Time-Dependent *CP* violation processes in B-meson decays

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on behalf of the BABAR Collaboration

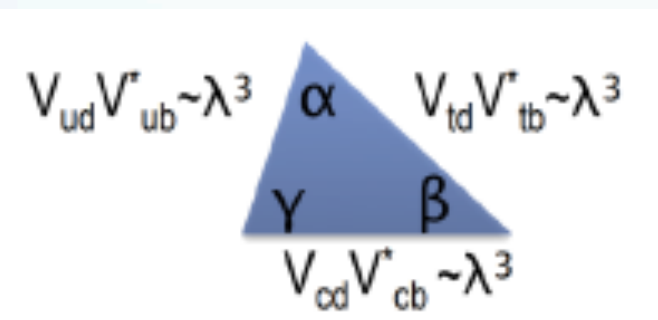
Thanks to LHCb, Belle, and Belle II coordinators for their inputs to this talk

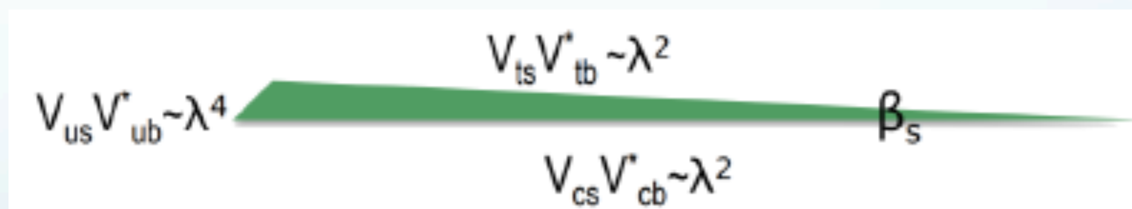
The CKM matrix and the Unitarity Triangles

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

- Describes the quark mixing in weak charged transitions
- The CKM is unitary
- 3 real parameters A, ρ, λ and 1 phase η ➡ V_{ij} are complex
- Interfering amplitudes can give *CP* violating asymmetries
- The CKM is the only source of *CPV* in the SM

The unitarity relations can be represented as triangles in the complex plane with angles related to CKM matrix elements

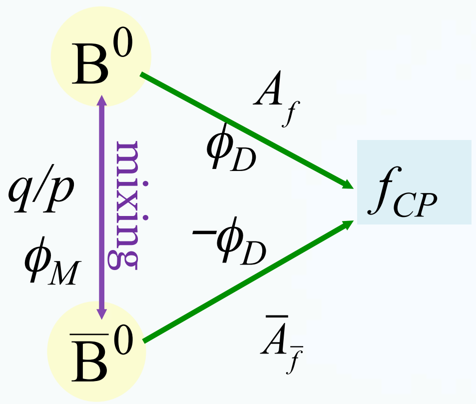




$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

$$V_{us}V^*_{ub} + V_{cs}V^*_{cb} + V_{ts}V^*_{tb} = 0$$

Time-dependent *CP* asymmetries



- *CP* violation arises from interference between the two paths (decay with and without mixing)

$$\lambda_f = |\lambda_f| e^{i\phi_{d,s}} = \frac{q}{p} \cdot \frac{\bar{A}_f}{A_f}$$

Independent of phase convention ← λ_f

Decay amplitude ratio → $\bar{A}_f / A_f$

Phase factor due to mixing → q/p

Time-dependent *CP* asymmetry:

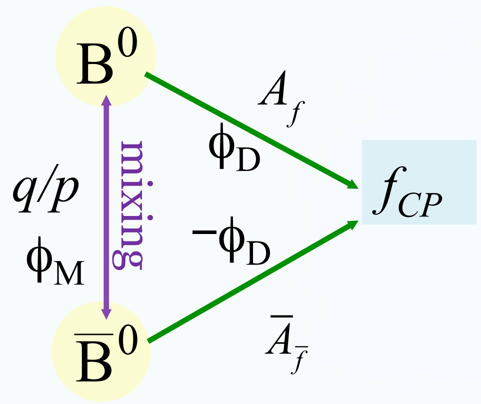
Direct CPV (C_f) ***Mixing-induced CPV*** (S_f)

$$A_{CP}(t) = \frac{\Gamma\left(\bar{B}^0(t) \to f\right) - \Gamma\left(B^0(t) \to f\right)}{\Gamma\left(\bar{B}^0(t) \to f\right) + \Gamma\left(B^0(t) \to f\right)} = \frac{-C_f \cos\left(\Delta m_{d,s} t\right) + S_f \sin\left(\Delta m_{d,s} t\right)}{\cosh\left(\frac{\Delta\Gamma_{d,s}}{2} t\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_{d,s}}{2} t\right)}$$

$$C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}, \quad S_f = \frac{2\, Im\lambda_f}{1+|\lambda_f|^2}, \quad A_f^{\Delta\Gamma} = \frac{-2\, Re\lambda_f}{1+|\lambda_f|^2}$$

Time-dependent (TD) asymmetries provide information on the weak phase $\phi_{d,s} = \phi_M - 2\phi_D$

Time-dependent *CP* asymmetries



- *CP* violation arises from interference between the two paths (decay with and without mixing)

Independent of phase convention ← $\lambda_f = |\lambda_f| e^{i\phi_{d,s}} = \frac{q}{p} \cdot \frac{\bar{A}_f}{A_f}$ ← ***Decay amplitude ratio***

Phase factor due to mixing

Time-dependent *CP* asymmetry:

Direct CPV ***Mixing-induced CPV***

$$A_{CP}(t) = \frac{\Gamma\left(\bar{B}^0(t) \to f\right) - \Gamma\left(B^0(t) \to f\right)}{\Gamma\left(\bar{B}^0(t) \to f\right) + \Gamma\left(B^0(t) \to f\right)} = \frac{-C_f \cos\left(\Delta m_{d,s} t\right) + S_f \sin\left(\Delta m_{d,s} t\right)}{\cosh\left(\frac{\Delta\Gamma_{d,s}}{2} t\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_{d,s}}{2} t\right)}$$

TD asymmetries of B^0_d decays do not have the $A^{\Delta\Gamma}$ term ($\Delta\Gamma_d \approx 0$)

$$A_{CP}^{B_d}(t) = -C_f \cos\left(\Delta m_d t\right) + S_f \sin\left(\Delta m_d t\right)$$

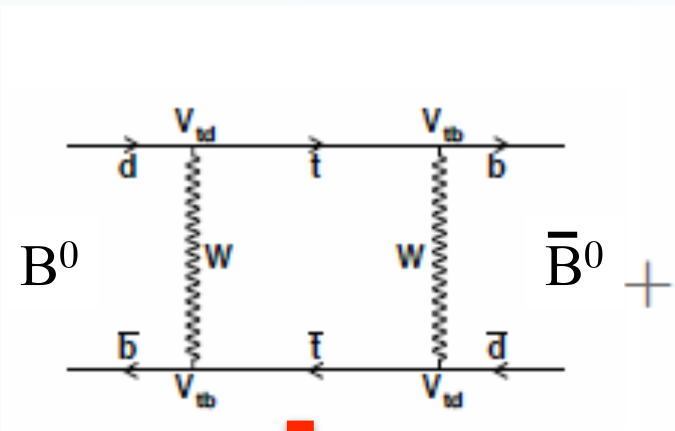
β/ϕ_1

<u>Remember:</u>

α.β,γ at *BABAR* and LHC experiments <=> ϕ_2,ϕ_1,ϕ_3 at Belle and Belle II

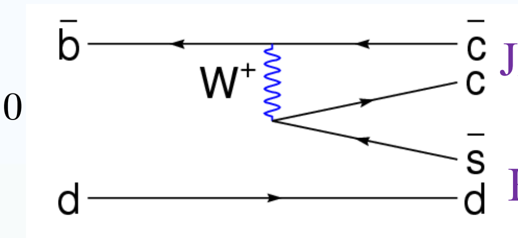
Measuring β in $b \to c$ transitions

- The angle β can be experimentally accessed exploiting the interference between B^0-$\bar{B}^0$ box diagram (phase 2β) and $b \to c$ decay amplitudes (no weak phase)
- **Not all $b \to c$ decays are equivalent!**



$e^{-i2\beta}$

B^0



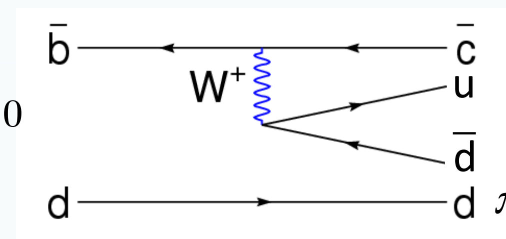
J/Ψ

K^0

$b \to c\bar{c}s$

The golden modes

B^0



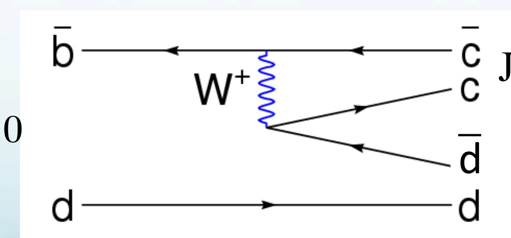
$D^{(*)0}$

π^0, η, ω

$b \to c\bar{u}d$

No penguin pollution. Benchmark for SM.

B^0



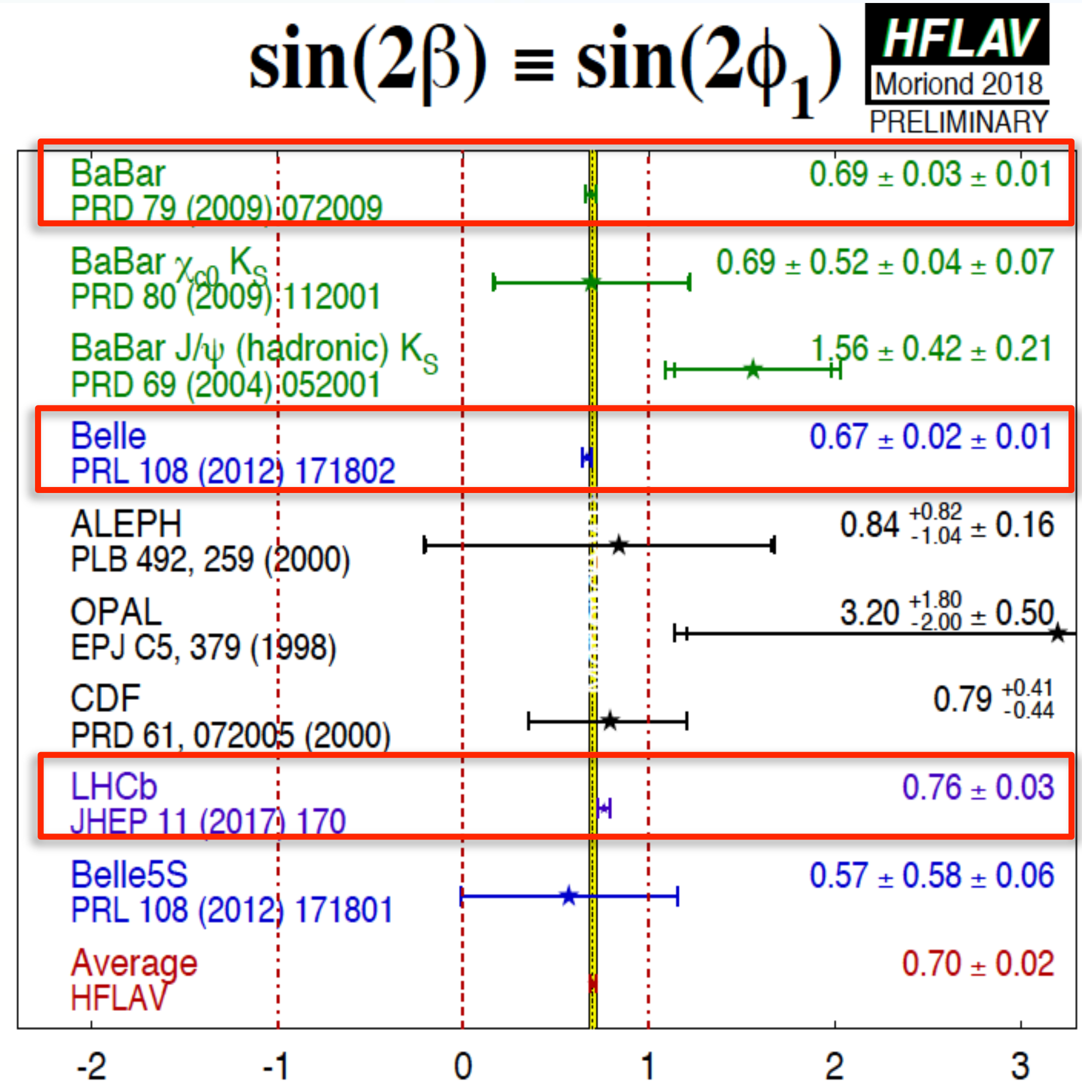
J/Ψ

$\pi^0, \eta, \rho^0, \omega$

$b \to c\bar{c}d$

Constraints for penguin pollution.

