Constraining BSM (Simplified) models with SM measurements

Jon Butterworth, David Grellscheid (IPPP),
Michael Krämer (Aachen), David Yallup

CERN workshop on (re)interpreting the results of new physics searches at the LHC

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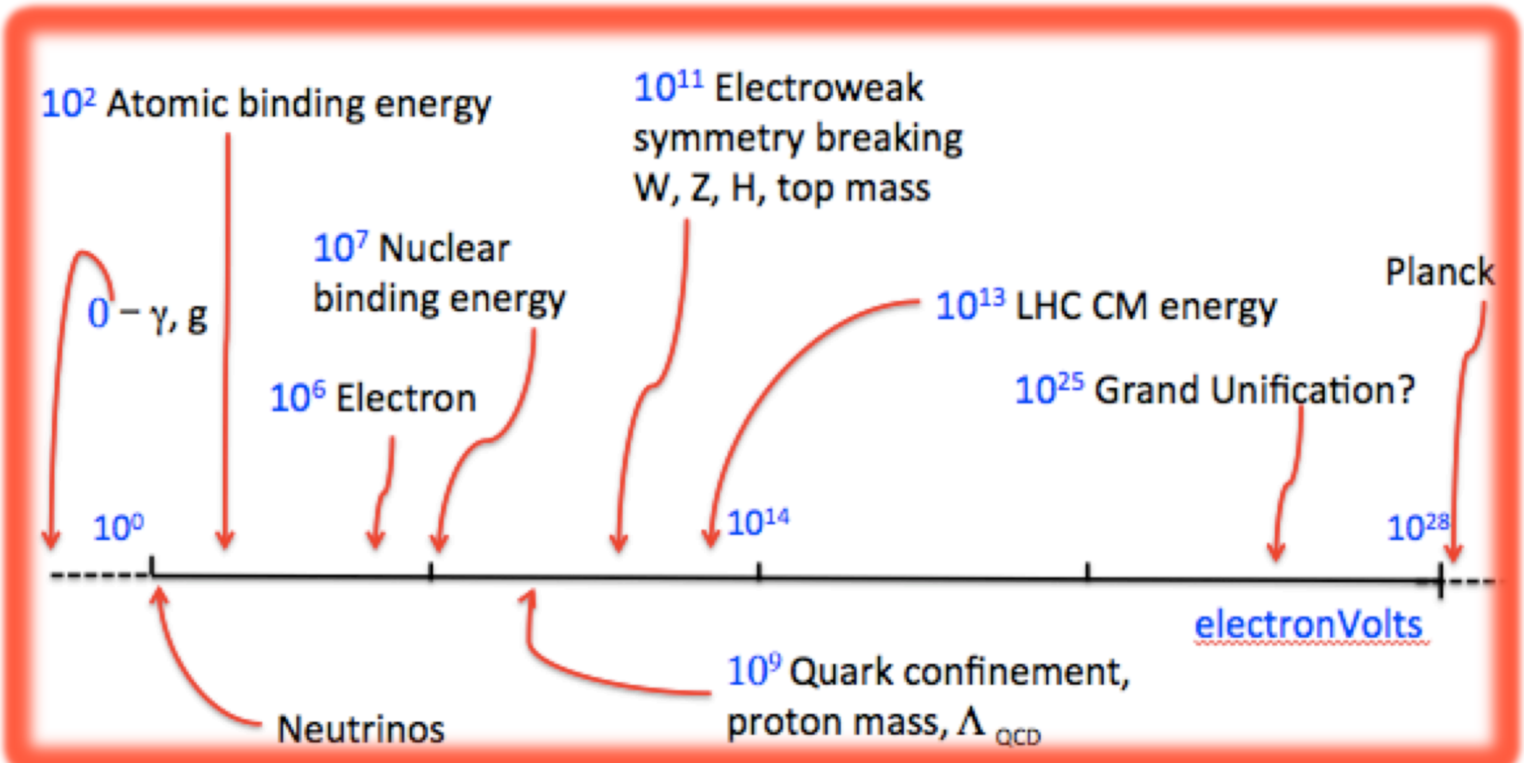
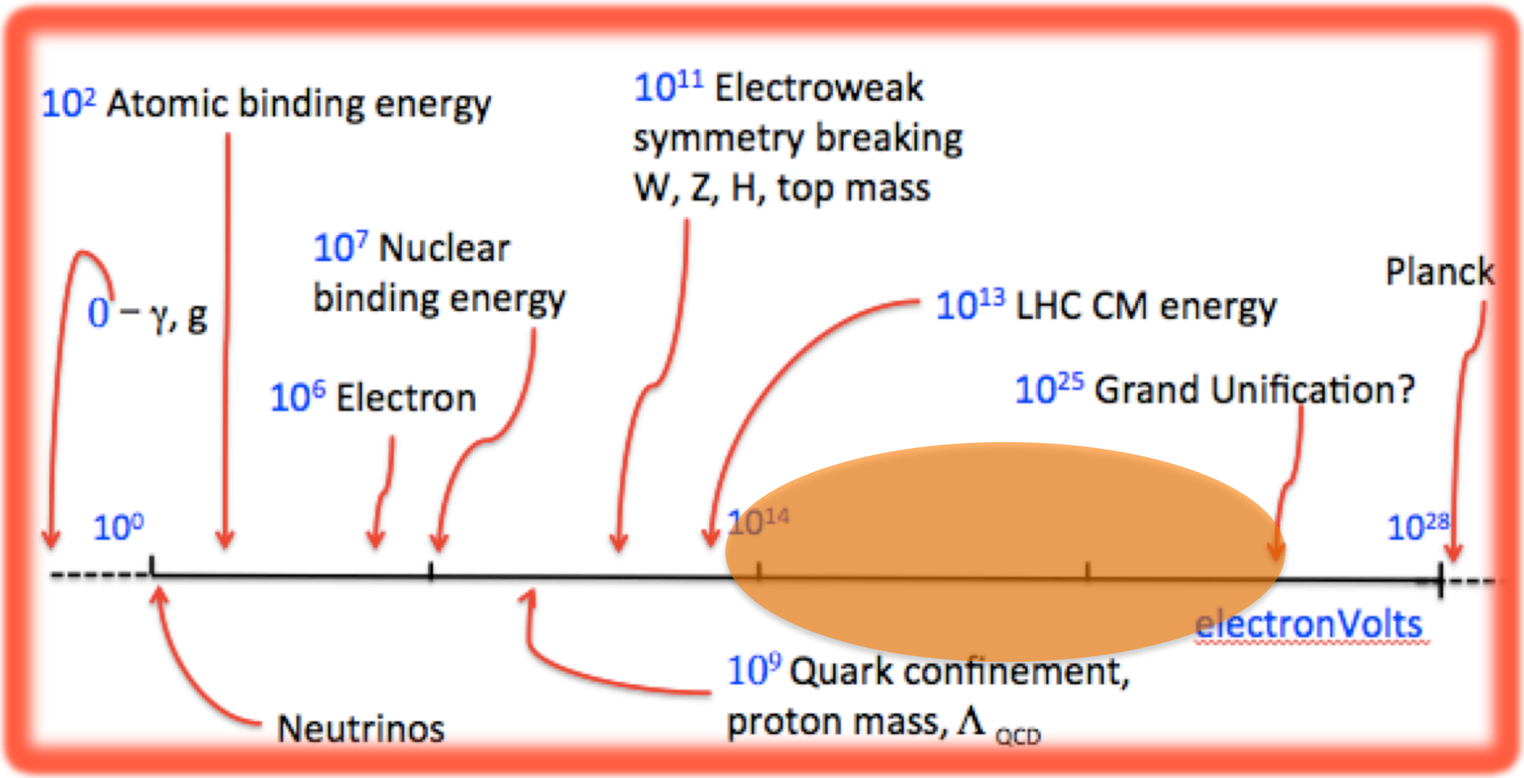
The Standard Model



