Analysis of $B^0 \to K^{*0}\mu^+\mu^-$ decay using a dispersion relation

Ulrik Egede, Monash University

14 July 2026

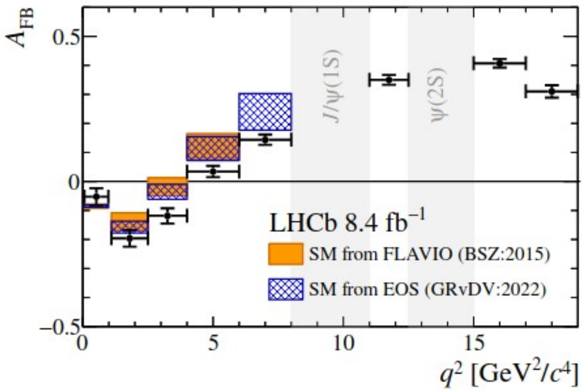
Different measurements of the same thing

Bin it

No theory model

Allow for CP violation

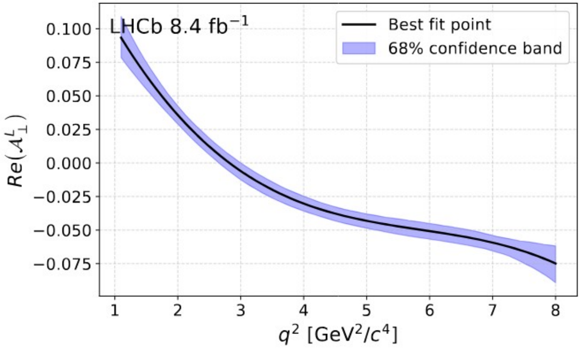
PRL 137, 021802 (2026), arXiv:2512.18053



Parametrise it

"Weak" theory model

LHCb-PAPER-2026-023



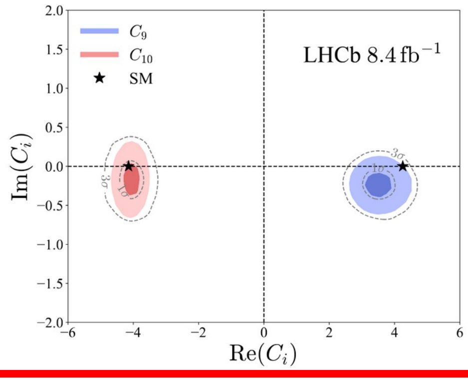
Model it

Theory model

Fit QCD

Allow for CP violation

JHEP 09 (2024) 026, arXiv:2405.17347 and arXiv:2605.07582



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Data

- Full run 1 and run 2 data from LHCb used
- Efficiency corrections and fit are performed in the variable (q^2, θ_K, θ_l,φ)
  - The $m_{K\pi}$ dependence is integrated out in region $796 < m_{K\pi} < 996$ MeV
  - Almost full q^2 region, $0.1 < q^2 < 18.0\ \mathrm{GeV}^2$

Fit local, non-local and WCs simultaneously

- Usual expression for amplitudes

$$
\begin{aligned}
A_0^{L,R}(q^2) =& N_0 \Big\{ \Big[\Big(\mathcal{C}_9^{(\mathrm{eff}),0}(q^2) - \mathcal{C}_9'\Big) \mp \Big(\mathcal{C}_{10} - \mathcal{C}_{10}'\Big)\Big] A_{12}(q^2) \\
&+ \frac{m_b}{m_B + m_{K^*}} \Big(\mathcal{C}_7^{(\mathrm{eff}),0} - \mathcal{C}_7'\Big) T_{23}(q^2) \Big\}, \\
A_\parallel^{L,R}(q^2) =& N_\parallel \Big\{ \Big[\Big(\mathcal{C}_9^{(\mathrm{eff}),\parallel}(q^2) - \mathcal{C}_9'\Big) \mp \Big(\mathcal{C}_{10} - \mathcal{C}_{10}'\Big)\Big] \frac{A_1(q^2)}{m_B - m_{K^*}} \\
&+ \frac{2m_b}{q^2} \Big(\mathcal{C}_7^{(\mathrm{eff}),\parallel} - \mathcal{C}_7'\Big) T_2(q^2) \Big\}, \\
A_\perp^{L,R}(q^2) =& N_\perp \Big\{ \Big[\Big(\mathcal{C}_9^{(\mathrm{eff}),\perp}(q^2) + \mathcal{C}_9'\Big) \mp \Big(\mathcal{C}_{10} + \mathcal{C}_{10}'\Big)\Big] \frac{V(q^2)}{m_B + m_{K^*}} \\
&+ \frac{2m_b}{q^2} \Big(\mathcal{C}_7^{(\mathrm{eff}),\perp} - \mathcal{C}_7'\Big) T_1(q^2) \Big\}, \\
A_t(q^2) =& N_t \Big\{ 2 \Big[\mathcal{C}_{10} - \mathcal{C}_{10}'\Big] A_0(q^2) \Big\},
\end{aligned}
$$

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Local form factors

- Form factors use the combined LCSR+LQCD fit

Gubernari, Reboud, van Dyk Virto, arXiv:2206.03797

$$F_i(q^2) = \frac{1}{1 - q^2/m_{R,i}^2} \sum_{k=0}^{2} \alpha_k^i [z(q^2) - z(0)]^k$$

$$F_i \in \{V, A_0, A_1, A_{12}, T_1, T_2, T_{23}\}$$

- Implemented in fit as Gaussian constraint on α parameters, including correlations

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Fit anomalies and QCD simultaneously

Dispersion Relation

$$C_9^{\mathrm{eff},\lambda}(q^2) = \underbrace{C_9^{\mu}}_{\text{Local}} + \underbrace{Y_{c\bar{c}}^{(0),\lambda} + Y_{c\bar{c}}^{1P,\lambda}(q^2) + Y_{\mathrm{light}}^{1P,\lambda}(q^2) + Y_{c\bar{c}}^{2P,\lambda}(q^2)}_{\text{Non-local contributions}} + Y_{\tau\bar{\tau}}(q^2)$$

$$C_7^{\mathrm{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

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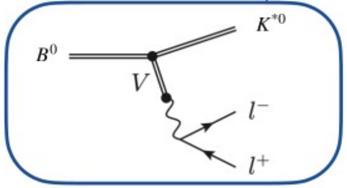

1-particle contributions

Includes:

$\omega(782)$,	$\psi(2S)$,
$\rho(770)$,	$\psi(3770)$,
$\phi(1020)$,	$\psi(4040)$,
J/ψ,	$\psi(4160)$

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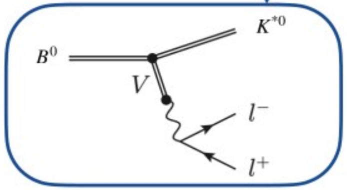

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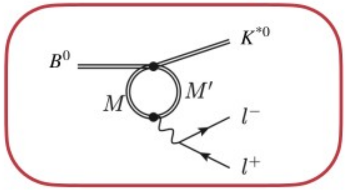

2-particle contributions

Includes:
$D\overline{D}$,
$D^*\overline{D}$,
$D^*\overline{D}^*$

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

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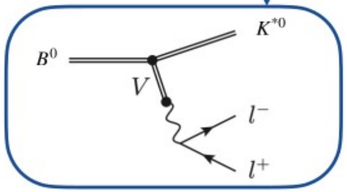

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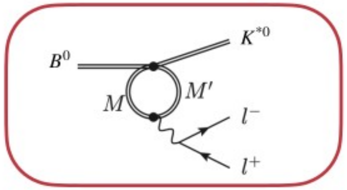

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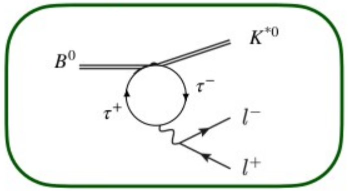

