Impact on L-observables of a new combined analysis $B_{d,s} \to K^{(*)}$ form factors

Experimental determination of $L_{K^*\bar{K}^*}$ at LHCb

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UNIVERSITÄT BONN

Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

Imperial College London

LHCb

Talk outline

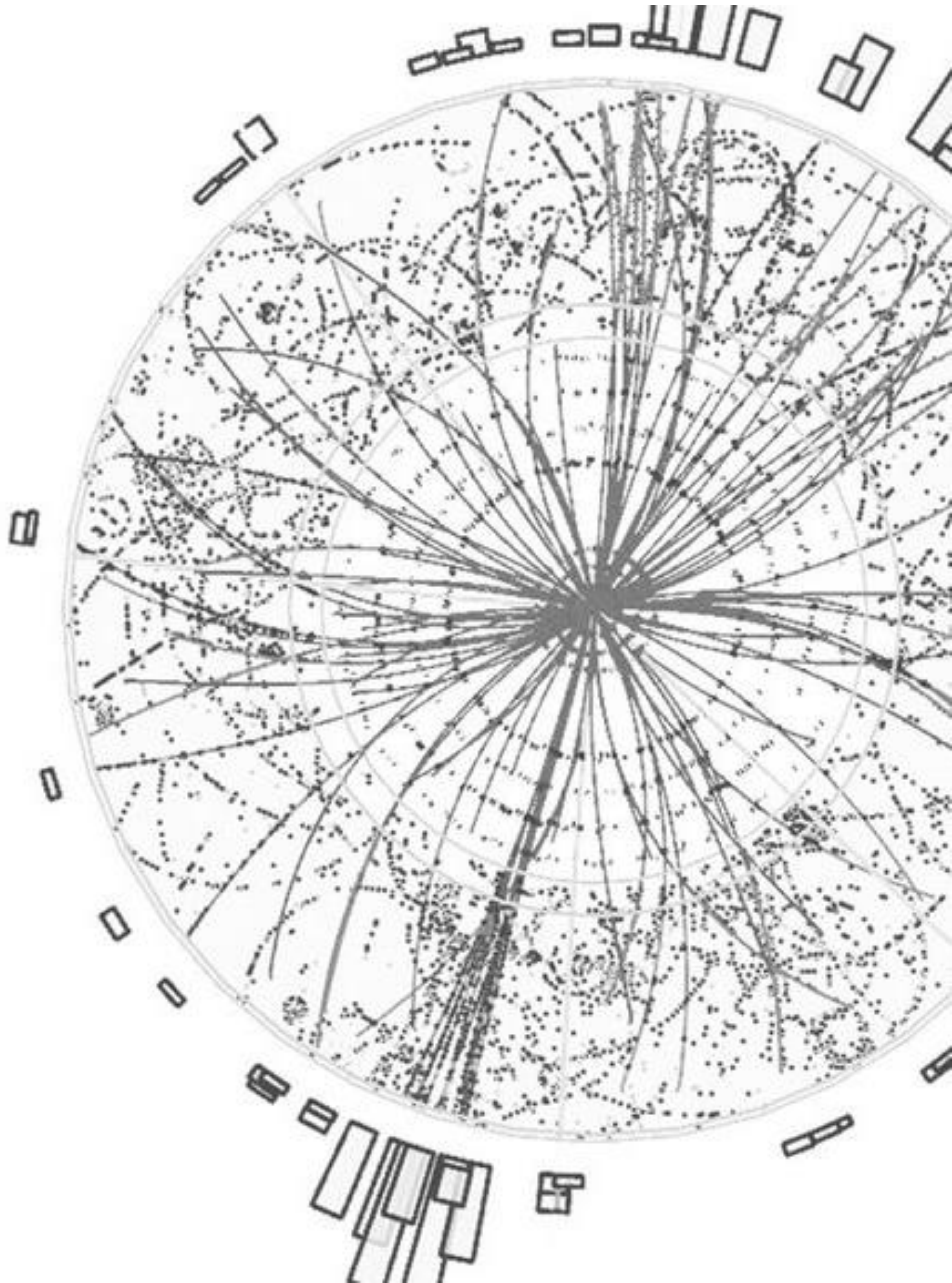
Introduction: QCD factorization

Calculation of hadronic matrix elements

Prediction of L-observables

Measurement of L-observables in the $B \to K^*(892)K^*(892)$ system

Conclusions



Hadronic decays and QCD factorization

Motivations to study hadronic *B* decays

Theory side

Understanding QCD dynamics
(complicated strong interaction effects)

Experimental side

Large branching fractions (rich pheno)
No neutrinos $\Longrightarrow$ easier to reconstruct

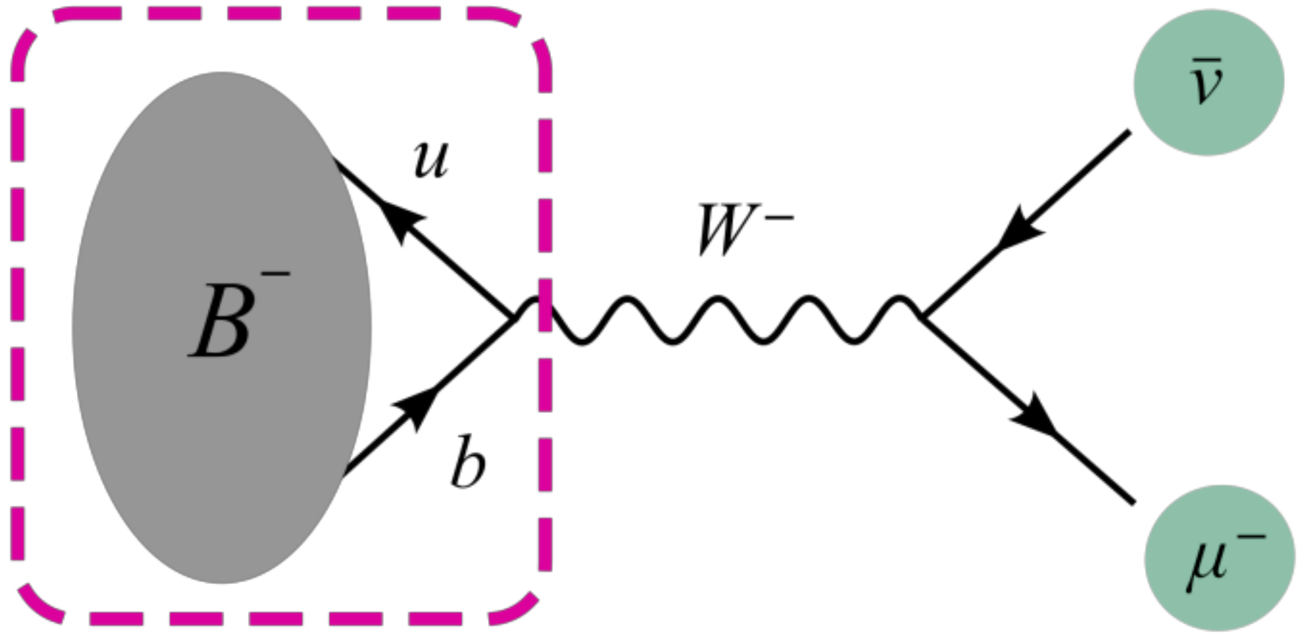
Testing the SM and searching for New Physics

Need precise and accurate SM predictions and measurements

Definition of the form factors

Decay constant parametrize vacuum-to-hadron matrix elements

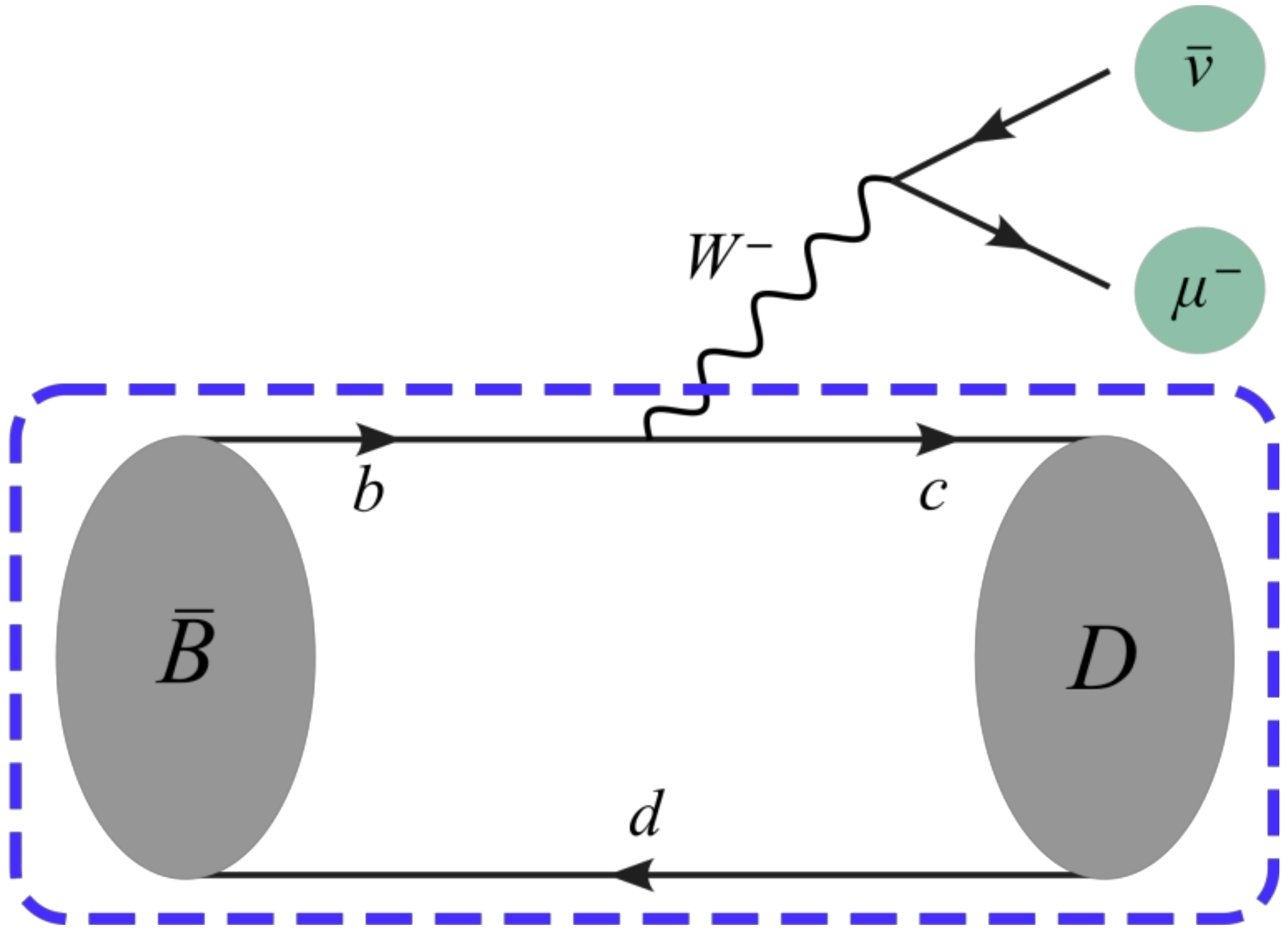
$$\langle 0|\bar{u}\,\gamma^{\mu}\gamma_5\, b|B(p)\rangle = ip^{\mu} f_B$$



Form factors (FFs) parametrize hadron-to-hadron matrix elements

$$\langle D(k)|\bar{c}\,\gamma_{\mu} b|B(q+k)\rangle = q_{\mu}\frac{m_B^2 - m_D^2}{q^2}\, F_0(q^2) + \cdots$$

$$\langle D^*(k,\eta)|\bar{s}\,\gamma_{\mu}\gamma_5 b|B(q+k)\rangle = q_{\mu}(\eta\cdot q)\frac{2\, m_{D^*}}{q^2} A_0(q^2) + \cdots$$



FFs are functions of the momentum transferred q^2

Hadronic decays: naive factorization

The amplitude $\mathcal{A} \sim \langle K\bar{K}|O_i|\bar{B}\rangle$ does not trivially factorize

Very complicated matrix element $\Longrightarrow$ cannot be calculated directly

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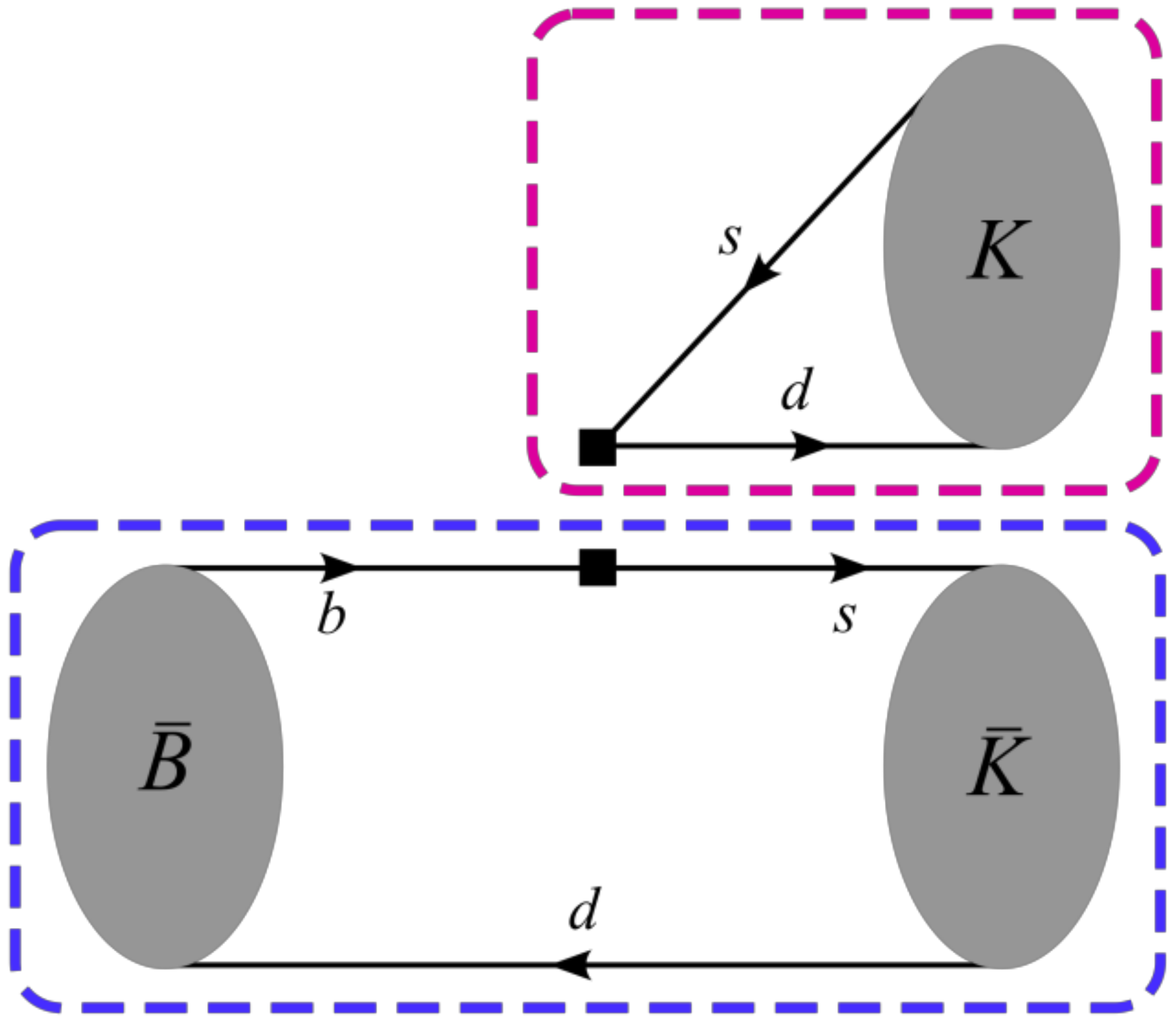
Decompose a into simpler ones

$$\langle K\bar{K}|O_i|\bar{B}\rangle \sim \langle K|j_a|0\rangle\langle\bar{K}|j_b|\bar{B}\rangle \propto f_K\, F_0^{B\to K}(0)$$

