Rare decays at LHCb

A selection of news and future possibilities

Miami 2024 Physics Conference

Anja Beck (MIT) on behalf of the LHCb Collaboration

Rare decays

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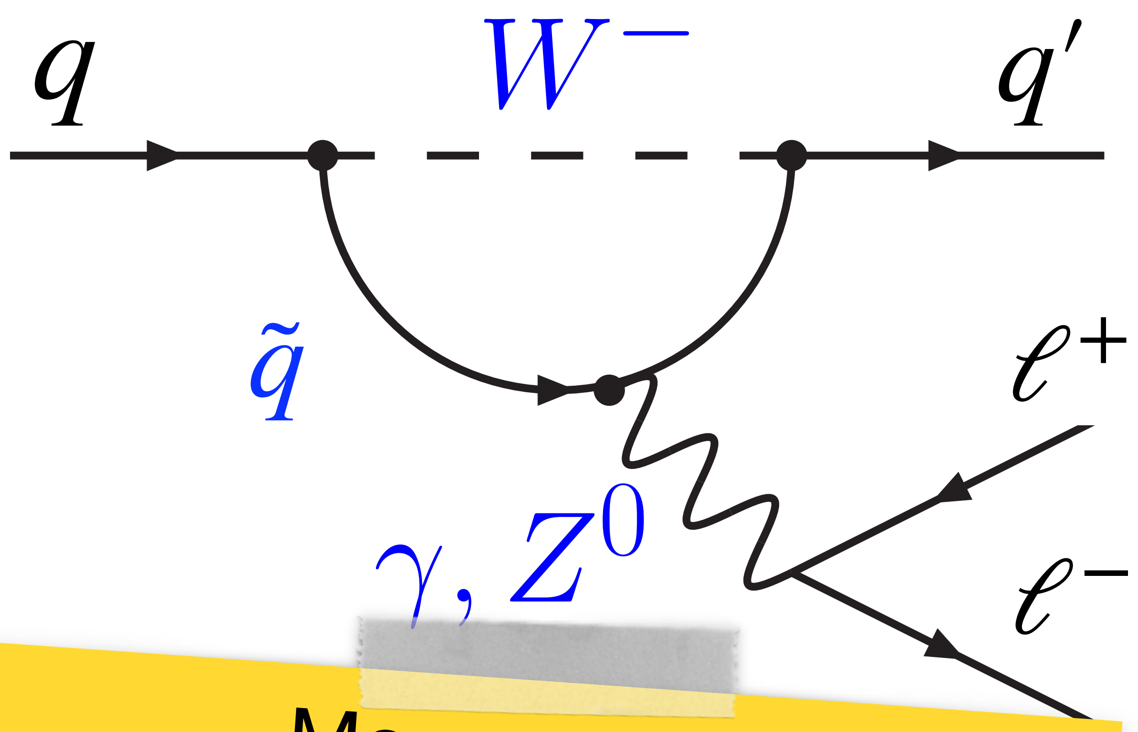

Decays without the tree-level diagram in the SM (e.g. $b \to s\mu\mu$)

More vertices
=> lower branching fraction

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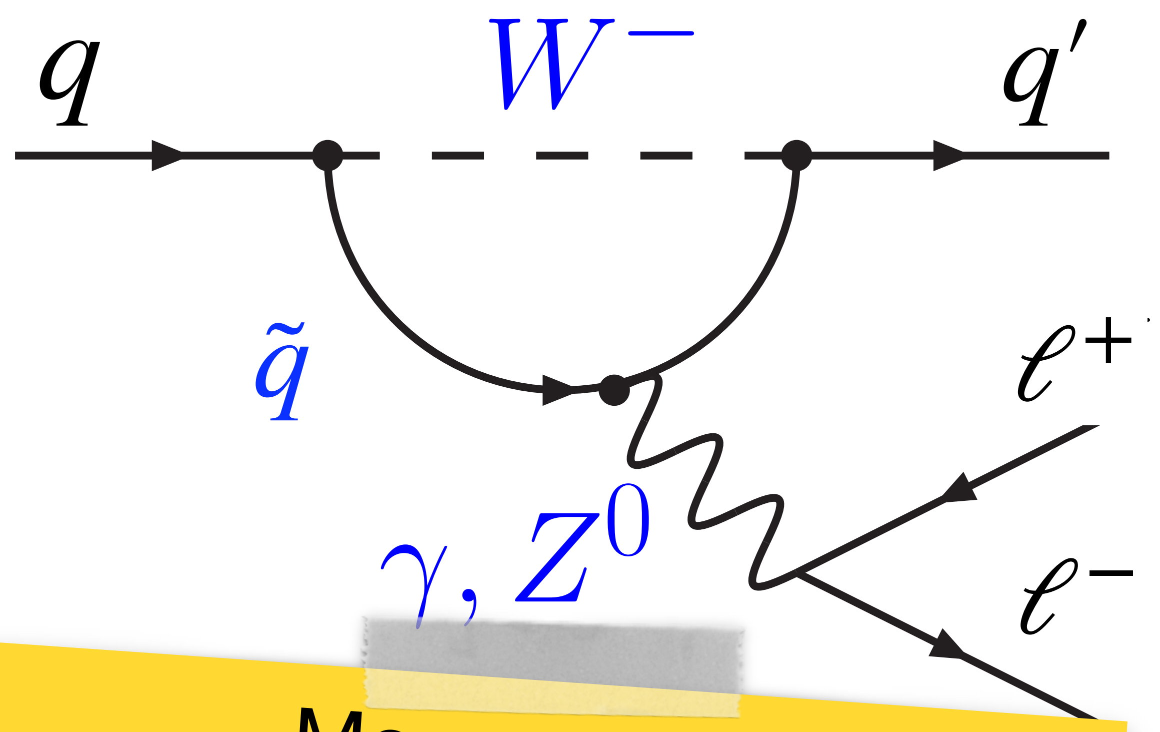
1. BSM physics is potentially more prominent
2. Loop allows access to virtual contributions



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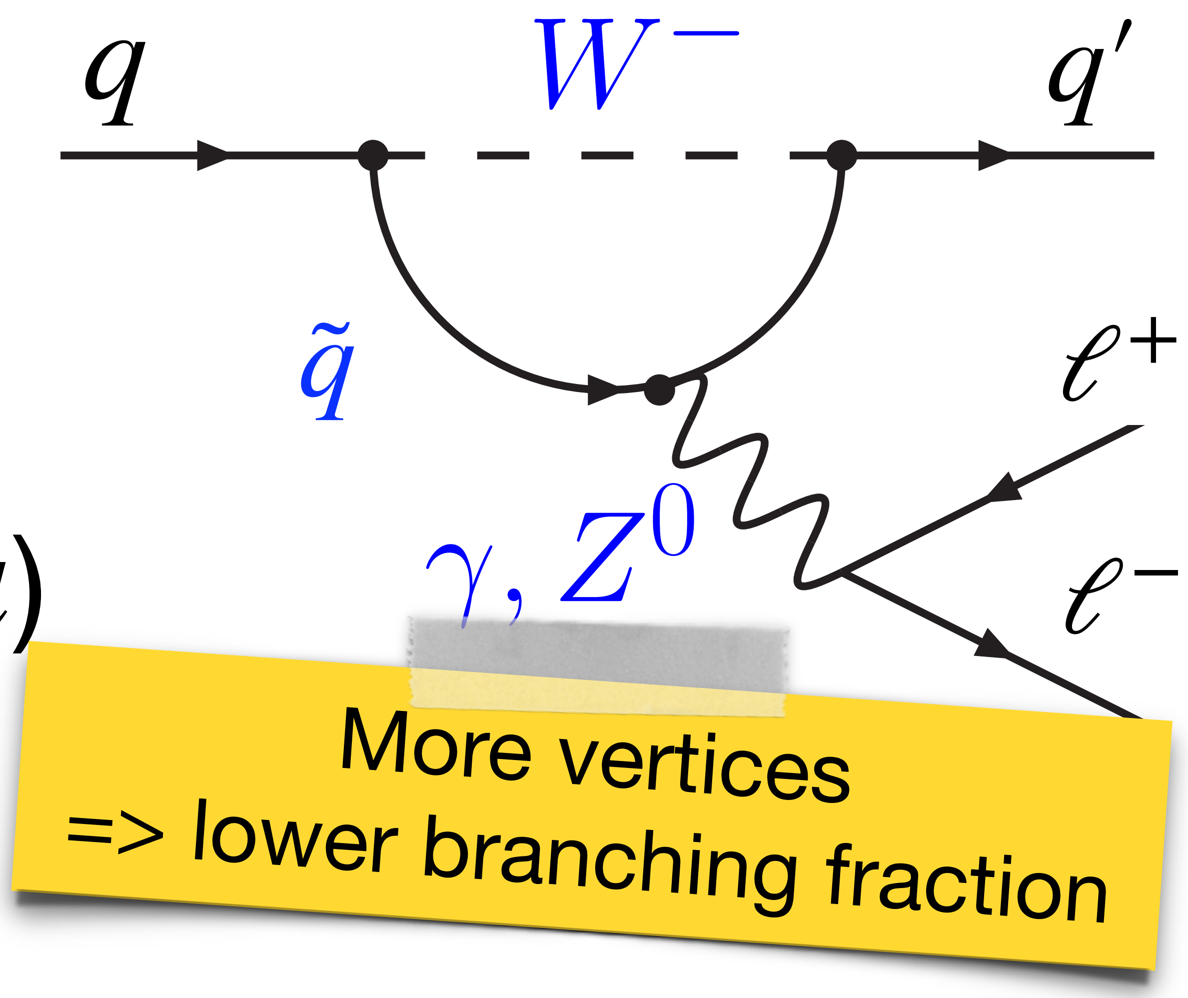

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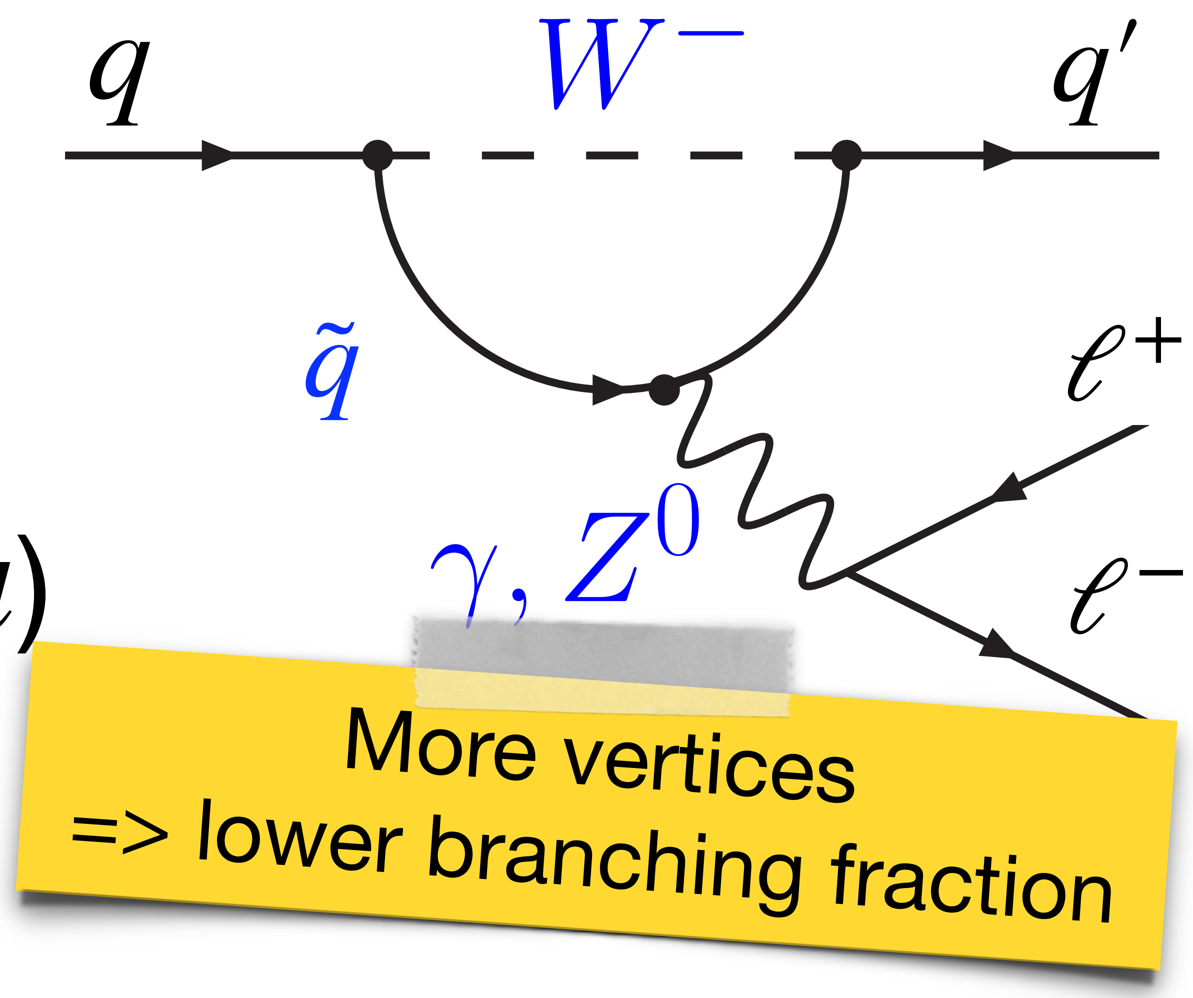

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$b \to s$ and $b \to d$

(more CKM-suppressed, less GIM-suppressed)

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$s \to d$

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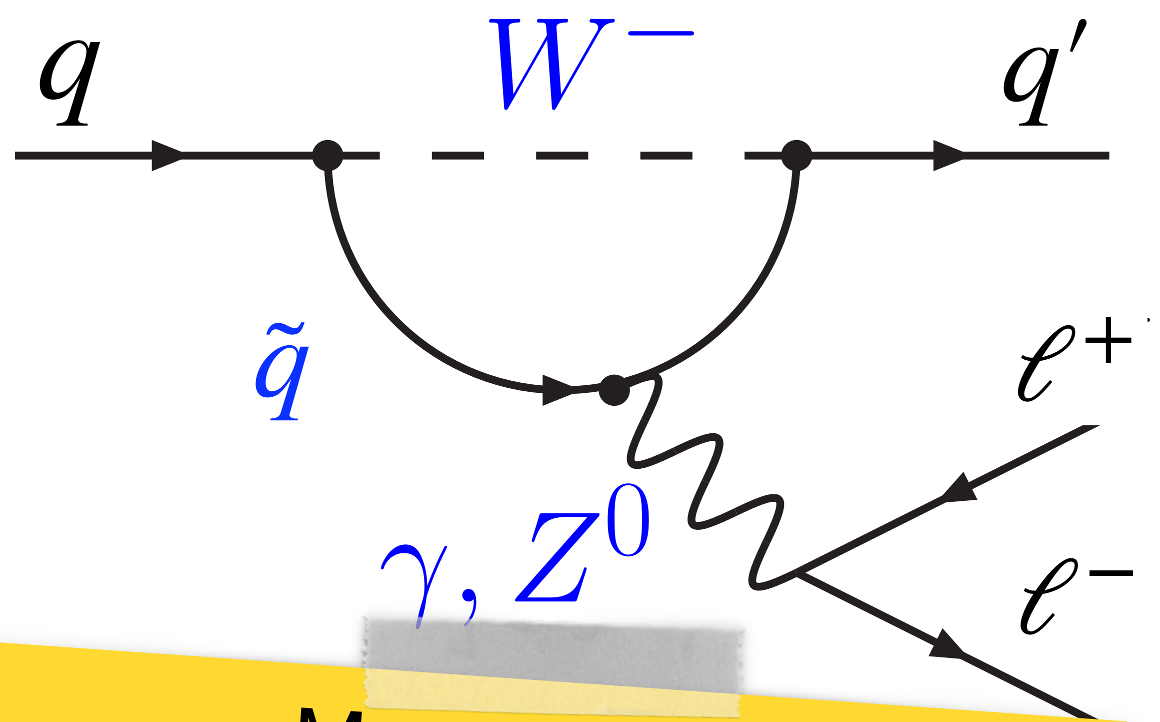

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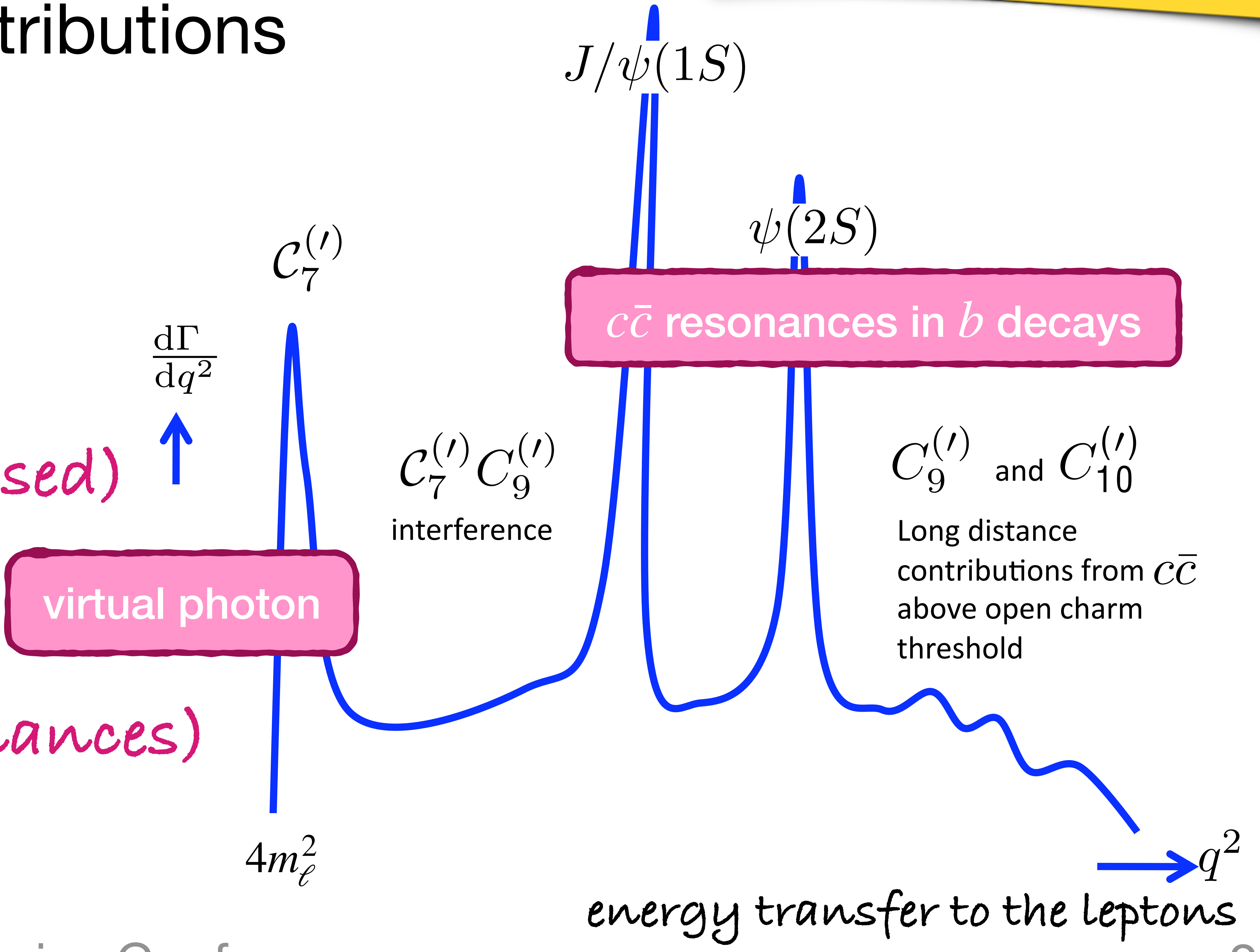
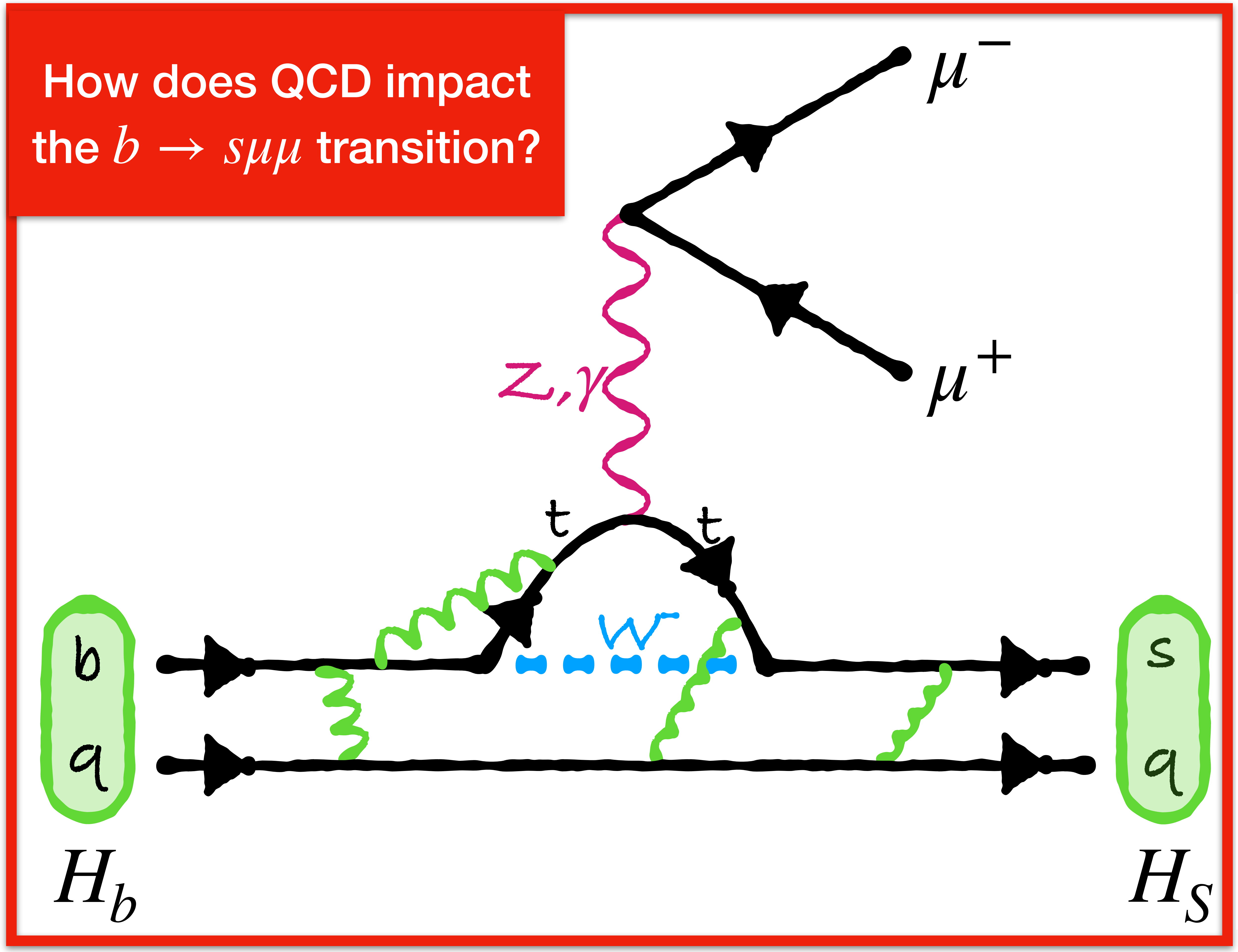


QCD meets penguins



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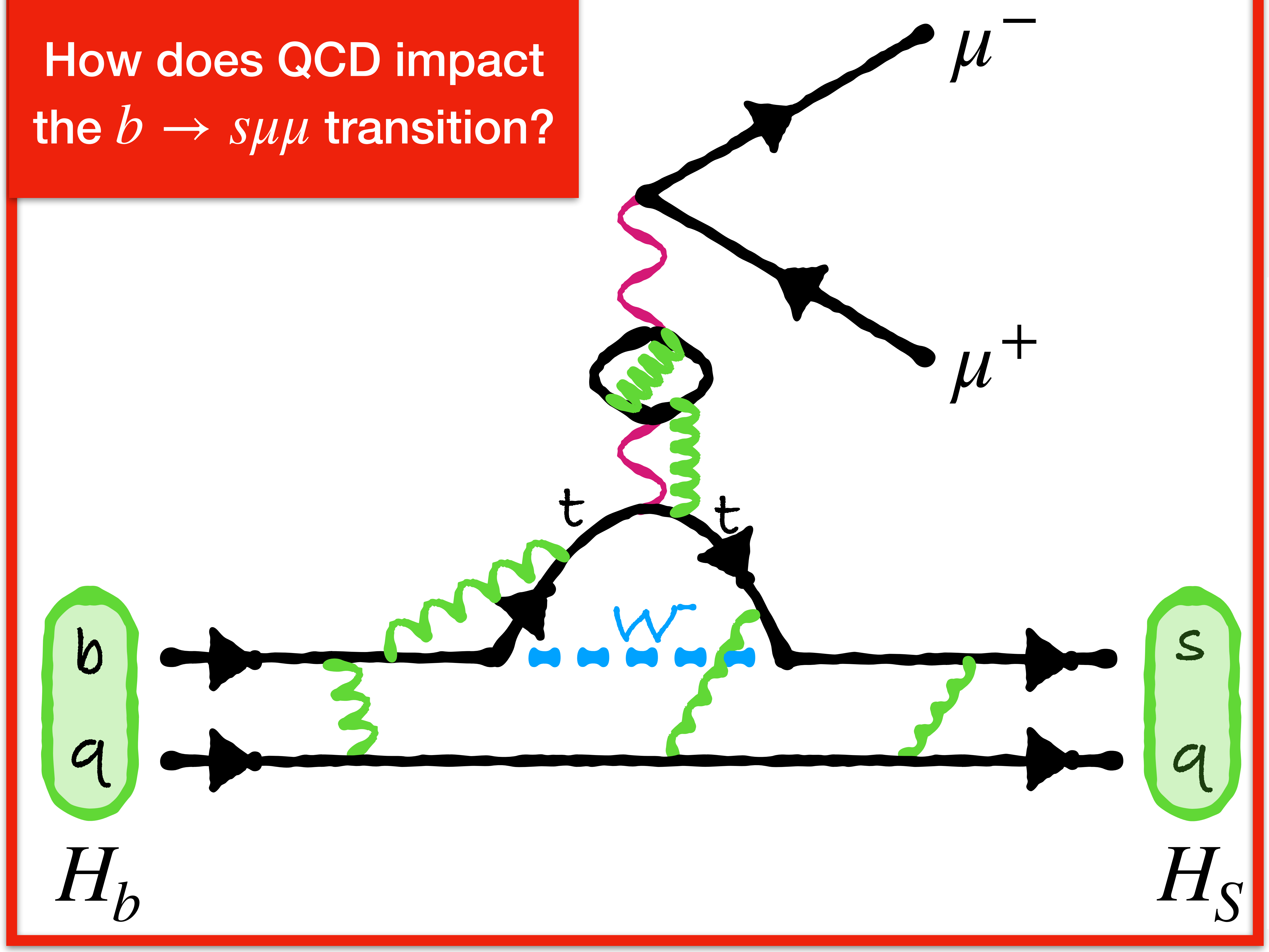
How does QCD impact the $b \to s\mu\mu$ transition?



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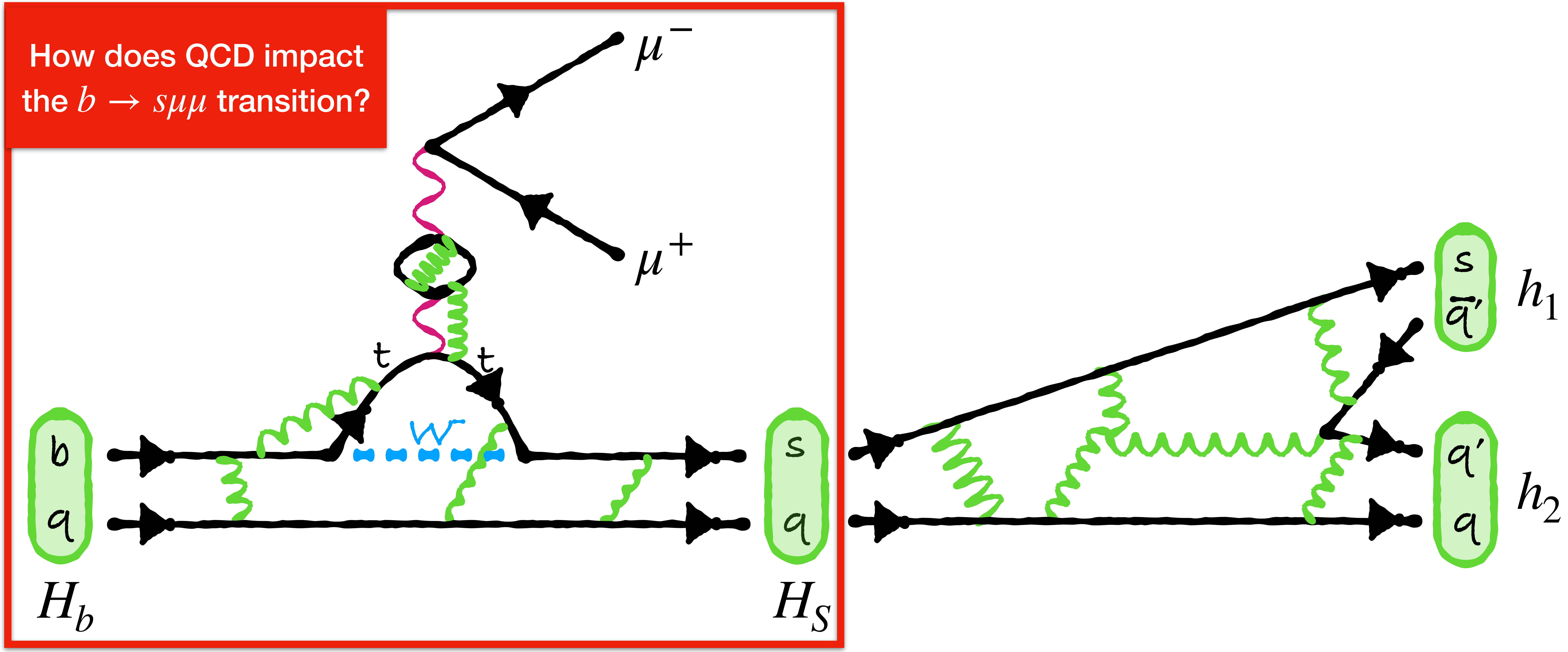

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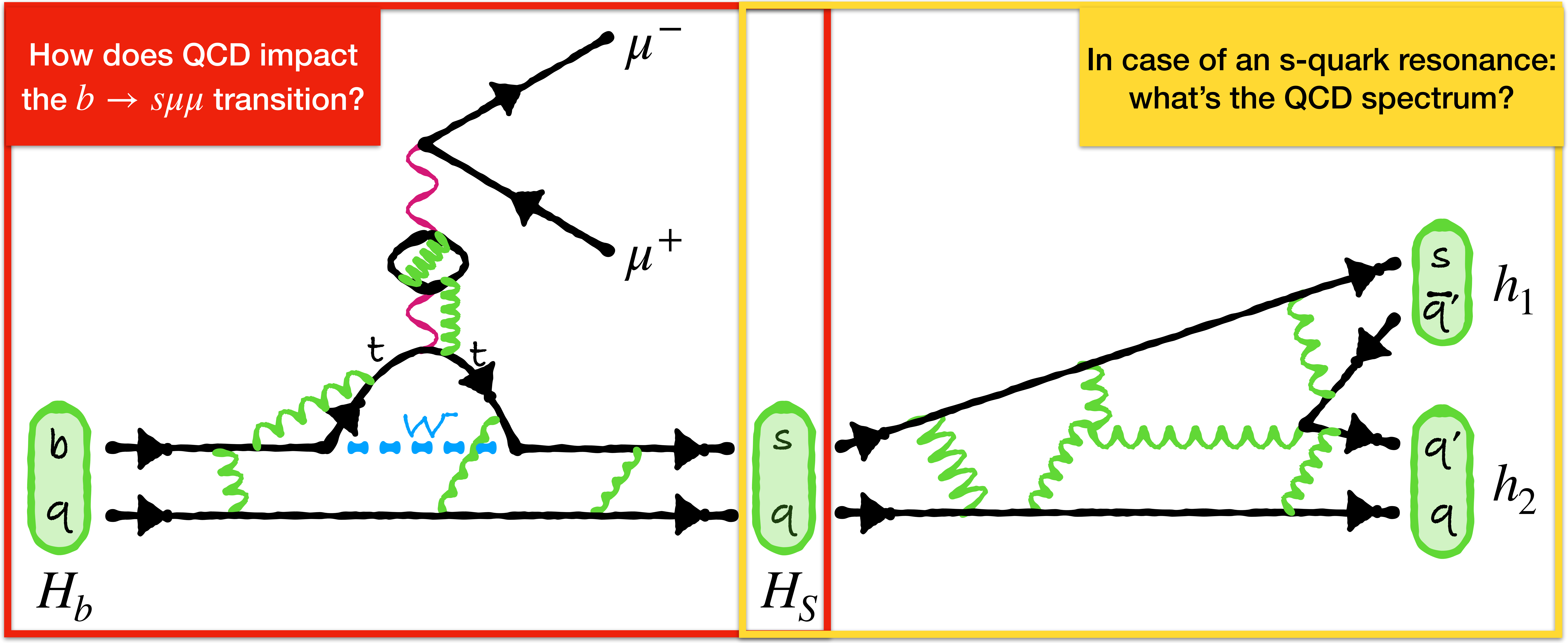

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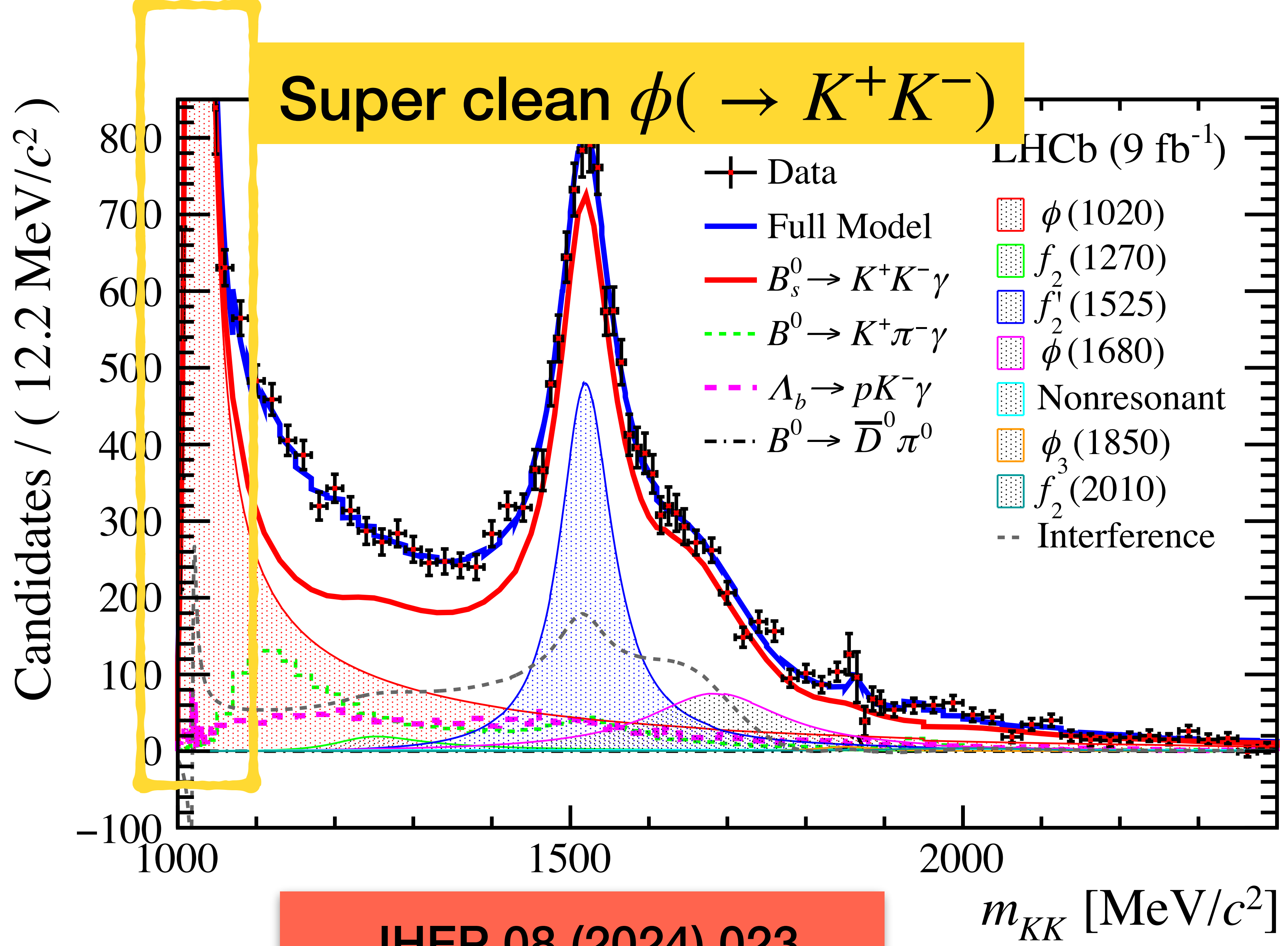

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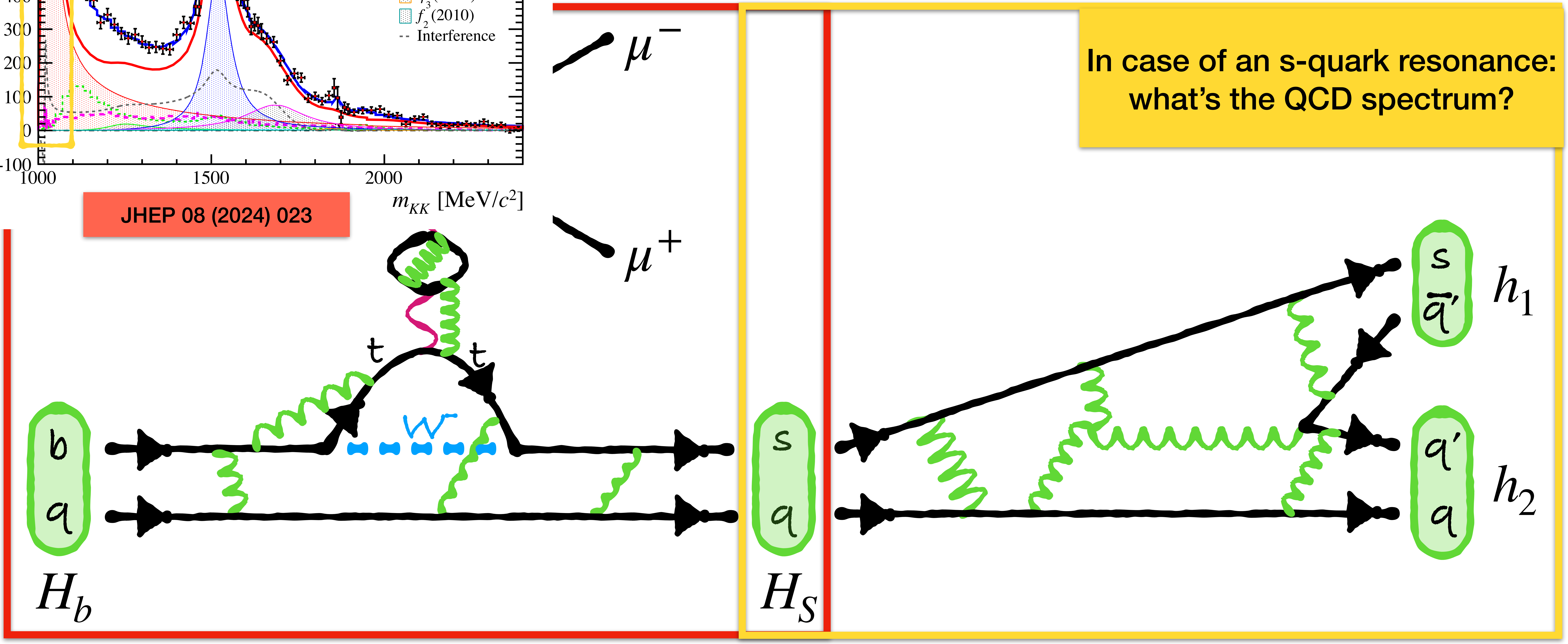

