Dijet searches in ATLAS

Georgios Choudalakis*
ATLAS Collaboration

*University of Chicago

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Overview

Two complementary ways of analyzing dijet events:

- Dijet resonance search in m_{jj}.
- Dijet angular distribution analysis.

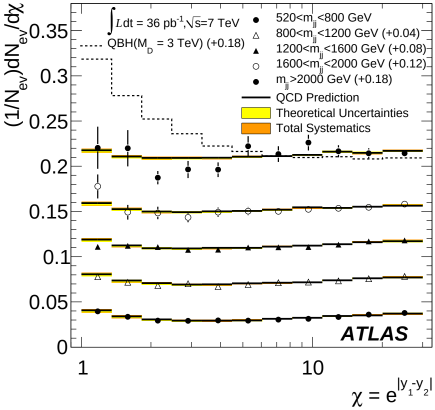
In this presentation:

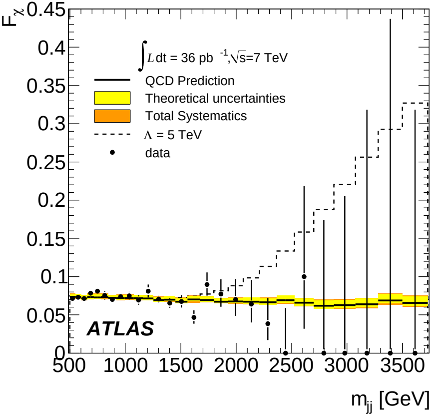
- Flashback of 36 pb^{-1} results [Latest dijet angular analysis].
- Dijet resonance search in m_{jj} with 0.81 fb^{-1}.
- Some deeper discussion about:
  - Model-independent search [BumpHunter].
  - Model-independent limits

Quick flashback to 36 pb^{-1} results,
the latest results of the dijet "angular" analysis.

From:
New J. Phys. 13 (2011) 053044, [arXiv:1103.3864v1 [hep-ex]],
where both dijet angular and mass distributions are analyzed.

The observables of the angular analysis





The signal is expected in $|y_1 - y_2| < 1.2$, namely $\chi < 3.32$.

F_χ = fraction of events in $|y_1 - y_2| < 1.2$.

Background: Pythia QCD $\times$ k-factor from NLOJET++.

Systematics: Jet Energy Scale, μ_R and μ_F , PDF.

Summary of results with 36 pb^{-1}

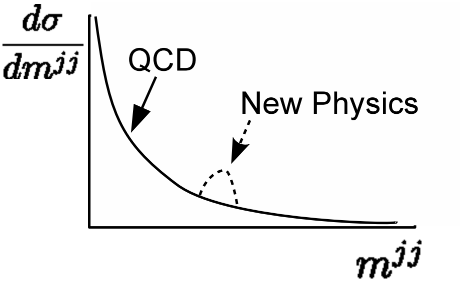
Analysis / observable	95% C.L. Limits (TeV) Expected	Observed
Excited Quark q^*		
Resonance in m_{jj} [Bayesian]	2.07	2.15
$F_\chi(m_{jj})$ [Frequentist]	2.12	2.64
Randall-Meade Quantum Black Hole for $n = 6$		
Resonance in m_{jj} [Bayes.]	3.64	3.67
$F_\chi(m_{jj})$ [Freq.]	3.49	3.78
F_χ for $m_{jj} > 2$ TeV [Freq.]	3.37	3.69
$\frac{dN}{d\chi}$ for $m_{jj} > 2$ TeV [Freq.]	3.46	3.49
Axigluon		
Resonance in m_{jj} [Bayes.]	2.01	2.10
Contact Interaction Λ		
$F_\chi(m_{jj})$ [Freq.]	5.7	9.5
$F_\chi(m_{jj})$ [Bayes.]	5.7	6.7
F_χ for $m_{jj} > 2$ TeV [Freq.]	5.2	6.8
$\frac{dN}{d\chi}$ for $m_{jj} > 2$ TeV [Freq.]	5.4	6.7

Three observables used in the angular analysis:

1. Whole $F_\chi(m_{jj})$ spectrum
2. F_χ for $m_{jj} > 2 TeV$
3. $\frac{dN}{d\chi}$ in 11 χ bins, for $m_{jj} > 2$ TeV

On to some new results now, from the dijet resonance search in m_{jj}.

