Non-leptonic B anomalies - a view from the top

Matthew Kirk

Quirks in Quark Flavour Physics 2024
21 June 2024
(based on 240?.xxxxx with Tetlalmatzi Xolocotzi, Englert, Atkinson)

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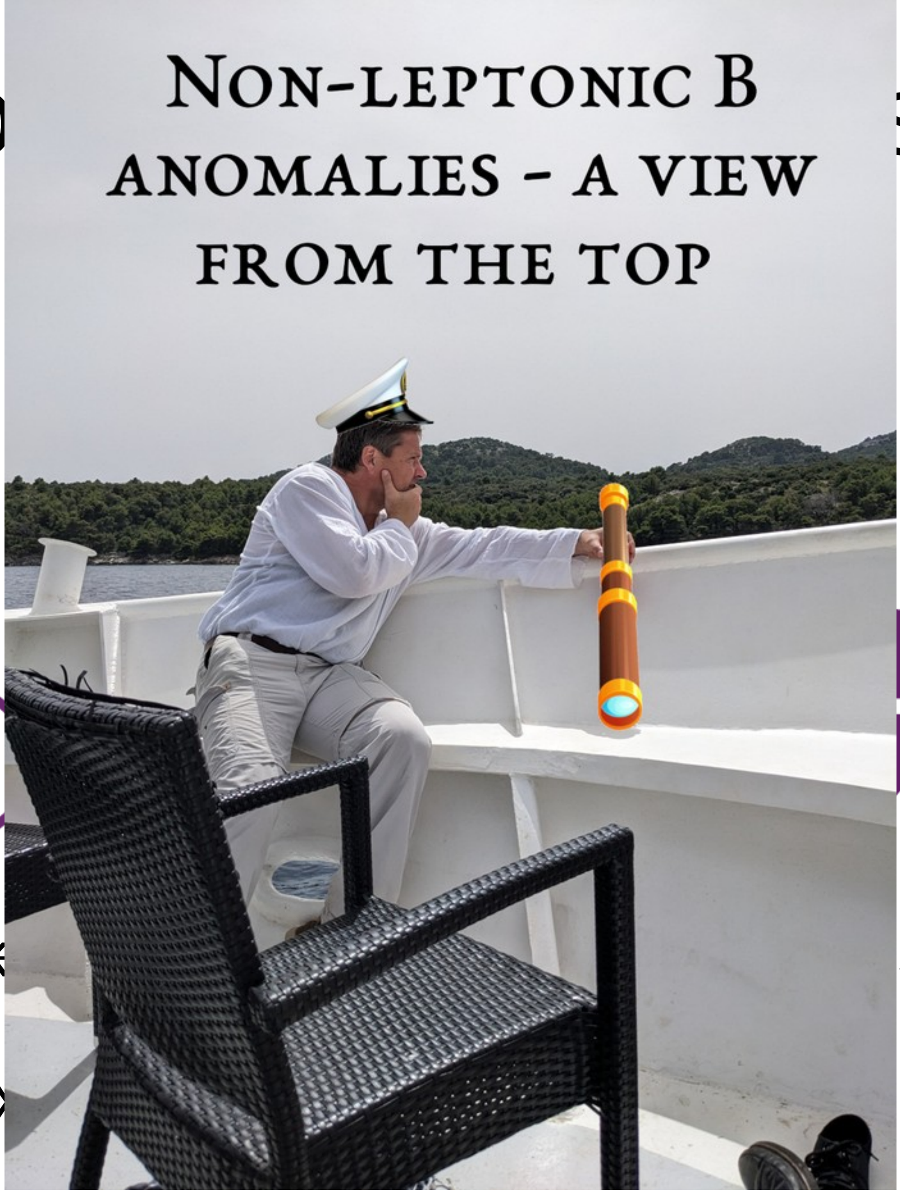
Non-lep s – a view



