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DETECTION OF NEW HEAVY GAUGE BOSONS W' IN CMS*

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A first feasibility study of the search for a new heavy charged gauge boson with the CMS detector at the Large Hadron Collider LHC is presented. The used model assumes the existence of a heavy carbon copy of the Standard Model W (Reference Model by Altarelli), generically denoted as W'. Such a boson has been investigated in the decay channel $W' \to \mu\nu$ using the full detector simulation including minimum bias events (pile-up) according to the luminosity expected in the first years. All relevant Standard Model backgrounds have been considered. Such a new boson is expected to be discovered, if existing, with a mass up to 4.6 TeV for an integrated luminosity of $10\,\mathrm{fb}^{-1}$. The range can be expanded to 6.1 TeV with an integrated luminosity of $300\,\mathrm{fb}^{-1}$. If no signs for a W' boson appear 95% CL exclusion limits of 4.7 TeV and 6.2 TeV can be set, respectively.

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1. Introduction

Several theories beyond the Standard Model (SM) introduce new charged gauge bosons in order to enlighten phenomena which cannot be explained in the context of the Standard Model.

In principle, every extension of the Standard Model gauge groups leads to new gauge bosons, which are related to the generators of the new symmetry. Therefore, a huge variety of models demanding new gauge bosons exists. So far, only the Standard Model bosons (γ, W, Z and the gluons) have been discovered. New charged particles are expected to have masses at the TeV scale which will be explored at the LHC. The decay of such bosons into high energy final state particles induce prominent signatures for physics beyond the Standard Model.

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2. The CMS experiment at the LHC

The LHC is a proton–proton collider with a centre-of-mass energy of $\sqrt{s} = 14$ TeV. In an initial phase the collider is foreseen to be driven at an instantaneous luminosity of $\mathcal{L} = 2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. At the four interaction points where the detectors (ALICE, ATLAS, CMS and LHCb) are located, bunches of protons collide every 25 ns.

CMS, designed to study proton–proton collisions as well as heavy ion collisions, is one of the two multi-purpose detectors being operated at the LHC. The cylindrical shape is determined by the large superconducting coil generating a solenoidal magnetic field of 4 T strength and by the iron return yoke. The yoke is divided into five wheels and a group of three endcap discs at each end of the detector. The magnet yoke is instrumented with the muon detectors, while the tracker, together with the electromagnetic and hadronic calorimeters are located inside the magnetic coil.

CMS has a two-level trigger and data acquisition system designed to select and store events at a maximal rate of 100 Hz. The first level trigger is a hardware trigger reducing the event rate to 100 kHz based on a coarse identification of muons, electrons, photons, jets, and missing transverse energy. The second level trigger, called High Level Trigger (HLT), is a software trigger, running on a dedicated farm of commercial processors. The HLT reduces the accepted events to 100 Hz by performing a detailed reconstruction of all physics objects.

3. W' models

Several theoretical models predict, in addition to the well known electroweak vector bosons γ, W, Z, further heavy gauge bosons. These additional particles are postulated for example in Left–Right Symmetric Models [2–5], based on the gauge group $\mathrm{SU(3)_C} \times \mathrm{SU(2)_L} \times \mathrm{SU(2)_R} \times \mathrm{U(1)_{B,L}}$ (B,L: baryon-, lepton-number), in theories predicting a substructure of the known "elementary particles", and in Little Higgs Models [6].

Here we investigate the detection capabilities for a hypothetical heavy partner of the W, a charged spin-1 boson W'. Its properties are derived from the Reference Model by Altarelli [7]. This model has been used in several earlier experiments, so that the resulting limits can be compared easily. Within the Reference Model the W' is a carbon copy of the W, with the very same left-handed fermionic couplings (including CKM matrix elements). Interactions with the Standard Model gauge bosons or with other heavy gauge bosons like a Z' are forbidden or "manually" suppressed. Therefore, the W' decay modes and the corresponding branching fractions are similar to those of the W, with the notable exception of the $t\bar{b}$ channel, which opens for W' masses beyond 180 GeV.

In hadron collisions W' bosons can be created through $q\bar{q}$ annihilation, analog to the W production. Previous searches for the Reference W' at LEP and at the Tevatron give rise to lower W' mass limits approaching 1 TeV [8].

This analysis is based on the decay $W' \to \mu\nu$, which has a branching ratio of roughly 10%. The resulting signature of a high energy muon accompanied by missing energy allows an easy separation of signal and background reactions.

