Imperial College London

Puzzles in $B \to VV$ decays and measurements of optimised L observables

MITP - Flavourful Opportunities in Semileptonic B Decays

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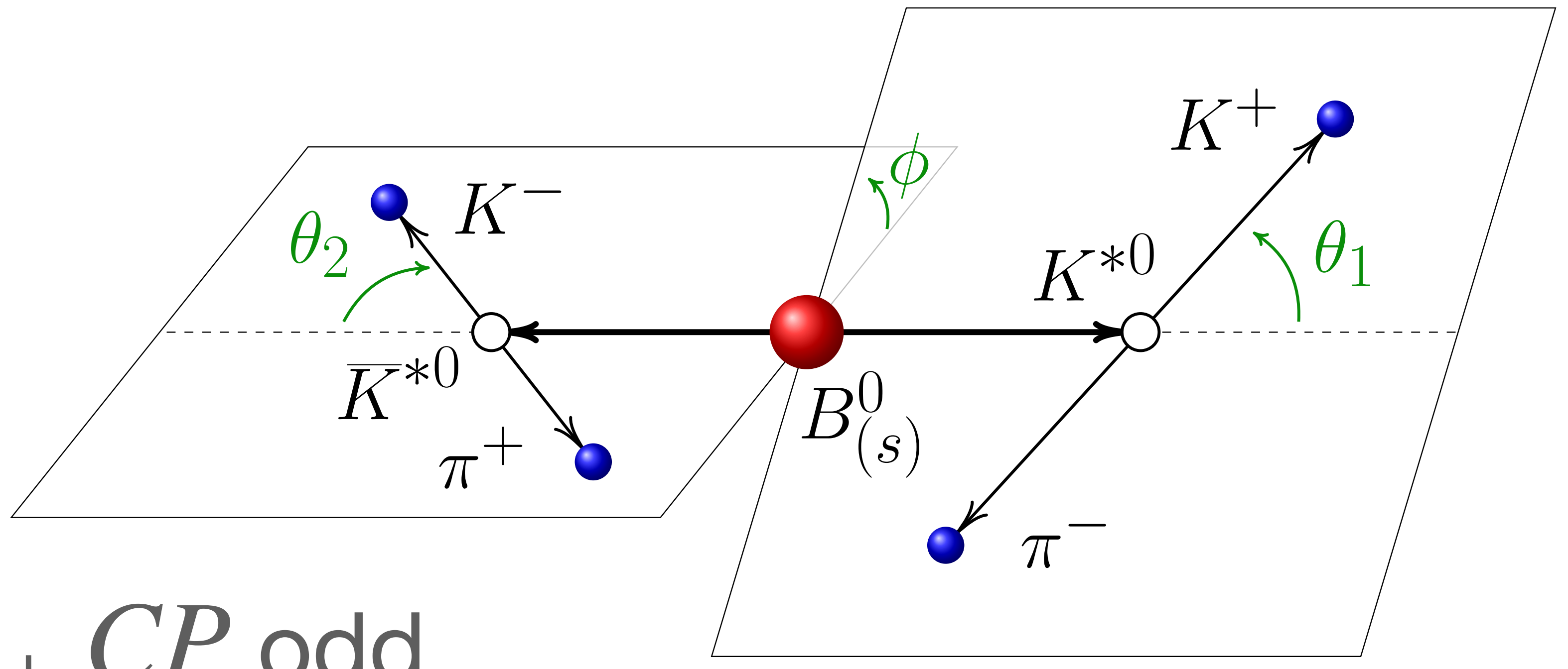
8th July 2026

Angular analyses of $B \to VV$ decays

- In a $B \to VV$ decay the total amplitude is decomposed in three independent helicity states A_0, A_+, A_-
  - Recast in transversity basis where:



$$A_0,\ A_\perp = \frac{A_+ - A_-}{\sqrt{2}},\ A_\parallel = \frac{A_+ + A_-}{\sqrt{2}}$$

  - Transversity amplitdutes are CP eigenstates with $A_0, A_\parallel$ CP even and $A_\perp$ CP odd

$$f_{L,\parallel,\perp} = \frac{|A_{0,\parallel,\perp}|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2}$$

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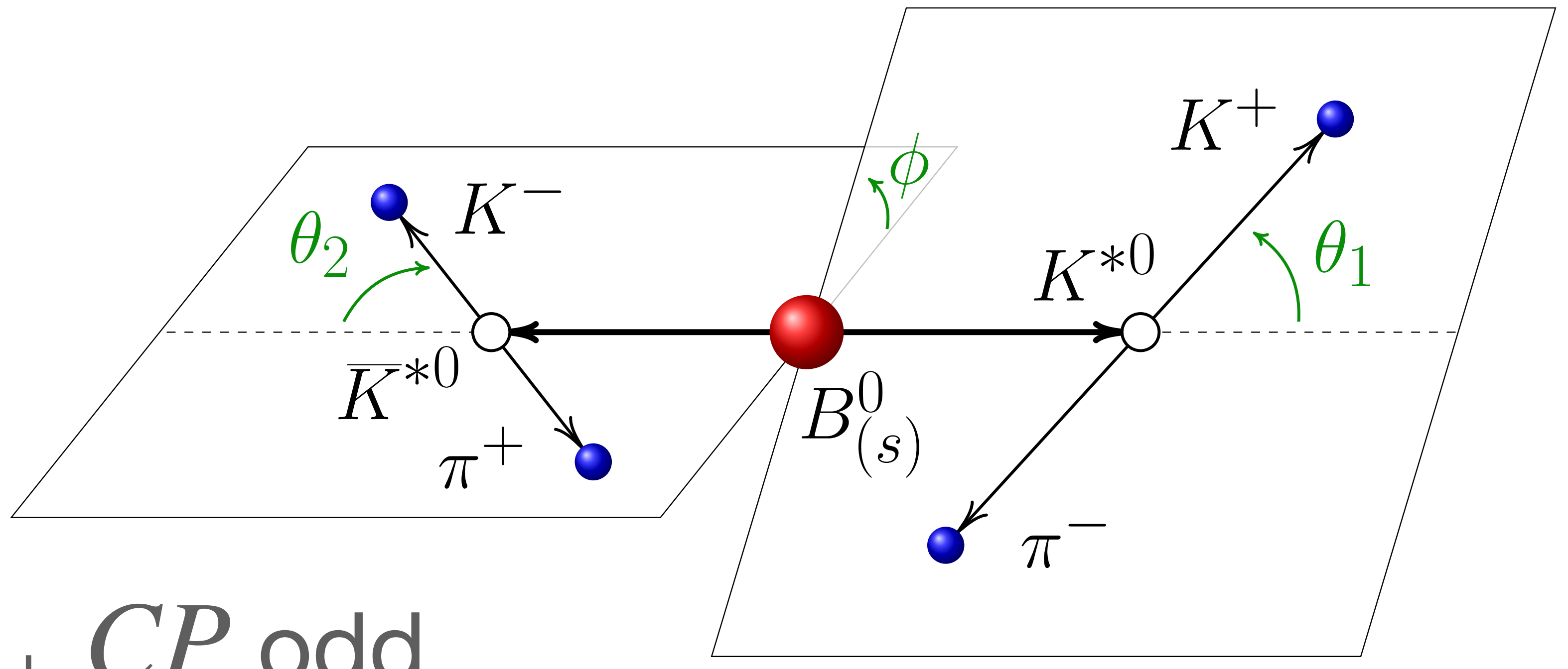

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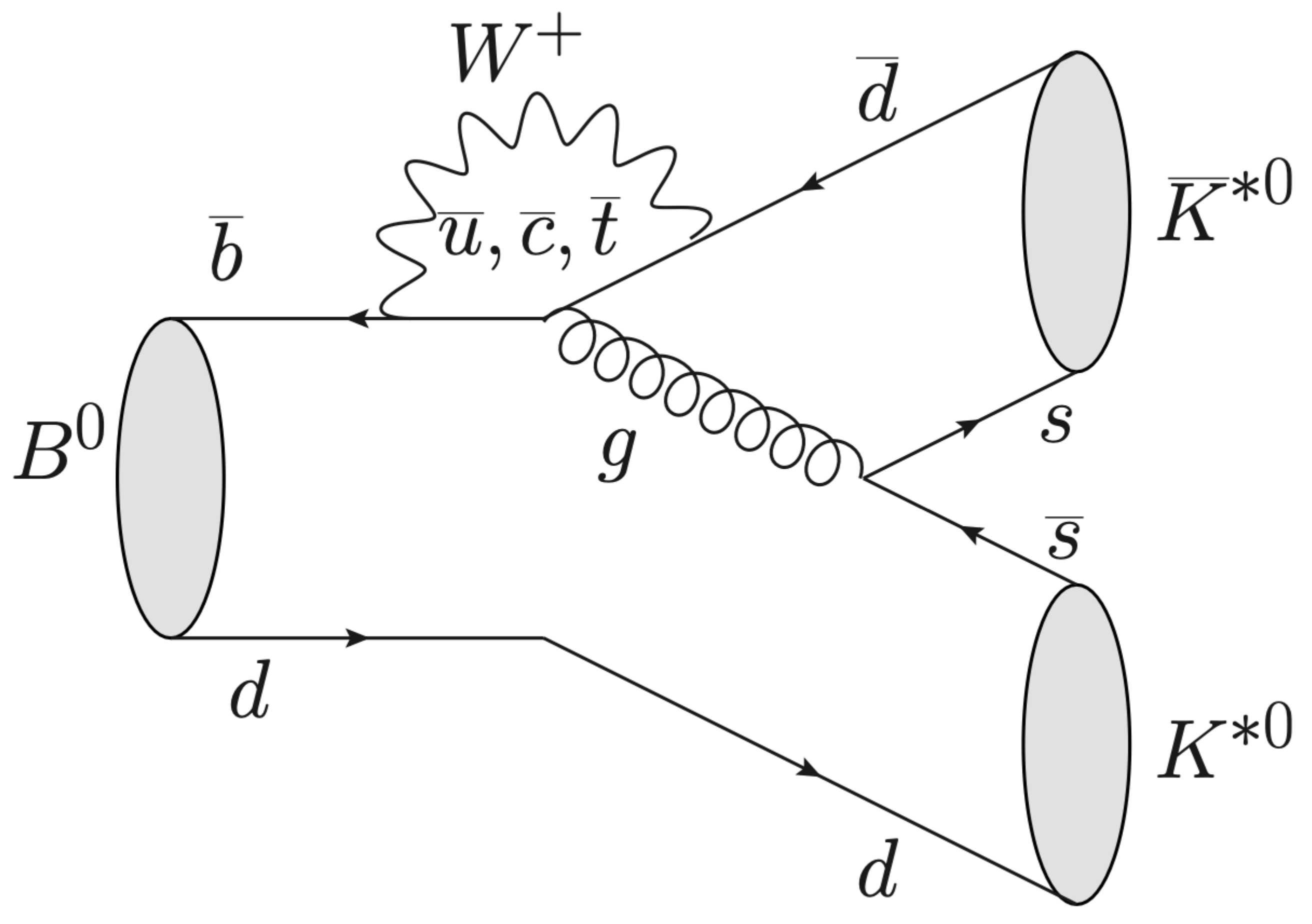
$$f_{L,\parallel,\perp} = \frac{|A_{0,\parallel,\perp}|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2}$$

- Expectation from heavy quark symmetry is that in for a $V - A$ coupling, A_0 should prevail over the other two:

$$\boxed{A_0 : A_- : A_+ \sim 1 : \left(\frac{\Lambda_{\text{QCD}}}{m_B}\right) : \left(\frac{\Lambda_{\text{QCD}}}{m_B}\right)^2 \Rightarrow f_T = f_\parallel + f_\perp = 1 - f_L = O(m_V^2/m_B^2),\quad f_\parallel/f_\perp = 1 + O(m_V/m_B)}$$

The polarisation puzzle

- This amplitude hierarchy seems to be respected in tree level decays but not in loop induced $B \to VV$ decays
  - This puzzle predates LHCb, and was initiated by the B-factories unexpectedly low f_L in $B^0 \to \phi \bar{K}^{*0}$ decays [Nucl.Phys.B774:64-101,2007]
  - Gluonic penguin mediated $B_s^0 \to K^{*0} \bar{K}^{*0}$ decays have exhibited breaking of this hierarchy since when first measured at LHCb



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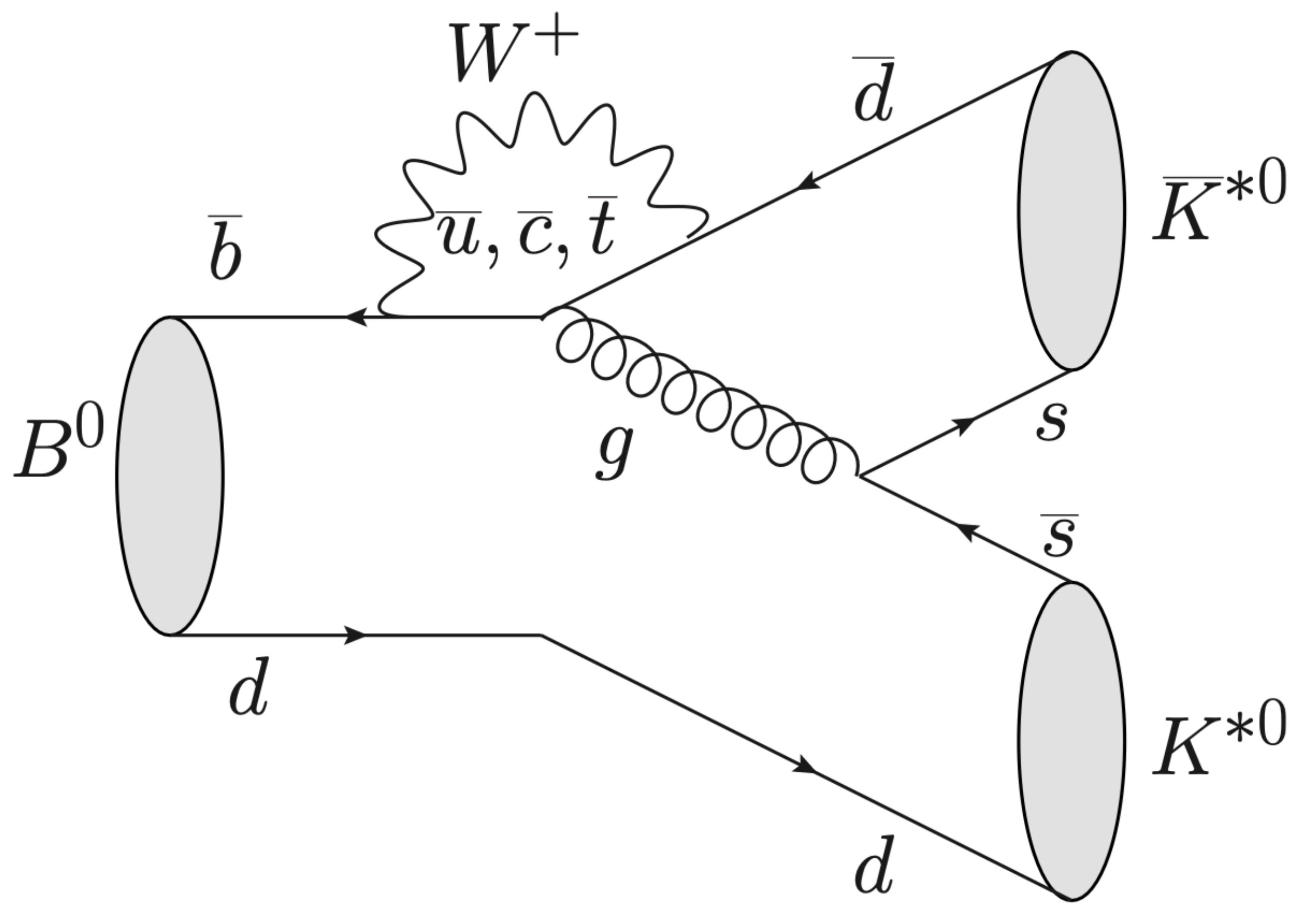

[JHEP 03 (2018) 140]

- TD angular analysis determined $f_L^{B_s}$ with 3fb^{-1} of data

$$f_L^{B_s} = 0.208 \pm 0.032(\text{stat}) \pm 0.046(\text{syst})$$
$$\phi_s^{d\bar{d}} = -0.10 \pm 0.13(\text{stat}) \pm 0.14(\text{syst})$$

[JHEP 07 (2019) 032]

- TI angular analysis determined f_L in both B^0 and B_s with 3fb^{-1} of data

$$f_L^{B_s^0} = 0.240 \pm 0.031(\text{stat}) \pm 0.025(\text{syst})$$
$$f_L^{B^0} = 0.724 \pm 0.051(\text{stat}) \pm 0.016(\text{syst})$$

Optimised L observables

- Recently, a series of optimised observables was introduced, involving ratios of (longitudinal) branching fractions of U-spin related $B \to VV$ decays [JHEP 09 (2025) 188]

- If we consider $B^0_{(s)} \to K^{*0}\bar{K}^{*0}$, by decomposing of the amplitude as

$$\bar{A}_f \equiv A(\bar{B}_q \to K^{*0}\bar{K}^{*0}) = \lambda_u^{(q)} T_q + \lambda_c^{(q)} P_q = \lambda_u^{(q)} \Delta_q - \lambda_t^{(q)} P_q$$

with $\lambda_U^q = V_{Ub} V_{Uq}^*$, one can construct the following observable:

$$L_{K^*\bar{K}^*} = \frac{|A_0^s|^2 + |\bar{A}_0^s|^2}{|A_0^d|^2 + |\bar{A}_0^d|^2} = \kappa \left| \frac{P_s}{P_d} \right|^2 \left[\frac{1 + |\alpha^s|^2 \left| \frac{\Delta_s}{P_s} \right|^2 + 2\mathrm{Re}\left(\frac{\Delta_s}{P_s} \right) \mathrm{Re}(\alpha^s)}{1 + |\alpha^d|^2 \left| \frac{\Delta_d}{P_d} \right|^2 + 2\mathrm{Re}\left(\frac{\Delta_d}{P_d} \right) \mathrm{Re}(\alpha^d)} \right]$$

- α_d is Cabibbo allowed, α_s is $O(\lambda^2)$ suppressed, Δ_q/P_q expt. to be small in case of penguin mediated decays

- L observables are directly related to $|P_s/P_d|^2$, which can be predicted with good accuracy within QCDF and is protected by U-spin symmetry from large $1/m_b$ power corrections

Optimised L observables

- Experimentally, this translates to the measurement of:

$$L_{K^*\bar{K}^*} = \rho(m_{K^{*0}}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \to K^{*0}\bar{K}^{*0})} \frac{f_L^{B_s}}{f_L^{B_d}}$$

$$L_{K^*\bar{K}^*}^{I,\mathrm{SM}} = 18.34^{+7.47}_{-5.83}, \qquad L_{K^*\bar{K}^*}^{II,\mathrm{SM}} = 26.08^{+5.70}_{-4.72}$$

$$L_{K^*\bar{K}^*}^{III,\mathrm{SM}} = 22.88^{+15.35}_{-8.46}.$$

$$L_{K^*\bar{K}^*}^{\mathrm{exp}} = 4.43 \pm 0.92$$

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$$L_{K^*\bar{K}^*} = \rho(m_{K^{*0}}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^{*0})}{\mathcal{B}(\bar{B}\ldots} \frac{f_L^{B_s}}{\ldots}$$

$L^{I,\mathrm{SM}}_{K^*\bar{K}^*}$ ...

