

Constraints on new theories using Rivet (Contur)

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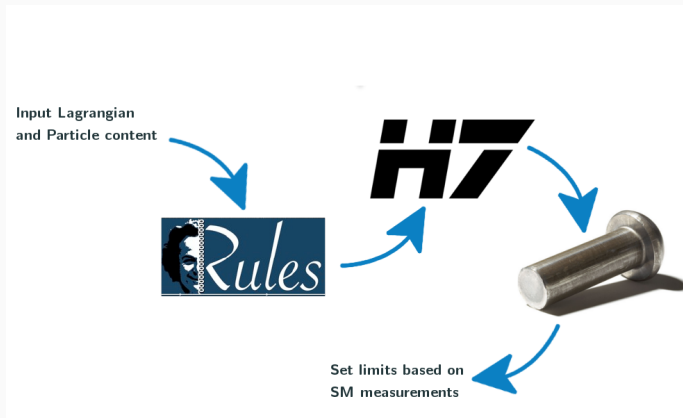
Introduction and Aims

- **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](#).

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](#).

CONTUR Category	Rivet/ Inspire ID	Rivet description
ATLAS 7 Jets	ATLAS_2014.J1325553 [28]	Measurement of the inclusive jet cross-section
	ATLAS_2014.J1268975 [30]	High-mass dijet cross section
	ATLAS_2014.J1326641 [32]	3-jet cross section
	ATLAS_2014.J1307243 [31]	Measurements of jet vetoes and azimuthal decorrelations in dijet events
CMS 7 Jets	CMS_2014.J1298810 [29]	Ratios of jet pT spectra, which relate to the ratios of inclusive, differential jet cross sections
ATLAS 8 Jets	ATLAS_2015.J1394679 [34]	Multijets at 8 TeV
ATLAS 7 Z Jets	ATLAS_2013.J1230812 [35]	Z + jets
CMS 7 Z Jets	CMS_2015.J1310737 [38]	Jet multiplicity and differential cross-sections of Z+jets events
CMS 7 W Jets	CMS_2014.J1303894 [37]	Differential cross-section of W bosons + jets
ATLAS 7 W jets	ATLAS_2014.J1319490 [36]	W + jets
ATLAS 7 Photon Jet	ATLAS_2013.J1263495 [42]	Inclusive isolated prompt photon analysis with 2011 LHC data
	ATLAS_2012.J1093738 [44]	Isolated prompt photon + jet cross-section
CMS 7 Photon Jet	CMS_2014.J1266056 [45]	Photon + jets triple differential cross-section
ATLAS 7 Diphoton	ATLAS_2012.J1199269 [43]	Inclusive diphoton +X events
ATLAS 7 ZZ	ATLAS_2012.J1203852 [39]	Measurement of the ZZ(*) production cross-section
ATLAS W/Z gamma	ATLAS_2013.J1217863 [40]	W/Z gamma production

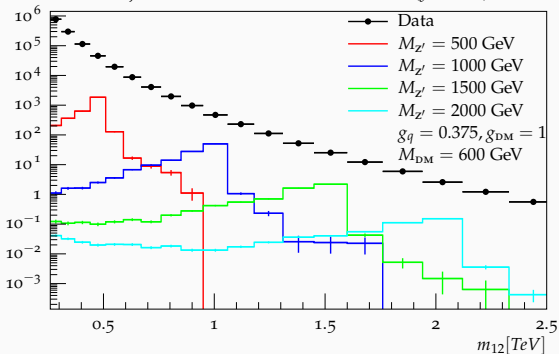
Table 1: Table of all Rivet routines currently included in the limit-setting scan. With the one indicated exception, they are all based on 7 TeV data.

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

Examining the Rivet output

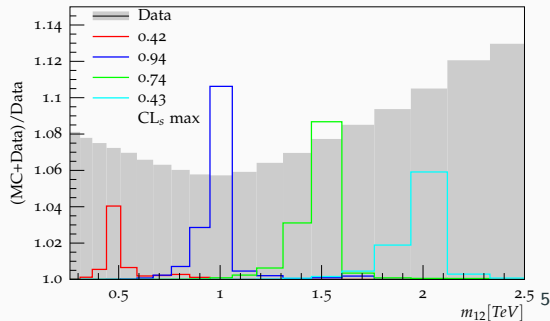
ATLAS Dijet double-differential cross sections ($y^* < 0.5$)



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.



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:

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

- **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 1σ 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 $[k] = s$.

