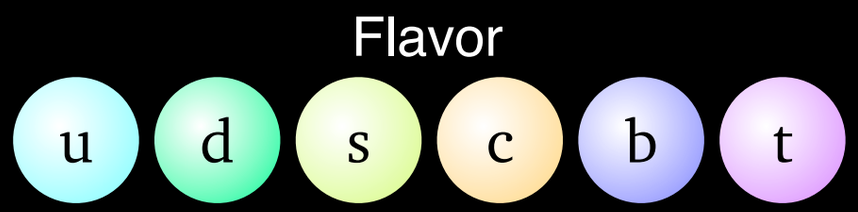
Target and Prospect of Belle-II experiment

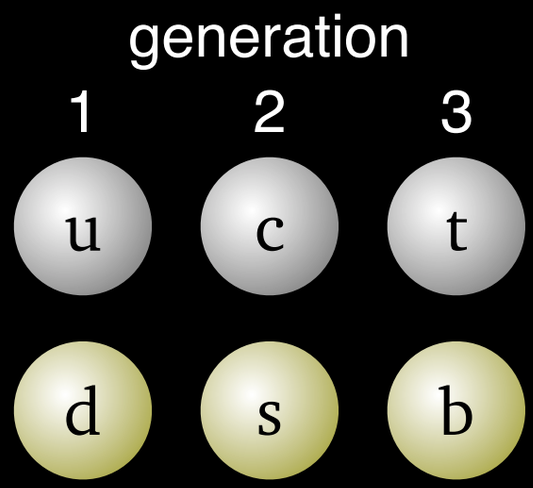
Nanae Taniguchi (KEK)

Motivation

- Questions
  - origin of generation and mechanism of flavor
  - baryon asymmetry (in Universe) and CP violation

- Both involve 3 generation → motivated to study heavy quarks





B physics experiments

Designed by Freepik.com

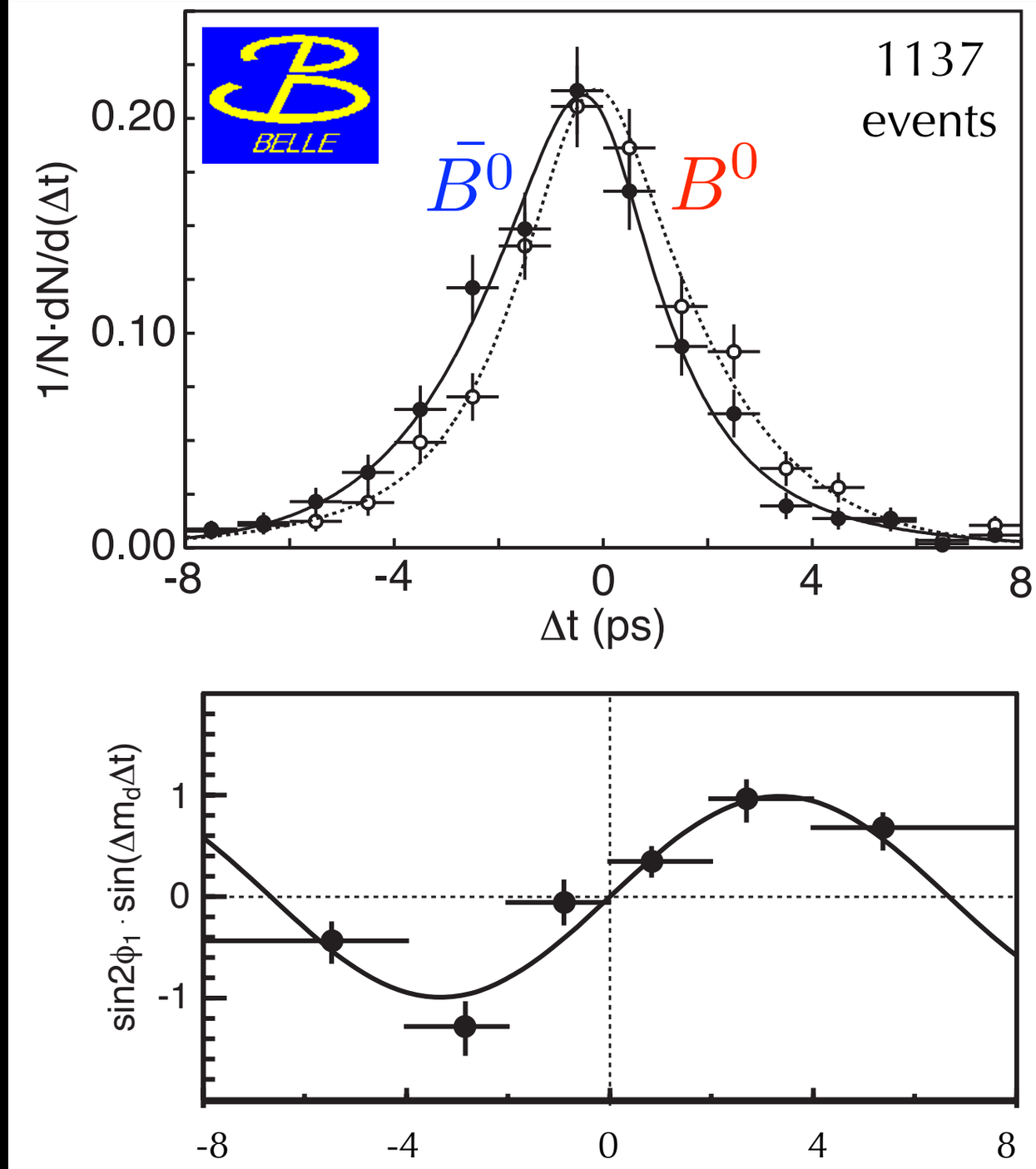
heavy flavor (b) factories

- Current/Recent
  - B factories : KEKB/Belle, PEP-II/Babar
    - 1999 - 2010 : $772 \times 10^6 + 471 \times 10^6$ BB
    - e+e- collider at 10.6 GeV (CMS)
  - LHCb **Running**
    - 2008 - : ~9 fb-1 ~ $O(10^{12})$ b's
    - pp collider at 7-13 TeV
- Upcoming
  - SuperKEKB/Belle II **Just started**
    - 2018 - : target is ~50 ab^{-1} by 2024, 5×10^{10} BB
    - e+e- collider at 10.6 GeV (CMS)

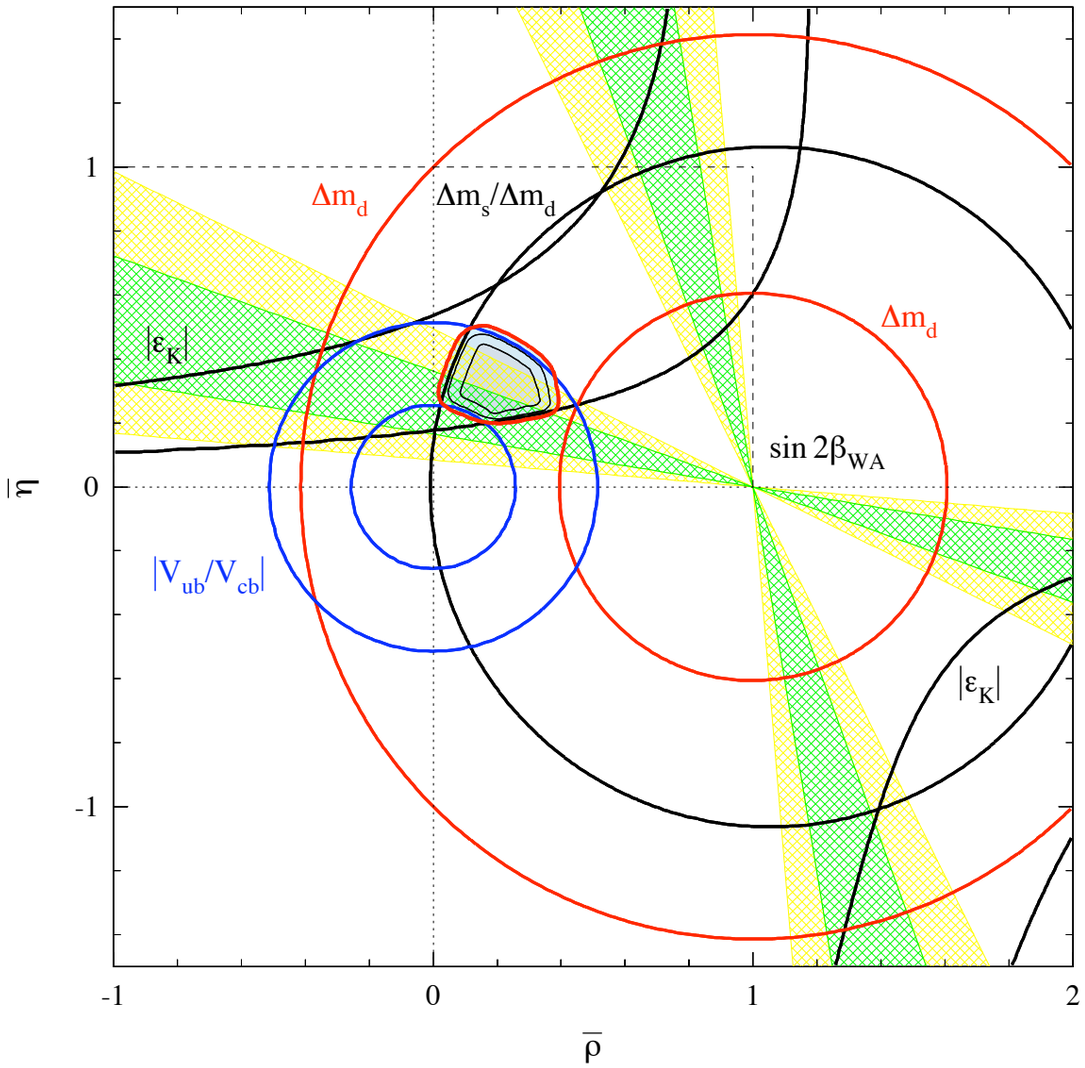
Achievement from Belle/Babar

- Discovery of CP violation in B meson
- Confirmed Kobayashi-Maskawa mechanism
- Precise measurement of CKM parameters
  - Study for origin of CP Violation
- Study rare phenomena for new physics search
- Obtain hints for new physics