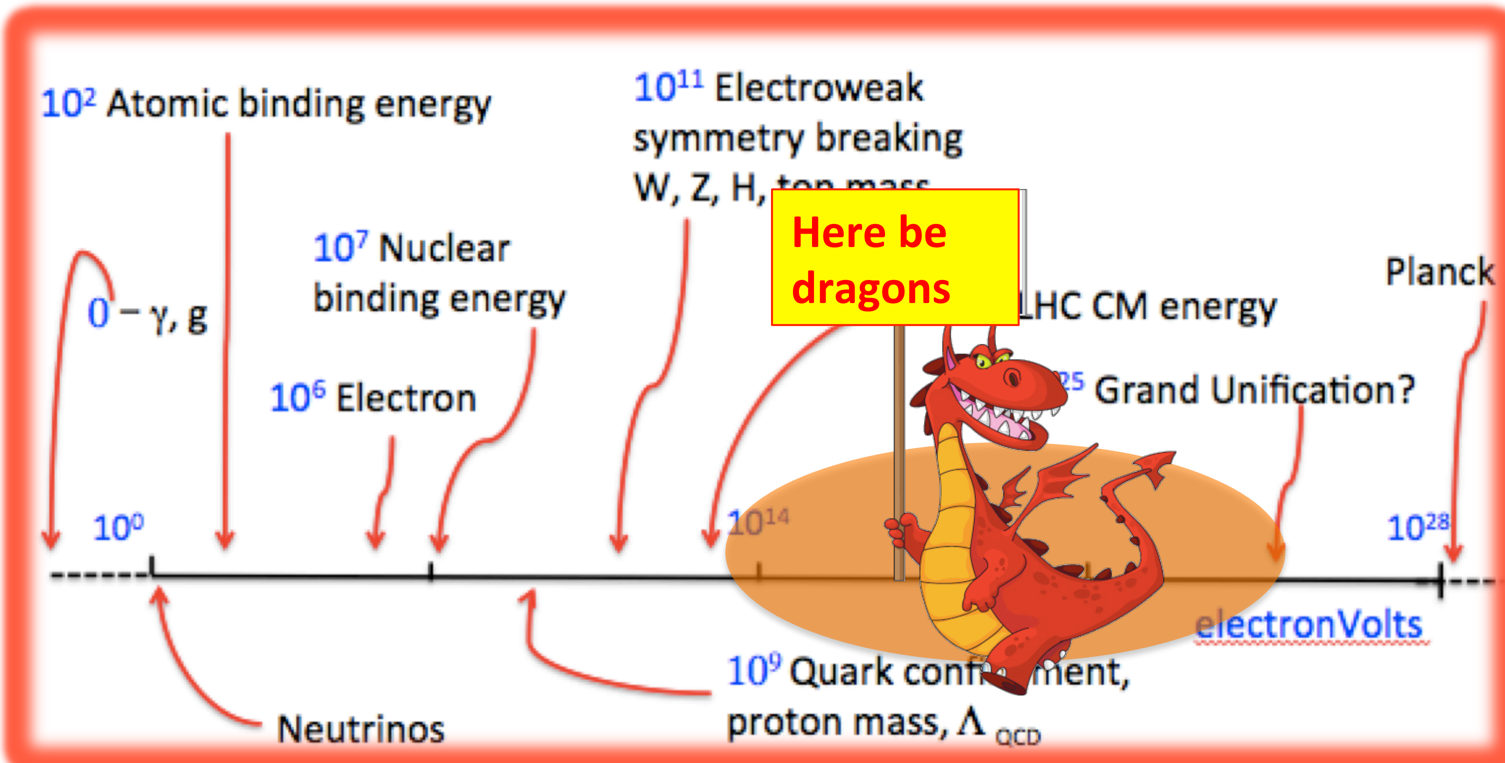
The Standard Model

- Is there anything out there?



