# BSM in non-leptonic B decays?




Matthew Kirk




LHCb Implications
5 November 2026
(based on 2604.25998 with Araz, Englert, Tetlalmatzi-Xolocotzi)

# Non-leptonic B decays

- Fully non-leptonic decays? Sounds nasty!
- So why think about them?
- Two reasons…

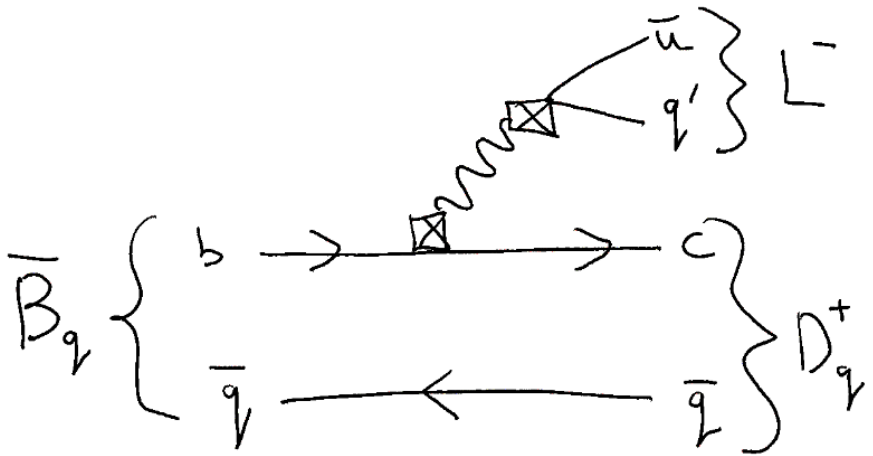
# Non-leptonic B decays

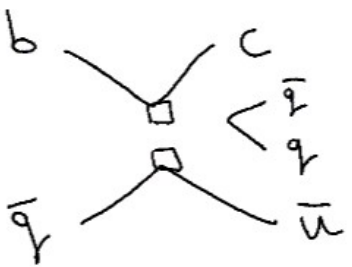
- In heavy quark limit, certain B meson decays factorise in a simple way:

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

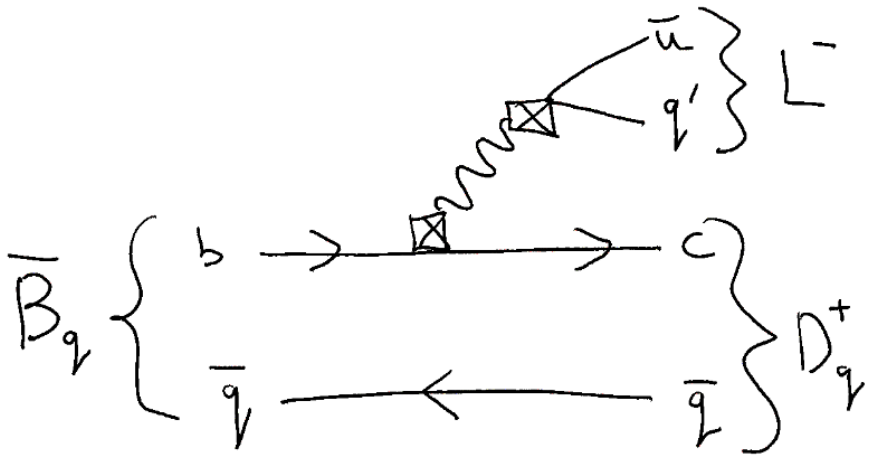
- In general, $O(1/m_b)$ corrections expected to be sizeable, generated from annihilation and/or penguin topologies

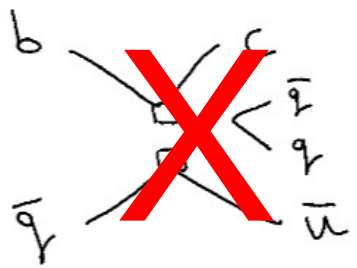
# $B \to DL$ decays



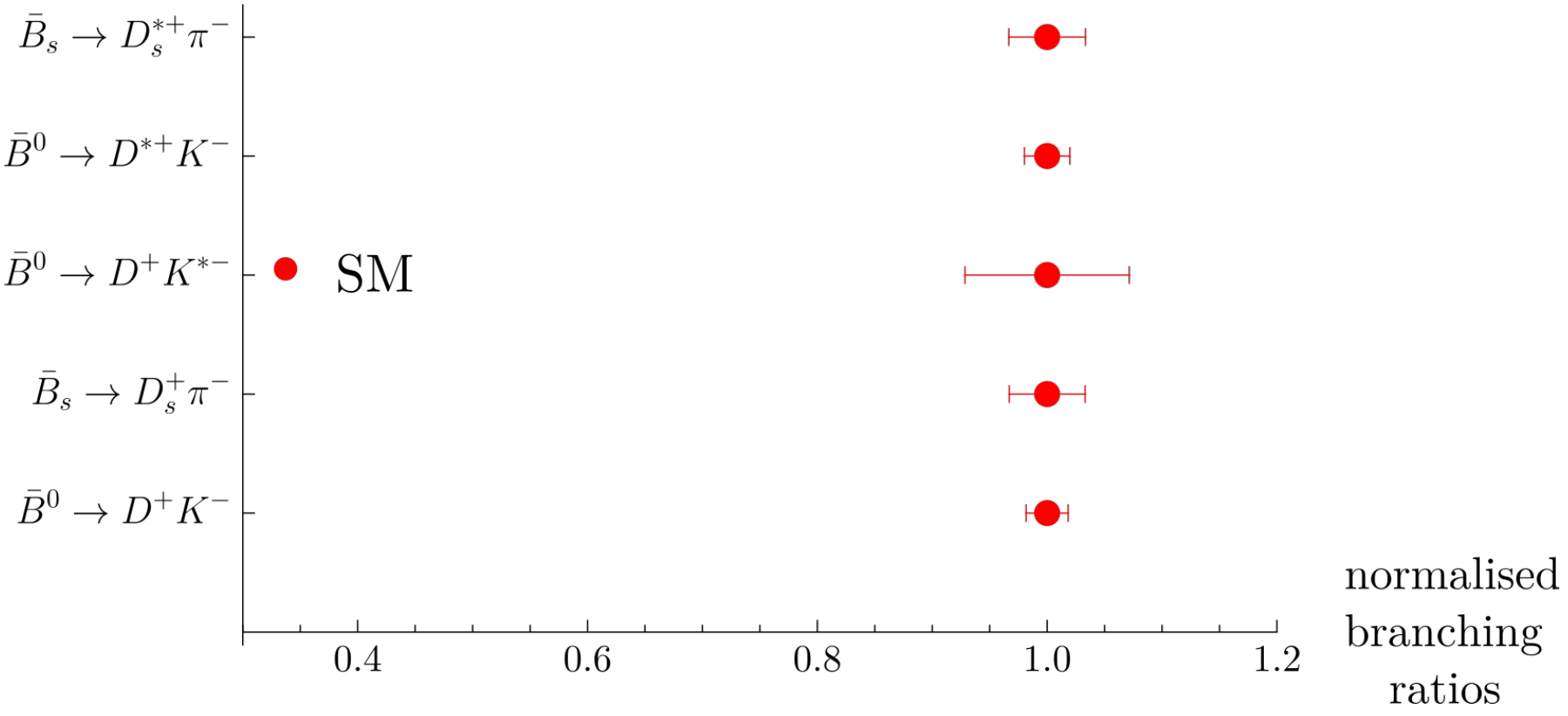
# Why $B \to DK$ & $B_s \to D_s\pi$?



