High Energy Theory

Junta de Andalucía

Universidad de Granada

Round table: The flavor problem vs. the Higgs-hierarchy problem

Javier Fuentes-Martín
University of Granada

The Flavor Path to New Physics, Zurich, 5-7 June 2024

The EFT approach

No clear evidence for New Physics: either it is **heavy** or **light and weakly-coupled**

EFT approaches provide an excellent "language" to parametrize the experimental information in a meaningful way

SMEFT [$E \ll M_{\rm NP}$]

$$\mathscr{L}_{\rm SMEFT} = \mathscr{L}_{\rm SM} + C_{\ell q}^{\alpha\beta ij}\,(\ell_L^\alpha \gamma_\mu q_L^j)(q_L^i \gamma^\mu \ell_L^\beta) + \ldots \qquad [C_{\ell q} \sim \Lambda^{-2} \sim g_{\rm NP}^2/m_{\rm NP}^2]$$

★ 59 new possible interactions (2499 new flavorful couplings) at $\mathscr{O}(\Lambda^{-2})$ [Complicated inverse problem]

★ NP is unlikely to produce them all with the same strength or at the same scale

Can we infer anything about them from the SM couplings?

The SM Lagrangian: Naturalness problems

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + |D_\mu \phi|^2 - V(\phi) + \bar{\psi}_i y_{ij} \psi_j \phi + h.c.$$

The SM Lagrangian contains two (three, θ-term) unnatural features pointing towards NP

Higgs hierarchy problem

[Higgs mass instability under quantum corrections]

TeV-scale NP?

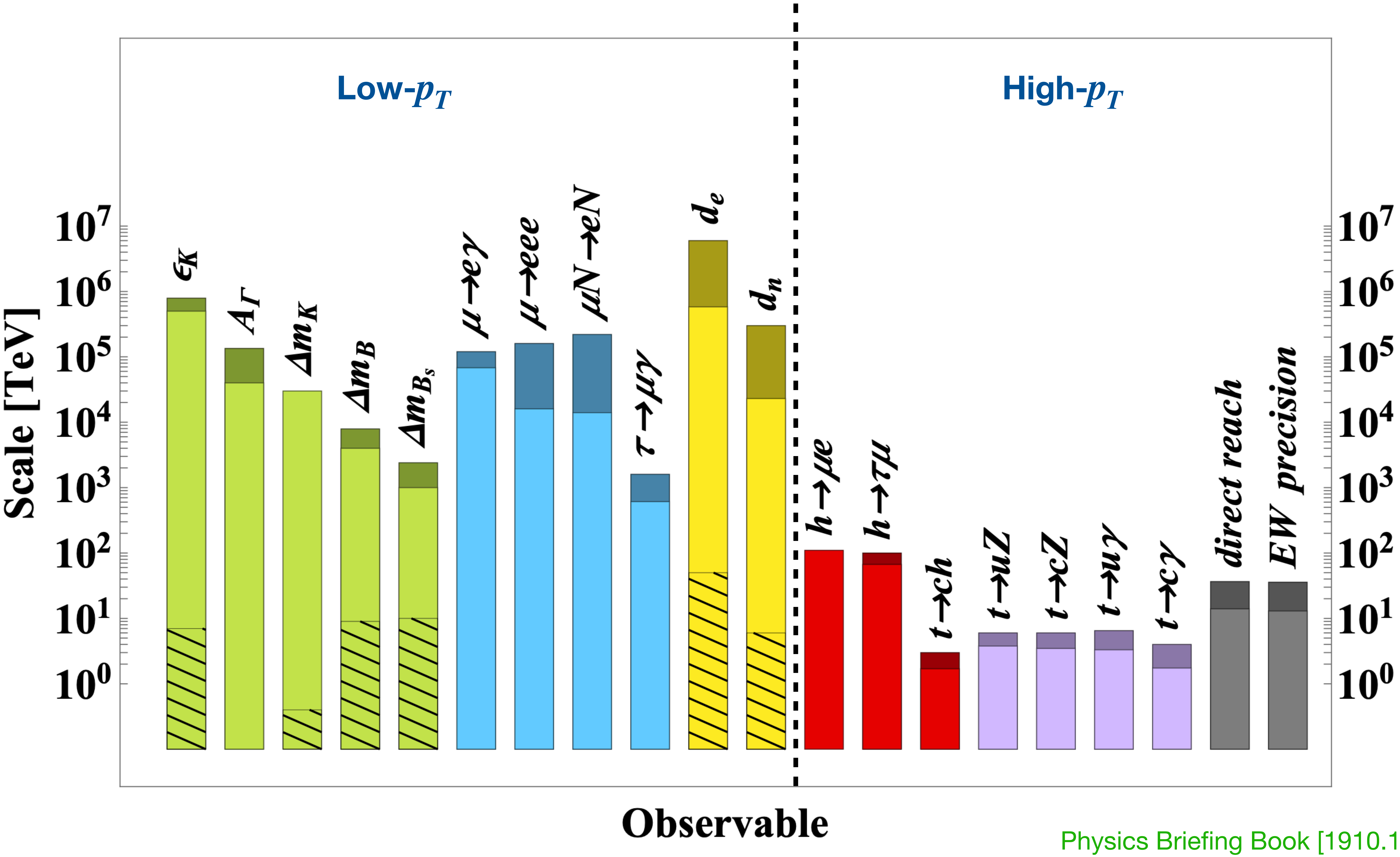
SM flavor puzzle

[Accidental symmetries in the SM Yukawas]

Similar structure also for NP?

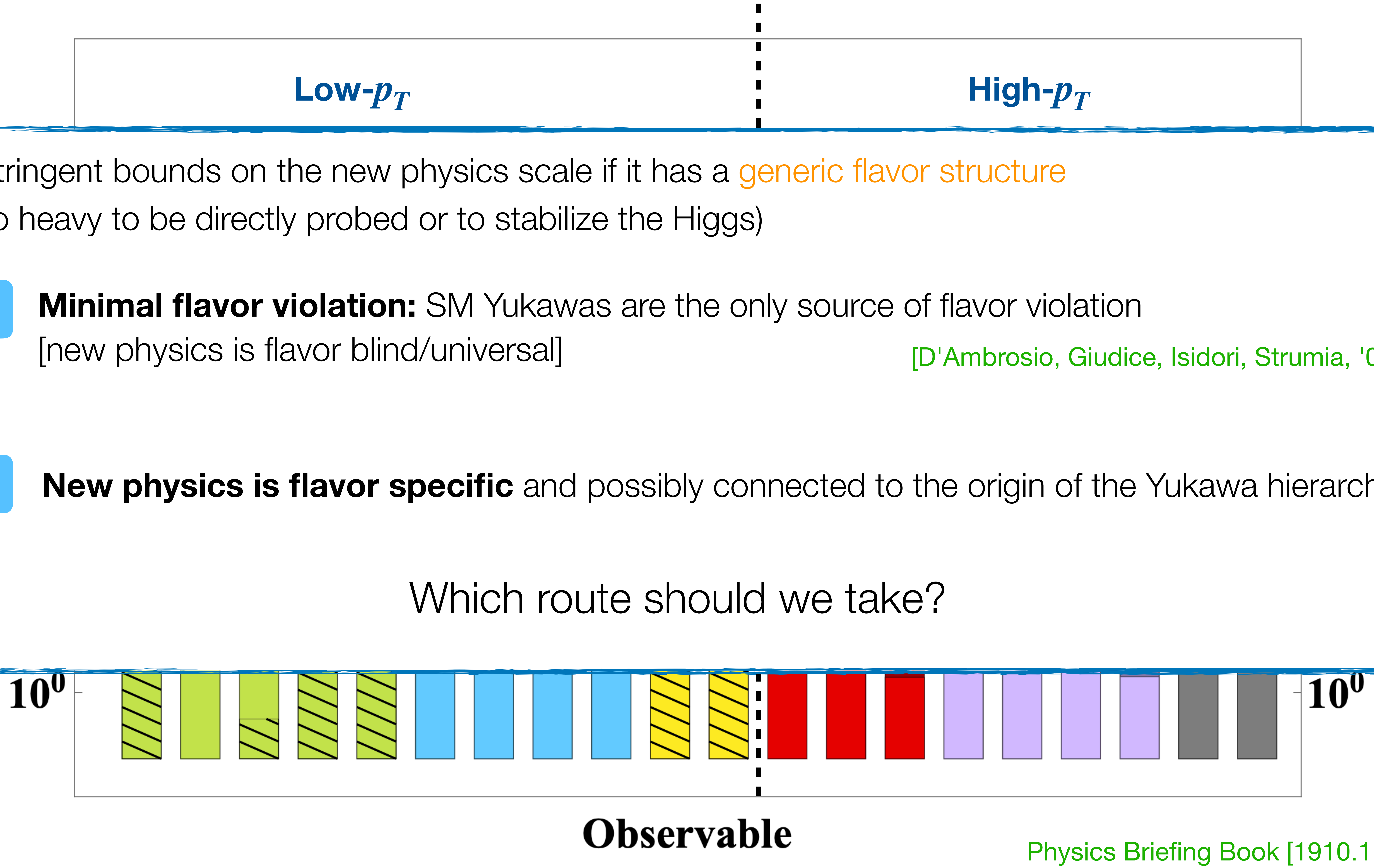
Are these two features connected?

