# Beauty to Charmonium Decays at LHCb

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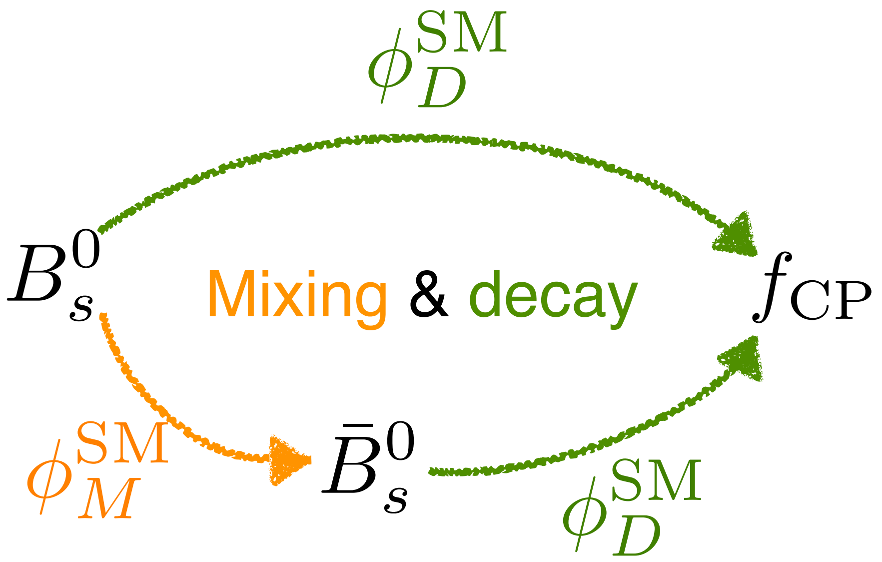
# Outline

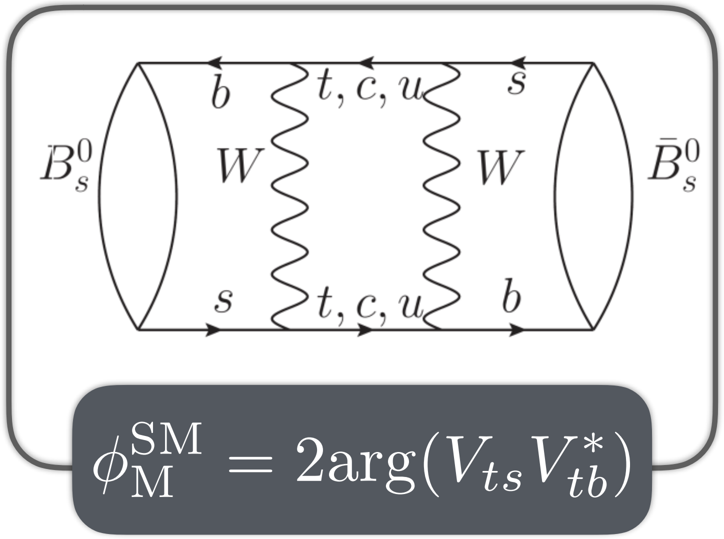
- Measurements of time-dependent CP violation parameters $\phi_s$
  - $B_s \to J/\psi K^+K^-$ [EPJC 79 (2019) 706]
  - $B_s \to J/\psi \pi^+\pi^-$ [PLB 797 (2019) 134789]
- Direct CP asymmetry measurements in $B^+ \to J/\psi \rho^+$ decays

  [EPJC 79 (2019) 537]
- First isospin amplitudes studies in $\Lambda_b^0 \to J/\psi\Lambda(\Sigma^0)$ and $\Xi_b^0 \to J/\psi\Xi^0(\Lambda)$

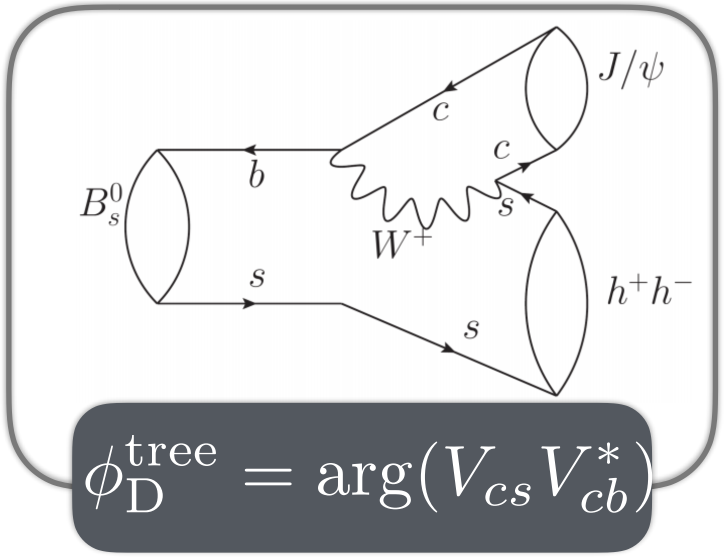
  see talk by Sheldon Stone on Tuesday

# $\phi_s$ in $b \to c\bar{c}s$ Transition





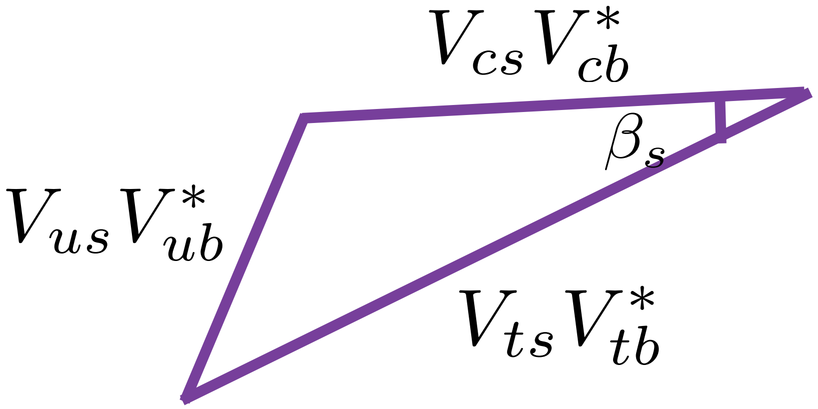
$\phi_{\rm M}^{\rm SM} = 2\arg(V_{ts}V_{tb}^*)$



$\phi_{\rm D}^{\rm tree} = \arg(V_{cs}V_{cb}^*)$

- $\phi_s$ mixing-induced CPV phase in $B_s^0$ decays through $b \to c\bar{c}s$ transitions

$$\phi_s^{\rm SM} \approx \phi_{\rm M}^{\rm SM} - 2\phi_{\rm D}^{\rm tree}$$
$$= -2\beta_s = -2arg(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}),$$

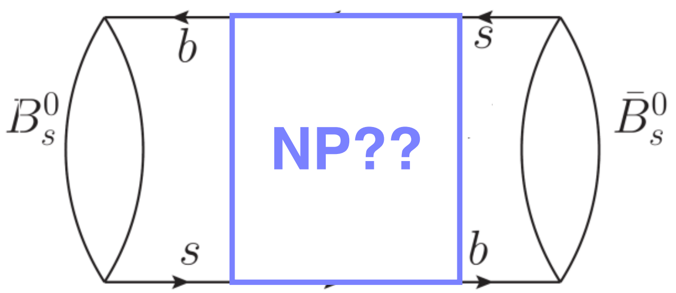


ignoring penguin contribution

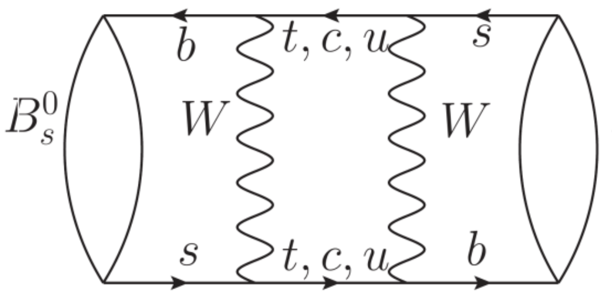
$$\Delta\phi_s^{c\bar{c}s} \approx -\epsilon\left(\phi_d{}^{J/\psi\,\rho^0} - 2\beta\right)$$ [PLB742(2015)38-49]

small penguin shift (0.9±9.8) mrad, less than statistical σ($\phi_s$)~0.031 rad

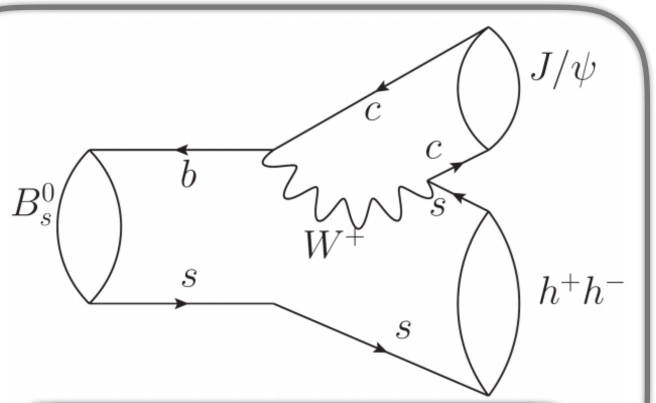
# $\phi_s$ in $b \to c\bar{c}s$ Transition



