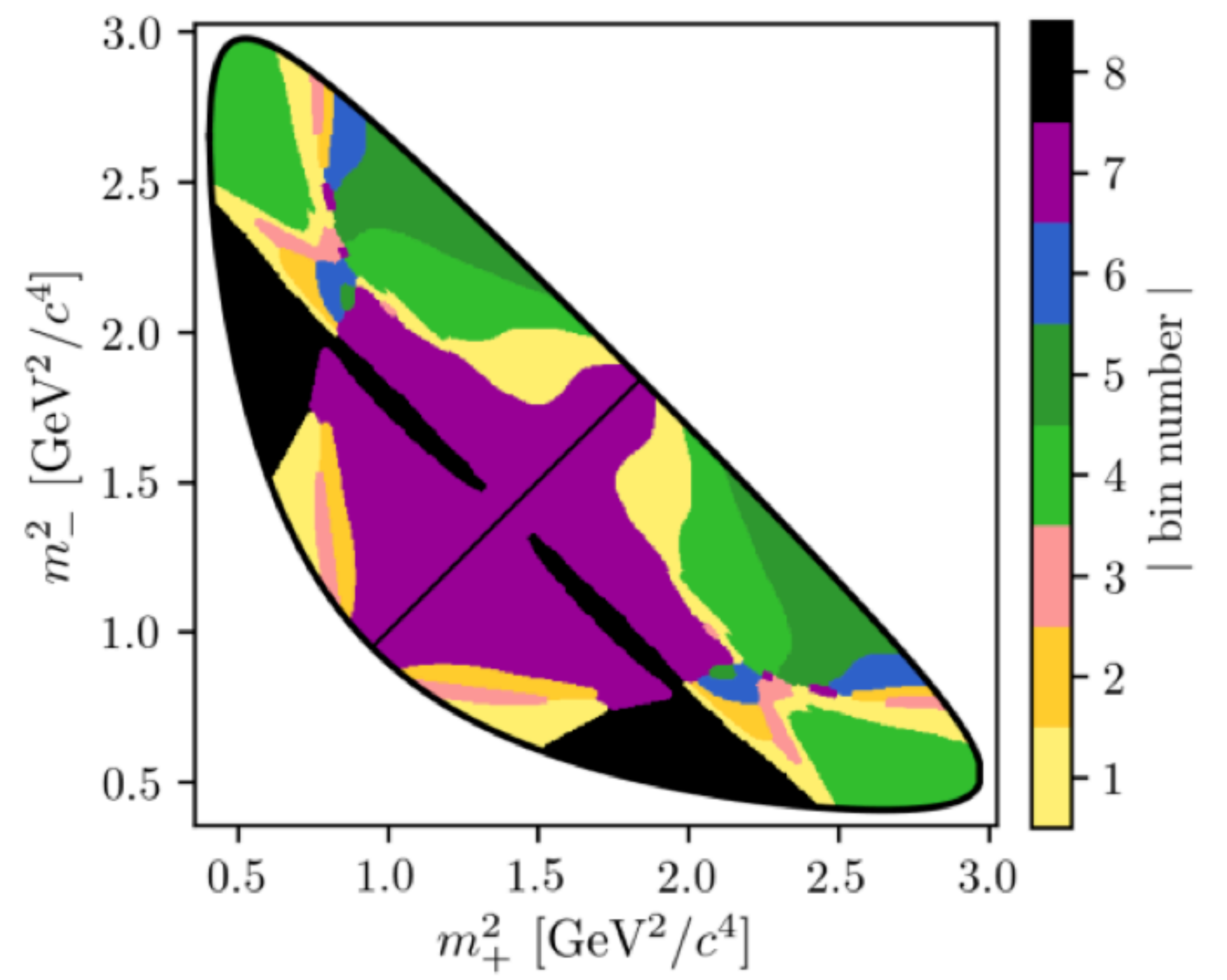
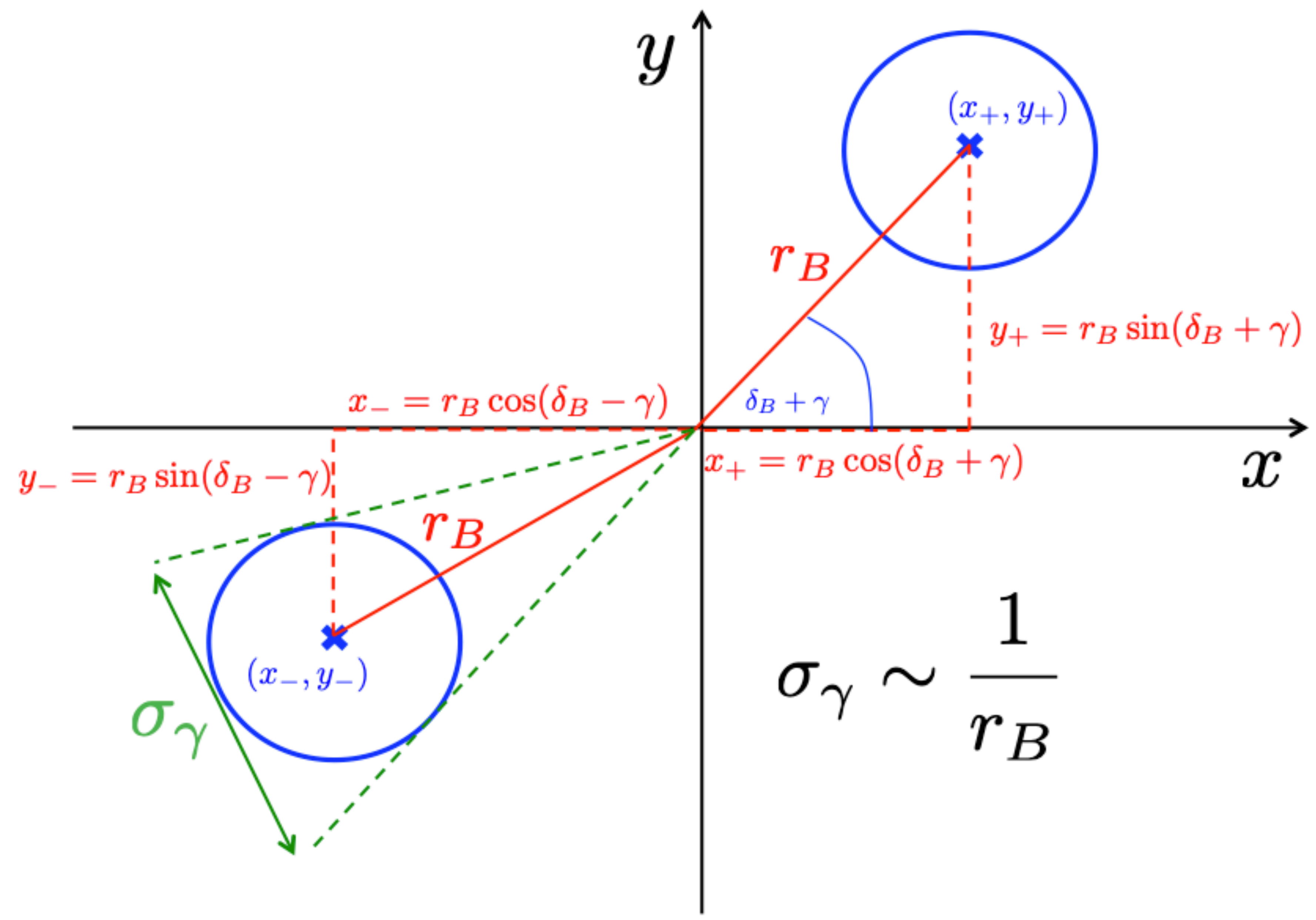
BPGGSZ method (golden channel)

- D decays to self conjugated multi-body final states.
- Binned way to gain more sensitivity from interference between various partial waves in local region(bin).
- D information, $|A|_i$, c_i, s_i, are measured by CLEO-c and BESIII.

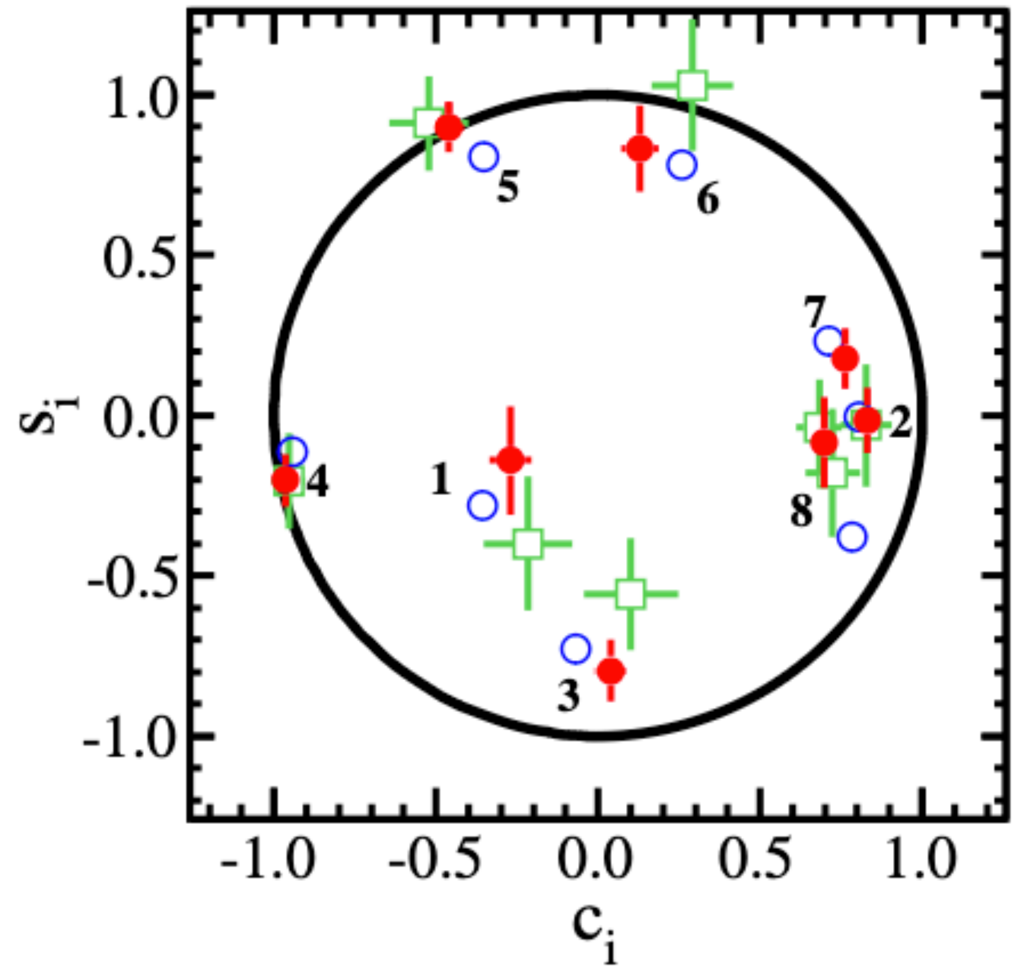
$$d\Gamma_{B^\pm}(\mathbf{x}) = A^2_{(\pm,\mp)} + r_B^2 A^2_{(\mp,\pm)} + 2A_{(\pm,\mp)}A_{(\mp,\pm)}\left[\underbrace{r_B\cos(\delta_B \pm \gamma)}_{x_\pm}\ \underbrace{\cos(\delta_{D(\pm,\mp)})}_{c_i} + \underbrace{r_B\sin(\delta_B \pm \gamma)}_{y_\pm}\ \underbrace{\sin(\delta_{D(\pm,\mp)})}_{s_i}\right]$$

$D \to K_S^0\pi^+\pi^-$



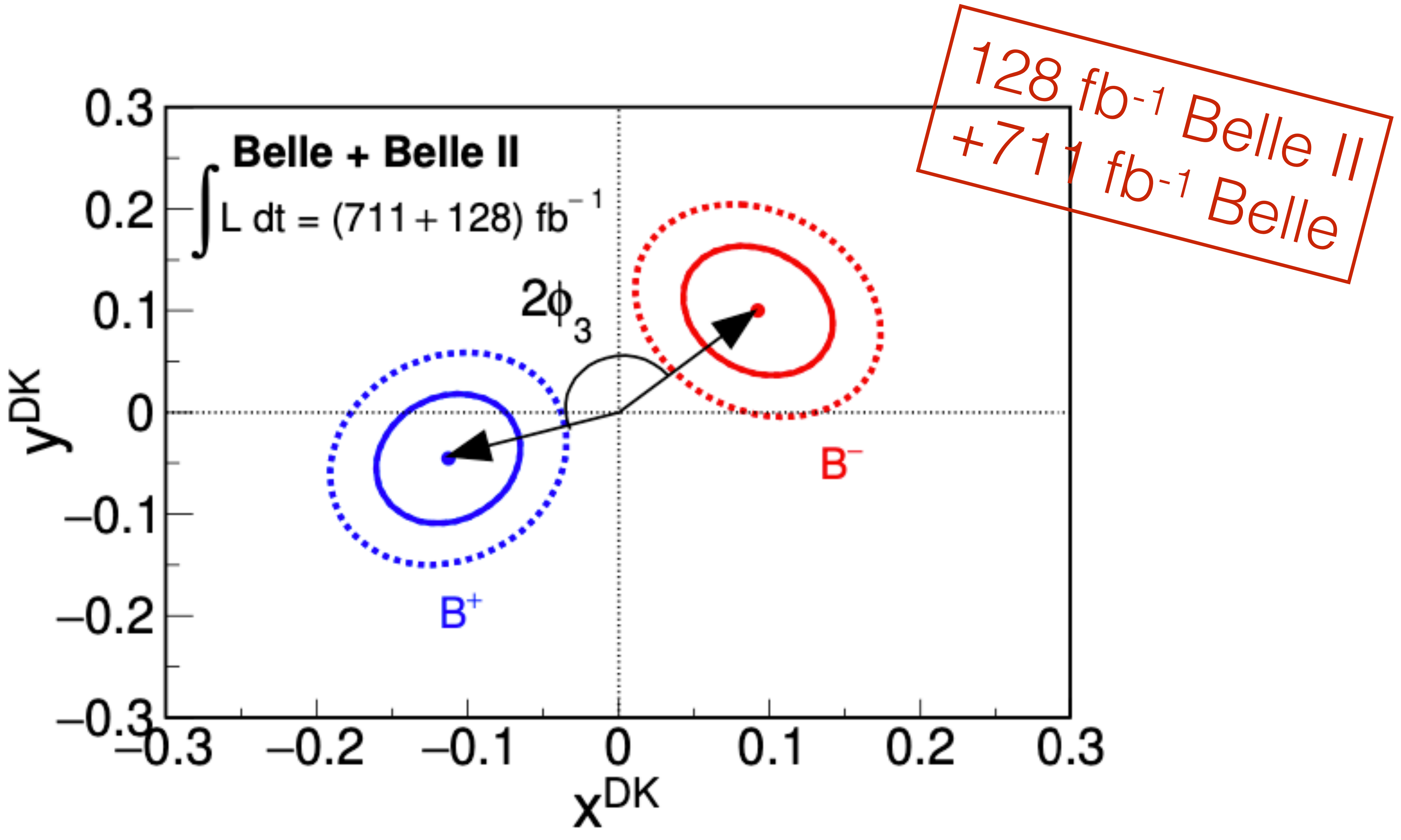


- ϕ_3's precision highly depends on the r_B's value!
- Large r_B -> large interference in B->DK-> more sensitive to ϕ_3.