Tau loop contribution

Sensitive to C_9^{τ}

C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

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Dispersion Relation

Local | Non-local contributions

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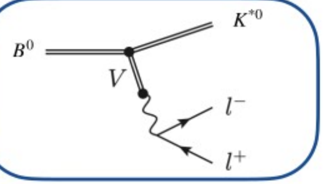
$$C_7^{\mathrm{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$

This is determined theoretically at negative q^2 values

Subtraction term

Asatrian, Greub, Virto [JHEP 04 (2020) 012]

Negligible impact from light quarks



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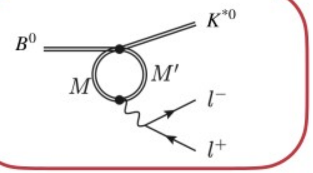

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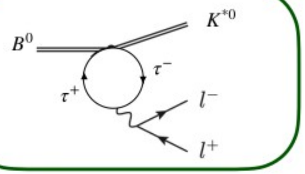

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$$C_7^{\text{eff},\lambda}(q^2) = C_7^{\mu} + \epsilon^{\lambda} e^{i\omega^0}$$

ΔC_7^{λ}

Polarisation dependent shift to C_7

This is determined theoretically at negative q^2 values

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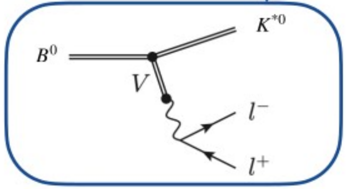

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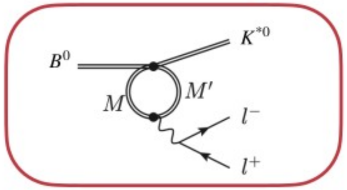

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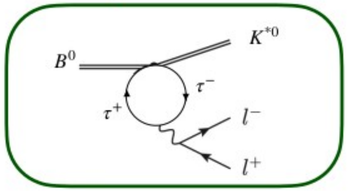

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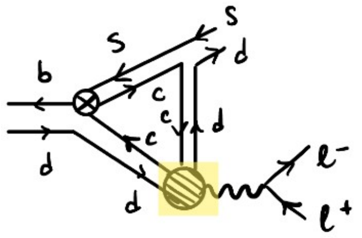
Rescattering terms not implemented

Ciuchini et al,
Phys.Rev.D 107 (2023) 5, 055036

Isidori, Polonsky, Tinari
Phys.Rev.D 111 (2025) 9, 093007



C. Cornella, G. Isidori, M. König, S. Liechti, P. Owen, N. Serra [Eur.Phys.J.C 80 (2020) 12, 1095]

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Dispersion relation

- The non-local terms are expressed through dispersion relation

Bordone, Isidori, Mächler, Tinari arXiv:2401.18007]

$$\Delta Y^{1P}_{q\bar{q},\lambda}(q^2) = \sum_j H_j^\lambda \frac{(q^2 - q_0^2)}{m_j^2 - q_0^2} BW_j(q^2) \equiv \sum_j |H_j^\lambda| e^{i\delta_j^\lambda} \frac{(q^2 - q_0^2)}{m_j^2 - q_0^2} BW_j(q^2)$$

$$\begin{aligned}\Delta Y^{2P}_{q\bar{q},\lambda}(q^2) =& A^\lambda_{D^*\bar{D}} h_S(m_{D^*\bar{D}}, q^2) + \sum_{n=D\bar{D},D^*\bar{D}^*} A_n^\lambda h_P(m_n, q^2), \\ \equiv& |A^\lambda_{D^*\bar{D}}| e^{i\delta^\lambda_{D^*\bar{D}}} h_S(m_{D^*\bar{D}}, q^2) + \sum_{n=D\bar{D},D^*\bar{D}^*} |A_n^\lambda| e^{i\delta_n^\lambda} h_P(m_n, q^2)\end{aligned}$$

$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha_{\rm em}}{2\pi} \mathcal{C}_{9\tau} \left[h_S(m_\tau, q^2) - \frac{1}{3} h_P(m_\tau, q^2) \right]$$

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Phases and amplitudes of resonances

- The full fit is normalised to the branching fraction of $B^0 \to J/\psi K^{*0}$

$$|A_j^\lambda|^2 = f_j^\lambda \mathcal{B}(B^0 \to V K^{*0}) \mathcal{B}(V \to \mu^+ \mu^-)$$

  - This BF is taken from Belle paper only (arXiv:1408.6457) to ensure consistent treatment of S-wave and T_{cc} contamination.
- Phases for J/ψ and $\Psi(2S)$ are defined such that δ^0 is relative to local phase, while $\delta^{\parallel}$ and $\delta^{\perp}$ are relative to δ^0
- For all other resonances the phases are all relative to local phase

Shift in C_7

- The signal model also include a helicity dependent complex valued shift in C_7 for the amplitudes
- For the real parts, this is degenerate with constant term in form factor parametrisation
  - Fit implements this by leaving those fixed
- Side effect is that $\mathcal{A}_0^{L,R}$ have no sensitivity to C_9

$$\mathcal{A}_0^{L,R}(q^2) = N_0\Big\{\Big[\Big(\mathcal{C}_9^{(\mathrm{eff}),0}(q^2) - \mathcal{C}_9'\Big) \mp \Big(\mathcal{C}_{10} - \mathcal{C}_{10}'\Big)\Big] A_{12}(q^2) + \frac{m_b}{m_B + m_{K^*}}\Big(\mathcal{C}_7^{(\mathrm{eff}),0} - \mathcal{C}_7'\Big) T_{23}(q^2)\Big\},$$

$$\mathcal{A}_\parallel^{L,R}(q^2) = N_\parallel\Big\{\Big[\Big(\mathcal{C}_9^{(\mathrm{eff}),\parallel}(q^2) - \mathcal{C}_9'\Big) \mp \Big(\mathcal{C}_{10} - \mathcal{C}_{10}'\Big)\Big] \frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2}\Big(\mathcal{C}_7^{(\mathrm{eff}),\parallel} - \mathcal{C}_7'\Big) T_2(q^2)\Big\},$$

$$\mathcal{A}_\perp^{L,R}(q^2) = N_\perp\Big\{\Big[\Big(\mathcal{C}_9^{(\mathrm{eff}),\perp}(q^2) + \mathcal{C}_9'\Big) \mp \Big(\mathcal{C}_{10} + \mathcal{C}_{10}'\Big)\Big] \frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2}\Big(\mathcal{C}_7^{(\mathrm{eff}),\perp} - \mathcal{C}_7'\Big) T_1(q^2)\Big\},$$

$$\mathcal{A}_t(q^2) = N_t\left\{2\left[\mathcal{C}_{10} - \mathcal{C}_{10}'\right] A_0(q^2)\right\},$$

S-wave component

- A separate set of Wilson coefficients are added as nuisance parameters for the S-wave
  - This avoids that uncertainties in the form factors pollute the P-wave measurement.
- Non-local form factors treated in same way for S-wave as for P-wave, but includes only J/ψ and ψ(2S) resonances
- No ΔC_7 components

$$\mathcal{A}_{00}^{L,R} = -N \frac{\lambda_{K_0^{*0}}}{\sqrt{q^2}} \left[F_{\text{eff}}(q^2) \left(\mathcal{C}_9^{(\text{eff})S} \mp \mathcal{C}_{10}^S + \frac{2m_b}{m_B + m_{K_0^{*0}(700)}} \mathcal{C}_7^S \right) \right]$$

