Building heavy-particle Lagrangians using Foldy-Wouthuysen representation

V. Lensky[(a)], B. Long[(b)]

[(a)] Theoretical Physics Group, School of Physics and Astronomy,
The University of Manchester, Manchester M13 9PL, UK
[(b)] European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*),
I-38050 Villazzano (TN), Italy

We use the Foldy-Wouthuysen representation [1] to construct Lorentz-invariant interactions of heavy fields, following the so-called bottom-up approach [2], when one builds the interactions starting from non-relativistic heavy particle fields, as opposed to the top-bottom approach [3], when one starts with the relativistic Hamiltonian (Lagrangian) and then disentangles the heavy particle and antiparticle fields in order to integrate the latter out. We show that the couplings obtained in the bottom-up approach feature a straightforward $1/m$ (where m is the mass of the heavy particle) expansion, which ensures Lorentz invariance order by order in effective field theories.

We illustrate possible applications on the examples of pion-nucleon and pion-nucleon-delta couplings in chiral effective field theory. In the case of the $\pi N\Delta$ coupling, we show that one of the terms usually considered to be a part of chiral index-1 $\pi N\Delta$ vertex is in fact redundant. We discuss the implications of this fact. For instance, we show that this redundant term should be dropped if one wants to use low energy constants fitted from πN scattering in calculations of $NN \to NN\pi$ reactions.

We also argue that this approach can be useful in many other instances, e.g., in constructing Lorentz-invariant polilinear interactions such as $NNNN$ [4], $NNN\Delta$, etc., contact terms — a problem that is not so easily addressed in the top-bottom approach, where the fact that the interactions are bilinear in the fields is essential.

[1] L. L. Foldy and S. A. Wouthuysen, *Phys. Rev.* **78** (1950) 29; L. L. Foldy, *Phys. Rev.* **102** (1956) 568.

[2] C. Ordóñez, L. Ray, and U. van Kolck, *Phys. Rev. Lett.* **72** (1994) 1982; *Phys. Rev.* **C53** (1996) 2086; T. D. Cohen, J. L. Friar, G. A. Miller, and U. van Kolck, *Phys. Rev.* **C53** (1996) 2661; B. Long and U. van Kolck, `arXiv:0907.4569 [hep-ph]`.

[3] E. Jenkins and A. V. Manohar, *Phys. Lett.* **B255** (1991) 558; G. Ecker and M. Mojžiš, *Phys. Lett.* **B365** (1996) 312; N. Fettes, U.-G. Meißner, M. Mojžiš, and S. Steininger, *Annals Phys.* **283** (2000) 273; T. R. Hemmert, B. R. Holstein, and J. Kambor, *Phys. Lett.* **B395** (1997) 89; *J. Phys.* **G24** (1998) 1831; A. Gårdestig, K. Kubodera, and F. Myhrer, *Phys. Rev.* **C76** (2007) 014005.

[4] L. Girlanda, S. Pastore, R. Schiavilla and M. Viviani, *P*hys. Rev. **C81** (2010) 034005.

E-mail: lensky@theoserv.phy.umist.ac.uk