The new-physics flavor problem



Physics Briefing Book [1910.11775]

The new-physics flavor problem



Very stringent bounds on the new physics scale if it has a generic flavor structure
(far too heavy to be directly probed or to stabilize the Higgs)

1. **Minimal flavor violation:** SM Yukawas are the only source of flavor violation
[new physics is flavor blind/universal] [D'Ambrosio, Giudice, Isidori, Strumia, '02]

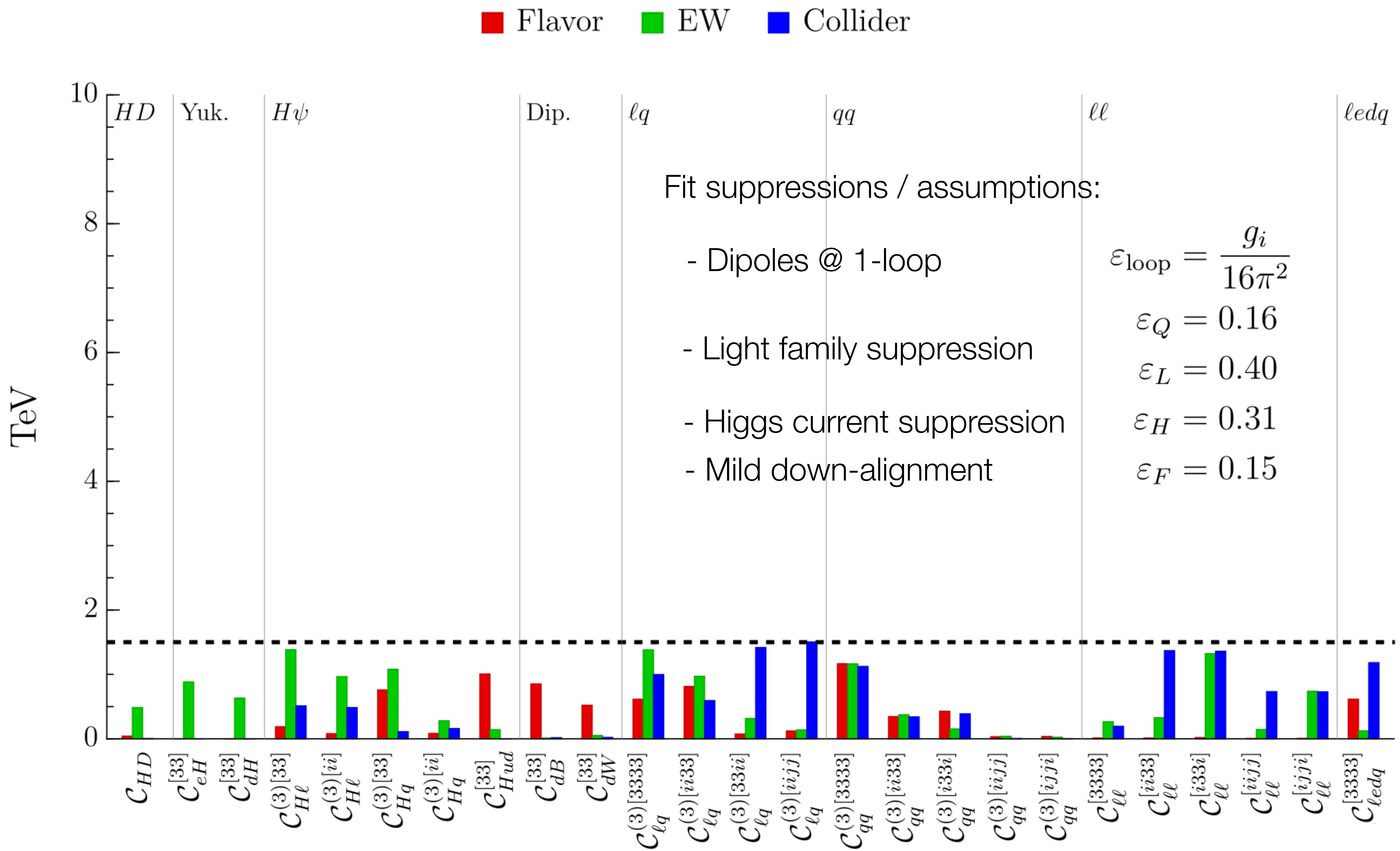
2. **New physics is flavor specific** and possibly connected to the origin of the Yukawa hierarchies

Which route should we take?

Physics Briefing Book [1910.11775]

New-physics bounds with $U(2)^5$

[Allwicher, Cornella, Isidori, Stefanek, 2311.00020]

