

Measurement of $R(K)$ and $R(K^*)$ at LHCb

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7th Red LHC, 10-12/05/23 Madrid



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New measurements bring surprises



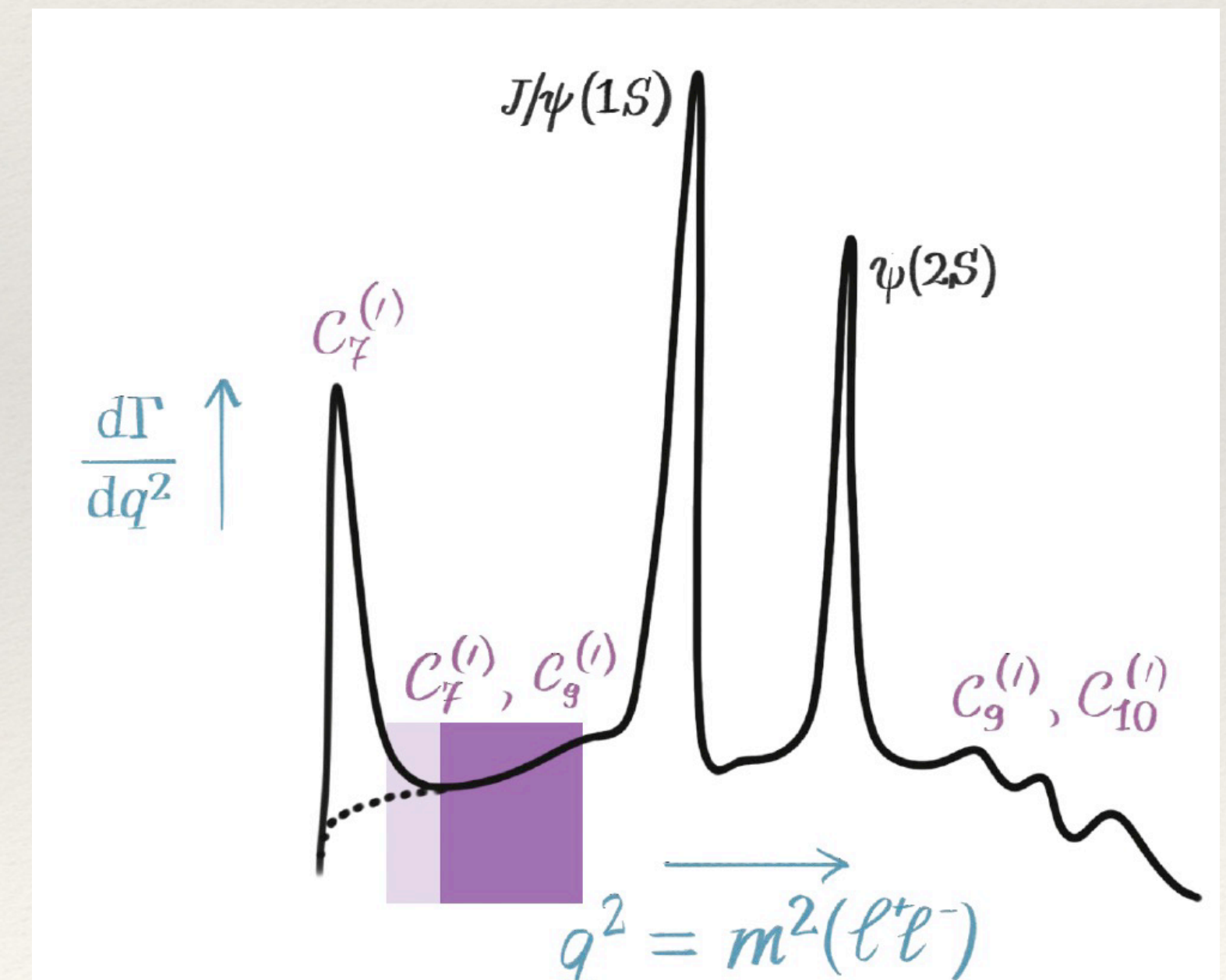
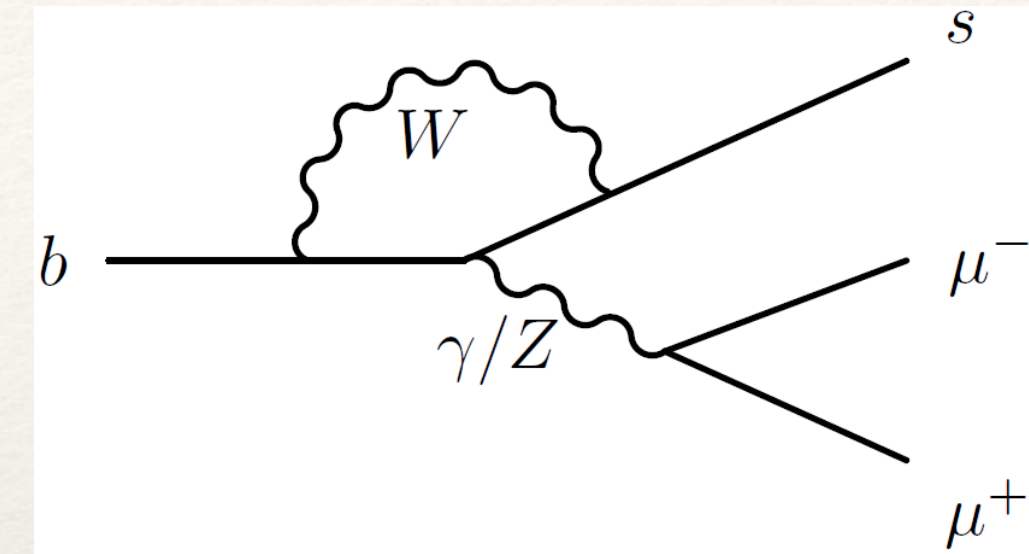
New Physics in $b \rightarrow sll$ decays

- ❖ $b \rightarrow sll$ decays are heavily (loop-)suppressed in the SM.
- ❖ New heavy particles can significantly contribute and affect decay rates, angular distributions, and rate asymmetries.
- ❖ Transitions described model-independently in effective theory.

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \boxed{\mathcal{C}_i} \boxed{\mathcal{O}_i}$$

↑ Wilson coefficient ("effective coupling") ↑ local operator

- ❖ Different $q^2 = m^2(l^+l^-)$ regions probe different operator combinations.



