Relazione triennale (2014-16) di Francesco Santanastasio

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Current Position

Assistant Professor (Ricercatore Tempo Determinato di Tipo B) from 01/03/2014
Department of Physics, Sapienza Università di Roma, Rome, Italy

Teaching

AA 15-16 **Corso di Fisica I, Sapienza, Corso di Laurea in Chimica Industriale (9 CFU)**
Mechanics and Thermodynamics

AA 14-15 **Corso di Fisica I, Sapienza, Corso di Laurea in Chimica Industriale (9 CFU)**
Mechanics and Thermodynamics

Academic Responsibilities

10/2014 - today **Representative of "Facoltà di SMFN" at "Conferenza Nazionale dei Presidenti e dei Direttori delle Strutture Universitarie di Scienze e Tecnologie (con.Scienze)"**
Organization of verification-of-knowledge tests for science majors required for registration at first year of university.

09/2015 - today **Member of "Commissione Didattica del CdL in Chimica Industriale"**

Research Groups

2005 - today **Member of the CMS collaboration at the CERN Large Hadron Collider (LHC)**
CMS is one of the two general purpose particle physics detectors operated at LHC.

2014 - today **Member of the i-MCP collaboration**
i-MCP is an R&D project within INFN CSN5 aimed at use of micro-channel plates for precise timing measurement of single particles and electromagnetic showers at collider experiments.

Publications

2016 **117 publications:** see link to inspire
http://inspirehep.net/search?ln=en&ln=en&p=find+a+santanastasio+and+tc+p+and+date+2016&of=hb&action_search=Search&sf=&so=d&rm=&rg=25&sc=0

2015 **131 publications:** see link to inspire
http://inspirehep.net/search?ln=en&ln=en&p=find+a+santanastasio+and+tc+p+and+date+2015&of=hb&action_search=Search&sf=&so=d&rm=&rg=25&sc=0

2014 **109 publications:** see link to inspire

http://inspirehep.net/search?ln=en&ln=en&p=find+a+santanastasio+and+tc+p+and+date+2014&of=hb&action_search=Search&sf=&so=d&rm=&rg=25&sc=0

Total number of publications: 541 (ISI), 562 (inspire)
h-index: 61 (ISI)

Research Grants

03/2014 **Winner of "Programma Per Giovani Ricercatori Rita Levi Montalcini"**
Risultati Bando 2010 del 08/2013
Three-year grant of about 220000 euros for research in experimental high-energy physics with the CMS detector at the CERN LHC, of which 44000 euros for research costs.

Scientific Coordination in the Period 2014-2016

09/2016 - today **Coordination of the *CMS Exotica Jets+X Working Group***
I started my 2-year mandate on September 1st, 2016. This analysis group works on searches for new physics beyond the Standard Model in final states containing jets. The group, constituted by more than 50 physicists working in universities and research institutions from all the world, performs about 10 physics analyses in this final state. The results of these searches are expected to be published in 2017.

09/2014 - 09/2016 **Coordination of the *Dijet Resonance Team* of the CMS experiment**
This analysis team works on searches for new massive resonances at the TeV scale decaying into a pair of jets using the dijet mass spectrum. It is constituted by about 15 physicists from several institutions from all the world. This group produced two high-impact papers using proton-proton collisions at $\sqrt{s} = 13$ TeV [1, 2] including the first published limits in the dijet final state on the mass of a mediator of the interaction between a hypothetical *dark matter* particle and the Standard Model quarks.

01/2013 - 01/2015 **Coordination of the *CMS Exotica Leptons+Jets Working Group***
This analysis group works on searches for new physics beyond the Standard Model in final states containing leptons and jets. The group, constituted by more than 50 physicists working in universities and research institutions from all the world, performed about 15 physics analyses in this final state. During my convenership, the group produced 3 publications [8, 9, 10] and 7 preliminary results that were then published or submitted for publication in 2015 (including [4, 5, 6]).

