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Experimental Aspects of Diffractive Higgs Production

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In these proceedings, we briefly review the Central Exclusive Process $pp \rightarrow p + H + p$ as an independent means of exploring the Higgs sector at the LHC. We highlight its unique advantages over the more usual inclusive channels, its discovery potential, and also discuss the experimental challenges that observation of central exclusive production would pose in the environment of the LHC. We briefly examine the issue of controlling backgrounds in the presence of pile-up when running at high luminosity, and the challenge of triggering on a diffractively-produced light standard model Higgs with the CMS & TOTEM detectors. Particular emphasis is made on FP420, an R&D project with the purpose of examining the feasibility of installing near-beam tracking stations ±420m from the CMS &/or ATLAS interaction point(s).

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1. Introduction

In terms of the search for the Higgs boson, the physics potential of forward proton tagging at the LHC is based upon the gluon-mediated central exclusive production process (CEP), illustrated in figure (1). The experimental observables for this channel are two leading protons and some kind of central activity, (e.g. two co-planar jets). These are well separated in phase-space, producing the 'rapidity gaps' that are characteristic of diffractive interactions, and which may also be observed in the absence of pile-up[1]. Essentially, any colourless $J^{PC} = 0(2)^{++}$ state that couples strongly to the gluon can be produced in this manner. Moreover, if the final-state protons can somehow be tracked down the beam-line, and their momenta measured precisely, then simple four-vector conservation will allow us to make very high resolution measurements of the mass of the central system. A lot of physics that would be difficult to observe inclusively, because of a low signal to background ratio, may be accessible via CEP.

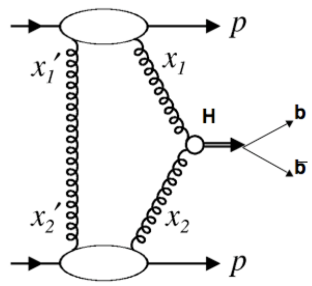

Figure 1: $H \to b\bar{b}$ via CEP

Let us begin by considering conventional inclusive production of a light scalar Higgs. This is dominated by the QCD process $gg \to H$, and for $M_H \sim 120$ GeV, the Higgs decays almost exclusively to a $b\bar{b}$ pair. However, the principal QCD background ($gg \to b\bar{b}$) for this channel is so large, in comparison to the cross-section for inclusive Higgs production, that it would be completely impossible to extract any signal. The situtation, however, becomes much more tenable if we consider CEP of a light Higgs boson. In this case, our centrally produced Higgs is forced to have certain quantum numbers, namely $J^{PC} = 0^{++}$. As a result, the corresponding QCD background $gg \to b\bar{b}$ is suppressed by a factor of M_b^2/E_T^2 because of the $J_z = 0$ selection rule.

It should be noted that the b-jet channel for exclusive Higgs production becomes very important in certain SUSY scenarios, in particular for the 'intense-coupling' regime of the MSSM [1]. In this region of parameter space, $\tan\beta$ (i.e. the ratio of the VEVs of the two Higgs doublets) is large, and the three electrically neutral Higgs particles are very close in mass. Under these conditions, the coupling of the Higgs to the electroweak gauge bosons is heavily suppressed, making discovery via inclusive channels, such as $H \to \gamma\gamma$, $H \to WW^*/ZZ^*$, very challenging. At the same time, the cross-sections for central exclusive scalar Higgs production are greatly enhanced. In addition, the pseudo-scalar Higgs (A) is almost completely absent from the CEP-channel, allowing for a clean separation of the scalar from the pseudo-scalar Higgs, which would impossible to observe in inclusive production.

CEP also has the potential to be the Higgs discovery channel in some extensions of the MSSM. As an example, a recent study [2] which takes the MSSM with non-vanishing CP phases in the gaugino masses and squark couplings shows that, for large values of $\tan\beta$, the three neutral Higgs bosons are almost degenerate in mass. It is thought that the only way one could explore this Higgs sector at the LHC is by using forward proton tagging to make high resolution measurements of the missing mass spectrum.