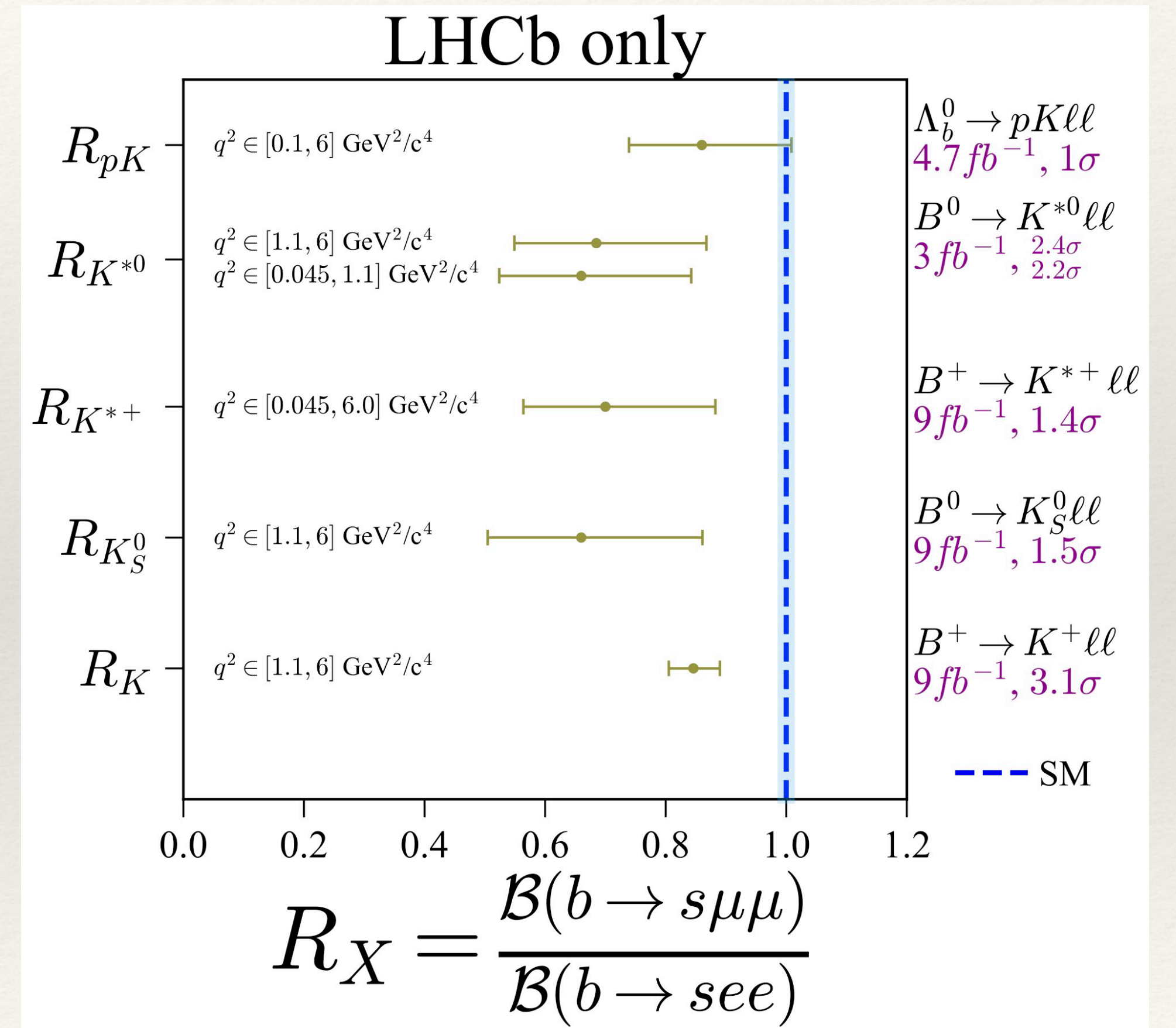
LFU in $b \rightarrow sll$ decays

- ❖ Use ratios of $b \rightarrow sll$ decays with many possible final states. Except different Yukawa couplings and kinematic effects, ratios are expected to be unity.
[PRD 69 (2004) 074020, EPJC 76 (2016) 440]

$$R_{K,K^*} = \frac{\mathcal{B}(B^{(+,0)} \rightarrow K^{(+,*0)} \mu^+ \mu^-)}{\mathcal{B}(B^{(+,0)} \rightarrow K^{(+,*0)} e^+ e^-)}$$

- ❖ Hadronic uncertainties (form-factors and $c\bar{c}$ -loop effects) cancel in the ratio.

Status late 2022



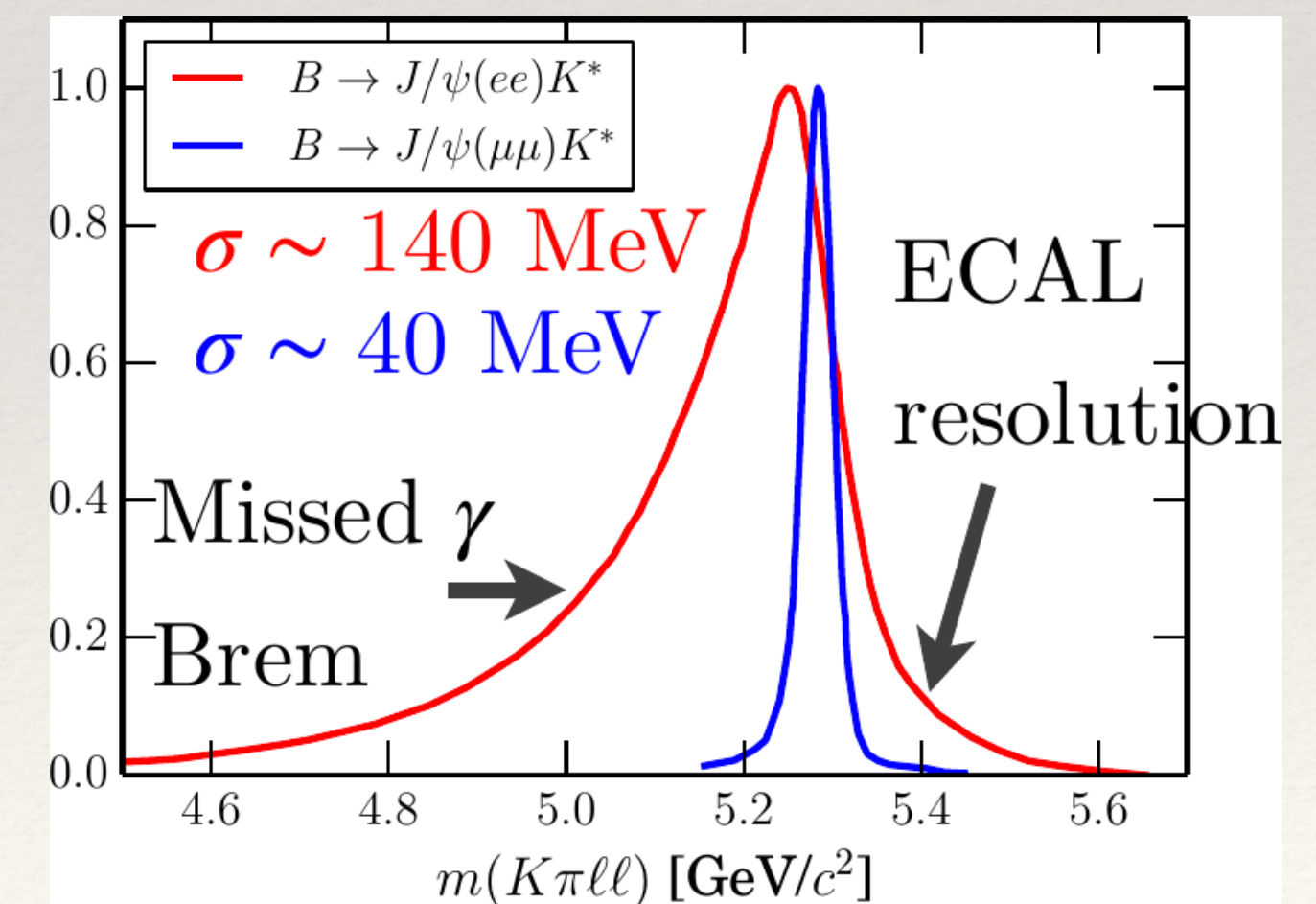
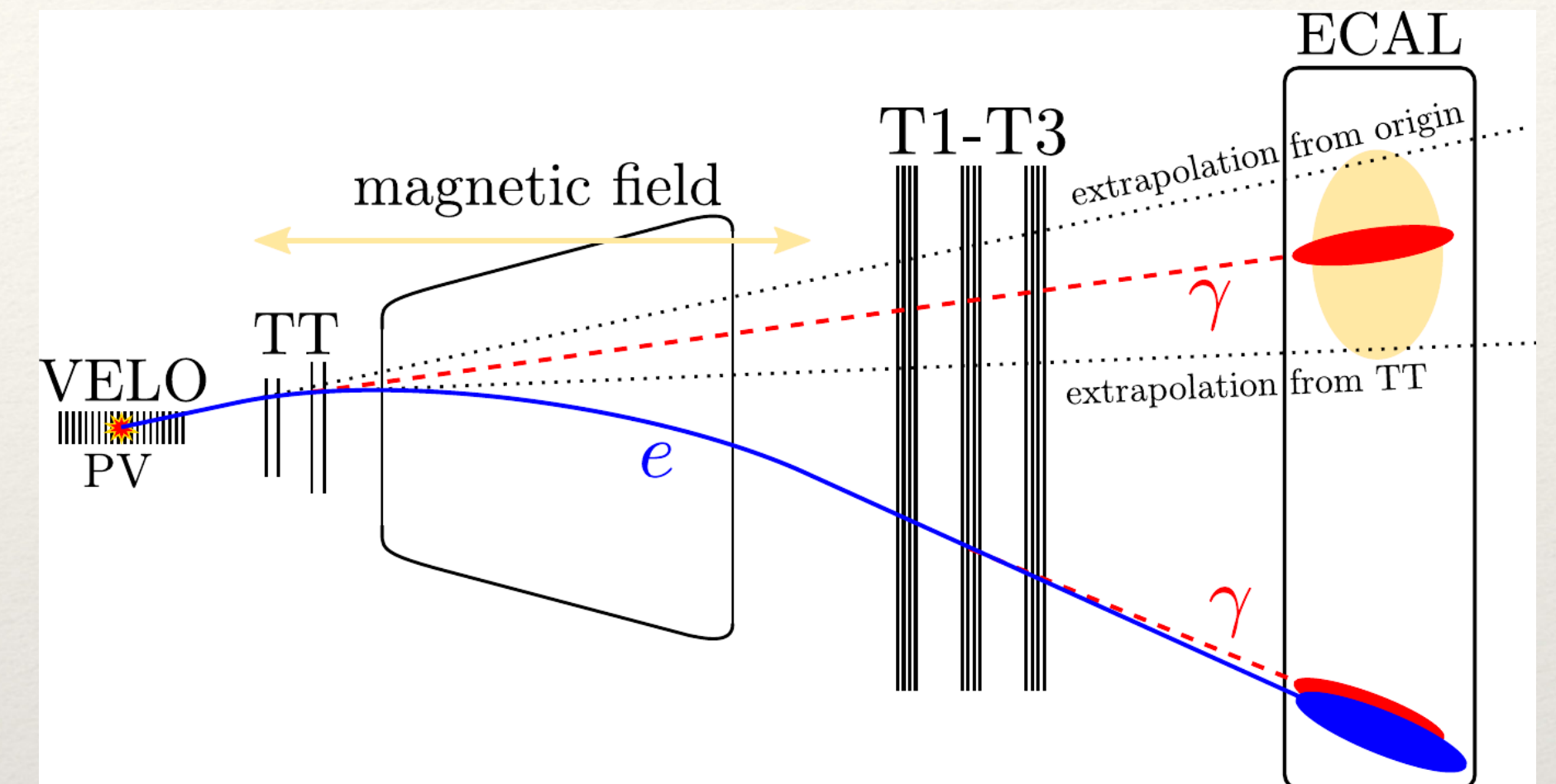
Latest measurement