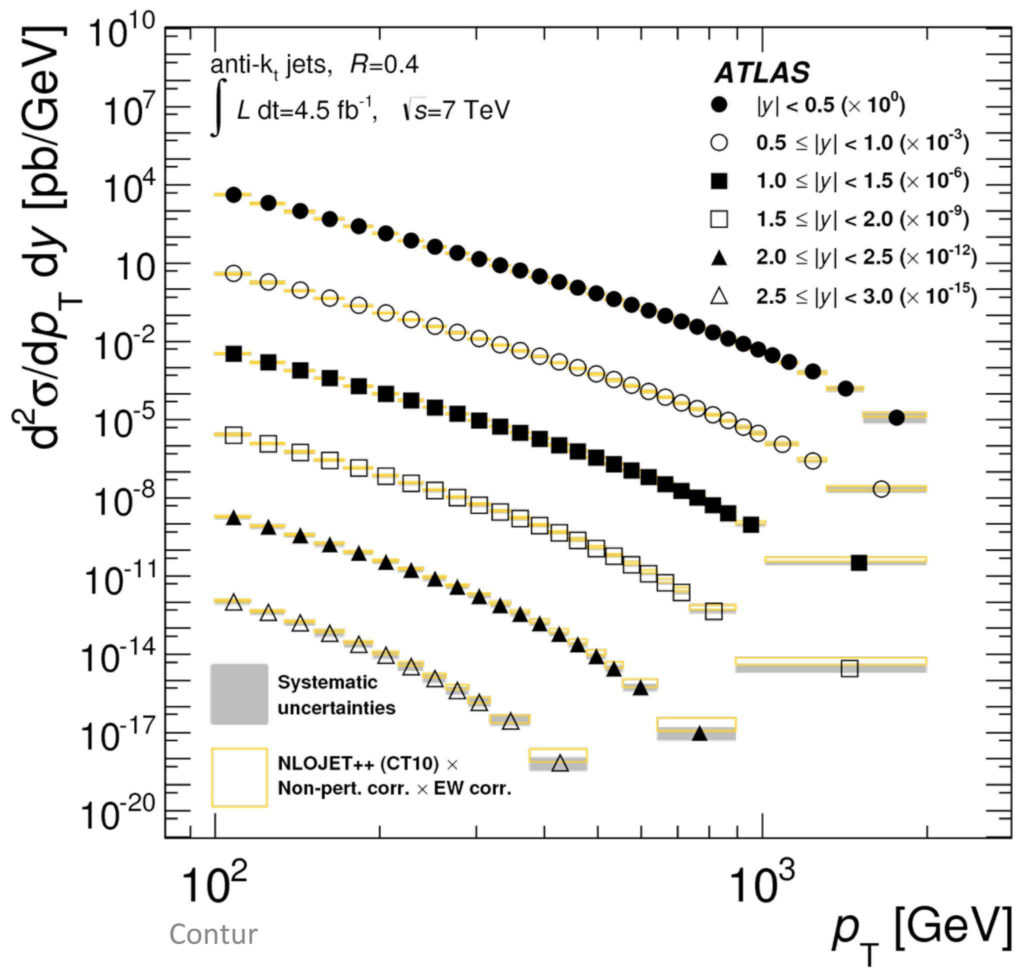
The Standard Model

- Is there anything out there?
  - Tread carefully
  - High energies, high luminosities, model independence…



Precision 'Standard Model' Measurements

- They should not (and mostly do not) assume the SM
- They agree with the SM
- Thus they can potentially exclude extensions



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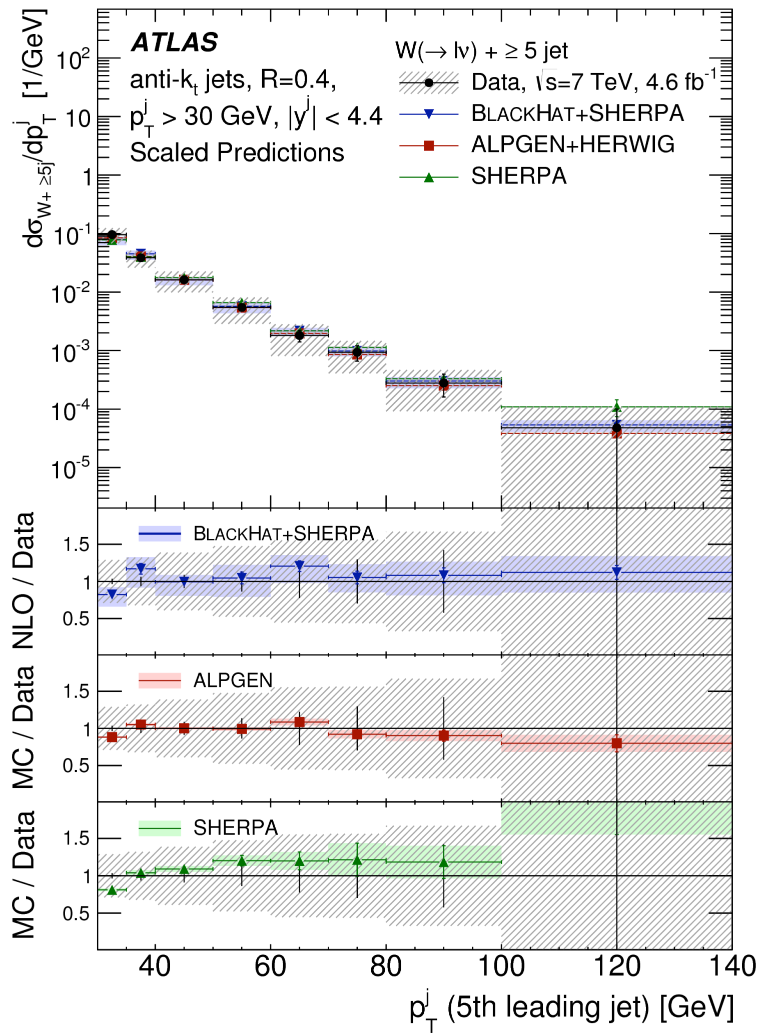
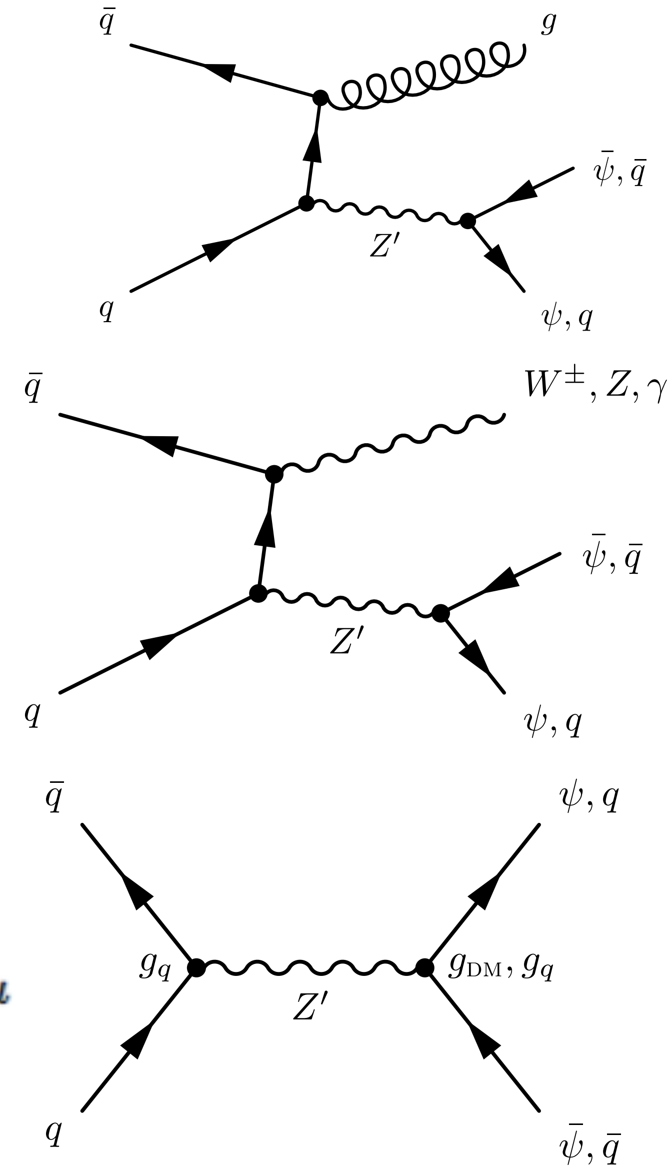


Simplified Model(s)