$\phi_{\mathrm{M}} = \phi_{\mathrm{M}}^{\mathrm{SM}} + \Delta\phi_{\mathrm{NP}}$



$\phi_{\mathrm{M}}^{\mathrm{SM}} = 2\arg(V_{ts}V_{tb}^*)$



$\phi_{\mathrm{D}}^{\mathrm{tree}} = \arg(V_{cs}V_{cb}^*)$

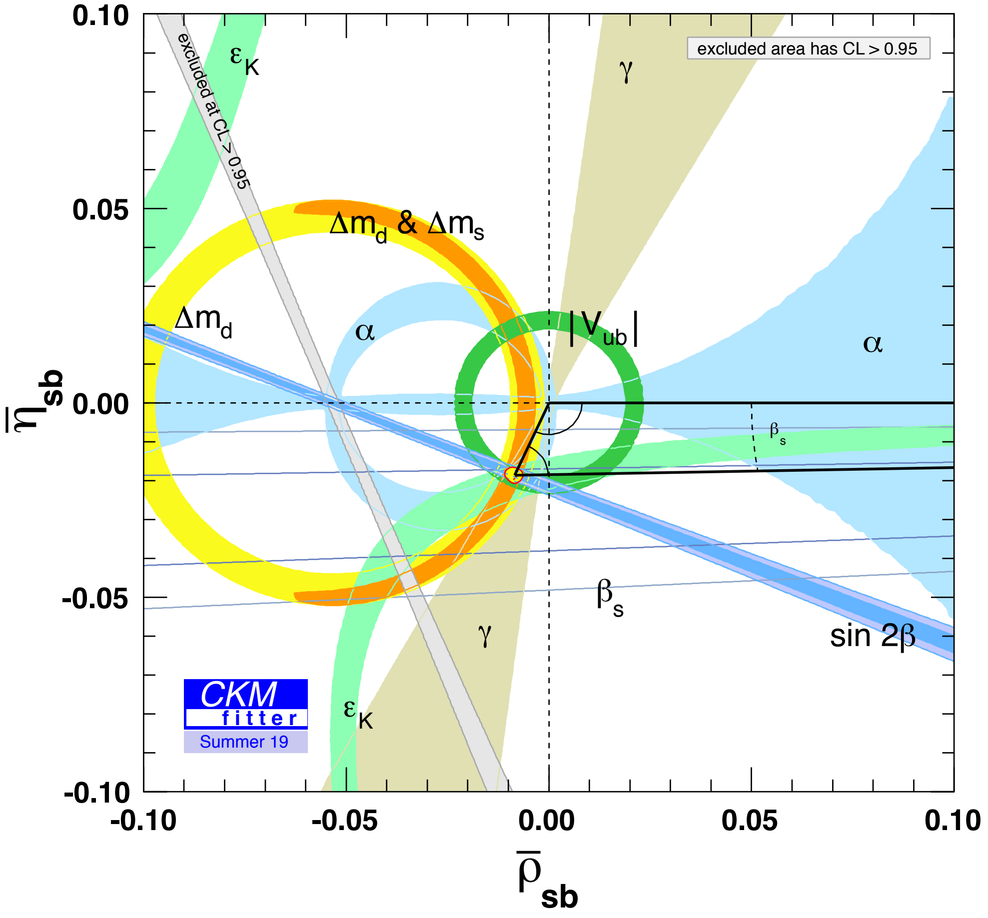
- Phase $\phi_s$ sensitive to physics beyond the SM even at high energy scales that might be unaccessible in direct searches
- Physics BSM could enter in the $B_s^0 - \bar{B}_s^0$ mixing O(10%)

$$\phi_s \approx \phi_{\mathrm{M}} - 2\phi_{\mathrm{D}}^{\mathrm{tree}} = -2\beta_s + \Delta\phi_{\mathrm{NP}}$$

Assuming unitarity of the CKM matrix

$$\phi_s^{\mathrm{SM}} = (-0.03688^{+0.00092}_{-0.00075})\ \mathrm{rad}$$

If $\phi_s^{\mathrm{exp}} \neq \phi_s^{\mathrm{SM}}$, New Physics is found!



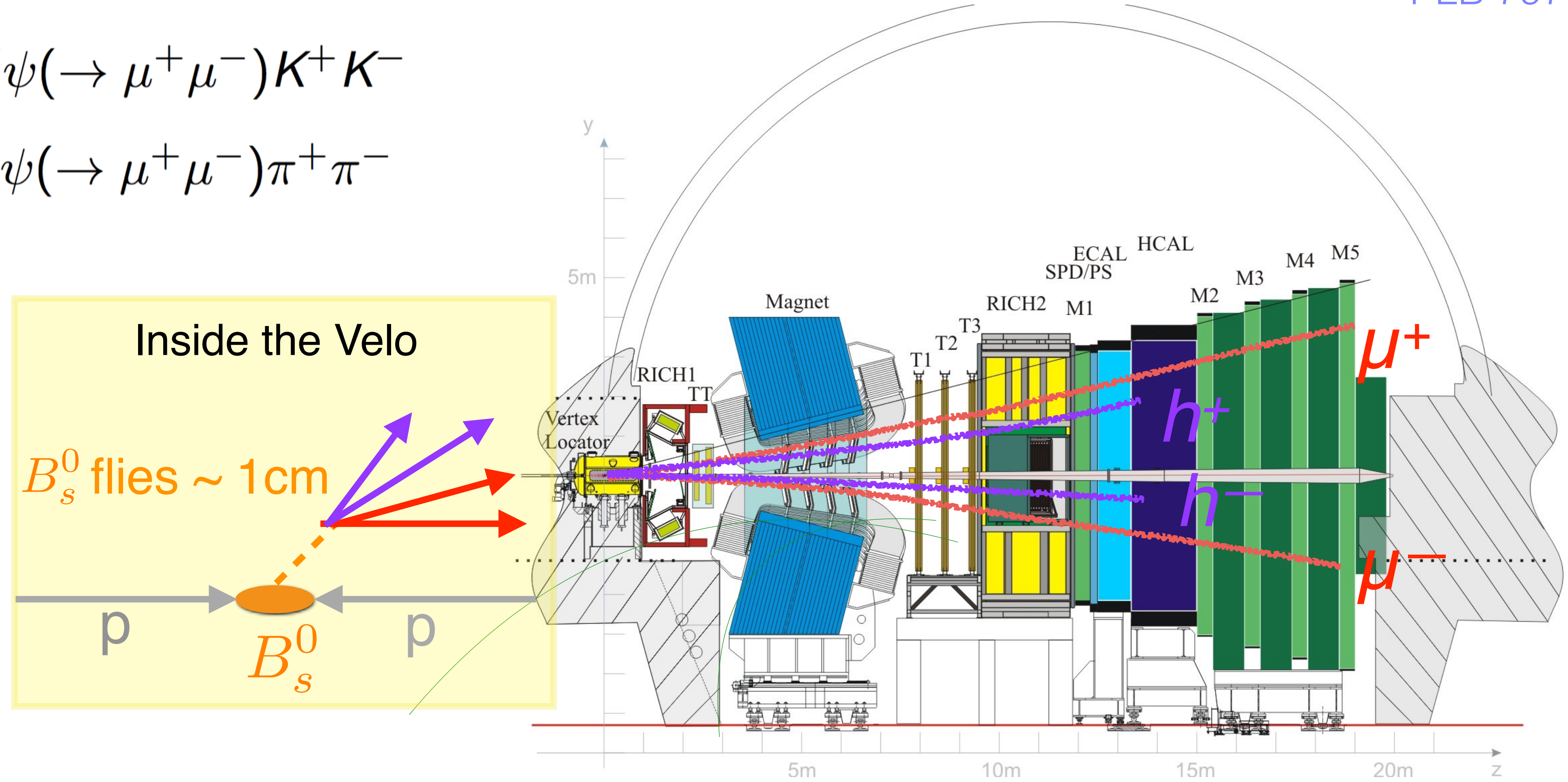
# $\phi_s$ in $B_s^0 \to J/\psi h^+ h^-$ at LHCb

EPJC 79 (2019) 706

PLB 797 (2019) 134789

$B_s^0 \to J/\psi(\to \mu^+\mu^-)K^+K^-$

$B_s^0 \to J/\psi(\to \mu^+\mu^-)\pi^+\pi^-$



- Excellent decay time resolution $\sigma_t$~45 fs, fast $B_s^0$ oscillations T~350 fs
- Good tagging power~5%
- Very nice momentum resolution (Δp/p=0.5-0.8%)
- Identification: ε(h→h) ~90%, $\varepsilon_\mu$~97%
- Time-dependent measurements

**LHCb measurements with 2015 (0.3 $\text{fb}^{-1}$)+2016 (1.6 $\text{fb}^{-1}$)**

# $\phi_s$ in $B_s^0 \to J/\psi h^+ h^-$ at LHCb

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$B_s^0 \to J/\psi(\to \mu^+\mu^-)K^+K^-$

- Relatively large BF, O($10^{-3}$)
- Final state is a mixture of CP-event (L=0, 2) and CP-odd (L=1) components
- Allows to obtain $\phi_s$, $\Gamma_s$, $\Delta\Gamma_s$, $\Delta m_s$

$B_s^0 \to J/\psi(\to \mu^+\mu^-)\pi^+\pi^-$

- BF, O($10^{-4}$)
- Dominated by CP-odd components
- Allows to measure $\phi_s$, $\Gamma_H$

$$\boxed{\Gamma_s = \frac{\Gamma_H+\Gamma_L}{2},\ \Delta\Gamma_s = \Gamma_L - \Gamma_H,\ \Delta m_s = m_H - m_L}$$

$|B_L> = p|B_s^0> + q|\bar{B}_s^0>$ CP-even

$|B_H> = p|B_s^0> - q|\bar{B}_s^0>$ CP-odd

*H*: Heavy mass eigenstate

*L*: Light mass eigenstate

Parametrize the CP Violation with: $\lambda = \eta \frac{q}{p}\frac{\bar{A}_f}{A_f}$

$A_f = < f|B_s^0 >$

$\bar{A}_f = < f|\bar{B}_s^0 >$

$|\lambda|=1$ within SM prediction of no CPV

Angular analysis is required to disentangle CP-even and CP-odd final states admixture

# $\phi_s$ in $B_s^0 \to J/\psi h^+ h^-$ at LHCb

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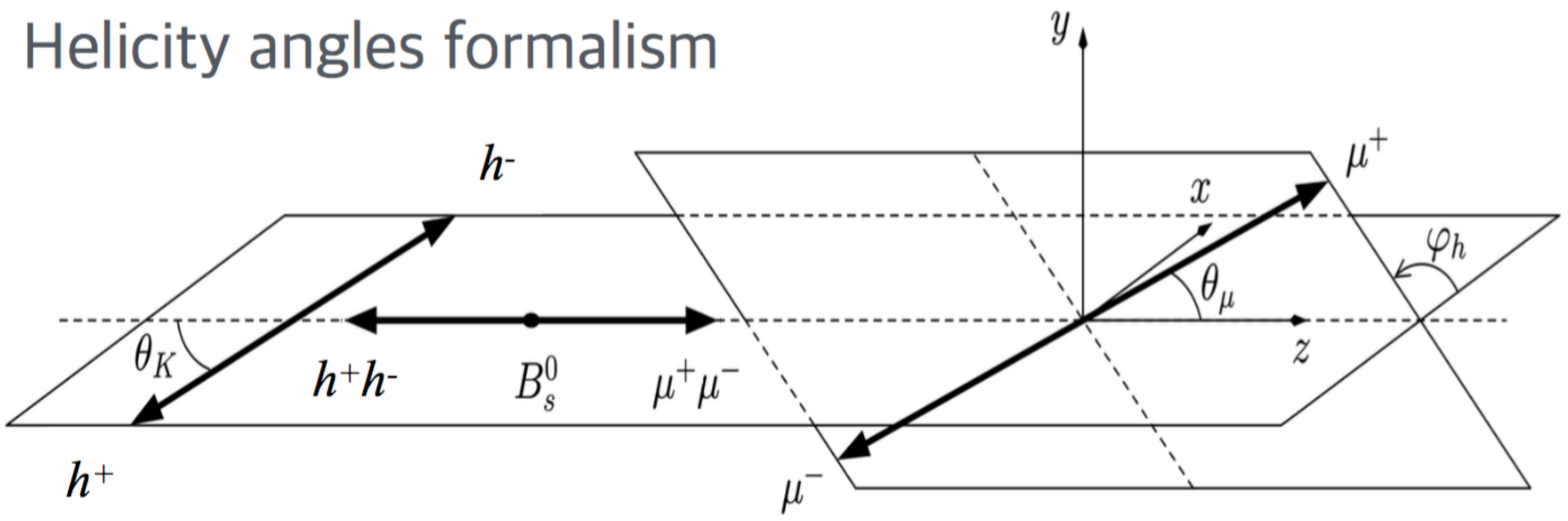
The distribution of the decay-time and angles is described as:

$$\frac{d^4\Gamma}{dt\,d\Omega} \sim \sum_k f_k(\Omega)\epsilon(t,\Omega)(1-2w)h_k(t|B_s^0) \otimes G(t|\sigma_t)$$

