Printed ISSN 1330–0016
Online ISSN 1333–9133
CD ISSN 1333–8390
CODEN FIZBE7

DIFFRACTIVE HIGGS AND DIJET PRODUCTION AT COLLIDERS

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Received 13 November 2007; Accepted 20 February 2008
Online 11 July 2008

Theoretical and phenomenological aspects of diffractive production of Higgs boson and dijets at high-energy colliders are briefly reviewed.

PACS numbers: 13.85.-t, 14.80.Bn, 13.87.-a UDC 539.125
Keywords: diffraction, Higgs, jet

1. Introduction

The advent of high-energy particle colliders, such as DESY HERA, Fermilab Tevatron and forthcoming CERN LHC, provides a good opportunity to study diffractive (rapidity gap) physics which is intimately related with hard QCD diffraction, i.e., diffraction based on the partonic structure of Pomeron [1]. The partonic structure of Pomeron is established by diffractive jet production in hadron-hadron [2 – 5] and lepton-hadron [6] processes.

For the intermediate mass Higgs boson ($m_{\rm H} \leq m_{\rm W}$) searches at LHC, the diffractive processes can be the most important tool for its discovery. The experimental signatures for the heavier Higgs boson mass should be very pronounced, while for the intermediate mass the usual inelastic inclusive Higgs boson production faces a huge background.

Originally, large rapidity gap physics for Higgs boson searches in hadronic collisions via electroweak boson fusion was suggested in Ref. [7]. The idea was that, due to colourless exchange by electroweak bosons, there is no hadron activity in wide rapidity intervals. Basically, one should see Higgs boson signal with rapidity gaps without strong hadronic background.

The double-diffractive Higgs boson production in the central region via double-Pomeron exchange, another process with colourless flow in the t-channel and a larger cross section, was proposed in Refs. [8 – 10]. Such a process, shown in Fig. 1, which is also called double-Pomeron-exchange process, belongs to the class of multi-Regge processes. The multi-Regge processes, in particular the double-Pomeron exchange, were introduced in Ref. [11] and they have been considered in numerous papers, see, e.g., Refs. [12].

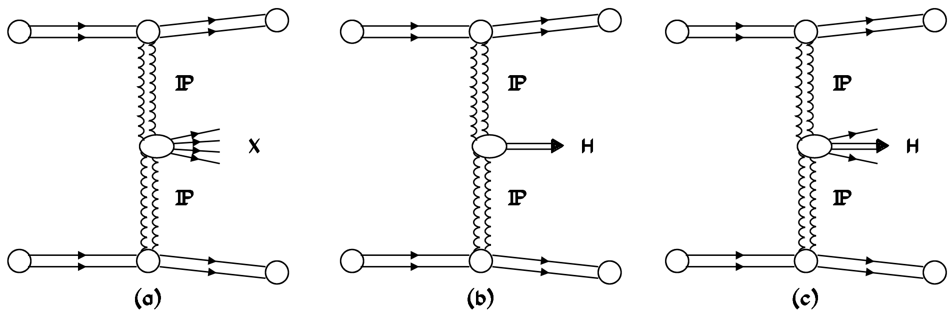

Fig. 1. The double-diffractive processes for production in central region via double-Pomeron exchange: (a) double-Pomeron exchange for inelastic central production; (b) exclusive central Higgs boson production; (c) inclusive central inelastic Higgs boson production.

Unfortunately, the available theoretical predictions on double-diffractive Higgs boson production in the central region [8], [13] – [19] are very spread in the predicted values for the cross sections. The spread of the predictions is about 10^3(!). This is because of the very complicated problems of QCD diffraction, such as factorisation, survival probabilities, etc.

In such circumstances it is impossible to figure out definite expectations for double-diffractive Higgs boson production, which has a unique discovery potential at the Tevatron and especially at the LHC (see Refs. [20] – [22]).

The most important issue concerning the uncertainty is a large factorisation breaking of hard diffractive processes. It is known from data that, according expectations of the partonic model for Pomeron by Ingelman-Schlein, the diffractive structure function factorises into flux factor of Pomeron and Pomeron structure function in both $\bar{p}p$- and ep-data. However, diffractive structure function extracted from $\bar{p}p$-collisions of CDF at Tevatron is below the ep data from HERA by an order of magnitude.

The difference may be caused by the different survival probabilities [23, 24], related to the nonperturbative multi-Pomeron exchanges in hadron-hadron and lepton-hadron processes.

