Search in the Two-Photon Final State for Evidence of New Particle Production at the Large Hadron Collider

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November 23, 2011

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Introduction

Chapter 2

Overview of the Standard Model of Particle Physics

I call it...the Aristocrats.

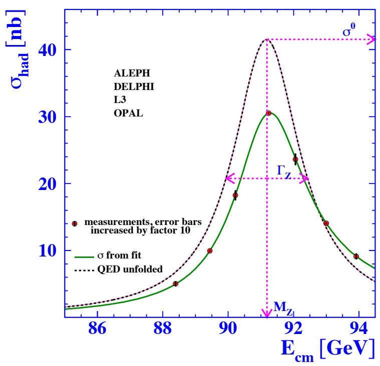
In the 1960s, Sheldon Glashow, Steven Weinberg, and Abdus Salam proposed a mathematical framework that unified the electromagnetic and weak forces at an energy scale in the hundreds of GeV/c, as well as a mechanism for breaking the electroweak symmetry at low energies [1]. At the same time, Murray Gell-Mann introduced the concept of quarks to describe hadron spectroscopy, a concept that would later grow into quantum chromodynamics (QCD), the full theory of the strong force [2]. These two key developments motivated the unified representation of particle physics as a set of fields whose dynamics are invariant under the Standard Model gauge group

$$SU(3)_C \bigotimes SU(2)_L \bigotimes U(1)_{EM} \tag{2.1}$$

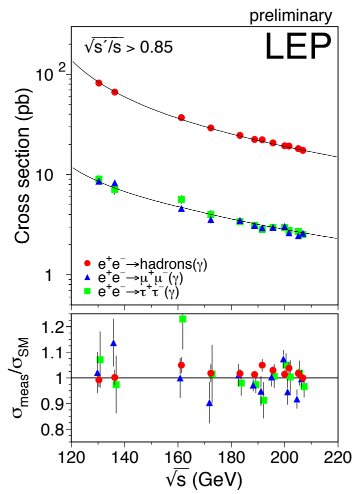
where $SU(3)_C$ describes the quark QCD interactions, $SU(2)_L$ describes the weak interactions among quarks and leptons, and $U(1)_{EM}$ describes the electromagnetic interaction.

The Standard Model, in particular the electroweak theory, has been an extremely successful predictor of particle production and interaction cross-sections and decay rates, as well as of the exact masses of the electroweak force carriers. The case for the validity of the Standard Model was bolstered by the many precision QCD and electroweak measurements carried out at the Large Electron-Positron (LEP) collider, which ran from 1989-2000 at center-of-mass energies between 65 and 104 GeV/c [3]. Figure 1 shows some of the highlights of the LEP program.

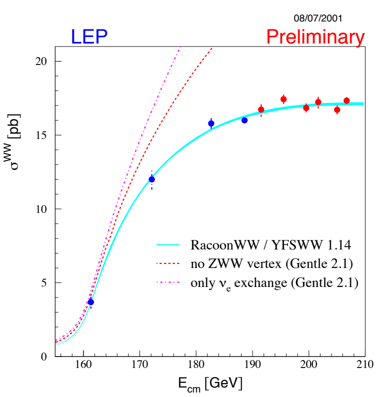
However, there are still deep theoretical problems with the Standard Model, stemming from the introduction of the Higgs scalar into the theory to break electroweak symmetry [4]. Since the Higgs self-energy diagram is quadratically sensitive to the ultraviolet cutoff scale(footnote: this is a general property of scalar fields), and assuming that there are no new important energy scales of physics between the weak scale ($\mathcal{O}(10^2\ GeV/c)$) and the Planck scale ($\mathcal{O}(10^{19}\ GeV/c)$), in order to be consistent with experimental measurements, this diagram must include a remarkable 17-orders-



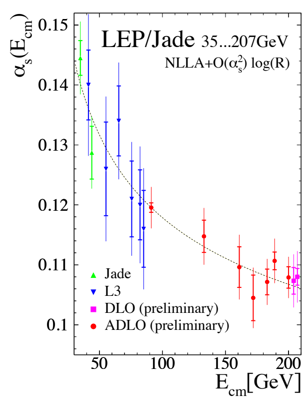
(a) Total hadronic cross-section as a function of collider center-of-mass energy.



