First Searches for New Physics at the LHC

Outline

- Overview
- Dijet Resonances
- Dijet Angular Effects
- Multibody States

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Physics at the Terascale
Dresden, 1–3.12.2010

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

ATLAS and CMS BSM Search Results 2010

Based on a few months of data taking ($L \sim 100\,nb^{-1} - 10\,pb^{-1}$)

CMS

Dijet Resonances	PRL 105, 211801
Quark Compositeness with the Dijet Centrality Ratio	arXiv:1010.4439, accepted by PRL
Stopped Gluinos	arXiv:1011.5861, submitted to PRL
Scalar Leptoquarks Using Events Containing Two Electrons And Two Jets	CMS-PAS-EXO-10-005
Heavy Stable Charged Particles	CMS-PAS-EXO-10-004
Methods for Data-Driven Background Estimation in SUSY Searches	CMS-PAS-SUS-10-001

ATLAS

New Particles in Two-Jet Final States	PRL 105, 161801
Quark Contact Interactions in Dijet Angular Distributions	arXiv:1009.5069, accepted by PLB
High-mass states with electron plus missing transverse energy	ATLAS-CONF-2010-089
Multi-body final states at high invariant masses	ATLAS-CONF-2010-088
Supersymmetry with missing E_T and b-jets	ATLAS-CONF-2010-079
Background studies to searches for long-lived stopped particles	ATLAS-CONF-2010-071
Supersymmetry with jets, missing E_T and one or more leptons	ATLAS-CONF-2010-066
Supersymmetry with jets and missing E_T	ATLAS-CONF-2010-065

ATLAS and CMS BSM Search Results 2010

Based on a few months of data taking ($L \sim 100\,\text{nb}^{-1} - 10\,\text{pb}^{-1}$)

- **CMS**
  7 contributions prepared for conferences 2010
  3 results subsequently submitted for publication
- **ATLAS**
  8 contributions prepared for conferences 2010
  2 results subsequently submitted for publication

This talk: results extending previous limits, or searches of new type

$\longrightarrow$ **Exotic signatures involving jets**

- Dijet resonances
- Dijet angular effects
- Multi-body final states

Searches for Narrow Dijet Resonances

Generic search for resonance shape in dijet mass spectrum

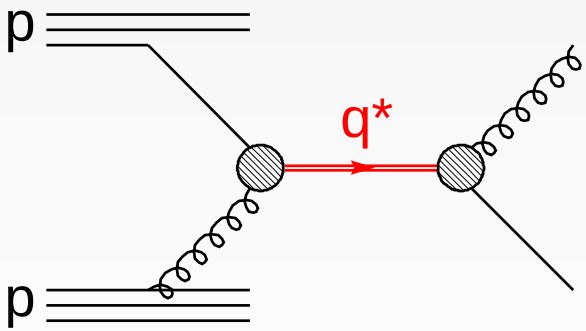
Typical first search: simple signal and possibly large cross-section of new physics

Models

- Excited quarks

  If quarks have substructure, expect excited states
  Benchmark model as used in previous searches of this kind

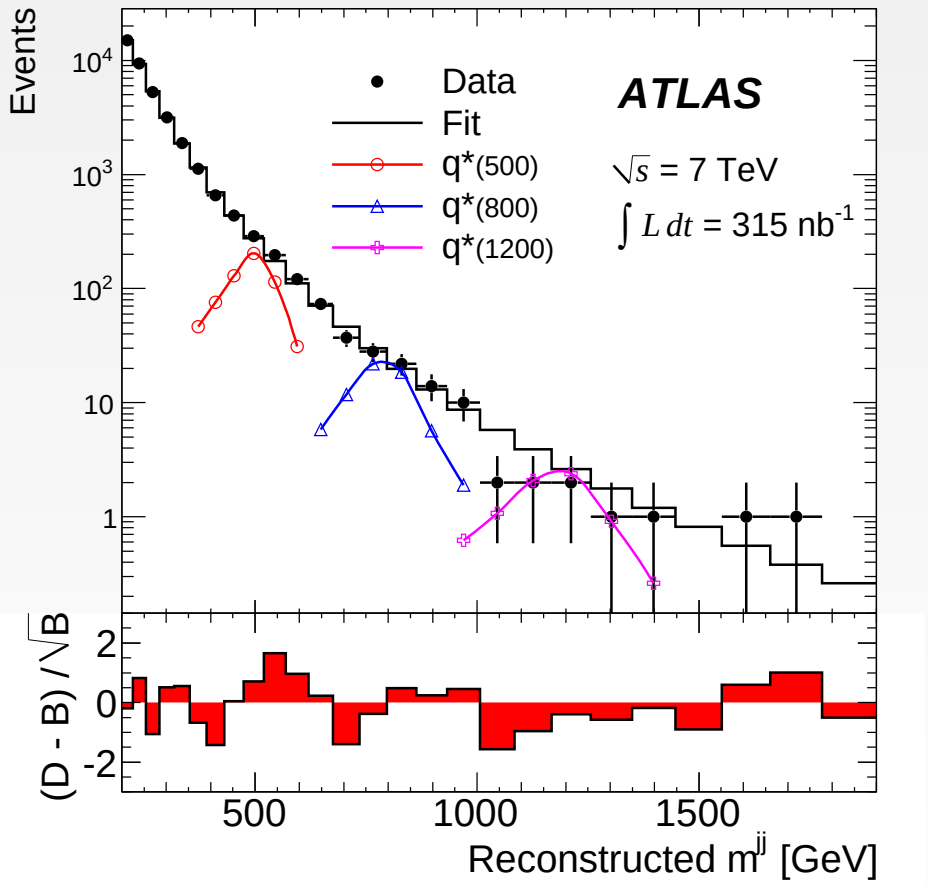
- String resonances
- Axigluons in chiral color models
- Flavour-universal color-octet colorons
- Techni-ρ meson in extended technicolor models
- Diquarks in superstring-inspired E_6 GUT model
- W' / Z' resonances in GUT theories
- Graviton excitations in warped extra dimensions