- $f_k(\Omega)$ - angular functions
- $\varepsilon(t,\Omega)$ - efficiency as a function of decay time and angles
- $w$ mistag probability of flavour tagging
- $\sigma_t$ decay time resolution
- $h_k(t|B_s^0) = e^{-\Gamma_s t}(a_k cosh\frac{\Delta\Gamma_s t}{2} + b_k sinh\frac{\Delta\Gamma_s t}{2} + c_k cos(\Delta m_s t) + d_k sim(\Delta m_s t))$

Helicity angles formalism



# $\phi_s$ in $B_s^0 \to J/\psi h^+ h^-$ at LHCb

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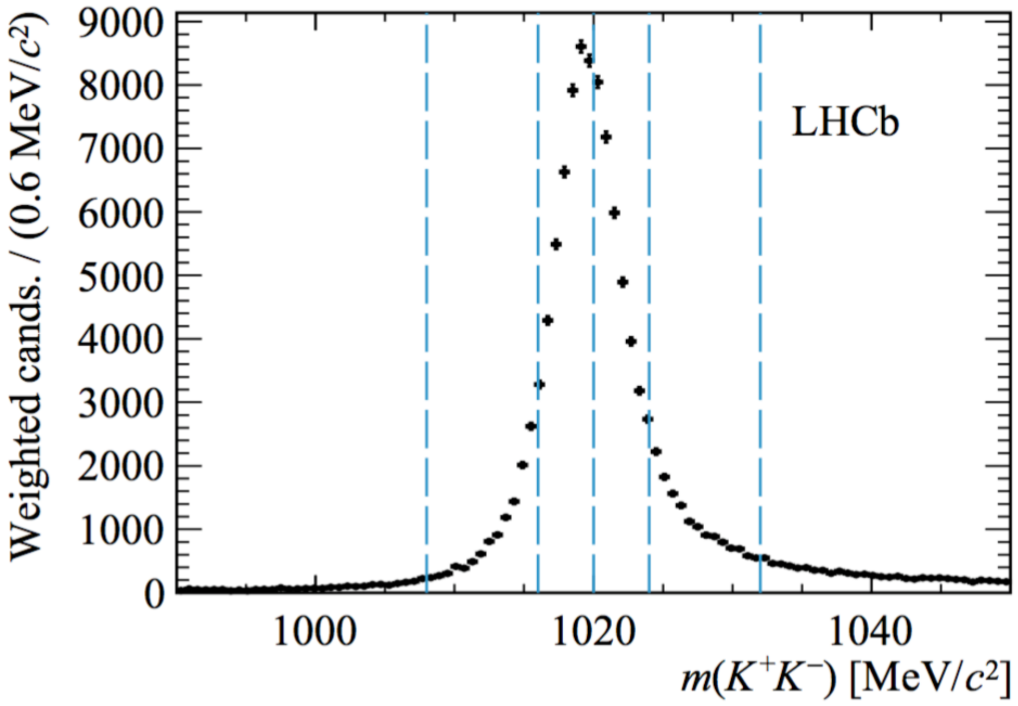
$B_s^0 \to J/\psi(\to \mu^+\mu^-)K^+K^-$

6 M($K^+K^-$) bins in ϕ mass region

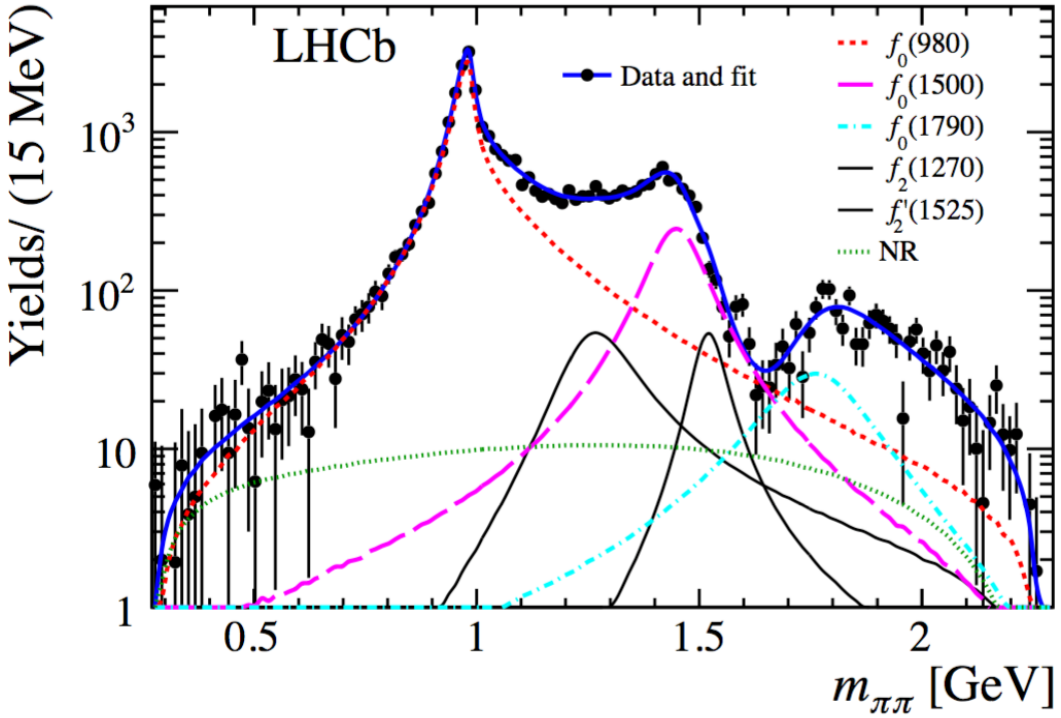


* S-wave contributions differ in different M($K^+K^-$) bins

* Observables $\phi_s$ , $\lambda$, $\Delta m_s$, $\Delta\Gamma_s$, $\Gamma_s$

$B_s^0 \to J/\psi(\to \mu^+\mu^-)\pi^+\pi^-$

different M($\pi^+\pi^-$) components



* Consider all possible resonances

* Fix $\Delta m_s$=17.757 ps$^{-1}$ and $\Gamma_L$=0.6995 ps$^{-1}$

* Assume same $\phi_s$ & λ for all the resonances

- Fit to 3 helicity angles and $B_s^0$ candidates decay time +( M($\pi^+\pi^-$) for $B_s^0 \to J/\psi\pi\pi$ )

# $\phi_s$ in $B_s^0 \to J/\psi h^+ h^-$ at LHCb

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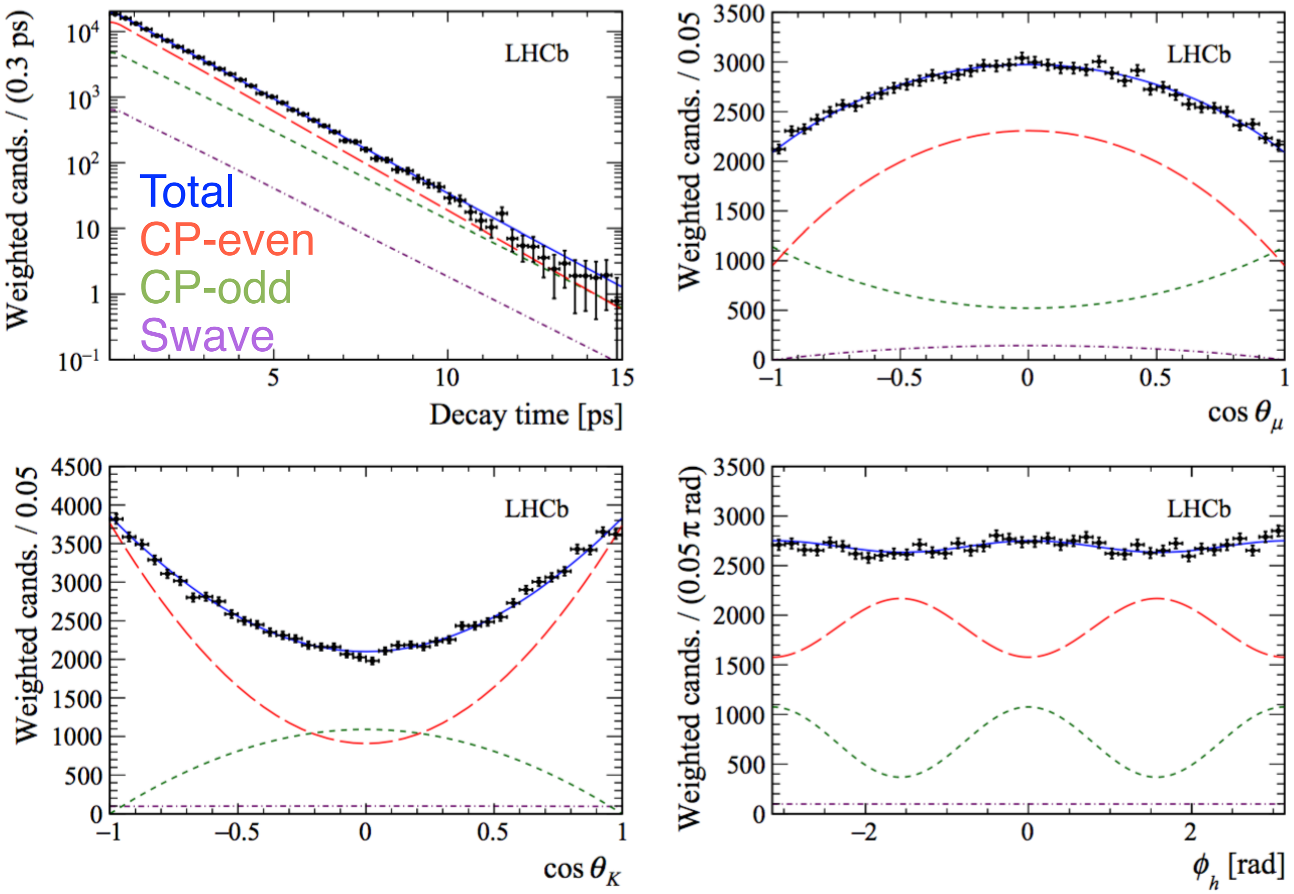
## $B_s^0 \to J/\psi(\to \mu^+\mu^-)K^+K^-$



