

Top BSM phenomenology of

$$B \rightarrow DK \text{ \& } B_s \rightarrow D_s \pi$$



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Nonleptonic Decays of Heavy Mesons

24 March 2026

(based on 2411.00940 & 260x.yyyyy with Araz, Atkinson, Englert,
Tetlalmatzi-Xolocotzi)

Why $B \rightarrow DK$ & $B_s \rightarrow D_s \pi$?

- In heavy quark limit, certain heavy meson decays factorise in a simple way:

$$B_q \rightarrow D_q L \sim F^{B \rightarrow D}(M_L^2) \times (T^I \otimes \Phi_L) + O(1/m_b)$$

- In general, $O(1/m_b)$ corrections expected to be sizeable, generated from annihilation and/or penguin topologies

Why $B \rightarrow DK$ & $B_s \rightarrow D_s \pi$?

- But for $B \rightarrow DK$ and $B_s \rightarrow D_s \pi$, annihilation and penguin topologies are missing, as all four quarks in the final state are different
 - As we already heard from Stefan, corrections (that we have calculated) are small
- Perfect test case for QCD factorisation

$B \rightarrow DK$

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

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Huber, Kränkl, Li Cai, Deng, Li, Yang & Meiser, van Dyk, Virto
- Power corrections: $\sim \text{few } \%$ unc. (?)
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

Topics in B Physics, 4th Workshop on Recent Developments in High-energy Physics (1988)

appearing in semileptonic decays. What is implied, therefore, is a direct relationship between the nonleptonic pionic decay and semileptonic decays. An easy calculation gives¹⁵

$$\frac{\Gamma(\Lambda_b \rightarrow p\pi^-)}{\frac{d\Gamma}{dM^2}(\Lambda_b \rightarrow pe^-\nu_e)_{M^2=0}} = 6\pi^2 F_\pi^2 \simeq 1.0 \text{ GeV}^2 \quad (4.5)$$

This is indeed a general test of factorization; the p can be replaced by any low-mass hadron system, and the Λ_b by any b -meson B . It is quite important to test sharply this factorization hypothesis wherever possible. There may already be a way to do this in decays such as $B \rightarrow D\pi$ and $B \rightarrow D^*\pi$.

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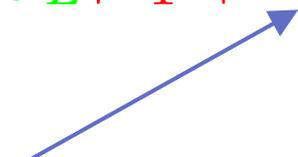
15. I am told this is in the folklore but do not know a good reference.

Make a ratio

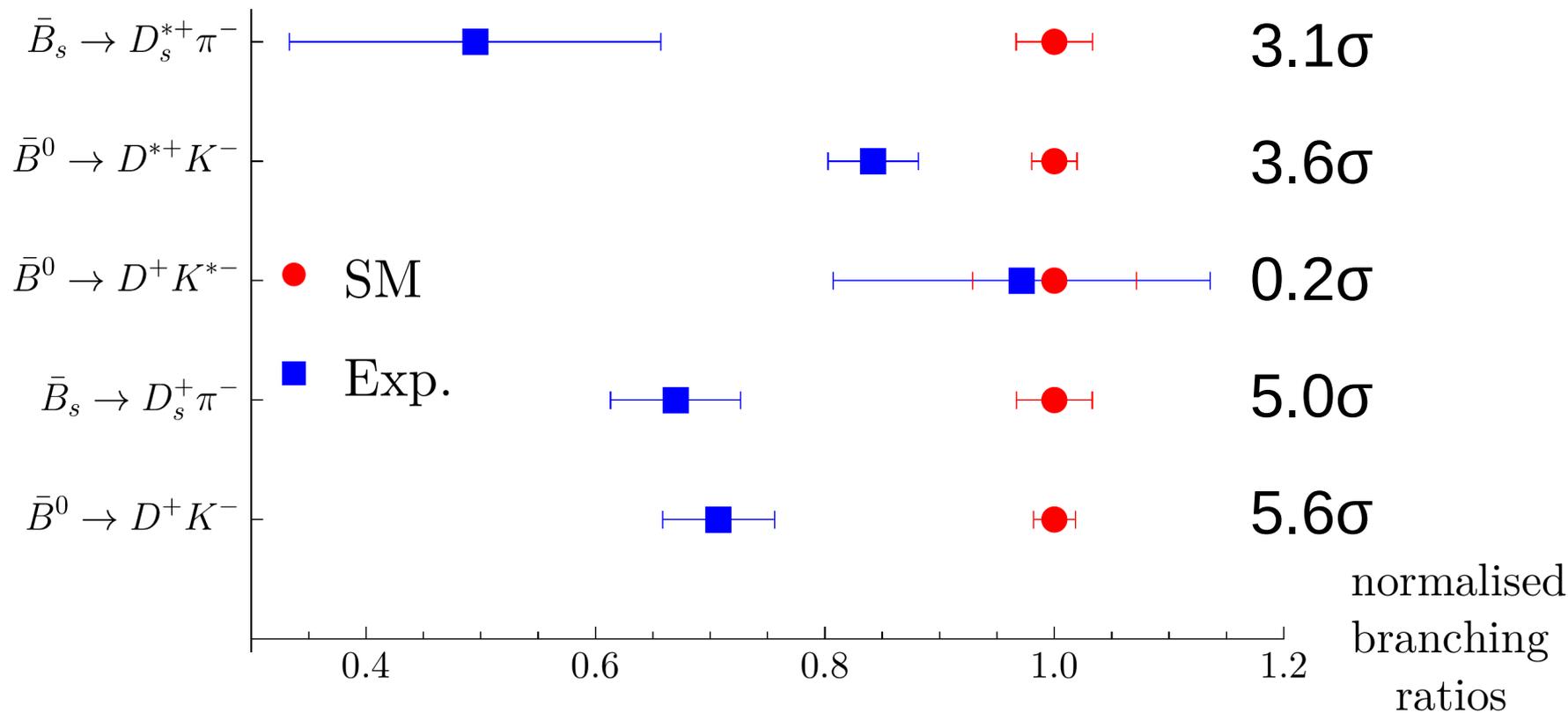
- We normalise by semi-leptonic decays to remove V_{cb} dependence, and reduce form factor dependence

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

form factor ratio, < 1% unc



Non-leptonic anomalies



Is there a BSM explanation?
Part 1: SMEFT analysis

Why SMEFT?

- Assumes gauge symmetry above EW scale is really $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
- Quark doublets are the correct degree of freedom
- Therefore any NP affecting left-handed bottoms also affects tops
 - Collider probes can help reveal nature of BSM

BSM from bottom to top

- In Cai, Deng, Li, Yang ([2103.04138](#)) they analysed data with low energy Lagrangian
- Found potential explanation from 3 operator structures, including interactions with LH bottom quarks

