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
Precision ‘Standard Model’ Measurements

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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.

\[ \mathcal{L} \supset g_{\text{DM}} \bar{\psi} \gamma_\mu \gamma_5 \psi Z'^\mu + g_q \sum_q \bar{q} \gamma_\mu q Z'^\mu \]
Key tools:

- BSM Model in FeynRules
- UFO interface
- Final State Particles
- New processes in Herwig7
- 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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• 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 $C_{L_s}$ 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, γγ, 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
<table>
<thead>
<tr>
<th>CONTUR Category</th>
<th>Rivet/ Inspire ID</th>
<th>Rivet description</th>
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<tr>
<td>CMS 7 Jets</td>
<td>CMS_2014.I1298810 [29]</td>
<td>Ratios of jet pT spectra, which relate to the ratios of inclusive, differential jet cross sections</td>
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<td>ATLAS 8 Jets</td>
<td>ATLAS_2015.I1394679 [34]</td>
<td>Multijets at 8 TeV</td>
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<td>CMS 7 Z Jets</td>
<td>CMS_2015.I1310737 [38]</td>
<td>Jet multiplicity and differential cross-sections of Z+jets events</td>
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<td>CMS 7 W Jets</td>
<td>CMS_2014.I1303894 [37]</td>
<td>Differential cross-section of W bosons + jets</td>
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<td>ATLAS_2012.I1093738 [44]</td>
<td>Isolated prompt photon + jet cross-section</td>
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<td>ATLAS 7 Diphoton</td>
<td>ATLAS_2012.I1199269 [43]</td>
<td>Inclusive diphoton + X events</td>
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Key tools: Constraints On New Theories Using Rivet

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https://contur.hepforge.org/
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

$\frac{d^{2}\sigma}{d^{2}m_{12}}$

- Data
- $M_{Z'} = 100$ GeV
- $M_{Z'} = 300$ GeV
- $M_{Z'} = 600$ GeV
- $M_{Z'} = 1000$ GeV
- $\sigma_q = 0.375, \sigma_{DM} = 1$
- $M_{DM} = 600$ GeV

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

$\sigma$ [fb]

- Data
- $M_{Z'} = 300$ GeV
- $M_{Z'} = 500$ GeV
- $M_{Z'} = 1000$ GeV
- $M_{Z'} = 1500$ GeV
- $\sigma_q = 0.375, \sigma_{DM} = 1$
- $M_{DM} = 100$ GeV
Heat Maps

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

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

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

(d) $g_q = 0.375$ and $g_{DM} = 0.25$
95\% \text{ CL}_S \text{ Contour}

Figure 7: Contours in the $M_{Z'}$ and $M_{\text{DM}}$ plane for the considered values of $g_{\text{DM}}$ 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.
Heat Maps

Preliminary - to be checked
95% $\text{CL}_s$ Contour

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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