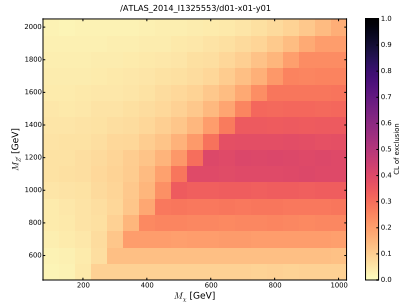
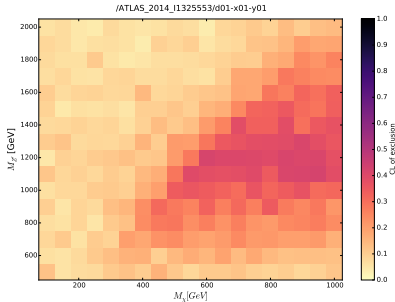
Statistical Analysis - cont.

- 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 \implies 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 \implies multiply by Integrated **Lumi**, possible to test additional metrics?

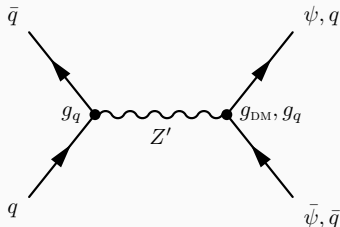
Statistical Analysis - Approximate distributions

- Testing framework consists of **python** scripts, constructing the **covariance matrix** to extract variance in μ
 - ⇒ Construct \tilde{q}_μ test statistic set one sided upper limit on confidence in **full** signal strength hypothesis
- Rely on **asymptotic limit** formula, well founded for current depth of scans, need to reintroduce MC tester...

ALERT, these are old, form/presentation different, left MC, right asymptotic formulae



Simplified Dark Matter Model

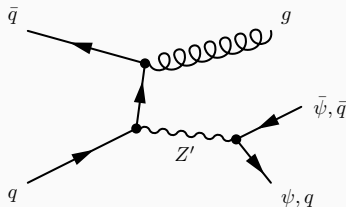
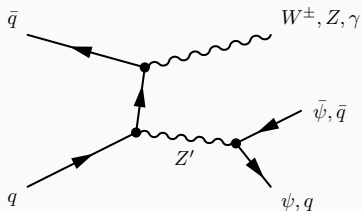


Simplified Dark Matter model, enable a description of **weakly coupled, low mass resonances**.

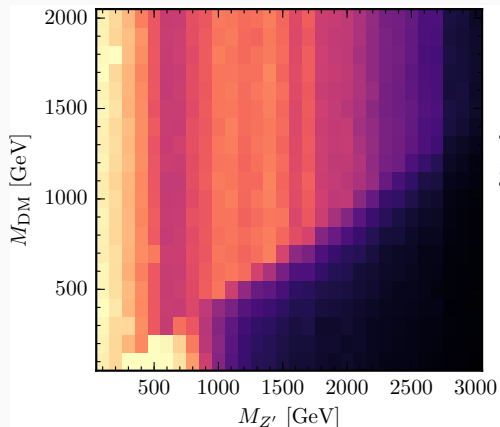
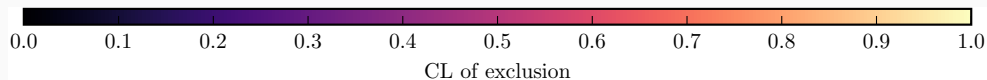
$$\mathcal{L} \supset g_{\text{DM}} \bar{\psi} \gamma_\mu \gamma_5 \psi Z'^\mu + g_q \sum_q \bar{q} \gamma_\mu q Z'^\mu$$

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

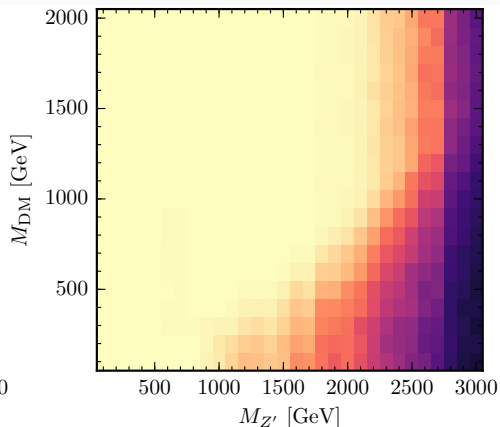
Model introduces **DM** candidate, ψ , dark . Experimental signatures hence typically rely on '**Mono-X**' style final states at colliders. Probe sensitivity in detecting decay of mediator back to **SM** final states.



