Experimental overview on B anomalies

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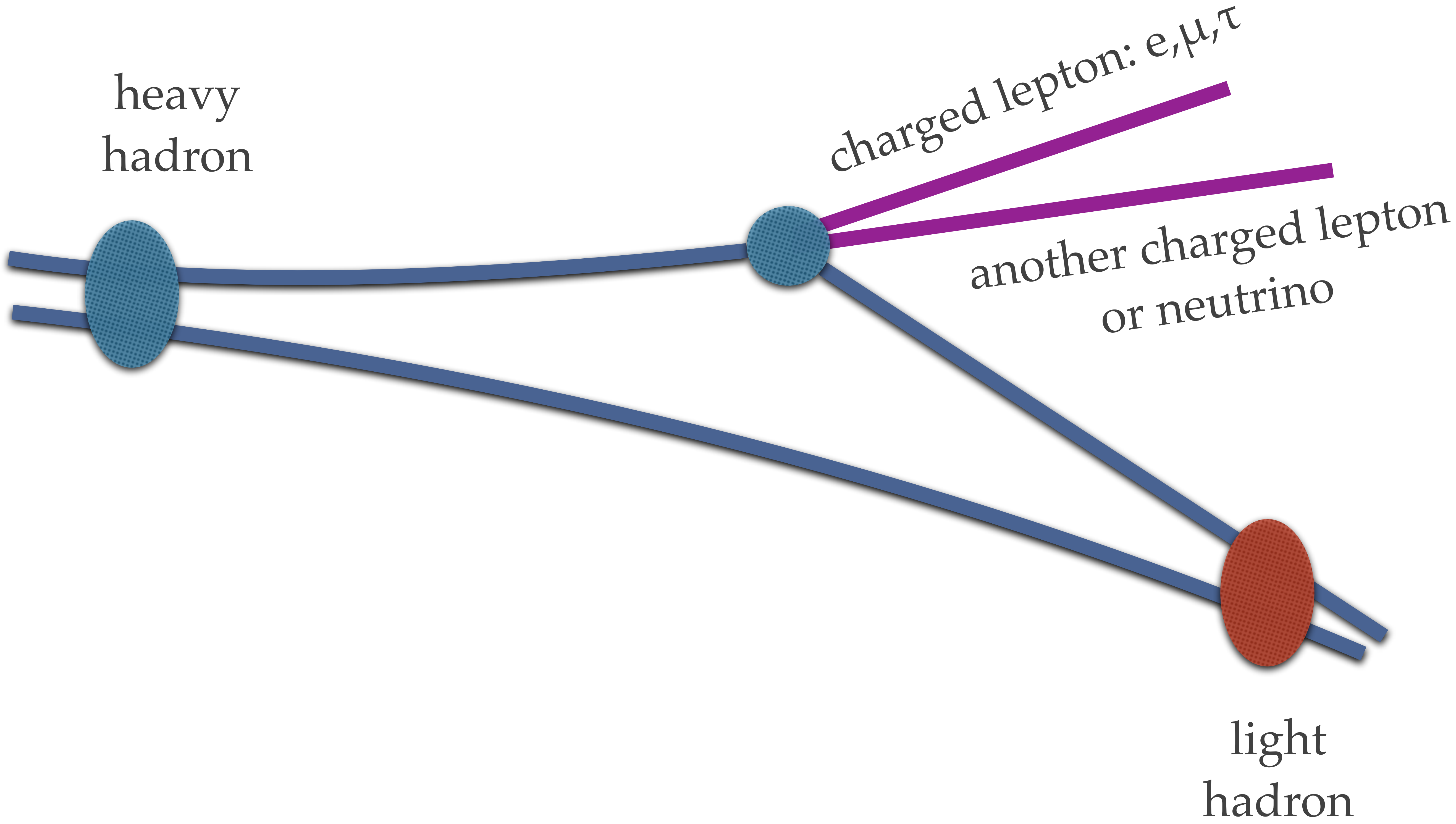
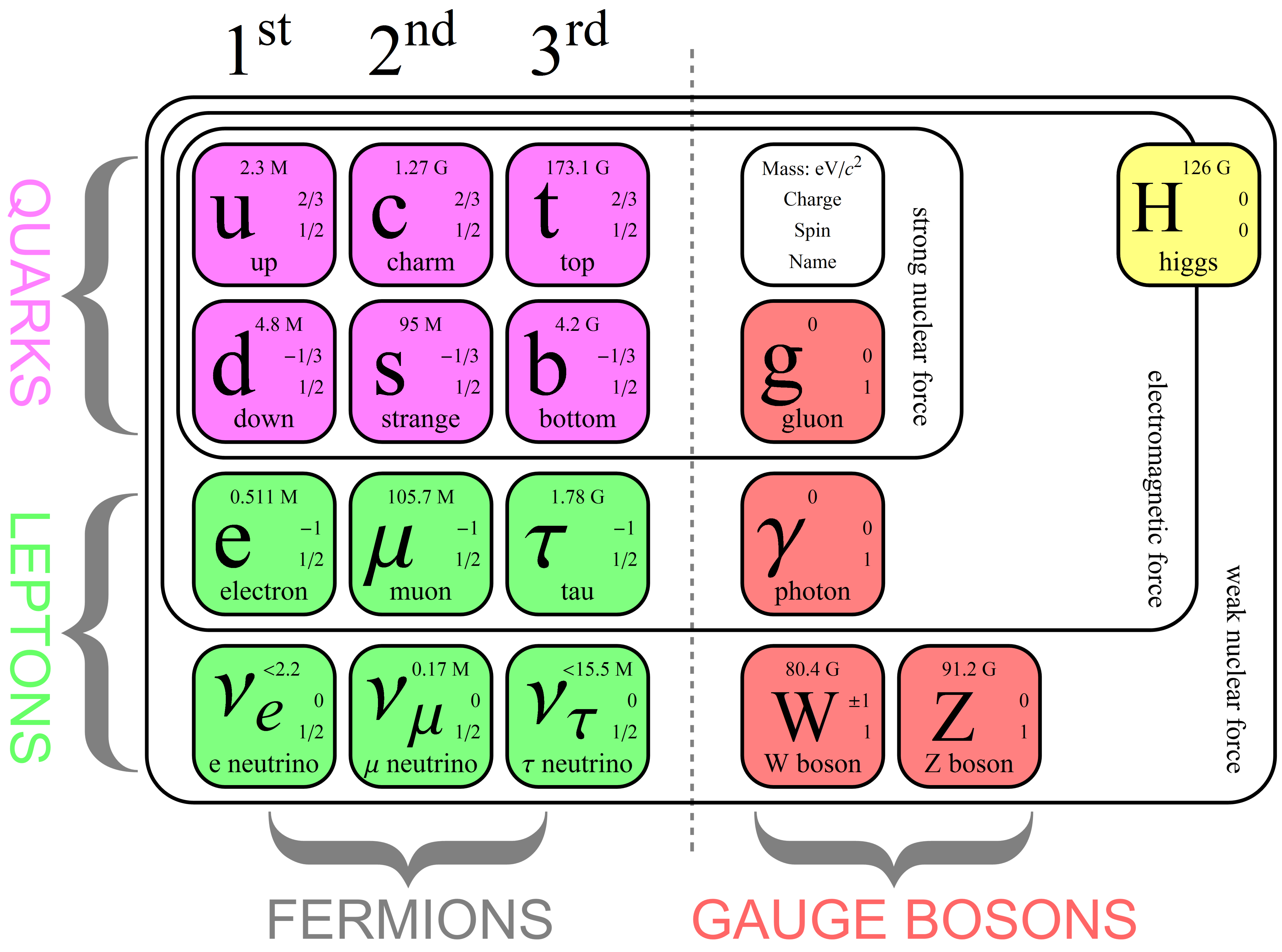
ICCUB Winter Meeting, 7-8/02/22

In this talk

- Give a broad overview of the status of the art on B-anomalies.
- Not only LHCb results.
- Special focus on Lepton Flavour Universality tests.
- Try not to give hundreds of experimental details.



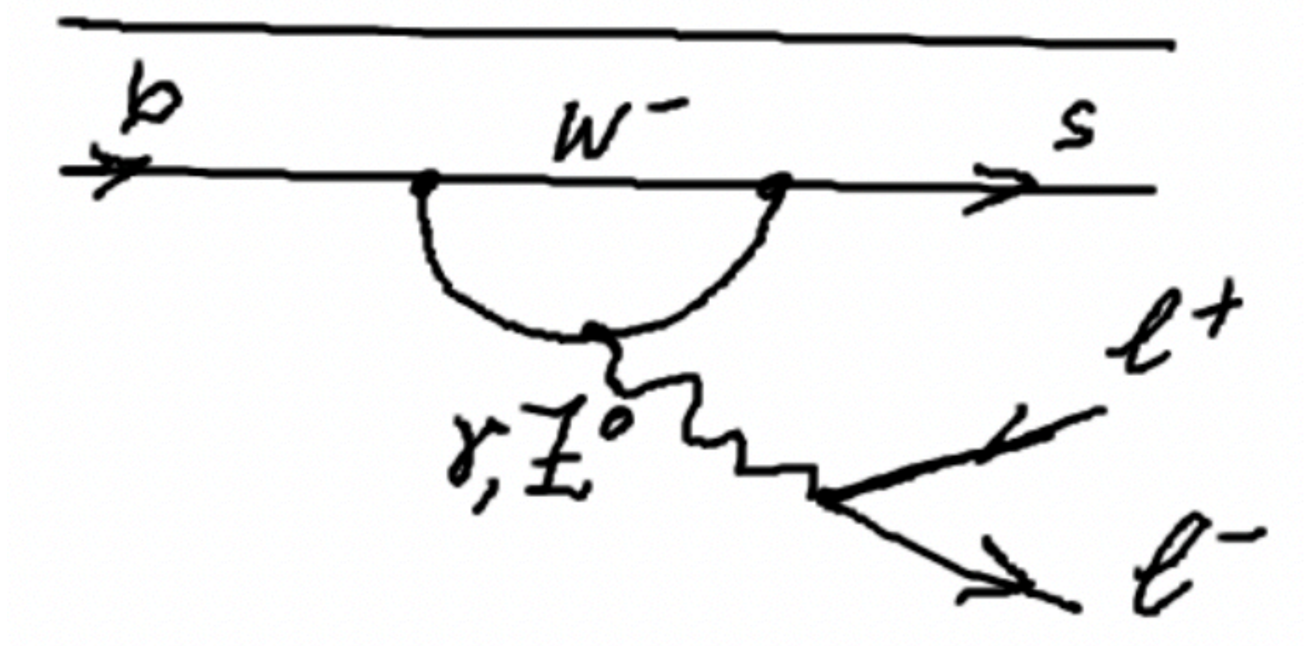
Lepton Flavour Universality in the SM



- The three families of leptons are identical with the exception of their masses (couplings with the Higgs boson).
- For the other interactions, they interact equally => **lepton flavour universality.**
- Families can be mixed through the decay of quarks and neutrinos (flavour changing currents).

