LHC Ski 2016, Obergurgl, 11 April 2016

Constraining composite Higgs models with direct and indirect searches

Presented by Peter Stangl

Excellence Cluster Universe
Technische Universität München

Outline

Based on:

Christoph Niehoff, PS, David M. Straub [arXiv:1508.00569]

Outline

Composite Higgs models

Solving the naturalness problem

- Higgs not elementary but bound state of new strong interaction.
- Lightness of Higgs compared to new physics scale: **Higgs as pseudo-Nambu-Goldstone boson** (pNGb) of spontaneously broken global symmetry.

Kaplan, Georgi, Phys.Lett. B136 (1984) 183
Dugan, Georgi, Kaplan, Nucl.Phys. B254 (1985) 299
see also talks by Brian Batell and Kiel Howe

$$\mathcal{L} = \mathcal{L}_{elemenary} + \mathcal{L}_{composite}$$

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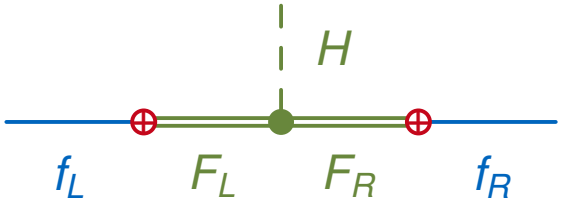
$$\mathcal{L} = \mathcal{L}_{elemenary} + \mathcal{L}_{composite} + \mathcal{L}_{mixing}$$

Avoiding flavour constraints

- Elementary fermions couple linearly to composite fermions.
- Mass eigenstates are mixture of both: **partial compositeness**.

Kaplan, Nucl. Phys. B365 (1991) 259–278



see talk by Francesco Sannino for problems of UV completions and alternatives

Outline

The Goal and the challenge

The goal

Use a single framework to constrain the parameter space of a CHM by

- Radiative electroweak symmetry breaking
- Higgs physics
- Electroweak precision tests
- Flavour physics
- Direct LHC bounds on fermion and vector boson resonances

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The challenge

Parameter space does not “factorize” into Standard Model and new physics parameters.

- **Partial compositeness:** fermion masses and CKM parameters are complicated functions of many model parameters.
- **Dynamically generated Higgs potential:** depends on gauge boson and fermion masses and couplings.

Strategy

The method

- Brute-force scan of parameter space not applicable.
- Instead, construct χ^2-function from all observables:

$$\chi^2(\vec{\theta}) \equiv \sum_{i \in \text{observables}} \left(\frac{\mathcal{O}_i^{\text{th}}(\vec{\theta}) - \mathcal{O}_i^{\text{exp}}}{\sigma_i^{\text{error}}} \right)^2$$

  Given a parameter point $\vec{\theta}$, it measures "how close" theoretical predictions $\mathcal{O}_i^{\text{th}}(\vec{\theta})$ are to experimental observations $\mathcal{O}_i^{\text{exp}}$.
- Numerically minimizing χ^2-function yields "good" parameter points.

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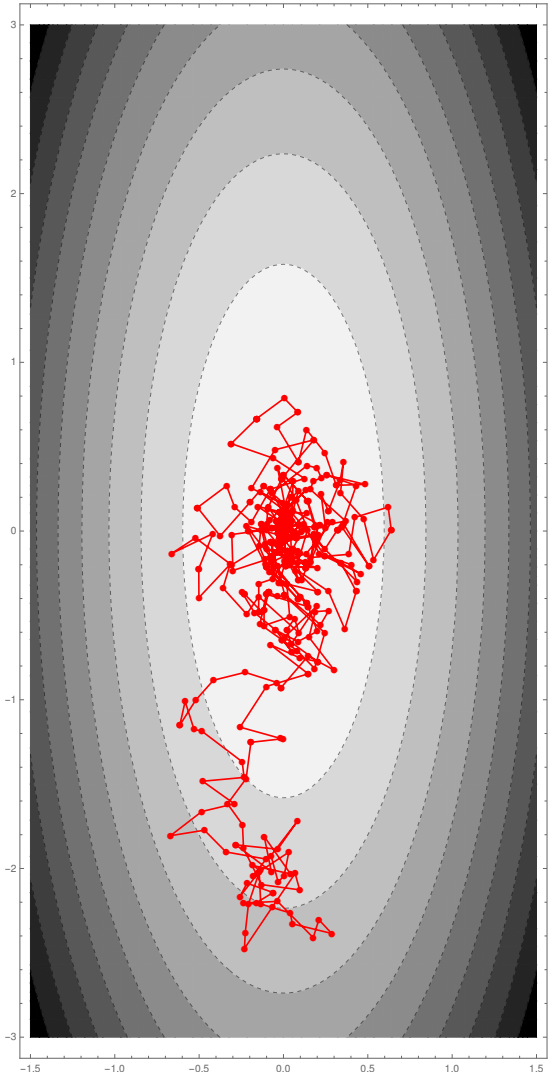
Still technically challenging

- Large dimensionality (ca. 30-50 parameters depending on specific model).
- Complicated dependence on all parameters.

Implementation



Numerical minimization

1. Generate (random) starting points.
2. Use global minimizer [NLopt] to find viable region.
3. Use Markov Chain Monte Carlo [pypmc] to sample viable parameter space.
4. Keep only points satisfying each individual constraint at 3σ level.

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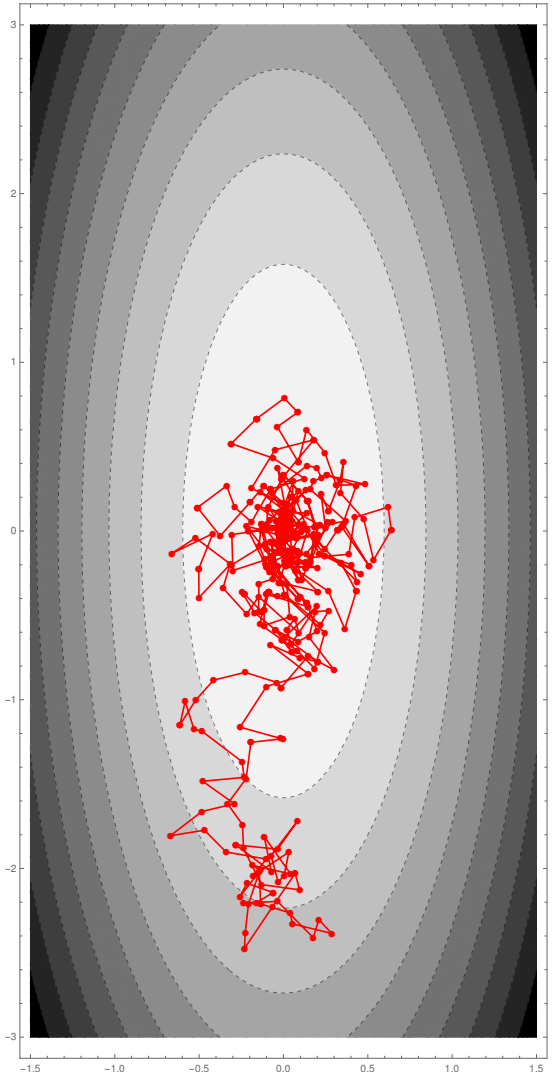

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Computations

performed on the C2PAP computing cluster in Munich.

