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Department of Physics and Astronomy
Experimental Particle Physics Group
Kelvin Building, University of Glasgow,
Glasgow, G12 8QQ, Scotland
Telephone: +44 (0)141 330 2000 Fax: +44 (0)141 330 5881

Detection of new states using forward proton tagging at the LHC

P. J. Bussey [1]

University of Glasgow.
for the FP 420 Collaboration.

Abstract

This talk summarises the ongoing proposals to upgrade the ATLAS and CMS detectors by the installation of forward silicon detector systems close to the beam line at distances of approximately 220 m and 420 m from the respective Interaction Points. The physics motivation is outlined, with emphasis on detection of Higgs and Supersymmetric states, and some of the aspects of the apparatus and its performance are briefly described.

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[1] Royal Society of Edinburgh Scottish Executive Support Research Fellow.

1 Introduction and basic proposal for forward detectors.

An important part of the programme of physics at HERA and the Tevatron has been the measurement of diffractive processes, in which the proton exchanges a colourless object, commonly referred to as the pomeron. Of particular interest here are the production of exclusive final states, such as vector mesons, and hard processes in which the partonic components of the structure of the pomeron engage in the interaction. The hard processes were induced at HERA by photons of varying virtuality, ranging from quasi-real photons to highly virtual photons giving deep inelastic scattering off the partons associated with the pomeron. At LHC, much higher energies are becoming available, enabling the diffractive programme to be extended into areas where new physics can be studied. To do this it is proposed to install detector systems close to the beam line at suitable locations downstream of the interaction points. A summary is presented here of some of the new processes that should be open to investigation, and we finally return to outline the capabilities of the physical apparatus in more detail.

The LHC beamline has separate incoming and outgoing beams, and at distances greater than 260 m, the beam is steered by the main bending magnets. At two regions, namely around 220 m and 420 m from the interaction point, there are intervals in the beamline unoccupied by magnets, each of which provides approximately ten metres of clear space within which physics detectors can be stationed. Sets of silicon detectors will be installed in these regions, allowing them to approach as closely as possible to the outgoing beam. These detectors will detect diffractively scattered outgoing protons.

One or both protons in a pp collision may be scattered diffractively. The fractional energy loss ξ suffered by the proton is typically small, as is the angle of scatter. These protons will continue to travel along the beam line, but eventually they will no longer be contained by the beam optics and will be bent either into a collimator or out of the beam line altogether. It is found that protons that have lost a few tens of GeV in the initial collision emerge out of the beam typically in the 420 m regions, and those that have lost a few hundreds of GeV emerge in the 220 m regions. By installing detector systems in these regions, we can identify the double diffractive production of exclusive centrally produced states whose mass is above a minimum value of the order of 100 GeV/c^2, provided that the state gives a suitable signature in the central detector to allow its identification. A measurement of the energies of the outgoing protons gives a good determination of the mass of the centrally produced object.

2 Physics studies

Standard Model Higgs production at the LHC has been calculated by a number of authors. The detected cross section of course depends on the ability to trigger the process in the apparatus. Unfortunately the present electronics in ATLAS and CMS do not allow a first-level trigger to be based on a proton detection at 420 m, since the signal arrives too late. This forces the detection of a 120 GeV/c^2 central state to be based on central detector triggers, which are not highly efficient for a SM Higgs at this mass. In our favour is that the background of quark-antiquark jets is suppressed by the $J_z = 0$ selection rule [1]. An exclusive double-diffractively produced state is constrained to have $J^{PC} = 0^{++}$, so that if a Higgs or other particle is seen at all in this process, we have a good determination of its quantum numbers which may be hard to determine unambiguously by central detector measurements alone.

With the present set-up the prospects for SM Higgs detection in double diffraction at the LHC seem rather marginal. However there are additional opportunities if the Higgs is found within a supersymmetric framework. There are two particularly important parameters of the SUSY scenario, denoted as m_A and $\tan\beta$, in whose parameter space a number of the features of the theory can be illustrated. In certain regions, enhancements to the SM Higgs cross section might be obtained for the lighter of the two neutral SUSY Higgs particles, denoted as h. On this basis, the quantity of LHC luminosity needed for 3-σ evidence and 5-σ discovery of neutral SUSY Higgs in the exclusive double-diffractive mode can be estimated, as illustrated for the heavier SUSY Higgs H in Fig. 1. Contour plots of this kind have been presented by Heinemeyer et al. [2] for the h and H in a variety of related situations. This gives improved hope of being able to make Higgs studies with forward detectors at the LHC, although there is no advance guarantee that the values of the SUSY parameters will be favourable, and the integrated luminosity needed might be substantial.

More cleverly thought-out triggers and cuts may improve the situation. Pilkington et al. [3] have reconstructed the mass of the central object as reconstructed using modelled measurements of the forward proton trajectories at 420 m, with estimated backgrounds from other processes included. During the first years of running, a measurement using 60 fb^{-1} seems a reasonable target. Higher luminosities will clearly assist, but will generate combinatorial backgrounds from overlapping events. If these can be removed, as is envisaged, using precise timing measurements to isolate the event of interest, a signal might be seen giving a 5-σ discovery with 100 fb^{-1} of running.