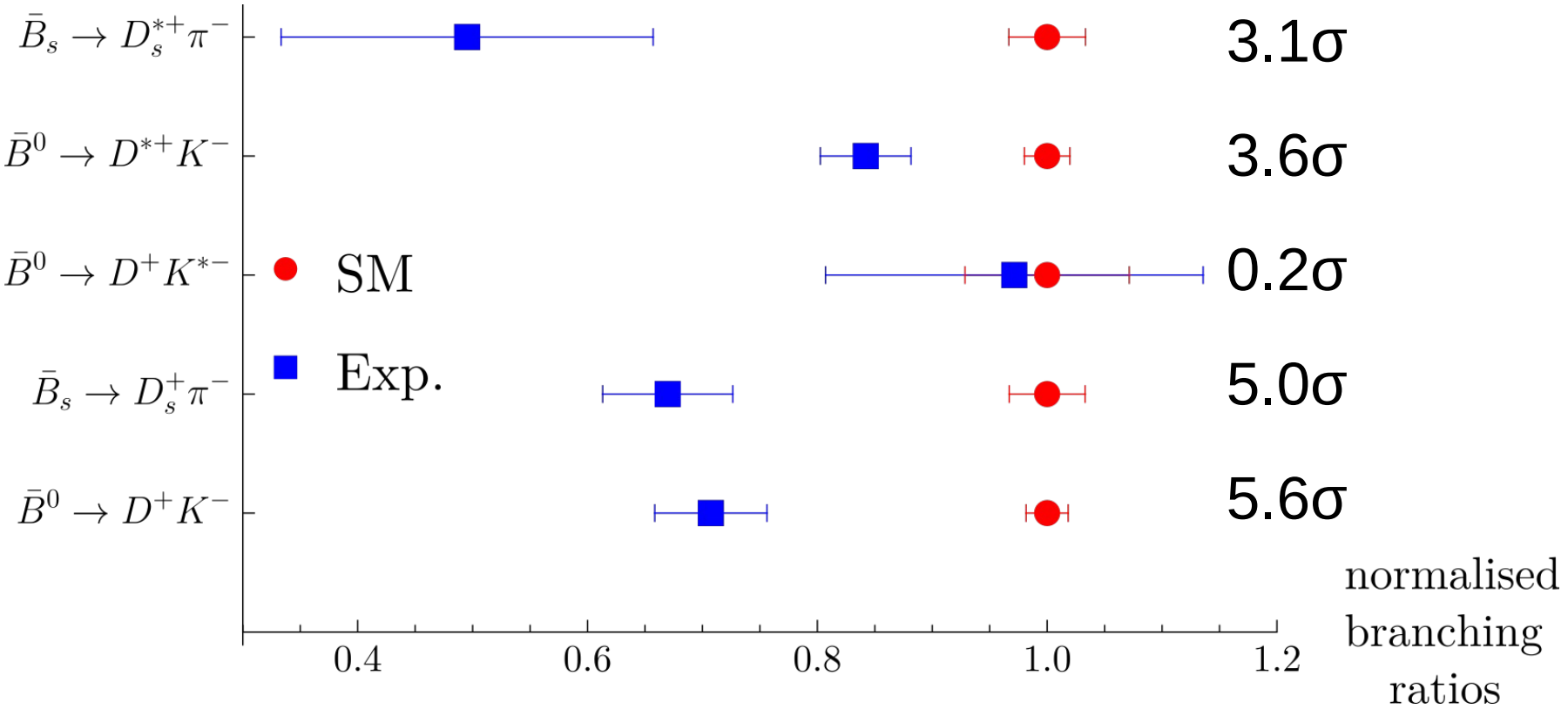




- But for $B \to DK$ and $B_s \to D_s\pi$, annihilation and penguin topologies are missing, as all four quarks in the final state are different
- Perfect test case for QCD factorisation

# Theory vs Experiment



# Theory vs Experiment



# BSM explanation?

# Di-jets as bounds

- Since our NP must* couple to four-quark operators, it will affect pp→jj observables
  - *unless it modifies W couplings, so that 4-quark interactions only arise after integrating out the W, 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**

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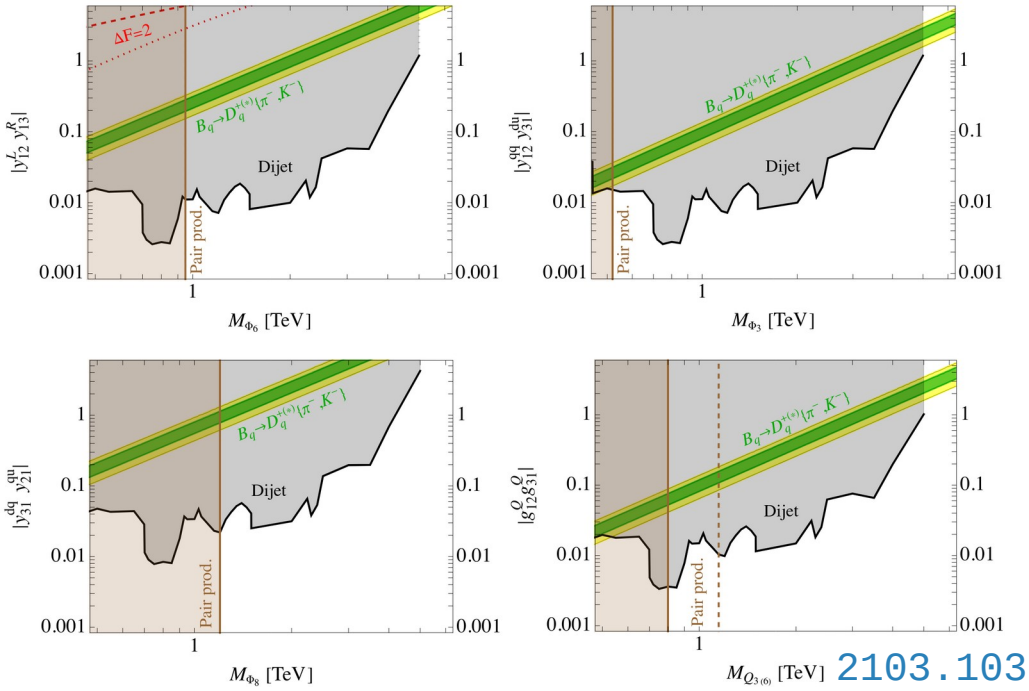
2103.10332

**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 lim spin and colour charge
- Find conflict between BSM favoured and LHC allowed regions