~~Quirk~~ s 2024

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Non-leptonic physics

- Fully non-leptonic decays? Sounds nasty!
- Generally anomalies are in observables where:

a) It is clear we understand the physics

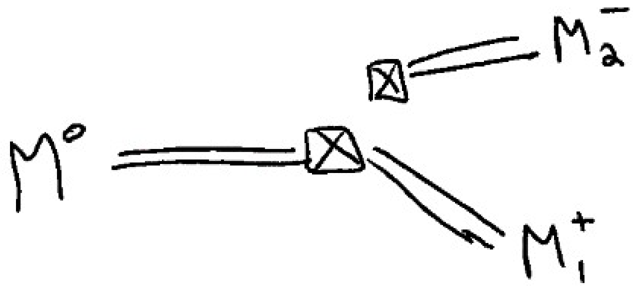
or

b) or the bits we don't cancel out

- i.e. "Optimised observables", "ratios", ...

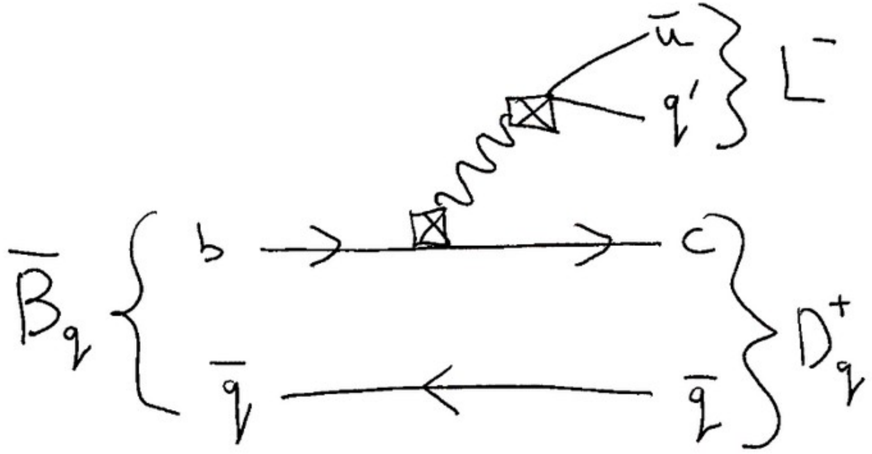
Class I non-leptonic decays

- $M^0 \to M^+ M^-$
  - No annihilation topologies
- QCD factorisation should work decently



$B_{(s)} \to D_{(s)}^{(*)}\{\pi, K^{(*)}, \rho\}$

- $M^0 \to M^+ M^-$
  - Annihilation topologies power suppressed (if present)



- $b \to c\bar{u}\{d, s\}$
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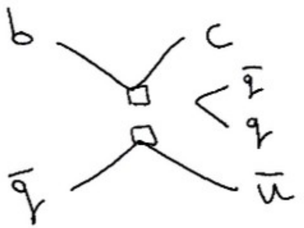

$$\bar{B}^0 \to D^+ K^-$$

- $\mathcal{M}(\bar{B} \to D^+ K^-) \propto V_{cb} f_K f_0^{B\to D}(M_K^2) a_1^{\text{eff}} + \mathcal{O}\left(\frac{\Lambda}{m_b}\right)$
- V_{cb}
- Decay constants
- Form factors
- WC a_1
- Power corrections

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- V_{cb}: Inclusive vs exclusive ~ 5% `PDG review`
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- WC a_1: NNLO, 1% unc. Huber, Kränkl, Li
- Power corrections: ~few % Bordone, Gubernari, Huber, Jung, van Dyk

Make a ratio

- We normalise by semi-leptonic decays to remove V_{cb} dependence, and reduce form factor dependence
  - Known since Bjorken

ic decays. An easy calculation gives[15]

$$\frac{\Gamma\left(\Lambda_b \to p\pi^-\right)}{\frac{d\Gamma}{dM^2}\left(\Lambda_b \to pe^-\bar{\nu}_e\right)_{M^2=0}} = 6\pi^2 F_\pi^2 \cong 1.0\ \mathrm{GeV}^2$$

Topics in B Physics, 4th Workshop on Recent Developments in High-energy Physics

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Topics in B Physics, 4th Workshop on Recent Developments in High-energy Physics

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15. I am told this is in the folklore but do not know a good reference.

