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Tesi di Dottorato

Search for heavy resonances decaying into a Z boson and a vector boson in the $\nu\nu\ q\bar{q}$ final state at CMS

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"I have no special talent. I am only passionately curious."
(A. Einstein)

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¹ **Abstract**

Chapter 1

Introduction

This analysis searches for signal of heavy resonances decaying into a pair of heavy vector bosons. One Z boson is identified through its invisible decay ($\nu\nu$), while the other is required to decay hadronically into a pair of quarks. The final states probed by this analysis therefore consists in two quarks and two neutrinos, reconstructed as missing transverse energy (met). The hadronically decaying boson (Z, W) is reconstructed as a fat jet, whose mass is used to define the signal region. Two purity categories are exploited, based on the n-subjettiness of the fat jet.

The search is performed by examining the distribution of the diboson reconstructed transverse mass of the resonance VZ (m_{TVZ}) for a localized excess. The shape and normalization of the main background of the analysis (V +jets) are estimated with an hybrid approach using the distribution of data in the sidebands, corrected for a function accounting for potential differences between the signal region and the sidebands, while the minor background sources are taken from simulations. [?]

Chapter 2

Theoretical motivation

The Standard Model (SM) of particles represents, so far, the best available description of the particles and their interactions. It is the summation of two gauge theories: the electroweak interaction, that pictures together the weak and electromagnetic interactions, and the strong interaction, or Quantum Chromodynamics (QCD). Particles, namely quarks and leptons, are described by spin 1/2 fermions, whilst interactions are embodied by spin 1 bosons. The symmetry group of the standard model is:

$$SU_C(3) \times SU_L(2) \times U_Y(1), \quad (2.1)$$

where the first factor is related to strong interactions, whose mediators are eight gluons, whilst $SU_L(2) \times U_Y(1)$ is the electroweak symmetry group, whose mediators are photons and Z - W^\pm bosons.

In renormalizable theories, with no anomalies, all gauge bosons are expected to be massless, in contrast with our experimental knowledge (cite W-Z discovery). This kind of dilemma can be solved by introducing a new scalar particle, the Higgs boson (cite Higgs article), that can give mass to weak bosons and fermions via the spontaneous symmetry breaking mechanism.

In the last decades, Standard Model has been accurately probed by many experimental facilities (LEP, Tevatron), demonstrating an impressive agreement between theoretical predictions and experimental results. The discovery of the Higgs boson at the Large Hadron Collider, measured by both CMS and ATLAS collaborations (cite discovery), represents not only an extraordinary confirmation of the model, but also the latest biggest achievement in particle physics as a whole.

2.1 Beyond Standard Model theories

Even though the Standard Model is the most complete picture of the universe of the particles, many questions are still left open by the model. From a phenomenological point of view, some experimental observations are not included in the theory:

- in SM, neutrinos are massless (whilst experimentally it has been confirmed to be non-zero, i.e. by the neutrino oscillation);
- no candidate for the dark matter is foreseen (whilst it has been observed in cosmology);
- no fields included in the SM can explain the cosmological inflation;
- SM can not justify the matter-antimatter asymmetry.

From a purely theoretical perspective, some issues are still relevant in the formulation of the model:

44 • *Flavour problem.*

45 The Standard Model has 18 free parameters: 9 fermionic masses; 3 angular parameters in
46 Cabibbo-Kobayashi-Maskawa matrix, plus 1 phase parameter; electromagnetic coupling α ;
47 strong coupling α_{strong} ; weak coupling α_{weak} ; Z mass; the mass of the Higgs boson. Such a
48 huge number of degrees of freedom is considered as weakly predictive.

49 • *Unification.*

50 There is not a “complete” unification of strong, weak and electromagnetic interactions, since
51 each one has its own coupling constant, behaving differently at different energy scales; not
52 to mention the fact that gravitational interaction, completely excluded from the SM.

53 • *Hierarchy problem.*

54 From Quantum Field Theory, it is known that perturbative corrections to the mass of the
55 scalar bosons included in the theory tend to make it increase towards the energy scale at
56 which the considered theory is valid [cite n. 4 of master thesis]. If the Standard Model is
57 seen as a low-mass approximation of a more general theory valid up to the Planck mass
58 scale (i.e., $\approx 10^{19}$ GeV), a fine-tuning cancellation of the order of 1 over 10^{34} is needed in
59 order to protect the Higgs mass at the electroweak scale (≈ 100 GeV). Such an astonishing
60 correction is perceived as very unnatural.

61 Numerous Beyond Standard Model theories (BSM) have been proposed in order to overcome
62 the limits of the Standard Model.

63 **2.1.1 Warped extra dimension**

64 **2.1.2 Heavy Vector Triplet**

⁶⁵ Chapter 3

⁶⁶ Data and Monte Carlo samples

⁶⁷ Chapter 4

⁶⁸ Physics objects

⁶⁹ Chapter 5

⁷⁰ Diboson candidate reconstruction

⁷¹ Chapter 6

⁷² Background estimation

⁷³ Chapter 7

⁷⁴ Systematic uncertainties

⁷⁵ Chapter 8

⁷⁶ Results

⁷⁷ **Chapter 9**

⁷⁸ **Conclusions**