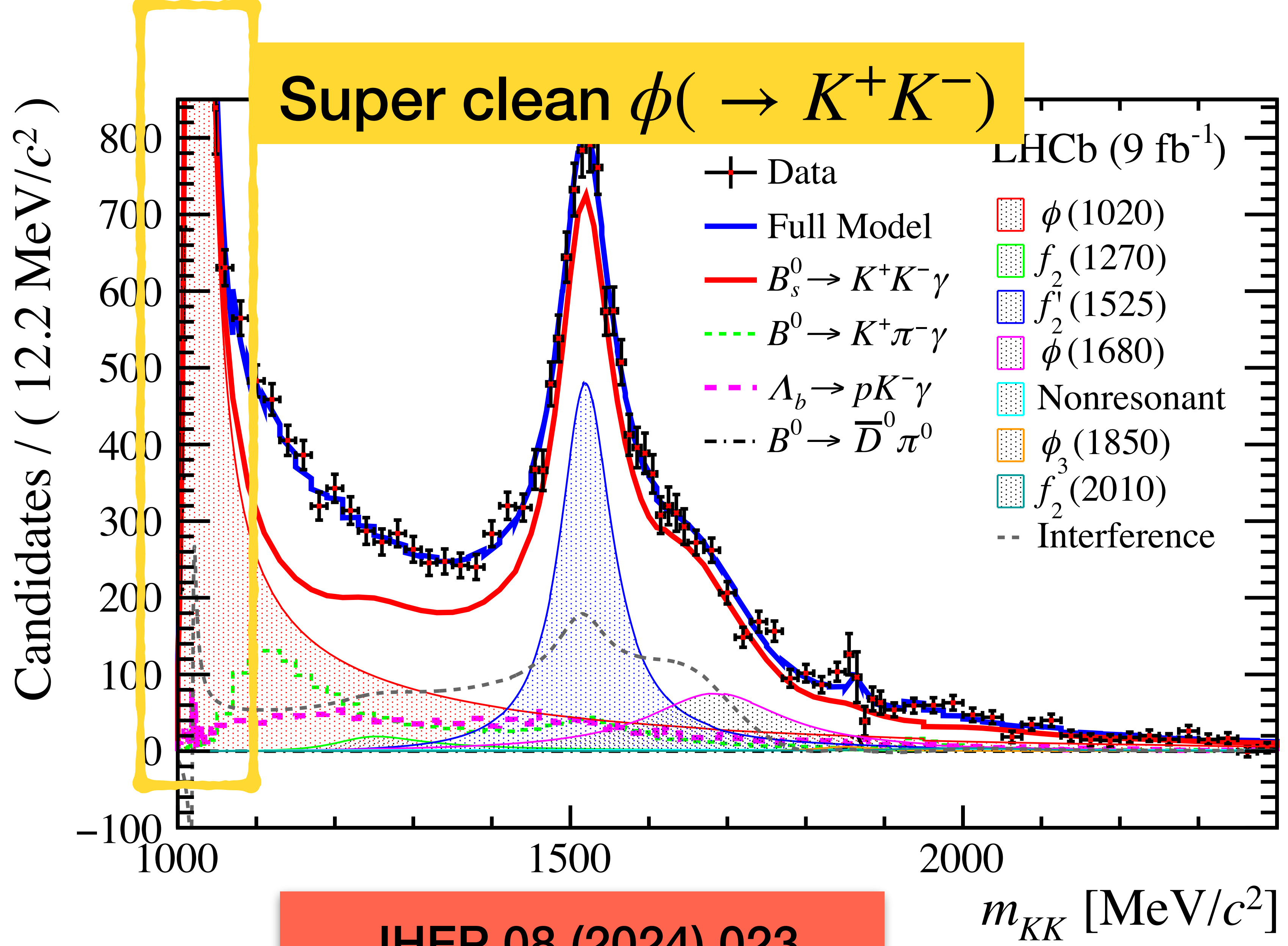

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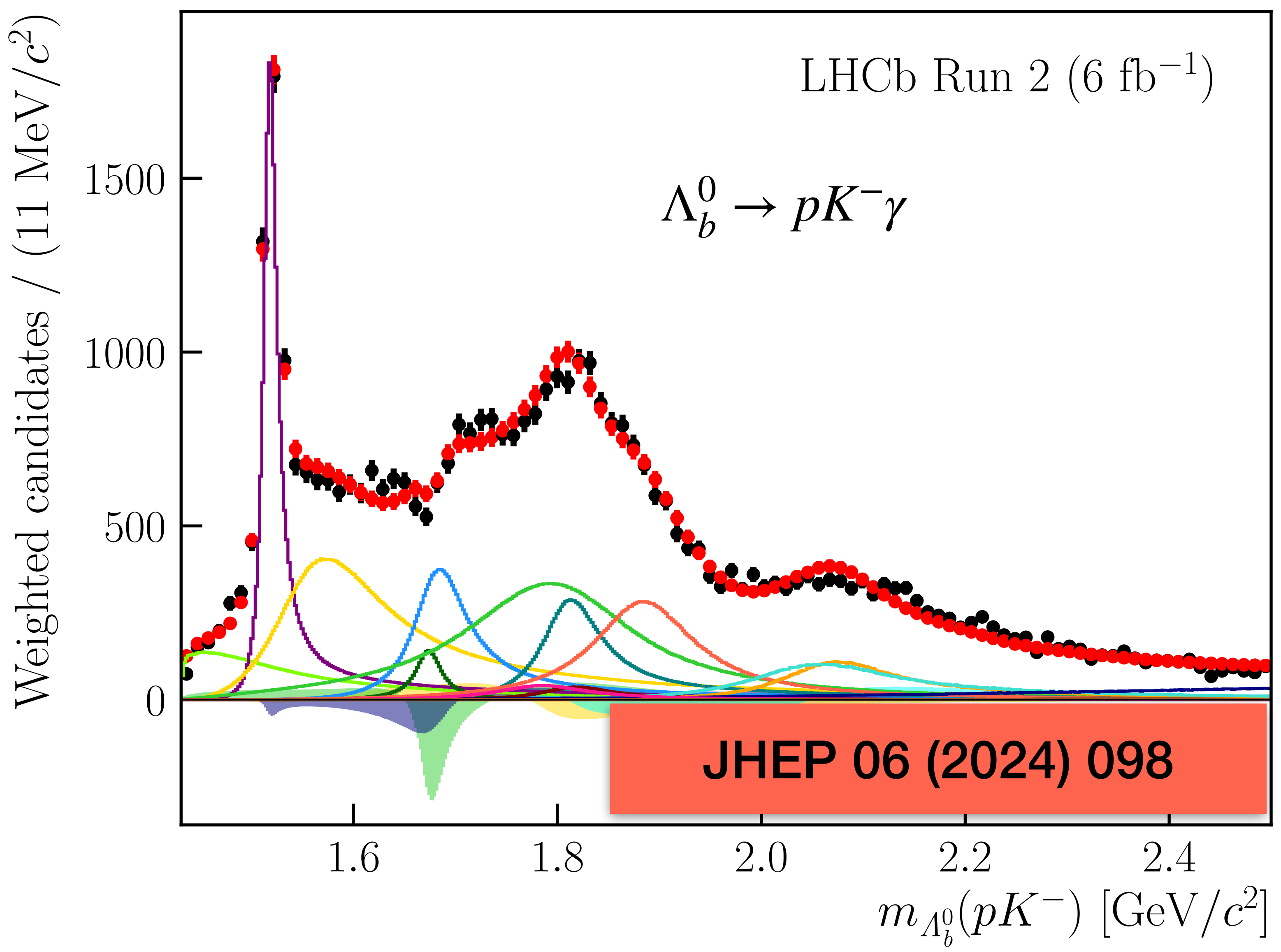

JHEP 06 (2024) 098

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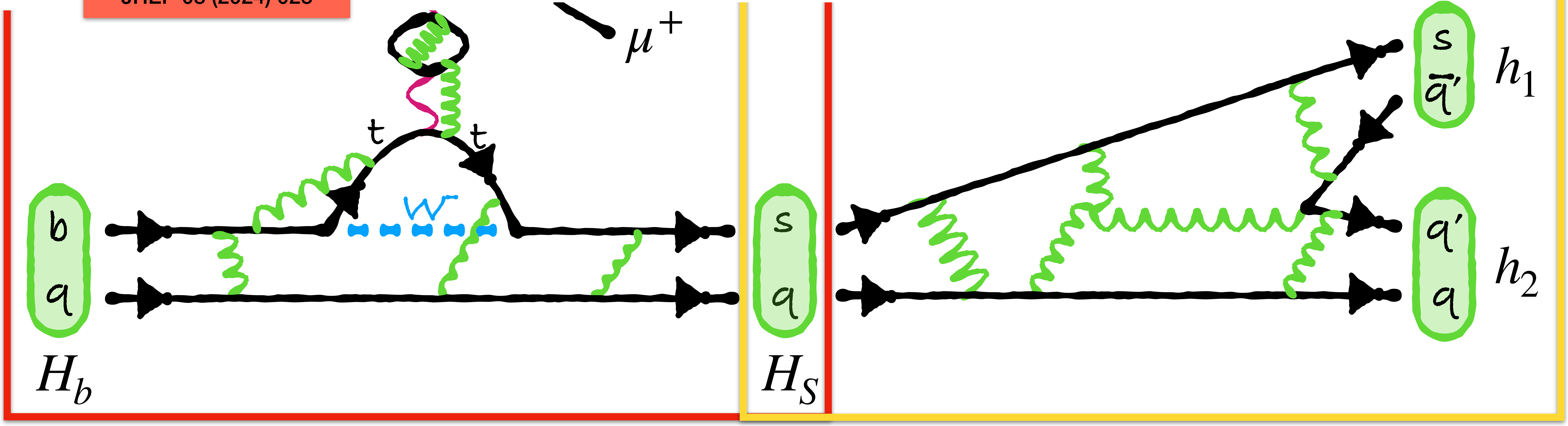
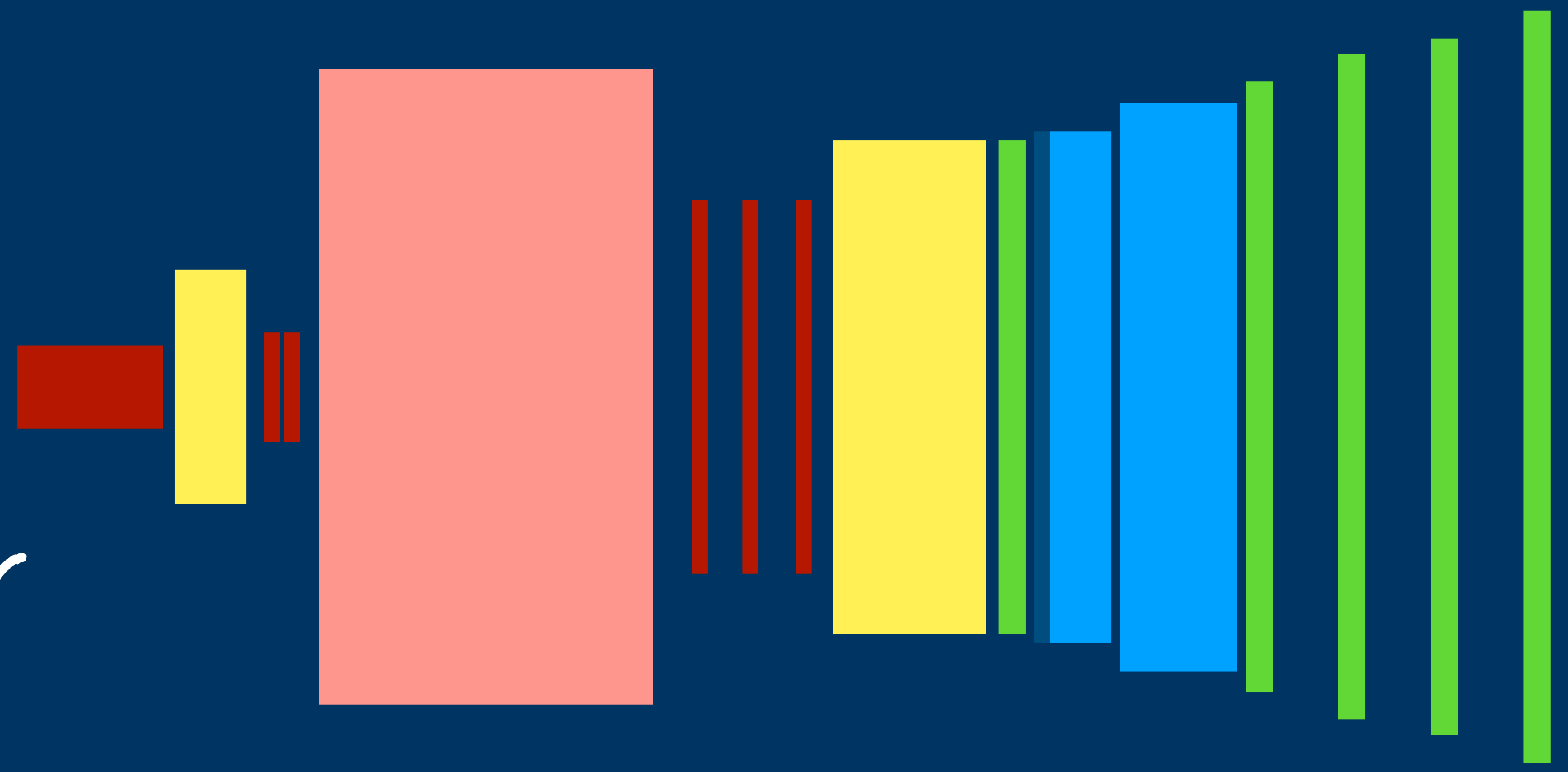
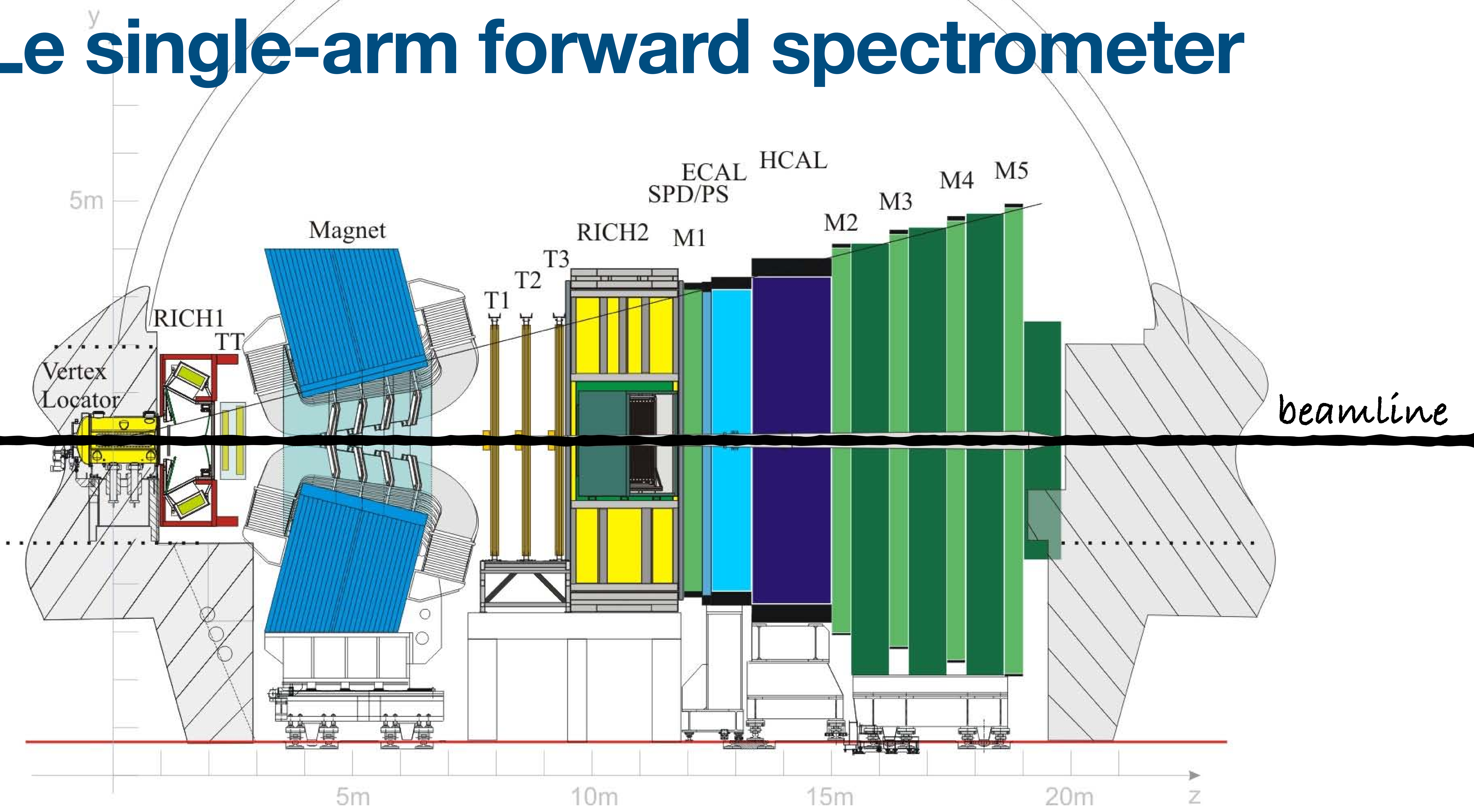


The LHCb detector

so far



Le single-arm forward spectrometer



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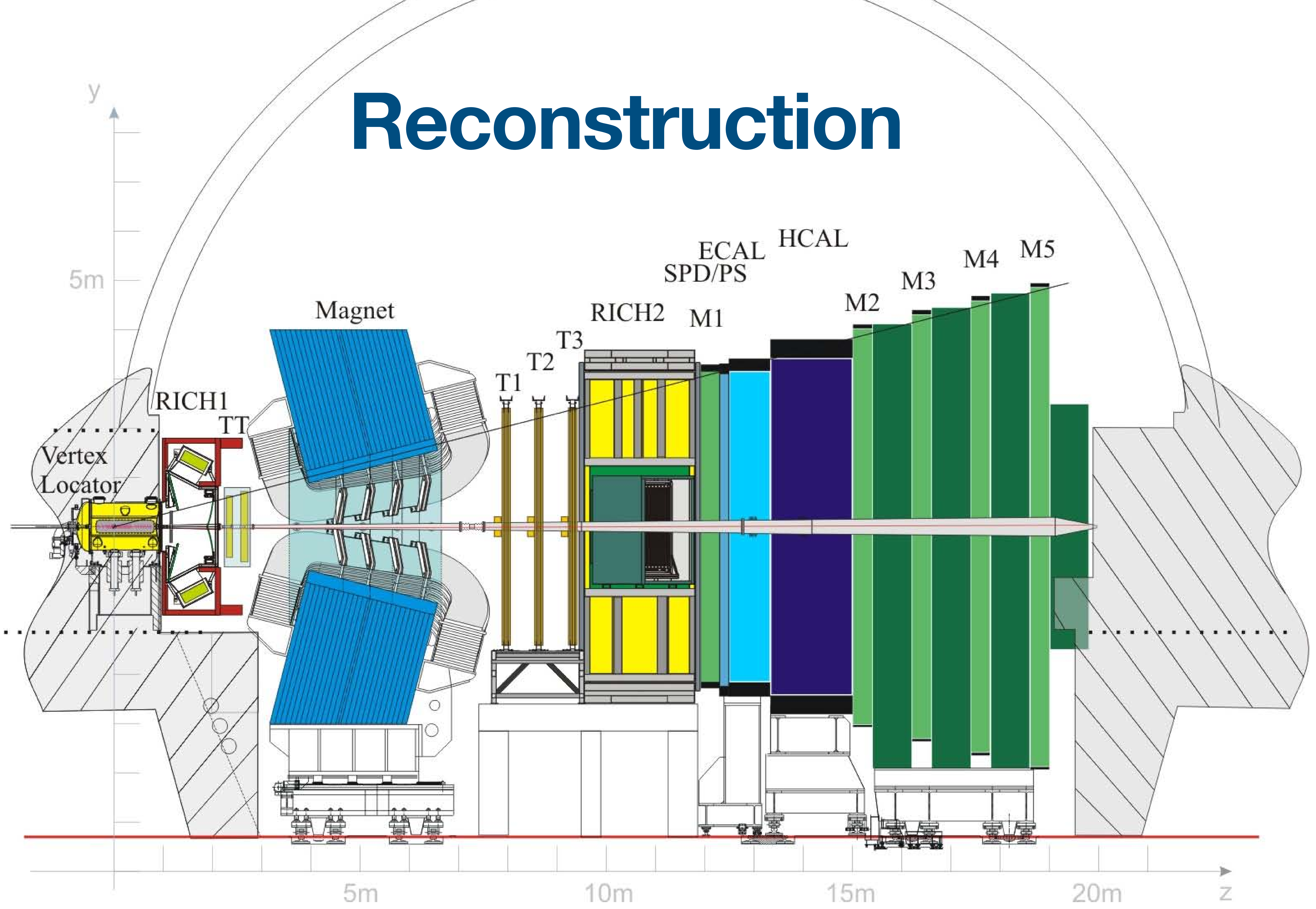

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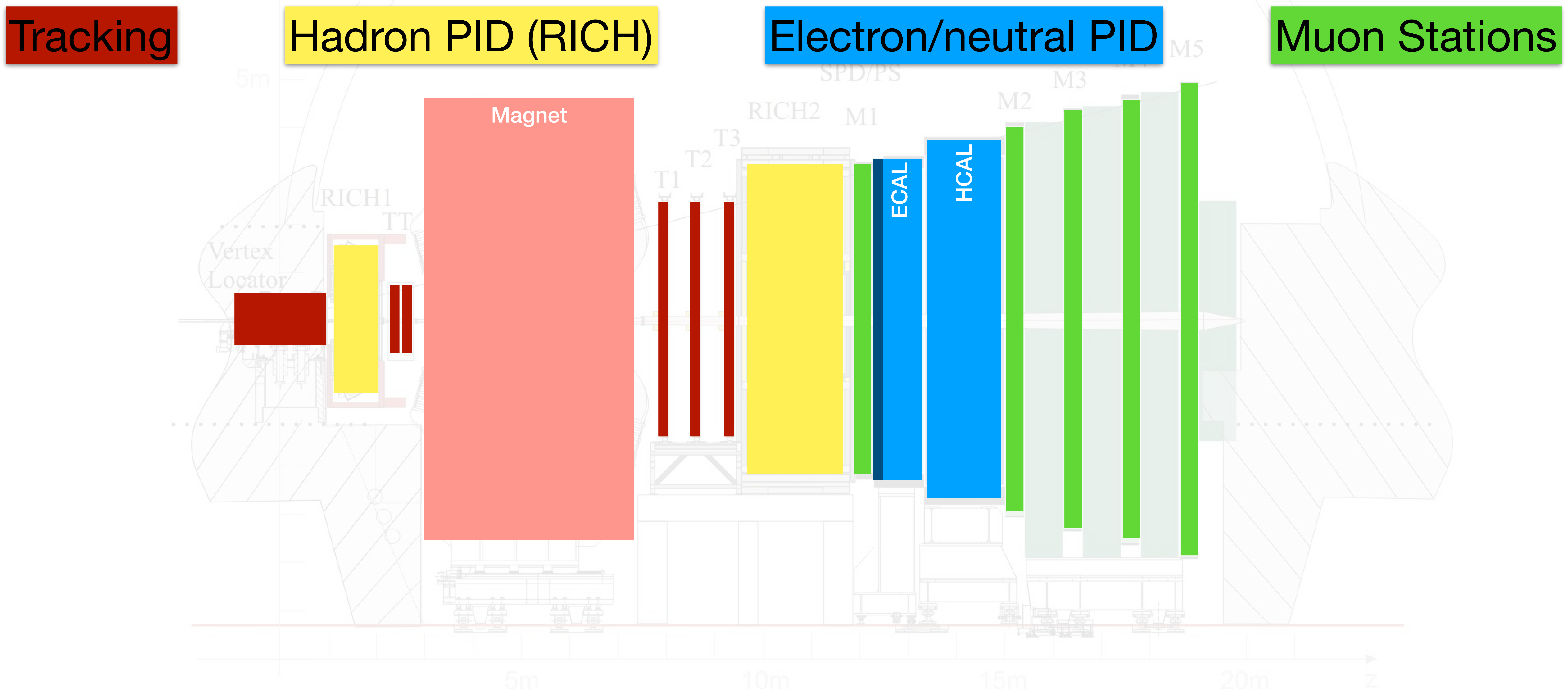

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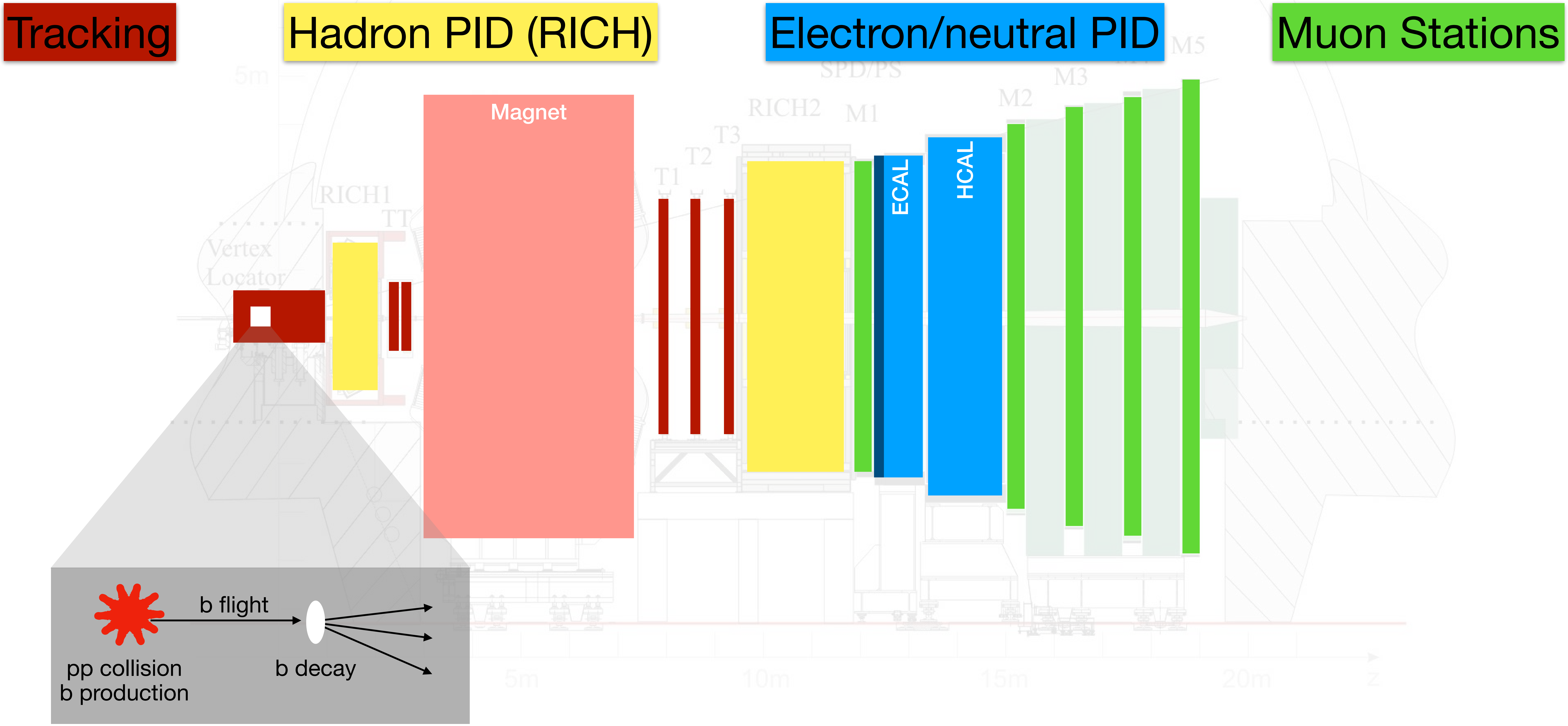

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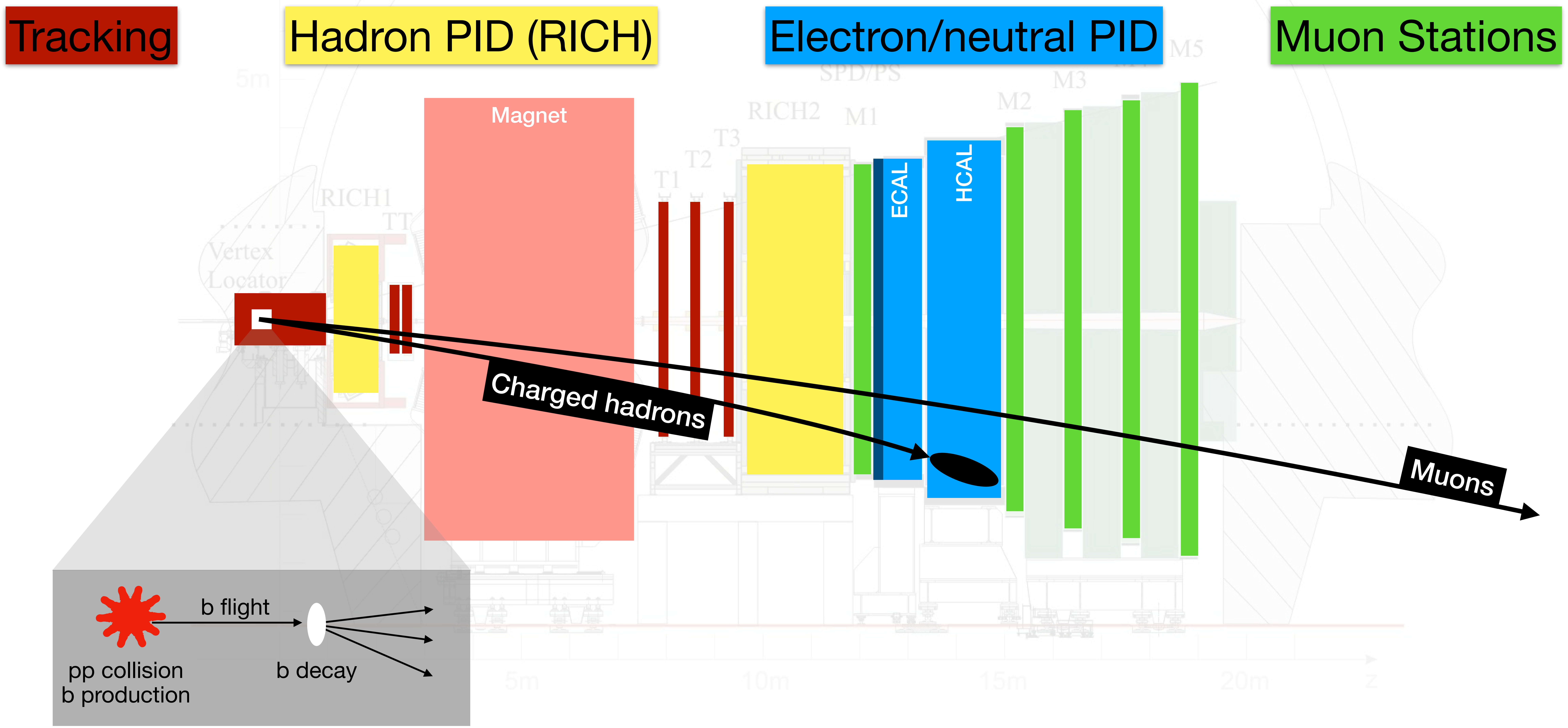

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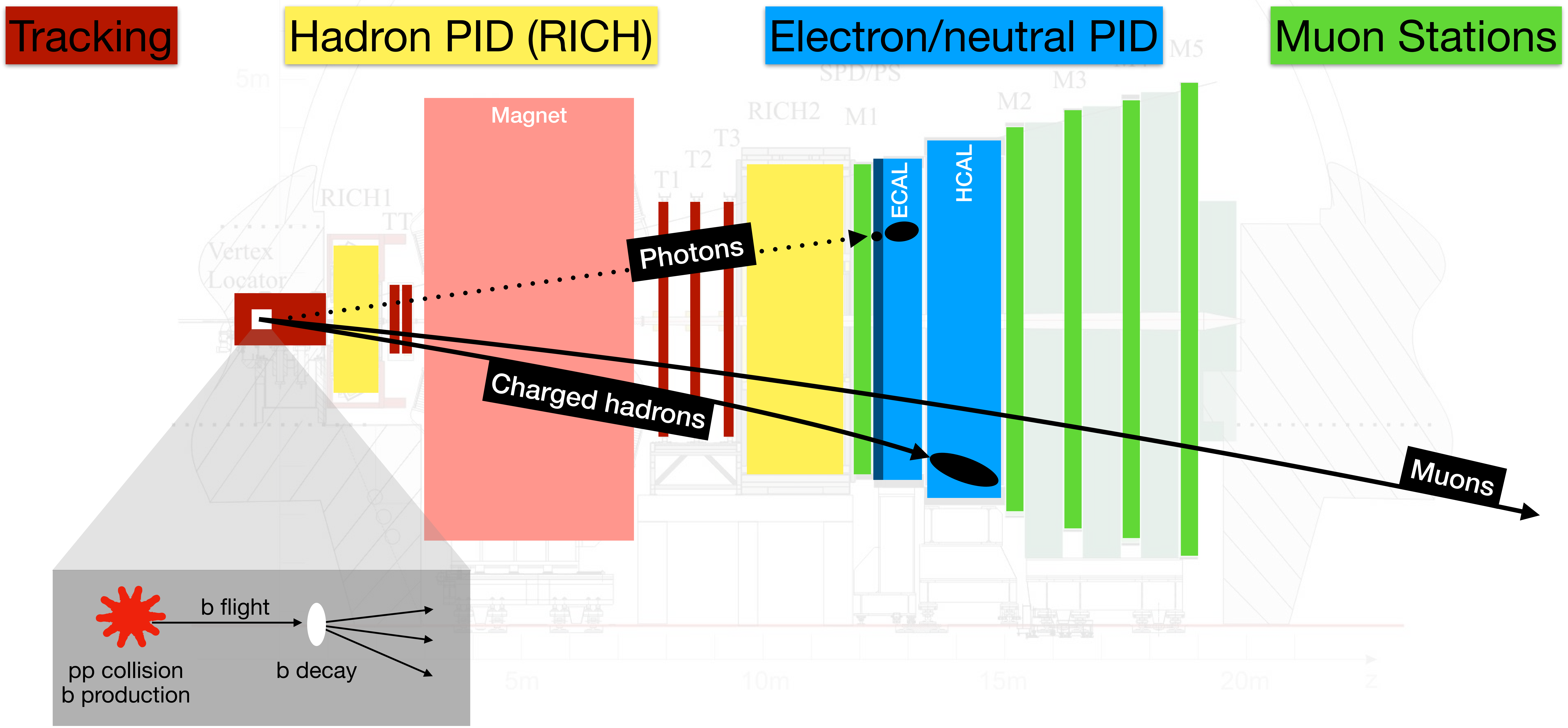

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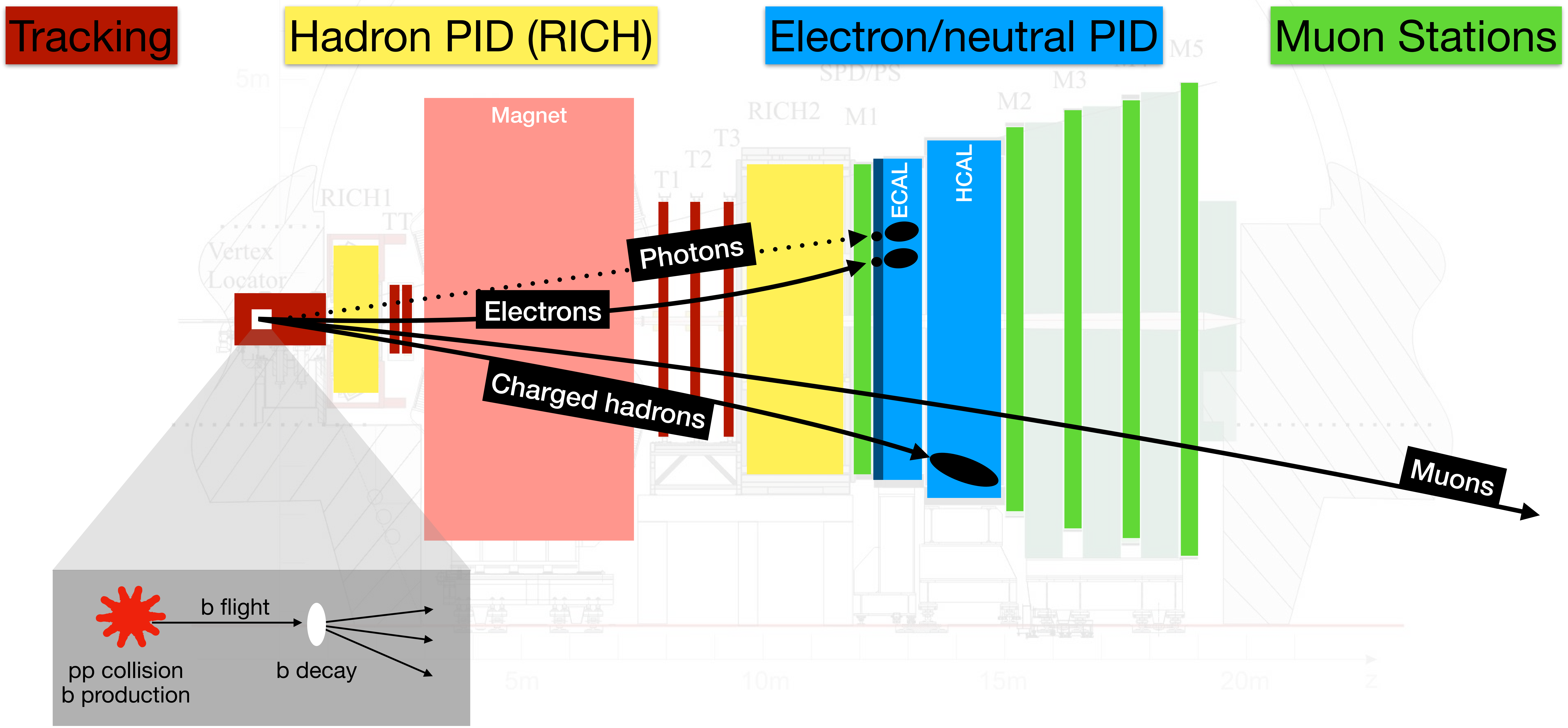

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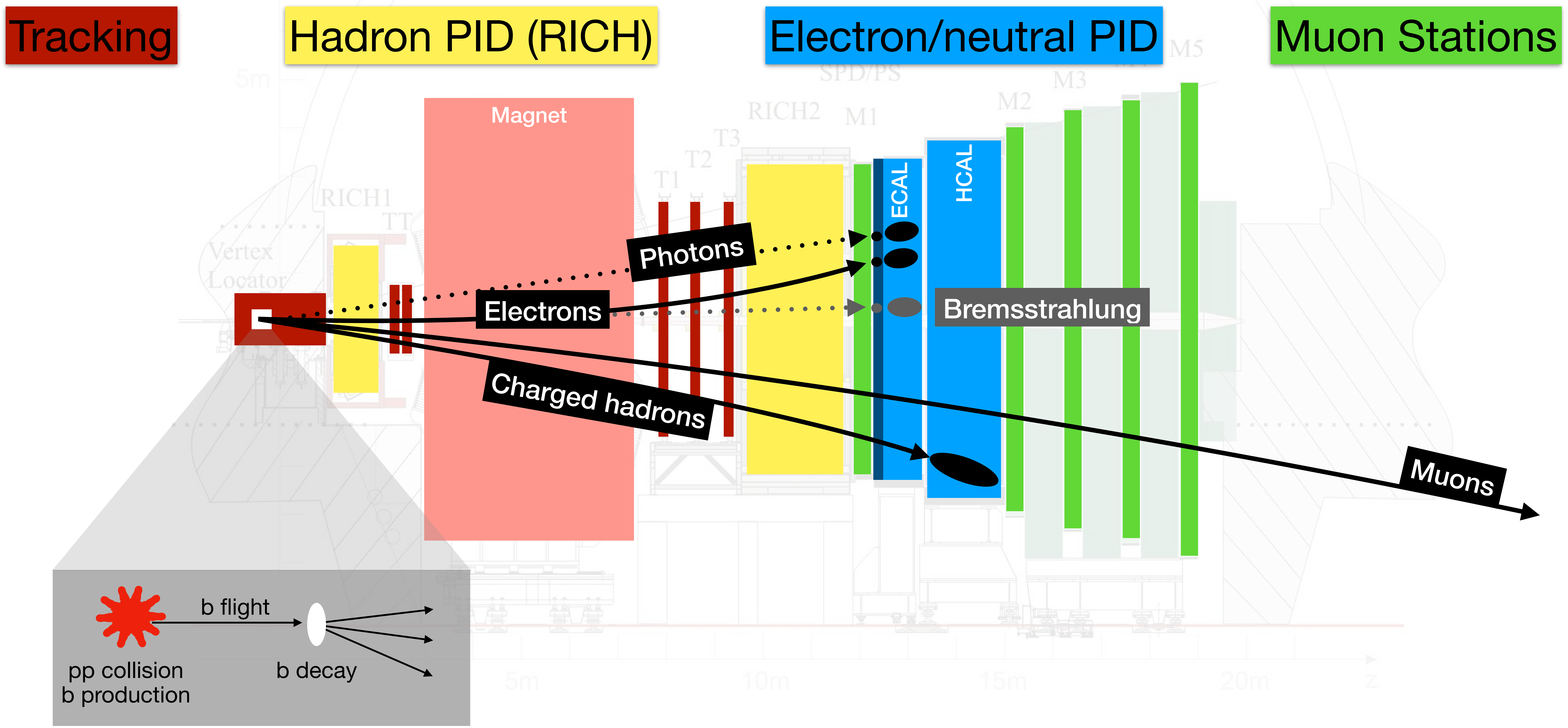