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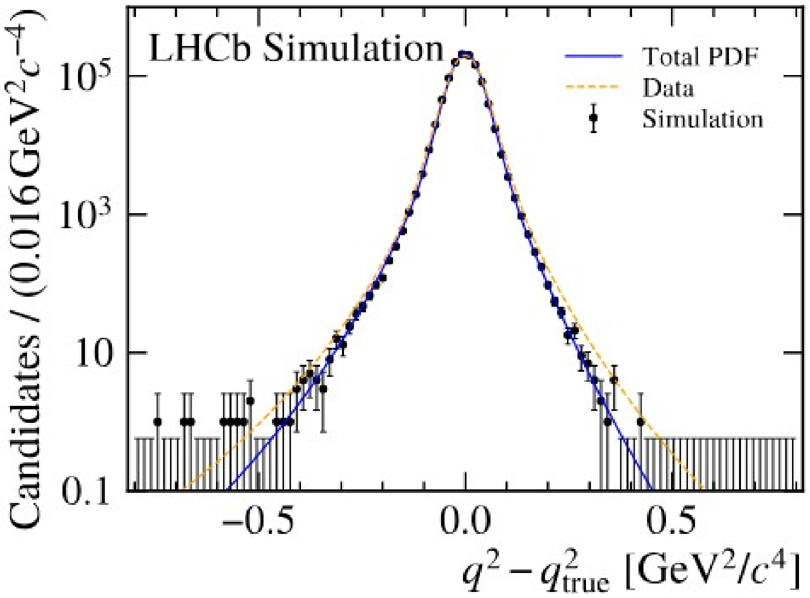
Resolution function

- As fit is unbinned and include the extremely narrow charmonium resonances, understanding the smearing in q^2 is extremely important



$$\mathcal{P}_{\mathrm{Sig},i}(\cos\theta_\ell, \cos\theta_K, \phi, q^2) = \frac{1}{\mathcal{N}}\left[\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})(B^0 \to K^{*0}\mu^+\mu^-)}{\mathrm{d}q^2_{\mathrm{true}}\mathrm{d}\vec{\Omega}} \otimes R_i(q^2 - q^2_{\mathrm{true}})\right]$$
$$\times\, \epsilon(\cos\theta_\ell, \cos\theta_K, \phi, q^2),$$

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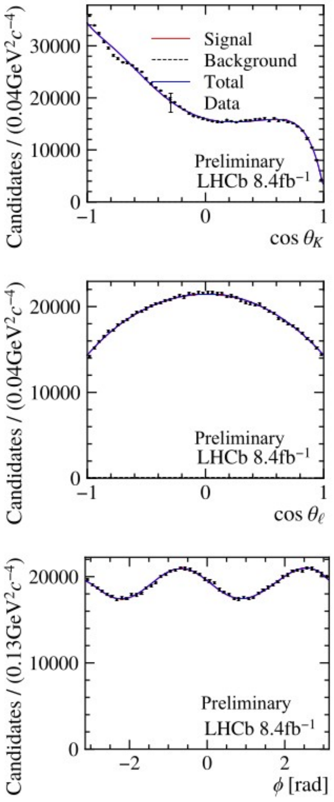
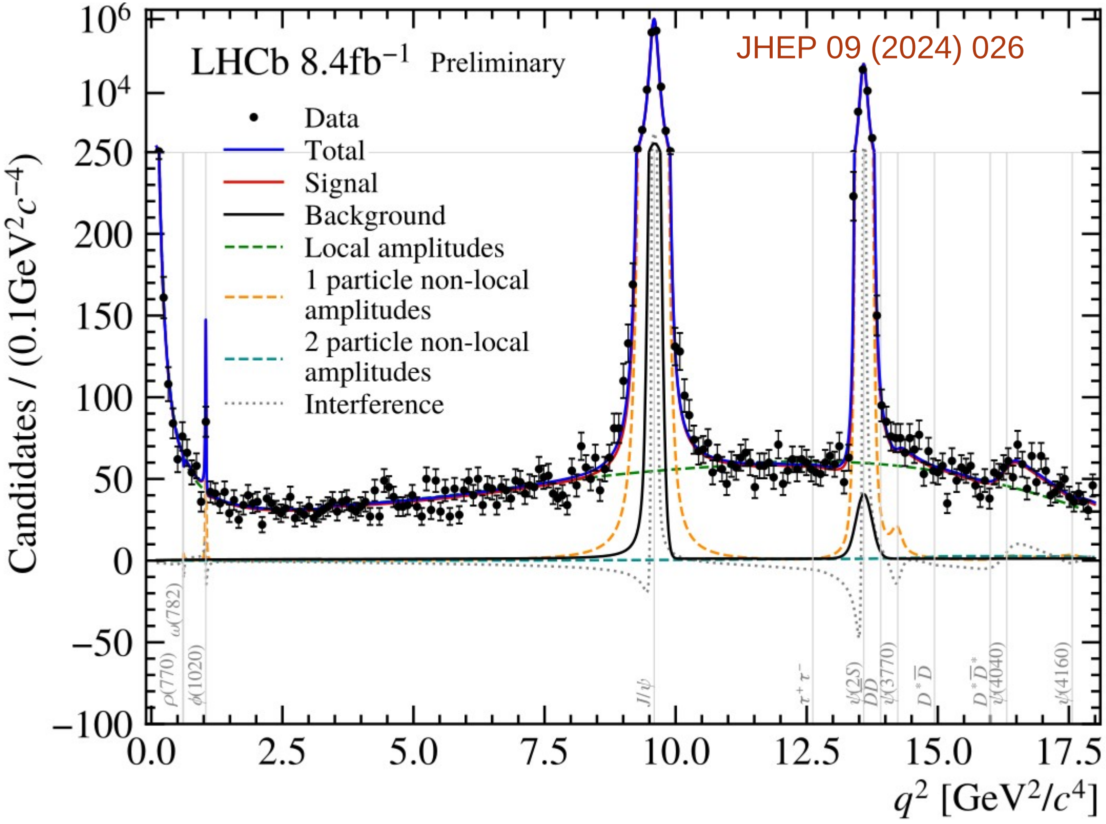
Fit provides a very good description of data

- An unbinned analysis in the dimuon mass - In total 150 parameters





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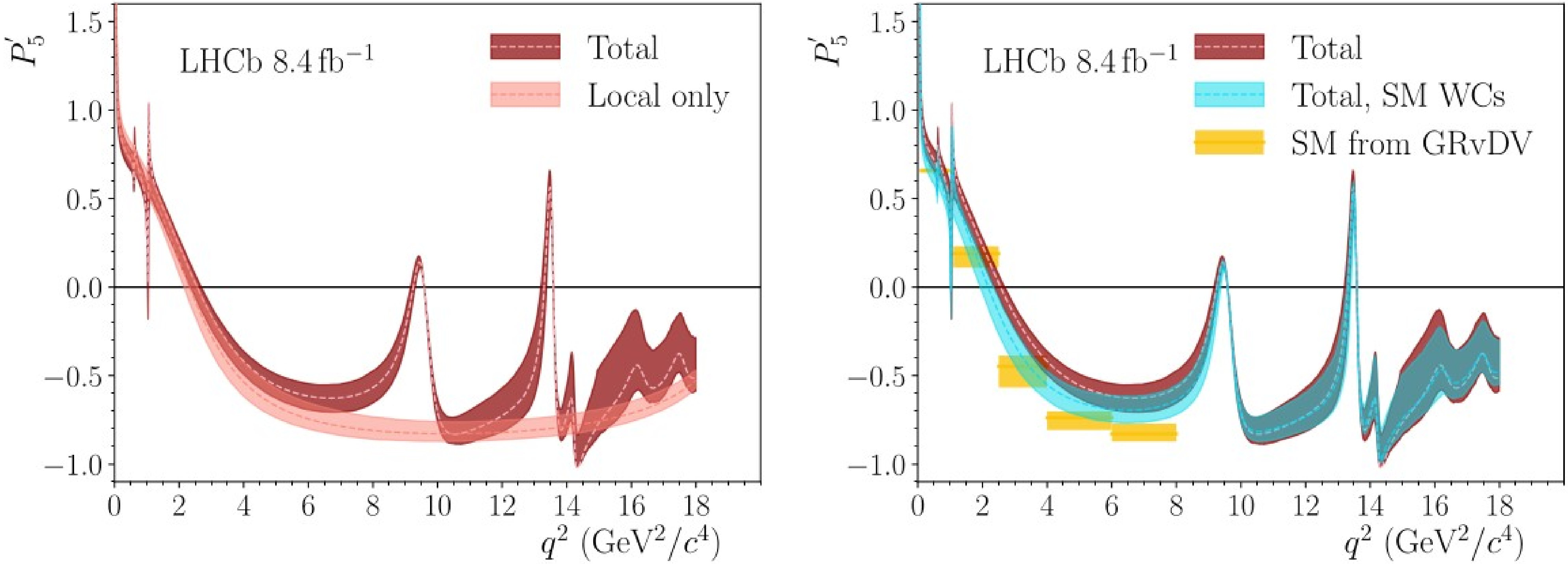
Observables

