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HIGH MASS DIFFRACTION AT THE LHC

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We use a Monte Carlo implementation of recently developped models of exclusive diffractive W, top, Higgs and stop productions to assess the sensitivity of the LHC experiments.

1 Theoretical framework

Let us introduce the model [1] we shall use for describing exclusive SUSY Higgs bosons and stop pair production in double diffractive production. In [1], the diffractive mechanism is based on two-gluon exchange between the two incoming protons. The soft pomeron is seen as a pair of gluons non-perturbativelycoupled to the proton. One of the gluons is then coupled perturbatively to the hard process, either the SUSY Higgs bosons, or the $\tilde{t}\bar{\tilde{t}}$ pair, while the other one plays the rôle of a soft screening of colour, allowing for diffraction to occur. The corresponding cross-sections for Higgs bosons and $\tilde{t}\bar{\tilde{t}}$ production read:

$$d\sigma_h^{exc}(s) = C_h \left(\frac{s}{M_h^2}\right)^{2\epsilon} \delta\left(\xi_1\xi_2 - \frac{M_h^2}{s}\right) \prod_{i=1,2} \left\{d^2v_i \frac{d\xi_i}{1-\xi_i}\ \xi_i^{2\alpha' v_i^2} \exp(-2\lambda_h v_i^2)\right\} \sigma(gg \to h)$$

$$d\sigma_{\tilde{t}\bar{\tilde{t}}}^{exc}(s) = C_{\tilde{t}\bar{\tilde{t}}} \left(\frac{s}{M_{\tilde{t}\bar{\tilde{t}}}^2}\right)^{2\epsilon} \delta\left(\sum_{i=1,2}(v_i+k_i)\right) \prod_{i=1,2} \left\{d^2v_i d^2k_i d\xi_i\ d\eta_i\ \xi_i^{2\alpha' v_i^2} \exp(-2\lambda_{\tilde{t}\bar{\tilde{t}}} v_i^2)\right\} \sigma(gg \to \tilde{t}\bar{\tilde{t}}\ )$$

where, in both equations, the variables v_i and ξ_i respectively denote the transverse momenta and fractional momentum losses of the outgoing protons. In the second equation, k_i and η_i are respectively the squark transverse momenta and rapidities. $\sigma(gg \to H), \sigma(gg \to \tilde{t}\bar{\tilde{t}})$ are the hard production cross-sections which are given later on. The model normalisation constants $C_h, C_{\tilde{t}\bar{\tilde{t}}}$ are fixed from the fit to dijet diffractive production.

In the model, the soft pomeron trajectory is taken from the standard Donnachie-Landshoff parametrisation [2], namely $\alpha(t) = 1 + \epsilon + \alpha' t$, with $\epsilon \approx 0.08$ and $\alpha' \approx 0.25\mathrm{GeV}^{-2}$. $\lambda_h, \lambda_{\tilde{t}\bar{\tilde{t}}}$ are kept as in the original paper [1] for the SM Higgs and $q\bar{q}$ pairs. Note that, in this model, the strong (non perturbative) coupling constant is fixed to a reference value $G^2/4\pi$, which will be taken from the fit to the observed centrally produced diffractive dijets.

In order to select exclusive diffractive states, it is required to take into account the corrections from soft hadronic scattering. Indeed, the soft scattering between incident particles tends to mask the genuine hard diffractive interactions at hadronic colliders. The formulation of this correction [3] to the scattering amplitudes consists in considering a gap survival probability. The correction factor is commonly evaluated to be of order 0.03 for the QCD exclusive diffractive processes at the LHC.

More details about the theoretical model and its phenomenological applications can be found in Refs. [4] and [5]. In the following, we use the BL model for exclusive Higgs production recently implemented in a Monte-Carlo generator [4].

2 Experimental context

The analysis is based on a fast simulation of the CMS detector at the LHC (similar results would be obtained using the ATLAS simulation). The calorimetric coverage of the CMS experiment ranges up to a pseudorapidity of $|\eta| \sim 5$. The region devoted to precision measurements lies within $|\eta| \leq 3$, with a typical resolution on jet energy measurement of $\sim 50\%/\sqrt{E}$, where E is in GeV, and a granularity in pseudorapidity and azimuth of $\Delta\eta \times \Delta\Phi \sim 0.1 \times 0.1$.

In addition to the central CMS detector, the existence of roman pot detectors allowing to tag diffractively produced protons, located on both p sides, is assumed [6]. The ξ acceptance and resolution have been derived for each device using a complete simulation of the LHC beam parameters. The combined ξ acceptance is $\sim 100\%$ for ξ ranging from 0.002 to 0.1, where ξ is the proton fractional momentum loss. The acceptance limit of the device closest to the interaction point is $\xi > \xi_{min}$ =0.02.

