Università degli studi di Padova
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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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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-subjettines of the fat jet.

The search is performed by examining the distribution of the diboson reconstructed transverse mass of the resonance VZ (mtVZ) 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 strog 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 simmetry group of the standard model is:

$$SU_C(3) \times SU_L(2) \times U_Y(1), \tag{2.1}$$

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 simmetry 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 CERN Large Hadron Collider, measured by both CMS and ATLAS collaborations [1]- [2]- [3]- [4]- [5]- [6]- [7], 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:

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

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

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

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

Grand Unified Theories (GUT) aim at extending the symmetry group of the SM (eq. 2) into largest candidates, such as $S0(10)$, $SU(5)$ and $E(6)$. At GUT scale, approximately at 10^{16} GeV, non-gravitational interactions are expected to be ruled by only one coupling constant, α_{GUT}.

Super Symmetryc (SUSY) models state that every fermion (boson) of the Standard Model has a bosonic (fermionic) superpartner, with exactly the same quantum numbers, except the spin. If SUSY is not broken, each couple of partners and superpartners should have the same masses, hypotesis easily excluded by the non-observation of the s-electron. Super Symmetry represents a very elegant solution of the hierarchy problem of the Higgs boson mass, since the perturbative corrections brought by new SUSY particles exactly cancel out the divergences caused by SM particles corrections. A particular sub-class of SUSY models, Minimal Super Symmetric Standard Models, is characterized by the introduction of a new symmetry, the R-parity, that guarantees the proton stability and also the stability of the lightest SUSY particle, a possible good candidate for dark matter.

Two other possible theoretical pictures are extensively described in sec. 2.1.1-2.1.2.

2.1.1 Heavy Vector Triplet

2.1.2 Warped extra dimension

Chapter 3

Data and Monte Carlo samples

Chapter 4

Physics objects

Chapter 5

Diboson candidate reconstruction

Chapter 6

Background estimation

Chapter 7

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Chapter 8

Results

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