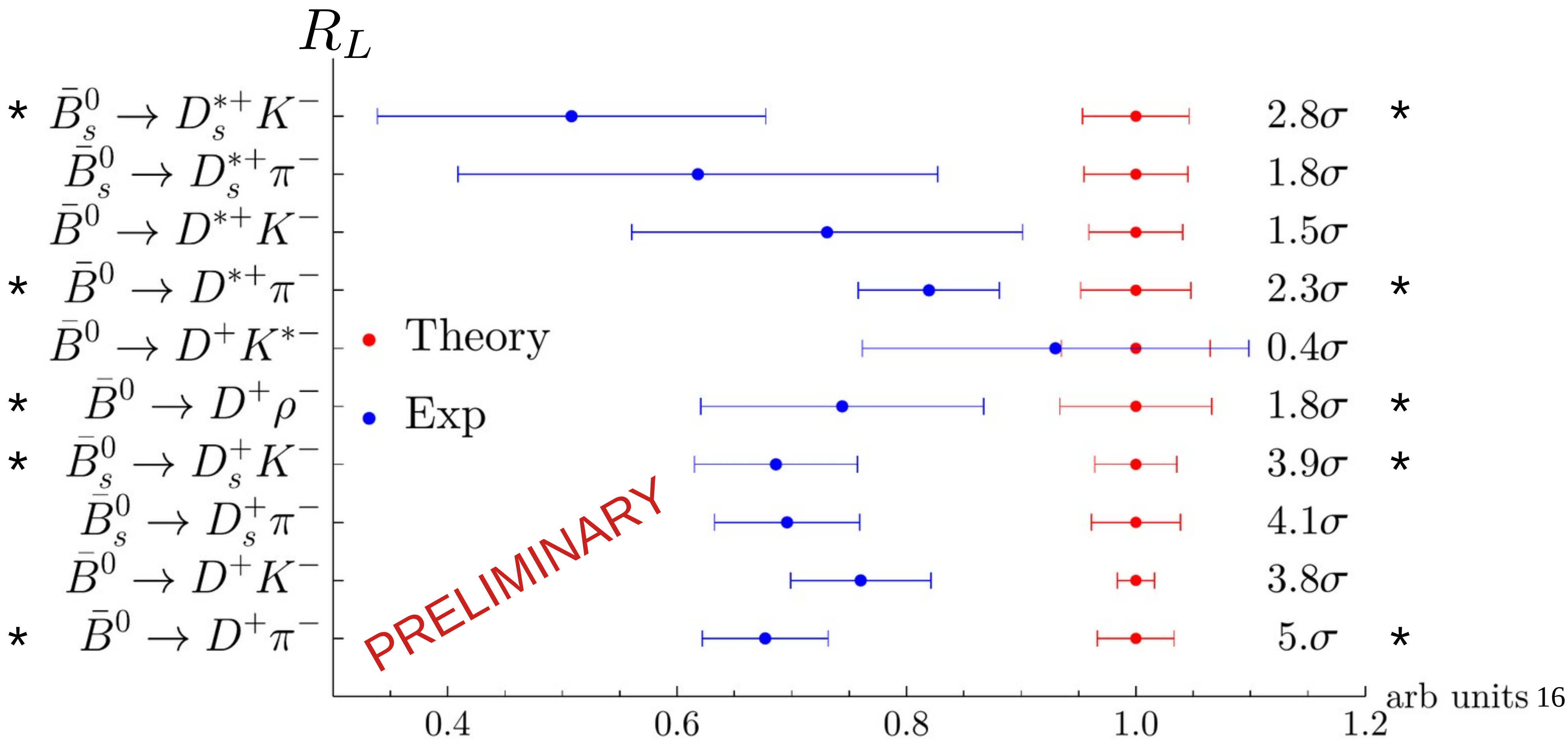
Make a ratio

- We normalise by semi-leptonic decays to remove V_{cb} dependence, and reduce form factor dependence