Blue:model
Red:BESIII
Green:CLEO

BPGGSZ results from Belle and Belle II



$B^+ \to Dh^+, D \to K_S^0 h^+ h^-$

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$(78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ$

Stat Syst ci/si

LHCb got $(68.7^{+5.2}_{-5.1})^\circ$

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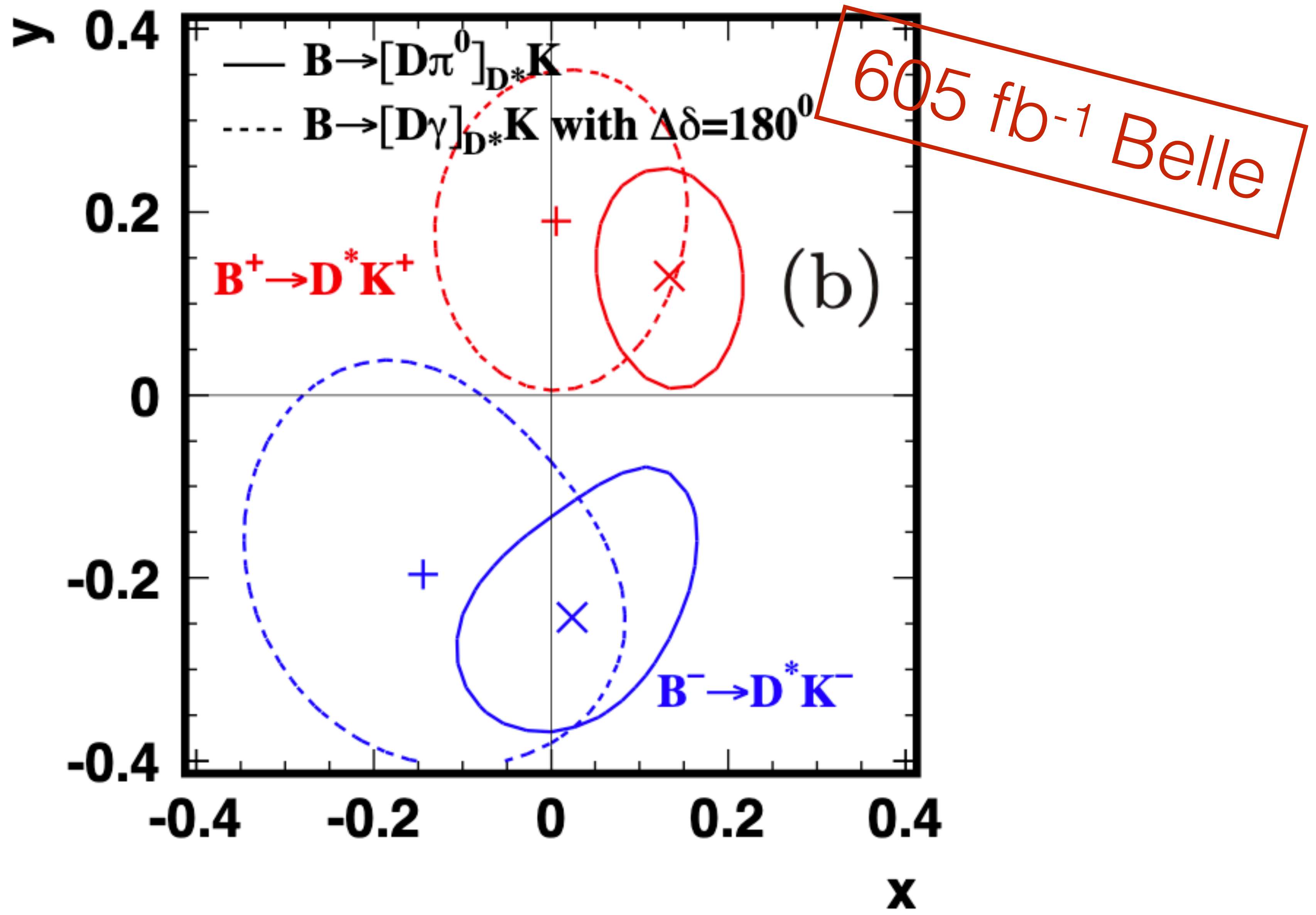


$B^+ \to D^* h^+, D \to K_S^0 \pi^+ \pi^-$

Phys. Rev. D 81 (2010) 112002

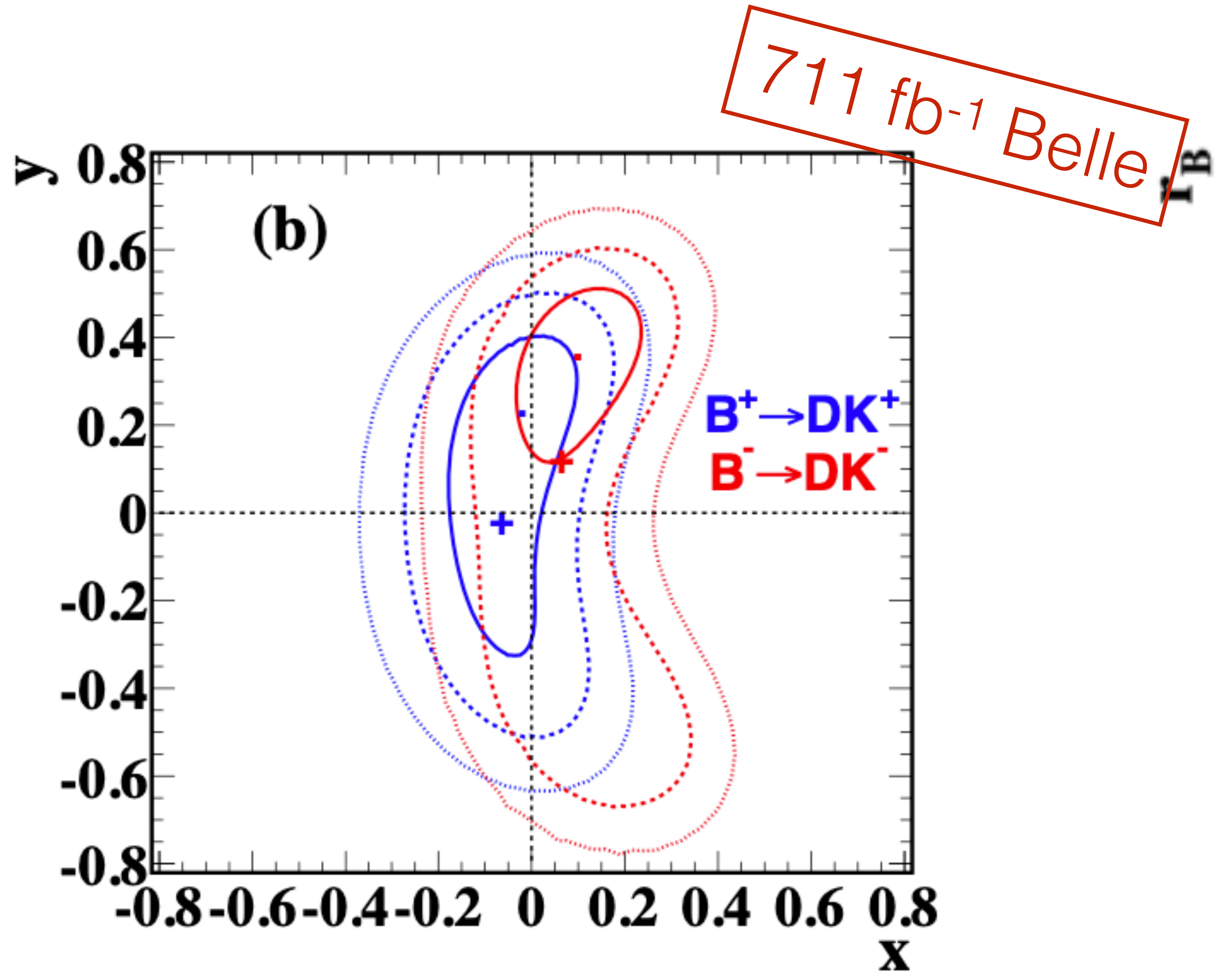
$(73.9^{+18.9}_{-20.2} \pm 4.2 \pm 8.9)^\circ$