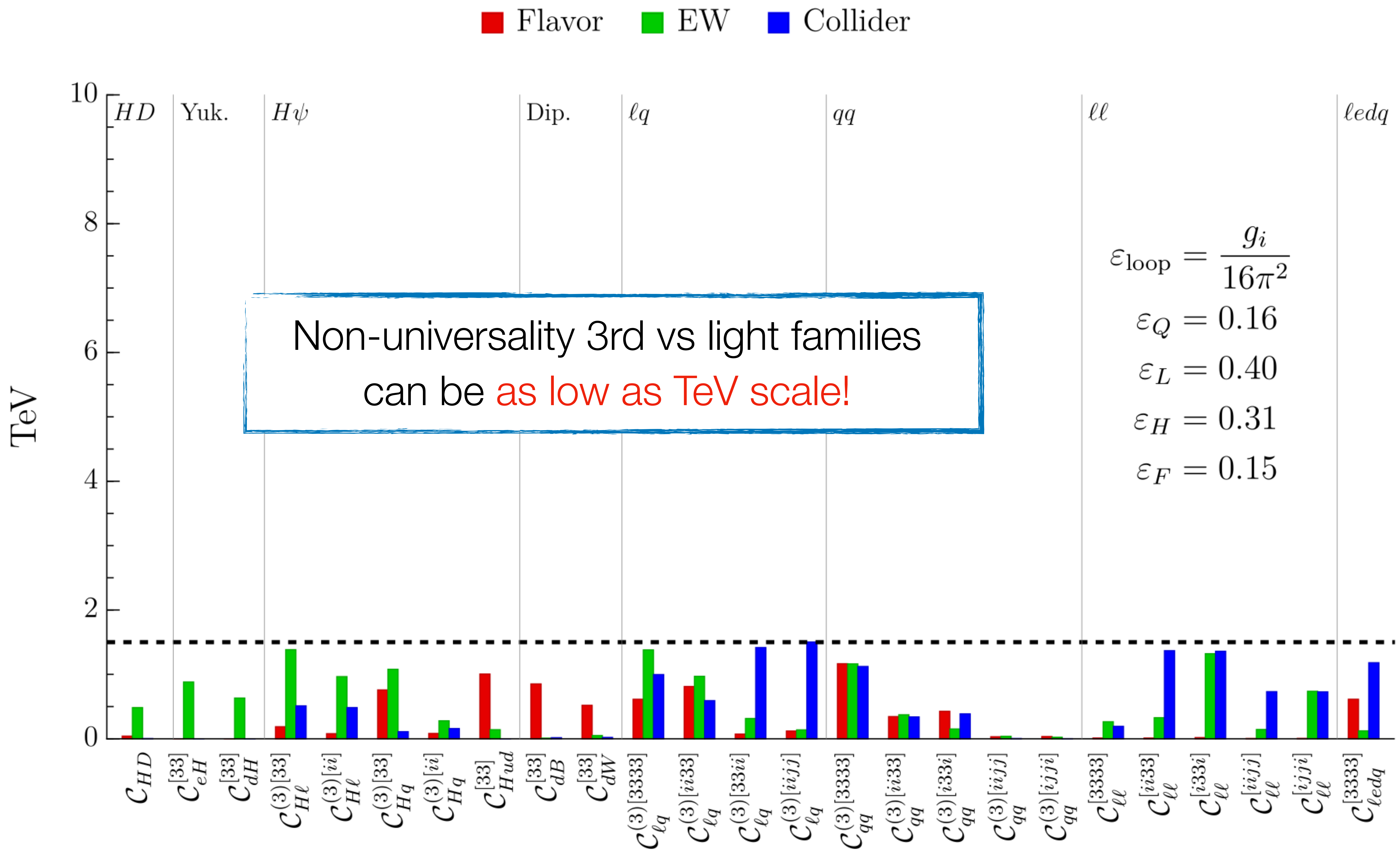


Fit suppressions / assumptions:

- Dipoles @ 1-loop $\qquad \varepsilon_{\rm loop} = \frac{g_i}{16\pi^2}$
- Light family suppression $\qquad \varepsilon_Q = 0.16$, $\varepsilon_L = 0.40$
- Higgs current suppression $\qquad \varepsilon_H = 0.31$
- Mild down-alignment $\qquad \varepsilon_F = 0.15$

New-physics bounds with $U(2)^5$

[Allwicher, Cornella, Isidori, Stefanek, 2311.00020]

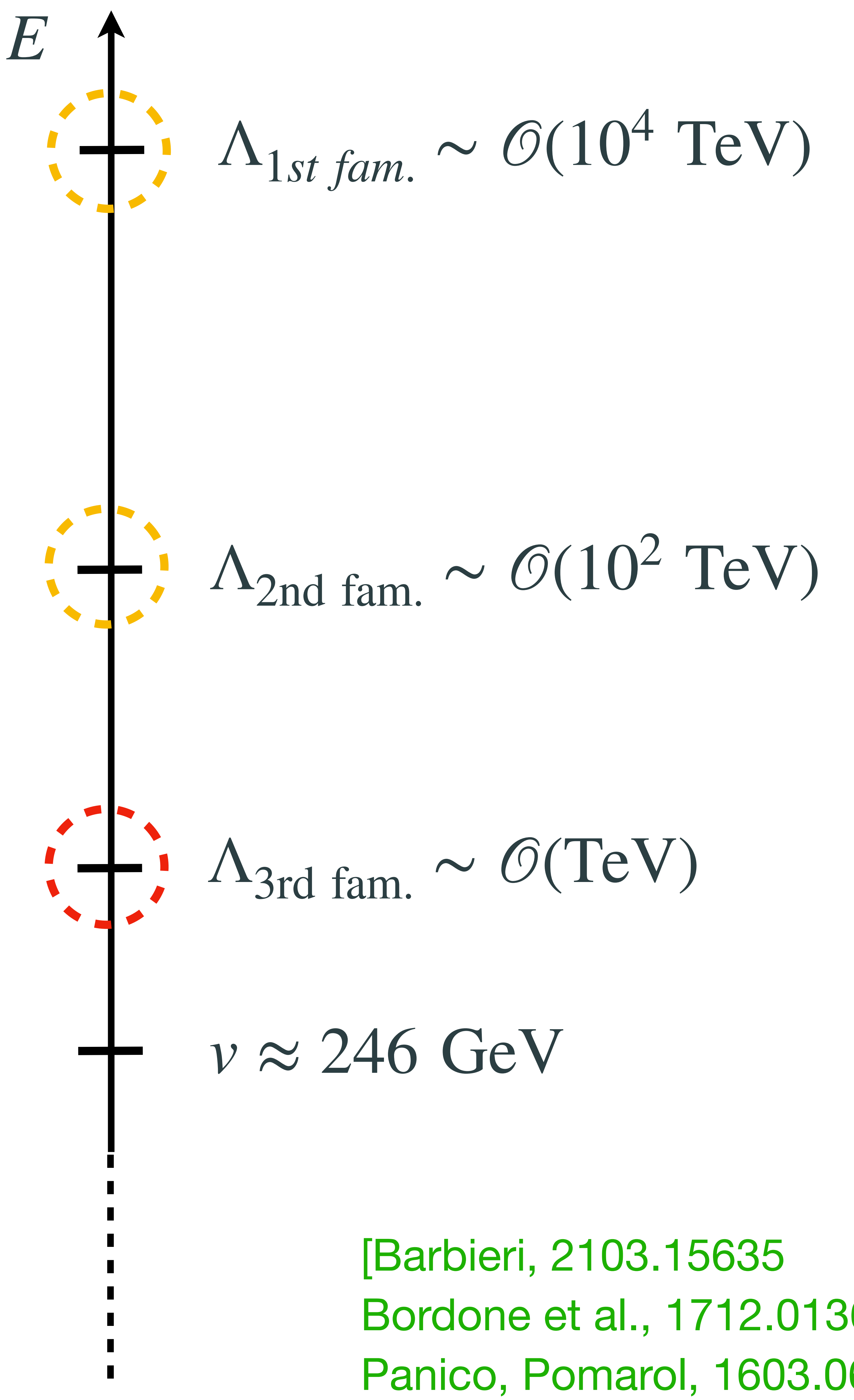


Non-universality 3rd vs light families
can be as low as TeV scale!

Multi-scale solution of the flavor problem/puzzle

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{Gauge}} + \mathscr{L}_{\text{Higgs}} + \mathscr{L}_{\text{Yukawa}} + \sum_{i,d} \frac{1}{\Lambda_i^{d-4}} C_i \mathscr{O}_i^d$$

Non-trivial UV imprints



- Flavor universality emerges as an *accidental symmetry*
- The Yukawas are very different because they originate at separate scales!
- TeV-scale NP dominantly coupled to third family
  [protection from flavor constraints]
- Direct production of new states at the LHC is naturally more suppressed
  [NP scale can be lower!]

[Barbieri, 2103.15635
Bordone et al., 1712.01368
Panico, Pomarol, 1603.06609
Dvali, Shiftman, '00, …]