Luminosity scaling from including Run2 will make $f_L^{B_s}$ systematic dominated

+ need to reduce syst. uncert. in $\phi_s^{d\bar{d}}$ measurement

Leading contributions to systematic uncert. are the Blatt-Weisskopf barrier factors (TD analysis) and S-wave parametrisation in (TI analysis)

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Measurement of $L_{K^*\bar{K}^*}$ using Run 1+Run 2 data

Covariant tensor formalism: motivation

$$\frac{d\Gamma}{d\Phi_4} \propto |\sum_i A_i(\Phi_4)|^2$$

- Terms in the amplitude can be decomposed as:

$$A(\Phi_4) \equiv B_{(K^+\pi^-)(K^-\pi^+)}(\Phi_4)\left[B_{(K^+\pi^-)}(\Phi_4)T_{(K^+\pi^-)}(\Phi_4)\right]\left[B_{(K^-\pi^+)}(\Phi_4)T_{(K^-\pi^+)}(\Phi_4)\right]S(\Phi_4)$$

- Where $B(\Phi_4)$ are Blatt-Weisskopf barrier factors, $T(\Phi_4)$ mass propagators (e.g. Breit-Wigner, LASS, dispersive scattering model..) and $S_i(\Phi_4)$ angular terms

$$B(q,L) \equiv \begin{cases} 1 & \text{if } L=0\,, \\ \dfrac{1}{\sqrt{1+(qr)^2}} & \text{if } L=1\,, \\ \dfrac{1}{\sqrt{9+3(qr)^2+(qr)^4}} & \text{if } L=2\,. \end{cases}$$

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- The angular model in helicity formalism is fine, the problem arises in the mass variables:
  - A_0 and $A_{||}$ amplitudes are not eigenstates of angular momentum but rather a superposition of $\ell = 0,\ 2$
- Set $\ell = 0$ as baseline for Blatt-Weisskopf barrier factors, trial $\ell = 2$ as systematic
  - Leads to sizeable systematics, switch to covariant tensor formalism where angular amplitudes are eigenstates of L

Covariant tensor formalism

[PhysRevD.57.431] [PhysRev.140.B97]

- For a J-spin particle with momentum p polarisation λ define the projection operator P as

$$P_{\mu_1 \ldots \mu_J, \nu_1 \ldots \nu_J}(p) = \sum_{\lambda} \epsilon_{\mu_1 \ldots \mu_J}(p, \lambda) \epsilon^*_{\nu 1 \ldots \nu J}(p, \lambda)$$

Where $\varepsilon_{\mu_1 .. \mu_L}(p, \lambda)$ rank-J tensor with Lorentz indices μ_i satisfying the Rarita-Schwinger conditions:
$\varepsilon_{\mu_1 \ldots \mu_L}(p, \lambda)$ is symmetric traceless and orthogonal to p

- If that state is undergoing 2-body decay with relative momentum $q \equiv p_1 - p_2$ between decay products the relative orbital angular momentum tensor is given by

$$L_{\mu_1 \ldots \mu_J}(p, q) = P_{\mu_1 \ldots \mu_J, \nu_1 \ldots \nu_J} q^{\nu_1 \ldots \nu_J}$$

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- Individual spin densities S are obtained by contracting $\varepsilon_{\mu_1 .. \mu_L}(p, \lambda)$ with corresponding $L_{\mu_1 .. \mu_L}(p, q)$
- For a $B \to VV$ decay, 6 amplitudes in total
- Fit basis: the set of final state four-momenta of particles Φ_4

$B^0_{(s)}$ decay topology	$S(\Phi_4)$
$B \to V\bar{V}[S]$	$L_\mu(p_V, q_V) L^\mu(p_{\bar{V}}, q_{\bar{V}})$
$B \to V\bar{V}[P]$	$\epsilon_{\mu\nu\rho\sigma} p_B^\sigma L^\rho(p_B, q_B) L^\nu(p_V, q_V) L^\mu(p_{\bar{V}}, q_{\bar{V}})$
$B \to V\bar{V}[D]$	$L_{\mu\nu}(p_B, q_B) L^\nu(p_V, q_V) L^\mu(p_{\bar{V}}, q_{\bar{V}})$
$B \to V\bar{S}$	$L_\mu(p_B, q_B) L^\mu(p_V, q_V)$
$B \to S\bar{V}$	$L_\mu(p_B, q_B) L^\mu(p_{\bar{V}}, q_{\bar{V}})$
$B \to S\bar{S}$	1

Surfing the S-wave

- Within the $K\pi$ system:
  - P-wave: relative $\ell = 1$ between K^+ and π^- , e.g. $K^*(892)^0 \to K^+\pi^-$
  - S-wave: relative $\ell = 0$ between K^+ and π^- , e.g. $K^*(700)^0 \to K^+\pi^-, K^*(1430)^0 \to K^+\pi^-$
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- Increase the lever arm into S-wave constraint:

  $((K^\pm\pi^\mp)$ threshold $< m(K^\pm\pi^\mp) < 1042)$ MeV/c^2

  - Upper limit is chosen to remain in the elastic region (i.e. below $K\eta^{(\prime)}$ production) where the S-wave parametrisation is simpler
  - First time at LHCb fitting the $K^\pm\pi^\mp$ S-wave down to threshold

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- $S_{K\pi}$ mass propagator model built on top of Peláez-Rodas parametrisation [PHYS. REP. 969 (2022) 1]
  - Lineshapes obtained in χ-PT framework fulfilling unitarity, causality and crossing symmetry
  - Improve on description of lineshape by including QMI description of direct production of resonances from B decay

Surfing the S-wave

$$\omega(y) \equiv \omega\big(y(s)\big) = \frac{\sqrt{y(s)} - \alpha\sqrt{y_0 - y(s)}}{\sqrt{y(s)} + \alpha\sqrt{y_0 - y(s)}}\,, \quad y(s) = \left(\frac{s - \Delta_{K\pi}}{s + \Delta_{K\pi}}\right)^2\,, \quad y_0 \equiv y(s_0)$$

- Explicit expression for the Peláez-Rodas [PHYS. REP. 969 (2022) 1] parametrisation ($I = 1/2$) reads

$$T^{\text{scat}}_{\pi K \to \pi K}(s) = \frac{1}{\cot\delta_0^{1/2}(s) - i} \qquad \cot\delta_0^{1/2}(s) = \frac{\sqrt{s}}{2q(s)(s - s_A)}\big(B_0 + B_1\omega(s)\big)$$

- Where q is the momentum from the $\lambda(M; m_1, m_2)$ function, s_A is the Adler zero (the amplitude limit for soft pion/kaon) and $\omega(s)$ is a conformal mapping
  - Numeric values for $\alpha, s_0, s_A, B_0, B_1$ from a constrained fit to scattering data
- Include an additional term that accounts for direct production of resonances in B-decay, besides the possible re-scattering after hadronisation

$$T(s) = P(s)\, S^{\text{scat}}_{\pi K - \pi K}(s) = P(s)\, \left(1 + i\, T^{\text{scat}}_{\pi K - \pi K}(s)\right)$$

- $P(s)$ unknown production function → use QMI approach and parametrise with complex polynomial of degree 4 with parameters $c_i^{\text{Abs}}, c_i^{\text{Arg}}$ determined from a fit to the data ($X(s)$ conformal mapping)

$$P(s) = \left(1 + c_1^{\text{Abs}}\, X(s) + c_2^{\text{Abs}}\, X^2(s) + \ldots\right)\, e^{i\left(c_1^{\text{Arg}}\, X(s) + c_2^{\text{Arg}}\, X^2(s) + \ldots\right)}$$

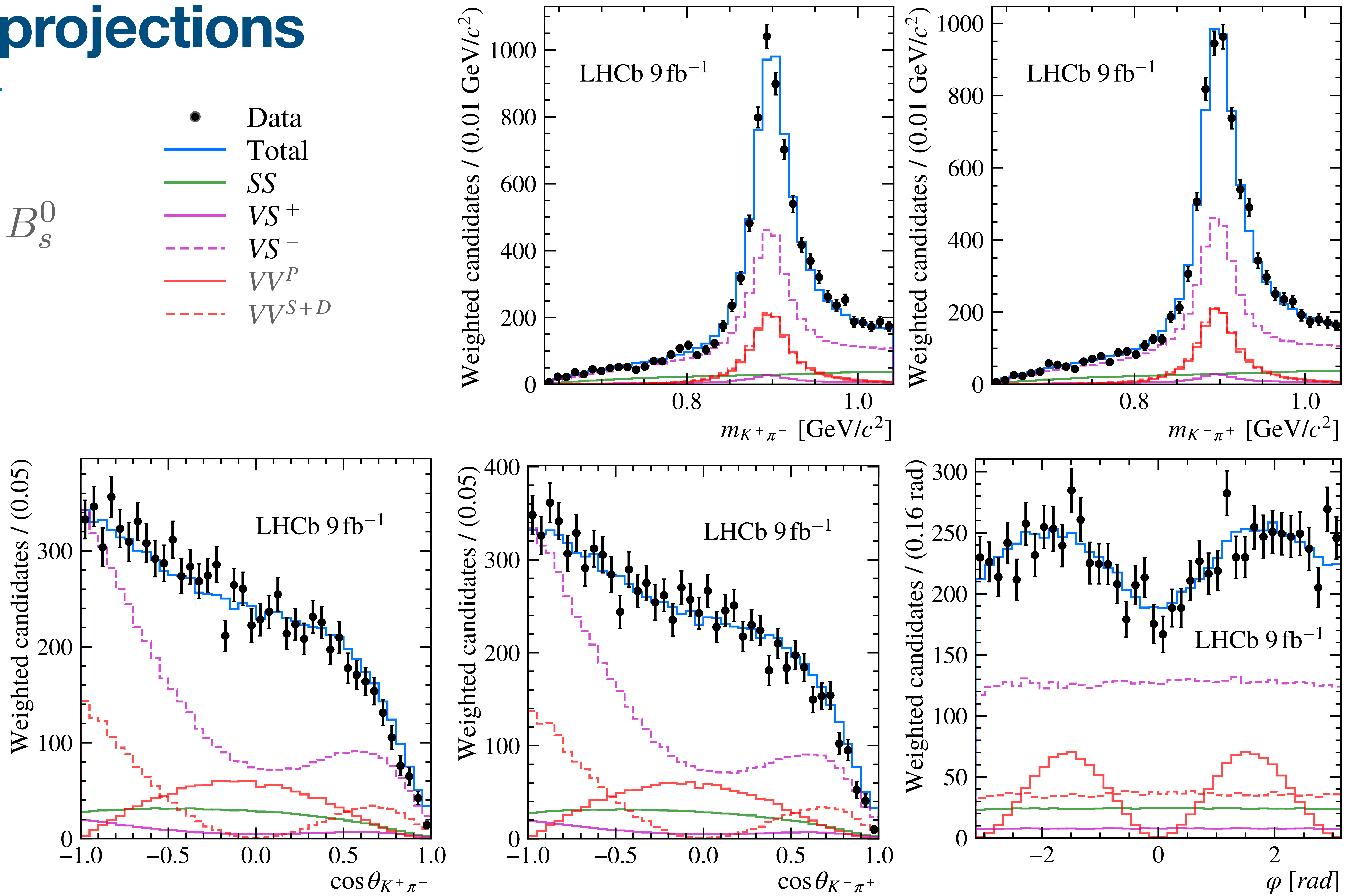
[Phys. Rev. D 113 (2026), 092002]

Angular fit projections

- $B \to SV$ and $B \to VS$ are not CP eigenstates. Rotate to:

$$|VS^{+}\rangle = \frac{1}{\sqrt{2}}\left(|VS\rangle + |SV\rangle\right) \, ,$$
$$|VS^{-}\rangle = \frac{1}{\sqrt{2}}\left(|VS\rangle - |SV\rangle\right) \, .$$

B_s^0



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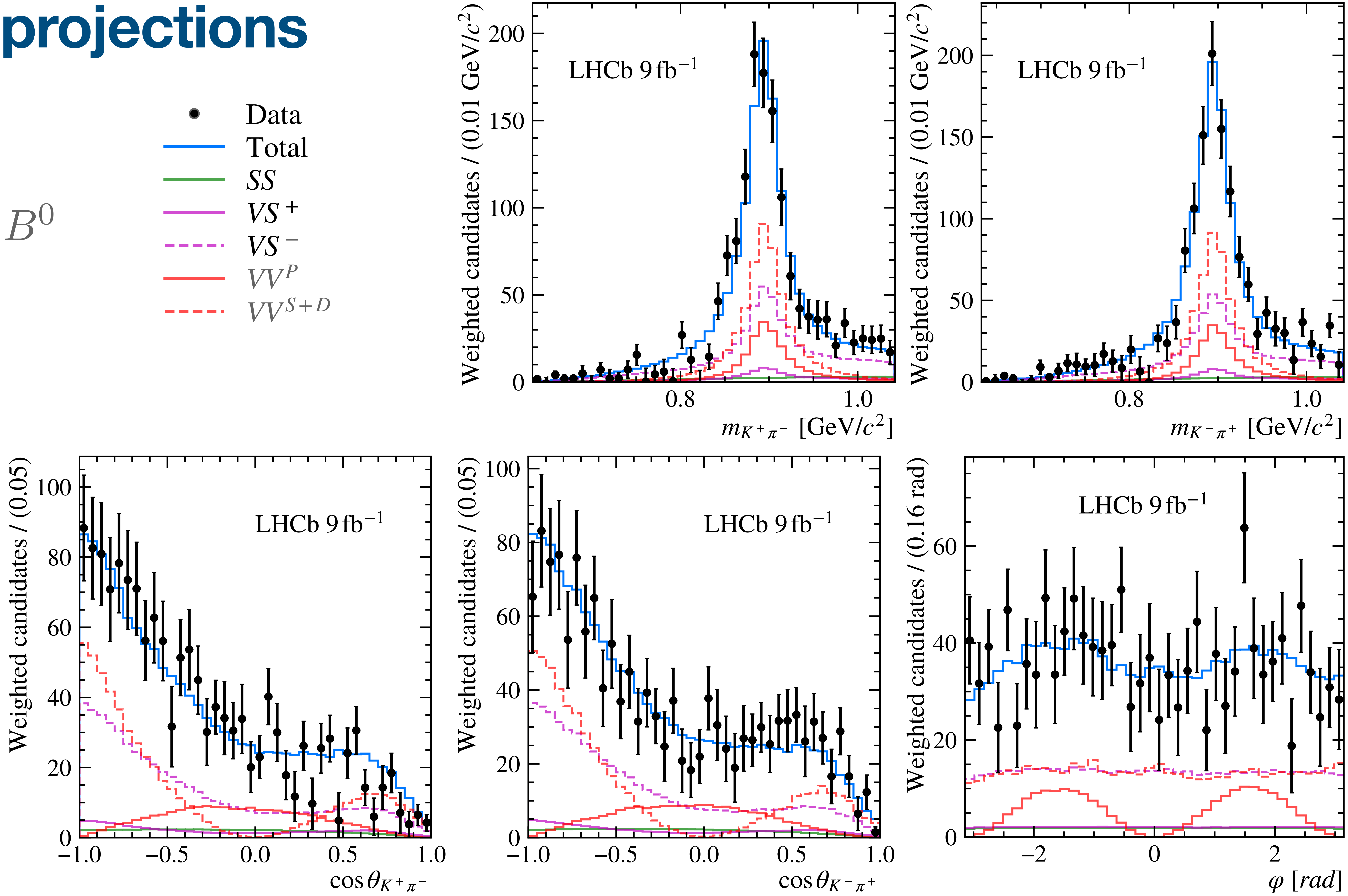

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Result recasting to helicity basis

- Measured quantities are CP-averaged fit fractions, and strong phase differences

$$\mathcal{F}_i \equiv \frac{\int_m [|a_i A_i(\Phi_4)|^2 + |a_i \bar{A}_i(\Phi_4)|^2] \ \mathrm{d}\Phi_4}{\int_m [|\sum_i a_i A_i(\Phi_4)|^2 + |\sum_i a_i \bar{A}_i(\Phi_4)|^2] \ \mathrm{d}\Phi_4}$$

	Parameter	Value	Parameter	Value
B^0	$\mathcal{F}_{VV}^{S+D}$ (%)	$37 \pm 2 \pm 2$	$\mathcal{F}_{VV}^{P}$ (%)	$14 \pm 1 \pm 0.7$
B_s^0	$\mathcal{F}_{VV}^{S+D}$ (%)	$15.6 \pm 0.63 \pm 0.26$	$\mathcal{F}_{VV}^{P}$ (%)	$15.55 \pm 0.56 \pm 0.38$

- To recast results in transversity basis generate pseudo-experiments from the fit result:
  - Fit back with angular amplitude in trasversity basis in 3D

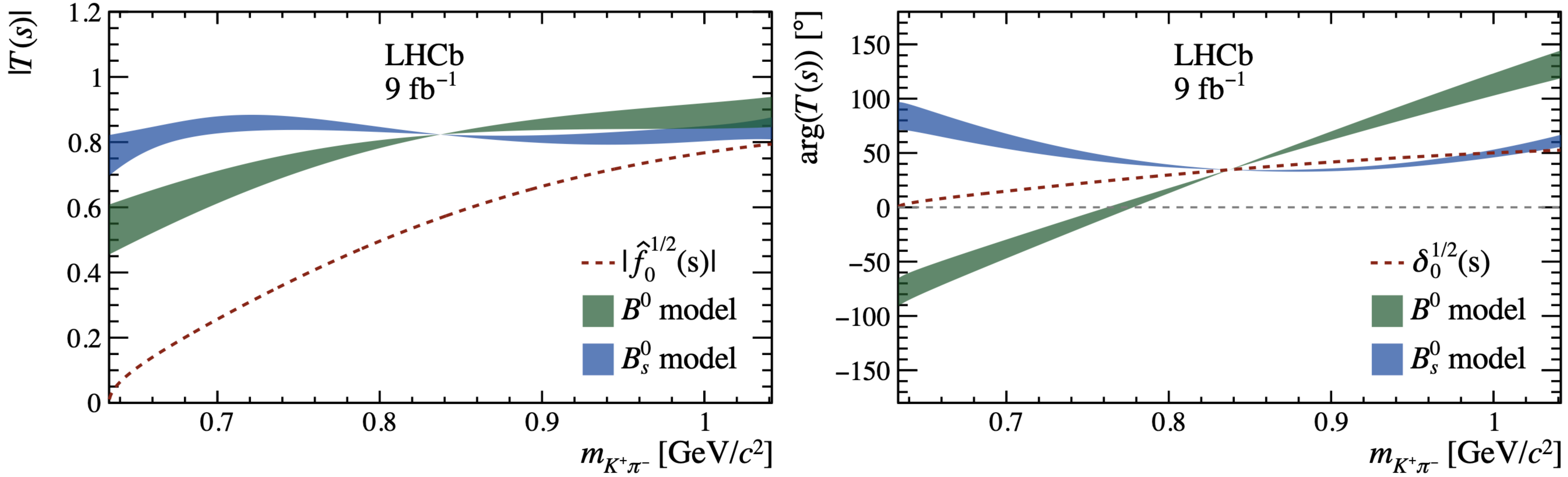
$$A_{V\overline{V}}(\theta_{K^+\pi^-}, \theta_{K^-\pi^+}, \varphi) \propto A_L \cos\theta_{K^+\pi^-} \cos\theta_{K^-\pi^+} + \frac{A_{\parallel}}{\sqrt{2}} \sin\theta_{K^+\pi^-} \sin\theta_{K^-\pi^+} \cos\varphi + \frac{A_{\perp}}{\sqrt{2}} \sin\theta_{K^+\pi^-} \sin\theta_{K^-\pi^+} \sin\varphi$$

- Only P-odd amplitudes are $A_{\perp}$ in helicity and A_P in covariant formalism: important cross check of consistency

[Phys. Rev. D 113 (2026), 092002]

Surfing the S-wave: results

- Run1 + Run2 result for the transition amplitude $T_{(K\pi)_S}(s)$ in $B^0_{(s)} \to (K^+\pi^-)(K^-\pi^+)$ decays



- Dashed curve is pure $I = 1/2$ scattering transition amplitude $T_{K\pi\to K\pi}(s)$
  - Clear departure from pure $I = 1/2$, deviation in magnitude showing impact of production amplitude
  - Watson's theorem: phase is the same for s, t and u diagrams, i.e. the phase of the re-scattering term is the same as the production term
    - Significant shift in $Arg(T(s))$ indicate that naive Watson's theorem might not be applicable here

[Phys. Rev. D 113 (2026), 092002]