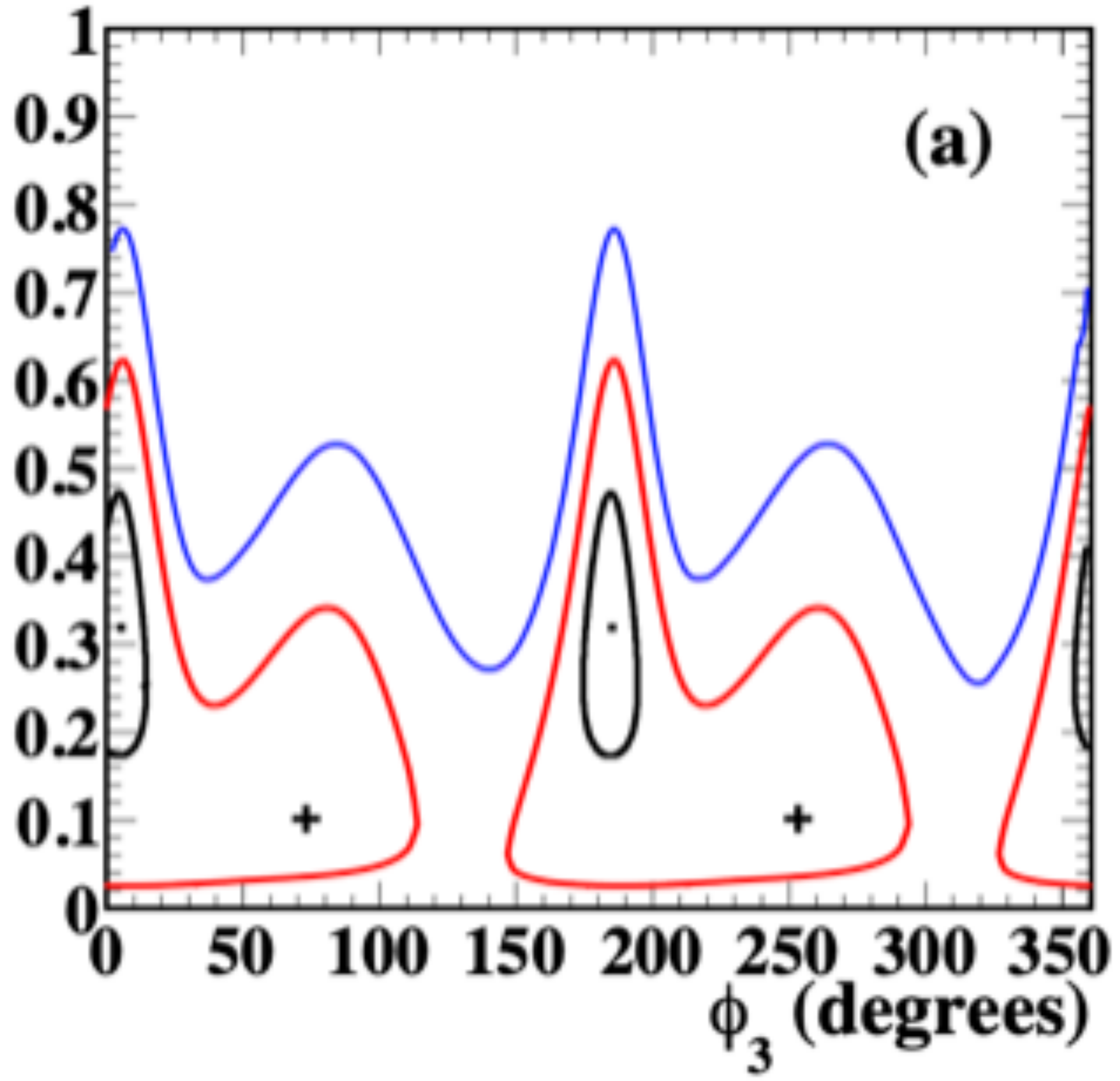
LHCb got $(69 \pm 14)^\circ$

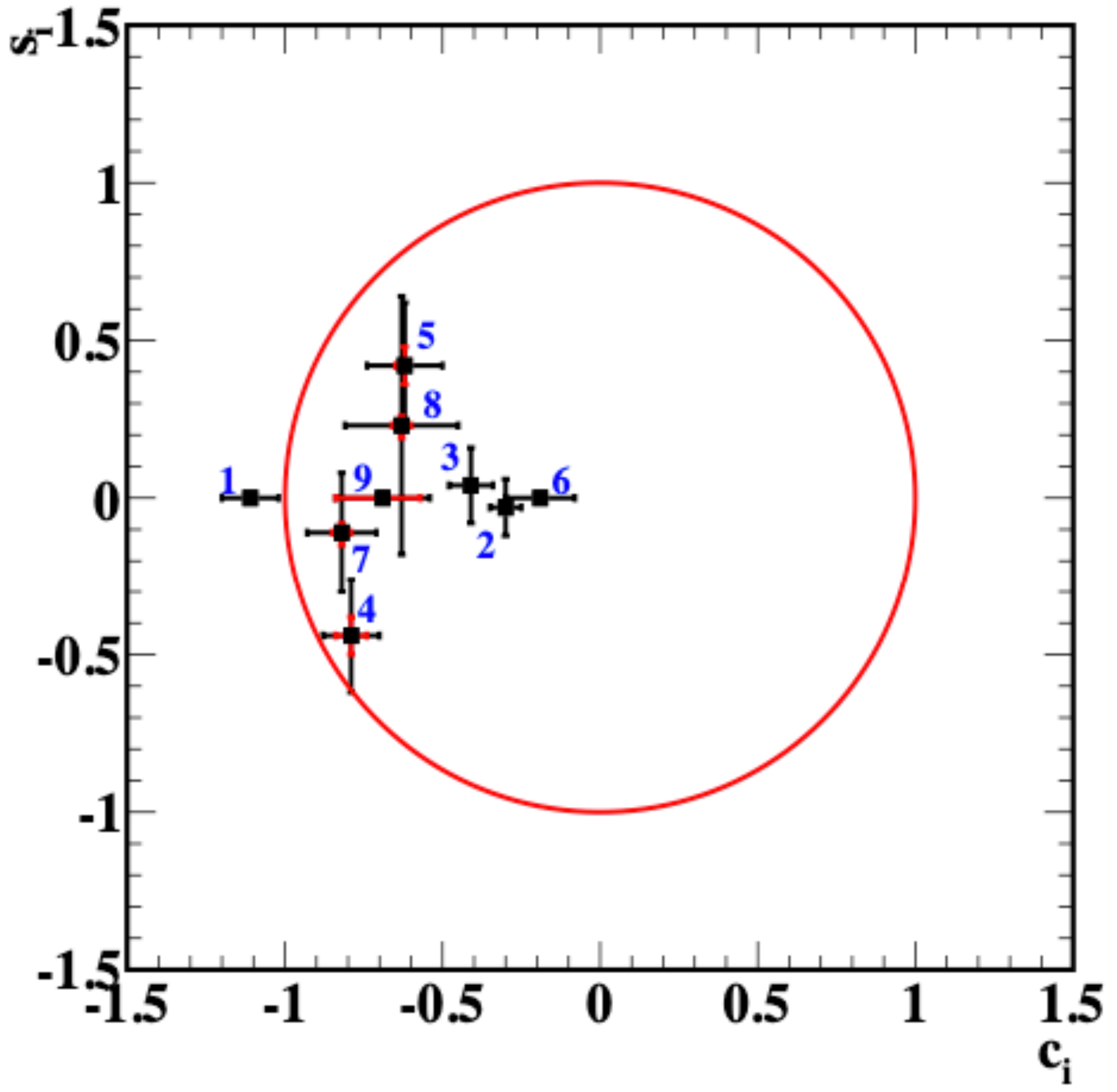
Preliminary on LP 2023

BPGGSZ results from Belle and Belle II

$$N_i^{\pm} = h_B[K_{\pm i} + r_B^2 K_{\mp i} + \sqrt{K_i K_{-i}}(x_{\pm} c_i \pm y_{\pm} s_i)],\quad x_{\pm} = r_B \cos(\delta_B \pm \phi_3)$$
$$y_{\pm} = r_B \sin(\delta_B \pm \phi_3)$$







$B^+ \to Dh^+, D \to K_S^0\pi^+\pi^-\pi^0$

JHEP 10(2019)178

$(5.7^{+10.2}_{-8.8} \pm 3.5 \pm 5.7)^{\circ}$

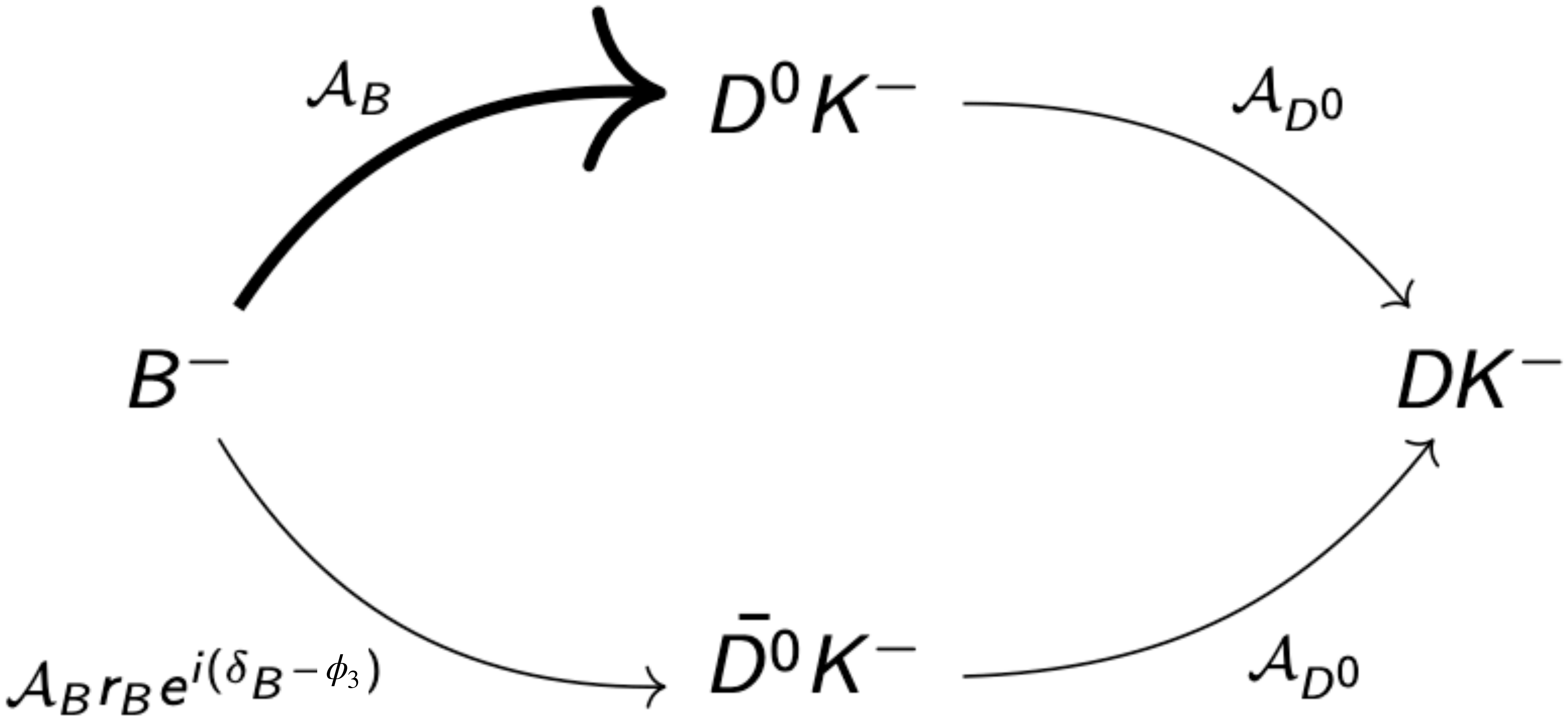
CLEO-c JHEP 01 (2018) 082

Binning scheme of $D \to K_S^0\pi^+\pi^-\pi^0$ is **not** optimized for ϕ_3.

Less sensitive. Some si are 0, so large uncertainty of y.

Looking for the optimized scheme and ci/si from BESIII!

GLW methods



- D decays to CP eigenstates, e.g. K^+K^- (CP+) $K_S^0\pi^0$ (CP-).
- Size of CPV ~ r_B (10%).

- Observables:

$$R_{CP\pm} = \frac{\mathcal{B}(B^-\to D_{CP\pm}K^-)+\mathcal{B}(B^+\to D_{CP\pm}K^+)}{\mathcal{B}(B^-\to D^0K^-)+\mathcal{B}(B^+\to \bar{D}^0K^+)},$$
$$= 1 + r_B^2 + 2\eta_{CP} r_B \cos(\delta_B)\cos(\phi_3),$$
$$A_{CP\pm} = \frac{\mathcal{B}(B^-\to D_{CP\pm}K^-)-\mathcal{B}(B^+\to D_{CP\pm}K^+)}{\mathcal{B}(B^-\to D_{CP\pm}K^-)+\mathcal{B}(B^+\to D_{CP\pm}K^+)},$$
$$= 2\eta_{CP} r_B \sin(\delta_B)\sin(\phi_3)/R_{CP\pm}.$$

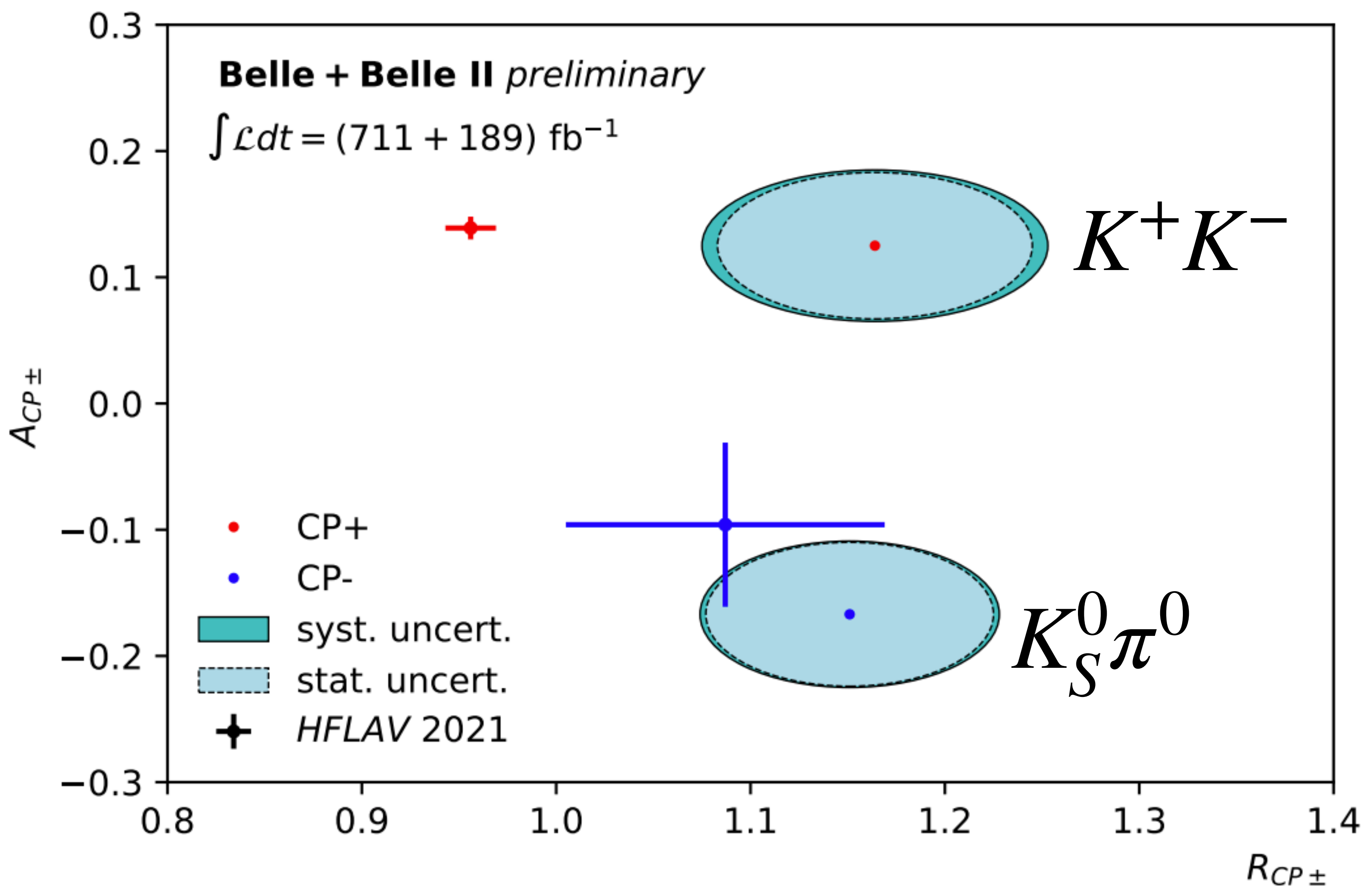
- Can't determine ϕ_3 from GLW only: $(\phi_3, \delta_B) \leftrightarrow (\delta_B, \phi_3)$ or $(\delta_B - \pi, \phi_3 - \pi)$..

