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Search for New Physics in the Dijet Mass Distribution using 1 fb^{-1} of pp Collision Data at $\sqrt{s} = 7$ TeV collected by the ATLAS Detector

ATLAS Collaboration

Invariant mass distributions of jet pairs (dijets) produced in LHC proton-proton collisions at a centre-of-mass energy $\sqrt{s} = 7$ TeV have been studied using a data set corresponding to an integrated luminosity of 1.0 fb^{-1} recorded in 2011 by ATLAS. Dijet masses up to ~ 4 TeV are observed in the data, and no evidence of resonance production over background is found. Limits are set at 95% CL for several new physics hypotheses: excited quarks are excluded for masses below 2.99 TeV, axigluons are excluded for masses below 3.32 TeV, and colour octet scalar resonances are excluded for masses below 1.92 TeV.

I. Introduction

The Standard Model (SM) description of high energy proton-proton (pp) collisions is based on the framework of quantum chromodynamics (QCD) in the perturbative regime, where the most energetic collisions result from the $2 \to 2$ scattering of a pair of partons (quarks or gluons). Partons emerging from the collision shower and hadronise, in the simplest case producing two jets of particles, a "dijet", that may be reconstructed to determine the dijet invariant mass, m_{jj}, the mass of the two-parton system.

Previous studies of dijet mass distributions [1–6] have shown that these analyses are sensitive to the highest mass scales accessible with hadronic final states. In the present study, the dijet mass distribution is examined in a search for resonances due to new phenomena localised near a given mass, employing a data-driven background estimate that does not rely on detailed QCD calculations.

In addition to new physics benchmarks used in previous ATLAS dijet analyses, namely excited quarks (q^*) [7, 8], and axigluons [9–11], the present study includes a third hypothetical object: the colour octet scalar (s8), one of many possible exotic colour resonances [12]. Any of these objects could produce a peak in the dijet spectrum in the vicinity of their mass.

The present study is based on pp collisions at a centre-of-mass (CM) energy of 7 TeV produced at the CERN Large Hadron Collider (LHC), measured by the ATLAS detector. This data set corresponds to an integrated luminosity of 1.0 fb^{-1} recorded between March and June 2011. The most stringent limits set previously by the ATLAS Collaboration were based on the full 2010 data sample, corresponding an integrated luminosity of 36 pb^{-1} [6]. Excited quarks were excluded below 2.15 TeV, and axigluons below 2.10 TeV. The CMS Collaboration has recently completed a dijet resonances analysis in 1.0 fb^{-1} of 2011 data, excluding excited quarks below 2.49 TeV and axigluons below 2.47 TeV, along with other limits [13].

A detailed description of the ATLAS detector is available in [14]. The detector is instrumented over almost the entire solid angle around the pp collision point with layers of tracking detectors, calorimeters, and muon chambers. Jet measurements are made using a finely segmented calorimeter system designed to detect the high energy jets that are the focus of this study with high efficiency and excellent energy resolution. ATLAS has a three-level trigger system, with the first level trigger (L1) being based on custom-built hardware and the two higher level triggers (HLT) being realised in software.

ATLAS uses a right-handed coordinate system with the z-axis along the beam pipe. The x-axis points to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r,ϕ) are used in the transverse plane, ϕ being the azimuthal angle. The pseudorapidity is defined in terms of the polar angle θ as $\eta \equiv -\ln\tan(\theta/2)$. Transverse momentum and energy are defined as $p_T = p\sin\theta$ and $E_T = E\sin\theta$, respectively.

The dijet mass, m_{jj}, is derived from the vectorial sum of the four-momenta of the two highest p_{T} jets in the event. Kinematic criteria based on momentum and angular variables are applied to increase the sensitivity to centrally produced high mass resonances.

The angular distribution for $2 \to 2$ parton scattering is predicted by QCD in the CM frame of the colliding partons, which moves along the beamline due to the differing momentum fractions (Bjorken x) of the colliding partons. If E is the jet energy and p_z is the z-component of the jet's momentum, the rapidity of the jet is given by $y \equiv \frac{1}{2}\ln(\frac{E+p_z}{E-p_z})$. The rapidities of the two highest p_{T} jets are denoted by y_1 and y_2, and the corresponding rapidity of these partons in their mutual CM frame is $y^* = \frac{1}{2}(y_1 - y_2)$.

II. Jet reconstruction and event selection

Individual jets are reconstructed using the anti-k_t jet clustering algorithm [15, 16] with the distance parameter $R = 0.6$. The inputs to this algorithm are clusters [17] of calorimeter cells with energy depositions significantly above the measured noise. Jet four-momenta are constructed as the vectorial sum of clusters of cells, treating each cluster as an (E, $\vec{p}$) four-vector with zero mass, assuming that the corresponding particle stems from the primary vertex.

The jet four-momenta are then corrected [18] as a function of η and p_{T} for various effects, the largest of which are the hadronic shower response and detector material distribution. This is done using a calibration

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scheme based on Monte Carlo (MC) studies including full detector simulation, and validated with extensive test-beam [19] and collision data [20–22] studies. Measured dijet mass distributions are not corrected for detector resolution, which, in terms of mass smearing, is $\frac{\sigma_{m_{jj}}}{m_{jj}} \simeq 5\%$ at $m_{jj} \simeq 1$ TeV, drops to 4.5% at 2 TeV, and asymptotically approaches 4% at m_{jj} of 5 TeV and above.

The event selection starts with the first-level trigger, which selects events that have at least one large transverse energy deposition in the calorimeters, with the transverse energy threshold increasing over the period of the data-taking as the instantaneous luminosity of the LHC pp collisions increased.

To achieve the highest possible effective integrated luminosity, the current data set has been recorded using a jet trigger that was usually not prescaled. The chosen trigger has a nominal jet p_{T} threshold of 180 GeV. After applying all other analysis cuts, m_{jj} is required to be greater than 717 GeV in order to attain a trigger efficiency of at least 99% over the full range of the dijet mass distribution.

Events are required to have a primary collision vertex defined by at least five charged-particle tracks. Events with a poorly measured jet [23] with p_{T} greater than 30% of the p_{T} of the next-to-leading jet are vetoed, to avoid cases where such a jet would cause incorrect identification of the two leading jets. This rejects less than 0.002% of the events.

Additional kinematic criteria are applied, requiring that the two leading jets each satisfy $|\eta_j| < 2.8$ and that the rapidity in the parton CM frame satisfies $|y^*| < 0.6$. These criteria favour central collisions and have been shown, based on studies of expected signals and QCD background, to optimise the analysis sensitivity.

A final selection is made to avoid the calorimeter region from -0.1 to 1.5 in η and from -0.9 to -0.5 in ϕ, which was in large part affected by readout problems for most of the data used in these studies. Events with jets in this region are discarded. This requirement reduces the data set by 3.7%.

III. Comparing data to a smooth background

The observed dijet mass distribution after all selection cuts is shown in Fig. 1. As in the previous ATLAS studies, the m_{jj} spectrum is fit to the smooth functional form

$$f(x) = p_1(1-x)^{p_2} x^{p_3 + p_4 \ln x}, \qquad (1)$$

where $x \equiv m_{jj}/\sqrt{s}$ and the p_i are fit parameters. This ansatz has been shown empirically to accurately model the steeply falling QCD dijet mass spectrum [3–6]. The m_{jj} bins are of variable width, increasing from ~ 50 to ~ 200 GeV for dijet masses from 0.85 to 4.5 TeV, respectively, to optimise the performance of the resonance search algorithm discussed in the next section.