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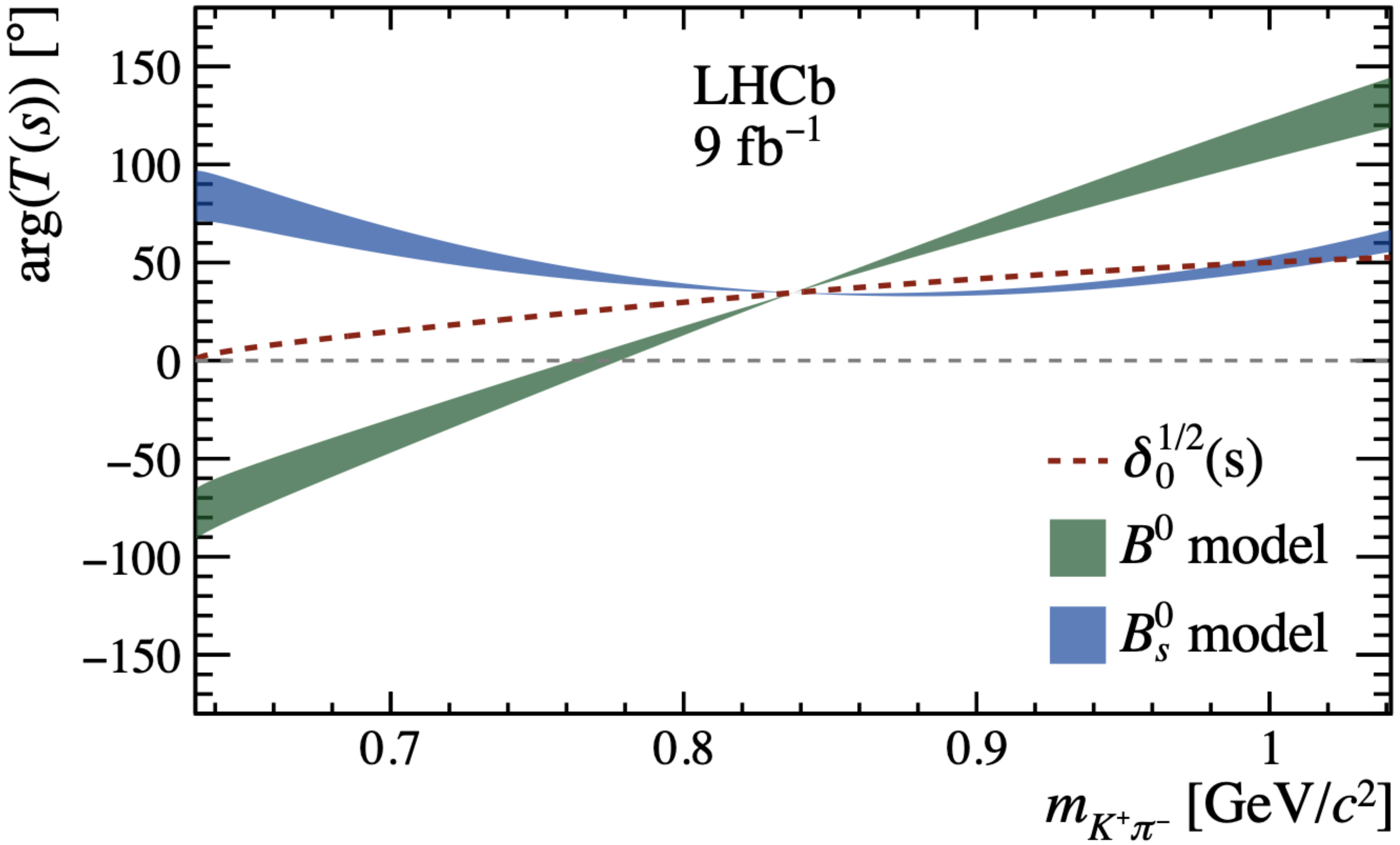
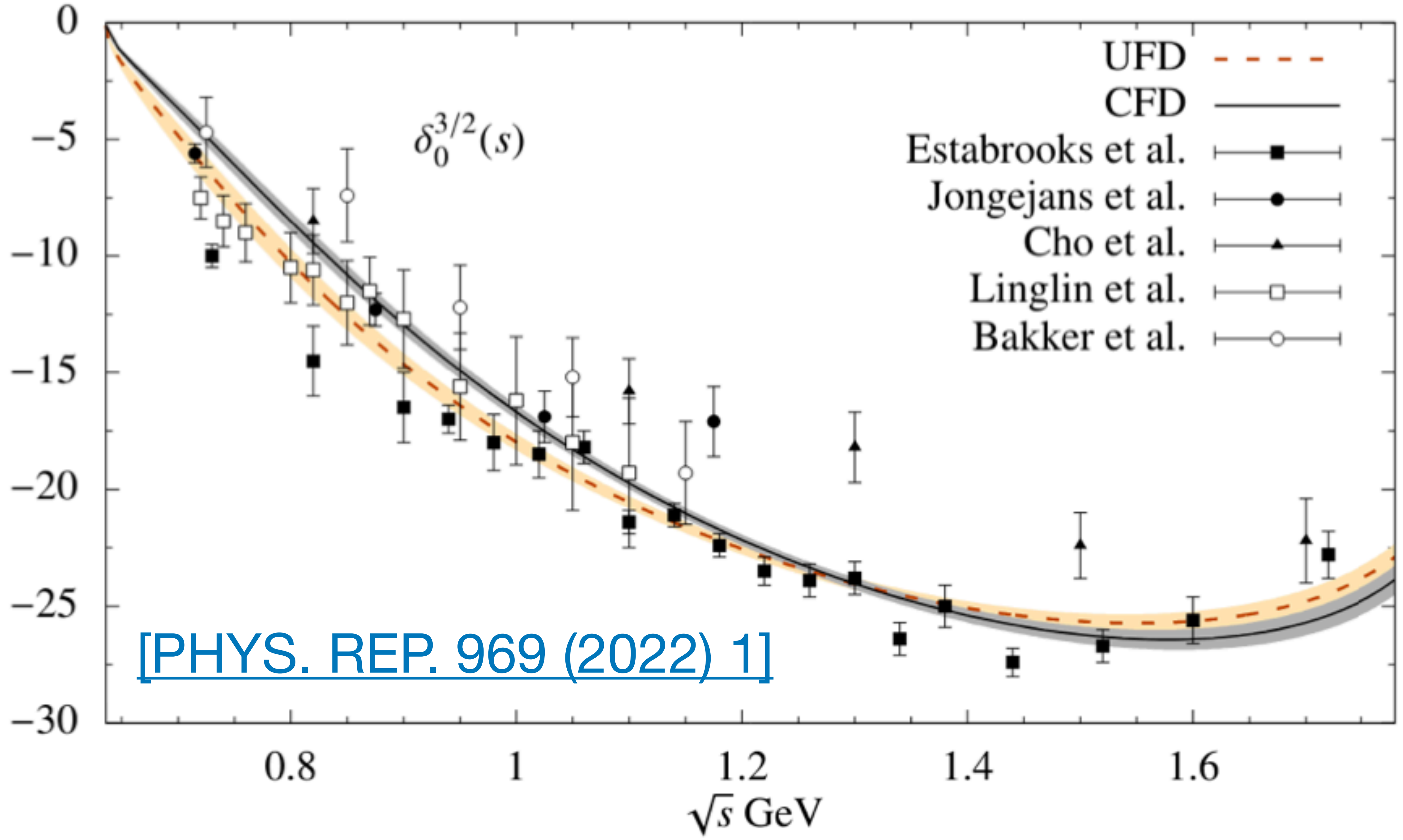
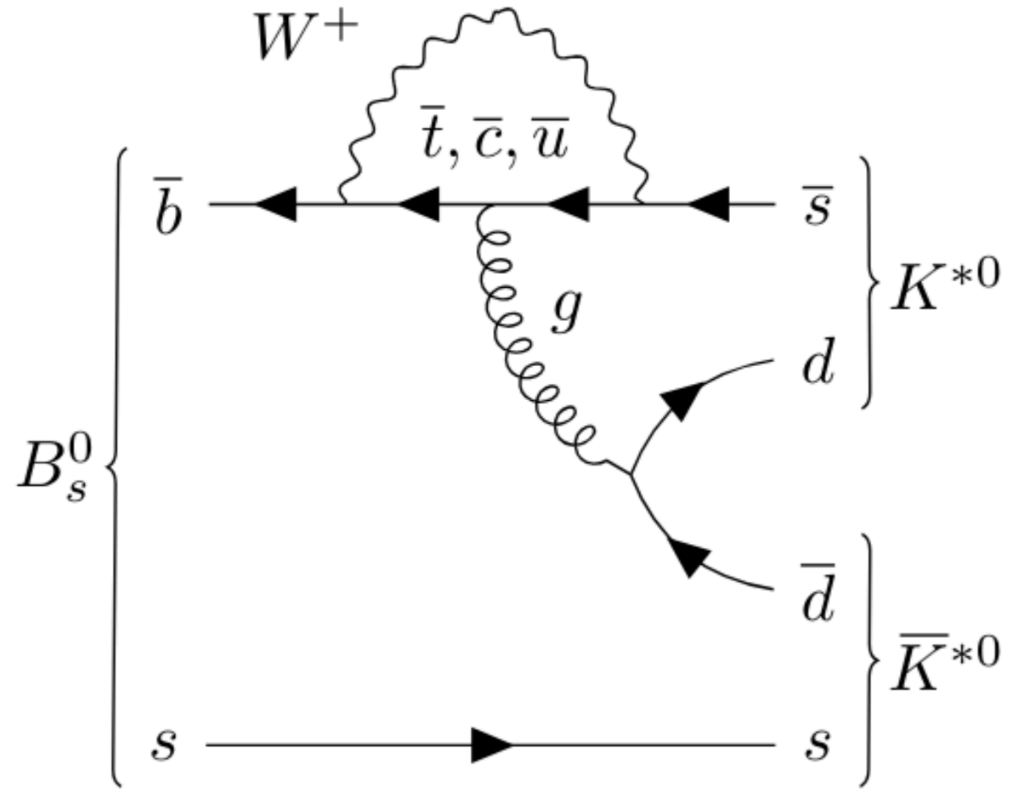




[PHYS. REP. 969 (2022) 1]

- Might indicate that S-wave in B_s^0 decays dominated by $I = 3/2$ amplitude
- While interference $I = 1/2$ between $I = 3/2$ could explain B^0 phase motion
- In untagged analysis $(K^+\pi^-)^0_S$ could come either from gluon loop or spectator interaction
  - Adding flavour tagging will allow to split the S-wave by production mechanism



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$B^0_{(s)} \to K^{*0}\bar{K}^{*0}$: results

- Most precise branching fractions measurements, improving over the PDG uncertainties a factor 5 for $B^0_s \to K^{*0}\bar{K}^{*0}$ and 4 for $B^0 \to K^{*0}\bar{K}^{*0}$
- $L_{K^{*0}\bar{K}^{*0}}$ in good agreement with previous exp value of $L_{K^{*0}\bar{K}^{*0}} = 4.43 \pm 0.92$

- Now f_L and L observables stat dominated
  - Different sources of syst uncert leading for B^0 (background model) and B_s (signal model)
- Tension with SM+QCDf persists number of σ though depend on SM FF assumptions

$$f_L^{B^0_s} = 0.159 \pm 0.010(\mathrm{stat}) \pm 0.007(\mathrm{syst})$$

$$f_L^{B^0} = 0.600 \pm 0.022(\mathrm{stat}) \pm 0.017(\mathrm{syst})$$

$$\mathcal{B}(B^0_s \to K^{*0}\bar{K}^{*0}) = (0.932 \pm 0.025\,(\mathrm{stat}) \pm 0.018\,(\mathrm{syst}) \pm 0.036\,(\mathrm{ext})) \times 10^{-5},$$

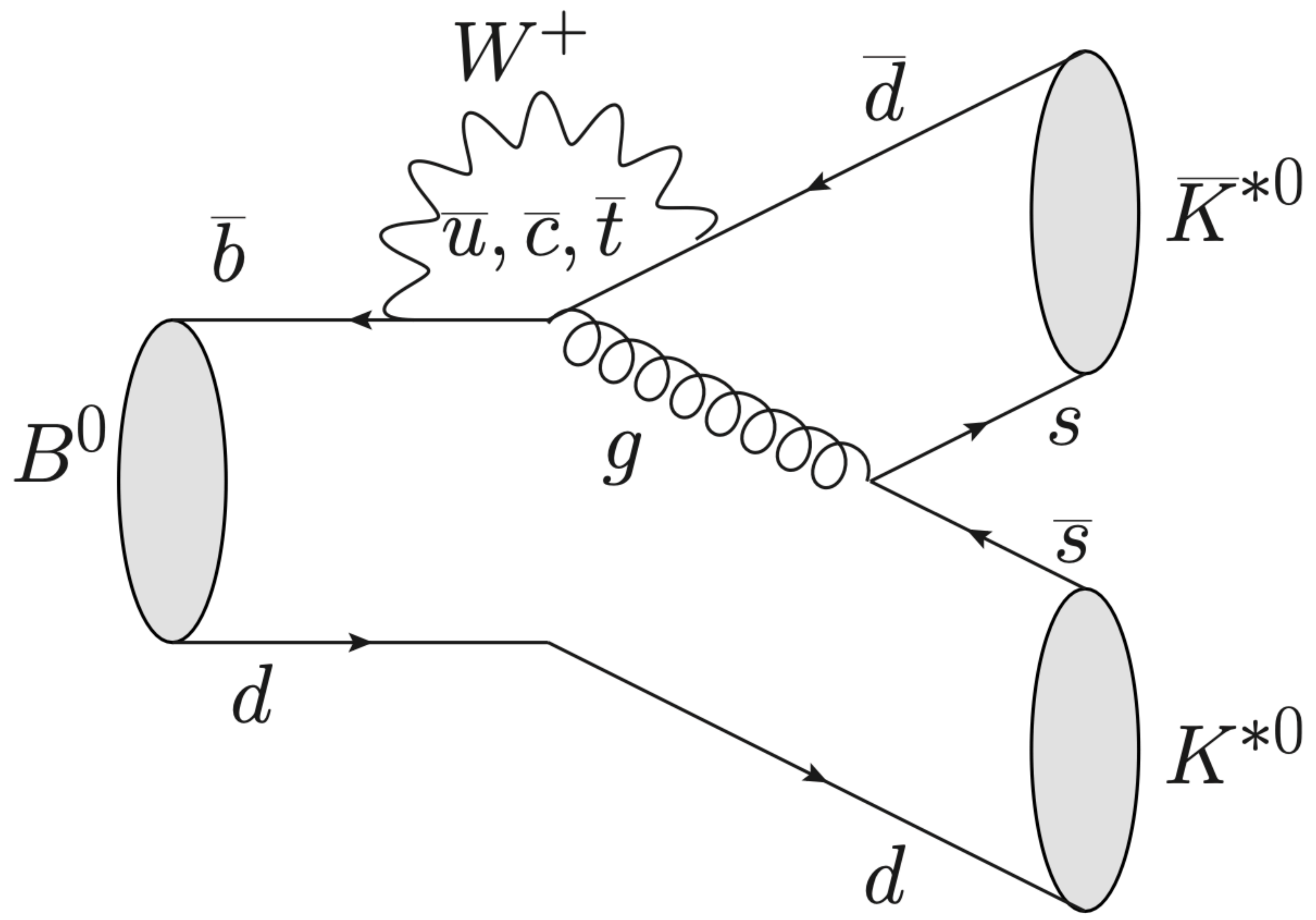
$$\mathcal{B}(B^0 \to K^{*0}\bar{K}^{*0}) = (4.69 \pm 0.29\,(\mathrm{stat}) \pm 0.43\,(\mathrm{syst}) \pm 0.16\,(\mathrm{ext})) \times 10^{-7},$$

$$L_{K^{*0}\bar{K}^{*0}} = 4.92 \pm 0.55\,(\mathrm{stat}) \pm 0.47\,(\mathrm{syst}) \pm 0.02\,(\mathrm{ext}) \pm 0.10\,(f_s/f_d).$$

$L^{II,\mathrm{SM}}_{K^*\bar{K}^*} = 26.08^{+5.70}_{-4.72}$. $L^{III,\mathrm{SM}}_{K^*\bar{K}^*} = 22.88^{+15.35}_{-8.46}$. [JHEP 09 (2025) 188]

$B^0_{(s)} \to K^{*0}\bar{K}^{*0}$: Run 3 prospects

- Experimentally, the branching fractions and angular observables in $B^0_{(s)} \to K^{*0}\bar{K}^{*0}$ are far more precise than their SM prediction
  - Nonetheless the Run3 update of those observables is ongoing
  - Expect to reduce systematic uncertainties related to limited simulated sample size
  - Thorough studies to understand the abundant new data collected in Run3



- This will lay the groundwork for a future update of ϕ_s measurement using $b \to sd\bar{d}$ transitions
  - TD + FT performances are crucial ingredients

Prospects for L_{total} measurement in Run 3

L observables from $B \to PV$ decays

- Among the observables proposed in [JHEP 09 (2025) 188] the L ratios of $B_{d/s} \to K^0 K^*(892)^0$ decays have no experimental determination.

  - The BF of the suppressed $B_d \to K^0 K^*(892)^0$ has never been measured

$$L_{\text{total}} = \rho(m_{K^0}, m_{K^{*0}}) \left(\frac{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^0) + \mathcal{B}(\bar{B}_s \to K^0\bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \to \bar{K}^{*0}K^0) + \mathcal{B}(\bar{B}_d \to \bar{K}^0 K^{*0})} \right)$$

$$L_{\text{total}}^{I,\,\text{SM}} = 22.69^{+5.32}_{-5.32}\,, \qquad L_{\text{total}}^{II,\,\text{SM}} = 21.38^{+3.18}_{-3.06}\,, \qquad L_{\text{total}}^{III,\,\text{SM}} = 19.55^{+4.83}_{-4.53}\,.$$

  - Different form factor treatment yields different SM predictions and uncertainties (I - LCSR only, II combined analysis including LCSR and lattice, III lattice only)

    - For L^{III} observables relying only on $B_{d,s} \to K^*$ FF, II and III are in greater disagreement since $B_{d,s} \to K^*$ lattice FF determinations have large uncertainties and are only available at high q^2

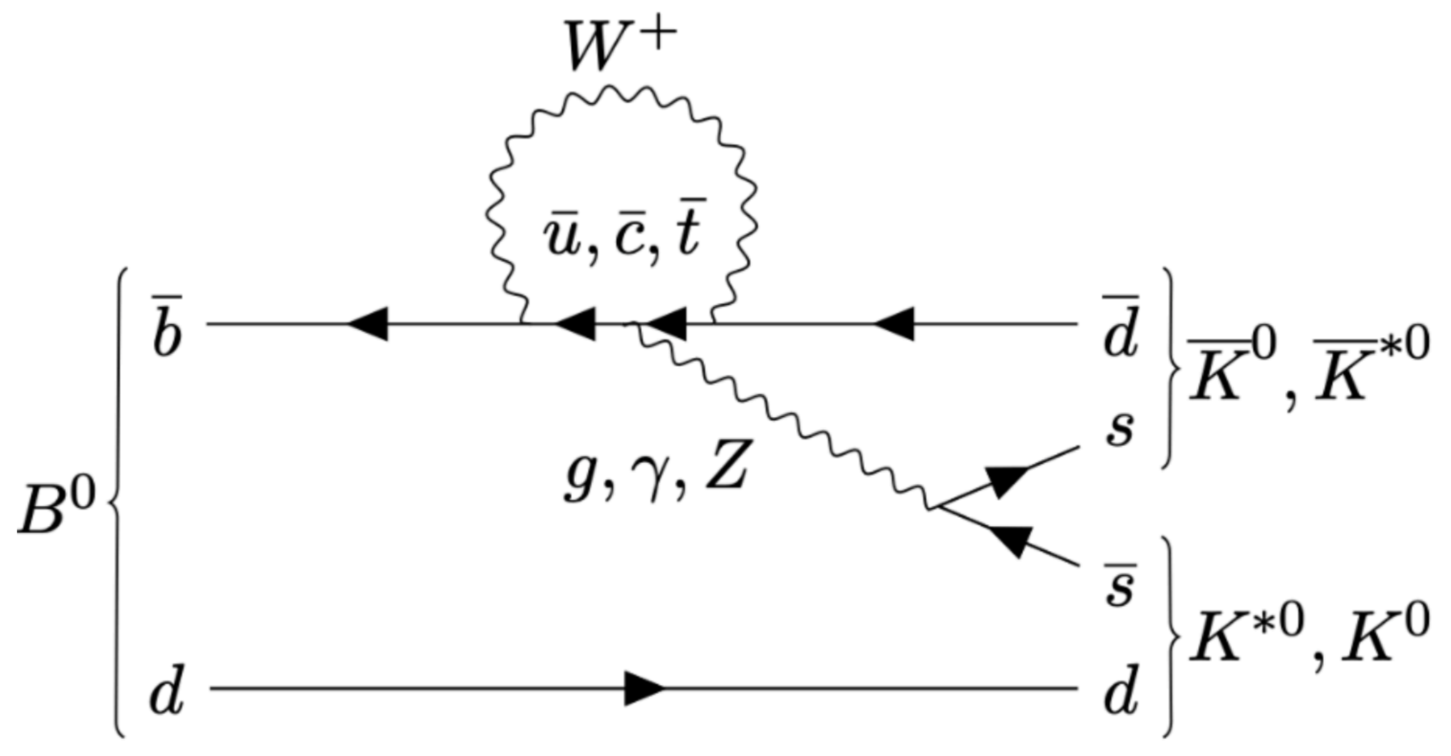
    - For L^{tot} where both $B_{d,s} \to K^*$ and $B_{d,s} \to K$ contribute the II - III disagreement is lower

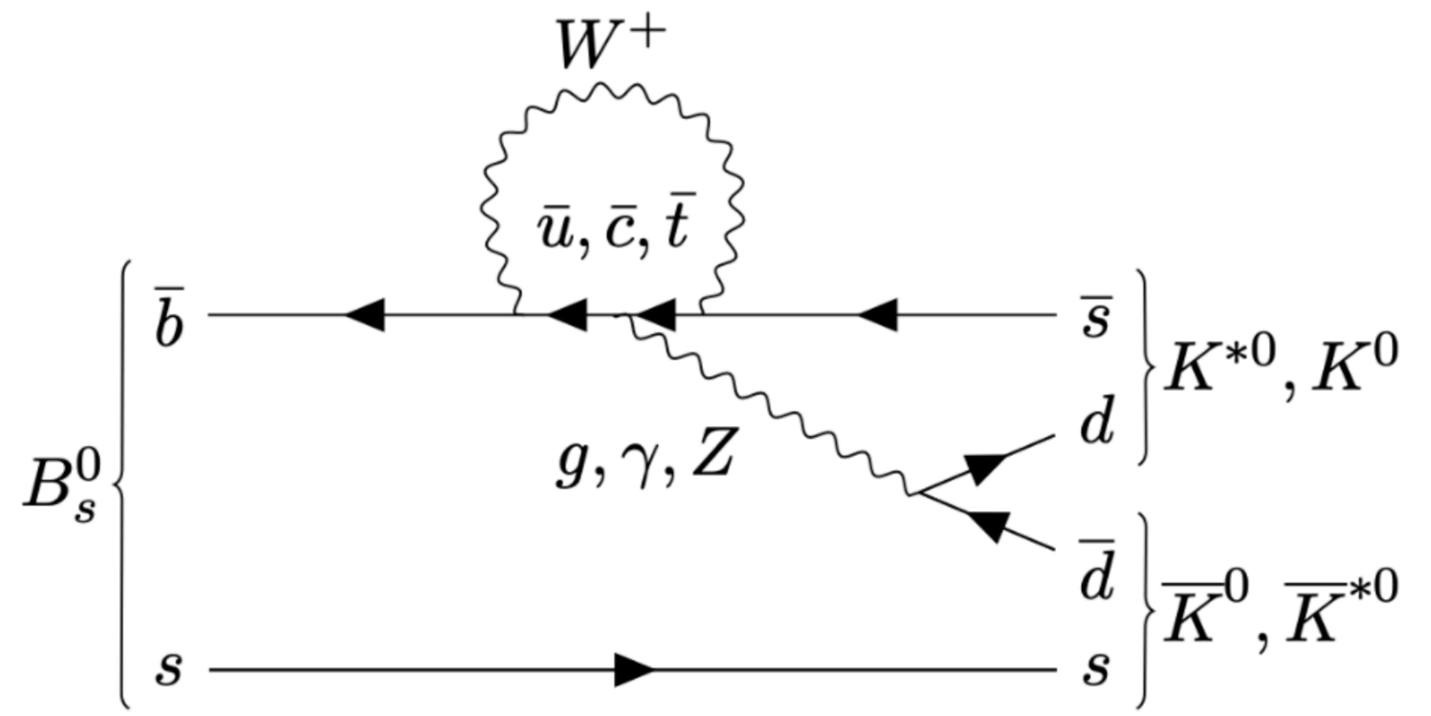
Several L

[JHEP 09 (2025) 188]

- Different L observables built with $B \to PV$ decays depending on which final state meson picks up the spectator quark have different NP sensitivity. (L_h stands for h picks up the spectator quark)

- Even though the final state is not CP symmetric, the decay is not self-tagged. As opposed to $B_{d/s} \to \bar{K}^* K^*$ FT alone will not tell you which meson picked up the spectator quark