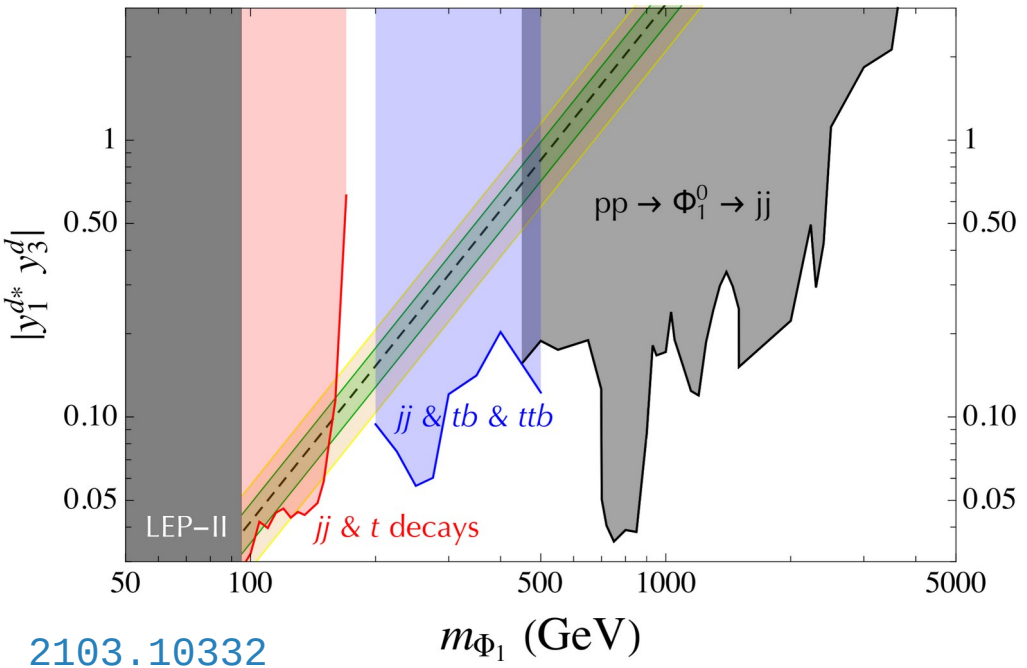

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# Going beyond minimal models

# 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 sector
   - Multiple particles combine to give anomaly

# What we tried: 2HDM



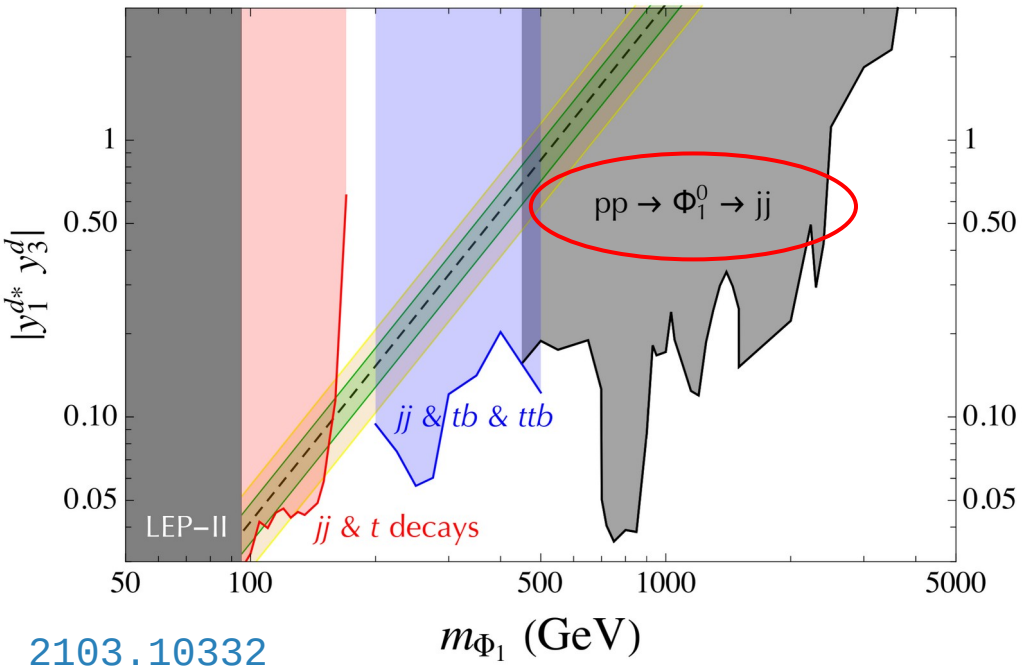

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- BGM use minimal couplings:

$$\mathcal{L}_{\rm BSM} = -y_i^d \Phi^\dagger d_R^i \overline{Q_L^i}$$

with $y_1^d = y_2^d$

# Top hiding places




2103.10332

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

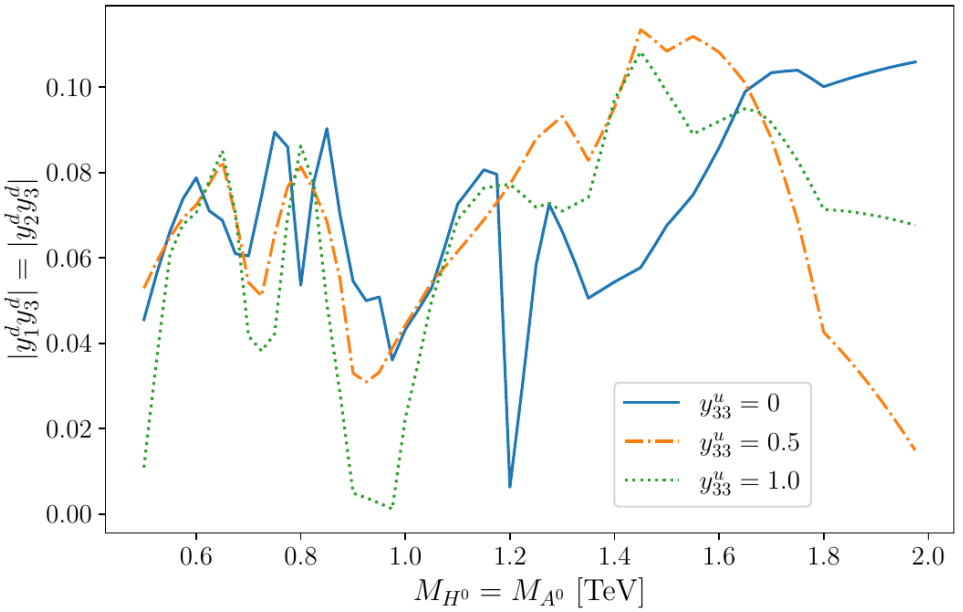
# Top hiding places

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

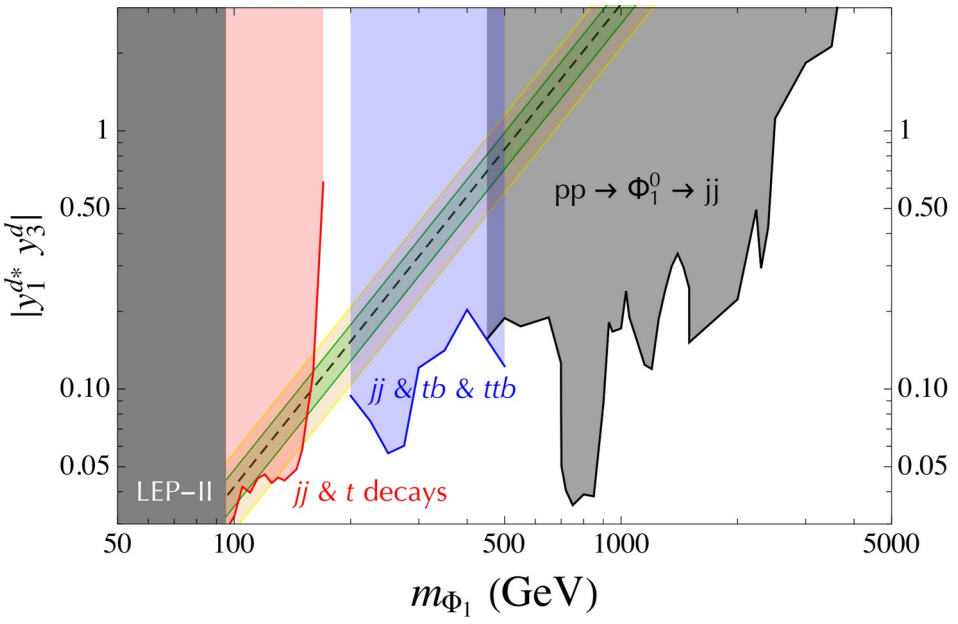
- We perform a direct simulation of this model (FeynRules → UFO → MadGraph) and compared to the experimental cross-section limits

