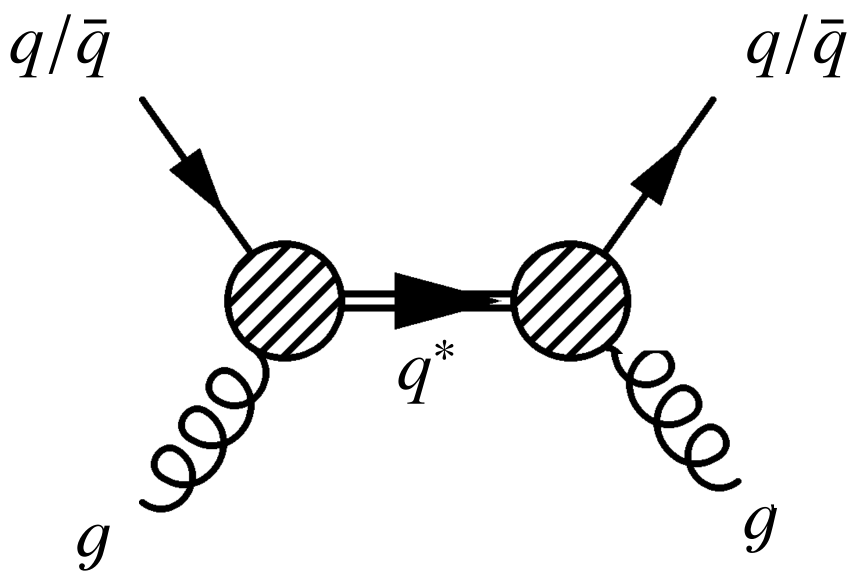
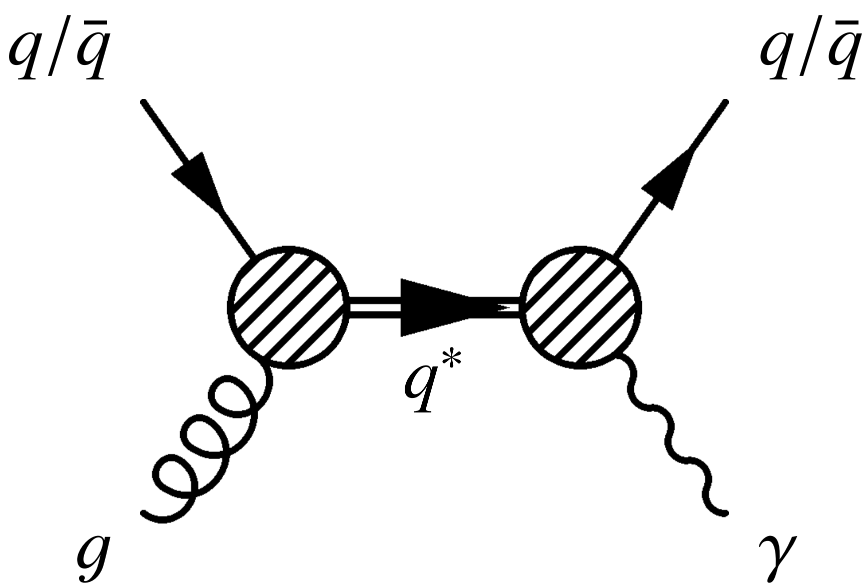
Search for **New Physics** in dijet and γ+jet angular and mass distributions with the ATLAS detector





Dag Gillberg
for the ATLAS Collaboration

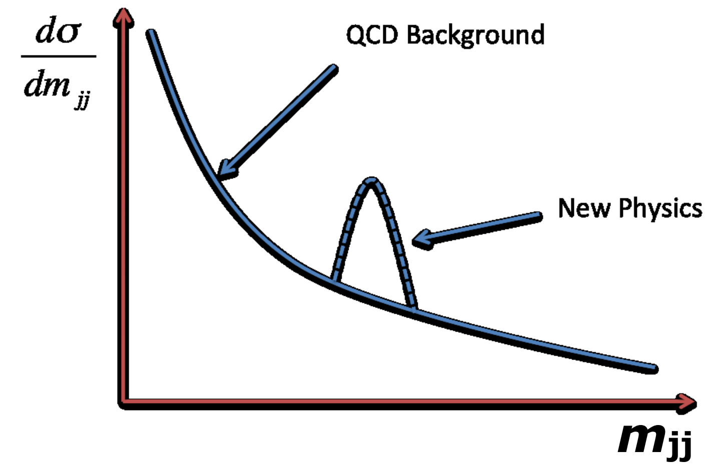
2012-07-04

Outline

Analyses presented:

1. **Dijet mass resonance search**

   Example theories probed:
   Excited quarks, colour octets



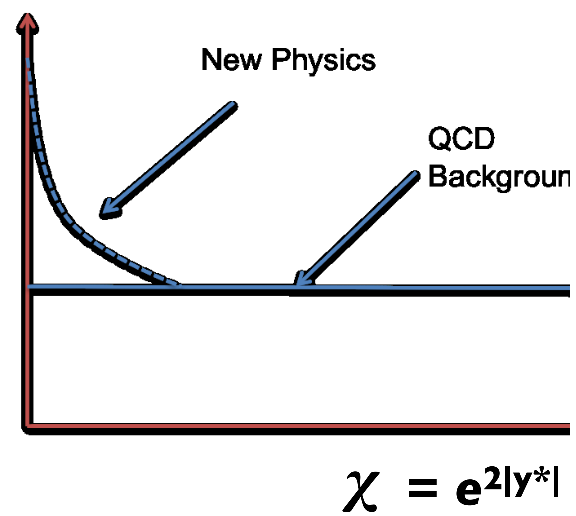
2011 data:
√s = 7 TeV, 4.8 fb⁻¹

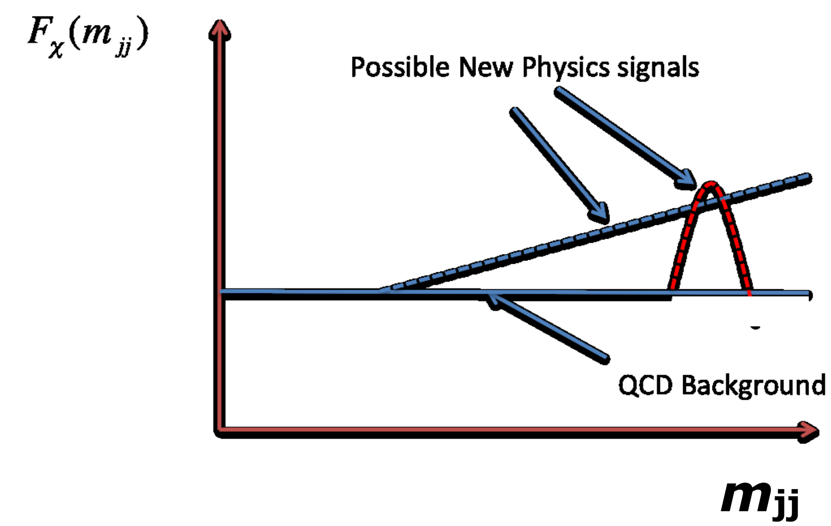
2012 data:
√s = 8 TeV, 5.8 fb⁻¹

2. **Searches in dijet angular distributions**

   Example theories probed:
   Quantum black hole,
   Contact interaction

2011 data: √s = 7 TeV, 4.8 fb⁻¹

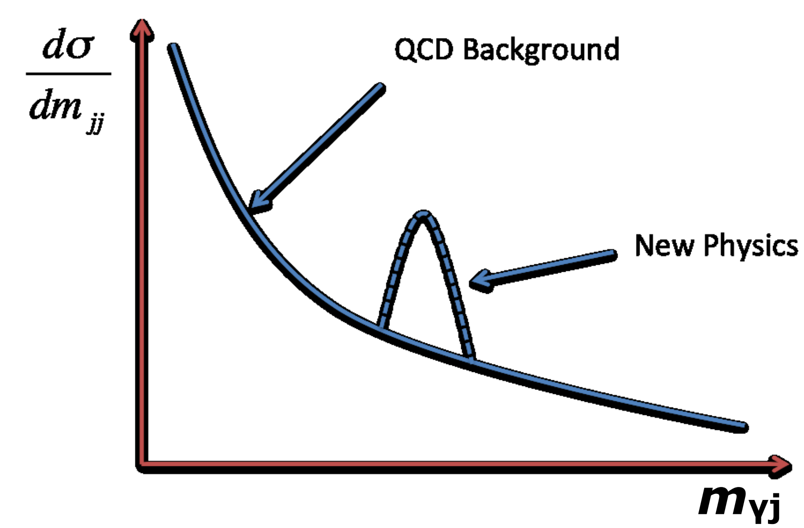




3. **Photon+jet mass resonances**

   Example theories probed:
   excited quarks, *quirks*, ***Regge string excitations***, *topological pions)*

2011 data: √s = 7 TeV, 2.11 fb⁻¹



Dijet production & kinematics

Resonance

- Dijet mass calculated from jet 4-vectors
  $m_{jj} = E^*_1 + E^*_2 = \sqrt{(p_{j1}+p_{j2})^2}$

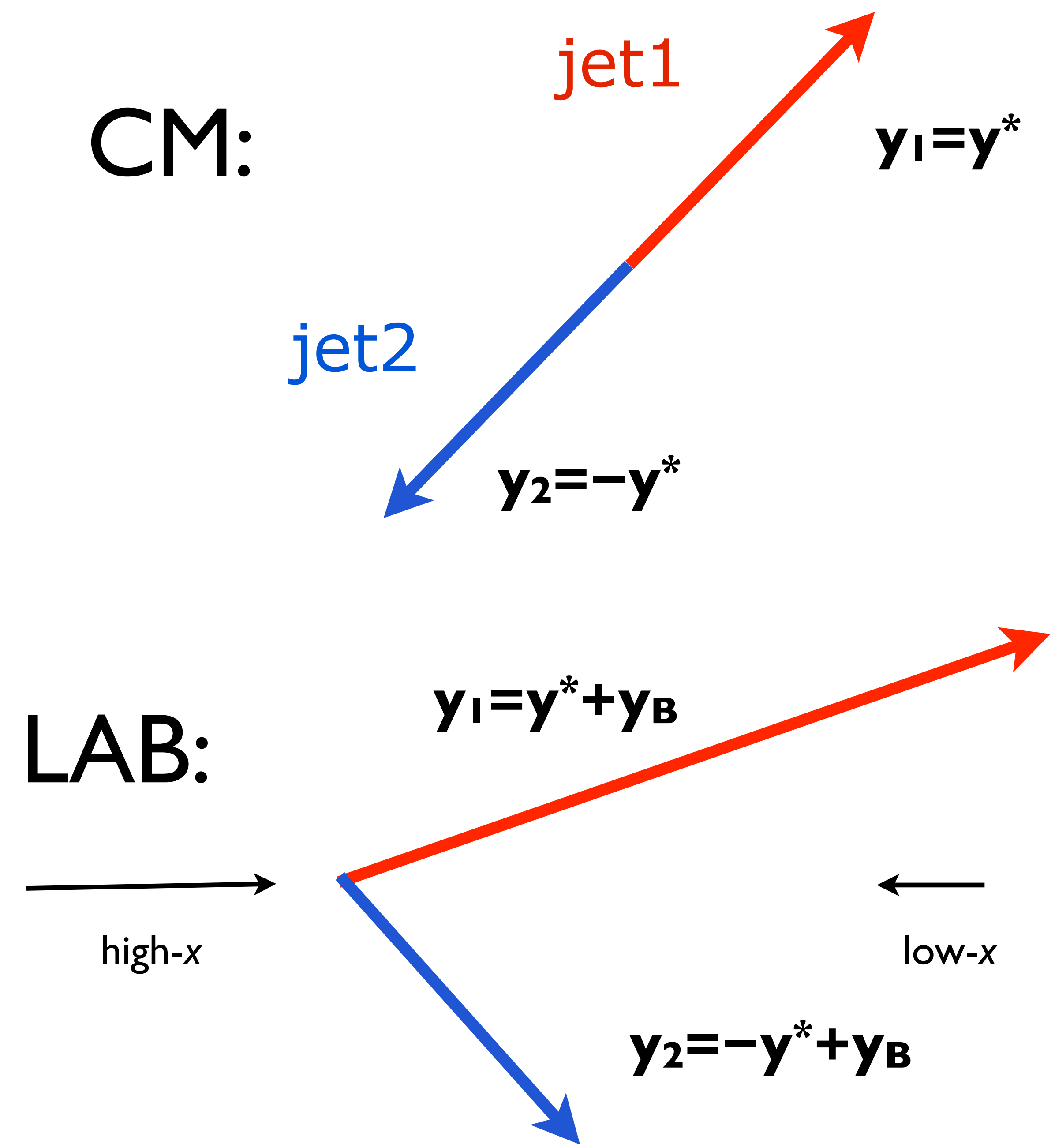
Angular variables

- Jets balance in transverse plane
- Jet rapidity in CM frame:
  $y^* = |y_1 - y_2|/2$
- $\chi = e^{2|y^*|}$
- Boost of dijet system:
  $y_B = |y_1 + y_2|/2$