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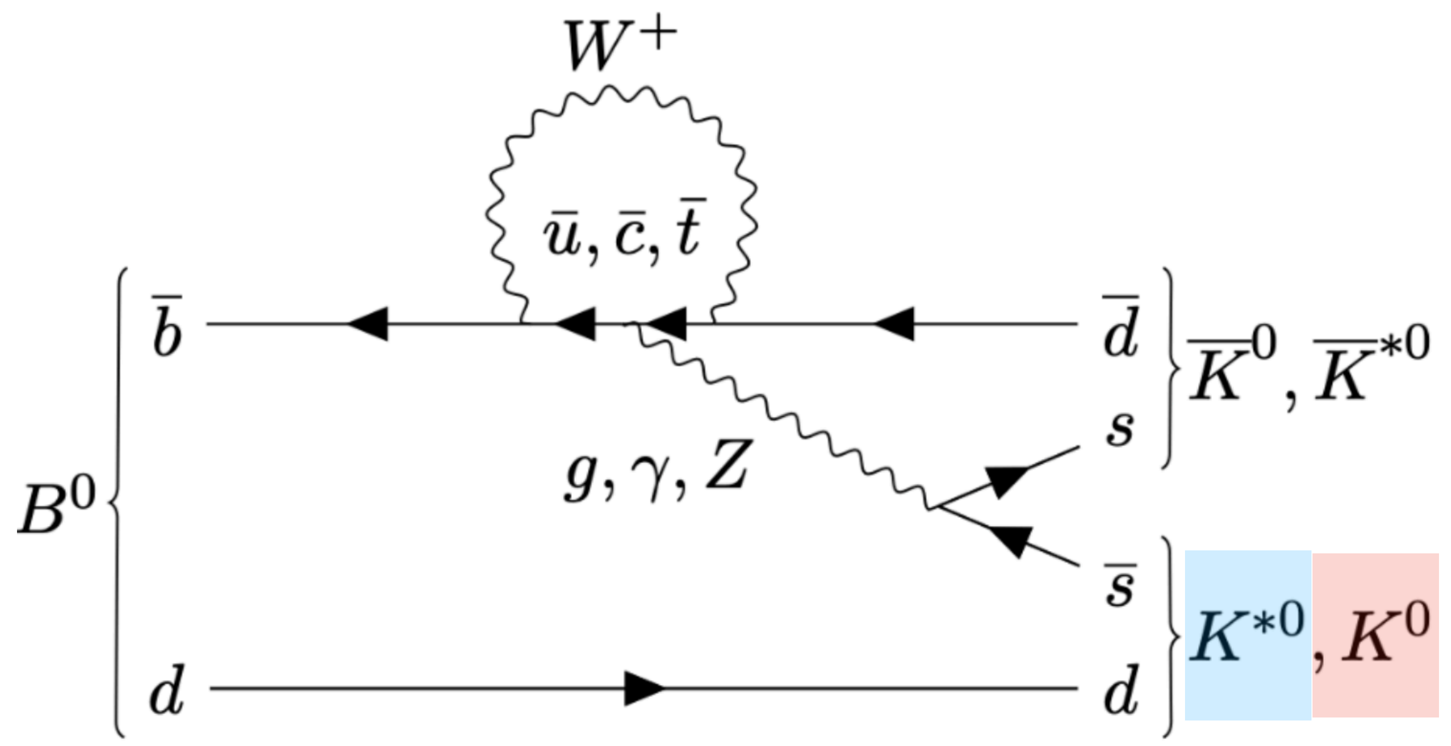
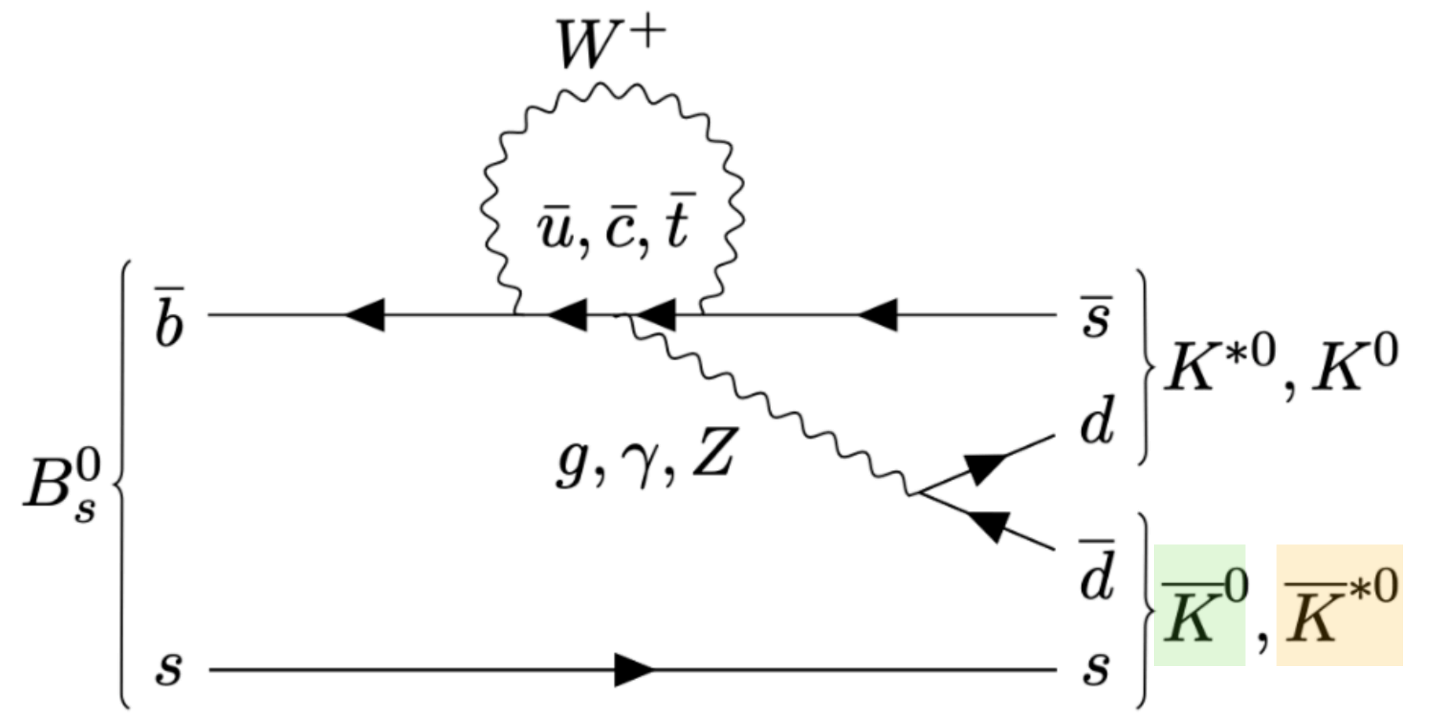
Need FT+TD analysis on both $B_{d/s}$
unlikely with dataset collected until now





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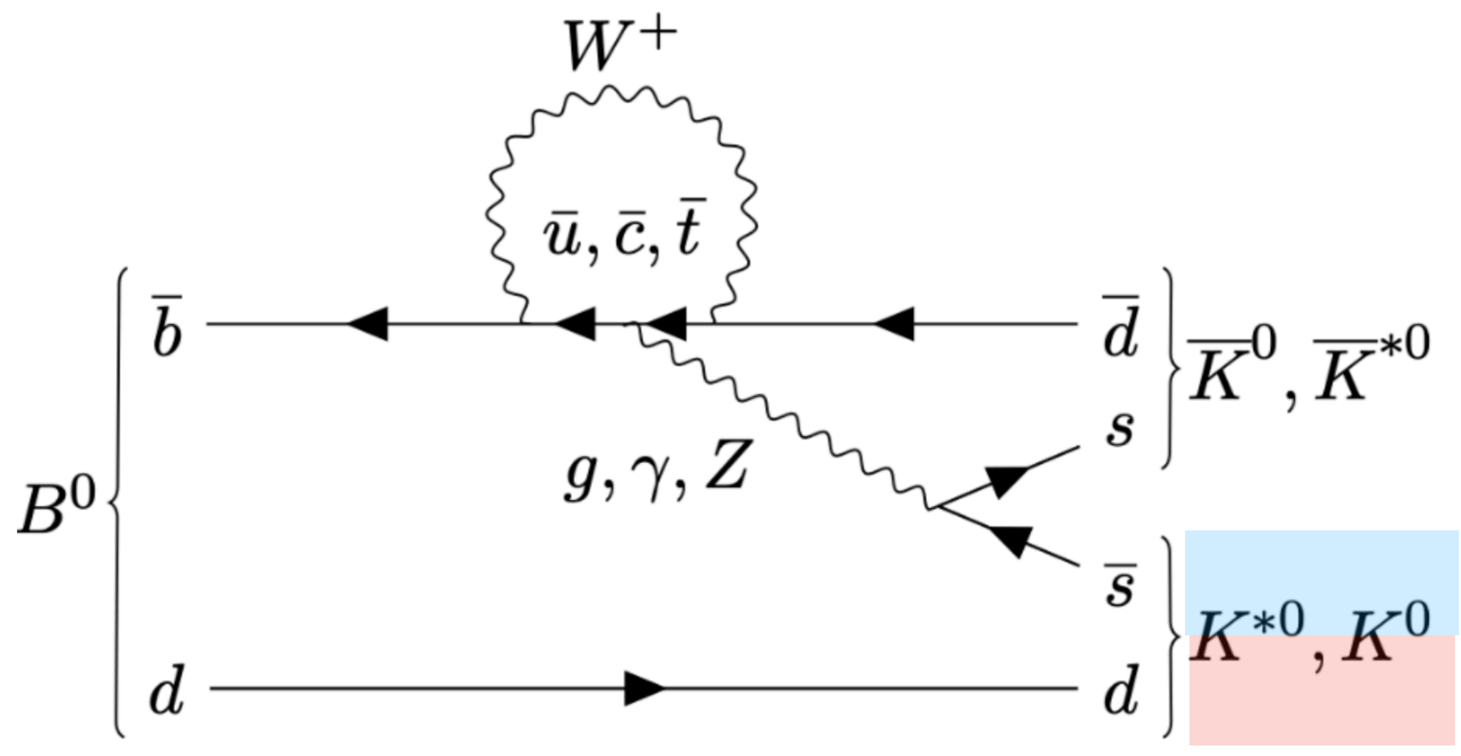
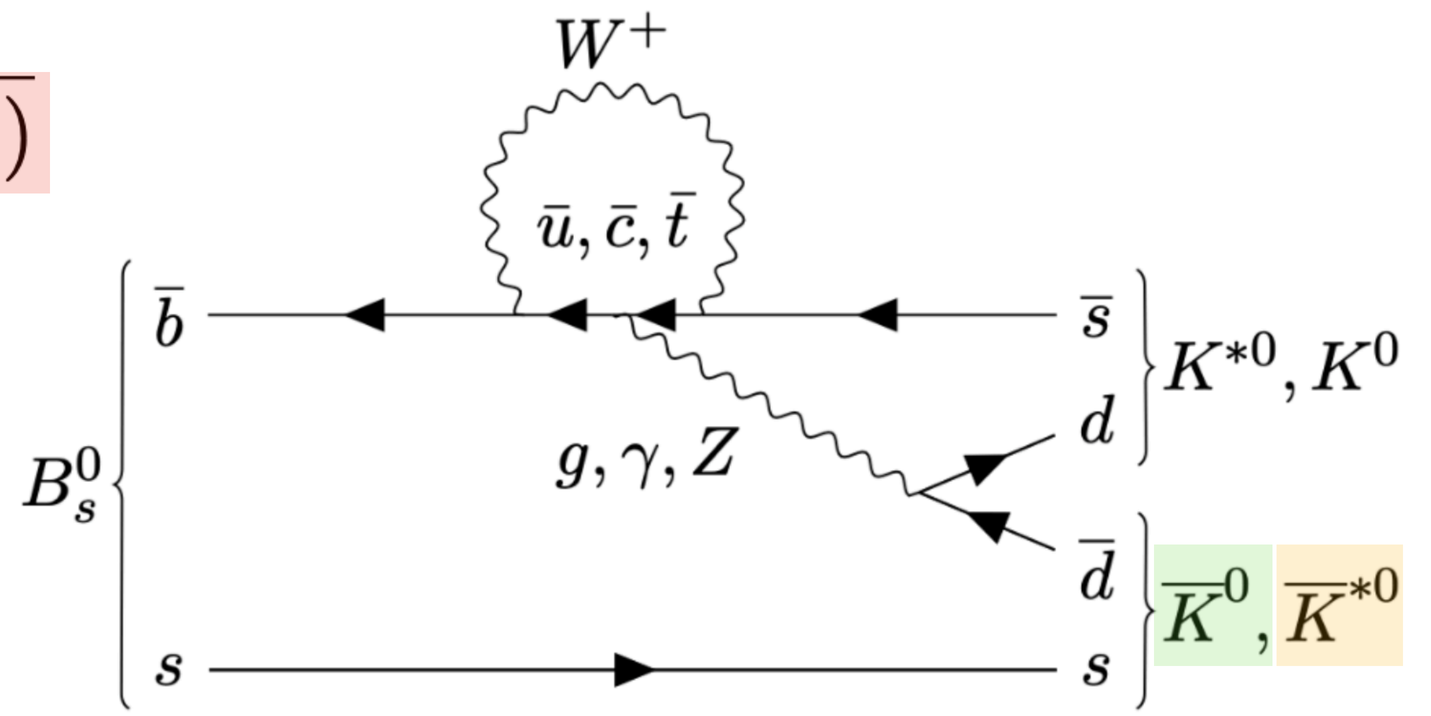
$$L_{K^*} \propto \frac{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^0)}{\mathcal{B}(\bar{B}_d \to \bar{K}^{*0}K^0) + \mathcal{B}(\bar{B}_d \to \bar{K}^0K^{*0})} \qquad L_K \propto \frac{\mathcal{B}(\bar{B}_s \to K^0\bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \to \bar{K}^{*0}K^0) + \mathcal{B}(\bar{B}_d \to \bar{K}^0K^{*0})}$$

Need FT+TD analysis on denominator, but fast B_s oscillations would heavily impact exp. sensitivity





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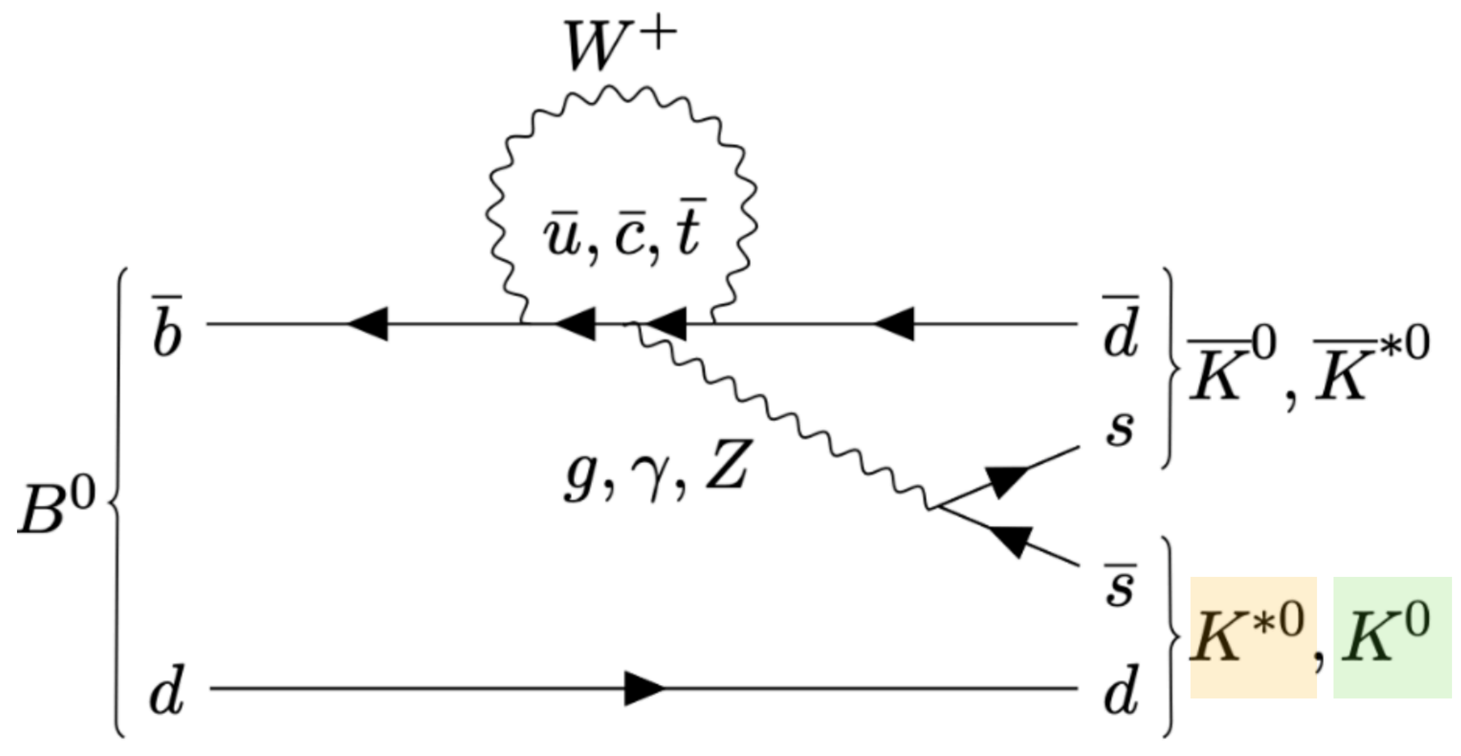
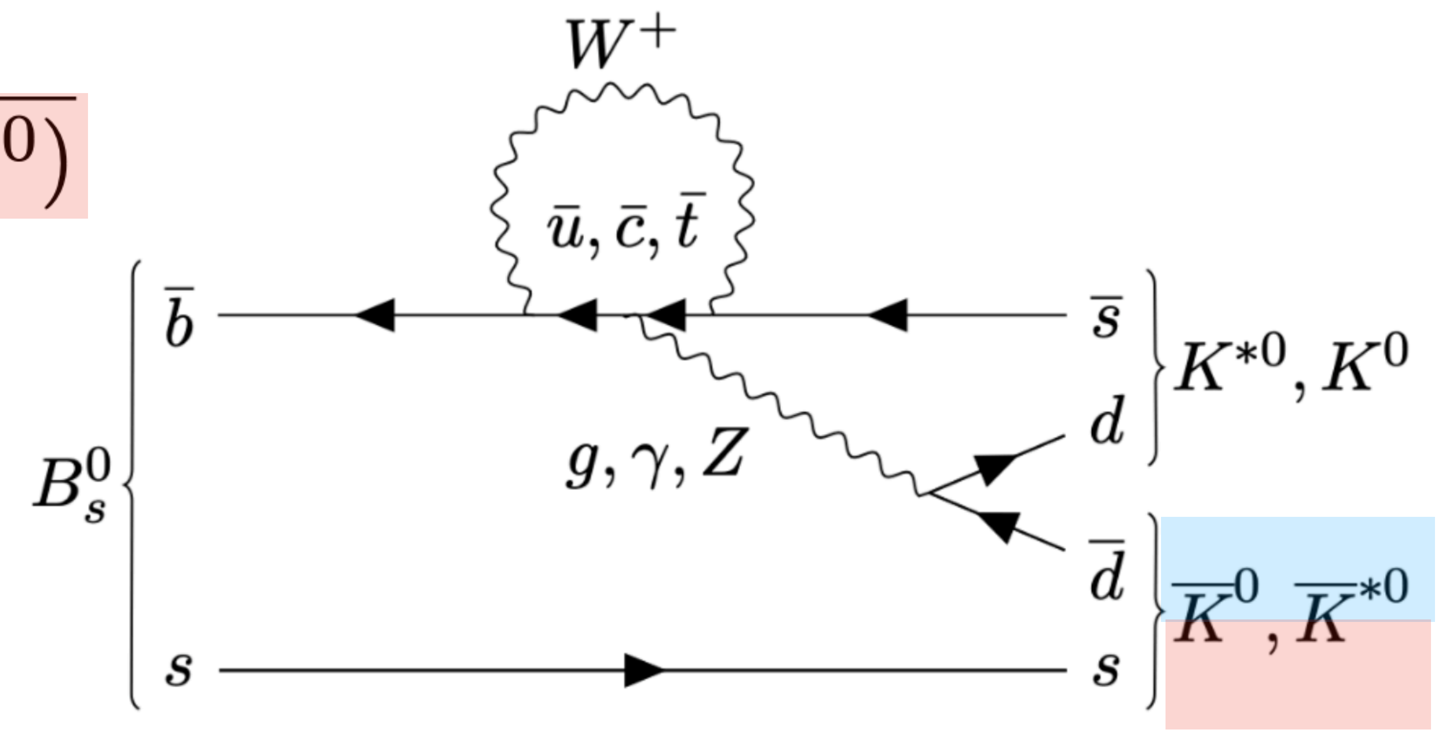
$$\tilde{L}_{K^*} \propto \frac{\mathcal{B}(\bar{B}_d \to \bar{K}^{*0}K^0)}{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^0) + \mathcal{B}(\bar{B}_s \to K^0\bar{K}^{*0})} \qquad \tilde{L}_K \propto \frac{\mathcal{B}(\bar{B}_d \to \bar{K}^0 K^{*0})}{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^0) + \mathcal{B}(\bar{B}_s \to K^0\bar{K}^{*0})}$$

Single out the B_d at numerator to reduce impact of oscillations. FT+TD analysis still needed, Run 3 possible ?