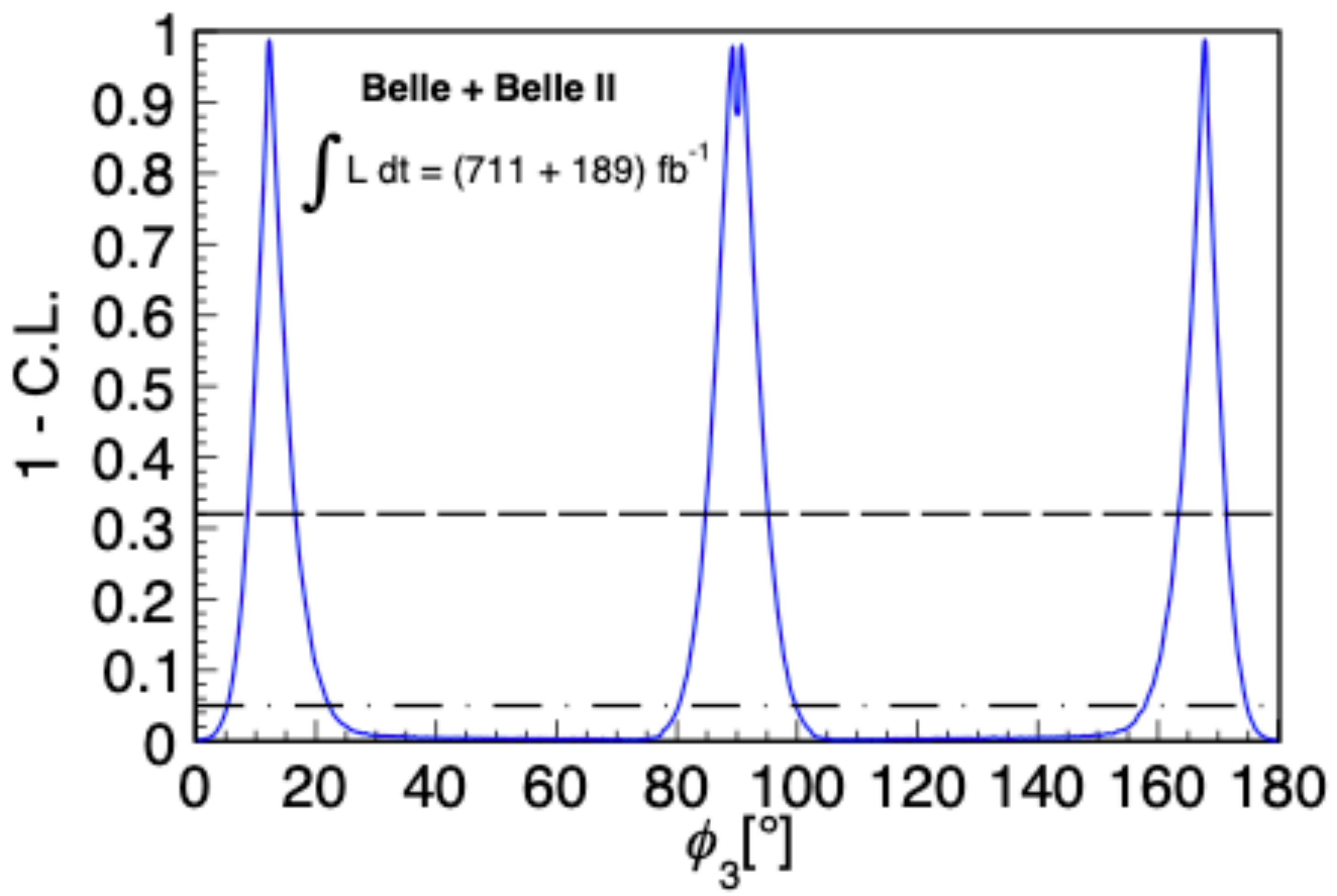
GLW results from Belle and Belle II

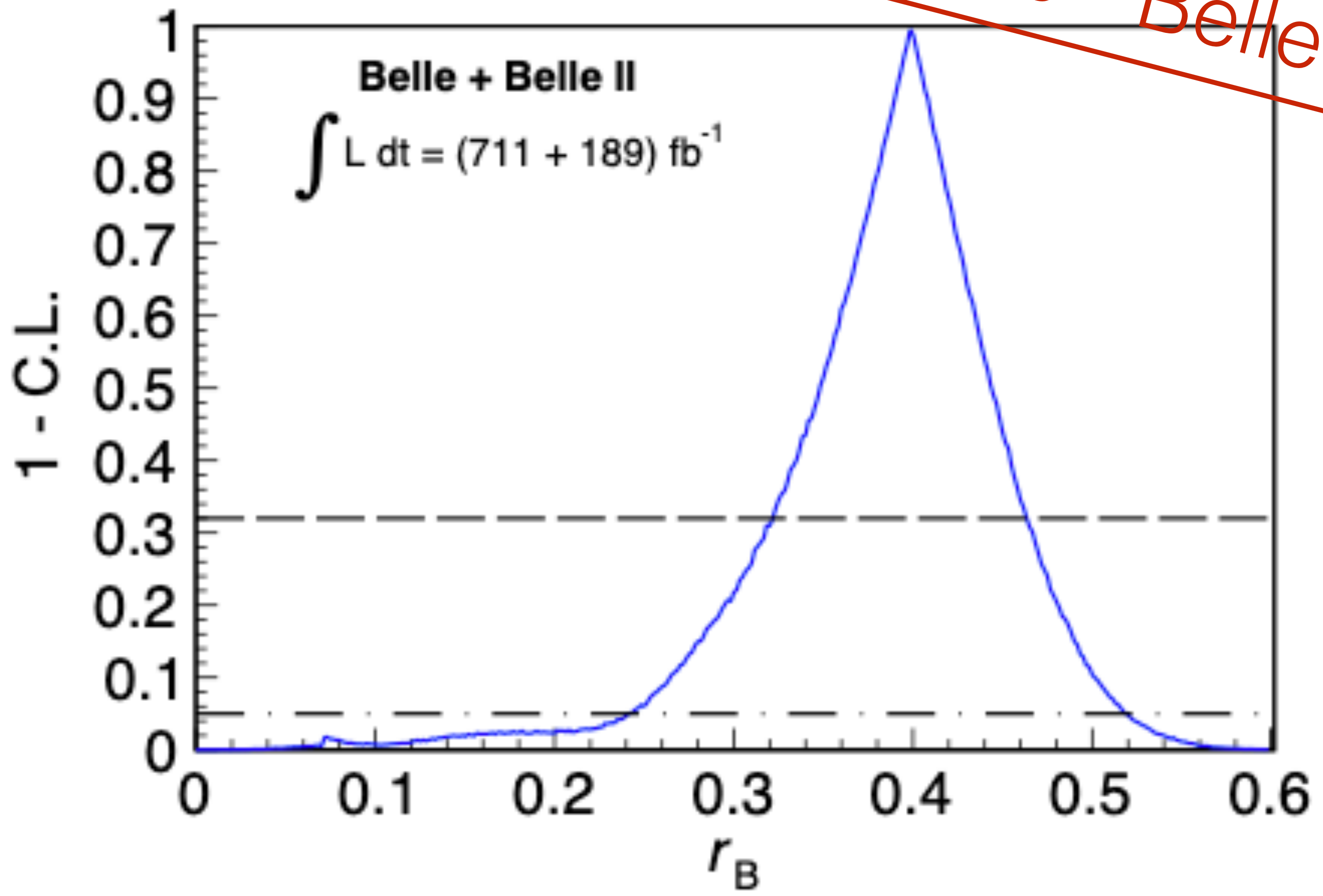
$B^+ \to Dh^+, D \to K_S^0\pi^0, K^+K^-$

arXiv:2308.05048 submit to JHEP

189 fb-1 Belle II +711 fb-1 Belle







$B^+ \to D^*K^+, D \to K_S^0\pi^0, K^+K^-, \pi^+\pi^-, K_S^0\phi, K_S^0\omega,$

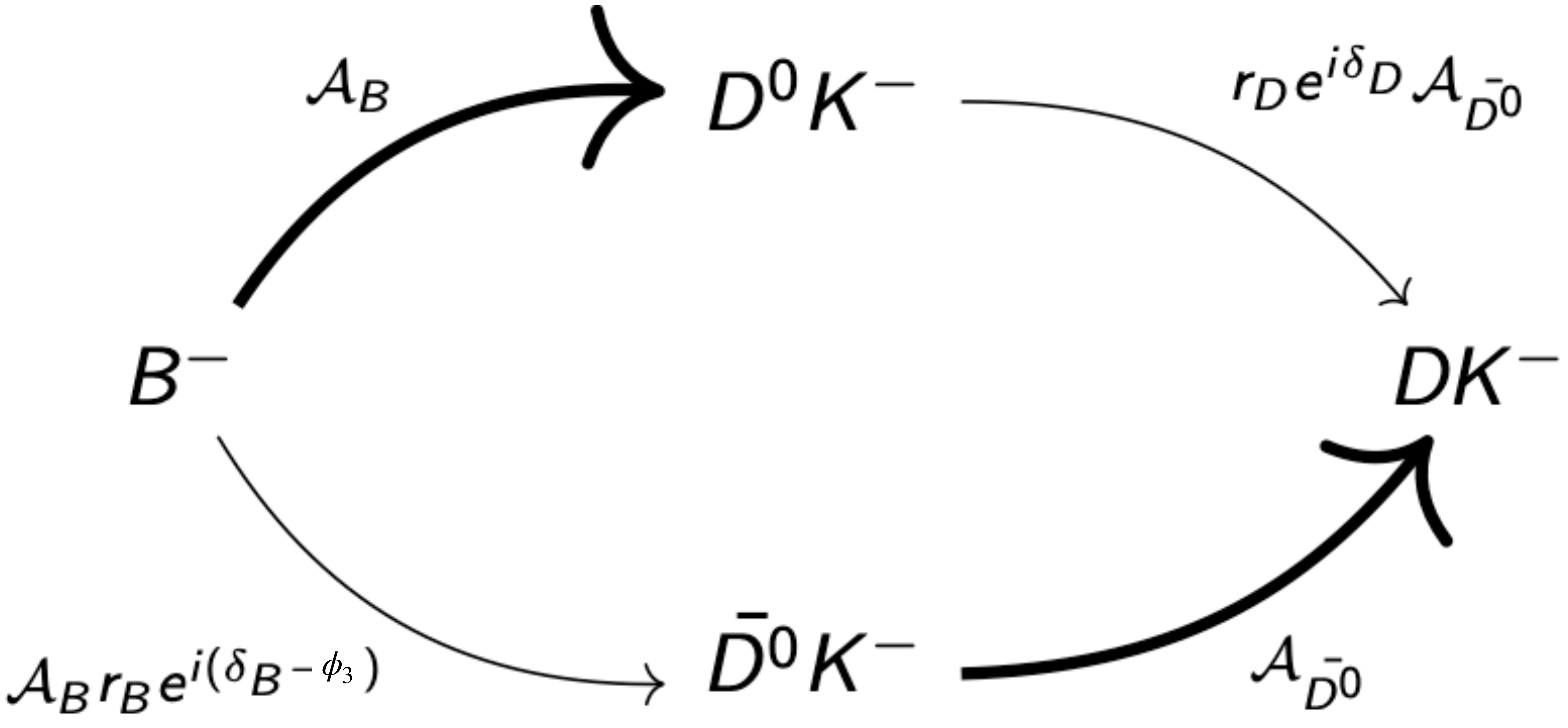
Phys. Rev. D 73 (2006) 051106

250 fb-1 Belle

$$\mathcal{A}_1^* = -0.20 \pm 0.22(\text{stat}) \pm 0.04(\text{sys})$$
$$\mathcal{A}_2^* = \ 0.13 \pm 0.30(\text{stat}) \pm 0.08(\text{sys}),$$

$$\mathcal{R}_1^* = \ 1.41 \pm 0.25(\text{stat}) \pm 0.06(\text{sys})$$
$$\mathcal{R}_2^* = 1.15 \pm 0.31(\text{stat}) \pm 0.12(\text{sys}).$$

ADS methods



- D decays to CF/DCS eigenstates, e.g. $K^+\pi^-$,$K^+\pi^-\pi^0$
- Would be best if r_D/r_B~1, then similar amplitude—> enhanced interference.

- Observables:

$$R_{\text{ADS}}^{K\pi} = \frac{\mathcal{B}(B^- \to [f]_D K^-) + \mathcal{B}(B^+ \to [\bar{f}]_D K^+)}{\mathcal{B}(B^- \to [\bar{f}]_D K^-) + \mathcal{B}(B^+ \to [f]_D K^+)},$$
$$= r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\phi_3,$$
$$A_{\text{ADS}}^{K\pi} = \frac{\mathcal{B}(B^- \to [f]_D K^-) - \mathcal{B}(B^+ \to [\bar{f}]_D K^+)}{\mathcal{B}(B^- \to [f]_D K^-) + \mathcal{B}(B^+ \to [\bar{f}]_D K^+)},$$
$$= 2 r_B r_D \sin(\delta_B + \delta_D) \sin\phi_3 / R_{\text{ADS}},$$

- For both $K^+\pi^-$,$K^+\pi^-\pi^0$, $\delta_D \sim 180°$, then similar to GLW. Can't determine ϕ_3 from ADS only.