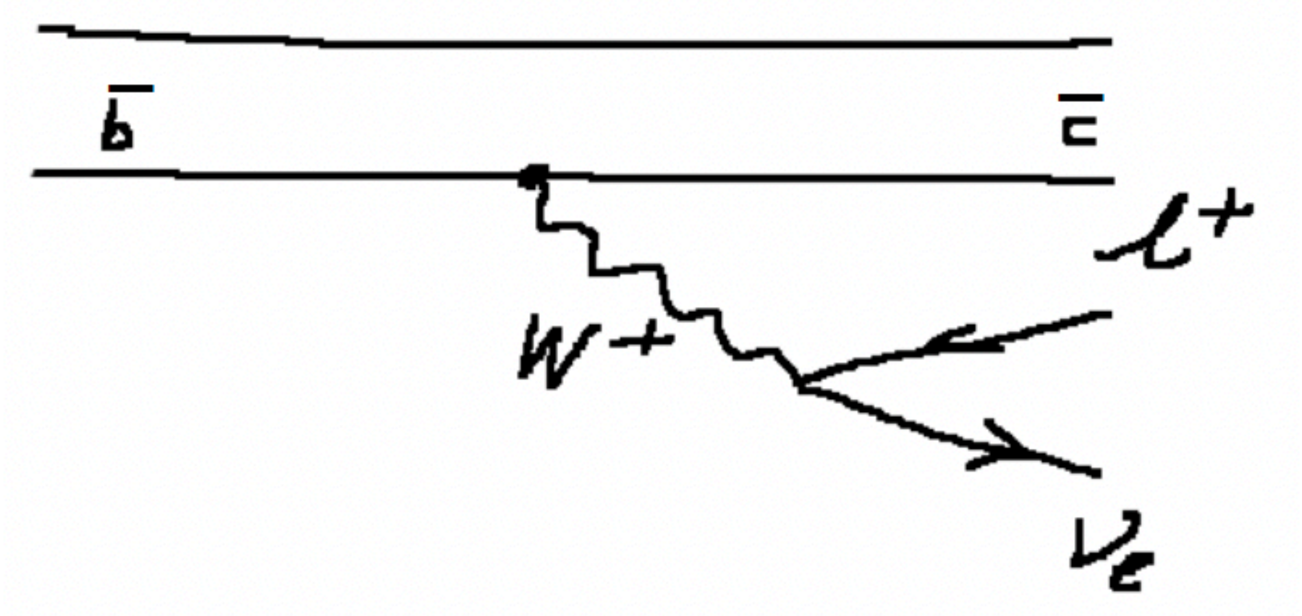
Places to look for anomalies

Flavour Changing **Neutral** Currents
$(b \to s l^+ l^-)$



- Rare decays. Loop transitions.
  - NP can be of the same size as SM contribution.
- Experimentally convenient.
- Theoretically clean.

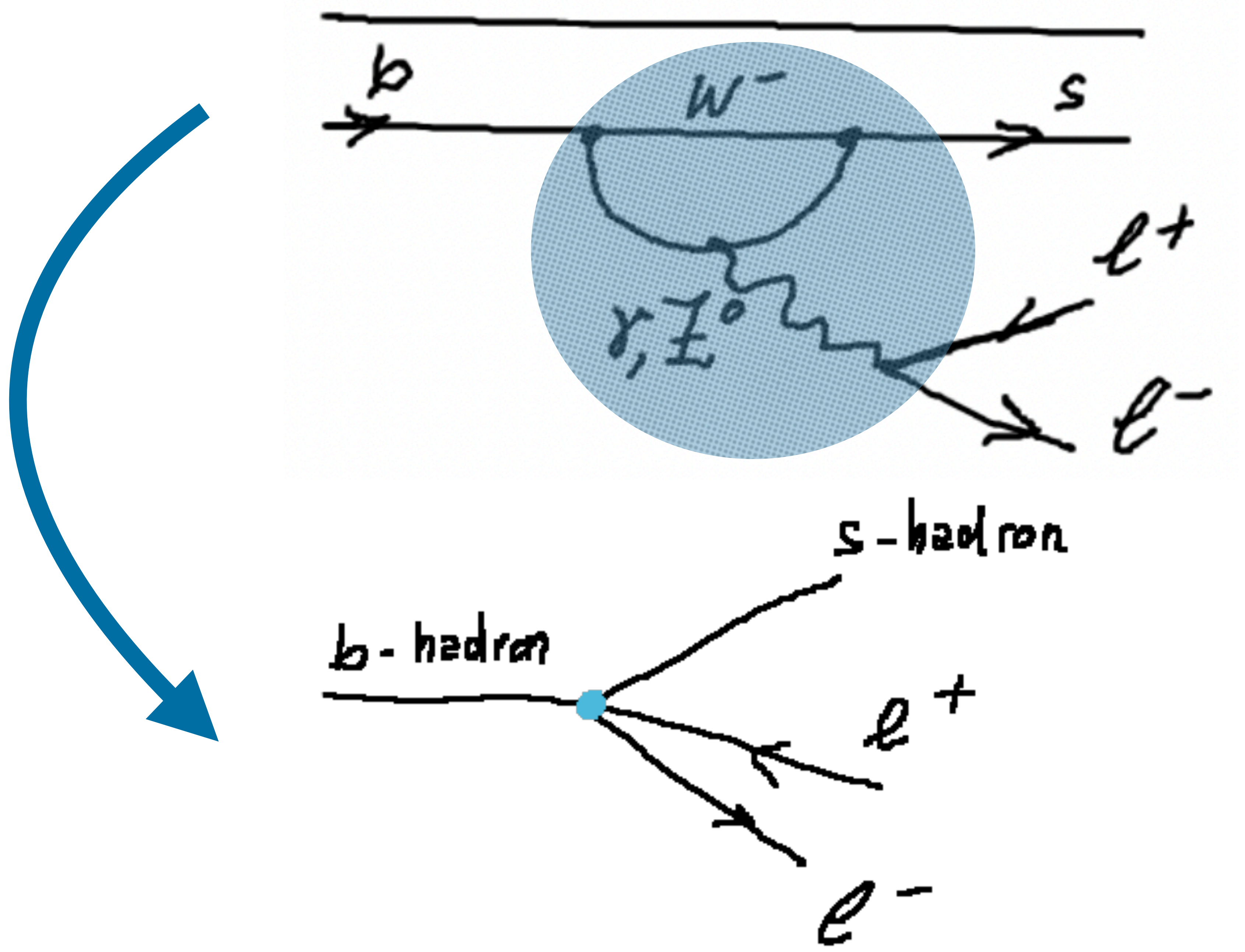
Flavour Changing **Charged** Currents
$\bar{b} \to \bar{c} l^+ \nu_l$



- Semileptonic decays. Very abundant.
- Experimentally challenging.
- Theory uncertainties are controllable.
  - Need Lattice QCD to reduce uncertainties in calculations.

How to do calculations

Flavour Changing **Neutral** Currents
$(b \to s l^+ l^-)$



Flavour Changing **Charged** Currents
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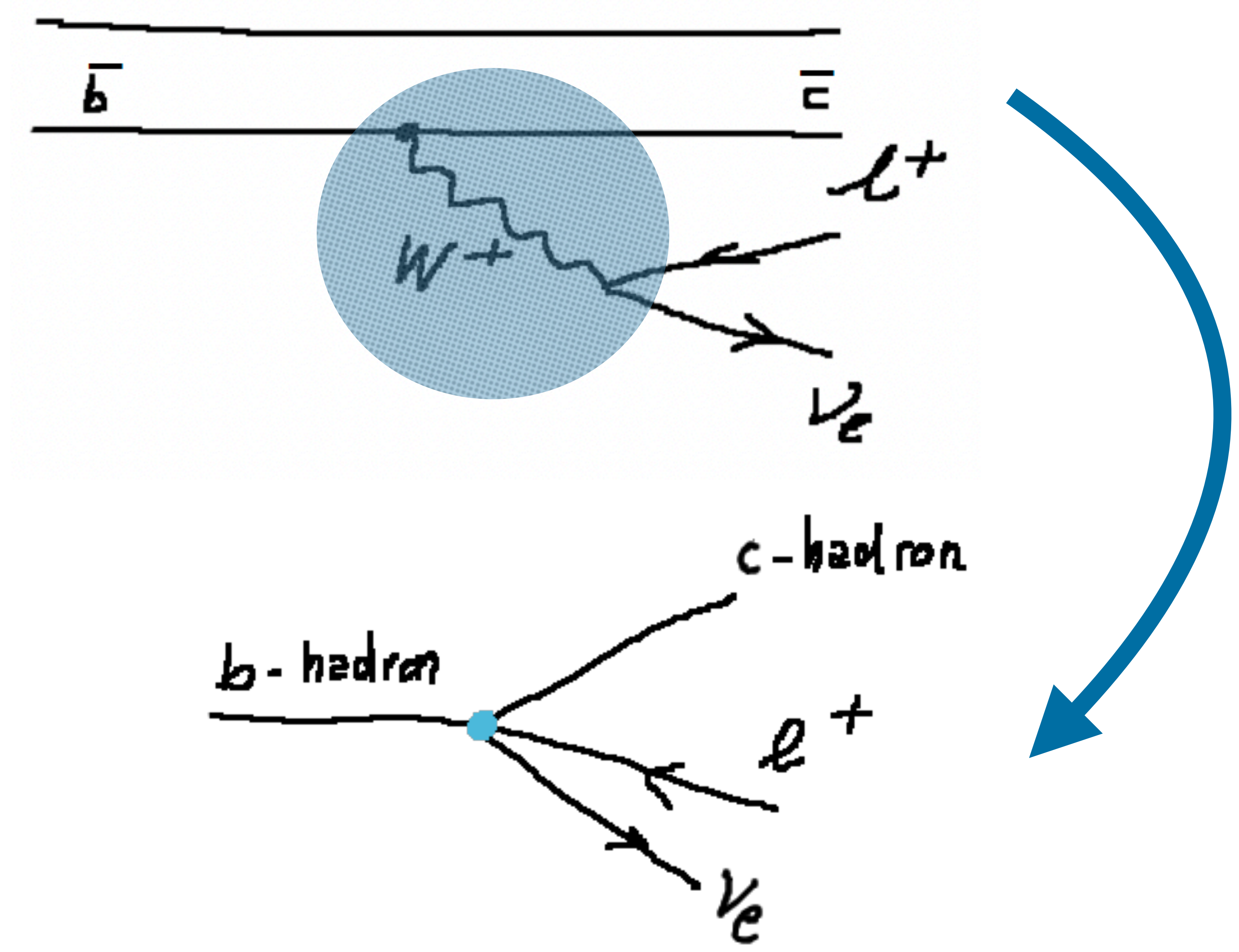


$$H_{eff} = \frac{G_F}{\sqrt{2}} V_{tb} V_{tq}^* \sum_i C_i O_i$$

$C_i = C_i^{SM} + C_i^{NP}$ are coefficients that can be modified by NP

O_i are operators that depend on the type of transition (4q, 2q-2l,2q-1γ,…)

