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Non-SUSY Beyond Standard Model Searches: Recent Results from ATLAS and CMS

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Abstract. The Standard Model of particle physics is a sensational success, especially since the discovery of the 125 GeV Higgs boson. However, there are still numerous unanswered questions. Why is the Higgs so light? Do the interactions couplings unify and how can gravity be included? Why three fermion generations? What is dark matter? Theories Beyond the Standard Model (BSM), such as Grand Unified Theories, Extra Dimensions or Technicolour are trying to answer these questions. In these proceedings, we will focus on the most recent results obtained by the ATLAS and CMS experiments at the LHC for BSM searches, excluding Higgs and supersymmetry searches. New results on Dark Matter, heavy narrow-width resonances, new heavy quarks and third generation leptoquarks are presented. A summary of the prospects at 14 TeV and at the High Luminosity LHC period is given.

1. Introduction

The LHC is a proton-proton collider, designed to operate at a center-of-mass energy of $\sqrt{s} = 14$ TeV and to collect of the order of 100-300 fb⁻¹ of data [1]. At the end of 2012, the two multi-purpose LHC experiments, ATLAS [2] and CMS [3], concluded what has come to be known as “Run I” in which the LHC operated at $\sqrt{s} = 7$ and 8 TeV, collecting integrated luminosities of approximately 5 fb⁻¹ and 20 fb⁻¹, respectively at the two energies. Even at these reduced energies, the LHC has well explored the TeV scale and the discovery of a particle in July 2012, which appears to be compatible with the Standard Model (SM) Higgs Boson [4,5], was confirmed.

The search for BSM physics has already been a strong activity at the LHC. So far, these searches show no evidence for new physics and have set stringent limits on many BSM models. The searches are based on distinct experimental signatures, and are sensitive to a wide range of models.

In this paper, we summarize the current status of the most recent searches, excluding BSM Higgs and supersymmetry (SUSY) searches. The review is limited to search results at 8 TeV which have been published or submitted for publication between July and December 2014. The full list of results, both preliminary and published can be found in Refs [6,7]. Also, an exhaustive review of so many signatures in so many models is not possible. The selection made here includes a limited number of signatures for Dark Matter, heavy narrow-width resonances and other new particles such as leptoquarks or Vector-Like quarks.



2. Dark Matter

The existence of Dark Matter (DM) is firmly established by a large number of cosmological and astrophysical observations, but little is known about what it is made of. The most popular candidates are the Weakly Interacting Massive Particles (WIMP). At a collider, one searches for pair production of WIMPs, which escape the detector without interacting. Therefore, an additional object is needed, typically radiated in the initial state and recoiling against the escaping WIMP pair, leading to missing transverse energy (MET) [9–13]. Fig. 1 shows Feynman diagrams of the DM pair production.

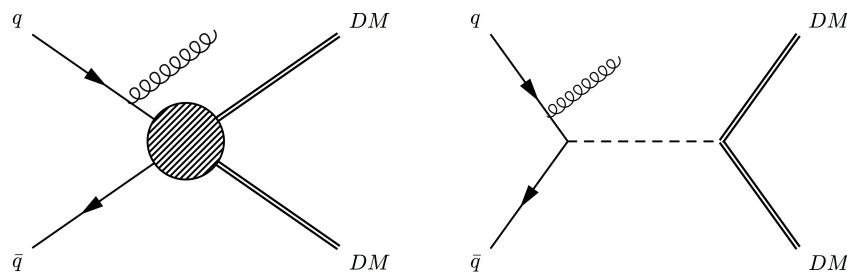


Figure 1. Feynman diagrams for the pair production of DM particles for the case of a contact interaction or heavy mediator exchange (left) and the exchange of a light mediator (right).

These signatures are referred to as mono-X signatures. The ATLAS and CMS experiments have performed searches for DM in the mono-jet, mono-photon, mono-top, mono- W and mono- Z channels. The interpretation of these searches use an effective field theory (EFT) to describe the interaction between SM and DM particles. This makes the assumption that the interaction is mediated by a particle which is itself too heavy to be directly produced at the LHC and can thus be integrated out, leading to a contact interaction. Different operators describe different initial states and different types of interactions [8]. A subset of all possible operators is used in the different mono-X analyses. The cross section for DM pair production via such an operator depends on the mass of the WIMP (m_χ) and the contact interaction scale of the effective theory, M_* . Limits on the M_* can be translated into limits on the χ -nucleon scattering cross section, $\sigma_{\chi-N}$. The virtue of the effective theory is that it allows for a comparison to the results of direct searches, which look for the recoil of a target nuclei due to a WIMP scattering off it.

This section discusses the results of DM searches through three signatures: mono-jet, mono-photon and heavy quark (HQ) plus MET.

2.1. The mono-jet signature

Initial state radiation of a jet has a large cross section at the LHC and therefore the mono-jet analysis is a promising channel for the DM search. It is moreover the only one that is sensitive to the gluon-gluon operator. The example chosen to illustrate that type of search is taken from the CMS experiment [9]. Here, events are required to have one highly energetic jet with a p_T greater than 110 GeV. Events with more than two jets with $p_T > 30$ GeV and pseudorapidity $|\eta|$ less than 4.5 are discarded, thereby significantly reducing background from top-quark pair and QCD multijet events. Processes producing leptons, such as W and Z , dibosons, and top quarks are suppressed by rejecting events with well reconstructed and isolated electrons with $p_T > 10$ GeV, reconstructed muons with $p_T > 10$ GeV and well-identified hadronically decaying tau leptons with $p_T > 20$ GeV. The analysis is performed in seven inclusive regions of $MET > 250, 300, 350, 400, 450, 500$ and 550 GeV.

