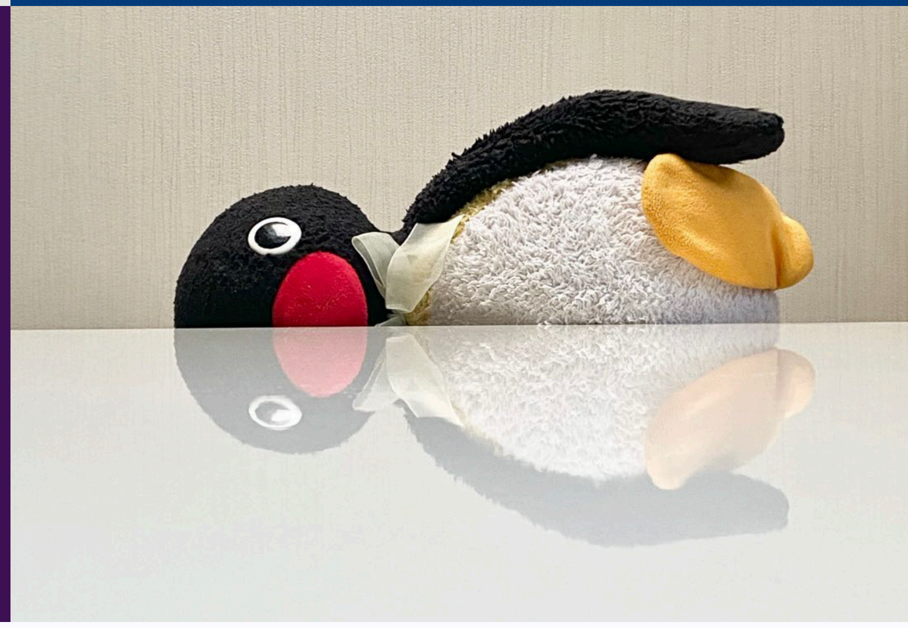


credit: @pingmyping on Instagram

Strange penguins at LHCb

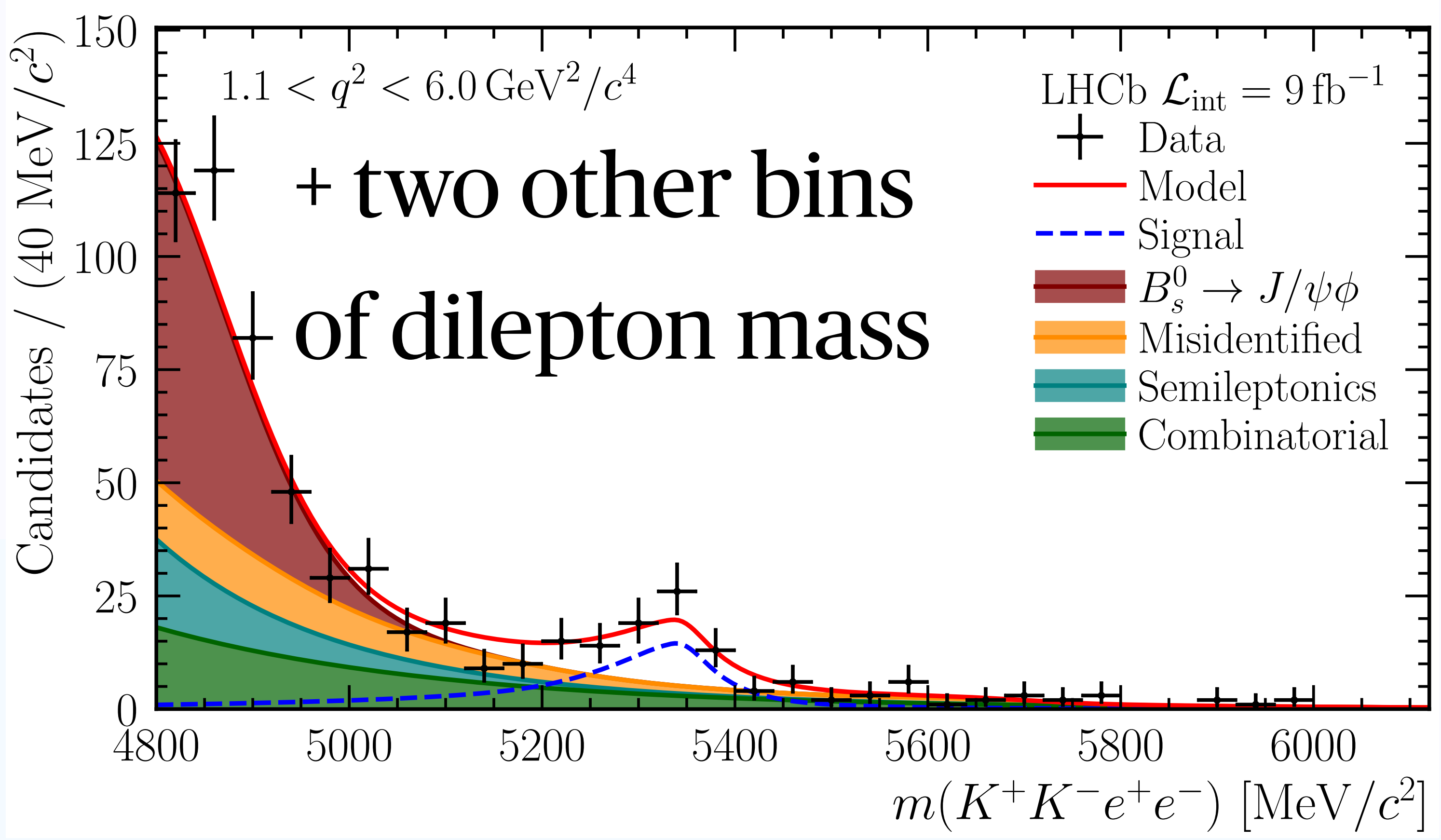
An angular analysis of $B_s^0 \to \phi e^+ e^-$ decays

