# Fundamental parameters of QCD from non-perturbative methods for two and four flavors

GRADUIERTENKOLLEG Masse-Spektrum-Symmetrie

HUMBOLDT-UNIVERSITÄT ZU BERLIN

## Motivation

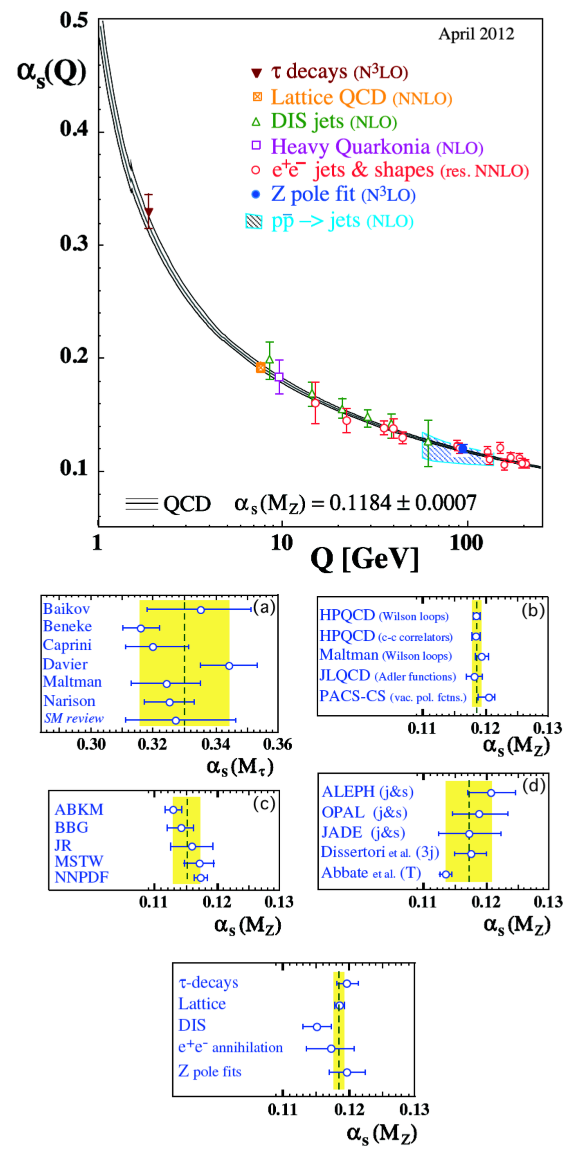
**Precision predictions of Standard Model:**

- Amazing agreement between experiment and Standard model predictions
- New physics possible only in small effect behind the Standard model
- Precision experiments and precision theory needed for further tests of the SM

**Fundamental parameters of Quantum Chromodynamics (QCD) from non-perturbative (NP) methods:**

- Currently most accurate tests of SM based on predictions of the perturbation theory (PT)
- Perturbative treatment needs as input the fundamental parameters of QCD: the $\Lambda$ – parameter and the renormalization group invariant (RGI) quark masses $M_i^{RGI}$
- More precise knowledge of $\Lambda$ and $M_i^{RGI}$ is needed for improving current theoretical predictions

## $\alpha_s$ the strong coupling constant of QCD




Particle Data Group 2012

**Determining $\alpha_s$ . . .**

- $\alpha_s$ only defined perturbatively
- not directly accessible in experiment $\rightarrow$ match to perturbation theory
- uncertainties vanish only as $\mu \rightarrow \infty$

**. . . or the Lambda parameter . . .**

- scale independent integration constant
- well defined from asymptotic behavior of the coupling
- trivial scheme dependence; exact conversion between two schemes

**. . . in lattice QCD**

- error of world average dominated by one lattice result ($N_f = 2 + 1$, PT matching)
- use lattice QCD to its full potential $\rightarrow$ fully non-perturbative determination

## ALPHA Collaboration general strategy

**Connect low & high energies non-perturbatively**

- Not possible on a single lattice, since $L/a \lesssim 100$ in currently achievable simulations
- use intermediate coupling that scales with physical box size: $\mu = 1/L$, known as Schrödinger functional (SF) coupling
- bridge low/high energies by several steps of finite size scaling by factors of two: $L \rightarrow L/2$

