Constraints on new theories using Rivet (Contur)

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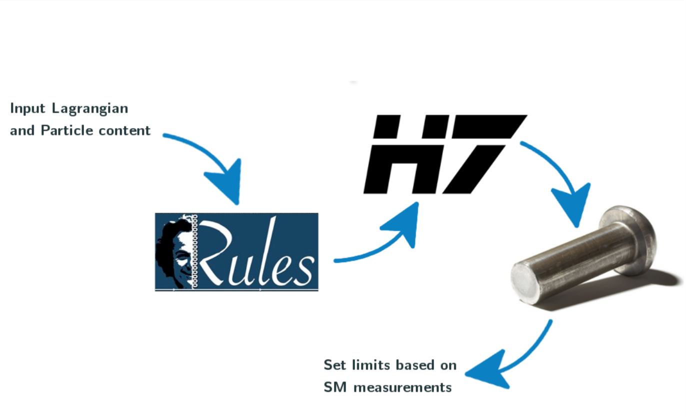
Introduction and Aims

- Goal: Create a flexible framework to confront BSM theories with precision SM measurements **OR** quantify what room the errors on SM measurements leave for new physics.
- Requirements:
  - Flexible physics input, desire a framework capable of applying to as broad a class of models as possible
  - Utilize existing pheno tools where possible, rich landscape of mature tools available, utilise this!
  - Robust statistical testing framework, constrained inputs, machinery can be lightweight.
- Use unfolded fiducial cross section measurements - Differentiates from current LHC limit programs using detector level search data

White paper: arXiv:1606.05296

HepForge site (Work in progress): contur.hepforge.org

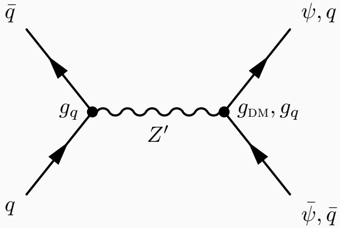
Building a framework



- Feynrules - Mathematica package, generate Feynman rules from input Lagrangian
- Herwig 7 - Event Generator, Feynman rules to fully hadronized final state
- Rivet - Library of analyses, plug and play ATLAS and CMS measurements. (Data taken from records in HepData)

Illustrate process by considering a simple model.

Simplified Dark Matter Model

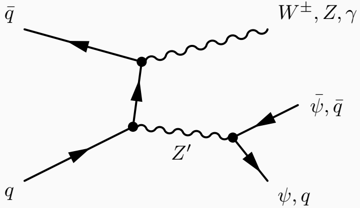


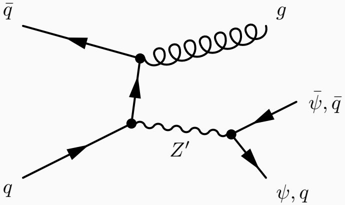
Simplified Dark Matter model, enable a description of weakly coupled, low mass resonances.

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

Vector mediator to dark sector, purely vector coupling to SM, purely axial coupling to DM.

Model introduces DM candidate, ψ, dark . Experimental signatures hence typically rely on either 'Mono-X' style final states or enhancement to dijet production at colliders.





Standard Model measurements

Standard Model measurements

- should not assume Standard Model
- but they match the Standard Model very well
- can use them to rule out new theories

Make use of all suitable analyses in Rivet simultaneously.

