Constraining New Physics with Standard Model measurements

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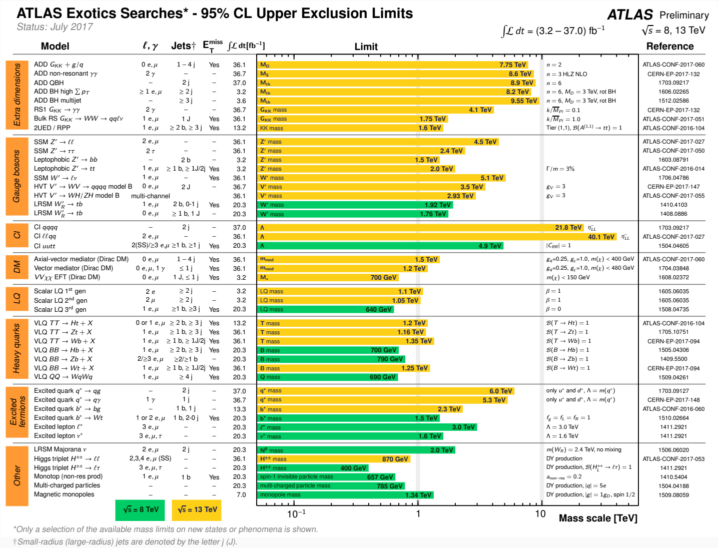
Introduction - What do we measure at the LHC?

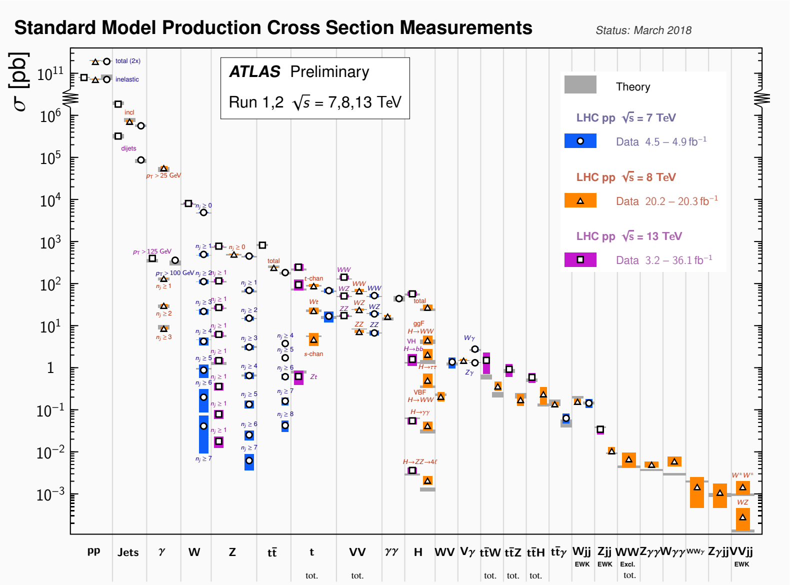
- Results - What is the goal of the experimental programs at the LHC (Specifically ATLAS and CMS)
  - Measure known phenomena as accurately as possible.
  - Seach for something new!
- Information
  - What do we provide
  - What do people want
  - Will anyone actually use additional information
- Tools
  - Where/How do we best interface to theory

Results - Searching for the unknown



- A huge array of analyses at ATLAS and CMS searching for new physics ([L] ATLAS exotics summary)
- A huge array of no observed excesses, can only constrain models
- How do we use this to comment on arbitrary new physics models not originally considered?
- What information do we provide to interpret these results?

Results - Measuring the known



- An equally large array of unfolded particle level measurements
- This information can also be used to constrain new physics (important distinction: can't search here!)
- How do we go about this?