- Effective lagrangian including minimal new couplings *and* particles
- Our starter example: leptophobic Z' with vector coupling to u,d quarks, axial vector to a DM candidate ψ.

$$\mathcal{L} \supset g_{\mathrm{DM}}\,\overline{\psi}\gamma_\mu\gamma_5\psi\,Z'^\mu + g_q\sum_q \bar{q}\gamma_\mu q\,Z'^\mu$$



Key tools:

- BSM Model in FeynRules

UFO interface

- New processes in Herwig7

Final State Particles

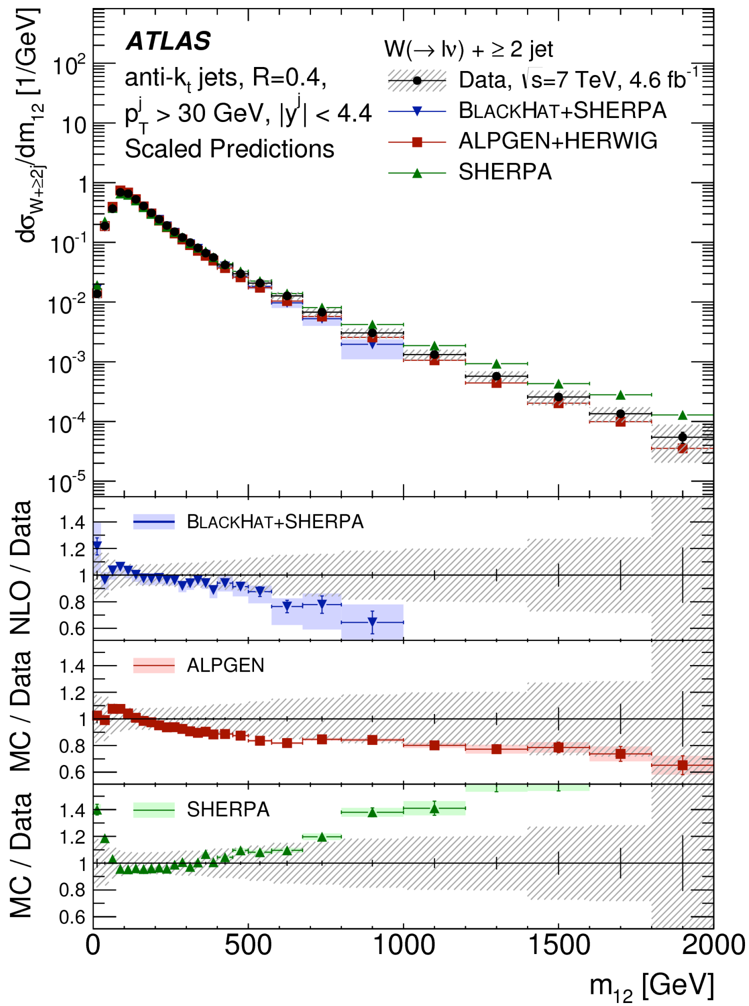
- Rivet, and data from HepData

Exclusion

Strategy

- Use measurements shown to agree with the Standard Model
  - Not a search! Guaranteed not to find anything
  - Will be slower, but more comprehensive and model independent
  - Assume the data = the background!

Will miss this kind of thing…



Strategy

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  - Not a search! Guaranteed not to find anything
  - Will be slower, but more comprehensive and model independent
  - Assume the data = the background!
- Key for constraining new models if there is a signal (unintended consequences)
- Key for constraining scale of new physics if there is no signal

Statistics

- Construct likelihood function using
  - BSM signal event count
  - Background count (from central value of data points)
  - Gaussian assumption on uncertainty in background count, from combination of statistical and systematic uncertainties
  - BSM signal count error from statistics of generated events (small!)
- Make profile likelihood ratio a la Cowan et al (Asimov data set approximation is valid)
- Present in CL_s method (A. Read)
- Systematic correlations not fully treated - take only the most significant deviation in a given plot (conservative)

Dynamic data selection

- SM measurements of fiducial, particle-level differential cross sections, with existing Rivet routines
- Classify according to data set (7, 8, 13 TeV) and into non-overlapping signatures
- Use only one plot from each given statistically correlated sample
- Jets, W+jets, Z+jets, γ, γ+jets, $\gamma\gamma$, ZZ, W/Z+γ
- Sadly no Missing E_T+jets, not much 8 TeV, no 13 TeV yet, though much is on the way… Also can use suitably model-independent Higgs and top measurements in future.
- Most sensitive measurement will vary with model and model parameters

Contur Category	Rivet/ Inspire ID	Rivet description
ATLAS 7 Jets	ATLAS_2014_I1325553 [28]	Measurement of the inclusive jet cross-section
	ATLAS_2014_I1268975 [30]	High-mass dijet cross section
	ATLAS_2014_I1326641 [32]	3-jet cross section
	ATLAS_2014_I1307243 [31]	Measurements of jet vetoes and azimuthal decorrelations in dijet events
CMS 7 Jets	CMS_2014_I1298810 [29]	Ratios of jet pT spectra, which relate to the ratios of inclusive, differential jet cross sections
ATLAS 8 Jets	ATLAS_2015_I1394679 [34]	Multijets at 8 TeV
ATLAS 7 Z Jets	ATLAS_2013_I1230812 [35]	Z + jets
CMS 7 Z Jets	CMS_2015_I1310737 [38]	Jet multiplicity and differential cross-sections of Z+jets events
CMS 7 W Jets	CMS_2014_I1303894 [37]	Differential cross-section of W bosons + jets
ATLAS W jets	ATLAS_2014_I1319490 [36]	W + jets
ATLAS 7 Photon Jet	ATLAS_2013_I1263495 [42]	Inclusive isolated prompt photon analysis with 2011 LHC data
	ATLAS_2012_I1093738 [44]	Isolated prompt photon + jet cross-section
CMS 7 Photon Jet	CMS_2014_I1266056 [45]	Photon + jets triple differential cross-section
ATLAS 7 Diphoton	ATLAS_2012_I1199269 [43]	Inclusive diphoton $+X$ events
ATLAS 7 ZZ	ATLAS_2012_I1203852 [39]	Measurement of the $ZZ(*)$ production cross-section
ATLAS W/Z gamma	ATLAS_2013_I1217863 [40]	W/Z gamma production