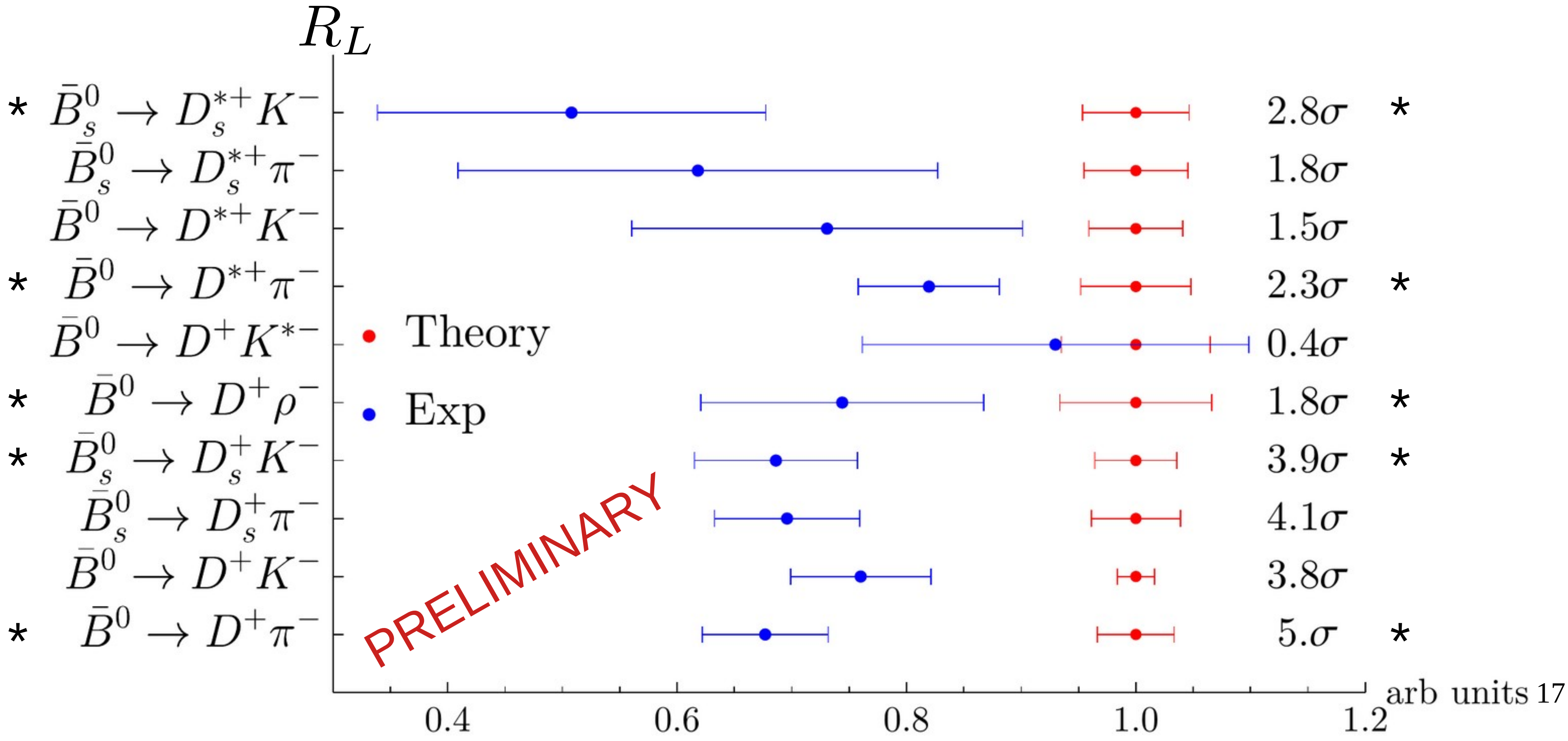
$$R_L = \frac{\mathcal{B}(B \to D^+ L^-)}{d\Gamma(B \to D^+ \ell^- \nu)/dq^2|_{q^2=M_L^2}} = 6\pi^2 |V_{uq}|^2 f_L^2 |a_1^{\mathrm{eff}}|^2 X_L$$

form factor ratio

Non-leptonic anomalies



Non-leptonic ~~anomalies~~ quirks



Could BSM be responsible?

