New Physics search via CP observables in $B_s^0 \to \phi\phi$ decay

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Introduction

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Motivation: $b \to s\bar{s}s$ pure penguin process

Penguin Quantum Loop -> new heavy particles

No tree-penguin interference -> clean channel

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SM Prediction: $\phi_s^{s\bar{s}s}$ = 0 (phases cancel out)

$$\arg\left(\frac{q}{p}\right) = 2\beta_s,\ \arg\left(\frac{\bar{A}}{A}\right) = -2\beta_s,\ \beta_s = \arg\left(\frac{-V_{tb}^* V_{ts}}{V_{cb}^* V_{cs}}\right)$$

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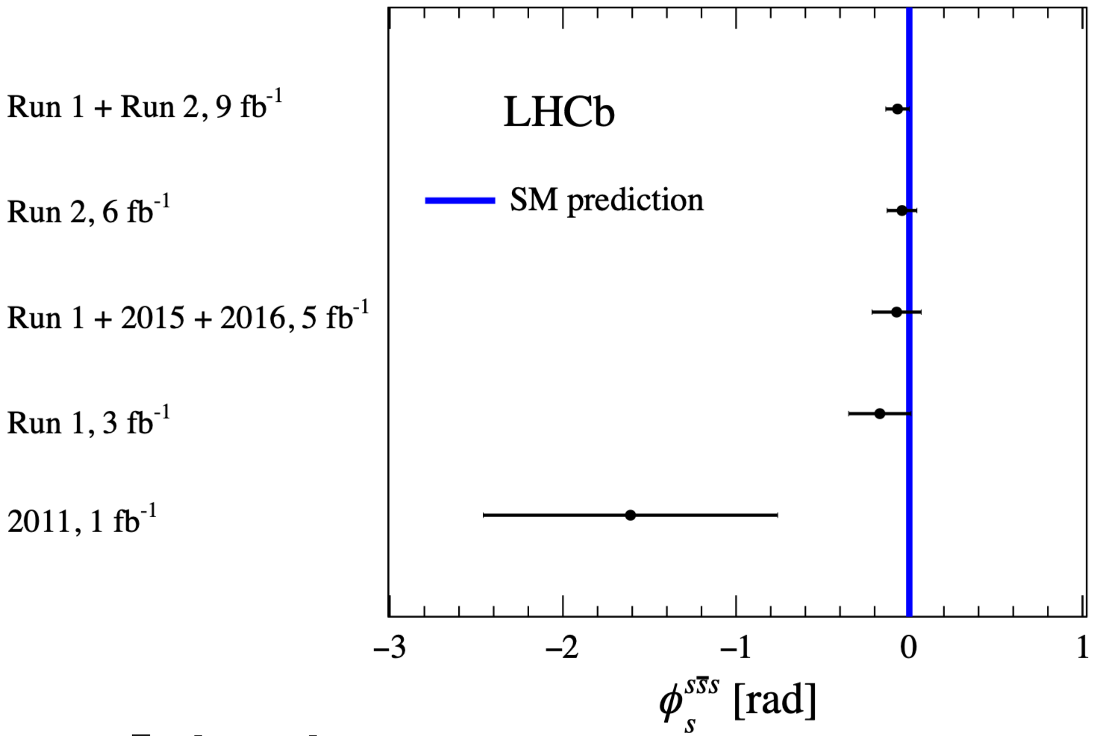

$\phi_s^{s\bar{s}s}$ [rad] $\quad -0.042 \pm 0.075 \pm 0.009$

LHCb arXiv: 2304.06198 [hep-ex]

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Plan:
How exactly is this phase measured (and parameterisation used) ?
What are the assumptions taken ?
What can we infer from it (especially about NP)?

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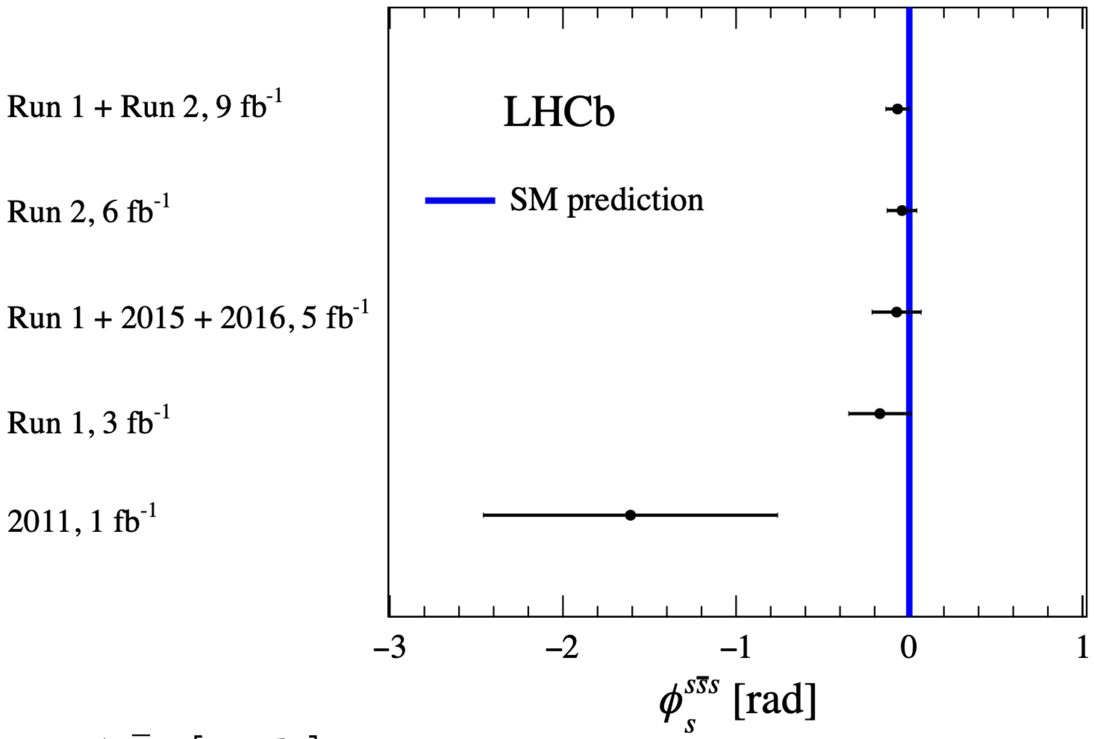

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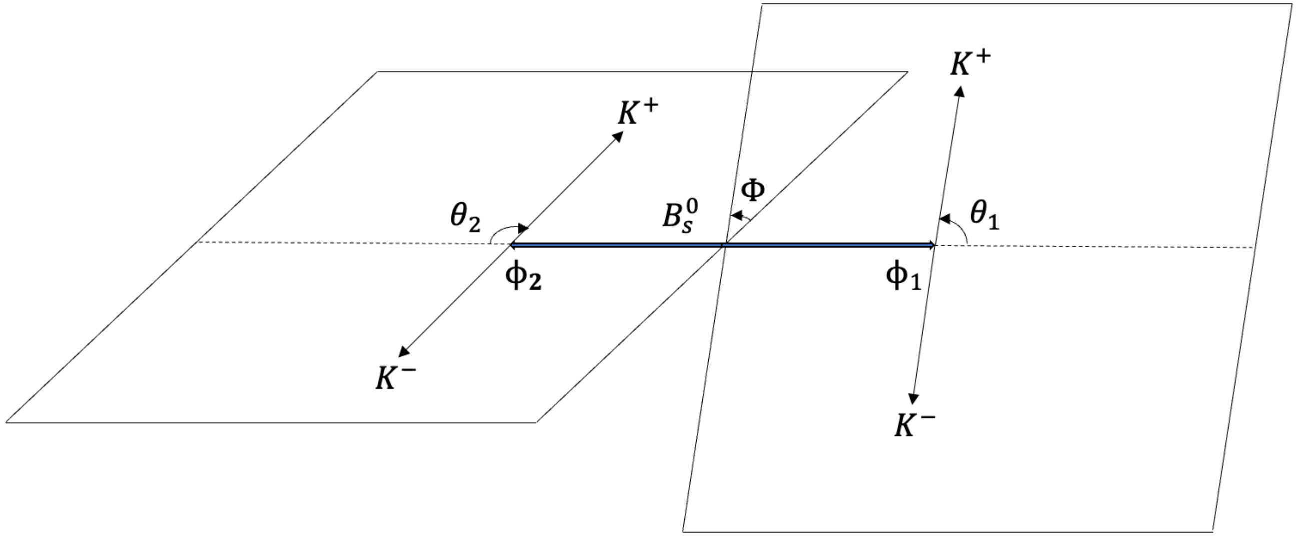

