Exotic Dijet Searches in ATLAS

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On behalf of
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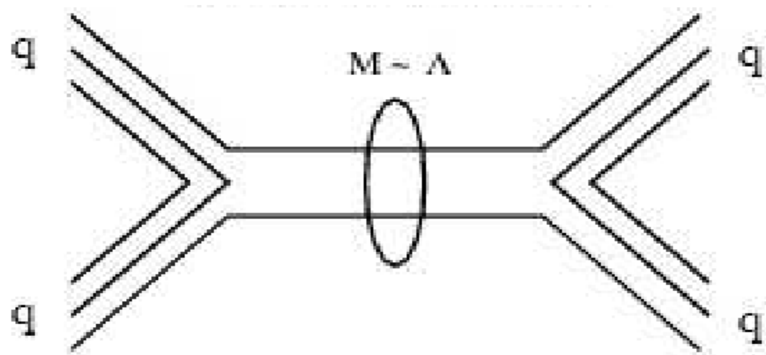
Introduction

- Dijet events in the Standard Model (SM) are well described by perturbative QCD.

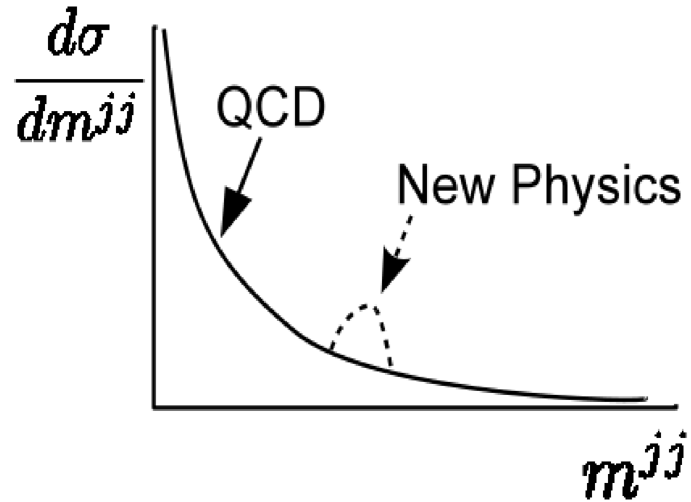
- However, many new physics scenarios predicting excess of dijet events over SM, can be studied *at the energy regime provided by the LHC;*
  - **Compositeness** (exemplifying quark substructure) → this talk
  - Extended Technicolour models
  - Chiral colour models (axigluons)

Compositeness; excited quark decays
(first part of the talk)

- Quarks may not be fundamental, but with substructure (preons)
- The substructures are visible above a compositeness scale Λ, below which quarks appear point-like
- If Λ is sufficiently low, narrow resonant states of excited quarks could be produced at the LHC energies.



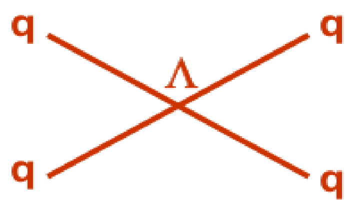
$$L = \frac{g_s f_s}{4M} \bar{q}*_R \sigma^{\mu\nu} \lambda_a G^a_{\mu\nu} q_L + h.c.$$



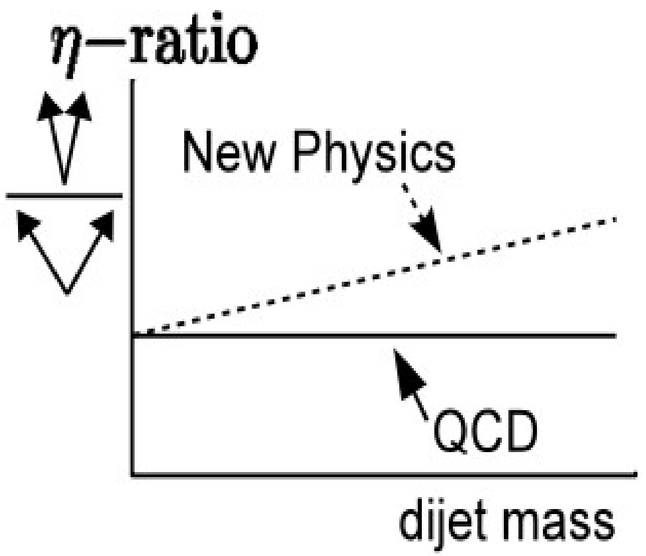
Compositeness; quark contact interactions
(second part of the talk)

- If Λ is much larger than the centre of mass energy of the colliding partons, the manifestation of compositeness will be an effective 4-fermion contact interaction

$$L_{qqqq}(\Lambda)=\frac{\xi g^2}{2\Lambda_q^2}\bar{\Psi}_q^L\gamma^\mu\Psi_q^L\bar{\Psi}_q^L\gamma^\mu\Psi_q^L, g/4\pi=1, \eta=+1$$



- New processes produce more central activity than QCD → *an increase in the centrality ratio R_C above some dijet mass threshold ;*
  - R_C; ratio of dijet events with the 2 highest pt jets both in the central region(| η | < 0.7) to those with the 2 highest pt jets in the non-central region(0.7 < | η | < 1.3).
  - The Jet Energy Scale(JES) is uniform to within 1% in the region | η | < 1.3.