Top bounds

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

Top bounds

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

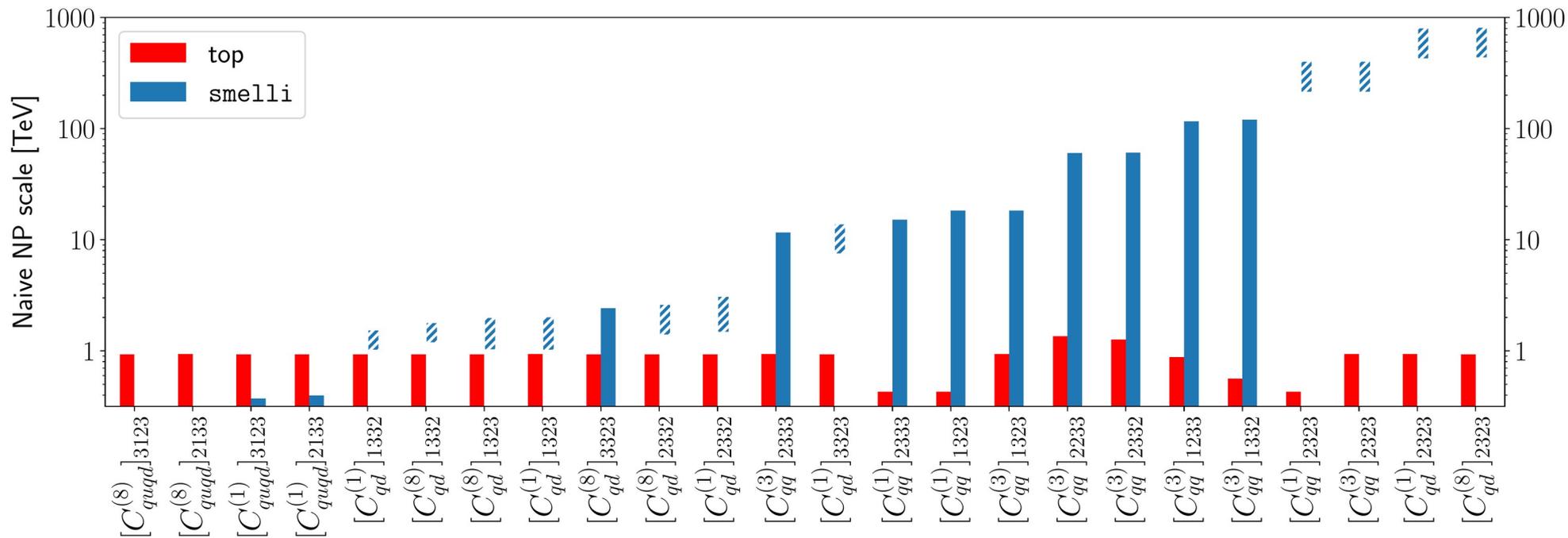
Top bounds

- Use SMEFTsim + MadGraph to simulate (LO) cross-section in BSM scenarios
 - Rescale to match NNLO+NNLL SM
- Constrained by the ATLAS measurement

NP scale

- As a comparison, we use smelli global fit (includes >500 observables)
 - Fit to our WCs dominated by quark physics
- Convert WC range $\frac{-x}{\text{GeV}^2} \leq C \leq \frac{y}{\text{GeV}^2}$ to a hypothetical NP scale $\Lambda \geq \Lambda_{\pm} = 1/\sqrt{x, y}$

Top bounds on top?



Top bounds on top?

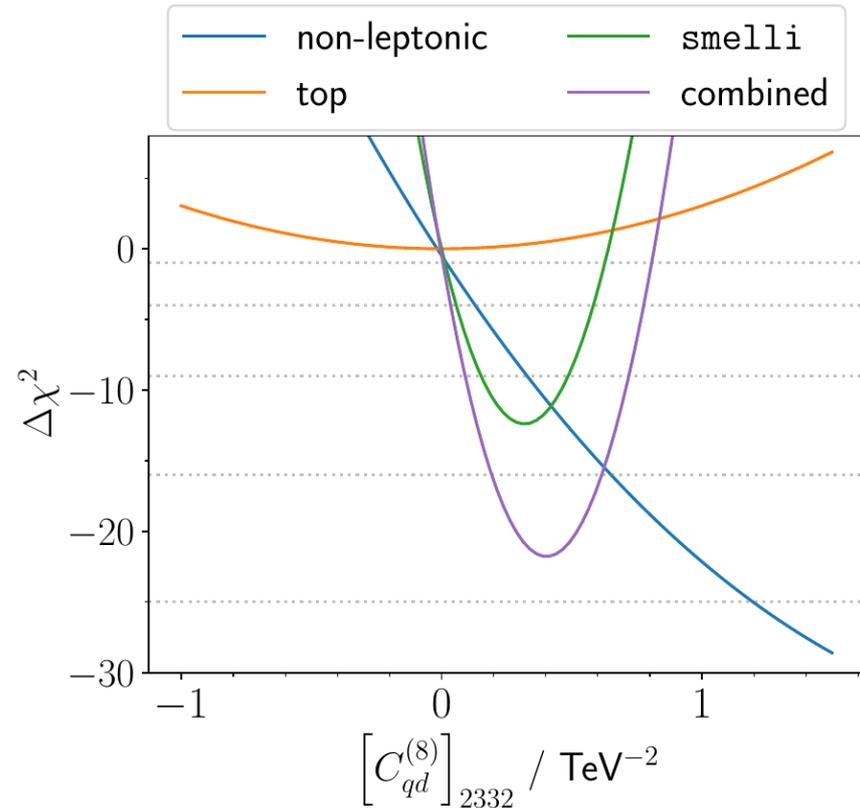
- In half of cases flavour is much stronger
- But for many coefficients, only stronger by factor of a few
- And for a handful, top comes out on top – tells us more than flavour right now!

Single WC scenarios

- Our study identified several SMEFT coefficients which can lead to χ^2 reduction of more than 9 (i.e. a 3σ pull relative to SM)
- I will show just three of them here:
 - $[O_{qd}^{(8)}]_{2332}, [O_{quqd}^{(1)}]_{3123}, [O_{ud}^{(1)}]_{1232}$

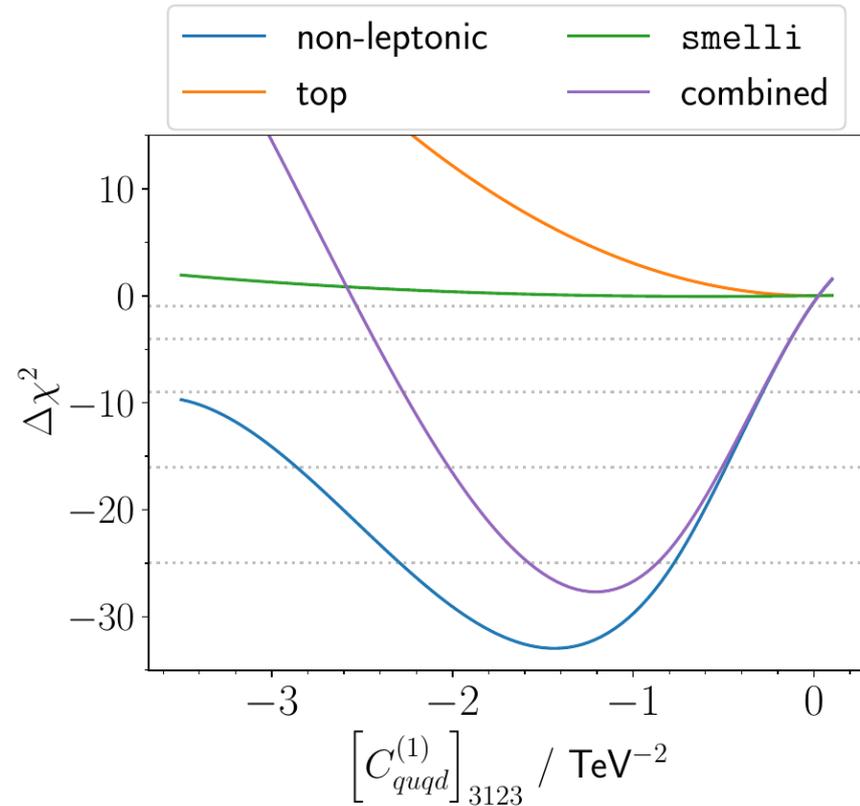
$$[O_{qd}^{(8)}]_{2332} = (\overline{Q_L^2} \gamma^\mu t^a Q_L^3) (\bar{b}_R \gamma_\mu t^a s_R)$$

- We find top & smelli & non-leptonic all relevant
- A global analysis is important!