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The first model we analysed

- Calculable Higgs potential
- Minimal particle content

$\Rightarrow$ Deconstructed model **4DCHM with two sites**.

De Curtis, Redi, Tesi, arXiv:1110.1613

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$\Rightarrow$ Composite quarks in fundamental **5**-representations, no composite leptons.

Agashe et al., arXiv:hep-ph/0605341
Contino et al., arXiv:hep-ph/0612048

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- Suppression of contributions to $\Delta F = 2$ observables

$\Rightarrow$ **Flavour symmetry** only broken by $\mathcal{L}_{mixing}$. We consider four cases: $U(3)^3_{LC}$, $U(3)^3_{RC}$, $U(2)^3_{LC}$ or $U(2)^3_{RC}$.

Cacciapaglia et al., arXiv:0709.1714, Redi, Weiler, arXiv:1106.6357
Barbieri, Buttazzo, Sala, Straub, arXiv:1203.4218

Results

No viable parameter points for $\mathrm{U}(3)^3_{\mathrm{LC}}$

- Very strong constraints from electroweak precision tests and CKM unitarity.

cf. Barbieri, Buttazzo, Sala, Straub, arXiv:1211.5085

$\mathrm{U}(2)^3_{\mathrm{LC}}$, $\mathrm{U}(2)^3_{\mathrm{RC}}$ and $\mathrm{U}(3)^3_{\mathrm{RC}}$ flavour structures

- All constraints can be passed.
- Fine tuning $\Delta_{\mathrm{BG}} < 100$ possible. $\Delta_{\mathrm{BG}} = \max_{i \in \text{parameters}} \left| \frac{\partial \ln m_Z}{\partial \ln \theta_i} \right|$

Barbieri, Giudice, Nucl. Phys. B306 (1988) 63

- Tensions in rare B decays can be explained in some part of parameter space.
- Tension in $\Delta F = 2$ observables could be reduced in $U(2)^3$ models.
- LHC run 2 can test many of viable parameter points.

Outline

Conclusions

New numerical method

Employing a new numerical method, it is possible to constrain composite Higgs models by both direct and indirect constraints in a single framework.

Findings of first analysis

- $U(3)^3_{\mathrm{LC}}$ flavour structure disfavoured.
- Fine tuning $\Delta_{\mathrm{BG}} < 100$ possible.
- Tensions in rare B decays could be explained.
- Tension in $\Delta F = 2$ observables could be reduced in $U(2)^3$ models.
- LHC run 2 can test many of viable parameter points.

More details

Christoph Niehoff, PS, David M. Straub [arXiv:1508.00569]

Backup slides

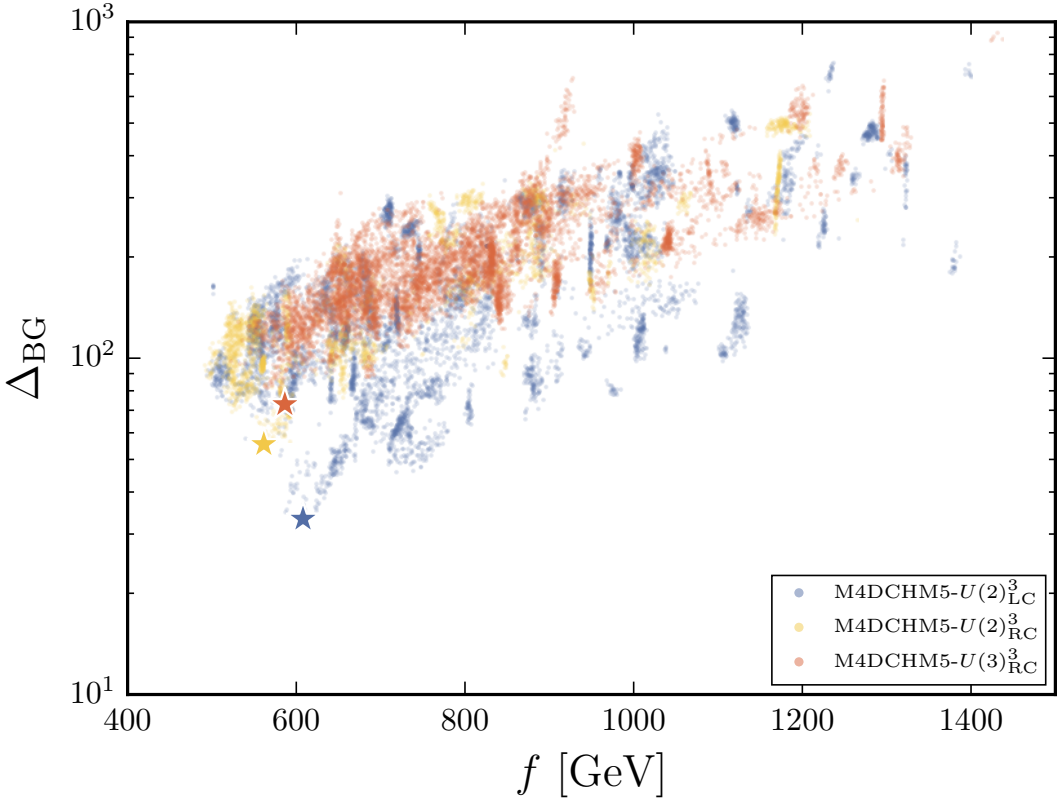
Fine-tuning

Barbieri-Giudice measure

$$\Delta_{\mathrm{BG}} = \max_{i \in \text{parameters}} \left| \frac{\partial \ln m_Z}{\partial \ln \theta_i} \right|$$

Barbieri, Giudice, Nucl. Phys. B306 (1988) 63

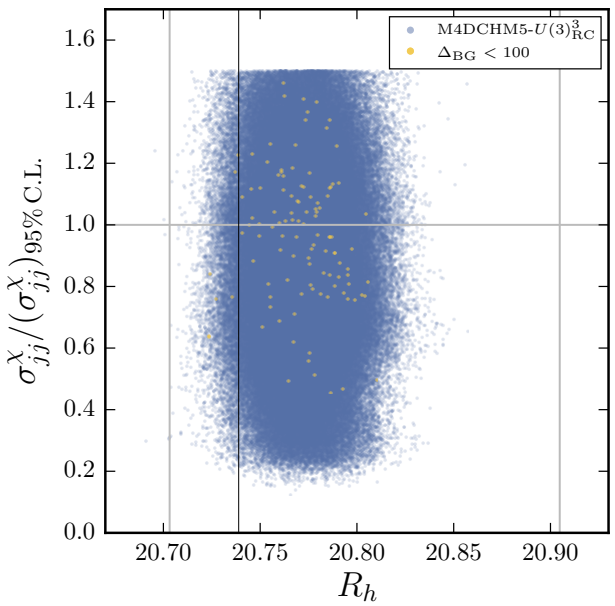
quantifies sensitivity of weak scale to variations in model parameters θ_i.

