Institute for Theoretical Particle Physics and Cosmology | RWTH AACHEN UNIVERSITY

MITP, March 2018

``BSM summary”

Michael Krämer (RWTH Aachen University)

Aachen Bonn Heidelberg Mainz

DFG Deutsche Forschungsgemeinschaft

Bundesministerium für Bildung und Forschung

BSM physics at the LHC?

- Flavour
  - hierarchy of fermion masses, in particular ν
  - mixing pattern: small mixing for q versus large mixing for ν
- Anomalies
  - $(g-2)_\mu$
  - b-physics:

$$R_{D^{(*)}} = \frac{\Gamma(\bar{B} \to D^{(*)}\tau\bar{\nu})}{\Gamma(\bar{B} \to D^{(*)}l\bar{\nu})}\ (l = e, \mu) \qquad , \ R_{K^{(*)}} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}^{(*)}e^+e^-)}$$

  - ...
- Cosmology
  - Dark matter
  - Baryon asymmetry of the Universe

see Werner's talk

BSM physics at the LHC?

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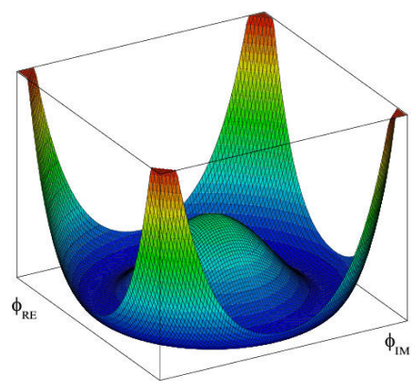
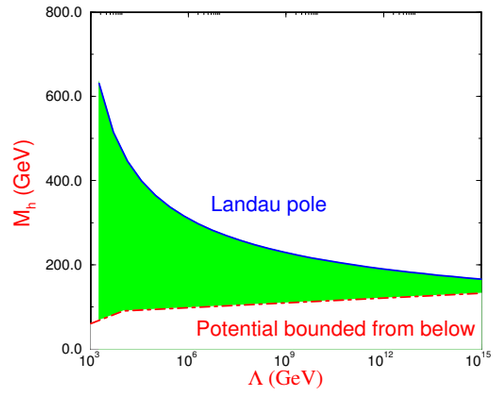
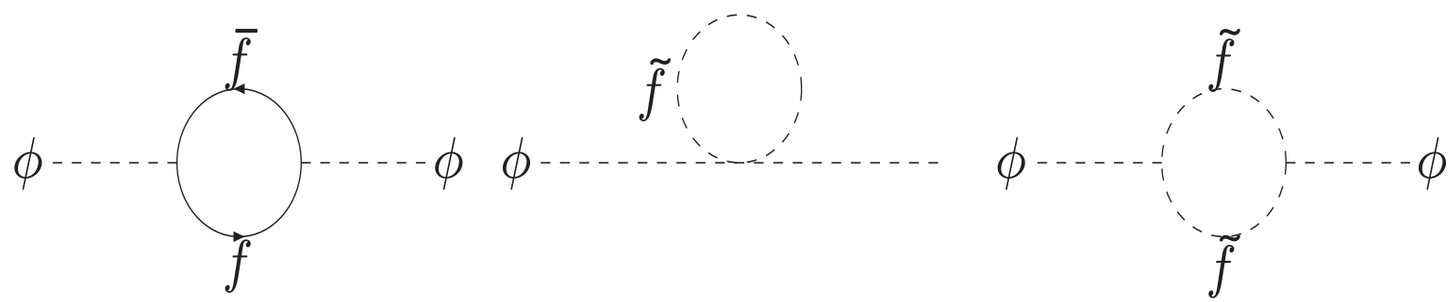
  - ...
- Cosmology
  - Dark matter
  - Baryon asymmetry

- SM & $m_h = 125.1$ GeV: potentially meta-stable (G. Degrassi *et al.*, arXiv:1205.6497)





- "Why does electroweak symmetry break?" or "Why is $\mu^2 < 0$ in the SM?"
- Hierarchy problem (?)



$\delta m_h^2 \propto \Lambda^2$: Sensitivity to highest mass scale of unknown physics

Naturalness, Hierarchy, and Fine Tuning

28 February 2018 to 2 March 2018
Aachen
Europe/Zurich timezone

Search...

Support
harlander@physik.rwth-...
+49-241-80-27045

The requirement of naturalness has long served as an influential constraint on model-building in theoretical particle physics. Yet there are many ways of understanding what, precisely, this requirement amounts to, from restrictions on the amount of fine-tuning that a model can exhibit, to prohibitions on sensitive dependence between physics at different scales, to the requirement that dimensionless parameters defining the Lagrangian of a theory all be of order one unless they are protected by a symmetry. This workshop aims to clarify the relationships among these concepts of naturalness and their connection to the hierarchy problem, as well as to assess arguments for and against imposing various forms of naturalness as a requirement on particle physics model-building.

This workshop is part of the DFG research unit "Epistemology of the Large Hadron Collider".

Starts 28 Feb 2018, 08:45
Ends 2 Mar 2018, 18:00
Europe/Zurich

Robert Valentin Harlander

Aachen
SuperC (Generali-Saal)
RWTH Aachen, Templergraben 57, 52062 Aachen

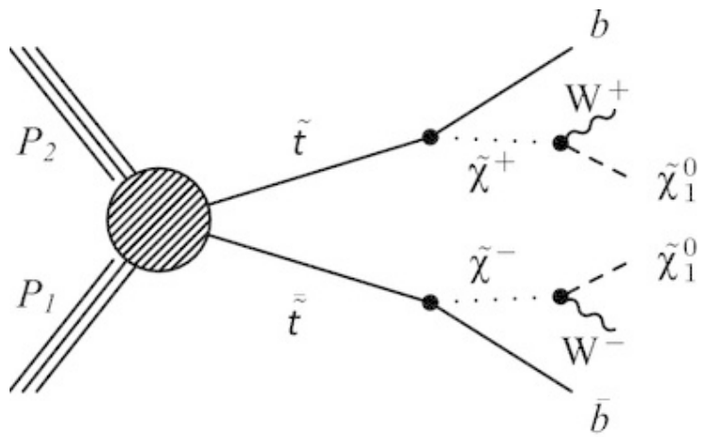
BSM physics at the LHC

- BSM searches with Standard Model cross sections
- Effective field theories and (simplified) models:
  BSM searches and novel/subtle LHC signatures

BSM searches with Standard Model cross sections

Search for BSM signals which are similar to SM ``background”

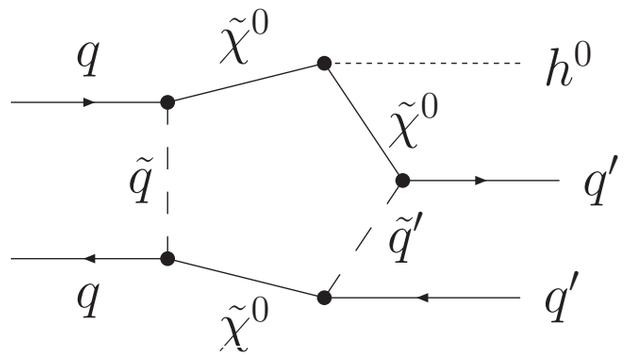
e.g.



for $m_{\tilde{t}_1} \approx m_W + m_b + m_{\tilde{\chi}_1^0}$

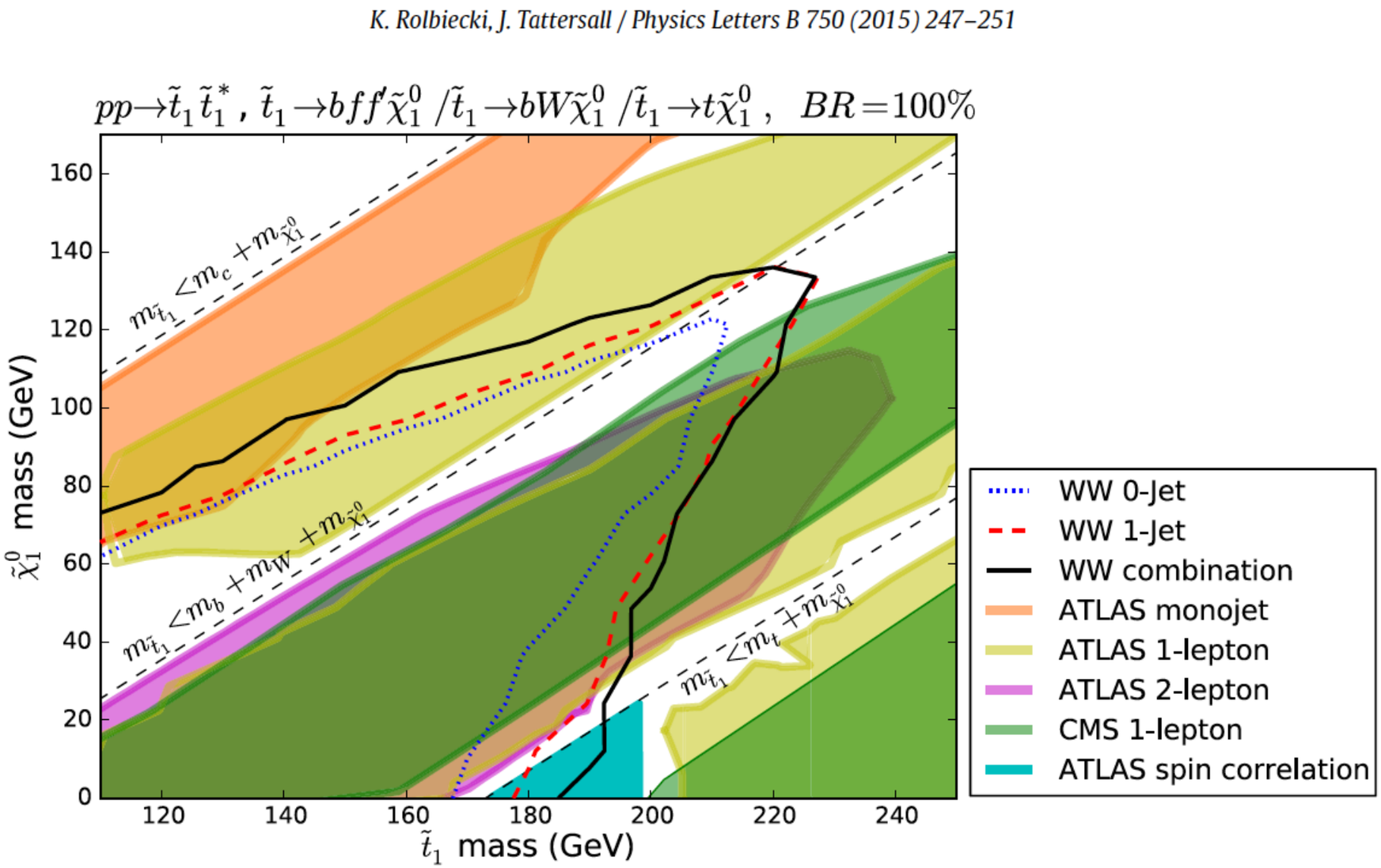
Search for virtual BSM effects

e.g.



Reinterpreting diboson cross sections

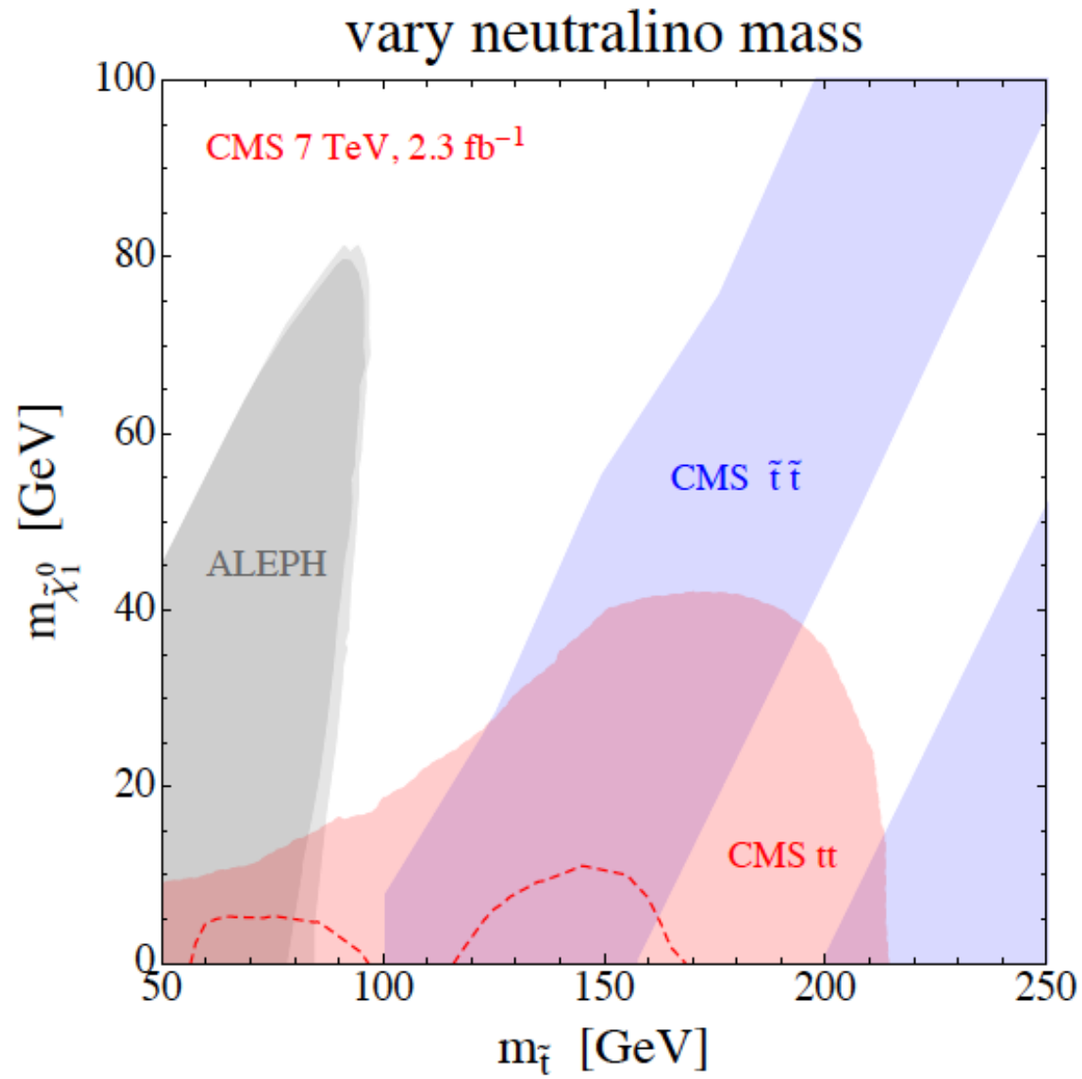
e.g. to search for SUSY through $pp \to \tilde{t}\tilde{t}^* \quad \text{with} \quad \tilde{t} \to W + \tilde{\chi}^0 + b$



cf. Feigl, Rzehak, Zeppenfeld, arXiv:1205.3468 [hep-ph]; Curtin et al., arXiv:1406.0848 [hep-ph]

Reinterpreting top-quark cross-sections

Stop production might be hiding in the top cross section: $\sigma_{\mathrm{exp}} = \sigma_{t\bar{t}} + \sigma_{\tilde{t}\tilde{t}^*}$



Czakon et al., arXiv:1407.1043 [hep-ph]