(b) Measured and predicted dependence of the $q\bar{q}$, $\mu^+\mu^-$, and $\tau^+\tau^-$ pair production cross sections on LEP center-of-mass energy.



(c) Measured and predicted dependence of the W^+W^- pair production cross section on LEP center-of-mass energy.



(d) Measured and predicted dependence of the strong coupling constant α_s on LEP center-of-mass energy.

Figure 2.1: Selected LEP measurements demonstrating its contribution to the precise understanding of the Standard Model. Reprinted from [3].

of-magnitude cancellation that is otherwise poorly motivated [5]. The quest to find new physics at an intermediate energy scale between the weak and Planck scales, and thus extend the Standard Model, was the driving force behind the construction of the Large Hadron Collider (LHC) in 2009, the world's highest energy particle accelerator to date.

In this chapter I will briefly describe the Standard Model particle content, the theory and major results of electroweak symmetry breaking (EWSB), and the problems that the Standard Model is as yet ill-prepared to address.

2.1 Particle Content

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The search for evidence of supersymmetry at colliders began in earnest in the 1980s ([**?**]) and continues to this day. Most recently, the LHC and Tevatron[1] experiments have set the strictest limits on a variety of SUSY breaking scenarios, including GMSB, mSUGRA, and R-parity violation (RPV).

Figure X shows the current limits set by the CMS experiment on the mSUGRA model (with $tan\beta = 10$) in the m_0-$m_{\frac{1}{2}}$ plane.

[1]Located on the Fermilab site in Batavia, Illinois, the Tevatron was a proton-antiproton collider operating at 1.96 TeV center-of-mass energy. The Tevatron ran from 1987 to 2011 [6].

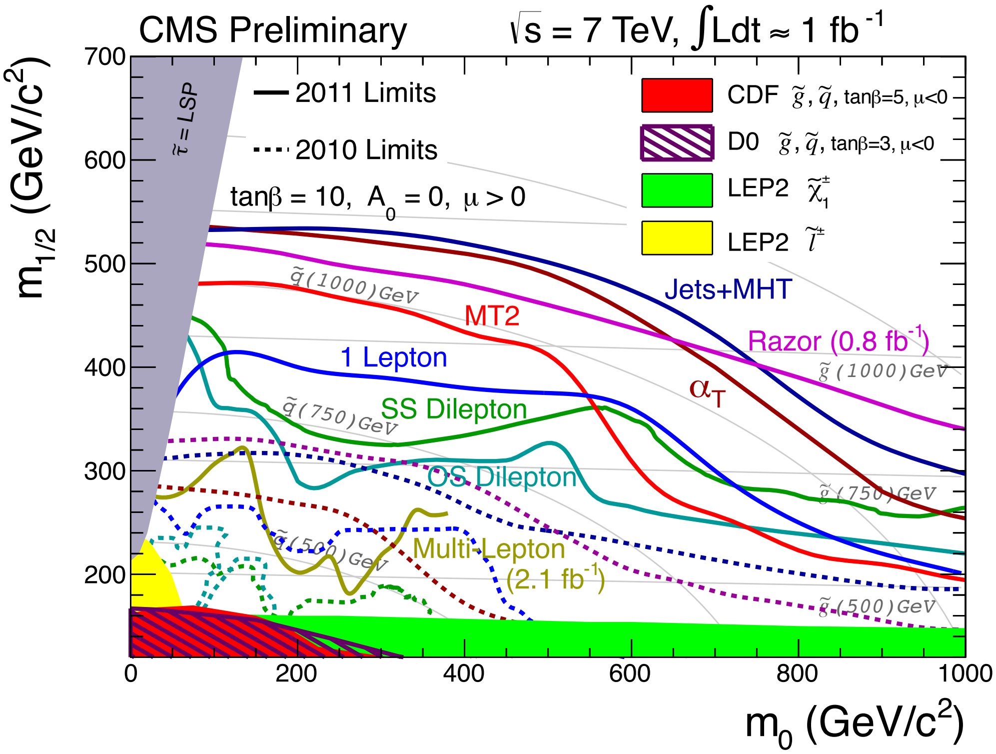

Figure 3.1: CMS limits on mSUGRA with $tan\beta = 10$. The limits set by individual searches are shown as separate colored lines. Solid lines refer to 2011 searches (i.e. using an integrated luminosity of 1 fb^{-1}), while dashed lines refer to 2010 searches (36 pb^{-1}).

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