Observables

- First part: Dijet Resonance searches with 3.1 pb^{-1} of 7 TeV LHC data;
  - With the dijet invariant mass as the observable:

$$m_{jj} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

- Second part: Quark contact interactions searches with 3.1 pb^{-1} of 7 TeV LHC data;
  - With the dijet η-ratio R_C as the observable:

$$R_C = \frac{N(|\eta_{1,2}| < 0.7)}{N(0.7 < |\eta_{1,2}| < 1.3)}, N: number\ of\ events$$

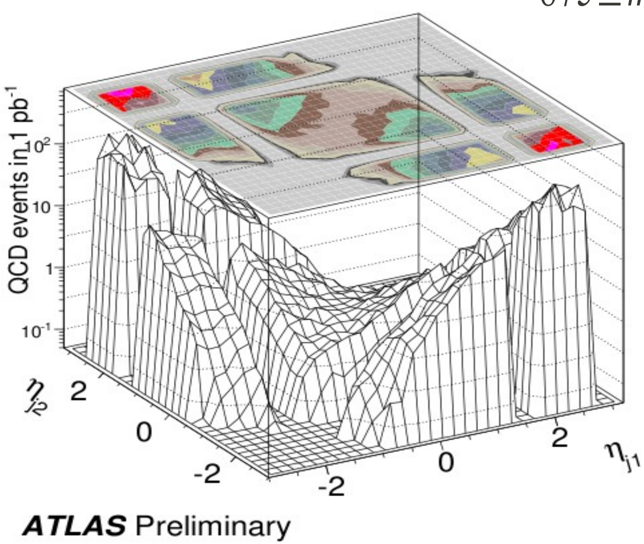
Dijet Resonance Searches

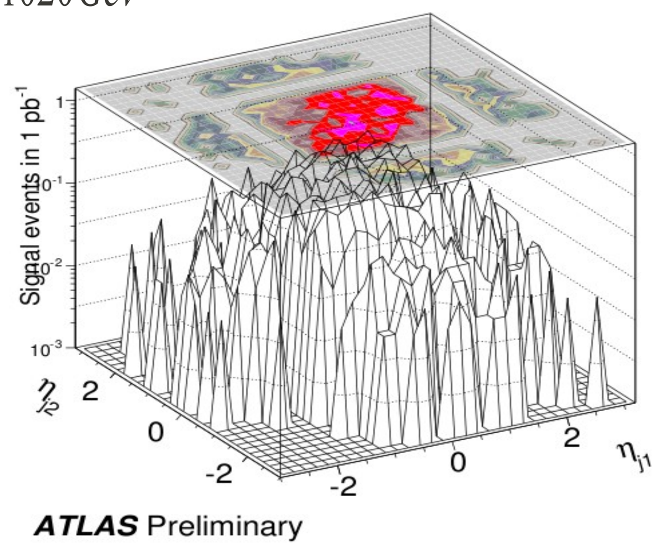
Event Selection

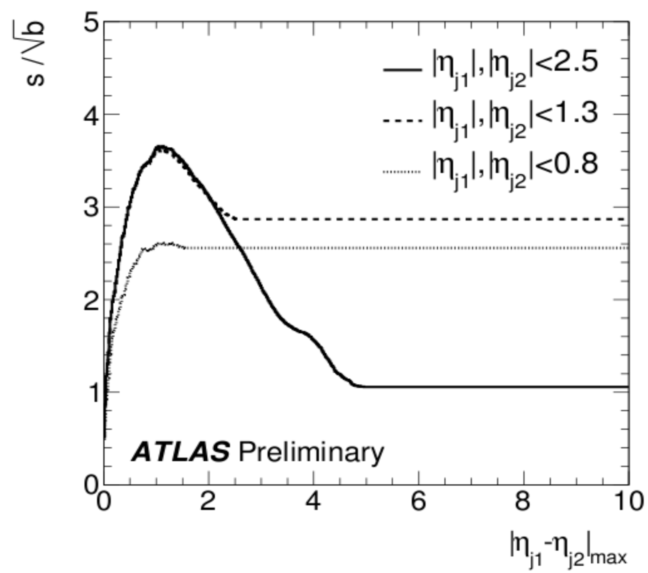
Jet algorithm: AntiK$_t$ with a radius parameter R = 0.6
Input to jet finding: Topological Clusters
Jet Calibration: p_t- η dependent calibration factors based on Monte Carlo