- Observables can be calculated from fit, and separated in local and non-local effects

JHEP 09 (2024) 026



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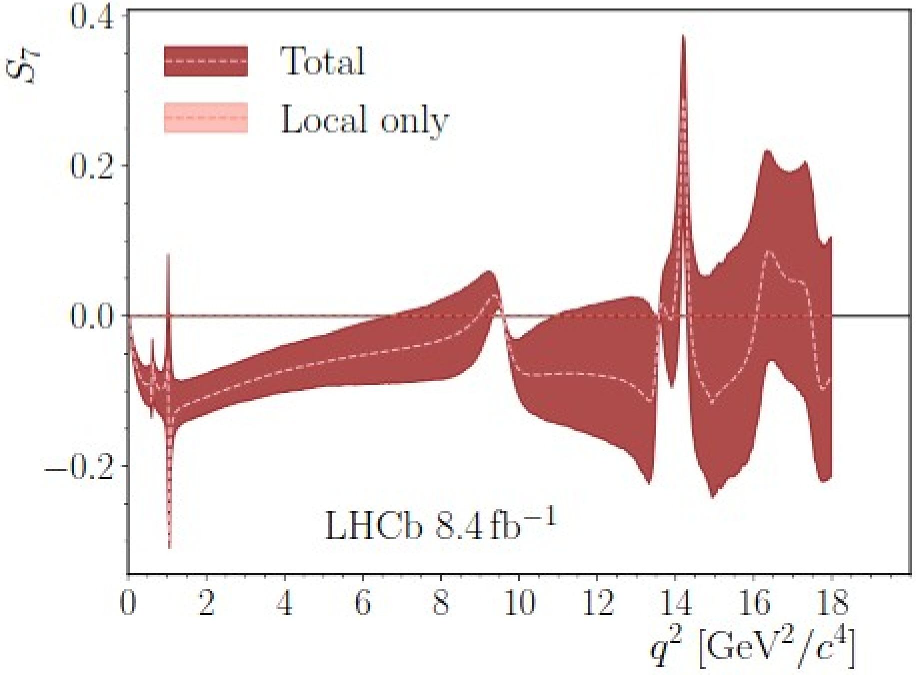

