Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions

The ATLAS Collaboration

Abstract

A search for squarks and gluinos in final states containing jets, missing transverse momentum and no electrons or muons is presented. The data were recorded by the ATLAS experiment in $\sqrt{s} = 7$ TeV proton-proton collisions at the Large Hadron Collider. No excess above the Standard Model background expectation was observed in 35pb$^{-1}$ of analysed data. Gluino masses below 500 GeV are excluded at the 95% confidence level in simplified models containing only squarks of the first two generations, a gluino octet and a massless neutralino. The exclusion increases to 870 GeV for equal mass squarks and gluinos. In MSUGRA/CMSSM models with $\tan\beta = 3$, $A_0 = 0$ and $\mu > 0$, squarks and gluinos of equal mass are excluded below 775 GeV. These are the most stringent limits to date.

1. Introduction

Many extensions of the Standard Model (SM) include heavy coloured particles, some of which could be accessible at the LHC. The squarks and gluinos of supersymmetric theories are one example of such particles. This letter presents the first ATLAS search for squarks and gluinos in final states containing only jets and large missing transverse momentum. Interest in this final state is motivated by the large number of R-parity conserving models in which squarks and gluinos can be produced in pairs $(\tilde{g}, \tilde{q}, \tilde{q})$ and can generate that final state in their decays $\tilde{g} \rightarrow q\tilde{q}_1^0$ and $\tilde{q} \rightarrow q\tilde{q}_1^0$ to weakly interacting neutralinos, $\tilde{\chi}_1^0$, which escape the detector unseen. The analysis presented here is based on a study of purely hadronic final states; events with reconstructed electrons and muons are vetoed to avoid overlap with a related ATLAS search which requires a lepton. The search strategy was optimised for maximising exclusion with missing transverse momentum. Currently, the most stringent limits on squark and gluino masses are obtained in simplified models containing only squarks of the first two generations, a gluino octet and a massless neutralino. The exclusion increases to 870 GeV for equal mass squarks and gluinos. In MSUGRA/CMSSM models with $\tan\beta = 3$, $A_0 = 0$ and $\mu > 0$, squarks and gluinos of equal mass are excluded below 775 GeV. These are the most stringent limits to date.

2. The ATLAS Detector and Data Samples

The ATLAS detector is a multipurpose particle physics apparatus with a forward-backward symmetric cylindrical geometry and nearly 4$\pi$ coverage in solid angle. The layout of the detector is dominated by four superconducting magnet systems, which comprise a thin solenoid surrounding inner tracking detectors and three large toroids supporting a large muon tracker. The calorimeters are of particular importance to this analysis. In the pseudorapidity region $|\eta| < 3.2$, high-granularity liquid-argon (LAr) electromagnetic (EM) sampling calorimeters are used. An iron-scintillator tile calorimeter provides hadronic coverage over $|\eta| < 1.7$. The end-cap and forward regions, spanning $1.5 < |\eta| < 4.9$, are instrumented with LAr calorimetry for both EM and hadronic measurements.

The data sample used in this analysis was taken in 2010 with the LHC operating at a centre-of-mass energy of 7 TeV. Application of beam, detector and data-quality requirements resulted in a total integrated luminosity of 35pb$^{-1}$. The detailed trigger specification varied throughout the data-taking period, partly as a consequence of the rapidly increasing LHC luminosity, but always guarantees a trigger efficiency above 97% for events with a reconstructed jet with transverse momentum ($p_T$) exceeding 120 GeV and more than 100 GeV of missing $p_T$.

3. Object Reconstruction

Jet candidates are reconstructed by using the anti-$k_t$ jet clustering algorithm with a distance parameter of 0.4. The inputs to this algorithm are clusters of calorimeter cells seeded by those with energy significantly above the measured noise. Jet momenta are constructed by performing a four-vector sum over these cell clusters, treating each as an $(E, \vec{p})$ four-vector with zero mass. These jets are corrected for the effects of calorimeter non-compensation and inhomogeneities by using $p_T$- and $\eta$-dependent calibration factors based on Monte Carlo (MC) corrections validated with extensive test-beam and collision-data studies. Only jet candidates with $p_T > 20$ GeV and $|\eta| < 4.9$ are retained hereafter.

Electron candidates are required to have $p_T > 10$ GeV, to have $|\eta| < 2.47$, to pass the ‘medium’ electron shower shape and track selection criteria of Ref. [8], and to be outside problem-
atic regions of the calorimeter. Muon candidates are required to have $p_T > 10 \text{ GeV}$ and $|\eta| < 2.4$. The sum of the transverse momenta of charged particle tracks within a cone of radius $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} = 0.2$ around the muon trajectory is required to be less than 1.8 GeV.