- Events with at least 2 jets with:
    - Leading jet p_T > 150 GeV, 2[nd] jet p_T > 30 GeV
    - $|\eta_{1,2}| < 2.5$ (except $1.3 < |\eta| < 1.8$) & $|\Delta\eta_{1,2}| < 1.3$, for the 2 leading jets
        - By optimising the signal from q* decay compared to the SM QCD background.
- Veto on events with a poorly measured jet above 15 GeV
- Apply the standard event quality cuts (Back Up)

$$875 \le m^{jj} \le 1020\,Gev$$



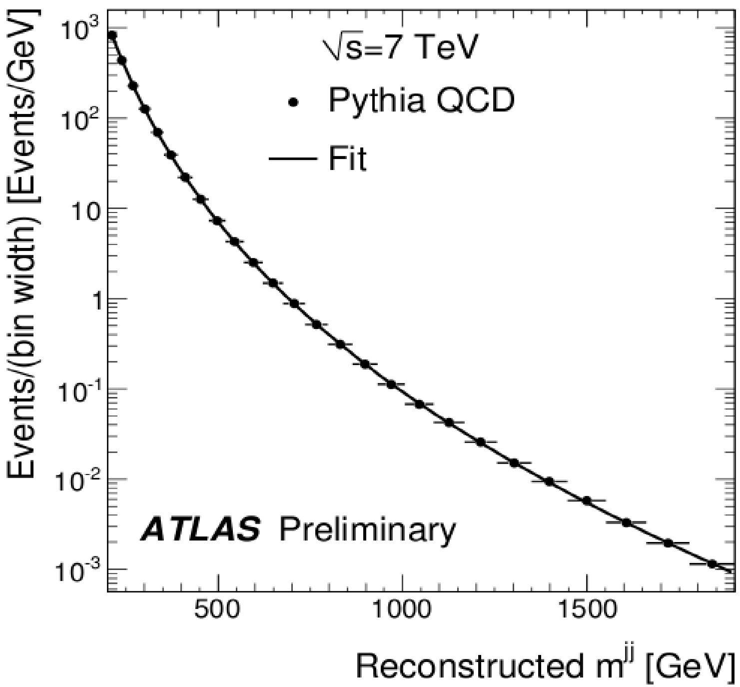




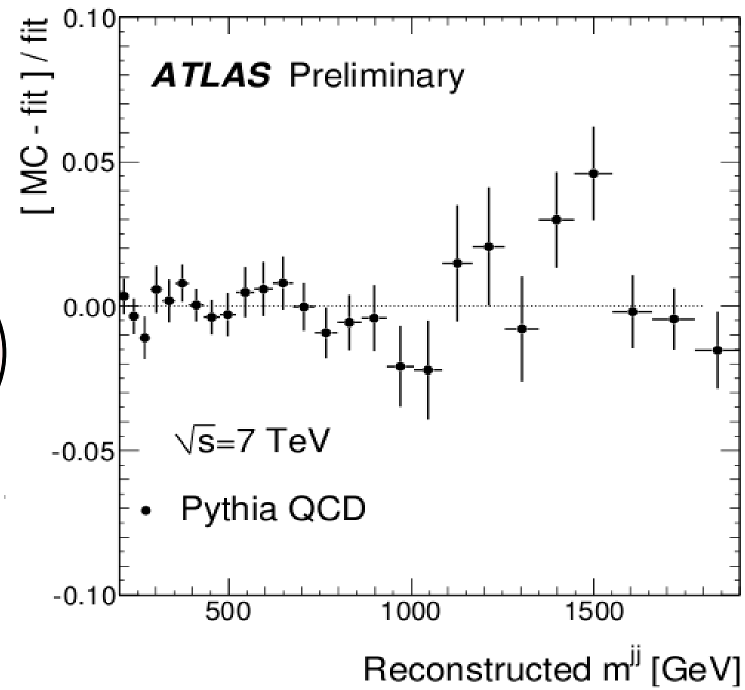
Background Determination

- The QCD background shape is determined by fitting this smooth & monotonically decreasing function to *data*:

$$f(x) = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x}, \quad x \equiv m^{jj}/\sqrt{s} \qquad (1)$$



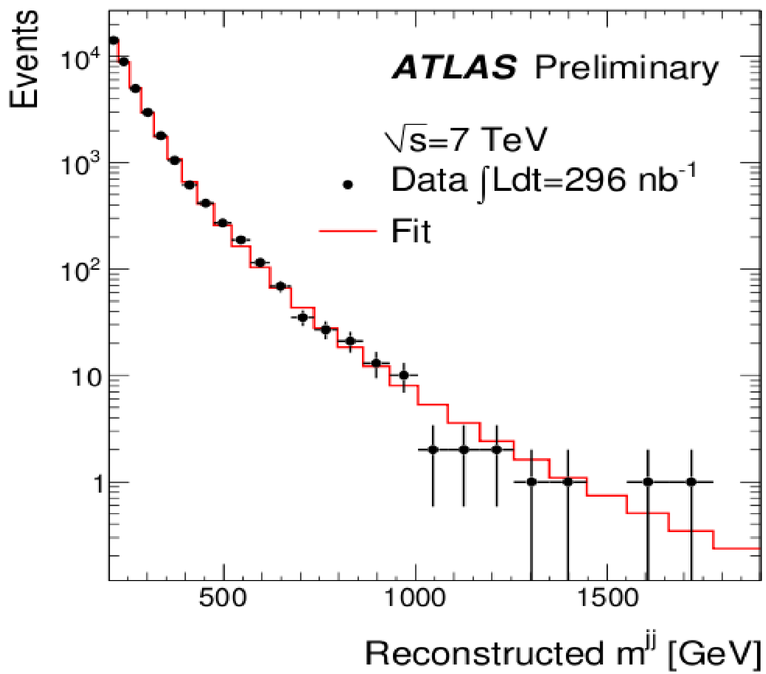
The fit function describes QCD dijet-mass distribution well; χ^2/NDF of 27/22

