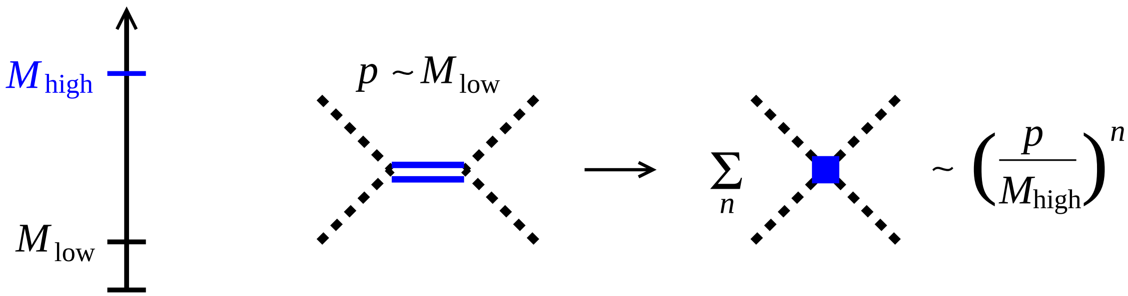
Short-range correlations in Effective Field Theory: Introduction

C. Weiss (JLab), EMS and SRC Workshop, MIT, 2-5 Nov 2016

- Basic concept
- Chiral EFT for πN dynamics
- EFT for NN interactions and light nuclei
- Field redefinition, observables $\leftrightarrow$ non-observables
- Factorization and scheme dependence in high-momentum processes
- Toward SRCs in EFT

Review: Epelbaum, Hammer, Meissner 09 + more recent literature

EFT: Concept



- EFT $\equiv$ general method for describing low-energy behavior of dynamical systems with widely separated scales
  Weinberg 79; Wilson 83. Reviews Georgi 93, Manohar 96

- Formulated as quantum field theory

  Low-energy degrees of freedom described by fields

  High-energy dynamics encoded in couplings

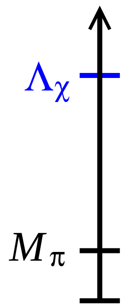
  Form of Lagrangian constrained by symmetries of microscopic dynamics

  Constructed & solved by parametric expansion in $\{p, M_{\rm low}\}/M_{\rm high}$

  Quantum loops $\rightarrow$ renormalization

- Simple systems: Derive $L_{\rm eff}$ from microscopic dynamics
  Complex systems: Use symmetries, determine constants empirically

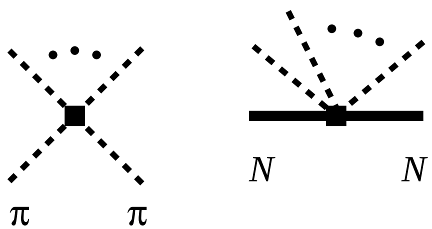
EFT: Chiral EFT



- Dynamical chiral symmetry breaking in QCD

  Pion as Goldstone boson: $M_\pi \ll \Lambda_\chi$ ($\sim M_\rho$), coupling to hadrons $\propto p^\mu$

- Expansion in $\mathcal{Q}/\Lambda_\chi$ with $\mathcal{Q} = \{M_\pi, p\}$ Gasser, Leutwyler 84+



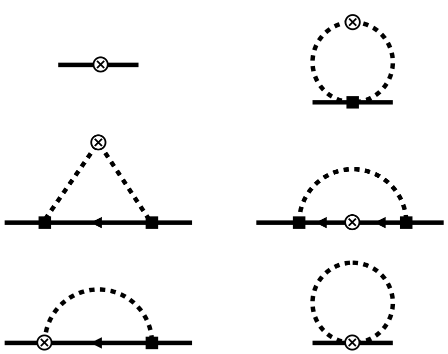
- Chiral Lagrangian

  Structures constrained by chiral symmetry

  Constants from measurements, LQCD (on-shell vertices!)

  Nucleon as heavy source, non-relativistic or relativistic

$\langle N'|J^\mu|N\rangle =$



- Numerous applications Review Bernard, Meissner 07

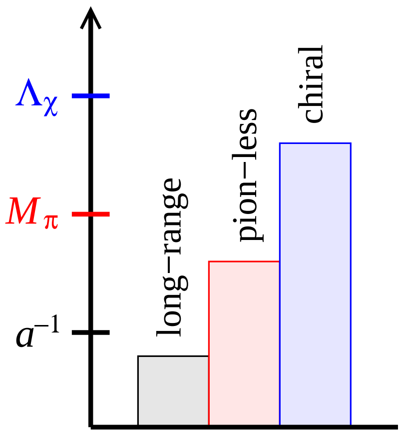
  $\pi\pi$, πN scattering

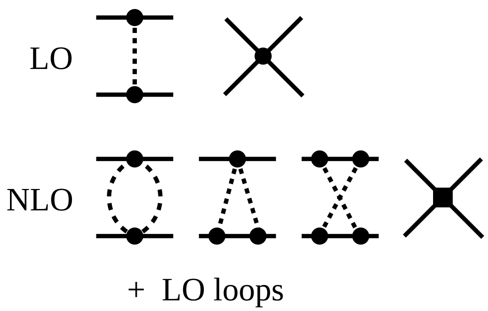
  $\langle N|J^\mu|N\rangle$, EM processes