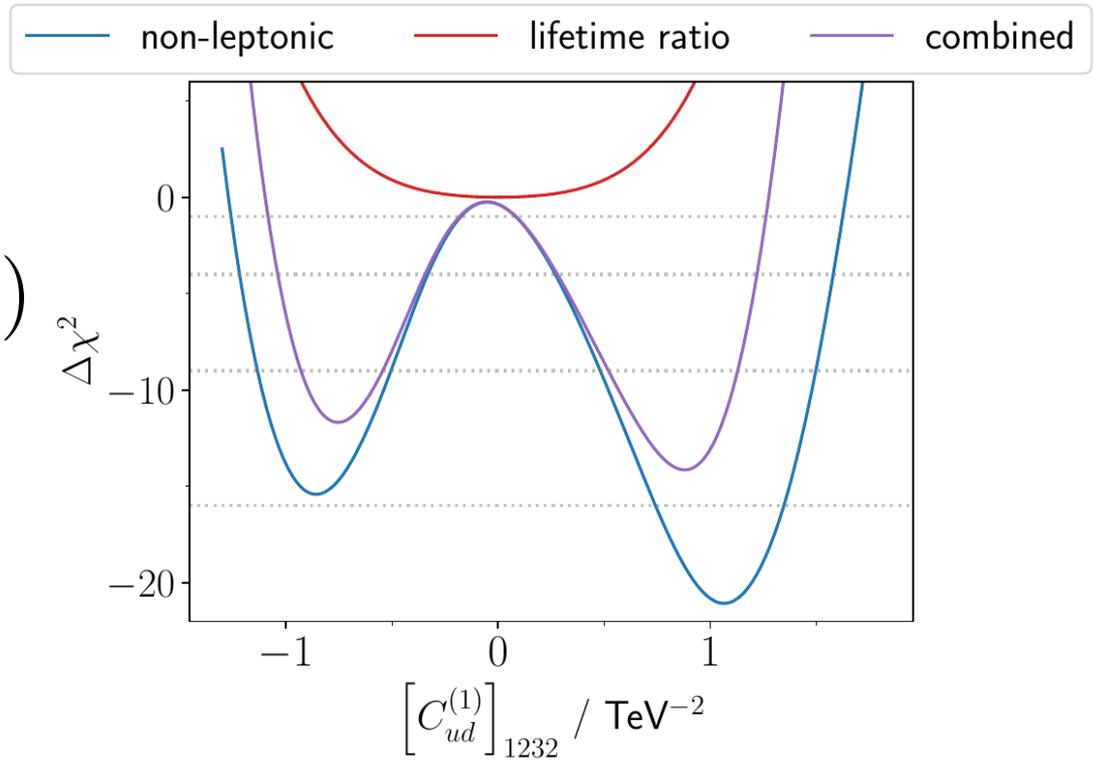
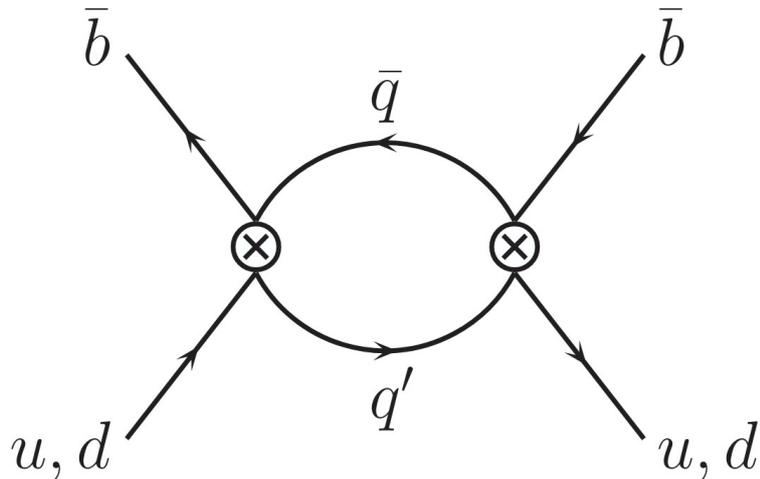
$$[O_{quqd}^{(1)}]_{3123} = (\overline{Q}_L^3 u_R)(\overline{Q}_L^2 b_R)$$

- Other flavour bounds weak, top is top



$$[O_{ud}^{(1)}]_{1232} = (\bar{u}_R c_R)(\bar{b}_R s_R)$$

- Lifetime ratio important
- We use $\tau(B^+)/\tau(B_d)$



Is there a BSM explanation? Part 2: UV model analysis

Di-jets as bounds

- Since our NP must* couple to four-quark operators, it will affect $pp \rightarrow jj$ observables
 - * unless it modifies W couplings, so that 4-quark interactions only arise in LEFT, but this is strongly constrained by semi-leptonics
- Bordone, Greljo, Marzocca did a nice analysis in 2021

Bordone, Greljo, Marzocca

- List all single particle mediators which give 4-quark interactions

Exploiting dijet resonance searches for flavor physics

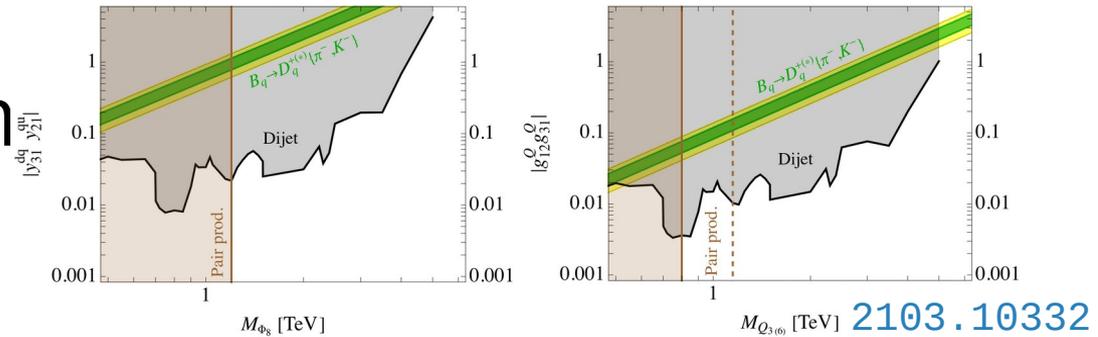
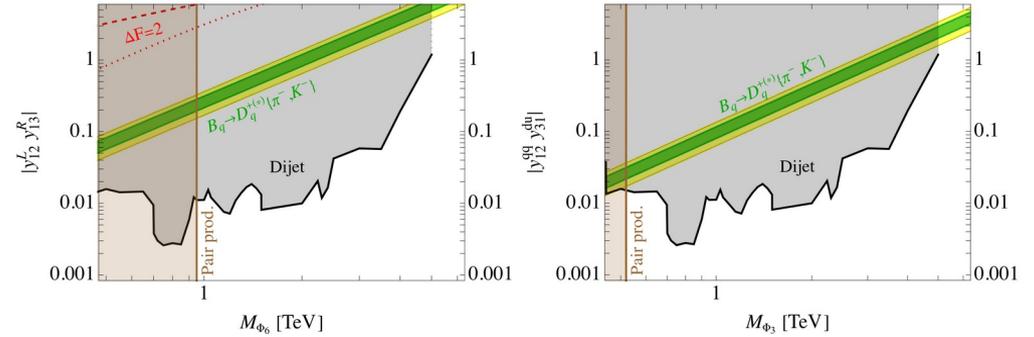
2103.10332

Marzia Bordone,^{a,b} Admir Greljo,^{c,d} and David Marzocca^e

- Reinterpret LHC dijet limits on Z' for different spin and colour charge

Bordone, Greljo, Marzocca

- List all single particle mediators which give 4-quark interactions
- Reinterpret LHC dijet limit spin and colour charge
- Find conflict between BSM favoured and LHC allowed regions



