"Search for resonances in the dijet mass spectrum from 7 TeV pp collisions at CMS"

CMS Collaboration; Quertenmont, Loïc; Chatrchyan, Serguei; Basegmez, Suzan; Bruno, Giacomo; Caudron, Julien; Ceard, Ludivine; Cortina Gil, Eduardo; de Favereau de Jeneret, Jérôme; Delaere, Christophe; Favart, Denis; Forthomme, Laurent; Giammanco, Andrea; Grégoire, Ghislain; Hollar, Jonathan; Lemaitre, Vincent; Liao, Junhui; Militaru, Otilia; Nuttens, Claude; Ovyn, Séverine; Pagano, Davide; Pin, Arnaud; Piotrzkowski, Krzysztof; Schul, Nicolas

ABSTRACT

A search for narrow resonances with a mass of at least 1 TeV in the dijet mass spectrum is performed using pp collisions at View the MathML source corresponding to an integrated luminosity of 1 fb−1, collected by the CMS experiment at the LHC. No resonances are observed. Upper limits at the 95% confidence level are presented on the product of the resonance cross section, branching fraction into dijets, and acceptance, separately for decays into quark–quark, quark–gluon, and gluon–gluon pairs. The data exclude new particles predicted in the following models at the 95% confidence level: string resonances with mass less than 4.00 TeV, E6 diquarks with mass less than 3.52 TeV, excited quarks with mass less than 2.49 TeV, axigluons and colorons with mass less than 2.47 TeV, and W′ bosons with mass less than 1.51 TeV. These results extend previous exclusions from the dijet mass search technique.

CITE THIS VERSION


Le dépôt institutionnel DIAL est destiné au dépôt et à la diffusion de documents scientifiques émanants des membres de l'UCLouvain. Toute utilisation de ce document à des fin lucratives ou commerciales est strictement interdite. L'utilisateur s'engage à respecter les droits d'auteur lié à ce document, principalement le droit à l'intégrité de l'oeuvre et le droit à la paternité. La politique complète de copyright est disponible sur la page Copyright policy.

DIAL is an institutional repository for the deposit and dissemination of scientific documents from UCLouvain members. Usage of this document for profit or commercial purposes is strictly prohibited. User agrees to respect copyright about this document, mainly text integrity and source mention. Full content of copyright policy is available at Copyright policy.
Search for resonances in the dijet mass spectrum from 7 TeV pp collisions at CMS

CERN Collaboration

A search for narrow resonances with a mass of at least 1 TeV in the dijet mass spectrum is performed using pp collisions at \( \sqrt{s} = 7 \text{ TeV} \) corresponding to an integrated luminosity of 1 fb\(^{-1}\), collected by the CMS experiment at the LHC. No resonances are observed. Upper limits at the 95% confidence level are presented on the product of the resonance cross section, branching fraction into dijets, and acceptance, separately for decays into quark–quark, quark–gluon, and gluon–gluon pairs. The data exclude new particles predicted in the following models at the 95% confidence level: string resonances with mass less than 4.00 TeV, \( E_q \) diquarks with mass less than 3.52 TeV, excited quarks with mass less than 2.49 TeV, axigluons and colorons with mass less than 2.47 TeV, and \( W' \) bosons with mass less than 1.51 TeV. These results extend previous exclusions from the dijet mass search technique.

© 2011 CERN. Published by Elsevier B.V. All rights reserved.
measured in the ECAL and the HCAL within each projective tower are summed to find the calorimeter tower energy. A more detailed description of the CMS experiment can be found elsewhere [1].

The CMS coordinate system has the origin at the center of the detector. The $z$-axis points along the direction of the anticlockwise beam, with the transverse plane perpendicular to the beam; $\phi$ is the azimuthal angle, $\theta$ is the polar angle, and the pseudorapidity is defined as $\eta \equiv -\ln(\tan(\theta/2))$.