Observables to detect New Physics

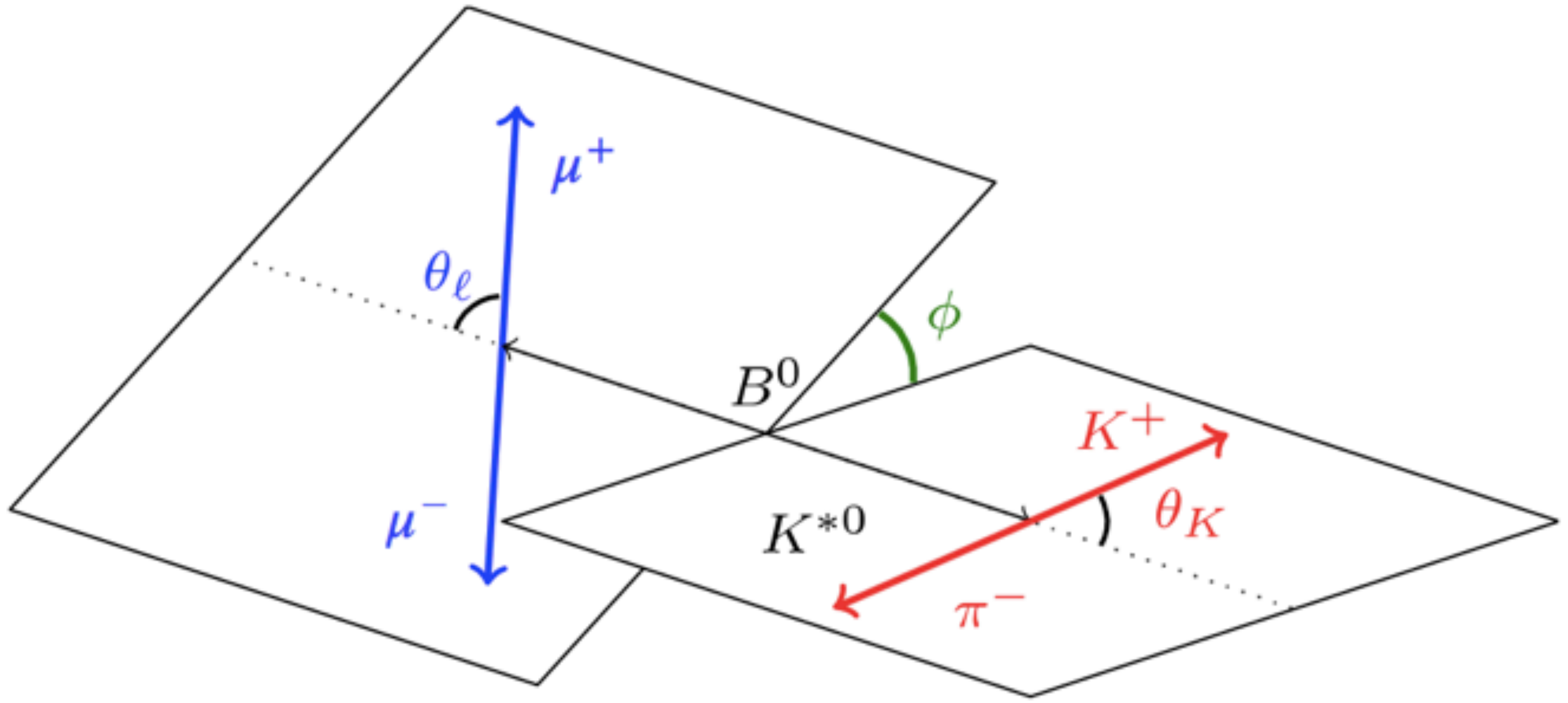
- Integrated and differential branching fractions of $b \to s\mu^+\mu^-$ and $\overline{b} \to \overline{c}\mu^+\nu_\mu$ decays.
- Angular observables.
- Fully leptonic decays (e.g. $BR(B_s \to \mu^+\mu^-)$).
- Lepton Universality Tests.

Increasing precision in the SM predictions

Will focus on Lepton Universality Tests but anomalies are reported everywhere.

Kinematics of the decays

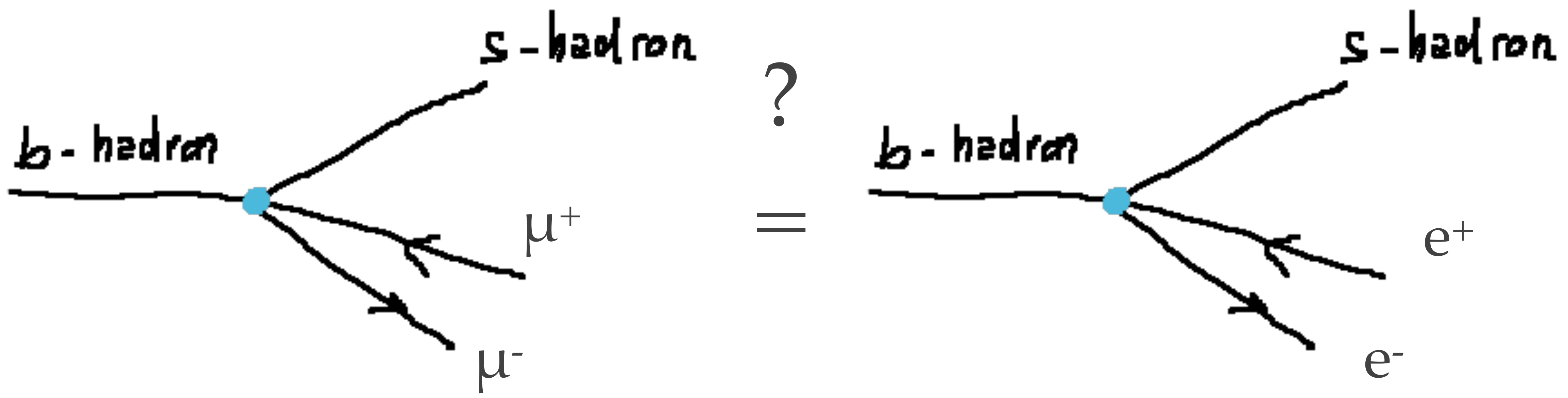
Example of $B^0 \to K^* \mu^+ \mu^-$ decay



- The decay is governed by the angles θ_l, ϕ, θ_K (angular analysis) and the squared momentum transfer to the dilepton system ($q^2 = (p_{B^0} - p_{K^*})^2$).
- At $q^2 = 0$ the two leptons are at rest.
- Usually lower values of q^2 have less uncertainties from the theory => many observables are measured on the low q^2 region.

Lepton Universality in rare decays

- Very precise SM predictions.
- QCD uncertainties cancel up to O(10^{-4}).
- Main experimental differences:
  - **LHCb**: fewer efficiency for electrons than for muons and with worse resolution.
  - **Belle**: similar efficiency and resolution for electrons and muons.

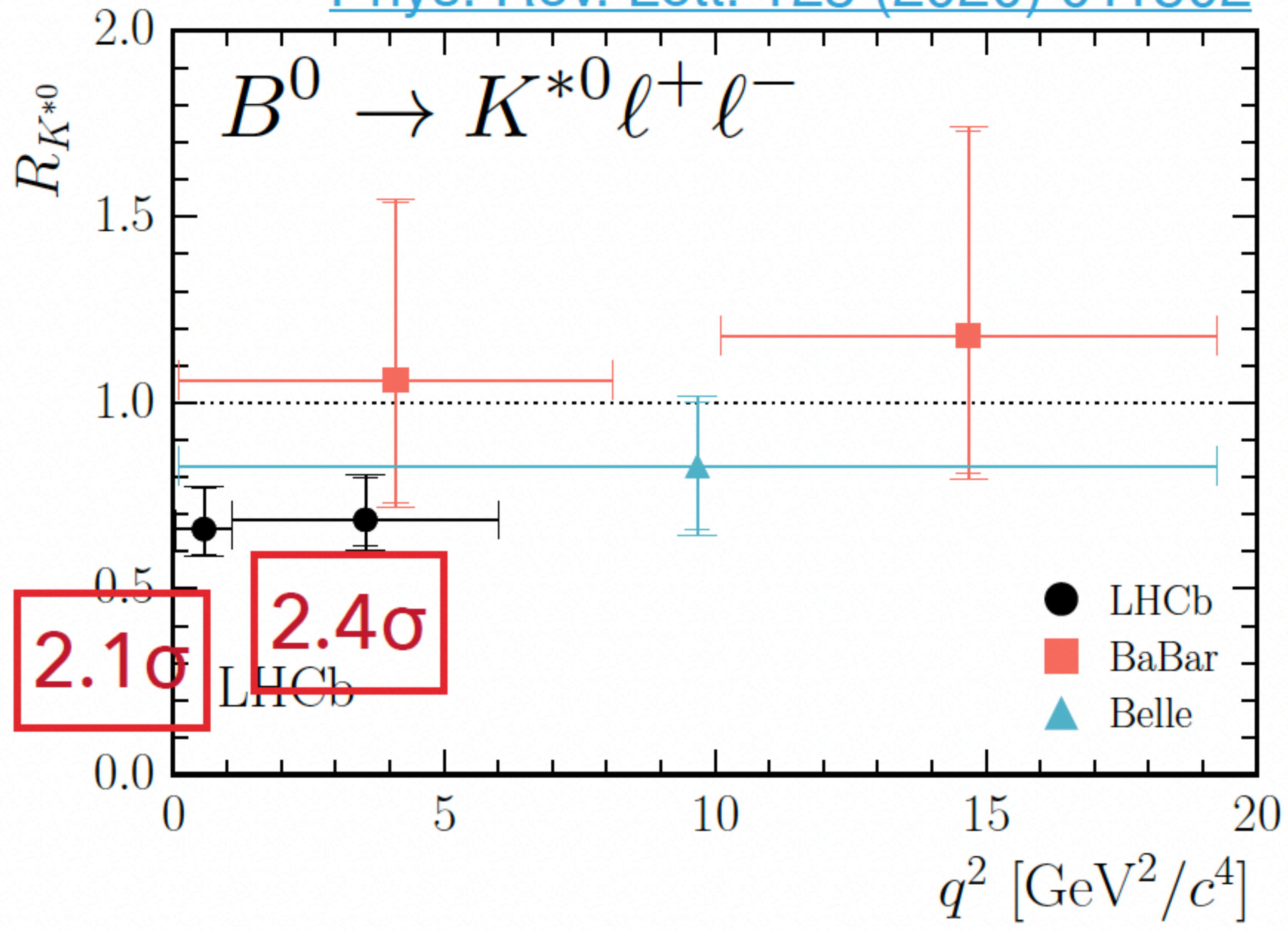


In the SM

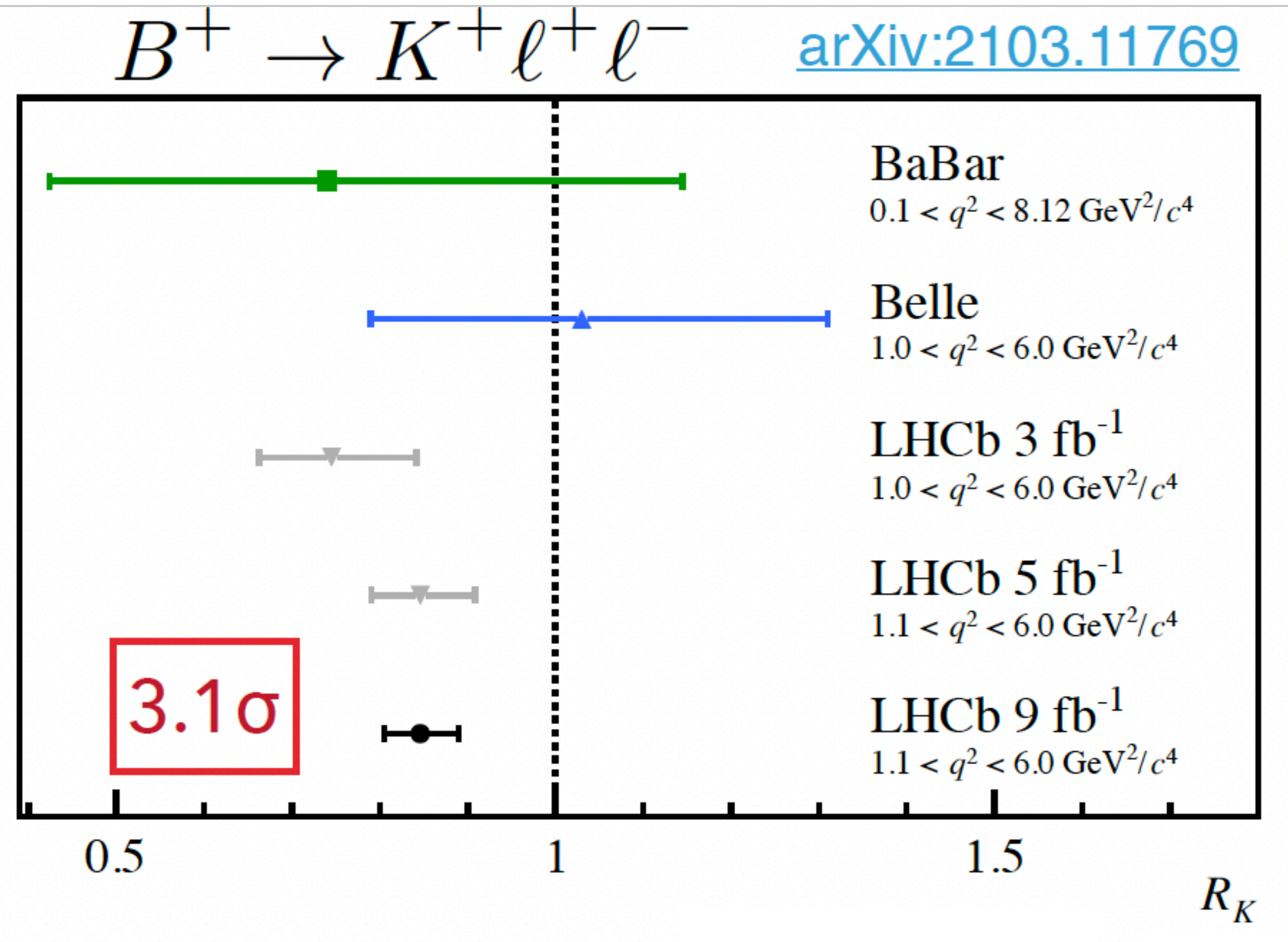
$$R_H = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B \to H\mu^+\mu^-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B \to He^+e^-)}{dq^2} dq^2} \simeq 1$$