3 potential paths

1) Non minimal couplings

- Reduce BR to dijet => weaken collider bounds

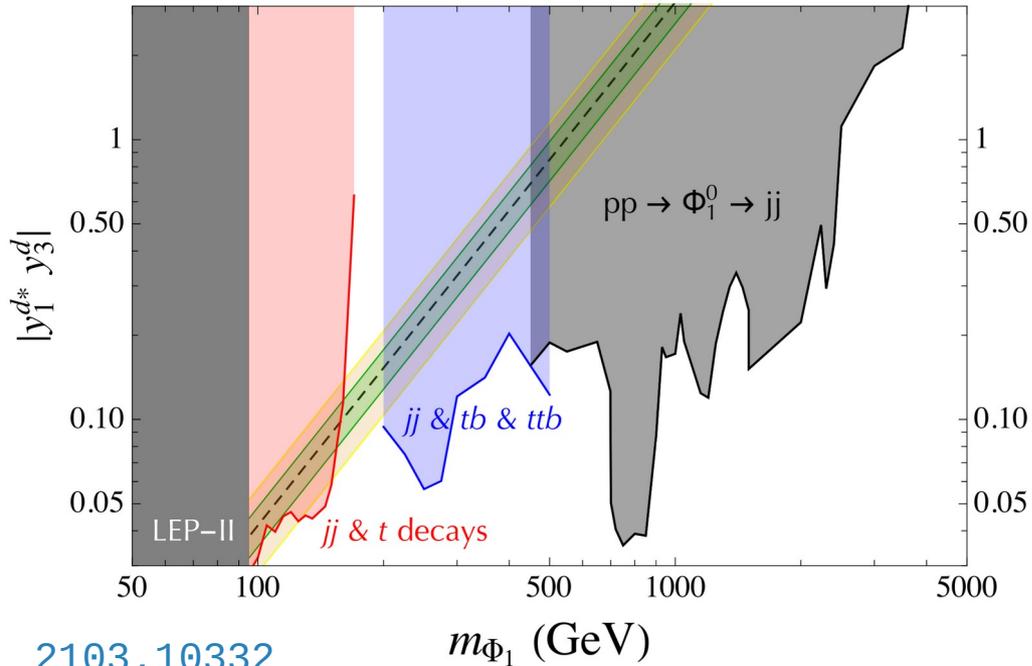
2) Unexpected power corrections

- Reduce size of BSM couplings for anomaly

3) Non minimal BSM

- Multiple particles combine to give anomaly

What we tried: 2HDM

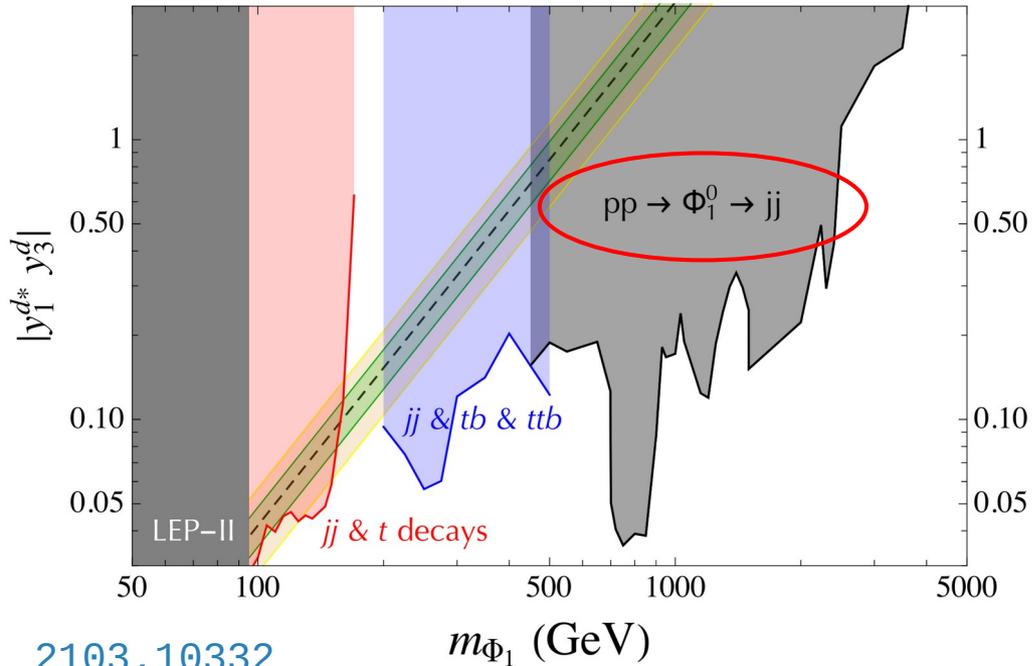


- BGM use minimal couplings:

$$\mathcal{L}_{\text{BSM}} = -y_i^d \Phi^\dagger d_R^i \overline{Q}_L^i$$

with $y_1^d = y_2^d$

Top hiding places



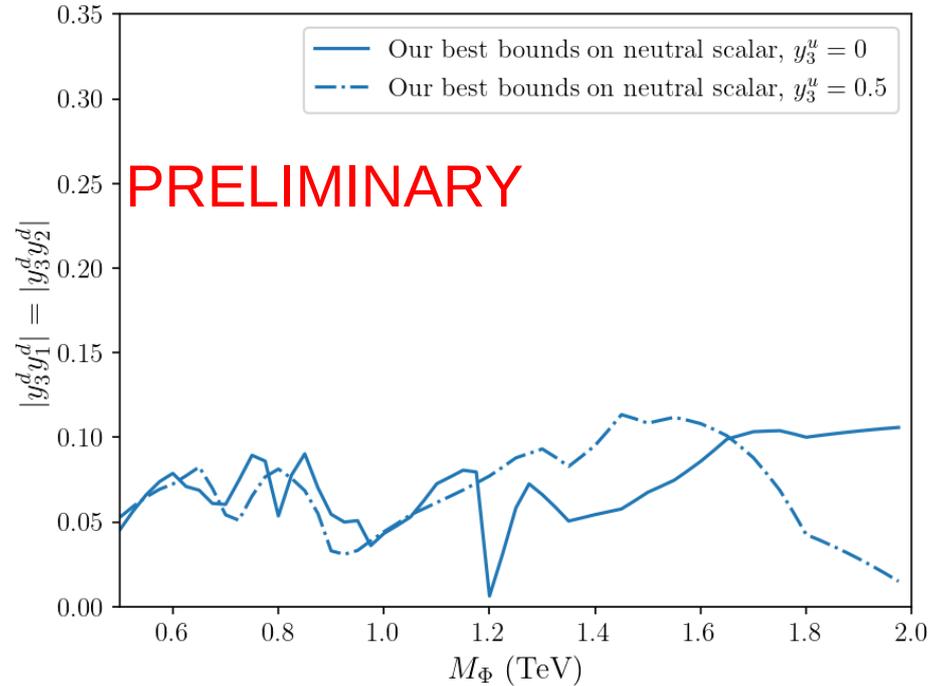
- BGM state that above 500 GeV, strongest bounds are neutral scalar \rightarrow light dijets
- If we reduce the BR to dijet with a large $t\bar{t}$ coupling, can we weaken collider limits?

Top hiding places

- $\mathcal{L}_{\text{BSM}} = -y_i^d \Phi^\dagger d_R^i \overline{Q_L^i}$
 $-y_i^u \tilde{\Phi}^\dagger u_R^i \overline{Q_L^i}$
- With $y_3^u = 0.5$, $\text{Br}(tt) \sim$
 $\text{Br}(jj) \sim 50\%$

