Central Production of New Physics

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Abstract
We discuss some of the physics which can be explored through a study of the Central Exclusive Process (CEP), $pp \to p + X + p$, where X is some system of particles produced centrally in pseudo-rapidity. In particular, we talk about the case where X is a single Higgs boson, with properties determined either by the SM, the MSSM or the NMSSM. The possibility that X could be a pair of long-lived gluinos is also discussed.

1 Introduction

The interest in measuring the CEP process $pp \to p + X + p$ at the LHC is very substantial, for example see the contributions to the proceedings of this conference from de Roeck [1], Khoze et al [2] and Tasevsky [3]. The FP420 collaboration aims to install suitable proton detectors at 420m from the interaction point (IP), which is the ideal place to guarantee acceptance for central systems in the 70-150 GeV range [4]. This reach can be increased to higher masses upon using also detectors stationed at 220m from the IP. In addition, the theoretical modelling [5] (for an introduction see [6]) has recently received a reassuring degree of validation with the recent CDF measurements of CEP dijet production, as presented in the talk by Goulianos [7]. Most recently, there have been two studies of SM and MSSM Higgs production which deal with the relevant physics to a high level of detail [8, 9]. In this short review I'd like, in the next section, to discuss these recent developments before moving on in the remaining sections to discuss a potentially very interesting scenario in the NMSSM and then the possibility to measure the gluino mass through CEP in models where the gluino is stable. Particular attention is paid to the possibility of making measurements at high luminosities, i.e. $\sim 10^{34}$ cm^{-2}s^{-1}.

2 SM & MSSM Higgs

CEP of a SM Higgs and its decay to WW has been explored in [10] where it was shown that triggering is not a problem and the backgrounds can safely be eliminated. The bottom line is that it is possible to measure the SM Higgs this way, with a handful of events per 30 fb^{-1} of data collected at modest luminosities (i.e. $\sim 2 \times 10^{33}$ cm^{-2}s^{-1}) for Higgs masses in the range 140-200 GeV. It is pretty clear that these are conservative estimates and that improvements in efficiency could readily be achieved through lowering the trigger threshold for the leptons.

More of a challenge is the detection of Higgs bosons via their decay to bottom quarks. Of course this channel is swamped by background in inclusive production and it would be of immense value if it could be observed using CEP. The challenge of establishing whether $H \to b\bar{b}$

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can be observed in CEP was taken up in the recent papers of Cox, Loebinger & Pilkington [8] and Heinemeyer et al [9] with the latter focussing on the case of MSSM Higgses (and other decay channels). We'll discuss the Heinemeyer et al paper first (briefly since more details can be found in [2, 3]).

It is expected that the LHC will be able to discover the lightest MSSM Higgs boson without too much trouble. However, the challenge is to distinguish it from a SM Higgs and to observe the heavier Higgses predicted by supersymmetry. It is in the pursuit of this goal that problems emerge. There is a region of MSSM parameter space (the lower portion of the $\tan\beta - M_A$ plane called the 'wedge region') where it could be very difficult to detect the heavier neutral Higgs bosons. Moreover, the existence of this wedge region is rather robust against variations in the MSSM input parameters. The conclusion of [9] is that CEP offers the unique possibility to observe a previously discovered CP even[1] heavier Higgs, H, directly through its decay to b quarks and with excellent resolution on its mass. It also has the feature that the discovery contours extend slightly into the previously excluded wedge region, making it the discovery channel in that region provided measurements can be made at high luminosities ($\sim 10^{34}$ cm^{-2}s^{-1}).

