CONTUR update

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University College London

Reinterpretation Forum, Imperial
3/4/2019

The Idea

- We have many, increasingly precise and detailed, measurements of final states (typically differential cross sections).
- We (usually) take great care to define & make them without assuming the SM (fiducial).
- They are corrected for detector effects and can be compared to particle-level predictions
- BSM particle level predictions are quick, given a model file.
- **Use our growing library of measurements (in Rivet) for quick sensitivity scans of models across a very wide range of final states → Contur**

Key tools:

- BSM Model in FeynRules

UFO interface

Final State Particles

- New processes in Herwig7

- Rivet, and data from HepData

Exclusion

Key tools: Constraints On New Theories Using Rivet

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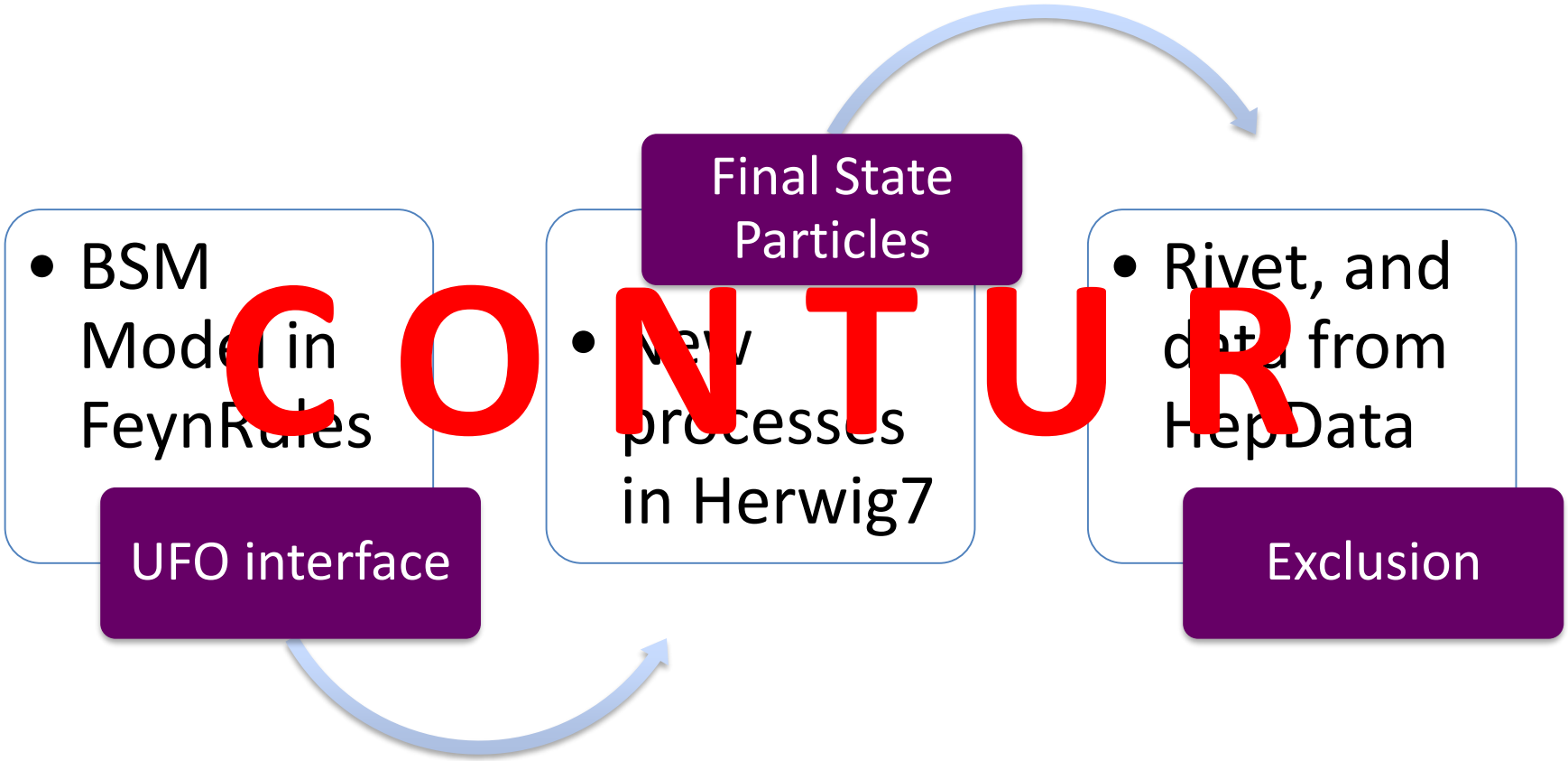


JMB, D Grellscheid, M Krämer, B Sarrazin, D Yallup
JHEP, 03:078, 2017. arXiv:1606.05296.

contur.hepforge.org

Strategy

- Use measurements shown to agree with the Standard Model
  - (Currently) assume the data == the background, as in a typical search control region
  - Excellent for quick sensitivity/limit scans of new models
- Constrain new models if there is a signal somewhere else (unintended consequences)
- Constraining wide variety of models (scale of new physics?) if there is no signal

Dynamical data selection

- Classify into statistically-independent "pools" according to data set (7, 8, 13 TeV) and non-overlapping signatures
- Use only one bin from one plot from each given statistically correlated sample
  - *e.g.* Jets, lv+jets, ll+jets, γ (+jets), $\gamma\gamma$, 4l, etc □.
- "Most sensitive measurement" will vary with model and model parameters

Has been tried with…

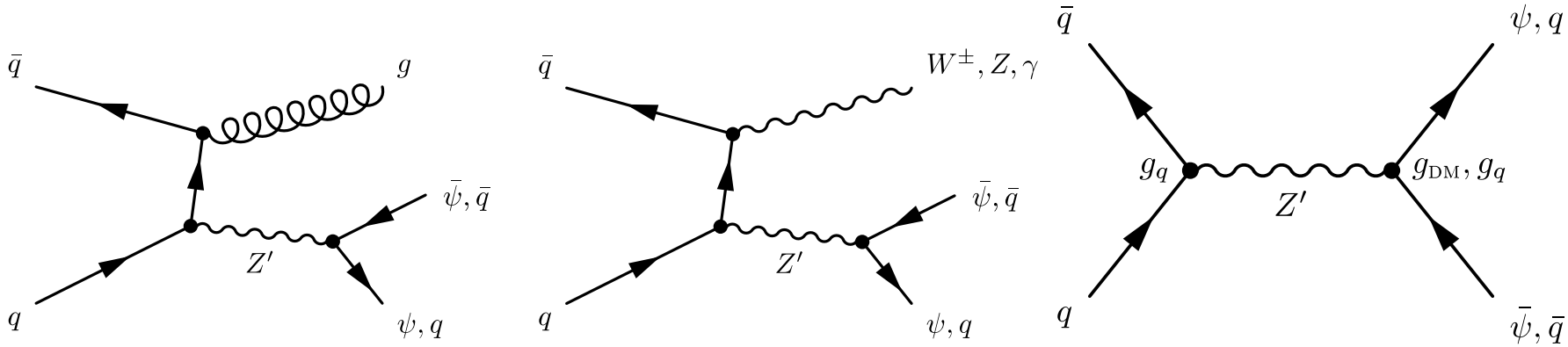
- Spontaneously-broken B-L gauge theory
  - (See Wei Liu's talk yesterday)
- Simplified Dark Matter models
- 2HDM with pseudoscalar mediator to DM
- Generic Light Scalar Model
- Vector-like quarks
- …

Simplified Dark Matter Model

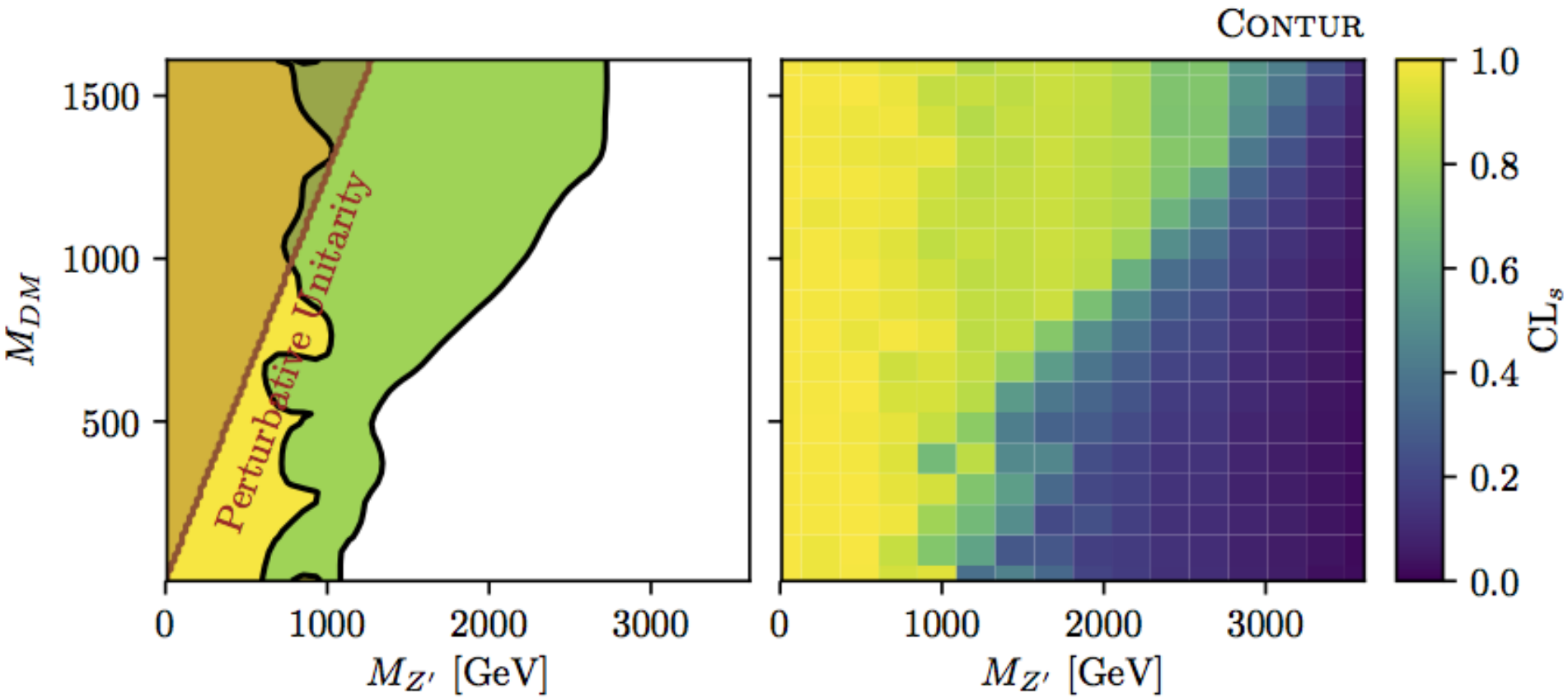
- Introduce Z' mediator, a Majorana fermion DM candidate, and two couplings

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

- Variant considered in Z' which couples only to first generation quarks
  - arXiv:1606.05296
- Have since also looked at coupling to all generations