Discovery CPV

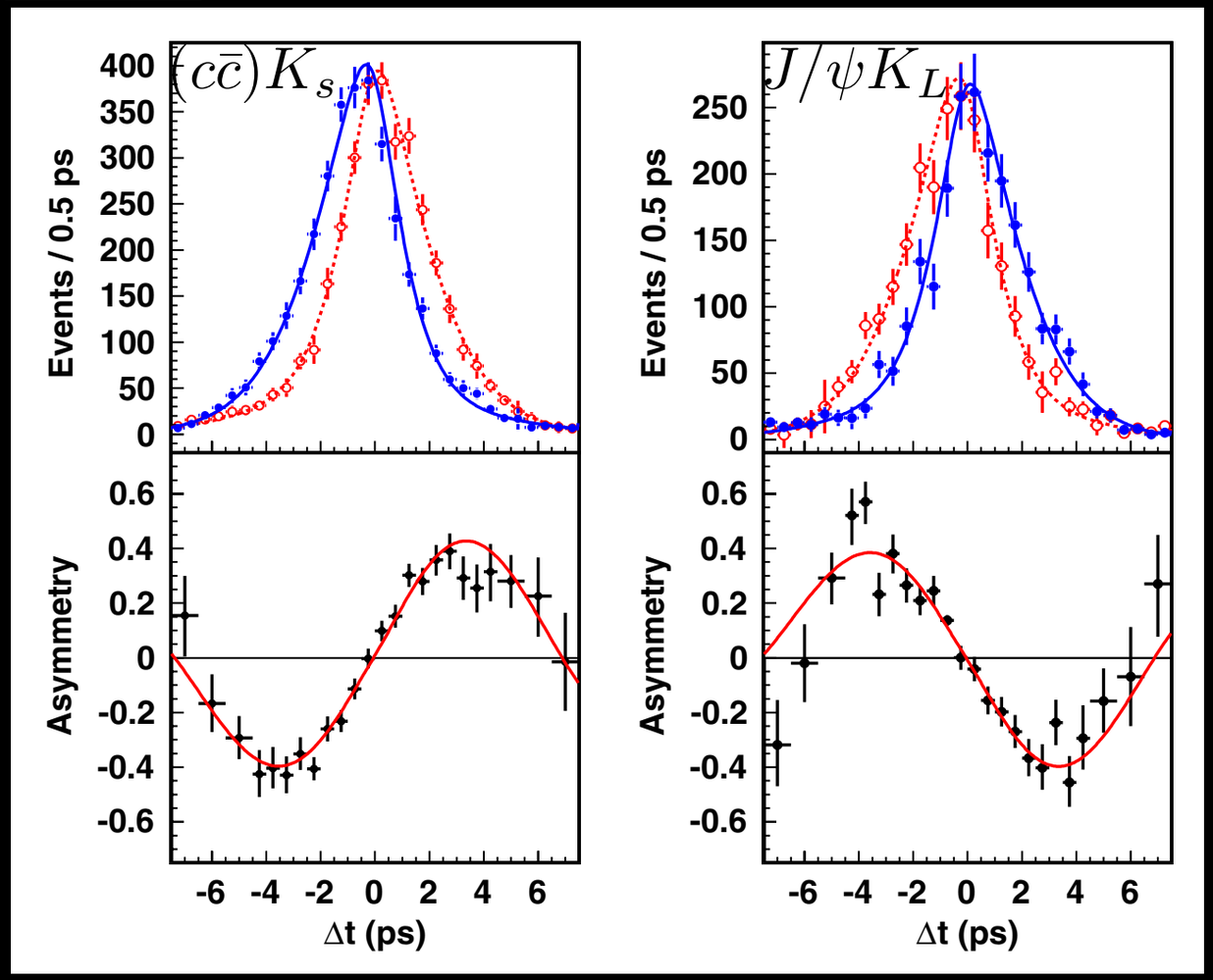


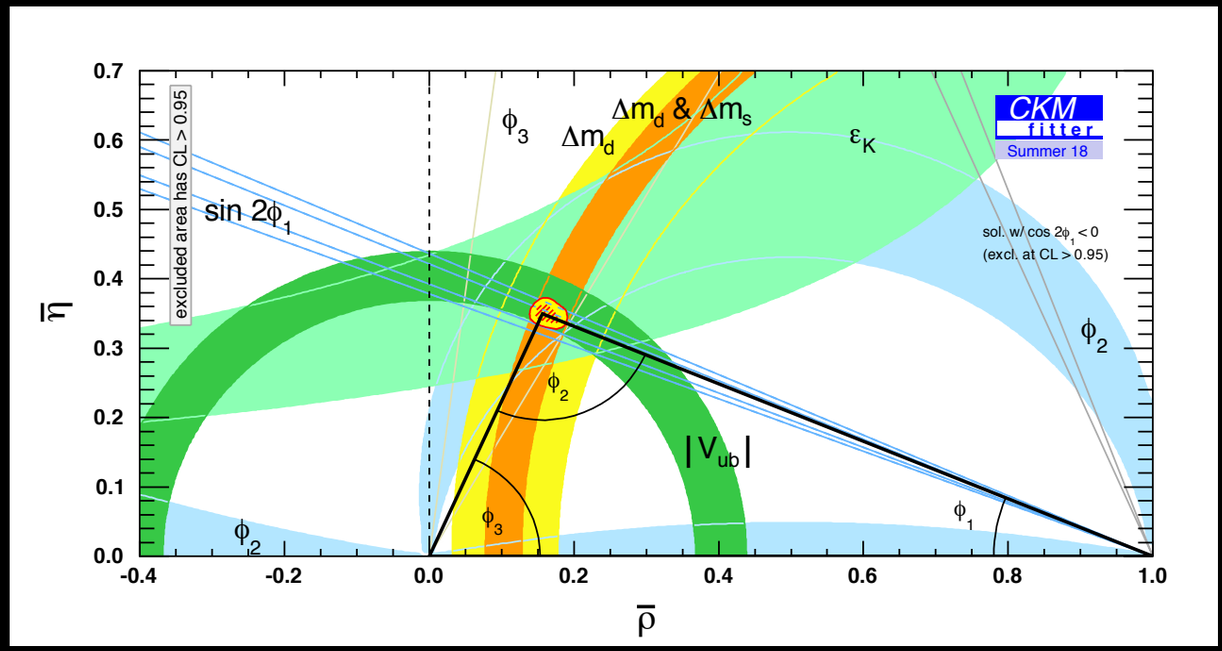
$31 \times 10^6 B\bar{B}$ 2001 summer



Discovery CPV

Full data : 772M BB





determine CKM unitarity triangle

$$\delta(\sin 2\phi_1) \sim 4\%$$

$$\delta\phi_2, \delta\phi_3 \sim O(10\%)$$

$$\sin 2\phi_1 = 0.667 \pm 0.023(\text{stat}) \pm 0.012(\text{syst})$$

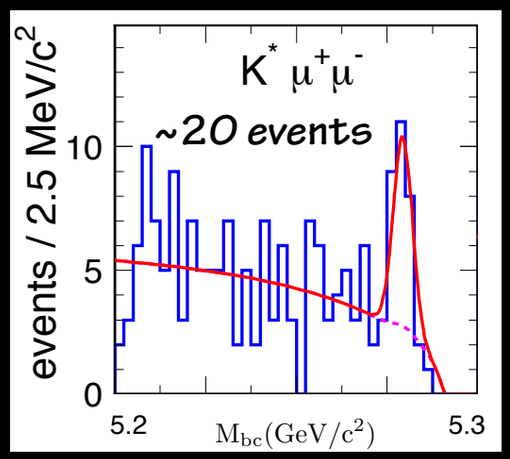
$$\mathcal{A}_f = 0.006 \pm 0.016(\text{stat}) \pm 0.012(\text{syst})$$

Study rare phenomena

$\sim 100\ \mathrm{fb}^{-1}$ $\sim 400\ \mathrm{fb}^{-1}$ $\sim 1\ \mathrm{ab}^{-1}$

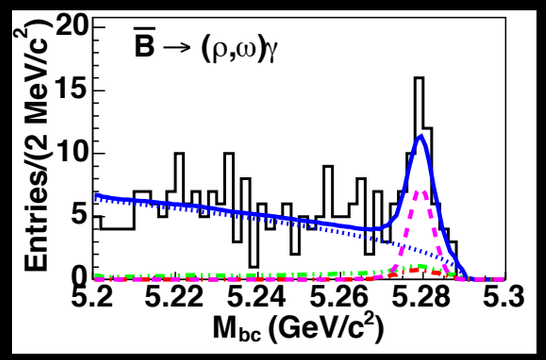
$b \to s\ell^+\ell^-$

observation (2003)



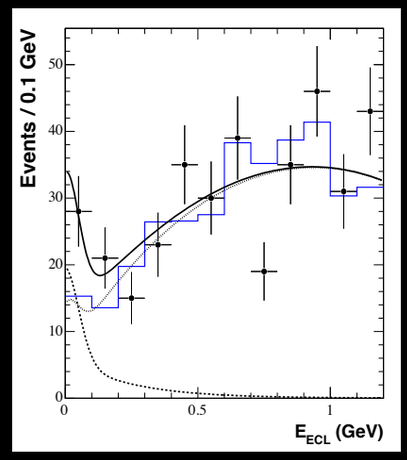
$b \to d\gamma$

observation (2006)



$B \to \tau\nu$

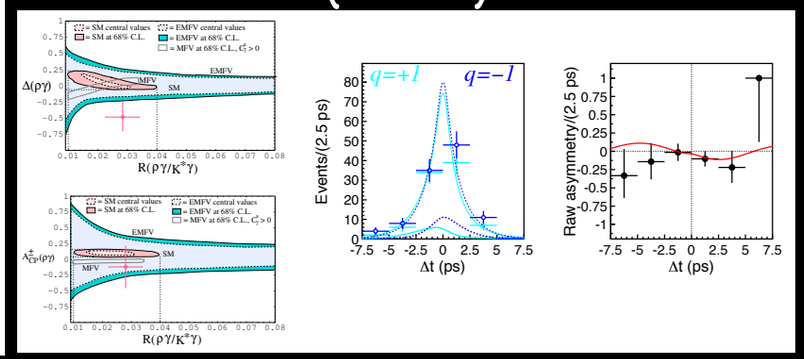
evidence (2006)



