Constraining BSM (Simplified) models with SM measurements

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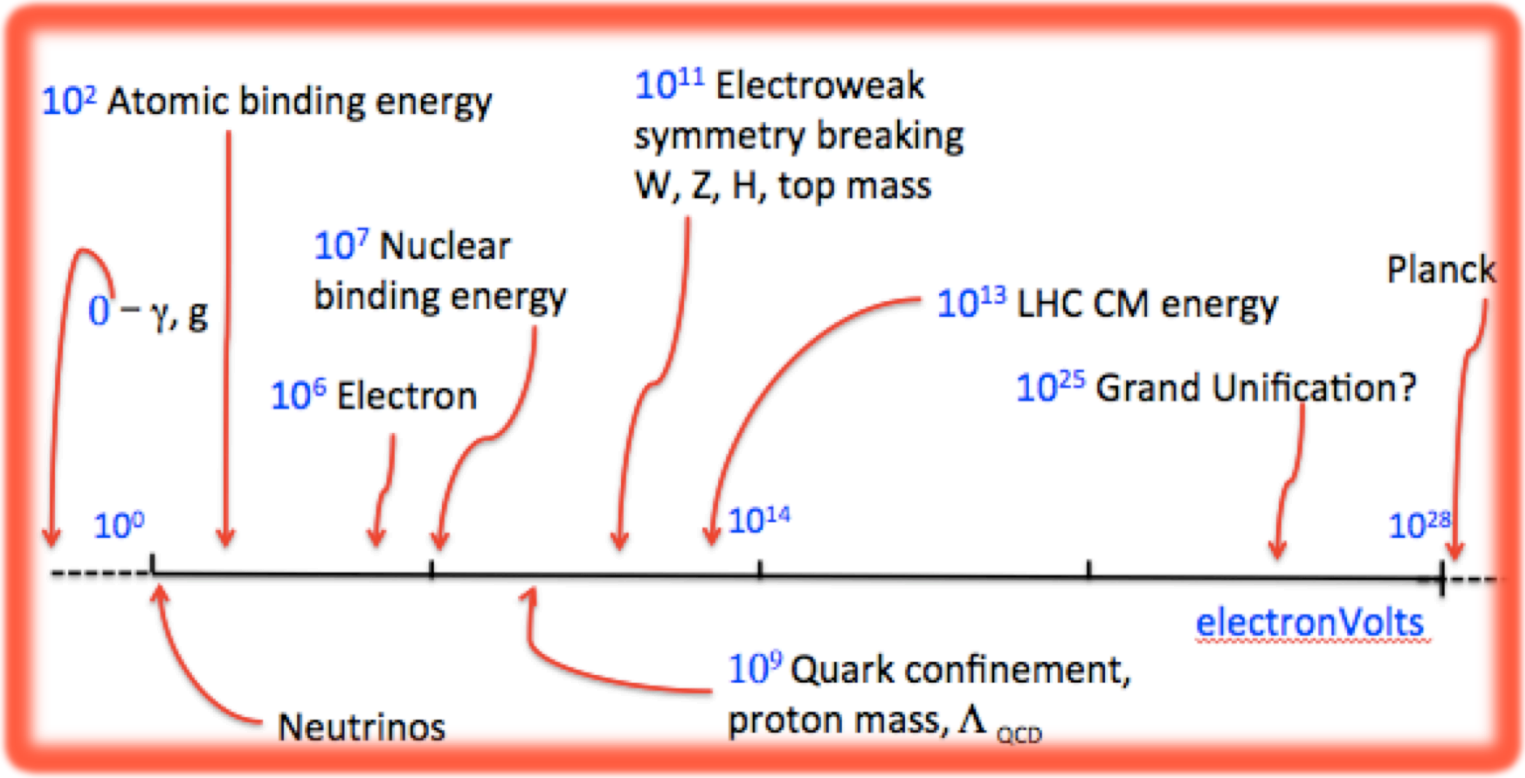
Fit(s) for LHC run-2' workshop:

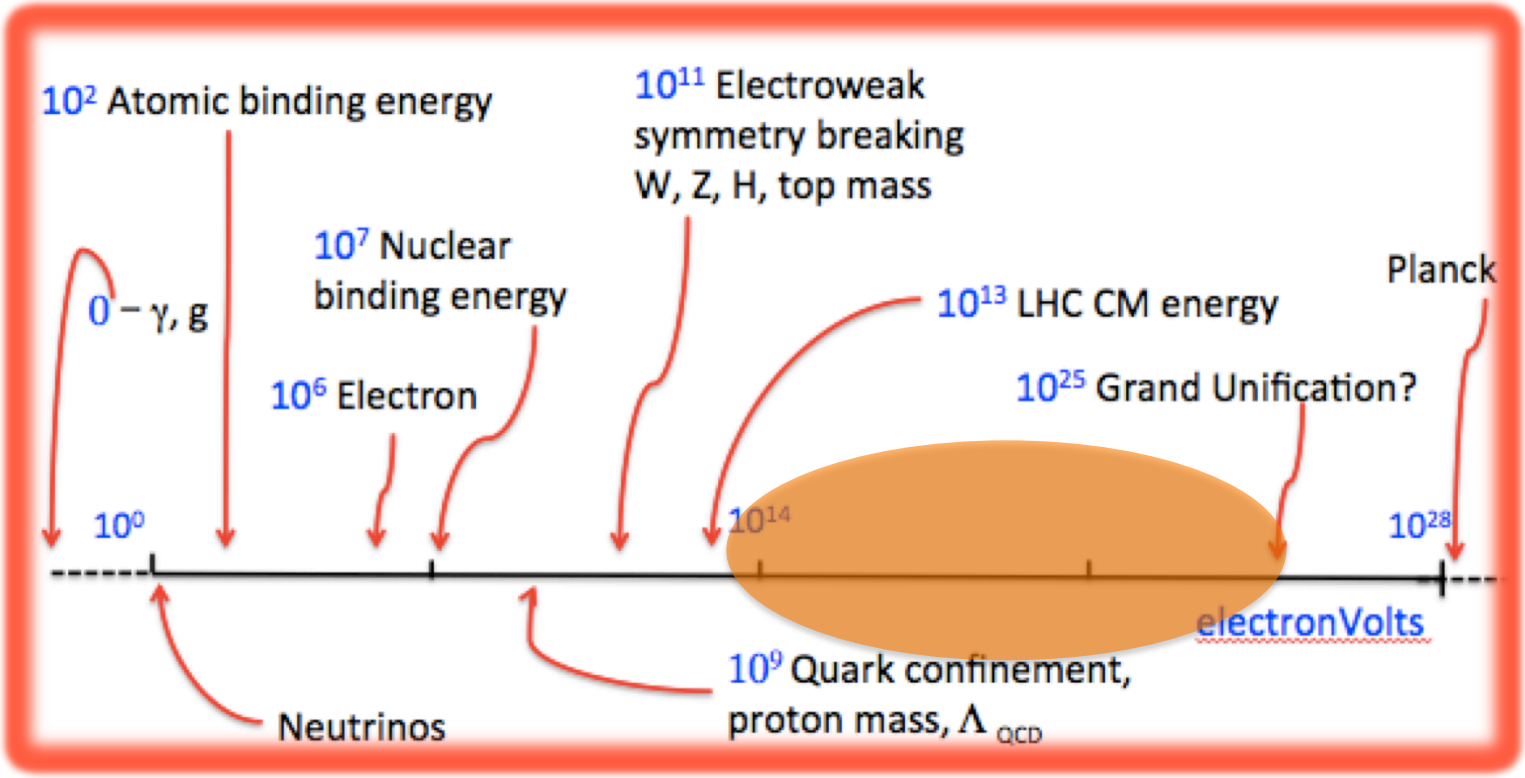
12 Oct 2016

The Standard Model



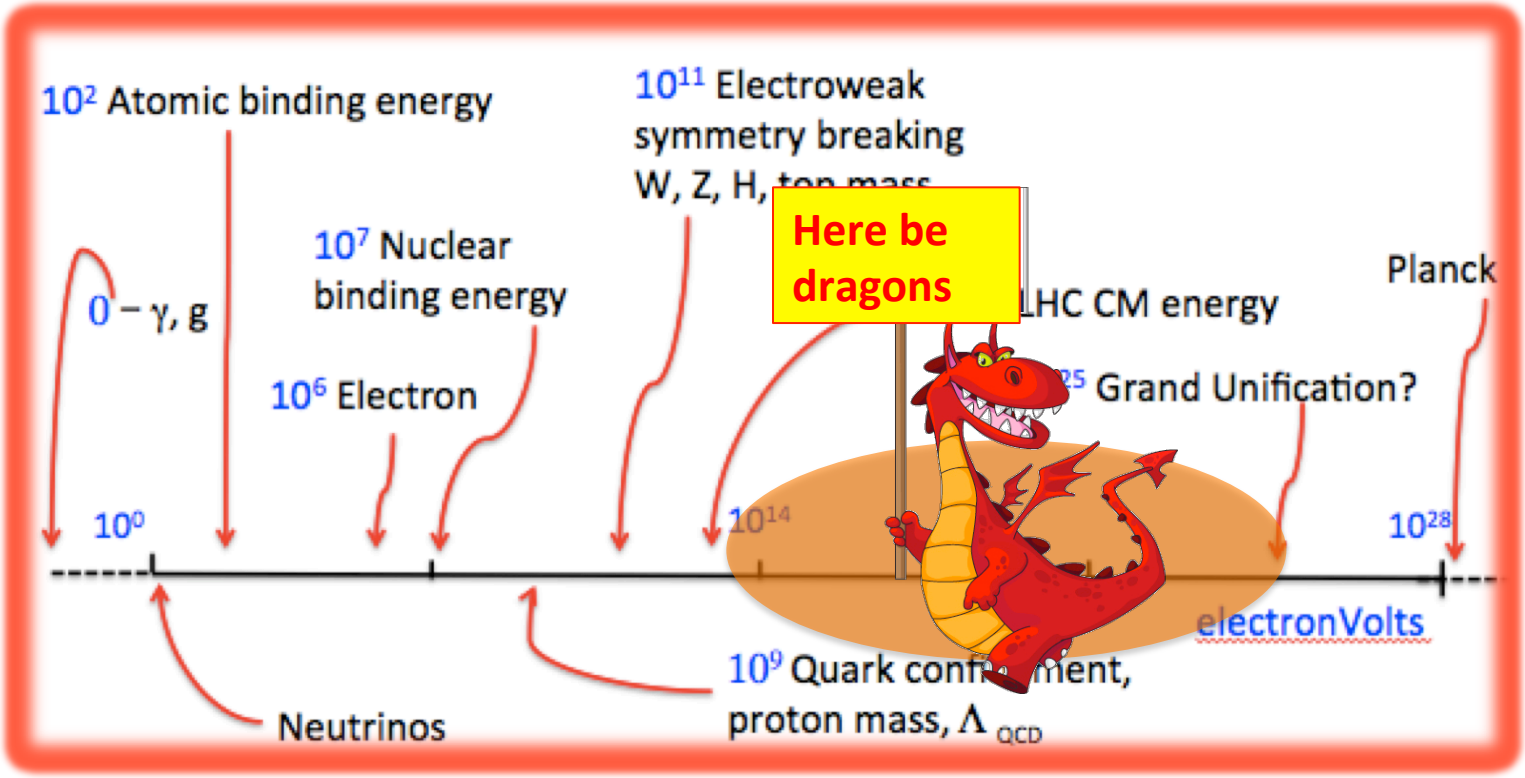
The Standard Model

- Is there anything out there?