4. Data samples

For this study an integrated luminosity of 10 fb^{-1} and an instantaneous luminosity of $\mathcal{L} = 2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ corresponding to an average pile-up of 3.5 pp collisions per bunch crossing are assumed.

In total about 300 000 Reference Model W' events (PYTHIA v6.319) decaying into muons and neutrinos have been produced for W' masses between 1 TeV and 8 TeV using the full CMS detector simulation. The product of LO cross section and branching fraction varies between 3.0×10^3 fb (1 TeV) and 3.3×10^{-4} fb (8 TeV), to be compared with 1.7×10^7 fb for Standard Model W production and muonic decay.

As background samples W $\to \mu\nu$, $Z \to \mu\mu$, WW inclusive, ZZ inclusive, ZW inclusive, $t\bar{t}$ inclusive, which all have been produced in the CMS Data Challenge 2004, are analyzed. On average 3.5 minimum bias reactions have been overlaid on each event.

5. Event selection and analysis

Events have been preselected requiring at least one globally reconstructed muon which passes the trigger criteria. The final cuts to select $W' \to \mu\nu$ candidate events are:

- **muon quality:** at least 13 hits along the global track, $\chi^2/N_{\mathrm{dof}} < 50$ for the fit;
- **single muon** requirement;
- **muon isolation:** no additional track within a cone of the size $\Delta R = 0.17$.

These cuts have been chosen to maximize the signal/background ratio.

For the selected events the transverse mass

$$M_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}_\mu} \not{E}_{\mathrm{T}} (1 - \cos \Delta\phi_{\mu,\not{E}_{\mathrm{T}}})}$$

is calculated from the muon transverse momentum p_{T_μ}, the missing energy component in the transverse plane $\not{E}_{\mathrm{T}}$ and the angular difference $\Delta\phi_{\mu,\not{E}_{\mathrm{T}}}$ between the muon and the transverse energy in the transverse plane.

Fig. 1 shows the resulting distribution for signal (1 and 5 TeV) and background events. The W' boson distributions show a Jacobian peak which is spread out for large M_{T} values due to the detector resolution. Apparently, a 1 TeV boson can be discovered or excluded easily, while for higher masses a statistical analysis is needed to quantify the sensitivity.

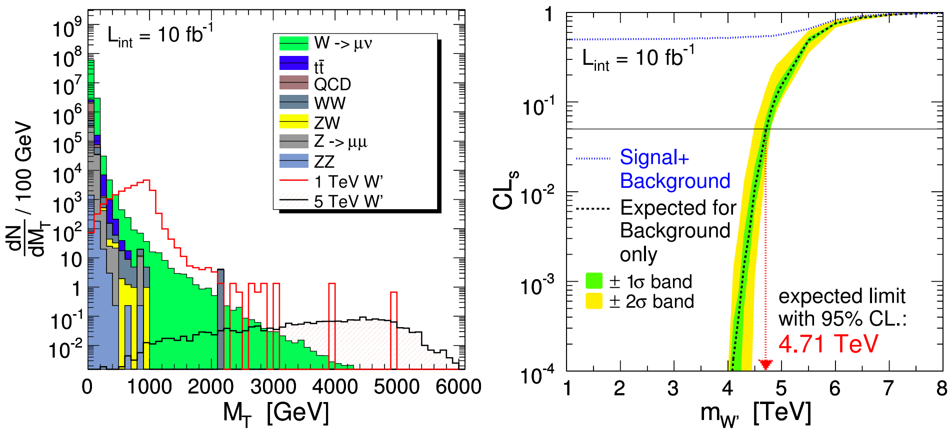

Fig. 1. Left: transverse invariant mass spectrum of signal (1 and 5 TeV, non-stacked) and background (stacked) after applying the selection cuts. Right: result of the $\mathrm{CL_s}$ method: with an integrated luminosity of $10\,\mathrm{fb}^{-1}$. Reference W' bosons can be excluded up to a mass of 4.7 TeV.