The integrated luminosity of the data sample selected for this analysis is $1.01 \pm 0.06$ fb$^{-1}$. Events are recorded using a two-tier trigger system. Objects satisfying the requirements at the first level (L1) are passed to the High Level Trigger (HLT). The sample was collected with a multijet trigger at the HLT, which is based on $H_T$, the sum of the transverse energies of all jets in the event with $p_T$ above 40 GeV. The trigger selects events with $H_T$ in the HLT exceeding 550 GeV. Another multijet trigger with a lower $H_T$ threshold and a prescaling of events is used for the purpose of measuring trigger efficiencies. The trigger efficiency is measured from the data to be larger than 99.9% for dijet masses above 838 GeV.

To remove possible instrumental and non-collision backgrounds in the selected sample, jets are required to pass identification criteria that are fully efficient for signal [12]. Events are required to have a reconstructed primary vertex within the range $|z| < 24$ cm.

We consider two types of standard jets with different inputs: particle-flow jets, which we use for the search, and calorimeter jets, which we use as a check. The particle-flow algorithm [13] reconstructs all stable particles in an event by combining information from all subdetectors. The algorithm categorizes all particles into the following five types: muons, electrons, photons, charged hadrons, and neutral hadrons. Particle-flow jets use reconstructed particles as input to the jet reconstruction algorithm, while calorimeter jets use calorimeter energy deposits as the input.

The reconstructed jet energy $E$ is defined as the scalar sum of the energies of the constituents of the jet, and the jet momentum $\vec{p}$ is the corresponding vector sum of the momenta of the inputs. The jet transverse momentum $p_T$ is the component of $\vec{p}$ perpendicular to the beam. The values of $E$ and $\vec{p}$ of a reconstructed jet are corrected for the response of the detector to a generated jet, using Monte Carlo simulations, test beam results, and collision data [14]. Separate corrections are derived for calorimeter jets and for particle-flow jets. The corrections account for pileup of multiple $pp$ collisions [15].

This analysis combines particle-flow jets reconstructed with the anti-$k_T$ algorithm [16] into “wide jets”, which we use to measure the mass spectrum and search for new physics. Wide jets are the result of a radiation recovery algorithm for dijets, inspired by recent jet-grooming algorithms [17–19]. The partons from the decay of heavy objects can radiate additional partons, which are often produced at a large angle with respect to the original parton direction and thus are clustered into a separate jet by the anti-$k_T$-jet-clustering algorithm. Wide jets collect more of this final-state radiation and therefore improve the mass resolution for dijet resonances. First, we reconstruct jets using the anti-$k_T$ algorithm with distance parameters $R = 0.5$ (AK5 jets) and $R = 0.7$ (AK7 jets), which are the two standard choices we support for analysis at CMS. In our previous search [2] we used AK7 jets, since they have a larger distance parameter than AK5 jets and capture more radiation. Here we introduce wide jets reconstructed from AK5 jets to produce a wider jet than AK7. We correct the AK5 jet energy and select the two AK5 jets with the highest $p_T$ in the event (leading AK5 jets). Then we add the Lorentz vectors of all other AK5 jets with $p_T > 10$ GeV and $|\eta| < 2.5$ to the closest AK5 leading jet, if within $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} < 1.1$, to obtain the two leading wide jets. The parameter $\Delta R$ sets the maximum size of the wide jet.

The dijet system is composed of the two leading jets. We require that the pseudorapidity separation $\Delta \eta$ of the two leading jets satisfy $|\Delta \eta| < 1.3$, and that both jets be in the region $|\eta| < 2.5$. These $\Delta \eta$ and $\eta$ requirements maximize the search sensitivity for isotropic decays of dijet resonances in the presence of QCD background. The dijet mass is given by $m = \sqrt{(E_1 + E_2)^2 - (p_1 + p_2)^2}$. We select events with $m > 838$ GeV without any requirements on the $p_T$ of the leading jet.

