Relatório Científico

Busca por Física Além do Modelo Padrão no Canal Díbosons Vetoriais

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Bolsa de Doutorado:	Processo 2012/24593–8
Vigência:	01/Agosto/2013 a 18/Janeiro/2017
Relatório III:	10/Maio/2016 a 05/Dezembro/2016

Contents

1. Introduction

The scope of this project includes the analysis of proton-proton collision data collected by the CMS experiment in 2015. Concretely, we performed the experimental search of a new resonances X in the semileptonic channel $X \rightarrow ZV$, by selecting events with final state consisting of two leptons plus one jet. The oppositely charged lepton pair $\ell^{+}\ell^{-}$ corresponds to the decay of a Z boson in the electron ($\ell = e$) or muon ($\ell = \mu$) channel.

The main achievements since the last report can be summarised below:

- 31-05-2016: Pre-approval of the analysis B2G-16-010 [1] by the B2G (beyond two generations) conveners.
- 06-07-2016: Approval of the analysis by the CMS Collaboration
- 03-08-2016: Presentation of the analysis at ICHEP 2016 [2]
- 02-09-2016: Presentation of the analysis at ENF 2016 [3]

In the following section we describe details of the analysis and its results. In section 3 we include the collaborative activities. Section 4 mentions the conferences and participation in events. Finally, section 5 contains the schedule and extension proposal.

2. Analysis work

2.1 CMS detector and online selection

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Contained within the superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in ref. [4].

Events are recorded with an online selection that requires a single electron or muon. Electrons must have transverse momentum $p_{\mathrm{T}} > 22$ GeV and pseudorapidity $|\eta| < 2.1$, while muons must have $p_{\mathrm{T}} > 20$ GeV; in both cases, leptons satisfy loose identification and isolation requirements. An alternative analysis strategy targeting high mass resonances requires electrons with $p_{\mathrm{T}} > 105$ GeV and muons with $p_{\mathrm{T}} > 45$ GeV; in this high mass strategy the isolation requirement is dropped in order to avoid efficiency loss due to close-by lepton effects.

2.2 Analysis with 2015 data

The data taken by CMS, as well as simulated samples for comparison, are available for members of the CMS collaboration only. Our membership is possible through the São Paulo Research and Analysis Center (SPRACE), which is part of the Worldwide LHC Computing Grid (WLCG). In the hierarchy of the WLCG, SPRACE is a Tier-2 linked to the Fermilab Tier-1, which in turn is linked to the Tier-0 at CERN.

Our analysis requires two types of samples: real collision data (Table 1), and simulated samples (Table 2). The real data was recorded by the CMS Detector during the run 2015 of the LHC, operating at a centre-of-mass energy of 13 TeV. The amount of data corresponds to an integrated luminosity of 2.7 fb^{-1}.

Simulated samples include the SM background with the experimental signature of interest. The signature consists of one jet and two leptons, and the SM processes contributing to this channel are Z+Jets, Diboson (WW, WZ, ZZ), and $t\bar{t}$ production. For signal modelling we use Bulk Graviton samples with different mass hypotheses ranging from 0.8 to 2.5 TeV. The generation of the samples employs MadGraph [5] for matrix element calculations, Pythia8 [6] for showering and hadronization, and Geant4 [7] to simulate the interactions of the particles with the detector.

Table 1: Real collision data.

Dataset name	**Run range**	$\mathcal{L}$ [pb^{-1}]
/SingleElectron/Run2015C_25ns-16Dec2015-v1	254231-254914	15.3
/SingleElectron/Run2015D-16Dec2015-v1	256630-258750	2615.0
/SingleMuon/Run2015C_25ns-16Dec2015-v1	254231-254914	15.3
/SingleMuon/Run2015D-16Dec2015-v1	256630-258750	2615.0

Table 2: Simulated SM backgrounds and Bulk Graviton signal samples.