Dijet Mass Distributions

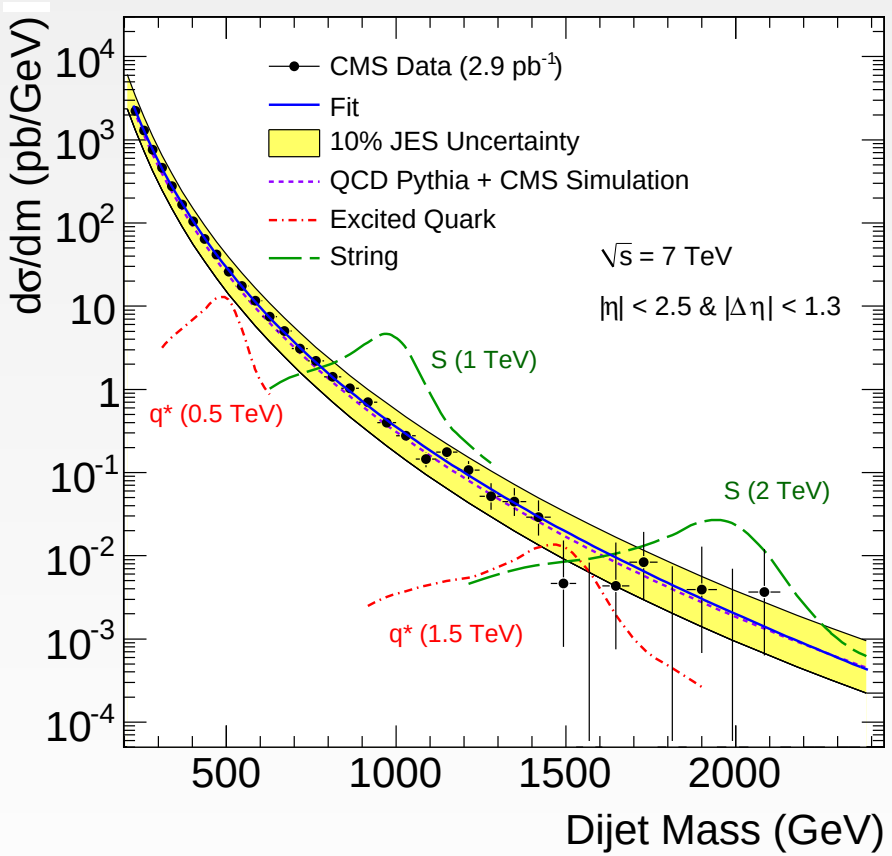
ATLAS $L = 315\,nb^{-1}$

PRL 105 (2010) 161801



CMS $L = 2.9\,pb^{-1}$

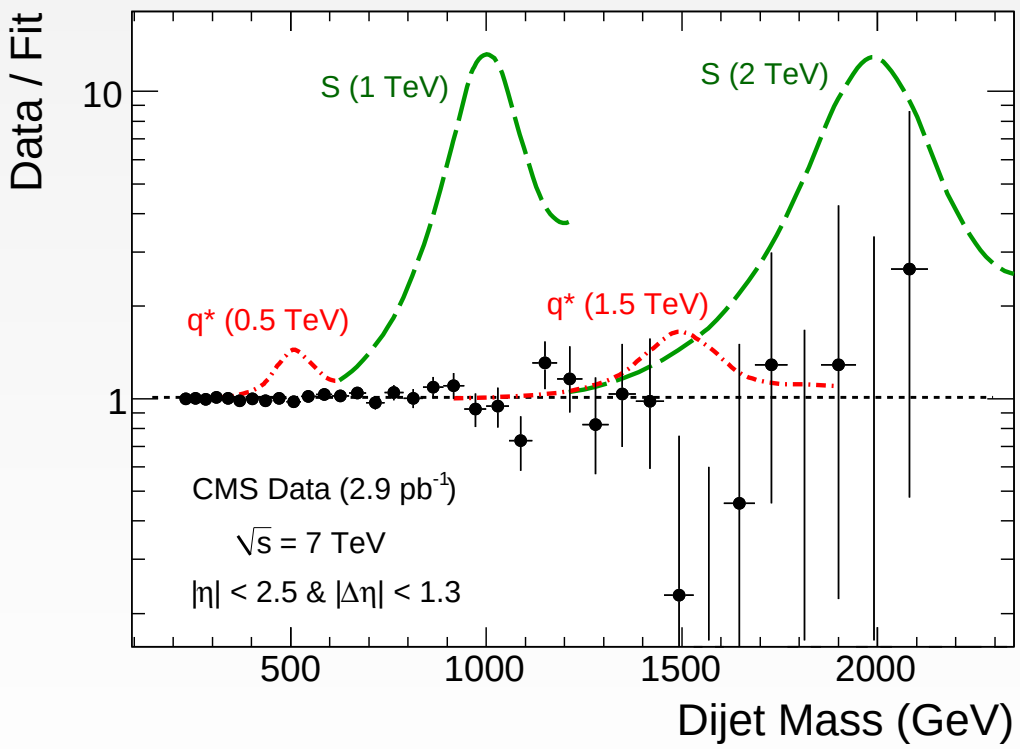
PRL 105 (2010) 211801



$S/\sqrt{B}$ Optimisation: $|\Delta\eta_{12}| < 1.3$

Dijet Resonance Search Analysis

- Fit the M_{jj} spectrum by a smooth function
  The same functional form is used by CMS and ATLAS
- Test statistical compatibility of the fit with null hypothesis
  ATLAS: 6 different statistical tests
- Use simulated resonance shapes
  at different M_{jj} points to set limits
  CMS tested different models and
  studied shapes for qq, qg, gg separately

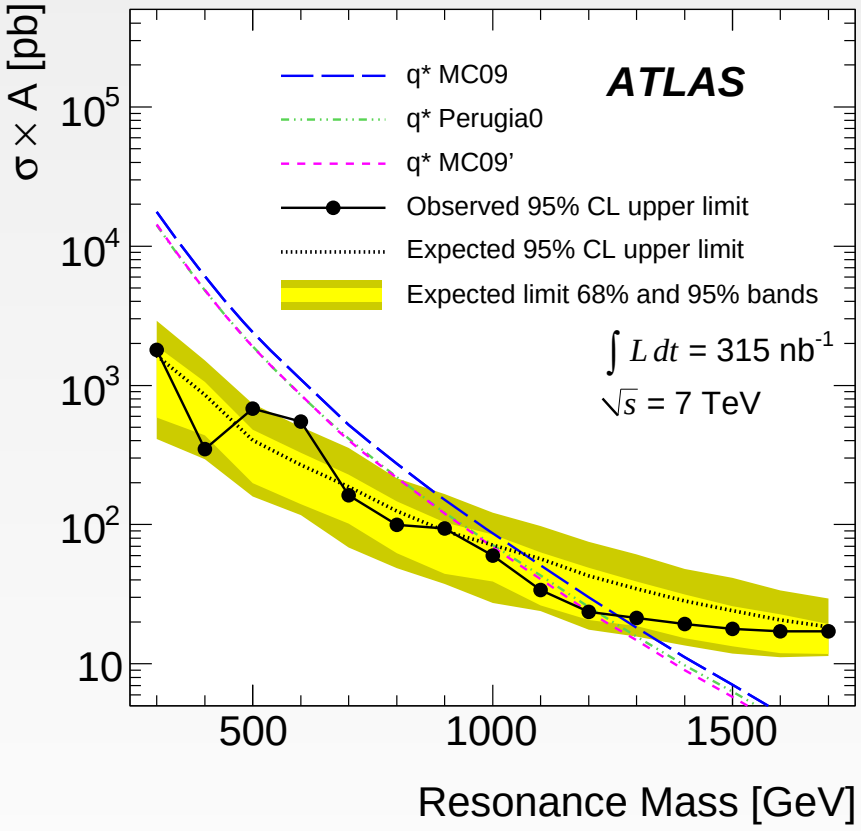


Main systematics

- Jet Energy Scale (JES)
- Integrated luminosity
- Choice of background fitting function
- Jet Energy Resolution (JER)