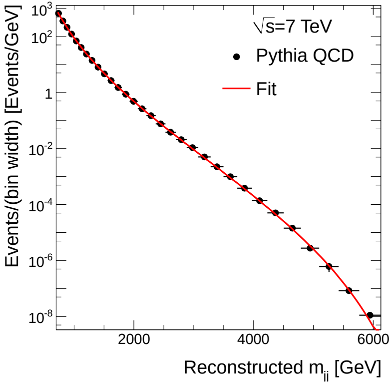
Resonance search in dijet mass



Background determined by (smart) fitting $f(x) = p_0 \frac{(1-x)^{p_1}}{x^{p_2+p_3 \ln x}}, \quad x \equiv \frac{m_{jj}}{\sqrt{s}}$.

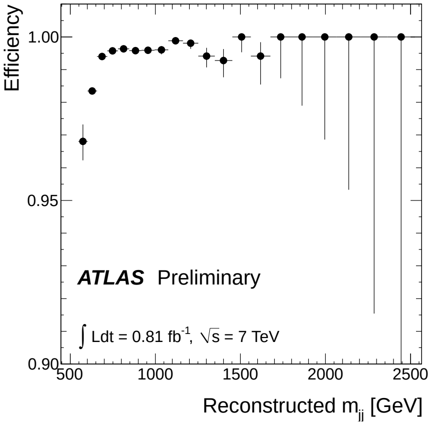
About the function $f(x) = p_0 \frac{(1-x)^{p_1}}{x^{p_2+p_3 \ln x}}, \quad x \equiv \frac{m_{jj}}{\sqrt{s}}$

- Able to fit wonderfully PYTHIA QCD, ALPGEN, HERWIG, NLOJET++.
- No inflection points. [Unable to fit big bumps.]
- $f(m = \sqrt{s}) = 0$. [A physical property.]
- It is a parabola in log-log scale, except for the numerator which is added to make it go to 0 at $\sqrt{s}$.
- Known, and used several times before. [e.g., CDF, Phys.Rev.D 79 (2009) 112002].



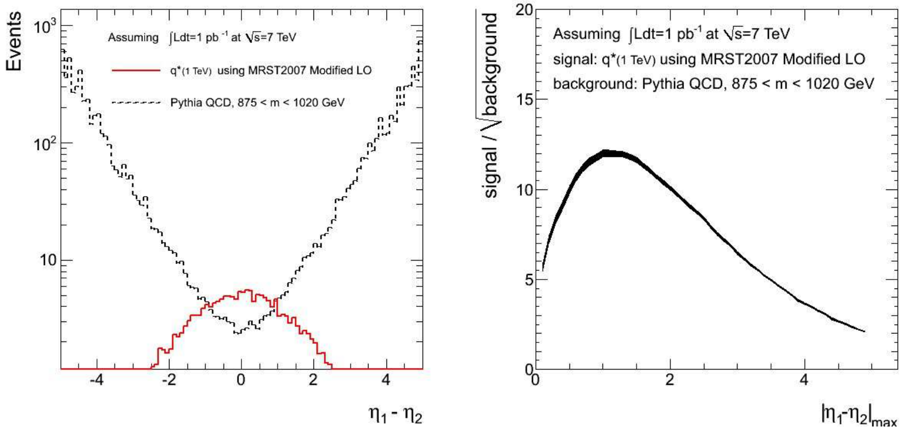
Event selection

- The obvious: Stable beams, good detector conditions, good vertex, etc.
- m_{jj} in trigger plateau. [>717 GeV]
- Two leading jets be of good quality. [well-measured, away from bad calorimeter regions.] Cost: $\sim 3.7\%$, due to temporary "hole" in calorimeter.
- No other jet of poor quality that has $p_T > 0.3 p_T^{j2}$. [Avoid accidental re-ordering of jets in p_T]. Cost: 0.3%, and would be 0 if it was not for the "hole".
- $|\Delta y| < 1.2$ [Suppress t-channel QCD background.]