Sample name	**Cross section[pb]**	$\mathbf{N_{events}}$
/DYJetsToLL_M-50_HT-100to200_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/	147.40 x 1.23	2655294
/DYJetsToLL_M-50_HT-200to400_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/	40.99 x 1.23	962195
/DYJetsToLL_M-50_HT-400to600_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/	5.678 x 1.23	1069003
/DYJetsToLL_M-50_HT-600toInf_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/	2.198 x 1.23	1031103
/WW_TuneCUETP8M1_13TeV-pythia8	118.7	988418
/WZ_TuneCUETP8M1_13TeV-pythia8	66.1	1000000
/ZZ_TuneCUETP8M1_13TeV-pythia8	15.4	985600
/TT_TuneCUETP8M1_13TeV-amcatnlo-pythia8	831.76	19090400
/BulkGravToZZToZlepZhad_narrow_M-800_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-1000_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-1200_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-1400_13TeV-madgraph	1.0E03	49200
/BulkGravToZZToZlepZhad_narrow_M-1600_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-1800_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-2000_13TeV-madgraph	1.0E03	48400
/BulkGravToZZToZlepZhad_narrow_M-2500_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-3000_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-3500_13TeV-madgraph	1.0E03	50000
/BulkGravToZZToZlepZhad_narrow_M-4000_13TeV-madgraph	1.0E03	50000

The recorded events passing the online selection are subject to stringent offline requirements involving jet reconstruction algorithms and substructure techniques. Jets are clustered using the anti-k_{T} algorithm with distance parameter R equal to either 0.4 (AK4 jets) or 0.8 (AK8 jets). AK4 jets are used in the dijet reconstruction of the hadronically decaying boson, while AK8 jets are used in the boosted V jet reconstruction. For AK8 jets, a jet pruning algorithm is used to improve the resolution of the jet mass (m_{J}). The signal region (SR) is defined by requiring $65 < m_{\mathrm{J}} < 105$ GeV; events outside the SR are fitted with an appropriate distribution function in order to estimate the background in the SR via interpolation from the sideband region. A transfer function derived from simulation is used to correct the data-driven estimation of the background in the SR.

Additionally, the n-subjettiness $\tau_{21} \equiv \tau_2/\tau_1$ is used to define high purity (HP) and low purity (LP) categories by requiring $\tau_{21} < 0.45$ in HP events, and $0.45 < \tau_{21} < 0.75$ in LP events. Distributions of the jet mass and the invariant mass are shown in Fig. 1 for both the LP and HP categories in the muon channel. The data points are compared with a parametric model made out of two components; the dominant component accounts for the Z+jets background, and the subdominant component corresponds to diboson VV and $t\bar{t}$ production.

Table 3: Summary of the analysis selection.

Selection	**Value**	**Comments**
High Level Trigger		
Electron channel	Single electron, $E_T > 105$ GeV	
Muon channel	Single muon, $p_T > 45$ GeV, $\lvert\eta\rvert < 2.1$	
Electrons		
Electron identification	Loose working point	CMS EGamma POG [8]
Isolation	Particle-flow [9]	
Acceptance	$p_T > 115$ GeV, $\lvert\eta\rvert < 2.5$	leading electron
	$p_T > 20$ GeV, $\lvert\eta\rvert < 2.5$	second electron
Muons		
Muon identification	Tracker High p_T or High p_T	CMS Muon POG [10]
Isolation	Tracker-based isolation	
Acceptance	$p_T > 50$ GeV, $\lvert\eta\rvert < 2.1$	leading muon
	$p_T > 20$ GeV, $\lvert\eta\rvert < 2.4$	second muon
Dilepton selection		
Leptonic Z	$p_T > 170$ GeV	
	$70 < M_{\ell\ell} < 110$ GeV	
AK8 Jets		
Jet identification	PFJetID Loose	CMS JME POG [11]
Acceptance	$p_T > 170$ GeV, $\lvert\eta\rvert < 2.4$	
Pruned jet mass (signal)	$65 < m_{jet}^{pruned} < 105$ GeV	
Pruned jet mass (low-mass sideband)	$20 < m_{jet}^{pruned} < 65$ GeV	
Pruned jet mass (high-mass sideband)	$135 < m_{jet}^{pruned} < 220$ GeV	
Diboson candidate		
VZ candidate mass	$M_{\mathrm{VZ}} > 600$ GeV	

Upper limits on the cross section $\sigma(\mathrm{G_{bulk}} \to ZZ)$ as function of the resonance mass are shown in Fig. 2. The results obtained are compatible with the standard model prediction in the explored mass range. Given the low statistics in data and the low cross section of the bulk graviton model, the analysis with 2015 data did not reach the sensitivity required to establish exclusion limits on the theoretical cross section (red line in Fig. 2).