Measures of jet rapidity separation

$m_{jj} \approx 2p_T \cosh(y^*)$

Rest frame of the resonance



Dijet production & kinematics

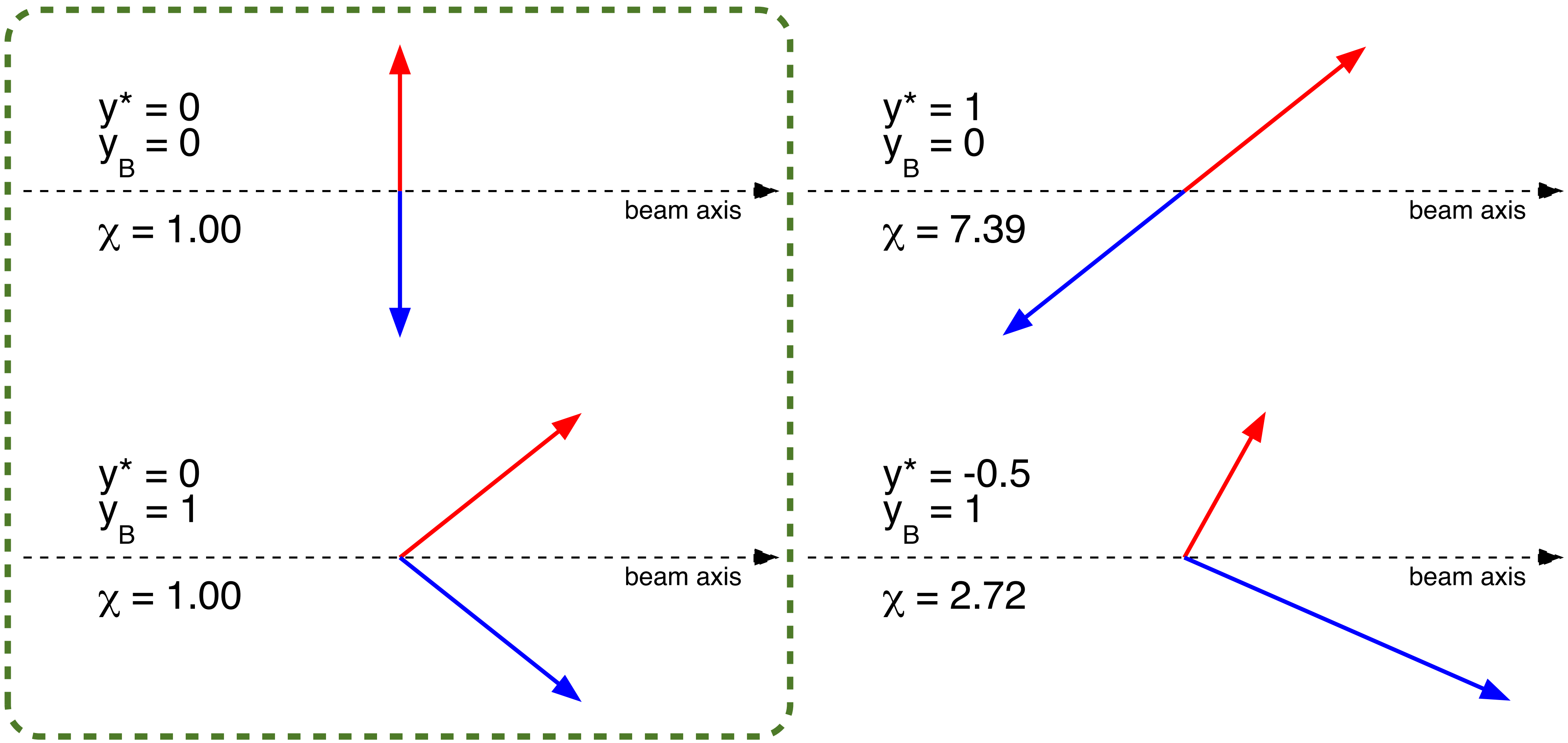
Angular variables

- Jets balance in transverse plane
- Jet rapidity in CM frame:
  $\mathbf{y^* = |y_1 - y_2|/2}$
- $\chi = e^{2|y^*|}$
- Boost of dijet system:
  $\mathbf{y_B = |y_1 + y_2|/2}$

Measures of jet rapidity separation

Many new physics scenarios with dijet final state have small rapidity separation

Illustration of 4 dijet events in the LAB frame



Dijet production & kinematics

Angular variables

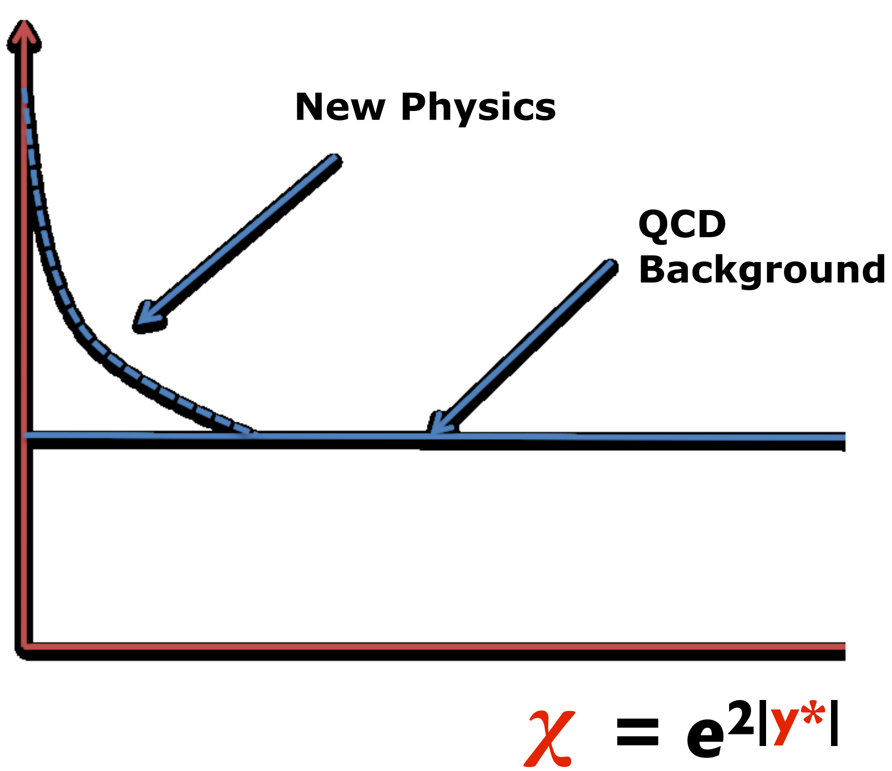
- Jets balance in transverse plane
- Jet rapidity in CM frame:
  $y^* = |y_1 - y_2|/2$
- $\chi = e^{2|y^*|}$
- Boost of dijet system:
  $y_B = |y_1 + y_2|/2$

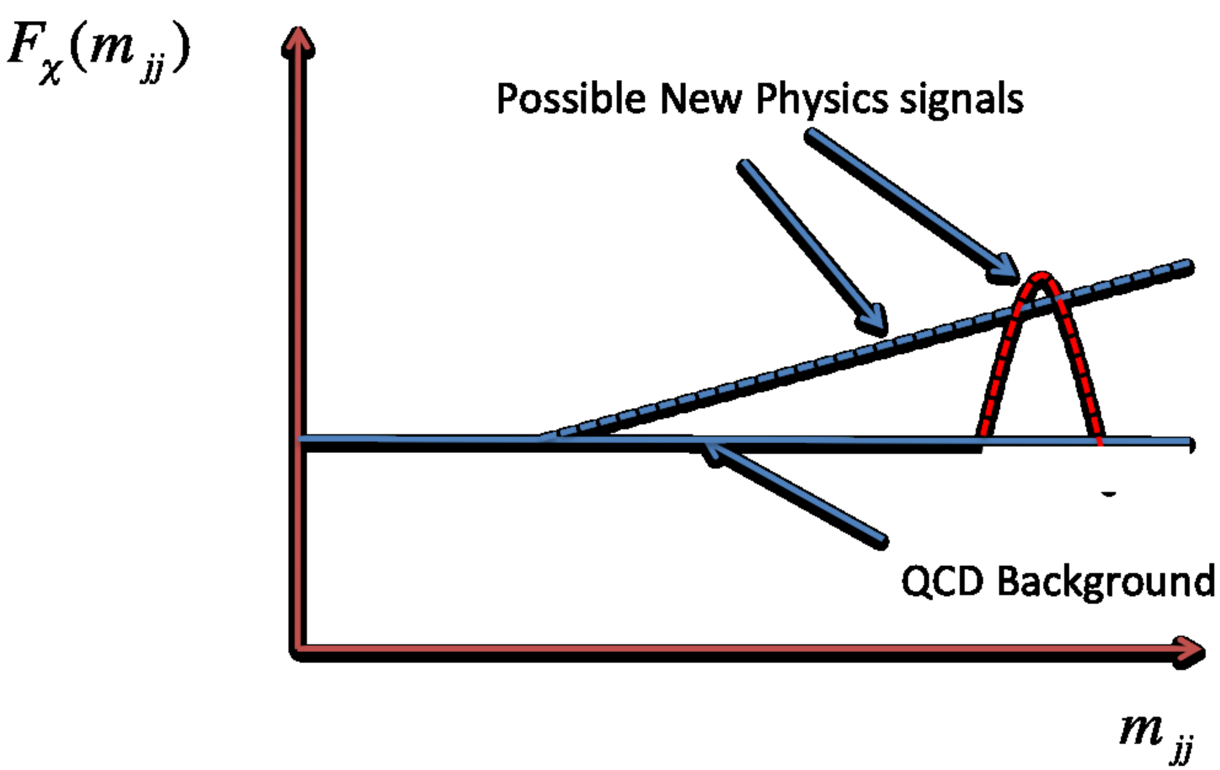
Measures of jet rapidity separation

Many new physics scenarios with dijet final state have small rapidity separation

An observable sensitive to such models is the ratio of "central" to total events:

F_χ = N(|y*|<0.6) / N(|y*|<1.7)





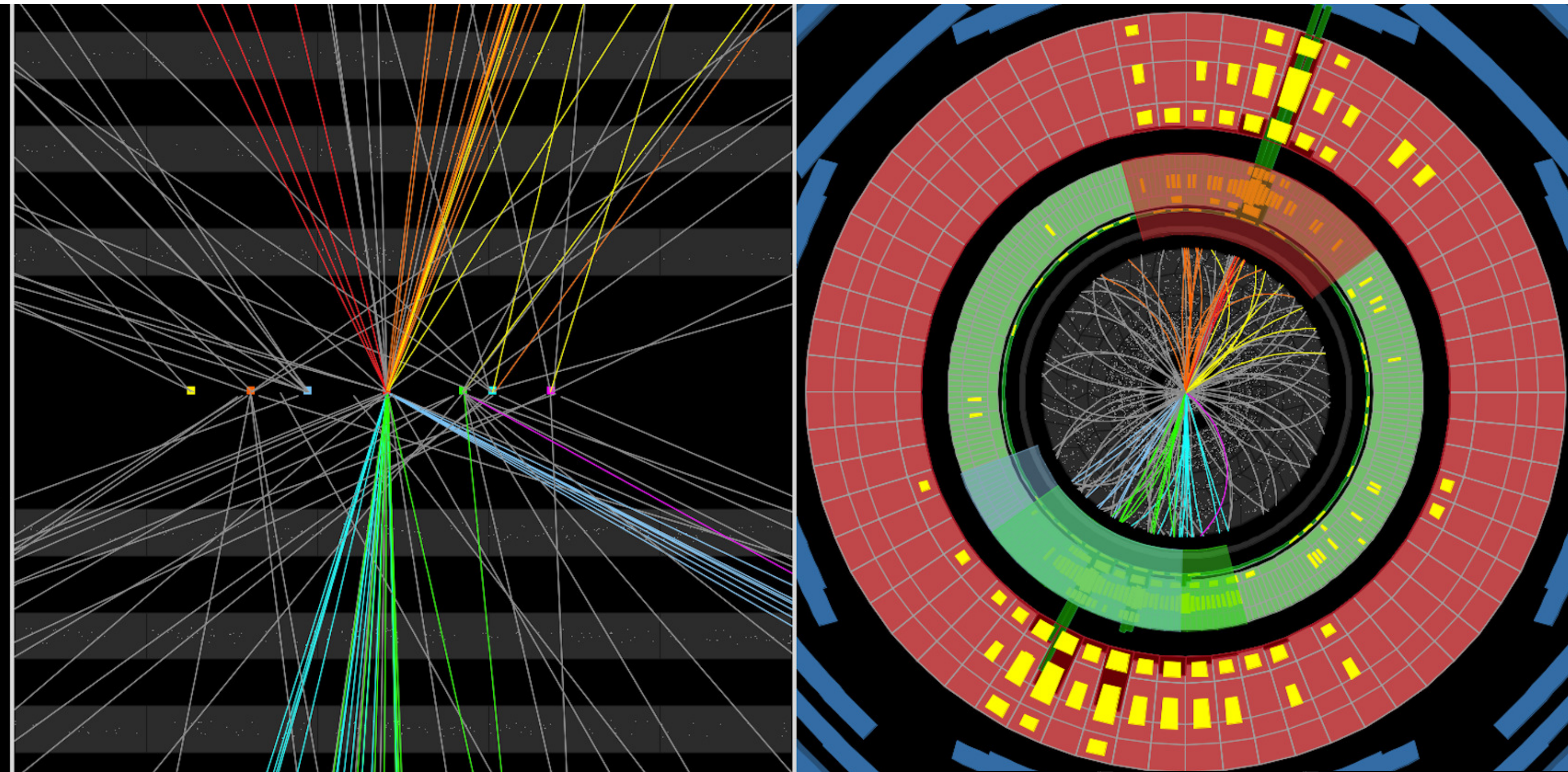
Dijet event selection

Highest-mass dijet event with central jets recored in ATLAS by May 2012

ATLAS EXPERIMENT

Run Number: 205113, Event Number: 34879440

Date: 2012-06-18 12:25:45 CEST



Kinematic selection, m_{jj} (acceptance)

- $|y^*| < 0.6$
- $|y_1| < 2.8$, $|y_2| < 2.8$
- $m_{jj} > 850$ (1000) GeV *for 2011 (2012)*

Kinematic selection, angular (acceptance)