Assume that gluon exchanges between $\bar{B}\bar{K}$ and K



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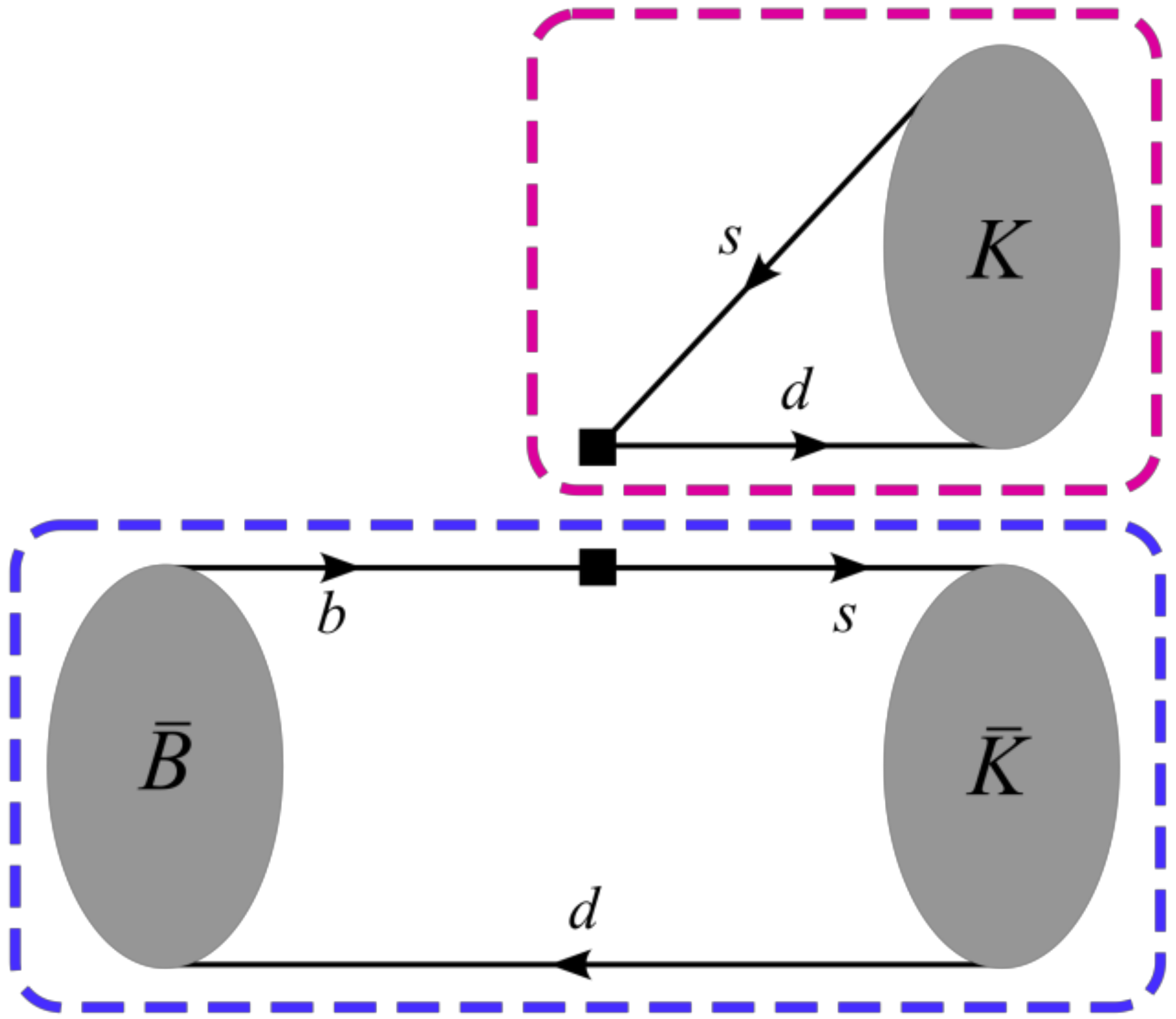
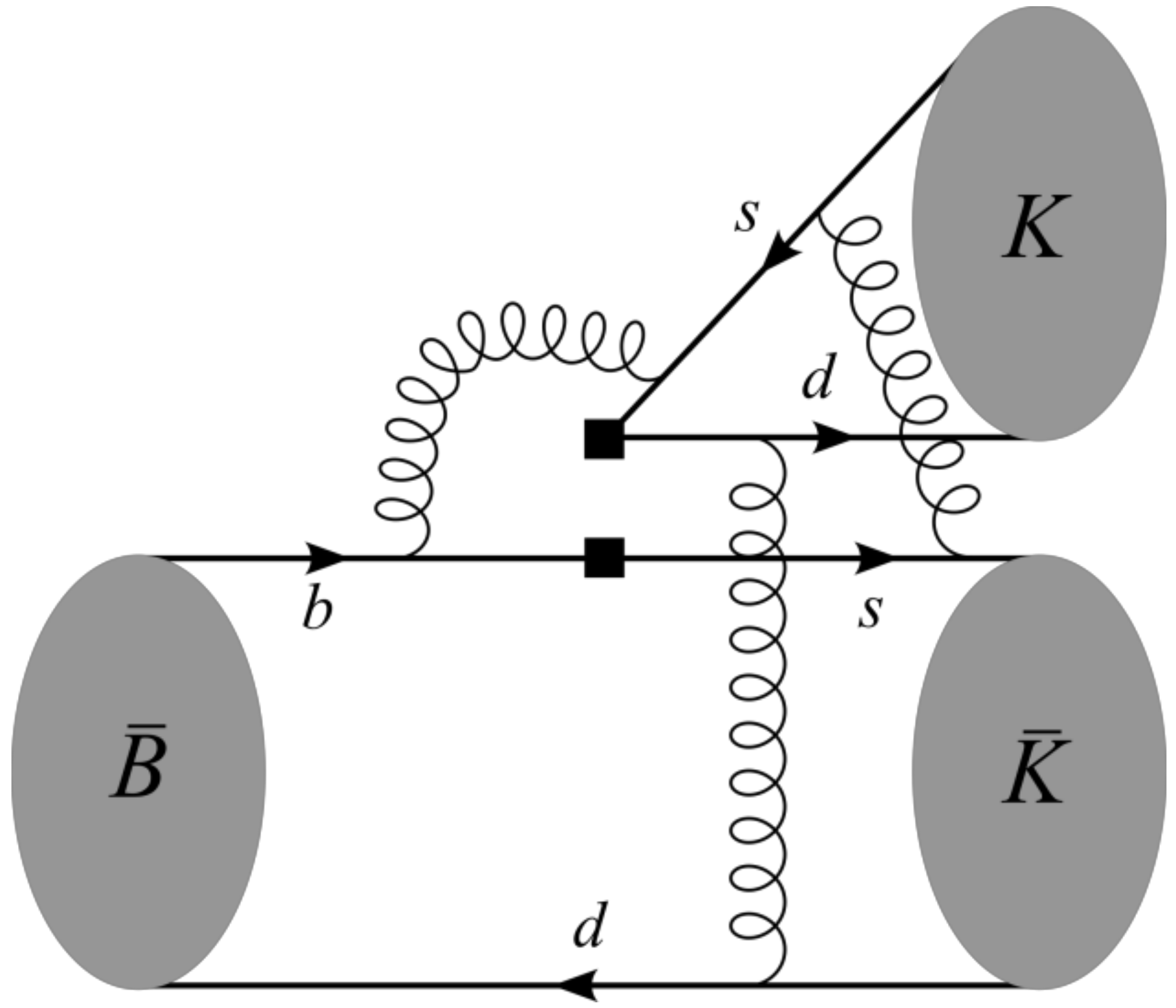
Assumption not justified

Naïve factorization is broken





QCD factorization

Beyond naïve factorization ⟹ QCD factorization approach [Beneke/Buchalla/Neubert/Sachrajda 2000]

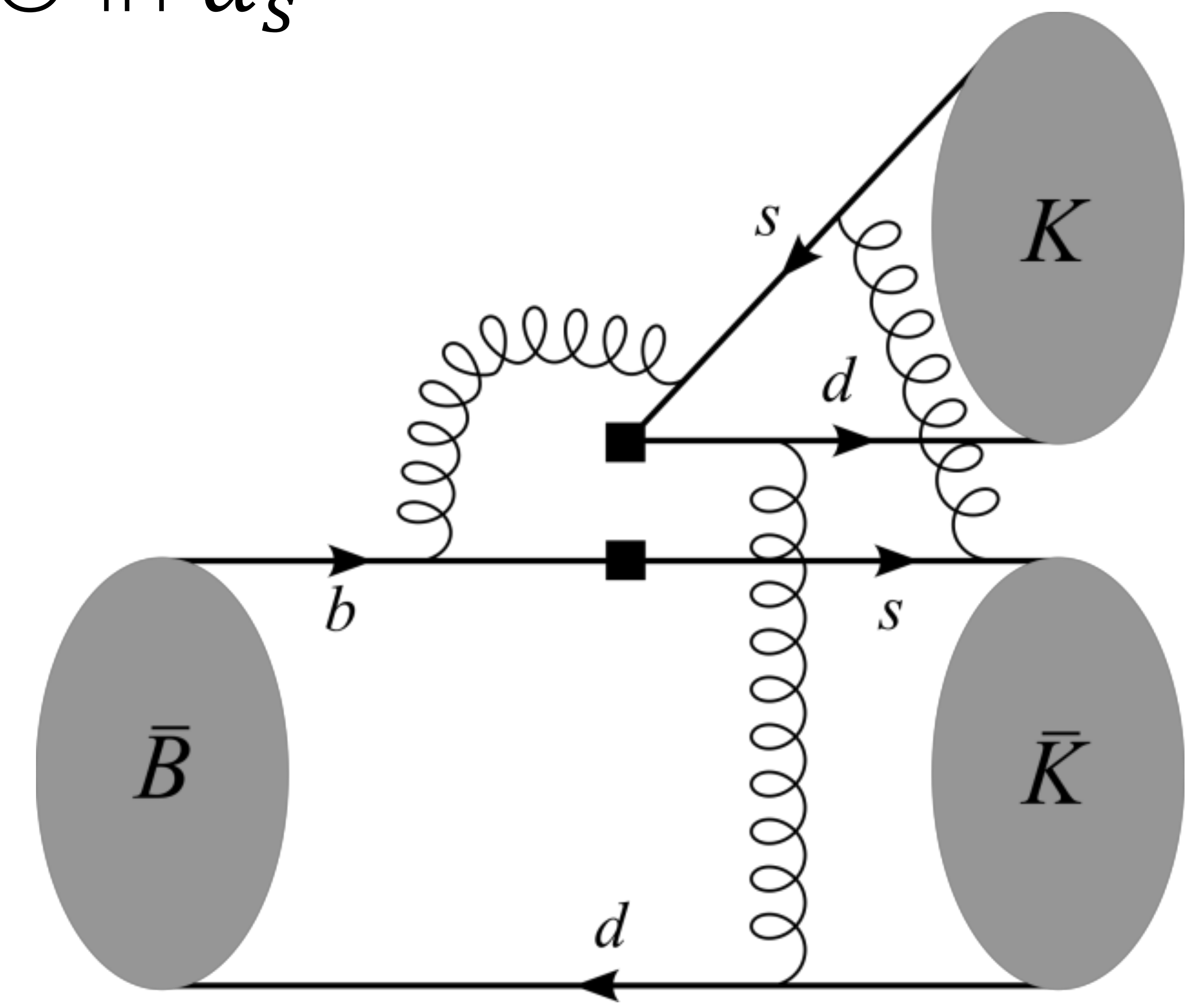
$$\langle K\bar{K}|O_i|\bar{B}\rangle = f_K\Phi_K * F_0^{B\to K}(0)T_i^I + T_i^{II} * f_K\Phi_K * f_B\Phi_B * f_K\Phi_K$$

where the distribution amplitudes are defined as

$$\Phi_K \sim \langle K\big|\bar{s}(x)\gamma_\mu\gamma_5 d(0)\big|0\rangle$$

Compute systematically α_s corrections ⟹ T_i^I and T_i^{II} calculated at NNLO in α_s

[Bell et al. 2020]



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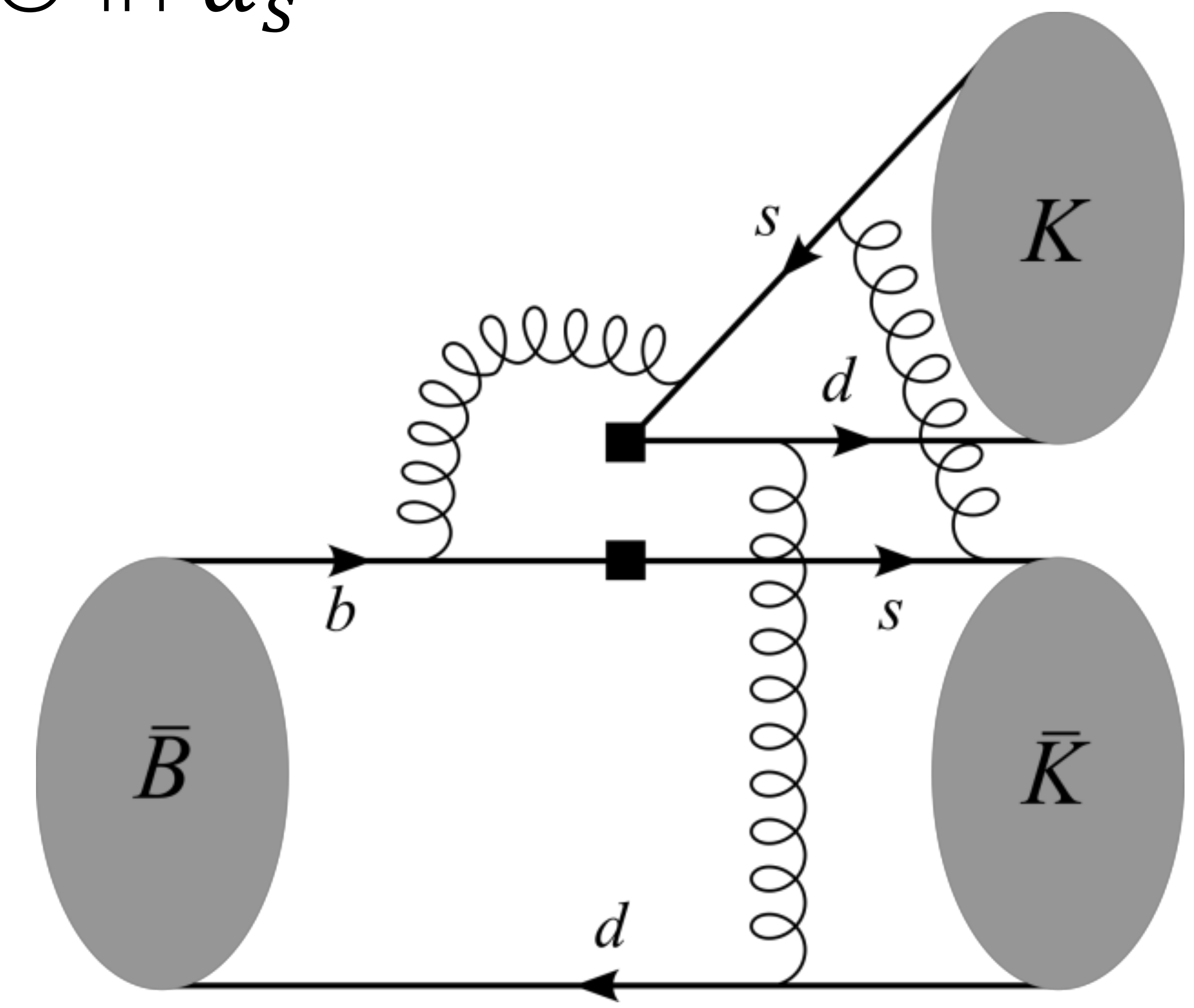
Neglect power corrections $\frac{\Lambda_{QCD}}{m_b}$

No systematic way to calculate power corrections

Unknown systematic uncertainties



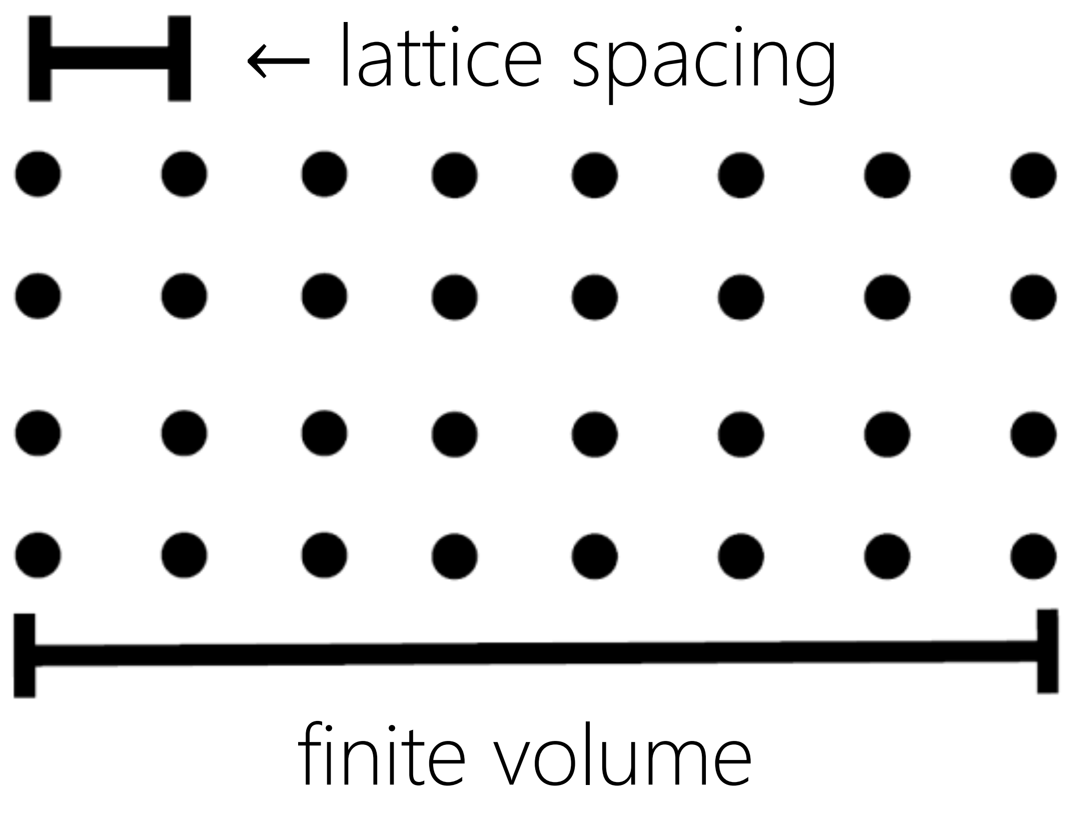
Calculation of hadronic matrix elements

Methods to compute hadronic matrix elements

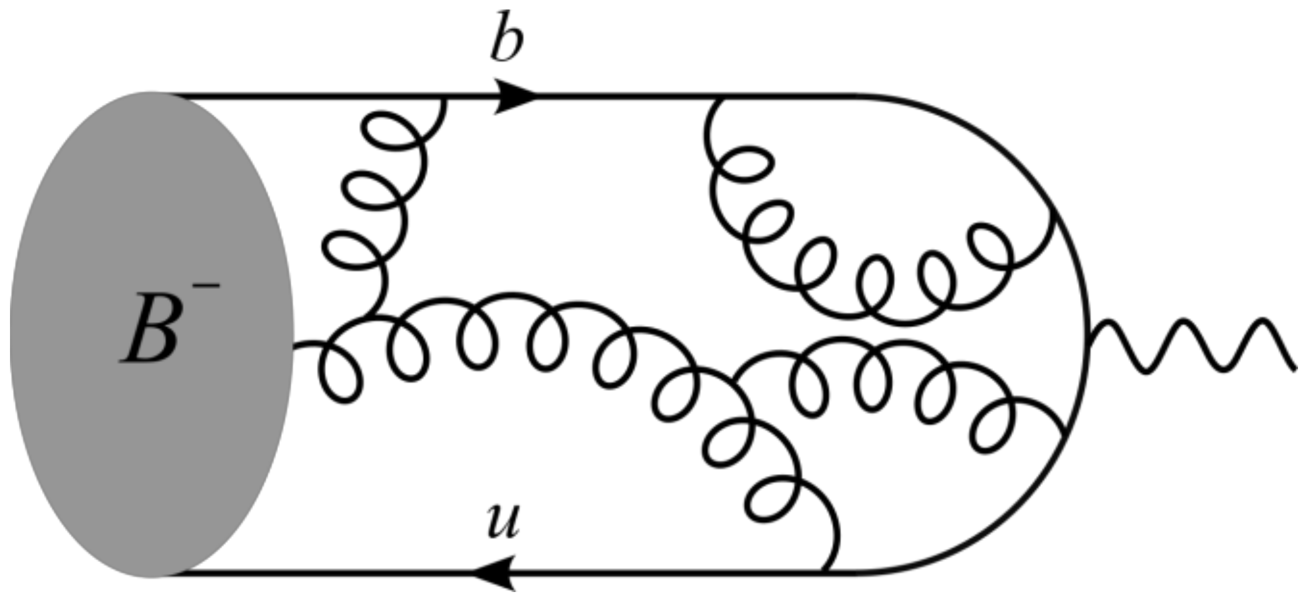
QCD perturbation theory breaks down at low energies ($\mu \sim \Lambda_{\mathrm{QCD}}$)