- ❖ Simultaneous measurement of R_K and R_{K^*} with full Run1+2 data sample (9fb^{-1}) in two regions of q^2 : $[0.1-1.1] \text{ GeV}^2/c^4$ and $[1.1-6.0] \text{ GeV}^2/c^4$.
- ❖ Constrain cross-feed background between two modes in fits to data.
- ❖ R_X is a double ratio as it helps in cancelling efficiencies and systematics. Use resonant modes also to check efficiency calibration and as a crosscheck.

$$R_X = \frac{\mathcal{B}(B \rightarrow K\mu^+\mu^-)}{\mathcal{B}(B \rightarrow Ke^+e^-)} \times \frac{\mathcal{B}(B \rightarrow KJ/\psi(\rightarrow \mu^+\mu^-))}{\mathcal{B}(B \rightarrow KJ/\psi(\rightarrow e^+e^-))}$$
$$= \underbrace{\left(\frac{N_{K\mu^+\mu^-}}{N_{Ke^+e^-}} \right) \left(\frac{N_{KJ\psi(\rightarrow \mu^+\mu^-)}}{N_{KJ\psi(\rightarrow e^+e^-)}} \right)}_{\text{Mass fits to data}} \times \underbrace{\left(\frac{\epsilon_{Ke^+e^-}}{\epsilon_{K\mu^+\mu^-}} \right) \left(\frac{\epsilon_{KJ\psi(\rightarrow \mu^+\mu^-)}}{\epsilon_{KJ\psi(\rightarrow e^+e^-)}} \right)}_{\text{Calibrated simulation samples}}$$