Exclusion Limits for Dijet Resonances

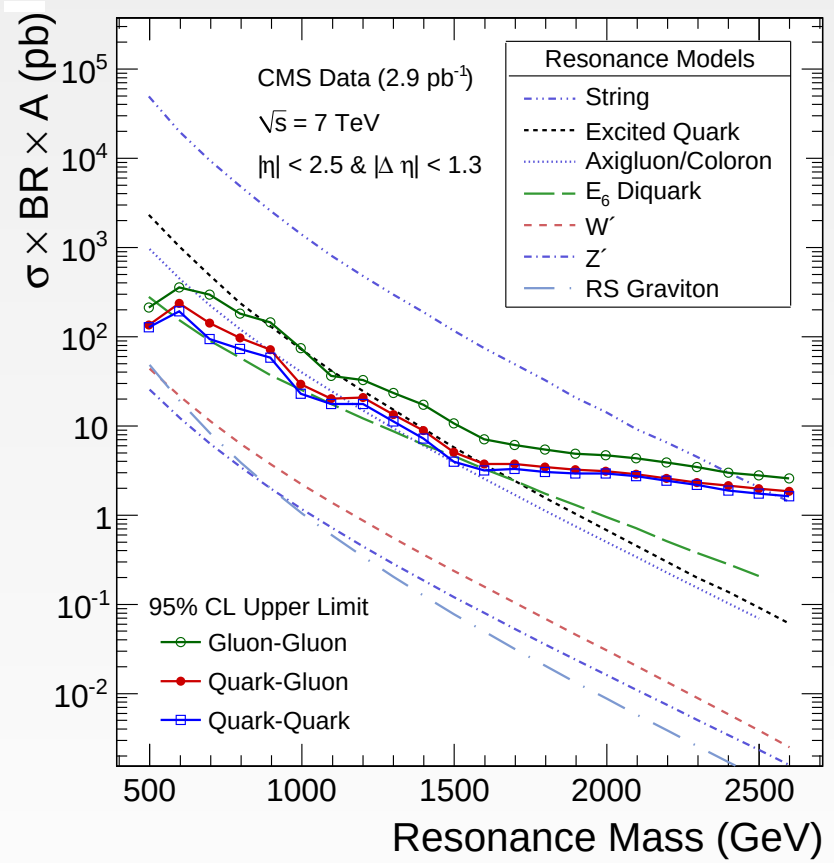
ATLAS $L = 315\,\mathrm{nb}^{-1}$



excited quarks: $0.30 < M_{q^*} < 1.26\,\mathrm{TeV}$

Tevatron: $260 < m_{q^*} < 870\,\mathrm{GeV}$ $(L = 1.13\,\mathrm{fb}^{-1})$

CMS $L = 2.9\,\mathrm{pb}^{-1}$



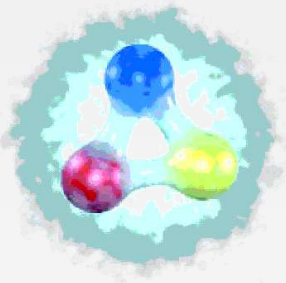
excited quarks: $0.50 < M_{q^*} < 1.58\,\mathrm{TeV}$,
string resonances: $0.50 < M_S < 2.50\,\mathrm{TeV}$,
axigluons, colorons, E_6 diquarks

Dijet Angular Distributions

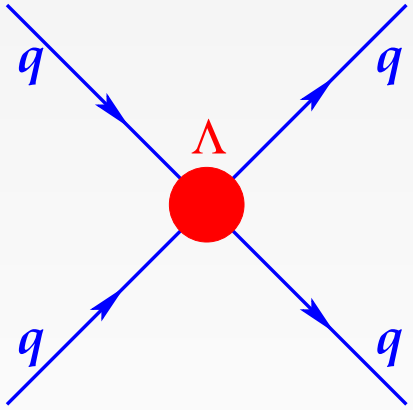
New physics may manifest itself as continuum deviation from SM in jet p_T spectra
Many models (see slide 3)

- Quark compositeness – benchmark model

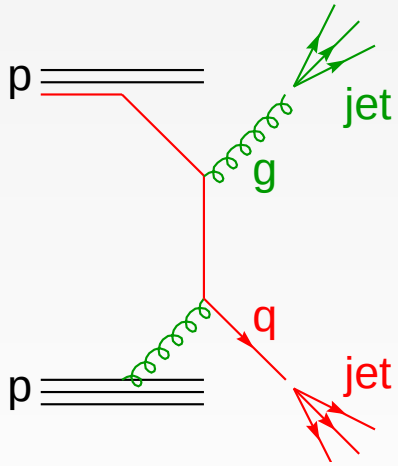
  Fundamental constituents are bound by new strong force with scale Λ
  At $E \ll \Lambda$ new force is visible in quark interactions as contact interaction



