Hard Diffraction at the LHC

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Abstract
A short review is given on the opportunities for hard diffractive and forward physics measurements at the LHC.

1 Introduction

The Large Hadron Collider (LHC) [1], is a proton-proton collider being installed in the Large Electron Positron (LEP) tunnel at the CERN Laboratory (the European Laboratory for Particle Physics near Geneva, Switzerland). It will be a unique tool for fundamental physics research and the highest energy accelerator in the world for many years following its completion. The LHC will provide two proton beams, circulating in opposite directions, at an energy of 7 TeV each (center-of-mass $\sqrt{s} = 14$ TeV). These beams upon collision will produce an event rate about 100 times higher than that presently achieved at the Tevatron $p\bar{p}$ collider. The first collisions at 14 TeV are now expected for summer/fall 2009.

Apart from the discovery potential the LHC will be also a pivotal instrument to study QCD at the highest energies. Diffraction is an important component in hadronic collisions, and the LHC will shed new light on these still relatively poorly understood interactions. The type of diffractive collisions, or collisions with rapidity gaps expected at the LHC, is shown in Fig. 1 (left).

Diffractive collisions are usually pictured as the result of a diffractive exchange (aka pomeron). In this language the high energy of the LHC beams effectively leads to "pomeron beams" with an energy close to a TeV, allowing to study partonic collisions with fractional momenta of the partons in the "pomeron" of 10^{-3}, and p_T^2 transfers of more than 1 (TeV$/c)^2$. The gap dynamics is presently not fully understood and events with multi-gaps will allow new insights.

2 Detectors for Diffraction

Diffractive events can be tagged by recording rapidity gaps in the events or by detecting the forward proton. The central detector of the CMS and ATLAS experiments have an acceptance in pseudorapidity η, of roughly $|\eta| < 2.5$ for tracking information and $|\eta| < 5$ for calorimeter information.

CMS plans to install a calorimeter that would cover the η range up to $\eta = 6.5$. At the time of this symposium a part of CASTOR was installed as shown in Fig.1 (right). In conjunction with the T2 detector of TOTEM, which has roughly the same acceptance in η, charged particles like electrons can be measured in this forward region. A view of this instrumented region is given in Fig. 2 (left).

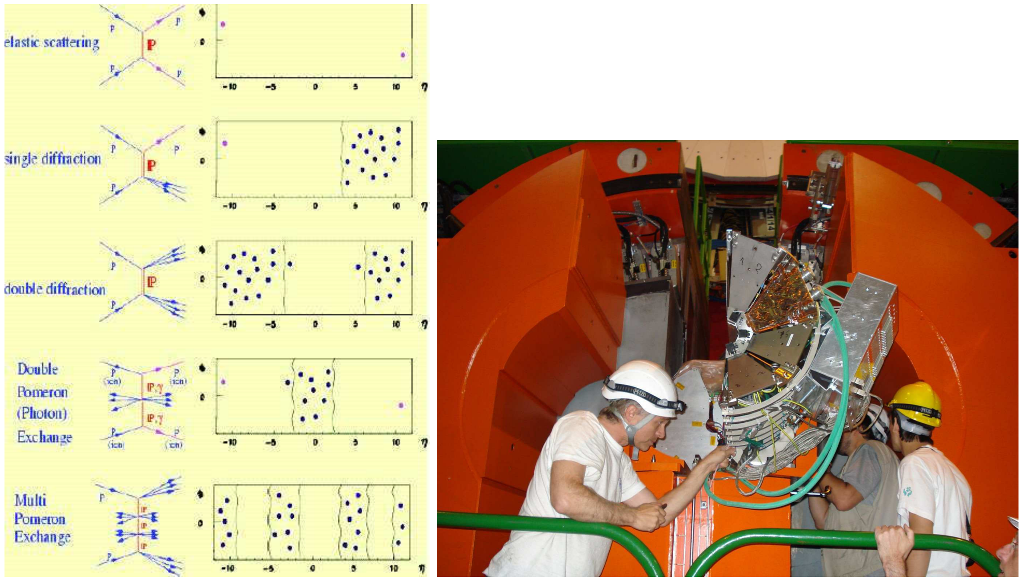

Fig. 1: (Left) Rapidity gap configurations for diffractive events at the LHC; (Right) Installation of part of the CASTOR detector.

CMS is studying the option to include scintillators or GEMs at places among the beamline up to 60-70m or so, to study the particle production in the forward region and backgrounds of the machine, as detailed in [4].

Several of the LHC experiments will have so called Zero Degree Calorimeters (ZDCs). These detectors are located at 140m from the interaction point, where the proton beams are separated in their own beampipe. Finally, TOTEM and ATLAS plan to install Roman Pots that would allow to detect protons which lot 1% to 10% of the total incident energy. A common data taking between TOTEM and CMS –which use the same interaction point– is foreseen [5].

3 FP420

The FP420 project proposes to complement the experiments CMS and ATLAS by installing additional near-beam detectors at 420m away from the interaction region [6]. The presence of these detectors will allow to measure exclusive production of massive particles, such as the Higgs particle, as discussed in the next section.

