Effective Field Theories

http://www.becher.itp.unibe.ch/eft24/

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Tools for QFT computations

Expansion
in the interaction
strength:
perturbation
theory

Expansion in
scale ratios:
Effective Field
Theories

Numerical
methods:
lattice simulations

Toy models:
solvable models
SUSY theories
AdS/CFT

Benefits of EFTs

- Expansion in scale ratios simplifies computations
- Factorization of physics at different energy scales
  - Separate perturbative from non-perturbative physics
  - Dimensional analysis
  - Perturbation theory works. (It cannot be applied in multi-scale problems due to large logarithms.)
- Symmetries
  - emergent: heavy-quark symmetry
  - approximate: chiral symmetry
- General framework also for cases where the full theory is not known, or cannot be used for computations

Wilsonian vs. Continuum EFT

- Wilsonian EFT integrates out high-energy physics above some cutoff exactly, using path integral
  - top down approach, difficult in practice
  - works with hard cutoffs
  - provides physical picture of renormalization
- Continuum EFT
  - write down the most general low energy L_{eff}
  - determine coefficients of terms in L_{eff} by matching
  - usually: dimensional regularization instead of hard cutoff

Traditional low energy EFTs

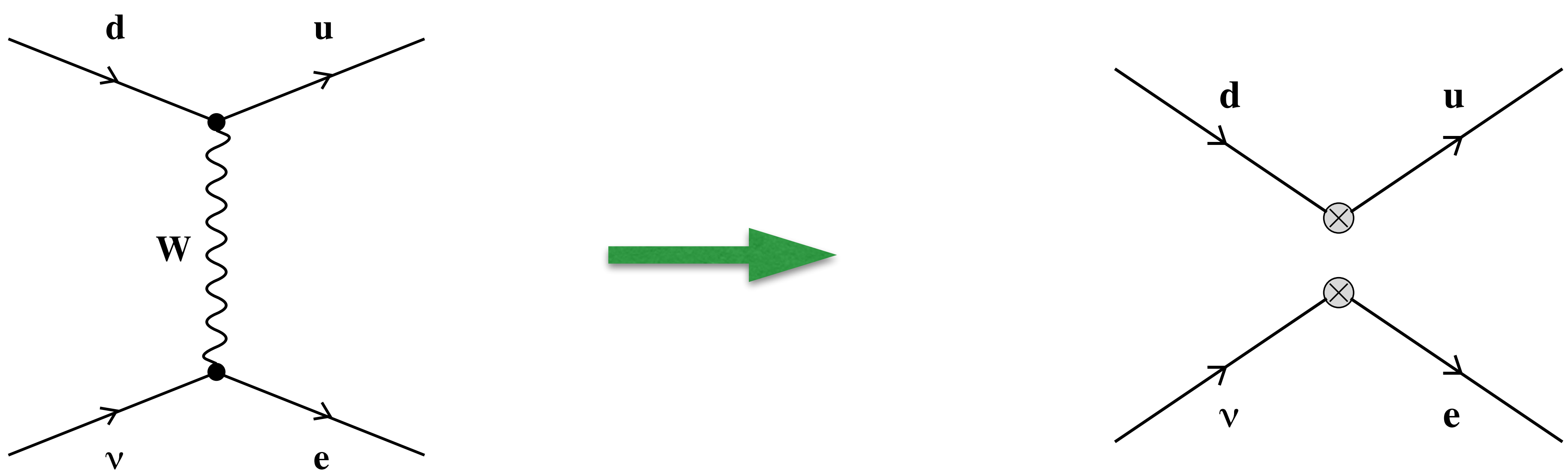
The effective theory is a standard relativistic quantum field theory, but includes non-renormalizable operators.

- higher-dim operators suppressed at low energies
- renormalizable up to a given power

Typically, such EFTs are obtained after integrating out heavy particles.

- Effective Lagrangian depends on light fields
- Higher-dim operators are induced from integrating out heavy degrees of freedom

Fermi theory



$$\frac{1}{p^2 - M_W^2}$$

$$\frac{1}{-M_W^2}\left(1 + \frac{p^2}{M_W^2} + \dots\right)$$

A tower of EFTS

effective theory	full theory	energy scale Λ	fields in L_{eff}
Fermi theory (QED+QCD+eff. weak)	SM	$M_W \approx 80$ GeV	l, ν, q, g, γ

A tower of EFTS

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CHPT + QED	QCD + QED + eff. weak	$m_\rho \approx 1$ GeV	π, K, $\gamma, \ldots$