- $|y^*| < \log(30)/2 \approx 1.7$
- $|y_B| < 1.1$
- $m_{jj} > 800$ GeV

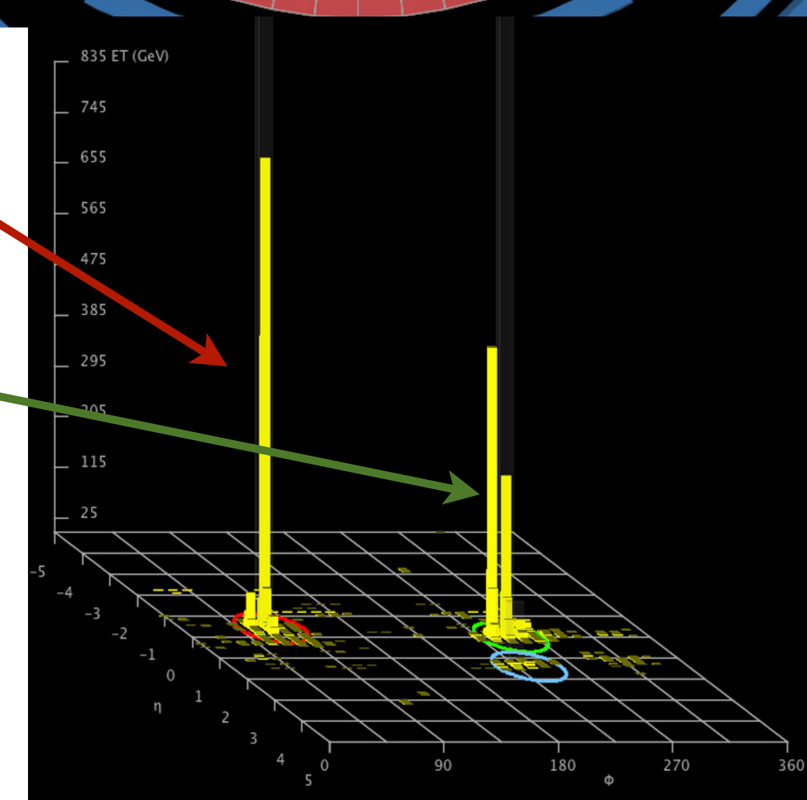
More viewpoints in backup slides

p_T **= 2.1 TeV**

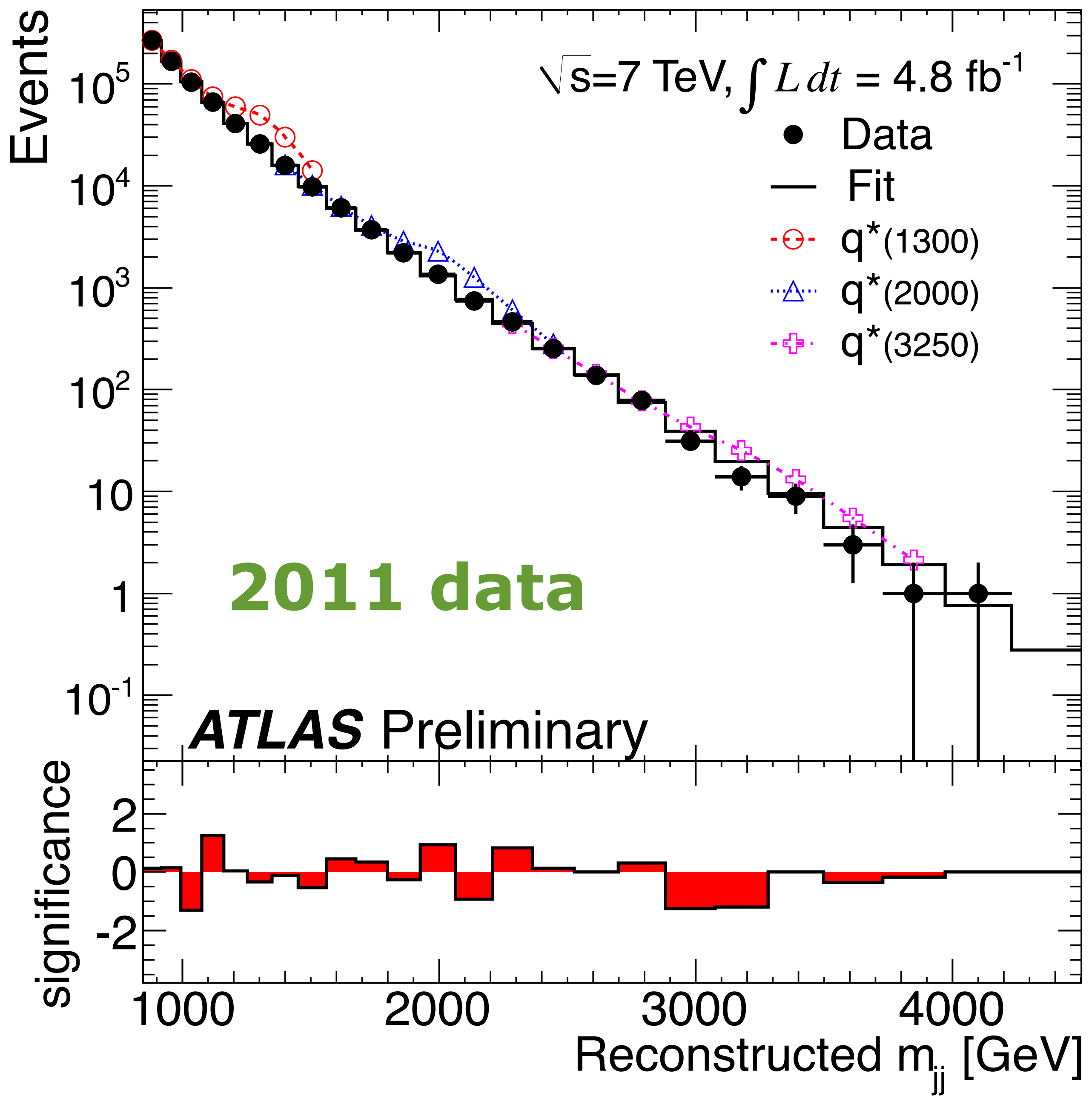
p_T **= 1.9 TeV**

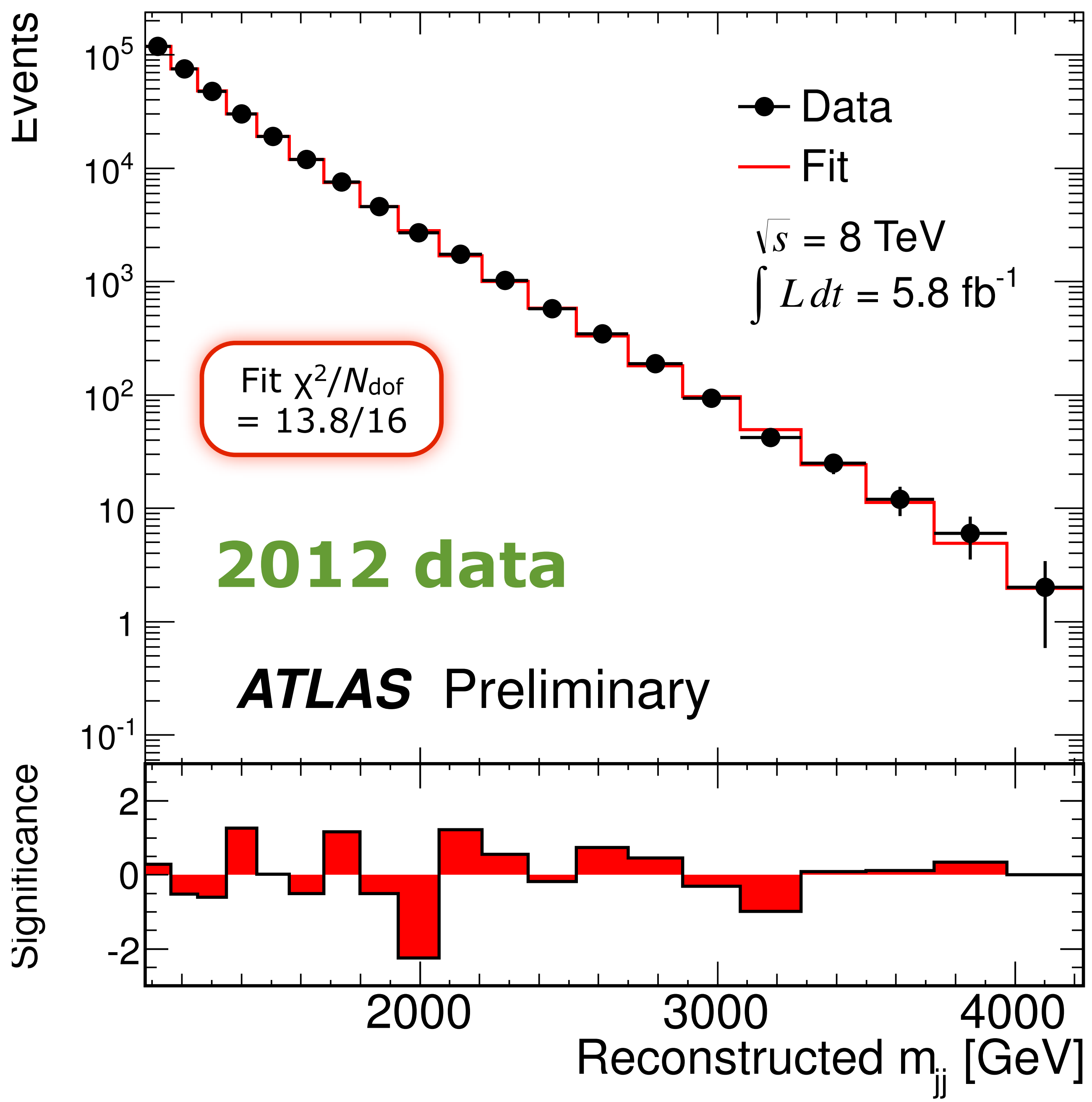
m_{jj} **= 4.1 TeV**

(there are higher m_{jj} events with forward jets)



Dijet mass results





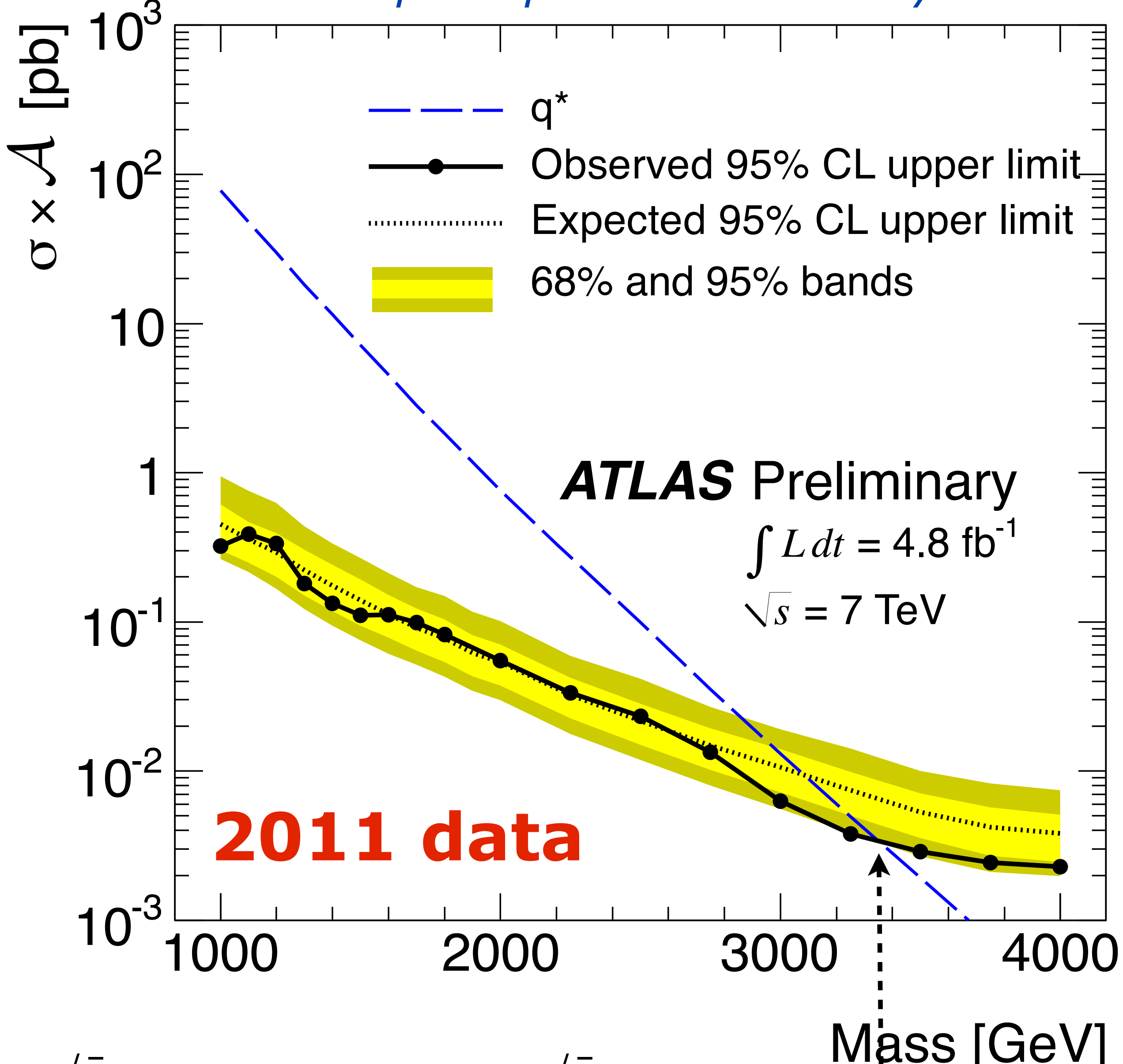
Background estimation from smooth fit over all bins. Significance from bin-wise comparison of N_{events} with fit

Mass fit function motivated by massless 2→2 scattering: $f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x}$