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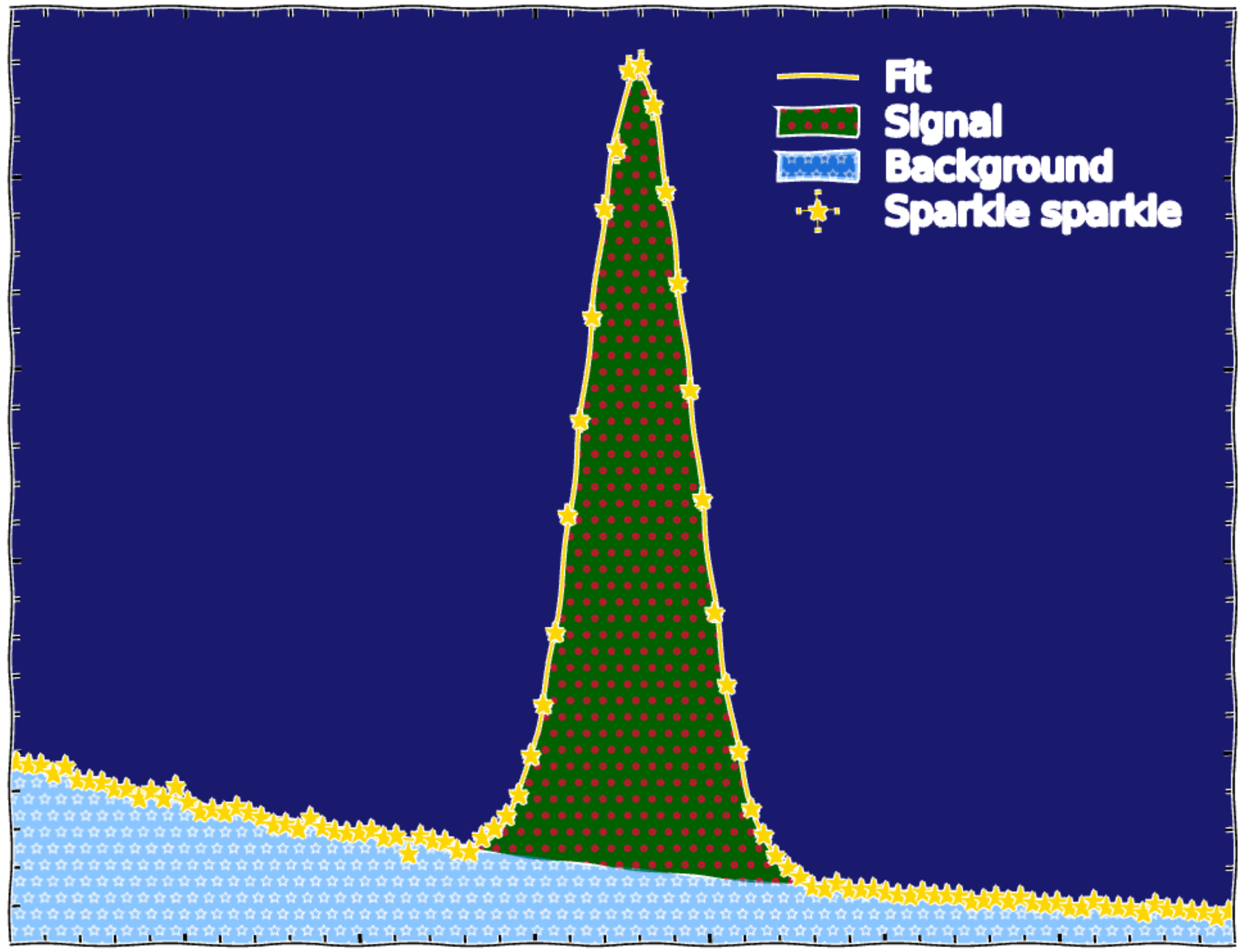
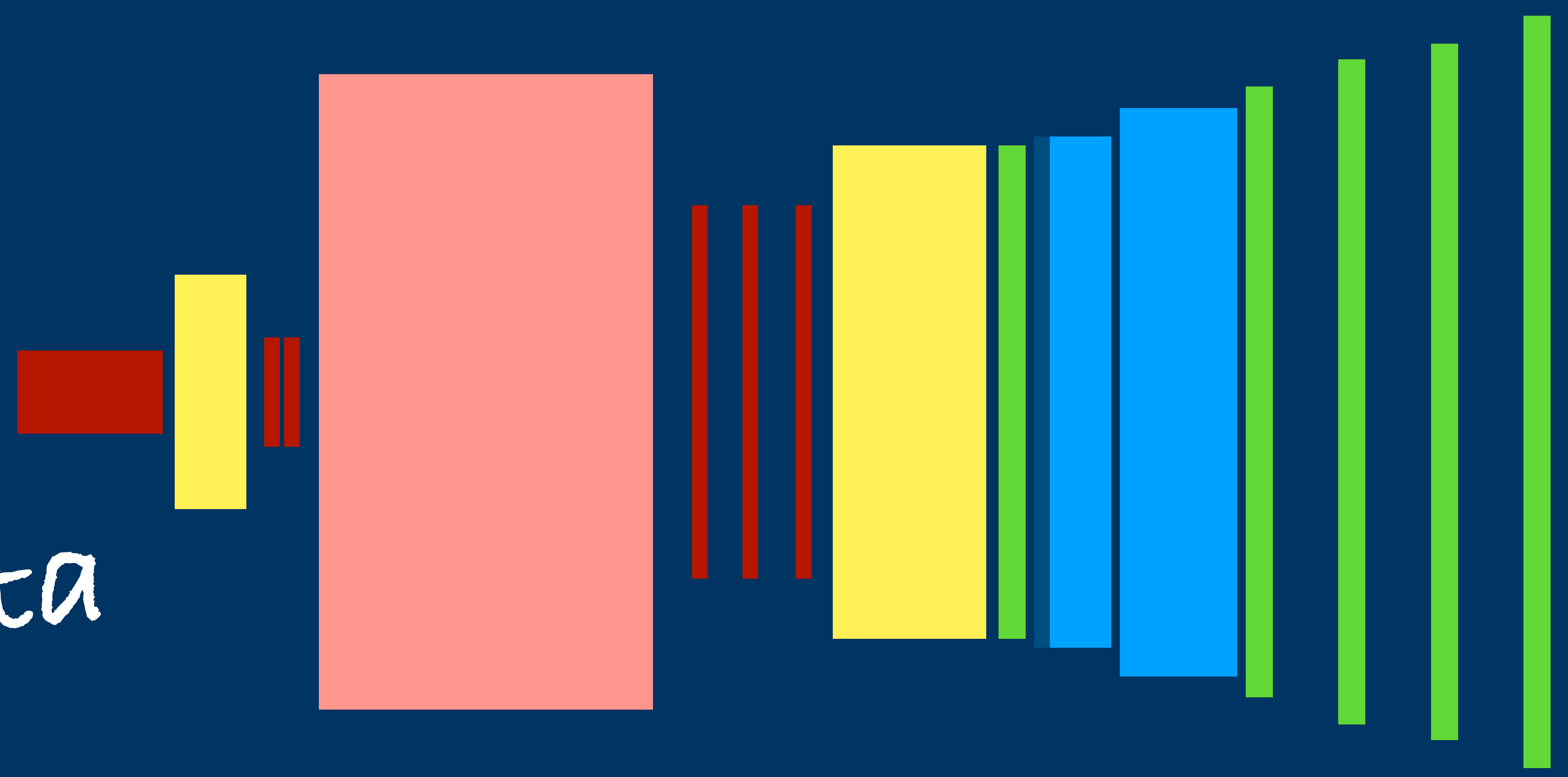
4. PID selections and multivariate classifiers
5. Fit to the final-state invariant-mass



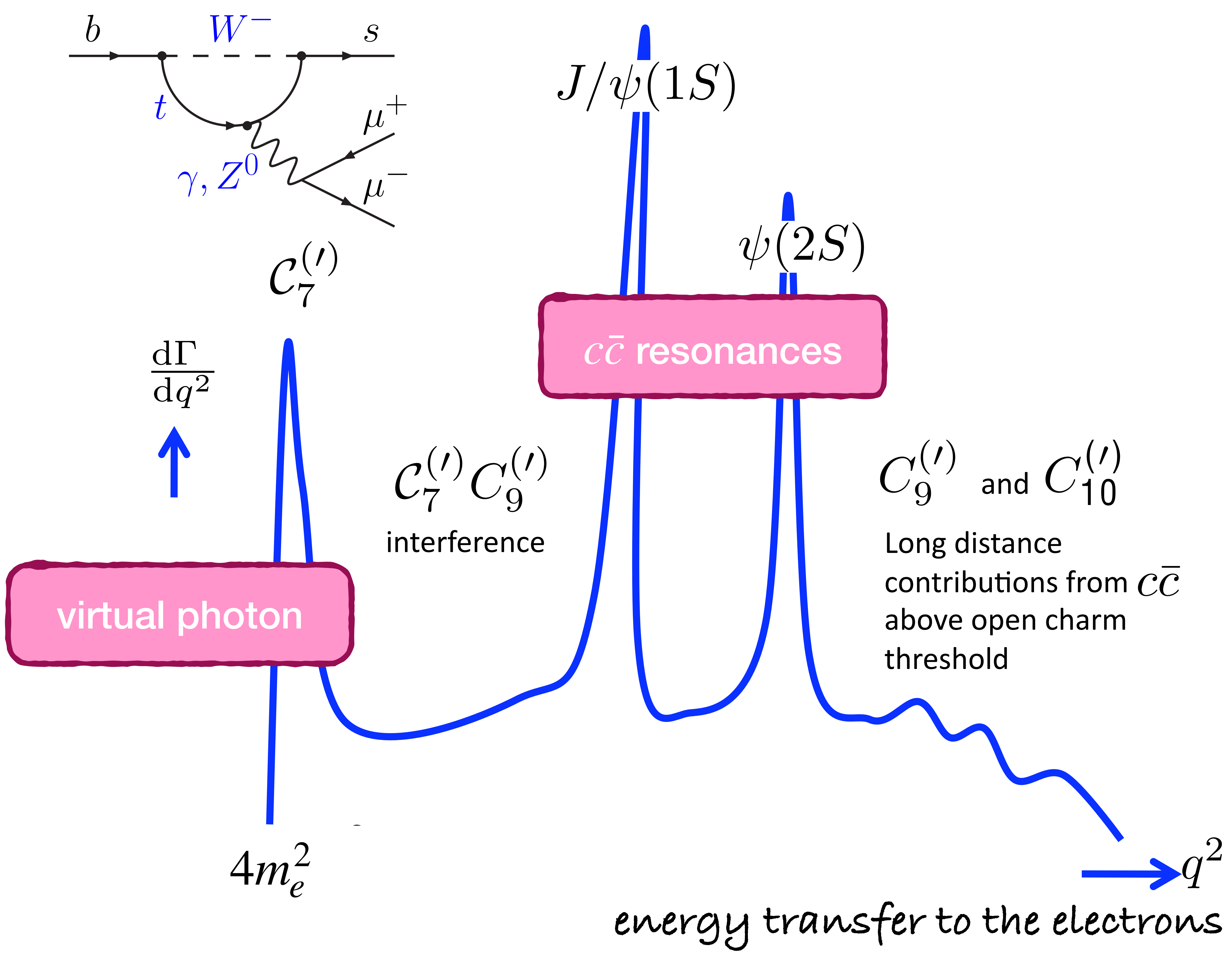
Measurements

using Run 1 and Run 2 data



Constraints on the photon polarisation in $B_s^0 \to \phi(\to K^+K^-)e^+e^-$

Using $0.0009 < q^2 < 0.2615$ GeV$^2/c^4$
(ca. 100 signal candidates)



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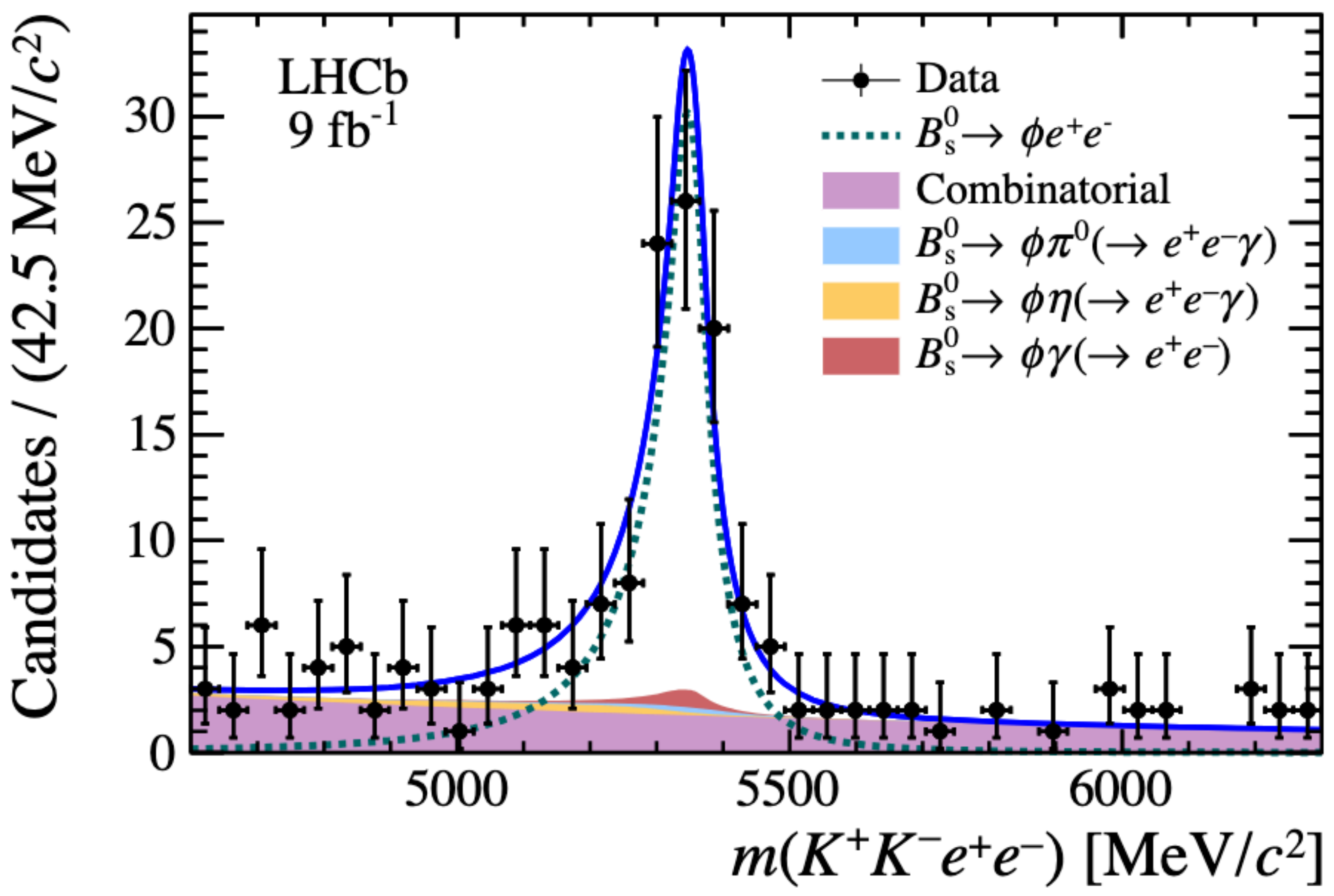

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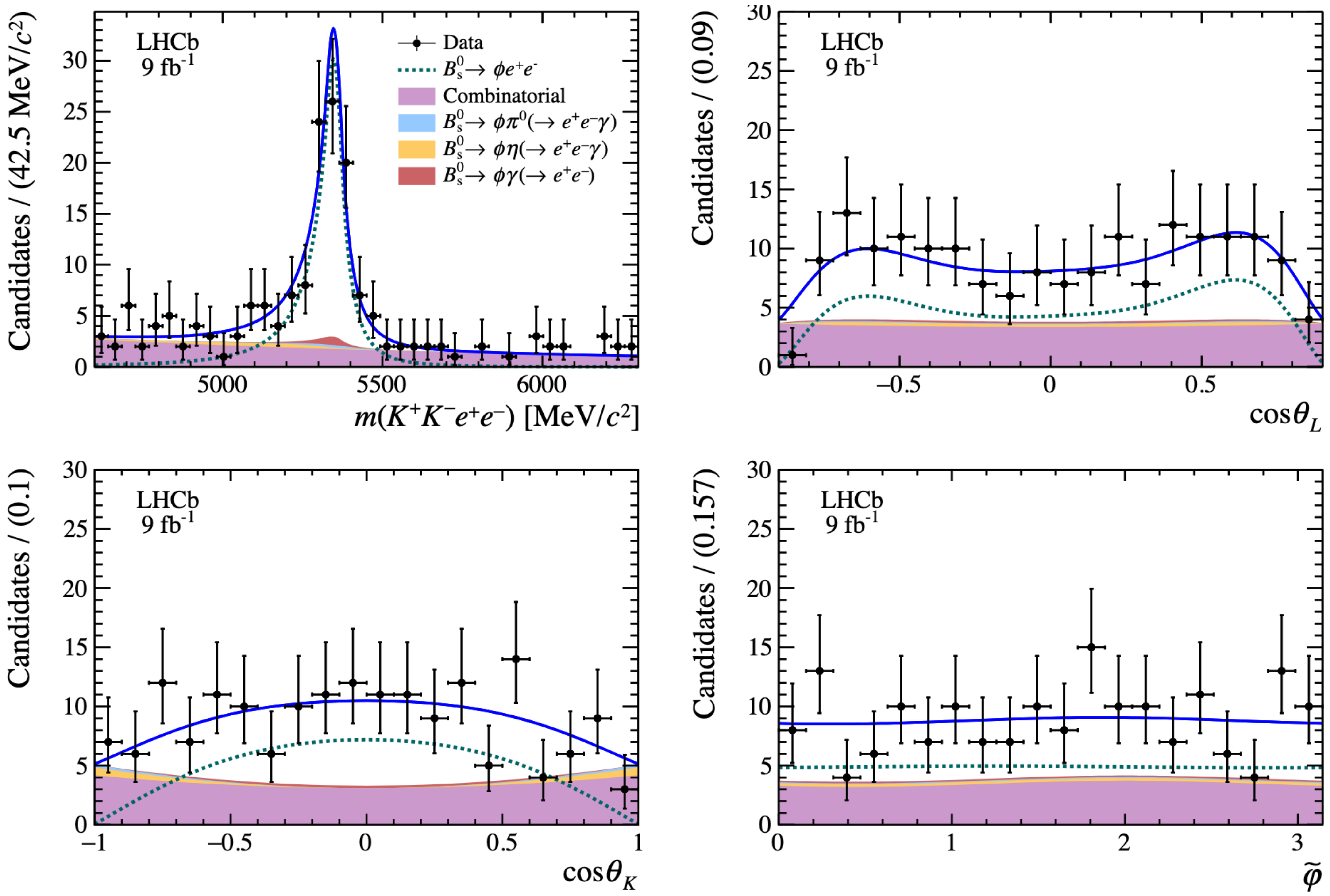

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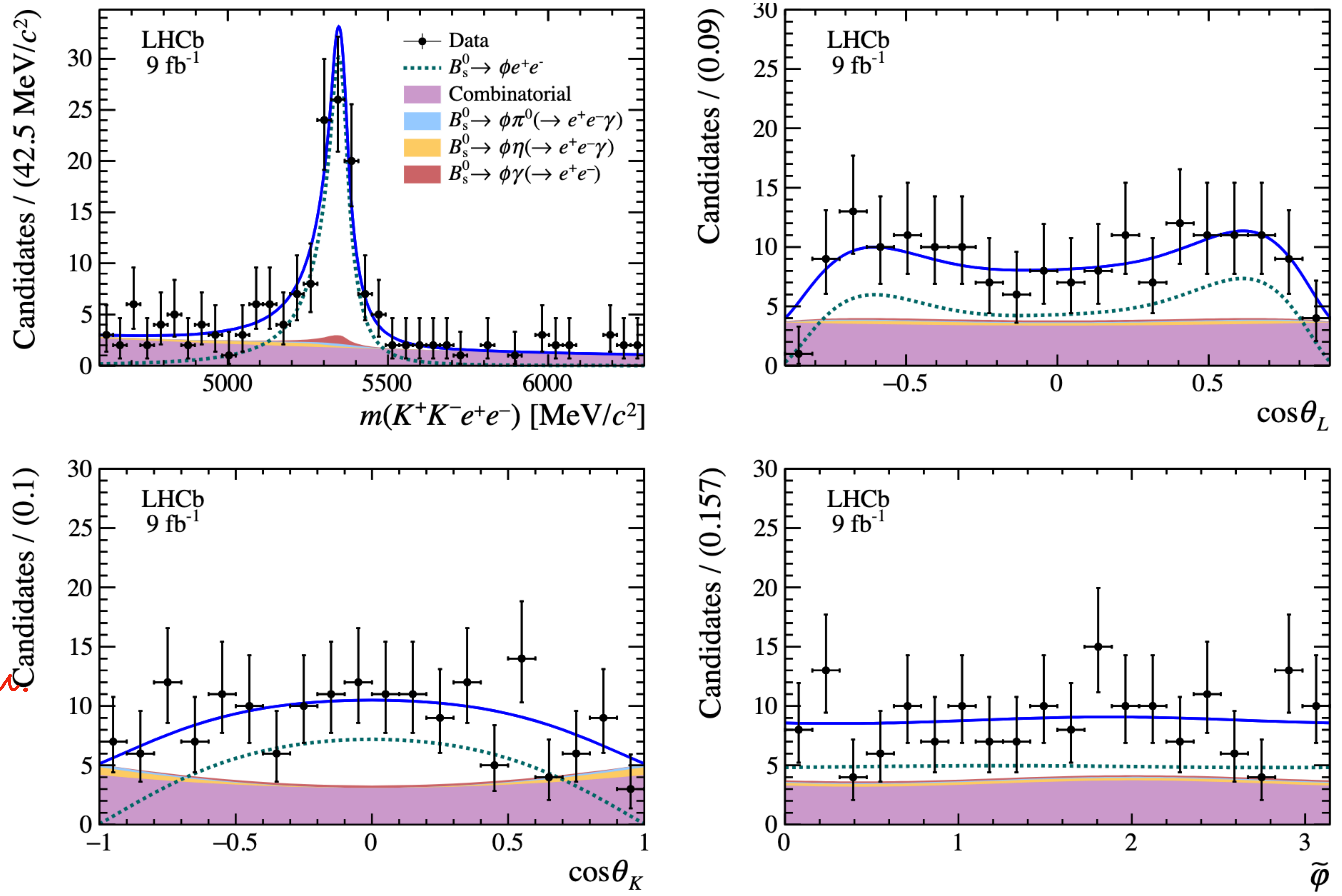
$$F_{\rm L} = (0.4 \pm 5.6 \pm 1.2)\%\,,$$ ϕ polarisation



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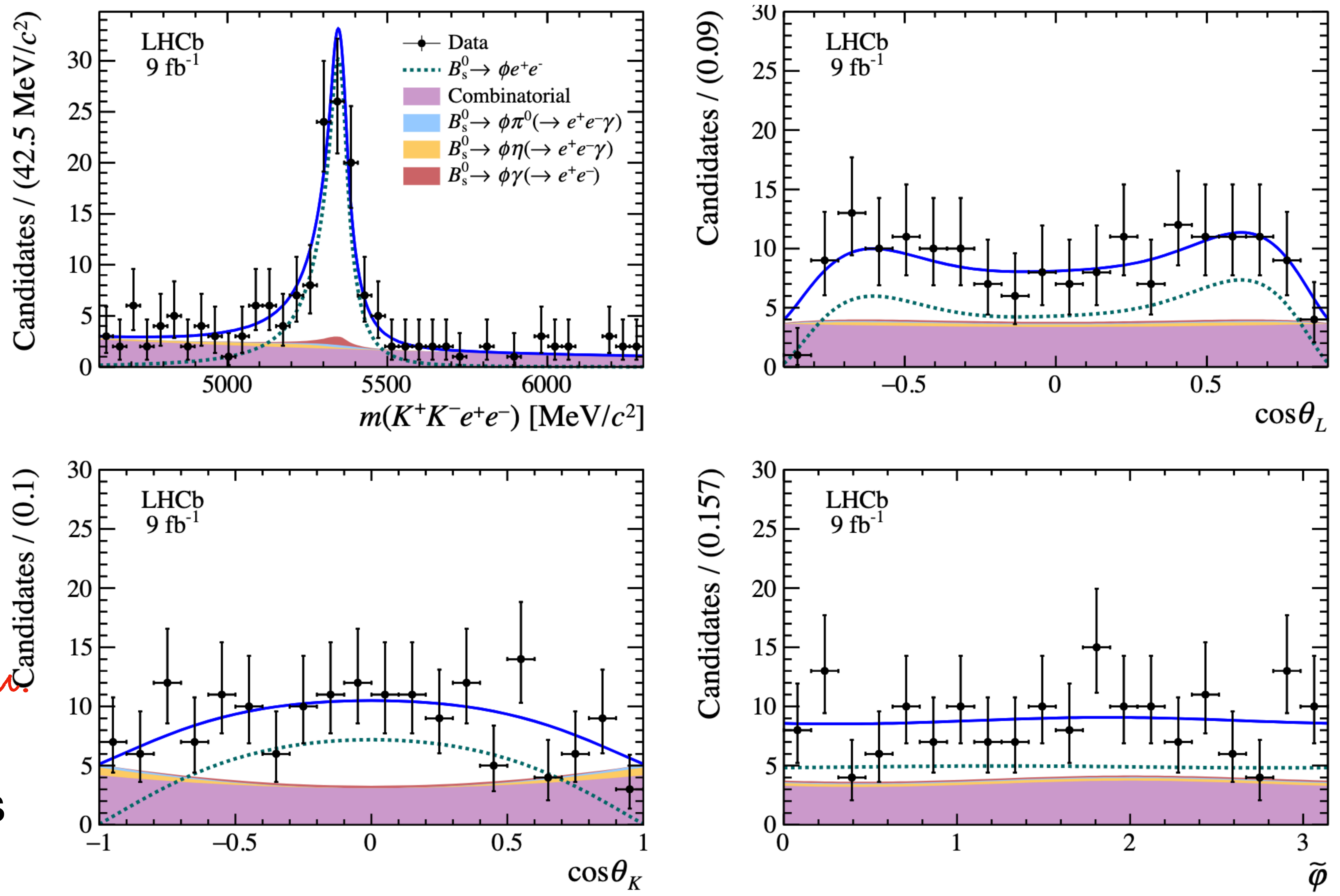

LHCb-PAPER-2024-030

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e^+e^- fwd-bwd asym.

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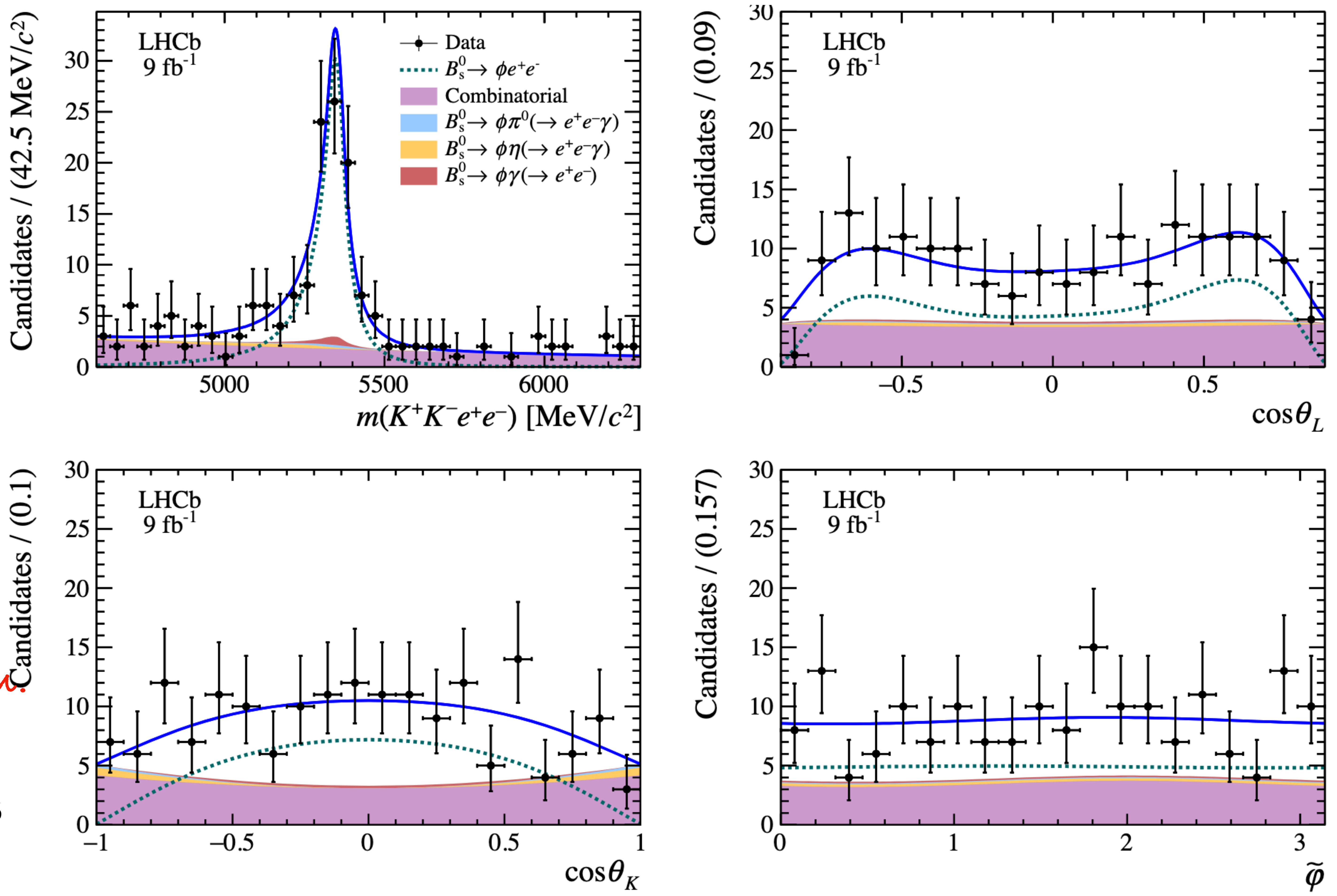
Statistically limited



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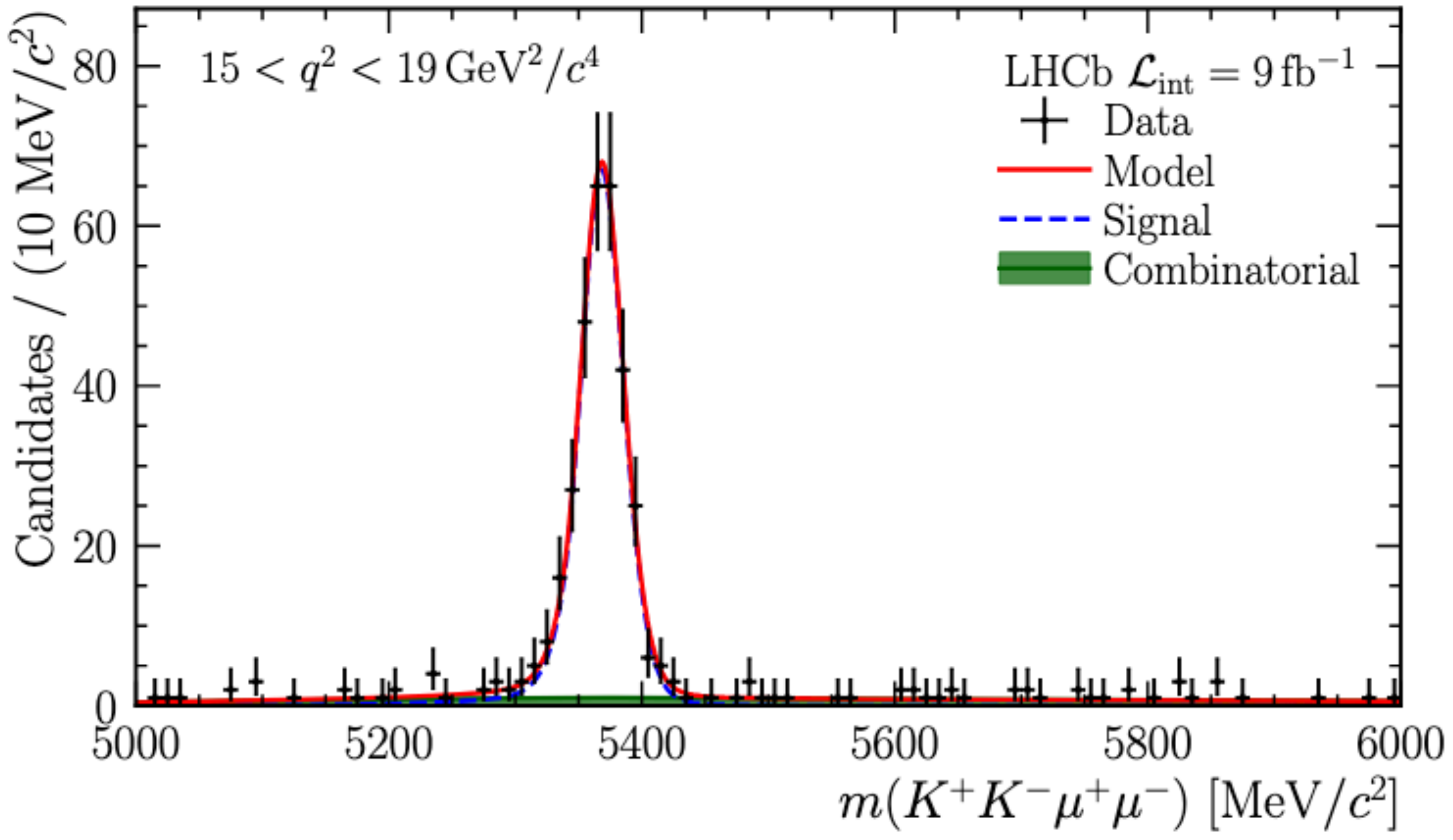
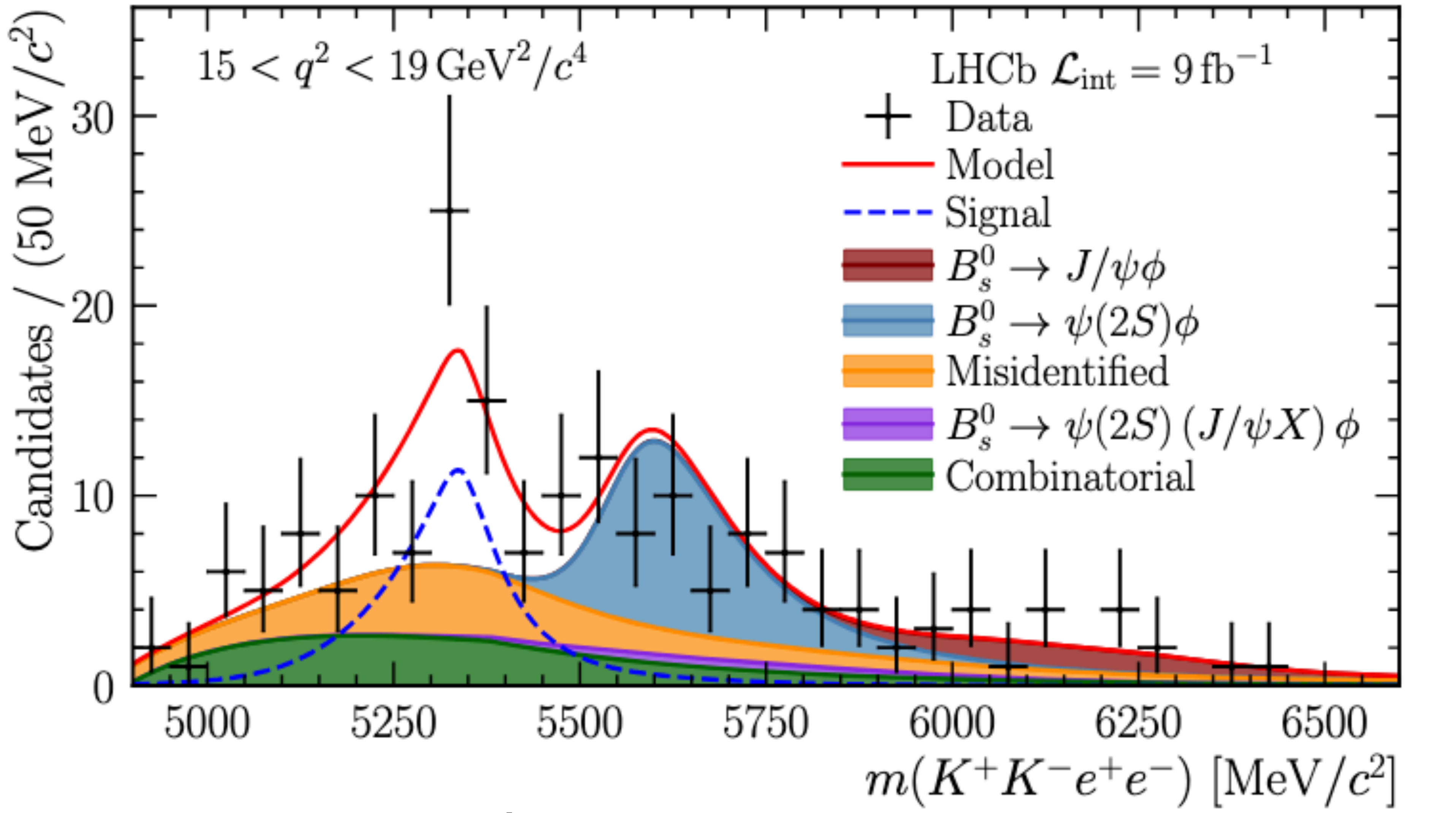
Test of lepton universality using $B_s^0 \to \phi(\to K^+K^-)\ell^+\ell^-$





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LHCb-PAPER-2024-032

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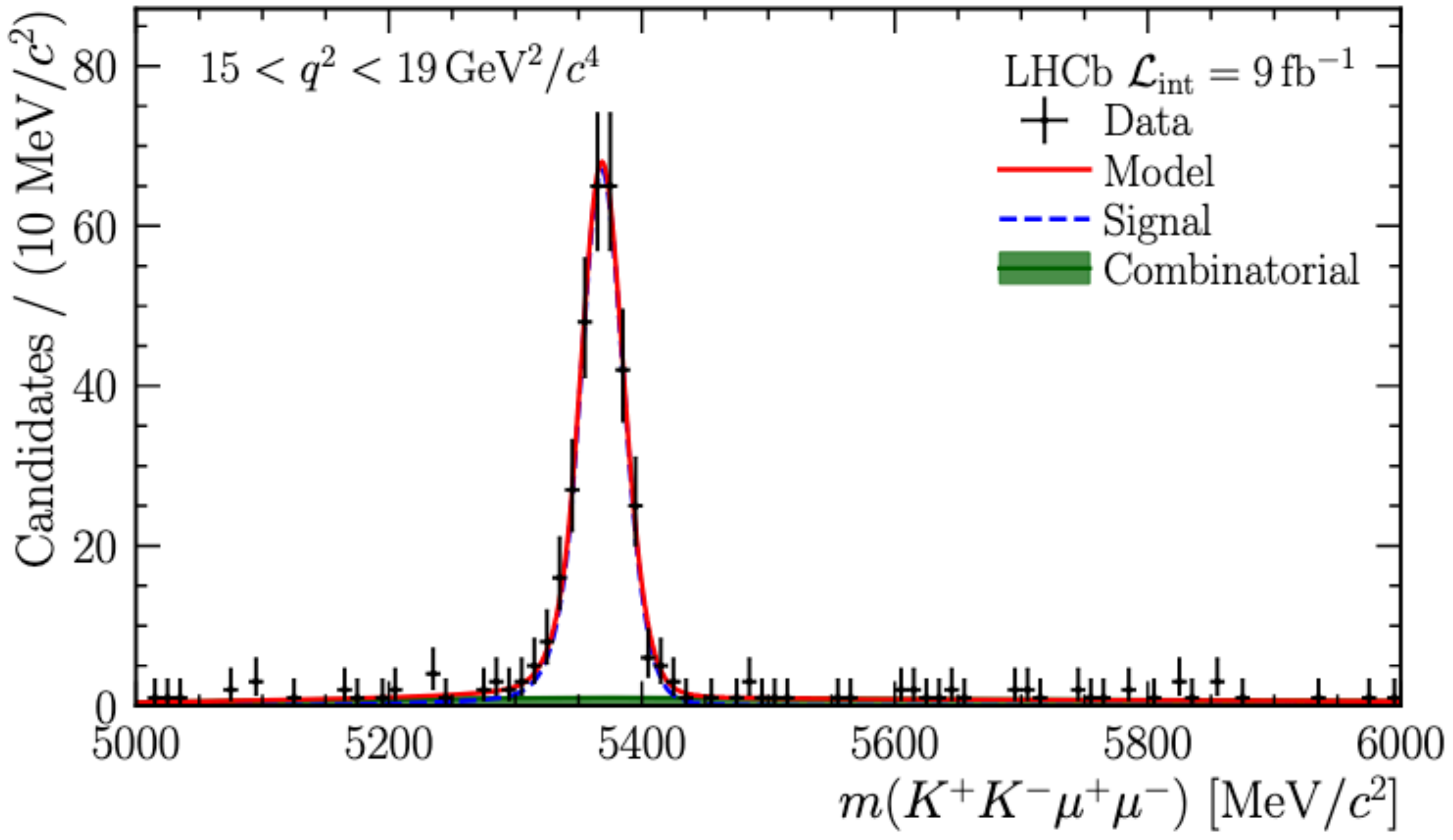