Trigger efficiency plateau of the 1st unprescaled single-jet trigger. [j180].

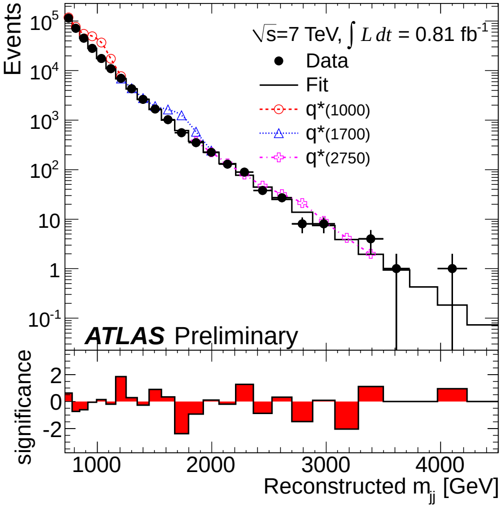
Suppression of QCD background



Great sensitivity boost, by selecting central events.

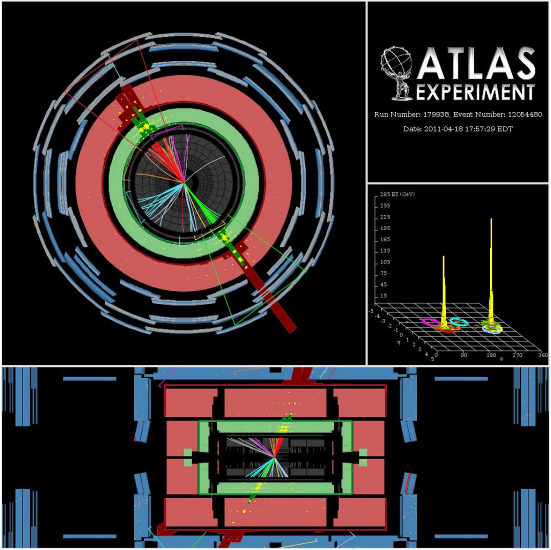
[This coheres with dijet angular analysis, where F_χ is, practically, the fraction of events passing this cut.].

The data



The fit, overall, is fantastic: The p-value of the $(-\log L)$ statistic is about 13%.

Event at $m_{jj} = 4$ TeV



Both jets at $p_T \simeq 1.8$ TeV.

The BumpHunter hypertest is used to look for excesses

Hypertests, and the BH in specific, are explained in arXiv:1101.0390 [physics.data-an].

What does it do, in brief?

- It counts events in all intervals, and computes Poisson p-values.
- It keeps the smallest Poisson *p*-value it finds. [This is the BH's "test statistic".]
- It generates several 0-signal pseudo-experiments and scans them too.
- It counts how often a pseudo-spectrum would have any interval that is more significantly discrepant than the one observed in the data. [This is the BH's *p*-value.]

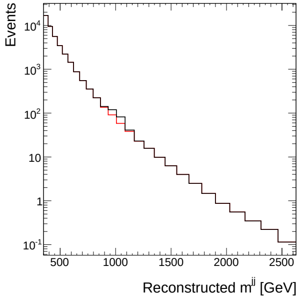
So, what's the point of all this?

- All particular tests combined into one hypertest. [What makes it a hypertest is that its test statistic is not just a metric of discrepancy (like χ^2), but the smallest from an ensemble of *p*-values .]
- Hypertests account for the trials factor. The BH is aware that many intervals were tried, and its *p*-value reflects that.
- Sensitive to excesses, without presuming their shape or location.
- It's just one hypertest. Obvious generalizations, e.g. TailHunter.