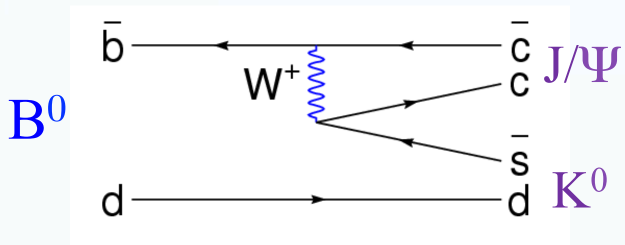
sin2β from $B^0 \rightarrow [c\bar{c}]\, K^0$



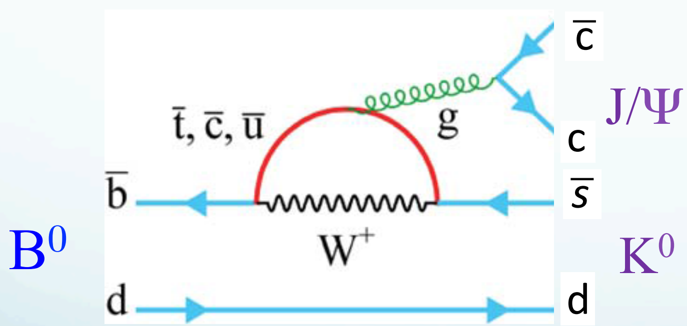
- Sin2β is becoming a precision measurement, even though single measurement uncertainties are still slightly dominated by statistics
- New data from LHCb Run 3 and Belle II will lower the overall uncertainty to $\lesssim 1°$, at the level of expected contamination of penguin diagrams

A closer look to $b \to c\bar{c}s$ transitions

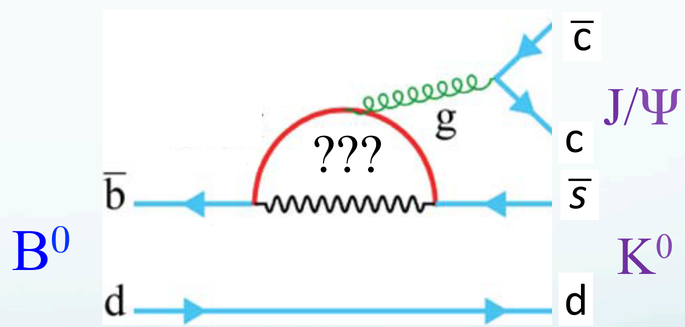
- Precision on sin2β already less than 3%. Expected to go down to less than 1% with the next LHC and Belle II data



Leading tree diagram:
No complex phase in decay amplitude

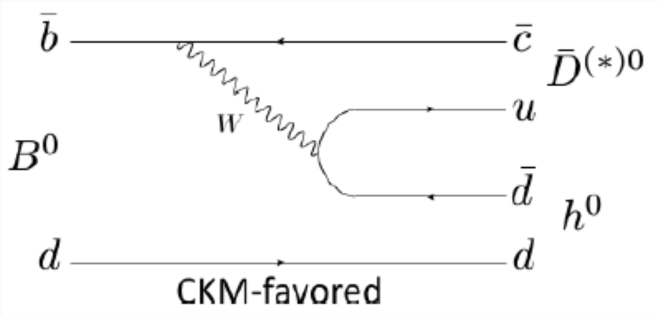


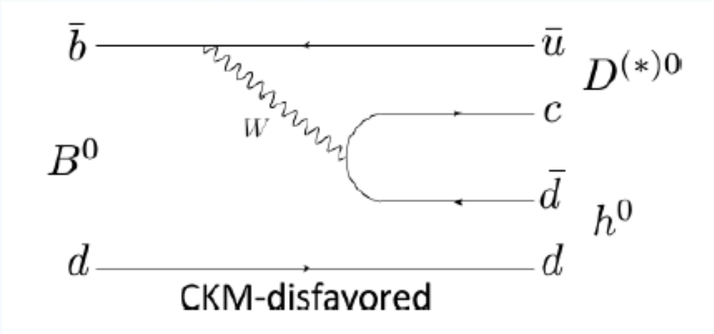
Suppressed SM penguin diagram:
$O(10^{-2})$ effects on sin2β



New Physics penguin diagrams could have a higher effect

Set a SM reference from $b \to c\bar{u}d$ decays





- $B^0 \to D^{(*)0} h^0$ ($h^0 = \pi^0,\eta,\omega$) decays are mediated only by tree-level amplitudes
  ==> penguin-pollution free
- Theoretically clean [NPB 659, 321 (2003)]
  - Allows to test the precision measurements in $b \to c\bar{c}s$ decays
  - Can provide a SM reference for sin2β

- Experimental difficulties:
  - If $D^0 \to D_{CP}$: low branching fractions (both for B and D_{CP} decays)
  - If $D^0 \to K_S\pi^+\pi^-$: many intermediate states => Dalitz-plot analysis
    - The time-dependent analysis is sensitive to both $\sin2\beta$ and $\cos2\beta$ [PLB 624, 1 (2005)]
  - Low reconstruction efficiencies and large background

Perform time-dependent *CP* analysis combining *BABAR* and Belle data sets. Overall ~1.1 ab^{-1} ➔ 1240 x 10^6 $B\bar{B}$ events

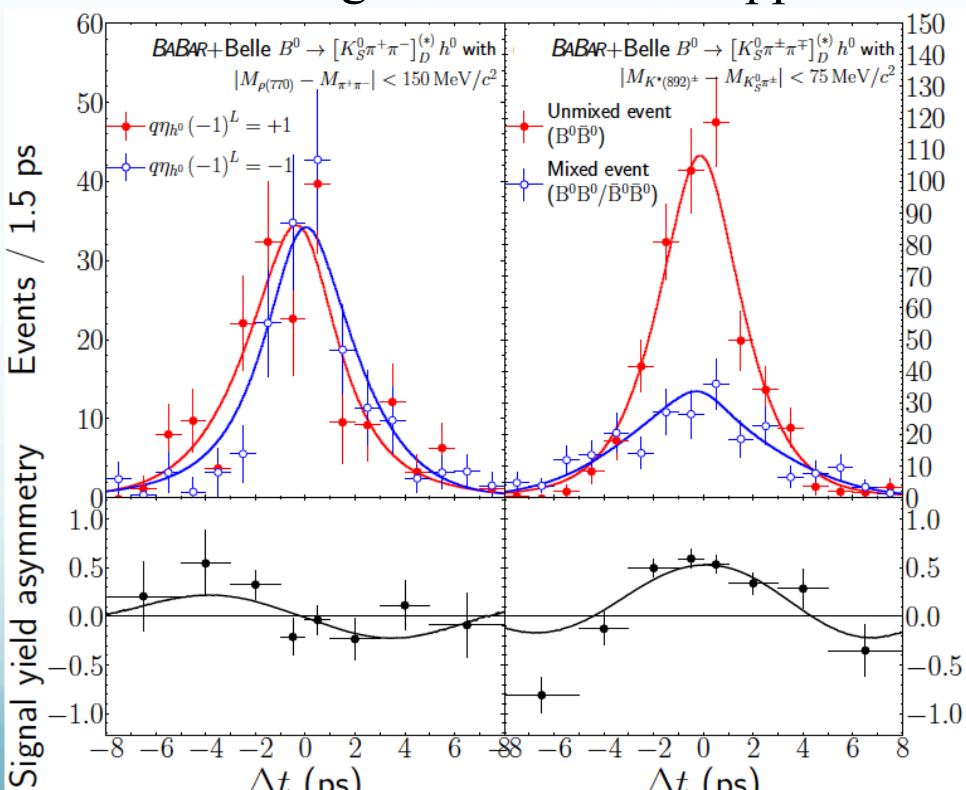
Combined BABAR-Belle analysis of $B^0 \to D^{(*)0} h^0$

- Apply similar selection on both data sets
- Suppression of $e^+e^- \to qq$ continuum events by a NN algorithm
- Signal extracted by a 3D fit to M_{bc}/M_{ES}, ΔE and Neural Network

- $B^0 \to D^{(*)}h^0$ reconstructed modes:
  $D^{*0} \to D^0\pi^0$; $D^0 \to K_S\pi^+\pi^-$
  h^0 modes : $\pi^0\to\gamma\gamma$, $\eta\to\gamma\gamma$, $\eta\to\pi^+\pi^-\pi^0$, $\omega\to\pi^+\pi^-\pi^0$

Signal: *BABAR* 1129 ± 48; Belle 1567 ± 56

- A common signal DP model is applied



PRL 121 (2018) 261801
PRD 98 (2018) 112012

$\sin 2\beta = 0.80 \pm 0.14 \pm 0.06 \pm 0.03$
$\cos 2\beta = 0.91 \pm 0.22 \pm 0.09 \pm 0.07$
$\beta \equiv \phi_1 = (22.5 \pm 4.4 \pm 1.2 \pm 0.6)°$

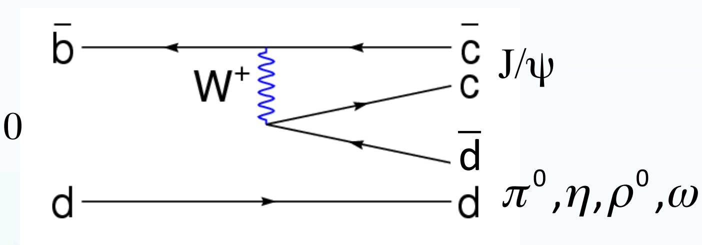
✓ Observation of *CP* violation at 5.1 σ
✓ **First evidence for $\cos 2\beta > 0$ (3.7 σ)**
✓ Direct exclusion of the 2nd solution: $\pi/2 - \beta = (68.1 \pm 0.7)°$ at 7.3 σ

Constraining the effect of penguin pollution in $b \to c\bar{c}s$

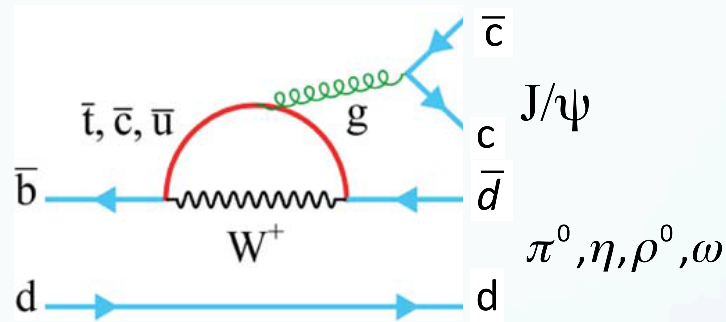
- Penguin diagrams in $b \to c\bar{c}s$ with different weak phase are doubly Cabibbo-suppressed
- Penguin diagrams in $b \to c\bar{c}d$ are of the same order as the tree diagram

⇒ Use $2\beta_{eff} = 2\beta + \Delta 2\beta$ measured in these decays, together with SU(3) symmetry, to constrain size and phase shift due to penguin pollution in favored $b \to c\bar{c}s$: $\delta_p \sim \varepsilon \Delta 2\beta$, where $\varepsilon = \lambda^2/(1-\lambda^2) \sim 0.053$, is the *P/T* Cabibbo-suppression factor

B^0



B^0

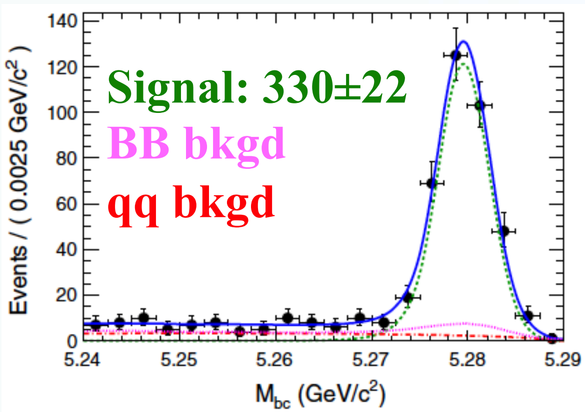


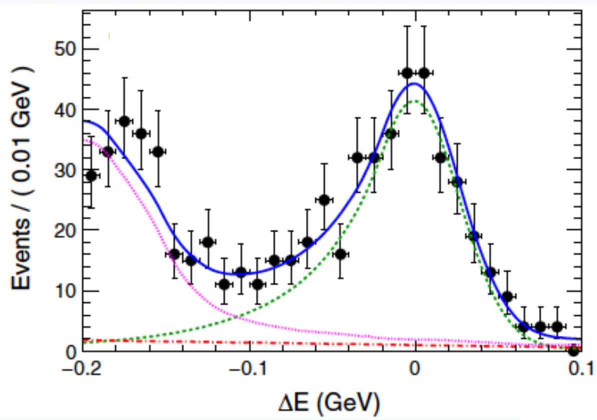
Examples:

- $\boldsymbol{B_d \to J/\psi\, \pi^0, J/\psi\, \rho^0}$ to constrain $\boldsymbol{\Delta 2\beta \equiv \Delta\phi_d}$ **in** $\boldsymbol{B_d \to J/\psi\, K^0}$ [Ciuchini *et al.*, PRL 95, 221804; Faller *et al.*, PRD 79, 014030]
- $\boldsymbol{B_d \to J/\psi\, \pi^+\pi^-}$ **and** $\boldsymbol{B_s \to J/\psi\, K^{*0}}$ to constrain $\boldsymbol{\Delta\phi_s}$ **in** $\boldsymbol{B_s \to J/\psi\, \phi}$ [Faller *et al.*, PRD 79, 014005]
- Similar arguments hold for other charmonium states

$B^0 \to J/\psi\, \pi^0$ at Belle

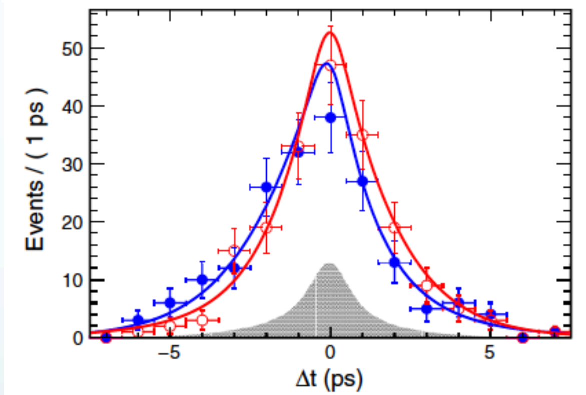
PRD98 (2018) 112008





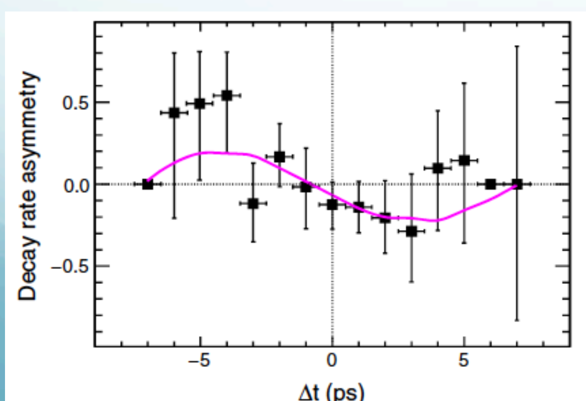
$B_d \to J/\psi\, \pi^0$,
$J/\psi \to \mu^+\mu^-, e^+e^-$,
$\pi^0 \to \gamma\gamma$.

