

The ILC Energy Requirements from the Constraints on New Boson Production at the Tevatron

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Direct constraints on the masses of new heavy bosons by the Tevatron data are discussed. Some excesses in the experimental data are interpreted as a resonance production of new charged and ‘leptophobic’ neutral chiral bosons with masses 500 GeV and 700 GeV, respectively. The interpretation was provided on the basis of the theoretical model, proposed by the author about 15 years ago. New Tevatron data and the LHC results will definitely confirm or reject this interpretation. The ILC with an energy above 1 TeV would be an ideal place to produce and to study the properties of these particles.

1 Introduction

The hadron colliders, due to the biggest center-of-mass energy and their relatively compact sizes, still remain a main tool for discoveries of very heavy particles. Thus, in 1983 the two dedicated experiments UA1 [1] and UA2 [2] discovered the intermediate vector bosons at the CERN SPS Collider. One faces, however, a very large background from the strong interactions.

In any case, besides the simple manifestation of the existence of the weak bosons, one needs a precise study of their properties following from the Standard Model (SM). This task has been excellently fulfilled by the Large Electron-Positron (LEP) storage ring at CERN and the Stanford Linear Collider (SLC) at SLAC. However, the masses of the t quark and the undiscovered yet Higgs boson happened to be too high to be discovered at these colliders.

I remember the words by Samuel Ting at one of the LEP meetings in defence of continuation of the LEP running: “Each collision at the lepton colliders is an event, while it is a background at the hadron colliders”. So, the precision of the electroweak measurements at the lepton colliders was so high, that the predicted from the radiative loop corrections mass of the top-quark $m_t = 180^{+8}_{-9} \text{ }^{+17}_{-20}$ GeV [3] has been found in agreement and with a comparable accuracy of its first direct measurements at the Fermilab Tevatron by the CDF [4] $m_t = 176 \pm 8 \pm 10$ GeV and the D0 [5] $m_t = 199^{+19}_{-21} \pm 22$ GeV collaborations.

Nevertheless, in spite of the overwhelming background for the top-quark pair production by the strong interactions at the hadron collider, the uncertainty of the top-quark mass $m_t = 170.9 \pm 1.1 \pm 1.5$ GeV [6] is considerably reduced at present. Moreover, recently, the evidence for a single top-quark production [7] through the weak interactions and the direct measurement of $|V_{tb}|$ at the Fermilab Tevatron hadron collider became possible. Another achievement in precise measurements at the hadron collider is the W -mass measurement $m_W = 80.413 \pm 0.048$ GeV [8] by the CDF collaboration at a comparable with the LEP

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experiments accuracy, which represents the single most precise measurement to date. All these measurements will allow to constrain further the mass of the Higgs particle, which discovery is a priority task of the running Tevatron and the Large Hadron Collider (LHC).

The discovery of the theoretically predicted heavy particles and the establishment of the SM without any surprises are characteristic for the experimental high energy physics during the last thirty years. Therefore, the LHC construction is connected not only with the Higgs discovery, but with the hope to find the physics beyond the SM. Up to now it is not clear what kind of physics it will be. Therefore, any inputs like constraints on the new physics from low-energy precise experiments or from the presently most powerful Tevatron collider at FNAL are badly needed when discussing the properties of future colliders, in particular, the International Linear Collider (ILC).

This talk is dedicated to the energy requirements for the future lepton colliders, which follow from the constraints on the new boson production at the Tevatron. In order to investigate the properties of the new bosons and eventually to distinguish among different models of the new physics, the energy of the future ILC should be enough to produce them. Although it is still possible to investigate some properties of the new bosons at low-energy, we will consider the case of their resonance or threshold production, as an optimal possibility.

In the second part of the talk we will consider one of the possible scenarios of new physics in the boson sector, for which some confirmation from the Tevatron data already exists. A quantitative model of such a new physics will be very valuable in interpreting the data from the hadron colliders, Tevatron and LHC, that presents concrete requirements for the ILC energy design.

2 Tevatron constraints

Let us start with the case of new neutral massive bosons, Z' , which can be produced at the lepton colliders as resonances. Such a type of bosons is very difficult to detect in the low-energy experiments due to the huge background from the electromagnetic interactions. Some guiding principle is necessary to distinguish them from the known interactions. For example, the neutral weak currents were detected in the deep-inelastic electron scattering through the measurements of P -odd quantities. Therefore, we expect that direct constraints from the high-energy hadron colliders should be more restrictive.