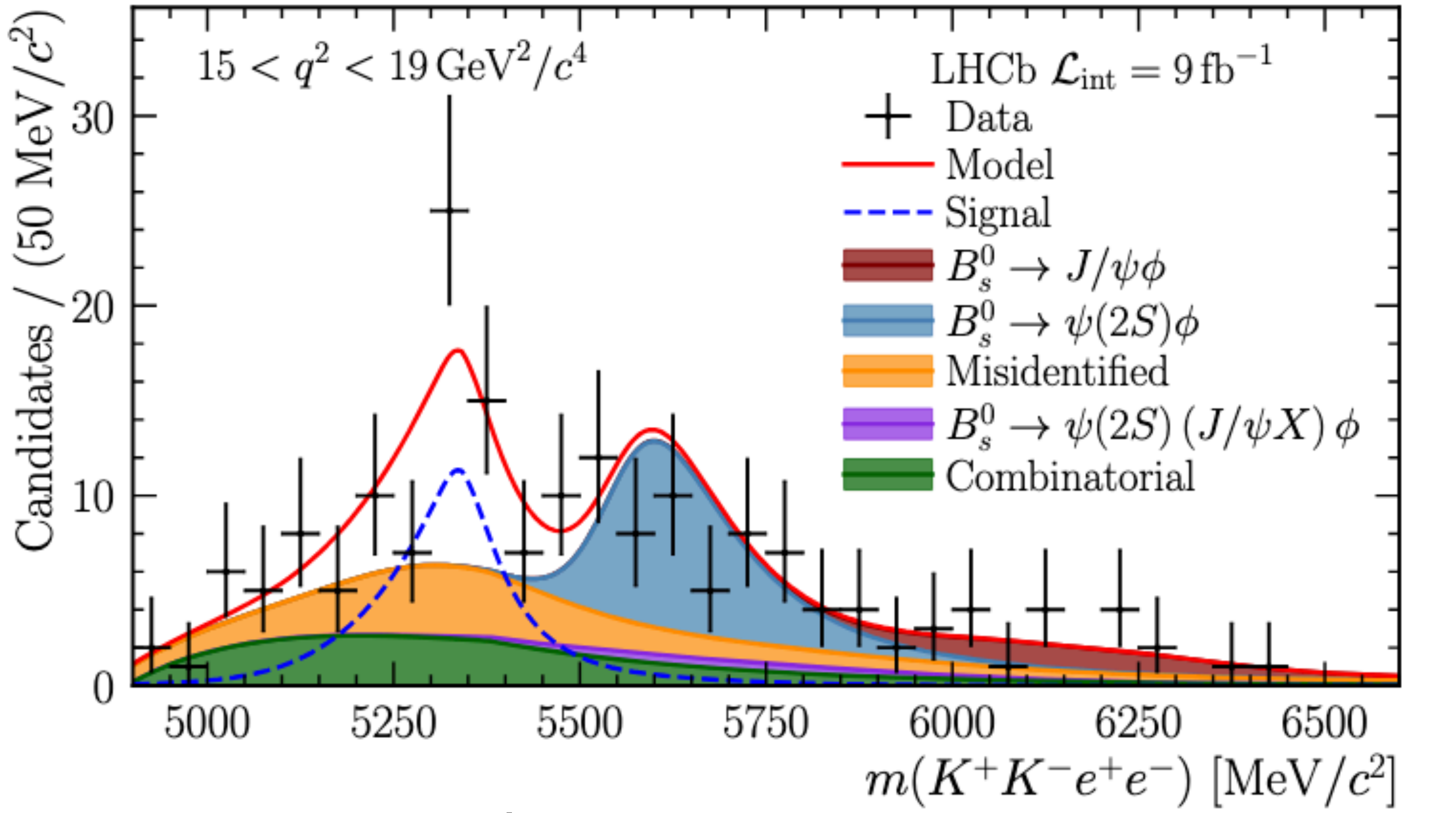

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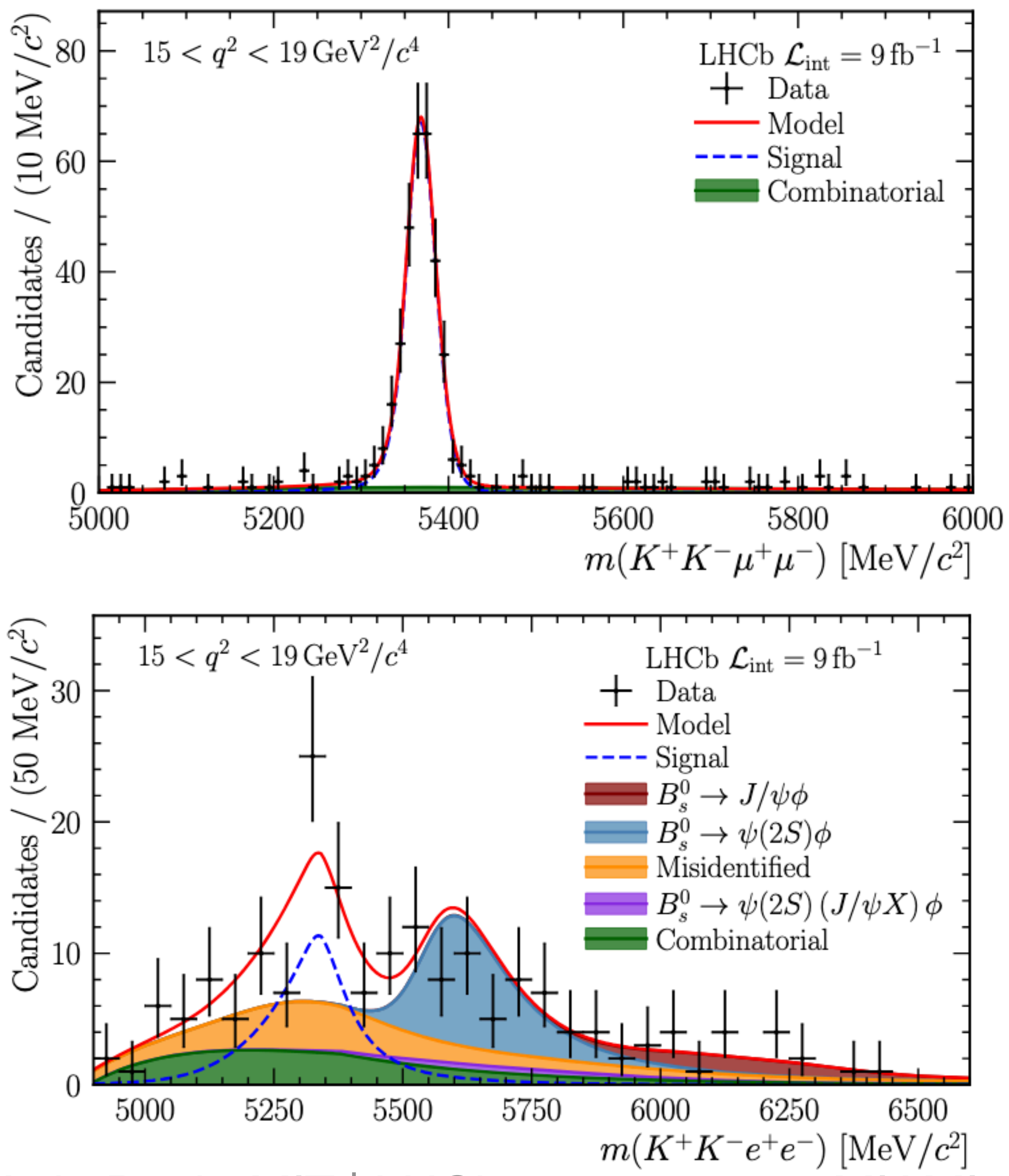

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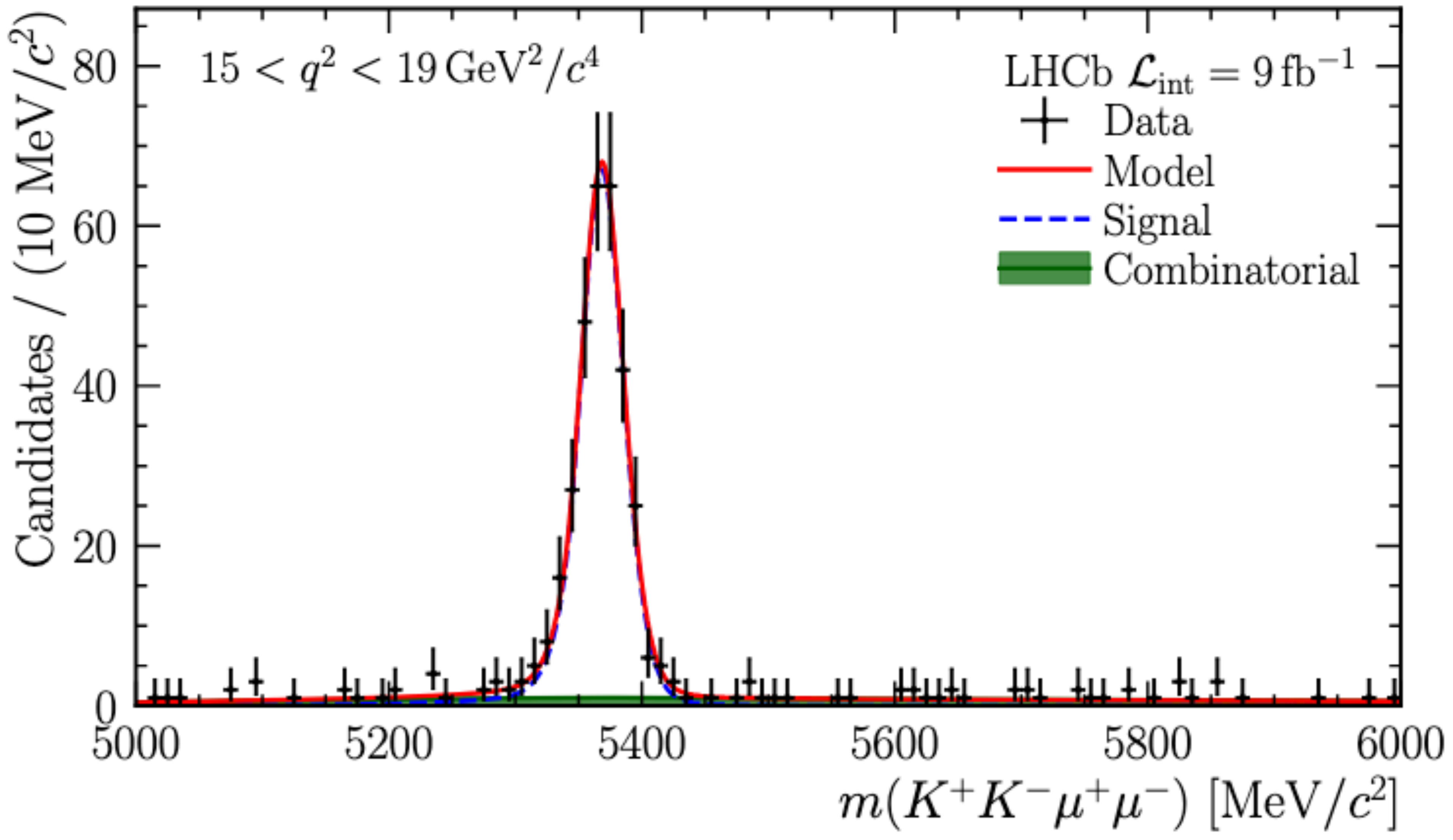

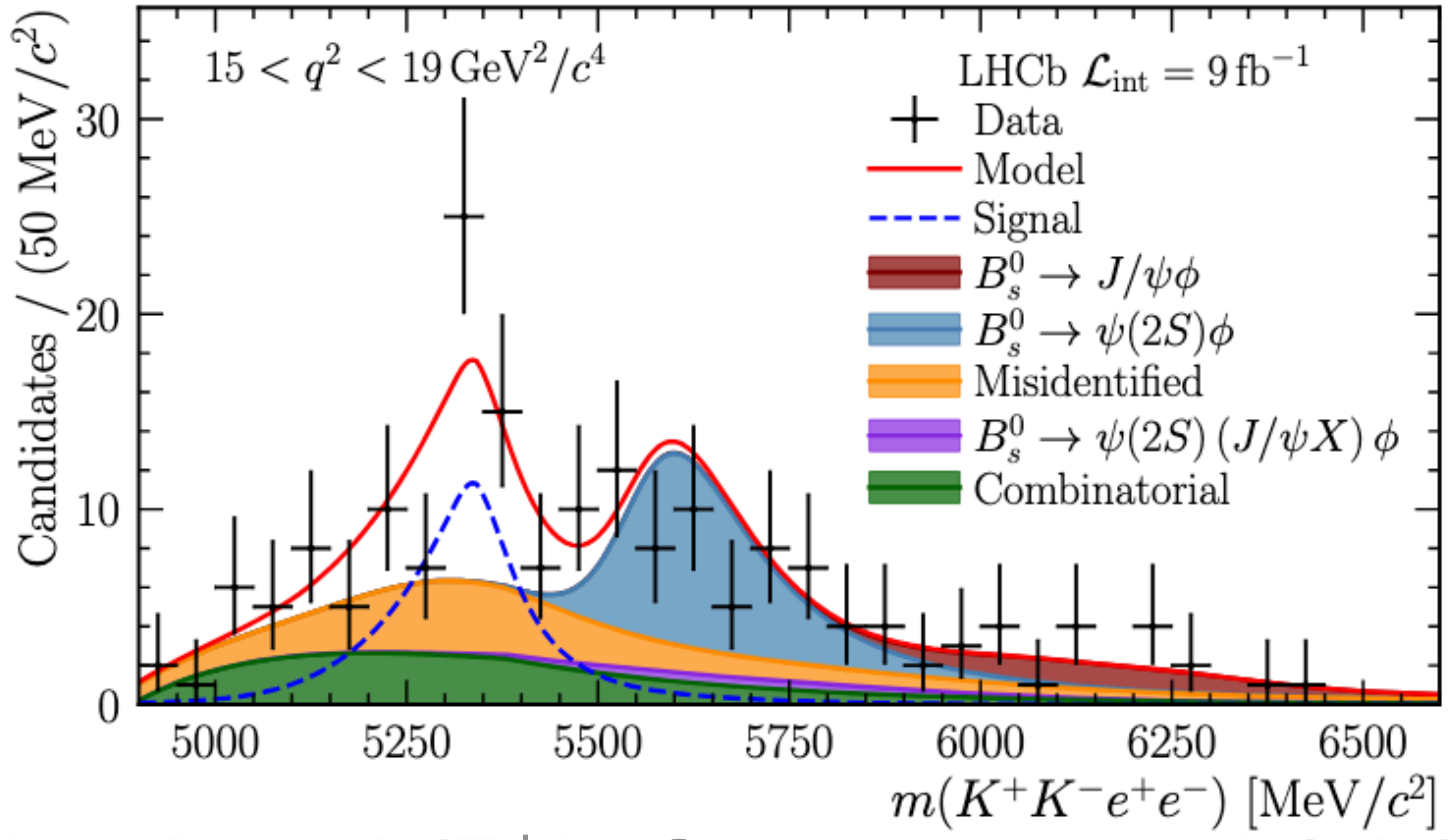

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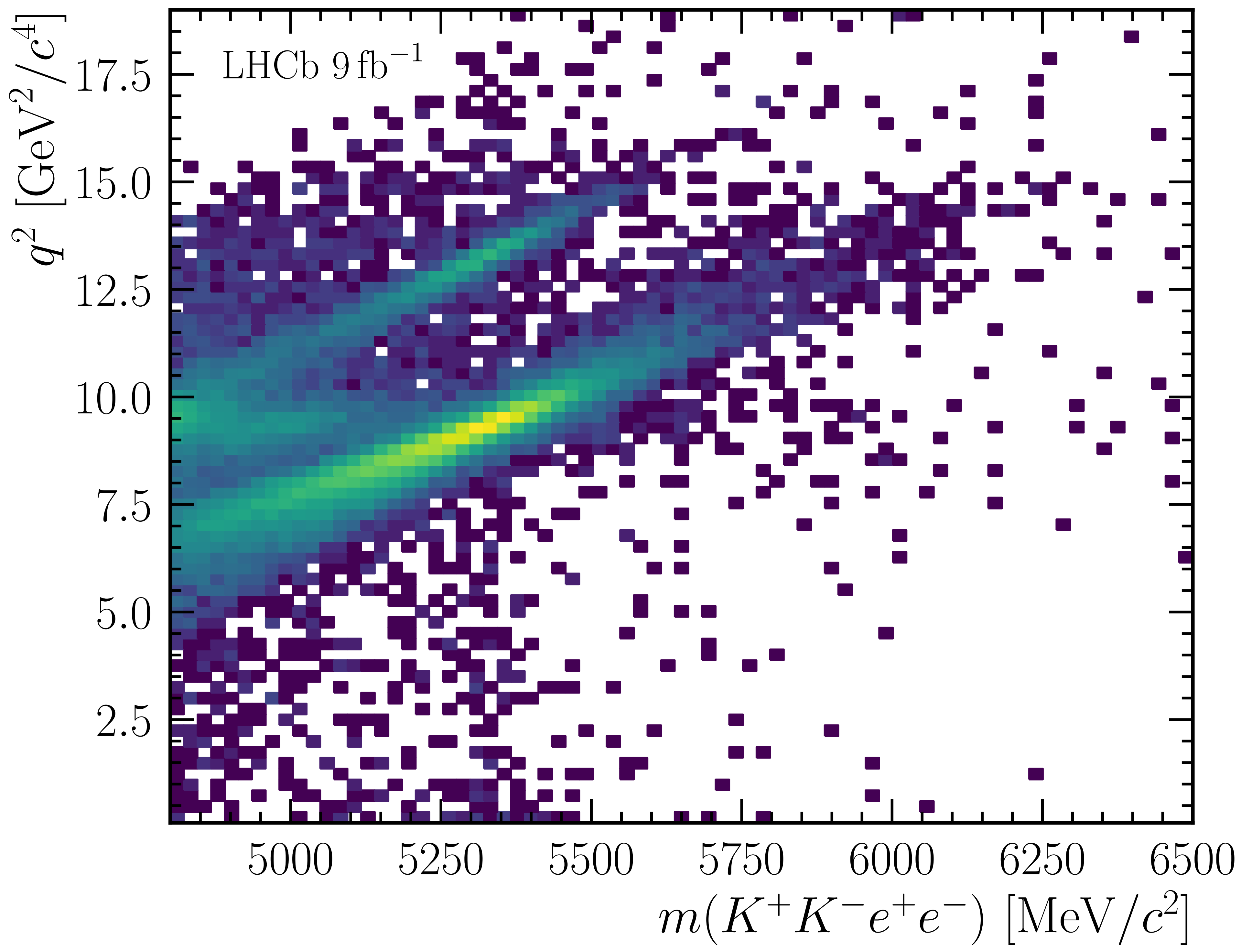

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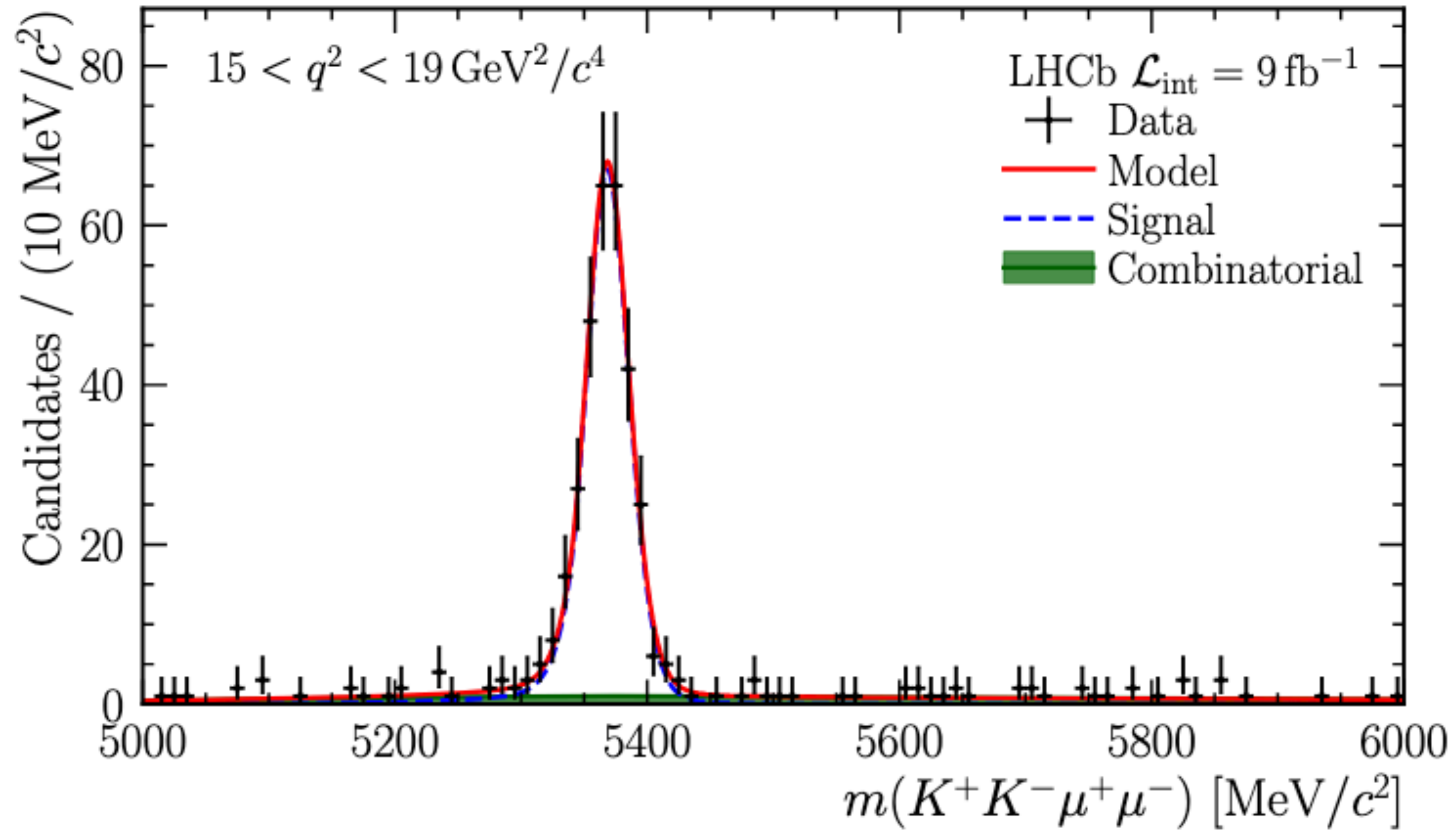

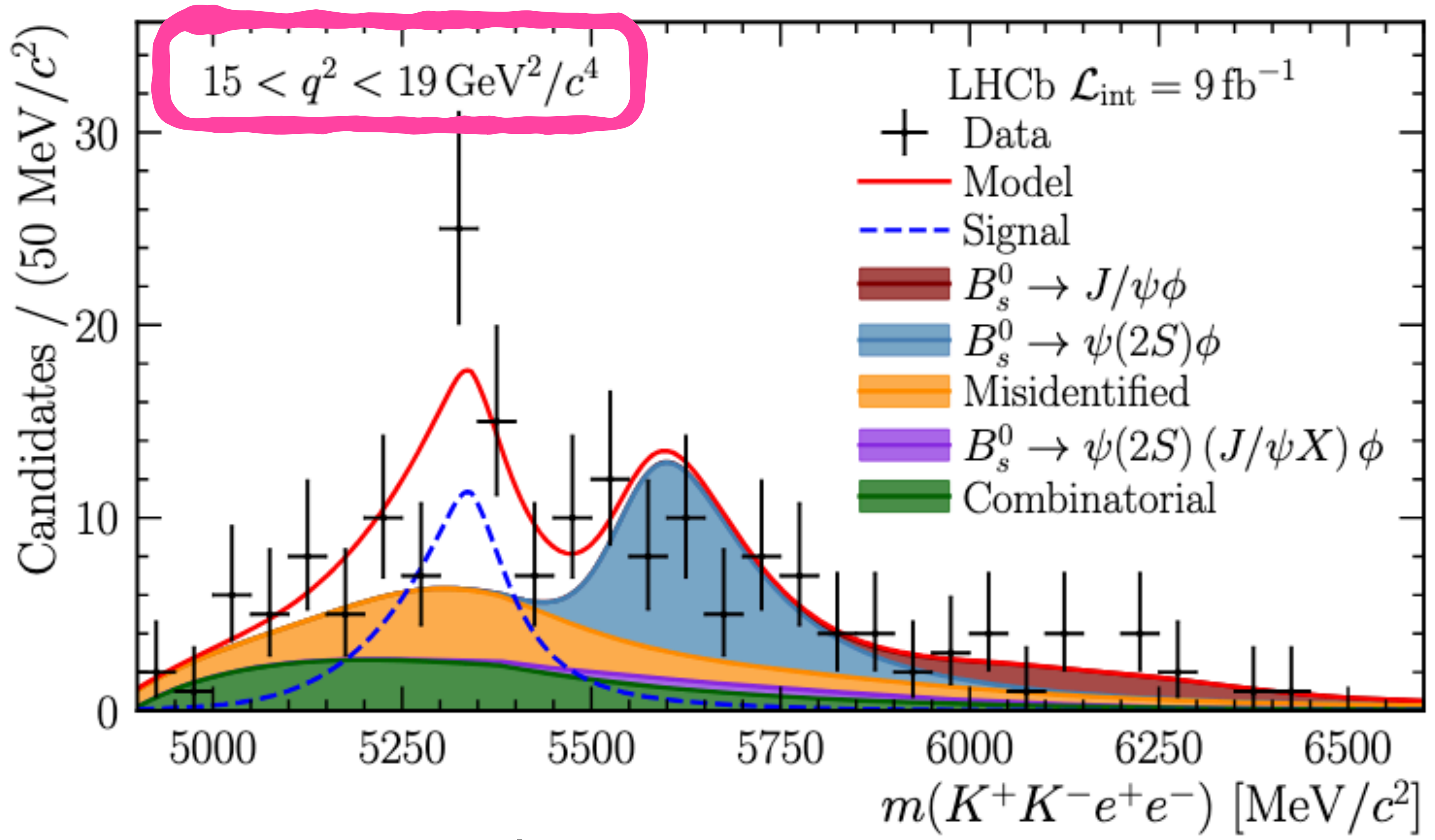

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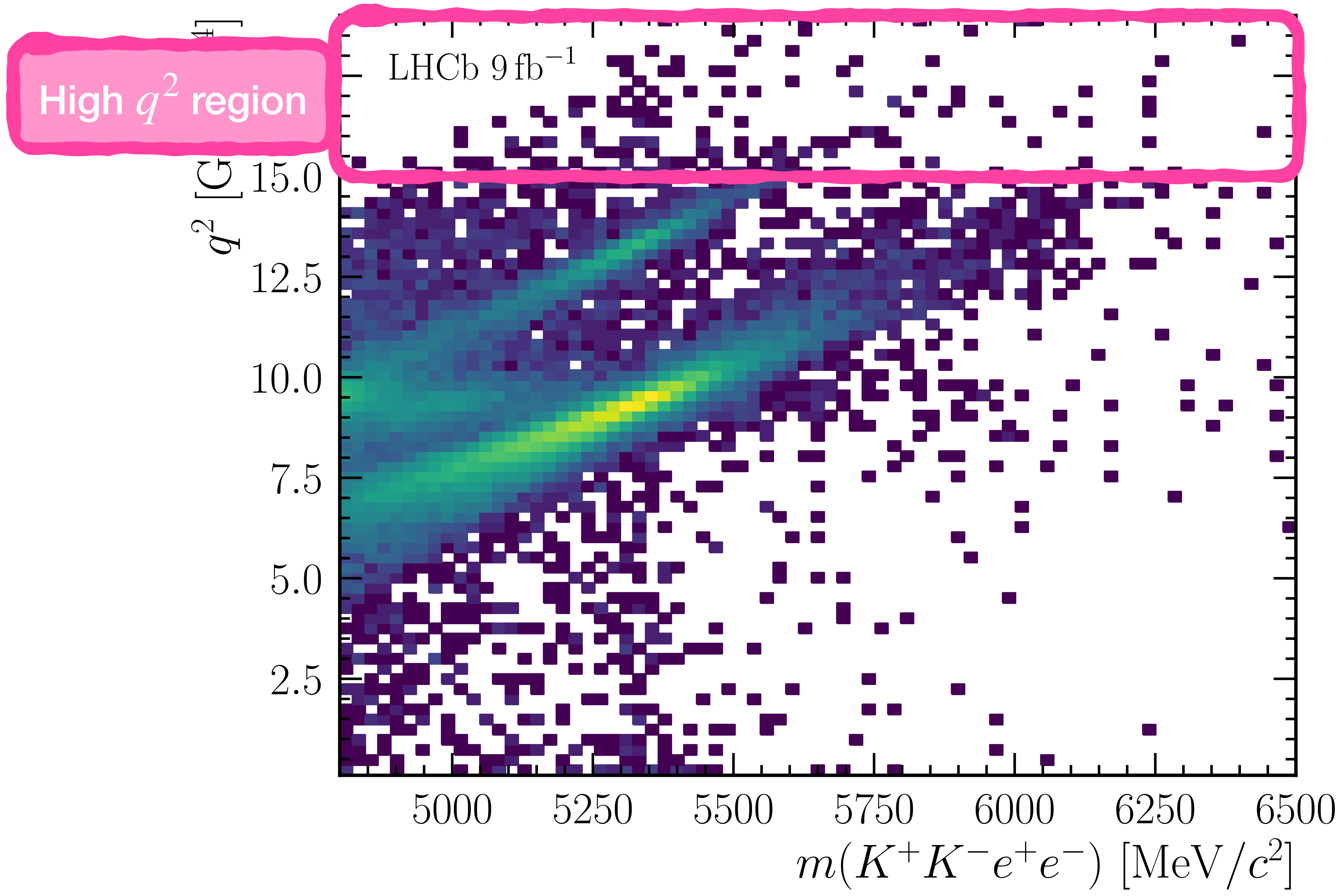

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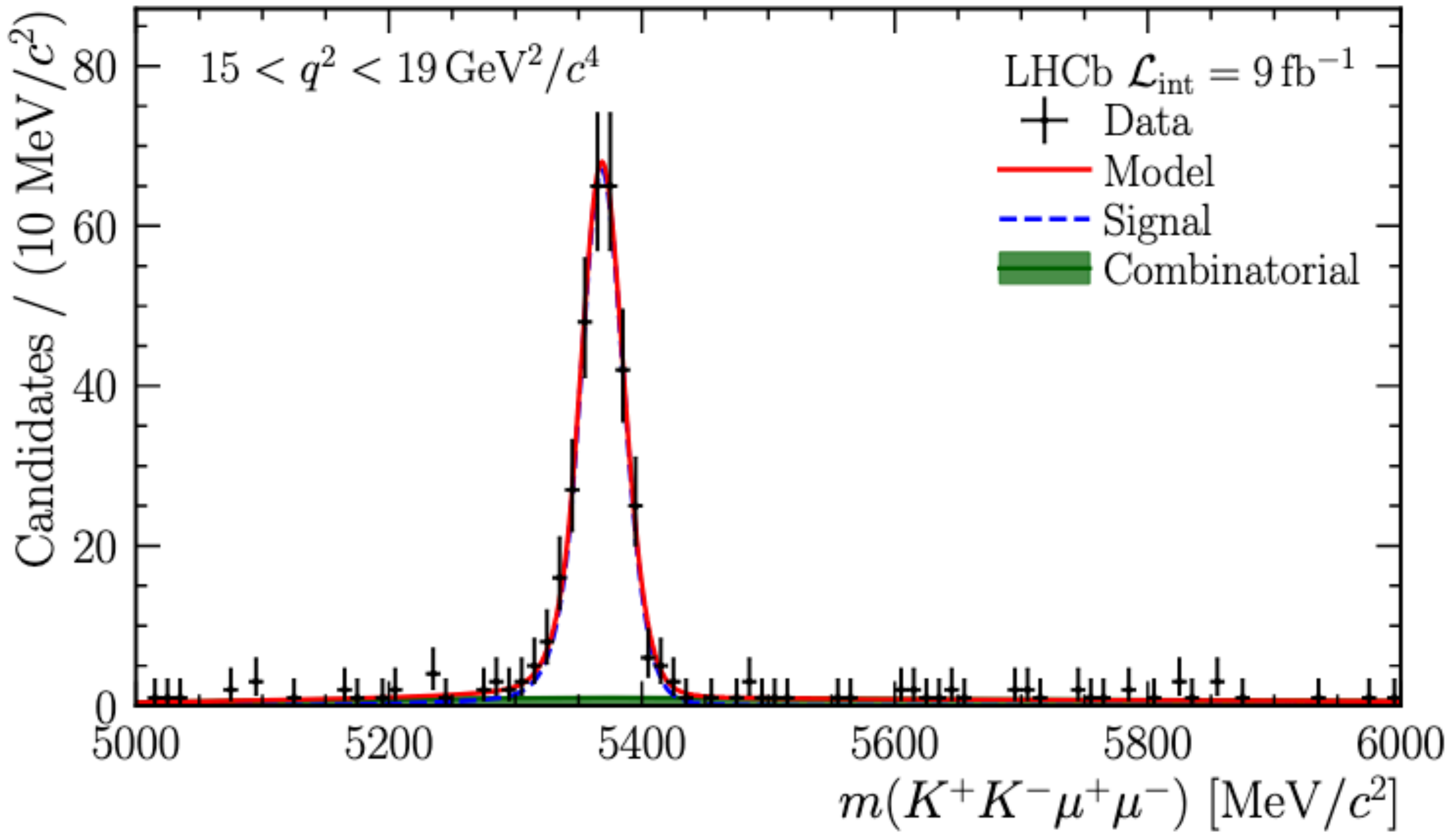

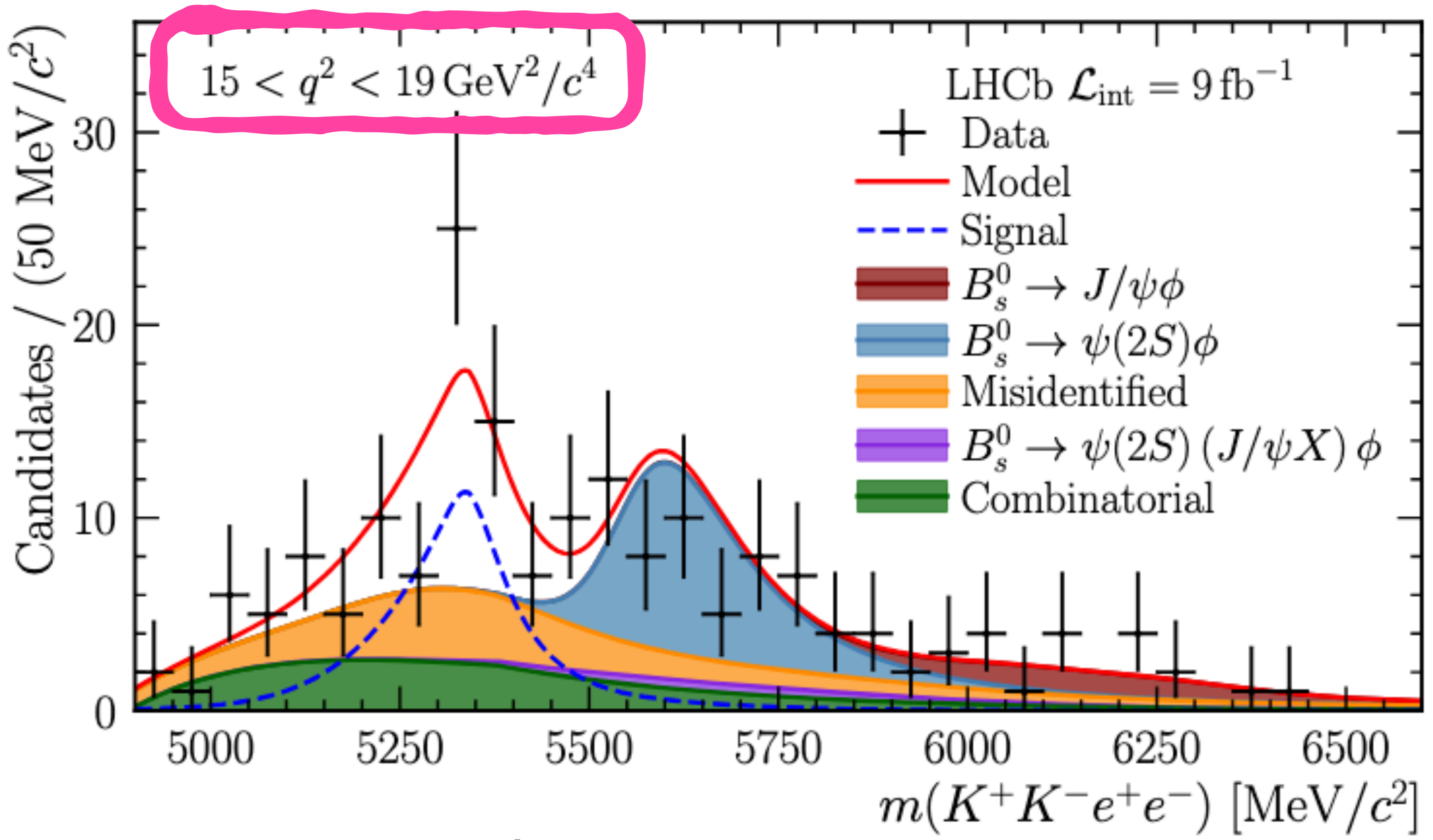

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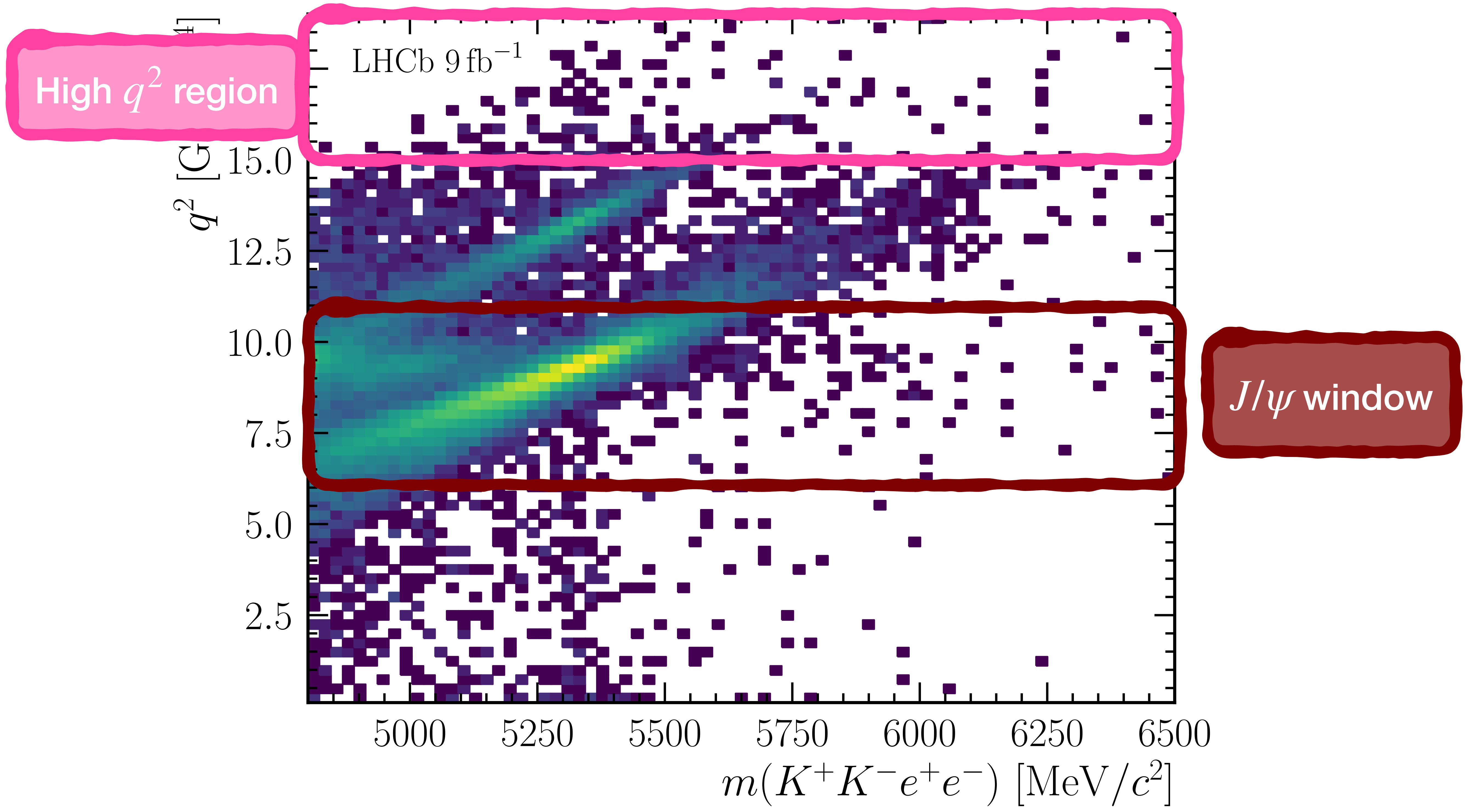