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$A_{0,\parallel,\perp}$(t): transversity amplitudes of $B_s^0 \to \phi\phi$ decay

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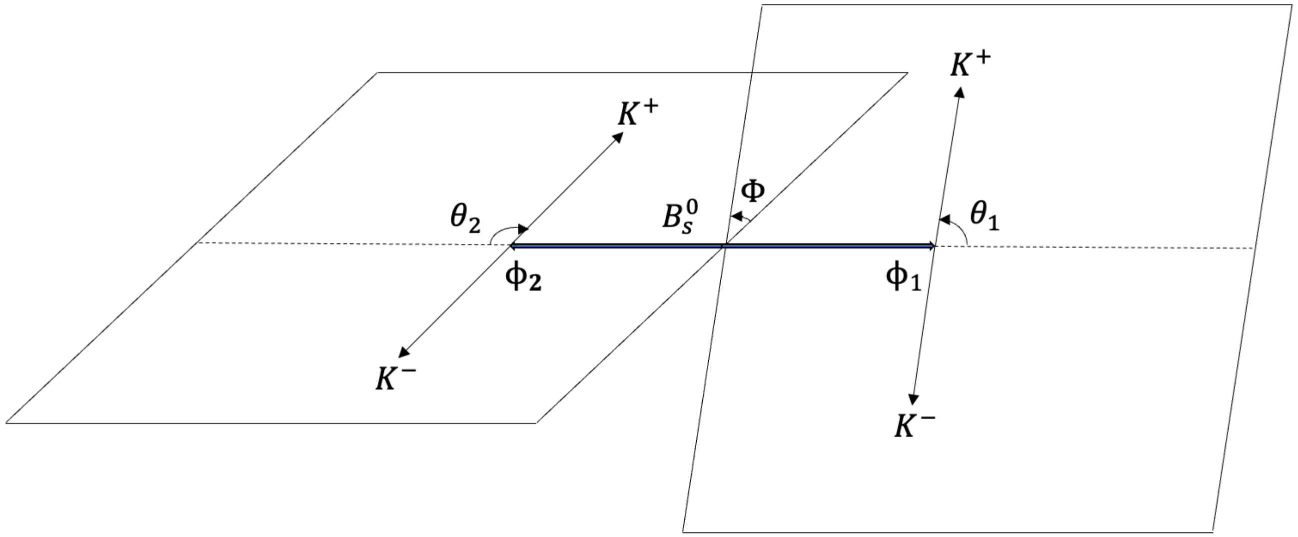

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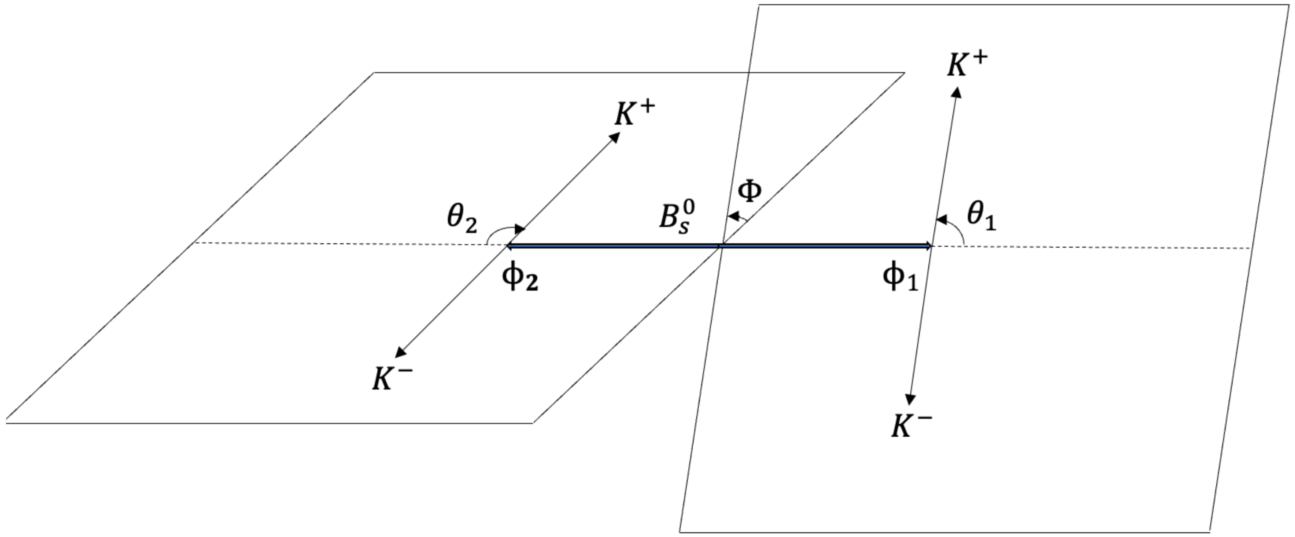

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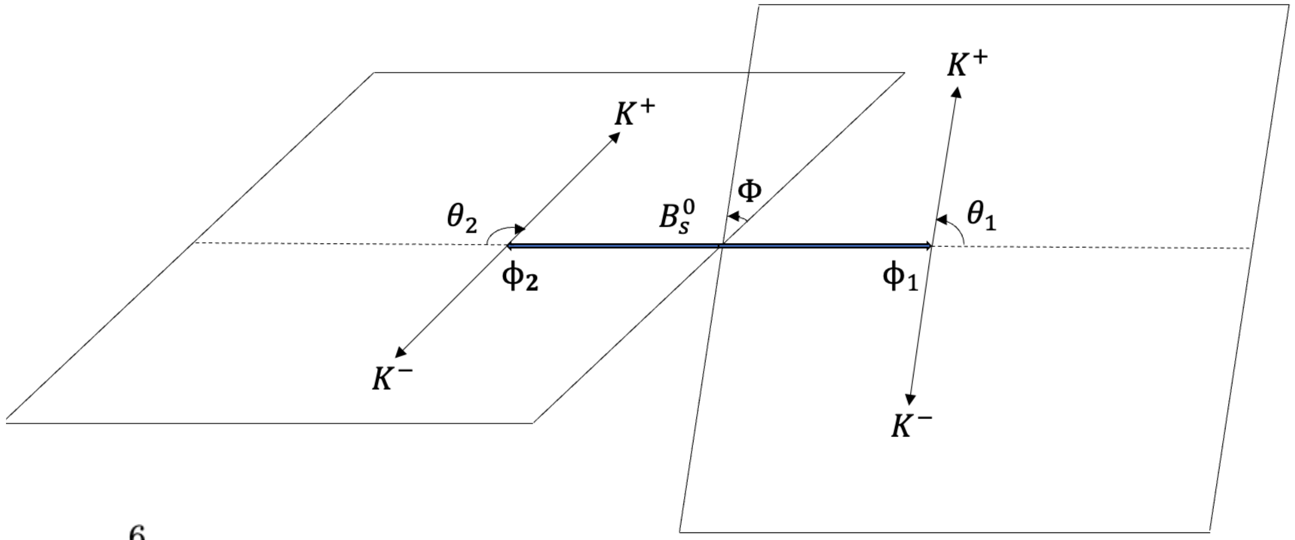