Compositeness



SM forward peak



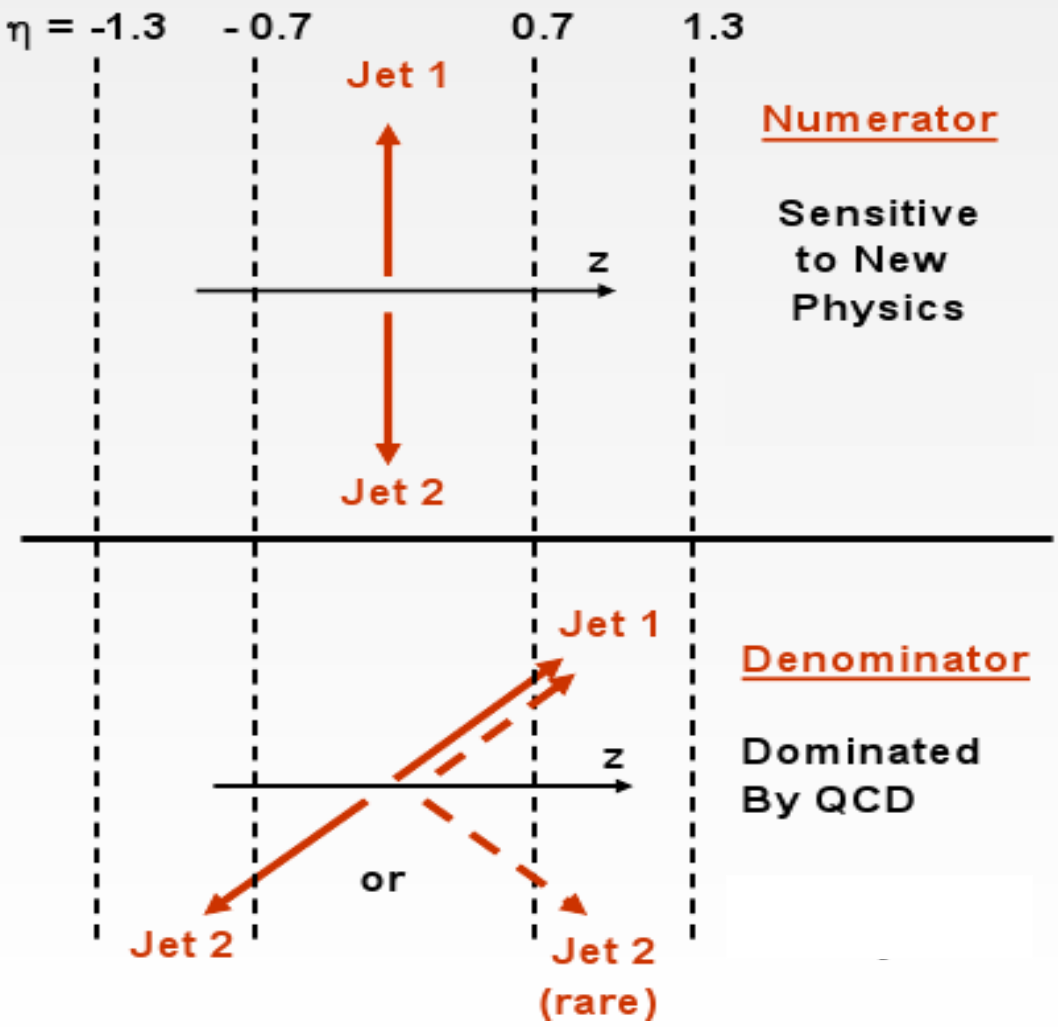
Require very good knowledge of JES and precise QCD predictions
Instead, make use of angular distributions → many systematics are cancelled

Dijet Centrality Ratio

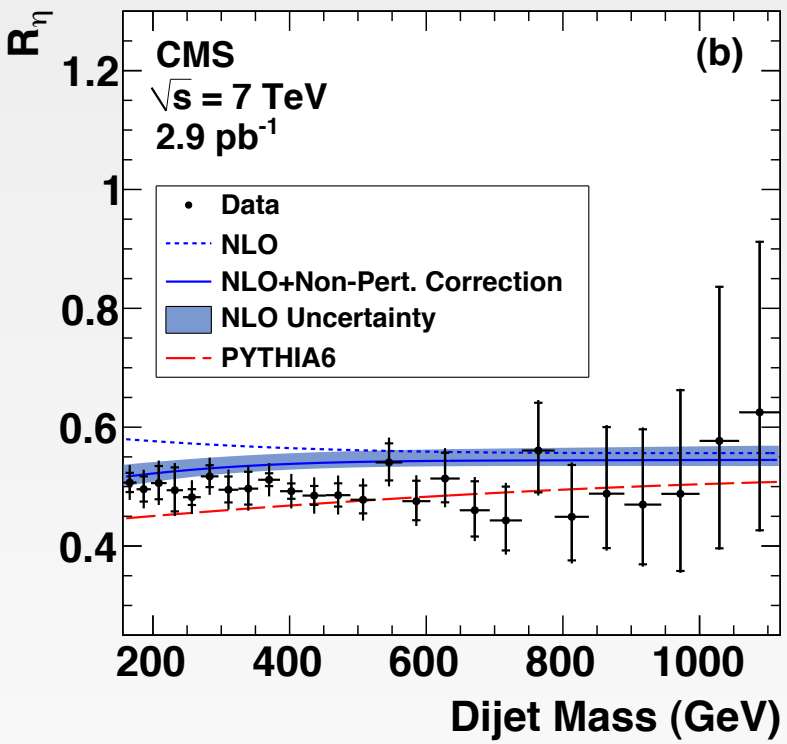
CMS $L = 2.9\,pb^{-1}$

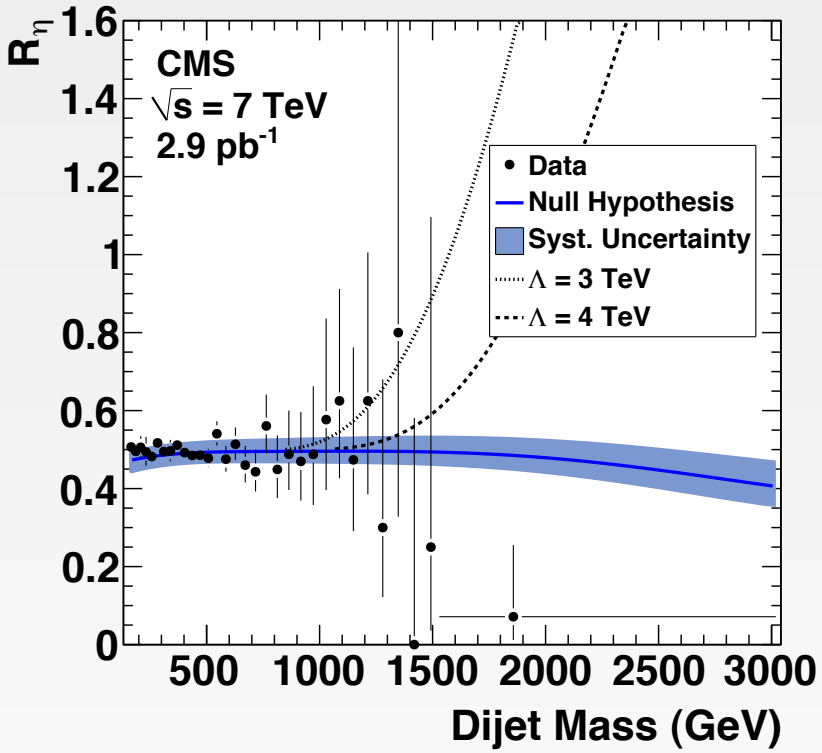
arXiv:1010.4439 (acc. by PRL)