The bottom plot of Fig.1 shows the significance, in standard deviations, of the difference between the data and the prediction in each bin. These are purely statistical, and based on Poisson distributions. The contents of a given bin are used to determine the p-value - the probability of the background fluctuating higher than the observed excess, or lower than the observed deficit. The p-value is transformed to a significance, in terms of an equivalent number of standard deviations (the z-value). Where there is an excess (deficit) in data in a given bin, the significance is plotted as positive (negative). In mass bins with small expected number of events, where the observed number of events is similar to the expectation, the Poisson probability of a fluctuation at least as high (low) as the observed excess (deficit) can be greater than 50%, as a result of the asymmetry of the Poisson distribution. Such bins present no statistical interest and, for simplicity, bars are not drawn for them.

To determine the degree of consistency between data and the fitted background, the p-value of the fit is obtained by calculating the χ^2 from the data, and comparing this result to the χ^2 distribution obtained from pseudoexperiments. The resulting p-value is 0.96, showing that there is good agreement between the data and the functional form.

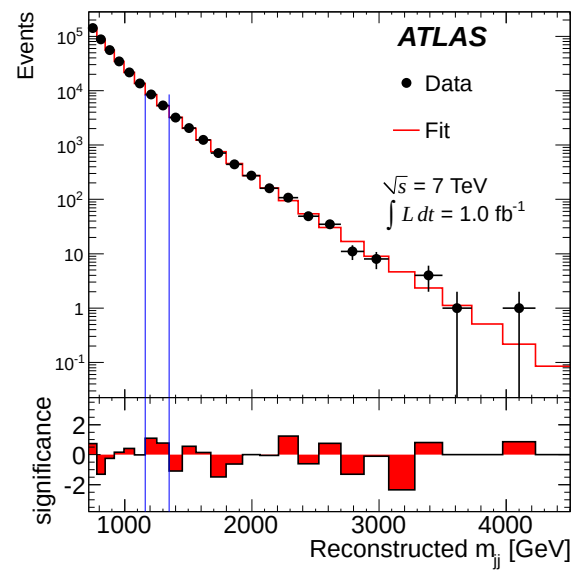


FIG. 1. The reconstructed dijet mass distribution (filled points) fitted with a smooth functional form describing the QCD background. The bin-by-bin significance of the data-background difference is shown in the lower panel. Vertical lines show the most significant excess found by the BumpHunter algorithm (see text).

IV. Search for resonances

As a more sensitive test, the BumpHunter algorithm [24, 25] is used to establish the presence or absence of a resonance in the dijet mass spectrum. To optimise the sensitivity of this algorithm, the m_{jj} binning strategy is to establish a minimum width for resonances to be considered physical. To this end, the relatively narrow q^* m_{jj} template from full MC simulation [26], described below for subsequent studies, has been used to establish

the binning. If the width of the resonance is defined as $\pm 1\sigma$, the greatest sensitivity at the minimum width is achieved by setting the bin width to 1σ, half the resonance width. The final result of this procedure is that the variable bin sizes are typically 6.5% to 7.0% of m_{jj} in width, somewhat wider than detector resolution due to the finite natural width of q^*, which varies between about 3% and 3.5% of the q^* mass.

In the current implementation, the BumpHunter algorithm searches for the signal window with the most significant excess of events above background. Starting with a two-bin window, the algorithm increases the signal window and shifts its location until all possible bin ranges, up to half the mass range spanned by the data, have been tested. The most significant departure from the smooth spectrum ("bump") is defined by the set of bins that have the smallest probability of arising from a background fluctuation assuming Poisson statistics.

The BumpHunter algorithm accounts for the so-called "look elsewhere effect" (or "trials factor effect") [27] by performing a series of pseudoexperiments to determine the probability that random fluctuations in the background-only hypothesis would create an excess as significant as the one observed anywhere in the spectrum. Variable width binning reduces the penalty due to this effect, while retaining sensitivity.

To prevent any new physics signal from biasing the background estimate, if the biggest local excess from the background fit has a p-value smaller than 0.01, this region is excluded and a new background fit is performed. No such exclusion is needed for this data set.

The most significant discrepancy identified by the BumpHunter algorithm in the observed dijet mass distribution reported in Fig. 1 is a 2-bin excess in the interval 1.16 to 1.35 TeV. The probability of observing such an excess or larger somewhere in the mass spectrum for a background only hypothesis is 0.82. This test shows that there is no evidence for a resonance signal in the m_{jj} spectrum.

V. New physics models

Exclusion limits are set on three new physics scenarios expected to give rise to resonant dijet production.

For the first of these, excited quarks, q^*, a $qg \to q^*$ production model [7, 8] is used, with the assumption of spin 1/2 and quark-like SM coupling constants. The compositeness scale (Λ) is set to the q^* mass. Signal events are produced using the Pythia event generator [28], a leading-order parton-shower MC generator, with the MRST2007LO* [29] parton distribution functions (PDF's), with settings established by the ATLAS default MC10 [30] Monte Carlo tune. The renormalization and factorization scales are set to the mean p_{T} of the two leading partons for each event. Pythia is also used to decay the excited quarks to all possible SM final states, which are predominantly qg, but also qW, qZ, and $q\gamma$. The generated events are passed through the detailed simulation of the ATLAS detector [26], which uses the Geant4 package [31] for simulation of particle transport, interactions, and decays. The simulated events are then reconstructed in the same way as the data to produce predicted dijet mass distributions that can be compared with the observed distributions.

The second model is axigluon production [9–11] via an interaction given by the Lagrangian

$$\mathcal{L}_{Aq\bar{q}} = g_{QCD}\bar{q}A^a_\mu \frac{\lambda^a}{2}\gamma^\mu\gamma_5\ q, \tag{2}$$

where $g^2_{QCD} = 4\pi\alpha_s$ is the QCD coupling constant and A^a_μ is the axigluon field representing a massive state with axial coupling to quarks. Parity conservation prevents the axigluon from coupling to two gluons. Parton-level events are generated, at leading-order approximation, using the CalcHEP Monte Carlo package [32], for chosen masses, m, of the axigluon. The MRST2007LO* PDF set was used. The axigluon dijet mass has longer tails at high and low masses than the q^* distribution, but these two shapes are interchangeable within the range $0.7m$ to $1.3m$ for all masses of interest. Since the axigluon tails outside this range are well below the SM background, the predicted signal may be analyzed by cutting events beyond this range and accounting for the reduced acceptance. The axigluon MC prediction for $\sigma \times \mathcal{A}$, the production cross section within the acceptance, is defined to include these cuts by applying them at the level of CalcHEP generation, along with the kinematic cuts in p_{T} and rapidity. In the limit setting analysis, these axigluon results are compared to the observed $\sigma \times \mathcal{A}$ limits from the q^* analysis. This method is discussed in more detail in Section VI.