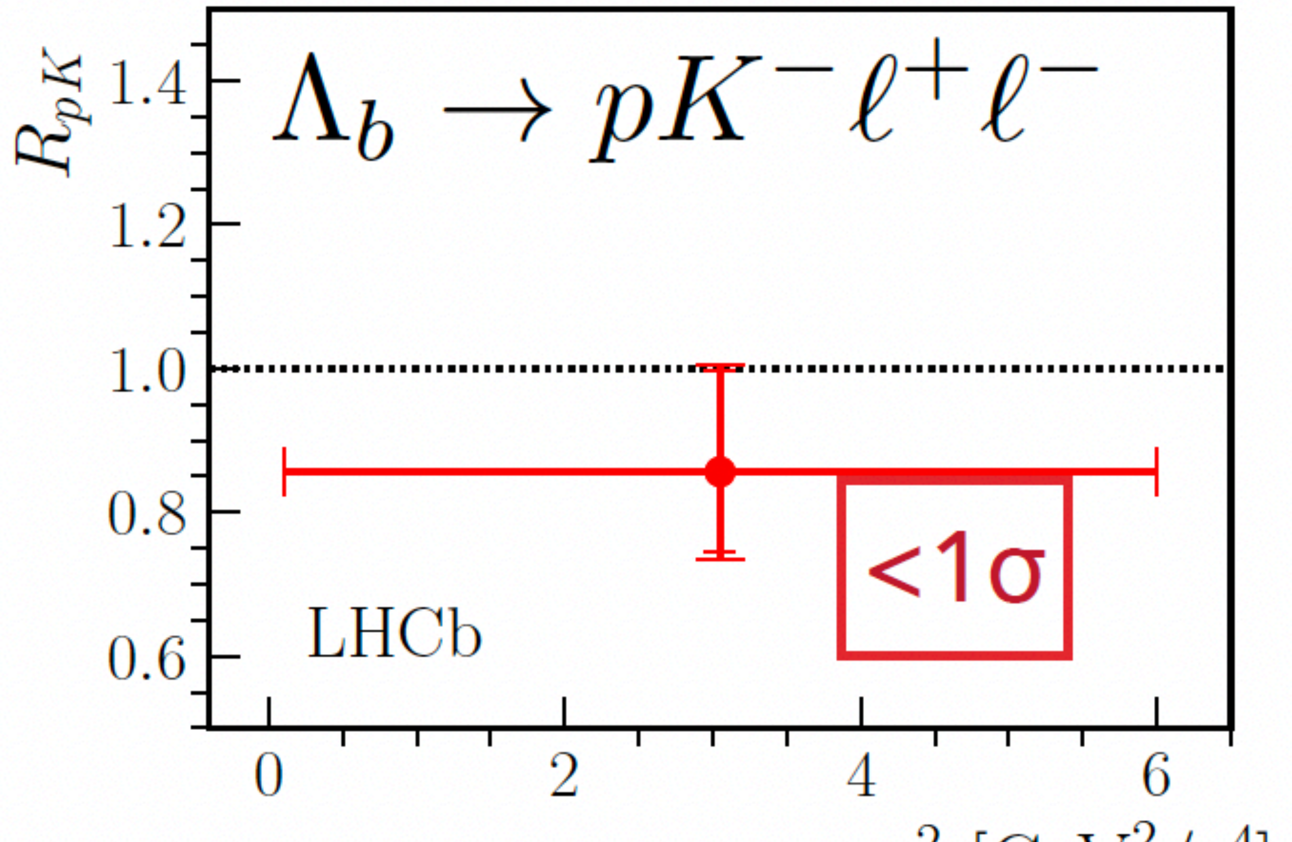
Lepton Universality summary

Phys. Rev. Lett. 125 (2020) 011802

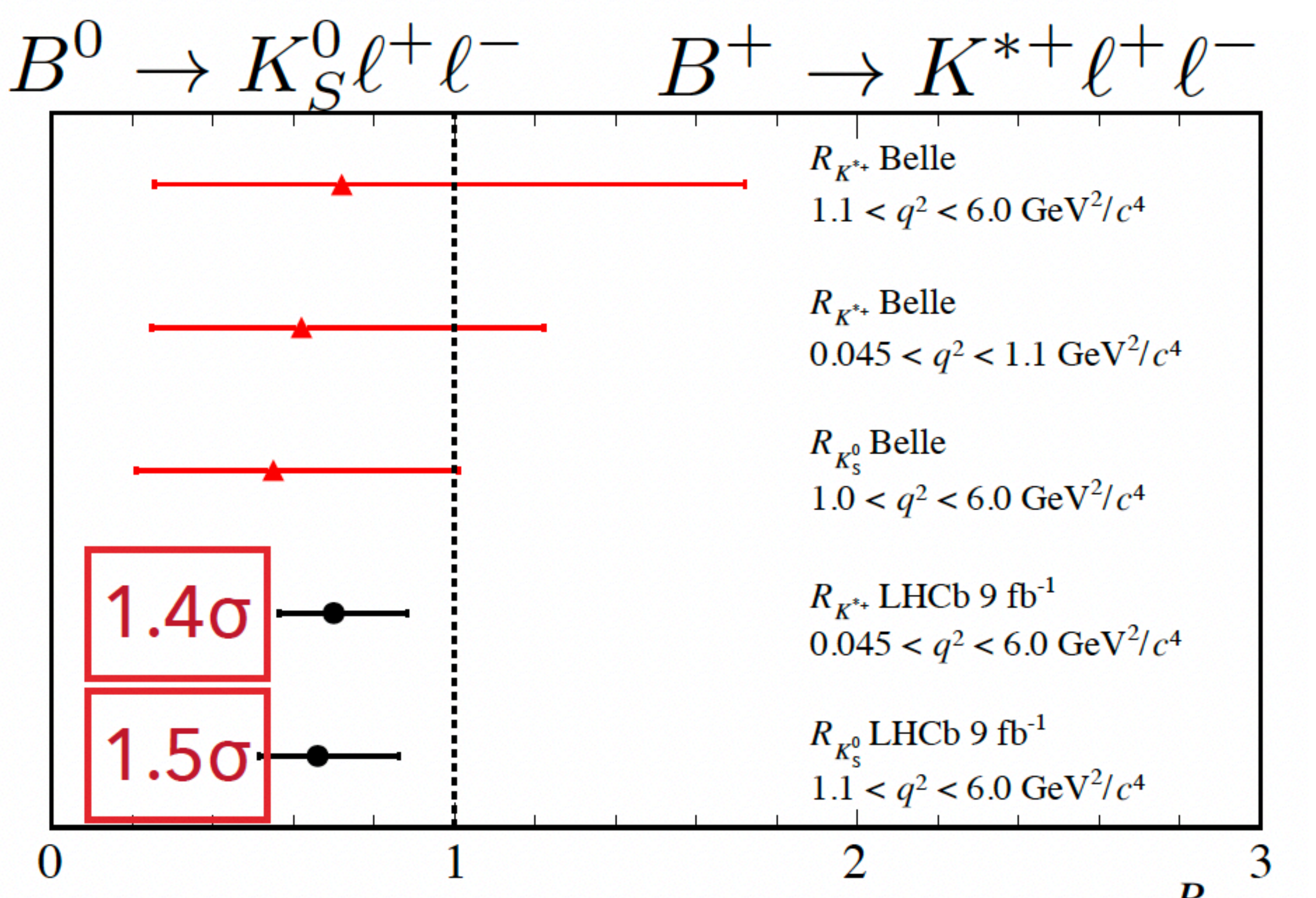


$B^+ \to K^+\ell^+\ell^-$ arXiv:2103.11769





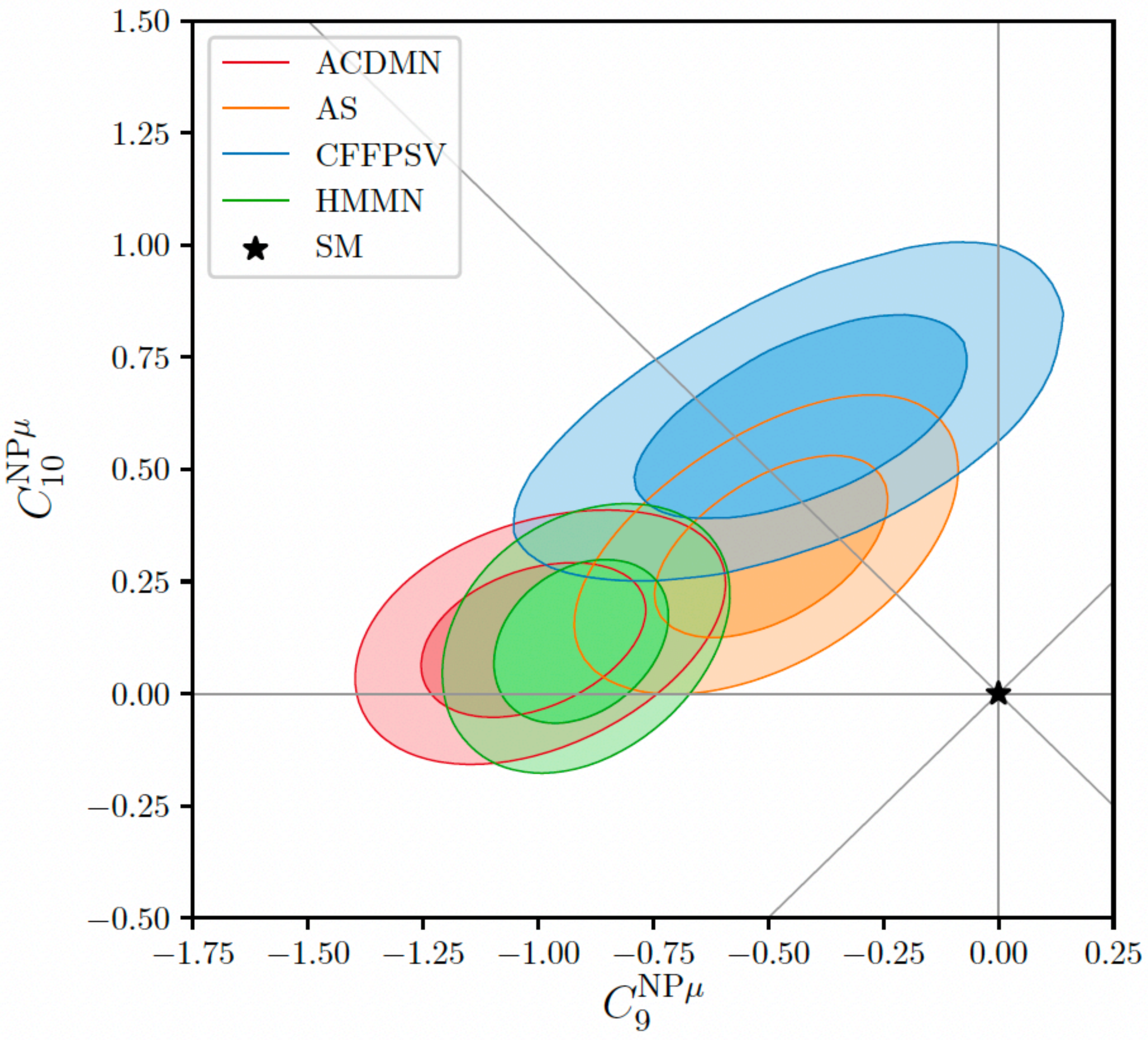
JHEP 05 (2020) 040



arXiv:2110.09501

Lepton Universality interpretation

- Combine the information from different observables (150-250) fitting the EFT coefficients using different fitting techniques, sets of observables and theory assumptions.
- Remarkable agreement between fits from different groups despite different approaches.
- Combined global significance of 4.3σ.
