Constraints On New Theories with Precision Measurement

David Yallup

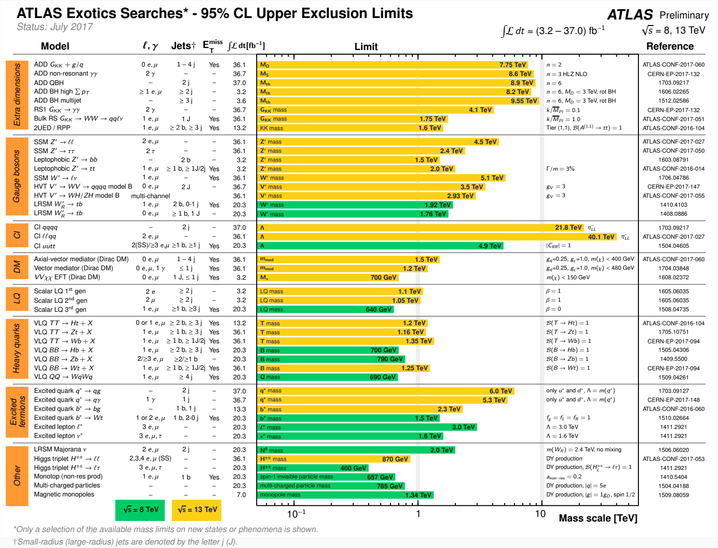
April 13, 2018

MCnet CERN network meeting 2018 - CEDAR session

Introduction - What do we measure at the LHC?

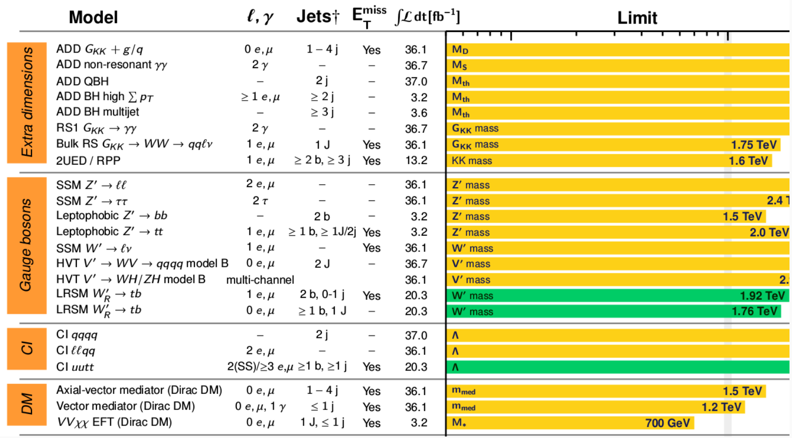
- Results - What is the goal of the experimental programs at the LHC
  - Measure known phenomena as accurately as possible.
  - Seach for something new!
- Information
  - What do we provide
  - What do people want
  - Will anyone actually use additional information
- Tools
  - Where/How do we best interface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