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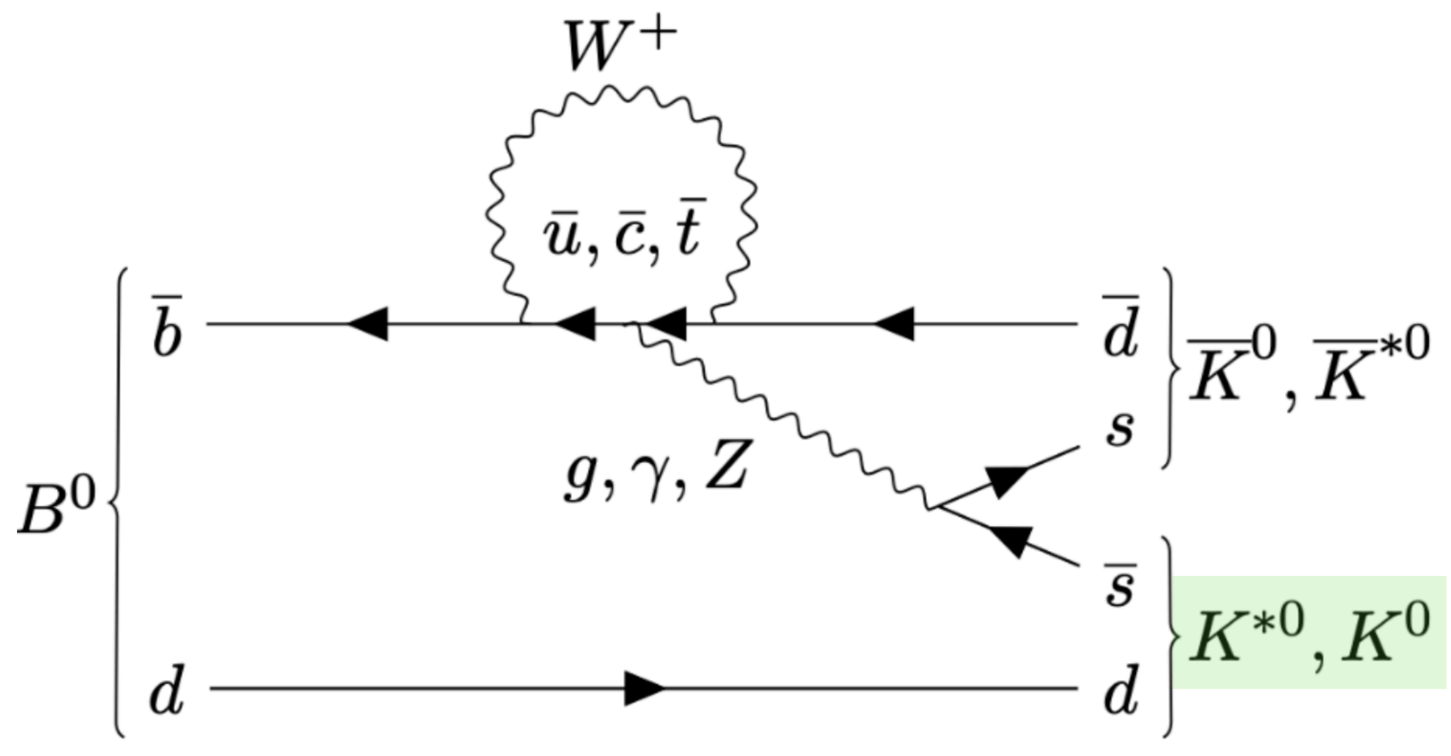
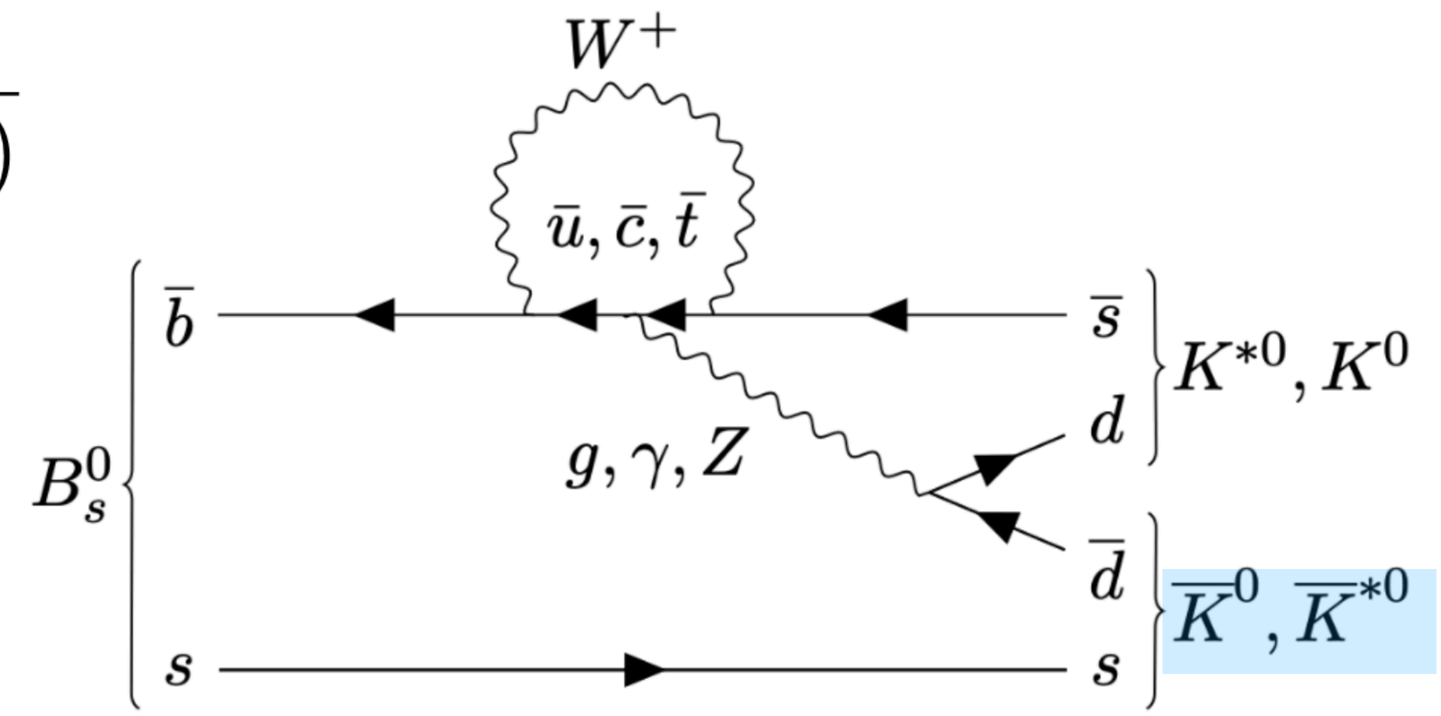
$$L_{\text{total}} \propto \left(\frac{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^0) + \mathcal{B}(\bar{B}_s \to K^0\bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \to \bar{K}^{*0}K^0) + \mathcal{B}(\bar{B}_d \to \bar{K}^0 K^{*0})}\right)$$

Easiest and first stepping stone for this class of observables + would be first measurement of B_d mode



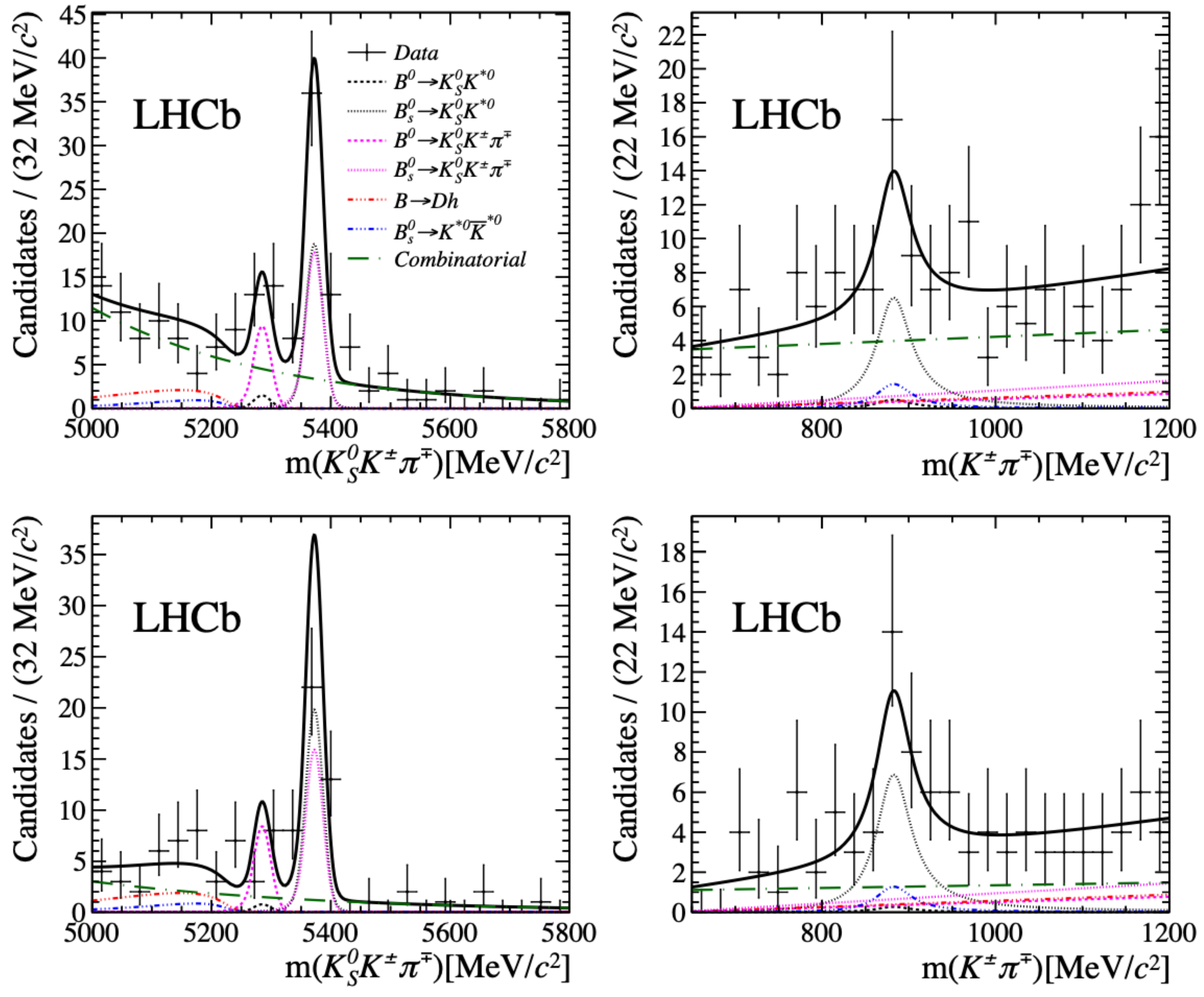


Related LHCb results

- Measurement of the untagged branching $B_s \to K_S K^*(892)$ ratio using 1 fb^{-1}

  - First observation of the B_s mode and upper limit on the B_d mode, used $B_s \to K_S \pi\pi$ as control mode

[JHEP01(2016)012]

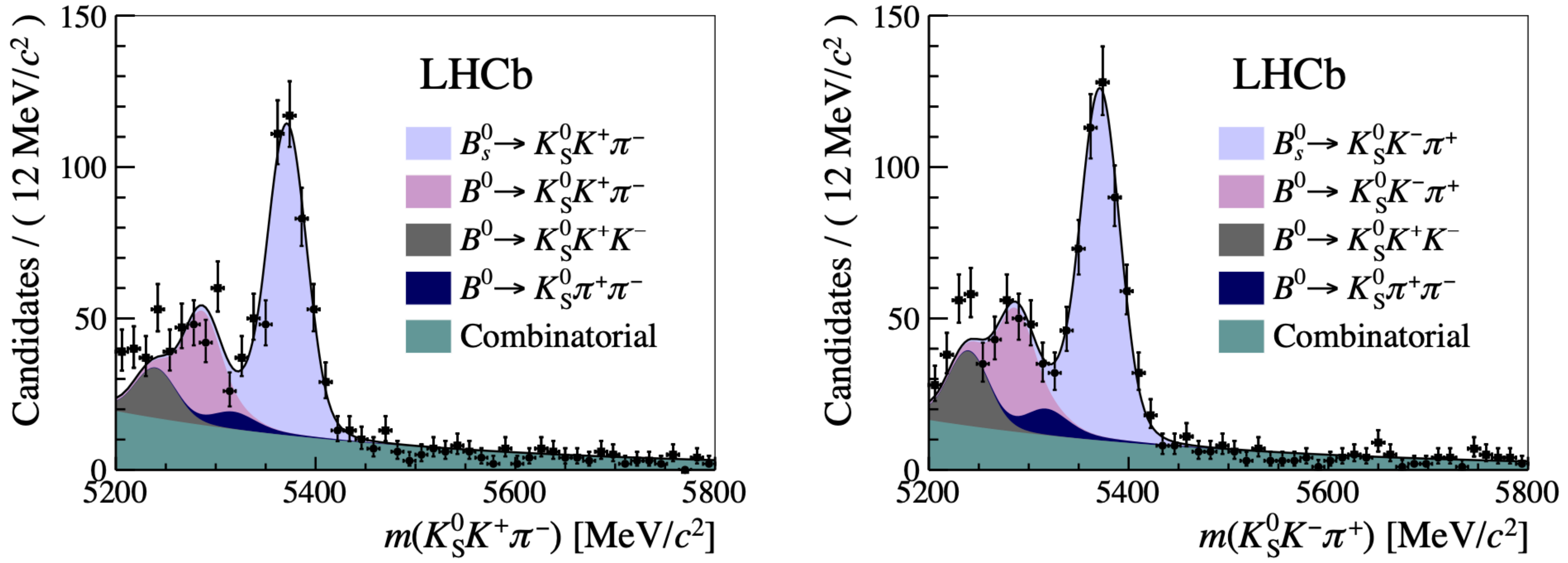


$$\mathcal{B}(B_s^0 \to \bar{K}^0 K^*(892)^0) + \mathcal{B}(B_s^0 \to K^0 \bar{K}^*(892)^0) = (16.4 \pm 3.4 \pm 1.9 \pm 1.0 \pm 0.7) \times 10^{-6},$$
$$\mathcal{B}(B^0 \to \bar{K}^0 K^*(892)^0) + \mathcal{B}(B^0 \to K^0 \bar{K}^*(892)^0) = (0.25 \pm 0.34 \pm 0.05 \pm 0.01) \times 10^{-6},$$
$$< 0.96\ (1.04) \times 10^{-6} \text{ at } 90\%\ (95\%) \text{ CL},$$

- Amplitude analysis of $B_{d/s} \to K_S K \pi$ using Run1 data

  - Untagged decay-time-integrated amplitude analysis that determined among other resonant states the BF of the unsuppressed mode:

[JHEP06(2019)114]



$$\mathcal{B}\left(B_s^0 \to \overset{(-)}{K}{}^*(892)^0\, \overset{(-)}{K}{}^0;\ \overset{(-)}{K}{}^*(892)^0 \to K^\mp \pi^\pm\right) = (13.2 \pm 1.9 \pm 0.8 \pm 2.9 \pm 1.4) \times 10^{-6},$$
$$\mathcal{B}\left(B_s^0 \to (K^\mp \pi^\pm)^*_0\, \overset{(-)}{K}{}^0\right) = (26.2 \pm 2.0 \pm 0.7 \pm 7.3 \pm 2.8) \times 10^{-6},$$

- total Kπ S-wave that is modelled by the LASS lineshape.

Toy setup - generation numbers

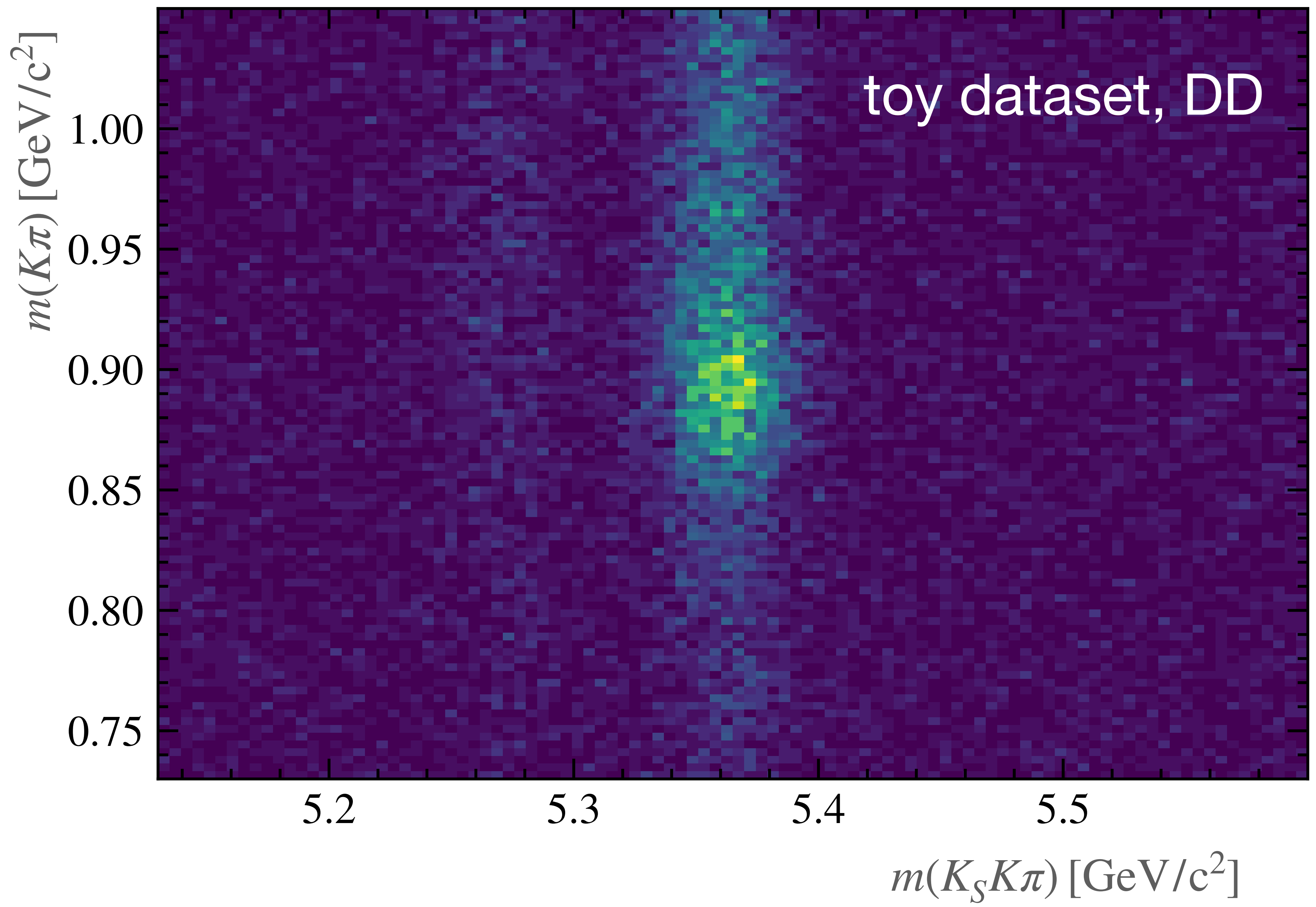
- Generate toy dataset using:
  - $|A_0^{d,s}|^2$ from Run1 analysis, $L_{K_S K^*}^{tot} = 25$ inspired by theory prediction
  - $N(B_s)$ from luminosity scaling + ratios of branching fractions from [JHEP01(2016)012] and [LHCb-PAPER-2024-029]
  - Assume hardware trigger removal leads to 1.5x increase in efficiency

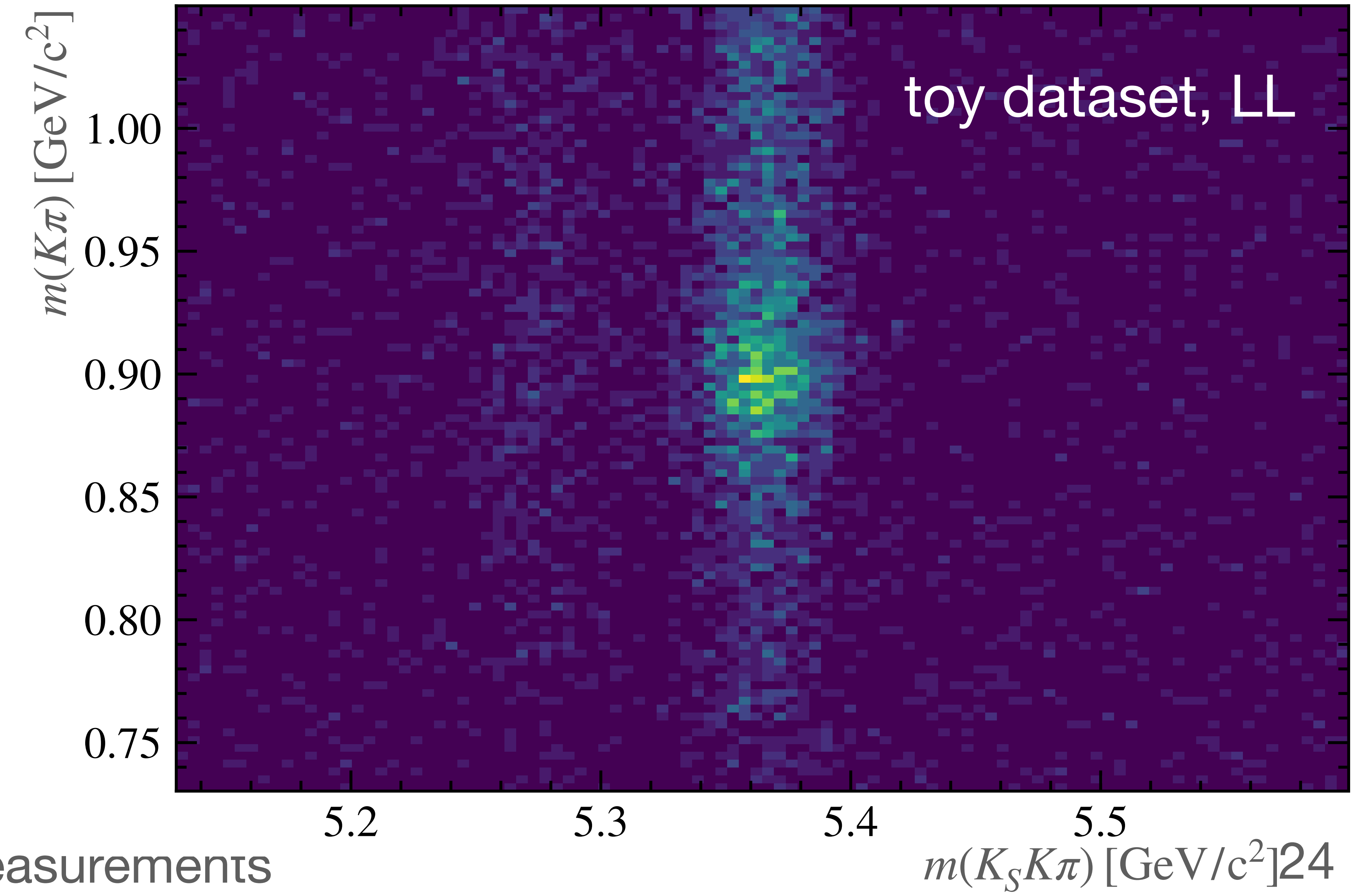
$$N_{\rm DD}(B_s) \sim 7000,\ N_{\rm LL}(B_s) \sim 3000$$

  - Signal fraction is kept at 0.6 (0.8) for DD (LL) categories, background is combinatorial (exp) in both mass dimensions

- Convolve generated mass peaks with gaussian core to include resolution effects
- S-wave parametrised by LASS with parameters from Nucl. Phys. B296 (1988) 493.

