Inclusive Double Diffractive Production of SUSY Particles at the LHC

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Abstract

We estimate the inclusive double diffractive production of SUSY particles at the LHC using a modified version of the POMWIG Monte Carlo event generator. The diffractive events are produced via the Ingelman–Schlein model for double pomeron exchange. The MSSM parameter space is scanned using the "Snowmass benchmark points" and it is shown that the lightest Higgs boson is the only SUSY particle with a large enough rate to be detected using these diffractive events.

1 Introduction

In this Letter we investigate inclusive hard diffractive production of supersymmetric (SUSY) particles at the Large Hadron Collider (LHC) at CERN. In these processes the hard scale is provided by the mass of the centrally produced system, in our case the mass of the heavy SUSY particles present in the Minimal Supersymmetric Standard Model (MSSM). In these reactions the distinctive feature is that the protons remain intact after the interaction, losing only a small fraction of their initial energy and escaping the central detectors. The signal would be a clear one with SUSY particles tagged in the central region of the detector accompanied by regions of low hadronic activity, the so-called "rapidity gaps". For the study of these diffractive interactions we have modified POMWIG [1], a modified version of the Monte Carlo event generator HERWIG [2,3,4,5], to include production of SUSY spectra. In Ref. [6] POMWIG has been used to predict the cross–sections for double diffractive Standard Model Higgs and di–photon production at the Tevatron and the LHC. SUSY particle production has been considered in other approaches in [7,8].

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The formalism used in POMWIG to estimate diffractive cross-sections is the Ingelman–Schlein model for diffractive hard scattering [9]. In this model the interaction is triggered by a "double pomeron exchange" and the production cross–section factorises into a product of a Regge flux factor and a parton distribution function. If the concept of Regge factorisation is to a good approximation universal then it can be applied to the present study using the diffractive parton distributions measured in deep inelastic scattering experiments at HERA, where this model has proved to be successful [10]. For the large centre–of–mass energy of the LHC the only Regge exchange needed to be taken into account is pomeron exchange, this is done using a pomeron flux factor $f_{\mathbb{P}/p}$ and a pomeron parton density $g(x, m_{\mathrm{X}}^2)$. In POMWIG the pomeron flux is parameterised as

$$f_{\mathbb{P}/p}(x_{\mathbb{P}}) = \int_{t_{\max}}^{t_{\min}} \frac{e^{B_{\mathbb{P}}\, t}}{x_{\mathbb{P}}^{2\,\alpha_{\mathbb{P}}(t)-1}} \qquad (1)$$

with $x_{\mathbb{P}}$ being the proton's energy fraction carried by the pomeron, t the proton momentum transfer, $B_{\mathbb{P}} = 4.6$ the diffractive slope and $\alpha_{\mathbb{P}}(t) = 1.20 + 0.26\, t$ the pomeron trajectory. For details on the choice of these values see Ref. [1]. This approach works well for the description of dijets at the Tevatron [11].

A theoretical uncertainty in the present estimates stems from the fact that, in processes where the incoming beam particles have hadronic structure, the rapidity gaps can be filled due to secondary interactions spoiling the clean signal [12,13]. This affects the prediction for the cross–sections by a normalisation factor mainly depending on the centre–of–mass energy. Based on recent estimates for LHC energies it is possible to take into account these effects by multiplying the obtained cross–section by a gap survival probability factor of $\sim 0.02 - 0.026$ [14,8].

In this Letter the focus is on double diffractive collisions of the form $p + p \rightarrow p + \mathrm{gap} + X + \mathrm{gap} + p$, where X represents the decay products of the SUSY particles and some pomeron remnants. To have a diffractive process the energy fraction lost by the incoming hadrons, which we call ξ, should be smaller than $\xi_{\max} = 0.1$. Ideally, proton tagging detectors in the forward and backward directions would be needed to take full advantage of these signals and to be able to reconstruct the masses of the new particles. The analysis of diffractive collisions is experimentally challenging, even at medium luminosity at the LHC the diffractive events would be contaminated by other non–diffractive interactions taking place in the same bunch crossing. In principle, to reconstruct the gap in the hard subprocess, it would be possible to use tracking subdetectors, for a discussion on this issue see Ref. [15]. In this work only signals are estimated, leaving the calculation of possible backgrounds for a future publication.