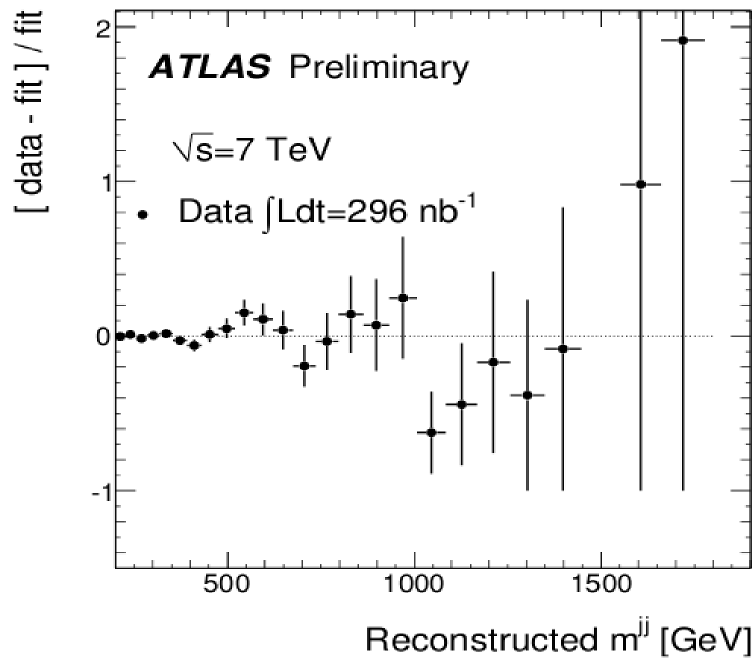


Search for a Shape Difference

- Consistency between data and background is checked using an array of statistical tests, sensitive to bumpy structures and overall disagreement.
- Large p-values of "data being described by SM prediction", from all the tests were obtained

→ **No significant discrepancy**

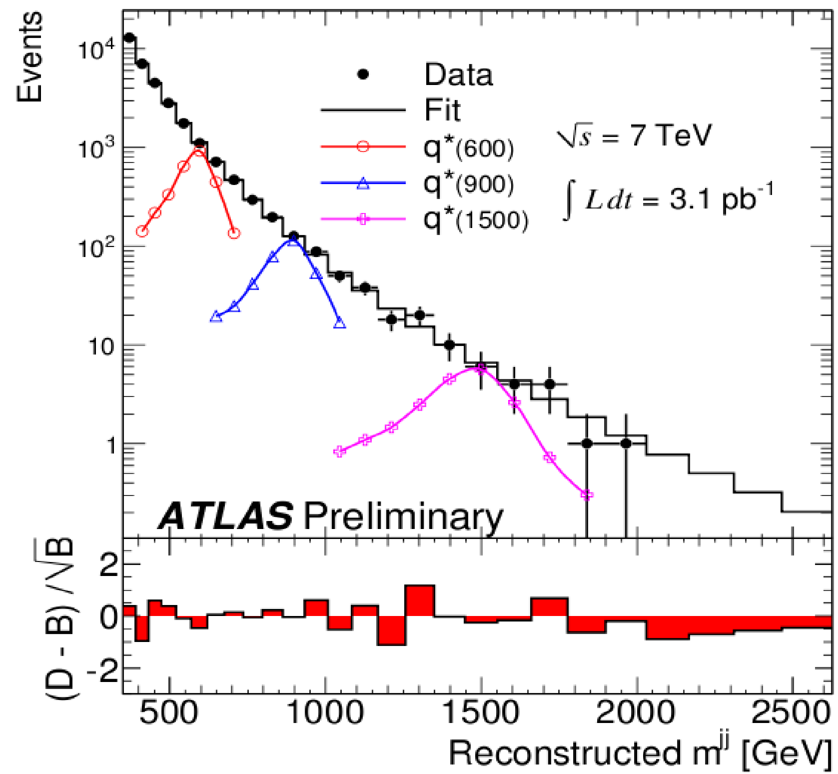




Set Limits on the q* mass

- A Bayesian approach to set 95% confidence level upper limits on σ.*A* (cross-section * Detector Acceptance)
    - A flat prior in the signal yield is assumed.
    - Systematic uncertainties considered as nuisance parameters in the calculation of the likelihood
- *Data-driven* normalisation of the background;
    - A simultaneous fit of background (eq1) and signal to data.