Simplified DM model coupling to light flavours



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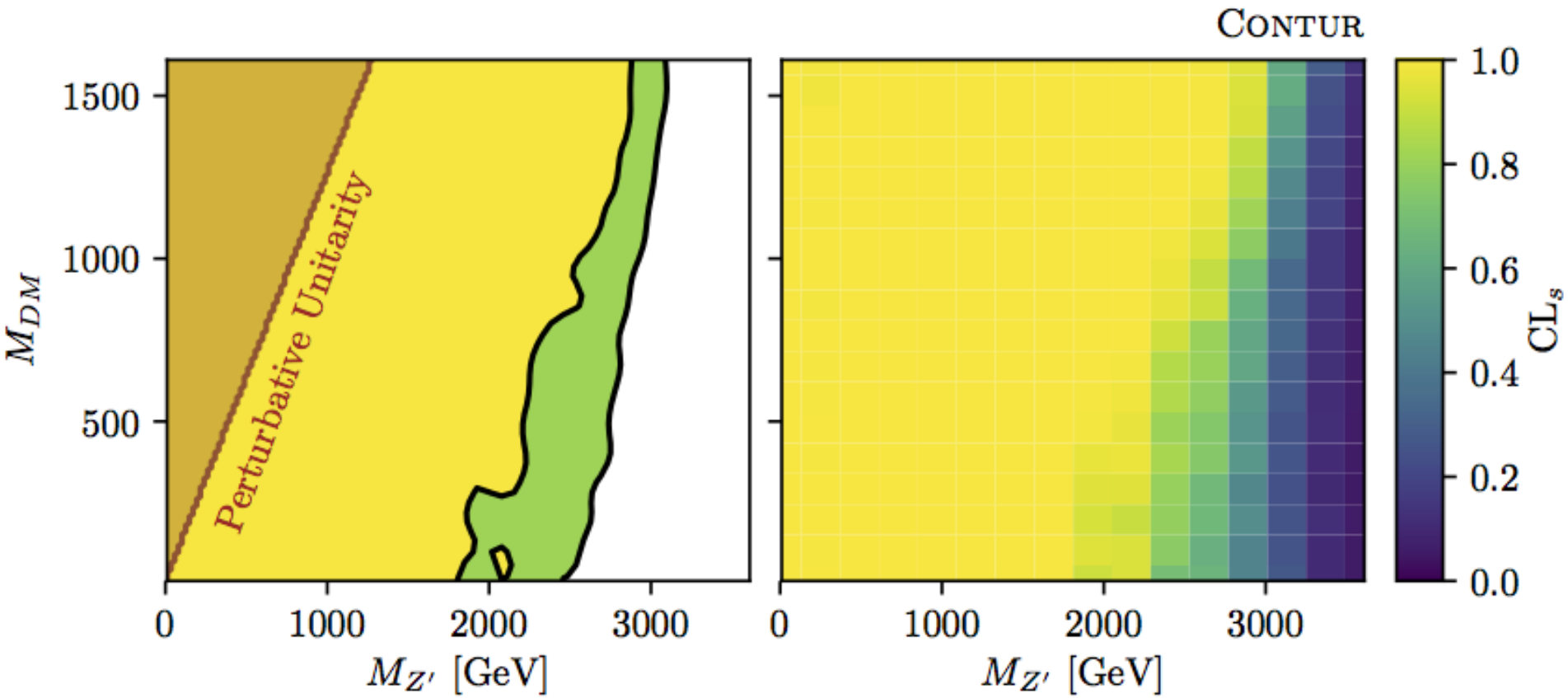
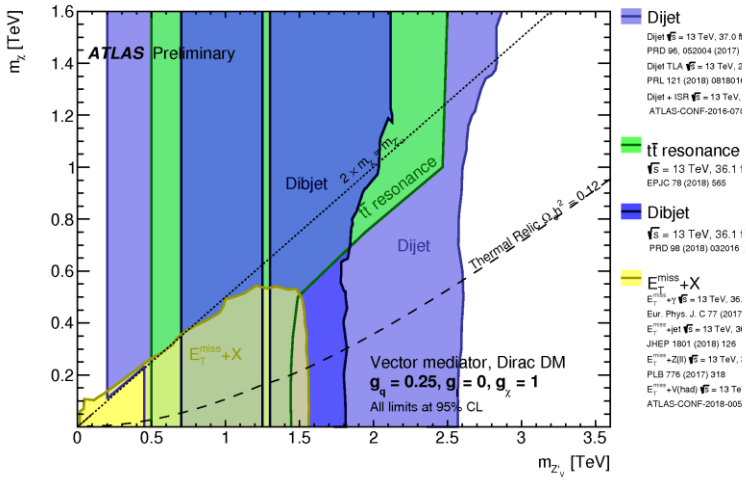
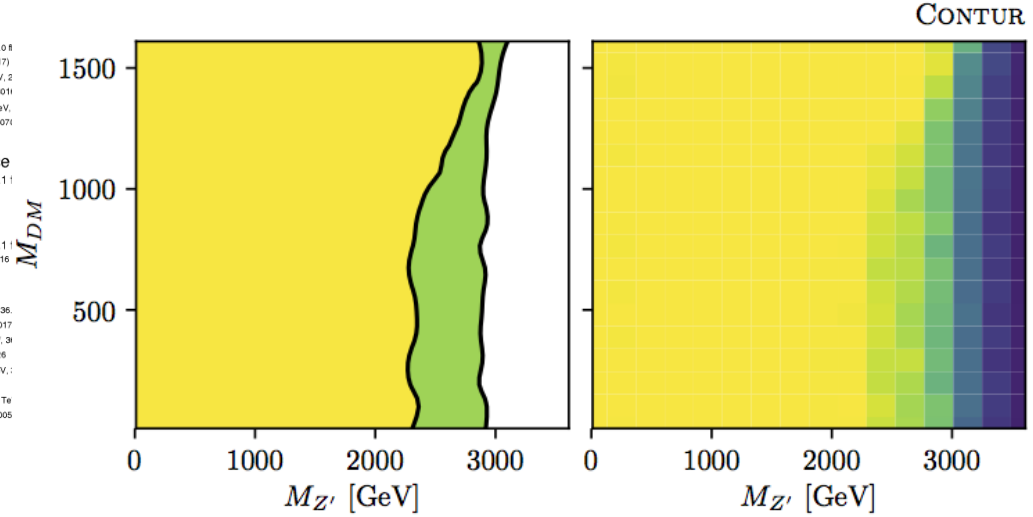
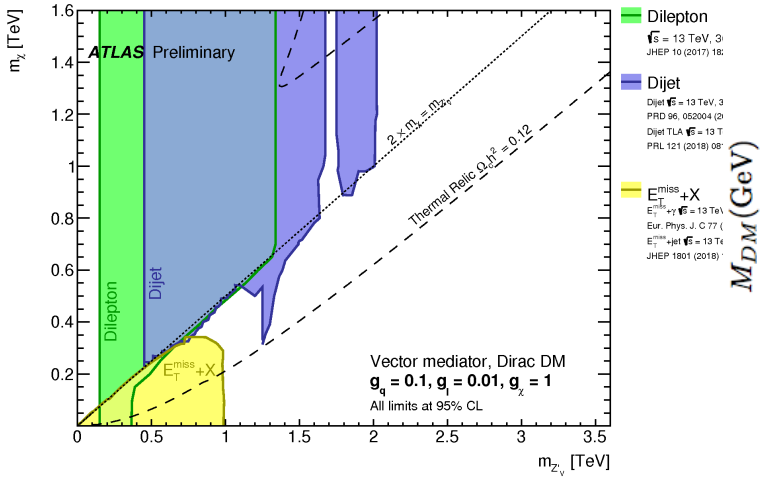
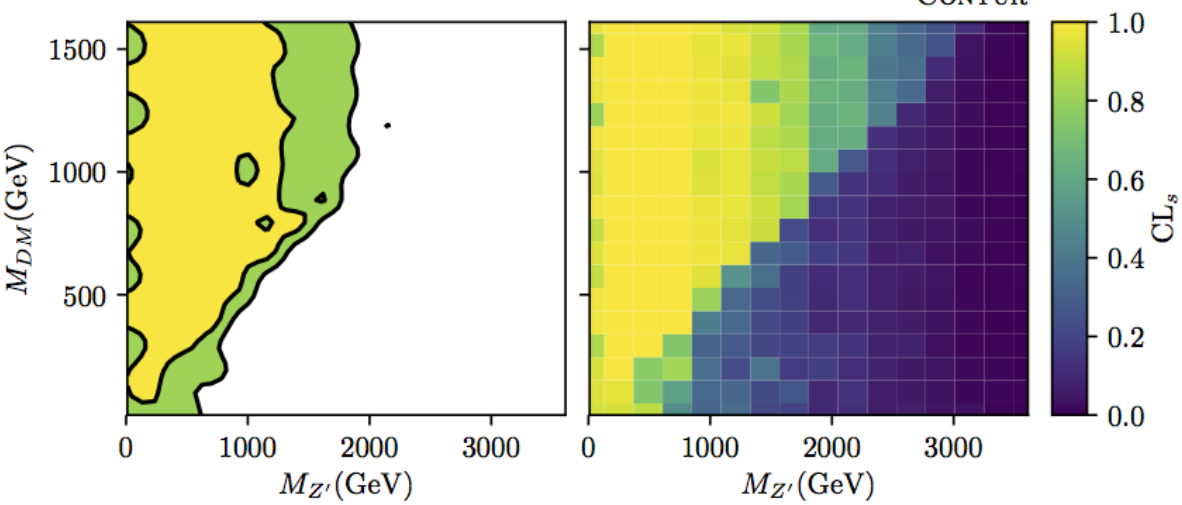