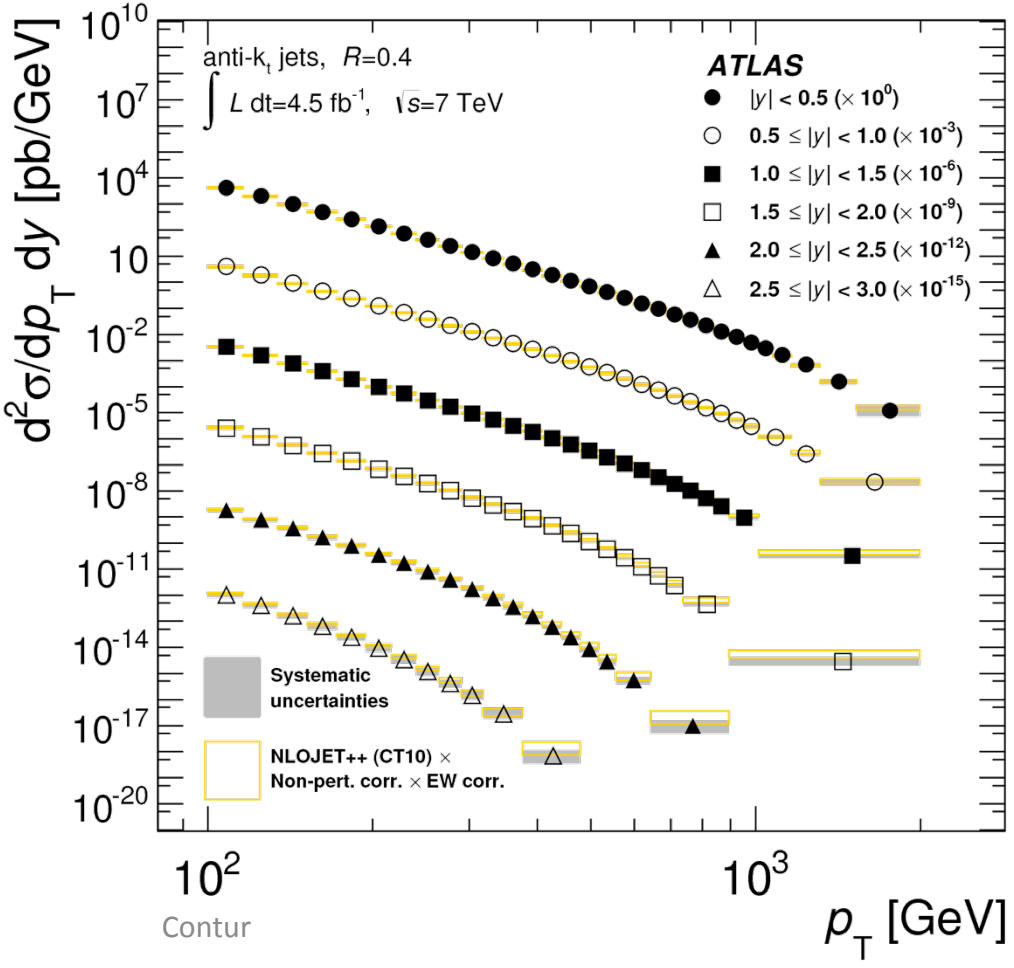
The Standard Model

- 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



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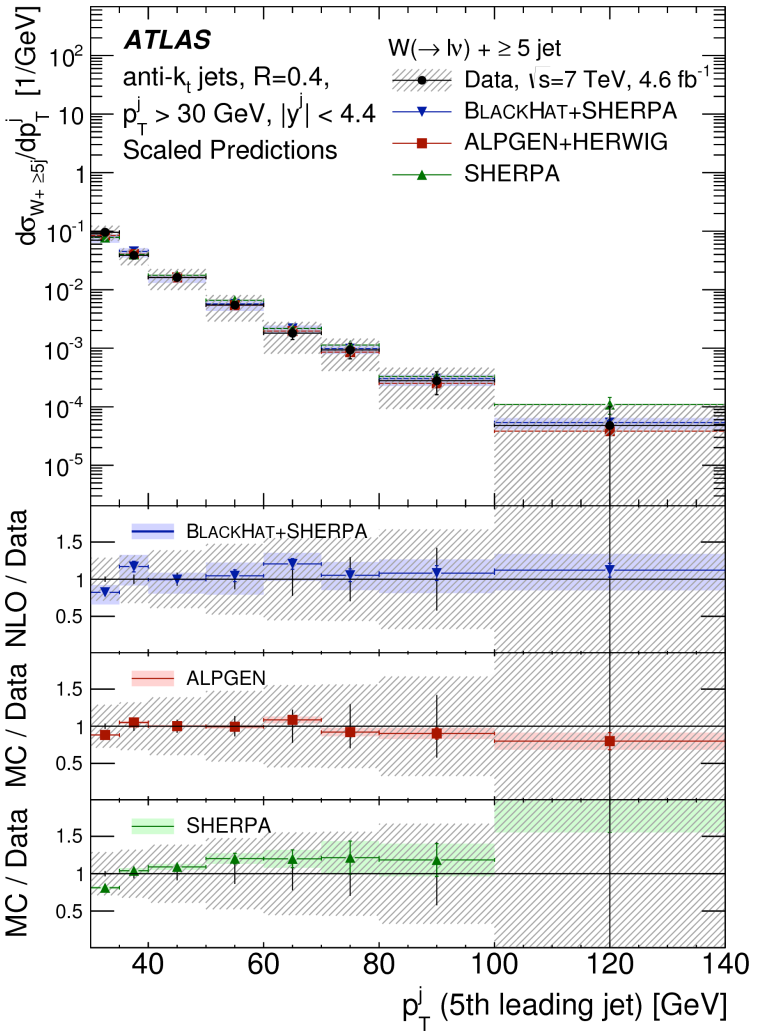

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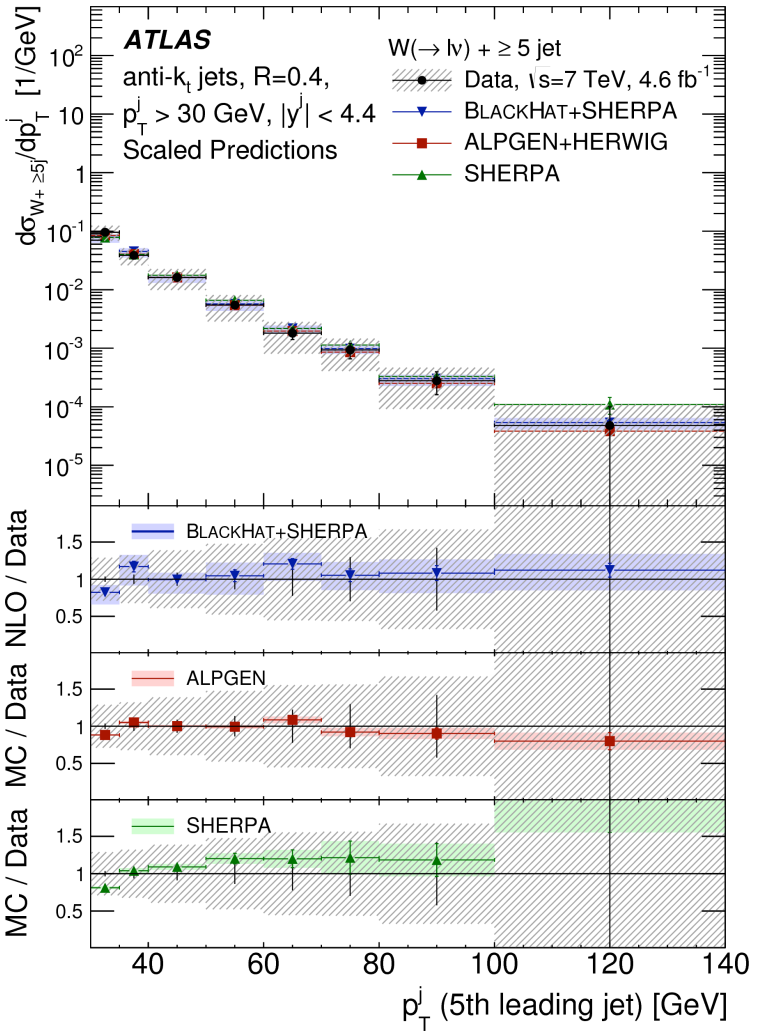

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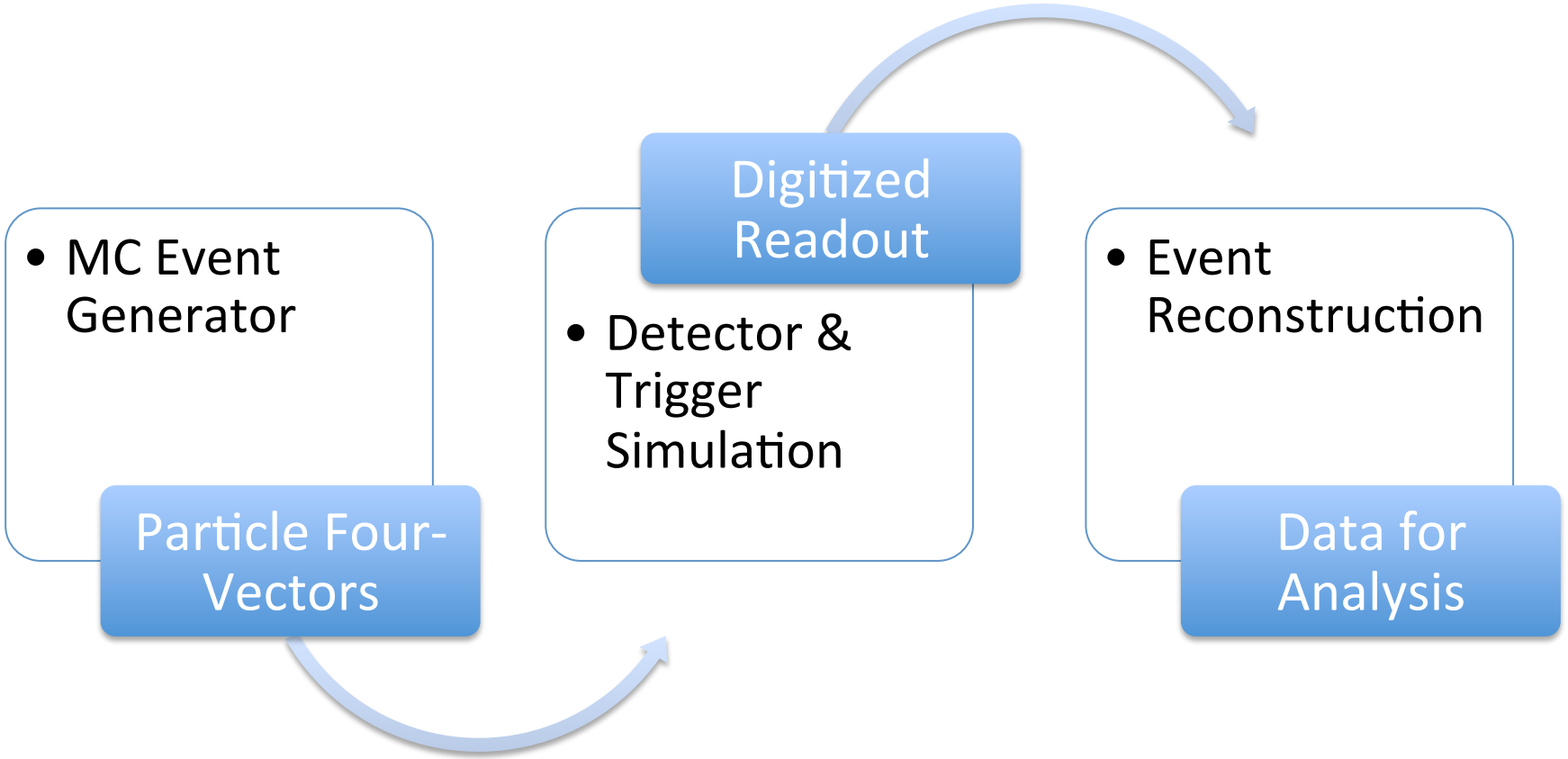

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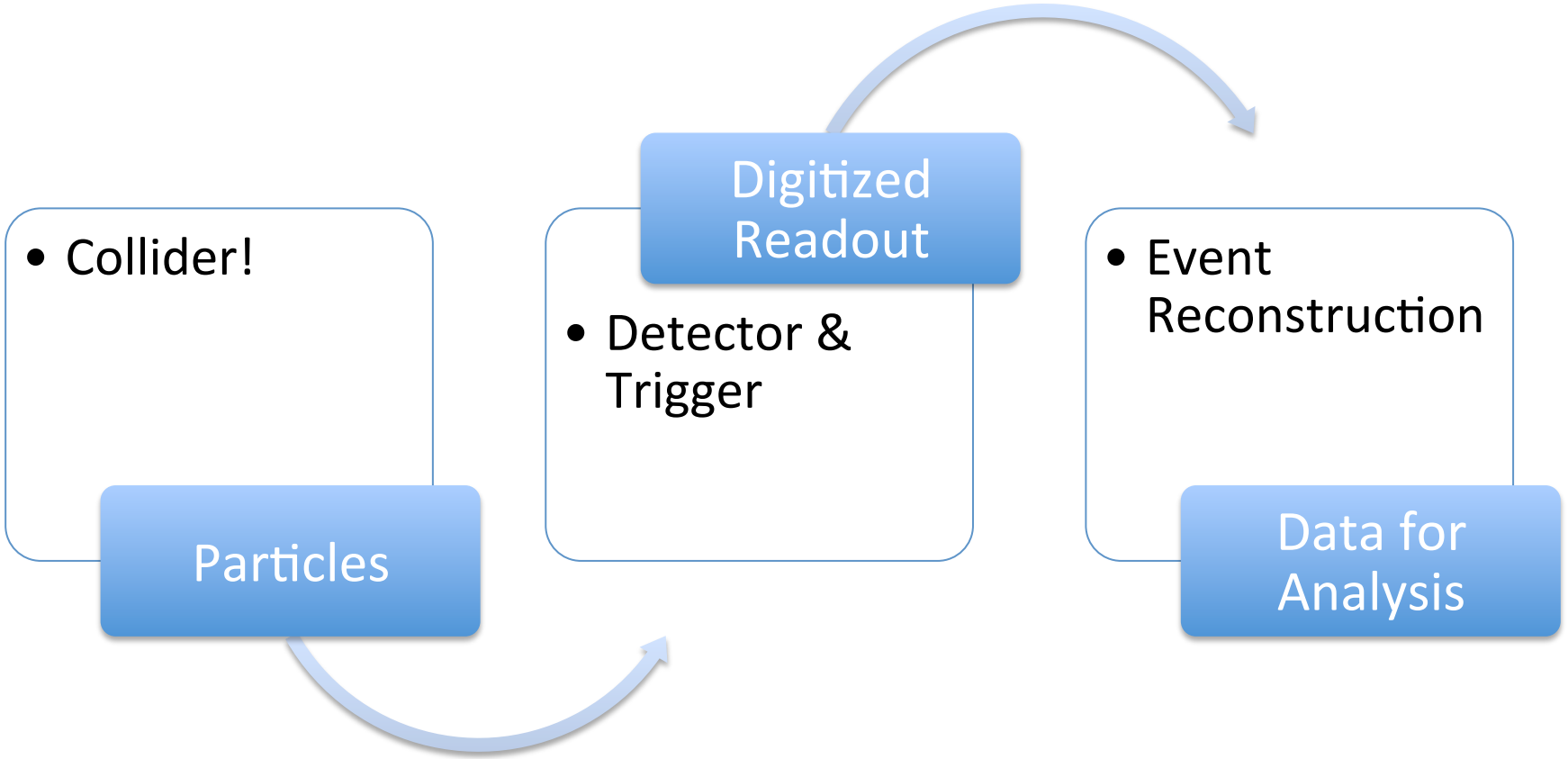