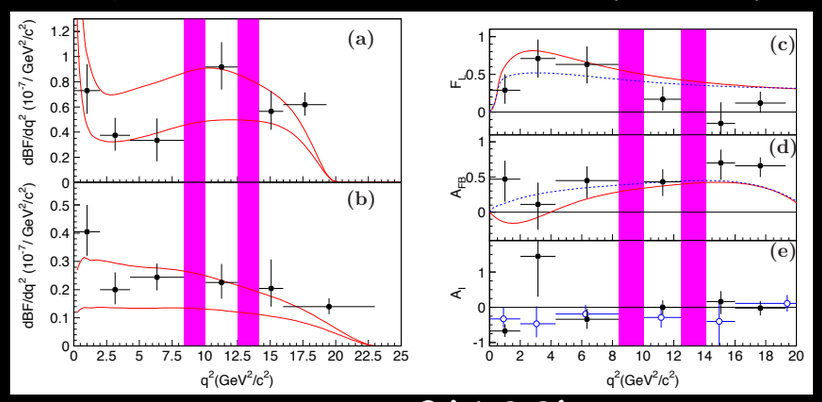
detail analysis can be done thanks to many data

Asymmetry

Time dependent CPV (2009)

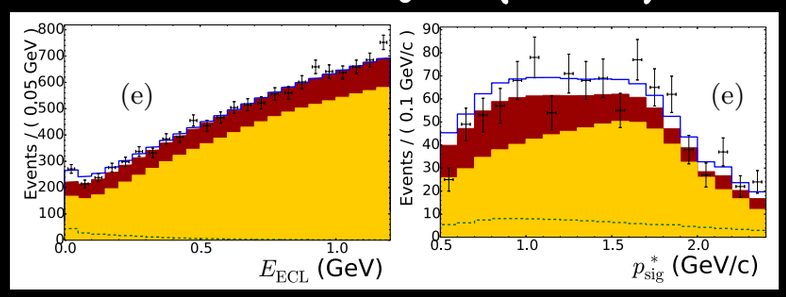


angular analysis 660MBB (2008)



event ~ O(100)

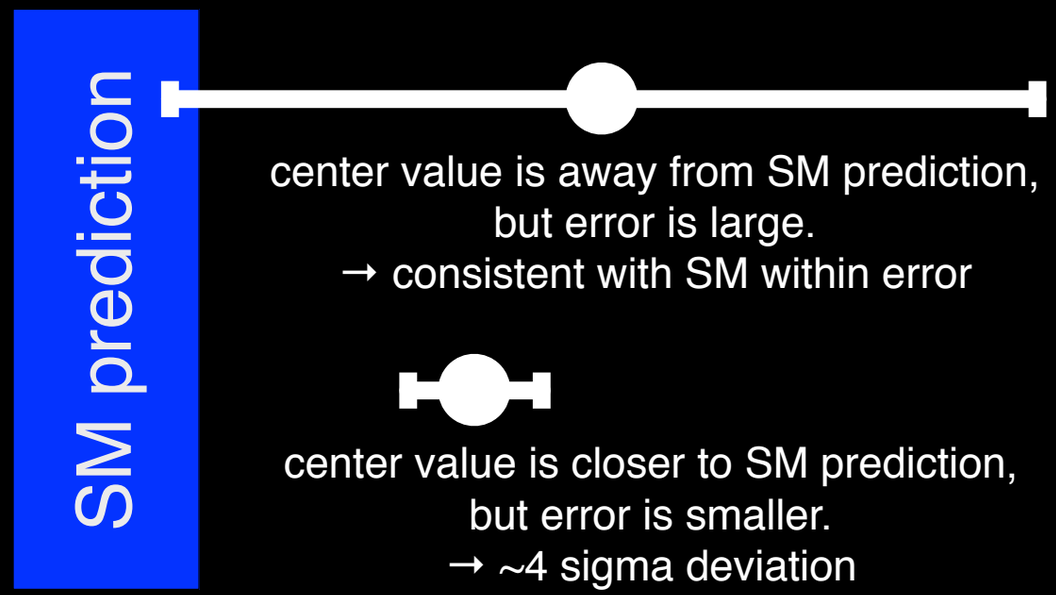
Full data analysis (2014)



Branching fraction measurement

hints ? for new physics

- Contribution of new physics may appear as deviation from SM prediction



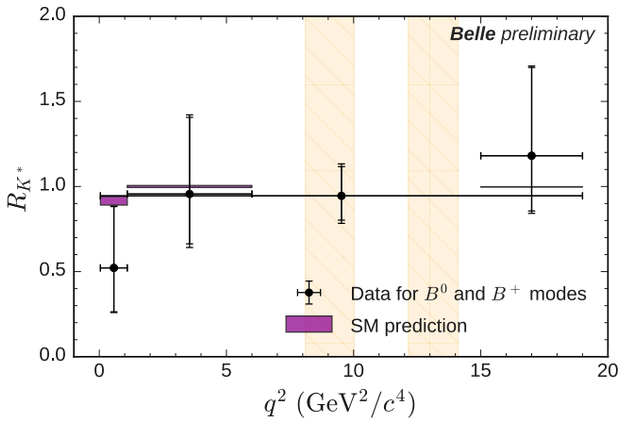
Anomaly is reported by LHCb

Belle result is consistent with SM

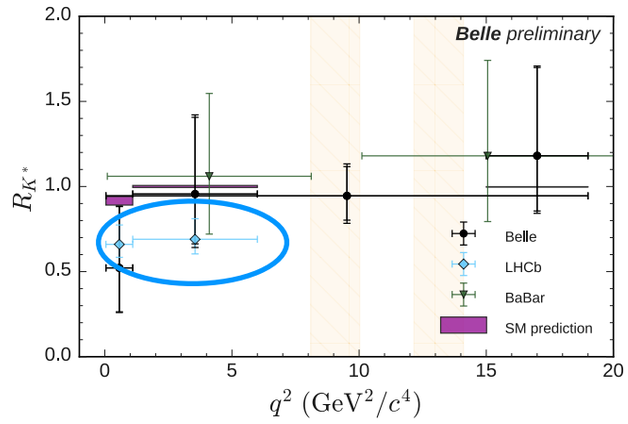
~3 sigma deviation

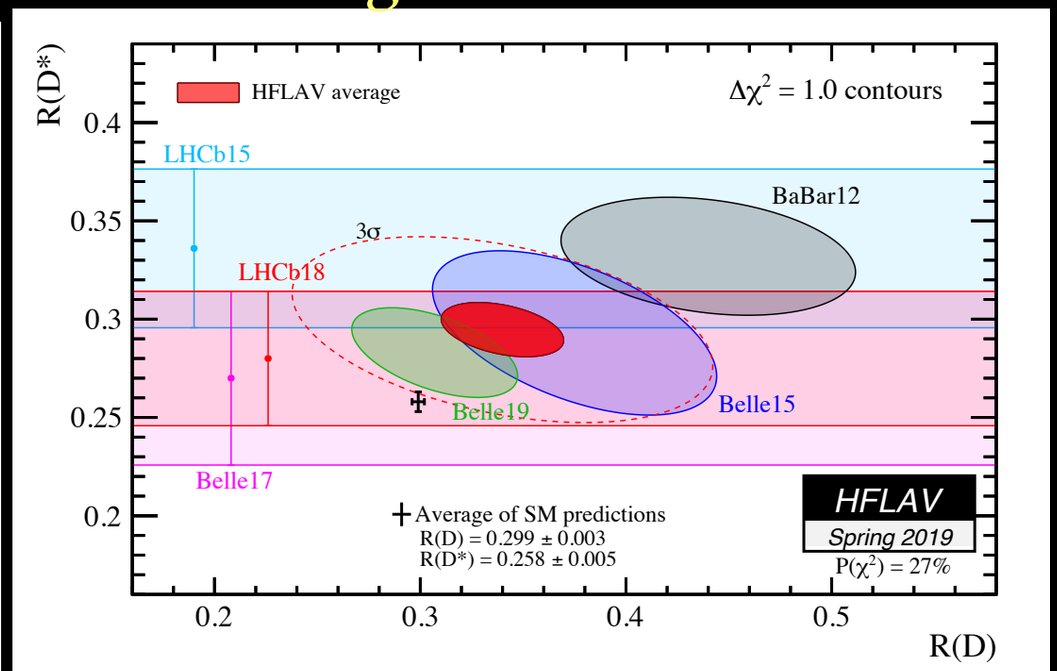
Lepton universality test

R_{K^*} (Belle)