The MET spectrum obtained is presented in Fig. 2(left) in comparison to the SM prediction and possible signal distributions. The data are in agreement with the background-only

hypothesis. Within the framework of the effective field theory, limits on the contact interaction scale and on $\sigma_{\chi-N}$ are extracted. The confidence level (CL) chosen for these limits is 90%, to enable a direct comparison with the results from the direct detection experiments. Shown in Fig. 2(right) are upper limits on $\sigma_{\chi-N}$ as a function of m_χ compared with previously published results together with results from direct detection experiments, for the vector and scalar operators (spin independent). For a m_χ of 10 GeV, the upper limit on $\sigma_{\chi-N}$ was found to be $7.06 \times 10^{-40} \text{ cm}^2$ for the vector operator (spin independent). Limits on $\sigma_{\chi-N}$ were also derived for the case of the axial-vector operator (spin dependent) and the upper one was found to be $2.70 \times 10^{-41} \text{ cm}^2$ for the same m_χ value.

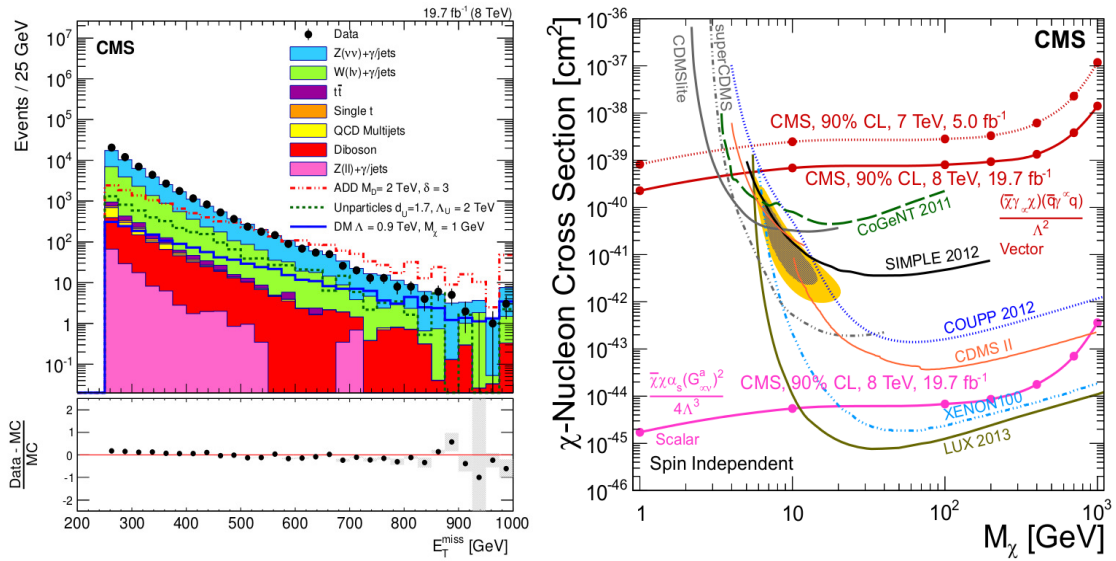


Figure 2. DM searches, the mono-jet signature [9]: (left) Missing transverse energy after all selections for data and SM backgrounds. The processes contributing to the SM background are from simulation, normalized to the estimation from data using a MET threshold of 500 GeV. The shaded bands in the lower panel represent the statistical uncertainty. (right) Upper limits on $\sigma_{\chi-N}$ at 90% CL, plotted against m_χ and compared with previously published CMS results together with results from the CoGeNT, SIMPLE, COUPP, CDMS, SuperCDMS, XENON100, and LUX collaborations. The solid and hatched yellow contours show the 68% and 90% CL contours respectively for a possible signal from CDMS.

2.2. The mono-photon signature

Events with a photon radiated in the initial state have been used to search for DM candidates as well. An analysis by CMS [10] and another by ATLAS [11] are described here. In the CMS analysis, events are selected with a photon with an E_T larger than 145 GeV. In order to reduce QCD multijet backgrounds, events are rejected if there is more than one jet with $p_T > 30$ GeV and $\Delta R > 0.5$ (ΔR being the radius of a cone centered on the shower axis) relative to the photon. Events with isolated leptons (electron or muon) with $p_T > 10$ GeV and $\Delta R > 0.5$ relative to the photon, are also rejected to suppress $W\gamma \rightarrow l\nu\gamma$ and $W \rightarrow l\nu$ backgrounds. The candidate events are required to have a MET larger than 140 GeV. The MET spectrum obtained from that analysis is presented in Fig. 3(left) in comparison to the SM prediction and possible signal distributions. No excess at large MET is observed and limits on the interaction scale and $\sigma_{\chi-N}$ are derived. Fig. 3(right) shows the 90% CL upper limits on $\sigma_{\chi-N}$ as a function

of m_χ for spin independent scattering. Also shown are the limits from selected direct detection experiments results. For a m_χ of 10 GeV, $\sigma_{\chi-N}$ is constrained to be less than $9.6 \times 10^{-41} \text{ cm}^2$ ($2.6 \times 10^{-39} \text{ cm}^2$) for a spin dependent (spin independent) interaction at 90% CL.

In the same channel, an analysis was performed by ATLAS [11]. The main result gives values of M_* excluded below 760, 760 and 1010 GeV for the spin independent (D5 operator) and spin dependent (D8 and D9 operators) interactions respectively. These limits on M_* can be translated into upper limits on $\sigma_{\chi-N}$. They are shown in Fig. 4 as a function of m_χ for spin independent (left) and spin dependent (right) interactions. The results obtained by ATLAS with 7 TeV data for the same channel are shown for comparison. Also shown are results from various DM direct detection experiments.