So, now it is generally accepted that the most reliable predictions for diffractive Higgs boson production should reproduce hard difraction data in $\bar{p}p$-collisions of CDF at Tevatron. The other existing $\bar{p}p$-collision data from $S\bar{p}pS$-collider at CERN by UA8 Collaboration are not suitable for a complete analysis, because they are uncorrected for detector acceptance/efficiency. But soon some new results from UA8 will be available [25].

In the next sections we consider the available predictions for Higgs boson production by double-Pomeron-exchange and single-Pomeron-exchange processes, and present some summary remarks.

2. *Higgs boson production in double-Pomeron-exchange processes*

Single diffraction cross section via single-Pomeron exchange reads

$$\frac{\mathrm{d}\sigma^{\mathrm{SPE}}}{\mathrm{d}t\mathrm{d}\xi} \quad = \quad F_{I\!P/N}(t,\xi)\cdot\sigma^{\mathrm{tot}}_{I\!PN}(s'), \tag{1}$$

where ξ is a fraction of the momentum loss by the diffracting nucleon, $-t$ is the squared transferred momentum, $\alpha_{I\!P}(t)$ is the Pomeron trajectory, $F_{I\!P/N}(t,\xi)$ is the flux factor of the Pomeron.

In the case of the double-diffraction due to double-Pomeron-exchange process with production in central region, the following factorisation relation holds (it has been obtained by the UA8 Collaboration [4])

$$\sigma^{\mathrm{tot}}_{I\!PI\!P}(s') = \frac{\left[\sigma^{\mathrm{tot}}_{I\!PN}(s')\right]^2}{\sigma^{\mathrm{tot}}_{NN}(s')}, \tag{2}$$

where $\sigma^{\mathrm{tot}}_{I\!PI\!P}$, $\sigma^{\mathrm{tot}}_{I\!PN}$ and $\sigma^{\mathrm{tot}}_{NN}$ are the total cross sections of Pomeron-Pomeron, Pomeron-proton and proton-proton collisions, correspondingly.

Therefore, the double-diffraction cross section with production in the central region via double-Pomeron exchange, depicted in Fig. 1a, is of the form

$$\frac{\mathrm{d}\sigma^{\mathrm{DPE}}}{\mathrm{d}\xi_1\mathrm{d}\xi_2\mathrm{d}t_1\mathrm{d}t_2\mathrm{d}\phi_1\mathrm{d}\phi_2} = F_{I\!P/N}(t_1,\xi_1)\cdot F_{I\!P/N}(t_2,\xi_2)\cdot\sigma^{\mathrm{tot}}_{I\!PI\!P}(s'), \tag{3}$$

where ξ_1 and ξ_2 are momentum fractions carried by the colliding Pomerons, $s' = \xi_1\xi_2 s = m_X^2$ is the squared invariant mass of the produced system by the Pomeron-Pomeron collision.

The hard diffraction, according Ingelman-Schlein, implies that the above Pomeron-proton $\sigma^{\mathrm{tot}}_{I\!PN}(s')$ and Pomeron-Pomeron $\sigma^{\mathrm{tot}}_{I\!PI\!P}(s')$ total cross sections factorise into parton-parton cross section and Pomeron structure function(s).

The parton distribution of the Pomeron can be taken in the following form

$$F_{p/I\!P}(x) = (1-P_g)\cdot\Big(F_{q/I\!P}(x)+F_{\bar{q}/I\!P}(x)\Big)+P_g\cdot F_{g/I\!P}(x), \tag{4}$$

where P_g and $(1 - P_g)$ are fractions of the gluon and quark-antiquark contents of the Pomeron, respectively. According to the diffraction HERA data, the partonic structure of the Pomeron is dominant by gluons, $P_g \simeq 0.7 - 0.8$.

If a partonic nature of the Pomeron is assumed, then the parton distributions of the effective Pomeron should obey the following momentum sum rule

$$\begin{aligned} \int_0^1 dx \cdot xF_{N/I\!P}(x) &= \int_0^1 \mathrm{d}x \cdot x(2F_{q/I\!P}(x) + F_{g/I\!P}(x)) \\ &= 2 < x_q > + < x_g > = (1 - P_g) + P_g = 1. \end{aligned} \tag{5}$$

The dominant contribution for diffractive jet (and Higgs) production comes, like in the usual inelastic collisions, from the gluon distributions. As shown by UA8 data on diffractive jet production [2], gluon distribution in Pomeron can be parameterised in the following way

$$F_{g/I\!P}(x) = 0.13 \cdot 6(1-x)^5/x + 0.57 \cdot 6(1-x) + 0.3 \cdot \delta(1-x)\,. \tag{6}$$

This parameterisation is compatible with the HERA data [6]. Note, that the probability of about 0.3 to have the "super-hard" gluon component of the Pomeron [2] corresponds to the case when the total momentum of the colliding Pomeron is carried by one gluon. A more detailed discussion on the "super-hard" Pomeron component as a coherent effect can be found in Refs. [26].

