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THE ATLAS FORWARD PHYSICS PROJECT*

Christophe Royon

IRFU-SPP, CEA Saclay, F91191 Gif-sur-Yvette cedex, France

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After defining briefly the diffractive processes, we describe the two main physics motivation of the ATLAS Forward Physics Project, namely the diffractive Higgs production and the anomalous couplings between γ and W or Z at the LHC. We finish the report by describing the project itself.

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1. Exclusive diffraction and exclusive Higgs boson production

The first experimental definition of diffraction deals with the existence of a rapidity gap (in other words a domain in the forward region of the D0, CDF, ATLAS or CMS detectors where no energy is deposited above noise level). The second experimental method to detect diffractive events is to detect directly the intact proton in the final state. The proton loses a small fraction of its energy and is thus scattered at very small angle with respect to the beam direction. Some special detectors can be used to detect the protons close to the beam. The basic idea is simple: the proton detectors are located far away from the interaction point and can move close to the beam, when the beam is stable, to detect protons scattered at vary small angles. This method is the only one possible at high luminosity at the LHC because the number of pile up events which fill the rapidity gaps.

In diffractive events, there is a special class of events called "exclusive" which is specially interesting. In this kind of events, the full energy is used to produce the heavy object (Higgs boson, dijets, diphotons, ...) and no energy is lost in Pomeron remnants [1]. There is an important kinematical consequence: the mass and kinematical properties of the produced object can be computed using roman pot detectors and tagged protons. Higgs boson production via this mechanism leads to a good mass resolution of

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2 to 3% after detector simulation benefitting from the good resolution of the forward detectors. Even if the production cross-section for Higgs boson at the Tevatron is too low to be observable, it is possible to search for exclusive diffractive events in the jet, diphoton or χ_C channels for instance which has been performed by the D0 and CDF collaborations [2].

At the LHC, the exclusive diffractive Higgs boson production is specially of interest. In Fig. 1, we give the number of background and MSSM Higgs signal events for a Higgs mass of 120 GeV for $\tan\beta \sim 40$ [3]. The signal significance is larger than 3.5σ for 60 fb^{-1} (see Fig. 1 left) and larger than 5σ after three years of data taking at high luminosity at the LHC and using timing detectors with a resolution of 10 ps (see Fig. 1 right).

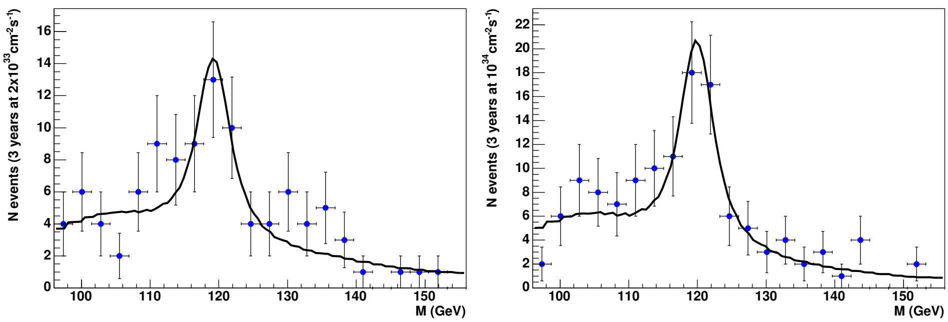

Fig. 1. Higgs signal and background obtained for MSSM Higgs production. The signal significance is larger than 3.5σ for 60 fb^{-1} (left plot) and larger than 5σ after three years of data taking at high luminosity at the LHC and using timing detectors with a resolution of 2 ps (right plot).

2. Quartic anomalous coupling

In the second part of this report, we discuss a different application using the forward proton detectors, namely the possibility to probe anomalous quartic couplings between photons and W or Z bosons at the LHC with an unprecedented precision [4]. In the Standard Model (SM) of particle physics, the couplings of fermions and gauge bosons are constrained by the gauge symmetries of the Lagrangian. The measurement of W and Z boson pair productions via the exchange of two photons allows to provide directly stringent tests of one of the most important and least understood mechanism in particle physics, namely the electroweak symmetry breaking [5]. The non-Abelian gauge nature of the SM predicts the existence of quartic couplings $WW\gamma\gamma$ between the W bosons and the photons which can be probed directly at the Large Hadron Collider (LHC) at CERN. The quartic coupling to the Z boson $ZZ\gamma\gamma$ is not present in the SM. Quartic anomalous couplings between the photon and the Z or W bosons are specially expected to occur in higgsless or extra-dimension models [6].