The third resonant hypothesis, the colour octet scalar (s8) model, is a prototype for many possible exotic coloured resonances [12]. Colour octet resonances can couple to gluons, which have large parton luminosity at the LHC. One possible interaction is

$$\mathcal{L}_{gg8} = g_{QCD} d^{ABC} \frac{\kappa_s}{\Lambda_s} S^A_8 F^B_{\mu\nu} F^{C,\mu\nu}, \tag{3}$$

where S^A_8 is the colour octet scalar field, κ_s is the scalar coupling (assumed to be unity), and d^{ABC} is the SU(3) isoscalar factor; Λ_s is the new physics scale which is set to the resonance mass, M_{s_8}. This model leads to a very simple event topology, with two gluons in the initial and final states, yielding high p_T dijets. MadGraph 5 [33] is used to generate parton level events at leading-order approximation. Pythia with CTEQ6L1 PDF's is used in this generation, with the ATLAS MC09' tune [34]. These samples are processed through the full ATLAS detector simulation.

The observed limits on s8 are less strict than the corresponding q^* limits, in part because the s8 signal is much wider than q^*. Much of this width increase is due to final state radiation, which is larger for gluon-jets than for quark-jets. In addition, the initial state for s8 production contains gluons, which have small parton density at high mass. Thus, s8 are much more likely to be off-mass-shell than q^*.

VI. Model dependent limit setting

In the absence of any observed significant discrepancy from the zero-signal hypothesis, the Bayesian method documented in [6] is used to set 95% credibility-level (CL) upper limits.

Bayesian credibility intervals are set by defining a posterior probability density from the Poisson likelihood function for the observed mass spectrum, obtained by a fit to the background functional form and a signal shape derived from MC simulations. A prior probability density constant in all positive values of signal cross section, and zero at negative values, is used. The posterior probability is then integrated to determine the 95% CL for a given range of models, usually parameterised by the mass of the resonance.

Limits are determined on $\sigma \times \mathcal{A}$ for a hypothetical new particle decaying into dijets. The acceptance includes all reconstruction steps and analysis cuts described above, and assumes that the trigger is fully efficient. (The efficiency is greater than 99% for all analyses.)

The effects of systematic uncertainties due to the knowledge of the luminosity and of the jet energy scale (JES) are included. The luminosity uncertainty for the 2011 data is 3.7% [35]. The systematic uncertainty on the JES is taken from the 2010 data [18] analysis, and is adapted to the 2011 analysis taking into account in particular the new event pileup conditions (described below). The JES uncertainty shifts resonance peaks by less than 4%. The background parameterization uncertainty is taken from the fit results, as described in [6]. The effect of the jet energy resolution (JER) uncertainty is found to be negligible. All of these uncertainties are incorporated into the fit by varying all sources according to Gaussian probability distributions and convolving them with the Bayesian posterior probability distribution. Credibility intervals are then calculated numerically from the resulting convolutions. No uncertainties are associated with the theoretical model of new physics, as in each case the model is a benchmark that incorporates a specific choice of model parameters, of PDF set, and of MC tune. Previous ATLAS studies have already explored the impact of different MC tunes and PDF sets on the q^* theoretical prediction [4].

In 2011, the instantaneous luminosity has risen to a level where corrections must be made for multiple pp collisions occurring in the same bunch crossing ("pileup"), whose presence affects the measurement of calorimeter energy depositions associated with the hard-scattering event under study. All simulated samples used in this analysis include a Poisson distributed number of MC minimum bias events added to the hard interaction to account for "in-time" pileup caused by additional collisions in the same bunch crossing. Further account must be taken of "out-of-time" pileup originating from collisions in bunches preceding or following the one of interest, due to the long response time of the liquid argon calorimeters. With the 50 ns bunch spacing in the LHC for these data, up to 12 preceding bunches and 1-2 following bunches contribute to out-of-time pileup. Although the conditions modelled in MC are realistic, they may not perfectly match the data due to bunch train structure and instantaneous luminosity variations in the LHC. The MC events are therefore reweighted to remove these residual differences. Following this procedure the pileup description in MC is sufficiently good that no additional uncertainty on the JES is required for jets with $p_{\mathrm{T}} > 100$ GeV.

The resulting limits are shown in Fig. 2. For excited quarks, the acceptance $\mathcal{A}$ ranges from 37 to 51% for m_{q^*} varying from 0.8 to 5.0 TeV, and is never lower than 47% above masses of 1.1 TeV. The main impact on the acceptance comes from the rapidity requirements. Using the theoretical prediction for q^* production described above, the expected mass limit at 95% CL is 2.81 TeV, and the observed limit is 2.99 TeV.

The axigluon results are obtained from the $\sigma \times \mathcal{A}$ limits determined from the q^* analysis. The axigluon theoretical prediction is derived from the cross section provided by CalcHEP at each simulated mass, m, within the restricted mass range $0.7m$ to $1.3m$, after applying the kinematic selections. Using the axigluon theoretical $\sigma \times \mathcal{A}$ thus defined, the expected axigluon mass limit at 95% CL is 3.07 TeV, and the observed limit is 3.32 TeV. This method has been confirmed by full simulation of axigluon samples at three mass points, showing that the differences between parton level and full simulation are negligible compared to the effects of other uncertainties.

Figure 2(b) shows the limits on the accepted cross section $\sigma \times \mathcal{A}$ for colour octet resonances. The expected mass limit at 95% CL is 1.77 TeV, and the observed limit is 1.92 TeV. Since the colour octet scalar cross section decreases much more rapidly with m than those for excited quark and axigluon production, the resulting limits are considerably lower.

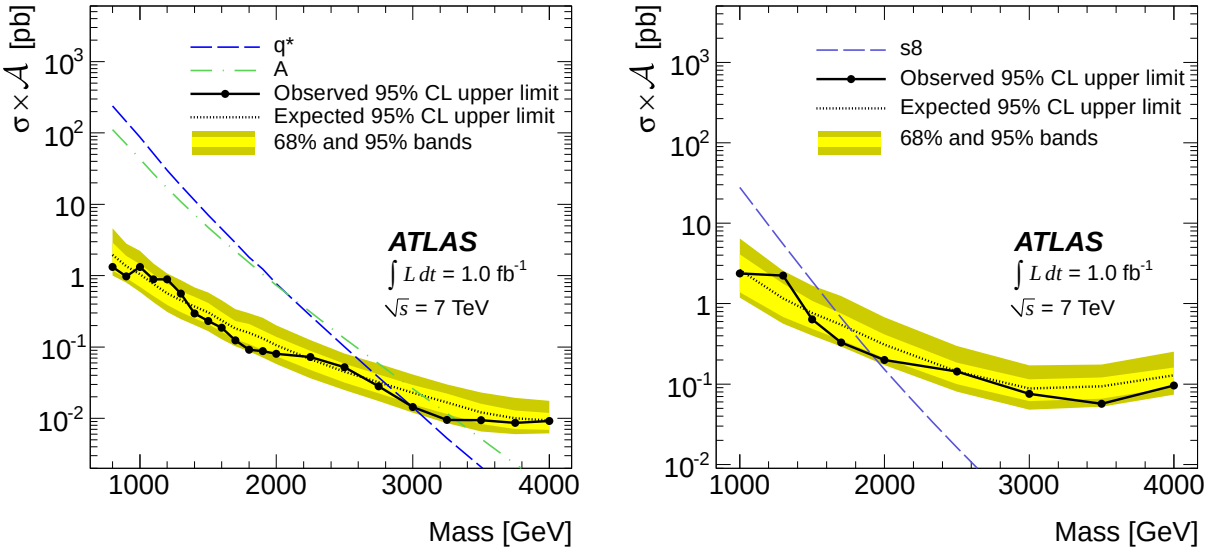
For all three models used in these studies, if systematic uncertainties had not been included the exclusion limits would be approximately 60 GeV higher.

