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PHYSICS BEYOND THE STANDARD MODEL AT ATLAS

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This report briefly reviews the potential of the ATLAS experiment to discover new phenomena beyond the Standard Model like new gauge bosons, extra dimensions and SUSY particles.

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1. Introduction

When the Large Hadron Collider (LHC) will start providing data from the experiments, unprecedented opportunities to explore the frontier of high-energy physics as we know it today will become available [1]. The LHC is a proton-proton collider with a center-of-mass energy of 14 TeV, currently under construction at CERN, Geneva. The first collisions at $\sqrt{s} = 14$ TeV are expected in the summer of 2008.

The physics beyond the Standard Model (SM) is traditionally divided into the part connected with the SUSY and part including all other physics like extra gauge bosons and simmetries, extra dimensions. This review does not cover all studies in ATLAS for search of new particles, only a few topics were selected.

2. Z' searches at ATLAS

A particle of mass $1-2$ TeV decaying into e^+e^- pairs, such as the possible new gauge boson Z', is probably the easiest object to discover at the LHC. Z' arise from many beyond the SM scenarios, like GUT (E_6), Little Higgs model, Kaluza-Klein excitations in the models with extra dimensions. Main background is the process of Drell-Yan dilepton production, falling rapidly with invariant mass of dileptons, and would be negligible compared to the signal. The signal will be indisputable, since it will appear as a resonant peak on top of a smooth background, and not just as an overall excess in the total number of events. These expectations are not based on ultimate detector performance, since they hold also if the calorimeter response is assumed at conservative level of a few percent. About ten events are expected for an integrated luminosity 300 pb^{-1} for Z' in e^+e^- decay mode with the mass of 1.5 TeV, after typical cuts [1].

The possibility of Z' detection depends strongly on the mass of Z' and coupling constants. The CDDT parametrization [2] adopted by the CDF collaboration takes into account both experimental limits and general theoretical assumptions to constraint the models with an additional neutral gauge boson. Four classes of solution were found, three parameters remaining totally free in the four classes, these parameters are the mass of the additional gauge bozon, the global coupling strength and a parameter x describing the relative coupling strength to the different fermions. The results [3] corresponding to 5 sigma signal for one of the classes are presented in Fig. 1 for the integrated luminosity $L = 400\ \mathrm{pb}^{-1}$. If the number of observed events will be sufficient, it will be possible to distinguish the model values of the cross section, branchings ratios for the different channels and forward-backward symmetry.

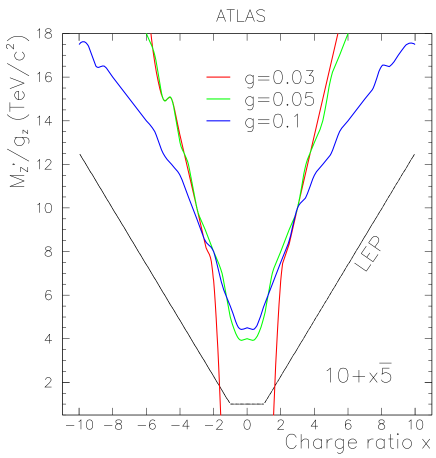

Fig. 1. ATLAS discovery capability for observation of Z' with integrated luminosity of 400 pb^{-1}.

3. *Extra dimensions*

The main motivation for the development of theories beyond the Standard Model is the hierarchy problem, i.e., why the gravity energy scale (or Planck mass) and the electroweak energy scale are so different: 10^{19} GeV compared to 10^3 GeV, respectively. Several possibilities have been suggested to solve this naturality problem: perturbative solutions like supersymmetry, and non-perturbative solutions like compositeness and technicolor. Alternatively, one can exploit the geometry of space-time via extra dimensional theories. Several scenarios of the models with extra dimensions have been developed in the last years: Arkani-Hamed, Dimopoulos and Dvali (ADD) model [4], Randall-Sundrum (RS) or warped extra dimensions model [5], TeV^{-1} size dimensions [6] and universal extra dimensions (UED) [7].

There are two types of processes with Kaluza-Klein exitations of graviton in ADD model: via direct production and via virtual graviton exchange. The process of direct graviton production is characterized by the presence of high missing transversal momentum due to the graviton emission and jet or gamma that keep balance in the reaction. Analisys [8] shows that the maximum reach in new Planck scale M_D for low luminosity 30 fb^{-1} is 7.7, 6.1 and 5.2 TeV, corresponding to 2, 3 and 4 extra dimensions.

More exclusive limits on the ADD model come from searches for graviton exchange channel. The excess of the dijet, digamma or dileptons events with high values of the invariant masses can be used to find the effects of extra dimensions. Analysis [9] shows that ATLAS can reach up to 5 TeV in M_D for integrated luminosity 10 fb^{-1} and upto 7 TeV with 100 fb^{-1} in dilepton channel.

One of experimental signature of the RS model is the narrow high-mass resonance with dilepton, diphoton and dijet decay channels. The possibility to observe this resonance in ATLAS experiment was studied [10]. It was shown that the angular distribution of the lepton pair (Fig. 2) can be used to determine the spin of the state. In the test model, the angular distribution favours a spin-2 hypothesis over a spin-1 hypothesis at 90% confidence level for graviton masses up to 1440 GeV.