ATLAS Benchmarks

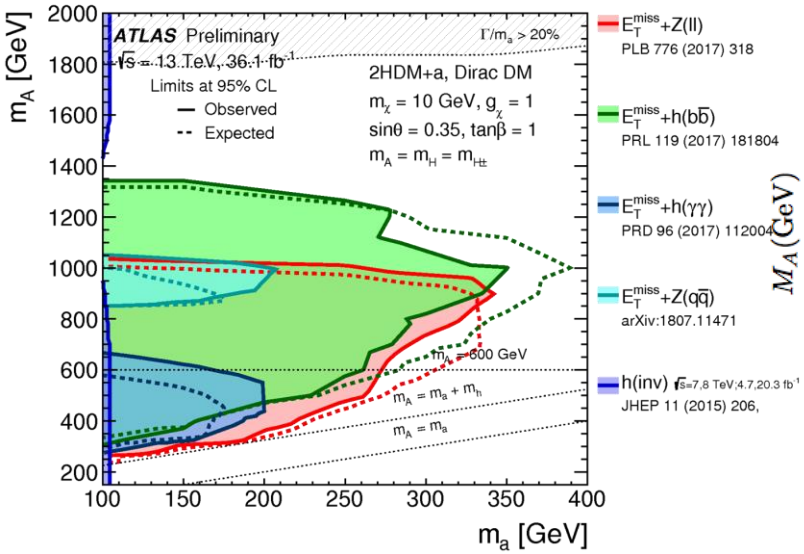


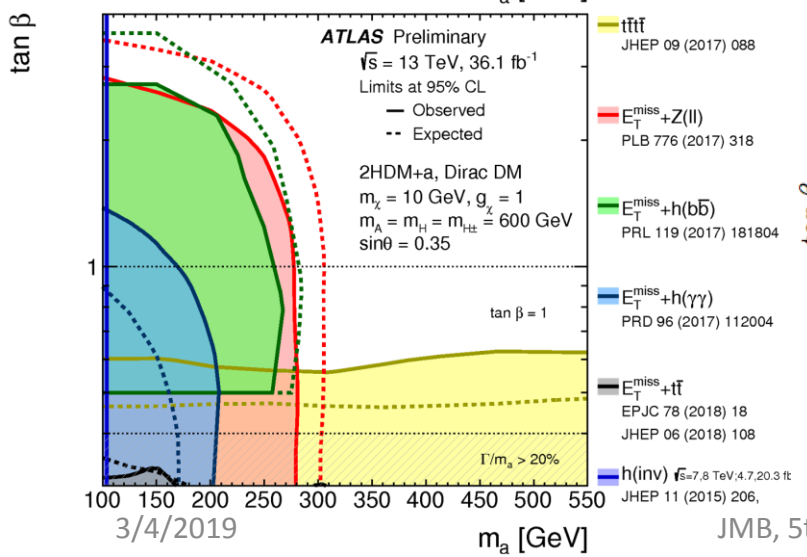


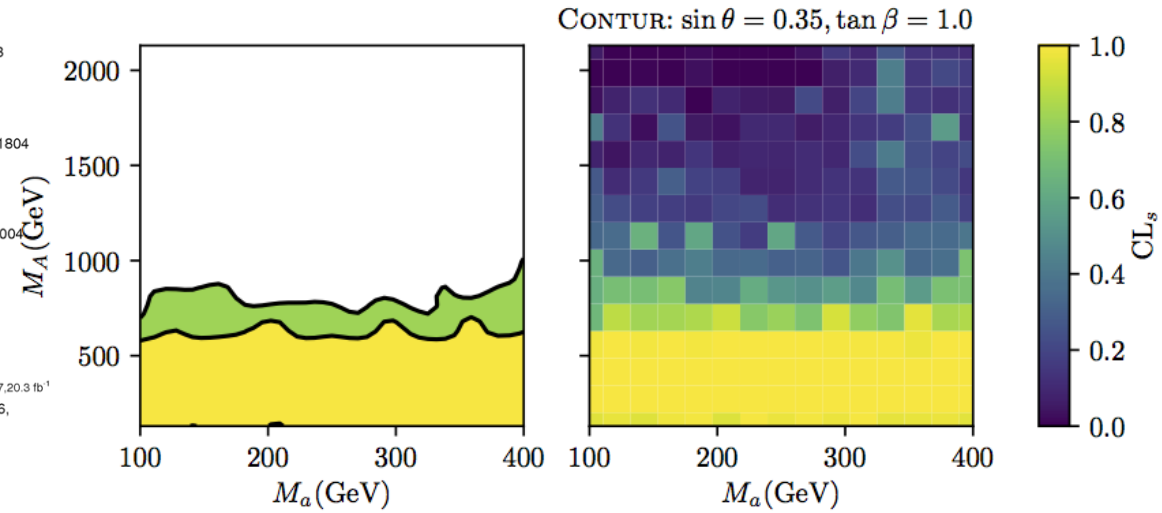


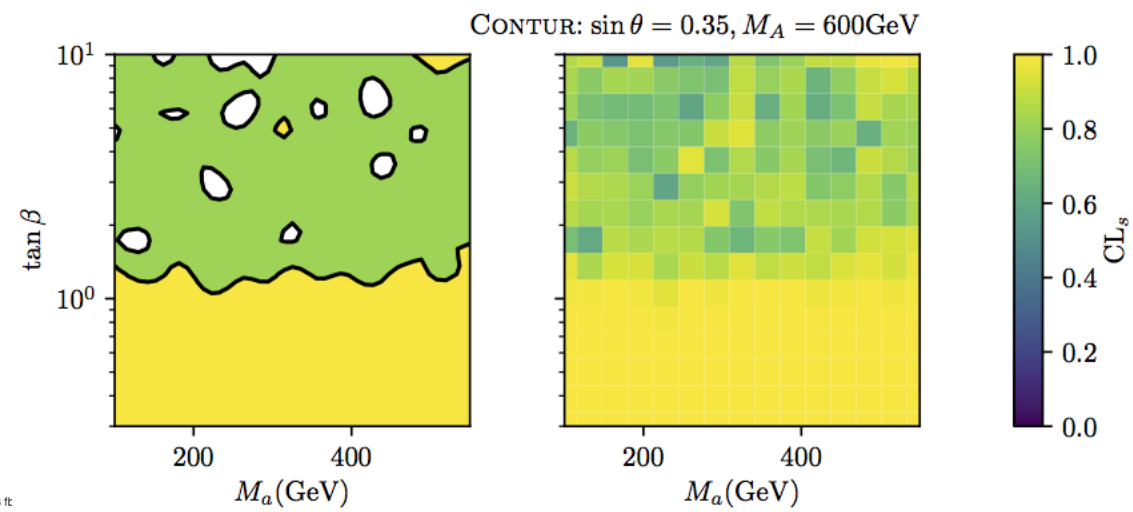


2HDM with pseudoscalar mediator









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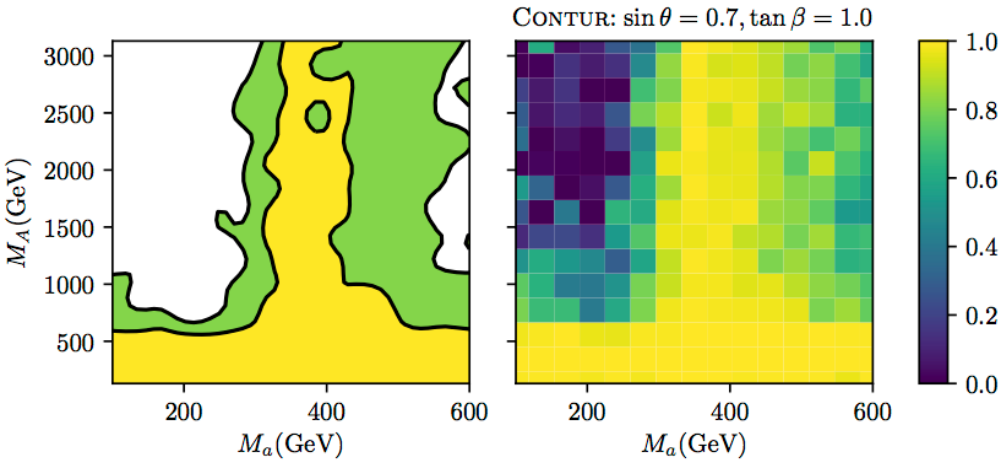
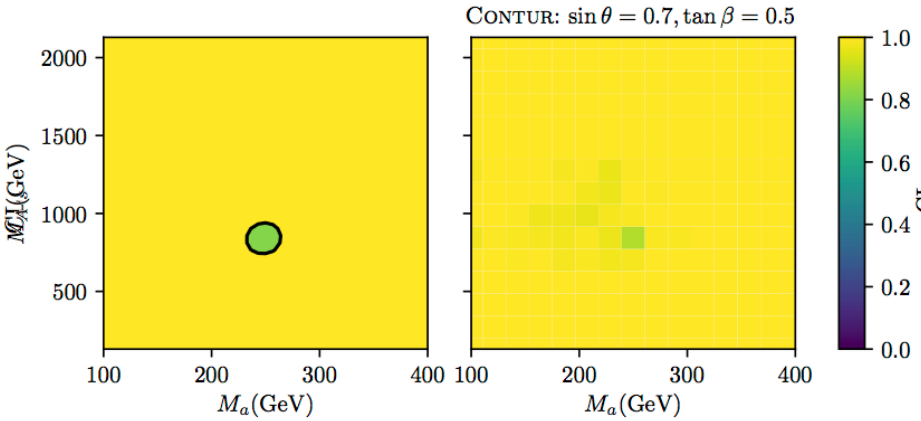
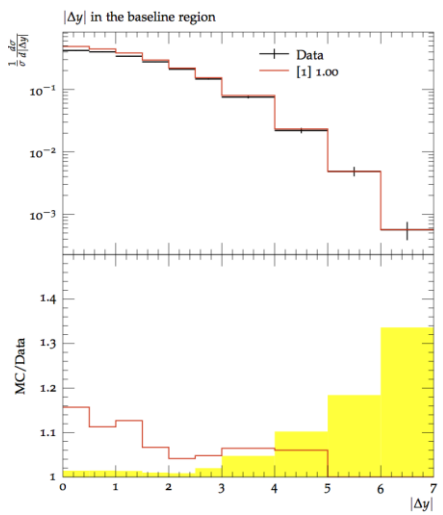
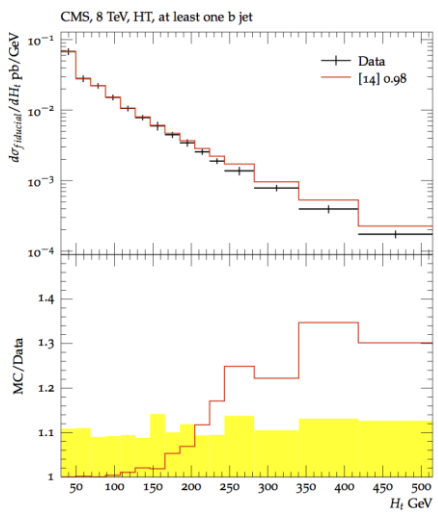
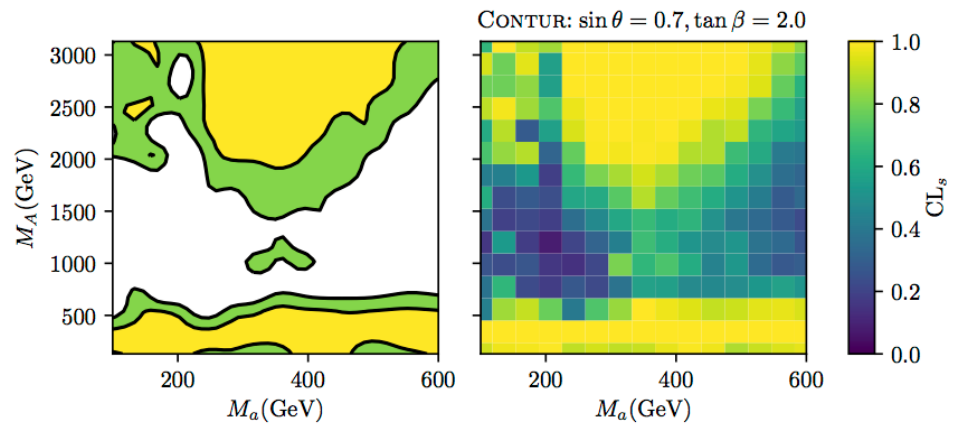










M_A=3130 GeV, M_a=314 GeV, a decays to Z+h_1 with a 20% BR, $\sigma(gg \to ah_1)$ ~ 12 pb. Enhancement in fiducial region of most Z+ jet measurements,e.g., the H_T distribution from CMS Z+b jets arXiv:1611.06507 and $|\Delta\eta|$ from the ATLAS Electroweak Z jets arXiv:1401.7610 .