$\phi_s$ = (-0.080 ± 0.041 ± 0.006) rad

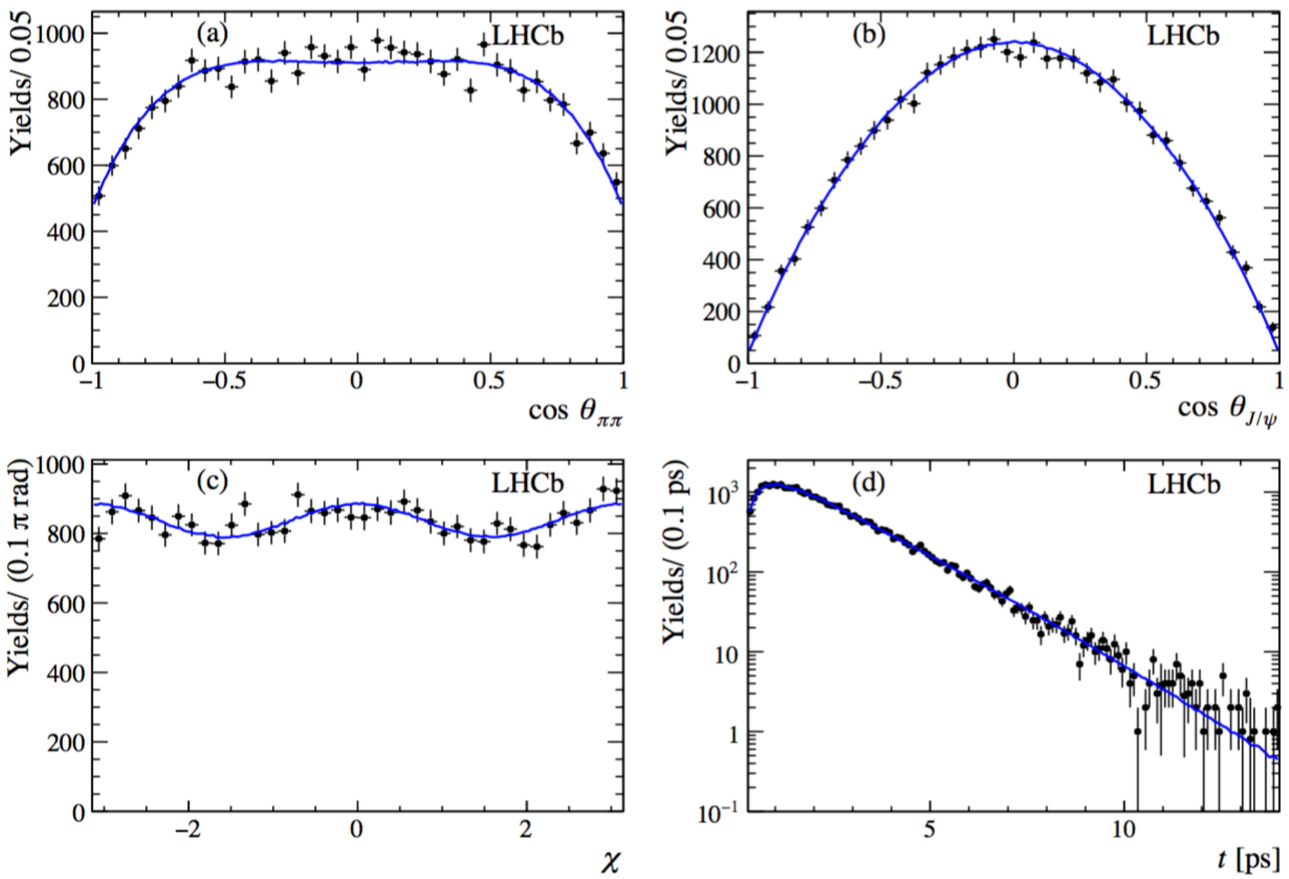
$|\lambda| = 1.012 \pm 0.016 \pm 0.006$

$\Delta\Gamma_s = (0.077 \pm 0.008 \pm 0.003)\ \mathrm{ps}^{-1}$

$\Gamma_s - \Gamma_{B^0} = (-0.0041 \pm 0.0024 \pm 0.0015)\ \mathrm{ps}^{-1}$

$\Delta m_s = (17.703 \pm 0.059 \pm 0.018)\ \mathrm{ps}^{-1}$

## $B_s^0 \to J/\psi(\to \mu^+\mu^-)\pi^+\pi^-$



* CP-odd is greater than 97% at 95% C.L.

$\phi_s$ = (-0.057 ± 0.060 ± 0.011) rad

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

$\Delta\Gamma_s = (0.0813 \pm 0.0048)\ \mathrm{ps}^{-1}$

$\Gamma_H - \Gamma_{B^0} = (-0.050 \pm 0.004 \pm 0.004)\ \mathrm{ps}^{-1}$

# $\phi_s$ combinations

EPJC 79 (2019) 706

$$\phi_s = (-0.040 \pm 0.025)\ \mathrm{rad}$$
$$|\lambda| = 0.991 \pm 0.010$$
$$\Delta\Gamma_s = (0.0813 \pm 0.0048)\ \mathrm{ps}^{-1}$$
$$\Gamma_s - \Gamma_d = (-0.0024 \pm 0.0018)\ \mathrm{ps}^{-1}$$

$\phi_s$ consistent with SM prediction with no CPV

$|\lambda|$ consistent with 1, no direct CPV

$\Gamma_s/\Gamma_d$ consistent with HQE prediction

Latest world-average value:

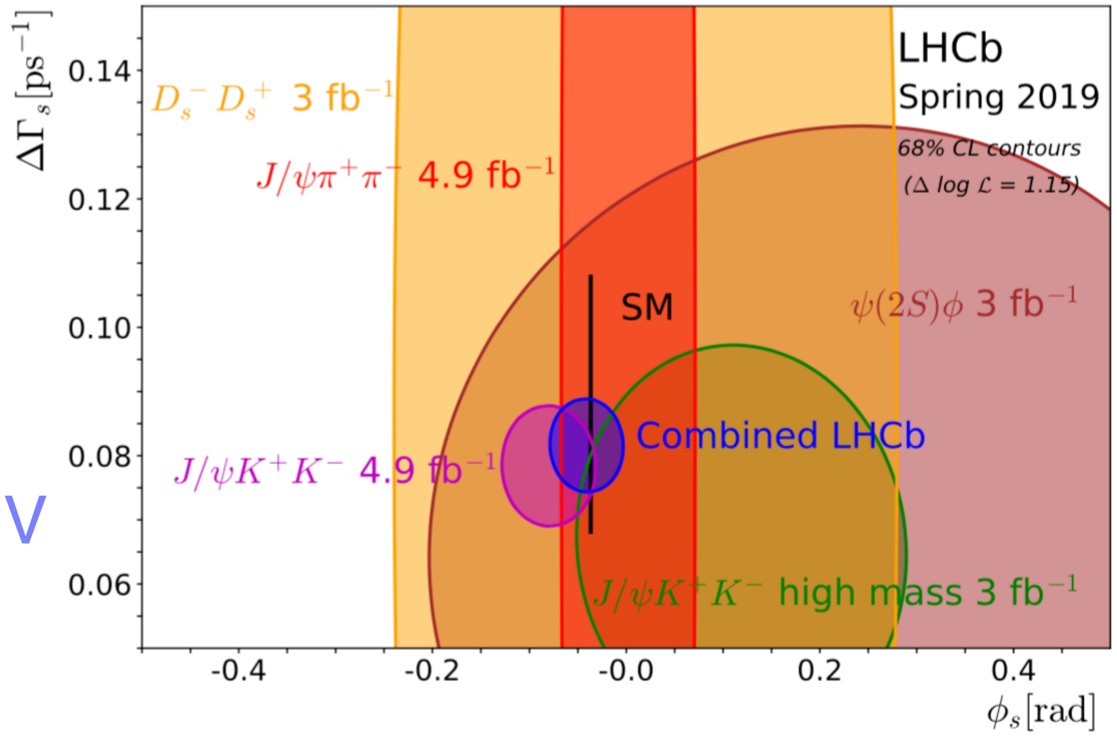
$\phi_s = (-0.051 \pm 0.023)$ rad

dominated by LHCb

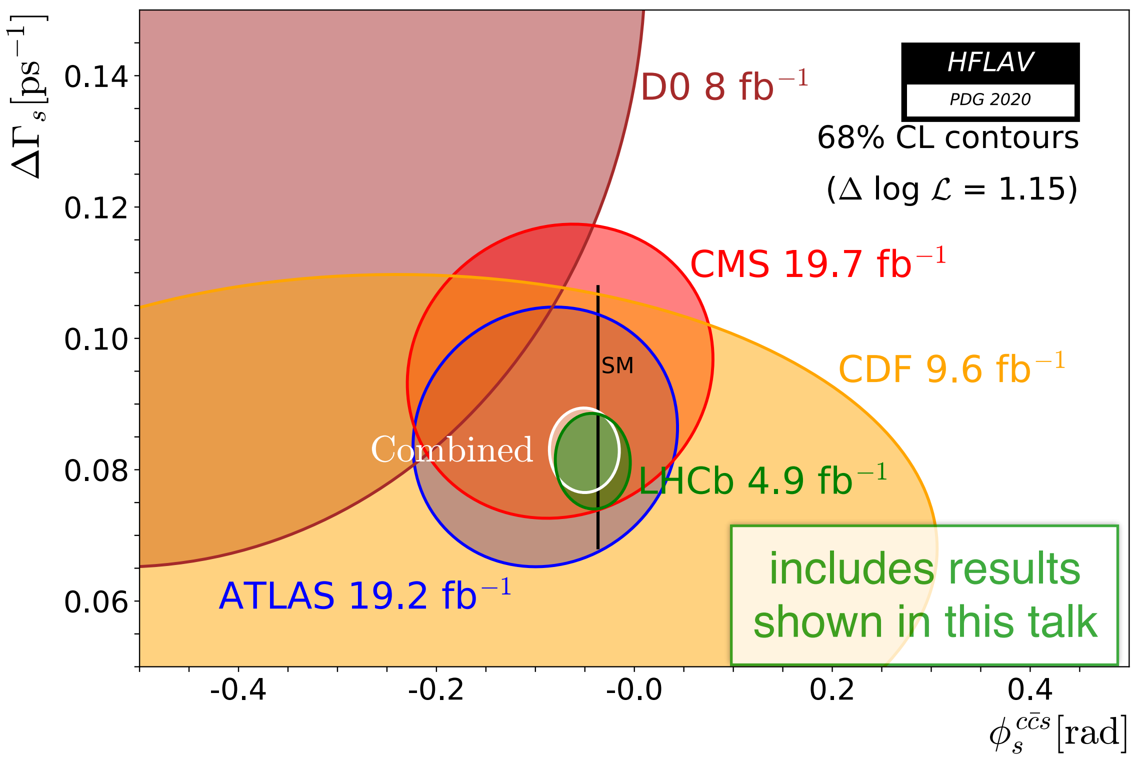
SM Prediction:

$$\phi_s^{\mathrm{SM}} = (-0.03688^{+0.00092}_{-0.00075})\ \mathrm{rad}$$

LHCb combination

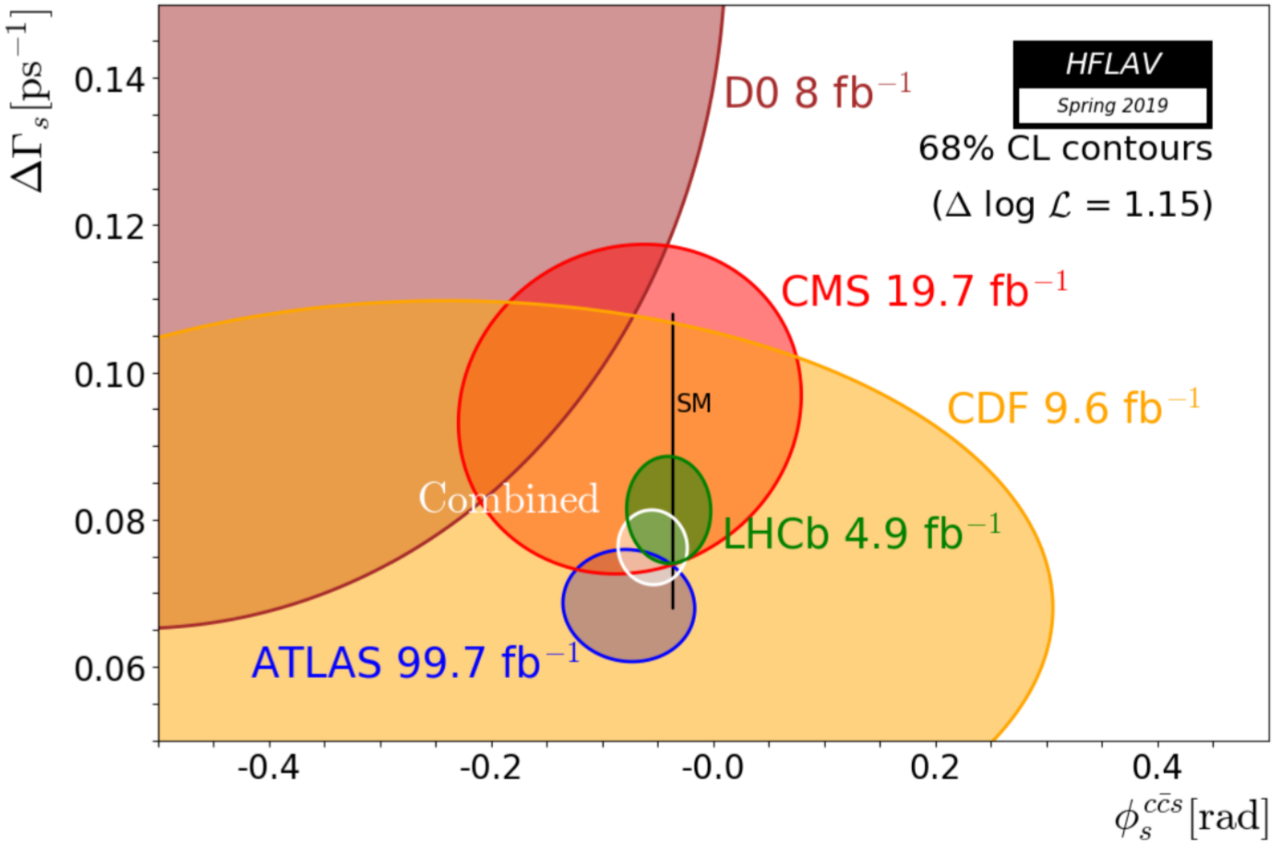


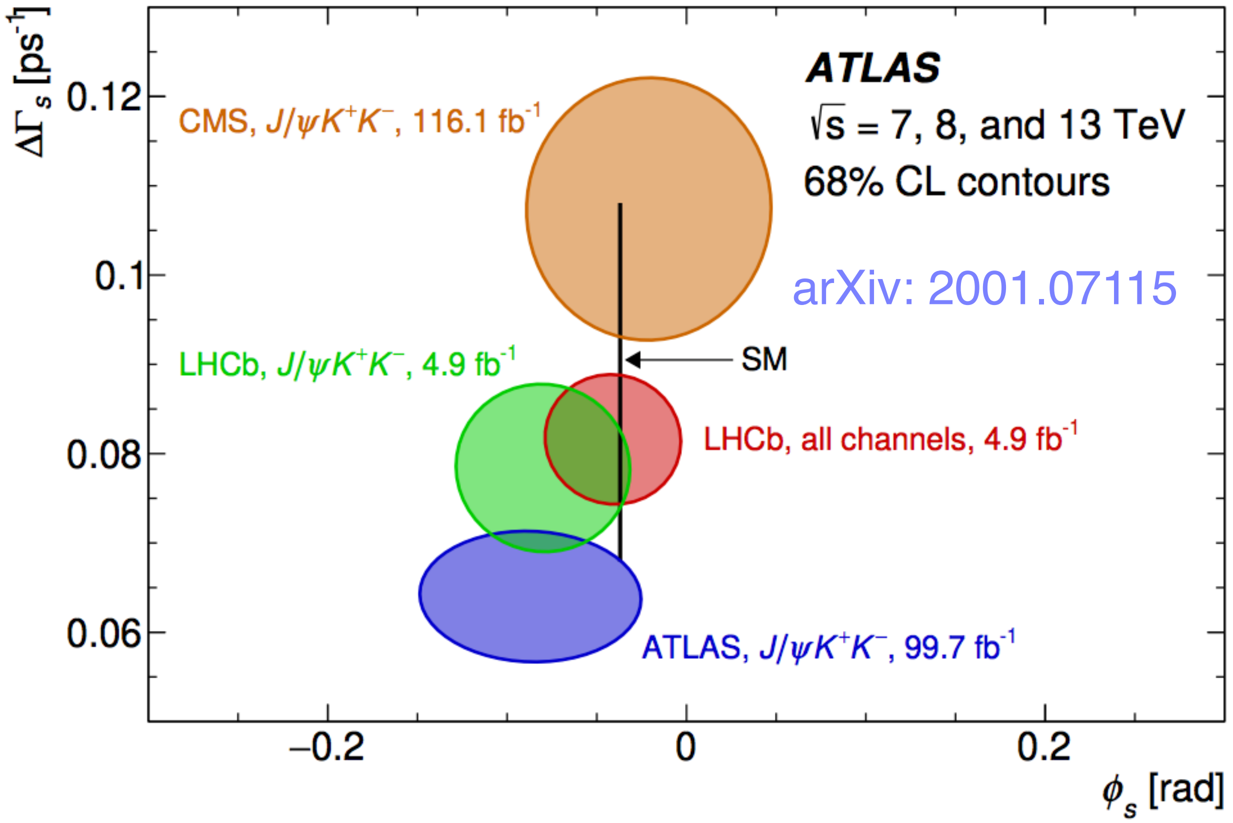
All measurements



includes results shown in this talk

# $\phi_s$ combinations





arXiv: 2001.07115

$\phi_s$ = (-0.055 ± 0.021) rad

$\Delta\Gamma_s$=(0.0764 ±0.0024) ps$^{-1}$

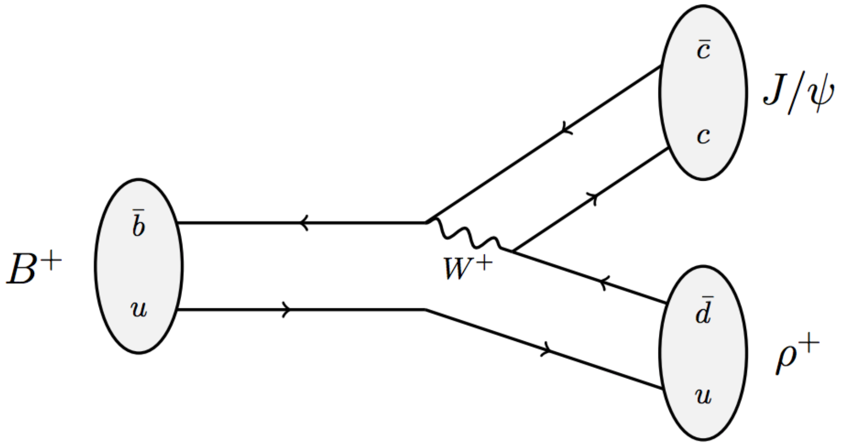
some deviation in ATLAS, CMS, and LHCb, but still consistent with SM

# Direct CP asymmetry in $B^+ \to J/\psi\rho^+$

[EPJC 79 (2019) 537]

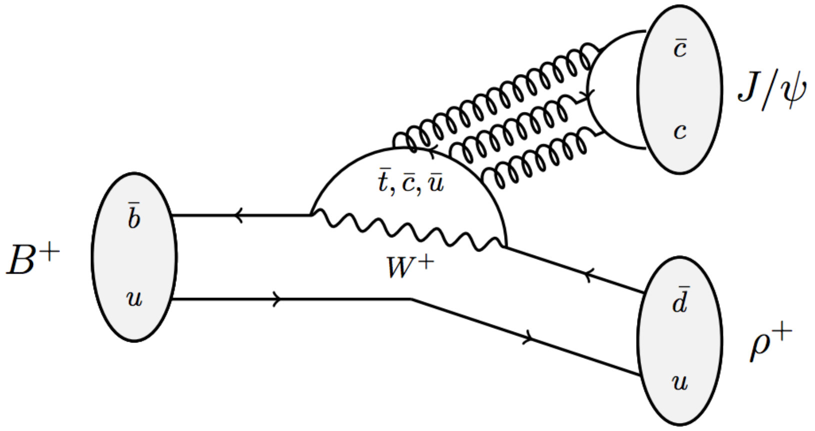
- $B^+ \to J/\psi\rho^+$ proceeds predominantly via a $b \to c\bar{c}d$ transition involving tree and penguin amplitudes
- Interference between these two amplitudes can leads to direct CP violation

$$\mathcal{A}^{CP} \equiv \frac{\mathcal{B}(B^- \to J/\psi\,\rho^-) - \mathcal{B}(B^+ \to J/\psi\,\rho^+)}{\mathcal{B}(B^- \to J/\psi\,\rho^-) + \mathcal{B}(B^+ \to J/\psi\,\rho^+)}$$



- No precise prediction for $A^{CP}$ exists, expected to have an absolute value < 0.35 assuming isospin symmetry between the $B^0 \to J/\psi\rho^0$ and $B^+ \to J/\psi\rho^+$
- $A^{CP}$ places constraints on penguin effects ($\Delta\phi_s^{\text{peng}}$) in the measurements of the CP-violating phase $\phi_s$ assuming SU(3) flavor symmetry and neglecting exchange and annihilation diagrams

