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Review of experimental results in high-energy physics reported at recent conferences

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Contents

Abstract. **The current status of experimental high-energy physics is reviewed based on recent conference sources and taking into account the forthcoming LHC (Large Hadron Collider) experiments when selecting the material. The latest experimental data discussed relate closely to the ATLAS, CMS, and LHCb physics programs.**

1. Introduction

In the near future, the Large Hadron Collider (LHC) will become operational, and the physical community is waiting with anticipation for new results from the collaborations working at LHC. The enormity of this project and the importance of its goals make it possible to say that a new era in high-energy physics is about to begin. By tradition, this is just the time to sum up. However, the present article does not claim to be a comprehensive review of the present state of experimental high-energy physics. The main criterion in collecting the material for this report was the presence of links between the experimental results discussed at the latest conferences and the goals and possibilities of the ATLAS (A Toroidal LHC Apparatus), CMS (Compact Muon Solenoid), and LHCb (LHC beauty) collaborations. For instance, such important topics as neutrino physics, the physics of ion – ion collisions, experiments in the search for black matter, and the problem of recording ultrahigh-energy cosmic rays have been left out. Each of these actively developing areas of research merits a separate review.

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So what are the goals set forth by the ATLAS, CMS, and LHCb experiments? First and foremost, the goal is to discover new particles and phenomena that do not fit into the Standard Model (SM) or, as is customary to say today, the search for the New Physics. There are also weighty theoretical arguments in favor of the hypothesis that such phenomena exist, as well as the experimental clues to this. Deviations from the predictions of the Standard Model have been found in a number of highly accurate experiments and in the results of analysis of data with large statistics. All exact information about the deviations of the experimental results from the predictions of the Standard Model is extremely important, since if future LHC experiments reveal the presence of such deviations, they will help to interpret new phenomena falling outside the scope of the Standard Model. Experiments in which such deviations have been discovered are discussed in Section 6.

Another important goal is the discovery of the Higgs boson, the only particle predicted by the Standard Model that has not yet been detected. Modern experiments have already placed severe limits on the interval of possible magnitudes of the Higgs boson mass, thus competing with LHC. At present, the search for the Higgs boson is a very hot topic in experimental high-energy physics. And I will begin my review with discussing just this problem in the context of the present state of experimental high-energy physics.

2. The search for the Higgs boson at the Tevatron collider

In the Standard Model, the breaking of local $SU(2) \times U(1)$ gauge symmetry and the emergence of mass in W- and Z-bosons are explained by the presence of an additional field which was named the Higgs field in honor of Peter Higgs of Edinburgh University, who in 1964 proposed a mechanism for symmetry breaking [1]. What is interesting is that Higgs's original paper was rejected by the editorial board of the *Phys. Rev. Lett.* journal because it made no predictions that could be verified by experiments. Higgs then added a small paragraph at the end of the paper in which he suggested that there must be a new massive scalar boson lacking in the theory, a boson needed to complete the symmetry picture. This is how the idea of the Higgs boson emerged, and the search for this particle has gone on for about four decades.

In 2000, on the basis of the statistics gathered at the e^+e^- LEP-2 collider (Large Electron Positron collider), the following limit was placed on the mass of the Higgs boson: $M_H > 114.4$ [GeV/c^2] [2]. Today, the only operating accelerator in which the creation and annihilation of such a massive particle might be observed is the Tevatron. Hence, the search for the Higgs boson is a high-priority problem in the physics program of experiments at the Tevatron (the CDF and D0 collaborations). The inclusive cross section of production of a Higgs boson in proton – antiproton collisions, expected in the Standard Model, is extremely small: 1 pb. The main process in which a Higgs boson may be created is the three-particle reaction of the fusion of two gluons. Also important is the process of associative production of a Higgs boson in a pair with a W- or Z-boson, However, the probability of such a reaction is almost ten times smaller. The decay mode of the Higgs boson is primarily determined by its mass. For $M_H < 140$ [GeV/c^2], the dominating process is the decay into a pair of b- and anti-b-quarks, while the more massive bosons mainly decay into a pair of W^+- and W^--bosons. Here, the W-bosons do not necessarily lie on the mass surface, with the result that such a decay may occur for a Higgs boson mass below the threshold mass needed for the production of a pair of W-bosons.

