SENSITIVITY ON QUARTIC ANOMALOUS COUPLING BETWEEN PHOTON AND W/Z BOSON USING THE ATLAS FORWARD PHYSICS (AFP) PROJECT

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We study the W/Z pair production via two-photon exchange at the LHC and give the sensitivities on quartic gauge anomalous couplings between photons and W/Z bosons for an integrated luminosity of 30 and 200 fb^{-1}. For simplicity and to obtain lower backgrounds, only the leptonic decays of the electroweak bosons are considered. The intact protons in the final states are detected in the ATLAS Forward Proton detectors. We describe the main components of the ATLAS Forward Physics project, namely the movable beam pipes, the tracking and timing detectors which allow to detect intact protons in the final state.

1 Photon exchange processes in the Standard Model

The process that we intend to study is the W pair production shown in Fig. 1 left induced by the exchange of two photons [1]. 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 cross section of the $pp \to pWWp$ process which proceeds through two-photon exchange is calculated as a convolution of the two-photon luminosity and the total cross section $\gamma\gamma \to WW$. The total two-photon cross section is 95.6 fb.

All considered processes (signal and background) were produced using the Forward Physics Monte Carlo [2] (FPMC) generator. The aim of FPMC is to produce different kinds of processes such as inclusive and exclusive diffraction, photon-exchange processes. FPMC was interfaced to a fast simulation of the ATLAS detector [3]. To reduce the amount of considered background, we only consider leptonic (electrons and muons) decays of Z and W bosons. The clean two-leptonic signature of the two boson signal process $\gamma\gamma \to W^+W^- \to ll\nu\nu$ can be mimicked by several background processes which all have two intact protons in the final state. They are the following:

1. $\gamma\gamma \to l\bar{l}$ - two-photon dilepton production
2. DPE$\to l\bar{l}$ - dilepton production through double pomeron exchange
3. DPE$\to W^+W^- \to ll\nu\ \nu$ - diboson production through double pomeron exchange

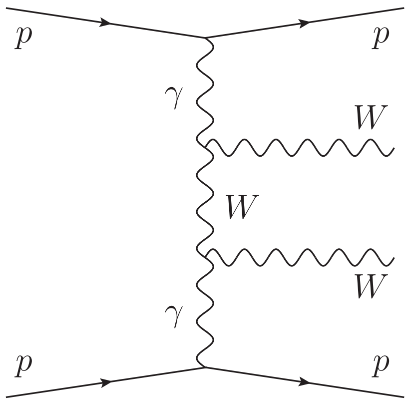


Figure 1: Sketch diagram showing the two-photon production of a central system.

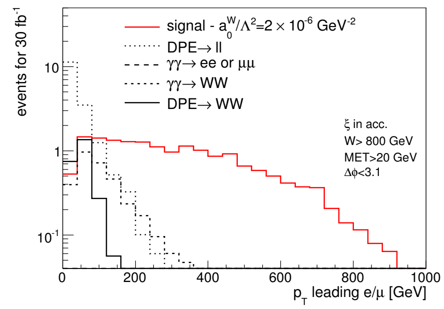


Figure 2: Distribution of the transverse momentum of the leading lepton for signal and background after the cut on W, $\not{E}_T$, and $\Delta\phi$ between the two leptons.

After simple cuts to select exclusive W pairs decaying into leptons, such as a cut on the proton momentum loss of the proton ($0.0015 < \xi < 0.15$) — we assume the protons to be tagged in the ATLAS Forward Physics detectors [4] — on the transverse momentum of the leading and second leading leptons at 25 and 10 GeV respectively, on missing transverse energy $\not{E}_T > 20$ GeV, difference in azimutal angle $\Delta\phi > 2.7$ between leading leptons, and $160 < W < 500$ GeV, the diffractive mass reconstructed using the forward detectors, the background is found to be less than 1.7 event for 30 fb^{-1} for a SM signal of 51 events. In this channel, a 5 σ discovery of the Standard Model $pp \to pWWp$ process is possible after 5 fb^{-1}.