3. Generic Light scalars

- Effective couplings to gauge bosons.
  - Dominant decay to photons → sensitivity in inclusive, diphoton and V+photon measurements
  - Model from S. Fichet, G. Moreau. See Les Houches 2017 proceedings arXiv:1803.10379, *Contribution 20*

Generic Light scalars

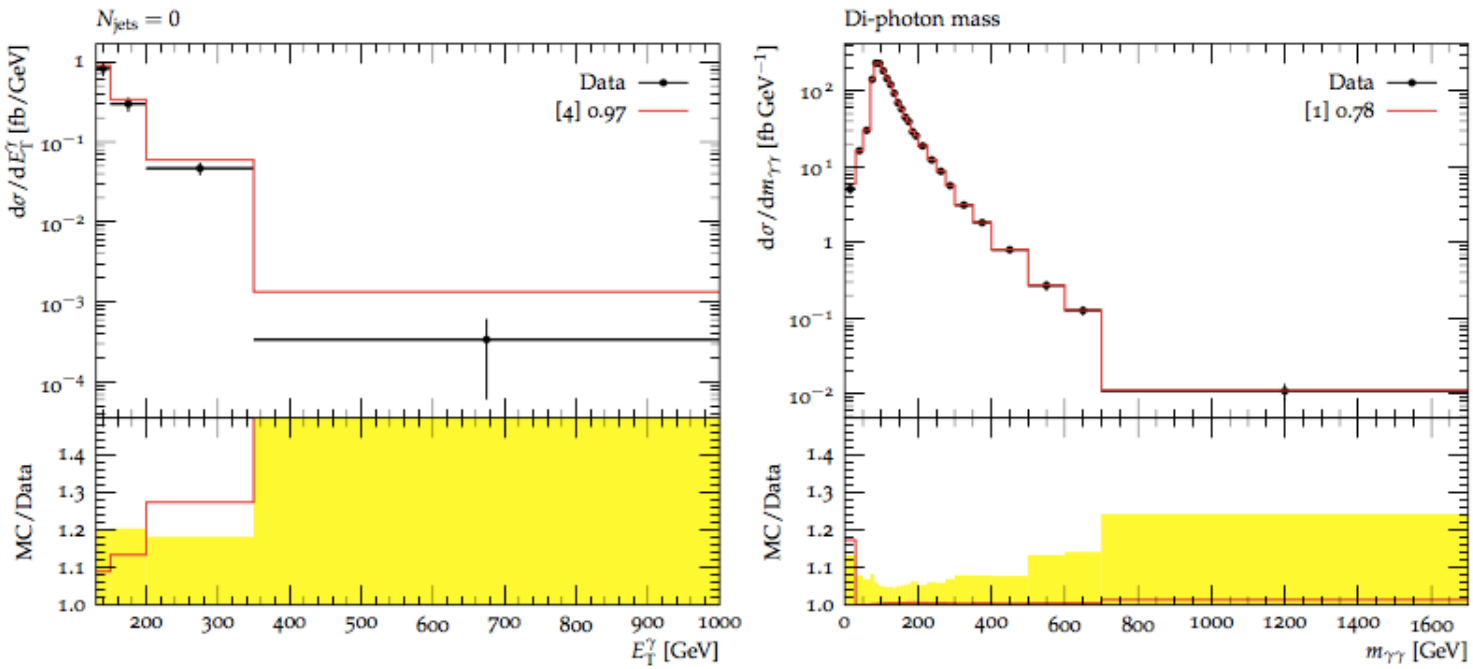
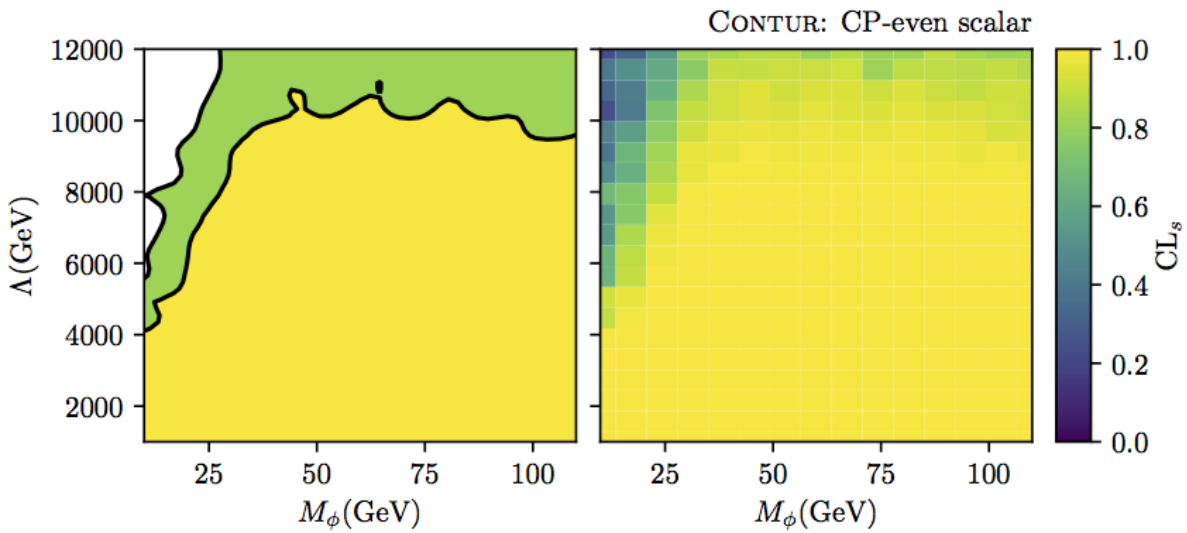


Figure 1: Projection of the contribution of the CP-odd model, (left) for $M_\varphi = 10$ GeV and $\Lambda = 3500$ TeV, on to the 8 TeV ATLAS $\gamma + E_T^{\text{miss}}$ differential E_T^γ cross-section measurement and (right) on the diphoton mass measurement, now with $M_\varphi = 20$ GeV – which brings the mass peak from the φ within the range of the measurement. Black points indicate the data, the red upper histogram is the data+BSM. The lower sections of the plots show the ratio of (data+BSM)/data, with the yellow band indicating the uncertainty in the measurement. The numbers in the legend show the bin number of the most powerful bin, and the exclusion from that bin expressed as a probability.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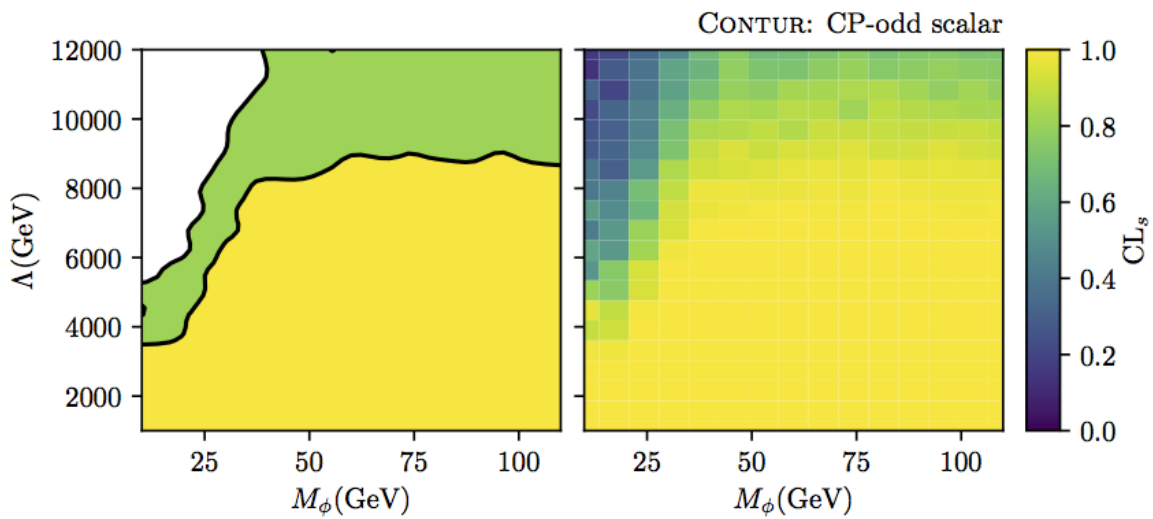
12000
10000
8000
6000
4000
2000
Λ(GeV)
25
50
75
100
M_ϕ(GeV)
25
50
75
100
M_ϕ(GeV)
1.0
0.8
0.6
0.4
0.2
0.0
CL_s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M_ϕ(GeV)
25
50
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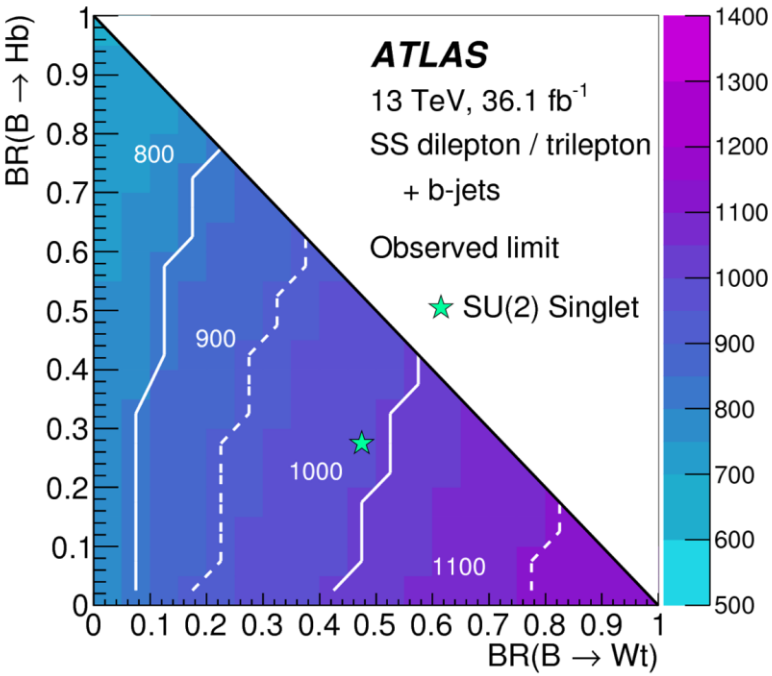
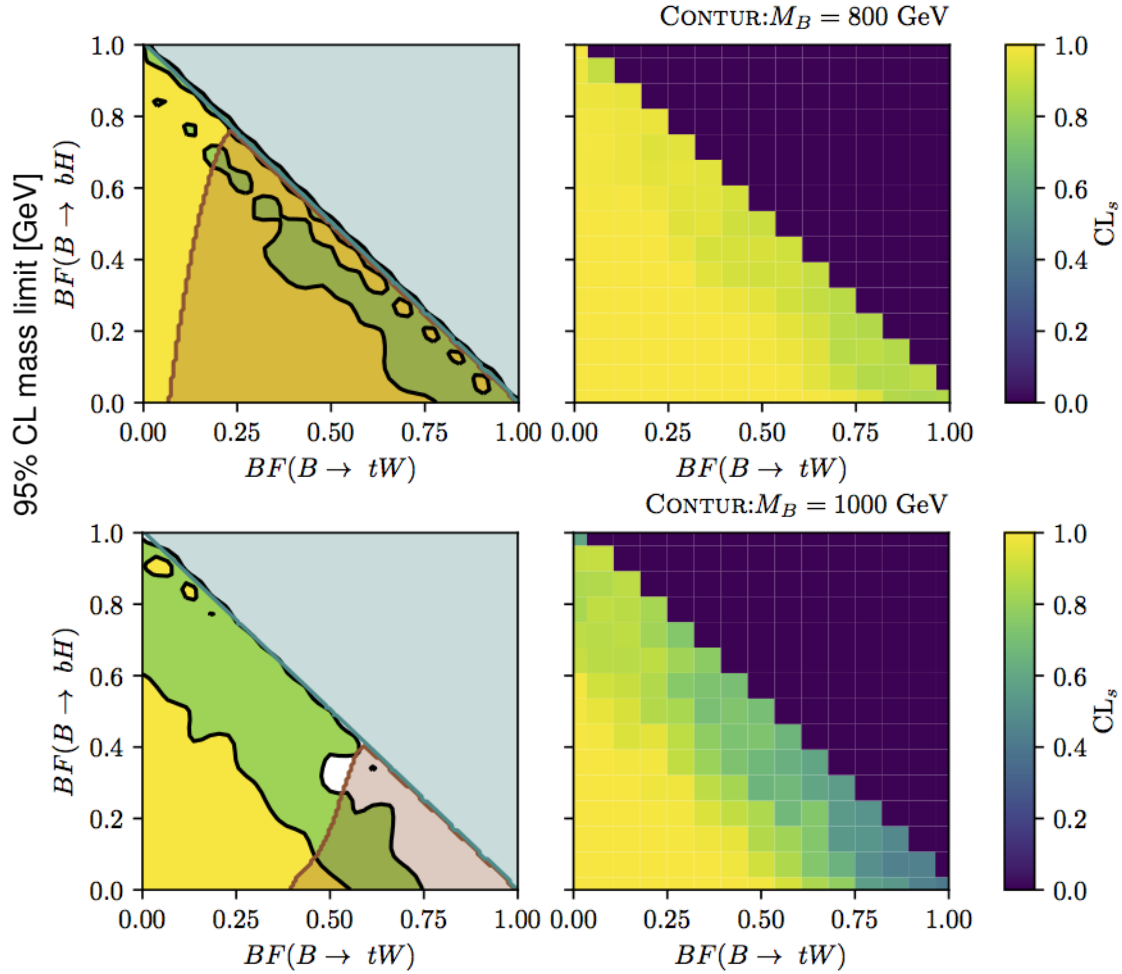
100
M_ϕ(GeV)
1.0
0.8
0.6
0.4
0.2
0.0
CL_s