Moreover, up to now, the Drell-Yan process with high-energy invariant mass of the lepton pairs remains the most clear indication of the heavy boson production at the hadron colliders. Therefore, the constraints from these investigations can be directly applied to the resonance boson production at the lepton colliders. So, using only a modest integrated luminosity of 200 pb^{-1} collected during RUN II, the D0 Collaboration puts tight restrictions on the Z' masses for the different models from the di-electron events [9]: $M_{Z'_{SM}} < 780 \text{ GeV}$, $M_{Z'_\eta} < 680 \text{ GeV}$, $M_{Z'_\psi} < 650 \text{ GeV}$, $M_{Z'_\chi} < 640 \text{ GeV}$ and $M_{Z'_I} < 575 \text{ GeV}$. A comparable statistics in the di-muon channel leads approximately to the same constraint $M_{Z'_{SM}} < 680 \text{ GeV}$ [10]. The CDF constraints from the di-electron channel are based on more data, 1.3 fb^{-1} , which lead to tighter restrictions [11]: $M_{Z'_{SM}} < 923 \text{ GeV}$, $M_{Z'_\eta} < 891 \text{ GeV}$, $M_{Z'_\psi} < 822 \text{ GeV}$, $M_{Z'_\chi} < 822 \text{ GeV}$ and $M_{Z'_I} < 729 \text{ GeV}$.

Another possible channel, which can indicate the production of the neutral heavy bosons, is their hadronic decay into $t\bar{t}$ pairs. While the light quark decay channels are swamped by multijet background, the $t\bar{t}$ pairs can be detected, for example, through their decays

into two energetic b -jets and two W 's, where one W boson decays hadronically and one leptonically. Although the constraints from this channel cannot be applied directly to the energy requirements for the lepton collider due to the possible leptophobic character of the bosons, it is interesting to detect the eventual peaks in the Tevatron data. So the latest results both of the D0 [12] and of the CDF [13] Collaborations show some excess in the invariant mass distributions around 700 GeV (Fig. 1). A possible explanation of this excess will be discussed in the next section.

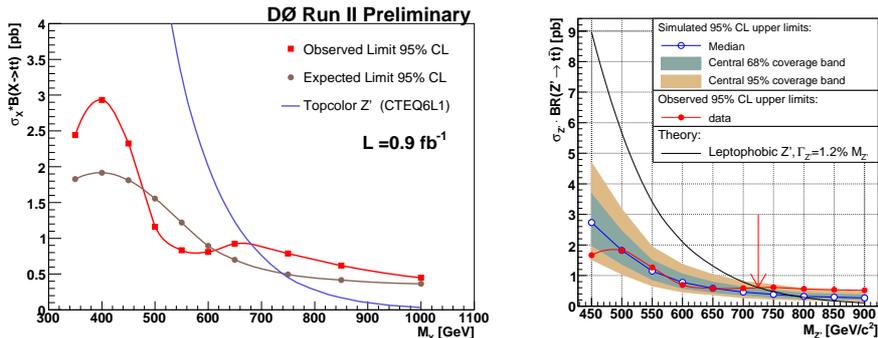


Figure 1: Expected and observed 95% C.L. upper limits on $\sigma_X \times \mathcal{B}(X \rightarrow t\bar{t})$ in comparison with the predicted leptophobic topcolor Z' cross section (left panel from [12] – D0 data, right panel from [13] – CDF data of 680 pb^{-1}).

Let us consider the case of the new heavy charged bosons, generically noted by W' . They could be produced at the lepton colliders only in pairs or in association with other charged boson, like W . Therefore, restrictions on their masses lead to the following energy requirements for their threshold production $E > M_{W'} + M_W$ at the lepton colliders. Here again we will consider leptonic and hadronic channels of their decays.

The leptonic decay of the new heavy charged boson into high-energy pair of a lepton and a corresponding antineutrino is the most clear signature of its production at the hadron colliders. So, already from 205 pb^{-1} of RUN II data, the CDF Collaboration obtained a tight constraint on possible W' mass $M_{W'} > 788 \text{ GeV}$ [14]. The most rigid constraint comes from the D0 Collaboration [15] $M_{W'} > 965 \text{ GeV}$, based on bigger statistics, 900 pb^{-1} , and better calorimetry than the CDF detector.

