Lattice Field Theory @ CERN

People

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Liam Keegan (fellow)

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Philippe de Forcrand (ETH, long-term guest)

Martin Lüscher (emeritus)

Guido

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Martin

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The two souls of our group

- Lattice QCD
- Lattice Gauge Theories beyond QCD

We are a small team...

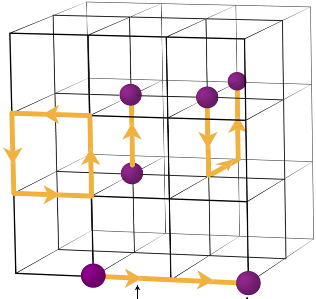
- Industrial QCD is not an option
- My vision:
  - Provide theoretical support to the community
  - Develop and explore new techniques
  - Develop simulation code or extensions of existing codes

But we are not an island...

Ongoing collaborations with:

- ALPHA (DESY Zeuthen, Berlin, Madrid, Roma, Mainz, ...)
- CLS (DESY Zeuthen, Madrid, Regensburg, Roma, Mainz, ...)
- RBC-UKQCD (Southampton, Edinburgh, Columbia, RIKEN, BNL, ...)
- ETMC (Roma, Valencia, Münster, Cyprus, Orsay, ...)
- UKBSM (Edinburgh, Swansea, Plymouth, Odense)

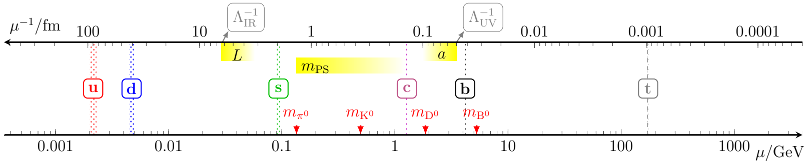
Lattice QCD



- A regularization of QCD (it is QCD, not a model of QCD). The lattice spacing a is the UV cutoff.
- The only known consistent way to define QCD at all energy scales.
- Free parameters (in isolation): $m_u, m_d, m_s, m_c, m_b, m_t$.
- When restricted to a finite box, suitable for numerical calculation of the path integral
- Limits to be taken in numerical calculations

$$a \to 0 \,, \qquad L \to \infty$$

Various scales of QCD



u d	Dynamical Degenerate Physical mass	Minor challenge: Physical mass requires larger volumes. Major challenge: Isospin breaking effects.
s	Dynamical Physical mass	–
c	Dynamical	$M_{D_0} \simeq .5a^{-1}$ Major challenge: Significantly finer lattices are required.
b	Heavy quark effective theory	Challenge: HQET includes a number of parameters that need to be tuned. Systematic errors need to be properly assessed.
	Step-scaling techniques	Interpolation between lighter masses and static limit in finite volume.

Charm quark

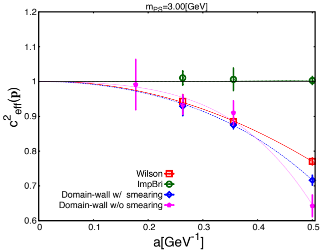
- Charm scales $\quad c \sim 1.3\text{GeV} \quad D_0 \sim 1.9\text{GeV} \quad \eta_c(1S) = 3\text{GeV}$
- Finest lattice spacing produced by CLS $\quad a^{-1} \simeq (0.05\text{fm})^{-1} \simeq 4\text{GeV}$
- Let us say that we want to double the cutoff

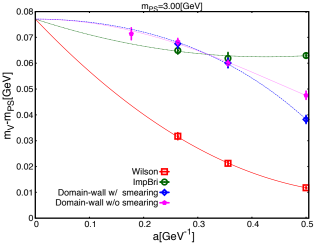
  $$a \to a/2$$

  If we use the same machines, we need more time...

  $$\text{time} \to \text{time} \times 2^4 \times 2^2 \times 2 = \text{time} \times 128$$

  Or we wait 14 years (Moore's law) and we get to do it in the same time CLS has produced the last generation of configurations.
- It is imporant to assess the systematics. (Marina)





Isospin breaking corrections

- Isospin limit is a very good approximation

$$\frac{m_u - m_d}{M_P} \simeq 2\% \qquad \alpha_{em} \simeq 1\% \qquad \frac{M_n - M_p}{M_p} \simeq 1\%$$

- Isospin breaking effects relevant to explain the stability of the proton and of the hydrogen atom.