These conclusions are in line with those drawn in [8]. In that paper, special attention was paid to the challenge of running at high luminosity and in particular the effect of pileup. Pileup refers to the fact that at high enough luminosities there are many proton-proton interactions per collision with typically 35 interactions per collision at 10^{34}cm^{-2}s^{-1}. Clearly these extra collisions produce ambient activity in the detector which contaminates signal events. Moreover it can generate fake signal events as a result of the co-incidence of two or more separate interactions, e.g. for a $p + (H \to b\bar{b}) + p$ signal the dominant background comes from the threefold coincidence of two single diffractive events ($pp \to p + X$) with a third inclusive $pp \to X$ event. It is this overlap background which renders a measurement of the SM Higgs through its decay to $b\bar{b}$ extremely challenging. With its $\tan\beta$ enhanced cross-section, the situation is more favourable for a MSSM Higgs. In that context, one of the major results of [8] is the establishment of the fact that pileup can be brought under control even at 10^{34}cm^{-2}s^{-1} as a result primarily of time-of-flight vertexing (the primary pp vertex can be located very accurately as a result of the 10ps timing resolution of the base FP420 design) and cuts on the number of charged tracks. Various triggering options have also been explored and shown to be viable. That said, it should also be noted that if the Higgs sector were in fact to correspond to something like the m_h^{max} scenario considered in [8] then one would almost certainly be keen to make every effort to put the 420m detectors into the L1 trigger. Additionally, further improvements may be made on the fast-timing rejection of the overlap background. In such a setup, it is claimed that a 10σ observation could be made with a measurement of the Higgs mass to much better than 1 GeV with 300 fb^{-1} of data.

3 NMSSM Higgs

The unsettling possibility that the only light scalar Higgs boson could decay predominantly to four taus arises in the NMSSM. It occurs as a result of the decay chain $h \to aa \to \tau^+\tau^-\tau^+\tau^-$ where a represents a light pseudo-scalar Higgs.

[1]The CP odd Higgs would be filtered out.

The NMSSM extends the MSSM by the introduction of a singlet superfield, $\hat{S}$. To do so provides the possibility to solve the fine tuning and little heirarchy problems present in the MSSM and it provides a natural solution to the μ-problem [11]. The Higgs sector of the NMSSM contains three CP-even and two CP-odd neutral Higgs bosons, and a charged Higgs boson.

In [12], a partial 'no-lose' theorem for NMSSM Higgs discovery was established. The theorem states that the LHC would be able to detect at least one of the NMSSM Higgs bosons, utilizing Higgs decay modes other than Higgs-to-Higgs decays. However, in [13] it was shown that there exists a small part of the NMSSM parameter space where Higgs-to-Higgs decays are in fact dominant. Benchmark points were presented for which the primary decaying neutral Higgs boson has strong coupling to gauge bosons and has mass in the range [90 GeV, 150 GeV] but decays almost entirely to a pair of lighter higgses. Both of these Higgs bosons could have escaped the LEP searches and would quite possibly also evade the standard LHC search modes [13].

Fortunately the troublesome region can be covered using CEP. In [14] attention is focussed on scenario 1 of [13], for which the scalar Higgs, h, has mass 92.9 GeV and the pseudo-scalar Higgs, a, has mass 9.73 GeV.[2] The $h \rightarrow aa$ decay occurs with a branching ratio of 92% and is troublesome since each a decays to $\tau^+\tau^-$ with a branching ratio of 81% [15, 16]. The signal process has been incorporated into the ExHuME v.1.3.4 Monte Carlo [17] and the backgrounds were generated using ExHuME for $pp \rightarrow p + gg + p$ and $pp \rightarrow p + b\bar{b} + p$. We do not need to simulate light quark production because these backgrounds are suppressed relative to $b\bar{b}$ by a factor of m_q^2/m_b^2. POMWIG [18] is used to simulate this source of background and the version used incorporates the latest diffractive parton distribution functions from the H1 experiment at HERA [19]. In addition to these direct backgrounds, at sufficiently high luminosity it becomes necessary to consider the OLAP background. Specifically, the possibility of a threefold coincidence of two single diffractive $pp \rightarrow p + X$ events with a generic $pp \rightarrow X$ inelastic process was considered. The inclusive QCD events $pp \rightarrow X$ were generated using PYTHIA, with the 'ATLAS tune' to Tevatron data. The forward protons (from single diffraction) were then added to the event using the prescription presented in [8], which also allows one to estimate the probability of the threefold coincidence as a function of instantaneous luminosity. The two protons detected by the 420m detectors do not originate from the same vertex as the primary scatter which produces the muon and this can be exploited to reduce the OLAP background. According to the results presented in [8], a rejection factor of 18 (15) should be obtained at low (high) luminosity running. Overlap backgrounds from twofold coincidences are not considered since it was shown in [8] that the largest twofold background is a factor of ~ 5 smaller than that for threefold coincidences. Finally, the pure QED backgrounds: $pp \rightarrow p + \tau^+\tau^- l^+ l^- + p$ (where l is any charged lepton) were also considered and simulated using MADGRAPH [20]. All final state particle four-momenta were smeared according to the relevant detector component resolution [21] with the outgoing proton momenta smeared by the amount given in [22] and the effects of pileup were accounted for by superimposing additional inelastic pp collisions simulated using PYTHIA on top of both signal and background events. The above numbers are quoted assuming that triggering requires a single muon with $p_T > 6$ GeV, although increasing this threshold to 20 GeV may be more appropriate at high luminosity (see [14] for details).