Angular Decay Distribution:

$$\frac{d^4\Gamma}{dtd\cos\theta_1\, d\cos\theta_2\, d\Phi} \propto |\mathcal{A}(t,\theta_1,\theta_2,\Phi)|^2 = \frac{1}{4}\sum_{i=1}^{6} K_i(t) f_i(\theta_1,\theta_2,\Phi)$$

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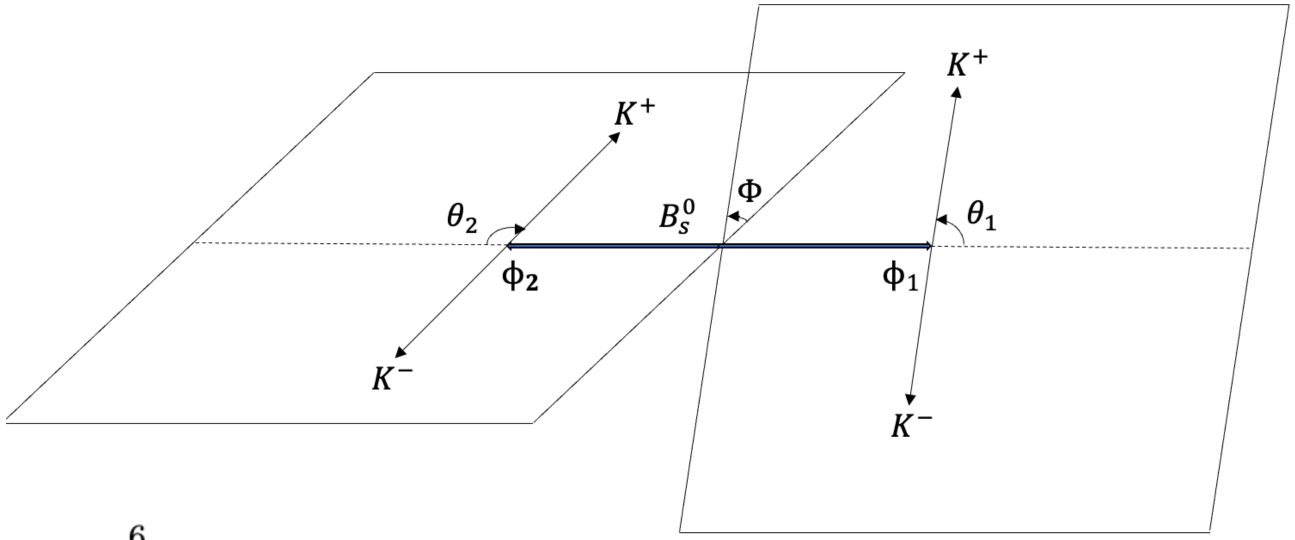

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$\Delta\Gamma_s = \Gamma_L - \Gamma_H$
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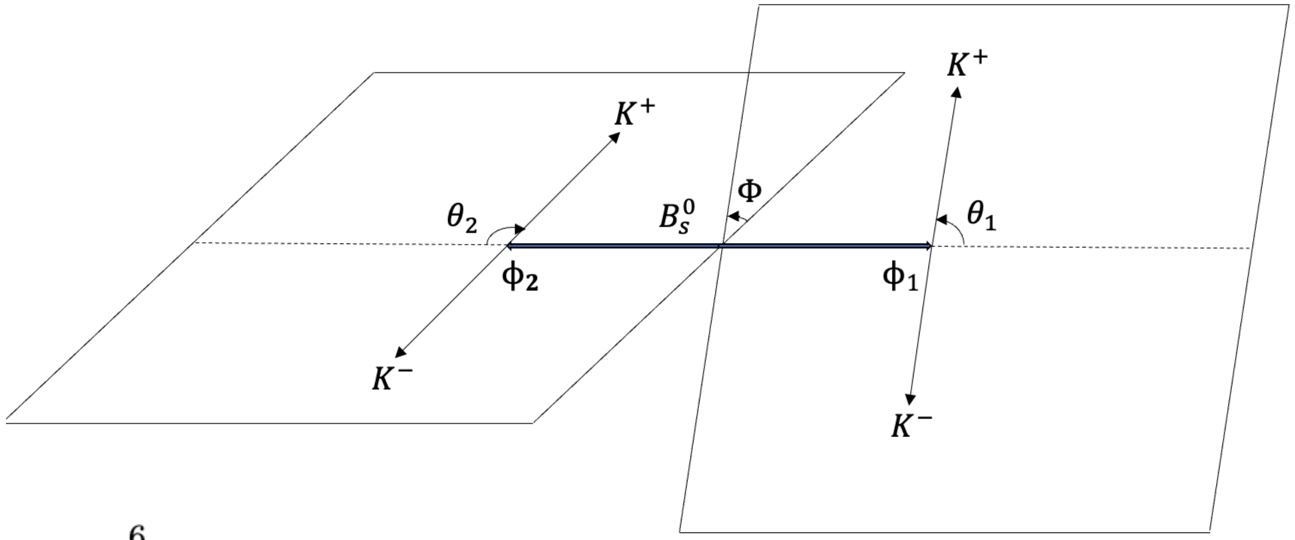

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$N_i, a_i,\ b_i,\ c_i,\ d_i$ are Experimental Observables, their structure depend upon form of A_k

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Transversity Decay Amplitude: $A_k = \left|A_k^{SM}\right| e^{i\phi^{SM}} e^{i\delta_k^{SM}} + \left|A_k^{NP}\right| e^{i\phi_k^{NP}} e^{i\delta_k^{NP}}$