Following the steps above, overlaps between candidate jets with $|\eta| < 2.5$ and leptons are resolved using the method of Ref. [9] as follows. First, any such jet candidate lying within a distance $\Delta R < 0.2$ of an electron is discarded. Then the whole event is rejected if any electron candidate remains in the calorimeter transition region $1.37 < |\eta| < 1.52$ between barrel and end-cap. Finally, any lepton candidate remaining within a distance $\Delta R = 0.4$ of such a jet candidate is discarded.

The measurement of the missing transverse momentum two-vector $\vec{P}_T^{\text{miss}}$ (and its magnitude $E_T^{\text{miss}}$) is then based on the transverse momenta of all remaining jet and lepton candidates and all calorimeter clusters not associated to such objects. Following this, all jet candidates with $|\eta| > 2.5$ are discarded.

Thereafter, the remaining lepton and jet candidates are considered “reconstructed”, and the term “candidate” is dropped.

4. Event Selection

Following the object reconstruction described above, events are discarded if any electrons or muons remain, or if they have any jets failing quality selection criteria against detector noise and against non-collision backgrounds [10], or if they lack a reconstructed primary vertex associated with five or more tracks.

In order to achieve maximal reach over the $(m_q, m_\tilde{g})$-plane, several signal regions are defined. When production of squark pairs $\tilde{q}\tilde{q}$ is dominant, only a small number of jets (one per squark from $\tilde{q} \rightarrow q \tilde{\chi}^0_1$) is expected. The optimal strategy for the $\tilde{q}\tilde{g}$ region therefore makes requirements on two jets only. When production involves gluinos ($\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{g}$), extra jets are expected from $\tilde{g} \rightarrow qq\tilde{\chi}^0_1$. In these regions, requiring at least three jets yields better sensitivity. The higher total cross section in the associated $\tilde{q}\tilde{g}$ region where both species are accessible permits the use of tighter criteria than in the $\tilde{g}\tilde{g}$ region. Four signal regions A, B, C and D are thus defined (targeting light-$\tilde{q}\tilde{q}$, heavy-$\tilde{q}\tilde{q}$, $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{g}$ production, respectively) as shown in Table 1. In this table, $\Delta \phi(\text{jet}, \vec{P}_T^{\text{miss}})$ is the smallest of the azimuthal separations between $\vec{P}_T^{\text{miss}}$ and jets with $p_T > 40 \text{ GeV}$ (up to a maximum of three, in descending order of $p_T$, whether pre-selected or not). The variable $m_{T2}$ is defined to be the maximal lower bound on the mass of a pair produced particle which decays into one of the pre-selected jets and a massless undetected particle, assuming the two undetected particles are the only source of the event $\vec{P}_T^{\text{miss}}$. The effective mass, $m_{\text{eff}}$, is defined as the sum of $E_T^{\text{miss}}$ and the magnitudes of the transverse momenta of the two highest $p_T$ jets (in signal region A) or three highest $p_T$ jets (in signal regions C and D). The $\tilde{q}\tilde{g}$ channel has two signal regions, A and B, because the $m_{T2}$ distribution has the best expected reach in $m_q$, but $m_{\text{eff}}$ offers better coverage for lighter squarks.

5. Backgrounds, Simulation and Normalisation

Standard Model background processes contribute to the event counts in the signal regions. The dominant sources are $W$-jets, $Z$-jets, top pair, QCD multi-jet (hereafter, the expression “multi-jet” is dropped) and single top production. Non-collision backgrounds are negligible. The majority of the $W$-jets background is composed of $W \rightarrow \tau \nu$ events, or $W \rightarrow l \nu$ events in which no electron or muon candidate is reconstructed. The largest part of the $Z$+jets background comes from the irreducible component in which $Z \rightarrow \nu \nu$ generates large $E_T^{\text{miss}}$.

Hadronic $\tau$ decays in $t\bar{t} \rightarrow b\bar{b}r\nu qq$ can generate large $E_T^{\text{miss}}$ and pass the jet and lepton requirements at a non-negligible rate. The QCD background in the signal regions is predominantly caused by poor reconstruction of jet energies in calorimeters leading to ‘fake’ missing transverse momentum. There is also a contribution from neutrinos when events contain leptonic decays of heavy quarks. Extensive validation of MC against data has been performed for each of these background sources and for a wide variety of control regions. The excellent agreement found motivates an approach in which both the shape and the normalisation of the $W$+jets, $Z$+jets and top backgrounds are taken from MC simulation. In contrast, the QCD background is normalised to data in control regions as described below.