In exclusive double Pomeron exchange, the mass of the central heavy object is given by $M^2 = \xi_1 \xi_2 s$, where ξ_1 and ξ_2 are the proton fractional momentum losses measured in the roman pot detectors.

3 Existence of exclusive events

The question arises if exclusive events exist or not since they have never been observed so far. The DØ and CDF experiments at the Tevatron (and the LHC experiments) are ideal places to look for exclusive events in dijet or χ_C channels for instance where exclusive events are expected to occur at high dijet mass fraction. So far, no evidence of the existence of exclusive events has been found. A nice way to show the existence of such events would be to study the correlation between the gap size measured in both p and $\bar{p}$ directions and the value of $log 1/\xi$ measured using roman pot detectors, which can be performed in the DØ experiment. The gap size between the pomeron remnant and the protons detected in roman pot detector is of the order of $log 1/\xi$ for usual diffractive events (the measurement giving a slightly smaller value to be in the acceptance of the forward detectors) while exclusive events show a much higher value for the rapidity gap since the gap occurs between the jets (or the χ_C) and the proton detected

M_{Higgs}	cross section	signal	backg.	S/B	σ
120	3.9	27.1	28.5	0.95	5.1
130	3.1	20.6	18.8	1.10	4.8
140	2.0	12.6	11.7	1.08	3.7

Table 1: Exclusive Higgs production cross section for different Higgs masses, number of signal and background events for 100 fb^{-1}, ratio, and number of standard deviations (σ).

in roman pot detectors (in other words, there is no pomeron remnant) [a]. Another observable leading to the same conclusion would be the correlation between ξ computed using roman pot detectors and using only the central detector.

4 Results on diffractive Higgs production

Results are given in Fig. 1 for a Higgs mass of 120 GeV, in terms of the signal to background ratio S/B, as a function of the Higgs boson mass resolution.

In order to obtain an S/B of 3 (resp. 1, 0.5), a mass resolution of about 0.3 GeV (resp. 1.2, 2.3 GeV) is needed. The forward detector design of [6] claims a resolution of about 2.-2.5 GeV, which leads to a S/B of about 0.4-0.6. Improvements in this design would increase the S/B ratio as indicated on the figure. As usual, this number is enhanced by a large factor if one considers supersymmetric Higgs boson production with favorable Higgs or squark field mixing parameters.

The cross sections obtained after applying the survival probability of 0.03 at the LHC as well as the S/B ratios are given in Table 1 if one assumes a resolution on the missing mass of about 1 GeV (which is the most optimistic scenario). The acceptances of the roman pot detectors as well as the simulation of the CMS detectors have been taken into account in these results.

Let us also notice that the missing mass method will allow to perform a W mass measurement using exclusive (or quasi-exclusive) WW events in double Pomeron exchanges, and QED processes. The advantage of the QED processes is that their cross section is perfectly known and that this measurement only depends on the mass resolution and the roman pot acceptance. In the same way, it is possible to measure the mass of the top quark in $t\bar{t}$ events in double Pomeron exchanges.

The diffractive SUSY Higgs boson production cross section is noticeably enhanced at high values of $\tan\beta$ and since we look for Higgs decaying into $b\bar{b}$, it is possible to benefit directly from the enhancement of the cross section contrary to the non diffractive case. A signal-over-background up to a factor 50 can be reached for 100 fb^{-1} for $\tan\beta \sim 50$ [8]. We give in Figure 2 the signal-over-background ratio for different values of $\tan\beta$ for a Higgs boson mass of 120 GeV.

5 Threshold scan method: W, top and stop mass measurements

We propose a new method to measure heavy particle properties via double photon and double pomeron exchange (DPE), at the LHC [7]. In this category of events, the heavy objects are produced in pairs, whereas the beam particles often leave the interaction region intact, and can be measured using very forward detectors.

Pair production of WW bosons and top quarks in QED and double pomeron exchange are described in detail in this section. WW pairs are produced in photon-mediated processes, which

[a] To distinguish between pure exclusive and quasi-exclusive events, other observables such as the ratio of the cross sections of double diffractive production of diphoton and dilepton, or the b-jets to all jets are needed [5].