Details of Research Activity in the Period 2014-2016

My research field is the experimental high energy physics. Since 2005 I am part of the CMS collaboration, one of the 4 experiments running at the CERN Large Hadron Collider (LHC). During these years, I have been involved in several detector activities including calibration of the CMS electromagnetic calorimeter, commissioning of the CMS hadronic calorimeter, performance studies of the missing transverse energy reconstructed in the event, and I participated to several physics analyses. In the 2014-2016 period I focused on searches for physics beyond the Standard Model (SM) and on jet calibration studies. Since 2014 I'm also part of the i-MCP collaboration. This is an R&D project within INFN CSN5 aimed at use of micro-channel plates for precise timing measurement of single particles and electromagnetic showers at collider experiments.

Search for new resonances in the dijet final state

I have been working on a search for new resonances with mass at the TeV scale that decay to a pair of jets (dijet). This search is one of the most sensitive probes for new physics at LHC because any hypothetical new particle that might be produced is originated from the colliding protons and therefore it must couple to quarks and/or gluons, thus producing jets. The analysis strategy consists in reconstructing the invariant mass of the dijet system and searching for a resonant peak in its data spectrum. I have been the leading author of this search in CMS since 2012 publishing a paper on this topic with the full dataset collected at $\sqrt{s} = 8$ TeV [7]. After a 2-year shutdown, the LHC has restarted proton-proton collisions in 2015 with an increased center-of-mass energy of 13 TeV. This energy jump has largely enhanced the sensitivity of the dijet search to new physics. In the last two years, I coordinated the group made of about 15 physicists devoted to the analysis of the early 13 TeV data. The analysis performed on the data collected in 2015 and 2016 has shown no sign of new particle production, setting the most stringent limits in this final state for several new physics models. I was primary author of two high-impact papers using proton-proton collisions at $\sqrt{s} = 13$ TeV [1, 2]. These include the first published limits in the dijet final state on the mass of a mediator of the interaction between a hypothetical *dark matter* particle and the SM quarks.

The novel *data scouting* technique in hadronic resonance searches

At LHC, it is important to extend the search for resonances in fully hadronic final states in the mass region below 1 TeV in order to probe small couplings to quarks and gluons not yet excluded by previous colliders. The main experimental difficulties at LHC originate from the large cross section of multijet events at low jet transverse momentum and the finite computing resources for processing and storing these data. To solve this issue, I proposed in 2011 a new technique - known as *data scouting* - in the CMS experiment. This technique, by significantly reducing the event size compared to the standard CMS data stream, enabled to relax the trigger thresholds and record 1 KHz of fully hadronic events to extend the search in the sub-TeV mass region. With this approach, the analysis is performed using jets reconstructed online in the CMS trigger computing farm. This novel trigger strategy was fully integrated in the CMS physics program in 2012, when I was convener of the *"CMS Dataset Definition Team"*, allowing to collect data corresponding to almost 19 fb^{-1} of integrated luminosity at $\sqrt{s} = 8$ TeV; this technique was implemented also by LHCb and ATLAS experiments at LHC in the following years. Since 2014, I worked at a search for sub-TeV dijet resonances using these data. No evidence for new particle production was found and the most stringent limits to date were set on the production cross section of dijet resonances in the mass range from 500 to 800 GeV. These results were published in 2016 by PRL [3].

Search for new resonances in diboson final states

Many theories beyond the SM predict the existence of massive particles at the TeV scale that decays into pairs of SM bosons. The bosons coming from the massive particle can be W, Z, H or γ. As convener of the *CMS Exotica Leptons+Jets Working Group* in 2013 and 2014, I contributed to various diboson analyses in final states involving leptons and jets, documented in 3 papers [4, 5, 10]. In particular, I was deeply involved in the search for massive resonances in the WW and ZZ final states using proton-proton collisions at $\sqrt{s} = 8$ TeV, focusing on the analysis of the semi-leptonic ($\ell\ell qq$ and $\ell\nu qq$) [10] and fully-hadronic ($qqqq$) decay modes [11]. These decay channels have the largest branching fraction,