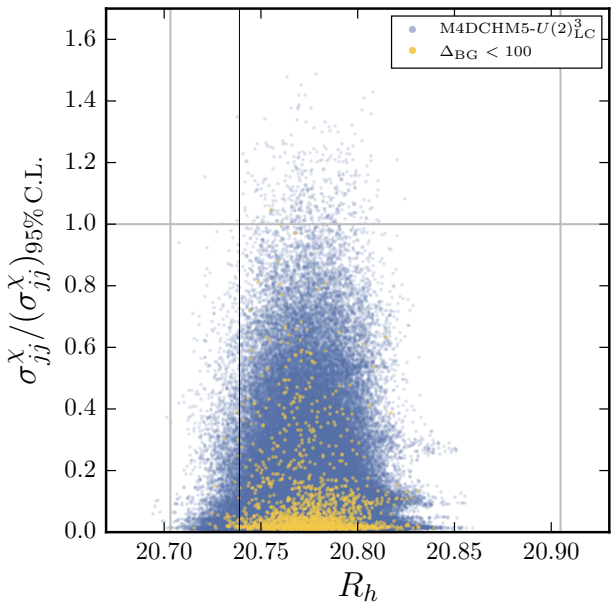


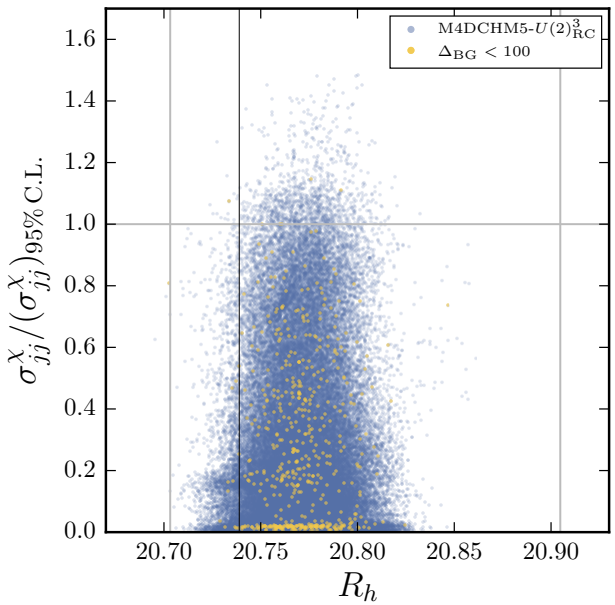
- $\mathrm{U}(2)_{\mathrm{LC}}$: $\Delta_{\mathrm{BG}}^{(\mathrm{min})} = 33$
- $\mathrm{U}(2)_{\mathrm{RC}}$: $\Delta_{\mathrm{BG}}^{(\mathrm{min})} = 55$
- $\mathrm{U}(3)_{\mathrm{RC}}$: $\Delta_{\mathrm{BG}}^{(\mathrm{min})} = 73$

Light quark compositeness

Results for hadronic Z width and dijet angular distributions

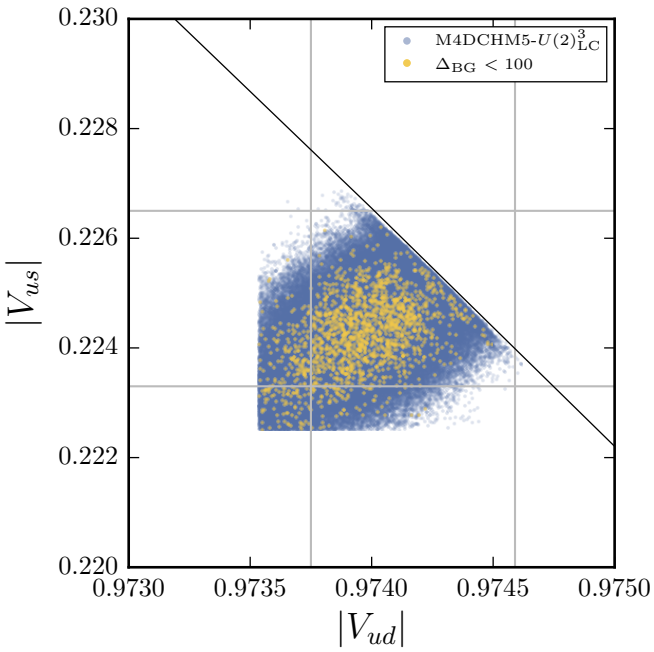






Light quark compositeness

Results for CKM unitarity

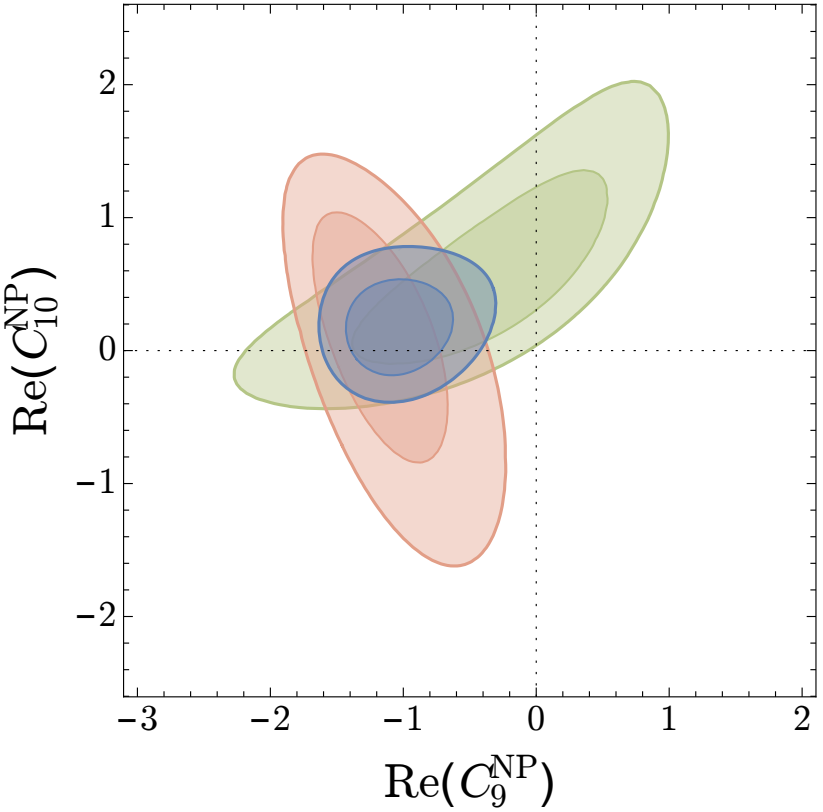


No relevant constraint from first-row CKM unitarity on *RC* models.