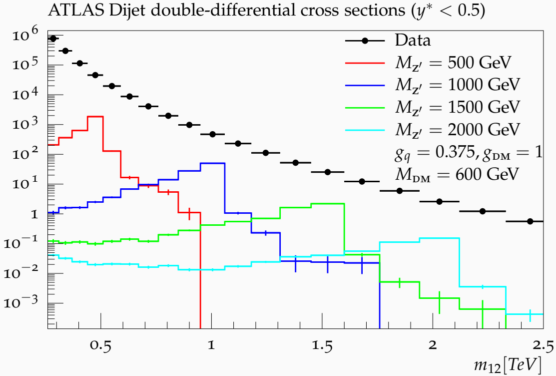
Rivet Analysis base

CONTUR Category	Rivet/ Inspire ID	Rivet description
ATLAS 7 Jets	ATLAS_2014_I1325553 [12]	Measurement of the inclusive jet cross-section
	ATLAS_2014_I1268975 [13]	High-mass dijet cross section
	ATLAS_2014_I1326641 [14]	3-jet cross section
	ATLAS_2014_I1307243 [15]	Measurements of jet vetoes and azimuthal decorrelations in dijet events
CMS 7 Jets	CMS_2014_I1298810 [16]	Ratios of jet pT spectra, which relate to the ratios of inclusive, differential jet cross sections
ATLAS 7 Z Jets	ATLAS_2013_I1230812 [17]	Z + jets
CMS 7 Z Jets	CMS_2015_I1310737 [18]	Jet multiplicity and differential cross-sections of Z+jets events
CMS 7 W Jets	CMS_2014_I1303894 [19]	Differential cross-section of W bosons + jets
ATLAS 7 W jets	ATLAS_2014_I1319490 [20]	W + jets
ATLAS 7 Photon Jet	ATLAS_2013_I1263495 [21]	Inclusive isolated prompt photon analysis with 2011 LHC data
	ATLAS_2012_I1093738 [22]	Isolated prompt photon + jet cross-section
CMS 7 Photon Jet	CMS_2014_I1266056 [23]	Photon + jets triple differential cross-section
ATLAS 7 Diphoton	ATLAS_2012_I1199269 [24]	Inclusive diphoton $+X$ events
ATLAS 7 ZZ	ATLAS_2012_I1203852 [25]	Measurement of the $ZZ(*)$ production cross-section
ATLAS W/Z gamma	ATLAS_2013_I1217863 [26]	W/Z gamma production
ATLAS 8 Jets	ATLAS_2015_I1394679 [27]	Multijets at 8 TeV
ATLAS 8 Z Jets	ATLAS_2014_I1279489 [28]	Measurements of electroweak production of dijets + Z boson, and distributions sensitive to vector boson fusion
	ATLAS_2015_I1408516 [29]	Z p_T and Z ϕ^* (Drell-Yan)
ATLAS 8 Photon Jet	ATLAS_2016_I1457605 [30]	Inclusive prompt photons at 8 TeV

Derive sensitivity from as broad a range of SM measurements as available in HepData/Rivet. Sensitivity in as many final states/variables as possible

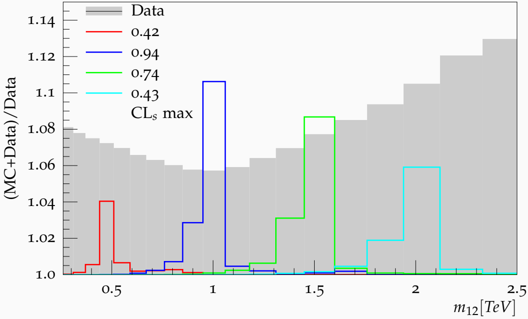
Note: Category defines non overlapping signatures, safe to combine into single metrics, more later

Examining the Rivet output (Hadronic Final States)

