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Electroweak and Beyond the Standard Model results at DIS2013

Alexander Oh
University of Manchester
E-mail: alexander.oh@cern.ch

Markus Stoye
CERN
E-mail: Markus.Stoye@cern.ch

Alessandro Vicini
University of Milano and INFN - Sezione di Milano
E-mail: alessandro.vicini@mi.infn.it

We present some highlights of the presentations given in the parallel sessions of the Working Group 3 “Electroweak and Beyond the Standard Model Physics”

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1. Introduction

The "Electroweak Physics and Beyond the Standard Model" working group covered the areas of electro-weak precision measurements, multi-boson production, Higgs physics, searches for supersymmetry and new physics. Additionally, combined sessions with the working groups "QCD and Hadronic Final States" and "Structure Functions and Parton Densities" discussed overlapping areas. The combined sessions are not covered in this summary.

2. Standard Model Physics

Many new results in different sectors of the Standard Model (SM) framework have been presented during the conference. We try to group them in categories.

2.1 Single boson production and precision tests of the SM

The production of a pair of high transverse-momentum leptons, the Drell-Yan (DY) process, offers the possibility of high-precision measurement of the main electroweak (EW) parameters such as the masses and decay-widths of the W and Z gauge bosons and the weak mixing angle. The measurement of these quantities requires a careful comparison between the experimental data and the best simulation tools. The recent developement of the POWHEG Montecarlo, including the exact NLO-(QCD+EW) corrections properly matched with multiple parton emission via QCD and QED Parton Shower (PS), has been presented by L. Barzè [1], who emphasized the role of mixed $\mathcal{O}(\alpha\alpha_s)$ terms.

The consistent description at NLO-EW partonic processes at a hadron collider requires the presence of a photon parton density in the proton. The preliminary results on this topic by the NNPDF collaboration have been presented in the talk by S. Carrazza [2], who stressed the fact that a non-vanishing, but still compatible with zero, photon densities emerges from the fit to DIS data; on the other hand the constraining power of LHC data improves the description of this density, reducing the uncertainties, increasing the quality of the fit and favouring a non-vanishing distribution.

The DY process is studied in very different kinematical regimes. At large invariant masses it represents one of the main background to the searches for new massive gauge bosons, which decay into a lepton pair. The ATLAS [3] (K. Nikolics) and the CMS [4] (A. Khukhunashvili) results in the neutral-current channel have been presented, showing events up to 1.5 TeV of invariant mass, with a global good agreement with the SM predictions. The latter receive important QCD and EW radiative corrections which should be taken into account in the comparison with the data.

The gauge boson rapidity and the lepton pseudo-rapidity distributions allow a stringent test of the various parametrizations of the proton parton density functions (PDF): the comparison with the data of predictions computed with different PDF sets extacted with NNLO-QCD accuracy demonstrates the constraining power of these observables.

The determination of the W-boson mass is based on the measurement of the leptonic decay channel, which involves a neutrino, thus forbidding the study of the invariant mass distribution of the lepton pair. The transverse mass of the pair can be studied, once the transverse component of the neutrino momentum is clearly identified. The separation of the missing transverse momentum into a neutrino and a recoil component requires a precise understanding of the latter. The recoil of the lepton pair against QCD radiation receives a non-vanishing contribution also from gluon radiation at low momenta, typically in a non-perturbative regime. The modelling of these contributions can be inferred from the study of the lepton-pair distributions in the neutral current channel, where the kinematics of the event is fully reconstructed. Two observables are available to probe the QCD dynamics at low transverse momenta: the lepton-pair transverse momentum distribution and the distribution with respect to the variable ϕ^*. The former has a direct interpretation but suffers the lepton energy scale uncertainties, particularly relevant at low tansverse momenta of the lepton pair. The latter probes the same degrees of freedom, but is defined in terms of angular measurements, which turn out to be more precise in the region which corresponds to low transverse momentum of the lepton pair, making possible a fine binning of the distribution. The results on the $p_\perp^Z$ distribution by ATLAS [5] (E.Yatsenko) and by CMS (A. Khukhunashvili) show the important role of the QCD PS at low transverse momenta of the lepton pair. The phenomenological parameters that control the behaviour of the PS in this region have to be fitted from the data, by using the full information available from the shower Montecarlo matched with NLO matrix elements, considering both NLO-QCD and NLO-EW corrections. The results by ATLAS (E.Yatsenko) on the ϕ^* distribution are impressive for the already very high experimental accuracy reached with the available 2011 data. An updated theoretical analysis by L. Tomlinson, presenting the impact of the resummation of logarithmically enhanced correcctions to this observable, with NNLL+NNLO QCD accuracy, shows the still large scale uncertainties that plague the ϕ^* distribution. A general remark valid for both $p_\perp^Z$ and ϕ^* distributions concerns their role in the fit of the PS phenomenological parameters: as long as the perturbative scale uncertainty is present and is, e.g. in the ϕ^* case, large, it would be important to perform a systematic set of fits, for different perturbative scale choices; the resulting phenomenological parameters would be different for each scale choice, but, most relevant, the χ^2 of the fit would be different in each case. Such a procedure would allow us to appreciate which combination of parameters best describes the data and, at the same time, would offer a consistent estimate of the perturbative theoretical uncertainty.