- Is this relevant? FLAG world average

$$F_K/F_\pi = 1.194(5) \quad \sim \quad 0.4\%$$

$$F_+^{K\pi} = 0.967(4) \quad \sim \quad 0.4\%$$

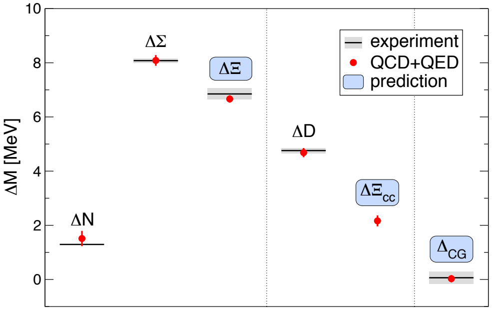
Isospin breaking correction, as estimated in χPT

$$F_K/F_\pi \quad \sim \quad 0.8\%$$

$$F_+^{K\pi} \quad \sim \quad 3.5\%$$

Isospin breaking corrections

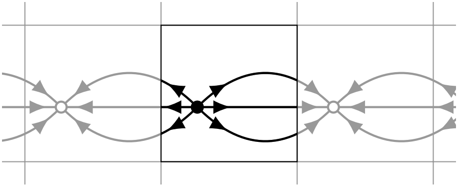
- Hadron mass splitting due to isospin breaking effect is within the reach of current lattice simulations.



BMW collaboration

- Lattice simulations require a finite box, typically chosen with periodic boundary conditions.
- Gauss' law does not allow a single proton in a periodic box.
- Previous treatments of this problem spoil locality.

  $\tilde{A}(p_0, \vec{0}) = 0 \quad \text{for any } p_0$
- C^* boundary conditions can be used to describe consistently a single charged hadron.
  (Agostino, Alberto)



- We are starting the exploratory stage of a big numerical projects to simulate QCD+QED in this framework. (Agostino, Alberto, Marina, Liam, Vincent)
- Future challenge: inclusion of QED effects in leptonic decay rates, e.g. $\pi^+ \to \mu^+ \nu_\nu$.
  What is the correct way to treat soft photons?

LGT beyond QCD

Large-N theories (Alberto,Liam)

Theoretical motivations

- Large-N $\equiv$ classical limit (in loop space)

  $$\langle L_1 L_2 \rangle \simeq \langle L_1 \rangle \langle L_2 \rangle$$

- (Under certain assumptions) Volume-independence
- Series of non-trivial equivalences (e.g. orientifold planar equivalence)
- ...

Non-QCD like confining theories (Vincent)

Phenomenological motivations

- As we change the gauge group, number of fermions, fermion representation, strongly-coupled gauge theories generate a diverse phenomenology that may be very different from QCD.
- Some of this model have a tendency to prefer light isosinglet scalars (Higg's quantum numbers).
- Some of this models are potentially interesting as composite dark matter models.
- Can we calculate phenomenologically relevant observables?

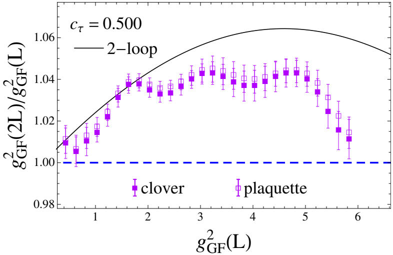
Conformal window (Agostino, Alberto, Liam, Vincent)

Theoretical motivations

- How does the trace anomaly decouple from the IR physics?
- What is the interplay with spontaneous chiral symmetry breaking?
- What is the spectrum of anomalous dimensions? Are large anomalous dimensions generated?

(Pseudo)phenomenological motivations

- Unparticles(?)
- Confining gauge theories may display approximate scale invariance in intermediated energy regimes.
- Spontaneous dilation symmetry? Dilatons?



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