The hadronic decay of the new heavy charged boson into a $t\bar{b}$ pair of a heavy b quark and a short living t quark with its subsequent decay to Wb pair allows to make jet b -tagging, where one of the jets must have a displaced secondary vertex. A search for the intermediate heavy bosons in this channel has been fulfilled by both the D0 and CDF collaborations, and for this purpose the part of the same data sets of the single top production analysis has been used. Owing to boson high masses this analysis is even simpler than the single top production searches, because at such energies the background is considerably reduced.

So the D0 Collaboration, based on 230 pb^{-1} of integrated luminosity, puts the following constraints on the W' mass depending on the model: $M_{W'_{SM}} > 610 \text{ GeV}$, $M_{W'_{R}(\rightarrow \ell \text{ and } q)} > 630 \text{ GeV}$, and $M_{W'_{R}(\rightarrow q \text{ only})} > 670 \text{ GeV}$ [16]. The CDF constraints are tighter (Fig. 2): $M_{W'} > 760 \text{ GeV}$ for $M_{W'} > M_{\nu_R}$ and $M_{W'} > 790 \text{ GeV}$ for $M_{W'} < M_{\nu_R}$, since they are

based on 955 pb^{-1} [17].

Taking into account the most stringent constraints from the Tevatron data, we can conclude, that in order to produce the heavy charged boson in association with the W boson or the heavy neutral boson a lepton collider with energy above 1 TeV is necessary. Also it is interesting to note the presence of some excesses in the observed data in Figs. 1 and 2, which we will discuss in the next section.

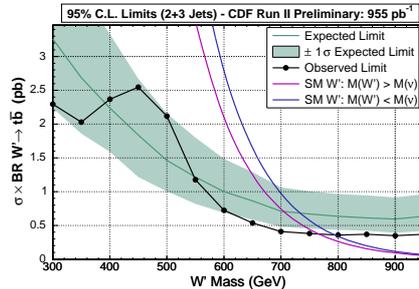


Figure 2: Observed limits from [17].

3 New spin-1 chiral bosons

Additional chiral bosons, which have anomalous interactions with fermions, were proposed in [18]. An exchange through these bosons leads to effective tensor interactions with the coupling constant by two orders of magnitude smaller than G_F . This follows from the precise low-energy experiments of the radiative pion decay [19]. Assuming the universality of these interactions we can explain the long standing discrepancy between the two pion production in the e^+e^- annihilation and the τ decay [20], which now reaches 4.5σ [21].

The universality of the interactions of the new bosons and the hypothesis about a dynamical generation of their kinetic terms allow to predict their masses [22]. Due to the mixing between two charged chiral bosons the lightest state corresponds to U^{\pm} -boson with a mass $M_L \approx 509 \text{ GeV}$ and the heaviest one is T^{\pm} -boson with a mass $M_H \approx 1137 \text{ GeV}$. The neutral physical states come as CP -even U^R and CP -odd U^I bosons with approximately the same masses $M_U \approx 719 \text{ GeV}$, which couple only to the up fermions, and analogous but heavier bosons T^R and T^I with a common mass $M_T \approx 1017 \text{ GeV}$, coupling to the down fermions.

Due to the anomalous interactions the angular distribution of the chiral boson decays differs drastically from the analogous distribution of the gauge bosons. This leads to a specific transverse momentum distribution [23], which has a broad smooth bump with a maximum below the kinematical endpoint $p_T = M/2$, instead of a sharp Jacobian peak (Fig. 3). The form of the decay distribution for the chiral bosons resembles the bump anomalies in the inclusive jet E_T distribution (Fig. 4), reported by the CDF Collaboration [24] many years ago.

Analysing the bumps in the jet transverse energy distribution in Fig. 4, we can find the endpoint of the first bump at 250 GeV and guess about the second bump endpoint from the minimum around 350 GeV. If we assign

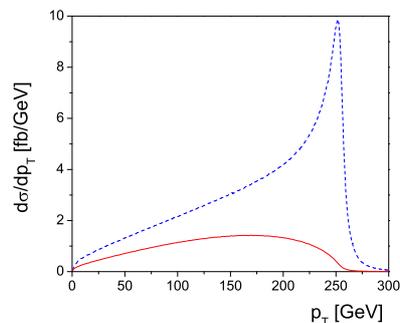


Figure 3: The distributions for the gauge W' (dashed) and for the chiral U^{\pm} (solid) bosons as functions of the lepton transfers momentum.

the first bump to the hadron decay products of the lightest charged bosons, which exactly corresponds to the estimated mass, the second endpoint hints to a mass around 700 GeV, which is also in a quantitative agreement with our estimations for the mass of the lightest neutral boson. However, taking into account the large systematic uncertainties in jet production, these conclusions may be premature, unless they are confirmed in other channels.

