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KINEMATICAL OBSERVABLES FOR *Z´*-BOSON SEARCHES IN THE DRELL-YAN SCATTERING AT THE TEVATRON

In the present paper we investigate the kinematical structure of the Drell-Yan cross section within the Standard model extended by an Abelian *Z´* boson. The *Z´* boson is described using an effective low-energy Lagrangian in a model-independent parameterization. Also we take into account the results of our previous investigations, namely, the obtained set of kinematical variables, which allows to investigate the two components of the Drell-Yan process cross section – the partonic cross section and the parton density factor separately. In our present study we analize the kinematical structure of the partonic cross section and show that it is possible to reduce the number of unknown *Z´* parameters in this cross section using kinematical properties of the partonic cross section at energies near the Z peak (66 GeV to 116 GeV). The obtained result can be applied to constructing a model-independent observable suitable for *Z´* signal searches at the Tevatron. We propose observables for the *Z´* with general couplings to the SM fermions and for the popular case of a leptophobic *Z´* boson.

Keywords: new gauge bosons, Drell-Yan process, Tevatron, model-independent searches.

У роботі досліджується кінематична структура перерізу Дрелла-Яна в Стандартній моделі, розширеній за рахунок *Z´*-бозона. *Z´*-бозон описано за допомогою ефективного низькоенергетичного лагранжіана з використанням модельно-незалежної параметризації. Також враховуються проведені раніше дослідження, у результаті яких було запропоновано набір кінематичних змінних, що дає змогу окремо вивчати два компоненти перерізу процесу Дрелла-Яна – переріз партонного процесу та множник партонних розподілів. У роботі проаналізовано кінематичну структуру перерізу на партонному рівні з урахуванням внеску *Z´*-бозона та показано, що кількість невідомих параметрів *Z´*-бозона, що входять до перерізу цього процесу, можна скоротити за допомогою кінематичних особливостей партонного перерізу розсіяння в області енергій поблизу піку Z-бозона (від 66 ГеВ до 116 ГеВ), у якій зібрано найбільший об'єм експериментальних даних. Цей результат важливий для побудови модельно-незалежної спостережуваної величини, яку можна було б використати для відокремлення сигналу *Z´*-бозона в даних експериментів, що проходили на прискорювачі Теватрон. Запропоновано спостережувані величини для загального випадку констант зв'язку *Z´*-бозона з ферміонами Стандартної моделі та для популярної моделі лептофобного *Z´*-бозона.

Ключові слова: нові калібрувальні бозони, процес Дрелла-Яна, Теватрон, модельно-незалежний підхід.

В работе исследуется кинематическая структура сечения Дрелла-Яна в Стандартной модели, расширенной абелевым *Z´*-бозоном. *Z´*-бозон описывается с помощью эффективного низкоэнергетического лагранжиана с использованием модельно-независимой параметризации. Также учитываются проведенные ранее исследования, в результате которых был предложен набор кинематических переменных, позволяющий по отдельности изучать два компонента сечения процесса Дрелла-Яна – сечение партонного процесса и множитель партонных распределений. В работе проанализирована кинематическая структура сечения на партонном уровне с учетом вклада *Z´*-бозона и показано, что число неизвестных параметров *Z´*-бозона, входящих в сечение этого процесса, можно сократить, используя кинематические особенности партонного сечения в области высоких энергий вблизи пика Z-бозона (от 66 ГэВ до 116 ГэВ), в которой набран большой объем экспериментальных данных. Этот результат важен с точки зрения построения модельно-независимой наблюдаемой величины, подходящей для выделения сигнала *Z´*-бозона в экспериментальных данных, собранных на ускорителе Теватрон. Предложены наблюдаемые величины для общего случая констант связи *Z´*-бозона с фермионами Стандартной модели и для популярной модели лептофобного *Z´*-бозона.

Ключевые слова: новые калибровочные бозоны, процесс Дрелла-Яна, Теватрон, модельно-независимый подход.