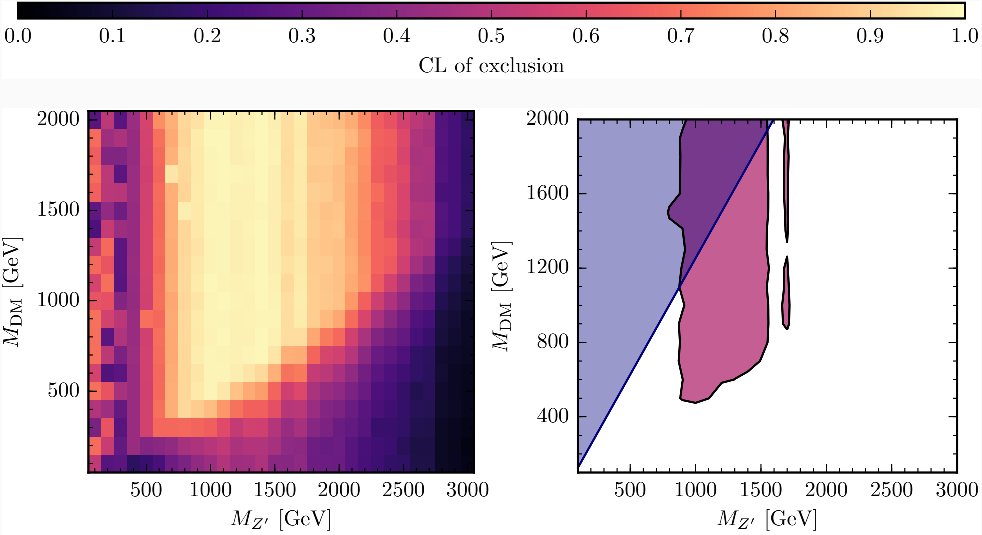


Default Rivet output, seek to quantify to what extent the measured values and errors exclude these simulations. Working under the assumption that what has been measured by the data points is only Standard Model diagrams

Stack simulated signal on data points, here display ratio. Legend displaying the CL of exclusion obtained from the least compatible bin.



Results - Combined 'Strong' measurements

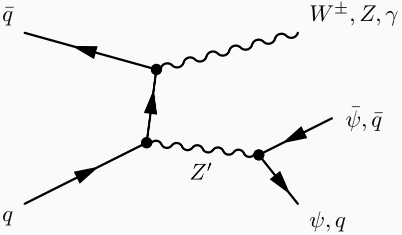


(a) Heatmap of $\mathrm{CL_s}$ at each point

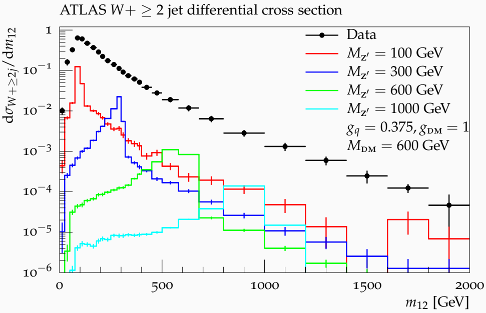
(b) Derived 95% $\mathrm{CL_s}$ contour

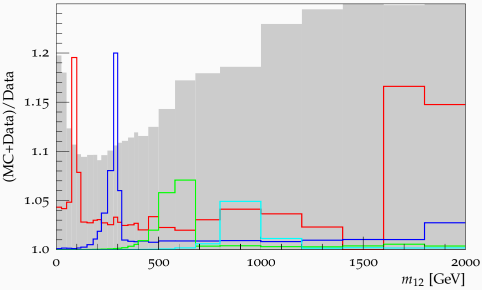
Maps in mass plane for combined sensitivity from Strong measurements $g_q = 0.375$ and $g_{\mathrm{DM}} = 1$ [Perturbative Unitarity bound on $\psi\bar{\psi}$ interaction in blue]