Lorenzo Paolucci (he/him), on behalf of the LHCb Collaboration

59th Rencontres de Moriond — Young Scientist Forum — 23rd - 30th March 2025

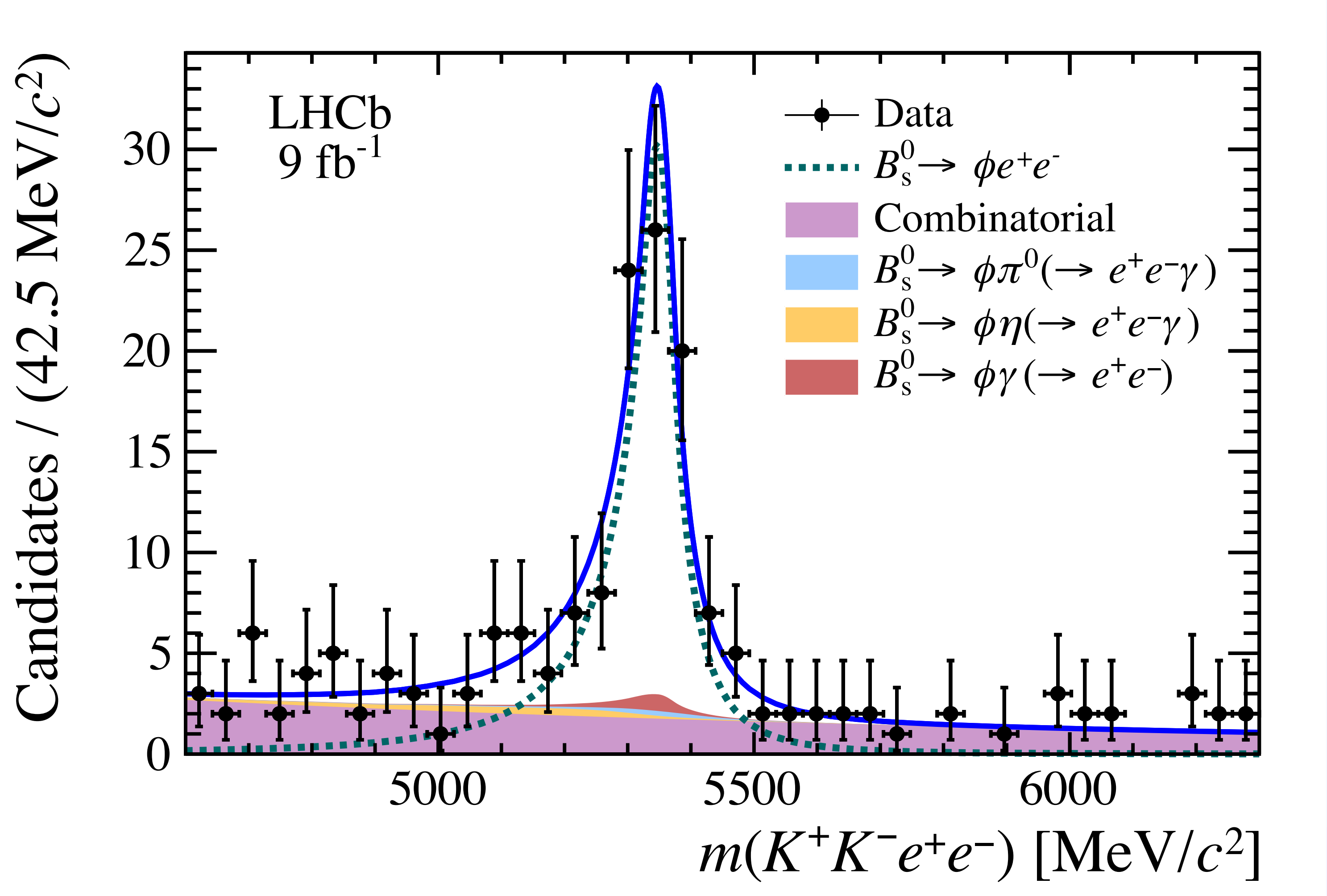
A new penguin on the block

- First observation of the $B_s^0 \to \phi e^+ e^-$ mode by two LHCb analyses.
- Results consistent with LFU, but tension remains in the differential decay rate $\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}$.
- LFU can be tested further at the level of **angular observables**.
- **Today's talk:** an angular analysis which follows from the LFU measurement, in the same $q^2 = m^2(e^+e^-)$ bins.



"Test of lepton flavour universality with $B_s^0 \to \phi \ell^+ \ell^-$ decays", LHCb-PAPER-2024-032

$q^2 \in [0.1,1.1],\ [1.1,6.0],\ [15.0,19.0]\ \mathrm{GeV}^2/c^4$



"Constraints on the photon polarisation in $b \to s\gamma$ transitions using $B_s^0 \to \phi e^+ e^-$ decays", JHEP 03 (2025) 047

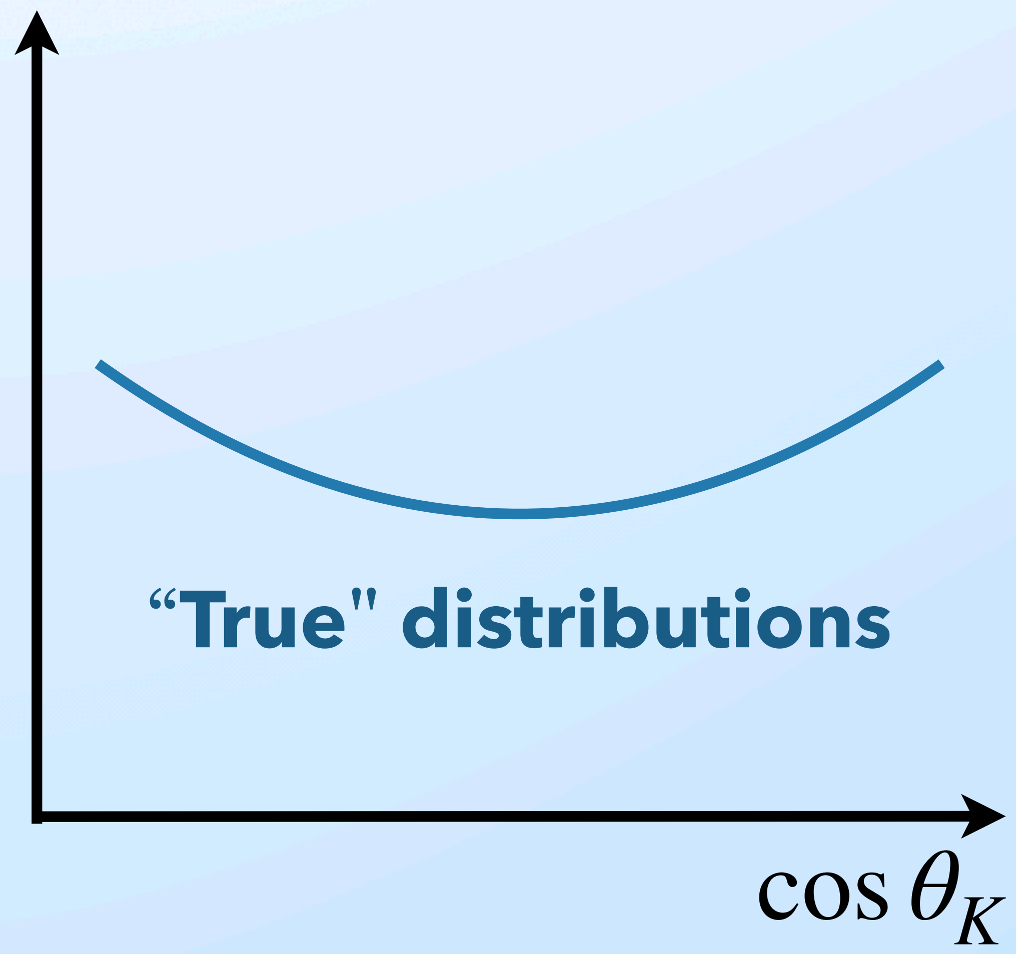
$q^2 \in [0.0009,0.2615]\ \mathrm{GeV}^2/c^4$