Rare B decays

Tensions between SM and data

Recent fits prefer a negative shift in Wilson coefficient C_9 (and possibly positive in C_{10}):

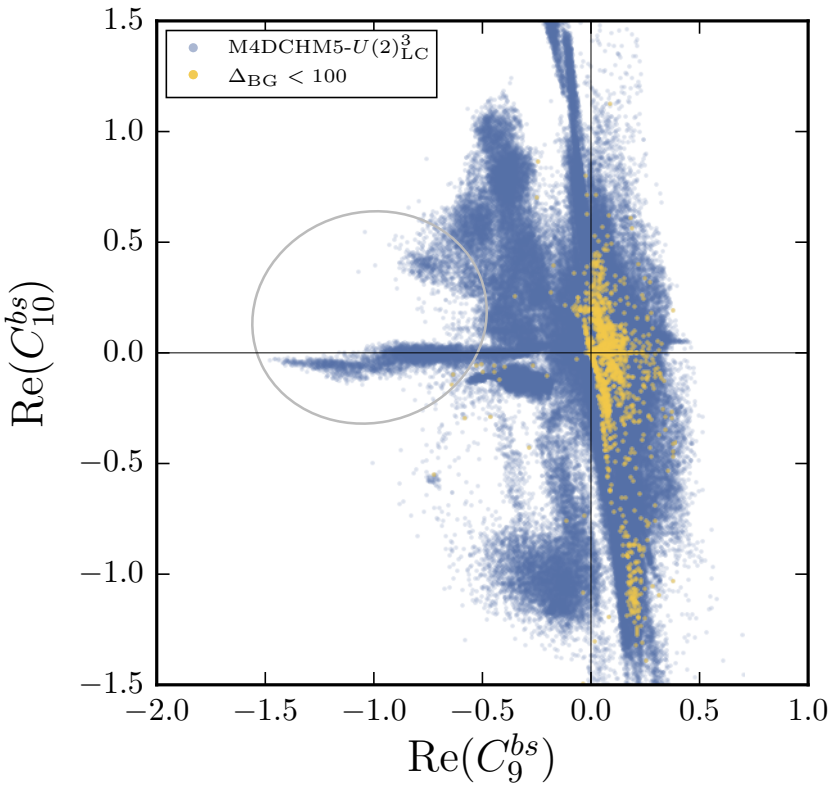


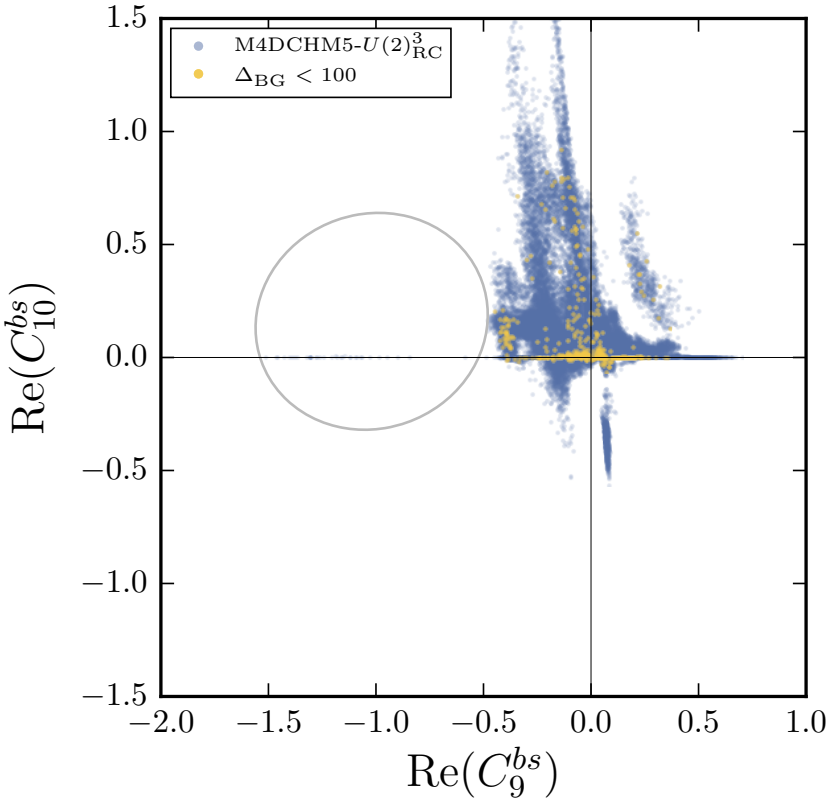
Altmannshofer, Straub, arXiv:1411.3161

Rare B decays

Tensions could be explained

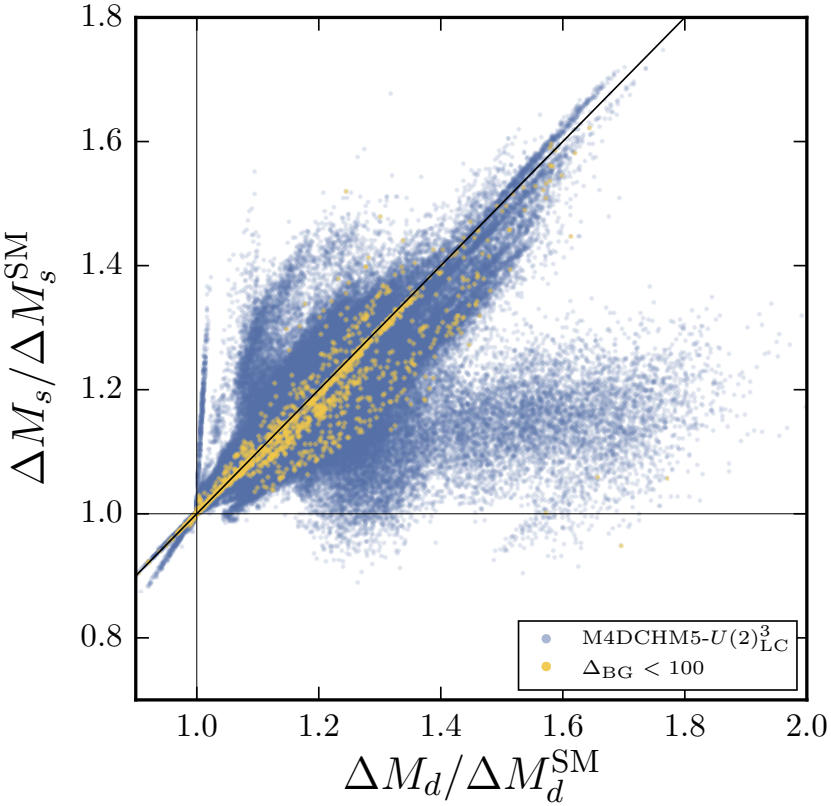
- We find points with negative shift in C_9.
- Then, we predict light neutral vector resonance (with large BR to $t\bar{t}$).