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i	N_i	a_i	b_i	c_i	d_i	f_i
1	$\|A_0\|^2$	$(1+\lambda_0^2)/2$	$-\lambda_0 \cos(\theta_0^c - \theta_0)$	$(1-\lambda_0^2)/2$	$-\lambda_0 \sin(\theta_0^c - \theta_0)$	$4\cos^2\theta_1 \cos^2\theta_2$
2	$\|A_\parallel\|^2$	$(1+\lambda_\parallel^2)/2$	$-\lambda_\parallel \cos(\theta_\parallel^c - \theta_\parallel)$	$(1-\lambda_\parallel^2)/2$	$-\lambda_\parallel \sin(\theta_\parallel^c - \theta_\parallel)$	$\sin^2\theta_1 \sin^2\theta_2(1+\cos 2\Phi)$
3	$\|A_\perp\|^2$	$(1+\lambda_\perp^2)/2$	$\lambda_\perp \cos(\theta_\perp^c - \theta_\perp)$	$(1-\lambda_\perp^2)/2$	$\lambda_\perp \sin(\theta_\perp^c - \theta_\perp)$	$\sin^2\theta_1 \sin^2\theta_2(1-\cos 2\Phi)$
4	$\|A_\parallel\|\|A_\perp\|/2$	$\sin(\delta_\perp - \delta_\parallel + \theta_\perp - \theta_\parallel)$ $-\lambda_\perp\lambda_\parallel \sin(\delta_\perp - \delta_\parallel + \theta_\perp^c - \theta_\parallel^c)$	$\lambda_\perp \sin(\delta_\perp - \delta_\parallel + \theta_\perp^c - \theta_\parallel)$ $-\lambda_\parallel \sin(\delta_\perp - \delta_\parallel + \theta_\perp - \theta_\parallel^c)$	$\sin(\delta_\perp - \delta_\parallel + \theta_\perp - \theta_\parallel)$ $+\lambda_\perp\lambda_\parallel \sin(\delta_\perp - \delta_\parallel + \theta_\perp^c - \theta_\parallel^c)$	$-\lambda_\perp \cos(\delta_\perp - \delta_\parallel + \theta_\perp^c - \theta_\parallel)$ $-\lambda_\parallel \cos(\delta_\perp - \delta_\parallel + \theta_\perp - \theta_\parallel^c)$	$-2\sin^2\theta_1 \sin^2\theta_2 \sin 2\Phi$
5	$\|A_\parallel\|\|A_0\|/2$	$\cos(\delta_0 - \delta_\parallel + \theta_0 - \theta_\parallel)$ $+\lambda_0\lambda_\parallel \cos(\delta_0 - \delta_\parallel + \theta_0^c - \theta_\parallel^c)$	$-\lambda_0 \cos(\delta_0 - \delta_\parallel + \theta_0^c - \theta_\parallel)$ $-\lambda_\parallel \cos(\delta_0 - \delta_\parallel + \theta_0 - \theta_\parallel^c)$	$\cos(\delta_0 - \delta_\parallel + \theta_0 - \theta_\parallel)$ $-\lambda_0\lambda_\parallel \cos(\delta_0 - \delta_\parallel + \theta_0^c - \theta_\parallel^c)$	$-\lambda_0 \sin(\delta_0 - \delta_\parallel + \theta_0^c - \theta_\parallel)$ $+\lambda_\parallel \sin(\delta_0 - \delta_\parallel + \theta_0 - \theta_\parallel^c)$	$\sqrt{2}\sin 2\theta_1 \sin 2\theta_2 \cos\Phi$
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$$K_i(t) = N_i e^{-\Gamma_s t}\left[a_i \cosh\left(\frac{1}{2}\Delta\Gamma_s t\right) + b_i \sinh\left(\frac{1}{2}\Delta\Gamma_s t\right) + c_i \cos(\Delta m_s t) + d_i \sin(\Delta m_s t)\right]$$

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Many experimental observables, but LHCb needed assumptions to reduce the parameters

LHCb Assumptions: Fit Schemes

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LHCb arXiv 1907.10003

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Helicity-Independent (HI) Assumption

- Interference phase ($\phi_{s,k} = \theta_k - \theta_k^c$) same for all transversities

$\phi_{s,0} = \phi_{s,\|} = \phi_{s,\perp} = \phi_s^{s\bar{s}s}$ -> 1 free parameter

- Direct CPV measurement parameter same for all transversities

$\lambda_0 = \lambda_\| = \lambda_\perp = \lambda$ -> 1 free parameter

- The plot on first page shows measurement under this assumption

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$\phi_{s,\|}$ [rad]	0.014 ± 0.055
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New Physics Model: Chromomagnetic Operator

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arXiv: 2303.04494
T.K., E. Kou

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Interference Phase and direct CPV measurement paremeters are "clean observables" to search for NP! (null-test parameters)

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	Data HD		Data HI	
Fit Parameter	Central Value	σ	Central Value	σ
λ_0	0.978	0.058	0.984	0.070
$\lvert A_0\rvert^2$	0.386	0.025	0.385	0.032
$\lvert A_\perp\rvert^2$	0.287	0.018	0.288	0.036
$\theta_0 - \theta_0^c$	-0.002	0.055	0.066	0.053
$\delta_\parallel - \delta_\perp$	-0.259	0.054	-0.261	0.056
$\delta_\parallel - \delta_0 - \theta_0$	2.560	0.071	2.589	0.079

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Sensitivity on CP violating parameters with the current statistics : $\theta_0 - \theta_0^c$ ~ 6% and λ_0~ 7%

Why $B_d^0 \to \phi K_s$?

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Question: Both $B_s^0 \to \phi\phi$ and $B_d^0 \to \phi K_s$ are $\bar{b} \to \bar{s}s\bar{s}$ decays at quark level. Why do both?

Answer: If NP is present, the observed signature could still be different in both.

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NP signatures are different, one can be bigger/smaller than the other

Role of $B_d^0 \to \phi K_s$ decay

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arXiv: 2303.04494

T.K., E. Kou

Is NP left- or right-handed ?

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Chirality of NP can be determined, under the assumption that NP is either only LH or RH

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- $B_d^0 \to \phi K_s$: Important, could be used to get chirality of NP

”Thank you for your attention ☺ ”

Backup Slides

CP Violation

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CPV Types

- Decay: $\lambda = \frac{|A|}{|A|} \neq 1$
- Mixing: $\left|\frac{q}{p}\right| \neq 1$
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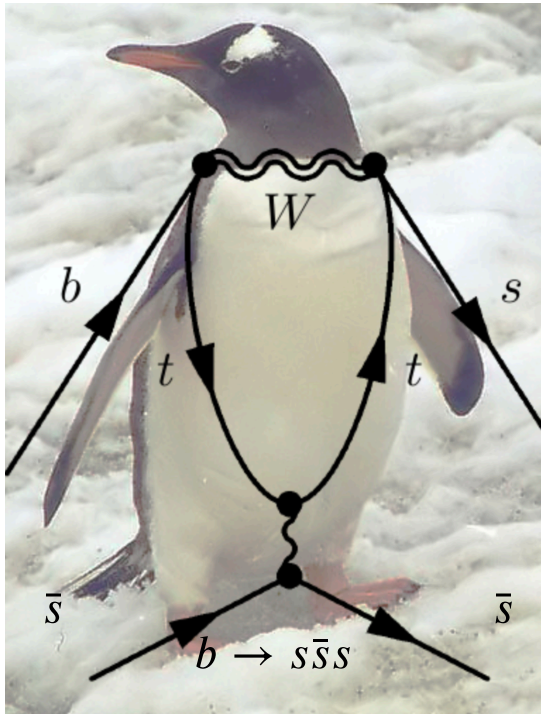

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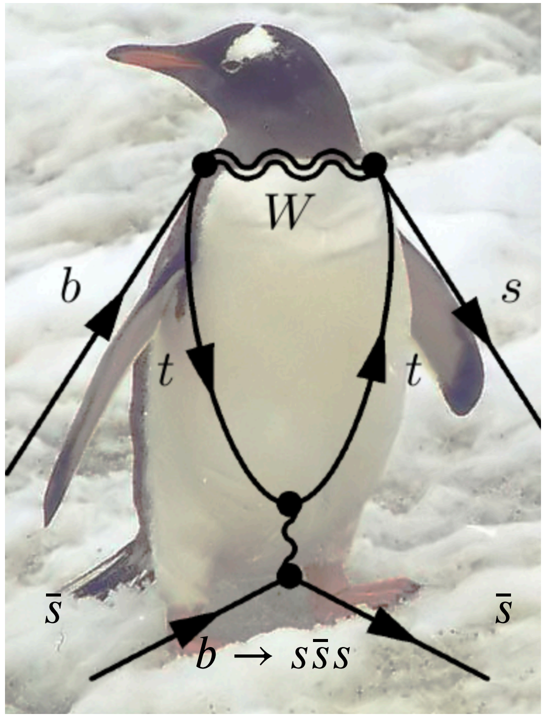

