BSM interpretation of SM measurements

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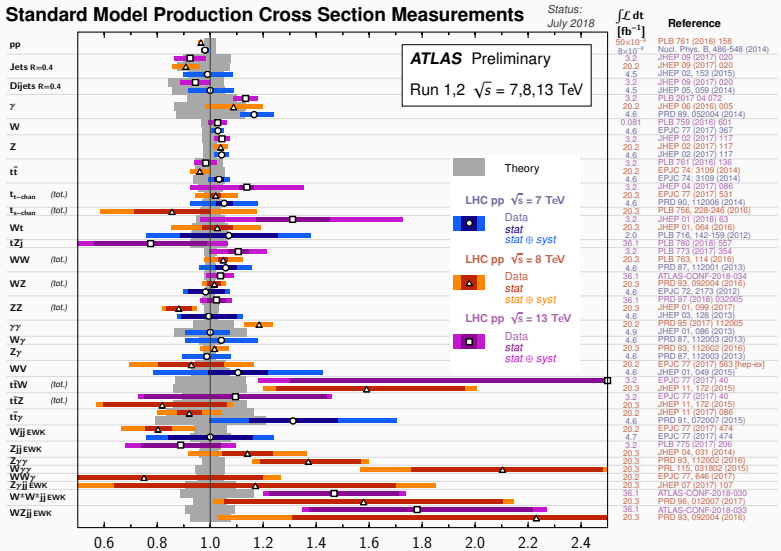
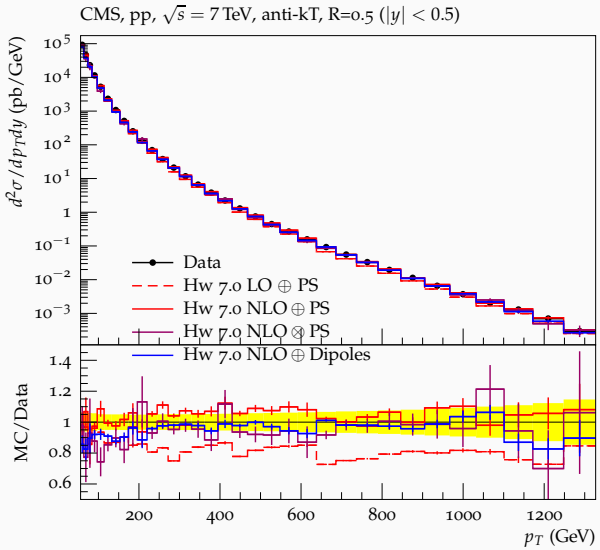
LHC Results - Measuring the known



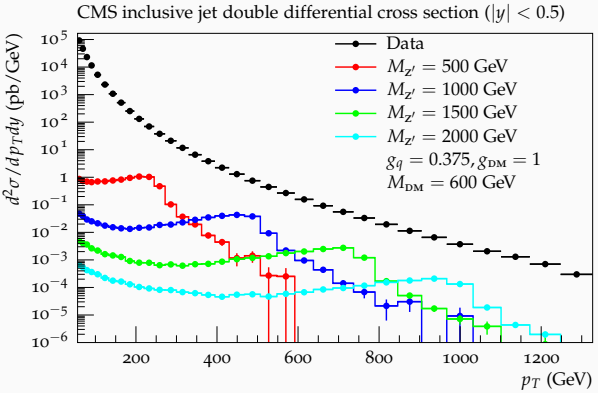
- A large array of unfolded particle level measurements produced by the experiment
- This information can also be used to constrain new physics
  - We have here a large array of (often differential) "Signal Regions"
  - "Global" LHC fit to Standard Model observables
- How do we go about this?

Rivet - A closer look



- Zoom in on one of those SM summary measurements, Inclusive Jets @ 7TeV CMS, 1406.0324
- Rivet plugin used to replicate experimental definition for generator studies, here validation provided by Herwig authors, Validation summary
- We have a good understanding of the SM here
- We have a fast flexible way of reproducing the theory here
- Rivet key here to reproducing the exact validated fiducial definition. To do this across all measurements need a universally adopted tool