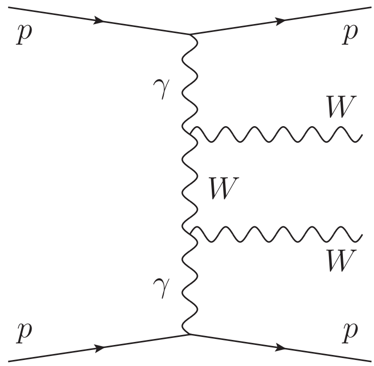

Fig. 2. Sketch diagram showing the two-photon production of a central system.

The process that we intend to study is the W pair production shown in Fig. 2 induced by the exchange of two photons [4]. It is a pure QED process in which the decay products of the W bosons are measured in the central detector and the scattered protons leave intact in the beam pipe at very small angles, contrary to inelastic collisions. Since there is no proton remnant the process is purely exclusive; only W decay products populate the central detector, and the intact protons can be detected in dedicated detectors located along the beam line far away from the interaction point.

The parameterization of the quartic couplings based on [4,7] is adopted. We concentrate on the lowest order dimension operators which have the correct Lorentz invariant structure and obey the $\mathrm{SU}(2)_\mathrm{C}$ custodial symmetry in order to fulfill the stringent experimental bound on the ρ parameter. The lowest order interaction Lagrangians which involve two photons are dim-6 operators. We allow the W and Z parts of the Lagrangian to have specific couplings, *i.e.* $a_0 \rightarrow (a_0^W,\ a_0^Z)$ and similarly $a_\mathrm{C} \rightarrow (a_\mathrm{C}^W, a_\mathrm{C}^Z)$. The WW and ZZ two-photon cross-sections rise quickly at high energies when any of the anomalous parameters are non-zero. The cross-section rise has to be regulated by a form factor which vanishes in the high energy limit to construct a realistic physical model of the BSM theory [4].

The cuts to select quartic anomalous gauge coupling WW events are $0.0015 < \xi < 0.15$ so that the protons can be detected in the forward detectors — ξ is the momentum loss of the proton measured by the forward proton detectors — $\not{E}_\mathrm{T} > 20$ GeV, $\Delta\phi < 3.13$ between the two leptons. They were all implemented in the FPMC Monte Carlo [8]. In addition, a cut on the p_T of the leading lepton $p_\mathrm{T} > 160$ GeV and on the diffractive mass

$W > 800$ GeV are requested since anomalous coupling events appear at high mass. After these requirements, we expect about 0.7 background events for an expected signal of 17 events if the anomalous coupling is about four order of magnitude lower than the present LEP limit ($|a_0^W/\Lambda^2| = 5.410^{-6}$) for a luminosity of 30 fb^{-1}. The strategy to select anomalous coupling ZZ events is analogous and the presence of three leptons or two like sign leptons are requested. Table I gives the reach on anomalous couplings at the LHC for a luminosity of 30 and 200 fb^{-1} compared to the present OPAL limits [9]. We note that we can gain almost four orders of magnitude in the sensitivity to anomalous quartic gauge couplings compared to LEP experiments, and it is possible to reach the values expected in Higgsless or extra-dimension models which are of the order of 5×10^{-6}. The tagging of the protons using the ATLAS Forward Physics detectors is the only method at present to test such small values of quartic anomalous couplings and thus to probe the higgsless models in a clean way. The reach on anomalous triple gauge couplings is less improved at the LHC compared to LEP experiments [10].

The ATLAS Forward Physics program (and the CMS one) will allow to study Higgsless models with an unprecedented precision as well as to probe the Higgs boson by allowing its mass and spin measurements using the forward detectors proposed for installation at 220 and 420 m in ATLAS and CMS.

TABLE I

Reach on anomalous couplings obtained in γ induced processes after tagging the protons in the final state in the ATLAS Forward Physics detectors compared to the present OPAL limits. The 5σ discovery and 95% C.L. limits are given for a luminosity of 30 and 200 fb^{-1}.

Couplings	OPAL limits [GeV^{-2}]	Sensitivity at $\mathcal{L} = 30$ (200) fb^{-1} 5σ	95% C.L.
a_0^W/Λ^2	$[-0.020, 0.020]$	$5.4\ 10^{-6}$ ($2.7\ 10^{-6}$)	$2.6\ 10^{-6}$ ($1.4\ 10^{-6}$)
a_C^W/Λ^2	$[-0.052, 0.037]$	$2.0\ 10^{-5}$ ($9.6\ 10^{-6}$)	$9.4\ 10^{-6}$ ($5.2\ 10^{-6}$)
a_0^Z/Λ^2	$[-0.007, 0.023]$	$1.4\ 10^{-5}$ ($5.5\ 10^{-6}$)	$6.4\ 10^{-6}$ ($2.5\ 10^{-6}$)
a_C^Z/Λ^2	$[-0.029, 0.029]$	$5.2\ 10^{-5}$ ($2.0\ 10^{-5}$)	$2.4\ 10^{-5}$ ($9.2\ 10^{-6}$)

