Research Proposal

The research project introduced here describes steps to a systematic and model-independent analysis of the Tevatron data.

Introduction and Motivation

The so-called standard model of elementary particle physics describes the characteristics of quarks and leptons and their strong and electroweak interaction. There are six quarks in nature, the up, down, strange, charm, bottom and top quark and six leptons, the electron, muon, tau and the corresponding neutrinos. They are arranged in three pairs ("generations"), which differ only by their masses, as shown in Table 1. The up quark, down quark, and electron make up the matter with which we are familiar.

$$\text{quarks:} \quad \begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix}$$

$$\text{leptons:} \quad \begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

Table 1: The six quarks and leptons, combined in three generations.

The standard model contains at present 26 free parameters: 6 lepton masses, 6 quark masses, 4 to describe how the leptons mix, 4 to describe how the quarks mix, 3 couplings the strength of the strong, weak and electromagnetic interactions, the masses of the W and Higgs boson, and a strong CP violating phase θ.

So far the standard model of elementary particle physics extraordinarily successfully describes the characteristics of the quarks and leptons measured at accelerator experiments, and their strong and electroweak interaction. However, the expansion of the standard model to energies larger than about 1 TeV is an unresolved problem. A large number of new phenomena are expected to appear in this energy region. Possibilities include: supersymmetry, compositeness, technicolor, magnetic monopoles, additional space dimensions, exited quarks and fermions, heavy gauge bosons, or additional fermion generations.

The primary goal of the experiments at the Tevatron and the LHC is therefore to test the standard model up to its limits and to search for new phenomena. The large number of possible theories, each of which possesses a number of adjustable parameters, have very different phenomenological consequences. The lack of clarity is nicely captured in a slide shown during the summary talk of the Lepton Photon 2003 conference, reproduced in Figure 1.

Figure 1: The theoretical landscape, as depicted in the summary talk of the Lepton Photon conference in 2003 [1].

As an example, a minimum supersymmetrical extension of the standard model has 105 additional free parameters. Generally these are reduced by *ad hoc* choices to two parameters. Searches in data are typically performed by scanning this two-dimensional parameter space.

In contrast to this, the research project suggested here is not led by individual models, but starts with a complete and coherent analysis of the data at largest energies.

In a similar manner a search for the Higgs boson was performed [2] using data from OPAL, one out of four experiments at the LEP collider at CERN. The analysis does not specify the decay mode of the boson and therefore is independent of the model in which the Higgs boson is produced.

Experiments at the Tevatron

The accelerator complex at FERMILAB was upgraded starting 1996 after a successful running period from 1992-1996 ("Run I"). The work included an increase of the center-of-mass energy from 1.8 TeV to now 1.96 TeV. Improvements on the existing proton linear accelerator, booster, and on the antiproton accumulator and the construction of the Main Injector and Antiproton Recycler permit a possible increase of the instantaneous luminosity by a factor of 8 in comparison to Run-I. The second phase ("Run-II") started in March 2001. In February 2004 a data set of approximately 260 pb^{-1} per experiment, double the data collected in Run I, was available for data analysis. The goal for 2004 is to receive an additional data set of $310-380$ pb^{-1}. By the end of 2005, 1000 pb^{-1} should be collected by each experiment. In addition, upgrades to the CDF [3] and the DØ detectors [4], have led to improved detection and imaging of proton-antiproton collisions. All these improvements result in a larger sensitivity for new, undiscovered physics.

Until the start of the LHC at CERN, the FERMILAB Tevatron presents on of the our best hopes for discovering new physics.

Research Project

The research project presented focuses on a systematic and model-independent investigation of the data collected at high-energy accelerator experiments. The goals of the project are to search for and to discover new phenomena in the Tevatron data and to establish the new analysis strategy.

The primary analysis of high-energy data contains the following steps:

- Define the physical objects and identify electrons, muons, taus, photons, jets, jets from a bottom quark, and missing transverse energy.
- Select all events with high transverse momentum.
- Determine all background contributions expected by the standard model. This involves the computation of millions of Feynman diagrams.
- Simulate the detector response. Simulating a sufficiently large number of events in a reasonable amount of time is critical for the success of the analysis and is discussed in more detail in the following.
- Introduce experimental fudge factors, which account for inadequacies in the detector simulation.
- Introduce theoretical fudge factors.

