Search for new phenomena using jets

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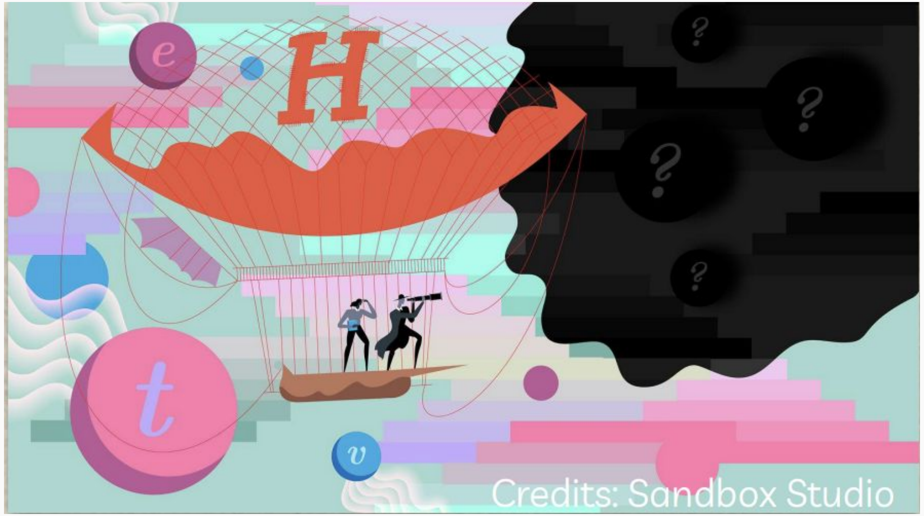
BSM: Why do we search?

- Many theories:
  - Supersymmetry, string theory, M-theory, extra dimensions
- Almost all have predictions of new, yet to be discovered particles
- So far nothing, but the search continues



Paper

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Search for new phenomena in dijet events using 37 fb^{-1} of pp collision data collected at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration

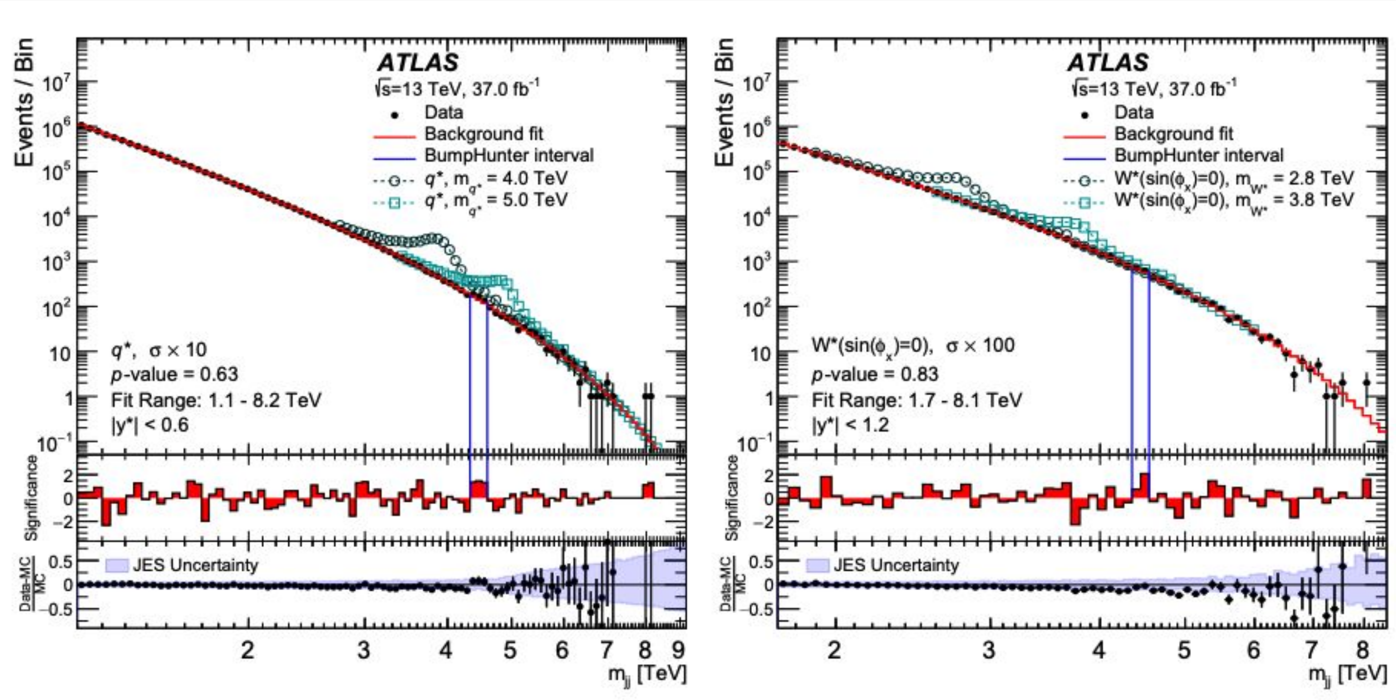
Why dijets?