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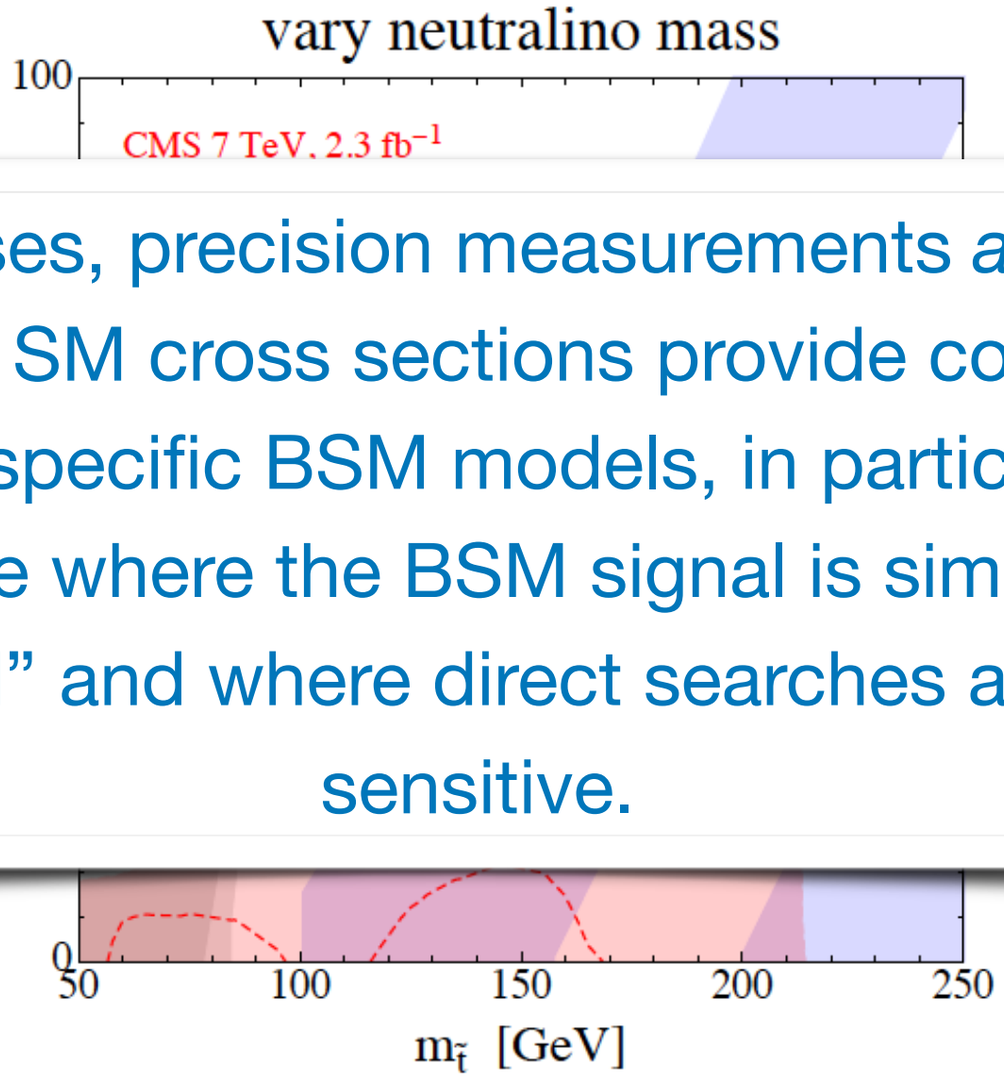


In both cases, precision measurements *and NNLO calculations* of SM cross sections provide complementary information on specific BSM models, in particular in regions of model space where the BSM signal is similar to the SM ``background" and where direct searches are thus less sensitive.

Czakon et al., arXiv:1407.1043 [hep-ph]

Constraints on new theories using Rivet (Contur)

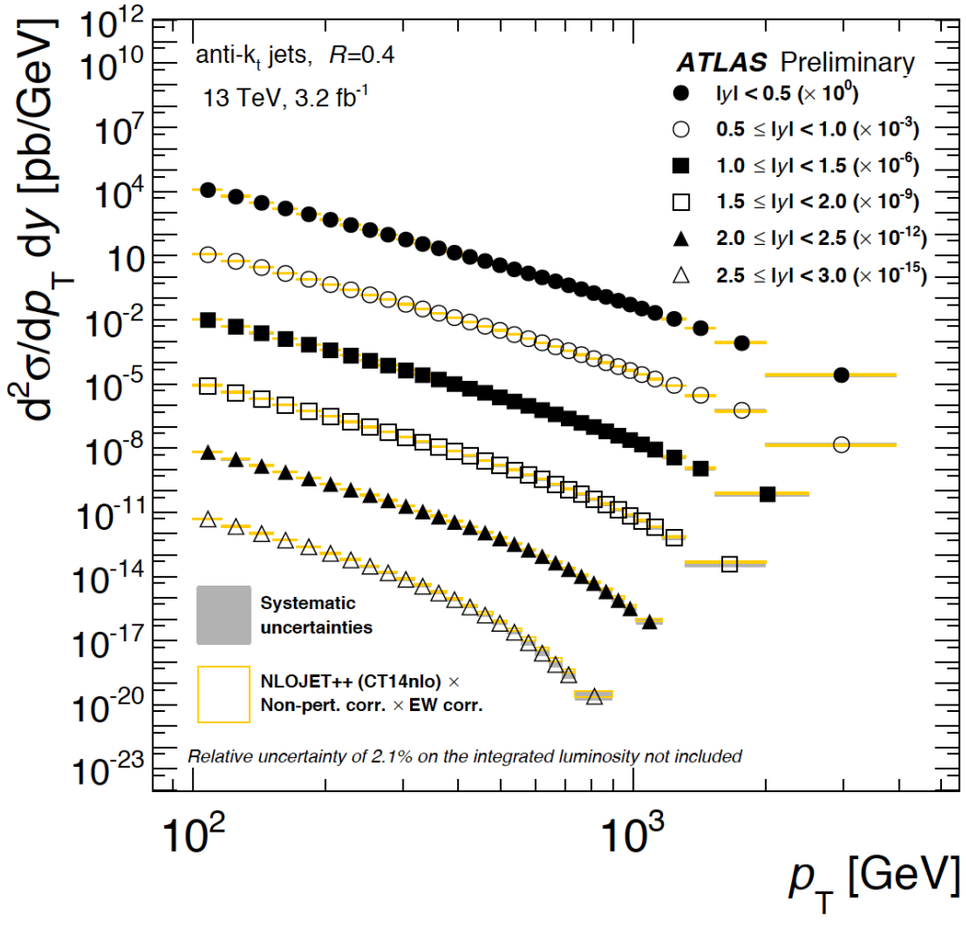
J. Butterworth, MK, D. Grellscheid, B. Sarrazin and D. Yallup

JHEP 1703 (2017) 078 & contur.hepforge.org

We rely on precision SM cross section measurements.

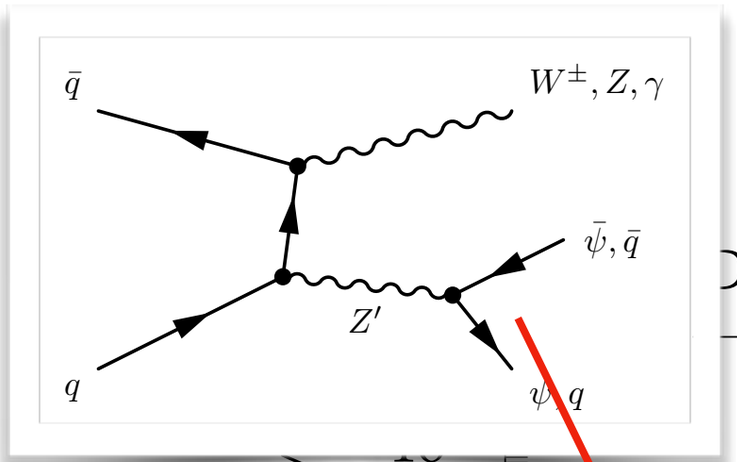
They should

- not assume the SM
- agree with the SM prediction

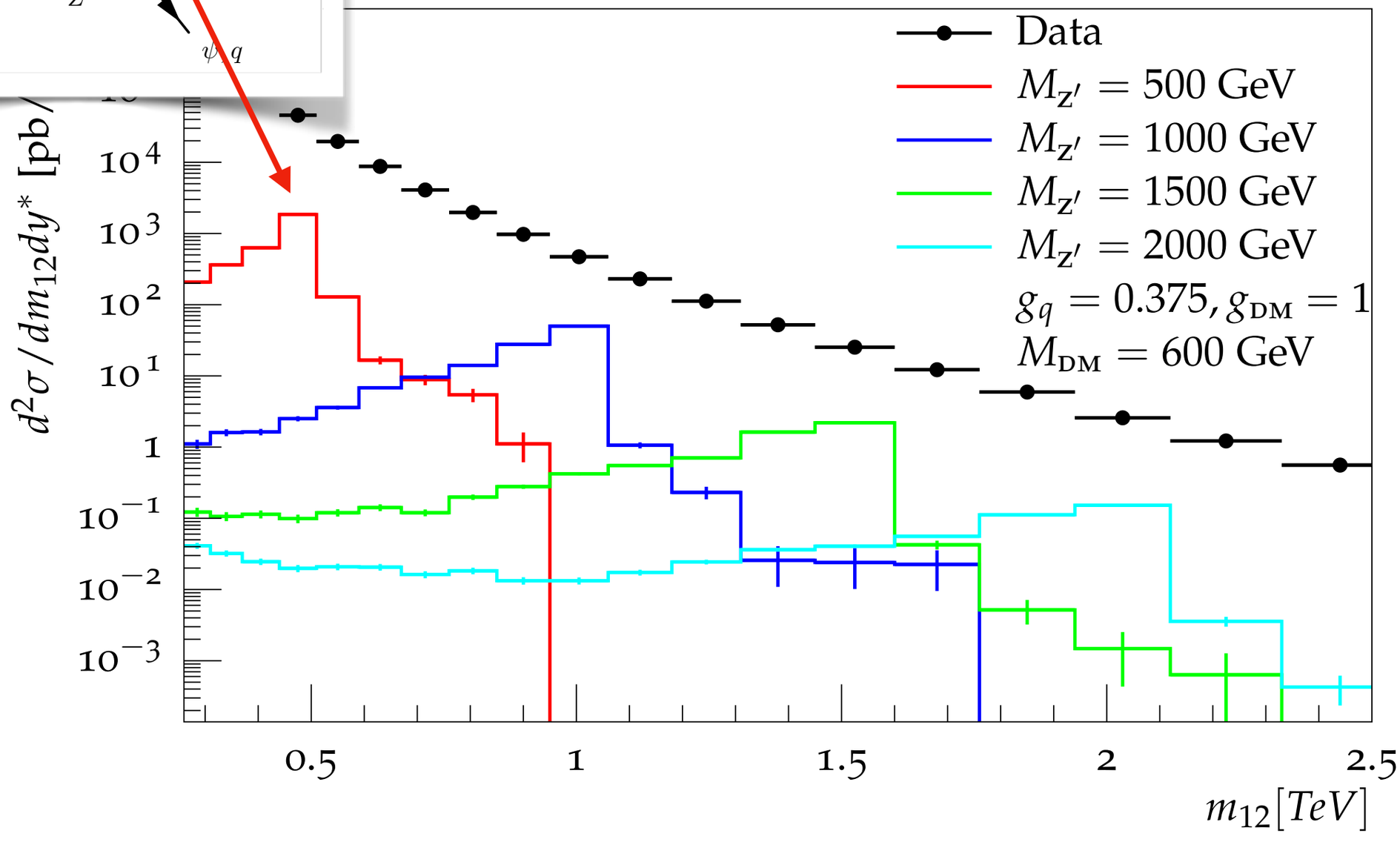


Thus they can potentially constrain BSM processes with SM-like signatures

Constraints on new theories using Rivet (Contur)



Dijet double-differential cross sections ($y^* < 0.5$)



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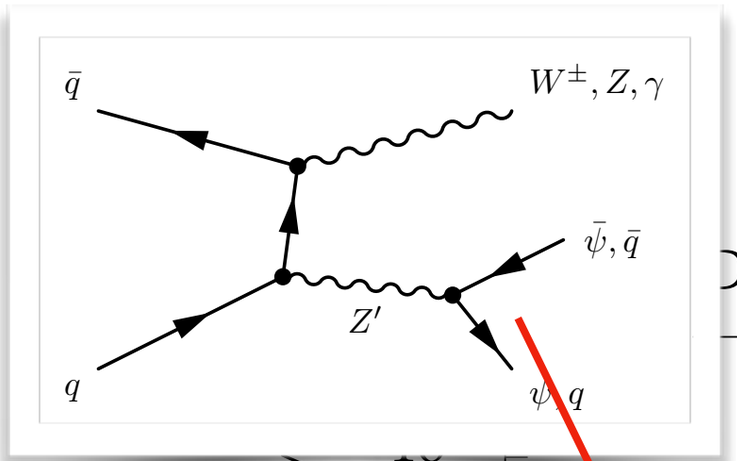