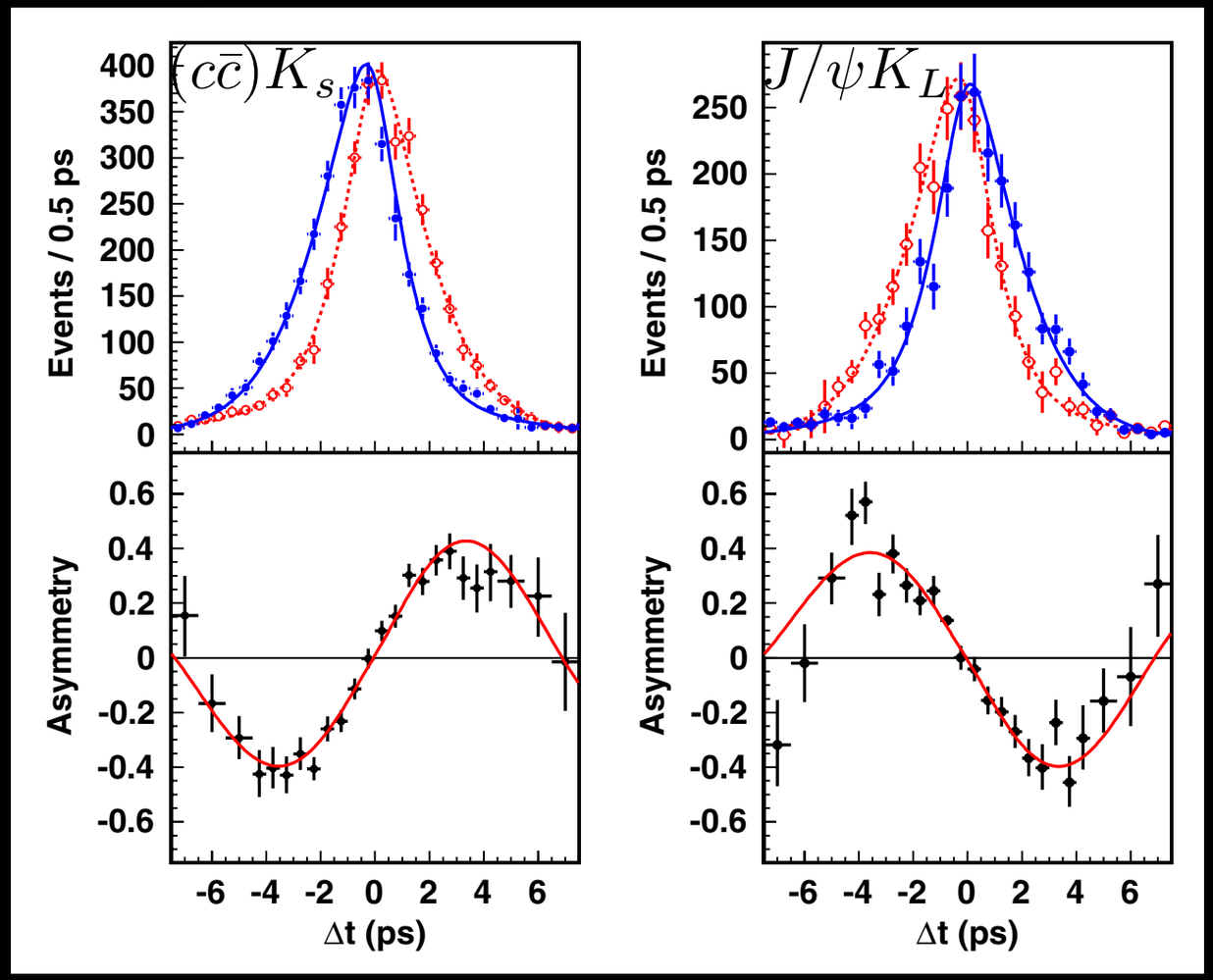
R_{K^*} (all)

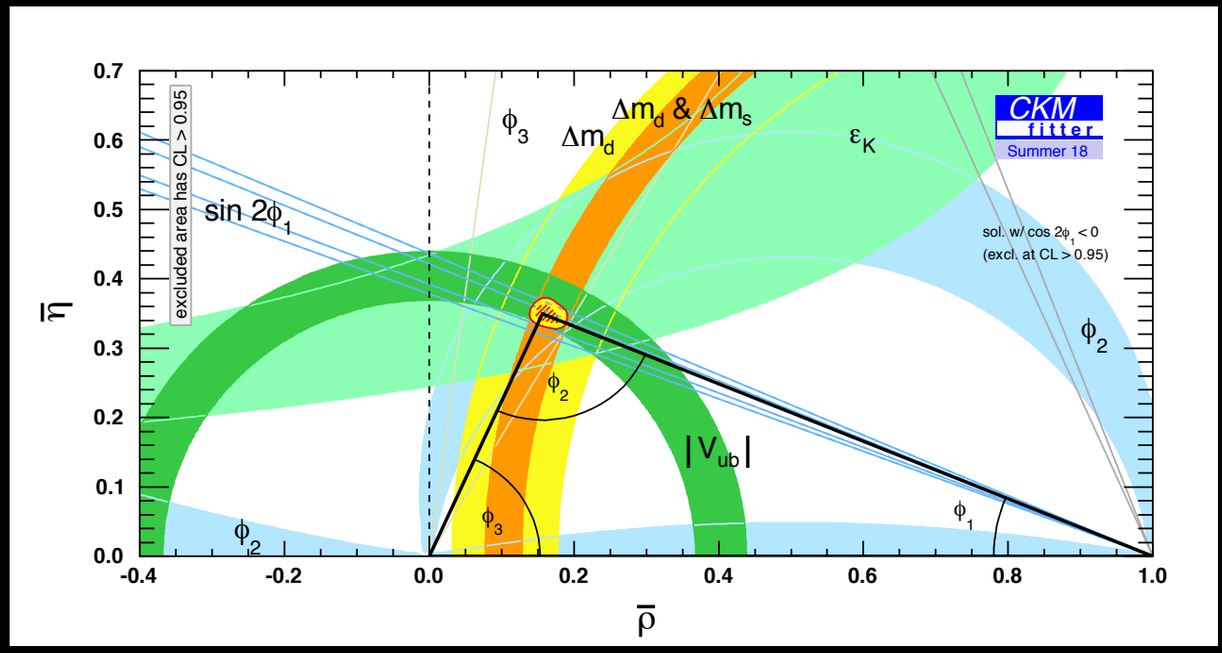




Discovery CPV

Full data : 772M BB





determine CKM unitarity triangle

$$\delta(\sin 2\phi_1) \sim 4\%$$

$$\delta\phi_2, \delta\phi_3 \sim O(10\%)$$

$$\sin 2\phi_1 = 0.667 \pm 0.023(\text{stat}) \pm 0.012(\text{syst})$$

$$\mathcal{A}_f = 0.006 \pm 0.016(\text{stat}) \pm 0.012(\text{syst})$$

still room for NP

Motivation for the higher luminosity B factory

Higher luminosity B factory provide rich physics programs to approach big questions.
There are many modes as good probe to search new physics.
B factory is also charm and tau factories.

Precise measurement of CKM

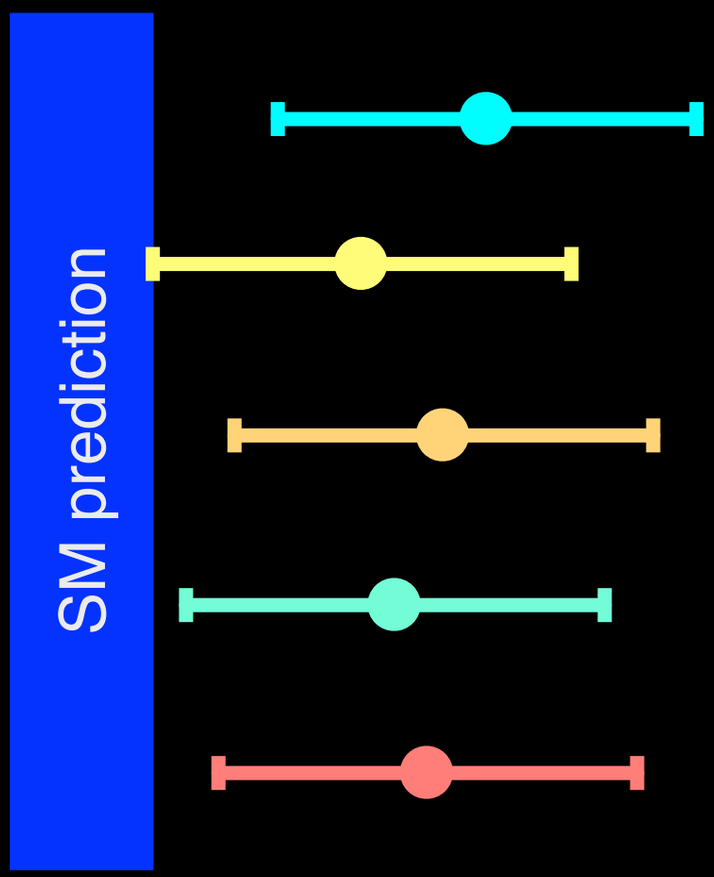
- new CP V phase — $\sin 2\phi_1$ from time dependent CPV — matter-antimatter asymmetry
- new flavor coupling — CPV in charm — origin of flavor

Study rare phenomena for new physics search

- interaction between charged Higgs and quark-lepton — $B \to D^{(*)}\tau\nu,\ \tau\nu$ — beyond Standard Model
- Right handed current — TCPV in $B \to X_s\gamma$ — Chirality
- LeptonFlavorViolation — $\tau \to \mu\gamma, \ell\ell\ell$

what is the main mode in Belle-II ?

- Belle (1999 - 2010)
  - CP violation in B meson system
- Belle -II
  - ??