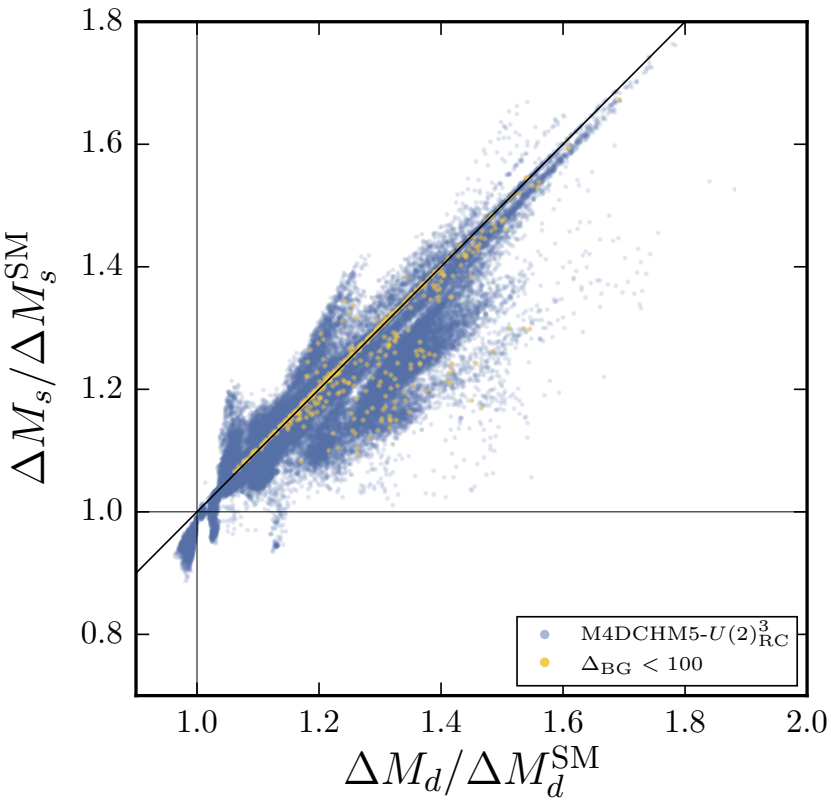




Meson-Antimeson mixing

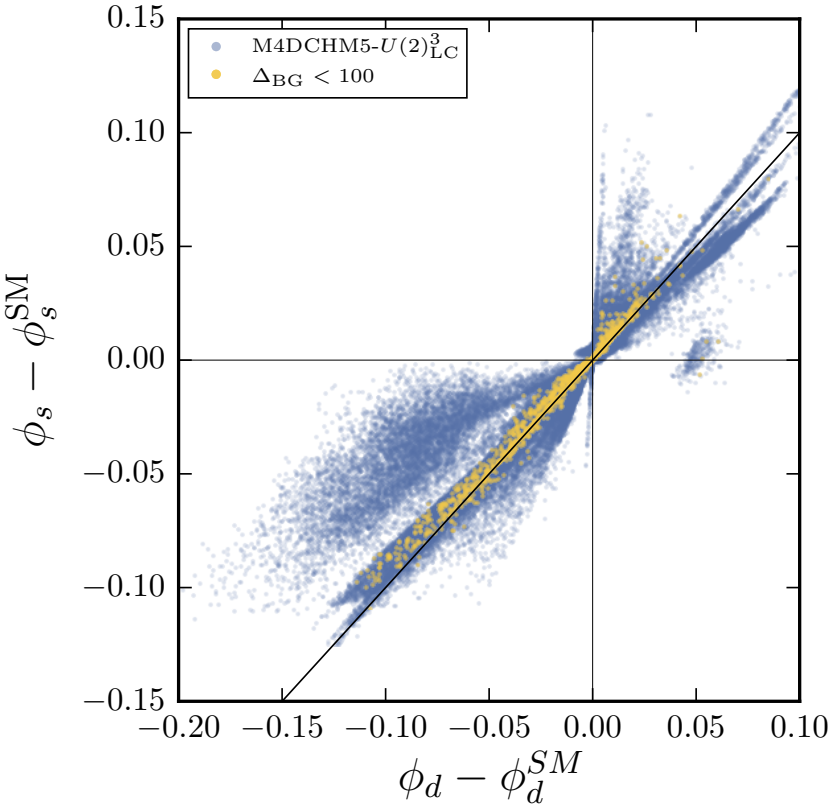
Mass differences in B_d^0 and B_s^0 system