The aims of the FP420 R&D study are

- Redesign the area of the machine around 420m. Right now this area contains a connecting cryostat, but no magnet elements.
- Study the mechanics, stability and services for detectors at 420m
- Design and test tracking detectors to operate close to the beam
- Design fast timing detectors (with O(10) psec resolution)
- Study RF pickup, integration, precision alignment, radiation and resolution issues for the

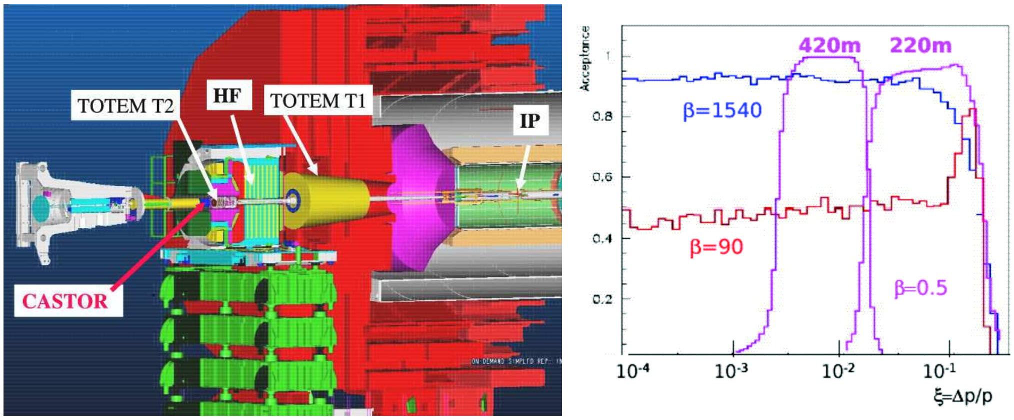

Fig. 2: (Left) Schematics of the CMS forward region. (Right) ξ acceptance of the Roman Pots of TOTEM and detectors at 420m.

FP420 setup.

- Study trigger, event selection, and pile-up issues.
- Study the operation of FP420 detectors at the highest LHC luminosity.

The FP420 project has members from ATLAS, CMS, and "independent" physicists, with excellent contacts with the LHC machine group. In the emerging design the principle of FP420 is based on moving "pockets" which contain tracking and timing detectors. The tracking detectors that are developed are 3D silicon pixel detectors, which are radiation hard and can detect particles close to the edge. Timing detectors include both gas and crystal radiators. The first test beam results of all these detector types are very encouraging and a full pocket beam-test was performed October 2007. Discussions on the implementation of FP420 in the ATLAS and CMS experiments have started. More technical details on FP420 can be found in [7].

4 Diffraction and QCD

The acceptance for diffractive physics with tagged protons is given in Fig. 2(right), for TOTEM and for detectors at 420m. Similar numbers hold for the ATLAS RPs. It shows that special runs with high β^* optics allow to detect protons over essentially the whole ξ range, but this corresponds essentially to luminosities below 10^{31} cm^{-1} s^{-1}. At the nominal high luminosity β^* detectors at 220m (TOTEM or RP220) and detectors at 420m are complementary on the region they cover. Physics topics include QCD and diffraction.

With special optics and rather short running time (perhaps a week) processes with cross sections of μbarns are accessible, while with high luminosity processes with nbarn and pbarn cross sections can be studied. As an example for jet events, generator studies show that with about 300 nb^{-1} about 60000 SD events and 2000 DPE events are produced with jets having an E_T larger than 20 GeV. With 100 pb^{-1} we have 500000 and 30000 events with jets with an E_T larger than 50 GeV. Low luminosities will allow initial studies while high luminosity samples will allow for detailed t, M_x, p_T dependence studies.

An extensive program of two photon physics and photon-proton physics becomes accessible as well. In particular the study of the processes $\gamma\gamma \rightarrow WW$ and ZZ is of interest and can give precise measurements of the anomalous couplings. The QED processes $\gamma\gamma \rightarrow \mu\mu, ee$ can be precise monitors of the luminosity. Two photon processes can also be used to search for chargino pair production.

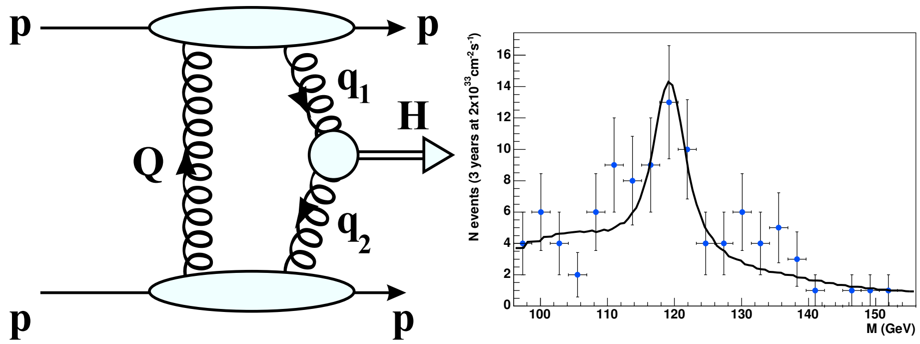

Fig. 3: (Left) Diagram for the CEP process; (Right) A typical mass fit for 3 years of data taking at 2×10^{33} cm^{-2} s^{-1} (60 fb^{-1}). The significance of the fit is 3.5σ and uses only events with both protons tagged at 420m.