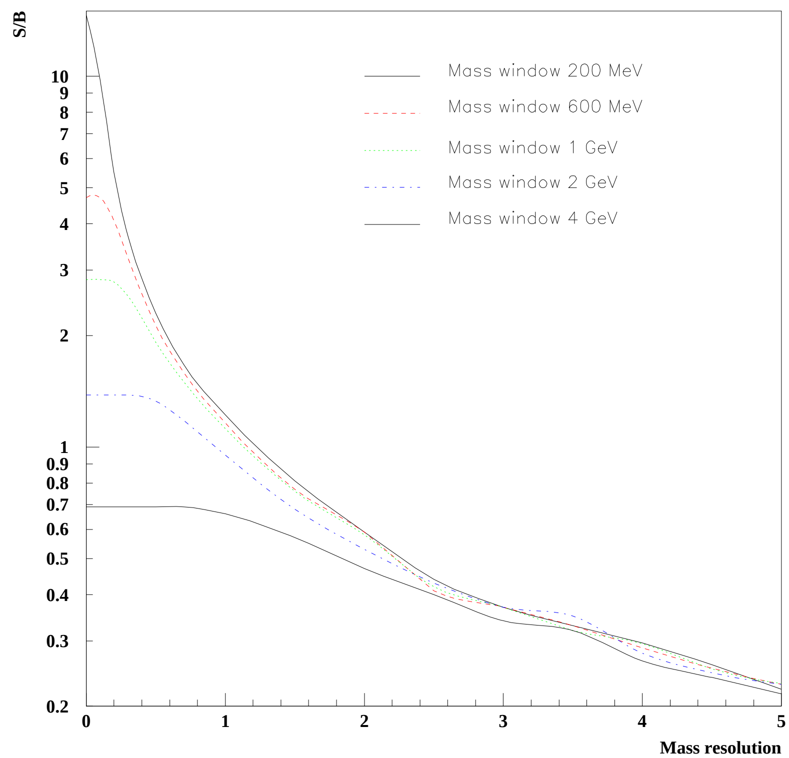

Figure 1: Standard Model Higgs boson signal to background ratio as a function of the resolution on the missing mass, in GeV. This figure assumes a Higgs boson mass of 120 GeV.

are exactly calculable in QED. There is basically no uncertainty concerning the possibility of measuring these processes at the LHC. On the contrary, $t\bar{t}$ events, produced in exclusive double pomeron exchange, suffer from theoretical uncertainties since exclusive diffractive production is still to be observed at the Tevatron, and other models lead to different cross sections, and thus to a different potential for the top quark mass measurement. However, since the exclusive kinematics are simple, the model dependence will be essentially reflected by a factor in the effective luminosity for such events.

5.1 Explanation of the methods

We study two different methods to reconstruct the mass of heavy objects double diffractively produced at the LHC. The method is based on a fit to the turn-on point of the missing mass distribution at threshold.

One proposed method (the "histogram" method) corresponds to the comparison of the mass distribution in data with some reference distributions following a Monte Carlo simulation of the detector with different input masses corresponding to the data luminosity. As an example, we can produce a data sample for 100 fb^{-1} with a top mass of 174 GeV, and a few MC samples corresponding to top masses between 150 and 200 GeV by steps of. For each Monte Carlo sample, a χ^2 value corresponding to the population difference in each bin between data and MC is computed. The mass point where the χ^2 is minimum corresponds to the mass of the produced object in data. This method has the advantage of being easy but requires a good simulation of the detector.