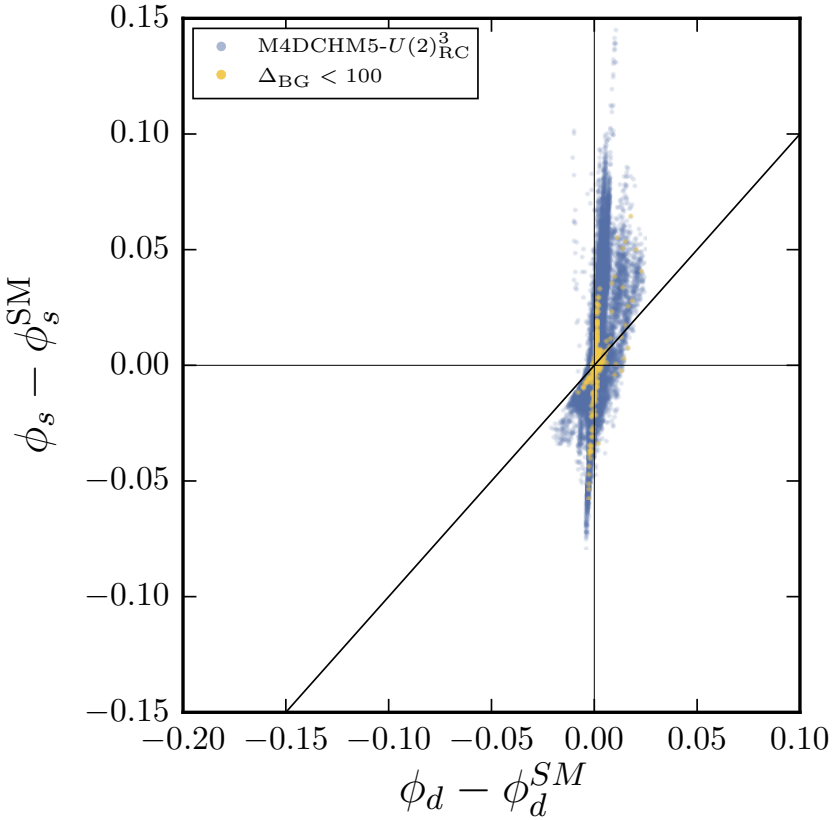




Meson-Antimeson mixing

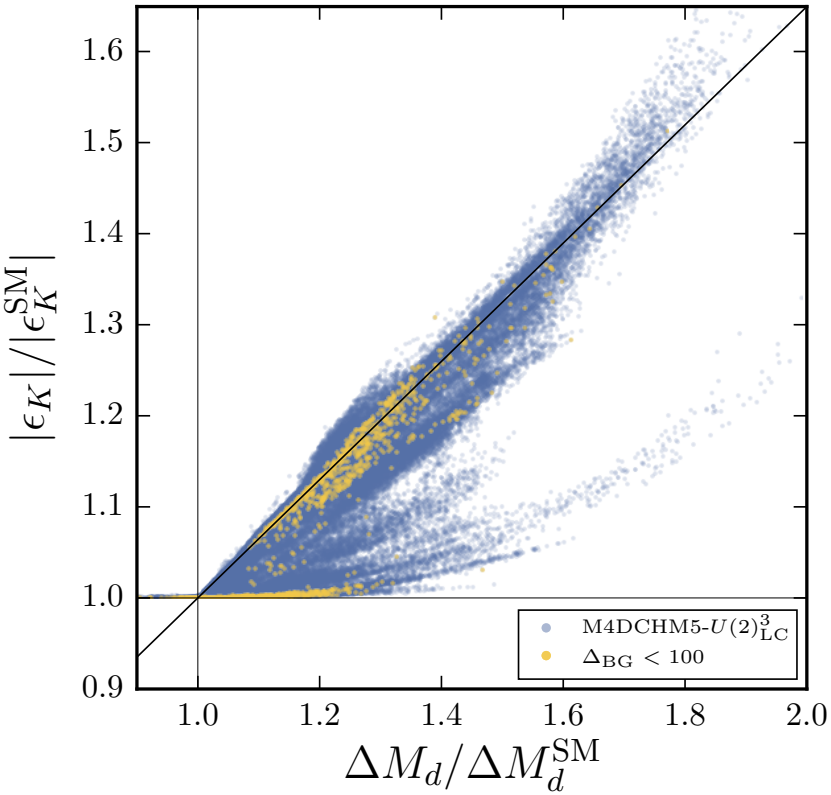
Mixing phases in B_d^0 and B_s^0 system

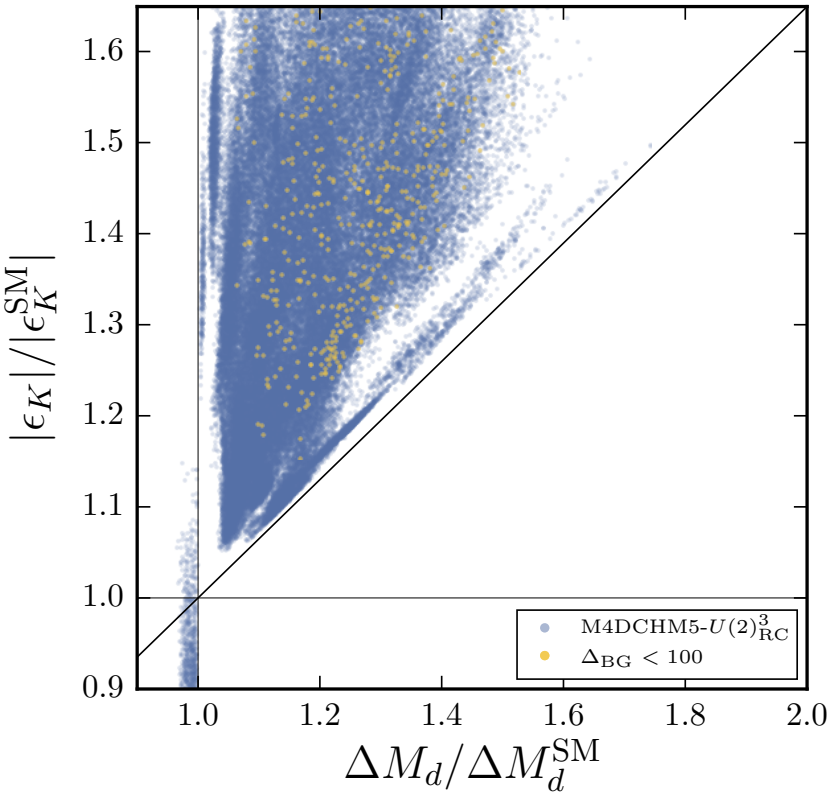




Meson-Antimeson mixing

Indirect CP violation in K^0 mixing





Meson-Antimeson mixing

Facing new lattice results

Tension between $\Delta M_d/\Delta M_s$ and ϵ_K increased.

Fermilab Lattice, MILC, arXiv:1602.03560
Blanke, Buras, arXiv:1602.04020

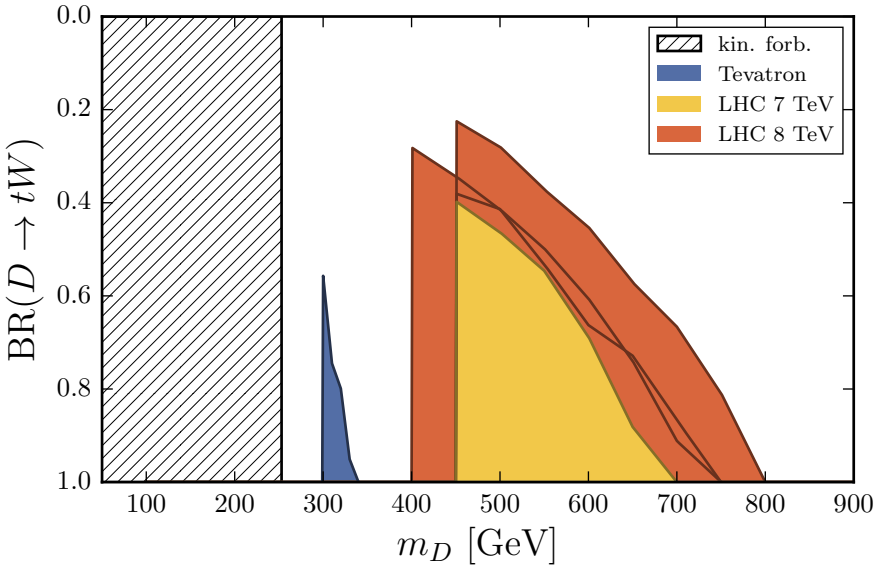
Reducing the tension	$U(2)^3_{LC}$	$U(2)^3_{RC}$	$U(3)^3_{RC}$
$\Delta M_d/\Delta M_d^{\mathrm{SM}} < \Delta M_s/\Delta M_s^{\mathrm{SM}}$	✓	✓	✗
$\phi_d - \phi_d^{\mathrm{SM}} \neq 0$	✓	✗	✗
$\lvert\epsilon_K\rvert/\lvert\epsilon_K^{\mathrm{SM}}\rvert > \Delta M_d/\Delta M_d^{\mathrm{SM}}$	✗	✓	✗