Non-perturbative techniques are needed
to obtain decay constants and FFs

1. Lattice QCD (LQCD)



2. QCD sum rules for decay constants
   Light-cone sum rules (LCSRs) for FFs



Complementary approaches to calculate FFs

Decay constants predictions

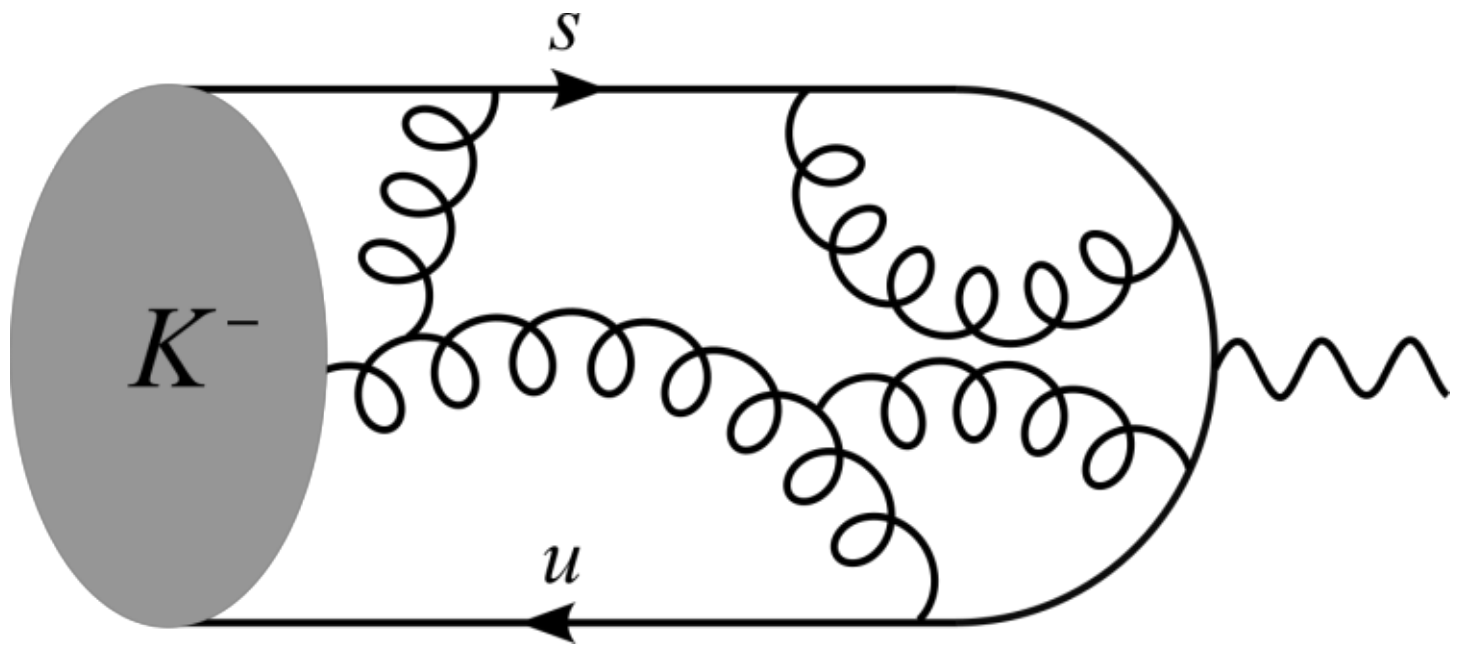
Reminder: decay constants parametrize a meson-to-vacuum matrix elements:

$$\langle 0|\bar{u}\,\gamma^\mu\gamma_5\, s|K\rangle \propto f_K$$

Available theory calculations for decay constants of interest:

FLAG average, many **LQCD** predictions

$$f_K = 155.7 \pm 0.3\ \mathrm{MeV}$$



K^* not stable in QCD $\Longrightarrow$ LQCD computation very challenging

QCD sum calculation possible but large uncertainties

Use **data driven** method, extract f_{K^*} from $\tau^+ \to K^{*+}\nu$ decays [Bharucha/Straub/Zwicky 2015]

$$f_{K^*} = 204 \pm 7\ \mathrm{MeV}$$

Form factors predictions

Reminder: the FFs parametrize a meson-to-meson matrix element:

$$\langle K|\bar{s}\gamma_\mu b|B\rangle \propto F_0(q^2) + \cdots$$

Available theory calculations for FFs of interest:

$B_{(s)} \to K$:

- LQCD calculations at high (and intermediate) q^2
  [HPQCD 2013+2014+2023] [FNAL/MILC 2015+2019] [RBC/UKQCD 2023]
- LCSR at low q^2
  [Khodjamirian/Rusov 2017] [NG/Kokulu/van Dyk 2018]

$B_{(s)} \to K^*$:

- LQCD calculations at high q^2
  [Horgan et al. 2015]
- LCSR calculation at low q^2
  [Bharucha/Straub/Zwicky 2015]
  [NG/Kokulu/van Dyk 2018]

$B_{(s)} \to K$ FFs excellent status, more LQCD results needed for $B_{(s)} \to K^*$ FFs

Combine FFs results

Combine different calculations using the parametrization of [Bharucha/Straub/Zwicky 2015]

$$F_i(q^2) = \frac{1}{1 - \frac{q^2}{m_{R,i}^2}} \sum_{n=0}^{2} \alpha_n^i \left(z(q^2) - z(0)\right)^n \qquad z(q^2) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

Fit α_n^i coefficients to available LQCD results and new LCSR results

Two problems:

Correlations among many FFs are unknown

E.g., cannot correctly propagate the unc. of

$$L_{K^*\bar{K}^*} \propto \frac{Br(\bar{B}_s \to K^{*0}\bar{K}^{*0})}{Br(\bar{B}_d \to K^{*0}\bar{K}^{*0})}$$

solution for LCSR in the next slide

LQCD results for $B_s \to K$ FFs incompatible

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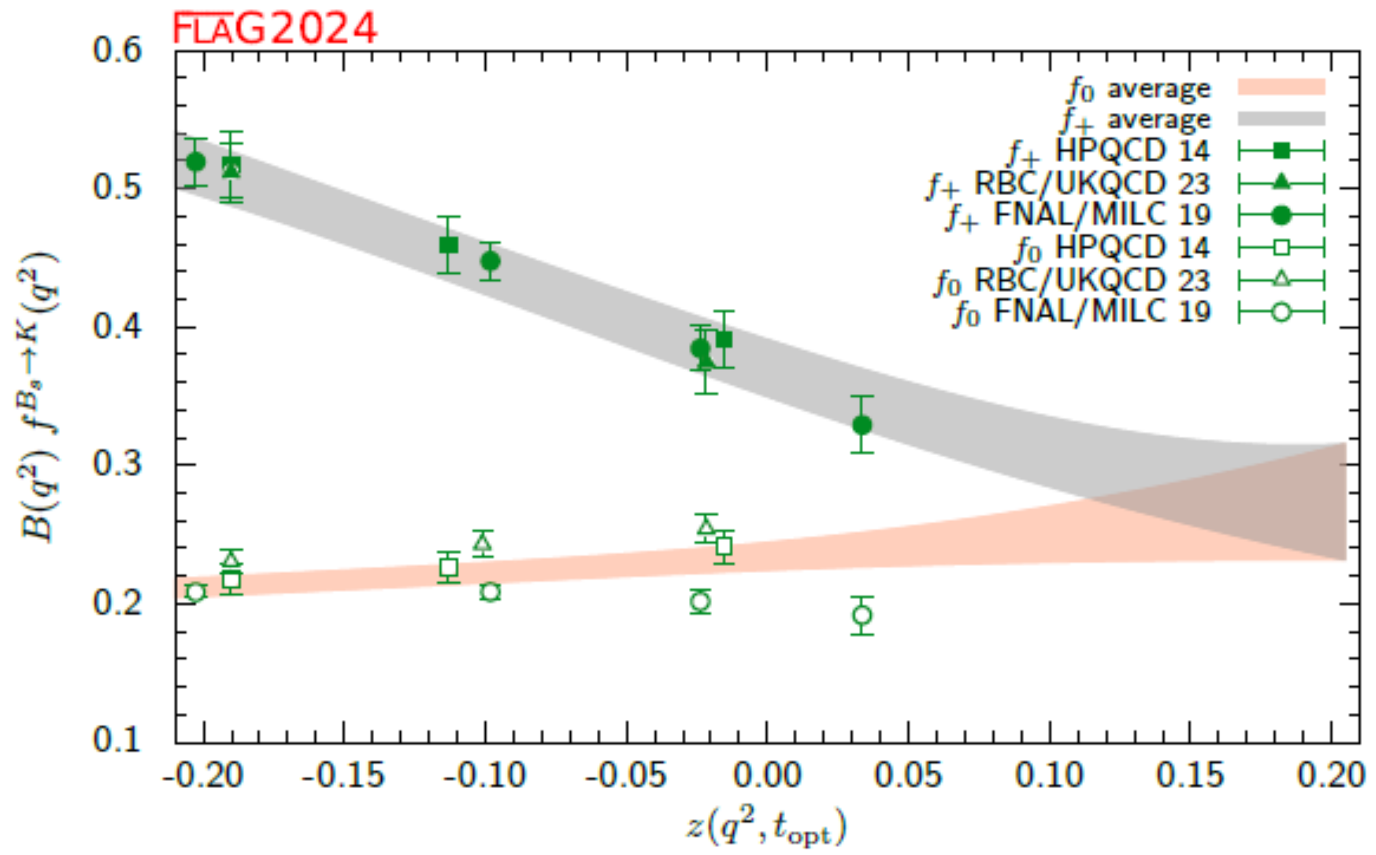

New LCSR analysis

Steps to obtain the correlations between $B_{(s)} \to K$ and $B_{(s)} \to K^*$ FFs

- Use analytical results derived in [NG/Kokulu/van Dyk 2018]

$$F_0^{B_{(s)}\to K}(q^2) \sim \sum_{t\leq 4} C_t(q^2)\, \Phi_{B,t}\left(q^2; \lambda_{B_{(s)}}\right)$$

  Main source of correlation $\lambda_{B_{(s)}}$ paramenter

- Perform a Bayesian analysis to extract
  LCSR pameters (effective thresholds) from contraints

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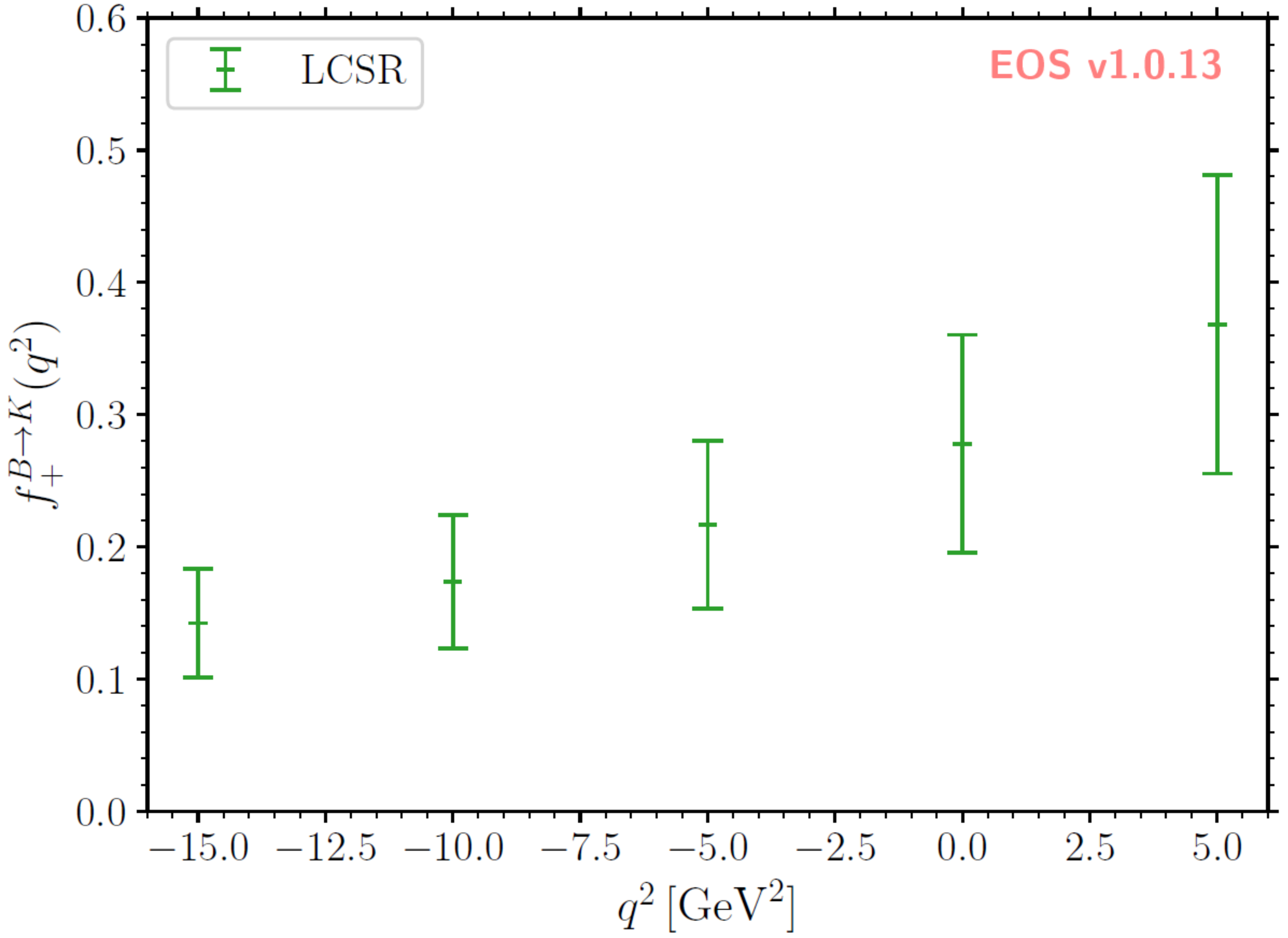
Main source of correlation $\lambda_{B_{(s)}}$ paramenter

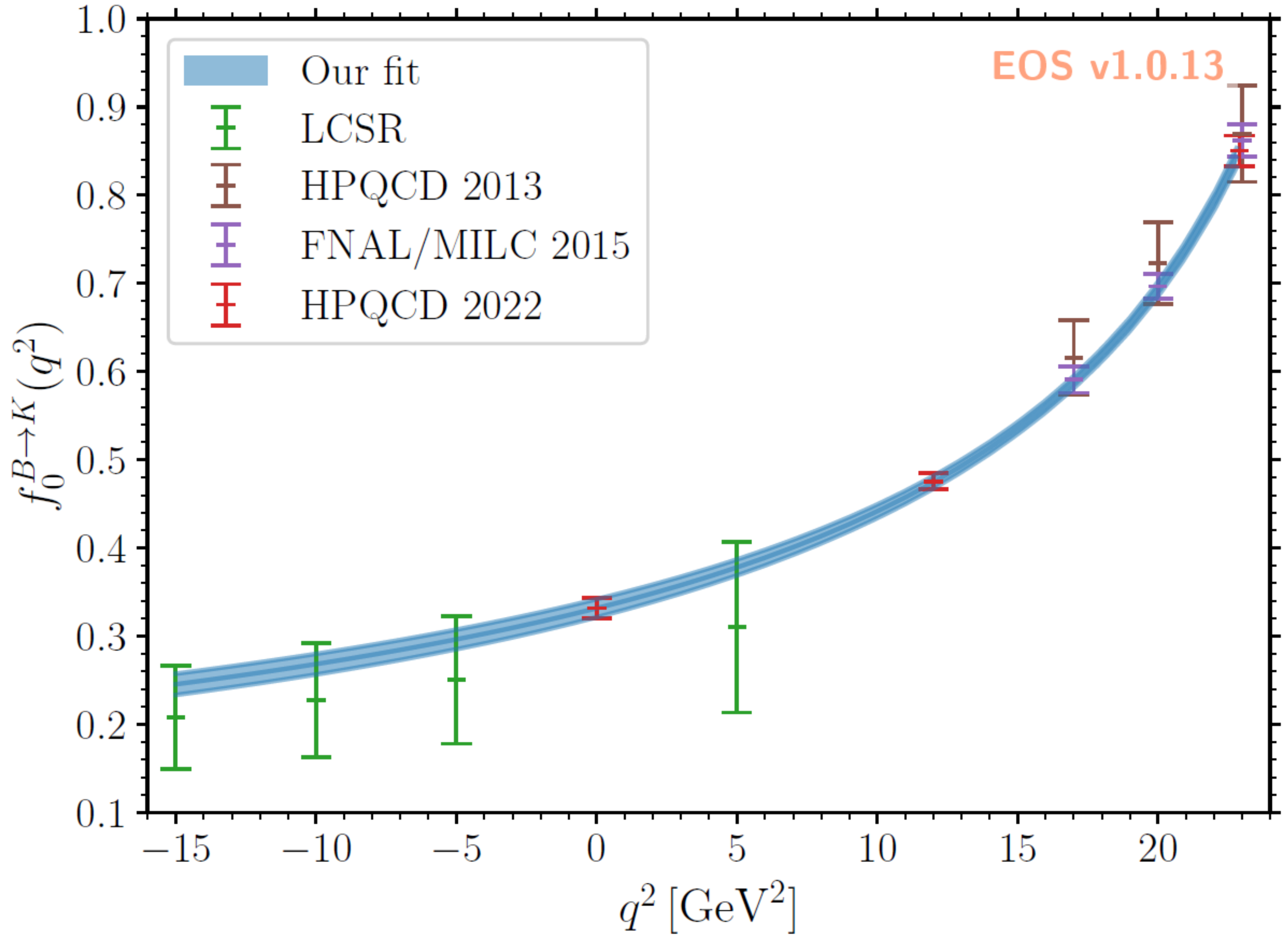
- Perform a Bayesian analysis to extract
LCSR pameters (effective thresholds) from contraints