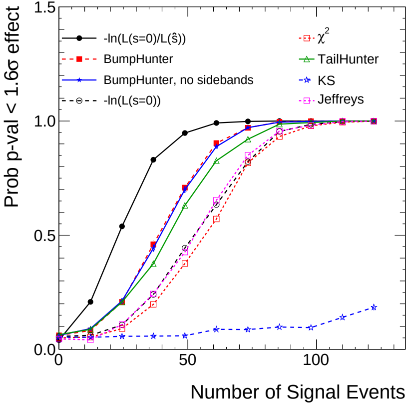
A demo of sensitivity

Toy MC used; no ATLAS data involved.

Gassian signal is injected, as shown here [At 1000±50 GeV]:

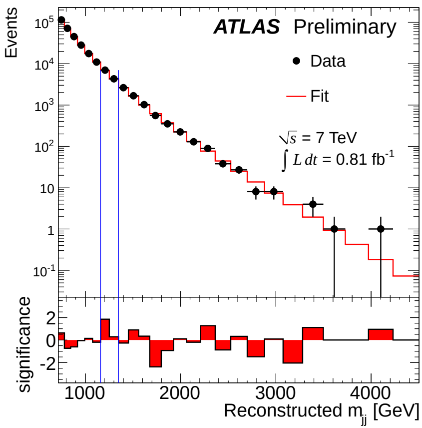


We find the probability of making a claim, as a function of expected signal.

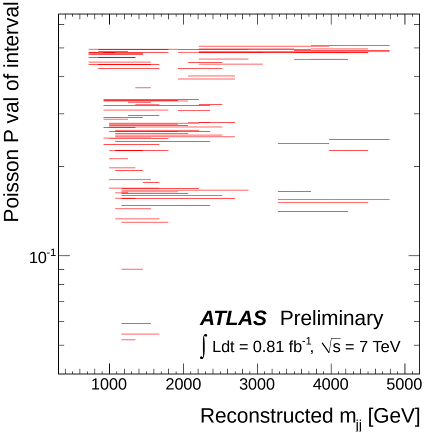


The BumpHunter [followed by the TailHunter], is more sensitive than other tests to this signal. The absolute winner [black] is “cheating”: It knows a-priori the signal shape and location.

The search phase of the analysis

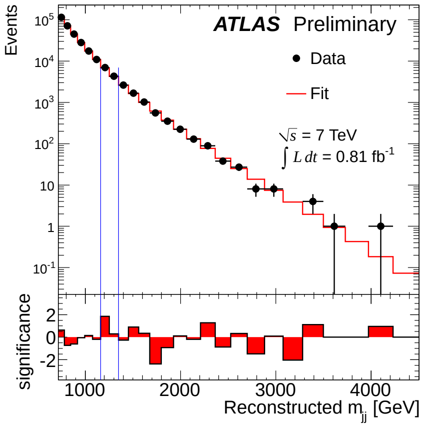


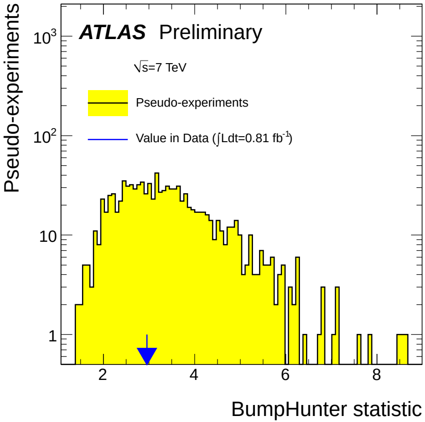
The most significant excess found in the data.



All mass intervals, and their Poisson p-values, are summarized in this "tomography" plot.

The search phase of the analysis

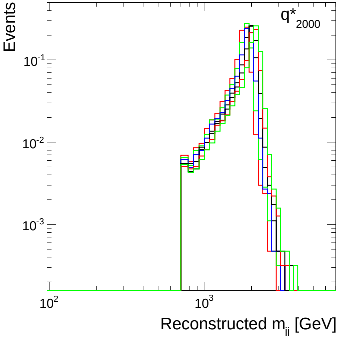




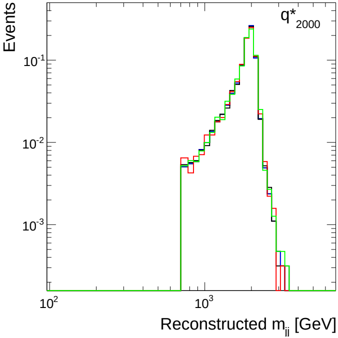
The *p*-value of the BumpHunter statistic is **62%**.
Totally insignificant.