The project to analyze the data, as discussed here, requires a large number of simulated events. The existing simulation programs are very CPU-time intensive. Faster simulations based on parameterization need careful fine tuning, which is work intensive by itself. For each improved simulation or reconstruction, complex optimizations of the fast simulation have to be performed. An alternative approach uses so-called “lookup tables”. Those reflect the relationship between one or more partons and the reconstructed objects. The method is independent of the respective experiment and optimizes itself with existing detector simulation and reconstruction programs.

The prediction of the standard model is compared globally with the measured data after these steps. The events are classified into exclusive categories, characterized by the kind of the objects they contain. In each exclusive final state the number of observed events is compared with standard model expectation, and all relevant kinematic distributions are compared using a simple Kolmogorov Smirnov test. The scientific result is a catalog of all gross deviations between high-energy data and the standard model prediction.

Side effects of this investigation include the following:

- Improvements in the object identification.
- The introduction of a fast and easy maintainable detector simulation.
- A comprehensive analysis of all standard model background contributions.
- The examination of the detector simulation by the comparison with data.
- The examination of the data by the comparison with the standard models prediction.
- A systematic determination of experimental and theoretical fudge factors. The simultaneous adjustment of the fudge factors produces a complete error matrix, which permits a consistent and global treatment of systematic uncertainties.

If the rough characteristics of the data should point to deviations from the standard model prediction that cannot be explained by experimental inadequacies, then the results must be published immediately. If all characteristics of the data are in agreement, the attention should be directed toward regions in the data in which theoretical prejustice suggests new physics.

Since a small signal is expected, caution is required in the search for interesting effects. The algorithm must be carefully defined before the data is analyzed to exclude possible bias. The algorithm to search for new physics to be used in high-energy data recorded by the CDF collaboration is based on the following well justified assumption:

- The data can be divided into exclusive categories regions, such that a new signal will fall predominantly in a single category.

- New physics will have objects at large transverse momentum.
- New physics will appear as an excess of events. A deficit of events is generally very difficult to produce without creating a signal at another place.

The algorithm contains three steps, following the three assumptions:

- The data are divided into exclusive categories.
- In all of these exclusive final state one variable is defined. This is $\sum p_T$, the sum of the transverse momentum of all objects in event. The missing energy in the event is considered in this sum, if it can be ranked among the objects, which define the final state.
- In each final state, regions are defined, which consist of half-open intervals, whose lower limit is a data point in the distribution of $\sum p_T$. The interestingness p_N of a region that the background fluctuates up to the observed number of events N in this region is given by the Poisson probability.

The most interesting region R with N data points, is this one where p_N is minimal. The fraction P of hypothetically similar experiments, in which a region is more interesting than R in an examined final state is determined with pseudo experiments . Additionally, the fraction $\tilde{P}$ for all final states can be determined. The circumstance that many different regions are examined is explicitly taken into account, because not p_N but $\tilde{P}$ is considered, in order to compute the significance for deviation from the standard model.

Summary

The search for physics beyond the standard model is one of the driving forces in elementary particle physics. Giving the variety of possible forms physics beyond the standard model may take, the question of how to search for something we know only vaguely becomes important.

The research project presented here dedicates itself to this search in the data collected with the CDF detector at FERMILAB. Based on an alternative approach, the algorithm searches for new physics model-independent and in a rigorous and systematic way.

If the Tevatron data should not save surprises, then the employment of the method at the Tevatron will establish the new method within the particle physicists community and the method will find broad application at the LHC experiments at CERN.