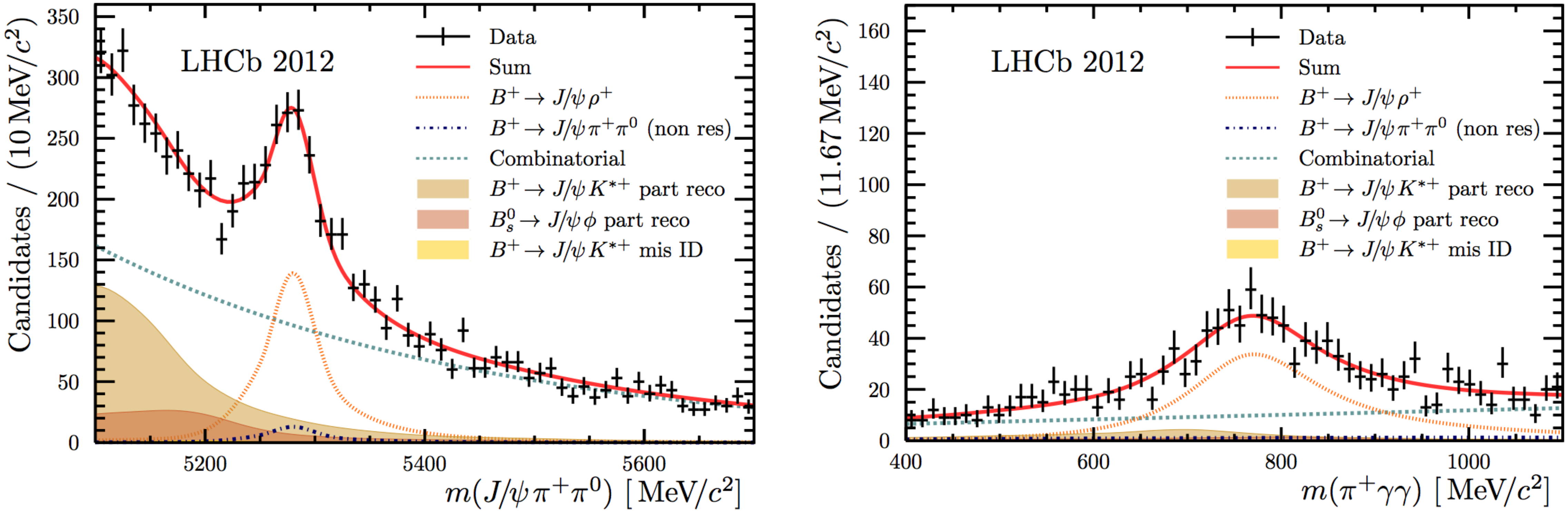
[PLB742(2015)38-49]



# Direct CP asymmetry in $B^+ \to J/\psi\rho^+$

[EPJC 79 (2019) 537]

2D [$m(J/\psi\pi^+\pi^0)$ & $m(\pi^+\gamma\gamma)$] simultaneous fit to 2011 and 2012 data



- $B^+ \to J/\psi K^+$ as control channel

$$\mathcal{B}(B^+ \to J/\psi\,\rho^+) = \mathcal{B}(B^+ \to J/\psi\,K^+) \times \frac{N_{B^+ \to J/\psi\,\rho^+}}{N_{B^+ \to J/\psi\,K^+}} \times \frac{\varepsilon_{B^+ \to J/\psi\,K^+}}{\varepsilon_{B^+ \to J/\psi\,\rho^+}} \times \frac{1}{\mathcal{B}(\pi^0 \to \gamma\gamma)}$$

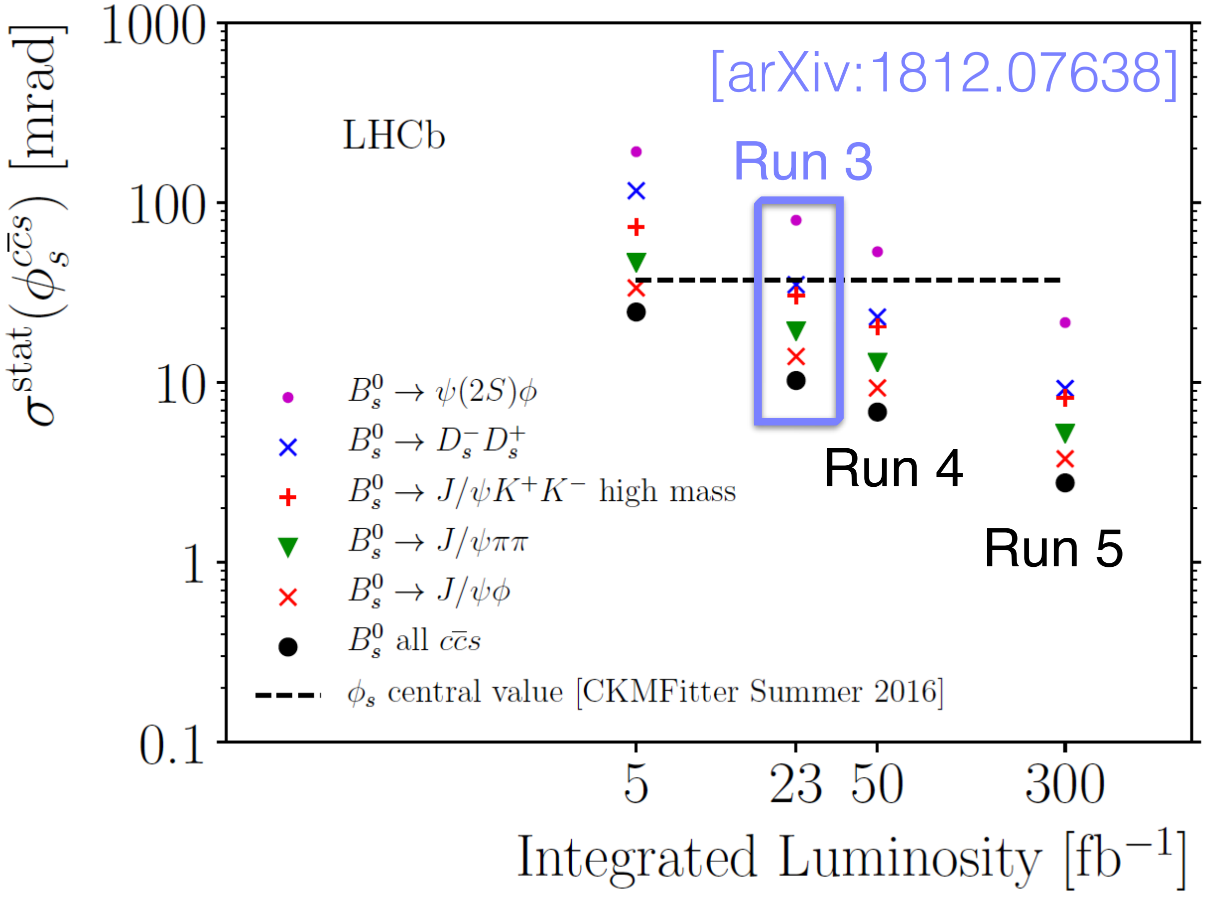
$$= (3.81^{+0.25}_{-0.24} \pm 0.35) \times 10^{-5}$$

$$\boxed{\mathcal{A}^{CP}(B^+ \to J/\psi\,\rho^+) = -0.045^{+0.056}_{-0.057} \pm 0.008}$$

consistent with the measurements using $B^0 \to J/\psi\rho^0$ decays [PLB742(2015)38-49]

# Summary & Prospects

- Time-dependent CP violation measurement for $\phi_s$ in the $b \to c\bar{c}s$ transitions are presented, and the world average is dominated by LHCb's measurements
- Direct CP asymmetry measurement in $B^+ \to J/\psi\rho^+$ would be helpful to place better constraint on the penguin contribution in $\phi_s$
- Measurements with full Run 2 data (6 $\text{fb}^{-1}$) and with more decay channels are in good progress, more precise measurements come soon



- Exploring more decay modes:

  $$J/\psi(\to ee),\ \eta\prime(\to \rho^0\gamma, \eta\pi\pi, \gamma\gamma)$$

- Careful consideration for penguin contribution
- Independent CP violation effects in each polarization state
- Improved measurements of B-mixing parameters and lifetime

Stay tuned!

Thanks for you attention!

# Penguin Pollution in $\phi_s$

$$A_i'(b \to c\bar{c}s) = \left(1-\frac{\lambda^2}{2}\right)\mathcal{A}_i'\left[1+\epsilon a_i' e^{i\theta'} e^{i\gamma}\right]$$

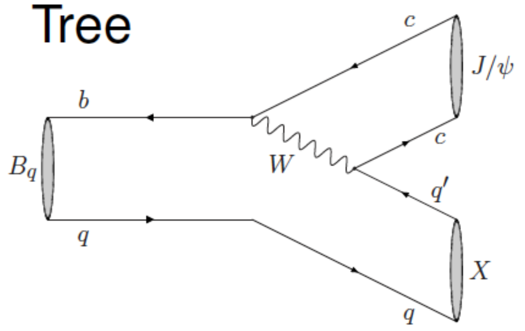
$$A_i(b \to c\bar{c}d) = -\lambda\mathcal{A}_i\left[1+a_i e^{i\theta} e^{i\gamma}\right]$$

$a_i' e^{i\theta'}$ $(a_i e^{i\theta})$: Penguin/Tree ratio in $b \to c\bar{c}s(d)$

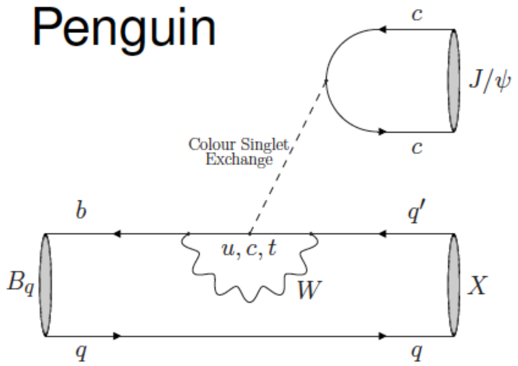
SU(3) : $a_i' = a$, $\theta_i' = \theta_i$.

extract $\Delta\phi_s^{\text{peng}}(a_i', \theta_i')$ $\Delta\beta^{\text{peng}}(a_i, \theta_i)$ from t to CP parmeters

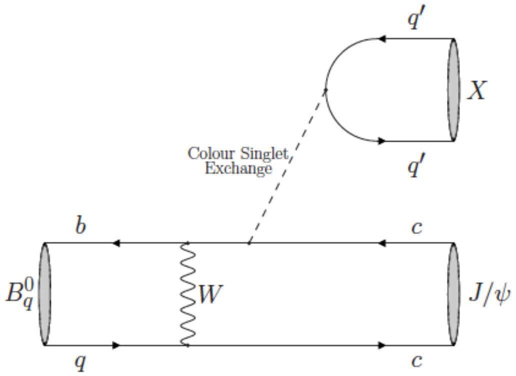
**Tree**



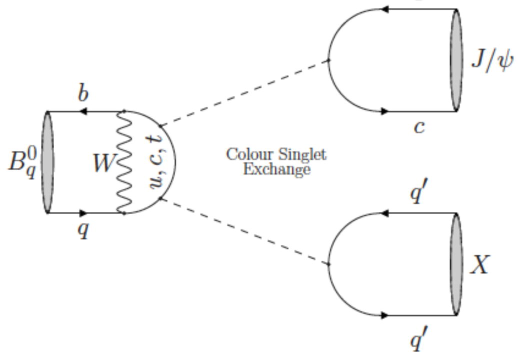
**Penguin**



**Exchange**



**Penguin-Annihilation**



Studied at LHCb with 3 fb$^{-1}$:

- $^*B^0 \to J/\psi\rho^0$ (BF, C & S) [PLB742(2015)38-49]
- $^*B_s^0 \to J/\psi K^{*0}$ (BF & C), has no PA and PE [JHEP11(2015)082]

- Measure penguin phase shift for each polarization state (0, ⊥, //, S)

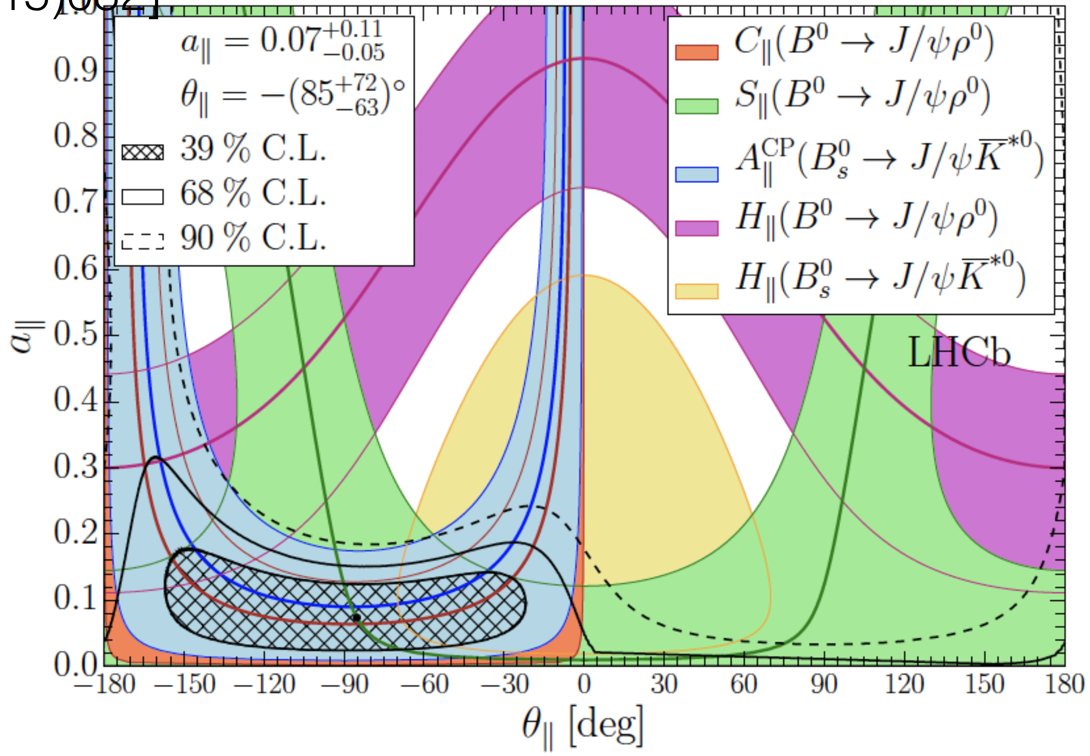
$$\Delta\phi_s^0 = 0.000^{+0.011}_{-0.009}(\text{stat})^{+0.009}_{-0.004}(\text{syst})$$

$$\Delta\phi_s^{\parallel} = 0.001^{+0.010}_{-0.014}(\text{stat}) \pm 0.008(\text{syst})$$

$$\Delta\phi_s^{\perp} = 0.003^{+0.010}_{-0.014}(\text{stat}) \pm 0.008(\text{syst})$$

small penguin shift w.r.t. experimental precision

[JHEP 03 (2015) 145]



# Time-dependent Angular Function

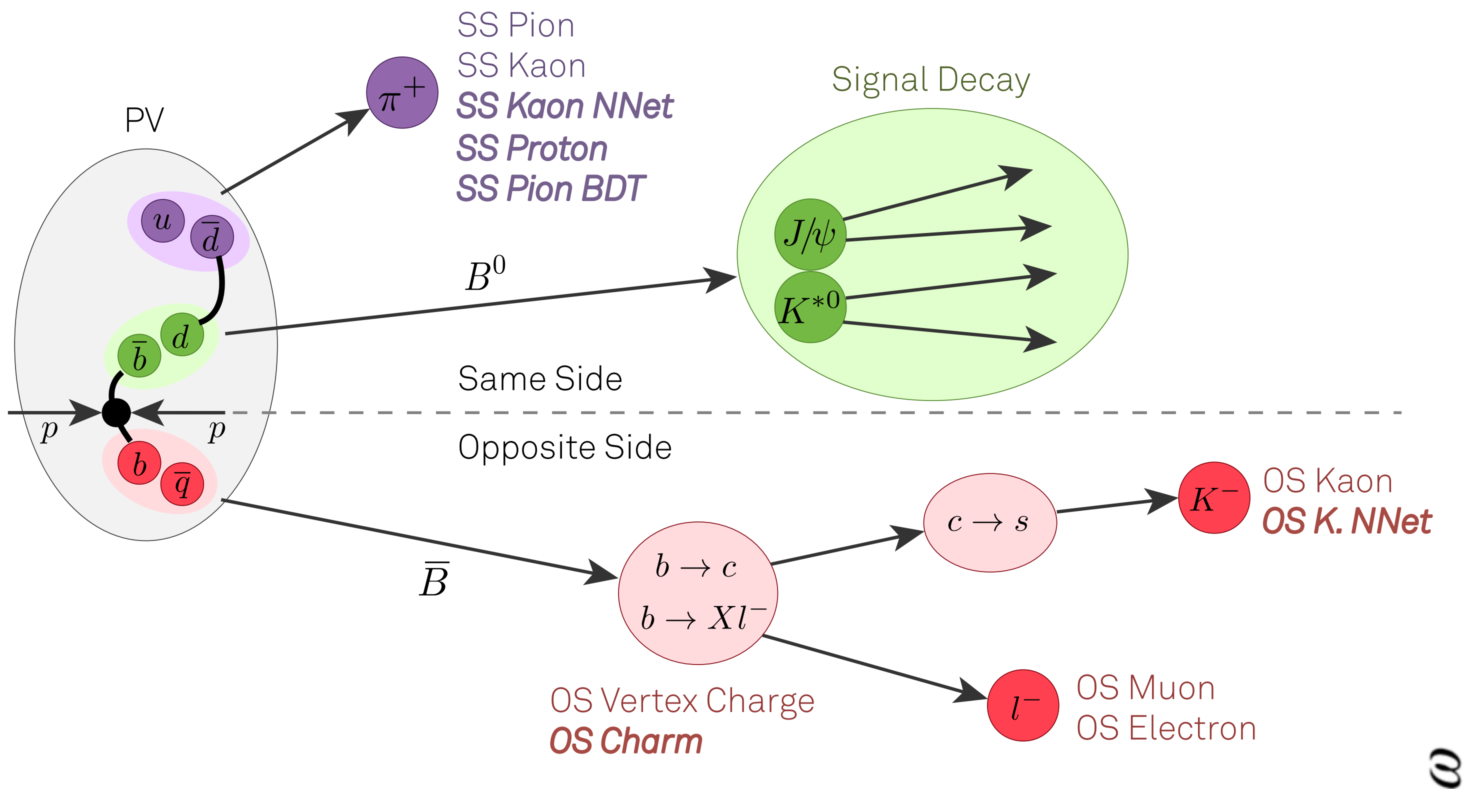
$$\frac{d^4\Gamma(B_s^0 \to J/\psi\,\phi)}{dt\,d\Omega} \propto \sum_{k=1}^{10} h_k(t) f_k(\Omega)$$

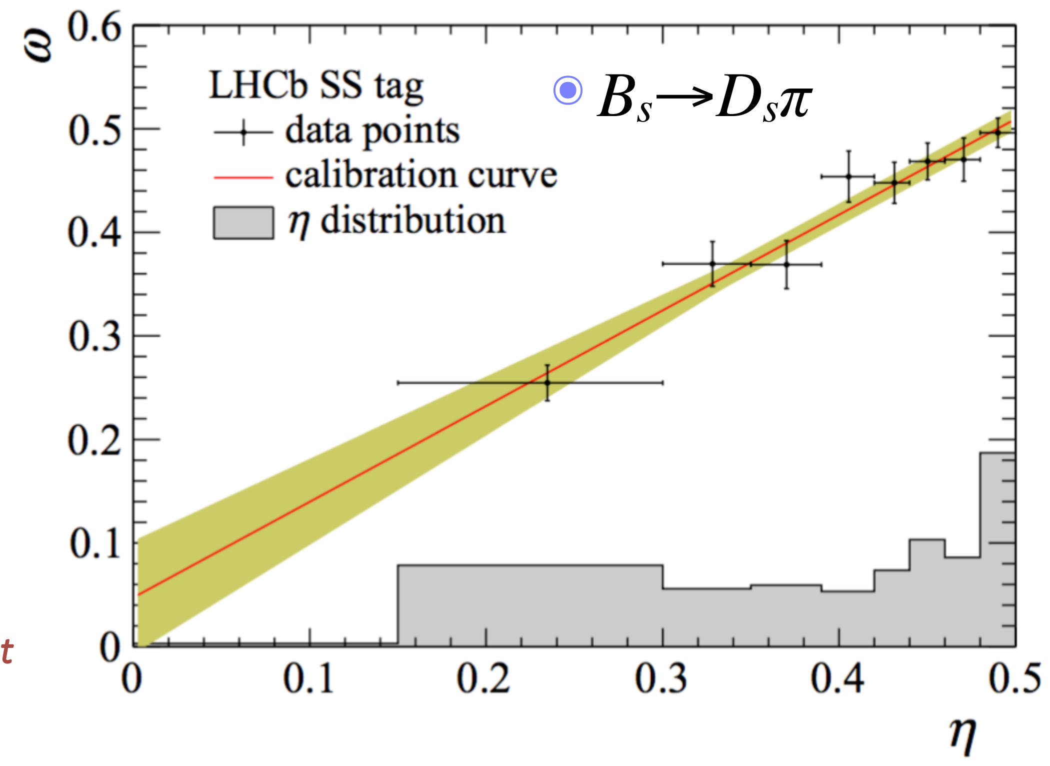
$$h_k(t) = N_k e^{-\Gamma t}\left[a_k \cosh\frac{\Delta\Gamma_s t}{2} + b_k \sinh\frac{\Delta\Gamma_s t}{2} + c_k \cos(\Delta m_s t) + d_k \sin(\Delta m_s t)\right]$$