It is practically impossible to detect a light Higgs boson decaying into a pair of b-quarks because of the huge background of the inclusive pair production of b-quarks. Hence, experimenters try to detect the light Higgs boson in a pair with a W- or Z-boson, initially assuming that relatively rare processes of associative production of a Higgs boson are involved. The signature of such events is the presence of an energetic lepton and a lacking transverse energy in the event (the $W \to l + \nu$ decay), as well as the presence of two hadronic jets that form as a result of fragmentation of b-quarks from the decay of the Higgs boson. In analyzing such events, the method of artificial neural networks is used to identify the events. The overall statistics processed by the CDF and D0 collaborations are insufficient for the detection of the light Higgs boson or for placing limits on its existence in the Standard Model. However, if one assumes that the Higgs boson is created three to five times more often than predicted by the Standard Model, the CDF and D0 experiments are capable of excluding such reactions at a 95% confidence level. Figure 1 depicts the ratio of the cross section, exceeding which makes the production of a Higgs boson impossible at a 95% confidence level, to the theoretical (SM) cross section as a function of the Higgs boson mass [3]. The dependence, which is a preliminary combined result of the CDF and D0 experiments, appeared as such in March 2008. As the statistics accumulate, the curve will gradually move down and the ranges of a Higgs boson mass, in which the curve is below the horizontal line at unity, will be ruled out.

In searching for the heavier Higgs bosons it is not really necessary that the Higgs boson be created in combination with a W-boson (or a Z-boson). Due to the decay of a heavy Higgs boson into W^+- and W^--bosons, it is enough to isolate events with two energetic leptons and the large lacking transverse energy. What is interesting is that because the W-bosons are polarized, the momenta of the final leptons

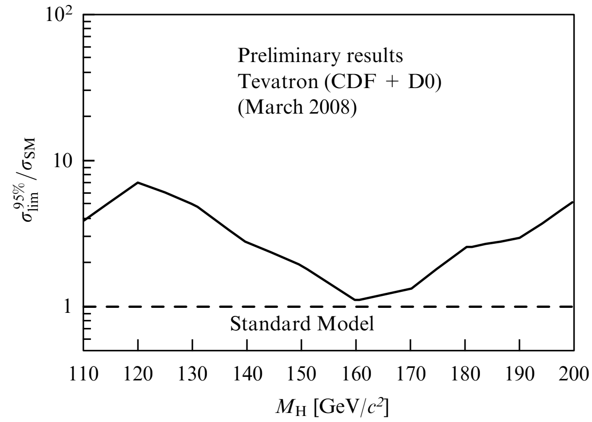

Figure 1. The ratio of the cross section $\sigma_{\mathrm{lim}}^{95\%}$, exceeding which makes the production of a Higgs boson impossible in SM at a 95% confidence level, to the theoretical cross section σ_{SM} predicted by the Standard Model as a function of the Higgs boson mass. The dependence, which is a preliminary combined result of the CDF and D0 experiments, appeared as such in March 2008 [3].

point in the main in the same direction, while the momenta of the background-event leptons point primarily in opposite directions. Such a unique signature on the already existing statistics ensures that the CDF and D0 experiments will become sensitive to the production of Higgs bosons with a mass M_H of roughly 160 [GeV/c^2] (see Fig. 1). It goes without saying that in the nearest future either this mass range will be excluded or a Higgs boson with a mass of about 160 [GeV/c^2] will be discovered in a Tevatron experiment.

3. The properties of the t-quark

The heaviest of the six quarks, the t-quark, was discovered in 1995 at the Tevatron accelerator in the CDF [4] and D0 [5] experiments. The measured mass of the t-quark was about 175 [GeV/c^2], so that the Tevatron was the only accelerator in the world over at which the production of t-quarks was possible kinematically. The two basic diagrams of t-quark pair production at the Tevatron are shown in Fig. 2. Due to the large mass of the t-quark, its lifetime is shorter than the time needed for hadron formation, with the result that the t-quark decays in its free state, in contrast to the lighter quarks whose properties can be studied only in the decays of the hadrons of which they are constituents. In its decay, a t-quark becomes a b-quark with a W-boson emitted in the process. This boson decays, in turn, either into a pair of a lighter quark and antiquark or into a lepton and neutrino. The energetic quarks are recorded in the detector as isolated dense jets of hadrons. Hence, the decay products classify the t-quark pair production events: the dileptonic (12%), the

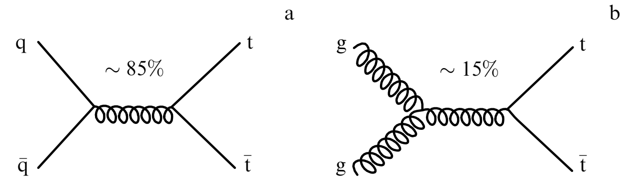

Figure 2. The basic diagrams of t-quark pair production at the Tevatron: (a) annihilation of the quark – antiquark pair, and (b) fusion of two gluons.

lepton plus jets (44%), and the fully hadronic decay mode (44%). The dileptonic topology makes possible a most distinct separation of t-quark production events from background events, but unfortunately the data with such a topology are very scant. The fully hadronic decay mode has a characteristically high combinatorial background. The optimal topology for studying the properties of t-quark production turned out the one with a lepton and hadronic jets.

