W, Z and jet central exclusive production at the LHC

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We study the W/Z pair production via two-photon exchange at the LHC and give the sensitivities on trilinear and quartic gauge anomalous couplings between photons and W/Z bosons. Tagging the protons in the final state in the ATLAS Forward Physics detectors as an example allows to improve the reach on anomalous couplings by four orders of magnitude reaching the values predicted by extra-dimension theories. The measurement of the exclusive jet production using the same detectors at the LHC will also be described.

1 Probing Anomalous Couplings

The studies presented in this section involve exclusive diffractive processes at the LHC. Diffractive events are characterized by an object produced in the central detector, two intact protons after interaction and nothing else (no energy loss or remnants). Events are generated using FPMC, a generator implementing diffractive or photon induced processes. We also make use of the ATLAS Forward Physics project (AFP), which is an upgrade of the ATLAS experiment. It will consist of forward proton detectors to be installed on both sides of the ATLAS detector, at about 220 meters from the interaction point, in movable beam pipes. Each station will welcome both silicon and timing detectors, that respectively measure the position and the time of flight to remove pile-up.

We study the QED process $pp \to ppWW$, in which the W boson pair is produced *via* a photon exchange between the two protons. We use the photon equivalent approximation (Budnev flux). Photons have typically a low virtuality Q^2 but can have a high energy. In particular we can have a high missing mass $M_{\gamma\gamma} = \sqrt{s\xi_1\xi_2}$ (where ξ is the momentum fraction loss of the proton). The cross section for this process is fairly large in the Standard Model ($\sigma_{pp\to ppWW} = 95.6$ fb), even at high missing mass ($\sigma_{pp\to ppWW}(W = M_X > 1\,\text{TeV}) = 5.9$ fb). As we will see, this process is highly sensitive to beyond Standard Model effects, especially anomalous gauge couplings.

We consider dimension 6 operators for the implementation of the anomalous quartic $\gamma\gamma WW$ and $\gamma\gamma ZZ$ couplings:

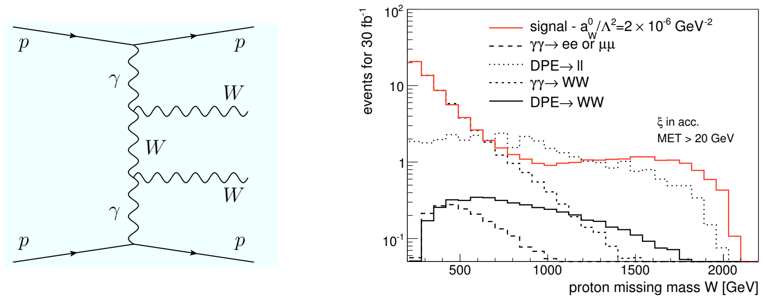

Figure 1: Left: Feynman diagram for $pp \to ppWW$. Right: proton missing mass distribution for signal ($a_0^W/\Lambda^2 = 2 \times 10^{-6}\,\mathrm{GeV}^{-2}$) and background.

$$\mathcal{L}_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W_\alpha^- - \frac{e^2}{16\cos^2\Theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha \quad (1)$$

$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W_\beta^- + W^{-\alpha}W_\beta^+) - \frac{e^2}{16\cos^2\Theta_W}\frac{a_C^Z}{\Lambda^2}F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta \quad (2)$$

All anomalous parameters (a_0^W, a_0^Z, a_C^W, a_C^Z) are equal to zero in the Standard Model. We only consider $\gamma\gamma WW$ and $\gamma\gamma ZZ$ anomalous parameters (the latter being not discussed here), but many more are possible ($\gamma\gamma$, Higgs, etc.). It is worth noting that because these are dimension 6 operators, they violate unitarity at high energy, so that we need the introduction of form factors to avoid quadratical divergences of scattering amplitudes: $a_0^W/\Lambda^2 \to \frac{a_0^W/\Lambda^2}{(1+W_{\gamma\gamma}/\Lambda_{\mathrm{cutoff}})^2}$ where $\Lambda_{\mathrm{cutoff}} \sim 2\,\mathrm{TeV}$ is the scale of new physics.