Systematic uncertainties

- Jet Energy Scale: From 2 to 4% at p_T above 100 GeV.
- Jet Energy Resolution: 5% relative uncertainty. Negligible impact on limits.
- Fit uncertainty: Ranges from $< 1\%$ at 1 TeV, to $\sim 20\%$ at 4 TeV.
- Luminosity uncertainty: 4.5%

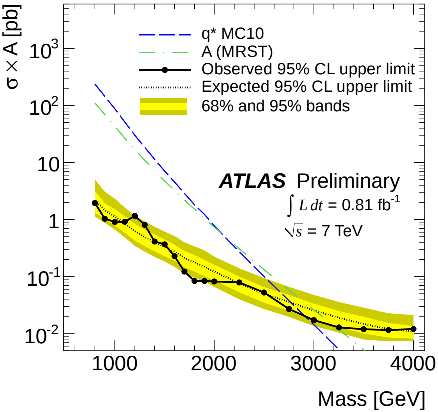


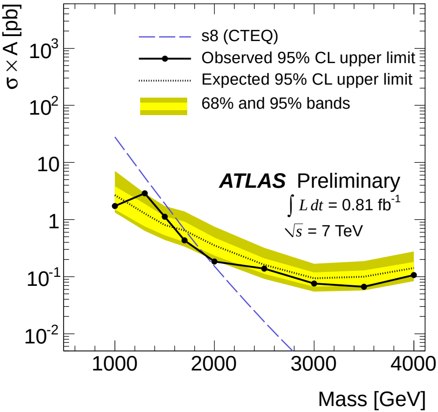
Overlaid JES variations, from -3σ to +3σ.



Overlaid JER variations, from -3σ to +3σ.

Limits to specific models





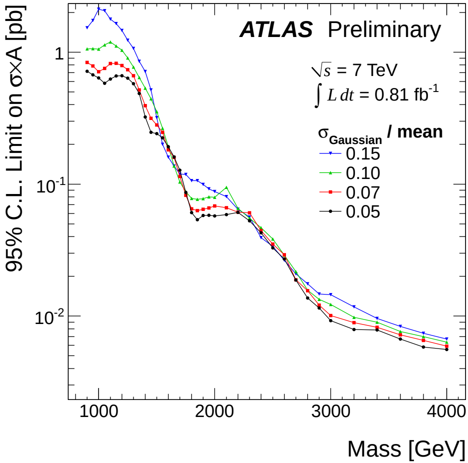
At 95% credibility level, with constant priors:

$m_{q^*} > 2.91$ TeV. [expected 2.77]

$m_A > 3.21$ TeV. [expected 3.02]

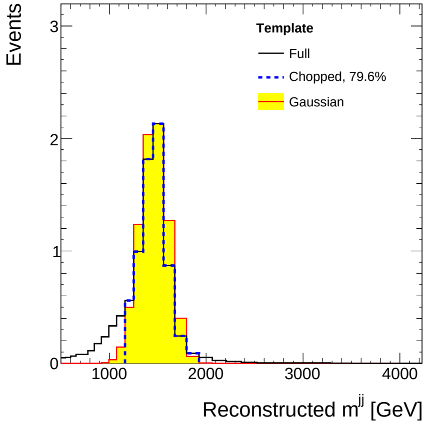
$m_{s8} > 1.91$ TeV. [expected 1.71]

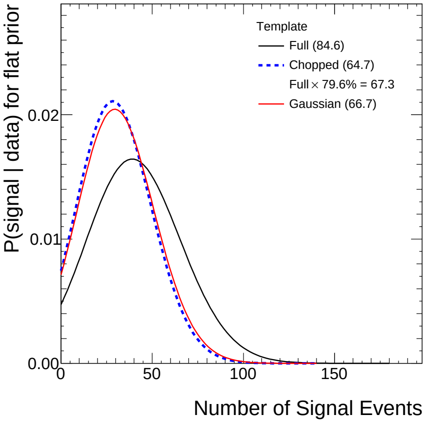
Limits to Gaussian signal templates



- Gaussian “signals”, of various means and widths.
- Approximation to virtually any resonance.
- Systematic uncertainties included, just like for specific models.