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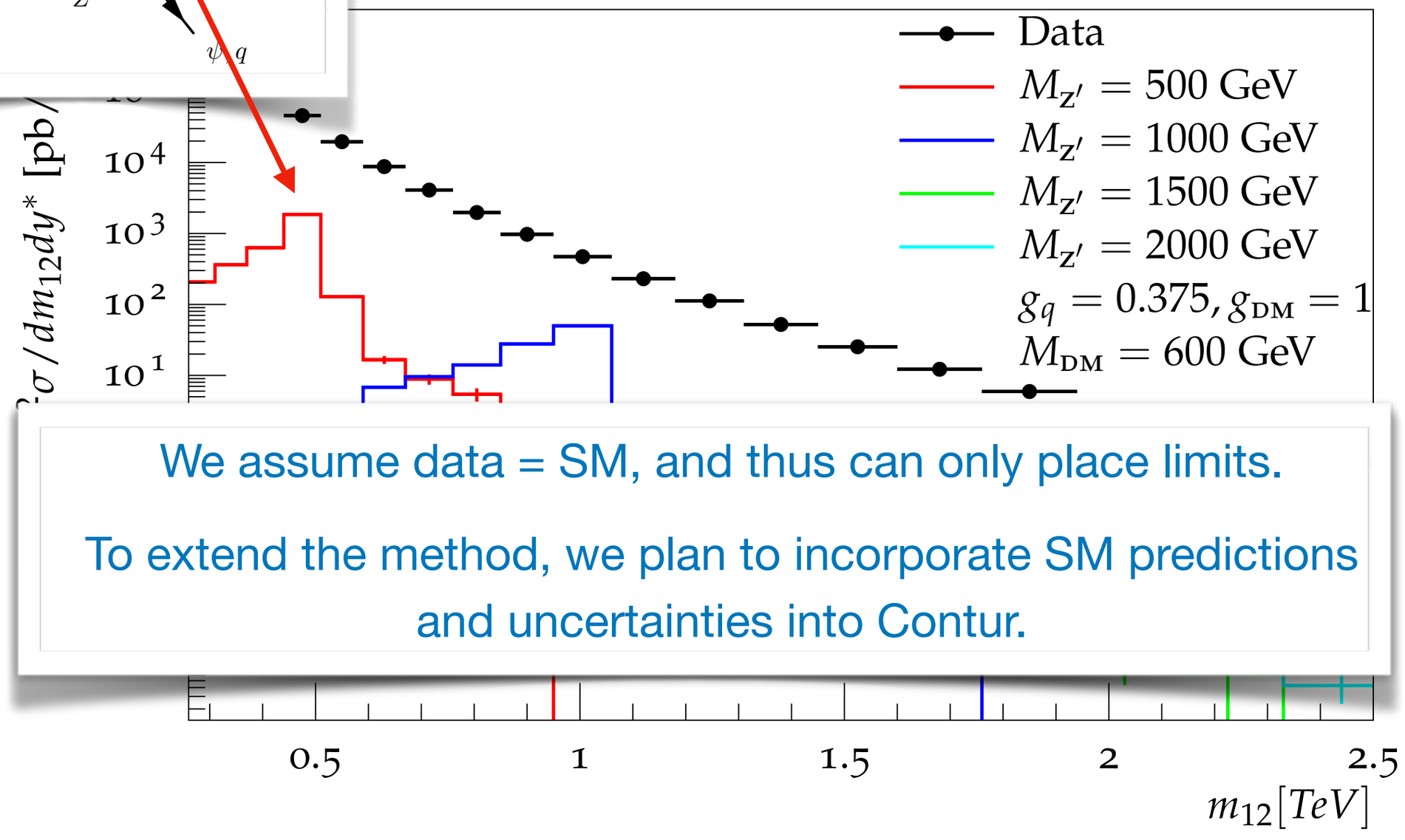
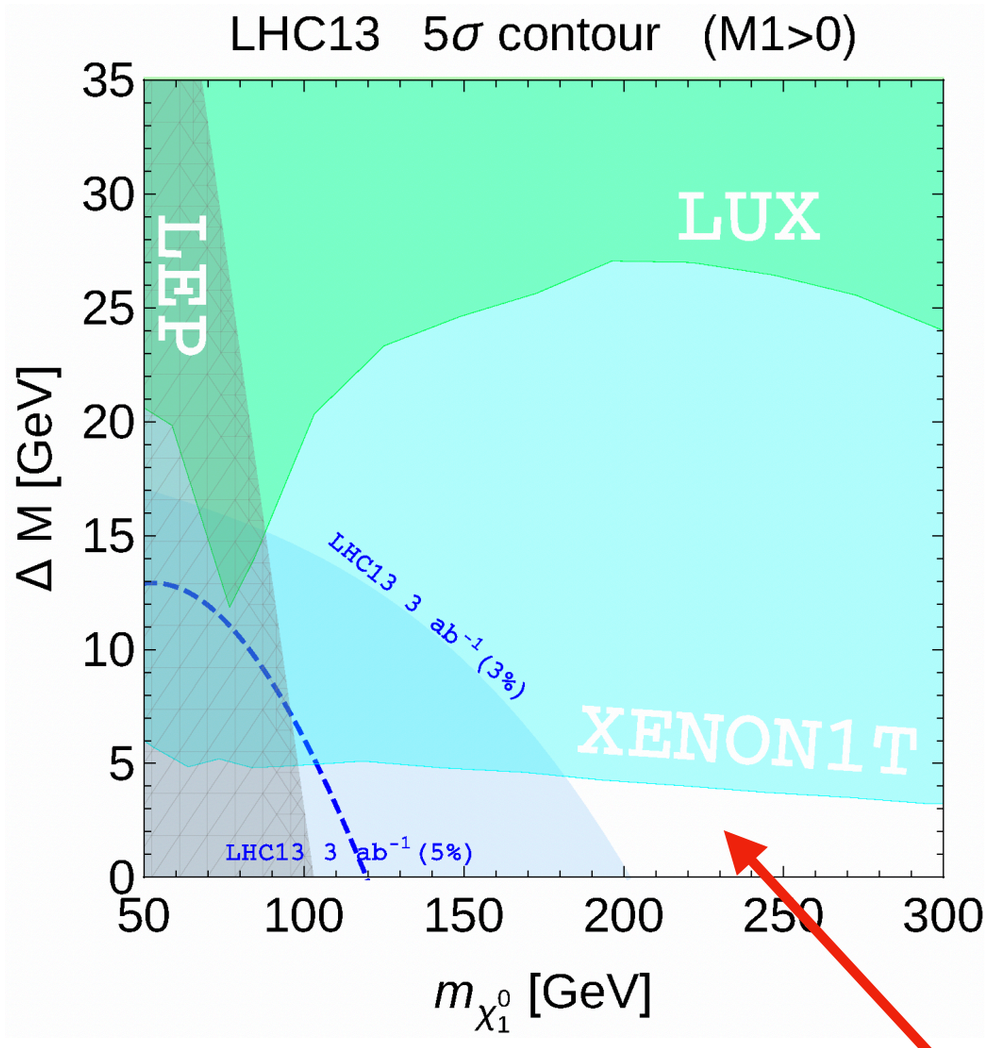


We assume data = SM, and thus can only place limits.

To extend the method, we plan to incorporate SM predictions and uncertainties into Contur.

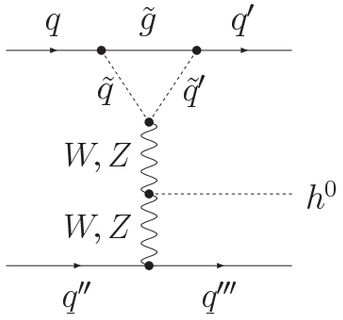
Search for virtual BSM effects

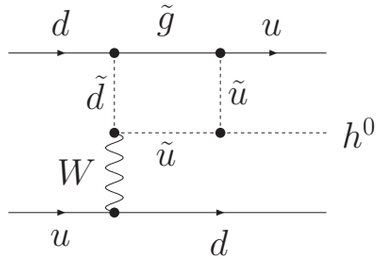


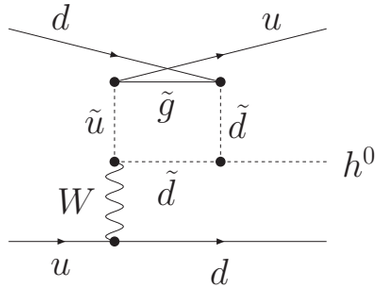
see Werner's talk

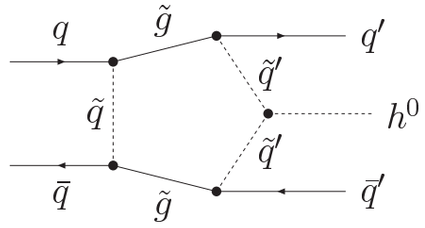
Can we probe this region through indirect precision?

Search for virtual BSM effects



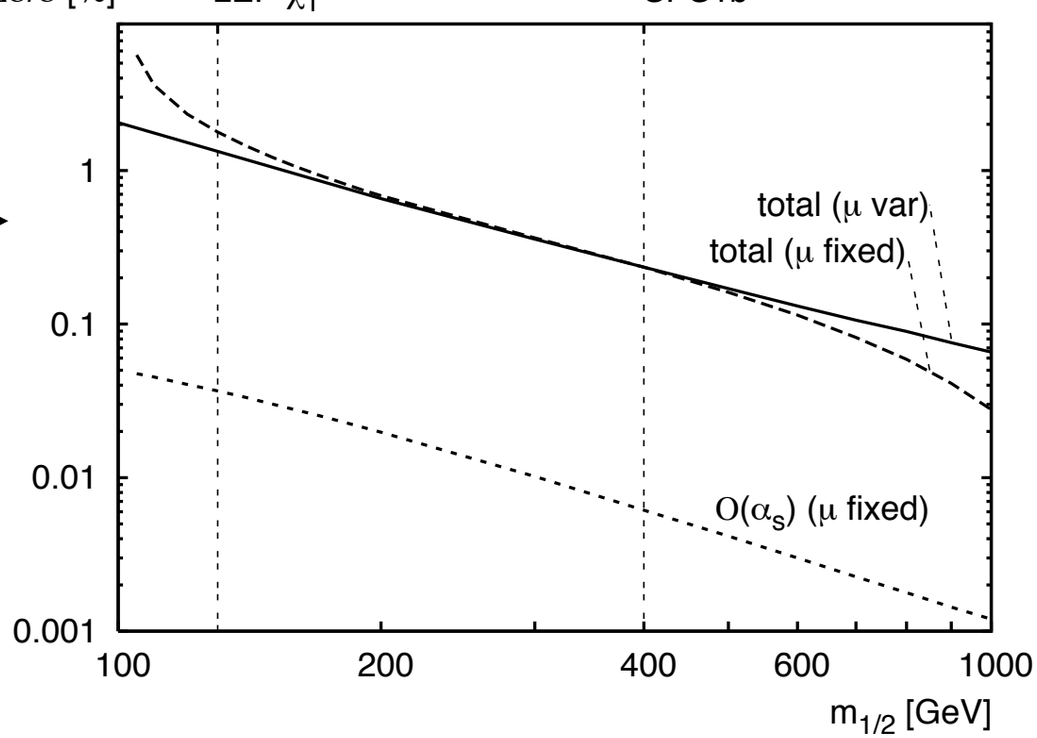




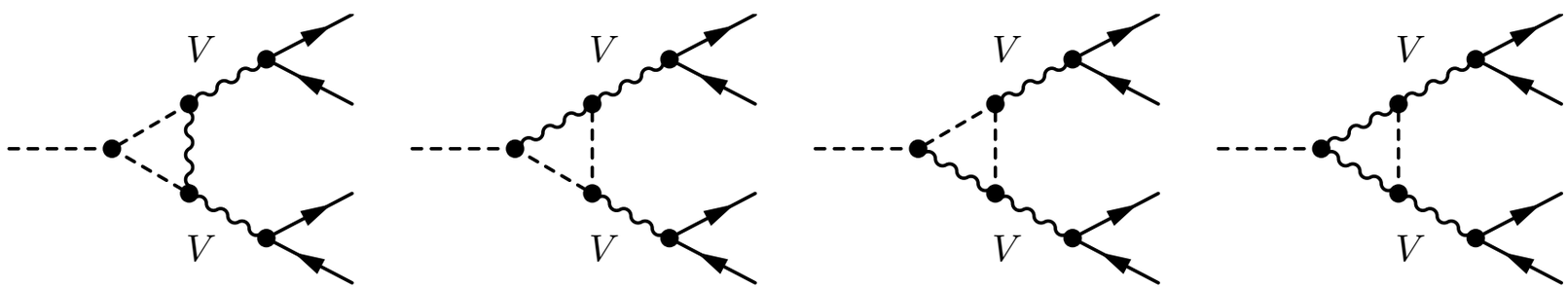


$$\Delta\sigma/\sigma \lesssim \mathcal{O}(1\%)$$

Hollik, Plehn, Rauch, Rzehak, arXiv:0804.2676 [hep-ph]



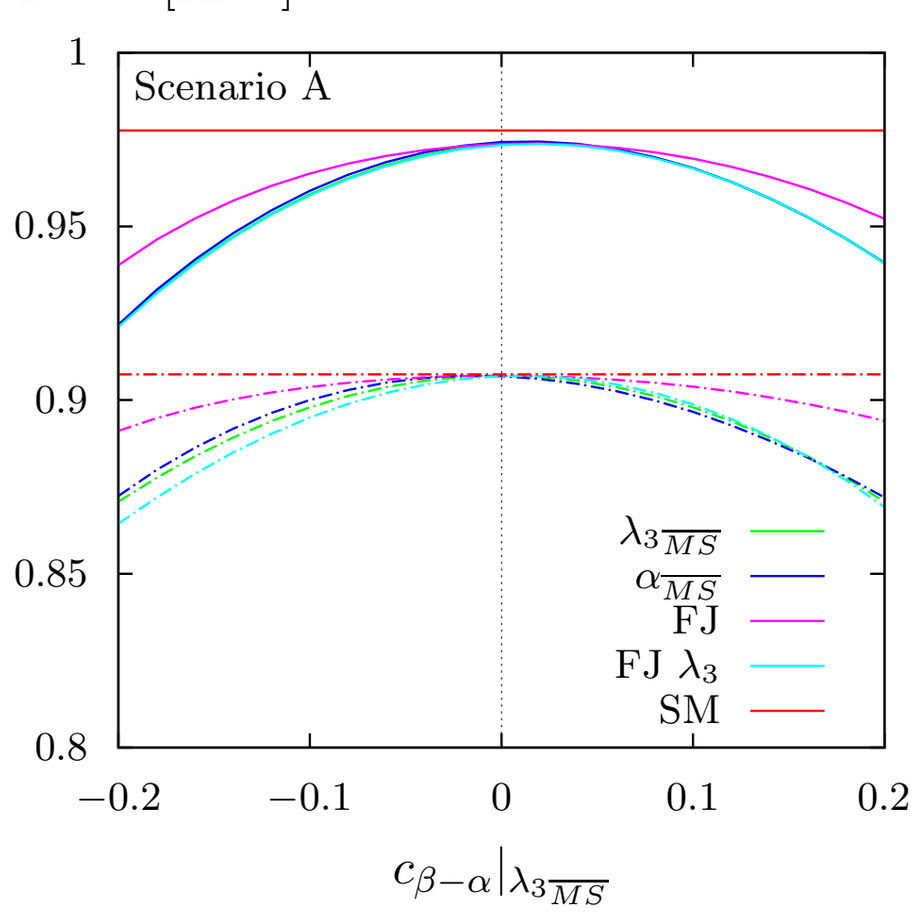
Search for virtual BSM effects



see Heidi's talk

$$\Delta\Gamma_{\mathrm{THDM}}/\Gamma_{\mathrm{SM}} \lesssim 6\% \longrightarrow$$

Altenkamp, Dittmaier, Rzehak, arXiv:1710.07598 [hep-ph]



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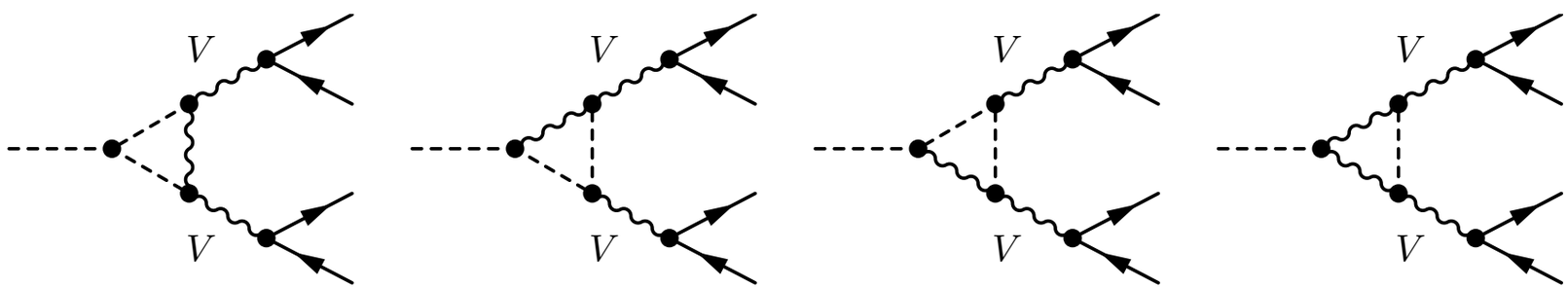