2 Quartic anomalous couplings

The parameterization of the quartic couplings based on [5] is adopted. We concentrate on the lowest order dimension operators which have the correct Lorentz invariant structure and obey the $SU(2)_C$ 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. The following expression for the effective quartic Lagrangian is used

$$\begin{aligned}
\mathcal{L}_6^0 &= \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha \\
\mathcal{L}_6^C &= \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta) - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta \qquad (1)
\end{aligned}$$

where a_0, a_C are the parametrized new coupling constants and the new scale Λ is introduced so that the Lagrangian density has the correct dimension four and is interpreted as the typical mass scale of new physics. In the above formula, we allowed the W and Z parts of the Lagrangian to have specific couplings, i.e. $a_0 \to (a_0^W, a_0^Z)$ and similarly $a_C \to (a_C^W, a_C^Z)$.

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. We therefore modify the couplings by form factors that have the desired behavior, i.e. they modify the coupling at small energies only slightly but suppress it when the center-of-mass energy $W_{\gamma\gamma}$ increases. The form of the form factor that we consider is the following

$$a \to \frac{a}{(1 + W_{\gamma\gamma}^2/\Lambda^2)^n} \qquad (2)$$

where n=2, and $\Lambda \sim$2 TeV.

Couplings	OPAL limits	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1}	
	[GeV^{-2}]	5σ	95% CL
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})

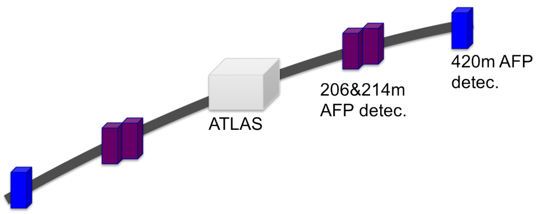
Table 1: Reach on anomalous couplings obtained in γ induced processes after tagging the protons in the final state in the ATLAS Forward Physics detectors compared to the present OPAL limits. The 5σ discovery and 95% C.L. limits are given for a luminosity of 30 and 200 fb^{-1}.

The requirements to select quartic anomalous gauge coupling WW events are similar as the ones we mentioned in the previous section, namely $0.0015 < \xi < 0.15$ for the tagged protons, $\not{E}_T > 20$ GeV, $\Delta\phi < 3.13$ between the two leptons. In addition, a cut on the p_T of the leading lepton $p_T > 160$ GeV and on the diffractive mass $W > 800$ GeV are requested since anomalous coupling events appear at high mass. Fig 2 displays the p_T distribution of the leading lepton for signal ($|a_0^W/\Lambda^2| = 2\ 10^{-6}$) and the different considered backgrounds. After these requirements, we expect about 0.7 background events for an expected signal of 17 events if the anomalous coupling is about four orders of magnitude lower than the present LEP limit ($|a_0^W/\Lambda^2| = 5.4\ 10^{-6}$) 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 1 gives the reach on anomalous couplings at the LHC for luminosities of 30 and 200 fb^{-1} compared to the present OPAL limits [6]. 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. The tagging of the protons using the ATLAS Forward Physics detectors is the only method at present to test so small values of quartic anomalous couplings and thus to probe the higgsless models in a clean way. The results after a full simulation of the ATLAS results leads to a similar result [4].

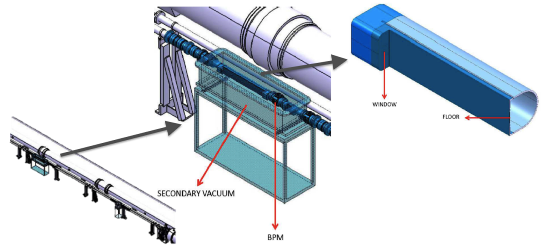
To achieve this experimental program, a proposal to add forward proton detectors located at 210 and 420 m from the interaction point was submitted to the ATLAS collaboration. Both detectors allow a good acceptance in mass between 110 GeV and 1.3 TeV. By 2014, only the 210m detectors are foreseen. They are sensitive to high diffractive masses and will allow to fulfill the program to look for anomalous couplings in higgsless or extra-dimension models with an unprecedented precision. This project is under approval procedures by the ATLAS collaboration.