TeV-energy protons are surprisingly efficient at radiating high energy photons. Single photoproduction off the second proton and photon-photon processes are both of interest at LHC. Kinematically, photoproduction resembles diffractive scattering but with the tendency to smaller transverse momentum transfers to the proton. Since diffraction produces mainly gluon jets and photoproduction produces quark jets, there is little interference between the processes. Single photoproduction will be of interest at the LHC in the production of electroweak particles. There are possibilities for the associated production of Higgs bosons and for the production of anomalous single top via FCNC. These processes are tagged by a single forward proton but must be triggered and identified in the central detectors, and there will be potential difficulties at high luminosities since the use of timing to associate the forward protons with a central vertex requires two such forward protons.

The $\gamma\gamma$ process is capable of inducing the production of any type of charged particle-antiparticle pair. Of particular interest is the possible production of charged SUSY particles, such as charginos and sleptons, whose signatures in the central detector will be high transverse energy leptons and missing energy carried by neutrinos or the lightest SUSY particle (LSP) if it is neutral. W^+W^- production is likely to be a very prolific background.

There are many SUSY mass scenarios. Some possibilities have been studied here in terms of the so-called LM1 scenario, which involves a light LSP and light sleptons and charginos. This type of scenario would give the most favourable set of cross sections. The most natural variable to plot in order to separate SUSY signals from WW background would be the $W_{\gamma\gamma}$ value reconstructed from the forward protons (Fig. 2a) However the background is much more tractable when the variable $W_{miss} = \sqrt{E_{miss}^2 - P_{miss}^2}$ is plotted (Fig. 2b), where the missing energy and momentum are easy calculated from the forward protons and the kinematics of the observed final state particles. Combinations of $W_{\gamma\gamma}$ and W_{miss} give even more power and can generate a distribution that might give a 5-σ discovery with only 25 fb^{-1} of integrated luminosity.

An extended range of SUSY processes may be accessible. One that has been studied is the detection of pairs of long-lived gluinos, for which the forward detectors at 220m and 420 m give access to the wide range of masses that such particle pairs may have [6]. An intriguing example of completely new physics has been proposed by A. White in which a new SU(5) gauge theory obviates the need for a Higgs particle and gives remarkable experimental signatures for which pomeron physics may be an essential diagnostic tool [7].

Space is too limited here to mention more than briefly other items in the range of physics processes that will be made observable by the use of forward tagging systems. The work initiated at HERA on hard pomeron

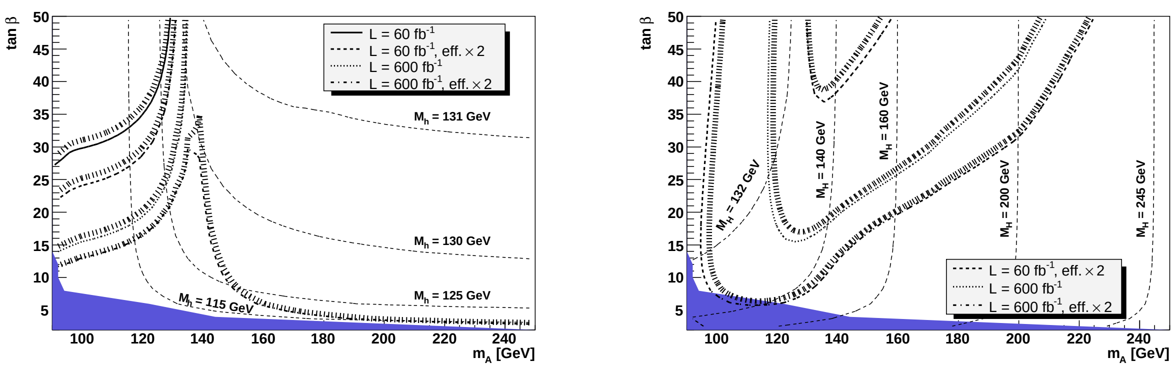

Figure 1: Contours for 3-σ evidence (left) and 5-σ discovery (right) for the h and H SUSY Higgs (see text).

(a) (b)

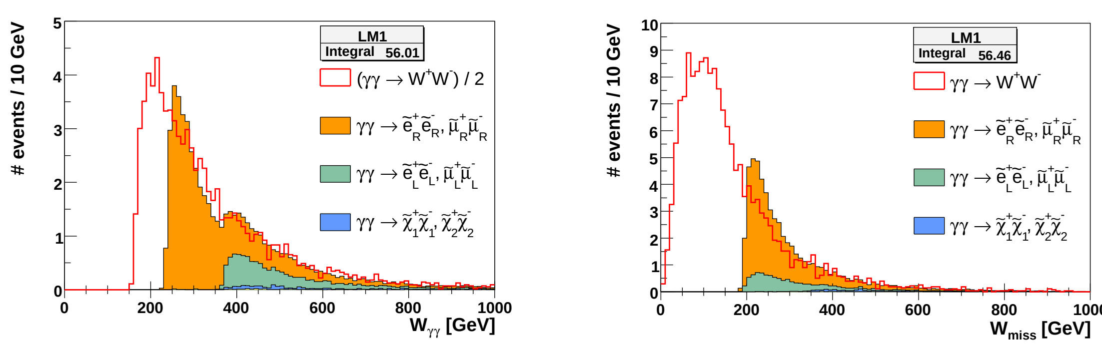

Figure 2: Examples of the analysis of the double photoproduction of SUSY particles, as a function of the parameters $W_{\gamma\gamma}$ and W_{miss}, to illustrate a possible way to isolate a clean SUSY signal (N. Schul)