[1] i.e. multiple $p-p$ interactions / bunch-crossing

2. Experimental Setup

A simple layout of detectors is foreseen in the experimental areas of CMS and / or ATLAS at the LHC accelerator ring. Situated in the immediate vicinity of the interaction point itself will be a general purpose detector, which will observe any central activity. Next, positioned along the beam-line downstream of the central detector, will be a set of high-precision near-beam tracking stations located at ±220m and ±420m from the interaction point.

The low cross-section for diffractive Standard Model Higgs production ($\sim 1-3$fb) [3] makes it desirable to run at high luminosity (i.e. 10^{33}-10^{34} cm^{-2}s^{-1}) to make observation of this channel feasible. Under such conditions, the LHC accelerator operates using its standard $\beta^* = 0.5m$ optics to produce the required tight-focusing of the beams at the interaction point. The combination of near-beam tracking stations at ±220m & ±420m provides a broad acceptance range for leading protons when running with standard optics. Figure (2) shows the variation in the acceptance of $pp \to pHp$ with respect to the Higgs mass, for the case where we have detectors at just ±420m, and where we have detectors at ±420m and ±220m. What is clear from this plot is that the stations at 220m provide excellent acceptance for central systems with relatively high mass. FP420 complements this by covering the low-mass region, as outgoing protons with small fractional momentum loss (ξ) are emitted at very shallow angles with respect to the beam, and do not develop sufficient transverse displacement to be seen at 220m.

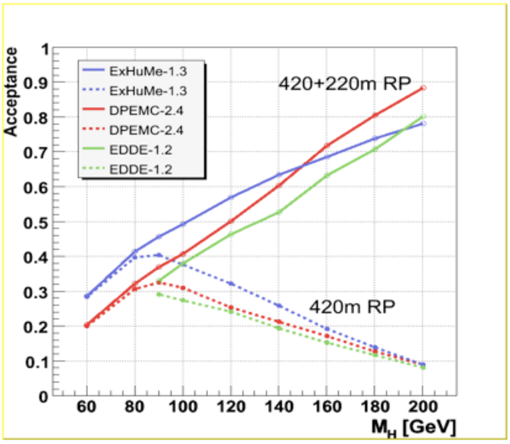

Figure 2: Higgs Acceptance for a variety of CEP montecarlos [4]

2.1 Near beam detectors at 220m

We look first at IP5 where, in addition to CMS, the experimental area will house a second LHC experiment, TOTEM [5]. TOTEM consists of a series of Roman-Pot based near-beam tracking systems, and a set of inelastic detectors (T1 & T2) that will be installed in the forward region of CMS and will cover the rapidity range $3.2 < |\eta| < 6.6$. While TOTEM was primarily designed to measure the total and elastic cross-sections at the LHC, the collaboration has also worked on establishing a substantial forward-physics programme. TOTEM's DAQ and trigger systems were designed to be fully compatible with those of CMS, allowing the two to operate as a single detector with a very broad acceptance. Of particular interest is the fact that TOTEM will deploy near-beam tracking systems located as far out as ±220m from the IP.

Now considering IP1, which houses the general-purpose ATLAS detector. There are a number of institutions that are looking into the placement of near-beam detectors at ±220m from the ATLAS interaction point [6], notably the groups at Saclay, Prague, Cracow and Stony Brook. At the present time, silicon-based detectors are being considered for the tracking, with additional Cherenkov-based detectors to implement fast-timing.

2.2 Near beam detectors at 420m: The FP420 Project

FP420 is an R&D project, acknowledged by the CERN LHCC, with the purpose of investigating the feasibility of installing near-beam detectors in the region ±420m away from the CMS and / or ATLAS interaction points [7]. The current idea is for a system that combines radiation-hard silicon pixel detectors for the tracking and measurement of leading proton candidates, in addition to fast-timing detectors to help suppress pile-up induced background. A schematic outline of an FP420 module is shown in figure (3). The silicon-based tracking system is comprised of several separate units, each of which consists of ∼8 planes of pixel detectors. The QUARTIC subunit located towards the back of the station is a Cherenkov-based fast timing detector, and is briefly discussed in section (3). Also shown in the schematic are two beam position monitors (BPMs), located at the front and rear of the station. During LHC beam injection, the FP420 detectors must be kept clear of the beam-pipe aperture, as it takes time for a stable running environment to be achieved. Once the beam is stabilised, the detectors are then moved into their working position, as close to the beam as possible. The resolving power of the FP420 detectors is limited by the uncertainty in the momentum of the incoming beams, which ultimately leads to a maximum achievable resolution of ∼1.5 GeV on the mass of the central system. This corresponds to a position uncertainty of the tracking stations, with respect to the beam, of some 50 microns. Consequently, it is necessary to be able to align the detector with a precision better than this imposed 50 micron limit. Provided that the FP420 BPMs are sufficiently well calibrated and aligned, it should be possible to measure the distance between the silicon detectors and the beam to within a few 10's of microns.