- Primary source of new particles
- The dijet invariant mass distribution, m_{jj}, is well predicted by QCD.
- Easy to look for localized excesses near the mass of resonance.
- Moreover, QCD predicts jets at a small angle θ^*, while some BSM theories predict more isotropic signatures.

Event selection

- Anti-k_t algorithm with R = 0.4
- Jets with $p_t > 20GeV$ are considered
- Rapidity difference $y^* = \frac{y_1 - y_2}{2}$ was chosen to be $|y^*| < 1.2$
- To reduce the background from QCD processes, additional subset with $|y^*| < 0.6$ was analyzed
- Full efficiency for both y^* and p_t requirements is reached for $m_{jj} > 1.7TeV$ and $m_{jj} > 1.1TeV$ respectively

Dijet mass distribution



Resonance Search

Prior analysis shown that

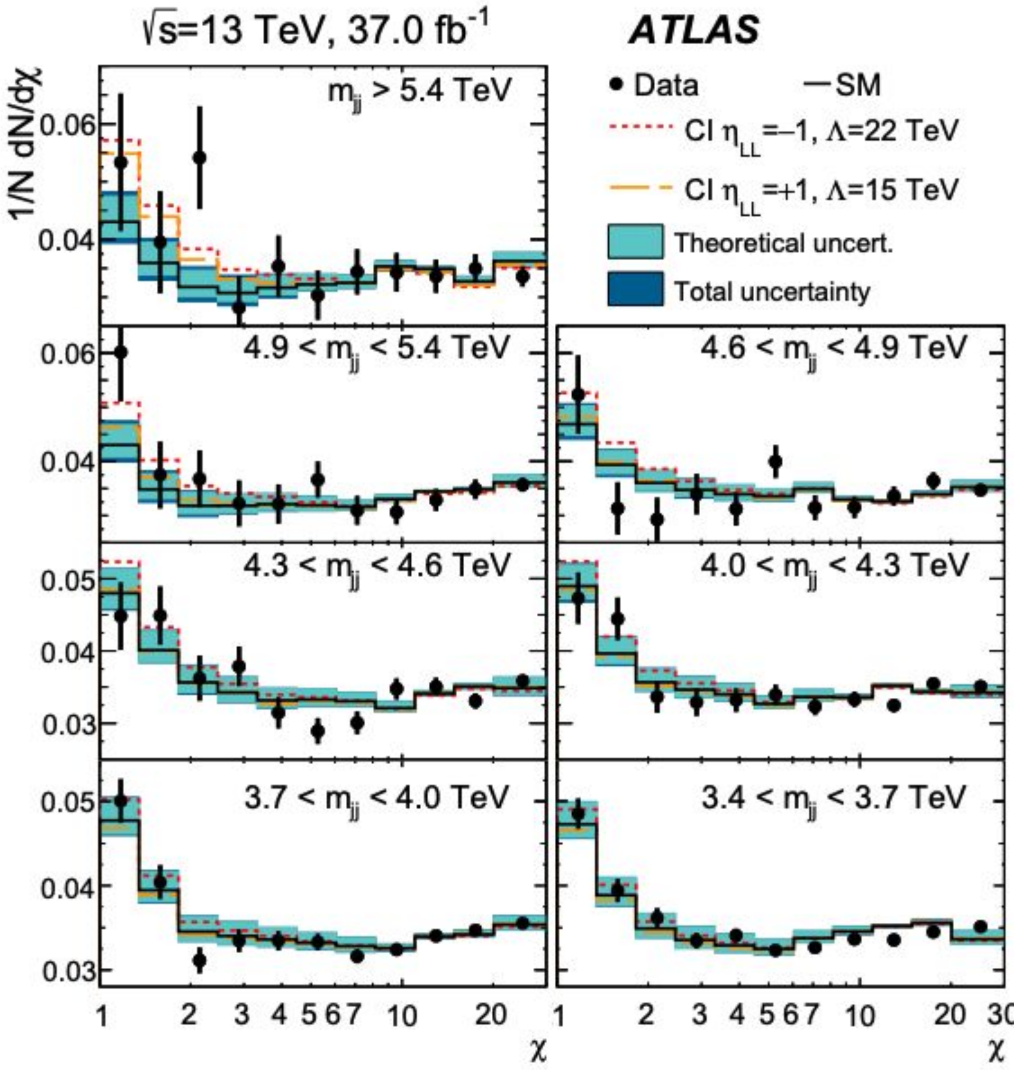
$$f(z) = p_1(1-z)^{p_2} z^{p_3} z^{p_4 log(z)}$$