VII. Model independent limit setting

In addition to specific theoretical models, limits are set to a collection of hypothetical signals that are assumed to be Gaussian-distributed in m_{jj} with mean (m_{G}) ranging from 0.9 to 4.0 TeV and standard deviation (σ_{G}) from 5% to 15% of the mean.

Systematic uncertainties are treated using the same methods as applied in model dependent limit setting. The only difference for the Gaussian analysis arises from the decay of the dijet final state not being simulated. In place of this, it is assumed that the dijet signal distribution is Gaussian in shape, and the JES is adjusted by modelling it as an uncertainty of 4% in the central value of the Gaussian signal.

The resulting limits on $\sigma \times \mathcal{A}$ for the Gaussian template model are shown in Fig. 3. Relative to previous studies [6] they are substantially improved in the region above 900 GeV. These results may be utilised to set limits on new



(a)Excited-quark and axigluon models.

(b)Colour octet scalar model.

FIG. 2. The 95% CL upper limits on $\sigma \times \mathcal{A}$ as a function of particle mass (black filled circles). The black dotted curve shows the 95% CL upper limit expected from Monte Carlo and the light and dark yellow shaded bands represent the 68% and 95% contours of the expected limit, respectively. Theoretical predictions for $\sigma \times \mathcal{A}$ are shown in (a) for excited quarks (blue dashed) and axigluons (green dot-dashed), and in (b) for colour octet scalar resonances (blue dashed). For a given new physics model, the observed (expected) limit occurs at the crossing of its $\sigma \times \mathcal{A}$ curve with the observed (expected) 95% CL upper limit curve.

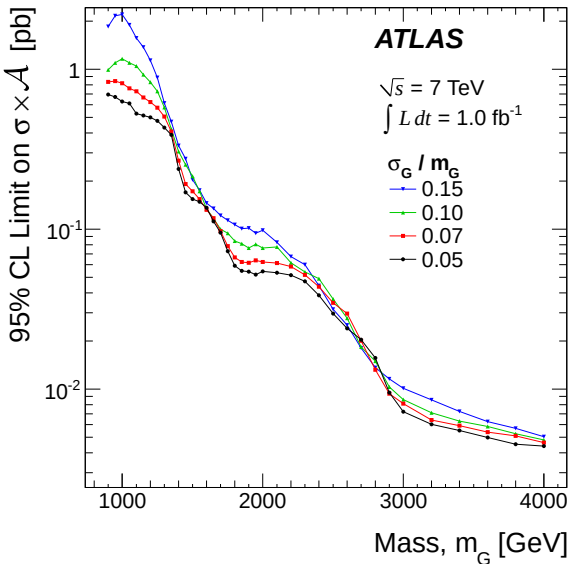


FIG. 3. The 95% CL upper limits on $\sigma \times \mathcal{A}$ for a simple Gaussian resonance decaying to dijets as a function of the mean mass, m_{G}, for four values of $\sigma_{\mathrm{G}}/m_{\mathrm{G}}$, taking into account both statistical and systematic uncertainties.

physics models beyond those considered in these studies, using the procedure described in the Appendix.

VIII. Conclusion

The dijet mass spectrum measured by the ATLAS experiment has been examined in a search for resonances from new phenomena, using 1.0 fb^{-1} of 7 TeV pp collision data taken in 2011. The observed distribution, which extends up to masses of ≈ 4 TeV, is in good agreement with a smooth function representing the SM expectation. No evidence for the production of new resonances is found. 95% CL mass limits using Bayesian methodology have been set in the context of several models of new physics, as summarized in Table I. For excited quarks and axigluons, the current results exceed the limits obtained by ATLAS with the 2010 data by approximately one TeV. Exclusion limits on colour octet scalar resonances have been established for the first time in ATLAS. The limits reported in this paper are the most stringent to date.

TABLE I. The 95% CL mass lower limits for the models of new physics examined in this study. They have been obtained with Bayesian analyses and include systematic uncertainties.

Model	95% CL Limits (TeV)	
	Expected	Observed
Excited Quark q^*	2.81	2.99
Axigluon	3.07	3.32
Colour Octet Scalar	1.77	1.92

Appendix: Setting limits on new models

The following procedure is appropriate for resonances that are approximately Gaussian near the core, and with tails that are well below the background. For convenience, the results of Fig. 3 are provided in Table II.

(1) For a MC sample generated with the mass of the hypothetical new particle set to M, compute an initial acceptance including the branching ratio into dijets. Then apply the kinematic cuts on the parton η, p_{T}, and $|y^*|$ used in this analysis. (2) Approximate the reduction of acceptance due to the calorimeter (temporary) readout problem by eliminating events where a parton enters the region -0.1 to 1.5 in η, and -0.9 to -0.5 in ϕ. (Indicatively, the acceptance of q^* is reduced by a factor 0.92.) (3) Smear the signal mass distribution to reflect the detector resolution. In the absence of a better detector simulation tool, use the mass resolution given in Section II, which is derived from full ATLAS simulation. (4) Since a Gaussian signal shape has been assumed in determining the limits, any long tails in the reconstructed m_{jj} should be removed in the sample under study. The recommendation (based on optimization using q^* templates) is to retain events with m_{jj} between $0.8M$ and $1.2M$. The mean mass, m, of this truncated signal should be calculated. (5) The fraction of MC events surviving the first four steps determines the modified acceptance, $\mathcal{A}$. (6) From Table II select m_{G} so that $m_{\mathrm{G}} = m$. If the exact value of m is not among the listed values of m_{G}, check the limit for the two values of m_{G} that are directly above and below m, and use the larger of the two limits to be conservative. (7) To retain enough of the information in the full signal template, and at the same time reject tails that would invalidate the Gaussian approximation, the following truncation procedure is recommended. For this mass point, choose a value of $\sigma_{\mathrm{G}}/m_{\mathrm{G}}$ such that the width $2\sigma_{\mathrm{G}}$ is well contained in the (truncated) mass range. For the q^* a good choice is empirically found to be $\sigma_G = (1.2M - 0.8M)/5$. This σ_G corresponds to a Gaussian distribution contained within the truncation interval of $[0.8M, 1.2M]$, since the interval $[0.8M, 1.2M]$ corresponds to $[m_G - 2.5\sigma_G, m_G + 2.5\sigma_G]$.

For the q^* case a good choice is $\sigma_{\mathrm{G}} = (1.2M\text{-}0.8M)/5$ so that 95% of the Gaussian spans $4 \times (0.4/5)M$. Use this value to pick the closest $\sigma_{\mathrm{G}}/m_{\mathrm{G}}$ value, rounded up to be conservative. (8) Compare the tabulated 95% CL upper limit corresponding to the chosen m_{G} and $\sigma_{\mathrm{G}}/m_{\mathrm{G}}$ values to the $\sigma \times \mathcal{A}$ obtained from the theoretical cross section of the model multiplied by the acceptance defined in step (5) above.