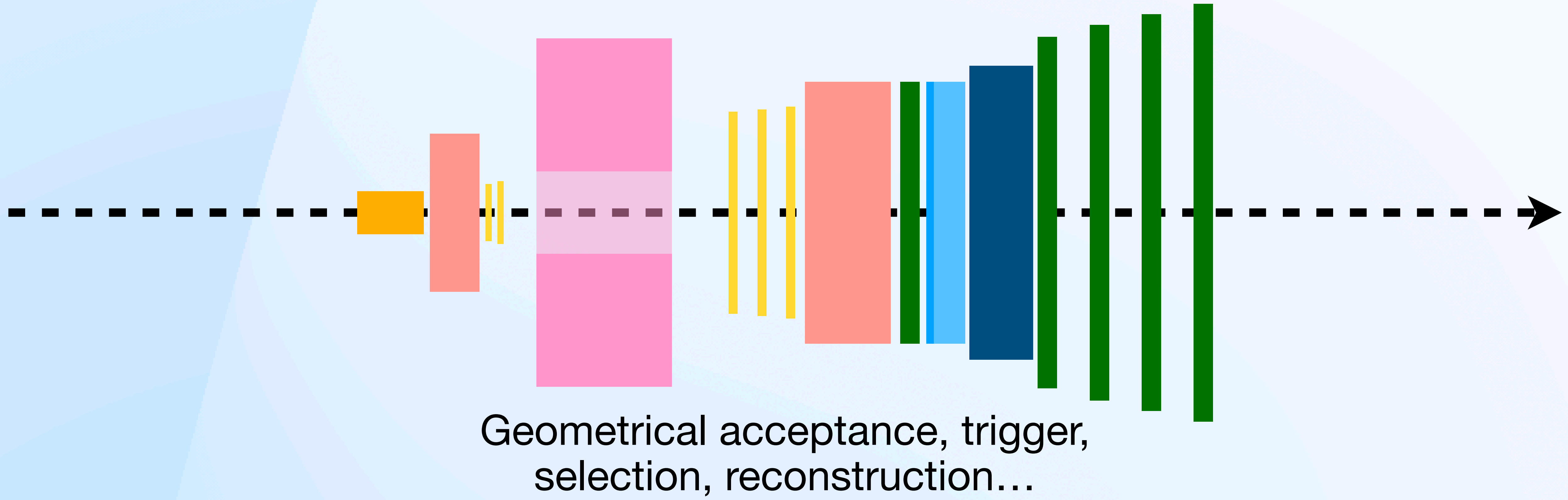
All about angles

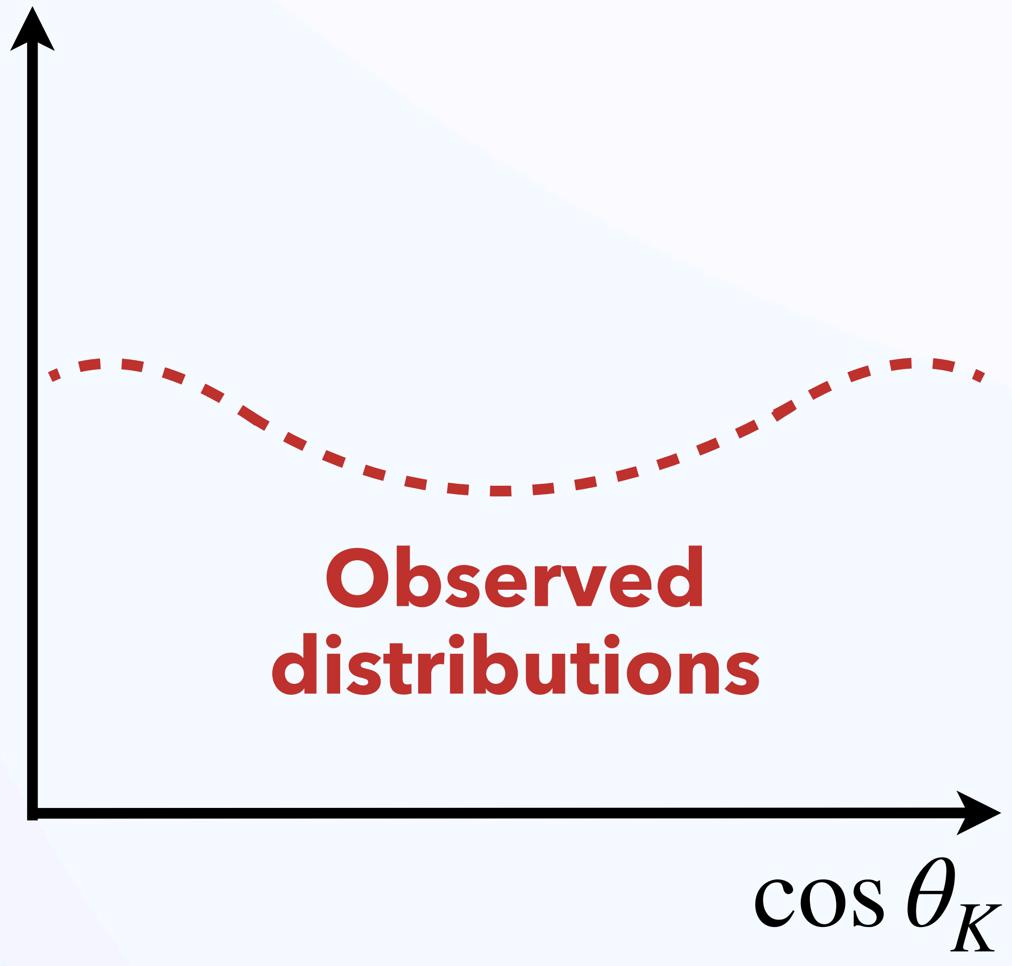
- Limited sample size, fit separately (θ_K, θ_e) and Φ **projections of *CP*-averaged and decay-time-integrated rate.**

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_K\,\mathrm{d}\cos\theta_e},\ \frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^2(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\,\mathrm{d}\Phi}$$

Sensitive to **four angular observables**, F_L, A_6', S_3, A_9







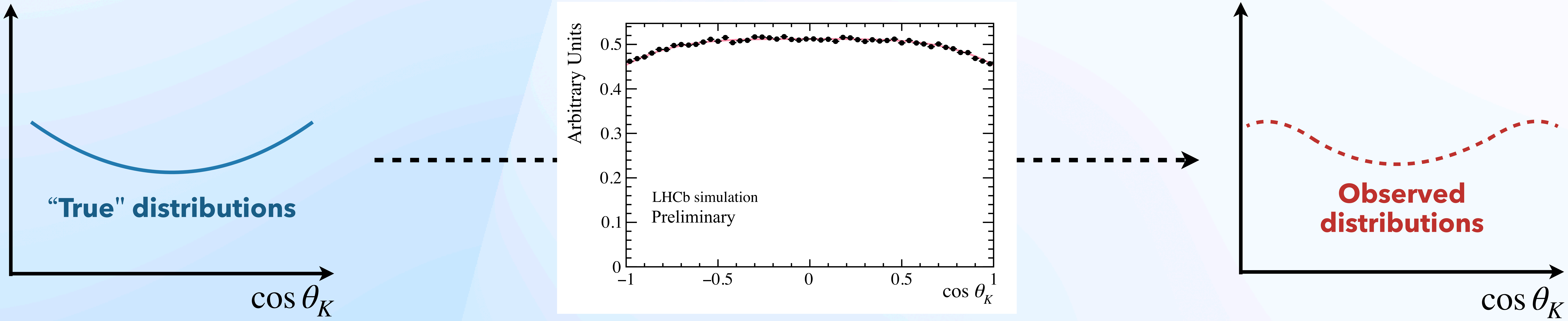
All about angles

- Limited sample size, fit separately (θ_K, θ_e) and Φ **projections of** ***CP*****-averaged and decay-time-integrated rate.**

Angular acceptance

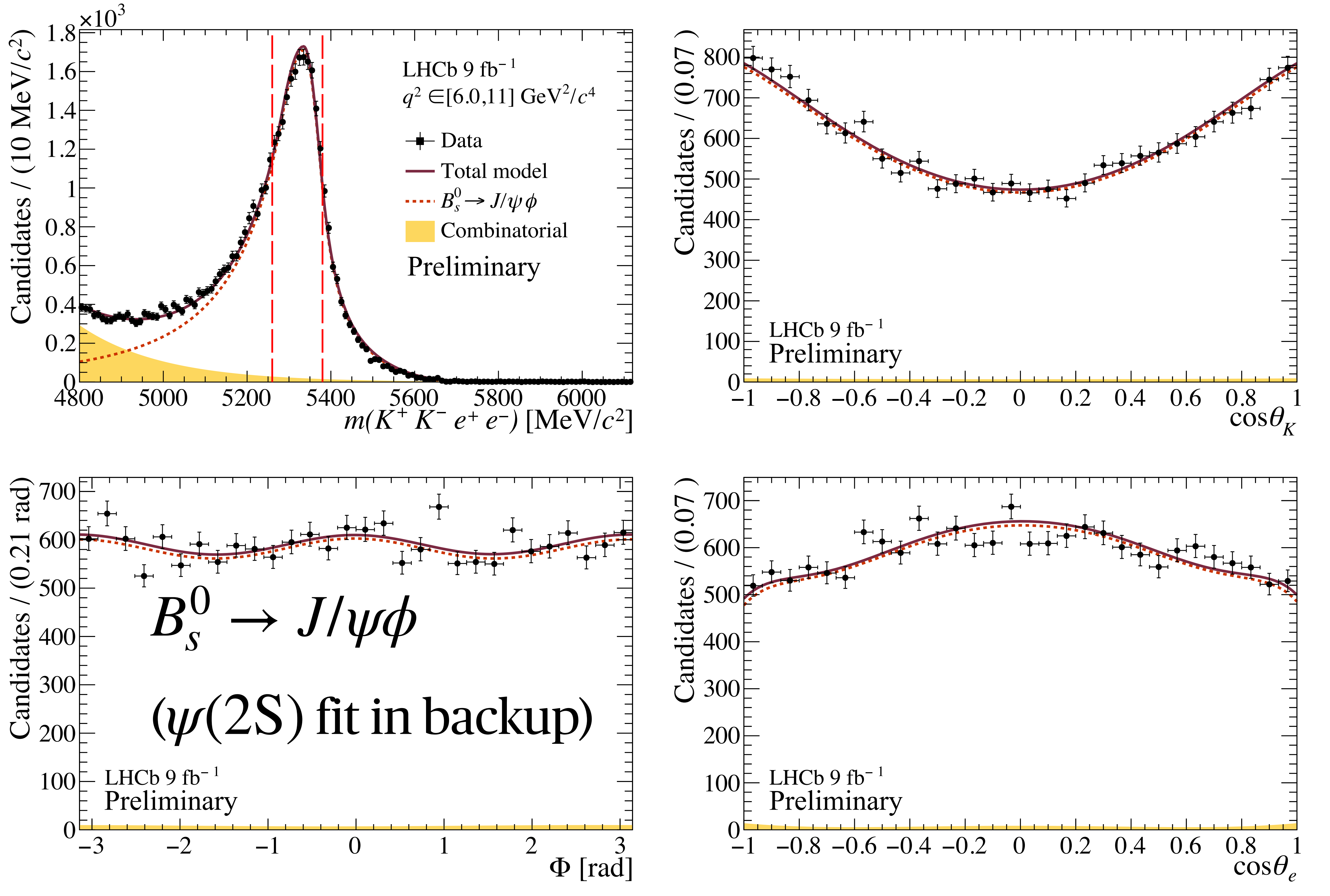
$\boldsymbol{\epsilon(\cos\theta_K, \cos\theta_e, \Phi \,|\, q^2)}$