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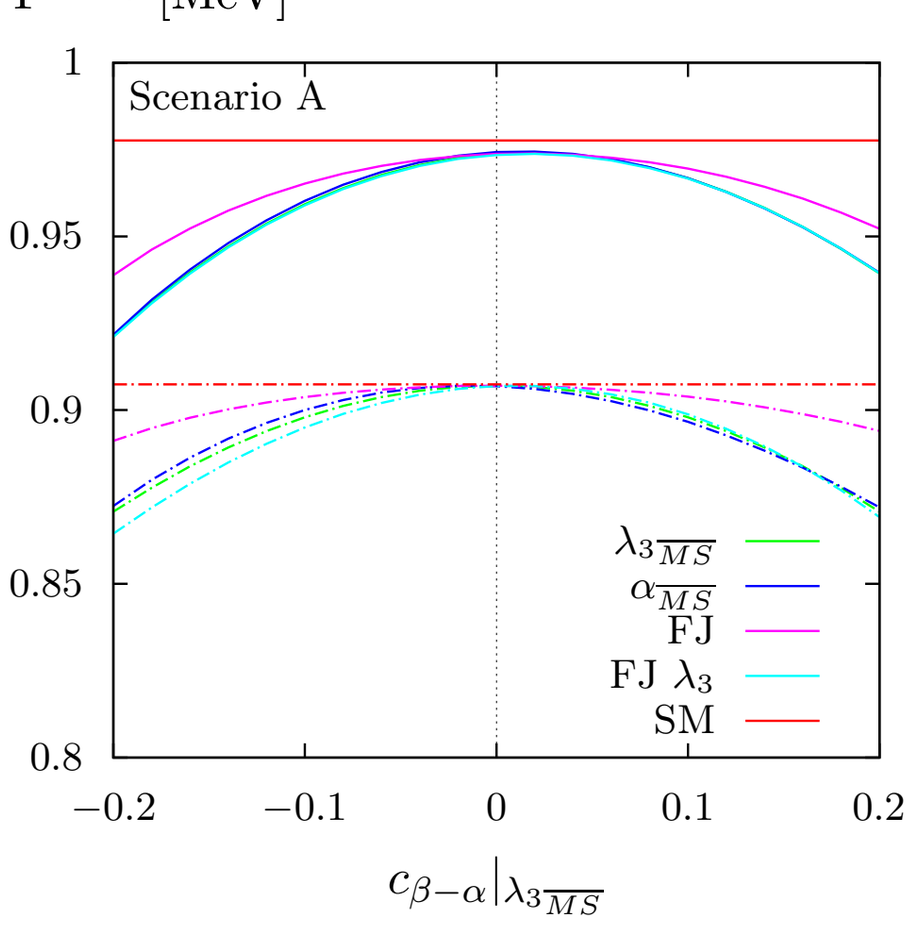

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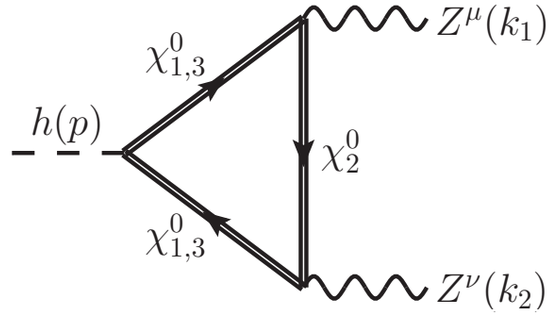
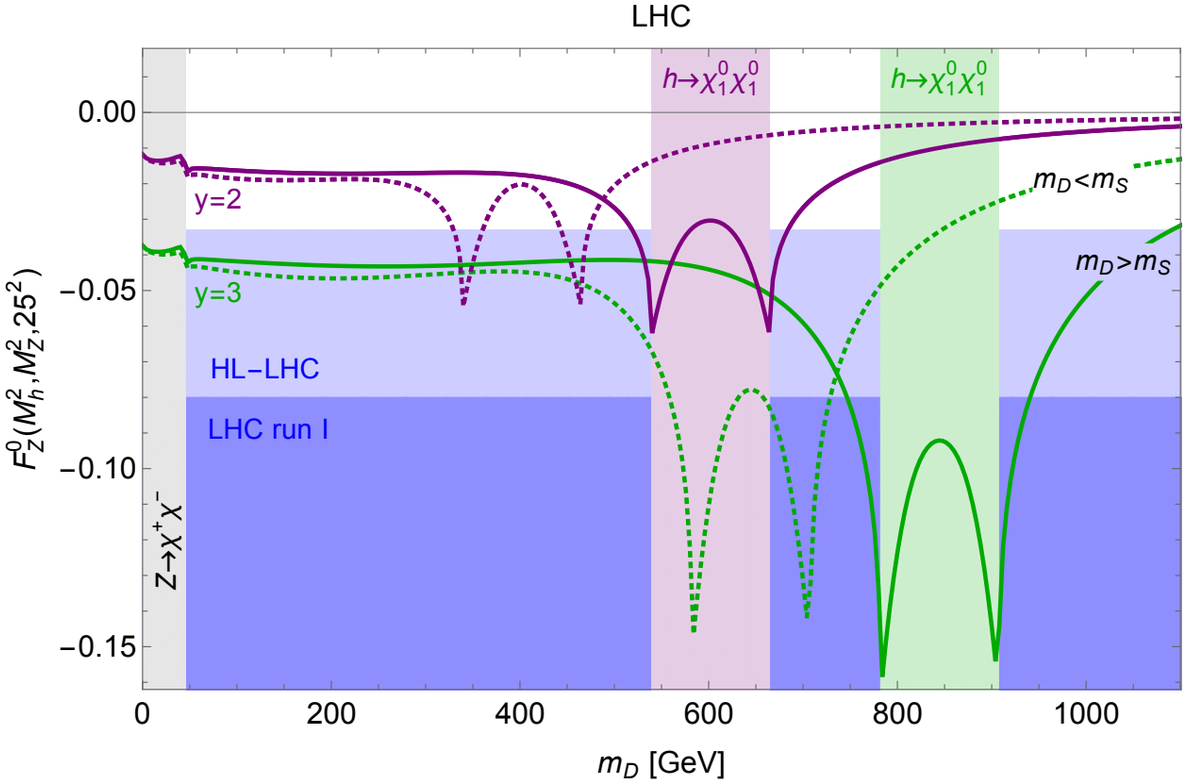
Could the new states (M_H = 300 GeV, M_{A/H^+} = 460 GeV) be discovered in direct searches?

Search for virtual BSM effects

Higgs portal model with dark fermions

$$\mathcal{L} \supset y\left[\sin(2\theta)(\chi_3\chi_3 - \chi_1\chi_1) - 2\cos(2\theta)\chi_3\chi_1\right]h$$





Voigt and Westhoff, arXiv:1708.01614 [hep-ph]

Search for virtual BSM effects

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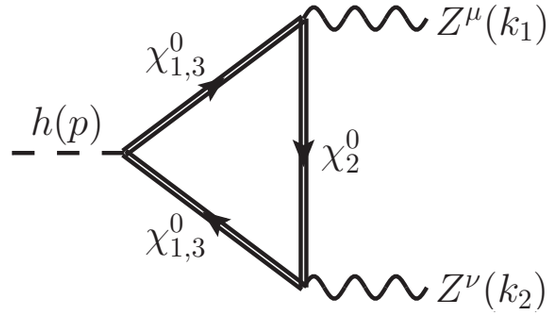

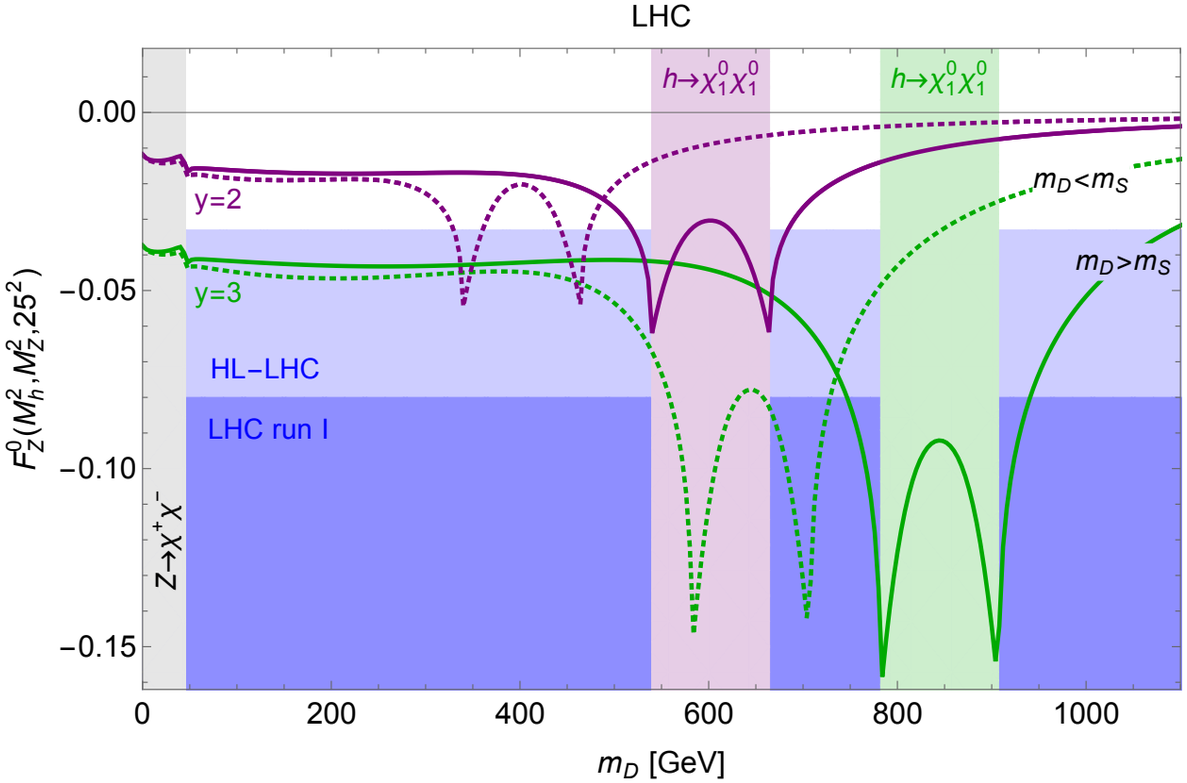

Voigt and Westhoff, arXiv:1708.01614 [hep-ph]

Virtual effects of dark fermions are sizeable for large Yukawa couplings, and can probe parameter regions with heavy mediators or compressed spectra, complementary to direct searches

Do we need BSM precision?

We need precision to explore BSM models after discovery

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Do we need precision to improve constraints on BSM models before a discovery?

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Do we need precision to improve constraints on BSM models before a discovery?

Why being an optimist?

- 10 years to develop a tool
- BSM predictions needed for discovery (and for limit setting?)
- Experience with one model can be used for others

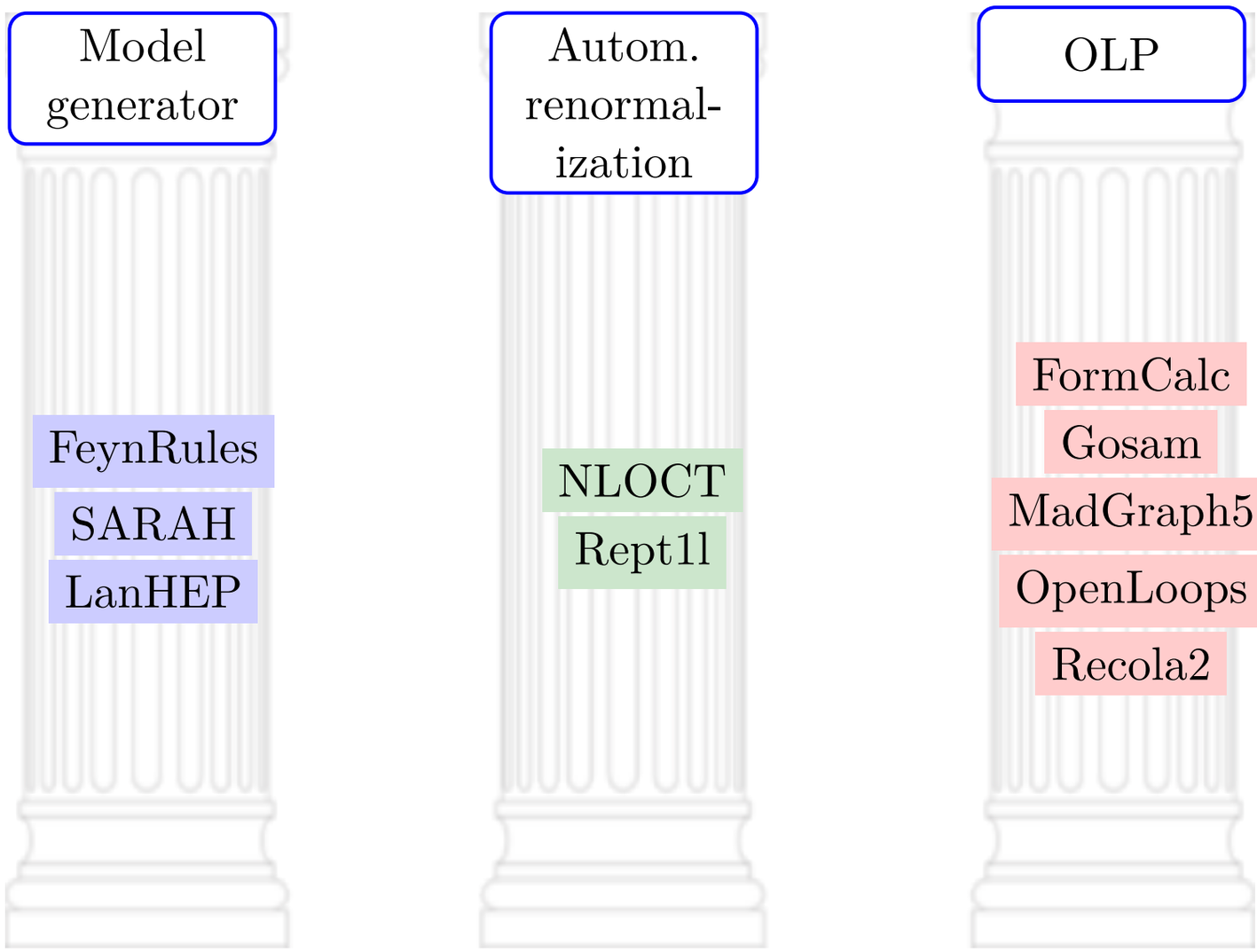
Need for both, optimists and pessimists

Do we need BSM precision?

Conclusion:

Modern OLP are (getting) ready for BSM theories.