$$R_\eta = \frac{N(|\eta| < 0.7)}{N(0.7 < |\eta| < 1.3)}$$



CMS Dijet Centrality Ratio Analysis



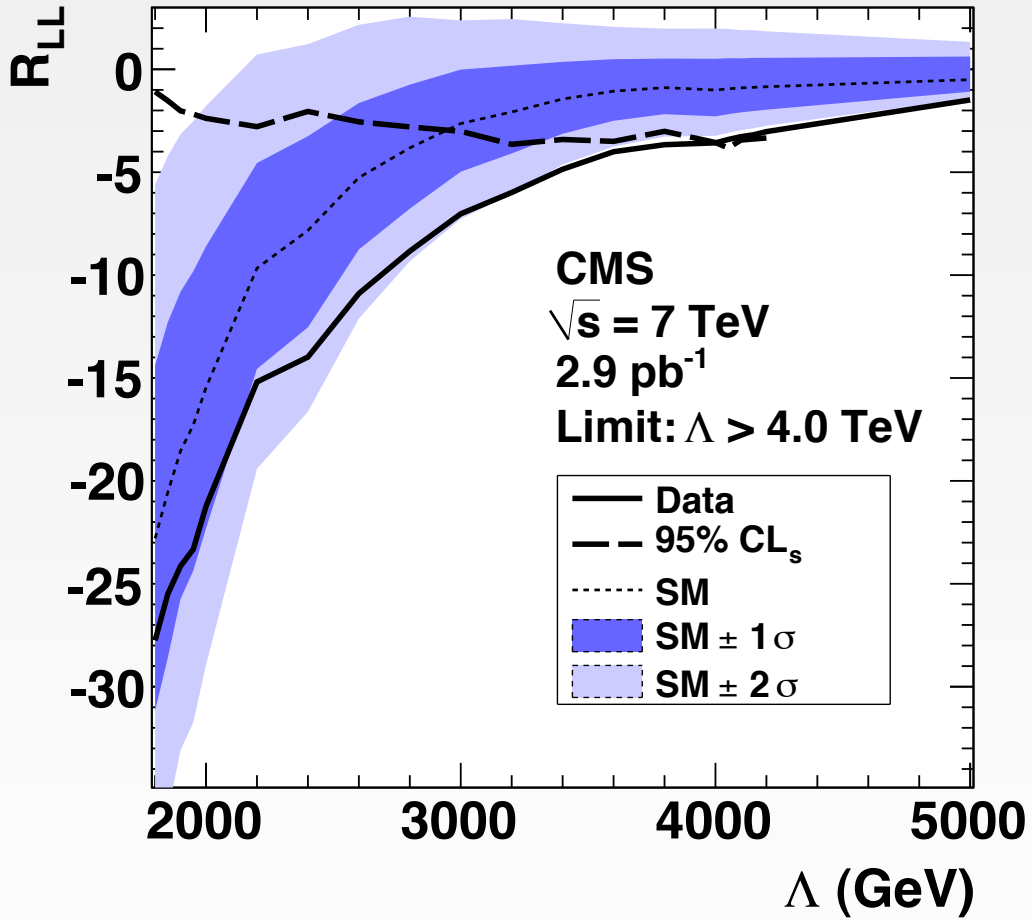


- In QCD, R_η is nearly flat as a function of M_{jj}
- Take NLO corrected for hadronisation as SM prediction
- Data lie between corrected NLO and Pythia predictions

- **Main systematics:** relative difference in JES
  QCD modelling (NLO ↔ Pythia)

Results of CMS Dijet Centrality Ratio Analysis

- Use log likelihood ratio: $\mathcal{R} = \ln \mathcal{L}_{\text{alt}} - \ln \mathcal{L}_{\text{QCD}}$



- Excluded: $\Lambda < 4\,\text{TeV}$ at 95% CL

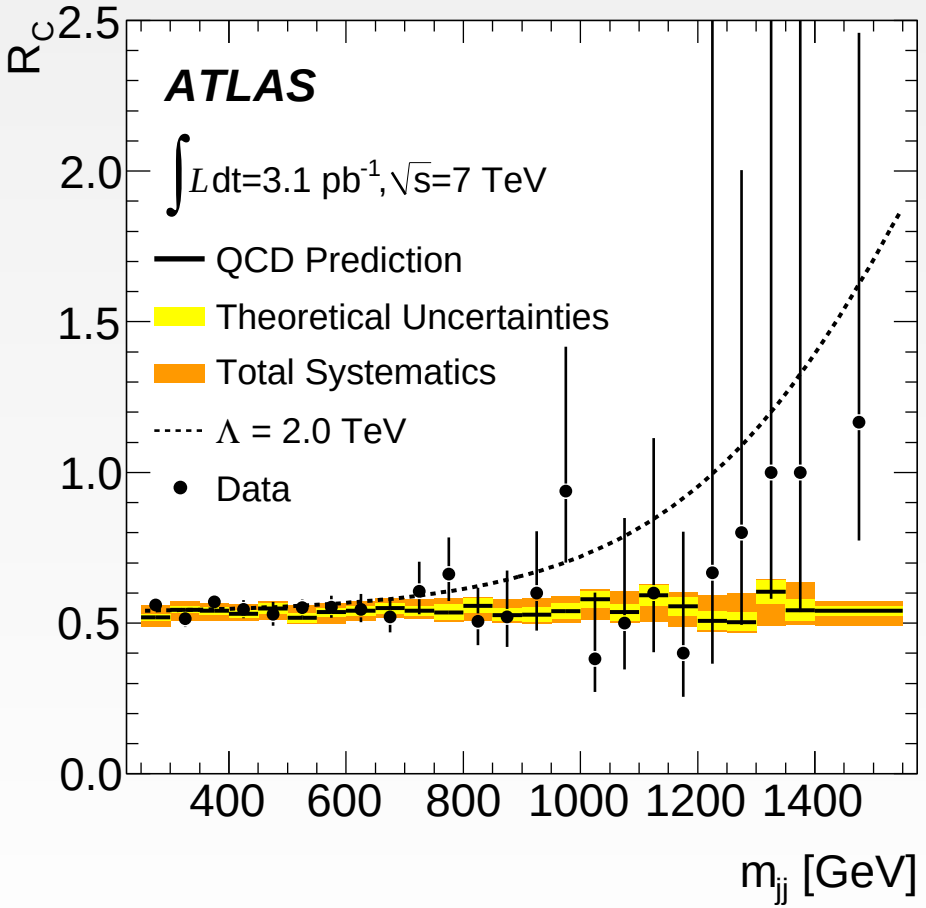
  Previous limits: $2.8 - 3.1\,\text{TeV}$