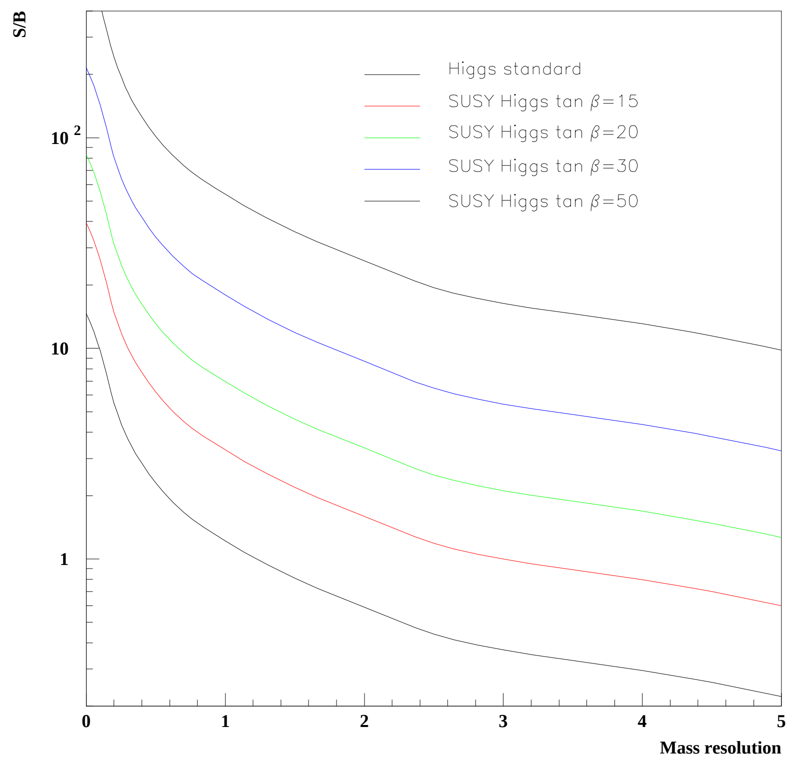

Figure 2: SUSY Higgs boson signal to background ratio as a function of the resolution on the missing mass, in GeV. This figure assumes a Higgs boson mass of 120 GeV.

The other proposed method (the "turn-on fit" method) is less sensitive to the MC simulation of the detectors. As mentioned earlier, the threshold scan is directly sensitive to the mass of the diffractively produced object (in the WWW case for instance, it is sensitive to twice the WW mass). The idea is thus to fit the turn-on point of the missing mass distribution which leads directly to the mass of the produced object, the WW boson. Due to its robustness, this method is considered as the "default" one in the following.

5.2 Results

To illustrate the principle of these methods and their achievements, we apply them to the WW boson and the top quark mass measurements in the following, and obtain the reaches at the LHC. They can be applied to other threshold scans as well. The precision of the WW mass measurement (0.3 GeV for 300 fb^{-1}) is not competitive with other methods, but provides a very precise calibration of the roman pot detectors. The precision of the top mass measurement is however competitive, with an expected precision better than 1 GeV at high luminosity. The resolution on the top mass is given in Fig. 3 as a function of luminosity for different resolutions of the roman pot detectors.

The other application is to use the so-called "threshold-scan method" to measure the stop mass in *exclusive* events. The idea is straightforward: one measures the turn-on point in the missing mass distribution at about twice the stop mass. After taking into account the stop width, we obtain a resolution on the stop mass of 0.4, 0.7 and 4.3 GeV for a stop mass of 174.3, 210 and 393 GeV for a luminosity (divided by the signal efficiency) of 100 fb^{-1}. We notice that one can expect to reach typical mass resolutions which can be obtained at a linear collider. The process is thus similar to those at linear colliders (all final states are detected) without the initial state radiation problem.

The caveat is of course that production via diffractive *exclusive* processes is model dependent, and definitely needs the Tevatron data to test the models. It will allow to determine more precisely the production cross section by testing and measuring at the Tevatron the jet and photon production for high masses and high dijet or diphoton mass fraction.

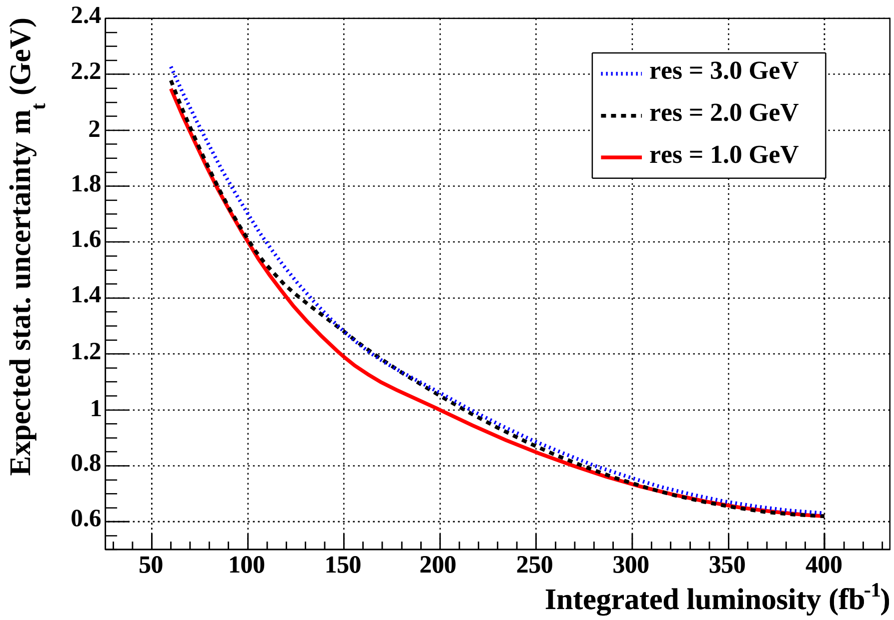

Figure 3: Expected statistical precision of the top mass as a function of the integrated luminosity for various resolutions of the roman pot detectors (full line: resolution of 1 GeV, dashed line: 2 GeV, dotted line: 3 GeV).

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