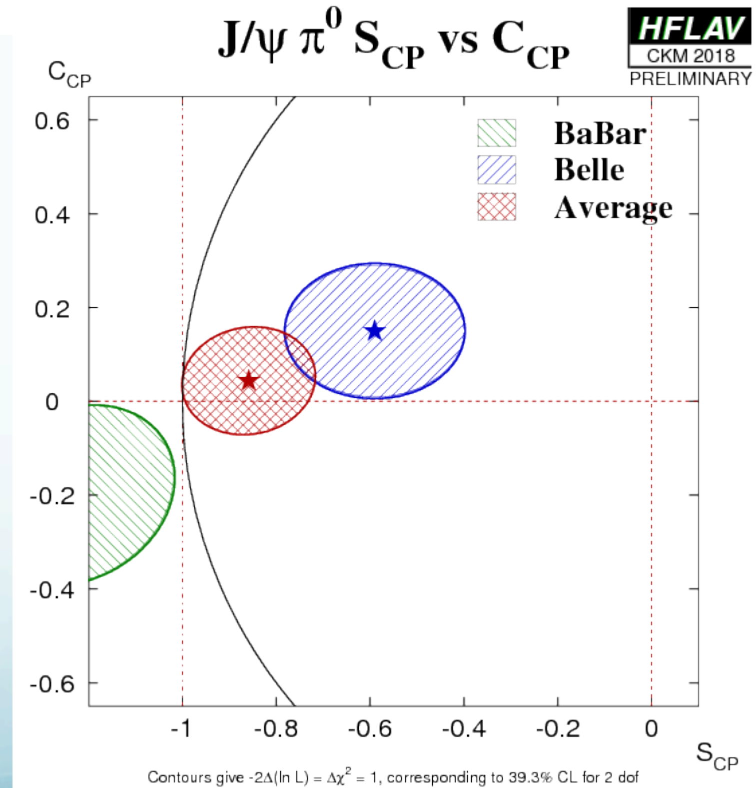
$$\mathcal{B} = (1.62 \pm 0.11 \pm 0.06) \times 10^{-5}$$



$$S = -0.59 \pm 0.19 \pm 0.03$$
$$A = -0.15 \pm 0.14^{+0.04}_{-0.03}$$

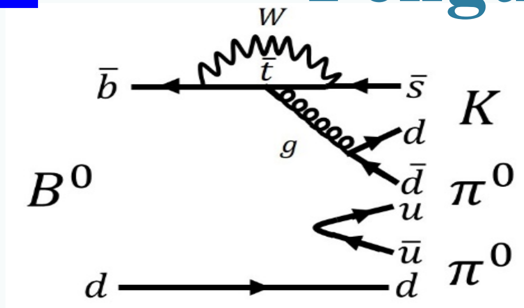
- Evidence for mixing-induced CPV ($S \neq 0$ at 3σ)
- $A \equiv -C$ consistent with zero





Penguin decays

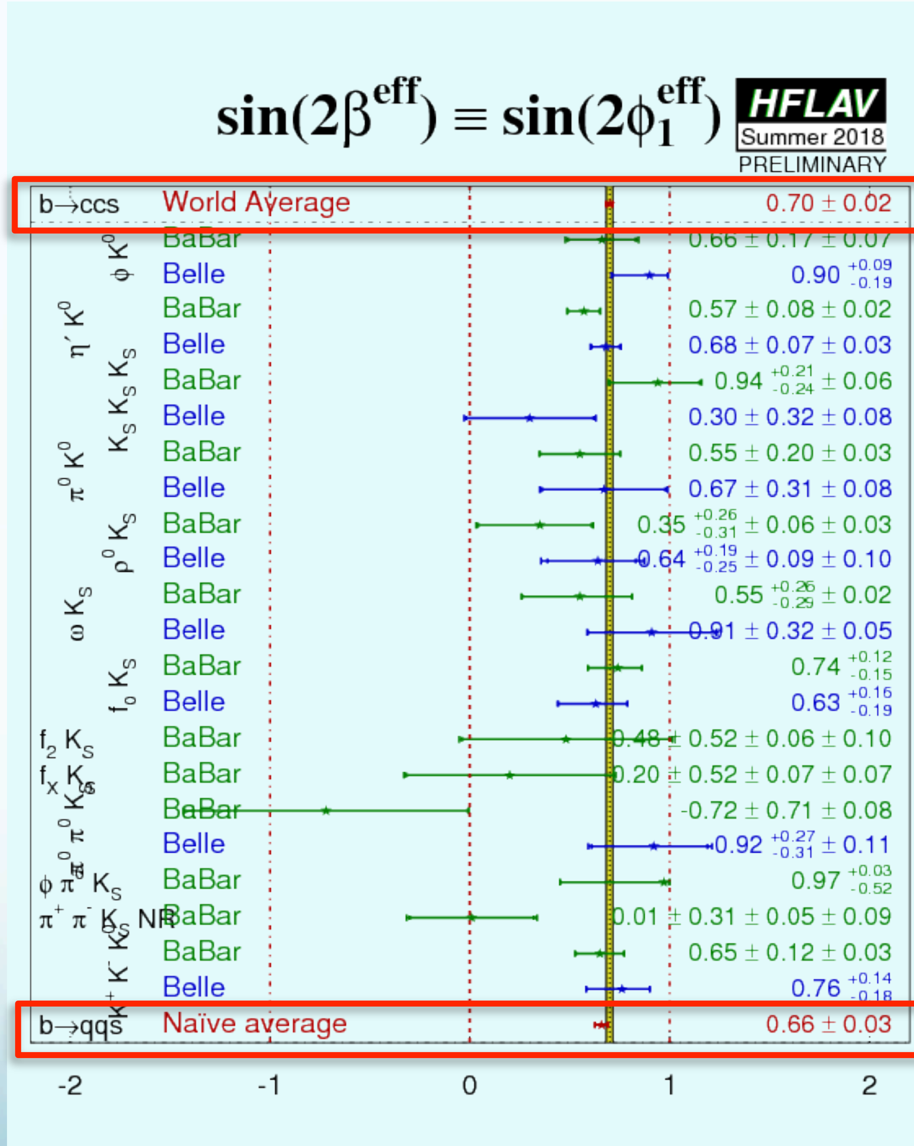
Penguin-dominated *B* decays



- $b \to s$ penguin are very sensitive to NP
- Contamination from tree diagrams (phase γ) Cabibbo and/or color suppressed

- Within the SM, same weak phase as $b \to c\bar{c}s$ processes:
  - $C_{sqq} \approx 0$, $S_{sqq} \approx -\eta_f \sin 2\beta$

- **Observing $S_{sqq} \neq S_{J/\psi Ks}$ might indicate presence of NP particles**
- Overall, good consistency between averaged penguins and $b \to c\bar{c}s$ *CPV*
  - but not always straightforward to make averages

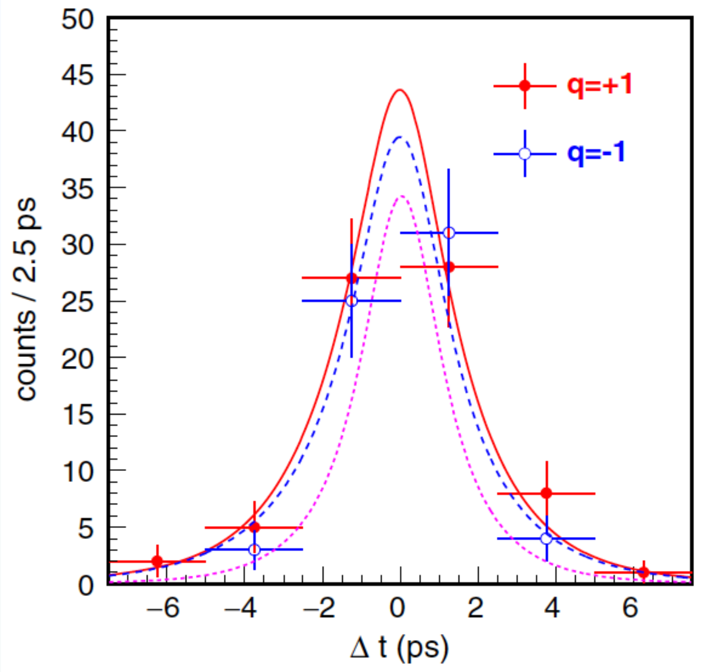


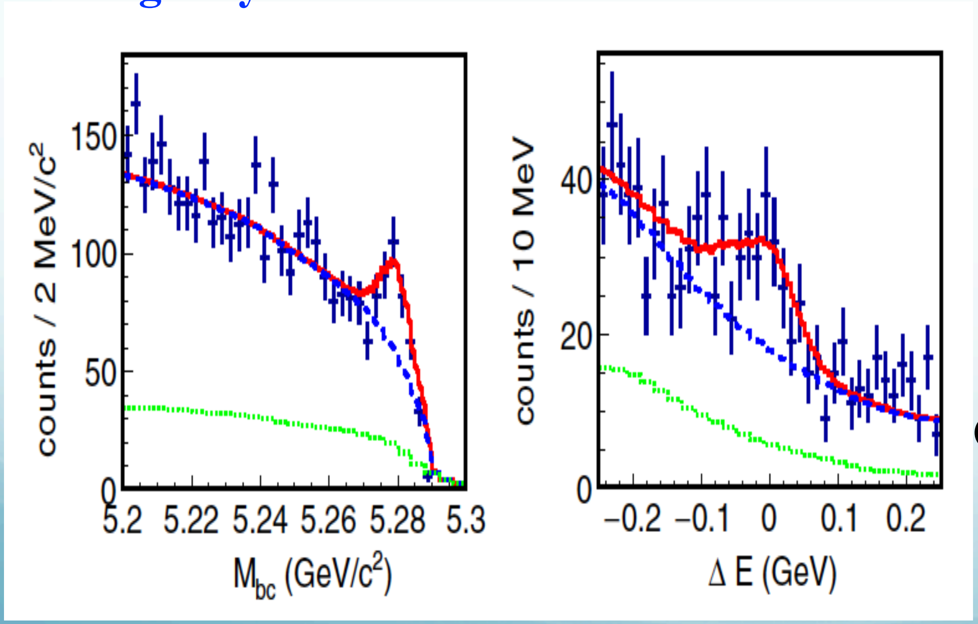
$B^0 \rightarrow K_S \pi^0\pi^0$ at Belle

PRD99 (2019) 011102

- 770M $B\bar{B}$ pairs (3.4X *BABAR* dataset)
- Reconstruct $K_S \rightarrow \pi^+\pi^-$, $\pi^0 \rightarrow \gamma\gamma$
- ee $\rightarrow$ $q\bar{q}$ background described with a likelihood based on event-shape variables
- Signal extraction via a 3D unbinned maximum likelihood fit to
  - ΔE, M_{bc}, $q\bar{q}$-likelihood distributions

- **Signal yield: 146.7 ± 23.6 events**





$$S = -0.92^{+0.31}_{-0.27} \pm 0.11$$
$$A \equiv -0.15 \pm 0.21 \pm 0.04$$

Consistent with *BABAR* PRD 76 (2007) 071101

$$\boldsymbol{S} = -0.72 \pm 0.71 \pm 0.08$$
$$\boldsymbol{C} \equiv \boldsymbol{-A} = 0.23 \pm 0.52 \pm 0.13$$

Charmless $B^0_{d,s} \rightarrow h^+h^-$ decays

$B^0 \rightarrow h^+h^-$ and $B^0_s \rightarrow h^+h^-$

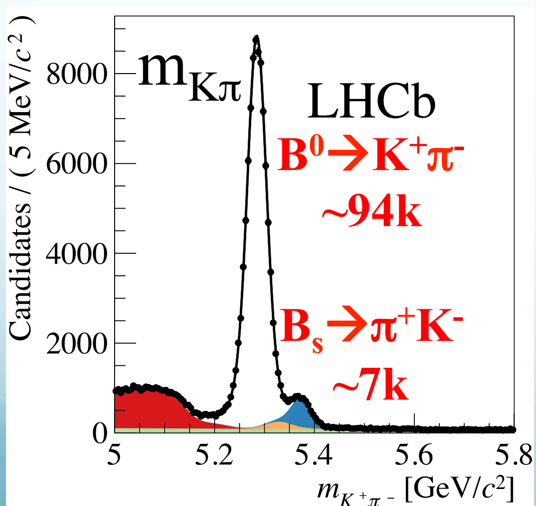
- $B^0 \rightarrow \pi^+\pi^-$ provides the determination of the UT angle α/ϕ_2 [PRL 65 (1990) 3381]
  - via the Gronau-London isospin relations with $B^0 \rightarrow \pi^0\pi^0$ and $B^+ \rightarrow \pi^+\pi^0$
- $B^0 \rightarrow \pi^+\pi^-$ and $B^0_s \rightarrow K^+K^-$ related by *U*-spin symmetry
  - The combined analysis of *BF*s and *CP* asymmetries allows for stringent constraints to the CKM angle γ and to the CP-violating phase $-2\beta_s$ [PLB 459 (1999) 306, PLB 482 (2000) 71, JHEP 10 (2012) 29]
  - Need to account for *U*-spin symmetry breaking effects

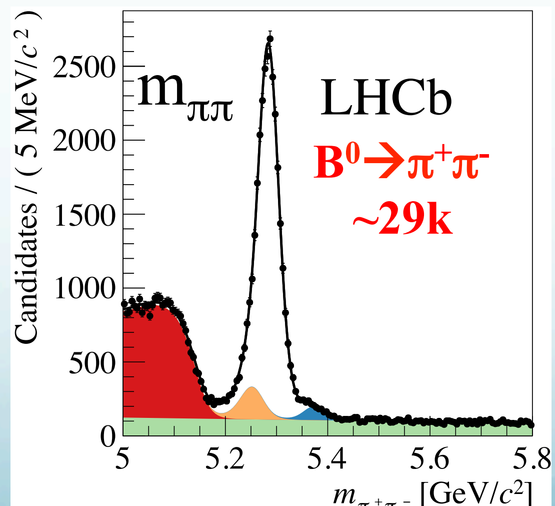
TD analysis of $B^0_{d,s} \rightarrow h^+h^-$ by LHCb

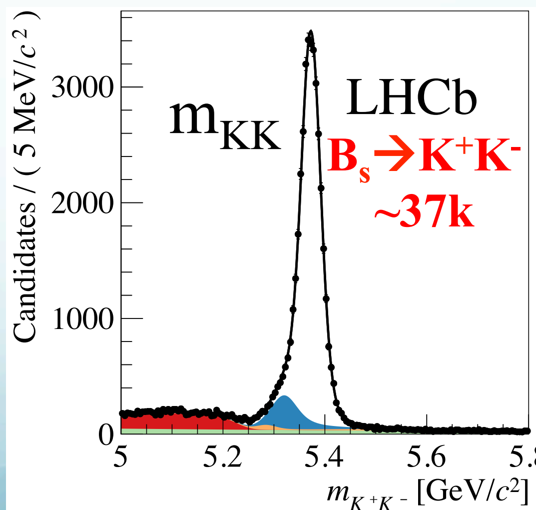
PRD98 (2018) 032004

Use a data sample of 3.0 fb^{-1} at 7 & 8 TeV from Run1

Selected candidates in mutually exclusive $\pi^+\pi^-$, K^+K^-, and $K^\pm\pi^\mp$ samples







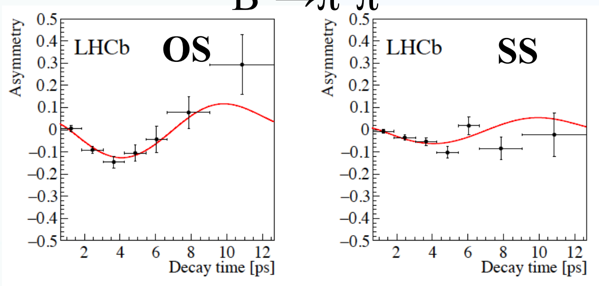
$B^0_d \to h^+h^-$ and $B^0_s \to h^+h^-$

PRD98 (2018) 032004

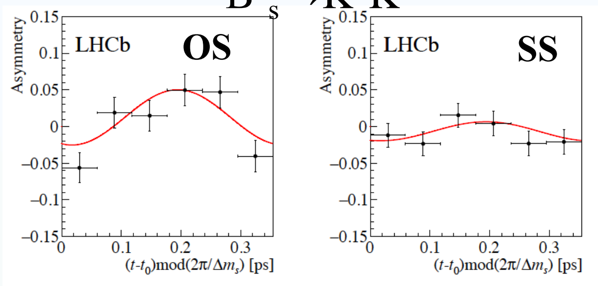
- *CP* asymmetries obtained by a simultaneous unbinned maximum likelihood fit to the $\pi^+\pi^-$, K^+K^- and $K^{+/-}\pi^{-/+}$ distributions