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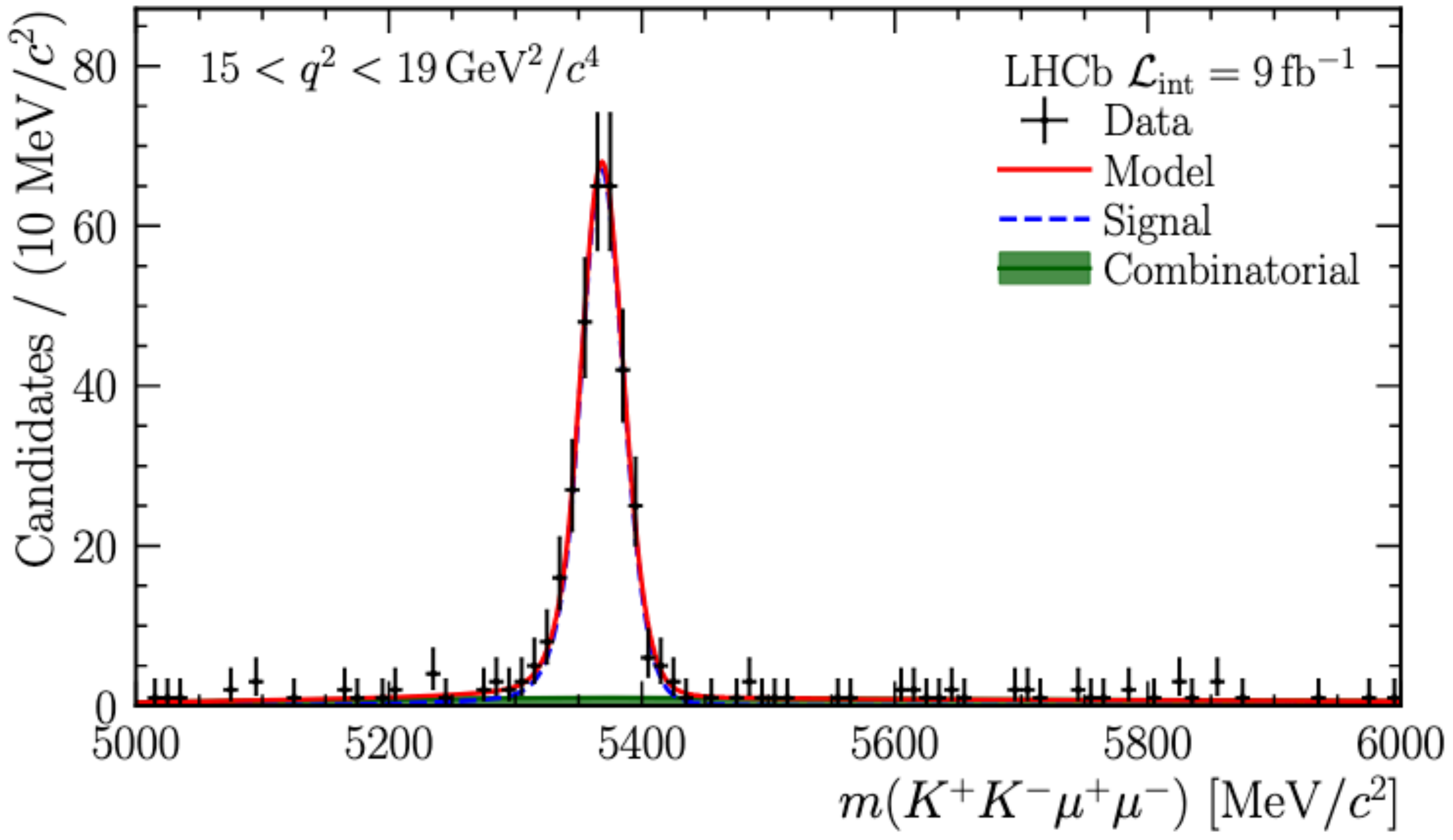

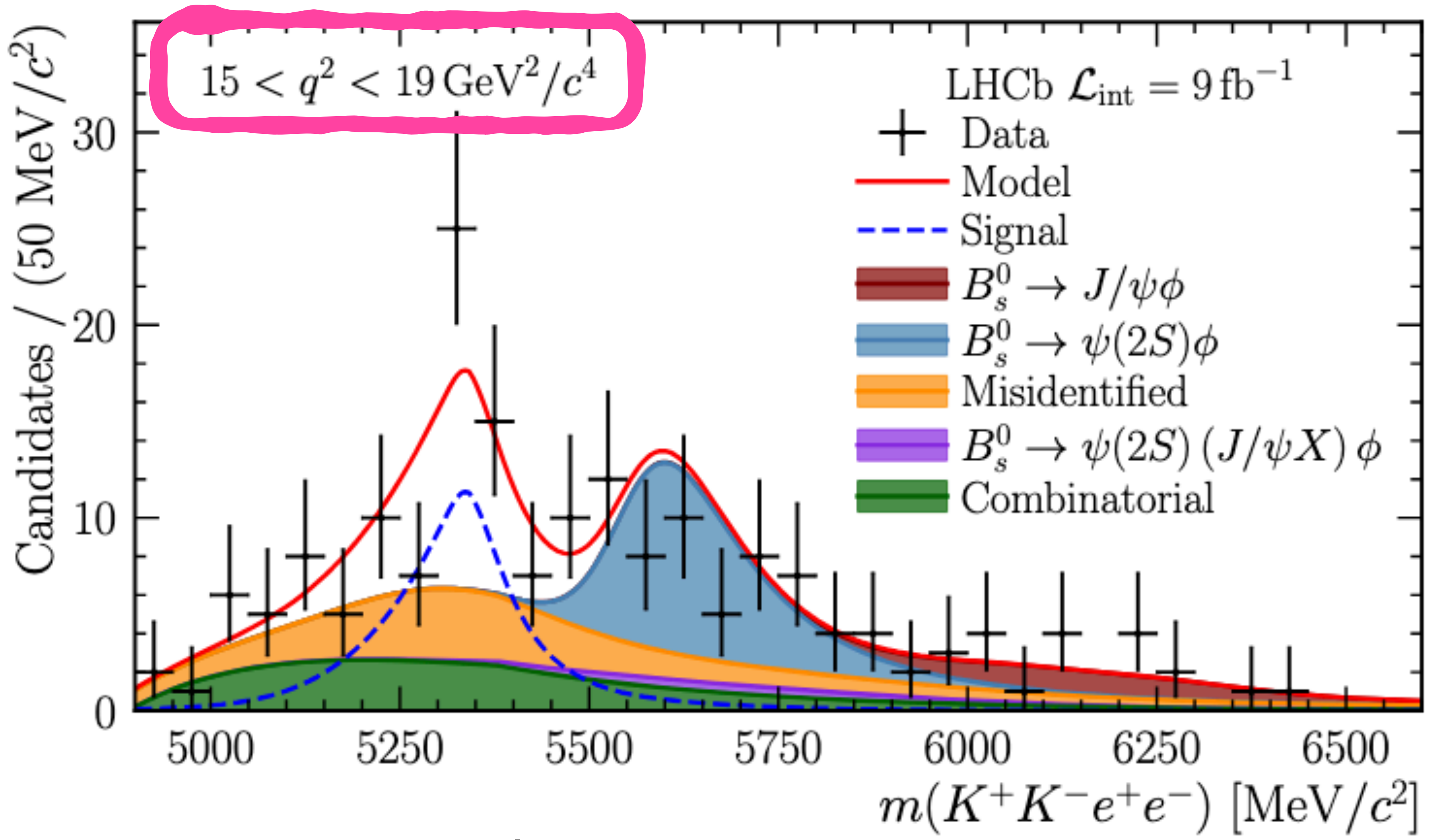

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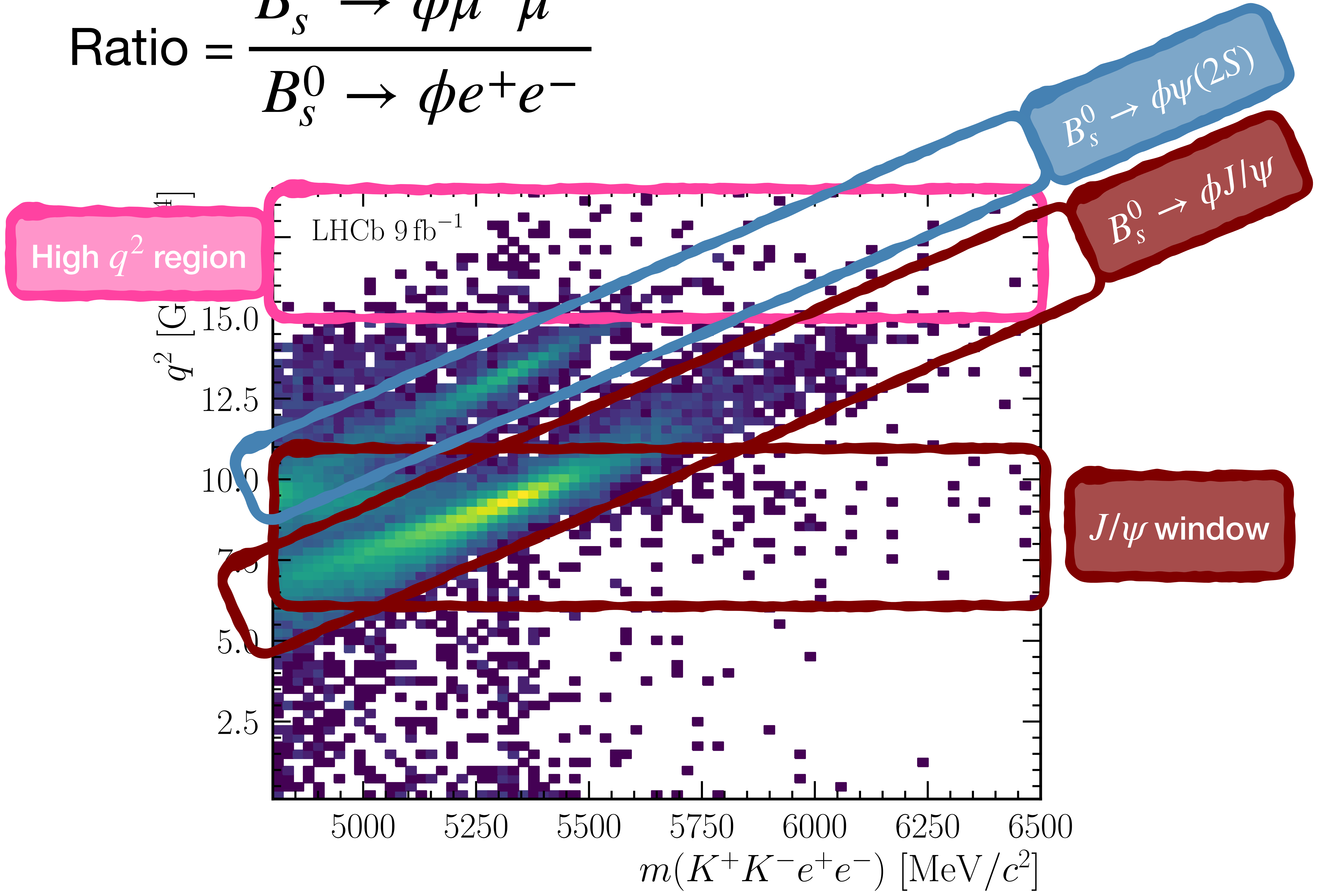

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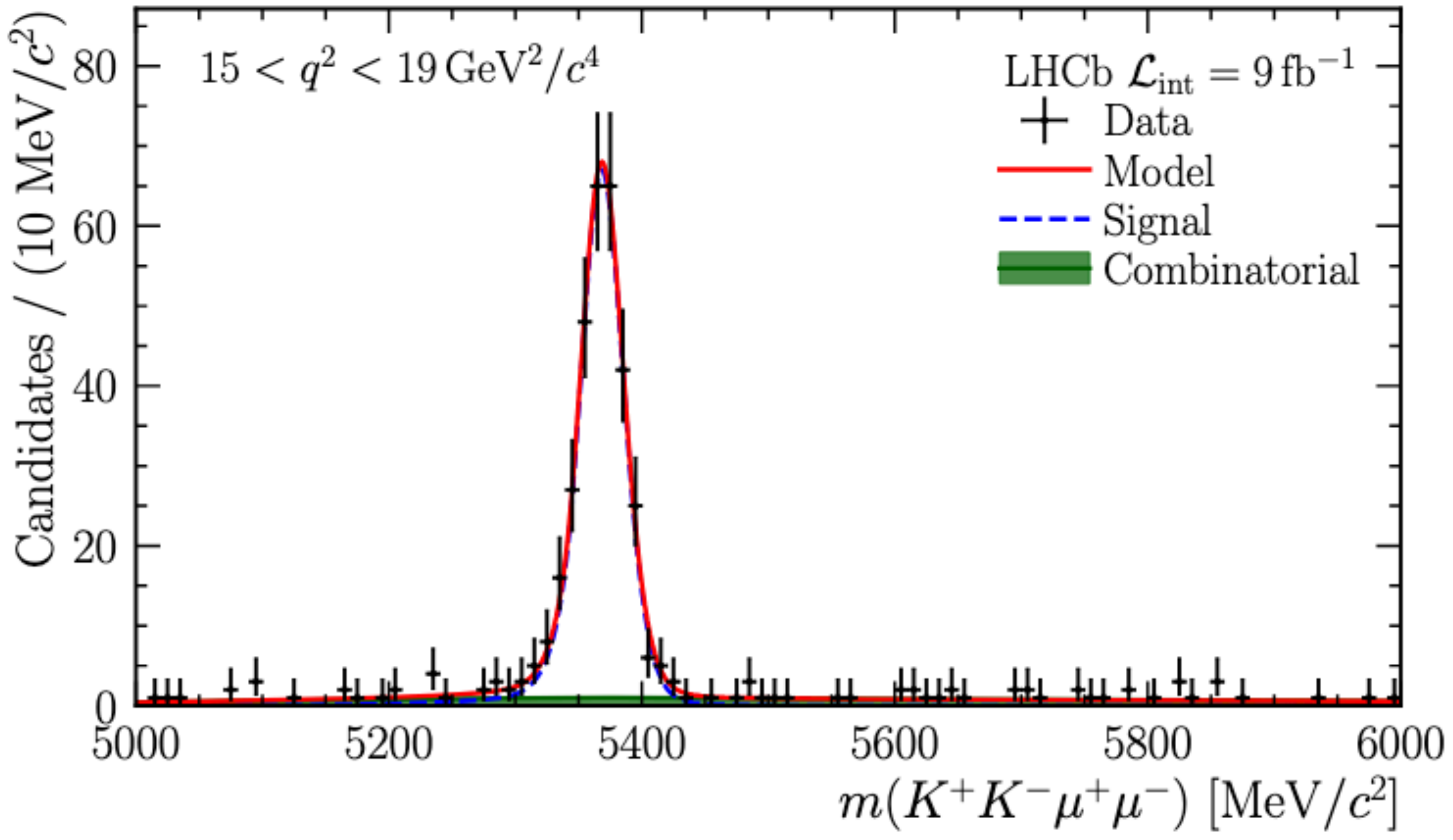

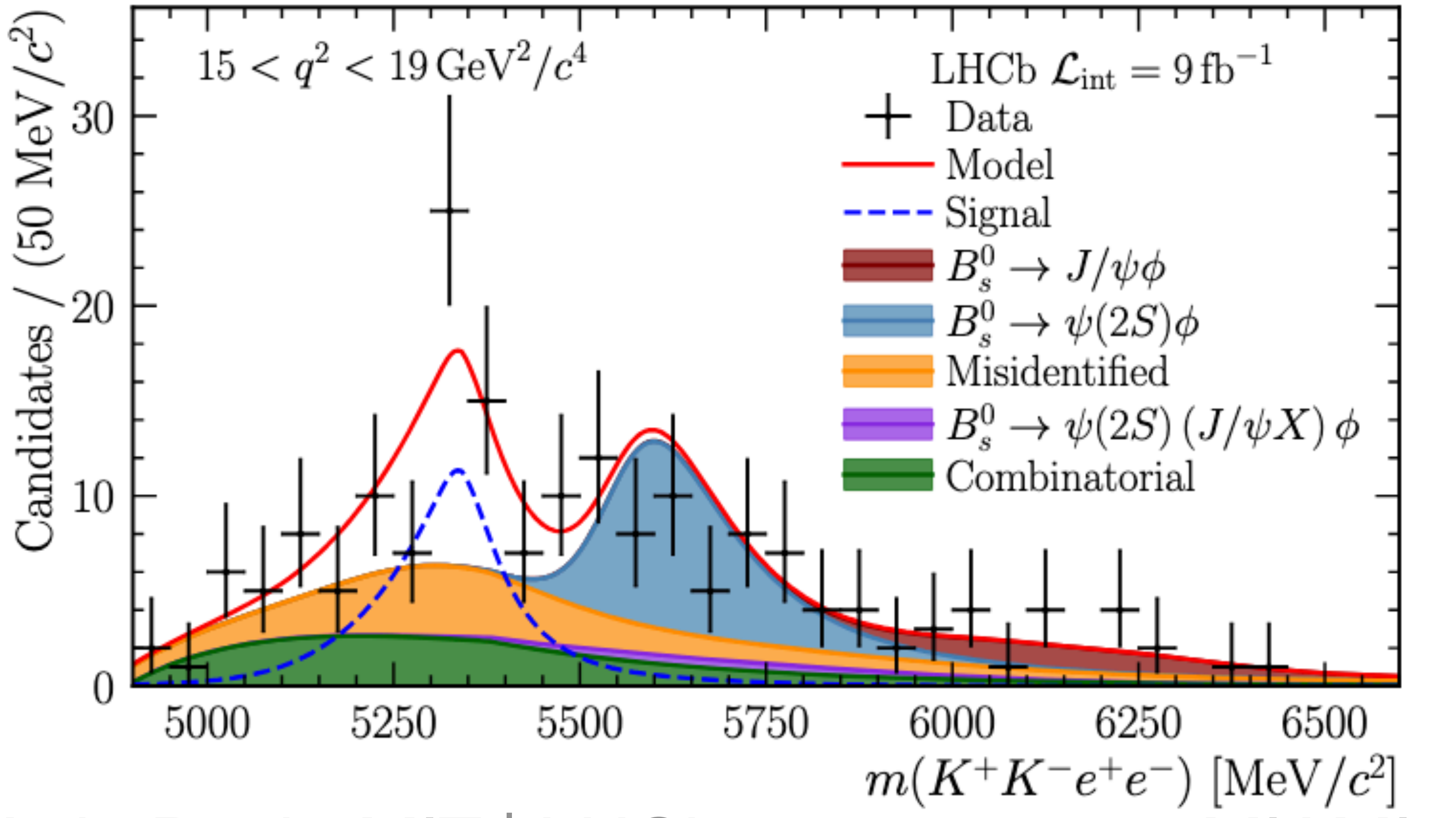

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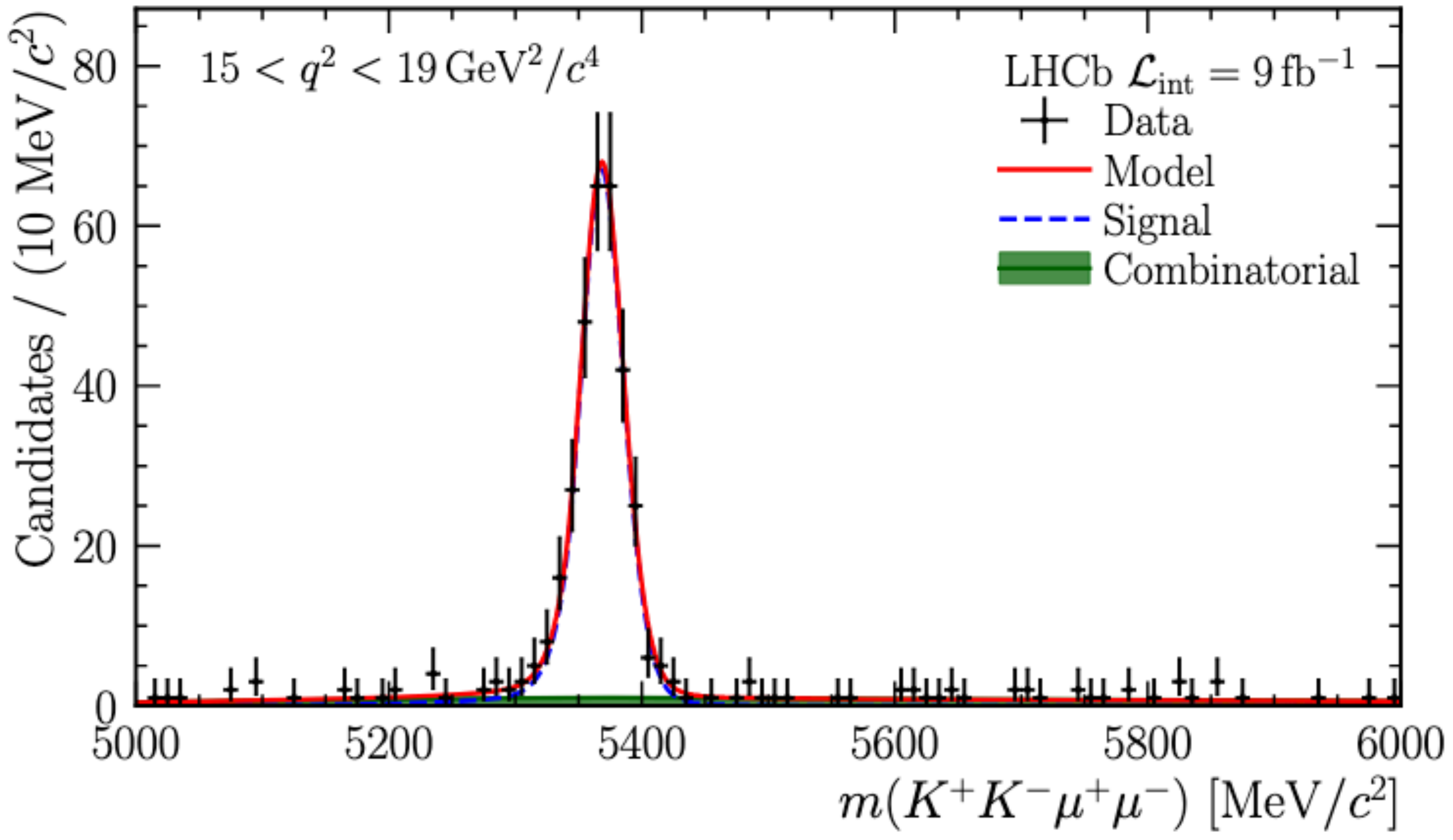
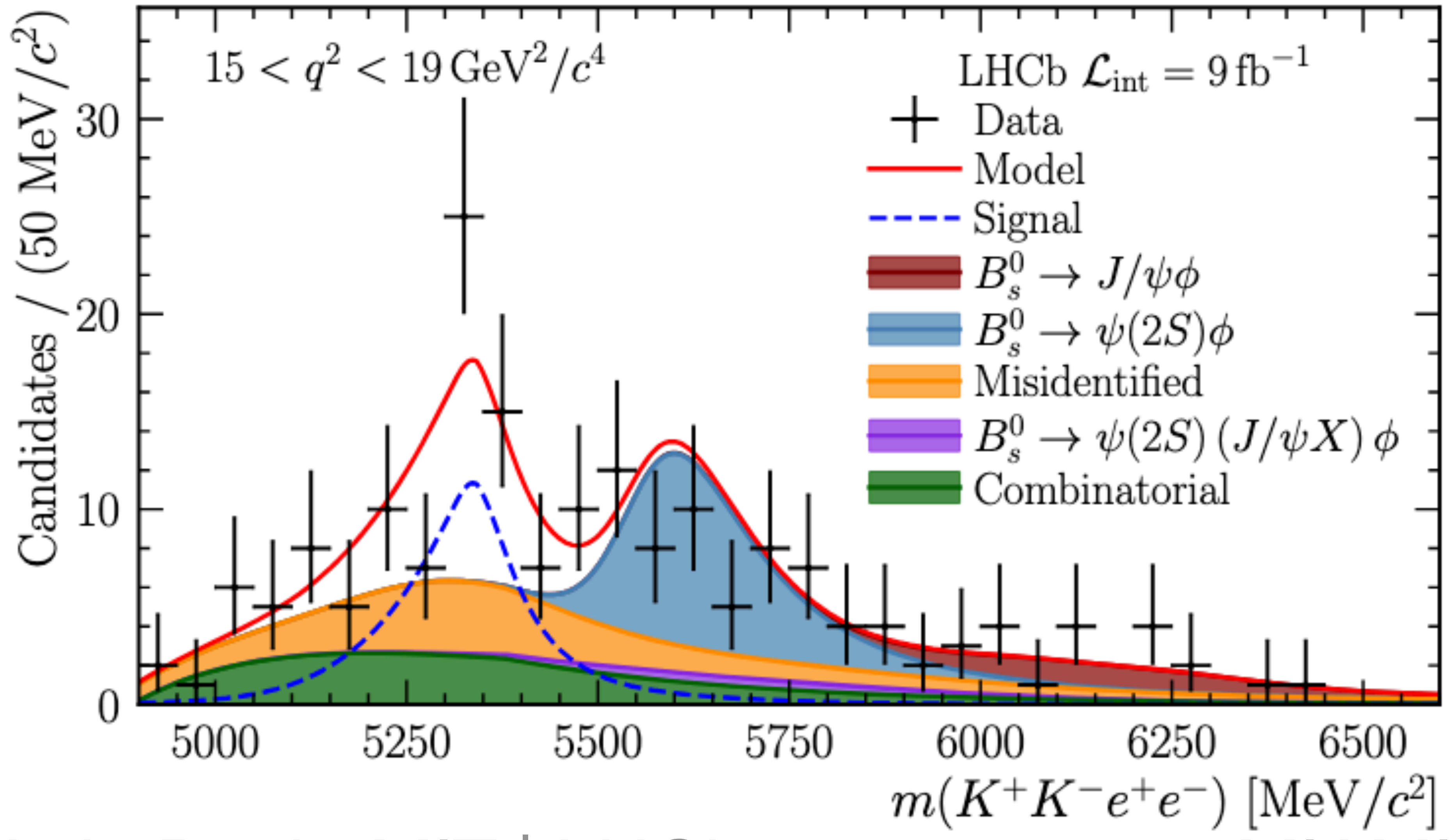




$$\text{Ratio} = \frac{B_s^0 \to \phi\mu^+\mu^-}{B_s^0 \to \phi e^+e^-}$$

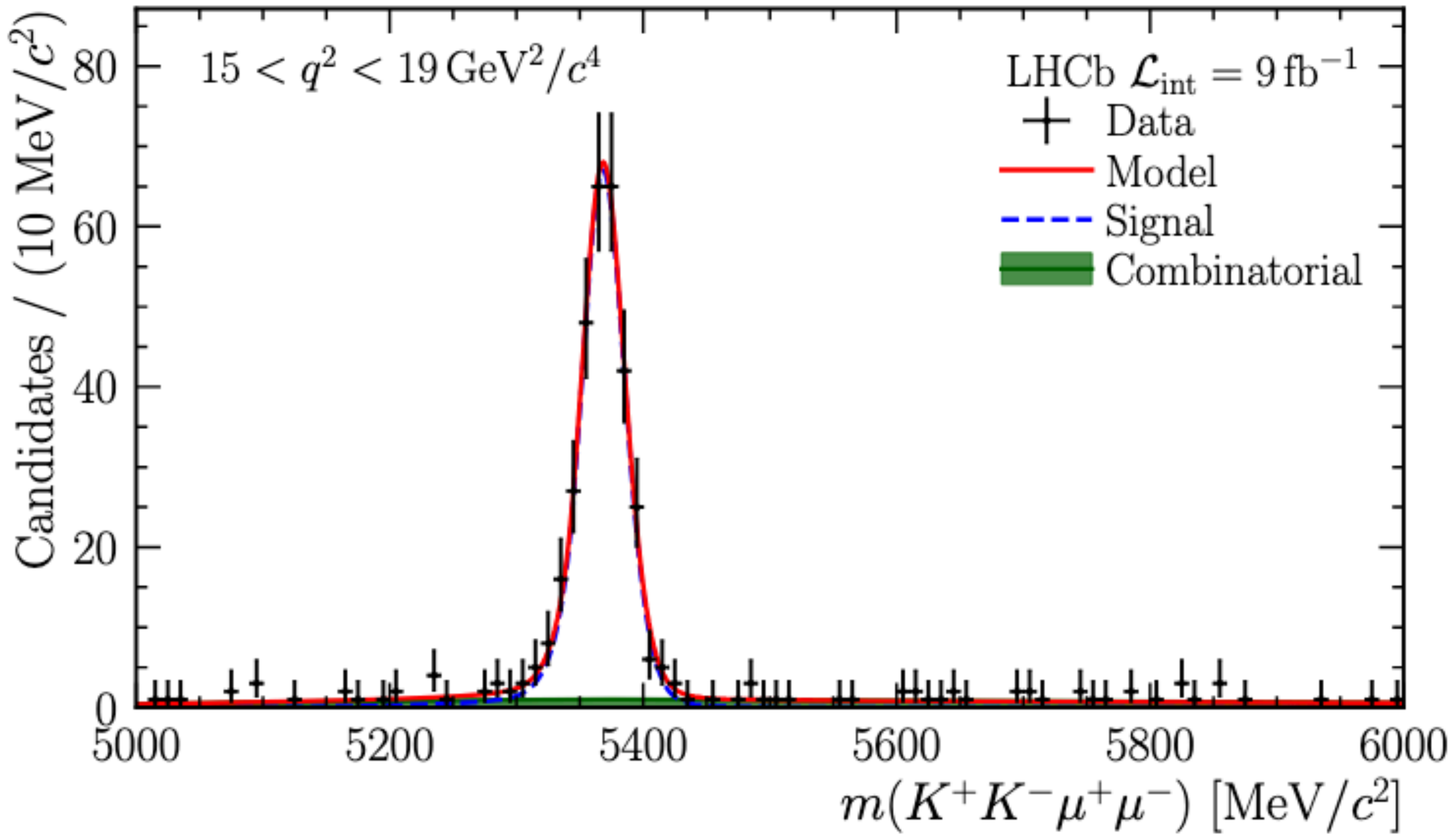
Fit to the four-body invariant-mass determines number of signal candidates for $\ell = e, \mu$

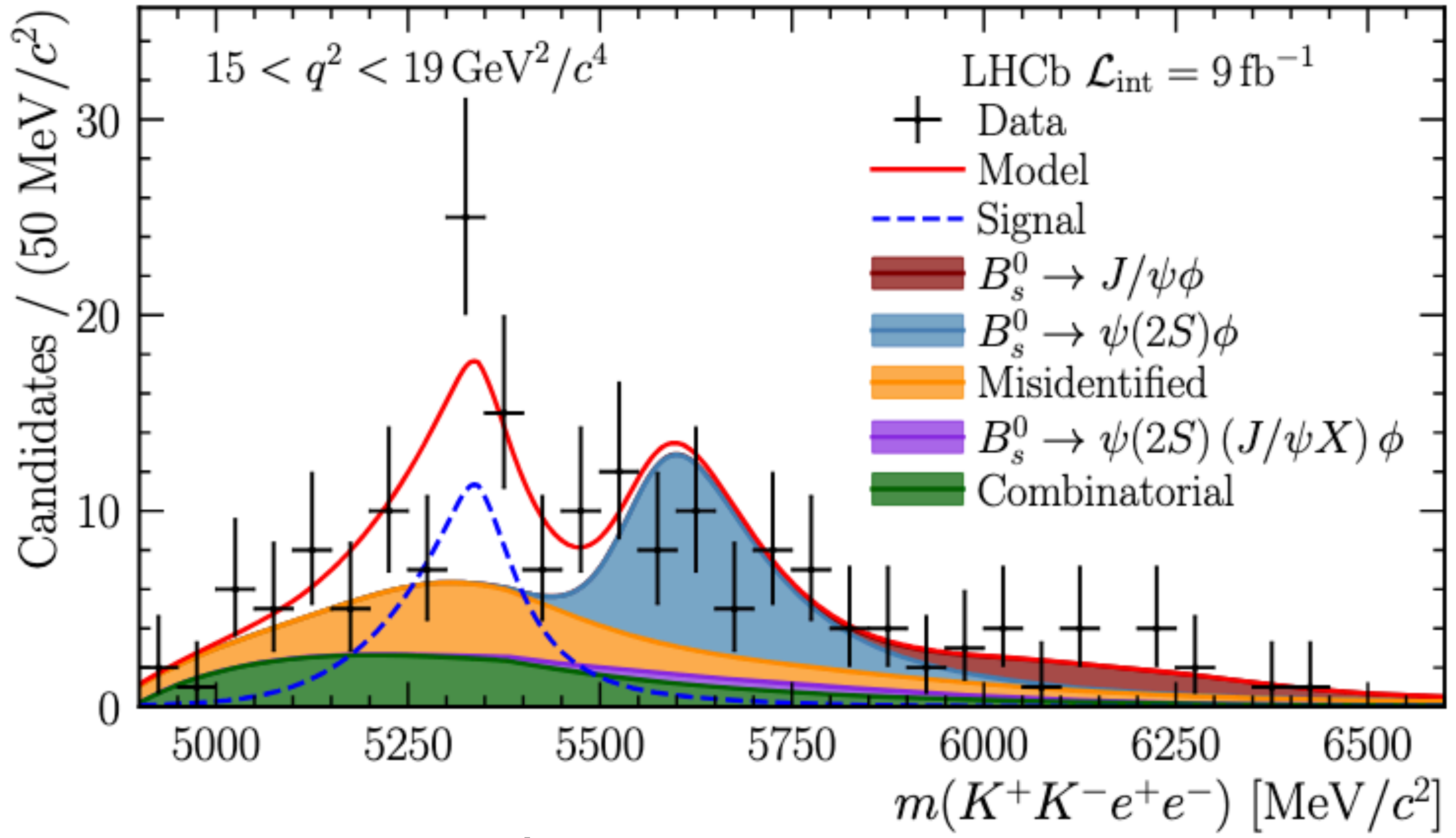
Challenging reconstruction of bremsstrahlung leads to additional backgrounds for electrons

Ratio of branching fractions is consistent with unity in all q^2 bins

LHCb-PAPER-2024-032

Test of lepton universality using $B_s^0 \to \phi(\to K^+K^-)\ell^+\ell^-$





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Model-independent analysis of $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decays

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Extract angular moments in bins
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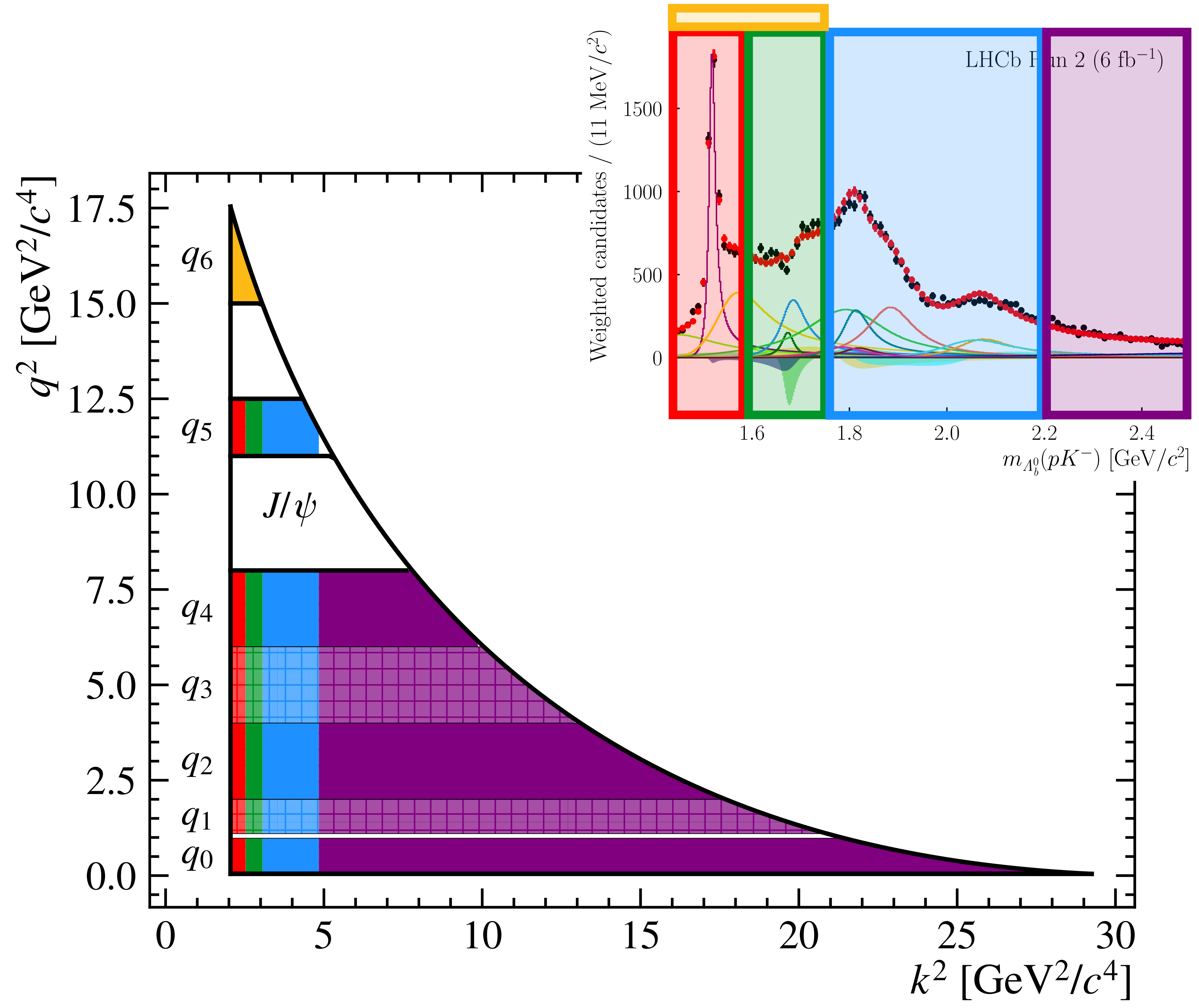

LHCb-PAPER-2024-024

Model-independent analysis of $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decays

Extract angular moments in bins
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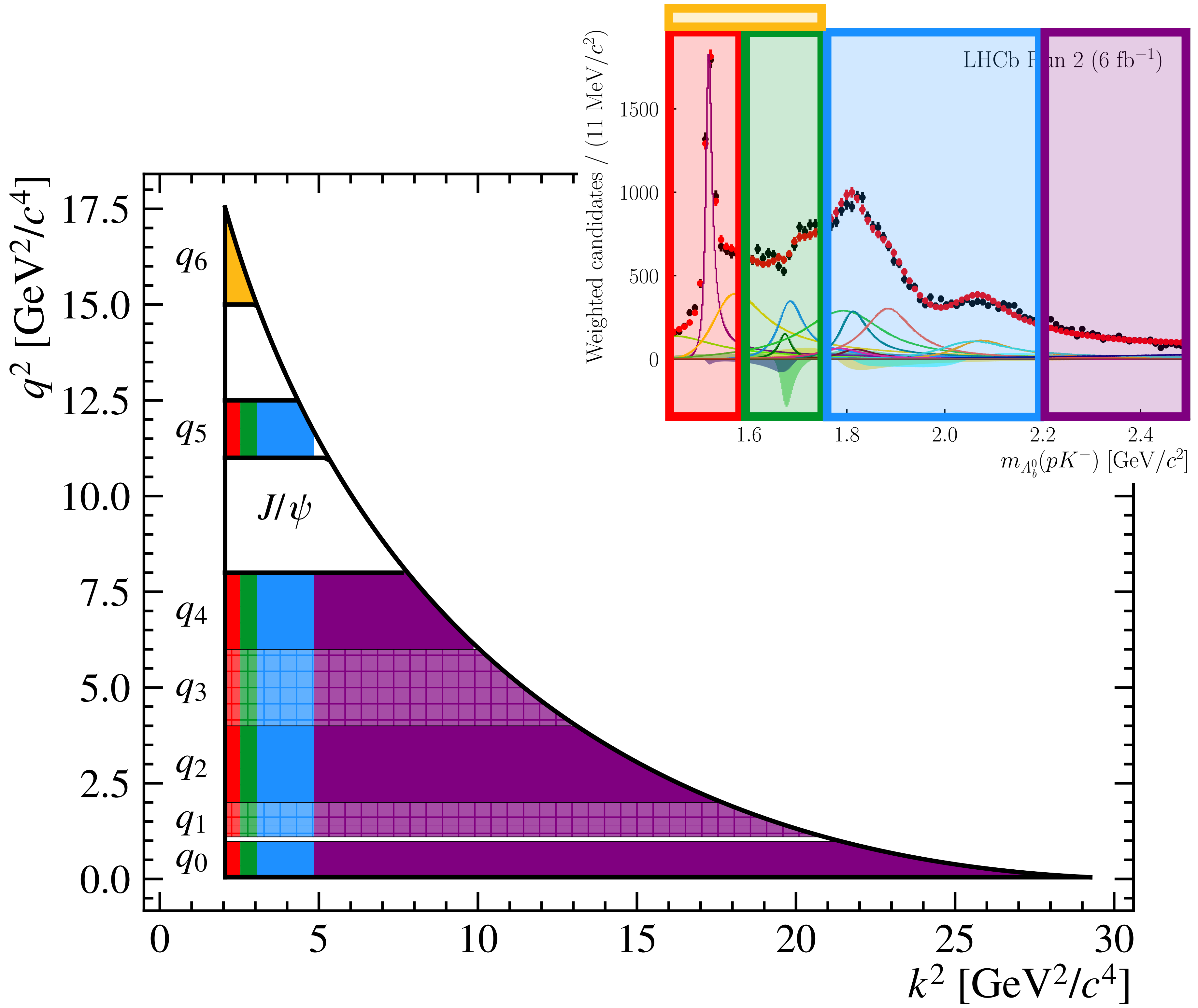