Therefore, the diffractive gluon structure function in nucleon reads as follows

$$xF^{\mathrm{D}}_{g/N} = xF_{I\!P/N} \otimes F_{g/I\!P}, \tag{7}$$

where $\otimes$ denotes the Mellin convolution of two functions

$$f \otimes h \equiv \int_0^1 \mathrm{d}y \int_0^1 \mathrm{d}z f(y)h(z)\delta(x - yz) = \int_x^1 (\mathrm{d}y/y) f(y) h(x/y)\,.$$

Then the total double-diffractive Higgs boson production cross section in the central region is

$$\sigma^{\mathrm{DPE}}\mathrm{H} = \int_{m_X} \mathrm{d}m \int \mathrm{d}x_1 \int \mathrm{d}x_2\ F^D_{g/N}(x_1) F^D_{g/N}(x_2) \cdot \sigma_{gg\to H}(M\mathrm{H}, \sqrt{x_1 x_2 s} = m)\,. \tag{8}$$

One can make an upper estimate of the exclusive double-diffractive Higgs boson production via the "super-hard" component of the Pomeron (Fig. 1b).

We present in Fig. 2 the results based on the UA8 data at $\sqrt{s} = 630$ GeV [4] for Higgs boson production via double-Pomeron exchange at Tevatron and LHC.

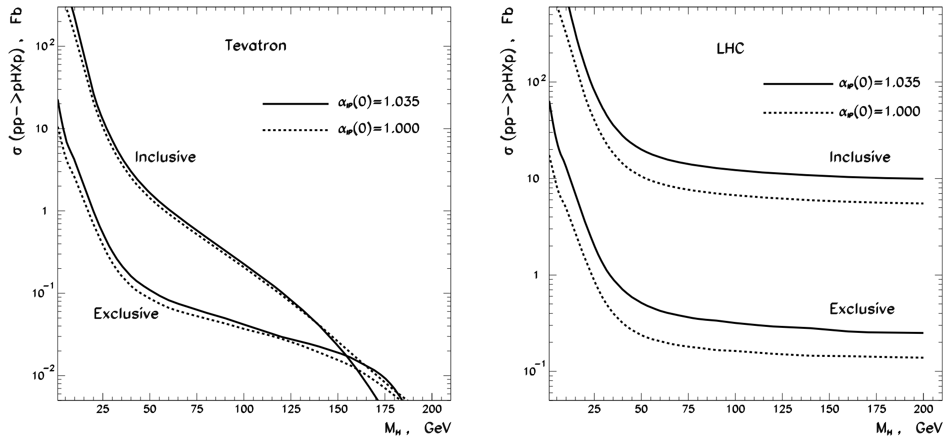

Fig. 2. The cross section of exclusive $pp \to pHp$ and inclusive $pp \to pHXp$ double-diffractive Higgs boson production suggested by UA8 data for: (a) the Tevatron and (b) the LHC.

At the Tevatron energy of $\sqrt{s} = 2$ TeV, the predictions yield too low values of the cross section in the exclusive channel to be observed.

Even at the LHC energy, the exclusive Higgs boson production via double-Pomeron-exchange process is practically out of reach: a few events per year.

The lowest-order perturbative QCD calculation for exclusive double-diffractive Higgs boson production [13] yieds a very tiny cross section: $\sim 10^{-7}$ fb for $M_{\rm H} = 120$ GeV at LHC. However, soft contributions and coherence effects drastically increase that result.

There are also predictions [28] based on the HERA data on diffractive structure functions. However, they are also very uncertain (the predictions are differ up to factor of about 600). The problem of compatibility of diffractive cross sections in deep inelastic lepton-hadron and hadron-hadron processes makes reliable theoretical predictions difficult due to the large factorisation violation.

A detailed discussion concerning the comparison of those phenomenological calculations can be found in Ref. [22]. According to Ref. [22], most of the predictions that yield large values for double-diffractive Higgs boson cross sections (≥ 100 fb) for the LHC will face a problem of considerable overestimation for diffractive jet production at Tevatron [5].