Key tools: Constraints On New Theories Using Rivet

- BSM Model in FeynRules

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CONTUR

https://contur.hepforge.org/

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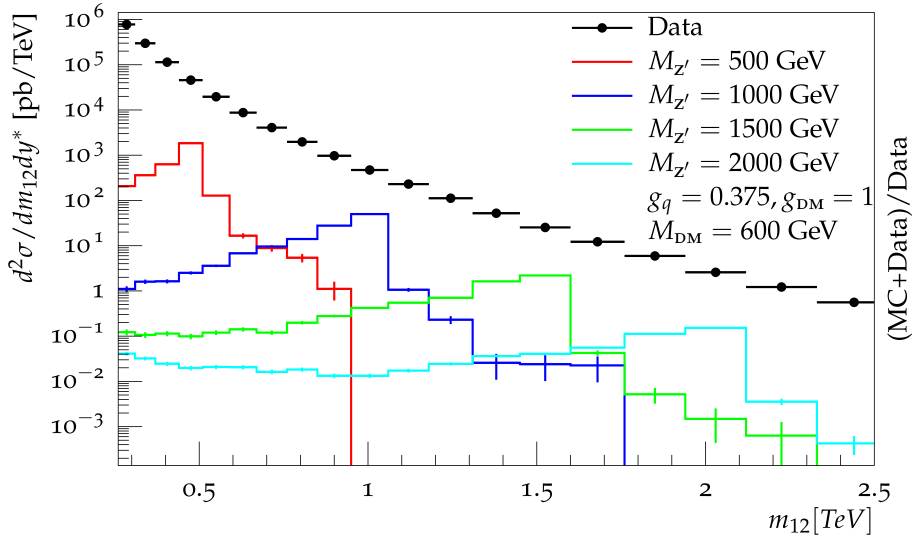
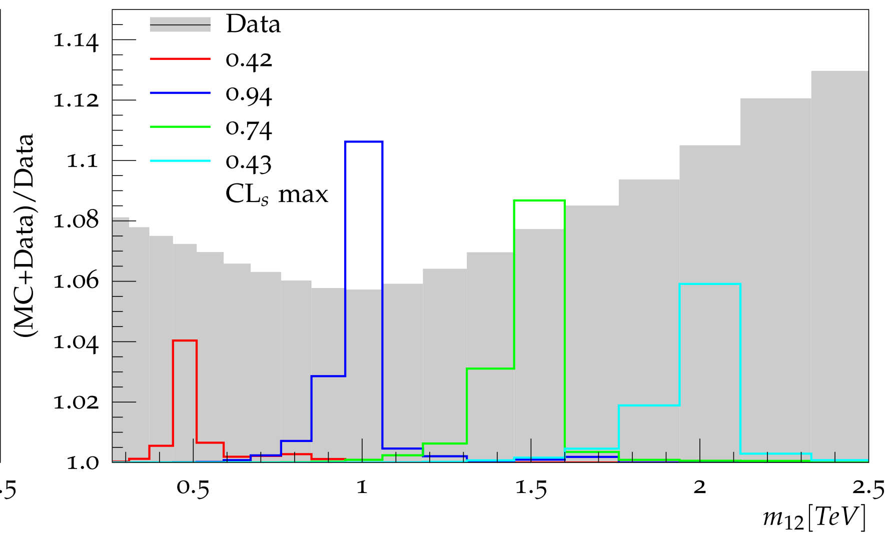
Parameter Choices

- Scan in M_{DM} and $M_{Z'}$
- Four pairs of couplings:
  - Challenging: $g_q = 0.25$; $g_{DM} = 1$
  - Medium: $g_q = 0.375$; $g_{DM} = 1$
  - Optimistic: $g_q = 0.5$; $g_{DM} = 1$
  - DM-suppressed $g_q = 0.375$; $g_{DM} = 0.25$

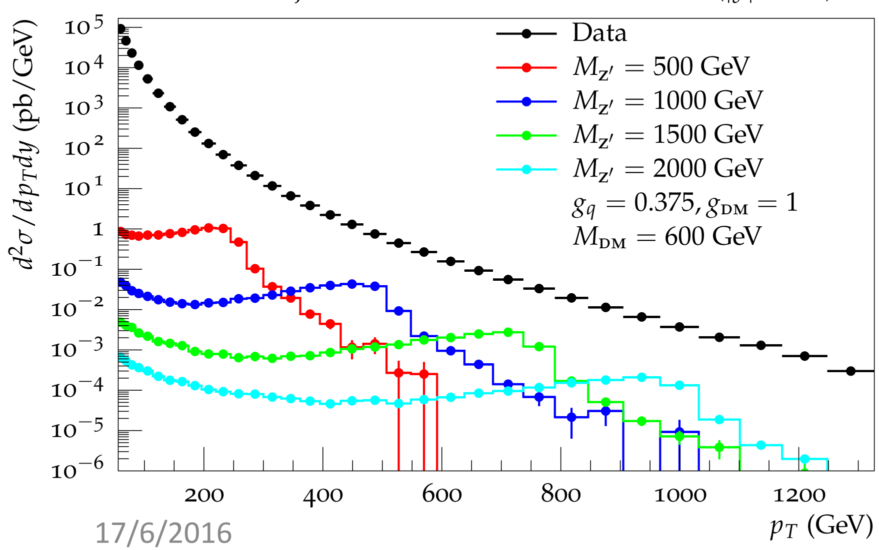
Data Comparisons

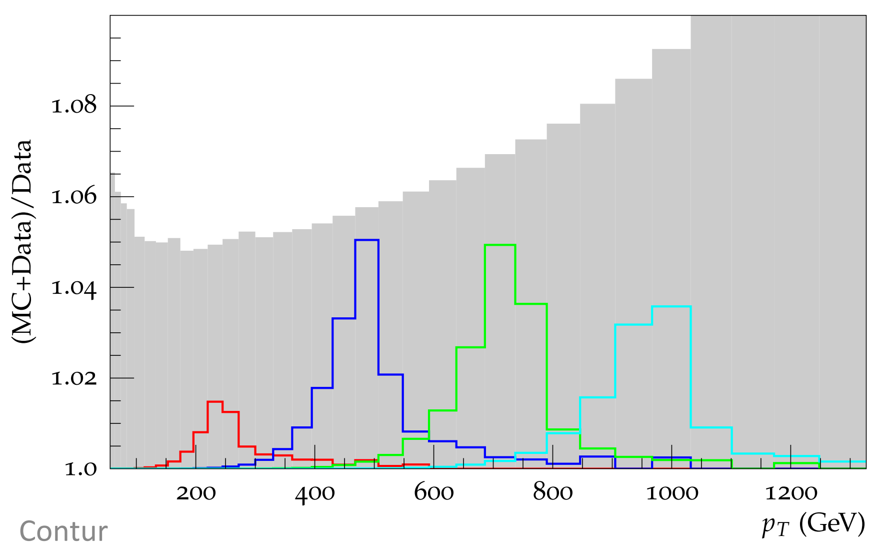
ATLAS Dijet double-differential cross sections ($y^* < 0.5$)