Fitted TD *CP* asymmetries by tagging

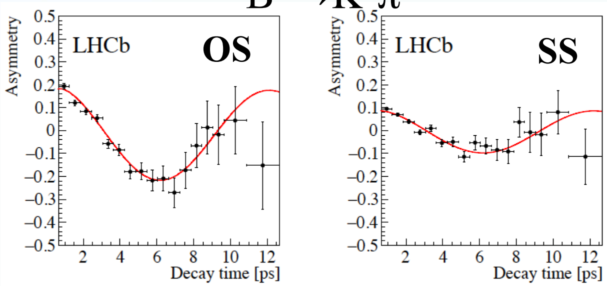
$B^0 \to \pi^+\pi^-$



$B^0_s \to K^+K^-$



$B^0 \to K^+\pi^-$



$$A_{CP}^{B^0} = -0.084 \pm 0.004 \pm 0.003$$
$$A_{CP}^{B^0_s} = 0.213 \pm 0.015 \pm 0.007$$
$$C_{\pi^+\pi^-} = -0.34 \pm 0.06 \pm 0.01$$
$$S_{\pi^+\pi^-} = -0.63 \pm 0.05 \pm 0.01$$
$$C_{K^+K^-} = 0.20 \pm 0.06 \pm 0.02$$
$$S_{K^+K^-} = 0.18 \pm 0.06 \pm 0.02$$
$$A^{\Delta\Gamma}_{K^+K^-} = -0.79 \pm 0.07 \pm 0.10$$

- Most precise single measurements.
- In agreement with previous measurements and SM predictions

HFLAV 2017
$(C_{\pi+\pi-}, S_{\pi+\pi-}) = (-0.31\pm0.05, -0.66\pm0.06)$
$(A^{B0d}, A^{B0s}) = (-0.082\pm0.006, -0.26\pm0.04)$

- The significance for $(C_{KK}, S_{KK}, A_{KK}) \neq (0,0,1)$ is $\sim 4\sigma$
- The addition of Run 2 data will provide the sensitivity for a discovery

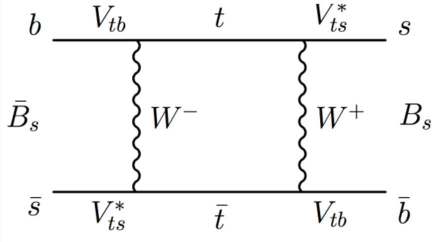
ϕ_s from $B_s \rightarrow J/\psi\, h^+h^-$

ϕ_s from $B_s \to J/\psi\ \phi$

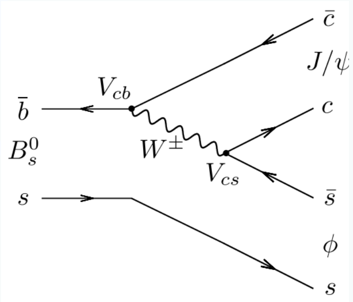
- Measuring ϕ_s is the analogue of the sin2β measurement.
- $B_s \to J/\psi\ \phi$ is the golden mode

$$\phi_s = \phi_M - 2\phi_D \cong -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) \equiv -2\beta_s$$

Mixing $\phi_M = 2\arg\left(V_{tb}V_{ts}^*\right)$



Decay $\phi_D = \arg\left(V_{cb}V_{cs}^*\right)$

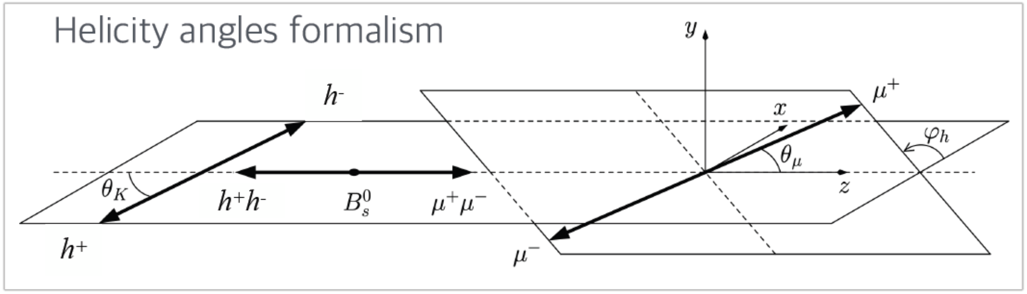


- SM values of ϕ_s strongly constrained by other CKM measurements
- Experimental determination much less precise

$$\phi_s \cong -2\beta_s = -36.9^{+1.0}_{-0.7}\ \text{mrad} \quad \text{[CKMfitter]}$$
$$\phi_s = -21 \pm 31\ \text{mrad} \quad \text{HFLAV 2018}$$

- $B_s \to J/\psi\ \phi$ (and $J/\psi\ K^+K^-$) is an admixture of *CP*-even and *CP*-odd final states, with a non-resonant S-wave component
  - ϕ: CP+ $(A_0+A_{||})$ + CP- $(A_\perp)$
  - S-wave: (A_S)

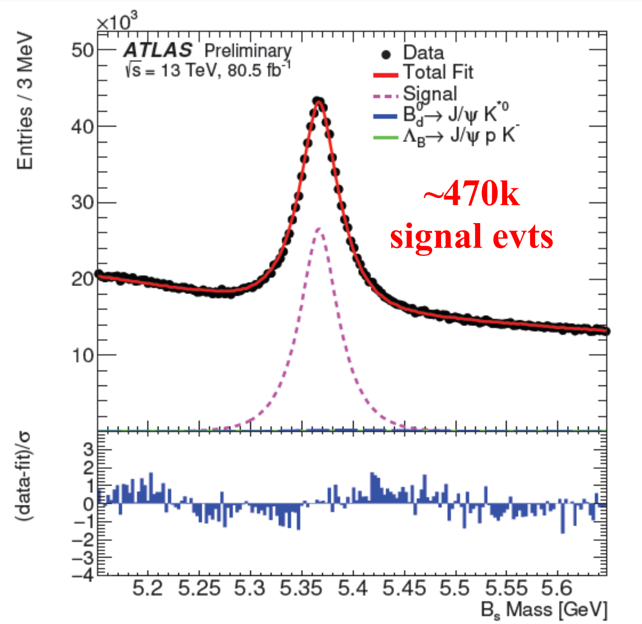
➔ Perform an angular analysis to disentangle the various components

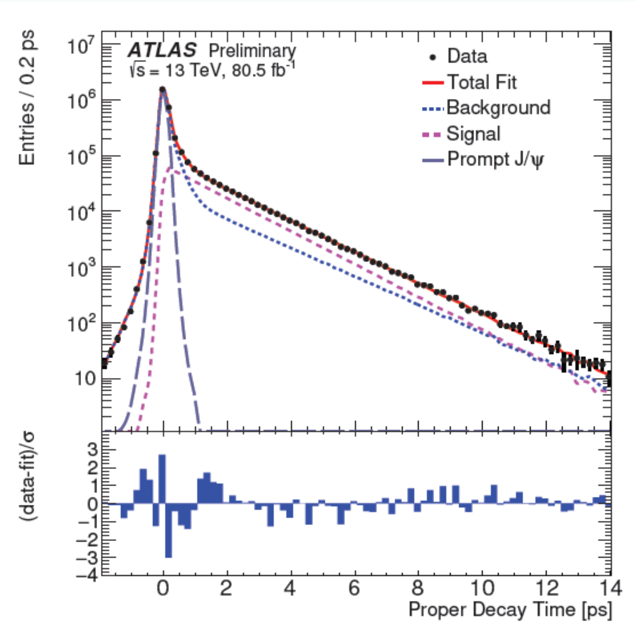


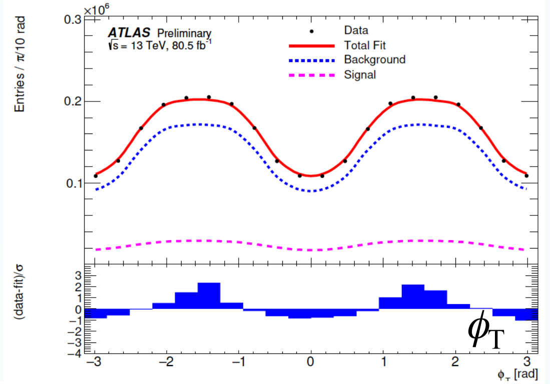
$B_s \to J/\psi\ \phi$

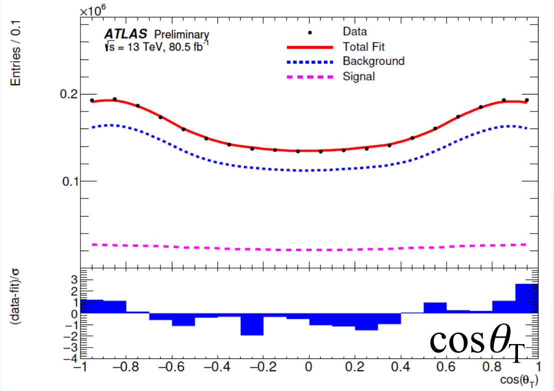
ATLAS-CONF-2019-009

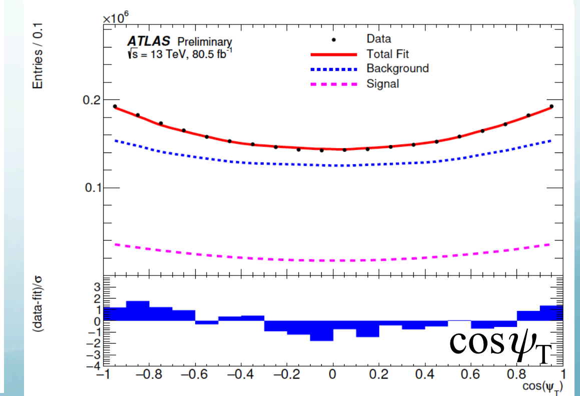
- Data set: 80.5 fb^{-1} at 13 TeV (Run 2)
- ~60fb^{-1} of Run 2 data yet to be analyzed
- Unbinned Maximum Likelihood fit to mass, proper decay time, its uncertainty, tagging probability and transversity angles.
- Tagging power $\varepsilon_{tag}D^2 \approx 1.65\%$
- Extract: ϕ_s, Γ_s, $\Delta\Gamma_s$, A_0, $A_{\parallel}$, $A_{\perp}$









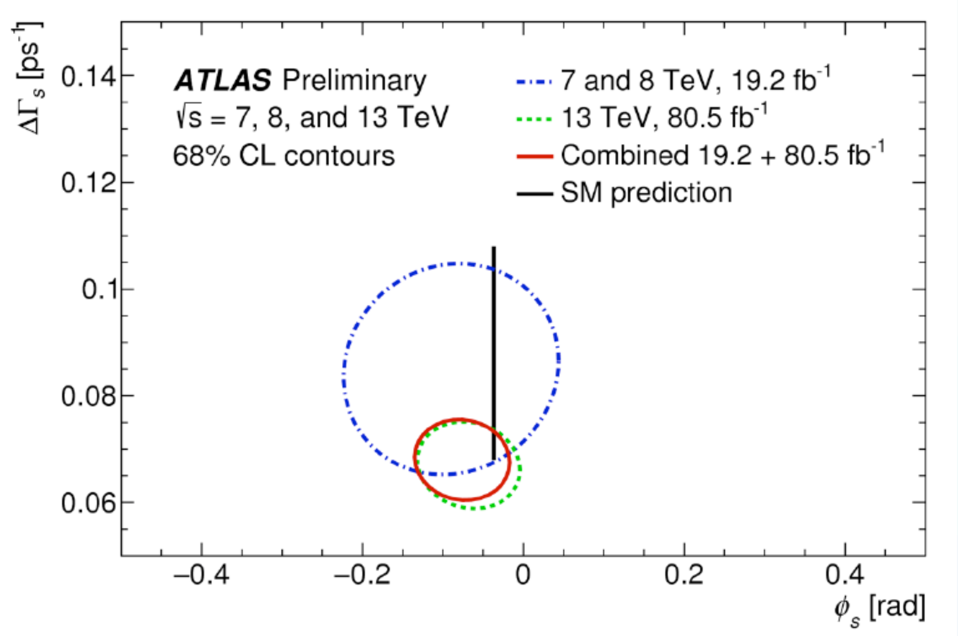


$B_s \rightarrow J/\psi\ \phi$

ATLAS-CONF-2019-009

Fit results on Run 2

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s[rad]	−0.068	0.038	0.018
$\Delta\Gamma_s$[ps^{-1}]	0.067	0.005	0.002
Γ_s[ps^{-1}]	0.669	0.001	0.001
$\lvert A_{\parallel}(0)\rvert^2$	0.219	0.002	0.002
$\lvert A_0(0)\rvert^2$	0.517	0.001	0.004
$\lvert A_S(0)\rvert^2$	0.046	0.003	0.004
$\delta_\perp$ [rad]	2.946	0.101	0.097
$\delta_\parallel$ [rad]	3.267	0.082	0.201
$\delta_\perp - \delta_S$ [rad]	−0.220	0.037	0.010



Combination of ATLAS results ($\sqrt{s}$ =7, 8 and 13 TeV):

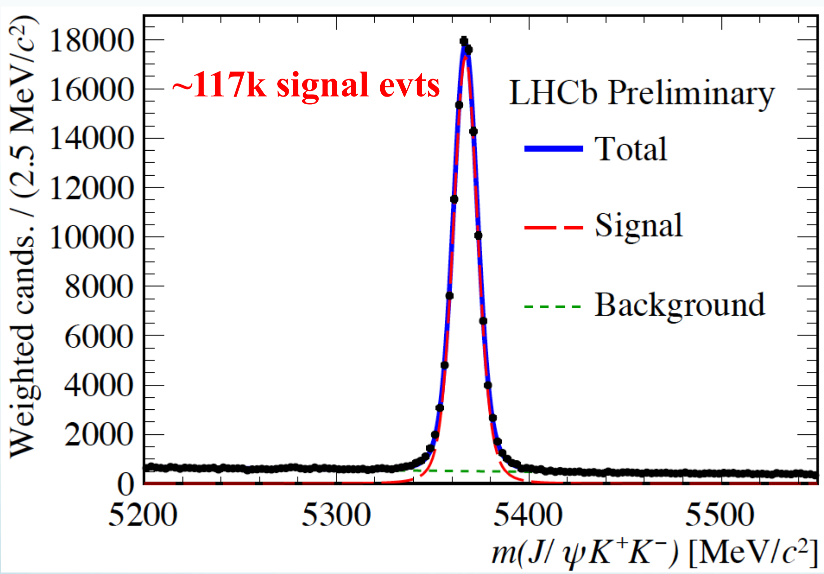
$$\phi_s = -0.076 \pm 0.034(stat) \pm 0.019(syst)\ \text{rad}$$
$$\Delta\Gamma_s = 0.068 \pm 0.004(stat) \pm 0.003(syst)\ \text{ps}^{-1}$$