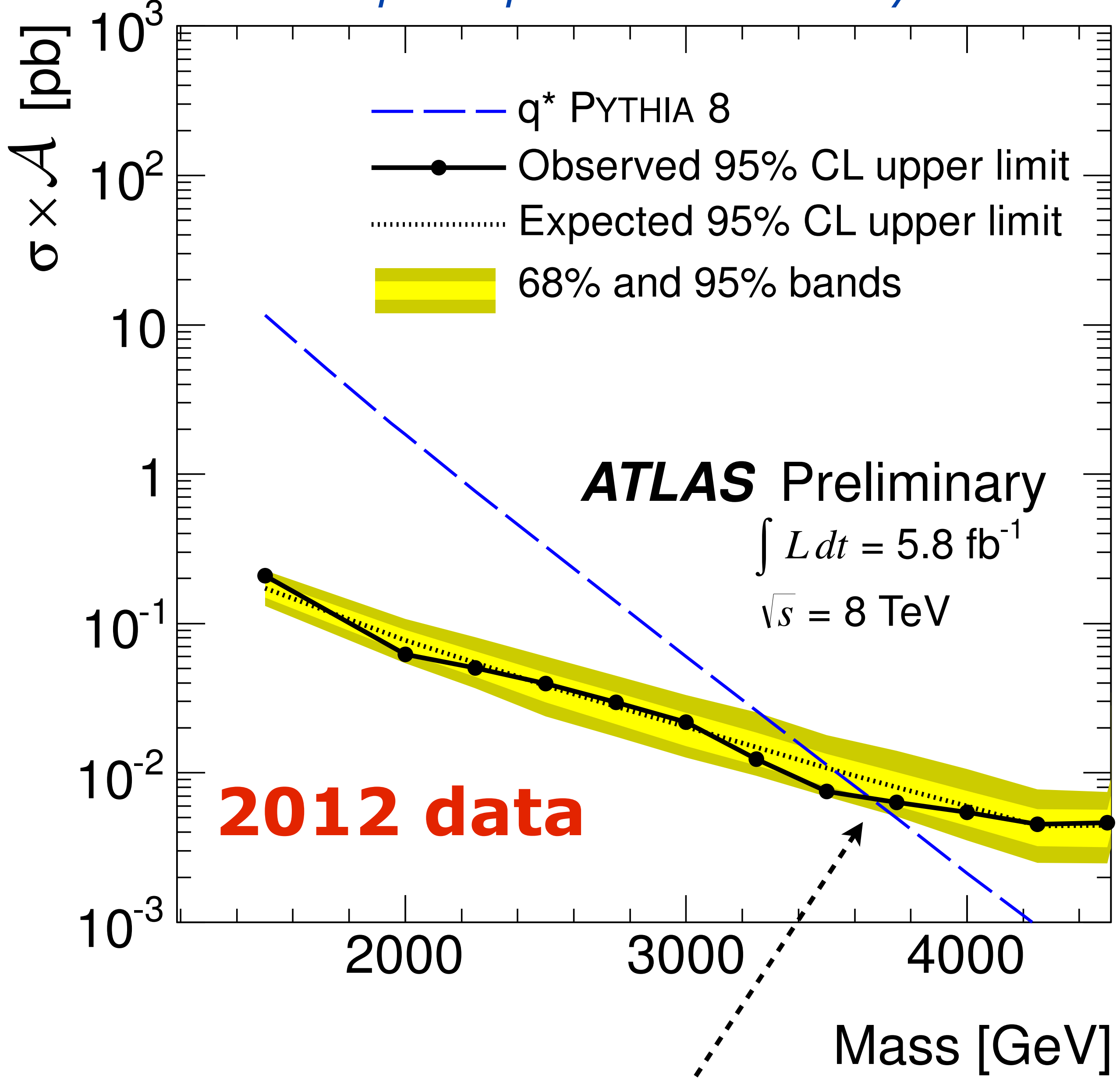
No excess observed

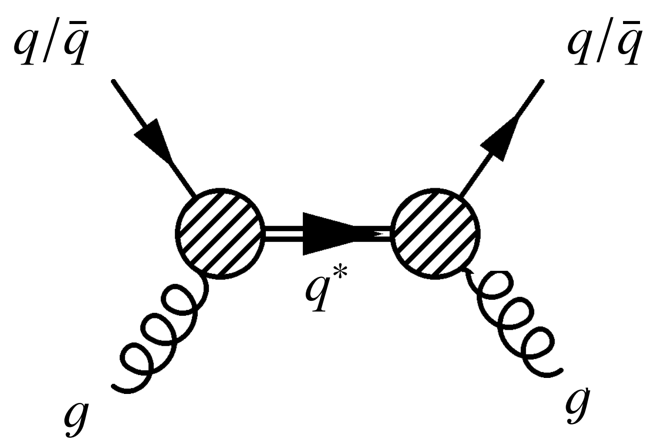
Limits on excited quark production

Excited quark prediction from Pythia 6



Excited quark prediction from Pythia 8

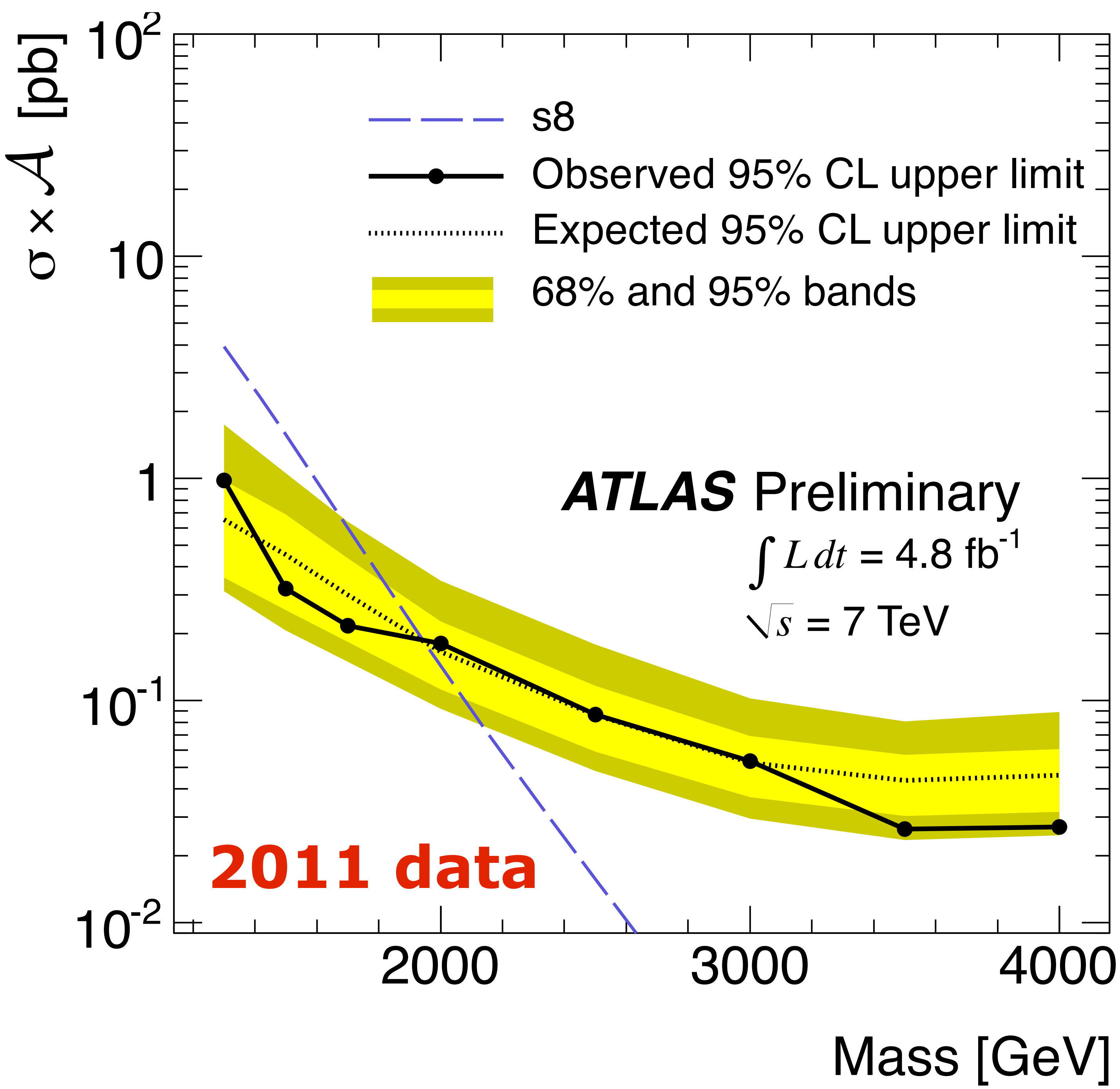




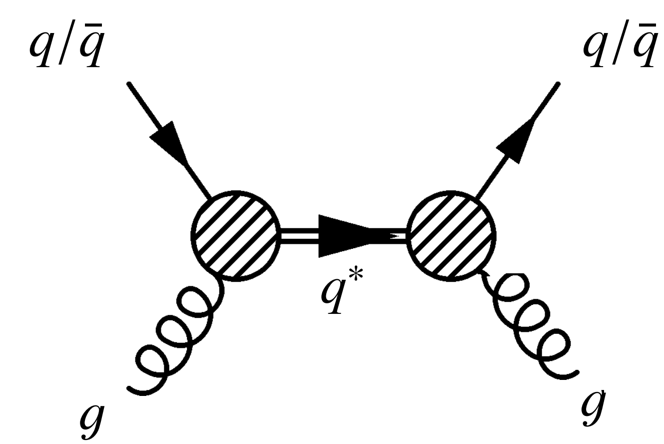
Limits @ 95% CL:

2011		2012	Using Pythia 6
3.35 TeV	**Observed**	**3.66 TeV**	3.79
3.09 TeV	**Expected**	**3.53 TeV**	3.71

Limit on colour scalar octets



- Mass spectrum used also to set limit on a colour scalar octet model



Limits @ 95% CL:

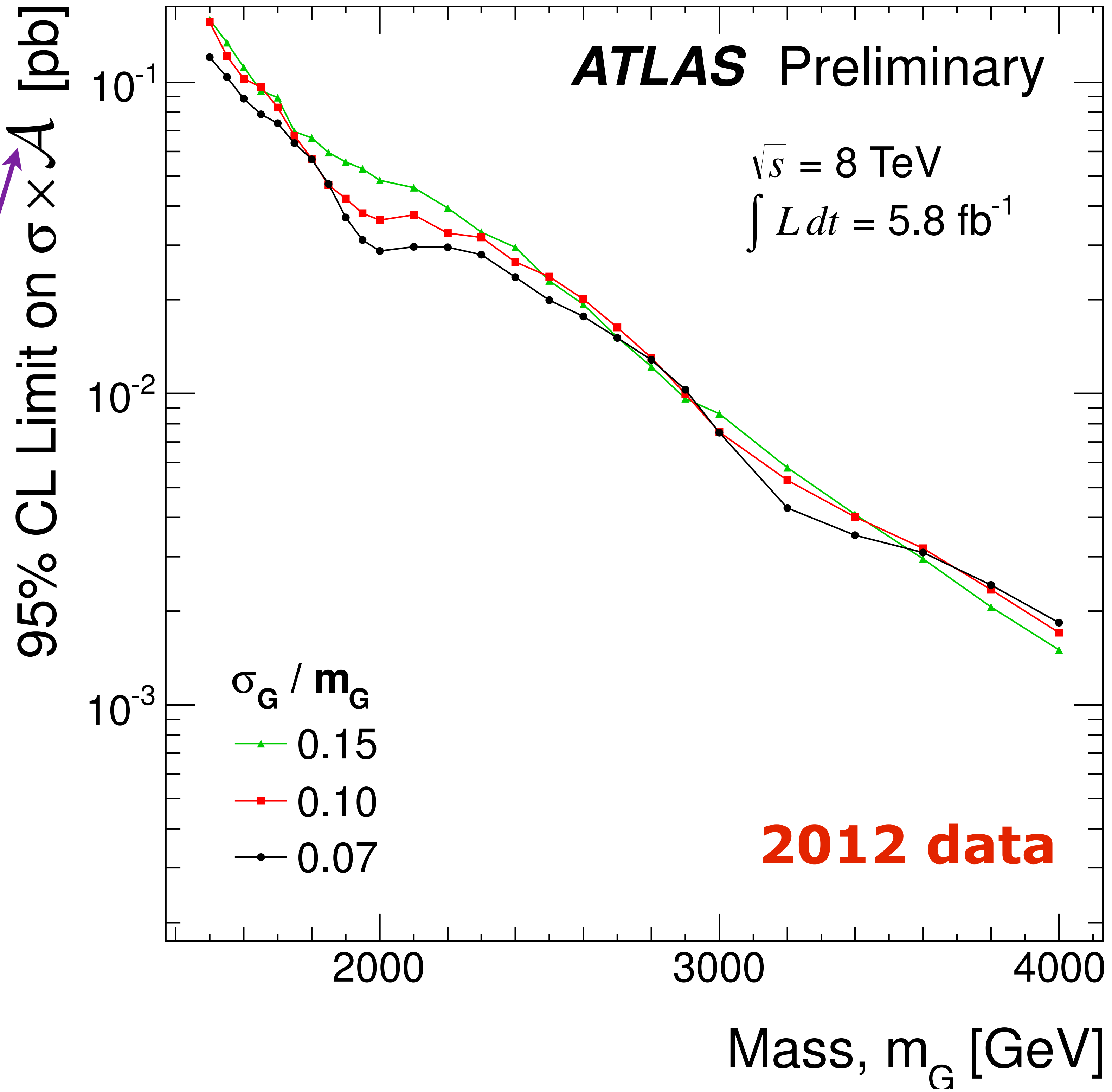
Observed	**1.94 TeV**
Expected	**1.94 TeV**

Model independent cross section limits

- **95% CL** upper **limits** on **cross section** times acceptance assuming **generic** Gaussian resonance decaying to dijets
- Separate limits for different relative width of the m_{jj} resonance: 7%, 10%, 15%

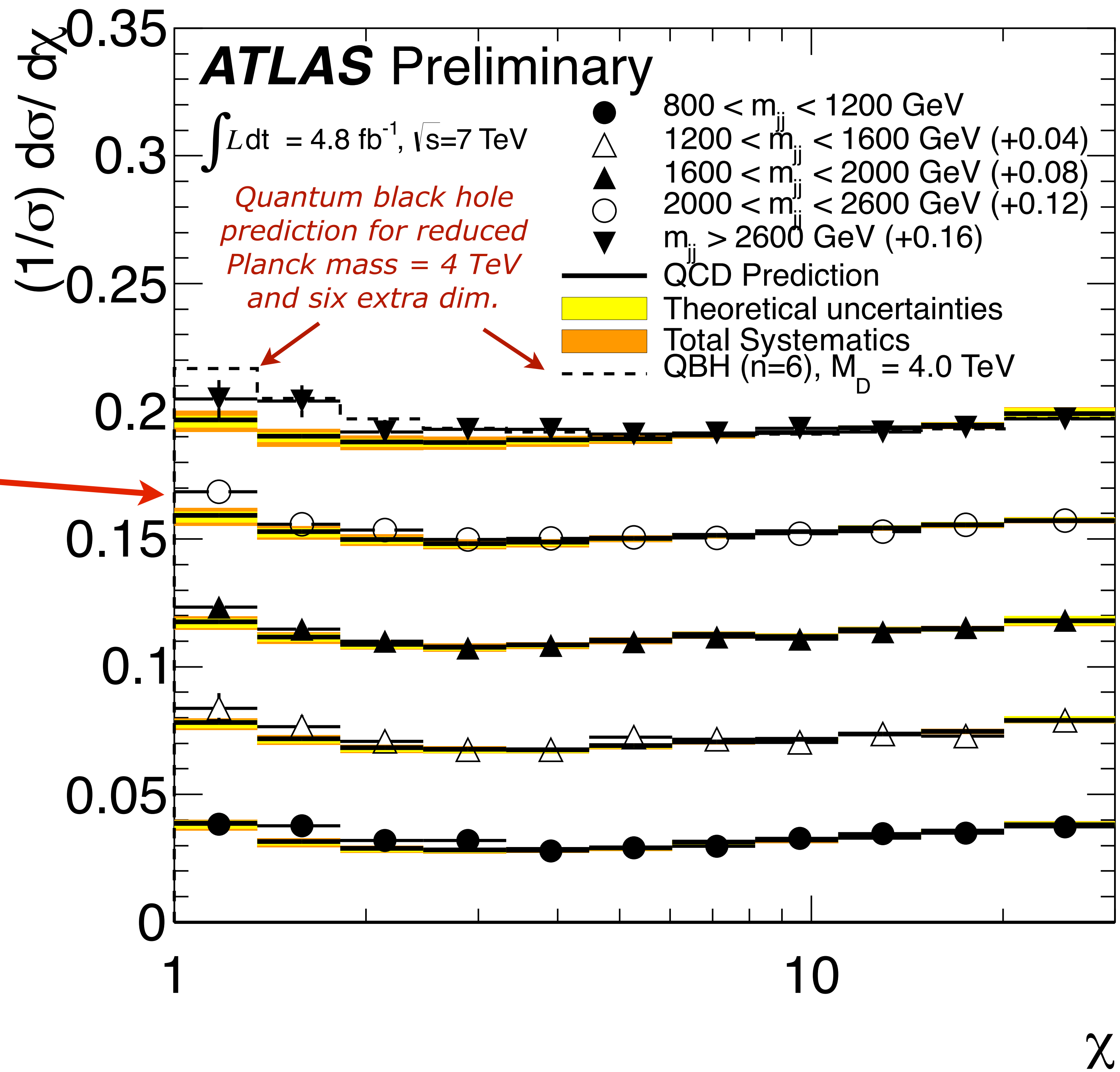
"Acceptance" defined as fraction of events passing the event selection:

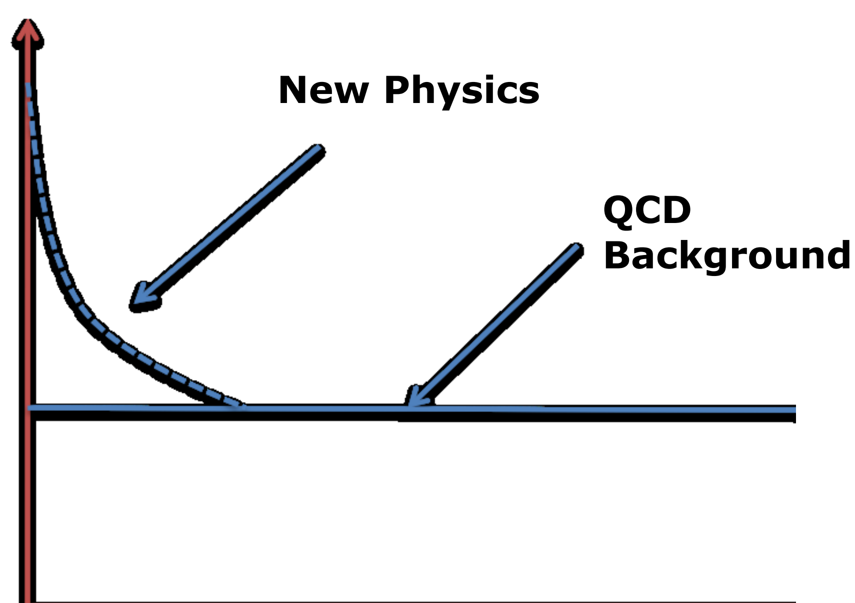
Kinematic selection, m_{jj} (acceptance)
- $|y^*| < 0.6$
- $|y_1| < 2.8$, $|y_2| < 2.8$
- $m_{jj} > 850$ (1000) GeV *for 2011 (2012)*



Dijet angular resonance searches

- Cross section measured in 5 dijet mass bins x 11 χ-bins
- Background prediction from Pythia 6 with bin-specific NLOJet++ *k*-factor
- The "BumpHunter" algorithm finds the largest discrepancy for the first five χ-bins at 2 TeV < m_{jj} < 2.6 TeV: p-value: 0.24





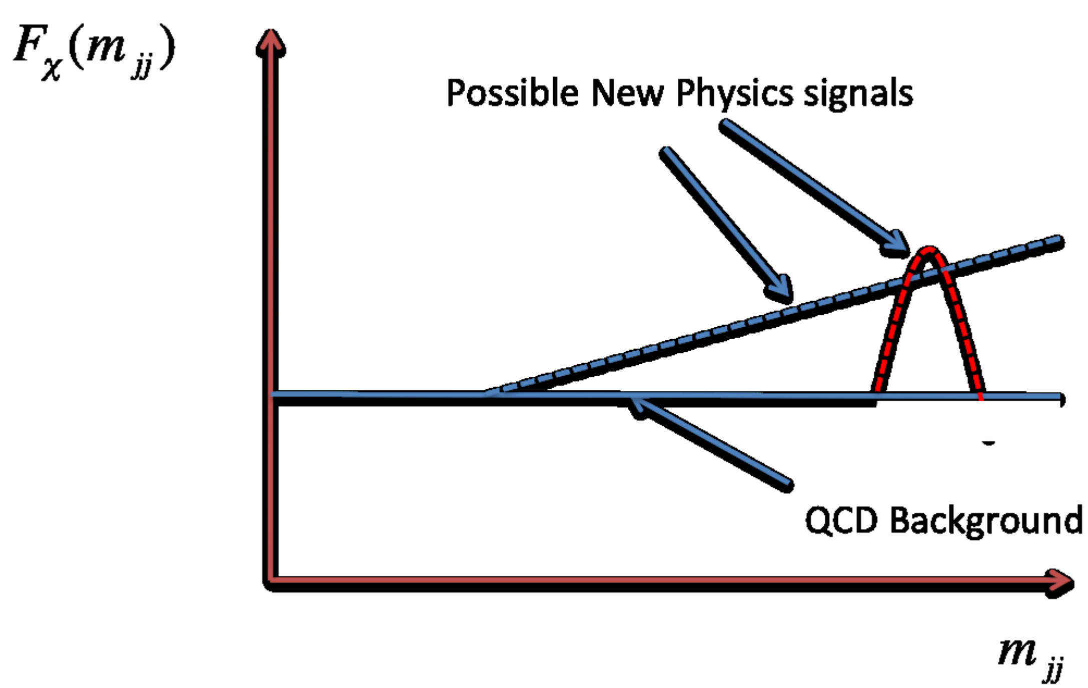
$\chi = e^{2|y^*|}$

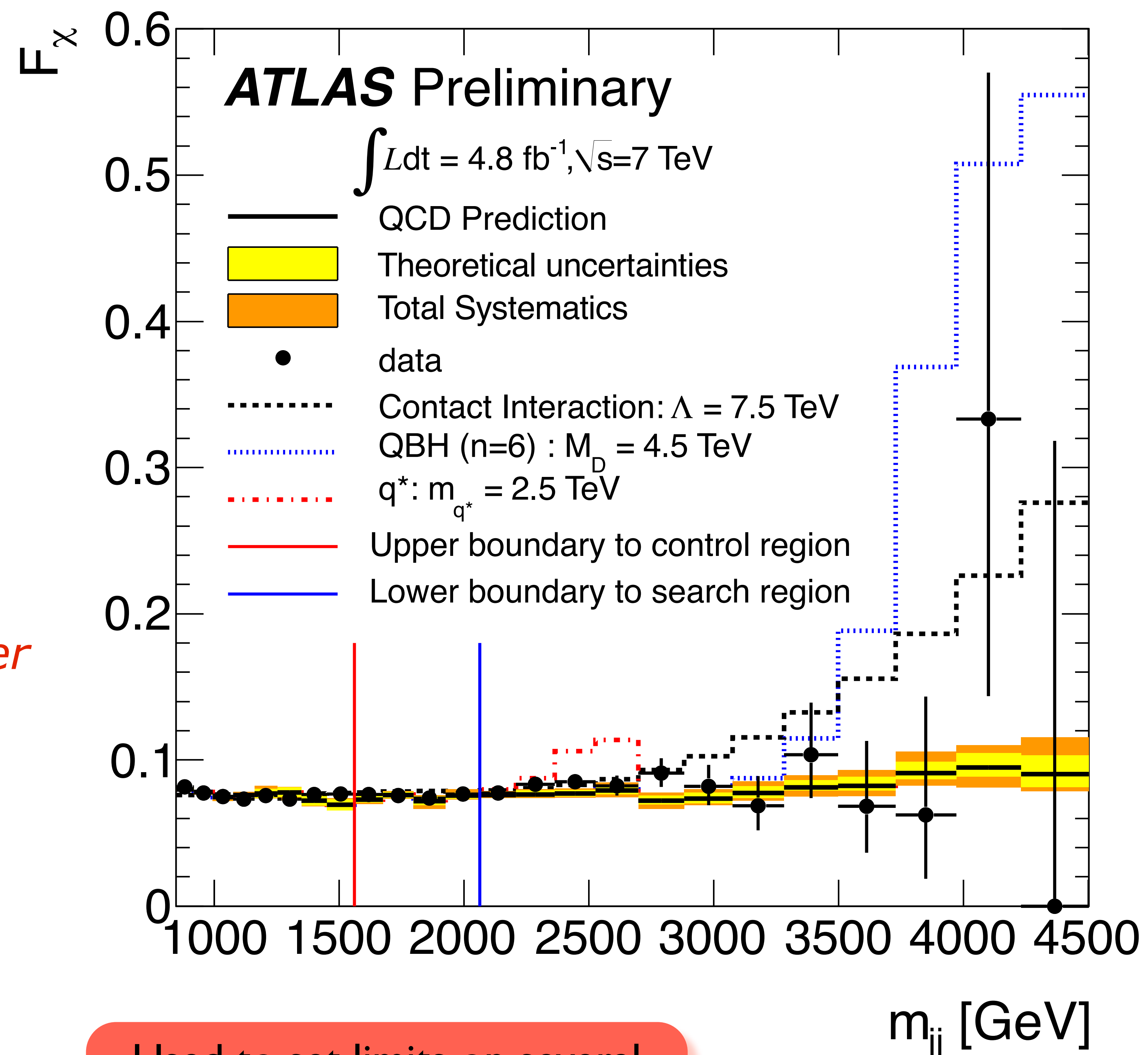
Dijet angular resonance searches

F_χ = N(|y*|<0.6) / N(|y*|<1.7)

- Background prediction from Pythia 6 with bin-specific NLOJet++ *k*-factor
- p-value with binned likelihood: 0.052
- Largest discrepancy: Global significance of 1.39σ (*p*-value 0.082) for masses in 2209-3498 GeV

BumpHunter





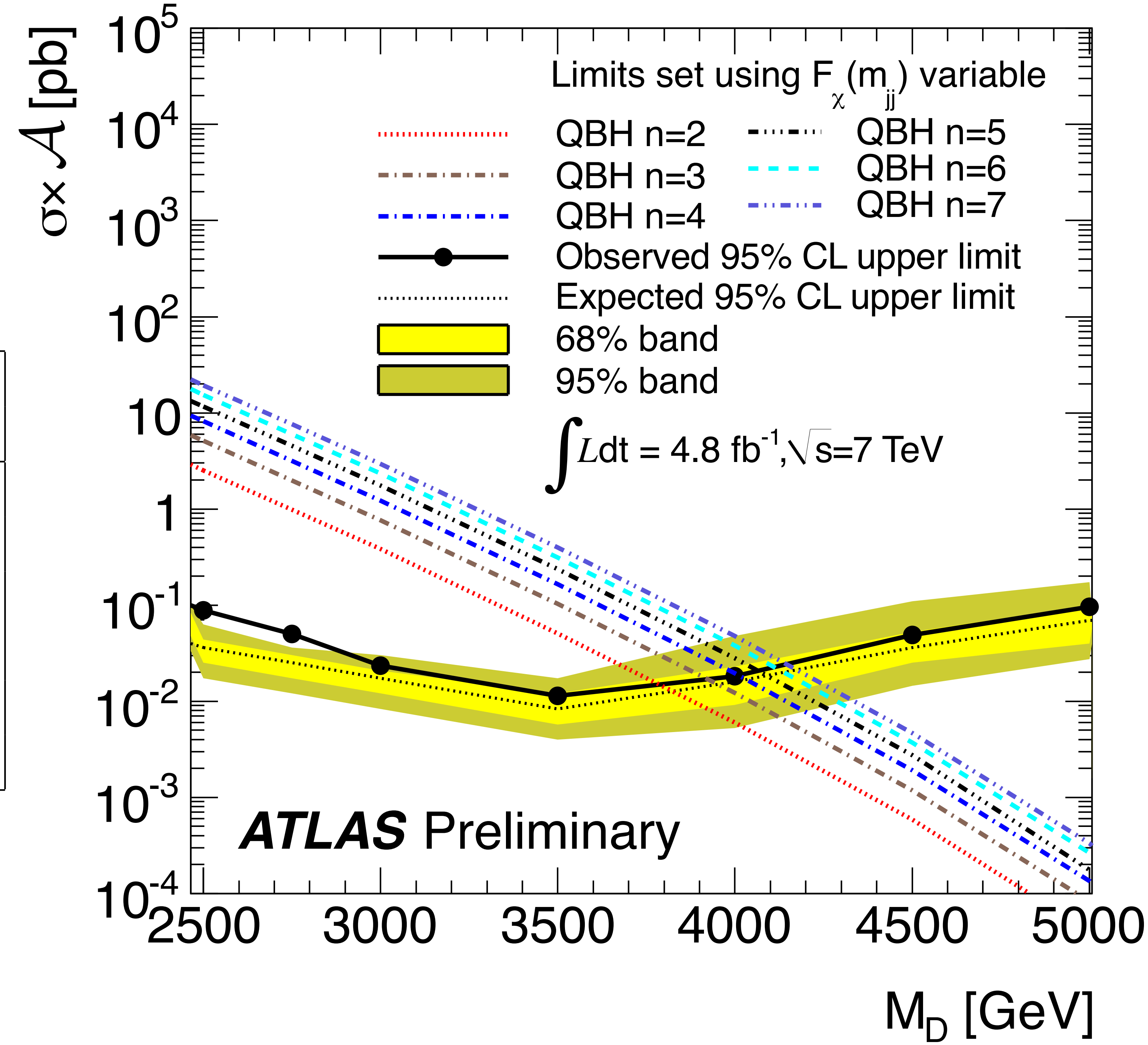
Used to set limits on several New Physics models

Dijet: Limits on extra dimensions

- Using the F_χ vs m_{jj} distribution, limits are set on several New Physics models
  - Semi-model independent **q**uantum **b**lack-**h**ole models

n extra dimensions	Expected limit (TeV)	Observed limit (TeV)
2	3.82	3.79
3	3.95	3.93
4	4.03	4.01
5	4.09	4.06
6	4.14	4.11
7	4.18	4.15

Lower limits at 95% C.L. on M_D of the QBH model with n=2 to 7 extra dimensions



Quark contact interactions:
Observed limit: $\Lambda > 7.6$ TeV
Expected limit: $\Lambda > 8.2$ TeV

M_D: Reduced Planck mass of the quantum black hole model

γ+jet resonance search

Phys. Rev. Lett. 108, 211802 (2012)

- The γ+jet final state is sensitive to a number of new physics scenarios: *excited quarks, Regge string excitations, topological pions*
- Despite the promising opportunities, this is the first published γ+jet resonance search in over a decade! Last γ+jet search published by CDF in 1994
- Pythia excited quark model used as benchmark
- An extension of the analysis including an angular resonance search is ongoing at ATLAS

Well-measured photon: better sensitivity where stats are available

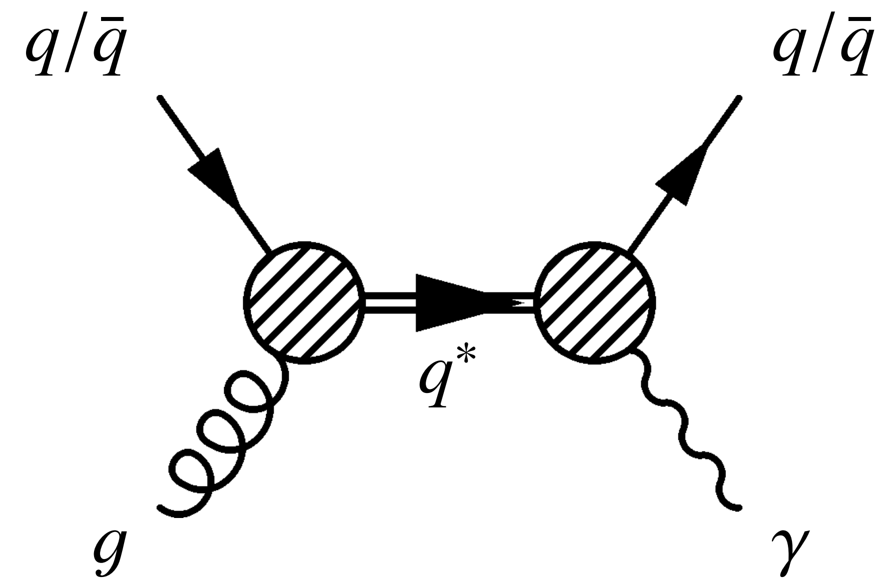


TABLE II. Relative branching ratios $B_G = \Gamma(f^* \to fV) / \sum_V \Gamma(f^* \to fV)$ for decays of excited fermions into gauge bosons for $m^* = \Lambda$, $f_s = f = f' = 1$, and $\alpha_s = 0.11$.