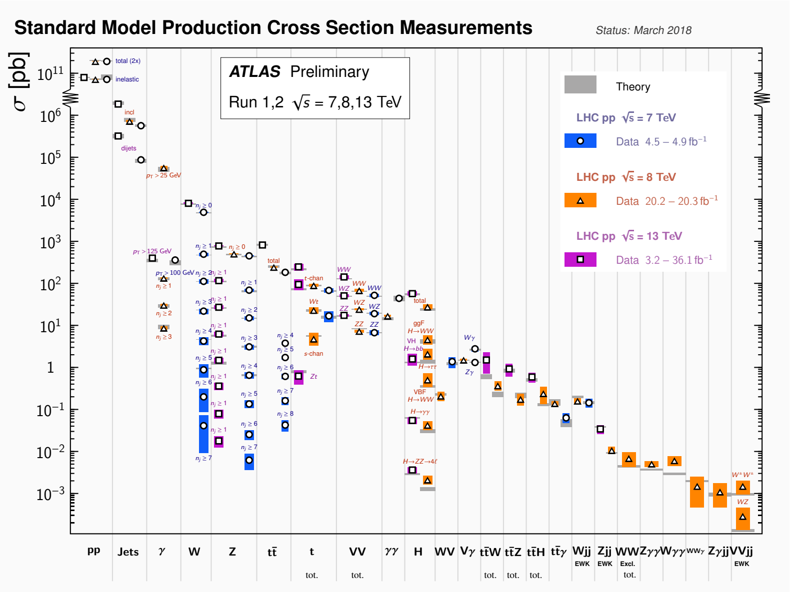
Results - Searching for the unknown



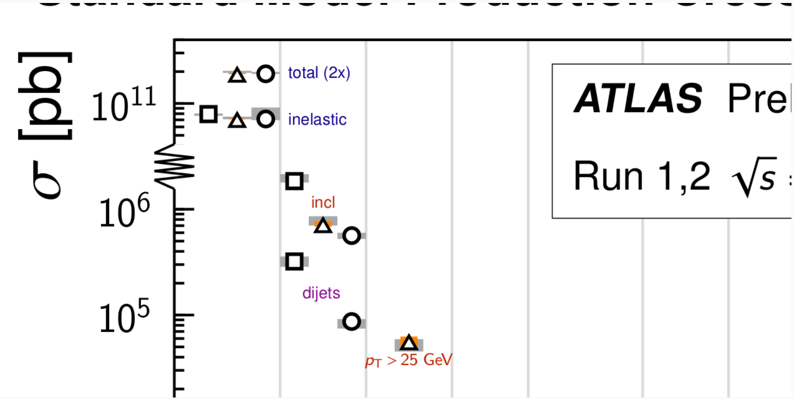
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Limit
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu$	$1-4$ j	Yes	36.1	M_D
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	36.7	M_S
	ADD QBH	–	2 j	–	37.0	M_{th}
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	3.2	M_{th}
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th}
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	36.7	G_{KK} mass
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	$1\ e, \mu$	1 J	Yes	36.1	G_{KK} mass 1.75 TeV
	2UED / RPP	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	36.1	Z' mass
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	Z' mass 2.4 T
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV
	Leptophobic $Z' \to tt$	$1\ e, \mu$	≥ 1 b, $\geq$ 1J/2j	Yes	3.2	Z' mass 2.0 TeV
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	36.1	W' mass
	HVT $V' \to WV \to qqqq$ model B	$0\ e, \mu$	2 J	–	36.7	V' mass
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.
	LRSM $W'_R \to tb$	$1\ e, \mu$	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV
	LRSM $W'_R \to tb$	$0\ e, \mu$	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV
CI	CI $qqqq$	–	2 j	–	37.0	Λ
	CI $\ell\ell qq$	$2\ e, \mu$	–	–	36.1	Λ
	CI $uutt$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	20.3	Λ
DM	Axial-vector mediator (Dirac DM)	$0\ e, \mu$	$1-4$ j	Yes	36.1	m_{med} 1.5 TeV
	Vector mediator (Dirac DM)	$0\ e, \mu, 1\ \gamma$	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV
	$VV\chi\chi$ EFT (Dirac DM)	$0\ e, \mu$	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV

- 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?