The final results are encouraging: after all cuts, the signal cross-section is around 0.08 fb

[2] These values are not exactly those quoted in [13].

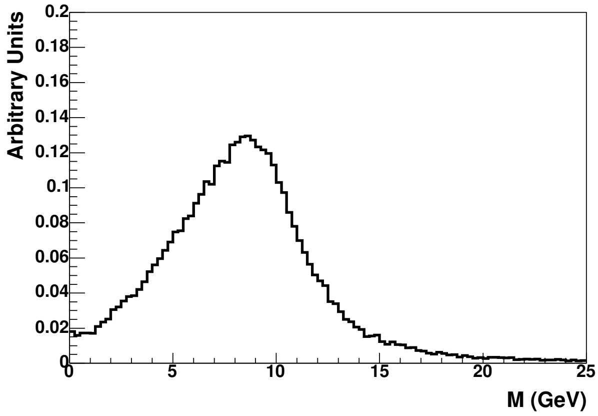

Fig. 1: The reconstructed a mass for the signal events.

with a total background of less than 0.02 fb excluding the OLAP background. By far the largest source of background is the DPE production of $pp \to p + jjX + p$ and the QED background is entirely negligible. The OLAP background is luminosity dependent, and estimated to be 0.1 fb at 10^{34} and 100 times smaller at 10^{33}. It should be noted that the results correspond to a wide central mass window from 70-110 GeV, which would be desirable if one is operating in search mode. Once a signal has been identified, a much tighter mass cut would lead to a further reduction in backgrounds. It is striking that even at high luminosities the effects of pileup are under control. The principal reason for the smallness of the backgrounds arises because the analysis strategy is very much oriented upon the use only of charged tracks, the muon detectors and the proton detectors, i.e. the calorimeter is barely needed (there is a muon isolation cut which is not critical for the analysis). In fact the principal cuts used to eliminate the backgrounds are cuts to insist on exactly 4 or 6 charged tracks and a series of cuts to ensure that the charged tracks have the right topology (i.e. they should cluster and form back-to-back pairs). It remains to be seen how much of this charged track philosophy can be exported to other CEP processes.

Another advantage of studying NMSSM Higgs production via CEP is that not only can the mass of the scalar Higgs be determined on an event by event basis, so too can the mass the the pseudo-scalar a. Knowledge of the mean rapidity and invariant mass of the central system (from the 420m detectors) in conjunction with the assumption that the a's are highly boosted (so that their decay products are roughly collinear with the original a direction) allows four a mass measurements per event. Fig.1 illustrates the a mass distribution: it is clearly peaked around the correct mass and the width is determined mainly by the collinearity approximation (not detector resolution).