Curriculum Vitae

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07/13/1975	Born in Düsseldorf, Germany.
1981 - 1985	Elementary school: Freiherr von Stein Grundschule in Bad Ems.
1985 - 1990	High school: Schiller-Schule in Bad Ems.
1990 - 1994	High school: Peter-Altmeier Gymnasium in Montabaur.
06/1994	Graduation from German High School: Abitur.
1994 - 2000	Study of physics and mathematics at the University of Bonn.
1999 - 2000	Diploma student at the University of Bonn (supervisor: Prof. Dr. N. Wermes). Title of thesis: "Decay Mode Independent Search for Higgs Bosons with the OPAL detector at LEP".
01/2000	Diploma degree in physics.
2000 - 2004	PhD student at the University of Bonn (supervisor: Prof. Dr. N. Wermes). Titel of thesis: "A Measurement of the $t\bar{t}$ Production Cross Section in Proton-Antiproton Collisions at $\sqrt{s} = 1.96$ TeV with the DØ Detector at the Tevatron using Final States with a Muon and Jets".
02/2000- 06/2001	Research at Centre Européen de Recherche Nucléaire (CERN) in Geneva, Switzerland.
06/2001- 08/2003	Research at Fermi National Accelerator Laboratory (FERMILAB) in Chicago, USA.
03/2004	PhD graduation in Physics.
02/2004	Postdoctoral Associate, Massachusetts Institute of Technology

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List of Publications

List of Published Papers

1. Search for the standard model Higgs boson using vector boson fusion at the LHC. Published in *Les Houches 2001, Physics at TeV colliders* 56-66
2. Decay mode independent searches for new scalar bosons with the OPAL detector at LEP, OPAL Collaboration (G. Abbiendi et al.), Eur.Phys.J.C27:311-329,2003

List of Internal and Conference Notes

1. FERMI-Conf-03/248-E, Update of the Measurement of the $t\bar{t}$ cross section at $\sqrt{s}$=1.96 TeV, July 2003
2. D0-note 4185, Measurement of the ttbar cross section in muon+jets events at $\sqrt{s}$=1.96 TeV, July 2003
3. D0-note 4178, Supplement to D0note 4116 on the measurement of the $t\bar{t}$ cross section at $\sqrt{s}$=1.96 TeV, May 2003
4. D0-note 4122, TopAnalyze - A Framework Analyze Package For Top Group Analyses, March 2003
5. FERMI-Conf-03/200-E, FERMILAB Moriond '03 Note, March 2003
6. D0-note 4116, Measurement of the $t\bar{t}$ cross section at $\sqrt{s}$=1.96 TeV, March 2003
7. D0-note 4041, Tool to determine L1 CEM(n,x) Trigger Efficiencies from data, October 2002
8. D0-note 4036, Certification Studies for the Level 3 Missing ET Tool, October 2002
9. D0-note 3949, Measurements of Level 1 Trigger Efficiencies from D0 Data, Mai 2002
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11. ATLAS-note, ATL-PHYS-2002-018, A study of the weak boson fusion, with H $\rightarrow \tau\tau$ and $\tau \rightarrow$ e(μ), March 2002

12. OPAL Physics Note 495, Decay mode independent searches for new scalar bosons with the OPAL detector at LEP, February 2002

13. OPAL Physics Note 449, Model Independent Searches for Scalar Bosons with the OPAL Detector at LEP, July 2000

List of Presentations

1. March 2003, Aachen, German Physical Society Meeting, "Measurement of the ttbar cross section in muon+jets events with the D0 detector"

2. February 2003, Lake Louise Winter Institute, Canada, "Recent D0 Results in Electroweak and Top Physics"

3. March 2002, Bonn, German Physical Society Meeting, "Commissioning of the D0 Silicon Mirco Vertex Detector SMT at the Tevatron"

4. March 2001, Bonn, German Physical Society Meeting, "Search for the Higgs Boson in Vector-Boson Production with the ATLAS-detector at LHC"

5. February 2001, Vanderbilt University, Nashville, "Prospects of Higgs Bosons at LHC"

6. March 2000, Bonn, German Physical Society Meeting, "Decay Mode Independent Search for Higgs Bosons with the OPAL-detector at LEP"

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[3] *CDF II Technical Design Report, FERMILAB-Pub-96 390-E (1996).*

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