- 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

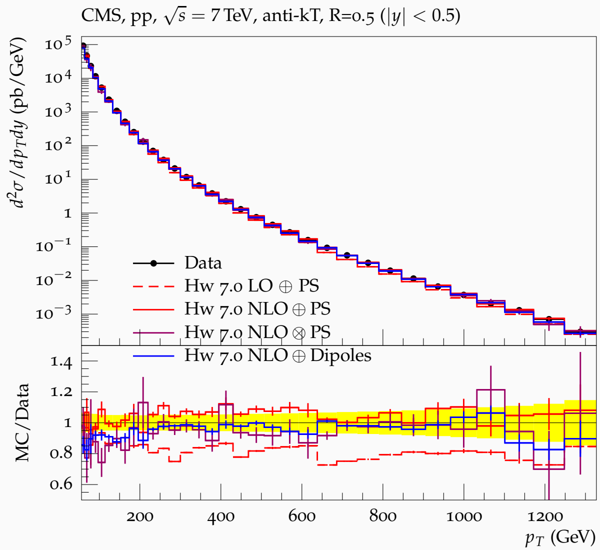
- **Rivet(+HepData)**, plugin directly on generator output to replicate analysis definition
- Experimentally validated plugins, no question of ambiguity on acceptance

THE LIMITS

Logo pending...

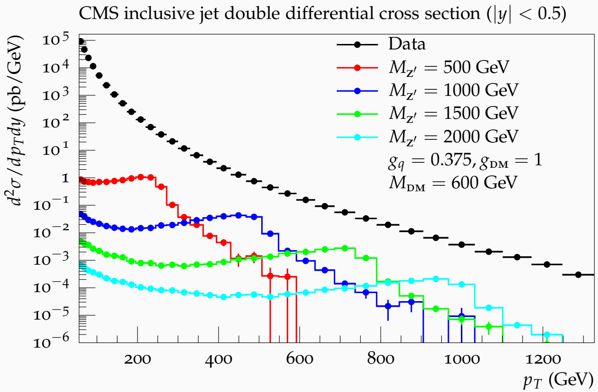
- **Contur**, Analysis framework plugin directly to Rivet output. Analyse deviations from data

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

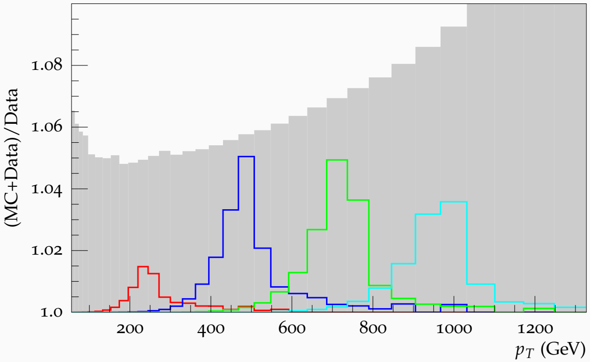
Contur - A Jetty Example Back to data



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

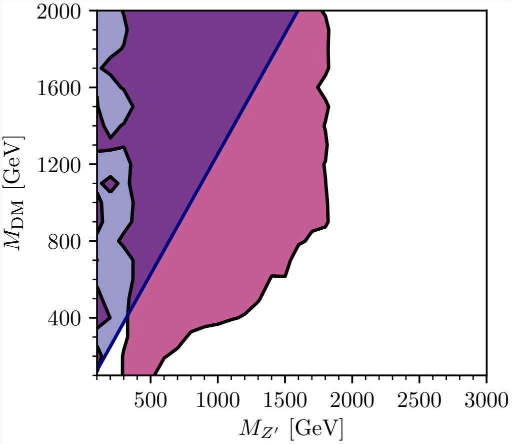


(BSM + data)/data cross section comparison for 1D parameter scan

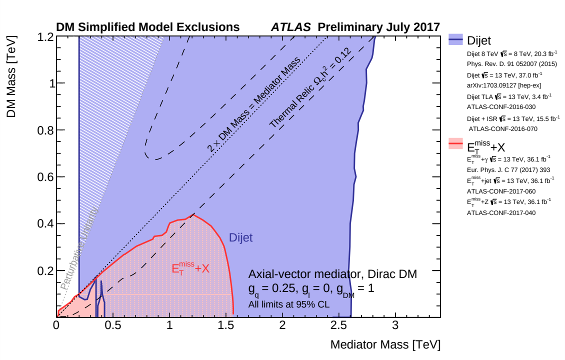
- Again, Inclusive Jets @ 7TeV CMS, 1406.0324
- This time apply analysis definition to BSM model, scan in 1 parameter dimension, $M_{Z'}$
- BSM produces shapes with distinguishable kinematics, lead jet $p_T \approx M_{Z'}/2$
- Stack reveals bump hunting idea