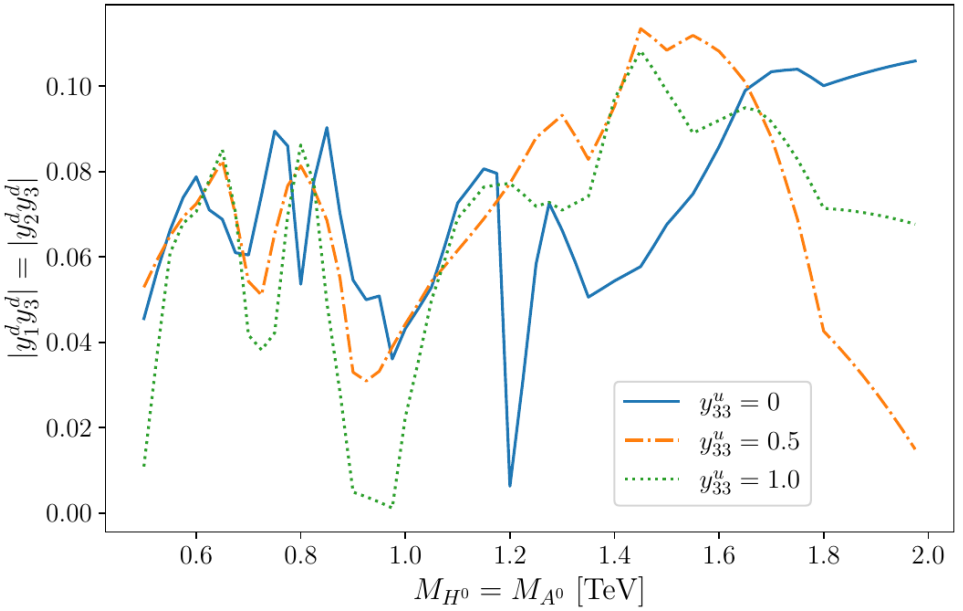
# Top hiding places

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  $-y_i^u \tilde{\Phi}^\dagger u_R^i \overline{Q_L^i}$
- With $y_3^u$ = 0.5, Br(tt) ~ Br(jj) ~ 50%
- Collider bound (sometimes) weakened



# Top hiding places




(sometimes) weakened

- But our bounds stronger than those from 2021

# Large power corrections

- Universal power corrections of ~-15% would remove anomaly

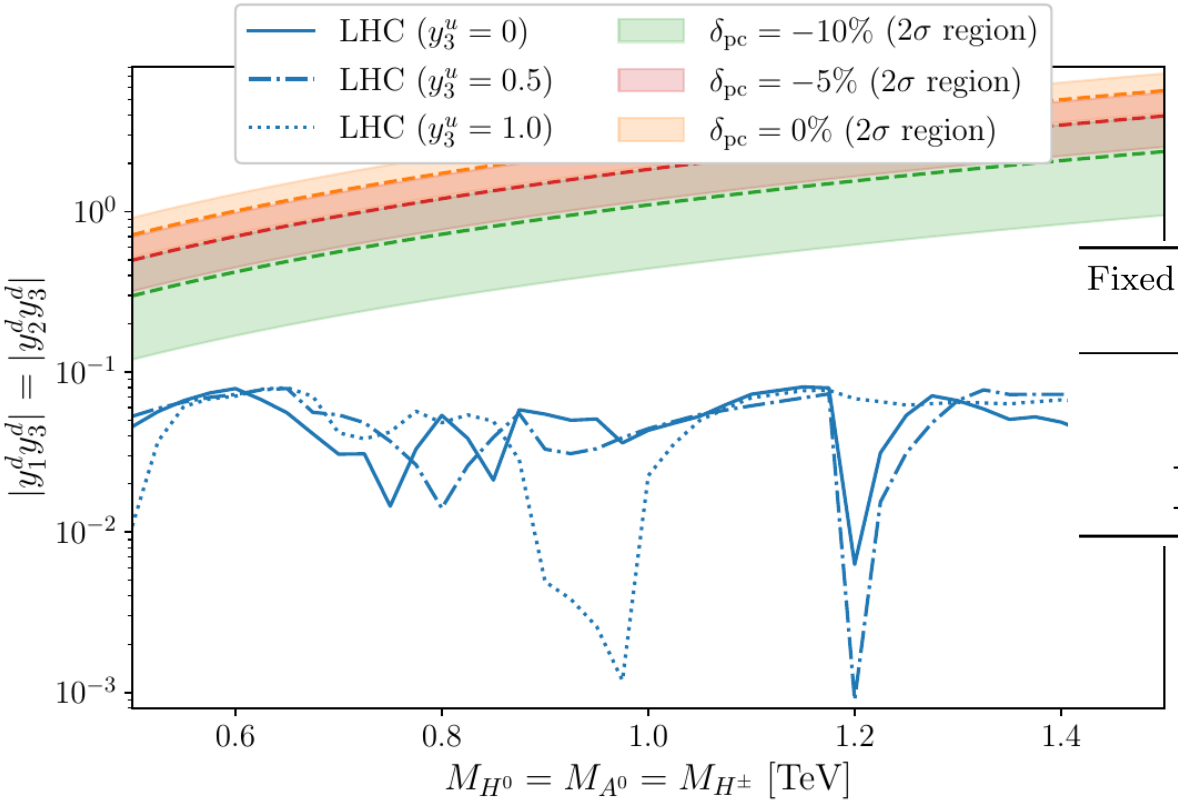
| Fixed PC (%) | SM $\chi^2$ |
|---|---|
| 0 | 66 |
| -5 | 34 |
| -10 | 16 |
| -15 | 9.5 |

# Large power corrections

- Universal power corrections of ~-15% would remove anomaly
- Assume 5% or 10% power corrections => reduce size of BSM couplings needed