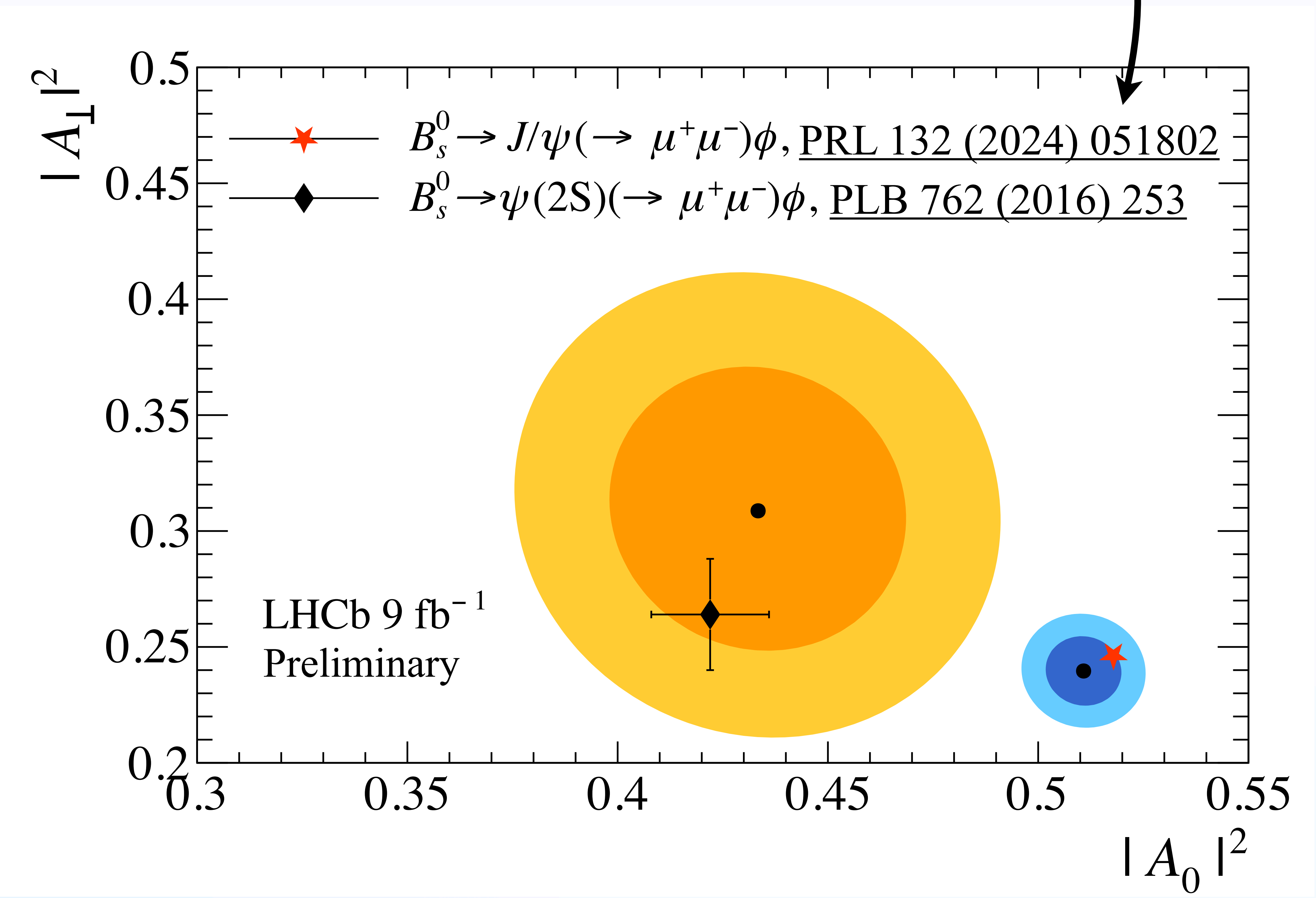
determined from corrected simulation



Validation with control modes

- Compare $B_s^0 \to J/\psi\phi$, $B_s^0 \to \psi(2S)\phi$ **with previous LHCb measurements using muons.**





$\psi(2S) \to e^+e^-$ $\quad J/\psi \to e^+e^-$

Systematics

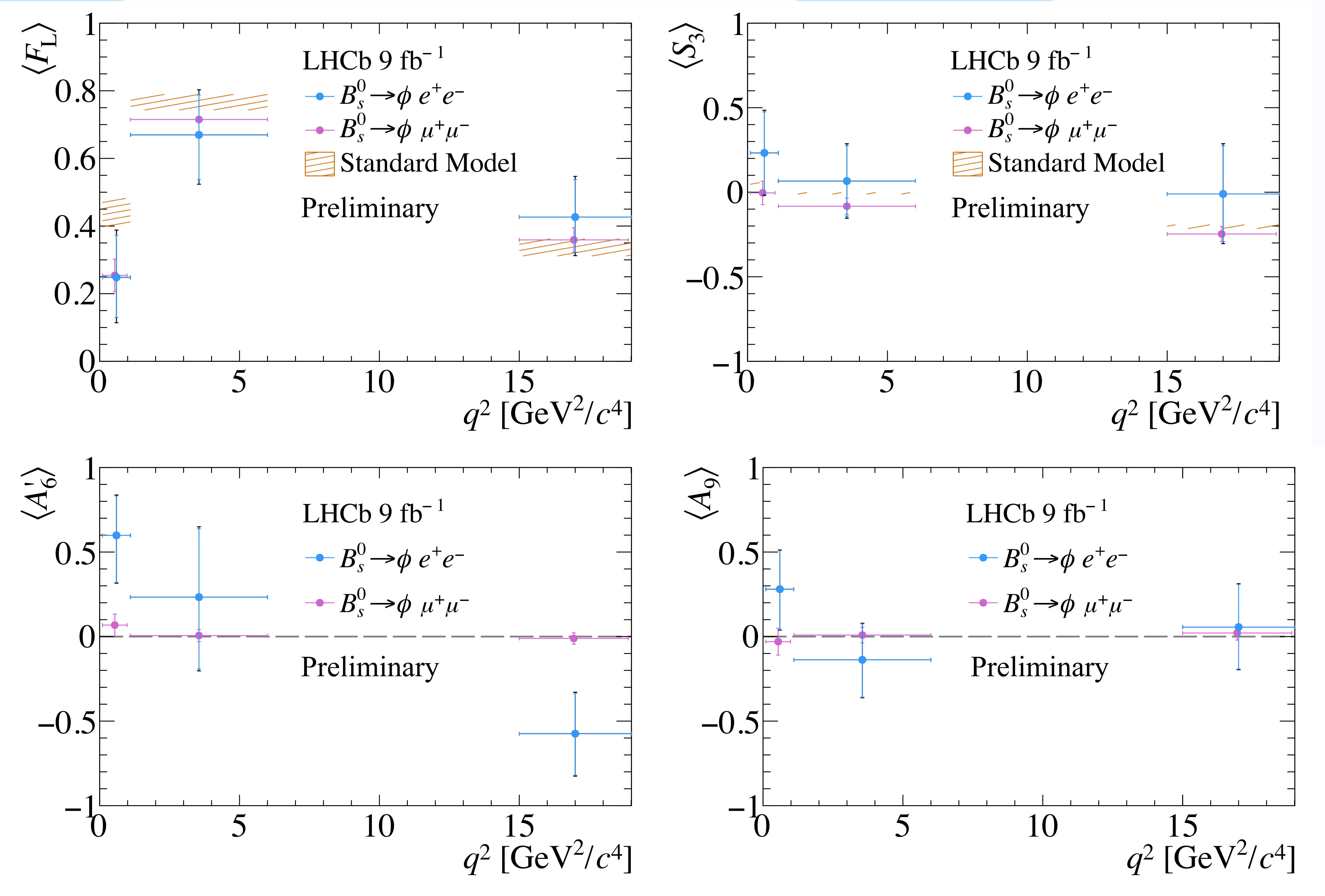
- Bins $q^2 \in [0.1,1.1]\,/\,[1.1,6.0]\,/\,[15.0,19.0]\ \mathrm{GeV}^2/c^4$ (in units of 10^{-2}).
- Largest sources are the models for the mass and angular distributions of the backgrounds (limited by available control / simulation sample sizes).