4 Gluinos

The possibility that the gluino may be long-lived is a hallmark of the 'Split Supersymmetry' scenario [23, 24], though long lived gluinos have been studied before, in the context of models in which the gluino is the Lightest Supersymmetric Particle (LSP) [25–27]. In Split Supersymmetry

$m_{\tilde{g}}$ (GeV)	$\sigma_{m_{\tilde{g}}}$ (GeV)	$\frac{\sigma_{m_{\tilde{g}}}}{\sqrt{N-1}}$ (GeV)	N
200	2.31	0.19	145
250	2.97	0.50	35.0
300	3.50	1.10	10.2
320	3.61	1.54	6.5
350	3.87	2.45	3.5

Table 1: The gluino mass resolution as a function of the gluino mass.

the SUSY breaking scale, m_S, is large ($m_S \gg$1 TeV) and the scalar particles acquire masses at this scale. The sfermions of the theory are protected by chiral symmetries and so can have masses at the TeV scale as can one neutral Higgs boson whose mass is allowed to be finely tuned. As a result the gluino can be long-lived on collider timescales since it can only decay via the massive scalar particles.

Data from the Tevatron have been used to place the limit $m_{\tilde{g}} > 170$ GeV on the mass of a long lived gluino [28], for the case in which the gluino forms only neutral hadrons which remain neutral as they pass through the detector. This limit is expected to rise to $\simeq 210$ GeV using Run II data [28]. We should stress that this is a conservative limit, since it is anticipated that these hadrons will undergo charge conversion reactions as they pass through the detector [29]. In the most optimistic case, the Tevatron may reach gluino masses of up to $\simeq 430$ GeV if no signal is observed [28].

In [22], the possibility of CEP gluino pair production was considered in the case where the gluinos are sufficiently long-lived that they do not decay within the detector.[3] According to that paper, there could be sufficient rate (with negligible backgrounds) for detection provided the gluinos have mass below $\simeq 350$ GeV and the gluino mass could be measured to an accuracy at the 1% level after 3 years of high luminosity running.

For CEP, triggering is on the fastest R-hadron[4] in the event (it looks like a delayed muon), in conjunction with a cross-check that the forward detector readout contains hits in either the same event or the previous one. Due to the relatively large masses that are of interest, good acceptance for central masses in the range $300 - 1500$ GeV requires use of at least one pot at 220m. Even in the most conservative scenario with 420m pots at 5mm from the beam and 220m pots at 3mm from the beam, the acceptance is more than 40% up to central masses of 950 GeV.

The resulting gluino mass resolution, given 3 years of high luminosity running, is shown in Table 1. In particular the final error on the gluino mass measurement is shown for N events. In conclusion, it should be possible to measure the gluino mass to an accuracy below 1% up to gluino masses of $\simeq 350$ GeV.

[3] It means we do not consider the case where the gluinos stop and subsequently decay within the calorimeter.
[4] The colour singlet bound state containing a gluino.

5 Conclusions

Central exclusive production is able to explore a wide range of interesting physics[5] and the experimental programme is already well developed [1]. In this short note we focussed upon Higgs boson and gluino production. The key points to note are as follows.

- The prospects for SM Higgs production are good for m_H in the range 140-200 GeV via the WW decay channel.
- The prospects for MSSM Higgs production are good, especially in regions of MSSM parameter space where there is a $\tan\beta$ enhancement of the rate. CEP offers the possibility to measure the scalar Higgses, h and H, through the decay to $b\bar{b}$.
- CEP is able to close the loop-hole in the NMSSM whereby the lightest scalar Higgs could be invisible at the LHC as a result of its decay to four taus. It offers the opportunity to measure the pseudo-scalar mass on an event-by-event basis. This analysis is very robust against pileup by virtue of the fact that it makes very little use of the calorimeters.
- Should there exist light, stable, gluinos, CEP could pair produce them if they have masses below 350 GeV and their mass could be measured.

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