The number of events as a function of dijet mass is shown in Fig. 1 for both calorimeter and particle-flow AK7 jets; the observed rates agree. Fig. 1 also shows that the observed wide jet dijet mass distribution is shifted to higher mass because wide jets collect more energy.

Fig. 2 presents the inclusive dijet mass distribution for $pp \to 2$ leading wide jets + $X$, where $X$ can be anything, including additional jets. Wide jets are used and we plot the measured differential cross section as a function of dijet mass in bins approximately equal to the dijet mass resolution [2]. The data are compared to a QCD prediction from PYTHIA v6.424 [20], which includes a simulation of the CMS detector and the jet energy corrections. The prediction uses a renormalization scale $\mu = p_T$ of the hard-scattered partons and CTEQ6L1 parton distribution functions [21], and has been normalized to the data by multiplying the prediction by a factor of 1.33. The shape of the PYTHIA prediction agrees with the data within the jet energy scale uncertainty, which is the dominant systematic uncertainty. To test the smoothness of our measured cross section as a function of dijet mass, we fit the following parameterization to the data:

$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^P_1}{(m/\sqrt{s})^P_2 + P_3 \ln(m/\sqrt{s})},$$

with four free parameters $P_0$, $P_1$, $P_2$, and $P_3$. This functional form is used in previous searches [22,23,24] to describe both data and QCD predictions. In Fig. 2 we show the fit, which has a chi-squared ($\chi^2$) of 27.5 for 28 degrees of freedom, as well as the bin-by-bin significance, defined as the difference between the data and the fit value, divided by the statistical uncertainty of the data. Fig. 3 displays the ratio of the data to the fit. The data are well described by the smooth parameterization.
We search for narrow resonances, for which the natural resonance width is small compared to the CMS dijet mass resolution. Figs. 2 and 3 present the predicted dijet mass distribution for excited quark signals using 	exttt{pythia v6.424} and the CMS detector simulation. The predicted mass distributions have a Gaussian core coming from the jet energy resolution and a tail towards lower mass from QCD radiation. This can be seen in Fig. 4, which shows examples of the predicted dijet mass distribution of resonances from three different parton pairings: \(q\bar{q}\) (or \(qq\)) resonances from the process \(G \rightarrow q\bar{q}\) \([11]\), \(qg\) resonances from \(q^* \rightarrow qg\) \([6]\), and \(gg\) resonances from \(G \rightarrow gg\) \([11]\). The increase of the width of the measured mass shape and the shift of the mass distribution towards lower masses are enhanced when the number of gluons in the final state is larger, because QCD radiation is larger for gluons than for quarks. The distributions in Fig. 4 are generically valid for other resonances with the same parton content and with a natural width small compared to the dijet mass resolution, and are examples of the shapes we use to set limits on dijet resonances. Wide-jet reconstruction gives a little better resolution than AK7-jet reconstruction, as shown in Fig. 4 for \(gg\) resonances. There is no indication of narrow resonances in our data, as shown in Figs. 2 and 3.

We use the dijet mass data from wide jets, the background (QCD) parameterization, and the dijet resonance shapes to set specific limits on new particles decaying to the parton pairs \(q\bar{q}\) (or \(qq\)), \(qg\), and \(gg\). The dominant sources of systematic uncertainty are the jet energy scale (2.2%), the jet energy resolution (10%), and the statistical uncertainty on the background parameterization, which are all considered nuisance parameters. The jet energy scale uncertainty is shown in Fig. 2 and is equivalent to a 15% uncertainty in the background cross section. For setting upper limits we use a Bayesian formalism with a uniform prior for the signal cross section \([25]\). To incorporate systematic uncertainties we use a fully Bayesian treatment, integrating the likelihood over these nuisance parameters. We calculate the posterior probability density as a function of resonance cross section independently at each value of the resonance mass. Table 1 lists the generic upper limits at the 95% confidence level (CL) on \(\sigma \times B \times A\), i.e. the product of the cross section \(\sigma\), the branching fraction \(B\), and the acceptance \(A\), for the kinematic requirements \(|\Delta \eta| < 1.3\) and \(|\eta| < 2.5\), for \(qq\), \(qg\), and \(gg\) resonances. The acceptance for isotropic decays is \(A \approx 0.6\) independent of resonance mass. The observed upper limits in Table 1 can be compared to predictions of \(\sigma \times B \times A\) at the parton level, without any detector simulation, in order to determine mass limits on new particles.
Table 1