3. The ATLAS Forward Physics Project

In this section, we describe briefly the project to install forward detectors at 220 and 420 m in the ATLAS Collaboration [11], called ATLAS Forward Physics (AFP). To obtain a good acceptance in mass (above 50% for masses between 115 and 650 GeV), both detectors at 220 and 420 m are needed, since many events even at low masses show an intact proton in the 220 m detector on one side and in the 420 m one on the other side. Two kinds of detectors namely the pixel Si and the timing detectors, will be hosted in movable beam pipes located at 220 and 420 m. In the first phase of the project, it is foreseen to install only the 220 m detectors allowing to study the anomalous coupling part of the physics program.

The idea of movable beam pipes is quite simple and was used already at HERA: when the beam is injected, the movable beam pipe is in its "home" position, so that the detectors can be far away from the beam and its halo, and when the beam is stable, the movable beam pipe moves so that the detectors go closer to the beam. A typical movement is of the order of 2 cm. Beam Pipe Monitors will be located in the fixed and movable beam pipe areas to measure how close the detectors are located with respect to the beam. The needed precision is of the order of 10–15 μm. Four horizontal pockets containing the silicon and timing detectors will be located within the movable beam pipe structure (for instance, at 220 m, we will have two sets of silicon and timing detectors located respectively at 216 and 224 m). The protons are emitted diffractively in the horizontal plane and this is why only horizontal detectors and pockets are needed.

It is assumed that it will be possible to go as close to the beam as 15 σ at 220 and 420 m. To get a full coverage for the diffracted protons, detectors of $2\,\mathrm{cm} \times 2\,\mathrm{cm}$ and of $0.6\,\mathrm{cm} \times 2\,\mathrm{cm}$ are needed at 220 and 420 m respectively. The position of the protons have to be measured with a precision of 10–15 μm in x-direction in a radiation environment and this is why the solution of silicon pixels has been chosen. The size of the pixels is of 50 μm $\times$ 400 μm read out by a FEI4 chip. There will be 5 layers of such Si detectors staggered in x and y directions perpendicular to the beam.

The other kind of detector which is crucial for this project is the timing detectors. At the LHC, up to 35 interactions occur at the same bunch crossing and we need to know if the observed protons in the final state originate from the main interaction producing for instance the Higgs boson or the WW event, or from a secondary one which is not related to the hard interaction. To achieve this goal, it is needed to know if the protons are coming from the main vertex of the event, and for this sake, to measure precisely the time of flight of the protons with a precision better than 10 ps. Two kinds of detectors have been proposed. The GASTOF measures the Cherenkov light emitted by the protons and collected in a multichannel photomultiplier. This detector has a very good intrinsic resolution measured in beam tests of about 10–15 ps, but present the inconvenient of showing no lateral space resolution which is needed in the case of multiple protons are produced in one bunch crossing. The other device, QUARTIC, uses quartz radiator bars to emit the photons and leads to a resolution per detector of 30–40 ps. Several detectors are thus needed to achieve the wanted resolution. The advantage of such detectors is that it can have a couple of mm space resolution and the inconvenient is the smaller number of photoelectrons produced. This kind of detectors is also specially interesting for medical applications since it would allow to improve the present resolution of the PET imaging detectors by one order of magnitude.

The timing detector at 220 m can also provide a L1 trigger (the 420 m detector is too far away to make it to the L1 trigger). Two kinds of triggers are considered. The first one triggers on events when both protons are detected at 220 m. The second (more difficult) triggers on events when only one proton is present at 220 m. In that case, the idea is to cut off the acceptance at 220 m corresponding to the possibility of a tag at 420 m. A typical jet trigger will be: two jets with a transverse momentum above 40 GeV, one proton at 220 m with a momentum loss smaller than 0.05 compatible with the presence of a proton at 420 m on the other side, and the exclusiveness of the process (most of the energy is carried by the two hard jets). With these cuts, the L1 rate is expected to be smaller than 1 kHz for a luminosity smaller than 2×10^{33} cm^{-2}s^{-1}. The expected output at L2 is assumed to be only a few Hz only since the timing and the 420 m detector informations will be available at this stage.

The AFP project is now under review by the ATLAS Collaboration and if approved, it is intended to install the movable beam pipes with the pixel silicon and timing detectors in 2013 at 220 m. It will allow to extend substantially the physics program at the LHC especially in QCD, searches for the Higgs boson, $W\gamma$ anomalous couplings.

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