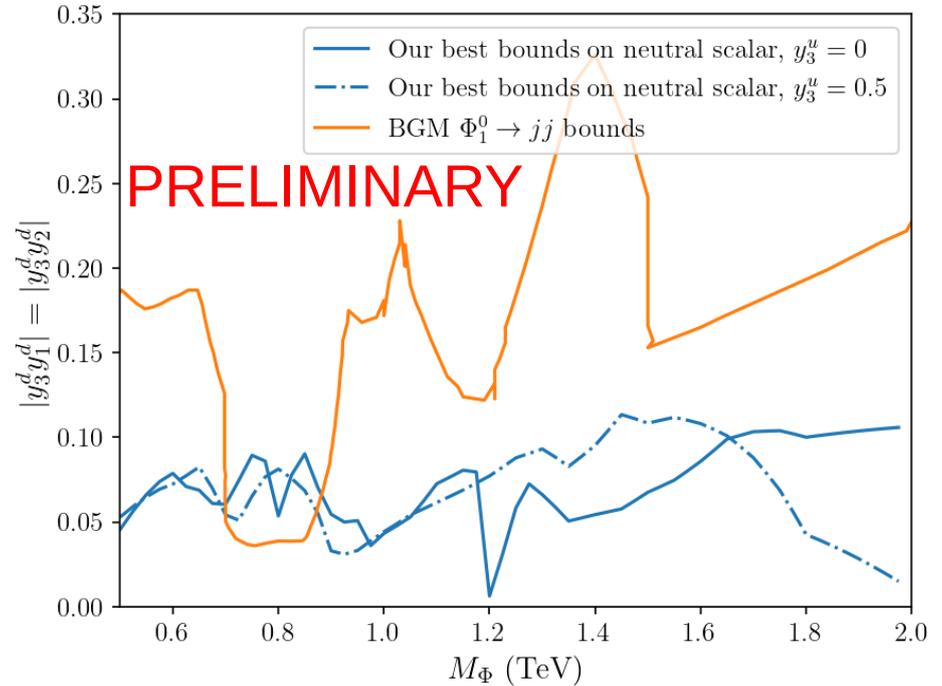
Top hiding places

- $\mathcal{L}_{\text{BSM}} = -y_i^d \Phi^\dagger d_R^i \overline{Q_L^i} - y_i^u \tilde{\Phi}^\dagger u_R^i \overline{Q_L^i}$
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- Collider bound weakened (sometimes)



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- With $y_3^u = 0.5$, $\text{Br}(tt) \sim \text{Br}(jj) \sim 50\%$
- Collider bound weakened (sometimes)
- But our bounds stronger



Large power corrections

- Universal power corrections of $\sim -15\%$ would remove anomaly

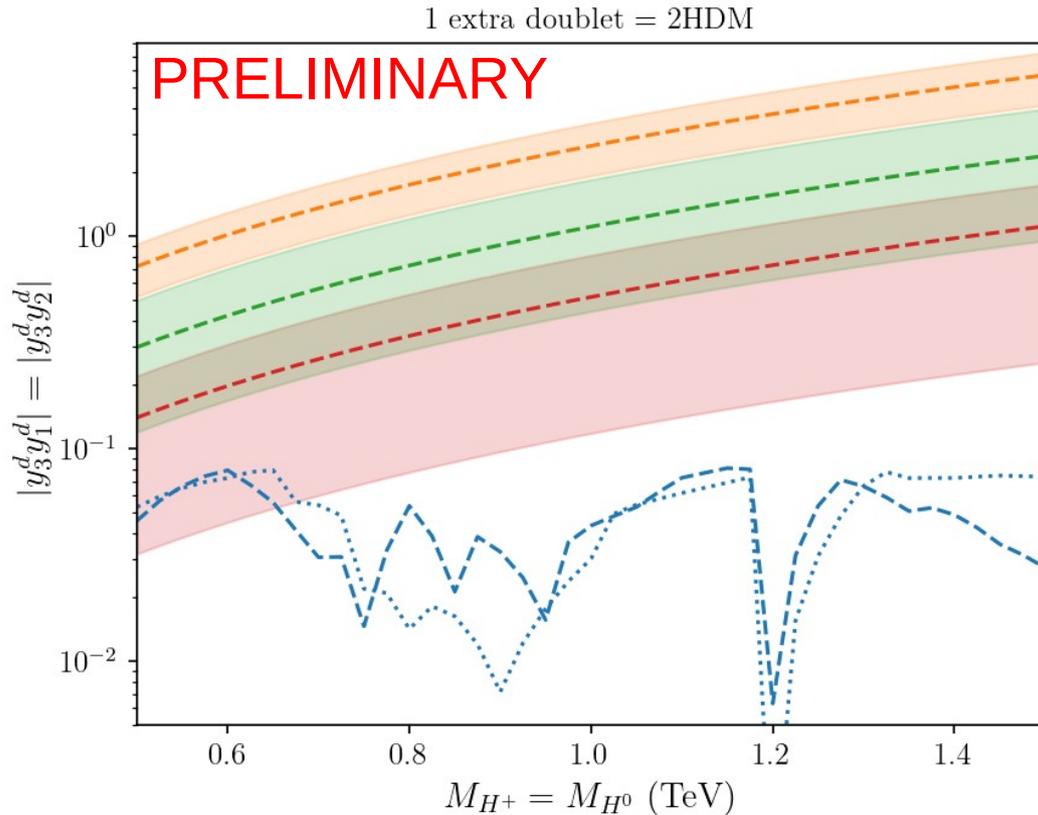
Fixed PC (%)	SM χ^2
0	66
-5	34
-10	16
-15	9.5

Large power corrections

- Universal power corrections of $\sim -15\%$ would remove anomaly
- Assume 5% or 10% power corrections \Rightarrow reduce size of BSM couplings needed

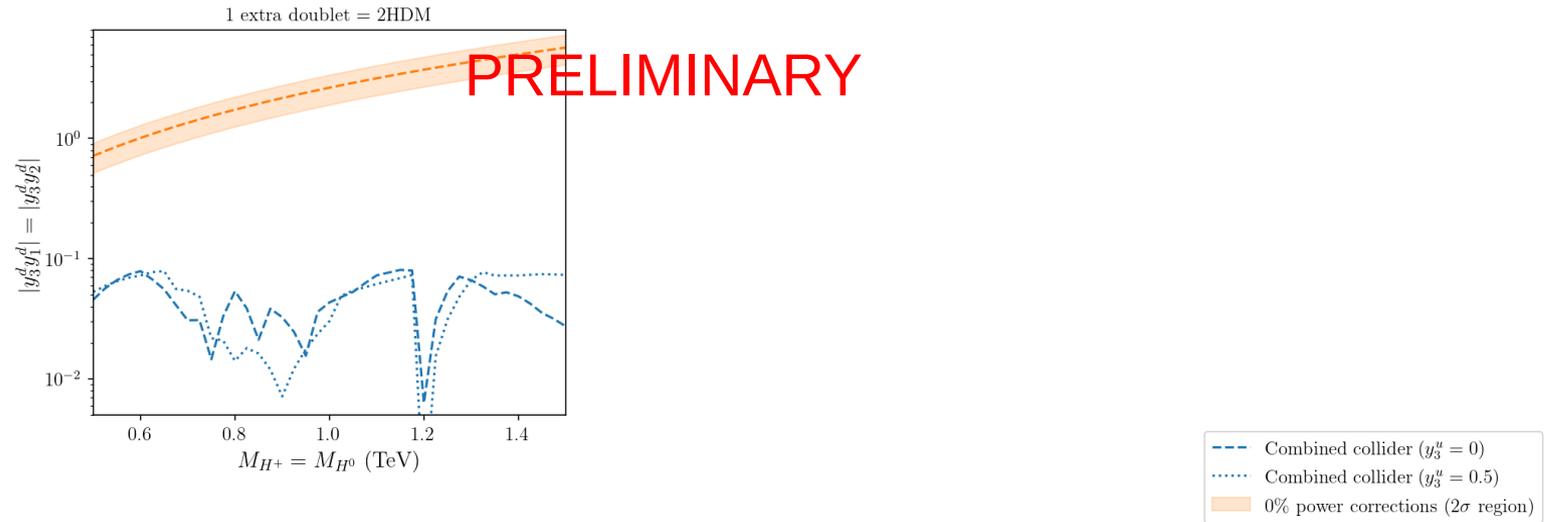
Fixed PC (%)	SM χ^2	BSM best fit		
		$y_1^d y_3^d / M^2$	$\Delta\chi^2$	pull
0	66	-3.6	-61	7.8σ
-5	34	-2.5	-30	5.5σ
-10	16	-1.5	-11	3.3σ
-15	9.5	-0.6	-1.9	1.4σ