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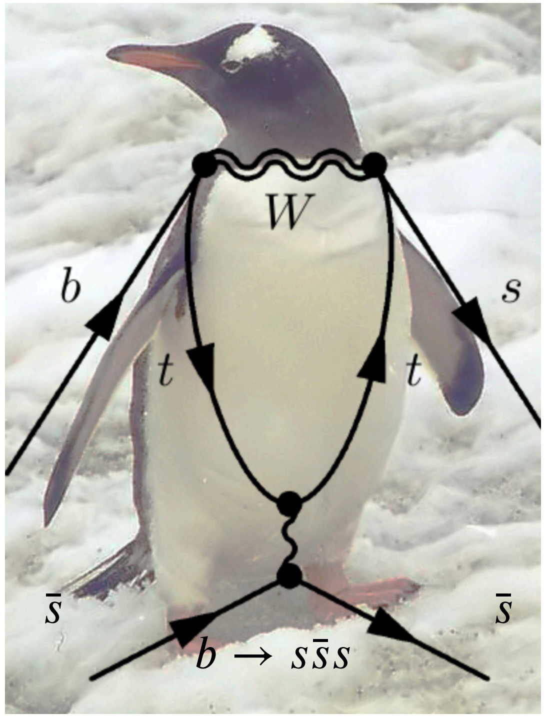

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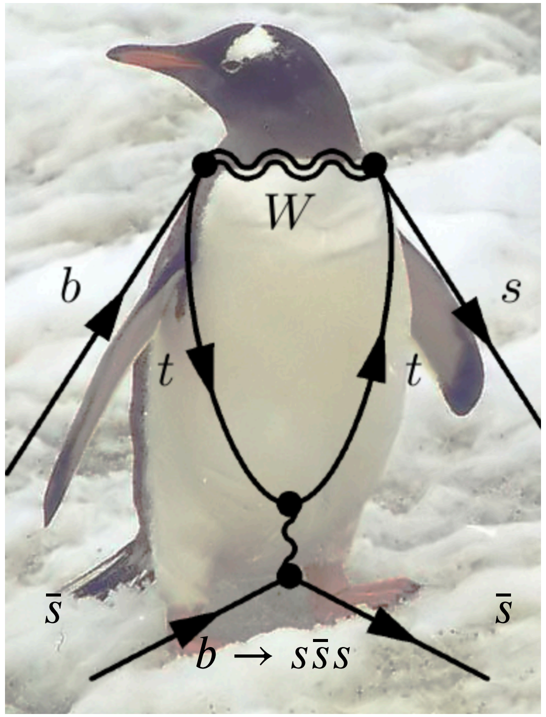

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CP Violating quantities are known precisely in SM
Quantum loop makes it sensitive to NP

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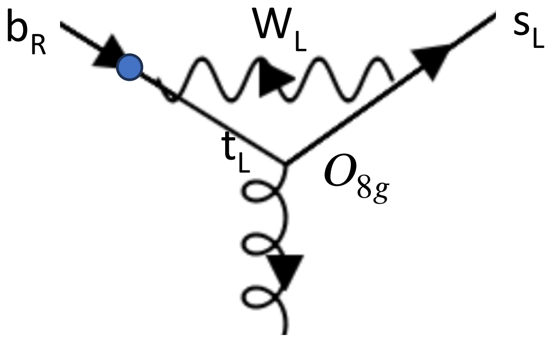

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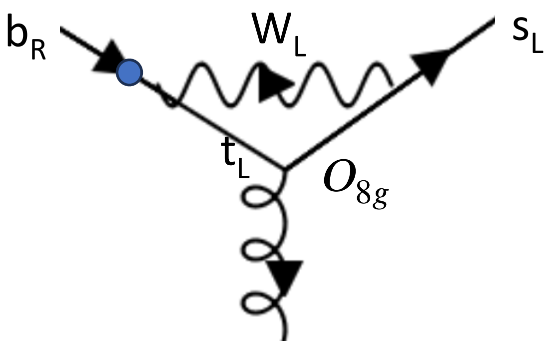

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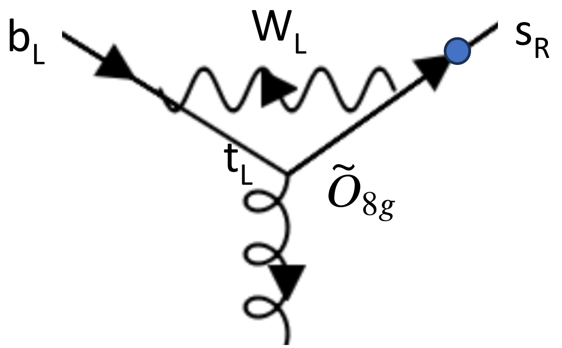

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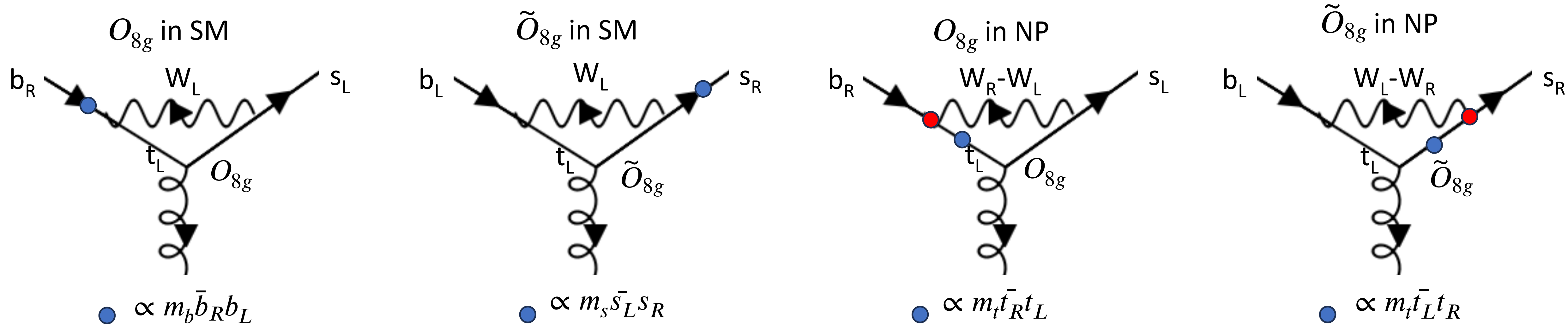

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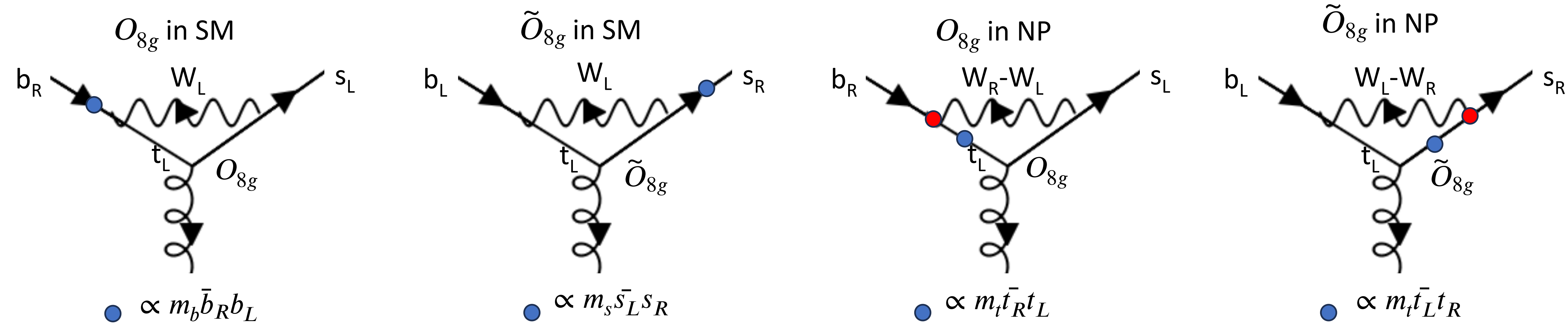