<table>
<thead>
<tr>
<th>Mass (TeV)</th>
<th>Upper limit (pb)</th>
<th>Mass (TeV)</th>
<th>Upper limit (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>qq</td>
<td>qg</td>
<td>gg</td>
</tr>
<tr>
<td>1.0</td>
<td>1.098</td>
<td>1.245</td>
<td>1.851</td>
</tr>
<tr>
<td>1.1</td>
<td>0.777</td>
<td>0.909</td>
<td>1.374</td>
</tr>
<tr>
<td>1.2</td>
<td>0.662</td>
<td>0.732</td>
<td>1.079</td>
</tr>
<tr>
<td>1.3</td>
<td>0.486</td>
<td>0.535</td>
<td>0.803</td>
</tr>
<tr>
<td>1.4</td>
<td>0.284</td>
<td>0.332</td>
<td>0.518</td>
</tr>
<tr>
<td>1.5</td>
<td>0.231</td>
<td>0.265</td>
<td>0.395</td>
</tr>
<tr>
<td>1.6</td>
<td>0.201</td>
<td>0.226</td>
<td>0.326</td>
</tr>
<tr>
<td>1.7</td>
<td>0.168</td>
<td>0.190</td>
<td>0.280</td>
</tr>
<tr>
<td>1.8</td>
<td>0.115</td>
<td>0.138</td>
<td>0.207</td>
</tr>
<tr>
<td>1.9</td>
<td>0.113</td>
<td>0.131</td>
<td>0.183</td>
</tr>
<tr>
<td>2.0</td>
<td>0.121</td>
<td>0.140</td>
<td>0.193</td>
</tr>
<tr>
<td>2.1</td>
<td>0.108</td>
<td>0.130</td>
<td>0.183</td>
</tr>
<tr>
<td>2.2</td>
<td>0.093</td>
<td>0.115</td>
<td>0.160</td>
</tr>
<tr>
<td>2.3</td>
<td>0.089</td>
<td>0.108</td>
<td>0.148</td>
</tr>
<tr>
<td>2.4</td>
<td>0.085</td>
<td>0.102</td>
<td>0.138</td>
</tr>
<tr>
<td>2.5</td>
<td>0.077</td>
<td>0.092</td>
<td>0.125</td>
</tr>
</tbody>
</table>

In addition to these observed upper limits, we also calculate the expected upper limits using pseudo-experiments: searches conducted on random samples of events generated from our smooth background parameterization. The use of wide jets instead of AK7 jets improves the expected upper limits on the resonance cross section by roughly 20% for gg, 10% for qg, and 5% for qq resonances.

In Fig. 5 we compare the observed upper limits to the model predictions as a function of resonance mass. The predictions are conducted on random samples of events generated from our smooth background parameterization. The use of wide jets instead of AK7 jets improves the expected upper limits on the resonance cross section by roughly 20% for gg, 10% for qg, and 5% for qq resonances.

In Fig. 6 we compare the observed upper limits to the model predictions as a function of resonance mass. The predictions are compared to theoretical predictions for string resonances and excited quarks.

In Fig. 5 we compare the observed upper limits to the model predictions as a function of resonance mass. The predictions are compared to theoretical predictions for string resonances and excited quarks. The data is presented using different colors for different models: String Resonance (solid line), Excited Quark (dotted line), Axigluon/Coloron (dashed line), and Randall-Sundrum Graviton (dashed-dotted line). The observed upper limits are shown as points, and the expected upper limits are shown as shaded bands.