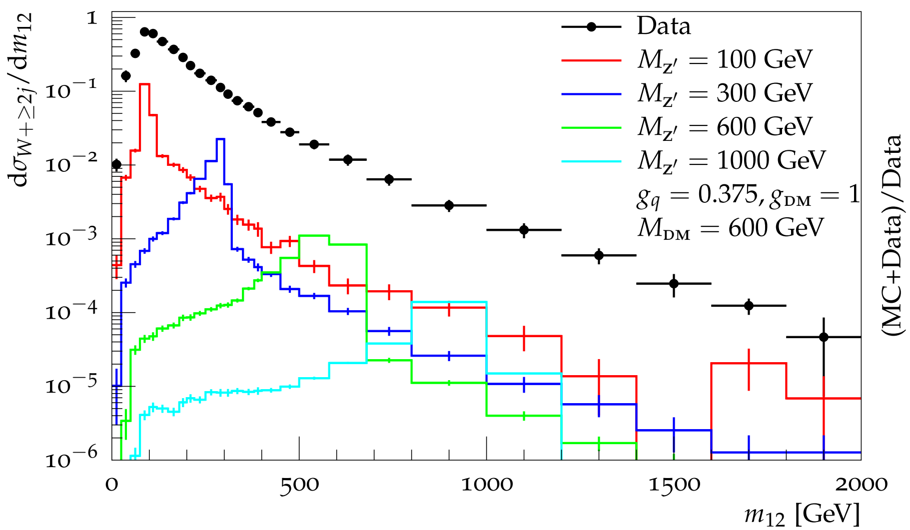
CMS inclusive jet double differential cross section ($|y| < 0.5$)