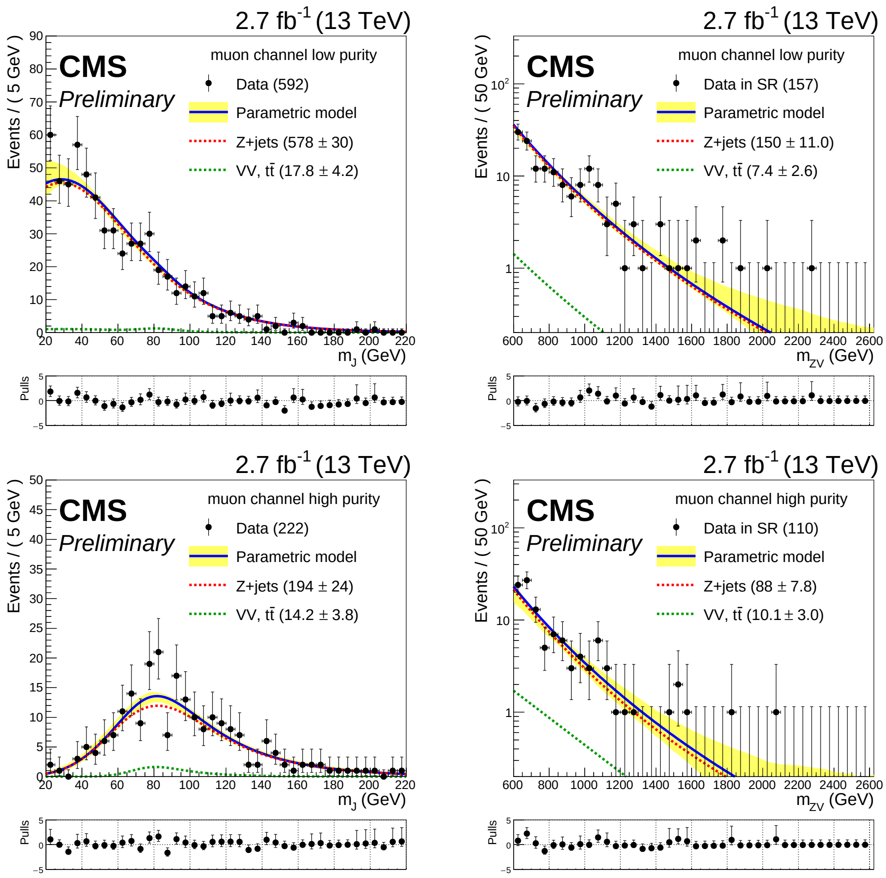

Figure 1: Jet mass (left) and invariant mass m_{ZV} (right) distributions for the low purity (top) and high purity (bottom) categories, in the muon channel.

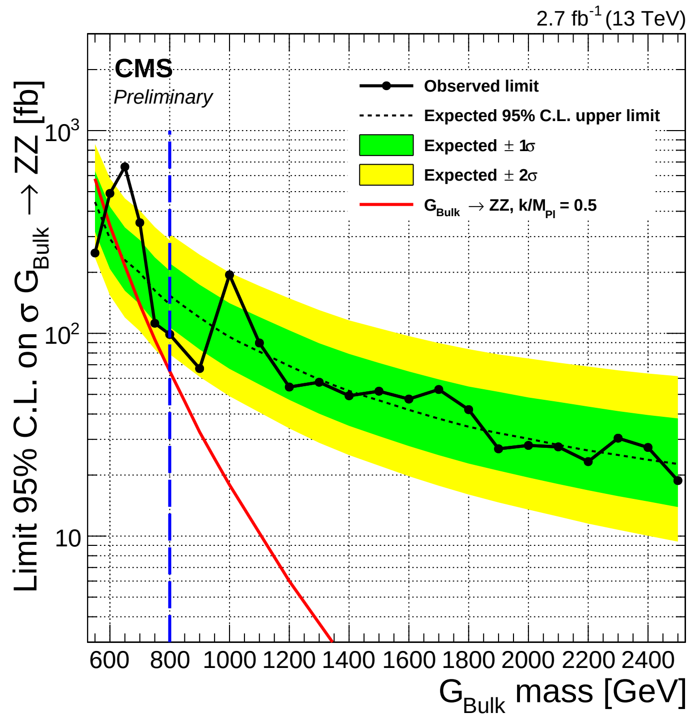

Figure 2: Observed and expected limits at 95% confidence level (C.L.) on the cross section $\sigma(\mathrm{G_{bulk}} \rightarrow ZZ)$. The 68% and 95% ranges of expectation for the background-only model are shown with green and yellow bands, respectively. The blue line sets the boundary at 800 GeV that separates the low mass and high mass searches.