- In Cai, Deng, Li, Yang (2103.04138) they analysed data with low energy Lagrangian
  - Found potential explanation from 3 operator structures, including $\gamma^{\mu} P_L \otimes \gamma_{\mu} P_L$
  - But assumed particular flavour structure
    - Shared coefficients between $b \to c\bar{u}d$ and $b \to c\bar{u}s$

Could BSM be responsible?

- First, we want to do a more general analysis, using SMEFT
  - If left-handed => link to top physics
- To build up to a study of UV models

Top bounds

- Recent LHC measurements of top physics are reaching percent level precision
  - ATLAS 2023: $\sigma(t\bar{t})$ @1.8% $(140\,\mathrm{fb}^{-1}, \sqrt{s} = 13\,\mathrm{TeV})$
- Top decay width known at 10% precision from CMS 2017 $(20\,\mathrm{fb}^{-1}, \sqrt{s} = 8\,\mathrm{TeV})$

Top bounds

- What can we learn from this?
- Enough to compete against flavour?

Top bounds

- Use SMEFTsim + MadGraph to simulate (LO) cross-section in BSM scenarios
  - Rescale to match NNLO+NNLL SM
- In the future, aim is to study differential distributions and include SMEFT dim6^2 and dim8 effects

Top bounds

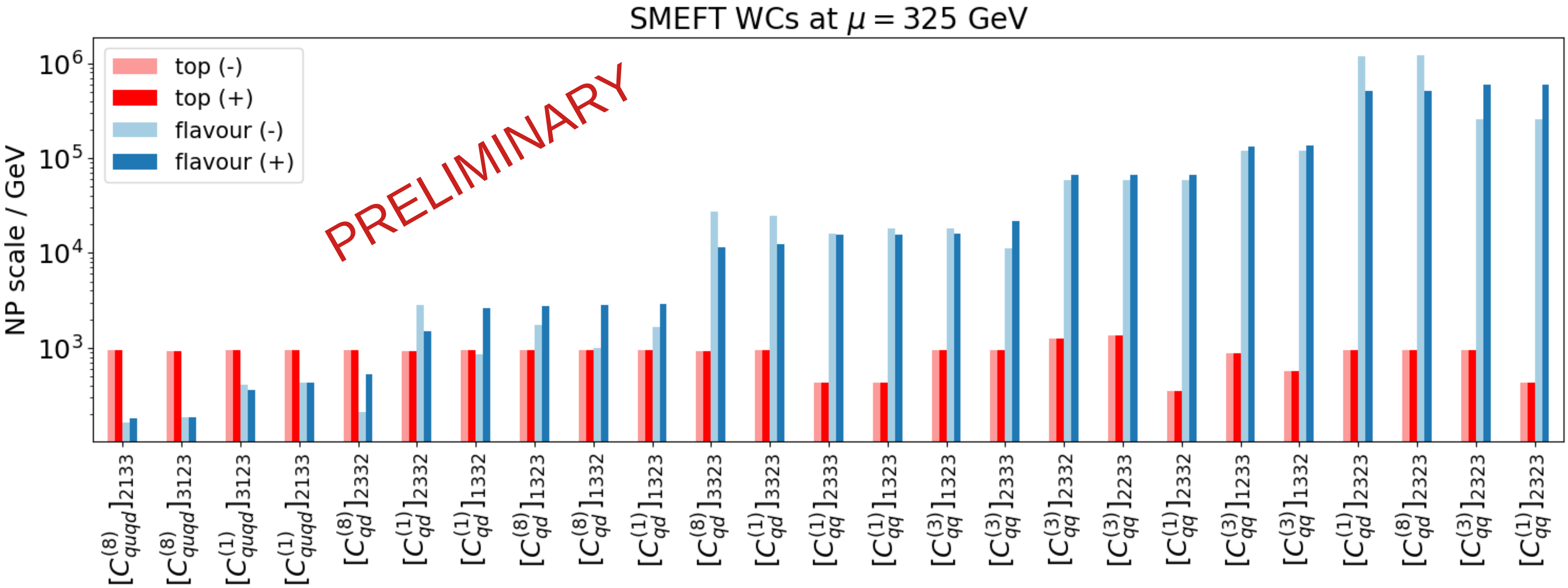
- Compare to ATLAS measurement to constraint SMEFT WCs
- As a comparison, we use smelli global fit (includes >500 observables)
  - Fit to our WCs dominated by quark physics