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1. Introduction

A new heavy neutral vector boson (*Z′* boson) [1] is a popular scenario of searching for physics beyond the Standard model (SM) of elementary particles in modern collider experiments. Both the Tevatron and LHC collaborations try to catch the particle as a resonance in the Drell-Yan process. Observing no peak they conclude that the *Z′* mass is no less than approximately 2.2 TeV [2] if one considers some predefined set of *Z′* models. Significant amount of the Tevatron data is collected at the *Z*-boson peak at 66-116 GeV. At these energies the *Z′* boson also can manifest itself as an off-shell state, since the *Z* coupling constants are influenced by the *Z*-*Z′* mixing, and these effects may allow to find *Z′* signals by fitting the experimental data.

In order to select *Z′* off-shell hints, proper observables have to be introduced to amplify possible signal. The signal generally means a deviation of some *Z′* parameter (i.e. a coupling constant) from zero at a specified confidence level. The key problem for off-shell *Z′* detection is to maximally reduce the number of the *Z′* couplings in the observable, which is used to fit the data. For example, the strategy of constructing observables driven by one or two parameters was successfully applied to analyze the final data of the LEP experiment leading to model-independent hints and constraints on *Z′* couplings [3–5]. In our previous work [6] we investigated a possibility of reducing the number of interfering *Z′* parameters in the $p\bar{p} \to l^+ l^-$ process at the Tevatron. For this purpose we integrated the differential cross-section by one of the kinematical variables with a specially constructed weighting function and reduced the total number of independent observables that enter the cross-section from six to only four.

In this paper we continue our investigation of few-parametric observables for the Drell-Yan process at $\sqrt{S} = 1.96$ TeV in a model-independent parameterization of the *Z′* couplings. We consider the general case of a *Z′* boson with non-universal couplings to fermion generations. It can be concluded that two-parametric observables exist at energies corresponding to *Z* peak, and we obtain all of them. These observables can be used as a key to find possible signals of the off-shell *Z′* boson.

2. Abelian *Z′* couplings to leptons and quarks

Being decoupled at energies of order of m_Z, the Abelian *Z′* boson interacts with the SM particles as an additional $\tilde{U}(1)$ gauge boson. Its couplings to the SM fermions are usually parameterized by the effective Lagrangian:

$$\begin{aligned} L_{Z\bar{f}f} &= \frac{1}{2} Z_\mu \bar{f} \gamma^\mu \left[(v_{fZ}^{\mathrm{SM}} + \gamma^5 a_{fZ}^{\mathrm{SM}}) \cos\theta_0 + (v_f + \gamma^5 a_f) \sin\theta_0 \right] f, \\ L_{Z'\bar{f}f} &= \frac{1}{2} Z'_\mu \bar{f} \gamma^\mu \left[(v_f + \gamma^5 a_f) \cos\theta_0 - (v_{fZ}^{\mathrm{SM}} + \gamma^5 a_{fZ}^{\mathrm{SM}}) \sin\theta_0 \right] f. \end{aligned} \qquad (1)$$

(Further details on the parameterization can be found in [7].) Here *f* is an arbitrary SM fermion state; a_f and v_f are the *Z′* couplings to the axial-vector and vector fermion currents, respectively; v_{fZ}^{SM}, a_{fZ}^{SM} are the SM couplings of the *Z* boson; θ_0 is the *Z*-*Z’* mixing angle. The a_f and v_f couplings are proportional to the *Z′* gauge coupling $\tilde{g}$. This parameterization is suggested by a number of natural conditions: 1) the *Z′* interactions of renormalizable types are to be dominant at low energies ~m_Z; 2) the *Z′* boson is the only neutral vector boson with the mass $\sim m_{Z'}$.

At low energies the Z' couplings enter the cross section together with the inverse Z' mass, so it is convenient to introduce the dimensionless couplings

$$\bar{a}_f = a_f m_Z / (\sqrt{4\pi} m_{Z'}), \quad \bar{v}_f = v_f m_Z / (\sqrt{4\pi} m_{Z'}), \tag{2}$$

which are constrained by experiments. Below the Z' decoupling threshold the effective $\tilde{U}(1)$ symmetry is a trace of the renormalizability of an unknown complete model with the Z' boson, and it leads to additional relations between the Z' couplings [3-4]

$$\bar{a}_{q_d} = \bar{a}_l = -\bar{a}_{q_u} = -\bar{a}_{\nu_l} = \bar{a}, \qquad \bar{v}_{q_d} = \bar{v}_{q_u} + 2\bar{a}, \qquad \bar{v}_l = \bar{v}_{\nu_l} + 2\bar{a}, \tag{3}$$

where q_u, q_d, l, and ν_l are an up-type and a down-type quark, a lepton, and a neutrino inside any fermion generation, correspondingly, and $\bar{a}$ is a universal coupling constant which defines also the Z-Z' mixing angle in (1)

$$\theta_0 \approx -2\bar{a} \sin\theta_W \cos\theta_W m_Z / (m_{Z'} \sqrt{\alpha_{\text{em}}}). \tag{4}$$