Vector-Like Quarks



arXiv:1807.11883



Preliminary, K.Bepari, J.Huang, B.Waugh, JMB & DY

Summary

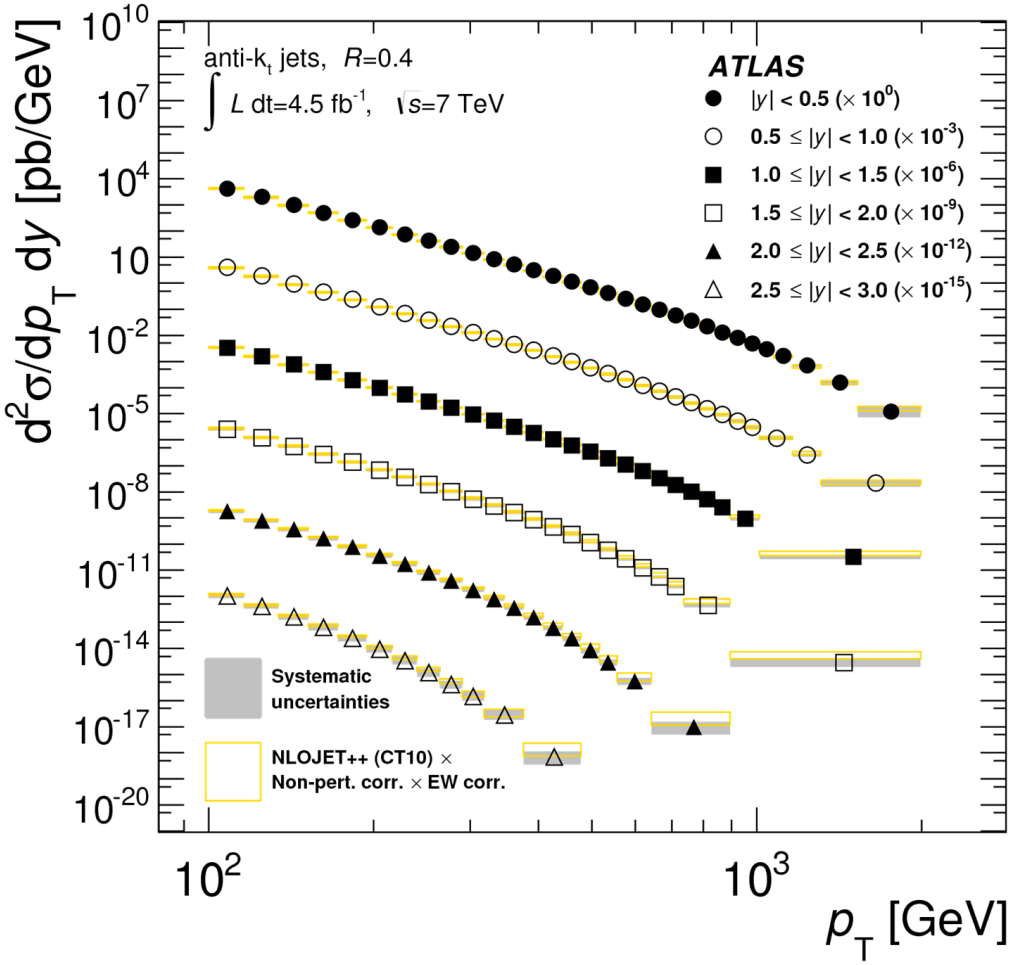
- Contur is a new tool for exploiting existing measurements
- Use-cases in this group:
  - pre-scan for parameter regions to focus searches, including all possible signatures of a model
  - Combination/reinterpretation of existing searches if implemented in Rivet
  - Free up resources to concentrate on true exotica (LLP, dark showers etc)
- Model-independent measurements stored in HepData and Rivet are a powerful and flexible resource
  - Keep adding more data
  - Treat correlations better, where available. Other/better statistical treatments
  - Use precision SM theory where available, could become an anomaly-hunter
- **Funded short-term placements (3-6 months) available through Mcnet to work on this for your paper**
  - Feynrules @Louvain, Herwig @Durham or KIT, Rivet+Contur @UCL or Glasgow… **(other projects also possible!)**
  - See https://montecarlonet.org/short-studentship or ask me…

Backup

Precision 'Standard Model' Measurements

- Measurements of final-state particles in well-defined fiducial regions
- Generally differential cross sections
- Should not (and mostly do not) assume the SM
- Agree with the SM (so far)
- Thus they can potentially exclude extensions

arXiv:1410.8857



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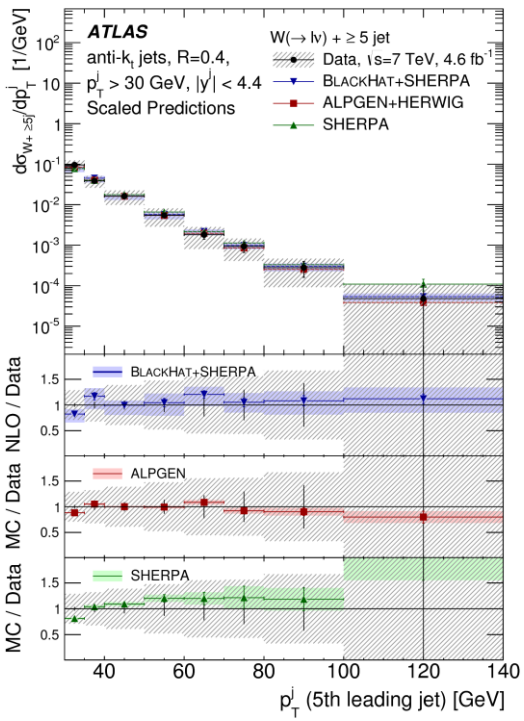
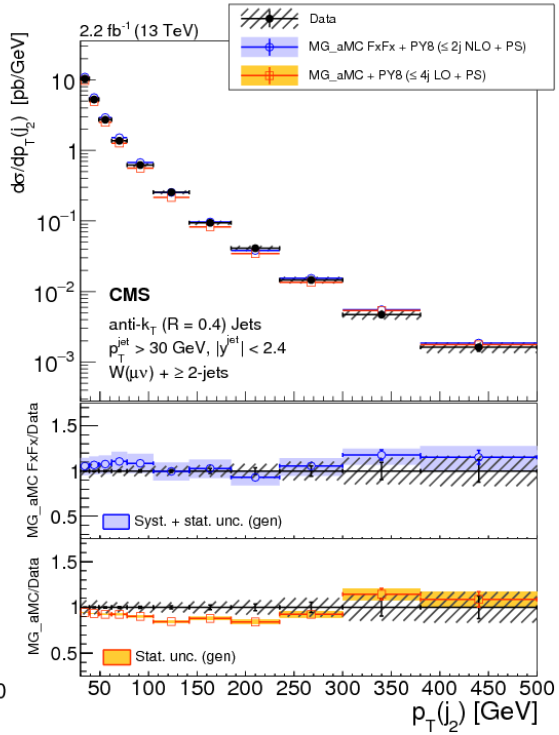


arXiv:1302.2929



arXiv:1707.05979

Spontaneously-broken B-L gauge theory

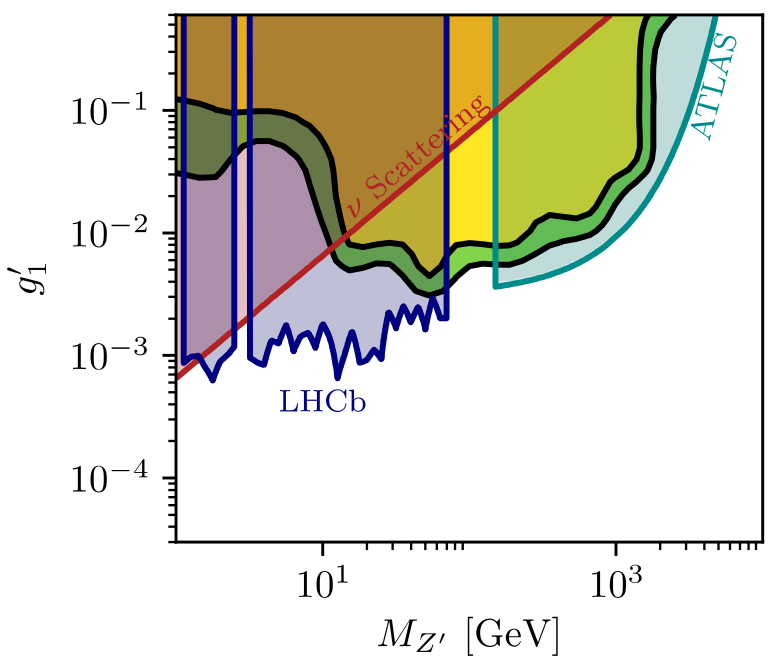
S. Amrith, JMB, F.F.Deppisch, W. Liu, A.Varma, D.Yallup

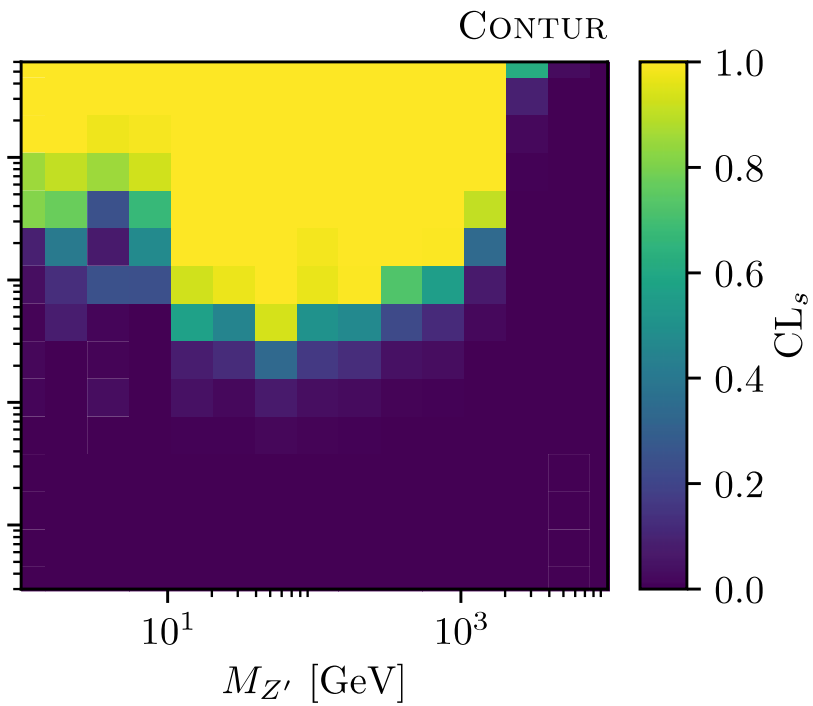
arXiv:1811.11452

- (Potentially) UV complete model
- Three pairs of parameters which interplay to give quite a rich phenomenology
  - New U(1) gauge symmetry from B-L
    - New gauge boson Z', coupling g_1'
  - Spontaneously broken
    - New Higgs boson, h_2, can mix with SM Higgs: $\sin\alpha$
  - RH neutrinos with Majorana masses, natural explanation of light neutrino masses (seesaw mechanism)
    - Lifetime of neutrino may lead to prompt decays, (far-)displaced-vertex, or effective stability for collider signatures