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Non-trivial UV imprints

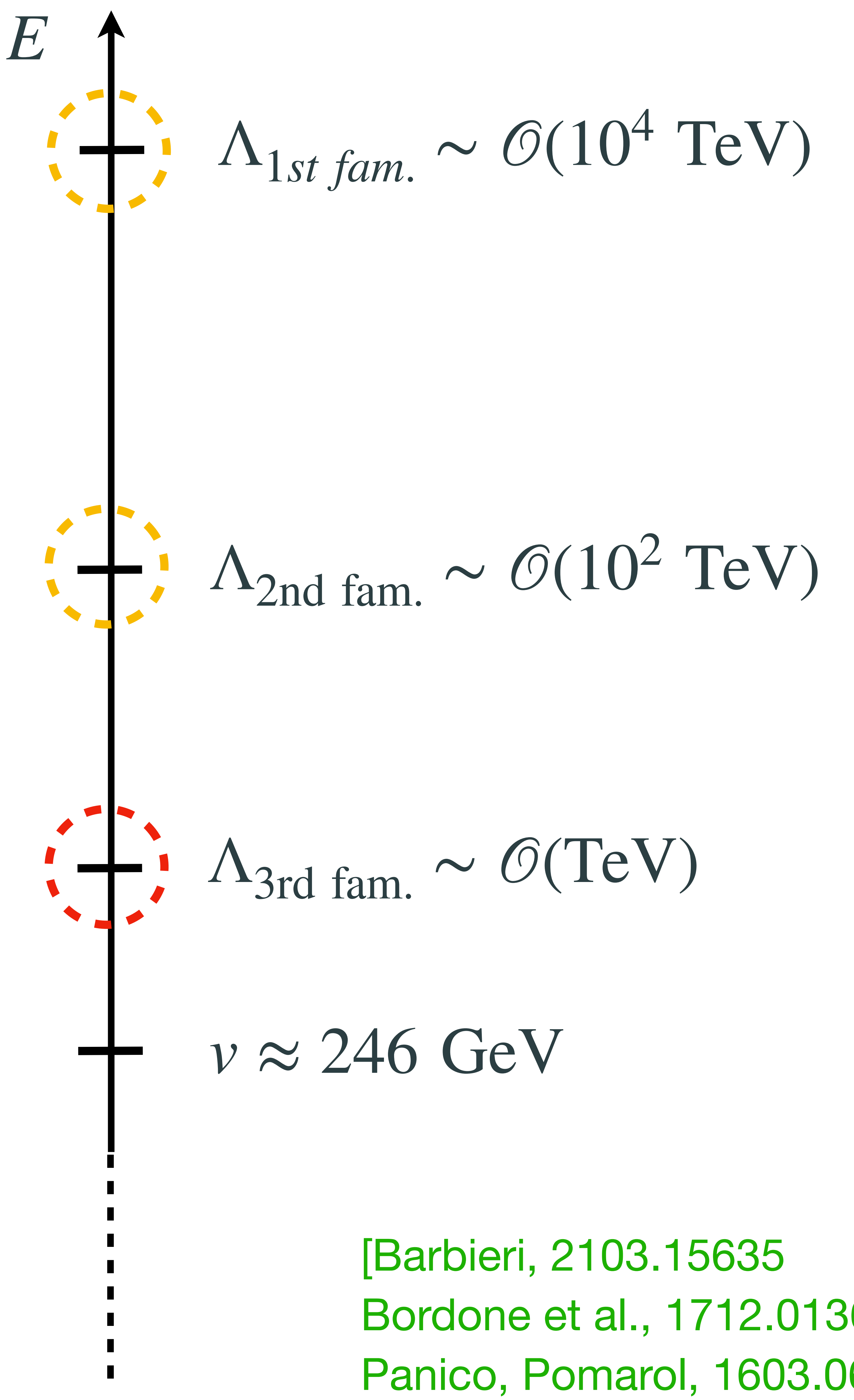
A multi-scale picture could arise from gauge non-universal interactions:

- Around the TeV scale, focus on universality of 3rd vs light families

$$\mathscr{G}_1^{[3]} \times \mathscr{G}_2^{[1,2]} \times H^U \rightarrow \mathscr{G}_{\text{SM}} \equiv SU(3)_c \times SU(2)_L \times U(1)_Y$$

SM subgroup that remains universal

- Direct production of new states at the LHC is naturally more suppressed
  [NP scale can be lower!]



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Gauge deconstructions… indeed, not a new idea

Lepton number as the fourth "color"

Jogesh C. Pati*
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy
and Imperial College, London, England
(Received 25 February 1974)

Pati, Salam, 1974

"Economical" model built to avoid bounds from $K \to e\mu$

D. Variants to the "basic" model

If electron number L_e and muon number L_μ correspond to *distinct* colors, the following simple variants may be considered:

(a) *The "economical" model.* Take as basic fermions the four 8-folds:

$$(\Psi_e)_{L,R} = \begin{pmatrix} \mathcal{P}_a & \mathcal{P}_b & \mathcal{P}_c & \nu \\ \mathcal{N}_a & \mathcal{N}_b & \mathcal{N}_c & e^- \end{pmatrix}_{L,R},$$

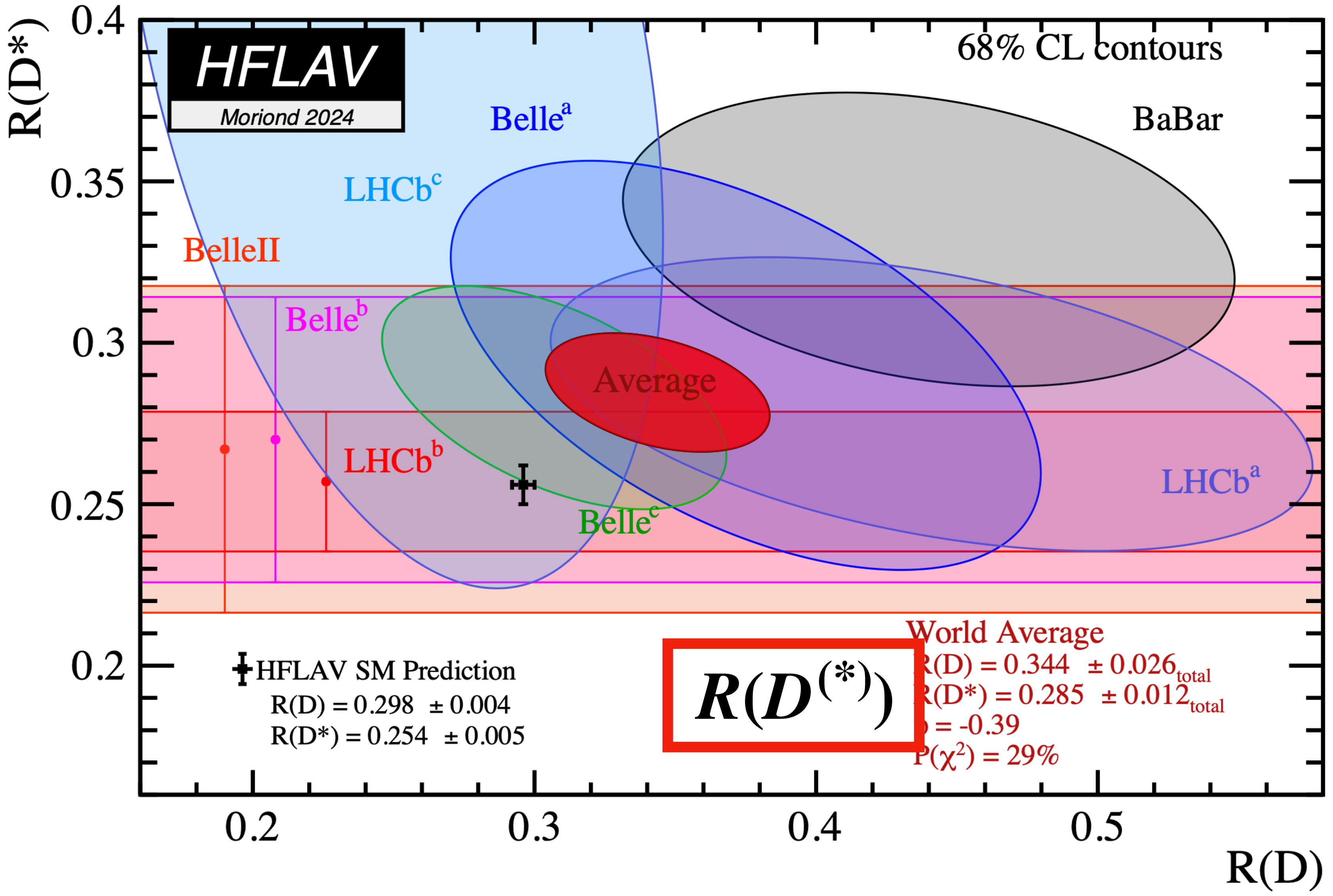
$$(\Psi_\mu)_{L,R} = \begin{pmatrix} \lambda_a & \lambda_b & \lambda_c & \mu^- \\ \chi_a & \chi_b & \chi_c & \nu' \end{pmatrix}_{L,R},$$