In Fig. 6 we compare the observed upper limits to the model predictions as a function of resonance mass. The predictions are compared to theoretical predictions for string resonances and excited quarks. The data is presented using different colors for different models: String Resonance (solid line), Excited Quark (dotted line), Axigluon/Coloron (dashed line), and Randall-Sundrum Graviton (dashed-dotted line). The observed upper limits are shown as points, and the expected upper limits are shown as shaded bands.
0.6 < M(A, C) < 2.1 TeV [24]. For W' bosons the expected mass limit is 1.40 TeV and we exclude masses less than 1.51 TeV; this extends the CDF exclusion of 0.3 < M(W') < 0.8 TeV from the dijet mass spectrum [22]. We do not set any mass limits on Z' bosons and RS gravitons. The systematic uncertainties included in this analysis reduce the excluded upper masses by 0.03 TeV or less for each type of new particle.

In summary, the dijet invariant mass distribution has been measured to be a smoothly falling distribution, as expected within the standard model. There is no evidence for new particle production. We present generic upper limits on the product M_{WW'} × δ_{WW'}. For each model we list the observed and expected upper values of the excluded mass range at 95% CL. The lower value of the excluded mass range from this search can be applied to any model of dijet resonance production. We set specific mass limits on string resonances, E6 diquarks, excited quarks, axigluons, flavour-universal colorons, and W/ bosons, all of which extend previous exclusions from the dijet mass search technique.

Table 2
For each model we list the observed and expected upper values of the excluded mass range at 95% CL. The lower value of the excluded mass range from this search is 1 TeV.

<table>
<thead>
<tr>
<th>Model</th>
<th>Observed (TeV)</th>
<th>Expected (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>String resonances</td>
<td>4.00</td>
<td>3.90</td>
</tr>
<tr>
<td>E6 diquarks</td>
<td>3.52</td>
<td>3.28</td>
</tr>
<tr>
<td>Excited quarks</td>
<td>2.49</td>
<td>2.68</td>
</tr>
<tr>
<td>Axigluons/colorons</td>
<td>2.47</td>
<td>2.66</td>
</tr>
<tr>
<td>W' bosons</td>
<td>1.51</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Acknowledgements

We wish to congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and elsewhere, without whom Physics at the LHC could not be carried out.

Open access

This article is published Open Access at sciencedirect.com. It is distributed under the terms of the Creative Commons Attribution License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

References


CMS Collaboration

S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Yerevan Physics Institute, Yerevan, Armenia


Institut für Hochenergiephysik der OeAW, Wien, Austria
V. Epshteyn, M. Erofeeva, V. Gavrilov, V. Kaftanov, M. Kossov, A. Krokhotin, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Institute for Theoretical and Experimental Physics, Moscow, Russia


Moscow State University, Moscow, Russia


PN. Lebedev Physical Institute, Moscow, Russia


State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia

P. Adzic, M. Djordjevic, D. Kric, J. Milosevic

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia


Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad Autónoma de Madrid, Madrid, Spain


Universidad de Oviedo, Oviedo, Spain


Instituto de Física de Cantabria (IFCA), CSIC – Universidad de Cantabria, Santander, Spain


CERN, European Organization for Nuclear Research, Geneva, Switzerland

Imperial College, London, United Kingdom

M. Barrett, M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leslie, W. Martin, I.D. Reid, L. Teodorescu

Brunel University, Uxbridge, United Kingdom

K. Hatakeyama, H. Liu

Baylor University, Waco, USA

C. Henderson

The University of Alabama, Tuscaloosa, USA


Boston University, Boston, USA


Brown University, Providence, USA


University of California, Davis, Davis, USA


University of California, Los Angeles, Los Angeles, USA


University of California, Riverside, Riverside, USA


University of California, San Diego, La Jolla, USA


University of California, Santa Barbara, Santa Barbara, USA


California Institute of Technology, Pasadena, USA
Northwestern University, Evanston, USA