An important characteristic that makes it possible to check the predictions of the Standard Model is the total t-quark production cross section. The value of the t-quark production cross section measured at the Tevatron collider is 7.3 ± 0.9 pb, which accords well with the Standard Model predictions [6]. The measured ratios of the probabilities of different decay modes for the t-quarks also agree with the Standard Model predictions. Searches for deviations from the Standard Model have also been conducted in studies of the mechanism of t-quark production. When two gluons fuse (Fig. 2b), in view of quantum chromodynamics (QCD) emission, more hadrons (on the average) are observed in the event of t-quark pair production than in the interaction of t-quarks (Fig. 2a). Such separation of events became possible by applying the method of artificial neural networks to analyzing the data. The result obtained indicates that t-quark pair production is due mainly to the process of quark interaction, in accord with the Standard Model predictions. If we assume that there exists an extremely heavy particle, a pair of t-quarks may also be produced as a result of such a particle decaying. In this case, the observed spectrum of invariant masses of the lepton and the hadronic jets would be distorted within the mass range of the decaying hypothetical particle. So far, the search for distortions has produced no positive results. Thus, no deviations from the Standard Model in the production and decays of the heaviest quark have been discovered yet.

In the Standard Model, the values of the masses of the t-quark, the W-boson, and the Higgs boson are related through loop diagrams. Hence, the accurate measurement of the t-quark and W-boson masses makes it possible to determine the range of possible values of the Higgs boson mass. The most precise values of the t-quark mass can be extracted from measuring events with the lepton-plus-jets topology. Here, the kinematic distributions are fitted by the maximum likelihood method to similar simulated distributions for various assumed values of the t-quark mass. At the same time, the decay of one of the W-bosons into two hadronic jets is used to refine the measurements of jet energies in the detector's calorimeter. Dileptonic and fully hadronic events are also utilized to measure the t-quark mass, but the results are less accurate. A combination of all measurements in the two Tevatron experiments, CDF and D0, yields the most precise experimental value to date of the t-quark mass: $M_{\mathrm{t}} = 172.6 \pm 1.4$ [GeV/c^2] [7]. The main contribution to the mass measurement error is provided by the inaccuracy in measuring the energies of the hadronic jets in the calorimeter. As the statistics accumulate, this part of the systematic error will diminish due to the employed *in situ* calibration of the calorimeter against the W-bosons produced from t-quark decays. The total error in measuring the t-quark mass at the Tevatron collider is expected to be reduced to 1.0 [GeV/c^2]. Using the obtained value of the t-quark mass, one can evaluate the Higgs boson mass in the Standard Model: $M_{\mathrm{H}} = 87^{+36}_{-27}$ [GeV/c^2] and set an upper limit on the Higgs boson mass, which amounts to 160 [GeV/c^2] at a 95% confidence level. The most probable value of the Higgs boson mass [8] lies within a range already excluded by LEP-2 data, which to a certain extent contradicts the Standard Model.

To make the picture complete, it is worth mentioning that t-quarks are also produced in the decay of a virtual charged W-boson. In this case, the t-quark is produced in a pair with the lighter b-quark, and the process itself is called single t-quark production. Experimentally, it is extremely difficult to distinguish single t-quark production against the high-level noise background (the signal-to-noise ratio is 1:25). Hence, to solve this problem, complex statistical methods of data analysis, such as the decision tree method and the method of artificial neural networks, are utilized. The decision tree method is based on the idea of making sequential decisions depending on the result of the previous decision. Such a concept makes it possible to minimize the ineffectiveness of selecting true events where a large number of kinematic variables are employed for selection. For instance, 49 kinematic variables are used in the analysis of the data presented by the D0 collaboration. As a result, in the CDF [9] and D0 [10] experiments, there were indications of the presence of single t-quark production with a level of statistical significance amounting to about three standard deviations. The values of the cross sections obtained in this manner do not contradict the Standard Model predictions. Measurements of the reaction of single t-quark production make it possible to determine directly the value of the Kobayashi–Maskawa (KM) quark mixing matrix element $|V_{\mathrm{td}}|$. It is assumed that as the statistics accumulate the accuracy of measuring $|V_{\mathrm{td}}|$ at the Tevatron collider will reach 10% and will be much improved in LHC experiments.

4. The structure of the proton

In the summer of 2007, the Hadron–Electron Ring Accelerator (HERA) stopped being operational. The data on deep inelastic scattering gathered for almost 15 years in the H1 and Zeus experiments at HERA made it possible to measure the proton structure functions within a broad kinematic range of the variables x (the fraction of the proton momentum transferred by a parton, $x > 10^{-5}$) and Q^2 (the virtuality of the interacting photon, $0 < Q^2 < 10^4$ GeV^2). The achieved accuracy of measurements of the structure function F_2 (1.5%–3%) agrees with the accuracy of earlier measurements done in experiments with fixed targets in the range of low values of Q^2 and large values of x. In turn, the precise measurement of the proton structure functions makes it possible to determine the density distributions of quarks and gluons in the proton. Figure 3 is an example of such a distribution [11].