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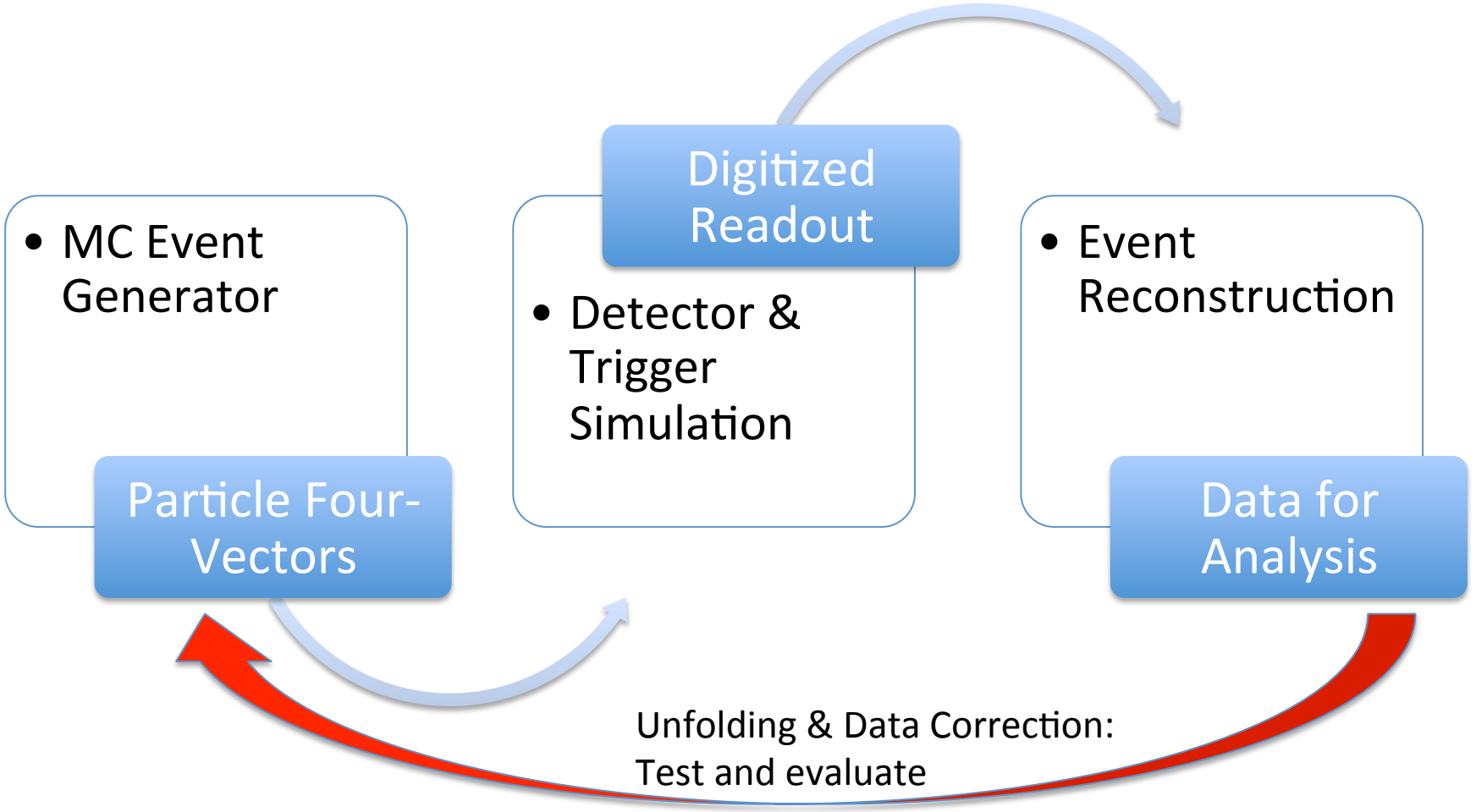

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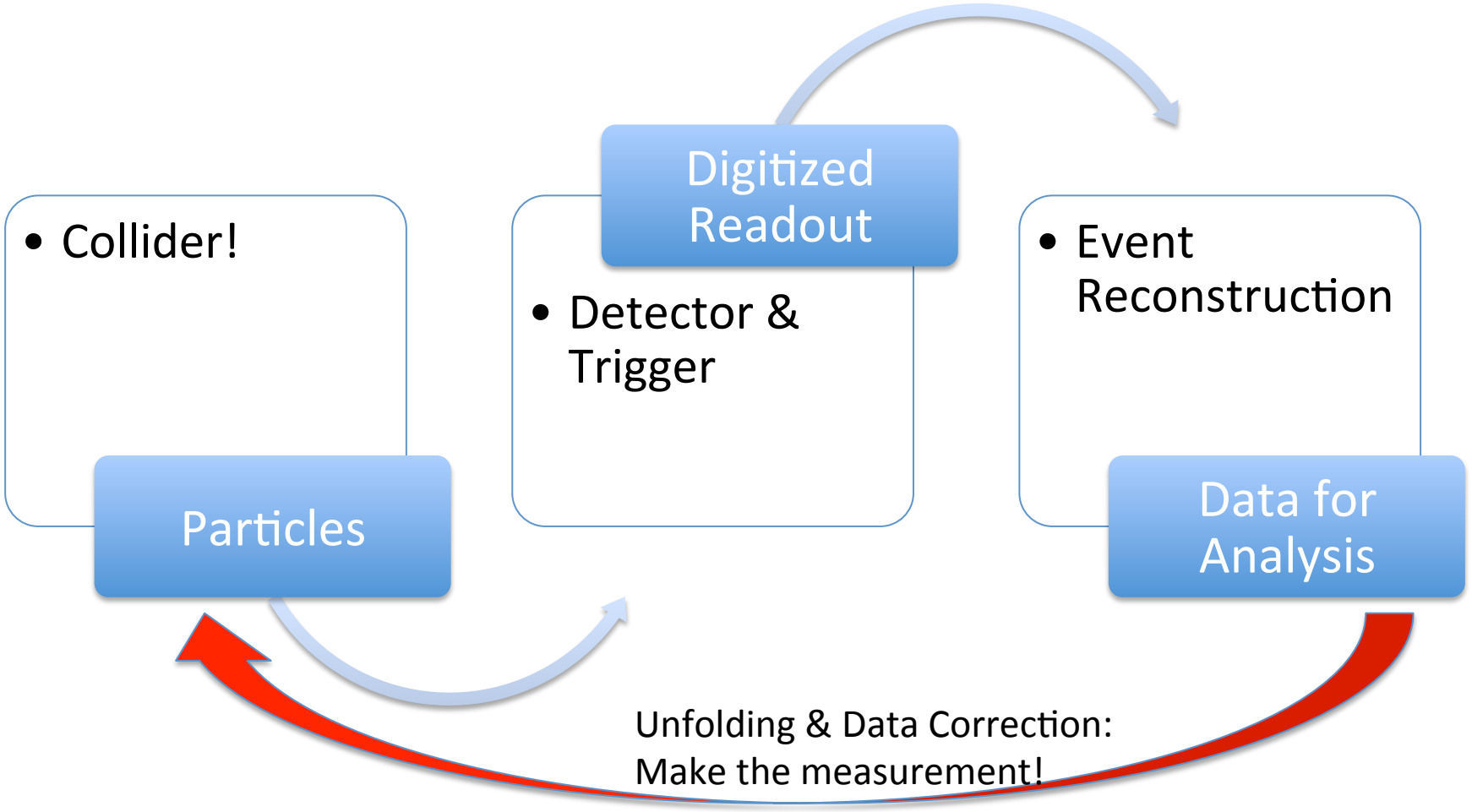


What do we actually *measure*?

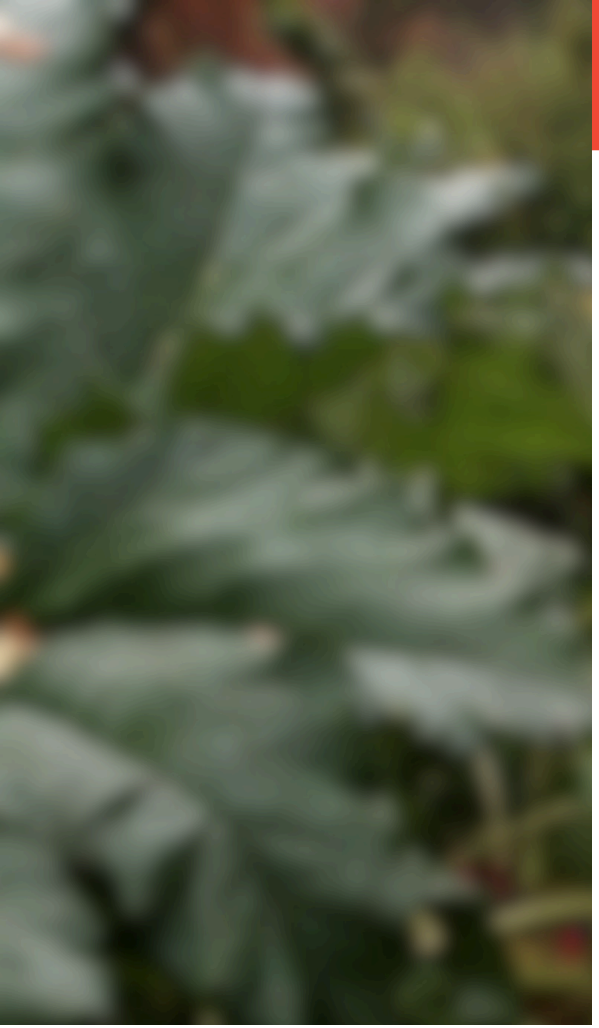
- The final state!
  - Quantum mechanics says so
- Clearly we can't, even in principle, tell the difference between amplitudes with identical final states
- If your measurement can't be defined in such terms, you should worry!
  - Model dependence
  - Physical meaning!

What is your final state?

- Quarks, gluons? (top?)
- W, Z, H?
- Taus?
- Hadrons? (lifetime cut? Do they propagate in B-field? In material?)
- Jets (what are the input objects?)
- Neutrinos? All of them? From hadronic decays too? Missing E_T
- Photons? Isolated photons? From hadronic decays too?
- Electrons, muons? From hadronic decays too? What about QED FSR?

Important considerations (for searches too)

- What is your final state?
  - A common choice is place a lifetime cut at 10ps, and where necessary to draw further distinction, draw the line at hadronisation.
  - Stable objects (hadrons, leptons, photons) can be combined algorithmically to give well-defined objects (jets, dressed leptons, isolated photons, missing E_T…)
  - Remember, this is about defining "truth", i.e. what we correct back to within some systematic uncertainty



Unfold

Increase acceptance

Increase acceptance

Extrapolate

But how reliably?