Case A

Scenario	$M_{Z'}$ [GeV]	g'_1	M_{h_2}	$\sin\alpha$	M_{N_i}
A	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0	$M_{Z'}/5$
B	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0.2	$M_{Z'}/5$
C	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	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]	$M_{Z'}/5$





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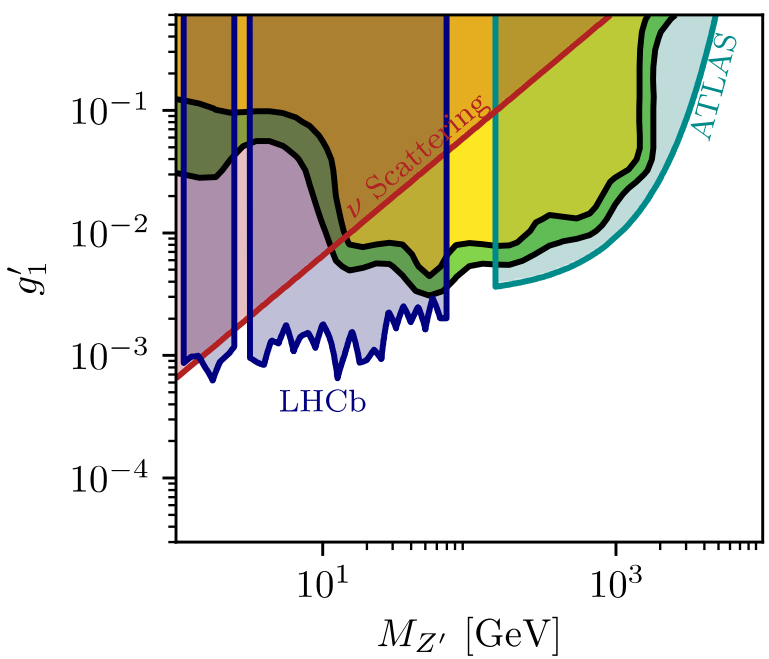

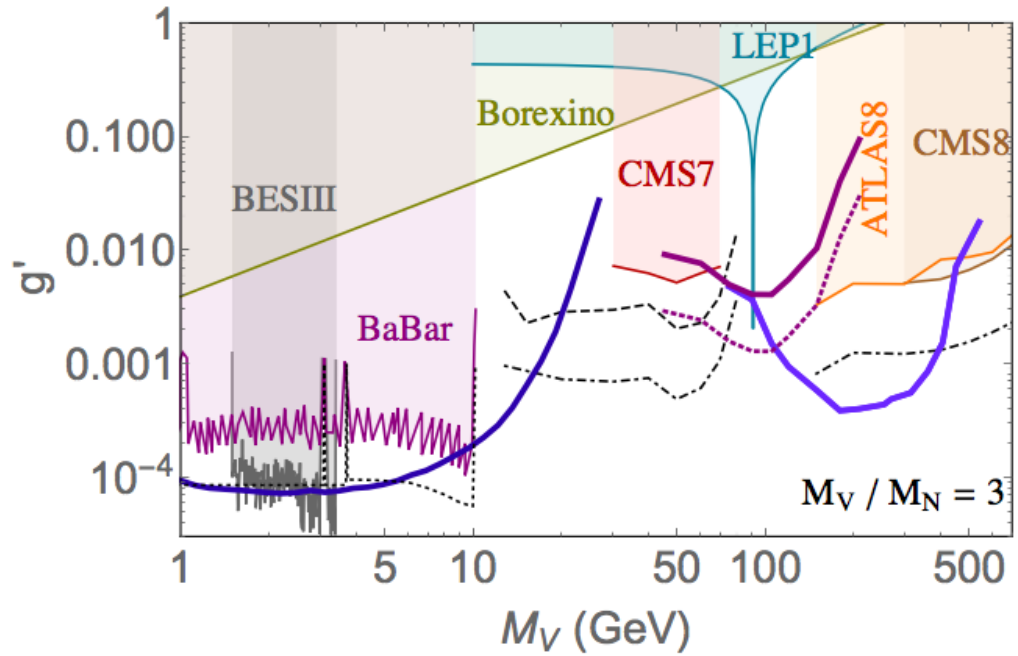

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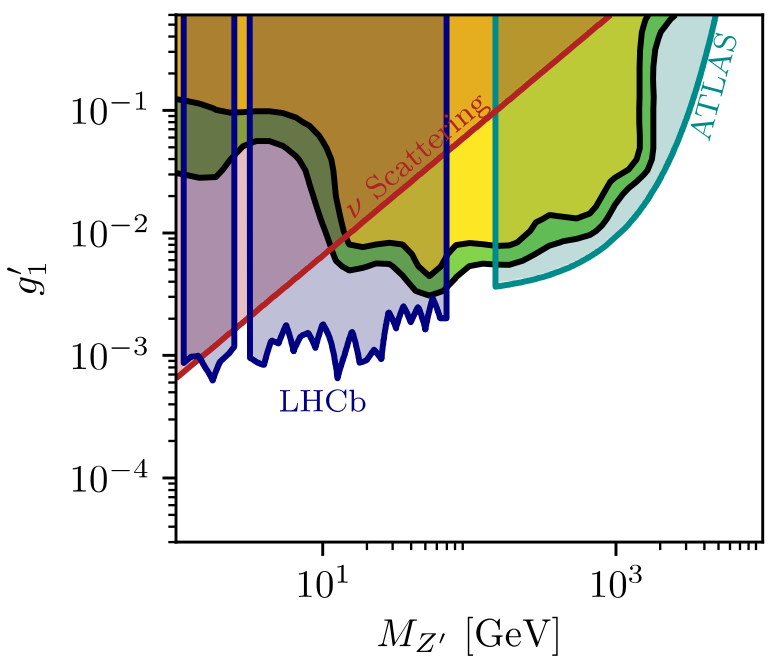

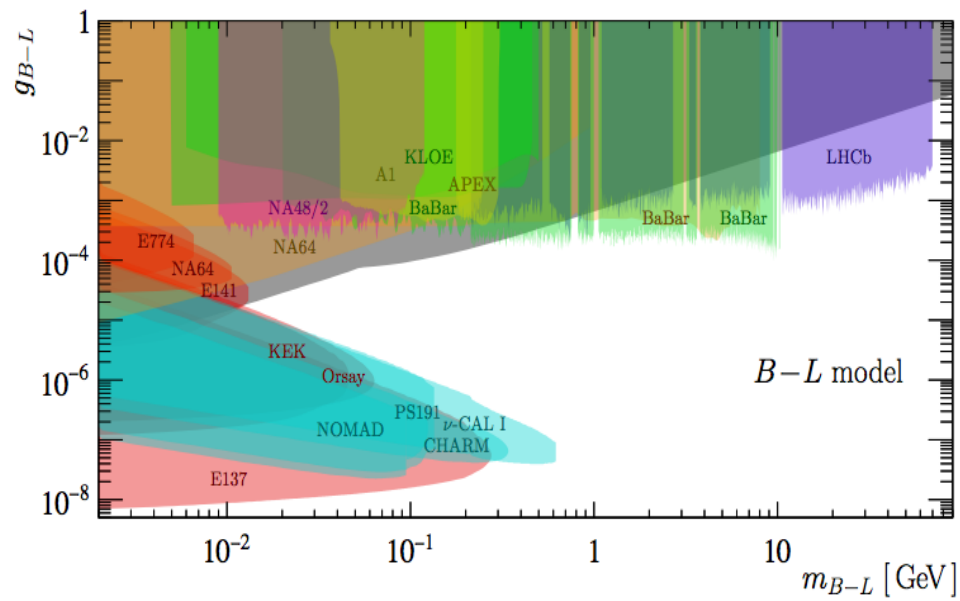

Figure 5. Constraints derived on $B-L$ decays to SM final states using the same experimental color scheme as in Fig. 4. The (orange) invisible constraints also apply to $B-L$ due to its coupling to neutrinos. The grey constraints are from Borexino [96, 97], Texono [92, 98], CHARM-II [92, 99], and from SPEAR, DORIS, and PETRA [100, 101].

NB: Reinterpreted Dark Photon Searches also provide strong constraints for some Parameters: See Ilten, Soreq, Williams, Xue arXiv:1801.04847

Case B

Scenario	$M_{Z'}$ [GeV]	g'_1	M_{h_2}	$\sin\alpha$	M_{N_i}
A	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0	$M_{Z'}/5$
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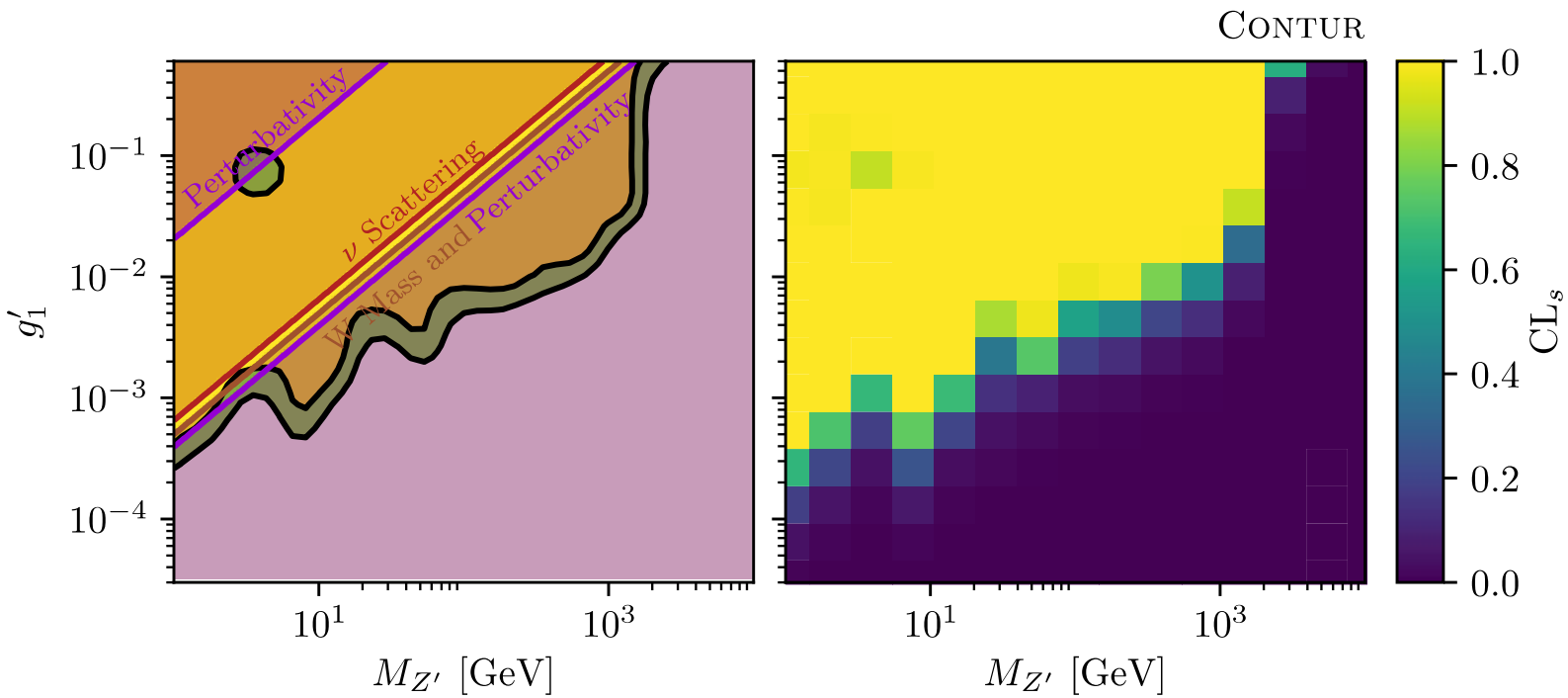