Dijet Centrality Ratio

ATLAS $L = 3.1\,pb^{-1}$

arXiv:1009.5069 (acc. by PLB)

$$R_C = \frac{N(|\eta| < 0.7)}{N(0.7 < |\eta| < 1.3)}$$



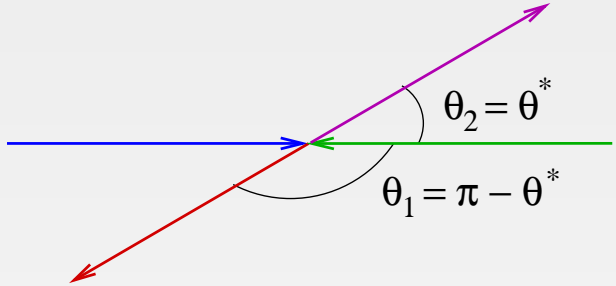
- Similar analysis. Excluded: $\Lambda < 2.0\,TeV$

Dijet χ Distribution

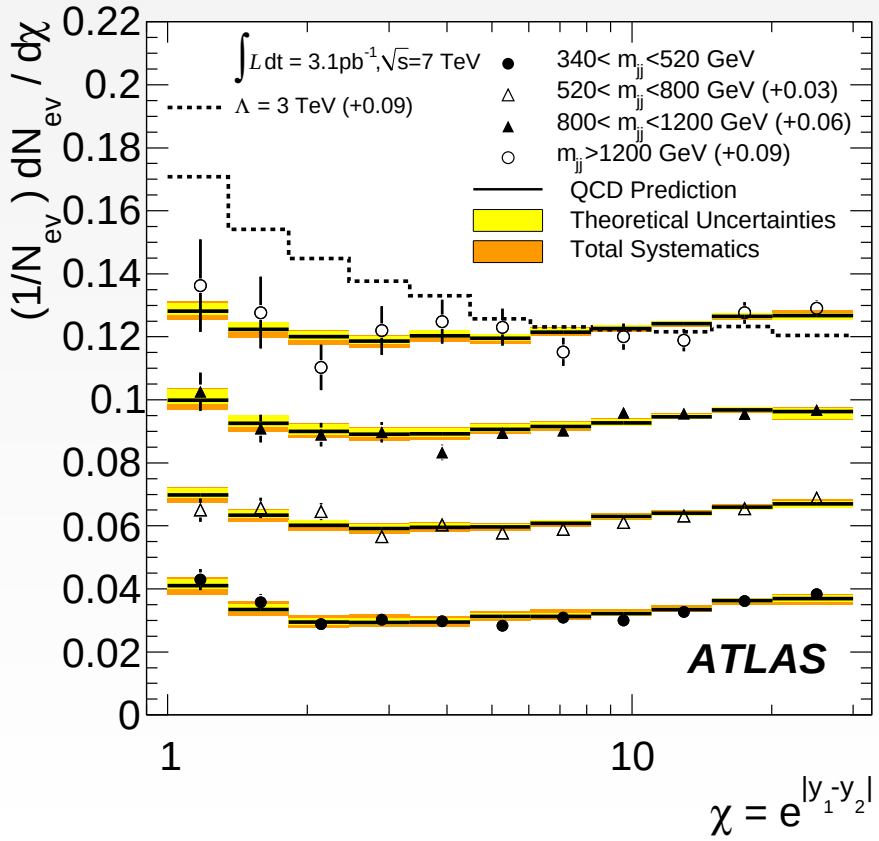
ATLAS $L = 3.1\,\mathrm{pb}^{-1}$

arXiv:1009.5069 (acc. by PLB)

$$\chi = e^{|y_1 - y_2|} = e^{|2y^*|}$$

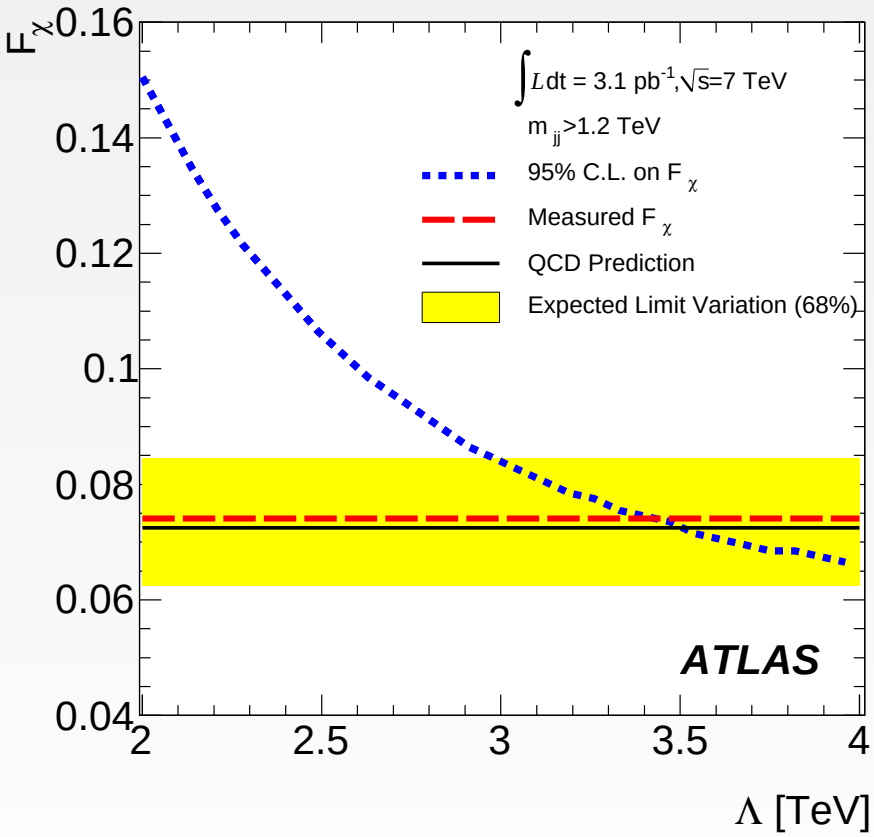


QCD: $\dfrac{dN}{d\cos\theta^*} \sim \sin^{-4}\dfrac{\theta^*}{2}$ (Rutherford) $\Rightarrow$ $\dfrac{dN}{d\chi} \approx \mathrm{const}(\chi)$



Results of ATLAS Dijet χ Analysis

- For the highest mass bin $M_{jj} > 1.2$ TeV define: $F_\chi = \frac{N_{1-4}}{N_{all}}$



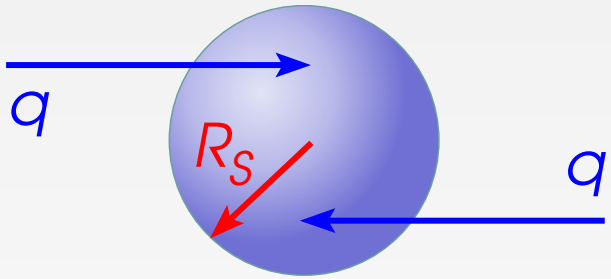
- Excluded: $\Lambda < 3.4$ TeV at 95% CL