Production of $W$ and $Z$ bosons, in association with jets, was simulated with ALPGEN [12] v2.13 at leading order (LO) and up to 2 $\rightarrow$ 5 partons using CTEQ6L1 PDFs [13]. Both were separately normalised to the next-to-next-to-leading-order inclusive $W$ and $Z$ cross sections from FEMZ [14] v2.0. Both resulting samples were found to be consistent with a variety of data-derived estimates, including methods based on: re-simulation of reconstructed leptons as hadronically decaying taus; removal of leptons from $W(l)\nu$+jet and $Z(l)l$+jet events; and by comparing MC predictions to data in control regions enriched with background events.

Production of top quarks (both singly and in pairs, assuming $m_{\text{top}} = 172.5 \text{ GeV}$) was simulated with HWWL0 [15] v3.41 using CTEQ6.6 next-to-leading-order (NLO) PDFs [16]. This estimate was found to be consistent with a data-driven cross-check based on replacement of reconstructed muons in the corresponding single lepton channels with simulated hadronic $\tau$ decays. Agreement was also found after reweighting the $t\bar{t}$ MC according to experimentally measured $b$-tag weights.

Simulated QCD events were generated both with PYTHIA [17] v6.4.21, which uses 2 $\rightarrow$ 2 LO matrix elements (ME) with the MRST2007 LO* PDF set [18], and with ALPGEN implement-
Table 2: Expected and observed numbers of events in the four signal regions. Uncertainties shown are due to "MC statistics, statistics in control regions, other sources of uncorrelated systematic uncertainty, and also the jet energy resolution and lepton efficiencies" [u], the jet energy scale [j], and the luminosity [L].

<table>
<thead>
<tr>
<th></th>
<th>Signal region A</th>
<th>Signal region B</th>
<th>Signal region C</th>
<th>Signal region D</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD</td>
<td>(7 \pm 7[u] )</td>
<td>0.6 (10^{0.6}[u+j])</td>
<td>9 (10^{0.9}[u+j])</td>
<td>0.2 (10^{0.3}[u+j])</td>
</tr>
<tr>
<td>W+jets</td>
<td>50 (\pm 11[u]) ( \pm 11[j]) ( \pm 6[L])</td>
<td>4.4 (\pm 3.2[u]) ( \pm 3.0[j]) ( \pm 0.5[L])</td>
<td>35 (\pm 9[u]) ( \pm 1.5[j]) ( \pm 4[L])</td>
<td>1.1 (\pm 0.7[u]) ( \pm 0.2[j]) ( \pm 0.1[L])</td>
</tr>
<tr>
<td>Z+jets</td>
<td>52 (\pm 21[u]) ( \pm 14[j]) ( \pm 6[L])</td>
<td>4.1 (\pm 2.9[u]) ( \pm 2.1[j]) ( \pm 0.5[L])</td>
<td>27 (\pm 12[u]) ( \pm 1.6[j]) ( \pm 3[L])</td>
<td>0.8 (\pm 0.7[u]) ( \pm 0.6[j]) ( \pm 0.1[L])</td>
</tr>
<tr>
<td>t\bar{t} and t</td>
<td>10 (\pm 0[u]) ( \pm 0[j]) ( \pm 1[L])</td>
<td>0.9 (\pm 0.1[u]) ( \pm 0.4[j]) ( \pm 0.1[L])</td>
<td>17 (\pm 1[u]) ( \pm 1.6[j]) ( \pm 2[L])</td>
<td>0.3 (\pm 0.1[u]) ( \pm 0.2[j]) ( \pm 0.0[L])</td>
</tr>
<tr>
<td>Total SM</td>
<td>118 (\pm 25[u]) ( \pm 19[j]) ( \pm 12[L])</td>
<td>10.0 (\pm 4.3[u]) ( \pm 1.9[j]) ( \pm 1.0[L])</td>
<td>88 (\pm 18[u]) ( \pm 2.6[j]) ( \pm 9[L])</td>
<td>2.5 (\pm 1.0[u]) ( \pm 0.4[j]) ( \pm 0.2[L])</td>
</tr>
<tr>
<td>Data</td>
<td>87</td>
<td>11</td>
<td>66</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 1: The distributions of \(m_{T2}\) (separately for the \(\geq 2\) and \(\geq 3\) jet regions) and \(m_{eff}\) are shown for data and for the expected SM contributions after application of all selection criteria – cuts on the variables themselves are indicated by the red arrows. Also shown is the \(E_{T}^{miss}\) distribution after the \(\geq 2\) jet preselection cuts only. For comparison, each plot includes a curve showing the expectation for an MSUGRA/CMSSSM reference point with \(m_0 = 200\) GeV, \(m_{1/2} = 190\) GeV, \(A_0 = 0\), \(\tan \beta = 3\) and \(\mu > 0\). This reference point is also indicated by the star on Figure 1. Below each plot may be seen the ratio of the data to the SM expectation. Black vertical bars show the statistical uncertainty from the data, while the yellow band shows the size of the Standard Model MC uncertainty.
ing the exact LO ME for up to 2 → 5 partons. The normalisation of these samples was fixed by a scaling designed to achieve a match to data in control regions obtained by reversing the Δφ requirements. After this scaling, both sets of simulations were in agreement within the experimental uncertainties, and therefore only PYTHIA QCD simulations are used further in this analysis. The resulting QCD simulation was found to be consistent with a data-driven QCD estimate in which high E_T^{miss} events were generated from data by smearing low E_T^{miss} events on a jet-by-jet basis with measured jet energy resolution functions. This latter technique has no MC dependencies; it provides a completely independent determination of the QCD background using only quantities measured from the data. Additional control regions having reversed E_T^{miss}/m_{eff} requirements were used as further checks on the normalisation.