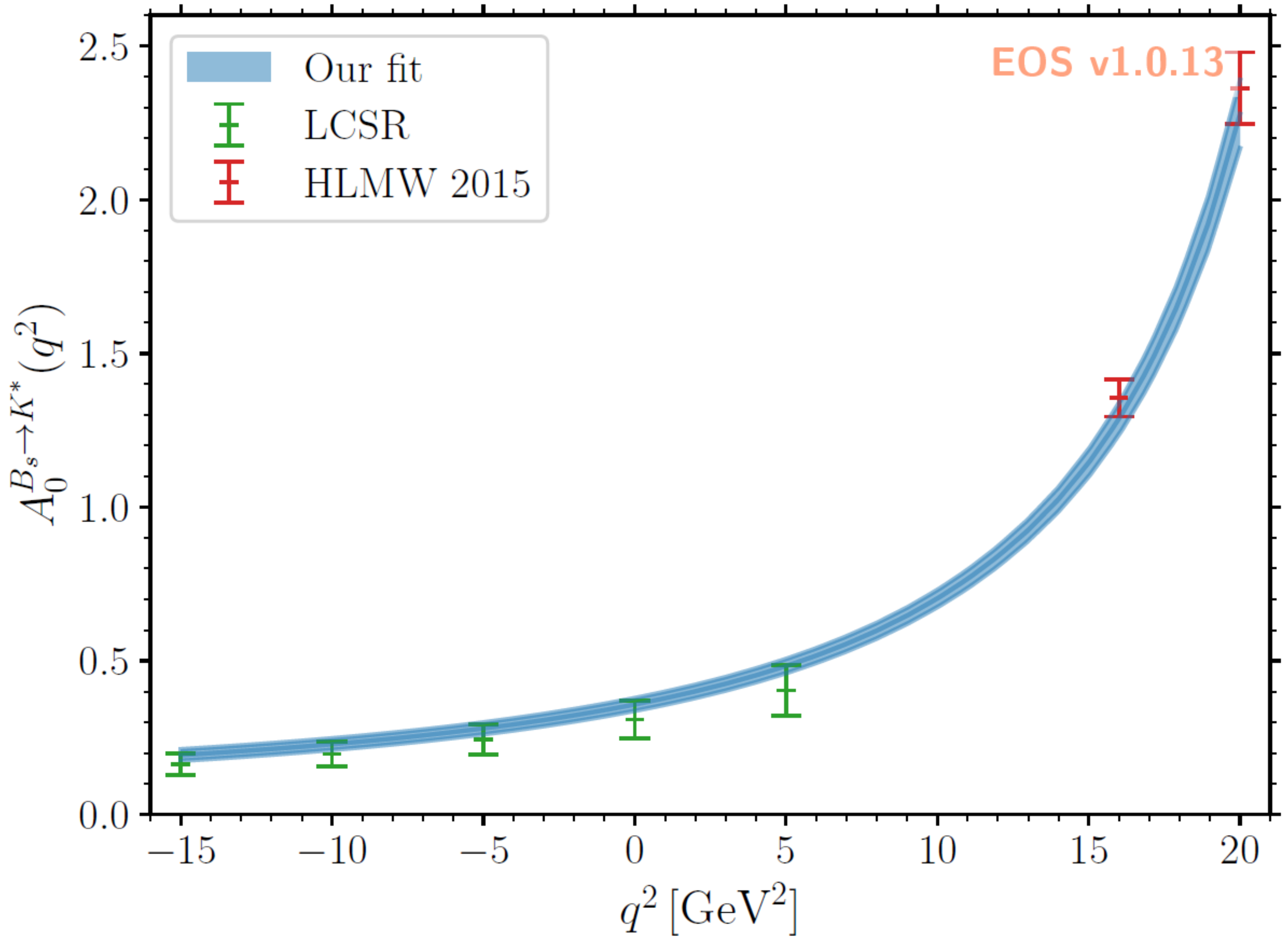
- Obtain means and correlations for all FFs
at $q^2 = \{-15, -10, -5,\ 0, +5\}\ \mathrm{GeV}^2$
(points at negative q^2 useful to constrain the fit)



Combined FFs analysis [results]

Good agreement between LQCD and LCSR results (all p-values $> 80\%$)





Results provided in machine-readable format

L-observables predictions

L-observables definition

Define **optimized observables** to cancel uncertainties
$\Longrightarrow$ higher sensitivity to NP

[Biswas/Descotes-Genon/Matias/Tetlalmatzi-Xolocotzi 2023]

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

$$L_{K\bar{K}} = \rho(m_{K^0}, m_{K^0}) \frac{Br(\bar{B}_s \to K^0\bar{K}^0)}{Br(\bar{B}_d \to K^0\bar{K}^0)}$$

$$\hat{L}_{K^*} = \rho(m_{K^0}, m_{K^{*0}}) \frac{Br(\bar{B}_s \to K^{*0}\bar{K}^0)}{Br(\bar{B}_d \to K^{*0}\bar{K}^0)}$$

$$\hat{L}_K = \rho(m_{K^0}, m_{K^{*0}}) \frac{Br(\bar{B}_s \to K^0\bar{K}^{*0})}{Br(\bar{B}_d \to K^0\bar{K}^{*0})}$$

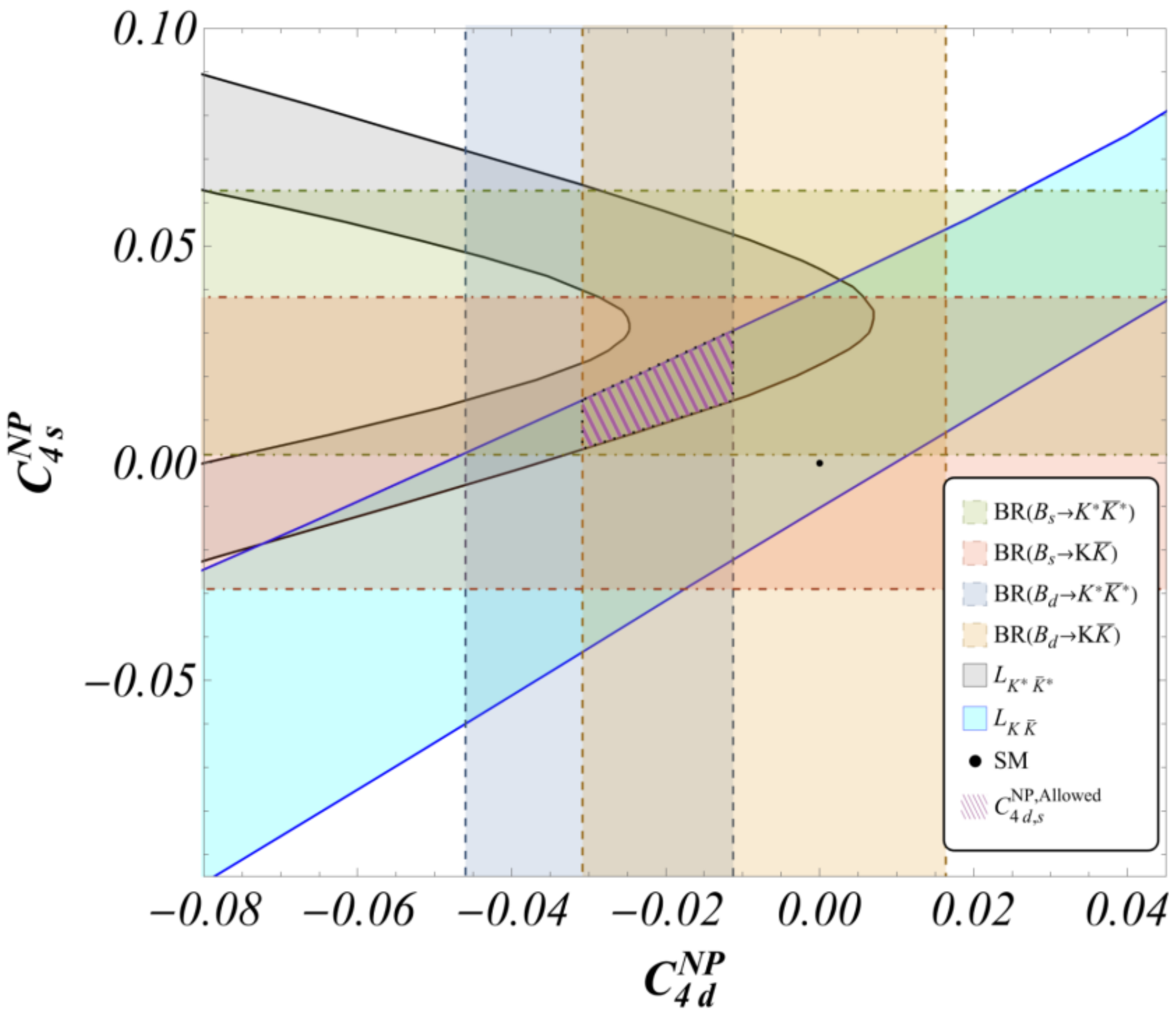
Predictions and comparison with data

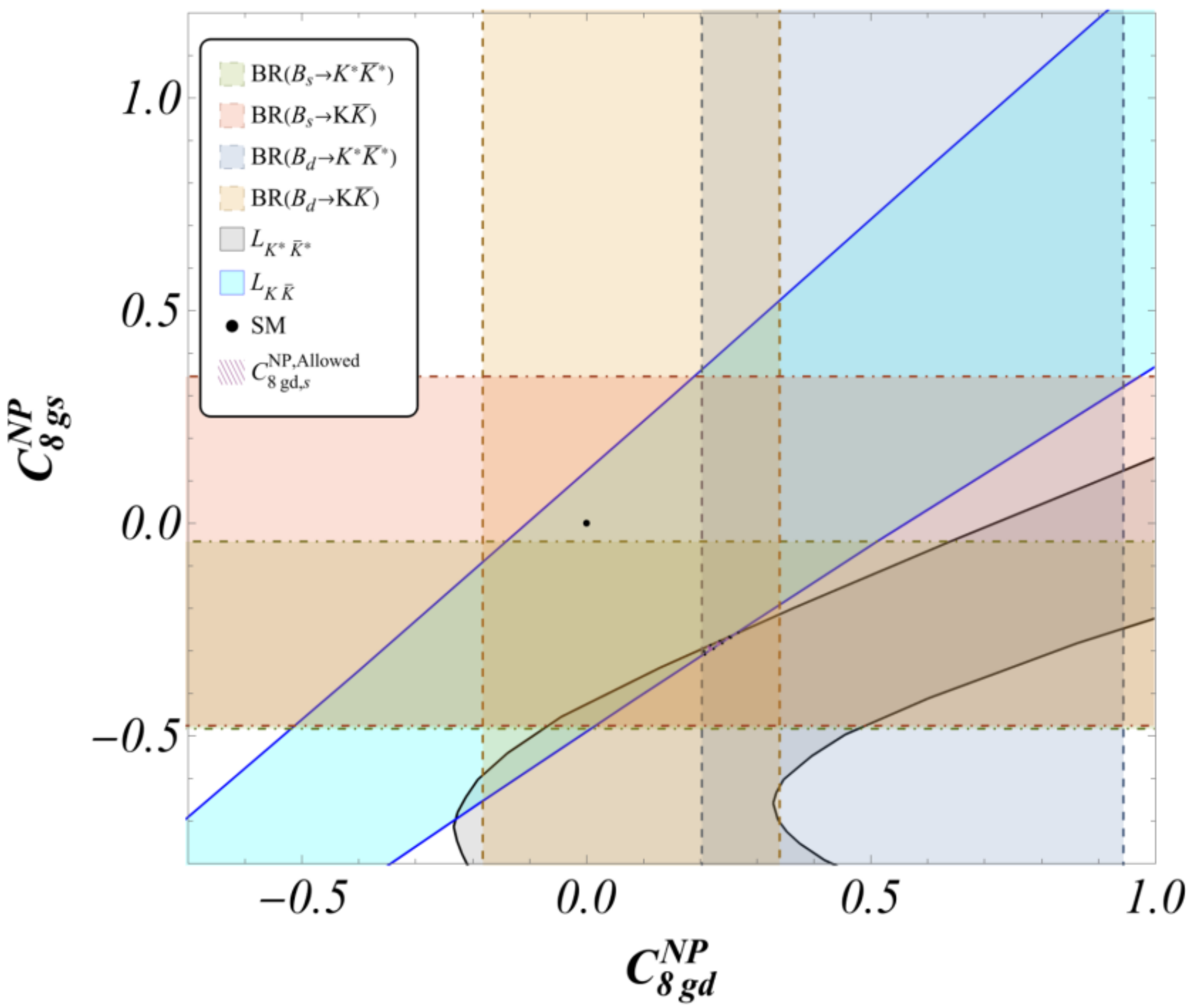
	Measurement (BaBar, LHCb, Belle)	LCSR	LQCD	LCSR+LQCD
$L_{K^*\bar{K}^*}$	4.43 ± 0.92	$18.32^{+7.47}_{-5.83}$ (2.3σ)	$22.88^{+15.35}_{-8.46}$ (2.2σ)	$26.08^{+5.70}_{-4.72}$ (4.4σ)
$L_{K\bar{K}}$	14.58 ± 3.37	$25.21^{+8.64}_{-7.67}$ (1.2σ)	$16.51^{+3.52}_{-3.27}$ (0.4σ)	$17.88^{+2.55}_{-2.42}$ (0.8σ)

Significant tension for $L_{K^*\bar{K}^*}$

Compatibility for $L_{K\bar{K}}$

Sensitivity to New Physics





$$Q_{4q} = (\bar{q}_i b_j)_{V-A} \sum_p (\bar{p}_i p_j)_{V-A}$$

$$Q_{8q} = (\bar{q}_i b_j)_{V-A} \sum_p \frac{3}{2} e_p (\bar{p}_i p_j)_{V+A}$$

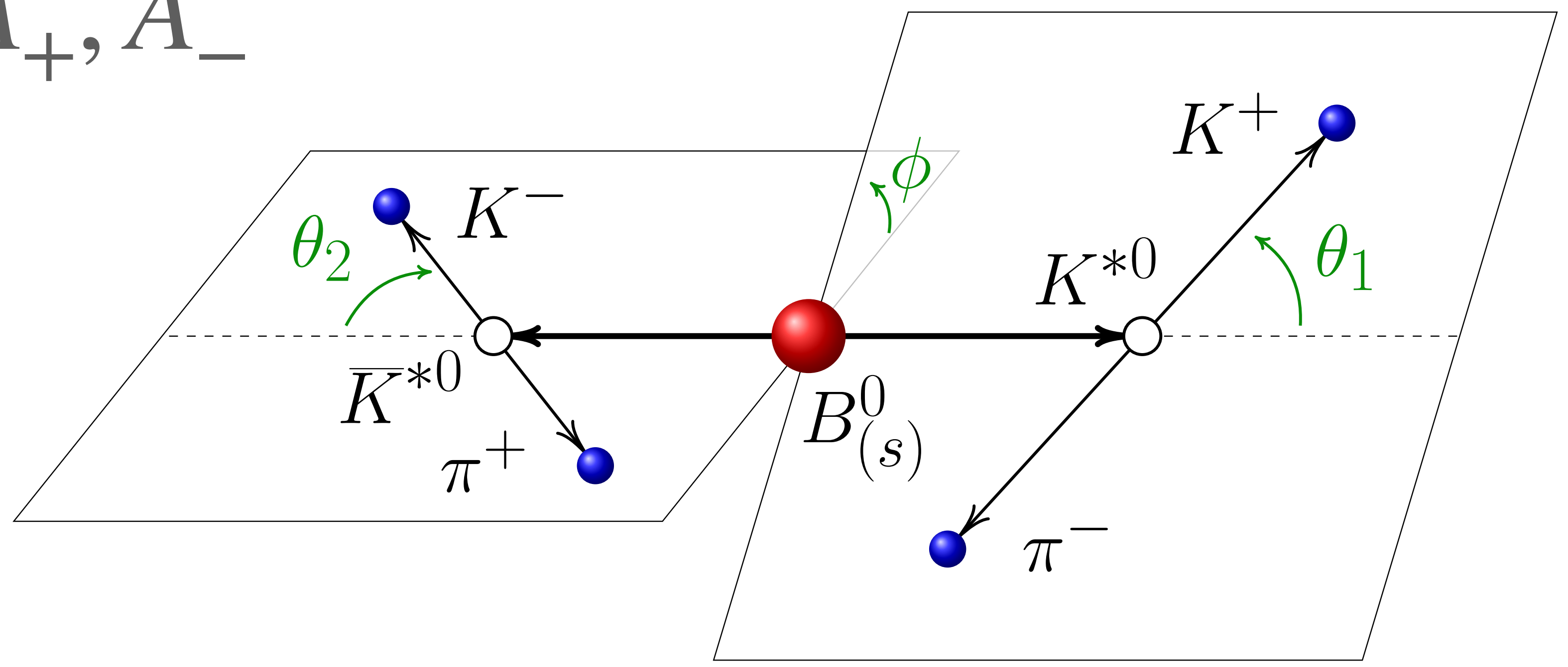
Coherent NP explanation possible

Angular analyses of $B \to VV$ decays

- L observables built from $B \to VV$ processes require amplitude analyses to access the angular properties of the decay (e.g. polarisation fractions, phases)