TABLE II. The 95% CL upper limit on $\sigma \times \mathcal{A}$ [pb] for the Gaussian "model-independent" scenario. The symbols m_{G} and σ_{G} are, respectively, the mean mass and standard deviation of the Gaussian.

m_{G}	$\sigma_{\mathrm{G}}/m_{\mathrm{G}}$			
(GeV)	5%	7%	10%	15%
900	0.69	0.83	0.99	1.9
950	0.67	0.84	1.1	2.2
1000	0.63	0.82	1.2	2.2
1050	0.61	0.76	1.1	1.9
1100	0.53	0.73	1.0	1.6
1150	0.51	0.67	0.93	1.4
1200	0.50	0.62	0.83	1.1
1250	0.48	0.58	0.73	0.89
1300	0.43	0.51	0.58	0.61
1350	0.39	0.41	0.42	0.47
1400	0.24	0.27	0.31	0.33
1450	0.17	0.19	0.25	0.28
1500	0.15	0.17	0.21	0.20
1550	0.15	0.15	0.17	0.18
1600	0.14	0.13	0.13	0.15
1650	0.11	0.12	0.12	0.13
1700	0.095	0.097	0.100	0.12
1750	0.073	0.078	0.094	0.11
1800	0.059	0.067	0.084	0.11
1850	0.055	0.062	0.081	0.10
1900	0.054	0.062	0.076	0.10
1950	0.052	0.064	0.081	0.094
2000	0.054	0.062	0.076	0.098
2100	0.053	0.061	0.078	0.083
2200	0.052	0.058	0.062	0.067
2300	0.047	0.052	0.054	0.060
2400	0.039	0.044	0.049	0.044
2500	0.030	0.035	0.037	0.032
2600	0.024	0.030	0.028	0.025
2700	0.020	0.020	0.018	0.018
2800	0.016	0.013	0.015	0.014
2900	0.009	0.009	0.010	0.012
3000	0.007	0.008	0.009	0.010
3200	0.006	0.006	0.007	0.009
3400	0.005	0.006	0.006	0.007
3600	0.005	0.005	0.006	0.006
3800	0.005	0.005	0.005	0.006
4000	0.004	0.005	0.005	0.005

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Schwindling[136], T. Schwindt[20], W.G. Scott[129], J. Searcy[114], E. Sedykh[121], E. Segura[11], S.C. Seidel[103], A. Seiden[137], F. Seifert[43], J.M. Seixas[23a], G. Sekhniaidze[102a], D.M. Seliverstov[121], B. Sellden[146a], G. Sellers[73], M. Seman[144b], N. Semprini-Cesari[19a,19b], C. Serfon[98], L. Serin[115], R. Seuster[99], H. Severini[111], M.E. Sevior[86], A. Sfyrla[29], E. Shabalina[54], M. Shamim[114], L.Y. Shan[32a], J.T. Shank[21], Q.T. Shao[86], M. Shapiro[14], P.B. Shatalov[95], L. Shaver[6], K. Shaw[164a,164c], D. Sherman[175], P. Sherwood[77], A. Shibata[108], H. Shichi[101], S. Shimizu[29], M. Shimojima[100], T. Shin[56], A. Shmeleva[94], M.J. Shochet[30], D. Short[118], M.A. Shupe[6], P. Sicho[125], A. Sidoti[132a,132b], A. Siebel[174], F. Siegert[48], J. Siegrist[14], Dj. Sijacki[12a], O. Silbert[171], J. Silva[124a,b], Y. Silver[153], D. Silverstein[143], S.B. Silverstein[146a], V. Simak[127], O. Simard[136], Lj. Simic[12a], S. Simion[115], B. Simmons[77], M. Simonyan[35], P. Sinervo[158], N.B. Sinev[114], V. Sipica[141], G. Siragusa[173], A. Sircar[24], A.N. Sisakyan[65], S.Yu. Sivoklokov[97], J. Sjölin[146a,146b], T.B. Sjursen[13], L.A. Skinnari[14], K. Skovpen[107], P. Skubic[111], N. Skvorodnev[22], M. Slater[17], T. Slavicek[127], K. Sliwa[161], T.J. Sloan[71], J. Sloper[29], V. Smakhtin[171], S.Yu. Smirnov[96], L.N. Smirnova[97], O. Smirnova[79], B.C. Smith[57], D. Smith[143], K.M. Smith[53], M. Smizanska[71], K. Smolek[127], A.A. Snesarev[94], S.W. Snow[82], J. Snow[111], J. Snuverink[105], S. Snyder[24], M. Soares[124a], R. Sobie[169,k], J. Sodomka[127], A. Soffer[153], C.A. Solans[167], M. Solar[127], J. Solc[127], E. Soldatov[96], U. Soldevila[167], E. Solfaroli Camillocci[132a,132b], A.A. Solodkov[128], O.V. Solovyanov[128], J. Sondericker[24], N. Soni[2], V. Sopko[127], B. Sopko[127], M. Sorbi[89a,89b], M. Sosebee[7], A. Soukharev[107], S. Spagnolo[72a,72b], F. Spanò[76], R. Spighi[19a], G. Spigo[29], F. Spila[132a,132b], E. Spiriti[134a], R. Spiwoks[29], M. Spousta[126], T. Spreitzer[158], B. Spurlock[7], R.D. St. Denis[53], T. Stahl[141], J. Stahlman[120], R. Stamen[58a], E. Stanecka[29], R.W. Stanek[5], C. Stanescu[134a], S. Stapnes[117], E.A. Starchenko[128], J. Stark[55], P. Staroba[125], P. Starovoitov[91], A. Staude[98], P. Stavina[144a], G. Stavropoulos[14], G. Steele[53], P. Steinbach[43], P. Steinberg[24], I. Stekl[127], B. Stelzer[142],