The preliminary results of the measurement of the weak mixing angle from the analysis of the invariant mass forward-backward asymmetry by ATLAS [6] (R.Caputo) illustrate the possibility at the LHC of having a determination of this coupling competitive with the one at electron-positron colliders. One of the major sources of systematic error in this measurement stems from the proton PDFs, whose role has been illustrated by J.Rojo [7]. The comparison between ATLAS, CMS and LHCb focuses on two points: the weak mixing angle LHCb measurement will most likely suffer a limitation by the amount of collected luminosity, which will not be a problem for ATLAS and CMS; on the other hand, the LHCb acceptance region forces the measurement of the Z resonance in a quite precise range of partonic $x_{1,2}$, where the PDFs are quite precisely known; in contrast, ATLAS and CMS include in their measurement also events generated by partonic subprocesses whose PDF weight might be quite uncertain, thus yielding a pronounced PDF uncertainty. Only the use of all the available LHC data will further constrain the PDF determination, reducing in turn the PDF uncertainty on the EW observables. The PDF uncertainty affecting the determination of the W boson mass extracted from the transverse mass distribution does not exceed the 16 MeV level, before any improvement of the PDF sets due to the LHC data. Only if such systematic errors will be reduced, a more stringent test of the SM will become possible. Progress in the study of the