Indeed, an excess about 2σ in the lepton channel has been pointed out recently by the CDF Collaboration [14] in the region $350 \text{ GeV} < M_T \simeq 2p_T < 500 \text{ GeV}$. At the same time the same collaboration, however, denies the peak in the quark channel in the same region (Fig. 2), claiming that “since the predictions in *the neighboring bins* agree with the observation, and since *the three jet bin* does not show a similar excess, we anticipate that the excess in this region is a statistical fluctuation”. But this signature means just a resonance and this excess is in some sense a confirmation of the excess in the leptonic channel!

Therefore, the independent result from the D0 collaboration is very important. Their published result [16] is based on 230 pb^{-1} of integrated luminosity and does not show any excess in the histogram with the bin’s width of 50 GeV. However, it should always be taken into account that the narrow peak could be missed due to the smearing effect of the detector resolution or an insufficient statistics. Indeed, the right histogram in the Fig. 3 of the conference paper [25] of the same collaboration with the bin’s width of the 45 GeV reveals, nevertheless, the weak peak in the same region of the 500 GeV. All these not statistically significant results for the separated analyses may give a more conclusive answer after their combination and an additional investigation of the angular distributions of the events in this region.

The small excess in the $t\bar{t}$ channel around 700 GeV (Fig. 1) can be explained in the framework of our model by the production and the decay of the lightest neutral chiral boson. The latter shows ‘leptophobic’ property, since it decays to ‘invisible’ $\nu\bar{\nu}$ leptonic channel, and can be detected only through its decay into a pair of up quarks. The D0 Collaboration even superimposed its plot of the $t\bar{t}$ invariant mass distribution with the expected signal for a topcolor-assisted technicolor Z' with $M_{Z'} = 750 \text{ GeV}$, which perfectly agrees with the data.

4 Conclusions

There are some hints for the existence of a lightest charged chiral boson with a mass around 500 GeV and a lightest neutral ‘leptophobic’ chiral boson with a mass around 700 GeV in the Tevatron data. In the positive case the LHC would be able to discover all predicted charged and neutral chiral bosons spanning in mass up to around 1 TeV (see their leptonic decay distributions in the Fig. 5). The ILC with such energy would be an ideal place to

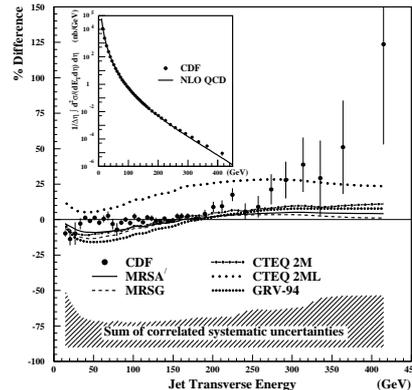


Figure 4: The Fig. 1 from [24]

produce and to study these particles.

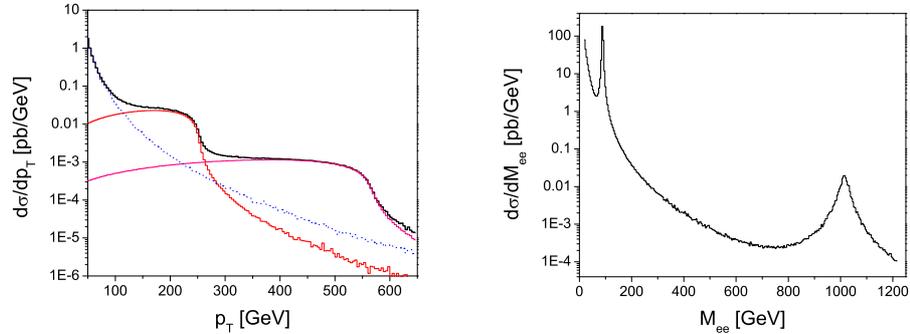


Figure 5: The distributions in the lepton channels at the LHC, namely $pp \rightarrow e\cancel{E}_T$ (left) and $pp \rightarrow e^+e^-$ (right).

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