H.J. Stelzer[88], O. Stelzer-Chilton[159a], H. Stenzel[52], K. Stevenson[75], G.A. Stewart[29], J.A. Stillings[20], T. Stockmanns[20], M.C. Stockton[29], K. Stoerig[48], G. Stoicea[25a], S. Stonjek[99], P. Strachota[126], A.R. Stradling[7], A. Straessner[43], J. Strandberg[147], S. Strandberg[146a,146b], A. Strandlie[117], M. Strang[109], E. Strauss[143], M. Strauss[111], P. Strizenec[144b], R. Ströhmer[173], D.M. Strom[114], J.A. Strong[76,*], R. Stroynowski[39], J. Strube[129], B. Stugu[13], I. Stumer[24,*], J. Stupak[148], P. Sturm[174], D.A. Soh[151,r], D. Su[143], HS. Subramania[2], A. Succurro[11], Y. Sugaya[116], T. Sugimoto[101], C. Suhr[106], K. Suita[67], M. Suk[126], V.V. Sulin[94], S. Sultansoy[3d], T. Sumida[29], X. Sun[55], J.E. Sundermann[48], K. Suruliz[139], S. Sushkov[11], G. Susinno[36a,36b], M.R. Sutton[149], Y. Suzuki[66], Y. Suzuki[67], M. Svatos[125], Yu.M. Sviridov[128], S. Swedish[168], I. Sykora[144a], T. Sykora[126], B. Szeless[29], J. Sánchez[167], D. Ta[105], K. Tackmann[41], A. Taffard[163], R. Tafirout[159a], N. Taiblum[153], Y. Takahashi[101], H. Takai[24], R. Takashima[69], H. Takeda[67], T. Takeshita[140], M. Talby[83], A. Talyshev[107], M.C. Tamsett[24], J. Tanaka[155], R. Tanaka[115], S. Tanaka[131], S. Tanaka[66], Y. Tanaka[100], K. Tani[67], N. Tannoury[83], G.P. Tappern[29], S. Tapprogge[81], D. Tardif[158], S. Tarem[152], F. Tarrade[28], G.F. Tartarelli[89a], P. Tas[126], M. Tasevsky[125], E. Tassi[36a,36b], M. Tatarkhanov[14], Y. Tayalati[135d], C. Taylor[77], F.E. Taylor[92], G.N. Taylor[86], W. Taylor[159b], M. Teinturier[115], M. Teixeira Dias Castanheira[75], P. Teixeira-Dias[76], K.K. Temming[48], H. Ten Kate[29], P.K. Teng[151], S. Terada[66], K. Terashi[155], J. Terron[80], M. Terwort[41,p], M. Testa[47], R.J. Teuscher[158,k], J. Thadome[174], J. Therhaag[20], T. Theveneaux-Pelzer[78], M. Thioye[175], S. Thoma[48], J.P. Thomas[17], E.N. Thompson[84], P.D. Thompson[17], P.D. Thompson[158], A.S. Thompson[53], E. Thomson[120], M. Thomson[27], R.P. Thun[87], F. Tian[34], T. Tic[125], V.O. Tikhomirov[94], Y.A. Tikhonov[107], C.J.W.P. Timmermans[104], P. Tipton[175], F.J. Tique Aires Viegas[29], S. Tisserant[83], J. Tobias[48], B. Toczek[37], T. Todorov[4], S. Todorova-Nova[161], B. Toggerson[163], J. Tojo[66], S. Tokár[144a], K. Tokunaga[67], K. Tokushuku[66], K. Tollefson[88], M. Tomoto[101], L. Tompkins[14], K. Toms[103], G. Tong[32a], A. Tonoyan[13], C. Topfel[16], N.D. Topilin[65], I. Torchiani[29], E. Torrence[114], H. Torres[78], E. Torró Pastor[167], J. Toth[83,x], F. Touchard[83], D.R. Tovey[139], D. Traynor[75], T. Trefzger[173], L. Tremblet[29], A. Tricoli[29], I.M. Trigger[159a], S. Trincaz-Duvoid[78], T.N. Trinh[78], M.F. Tripiana[70], W. Trischuk[158], A. Trivedi[24,w], B. Trocmé[55], C. Troncon[89a], M. Trottier-McDonald[142], A. Trzupek[38], C. Tsarouchas[29], J.C-L. Tseng[118], M. Tsiakiris[105], P.V. Tsiareshka[90], D. Tsionou[4], G. Tsipolitis[9], V. Tsiskaridze[48], E.G. Tskhadadze[51], I.I. Tsukerman[95], V. Tsulaia[14], J.-W. Tsung[20], S. Tsuno[66], D. Tsybychev[148], A. Tua[139], J.M. Tuggle[30], M. Turala[38], D. Turecek[127], I. Turk Cakir[3e], E. Turlay[105], R. Turra[89a,89b], P.M. Tuts[34], A. Tykhonov[74], M. Tylmad[146a,146b], M. Tyndel[129], H. Tyrvainen[29], G. Tzanakos[8], K. Uchida[20], I. Ueda[155], R. Ueno[28], M. Ugland[13], M. Uhlenbrock[20], M. Uhrmacher[54], F. Ukegawa[160], G. Unal[29], D.G. Underwood[5], A. Undrus[24], G. Unel[163], Y. Unno[66], D. Urbaniec[34], E. Urkovsky[153], P. Urrejola[31a], G. Usai[7], M. Uslenghi[119a,119b], L. Vacavant[83], V. Vacek[127], B. Vachon[85], S. Vahsen[14], J. Valenta[125], P. Valente[132a], S. Valentinetti[19a,19b], S. Valkar[126], E. Valladolid Gallego[167], S. Vallecorsa[152], J.A. Valls Ferrer[167], H. van der Graaf[105], E. van der Kraaij[105], R. Van Der Leeuw[105], E. van der Poel[105], D. van der Ster[29], B. Van Eijk[105], N. van Eldik[84], P. van Gemmeren[5], Z. van Kesteren[105], I. van Vulpen[105], W. Vandelli[29], G. Vandoni[29], A. Vaniachine[5], P. Vankov[41], F. Vannucci[78], F. Varela Rodriguez[29], R. Vari[132a], D. Varouchas[14], A. Vartapetian[7], K.E. Varvell[150], V.I. Vassilakopoulos[56], F. Vazeille[33], G. Vegni[89a,89b], J.J. Veillet[115], C. Vellidis[8], F. Veloso[124a], R. Veness[29], S. Veneziano[132a], A. Ventura[72a,72b], D. Ventura[138], M. Venturi[48], N. Venturi[16], V. Vercesi[119a], M. Verducci[138], W. Verkerke[105], J.C. Vermeulen[105], A. Vest[43], M.C. Vetterli[142,e], I. Vichou[165], T. Vickey[145b,aa], O.E. Vickey Boeriu[145b], G.H.A. Viehhauser[118], S. Viel[168], M. Villa[19a,19b], M. Villaplana Perez[167], E. Vilucchi[47], M.G. Vincter[28], E. Vinek[29], V.B. Vinogradov[65], M. Virchaux[136,*], J. Virzi[14], O. Vitells[171], M. Viti[41], I. Vivarelli[48], F. Vives Vaque[2], S. Vlachos[9], M. Vlasak[127], N. Vlasov[20], A. Vogel[20], P. Vokac[127], G. Volpi[47], M. Volpi[86], G. Volpini[89a], H. von der Schmitt[99], J. von Loeben[99], H. von Radziewski[48], E. von Toerne[20], V. Vorobel[126], A.P. Vorobiev[128], V. Vorwerk[11], M. Vos[167], R. Voss[29], T.T. Voss[174], J.H. Vossebeld[73], N. Vranjes[12a], M. Vranjes Milosavljevic[105], V. Vrba[125], M. Vreeswijk[105], T. Vu Anh[81], R. Vuillermet[29], I. Vukotic[115], W. Wagner[174], P. Wagner[120], H. Wahlen[174], J. Wakabayashi[101], J. Walbersloh[42], S. Walch[87], J. Walder[71], R. Walker[98], W. Walkowiak[141], R. Wall[175], P. Waller[73], C. Wang[44], H. Wang[172], H. Wang[32b,ab], J. Wang[151], J. Wang[32d], J.C. Wang[138], R. Wang[103], S.M. Wang[151], A. Warburton[85], C.P. Ward[27], M. Warsinsky[48], P.M. Watkins[17], A.T. Watson[17], M.F. Watson[17], G. Watts[138], S. Watts[82], A.T. Waugh[150], B.M. Waugh[77], J. Weber[42], M. Weber[129], M.S. Weber[16], P. Weber[54], A.R. Weidberg[118], P. Weigell[99], J. Weingarten[54], C. Weiser[48], H. Wellenstein[22], P.S. 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C. Wiglesworth[75], L.A.M. Wiik[48], P.A. Wijeratne[77], A. Wildauer[167], M.A. Wildt[41,p], I. Wilhelm[126], H.G. Wilkens[29], J.Z. Will[98], E. Williams[34], H.H. Williams[120], W. Willis[34], S. Willocq[84], J.A. Wilson[17], M.G. Wilson[143], A. Wilson[87], I. Wingerter-Seez[4], S. Winkelmann[48], F. Winklmeier[29], M. Wittgen[143], M.W. Wolter[38], H. Wolters[124a,i], W.C. Wong[40], G. Wooden[118], B.K. Wosiek[38], J. Wotschack[29], M.J. Woudstra[84], K. Wraight[53], C. Wright[53], B. Wrona[73], S.L. Wu[172], X. Wu[49], Y. Wu[32b,ac], E. Wulf[34], R. Wunstorf[42], B.M. Wynne[45], L. Xaplanteris[9], S. Xella[35], S. Xie[48], Y. Xie[32a], C. Xu[32b,ad], D. Xu[139], G. Xu[32a], B. Yabsley[150], S. Yacoob[145b], M. Yamada[66], H. Yamaguchi[155], A. Yamamoto[66], K. Yamamoto[64], S. Yamamoto[155], T. Yamamura[155], T. Yamanaka[155], J. Yamaoka[44], T. Yamazaki[155], Y. Yamazaki[67], Z. Yan[21], H. Yang[87], U.K. Yang[82], Y. Yang[61], Y. Yang[32a], Z. Yang[146a,146b], S. Yanush[91], Y. Yao[14], Y. Yasu[66], G.V. Ybeles Smit[130], J. Ye[39], S. Ye[24], M. Yilmaz[3c], R. Yoosoofmiya[123], K. Yorita[170], R. Yoshida[5], C. Young[143], S. Youssef[21], D. Yu[24], J. Yu[7], J. Yu[32c,ad], L. Yuan[32a,ae], A. Yurkewicz[148], V.G. Zaets [128], R. Zaidan[63], A.M. Zaitsev[128], Z. Zajacova[29], Yo.K. Zalite [121], L. Zanello[132a,132b], P. Zarzhitsky[39], A. Zaytsev[107], C. Zeitnitz[174], M. Zeller[175], M. Zeman[125], A. Zemla[38], C. Zendler[20], O. Zenin[128], T. Ženiš[144a], Z. Zenonos[122a,122b], S. Zenz[14], D. Zerwas[115], G. Zevi della Porta[57], Z. Zhan[32d], D. Zhang[32b,ab], H. Zhang[88], J. Zhang[5], X. Zhang[32d], Z. Zhang[115], L. Zhao[108], T. Zhao[138], Z. Zhao[32b], A. Zhemchugov[65], S. Zheng[32a], J. Zhong[151,af], B. Zhou[87], N. Zhou[163], Y. Zhou[151], C.G. Zhu[32d], H. Zhu[41], J. Zhu[87], Y. Zhu[172], X. Zhuang[98], V. Zhuravlov[99], D. Zieminska[61], R. Zimmermann[20], S. Zimmermann[20], S. Zimmermann[48], M. Ziolkowski[141], R. Zitoun[4], L. Živković[34], V.V. Zmouchko[128,*], G. Zobernig[172], A. Zoccoli[19a,19b], Y. Zolnierowski[4], A. Zsenei[29], M. zur Nedden[15], V. Zutshi[106], L. Zwalinski[29].