**Master formula for $N_f = 5$**

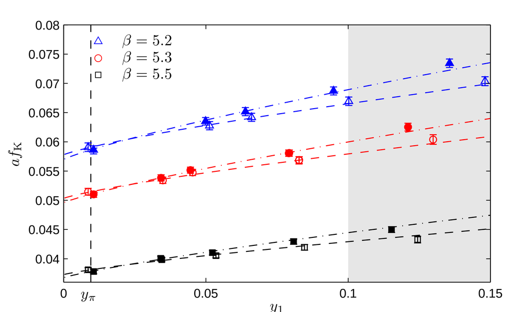
$$\boxed{\frac{\Lambda^{5}_{\overline{MS}}}{f_K} = \frac{1}{f_K L_{max}} \times \frac{L_{max}}{L_k} \times \Lambda^{(4)}_{SF} L_k \times / \frac{\Lambda^{(4)}_{\overline{MS}}}{\Lambda^{(4)}_{SF}} \times \frac{\Lambda^{(4)}_{SF}}{\Lambda^{(5)}_{\overline{MS}}}}$$

- $\frac{\Lambda^{(4)}_{\overline{MS}}}{\Lambda^{(4)}_{SF}} = 2.9065$, $L_{max} \approx 0.5 fm$, $L_k = 2^{-k} L_{max}$
- NP running from low energies $\alpha_{SF}(1/L_{max})$ to high energies $\alpha_{SF}(1/L_k)$.
- Finally obtain $\Lambda^{(4)}_{\overline{MS}} L_k$ at $\alpha_{SF}(1/L_k) \approx 0.1$ controllable from PT

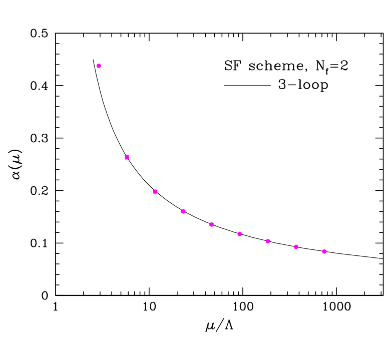
## Final results for $N_f = 2$ theory

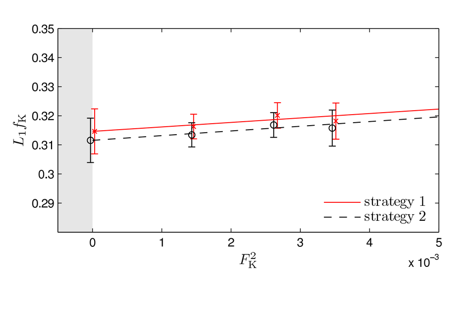
**Scale setting with $f_K$:**

- most expensive piece, joint effort with Coordinated Lattice Simulations Consortium ([https://twiki.cern.ch/twiki/bin/view/CLS])
- controlled extrapolation to physical point (quark mass, zero lattice spacing)
- finite volume corrections negligible ($m_\pi L \geq 4$)
- two strategies for chiral extrapolation



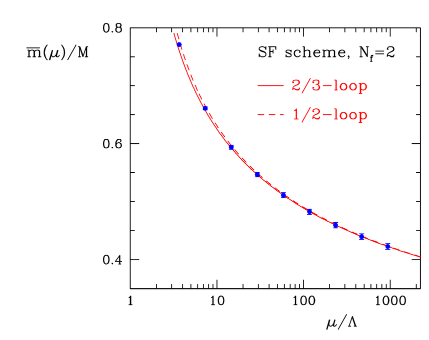
**The Lambda parameter $\Lambda^{(2)}$:**