Concept of a “fiducial” cross section

- Defines a region in which acceptance is ~100%
- Implies that some kinematic cuts must be implemented in whatever theory the data are compared to (easy for MC, less so for some high-order calculations)

Inaccessible. Removed by kinematics cuts, and not part of the fiducial cross section

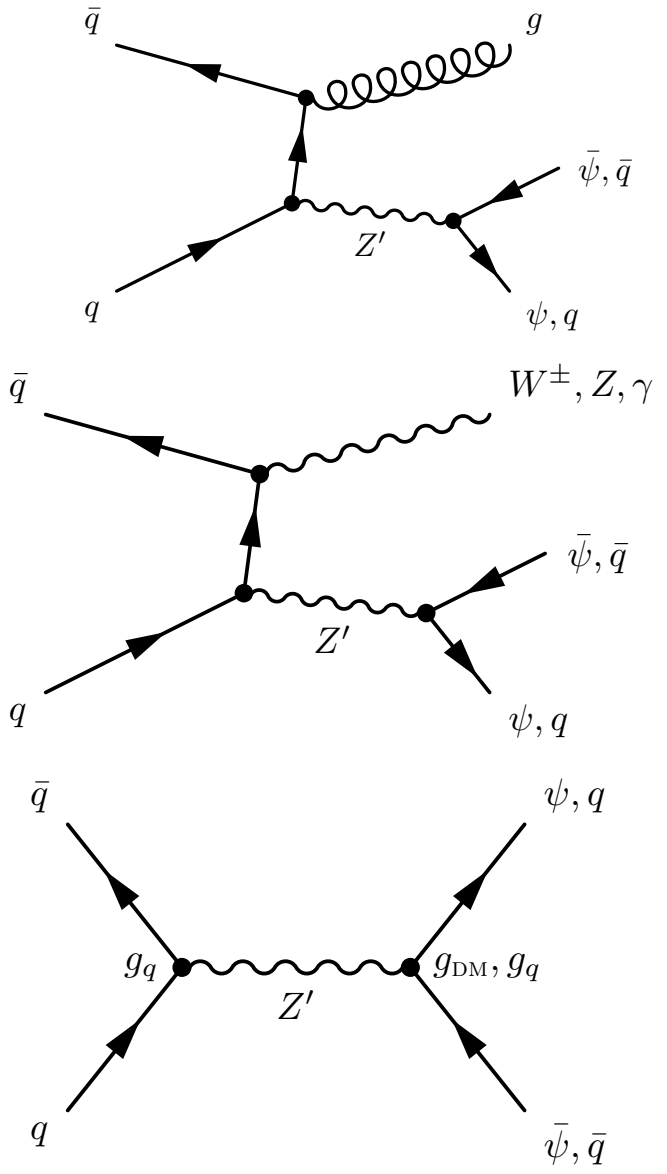
Concept of a “fiducial” cross section

- Defines a region in which acceptance is ~100%
- Implies that some kinematic cuts must be implemented in whatever theory the data are compared to (easy for MC, less so for some high-order calculations)
- Ideally of course, build an experiment which covers all the phase space of interest…

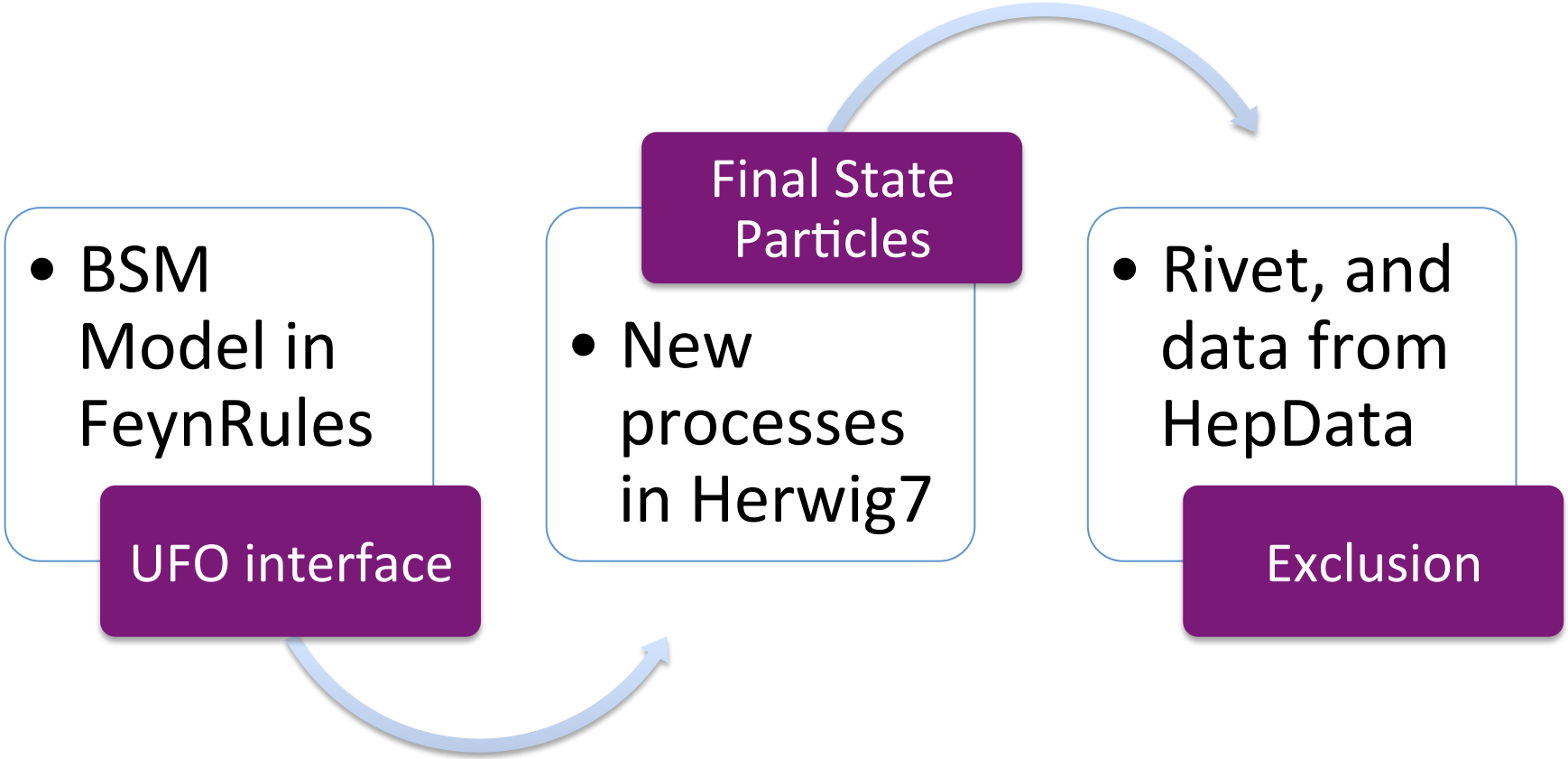
Simplified Model(s)

- 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.

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



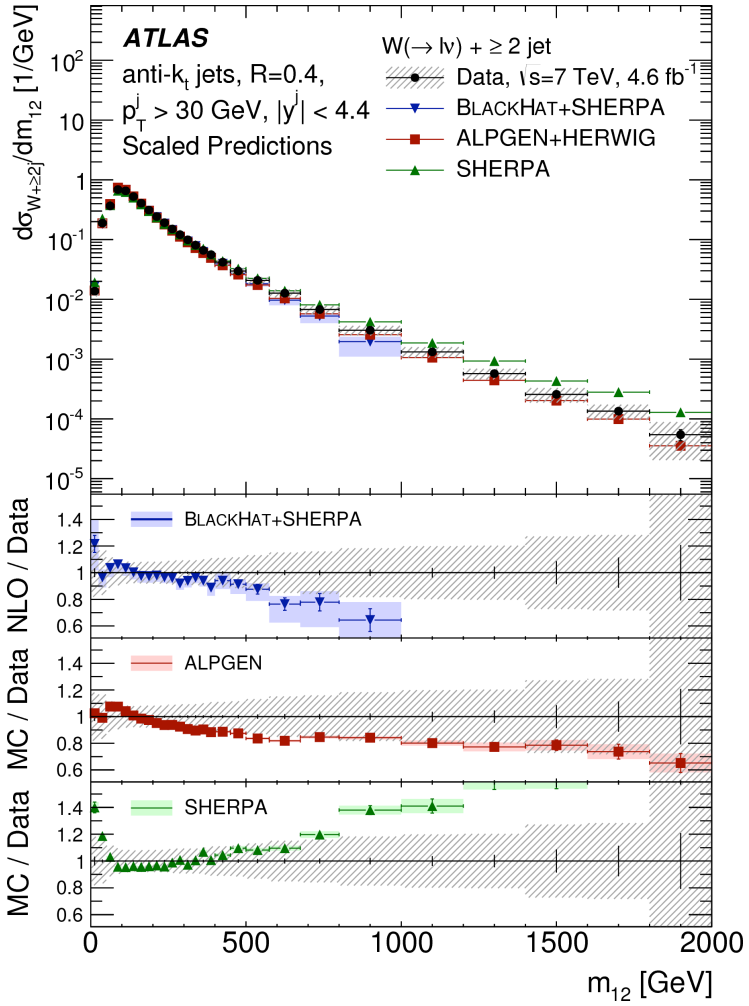
Key tools:


• 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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  - Not a search! Guaranteed not to find anything
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  - Assume the data = the background!
- 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

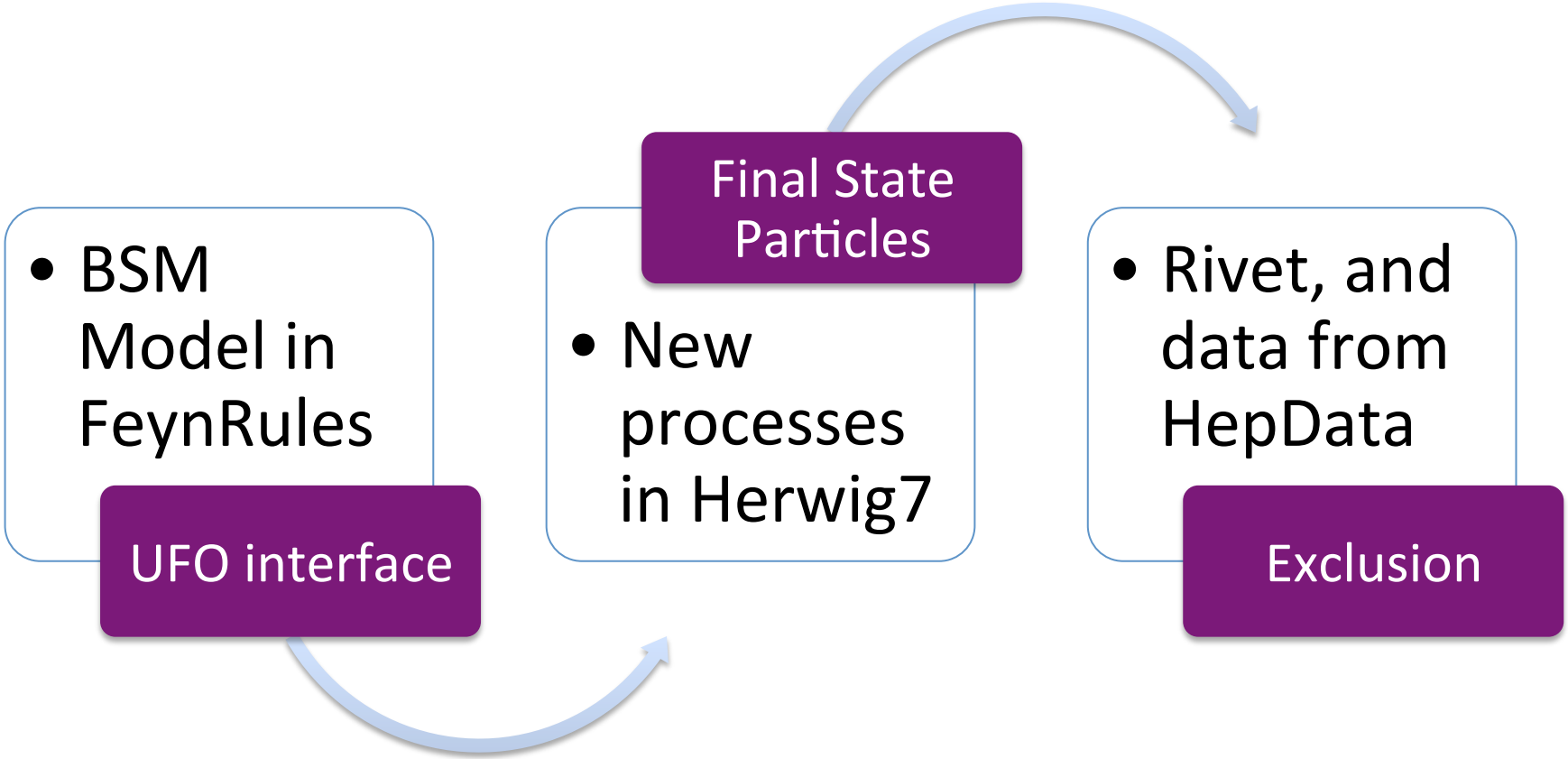
- Construct likelihood function using
  - BSM signal event count
  - Background count (from central value of data points)
  - Gaussian assumption on uncertainty in background count, from combination of statistical and systematic uncertainties
  - BSM signal count error from statistics of generated events (small!)
- Make profile likelihood ratio a la Cowan et al (Asimov data set approximation is valid)
- Present in CL_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 (+jets), $\gamma\gamma$, 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