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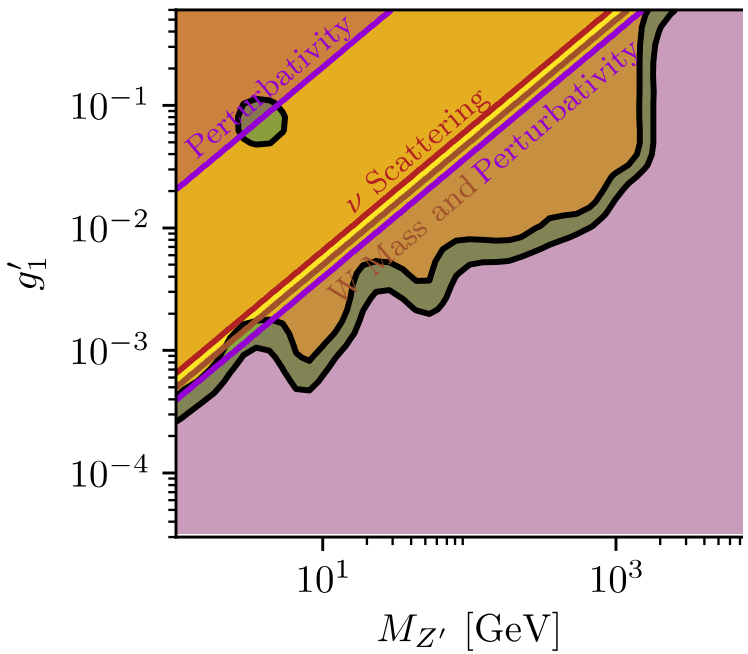

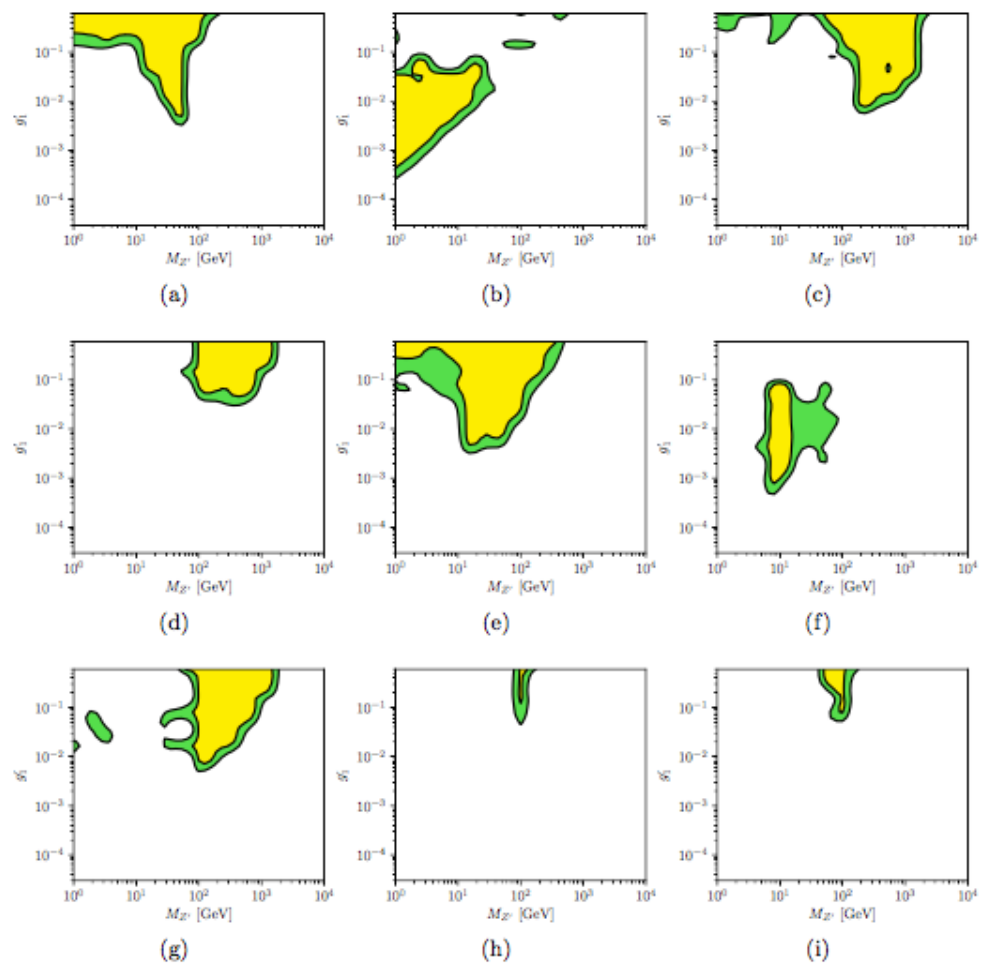

Figure 4: Disfavoured regions for different, independent measurement classes for Case B. (a) ATLAS 7 TeV Low mass Drell-Yan measurement [29], (b) ATLAS 7 TeV Four-lepton measurements [37], (c) ATLAS 8 TeV High mass Drell-Yan measurement [31], (d) ATLAS 8 TeV dilepton plus photon measurements [38], (e) ATLAS 8 TeV Dilepton plus jet measurements [30, 39, 40], (f) ATLAS 8 TeV Four-lepton measurements [36, 41], (g) ATLAS 8 TeV Dilepton plus missing transverse energy measurements [32, 42], (h) CMS 8 TeV dilepton plus jet measurements [43], (i) LHCb 7 TeV dimuon plus jet measurement [44].

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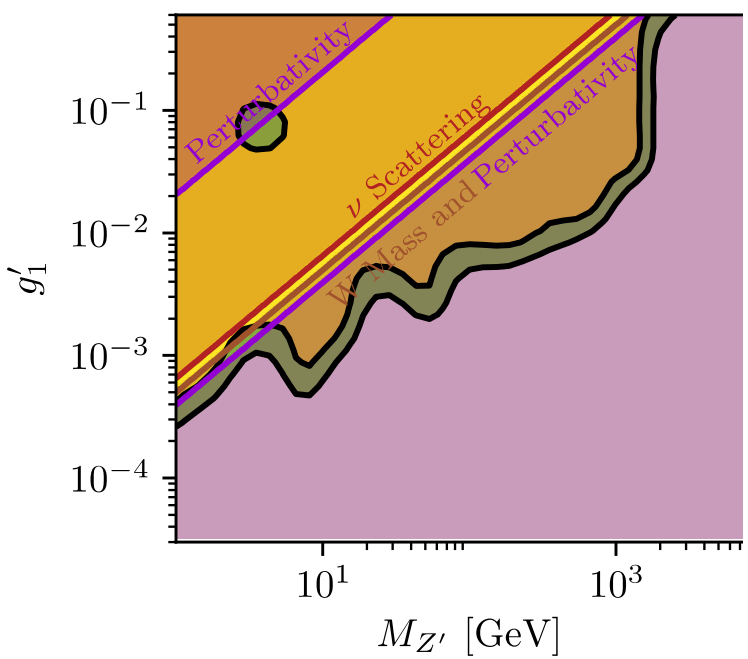


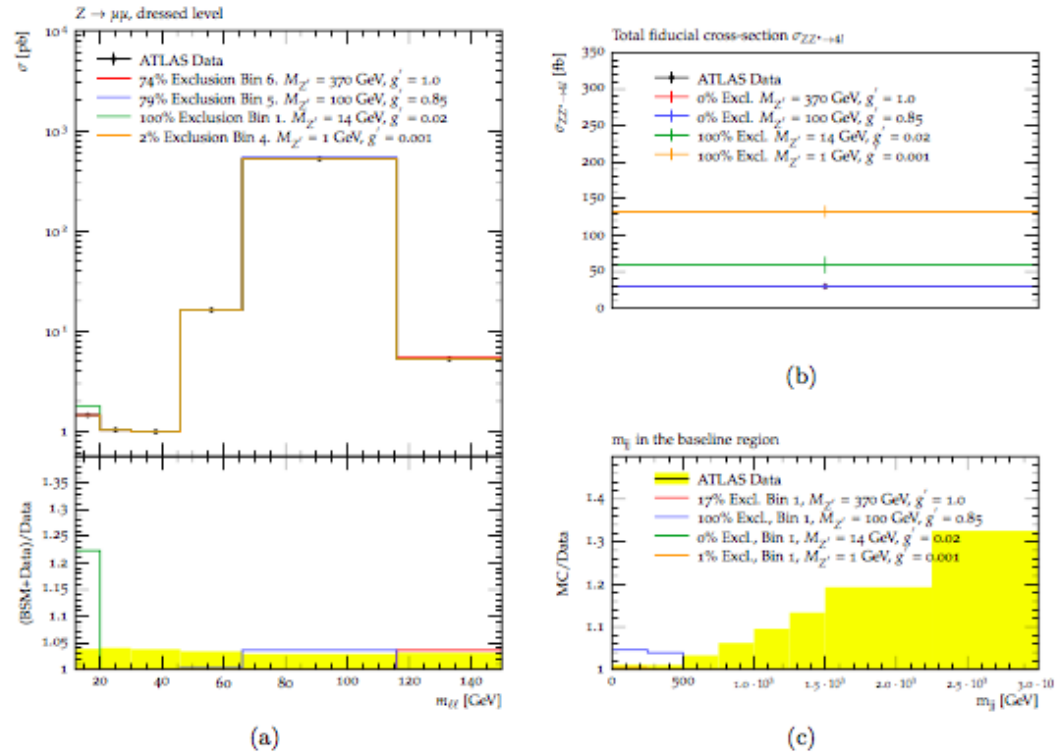
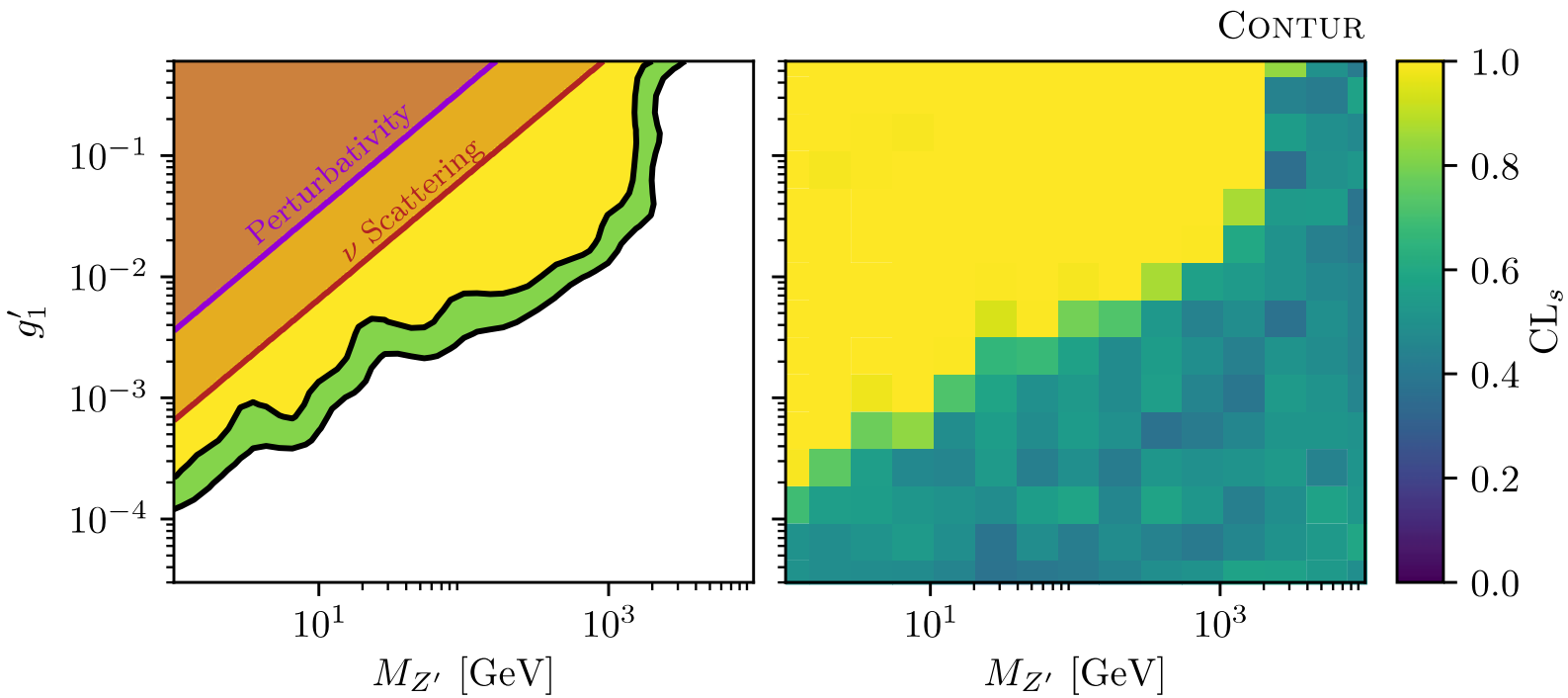