There are two primary technical issues that are being worked on for FP420, the first of which is the development and implementation of 'edgeless-detector' technology. 'Edgeless' detectors are so-called because they are sensitive up to their physical edges, and are a necessary technology choice for FP420, as they allow the distance between the detector and the beam envelope to be minimised. 3D silicon pixel detectors are one technology choice being investigated by teams at Brunel and Stanford. They are radiation tolerant, a vitally important quality in the harsh environment of the LHC, and have an active edge which acts as an electrode, which keeps the dead volume of the detector down to a thickness of less than 5 microns.

The second issue is that of integrating the FP420 modules with the LHC cryostat. The current LHC design includes a 15m long 'interconnection cryostat' at 420m that is used to connect the warm 'interaction' regions of the LHC with the cold superconducting regions. The cryostat must allow for the continuation of the beam and all the associated accelerator subsystems, including the insulation vacuum, electrical power, cryogenic circuits and accelerator shielding. The current idea is for the 15m long FP420 tracking stations to take the place of this interconnection cryostat.

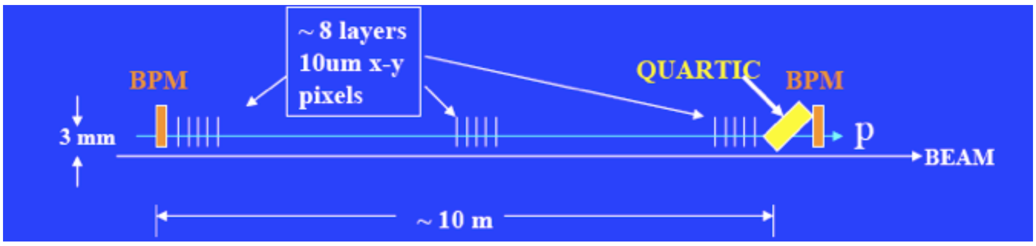

Figure 3: Schematic Representation of a 420m Tracking Station

3. Fast Timing Detectors

The low cross-sections predicted for CEP of a Standard Model Higgs boson require us to study this channel at high LHC luminosities. A direct result of this is that, for every bunch crossing, the number of minimum bias events that overlap the primary hard scattering process (i.e. the pileup) is very large. As an example, if we take our baseline running luminosity to be 2x10^{33}cm^{-2}s^{-1}, then there will be an average of 7 overlying events per machine bunch-crossing. Consequently, the dominant physics background that we need to consider, in the case of central exclusive Higgs production, is a pair of leading protons from two overlapping single-diffractive events that are tagged by the near-beam tracking stations, in addition to a central system produced by an independent hard scatter. There is a very simple reason for wanting high-resolution timing incorporated into the FP420 system. It would allow us to associate a tagged pair of protons with a particular vertex, somewhere along the beam-axis, from which the two final-state protons must have originated, if they were produced by the same scattering process. The QUARTIC fast-timing detector, which forms part of the FP420 module, will have a resolution of 10ps. This will allow the system to match the 'point-of-origin' of a pair of protons tagged at $\pm$420m with the primary vertex seen in the central detector, with a precision of $\sim$3 mm. While it is possible to eliminate a large proportion of the double-overlap background events by simply requiring that the missing mass measured by the near-beam detectors matches the mass of the central system, using the QUARTIC fast timing detector will enable us to reject all put a few percent of events with protons from pile-up.