The paper is organised as follows: In Section 2 we reproduce previous results in the literature regarding Standard Model Higgs production. In Section 3 we study the production of SUSY particles to conclude that only the lightest Higgs boson has large enough cross–sections. In Section 4 we study its production at the different benchmark points characterizing the MSSM parameter space. In Section 5 we present our conclusions.

2 Standard Model Higgs Production

In this Section we reproduce some of the results in Ref. [6] for the double diffractive production of the Standard Model Higgs at the LHC. In this way we explain the methodology which will later be used in the SUSY case. We set the mass of the Higgs boson to be 115 GeV. In double diffractive Higgs production the total cross–section is calculated for $\xi < \xi_{\rm max}$ and reads

$$\sigma \simeq \frac{G_F \alpha_s^2}{288\pi\sqrt{2}} \frac{m_h^2}{s} \int_{m_h^2/s}^{1} \frac{dx}{x}\, g_1(x, m_h^2)\, g_2(\frac{m_h^2}{s\,x}, m_h^2) \tag{2}$$

where $\sqrt{s}$ is the hadron–hadron centre–of–mass energy, and

$$g_i(x, Q^2) = \int_{x}^{\xi_{\rm max}} d\xi_i\, f_{\,\mathbb{P}/i}(\xi_i)\, g_{\,\mathbb{P}}\!\left(\frac{x}{\xi_i}, Q^2\right) \tag{3}$$

a convolution of the pomeron flux and a parton distribution in the pomeron.

To evaluate the differential cross–sections $d\sigma/d\xi$ and $d\sigma/d\beta$, with β being the fraction of the pomeron momentum carried by the gluon, we work with an updated version of POMWIG using HERWIG version 6.5, which includes SUSY hard subprocesses, to generate diffractive interactions. The incoming particles are set to be protons with an energy of 7000 GeV. From the generated events we select those for which $\xi < 0.1$ for both incoming protons, and extract the values of the variables β_i which are the ratios of gluon momentum to pomeron momentum for the pomeron radiated by proton i.

To calculate the differential cross–section $d^2\sigma/d\xi d\beta$ the weight of each event is added to the appropriate bin in (ξ, β) space. Half of each event's weight is added to the bin corresponding to its values of ξ_1 and β_1, and half to the bin corresponding to its values of ξ_2 and β_2. This has the effect of symmetrising the differential cross–section:

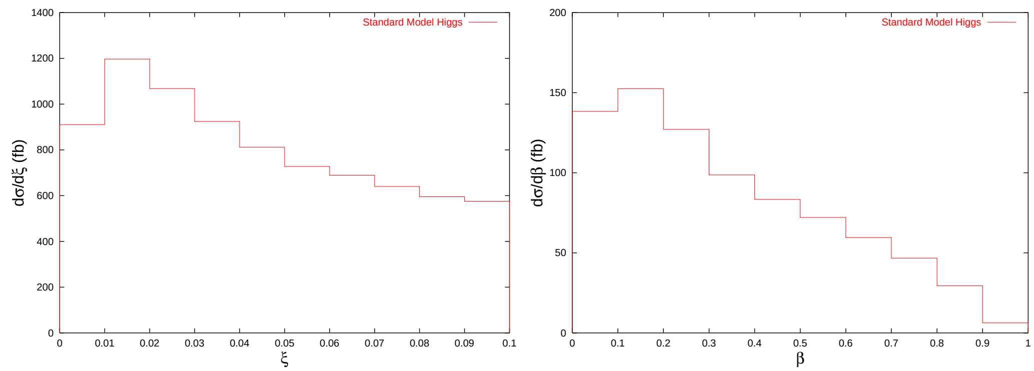

Fig. 1. Differential cross-sections for inclusive double diffractive production of the Standard Model Higgs at the LHC.

$$\frac{d\sigma}{d\xi d\beta} = \frac{1}{2}\left(\int_0^{0.1} d\xi_1 \int_0^1 d\beta_1 \frac{d\sigma}{d\xi_1 d\xi_2 d\beta_1 d\beta_2} + \int_0^{0.1} d\xi_2 \int_0^1 d\beta_2 \frac{d\sigma}{d\xi_1 d\xi_2 d\beta_1 d\beta_2}\right). \quad (4)$$

At the end, this expression is summed over all β or ξ to obtain the single–differential cross–sections. The results are shown in Fig. 1, they are consistent with those in Ref. [6] [1].