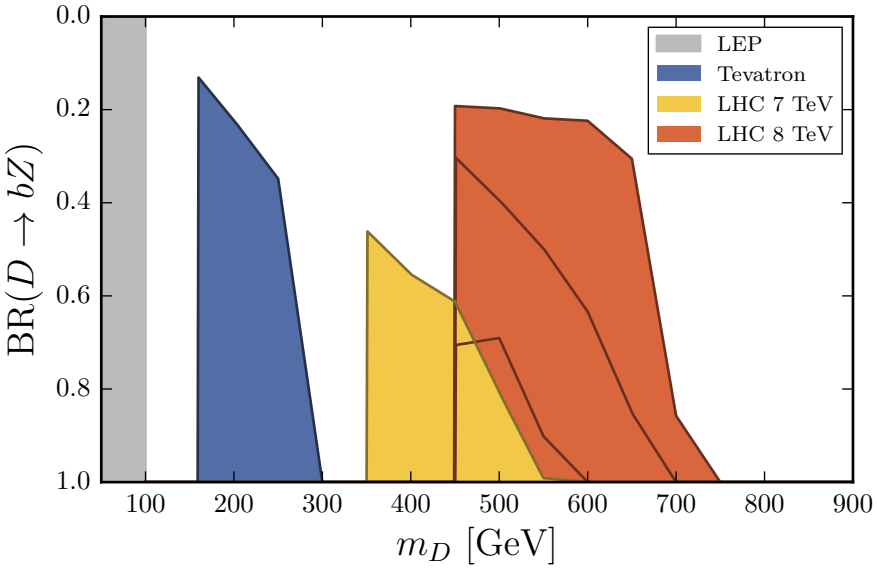
Quark partner searches

Included experimental analyses

20 different analyses from ATLAS, CMS and CDF included into numerics.

Gaps in experimental analyses





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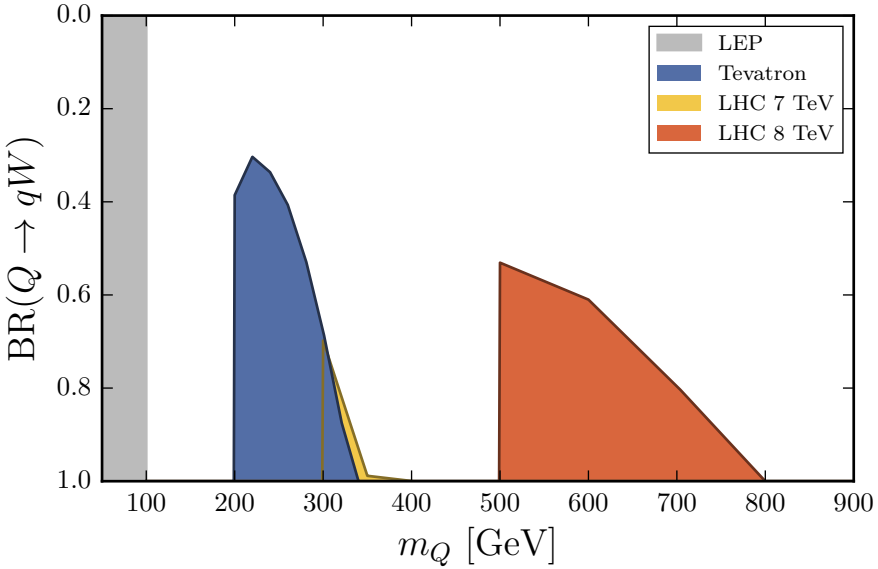