CONTUR Category	Rivet/ Inspire ID	Rivet description
ATLAS 7 Jets	ATLAS_2014_I1325553 [28]	Measurement of the inclusive jet cross-section
	ATLAS_2014_I1268975 [30]	High-mass dijet cross section
	ATLAS_2014_I1326641 [32]	3-jet cross section
	ATLAS_2014_I1307243 [31]	Measurements of jet vetoes and azimuthal decorrelations in dijet events
CMS 7 Jets	CMS_2014_I1298810 [29]	Ratios of jet pT spectra, which relate to the ratios of inclusive, differential jet cross sections
ATLAS 8 Jets	ATLAS_2015_I1394679 [34]	Multijets at 8 TeV
ATLAS 7 Z Jets	ATLAS_2013_I1230812 [35]	Z + jets
CMS 7 Z Jets	CMS_2015_I1310737 [38]	Jet multiplicity and differential cross-sections of Z+jets events
CMS 7 W Jets	CMS_2014_I1303894 [37]	Differential cross-section of W bosons + jets
ATLAS W jets	ATLAS_2014_I1319490 [36]	W + jets
ATLAS 7 Photon Jet	ATLAS_2013_I1263495 [42]	Inclusive isolated prompt photon analysis with 2011 LHC data
	ATLAS_2012_I1093738 [44]	Isolated prompt photon + jet cross-section
CMS 7 Photon Jet	CMS_2014_I1266056 [45]	Photon + jets triple differential cross-section
ATLAS 7 Diphoton	ATLAS_2012_I1199269 [43]	Inclusive diphoton $+X$ events
ATLAS 7 ZZ	ATLAS_2012_I1203852 [39]	Measurement of the $ZZ(*)$ production cross-section
ATLAS W/Z gamma	ATLAS_2013_I1217863 [40]	W/Z gamma production

Key tools: Constraints On New Theories Using Rivet



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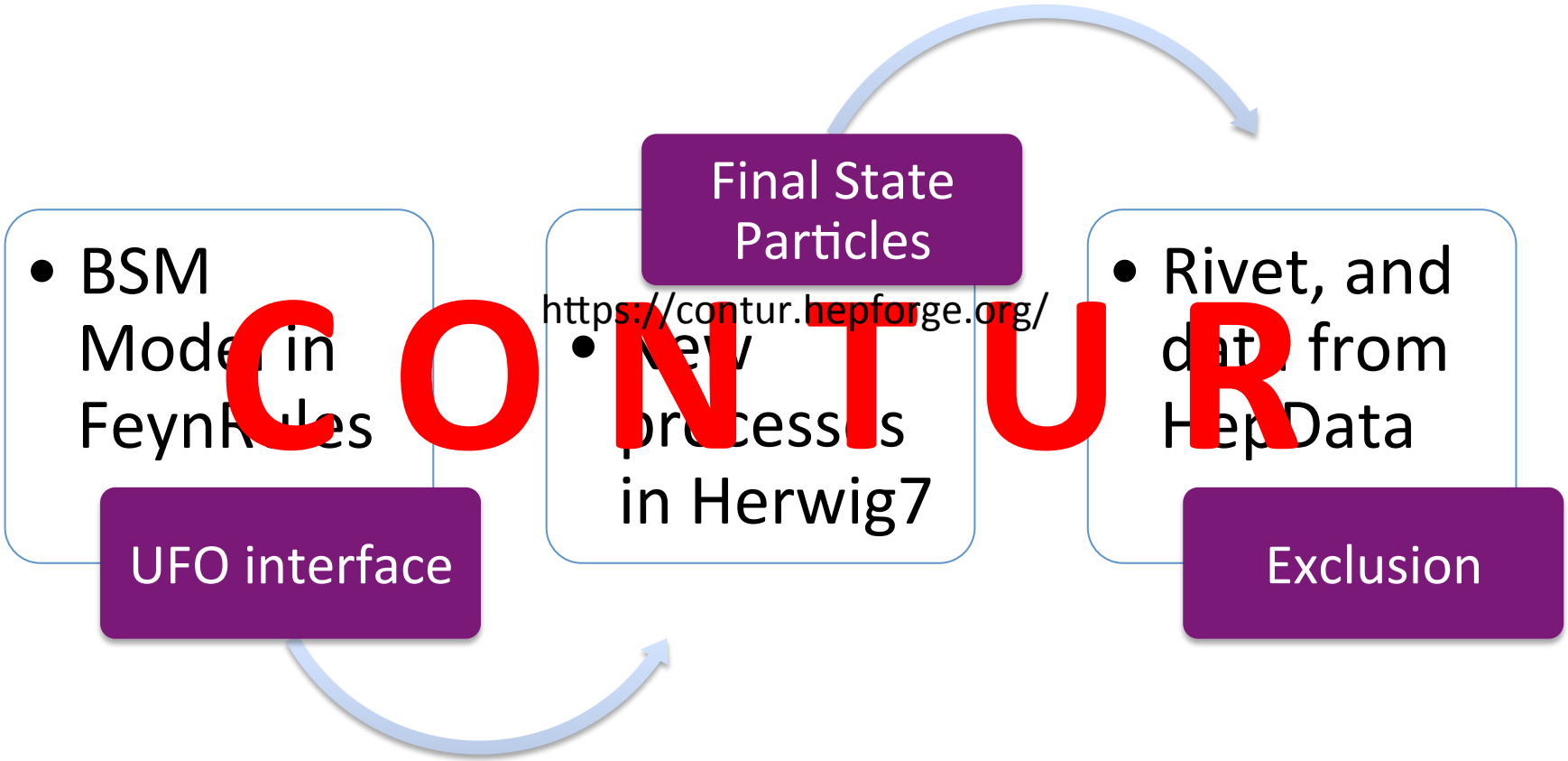


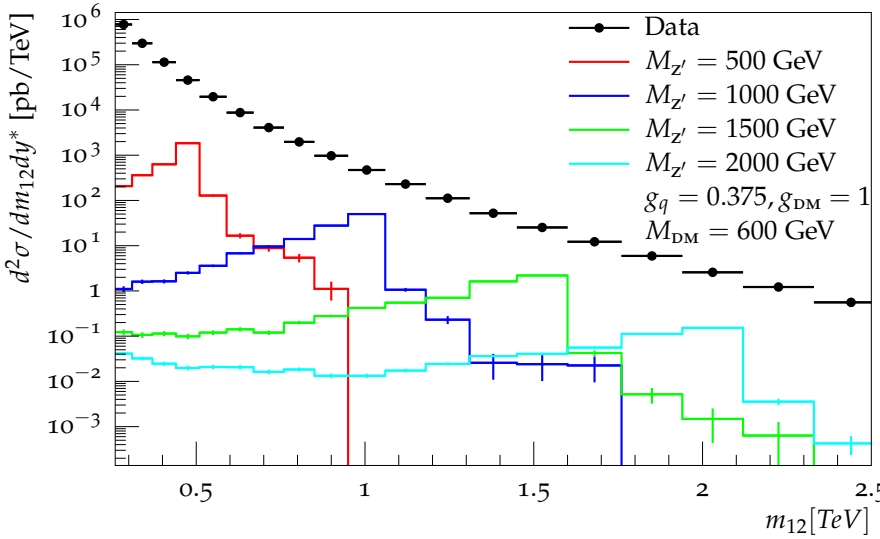
https://contur.hepforge.org/

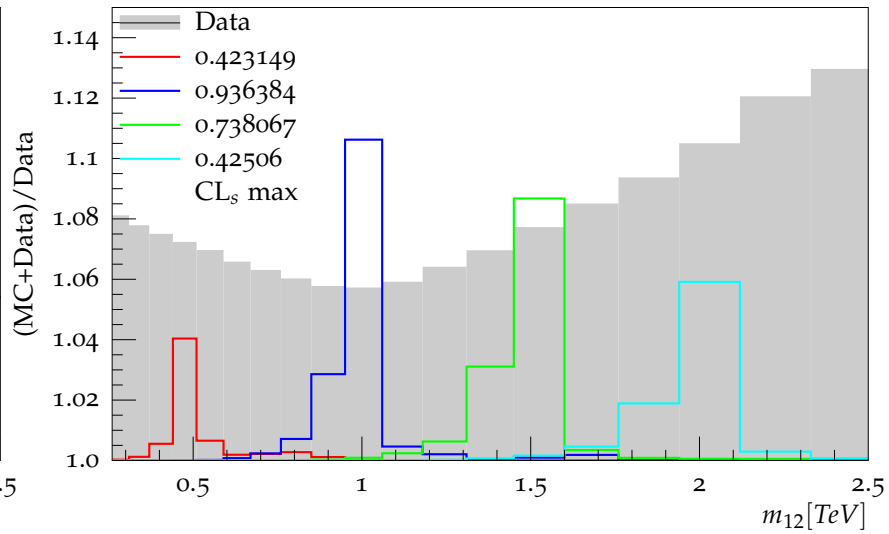
Parameter Choices

- 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 $g_q = 0.375$; $g_{DM} = 0.25$

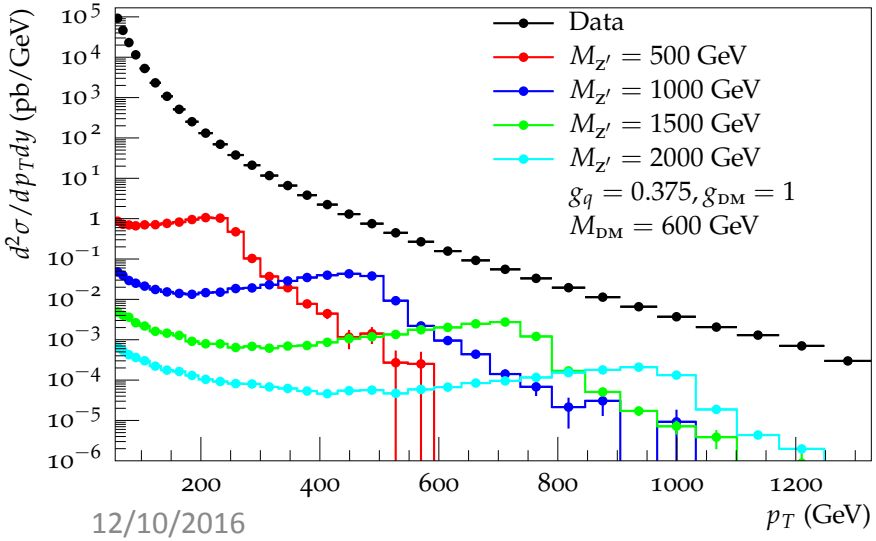
Data Comparisons

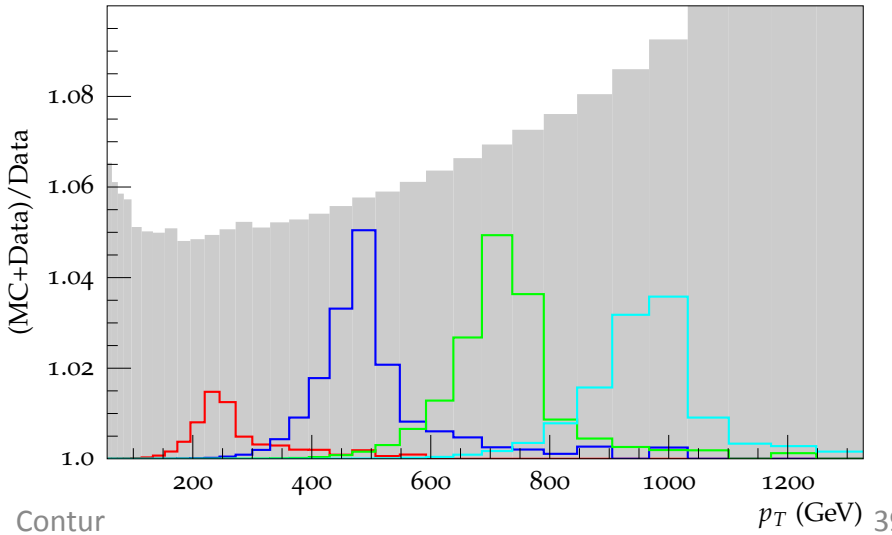
ATLAS Dijet double-differential cross sections ($y^* < 0.5$)





CMS inclusive jet double differential cross section ($|y| < 0.5$)