The inclusive double diffractive cross–section is 81.4 ± 1.0 fb, which is consistent with the result obtained in Ref. [6] when the POMWIG default fit of the H1 pomeron structure function was used. The fact that the distributions are not forced to high values of ξ and β implies that at the LHC the hadron–hadron centre–of–mass energy is large enough to easily generate a gluon–gluon centre–of–mass energy squared larger than the square of the mass of the produced particle, i.e. $\hat{s} = s\xi_1\xi_2\beta_1\beta_2 > m_h^2$. We will later see that this is also true in the SUSY case. The final result should be corrected to include the gap survival factor which, from theoretical considerations, at 14 TeV would be of order 2%.

Given these results for the Standard Model Higgs in the next Section we estimate what the cross–sections would be in the case of the MSSM.

3 Supersymmetric particles production

Once the Standard Model results have been obtained, to study the SUSY processes of interest, we should specify the regions of the MSSM parameter space we want to investigate. To define the masses, couplings and decay modes for the SUSY particles, we use the so–called "Snowmass Points and

[1] We take the results as given by HERWIG 6.5 and, differently to Ref. [6], we do not double the cross–section to estimate the effects of NLO QCD corrections.

Slopes" (SPS), a set of benchmarks for SUSY searches. In Ref. [16] an unconstrained version of the MSSM is proposed where all possible soft SUSY breaking terms are added to the Lagrangian and then different parameterisations of these terms are considered. As is well known, the number of free parameters in the theory is very large but it can be reduced if a particular SUSY breaking (SB) mechanism is assumed. The most popular ones are minimal supergravity (mSUGRA), gauge–mediated SUSY breaking (GMSB), and anomaly mediated SUSY breaking (AMSB) (for a brief description of these scenarios see, for example Ref. [16]). These SB scenarios have a reduced three or four dimensional parameter space.

We have calculated the diffractive production of all neutral MSSM Higgses (h^0, H^0, A^0), charged Higsses, gauginos, spartons and sleptons. The cross–sections for production of SUSY particles other than the lightest SUSY Higgs, h^0, are small and, at least for these SPS benchmarks, it renders the inclusive double diffractive channel as not an optimal one to study them (of all the cross–sections studied the second largest is that of squark production where even pushing the parameter space to low squark masses the cross–section is $\sim \mathcal{O}(40 \text{ fb})$). Although we are investigating double diffractive production in this Letter, it would be interesting to study if the rates of production for these SUSY heavy states are higher in other processes like single diffractive production. The situation for h^0 is far more positive. The production cross–sections, which are dominated by the gluon exchange channel, are larger than for the Standard Model case. We will show this in the next Section where we also include a brief description of the different MSSM benchmark points.

4 Inclusive Double Diffractive Production of MSSM lightest Higgs

In this Section we show the results for the production of the lightest MSSM Higgs. The analysis proceeds in the same way as in Section 2. For completeness we write down the matrix element used by HERWIG for the gluon–gluon $\rightarrow$ h^0 hard subprocess:

$$\overline{|M|^2} = \frac{\alpha_{\rm em}\alpha_s^2 m_{h^0}^4}{72\pi \sin^2\theta_W \,(N_c^2-1)\, m_W^2} \left| \sum_{\rm f} g_f^{h^0} A_f^{h^0} \left(\frac{4m_f^2}{m_{h^0}^2}\right) + \sum_{\tilde{\rm f}} g_{\tilde f}^{h^0} A_{\tilde f}^{h^0} \left(\frac{4m_{\tilde f}^2}{M_{h^0}^2}\right)\right|^2 \quad (5)$$

where the sum over fermion includes the loops of heavy quarks (b and t) and the sum over sfermions takes into account loops with squarks ($\tilde{b}$ and $\tilde{t}$). The expressions for the coefficients g and A can be found in Ref. [17].

The Snowmass points

We now give a very brief description of the Snowmass points used to scan the MSSM parameter space. For each of the points we have calculated the total and differential cross–sections for inclusive double diffractive production of the lightest MSSM Higgs. The value of the top–quark mass in all the SPS benchmark scenarios is 175 GeV and the sign of the μ–term in the superpotential is taken to be positive. The mass of the Higgs is kept close to 115 GeV (we show the exact values for each of the SPS points in the tables below) and the spectra for the other SUSY particles for all the benchmark points used here can be found in Ref. [16]. We again remind the reader that the values for the cross–sections should include a correcting factor to include gap survival probability effects.