  Previous limits: 2.8 – 3.1 TeV

Multi-Body Final States

Non-perturbative states in models with low scale gravity / string physics.
Typically models with large compactified extra dimensions. **Examples:**

Black Holes

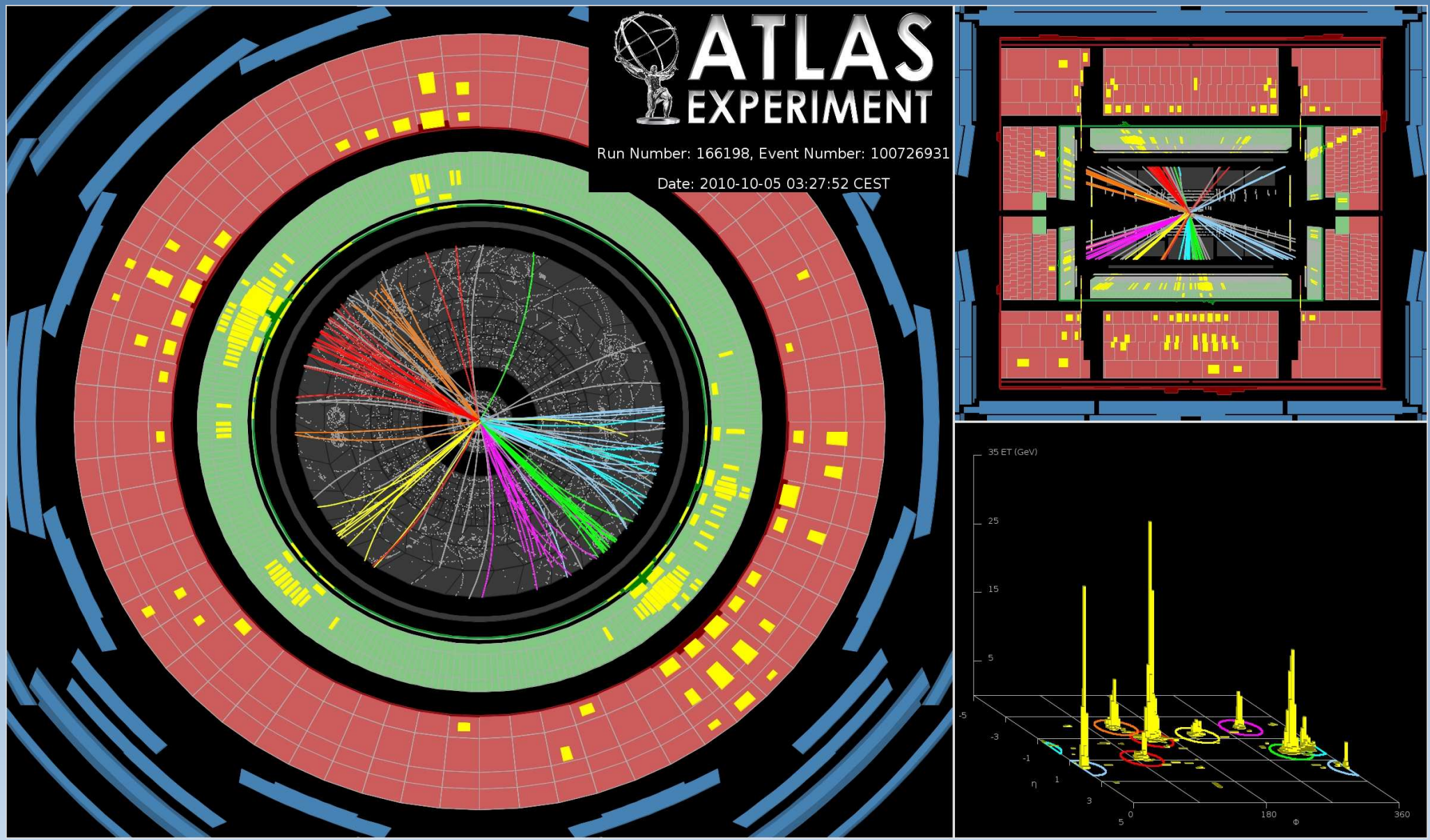


R_S – Schwarzschild radius

String Balls

- Look for threshold effect at high invariant masses
  Tevatron limits on ADD M_D: 800–940 GeV depending on N_{ED}
- No theory of quantum gravity $\longrightarrow$ No model for threshold behaviour
- Semi-classical: high multiplicity, roughly democratic decay $\longrightarrow$ dominated by jets
- Cross section can be huge [$\rightarrow \mathcal{O}(100\,\text{nb})$ at $\sqrt{s} = 7\,\text{TeV}$ depending on mass scale]