The discussed relations are also true for the THDM case. More details on this matter can be found in [5]. The full Lagrangian is written out in [7].

As a result, Z' couplings can be parameterized by seven independent constants $\bar{a}$, $\bar{v}_u$, $\bar{v}_c$, $\bar{v}_t$, $\bar{v}_e$, $\bar{v}_\mu$, $\bar{v}_\tau$. In case when the GUT model is unknown, these parameters remain potentially arbitrary numbers.

3. Abelian *Z′* in the Drell-Yan process

At the Tevatron the most prominent signal of the Abelian Z' boson is expected in the $p\bar{p} \to l^+ l^-$ scattering process. The general idea of our approach is equally applicable both for dielectrons and dimuons in the final state. To be definite, we shall consider the dimuon case. All the details on constructing the hadron-scattering cross section and the used kinematical variables are provided in [6]. Here we provide the obtained results briefly. The triple-differential cross section of this process can be written in the form of the partonic cross sections combined with the parton distribution functions (PDFs)

$$\frac{\partial^3 \sigma_{AB}}{\partial M \partial Y \partial y} = \sum_{q,\bar{q}} F_{q\bar{q}}(M, \mu_{\text{F,R}}, Y) \frac{\partial \sigma_{q\bar{q} \to \mu^+\mu^-}}{\partial y}, \quad \sigma_{q\bar{q} \to \mu^+\mu^-} = \sigma_{q\bar{q} \to \mu^+\mu^-}(M, y). \tag{5}$$

Here A, B mark the interacting hadrons (p or $\bar{p}$), and $F_{q\bar{q}}(x_q, x_{\bar{q}}, \mu_{\text{F,R}})$ is the PDF for the pair of partons $q\bar{q}$ in the hadron A with the momentum fraction x_q ($0 \le x_q \le 1$) at the factorization scale μ_F and renormalization scale μ_R. To access the parton distribution data, we use the MSTW 2008 package [8]. The quantity $\sigma_{q\bar{q} \to \mu^+\mu^-}$ is the parton-level cross section, which depends on the variables y and M – a relative scattering «angle» (converted to rapidity) of the invariant mass of a leptonic pair. The variable Y is a rapidity of the intermediate state.

Leading Z' contribution to the Drell-Yan process arises from interference between diagrams with γ^*/Z and Z' intermediate states, resulting in corrections of order of $O(\tilde{g}^2)$. The cross section reads as

$$\sigma_{\text{DY}} = \sigma_{\text{SM}} + \sigma_{Z'}, \quad \sigma_{Z'} = \bar{a}^2 \sigma_{\bar{a}^2} + \bar{a}\bar{v}_e \sigma_{\bar{a}\bar{v}_\mu} + \bar{a}\bar{v}_u \sigma_{\bar{a}\bar{v}_u} + \bar{v}_u \bar{v}_\mu \sigma_{\bar{v}_u \bar{v}_\mu} + \bar{a}\bar{v}_c \sigma_{\bar{a}\bar{v}_c} + \bar{v}_c \bar{v}_\mu \sigma_{\bar{v}_c \bar{v}_\mu}. \tag{6}$$

Here $\bar{a}$, $\bar{v}_f$ are the couplings defined in (2), (3), and $\sigma_{\bar{a}^2}$, $\sigma_{\bar{a}\bar{v}_f}$, $\sigma_{\bar{v}_f\bar{v}_{f'}}$ are numerical factors that depend on *M*, *Y*, *y*. In this approximation there are six independent unknown quantities entering the Drell-Yan process cross section. In (6) the factors that include $\bar{v}_u$ and $\bar{v}_c$ arise only due to contributions of first and second generation fermions, respectively. The contribution from the third generation is neglected due to the nature of (anti)protons. We consider two kinds of uncertainties: the PDF uncertainties (90% CL intervals provided by the MSTW PDF package) and the scale variation uncertainties ($\mu_R = \mu_F = \mu$, $M/2 \le \mu \le 2M$).