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

# Large power corrections

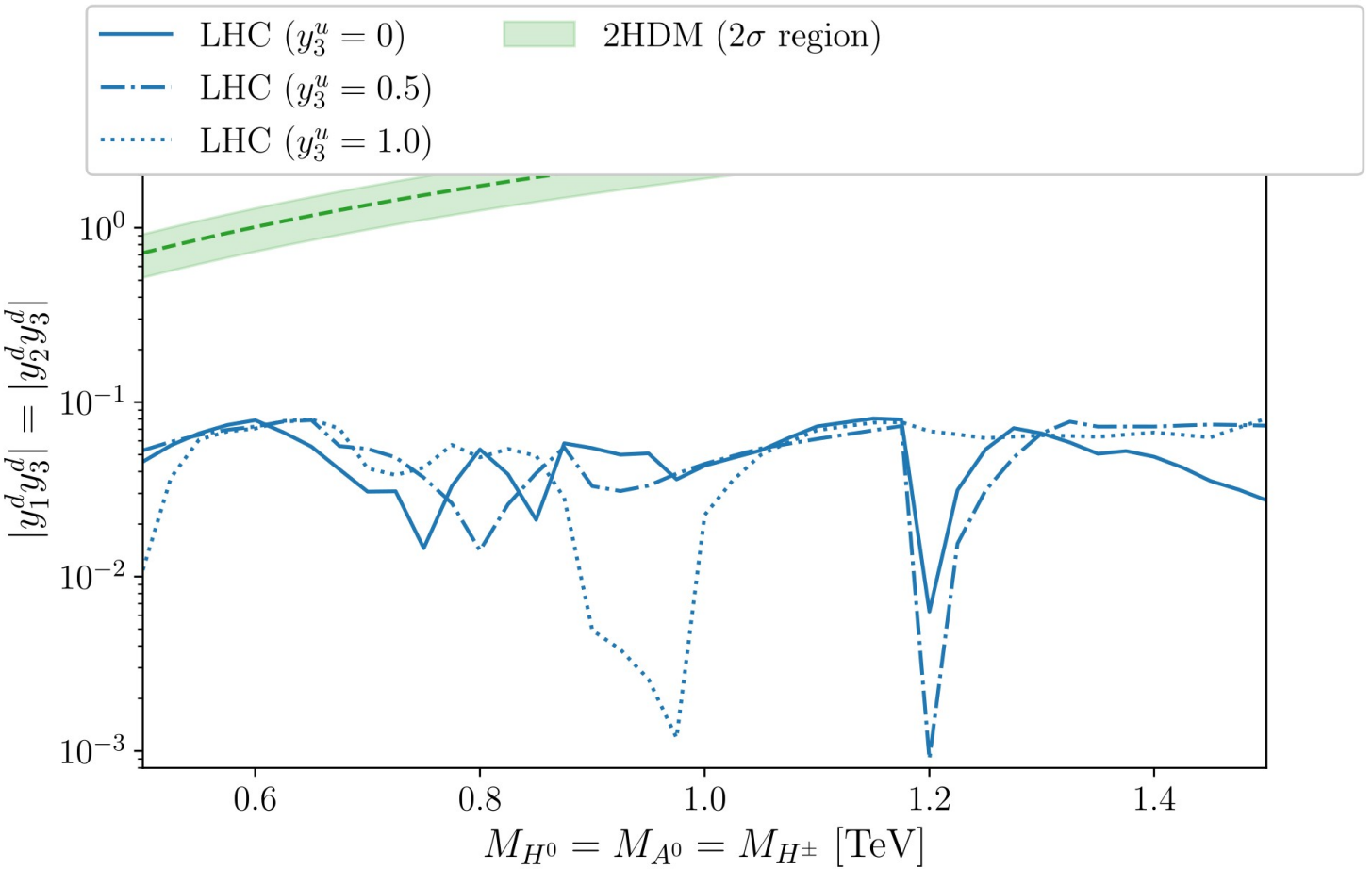



| Fixed PC (%) | SM $\chi^2$ | BSM best fit | | | BSM $2\,\sigma$ range |
|---|---|---|---|---|---|
| | | $y_1^d y_3^d/M^2$ | $\Delta\chi^2$ | pull | |
| 0 | 66 | -3.6 | -61 | $7.8\,\sigma$ | [-4.6, -2.6] |
| -5 | 34 | -2.5 | -30 | $5.5\,\sigma$ | [-3.5, -1.6] |
| -10 | 16 | -1.5 | -11 | $3.3\,\sigma$ | [-2.5, -0.6] |
| -15 | 9.5 | -0.6 | -1.9 | $1.4\,\sigma$ | [-1.6, 0.3] |

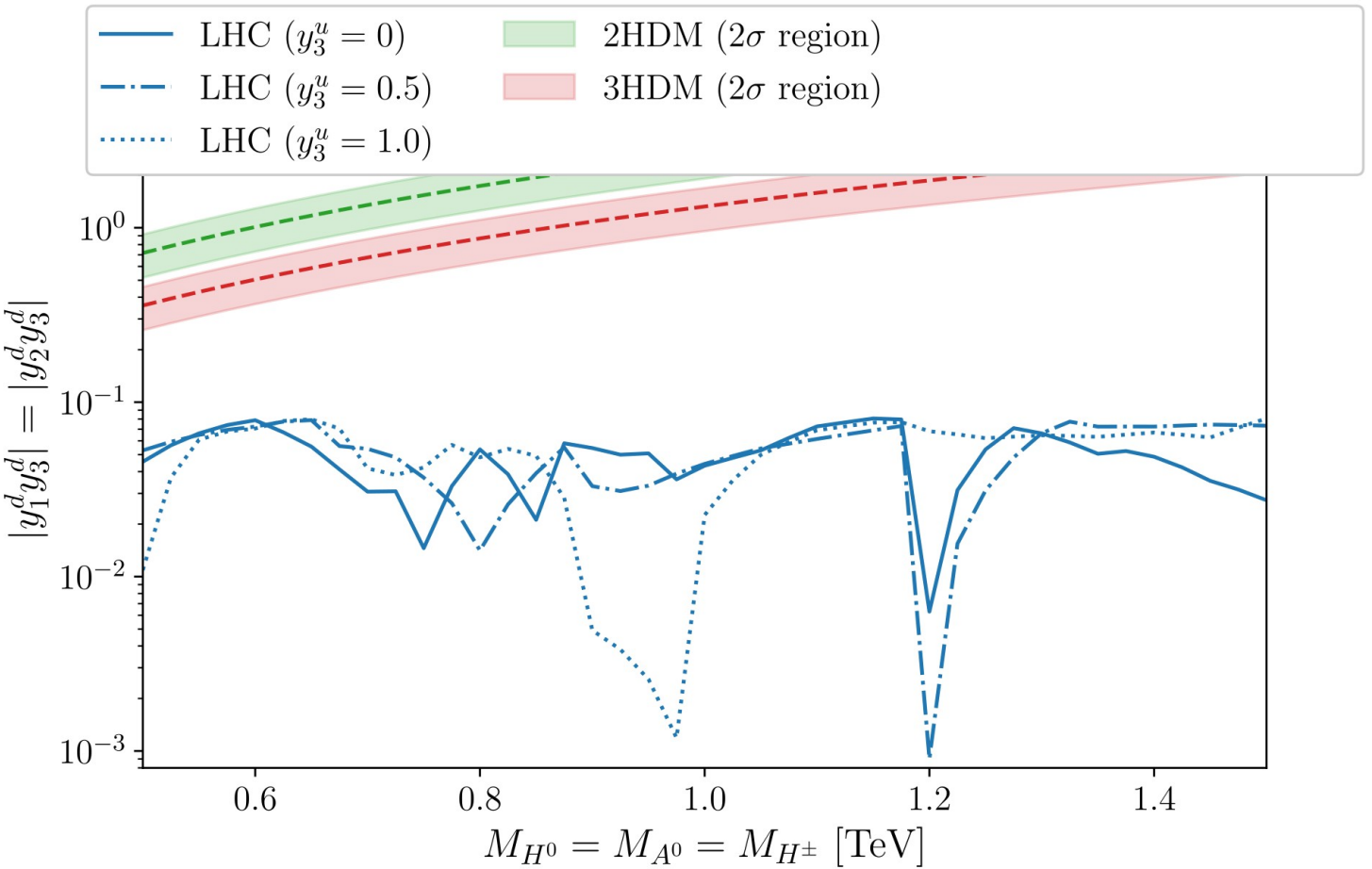
# Multi particle BSM

- If n BSM particles:
  - combine to give non-leptonic effects => $g^{\mathrm{BSM}} \to g^{\mathrm{BSM}}/\sqrt{n}$
  - But collider bounds are the same (assuming resonances don't sit exactly on top of each other)
- For what value of n does this work?
  - and/or what value of n is this stupid scenario?