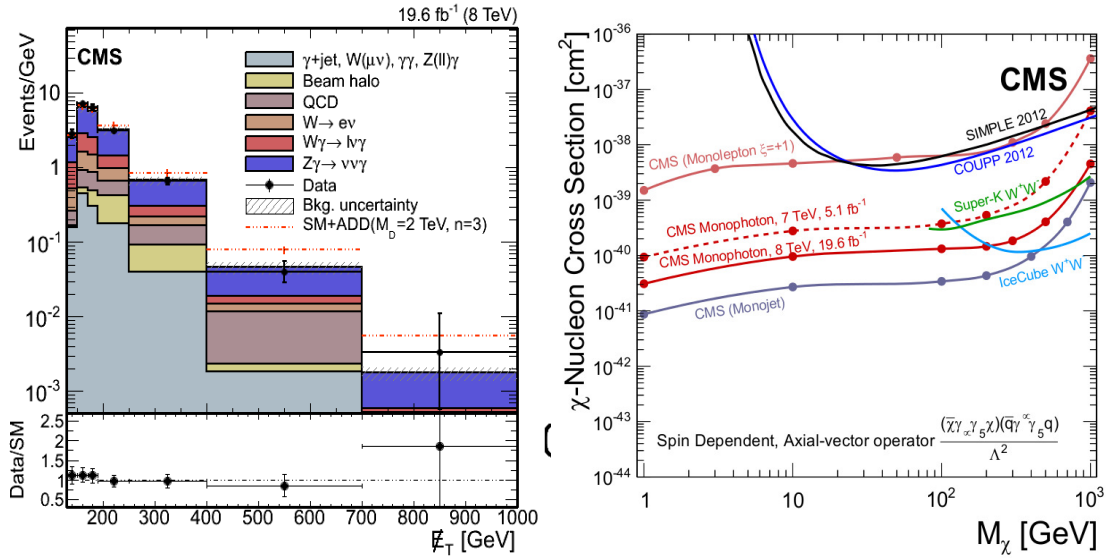


Figure 3. DM searches in CMS, the mono-photon signature [10]: (left) The MET distribution for the candidate sample, compared with estimated contributions from SM. The background uncertainty includes statistical and systematic components. The bottom panel shows the ratio of data and SM predictions. (right) The 90% CL upper limits on $\sigma_{\chi-N}$ as a function of the m_χ for spin independent scattering. Also shown are the limits from selected direct detection experiments results along with 7 and 8 TeV results.

2.3. The HQ plus MET signature

Other signatures such as MET and a top quark or a b quark are also used to search for DM in ATLAS [12] and CMS [13]. The analysis requires a large MET and a central high p_T jet.

In the case of the ATLAS experiment analysis [12], four orthogonal signal regions are defined. To optimize the sensitivity of the analysis, a requirement on the output of the b -tagging algorithm which provides a 60% (70%) b jet efficiency operating point is used in signal regions (SR) 1 and 2 (3 and 4). The first two signal regions focus on events with DM produced in conjunction with one (SR1) or two (SR2) b quarks in the final state. SR3 and SR4 target events in which DM is produced in conjunction with a $t\bar{t}$ pair, where either both top quarks decay hadronically (SR3) or one top quark decays hadronically and the other semileptonically (SR4). Events assigned to SR1 and SR2 are required to have a low jet multiplicity (less than five). The results are interpreted in the framework of an effective field theory to set stringent limits on scalar and tensor interactions between SM and DM particles. The data are found to be consistent with

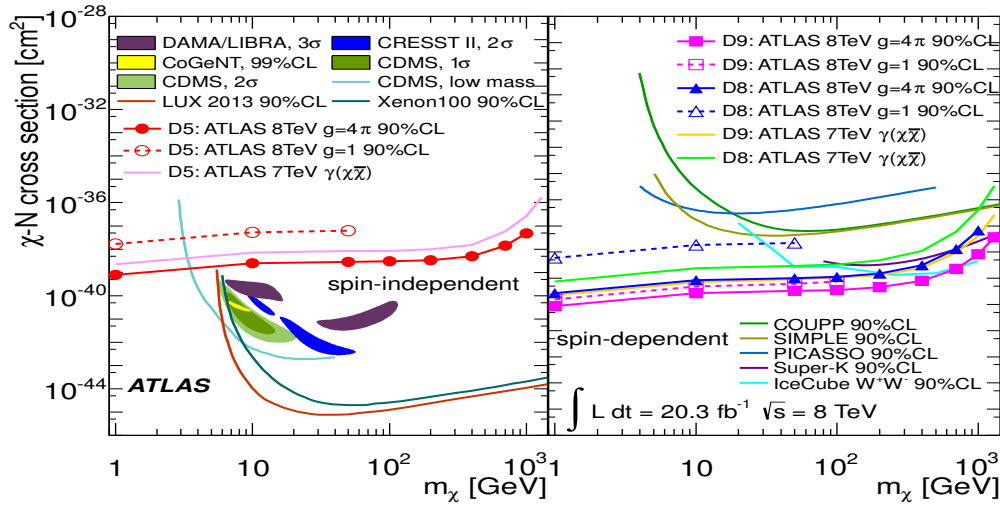


Figure 4. DM searches, the mono-photon signature [11]: Upper limits at 90% CL on $\sigma_{\chi-N}$ as a function of m_χ for spin-independent (left) and spin-dependent (right) interactions, for a coupling strength $g = \sqrt{(g_f * g_\chi)} = 1$. The results obtained from ATLAS with 7 TeV data for the same channel are shown for comparison. Also shown are results from various dark matter direct detection experiments.