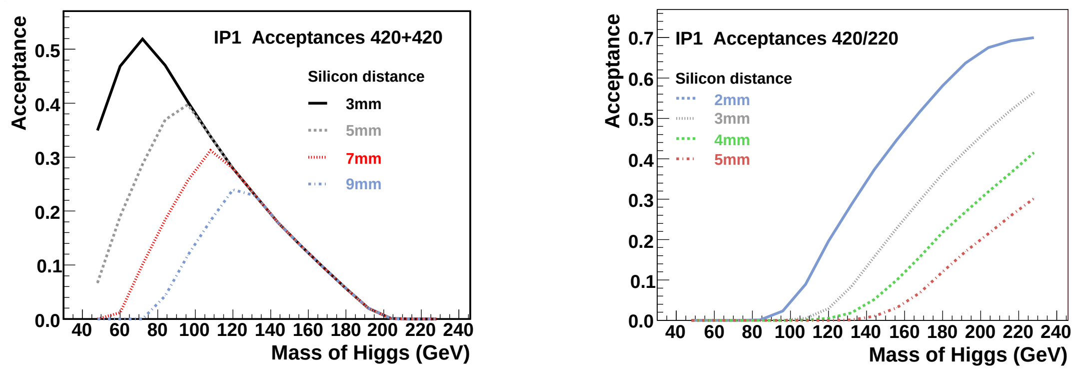

Figure 3: Acceptance of forward tagging systems as function of mass of the centrally produced object, taken here as a Higgs.

scattering and structure can be continued at LHC by means of photon-pomeron and pomeron-pomeron processes. There will be extended opportunities for further studies of the nature of the pomeron. In the early stages, at low LHC luminosities, the study of rapidity-gap survival will be interesting and important, generalised gluon distributions can be studied, and a variety of QCD effects can be investigated; a recent review by Khoze, Martin and Ryskin gives more details [5].

3 The proposed apparatus

The traditional idea of Roman Pots has been extended so that we plan to have an entire section of movable beam pipe, the so-called "Hamburg Pipe", within which sets of silicon detectors will be mounted. The cryostat connection between the portions of beamline either side of the 420 m installations must be replaced. Two optimise performance, two sets of detectors are installed in each pipe, separated by approximately 10 m, so that the position and angle of an emerging proton trajectory can be measured. In the horizontal plane, precisions of approximately 10 μm in position and 1 μrad in angle should be obtainable. Reduced precision in the less critical vertical plane will be accepted. The silicon detectors are of a recent "edgeless" technology to allow the sensitive area to be moved as close as possible to the main outgoing proton beam.

To perform the tracking of the protons into the relevant detector regions, two programs (FPtrack and Hector) have been written for ATLAS and CMS respectively [8]. They enable us to evaluate the acceptance of the apparatus under various conditions, as illustrated in Fig. 3. The 420 m systems used on their own provide substantial acceptance for exclusively produced masses up to approximately 150 GeV/c^2, and even if the silicon can be moved only to 7 mm from the beam, the acceptance at the critical region of 120 GeV/c^2 is not affected. By using the 420 m systems in conjunction with those at 220 m, a greatly extended mass range is achieved with excellent acceptances.

The mass M_X of an exclusively produced final state can be evaluated by reconstructing the momenta of the forward protons; this is achievable by means of polynomial-based formulae in terms of the horizontal position and angle in the detector regions. The value of M_X is then $2\sqrt{(p_0 - p_1)(p_0 - p_2)}$ for an incoming beam momentum p_0 and outgoing proton momenta p_1, p_2. Various uncertainties smear out this calculation, notably the intrinsic spread on p_0. A mass uncertainty of 3-4 GeV/c^2 is obtainable. This is nearly always better than the uncertainty obtained by direct measurement in the central detector. An exception is when the central state consists of two photoproduced muons. This promises to be a key process which we intend to use to calibrate the proton momentum measurements.

Pile-up backgrounds are a potential problem if there are many interaction verteces in a single beam crossing. To identify the correct vertex, very precise timing devices, based on Cherenkov radiation detection, will be installed in the forward detection regions. These are currently under study.

4 Conclusions

For more details, the full FP420 project report may be consulted [9]. Forward tagging opens up a wide range of diffraction and photoproduction processes at LHC. There is discovery potential in some cases, while in others, known processes can be studied in more depth. This is a major new area of physics potential for the LHC.

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