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

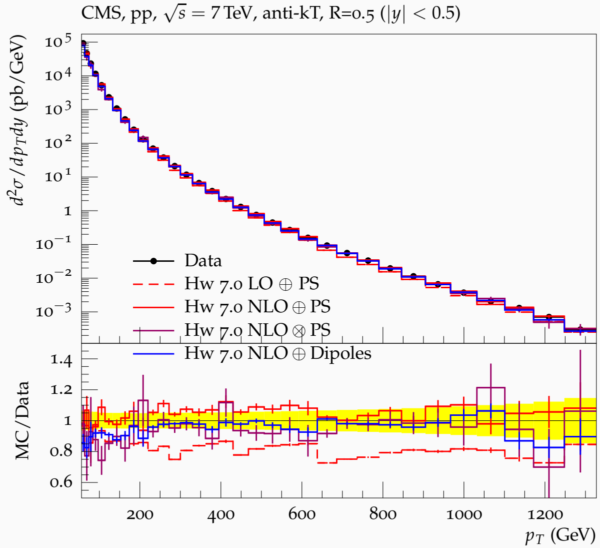
- **Rivet(+HepData)**, plugin directly on generator output to replicate analysis definition
- Experimentally validated plugins, no question of ambiguity on acceptance

THE LIMITS

Logo pending...

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

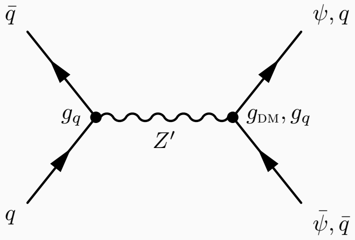
Contur - A Jetty Example

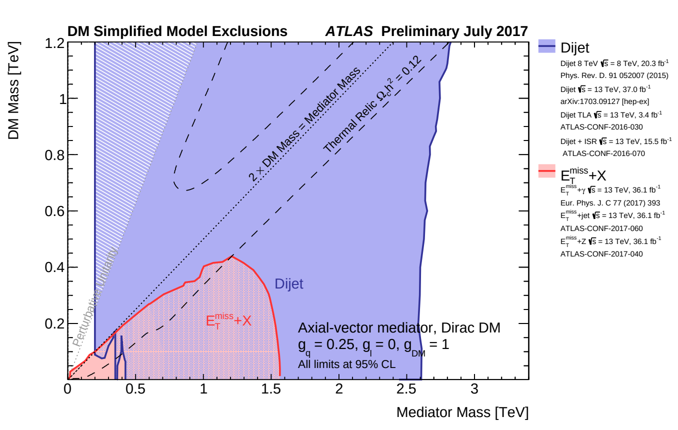


- Zoom in on one of those SM summary measurements, Inclusive Jets @ 7TeV CMS, 1406.0324
- Rivet plugin used to replicate experimental definition for generator studies, here validation provided by Herwig authors, Validation summary
- We have a good understanding of the SM here
- We have a fast flexible way of reproducing the theory here

Contur - A Jetty Example Model

One of the simplest SM extensions, often discussed for the context of Dark Matter searches, LHCDMWG - 1603.04156

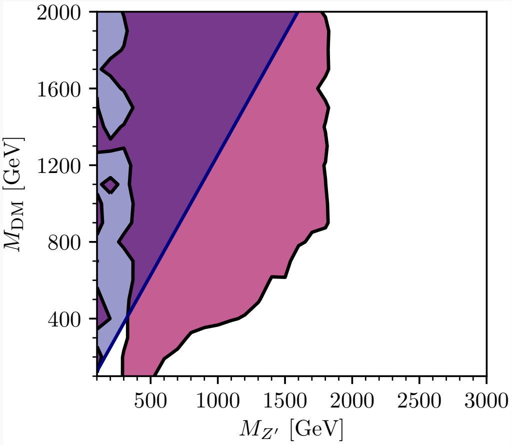




Simplified model forms 4D model parameter space: $g_q, g_{DM}, M_{DM}, M_{Z'}$. Easy to explore!

Searches in the collider context give MET-ey or Jet-ey signatures

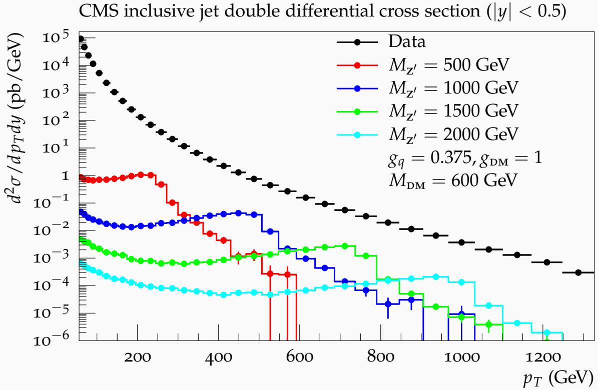
Contur - A Jetty Example, Mapping the parameter space