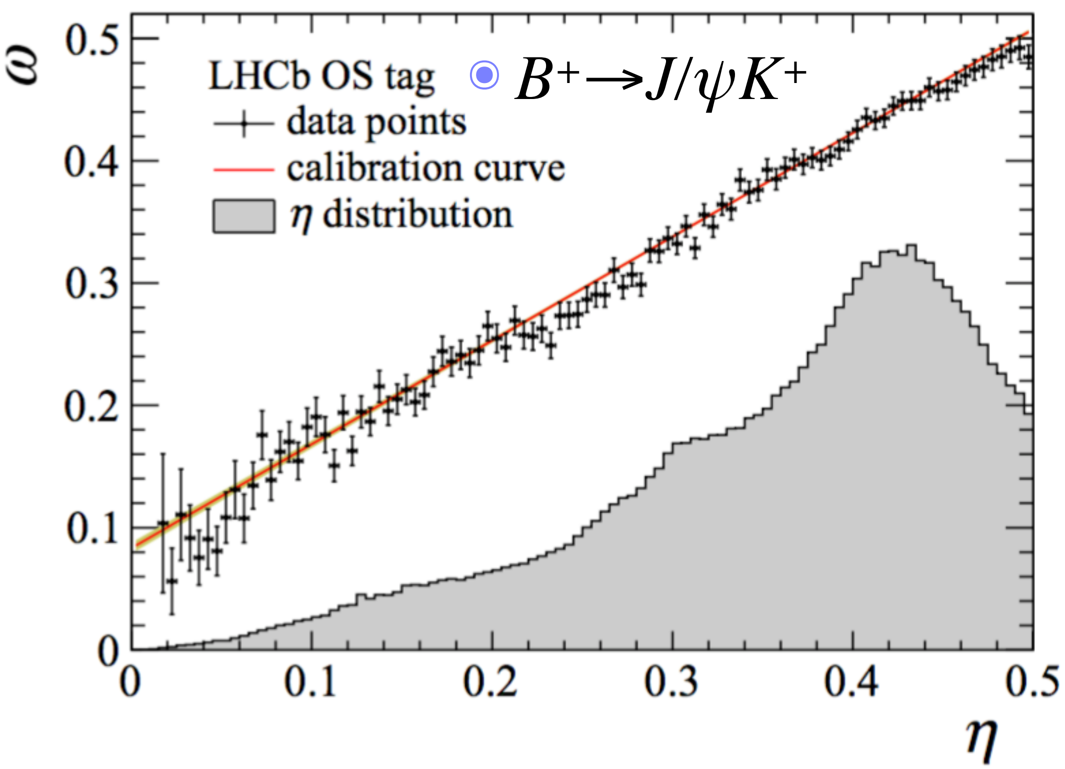
| $f_k$ | $N_k$ | $a_k$ | $b_k$ | $c_k$ | $d_k$ |
|---|---|---|---|---|---|
| $c_K^2 s_l^2$ | $\lvert A_0\rvert^2$ | $\frac{1}{2}(1+\lvert\lambda_0\rvert^2)$ | $-\lvert\lambda_0\rvert\cos(\phi_0)$ | $\frac{1}{2}(1-\lvert\lambda_0\rvert^2)$ | $\lvert\lambda_0\rvert\sin(\phi_0)$ |
| $\frac{1}{2}s_K^2(1-c_\phi^2 s_l^2)$ | $\lvert A_\parallel\rvert^2$ | $\frac{1}{2}(1+\lvert\lambda_\parallel\rvert^2)$ | $-\lvert\lambda_\parallel\rvert\cos(\phi_\parallel)$ | $\frac{1}{2}(1-\lvert\lambda_\parallel\rvert^2)$ | $\lvert\lambda_\parallel\rvert\sin(\phi_\parallel)$ |
| $\frac{1}{2}s_K^2(1-s_\phi^2 s_l^2)$ | $\lvert A_\perp\rvert^2$ | $\frac{1}{2}(1+\lvert\lambda_\perp\rvert^2)$ | $\lvert\lambda_\perp\rvert\cos(\phi_\perp)$ | $\frac{1}{2}(1-\lvert\lambda_\perp\rvert^2)$ | $-\lvert\lambda_\perp\rvert\sin(\phi_\perp)$ |
| $s_K^2 s_l^2 s_\phi c_\phi$ | $\lvert A_\perp A_\parallel\rvert$ | $\frac{1}{2}\Big[\sin(\delta_\perp-\delta_\parallel)-\lvert\lambda_\perp\lambda_\parallel\rvert \sin(\delta_\perp-\delta_\parallel-\phi_\perp+\phi_\parallel)\Big]$ | $\frac{1}{2}\Big[\lvert\lambda_\perp\rvert\sin(\delta_\perp-\delta_\parallel-\phi_\perp) +\lvert\lambda_\parallel\rvert\sin(\delta_\parallel-\delta_\perp-\phi_\parallel)\Big]$ | $\frac{1}{2}\Big[\sin(\delta_\perp-\delta_\parallel)+\lvert\lambda_\perp\lambda_\parallel\rvert \sin(\delta_\perp-\delta_\parallel-\phi_\perp+\phi_\parallel)\Big]$ | $-\frac{1}{2}\Big[\lvert\lambda_\perp\rvert\cos(\delta_\perp-\delta_\parallel-\phi_\perp) +\lvert\lambda_\parallel\rvert\cos(\delta_\parallel-\delta_\perp-\phi_\parallel)\Big]$ |
| $\sqrt{2}s_K c_K s_l c_l c_\phi$ | $\lvert A_0 A_\parallel\rvert$ | $\frac{1}{2}\Big[\cos(\delta_0-\delta_\parallel)+\lvert\lambda_0\lambda_\parallel\rvert \cos(\delta_0-\delta_\parallel-\phi_0+\phi_\parallel)\Big]$ | $-\frac{1}{2}\Big[\lvert\lambda_0\rvert\cos(\delta_0-\delta_\parallel-\phi_0) +\lvert\lambda_\parallel\rvert\cos(\delta_\parallel-\delta_0-\phi_\parallel)\Big]$ | $\frac{1}{2}\Big[\cos(\delta_0-\delta_\parallel)-\lvert\lambda_0\lambda_\parallel\rvert \cos(\delta_0-\delta_\parallel-\phi_0+\phi_\parallel)\Big]$ | $-\frac{1}{2}\Big[\lvert\lambda_0\rvert\sin(\delta_0-\delta_\parallel-\phi_0) +\lvert\lambda_\parallel\rvert\sin(\delta_\parallel-\delta_0-\phi_\parallel)\Big]$ |
| $-\sqrt{2}s_K c_K s_l c_l s_\phi$ | $\lvert A_0 A_\perp\rvert$ | $-\frac{1}{2}\Big[\sin(\delta_0-\delta_\perp)-\lvert\lambda_0\lambda_\perp\rvert \sin(\delta_0-\delta_\perp-\phi_0+\phi_\perp)\Big]$ | $\frac{1}{2}\Big[\lvert\lambda_0\rvert\sin(\delta_0-\delta_\perp-\phi_0) +\lvert\lambda_\perp\rvert\sin(\delta_\perp-\delta_0-\phi_\perp)\Big]$ | $-\frac{1}{2}\Big[\sin(\delta_0-\delta_\perp)+\lvert\lambda_0\lambda_\perp\rvert \sin(\delta_0-\delta_\perp-\phi_0+\phi_\perp)\Big]$ | $-\frac{1}{2}\Big[\lvert\lambda_0\rvert\cos(\delta_0-\delta_\perp-\phi_0) +\lvert\lambda_\perp\rvert\cos(\delta_\perp-\delta_0-\phi_\perp)\Big]$ |
| $\frac{1}{3}s_l^2$ | $\lvert A_S\rvert^2$ | $\frac{1}{2}(1+\lvert\lambda_S\rvert^2)$ | $\lvert\lambda_S\rvert\cos(\phi_S)$ | $\frac{1}{2}(1-\lvert\lambda_S\rvert^2)$ | $-\lvert\lambda_S\rvert\sin(\phi_S)$ |
| $\frac{2}{\sqrt{6}}s_K s_l c_l c_\phi$ | $\lvert A_S A_\parallel\rvert$ | $\frac{1}{2}\Big[\cos(\delta_S-\delta_\parallel)-\lvert\lambda_S\lambda_\parallel\rvert \cos(\delta_S-\delta_\parallel-\phi_S+\phi_\parallel)\Big]$ | $\frac{1}{2}\Big[\lvert\lambda_S\rvert\cos(\delta_S-\delta_\parallel-\phi_S) -\lvert\lambda_\parallel\rvert\cos(\delta_\parallel-\delta_S-\phi_\parallel)\Big]$ | $\frac{1}{2}\Big[\cos(\delta_S-\delta_\parallel)+\lvert\lambda_S\lambda_\parallel\rvert \cos(\delta_S-\delta_\parallel-\phi_S+\phi_\parallel)\Big]$ | $\frac{1}{2}\Big[\lvert\lambda_S\rvert\sin(\delta_S-\delta_\parallel-\phi_S) -\lvert\lambda_\parallel\rvert\sin(\delta_\parallel-\delta_S-\phi_\parallel)\Big]$ |
| $-\frac{2}{\sqrt{6}}s_K s_l c_l s_\phi$ | $\lvert A_S A_\perp\rvert$ | $-\frac{1}{2}\Big[\sin(\delta_S-\delta_\perp)+\lvert\lambda_S\lambda_\perp\rvert \sin(\delta_S-\delta_\perp-\phi_S+\phi_\perp)\Big]$ | $-\frac{1}{2}\Big[\lvert\lambda_S\rvert\sin(\delta_S-\delta_\perp-\phi_S) -\lvert\lambda_\perp\rvert\sin(\delta_\perp-\delta_S-\phi_\perp)\Big]$ | $-\frac{1}{2}\Big[\sin(\delta_S-\delta_\perp)-\lvert\lambda_S\lambda_\perp\rvert \sin(\delta_S-\delta_\perp-\phi_S+\phi_\perp)\Big]$ | $-\frac{1}{2}\Big[-\lvert\lambda_S\rvert\cos(\delta_S-\delta_\perp-\phi_S) +\lvert\lambda_\perp\rvert\cos(\delta_\perp-\delta_S-\phi_\perp)\Big]$ |
| $\frac{2}{\sqrt{3}}c_K s_l^2$ | $\lvert A_S A_0\rvert$ | $\frac{1}{2}\Big[\cos(\delta_S-\delta_0)-\lvert\lambda_S\lambda_0\rvert \cos(\delta_S-\delta_0-\phi_S+\phi_0)\Big]$ | $\frac{1}{2}\Big[\lvert\lambda_S\rvert\cos(\delta_S-\delta_0-\phi_S) -\lvert\lambda_0\rvert\cos(\delta_0-\delta_S-\phi_0)\Big]$ | $\frac{1}{2}\Big[\cos(\delta_S-\delta_0)+\lvert\lambda_S\lambda_0\rvert \cos(\delta_S-\delta_0-\phi_S+\phi_0)\Big]$ | $\frac{1}{2}\Big[\lvert\lambda_S\rvert\sin(\delta_S-\delta_0-\phi_S) -\lvert\lambda_0\rvert\sin(\delta_0-\delta_S-\phi_0)\Big]$ |

$c_K = \cos\theta_K$, $s_K = \sin\theta_K$, $c_l = \cos\theta_l$, $s_l = \sin\theta_l$, $c_\phi = \cos\phi$ and $s_\phi = \sin\phi$

# Flavor Tagging







- Use information in the event (e.g. charge of K associated with b-quark hadronization) to tag B flavor at production
- Precision on $A^{CP}$ scales with tagging power
- Calibrate tagging algorithm response using mode with known flavor (e.g. $B^+ \to J/\psi K^+$, $B_s \to D_s\pi$)