Results - heatmaps



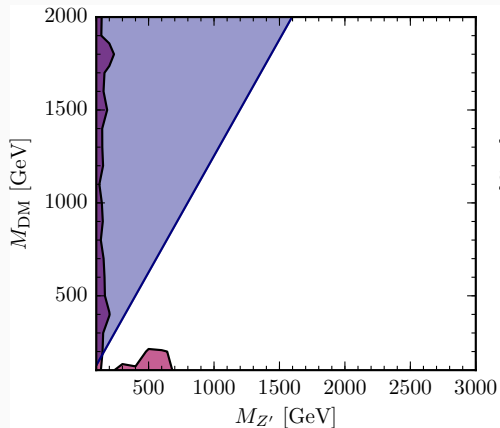
(a) $g_q = 0.25$ and $g_{DM} = 1$



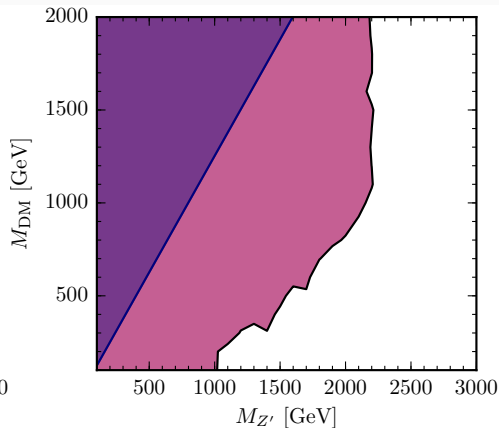
(b) $g_q = 0.5$ and $g_{DM} = 1$

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

Results - 95% CL Contours



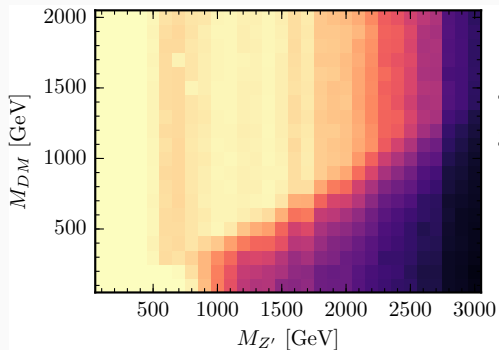
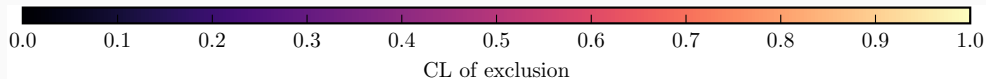
(a) $g_q = 0.25$ and $g_{DM} = 1$



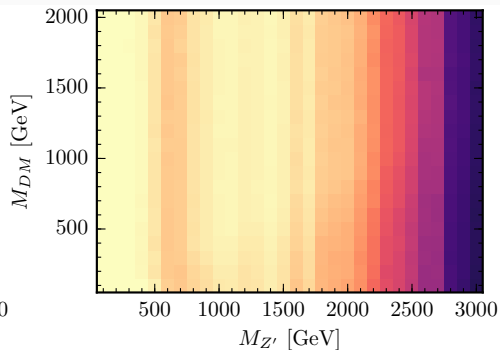
(b) $g_q = 0.5$ and $g_{DM} = 1$

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

Results cont. - Heatmaps



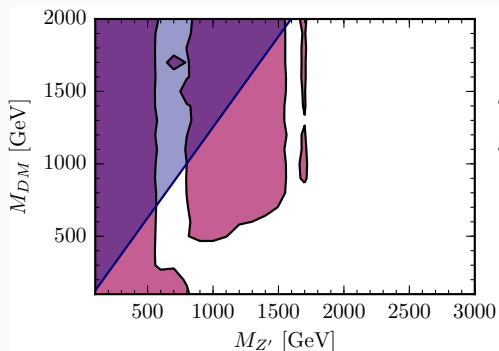
(c) $g_q = 0.375$ and $g_{DM} = 1$



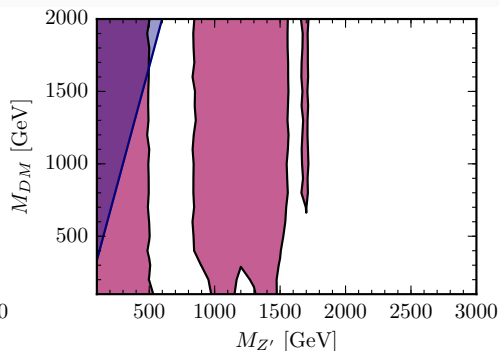
(d) $g_q = 0.375$ and $g_{DM} = 0.25$

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

Results cont. - 95% CL contour



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



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

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

Conclusions and Outlook

- 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.