A comparison of the predictions [27], based on the UA8 data and available theoretical predictions, is shown in Fig. 3 for the Tevatron and Fig. 4 for the LHC.

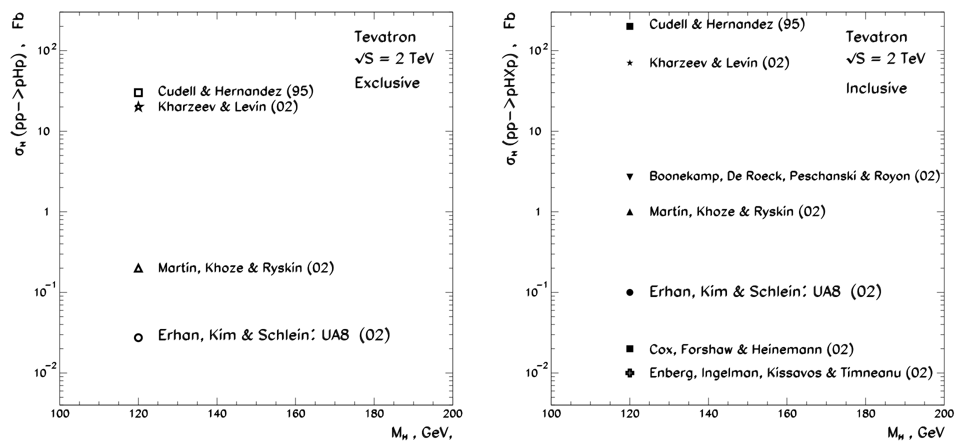

Fig. 3. Comparison of the predictions for the Tevatron, based on UA8 data, with available calculations for: (a) exclusive and (b) inclusive cross sections.

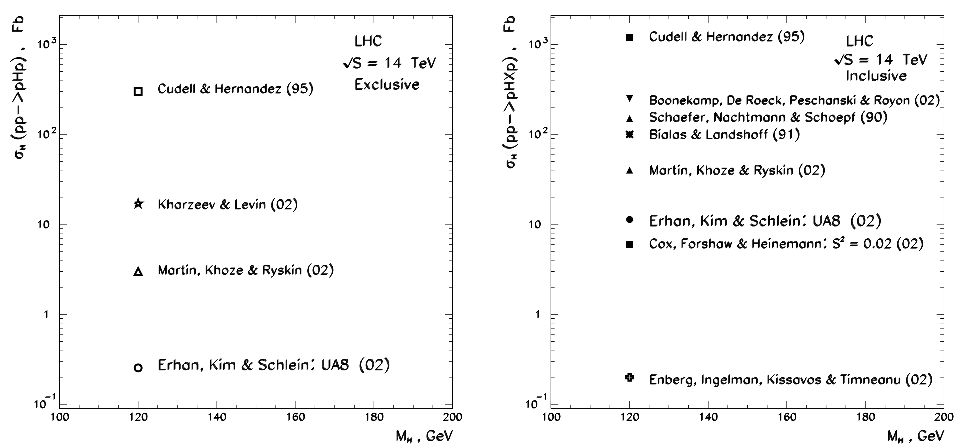

Fig. 4. Comparison of the predictions for the LHC, based on UA8 data, with available calculations for: (a) exclusive and (b) inclusive cross sections.

3. Higgs production in single-Pomeron-exchange processes

In the original papers [8, 9] for Higgs production in diffractive processes, along with the double-Pomeron exchange, also the single-Pomeron-exchange mechanism has been proposed (Fig. 5a).

It was shown in Ref. [29] that the inclusive single-Pomeron-exchange Higgs boson production is remarkably located in the central region like the double-Pomeron

Higgs production. So, because the single-Pomeron cross section is much larger, one would focus on the inclusive single-Pomeron-exchange Higgs boson production. However, in Refs. [28, 29] is shown that the inclusive single-Pomeron-exchange Higgs boson production does not have a particular advantage at the LHC, though in can be used as an additional channel for double-diffractive Higgs boson production studies. This is due to the fact that there is a huge backround by three orders of magnitude for dominant decay channel with b-quarks for inclusive case.

In the case of double-Pomeron exchange, one should use the *exclusive* channel, because one could apply final state selection rules [21] which reduce the background by a factor of about 3000! However, as it was mentioned above, the exclusive double-Pomeron-exchange process for Higgs boson productions yields very low rate.