Signal acceptance
(including reconstruction & trigger efficiencies)
~ 31% - 48%
for q* mass 300GeV-1.7TeV



Dominant Sources of Systematic Uncertainties

- The Jet Energy Scale (JES) uncertainty
  - as a function of jet p_T & η; within 6-9%
- The background fit parameters uncertainty
  - due to the finite statistics in determining the fit parameters from data.
  - Varies from ~ 3% at low dijet mass, to ~ 30% at high dijet mass.
- The integrated luminosity uncertainty
  - estimated to be ±11% on $\sigma.\mathcal{A}$.
- The Jet Energy Resolution (JER) uncertainty
  - taken to be ±14% on the fractional p_T resolution of each jet.
  - Found to have negligible effect compared to the other three sources.

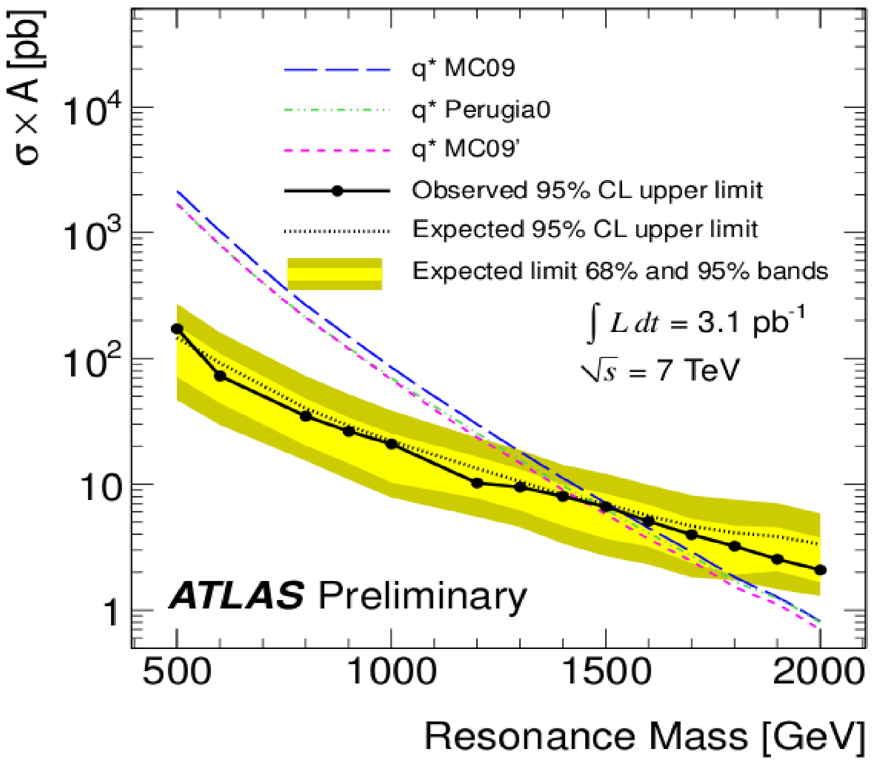
The 95% CL Upper Limits on σ.*A*

- Lower limits on the excited quark mass:
  - Intersection of the 95% CL curve with a theoretical prediction
  - Expected limits; by replacing data by pseudo-data*

A 95% CL q* exclusion mass region,
using MRST2007 PDF & MC09 tune:
[0.30,1.53] TeV

*pseudo-data: generated by random fluctuations around the fit of eq(1) to data.

*Yellow band: statistical fluctuations.



