New insights on dark matter using lattice gauge theories

E. Rinaldi[*1]

Dark matter is thought to be the dominant form of matter in our universe today. Its energy density is about five times larger than common visible matter according to recent cosmological observations. However, dark matter is very elusive and it has not yet been detected despite large experimental efforts. Moreover, the particle dark matter candidate generally used as a template for all the experimental analysis, the so-called WIMP (weakly interacting massive particle) dark matter, is a product of supersymmetric theories and these theoris have not been discovered yet.

From the theoretical point of view, it is interesting to start exploring dark matter models where the candidates are more exotic than the usual WIMPs and that can naturally explain why all the experimental searches have turned out empty handed. This research program focuses on composite dark matter, a framework for dark matter models where the candidate new particle is a bound state of a new strong interaction. Composite dark matter has a non-trivial internal structure and its main properties are dictated by non-perturbative strong dynamics, which naturally include self interactions.

This type of picture is familiar to everyone working in Quantum Chromodynamics (QCD), the theory of quarks and gluons that explains how composite particles like protons and neutrons are created. Moreover, methods that are succesfull in exploring non-perturbative QCD properties can be applied to composite dark matter theories. This is the case for lattice gauge theory simulations. They provide a systematic way of solving the strong dynamics of the theory with improvable and controllable errors.

Applying lattice field theory methods to models of composite dark matter has been very fruitful. In particular, for the case of Stealth Dark Matter, they have helped determining the strength of the dominant interactions with the photon[1)] and the Higgs boson[2)]. Stealth Dark matter is a model with a SU(4) gauge group and dark fermions that have electric charges and are bound together into a heavy neutral four-fermion object that constitutes dark matter. Since this object has constituents with electric charge and mass, it will interact with Standard Model particles through the exchange of the corresponding gauge bosons, the photon and the Higgs. While the dominant interaction with the Higgs boson depends on unknown parameters of the model at high energy and can only be bound using existing experimental results, the electro-magnetic interaction between the dark matter and the nuclear matter in detectors like LUX or XENON1T can be directly calculated with lattice simulations.

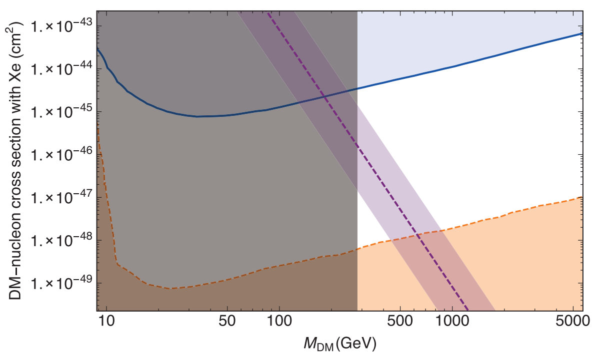

Fig. 1. The DM spin-independent scattering cross section per nucleon evaluated for xenon is shown as the purple band obtained from the SU(4) polarizability, where the width of the band corresponds to $1/3 < M_F^A < 3$ from low to high. The blue curve and the light blue region above it is excluded by the LUX constraints. The vertical, darker shaded region is excluded by the LEP II bound on charged mesons[1)].

The operator

$$\mathcal{O}_F = C_F B^* B\, F^{\mu\alpha} F^{\nu}_{\alpha} v_\mu v_\nu \,, \quad (1)$$

where C_F is the EM polarizability, corresponds to a cross section with a nucleon of

$$\sigma_{\rm nucleon}(Z,A) = \frac{Z^4}{A^2}\frac{144\pi\alpha^2\mu^2_{nB}(M_F^A)^2}{M^6_{\rm DM}R^2}[\alpha\tilde{m}^3_B\tilde{C}_F]^2 \,, \quad (2)$$

where Z and A are the usual atomic number and mass, while $M_{\rm DM}$ is the unknown dark matter mass. The cross section *per nucleus* scales as Z^4 and not A^2, and so the cross section *per nucleon* must be calculated for each nucleus separately in order to compare with experiments.

Comparing to LUX gives the cross section in Figure 1 as a function of the dark matter mass. Stealth Dark matter of mass 500 GeV is not excluded by experiments.

These results have been presented at the BNL Early Career Researcher Symposium in December 2016 and the presentation won an award for its originality[3)].

References

1) Lattice Strong Dynamics (LSD) Collaboration, Phys. Rev. Lett. **115**, 171803 (2015), Editors' Suggestion.
2) Lattice Strong Dynamics (LSD) Collaboration, Phys. Rev. D**92**, 075030 (2015), Editors' Suggestion.
3) Outstanding oral presentation award, Early Career Researcher Symposium 2016, Brookhaven National Laboratory.

*1 RIKEN Nishina Center