We need to know the density distributions of quarks and gluons in the proton in order to calculate the cross sections of various QCD processes proceeding in LHC. Since most processes in LHC involve gluons, it is important to narrow the uncertainty gap in the density distribution of gluons in the proton. In contrast to quark distributions which are proportional to the measured structure functions, the gluon density determines the variation of the structure function versus the variable Q^2 (scaling violation). The structure functions are weakly dependent on Q^2, with the result that the sensitivity of experimental data to gluons is weaker than it is to quarks. This is evident from Fig. 3 where the error in the gluon distribution in the region of small x's is several times bigger

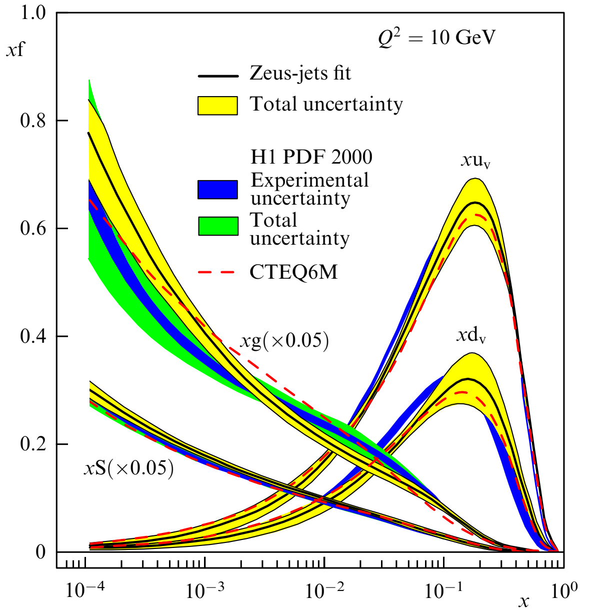

Figure 3. Example of parton density distributions xf in the proton at $Q^2 = 10$ GeV^2, obtained on the basis of the data from H1 and Zeus experiments at the HERA accelerator [11]. Here, xu_v is the density of valence u-quarks in the proton, xd_v is the density of valence d-quarks in the proton, xS is the density of sea quarks, and xg is the gluon density.

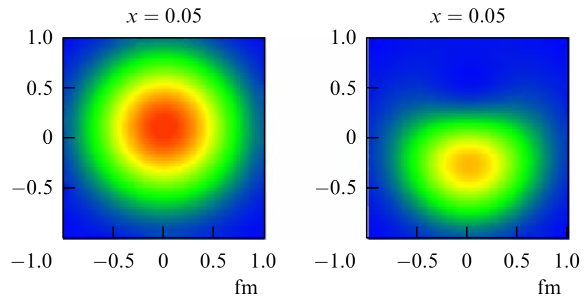

Figure 4. Tomography of a proton. An example of the density distributions of u-quarks (a) and d-quarks (b) in the proton at $x = 0.05$ [12]. The proton polarization axis is directed from right to left.

than the errors in the quark distribution. Moreover, the gluon densities extracted from the H1 and Zeus data differ significantly from each other. The reason is that the solution of equations for calculating the gluon distribution is unstable and depends on local features of the experimental data used. The immediate goal is to combine the data of the H1 and Zeus experiments to reduce the statistical and systematic errors in measuring the proton structure function to 1 – 2% and, hence, to reduce the uncertainty in the values of gluon density.

Parton densities extracted from data on inclusive deep inelastic scattering carry information about the distributions of quarks and gluons in the protons in relation to transverse momentum, while nucleon form factors measured in elastic scattering reactions contain information about the transverse distribution of charge in the nucleon. In order to obtain a fuller picture of the proton, researchers use what is known as generalized parton distributions (GPDs). GPDs take into account the correlations between two partons of the same type, which differ in longitudinal $(x_1 - x_2)$ and transverse (t) momenta. At $x_1 = x_2 = x$ and $t = 0$, they are reduced to the inclusive distributions of quarks and gluons, and after integration with respect to x, to the nucleon form factor. A GPD Fourier transform provides a complete spatial picture of a nucleon. Figure 4 depicts the transverse distributions of u- and d-quarks in the proton at $x = 0.05$ [12]. The GPD plays a key role in Ji's sum rules [13] which make it possible to determine the contribution of the total angular momentum of different partons to the proton spin. The total angular momentum of partons is the sum of the parton spin and the parton angular momentum. The contribution of the total spin of the partons to the proton spin amounts to only about 30% [14]. Here, the spins of u- and d-quarks in the proton point in opposite directions (on the average). This remarkable experimental fact became known as the proton spin crisis. Thus, GPD measurements present a unique chance to explain the nature of nucleon spin.