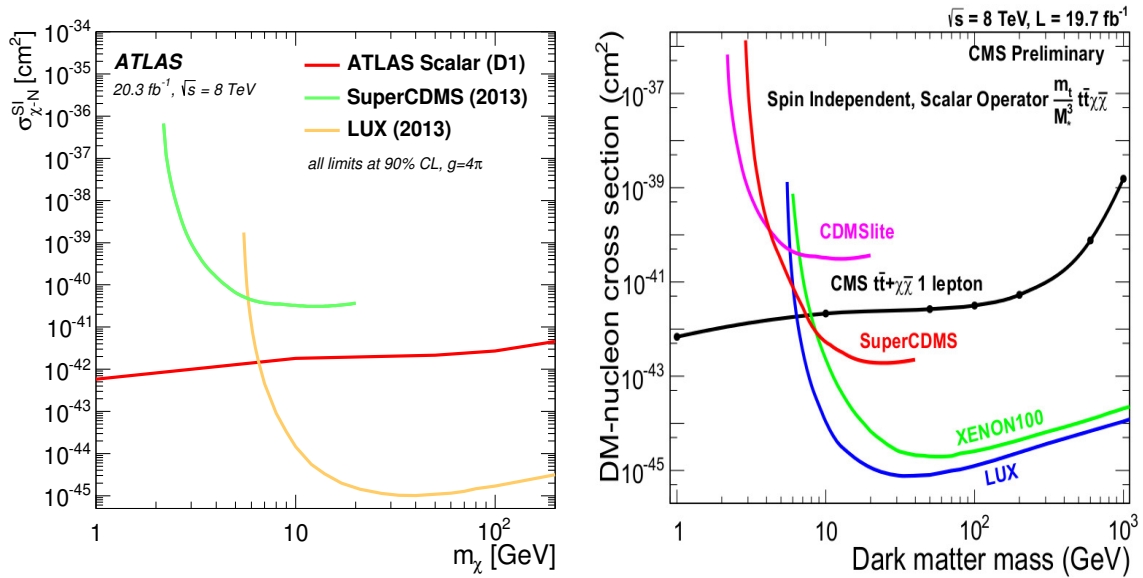


Figure 5. DM searches, HQ+MET signature [12,13]: (left) ATLAS: Upper limits at 90% CL on the spin independent $\sigma_{\chi-N}$ for the scalar operator D1 (red) as a function of m_χ . The yellow and green curves represent the exclusion limits recently set by the LUX and Super-CDMS collaborations. (right) CMS: The 90% CL upper limits on the spin independent $\sigma_{\chi-N}$ as a function of m_χ for the scalar operator D1. Also shown are 90% CL limits from selected direct detection experiments.

the Standard Model expectations. Limits are also set on the mass scale of the effective field theories.

Fig. 5(left) shows the corresponding 90% CL exclusion curves on $\sigma_{\chi-N}$ for the spin independent interaction for the scalar operator D1 as a function of m_χ . The most stringent limits set by direct detection experiments are also shown. The limits shown are especially strong in the low-mass region where several collaborations (DAMA, COGENT, CDMS) have recently claimed possible observations of DM [14]. The results reported in this analysis improve significantly the sensitivity to WIMP nucleon interactions mediated by the scalar operator D1 (approximately $1 \times 10^{-42} \text{ cm}^2$ for a m_χ of 10 GeV) compared to previous ATLAS results. Limits are also set on the D9 vector operator.

In the case of CMS analysis [13], the search focused on the production of DM particles with a pair of top quarks in the single-lepton channel. Therefore, the events are selected with exactly one identified isolated lepton, at least three jets and at least one b -tagged jet. Signal events are expected to be produced with large MET due to the production of two DM particles which escape from the detector, events are thus preselected with $\text{MET} > 160 \text{ GeV}$. No excess of events was found above the Standard Model expectation. Interpreting the findings in the context of a scalar interaction between DM particles and top quarks and assuming a DM particle with a mass of 100 GeV, the interaction scale, M_* is excluded at 90% CL below 118 GeV, representing the most stringent limit to date. The limits on the interaction scale are interpreted as limits on $\sigma_{\chi-N}$ as shown in Fig. 5(right) for the spin independent scalar operator D1. More stringent limits are obtained from this analysis compared to direct DM detection in the low χ mass region of less than about 6 GeV. These masses are excluded for $\sigma_{\chi-N}$ higher than $1 - 2 \times 10^{-42} \text{ cm}^2$.

3. New heavy gauge bosons

The existence of heavy resonances is predicted by a variety of BSM models which are alternatives to SUSY in the explanation of the electroweak symmetry breaking. They are heavy new states with integer spin. Left-right symmetric and Extended Gauge models predict spin-1 states [15] while Randall-Sundrum models predict heavy spin-2 states [16].

In general, the analysis basically consists of searching for a bump in the two-body invariant mass spectra. The background is either small or could be modelled from the data control samples. ATLAS and CMS have searched for dilepton (including lepton+ ν), diphoton, dijet and jet+ γ resonances. Relatively simple topologies allow for a robust analysis to be done rapidly. The most recent searches focused on fully hadronic or semi-hadronic signatures such as $W' \rightarrow tb \rightarrow q\bar{q}b\bar{b}$ [17] and $W' \rightarrow tb \rightarrow l\nu b\bar{b}$ [18].

For the fully hadronic final state, the analysis performed by the ATLAS experiment is done in the $W' \rightarrow tb \rightarrow q\bar{q}b\bar{b}$ mode for W' masses above 1.5 TeV, where the W' decay products are highly boosted [17]. Copious multijets background is present thus necessitating efficient jet substructure techniques, described in the published paper for this analysis, to identify jets from high-momentum top quarks to ensure high sensitivity, independent of W' mass, up to 3 TeV; b -tagging is also used to identify jets originating from b quarks.

The data are consistent with SM expectations and upper limits at 95% CL are set on the $W' \rightarrow tb$ cross section times branching ratio ranging from 0.16 pb to 0.33 pb for left-handed W' bosons, and ranging from 0.10 pb to 0.21 pb for W' bosons with purely right-handed couplings. As shown in Fig. 6, the observed limits agree with the expected limits roughly within 1σ over the whole range for both W' models. For a coupling $g' = g_{SM}$, the limits on the cross section times branching ratio translate to observed (expected) lower limits on the mass to 1.68 TeV (1.63 TeV) and 1.76 TeV (1.85 TeV) in the left- and right-handed models, respectively.

The $W' \rightarrow tb \rightarrow l\nu b\bar{b}$ channel, analysed by CMS experiment [18], necessitates in addition to the techniques used above for the fully hadronic channel, the selection of a high MET. The search covers masses between 0.5 and 3.0 TeV, for right-handed or left-handed W' bosons. No