Large power corrections



Fixed PC (%)	SM χ^2	BSM best fit			BSM 2σ range
		$y_1^d y_3^d / M^2$	$\Delta\chi^2$	pull	
0	66	-3.6	-61	7.8σ	[-4.6, -2.6]
-5	34	-2.5	-30	5.5σ	[-3.5, -1.6]
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-15	9.5	-0.6	-1.9	1.4σ	[-1.6, 0.3]

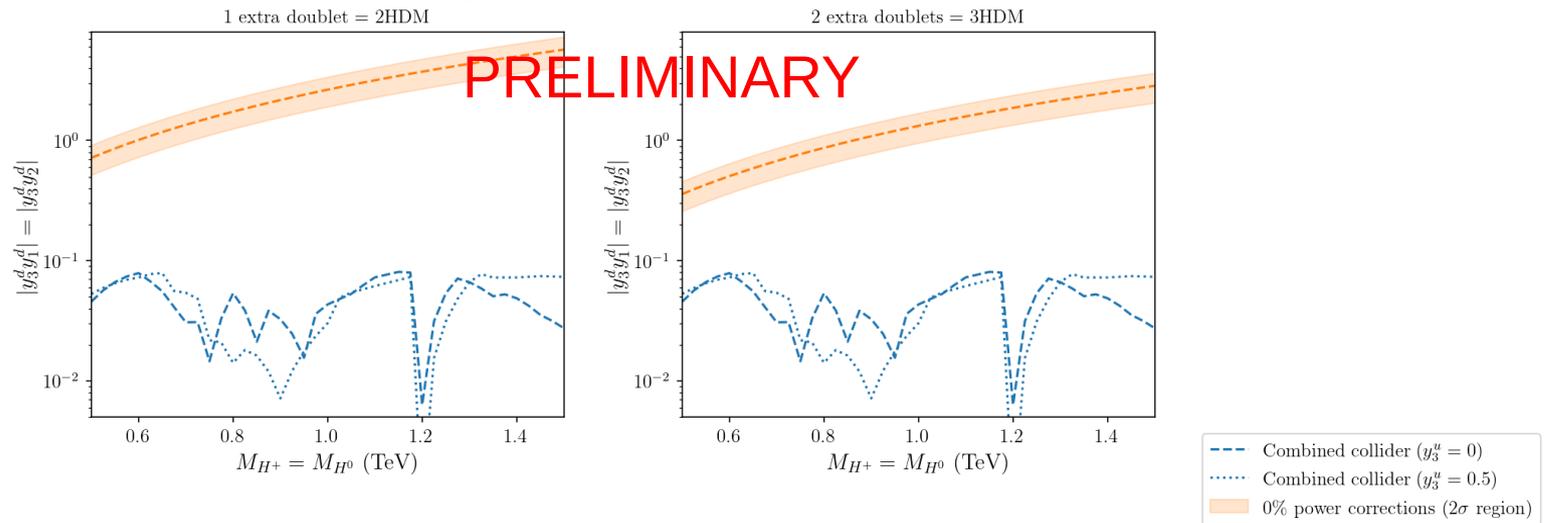
Multi particle BSM



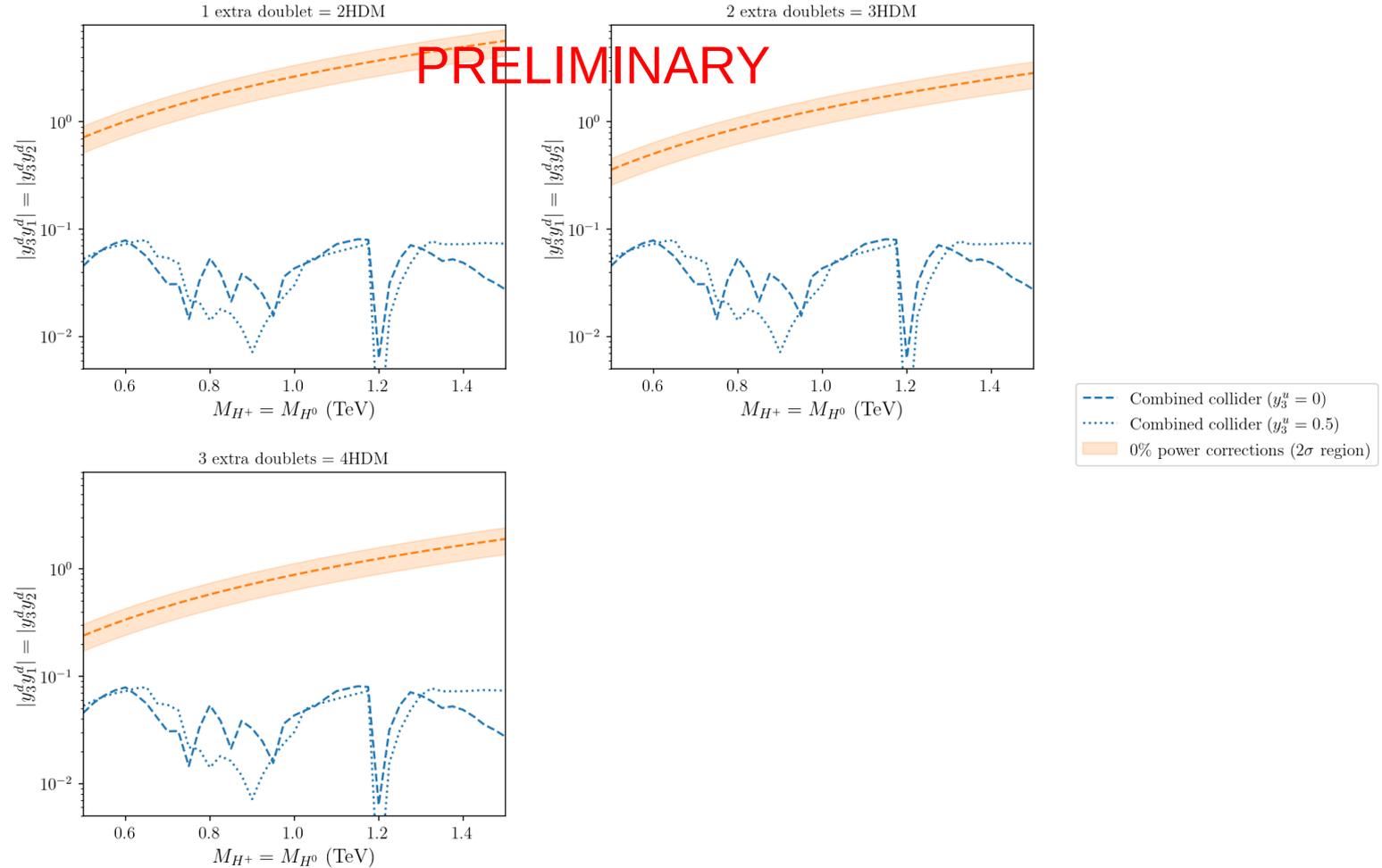
Multi particle BSM

- If n BSM particles:
 - combine to give non-leptonic effects =>
$$g^{\text{BSM}} \rightarrow g^{\text{BSM}} / \sqrt{n}$$
 - But collider bounds are the same
- For what value of n does this work?
 - and/or what value of n is this stupid scenario?