Mass Insertion Approximation

Right-Handed CKM Matrix elements

Chromomagnetic operator sensitive to Right-Handed currents

CP Violating parameters

Total amplitude is sum of SM and NP amplitude (at t=0)

$\delta_k^{SM(NP)}$: Strong phase in SM (NP) ,

$\phi_{(k)}^{SM(NP)}$: Weak phase in SM (NP) ($k = \{ \parallel, \perp, 0\}$)

$$
\begin{aligned}
A_k &= A_k^{\rm SM} + A_k^{\rm NP} \\
&= |A_k^{\rm SM}| e^{i\delta_k^{\rm SM}} e^{i\phi^{\rm SM}} + |A_k^{\rm NP}| e^{i\delta_k^{\rm NP}} e^{i\phi_k^{\rm NP}} \\
&= |A_k^{\rm SM}| e^{i\delta_k^{\rm SM}} e^{i\phi^{\rm SM}} \left(1 + r_k^{\rm NP} e^{i(\phi_k^{\rm NP} - \phi^{\rm SM})} e^{i(\delta_k^{\rm NP} - \delta_k^{\rm SM})}\right) \\
&= |A_k^{\rm SM}| e^{i\delta_k^{\rm SM}} e^{i\phi^{\rm SM}} X_k e^{i\theta_k},
\end{aligned}
$$

$$
\begin{aligned}
\bar{A}_k &= \eta_k |A_k^{\rm SM}| e^{i\delta_k^{\rm SM}} e^{-i\phi^{\rm SM}} \left(1 + r_k^{\rm NP} e^{-i(\phi_k^{\rm NP} - \phi^{\rm SM})} e^{i(\delta_k^{\rm NP} - \delta_k^{\rm SM})}\right) \\
&= \eta_k |A_k^{\rm SM}| e^{i\delta_k^{\rm SM}} e^{-i\phi^{\rm SM}} X_k^c e^{i\theta_k^c}.
\end{aligned}
$$

$$r_k^{NP} = \frac{|A_k^{NP}|}{|A_k^{SM}|}$$

$\theta_k^{(c)}$ is a mixture of 'weak' and 'strong' phases!

The interference phase is then given by $\theta_k - \theta_k^c$

$$\frac{q}{p}\frac{\bar{A}_k}{A_k} = \eta_k \lambda_k e^{-i(\theta_k - \theta_k^c)}$$

NP Search - Null-test parameters:

1. Interference Phase
($\theta_k - \theta_k^c = 0$ in SM)
2. Direct CP Violation parameter
($\lambda_k - 1 = 0$ in SM)

"If these quantities deviate from 0, it indicates the presence of NP!"

New Physics Model: Chromomagnetic Operator

- Effective Hamiltonian of $B_s^0 \to \phi\phi$ decay:

$$\mathcal{H}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{tb}^* V_{tq} \left[\sum_{i=3}^{6} (C_i^{\text{SM}} O_i) + C_{8g} O_{8g} + \tilde{C}_{8g} \tilde{O}_{8g} \right] + \text{h.c.}$$

$$O_{8g} = \frac{g_s}{8\pi^2} m_b \bar{b}_\alpha \sigma^{\mu\nu} (1+\gamma^5) \frac{\lambda^a_{\alpha\beta}}{2} s_\beta G^a_{\mu\nu}.$$

- Amplitude: $B_s^0 \to \phi\phi$ final state has three helicity states $\Rightarrow$ three amplitudes

A_k: Transversity Amplitudes

$$A_0 = H_0\,, \qquad A_\parallel = \frac{1}{\sqrt{2}}(H_+ + H_-)\,,\ A_\perp = \frac{1}{\sqrt{2}}(H_+ - H_-)$$

H_k: Helicity Amplitudes

- Hierarchy of amplitudes (V-A structure of current)

$$H_0 : H_+ : H_- \approx 1 : \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right) : \left(\frac{\Lambda_{\text{QCD}}}{m_b}\right)^2$$

Ann. diagrams contribute to transverse amplitudes

BUT

Followed in O_{8g} (Ann. contribution subsubleading)

"Contribution from O_{8g} is suppressed in Transverse Penguin Operator"

New Fit Configuration

➢ Total NP Amplitude (longitudinal):

$$\mathcal{M}_{0,\phi\phi}^{\rm Total} = -\frac{G_F}{\sqrt{2}} V_{tb}^* V_{ts} (\xi_0^{\rm SM} \mathcal{F}_{0,\phi\phi}^{\rm SM} + \xi_0^{\rm L} \mathcal{F}_{0,\phi\phi}^{\rm NP} - \xi_0^{\rm R} \mathcal{F}_{0,\phi\phi}^{\rm NP})$$

Notice Sign Change! Comes from $V \pm A$ structure of current

$\mathscr{F}_0^{\,p}(\rm p = \{SM, NP\})$ contains contribution from matrix elements (can be calculated in any model)

- *contains strong (CP-even) phases (σ)*

$\xi_0^h(\rm h = \{SM,\ L, R\})$ are combination of Wilson Coefficients

- *contains weak (CP-odd) phases ($\omega_L,\ \omega_R$)*

➢ Our Fit Scheme

$$\frac{q}{p}\frac{\bar{\mathcal{M}}_{0,\phi\phi}^{\rm Total}}{\mathcal{M}_{0,\phi\phi}^{\rm Total}} = \lambda_0 e^{-i(\theta_0 - \theta_0^c)}$$

$\theta_{\parallel} = \theta_{\parallel}^c = \theta_{\perp} = \theta_{\parallel}^c = 0$ and
$\lambda_{\parallel} = \lambda_{\perp} = 1$ and (SM Values).
λ_0 *and* $\theta_0 - \theta_0^c$ are free parameters.

➢ LHCb Fit Scheme ($\phi_k = \theta_k - \theta_k^c$)

Helicity-Independent (HI) Scheme:

$\lambda_k = \lambda\ ,\ \phi_k = \phi\ \forall\ k\ \epsilon\ \{0, \parallel, \perp\}.$

Free parameters: ϕ and λ.

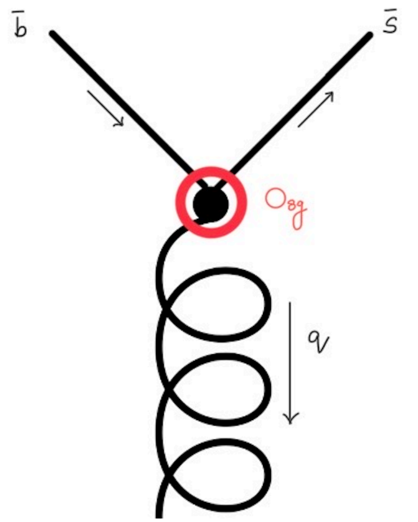
Helicity-Dependent (HD) Scheme:

$\phi_0 = 0,\ \ \lambda_k = 1\ \forall\ k\ \epsilon\ \{0, \parallel, \perp\}.$

Free parameters: $\phi_{\parallel}$ and $\phi_{\perp}$.

