Diffractive Higgs boson production
(A brief guide to the main Durham results)

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1 The possible processes for Higgs production with two rapidity gaps

Within the perturbative QCD framework, we have considered the Central Exclusive Diffractive (CED) process

$$pp \to p \ + \ H \ + \ p, \tag{1}$$

the inclusive Central process, with the Diffractive Dissociation (CDD) of both protons,

$$pp \to M_1 \ + \ H \ + \ M_2, \tag{2}$$

and Central inelastic (C-inel.)

$$pp \to p \ + \ (M \to HX) \ + \ p \tag{3}$$

diffractive Higgs production[1, 2, 3]. In each case a + sign denotes the presence of a large rapidity gap.

A critical review of the relative merits of searching for Higgs bosons by these types of diffractive processes is given in Ref. [3]. The situation is briefly summarized in Fig. 1, together with the leading order QCD diagram of each process.

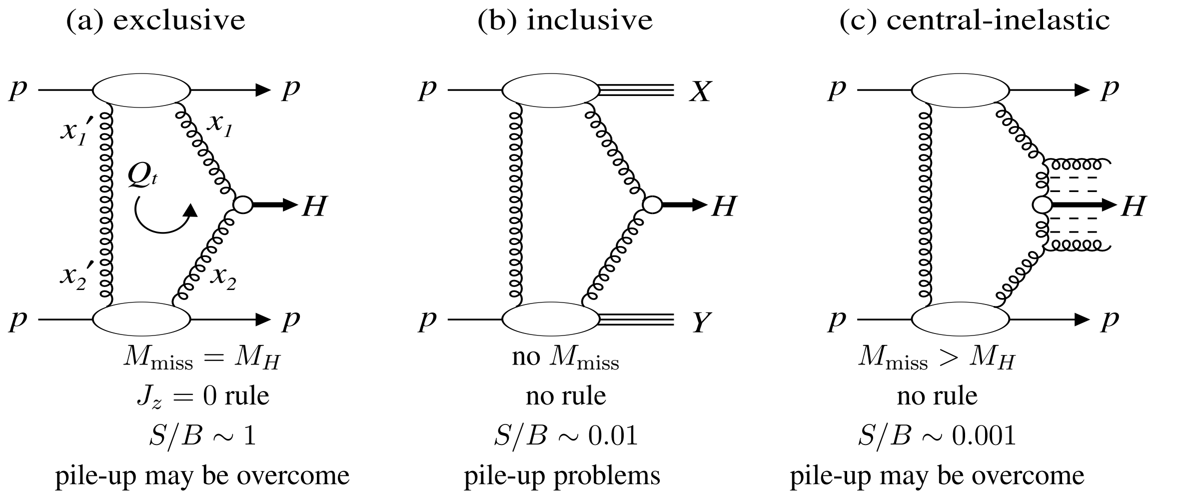

Fig. 1: Different processes for double-diffractive Higgs production in pp collisions in terms of perturbative QCD. The signal-to-background ratios, S/B, are given for $H \to b\bar{b}$. Pile-up refers to the multiple interactions per bunch crossing at the LHC.

2 The advantages of exclusive production

In spite of a small cross section[4] (at LHC $\sigma^{\mathrm{excl.}}(H) \sim 10^{-4}\sigma^{\mathrm{tot}}_{\mathrm{incl.}}(H)$) the exclusive reaction (1) has the following advantages.

a) The mass of the Higgs boson (and, in some cases, the width) can be measured with high accuracy by the missing mass method, if the forward outgoing protons are tagged. This allows the possibility of matching the missing mass measured by the forward proton detectors with the mass of the Higgs decay products observed in the central detector.

b) The leading order $b\bar{b}$ QCD background is suppressed by a P-even $J_z = 0$ selection rule (where the z axis is along the direction of the proton beam). Therefore one can observe a light Higgs boson (of mass $M_H \lesssim 130$ GeV) via the main decay mode $H \to b\bar{b}$.

c) The quantum numbers of the central object (in particular C- and P-parities) can be analysed by studying the azimuthal angular distribution of the tagged protons[5]. This is quite general and applies, not just to $H \to b\bar{b}$, but to $H \to WW^*, \tau\tau$ etc. Due to the selection rules, the production of 0^{++} states are strongly favoured. Note that there is no obvious way to establish the H spin-parity by conventional approaches at the LHC. For $M_H \gtrsim 140$GeV the WW^* decay mode takes over, with essentially negligible background in the mixed lepton-hadron final state.

d) There is a very clean environment for exclusive production – the soft background is strongly suppressed.