ADS results from Belle

$B^+ \to Dh^+, D \to K^+\pi^-$

711 fb-1 Belle

Phys. Rev. Lett. 106 (2011) 231803

$$\begin{aligned}
\mathcal{R}_{DK} &= [1.63^{+0.44}_{-0.41}(\text{stat})^{+0.07}_{-0.13}(\text{syst})] \times 10^{-2}, \\
\mathcal{R}_{D\pi} &= [3.28^{+0.38}_{-0.36}(\text{stat})^{+0.12}_{-0.18}(\text{syst})] \times 10^{-3}, \\
\mathcal{A}_{DK} &= -0.39^{+0.26}_{-0.28}(\text{stat})^{+0.04}_{-0.03}(\text{syst}), \\
\mathcal{A}_{D\pi} &= -0.04 \pm 0.11(\text{stat})^{+0.02}_{-0.01}(\text{syst}),
\end{aligned}$$

$B^+ \to Dh^+, D \to K^+\pi^-\pi^0$

711 fb-1 Belle

Phys. Rev. D 88 (2013) 9, 091104

$$\begin{aligned}
R_{DK} &= [1.98 \pm 0.62(\text{stat.}) \pm 0.24(\text{syst.})] \times 10^{-2}, \\
R_{D\pi} &= [1.89 \pm 0.54(\text{stat.})^{+0.22}_{-0.25}(\text{syst.})] \times 10^{-3}.
\end{aligned}$$

$$\begin{aligned}
A_{DK} &= 0.41 \pm 0.30(\text{stat.}) \pm 0.05(\text{syst.}), \\
A_{D\pi} &= 0.16 \pm 0.27(\text{stat.})^{+0.03}_{-0.04}(\text{syst.}).
\end{aligned}$$

GLS results from Belle and Belle II

$B^{\pm} \to DK^{\pm}, D\pi^{\pm}$ with $D \to K_S^0 K^{\pm}\pi^{\mp}$: SS: same-sign, OS: opposite sign.

Two sets of results: in full D phase space and in the K*K region (expected large δ_D).

Observe 4 Acp and 3 BR ratios.

362 fb-1 Belle II
+711 fb-1 Belle

$$A_{SS}^{DK} = \frac{2r_B^{DK} r_D \kappa_D \sin(\delta_B^{DK} - \delta_D)\sin\phi_3}{1 + (r_B^{DK})^2 r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} - \delta_D)\cos\phi_3},$$

$$A_{OS}^{DK} = \frac{2r_B^{DK} r_D \kappa_D \sin(\delta_B^{DK} + \delta_D)\sin\phi_3}{(r_B^{DK})^2 + r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} + \delta_D)\cos\phi_3},$$

$$A_{SS}^{D\pi} = \frac{2r_B^{D\pi} r_D \kappa_D \sin(\delta_B^{D\pi} - \delta_D)\sin\phi_3}{1 + (r_B^{D\pi})^2 r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} - \delta_D)\cos\phi_3},$$

$$A_{OS}^{D\pi} = \frac{2r_B^{D\pi} r_D \kappa_D \sin(\delta_B^{D\pi} + \delta_D)\sin\phi_3}{(r_B^{D\pi})^2 + r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} + \delta_D)\cos\phi_3}.$$

$$R_{SS}^{DK/D\pi} = R\frac{1 + (r_B^{DK})^2 r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} - \delta_D)\cos\phi_3}{1 + (r_B^{D\pi})^2 r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} - \delta_D)\cos\phi_3},$$

$$R_{OS}^{DK/D\pi} = R\frac{(r_B^{DK})^2 + r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} + \delta_D)\cos\phi_3}{(r_B^{D\pi})^2 + r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} + \delta_D)\cos\phi_3},$$

$$R_{SS/OS}^{D\pi} = \frac{1 + (r_B^{D\pi})^2 r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} - \delta_D)\cos\phi_3}{(r_B^{D\pi})^2 + r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} + \delta_D)\cos\phi_3}.$$

In K*K region:

$$A_{\rm SS}^{DK} = 0.055 \pm 0.119 \pm 0.020,$$

$$A_{\rm OS}^{DK} = 0.231 \pm 0.184 \pm 0.014,$$

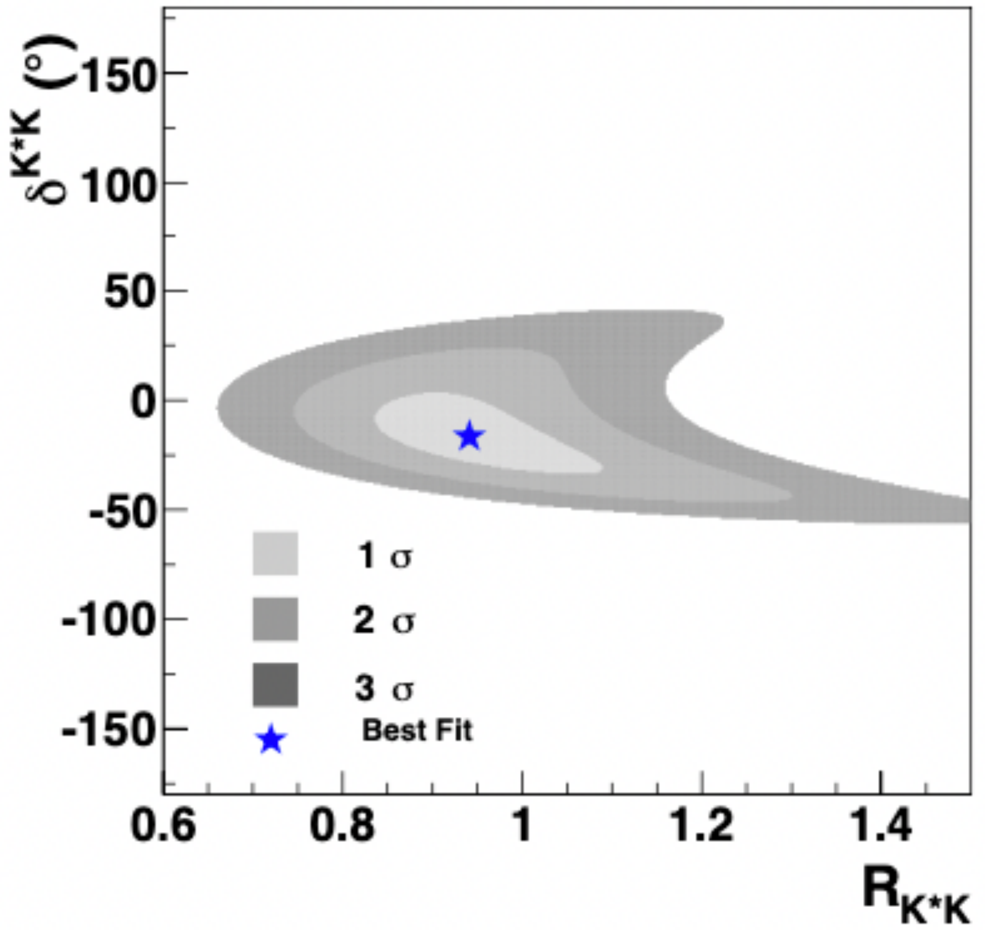
$$A_{\rm SS}^{D\pi} = 0.046 \pm 0.029 \pm 0.016,$$

$$A_{\rm OS}^{D\pi} = 0.009 \pm 0.046 \pm 0.009,$$

$$R_{\rm SS}^{DK/D\pi} = 0.093 \pm 0.012 \pm 0.005,$$

$$R_{\rm OS}^{DK/D\pi} = 0.103 \pm 0.020 \pm 0.006,$$

$$R_{\rm SS/OS}^{D\pi} = 2.412 \pm 0.132 \pm 0.019,$$



- Model-independent result from CLEO-c.[arXiv:1203.3804]

arXiv:2306.02940 submit to JHEP

Outline

- Why CPV is interesting and what is CKM matrix
- About γ/ϕ_3
- SuperKEKB and Belle II
- All γ/ϕ_3 results from Belle and Belle II
- **Discussion and outlook**

Combination at Belle & Belle II?

HFLAV doesn't think there is a Belle's ϕ_3.

(*) Belle presented in 2012 a preliminary combination of their results, but this remains unpublished after more than two years and therefore we do not list it.

BaBar obtain **$\gamma = (69\,^{+17}_{-16})°$** $r_B(DK^+) = 0.092\,^{+0.013}_{-0.012}$ $\delta_B(DK^+) = (105\,^{+16}_{-17})°$ $r_B(D^*K^+) = 0.0106\,^{+0.019}_{-0.036}$ $\delta_B(D^*K^+) = (294\,^{+21}_{-31})°$ $r_B(DK^{*+}) = 0.143\,^{+0.048}_{-0.049}$ (*) $\delta_B(DK^{*+}) = (101 \pm 43)°$ (*) PRD 87 (2013) 052015	LHCb obtain **$\gamma = (67 \pm 4)°$** $r_B(DK^+) = 0.0989 \pm 0.0050$ $\delta_B(DK^+) = (131.2\,^{+5.1}_{-5.9})°$ $r_B(D^*K^+) = 0.191\,^{+0.045}_{-0.038}$ $\delta_B(D^*K^+) = (332\,^{+8}_{-10})°$ $r_B(DK^{*+}) = 0.092\,^{+0.018}_{-0.033}$ $\delta_B(DK^{*+}) = (40\,^{+92}_{-20})°$ $r_B(DK^{*0}) = 0.221\,^{+0.044}_{-0.047}$ $\delta_B(DK^{*0}) = (187\,^{+21}_{-23})°$ $r_B(DK\pi\pi) = 0.081\,^{+0.025}_{-0.027}$ $\delta_B(DK\pi\pi) = (351\,^{+9}_{-37})°$ $r_B(D_sK) = 0.30 \pm 0.09$ $\delta_B(D_sK) = (355\,^{+17}_{-16})°$ $\delta_B(D\pi) = (17\,^{+29}_{-17})°$ LHCb-CONF-2018-002, LHCb-CONF-2020-003

- Belle II now have three ϕ_3-results: $B^+ \to Dh^+, D \to K_S^0 h^+ h^-, K_S^0\pi^0, K^+K^-, K_S^0 K^{\pm}\pi^{\mp}$
- It's time to have a Belle(II)'s ϕ_3 now, especially we can have a better feeling on the coming Belle II data.

Some discussion about ϕ_3 combination

- We're working on the combination. Plan to release at CKM conference at September 18-22, 2023.
- Now, let's discuss with all public information…

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- From the golden channel $B^+ \to Dh^+, D \to K_S^0 h^+ h^-$(JHEP 02(2022)063):

$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ ,$$
$$r_B^{DK} = 0.129 \pm 0.024 \pm 0.001 \pm 0.002,$$
$$\delta_B^{DK} = (124.8 \pm 12.9 \pm 0.5 \pm 1.7)^\circ ,$$
$$r_B^{D\pi} = 0.017 \pm 0.006 \pm 0.001 \pm 0.001,$$
$$\delta_B^{D\pi} = (341.0 \pm 17.0 \pm 1.2 \pm 2.6)^\circ .$$

Comparing to W.A.: [HFLAV]

$$\phi_3 = (65.9^{+3.3}_{-3.5})^\circ$$
$$r_B(DK^-) = (0.0994 \pm 0.0026)$$
$$\delta_B(DK^-) = (127.7^{+3.6}_{-3.9})^\circ$$
$$r_B(D\pi^-) = (0.0049 \pm 0.0006)$$
$$\delta_B(D\pi^-) = (294^{+9.7}_{-11})^\circ$$

- Large r_B observed now, so if future Belle II's data favor the w.a. r_B, the ϕ_3's precision will be worse a bit with same data size.

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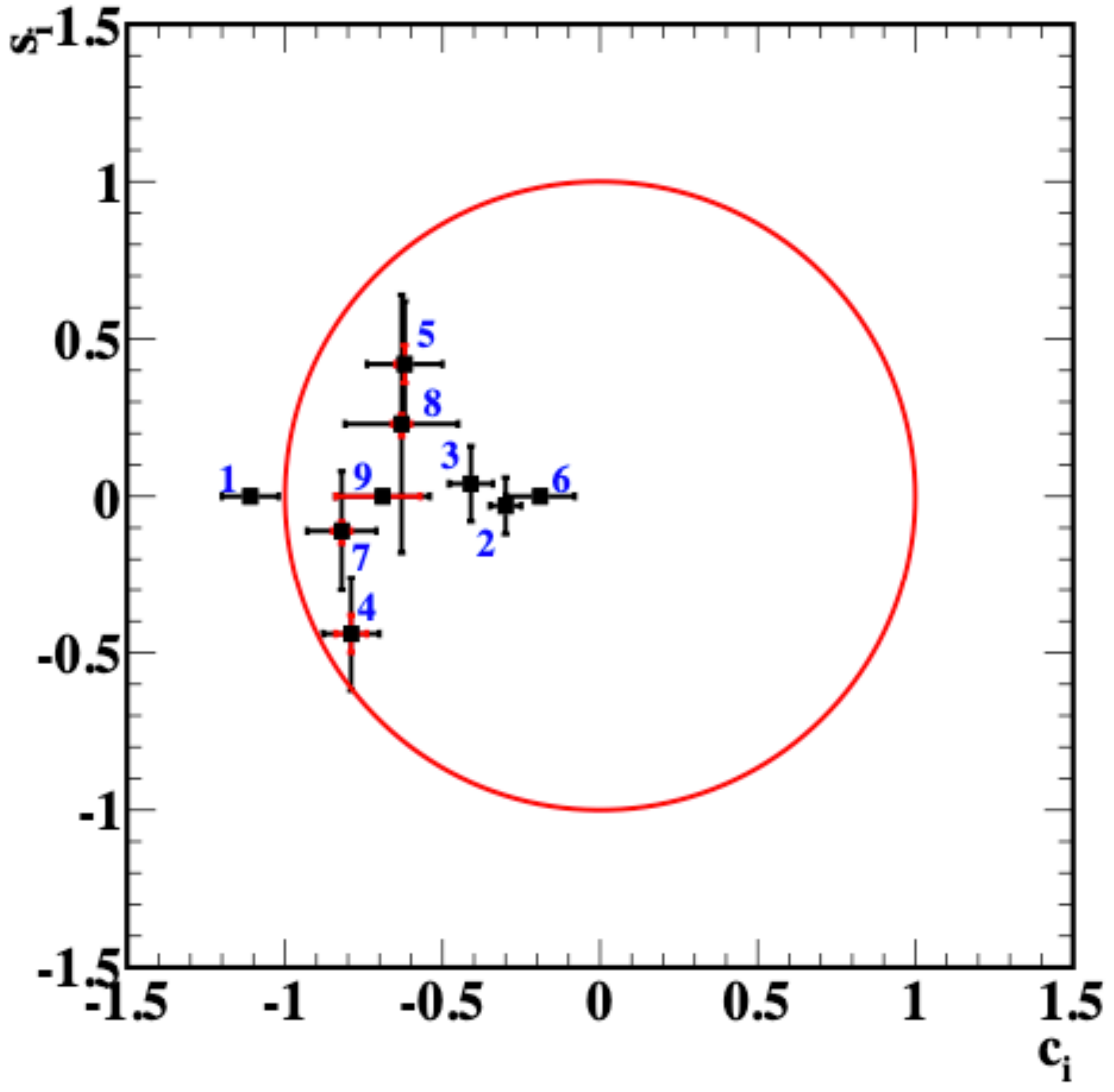
- $(\delta_B(D\pi) + \delta_D) \sim 180^\circ$, $\cos(\delta_B(D\pi) + \delta_D)$'s uncertainty is much smaller than expected -> unexpected precision from ADS method. Not true anymore with w.a. $\delta_B(D\pi)$.