Contur - A Jetty Example

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



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



The procedure gives comprable results to the official searches, differences are understood

Contur - A recent example analysis

Contur - Light Scalars

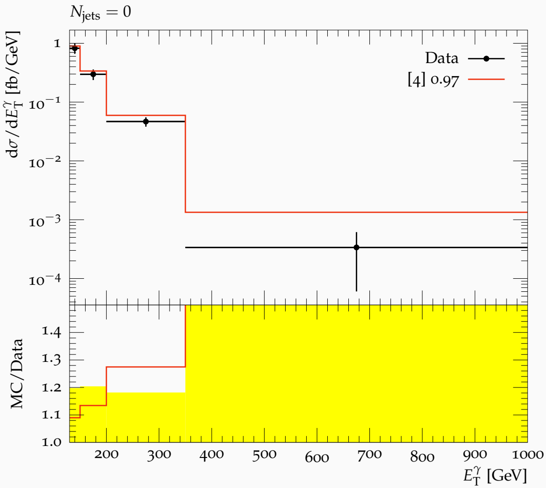
A different model, Light Scalars at the LHC 1607.08653, contributions made to Les Houches proceedings (pending).

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

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

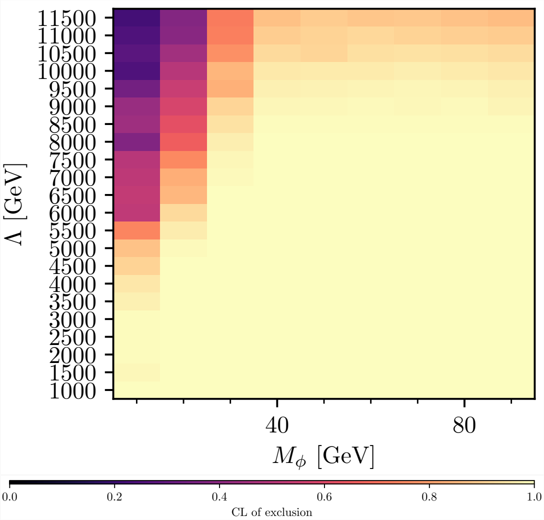
- EFT Model behaviour dictated by 2 parameters in this case, suppresion scale Λ, scalar mass m_ϕ
- Well motivated extension of many BSM models is an extended Higgs Sector (e.g. 2HDM)
- Low mass scalars sector not fully excluded by low mass diphoton searches
- Decays to massive dibosons kinematically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

Contur - Light Scalars



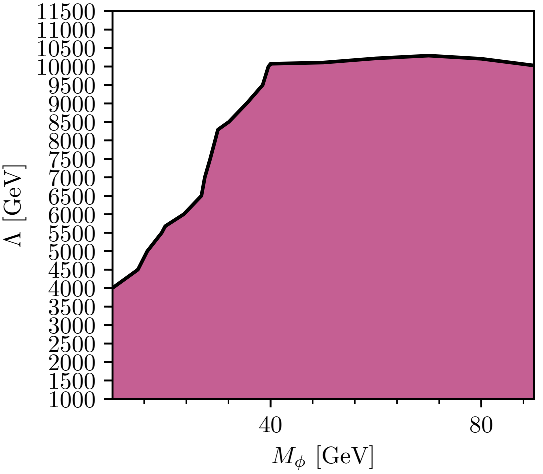
(BSM + data) vs data cross section comparison for 1 model point in 0 jet bin of ATLAS Z($\nu\nu$)+γ as a function of E_T^γ

- 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.