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# Search for new physics in dilepton final states at the CMS experiment

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# 摘要

该论文介绍了利用双电子末态寻找新的重共振态和在顶夸克产生过程寻找新物理的研究。论文的第一章介绍了粒子物理中的标准模型。紧接着在第二章介绍了一些与研究相关的超标准模型。在第三章介绍了欧洲大型强子对撞机（LHC）和紧凑缪子线圈探测器（CMS）。在随后的一章介绍了 CMS 中粒子的重建技术和过程。最后给出这两个研究的具体介绍。

第一个研究是在双电子末态寻找重的共振态。这个新的共振态是许多超标准模型所预言的，例如大统一理论（GUT）和额外维理论。如果存在这种共振态，那么我们将会在双电子不变质量谱中观察到一个新的质量峰。该研究利用了 CMS 在 2016 年采集到的 35.9 $\text{fb}^{-1}$ 和在 2017 年采集到的 41.4 $\text{fb}^{-1}$ 的数据。采用了优化的事例选择条件以增加其对信号事例选择效率。该分析的主要本底来自 Drell-Yan 过程，该过程利用蒙特卡洛样本（MC）来模拟。对于次要的顶夸克对和类顶夸克对过程，该分析也采用 MC 来模拟，同时利用数据来对 MC 进行检查。对于喷注（jet）误判为电子的本底，该分析利用 data-driven 的方法来估计该本底的贡献。在观察研究了最终的双电子不变质量谱后发现数据的分布与标准模型的预期相符合，并没有看到新物理存在的迹象。因此，在研究的最后给出了相关的新共振态产生截面乘以衰变分支比的上限和对应的新共振态的质量下限。

第二个研究是利用双电子和双缪子末态在顶夸克产生过程中寻找新物理。由于顶夸克是基本粒子中最重的粒子，其与 Higgs 粒子和 W 玻色子有很强的耦合。因此，顶夸克在许多新物理模型中占有重要地位。该研究利用了 CMS 在 2016 年采集到的 35.9 $\text{fb}^{-1}$ 的数据。所研究的过程包括顶夸克对（$\mathrm{t\bar{t}}$ ）产生过程和单个顶夸克伴随一个 W 玻色子产生过程（tW）。同时，由于 $\mathrm{t\bar{t}}$ 和 tW 过程很接近，该研究利用了多变量分析的方法去区分 $\mathrm{t\bar{t}}$ 和 tW 过程。由于最终的数据分布和标准模型预期的分布一致，因此并没有发现新物理。最终该研究利用有效场理论给出了对可能存在的新耦合的强度的限制。



**关键词:** 新物理，双电子，双缪子，重共振态，顶夸克，CMS实验，有效场理论，多变量分析

# Résumé

Cette thèse décrit la recherche de nouvelles résonances massives qui se désintègrent en une paires d' électrons et la recherche de nouvelle physique dans le secteur des quarks top. Le modèle standard des particules élémentaires est présentédans le premier chapitre. Ensuite, nous décrivons une sélection de théories au-delàdu modèle standard prédisant l'existence de nouvelles résonances massives, ainsi qu'une introduction àla théorie effective des champs utilisée pour la recherche de nouvelles physiques dans le secteur des quark top. Après cela, le collisionneur LHC (Large Hadron Collider) et le détecteur CMS (Compact Muon Solenoid) sont introduits, et les techniques utilisées afin de reconstruire les particules produit dans les collisions sont discutées ensuite. Finalement, deux analyses séparées sont présentées.