Updates expect in near future

$B^+ \to Dh^+, D \to K_S^0\pi^+\pi^-\pi^0$ $((5.7^{+10.2}_{-8.8} \pm 3.5 \pm 5.7)^\circ)$, currently only CLEO's ci,si, binning scheme is available, which is **not** optimized for ϕ_3.

Large Br: 5.2%; F_+ ~ 0.3, $\sum c_i\sqrt{T_i\bar{T}_i} \sim -0.2$

Bin	Bin region	m_L (GeV/c²)	m_U (GeV/c²)
1	$m_{\pi^+\pi^-\pi^0} \approx m_\omega$	0.762	0.802
2	$m_{K_S^0\pi^-} \approx m_{K^{*-}}$ &	0.790	0.994
	$m_{\pi^+\pi^0} \approx m_{\rho^+}$	0.610	0.960
3	$m_{K_S^0\pi^+} \approx m_{K^{*+}}$ &	0.790	0.994
	$m_{\pi^-\pi^0} \approx m_{\rho^-}$	0.610	0.960
4	$m_{K_S^0\pi^-} \approx m_{K^{*-}}$	0.790	0.994
5	$m_{K_S^0\pi^+} \approx m_{K^{*+}}$	0.790	0.994
6	$m_{K_S^0\pi^0} \approx m_{K^{*0}}$	0.790	0.994
7	$m_{\pi^+\pi^0} \approx m_{\rho^+}$	0.610	0.960
8	$m_{\pi^-\pi^0} \approx m_{\rho^-}$	0.610	0.960
9	Remainder	-	-



We expect an optimized binning scheme and a precise ci/si from BESIII's 8fb^{-1}(~ 10 times than CLEO's).

Expect a more "normal" result from this channel.

By Toy MC, @50/ab, from $B^+ \to Dh^+, D \to K_S^0\pi^+\pi^-\pi^0$,

- with current Ti/ci/si, ~5°
- With Kspipi's Ti/ci/si, ~2°

Updates expect in future

Extra channels: (https://confluence.desy.de/display/BI/Physics+BtoCharm)

$B^+ \to Dh^+, D \to K_L\pi^+\pi^-$: Unique to Belle/BelleII

$B^+ \to Dh^+, D \to K^-\pi^+\pi^-\pi^+$: BESIII tells the local information.

$B^+ \to Dh^+, D \to K^-K^+\pi^0/\pi^-\pi^+\pi^0$: BESIII will measure the local information.

$B^+ \to Dh^+, D \to \pi^-\pi^+\pi^0\pi^0$: Belle/BelleII's advantage

$B^+ \to Dh^+, D \to K^-\pi^+\pi^0$: local information? Will also be helpful for mixing study.

~6° @50/ab; may better with optimized bins

New novel methods when we have 20 ab^{-1}?

Un-binned way (Fourier analysis) in $B^+ \to Dh^+, D \to K_S\pi^+\pi^-$ [Eur.Phys.J.C 78 (2018) 2, 121]

Combined fit between B data and charm data (BESIII). (LHCb are doing it now.)

…

Determine hadronic parameter independently?

Measure r_B^{DK} solo? Now in all methods, we determine $r_B^{DK}, \delta_B^{DK}, \phi_3$ simultaneously.

And we know the ϕ_3's precision highly depends on r_B^{DK}'s value.

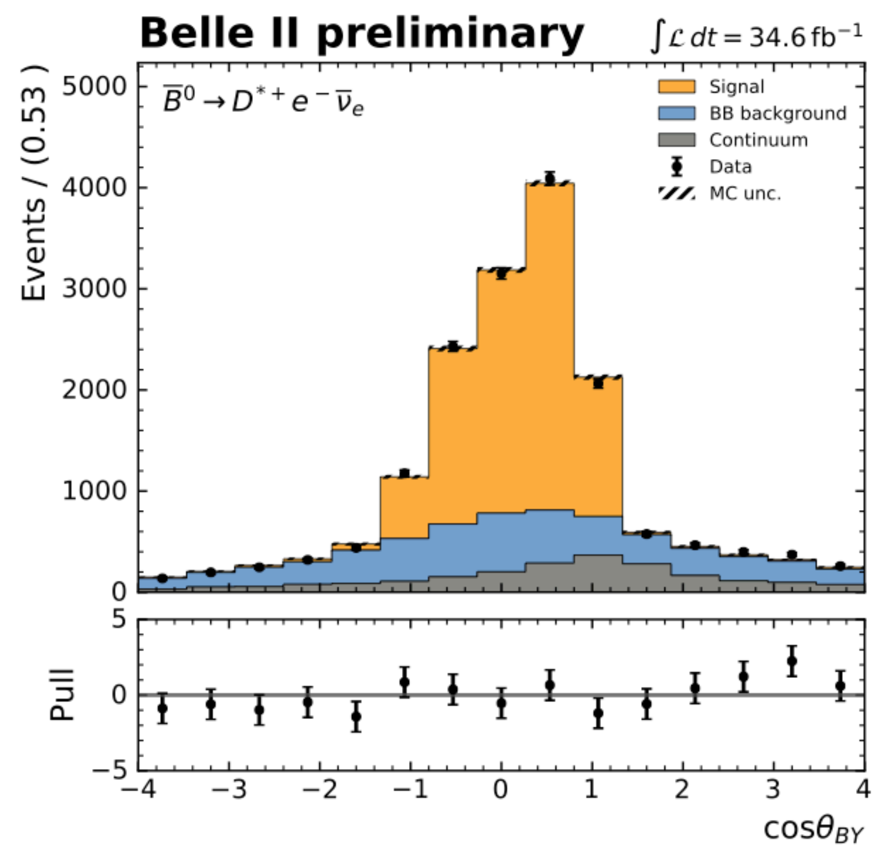
Can we determine r_B^{DK} solo? Will be an important extra constrain on ϕ_3!

Experimentally: N($B^+ \to D^0 K^+, D^0 \to K^- e^+ \nu_e$)/N($B^+ \to \bar{D}^0 K^+, \bar{D}^0 \to K^+ e^- \bar{\nu}_e$),

Rough estimation: for CF channel: N(raw)/1ab^{-1} ~ 6500

- If use hadronic tag (FEI): eff ~ 0.2%? N(CF) ~600 at 50 ab^{-1}
- Untag? Fit cosθ_{BY}, like semi-leptonic study. Maybe more difficult, due to small p(ν_e).

N(CF) ~60000 at 50 ab^{-1}, 4% precision? Won't be useful.



$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$$

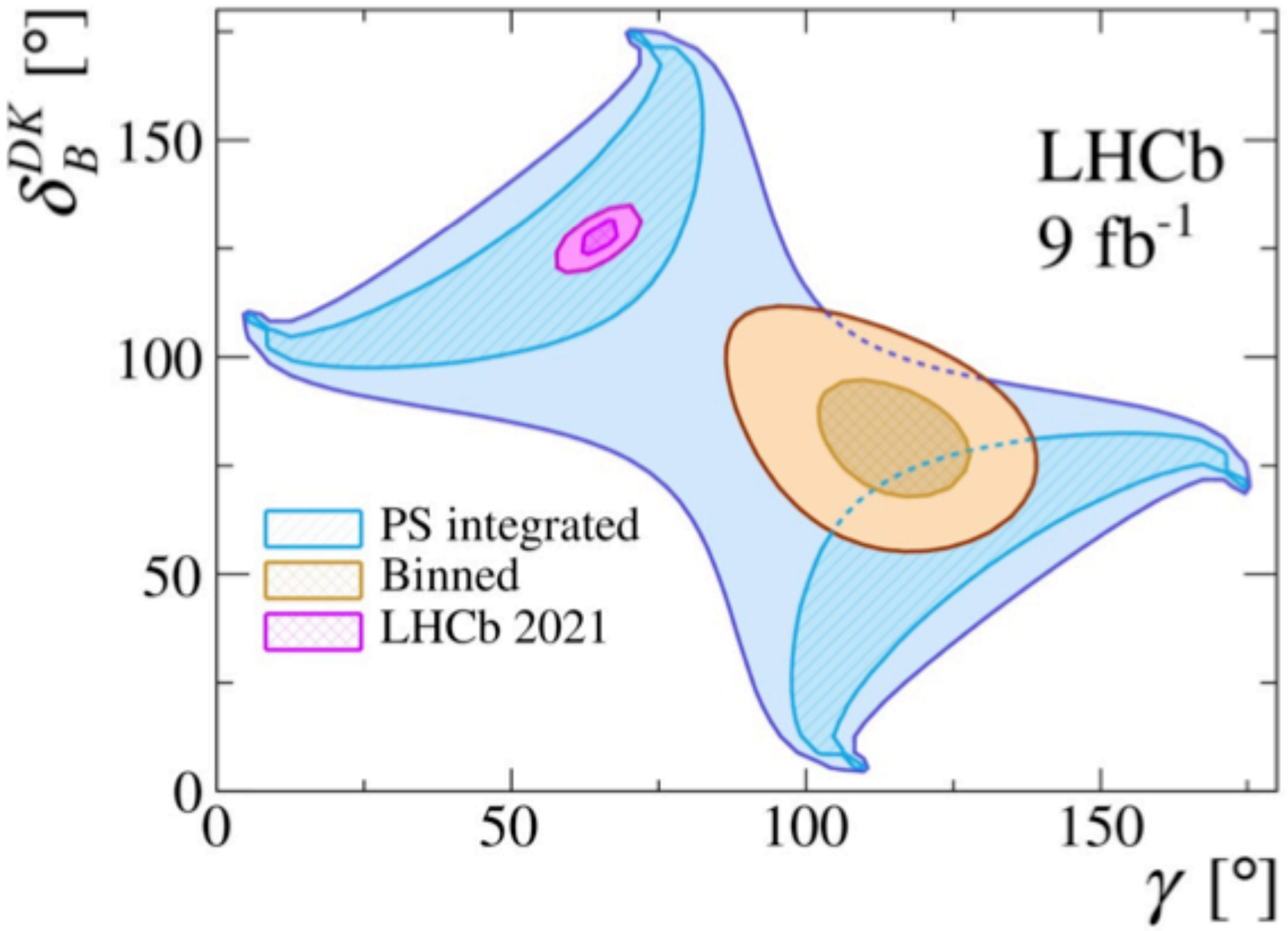
More idea? In paper arXiv:1606.09129, they use branching ratios and r_B^{DK} to determine $r_B^{D\pi}$ with SU(3) symmetry.

(Before summary) why Belle II still work on ϕ_3?

- Almost all channels are full reconstructed. LHCb is a monster…
- ϕ_3 is a basic parameter, as another B-factory, we must give our ϕ_3, to confirm LHCb's ϕ_3.

(Before summary) why Belle II still work on ϕ_3?

- Almost all channels are full reconstructed. LHCb is a monster…
- ϕ_3 is a basic parameter, as another B-factory, we must give our ϕ_3, to confirm LHCb's ϕ_3.
- LHCb has interesting ϕ_3 in some channels. —> Need Belle II's crosscheck.