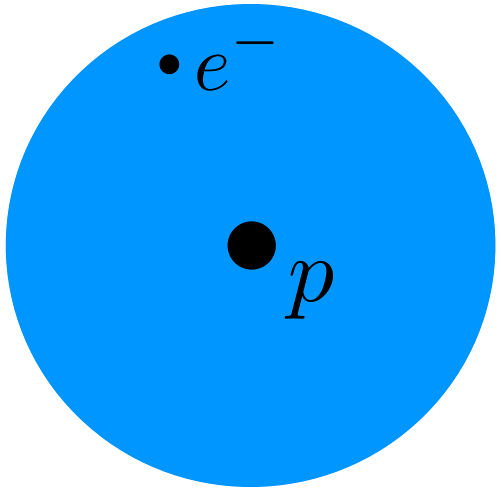
A tower of EFTS

effective theory	full theory	energy scale Λ	fields in L_{eff}
SM	?	Λ_{new} = ?	l, v, q, g, γ, H, W, Z
Fermi theory (QED+QCD+eff. weak)	SM	$M_W \approx 80$ GeV	l, v, q, g, γ
CHPT + QED	QCD + QED + eff. weak	$m_\rho \approx 1$ GeV	p, n, π, K, γ,...

Modern EFTs: e.g. NRQED

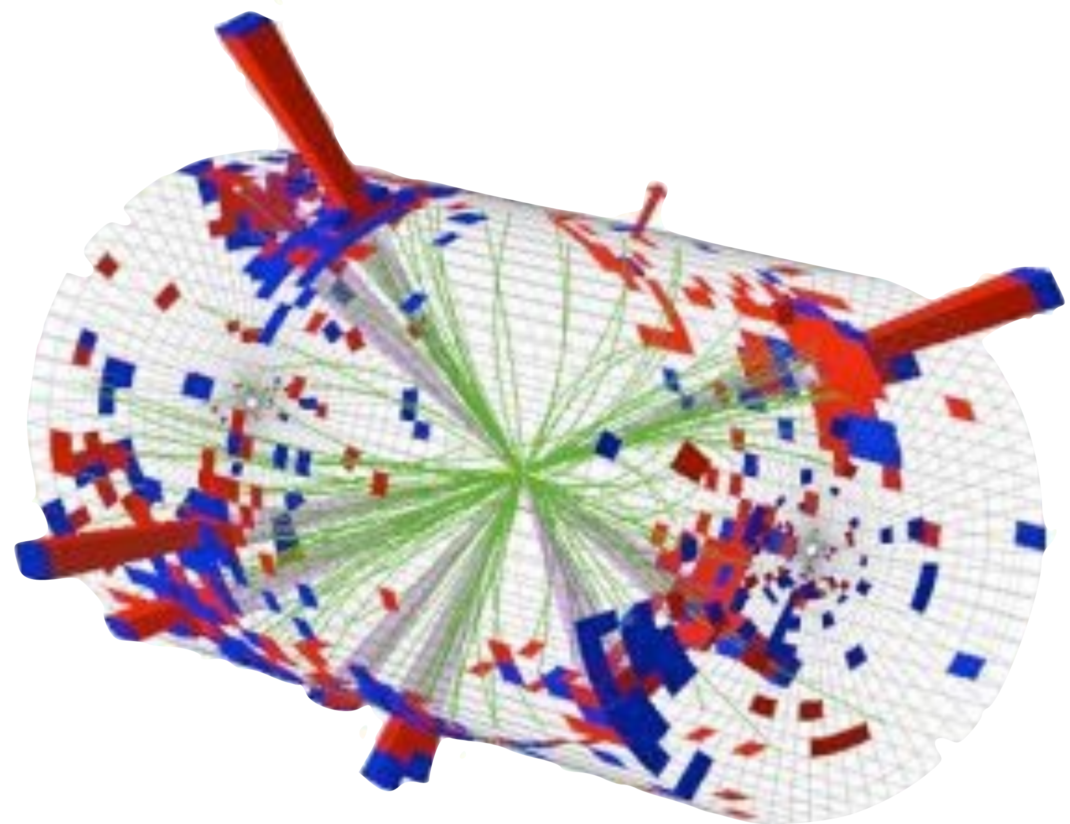
Many examples of scale hierarchies in QFT in which the low-energy part does not consist of light particles with low momentum.

e.g. non-relativistic problems $E_{\mathrm{kin}} \ll |\vec{p}| \ll m$



- Cannot simply integrate out e^- or p.
- Different components of the momentum scale differently

Jet physics at the LHC



Many scale hierarchies!

$$\sqrt{s} \gg p^T_{\rm Jet} \gg M_{\rm Jet} \gg E_{\rm out} \gg m_{\rm proton} \sim \Lambda_{\rm QCD}$$

→ Soft-Collinear Effective Theory (SCET)

Modern complications

- EFT is tailored to physics at hand: reference vectors,…
- Particles may be described by several fields (modes)
  - Two kinds of photon fields in NRQED: soft and ultra-soft
  - Various types of soft and collinear particles in SCET
- Not all momentum components are small: non-localities along the directions of large momenta
  - parton-distribution functions
  - Coulomb potential

Outline