Top bounds

- Compare to ATLAS measurement to constraint SMEFT WCs

- As a comparison, we use smelli global fit
- Convert WC range $\frac{-x}{\mathrm{GeV}^2} \leq C \leq \frac{y}{\mathrm{GeV}^2}$ to hypothetical NP scale $\Lambda \geq \Lambda_\pm = 1/\sqrt{x, y}$

Top bounds on top?



Top bounds on top?

- In half of cases flavour is much stronger
- But for many coefficients, only stronger by factor of a few
- And for a handful, top comes out on top – tells us more than flavour right now!

Running down from the top (scale)

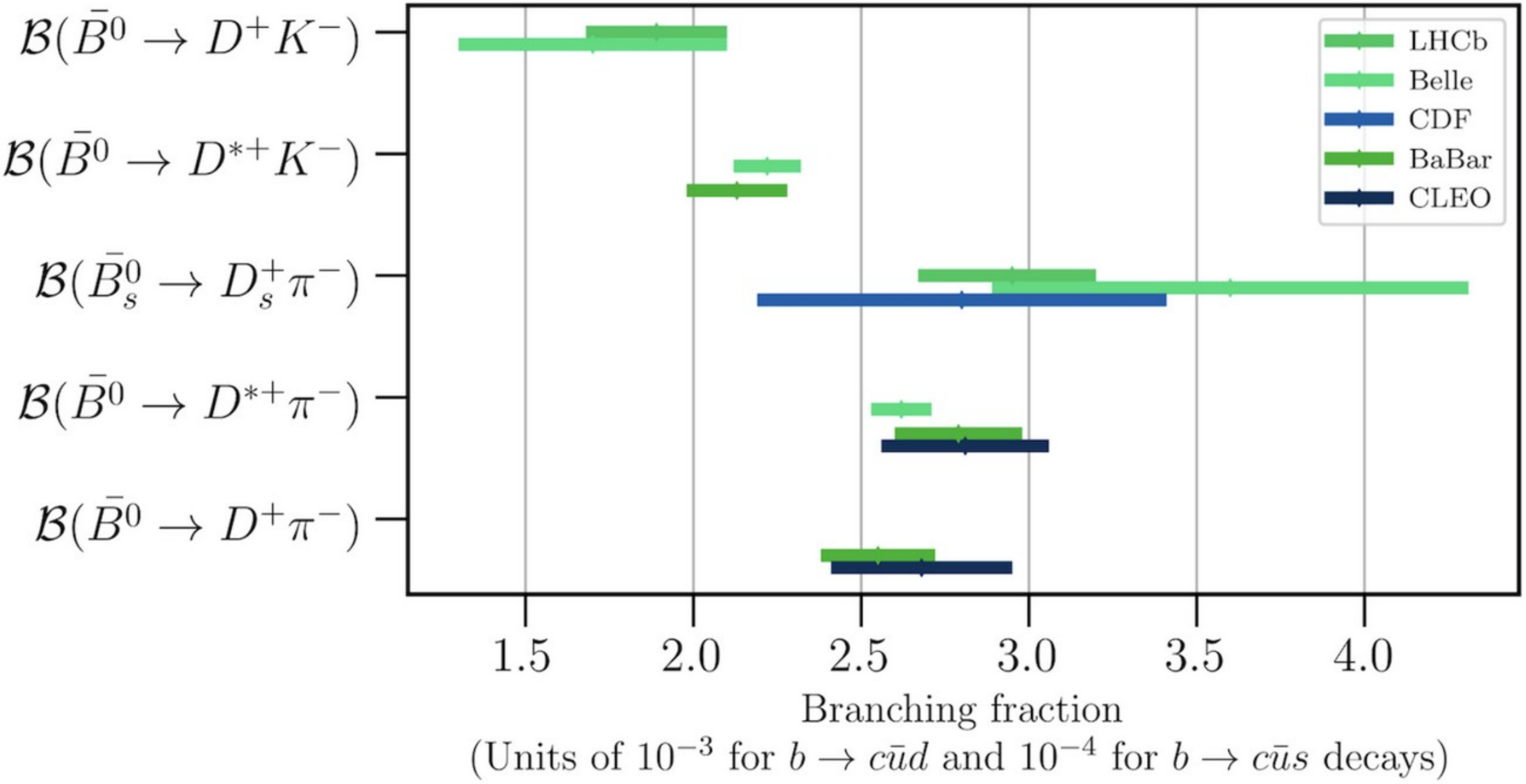
- Take our analysis of non-leptonic physics
- Run SMEFT coefficients down to see what high scale NP could generate $b \to c\bar{u}q$ at low energy
- Current work in progress:
  - Check one/two at a time coefficient bounds
  - Multi-particle NP