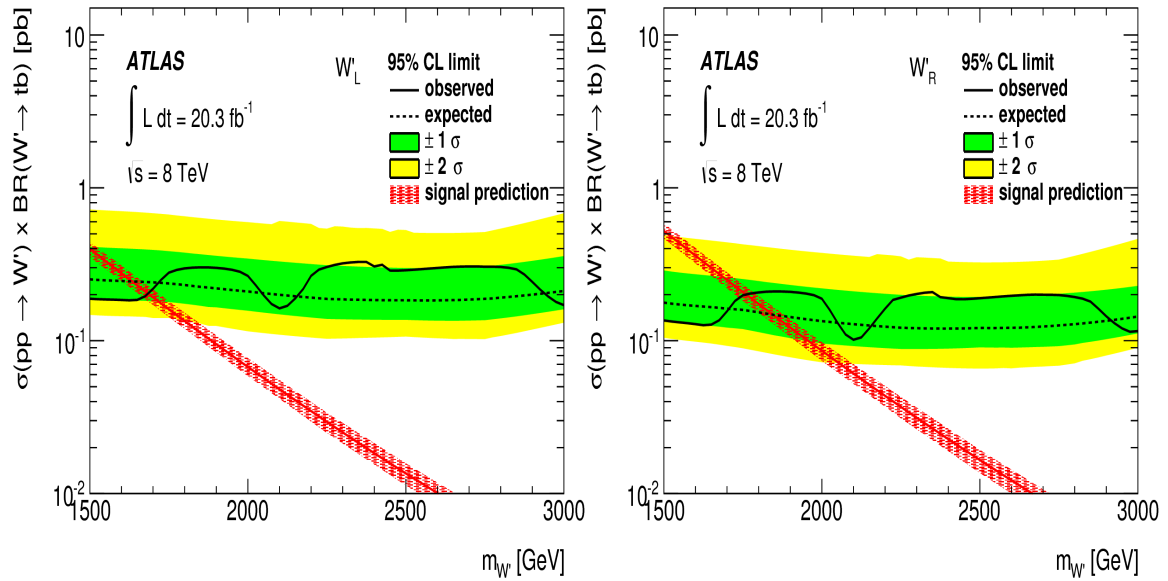


Figure 6. New heavy gauge bosons search, fully hadronic channel [17]: Upper limits at 95% CL on the cross section times branching ratio to tb for the left-handed (left) and for the right-handed (right) W' . The expected cross section for W' production with $g' = g_{SM}$ is also shown (in red).

significant deviation from the Standard Model expectation is observed and limits are set on the $W' \rightarrow tb$ cross-section times branching ratio and on the W' effective couplings as a function of the W' mass. For a left-handed (right-handed) W' , masses below 1.70 (1.92) TeV are excluded at 95% CL. These results are compatible with those from the ATLAS analysis, above.

4. Other new particles

4.1. Leptoquarks

Encountered in various extensions of the Standard Model, such as technicolor theories or GUT, new scalar or vector bosons called leptoquarks (LQ) are colour-triplet bosons that carry both lepton and baryon numbers, and fractional electric charge. Searches for pair-produced LQs assumed to couple only to quarks and leptons of the third SM generation have been issued by ATLAS and CMS recently. The most recent search [19], performed by CMS, looks for a signature of a LQ to a final state involving $b\bar{b}\tau\tau$. A particle-flow (PF) technique [20] is used for the reconstruction of hadronically decaying τ lepton candidates. In the PF approach, information from all subdetectors is combined to reconstruct and identify all final-state particles produced in the collision. The particles are classified as either charged hadrons, neutral hadrons, electrons, muons, or photons. Jets are reconstructed using the anti- k_t algorithm with a size parameter 0.5 using particle candidates reconstructed with the PF technique. The b -tagged jet with the highest p_T is selected, and then the remaining jet with the highest p_T is selected whether or not it is b -tagged. To discriminate between signal and background in the leptoquark search, the mass of the τ and a jet, denoted $M(\tau, \text{jet})$, is required to be greater than 250 GeV. The S_T distribution after the final selection is used to extract the limits on the leptoquark signal, where S_T is defined as the scalar sum of the p_T of the light lepton, the τ , and the two jets.

The S_T distribution of the selected events from the data and from the background predictions, combining e and μ channels is shown in Fig. 7(left). The distribution from a 500 GeV signal hypothesis is added to the background to illustrate how a hypothetical signal would appear above the background prediction. The data agree well with the SM prediction.

Fig. 7(right) shows the expected and observed combined upper limits on the third-generation LQ pair production cross section σ times the square of the branching fraction, B^2 , at 95% CL, as a function of the LQ mass. Third-generation scalar leptoquarks with masses below 740 GeV are excluded at 95% CL, assuming a 100% branching fraction for the leptoquark decay to a τ lepton and a bottom quark.

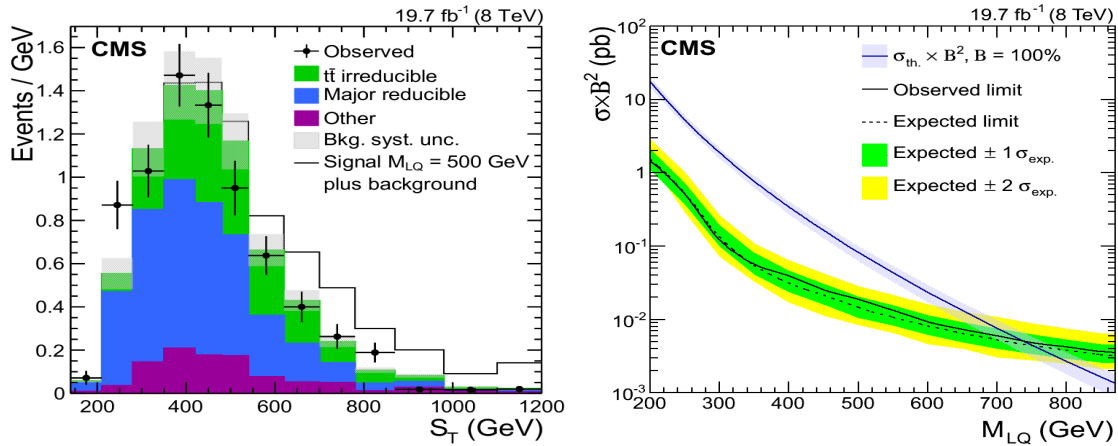


Figure 7. LQ search [19]: (left) The final S_T distribution for the leptoquark search with the e and μ channels combined. A signal sample for leptoquarks with a mass of 500 GeV is added on top of the background prediction. The last bin contains the overflow events. The horizontal bar on each observed data point indicates the width of the bin in S_T . (right) The expected and observed combined upper limits on the third-generation LQ pair production cross section σ times the square of the branching fraction, B^2 , at 95% CL, as a function of the LQ mass. The dark blue curve and the hatched light blue band represent the theoretical LQ pair production cross section, assuming $B = 100\%$, and the uncertainties due to the choice of PDF and renormalization/factorization scales.