The cross section then can be written as $\sigma_{DY} \pm \Delta\sigma_{PDF} \pm \Delta\sigma_{\mu}$.

In addition to the *Z′* couplings, there are another two unknown *Z′* parameters that affect σ_{DY}. These are the *Z′* mass $m_{Z'}$ and decay width $\Gamma_{Z'}$. The latest data from the CMS and ATLAS indicates that *Z′* is heavier than 2.27 TeV. This means, that for energies close to the *Z* peak the σ_{DY} dependencies on $m_{Z'}$ and $\Gamma_{Z'}$ can be neglected, assuming that the *Z′* peak is far away from this range of values.

The *Y* and *y* values that we can investigate are limited by detector. The selection citerium for muons at the D0 Collaboration is that the (anti)muon pseudorapidity must be in the range $|\eta_{\pm}| \le 2.35$ [9]. Therefore, $|Y| \le 2.35$. The limits for *y* are the same as for *Y*.

4. Integrating by *M* and *y*

The intermediate-state rapidity *Y* enters the PDF factors only. In our paper [6] we proposed a way of integrating the cross section by *Y* with an *M*-dependent weighting function. Such integration allowed to reduce the number of unknown free parameters that enter the cross section from 6 to 4. In what follows we will use the numerical results of our work [6] and investigate the *Y*-integrated cross section:

$$\sigma_1 \;=\; \sigma_{1SM} + \bar{a}^2\sigma_{1\bar{a}^2} + \bar{a}\bar{v}_\mu\sigma_{1\bar{a}\bar{v}_\mu} + \bar{a}\bar{v}_u\sigma_{1\bar{a}\bar{v}_u} + \bar{v}_u\bar{v}_\mu\sigma_{1\bar{v}_u\bar{v}_\mu}\,. \tag{7}$$

Our next step is to use the remaining two kinematic variables, *M* and *y*, to get rid of another two unknown combinations of the *Z′* couplings.

The difference of the pseudorapidities, *y*, enters the parton-level cross section of the Drell-Yan process, $\sigma_{q\bar{q}\to\mu^+\mu^-}$, only and is irrelevant for the PDF analysis. In general, the parton-level cross section depends also on *M* through four «resonant» functions:

$$\begin{aligned}
f_1(M) &= \frac{1}{(M^2/m_Z^2-1)^2+\Gamma_Z^2/m_Z^2}, \quad f_2(M)=\frac{(M^2/m_Z^2-1)}{(M^2/m_Z^2-1)^2+\Gamma_Z^2/m_Z^2},\\
f_{2'}(M) &= \frac{(M^2/m_{Z'}^2-1)}{(M^2/m_{Z'}^2-1)^2+\Gamma_{Z'}^2/m_{Z'}^2},\\
f_3(M) &= \frac{M^2\Gamma_Z\Gamma_{Z'}/(m_Z^3 m_{Z'})+(M^2/m_Z^2)(M^2/m_Z^2-1)(M^2/m_{Z'}^2-1)}{[(M^2/m_Z^2-1)^2+\Gamma_Z^2/m_Z^2][(M^2/m_{Z'}^2-1)^2+\Gamma_{Z'}^2/m_{Z'}^2]}.
\end{aligned} \tag{8}$$

Here $m_{Z,Z'}$ and $\Gamma_{Z,Z'}$ denote the masses and widths of the *Z* and *Z′* bosons. We investigate the energy region close to the *Z* boson peak. As it was noted earlier, in this case we do not care about the specific values of the *Z′* mass and decay widths. But at this point for numerical calculations we are going to set specific values for $m_{Z'}$ and $\Gamma_{Z'}$.