Source	$\langle F_{\mathrm{L}}\rangle$	$\langle A_6'\rangle$	$\langle S_3\rangle$	$\langle A_9\rangle$
Signal mass model	1.2 / 2.1 / 0.6	1.9 / 2.8 / 1.8	1.3 / 1.1 / 1.7	1.7 / 1.1 / 1.3
Efficiency model	1.3 / 1.9 / 1.9	2.6 / 5.0 / 2.3	2.1 / 1.9 / 1.9	1.8 / 1.7 / 1.7
S-wave contamination	0.5 / 1.6 / 0.8	1.3 / 1.8 / 0.8	1.3 / 0.8 / 1.4	0.9 / 0.9 / 0.7
Angular resolution	0.7 / 1.9 / 0.4	1.0 / 2.3 / 2.0	0.8 / 0.7 / 0.7	1.7 / 1.7 / 1.1
Misidentified background	5.6 / 2.8 / 3.1	2.3 / 4.0 / 2.3	4.3 / 5.4 / 7.1	1.9 / 1.5 / 2.4
Leakage background	0.0 / 1.6 / 1.7	0.0 / 3.2 / 2.4	0.0 / 2.1 / 2.9	0.0 / 1.4 / 2.2
Semileptonic background	1.4 / 1.1 / 0.0	2.0 / 3.8 / 0.0	1.4 / 3.0 / 0.0	1.4 / 1.4 / 0.0
Combinatorial background	2.0 / 3.2 / 1.5	1.2 / 4.0 / 1.9	4.3 / 0.9 / 1.1	1.0 / 1.3 / 2.3

Angular fit results

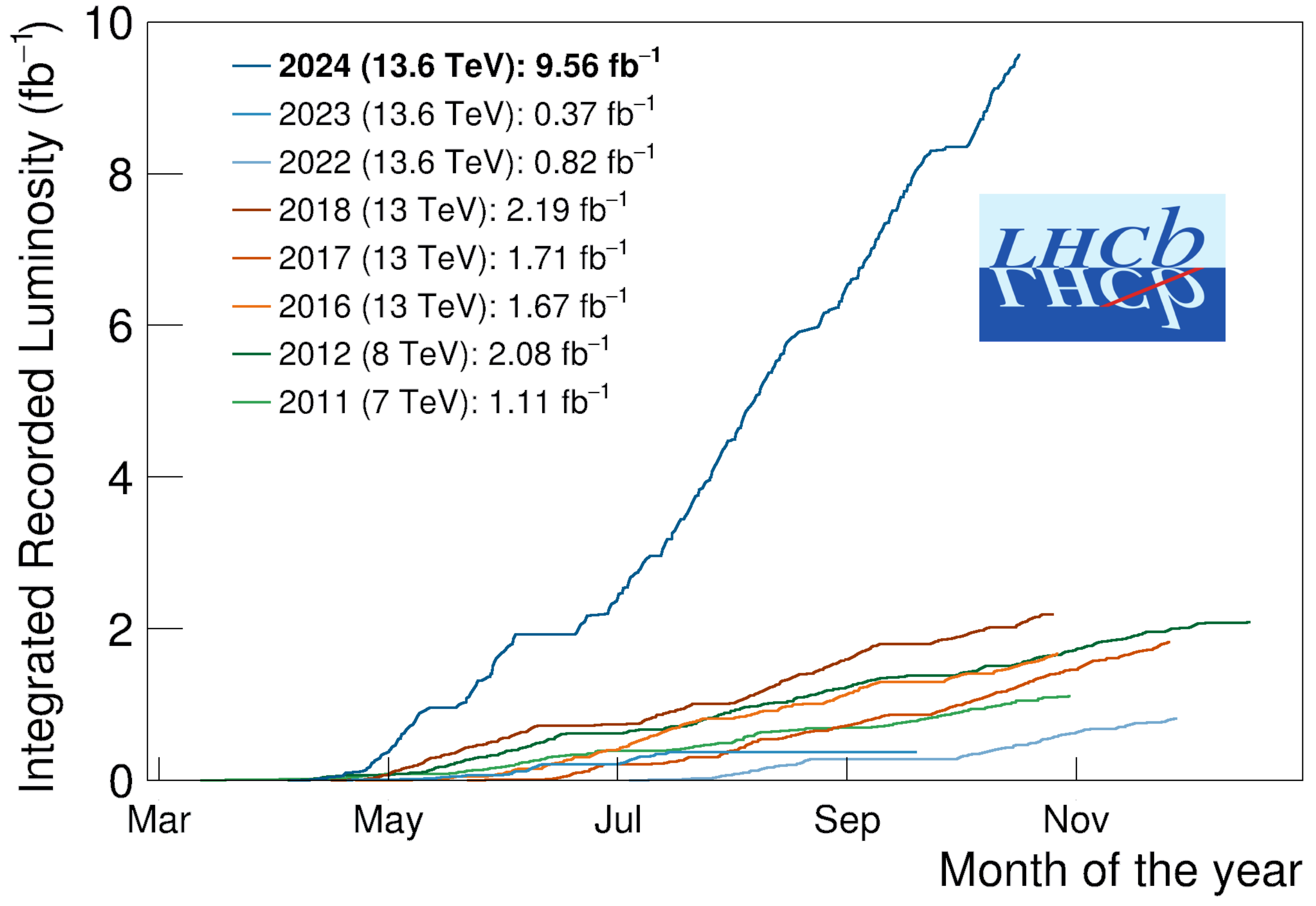
- Perform Feldman-Cousins procedure to properly treat parameter boundaries.
- Results are statistically limited.
- Compatible with SM and previous LHCb analysis of $B_s^0 \to \phi\mu^+\mu^-$ (JHEP 11 (2021) 043).

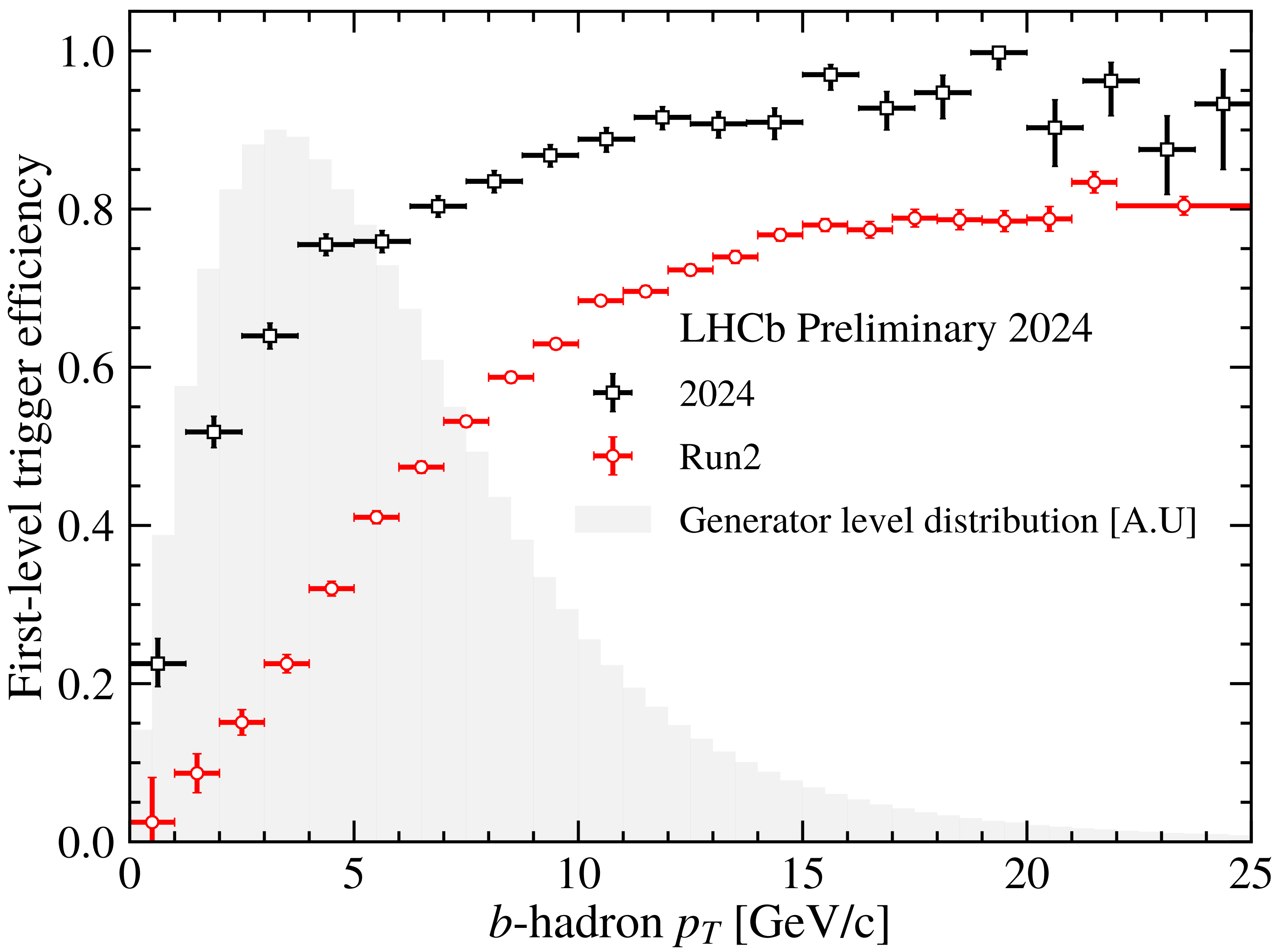
$\langle \cdot \rangle$ indicates decay-time-integrated observables



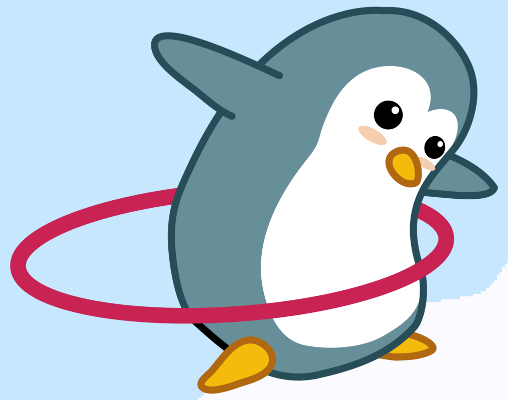
Summary

- Results are compatible with LFU, as well as with the SM prediction.
- Will soon be published on arXiv and submitted to JHEP.
- Statistically limited, look forward to Run 3 analyses which will benefit from:
  - > 3 times the Run 1+2 sample size.
  - Fully software trigger $\Longrightarrow$ higher efficiency and yield per fb^{-1}.