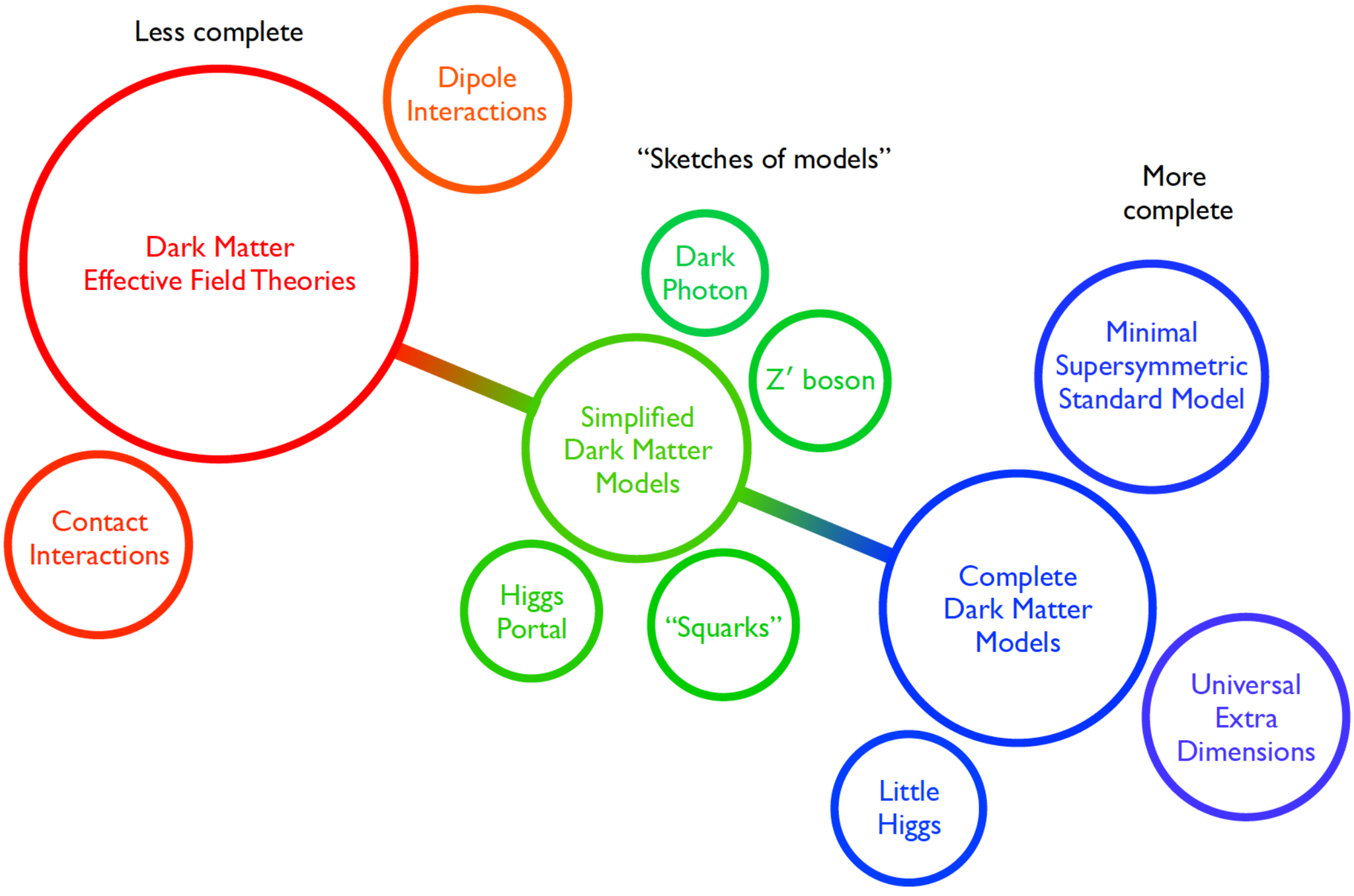
see Jean-Nicolas' talk



BSM physics at the LHC

- BSM searches with Standard Model cross sections
- Effective field theories and (simplified) models:
  BSM searches and novel/subtle LHC signatures

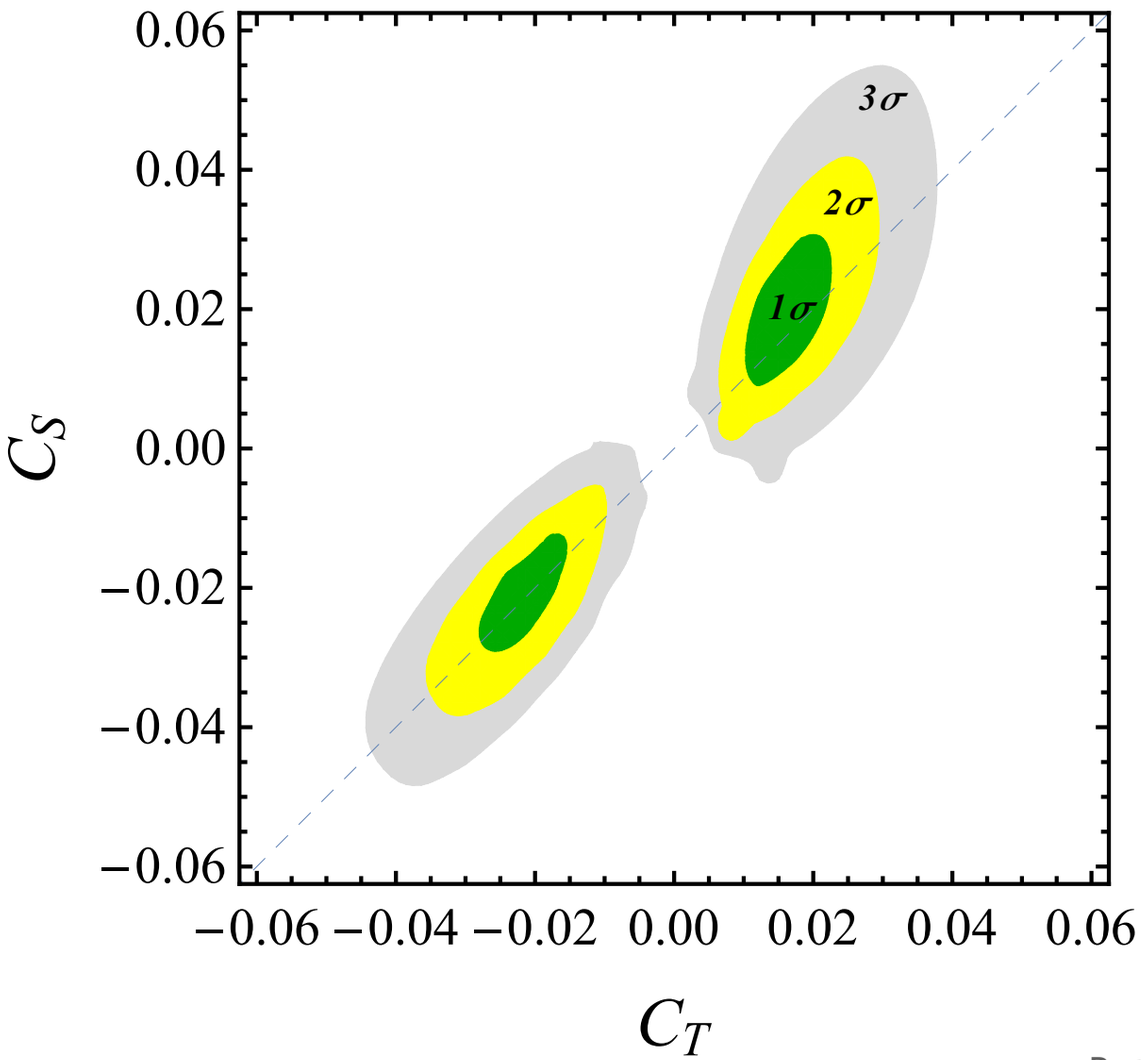
From EFTs to full models?



arXiv:1506.03116 [hep-ph]

From EFTs to full models

B physics anomalies $\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \frac{1}{v^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\left[C_T\ (\bar{Q}^i_L\gamma_\mu\sigma^a Q^j_L)(\bar{L}^\alpha_L\gamma^\mu\sigma^a L^\beta_L) + C_S\ (\bar{Q}^i_L\gamma_\mu Q^j_L)(\bar{L}^\alpha_L\gamma^\mu L^\beta_L)\right]$



Buttazzo, Greljo, Isidori, Marzocca, arXiv:1706.07808 [hep-ph]

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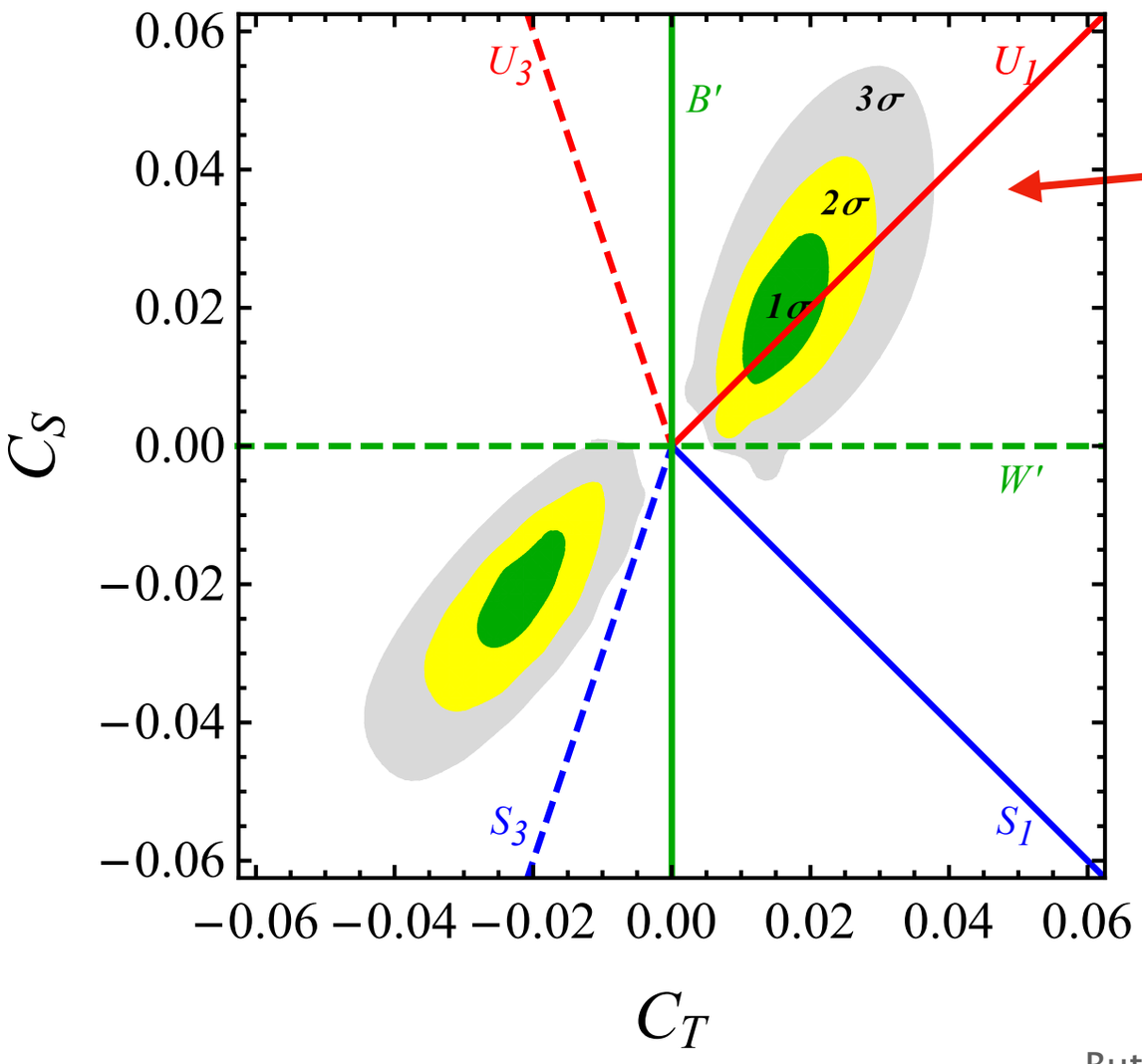

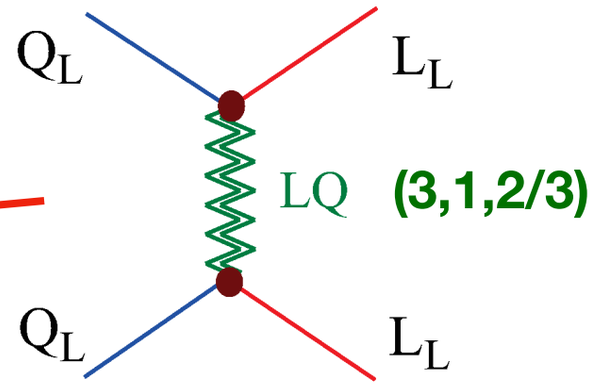

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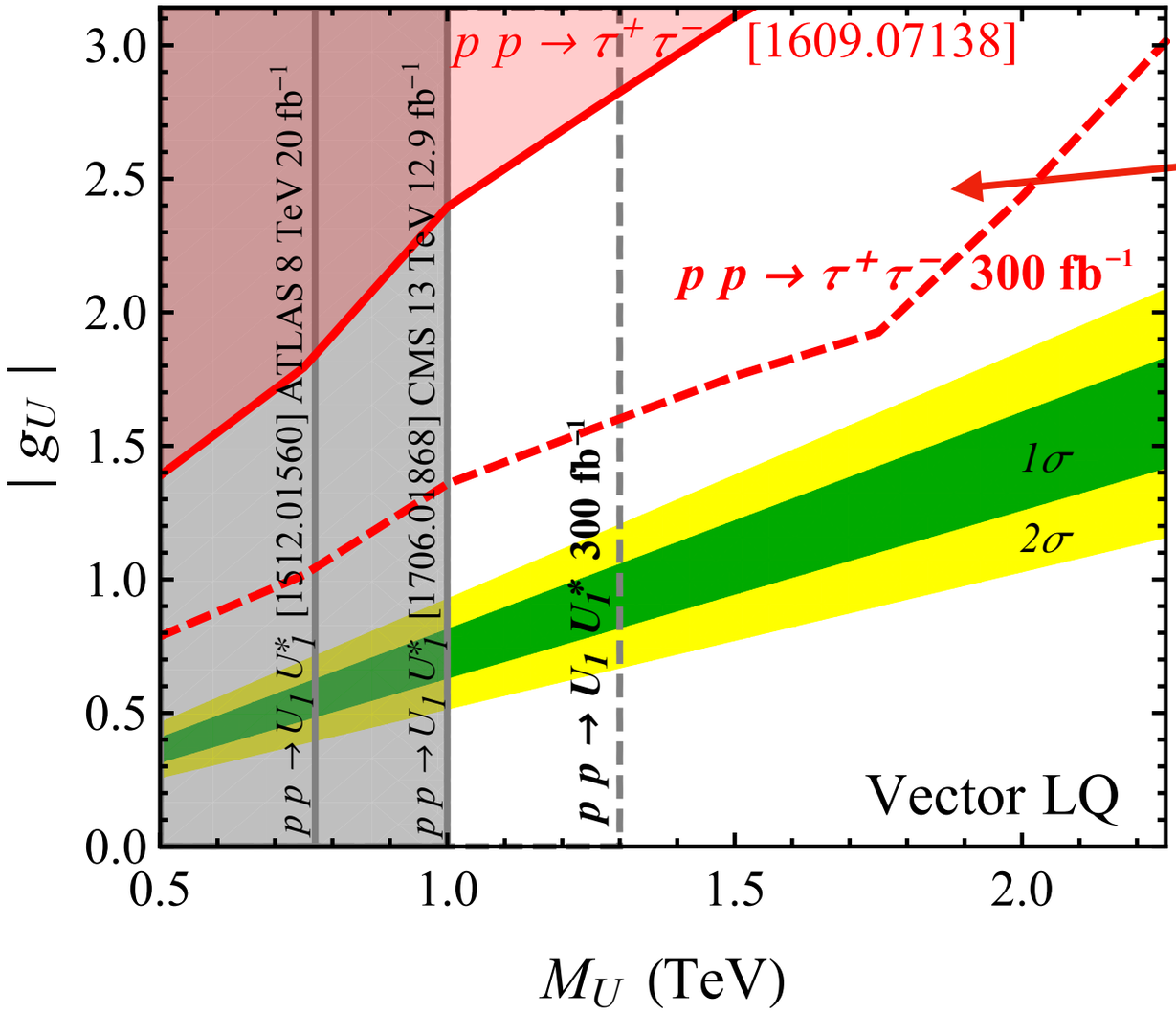