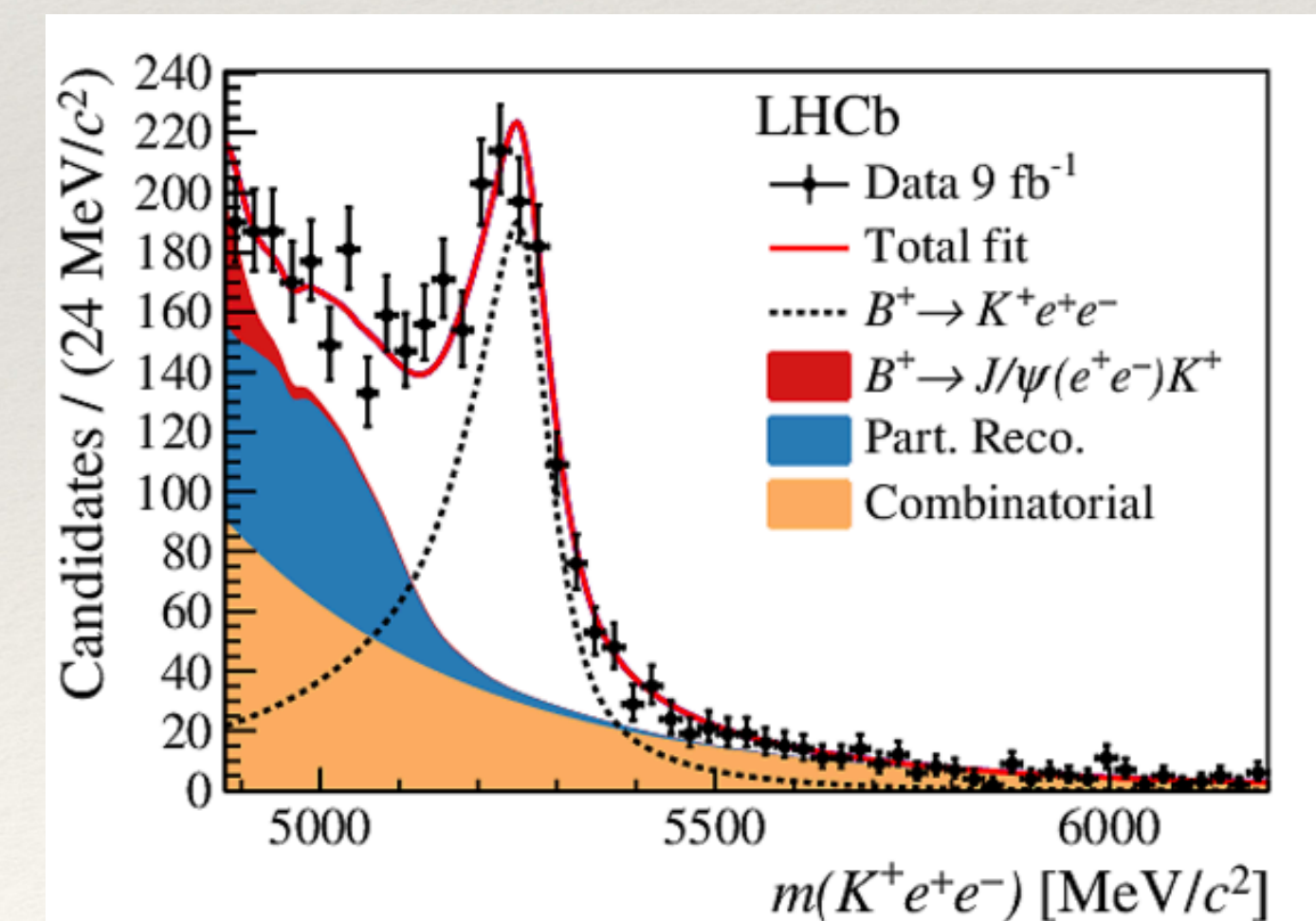
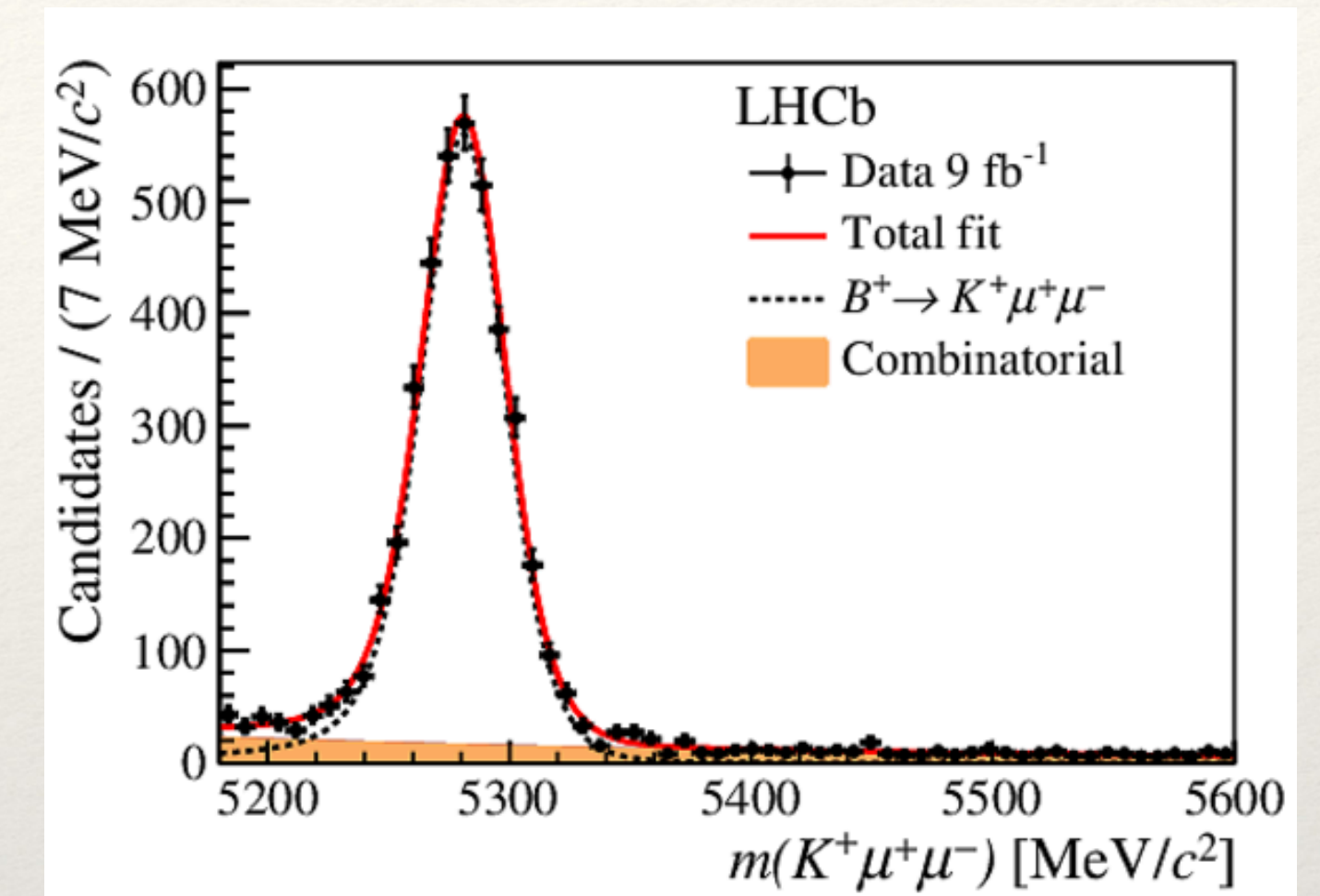
Electron reconstruction

- ❖ Lepton reconstruction and identification is anything but universal.
- ❖ Challenges for electron modes:
 - ❖ Higher trigger thresholds for electrons => lower efficiencies for electrons. Combine exclusive trigger categories to improve electron modes efficiencies.
 - ❖ Recovery procedure for electrons of bremsstrahlung photons. 50% efficient, well simulated.
 - ❖ Contribution from several background sources => bkg. modeling critical.



Situation pre December 2022

- ❖ Single R_K measurement in central- q^2 region $[1.1-6.0] \text{ GeV}^2/c^4$
- ❖ Muon signal is clear and with small background.
- ❖ Longer radiative tail in electron mode due to bremsstrahlung.
- ❖ Partially reconstructed background from $B^{0,+} \rightarrow K^{*0,+} e^+ e^-$ where a pion is lost.
- ❖ $B^+ \rightarrow K^+ J/\psi(e^+ e^-)$ where a photon is not reconstructed.
- ❖ Combinatorial background accounts for other possible unknown background sources.



R_X changes

[arXiv:2212.09152]

[arXiv:2212.09153]

- ❖ PID criteria based on likelihood and neural network showed discrepancy depending on runs.
- ❖ Scanning with respect to PID showed trend of the R-ratios.
 - ❖ Applied harder PID criteria for electrons.
- ❖ Various $B \rightarrow K^{(*)}hh'X$ doubly misID background, not properly described by the exponential contribution.
 - ❖ Most prominent double misID bkg: $B^+ \rightarrow K^+K^-K^+$
 - ❖ Residual backgrounds from misidentification explicitly modeled from data.