4. Triggering on CEP at CMS

The LHC is a high luminosity hadron collider, and therefore a very 'messy' environment. The hard interactions the are of interest to us are relatively rare, and are swamped by soft background. In fact, when operating at close to the LHC design luminosity, dozens of interactions occur for every crossing of the beam ($\sim$ 35 events / bx at $L = 10^{34}$cm^{-2}s^{-1}). Under nominal running conditions, the LHC operates with a bunch-crossing frequency of 40MHz. This must be brought down to something more manageable by the L1 trigger system. At CMS, the total output bandwidth available to the L1 trigger system is around 100 kHz [8], of which $\sim$1 kHz is allocated for diffractive trigger streams. In terms of the limits imposed by the High Level Trigger, it is thought that around 1 Hz of HLT output bandwidth will be made available for diffraction.

We now move to the specific case of triggering on CEP of $H \to b\bar{b}$, with $M_H = 120$ GeV [9]. This channel will generally produce 2 jets in the CMS calorimeter, with $E_T < 60$ GeV, in addition to any tagged leading protons. So essentially we are looking at a standard L1 dijet trigger, but with a very low value for the threshold energy (i.e the E_T of the second most energetic jet in the event).

Let us begin by considering triggering with just the central detector, where we have no access to any information on the leading protons in the event. At a low luminosity of 1x10^{32}cm^{-2}s^{-1}, where pile-up is absent, the dijet rate with $E_T > 40$ GeV is around 2 kHz. This can be brought down to less than 1 kHz by vetoing on any activity in TOTEM's forward inelastic detectors, which simply corresponds to the requirement that there are rapidity gaps observed in the event. However, at higher luminosity, the rapidity gaps that this technique relies upon are destroyed by activity in T1/T2 from overlying events, forcing us to adopt a different strategy.

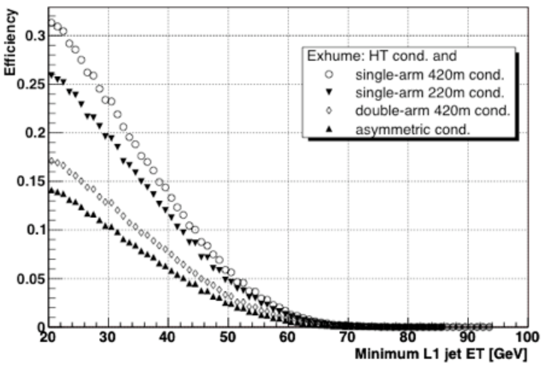

Figure 4: L1 Eff. for $pp \rightarrow p + H + p$ (generated with the ExHuME MC [10])

The L1 dijet rate, for a jet E_T cut-off of 40GeV, is $\sim$50 kHz when running at 2x10^{33} cm^{-2}s^{-1}. With no surviving rapidity gaps, it is clear that we cannot trigger with the central detector alone at high luminosity. Instead, we must introduce additional conditions at L1 to maintain an acceptable rate by incorporating the near-beam detectors into the trigger. In order to cope with such a high bunch-crossing frequency, every stage of the L1-trigger electronics is pipe-lined with no deadtime. This allows for a 'breathing-space' of 128 bunch-crossings (or 3.2 μs) from reading in an event via the front-end electronics to making a decision to discard data from that crossing. While there would be no difficulty in operating a L1 trigger scheme that used data from the tracking stations at $\pm$220m, 3.2μs is too short a time for a signal to propagate back from FP420 in time for the primary trigger decision, so this information cannot be exploited at L1.

A realistic trigger for CEP of a Higgs is to require two central jets with $E_T > 40$ GeV, and a tagged leading proton with $\xi < 0.1$ at $\pm$220m. Adding these conditions to our original dijet trigger for the central detector reduces the output rate of the L1 diffractive trigger stream by a factor of 10, at a luminosity of 2x10^{33} cm^{-2}s^{-1}. An additional reduction factor of 4 can be gained over the background by introducing two more conditions. The first of these is to correlate the direction of the tagged proton with that of the jets in the central detector, by requiring $p^z_{proton} \times (\eta_{Jet1} + \eta_{Jet2}) > 0$. Because the stations at 220m sit in the tail of the ξ-distribution for leading protons, we can only trigger on asymmetric events, i.e. events in which one of the protons provides most of the momentum transfer to the central system. This results in the production of one outgoing proton with relatively high ξ, which we observe at 220m, and a second low ξ proton which is missed (although may be seen at 420m). Conservation of longitudinal momentum requires that our jets and the 220m-tagged proton lie in the same hemisphere. Given that, for our primary QCD background, the processes that produce the jets and the processes that produce the leading protons are largely independent of one-another, this gains us a reduction factor of two. The second extra condition is to ask for the total E_T from jets in the event (known as H_T) to be concentrated in the the two highest E_T jets. By requiring $(E_T^{Jet1} + E_T^{Jet2})/H_T > 0.9$, we gain another factor of two over the background. This gives us a total reduction factor of 40, at 2x10^{33}cm^{-2}s^{-1}, which gives an acceptable L1 output rate. Looking at how this affects our signal, figure (4) gives the integrated L1 efficiency with respect to a cut on the E_T of the 2nd most energetic jet in the event, for various conditions on the near-beam detectors at 220m & 420m. Taking our realistic trigger scenario of a single tagged proton at 220m, the L1 efficiency is $\sim$ 12% at the 40 GeV threshold. We also note that an additional 10% of the b-decay channel can be retained by triggering on muons, (specifically with the jet+μ trigger).