- Discrepancies can be consistently explained by NP.



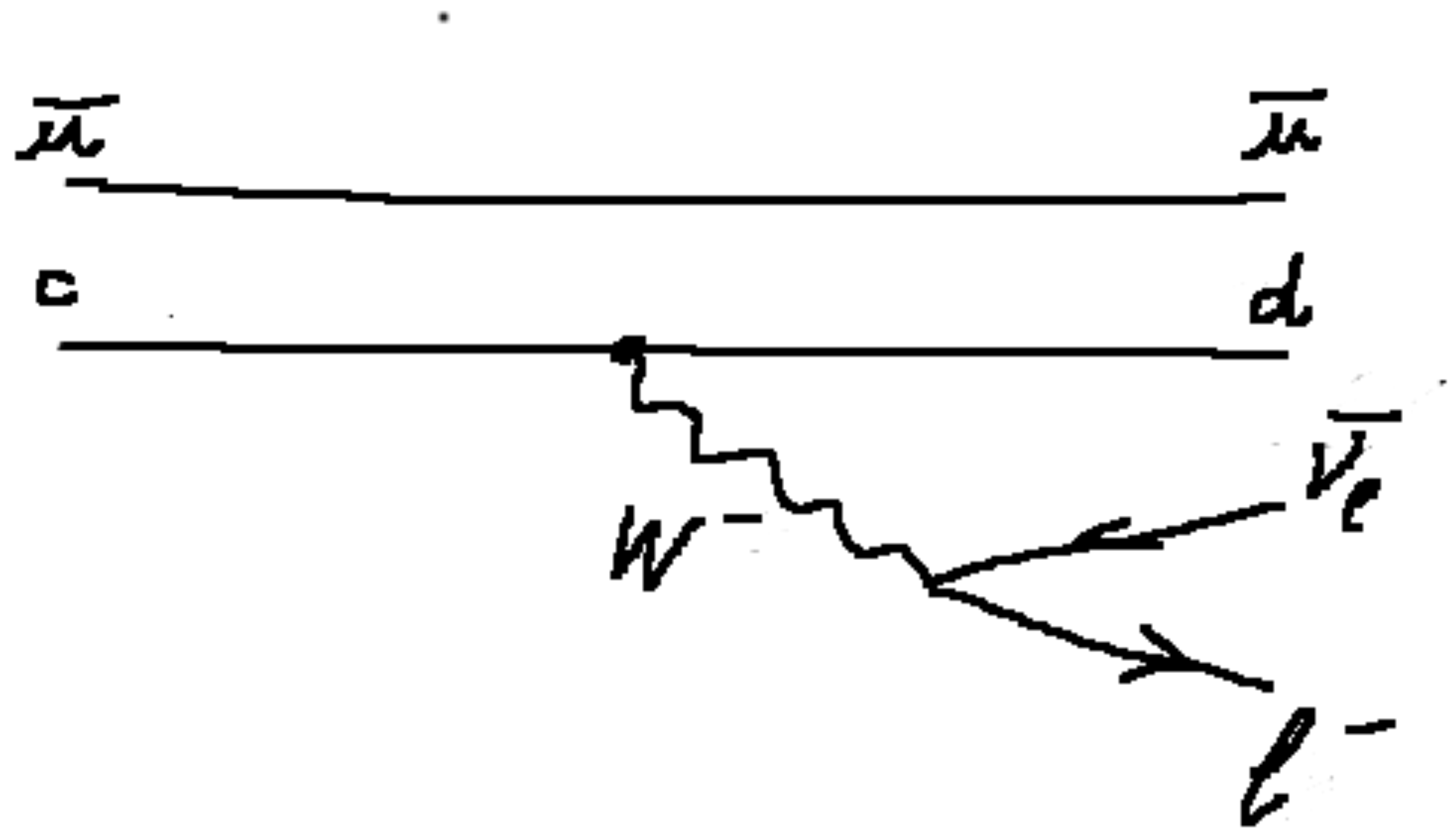
global fit

Lepton Universality in semileptonic decays - BES III

- Measurements from BES-III. e^+e^- collisions at variable center-of-mass energy

$$R(K^-) = \frac{\mathcal{B}(D^0 \to K^-\mu^+\nu_\mu)}{\mathcal{B}(D^0 \to K^-e^+\nu_\mu)} = 0.974 \pm 0.007(\text{stat}) \pm 0.012(\text{syst})$$

$$R(\rho^-) = \frac{\mathcal{B}(D^0 \to \rho^-\mu^+\nu_\mu)}{\mathcal{B}(D^0 \to \rho^-e^+\nu_\mu)} = 0.90 \pm 0.11$$



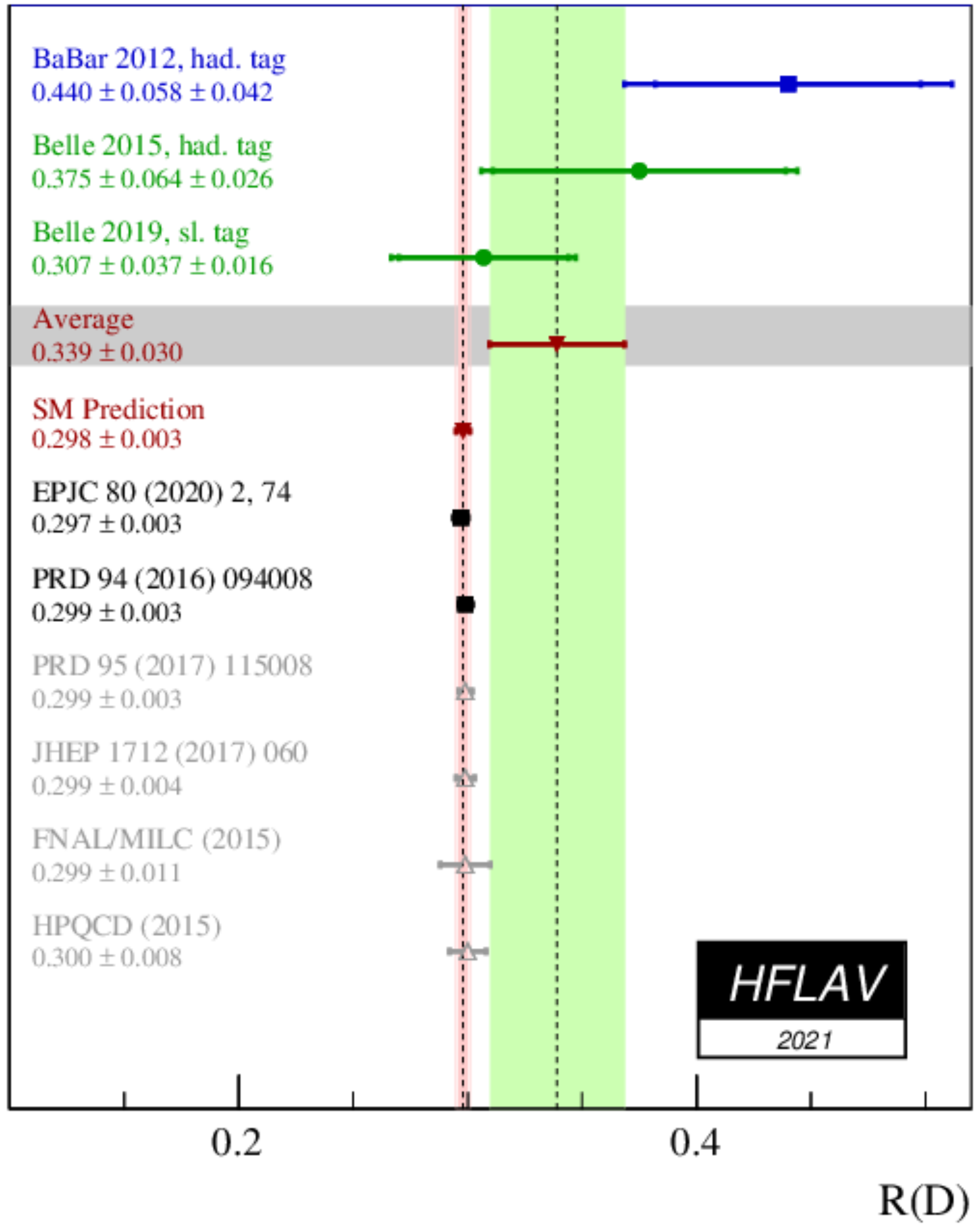
- No LFU violation signs with current sensitivity in charm decays.