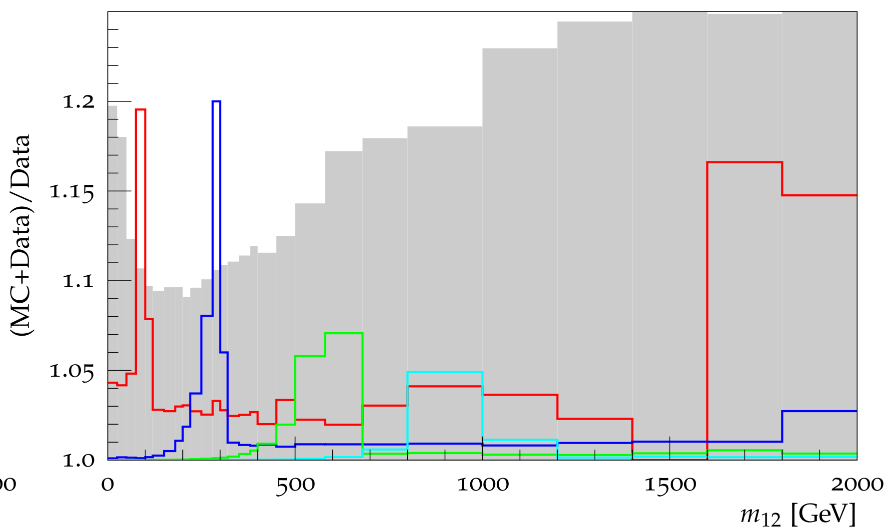




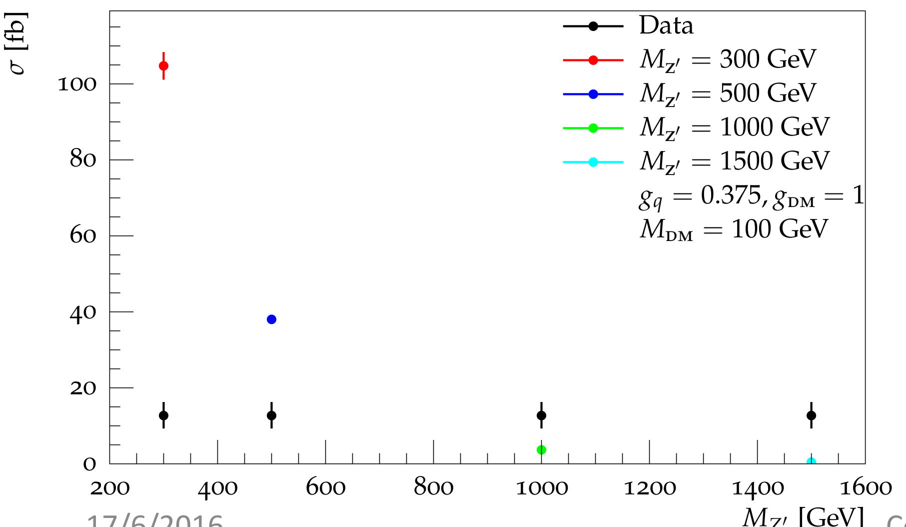
Data Comparisons

ATLAS $W+\geq 2$ jet differential cross section

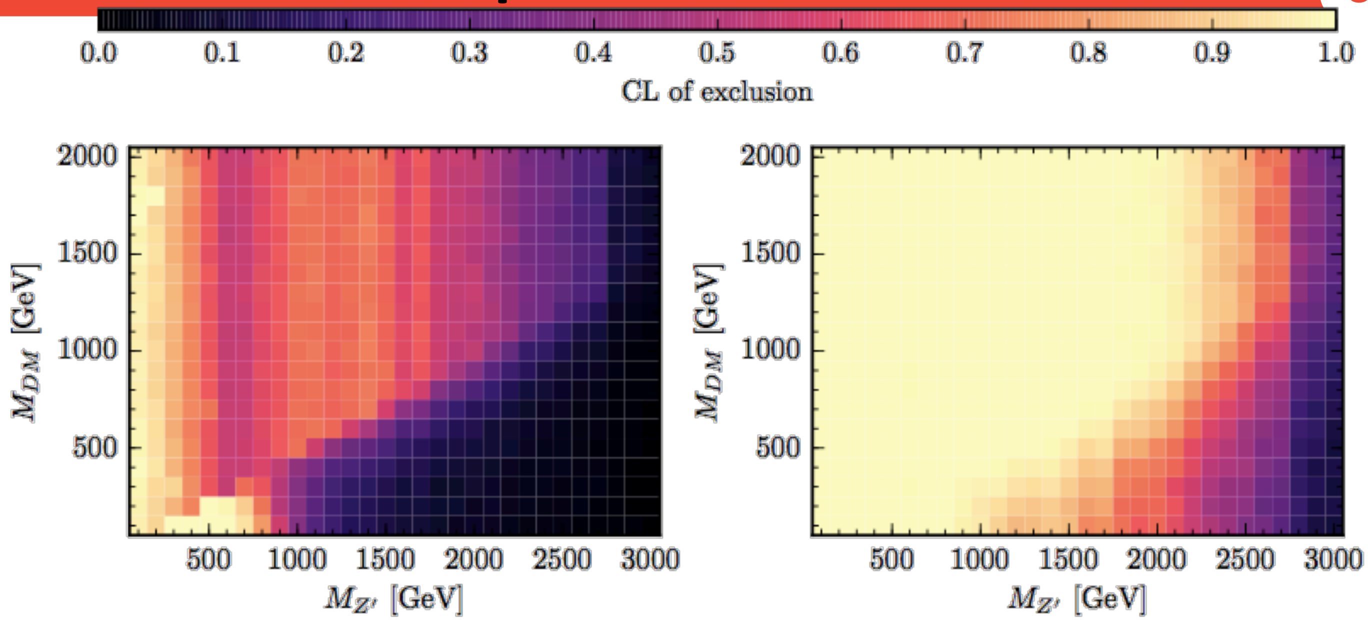




ATLAS total fiducial cross-section reconstructed $ZZ \rightarrow 2l2\nu$



Heat Maps



(a) $g_q = 0.25$ and $g_{\mathrm{DM}} = 1$

(b) $g_q = 0.5$ and $g_{\mathrm{DM}} = 1$

(c) $g_q = 0.375$ and $g_{\mathrm{DM}} = 1$

(d) $g_q = 0.375$ and $g_{\mathrm{DM}} = 0.25$

95% CL_s Contour

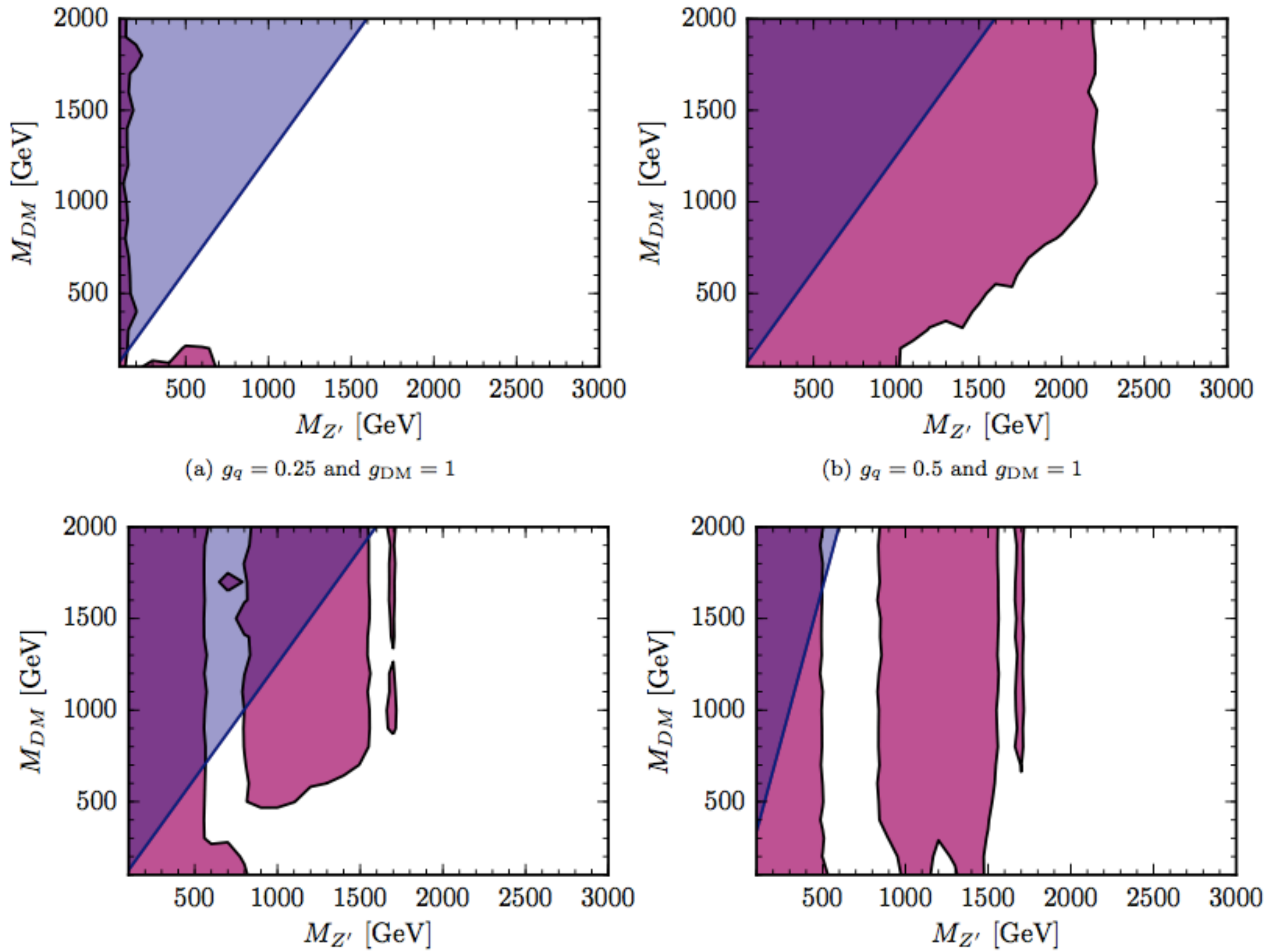


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Figure 7: Contours in the $M_{Z'}$ and $M_{\rm DM}$ plane for the considered values of $g_{\rm DM}$ and g_q, indicating the excluded region at 95% confidence level. The triangular shaded area is the region in which perturbative unitary is violated by the model.