[1] University at Albany, Albany NY, United States of America
[2] Department of Physics, University of Alberta, Edmonton AB, Canada
[3] [(a)]Department of Physics, Ankara University, Ankara; [(b)]Department of Physics, Dumlupinar University, Kutahya; [(c)]Department of Physics, Gazi University, Ankara; [(d)]Division of Physics, TOBB University of Economics and Technology, Ankara; [(e)]Turkish Atomic Energy Authority, Ankara, Turkey
[4] LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France
[5] High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America
[6] Department of Physics, University of Arizona, Tucson AZ, United States of America
[7] Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America
[8] Physics Department, University of Athens, Athens, Greece
[9] Physics Department, National Technical University of Athens, Zografou, Greece
[10] Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[11] Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
[12] [(a)]Institute of Physics, University of Belgrade, Belgrade; [(b)]Vinca Institute of Nuclear Sciences, Belgrade, Serbia
[13] Department for Physics and Technology, University of Bergen, Bergen, Norway
[14] Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
[15] Department of Physics, Humboldt University, Berlin, Germany
[16] Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
[17] School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
[18] [(a)]Department of Physics, Bogazici University, Istanbul; [(b)]Division of Physics, Dogus University, Istanbul; [(c)]Department of Physics Engineering, Gaziantep University, Gaziantep; [(d)]Department of Physics, Istanbul Technical University, Istanbul, Turkey
[19] [(a)]INFN Sezione di Bologna; [(b)]Dipartimento di Fisica, Università di Bologna, Bologna, Italy
[20] Physikalisches Institut, University of Bonn, Bonn, Germany
[21] Department of Physics, Boston University, Boston MA, United States of America
[22] Department of Physics, Brandeis University, Waltham MA, United States of America
[23] [(a)]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; [(b)]Federal University of Juiz de Fora (UFJF), Juiz de Fora; [(c)]Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; [(d)]Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
[24] Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
[25] [(a)]National Institute of Physics and Nuclear Engineering, Bucharest; [(b)]University Politehnica Bucharest, Bucharest; [(c)]West University in Timisoara, Timisoara, Romania
[26] Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
[27] Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[28] Department of Physics, Carleton University, Ottawa ON, Canada
[29] CERN, Geneva, Switzerland
[30] Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America

[31] [(a)]Departamento de Fisica, Pontificia Universidad Católica de Chile, Santiago; [(b)]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[32] [(a)]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; [(b)]Department of Modern Physics, University of Science and Technology of China, Anhui; [(c)]Department of Physics, Nanjing University, Jiangsu; [(d)]High Energy Physics Group, Shandong University, Shandong, China
[33] Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
[34] Nevis Laboratory, Columbia University, Irvington NY, United States of America
[35] Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
[36] [(a)]INFN Gruppo Collegato di Cosenza; [(b)]Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy
[37] Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
[38] The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[39] Physics Department, Southern Methodist University, Dallas TX, United States of America
[40] Physics Department, University of Texas at Dallas, Richardson TX, United States of America
[41] DESY, Hamburg and Zeuthen, Germany
[42] Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
[43] Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
[44] Department of Physics, Duke University, Durham NC, United States of America
[45] SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[46] Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 3, 2700 Wiener Neustadt, Austria
[47] INFN Laboratori Nazionali di Frascati, Frascati, Italy
[48] Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
[49] Section de Physique, Université de Genève, Geneva, Switzerland
[50] [(a)]INFN Sezione di Genova; [(b)]Dipartimento di Fisica, Università di Genova, Genova, Italy
[51] Institute of Physics and HEP Institute, Georgian Academy of Sciences and Tbilisi State University, Tbilisi, Georgia
[52] II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
[53] SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[54] II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
[55] Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
[56] Department of Physics, Hampton University, Hampton VA, United States of America
[57] Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America
[58] [(a)]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; [(b)]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; [(c)]ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
[59] Faculty of Science, Hiroshima University, Hiroshima, Japan
[60] Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
[61] Department of Physics, Indiana University, Bloomington IN, United States of America
[62] Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
[63] University of Iowa, Iowa City IA, United States of America
[64] Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America
[65] Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
[66] KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[67] Graduate School of Science, Kobe University, Kobe, Japan
[68] Faculty of Science, Kyoto University, Kyoto, Japan
[69] Kyoto University of Education, Kyoto, Japan
[70] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[71] Physics Department, Lancaster University, Lancaster, United Kingdom
[72] [(a)]INFN Sezione di Lecce; [(b)]Dipartimento di Fisica, Università del Salento, Lecce, Italy
[73] Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[74] Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
[75] Department of Physics, Queen Mary University of London, London, United Kingdom
[76] Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[77] Department of Physics and Astronomy, University College London, London, United Kingdom
[78] Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[79] Fysiska institutionen, Lunds universitet, Lund, Sweden
[80] Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
[81] Institut für Physik, Universität Mainz, Mainz, Germany