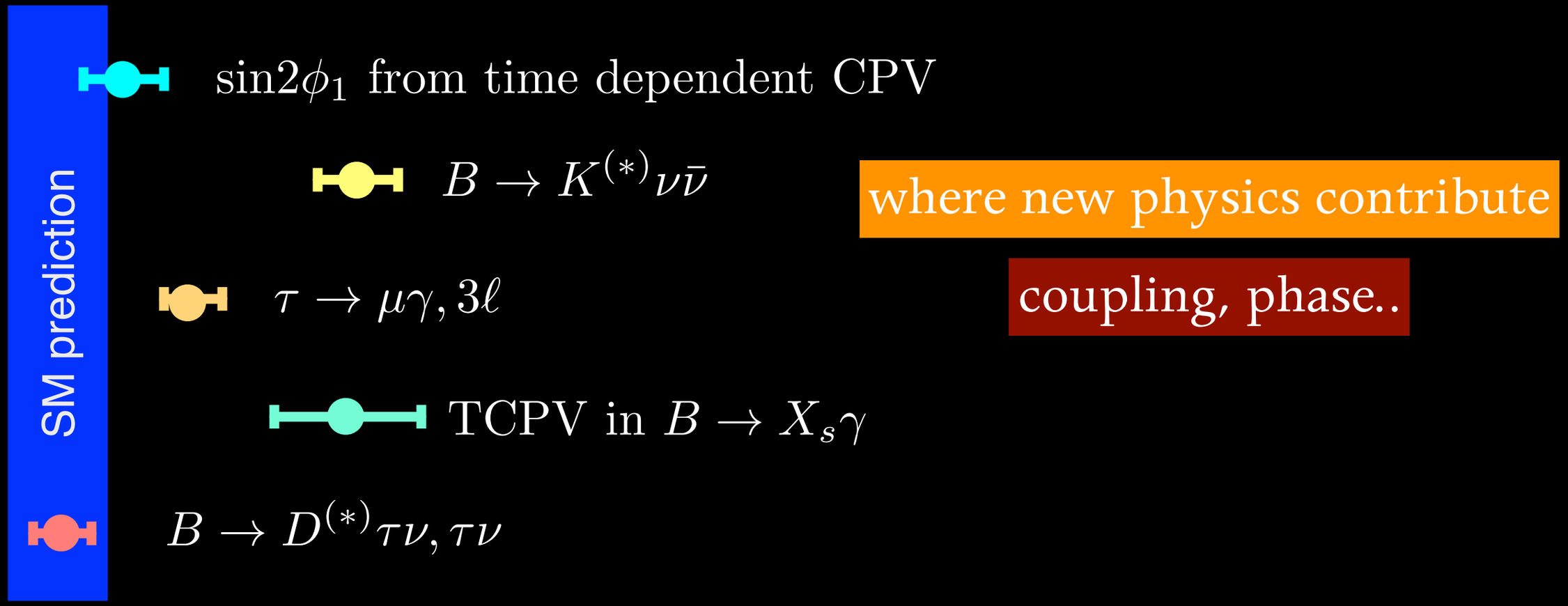
a fixed phrase …

"The results are consistent with SM within errors"

statistical error is dominant in almost all modes

what is the main mode in Belle-II ?

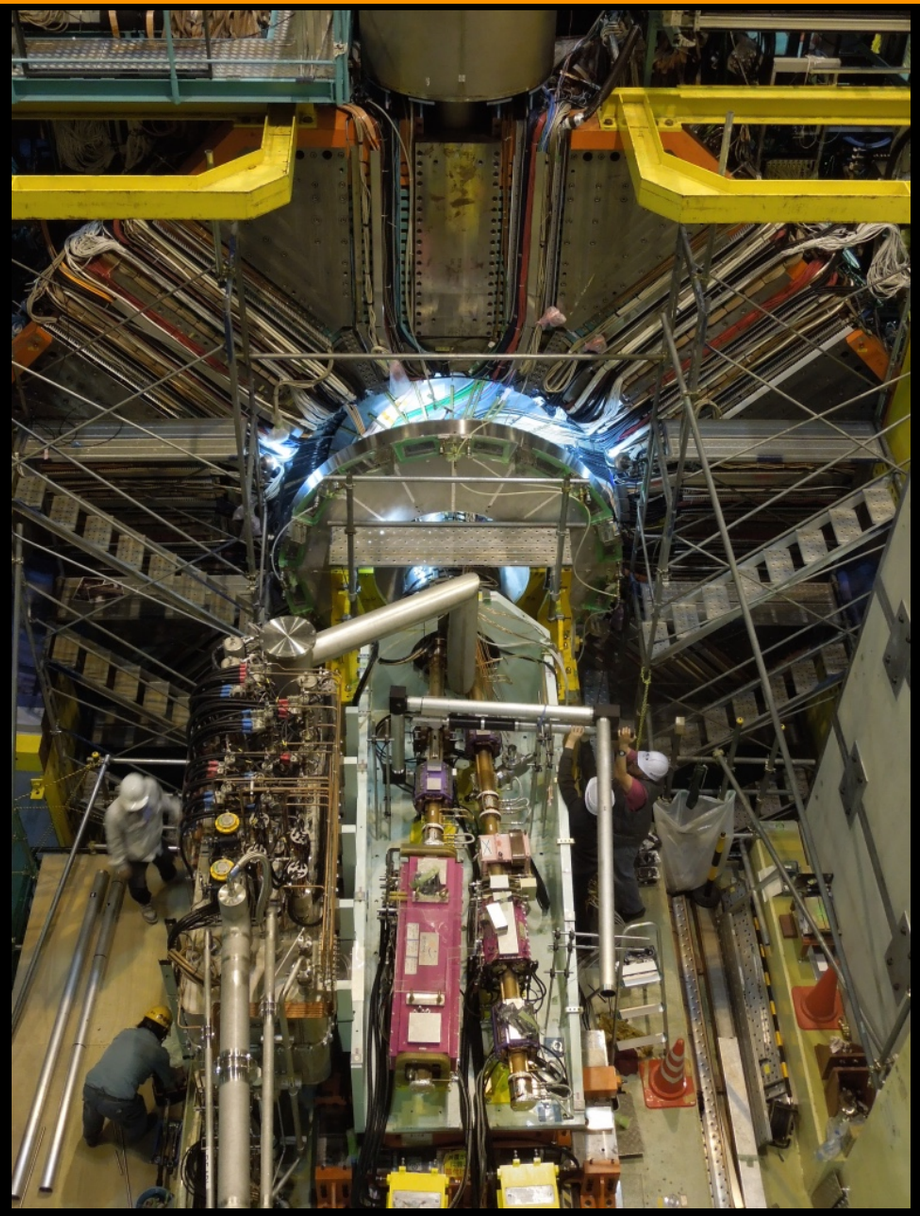
- Belle (1999 - 2010)
  - CP violation in B meson system
- Belle -II
  - to finalize the results with larger statistical data

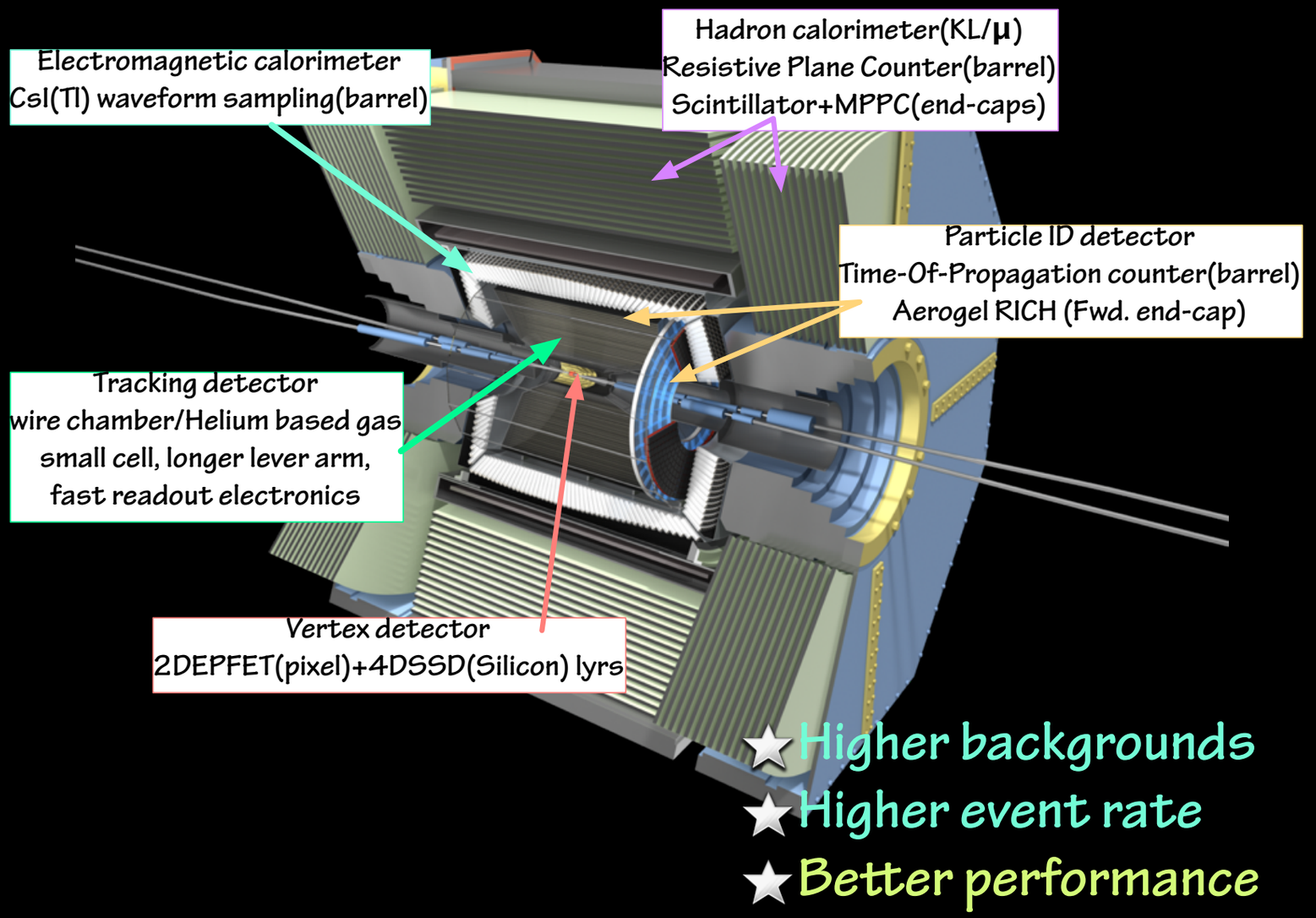


SuperKEKB / Belle-II

Target : $L = 8\text{x}10^{35}/\text{cm}^2/\text{s}$ (KEKB x40)
$L_{\text{int}} = 50/\text{ab}$ (Belle x50)

Belle II TDR, arXiv:1011.0352





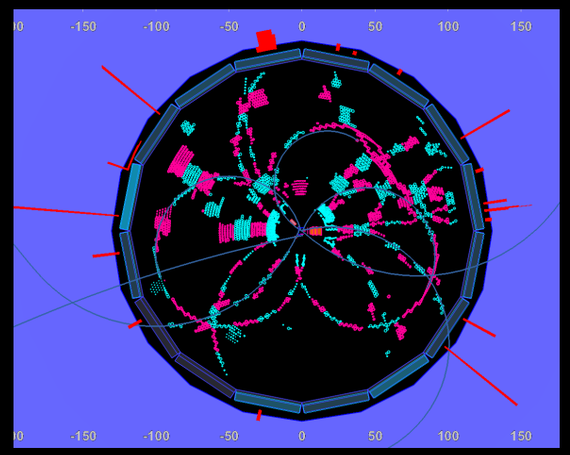
★ Higher backgrounds
★ Higher event rate
★ Better performance