Sample Rivet EW Measurements

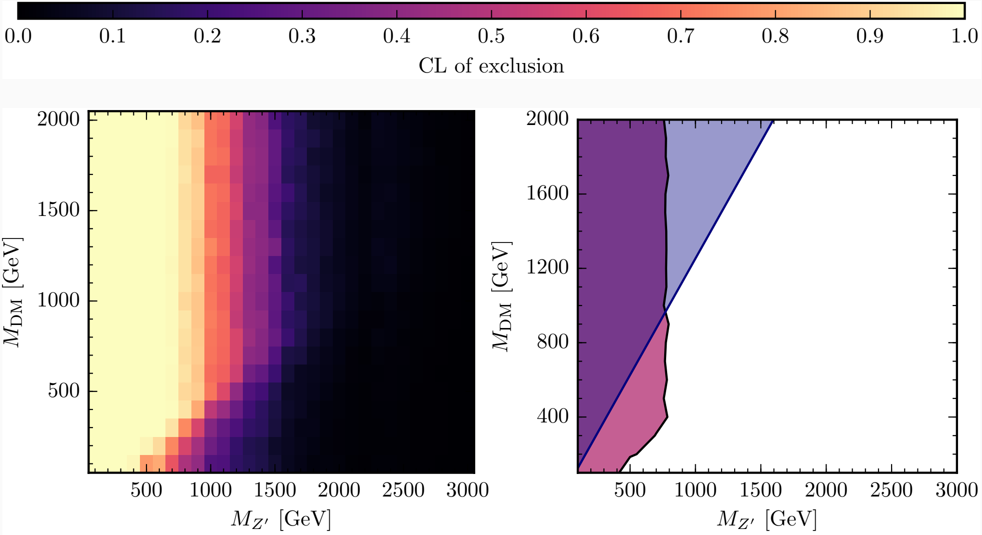


ATLAS W+Jet 7TeV





Results - Combined EW measurements

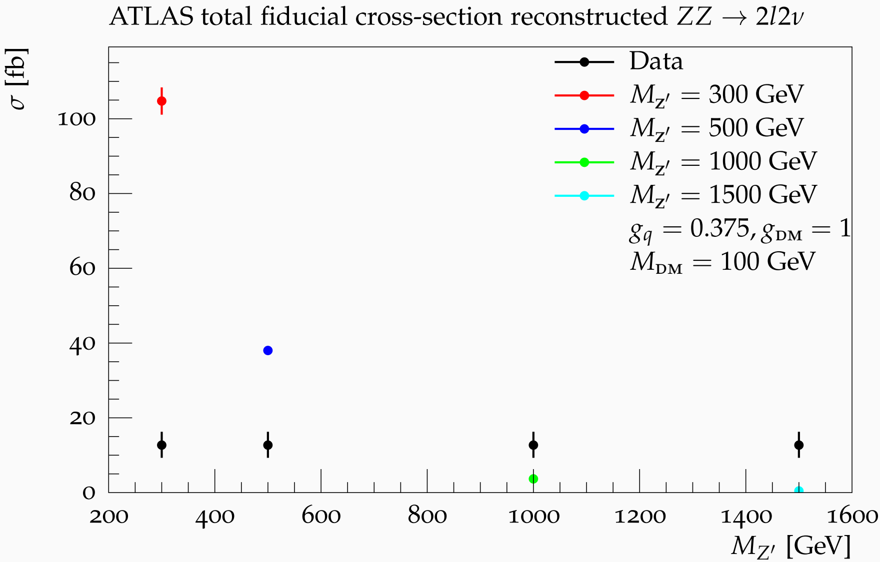


(a) Heatmap of $\mathrm{CL_s}$ at each point

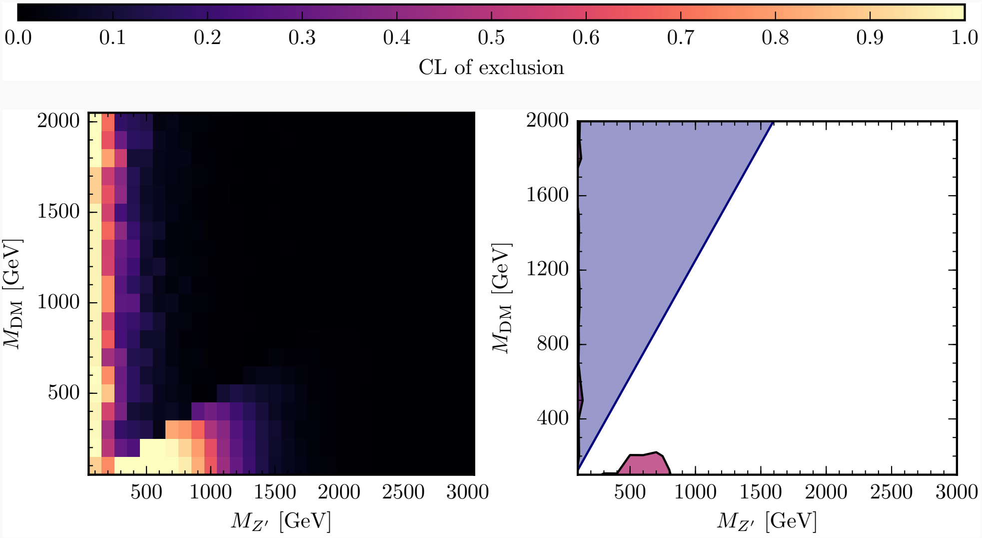
(b) Derived 95% $\mathrm{CL_s}$ contour

Maps in mass plane for combined sensitivity from EW measurements $g_q = 0.375$ and $g_{\mathrm{DM}} = 1$ [Perturbative Unitarity bound on $\psi\bar{\psi}$ interaction in blue]