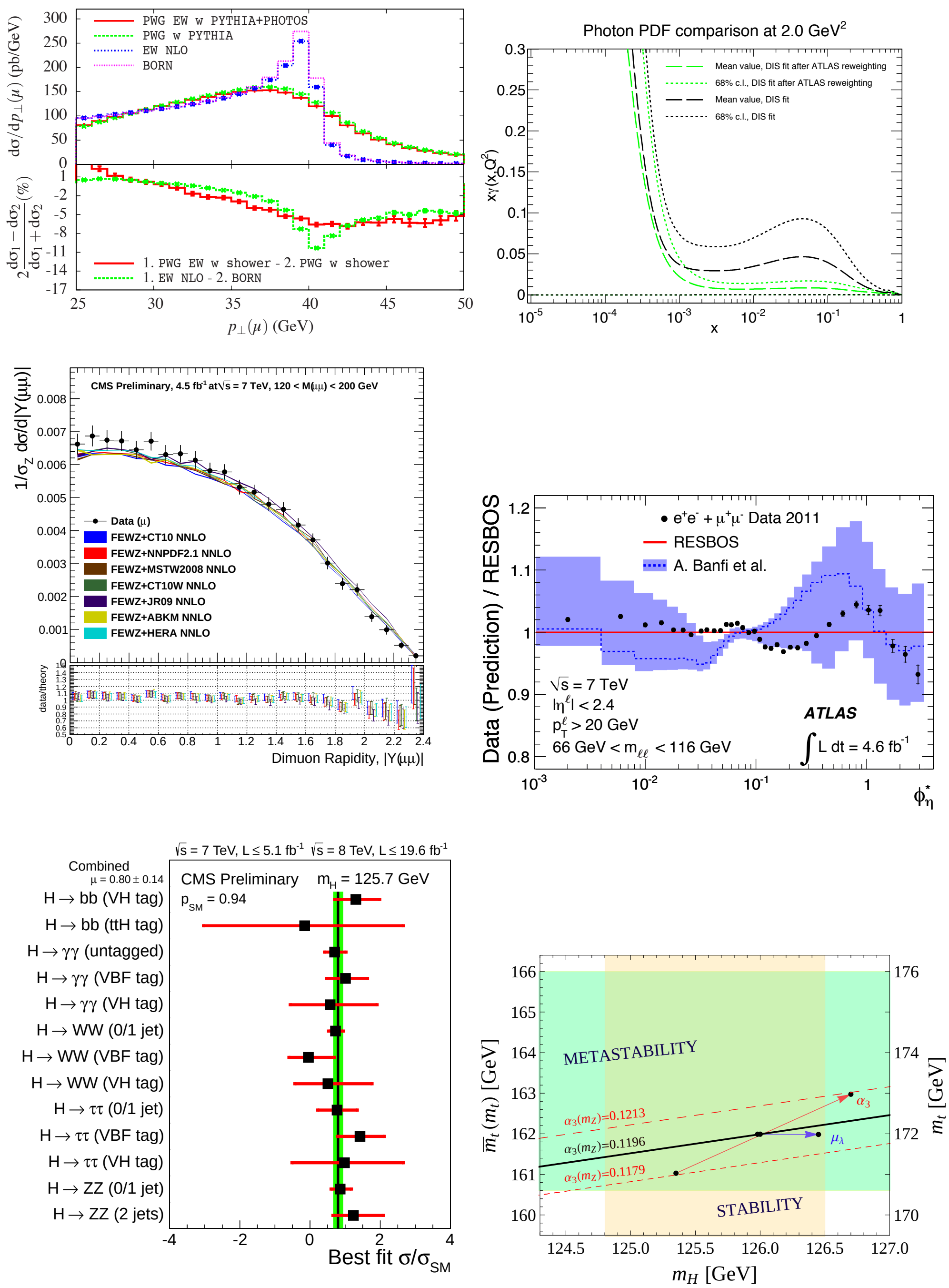


Figure 1: SM results: lepton transverse momentum distribution in charged-current Drell-Yan computed with `POWHEG` including NLO-(QCD+EW) corrections (top left); photon parton density extracted by NNPDF including the effect of LHC data (top right); lepton-pair pseudorapidity distribution at large invariant masses measured by CMS (center left); ϕ^* distribution measured by ATLAS (center right); strenght of Higgs couplings measured by CMS (bottom left); (meta-)stability region of the EW vacuum as a function of top quark and Higgs boson masses.

dijet production cross section, including NLO-EW corrections, has been reported by A.Huss [8]. This observable plays an important role in constraining the gluon parton density at large values of partonic x. The role of the final states containing a charm quark and a vector boson, and their contribution to constrain the strange quark density in the proton has been illustrated by E.Vryonidou [9].

2.2 Higgs searches and properties

The CMS (S.Meola) study of properties of the new resonance wiht 125 GeV of mass is already providing important informations about the nature of this new particle. The data favour the interpretation as a spin 0 state with even parity. The mass determination, altough different but compatible in the two main channels relevant for this measurement, yields a combined value $m_H = 125.7 \pm 0.4 GeV$. The test of the custodial symmetry, based on the comparison of the rates for the processes that involve a coupling of the Higgs boson to the W or to the Z bosons, points towards the presence of such a global symmetry. The strength of the couplings of the Higgs boson to the different SM fields is compatible with the SM expectation. On this latter point, it has been remarked, in the presentations by S.Choudhury [10] and by P.Giardino [11], that it is quite difficult to directly access the couplings to fermions and that a separate parametrization of up and down type quarks would be crucial to perform a sensible analysis also in the more general framework of two-Higgs doublet models.

The implications of the present measured values of the Higgs boson and of the top quark masses have been discussed by I.Masina [12], with emphasis on the stability of the EW vacuum and the possible role of the Higgs field at cosmological level to explain the inflation in the primordial universe.

2.3 Boson-pair production and searches for anomalous gauge couplings

The study of the diboson final states involves many different final states, purely leptonic, semi-leptonic or fully hadronic, which can be then interpreted as the decays of a pair of gauge bosons. The comparison of the total cross sections and of various relevant distributions with the corresponding theoretical predictions shows a general agreement with the SM, but a few comments are in order in some specific cases. The level of agreement between data and theoretical description, for final states that include one massive gauge boson and one photon, is different if one considers distributions that are inclusive or exclusive with respect to the presence of additional QCD radiation, the latter having a more accurate description than the former. Z.Liang presented the ATLAS results on Wγ and Zγ production [13], demonstrating the current level of agreement of data and theory calculation at the NLO in α_s.