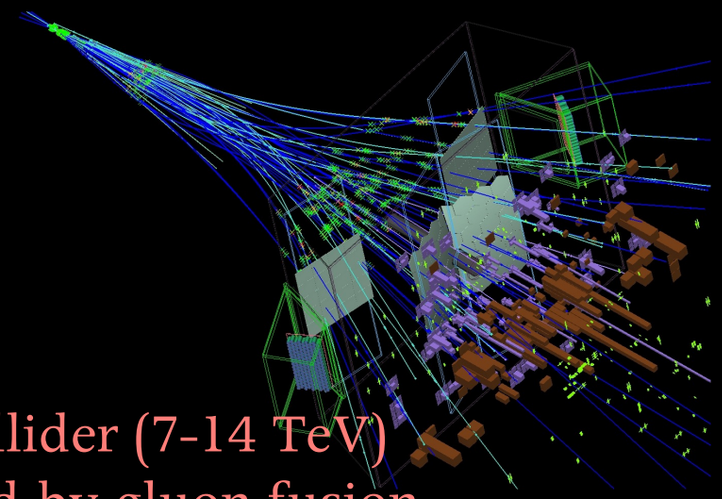
Belle II collaboration

- grown a lot in the last years
- ~1000 members in 26 countries, >100 institutes

KEK, Tsukuba, Japan

51 collaborators from Korea





electron -positron collider

$e^- e^+ \to \Upsilon(4S) \to B\bar{B}$

Exclusive production

$B_d \bar{B}_d$

$\sigma_{bb} \sim 1\text{nb}$; $\sim 1 \times 10^6$ $b\bar{b}$ pairs/fb^{-1}

proton -ptoron collider (7-14 TeV)
b quarks produced by gluon fusion

All b-hadron varieties produced

B_d, B_s, B_c, Λ_b

$\sigma_{bb} \sim \mathcal{O}(100)\mu\text{b}$; $\sim 1 \times 10^{11}$ $b\bar{b}$ pairs/fb^{-1}

low multiplicity and clean environment

B mesons almost at rest in lab frame
asymmetric beam energies boost for decay vertex separation

Hermetic 4π detector

Advantage in modes including γ, π^0, ν (missing)

high multiplicity and not clean environment

Highly boosted topology gives excellent decay vertex separation.

Longitudinally boosted bb pairs

Advantage in charged particles modes and Bs decays

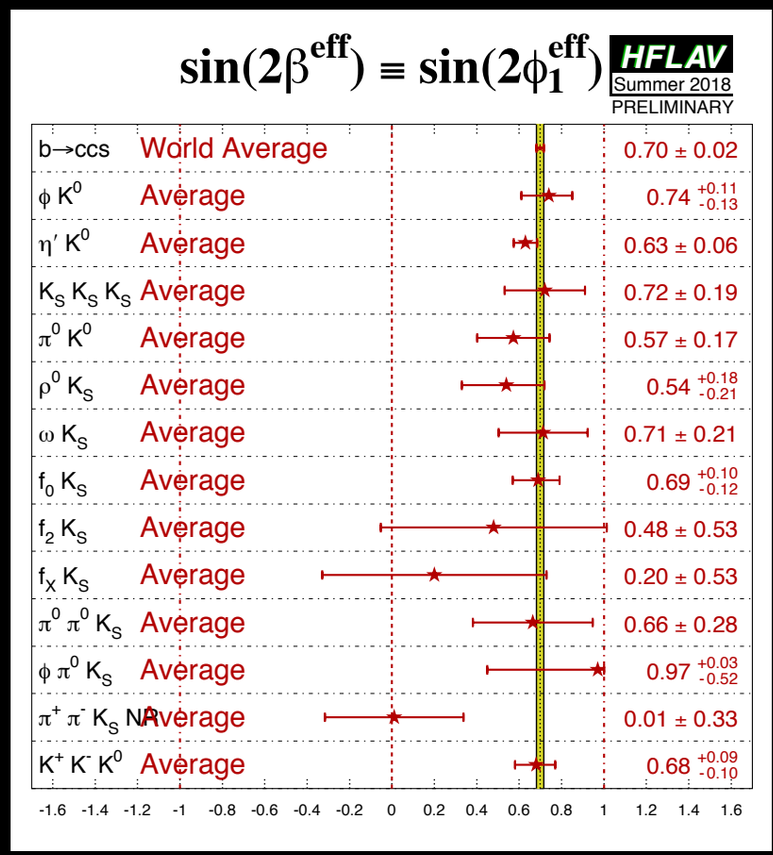
different systematics

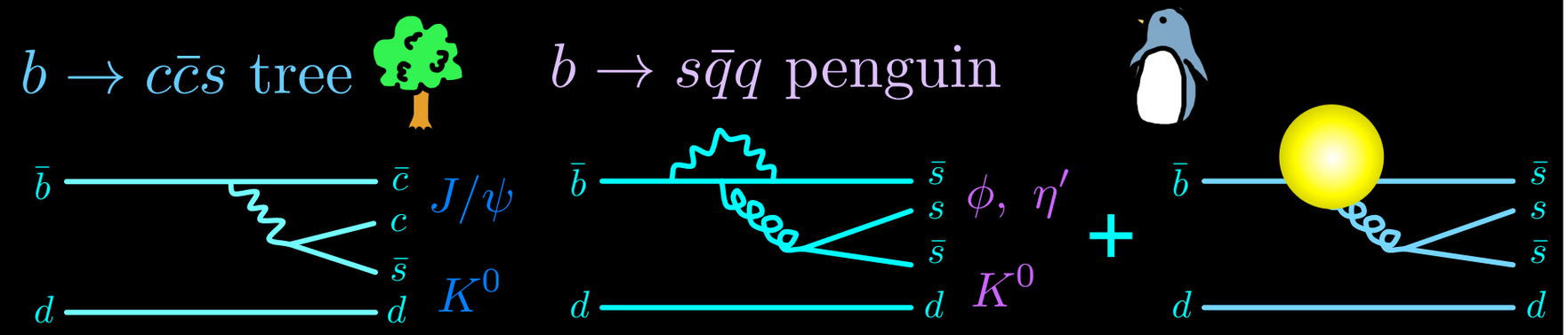
Two experiments are required to establish NP

sin2φ1 at Belle2 50/ab

- $\sin 2\Phi_1$
  - $b \to s$ transition
    - New physics can contribute to loop
    - promising way to probe additional CPV phase from New Physics
  - $b \to c$ transition
    - tree diagram is dominant
    - can be measured precisely as SM reference

More statistics is crucial for mode-by-mode studies





$\sin 2\phi_1^{\rm eff} \sim \sin 2\phi_1$ @SM

$\sin 2\phi_1^{\rm eff} \neq \sin 2\phi_1$

decay amplitude is dominated by
the short distance penguin transition $b \to s\bar{s}s$

Gold - plated modes

★★ $B \to \phi K_S^0$

★ $B \to \eta' K_S^0$

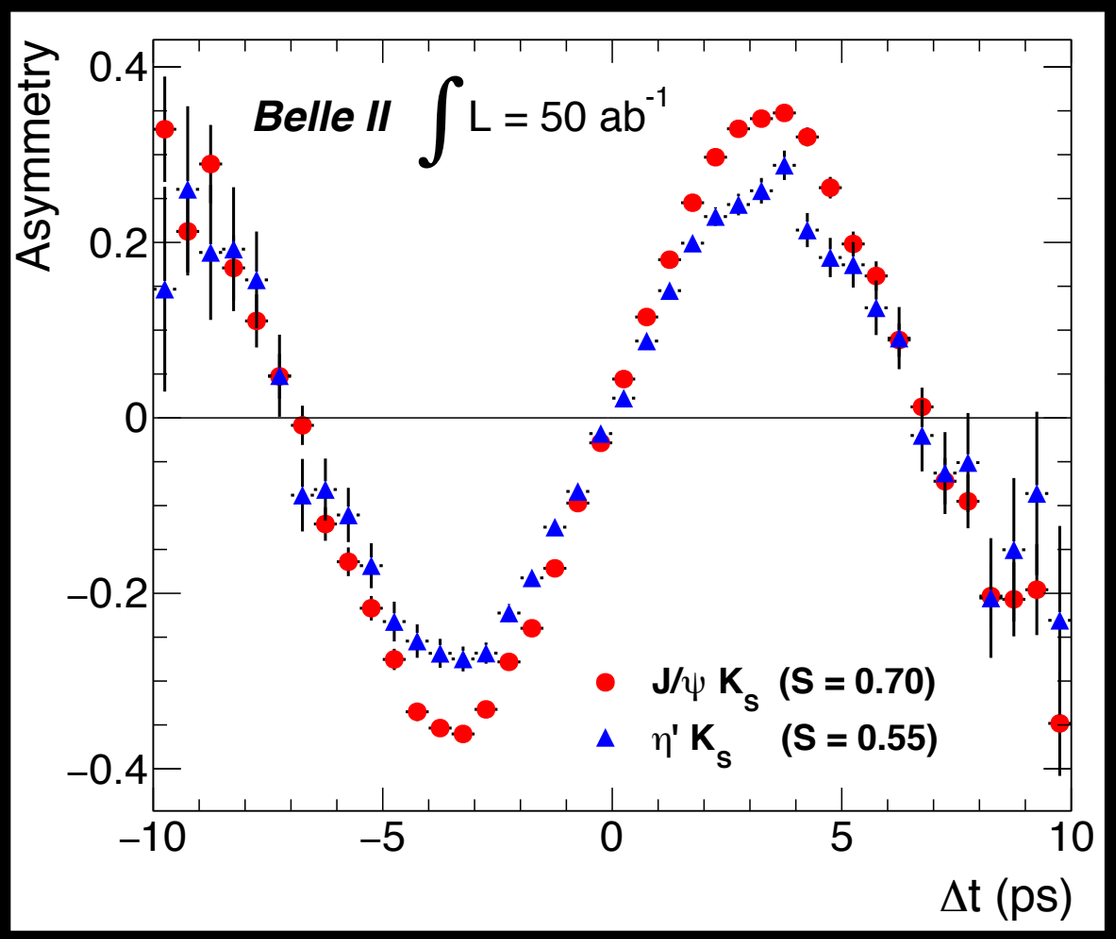
★ $B \to K_S^0 K_S^0 K_S^0$

sin2φ1 at Belle2 50/ab

soon the measurement will be systematics limited; need to control them

$B^0 \to (c\bar{c})K^0$ as SM reference

$\sin 2\phi_1$		$\mathcal{A}$symmetry		
0.67 ± 0.023	± 0.012	0.006 ± 0.016	± 0.012	Belle
$x.xx \pm 0.0027$	± 0.0044	$x.xx \pm 0.0033$	± 0.0037	Belle II (50/ab)