LHCb-PAPER-2024-024

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Extract angular moments in bins
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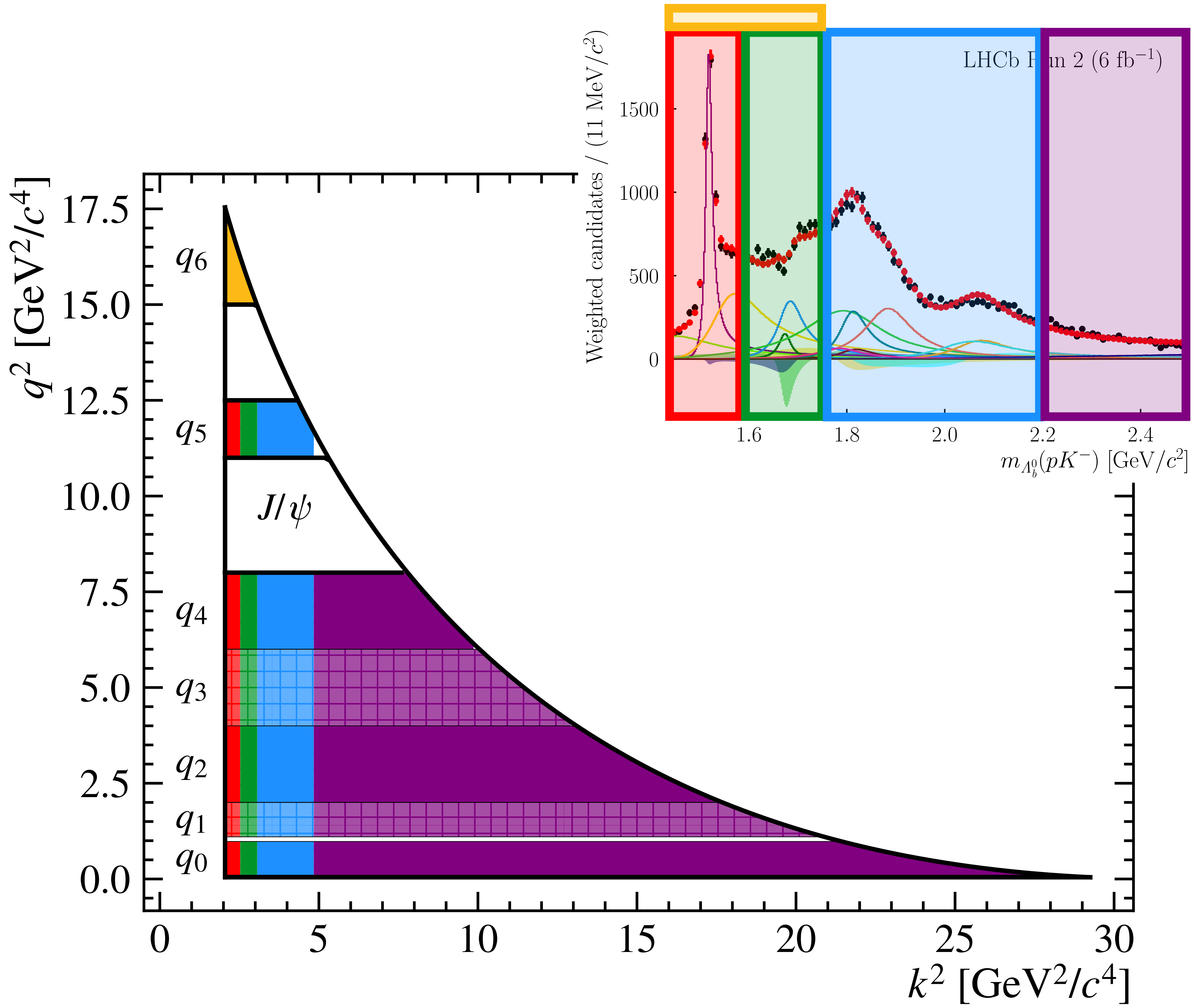
Statistically limited

Difficult interpretation
No SM prediction available



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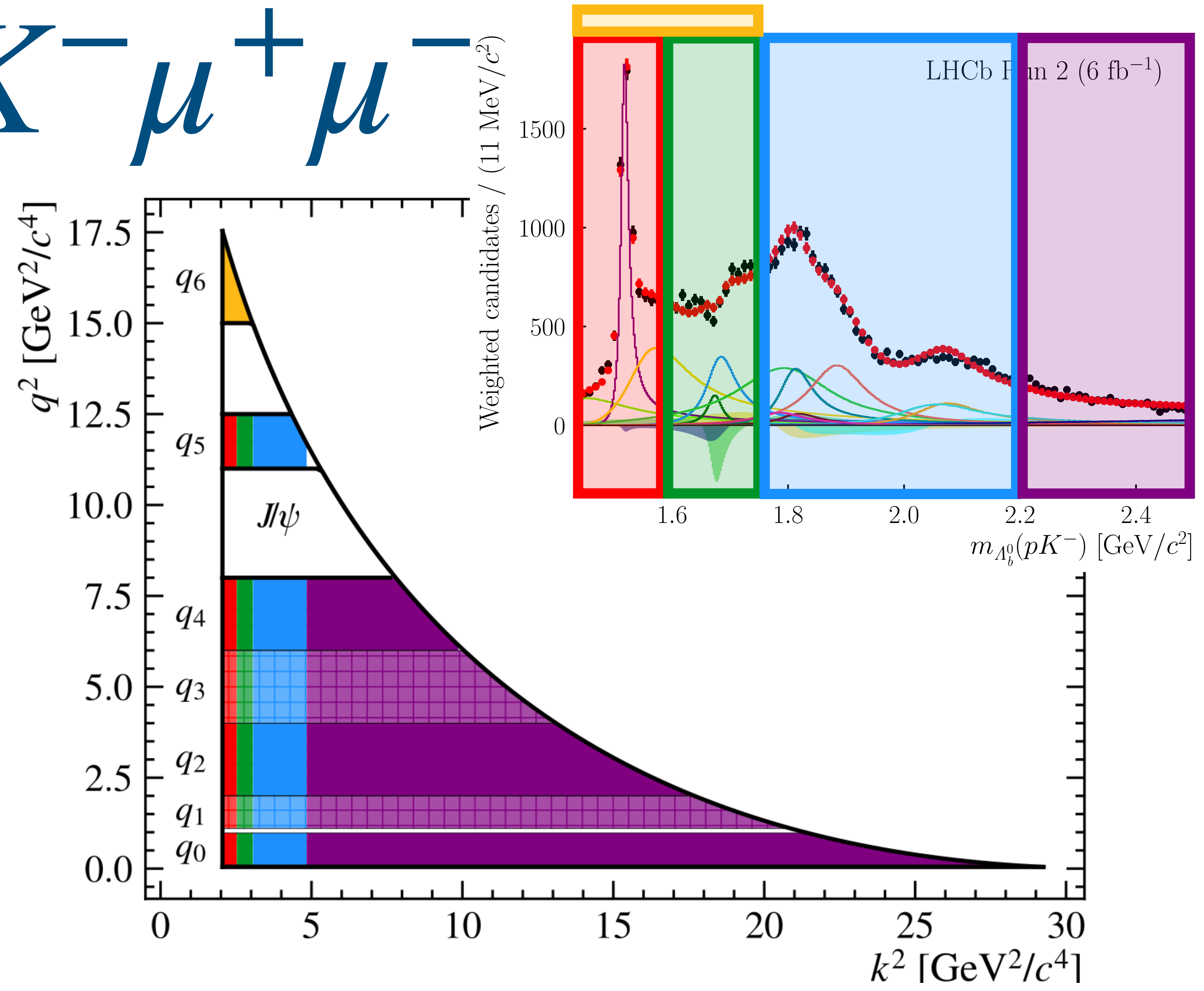

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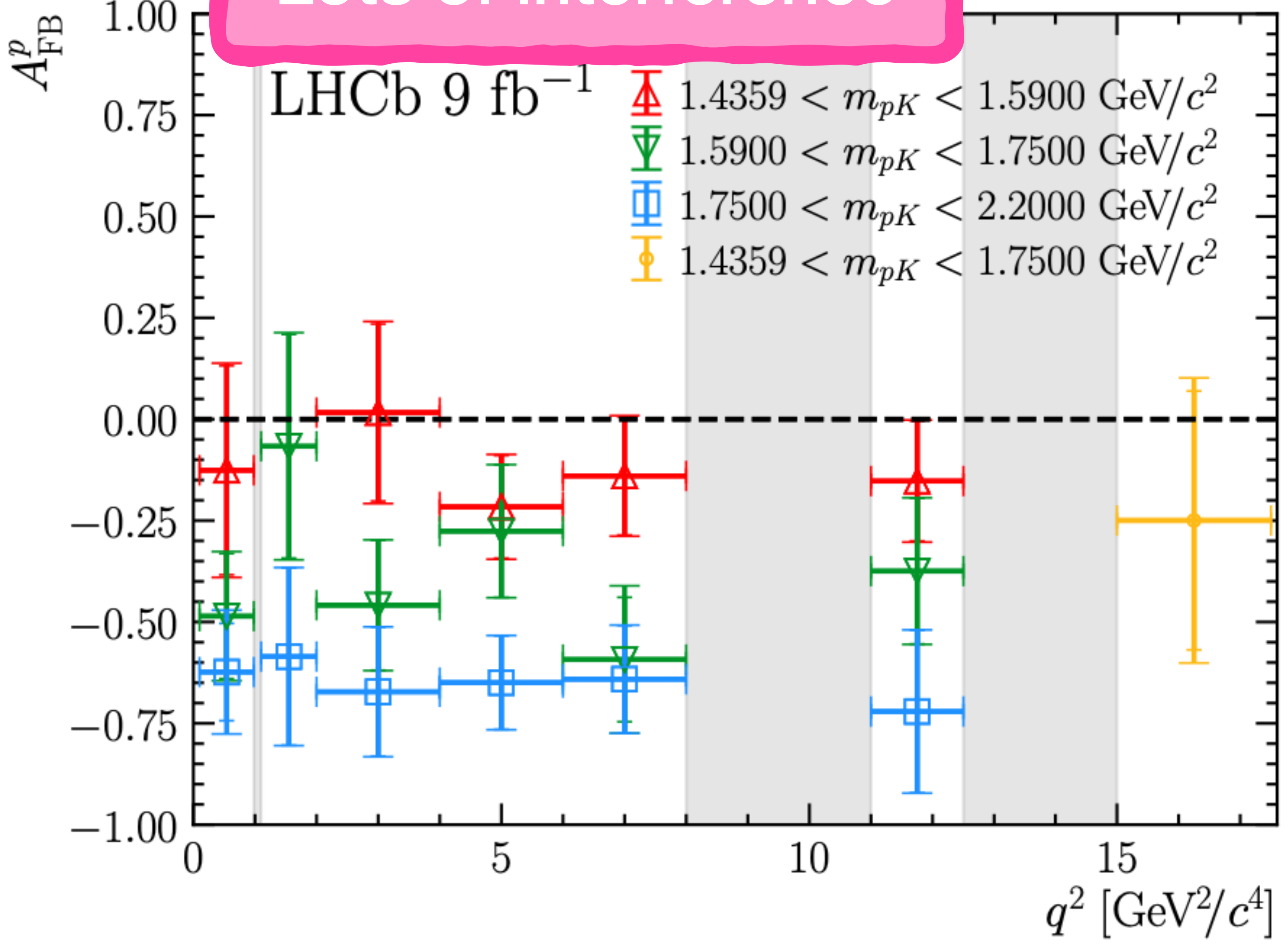
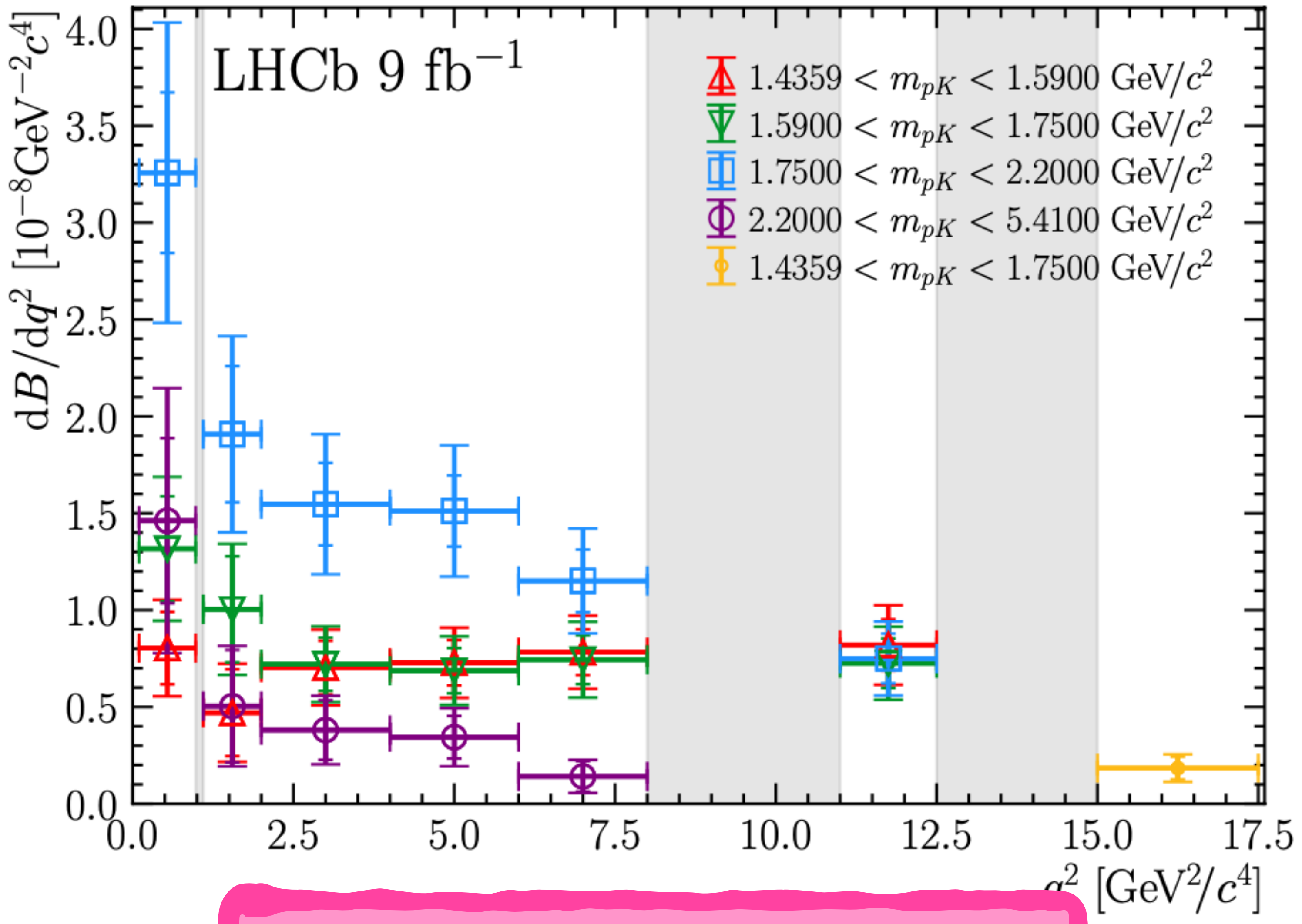
Lots of interference





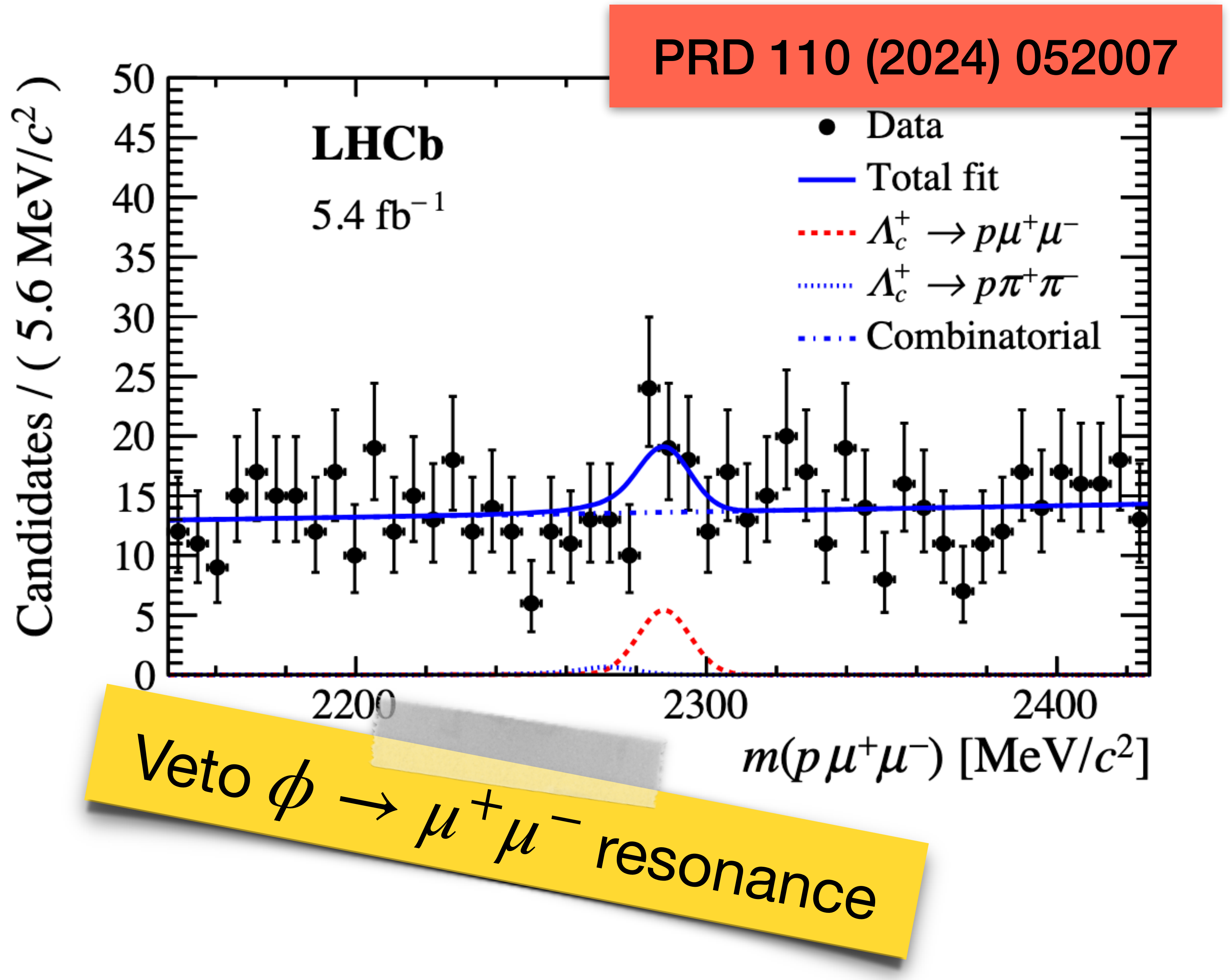
Enhancement at low q^2

Up and coming: rare charm and strange decays

Up and coming: rare charm and strange decays

Search for $\Lambda_c^+ \to p\mu^+\mu^-$ PRD 110 (2024) 052007

=> no significant signal is observed



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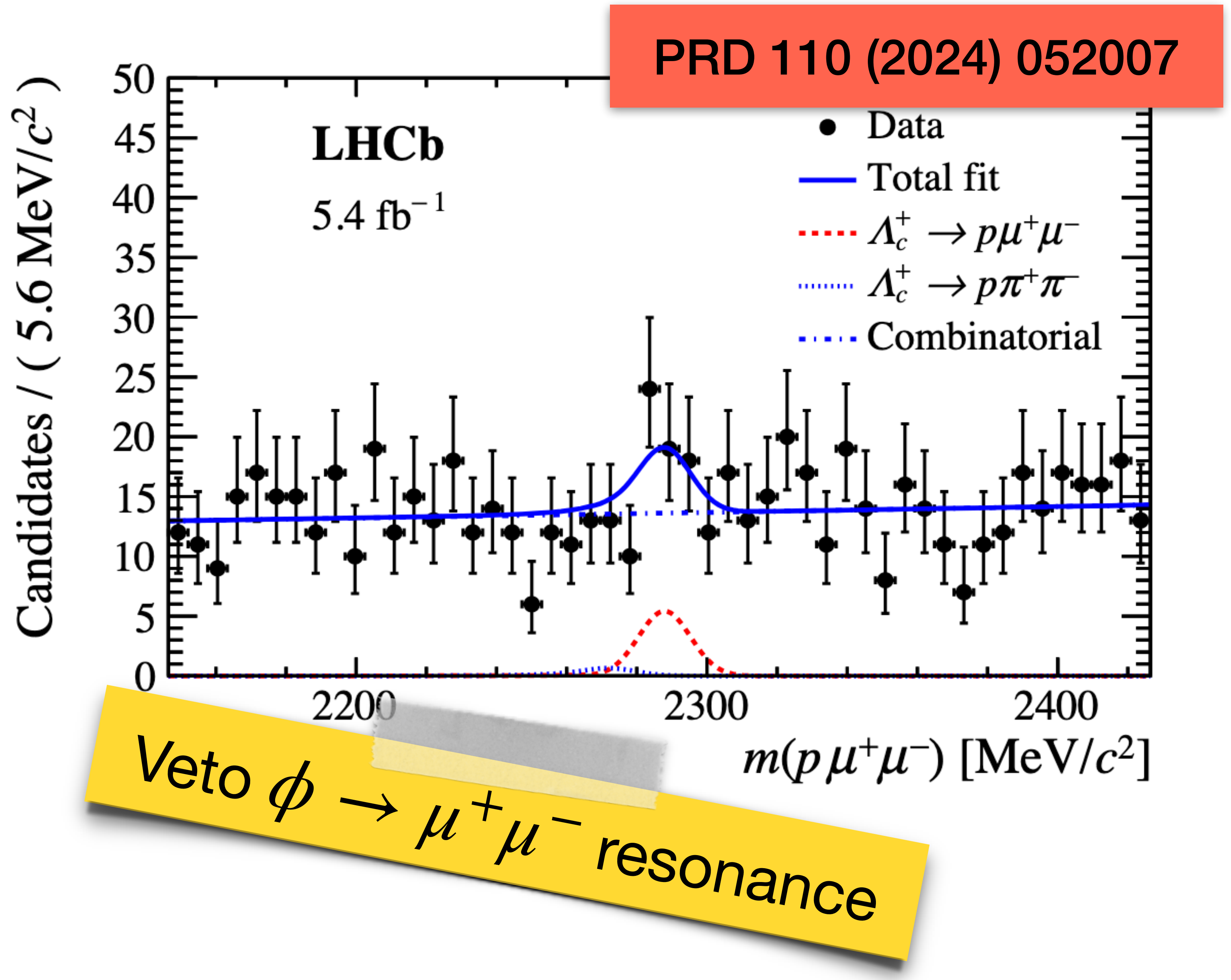
First observation of $D^0 \to \pi^+\pi^-e^+e^-$ LHCb-PAPER-2024-047

$$\mathcal{B}(D^0 \to \pi^+\pi^-[e^+e^-]_{m(e^+e^-)>2m_\mu}) = (13.3 \pm 1.1 \pm 1.7 \pm 1.8) \times 10^{-7}$$



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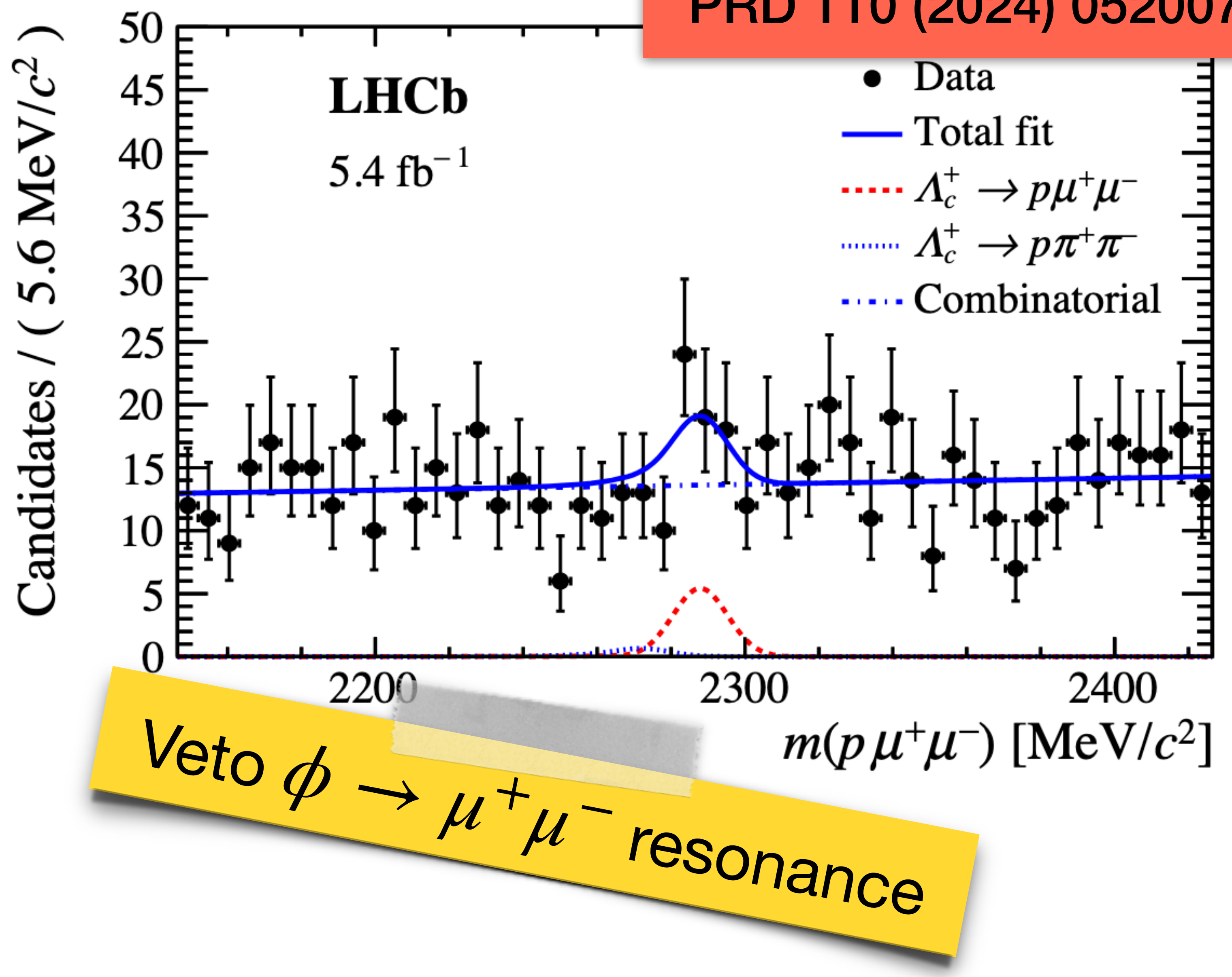

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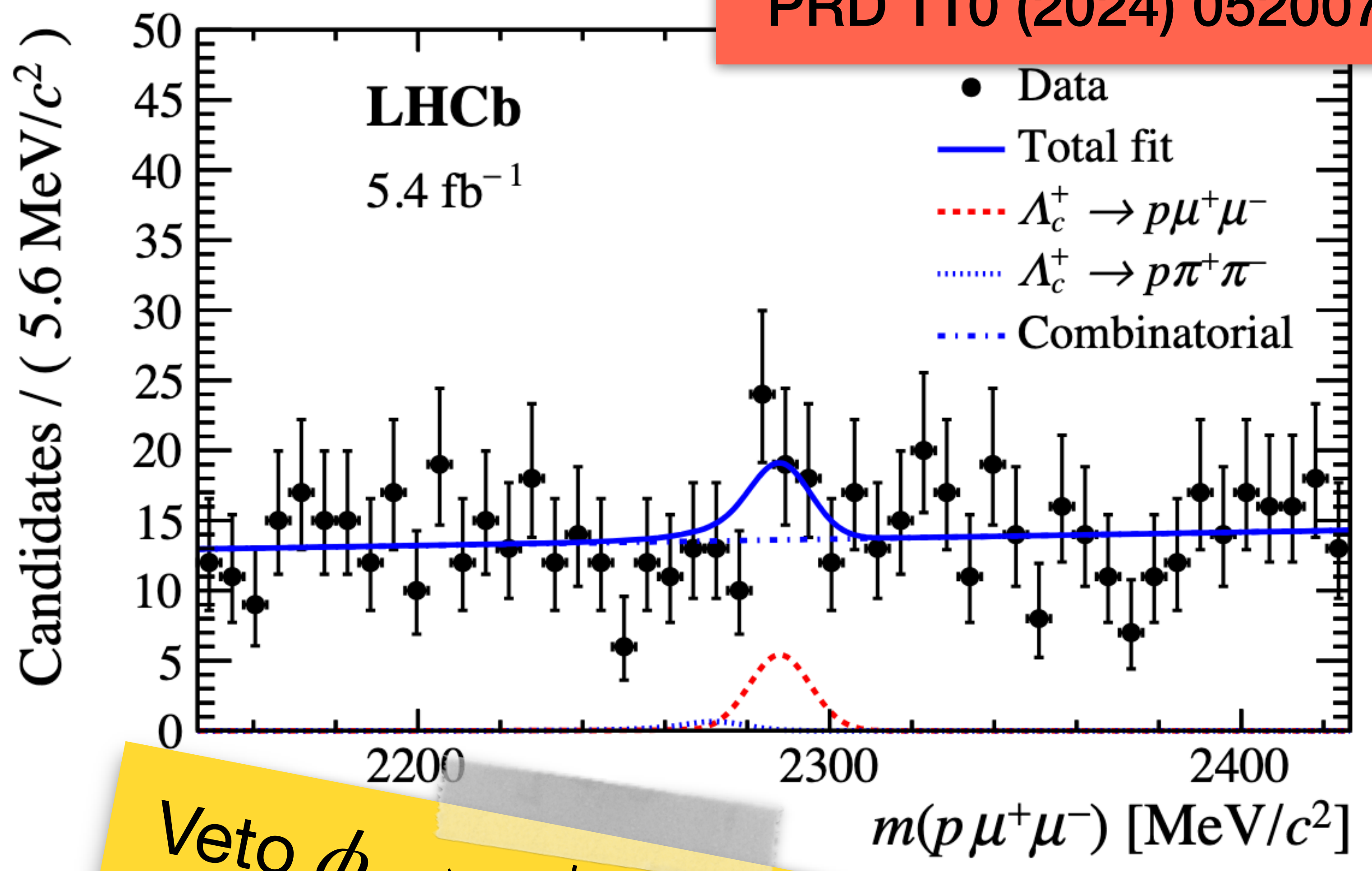
PRD 110 (2024) 052007



Veto $\phi \to \mu^+\mu^-$ resonance

Up and coming: rare charm and strange decays

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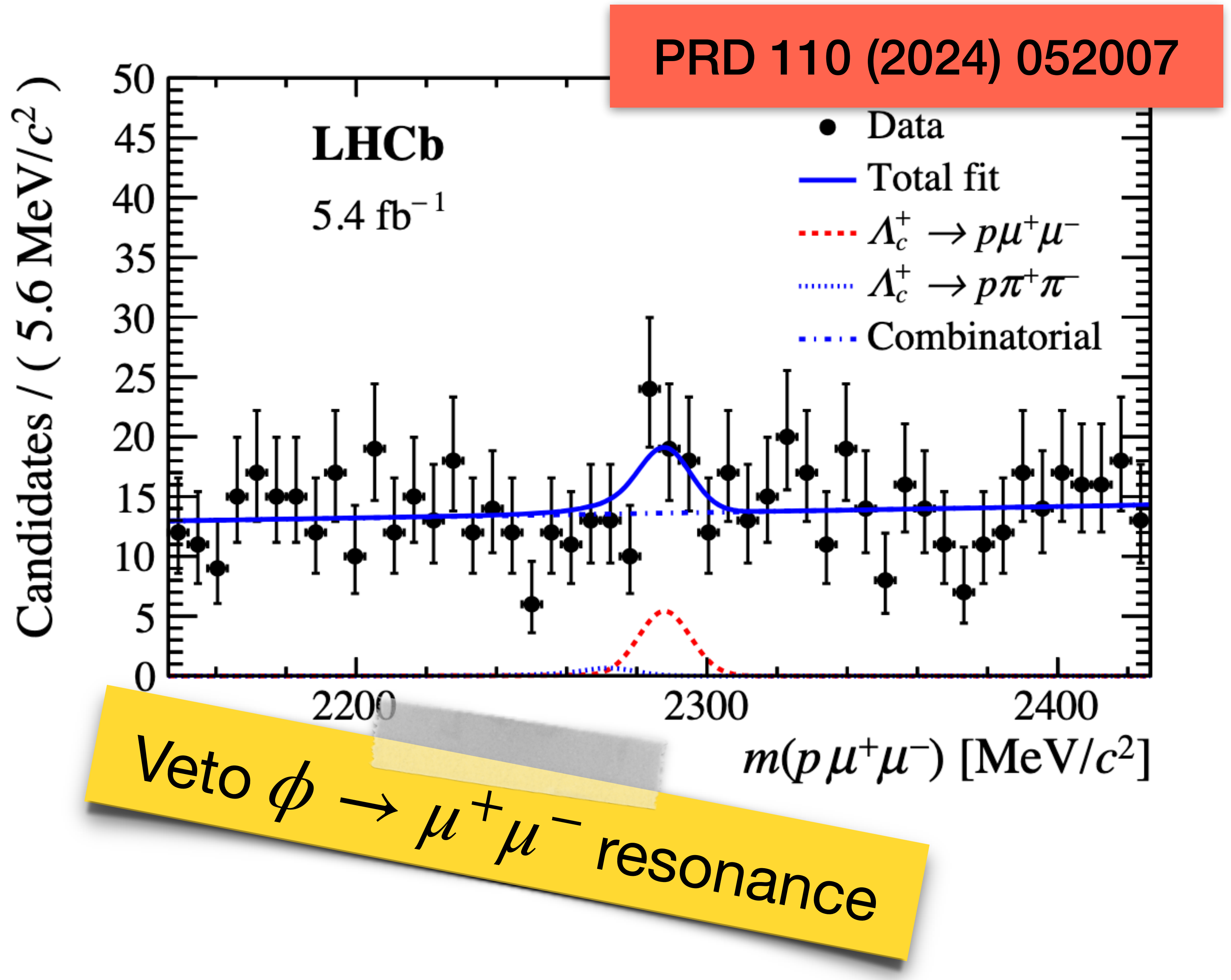
Angular analysis of $\Lambda_c^+ \to p\mu^+\mu^-$ around $\phi \to \mu^+\mu^-$



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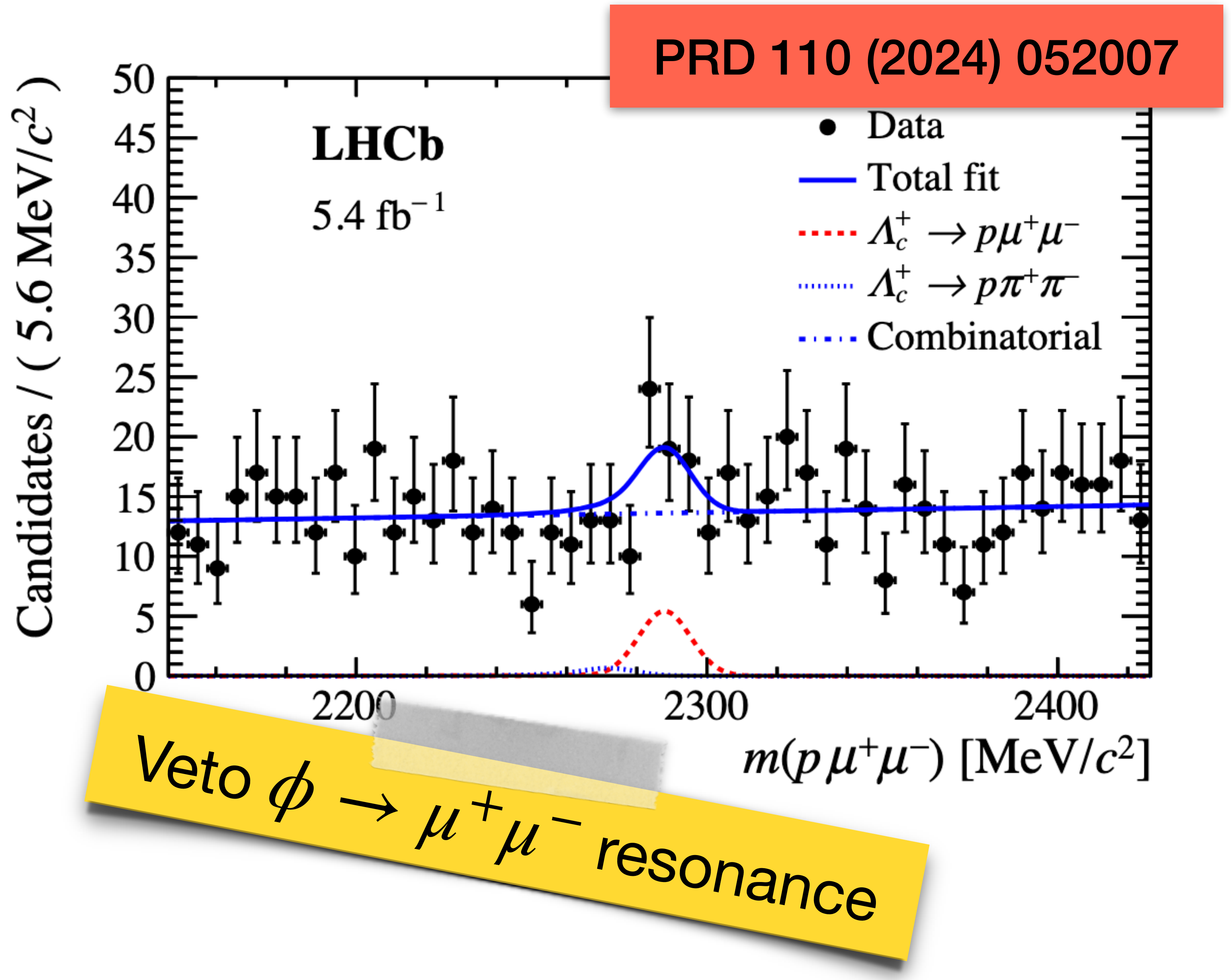

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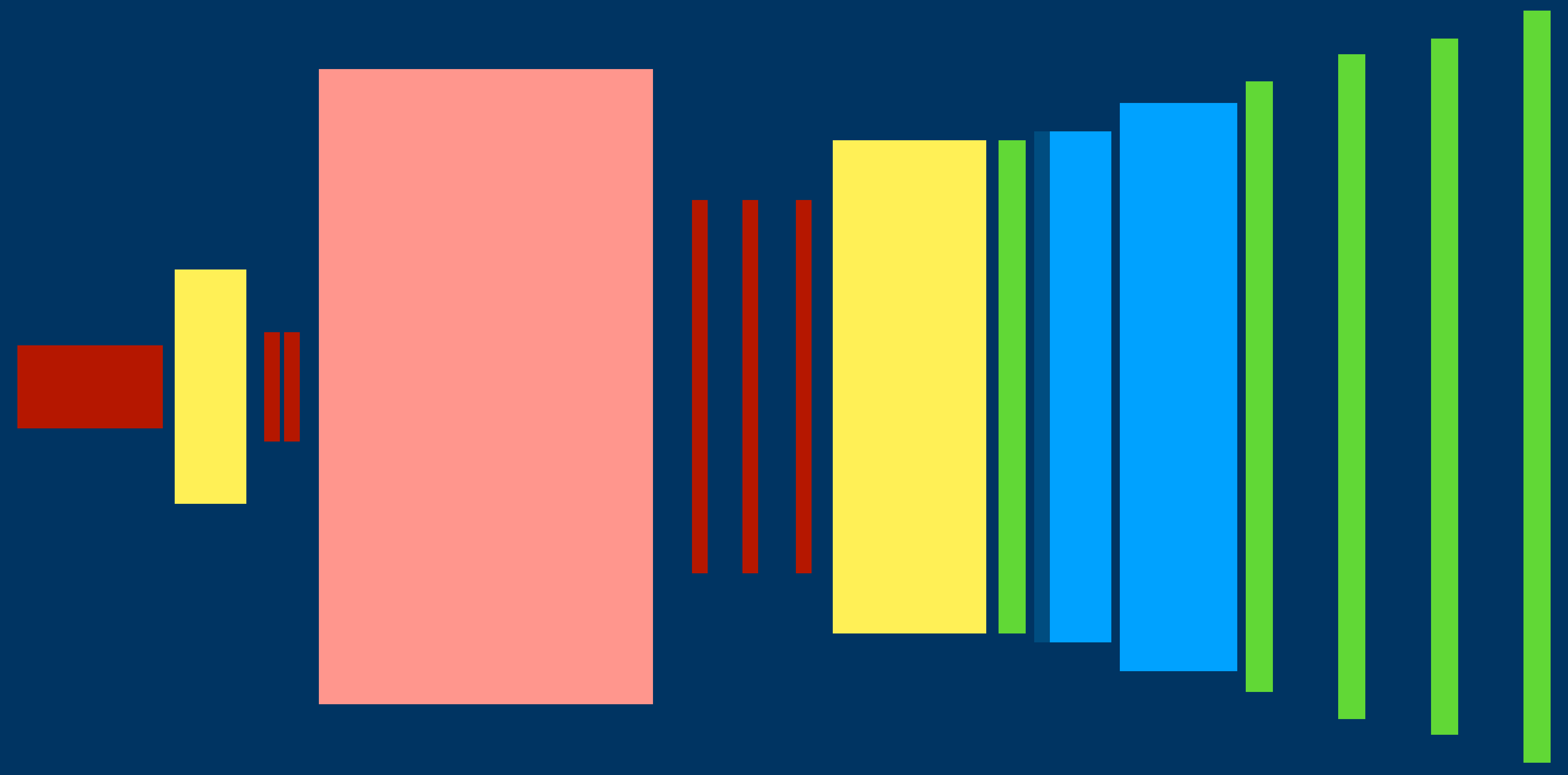
Search for $\Sigma^+ \to p\mu^+\mu^-$