- Decay 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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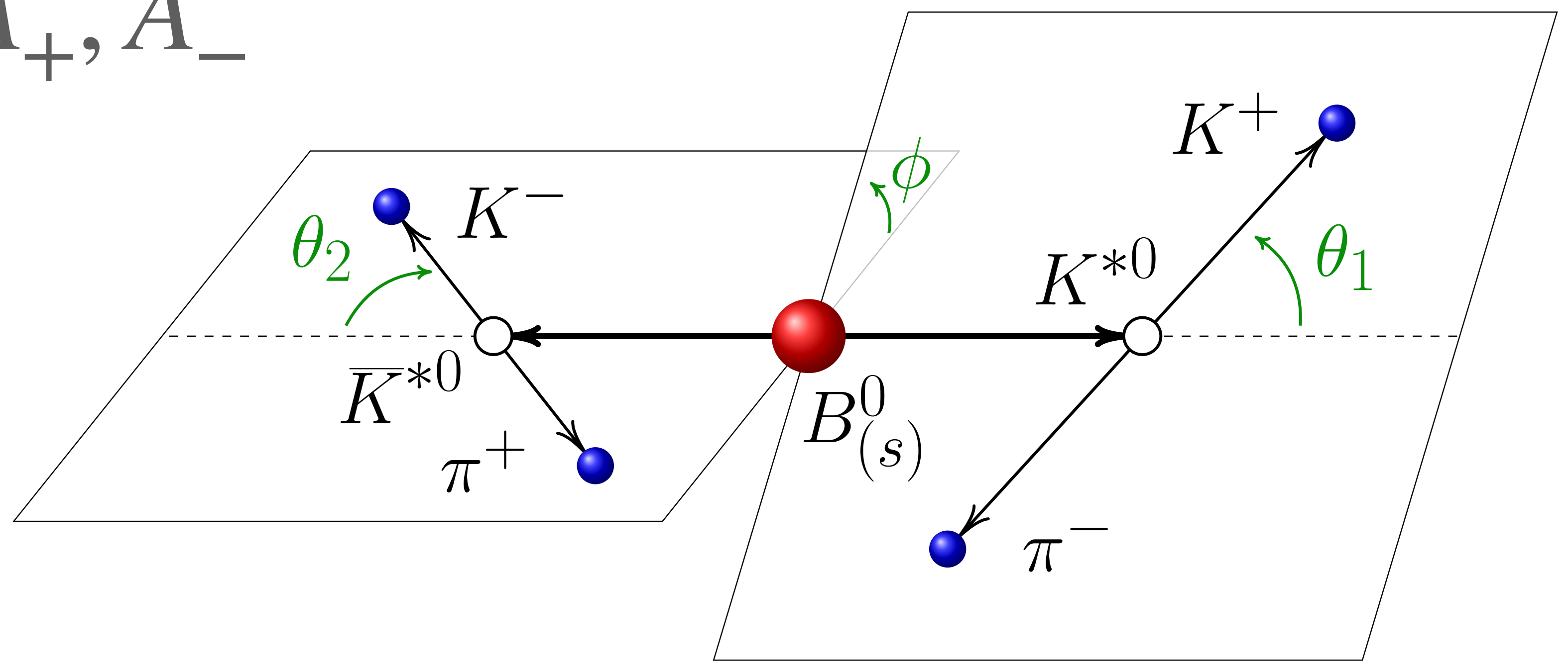

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$$f_{L,\parallel,\perp} = \frac{|A_{0,\parallel,\perp}|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2}$$

- Expectation from heavy quark symmetry is that A_0 should prevail over the other two:

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

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

- Part of long standing polarisation puzzle — this amplitude herarchy seems to be respected in tree level $B \to VV$ decays but not in loop induced $B \to VV$ decays
    - Penguin dominated $B^0_s \to K^{*0}\bar{K}^{*0}$ 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

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

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- Leading contributions to systematic uncert. are the Blatt-Weisskopf barrier factors (TD analysis) and S-wave parametrisation in (TI analysis)
  - Reduce syst. uncert. in ϕ_s measurement + luminosity scaling from including Run2 will make $f_L^{B_s}$ systematic dominated

Covariant tensor formalism: motivation

- Terms in the angular amplitude take the form:

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

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

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

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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. $K^*(700)^0 \to K^+\pi^-, K^*(1430)^0 \to K^+\pi^-$
- S-wave is the largest contribution in the $K^*(892)^0$ region (amounts to $50 - 70\,\%$)

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- Increase the lever arm into S-wave constraint:

  $((K^\pm\pi^\mp)_{\text{threshold}} < m(K^\pm\pi^\mp) < 1042)$ 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 rescattering after the process of hadronisation

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

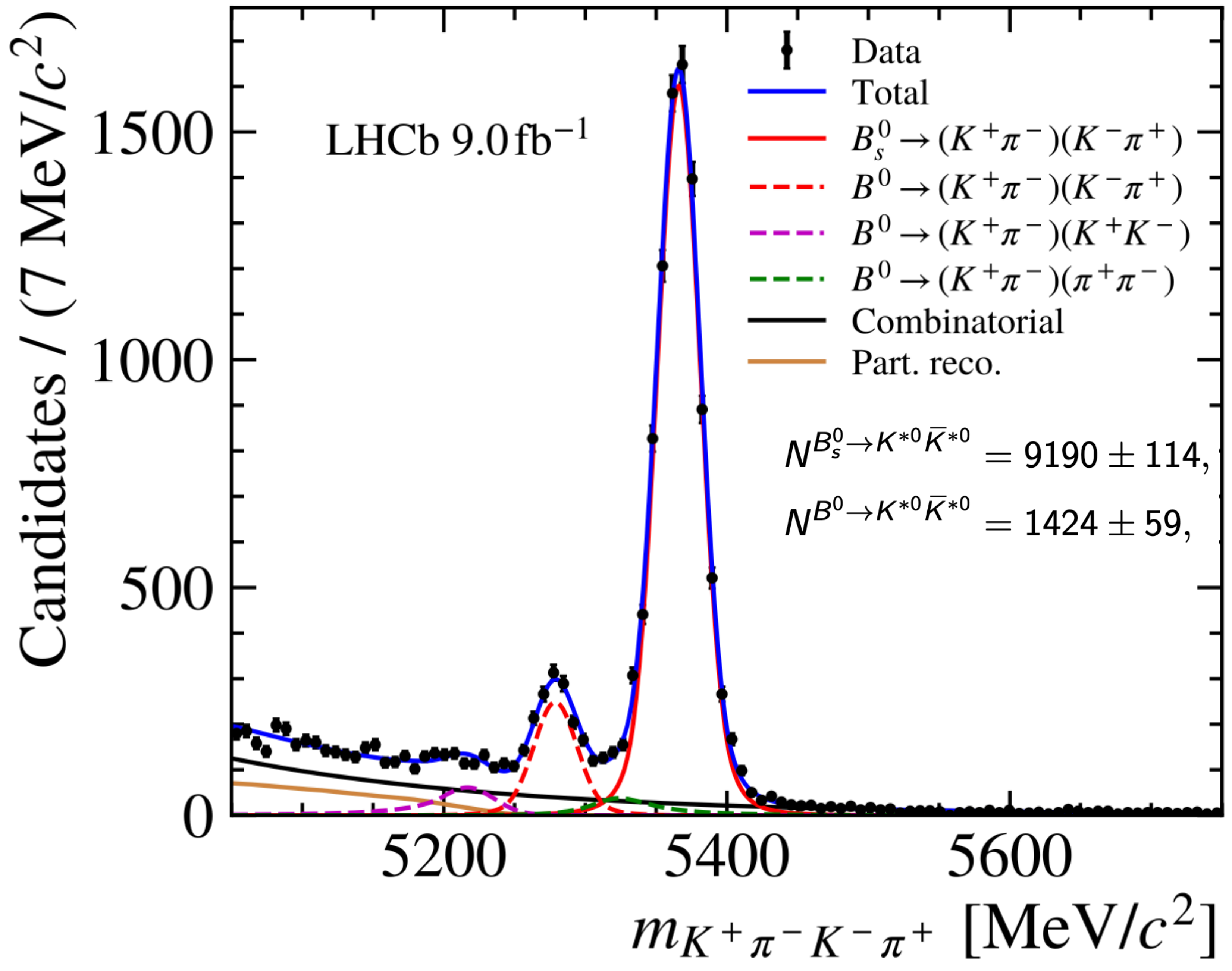
- $P(s)$ unknown production function → use QMI approach and parametrise with complex polynomial of degree 4 with parameters $c_i^{\text{Abs}}, c_i^{\text{Arg}}$ determined from a fit to the data ($X(s)$ conformal mapping)

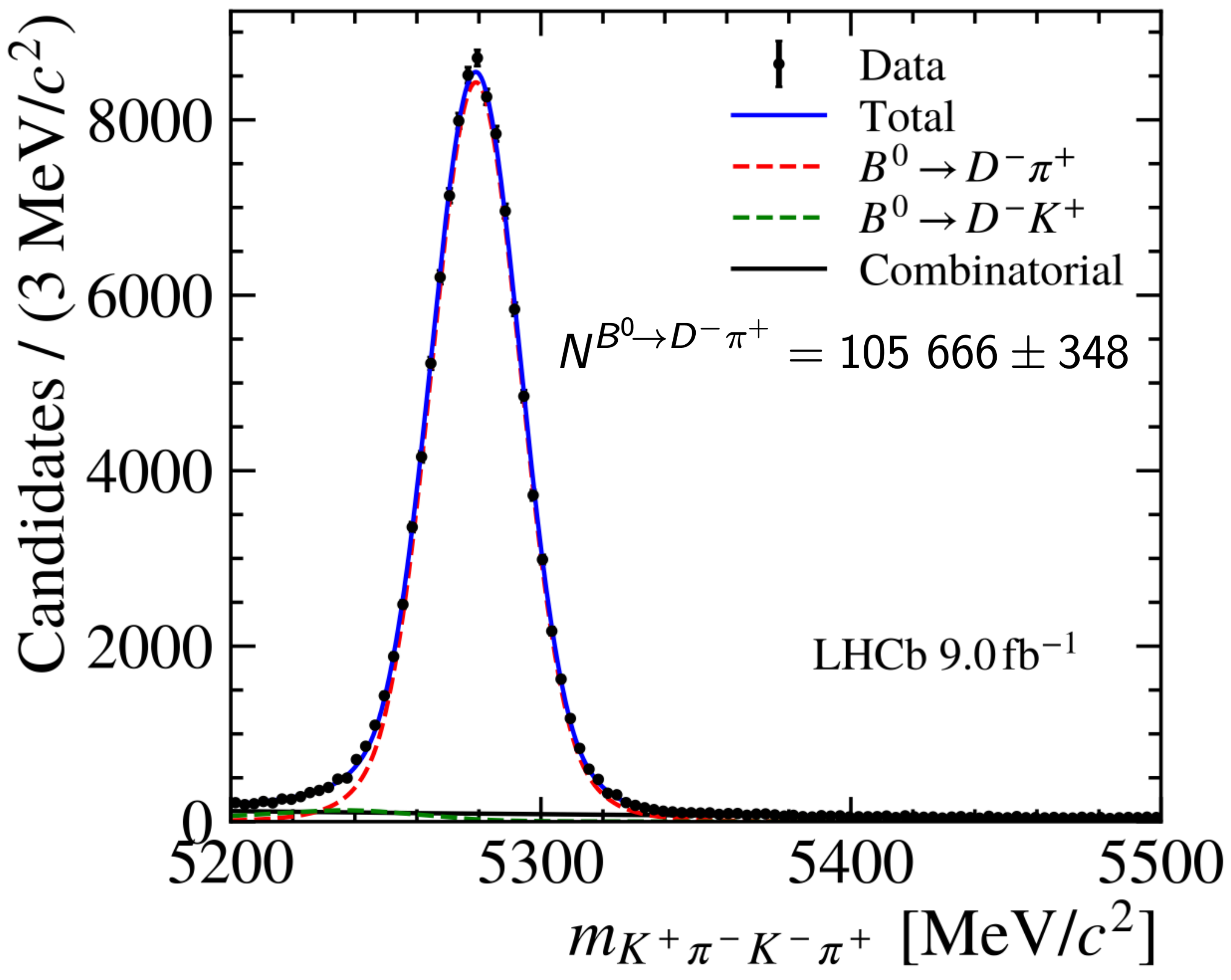
$$P(s) = \left(1 + c_1^{\text{Abs}}\, X(s) + c_2^{\text{Abs}}\, X^2(s) + \ldots\right)\, e^{i\left(c_1^{\text{Arg}}\, X(s) + c_2^{\text{Arg}}\, X^2(s) + \ldots\right)}$$

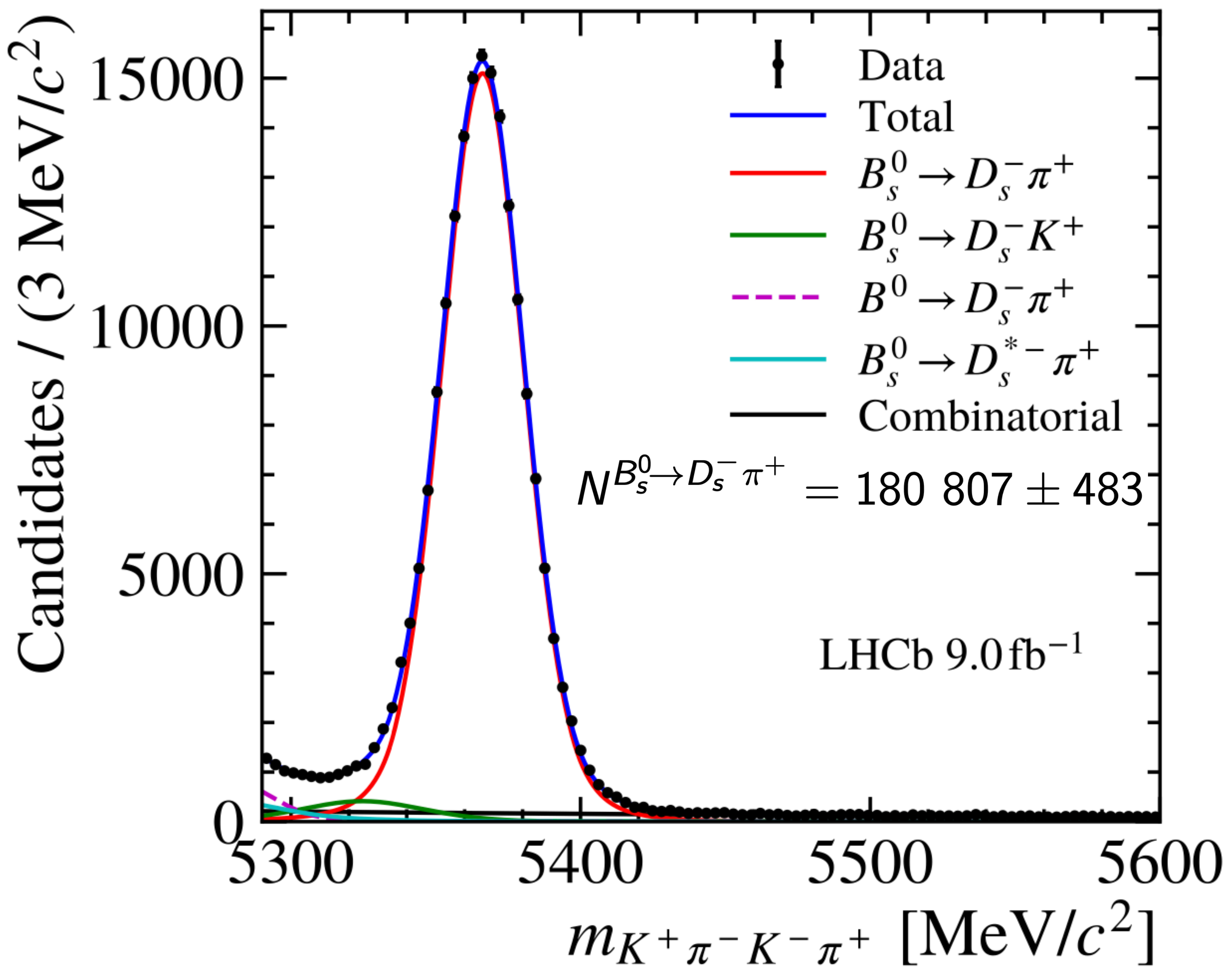
Invariant B mass fits

[arXiv:2512.05102] Accepted by PRD

- 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 $B_s^0 \to K^{*0}\bar{K}^{*0}$ and $B^0 \to K^{*0}\bar{K}^{*0}$ is also derived separately:
  - Normalise with respect to open charm decays $B_s^0 \to D_s^-\pi^+$ and $B^0 \to D^-\pi^+$ with identicalnumber of K and π in the final state:







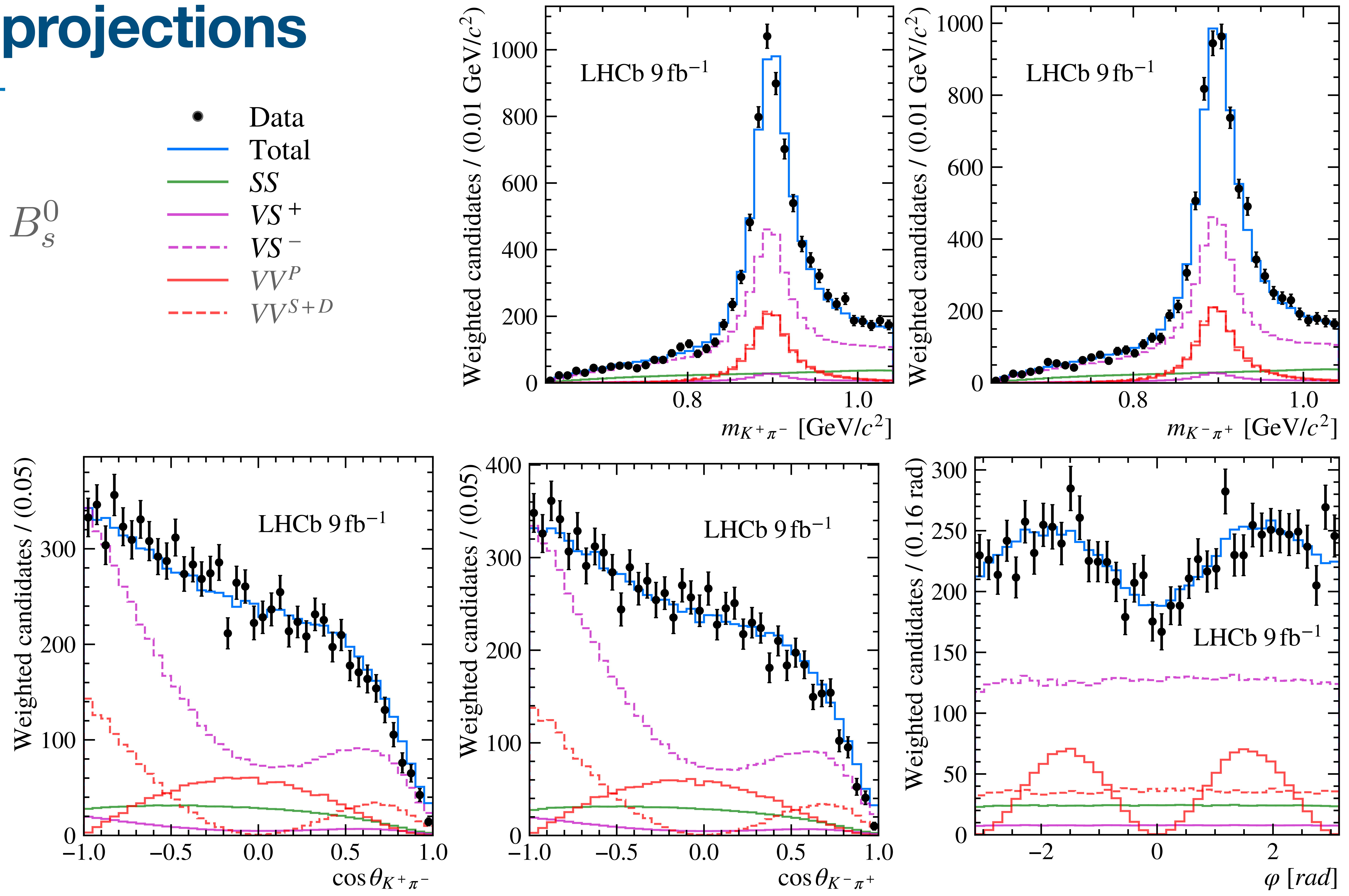
[arXiv:2512.05102] Accepted by PRD

Angular fit projections

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

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

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



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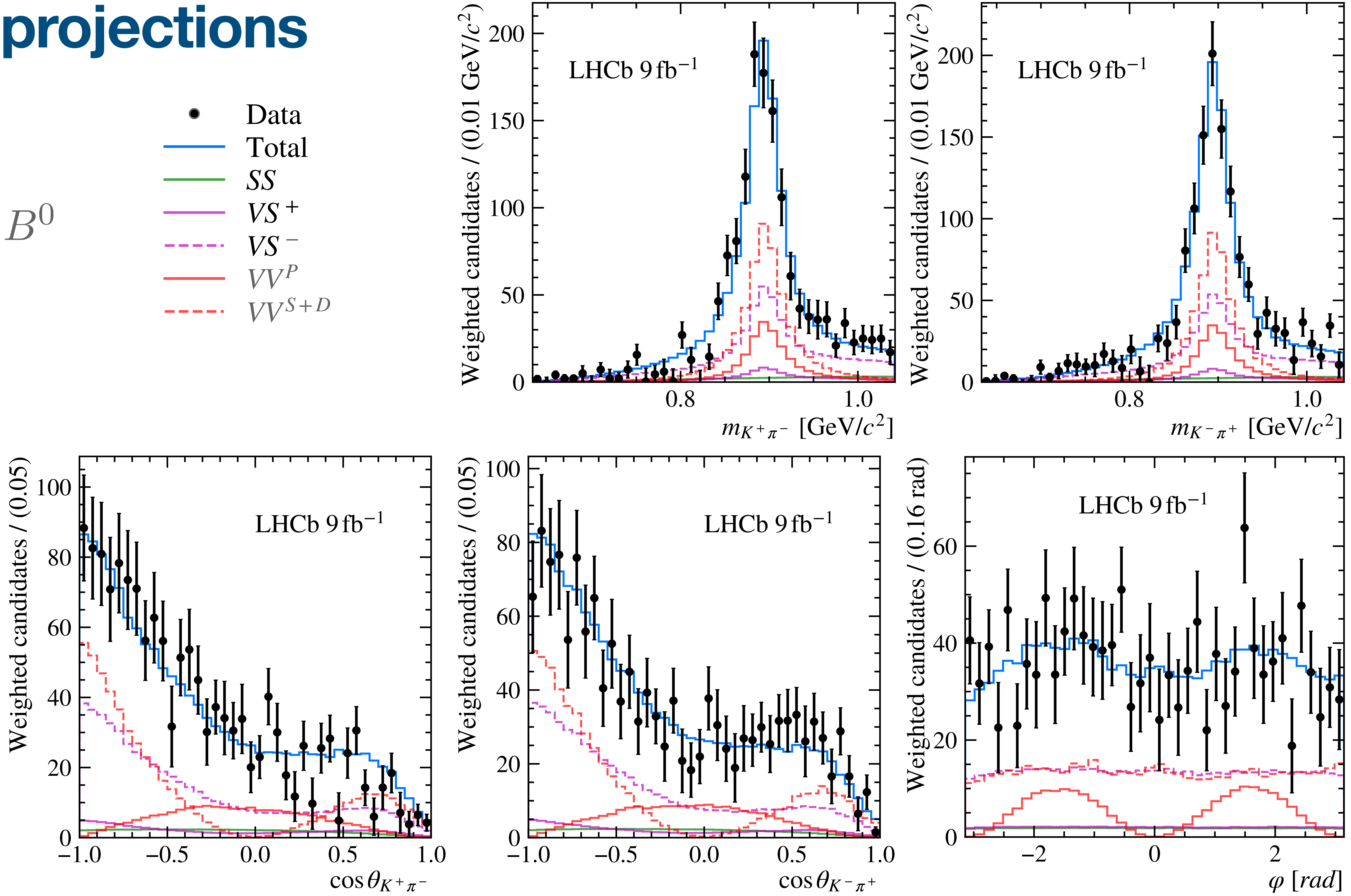


Result recasting to helicity basis

[arXiv:2512.05102] Accepted by PRD

- 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 pseudoexperiments from the fit result:
  - Fit back with angular amplitude in trasversity basis in 3D

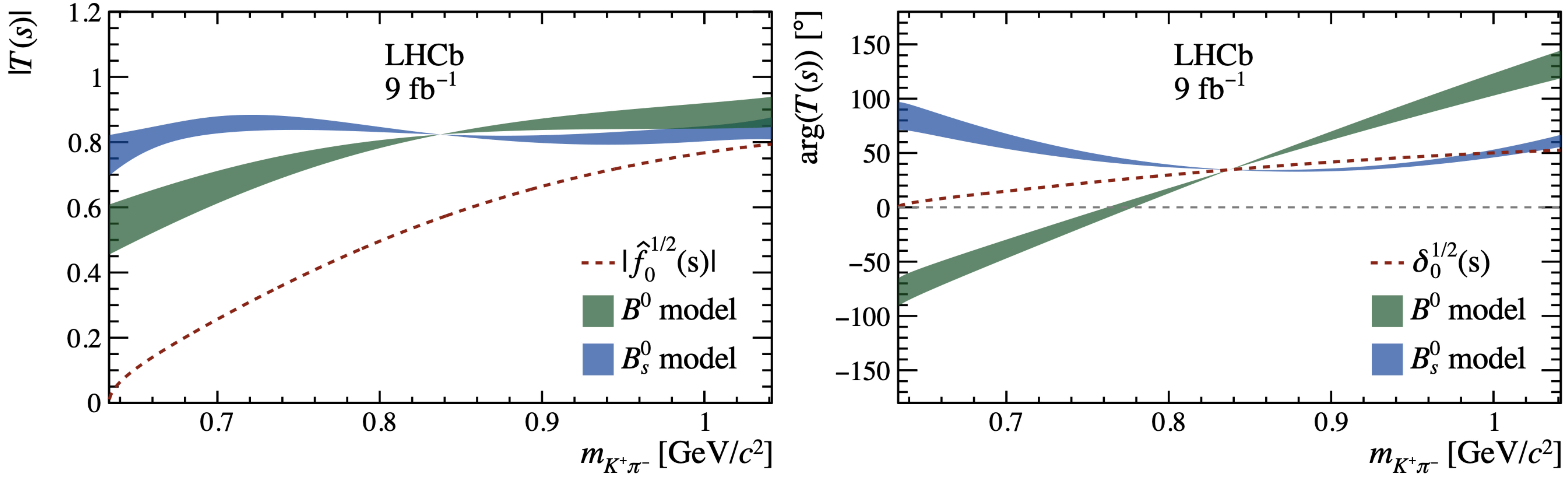
$$A_{V\overline{V}}(\theta_{K^+\pi^-}, \theta_{K^-\pi^+}, \varphi) \propto A_L \cos\theta_{K^+\pi^-} \cos\theta_{K^-\pi^+} + \frac{A_\parallel}{\sqrt{2}} \sin\theta_{K^+\pi^-} \sin\theta_{K^-\pi^+} \cos\varphi + \frac{A_\perp}{\sqrt{2}} \sin\theta_{K^+\pi^-} \sin\theta_{K^-\pi^+} \sin\varphi$$

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

Surfing the S-wave: results

[arXiv:2512.05102] Accepted by PRD

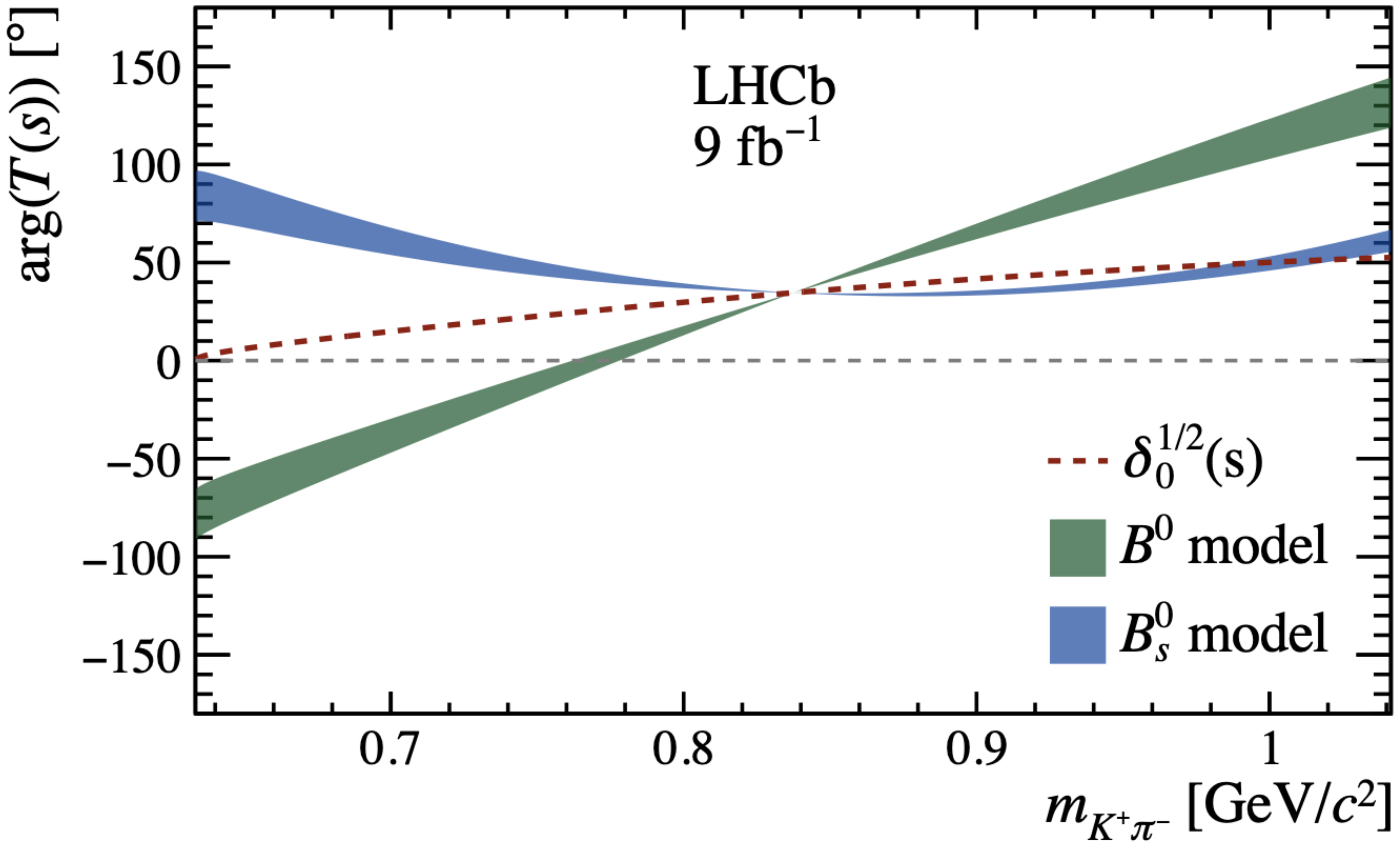
- Run1 + Run2 result for the transition amplitude $T_{(K\pi)_S}(s)$ in $B^0_{(s)} \to (K^+\pi^-)(K^-\pi^+)$ decays

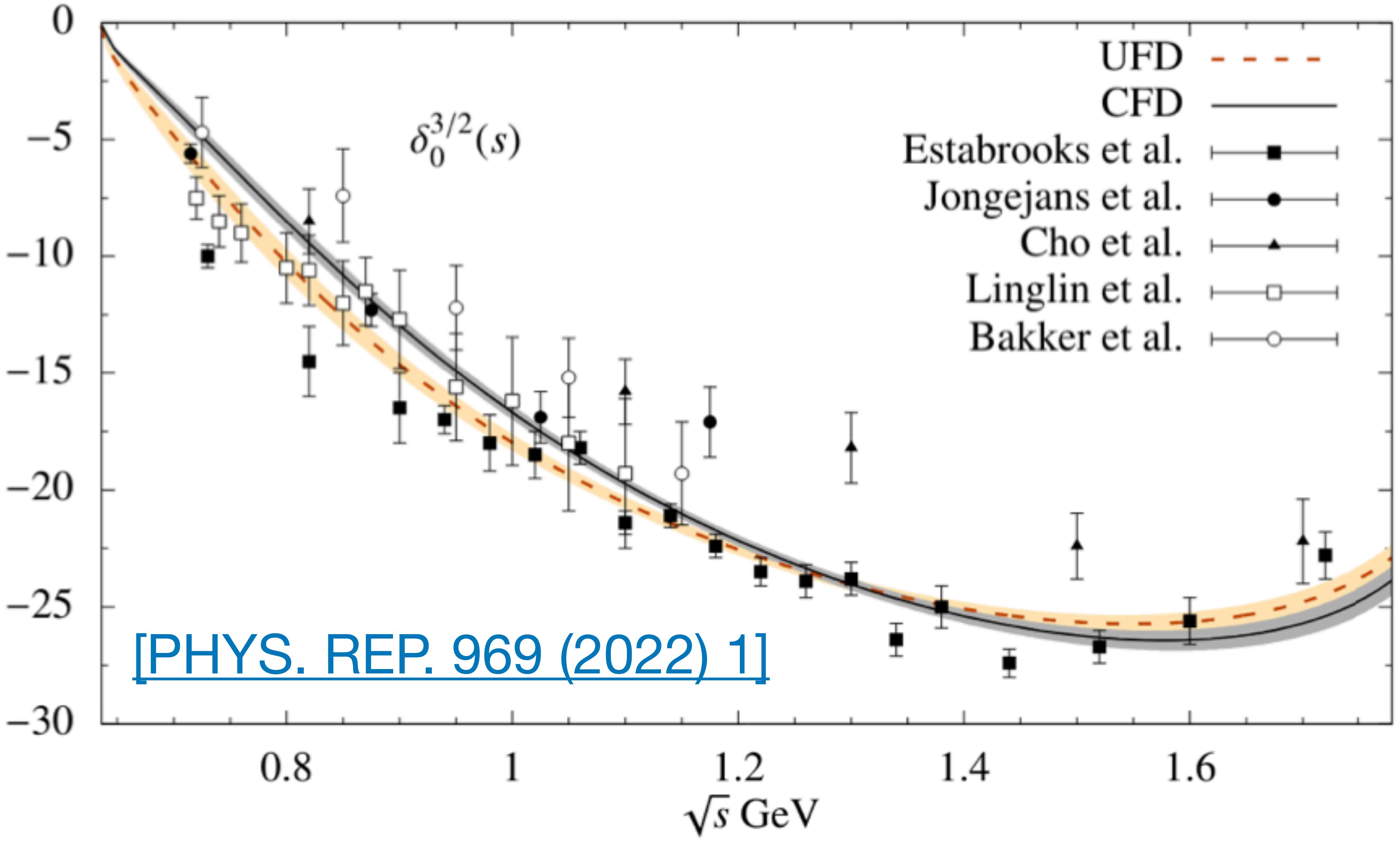


- Dashed curve is pure $I = 1/2$ scattering transition amplitude $T_{K\pi \to K\pi}(s)$
  - Deviation in magnitude showing impact of production amplitude
  - Watson's theorem: phase is the same for s, t and u diagrams, i.e. the phase from the re-scattering term is the same phase in the production term
    - Significant shift in $Arg(T(s))$ implies naive violation of Watson's theorem