Model-dependent $K^+K^-\pi^+\pi^-$

[Eur. Phys. J. **C83** (2023) 547]

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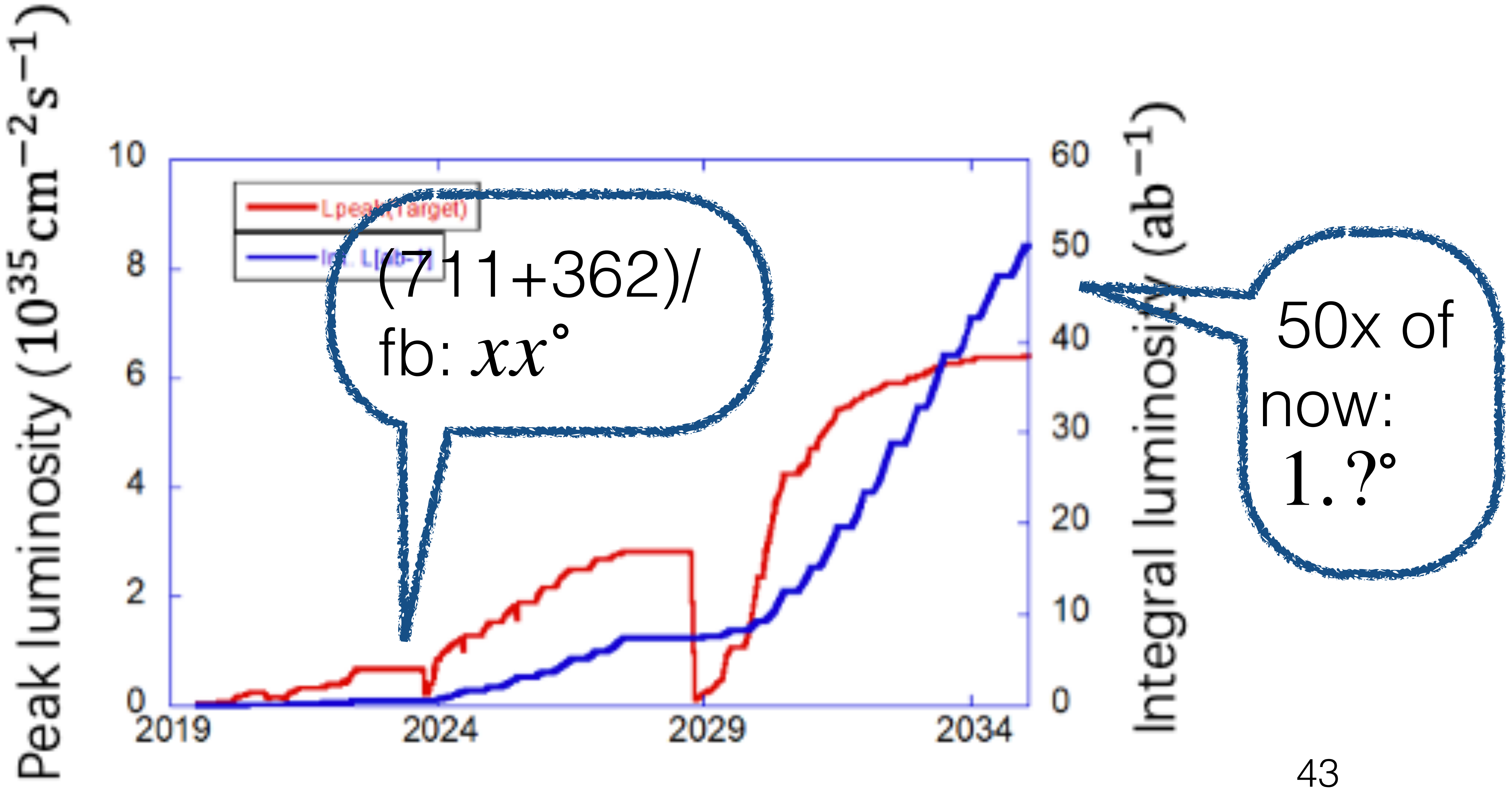


- Still a chance to show same sensitivity to ϕ_3!

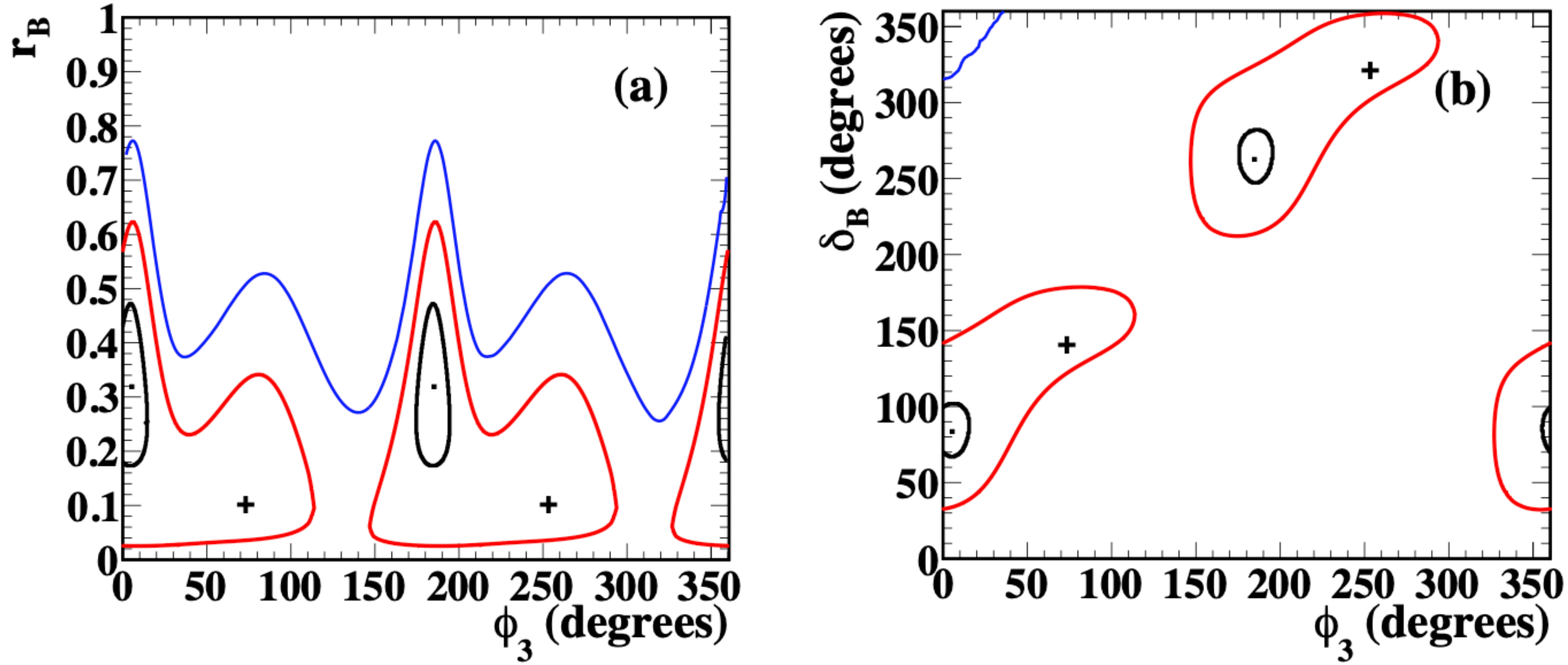
Summary

- Review the γ/ϕ_3 measurement at Belle (II). Discuss about combination of γ/ϕ_3 (CKM conference 2023).
- For future, important channels:
  - $B^+ \to Dh^+, D \to K_S^0\pi^+\pi^-\pi^0$, need wait BESIII's new binning scheme and ci/si
  - $B^+ \to Dh^+, D \to h^+h^-\pi^0$, BESIII may have local information few years later
  - $B^+ \to Dh^+, D \to K_L^0\pi^+\pi^-$, Belle II's unique channel.
  - $B^+ \to Dh^+, D \to \pi^+\pi^-\pi^0\pi^0$, Belle II's advantage.
  - $B^+ \to Dh^+, D \to K^-\pi^+\pi^0$: local information? Will also be helpful for mixing study.

- This CKM angle γ/ϕ_3 is not only B factory's task, also need BESIII's contribution.
- Let's make γ/ϕ_3 a **candle** parameter!

Thank you!

Back-Up



$$V_{CKM} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} + \mathcal{O}(\lambda^5) \sim \begin{pmatrix} 1 & 0.2 & 0.004 \\ 0.2 & 1 & 0.04 \\ 0.008 & 0.04 & 1 \end{pmatrix}$$

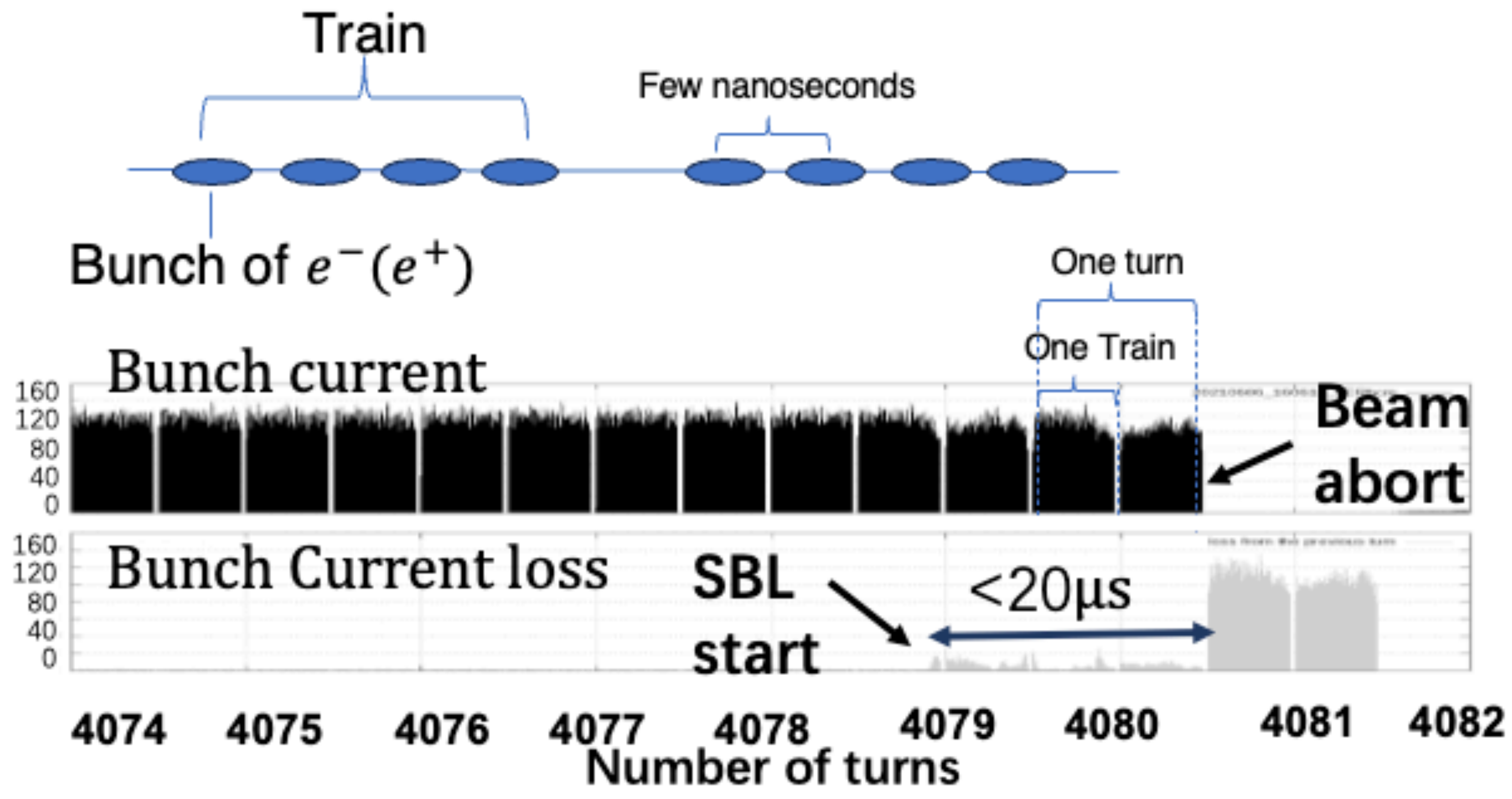
Introduction –Sudden beam loss

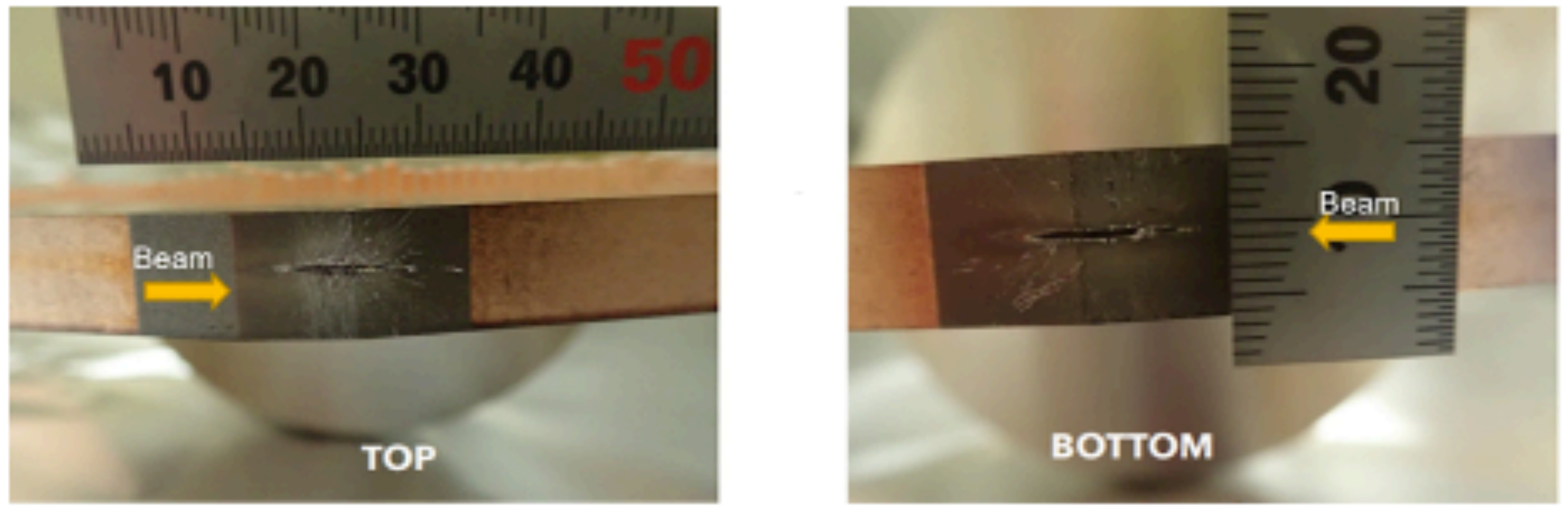
Sudden beam loss:

- Fast beam loss within three or four turns (1 turn ~10 μs)
- Reasons remain unknown
- More likely occurred in LER.