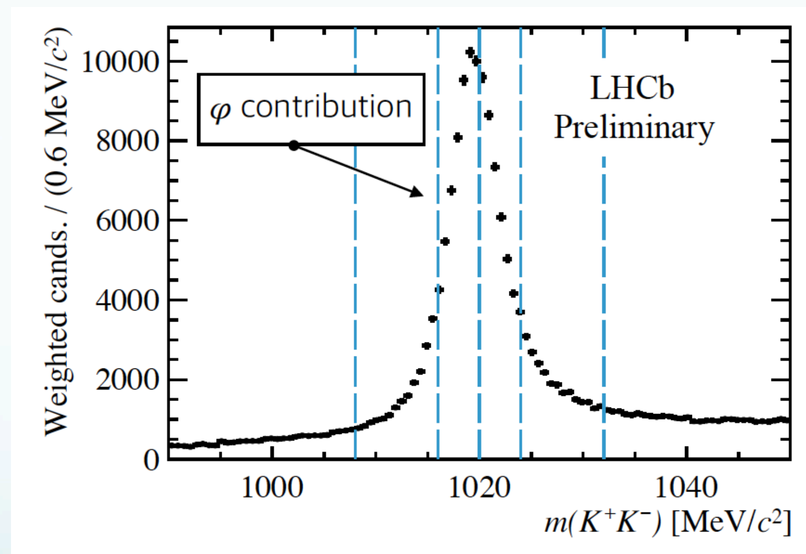
- Uncertainties comparable to that of LHCb
- Expect significant improvement with the inclusion of the not yet analyzed Run 2 data sample

$B_s \to J/\psi\ K^+K^-$

LHCB-PAPER-2019-013

- Dominated by resonant $\phi \to KK$ production.
- Analysis based on ~$2fb^{-1}$ Run 2 data (2015 and 2016 data)
- Improved tagging power w.r.t. previous Run 1 analyses: 4.7% *vs* 3.7%
- Fit TD distributions to measure ϕ_s, $|\lambda|$, $\Delta\Gamma_s$, and $\Gamma_s - \Gamma_d$





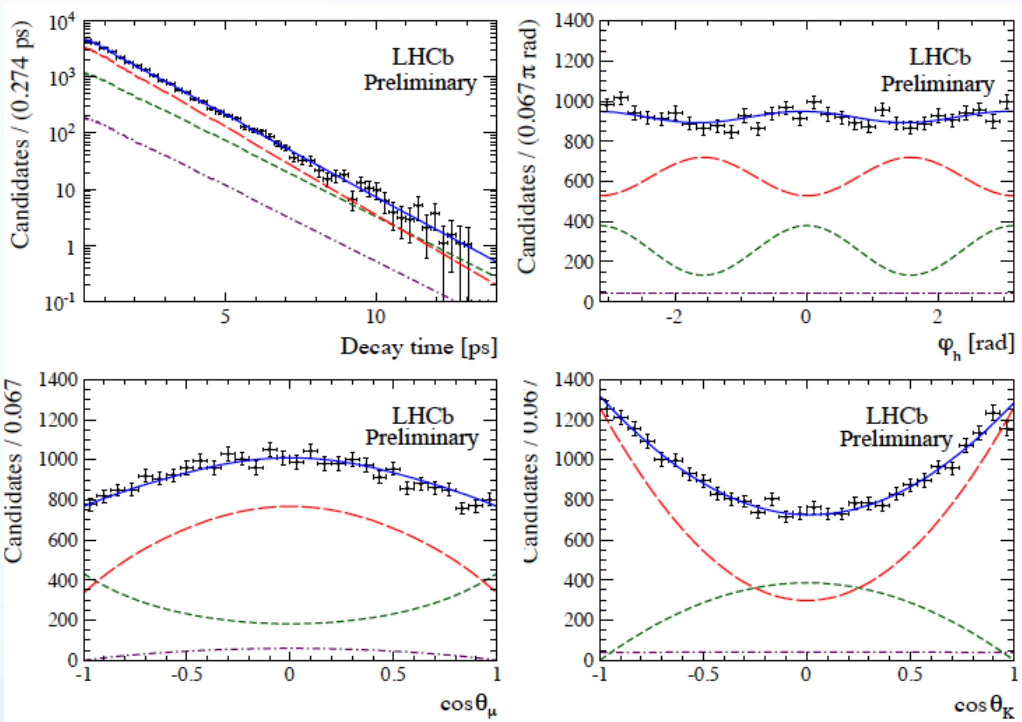
- Very low background and high statistics
- Peaking $\Lambda_b \to J/\psi\ pK^-$ background estimated from simulation and subtracted

- Data analyzed in 6 bins of m_{KK}, including the ϕ-resonance peak

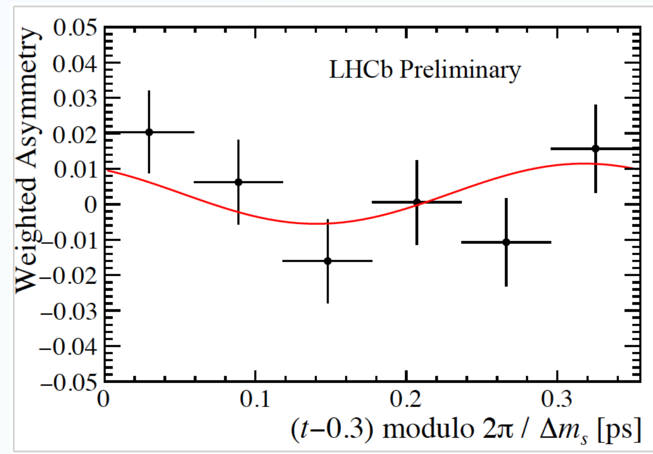
$B_s \to J/\psi K^+K^-$

LHCB-PAPER-2019-013

Simultaneous fit to the decay time and the three helicity angle distributions, in the 6 m_{KK} intervals



$$A_{CP}(t) = \frac{\Gamma_{\bar{B}^0_s \to f}(t) - \Gamma_{B^0_s \to f}(t)}{\Gamma_{\bar{B}^0_s \to f}(t) + \Gamma_{B^0_s \to f}(t)} \sim \sin(\phi_s)\sin(\Delta m_s t)$$



Total fit CP-odd
CP-even S wave

Preliminary

$$\phi_s^{c\bar{c}s} = -0.083 \pm 0.041 \pm 0.006 \text{ [rad]}$$

$$|\lambda| = 1.012 \pm 0.016 \pm 0.006$$

$$\Gamma_s - \Gamma_d = -0.0041 \pm 0.0024 \pm 0.0015 \text{ [ps}^{-1}]$$

$$\Delta\Gamma_s = -0.0772 \pm 0.0077 \pm 0.0026 \text{ [ps}^{-1}]$$

- **All results consistent with the SM**

Presented by Emmy Gabriel yesterday at parallel session

$B_s \rightarrow J/\psi\, \pi^+\pi^-$

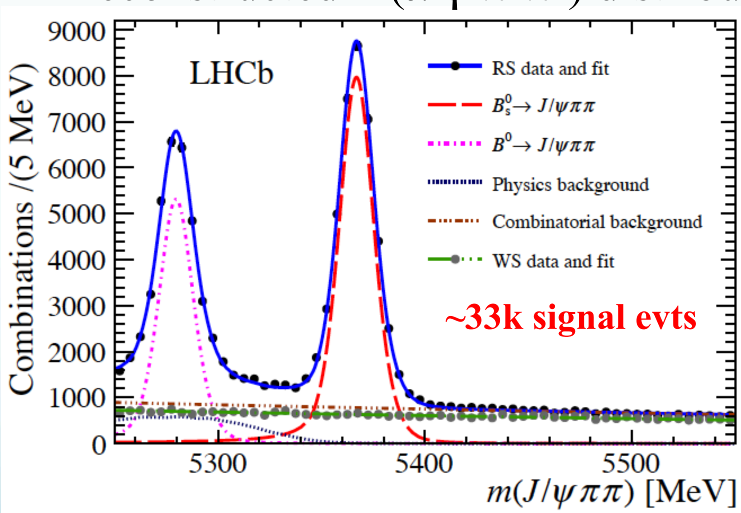
arXiv:1903.05530

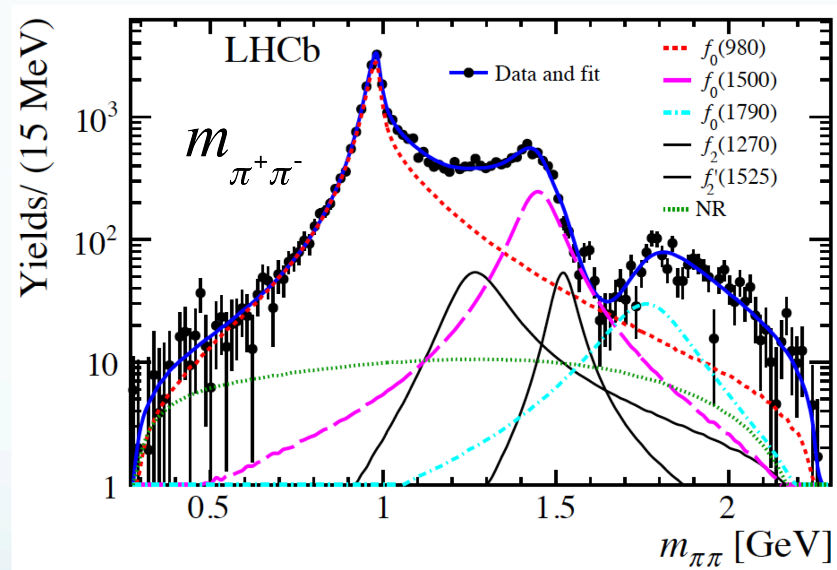
- $\pi^+\pi^-$ in S-wave (mainly $f_0(980) \rightarrow \pi^+\pi^-$) => J/ψ only longitudinally polarized

➔ $J/\psi\pi^+\pi^-$ entirely CP-odd (contamination of CP-even measured to be <2.3% at 95%C.L.).

- Nevertheless the full angular analysis is performed allowing for a CP-even component
- Analysis based on ~2fb^{-1} Run 2 data (2015 and 2016 data)
- Improved tagging power w.r.t. previous Run 1 analyses: 5.1% *vs* 3.9%

Reconstructed m($J/\psi\, \pi^+\pi^-$) distribution





Fit to the decay time, the three helicity angles and $m_{\pi\pi}$ distributions

Results from fit to Run2 data

$$\phi_s^{c\bar{c}s} = -0.057 \pm 0.060 \pm 0.011 \ \text{[rad]}$$

$$|\lambda| = 1.01^{+0.08}_{-0.06} \pm 0.03$$

$$\Gamma_H - \Gamma_d = -0.050 \pm 0.004 \pm 0.004 \ [\text{ps}^{-1}]$$

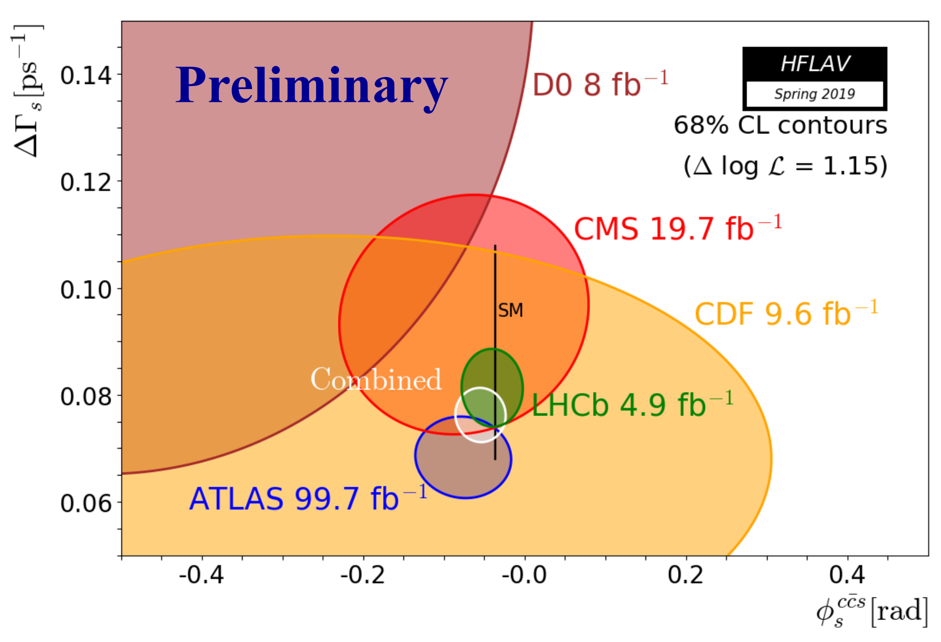
ϕ_s current status

Combinations of available measurements

	ϕ_s (rad)	$\Delta\Gamma_s$ (ps^{-1})
ATLAS [1]	-0.076 ± 0.034 ± 0.019	0.068 ± 0.004 ± 0.03
LHCb [2]	-0.040 ± 0.025	0.081 ± 0.005
New HFLAV aver.	-0.054 ± 0.021	0.0762 ± 0.0033

[1] ATLAS-CONF-2019-009; [2] Moriond QCD talk by Andrea Contu

Spring 2019 status: New HFLAV average



- Significant improvement after the latest ATLAS and LHCb results
- Overall consistency among measurements
- ϕ_s average is ~2σ away from zero
- Consistent with constraints from CKM measurements

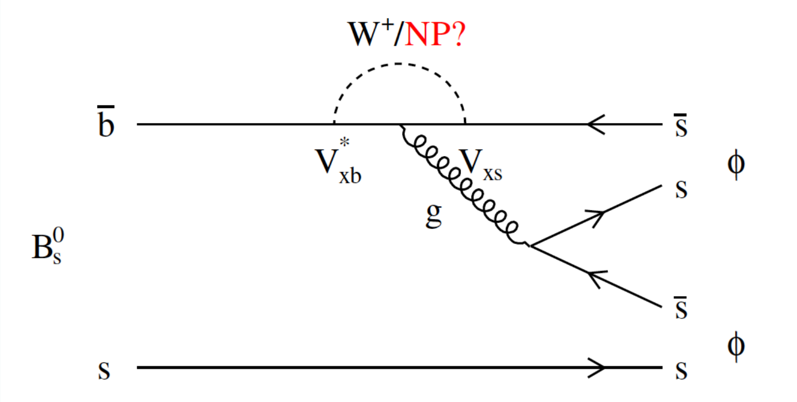
- Lots of data from LHC Run 2 still to be analyzed

Penguin-dominated decays

$$B_s \to VV$$

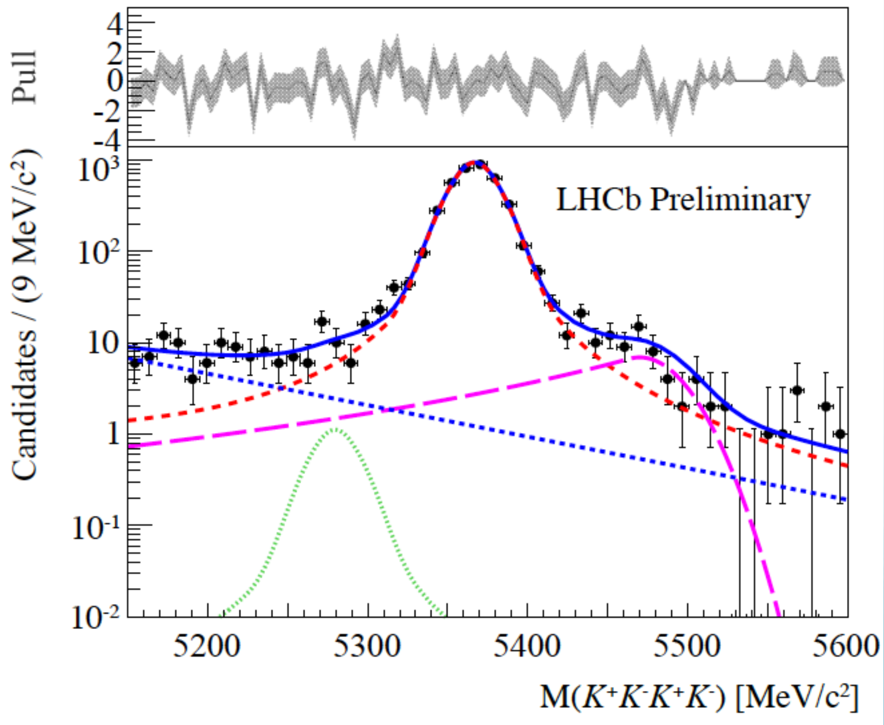
$B_s \rightarrow \phi\phi$

LHCb-PAPER-2019-019



- Forbidden at tree level
- Proceeds mainly via gluon penguin $b \rightarrow s\bar{s}s$
- Mixing and decay phase are expected to cancel => $\phi_s^{s\bar{s}s} \approx 0$
- UL from QCD factorization: $|\phi_s^{s\bar{s}s}| < 0.02$ rad
  [arXiv:0810.0249, PRD80 (2009) 114026]