5.1. Discovery and exclusion potential

To interpret the results, the $\mathrm{CL_s}$ method [9] is applied, which is based on the likelihood ratios, calculated for all bins of the M_{T} distribution. $\mathrm{CL_s}$ is defined as the ratio of the confidence levels for the signal and background hypotheses, $\mathrm{CL_s} = \mathrm{CL_{s+b}}\ /\mathrm{CL_b}$. Fig. 1 shows, that for an integrated luminosity of $10\,\mathrm{fb}^{-1}$ an exclusion limit of 4.7 TeV at the 95% CL is reachable, if no signal is present in the CMS data. Both, the expected discovery and exclusion limits are displayed in Fig. 2 as functions of the integrated luminosity and the W' mass. To investigate the sensitivity to the signal and background cross sections, both have been varied in a wide range. For example relative changes by factors of 2 or 10, respectively, lead to a lowering of the accessible mass range by only 0.5 TeV in the worst case.

5.2. Systematic uncertainties

The uncertainties arising from an imperfect knowledge of the PDFs at LHC energies and the error from the hard scale parameters have been investigated by using the Les Houches Accord PDFs and varying the hard scale.

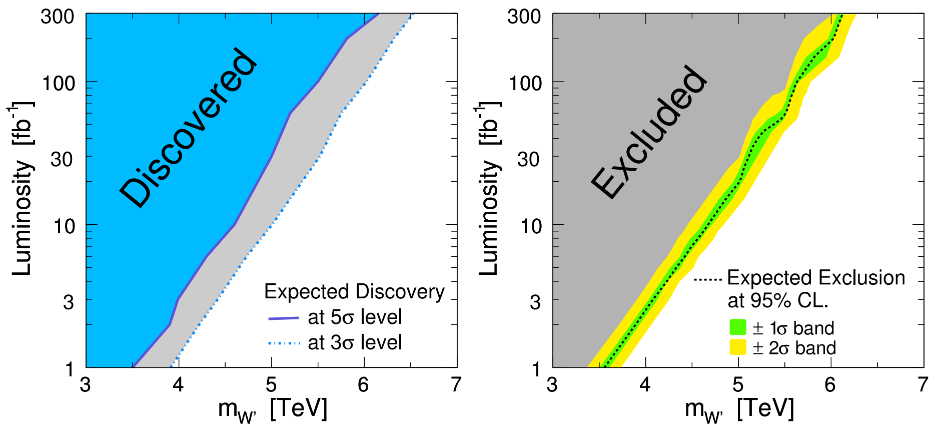

Fig. 2. The plots show which integrated luminosity is needed to discover (left) or exclude (right) W' bosons of a certain mass.

The relative errors on the cross-section of the signal are listed in Table I. The relative error on the background is comparable to that of the W' at the corresponding invariant mass.

TABLE I

Systematic uncertainties arising from an imperfect theoretical knowledge (parton density functions, hard scale) and the expected luminosity error for an integrated luminosity of $10\,\mathrm{fb}^{-1}$.

Systematic uncertainties for various W' masses					
Type	1 TeV	2 TeV	3 TeV	4 TeV	5 TeV
PDF $\Delta\sigma/\sigma$	$^{+3.6}_{-4.3}\%$	$^{+6.8}_{-5.9}\%$	$^{+6.2}_{-8.3}\%$	$^{+17.1}_{-10.6}\%$	$^{+33.7}_{-18.9}\%$
Hard scale $\Delta\sigma/\sigma$	$^{+4.1}_{-4.1}\%$	$^{+7.5}_{-6.9}\%$	$^{+10.4}_{-9.2}\%$	$^{+13.1}_{-10.3}\%$	$^{+14.8}_{-12.7}\%$
Luminosity $\Delta\mathcal{L}/\mathcal{L}$	$\pm 5\%$	$\pm 5\%$	$\pm 5\%$	$\pm 5\%$	$\pm 5\%$

The steeply falling invariant mass distribution especially of the W background holds a potential danger for the detection of W' bosons: if only a small fraction of these events is reconstructed with a by far too large mass, which might result from a mismeasured muon momentum, the detection of a W' signal becomes extremely difficult. Such a behavior would be visible in non-Gaussian tails for example in the p_{T} resolution. Analyzing a large sample of W events shows, that the alignment precision expected after an integrated luminosity of $10\,\mathrm{fb}^{-1}$ has only a small influence on the non-Gaussian tails of the muon p_{T} resolution.

The luminosity uncertainty at the considered integrated luminosity of $10\,\mathrm{fb}^{-1}$ is expected to be 5%, while other experimental errors (neutron background, dead detector components, *etc.*) are expected to be negligible.

6. Conclusion

For an integrated luminosity of $10\,\mathrm{fb}^{-1}$ W' bosons of the Reference Model can be discovered or excluded up to a mass of 4.5–5 TeV from an analysis of the muonic decay mode.

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