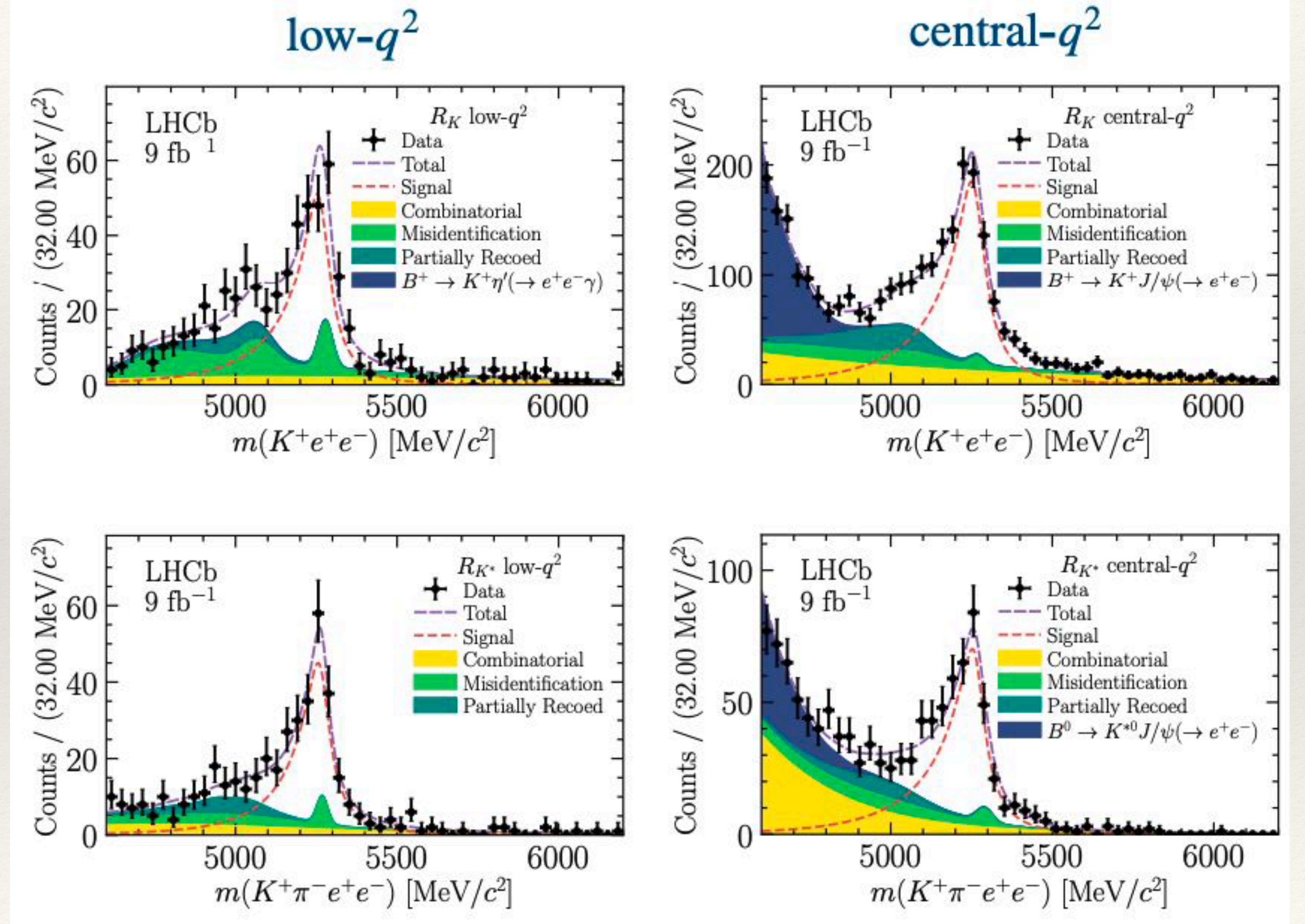
Electron mode fits

[arXiv:2212.09152]

[arXiv:2212.09153]

- ❖ Muon branching fraction consistent with published results.
- ❖ Brem tails from J/ψ entering rare modes contained in the simultaneous fit.
- ❖ Partially reconstructed background from $K^{*0}e^+e^-$ constrained in the $K^+e^+e^-$ mode.