Supersymmetric events were generated with HERWIG++ [19] v2.4.2. These samples were normalised using NLO cross sections determined by PROSPINO [20] v2.1.

All non-PYTHIA samples used HERWIG++ or HERWIG-6.510 [21] to simulate parton showering and fragmentation, while JIMMY [22] v4.31 was used to generate the underlying event. All samples were produced using an ATLAS ‘tune’ [23] and a full detector simulation [24].

6. Systematic Uncertainties

The primary sources of systematic uncertainties in the background estimates are: the jet energy scale (JES), the jet energy resolution (JER), the luminosity determination, the MC modelling, the lepton efficiencies, the extrapolation from control regions into signal regions, and the finite statistics of the MC samples and control regions. The uncertainty on the luminosity determination is estimated to be 11% [25]. The JES uncertainty has been measured from the complete 2010 data set using the techniques described in Ref. [27] and, though p_T and η dependent, is around 7%. The JER measured in data [26] was applied to all MC simulated jets and was propagated to E_T^{miss}. The difference between the re-calibrated and nominal MC is taken as the systematic uncertainty due to this effect. The uncertainty on the estimated top background is dominated by the JES uncertainty. Systematic uncertainties associated with mis-identification of leptons, jet energy scale inter-calibration, the rate of leptonic b-decay and the non-Gaussian tail of the jet response function have also been incorporated where appropriate.

Systematic uncertainties on the SUSY signal were estimated by variation of the factorisation and renormalisation scales in PROSPINO between half and twice their default values and by considering the PDF uncertainties provided by CTEQ6. Uncertainties were calculated for individual production processes (e.g. q~q~, g~g~, etc.).

7. Results, Interpretation and Limits

The number of observed data events and the number of SM events expected to enter each of the signal regions are shown in Table 2. The background model is found to be in good agreement with the data, and the distributions of m_{eff}, m_T and E_T^{miss} are shown in Figure 1.

An interpretation of the results is presented in Figure 2 as a 95% confidence exclusion region in the (m_{q~}, m_{g~})-plane for the simplified set of models with m_{q~}^0 = 0 for which the analysis was optimised. In these models the gluino mass and the masses of the squarks of the first two generations are set to the values given in the legend. The un-
of MSUGRA/CMSSM \cite{29} in Figure 3.

These figures also show the variation of the expected limit in response to \pm \sigma fluctuations of the SM expectation including the stated systematic uncertainties. The exclusion regions are constructed using a profile likelihood ratio method. Pseudo-experiments are used to compute one-sided upper limits on the signal contribution, which is assumed to be non-negative. At each point in the \((m_{\tilde{q}}, m_{\tilde{g}})} and CMSSM planes, the chosen test statistic is the likelihood ratio corresponding to the number of observed events in the signal region whose expected sensitivity was largest. Plots showing where each signal region is dominant may be found in \cite{30}. All signal regions contribute to the exclusion and to its boundary in the \((m_{\tilde{q}}, m_{\tilde{g}})}-plane. Region D is dominant near the CMSSM boundary. In the simplified model, changing the \(\tilde{m}^0_2\) mass from 0 to 100 GeV reduces the number of selected events by only \(< 20\%\) near the exclusion curve so only slightly modifies the excluded region in the \((m_{\tilde{q}}, m_{\tilde{g}})}-plane. In the CMSSM, varying \(A_0\) from 300 GeV, tan\(\beta\) to 30 or \(\mu\rightarrow -\mu\) leads to significant (\(< 5\%\) changes, among the strongly interacting particles, only in the stop and sbottom masses. Accordingly, the exclusion limits are not strongly sensitive to these parameters.