GPD measurements are done by utilizing the data on diffraction scattering. From the theoretical viewpoint, the diffraction deep inelastic Compton scattering of an electron (muon) by a proton is the simplest process used to measure GPDs. Figure 5 displays the diagram for deep inelastic Compton scattering (DICS). In this process, the proton absorbs a virtual photon (the process is sometimes called deeply virtual Compton scattering, or DVCS) and emits a real gamma quantum in the final state, remaining a proton as a whole. The reaction has been studied in experiments on electron (muon) – nucleon scattering. The measured difference in the DICS diffraction cross sections for different polarizations of the impinging electron and the nucleon target is proportional to a GPD combination. DICS on a polarized proton target is measured in the HERMES (HERA measurement of spin) experiment [15]. DICS by neutrons is measured at a JLAB (Jefferson Lab, a US Department of Energy national laboratory for nuclear research) experiment on the basis of the difference in scattering cross sections of a polarized electron beam on proton and deuteron targets [16]. The combined analysis of the results of these two experiments points to the fact that the total angular momentum of the u- and d-quarks in the proton accounts for an additional 30% of the nucleon spin [16]. The remaining 40% can, possibly, be explained by gluon dynamics in the nucleon. However, the accurate measurements of the GPDs of gluons are still extremely difficult to perform.

We see that diffraction processes have lately become a powerful tool for solving fundamental problems in elementary particle physics. A telling example is the suggestion to measure the diffraction Higgs-boson production in LHC [17]. In the Standard Model, the Higgs boson possesses vacuum

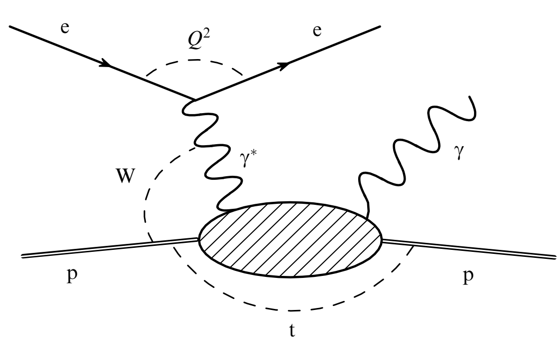

Figure 5. Schematic of a deep inelastic Compton scattering.

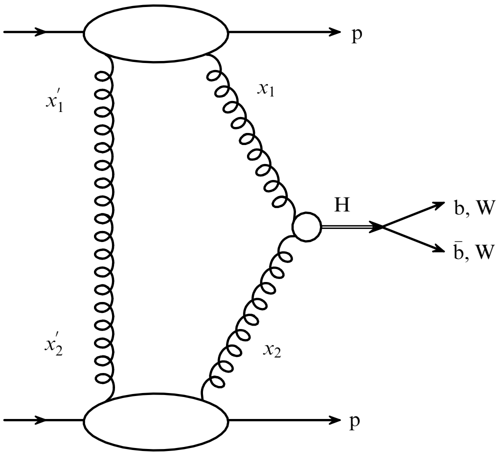

Figure 6. Diagram of exclusive diffraction production of a Higgs boson in LHC.

quantum numbers, so that it can be produced exclusively in the central range of rapidities in quasielastic proton scattering. Figure 6 presents the diagram for such a process. In such a diffraction reaction ($p + p \to p + H + p$), the protons scattered through small angles lose some of their energy, which is spent on the production of a massive Higgs boson, and can be recorded by detectors in the accelerator's beam tube. Precise measurements of the momenta of the scattered protons make it possible to determine the Higgs boson mass with unprecedented accuracy (3 – 4 GeV). The cross section of such a process at LHC is expected to be only about 3 fb. However, with the luminosity that is expected at LHC, measurements of the exclusive diffraction production of the Higgs boson promise success. The goal of the FP420 project prepared at LHC is to solve this problem.

5. New particles discovered in B-factories

The large amount of statistics accumulated at B-factories makes it possible to investigate rare decays accompanied by the formation of various charmonium states. Among the new particles were discovered the states (η_c' and χ_{c2}') predicted in the charmonium model, as well as unexpected charmonium states which are difficult to place in the well-established spectroscopic picture of the bound states of c- and anti-c-quarks. Among these new particles are X(3872) [18], Y(4260) [19] and some others. The Y(4260) particle is produced in e^+e^- annihilation and, hence, possesses the photon quantum numbers $J^{PC} = 1^{--}$. However, all the states with the quantum numbers 1^{--} in the modern charmonium model are occupied. To the great astonishment of researchers, three new resonances in this mass range with the quantum numbers 1^{--} were detected immediately after the discovery of Y(4260). Even more intriguing is the narrow X(3872) resonance. Its mass exceeds the threshold mass needed for the production of a pair of D mesons, but X(3872) decays into J/Ψ and hadrons. If the decay of X(3872) into D mesons is forbidden by quantum numbers, then a high probability of the $X(3872) \to \chi_c + \gamma$ transition is expected, but such a transition has never been discovered. Among the newly detected particles, the charged state of charmonium $Z^{\pm}$ (4430), which decays into $\Psi'\pi^{\pm}$, occupies a special place. This new state was discovered in the experiments of the Belle collaboration [20].