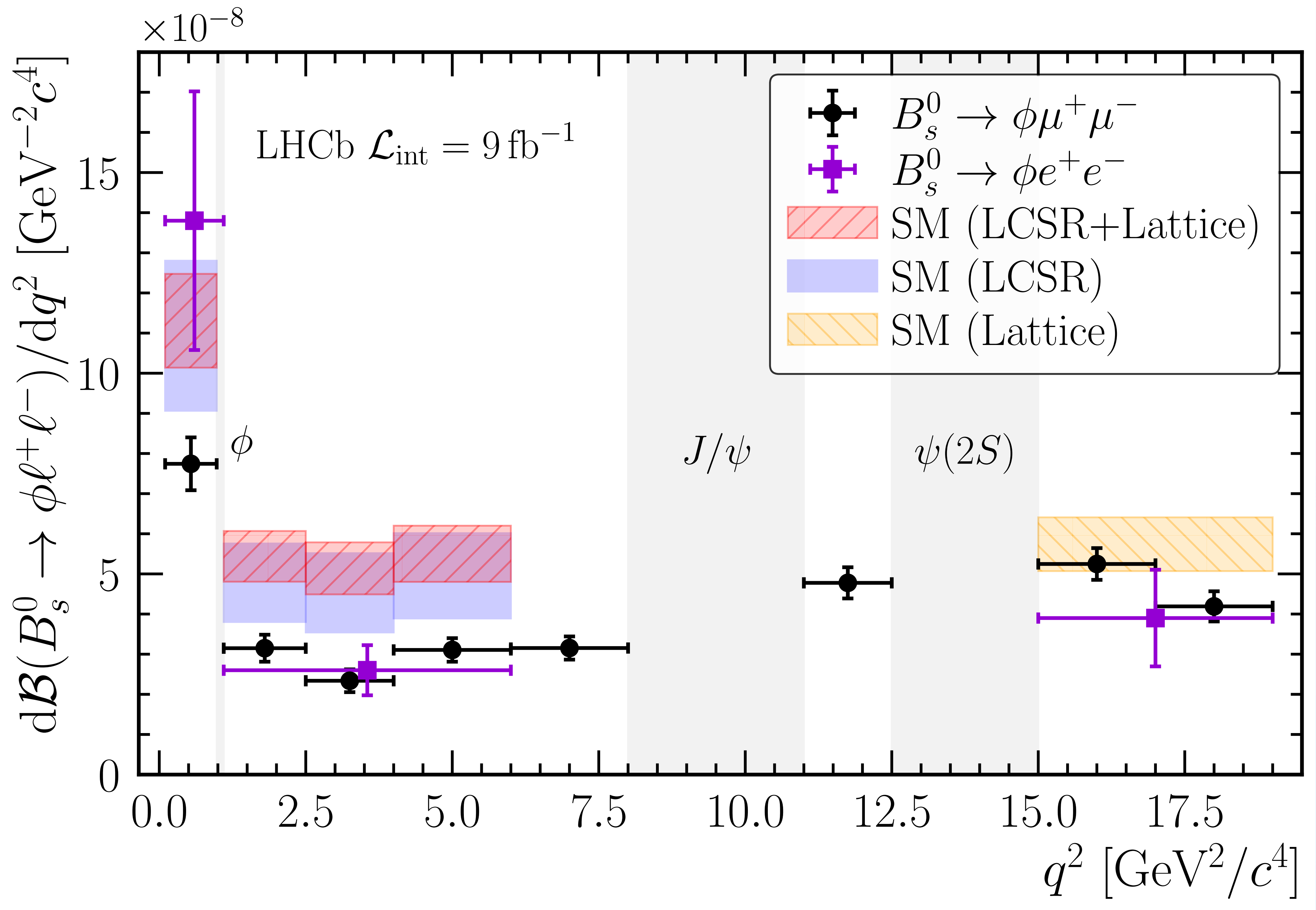


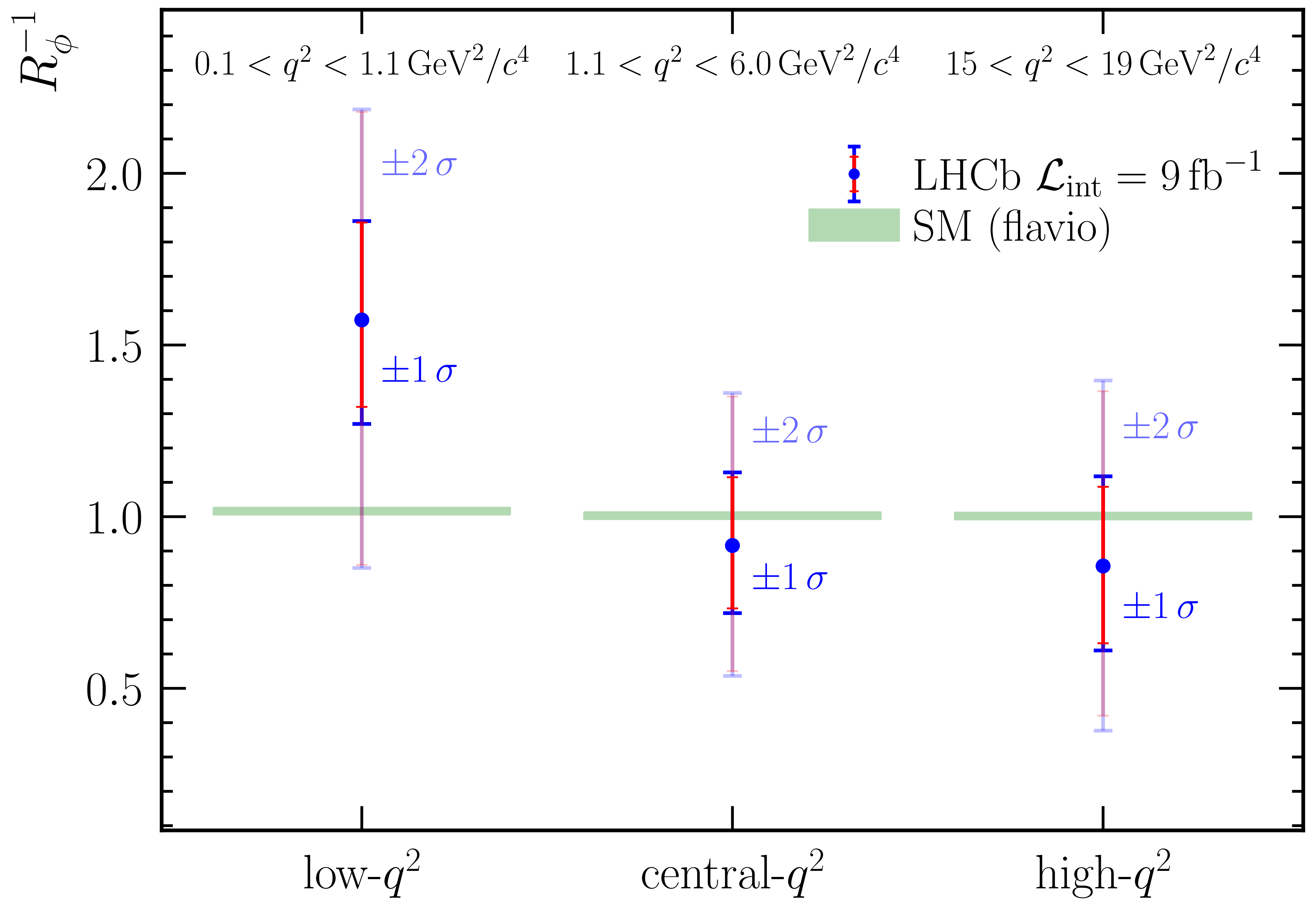
LHCb-FIGURE-2024-007



Extras

Tensions and LFU in $B_s^0 \to \phi\ell^+\ell^-$





"Test of lepton flavour universality with $B_s^0 \to \phi\ell^+\ell^-$ decays", LHCb-PAPER-2024-032