With $z = \frac{m_{jj}}{\sqrt{s}}$ and p_i's describing the distribution at lower collision energies.

Angular Analysis

Lorentz invariant: $\chi = e^{2|y^*|} \sim \frac{1+cos\theta^*}{1-cos\theta^*}$

$|y^*| < 1.7, |y_B| = \frac{y_1+y_2}{2} < 1.1$



Quantum Black Holes: Overview

- One of the tools to study quantum gravity
- “Quantumness” of a black hole is directly related to the Planck's mass
- Planck's mass can be varied in the **ADD** model (**large extra dimensions**)

Quantum Black Holes: Predictions

Existence of higher dimensions

↓

Fundamental scale of gravity ~ few TeV

↓

QBH are produced by LCH and decay into particles thus producing peaks in m_{jj} distribution

↓

Profit?

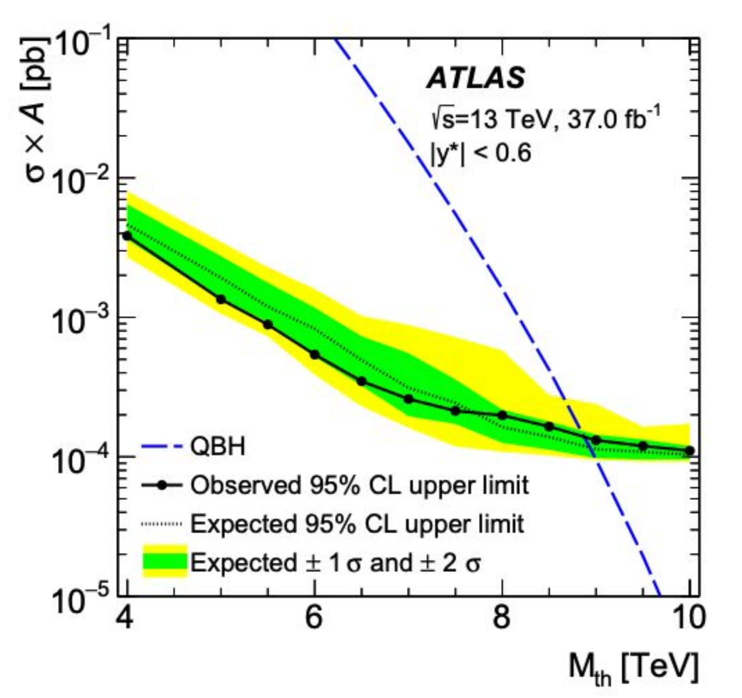
Quantum Black Holes: Benchmark

- **BlackMax** event generator
- Number of extra dimensions n = 6 and $M_D = M_{th}$
- Branching ratio to dijets $\geq 96\%$
- Acceptance ~53%

Quantum Black Holes: Results

95% CL exclusion limits:

- Observed: 8.9 TeV
- Expected: 8.9 TeV



Excited Quarks: Overview

- What if quarks are not as fundamental as we think?
- If so, we can “excite” them which would lead to radiation by the hypothetical constituents which is a great signature

Excited Quarks: Predictions

- Two main input parameters - mass and coupling constant
- Previous searches excluded masses below 3.5 TeV assuming the coupling constant of the same order as for the ordinary quarks.