	$(K\pi)_0^{*0}$ $J=0$
$m_J(\mathrm{MeV}/c^2)$	$1435 \pm 5 \pm 5$
$\Gamma_J(\mathrm{MeV}/c^2)$	$279 \pm 6 \pm 21$
$r(\mathrm{GeV}^{-1})$	...
$a(\mathrm{GeV}^{-1})$	$1.95 \pm 0.09 \pm 0.06$
$b(\mathrm{GeV}^{-1})$	$1.76 \pm 0.36 \pm 0.67$





L_{total} observable extraction strategy

- The differential decay width of $B_{d/s} \to K^0 K^*(\to K\pi)$ is parametrised in terms of the angle $\cos\theta_K$ and the K^* invariant mass $m_{K\pi}$ as:

$$\frac{d\Gamma}{d\cos(\theta_K) dm_{K\pi}} \propto |A_S|^2 |T_S(m_{K\pi})|^2 + 3|A_0|^2 \cos^2\theta_K |T_0(m_{K\pi})|^2$$
$$-2\sqrt{3}\cos\theta_k |A_S||A_0| \,\mathrm{Re}\left[\exp i\delta \cdot T_S(m_{K\pi}) T_0^*(m_{K\pi})\right]$$

- Where the A_0, A_S are the amplitudes for the P-wave and S-wave component respectively and $T_S(m_{K\pi}), T_0(m_{K\pi})$ are the corresponding line shapes. Integrating out the angular dependence one simply has:

$$\frac{d\Gamma}{dm_{K\pi}} \propto |A_S|^2 |T_S(m_{K\pi})|^2 + |A_0|^2 |T_0(m_{K\pi})|^2$$

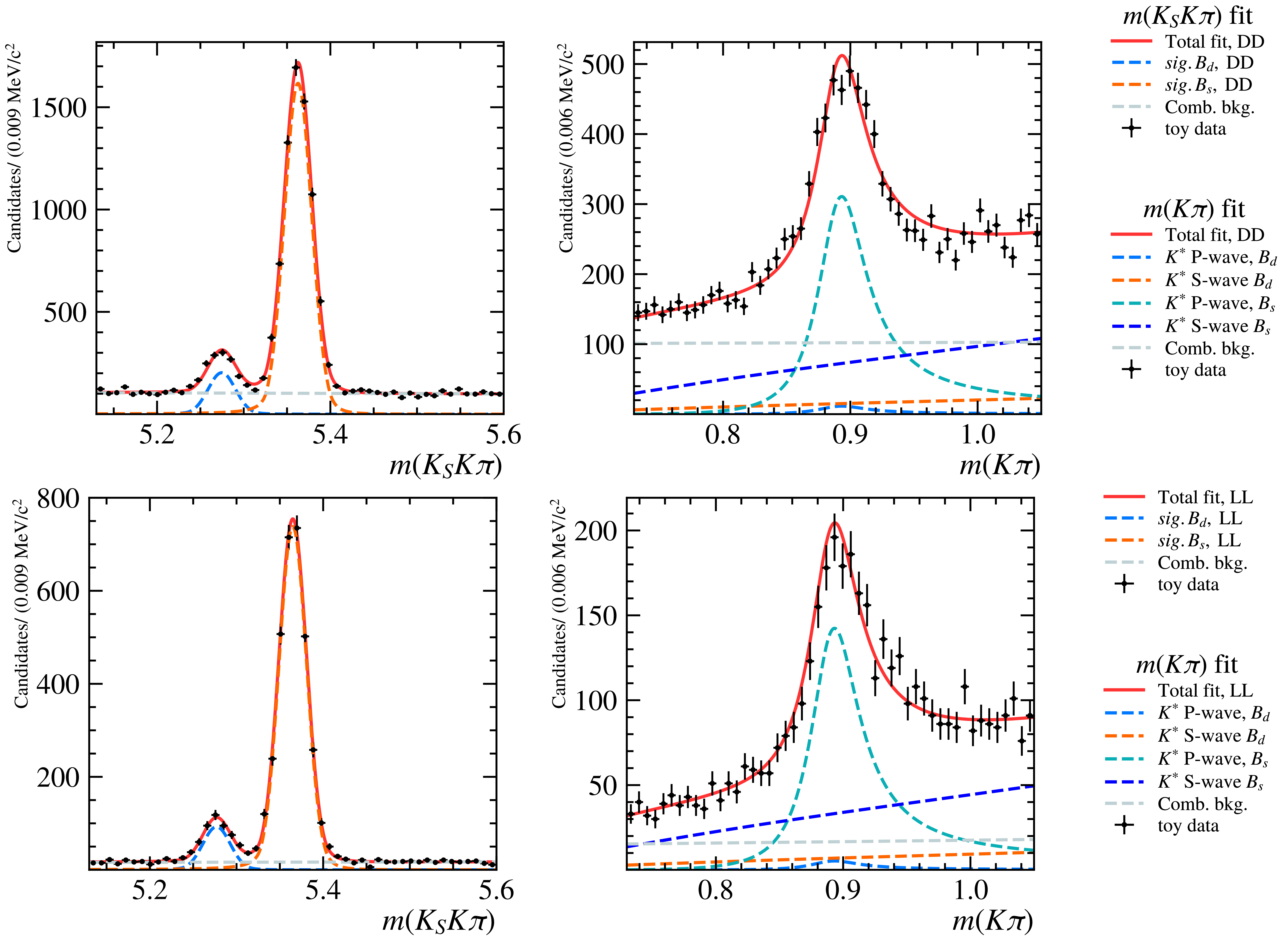
- Given the definition:

$$L_{\text{tot}} \propto \frac{|A_0^s|^2 \times \mathcal{N}(B_s \to K^0 K^*)}{|A_0^d|^2 \times \mathcal{N}(B_d \to K^0 K^*)}$$

- By normalising the $T_S(m_{K\pi}), T_0(m_{K\pi})$ to unity in the fit range of $m_{K\pi}$, one is tempted to determine L_{total} from a 2D simultaneous fit to the reconstructed B mass to tell the B_d and B_s apart and to the $m_{K\pi}$ to extract $|A_0|^2, |A_S|^2$

Toy setup v1 - fit results

- 2D unbinned ML fit to $m(K_S K\pi)$ mass and $m(K\pi)$, simultaneous in the LL and DD reconstruction categories
- As the B_d mode is suppressed, express the likelihood as a function of $L^{tot,-1}_{K_S K^*}$ to improve gaussianity of uncertainty on result
- Double sided CB for B mass shape, BW for P-wave, LASS for S-wave including K*(1430) and exponential for combinatorial
- Apply constraint to S-wave parameters around 1 sigma uncertainty from their determination (see table prev. slide)
- Share common shape parameters between track categories where possible
    - Reach statistical precision on L_{total} of $\sim 20\,\%$



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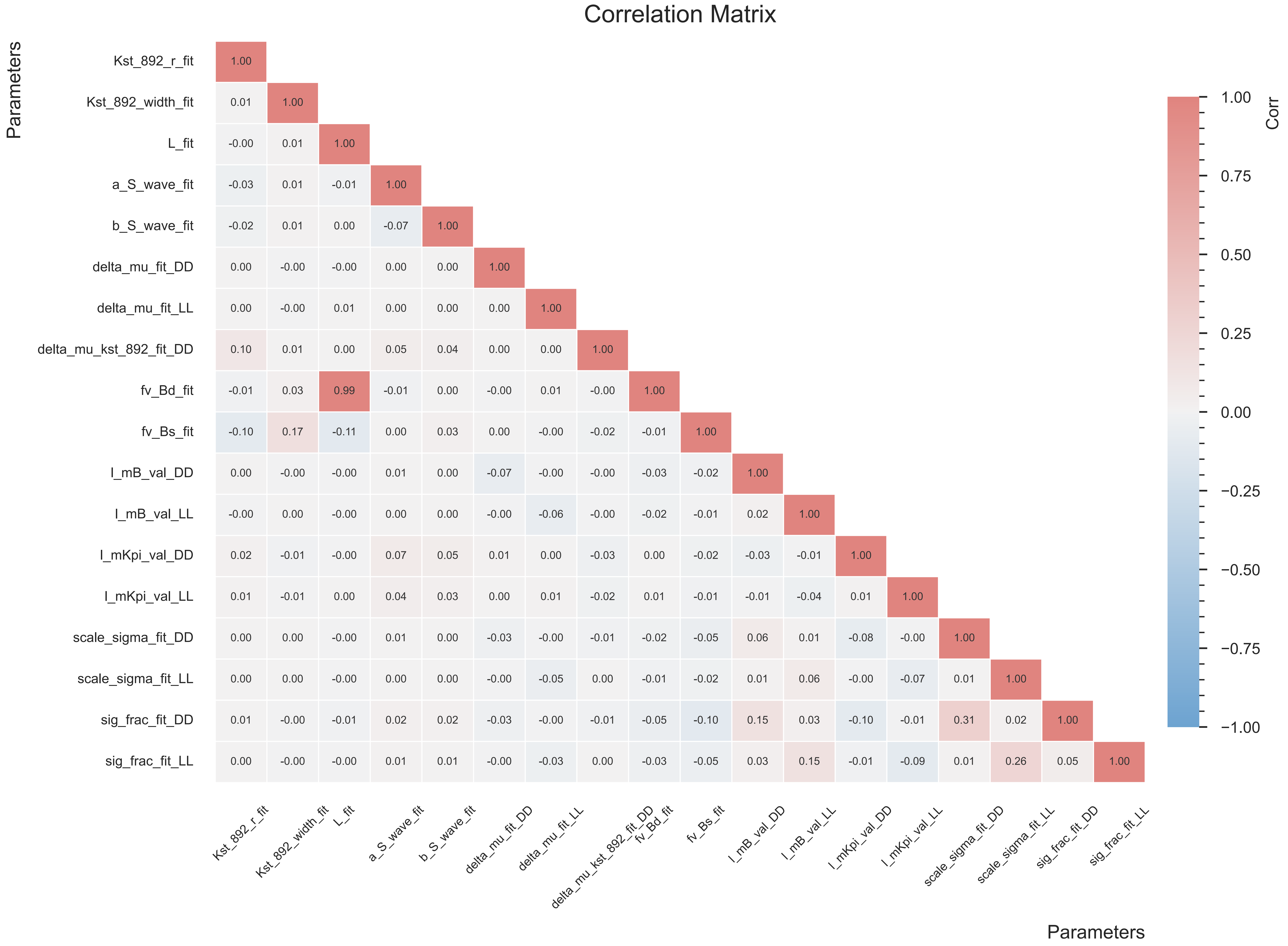


Angular acceptance effects

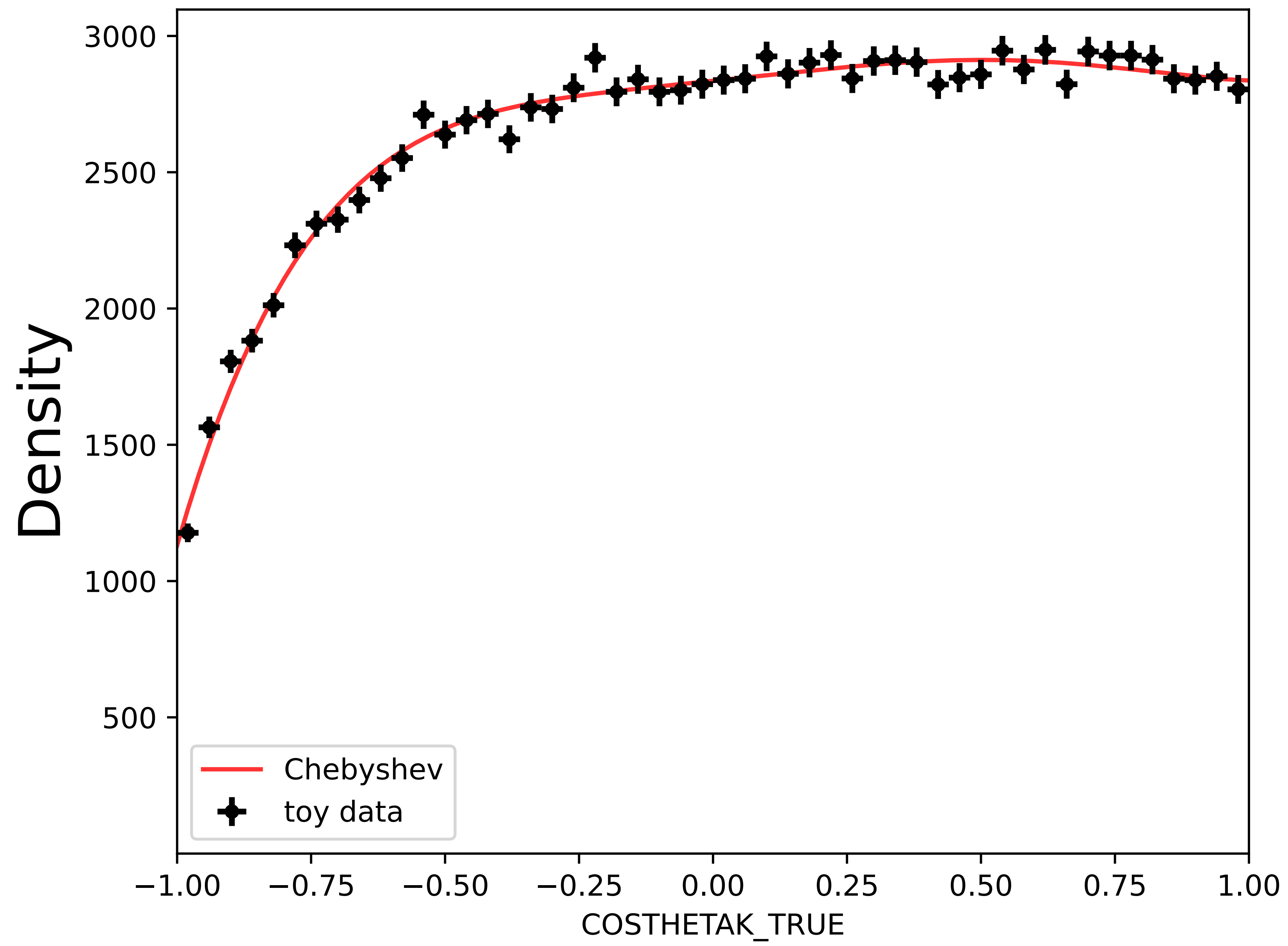
- Presence of selection cuts including cuts on minimum P, P_T of reconstructed tracks as well as geometric detector acceptance sculpt the $\cos\theta_K$ distribution

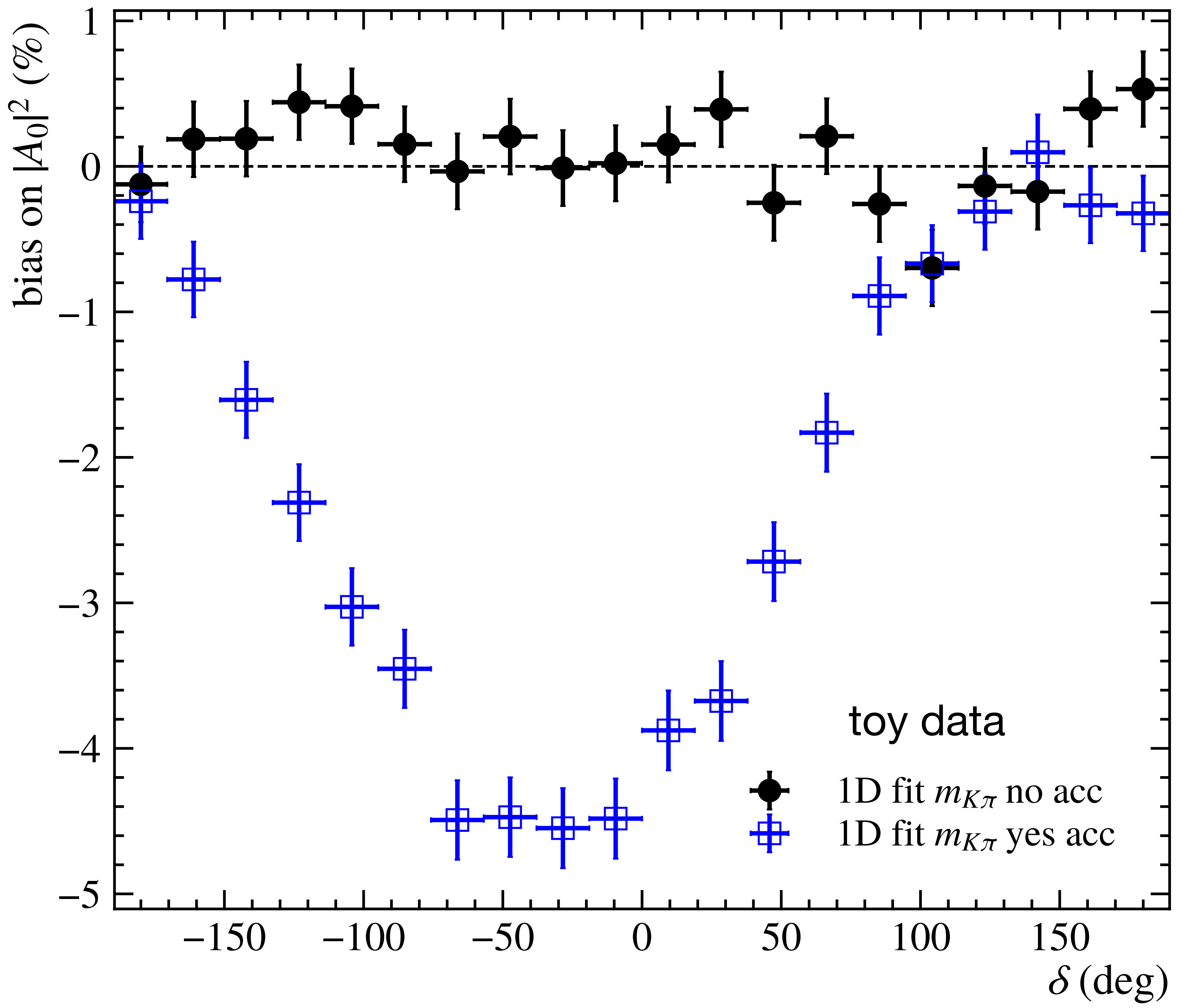
- Integral over $\cos\theta_K$ of the decay width doesn't cancel, and we become sensitive to interference terms in the amplitude

$$\frac{d\Gamma}{d\cos(\theta_K)dm_{K\pi}} \propto |A_S|^2|T_S(m_{K\pi})|^2 + 3|A_0|^2\cos^2\theta_K|T_0(m_{K\pi})|^2$$
$$\boxed{-2\sqrt{3}\cos\theta_k|A_S||A_0|\,\mathrm{Re}\left[\exp i\delta\cdot T_S(m_{K\pi})T_0^*(m_{K\pi})\right]}$$

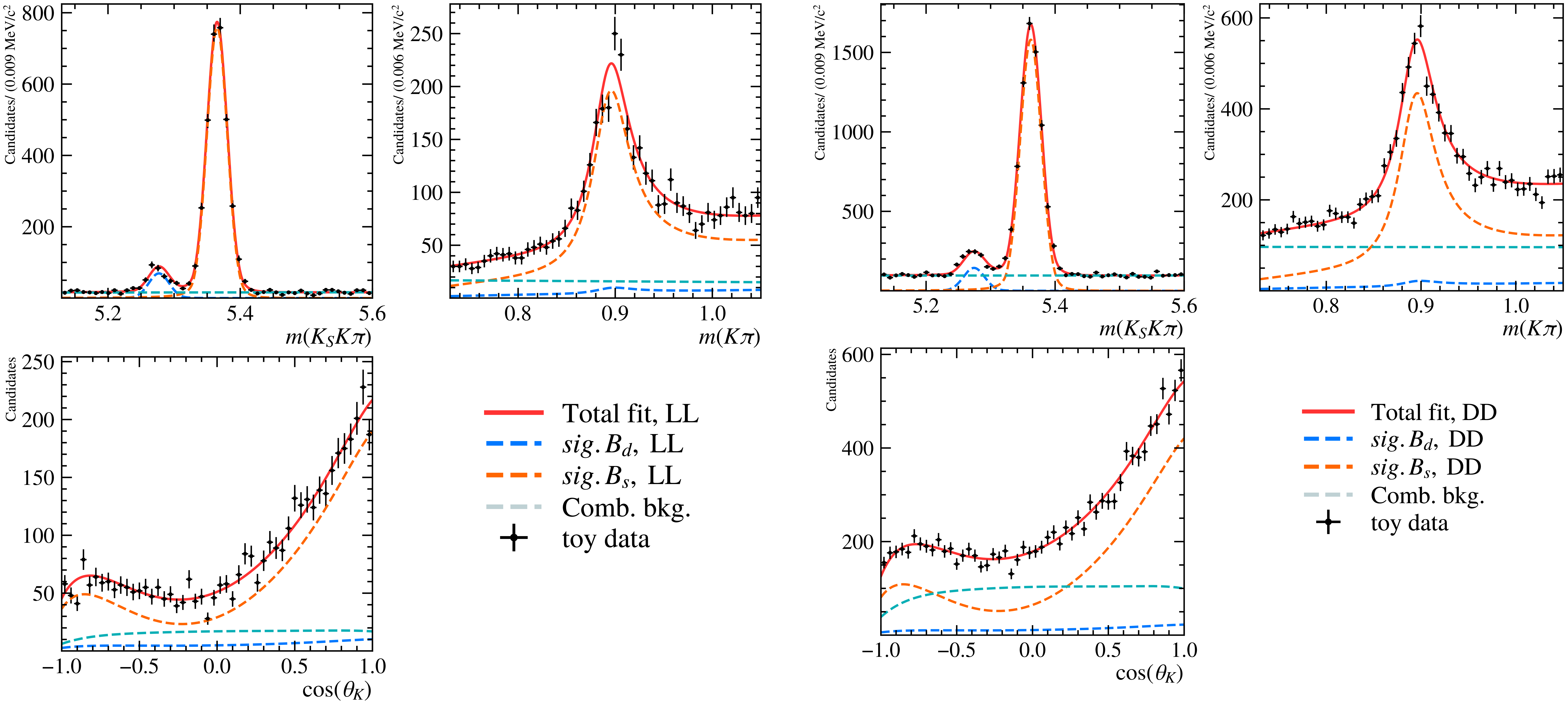
- The resulting bias is dependent of the phase difference between P and S wave, δ