University of Notre Dame, Notre Dame, USA

B. Bylsma, L.S. Durkin, J. Gu, C. Hill, P. Killewald, K. Kotov, T.Y. Ling, M. Rodenburg, C. Vuosalo, G. Williams
The Ohio State University, Columbus, USA

Princeton University, Princeton, USA

University of Puerto Rico, Mayaguez, USA

Purdue University, West Lafayette, USA

S. Guragain, N. Parashar
Purdue University Calumet, Hammond, USA

Rice University, Houston, USA

University of Rochester, Rochester, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian
The Rockefeller University, New York, USA

Rutgers, The State University of New Jersey, Piscataway, USA

G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York
University of Tennessee, Knoxville, USA

Texas A&M University, College Station, USA

Texas Tech University, Lubbock, USA


Vanderbilt University, Nashville, USA


University of Virginia, Charlottesville, USA

S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, M. Mattson, C. Milstène, A. Sakharov

Wayne State University, Detroit, USA


University of Wisconsin, Madison, USA

* Corresponding author.
E-mail address: Roberto.Tenchini@cern.ch (R. Tenchini).
1 Deceased.
1 Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
2 Also at Universidade Federal do ABC, Santo Andre, Brazil.
3 Also at California Institute of Technology, Pasadena, USA.
4 Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.
5 Also at Suez Canal University, Suez, Egypt.
6 Also at British University, Cairo, Egypt.
7 Also at Fayoum University, El-Fayoum, Egypt.
8 Also at Ain Shams University, Cairo, Egypt.
9 Also at Soltan Institute for Nuclear Studies, Warsaw, Poland.
10 Also at Massachusetts Institute of Technology, Cambridge, USA.
11 Also at Université de Haute-Alsace, Mulhouse, France.
12 Also at Brandenburg University of Technology, Cottbus, Germany.
13 Also at Moscow State University, Moscow, Russia.
14 Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
15 Also at Eötvös Loránd University, Budapest, Hungary.
16 Also at Tata Institute of Fundamental Research – HECR, Mumbai, India.
17 Also at University of Viova-Bharati, Santiniketan, India.
18 Also at Sharif University of Technology, Tehran, Iran.
19 Also at Shiraz University, Shiraz, Iran.
20 Also at Isfahan University of Technology, Isfahan, Iran.
21 Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
22 Also at Università della Basilicata, Potenza, Italy.
23 Also at Laboratori Nazionali di Legnaro dell’INFN, Legnaro, Italy.
24 Also at Università degli Studi di Siena, Siena, Italy.
25 Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia.
26 Also at University of California, Los Angeles, Los Angeles, USA.
27 Also at University of Florida, Gainesville, USA.
28 Also at Université de Genève, Geneva, Switzerland.
29 Also at Scuola Normale e Sezione dell’INFN, Pisa, Italy.
30 Also at INFN Sezione di Roma, Università di Roma “La Sapienza”, Roma, Italy.
31 Also at University of Athens, Athens, Greece.
32 Also at The University of Kansas, Lawrence, USA.
33 Also at Paul Scherrer Institut, Villigen, Switzerland.
34 Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
35 Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
36 Also at Gaziosmanpasa University, Tokat, Turkey.
37 Also at Adiyaman University, Adiyaman, Turkey.
38 Also at The University of Iowa, Iowa City, USA.
39 Also at Mersin University, Mersin, Turkey.
40 Also at Izmir Institute of Technology, Izmir, Turkey.
41 Also at Kafkas University, Kars, Turkey.
42 Also at Suleyman Demirel University, Isparta, Turkey.
43 Also at Ege University, Izmir, Turkey.
44 Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
45 Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
46 Also at INFN Sezione di Perugia, Università di Perugia, Perugia, Italy.
47 Also at Utah Valley University, Orem, USA.
48 Also at Institute for Nuclear Research, Moscow, Russia.
49 Also at Los Alamos National Laboratory, Los Alamos, USA.
50 Also at Erzincan University, Erzincan, Turkey.