3 The $J_z = 0$ selection rule

The $J_z = 0$, parity even, selection rule[6, 7] is an important ingredient in our approach. $J_z = 0$ originates from s-channel helicity conservation of the forward protons in the case when the transverse momenta of the protons $p_{ti} = 0$, with $i = 1, 2$. The admixture of the $|J_z| = 2$ amplitudes is governed by the product

$$(p_{t1} \cdot r)\,(p_{t2} \cdot r) \;\simeq\; \langle p_t^2 \rangle / Q_T^2, \tag{4}$$

where the transverse size of the digluon Pomeron $r \sim 1/Q_T$, and Q_T is the transverse momentum in the gluon loop. Thus the $|J_z| = 2$ contribution to the cross section is suppressed by a factor p_t^4/Q_T^4. Another important ingredient in the calculation of the cross section is the presence of the Sudakov form factor which provides the infrared stability of the Q_T integral over the gluon loop. Typically, the main contribution comes from the saddle-point region of the loop integral, namely $Q_T^2 \sim 4\ \mathrm{GeV}^2$ for the CED production of a Higgs of mass $M_H = 120$ GeV at the LHC energy, and so ensures that $J_z = 0$ is a very good approximation.

The P even selection reflects the symmetry between the active gluons emitted from the two incoming protons.

4 The cross sections for the exclusive signal and the $b\bar{b}$ background

We have evaluated the cross sections and background for the exclusive process, (1), and show that a signal-to-background ratio of up to

$$S/B \;\simeq\; 3\,(1\mathrm{GeV}/\Delta M) \tag{5}$$

can be reached for a 120 GeV Standard Model (SM) Higgs boson at the LHC. This corresponds to a statistical significance of roughly $3.7\sigma\ \sqrt(1\mathrm{GeV}/\Delta M)$. That is, if almost the whole Higgs signal can be collected within the interval $\Delta M = 1$ GeV, then $S/B \simeq 3$, corresponding to a 3.7σ signal for an integrated luminosity $\mathcal{L} = 30\ \mathrm{fb}^{-1}$. In the case of a Gaussian missing mass distribution of width σ, about 87% of the signal is contained in a bin $\Delta M = 3\sigma$, that is $M = M_H \pm 1.5\sigma$.

Other diffractive channels (2,3) are worse than the usual totally inclusive production – there is no precise missing mass measurement, no selection rule to suppress the background and more serious pile-up problems. The somewhat smaller density of soft secondary hadrons in the Higgs rapidity region does not compensate a much smaller statistics (cross sections) in diffractive processes.

We estimate the uncertainty of the prediction for a 0^+ Higgs boson production to be about factor of 2.5 (up or down)[8]; for example, the cross section for the CED production and $b\bar{b}$ decay of a $M_H = 120$ GeV SM Higgs boson is in the range $\sigma^{\rm excl} = 0.9\ -\ 5.5$ fb.

Note that the CED cross section may be written in the factorized form $\sigma = \mathcal{L}\hat{\sigma}$ where $\hat{\sigma}$ is the cross section of the *colour singlet* hard subprocess and $\mathcal{L}$ is the effective gg^{PP} luminosity. The mass dependence of $\mathcal{L}$ at the LHC can be approximated by $\mathcal{L} \propto (M + 16\ \mathrm{GeV})^{-3.3}$, see [8]. Plots of the luminosity $\mathcal{L}$ and the expressions for $\hat{\sigma}^{\rm excl}$ can be found in [1]. For example, for the production of a $M = 120$ GeV SM Higgs boson at the LHC ($\sqrt{s} = 14$ TeV) the exclusive luminosity $d\mathcal{L}^{\rm excl}/dyd\log M^2 = 6 \times 10^{-4}$ (see Fig.2 of [1]), while $\hat{\sigma}^{\rm excl} = 1 \cdot \delta(1 - M^2/M_H^2)$ pb. Thus $d\sigma^{\rm excl}/dy = 0.6$ fb.

We emphasize the importance of radiative corrections to the QCD $b\bar{b}$ background process. These are more crucial than in the conventional inclusive case, since the Born amplitude is additionally suppressed by the $J_z = 0$ selection rule. We estimated the NLO/NNLO effects in [2, 3].

5 Production by WW and $\gamma\gamma$ fusion

In Ref. [9] we suggested that it may be possible to observe the production of Higgs boson with large transverse momenta ($p_t > 30$ GeV) with a rapidity gap on either side, which originate from weak vector boson fusion. Events of this type formally belong to the class given by eq. (2). The $b\bar{b}$, WW^* and $\tau\tau$ decay modes of the Higgs were considered. This mechanism could be a viable way to study the Higgs boson at the LHC.

We have also calculated the effective $\gamma\gamma$ luminosities, and evaluated Higgs production at the LHC via $\gamma\gamma$ fusion[1, 10].