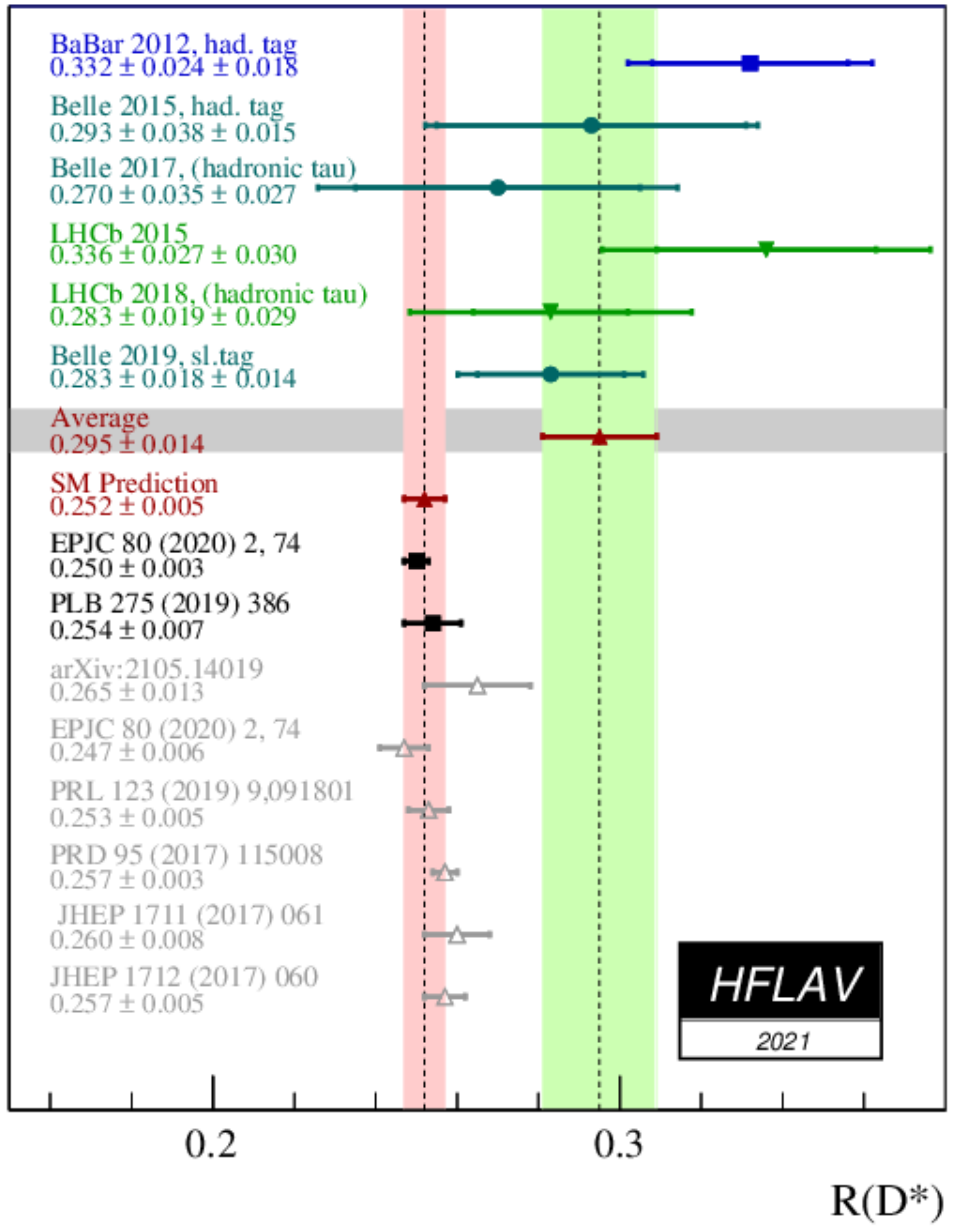
Lepton Universality in semileptonic decays - LHCb/Belle

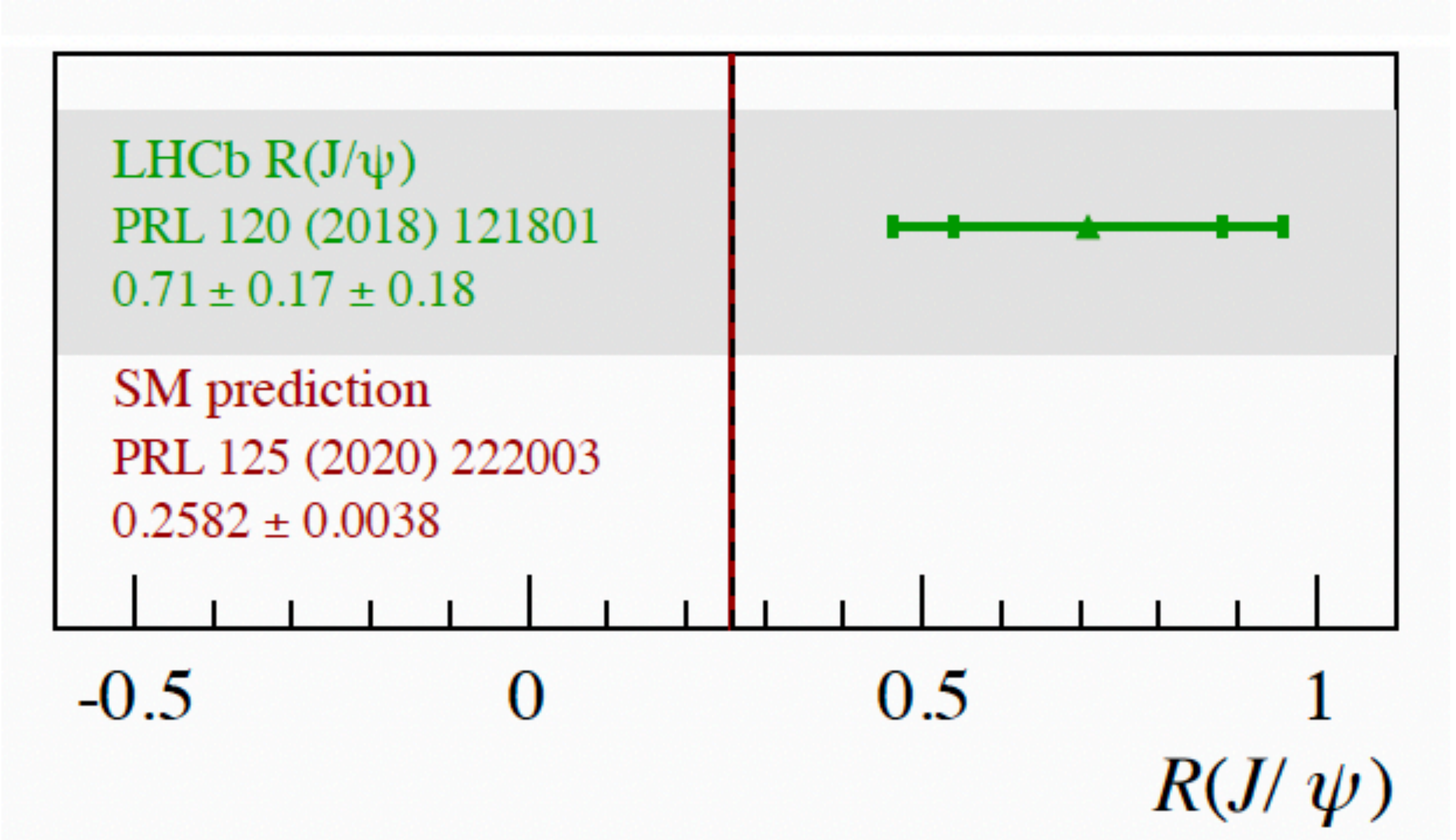
$$R(H_c) = \frac{\mathcal{B}(H_b \to H_c \tau^+ \nu_\tau)}{\mathcal{B}(H_b \to H_c l^+ \nu_l)}$$

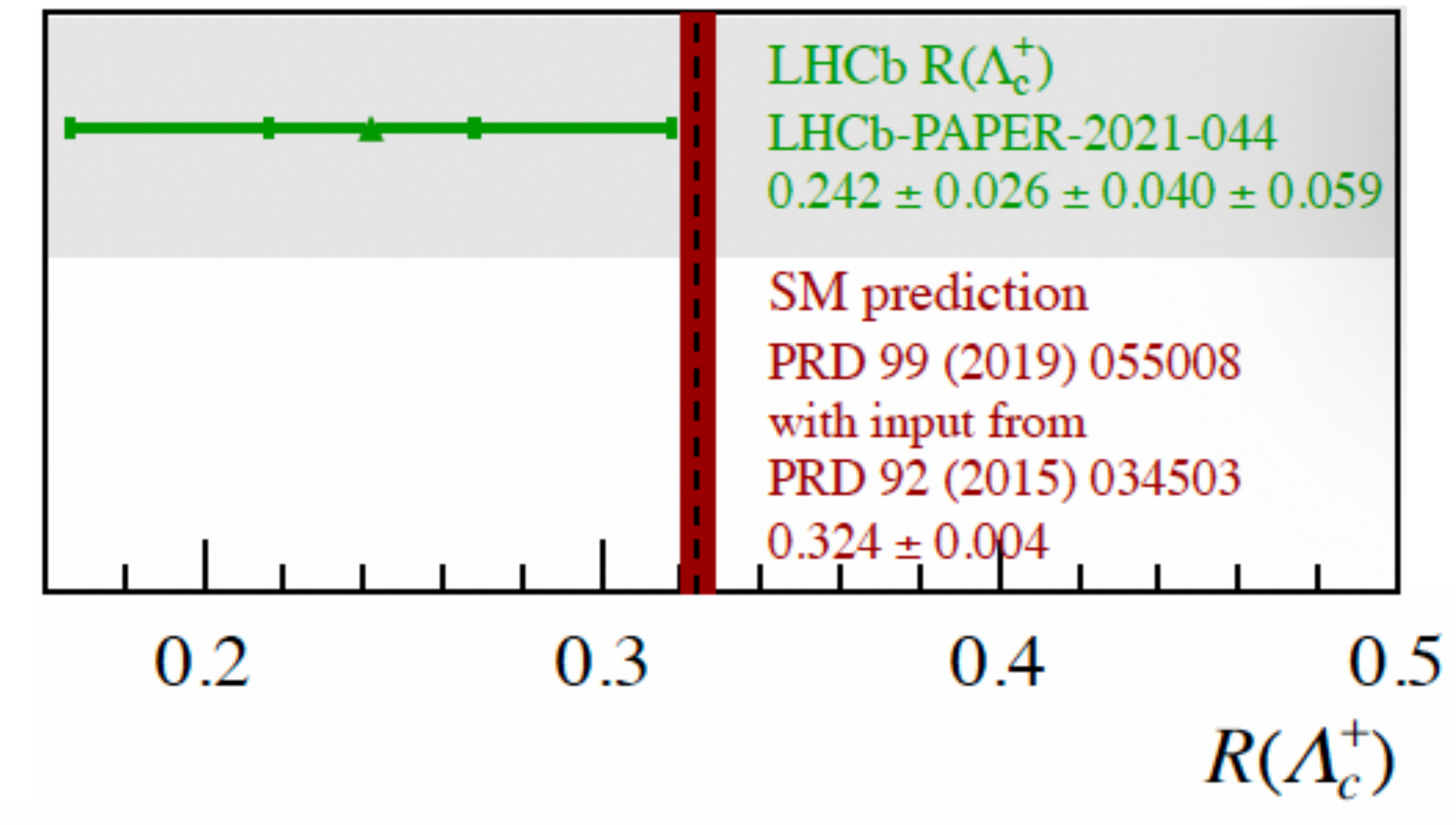
- Belle includes muon and electron in the denominator. LHCb includes only muons in the denominator.
- Two ways of pursuing the measurements:
  - Use muonic decay of tau. Direct extraction of $R(H_c)$. Three missing neutrinos => worse kinematic resolutions.
  - Use hadronic decay of the tau. Need external input to extract $R(H_c)$. Tau vertex gives better constrained kinematics.