Dijet Centrality Ratio Searches

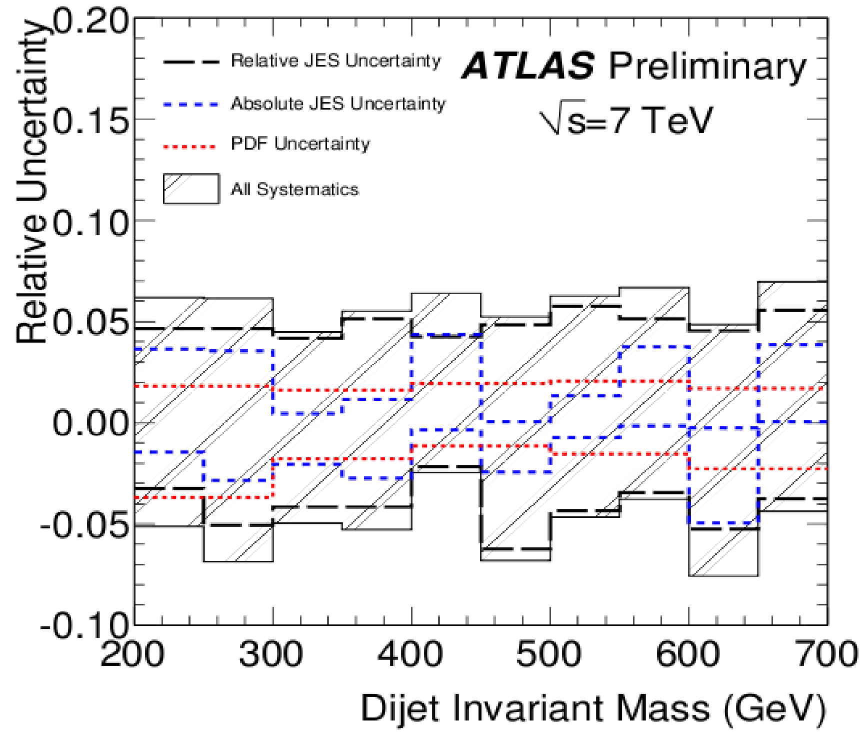
Event Selection

- Select events with at least two jets;
  - Leading jet $p_T > 60$ GeV, 2^{nd} jet $p_T > 30$ GeV
    - Asymmetric thresholds to avoid suppression of events with a 3^{rd} jet coming from radiation.
  - $|\eta| < 1.3$ for the 2 highest pt jets
    - where the jet energy scale is known with high precision.
    - Central events: $|\eta_{1,2}| < 0.7$ (R_C definition; slide 4)
    - Non-central events : $0.7 < |\eta_{1,2}| < 1.3$
- Veto on events with a poorly measured jet above 15 GeV
- Apply the standard event quality cuts

Systematic Uncertainties

- Experimental uncertainties:
  - Jet Energy Scale; p_T & η-dependent; 5-7%

    → results an uncertainty of up to 7% on R_C
- Theoretical uncertainties:
  - NLO QCD renormalisation & factorisation scales
  - PDF uncertainties; up to 2%.



→ Monte Carlo(MC) Pseudo-Experiments are generated to convolute these sources of uncertainties.

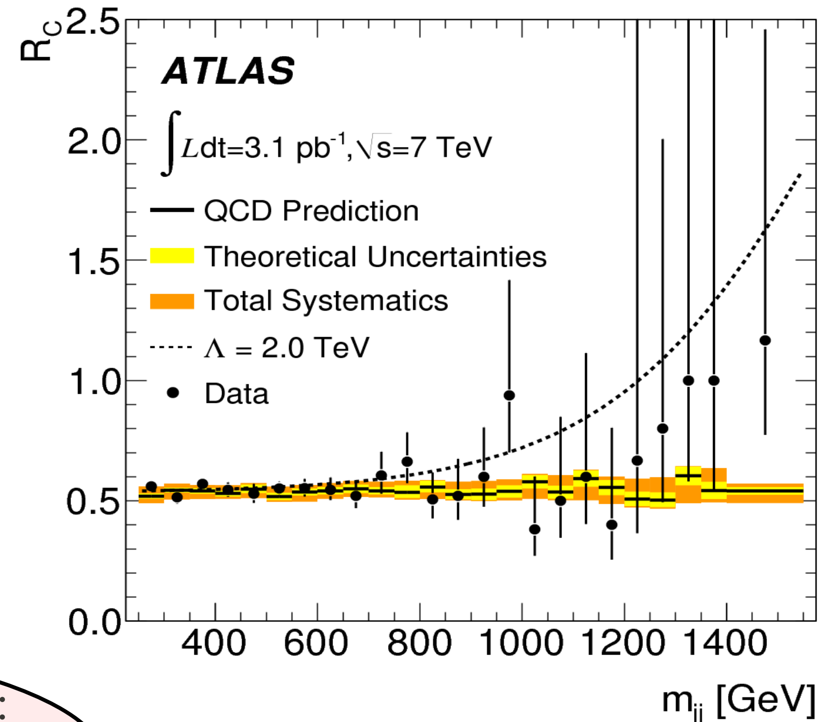
Comparison to QCD, and Bayesian Limits on the Compositeness Scale Λ

- Chi-square goodness-of-fit test;

  χ^2 / NDF = 0.66 , p-value = 0.85

  → good agreement with QCD prediction

- Bayesian method to set limits;
  - Background determination is based on QCD Monte Carlo
  - Flat priors in $1/\Lambda^2$ or $1/\Lambda^4$ are assumed.



95% CL lower limit on the quark compositeness scale:

Λ = 2.0 TeV

(Expected limit: 2.6 TeV)

Summary

- Dijet resonance search;
  - Data agrees well with the fit; no evidence of resonance
  - 95% CL limit on the excluded region of the q* mass with **3.1 pb^{-1}: [0.3,1.53] TeV**

    [arXiv :1008.2461]
    - Latest limit from Tevatron: [260,870] GeV [*arXiv: 0812.4036]*
    - Latest limit from CMS: [0.5,1.58] TeV, with 2.9 pb^{-1}
- Dijet centrality ratio search;
  - Good agreement with QCD
  - 95% CL lower limit of **2.0 TeV** on the compositeness scale, with **3.1 pb^{-1}** ***[arXiv: 1009.5069]***
    - Latest limit from D0: 2.4 TeV, with different η cuts in R_C definition: *[PRL 82: 2457–2462]*

Limits will be soon updated
using more LHC data!