with the symmetry group

$$SU(2)_L \times SU(2)_R \times SU(4')_e \times SU(4')_\mu .$$

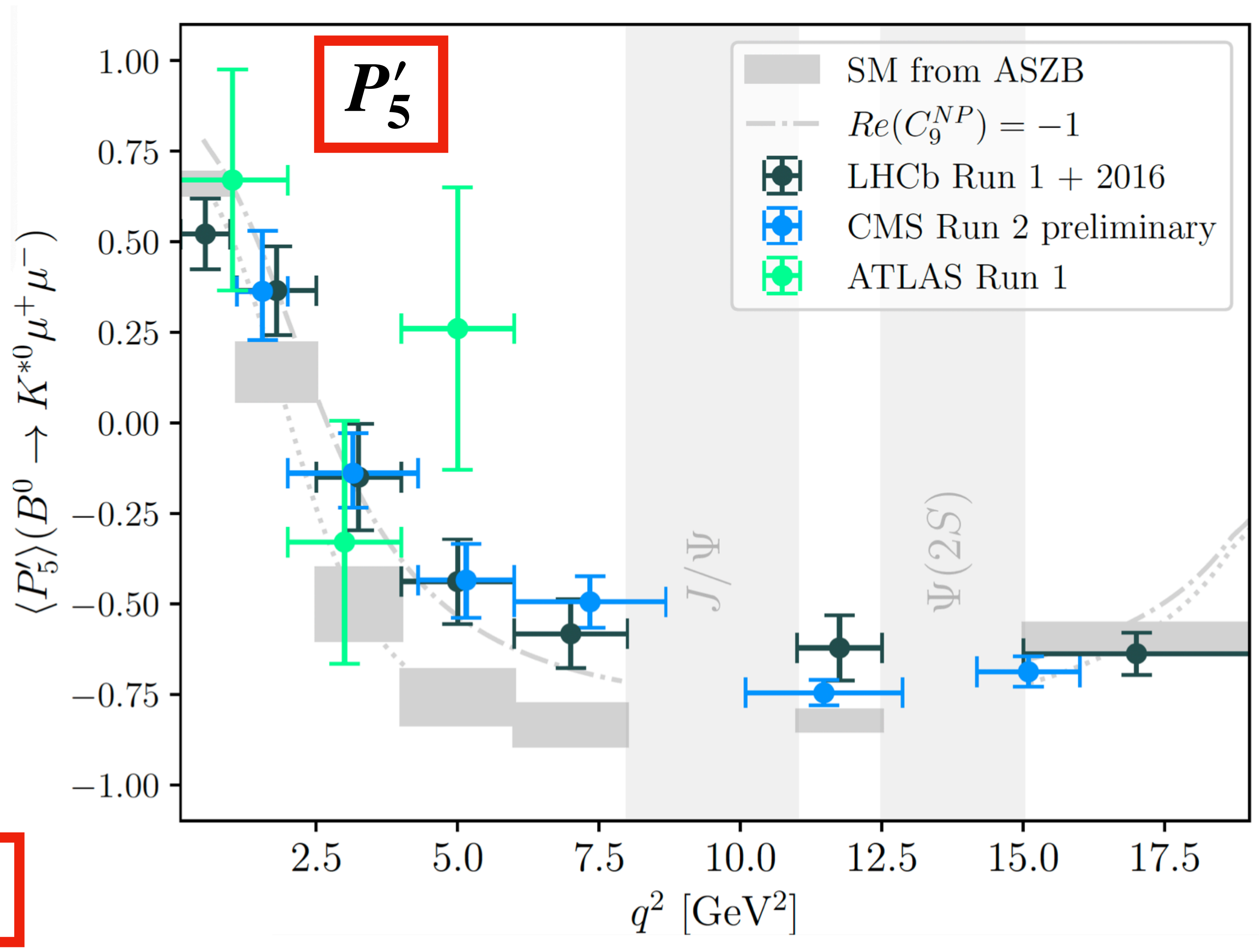
The number of fermions is the same as in the "basic" model; however, the number of gauge bosons has increased to $3+3+15+15=36$. The physical $SU(3')$ may now be identified with the diagonal sum of $SU(3')_e$ and $SU(3')_\mu$, whose emergence will require a more elaborate Higgs-Kibble set of scalars than are needed for the "basic" model (see Sec. IV).

Hints in low-energy data?