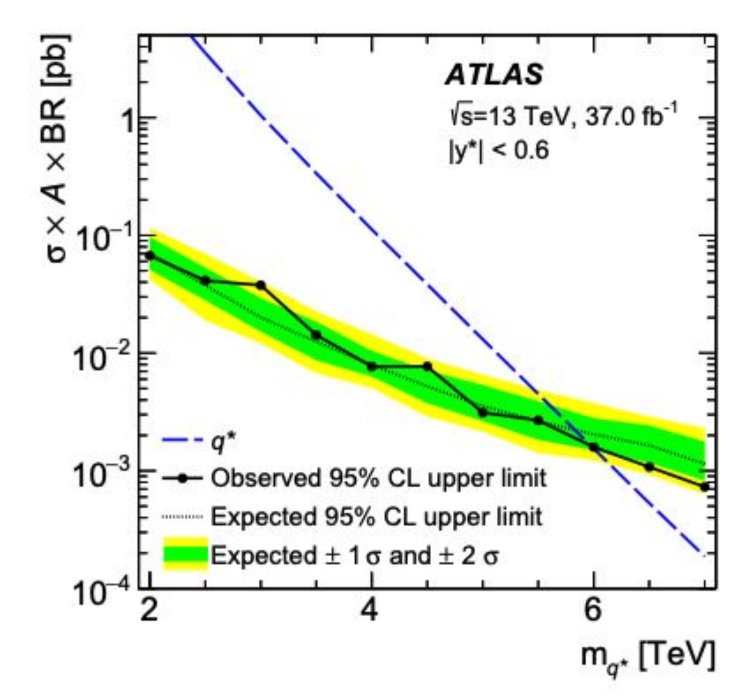
Excited Quarks: Benchmark

- Pythia 8.186
- Coupling constant for excited and regular quarks is the same
- No interference with the SM
- Only $q^* \to q + g$ is simulated, branching ratio 85%
- Acceptance for q^* of mass 4 TeV is 58%

Excited Quarks: Results

95% CL exclusion limits:

- Observed: 6.0 TeV
- Expected: 5.8 TeV



Excited W^*: Overview

- Similar to excited quarks
- Although both W and Z boson theoretically can be excited, W^* is lighter

Excited W^*: Predictions

- Main production mechanism is via $q\bar{q}$ resonance fusion
- Can distinguished from W' and Z' production due to different cross angular dependence of the cross-section:

$$\frac{\sigma(q\bar{q} \to Z^*/W^* \to f\bar{f})}{d\ \cos\theta} \propto cos^2\theta \qquad \frac{\sigma(q\bar{q} \to Z'/W' \to f\bar{f})}{d\ \cos\theta} \propto 1 + cos^2\theta$$

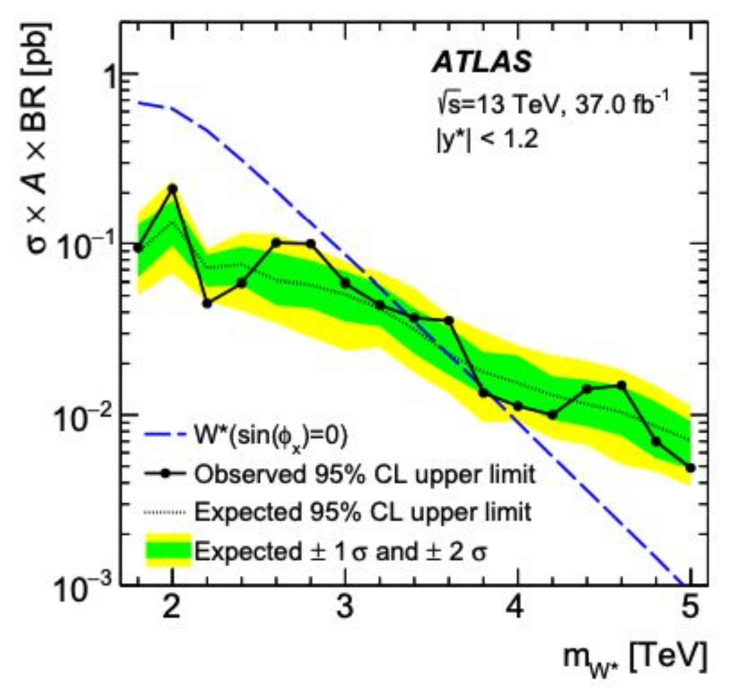
Excited W^*: Benchmark

- CalcHEP 3.6 + Pythia 8.210
- Mixing angle $\phi_X = 0$
- Unlike previous signals, peak for $y^* \approx 1$, so the region with $|y^*| < 1.2$ is chosen instead.
- Acceptance 33% for 2 TeV and 60% for highest masses.