Lepton Universality in semileptonic decays - summary

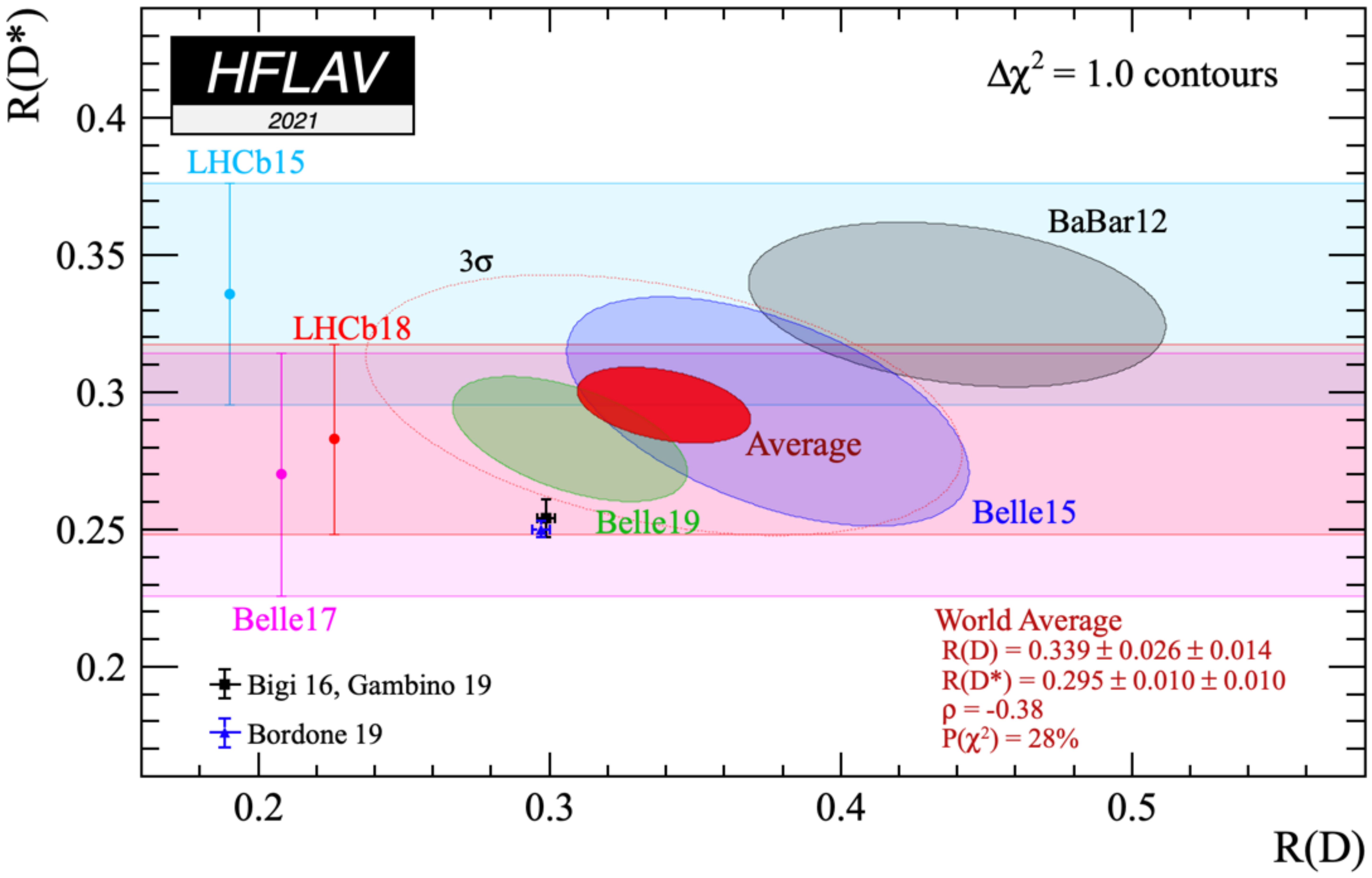








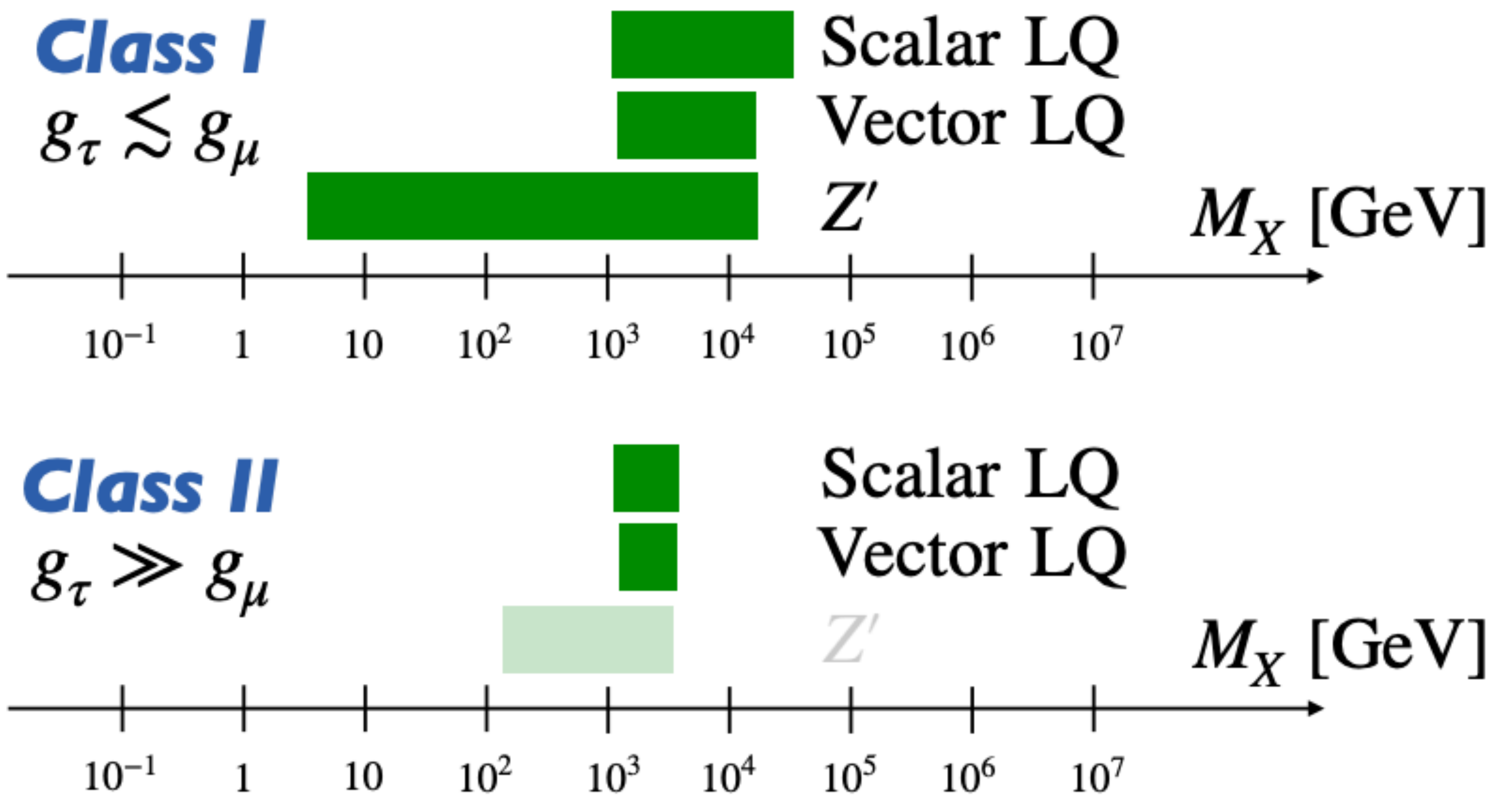
Lepton Universality in semileptonic decays - summary



- Experimental average shows 3.4σ tension with SM predictions on the $R(D) - R(D^*)$ plane.
- $R(J/\psi)$ and $R(\Lambda_c^+)$ are compatible with the SM within 2σ.
- All measurements are still statistically limited.

What is the new model?

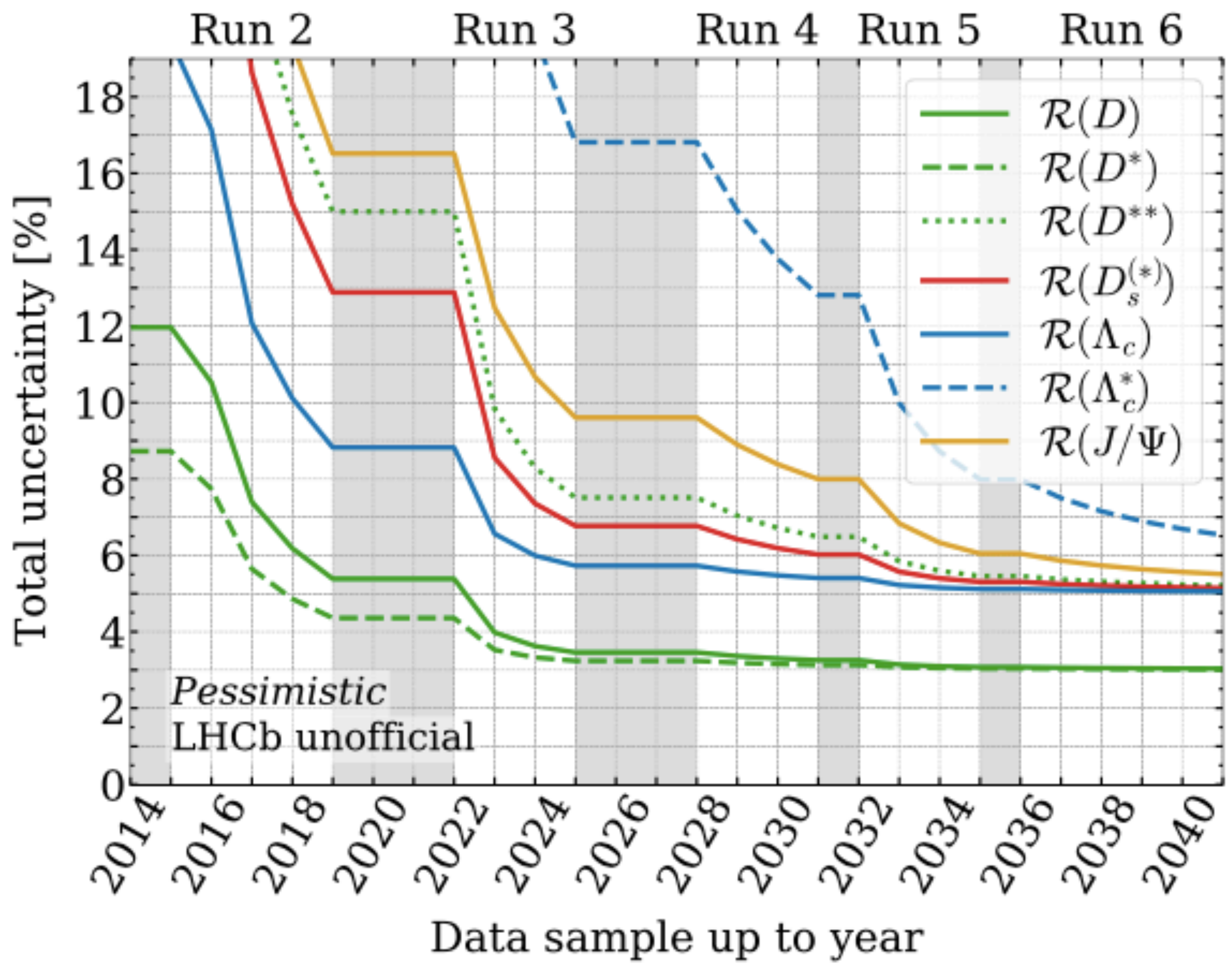
- There are several ways to explain (part of) the anomalies: Z′, scalar LQ, vector LQ.
  - Masses are usually above 1 TeV.
- Different models depending on the new mediator couples more strongly to muons or to taus.

