

Effective Field Theories for Heavy Quarks:

Heavy Quark Effective Theory, Heavy Quark Expansion, Non-Relativistic QCD

Lectures at Les Houches 2017

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Abstract

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1 Introduction

- Why can we use effective field theory methods for heavy quarks?
- Classification of the various types
- Some historical remarks

2 Heavy Quark Effective Theory HQET

2.1 Construction of the HQET Lagrangian

- Identifying heavy degrees of freedom
- Types of HQET Lagrangians

2.2 Symmetries of HQET

- Flavour Symmetry
- Spin Symmetry
- Reparametrization invariance
- Residual mass term

2.3 HQET at one loop

- HQET Feynman rules
- One loop diagrams
- Example: The $b \rightarrow c$ current

2.4 Results

3 Heavy Quark Expansion

3.1 Inclusive Decays

- Classes of decays

3.2 Operator Product Expansion (OPE)

- Set up of the OPE
- HQE parameters
- tree level results

3.3 QCD Corrections

- Pole mass
- Kinetic Mass
- 1S Mass Scheme

3.4 Results

3.5 End-Point Regions

- Twist Expansion
- Relation to SCET and Thomas Bechers Lecture

4 Non-Relativistic QCD (NRQCD)

4.1 Introduction: Why not just (HQET)²?

4.2 The NRQCD Lagrangian

4.3 Dynamically Generated Scales mv and mv^2

4.4 The case $mv^2 \leq mv \ll \Lambda_{\text{QCD}}$

4.5 The case $\Lambda_{\text{QCD}} \ll mv^2 \leq mv$ and pNRQCD

4.6 Results for Quarkonia Processes

4.7 Exotic States ?

References

- [1] A. G. Grozin, *Heavy quark effective theory*, Springer Tracts Mod. Phys. **201**, 1 (2004). doi:10.1007/b79301
- [2] T. Mannel, *Effective Field Theories in Flavour Physics*, Springer Tracts Mod. Phys. **203**, 1 (2004). doi:10.1007/b79301
- [3] A. V. Manohar and M. B. Wise, *Heavy quark physics*, Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. **10**, 1 (2000).
- [4] A. A. Petrov and A. E. Blechman, *Effective Field Theories*, World Scientific 2016