4.2. New heavy quarks

New heavy quarks, like the Vector-like Quarks (VLQ), are among the simplest extensions to the SM. They contribute to the regulation of quadratic divergence of one-loop contributions to the Higgs mass, so could provide a solution to the hierarchy problem. They are produced singly or in pairs as shown in Fig. 8(right) for the latter case. The production cross section of the VLQ particles is also shown on that figure, in the right part.

Searches have been performed by ATLAS [24–26] and CMS [27] for both single and pair-produced exotic top partners T or bottom partners B , decaying respectively into Zt, Wb, Ht and Zb, Wt, Hb . The results obtained from the three analyses performed by the ATLAS experiment [24–26] are reported here.

In the first analysis [24], the search looks for the production of new heavy quarks that decay to a Z boson and a third-generation SM quark. In the case of a new charge $+2/3$ quark T , the decay targeted is $T \rightarrow Zt$, while the decay targeted for a new charge $-1/3$ quark B is $B \rightarrow Zb$. The selected events for the analysis should contain a high transverse momentum Z boson candidate reconstructed from a pair of oppositely charged same-flavor leptons (electrons or muons). They are analyzed in two channels defined by the absence or presence of a third lepton. Hadronic jets, in particular those with properties consistent with the decay of a b hadron, are also required to be present in selected events.

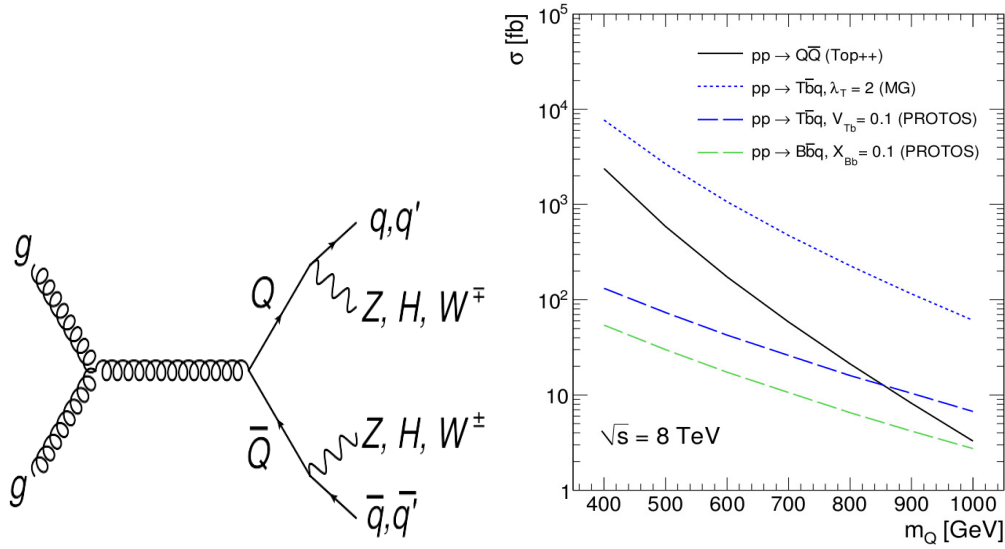


Figure 8. (left) A representative diagram illustrating the pair production and decay modes of a VLQ ($Q=T,B$). (right) The $\sqrt{s}=8$ TeV LHC cross section versus quark mass for pair production, denoted by the solid line, as well as for the $T\bar{b}q$ and $B\bar{b}q$ single production processes, denoted by dashed lines. The pair production cross section was calculated with TOP++ [21]. The single production cross sections were calculated with PROTOS [22] and MADGRAPH [23] using different electroweak coupling parameters.

The second analysis [25] is a search for pair production of heavy top-like quarks decaying to a high p_T W boson and a b quark in the lepton plus jets final state. The selected events for the analysis are characterized by a high p_T isolated electron or muon, large missing transverse energy and at least four jets, with at least one of them b tagged. The analysis strategy relies on the substantial boost of the W bosons in the T pair signal when the transverse mass $m_T > 400$ GeV.

The third search [26] is for anomalous production of events with same-sign dileptons and b jets. The final state considered requires the presence of exactly two leptons in the event, both with the same electric charge. In addition, two or more jets, at least one of which is consistent with being a b jet, and sizable MET are required.

No significant excess of events above the Standard Model expectation is observed in the three analyses. Lower limits are derived on the mass of vector-like T and B quarks under various branching ratio hypotheses, as well as upper limits on the magnitude of electroweak coupling parameters.

Using the results from the three analyses and for a given bin in the branching ratio (BR) plane, the strongest of all limits considered is plotted. Fig. 9(left) shows all available limits on the vector-like B quark assuming the pair production hypothesis and presented in the (Wt, Hb) branching ratio plane. No combination is made of the different analyses. Similarly, Fig. 9(right) shows all available limits on the vector-like T quark assuming the pair production hypothesis and presented in the (Wb, Ht) branching ratio plane. No combination is made of the different analyses, except for the $Ht + X$ and $Wb + X$ analyses which are combined.

In the left part of the figure, we see that the sensitivity is higher for a decay of the B pair to $ZbZb$. Therefore, if we assume that the corresponding branching fraction is 100%, one can put the limit on the B mass at ~ 800 GeV. Similarly, on the right part of the figure, we observe a high sensitivity of the T quark pair to decay to $ZtZt$ or to $HtHt$. Therefore, assuming a