providing a higher sensitivity to new physics for resonance masses above 1 TeV compared to the fully leptonic channels. These are quite complex analyses. For resonances with mass above 1 TeV, the momentum of the W and Z bosons greatly exceeds their rest mass, and the quarks from their decay are emitted with a small angular separation in the laboratory reference frame, thus resulting into a single massive jet. By exploiting the substructure of a wide jet, it is possible to discriminate between the dipolar structure of an hadronic boson decay (signal events) and a jet created by the hadronization of a single quark/gluon (background events). The WW and ZZ searches were among the first in CMS to include the jet-substructure reconstruction algorithms in a physics analysis and my work contributed to define the experimental methodology for this kind of research in CMS.

Work on jets

High momentum jets, coming from hadronization of energetic quarks and gluons, are present in almost every collision at the LHC. The detailed understanding of both the energy scale and resolution of the jets is of crucial importance for many physics analyses. I worked at the jet energy calibration using photon+jet events and I studied the energy scale and resolution of jets reconstructed at trigger level in the *data scouting* stream. I'm also involved in studies of jet substructure which are important for diboson analyses. Energetic W or Z bosons decaying to a pair of collimated quarks can be reconstructed as single massive jets in the detector. The effectiveness of algorithms to identify the jet substructure is studied using simulated events and it is sensitive to the details of Monte Carlo parton showering. Since it is crucial to validate these methods using real data, I studied these algorithms using a pure sample of energetic W bosons coming from top quark decays in $t\bar{t}$ semi-leptonic events. By comparing results in data and simulation, it is possible to derive correction factors for the jet mass scale/resolution and for the efficiency of the jet substructure requirements. These correction factors, measured with 5-10% uncertainty, are used in several searches for new physics in CMS.

Precise timing measurements at future colliders

Future hadron colliders will provide instantaneous luminosities exceeding 10^{35} $cm^{-2}s^{-1}$ and the large number of simultaneous collisions in each interaction (pileup events) will be a major challenge. While one collision contains the rare signatures of interest for discoveries or SM precision measurements, the contribution of the remaining pileup interactions must be reduced to maintain good performance of calorimeters in terms of energy measurements and particle identification. For example, in the High-Luminosity phase of the LHC (HL-LHC), more than 140 interactions per beam crossing, with a spread of approximately 10 cm and 300 ps along the beam axis, are anticipated. This represent an increase of more than a factor 5 with respect to the current LHC pileup conditions. A possible strategy to reduce the impact of increasing pileup, consists in complementing the transversal segmentation of the calorimeters with an extremely high time-resolution, which would enable the energy deposits coming from different interaction vertices to be resolved in time. Micro Channel Plates (MCPs) are good candidate detectors for this scope, thanks to their excellent time response. I'm involved in R&D studies on the ionization-MCP (i-MCP) where the avalanche formation is triggered by secondary emission of electrons directly on the MCP surface, when this is hit by relativistic charged particles. The advantage consists in the elimination of the photo-cathode, improving the radiation tolerance of the device. The demonstration of the i-MCP concept has been achieved on both commercial device and bare MCPs tested inside a custom vacuum chamber designed in Rome. In some configurations, detection efficiencies

to single particles above 80% are reached with time resolution around 20 ps. Initial results have been published on NIM [12] and a second publication based on test beams performed in the last two years is expected in 2017.

Invited Talks at Conferences

07/2016 **ICNFP2016** - International Conference on New Frontiers in Physics, Kolymbari, Crete, *"Searches for BSM physics in final states with jets and leptons+jets at CMS"*, Proceedings [13]

07/2014 **ICHEP2014** - International Conference on High Energy Physics, Valencia, Spain, *"Search for heavy resonances decaying to bosons with the ATLAS and CMS detectors"*, Proceedings [14]

Student Supervision

PhD (Dottorato)

2015-2017 S. Gelli, *"Search for new resonances in $V\gamma \to qq + \gamma$ final states at LHC"*, Thesis ongoing

2014-2015 G. D'Imperio, *"Search for narrow resonances in dijet final states at the LHC with $\sqrt{s} =$ 13 TeV"* [2] [thesis]

Undergraduate (Laurea)

2016-2017 A. Tanga, *"Ricerca di risonanze adroniche in stati finali con tre jet ad LHC"*, Thesis ongoing

References

Publications quoted in this document

[1] [CMS Collaboration], "Search for dijet resonances in proton-proton collisions at sqrt(s) = 13 TeV and constraints on dark matter and other models," Accepted for publication by Phys. Lett. B, arXiv:1611.03568 [hep-ex].