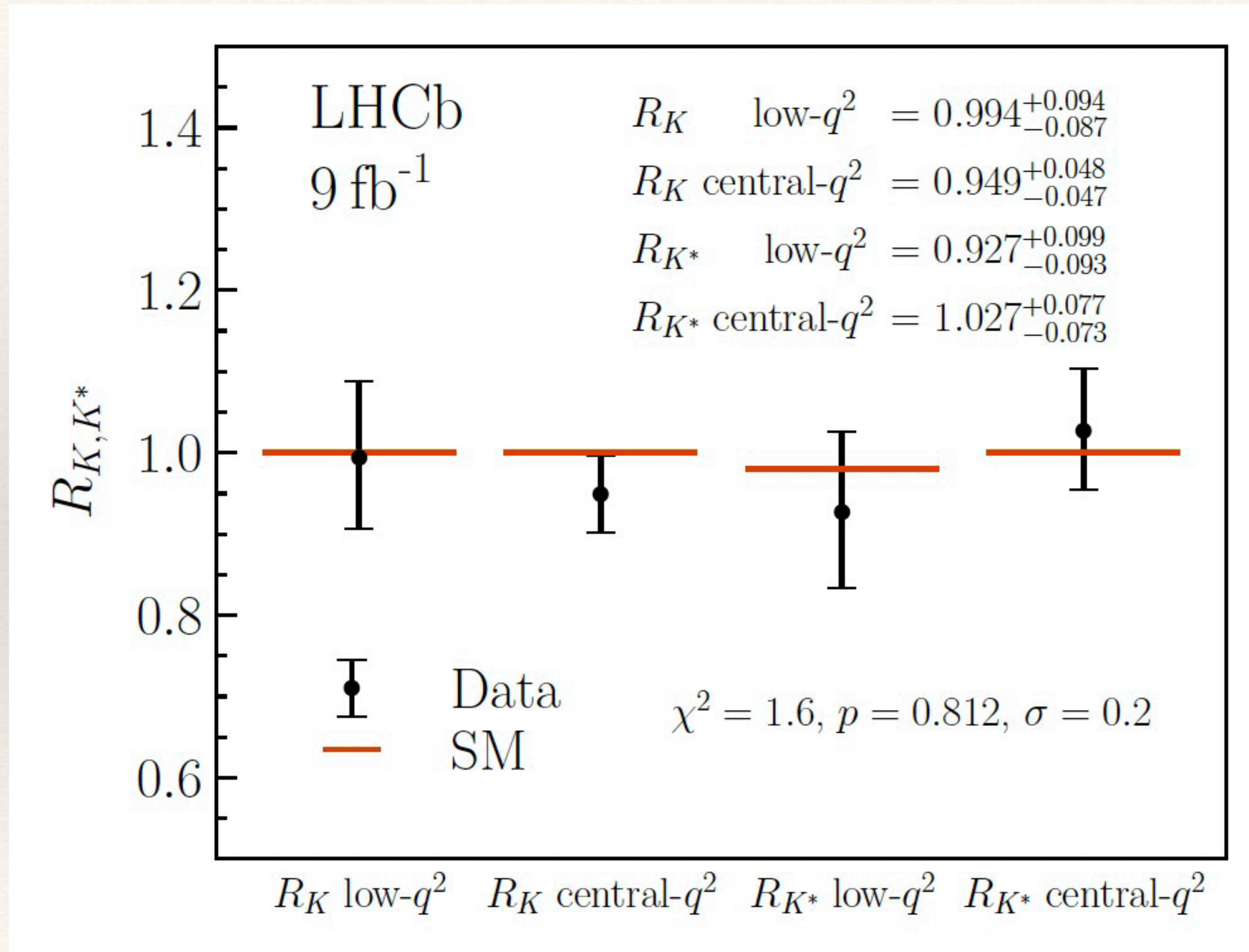
K^+



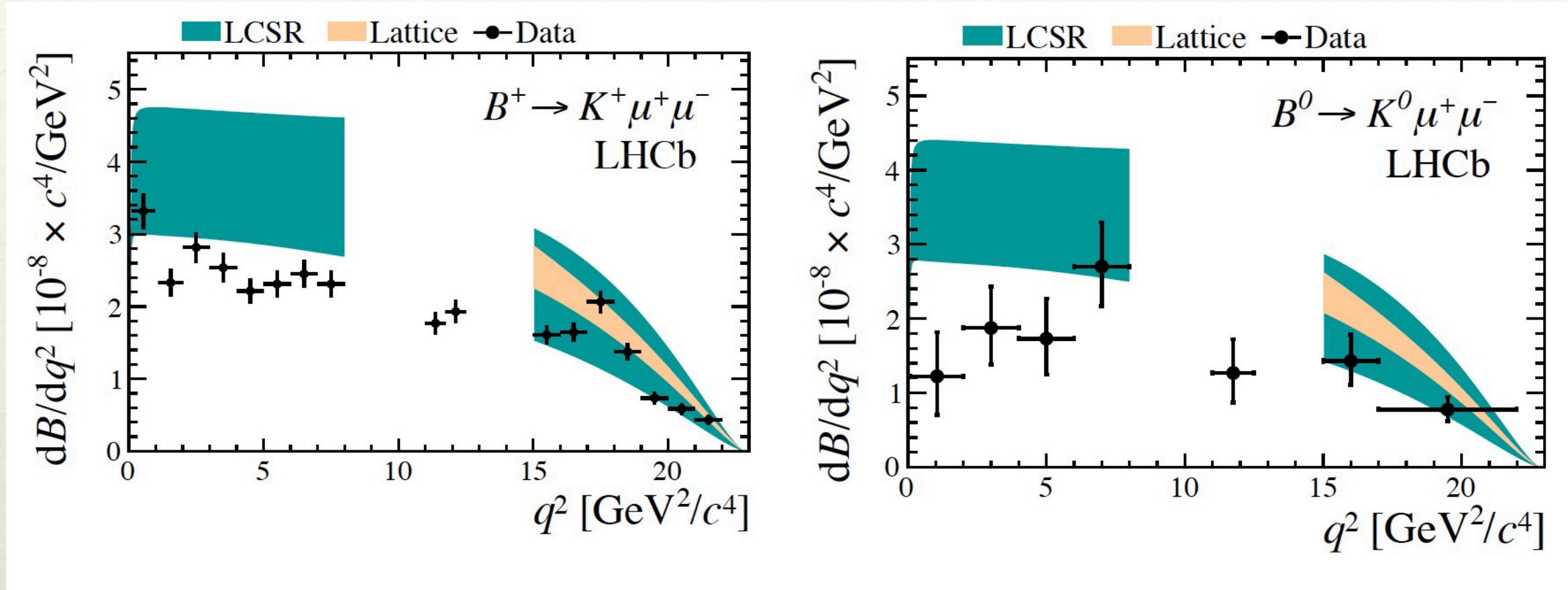
Latest LFU results

[arXiv:2212.09152]

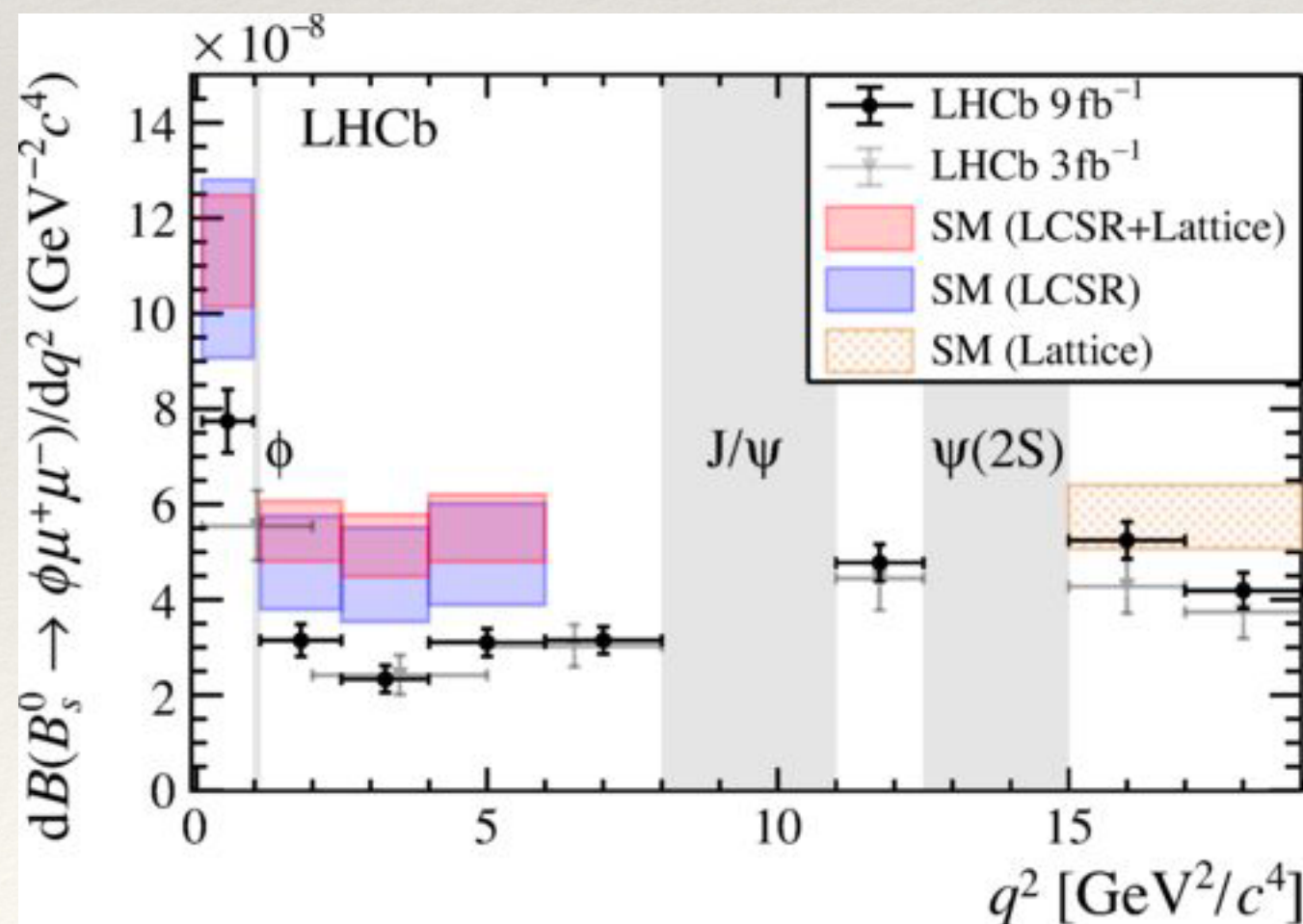
[arXiv:2212.09153]