$R(D^{(*)})$

$b \to c\tau\bar{\nu}$

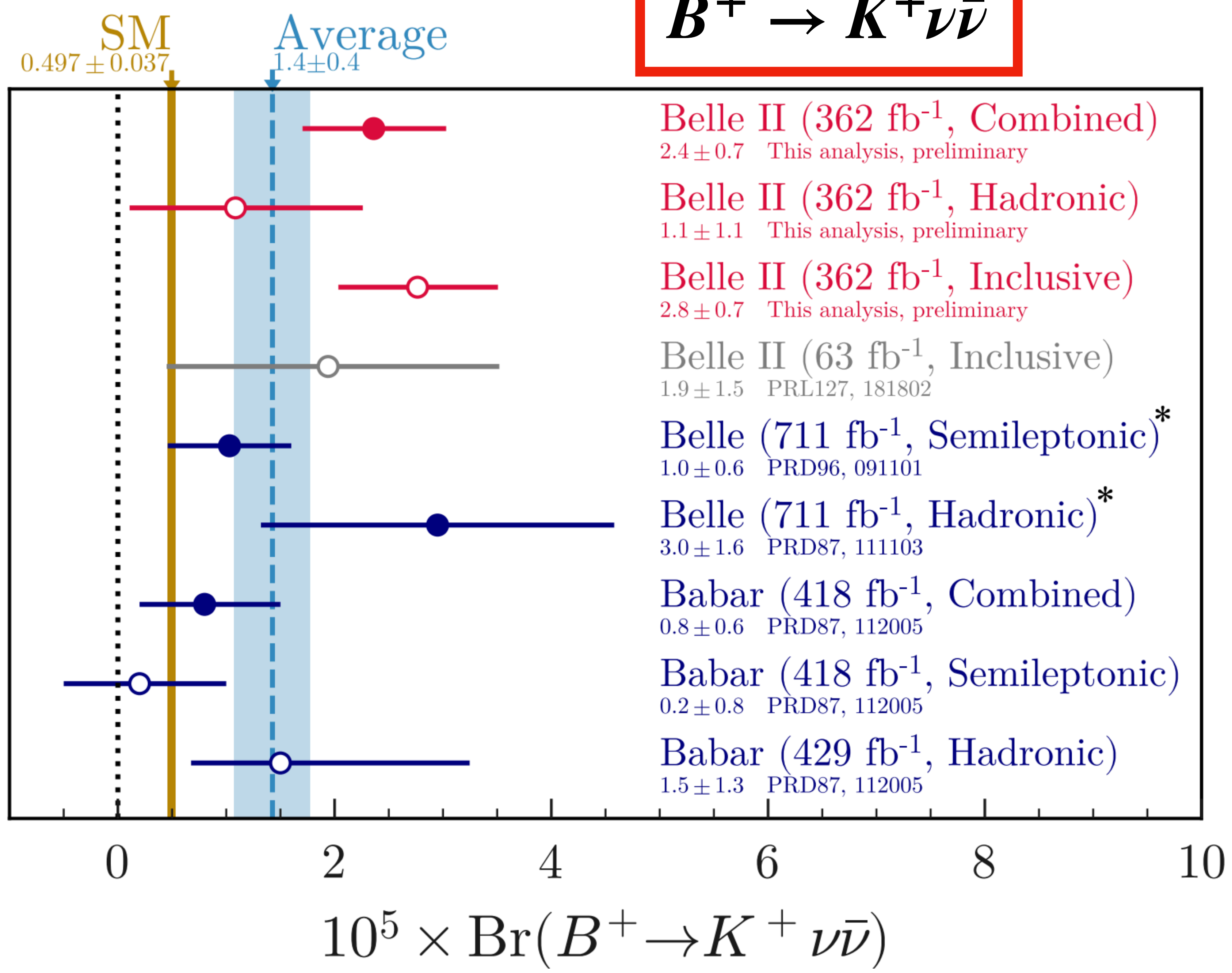


P'_5

$b \to s\mu^+\mu^-$

+ others

$B^+ \to K^+\nu\bar{\nu}$

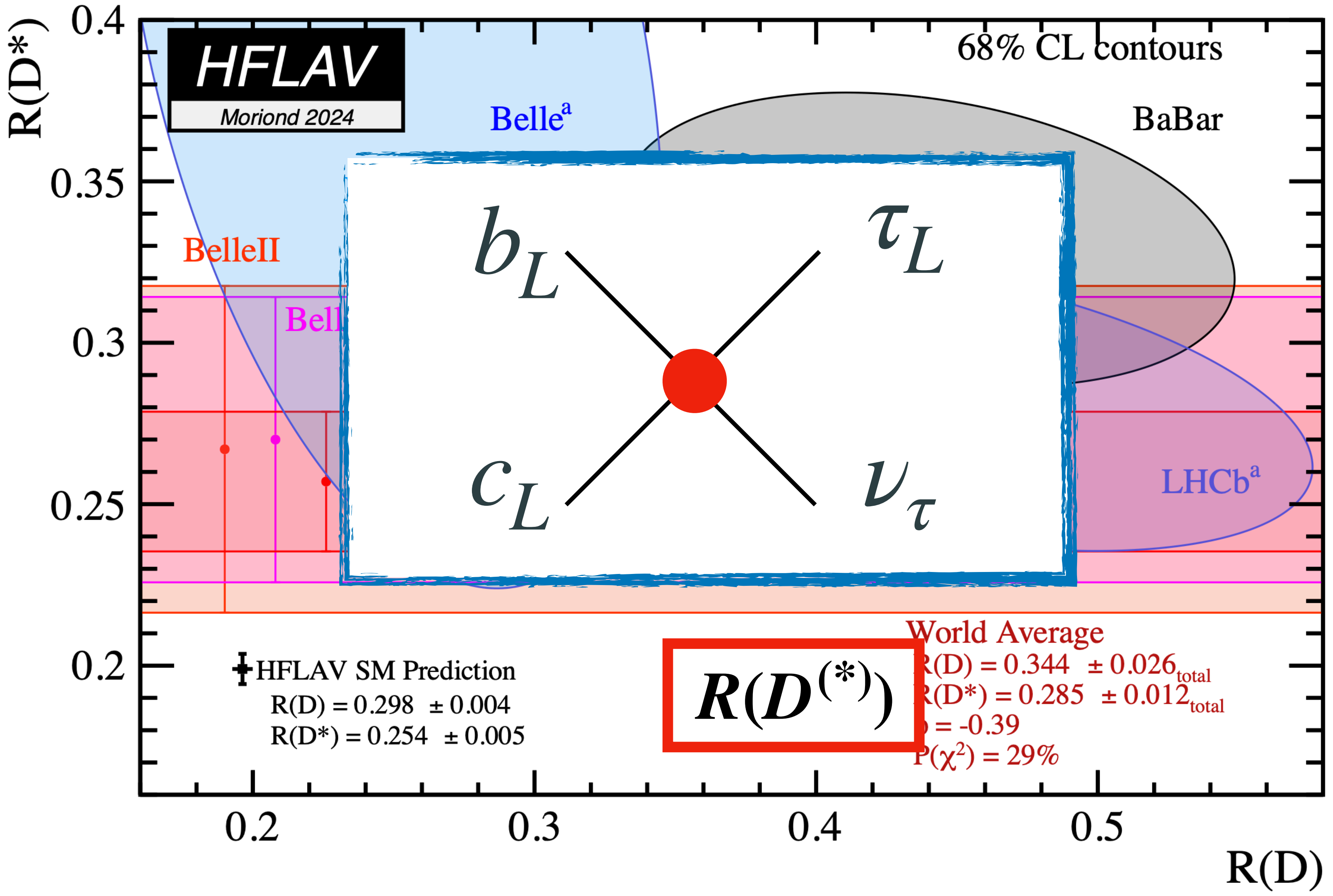


$b \to s\nu\bar{\nu}$

Many upcoming experimental results from LHCb, Belle II, ATLAS and CMS!

[$b \to s\tau^+\tau^-$, $b \to d\ell^+\ell^-$, $b \to u\ell\nu$, LFV…]

Hints in low-energy data? Dreaming a bit…



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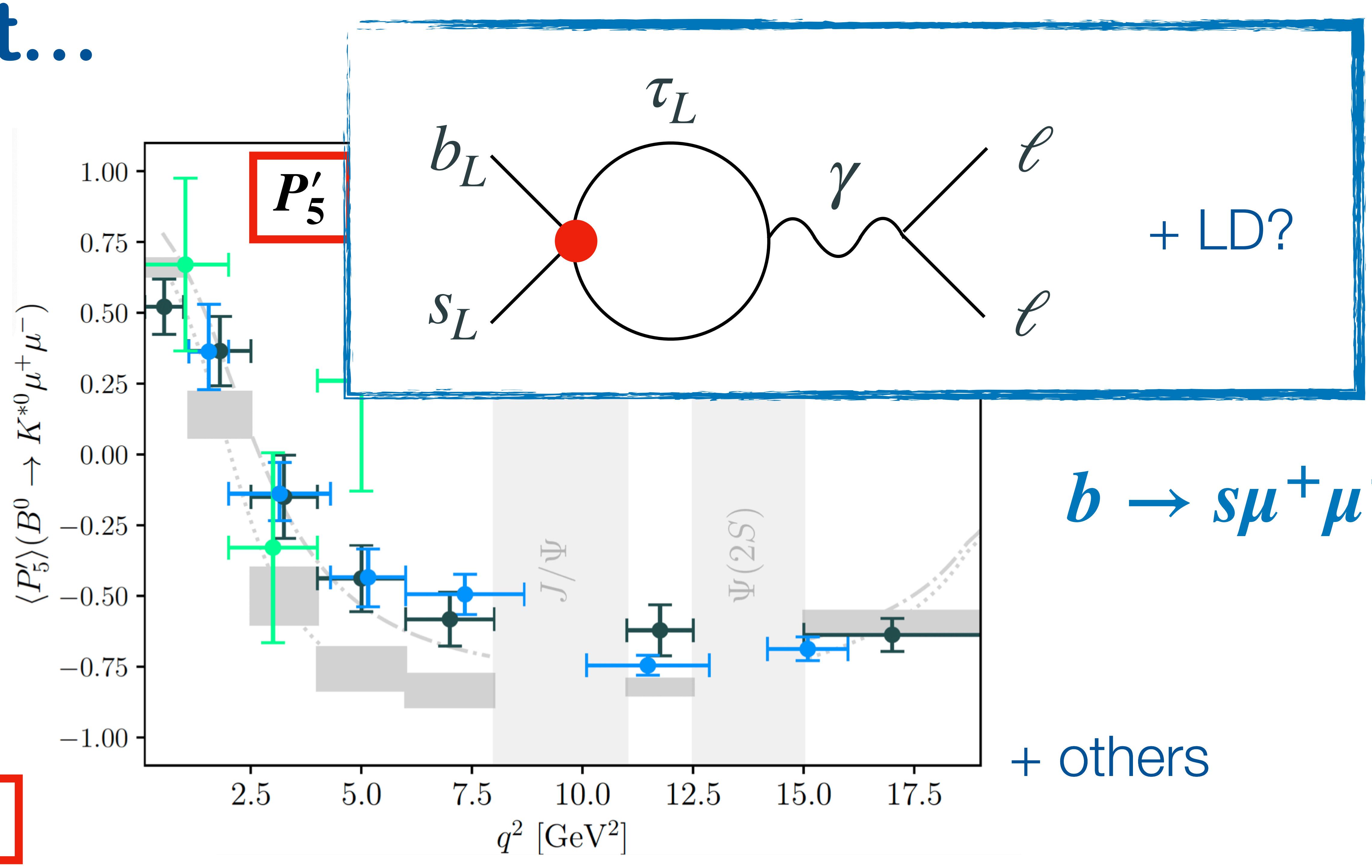