We focus on events where both W bosons decay leptonically. Our experimental signature is therefore two leptons, two tagged protons in the forward detectors, and nothing else in the detector. The possible backgrounds are inelastic WW production, dilepton through photon exchange, dilepton through double pomeron exchange (DPE), and WW through DPE. However dilepton production involves back-to-back leptons and no missing transverse energy ($\not{E}_T$); and DPE induces some energy flow in the forward regions as well as a higher number of tracks, because of the pomeron remnants.

More precisely, at preselection we require two reconstructed leptons (ee, $e\mu$ or $\mu\mu$) with $|\eta^{e,\mu}| < 2.5$ and $p_T^{e,\mu} > 10\,\mathrm{GeV}$, two tagged protons ($\xi \in [0.0015, 0.15]$), and nothing else. Additional cuts on $\not{E}_T$ and the opening angle between the two leptons ($\Delta\phi_{ll}$) help reject dilepton production. In order to reject DPE WW as well as increase the sensitivity to anomalous couplings, we also cut on the mass W of the central system reconstructed using AFP and on the leading lepton transverse impulsion. Our final selection is defined as $\not{E}_T > 20\,\mathrm{GeV}$, $W > 800\,\mathrm{GeV}$, $M_{ll} \notin [80, 100]$, $\Delta\phi_{ll} < 3.13$ and $p_T^{\mathrm{lep1}} > 160\,\mathrm{GeV}$. A yield table is given in Table 1.

Results obtained with fast simulation (ATLFAST++) are up to four orders of magnitude more sensitive than the LEP limits, or two orders of magnitude more sensitive than "standard" searches using $pp \to l^\pm\nu\gamma\gamma$ [3].

However, fast simulation does not allow to study the effect of pile-up and the rejection of non-diffractive backgrounds. This is why the analysis was also performed using the ATLAS full

cut / process	$\gamma\gamma \to ll$	$\gamma\gamma \to WW$	DPE $\to ll$	$\lvert a_0^W/\Lambda^2\rvert = 5.4 \cdot 10^{-6}\,\text{GeV}^{-2}$
$p_T^{\text{lep1,2}} > 10\,\text{GeV}$	50619	99	18464	202
Final selection	0	0.69	0.20	17

Table 1: Cut flow table. Events for 30fb^{-1} (fast simulation ATLFAST++).

a_0^W/Λ^2 Sensitivity	5σ	95% C.L.	OPAL limits
$\mathcal{L} = 40\,\text{fb}^{-1}$, $\mu = 23$	$5.5 \cdot 10^{-6}$	$2.4 \cdot 10^{-6}$	$[-0.020, 0.020]$
$\mathcal{L} = 300\,\text{fb}^{-1}$, $\mu = 46$	$3.2 \cdot 10^{-6}$	$1.3 \cdot 10^{-6}$	

Table 2: Sensitivity with full simulation.

simulation. The exclusivity of the event is defined thanks to the proton time of flight, but also the number of tracks fitted to the vertex. Indeed, for signal two tracks are expected from the vertex (from the leptonic decay of the W bosons), while for background (e.g. $t\bar{t}$) much more tracks are expected. In addition to the previously mentioned backgrounds considered with fast simulation, we also considered single-diffractive WW production and non diffractive backgrounds ($t\bar{t}$, diboson, $W/Z + jets$, Drell-Yan, single top). The simulation assumes a 10 ps resolution for the proton timing detectors, and two luminosity scenarios: respectively 40 (200) fb^{-1} of data with $\mu = 23$ (46) interactions per bunch crossing. Results from full simulation [4] are shown in Table 2 and are very similar to the prediction of fast simulation.

2 Exclusive Models Uncertainties

We study the sources of uncertainties on gluon-mediated exclusive diffractive processes, in the case of diffractive Higgs production and jets production at the LHC. Several models are available with similar predictions, such as Khoze, Martin, Ryskin (KMR [5]), or the one on which we focused: Cudell, Hernández, Ivanov, Dechambre exclusive (CHIDe [6]). The main sources of uncertainty are the rapidity gap survival probability (measured to be 0.1 at the Tevatron, not measured at the LHC and assumed to be 0.03), the gluon distributions and the Sudakov form-factors.