Managing the HLT output for the diffractive trigger stream is less challenging than at L1, as we are no longer limited by the L1 trigger latency and have access to the full event data. By correlating ξ of the leading protons as measured in the near-beam stations with the ξ-values reconstructed from jets in the central detector, and by exploiting information from FP420, we can maintain an acceptable output rate of $\sim$ 1Hz. Full details of the HLT strategy adopted for the original study can be found in [9]. It should also be stated that to go any higher in luminosity than 2x10^{33}cm^{-2}s^{-1} would not be possible, without access to the FP420 detector information at L1, as we would be unable to adequately control the rate, without almost completely suppressing our signal.

5. Conclusions

CEP offers a mechanism for the production of a Higgs boson, and other objects of interest, which is independent of 'conventional' inclusive processes. It also offers the possibility of making a range of precision measurements of the properties of the Higgs, such as its mass, spin and parity. This would be impossible by any other means at the LHC.

Single diffractive events, overlying an inclusive hard scatter, form the primary background to CEP of a Higgs. By including a high precision timing mechanism, such as the QUARTIC fast-timing detector, we can determine if tagged protons are connected to the primary vertex of the hard-scattering process. This provides us with excellent control of pile-up induced background when running at high LHC luminosity.

On the subject of triggering on CEP, the trigger latency limits the information from forward detectors that may be exploited at L1 to the $\pm$220m tracking stations. Adding these near-beam detectors into the L1 trigger makes the selection of $H_{m=120} \rightarrow b\bar{b}$ via CEP feasible, while remaining within the 1 kHz diffractive bandwidth allocation, at luminosities of up to 2x10^{33}cm^{-2}s^{-1}.

On a final note, we should mention the time-scale for the FP420 project. The research and development of the tracking stations is fully funded, and a Technical Design Proposal is to be sent to ATLAS and CMS by the first-half of 2007. If this is accepted by one or even both of the collaborations, the project will then be taken to the LHC Committee (LHCC) for approval. In terms of potential deployment of the hardware itself, it is thought that the first LHC long break would offer the ideal opportunity to replace the interconnection cryostats with the FP420 stations. Currently this is time-tabled for late 2008 - early 2009.

References

[1] Kaidalov *et al.*, Eur. Phys. J. C **33** (2004) 261 [arXiv:hep-ph/0207042].

[2] J. Ellis *et al.*, arXiv:hep-ph/0502251.

[3] Khoze *et al.*, Eur. Phys. J. C **23** (2002) 311 [arXiv:hep-ph/0111078].

[4] Boonekamp *et al.*, *Monte Carlo generators for Central Exclusive Diffraction*, Proceedings of The HERA-LHC Workshop, DESY-CERN, 2004-2005.

[5] F. Ferro, *Totem Experiment at the LHC: Status and Program*, these proceedings.

[6] C. Royon, *Luminosity Measurements and Diffractive Physics in ATLAS*, these proceedings.

[7] Albrow *et al.*, CERN Rep. CERN-LHCC-2005-025.

[8] CMS Collab., CERN-LHCC-2000-038.

[9] Arneodo *et al.*, CMS Note **2006**/054, TOTEM Note **2006**/01.

[10] J. Monk and A. Pilkington, arXiv:hep-ph/0502077 (2005).