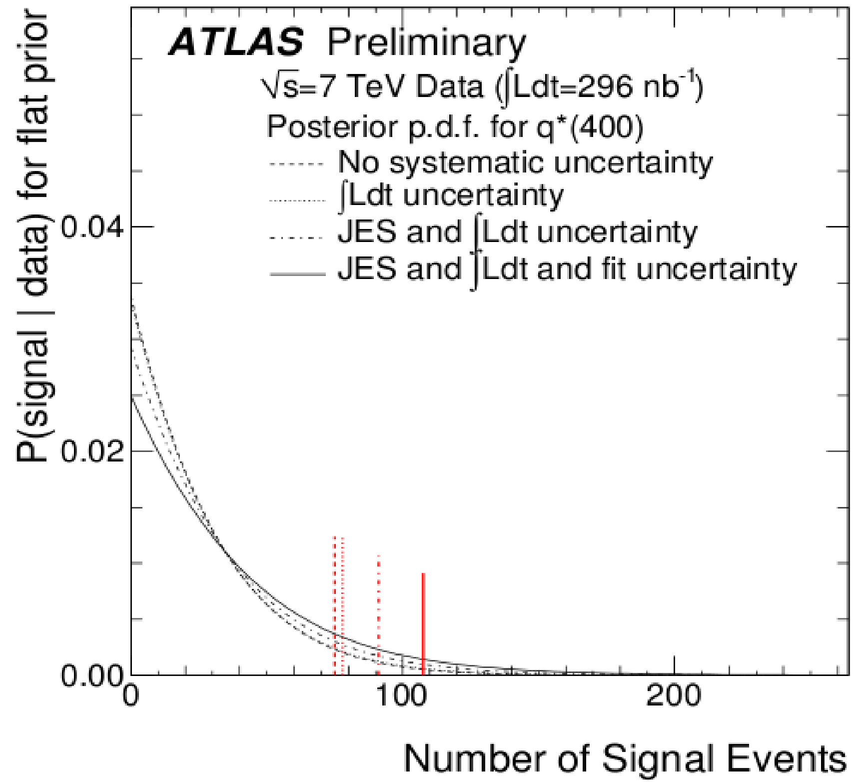
→ For the dijet χ distribution search, please see Lorraine Courneyea's slides [Tuesday Exotics Session] .

Back Up

Effect of Uncertainties on the Posterior

- All the four sources of uncertainties are treated as p_T and η-dependent *nuisance parameters* in the likelihood function

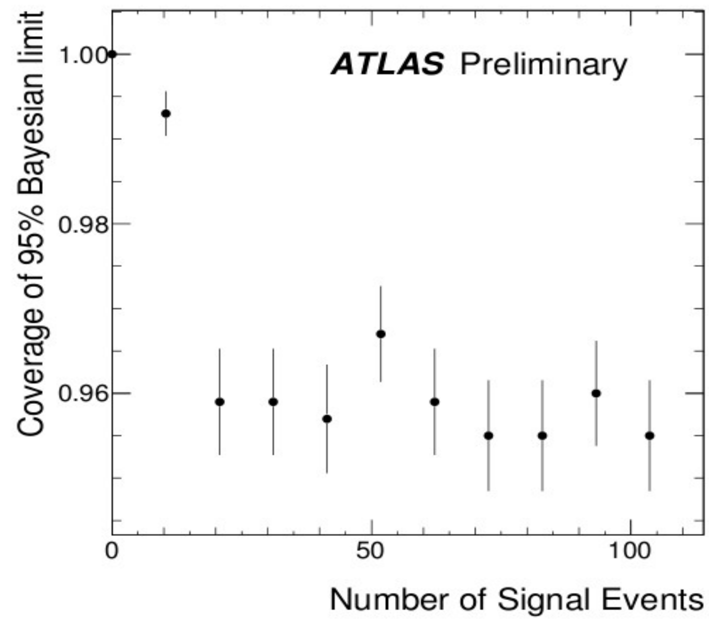
- Integrating the resulting posterior for each of the q* masses → 95% CL upper limits



Frequentist coverage of the Bayesian limit
(Dijet Resonance Search)