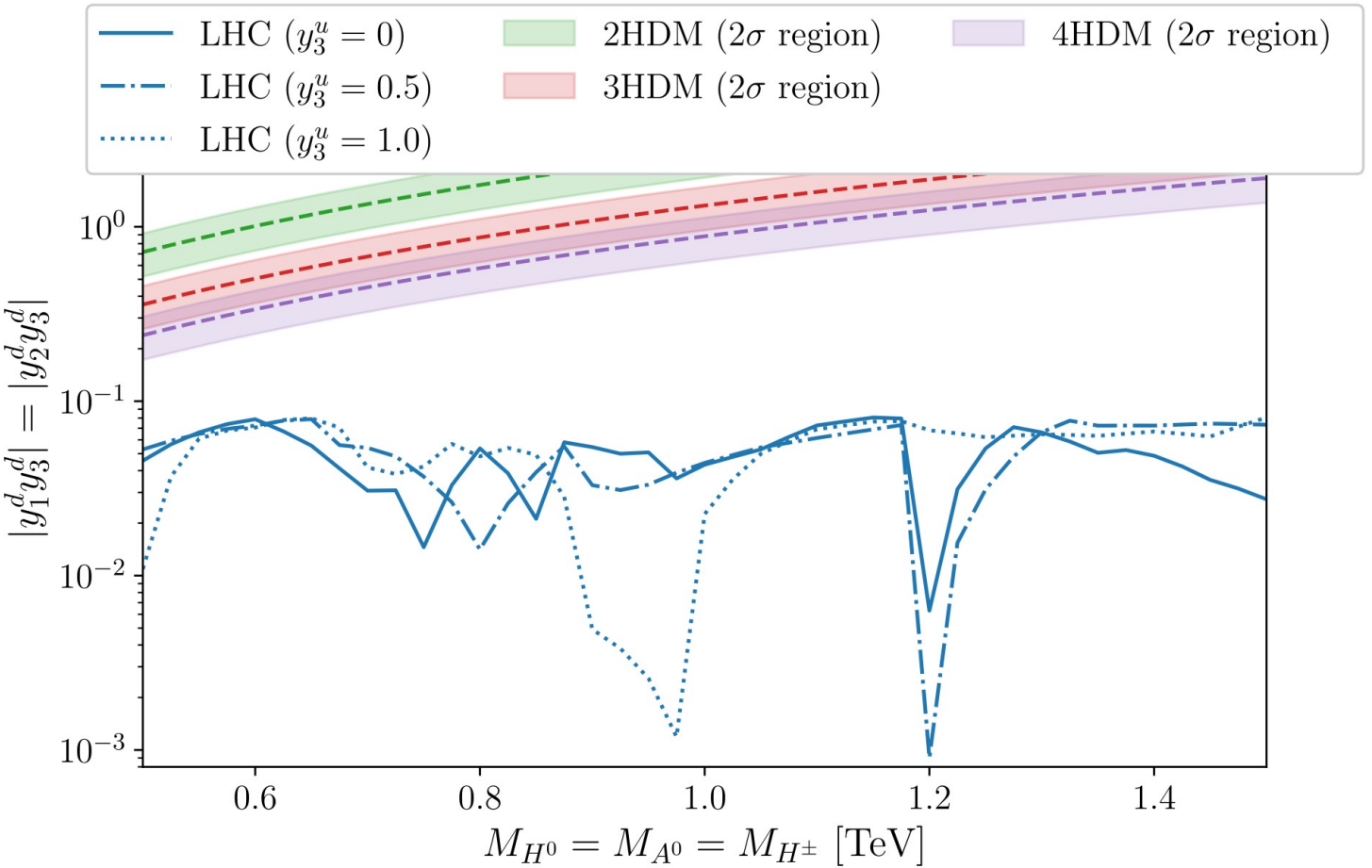
# Multi particle BSM



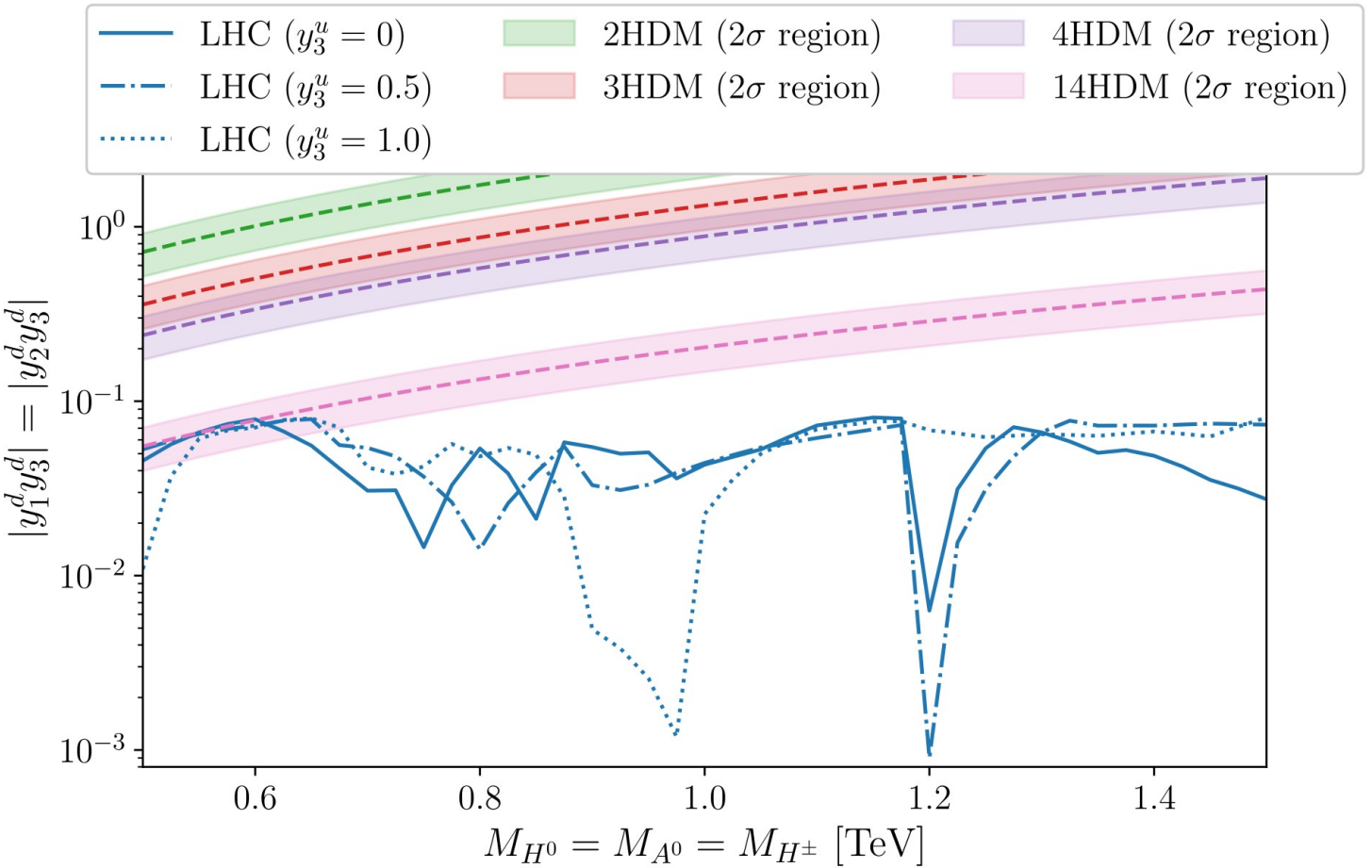
# Multi particle BSM



# Multi particle BSM



# Multi particle BSM



# Summary

- Some non-leptonic B decays should be well predicted by QCD factorisation, but show large discrepancy
- Minimal two Higgs doublet model is ruled out, and typical model-building routes remain constrained by collider measurements
- Hard work for theorists ahead!