[82] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[83] CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[84] Department of Physics, University of Massachusetts, Amherst MA, United States of America
[85] Department of Physics, McGill University, Montreal QC, Canada
[86] School of Physics, University of Melbourne, Victoria, Australia
[87] Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[88] Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
[89] [(a)]INFN Sezione di Milano; [(b)]Dipartimento di Fisica, Università di Milano, Milano, Italy
[90] B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[91] National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
[92] Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America
[93] Group of Particle Physics, University of Montreal, Montreal QC, Canada
[94] P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
[95] Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[96] Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
[97] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
[98] Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[99] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[100] Nagasaki Institute of Applied Science, Nagasaki, Japan
[101] Graduate School of Science, Nagoya University, Nagoya, Japan
[102] [(a)]INFN Sezione di Napoli; [(b)]Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
[103] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
[104] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[105] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[106] Department of Physics, Northern Illinois University, DeKalb IL, United States of America
[107] Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia
[108] Department of Physics, New York University, New York NY, United States of America
[109] Ohio State University, Columbus OH, United States of America
[110] Faculty of Science, Okayama University, Okayama, Japan
[111] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
[112] Department of Physics, Oklahoma State University, Stillwater OK, United States of America
[113] Palacký University, RCPTM, Olomouc, Czech Republic
[114] Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
[115] LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
[116] Graduate School of Science, Osaka University, Osaka, Japan
[117] Department of Physics, University of Oslo, Oslo, Norway
[118] Department of Physics, Oxford University, Oxford, United Kingdom
[119] [(a)]INFN Sezione di Pavia; [(b)]Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Pavia, Italy
[120] Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
[121] Petersburg Nuclear Physics Institute, Gatchina, Russia
[122] [(a)]INFN Sezione di Pisa; [(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[123] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
[124] [(a)]Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal; [(b)]Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
[125] Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[126] Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
[127] Czech Technical University in Prague, Praha, Czech Republic
[128] State Research Center Institute for High Energy Physics, Protvino, Russia
[129] Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[130] Physics Department, University of Regina, Regina SK, Canada
[131] Ritsumeikan University, Kusatsu, Shiga, Japan
[132] [(a)]INFN Sezione di Roma I; [(b)]Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[133] [(a)]INFN Sezione di Roma Tor Vergata; [(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[134] [(a)]INFN Sezione di Roma Tre; [(b)]Dipartimento di Fisica, Università Roma Tre, Roma, Italy
[135] [(a)]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; [(b)]Centre National de

l'Energie des Sciences Techniques Nucleaires, Rabat; [(c)]Université Cadi Ayyad, Faculté des sciences Semlalia Département de Physique, B.P. 2390 Marrakech 40000; [(d)]Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; [(e)]Faculté des Sciences, Université Mohammed V, Rabat, Morocco
[136] DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[137] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
[138] Department of Physics, University of Washington, Seattle WA, United States of America
[139] Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[140] Department of Physics, Shinshu University, Nagano, Japan
[141] Fachbereich Physik, Universität Siegen, Siegen, Germany
[142] Department of Physics, Simon Fraser University, Burnaby BC, Canada
[143] SLAC National Accelerator Laboratory, Stanford CA, United States of America
[144] [(a)]Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; [(b)]Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
[145] [(a)]Department of Physics, University of Johannesburg, Johannesburg; [(b)]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[146] [(a)]Department of Physics, Stockholm University; [(b)]The Oskar Klein Centre, Stockholm, Sweden
[147] Physics Department, Royal Institute of Technology, Stockholm, Sweden
[148] Department of Physics and Astronomy, Stony Brook University, Stony Brook NY, United States of America
[149] Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[150] School of Physics, University of Sydney, Sydney, Australia
[151] Institute of Physics, Academia Sinica, Taipei, Taiwan
[152] Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
[153] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[154] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[155] International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
[156] Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
[157] Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[158] Department of Physics, University of Toronto, Toronto ON, Canada
[159] [(a)]TRIUMF, Vancouver BC; [(b)]Department of Physics and Astronomy, York University, Toronto ON, Canada
[160] Institute of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan
[161] Science and Technology Center, Tufts University, Medford MA, United States of America
[162] Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
[163] Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
[164] [(a)]INFN Gruppo Collegato di Udine; [(b)]ICTP, Trieste; [(c)]Dipartimento di Fisica, Università di Udine, Udine, Italy
[165] Department of Physics, University of Illinois, Urbana IL, United States of America
[166] Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[167] Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingenierá Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
[168] Department of Physics, University of British Columbia, Vancouver BC, Canada
[169] Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
[170] Waseda University, Tokyo, Japan
[171] Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
[172] Department of Physics, University of Wisconsin, Madison WI, United States of America
[173] Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
[174] Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[175] Department of Physics, Yale University, New Haven CT, United States of America
[176] Yerevan Physics Institute, Yerevan, Armenia
[177] Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
[a] Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal
[b] Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal
[c] Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[d] Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[e] Also at TRIUMF, Vancouver BC, Canada
[f] Also at Department of Physics, California State University, Fresno CA, United States of America
[g] Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland

[h] Also at Fermilab, Batavia IL, United States of America
[i] Also at Department of Physics, University of Coimbra, Coimbra, Portugal
[j] Also at Università di Napoli Parthenope, Napoli, Italy
[k] Also at Institute of Particle Physics (IPP), Canada
[l] Also at Department of Physics, Middle East Technical University, Ankara, Turkey
[m] Also at Louisiana Tech University, Ruston LA, United States of America
[n] Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
[o] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[p] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
[q] Also at Manhattan College, New York NY, United States of America
[r] Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China
[s] Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
[t] Also at High Energy Physics Group, Shandong University, Shandong, China
[u] Also at Section de Physique, Université de Genève, Geneva, Switzerland
[v] Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
[w] Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
[x] Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
[y] Also at California Institute of Technology, Pasadena CA, United States of America
[z] Also at Institute of Physics, Jagiellonian University, Krakow, Poland
[aa] Also at Department of Physics, Oxford University, Oxford, United Kingdom
[ab] Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
[ac] Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[ad] Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[ae] Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[af] Also at Department of Physics, Nanjing University, Jiangsu, China
[*] Deceased