ATLAS ZZ 7TeV



Results - 'MET' measurements



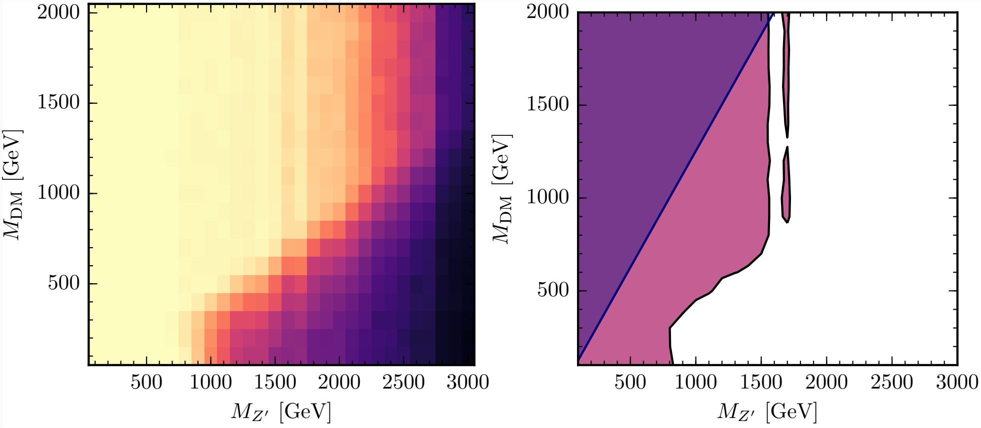
(a) Heatmap of $\mathrm{CL_s}$ at each point

(b) Derived 95% $\mathrm{CL_s}$ contour

Maps in mass plane for combined sensitivity from 'MET' measurements $g_q = 0.375$ and $g_{\mathrm{DM}} = 1$ [Perturbative Unitarity bound on $\psi\bar{\psi}$ interaction in blue]

Results - Putting it all together

Test has been constructed to enable combination of all previously shown maps into a single combined LHC Test

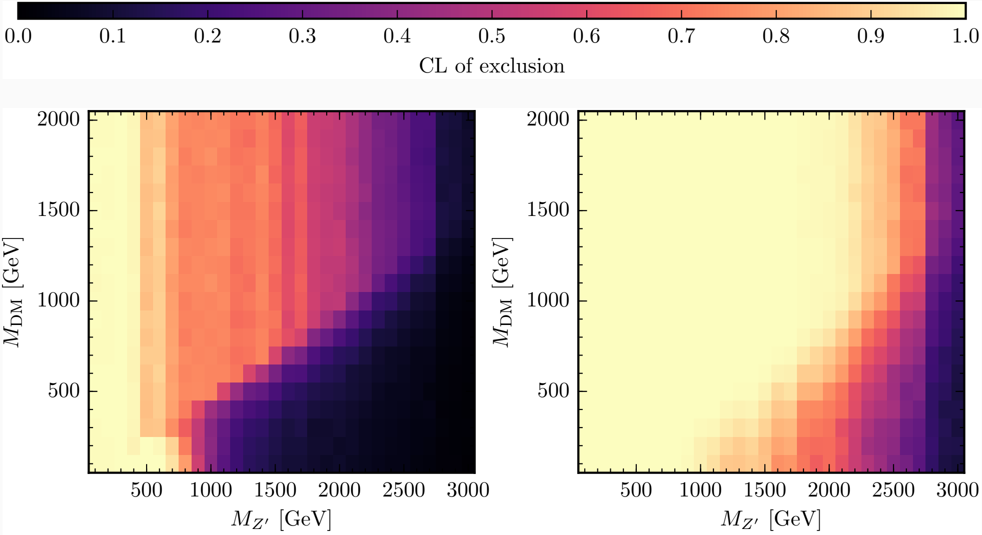


(a) Heatmap of $\mathrm{CL_s}$ at each point

(b) Derived 95% $\mathrm{CL_s}$ contour

Maps in mass plane for combined sensitivity from all channels, $g_q = 0.375$ and $g_{\mathrm{DM}} = 1$ [Perturbative Unitarity bound on $\psi\bar{\psi}$ interaction in blue]