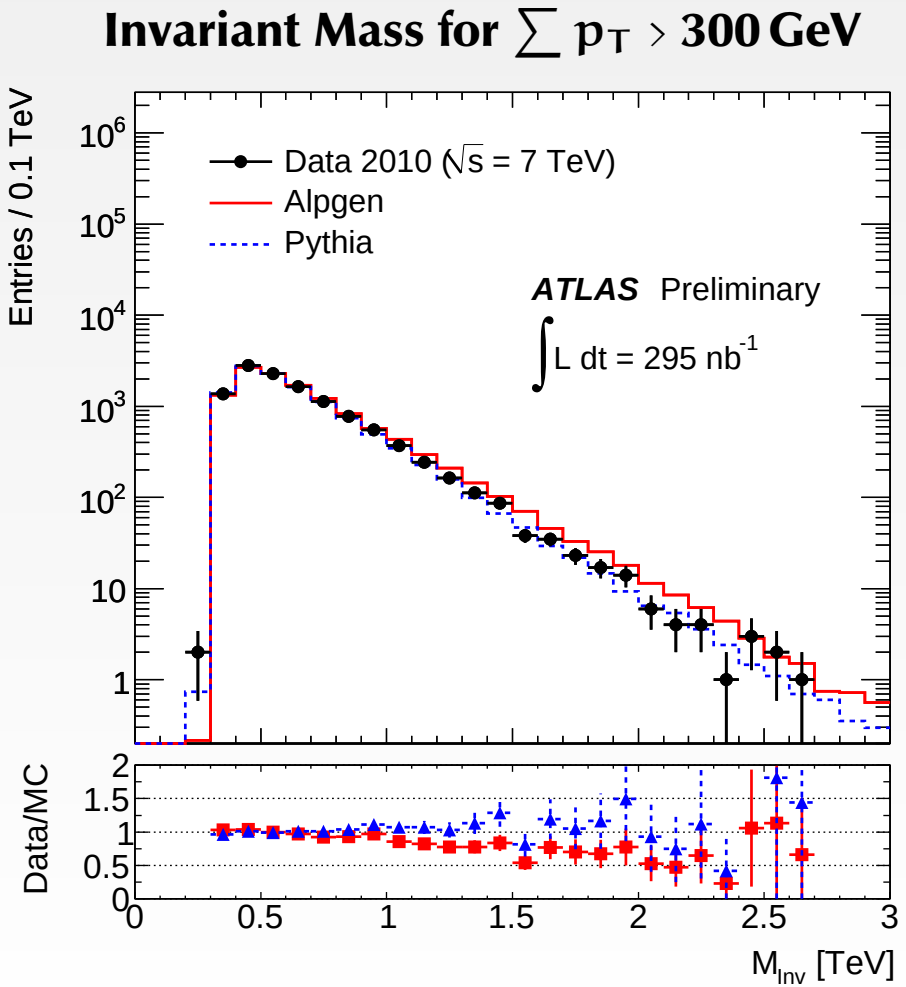
Multijet Event in ATLAS



ATLAS Multi-Object Search Strategy

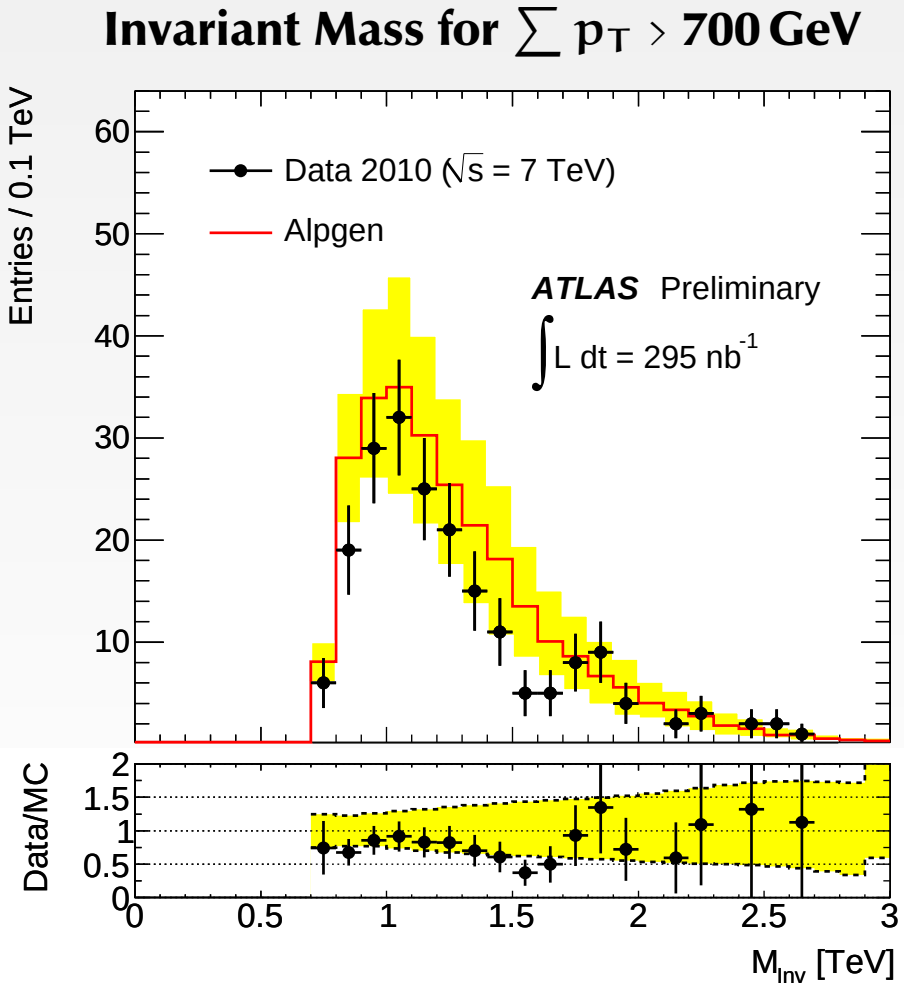
- Minimum model assumptions
  - Require at least 3 objects: jets, e, μ, γ
  - Require high $\sum p_T > 700\,\text{GeV}$
  - Look for deviations from SM at $M_{inv} > 800\,\text{GeV}$
- Main SM background: QCD multijets
  Use MC Alpgen and Pythia for modelling
- Normalise MC to data in Control Region
  $300 < M_{inv} < 800\,\text{GeV}$ and $\sum p_T > 300\,\text{GeV}$
- Extrapolate predictions to Signal Region
  Rely only on the shape of MC, not the overall normalisation
- Use the difference between Alpgen and Pythia to estimate QCD uncertainty
  [apart from PDFs]

ATLAS-CONF-2010-088



ATLAS Multi-Object Search Results

- Observed events: 193 in $L = 295\,\text{nb}^{-1}$ of data at $\sqrt{s} = 7\,\text{TeV}$
- SM Prediction: 254 $\pm$7% (stat.) $\pm$37% (syst.)
- Main systematics: QCD, PDF, JES, CR
- **Limit:** $\sigma \times A < \mathbf{0.34\,nb}$ at 95% CL
- No good model to estimate acceptance.
  For simple simulations with sharp threshold at 800 GeV: $A \sim 60\% \Rightarrow \sigma < 0.6\,\text{nb}$



Conclusions

- First searches based on $\sim 300\,\mathrm{nb}^{-1}$ – $3\,\mathrm{pb}^{-1}$ already surpassed Tevatron limits
  - Dijet resonances
  - Dijet angular distributions
  - Stopped gluinos [$10\,\mathrm{pb}^{-1}$, not covered in this talk]
- Search of a new type
  - Exclude new high multiplicity states at high invariant masses
- Looking forward to new results based on full statistics 2010 ($\sim 40\,\mathrm{pb}^{-1}$)

Acknowledgements

FSP 101 ATLAS

Announcement

LHC-D BSM/SUSY Workshop

5–6th Mai 2011 at DESY, Hamburg

Your talk proposals are welcome!

Contact LHC-D BSM/SUSY convenors

Theory	**Experiment**
Herbert Dreiner	Sascha Caron
Michael Kraemer	Victor Lendermann
	Christian Sander

Additional Information

ATLAS Multi-Object Search Strategy

Minimum model assumptions

ATLAS-CONF-2010-088

- Require at least 3 objects: jets, e, μ, γ
- Require high $\sum p_T > 700\,\text{GeV}$
- Look for deviations from SM at $M_{inv} > 800\,\text{GeV}$