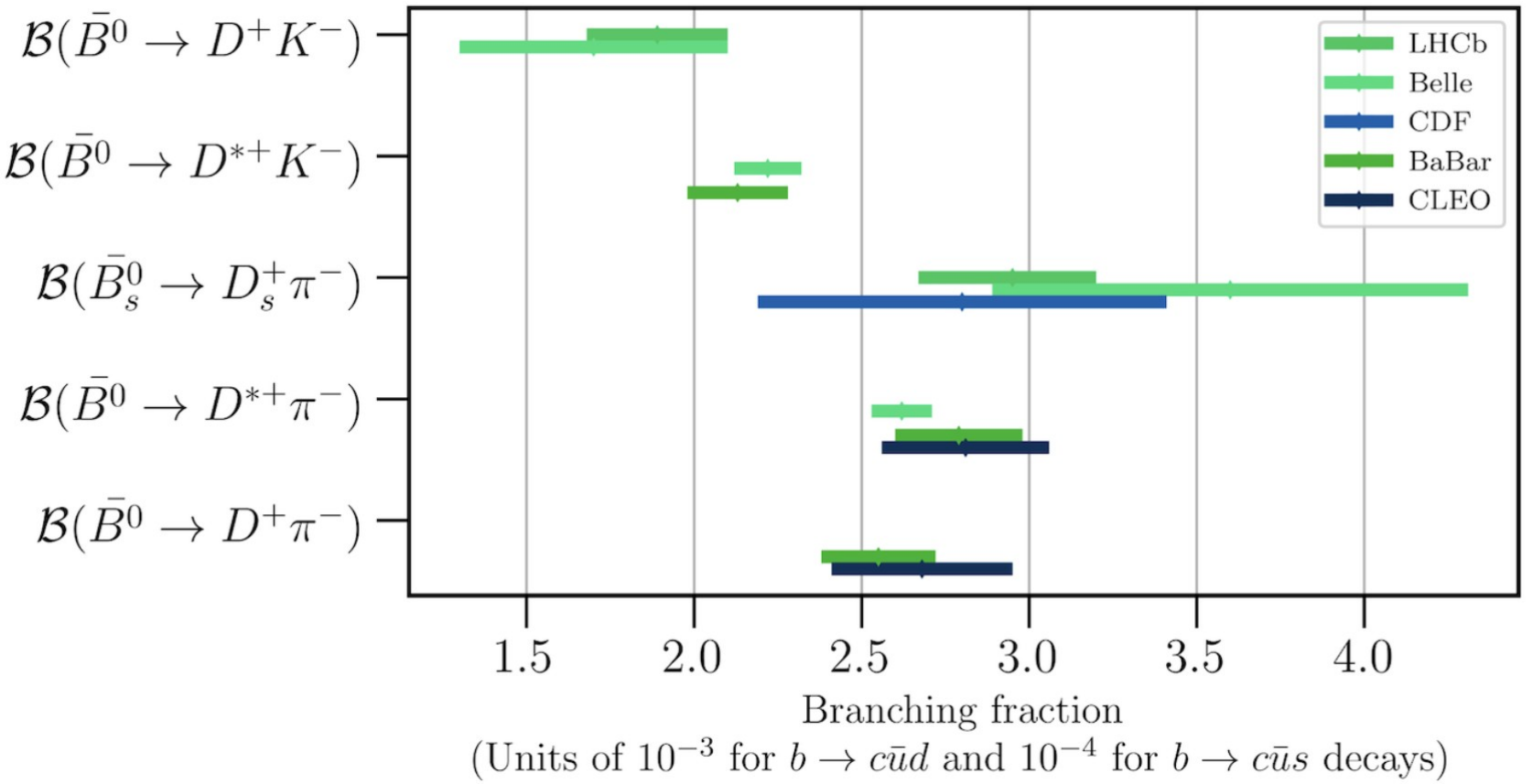
# BACKUP

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

- $\mathcal{M}(\bar{B} \to D^+ K^-) \propto V_{cb} f_K f_0^{B\to D}(M_K^2) a_1^{\text{eff}} + \mathcal{O}\left(\frac{\Lambda}{m_b}\right)$
- $V_{cb}$: Inclusive vs exclusive ~ 5% PDG review
- Decay constants: <1% unc. FLAG
- Form factors: 1–2% unc. Bordone,Gubernari,Jung,van Dyk
- WC $a_1$: NNLO, 1% unc. Huber,Kränkl,Li
- Power corrections: ~few %