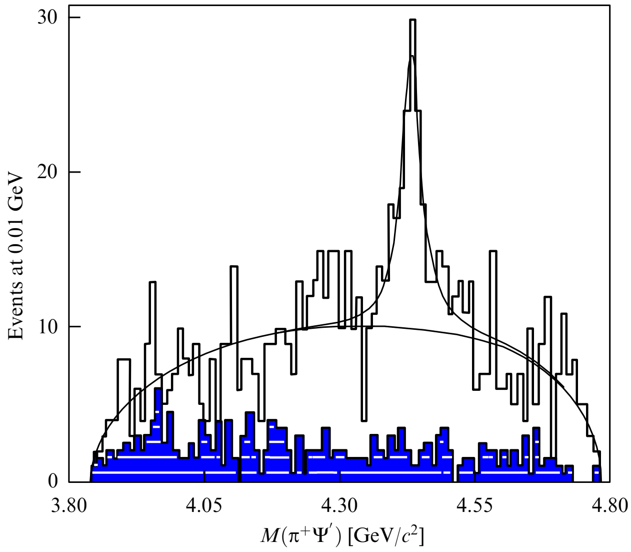

Figure 7. The spectrum of the invariant mass of the $\Psi'\pi^+$ system that follows from the decays of B-mesons in the Belle experiment [20]. Clearly visible is a narrow peak corresponding to the new particle $Z^{\pm}$ (4430). The hatched bar diagram corresponds to the combinatorial background noise not generated by decays of B mesons.

Figure 7 shows the invariant-mass distribution for the $\Psi'\pi^{\pm}$ system. Clearly, there is a narrow peak in the spectrum with a statistical significance of about three standard deviations. Obviously, to produce a charmonium charged state, to the pair consisting of c- and anti-c-quarks we must add at least one more pair consisting of a light quark and antiquark. Thus, the new particle $Z^{\pm}$ (4430) discovered in the decays of B mesons today is considered the first reliably established candidate for a four-quark state. Thus, unexpectedly, an entire zoo of new particles has been discovered in B-factories. The LHCb experiment will help in understanding the nature of these particles. The properties of the new particles are discussed in detail in Ref. [21].

6. Manifestations of deviations from the Standard Model

In recent years, a large program in precise measurements of the cross section of electron – positron annihilation into hadrons in a wide energy range has been implemented. The data on the annihilation cross section have made it possible to determine the correction for calculating the anomalous magnetic moment of the muon, a_{μ}, related to vacuum hadronic polarization. The uncertainty in the hadronic correction provides the main contribution to the error in the theoretical prediction of the value of a_{μ}. As is known, the experimental and theoretical values of a_{μ} differ, so one of the top priorities is to reduce the experimental and theoretical errors in determining a_{μ}. Precise data on the annihilation cross section have been gathered in several experiments, including the KMD-2 experiment carried out at the G I Budker Institute of Nuclear Physics in Novosibirsk. The results of these experiments have made it possible to reduce the theoretical error in determining a_{μ} to the experimental error. At present, the difference between the experimental and theoretical values of a_{μ} amounts to $(27.5 \pm 8.4) \times 10^{-10}$, with a statistical significance of 3.3 standard deviations [22]. Unfortunately, the experimental value of a_{μ} was obtained from the data of only one experiment, BNL E821 [23], which ended in 2004. A new experiment is needed if we want to verify and refine this result.

In 2008, the Belle collaboration reported on the discovery of a substantial difference in the magnitude of the effect of a direct violation of CP-invariance for neutral and charged B mesons [24]. The measured probability of the $B^0 \to K^+\pi^-$ decay exceeds that of the anti-$B^0 \to K^-\pi^+$ decay, while for charged B mesons, which decay into $K^{\pm}\pi^0$, the effect observed is just reversed in magnitude (Fig. 8). The difference in the violation of CP-invariance for neutral and charged B mesons amounts to $\Delta A_{K\pi} = 0.147 \pm 0.028$, which corresponds to a statistical significance of more than five standard deviations. From the theoretical viewpoint, the violation of CP-parity in the decays of charged and neutral B mesons must be practically the same. Indeed, the magnitude of the B-meson charge is determined by a light spectator quark which does not participate in a weak decay, with the result that, to the first approximation, the B-meson charge has no effect on the violation of CP-parity. However, one must bear in mind that a spectator quark participates in the production of the final hadrons which differ in such decays. This last effect is expected to be small and incapable of changing the sign of the CP-asymmetry to the opposite one. It is still difficult to judge the importance of this remarkable phenomenon. Suffice it to say that the report on the observed difference in the magnitude of the effect of a direct violation of CP-invariance for neutral and charged B mesons was published in *Nature*.

