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Treatment of systematic uncertainties with Bayesian networks: Dark Matter direct detection as a case study

In this contribution we will show an innovative approach based on Bayesian networks and linear algebra providing a solid and complete solution to the problem of the detector response and the related systematic effects. As a case study, we will consider the Dark Matter (DM) direct detection searches. In fact, in the past decades, a huge experimental effort has been developed to detect DM. However the failure of observing incontrovertible evidences of a DM signal stimulated, in direct detection experiments, the effort of examining alternative signals to nuclear recoil, including dark matter scattering on electrons or secondary signals, and motivated the interest in sub-GeV/c^2 DM.

In this context, it is crucial to develop a reliable analysis framework, which is able to take into account all the relevant systematic effects in a clean and accessible way. Since in fact the relations connecting the calibration parameters of the experiment to the final observed data spectrum are characterized by substantial complexity and non linearity, usual approaches to direct detection data analysis involve multi-templates techniques. These approaches, even if simple to use and implement, rely often on pre-defined morphing algorithms and ad-hoc prescriptions and assumptions to take into account all the correlations between the different parameters. By means of the Bayesian network technique however it is possible to represent the full detector response to any background/signal event keeping the dependence on the detector parameters explicit. We will show that the advantage of this kind of approach is twofold: from the statistical point of view it is a solid and rigorous way to perform the analysis as all the assumptions must be explicitly added to the network; from the computational point of view, we demonstrated that it is possible to represent the response of the detector by a set of matrices, allowing to use a GPU accelerated analysis code to improve the performance of the fit. As a consequence, we implemented the linear algebra needed for the analysis using the NVIDIA CUDA libraries, and we used the Metropolis-Hasting Markov Chain Monte Carlo needed for the fit as implemented in the BAT C++ libraries. The resulting software allowed us to demonstrate the benefits of this innovative approach in the achievement of physics results.

Significance

This contribution is about an innovative approach based on Bayesian networks and linear algebra providing a solid and complete solution to the problem of the detector response and the related systematic effects. This is the natural continuation of previous works we published in this context, which implemented bayesian analysis without accounting in an exhaustive way for the systematic uncertainties.

References

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Speaker time zone

Compatible with Europe

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