- One can show using toy study that the bias can reach order $5\,\%$ of $|A_0|^2$ which is considerable over a $\sim 20\,\%$ aimed precision on L_{total}
    - Motivates to include $\cos\theta_K$ as a fit variable



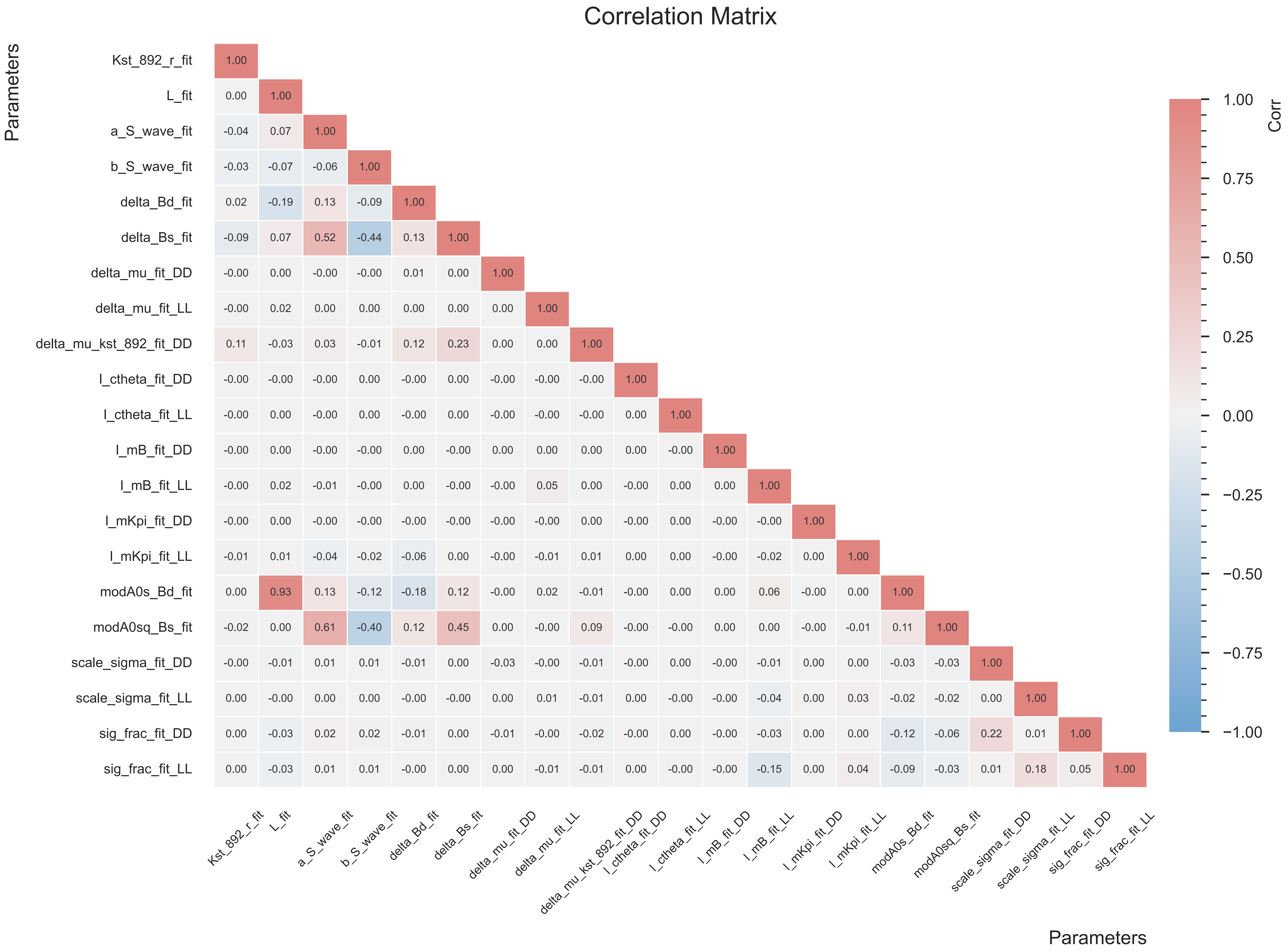


Toy setup v2 - fit results



Toy setup v2 - fit results

- 3D unbinned ML fit to $m(K_S K\pi)$ mass, $m(K\pi)$ and $\cos\theta_K$, simultaneous in the LL and DD reconstruction categories
- In the fit, a good knowledge of the background shapes in the 3 variables is assumed
  - Use control regions to extract the background angular distribution
- Share common shape parameters between track categories where possible
  - Inclusion of $\cos\theta_K$ allows to reach statistical precision on L_{total} of $\sim 12\,\%$



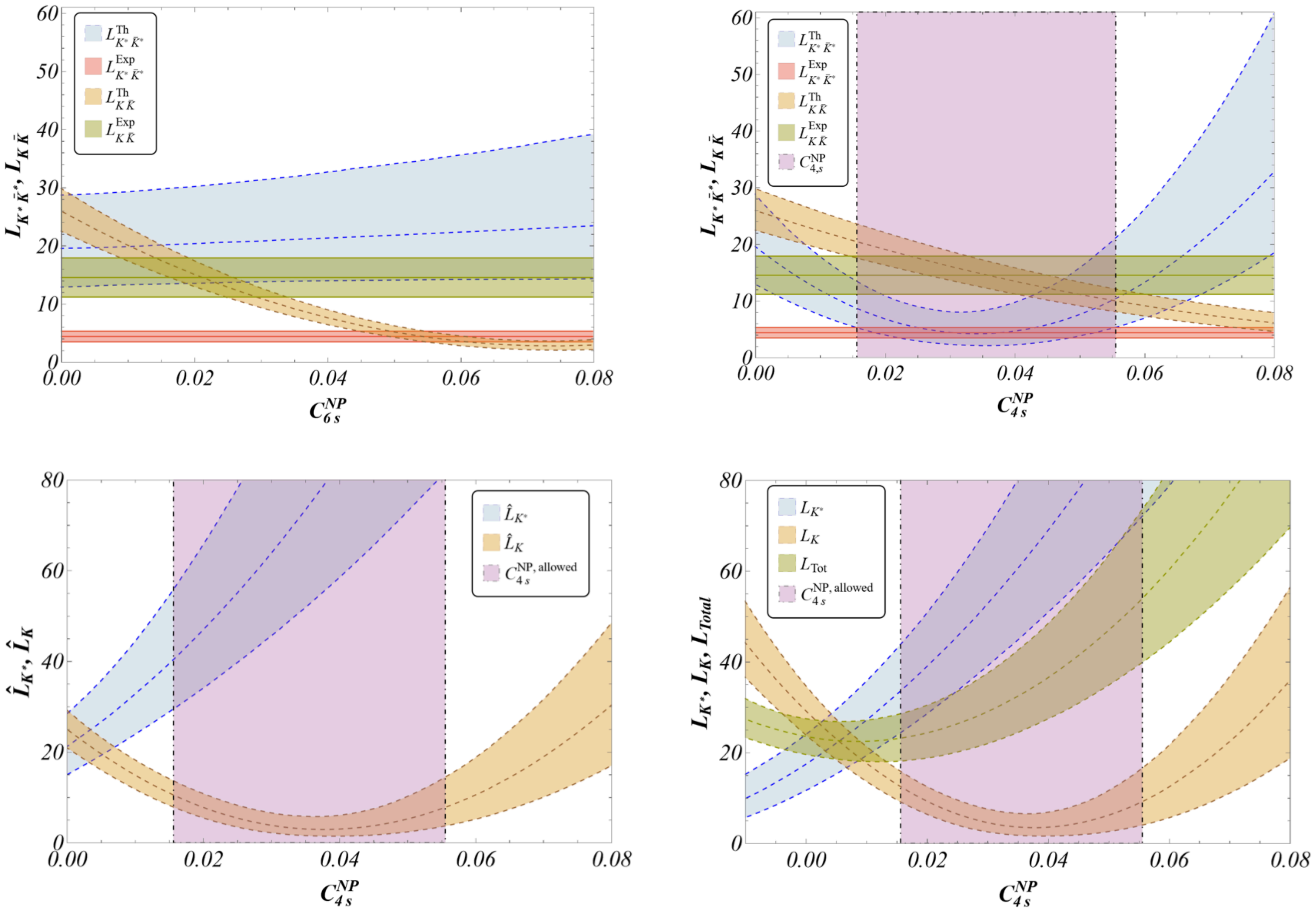
L_{total} Run 3 prospects

- From these studies, L_{total} is feasible with Run 3 data with a good precision.
  - Would constitute the first observation of $B_d \to K_S K^*(892)^0$, if normalised to $B_d \to K_S \pi^+ \pi^-$
  - Measurement explicitly optimised on L measurement
- Expect S-wave to be dominant systematic uncertainty here too
  - Aim to include all possible information that can be borrowed from Run1+Run2 $B^0_{(s)} \to K^{*0}\bar{K}^{*0}$ measurement
- Steps to singly tagged L observables such as $\tilde{L}_h$, $\hat{L}_h$ still not obvious due to limitations induced by oscillation
  - Probably this would constitute a dilution factor to be quantified
  - In Run 3, enough statistics in the Cabibbo suppressed mode to perform flavour tagging. FT performance + time acceptance crucial ingredients.

NP sensitivity

[JHEP 06 (2023) 108]

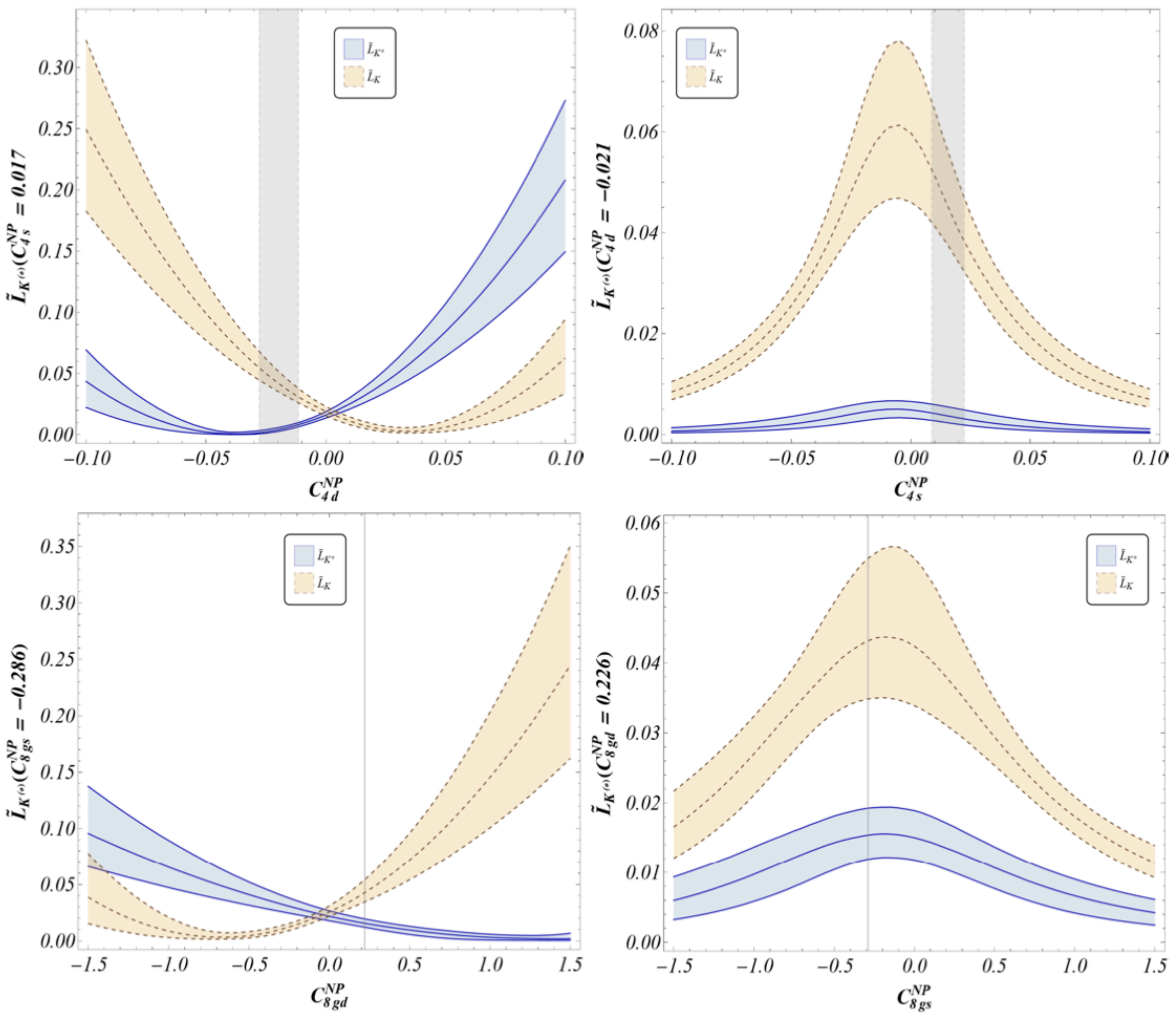
- Observables are sensitive to modifications to WC of local four-quark operators e.g. QCD penguin C_{4s}, chromomagnetic C_{8gs} as well as C_{6s}
- $\hat{L}$ observables are the most difficult experimentally but most sensitive to modifications to WC coefficients
- L could constitute a good compromise



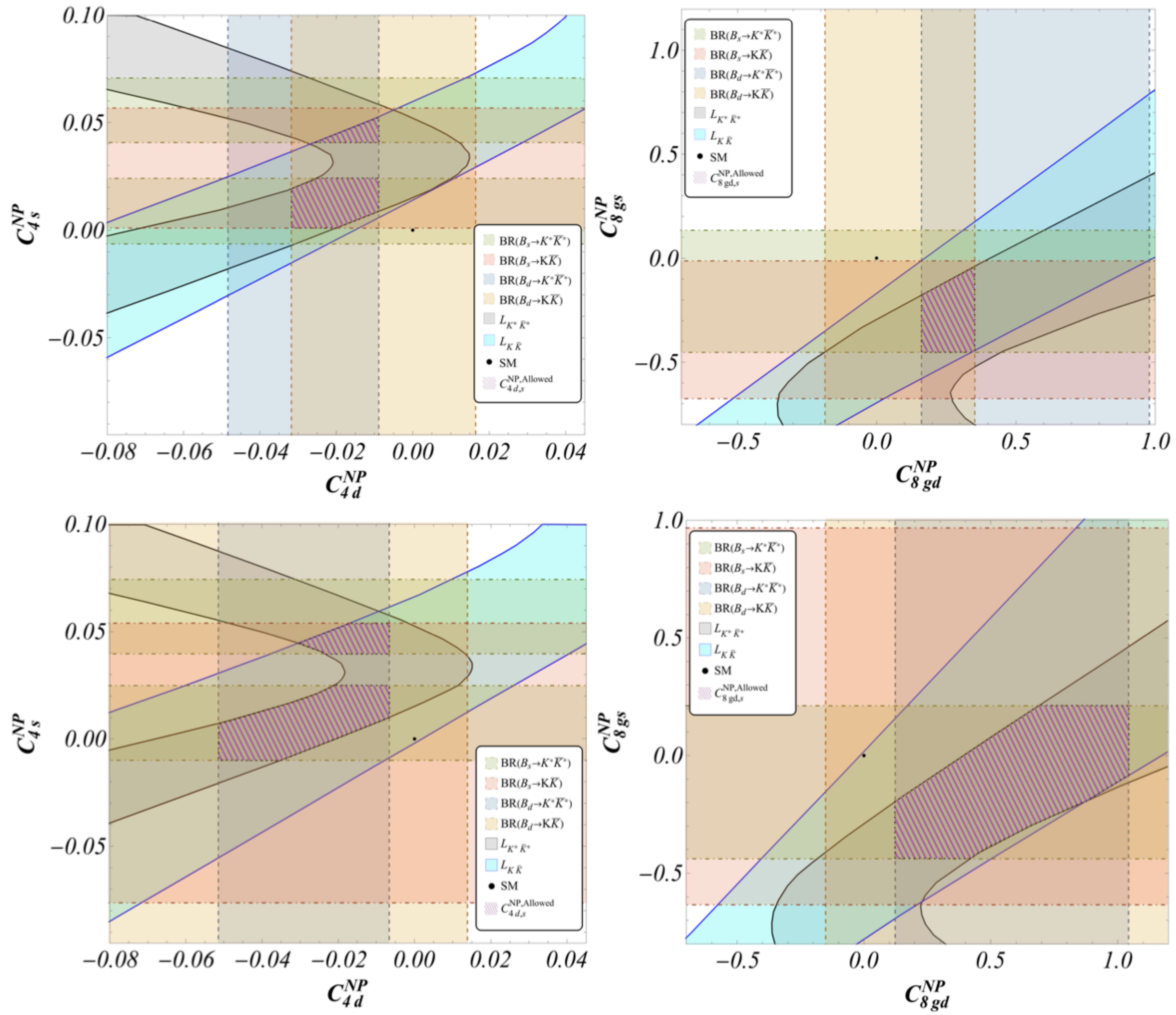
NP sensitivity

[JHEP 09 (2025) 188]

- $\tilde{L}$ observables, predictions based on LCSR + lattice



- Overlap of allowed regions from currently measured L obs.



Not only $b \to s\bar{d}d$ ...

[JHEP 06 (2023) 108]

[JHEP 08 (2024) 030]

- Several Run 1 + Run 2 $B \to VV$ analysis are ongoing, a non exhaustive list:
  - $B^0_{(s)} \to \phi K^{*0}$
  - $B^0_{(s)} \to \rho^0 K^{*0}$
  - $B^+ \to \phi K^{*+}$

Shed light on the polarisation puzzle

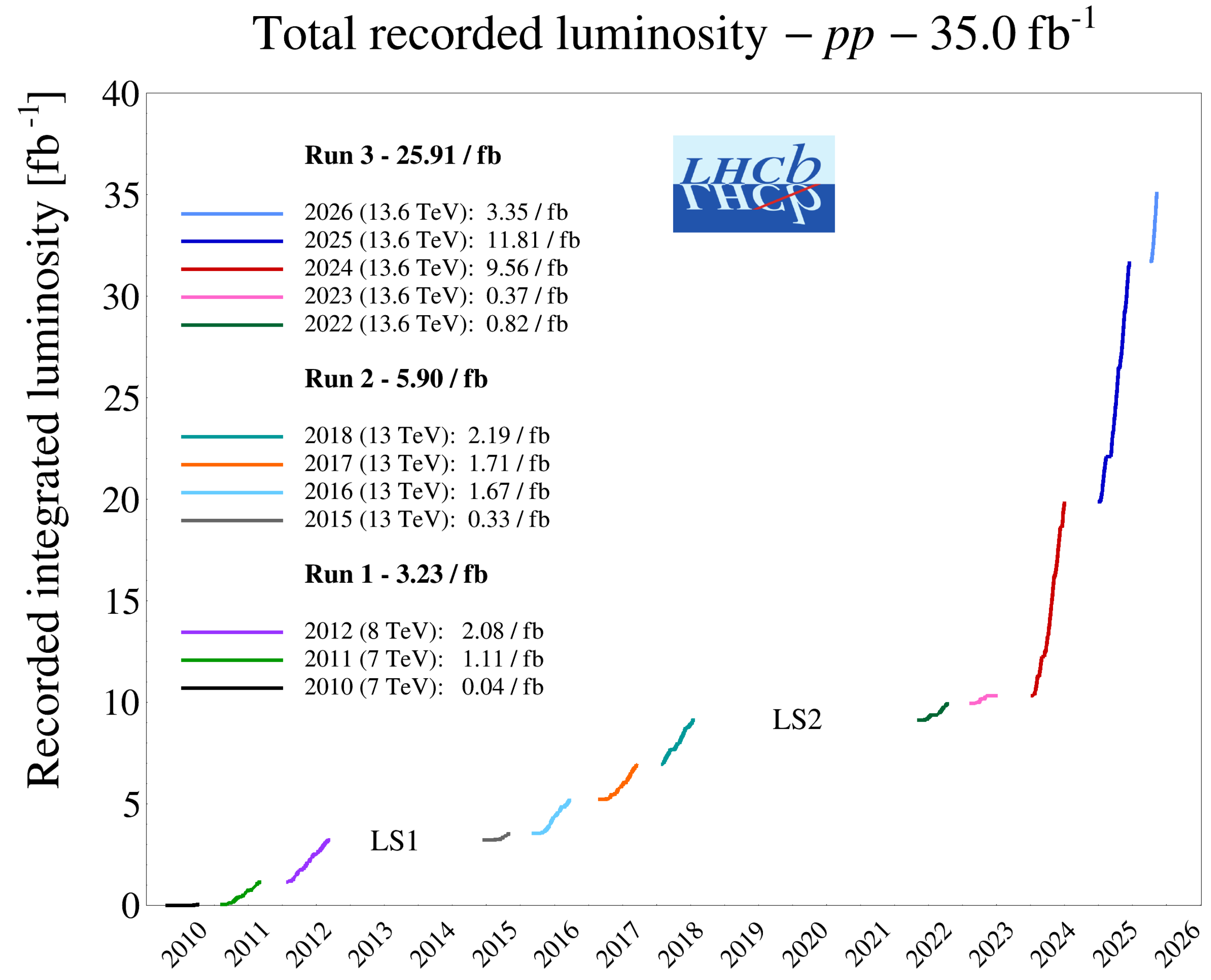
L measurements with other modes are inbound