Reconstructed mass distribution



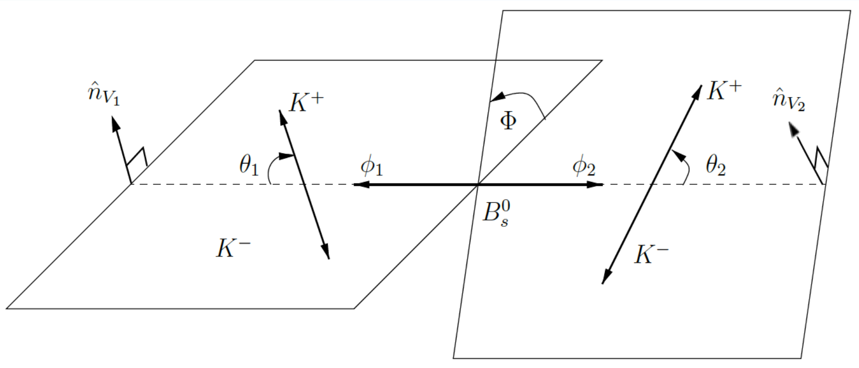
- Based on 5 fb^{-1} of data taken in Run1 and 2
- Update of previous measurement based on 3fb^{-1} of Run1 only
- Reconstruction of a 4-kaon vertex consistent with a ϕ decay

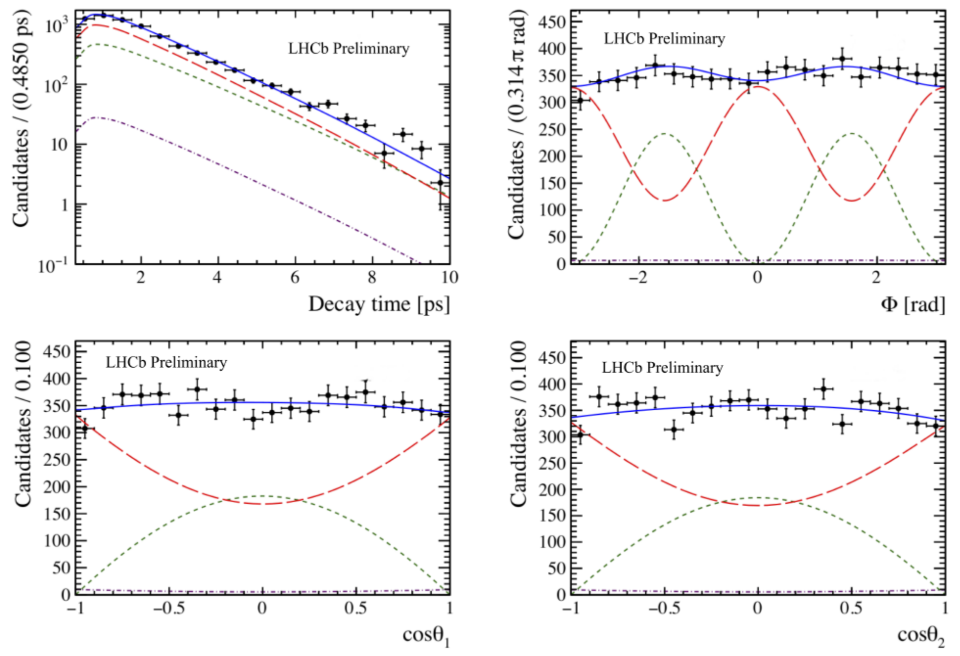
- Background removed with a MLP function
- Peaking bkg $\Lambda_b \rightarrow \phi p K^-$ estimated from data
- **Fitted signal: 8481±101 events**
- **Search also for B^0 decay:**
  - **$\mathcal{B}(B^0 \rightarrow \phi\phi) < 2.4 \times 10^{-8}$ at 90% C.L.**

$B_s \to \phi\phi$

LHCb-PAPER-2019-019

Angular analysis in helicity basis to disentangle the different CP components





Total fit
CP-even
CP-odd
S wave

Preliminary

$$\phi_s^{s\bar{s}s} = -0.073 \pm 0.115 \pm 0.027 \text{ [rad]}$$

$$|\lambda| = -0.99 \pm 0.05 \pm 0.01$$

Presented by Emmy Gabriel yesterday at parallel session

- Precision improved w.r.t. previous LHCb measurement, but still largely dominated by statistical uncertainty
- Additional search with triple asymmetries shows no *CP* violation

Prospects for the future

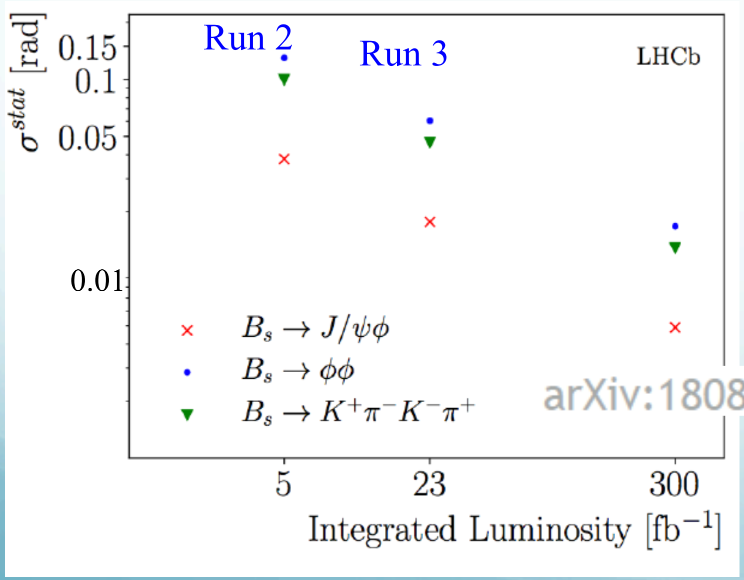
- LHCb and Belle II will be the major player in *B* physics in the coming years

LHCb

Raise operational Luminosity in Run 3 to $2\text{x}10^{33}\text{cm}^{-2}\text{s}^{-1}$ (5x higher than Run 2)

- Significant detector upgrade
- Move to a full sofware trigger to improve the collection of hadronic modes

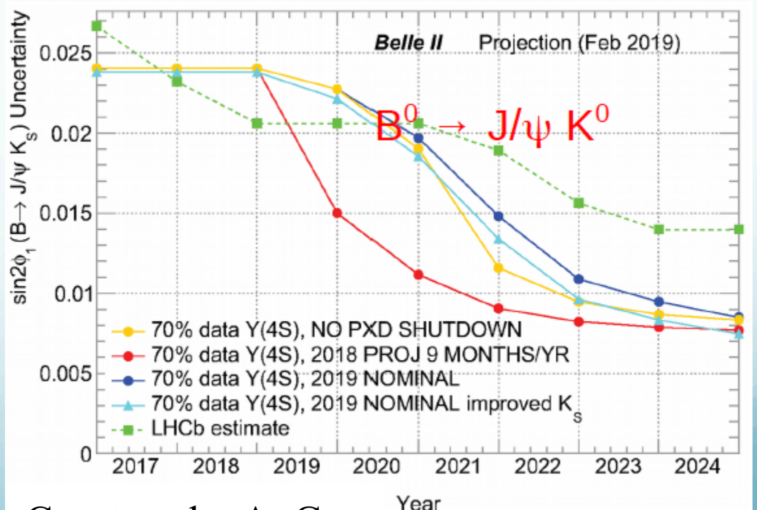
Sensitivity on ϕ_s with integrated luminosity



Belle II

- Physics reach complementary to LHCb
- Commissioning run (~500 pb^{-1}) in 2018, with no vertex detector (VXD)
- Physics run with VXD started in 2019
  - Expect 10 fb^{-1} by end of 2019 and ~500 fb^{-1} by of 2020
- Running time limited by available budget

Long term projection for sin2β in $B^0 \to J/\psi K^0$



Courtesy by A. Gaz

Prospects for the future

- LHC[...] years

See talks on Friday session on future of *B*-physics for a detailed discussion

Raise ope[...] LHCb

$2x10^{33}cm$[...] in 2018, with no vertex detector (VXD)

- Significant detector upgrade
- Move to a full sofware trigger to improv[...]dronic modes

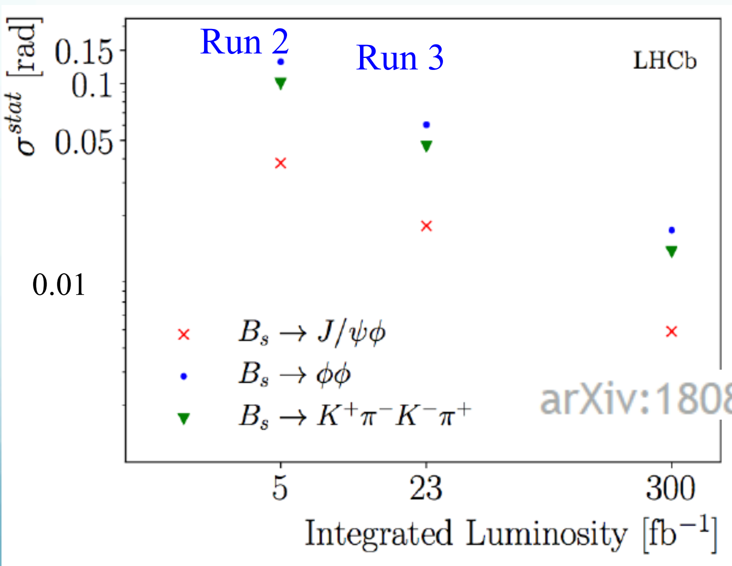
Silvia Gambetta

- Physics run with VXD started in 2019
  - Expect[...] and ~500 fb^{-1} by of 2[...]

Hulya Atmacan

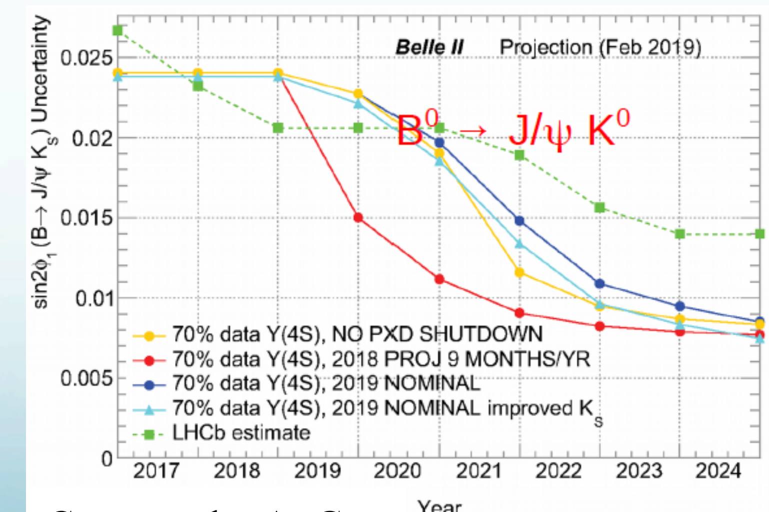
- Running time limited by available budget

Sensitivity on ϕ_s with integrated luminosity



arXiv:1808.08865

Long term projection for $\sin 2\beta$ in $B^0 \to J/\psi K^0$



Courtesy by A. Gaz

Summary

- TD analyses continue to be an important tools to study CP violation and test the SM
- The advent of LHC experiments (primary LHCb) opened the door to the systematic study of the B_s system
- The first-generation *B* factories are still competitive in the measurement of *CP* asymmetries within the B^0 system
- Belle II will join this effort soon
- The uncertainty on sin2β from $b \rightarrow c\bar{c}s$ decays is 0.02
  - almost at the level to see effects from SM (and possibly NP) penguin diagrams
- The precision on ϕ_s is rapidly improving thanks to the many new measurements of B_s decays
- All measurements shown today are (largely) statistically limited

==> **We need data, and then … more data!**

Summary

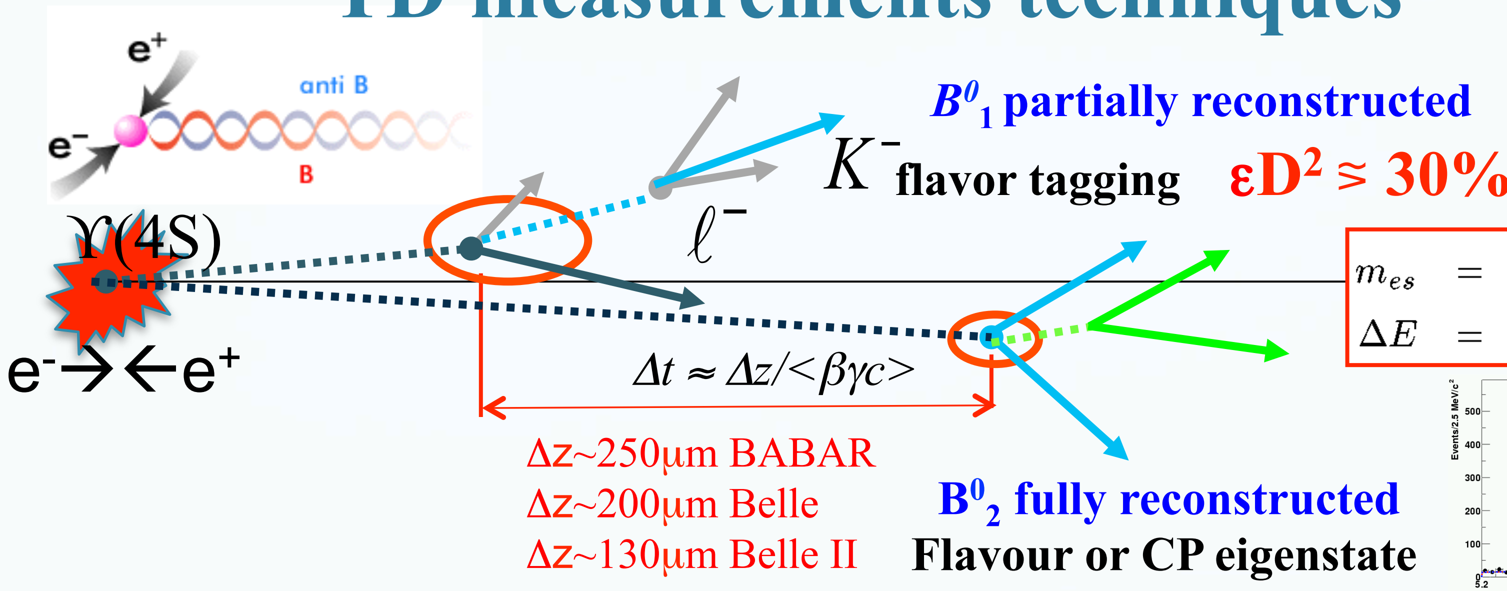
- TD analyses continue to be an important tools to study CP violation and test the SM
- The advent of LHC experiments (primary LHC… …ened the door to the systematic study of the B_s system
- The first-generation B factories a… …titive in the measurement of CP asym… …the B^0 system
- Belle II will join t… …n
- The meas… …in2β from $b \to c\bar{c}s$ decays at ~2% level
  - almost at th… …el to see effects from SM (and possibly NP) penguin diagrams
- The precision on ϕ_s is rapidly improving thanks to the many new measurements of B_s decays
- All measurements shown today are statistically limited

==> **We need data, and then … more data!**

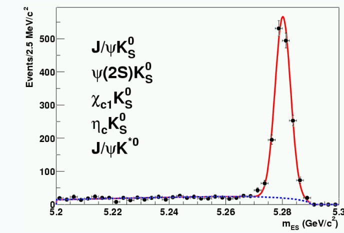
Thanks for your attention!