95% CL contour (pink), for a simplified dark matter model. Theoretical bound from perturbative unitarity (blue)

- Model studied in detail in the original Contur paper, 1606.05296
- Rolling updates with expanded data shown here from the Contur Webpage
- Fix two parameters, $g_q = 0.25, g_{DM} = 1.0$, equivalent to the ATLAS/CMS benchmarks, 2D scan in $M_{DM}, M_{Z'}$
- Profile likelihood fit across all datasets
- Report exclusion of model in terms of CL$_s$
- Build 95% CL exclusion contour
- Maps out the collider DM landscape!

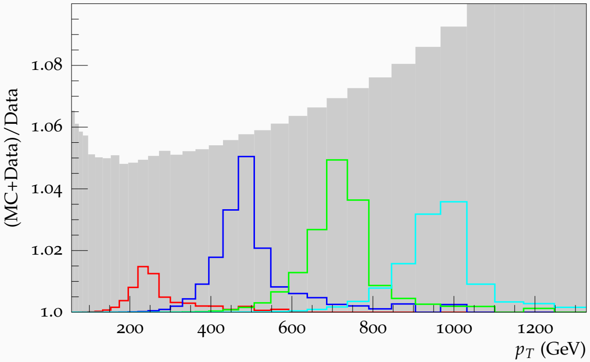
Contur - A Jetty Example Back to data



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, scan in 1 parameter dimension, $M_{Z'}$
- BSM produces shapes with distinguishable kinematics, lead jet $p_T \approx M_{Z'}/2$
- Stack reveals bump hunting idea

Contur - A Jetty Example Back to data



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

- Again, Inclusive Jets @ 7TeV CMS, 1406.0324
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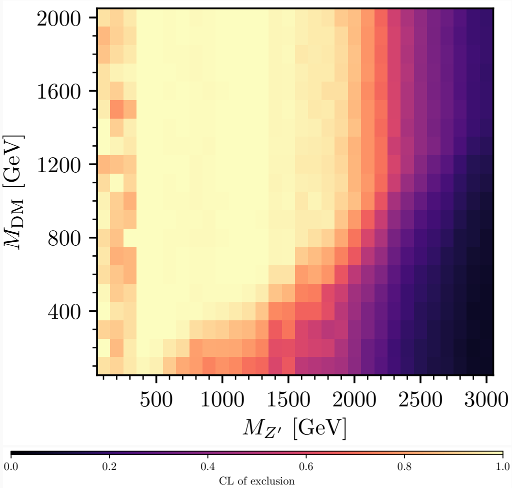
Contur - A Jetty Example, Mapping the parameter space



CL_s of a 2D scan of parameter space points

- Model studied in detail in the original Contur paper, 1606.05296
- Rolling updates with expanded data shown here from the Contur Webpage
- Fix two parameters, $g_q = 0.25, g_{DM} = 1.0$, equivalent to the ATLAS/CMS benchmarks, extend 1D scan shown previously to 2D scan in $M_{DM}, M_{Z'}$
- Profile likelihood fit across all datasets
- Report exclusion of model in terms of CL_s

Contur - A recent example analysis

Contur - Light Scalars

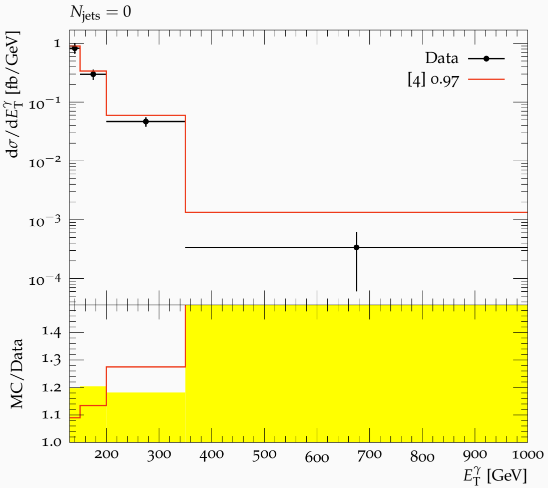
A different model, Light Scalars at the LHC 1607.08653, contributions made to Les Houches proceedings (pending).