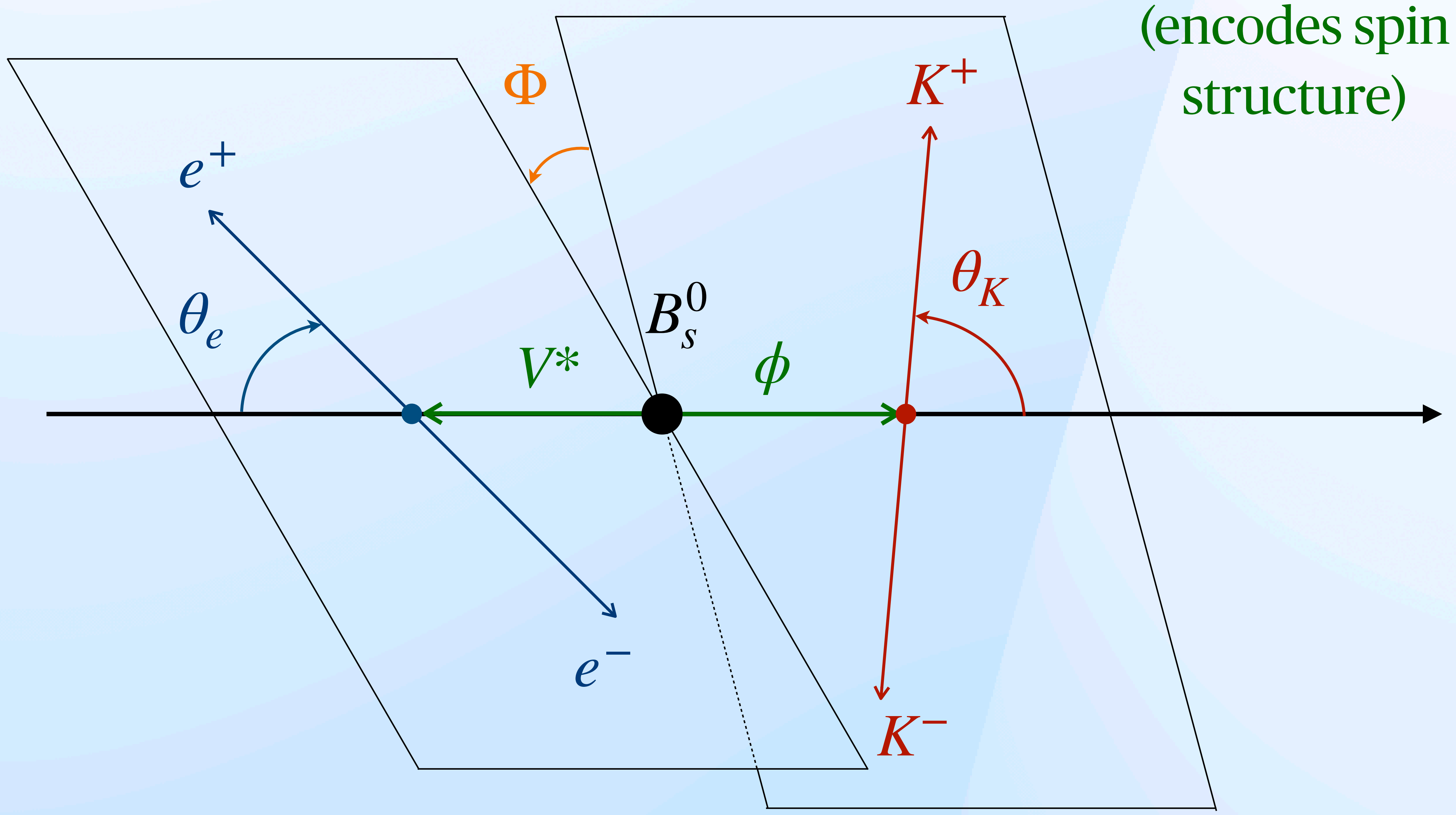
Full decay rate

Four-body decay rate

Angular coefficient (encodes decay amplitudes)

$$\frac{d\Gamma}{dq^2\, d\cos\theta_K\, d\cos\theta_e\, d\Phi} = \sum_i J_i(q^2)\;\; f_i(\cos\theta_K, \cos\theta_e, \Phi)$$

Angular function (encodes spin structure)



Flavour symmetric final state, no tagging:

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d(\Gamma+\bar{\Gamma})}{dq^2\, d\cos\theta_K\, d\cos\theta_e\, d\Phi} =$$

$$\frac{9}{32\pi}\Bigg[\frac{3}{4}(1-F_L)\sin^2\theta_K(1+\frac{1}{3}\cos 2\theta_e)$$

$$+ F_L\cos^2\theta_K(1-\cos 2\theta_e) + S_3\sin^2\theta_K\sin^2\theta_e\cos 2\Phi$$

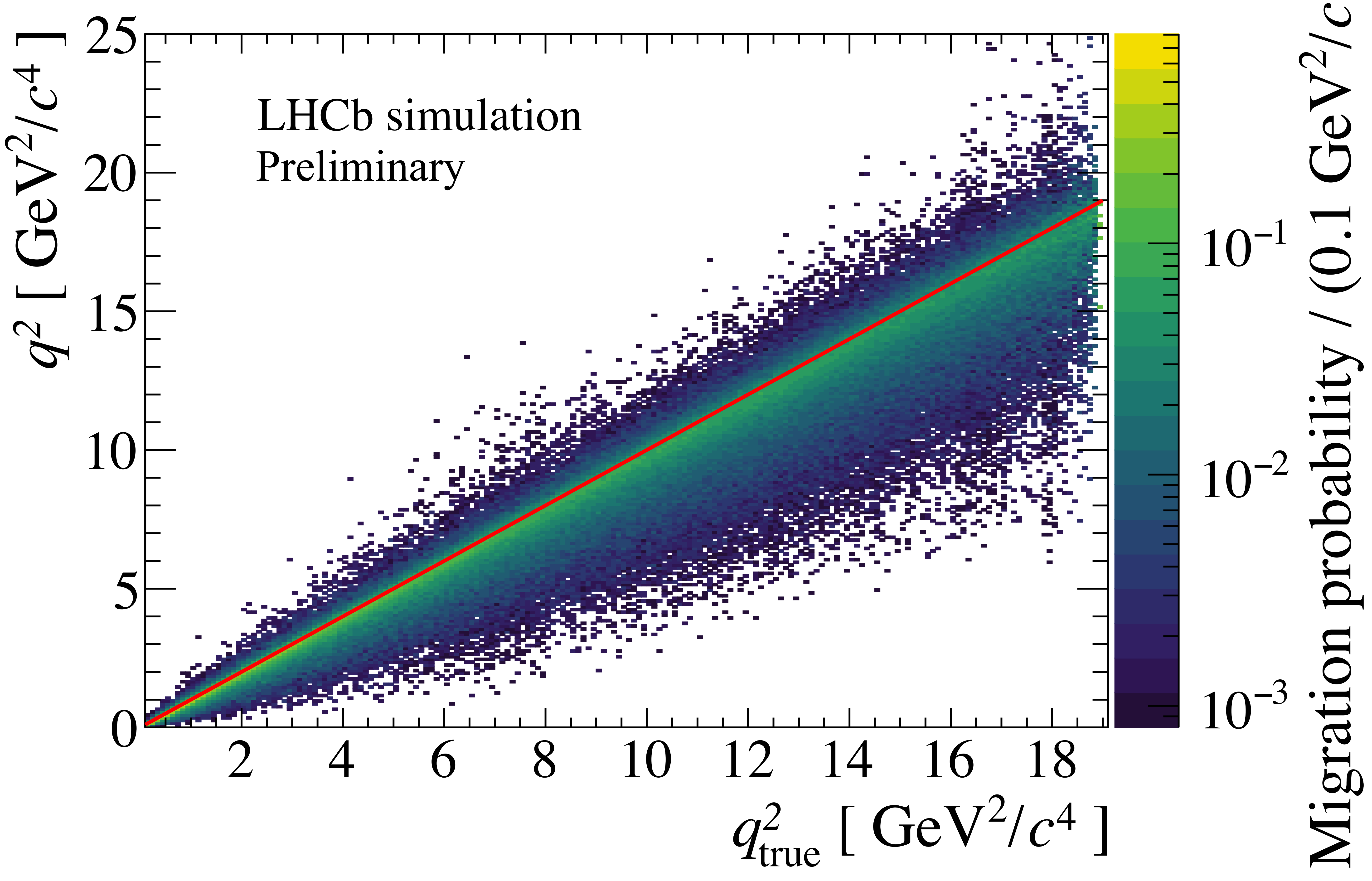
$$+ S_4\sin 2\theta_K\sin 2\theta_e\cos\Phi + A_5\sin 2\theta_K\sin\theta_e\cos\Phi$$

$$+ A_6\sin^2\theta_K\cos\theta_e \quad + S_7\sin 2\theta_K\sin\theta_e\sin\Phi$$

$$+ A_8\sin^2\theta_K\sin 2\theta_e\sin\Phi \;\; + A_9\sin^2\theta_K\sin^2\theta_e\sin 2\Phi\Bigg]$$

Alternative parametrisation $A_6 = (1-F_L)\,A_6'$

q^2 resolution



Angular acceptance

Model acceptance in four dimensions (angles + q^2).