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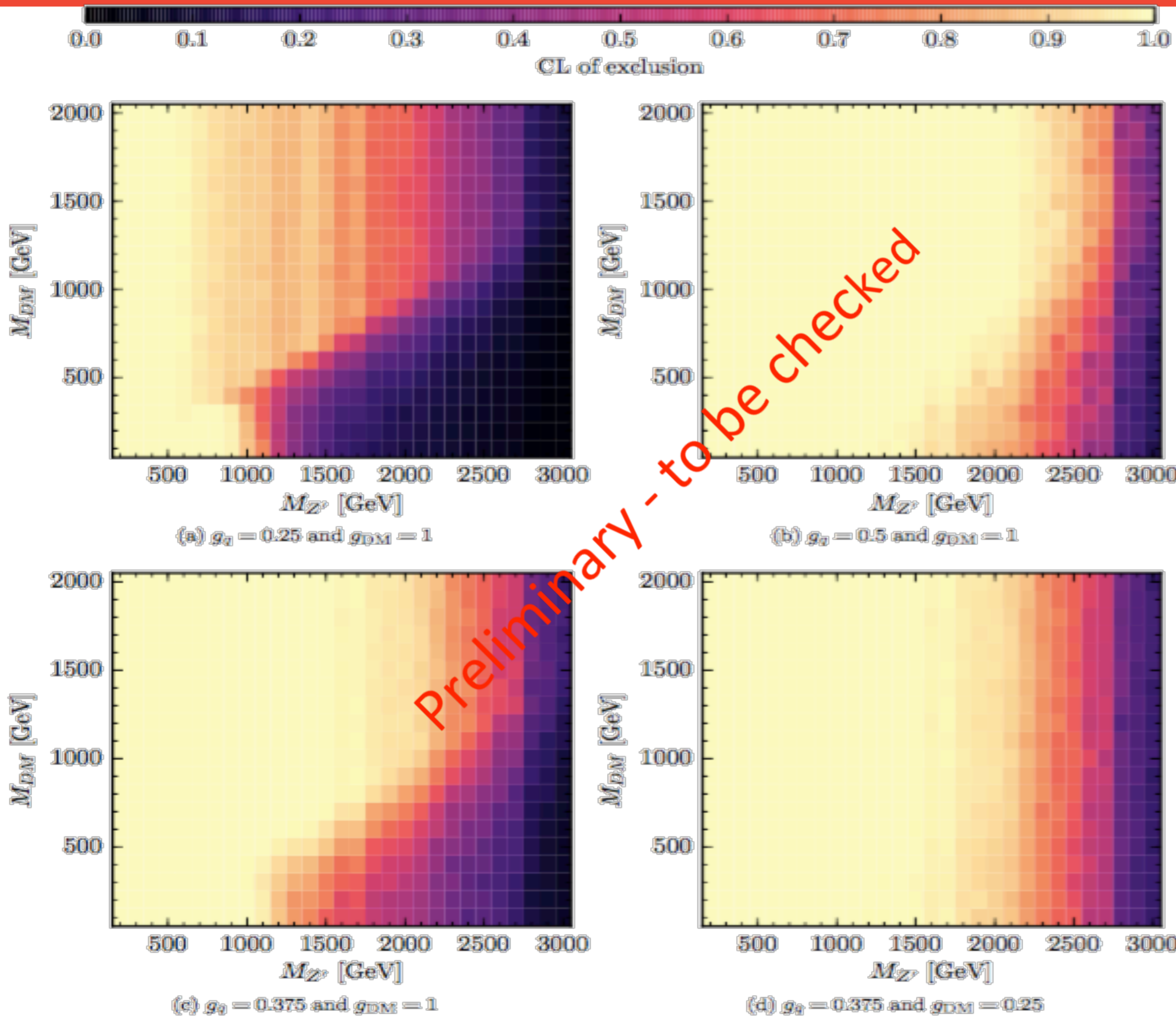
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
CL of exclusion
M_{DM} [GeV]
$M_{Z'}$ [GeV]
(a) $g_q = 0.25$ and $g_{DM} = 1$
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Preliminary - to be checked

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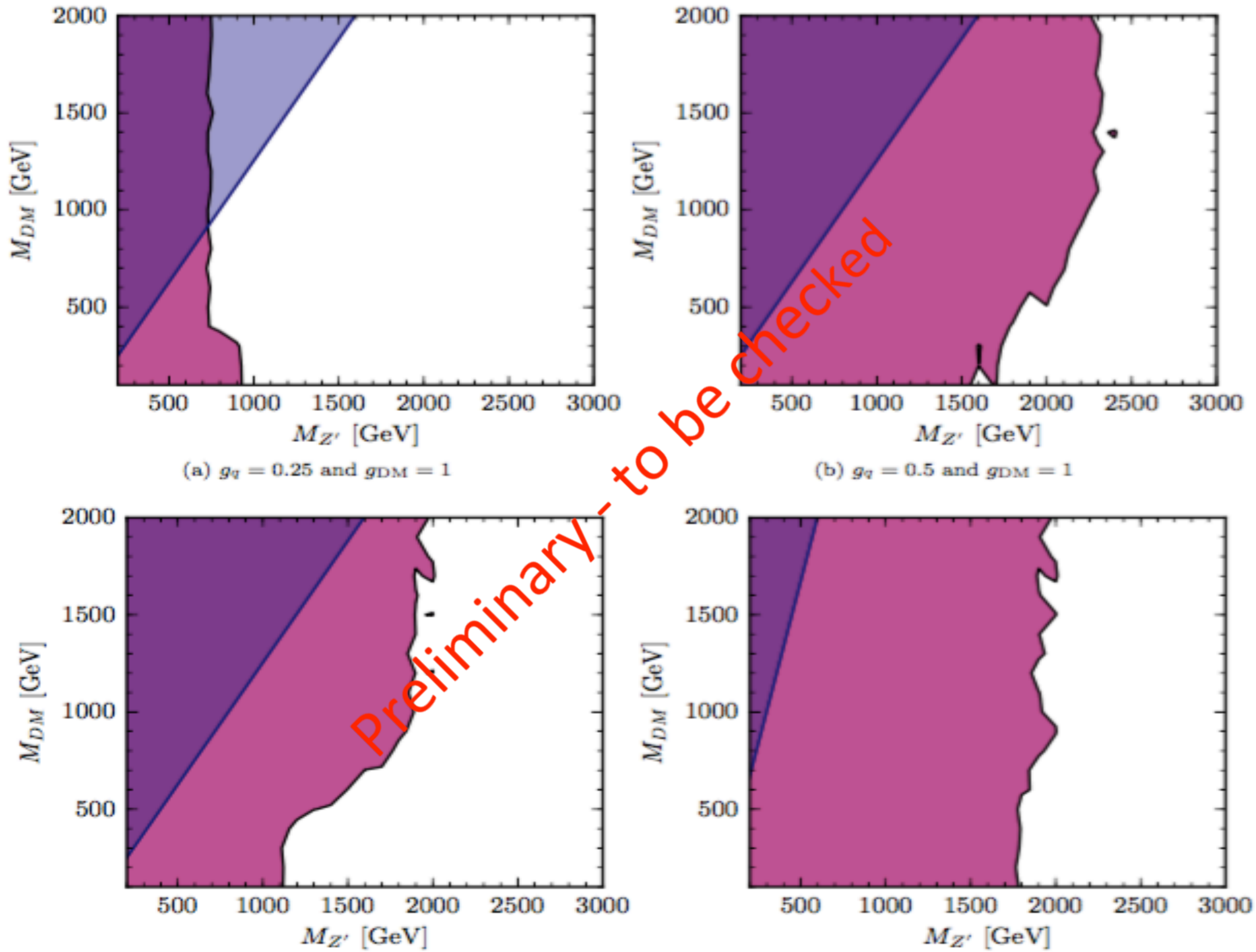

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Conclusions

- Particle-level measurements not only measure what is happening in our collisions, they constrain what is *not* happening.
- Limit-setting procedure developed; even with conservative treatment of correlations, limits are competitive with those from dedicated searches using comparable data-sets
- General framework developed:
  - consider all new processes in a given (simplified) model
  - consider all available final states. (e.g. V+jet shows previously unexamined sensitivity to the model considered)
- Highly scaleable to other models & new measurements – plan continuous rolling development
- See arXiv:1606.05296 (and references therein), & contur.hepforge.org