Following the recent LHC results [2], we set $m_{Z'}$ to 2.5 TeV and assume the decay width to be 10% of the mass. In fact this means an asymptotic approximation of f_2' and f_3 at $M \ll m_{Z'}$. As it can be seen from Eq. (8), the f_1 function is dominant. In the discussed *Z*-peak region the functions f_2, f_3 are odd-like with respect to $M = m_Z$, and the function f_2' is small. As a consequence, after integrating by *M* over the region the functions f_2, f_2', and f_3 are negligible compared to f_1. We are going to use the discussed feature in what follows.

When investigating the *M*-dependence of the hadronic cross section σ_1, we deal not with the resonant functions themselves, but with their products with the PDF factors. The general form of σ_1 can be written as

$$\sigma_1 - \sigma_{1\mathrm{SM}} = \mathrm{sech}^4 y \cosh 2y \left[a(M) \tanh 2y + b(M) \right], \tag{9}$$

where *a*(*M*) and *b*(*M*) are some functions that include the unknown couplings $\bar{a}$, $\bar{v}_u$, and $\bar{v}_\mu$. The *M*-dependence arises from the "resonant" functions multiplied by $F_{q\bar{q}}(M)$ from Eq. (5). The results obtained in [6] indicate that the factors $F_{q\bar{q}}(M)$ are smooth, monotonic, and slowly-varying in the considered region. Therefore, we stress that all the discussed properties of f_1, f_2, f_2', and f_3 are generally maintained when these functions are multiplied by $F_{q\bar{q}}(M)$.

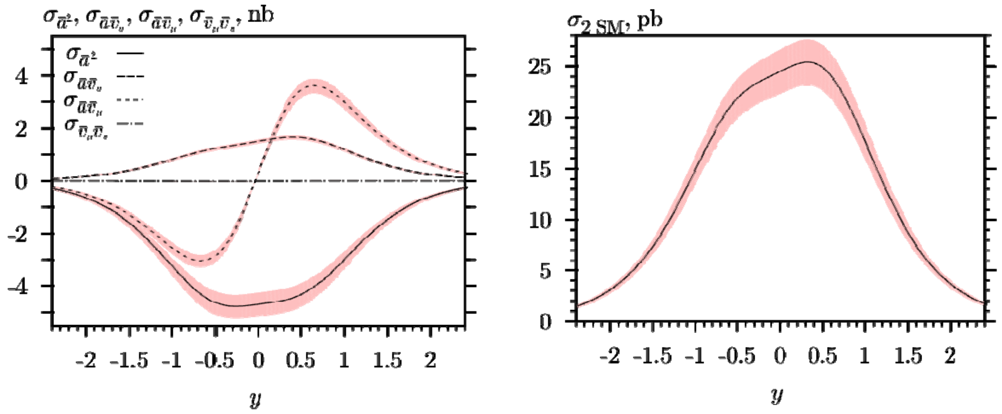
Naturally, f_2' and f_3 do not enter the SM part $\sigma_{1\mathrm{SM}}$. There are four factors entering the Z' contribution: $\sigma_{1\bar{a}^2}$, $\sigma_{1\bar{a}\bar{v}_\mu}$, $\sigma_{1\bar{a}\bar{v}_u}$, and $\sigma_{1\bar{v}_u\bar{v}_\mu}$ (see Eq. (7)). The factor $\sigma_{1\bar{v}_u\bar{v}_\mu}$ does not depend on f_1, and, therefore, according to our discussion of properties of the "resonant" functions we may eliminate it by the straightforward integration by *M* over the *Z*-peak region (66 GeV ≤ *M* ≤ 116 GeV). The resulting value is denoted σ_2:

$$\begin{aligned} &\sigma_2 - \sigma_{2\mathrm{SM}} = \int dM (\sigma_1 - \sigma_{1\mathrm{SM}}) = \mathrm{sech}^4 y \;\; \cosh 2y \left(a \tanh 2y + b \right), \\ &\sigma_2 = \sigma_{2\mathrm{SM}} + \bar{a}^2 \sigma_{2\bar{a}^2} + \bar{a}\bar{v}_\mu \sigma_{2\bar{a}\bar{v}_\mu} + \bar{a}\bar{v}_u \sigma_{2\bar{a}\bar{v}_u}, \quad a = \int dM\, a(M), \quad b = \int dM\, b(M). \end{aligned} \tag{10}$$

The factors $\sigma_{2\mathrm{SM}}$, $\sigma_{2\bar{a}^2}$, $\sigma_{2\bar{a}\bar{v}_\mu}$, $\sigma_{2\bar{a}\bar{v}_u}$, and $\sigma_{2\bar{v}_u\bar{v}_\mu}$ are plotted in Fig. 1. It can be seen that $\sigma_{2\bar{v}_u\bar{v}_\mu}$ is negligibly small compared to the other three factors.