Coefficients are determined from simulation, generated from a **flat distribution.**

$$\epsilon(q^2, \cos\theta_K, \cos\theta_e, \Phi) = \sum_{klmn} C_{klmn} \cdot P_k(q^2) \cdot P_l(\cos\theta_K) \cdot P_m(\cos\theta_e) \cdot \cos(n\Phi)$$

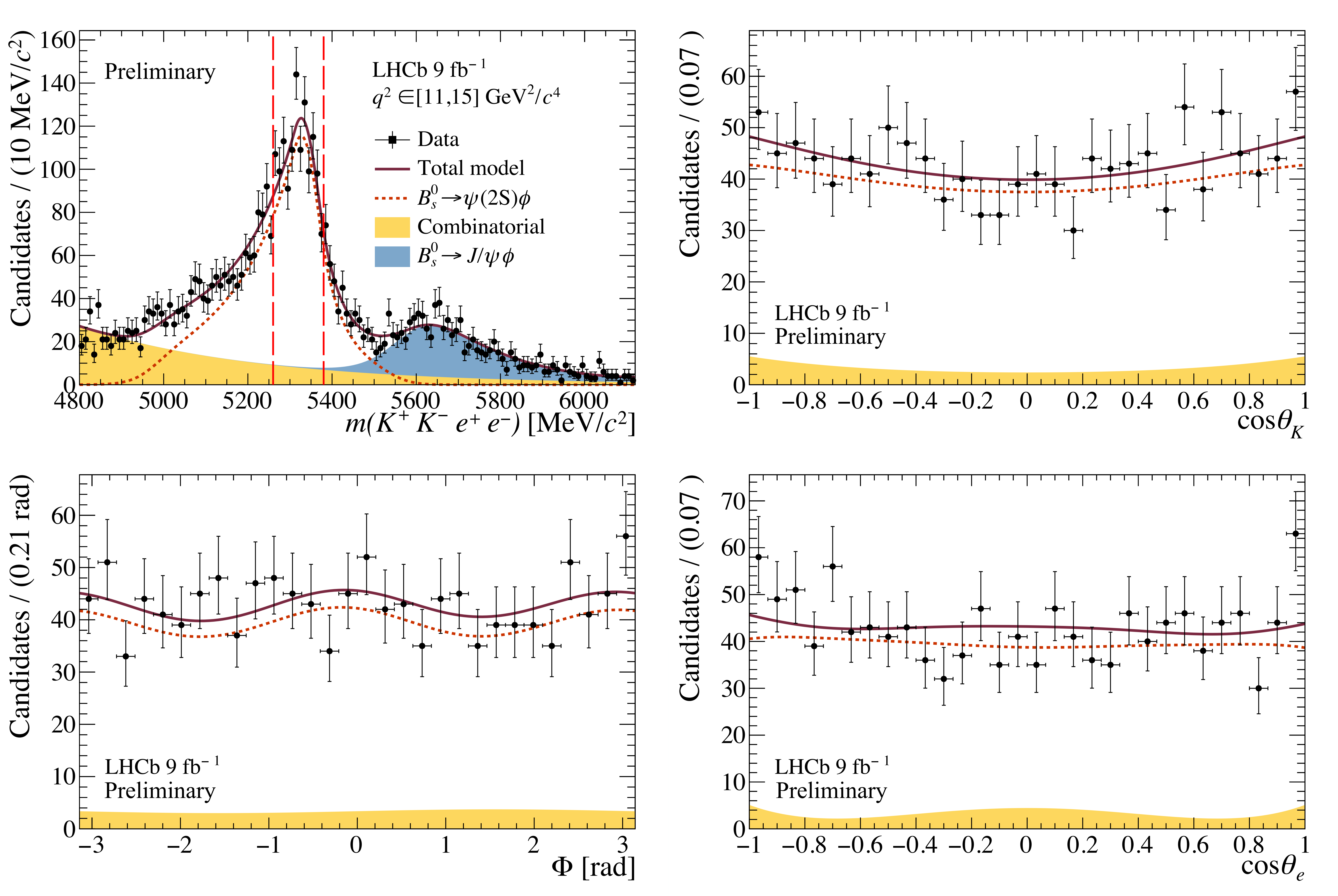
Legendre polynomials

Marginalise q^2 dependence:

$$\epsilon(\cos\theta_K, \cos\theta_e, \Phi) = \epsilon(\cos\theta_K, \cos\theta_e, \Phi, q^2 = q_0^2)$$

q_0^2 : median point of SM distribution in each bin

$B_s^0 \to \psi(2S)\phi$ fit result

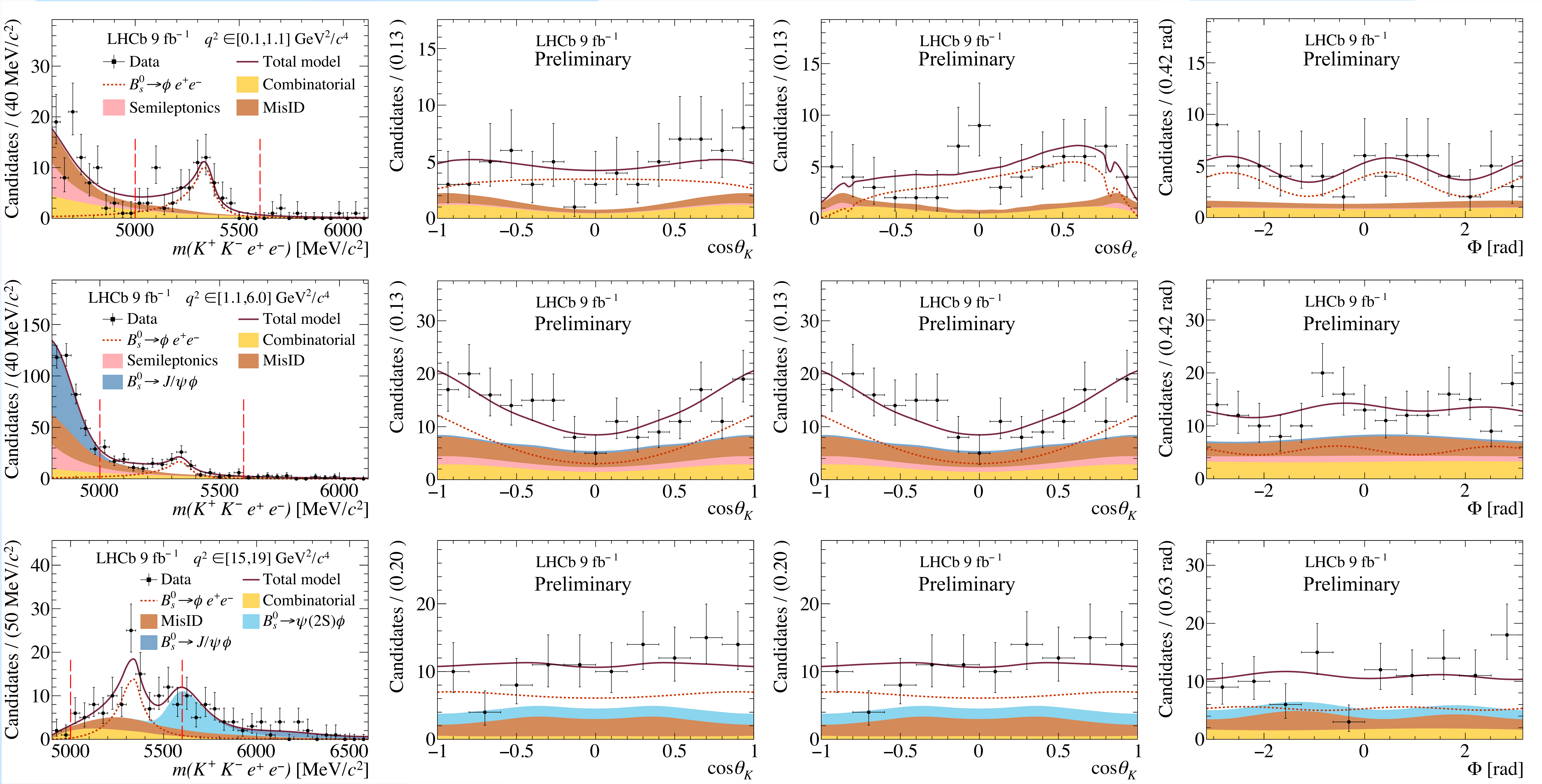


Angular fit projections

$[0.1,1.1]\ \mathrm{GeV}^2/c^4$

$[1.1,6.0]\ \mathrm{GeV}^2/c^4$

$[15.0,19.0]\ \mathrm{GeV}^2/c^4$



Systematics

For the low-q^2 / central-q^2 / high-q^2 bins (in units of 10^{-2}).

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