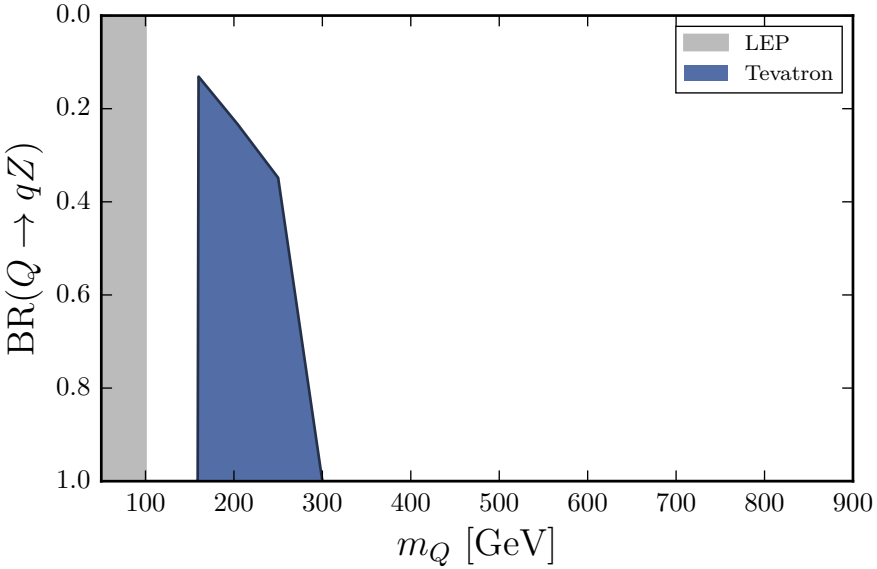

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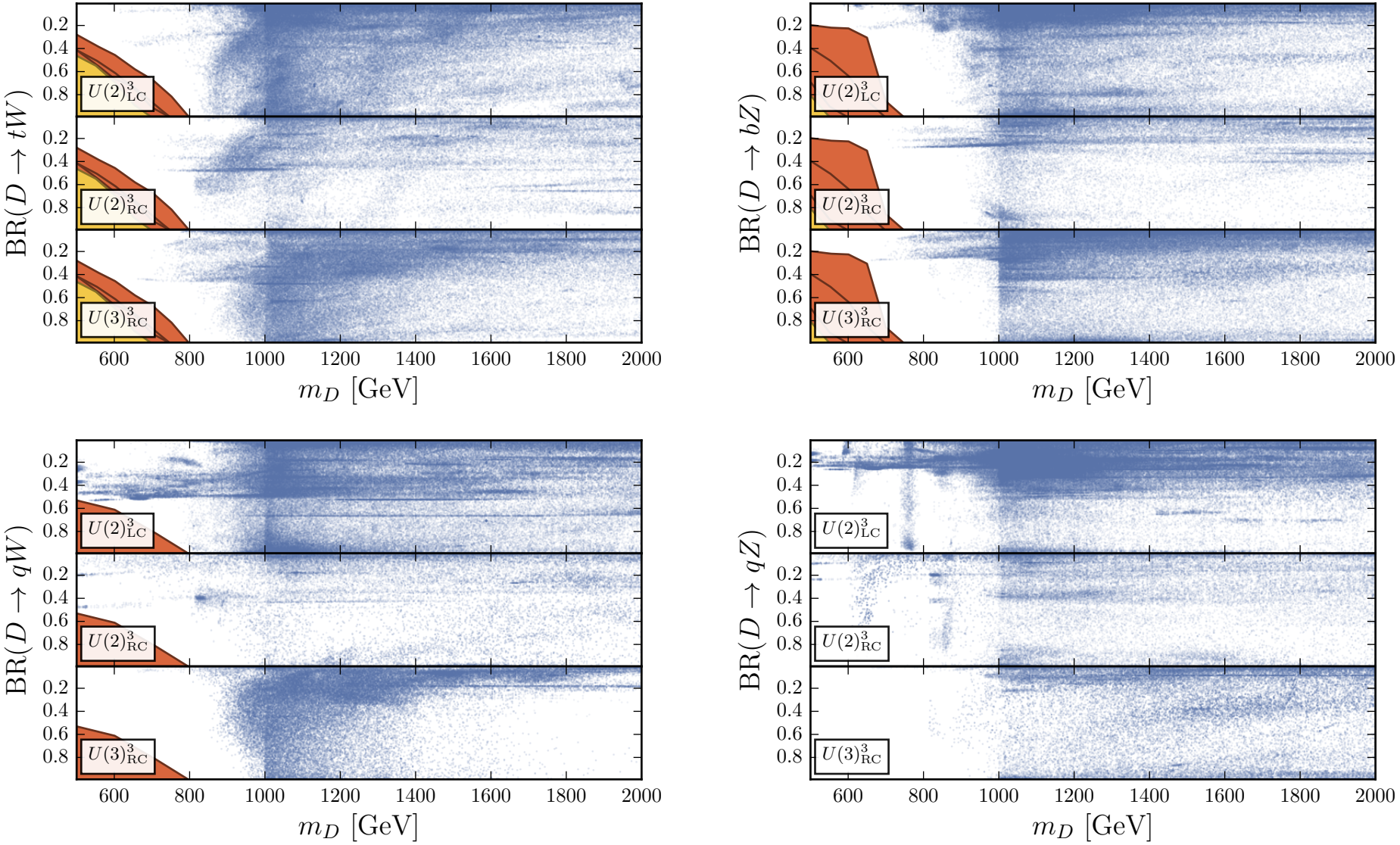
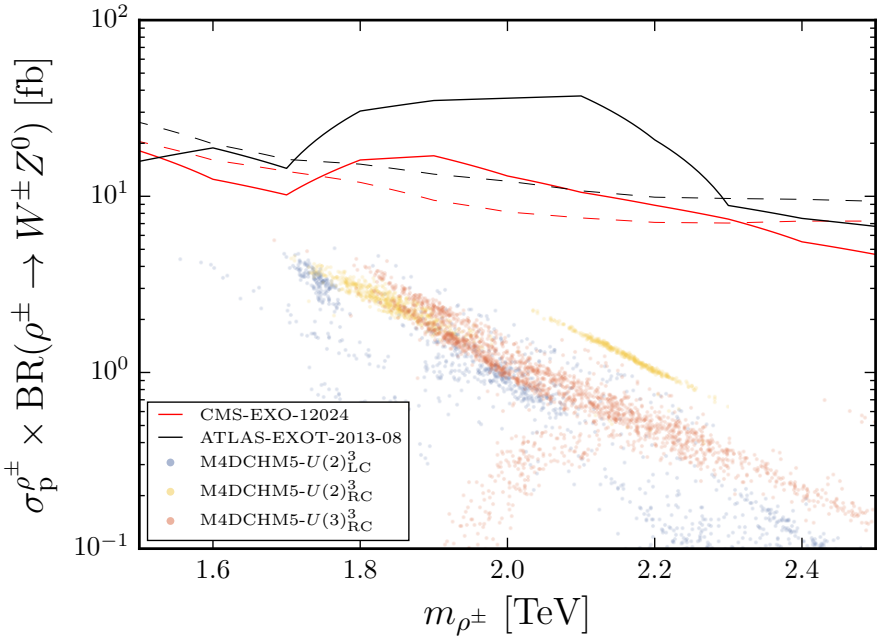


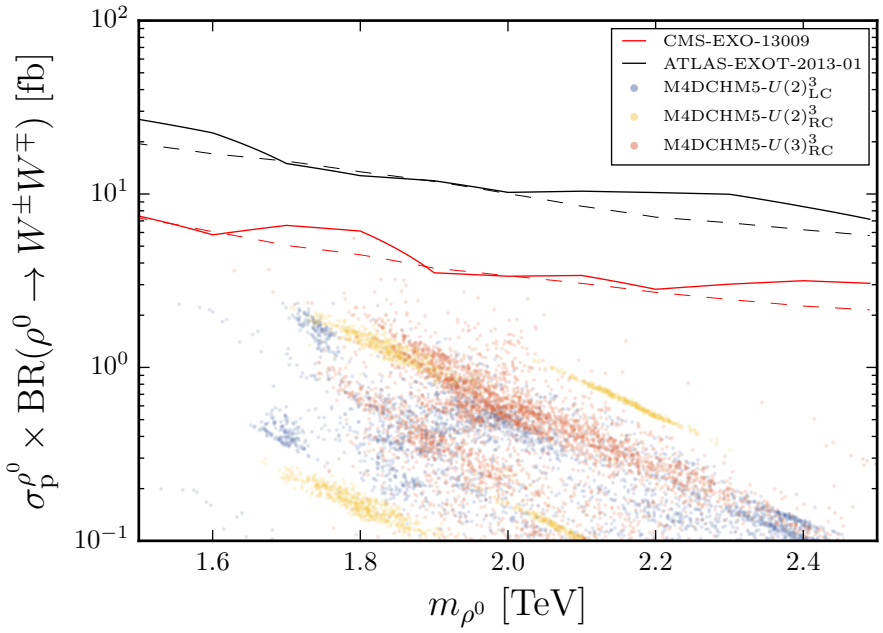
Vector partner searches

Included experimental analyses

14 different analyses from ATLAS and CMS included into numerics.

Results





Additional constraints

In addition to the ones discussed in these slides, our analysis includes constraints from

- Higgs production and decay
- Oblique parameters
- Top decays