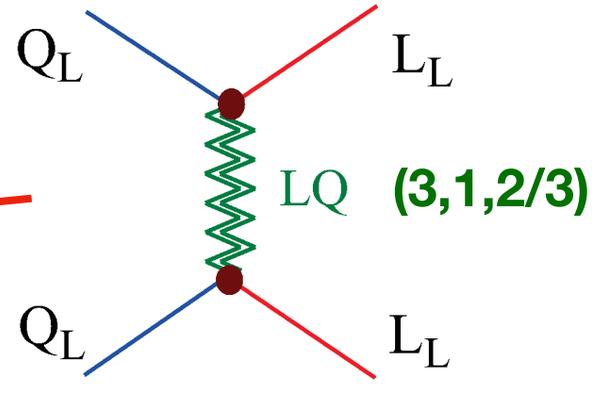

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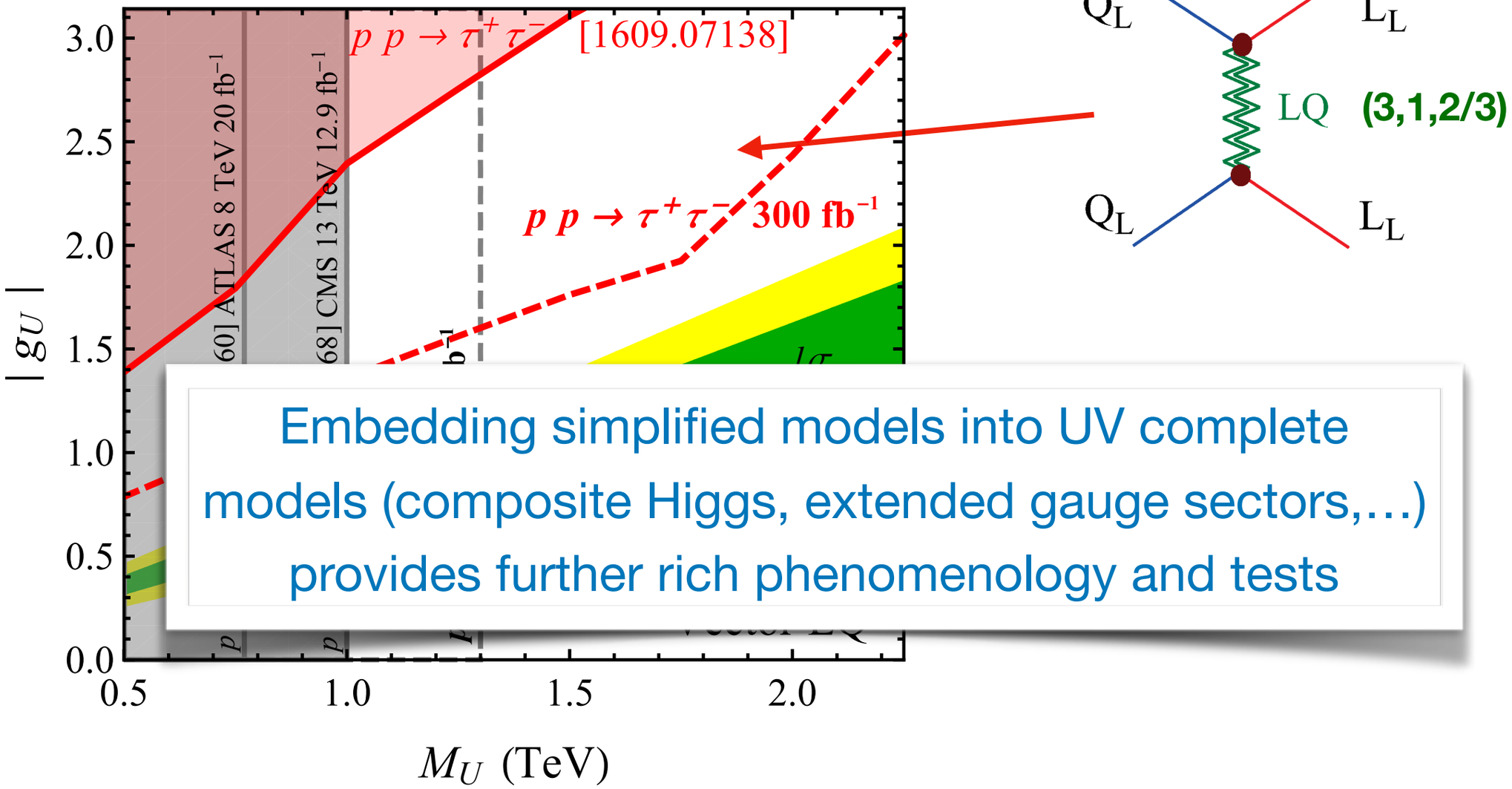
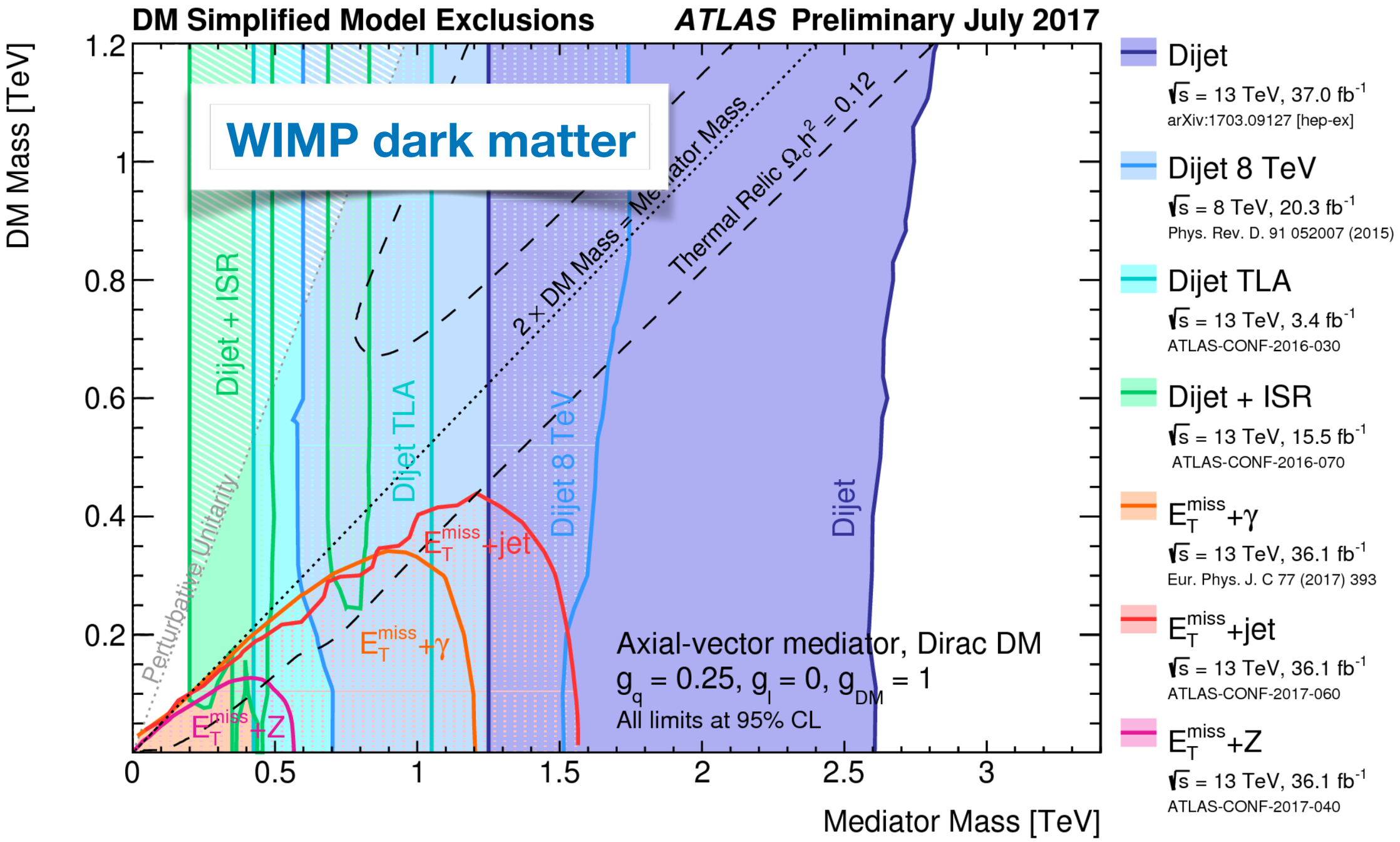


Embedding simplified models into UV complete models (composite Higgs, extended gauge sectors,…) provides further rich phenomenology and tests

Buttazzo, Greljo, Isidori, Marzocca, arXiv:1706.07808 [hep-ph]

BSM searches and novel/subtle LHC signatures: dark matter



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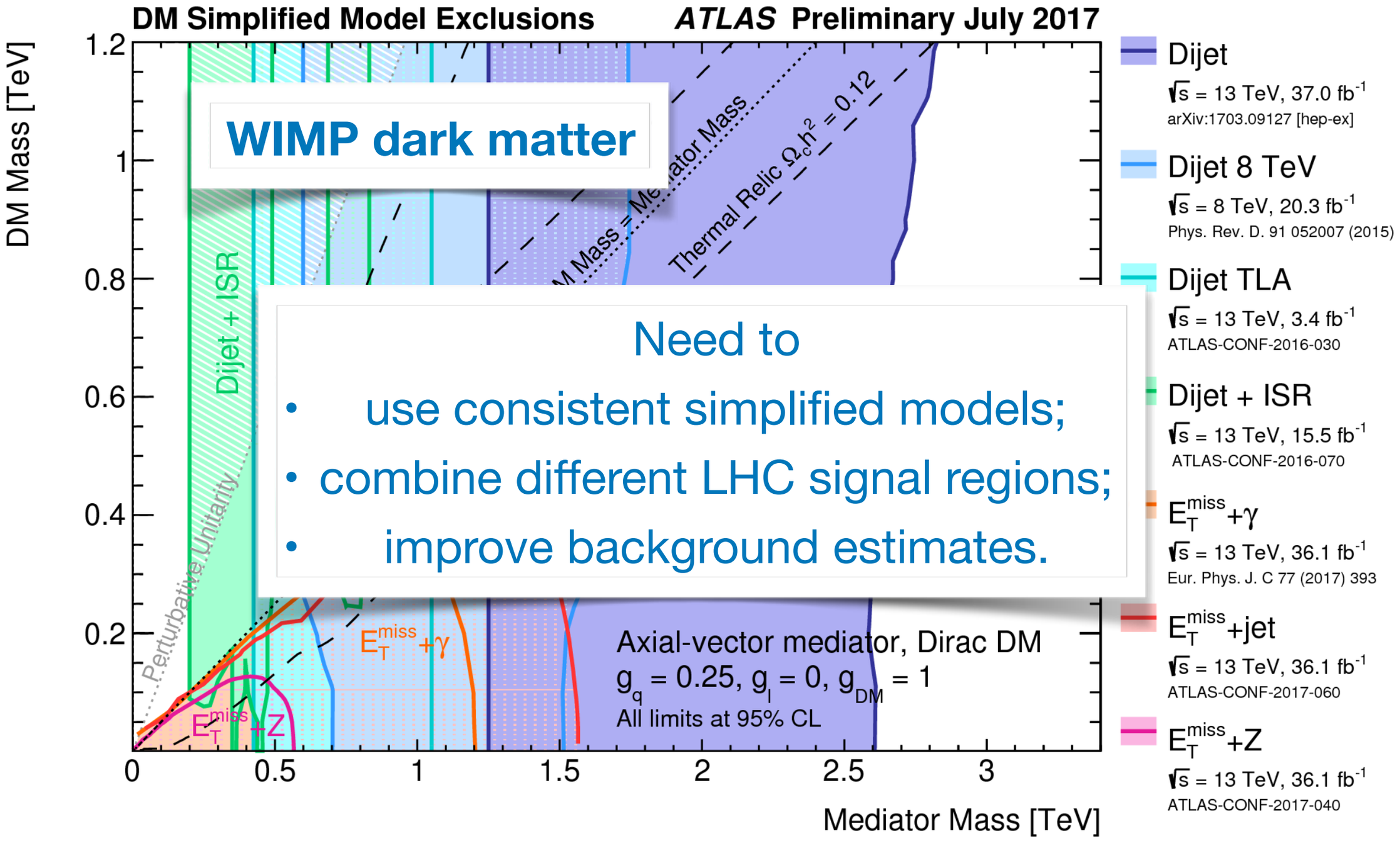


BSM searches and novel/subtle LHC signatures: dark matter

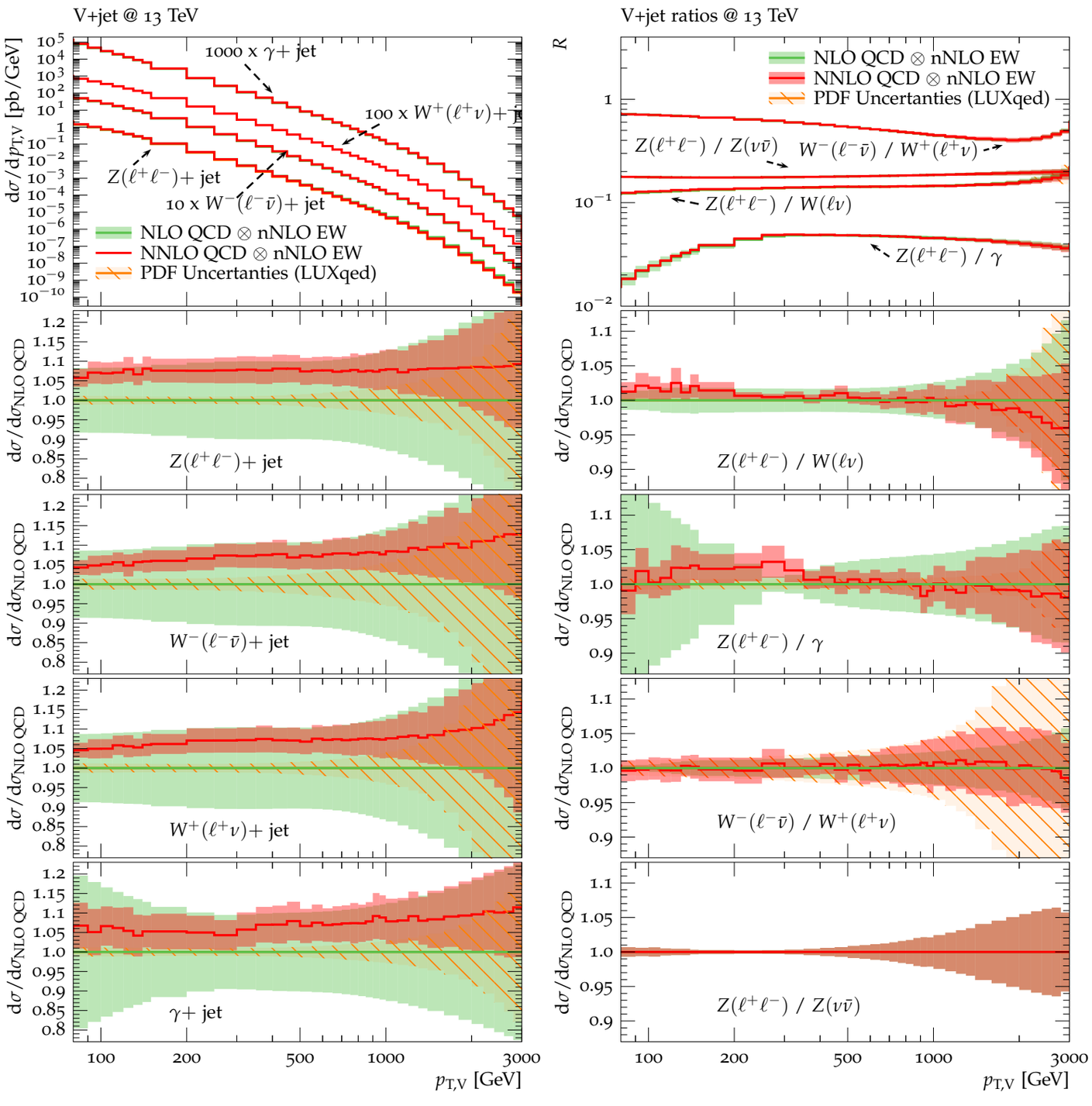
Reducing background uncertainties in jets + MET

see Luca's talk

$$\Delta\sigma/\sigma \lesssim 10\%$$

$$\text{for } p_T \lesssim 3 \text{ TeV}$$

Lindert et al., arXiv:1705.04664 [hep-ph]