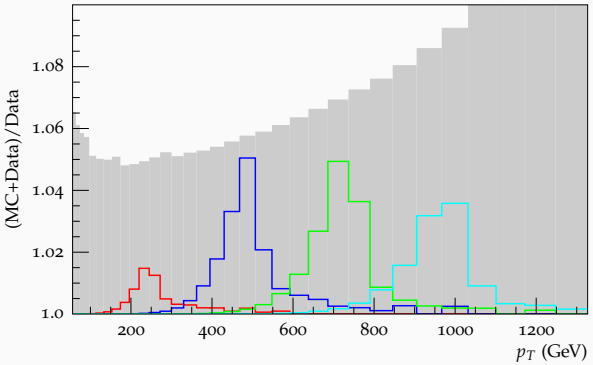
Rivet - BSM in SM measurements



BSM vs data cross section comparison for 1D parameter scan

- Again, Inclusive Jets @ 7TeV CMS, 1406.0324
- This time apply analysis definition to BSM model, Model not too important but here just a benchmark Simplified Dark Matter model
- BSM produces shapes with distinguishable kinematics, lead jet $p_T \approx M_{Z'}/2$
- Stack reveals bump hunting idea

Contur - BSM in SM measurements



(BSM + data)/data cross section comparison for 1D parameter scan

- Stack reveals bump hunting idea
- We have expected values, observed values, uncertainties (modulo correlation, see Louies talk). Everything we need to consider this as a series of signal regions.
- These signal regions are calculable observables of our theory (modulo the approximations needed to simulate LHC events and numerically estimate LHC cross sections)
- Inherent ambiguities of recasting not present at particle level

Contur - A recent example analysis

Contur- Constraints on New Theories using Rivet, our moniker for our attempt at organising these plugins under a limit setting program, 1606.05296

A recent application

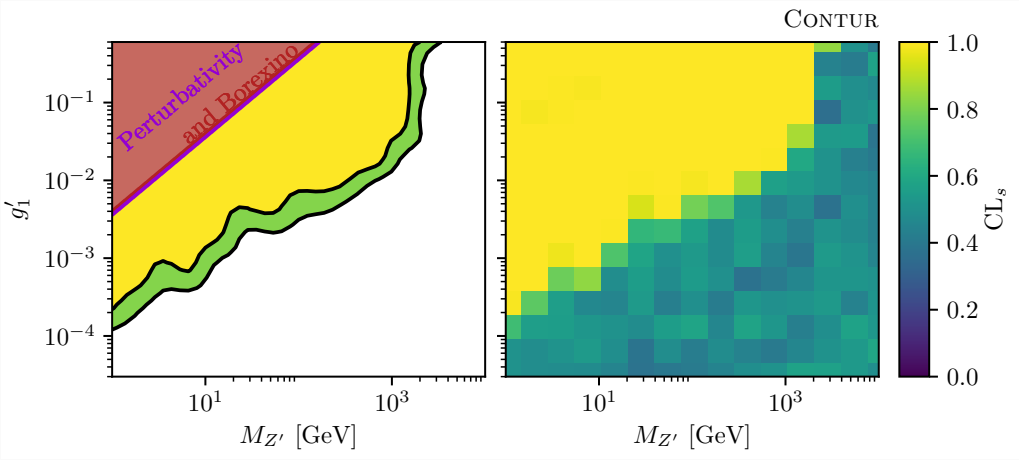
Recent study, Gauged $B - L$ model at the LHC, 1811.11452, no great detail here, just to illustrate how this looks

- Heavy neutrinos, new vector bosons, extended Higgs sector
- Non-trivial model dynamics in 6D parameter space, difficult to recast

Scenario	$M_{Z'}$ [GeV]	g_1'	M_{h_2}	$\sin\alpha$	M_{N_i}
A	[1, 10^4]	[3×10^{-5}, 0.6]	$M_{Z'}/(2g_1')$	0	$M_{Z'}/5$
B	[1, 10^4]	[3×10^{-5}, 0.6]	$M_{Z'}/(2g_1')$	0.2	$M_{Z'}/5$
C	[1, 10^4]	[3×10^{-5}, 0.6]	200 GeV	0.2	$M_{Z'}/5$
D	7000	0.2	[0, 800] GeV	[0, 0.7]	$M_{Z'}/5$
E	35	10^{-3}	[0, 800] GeV	[0, 0.7]	$M_{Z'}/5$

Table: Benchmark scenarios used in our analysis. In addition, the active-sterile neutrino mixing is fixed as $V_{lN} = \sqrt{0.1 \text{ eV}/M_N}$, independent of the generation of the heavy neutrino.