LHCb arXiv: 1907.10003 [hep-ex]

Chromomagnetic dipole operator



The Chromomagnetic operator for $\bar{b} \to \bar{s}g$ is given by

$$O_{8g} = \frac{g_s}{8\pi^2} m_b \bar{b}_\alpha \sigma^{\mu\nu}(1+\gamma^5)\frac{\lambda^a_{\alpha\beta}}{2} s_\beta G^a_{\mu\nu}.$$

To make it a 4-quark operator (in order to write the matrix elements): attach a quark current

$$O^4_{8g} = \frac{\alpha_s}{\pi}\frac{m_b}{q^2}\bar{b}_\alpha \gamma^\mu \not{q}(1+\gamma^5)\frac{\lambda^a_{\alpha\beta}}{2} s_\beta \bar{q}'_\rho \gamma_\mu \frac{\lambda^a_{\rho\sigma}}{2} q'_\sigma$$

Simplifying approximation: $q^\mu = \sqrt{\langle q^2 \rangle}\frac{p_b^\mu}{m_b}$ (for two body decays, when the 3-momenta of two quarks coming from gluon has same magnitude but opposite direction in b –quark rest frame)

Using Fierz identity and Dirac equation, we express

$$\frac{\lambda^a_{\alpha\beta}}{2}\frac{\lambda^a_{\rho\sigma}}{2} = \frac{1}{2}\left(\delta_{\alpha\sigma}\delta_{\beta\rho} - \frac{1}{3}\delta_{\alpha\beta}\delta_{\rho\sigma}\right)$$

$$\langle O^4_{8g}\rangle = \frac{\alpha_s}{4\pi}\frac{m_b}{\sqrt{\langle q^2\rangle}}\left[\langle O_4\rangle + \langle O_6\rangle - \frac{1}{3}(\langle O_3\rangle + \langle O_5\rangle)\right]$$

Effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V^*_{tb} V_{tq} \sum_{i=3}^{6} (C_i^{\text{SM}} O_i + C_i^{\text{L}} O_i + C_i^{\text{R}} \tilde{O}_i)$$

Effective Wilson Coefficients

$$C_{3,5}^{\text{L(R)}} = -\frac{1}{3}\frac{\alpha_s}{4\pi}\frac{m_b}{\sqrt{\langle q^2\rangle}} \overset{(\sim)}{C}_{8g}$$

$$C_{4,6}^{\text{L(R)}} = \frac{\alpha_s}{4\pi}\frac{m_b}{\sqrt{\langle q^2\rangle}} \overset{(\sim)}{C}_{8g}$$

Effect of Rescattering

With, dominant t-quark contribution, we can have c- and u- quark contribution too which can arise due to $c\bar{c} \to q\bar{q}$ and $u\bar{u} \to q\bar{q}$ rescattering from $\bar{b} \to \bar{c}c\bar{s}$ and $\bar{b} \to \bar{u}u\bar{s}$ tree diagrams.

$$A_k^{\rm SM} = \lambda_t P_{t,k} + \lambda_c R_{c,k} + \lambda_u R_{u,k}$$

$$\lambda_q = V_{qb}^* V_{qs}$$

Using Unitarity to eliminate c-quark term

$$\begin{aligned} A_k^{\rm SM} &= |V_{tb}^* V_{ts}| e^{-i\beta_s} |PR_{tc,k}| e^{i\delta_{tc,k}} + |V_{ub}^* V_{us}| e^{i\gamma} |RR_{uc,k}| e^{i\delta_{uc,k}} \\ &= |V_{tb}^* V_{ts}| e^{-i\beta_s} |PR_{tc,k}| e^{i\delta_{tc,k}} \left[1 + r_k^{\rm SM} e^{i(\gamma+\beta_s)} e^{i(\delta_{uc,k}-\delta_{tc,k})}\right] \\ &= |A_k^{\rm SM}| e^{i\phi^{\rm SM}} e^{i\delta_k^{\rm SM}}, \end{aligned}$$

$$r_k^{\rm SM} = \frac{|V_{ub}^* V_{us}||RR_{uc,k}|}{|V_{tb}^* V_{ts}||PR_{tc,k}|}$$

Depending upon rescattering contribution (say, 20-40% of dominant penguin amplitude) => $r_k^{SM} = O(\lambda^3)$

If CP violating observables are $O\left(\lambda^3\right)$ away from their SM value, it indicates NP!

New LHCb Results

<u>Helicity-Independent Fit</u>

LHCb arXiv: 2304.06198 [hep-ex]

Parameter	Result
$\phi_s^{s\bar{s}s}$ [rad]	$-0.042 \pm 0.075 \pm 0.009$
$\lvert\lambda\rvert$	$1.004 \pm 0.030 \pm 0.009$
$\lvert A_0\rvert^2$	$0.384 \pm 0.007 \pm 0.003$
$\lvert A_\perp\rvert^2$	$0.310 \pm 0.006 \pm 0.003$
$\delta_\parallel - \delta_0$ [rad]	$2.463 \pm 0.029 \pm 0.009$
$\delta_\perp - \delta_0$ [rad]	$2.769 \pm 0.105 \pm 0.011$

Issues:

Large Errors

No information given as to how the Helicity-Dependent fit done

No details of approximations

When doing HD fit, nuisance parameters (strong phases and amplitudes not given)

<u>Helicity-Dependent Fit</u>

$$\phi_{s,0} = -0.18 \pm 0.09 \text{ rad},$$
$$\phi_{s,\parallel} - \phi_{s,0} = 0.12 \pm 0.09 \text{ rad},$$
$$\phi_{s,\perp} - \phi_{s,0} = 0.17 \pm 0.09 \text{ rad},$$

$$|\lambda_0| = 1.02 \pm 0.17$$
$$|\lambda_\perp/\lambda_0| = 0.97 \pm 0.22$$
$$|\lambda_\parallel/\lambda_0| = 0.78 \pm 0.21$$

Sensitivity Study: Toy Monte-Carlo Method

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arXiv: 2303.04494
T.K., E. Kou

Generate pseudo data from “truth values”

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When we have large (infinite) statistics ($N \to \infty$):

- MLE gives truth values
- Sensitivity (σ) $\to 0$

Sensitivity Study: Toy Monte-Carlo Method

Generate pseudo data from "truth values"

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Use scaling $\sigma \propto \frac{1}{\sqrt{N}}$ to construct covariance matrix for given number of events

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Parameters of Interest $(\delta_k, \theta_k \ldots)$

Truth Values (Experimental Results)

Covariance Matrix →

$$V_{ij}^{-1} = N \int \left(\frac{\partial \hat{f}(x)_{\vec{v}}}{\partial v_i} \frac{\partial \hat{f}(x)_{\vec{v}}}{\partial v_j} \frac{1}{\hat{f}(x)_{\vec{v}}} \right) \Bigg|_{\vec{v}=\vec{v}^*} dx$$

← Phase Space (angles, time)

Number of events

Normalsed PDF (Angular Decay Distribution)

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Number of events

Normalsed PDF (Angular Decay Distribution)

Advantages: Fast and Easy to program

Experimental Observables: LHCb Version

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Transversity Amplitude:

$$A_k = \left| A_k \right| e^{i\delta_k}$$ → Strong Phase

Approximate Parameterisation
(no weak phase, single amp. (SM))

LHCb arXiv 1907.10003

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$$\frac{q\ \bar{A}_k}{p\ A_k} = \eta_k \left| \lambda_k \right| e^{-i\phi_{s,k}}$$

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$$\frac{q\ \bar{A}_k}{p\ A_k} = \eta_k \left| \lambda_k \right| e^{-i\phi_{s,k}}$$ → Interference Phase (Hel. Dep.)