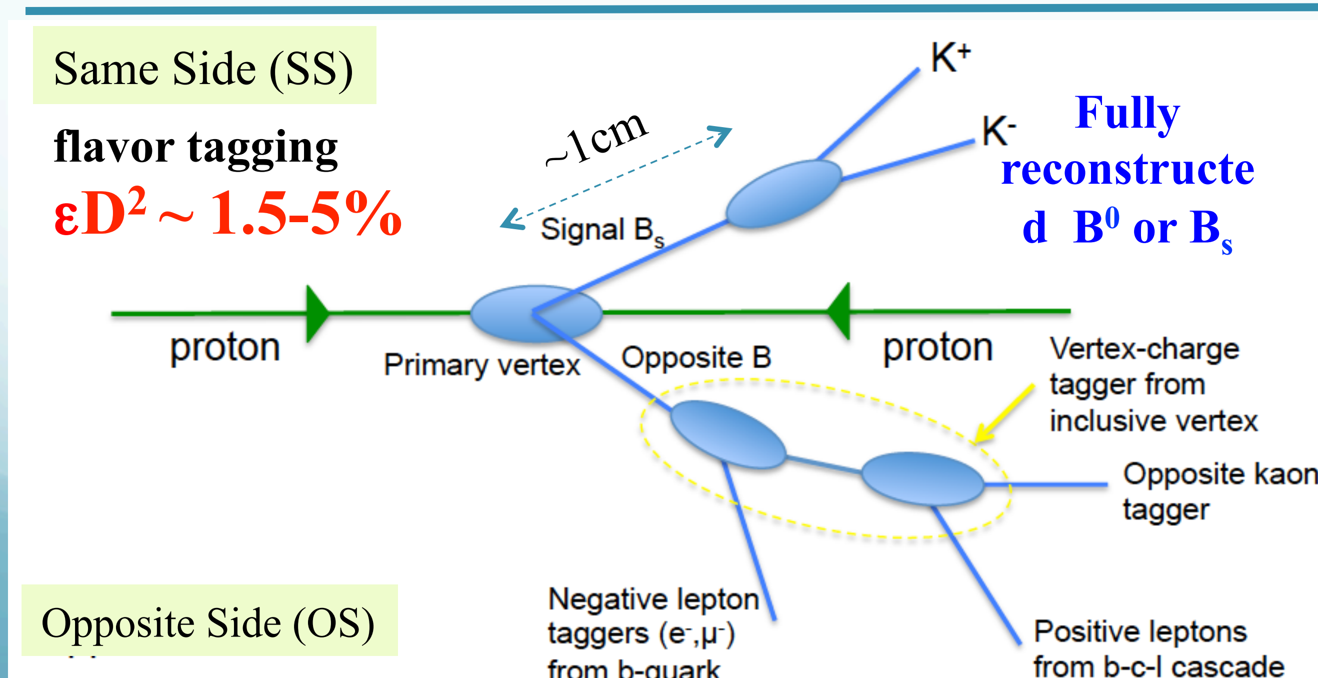
BACKUP
SLIDES

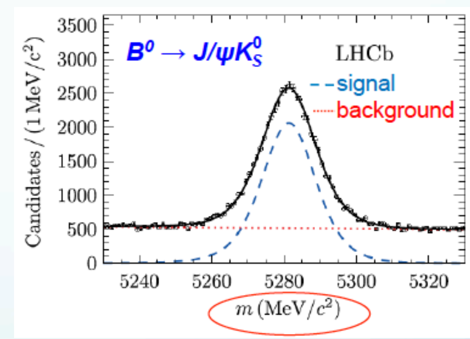
TD measurements techniques

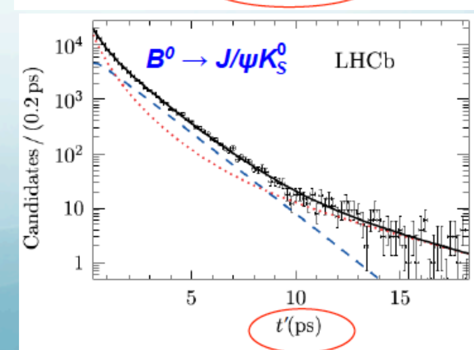


$$m_{es} = \sqrt{E^{*2}_{\mathrm{beam}} - \sum \vec{p}^{*}_{i}}$$
$$\Delta E = E^{*}_{B} - E^{*}_{\mathrm{beam}}$$



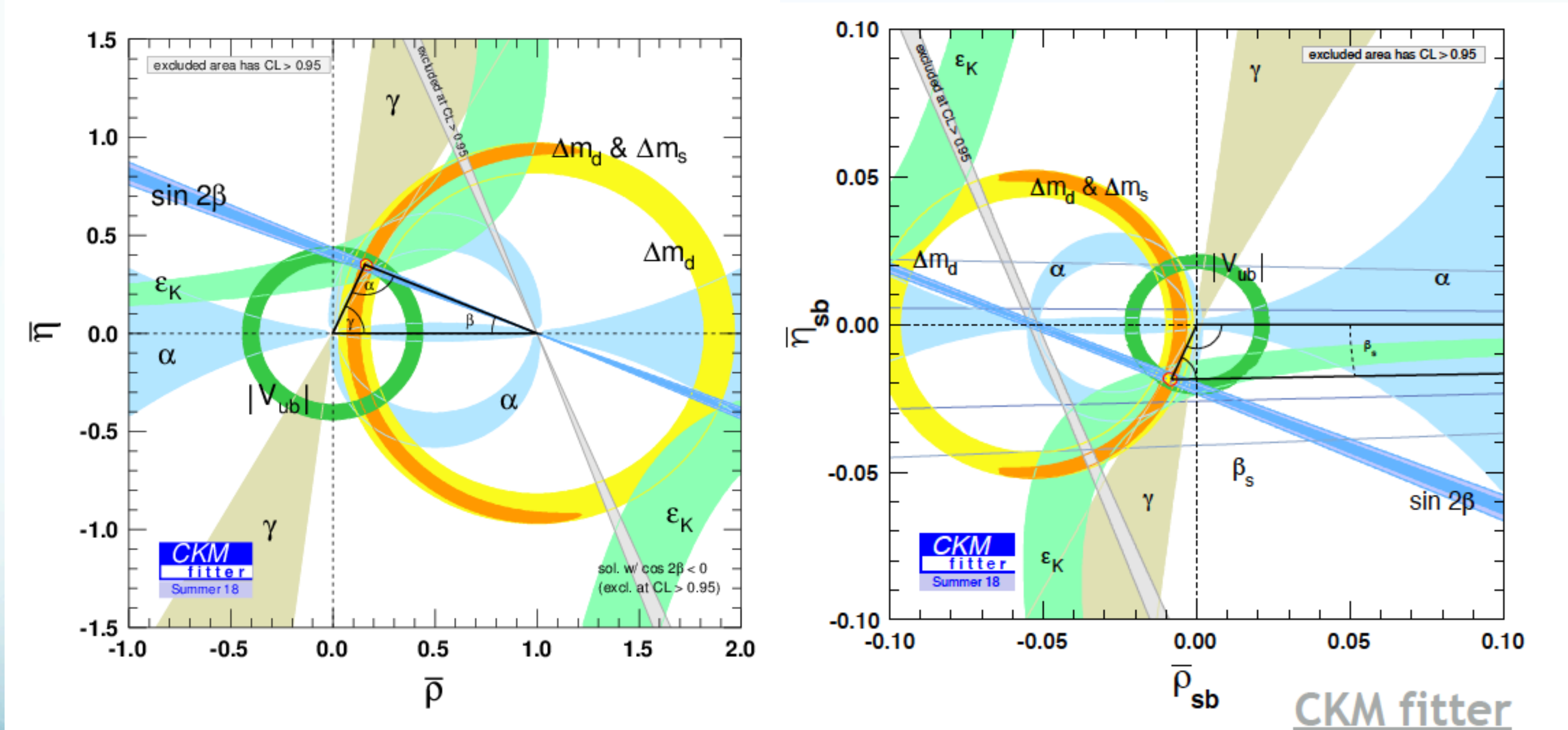






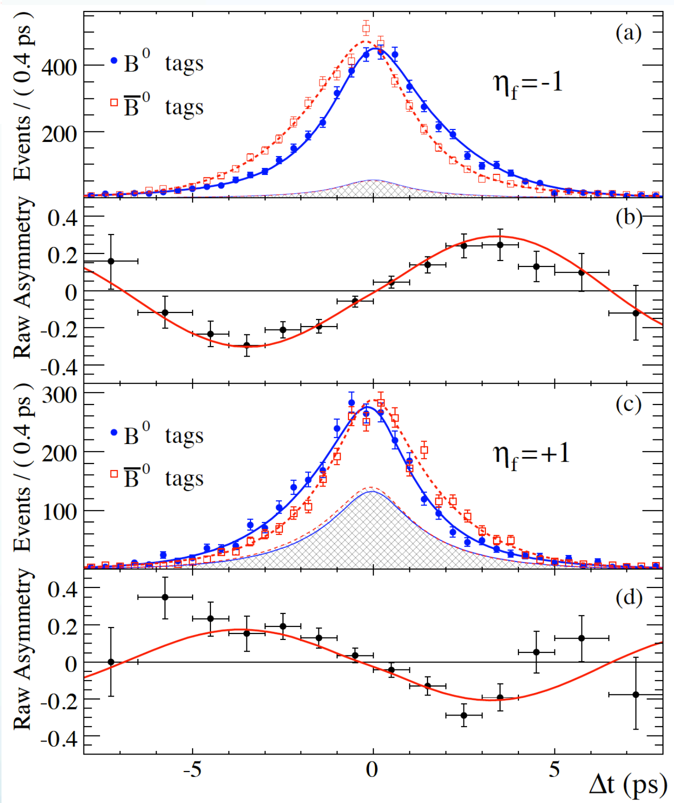
The CKM picture

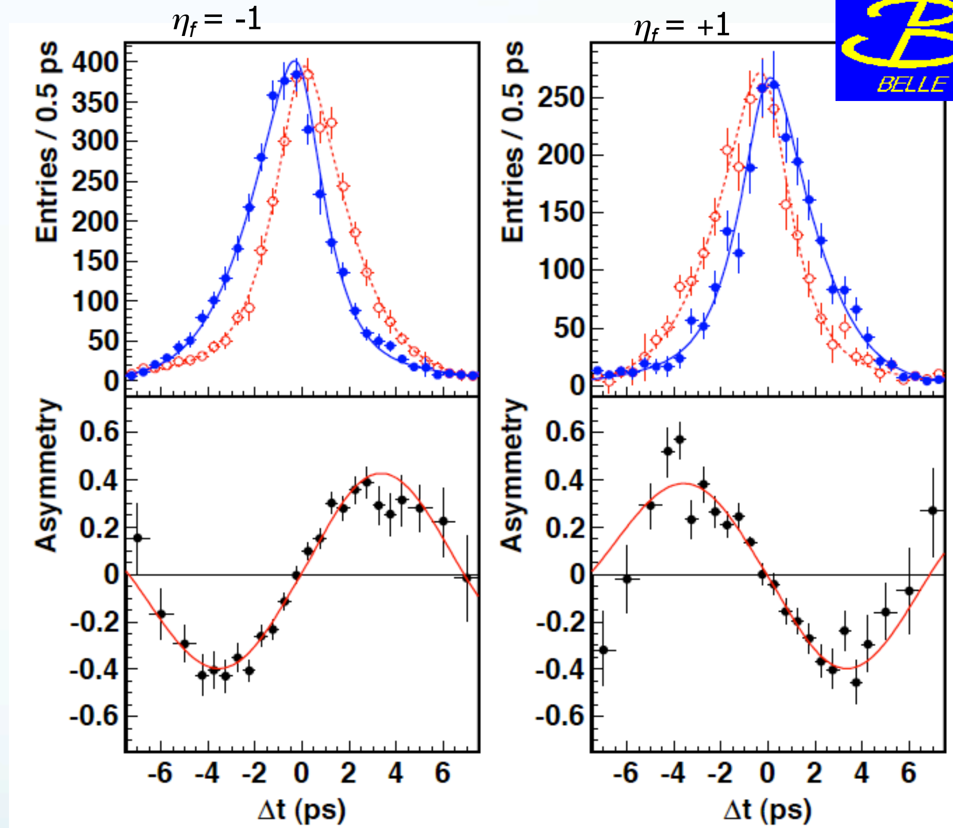
Summer 2018 global CKM fits by the CKMfitter collaboration,



sin2β from $b \to [c\bar{c}]s$

- BABAR and Belle established *CPV* in the B system, and brought the precision of the measurements of sin2β down to 3% ($\sigma_\beta < 1^o$)





***BABAR*, PRD 79, 072009 (2009)**

S = 0.687 ± 0.028 ± 0.012

C = 0.024 ± 0.020 ± 0.016

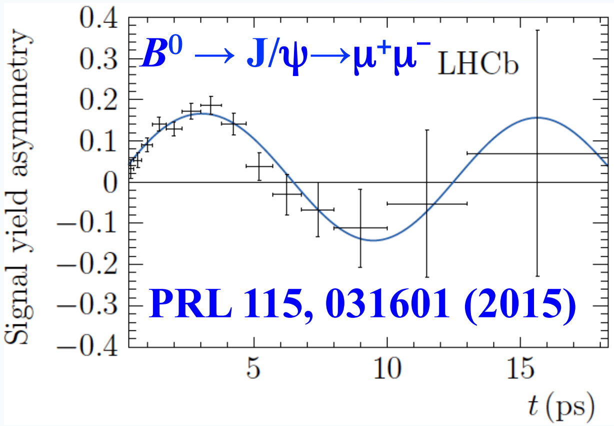
Belle, PRL 108, 171802 (2012)