Upgrades

LHCbetter



Run 3 and beyond

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Most rare decay measurements to-date are statistically limited

Run 1+2: ~1 visible pp interaction / bunch crossing at 30 MHz

Hardware trigger limited to 1 MHz (saturates on many modes)

Collected 9 fb^{-1} in six years

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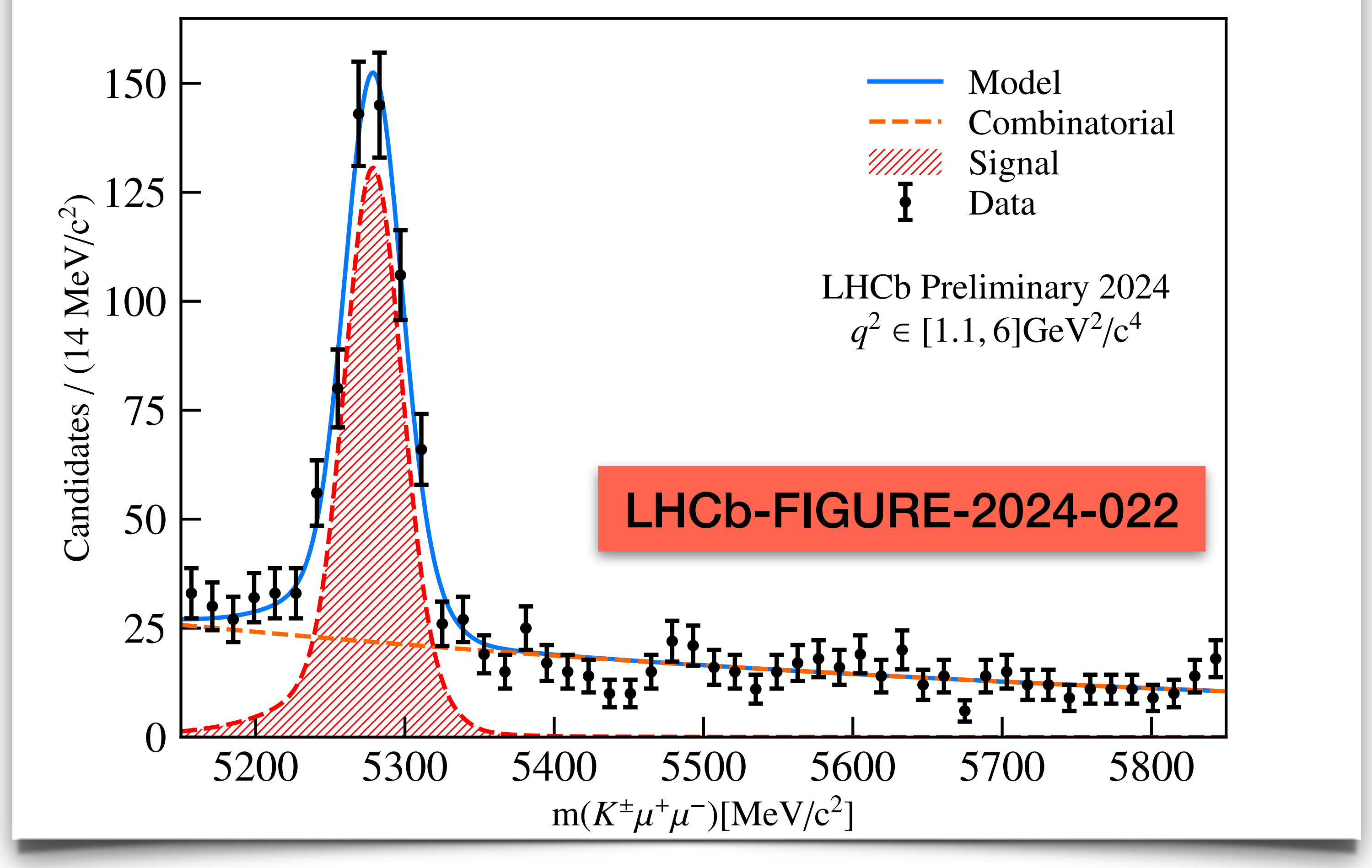

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=> Add timing
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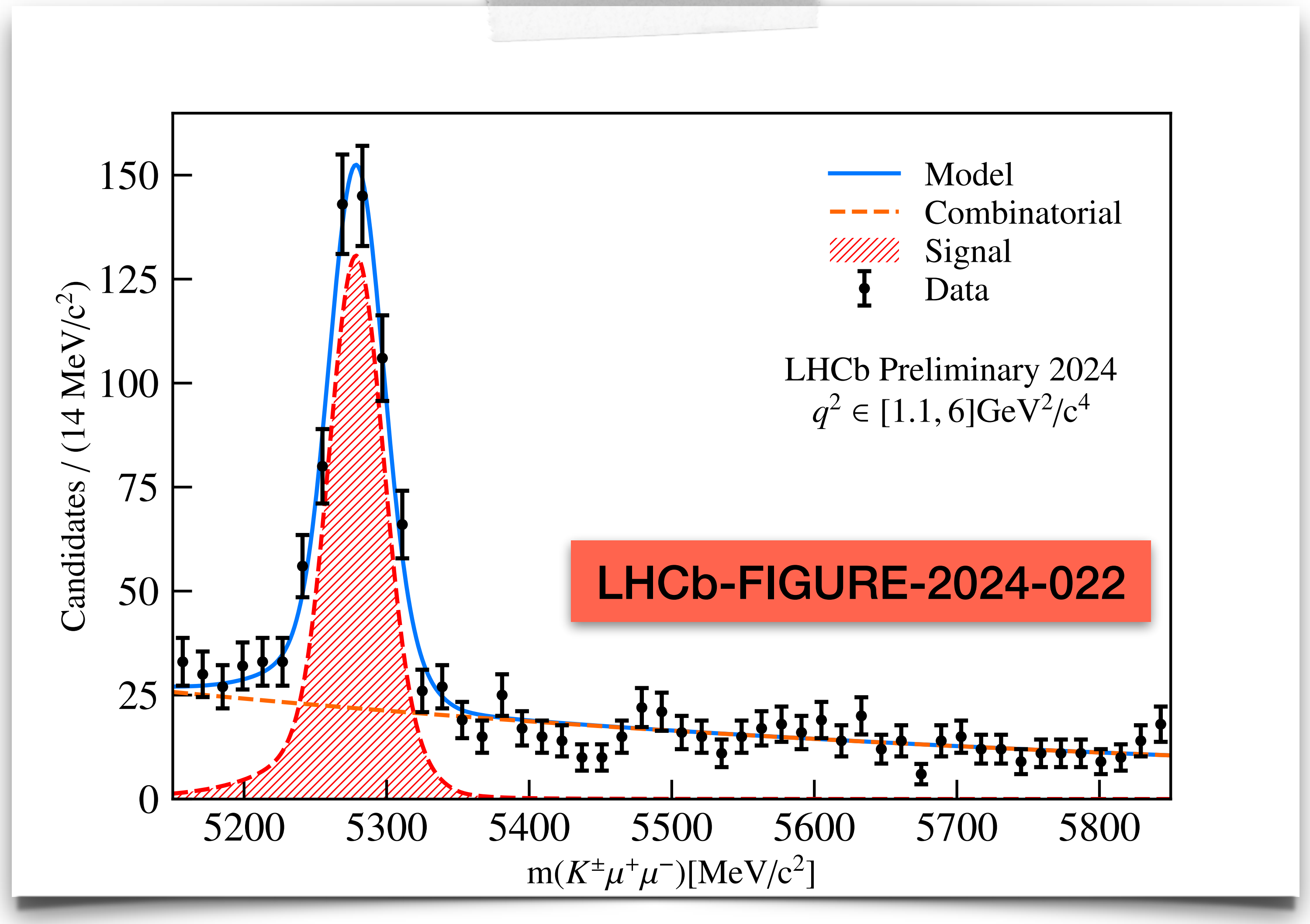

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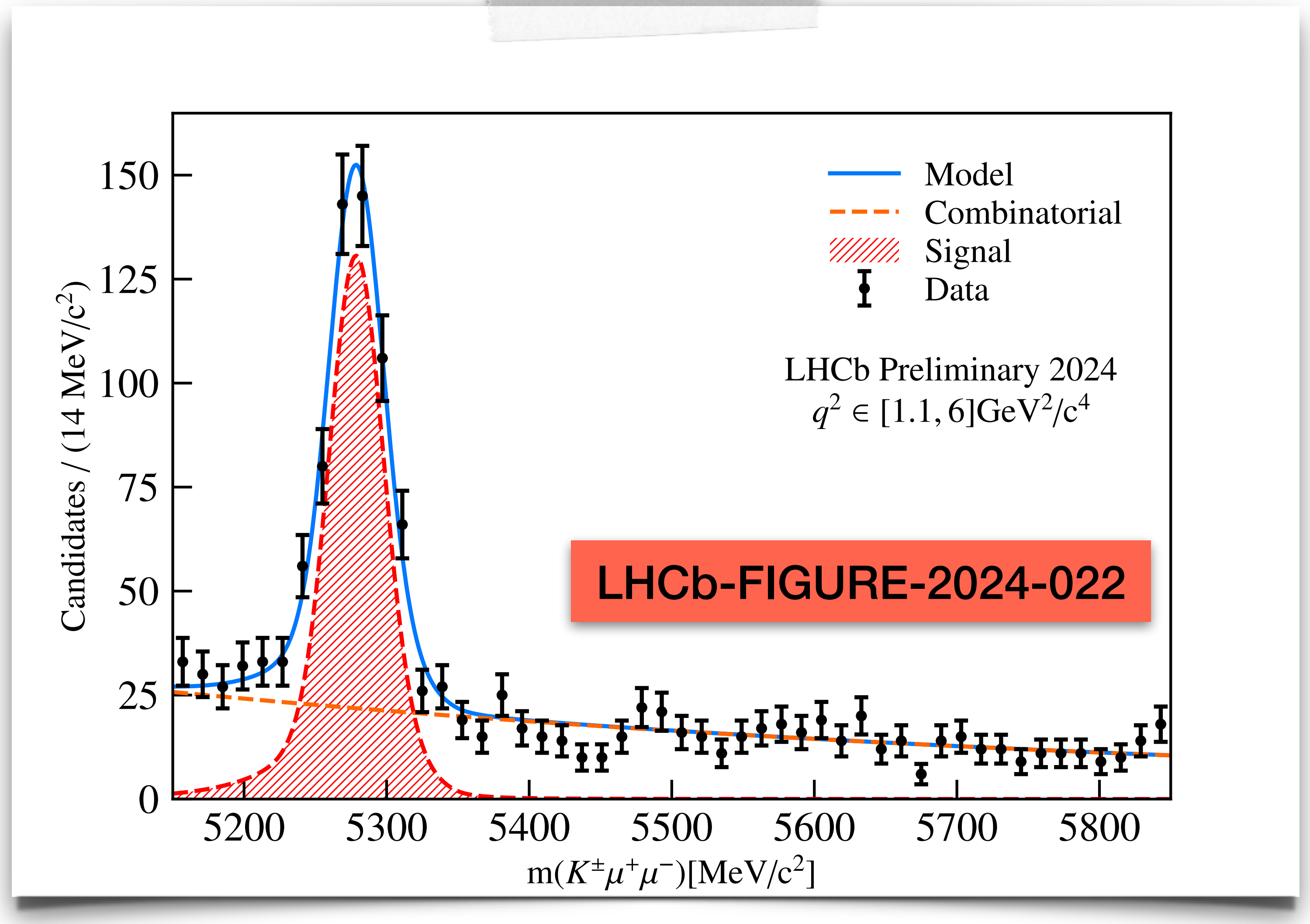
Run 5+: ~40 visible pp interactions / bunch crossing at 30 MHz
Expect 50 fb^{-1} per year



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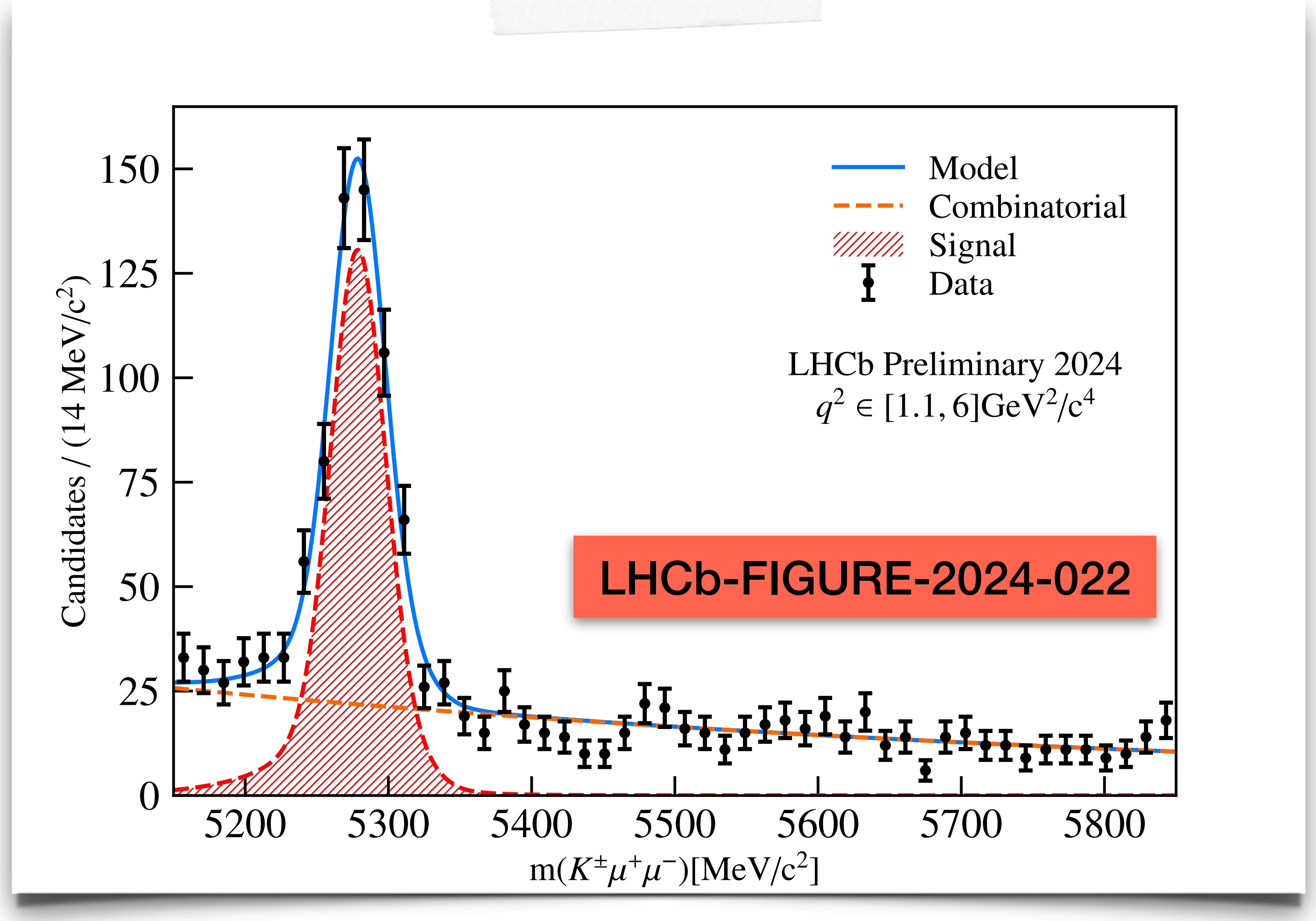

Run 3+4: ~5 visible pp interactions / bunch crossing at 30 MHz
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LHCb upgrade II
=> Add timing
=> Higher granularity
=> Improved radiation hardness

Expect large increase in sensitivity

Run 5+: ~40 visible pp interactions / bunch crossing at 30 MHz
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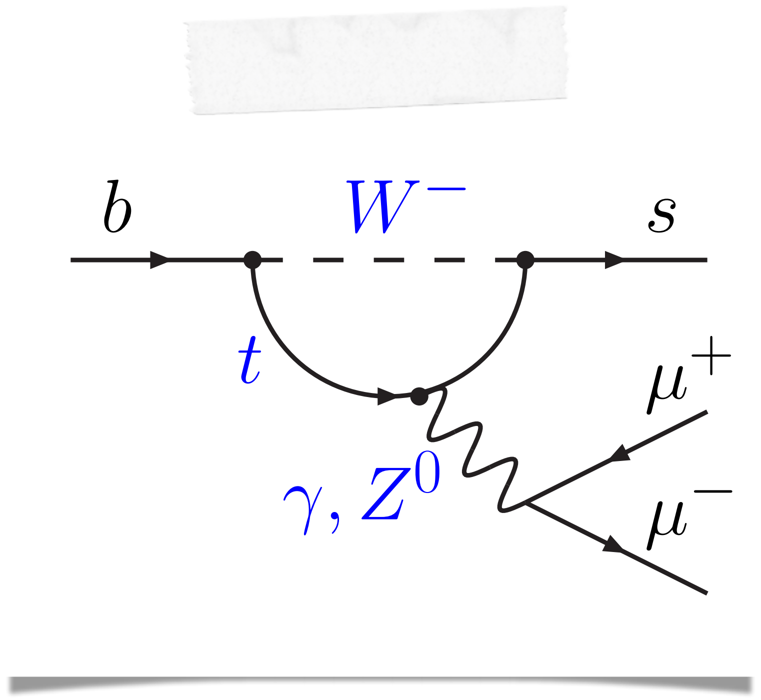
Summary

Summary

Rare decays and why QCD is hard



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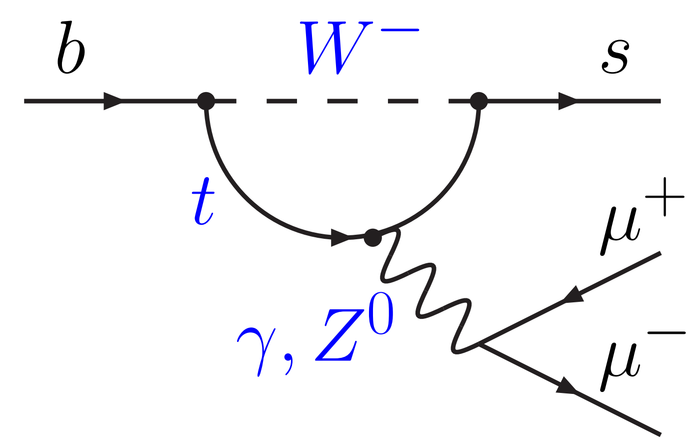
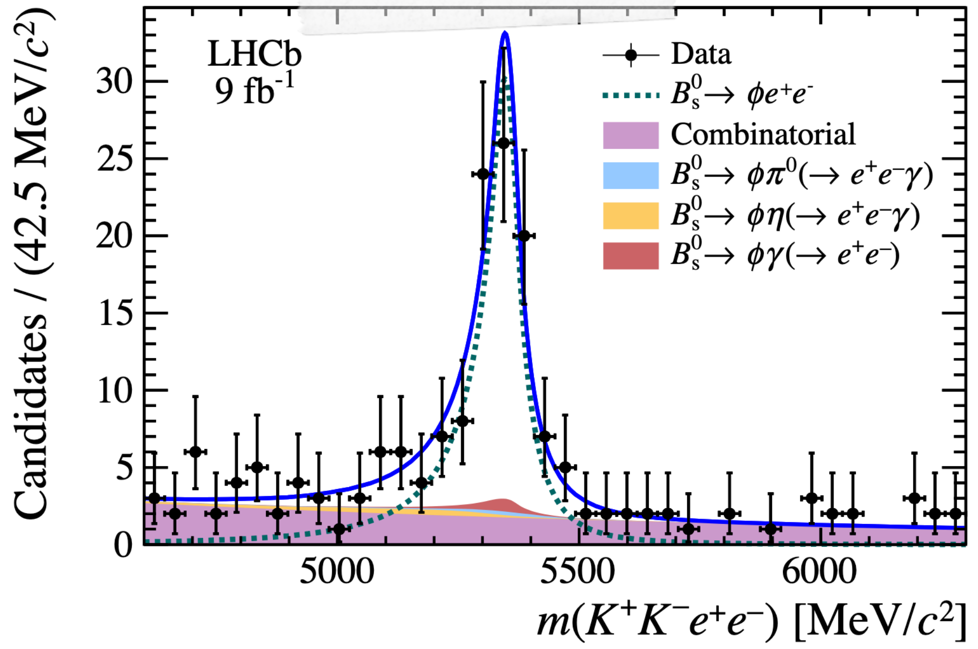
Rare decays and why QCD is hard

Measurements:

1. Photon polarisation from $B_s^0 \to \phi e^+ e^-$





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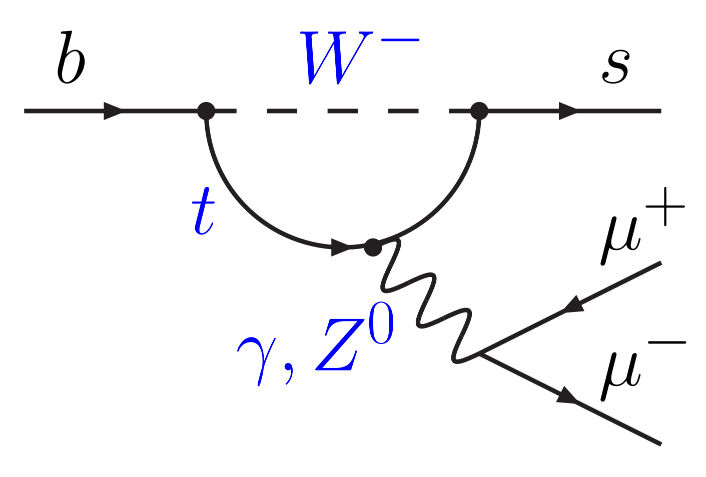

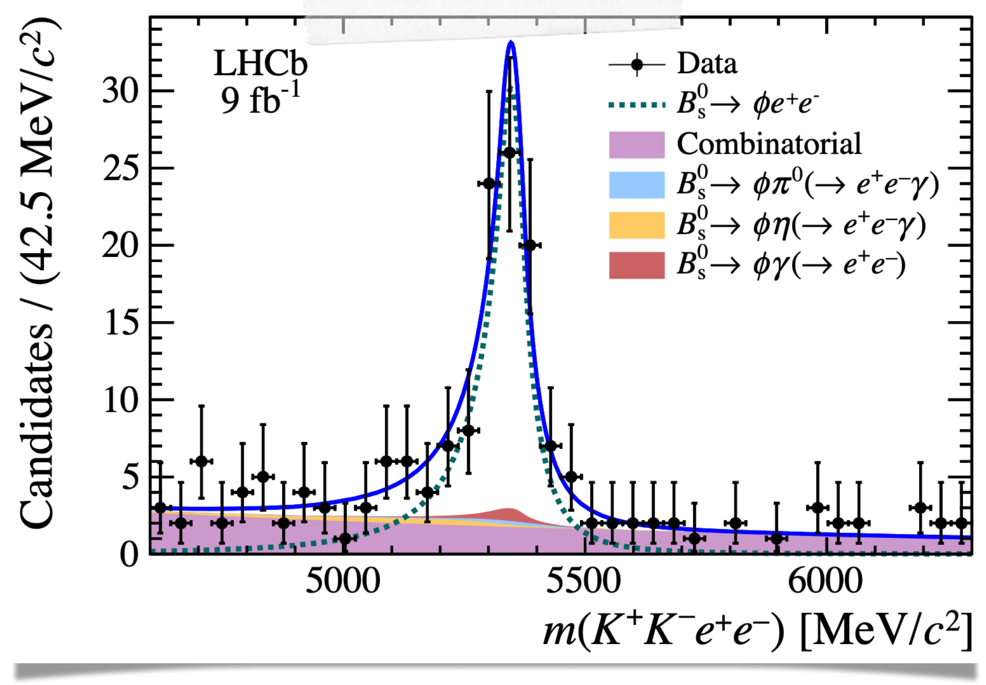

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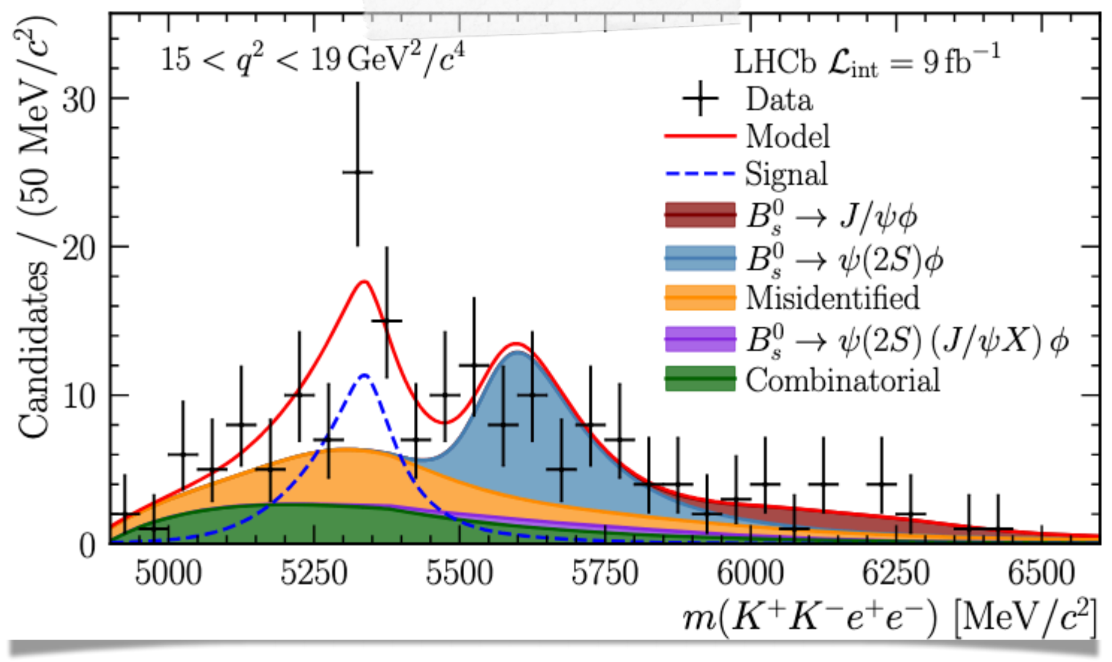

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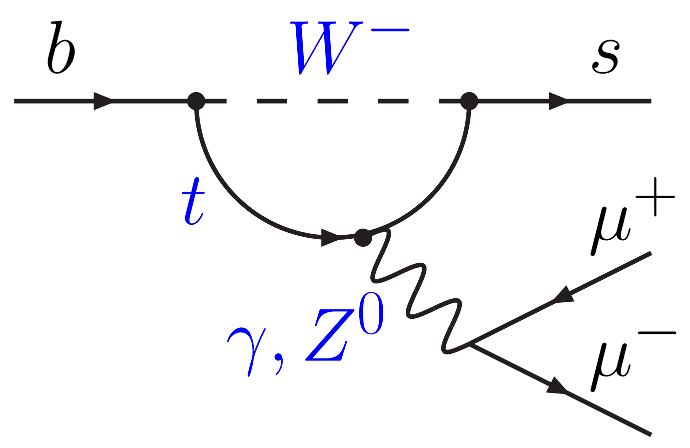

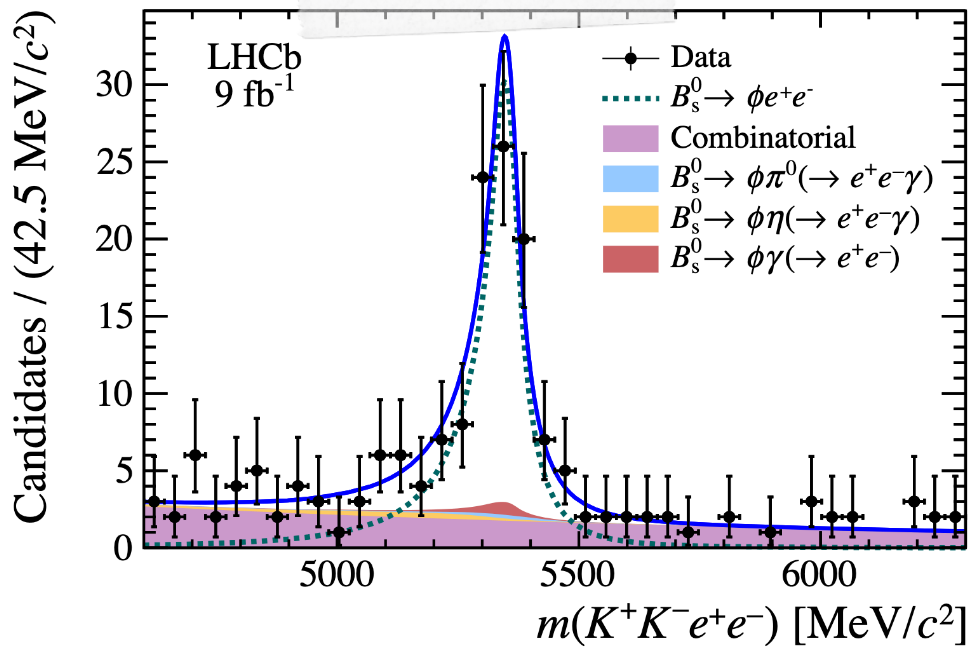

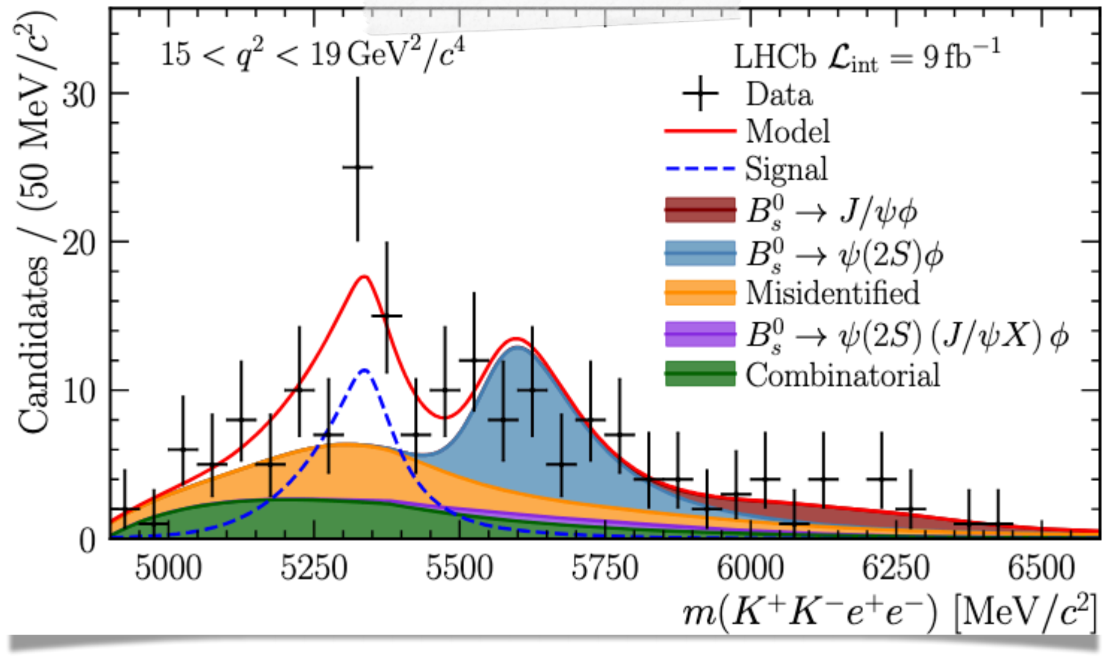

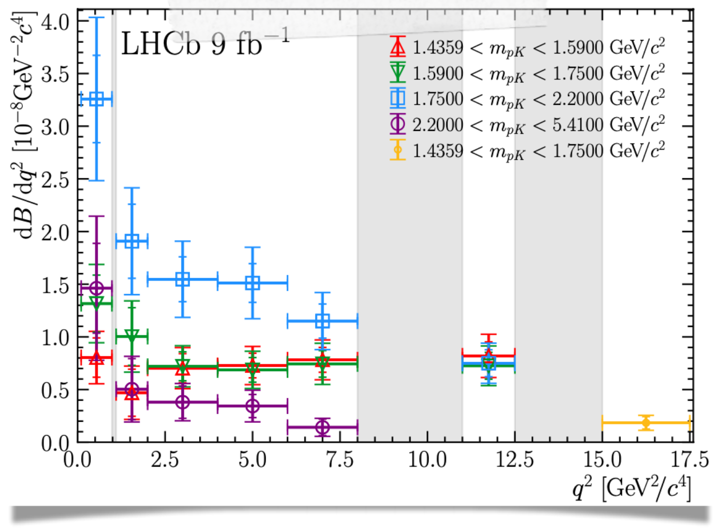

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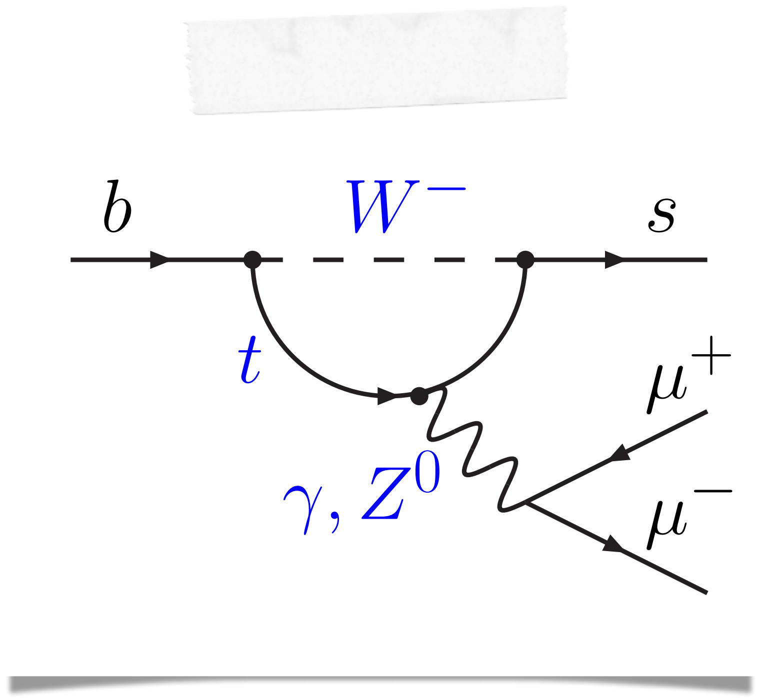