	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
ωK^0_S	0.21	0.14	0.08	0.06	0.024	0.020
$K^0_S \pi^0 \gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K^0_S \pi^0$	0.17	0.10	0.09	0.06	0.028	0.018

the two values would be unambiguously distinguishable, signifying the existence of New Physics

R(K*) at Belle2 50/ab

Lepton Flavor Universality is conserved in SM

R_K and R_{K^*} should be unity

~2 sigma tension is reported by LHCb in R_{K^*}

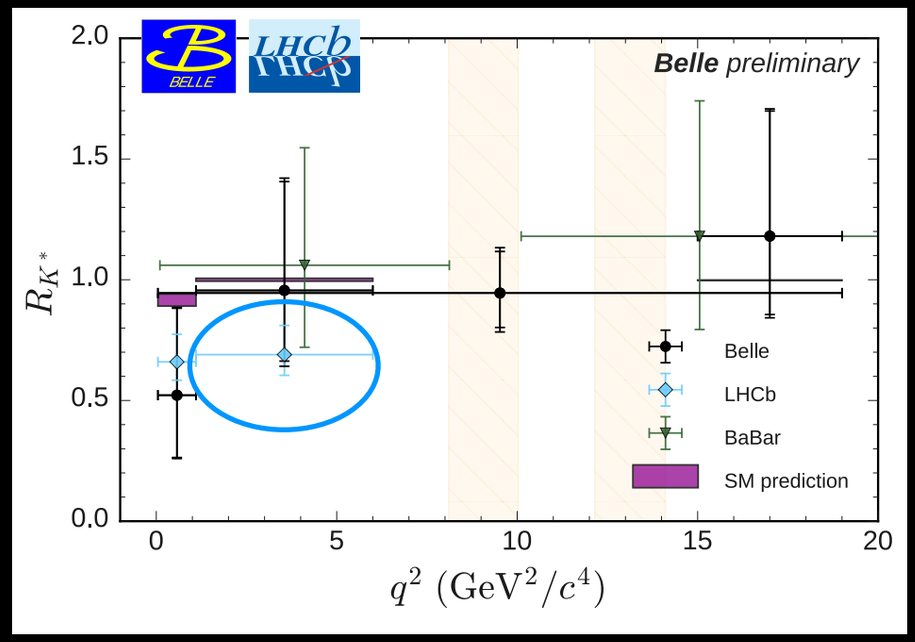
Belle results is consistent with SM,

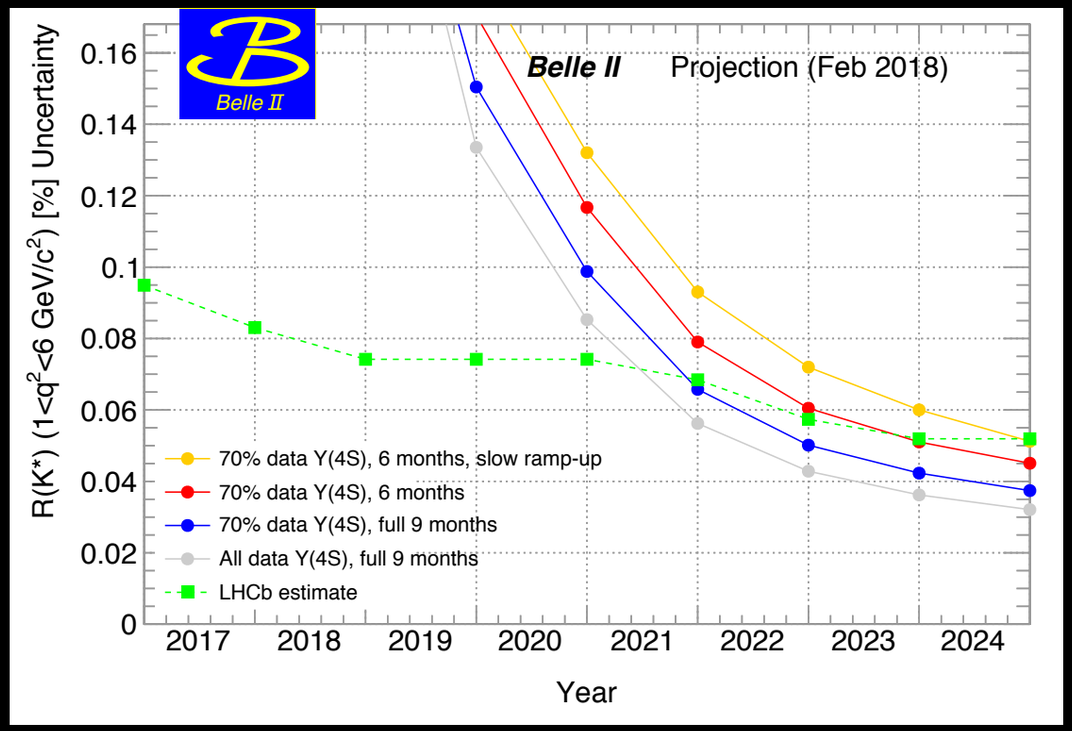
but error is still large

[Belle, arXiv:1904.02440]

$$R_{K^*} = 0.94^{+0.17}_{-0.14} \pm 0.08 \quad (q^2 > 0.045\mathrm{GeV}^2)$$

$R_{K^*} = \Gamma(B \to K^* \mu\mu)/\Gamma(B \to K^* ee)$





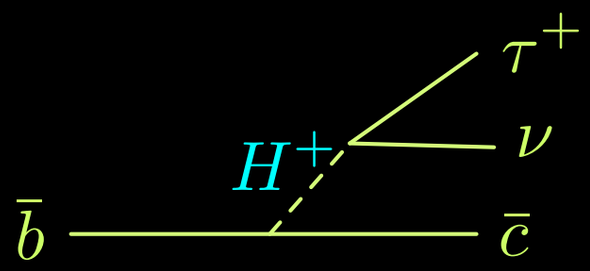
Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
R_K ($[1.0, 6.0]\,\mathrm{GeV}^2$)	28%	11%	3.6%
R_K ($> 14.4\,\mathrm{GeV}^2$)	30%	12%	3.6%
R_{K^*} ($[1.0, 6.0]\,\mathrm{GeV}^2$)	26%	10%	3.2%
R_{K^*} ($> 14.4\,\mathrm{GeV}^2$)	24%	9.2%	2.8%