We are not concerned about $\sigma_{2\mathrm{SM}}$ at the moment and shall turn to investigating the *y*-dependence of the *Z′*-related contribution presented in Eq. (10). The behavior of the $\sigma_{2\bar{a}\bar{v}_u}$ factor is governed by its odd part, while the $\sigma_{2\bar{a}^2}$ and $\sigma_{2\bar{a}\bar{v}_\mu}$ factors are obviously dominated by their even parts. From the plots in Fig. 1 (a), one can conclude that it is possible to suppress one of the three factors by integrating the cross section by *y* over a symmetric region. Remember, that the integration limits for *y* are the same as for *Y*. In our case -2.35 ≤ *y* ≤ 2.35. The resulting observable can be obtained by integrating σ_2 with a weight function $\omega(y)$

$$\sigma^* = \int dy\, \omega(y) \sigma_2, \quad \omega(y) = \tanh 2y + k. \tag{11}$$



(a) **(b)**

Fig. 1. Plots for (a) the ***Z′*** **factors and (b) $\sigma_{2\mathrm{SM}}$ from Eq. (10) (including the uncertainty bands).**

Just like the *Z′* contribution to σ_2, this is a sum of odd and even functions of *y*. Here *k* is a numerical constant. We will adjust the value of this constant, so that the contribution of one of the remaining three factors becomes negligible when integrated by *y*. After the integration we obtain

$$\begin{aligned}
\sigma^* - \sigma^*_{\mathrm{SM}} &= \int_{-Y_m}^{Y_m} dy(\tanh 2y + k)\sigma_2 \\
&= \{\frac{\tanh y}{3}\left[12a + bk\left(4 - \frac{1}{\cosh^2 y}\right)\right] - 4a\arctan(\tanh y)\}\Big|_{-Y_m}^{Y_m}, \qquad (12) \\
\sigma^* &= \sigma^*_{\mathrm{SM}} + \overline{a}^2\sigma^*_{\overline{a}^2} + \overline{a}\overline{v}_\mu\sigma^*_{\overline{av}_\mu} + \overline{a}\overline{v}_u\sigma^*_{\overline{av}_u}.
\end{aligned}$$

Note, that due to the symmetric integration region only the even part of the function $\omega(y)\sigma_2$ survives. The factors σ^*_{SM}, $\sigma^*_{\overline{a}^2}$, $\sigma^*_{\overline{av}_\mu}$, and $\sigma^*_{\overline{av}_u}$ are linear functions of *k*.

Let us construct an observable that is suitable for fitting of the axial-vector coupling $\overline{a}$ and the coupling to the up-quark vector current, $\overline{v}_u$. That is, the factor $\sigma^*_{\overline{av}_\mu}$ has to be suppressed. We choose the suppression criteria

$$|\sigma^*_{\overline{av}_\mu}| < 0.01|\sigma^*_{\overline{a}^2}|, \qquad |\sigma^*_{\overline{av}_\mu}| < 0.01|\sigma^*_{\overline{av}_u}| \qquad (13)$$

to calculate *k* in Eq. (12). Solving (13) one obtains $-9.18 \le k \le -8.55$. If we set $k = -9$, the resulting observable will contain only two unknown *Z′* parameters

$$\sigma^* = \sigma^*_{\mathrm{SM}} + \overline{a}^2\sigma^*_{\overline{a}^2} + \overline{a}\overline{v}_u\sigma^*_{\overline{av}_u}. \qquad (14)$$

The numerical values are presented in Table 1. This specific observable allows us to perform fitting of the $\overline{a}$ and $\overline{v}_u$ couplings. There are two other possible observables in this approach: the one with suppressed $\sigma^*_{\overline{av}_u}$ and the one with suppressed $\sigma^*_{\overline{a}^2}$. However, the latter case cannot be realized in our scheme with suppression factor 0.01, because the intervals obtained for the lower and upper bounds from (14) do not overlap.