Decay mode	B_G	Decay mode	B_G
		$e^* \to e\gamma$	0.28
$\nu^* \to \nu Z$	0.39	$e^* \to eZ$	0.11
$\nu^* \to eW$	0.61	$e^* \to \nu W$	0.61
$u^* \to ug$	0.85	$d^* \to dg$	0.85
$u^* \to u\gamma$	0.02	$d^* \to d\gamma$	0.005
$u^* \to uZ$	0.03	$d^* \to dZ$	0.05
$u^* \to dW$	0.10	$d^* \to uW$	0.10

Phys. Rev. D42 (1990) 815

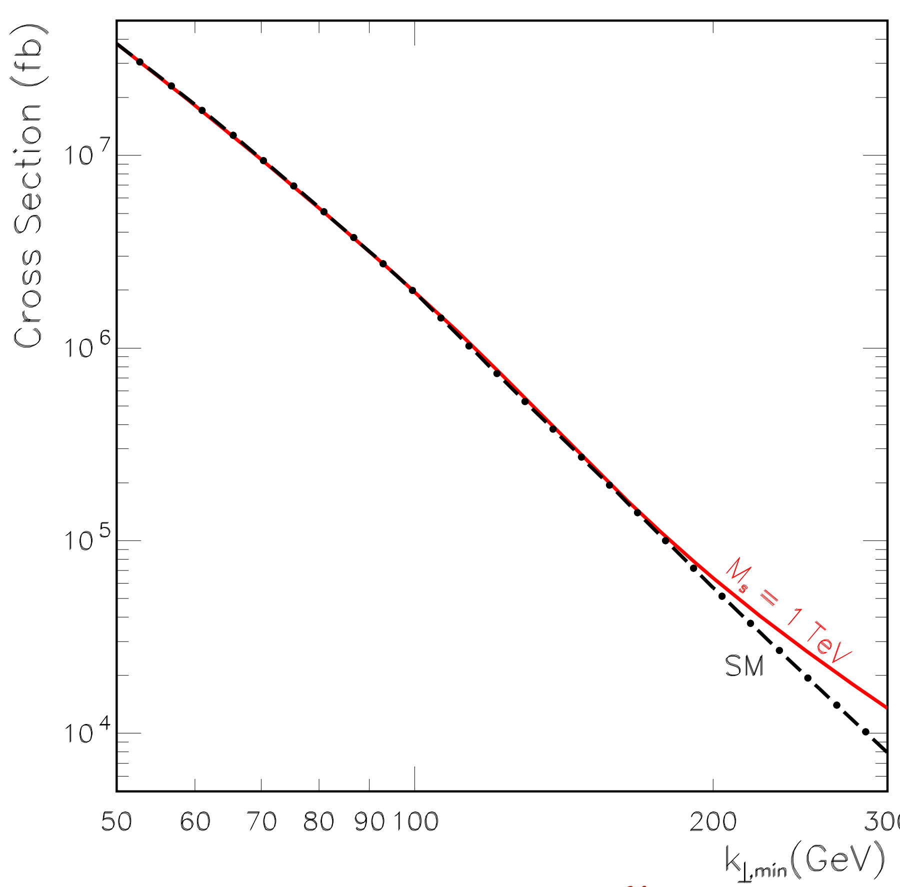
Example γ+jet New Physics scenario

γ+jet

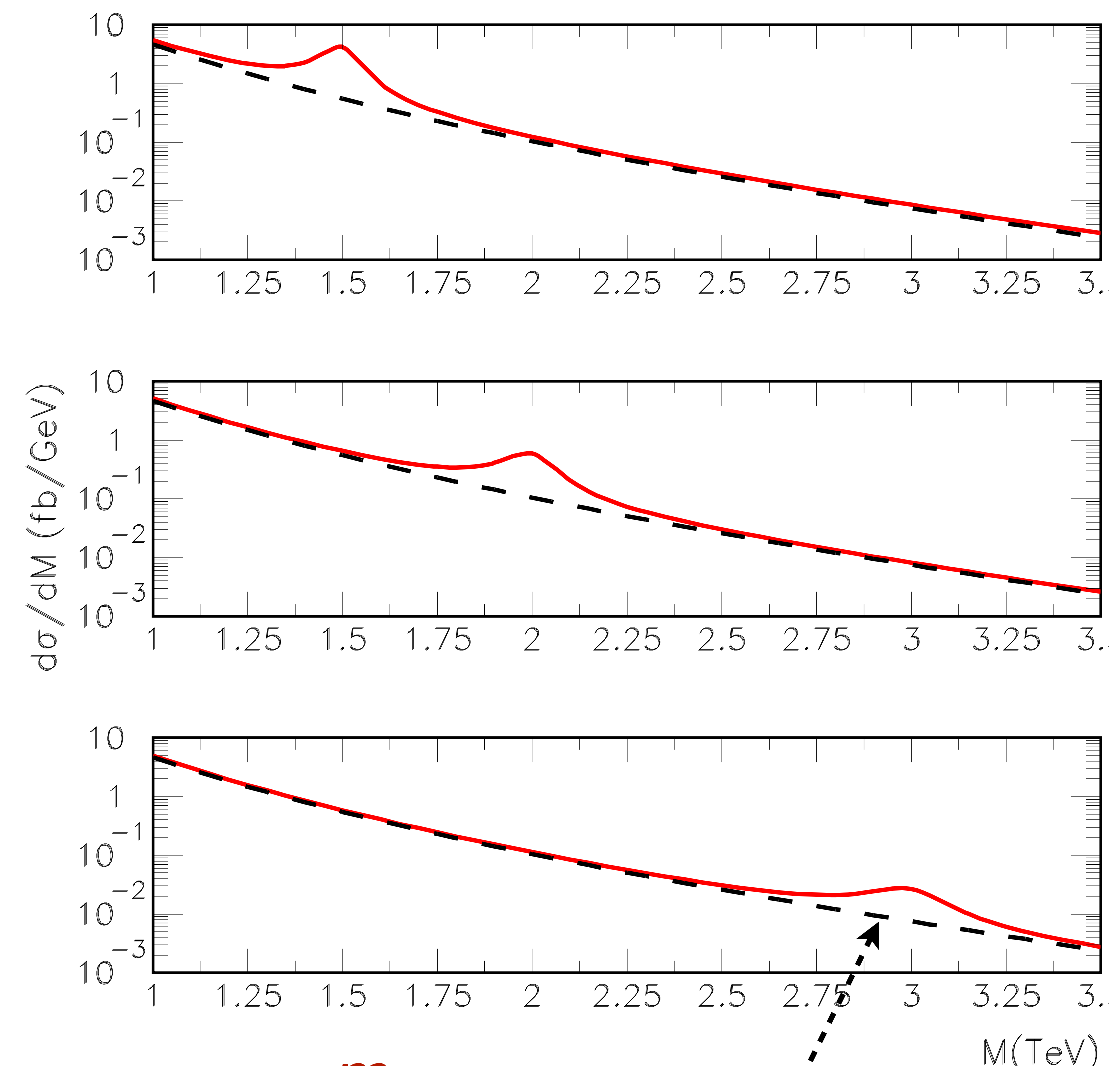
Regge excitations of a fundamental string at "string disk" level (tree level)

Results in Gaussian shaped $m_{\gamma j}$ resonance

[Phys. Rev. D78 016005 (2008)]