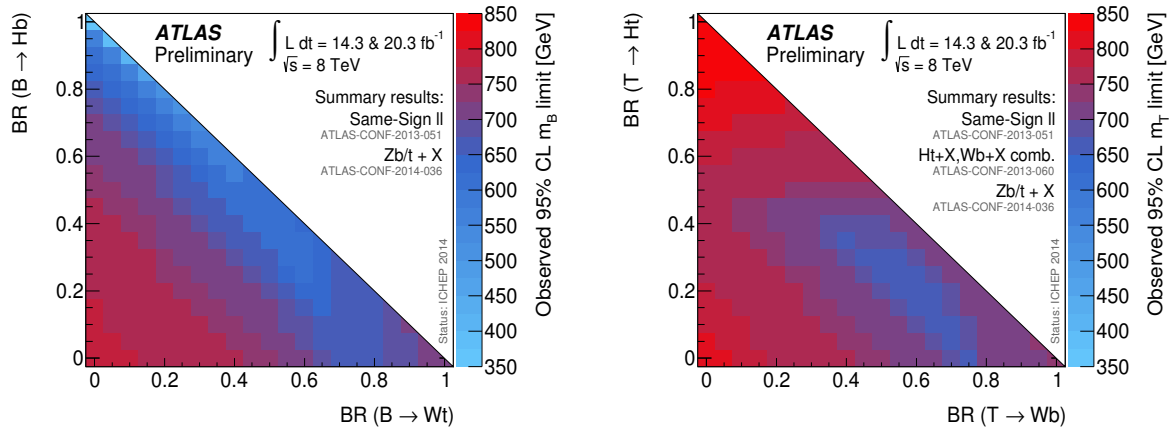


Figure 9. VLQ search [28]: (left) Observed lower limits at 95% CL on the mass of vector-like B quarks for ATLAS searches with 14 fb^{-1} and 20 fb^{-1} of 8 TeV data. For a given bin in the selected BR plane, the strongest of all limits considered is shown (i.e. no combination is made of the different analyses). This figure shows all available limits on the vector-like B quark. (right) Observed lower limits at 95% CL on the mass of vector-like T quarks for ATLAS searches with 14 fb^{-1} and 20 fb^{-1} of 8 TeV data. For a given bin in the selected BR plane, the strongest of all limits considered is shown (i.e. no combination is made of the different analyses, except for the $Ht + X$ and $Wb + X$ analyses which are combined). This figure considers all available limits on the vector-like T quark.

branching ratio of 100% for the decay $T \rightarrow Ht$, the limit of the T quark mass can be set to $\sim 830 \text{ GeV}$.

5. Prospects

From 2015 to 2017 (Run-II), the ATLAS and CMS experiments will collect about 100 fb^{-1} of data each, at a center-of-mass energy between 13 and 14 TeV. Following this, the accelerator will be upgraded to deliver two to three times more instantaneous luminosity. A total of $\sim 300 \text{ fb}^{-1}$ of data is expected to be collected by the end of Run-III in 2022. An upgrade to the LHC is proposed to provide an instantaneous luminosity of $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ in 2023, named HL-LHC (High Luminosity LHC).

The HL-LHC will provide a significant increase in discovery reach for new Higgs particles and sensitivity to non-Standard Model effects or direct searches such as new heavy gauge bosons (Z' and W'). Some examples of sensitivity studies to such signals are given here below.

5.1. Sensitivity to Z'

Studies of the sensitivity to a Z' boson in ATLAS were performed to illustrate the reach at the different LHC phases [29]. Only the Drell-Yan background is considered in this study. The Sequential Standard Model (SSM) Z'_{SSM} boson, which has the same fermionic couplings as the Standard Model Z boson, is used as the signal template. The dilepton invariant mass distribution, m_{ll} , for events above 200 GeV, and the resulting limits as a function of Z'_{SSM} pole mass are shown in Fig. 10 for the ee channel. The 95% CL expected limits in the absence of signal, using statistical errors only, are shown in Table 1 for ee and $\mu\mu$ decays. The increase of a factor of ten, from 300 to 3000 fb^{-1} in integrated luminosity, raises the sensitivity to high-mass dilepton resonances by up to 1.3 TeV.

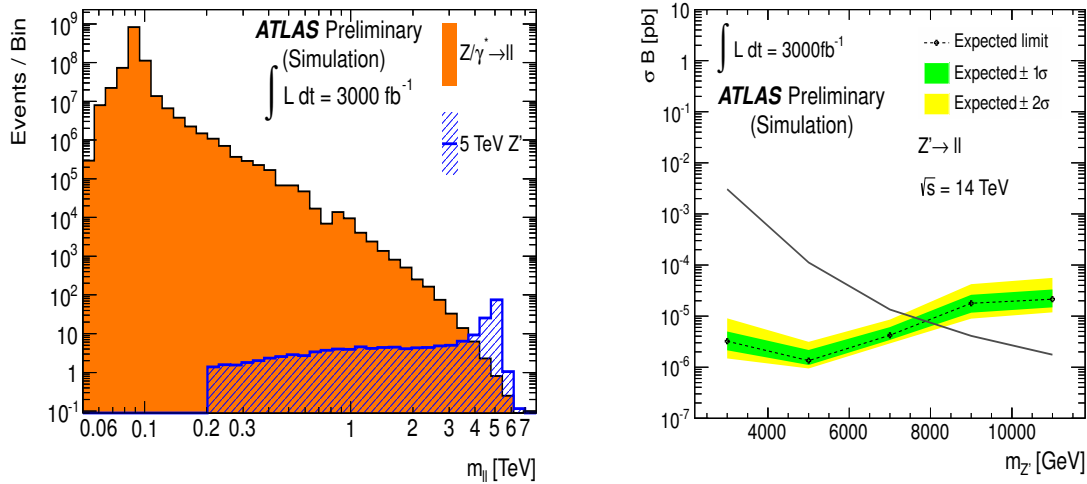


Figure 10. Z' prospects [29]: (left) The reconstructed dielectron mass spectrum for the Z' search with 3000 fb^{-1} of pp collisions at $\sqrt{s} = 14 \text{ TeV}$. (right) The 95% CL upper limit on the cross section times branching ratio. Also shown is the theoretical expectation for the Z'_{SSM} .