The study of diboson production is crucial to appreciate any deviation of the trilinear gauge boson couplings from their SM value or to observe evidence of the presence of anomalous couplings, absent in the SM lagrangian. Results on WW [14], WZ [15, 16] and ZZ [17, 18] production at ATLAS were presented by M. Zeman. The analyses used the purely leptonic channel to achieve a high signal purity and effectively suppress backgrounds, primarily from single vector boson and top quark production. The cross sections for these processes are measured in fiducial volumes and extrapolated to the total cross sections. Good agreement with the SM is found and limits on anomalous triple-gauge boson couplings were set. Differential unfolded distributions describing the di-boson dynamics are published as well to facilitate the comparison to generator level predictions. Results from ATLAS on semi-leptonic WW and WZ decays with one lepton (e or μ), missing transverse energy and two jets in the final state were shown by B. Lindquist [19]. The high background contaminations from mainly single W production with accompanying QCD jets and also from multi-jet and top quark production, requires an excellent understanding of the background shapes and systematic uncertainties. Evidence for the semi-leptonic channel was found, and a cross section compatible with the SM was measured. A study on ZZ production [20] and combination of di-boson channels to set limits on anomalous couplings with the D0 experiment was presented by J. Kraus [21]. The combination of WW and WZ production with lepton plus dijet final states, and a combination of these results with $W\gamma$, WW, and WZ production with leptonic final states provide stringent limits on the couplings parameters. It was noted that due to the use of different form factor scales a direct comparison between experiments is difficult.

The results of all the analyses presented are compatible with the SM predictions, in the framework of anomalous gauge couplings no evidence for non-SM couplings were reported.