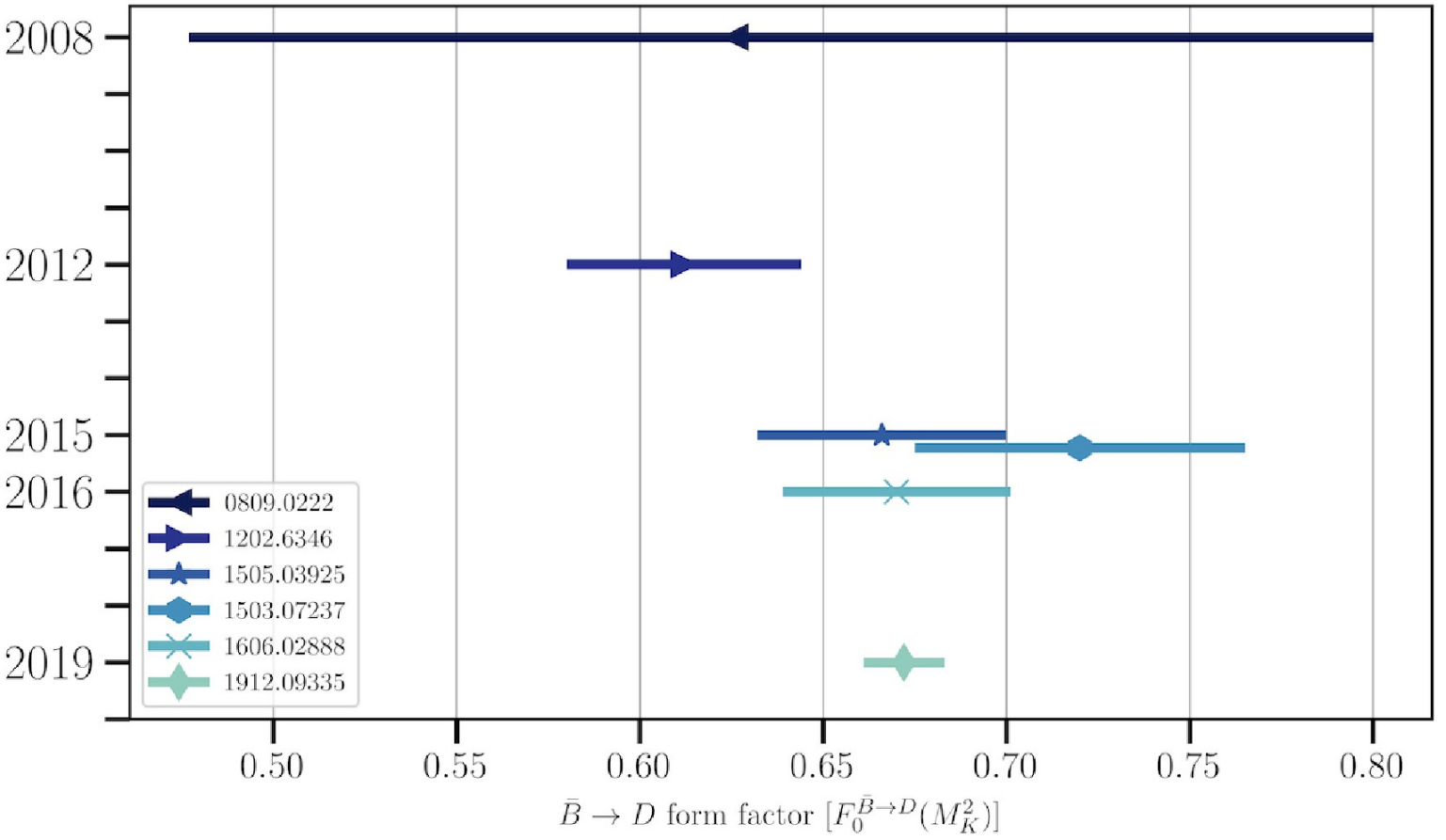
Bordone,Gubernari,Huber,Jung,van Dyk

# Exp error?



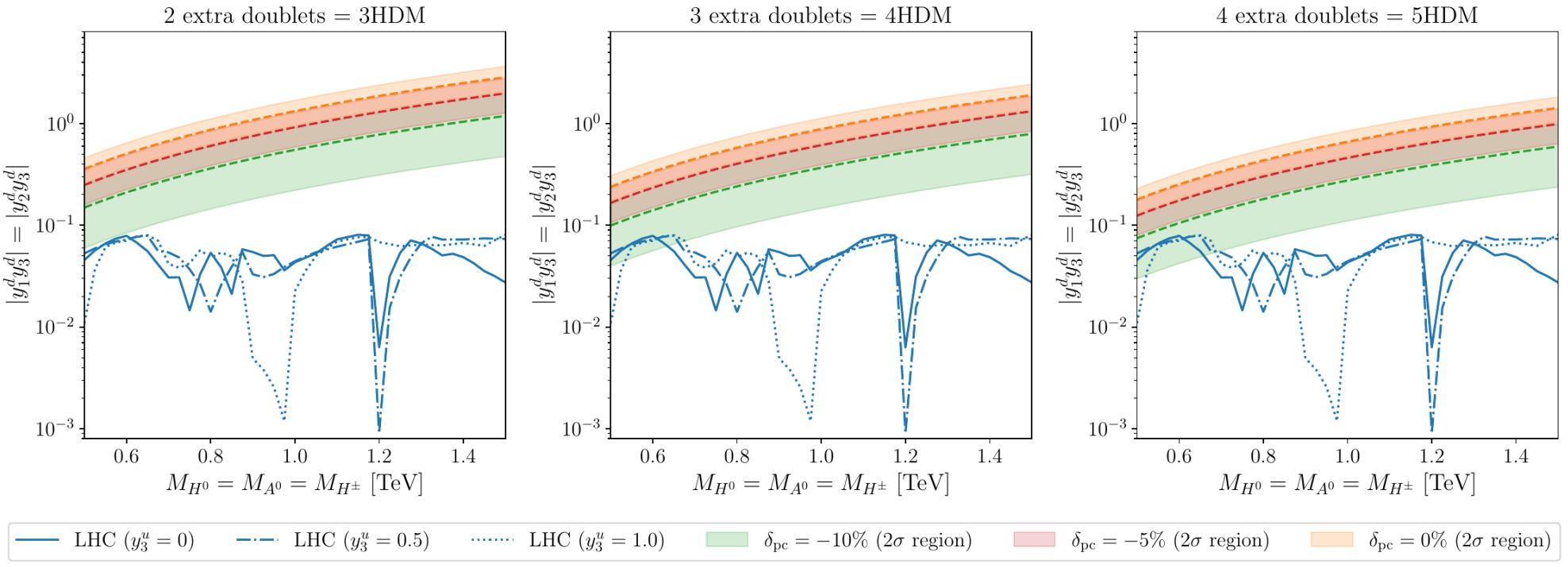

Piscopo, BFA V

# Progress on form factors




Piscopo, BFA V

# Power corrections + nHDM ?



# Collider simulation

Throughout this study, collider bounds are implemented via comparison against a set of analyses published by the ATLAS and CMS collaborations. Specifically, we use the observed cross-section upper limits provided by ATLAS-EXOT-2016-20 [30], CMS-EXO-16-056 [31], CMS-EXO-21-010 [32], and ATLAS-EXOT-2019-03 [33], all of which target dijet final states and span a wide range of dijet invariant masses, providing broad coverage of the signal parameter space considered here.

Signal events were generated, and partonic cross-sections computed using MadGraph5_aMC@NLO (version 3.5.11) [34]. Parton distribution function (PDF) effects were included via LHAPDF6 [35] using the NNPDF 4.1 set [36]. For the primary, naive cross-section comparison, a standard set of particle-level requirements was applied: all jets were required to carry transverse momentum $p_T > 100$ GeV, with the leading jet satisfying $p_T > 200$ GeV; the dijet invariant mass was required to exceed $m_{jj} > 450$ GeV; all jets were restricted to the pseudorapidity range $|\eta| < 2.8$; and the angular separation between the two leading jets was required to satisfy $0.4 < \Delta R < 1.2$. A parameter point is then excluded wherever the predicted signal cross-section, evaluated after these acceptance requirements, exceeds the observed upper limit provided by the most constraining analysis at that point.

To assess the reliability of this procedure, we additionally performed a full recast of ATLAS-EXOT-2019-03 within the MadAnalysis 5 (version 2.0.9) framework [33, 37–40], using the simplified fast-simulation (SFS) interface [41]. In this case, partonic events were passed to Pythia 8 [42] for parton showering and hadronisation, without the particle-level preselection described above. Exclusion limits were then computed from the resulting signal yields using the most sensitive signal region at each parameter point, with statistical inference performed via the Spey package (version 0.2.6) [43, 44].

The recast yields slightly looser bounds compared to the naive cross-section comparison, particularly at low mediator masses, where acceptance and efficiency corrections have the greatest impact. Since full recasts are not available for all four analyses, and given that the naive comparison provides consistently more conservative exclusions, we adopt the naive cross-section limits as our primary collider constraint throughout. This choice does not qualitatively affect our conclusions, as the parameter regions of interest are independently constrained by additional complementary probes.

# 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

ic decays. An easy calculation gives[15]

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

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