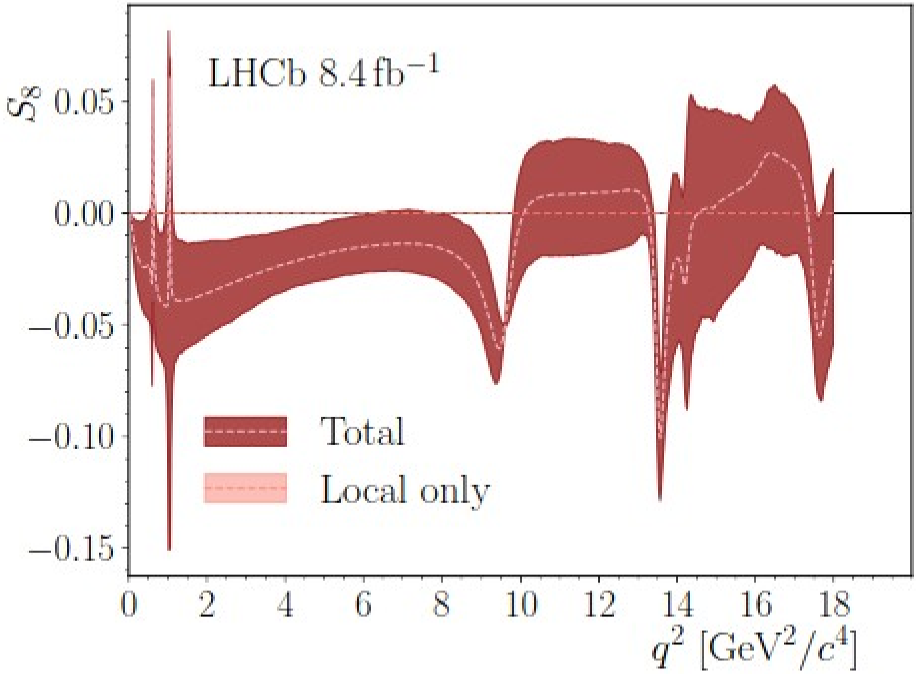

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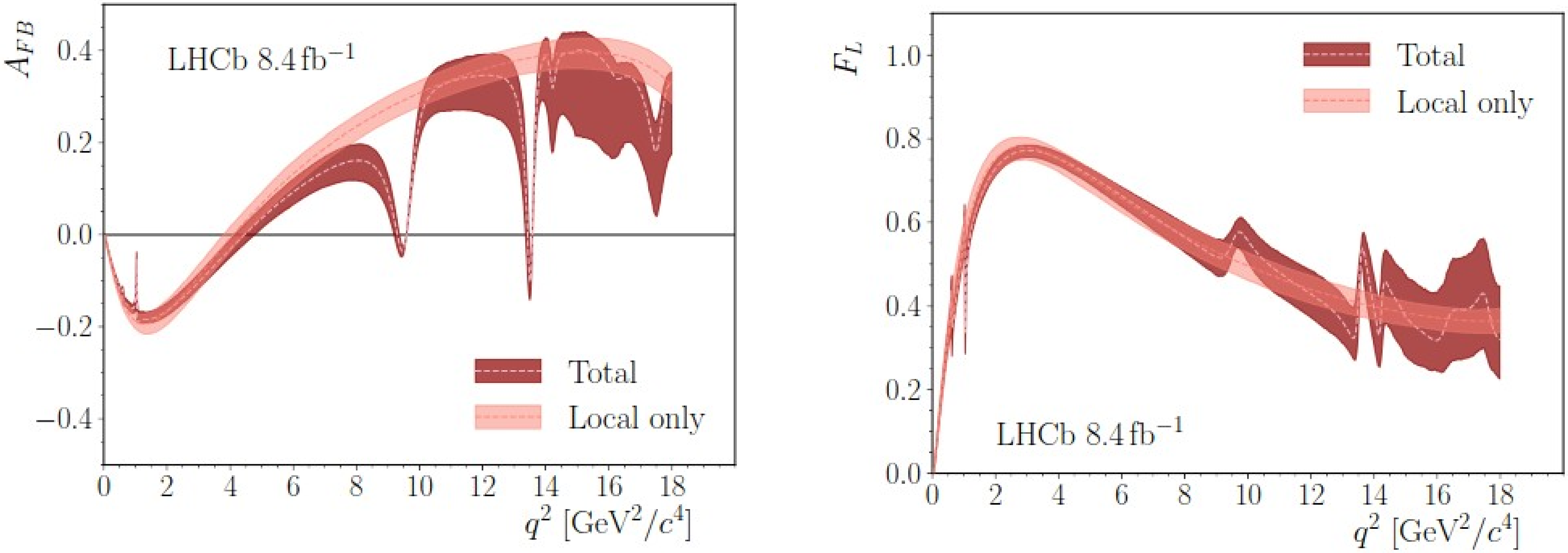
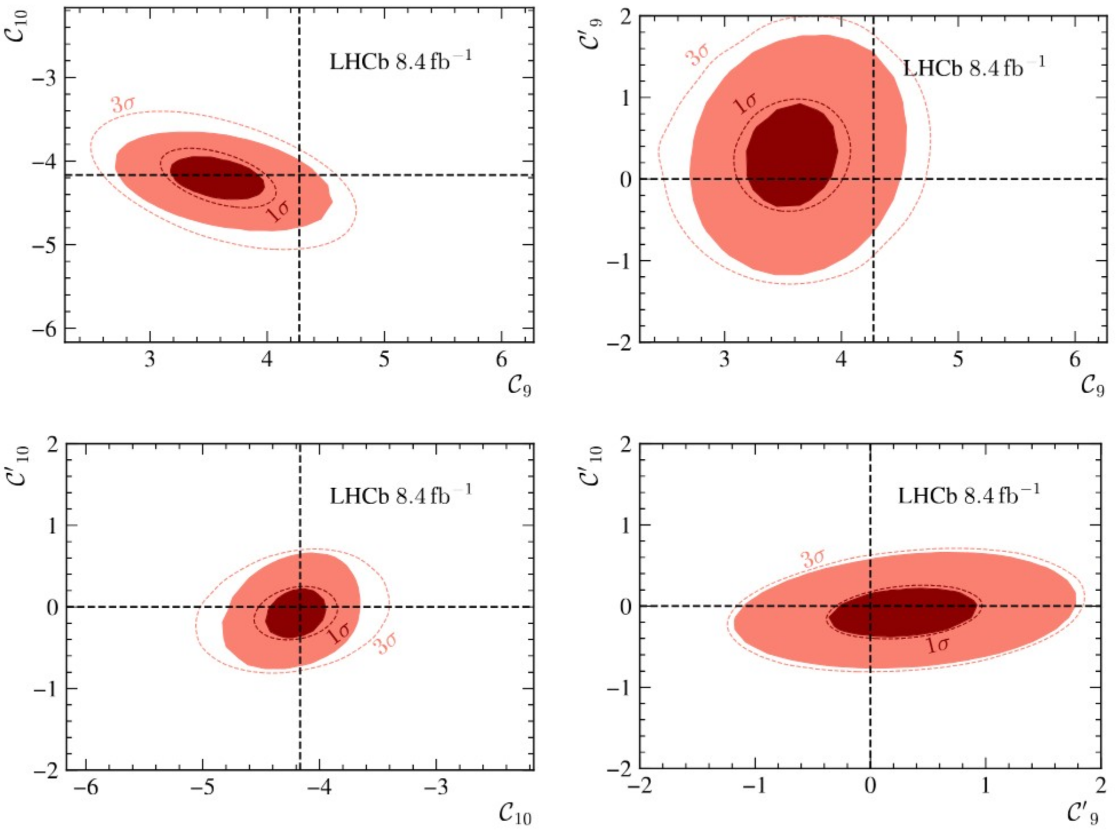
JHEP 09 (2024) 026



Wilson coefficients

- Shift in C_9 as in all other analyses
- Some of difference absorbed into non-local component

Wilson Coefficient results	
$\mathcal{C}_9$	$3.56 \pm 0.28 \pm 0.18$
$\mathcal{C}_{10}$	$-4.02 \pm 0.18 \pm 0.16$
$\mathcal{C}_9'$	$0.28 \pm 0.41 \pm 0.12$
$\mathcal{C}_{10}'$	$-0.09 \pm 0.21 \pm 0.06$
$\mathcal{C}_{9\tau}$	$(-1.0 \pm 2.6 \pm 1.0) \times 10^2$



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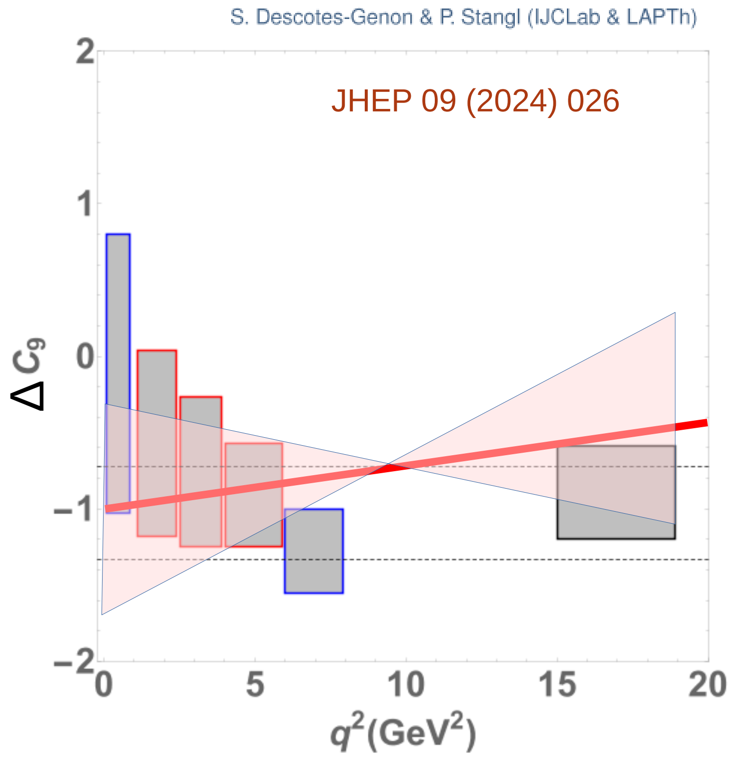
Cross checks

- The unbinned fit can be extended to allow for an unphysical change of Wilson coefficient as function of q^2
- For vector current (C_9), uncertainty is quite large due to resonances



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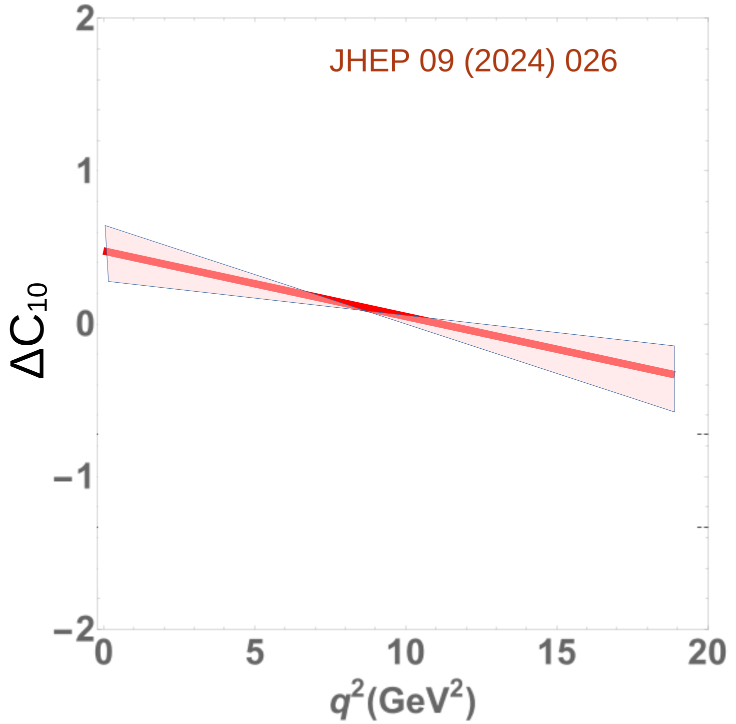
Cross checks