SUSY breaking in minimal supergravity (mSUGRA SPS 1-5)

In these scenarios the breaking of SUSY takes place in a hidden sector and is mediated to the visible MSSM sector via gravitational interactions. This proposal is parameterised by a scalar mass m_0, a gaugino mass $m_{1/2}$, a trilinear coupling A_0 and the ratio of the vacuum expectation values of the two Higgs doublets $\tan\beta$.

The values of the parameterisation for these scenarios are given in Table 1. The differential cross–sections obtained using the SUSY version of POMWIG are shown in Fig. 2. These plots show that the cross–sections are larger than the corresponding ones in the Standard Model. As can be seen in Table 1 the value of the diffractive total cross–sections ranges from 92 fb to 190 fb. These results are very similar for the rest of the MSSM points showing that the number of events would be large at the energies delivered at the LHC and, if the backgrounds are not very large, this diffractive channel would be an interesting one to identify the MSSM lightest Higgs.

SUGRA	m_0	$m_{1/2}$	A_0	$\tan\beta$	m_{h^0}	$\sigma_{\mathbb{P}}$(fb)
1a	100	250	-100	10	114	190
1b	200	400	0	30	118	167
2	1450	300	0	10	116	175
3	90	400	0	10	117	171
4	400	300	0	50	115	184
5	150	300	-1000	5	120	92

Table 1
Parameterisation of mSUGRA points and total diffractive cross–sections.

SUSY breaking in minimal supergravity (mSUGRA SPS 6)

mSUGRA

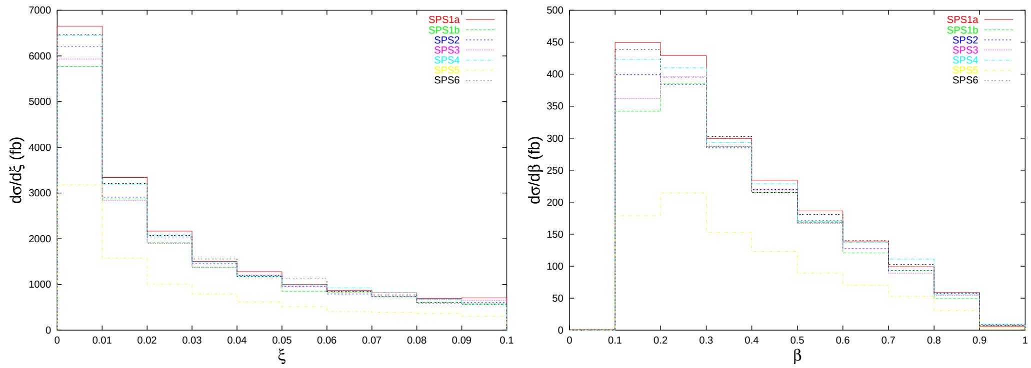

Fig. 2. Differential cross–section for inclusive double diffractive production of the lightest MSSM Higgs at the LHC for mSUGRA benchmark points.

This case corresponds to non-unified gaugino masses at the GUT scale with the bino having a mass parameter larger than previous mSUGRA models. The parameterisation is shown in Table 2. The differential and total inclusive double diffractive cross–section are not affected by these new values of the masses as can be observed in Table 2 and Fig. 2.

Non–Universal SUGRA	m_0	$m_{1/2}$	A_0	$\tan\beta$	m_1	$m_{2,3}$	m_{h^0}	$\sigma_{I\!P}$(fb)
6	100	250	-100	10	480	300	115	184

Table 2
Parameterisation of mSUGRA point SPS6 and total diffractive cross–section.

Gauge-mediated SUSY breaking (GMSB SPS 7-8)

In this framework SUSY is also broken in a hidden sector and the mediation to the visible one is via gauge interactions. In the minimal case the parameters are now a universal soft SUSY breaking mass scale Λ, the messenger mass $m_{\rm mes}$ and index $N_{\rm mes}$, and the usual $\tan\beta$. The values for the parameters in the SPS 7 and 8 points are indicated in Table 3, together with the large values for the cross–section. The differential cross–sections in ξ and β are shown in Fig. 3.

GMSB	Λ	$m_{\rm mes}$	$N_{\rm mes}$	$\tan\beta$	m_{h^0}	$\sigma_{I\!P}$(fb)
7	40000	80000	3	15	114	190
8	100000	200000	1	15	115	182

Table 3
Parameterisation of GMSB points and total diffractive cross–sections.