Results - heatmaps

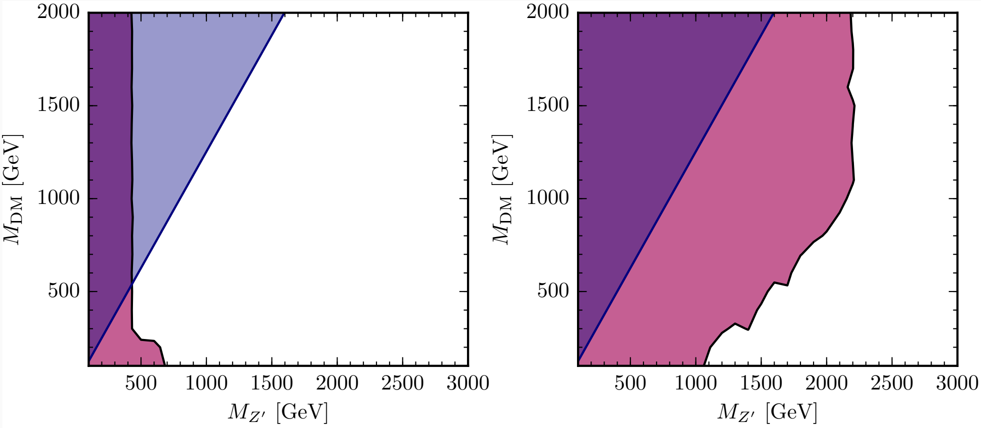


(a) $g_q = 0.25$ and $g_{\mathrm{DM}} = 1$

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

Heatmap showing two scenarios: a - weakly coupled, b - strongly coupled

Results - 95% CL Contours

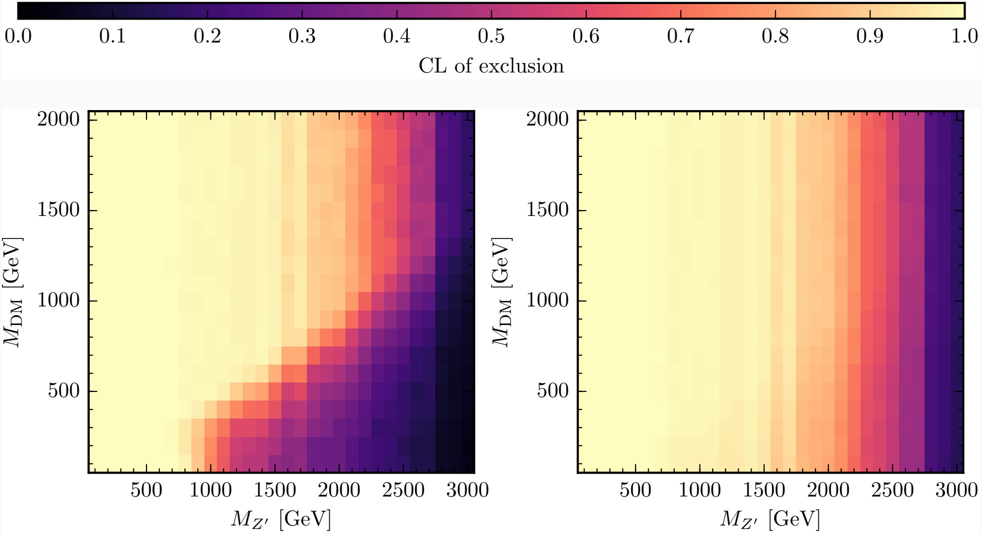


(a) $g_q = 0.25$ and $g_{\rm DM} = 1$

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

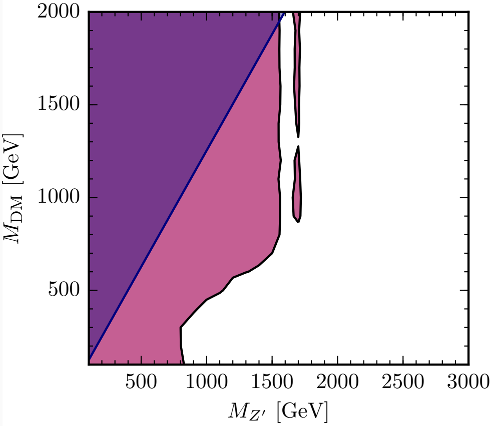
95% CL contour showing two scenarios: a - weakly coupled, b - strongly coupled [perturbative unitarity bound in blue]

Results cont. - Heatmaps

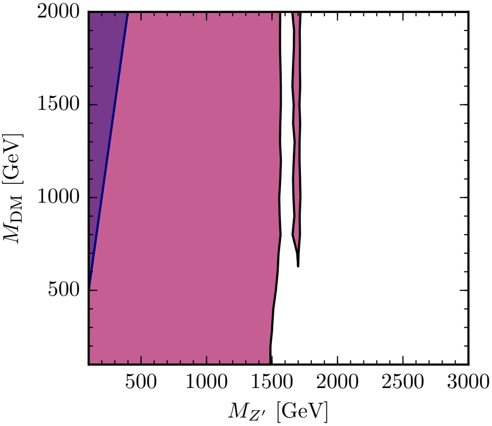


(c) $g_q = 0.375$ and $g_{\text{DM}} = 1$ **(d)** $g_q = 0.375$ and $g_{\text{DM}} = 0.25$

Heatmap showing two scenarios: c - medium coupling, d - DM suppressed



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



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

95% CL contour showing two scenarios: c - medium coupling, d - DM suppressed [perturbative unitarity bound in blue]

Conclusions and Outlook

- SM measurements can inform us about what is not happening
- Can utilize SM measurements as a test for BSM constraints, without any prior knowledge of the model
- Provide utility for model building **and**
- additional motivation for continued precision measurement programmes.

To do:

- Extend testing framework
- Include additional measurements as/when available
- Roll out to other models

Initial paper `arXiv:1606.0529`

Updated plots and all code available at `https://contur.hepforge.org/`

Backup

Statistical Analysis

- Lean heavily on Cowan et al. arXiv:1007.1727. Asymptotic formulae for likelihood-based tests of new physics.
- Construct Likelihood function for a single bin by bin test of:

$$L(\mu, b, \sigma_b, s) = \frac{(\mu s+b)^n}{n!} \exp\big(-(\mu s + b)\big) \times \frac{1}{\sqrt{2\pi}\sigma_b} \exp\left(-\frac{(m-b)^2}{2\sigma_b^2}\right) \times \frac{(s)^k}{k!} \exp\big(-s\big)$$

- Poisson event count: μ signal strength parameter, modulating between tested hypothesis.
- Gaussian encoding background error: σ_b, Uncertainty in b count taken from Rivet/HepData as 1 σ error on a Gaussian (uncertainties quoted as the combination of statistical and systematics uncertainties in quadrature. Typically the systematic uncertainty dominates).
- Poisson term describing statistical MC error on simulated BSM signal count, s
- Note that in the absence of a separate simulation of the background, take $[n] = [m] = b$ and $[k] = s$.

Statistical Analysis - cont.

- Test each bin of each plot of each analysis, selecting the most significant bins to combine into a total CL of exclusion (a simple extension of the Likelihood function to a product of the bins with the most prominent deviation). **Note:** guiding principal, construct combined CL limit from statistically independent counts.
- Selecting a single bin as a representative of a signature $\Longrightarrow$ mitigate impact of correlations between systematic uncertainties in a single final state
- Issues:
  - Methodology aims to build maximal safe limit out of available info. More advanced treatment possible?
  - Correlations between systematic errors between final states and datasets not a well posed question. Data certainly not available to account for this currently.
  - Currently rely on Differential xs measurements, need an event COUNT $\Longrightarrow$ multiply by Integrated Lumi, possible to test additional metrics?