The choice of the gluon distribution parametrization contributes to the model uncertainty both at the Tevatron (Figure 2) and at the LHC. For instance it gives an uncertainty of a factor about 3.5 on exclusive dijet and about 2 on exclusive Higgs cross section at the LHC.

The Sudakov form-factor takes the following form in the CHIDe model:

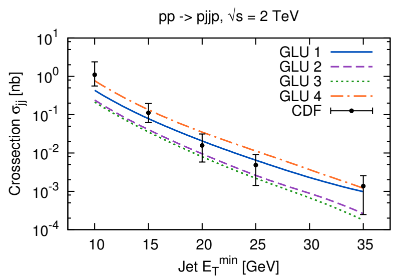

Figure 2: Exclusive diffractive jet production at the Tevatron for different gluon distribution parametrizations.

$$T(l_i, \mu) = \exp\left[-\int_{l_i^2/x'}^{\mu^2/x} \frac{\mathrm{d}\mathbf{q}^2}{\mathbf{q}^2} \frac{\alpha_s(\mathbf{q}^2)}{2\pi} \int_0^{1-\Delta} \left(zP_{gg} + \sum_q P_{qg}(z)\right) \mathrm{d}z\right] \tag{3}$$

The uncertainty comes from the limits of the integral, x and x' (the latter having a bigger impact), which have not yet been fixed by a theoretical calculation. They are constrained, to some extent, by the exclusive jet cross section measurement from CDF. However varying x' by a reasonable factor 2 can change the cross section by a factor up to 5, as shown on Figure 3. When propagated to the LHC, the uncertainty using the CDF constraint alone is even more sizable: a factor about 10 for jets or even 25 for Higgs exclusive production. Fortunately, a $100\,\mathrm{pb}^{-1}$measurement of the exclusive jet cross section at the LHC (easily doable with AFP) would help constrain the uncertainties, which would go down to a factor about 5 for Higgs.

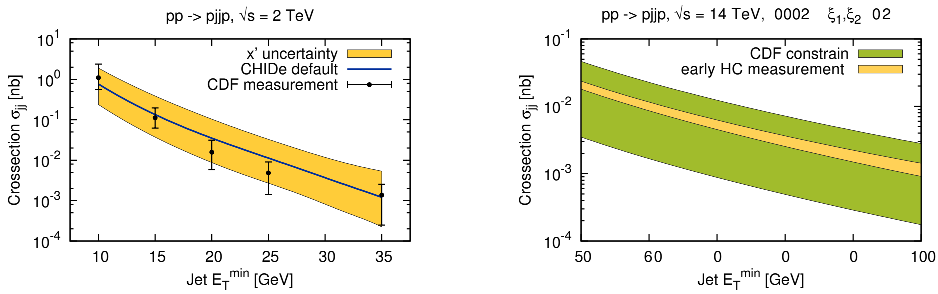

Figure 3: Left: impact of the uncertainty on x' on the exclusive diffractive jet cross section at the Tevatron. Right: impact of this uncertainty on the exclusive jet cross section at the LHC, with the CDF constrain alone and with the constrain of an early exclusive jet cross section measurement at the LHC.

Conclusion

We have presented two central exclusive studies possible at the LHC. Concerning anomalous couplings in two-photon processes, the analysis takes advantage of the AFP forward proton detectors, and improves the sensitivity of up to 4 orders of magnitude compared to the LEP. For uncertainties on exclusive diffractive Higgs and jets production, the main sources of theoretical uncertainties are coming from the gluon distributions parametrization and the Sudakov form-factors. An exclusive jet cross section at the LHC could improve a lot the constraint from CDF measurement.

Regarding AFP, the letter of intent has been approved in ATLAS and by the LHCC, and if the project is definitely approved, movable beam pipes, silicon detectors and timing detectors will be installed in 2014.

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