Charm loop effects in QCD

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Πανεπιστήμιο Κύπρου
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EUROPEAN JOINT DOCTORATES

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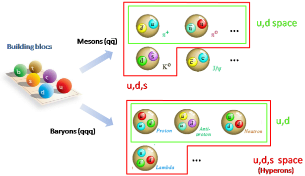
Quarks and Gluons

- Theoretical arguments and experimental evidences suggest that hadrons are made of:
  1. matter fields: quarks(q), antiquarks($\bar{q}$) ($s = \frac{1}{2}$)
  2. intermediate fields: gluons(g) ($s = 1$)
- q, $\bar{q}$ and g are never seen in isolation

Quarks, Baryons and Mesons



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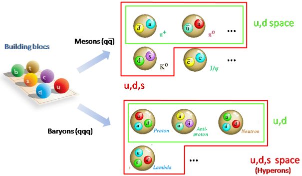
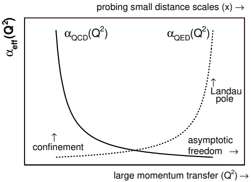


QCD: the theory of strong interactions

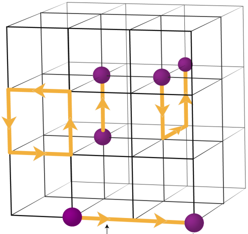
- QCD: theory proposed in 1973 to explain these properties.
- Gauge theory based on the group $SU(3)_c$.
- quarks have color $c = 1, 2, 3$.
- gluons have color $c = 1, 2, \cdots 8$.

Running coupling constant



Main ideas of the Lattice QCD approach

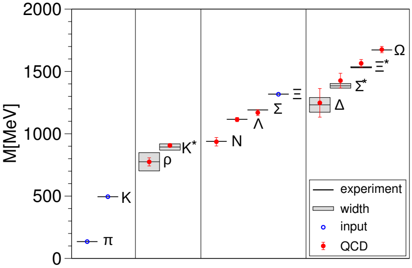
- Continuous space-time is replaced by an Euclidean ($N^3 N_t$) lattice ($x_4 = ix_0$).
- Lattice spacing a.
- Parameters and fields are dimensionless (e.g.$\hat{m} = ma$).
- Fermions lie on the sites of the lattice: $\psi(x) \rightarrow \psi(na)$
- Gluons described by links: $U_\mu(x) \rightarrow U_\mu(na)$



Motivation

- Most simulations of QCD are carried out only with light quarks (u,d,s).
- QCD($N_f = 2 + 1$) is a really good of approximation of the full theory.

Lightest particles: QCD(2+1)
[S. Durr et al.: Science 322, 1224 (2008) 209, 210]



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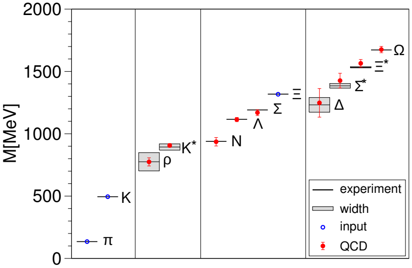

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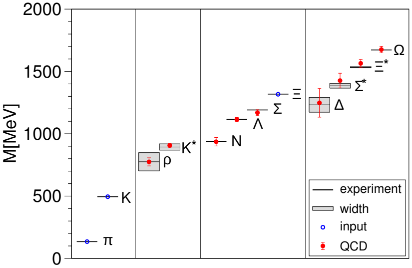

- experiments keep discovering new charm-states→ 4th quark?

Our main goal is to evaluate the effects of dynamical charm quarks

Strategy

- We compare QCD ($N_f = 2$) with $m = m_c$ to QCD ($N_f = 0$)
- Fine lattice spacings are required to control the extrapolation to zero lattice spacing [we use $0.15 < am_c < 0.32$]

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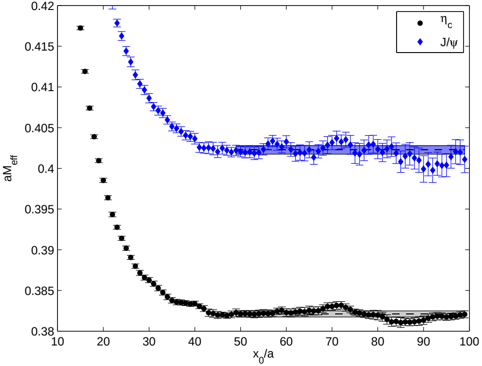
Simulation Details

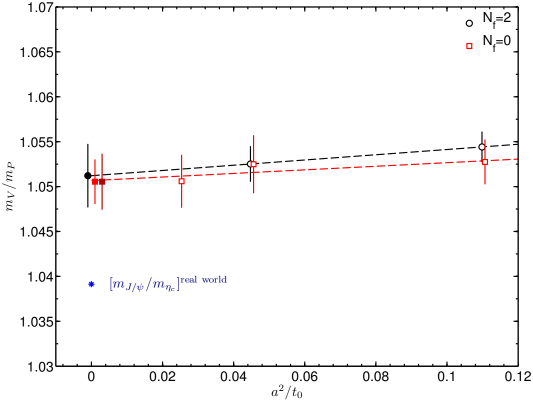
1. Dynamical Ensembles
   - S_G: Wilson's plaquette gauge action; $\beta \in 5.70, 5.88, 6.00$.
   - $r_0/a = 9.131(56), 11.971(99), 14.27(15)$.
   - S_F: twisted mass doublet at maximal twist $\psi = (c_1, c_2)$.
   - Lattice size (LS, LT): $(32, 120), (48, 192), (48, 192)$.
2. Quenched Ensembles
   - S_G: Wilson's plaquette gauge action; $\beta \in 6.340, 6.672, 6.900$.
   - $r_0/a = 9.029(80), 14.103(94), 18.65(24)$.
   - Lattice size (LS, LT): $(32, 120), (48, 192), (64, 192)$.