- The unbinned fit can be extended to allow for an unphysical change of Wilson coefficient as function of q^2
- For vector current (C_9), uncertainty is quite large due to resonances
- For axial-vector, we see agreement with no slope at 2.2σ level
  - Similar type of disagreement in $B \to K\mu\mu$ unbinned analysis



CP-violating fit

- CP violation is allowed for in fit by allowing C_9 and C_{10} to have a weak phase
- Not allowed in C_9' and C_{10}' as CP conserving fit showed they were insignificant
- T-odd symmetries require both strong and weak phase differences
  - We get this between the penguin amplitude and the vector resonances
- T-even symmetries are sensitive across all q^2
  - This also has interference terms between C_9 and C_{10}
  - Would cancel out if only fitting in q^2

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CP-violating fit

$$\mathcal{A}_\lambda^{L,R} = \mathcal{N}_\lambda(q^2)\lambda_t\Big\{\Big[(\mathcal{C}_{9\,\lambda}^{\text{eff}}(q^2) \pm \mathcal{C}_9') \mp (\mathcal{C}_{10} \pm \mathcal{C}_{10}')\Big]\mathcal{F}_\lambda(q^2)$$

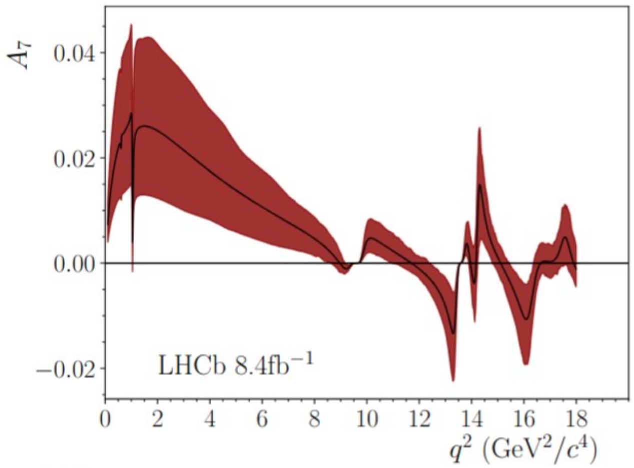
$$+k_\lambda(q^2)\Big[(\mathcal{C}_7 + \Delta\mathcal{C}_{7\,\lambda} \pm \mathcal{C}_7')\Big]\mathcal{T}_\lambda(q^2)\Big\},$$

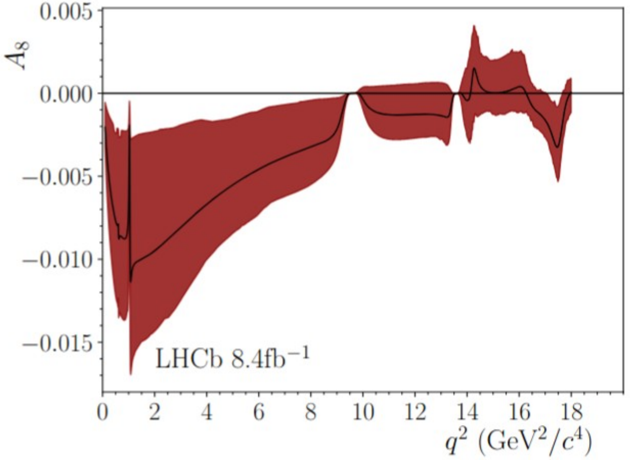
$$\mathcal{C}_{9\,\lambda}^{\text{eff}}(q^2) = \mathcal{C}_9 + \frac{\lambda_c}{\lambda_t}\left[Y_{c\bar{c}}(q_0^2) + \frac{(q^2 - q_0^2)}{\pi}\int_{4m_\mu^2}^{\infty}\frac{\rho_{c\bar{c},\lambda}(s)}{(s - q_0^2)(s - q^2 - i\epsilon)}\mathrm{d}s\right]$$

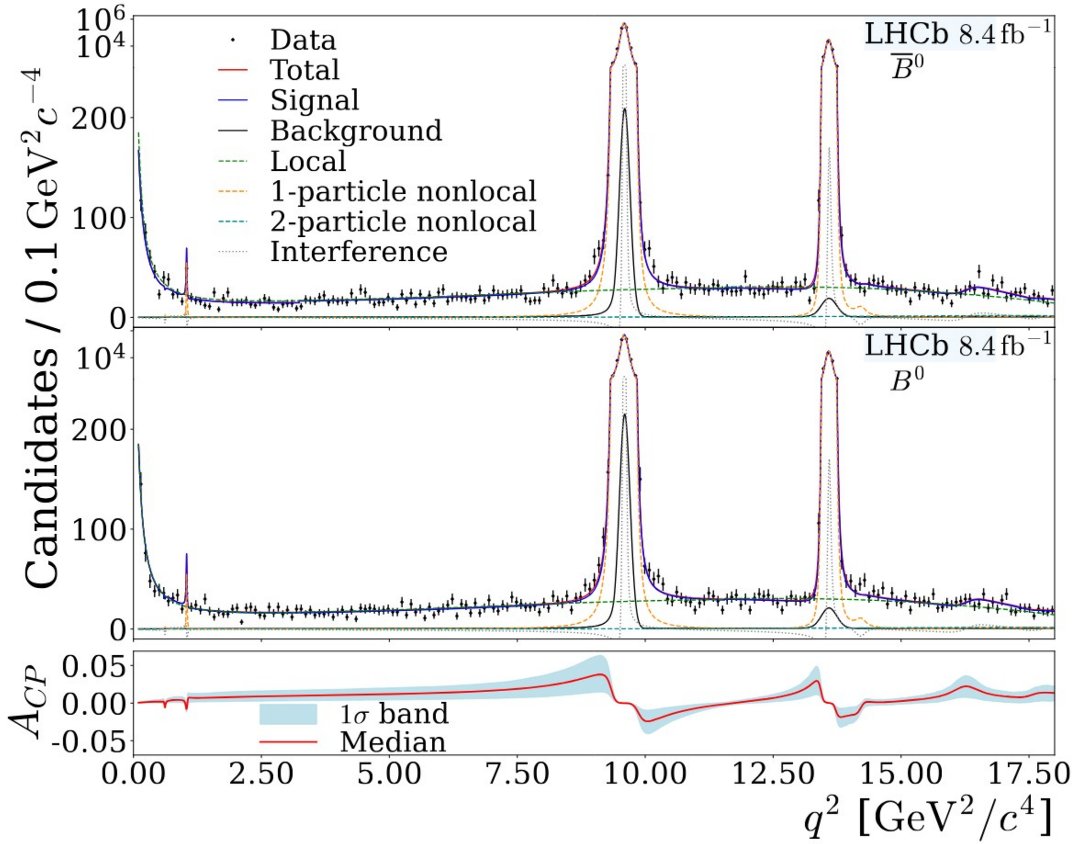
$$+\frac{\lambda_u}{\lambda_t}\frac{(q^2 - q_0^2)}{\pi}\int_{4m_\mu^2}^{\infty}\frac{\rho_{q\bar{q},\lambda}(s)}{(s - q_0^2)(s - q^2 - i\epsilon)}\mathrm{d}s,$$

- A weak phase of $\arg(V_{cb}V^*_{cs}/V_{tb}V^*_{ts})$ between penguin and $c\bar{c}$ resonances expected in SM