Summary

- Large tensions in non-leptonic decays still has no good non (B)SM explanation
- If high scale BSM, then could show up in top physics @ LHC, and LHC starting to have enough data to give useful constraints
- Ongoing: use SMEFT to connect to other low energy sectors and study UV models

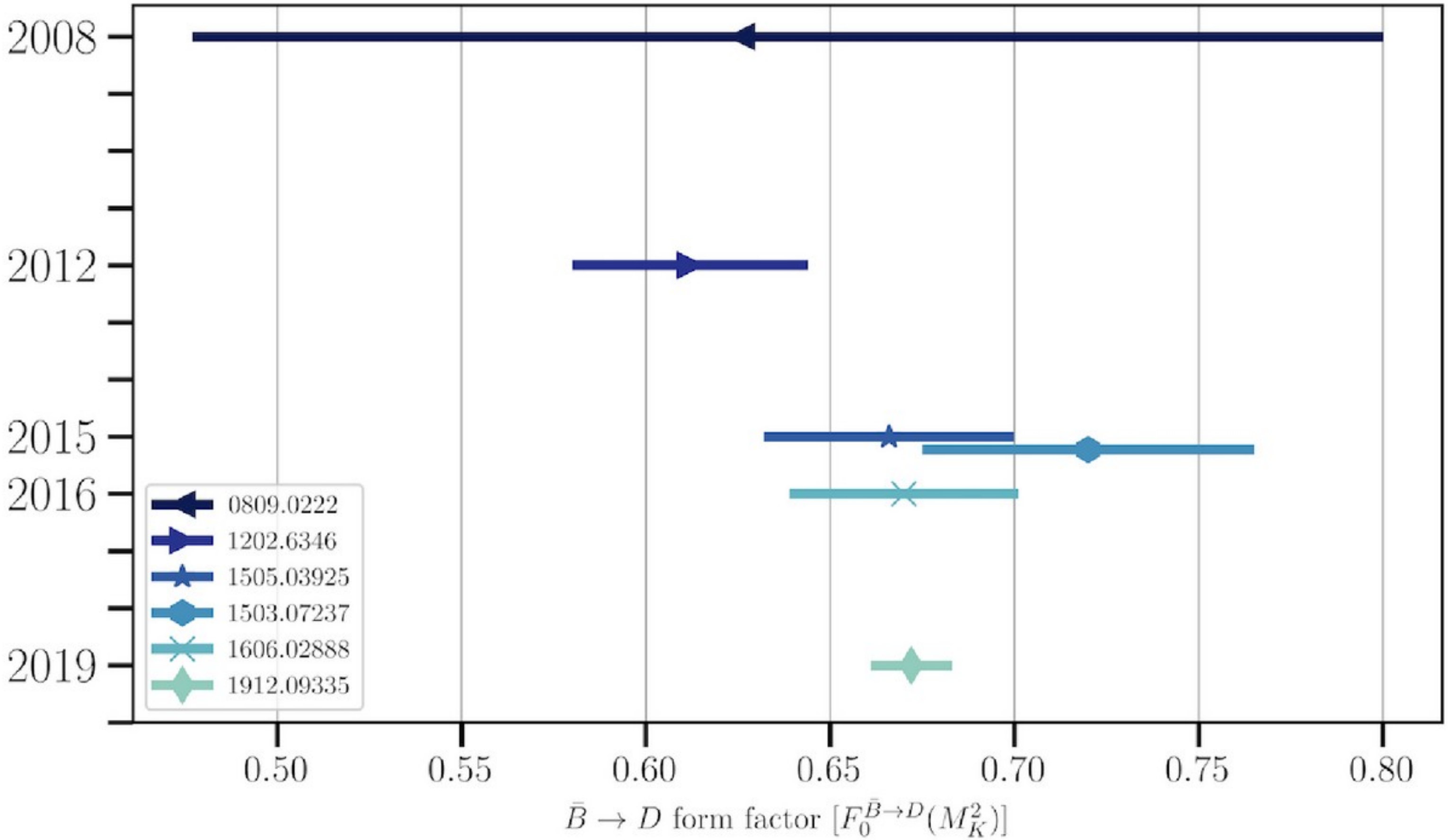