Example: CP-Even scalar has gauge sector interactions specified by the following Lagrangian:

$$\mathcal{L}_{\text{eff}} \supset \phi \left(\frac{1}{\Lambda} G^{\mu\nu\,a} G^{a}_{\mu\nu} + \frac{1}{\Lambda} W^{\mu\nu\,I} W^{I}_{\mu\nu} + \frac{1}{\Lambda} B^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda} |D^{\mu} H|^{2} \right)$$

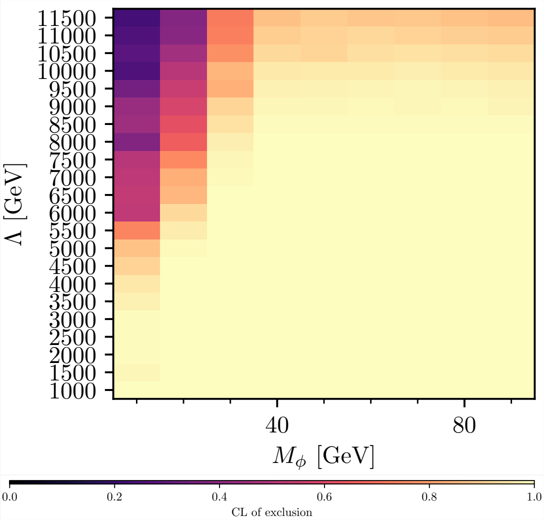
- EFT Model behaviour dictated by 2 parameters in this case, suppresion scale Λ, scalar mass m_{ϕ}
- Well motivated extension of many BSM models is an extended Higgs Sector (e.g. 2HDM)
- Low mass scalars sector not fully excluded by low mass diphoton searches
- Decays to massive dibosons kinematically unfavoured in these mass ranges $\rightarrow$ predominant decays to diphoton

Contur - Light Scalars



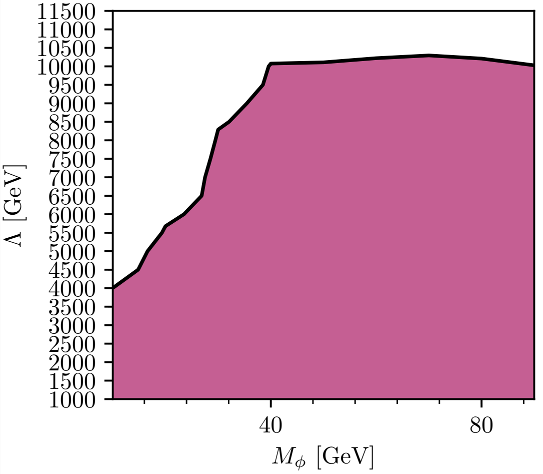
(BSM + data) vs data cross section comparison for 1 model point in 0 jet bin of ATLAS Z($\nu\nu$)+γ as a function of E_T^γ

- Gain exclusion limits from 7/8TeV gauge boson $+ \gamma(\gamma)$ measurements.
- Here show ATLAS 8TeV $Z\gamma(\gamma)$, 1604.05232
- Perhaps less expected, typically would only consider diphoton measurements/searches
- The power of our approach relies on a huge breadth of complementary analyses, can catch atypical channels



CL_s of a 2D scan of parameter space points

- Perform 2D Parameter scans (this case for CP-Even scalar) utilising as many Rivet plugins as possible
- Build orthogonal combinations of datasets
- Profile likelihood fit across all datasets
- Report exclusion of model in terms of CL_s



95% CL contour (pink), for a CP even light scalar

- Perform 2D Parameter scans (this case for CP-Even scalar) utilising as many Rivet plugins as possible
- Build orthogonal combinations of datasets
- Profile likelihood fit across all datasets
- Report exclusion of model in terms of CL$_s$
- Build 95% CL exclusion contour
- Maps out the low mass scalar landscape!

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 using Contur $\rightarrow$ the process is validated
- We can use these tools to demonstrate interesting phenomenological results $\rightarrow$ the process can tell us interesting/unexpected things about physics

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:

$$N_{\text{obs}} = L \cdot \sigma_{\text{Total}} \cdot A \cdot \epsilon \quad (1)$$

- 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

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.