If the anomaly is true,

5 sigma confirmation is possible before 50/ab

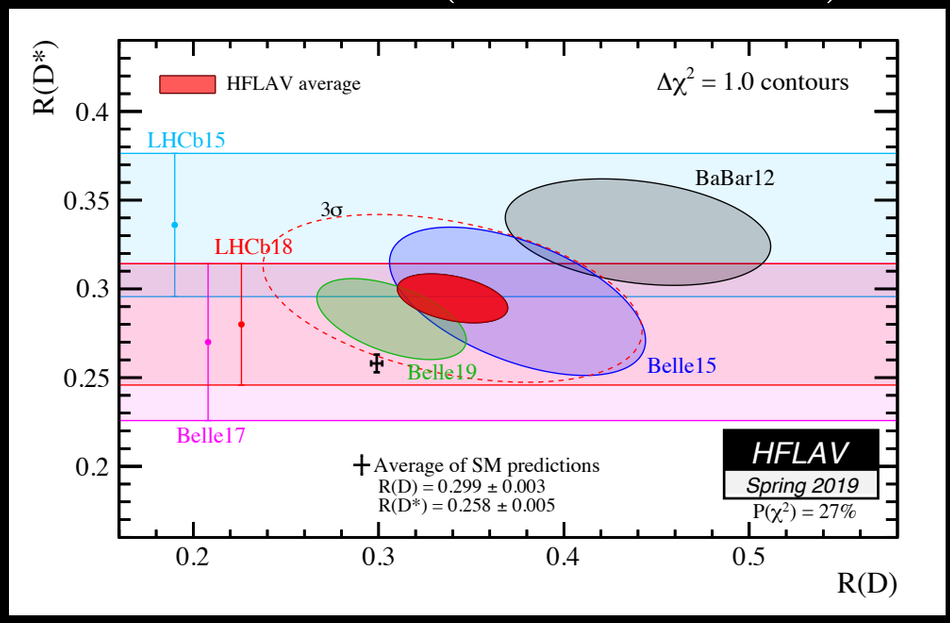
B->D$^{(*)}\tau\nu$ at Belle2 50/ab

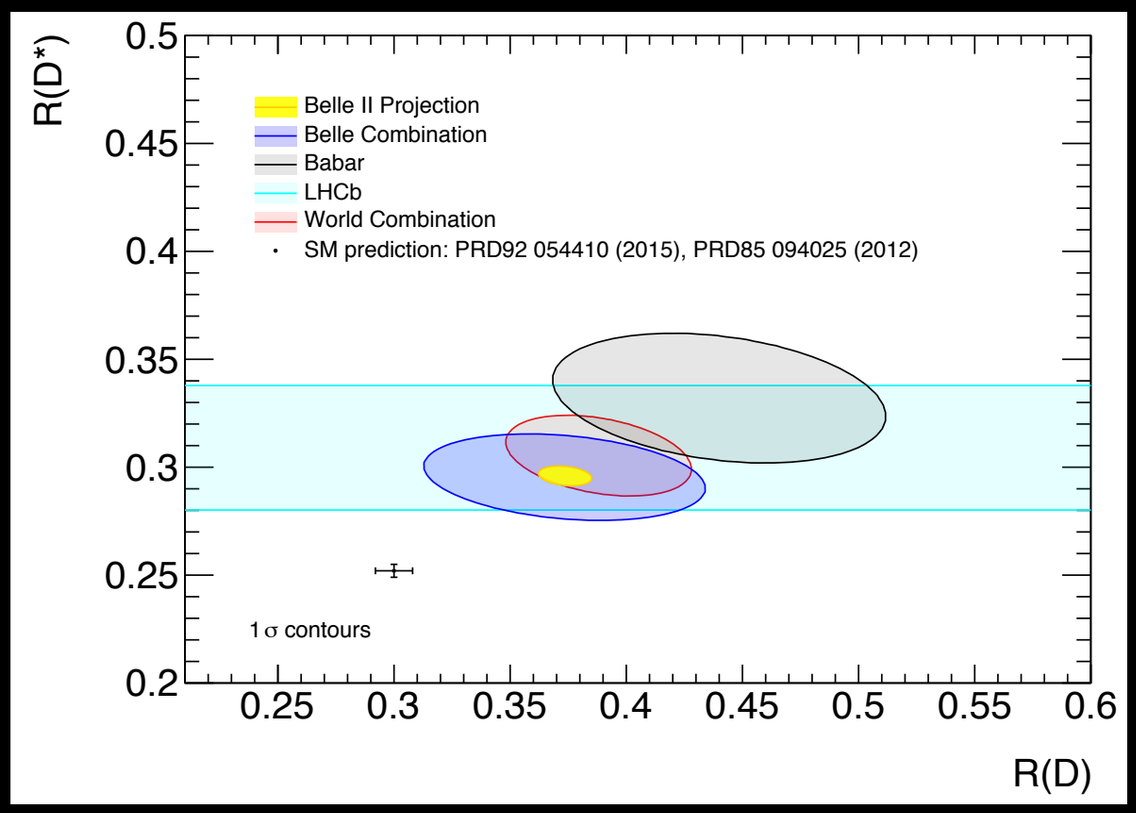
tree level process with intermediate $W^{\pm}$



sensitive to charged Higgs

$$R(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)}$$

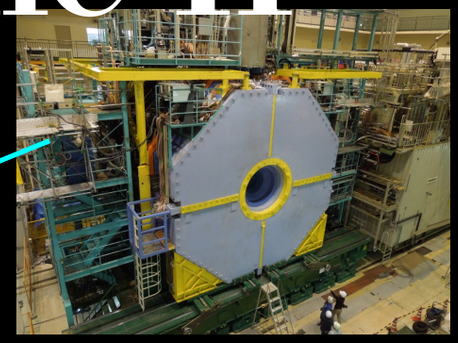




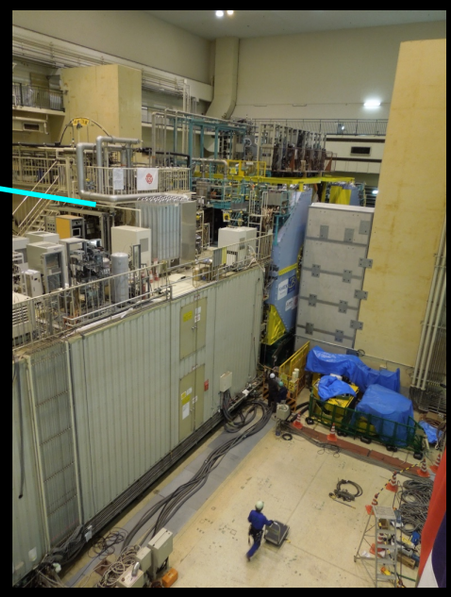
	5 ab^{-1}	50 ab^{-1}
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$

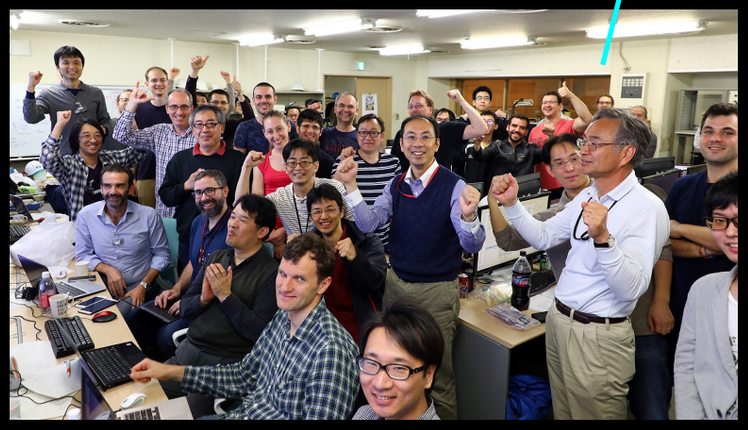
> 5 sigma discovery would be possible

status of SuperKEKB/Belle II



- Phase-1 : Accelerator commissioning without Belle2 detector
- Roll in of Belle2 detector : 2017 Apr.
- Phase-2 : Detector commissioning (~500 /pb)
- First collision : 2018 Apr.
- Phase-3 : physics data taking. 2019 Mar. -



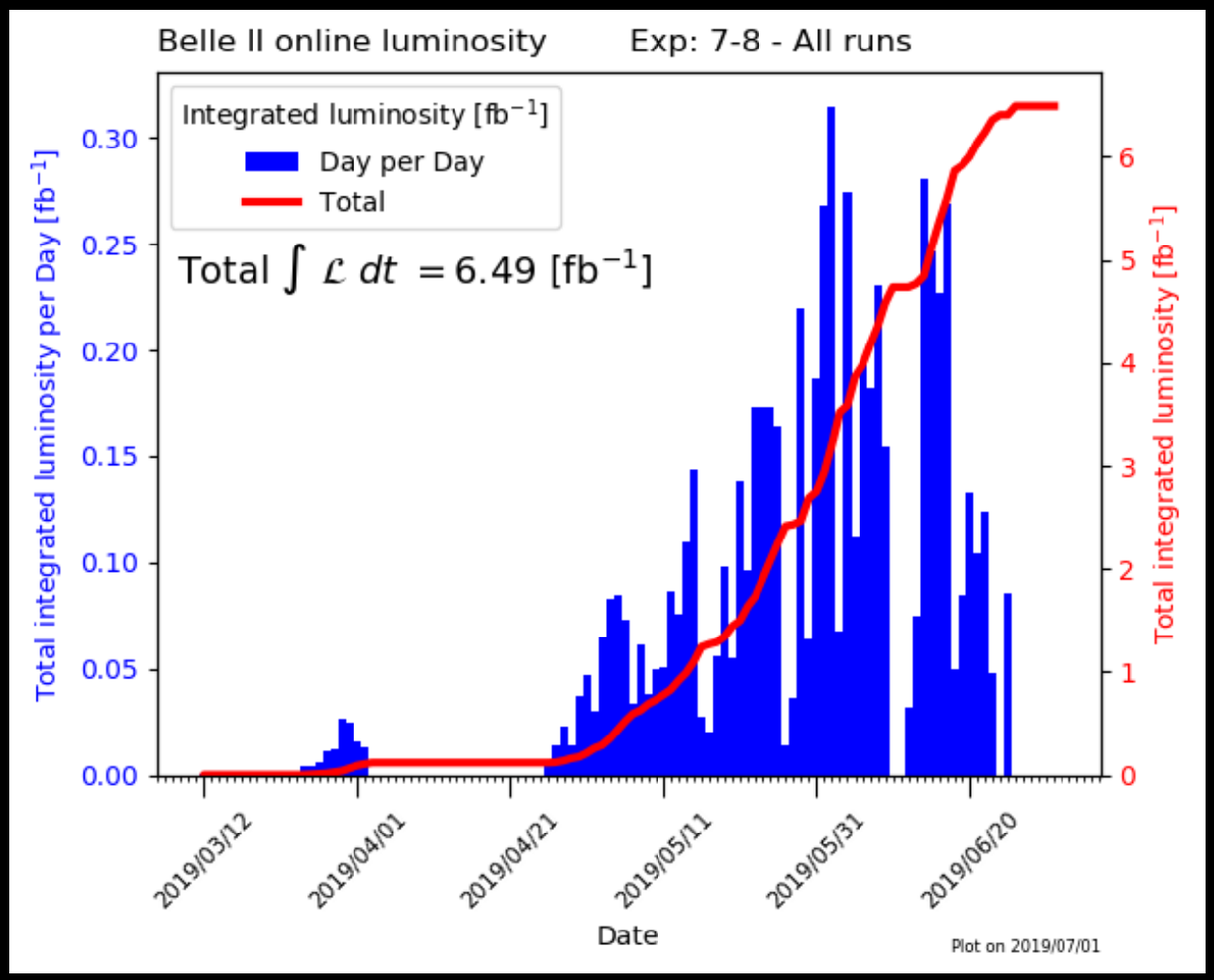


behind the scene

the day before first collision

(5:00 am)

status of SuperKEKB/Belle II



- phase-3 run began at the beginning of April
  - spring run ended in the morning on July 1st
  - will resume autumn run in Oct.
- Achieved:
  - beam current(max) = 660mA (target 2.6/3.6A)
  - βy^* : 2mm (target 0.3mm)
  - L_{peak} : 6.1×10^{33} (Belle-1 1×10^{34}, target 8×10^{35})

Belle II x5 = Belle III ??

- Flavor physics has potential of improvement to search new physics with larger data sample
- No concrete plan yet, just initial discussions..
  - Belle II (50/ab) x5 = 250/ab
  - baseline : Belle II structure, Belle II detector
    - studies to understand limitation of detectors
  - background reduction is crucial

summary

- Belle II experiment at SuperKEKB aims to find New physics beyond the SM with ultimate precision measurement of heavy flavor decays
- Belle II physics run has just started
- We expect many interesting and exciting results in coming years !!