S = 0.667 ± 0.023 ± 0.012

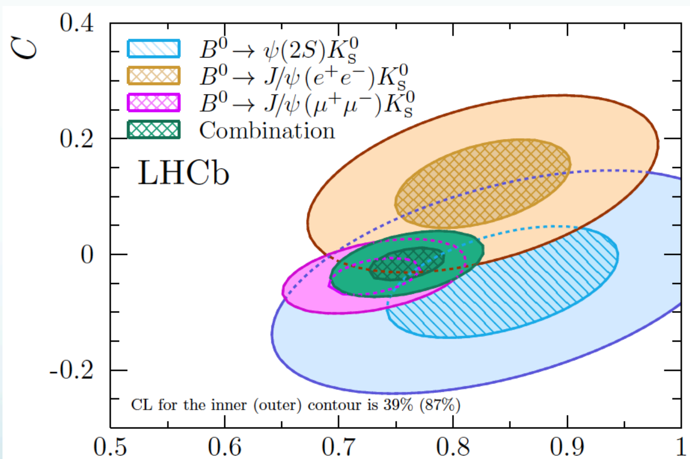
C = -0.006 ± 0.016 ± 0.012

$\sin 2\beta$ from $B^0 \to [c\bar{c}]\, K_S$ by LHCb

- Measured asymmetry

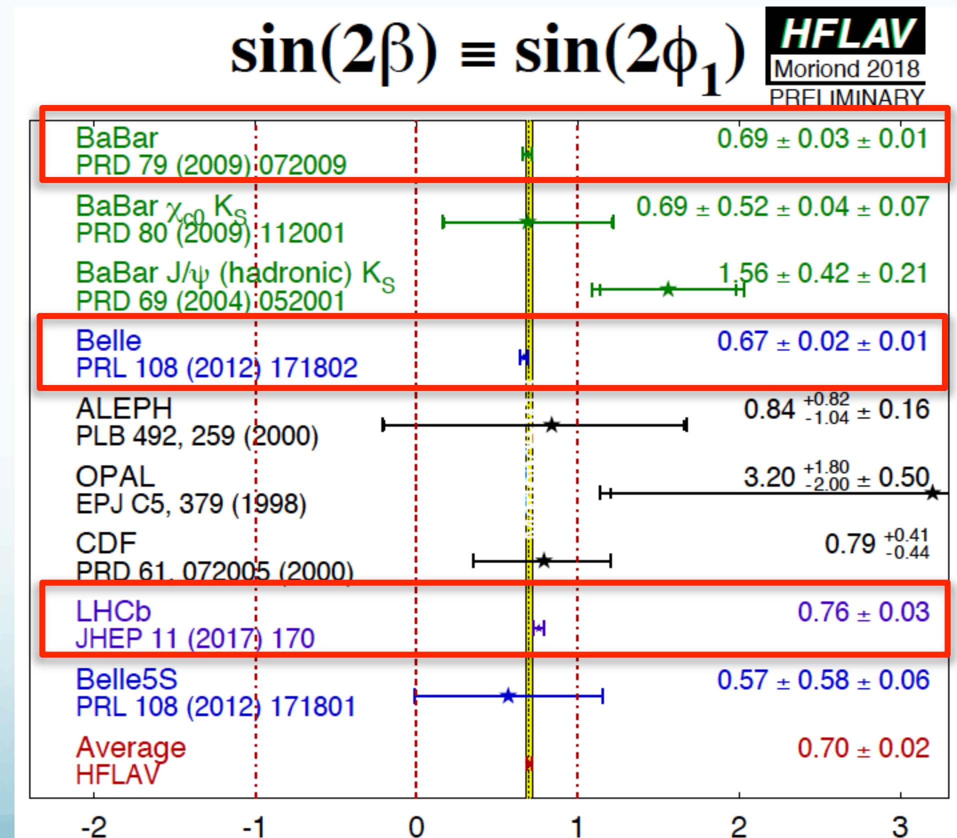


- Run1 data set of 3.1 fb^{-1}.
- Reconstruct $J/\psi \to \mu^+\mu^-$ [PRL115, 031601], and $J/\psi \to e^+e^-$ and $\psi(2S) \to \mu^+\mu^-$ [JHEP11, 170]
- Reconstruct $K_S \to \pi^+\pi^-$
- Excellent resolution on proper-time measurement (~60 fs)
- Effective tagging efficiency from 3 to 6%.

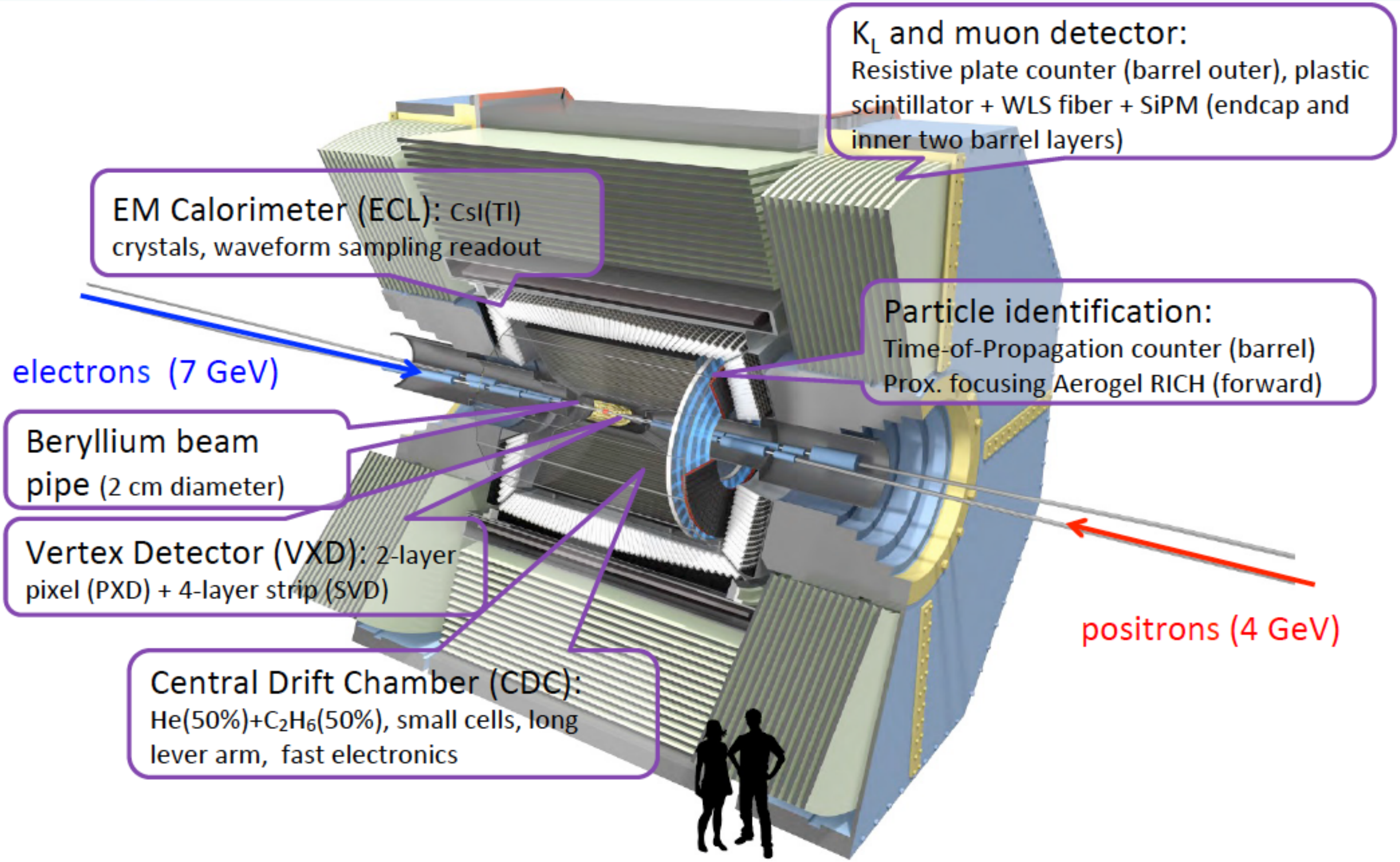


JHEP 11 (2017) 170: LHCb average

$$C(B^0 \to [c\bar{c}]K^0_S) = -0.017 \pm 0.029$$
$$S(B^0 \to [c\bar{c}]K^0_S) = 0.760 \pm 0.034$$



Belle II



K_L and muon detector:
Resistive plate counter (barrel outer), plastic scintillator + WLS fiber + SiPM (endcap and inner two barrel layers)
EM Calorimeter (ECL): CsI(Tl) crystals, waveform sampling readout
electrons (7 GeV)
Particle identification:
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)
Beryllium beam pipe (2 cm diameter)
Vertex Detector (VXD): 2-layer pixel (PXD) + 4-layer strip (SVD)
positrons (4 GeV)
Central Drift Chamber (CDC): He(50%)+C_2H_6(50%), small cells, long lever arm, fast electronics

Belle II

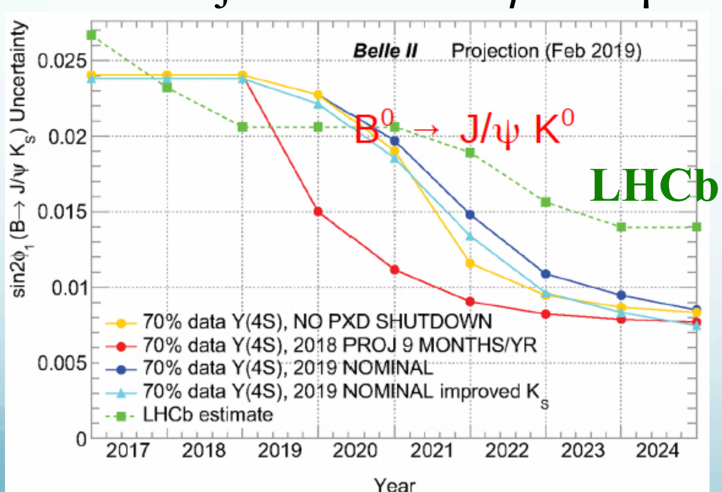
- LHCb and Belle II will be the major player in B physics in the coming years

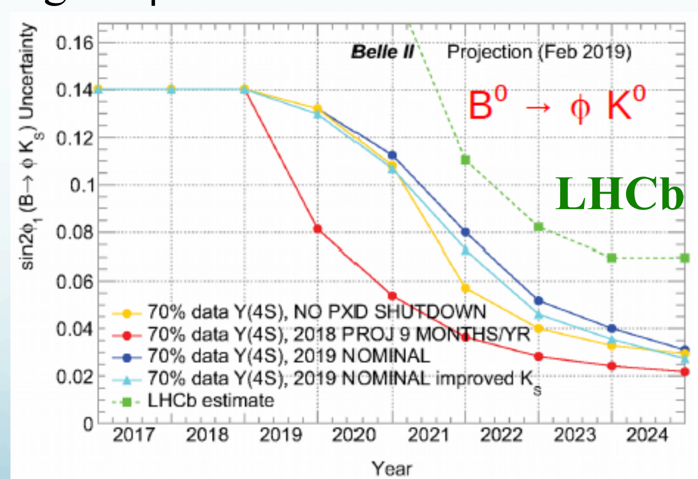
- SuperKEKB target luminosity: $8x10^{35} cm^{-2} s^{-1}$, with nano-beam scheme
- Major improvement w.r.t. the original Belle detector
- Physics reach complementary to LHCb
- Phase 2 (2018): beam commissioning and first physics studies with no vertex detector ~500 pb^{-1} collected.
- Phase 3 from 2019 on: Physics run with vertex.
  - Expect 10 fb^{-1} by end of 2019
- Complete installation of Vertex Detector in 2020
- Running time per year limited by available budget

	Integrated Lumi	Target
Short Term	10–60 fb^{-1}	Summer 2019
Medium Term	100-200 fb^{-1}	Winter 2020
Longer Term	~500 fb^{-1}	Summer 2020

≈BABAR data set

Projection for $\sin 2\beta$ in $J/\psi K^0$ and penguin ϕK^0 modes



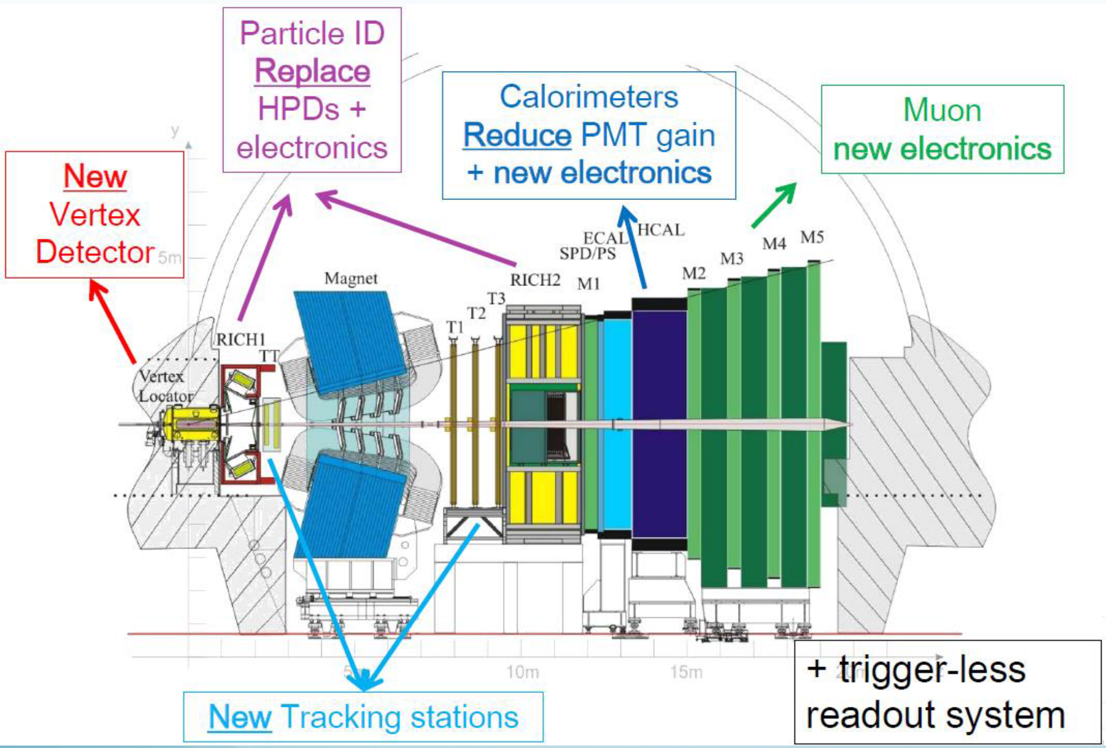


LHCb upgrade

- LHCb and Belle II will be the major player in B physics in the coming years

Raise operational Luminosity in Run3 to $2x10^{33}cm^{-2}s^{-1}$

- Significant detector upgrade (mainly tracking and vertexing, and electronics)
- Move to a trigger-less readout (i.e. full sofware trigger) to improve the collection of hadronic modes



Sensitivity on ϕ_s with integrated luminosity