Effects of Sudden beam loss

- Caused severe damage to the vertical collimators
- Caused quenches of final focusing magnets (QCS)
- Resulted in large radiation doses around the interaction region (IR)
- **limited the maximum bunch current**





Collimator head after catastrophic sudden beam loss

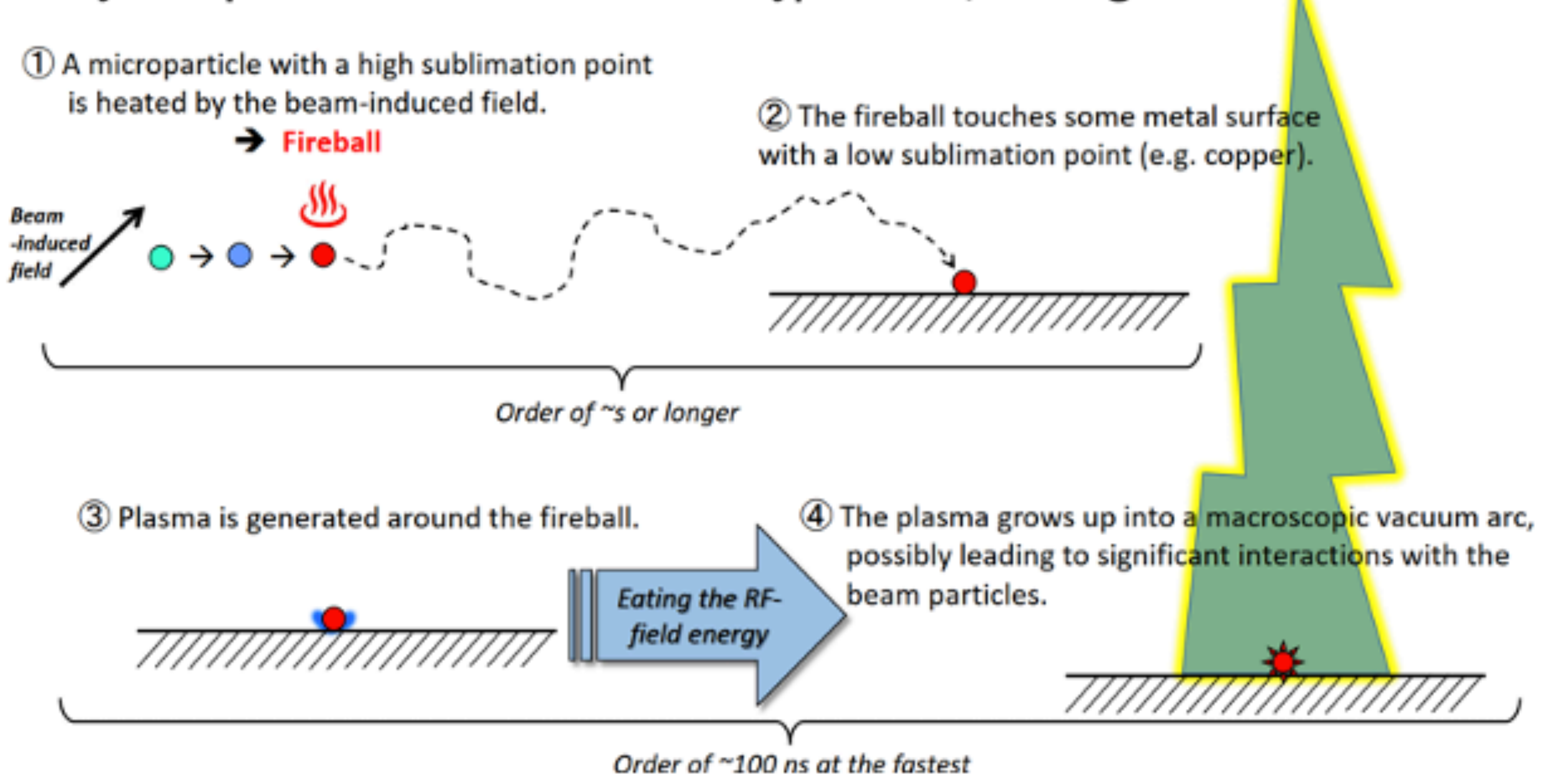
Discussion -- possible cause of Sudden Beam Loss

Can not be attributed to conventional beam instabilities: too fast (less than 3-4 turns) and no beam instabilities observed

May not be due to Beam-dust interaction: examined in simulation, in which the beam particles are lost mainly at the horizontal collimators while what we observed is mainly at vertical collimators.

“Fire ball” Hypotheses has been proposed as a possible reason for sudden beam loss.

Physical process of the “Fireball” hypothesis, leading to fast beam loss



$$d\Gamma_{B^\pm}(\mathbf{x}) = A^2_{(\pm,\mp)} + r_B^2 A^2_{(\mp,\pm)} + 2A_{(\pm,\mp)}A_{(\mp,\pm)}\Big[\underbrace{r_B\cos(\delta_B \pm \gamma)}_{x_\pm}\ \underbrace{\cos(\delta_{D(\pm,\mp)})}_{c_i} + \underbrace{r_B\sin(\delta_B \pm \gamma)}_{y_\pm}\ \underbrace{\sin(\delta_{D(\pm,\mp)})}_{s_i}\Big]$$

$$N_i^+ = h_{B^+}\left[F_{-i} + \left\{\left(x_+^{DK}\right)^2 + \left(y_+^{DK}\right)^2\right\}F_i + 2\sqrt{F_iF_{-i}}\left(x_+^{DK}c_i - y_+^{DK}s_i\right)\right],$$

$$N_{-i}^+ = h_{B^+}\left[F_i + \left\{\left(x_+^{DK}\right)^2 + \left(y_+^{DK}\right)^2\right\}F_{-i} + 2\sqrt{F_iF_{-i}}\left(x_+^{DK}c_i + y_+^{DK}s_i\right)\right],$$

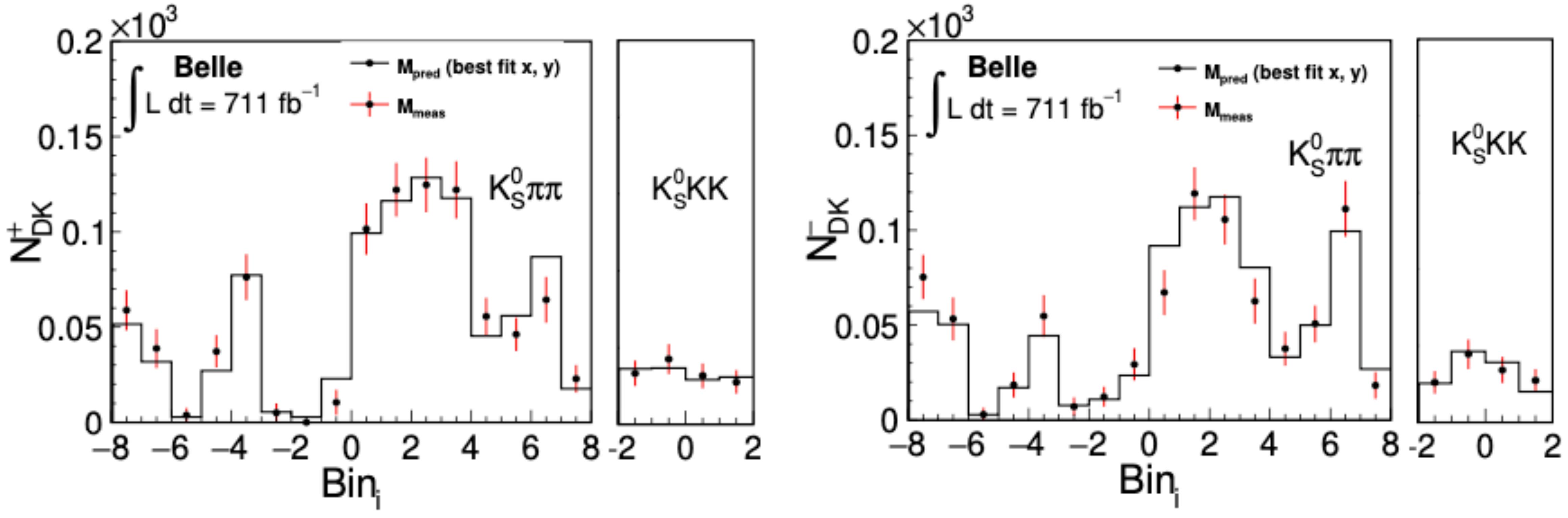
$$N_i^- = h_{B^-}\left[F_i + \left\{\left(x_-^{DK}\right)^2 + \left(y_-^{DK}\right)^2\right\}F_{-i} + 2\sqrt{F_iF_{-i}}\left(x_-^{DK}c_i + y_-^{DK}s_i\right)\right],$$

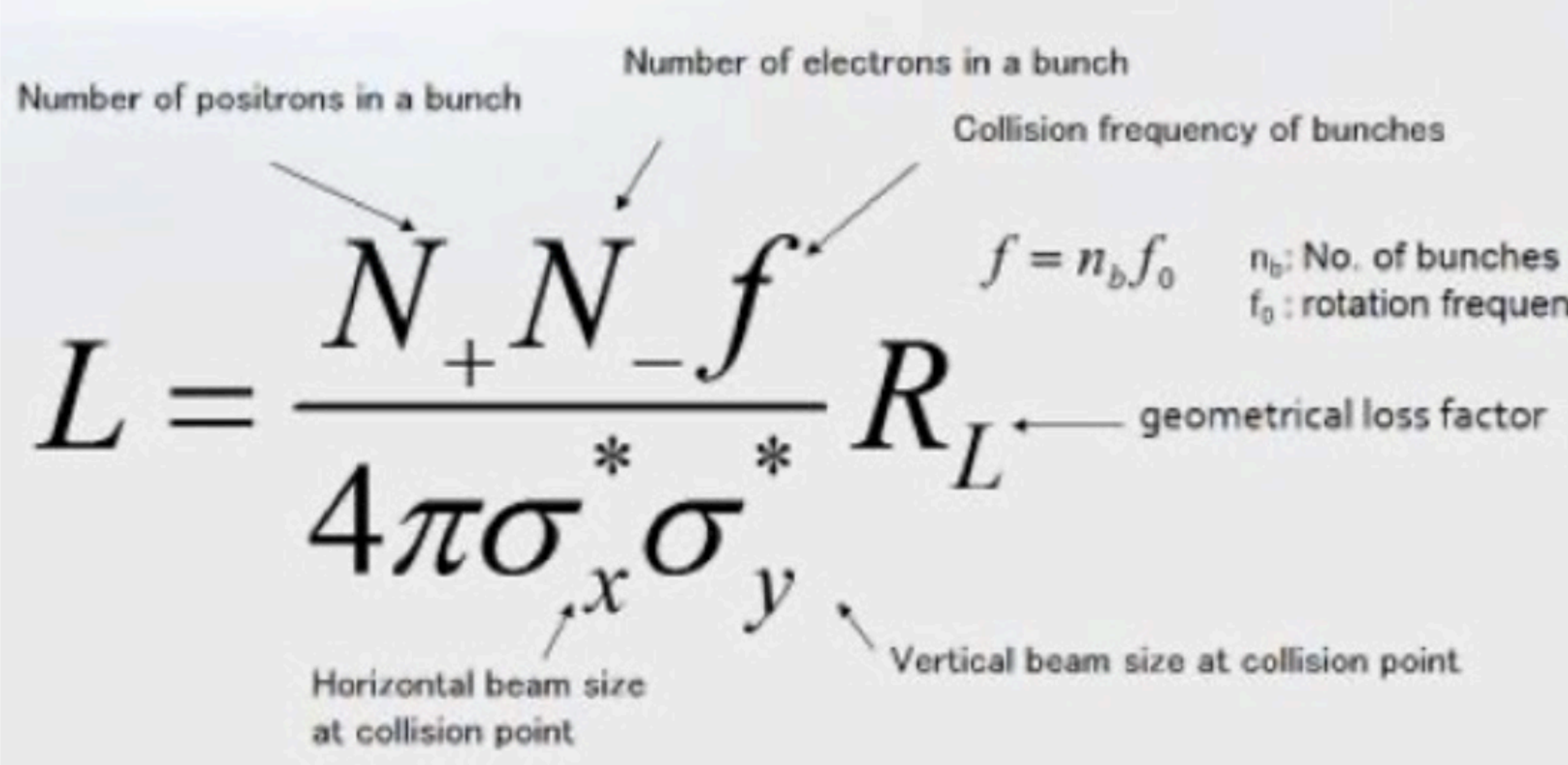
$$N_{-i}^- = h_{B^-}\left[F_{-i} + \left\{\left(x_-^{DK}\right)^2 + \left(y_-^{DK}\right)^2\right\}F_i + 2\sqrt{F_iF_{-i}}\left(x_-^{DK}c_i - y_-^{DK}s_i\right)\right],$$

← 9 fb^{-1} → ← Goal: 50 fb^{-1} → ← Goal: 300 fb^{-1} →

Upgrade I | Upgrade Ib | Upgrade II

Run 1	LS1	Run 2	LS2		Run 3	LS3	Run 4	LS4	Run 5	LS5	Run 6
2011 2012	2013 2014	2015 2016 2017 2018	2019 2020 2021	2022	2023 2024 2025	2026 2027 2028	2029 2030 2031 2032	2033 2034	2035 2036 2037 2038	2039	2040 2041





5×10^{-9}, and the small size of the interference, proportional to $r_B \approx c_F |V_{cs} V^*_{ub}|/|V_{us} V^*_{cb}| \approx 0.1$, where $c_F \approx 0.2$ is a color suppression factor [11–13]. Therefore a pre-