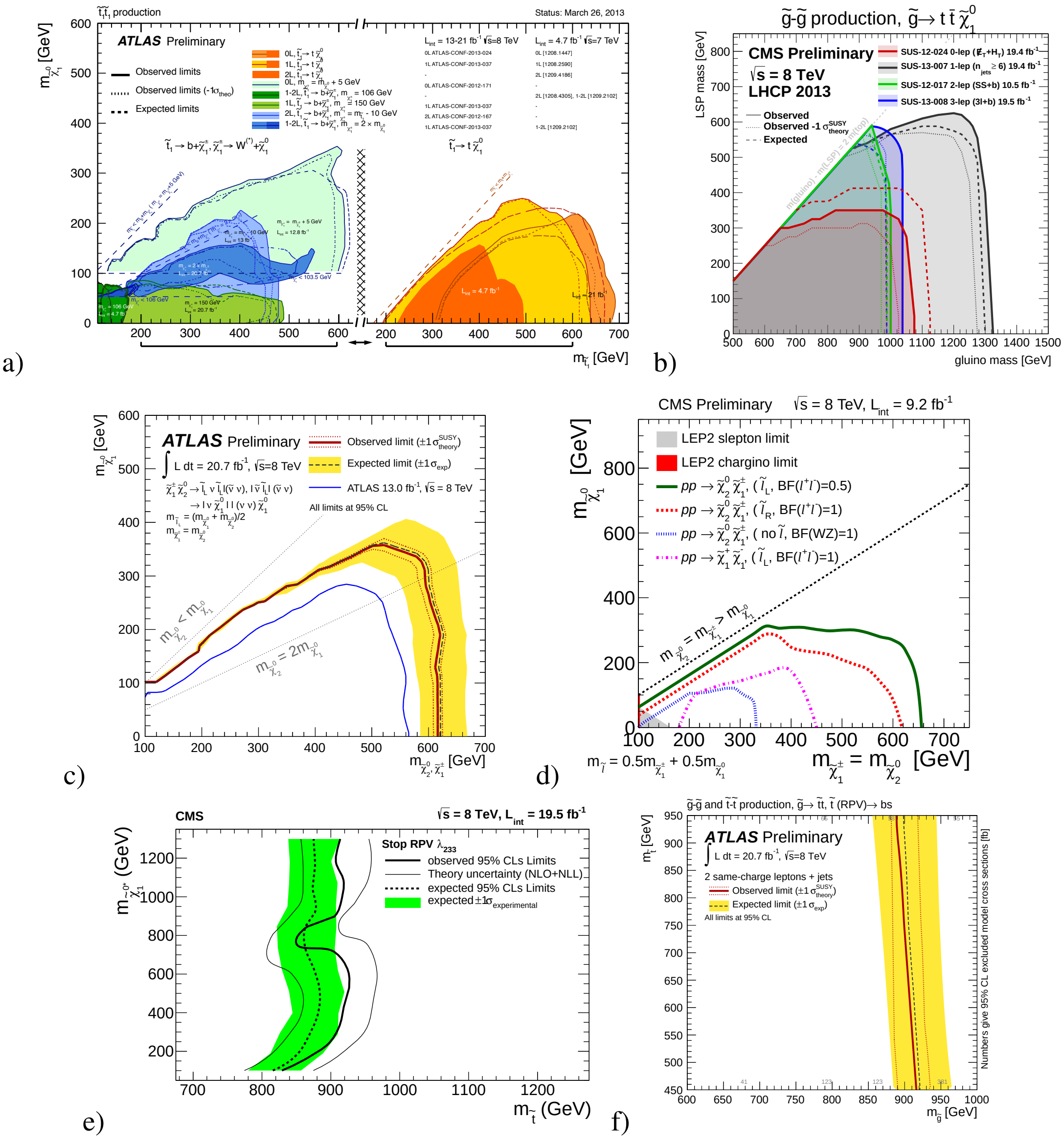
3. Beyond Standard Model Physics

Many results on searches for new physics have been presented, only a few highlights can be presented here.

3.1 Searches for Supersymmetry

Albeit extensive search for supersymmetry previous searches have found no evidence and the excluded masses of the first generation quarks are in the TeV range. Especially searches for the third generations are in the focus of several recent results of supersymmetry searches, since relatively light third generation squarks are needed in order to solve the "naturalness" problem of the Higgs by superpartners [22, 23]. Higher order correction lead also to constraints on the gluino mass for natural supersymmetry. Direct searches for $\tilde{t}s$ typically have a modest signal to background ratio and large $t\bar{t}$ background, therefor they need precise background predictions. The gluino induced searches on the other hand lead to spectacular signatures with many b-quarks and many $W^{(*)}$-bosons and typically have fewer background. The results of such searches are interpreted in simplified models [24, 25] in which the interpretations shown are assuming always 100% branching ratio for the decay-chain that does get constrained. Keeping this in mind we see in Figure 2 (a,b) the stop mass is constrained to larger than $\sim$500 GeV for χ^0 masses below $\sim$200 GeV. The limit on the gluino mass exceeds 1 TeV for several independent search channels.
The higgsinos are light and the elecroweakinos (superpartners of electroweak gauge bosons) are expected to be not too heavy as well for natural supersymmetry. Electorweakinos production leads to many leptons and missing energy and thus these searches have few background. This partially compensates the small production cross-section for these particles. Exclusion up to several hundred GeV have been reached mostly by multileptonic searches as shown in Figure 2(c,d). Also searches for $\tilde{t}$ in which R-parity violation (i.e. sparticles can decay to SM particles) is allowed were presented and interpretation of the results are shown in 2(e,f).

Figure 2: Different limits for supersymmetry searches interpreted in simplified model. a) Limits from direct searches for stop squarks [26]. b) Limits for gluino mediated stop squark generation [27]. c) Limit for direct stop search with RPV violation via leptonic decays [28]. d) Limit for gluino induced stop production with RPV via hadronic decays [29]. e) Limit on electroweakino masses [30]. f) Summary of limits on electroweakino masses from [27].



3.2 Searches for Resonances

Several searches for of new resonances decaying into a pair of particles were presented and only a few can be mentioned in the summary. Such searches are motivated by many extension to the Standard Model theories such as e.g. exited quarks or Z's. Figure 3 shows the dijet invariant mass of a resonace search and also the interpretation of the negative result for new physics for various

Figure 3: Left: Invariant mass of dijets from CMS [31]. Right: Excluded cross-section time branching ratio and various reference reference models.