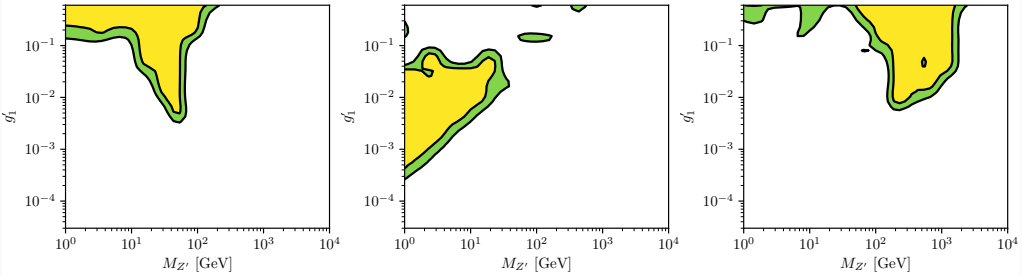
Example scan - Case C



[L] 95% (Yellow) and 68% (Green) CL of exclusion for one of the benchmark points (Case C). [R] Underlying calculated exclusion.

Pulling apart the combined limits

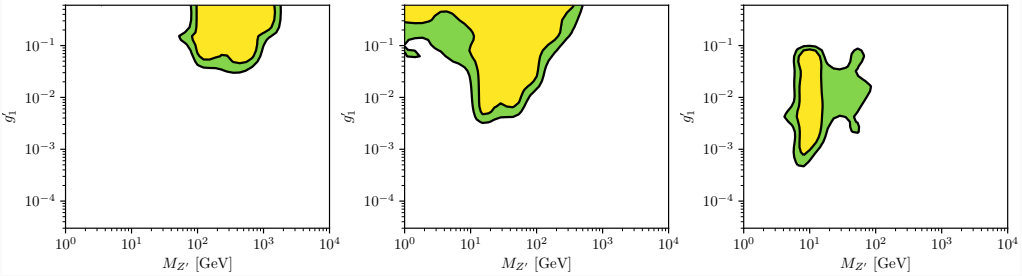
Strength in this analysis, and indeed Rivet in general is to combine as many of the possible channels and datasets as possible



(a) ATLAS 7TeV Low Mass DY **(b)** ATLAS 7TeV ZZ **(c)** ATLAS 8TeV High mass DY

Pulling apart the combined limits

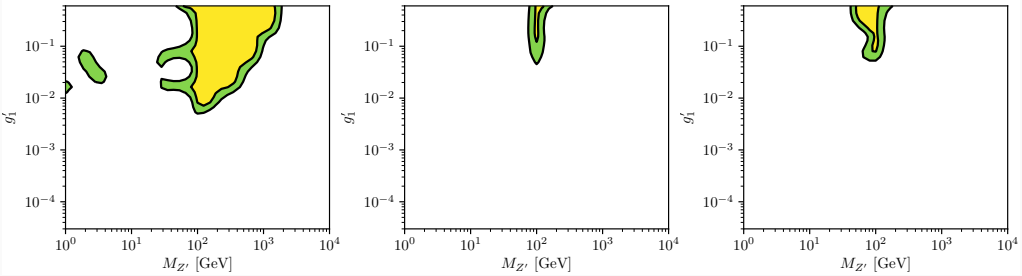
We can pull apart the combined limit shown into it's constituent orthogonal components, each of these groups of final states can be many analyses across the range



(d) ATLAS 8 TeV Zγ **(e)** ATLAS 8TeV Z+jets **(f)** ATLAS 8TeV ZZ

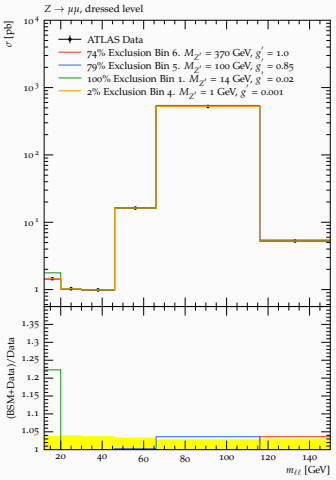
Pulling apart the combined limits

Unfortunately in this case the sensitive measurements available in Rivet for this parameter space are almost all from ATLAS