Demonstration: approximating $q^*_{1.5\,TeV}$ with a Gaussian



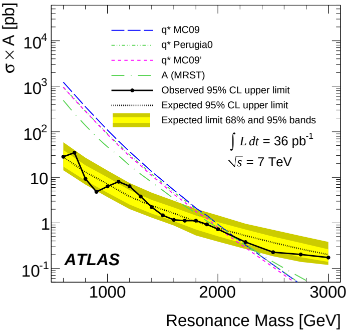


The two reasons this approximation works:

1. Limit of Gaussian $\simeq$ Limit of chopped template.
2. Limit $\propto$ acc/nce of chopping $\Rightarrow$ same mass limit, no info. lost.

Summary

- Reviewed the results from 36 pb^{-1} of 2010.
- Updated the dijet resonance search in m_{jj} with 0.81 fb^{-1} of data.
- Model-independent search (BumpHunter) found no significant discrepancy.
- Updated limits to benchmark models, like q^*. (2.91 TeV)
- Added scalar octet to the repertoire.
- Updated model-independent limits.



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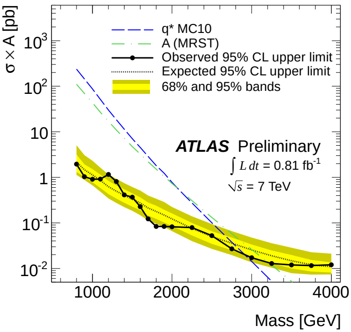


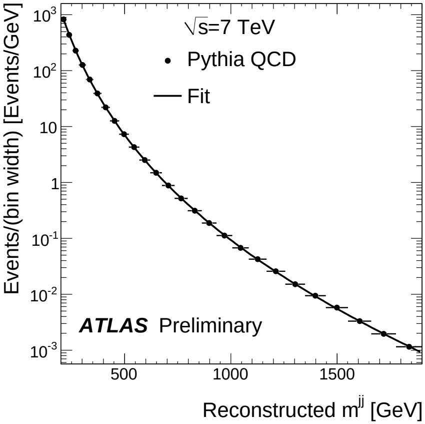
Our reach extended by about 1 TeV.

Backup

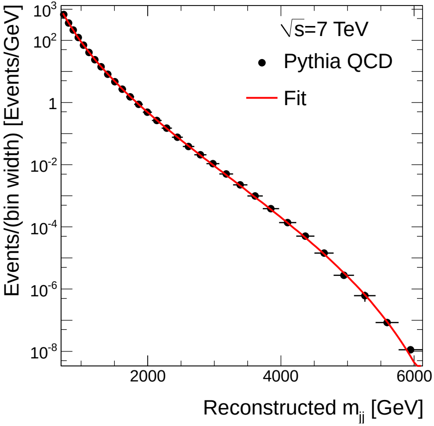
Why inclusive dijet searches?

- Well. . . because it's such an obvious thing to do! [Devil is in the detail.]
- Theoretical reasons:
  - q^* [our "benchmark"]
  - Axigluons, colorons, techni-mesons, etc.
  - Extra dimensions (e.g. Randall-Sundrum graviton, Quantum Black Holes, etc.)
  - Even String theory!
  - . . . and the list goes on . . . [Tao Han et al, arXiv:1010.4309 [hep-ph]]
- Experimental reasons:
  - Superior hadronic calorimetry.
  - Few %-level JES uncertainty [Accurate ATLAS MC, and in-situ calibration.]
  - Low sensitivity to pile-up etc.
- Analytic reasons:
  - Large SM statistics $\Rightarrow$
  - Data-driven background estimation.
  - Very high energies, from early on. [World-best results with just 0.3 pb^{-1} of data.]