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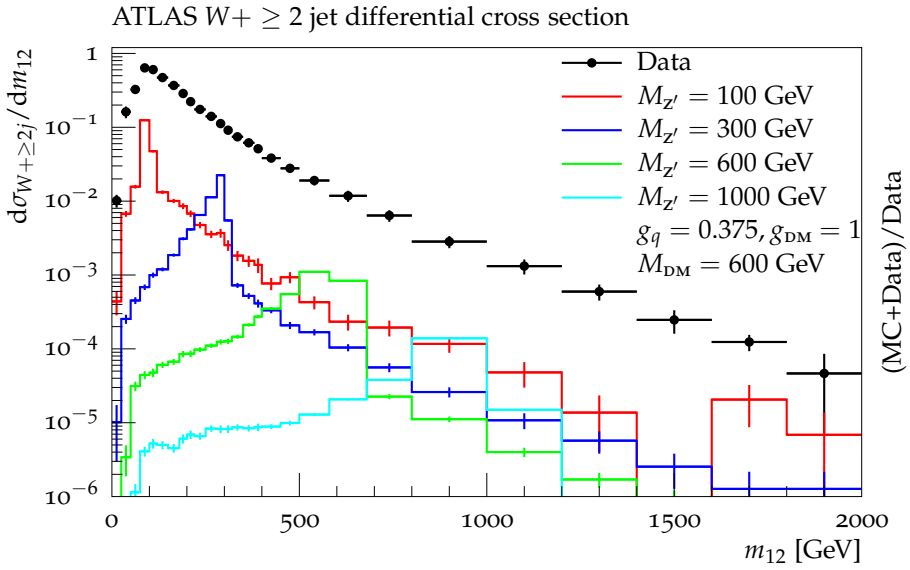
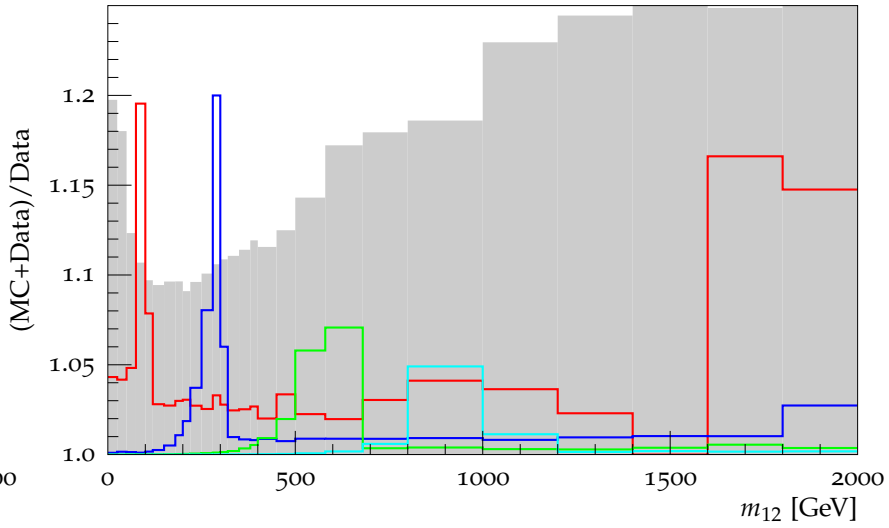
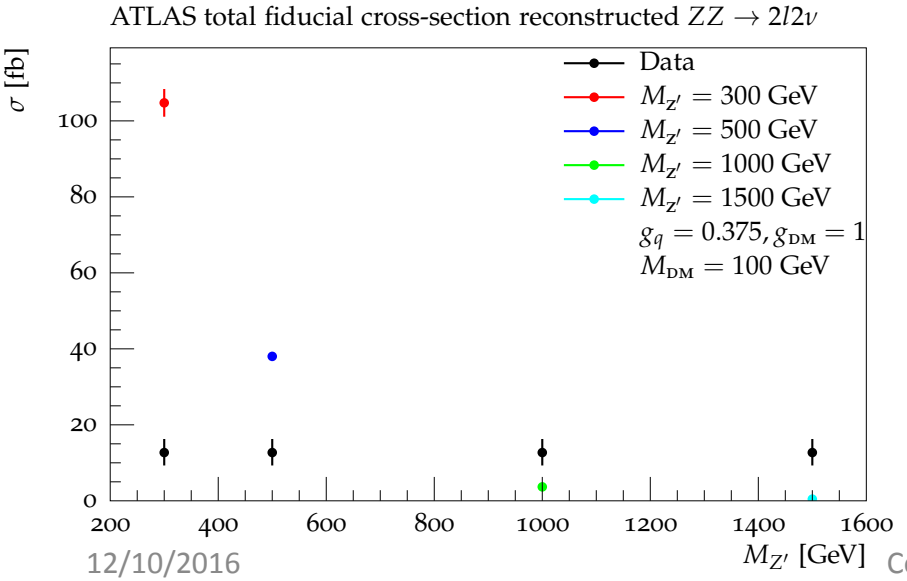
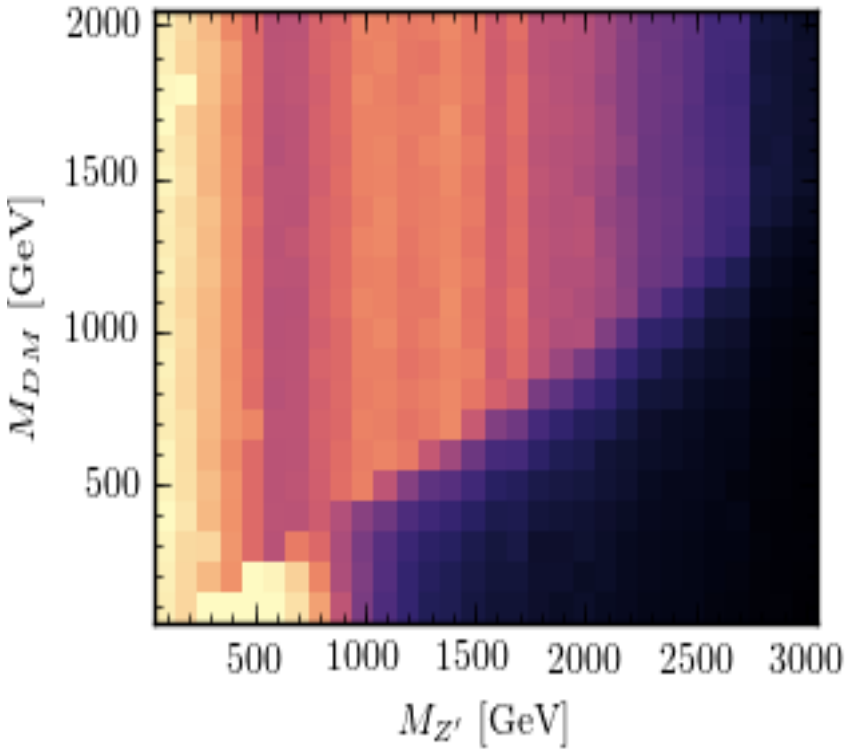






Heat Maps



Heatmap for g_q=0.25, g_{DM}=1 (Challenging scenario)

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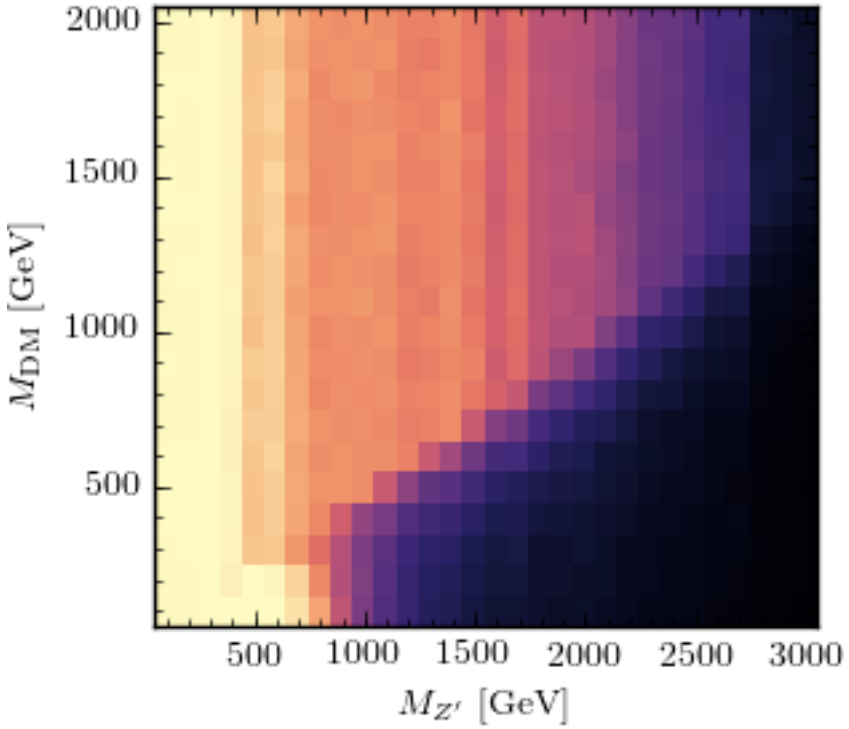

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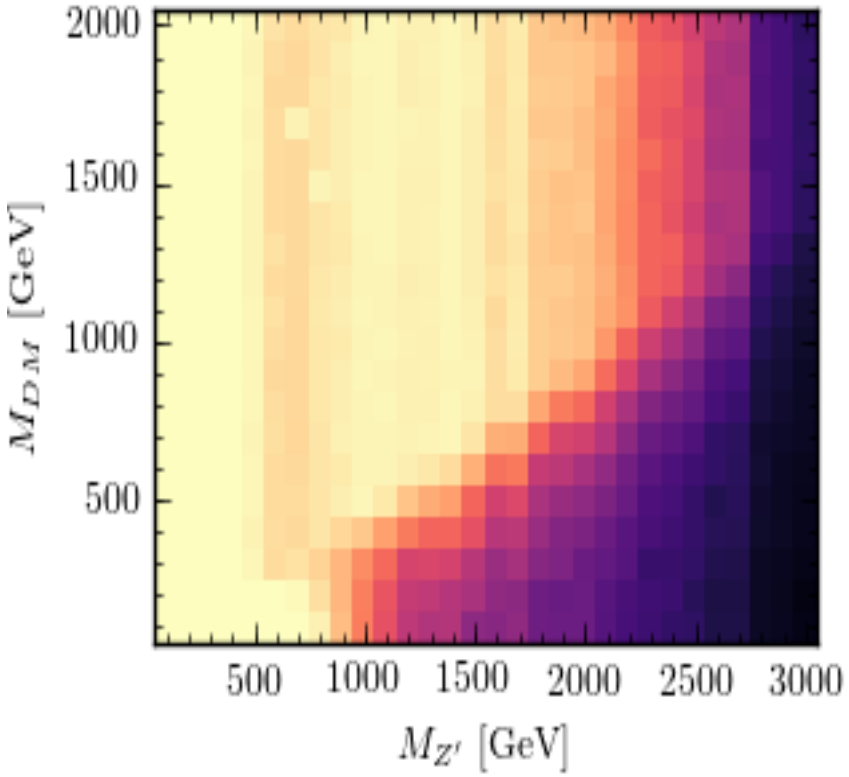

Heatmap for g_q=0.375, g_{DM}=1 (Medium scenario)

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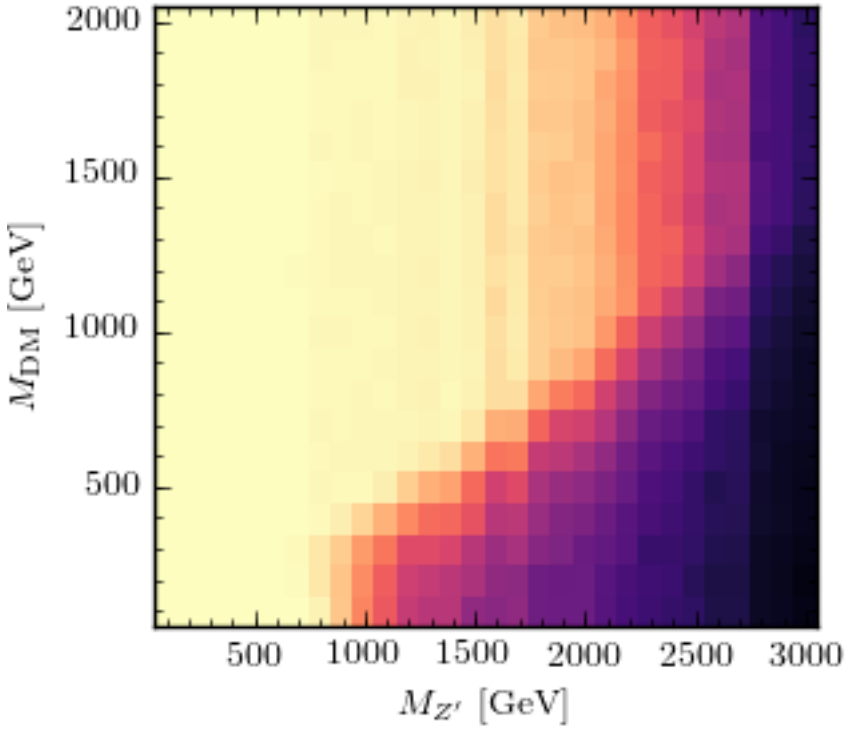