2.3 Analysis with 2016 data

Due to the excellent performance of the LHC in 2016 compared to 2015, delivering ten times more luminosity, we tried to concentrate our efforts in the analysis of 2016 data. Figure 3 shows the distribution of the jet mass in simulation and data, for the muon channel high purity category, using an integrated luminosity equivalent to 12.9 fb^{-1}.

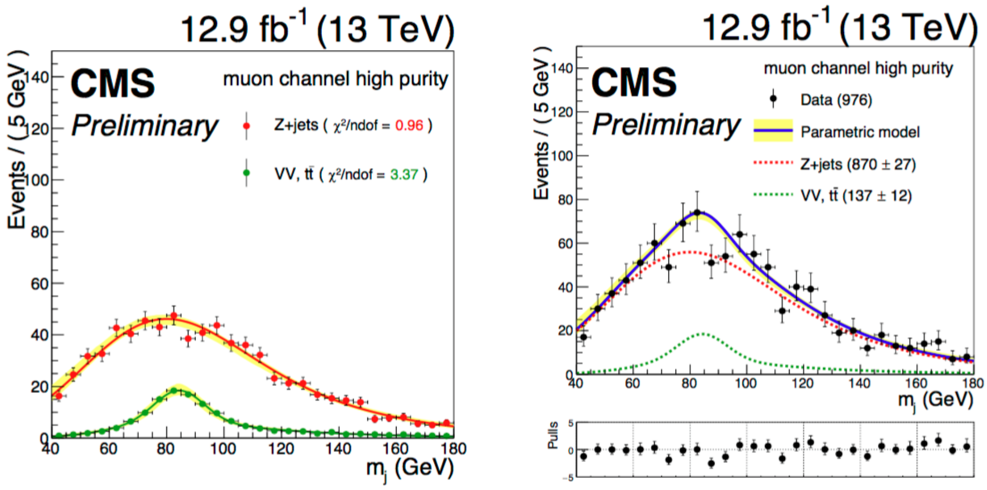

Figure 3: Jet mass distribution in simulation (left), and in the data (right), for the muon channel high purity.

The new operation conditions of the experiment require several updates in our analysis framework and these efforts did not converge in time; as such, we will restrict our Ph.D. thesis to document the results obtained with 2015 data only.

3. Collaborative activities

In addition to the research activities, every collaborator in CMS is appointed to a service work in order to guarantee the good operation of the experiment. In the following sections we describe the specific duties that has been that have been performed in 2016.

3.1 Trigger validation for Susy and Exotica

The CMS trigger system is responsible for selecting in real-time those interesting events that should be recorded for offline analysis. Every release of the CMS software (CMSSW) is accompanied with a set of validation samples with the end of monitoring the performance of individual triggers.

The responsibilities of the trigger validator include:

- Make systematic comparisons between consecutive CMSSW releases.
- Maintain the validation packages for Susy and Exotica analysis groups.
- Report to the trigger studies group in charge of the strategy for trigger evolution and monitoring.

Figure 4 shows one of the monitor elements for trigger validation with the efficiency to select high energy electrons ($E_{\mathrm{T}} > 105$ GeV). In this particular example we observe discrepancies in the efficiency in the central region of η, which is an indication of either an expected change in the configuration of the trigger or an actual issue. The validations between consecutive releases of the CMSSW is important to spot as early as possible any problem that can affect the normal behaviour of the trigger. Since the CMSSW is continuously evolving, the validation has to be performed in a regular weekly basis.