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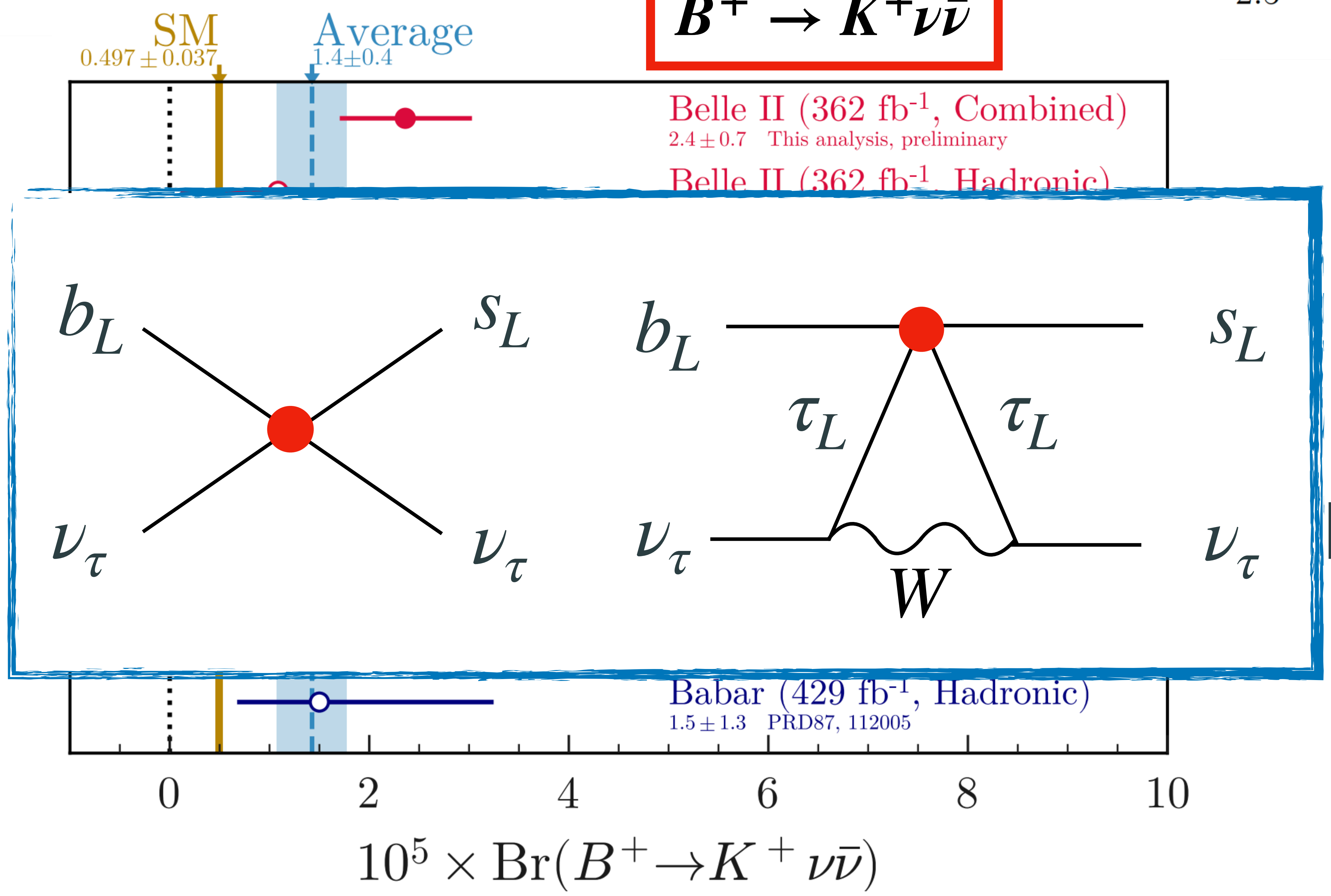
+ others