6 Exclusive SUSY Higgs production

We have studied the production of MSSM Higgs bosons. For large values of $\tan\beta$ the exclusive cross section $\sigma^{\rm excl}$ may be a factor 10 (or more) larger than that for the SM case[8]. CED may cover the so-called troublesome regions of MSSM parameter space, where the conventional approaches face difficulties. Indeed, there is a good chance to observe in the CED process, (1), both 0^+ and maybe even the 0^- boson from the MSSM Higgs sector.

0^- production can be studied in the CDD process, (2), where there is no P-even selection rule, if we select events in which the transverse energy flows $\vec{E}_{T1}, \vec{E}_{T2}$ are almost perpendicular ($\cos\phi = 0$) to each other. In this way one can suppress 0^+ boson production.

We have also considered the production of all three $J = 0$ bosons in MSSM with CP violation in the Higgs sector[11]. We discuss an asymmetry, in the angular distribution of the outgoing protons, which directly indicates the violation of CP-parity.

In [12] we study the feasibility of observing an invisible Higgs boson in the CED process as a peak in the missing mass distribution.

7 The survival factors for the rapidity gaps

To calculate the soft gap survival factor $\hat{S}^2$ we developed a formalism which describes all available high energy elastic and total pp-cross sections with $|t| < 0.5$ GeV^2[13]. This formalism may be used to calculate the survival factors of gaps in other diffractive reactions. The energy dependence of the survival factor, in going from the Tevatron to the LHC energy, is well described by $\hat{S}^2_{\rm excl} \sim s^{-0.16}$. Actually the exclusive cross section, $\sigma^{\rm CED}$, of the process shown in Fig. 1(a), is proportional to the factor $\hat{S}^2/b^2$, which is almost constant in the relevant interval $b = 4 \ - \ 6$ GeV^{-2}, where b is the t-slope of the CED cross section.

8 Unintegrated gluon distributions

The unintegrated skewed gluon densities (needed to obtain the effective Pomeron-Pomeron (gg^{PP}) luminosity) were calculated, up to single log accuracy, based on the integrated (non-skewed) partons from the global parton analyses using the prescription of Ref.[14] (to obtain the q_t dependence) and the Shuvaev transform[15] to account for the skewed effect.

Unintegrated partons we have used, also describe successfully forward dijet production at HERA[16], large p_T prompt photons[14], and diffractive vector meson (ρ, ψ, Υ) production at HERA[17].

Strictly speaking for the Higgs production, we need unintegrated gluons $f_g(x, Q_T, \mu)$ at $Q_T \ll \mu$. For this region, $Q_T \ll \mu$, the Kimber et al. prescription[14], incorporating a single log T factor, may be checked by data for the W, Z bosons p_t distributions in W, Z boson hadroproduction. These data are well described by unintegrated *quarks*[18] (not gluons unfortunately) obtained using the same prescription.

9 Experimental checks

Up to now the diffractive experimental are consistent with our approach. We explain:

(i) the very low cross section of CED high E_T dijet production measured by CDF at the Tevatron[7, 19].

(ii) the difference (factorization breaking) between the "effective Pomeron structure functions" measured in diffractive processes at the Tevatron (CDF) and in diffractive DIS at HERA[20]. This is an important check for the survival factor $\hat{S}^2$.

Other confirmations are:

(iii) the HERA data on diffractive high E_T dijet production, which were described[21] by the NLO QCD accounting for the $\hat{S}^2$ suppression of the hadron-like (resolve) photon component and using the value of $\hat{S}^2$ given by the model of Ref.[13],

(iv) the ratio of high E_T dijet production in diffractive processes with one and two rapidity gaps[22].

The proton opacity $\Omega(b_t)$ (used to calculate $\hat{S}^2$) can be checked by the measurements of the azimuthal correlations of the forward tagged protons in the CED production[23] of rather light central objects (where the cross sections are larger), or by studying the q^2 and azimuthal dependence in reactions mediated by photon (with momentum q) exchange; for example: the exclusive central production of J/ψ at RHIC or at the Tevatron, or QED $\mu^+\mu^-$ or W production at the LHC[10].

The best possibility to check the whole approach is to measure the CED high E_T dijet production, which can be used as an effective gg^{PP} 'luminosity monitor' just in the kinematical region of the Higgs production[24]. The corrresponding cross section was evaluated to be about 10^4 times larger than that for the SM Higgs boson.

In addition, the CED production of high-E_T $\gamma\gamma$[19], χ_c and χ_b[25, 6] states have been predicted.

10 Gluon factory

CED dijet production may be used as an excellent 'gluon factory' to study pure gluonic jets[26].

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