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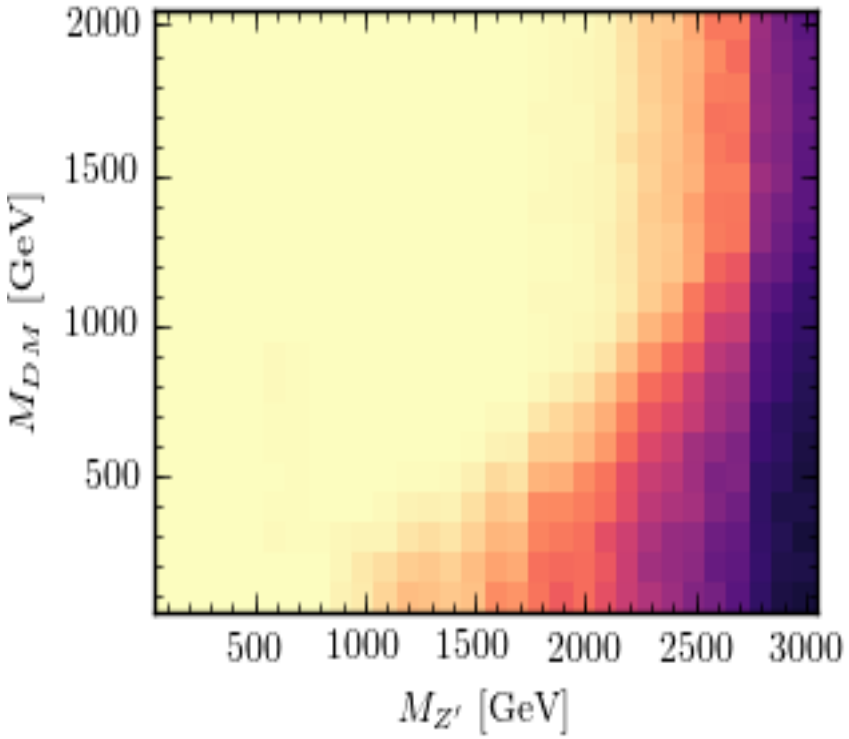

Heatmap for g_q=0.5, g_{DM}=1 (Optimistic scenario)

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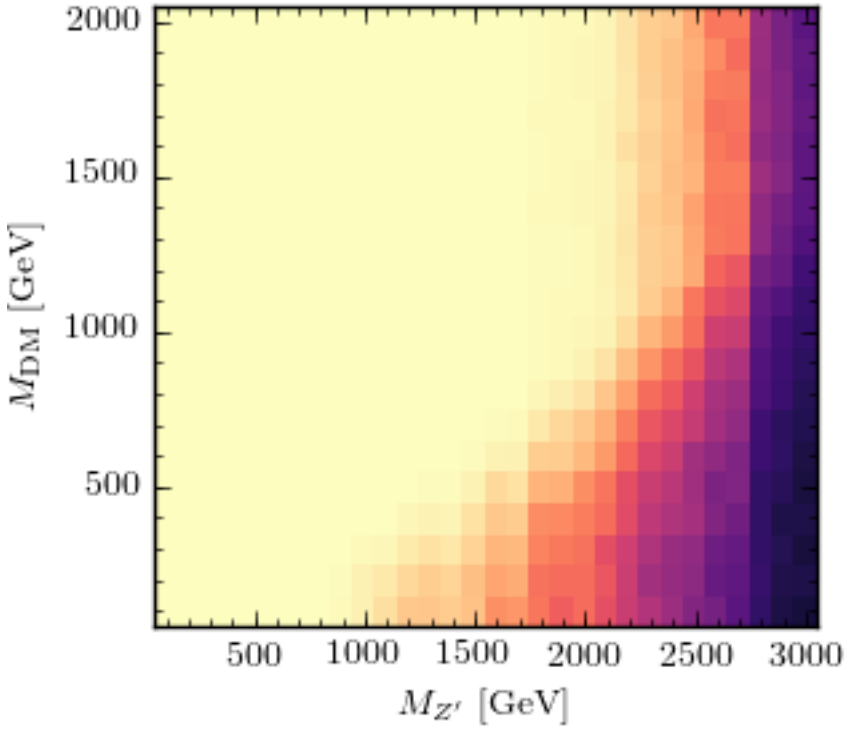

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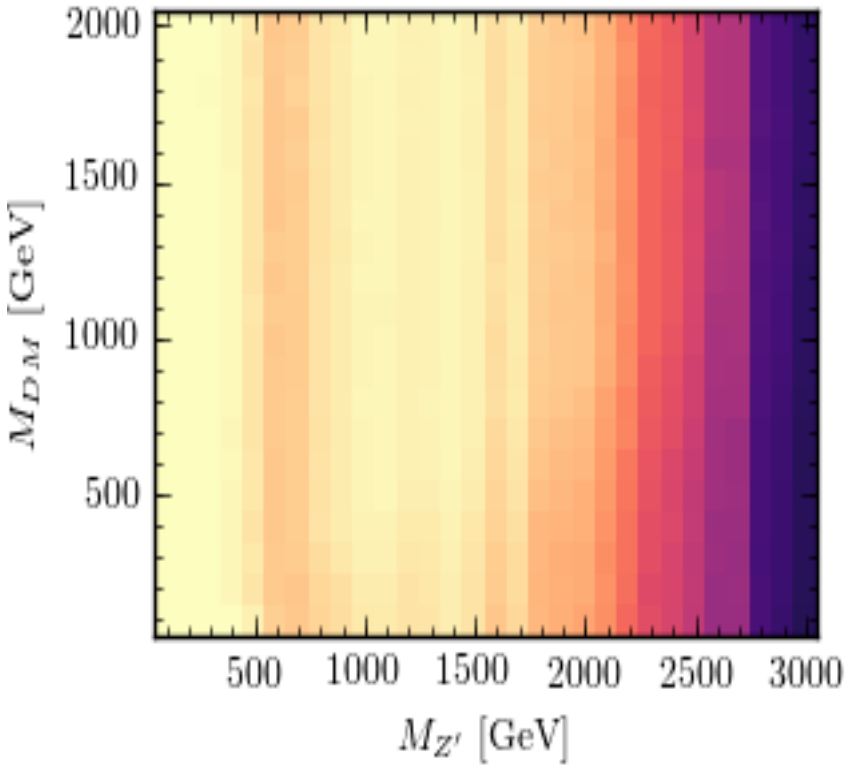

Heatmap for g_q=0.375, g_{DM}=0.25 (DM suppressed)

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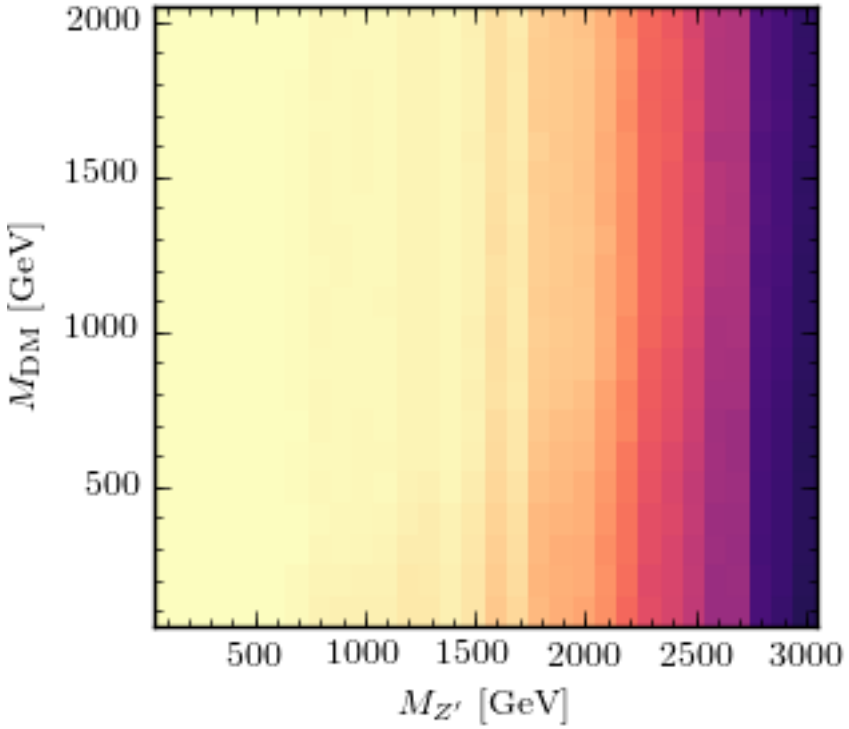

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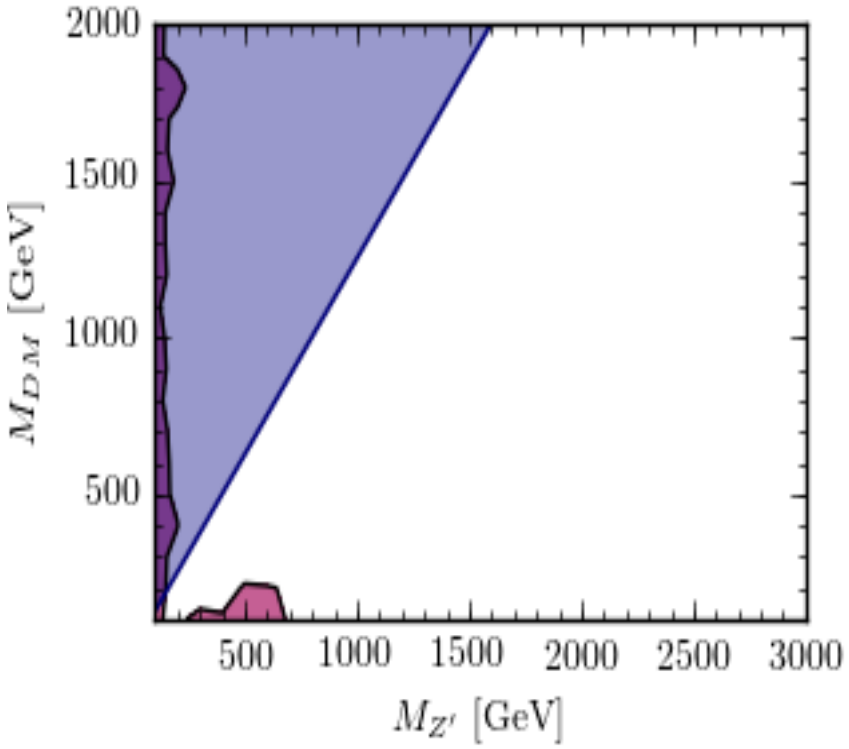
95% CL_s Contour



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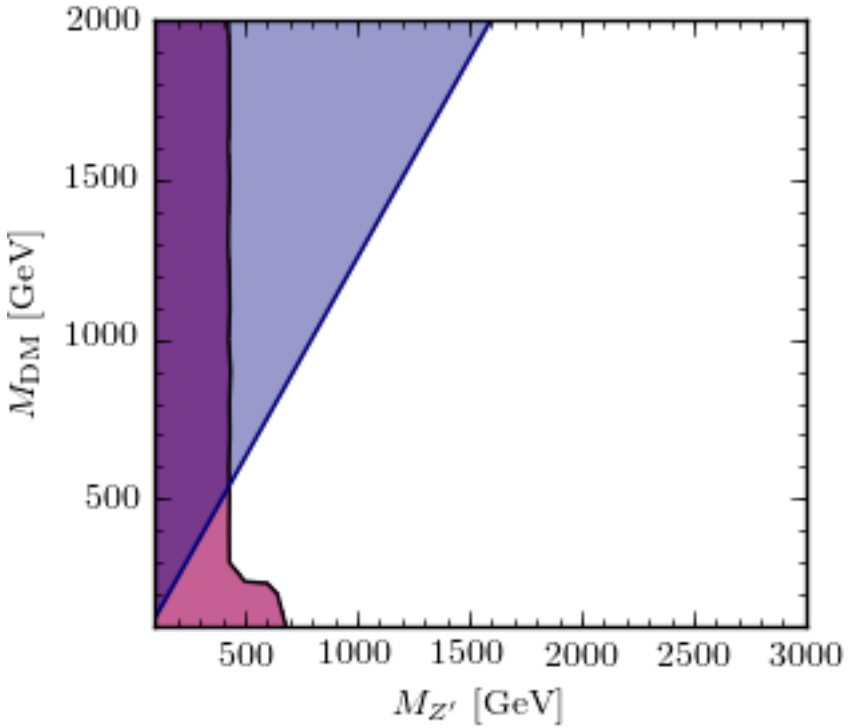