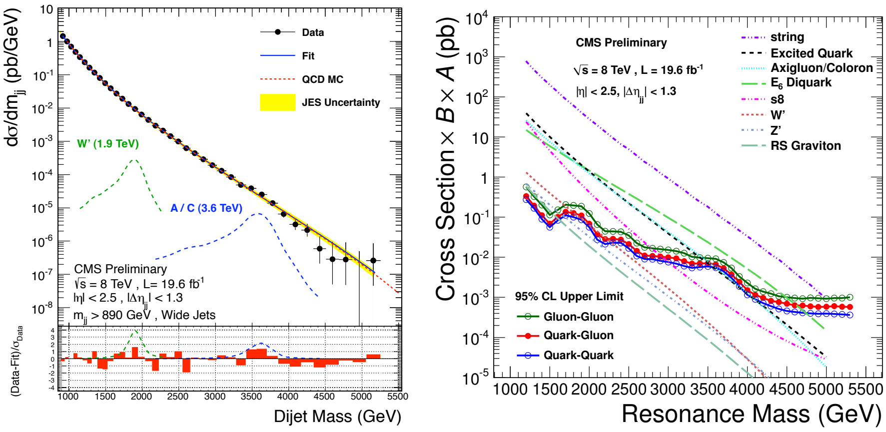
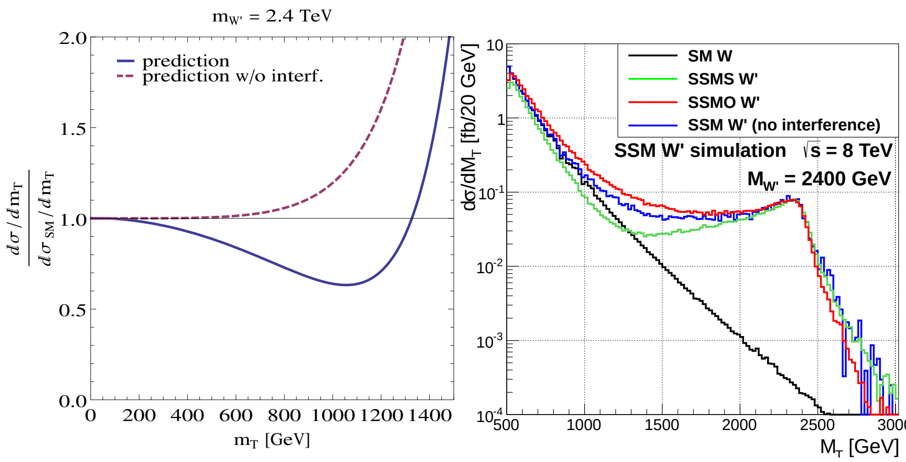


Figure 4: Left: ratio of differential cross-section of new physics over SM cross-section with and without interference [33]. Right: Differential cross-section for the Standard Model and different interference models for W' [34].



models. Exited quarks have been excluded to up to 3.5 TeV. The events with the highest dijet mass reached 5 TeV. To have good efficiencies for (hadronic) Z-boson reconstruction for large invariant masses ($>$ 1 TeV) of the Z-boson pair, special methods had been deployed to identify boosted Z boson where the decay products are very close to each other. As the energies probed in resonance searches at the LHC reach the TeV scale, several analysis showed special methods to reconstruct very high transverse momentum objects, such as boosted tops and boosted V-bosons.

The interpretation of results for resonances leads to the question of interference effect from new physics and the Standard Model. For the W' case predictions of the relative cross-section increase are show with and without interference term in Figure 4. A search accounted for the potential interference in their signal models as shown in Figure 4. The observed limit for the *W'* mass ranged from 3.8 TeV for positive interference to 3.1 TeV for negative interference.

3.3 Searches for Long Lived Particles

New physics can lead to long-lived particles which decay inside the detector or are even detector stable. Several such searches have been presented, one example using unusual methods is the search for heavy stable particles [35] which uses information such as the timing of the muon chambers and energy loss in the tracker to identify the “slow” heavy stable particles. An experimentally challenging search was presented which used precise measurements of the photon flight direction to detect displaced vertexes [36]. None of the searches found evidence of signal.

4. Conclusions

In the sessions of the "Electroweak Physics and Beyond the Standard Model" working group and in combined sessions with PDF and hadron final states working groups a total of 52 presentations were made. It is not possible to cover adequately all of the contributions and thus a subjective selection of the topics discussed has been made. We would like to thank the organisers of the DIS 2013 conference for their excellent support and hospitality.

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