p_T^{γ}



$m_{\gamma j}$

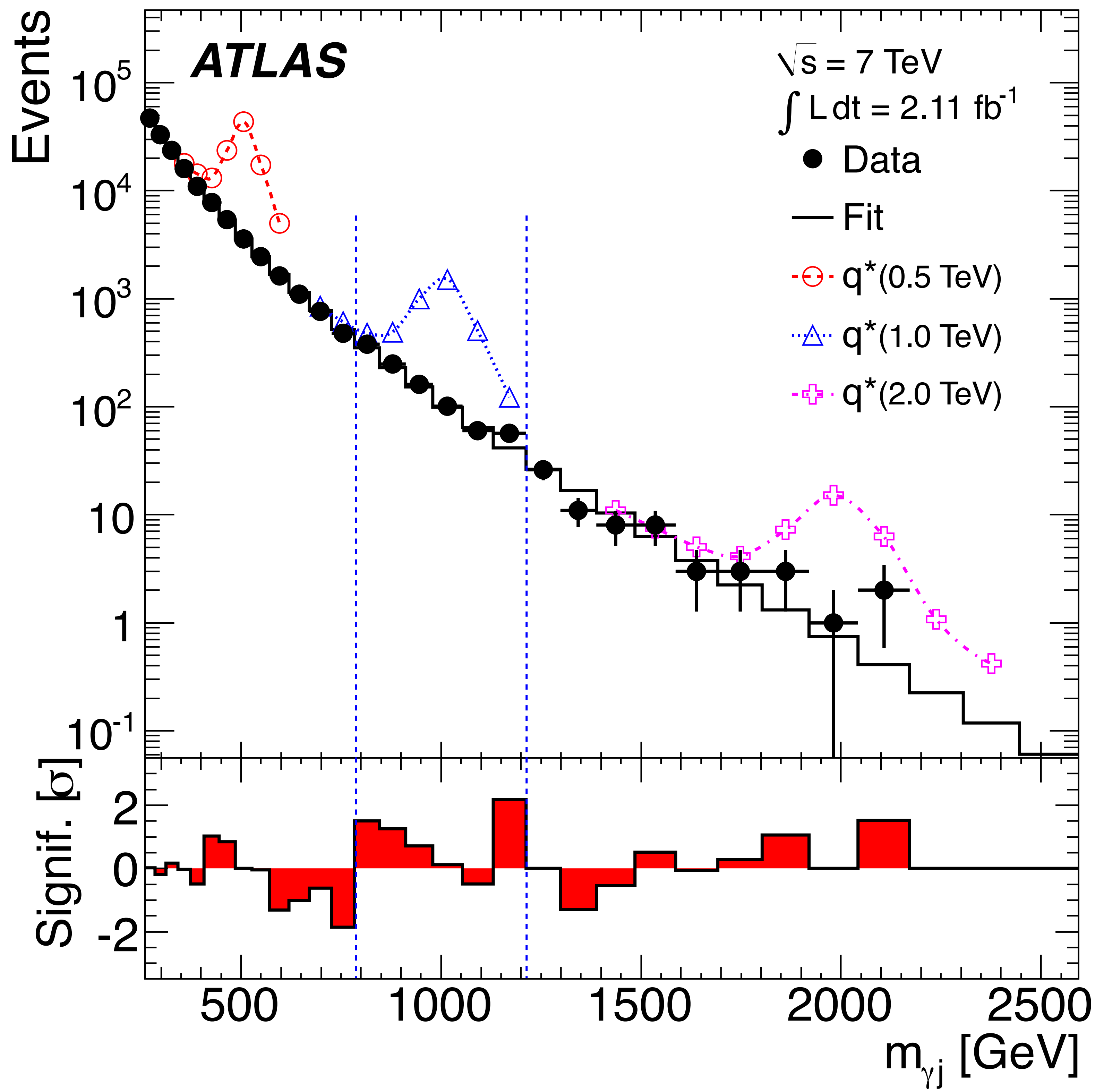
m_{string} = 3 TeV

Results: γ+jet resonance search

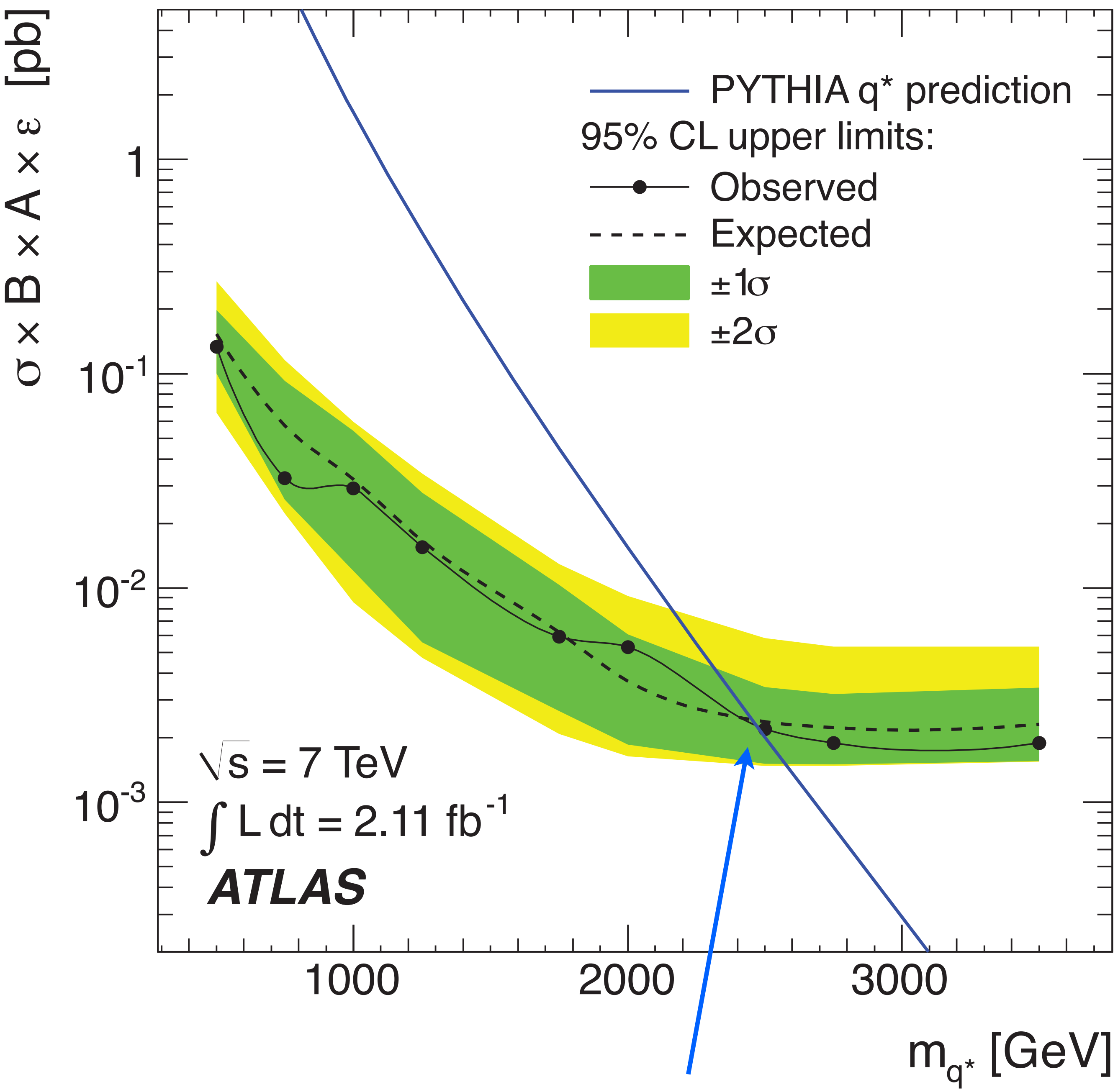
- Background estimated by fit to data across all bins using same functional form as for dijet analysis
- The "BumpHunter" algorithm finds most significant excess for 784< $m_{\gamma j}$ <1212 GeV with p-value = 0.20

Kinematic selection
(acceptance)
- $p_{T\gamma}$ > 85 GeV
- p_{Tjet} > 30 GeV
- $m_{\gamma j}$ > 260 GeV
- $\Delta R(\gamma,j)$ > 0.4

j is any jet w p_T > 30 GeV

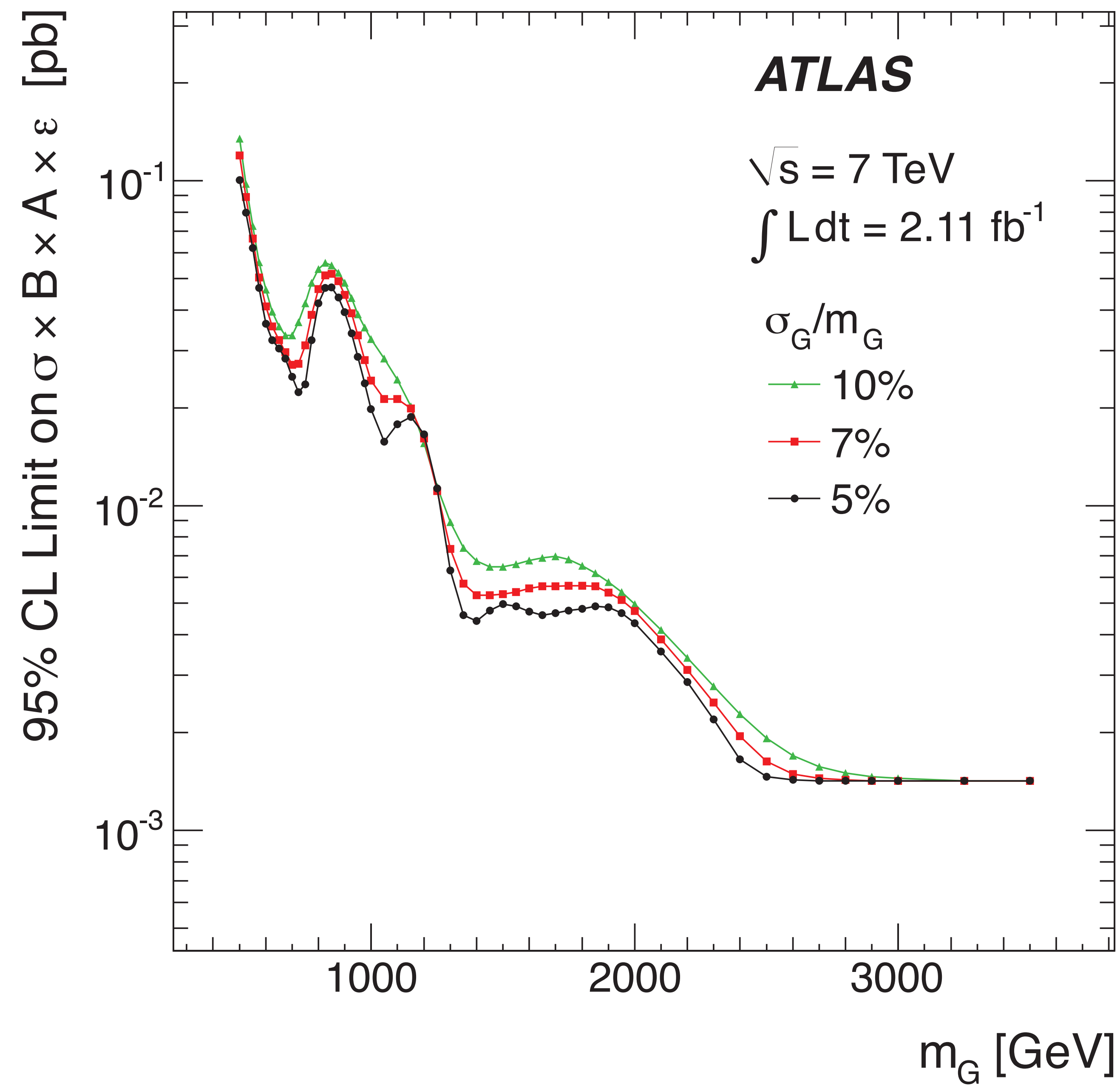


Results: γ+jet resonance search



Excited quark cross section limit: 2.46 TeV @ 95% CL

previous limit: 460 GeV (!)



Model-independent cross section limits on Gaussian signals

Summary

No significant excess observed

Limits on generic and several specific New Physics models

Dijet search results
$\sqrt{s}$ = 8 TeV, 5.3 fb^{-1}

- Cross section limits on generic Gaussian-shaped signals
- Excited quark below **3.66 TeV** excluded @ 95% CL

+300 GeV limit due to 7→8 TeV

γ+jet search results
$\sqrt{s}$ = 7 TeV, 2.1 fb^{-1}

- Cross section limits on generic Gaussian-shaped signals
- Excited quark below 2.46 TeV excluded @ 95% CL

previous limit: 460 GeV

Dijet results $\sqrt{s}$ = 7 TeV, 4.8 fb^{-1}

95% CL low limits on masses and energy scales of the New Physics models probed

Model, and Analysis Strategy	95% C.L. Limits (TeV) Expected	Observed
Excited quark, mass of q^*		
Resonance in m_{jj}	3.09	3.35
Resonance in $F_\chi(m_{jj})$	2.97	2.58
Colour octet scalar, mass of s8		
Resonance in m_{jj}	1.94	1.94
Quantum Black Hole for $n = 6$, M_D		
$F_\chi(m_{jj})$	4.14	4.11
11-bin χ , $m_{jj} > 2.6$ TeV	4.23	3.96
Contact interaction, Λ, destructive interference		
$F_\chi(m_{jj})$	8.2	7.6
11-bin χ , $m_{jj} > 2.6$ TeV	8.7	7.8

BACKUP SLIDES

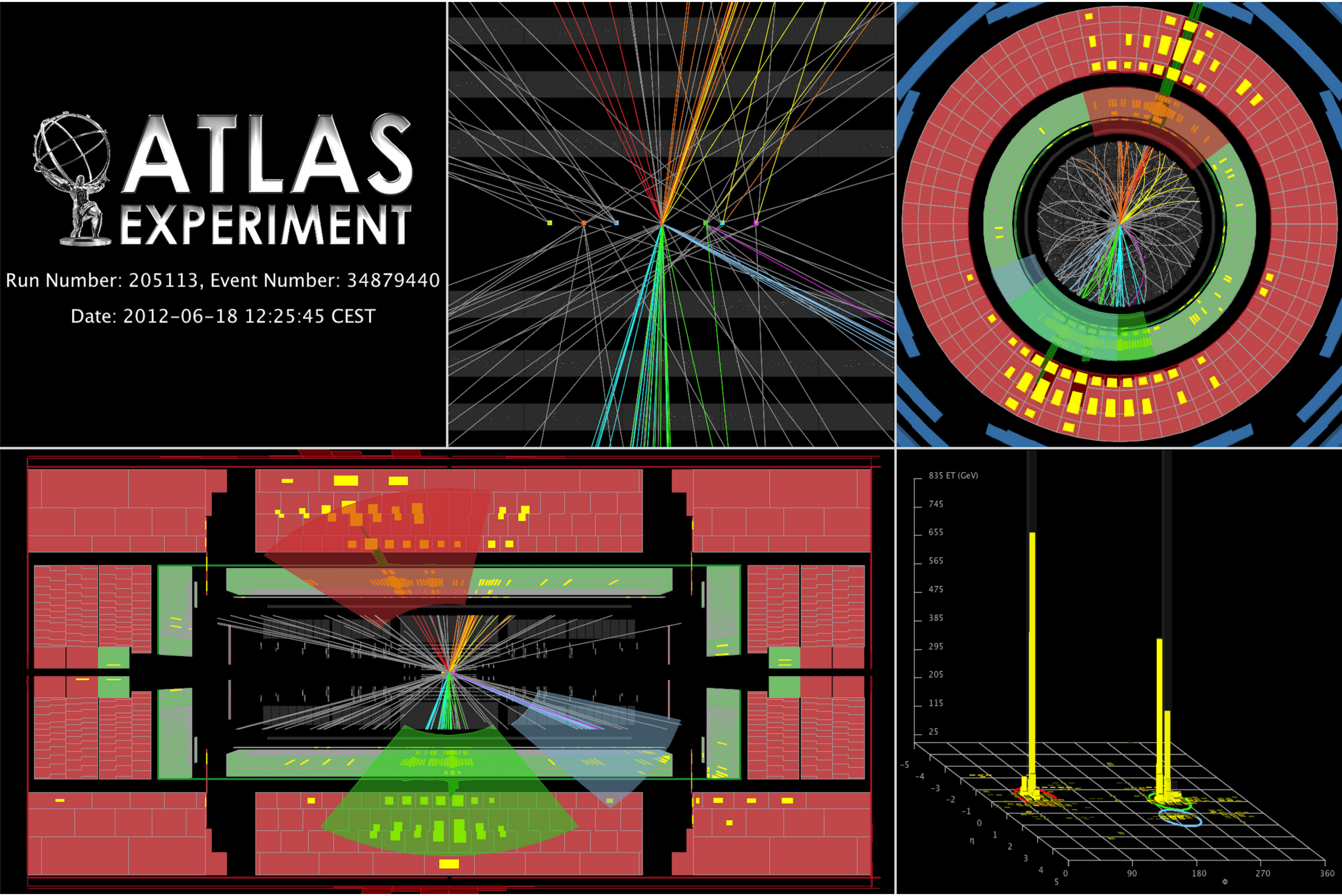
Publications and more info

Search for New Phenomena in the Dijet Mass Distribution using 5.8 fb^{-1} of pp Collisions at sqrt(s)=8 TeV collected by the ATLAS Detector

ATLAS-CONF-2012-088
July 2012

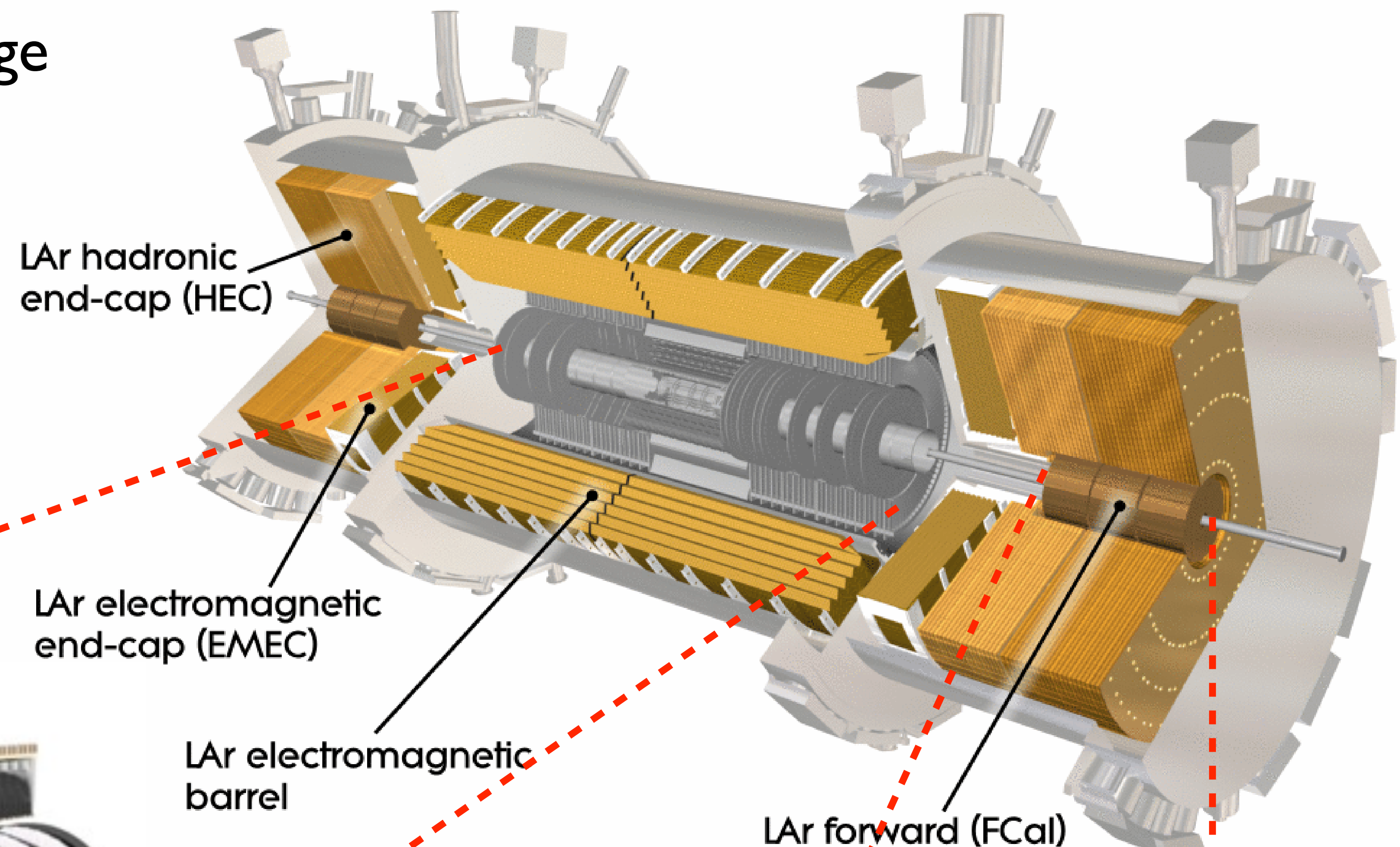
Search for New Phenomena in Dijet Mass and Angular Distributions
ATLAS-CONF-2012-038
4.8/fb. March 2012