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→ Direct CP Measurement Parameter

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LHCb arXiv 1907.10003

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LHCb arXiv 1907.10003

i	N_i	a_i	b_i	c_i	d_i	f_i
1	$\|A_0\|^2$	$1+\|\lambda_0\|^2$	$-2\|\lambda_0\|\cos(\phi)$	$1-\|\lambda_0\|^2$	$2\|\lambda_0\|\sin(\phi)$	$4\cos^2\theta_1\cos^2\theta_2$
2	$\|A_\|\|^2$	$1+\|\lambda_\|\|^2$	$-2\|\lambda_\|\|\cos(\phi_{s,\|})$	$1-\|\lambda_\|\|^2$	$2\|\lambda_\|\|\sin(\phi_{s,\|})$	$\sin^2\theta_1\sin^2\theta_2(1+\cos 2\Phi)$
3	$\|A_\perp\|^2$	$1+\|\lambda_\perp\|^2$	$2\|\lambda_\perp\|\cos(\phi_{s,\perp})$	$1-\|\lambda_\perp\|^2$	$-2\|\lambda_\|\|\sin(\phi_{s,\perp})$	$\sin^2\theta_1\sin^2\theta_2(1-\cos 2\Phi)$
4	$\frac{\|A_\|\|\|A_\perp\|}{2}$	$\sin(\delta_\| - \delta_\perp) - \|\lambda_\|\|\|\lambda_\perp\|\cdot$ $\sin(\delta_\| - \delta_\perp - \phi_{s,\|} + \phi_{s,\perp})$	$-\|\lambda_\|\|\sin(\delta_\| - \delta_\perp - \phi_{s,\|})$ $+\|\lambda_\perp\|\sin(\delta_\| - \delta_\perp + \phi_{s,\perp})$	$\sin(\delta_\| - \delta_\perp) + \|\lambda_\|\|\|\lambda_\perp\|\cdot$ $\sin(\delta_\| - \delta_\perp - \phi_{s,\|} + \phi_{s,\perp})$	$\|\lambda_\|\|\cos(\delta_\| - \delta_\perp - \phi_{s,\|})$ $+\|\lambda_\perp\|\cos(\delta_\| - \delta_\perp + \phi_{s,\perp})$	$-2\sin^2\theta_1\sin^2\theta_2\sin 2\Phi$
5	$\frac{\|A_\|\|\|A_0\|}{2}$	$\cos(\delta_\| - \delta_0) + \|\lambda_\|\|\|\lambda_0\|\cdot$ $\cos(\delta_\| - \delta_0 - \phi_{s,\|} + \phi)$	$-\|\lambda_\|\|\cos(\delta_\| - \delta_0 - \phi_{s,\|})$ $+\|\lambda_0\|\cos(\delta_\| - \delta_0 + \phi)$	$\cos(\delta_\| - \delta_0) - \|\lambda_\|\|\|\lambda_0\|\cdot$ $\sin(\delta_\| - \delta_0 - \phi_{s,\|} + \phi)$	$-\|\lambda_\|\|\sin(\delta_\| - \delta_0 - \phi_{s,\|})$ $+\|\lambda_0\|\sin(\delta_\| - \delta_0 + \phi)$	$\sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\Phi$
6	$\frac{\|A_0\|\|A_\perp\|}{2}$	$\sin(\delta_0 - \delta_\perp) - \|\lambda_0\|\|\lambda_\perp\|\cdot$ $\sin(\delta_0 - \delta_\perp - \phi + \phi_{s,\perp})$	$-\|\lambda_0\|\sin(\delta_0 - \delta_\perp - \phi)$ $+\|\lambda_\perp\|\sin(\delta_0 - \delta_\perp + \phi_{s,\perp})$	$\sin(\delta_0 - \delta_\perp) + \|\lambda_0\|\|\lambda_\perp\|\cdot$ $\sin(\delta_0 - \delta_\perp - \phi + \phi_{s,\perp})$	$\|\lambda_0\|\cos(\delta_0 - \delta_\perp - \phi)$ $+\|\lambda_\perp\|\cos(\delta_0 - \delta_\perp + \phi_{s,\perp})$	$-\sqrt{2}\sin 2\theta_1\sin 2\theta_2\sin\Phi$

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CP Violating parameters are inside the experimental observables

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3	$\|A_\perp\|^2$	$1+\|\lambda_\perp\|^2$	$2\|\lambda_\perp\|\cos(\phi_{s,\perp})$	$1-\|\lambda_\perp\|^2$	$-2\|\lambda_\|\|\sin(\phi_{s,\perp})$	$\sin^2\theta_1\sin^2\theta_2(1-\cos 2\Phi)$
4	$\frac{\|A_\|\|\|A_\perp\|}{2}$	$\sin(\delta_\|-\delta_\perp)-\|\lambda_\|\|\|\lambda_\perp\|\cdot \sin(\delta_\|-\delta_\perp-\phi_{s,\|}+\phi_{s,\perp})$	$-\|\lambda_\|\|\sin(\delta_\|-\delta_\perp-\phi_{s,\|}) +\|\lambda_\perp\|\sin(\delta_\|-\delta_\perp+\phi_{s,\perp})$	$\sin(\delta_\|-\delta_\perp)+\|\lambda_\|\|\|\lambda_\perp\|\cdot \sin(\delta_\|-\delta_\perp-\phi_{s,\|}+\phi_{s,\perp})$	$\|\lambda_\|\|\cos(\delta_\|-\delta_\perp-\phi_{s,\|}) +\|\lambda_\perp\|\cos(\delta_\|-\delta_\perp+\phi_{s,\perp})$	$-2\sin^2\theta_1\sin^2\theta_2\sin 2\Phi$
5	$\frac{\|A_\|\|\|A_0\|}{2}$	$\cos(\delta_\|-\delta_0)+\|\lambda_\|\|\|\lambda_0\|\cdot \cos(\delta_\|-\delta_0-\phi_{s,\|}+\phi)$	$-\|\lambda_\|\|\cos(\delta_\|-\delta_0-\phi_{s,\|}) +\|\lambda_0\|\cos(\delta_\|-\delta_0+\phi)$	$\cos(\delta_\|-\delta_0)-\|\lambda_\|\|\|\lambda_0\|\cdot \sin(\delta_\|-\delta_0-\phi_{s,\|}+\phi)$	$-\|\lambda_\|\|\sin(\delta_\|-\delta_0-\phi_{s,\|}) +\|\lambda_0\|\sin(\delta_\|-\delta_0+\phi)$	$\sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\Phi$
6	$\frac{\|A_0\|\|A_\perp\|}{2}$	$\sin(\delta_0-\delta_\perp)-\|\lambda_0\|\|\lambda_\perp\|\cdot \sin(\delta_0-\delta_\perp-\phi+\phi_{s,\perp})$	$-\|\lambda_0\|\sin(\delta_0-\delta_\perp-\phi) +\|\lambda_\perp\|\sin(\delta_0-\delta_\perp+\phi_{s,\perp})$	$\sin(\delta_0-\delta_\perp)+\|\lambda_0\|\|\lambda_\perp\|\cdot \sin(\delta_0-\delta_\perp-\phi+\phi_{s,\perp})$	$\|\lambda_0\|\cos(\delta_0-\delta_\perp-\phi) +\|\lambda_\perp\|\cos(\delta_0-\delta_\perp+\phi_{s,\perp})$	$-\sqrt{2}\sin 2\theta_1\sin 2\theta_2\sin\Phi$

CP Violating parameters are inside the experimental observables

Many experimental observables, only few parameters that can be fit!

η_k factor origin

Here, we take a moment to explain the η_k factors used. When we write the CP conjugate decay, we replace the particles by their antiparticles. The effect of this replacement on the helicity angle is $\phi \to 2\pi - \phi$, which gives rise to a negative sign in those terms which contain amplitudes having a negative CP parity ($A_\perp$ in our case). Therefore, using η_k in the definition of amplitude allows us to use the same angular functions for B_s^0 and $\bar{B}_s^0$ decays, which facilitates calculations in untagged samples [23].