ToDo:

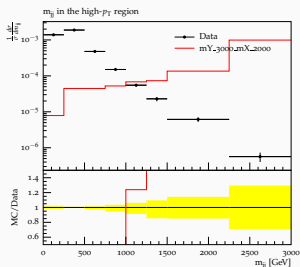
- Extended testing framework
- Include additional measurements as/when available
- Extend input compatibility, consider SUSY model frameworks

Thanks for listening

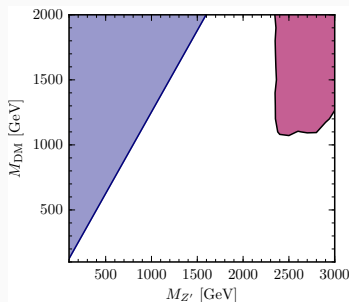
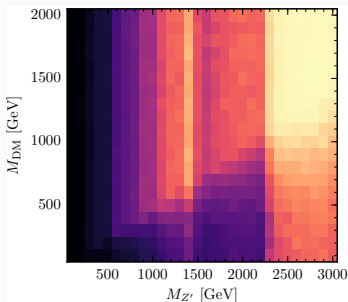
Backup

Update - 8TeV measurement

Noticeable dearth of 8TeV data unfolded and available, one measurement that was available but not included in original plots, [ATLAS Z+Dijet 8TeV](#)

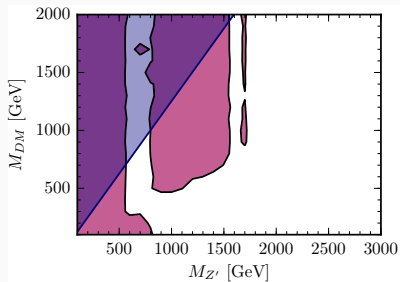
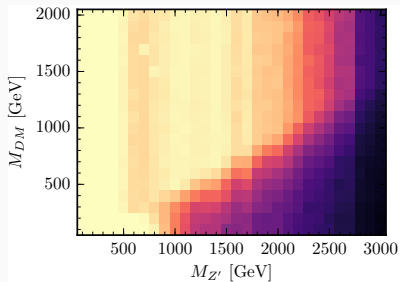


Default rivet output for a sample figure, **WARNING** normalised to total xs, 'undone' in the statistical process but not graphically yet.

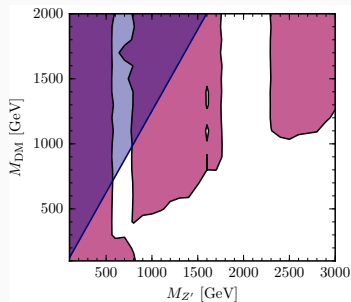
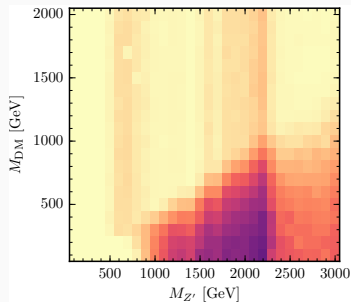


Update - 8TeV measurement

OLD

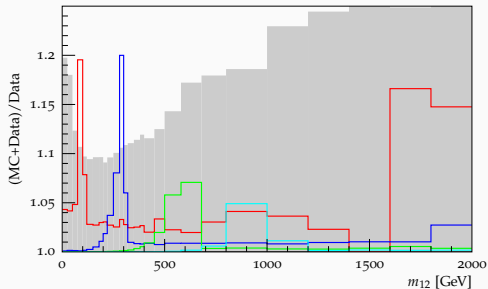
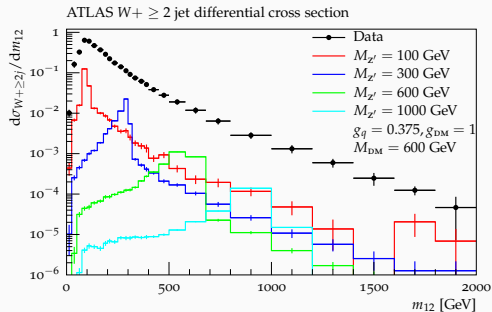


NEW



Additional example measurements - W + Jets

ATLAS W+Jet 7TeV



Additional example measurements - CMS incl Jets

CMS Inclusive Jets 7TeV