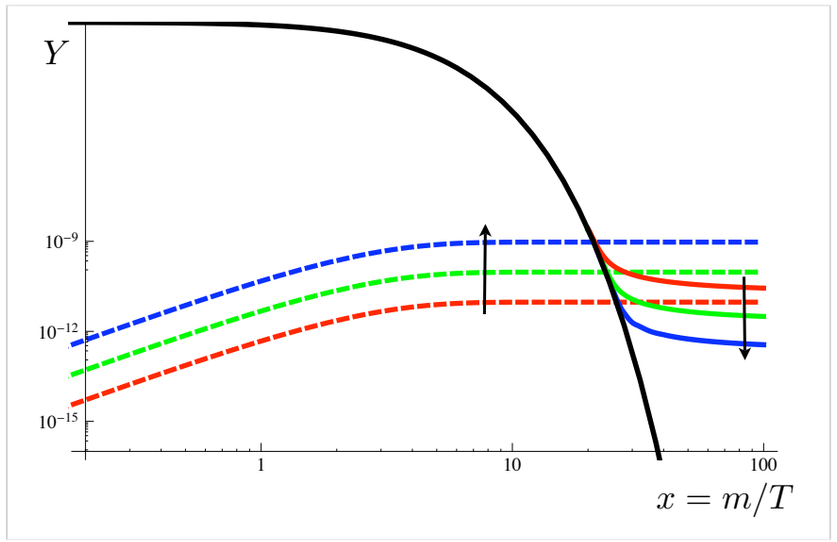


BSM searches and novel/subtle LHC signatures: dark matter

Freeze-in dark matter

Hall, Jedamzik, March-Russell, West arXiv:0911.1120 [hep-ph]

Implies tiny couplings between
SM and dark sector

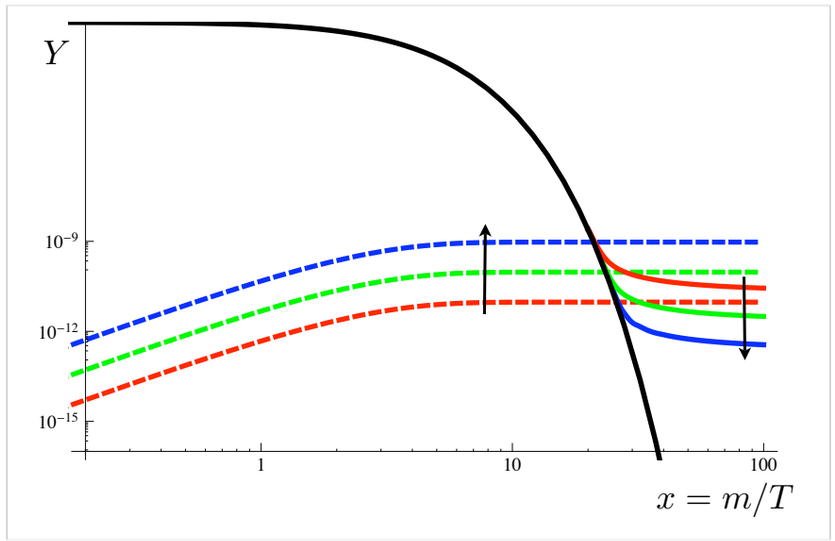


BSM searches and novel/subtle LHC signatures: dark matter

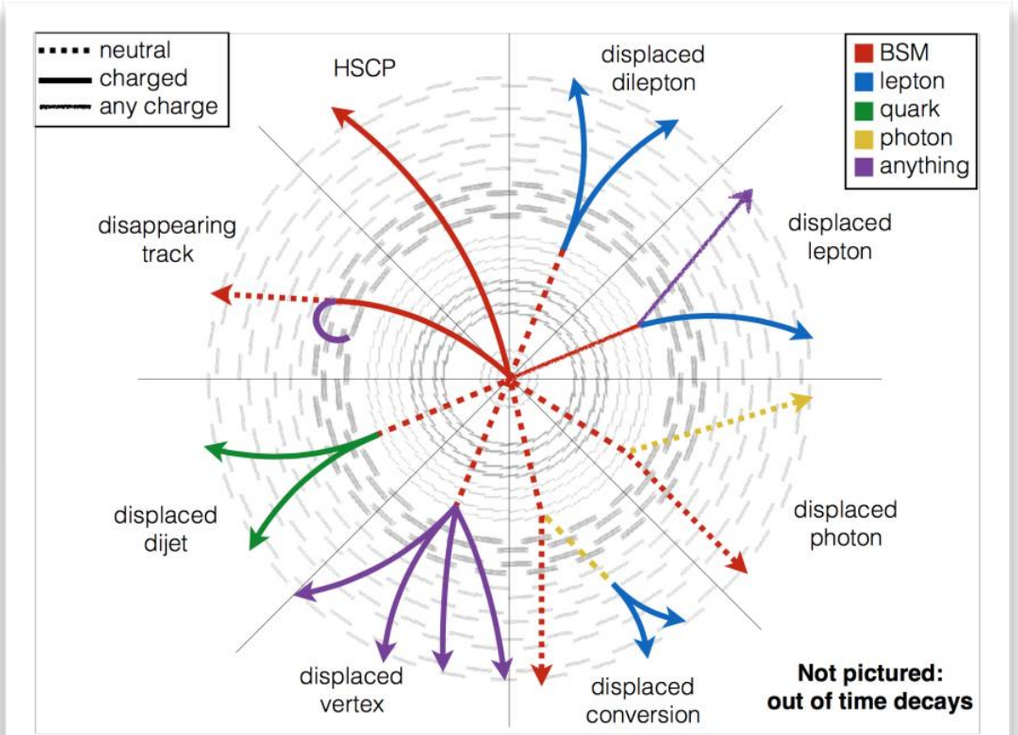
Freeze-in dark matter

Hall, Jedamzik, March-Russell, West arXiv:0911.1120 [hep-ph]

Implies tiny couplings between SM and dark sector



Search for long-lived particles and displaced decays



De Roeck

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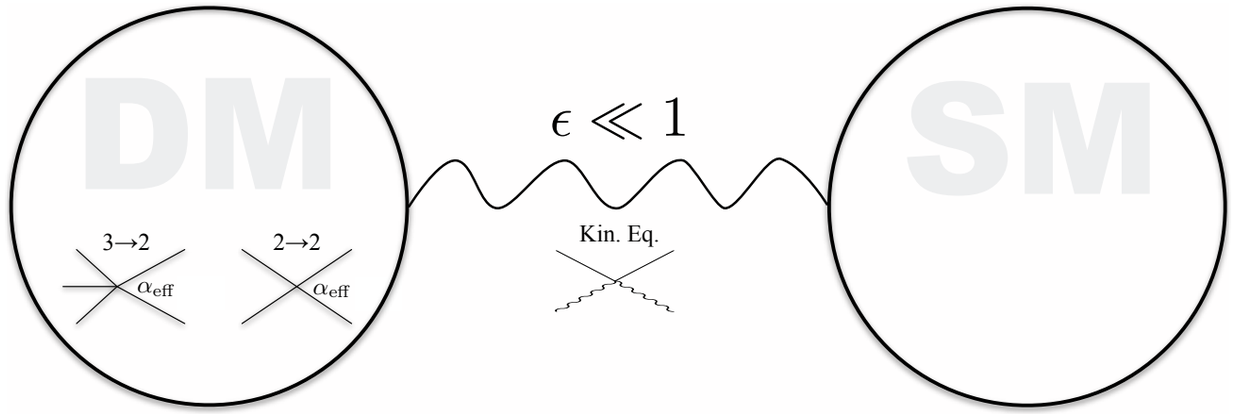
Strongly interacting dark matter

Implies strongly interacting hidden sector



Hochberg, Kuflik, Volansky, Wacker, arXiv:1402.5143 [hep-ph]

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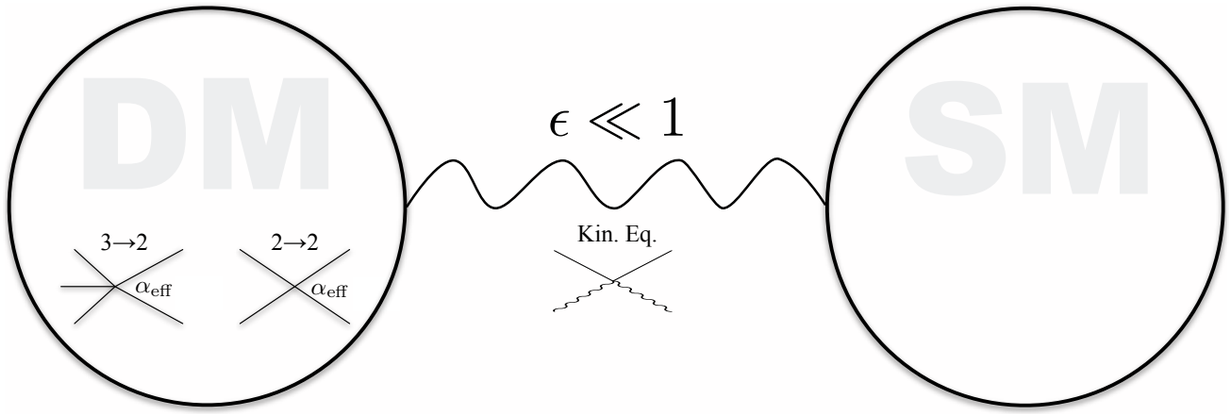
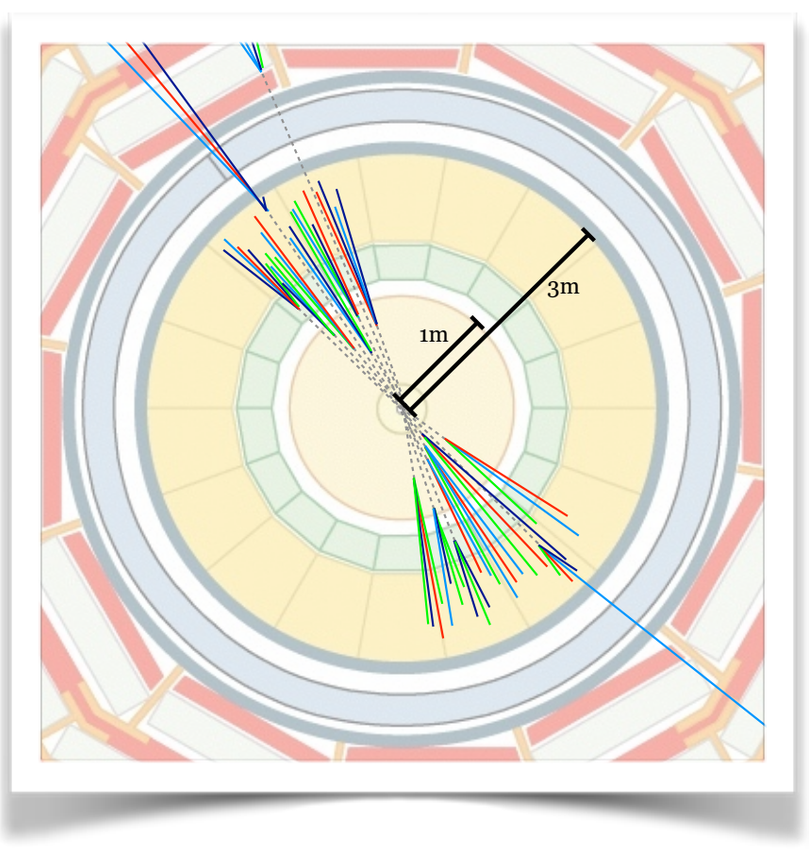


Hochberg, Kuflik, Volansky, Wacker, arXiv:1402.5143 [hep-ph]



Schwaller, Stolarski, Weiler, arXiv:1502.05409 [hep-ph]

Novel collider signatures, such as **emerging jets**, anomalous underlying events,…

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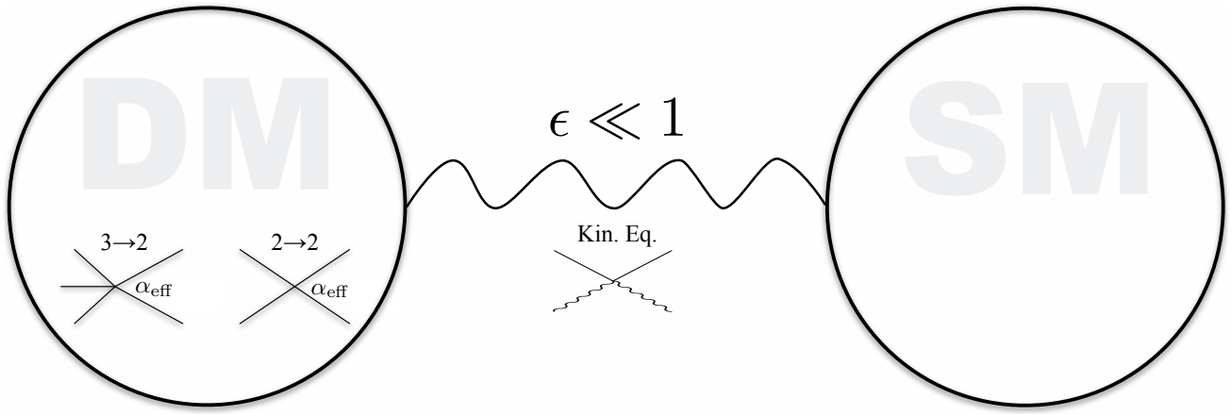

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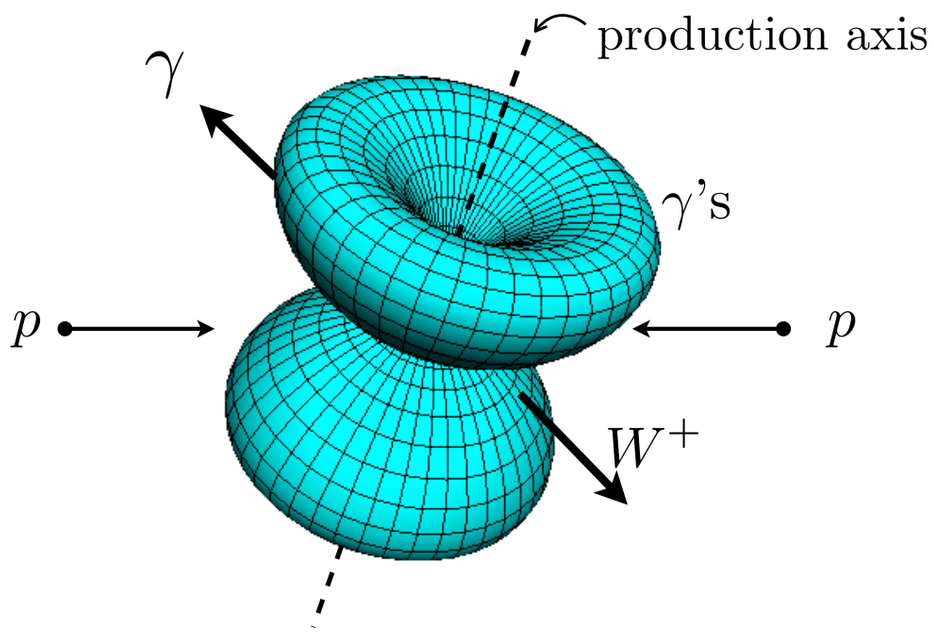