5 Central exclusive Higgs production

Central exclusive Higgs (CEP) production $pp \rightarrow p + H + p$ is of special interest. The diagram is shown in Fig. 3 (left). One of the key advantages of CEP is that the $gg \rightarrow b\bar{b}$ process is strongly suppressed in LO, hence the decay $H \rightarrow b\bar{b}$ has less background and becomes potentially observable. The Higgs to b-quark Yukawa coupling is otherwise very difficult to access at the LHC. The inclusive $H \rightarrow b\bar{b}$ channel is not accessible due to the too large QCD backgrounds. Recently, the ttH channel was analysed with detailed simulation in [8] and found not to be accessible even with 60 fb^{-1}. Also the WH associated channel was found to be marginally observable in the $b\bar{b}$ decay mode.

The cross section for CEP of Higgs bosons has been subject of many discussions over the last years, in particular during the HERA/LHC workshops [9], but now generally the calculations of [10] are taken as a reference. Note that there are still some issues and concerns on the CEP soft survival probability at the LHC and the uncertainties in the PDFs. Generator level calculations, including detector and trigger cuts, and estimates of selection efficiencies, show that the decay channels $H \rightarrow b\bar{b}$ and $H \rightarrow WW$ are accessable. Eg. $M_H = 120$ GeV/c^2 gives about 11 events with O(10) events background for 30 fb^{-1} in the $b\bar{b}$ decay mode. For M_H above 140 GeV/c^2 about 5-6 events with no appreciable background for 30 fb^{-1} in the WW decay mode [11] will be observed, using channels with at least one leptonic decay. There are however challenges: the signals from detectors at 420m cannot be used to trigger the events at the first trigger level in neither ATLAS nor CMS. Hence the event will have to be triggered at the first level with the information of the central detector. At the next trigger level the signals of FP420 can be used. While this is no problem for the WW decay channel, it is a challenge for the $b\bar{b}$ channel.

Several additional selection cuts for a low mass Higgs-like object decaying into jets can be used, but generally, with di-jet thresholds of O(40) GeV and these additional cuts, the rate at the first level for this trigger is very high: O(10) kHz. The usage of the FP420 information can however strongly reduce that rate at the next level, so this is not necessarily a show stopper. But in any case, studies both using detailed [5] and fast [12] simulations show that the measurement of the SM Higgs decay into $b\bar{b}$ will be very challenging, even with the highest luminosities.

The rate is much larger for MSSM Higgs production, thus leading to a much more favourable signal to background ratio than for the SM Higgs. The cross section can be a factor 10 or more larger than the SM model one. This has recently been explored in a systematic way in [13]. Fig. 3 (right) shows an example of a signal for 60 fb^{-1} after acceptance cuts, trigger efficiencies etc., for a MSSM Higgs with a cross section that is a factor 8 enhanced w.r.t the the SM Higgs, based on the so called m_h^{max} scenario [14], with $m_A = 120$ GeV and $\tan\beta = 40$. A clear signal over background is observable.

A detailed study of the backgrounds to this diffractive process was presented in [5]. At high luminosity, ie. 10^{33} cm^{-2}s^{-1} and higher, the pile-up is considerable, coming mainly from soft single diffractive interactions. Several techniques such as correlations between the detectors at 420/220m, vertices, event multiplicities and especially fast timing are essential to reduce the pile-up background. Rapidity gaps can obviously not be used due to the many interactions per bunch crossing.

To a very good approximation the central system in CEP is constrained to be a colour singlet, $J_Z = 0$ state, and, due to the strongly constrained three particle final state, the measurement of azimuthal correlations between the two scattered protons will allow to determine the CP quantum numbers of the produced central system [15]. Hence this is a way to get information on the spin of the Higgs, and is added value to the LHC measurements.

Other searches for new physics in the channel are possible as well. It has been pointed out that the mass of long lived gluinos, as predicted in split SUSY models, can be determined with CEP events to better than 1%, with 300 fb^{-1} for masses up to 350 GeV [16]. More spectacular are the predictions presented in [17], where a very high cross section of CEP WW and ZZ events is expected, in a color sextet quark model.

6 Conclusion

The LHC is coming on line, with the first 14 TeV collisions to be expected in summer/fall 2009.

Already with the first data the LHC will allow for novel measurements on hard diffraction, from jets to W, Z and heavy flavor production. When forward proton tagging systems are used, like FP420, a different way to study the Higgs will become accessible. In all, forward and diffractive physics is now well in the blood of the LHC experiments.

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