B-meson oscillations were discovered in the ARGUS experiment in 1987 [25]. In the Standard Model, B-meson oscillations occur in the second order in the weak interaction, so that they serve as a sensitive instrument for searching for new phenomena. The transition amplitude between B- and anti-B-mesons is proportional to the product of the respective elements of the KM quark mixing matrix. If the product of the matrix elements has an imaginary part, CP-invariance is violated in the process of B-meson oscillations. In recent years, violations of CP-invariance in the B_u-meson system have been studied intensively in B-factories in the Belle and BaBar experiments, but so far no deviations from the Standard Model predictions have been discovered. The imaginary part in the product of the matrix elements describing the oscillations of neutral B_s mesons is strongly suppressed, as distinguished from that in the case of B_u mesons, with the result that the Standard Model predicts no strong violation of 5P-invariance in the B_s-meson system. The magnitude of the effect of a direct violation of CP-parity in the B_s-meson system is characterized by the phase φ_{B_s}, which in the Standard Model amounts to $\varphi_{B_s} = -2°$. However, according to recent data gathered in the CDF [26] and D0 [27] experiments, the effect of violation of CP-invariance in the B_s-meson system may be significant. Measurements conducted in each experiment separately contain large errors and do not suggest any substantial deviation from the Standard Model predictions. However, the UTfit group carried out a combined processing of these results and arrived at $\varphi_{B_s} = -19.9 \pm 5.6°$, which exceeds three standard devia-

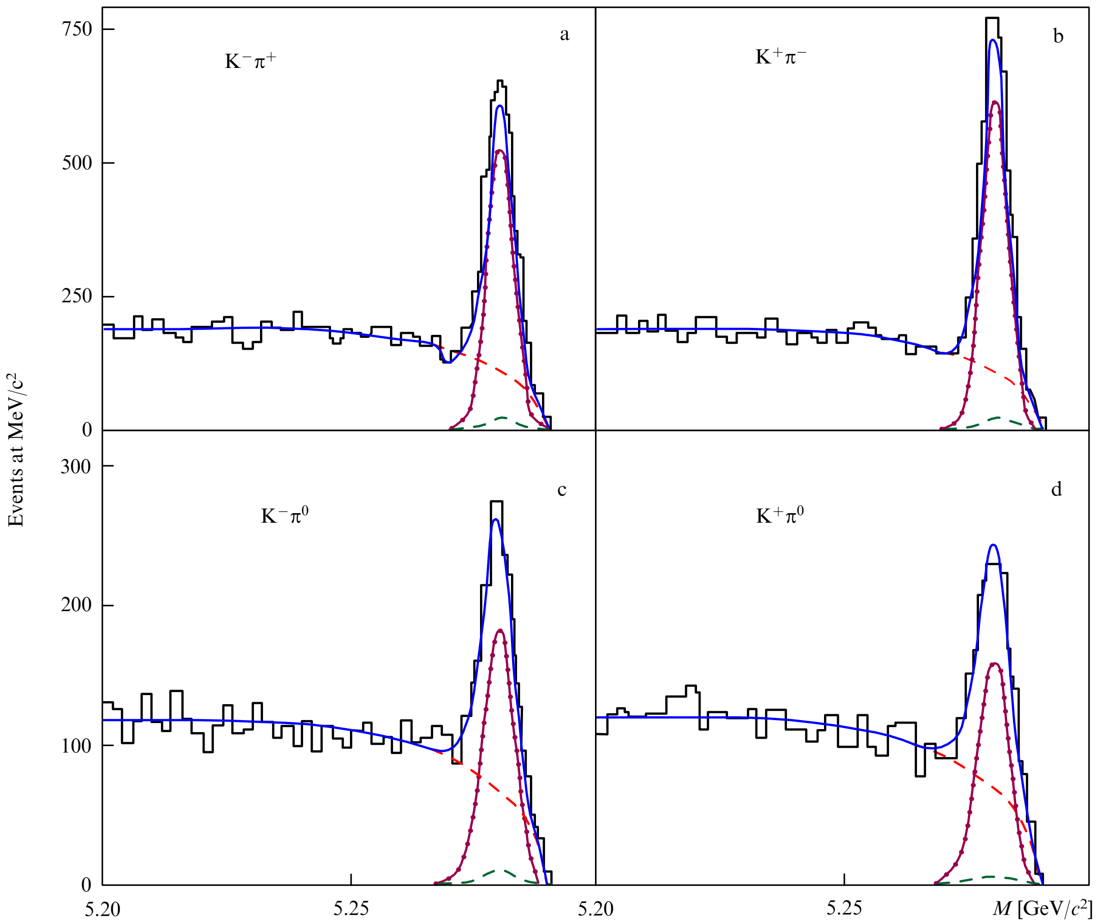

Figure 8. Spectra of the invariant masses of $K^-\pi^+$ (a), $K^+\pi^-$ (b), $K^-\pi^0$ (c), and $K^+\pi^0$ (d). Results of the Belle collaboration [24].

