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Vienna, 22 September 2013

Report on Dr. Karol Kovarik's Habilitation Thesis

"Higher-Order Corrections to Dark Matter Relic Density"

I am happy to have been asked to provide this report on Dr. Karol Kovarik's habilitation thesis "Higher-Order Corrections to Dark Matter Relic Density".

In his habilitation thesis Dr. Kovarik gives a complete and comprehensive treatment of the one-loop QCD and supersymmetric (SUSY) QCD corrections to the annihilation of a pair of lightest neutralinos into massive quarks and the co-annihilation of the lightest neutralino and a light scalar top quark into a quark and a Higgs boson or an electroweak gauge boson. These are the main processes assumed to lead to the relic density of cold dark matter (CDM) if weak-scale SUSY with R-parity conservation is realized in Nature. His habilitation thesis is based on three earlier publications in Physical Review D.

When reading his habilitation thesis, the first impression is that it is well-timed. On the one hand, in its next run at a center-of-mass energy of 14 TeV, the Large Hadron Collider (LHC) at CERN, Geneva, will definitely put more stringent limits on the masses of SUSY particles, in particular also on the mass of the lightest neutralino as the CDM particle. On the other hand, the future satellite experiments are also expected to improve the accuracy of the measured amount of CDM in the Universe. One of the main results of Dr. Kovarik's habilitation thesis is that already the current experimental accuracy requires the inclusion of the one-loop QCD and SUSY QCD corrections in the calculations of the annihilation rates of the lightest neutralinos. With the expected future accuracy this will be even more the case.

A central issue in Dr. Kovarik's habilitation thesis is the right choice of the appropriate method of regularization and renormalization, which is mandatory in any calculation of one-loop corrections. In particular, the correct renormalization of the squark sector is quite complicated, as the squark masses and the mixing angle have to be renormalized. Dr. Kovarik is a well-known expert in this field. He applies a hybrid on-shell/DRbar scheme,

which turns out to be an optimal choice for the renormalization of the squark sector and leads to stable numerical predictions in almost the whole SUSY parameter space. For the renormalization of the quark sector he follows standard procedures, including the resummation of the threshold corrections for the mass of the bottom quark. As he demonstrates in many numerical examples, the inclusion of the QCD and SUSY QCD one-loop corrections to the CDM relic density will be necessary in all future determinations of the SUSY parameters.

As he is applying the method of dimensional reduction, he is very accurate in his treatment of the cancellation of the infrared (IR) divergencies. He uses the dipole subtraction method in the case of neutralino annihilation into a quark pair and the phase-space slicing method for the co-annihilation process. This again allows him to obtain stable numerical results.

Dr. Kovarik's thesis involves the scientific fields of theoretical cosmology and theoretical particle physics. The calculation of the relic density of CDM requires the solution of the appropriate Boltzmann Equation. For this purpose he uses the public code "micrOMEGAS", taking his code for the neutralino pair annihilation and the neutralino – stop coannihilation cross sections at one-loop level as input. It is worth emphasizing that Dr. Kovarik and his coauthors plan to make their code public, so that it can also be used by other groups in future calculations of the CDM relic density.

Considering the scientific results of Dr. Kovarik's work and the methods he is using, it is obvious that the scientific value of his habilitation thesis is indeed very high. It demonstrates that he has excellent knowledge of particle physics, quantum field theory, and cosmology. He performs extremely well in all analytical and numerical calculations and he is also a complete professional in the technical and numerical tools he needs

The quality of the presentation of the methods used and his scientific results is also very high. Dr. Kovarik's habilitation thesis is written in a very clear way. Nevertheless, I would like to add a short remark. Parts of Sections 3 and 4 of his thesis he has taken from his three previous publications. Of course, this is absolutely OK. However, in this way he has introduced a partial overlap of the presentations of the methods of renormalization in Section 3 and in Section 4. For example, equations (4.4) – (4.6), (4.18), (4.19), (4.21) are a repetition of the corresponding ones in Section 3. Also the text between the equations is partly a repetition. Moreover, there are also a few typographical errors in the text. In my opinion, however, these all are only unimportant flaws, which do not really affect the high scientific level of the thesis. Dr. Kovarik's presentations of the difficult problems of the renormalization, the cancellation of the IR divergences, the details of the analytical and numerical techniques, as well as the introductory sections on SUSY and on CDM reflect the fact that he is a real expert in all these fields. Furthermore, in his presentation of the numerical results he compares his full one-loop results with the tree-level approximation and those obtained by micrOMEGAS. In this way he clearly demonstrates that the one-loop QCD and SUSY QCD corrections have to be taken into account.

In conclusion, I recommend Dr. Kovarik's habilitation at the University of Bratislava.

Alfred Bartl