GMSB

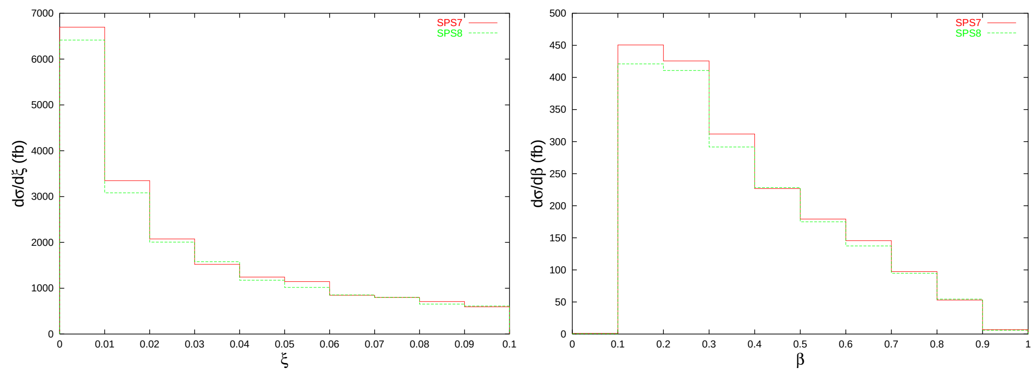

Fig. 3. Differential cross–section for inclusive double diffractive production of the lightest MSSM Higgs at the LHC for GMSB benchmark points.

AMSB

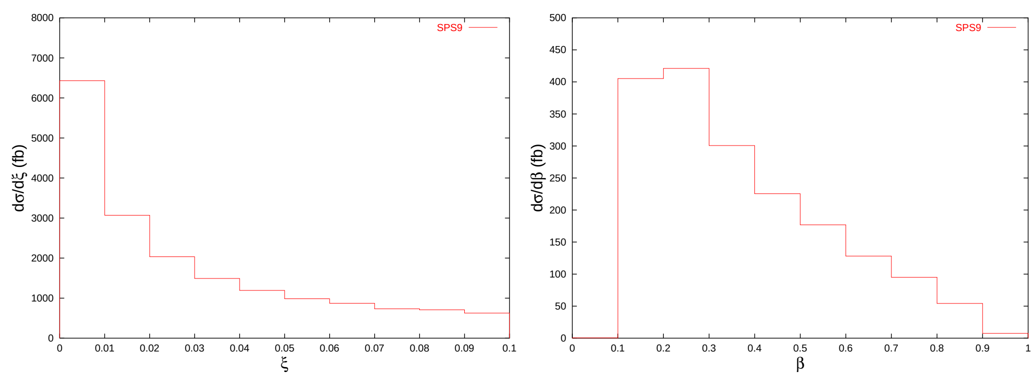

Fig. 4. Differential cross–section for inclusive double diffractive production of the lightest MSSM Higgs at the LHC for AMSB benchmark point.

Anomaly-mediated SUSY breaking (AMSB SPS 9)

In this theoretical framework the SUSY breaking is mediated to the visible sector using the so–called super–Weyl anomaly. The values of the parameters are given in Table 4. Again, as in all the MSSM Snowmass points studied in this Letter, the inclusive cross–sections for the production of the lightest Higgs are large, see Table 4 and Fig. 4.

AMSB	m_0	$m_{3/2}$	$\tan\beta$	m_{h^0}	$\sigma_{\mathbb{P}}$(fb)
9	450	60000	10	115	181

Table 4
Parameterisation of AMSB SPS 9 point and total diffractive cross–section.

5 Conclusions

We have numerically estimated the inclusive double diffractive production of SUSY particles at the energies available at the future Large Hadron Collider at CERN. We have shown that the only cross–section large enough to provide a clean signal in this inclusive channel is that of the production of the lightest MSSM Higgs boson. This is the case provided the backgrounds are not too large, a point which will be investigated in a future work. Nevertheless, and always understanding that our results suffer from a theoretical uncertainty mainly due to the gap survival factor, the results are encouraging, showing large cross–sections for the inclusive double diffractive channel. It would also be interesting to investigate the production rates for SUSY particles in other channels, like single diffractive production, and exclusive processes, where there are no pomeron remnants in the final state.

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