La première est la recherche de nouvelles résonances massives dans l'état final diélectron. Certaines théories au-delàdu modèle standard prédisent l'existence de nouvelles résonances massives pouvant se désintégrer en paires d' électrons, telles que les théories de grande unification et les théories qui introduisent des dimensions spatiales supplémentaires. L'observation d'un excès local d' événements dans le spectre de masse invariante diélectron serait la preuve de l'existence d'une nouvelle résonance massive. Les données utilisées proviennent de l'expérience CMS, et correspondent à35.9 $\mathrm{fb}^{-1}$ collectés en 2016 et 41.4 $\mathrm{fb}^{-1}$ en 2017. La sélection d'événements est optimisée pour les électrons de haute énergie et pour éviter de perdre des événements de signal potentiels. Le processus principal est le processus Drell-Yan et il est estiméàpartir de simulations. Les processus $\mathrm{t\bar{t}}$ et $\mathrm{t\bar{t}}$-like sont aussi important, et sont également estimés àpartir de simulations. La simulation de ce bruit de fond est validée par une méthode d' analyse de données. Le dernier bruit de fond, àsavoir les processus de chromodynamique quantique, est déterminéàpartir des données. Après inspection du spectre de masse invariante diélectron, aucun excès significatif par rapport au bruit de fond du modèle standard n'est observé, et une limite supérieure à95% de niveau de confiance est posée sur le rapport entre d' une part le produit de la section efficace de production d'une nouvelle résonance par son rapport de branchement en diélectron, et d' autre part ce même produit mesuréau pic du boson Z.

La deuxième analyse est la recherche de nouvelle physique dans le secteur des quarks top avec les états finaux diélectron et dimuon en utilisant les données collectées par l'expérience CMS en 2016 avec 35.9 $\mathrm{fb}^{-1}$. En raison de sa masse élevée et de sa masse proche de l' énergie de brisure de la symétrie électrofaible, le quark top devrait jouer un r?le important dans plusieurs scénarios de nouvelle physique. Nous recherchons cette nouvelle physique dans la production de paires de quarks top et dans la production d' un seul quark top associéàun boson, et une analyse multivariée est utilisée pour séparer ces deux processus. Aucun écart significatif par rapport aux prédictions du modèle standard n'est observé. Les résultats sont interprétés dans le cadre d'une théorie effective des champs et les contraintes sur les couplages effectifs correspondants sont définies àun niveau de confiance de 95%.



**Mots clés:** nouvelle physique, diélectron, dimuon, résonances massives, quark top, Expérience CMS, théorie effective des champs, analyse multivariée.

## Abstract

This thesis describes searches for new heavy resonances that decay into dielectron final state and searches for new physics in the top quark sector. The standard model of elementary particle is introduced in the first chapter. After that, a selection of theories beyond the standard model that predict the existence of new massive resonances are described together with an introduction to the effective field theory that is used to search for new physics in top quark sector. Then, the Large Hadron Collider (LHC) and the Compact Muon Solenoid (CMS) detector are introduced, and the techniques used in order to reconstruct the particles produced in the collisions are discussed afterwards. Finally, two separate analyses are presented.

The first one is searching for new heavy resonances using dielectron final state. As some beyond Standard Model theories predict the existence of new heavy resonances that can decay into dielectron pair, such as the grand unified theories and theories that introduce extra space-like dimensions. An observation of a local "bump" in the dielectron invariant mass spectrum will be an evidence for the existence of a new heavy resonance. The data used is from CMS experiment collected in 2016 with 35.9 $\mathrm{fb}^{-1}$ and in 2017 with 41.4 $\mathrm{fb}^{-1}$. The event selection is optimized in order to be highly efficiency for high energy electron and avoid loosing potential signal events. The leading background is the Drell-Yan process and it is estimated from simulation. The sub-leading background is from $\mathrm{t\bar{t}}$ and $\mathrm{t\bar{t}}$-like processes and it is estimated from simulation also. A data-driven method is used to validate the simulation of sub-leading background. The last background from quantum chromodynamics processes is determined by data-driven approach. After having inspected the final dielectron invariant mass spectrum, no significant excess over the standard model background is observed, and upper limit at 95% confidence level is set on the ratio of production cross-section times branching ratio of a new resonance to the one at the Z boson peak.

The second analysis is the search for new physics in the top quark sector with dielectron and dimuon final states using data collected by the CMS experiment in 2016 with 35.9 $\mathrm{fb}^{-1}$. Because of its high mass and close to electroweak symmetry breaking scale, the top quark is expected to play an important role in several new physics scenarios. The new physics in top quark pair production and in single top quark production in association with a W boson are investigated and a dedicated multivariate analysis is used to separate these two processes. No significant deviation from the standard model expectation is observed. Results are interpreted in the framework of an effective field theory and constraints on the relevant effective couplings are set at 95% confidence level.

**Key works:** new physics, dielectron, dimuon, heavy resonances, top quark, CMS experiment, effective field theory, multivariate analysis.

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