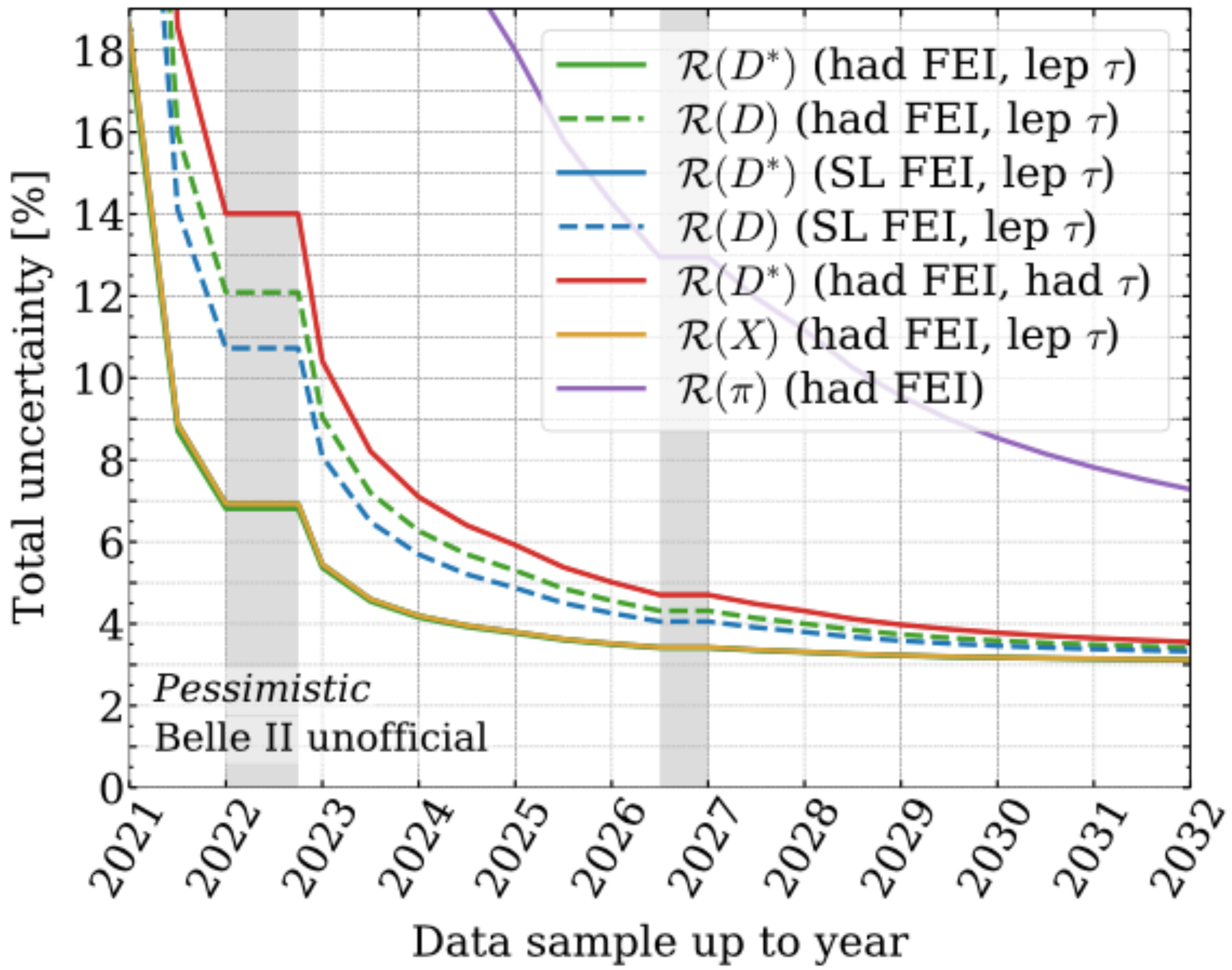


From Admir Greljo

What do we expect from the future?

- LHCb is finalising its upgrade, will start the Run3 in spring.
- Belle II is already starting to produce competitive results.

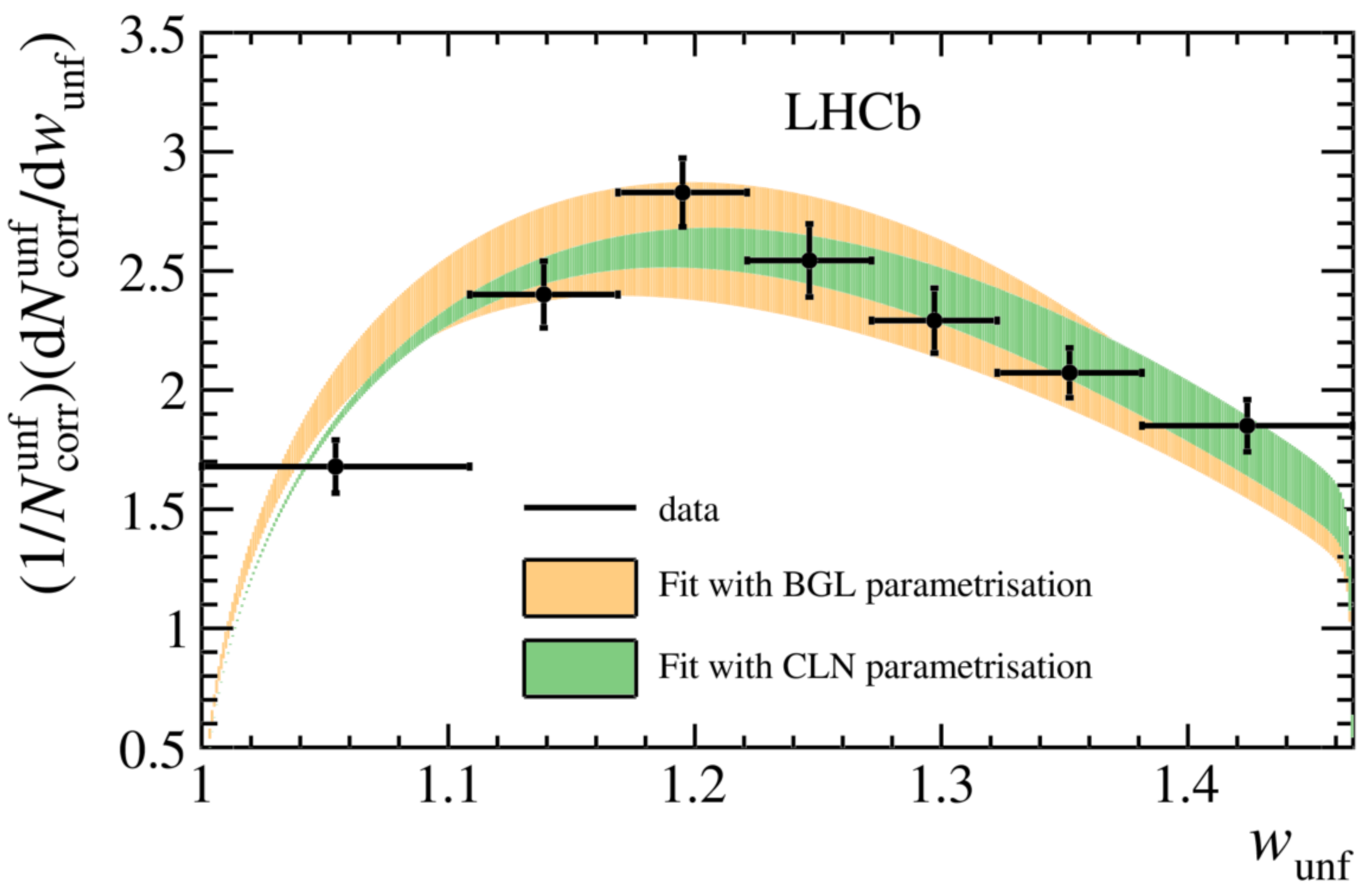


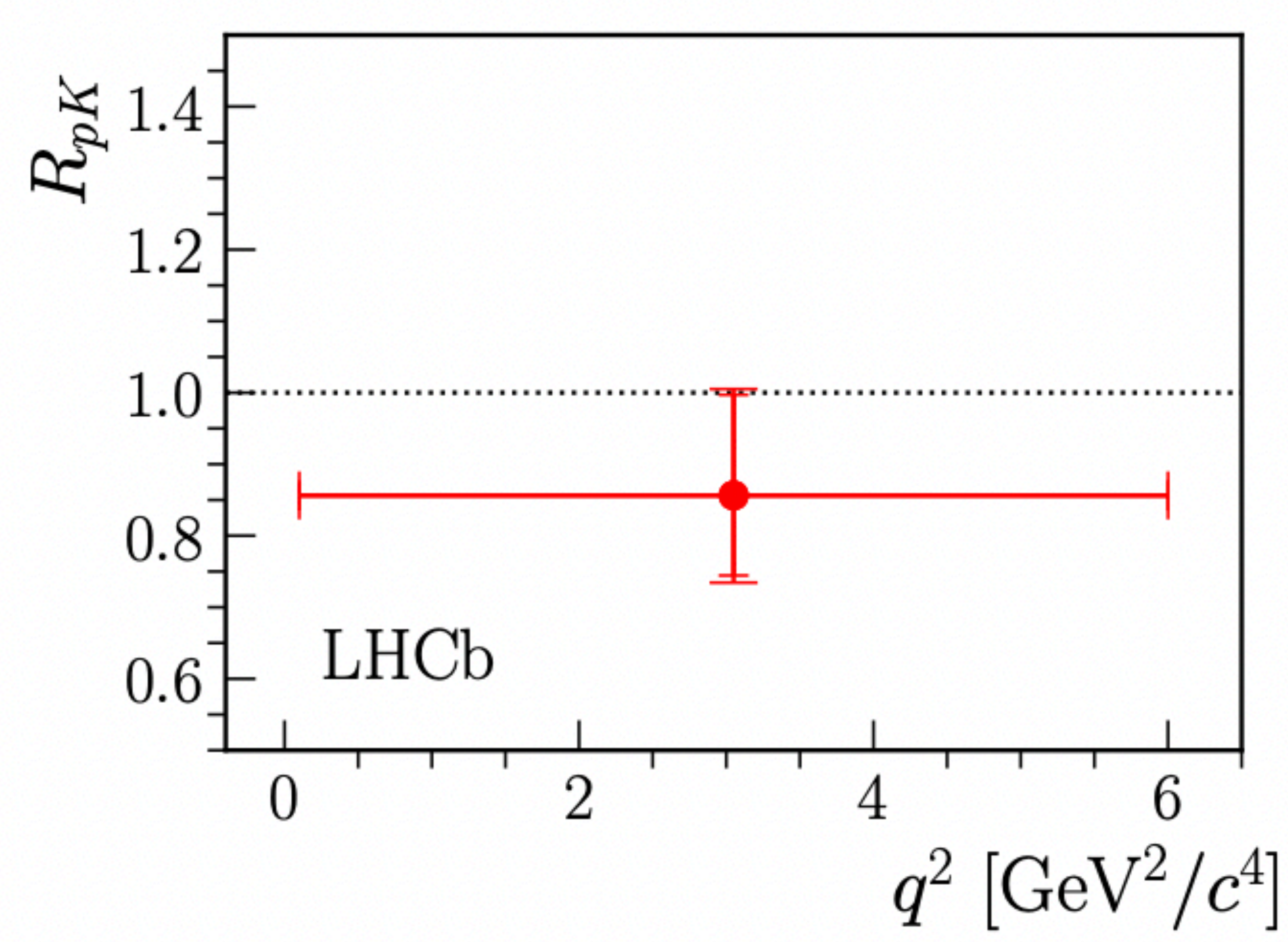


Even with pessimistic projections, the uncertainty can reach ~3% for some modes.

The role of ICCUB

- The experimental High Energy Physics group has led and is leading:
  - Analysis of the $B_s \to D_s^{*+}\mu^+\nu_\mu$ hadronic form factors and measurement of $R(D_s^{*+})$.
  - Analysis of LFU in $\Lambda_b \to pKl^+l^-$ (R_{pK}) and its update with full Run2 data sample.





Conclusions

- Several measurements from different experiments show deviations from the SM in LFU tests in rare and semileptonic decays.
  - No single 5σ observation yet.
- Coherent theoretical explanation based on fits to data.
  - There are few NP models that can explain the anomalies.
- Only more data (LHCb Upgrade and Belle-II) will shed light on the anomalies.
- People from ICCUB is leading some of the analysis.