Excited W^*: Results

95% CL exclusion limits:

- Observed: 3.4 TeV (3.77 TeV - 3.85 TeV)
- Expected: 3.6 TeV



W' and Z' : Overview

- Arise from symmetry breaking of extended gauge theories
- Examples: W'
  - $SU(3) \times SU(2) \times SU(2) \times U(1)$ with $SU(2) \times SU(2)$ breaking into a diagonal subgroup $SU(2)_W$
  - 331 model: $SU(2)_W$ is embedded into a larger $SU(3)$
- Examples: Z'
  - E6 model, Pati–Salam model, Little Higgs models

W' and Z' : Predictions

- Assuming low branching ratio to dark matter, the resonance width of Z' is dependent only on its coupling to quarks g_q
- Both Z' and W' are usually created from $q\bar{q}$ annihilation
- Only decays $W'/Z' \to tb$ considered

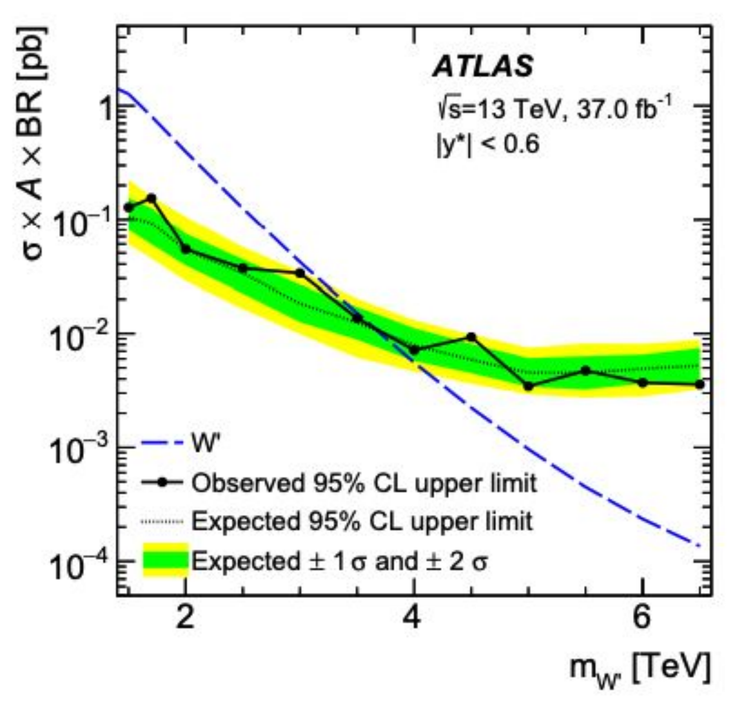
W' and Z' : Benchmark

- W':
  - Pythia 8.205
  - Restricted only to $W' \to q\bar{q}$
  - Assumes axial-vector SM coupling
- Z' :
  - MadGraph5_aMC@NLO v2.2.3 + Pythia 8.210
  - Assumes axial-vector coupling to SM quarks and Dirac fermion dark matter candidate
- No interference with the SM
- Coupling constant $g_q \leq 0.5$