Table 1. Summary of the expected mass limits for $Z'_{SSM} \rightarrow ee$ and $Z'_{SSM} \rightarrow \mu\mu$ searches in the Sequential Standard Model for pp collisions at $\sqrt{s} = 14 \text{ TeV}$. All values are quoted in TeV [29].

model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
$Z'_{SSM} \rightarrow ee$	6.5	7.2	7.8
$Z'_{SSM} \rightarrow \mu\mu$	6.4	7.1	7.6

5.2. Sensitivity to T quarks

A sensitivity study of the prospects for searching for heavy vector-like charge $+2/3$ quarks with the upgraded CMS detector has been performed [30]. With 3000 fb^{-1} of pp collision data collected at $\sqrt{s} = 14 \text{ TeV}$ with an average of 140 pileup interactions per bunch crossing, the mass reach for the discovery of a heavy T quark at 3σ and 5σ level is expected to be 1.65 TeV, and 1.48 TeV, respectively as shown in Fig. 11. The 95% CL exclusion reach is expected to be around 1.85 TeV, a factor of 2.6 higher than the current lower limit of 700 GeV. This result would have a significant impact on our understanding of the implications of a light Higgs at 125 GeV on composite Higgs models.

5.3. Sensitivity to Dark Matter

A study of the sensitivity of ATLAS to pair production of WIMP Dark Matter with pp collision data at $\sqrt{s}=14 \text{ TeV}$ in the mono-jet topology is presented. Different run periods and different integrated luminosities have been considered. As for the previous studies at 8 TeV, two classes of models have been investigated: the Effective Field Theory and the simplified models with an explicit light mediator.

According to the preliminary estimates obtained assuming EFT is a valid approach, the first data delivered early in 2015 may already be sufficient to test for the presence of new physics. Assuming a 5% systematic uncertainty on the background estimation, ATLAS could detect a

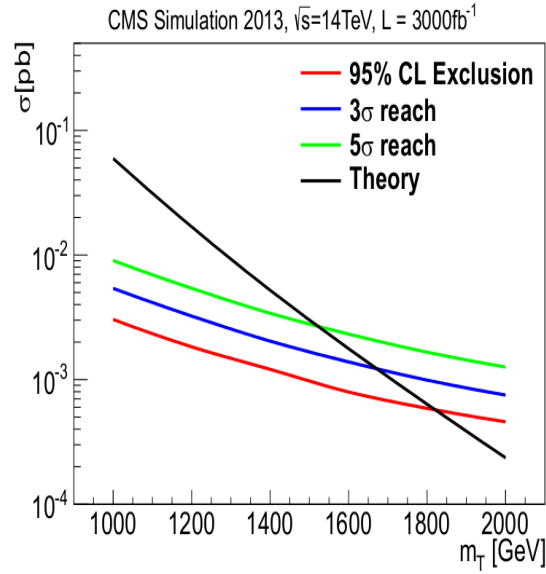


Figure 11. T quark prospects [30]: Expected sensitivity for a T quark pair production signal in the combined multilepton and single-lepton+jets sample. The 95% CL limits, 5σ discovery reach and the 3σ discovery reach are shown as a function of the T quark mass.

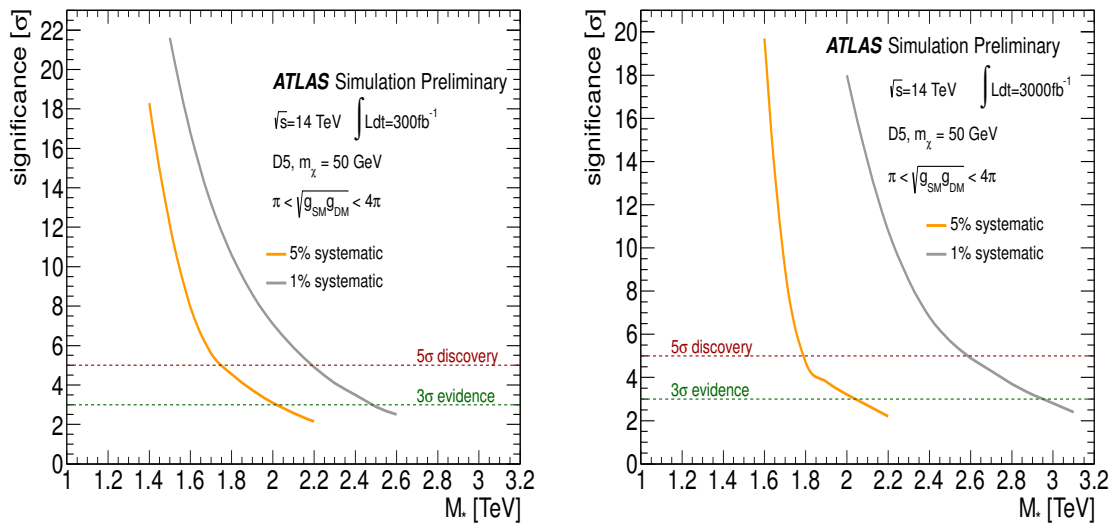


Figure 12. DM search prospects [31]: Discovery potential for DM signal with D5 operator and $m_\chi=50$ GeV with 300 fb^{-1} (left) and 3000 fb^{-1} (right). These results assume that the EFT is a valid approach.

signal within the EFT approach with M_* up to 1500 GeV at 5σ after one year of data-taking. The reach of ATLAS with a full luminosity of 300 fb^{-1} could go up to M_* values of 1800 GeV at 5σ with the same assumed background systematic uncertainty, see Fig. 12(left). Taking into account the expected ultimate precision on the Standard Model background determination (1% total systematic error), the reach extends to $M_* \sim 2200$ GeV with an integrated luminosity of

300 fb^{-1} and $M_* \sim 2600 \text{ GeV}$ for HL-LHC for a discovery at 5σ , see Fig. 12(right).

6. Conclusion

Using data collected in Run-I, ATLAS and CMS looked all over possible signatures for BSM hints or discoveries. These searches put limits on the mass of new particles, singly produced resonances up to $\sim 5 \text{ TeV}$, pair produced new particles up to $\sim 0.8 \text{ TeV}$. Limits were also set on the interaction scale in the EFT approach for different operators describing the type of interaction in the Dark Matter searches. No new physics was found.

From the sensitivity studies for 14 TeV runs, one can conclude that the first data delivered early in 2015 may already be sufficient to test for the presence of new physics. However, very important gains in the physics reach are possible with the HL-LHC with 3000 fb^{-1} . The luminosity upgrade would become even more interesting if new phenomena are seen during the 300 fb^{-1} phase of the LHC (Run-II + Run-III), as the ten-fold increase in luminosity would give access to improved measurements of the new physics.

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