8. Summary

This letter reports a search for new physics in final states containing high-\(p_T\) jets, missing transverse momentum and no electrons or muons. Good agreement is seen between the numbers of events observed in the four signal regions and the numbers of events expected from SM sources. Signal regions A, B, C and D exclude non-SM cross sections within acceptance of 1.3, 0.35, 1.1 and 0.11 pb respectively at 95\% confidence.

The results are interpreted in both a simplified model containing only squarks of the first two generations, a gluino octet and a massless neutralino, as well as in MSUGRA/CMSSM models with \(\tan\beta = 3\), \(A_0 = 0\) and \(\mu > 0\). In the simplified model, gluino masses below 500 GeV are excluded at the 95\% confidence level with the limit increasing to 870 GeV for equal mass squarks and gluinos. In the MSUGRA/CMSSM models equal mass squarks and gluinos below 775 GeV are excluded.

9. Acknowledgements

We wish to thank CERN for the efficient commissioning and operation of the LHC during this initial high-energy data-taking period as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; Yer-PhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DLR, DFNRC and Lundbeck Foundation, Denmark; ARTEMIS, European Union; IN2P3-CNRs, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Bennoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERSYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

References

\[1\] Yu.A. Golindon and E.P. Likhtman, JETP Lett. 13 (1971) 323-326.
\[16\] M. Cacciari et al., JHEP 04 (2008) 063.
\[18\] ATLAS Collaboration, ATLAS-CONF-2010-056.
\[21\] ATLAS Collaboration, ATLAS-CONF-2010-038.
\[26\] J. Pumplin et al., JHEP 07 (2002) 012.
\[28\] R. Gavin et al., arXiv:1011.3540 [hep-ph].
\[29\] S. Frixione et al., JHEP 06 (2002) 029.
\[30\] S. Frixione et al., JHEP 08 (2003) 007.
\[32\] T. Sjostrand et al., JHEP 05 (2006) 026.
\[36\] G. Corcella et al., JHEP 01 (2001) 010.
\[38\] ATLAS Collaboration, ATLAS-CONF-PUB-2010-002.
\[41\] ATLAS Collaboration, ATLAS-CONF-2010-054.
\[43\] http://hepdata.cedar.ac.uk/resource/atlas/
\[50\] http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/susy-Olepton_01/
Fachbereich Physik, Universität Siegen, Siegen, Germany
Department of Physics, Simon Fraser University, Burnaby BC, Canada
SLAC National Accelerator Laboratory, Stanford CA, United States of America
Department of Physics, University of Johannesburg, Johannesburg, South Africa
Instituto de Física Corpuscular (IFIC) and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain

Department of Physics, University of British Columbia, Vancouver BC, Canada
Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
Waseda University, Tokyo, Japan
Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
Department of Physics, University of Wisconsin, Madison WI, United States of America
Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
Department of Physics, Yale University, New Haven CT, United States of America
Yerevan Physics Institute, Yerevan, Armenia
Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal
Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal
Also at CPPM, Aix-Marseille Universite and CNRS/IN2P3, Marseille, France
Also at TRIUMF, Vancouver BC, Canada
Also at Department of Physics, California State University, Fresno CA, United States of America
Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
Also at Department of Physics, University of Coimbra, Coimbra, Portugal
Also at Università di Napoli Parthenope, Napoli, Italy
Also at Institute of Particle Physics (IPP), Canada
Also at Louisiana Tech University, Ruston LA, United States of America
Also at California Institute of Technology, Pasadena CA, United States of America
Also at Louisiana Tech University, Ruston LA, United States of America
Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
Also at Manhattan College, New York NY, United States of America
Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China
Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
Also at High Energy Physics Group, Shandong University, Shandong, China
Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
\textsuperscript{v} Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
\textsuperscript{w} Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
\textsuperscript{x} Also at Institute of Physics, Jagiellonian University, Krakow, Poland
\textsuperscript{y} Also at Department of Physics, Oxford University, Oxford, United Kingdom
\textsuperscript{z} Also at DSM/IRFU, CEA Saclay, Gif-sur-Yvette, France
\textsuperscript{aa} Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
\textsuperscript{ab} Also at Department of Physics, Nanjing University, Jiangsu, China

* Deceased