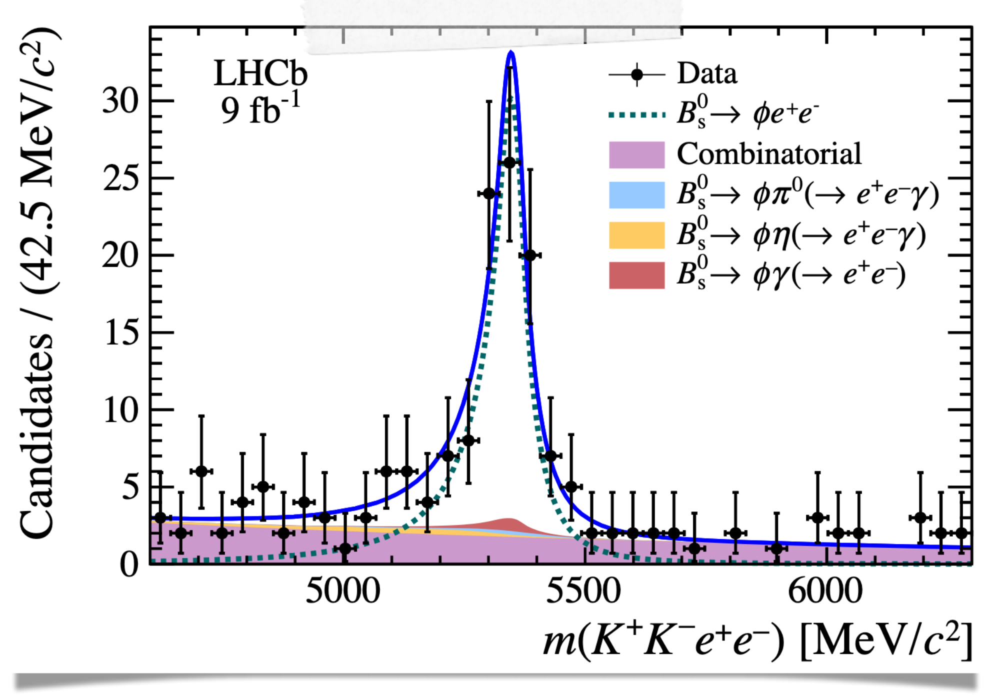

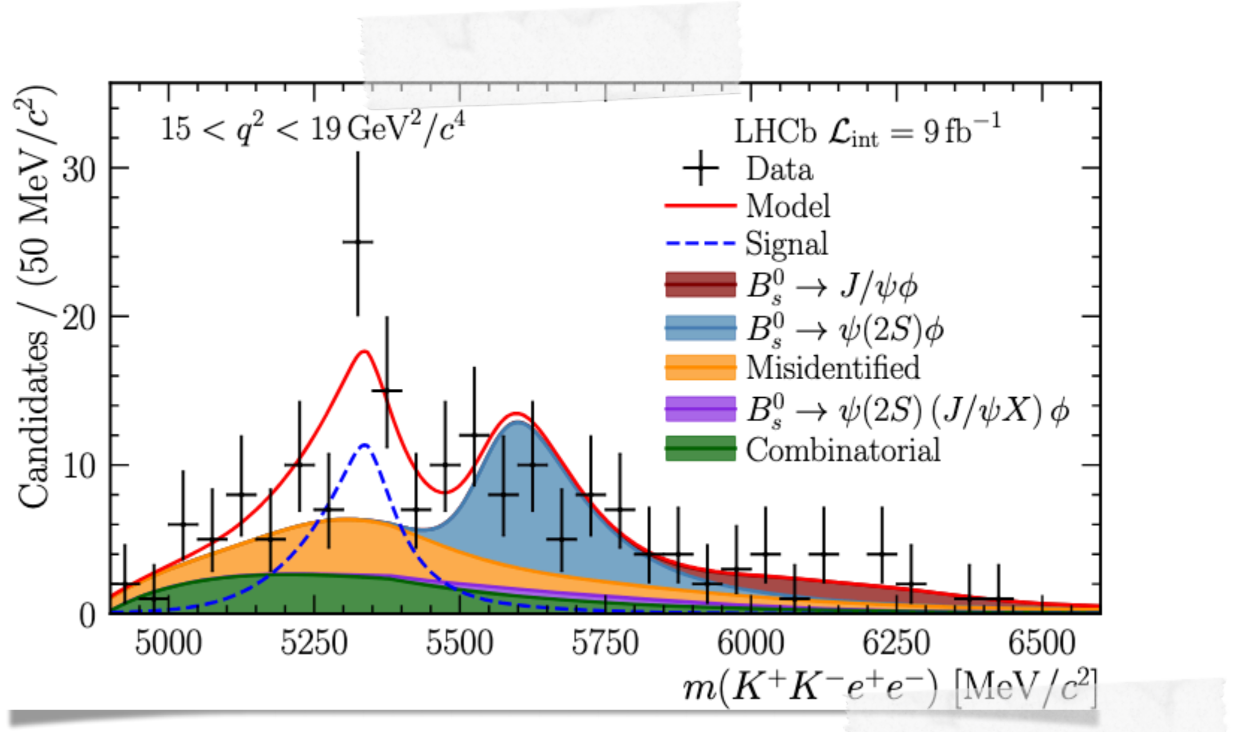

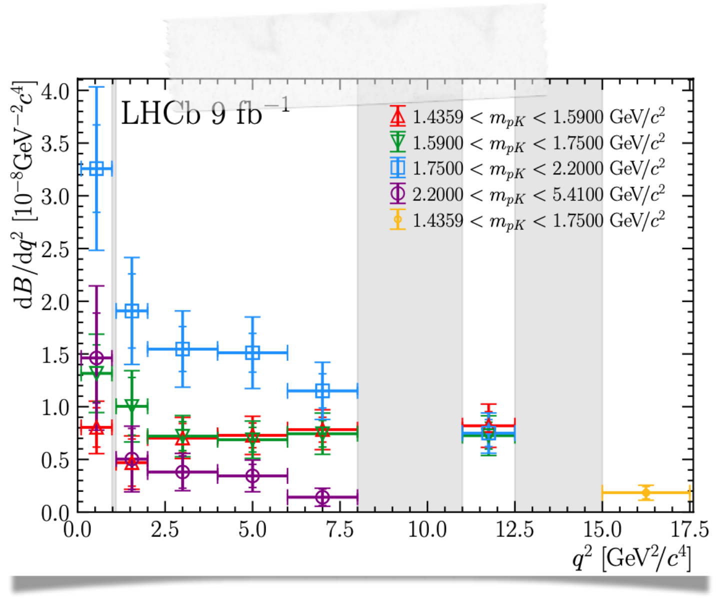

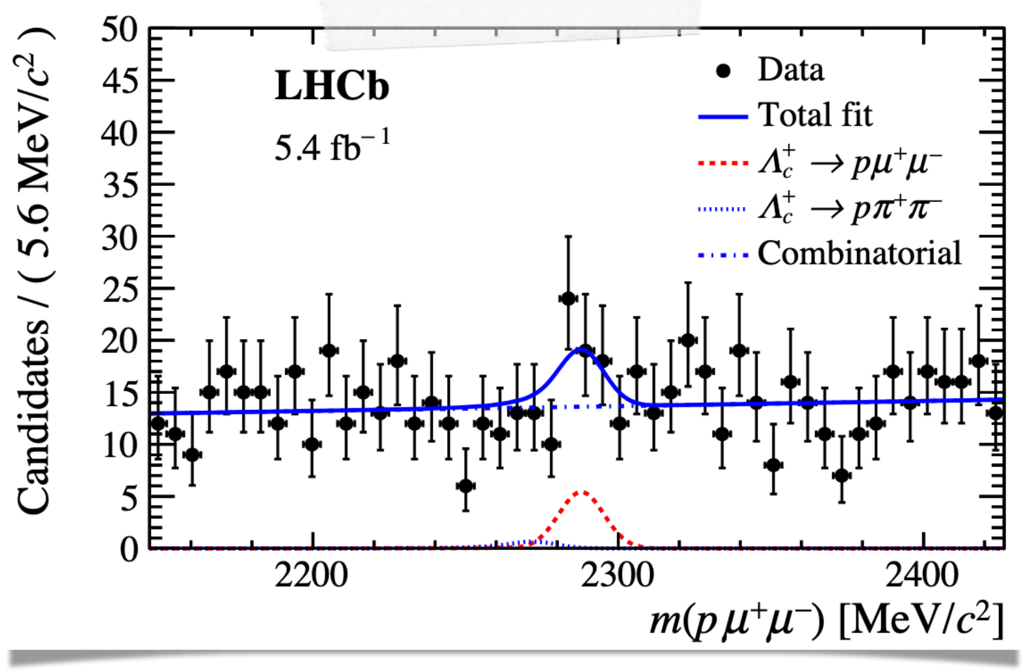

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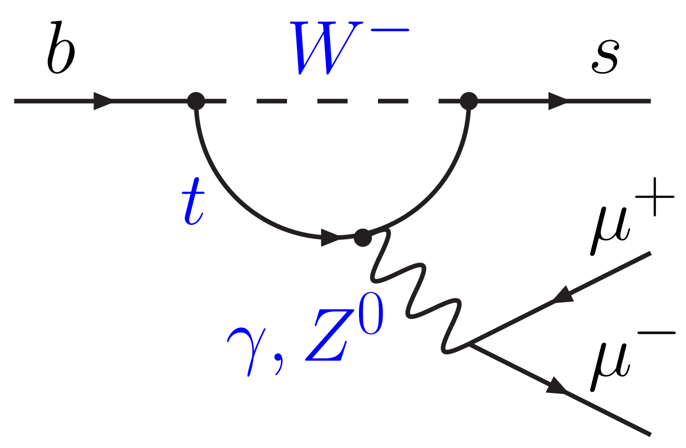
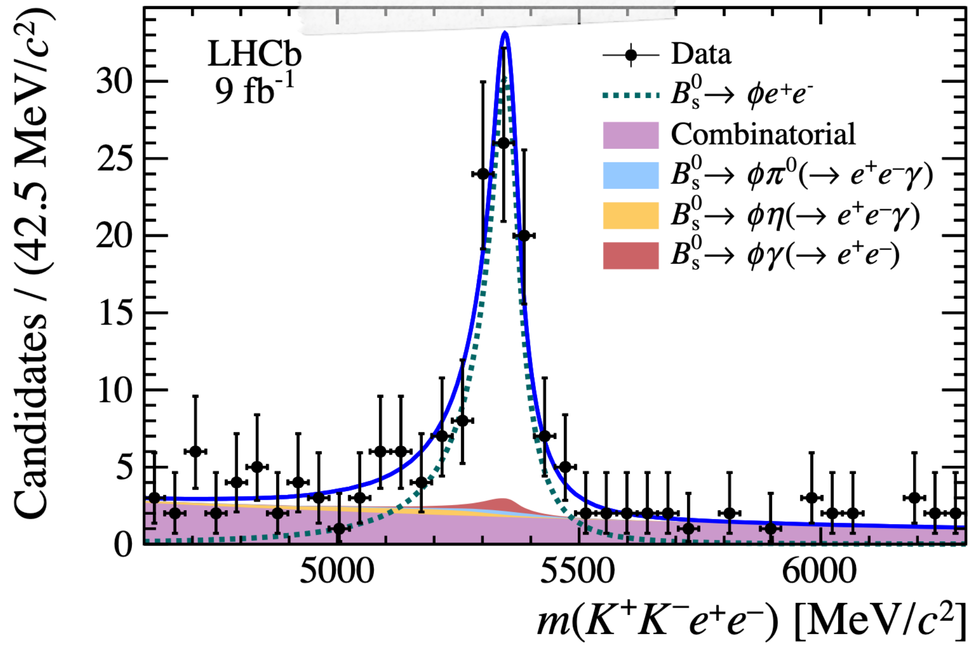
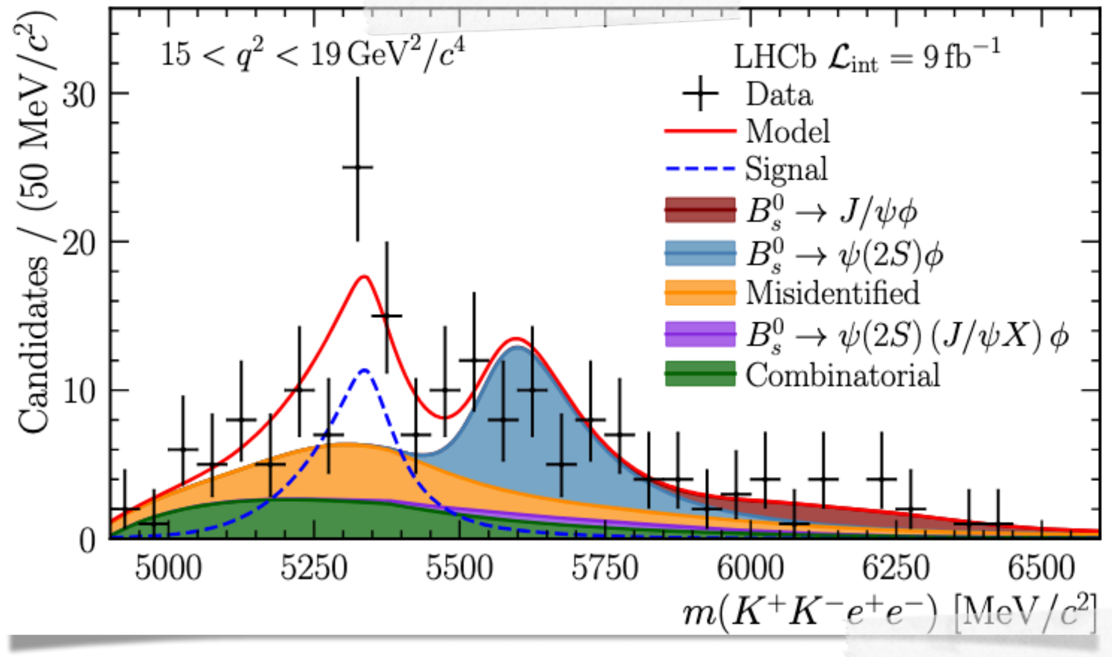
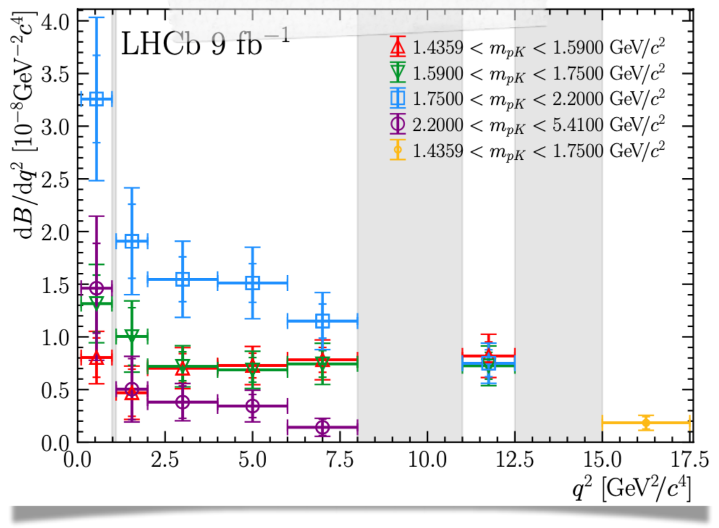
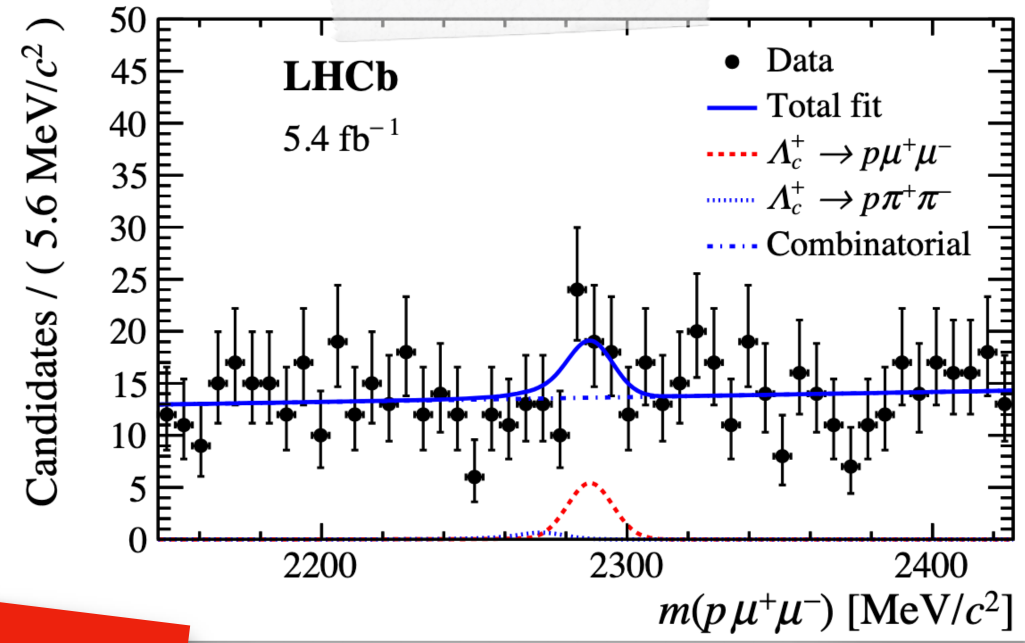
LHCb Upgrades







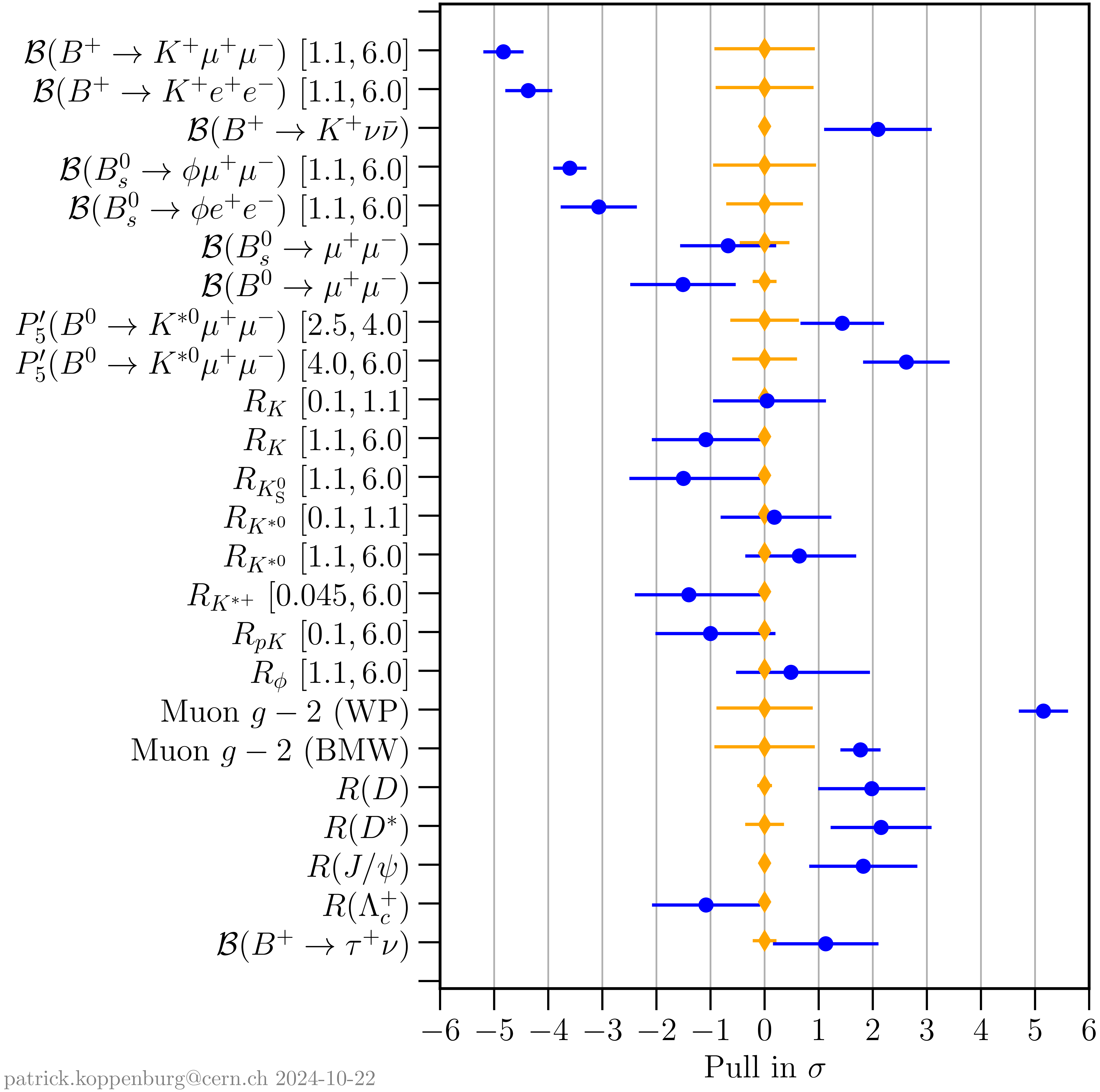




More data more good

Flavour anomalies in rare decays

Sometimes maybe a little tension with the SM



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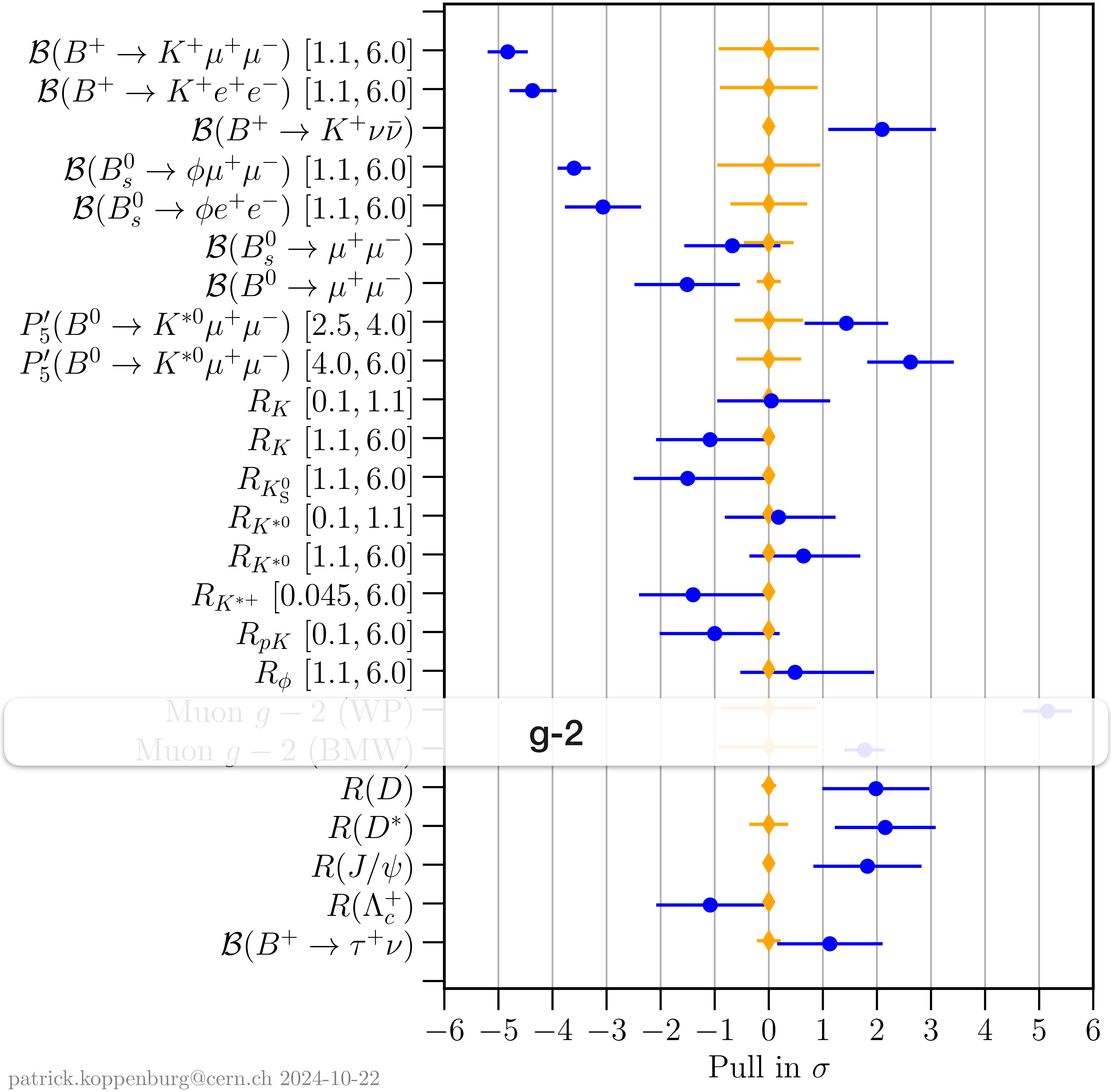

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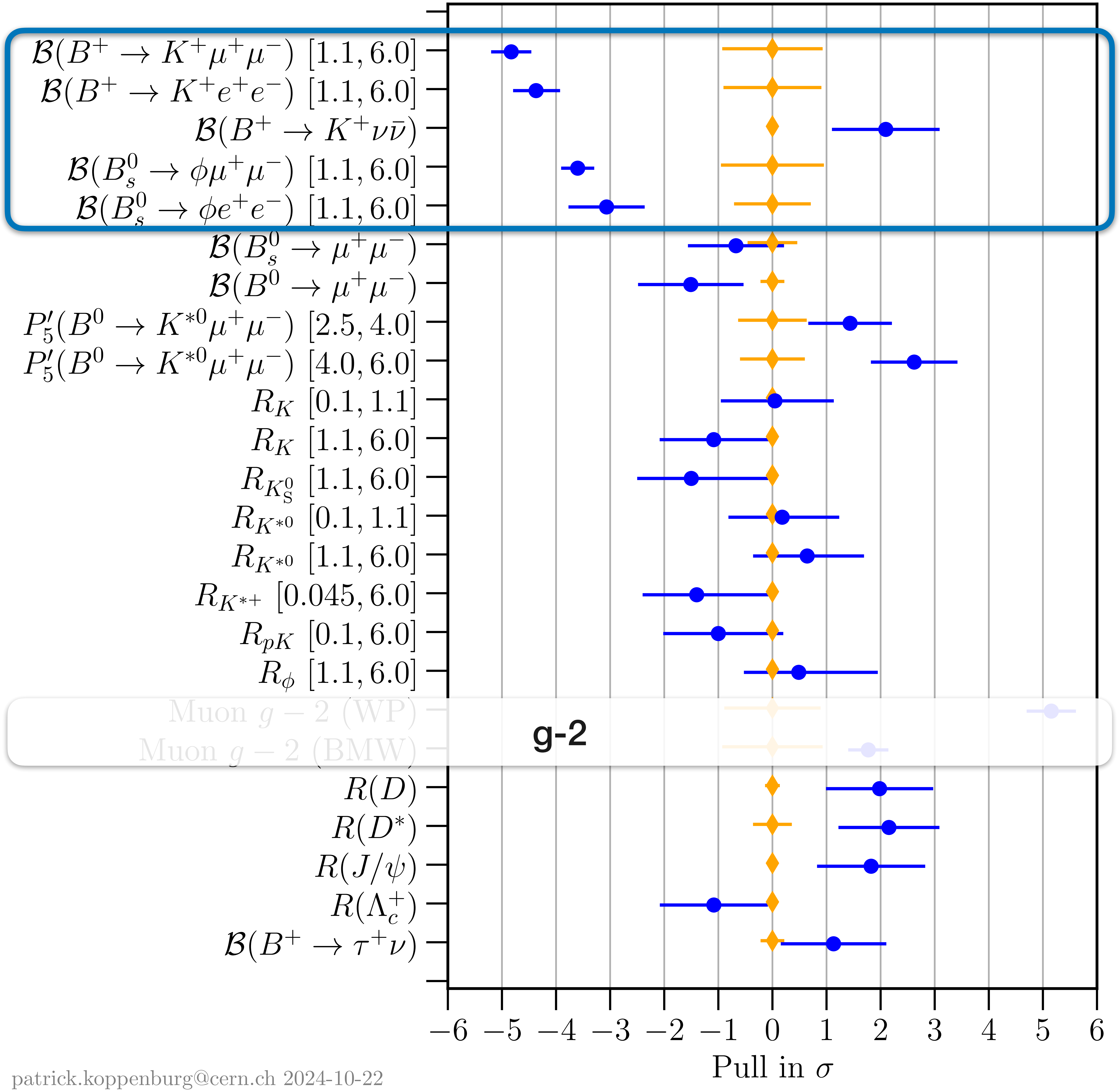

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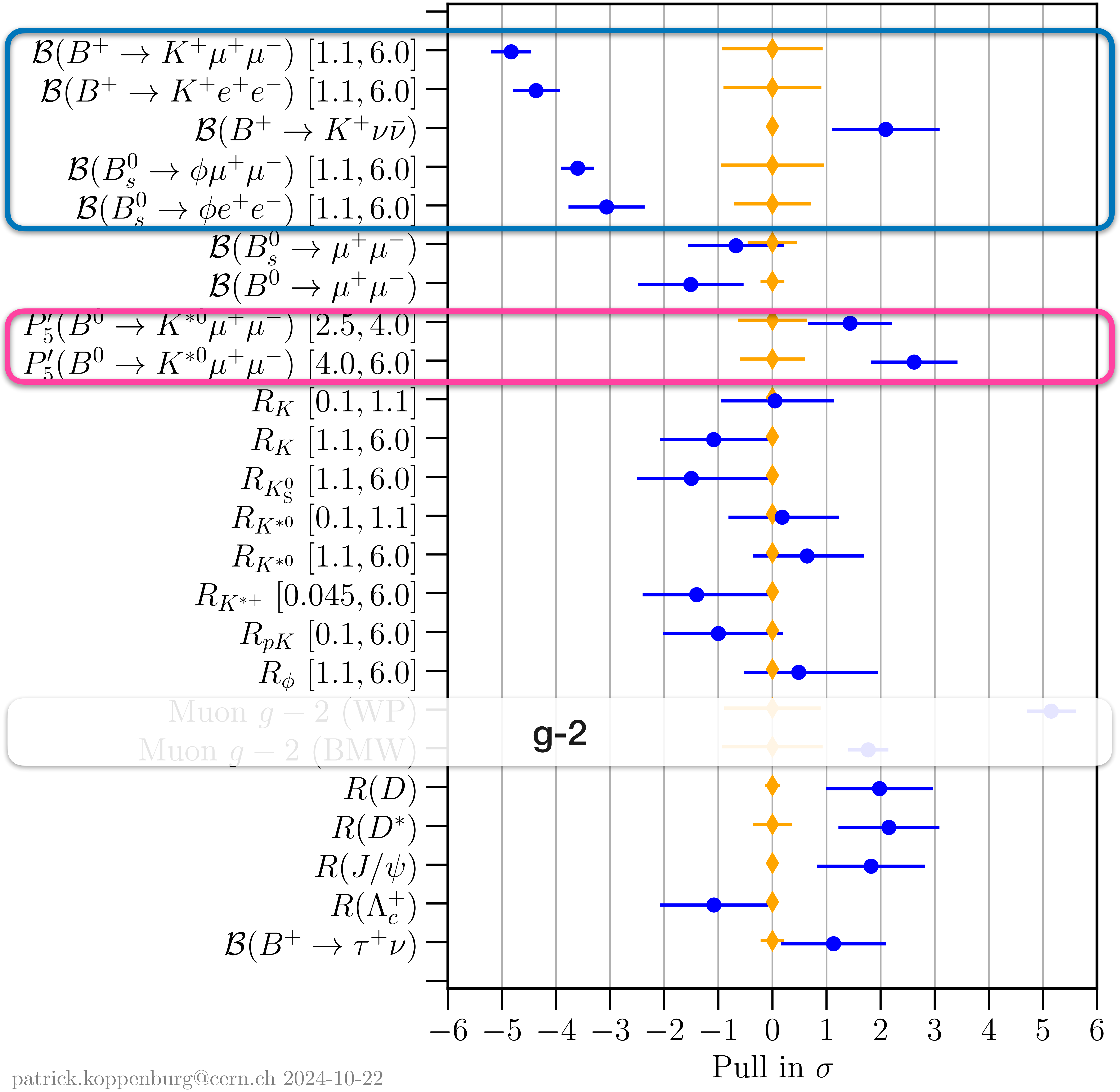

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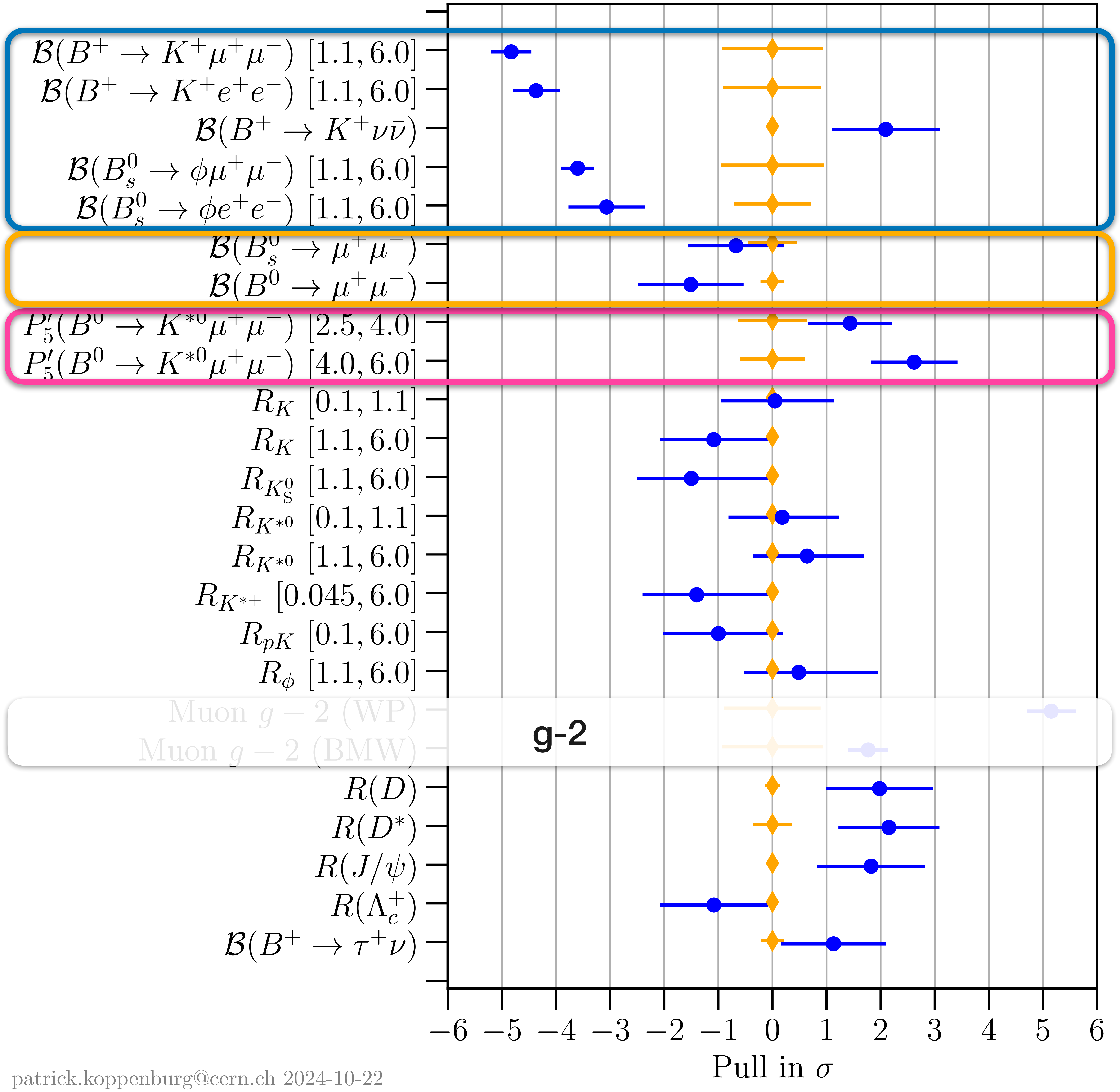
Branching fractions

Angular observables

$\mathcal{B}(B_{s/d} \to \mu^+\mu^-)$



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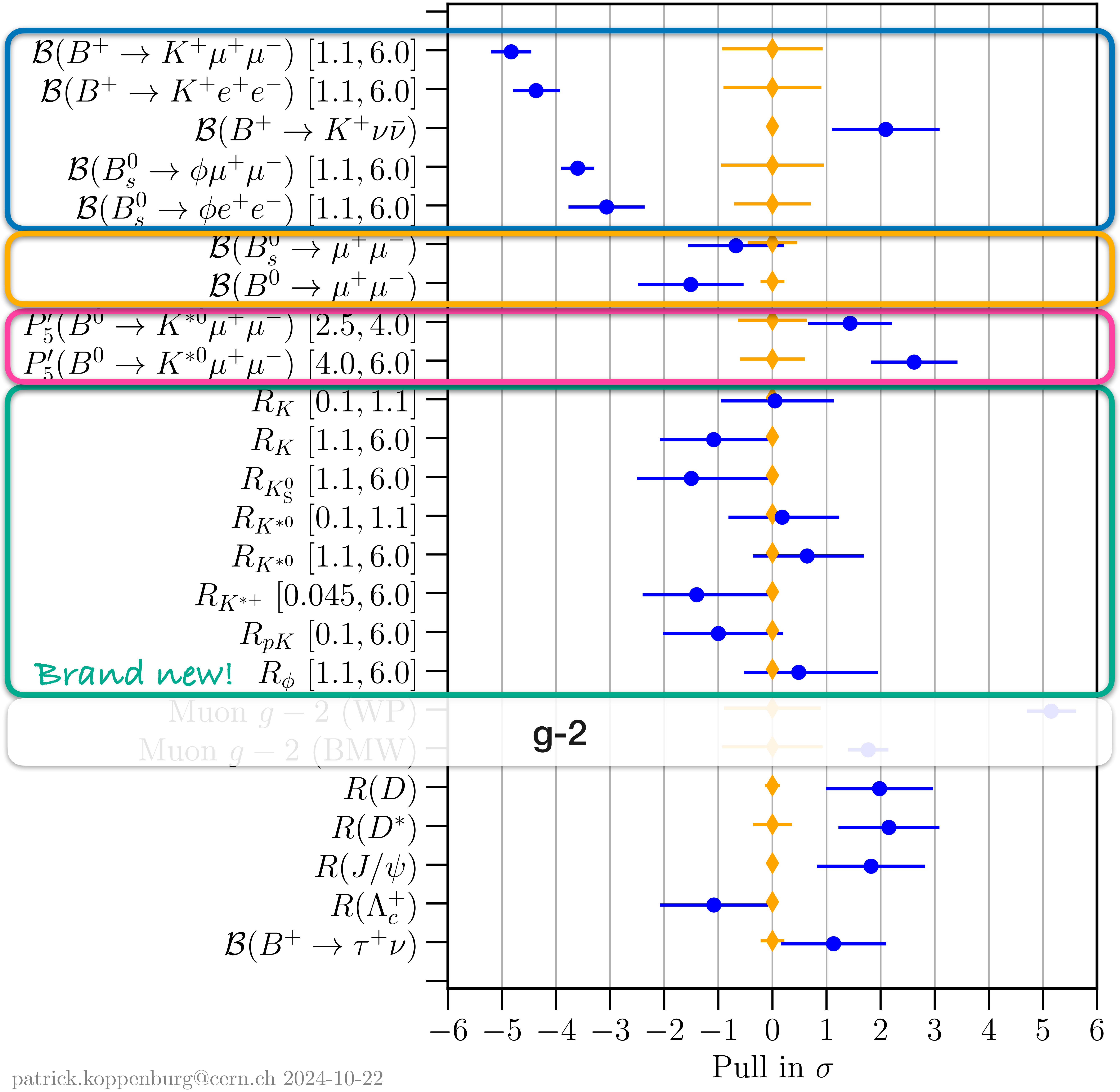
Branching fractions

Angular observables

$\mathcal{B}(B_{s/d} \to \mu^+\mu^-)$

LFU ratios

$$R_X = \frac{\mathcal{B}(H_b \to X_s \mu^+\mu^-)}{\mathcal{B}(H_b \to X_s e^+e^-)}$$



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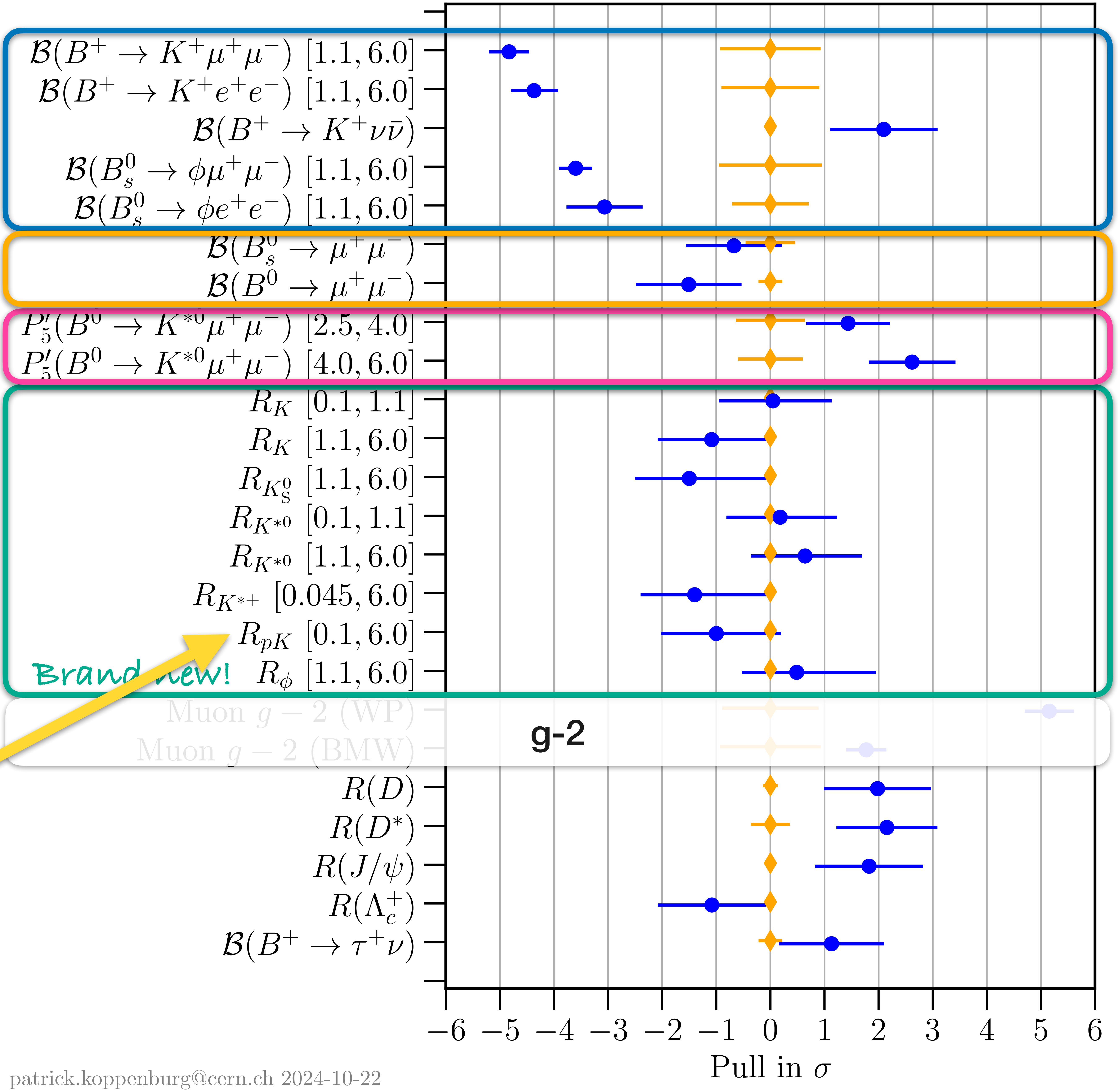
One baryon measurement with reliable prediction!

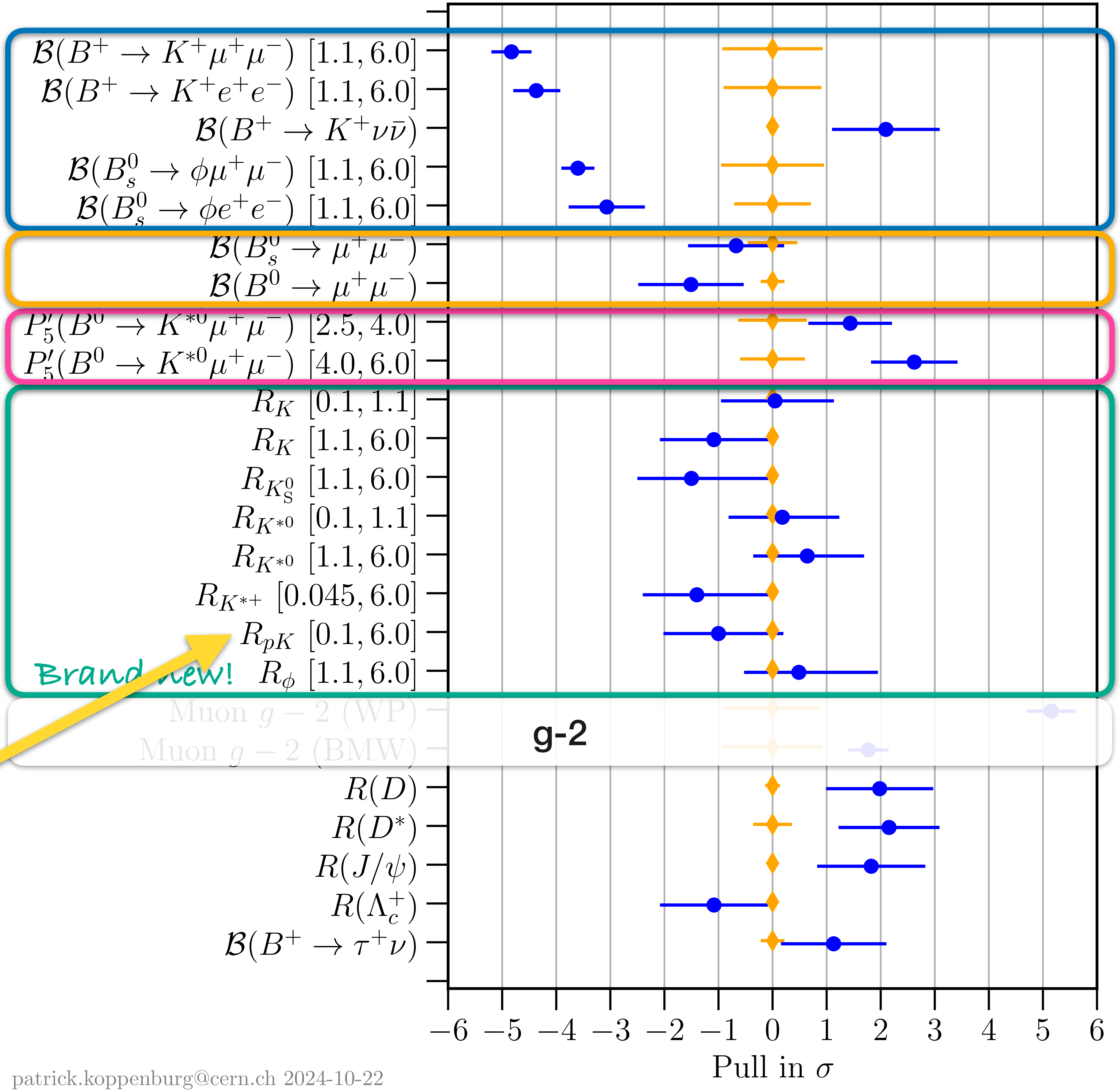


Flavour anomalies in rare decays

Sometimes maybe a little tension with the SM

Decreasing "pollution" from QCD

- Branching fractions
- Angular observables
- $\mathcal{B}(B_{s/d} \to \mu^+\mu^-)$
- LFU ratios
  $$R_X = \frac{\mathcal{B}(H_b \to X_s \mu^+\mu^-)}{\mathcal{B}(H_b \to X_s e^+e^-)}$$



One baryon measurement with reliable prediction!