Surfing the S-wave: results

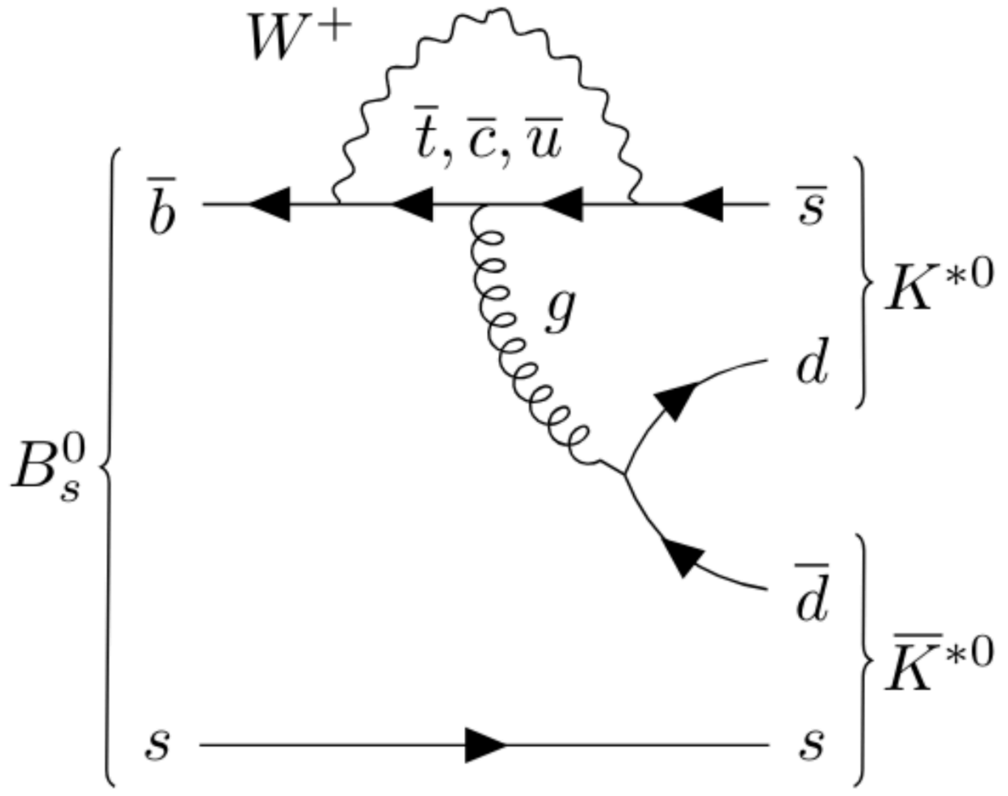
[arXiv:2512.05102] Accepted by PRD





[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



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

[arXiv:2512.05102] Accepted by PRD

- 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

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

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

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

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

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

Experimental prospects

[JHEP 06 (2023) 108]

[JHEP 08 (2024) 030]

- Several Run 1 + Run 2 $B \to VV$ 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

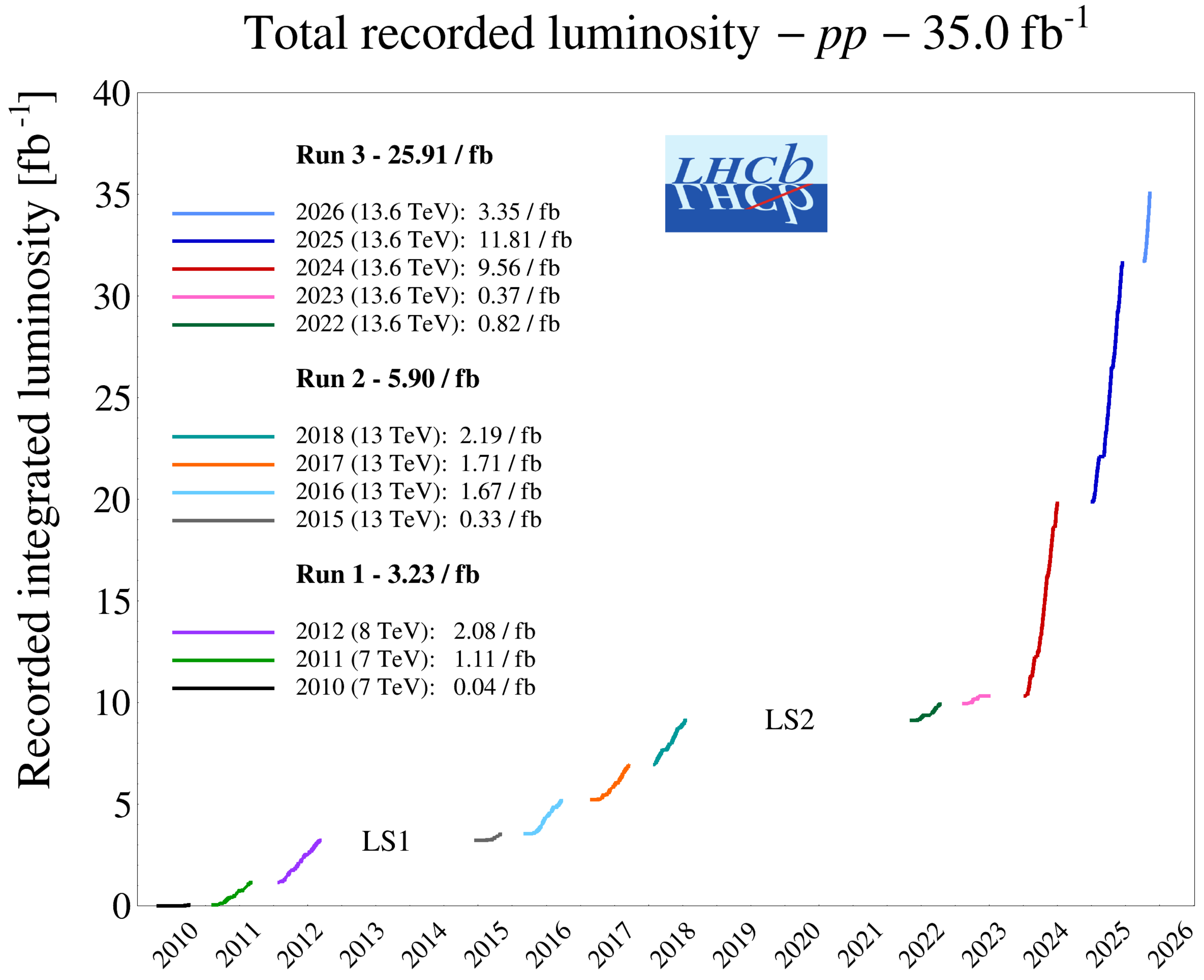
L measurements with other modes are inbound

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

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 is collecting record luminosity
- Having moved to fully software based trigger roughly doubles the number of signal candidates per pb^{-1}

  → huge dataset of charmless B decays to explore



Shown today

- New LCSR analysis for $B_{(s)} \to K$ and $B_{(s)} \to K^*$ FFs with correlations

  Combination with available Lattice QCD results (z expansion)

  New predictions for $B_{(s)} \to K$ and $B_{(s)} \to K^*$ FFs

- Updated QCD factorization predictions for L-observables

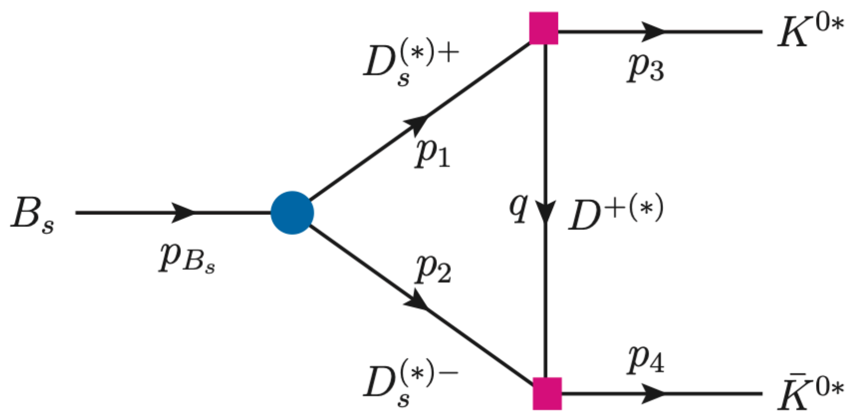
  Significant tension for $L_{K^*\bar{K}^*}$ (4.4σ), compatibility for $L_{K\bar{K}}$

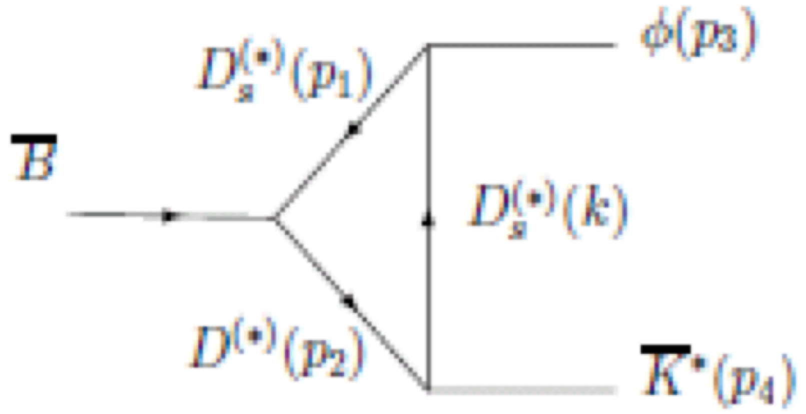
  Coherent NP explanation possible

- Updated measurement of $B^0_{(s)} \to K^{*0}\bar{K}^{*0}$ using Run1+Run2 data

  - Improved systematics related to S-wave modelling and amplitude parametrisation

Discussion





- Polarisation puzzle is confirmed by latest LHCb measurements.
  - But is this really a puzzle? What about long-distance rescattering contributions?
  - Eg see arXiv:2405.16054 (it is actually an old story started with $B^0_{(s)} \to \phi K^{*0}$: arXiv:0409317)
  - Coherence in different modes appearing from global fits might be suggesting otherwise? eg arXiv:2601.05324
- Can lattice improvements reduce the theory uncertainties on L observables?
- Can the improvements in $B^0_{(s)} \to K^{*0}\bar{K}^{*0}$ S-wave parametrisation be exported to other channels? Would there be any advantage?
  - Currently being used to model S-wave of misID contributions in $B^0_{(s)} \to \rho^0 K^{*0}$ analysis