3 The ATLAS Forward Physics detector

We describe the proposal to install the ATLAS Forward Proton (AFP) detector in order to detect intact protons at 206 and 214 meters on both side of the ATLAS experiment [4]. This one arm will consist of two sections (AFP1 and AFP2) contained in a special design of beampipe described. In the first section (AFP1), in one pocket of the beampipe, a tracking station composed by 6 layers of Silicon detectors described in Section 4 will be deployed. The second station AFP2 will contain two pockets: one with another tracking station similar to the one already described, and the other one, placed at a further distance from the ATLAS interaction point (IP), containing one or two stations of a timing detector described in Section 5. The aim of this setup, mirrored



(a) AFP detectors positioning.



(b) Sketch of the movable beam pipes.

Figure 3: Sketch of the ATLAS Forward Physics detector implementation.

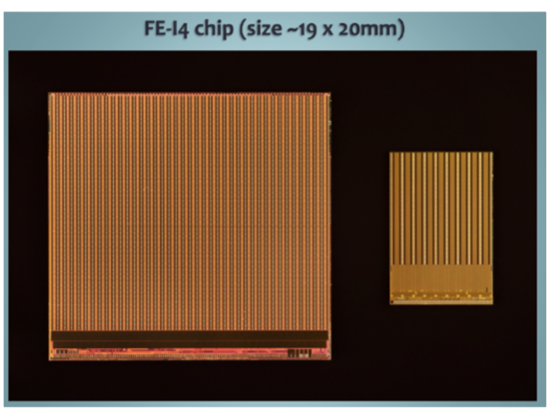
by an identical arm placed on the opposite side of the ATLAS IP, will be to tag the protons emerging intact from the *pp* interactions so allowing ATLAS to exploit the program of diffractive and photoproduction processes.

4 3D Silicon detectors

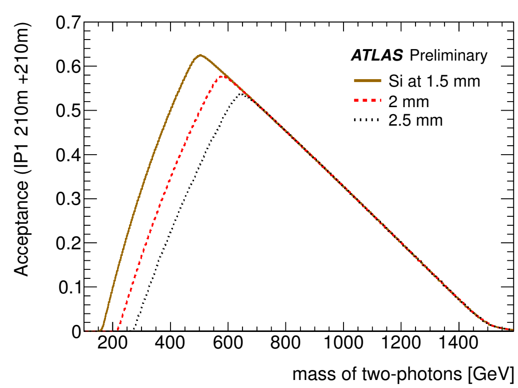
The purpose of the tracker system is to measure points along the trajectory of beam protons that are deflected at small angles as a result of collisions. The tracker when combined with the LHC dipole and quadrupole magnets, forms a powerful momentum spectrometer. Silicon tracker stations will be installed in Hamburg beam pipes (HBP) shown in Figure 3b [7] at $\pm$ 206 and $\pm$ 214 m from the ATLAS.

The key requirements for the silicon tracking system at 210 m are [8]:

- Spatial resolution of $\sim$ 10 (30) μm per detector station in x (y)
- High efficiency over an area of 20 mm $\times$ 20 mm.
- Capable of robust and reliable operation at high LHC luminosity



(a) FE-I4 detector chip.



(b) Mass acceptance of the 210m detector for three differents positions.

Figure 4: Silicon detector and mass acceptance.

For this purpose, six layers of 3D silicon sensors readout by the FE-I4 chips will be used. The chips have a 2×2 cm^2 active area made 50 μm $\times$ 250 μm in the x and y direction, respectively as shown in Figure 4. Therefore to achieve the required position resolution in the x-direction of $\sim$ 10 μm, six layers with sensors are required (this gives $50/\sqrt{12}/\sqrt{5} \sim 7$ μm in x and roughly 5 times worse in y). Offsetting planes alternately to the left and right by one half pixel will give