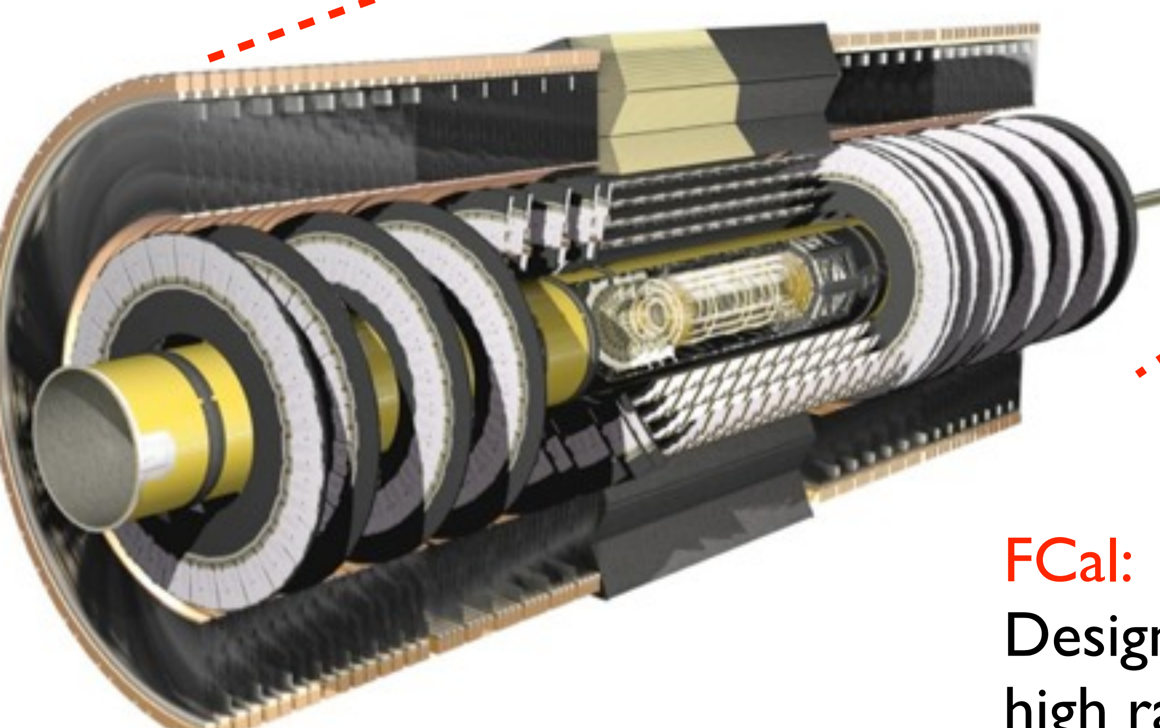
Search for production of resonant states in the photon-jet mass distribution using pp collisions at sqrt(s) = 7 TeV collected by the ATLAS detector
Plots and more Info
arXiv:1112.3580
Phys. Rev. Lett. 108, 211802 (2012)
2.11/fb December 2011

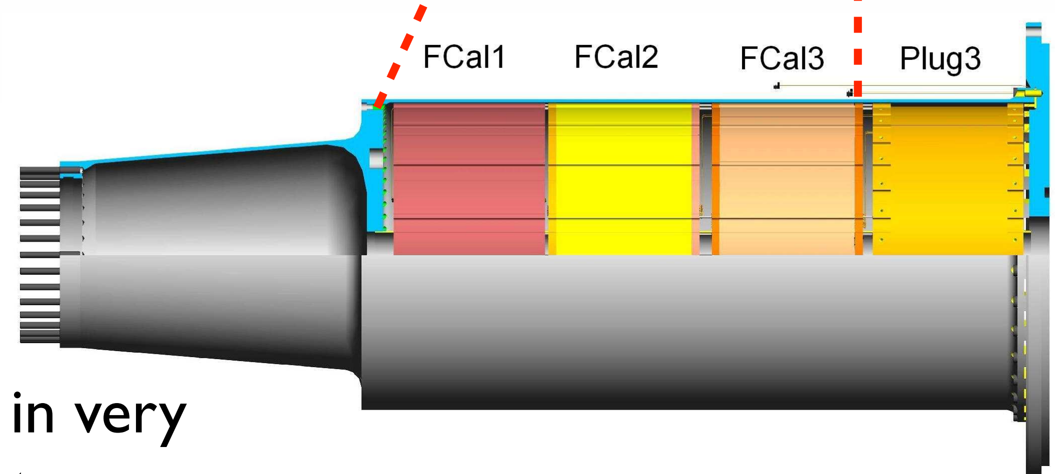

ATLAS
EXPERIMENT
Run Number: 205113, Event Number: 34879440
Date: 2012-06-18 12:25:45 CEST
835 ET (GeV)
745
655
565
475
385
295
205
115
25
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
φ

The ATLAS calorimeters

- Excellent LAr calorimeter, 200k channels, total coverage |η| < 4.9
- Hadronic tile scintillator/ steel calorimeter
- Inner tracker, |η| < 2.5
  Silicon pixel
  Silicon microstrip
  TRT







FCal: 3.1 < |η| < 4.9
Designed to operate in very high rate environment

Jet reconstruction and selection

- Jets reconstructed from calorimeter clusters using the anti-k_t jet finding algorithm with distance parameter $R = 0.6$
- Jet are calibrated to the hadronic scale in three steps:

Function of μ and NPV applied to the jet at constituent scale, i.e. EM- or LC-scale

Changes the jet direction to point to the primary vertex. Does not affect E.

Corrects the jet 4-vector to the particle level scale. Both the energy and direction (eta) are calibrated.

- JES uncertainly is about 2.5% for central jets (main uncertainty for the analyses)
- Jet triggers used to collect data

Kinematic selection, m_{jj}
(acceptance)
- p_T > 80 GeV *for both jets*
- $|y^*| < 0.6$
- $|y_1| < 2.8$, $|y_2| < 2.8$
- m_{jj} > 800 (850) GeV *for 2011 (2012)*

Kinematic selection, angular
(acceptance)
- p_T > 80 GeV *for both jets*
- $|y^*| < \log(30)/2 \approx 1.7$
- $|y_B| < 1.1$
- m_{jj} > 800 GeV

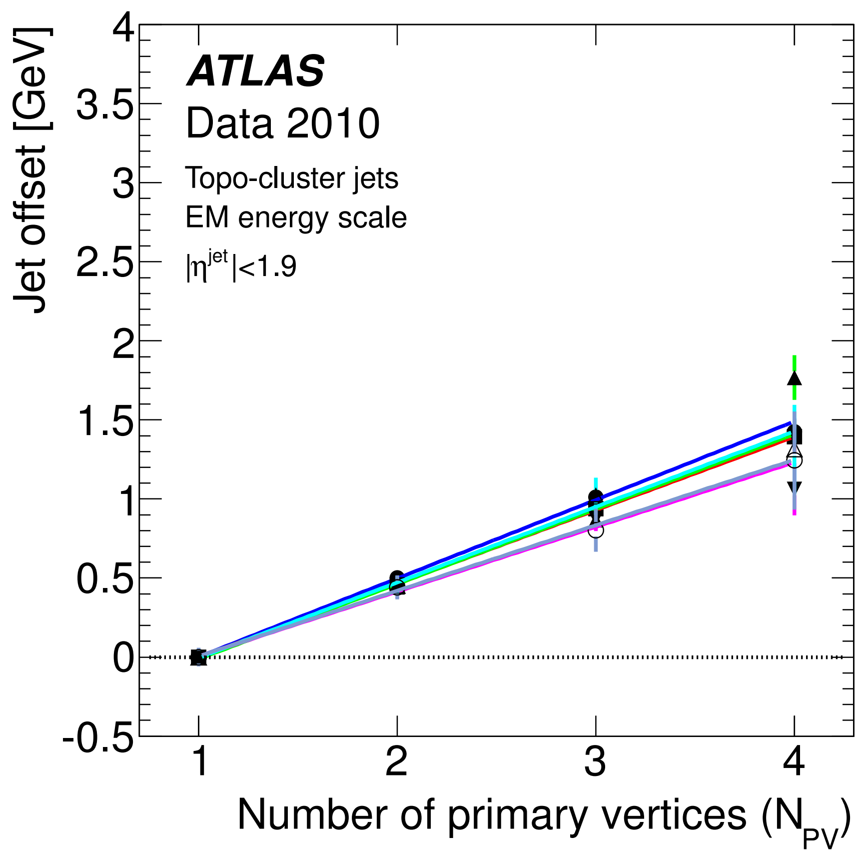
Jet calibration

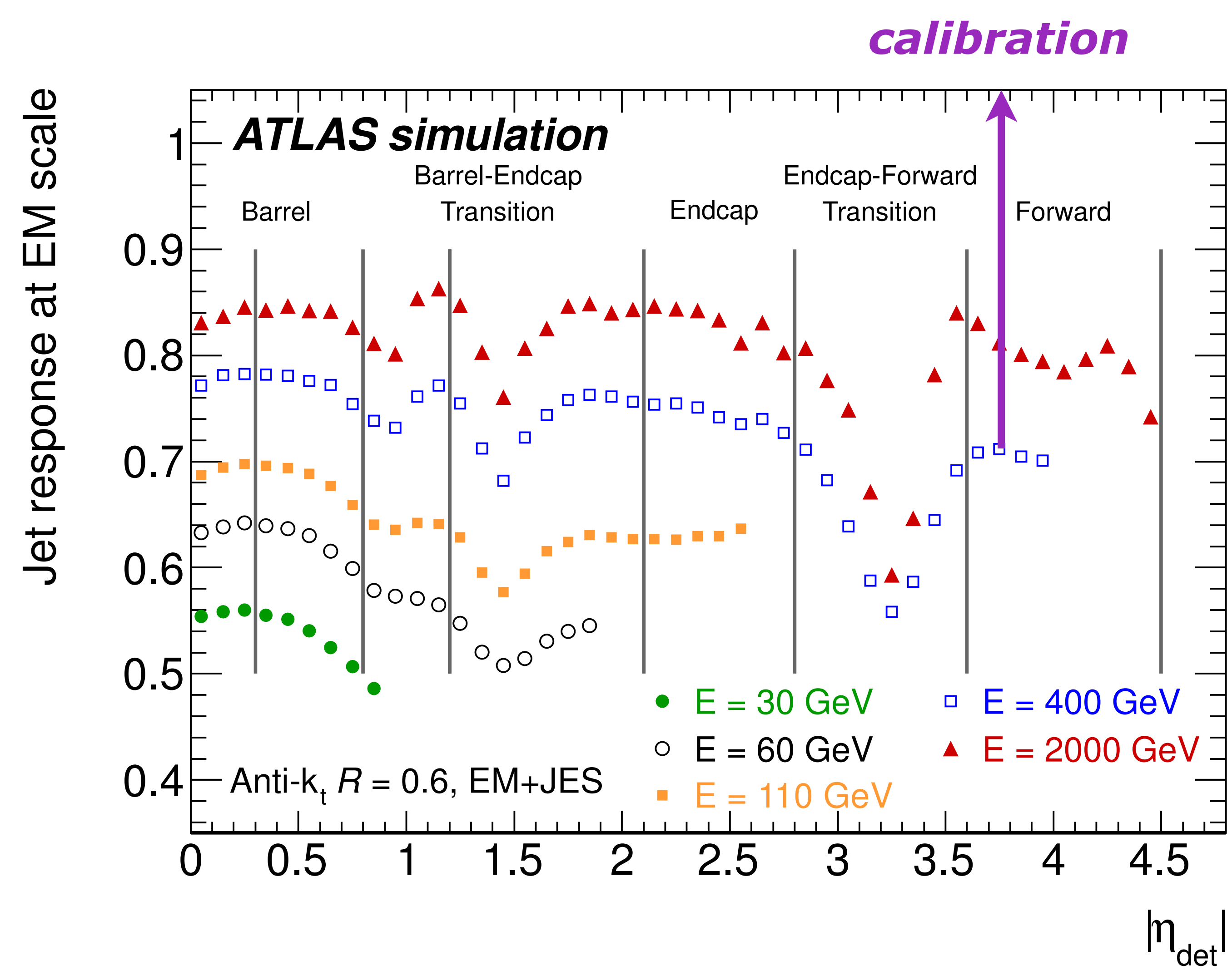
Pile-up Correction → **Origin Correction** → **Absolute EtaJES**

Function of μ and NPV applied to the jet at constituent scale, i.e. EM- or LC-scale

Changes the jet direction to point to the primary vertex. Does not affect E.

Corrects the jet 4-vector to the particle level scale. Both the energy and direction (eta) are calibrated.





Dijet kinematics

- Consider LO dijet production
- Both jets balanced in transverse plane
- Rapidity separation:
  Δy = $|y_1 - y_2|$ = 2 y^*
- Parton momentum fraction *x* given by

$$x_1 = \left(2p_T/\sqrt{s}\right) e^{y_{\rm boost}} \cosh y^*$$

$$x_2 = \left(2p_T/\sqrt{s}\right) e^{-y_{\rm boost}} \cosh y^*$$

$$y_{\rm boost} = 0.5 \ln(x_1/x_2)$$