Harnik, Wizansky, arXiv:0810.3948 [hep-ph]

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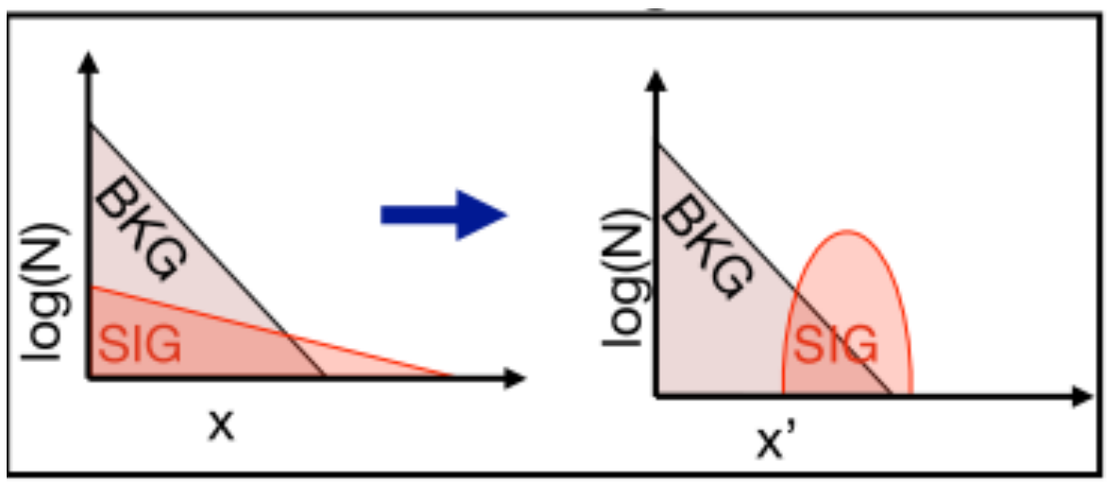
BSM searches and novel/subtle LHC signatures

How can we extract subtle BSM signatures from SM backgrounds?

see Luca's talk



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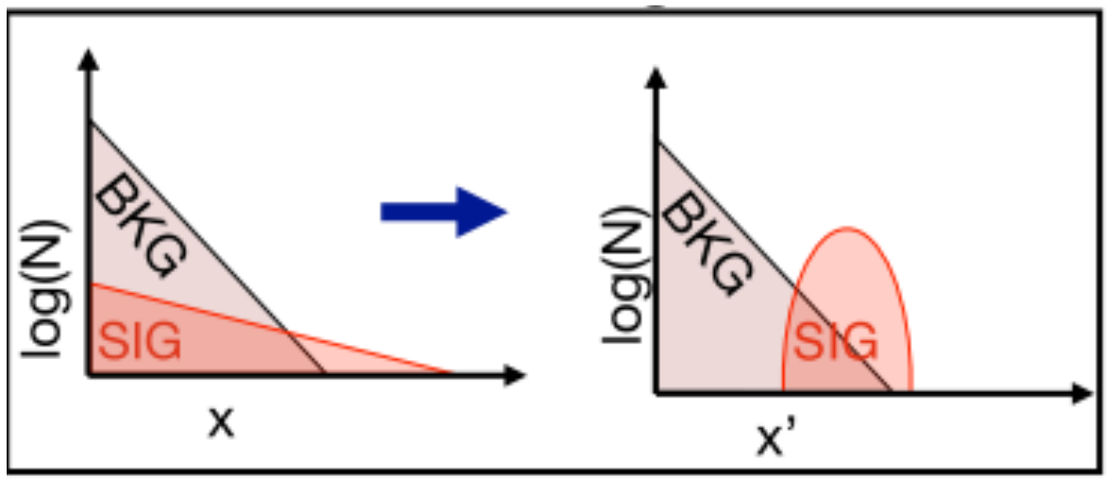
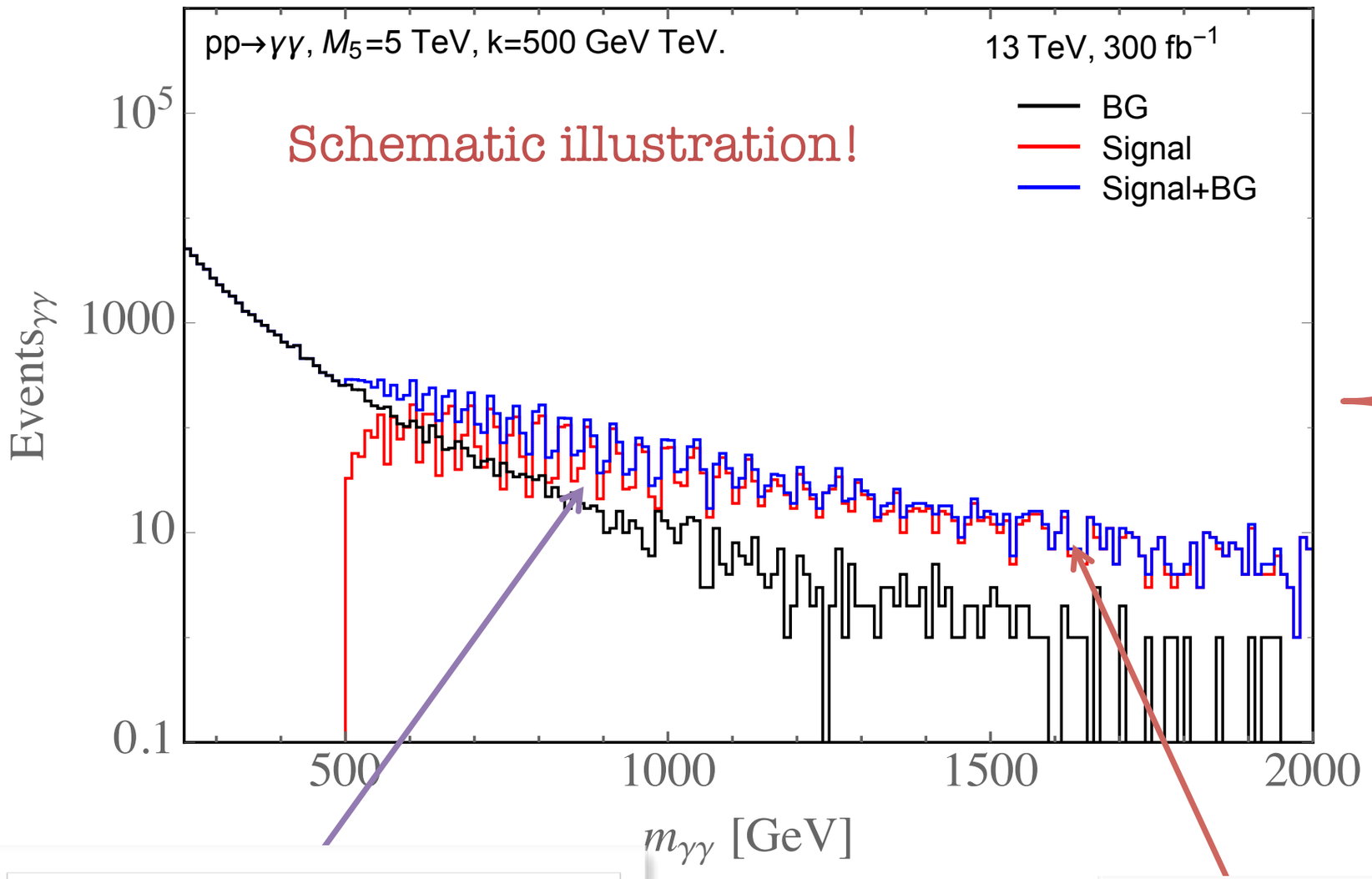
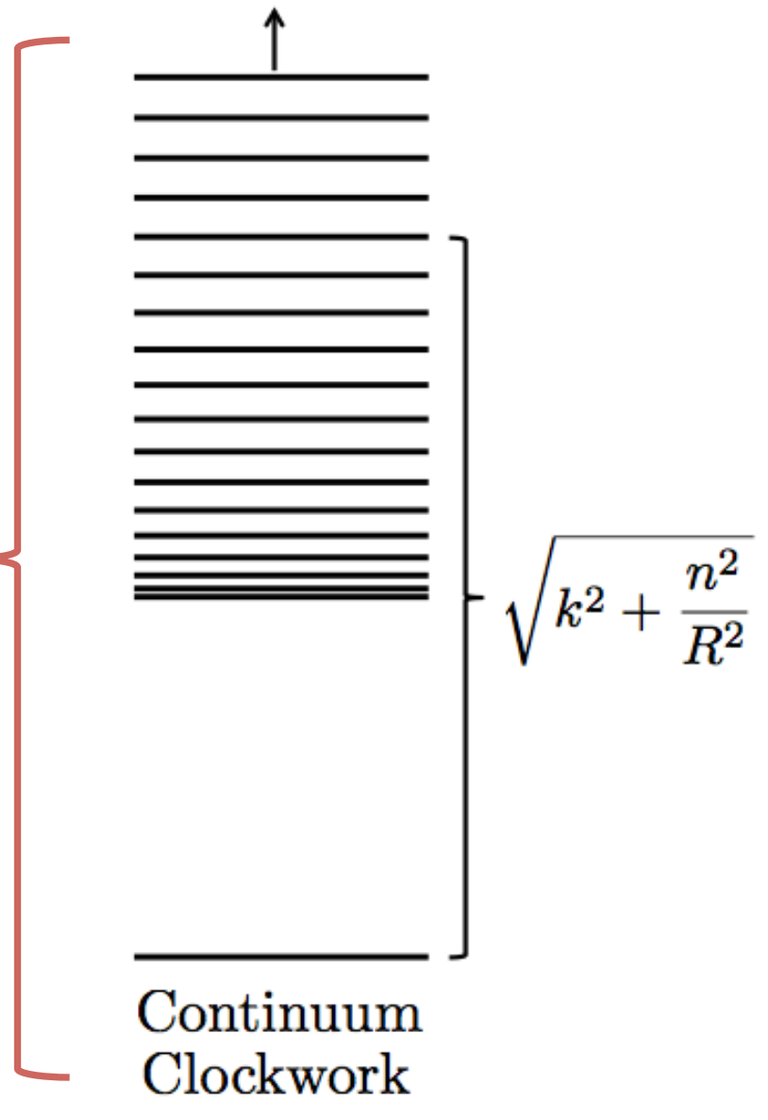


BSM searches and novel/subtle LHC signatures

Extra dimension theories, e.g. clockwork mechanisms

McCullough



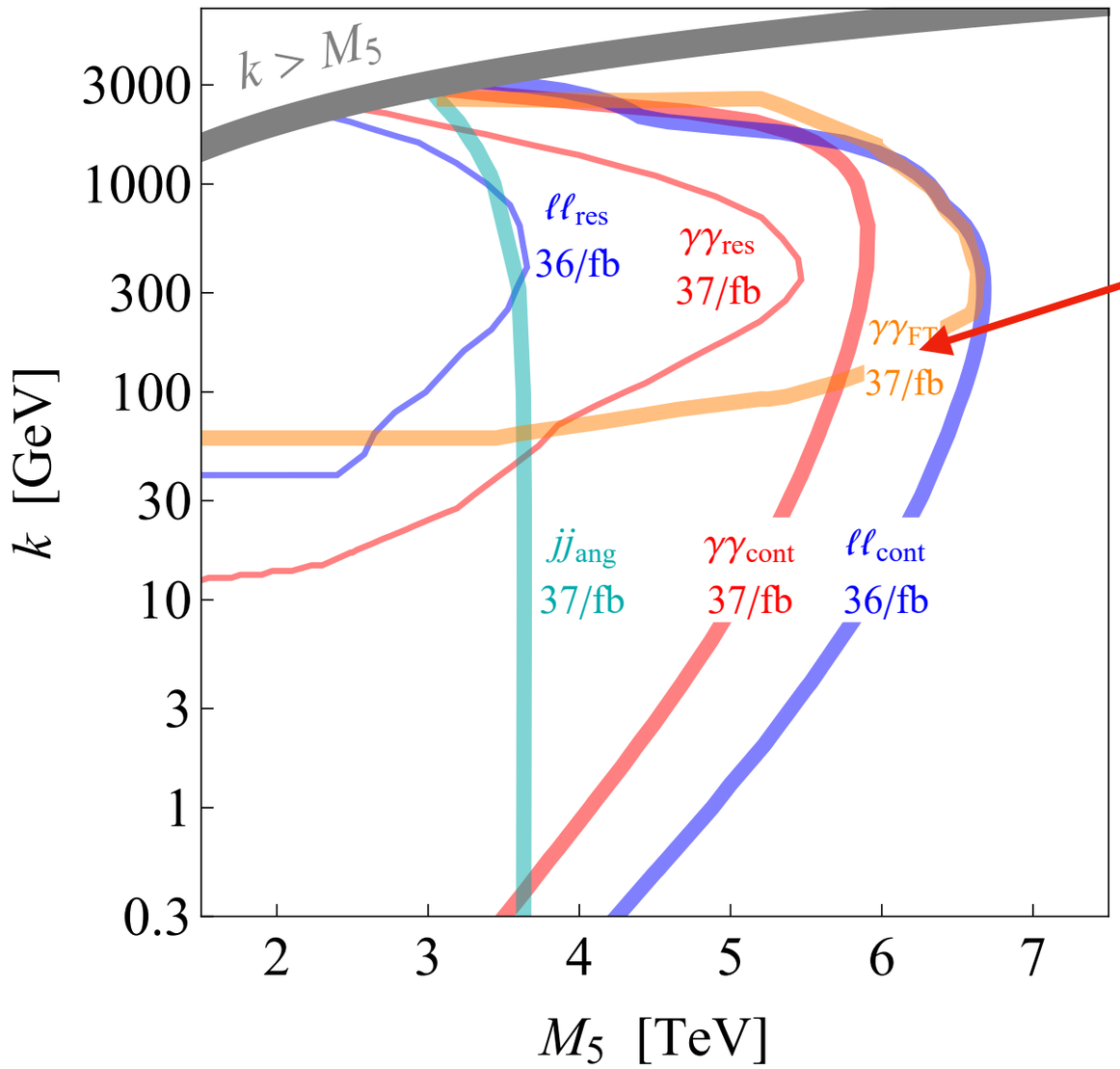


Spectral analysis to test for oscillating spectrum

Background modelling essential for tail

BSM searches and novel/subtle LHC signatures

Extra dimension theories, e.g. clockwork mechanisms



Spectral analysis

Giudice, Kats, McCullough, Torre, Urbano, arXiv:1711.08437 [hep-ph]

Summary of the summary

- The reinterpretation of SM measurements provides constraints on new physics, complementary to direct searches.
- Virtual effects of new particles can be probed in SM precision observables; need a global analysis of BSM models, incorporating both direct and indirect searches for new physics.
- NLO-automation is crucial to cover a wide range of BSM models.
- EFTs, simplified models and UV-complete models and their interplay are needed to explore BSM physics.
- Simplified and UV-complete models, in particular, can motivate BSM searches through novel and/or subtle LHC signatures.
- Can machine learning help to discovery BSM physics in LHC data in a more model-independent way?