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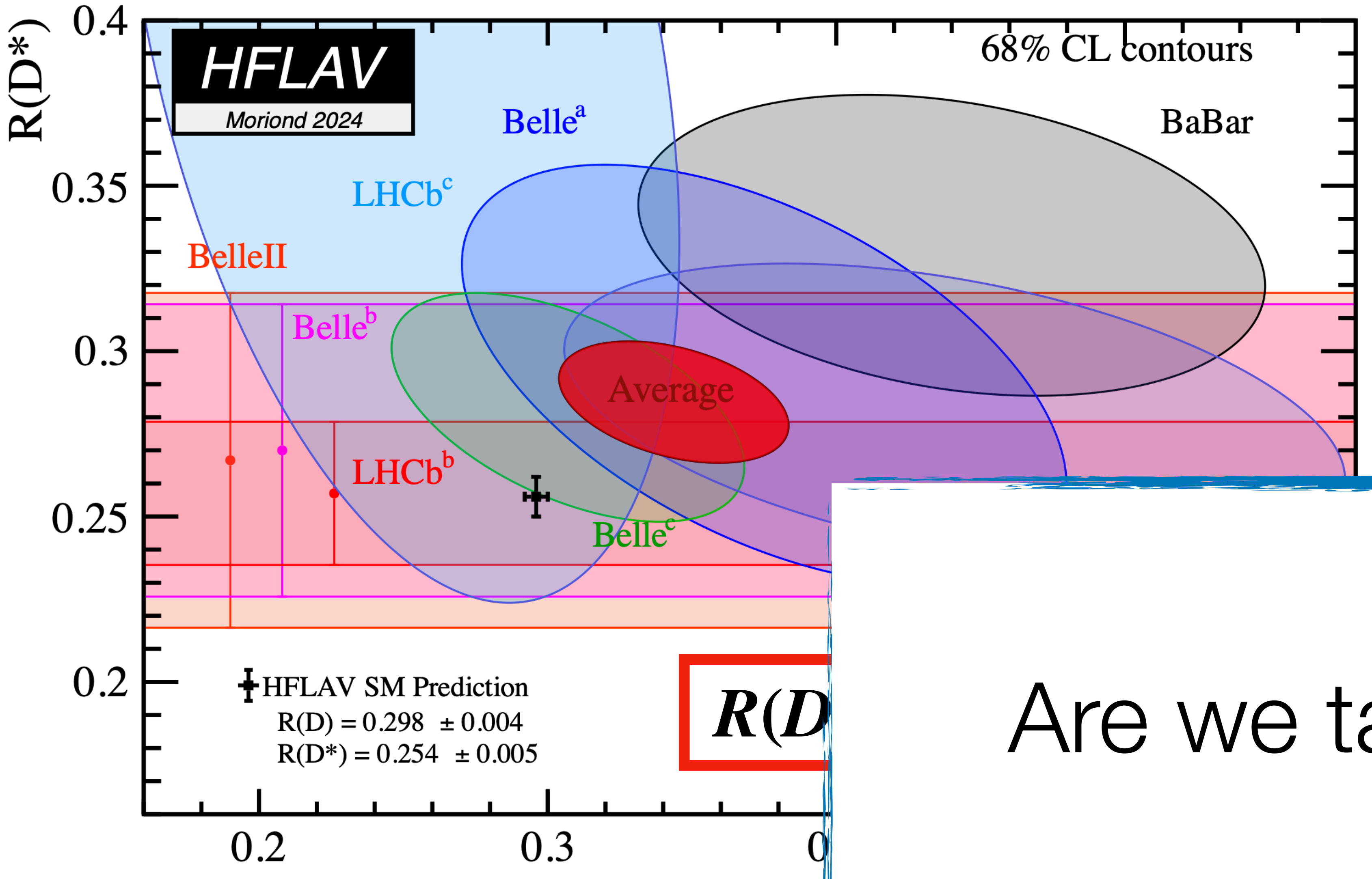
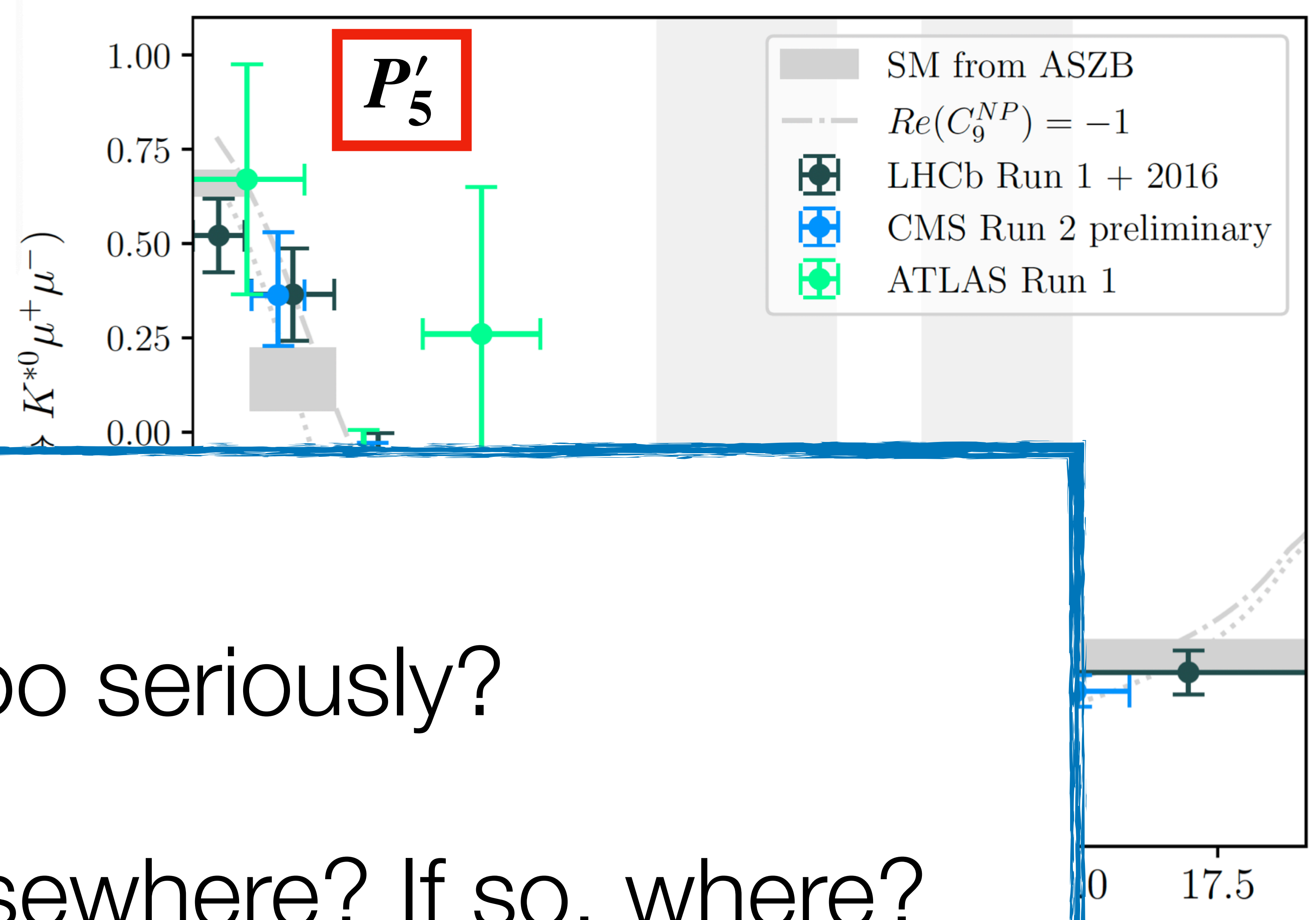


$b \to c\tau\bar{\nu}$



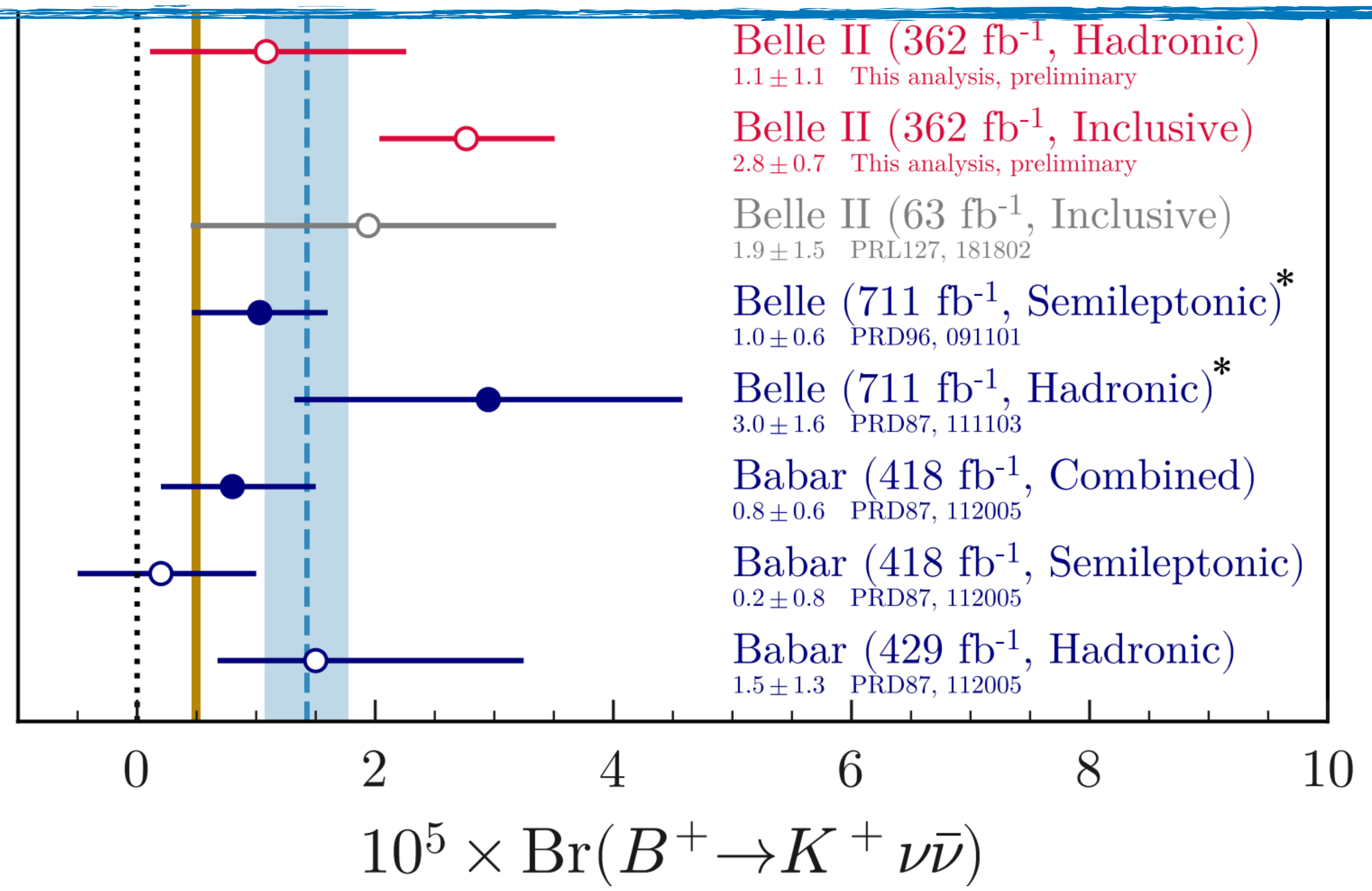
+ LD?

$b \to s\mu^+\mu^-$

+ others

Are we taking these hints too seriously?

Should we put the focus elsewhere? If so, where?



$b \to s\nu\bar{\nu}$

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