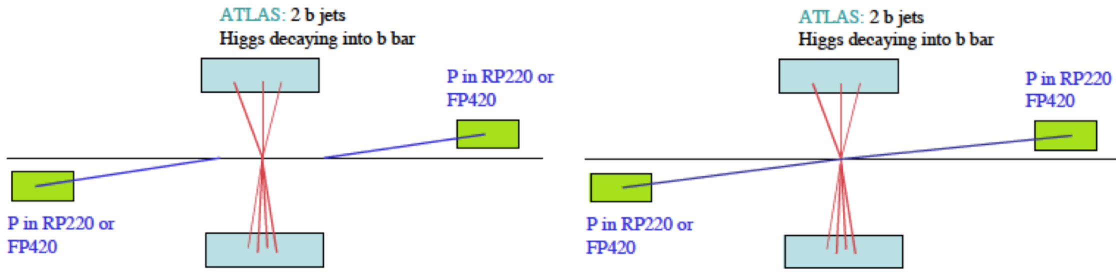


Figure 5: Sketch showing protons coming from pile-up (left) and true (right) event in AFP detectors.

a further reduction in resolution of at least 30%. The AFP sensors are expected to be exposed to a dose of 30 kGy per year at the full LHC luminosity of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

5 Timing detectors

A fast timing system that can precisely measure the time difference between outgoing scattered protons is a key component of the AFP detector. As shown on Figure 5, it is necessary to be able to reject event that did not originate from the same vertex as the central system. In order to do so, a time constraint on the difference of time-of-arrival of the two scattered protons allows to confirm that any observed signal originates from the main hard interaction. The final timing system should have the following characteristics: 10 ps or better resolution (20 ps is likely sufficient for the first couple of years of operation), high acceptance and efficiency, high rate capability, segmentation, and trigger capability [9].

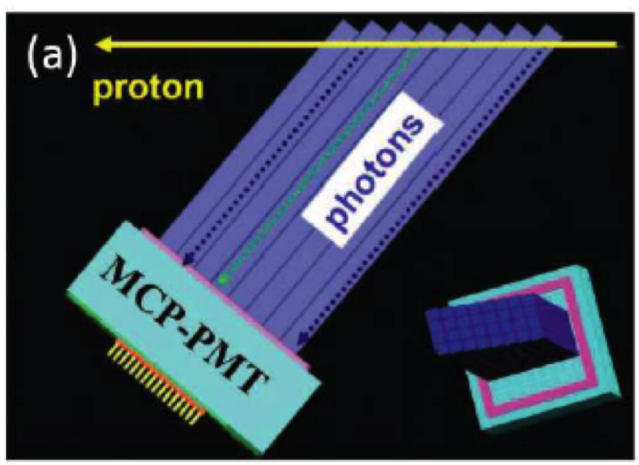


Figure 6: Scheme of the proposed timing detector. The protons passing through the quartz bar emit Cerenkov light detected by the MCP-PMT detector.

Figure 6 shows a scheme of the proposed timing detector, consisting of a quartz-based Cerenkov radiator coupled to a microchannel plate photomultiplier tube (MCP-PMT). It is followed by the readout electronics elements that will sample and digitize the very fast signals coming from the detector. The time-of-arrival is then extracted offline from the digitized waveform. The QUARTIC detector consists of an array of fused silica bars ranging in length from about 8 to 12 cm and oriented at the average Cerenkov angle. A proton that is sufficiently deflected from the beam axis will pass through a row of eight bars emitting Cerenkov photons, with those emitted in the appropriate azimuthal angular range accepted by the MCP-PMT, providing an overall time resolution that is approximately $\sqrt{8}$ times smaller than the single bar resolution of about 30 ps, thus approaching the 10 ps resolution goal without putting overly stringent requirements on any single measurement.

In order to reach the picosecond time resolution necessary for pile-up rejection in AFP, a very fast electronics to read-out the detector is necessary. It consists of a very fast (10 GHz sampling speed), high bandwidth (above 1GHz) and relatively low noise electronics (below 1mV). With a multi-gigahertz sampling the time of arrival of the pulse can afterwards be extracted down to under 10 picoseconds [10]. A Sampling chip for Picosecond time pick-off (SAMPIC) is under devlopment in CEA Saclay - IRFU, with a target timing resolution of a couple of picoseconds.

References

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