CPV fit results

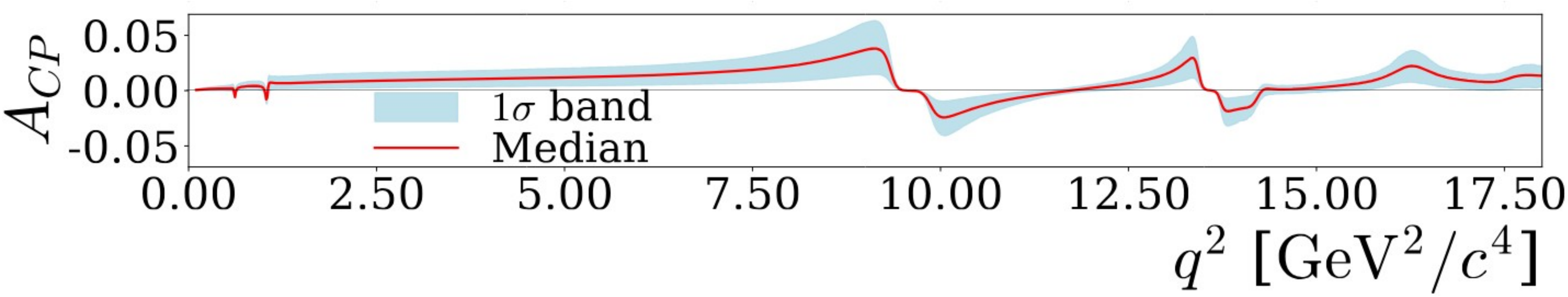




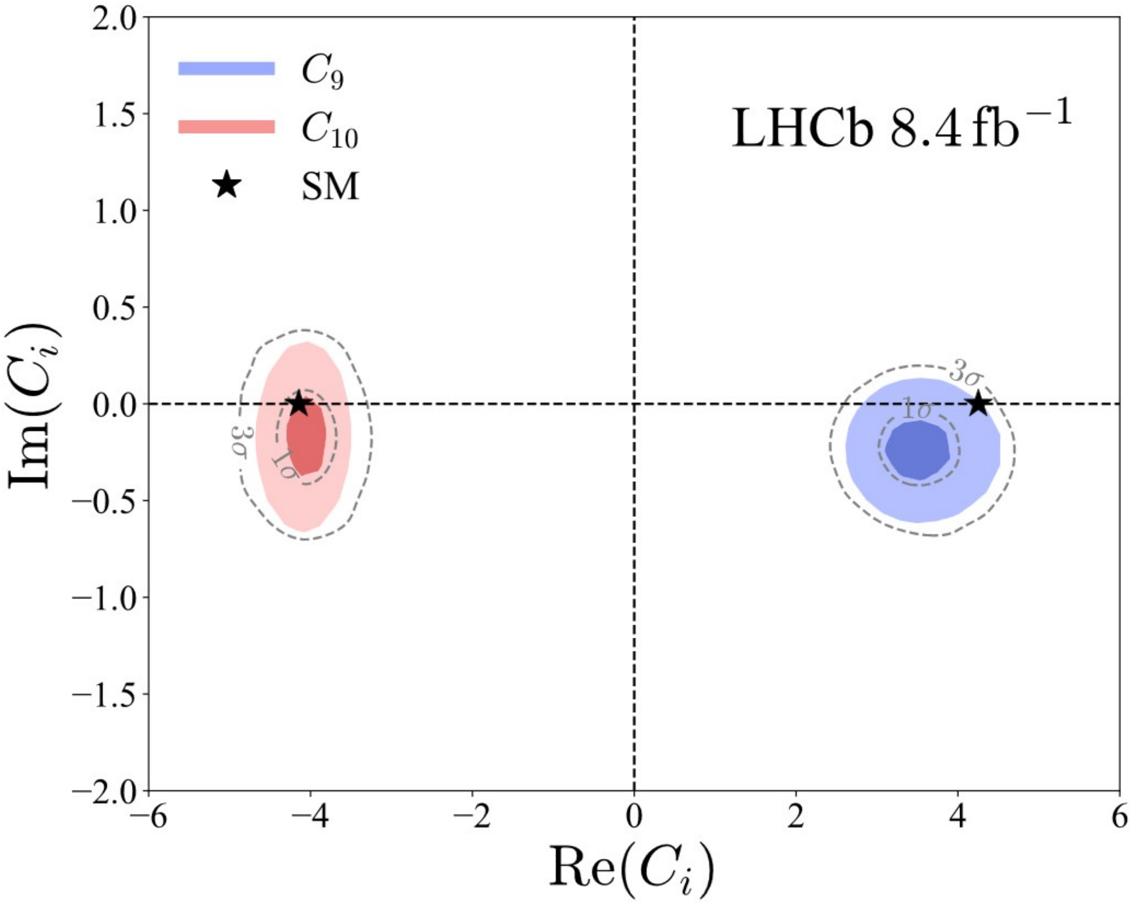


CPV fit result

- Direct CP violation



CPV fit result



Wilson coefficient results		
$\lVert\mathcal{C}_9\rVert$	3.50 ± 0.30	± 0.15
$\lVert\mathcal{C}_{10}\rVert$	4.04 ± 0.18	± 0.15
$\delta\phi_{\mathcal{C}_9}$	-0.067 ± 0.032	± 0.011
$\delta\phi_{\mathcal{C}_{10}}$	0.043 ± 0.035	± 0.010
$\mathcal{R}e(\mathcal{C}_9)$	3.50 ± 0.30	± 0.15
$\mathcal{I}m(\mathcal{C}_9)$	-0.23 ± 0.11	± 0.04
$\mathcal{R}e(\mathcal{C}_{10})$	-4.04 ± 0.18	± 0.15
$\mathcal{I}m(\mathcal{C}_{10})$	-0.17 ± 0.14	± 0.04
$\mathcal{R}e(\mathcal{C}'_9)$	0.39 ± 0.46	± 0.21
$\mathcal{R}e(\mathcal{C}'_{10})$	-0.12 ± 0.21	± 0.06

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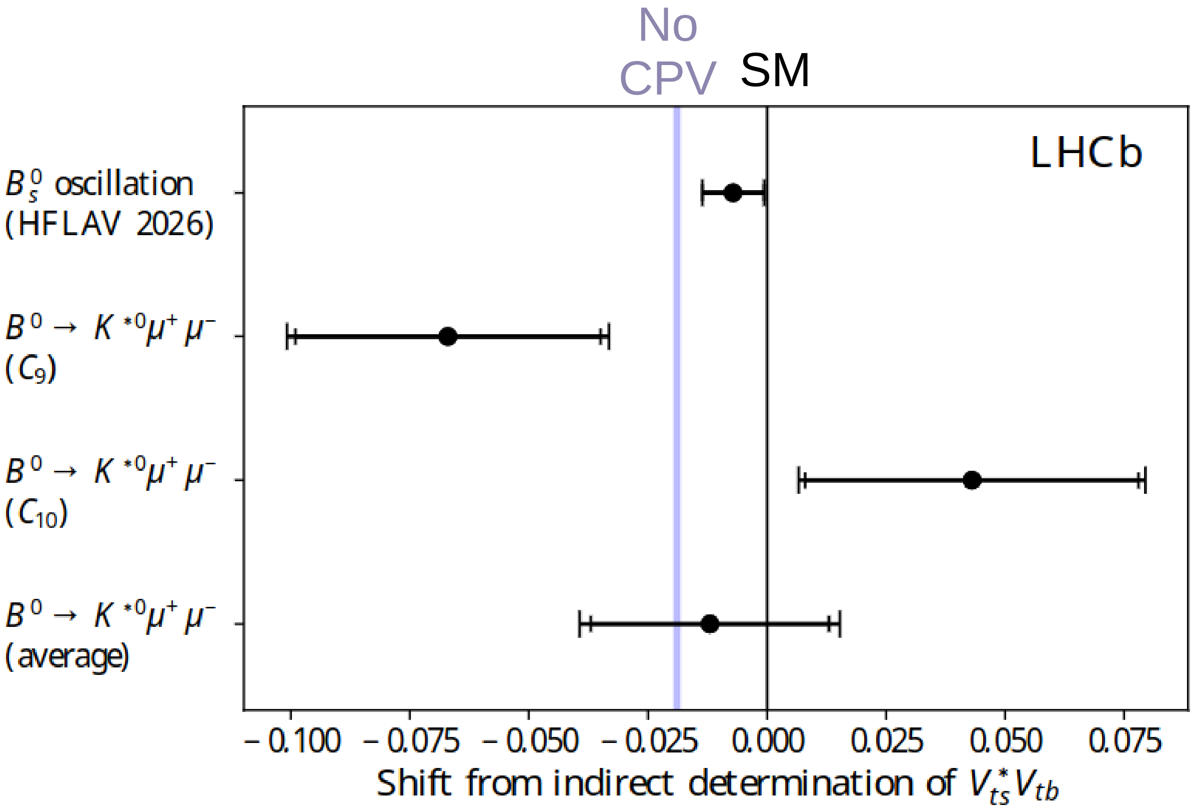
Weak phase comparison