Table 1. Measurements exhibiting statistically significant disagreements with the Standard Model predictions, including the limits on the magnitude of the Higgs boson mass.

Name of variable	Magnitude/deviation	Statistical significance	Experiment, source
Muon's anomalous magnetic moment	$a_{\mu}^{\exp} - a_{\mu}^{\mathrm{SM}} = (27.5 \pm 8.4) \times 10^{-10}$ [22]	$3.3\,\sigma$	BNL E821(finished)
Direct violation of CP-parity for neutral and charged B mesons	$\Delta A_{\mathrm{K}\pi} = 0.147 \pm 0.028$ [24]	$5.3\,\sigma$	Belle, BaBar
Violation of CP-parity in the $\mathrm{B_s}$-meson system	$\varphi_{\mathrm{B_s}}^{\exp} - \varphi_{\mathrm{B_s}}^{\mathrm{SM}} = -17.9 \pm 5.6^{\circ}$ [28]	$3.2\,\sigma$	CDF, D0, UTfit
Leptonic decay constant for the $\mathrm{D_s}$ meson	$f_{\mathrm{D_s}}^{\exp} - f_{\mathrm{D_s}}^{\mathrm{SM}} = 36 \pm 9$ MeV [29]	$4.0\,\sigma$	CLEO, BaBar, Belle
Limit on the Higgs boson mass	$114 < M_{\mathrm{H}} < 160$ [GeV/c^2] [8]	95 % CL	CDF, D0, EWWG

tions [28]. What is needed is a direct experimental investigation of CP-invariance violation in the $\mathrm{B_s}$-meson system, which will become possible in the LHCb experiment, where the expected accuracy of measuring $\varphi_{\mathrm{B_s}}$ will be about 2°.

Leptonic decays of mesons have no hadrons in the final state and, hence, may be calculated with high accuracy. Therefore, measurements of leptonic decays are traditionally considered sensitive to the New Physics outside the scope of the Standard Model. The leptonic decay of the $\mathrm{D_s}$ meson ($\mathrm{D_s} \to \mathrm{l} + \nu$) has been measured in the CLEO, BaBar, and Belle experiments. Within the Standard Model, the probability of this decay is proportional to the square of the decay constant $f_{\mathrm{D_s}}$, which in turn reflects the probability of finding the quark and antiquark that constitute the $\mathrm{D_s}$ meson at a single point. The data of the three experiments are in good agreement with each other and make it possible to extract the decay constant, which amounts to 277 ± 9 MeV [29]. On the other hand, the value of the $\mathrm{D_s}$-decay constant obtained with good accuracy in QCD calculations on a grid amounted to 241 ± 3 MeV [30]. Thus, the difference between the theoretical and experimental values of $f_{\mathrm{D_s}}$ amounts to four standard deviations. This is even more remarkable since the QCD calculations on grids yield correct results for the masses of D- and $\mathrm{D_s}$-mesons, and for the value of the D^+-meson decay constant. As a result, a relatively small fraction (about 2%) of the leptonic decays of $\mathrm{D_s}$ mesons occurs beyond the Standard Model predictions. If the experimental data and the theoretical predictions are correct, we can assume that this fraction of $\mathrm{D_s}$-meson decays occurs with the participation of a new massive charged particle.

7. Conclusion

The above results of precise measurements that exhibit a statistically significant deviation from the Standard Model predictions belong to the class of fundamental disagreements with the Standard Model. In this report, I have not mentioned the results of numerous measurements that also remain unexplained (the associative production of a hadron jet and a gamma quantum with a large transverse energy or the polarization of J/Ψ in the Tevatron, the production of b-quarks in electron–proton interactions in the HERA accelerator, etc.), which are not very important and most likely reflect the complexity of the QCD description of such phenomena. Nor did I mention the numerous direct searches for new particles and processes that are outside the scope of the Standard Model. Such searches have led to no positive results.

In conclusion, I have compiled a table of the existing fundamental disagreements with the Standard Model (Table 1). The data listed in the table reflect the situation that existed as of April 2008. All the measurements (with the exception of the measurement of the muon's anomalous magnetic moment) advance as the statistics accumulate and improve in the experiments listed in the table. We expect to have the final answer to the question of the true value and nature of the discovered principal disagreements with the Standard Model in the near future as LHC becomes operational.

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