Fitting PYTHIA QCD with $f(x) = p_0 \frac{(1-x)^{p_1}}{x^{p_2+p_3 \ln x}}, \quad x \equiv \frac{m_{jj}}{\sqrt{s}}$

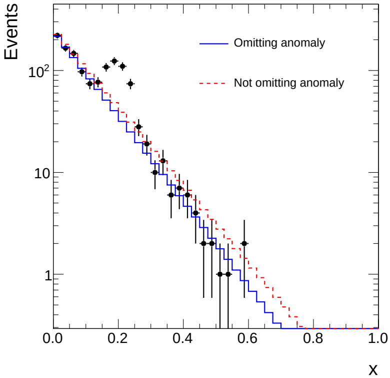


Lower masses



Higher masses

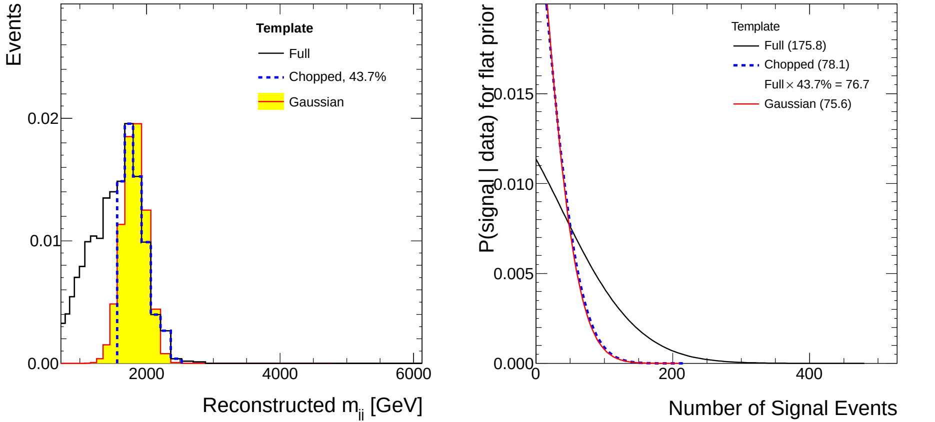
Smart fit



Demonstration taken from arXiv:1101.0390.

- To prevent potential signal from biasing the fit, we have an anti-bias mechanism.
- If the first fit gives a χ^2 p-value < 0.01, we search for windows to omit from the fit, trying to make the fit better in the sidebands.
- The window search is similar to how the BumpHunter looks for the signal.
- If a window is found that makes the χ^2 p-value > 0.01, we stop. If not, we exclude the window that does the best job.
- The result is that the signal is better defined, and easier to see, because we fit just the sidebands.
- This didn't do anything when fitting the data, but in pseudo-experiments it could kick in.

Demonstration: approximating $s8_{2TeV}$ with a Gaussian



The two reasons this approximation works:

1. Limit of Gaussian $\simeq$ Limit of chopped template.
2. Limit $\propto$ acc/nce of chopping $\Rightarrow$ same mass limit, no info. lost.

Model details

Excited quark (q^*)

- $qg \to q^* \to qg$, with SM-quark-like couplings, and compositeness scale $\Lambda = m_{q^*}$.
- PYTHIA $\to$ ATLAS sim.
- MRST2007LO* PDF [MC10 tuning, ATLAS-CONF-2010-031].

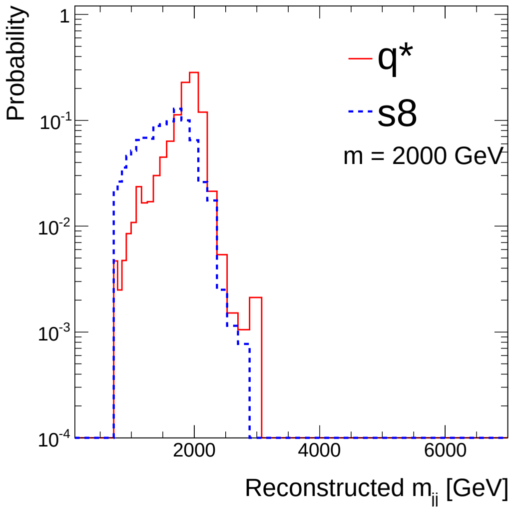
Scalar octet ($s8$)

- Taken from arXiv:1010.4309, by Tao Han et al.
- Like a spin-0 heavy gluon.
- MadGraph $\to$ PYTHIA $\to$ ATLAS sim.
- Used CTEQ6L1 PDFs [MC09' tuning, ATLAS-PHYS-PUB-2010-002].