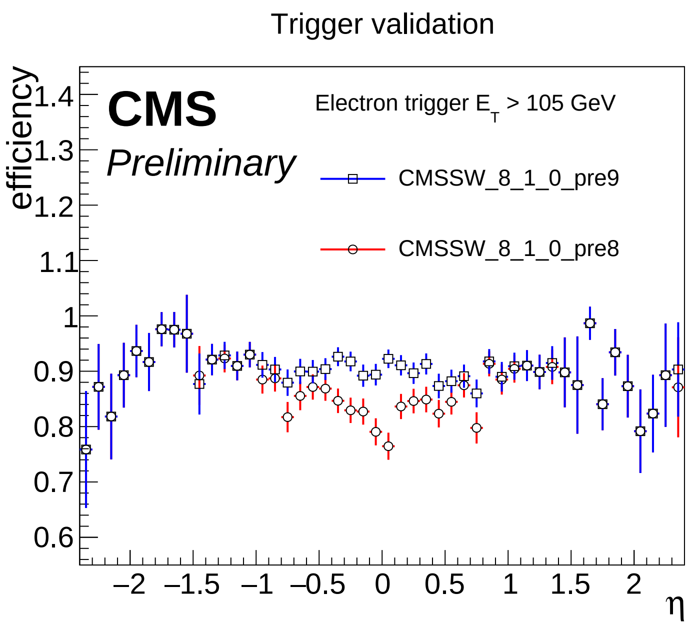

Figure 4: Efficiency of the high energy electron trigger $E_T > 105$ GeV as function of pseudorapidity η. The comparison of two consecutive pre-releases of the CMSSW is important to reveal either an expected change in the configuration of the trigger or the diagnostic of systematic problems.

Table 4: Trigger validation campaigns.

Release Name	Date
8_1_0_PRE4	May 15
8_1_0_PRE5	May 29
8_1_0_PRE6	Jun 15
8_0_10_HLT	Jun 16
8_1_0_PRE8	Jul 15
8_0_16	Aug 13
8_0_16_Tranch4GT	Aug 22
8_1_0_PRE10	Sep 1
8_0_19_Tranch4GT	Sep 13
8_1_0_PRE11	Sep 22
8_1_0_PRE12	Oct 11
8_1_0_PRE15	Nov 04
8_1_0_PRE16	Nov 22

4. Participation in events

International conferences

- Search for new resonances in the merged jet + dilepton final state in CMS,
  Poster presentation at 38th International Conference for High Energy Physics, ICHEP 2016, August 3–10 (2016), Chicago IL, United States.

National conferences

- Search for high mass resonances in the dilepton + jet final state,
  Oral presentation at Encontro Nacional de Física 2016,
  September 2–8 (2016), Natal RN, Brasil.

Weekly meetings

- Regular participation at SPRACE weekly meeting (Table 5).

Table 5: SPRACE weekly meeting.

Date	Link to agenda
29 Apr 2016	https://indico.cern.ch/event/525729/
06 May 2016	https://indico.cern.ch/event/525764/
13 May 2016	https://indico.cern.ch/event/525765/
20 May 2016	https://indico.cern.ch/event/525766/
27 May 2016	https://indico.cern.ch/event/525767/
03 Jun 2016	https://indico.cern.ch/event/539650/
09 Jun 2016	https://indico.cern.ch/event/539882/
16 Jun 2016	https://indico.cern.ch/event/539883/
23 Jun 2016	https://indico.cern.ch/event/539884/
30 Jun 2016	https://indico.cern.ch/event/539885/
07 Jul 2016	https://indico.cern.ch/event/539886/
14 Jul 2016	https://indico.cern.ch/event/539887/
21 Jul 2016	https://indico.cern.ch/event/539888/
28 Jul 2016	https://indico.cern.ch/event/560269/
18 Aug 2016	https://indico.cern.ch/event/539892/
25 Aug 2016	https://indico.cern.ch/event/565524/
01 Sep 2016	https://indico.cern.ch/event/567148/
15 Sep 2016	https://indico.cern.ch/event/569904/
22 Sep 2016	https://indico.cern.ch/event/571569/
29 Sep 2016	https://indico.cern.ch/event/573049/
06 Oct 2016	https://indico.cern.ch/event/575390/
13 Oct 2016	https://indico.cern.ch/event/577238/
20 Oct 2016	https://indico.cern.ch/event/579257/
27 Oct 2016	https://indico.cern.ch/event/580709/
03 Nov 2016	https://indico.cern.ch/event/586303/
10 Nov 2016	https://indico.cern.ch/event/587923/
17 Nov 2016	https://indico.cern.ch/event/589245/
24 Nov 2016	https://indico.cern.ch/event/580809/

5. Schedule and extension proposal

The execution of this project successfully achieved the objectives set four years ago. Concretely, we performed a full analysis using the data collected by CMS during 2015, we passed through the stringent approval process of the collaboration, and we presented the results in very prestigious conferences.

In 2016 the LHC delivered ten times more luminosity than in 2015, and we tried to continue the analysis of 2016 data. Unfortunately these efforts did not converge in time, and we will focus on finishing the Ph.D. thesis with 2015 data only. We will require an additional amount of time for the execution of the project; consequently, we ask for the following extension:

Original deadline	Requested extension
18 January, 2017	**18 July, 2017**

With the new schedule, the defence of the Ph.D. thesis is expected to occur on:

- Thesis defence: **17 July, 2017.**

São Paulo, 5 de Dezembro de 2016

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