Figure 5: Examples of the exclusion from four points in the parameter space moving along the lower edge of the theoretically allowed region of Case B, Fig.3b. (a) The dimuon mass measurement from [30], (b) The ZZ^* (four lepton) measurement from [37], (c) The dijet mass in Z events from [39]. The legend indicates the parameter point in $M_{Z'}$ and g_1' space and the bin of the plot which gives the sensitivity. $M_{h_2} = \frac{M_{Z'}}{2g_1'}$, $\sin\alpha = 0.2$

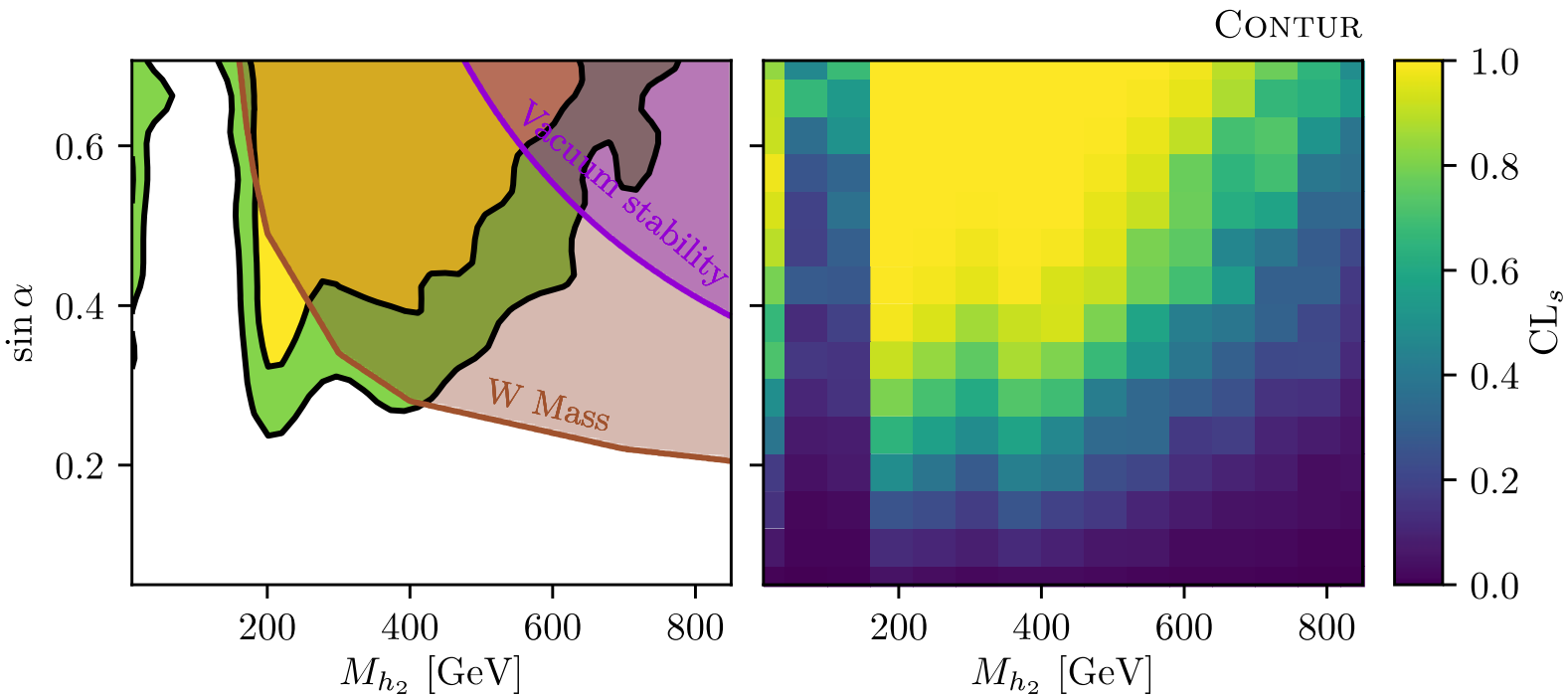
Case C

Scenario	$M_{Z'}$ [GeV]	g'_1	M_{h_2}	$\sin\alpha$	M_{N_i}
A	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0	$M_{Z'}/5$
B	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0.2	$M_{Z'}/5$
C	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	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]	$M_{Z'}/5$



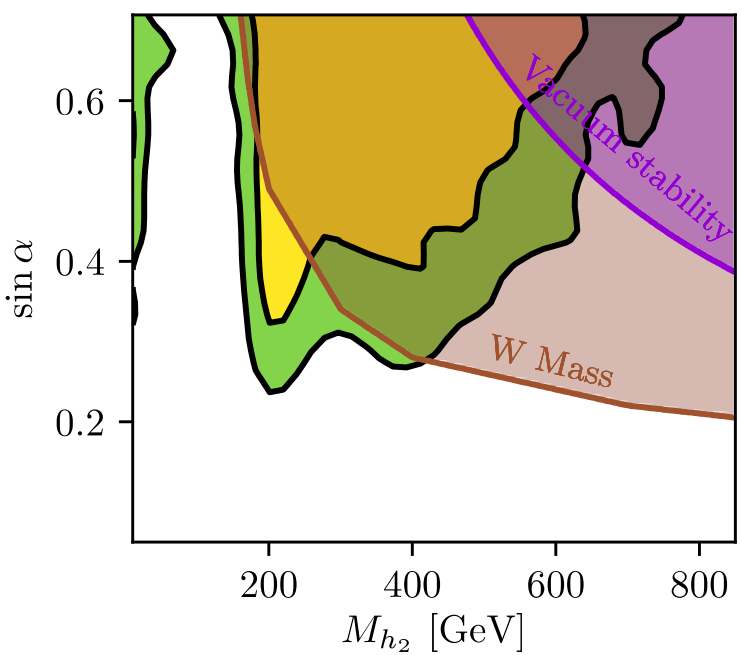
Case D

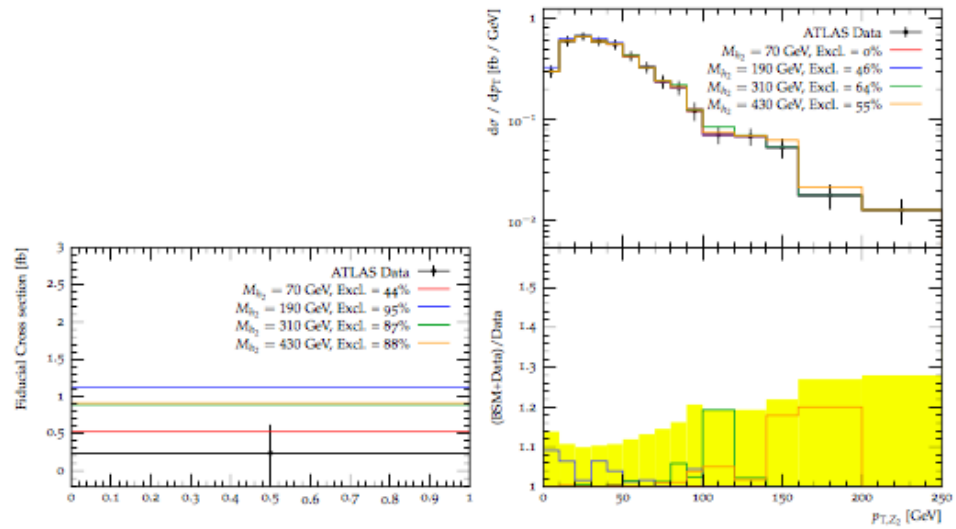
Scenario	$M_{Z'}$ [GeV]	g'_1	M_{h_2}	$\sin\alpha$	M_{N_i}
A	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0	$M_{Z'}/5$
B	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0.2	$M_{Z'}/5$
C	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	200 GeV	0.2	$M_{Z'}/5$
D	7000	0.2	[0, 800] GeV	[0, 0.7]	$M_{Z'}/5$
E	35	10^{-3}	[0, 800] GeV	[0, 0.7]	$M_{Z'}/5$



Case D

Scenario	$M_{Z'}$ [GeV]	g_1'	M_{h_2}	$\sin\alpha$	M_{N_i}
A	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g_1')$	0	$M_{Z'}/5$
B	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g_1')$	0.2	$M_{Z'}/5$
C	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	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]	$M_{Z'}/5$





(a) (b)

Figure 7: Examples of the exclusion from four points in the parameter space moving along the lower edge of the theoretically allowed region of Fig.6a. (a) The dilepton plus dijet measurement from [32], (b) The ZZ^* (four lepton) measurement from [35], The legend indicates the parameter point in $M_{Z'} = 7$ TeV, $g_1' = 0.2$, $\sin\alpha = 0.42$

Case E

Scenario	$M_{Z'}$ [GeV]	g'_1	M_{h_2}	$\sin\alpha$	M_{N_i}
A	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0	$M_{Z'}/5$
B	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	$M_{Z'}/(2g'_1)$	0.2	$M_{Z'}/5$
C	$[1, 10^4]$	$[3\times10^{-5}, 0.6]$	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]	$M_{Z'}/5$