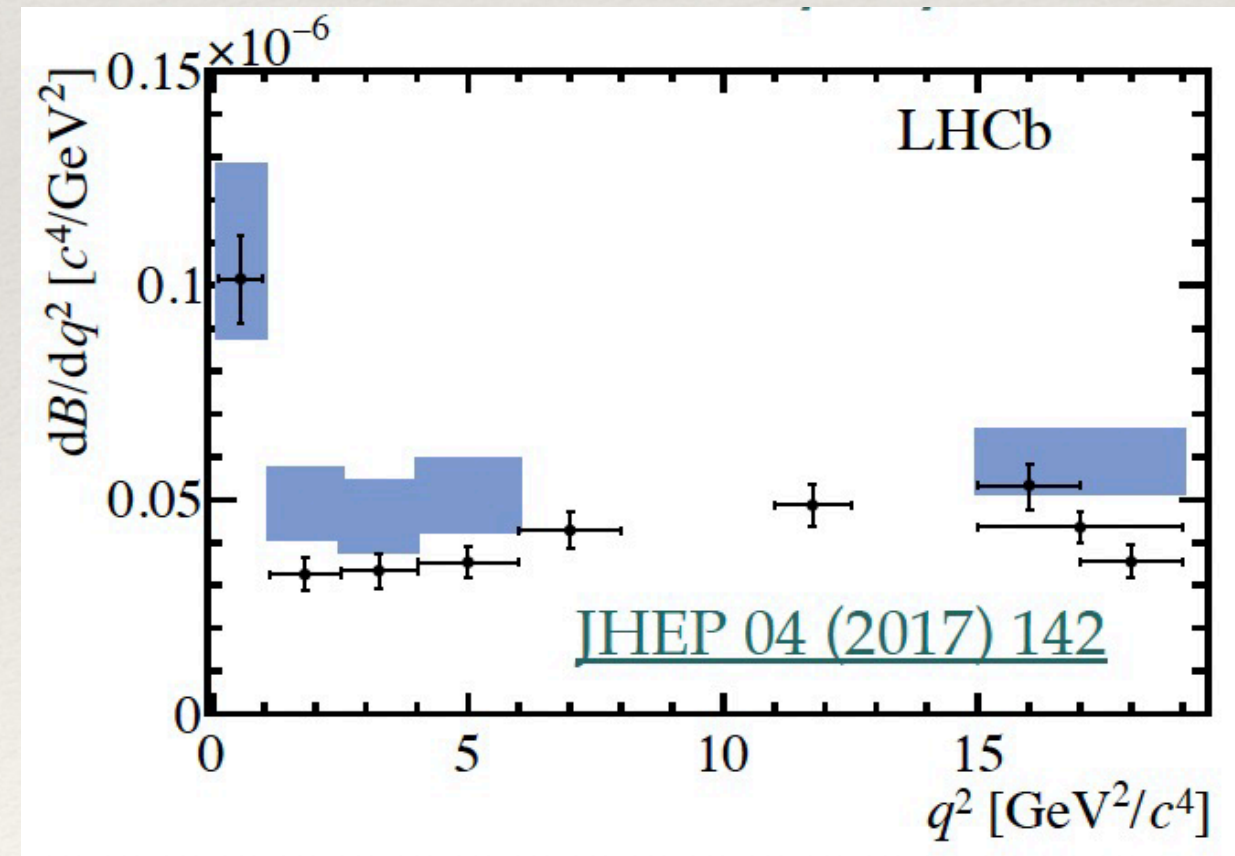
The other deviations



JHEP 1406 (2014) 133



PRL 127 (2021) 151801



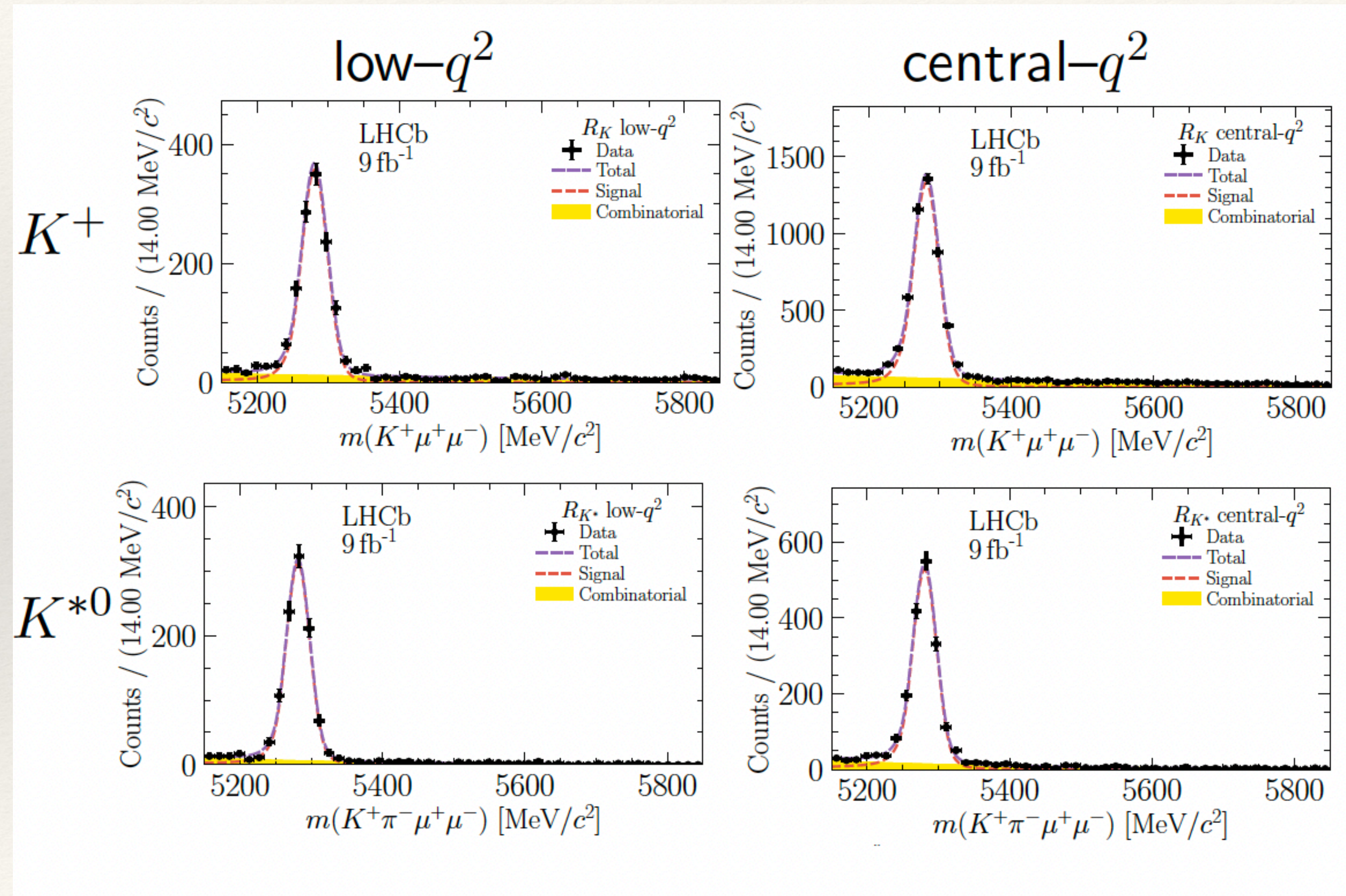
- ❖ Low values of branching fractions in muonic modes still persist.
- ❖ Angular analysis results are also unaffected.
- ❖ SM prediction heavily affected by hadronic uncertainties.
- ❖ Updates on branching fractions for muonic modes and first measurements on electronic modes are ongoing.

Conclusions

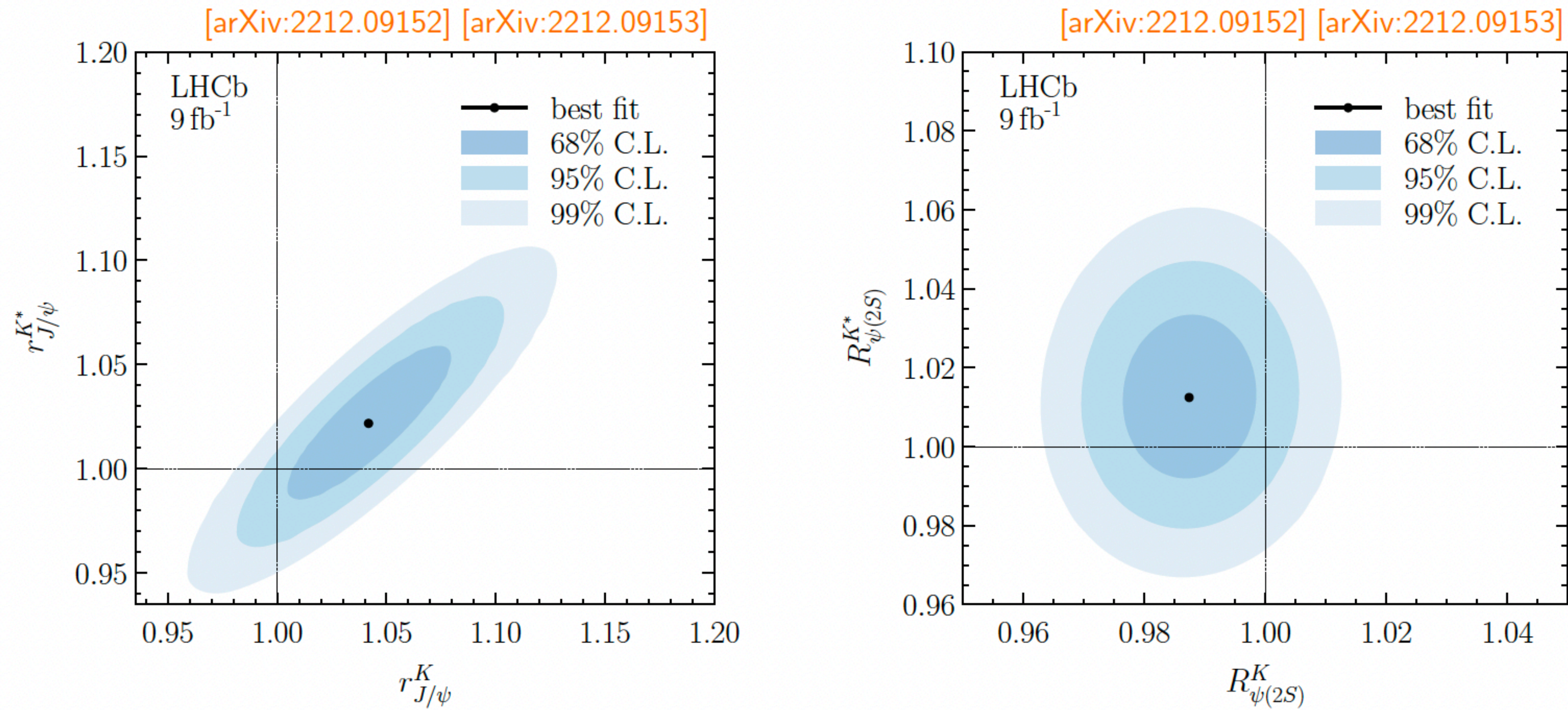
- ❖ New R_K and R_{K^*} results are the most precise to date, and superseeds previous results.
- ❖ Compatible with the SM prediction at 0.2σ .
- ❖ Other published results R_{pK} , R_{K_S} , $R_{K^{*+}}$ are not affected as they already accounted for double misID and are much more statistically dominated.
- ❖ Anomalies in differential branching fractions and angular analyses of the muons are not affected.