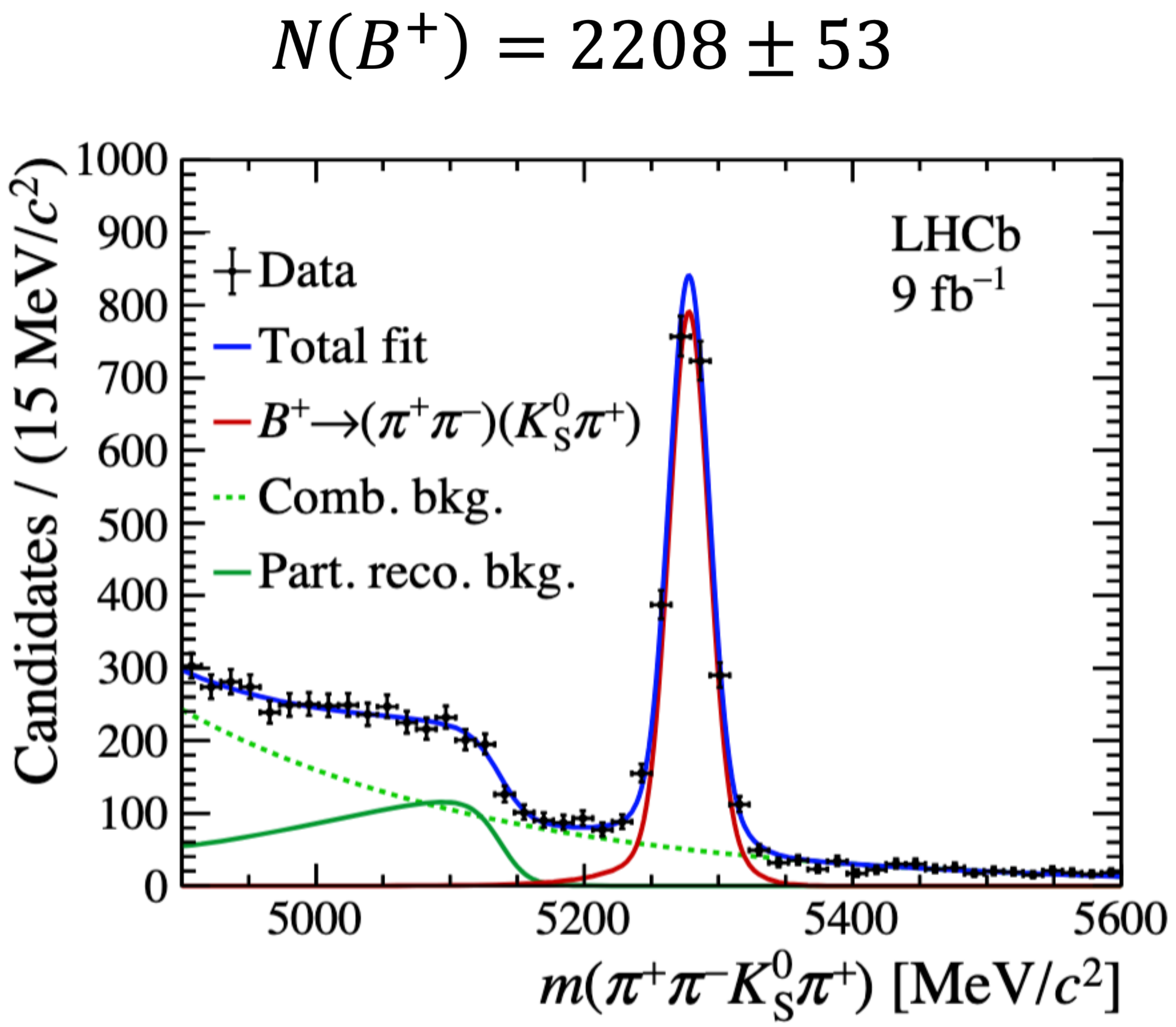
Thanks for listening

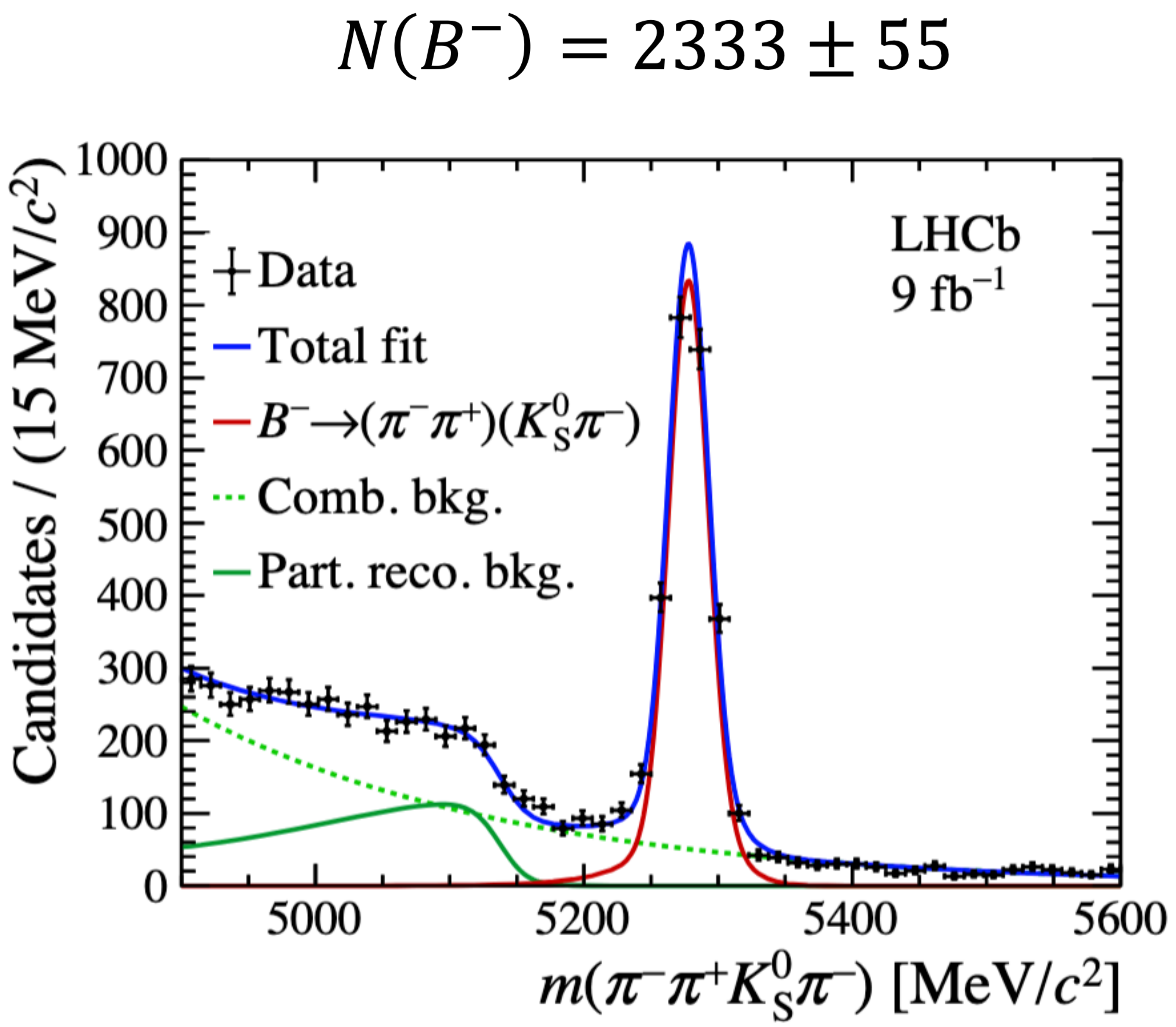
Spare slides

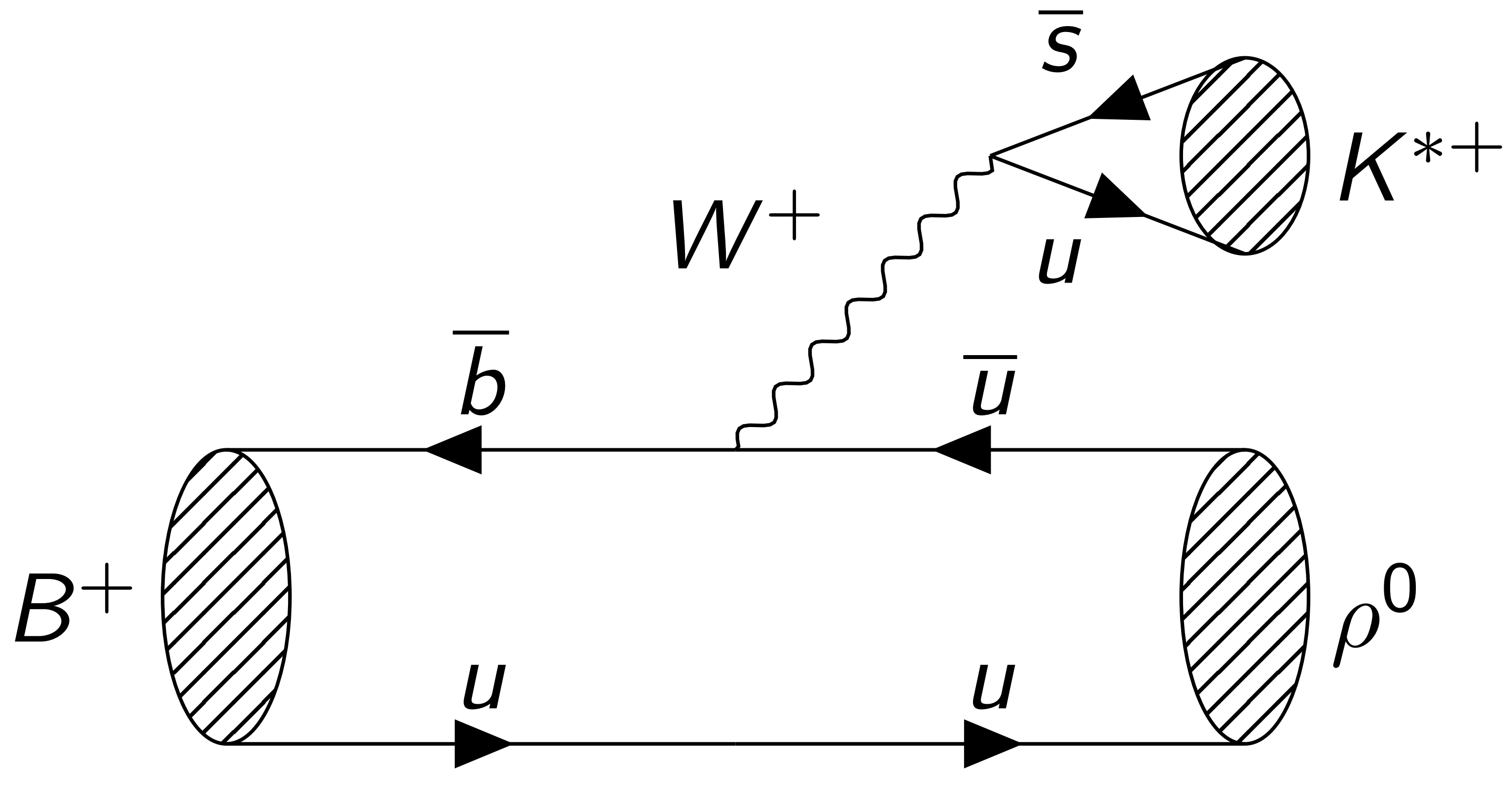
Amplitude analysis of $B^+ \to \rho^0 K^{*+}$

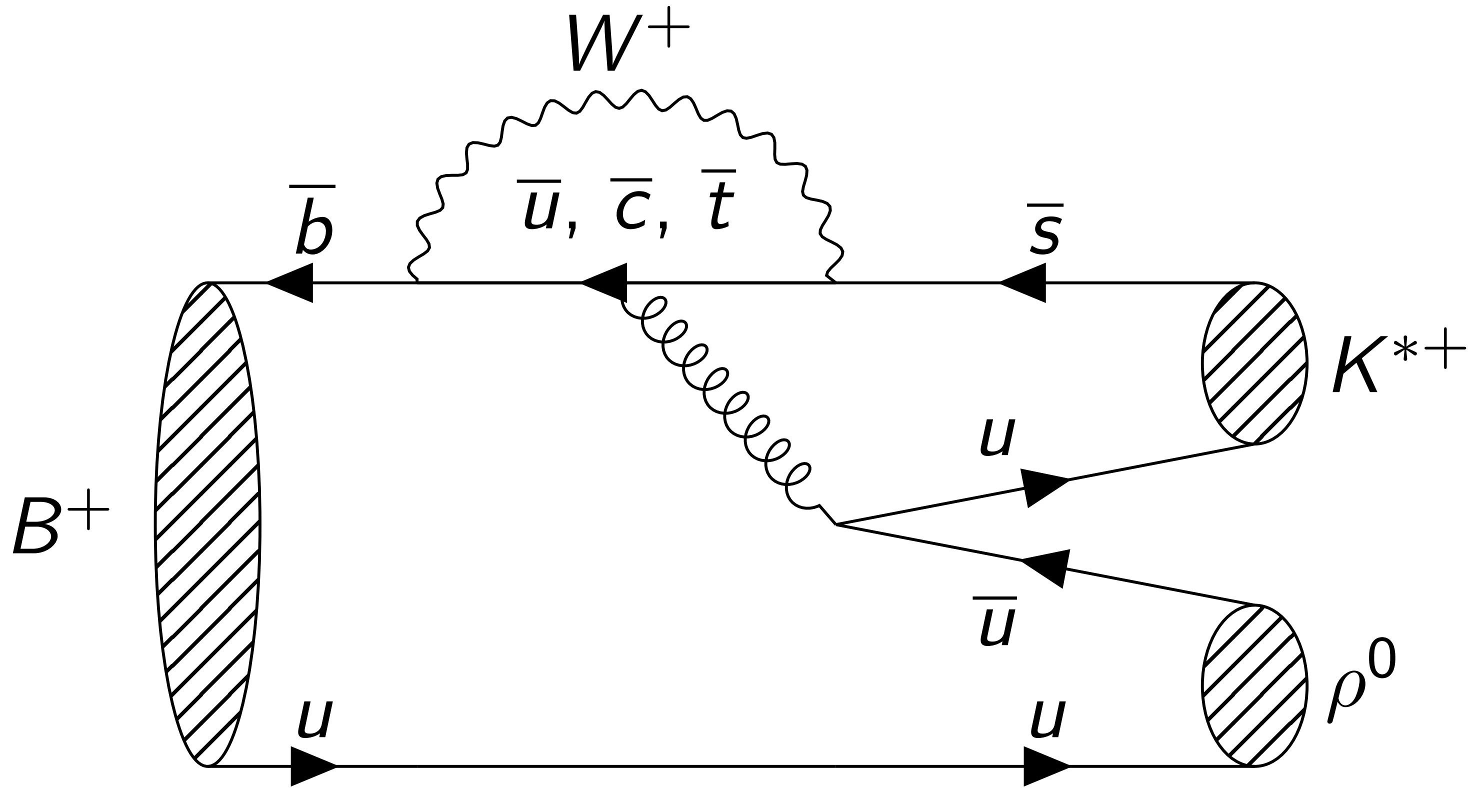
[PRL 136 (2026) 021803]

- 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 $\rho^0 \to \pi^+\pi^-$, $K^{*+} \to K^0_S\pi^+$









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

[PRL 136 (2026) 021803]

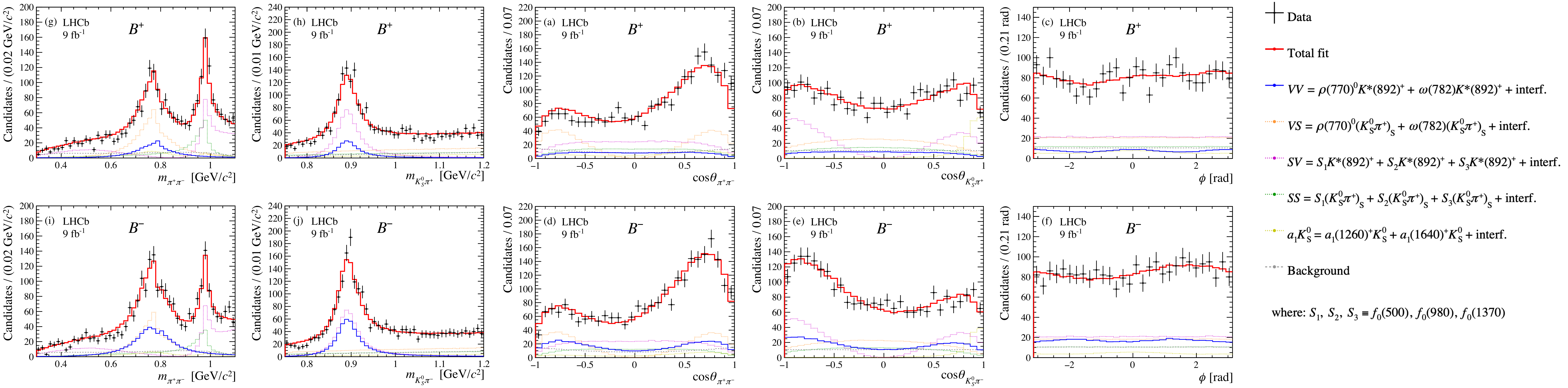
- 5D amplitude analysis of $B^+ \to (\pi^+\pi^-)(K_S^0\pi^+)$ in the phase-space regions of
  - $(0.3 < m(\pi^+\pi^-) < 1.1)$ GeV/c^2
  - $(0.75 < m(K_S^0\pi^+) < 1.2)$ GeV/c^2
- Simultaneous fit to B^+ and B^- candidates

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

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

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

$a_1(1260)$, $a_1(1640)$ $\otimes$ 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)

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

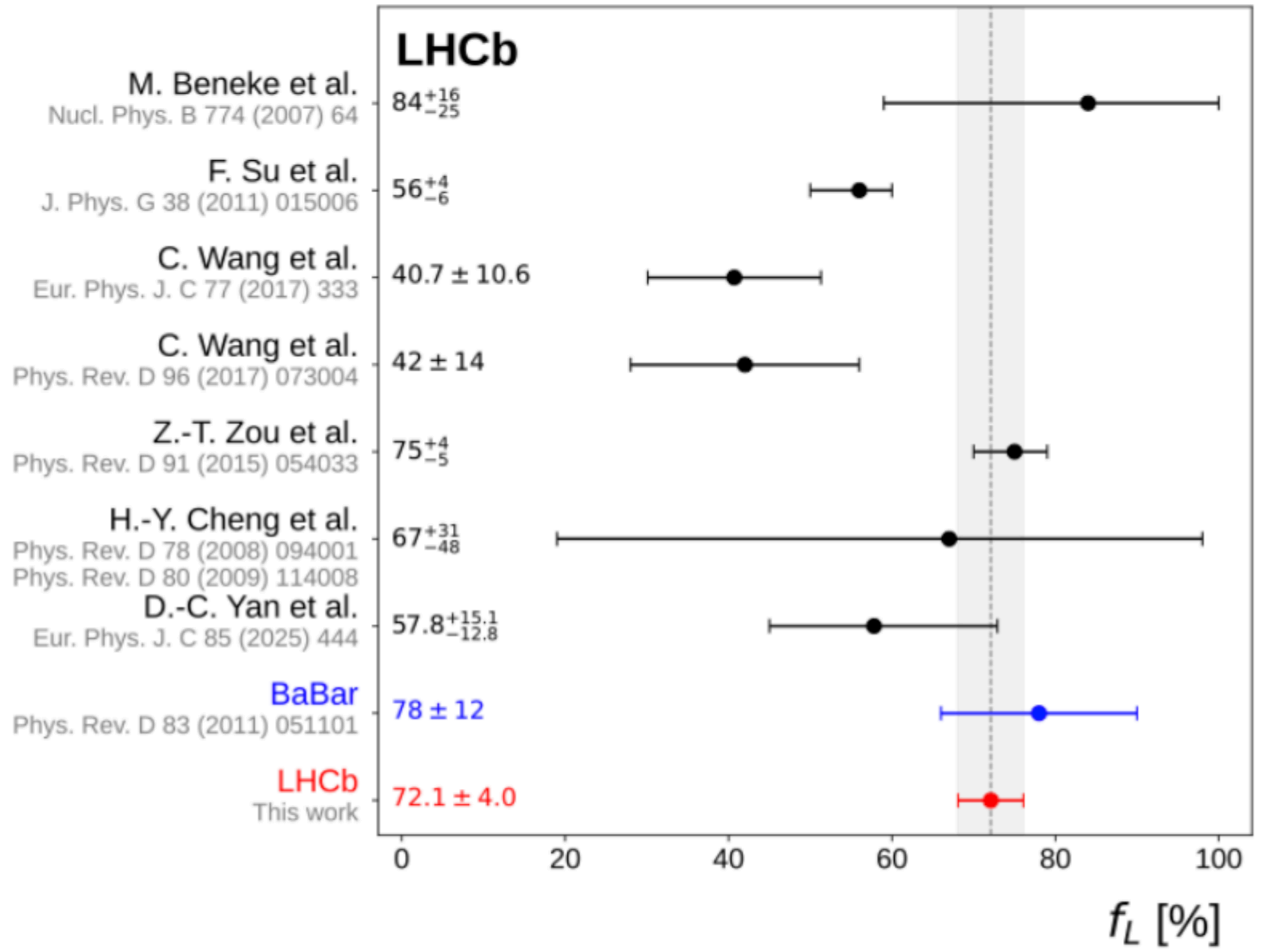
- Magnitude and phase of CP asymmetries for single polarisation amplitudes and fractions:

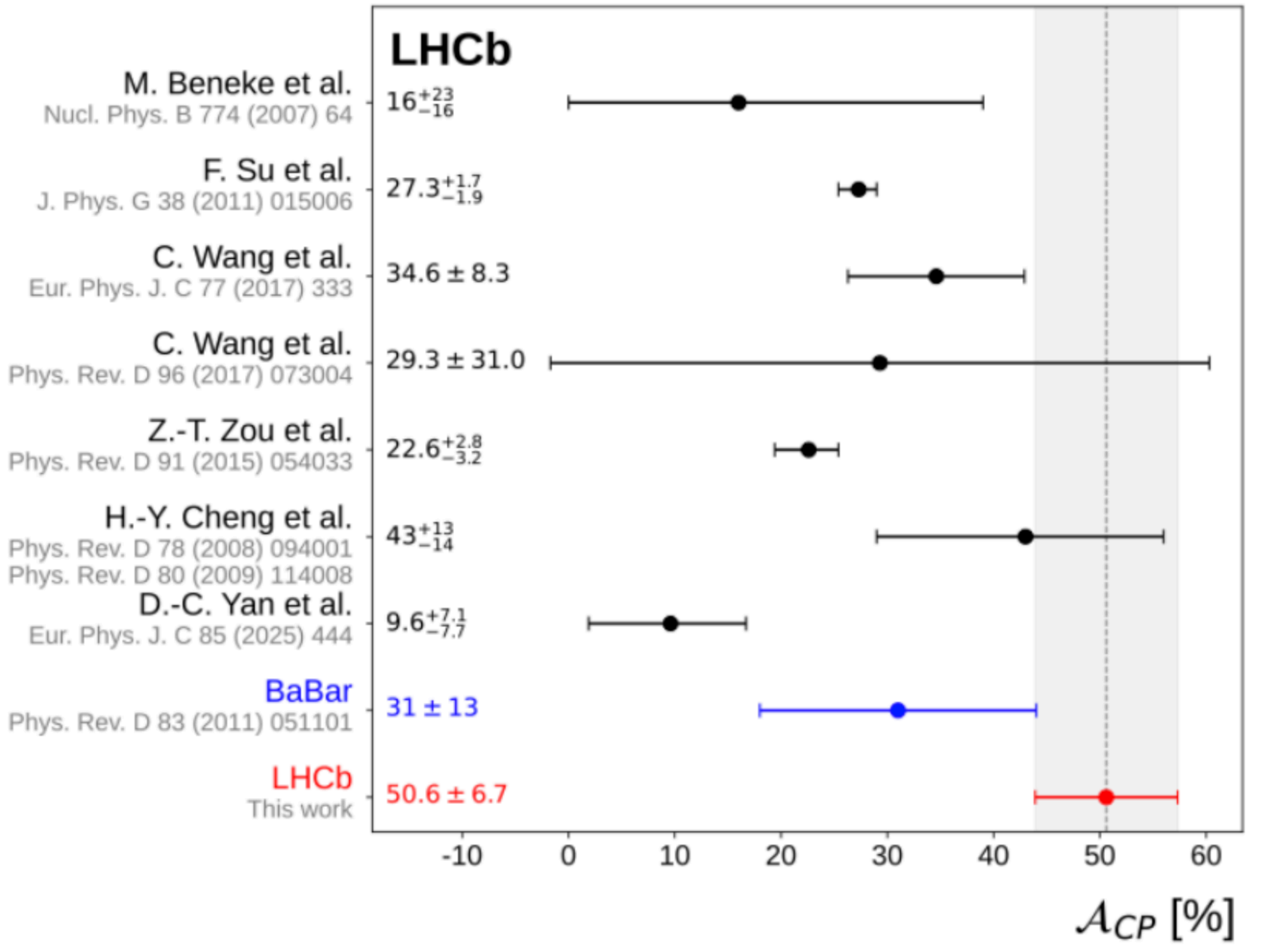
$$\mathcal{A}_{CP}(|A_0|^2) \equiv \frac{|\bar{A}_0|^2 - |A_0|^2}{|\bar{A}_0|^2 + |A_0|^2} = 0.666 \pm 0.081 \pm 0.048,$$

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

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

CP violation is driven by the longitudinal component





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
    - Trialled alternative parametrisations
  - S-wave and Blatt-Weisskopf not leading syst anymore
    - S-wave syst Assessed by moving to LASS parametrisation

Source	$\mathcal{B}(B^0 \to K^{*0}\bar{K}^{*0})$ $\times 10^{-8}$	$\mathcal{B}(B_s^0 \to K^{*0}\bar{K}^{*0})$ $\times 10^{-7}$	$\frac{\mathcal{B}(B^0\to K^{*0}\bar{K}^{*0})}{\mathcal{B}(B_s^0\to K^{*0}\bar{K}^{*0})}$ $\times 10^{-3}$	$L_{K^{*0}\bar{K}^{*0}}$
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