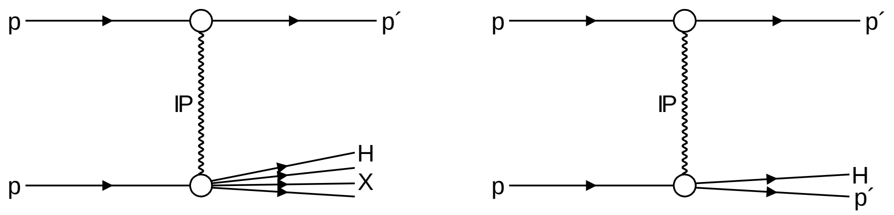

Fig. 5. Single-Pomeron-exchange diagrams for Higgs boson production in: (a) inclusive and (b) exclusive processes.

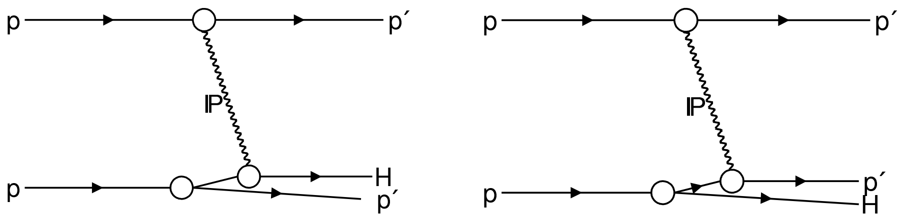

Fig. 6. Diagrams for Higgs boson emission (a) after and (b) before the exchange by Pomeron.

To avoid such problems, in Ref. [30], it has been suggested to consider the *exclusive* single-Pomeron-exchange process (see Fig. 5b and Fig. 6). The exclusive single-Pomeron-exchange process would be a very important channel for the searches of Standard Model Higgs boson with intermediate mass, due to its possible larger cross section. The caveat of this approach is that the prediction involves a rather uncertain factor, related with Higgs boson coupling to proton. In addition, in the exclusive process kinematics, the Higgs boson is produced in a very forward direction. Experimentally, it requires special dedicated subdetectors to the existing ATLAS, CMS and TOTEM detectors at the LHC. Because the main branching decay of the intermediate Higgs boson is $b\bar{b}$-channel [31], such a subdetector should tag b-jets with high accuracy.

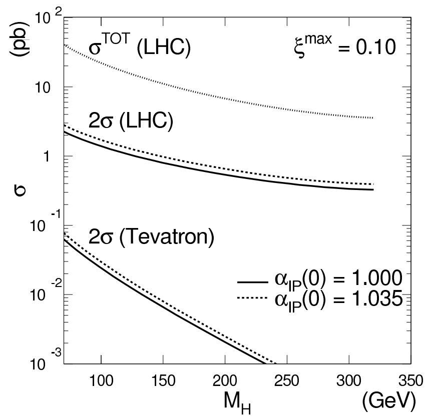

Fig. 7. The predictions for inclusive single-Pomeron exchange cross section at Tevatron and LHC energies based on UA8 data.

4. Summary

The present estimates for the exclusive diffractive production of Higgs boson in the double-Pomeron-exchange process yield low rates. Therefore, the outlooks for diffractive Higgs boson search at LHC are rather uncertain and bleak few events per year).

The new exclusive channel for diffractive Higgs boson production in the single-Pomeron-exchange is very promising, in spite of the unusual kinematics of very forward Higgs boson production. Unfortunately, the cross section contains some not very well known parameters which make the predictions rather uncertain.

It should be noted that most predictions are based on the diffractive structure function data from $\bar{p}p$-collisions of CDF at Tevatron, which are below the *ep* data from HERA by an order of magnitude. However, preliminary analysis [30] of CERN S$\bar{p}p$S data by UA8 does not show a large difference between the $\bar{p}p$- and *ep*-diffraction data. If confirmed, the absence of a large factorization breaking can be very important for searches of diffractive Higgs production at Tevatron and LHC colliders. Then Higgs boson production cross section in diffractive processes will be much larger than the current expectations.

Acknowledgements

V.T.K. is very grateful to the HS'07 organizers for their wonderful hospitality and support. The work is supported in part by the Russian Foundation for Basic Research, grant 06-02-72041.

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DIFRAKTIVNA TVORBA HIGGSA I DVOJNIH MLAZOVA U SUDARAČIMA

Dajemo kratak pregled teorijskih i fenomonoloških ocjena difraktivne tvorbe bozona Higgs i dvojnih mlazova u visokoenergijskim sudaračima.