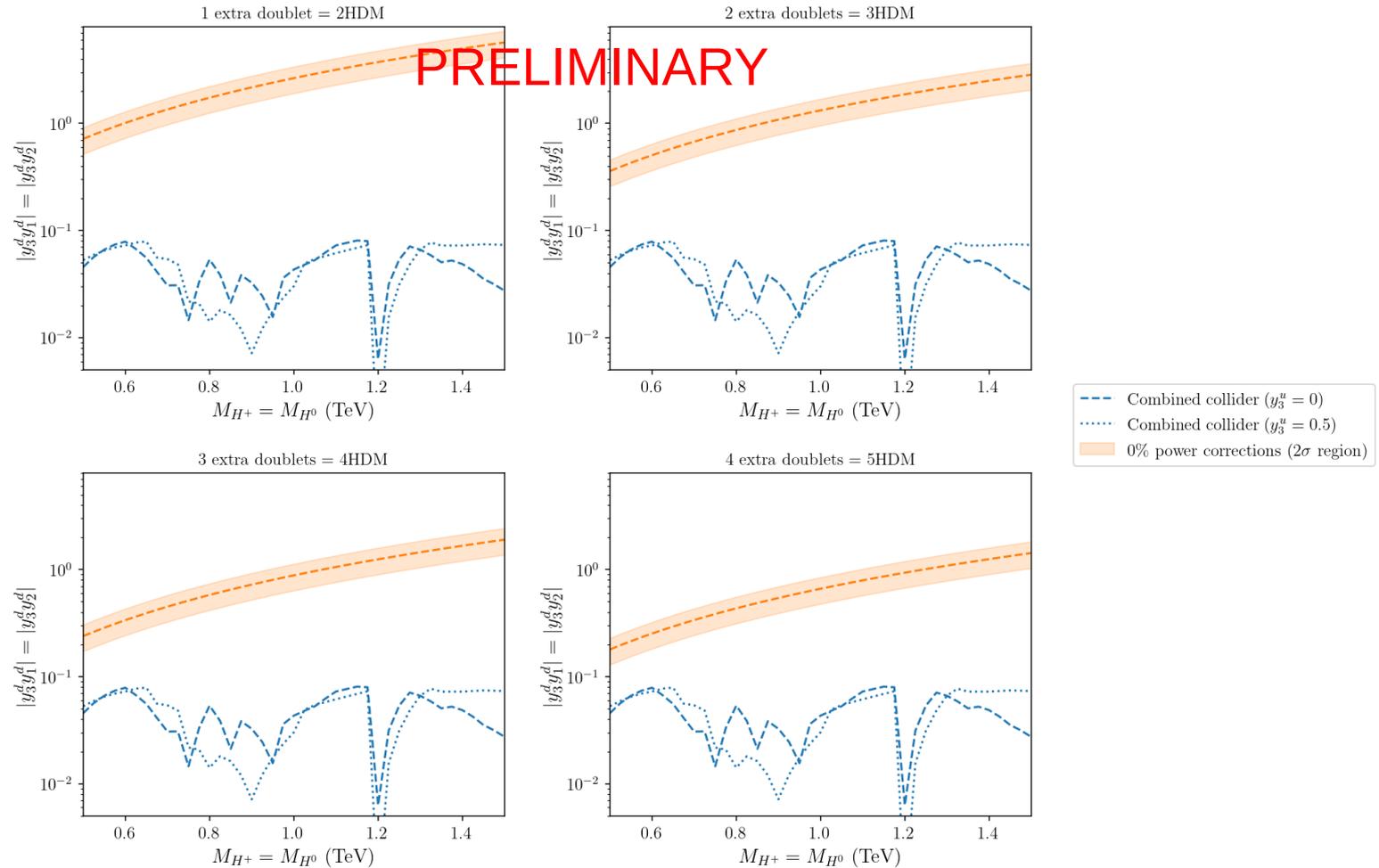
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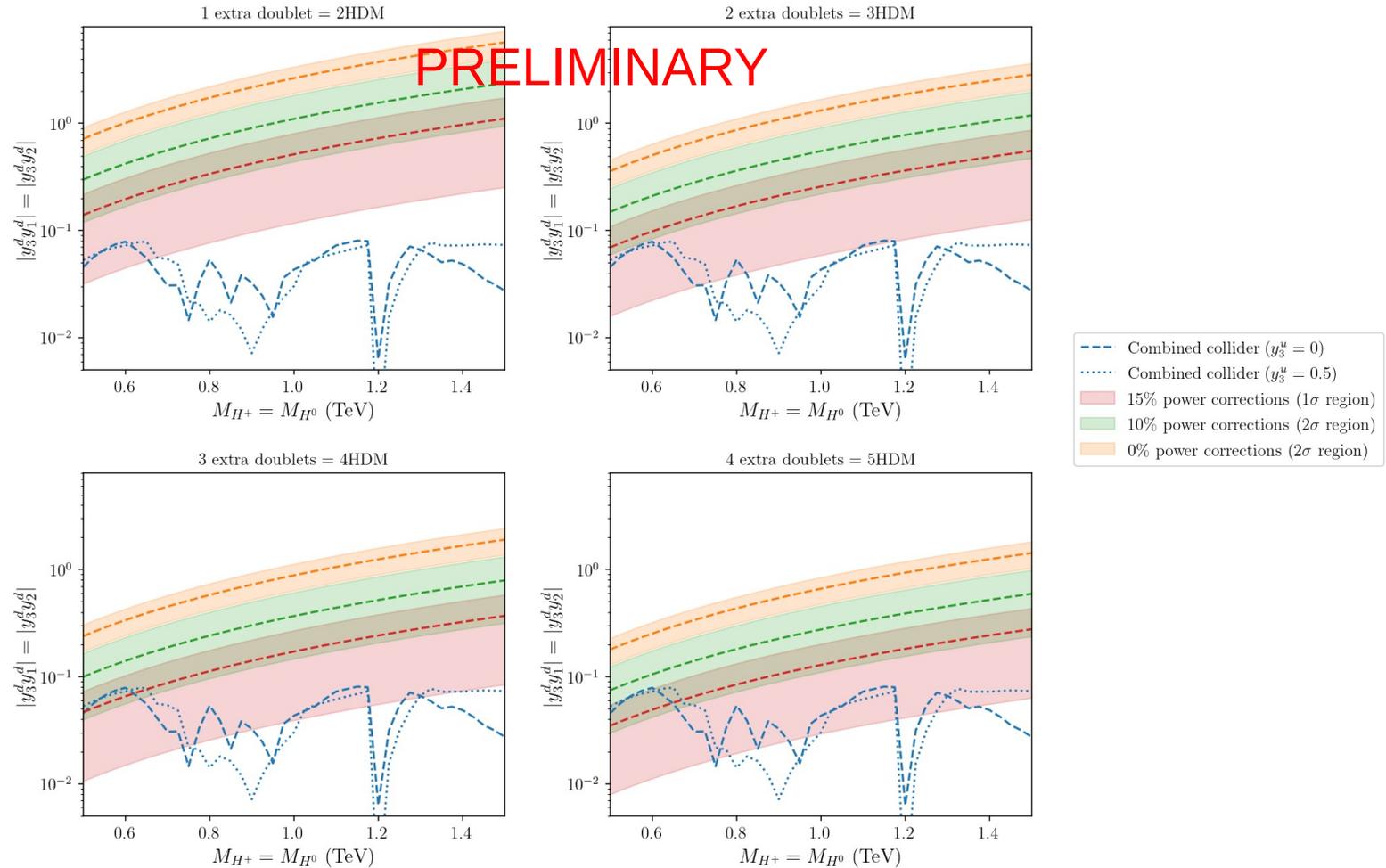
Multi particle BSM



Multi particle BSM



Power corrections + nHDM ?



Power corrections + nHDM ?