Charmonium: example for QCD($N_f = 2$), $\beta = 6.0$



- Extraction of the mass of states made of a q and a $\bar{q}$ (mesons), both with the mass of the charm quark
- Ground states of pseudo-scalar and vector channel.
- Mass is obtained from the plateau average.

Charmonium: QCD($N_f = 2$) vs QCD($N_f = 0$)



From this comparison dynamical charm effects are NOT resolvable at a precision of 0.2%.

Dynamical charm effects on the strong coupling

- Strong coupling from the static force $\alpha_{qq}(r) = \frac{1}{C_F} r^2 V'(r)$

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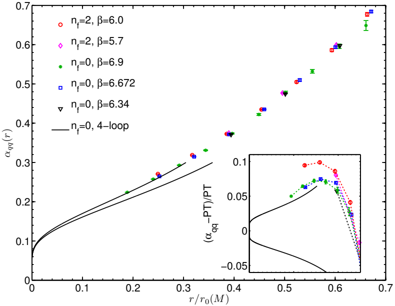

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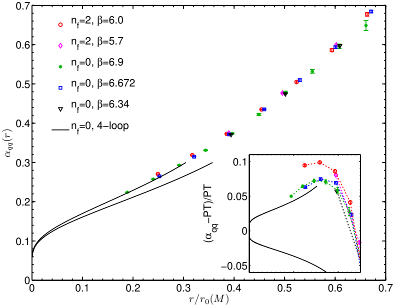
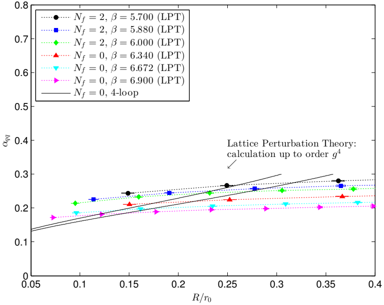


LPT predictions



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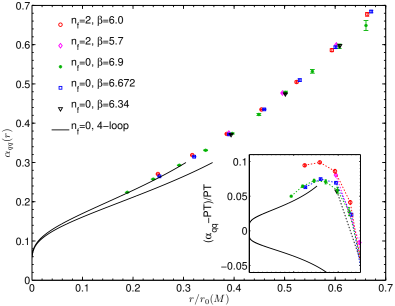

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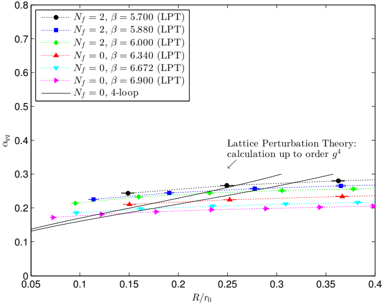

Significant effect at $\mu = 1/r \approx 1.6$ GeV and above.

Summary

From this study it turns out that the effects of dynamical charm quarks are:

- tiny in charmonium masses
- significant in α_{qq} at large energies

Outlook

1. Measure these observables using another lattice spacing with $N_f = 2$ $\rightarrow$ smaller errors
2. Evaluate these effects on other interesting quantities, like the decay constant f_{D_s}
3. Trying to extract the continuum limit of α_{qq} using Lattice Perturbation Theory predictions.

People involved in this project

My Supervisors

- Prof. Francesco Knechtli (University of Wuppertal)
- Prof. Haralambos Panagopoulos (University of Cyprus)

Other Collaborators

- Dr. Tomasz Korzec (University of Wuppertal)
- Dr. Björn Leder (Humboldt University of Berlin)
- Dr. Graham Moir (University of Cambridge)

Acknowledgments

These simulations require considerable computational resources which have been granted by the Jülich Supercomputing Centre.

Dissemination

Some of these results were shown in two symposia:

1. NIC Symposium, 11-12 February 2016, JSC (speaker: F. Knechtli).
2. 34th International Symposium on Lattice Field Theory, 24-30 July 2016, Southampton (speaker: T. Korzec)

Progress on these studies will be presented in

3. 35th International Symposium on Lattice Field Theory, 18-24 June 2017, Granada (speaker: S. Calì)

More details can be found in the following paper:

4. T. Korzec, F. Knechtli, S. Calì, B. Leder, G. Moir. *Impact of dynamical charm quarks*. In: *PoS (LATTICE2016), 126 (7 pages). arXiv: 1612.07634*.

Outreach

- 10th Researchers' night, 30 September 2016, Nicosia.

Connections with other fellows

- ESR5 (Simone Bacchio) and ESR11 (Aurora Scapellato)

Thank you very much for your attention.