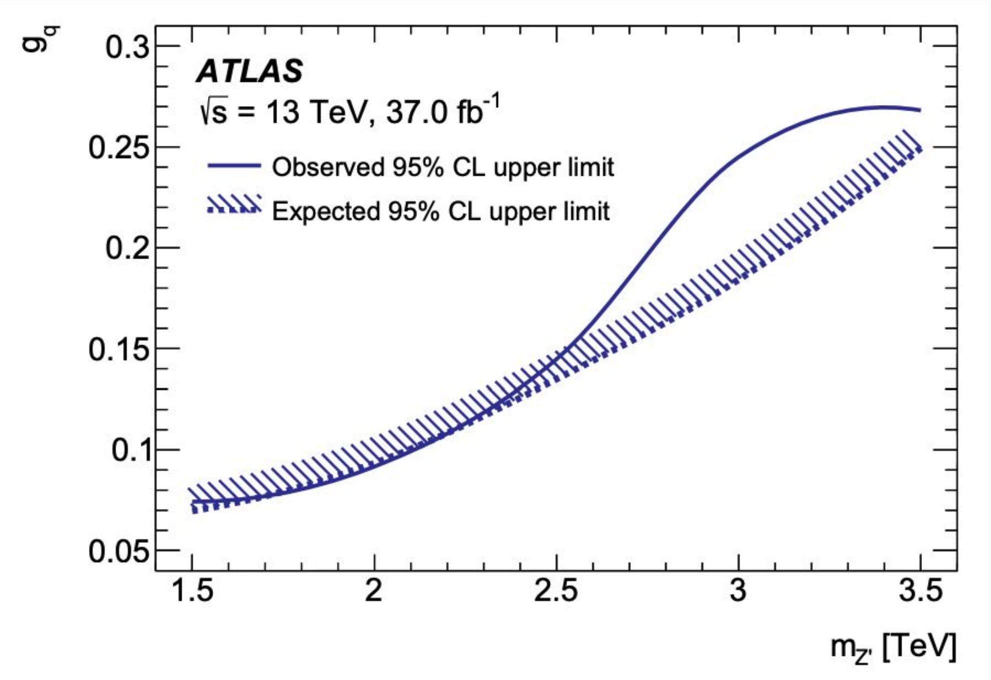
W': Results

95% CL exclusion limits:

- Observed: 3.6 TeV
- Expected: 3.7 TeV



Z' : Results



ATLAS
√s = 13 TeV, 37.0 fb-1
Observed 95% CL upper limit
Expected 95% CL upper limit
g_q
0.3
0.25
0.2
0.15
0.1
0.05
1.5
2
2.5
3
3.5
m_Z' [TeV]

Contact interaction: Predictions

- Mediating particles with masses that cannot be probed directly
- Might affect the dijet angular distributions
- Only $\eta_{LL} = \pm 1, \eta_{RR} = \eta_{RL} = 0$ is considered

$$\mathcal{L}_{qq} = \frac{2\pi}{\Lambda^2}[\,\eta_{\rm LL}(\bar{q}_{\rm L}\gamma^{\mu}q_{\rm L})(\bar{q}_{\rm L}\gamma_{\mu}q_{\rm L}) + \eta_{\rm RR}(\bar{q}_{\rm R}\gamma^{\mu}q_{\rm R})(\bar{q}_{\rm R}\gamma_{\mu}q_{\rm R}) + 2\eta_{\rm RL}(\bar{q}_{\rm R}\gamma^{\mu}q_{\rm R})(\bar{q}_{\rm L}\gamma_{\mu}q_{\rm L})]$$