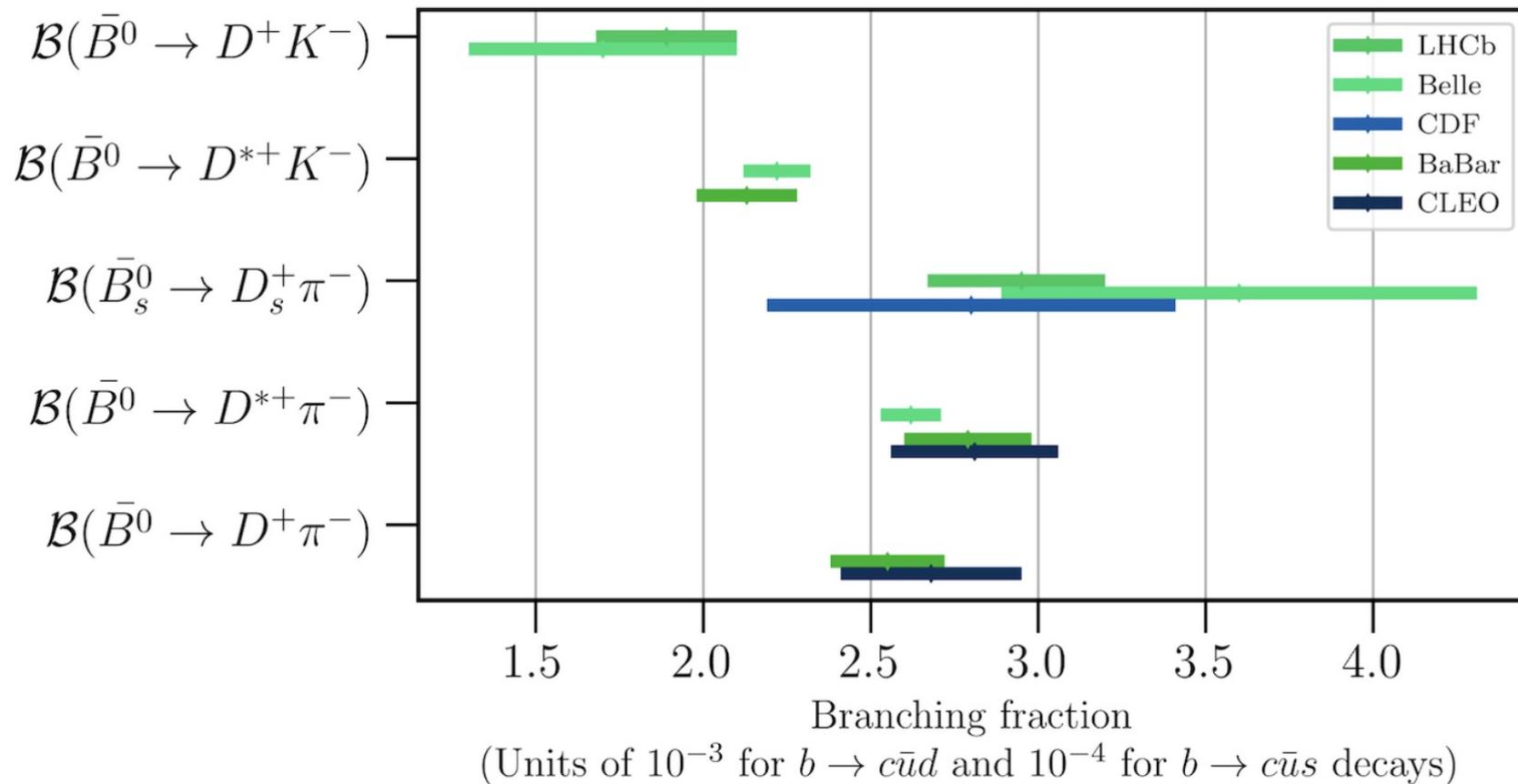
- 2HDM + 10% power corrections => ~1sigma improvement 😞
- 3HDM + 10% power correction => ~2sigma improvement 🖐️
- 4HDM + 10% power correction almost ~3sigma improvement 😜

Summary

- Top measurements are becoming competitive with low energy flavour for some Dirac structures
- Simple BSM models are strongly constrained by collider
- Even non-minimal nHDMs look awkward
- Anomaly will continue to puzzle...

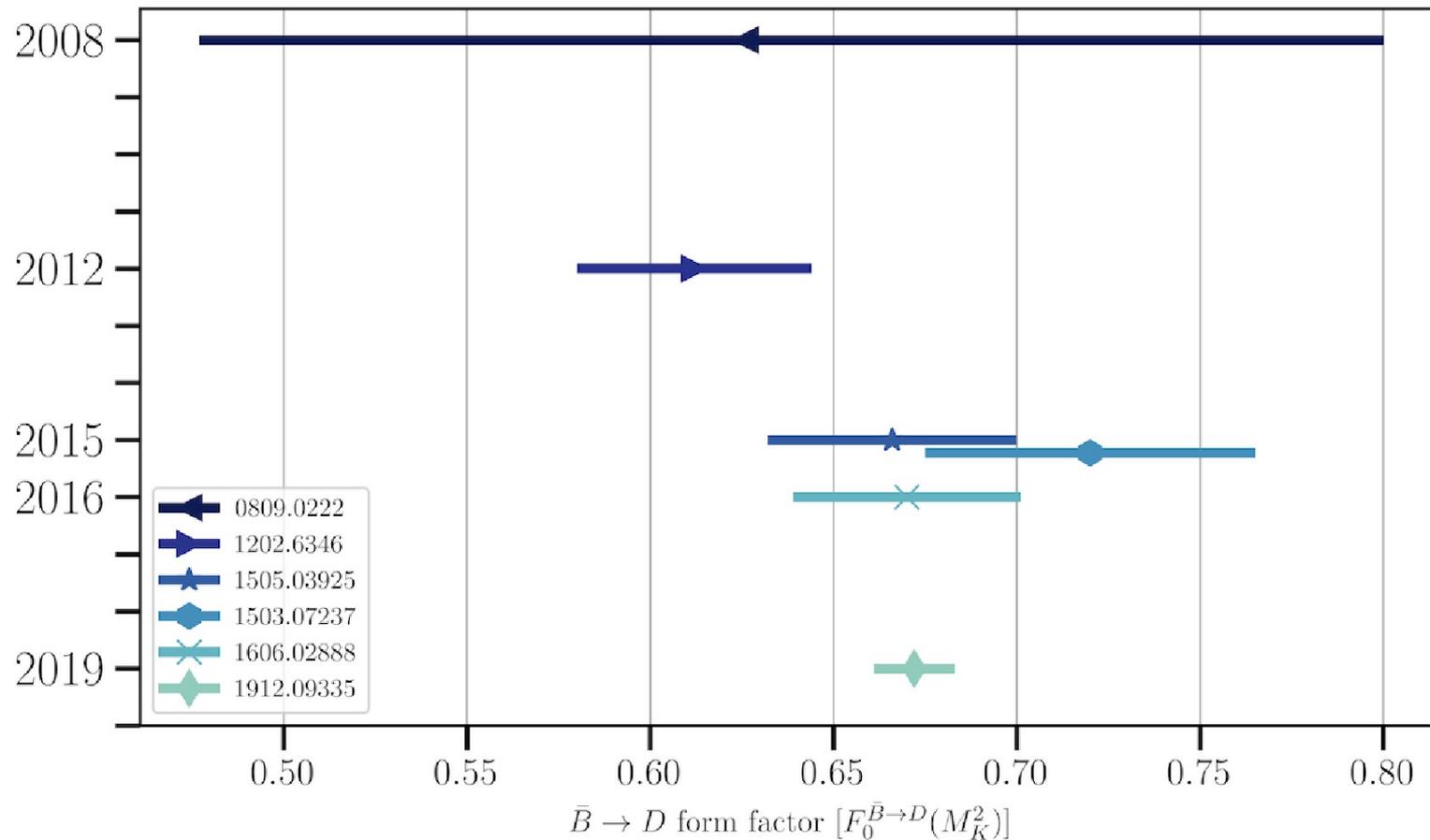
BACKUP

Exp error?



Piscopo, BFA V

Progress on form factors



Piscopo, BFA V

Form factor ratio definition

$$X_P = \frac{(m_B^2 - m_D^2)^2}{[m_B^2 - (m_D + m_P)^2][m_B^2 - (m_D - m_P)^2]} \left| \frac{F_0(m_P^2)}{F_1(m_P^2)} \right|^2 ,$$

$$X_P^* = [m_B^2 - (m_{D^*} + m_P)^2][m_B^2 - (m_{D^*} - m_P)^2]$$

$$\times \frac{|A_0(m_P^2)|^2}{m_P^2 \sum_{i=0,\pm} |H_i(m_P^2)|^2} .$$

hep-ph/9705292

Non-Leptonic Weak Decays of B Mesons

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