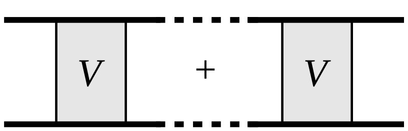
  $\langle N|O(\text{twist-2})|N\rangle$

  NN interaction

EFT: NN interactions and nuclei







- Multiple dynamical scales Kaplan, Savage, Wise 98+

$$\left.\begin{array}{rl} \text{scatt length} & a^{-1}(^1S_0) = 8\,\mathrm{MeV} \\ \text{deuteron} & \sqrt{\epsilon_D M_N} = 45\,\mathrm{MeV} \end{array}\right\} \ll M_\pi \ll \Lambda_\chi$$

- Chiral EFT in nuclei

  NN interaction from χEFT $\rightarrow$ Potential

  Large-distance scales from iteration $\rightarrow$ Schrödinger eq.

- Advantages over conventional interactions

  Controlled accuracy, systematic improvement

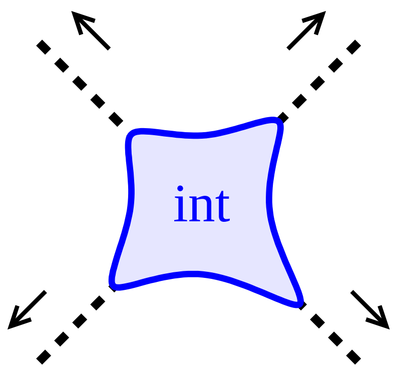
  $3N$, $4N$ forces included systematically

  Current operators consistent with dynamics

  On-shell information only $\leftrightarrow$ $\pi N/NN$ data, LQCD

  Very extensive work. NN interactions now available at N^{4}LO. Review Epelbaum 16

EFT: Fields and observables



- Field redefinition $\phi \to \phi[1 + a\phi + b\phi^2 + ...]$

  On-shell properties remain invariant:
  S-matrix elements, $\langle \ldots | J(\text{conserved}) | \ldots \rangle$ **observable**

  Off-shell Green functions changes,
  form of interaction changes **non-observable**

  Unitarity transformation in configuration space

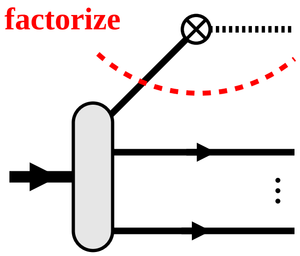
- Momentum density $\langle a_p^\dagger a_p \rangle$ generally not observable
  Furnstahl, Hammer 2001

  Operator not conserved, cf. gauge theories

- Factorization

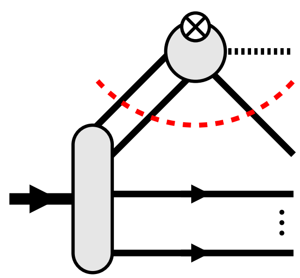
  Observable $=$ Structure $\times$ Reaction mechanism
  Review: Furnstahl, Schwenk 2010 $\to$ Talk Furnstahl

EFT: Factorization and scheme dependence



- High-momentum nucleon knockout $A(e, e'N)$...

  Factorization: Scale and scheme dependence
  cf. QCD factorization in DIS



- Unitary transformation
  More, König, Furnstahl, Hebeler 2015 → Talk More

one-body	$\leftrightarrow$	two-body current
high-momentum	$\leftrightarrow$	low-momentum wave function

- SRC in EFT: Representation of high-momentum knockout process which maximizes high-momentum components of WF and role of one-body current

  How to construct it? Is it unique?

  Can it be improved beyond LO?

  Are the high-momentum components of the WF universal?
  Do they work in processes with other one-body operators?

EFT: Relativistic dynamics

- Momentum transfers $\gtrsim 1$ GeV ($\gg \Lambda_\chi$): Process evolves along unique direction, probes system at fixed light-front time $t + z =$ const.

- Light-front quantization keeps off-shellness finite in high-energy limit, permits "composite" description of nuclear & hadronic structure
  Frankfurt, Strikman 81

- Non-nucleonic degrees of freedom: Δ isobar, πN

- Include in EFT framework!
  Light-front representation of chiral EFT for πN, Δ: Granados, Weiss 15-16