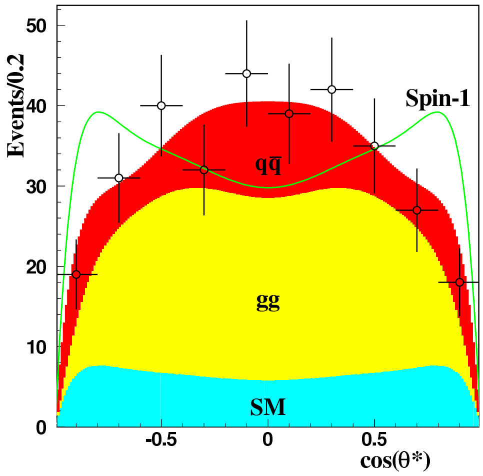

Fig. 2. The angular distribution of data in the test model for mG = 1000 GeV *and 100* fb^{-1}.

The discovery potential for the first KK exitation of Z and γ ($Z^{(1)}_{KK}/\gamma^{(1)}_{KK}$) has been investigated [11] in dilepton decay modes. It was shown that with ATLAS experiment it would be possible to detect a resonance to at a mass of 5.8 TeV with 100 fb^{-1} in dilepton channel. By measuring for interference in a mass window (1000 – 2000 GeV) rather then looking for a peak in invariant mass spectrum, it is possible to extend the discovery reach up to 8 TeV.

Another interesting property of the models with extra dimensions is the production of the black holes. Black holes will be produced at the LHC if the fundamental Planck scale is of order a TeV.

The potential of the ATLAS detector for discovering black holes produced at the LHC was analysed [12]. It was assumed that black holes decay by Hawking evaporation to all Standard Model particles democratically. Figure 3 gives a contour plot for integrated luminosity needed for the discovery in the (M_P, n) plane. It was found that the discovery potential hardly depends on the number of the extra dimensions n but has a strong dependence on M_P.

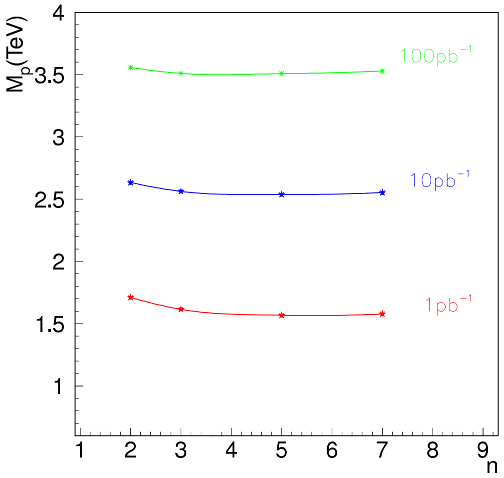

Fig. 3. ATLAS discovery capability for observation of black holes for different integrated luminosities.

4. Supersymmetry

Supersymmetry (SUSY) is a theoretically attractive candidate for physics beyond the Standard Model, and there are several arguments in favor of supersymmetry at the TeV scale accessible at the LHC. If the SUSY mass scale is only just above the Tevatron limits, SUSY is the prime candidate for an early discovery at the LHC. A search for SUSY in early data must be robust (able to cope with background uncertainties and a non-optimal detector) and general. Excellent opportunities exist in final states with high E_T jets, and significant missing transverse energy.

Discovery potential study within mSUGRA parameter space of inclusive searches for SUSY at ATLAS was analysed [13]. It was shown that inclusive searches will be sensitive to models with squark and gluino masses < 2 TeV for 10 fb^{-1}. The greatest discovery potential is obtained with the inclusive jets and missing energy channel.

After the initial discoveries, the challenge will be to extract information about particle masses. The special endpoint technique was developed for these goals. This technique allows to establish constraints on sparticle mass combinations and ultimately on the underlying sparticle spectra. This technique was used in several studies and Fig. 4 [14] illustrate it with the example of dilepton mass distribution for coannihilation region of SUSY parameters.

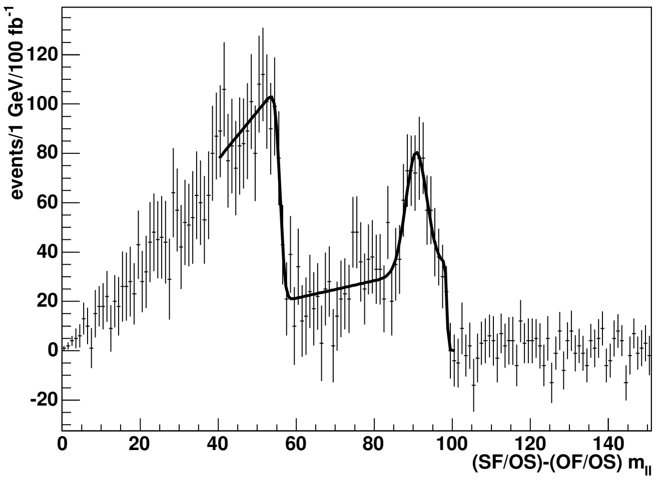

Fig. 4. Mass distibution for dilepton with different signs (OS) for flavour substraction combinations - the same (SF) and different (OF) flavours.

5. Conclusion

After the start of operation of LHC, ATLAS experiment will have unprecedented opportunities to explore the frontier of high-energy physics. ATLAS experiment will provide a powerful tool to discover or exclude many particles or effects predicted by theory.

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ISTRAŽIVANJA ATLASOM IZVAN STANDARDNOG MODELA

Daje se kratak pregled moćnosti mjerenja ATLAS-om u traženju novih pojava izvan Standardnog modela, kao novih baždarnih bozona, novih dimenzija i SUSY čestica.