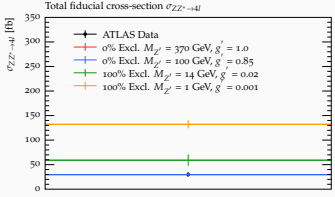


(g) ATLAS 8TeV WW **(h)** CMS 8TeV W+jets **(i)** LHCb 7TeV Z+jets

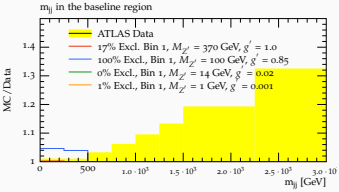
Zooming in again, the underlying Rivet



(j) Dimuon mass ATLAS

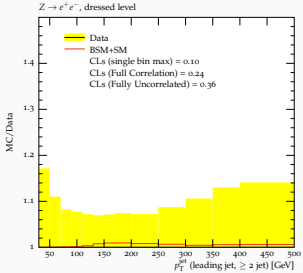


(k) ZZ^* (four lepton)



(l) Dijet mass in Z events

Some notes on Rivet for BSM



Example correlations for Z+jets

- Data pipeline through HepData reaching more complete status (See Louies talk).
  - Correlations! Access to more marginal signals, cumulative offshell effects etc.
  - Efforts around improving data pipeline vital to reinterpretability

- **Availability of Rivet routines**
  rivet.hepforge.org/rivet-coverage
- Unseen issues in fiducial definitions in Rivet.
  - Example: Some routines use identified neutrinos as a proxy for MET, Hard to use these for many BSM models that have varied MET sources

Key	ALICE	ATLAS	CMS	LHCb
Rivet wanted (total):	207	242	325	160
Rivet REALLY wanted:	39	39	68	10
Rivet provided:	**11**/218 = **5%**	**143**/385 = **37%**	**72**/397 = **18%**	**11**/171 = **6%**

Conclusion

Hopefully this has demonstrated some interesting ideas:

- We have fast simulations of calculable theoretical quantities through SM measurements, this can form a robust net of measured parameters to confront BSM simulation with
- We can use these tools to demonstrate interesting phenomenological results $\rightarrow$ the process can tell us interesting/unexpected things about physics
- Approach rides and dies on effort in preserving analyses in Rivet
  - This is effort on the experiments part but we hope to demonstrate closing the loop, utility in Rivet beyond generator development and tuning

Thanks for Listening!

Backup

The Search Recasting Problem

Roughly speaking need to know two quantities to translate a particle level simulation to a count in a detector volume:

$$N_{\text{obs}} = L \cdot \sigma_{\text{Total}} \cdot A \cdot \epsilon \tag{1}$$

- A - Acceptance, effectively the analysis definition, can be simple
  - Do we provide code or ATLAS/CMS approved analysis description, Rivet?
  - More complicated analyses, BDTs etc, impossible?
- ϵ - Efficiency, detector simulation
  - Usually done by theorists with approx fast sims, e.g. Delphes
  - ATLAS approved fast sims? Not going to happen?
  - Other ways around this, Folding matricies?

The community as devised a variety of ways to provide additional information (Efficieny maps, generic resonance/cross section limits, etc.) But it is a difficult and pressing question to keep on top of

Constructing a toolchain

HUGE development of tools for automated calculations of LHC physics, success depends on the toolchain!

THE MODELS

- **Feynrules**, de facto language to describe new physics Lagrangians
- **Herwig7** (MG,Sherpa etc.) Generate full LHC simulations of these events

THE DATA

- **Rivet(+HepData)**, plugin directly on generator output to replicate analysis definition
- Experimentally validated plugins, no question of ambiguity on acceptance

Logo pending...

THE LIMITS

- **Contur**, Analysis framework plugin directly to Rivet output. Analyse deviations from data

Contur - Methodology benefits/limitations

PROS

- "Model Independent" - Very dependent on the SM, but this seems the best model to be dependent on!
- Fast, no expensive detector simulation
- Builds on independent, actively developed codes, Very little bespoke information needed.
- Builds on already established route to market for experimental data, and feeds back directly on this pipeline

CONS

- Unfolded measurement data arrives slower than a search
- Limited analysis coverage (for now?) for some typical search regions (E.g. Large MET)
- Currently limited to profiling purely based on Data and BSM simulation, not entirely a con but a current internal limitation.