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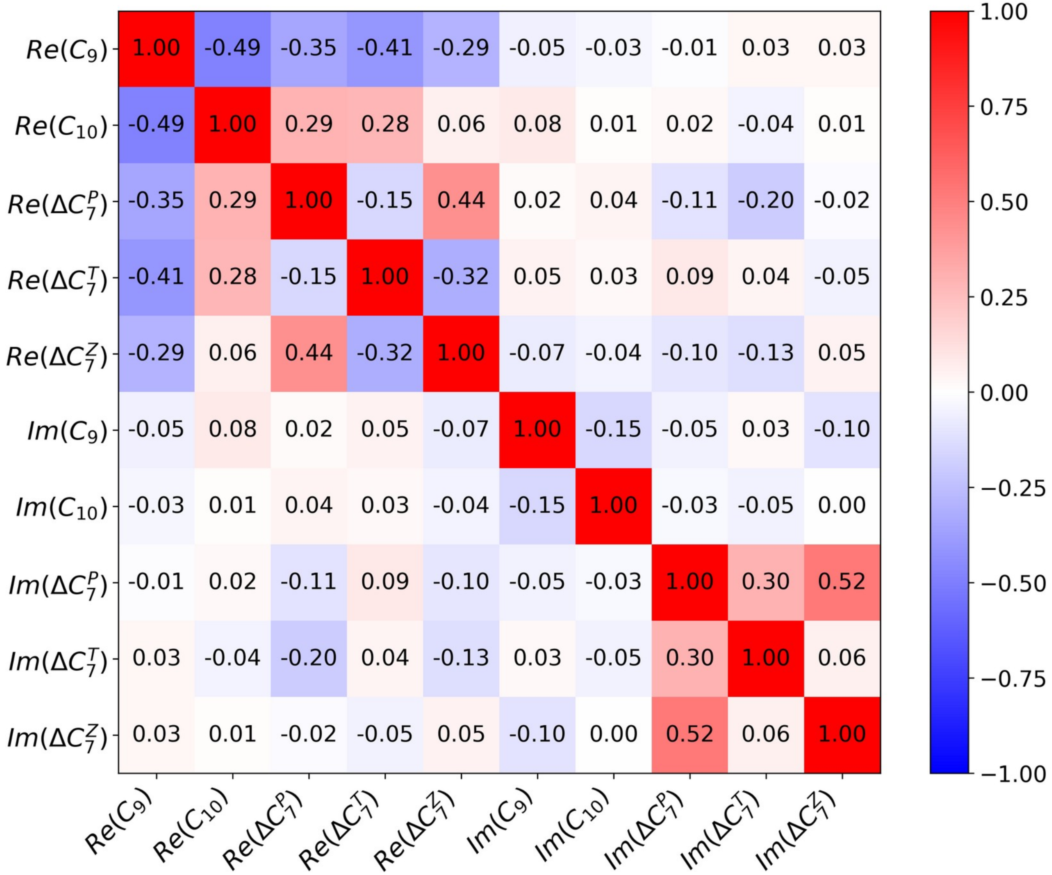
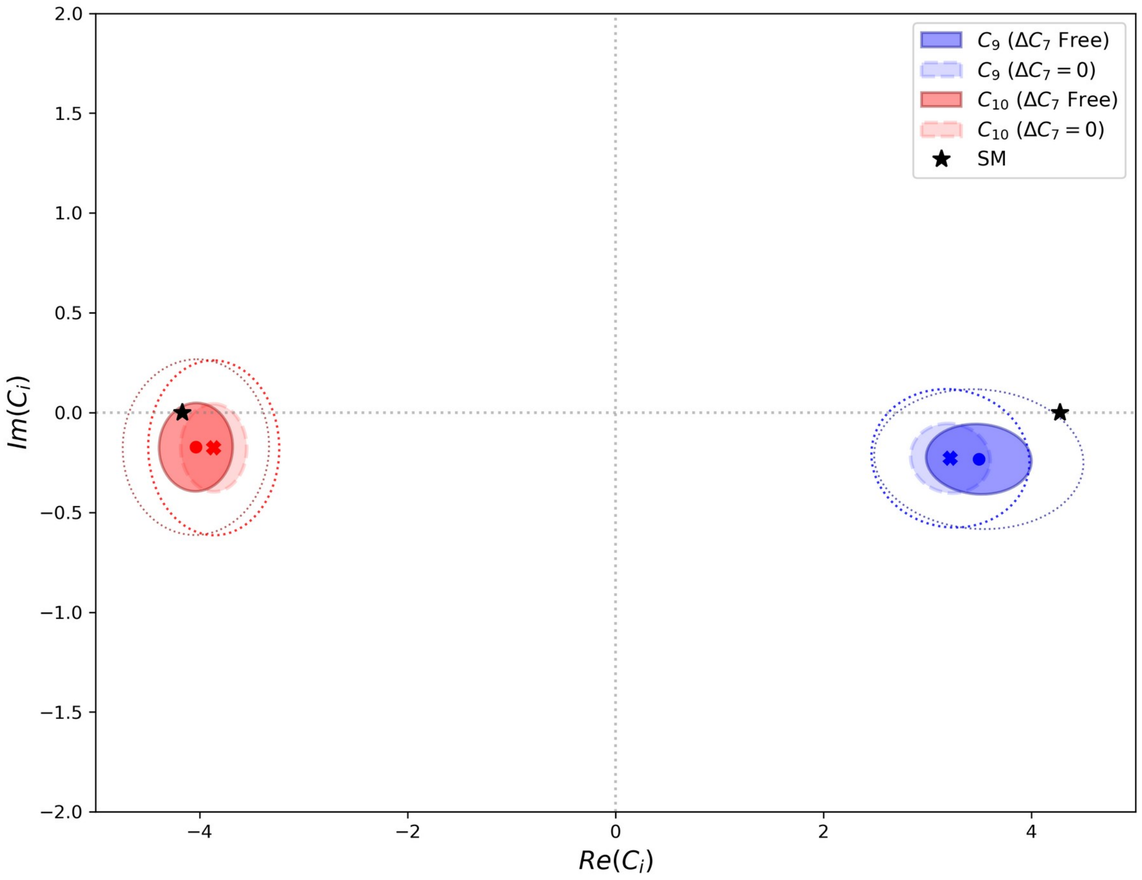
Correlations

- Using correlation matrix we can investigate influence of ΔC_7 parameters
- Setting all to zero is disfavoured by 2.6σ



Correlations

- Using correlation matrix we can investigate influence of ΔC_7 parameters
- Setting all to zero is disfavoured by 2.6σ
- Shift in WCs is very small for real part
- Insignificant for imaginary part



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