BACKUP

Exp error?



Piscopo, BFA V

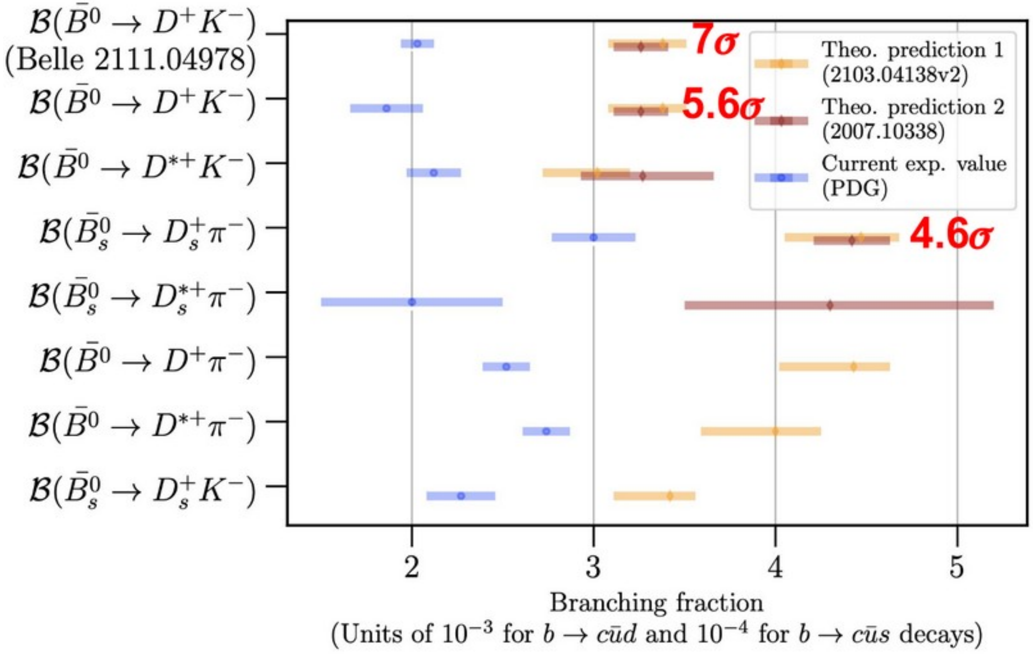
Progress on form factors



Piscopo, BFA V

Non-leptonic ~~anomalies~~ quirks

- From 2020 calculations showed serious discrepancy between theory and experiment



Nicole Skidmore (Status and Prospects of non-leptonic B meson decays, Siegen 2022)