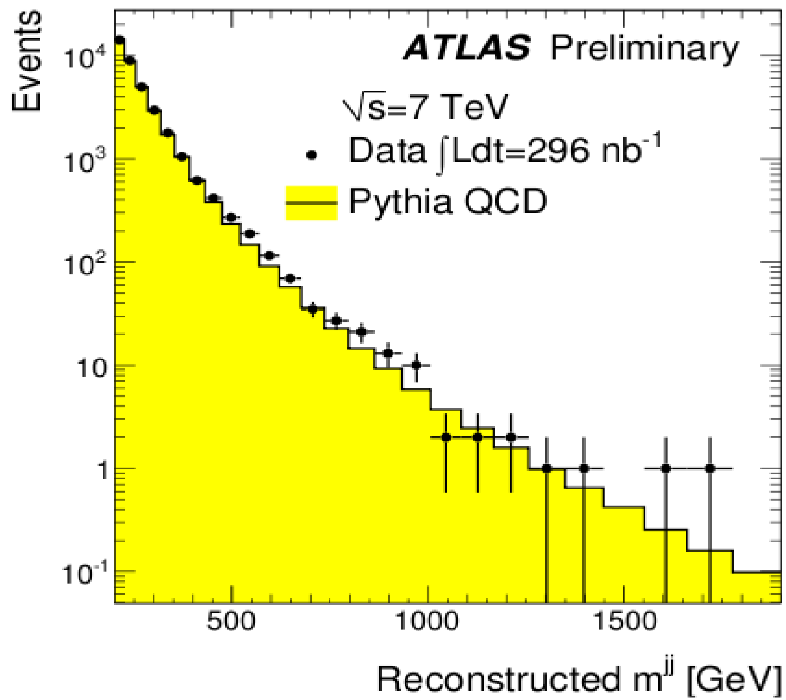
- A series of pseudo-experiments to determine the *coverage* of the 95% CL Bayesian limits;
  - *The fraction of pseudo-experiments with number of signal yield in the Bayesian confidence interval.*
- The coverage probabilities lie in the vicinity of 95% → compatibility between Bayesian & Frequentist approaches.

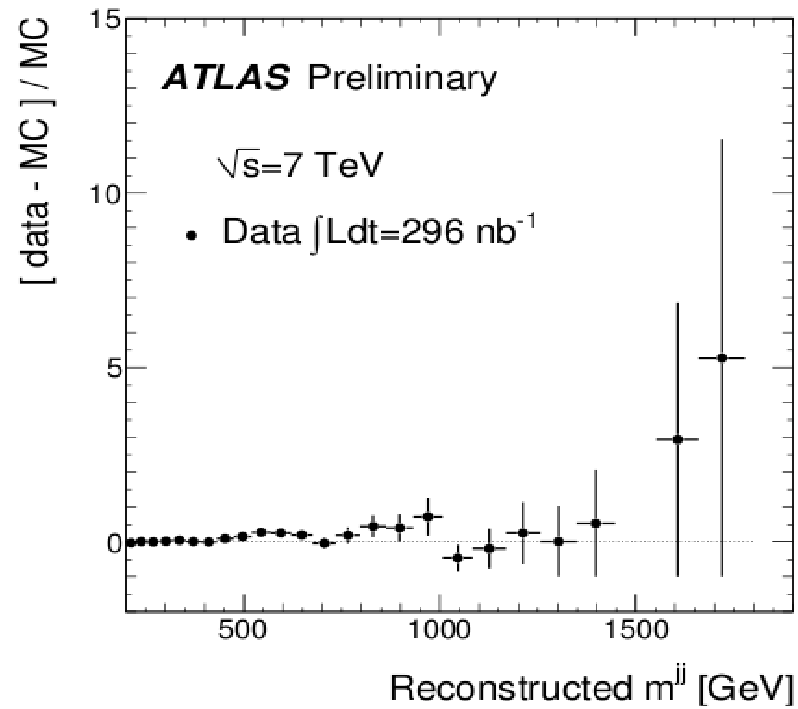
m_{q*} = 900 GeV



Comparing data to LO QCD from Pythia
(Dijet Resonance Search)

- Smaller p-values compared to those computed from the fit to eq(1)
  - Data agrees less well with the LO Pythia QCD prediction than with the fit.





Complete Event Selection

- At least one primary collision vertex with at least 5 tracks associated to it.
- Only jets with $| \eta | < 2.8$ are considered:
  - to avoid regions where the jet calibration has unknown systematic uncertainties.
- P_T Cut of the leading jet; based on the Level 1 jet trigger plateau
- P_T Cut of the next-to-leading jet; based on the jet reconstruction efficiency
- Bad quality jets:
  - Single-cell jets in the Hadronic End-Caps (HEC)
  - jets with bad-quality cells in the Electromagnetic calorimeter
  - Out-of-time jets (from large out-of-time energy depositions in the calorimeter)

q* mass limits with various PDFs

- 0.3 < m < 1.53 TeV (expected limit: 1.51 TeV) [MRST2007 LO*]
- 0.3 < m < 1.45 TeV (expected limit: 1.43 TeV) [CTEQ6L]

Anti-Kt Jet Algorithm

- For each input object (Topological Clusters), d_{ij} & d_{iB} are defined as:

$$d_{ij} = min(p_{Ti}^{-2}, p_{Tj}^{-2}) \frac{\Delta R_{ij}^2}{R^2}$$

$$d_{iB} = p_{Ti}^{-2}$$

$$\Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

- A list of d_{ij} & d_{iB} are formed;
  - If d_{ij} is the smallest entry; objects i & j are combined & the list is remade
  - If d_{iB} is smallest, it is a jet by itself
- Anti-Kt algorithm can be implemented in NLO QCD calculations
- The algorithm also produces geometrically well-defined (cone-like) jets.