backup

Muonic mode

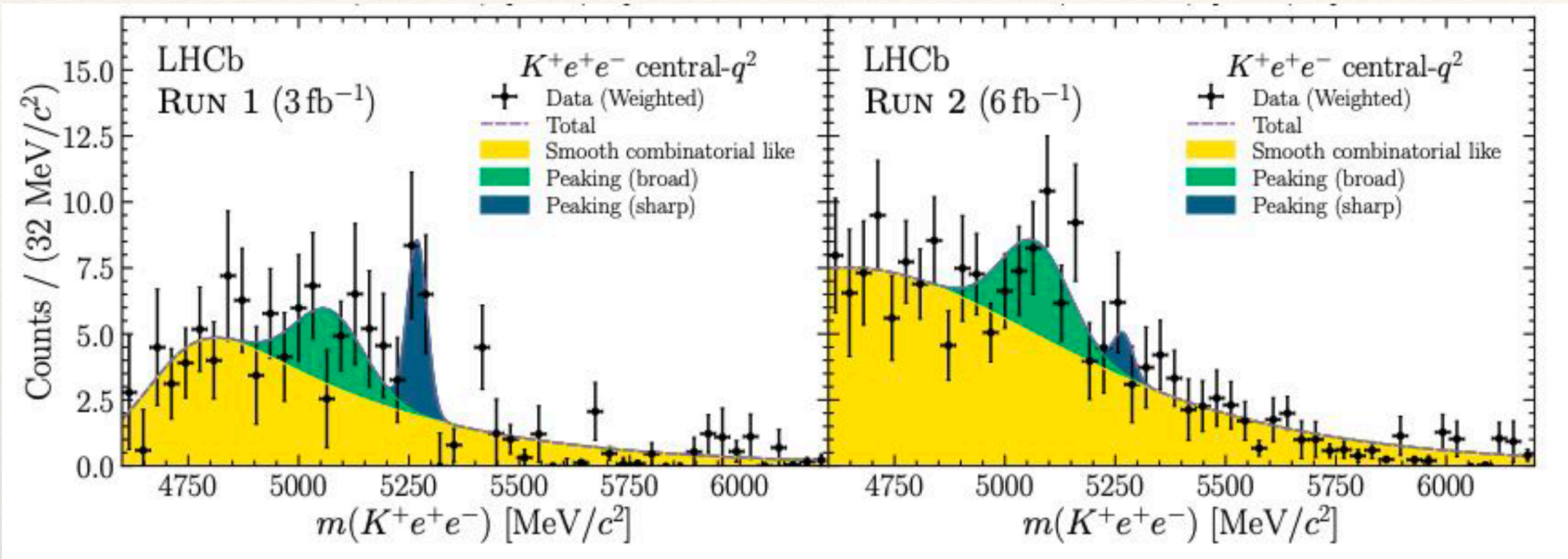


Crosschecks

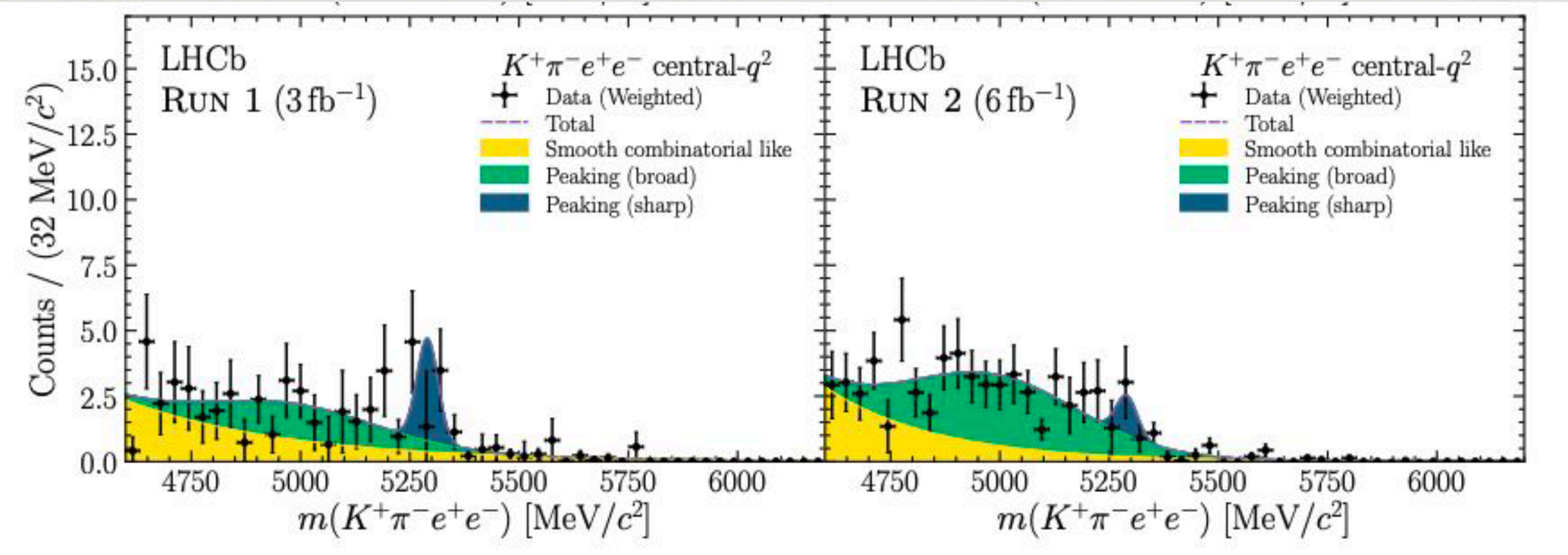


- Both $r_{J/\psi}$ and $R_{\psi(2S)}$ compatible with unity at better than 2σ

MisID bkg strategy



- ❖ Invert the electron PID requirement to have an enriched sample of misID non-resonant decays.
- ❖ Analytical model for the MisID bkg.
- ❖ Normalization with gaussian constraint.



Timeline

- ❖ R_K central q^2 paper put on arXiv on 03 / 2021.
- ❖ R_K central q^2 published online in Nature Physics 18 (2022) 277 on 03 / 2022.
- ❖ R_K arXiv updated in 09 / 2022 with minor editorial changes.
- ❖ R_X put on arXiv 12 / 22.