[2] [CMS Collaboration]. "Search for narrow resonances decaying to dijets in proton proton collisions at $\sqrt{s} = 13$ TeV," Phys. Rev. Lett. 116, 071801 (2016), arXiv:1512.01224 [hep-ex].

[3] [CMS Collaboration], "Search for narrow resonances in dijet final states at $\sqrt{s} = 8$ TeV with the novel CMS technique of data scouting," Phys. Rev. Lett. 117, 031802 (2016), arXiv:1604.08907 [hep-ex].

[4] [CMS Collaboration], "Search for massive WH resonances decaying into the $\ell\nu\mathrm{b\bar{b}}$ final state at $\sqrt{s} = 8$ TeV," Eur. Phys. J. C 76, 237 (2016), arXiv:1601.06431 [hep-ex].

[5] [CMS Collaboration], "Search for narrow high-mass resonances in proton–proton collisions at $\sqrt{s} = 8$ TeV decaying to a Z and a Higgs boson," Phys. Lett. B 748, 255 (2015), arXiv:1502.04994 [hep-ex].

[6] [CMS Collaboration], "Search for pair production of first and second generation leptoquarks in proton-proton collisions at $\sqrt{s} = 8$ TeV," Phys. Rev. D 93, 032004 (2016), arXiv:1509.03744 [hep-ex].

[7] [CMS Collaboration], "Search for resonances and quantum black holes using dijet mass spectra in proton-proton collisions at $\sqrt{s} = 8$ TeV," Phys. Rev. D 91, no. 5, 052009 (2015), arXiv:1501.04198 [hep-ex].

[8] [CMS Collaboration], "Search for pair production of third-generation scalar leptoquarks and top squarks in proton–proton collisions at $\sqrt{s} = 8$ TeV," Phys. Lett. B 739, 229 (2014), arXiv:1408.0806 [hep-ex].

[9] [CMS Collaboration], "Search for heavy neutrinos and W bosons with right-handed couplings in proton-proton collisions at $\sqrt{s} = 8$ TeV," Eur. Phys. J. C 74, no. 11, 3149 (2014), arXiv:1407.3683 [hep-ex].

[10] [CMS Collaboration], "Search for massive resonances decaying into pairs of boosted bosons in semi-leptonic final states at $\sqrt{s} = 8$ TeV,"' JHEP 1408, 174 (2014), arXiv:1405.3447 [hep-ex].

[11] [CMS Collaboration], "Search for massive resonances in dijet systems containing jets tagged as W or Z boson decays in pp collisions at $\sqrt{s} = 8$ TeV," JHEP 1408, 173 (2014), arXiv:1405.1994 [hep-ex].

[12] [F. Santanastasio *et al.*], "Response of microchannel plates to single particles and to electromagnetic showers," Nucl. Instrum. Meth. A 797, 216 (2015), arXiv:1504.02728 [physics.ins-det].

Conference Proceedings quoted in this document

[13] "Searches for BSM physics in final states with jets and leptons+jets at CMS"
F. Santanastasio
Proceedings will be published in European Physical Journal Web of Conferences
Prepared for the 5th International Conference on New Frontiers in Physics, Kolymbari, Crete, 6-14 July 2016

[14] "Search for heavy resonances decaying to bosons with the ATLAS and CMS detectors,"
F. Santanastasio
Nucl. Part. Phys. Proc. 273-275, 649 (2016)
Prepared for the XXXVII International Conference on High Energy Physics, Valencia, Spain, 2-9 July 2014

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