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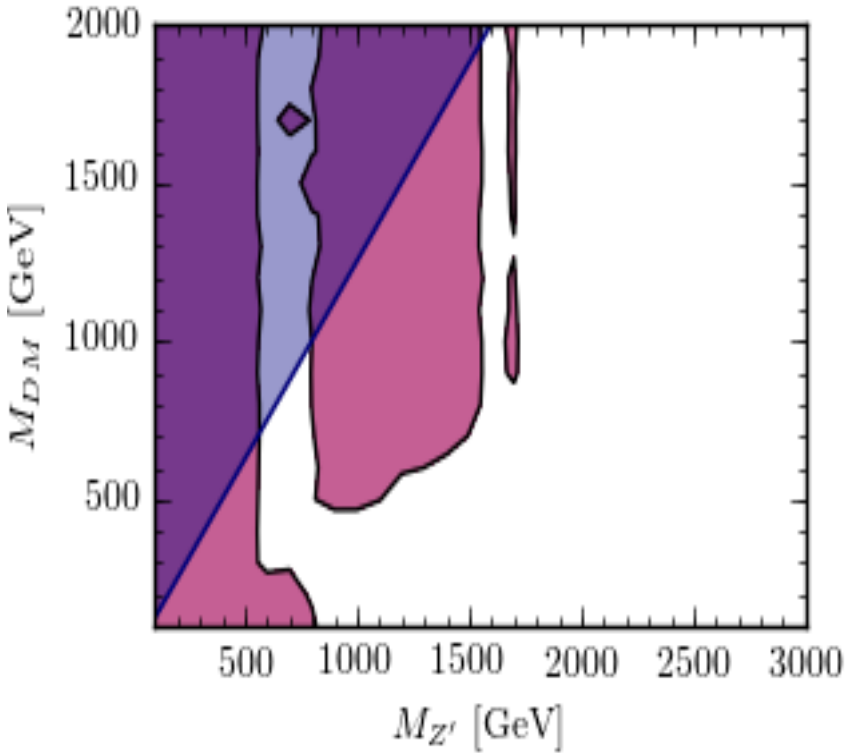

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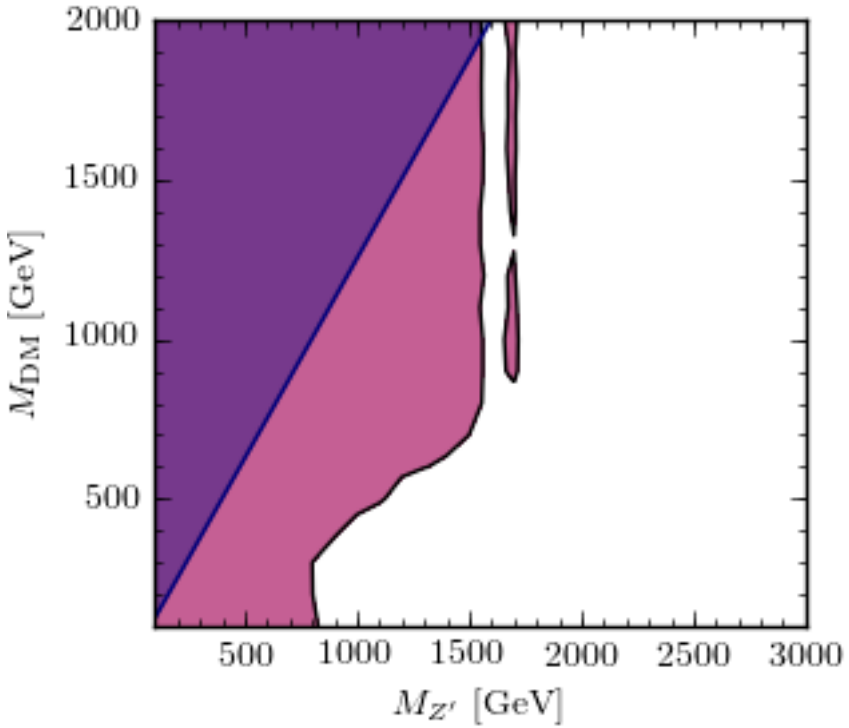

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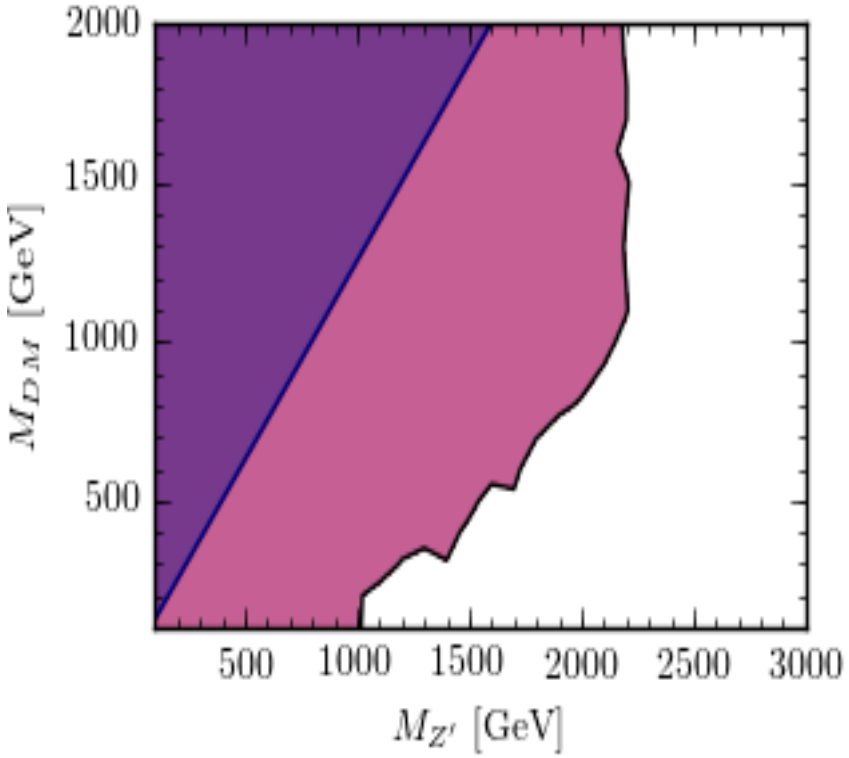

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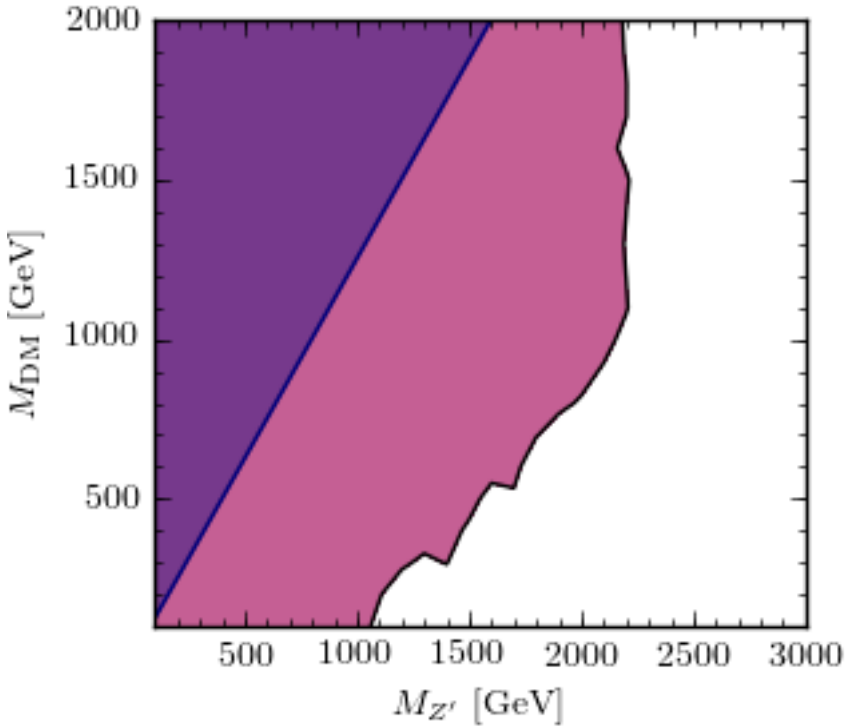

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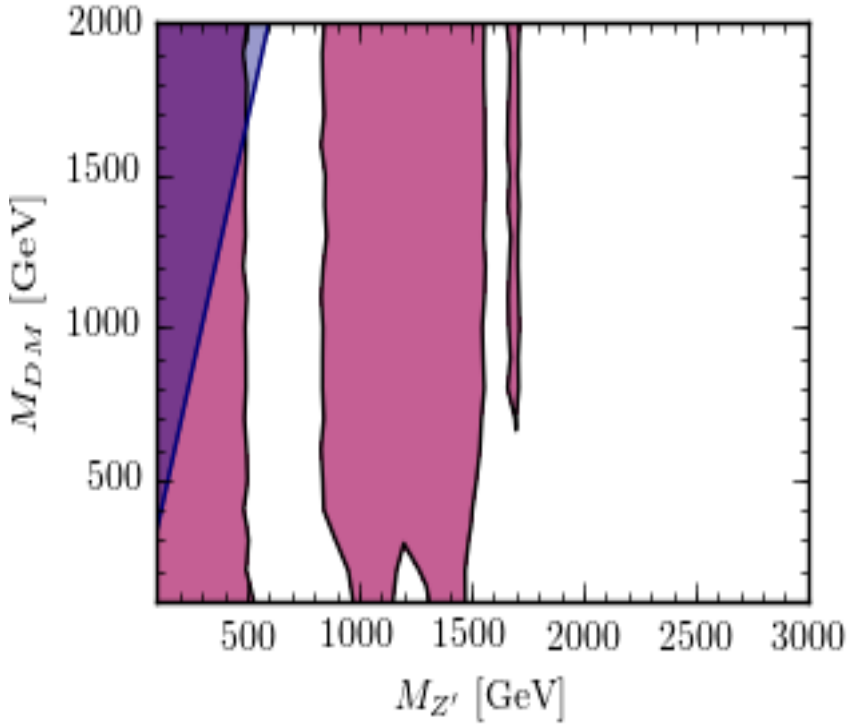
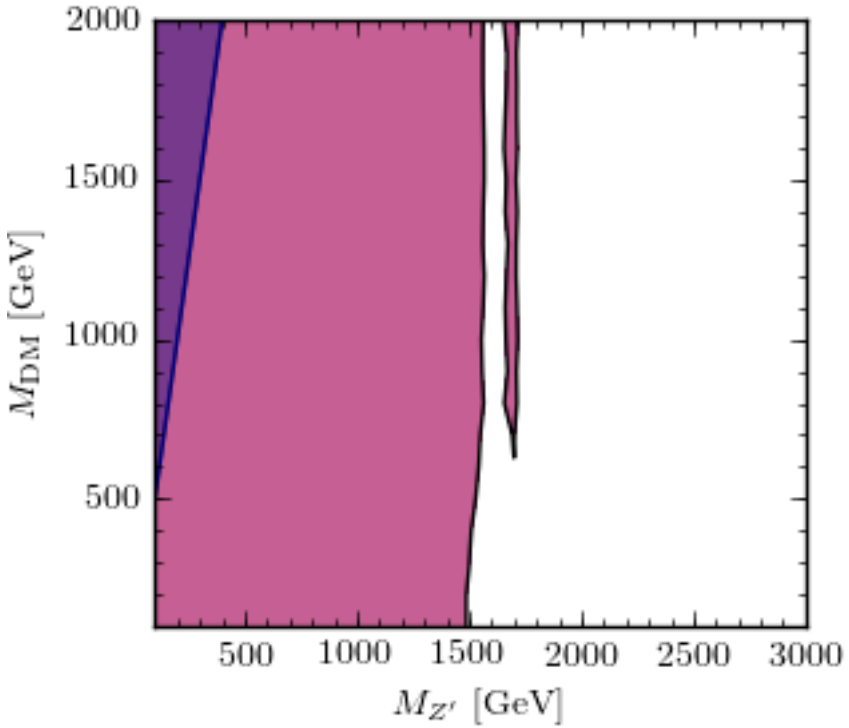
Heatmap for g_q=0.5, g_{DM}=1 (Optimistic scenario)

95% CL_s Contour



Heatmap for g_q=0.375, g_{DM}=0.25 (DM suppressed)

95% CL_s Contour



Contur Category	Inspire ID	Description
ATLAS 8 Z Jets	http://rivet.hepforge.org/analyses#ATLAS_2014_I1279489	Z + dijets (Vector boson fusion motivated)
ATLAS 8 Photons	http://rivet.hepforge.org/analyses#ATLAS_2016_I1457605	Inclusive photons
ATLAS 8 Z Jets	http://rivet.hepforge.org/analyses#ATLAS_2015_I1408516	Drell Yan dileptons

Heatmap for g_q=0.375, g_{DM}=0.25 (DM Suppressed)

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 (and references therein), and hepforge.org/contur