- $B^0_{(s)} \to K^0 \bar{K}^{*0}$
- $B^0_{(s)} \to K^0 \bar{K}^0$
- $B^0_{(s)} \to \phi K^{*0}$

Observable	SM	Experiment
$L_{K^*\bar{K}^*}$	$19.53^{+9.14}_{-6.64}$	4.43 ± 0.92
$L_{K\bar{K}}$	$26.00^{+3.88}_{-3.59}$	14.58 ± 3.37
$\hat{L}_{K^*}$	$21.30^{+7.19}_{-6.30}$	–
$\hat{L}_K$	$25.01^{+4.21}_{-4.07}$	–
L_{K^*}	$17.44^{+6.59}_{-5.82}$	–
L_K	$29.16^{+5.49}_{-5.25}$	–
R_d	$0.70^{+0.30}_{-0.22}$	–
L_{Total}	$23.48^{+3.95}_{-3.82}$	–

- Run 3 LHCb has collected record luminosity
- Having moved to fully software based trigger roughly doubles the number of signal candidates per pb^{-1}

$\to$ huge dataset of charmless B decays to explore



Thanks for your attention

Spare slides

$B^0_{d/s} \to K^{*0}\bar{K}^{*0}$, Invariant B mass fits

- Before we can proceed for the angular fit, isolate the signal of interest with a fit to $m(K\pi K\pi)$
- The branching ratio of $B^0_s \to K^{*0}\bar{K}^{*0}$ and $B^0 \to K^{*0}\bar{K}^{*0}$ is also derived separately:
  - Normalise with respect to open charm decays $B^0_s \to D^-_s\pi^+$ and $B^0 \to D^-\pi^+$ with identicalnumber of K and π in the final state:

[Phys. Rev. D 113 (2026), 092002]

Systematic uncertainties on branching ratios

- Leading systematic are
  - For B^0 the background modelling (worse S-B ratio) and acceptance weights (simulation sample size)
  - For B_s^0 signal mass shape modelling in the 4-body mass fit
    - Alternative parametrizations are trialled
  - S-wave and Blatt-Weisskopf not leading syst anymore
    - S-wave syst assessed by moving to LASS parametrisation

Source	$\mathcal{B}(B^0 \to K^{*0}\overline{K}^{*0})$ $\times 10^{-8}$	$\mathcal{B}(B_s^0 \to K^{*0}\overline{K}^{*0})$ $\times 10^{-7}$	$\frac{\mathcal{B}(B^0 \to K^{*0}\overline{K}^{*0})}{\mathcal{B}(B_s^0 \to K^{*0}\overline{K}^{*0})}$ $\times 10^{-3}$	$L_{K^{*0}\overline{K}^{*0}}$
Tail parameters	0.46	0.68	0.69	0.16
Signal model	0.76	0.83	1.98	0.21
Background model	3.36	0.21	4.84	0.37
Barrier factors	0.44	0.57	1.18	0.10
BDT	0.05	0.05	0.16	0.01
PID weights	0.53	0.02	0.64	0.17
Kinematic weights	1.13	0.61	2.26	0.27
Trigger correction	0.09	0.44	0.38	0.02
Total combined syst	3.72	1.45	5.91	0.56
Amplitude syst	2.07	1.07	4.84	0.21
Total syst	4.26	1.80	7.00	0.47
Total stat	2.93	2.47	3.66	0.55

Systematic uncertainties of amplitude fit

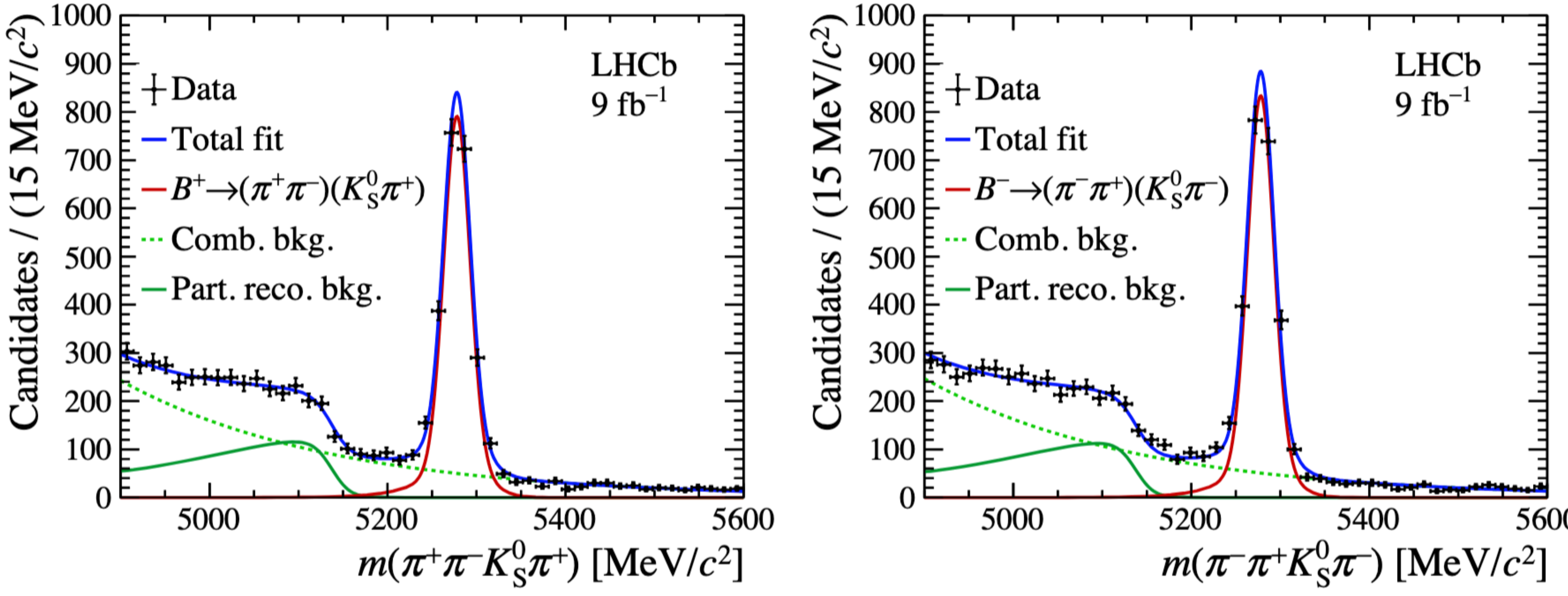
	Parameter	$sWeights$	KDE bandwidth	KDE kernel	Tracking	Fit bias	S-wave lineshape	Decay-time	S-wave shape	Tensor resonance	Total syst	Total stat
B_s^0	$\mathcal{F}_{VV}^{S+D}$	0.05	0.07	0.04	<0.01	0.05	<0.01	0.03	0.14	0.18	0.26	0.63
	$\mathcal{F}_{VV}^{P}$	0.19	0.06	0.08	<0.01	0.22	<0.01	0.13	0.15	0.08	0.38	0.56
	$\mathcal{F}_{VS}^{+}$	0.17	0.05	0.14	<0.01	0.19	<0.01	0.03	0.61	2.19	2.29	0.59
	$\mathcal{F}_{VS}^{-}$	0.48	0.11	0.04	<0.01	0.50	<0.01	0.11	0.81	0.26	1.11	0.89
	$\mathcal{F}_{SS}$	0.06	0.02	0.01	<0.01	0.05	<0.01	0.02	0.09	0.19	0.23	0.56
	δ_{VV}^{D}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01
	δ_{VS}^{+}	0.02	0.01	0.03	<0.01	0.01	0.01	<0.01	0.09	0.84	0.84	0.11
	δ_{VS}^{-}	0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	0.12	0.01	0.12	0.04
	δ_{SS}	0.02	0.01	0.02	<0.01	0.02	0.01	<0.01	0.25	0.01	0.25	0.06
B^0	$\mathcal{F}_{VV}^{S+D}$	0.05	0.79	2.06	<0.01	0.26	0.03	0.08	0.14	0.72	2.34	2.04
	$\mathcal{F}_{VV}^{P}$	0.19	0.38	0.45	<0.01	0.24	<0.01	0.12	0.15	0.28	0.74	1.35
	$\mathcal{F}_{VS}^{+}$	0.17	0.39	0.76	<0.01	0.27	0.02	0.05	0.61	0.11	1.10	2.17
	$\mathcal{F}_{VS}^{-}$	0.48	0.93	2.47	<0.01	0.11	0.01	0.08	0.81	0.72	2.89	2.27
	$\mathcal{F}_{SS}$	0.06	0.12	0.10	<0.01	0.12	0.02	0.01	0.09	0.10	0.24	1.00
	δ_{VV}^{D}	<0.01	0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.01	<0.01	0.02	0.04
	δ_{VS}^{+}	0.02	0.11	0.21	<0.01	0.02	0.01	<0.01	0.09	<0.01	0.25	0.22
	δ_{VS}^{-}	0.01	0.03	0.03	<0.01	0.01	0.01	<0.01	0.12	<0.01	0.13	0.11
	δ_{SS}	0.02	0.07	0.10	<0.01	0.01	0.01	<0.01	0.25	<0.01	0.28	0.15

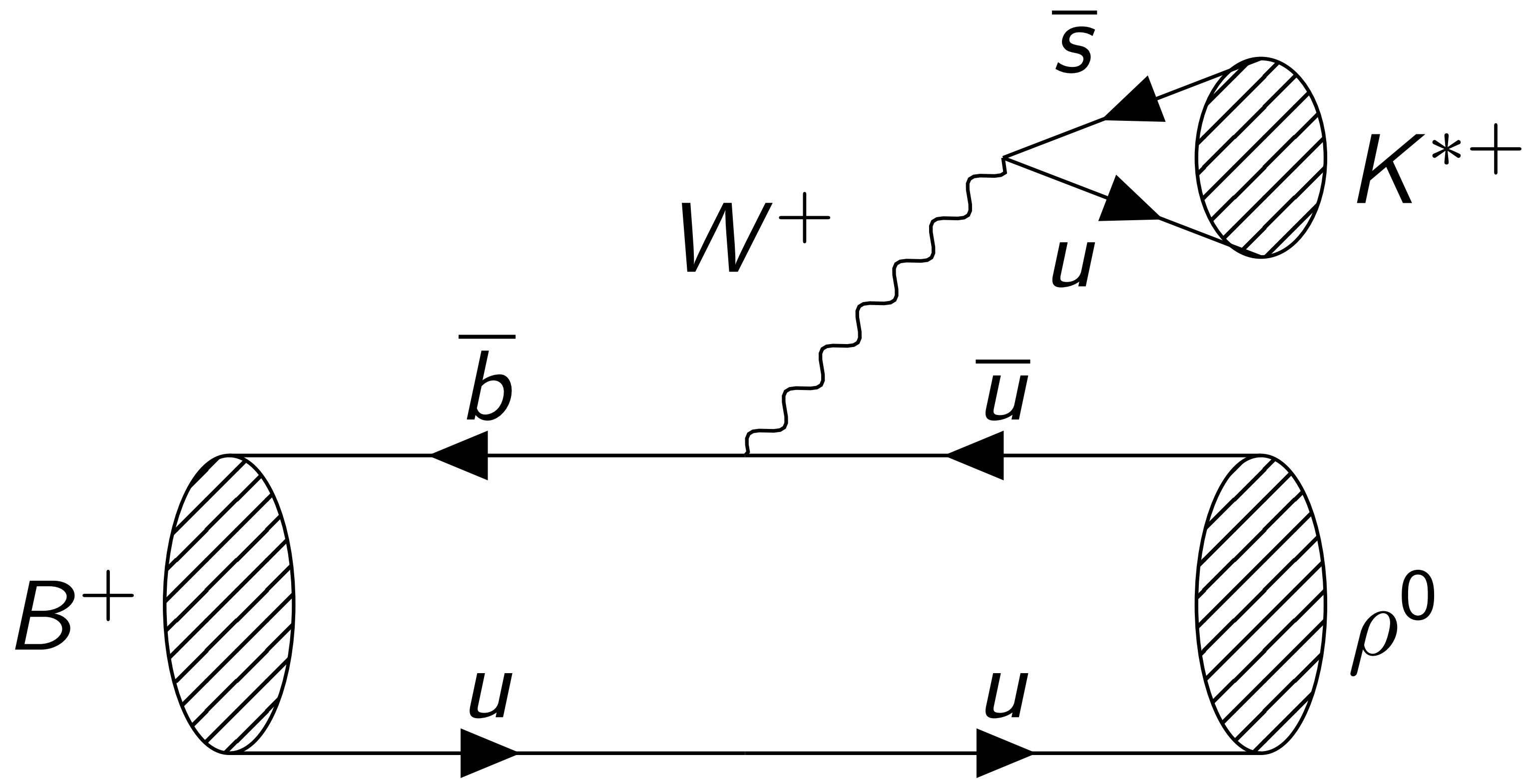
Amplitude analysis of $B^+ \to \rho^0 K^{*+}$

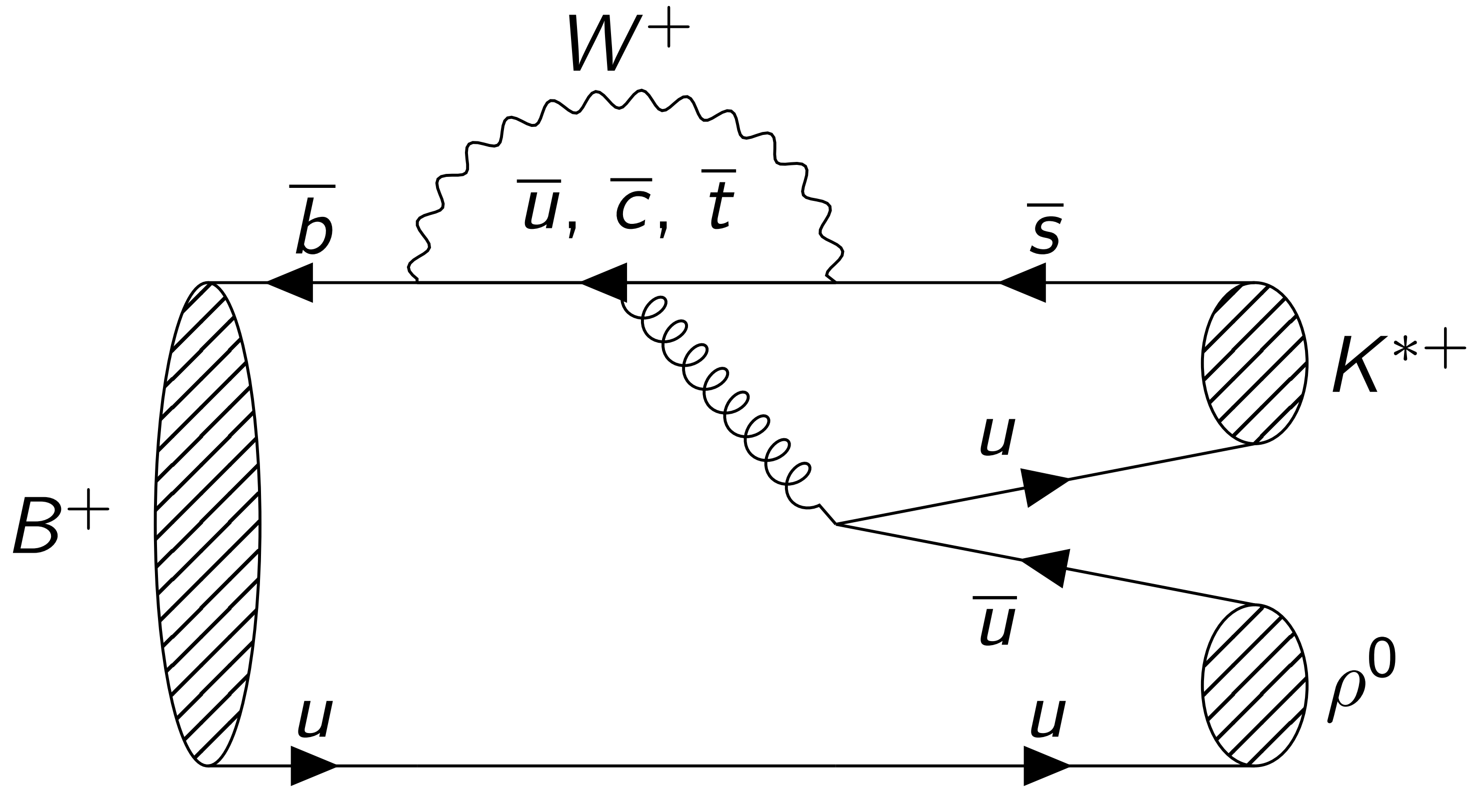
[PRL 136 (2026) 021803]

- The $B^+ \to \rho^0 K^{*+}$ decay was not studied at LHCb before
  - Amplitude analysis from BaBar: branching fraction, polarisation and CP asymmetry were measured ($f_L = 0.78 \pm 0.12$)
  - New analysis with full Run1 + Run2 LHCb datasets
- Recostructed with $\rho^0 \to \pi^+\pi^-$, $K^{*+} \to K_S^0\pi^+$

$N(B^+) = 2208 \pm 53$ $\quad$ $N(B^-) = 2333 \pm 55$







Amplitude analysis of $B^+ \to \rho^0 K^{*+}$

[PRL 136 (2026) 021803]

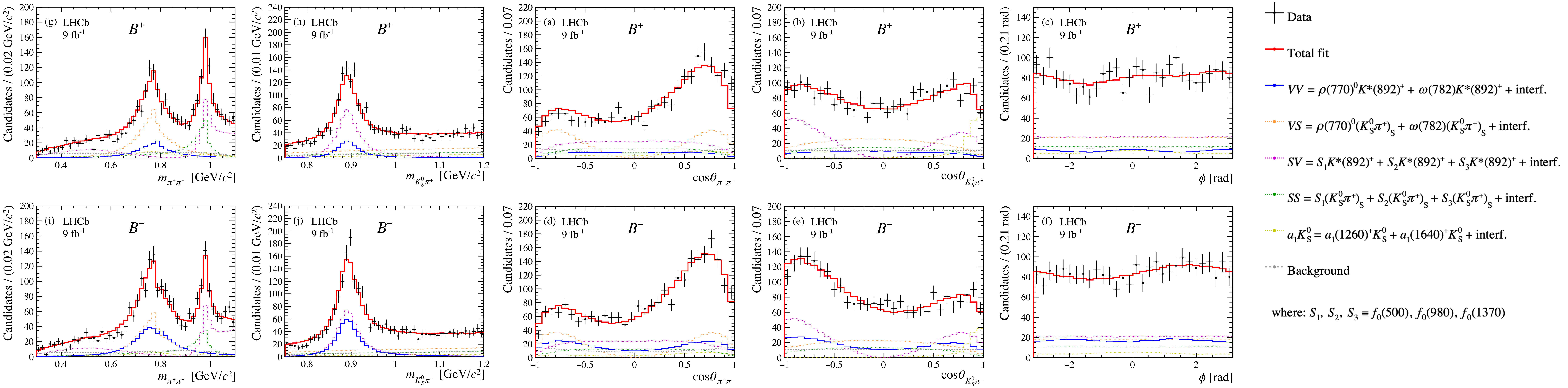
- 5D amplitude analysis of $B^+ \to (\pi^+\pi^-)(K_S^0\pi^+)$ in the phase-space regions of
  - $(0.3 < m(\pi^+\pi^-) < 1.1)$ GeV/c^2
  - $(0.75 < m(K_S^0\pi^+) < 1.2)$ GeV/c^2
- Simultaneous fit to B^+ and B^- candidates

$B^+ \to (\pi^+\pi^-)(K_S^0\pi^+)$

$\rho(770)^0$, $\omega(782)$, $f_0(500)$, $f_0(980)$, $f_0(1370)$ $\otimes$ $K^*(892)^+$, $(K_S^0\pi^+)_{S-\text{wave}}$

$B^+ \to (\pi^+\pi^-\pi^+)\, K_S^0$

$a_1(1260)$, $a_1(1640)$ $\otimes$ K_S^0



Amplitude analysis of $B^+ \to \rho^0 K^{*+}$

[PRL 136 (2026) 021803]

- Most precise CP averaged longitudinal polarisation fraction:

$$f_L^{\text{avg}} = \frac{|A_0|^2 + |\bar{A}_0|^2}{\sum_{\lambda\in\{0,\perp,\parallel\}}(|\bar{A}_\lambda|^2 + |A_\lambda|^2)} = 0.721 \pm 0.027\,\text{(stat)}\ \pm 0.030\,\text{(syst)}$$

  - Consistent with BaBar and theory predictions

- Direct CP asymmetry (first observation at > 5σ in this decay)

$$A_{CP} = \frac{\sum_{\lambda\in\{0,\perp,\parallel\}}(|\bar{A}_\lambda|^2 - |A_\lambda|^2)}{\sum_{\lambda\in\{0,\perp,\parallel\}}(|\bar{A}_\lambda|^2 + |A_\lambda|^2)} = 0.506 \pm 0.062\,\text{(stat.)}\ \pm 0.025\,\text{(syst.)}$$

- Magnitude and phase of CP asymmetries for single polarisation amplitudes and fractions:

$$\mathcal{A}_{CP}(|A_0|^2) \equiv \frac{|\bar{A}_0|^2 - |A_0|^2}{|\bar{A}_0|^2 + |A_0|^2} = 0.666 \pm 0.081 \pm 0.048,$$

$$\Delta_{CP}(\delta_0) \equiv \bar{\delta}_0 - \delta_0 = 0.774 \pm 0.172 \pm 0.078$$

$$\mathcal{A}_{CP}(f_L) \equiv \frac{\bar{f}_L - f_L}{\bar{f}_L + f_L} = 0.241 \pm 0.083 \pm 0.050$$

CP violation is driven by the longitudinal component