Table 1

Couplings entering each of the two considered observables, together with the corresponding values of *k*, the SM contribution σ^*_{SM}, and the factors $\sigma^*_{\bar{a}^2}$, $\sigma^*_{\overline{av}_u}$, and $\sigma^*_{\overline{av}_\mu}$.

Couplings	k	σ^*_{SM}, pb	$\sigma^*_{\bar{a}^2}$, nb	$\sigma^*_{\overline{av}_u}$, nb	$\sigma^*_{\overline{av}_\mu}$, nb
$\bar{a}^2$, $\overline{av}_u$	-9	-569±48	111±10	-34.5±1.5	suppressed
$\bar{a}^2$, $\overline{av}_\mu$	-0.12	-4.23±0.26	1.82±0.14	suppressed	7.02±0.52

The model-independent analysis of the LEP II data [3-5] resulted in obtaining upper bounds for $\bar{a}^2$ and $\bar{v}_\mu^2$ at 95% CL, both of order of (a few $\times 10^{-4}$). From Fig. 1 (a), (b) and Table 1 it can be seen that in case of the second observable (where $\sigma^*_{\overline{av}_u}$ is suppressed) these upper bounds are too large, since when substituted into Eq. (6) they lead to a large deviation from the SM, which is not confirmed by any of the experimental data. Therefore, we may expect at least some significant improvement of the LEP-motivated bounds.

Neither LEP data nor Tevatron or LHC data shows any explicit indications of the Abelian *Z'*. This provides motivation to investigate models with the so called leptophobic *Z'*. In these models *Z'* boson couplings to the SM leptons are strongly suppressed compared to the quark couplings. From the Lagrangian in Eq. (1) and the relations in eq. (3) it follows that in the leptophobic case v_l, a_l, and a_q are small compared to v_q, and the leading *Z'* contributions to the cross section are

$$\sigma_{\mathrm{DY}} = \sigma_{\mathrm{SM}} + \sigma_{Z'}, \quad \sigma_{Z'} = \overline{av}_u \sigma_{\overline{av}_u} + \bar{v}_u \bar{v}_\mu \sigma_{\bar{v}_u \bar{v}_\mu} + \overline{av}_c \sigma_{\overline{av}_c} + \bar{v}_c \bar{v}_\mu \sigma_{\bar{v}_c \bar{v}_\mu} + O(\bar{a}^2, \overline{av}_\mu). \qquad (15)$$

After applying all the integrations discussed in this paper and in [6], we end up with the observable where only the term $\overline{av}_u \sigma^*_{\overline{av}_u}$ survives. This observable is one-parametric:

$$\sigma^* \;=\; \sigma^*_{\mathrm{SM}} + \overline{av}_u \sigma^*_{\overline{av}_u}. \qquad (16)$$

The numerical values are the same as in the second line of Table 1.

5. Conclusions

The data analysis performed by the LHC and Tevatron collaborations resulted in setting model-dependent lower bounds on the *Z'* mass. In that analysis only the high-energy region of the Drell-Yan cross section was considered. In our paper we present a different approach that allows to search for a *Z'* signal in the $p\bar{p} \to l^+ l^-$ process at the energies near m_Z. In this region the most important contributions at the *Z* peak come from the *Z*-*Z'* mixing angle and *Z'*-induced contact couplings. Our approach utilizes the model-independent relations between the effective *Z'* couplings. Therefore, in case no signal is observed one would still be able to derive constraints for different *Z'* models and compare them to the ones presented in [2].

The obtained two alternative observables can be used in fitting the experimental data on the $p\bar{p} \to l^+ l^-$ scattering collected by the Tevatron collaborations. This allows to constrain the *Z'* vector axial-vector couplings to SM fermions. In the case of the leptophobic *Z'* boson, there is a one-parametric observable containing the combination of couplings $\overline{av}_u$. There is a large amount of data on leptonic scattering processes collected in the LEP and LEP II experiments. The second observable in Table 1 contains the coupling combinations $\overline{a}^2$ and $\overline{av_e}$ that also enter lepton scattering processes. It seems to be attractive for combined fits of the LEP and Tevatron data.

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