Axigluon (A)

- CalcHEP
- MRST2007LO* PDF
- Acceptance obtained from parton-level kinematic cuts, plus chopping at $[0.7m_A, 1.3m_A]$.
- Verified, using ATLAS sim., that the chopped A gives very similar limits to the full q^* template, so, instead of using actual A templates, we use observed limits from q^* templates. [Similar treatment of A have been used before. E.g. CDF, Phys.Rev.D 79 (2009) 112002, or CMS PhysRevLett.105.211801, and more recent works.]

Comparison of signal templates



BSM lagrangian densities

Excited quark

$L_{gqq^*} = g_{QCD} \frac{f_s}{4\Lambda} \bar{q}^*_R \sigma^{\mu\nu} \lambda_\alpha G^\alpha_{\mu\nu} q_L$, $f_s \to 1$, $\Lambda \to m_{q^*}$.

Axigluon

$L_{Aq\bar{q}} = g_{QCD} \bar{q} A^\alpha_\mu \frac{\lambda^\alpha}{2} \gamma^\mu \gamma_5 q$. $A \to gg$ forbidden by Parity.

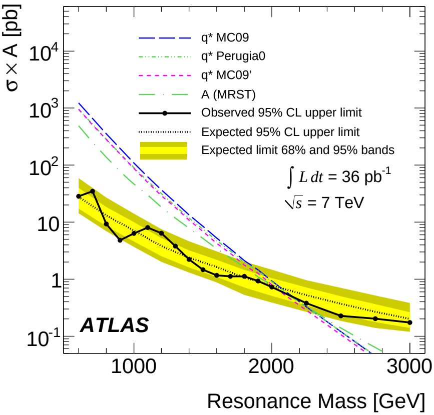
Scalar (color) octet

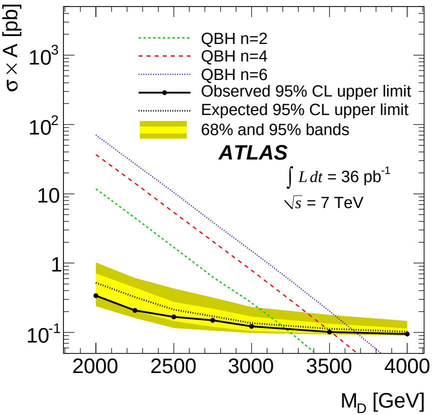
$L_{gg8} = g_{QCD} d^{ABC} \frac{\kappa_s}{\Lambda_s} S^A_8 F^B_{\mu\nu} F^{C,\mu\nu}$, S_8=scalar octet, κ_s = coupling = 1, $g^2_{QCD} = 4\pi\alpha_s$, d^{ABC}=$SU(3)$ isoscalar factor, $F_{\mu\nu}$= SM gluons tensor.

Quark contact Interaction

$L_{qqqq} = \frac{\xi g^2}{2\Lambda^2} \bar{\Psi}^L_q \gamma^\mu \Psi^L_q \bar{\Psi}^L_q \gamma_\mu \Psi^L_q$, $\frac{g^2}{4} = 1$, $\xi = +1$ (destructive interference).

Dijet m_{jj} limtis with 36 pb^{-1}





Angular analysis, in 36 pb^{-1}

- Systematic uncertainties: Jet Energy Scale, μ_R and μ_F , PDF
- Agreement between data and background:
  - The p-value of the likelihood test in $\frac{dN}{d\chi}$ is $> 30\%$ in all m_{jj} bins.

Example of Neyman construction, using $F_\chi(m_{jj} > 2$ TeV), to set QBH limits