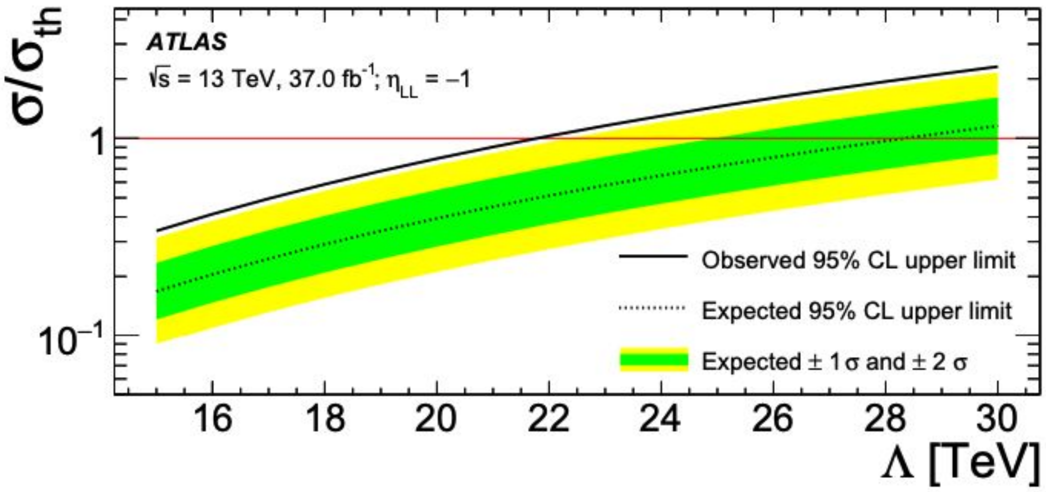
Contact interaction: Results

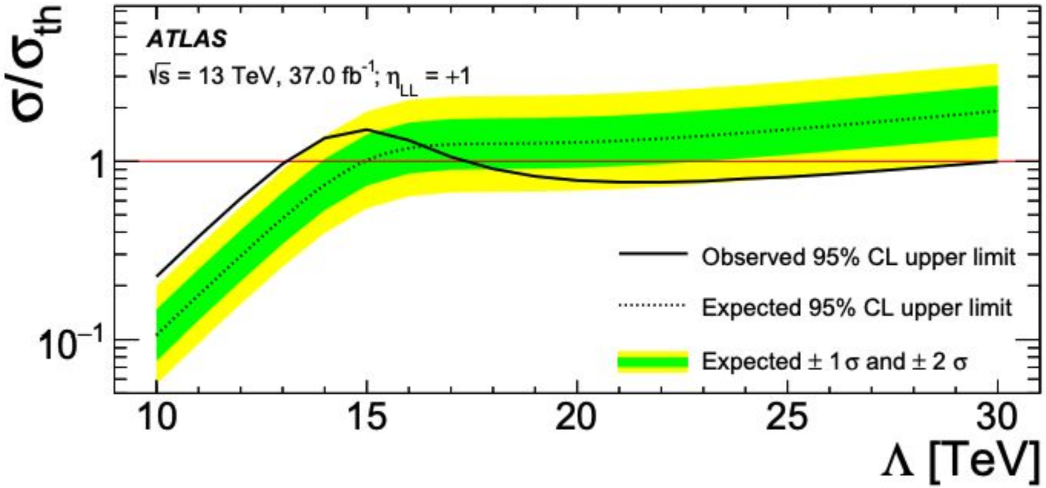
Top: Constructive interference

- Observed: 21.8 TeV
- Expected: 28.3 TeV

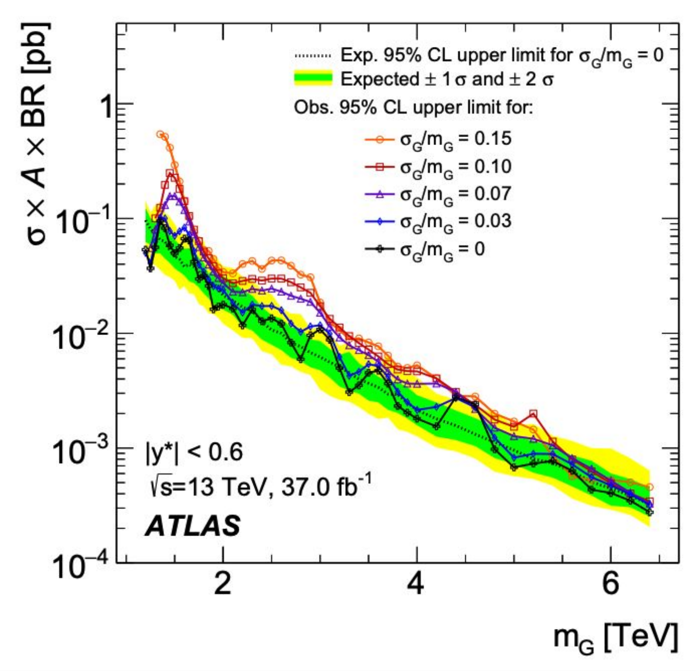
Bottom: Destructive interference

- Observed: 13.1 TeV (17.4 TeV - 29.5 TeV)
- Expected: 15.0 TeV





Generic Gaussian Signals



Conclusion

The dijet invariant mass distribution exhibited no significant deviations from the SM predictions. The dijet angular distribution also agreed to a MC simulation of the SM. New limits were set on the QBHs, excited quarks, excited W bosons, W' and Z', contact interaction, and generic Gaussian signals.

However, the usage of jets provides a great window of opportunity to test BSM theories.

References

1. The ATLAS Collaboration *"Search for new phenomena in dijet events using 37 fb−1 of pp collision data collected at √ s = 13 TeV with the ATLAS detector"*
2. *Dimopoulos, S.; Landsberg, G. L. (2001). "Black Holes at the Large Hadron Collider"*
3. *M. V. Chizhov, "A Reference Model for Anomalously Interacting Bosons"*
4. *P. Langacker, R. W. Robinett and J. L. Rosner "New heavy gauge bosons in pp and pp collisions"*