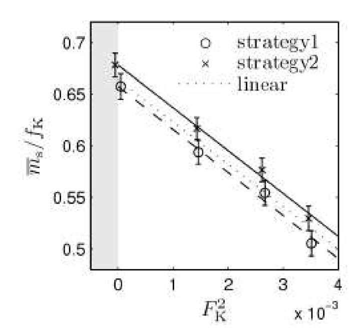




- $L_1/f_K = 0.315$
- $\Lambda^{(2)}_{SF} L_1 = 0.264(15) \Rightarrow \boxed{\Lambda^{(2)}_{\overline{MS}} = 310(20)\text{MeV}}$
- $\Lambda^{(2)}_{\overline{MS}}/\Lambda^{(2)}_{SF} = 2.382035(3)$
- Fully non-perturbative calculation

**The strange quark mass:**

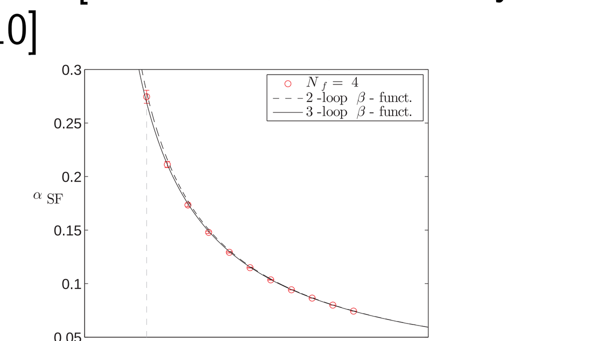




- RGI mass - scale independent $M_s = \frac{M}{\overline{m}(L_1) \times \overline{m}_s(L1)} \Rightarrow \frac{\overline{m}_s^{\overline{MS}}}{f_K} = \frac{\overline{m}_s^{\overline{MS}}}{M} \times \frac{M_s}{f_K}$
- $\overline{m}(L_1)/f_K = 0.678(12)(5)$
- $M/\overline{m}(L_1) = 1.308(16)$ from NP running
- $\overline{m}_s^{\overline{MS}}/M = 0.740(12)$ PT input, 4-loops

## $\alpha_s(\mu)$ in $N_f = 4$ theory

- Developed new program package (SF-MP-HMC) for performing SF simulations on modern supercomputers
- Improved the precision compared to the 2010 result [F.Tekin *et al.*,Nucl. Phys. B 840,2010]



## Collaborations

- ALPHA Collaboration, CLS

## Invited talks

- University of Southampton, Southampton, UK, 05/2012 “Lambda parameter and strange quark mass by the ALPHA Collaboration”
- Regensburg University, Regensburg, Germany, 04/2012 “Lambda parameter and strange quark mass by the ALPHA Collaboration”
- Seminar at Instituto Superior Tecnico, Lisbon, Portugal, 10/2010 “Lattice QCD simulations with dynamical quarks”
- Seminar at Institut of Physics Belgrade, Serbia, 12/2009 “Lattice QCD: Fundamental Parameters of Quantum Chromodynamics from Non-perturbative Methods”

## Publications


- P.Fritzsch, F. Knechtli, B. Leder, M. Marinkovic, S.Schaefer, R. Sommer, F. Virotta “The strange quark mass and Lambda parameter of two flavor QCD” Nucl. Phys. B 865 (2012) 397, arXiv:1205.5380
- M. Marinkovic, S.Schaefer, R. Sommer, F. Virotta “Strange quark mass and Lambda parameter by the ALPHA collaboration” PoS(LAT2011)232,arXiv:1112.4163
- M. Marinkovic, S. Schaefer “Comparison of the mass preconditioned HMC and the DD-HMC algorithm for the two-flavour QCD” PoS(LAT2010)031,arxiv:1011.0911


## Conference contributions

- Excited QCD Workshop, Peniche, Portugal, 05/2012 (Talk) “Advances in the Hybrid Monte Carlo methods for lattice QCD”
- Lattice 2011, Squaw Valley, Lake Tahoe, USA, 07/2011 (Talk) “Strange quark mass and Lambda parameter by the ALPHA collaboration”
- Lattice 2010, Villasimius,Sardinien, 06/2010 (Poster) “Comparison of the mass preconditioned HMC and the DD-HMC algorithm for the two-flavour QCD”

## Profit from the GK

- Numerous lectures organized during the semester by GK (Introduction to Supersymmetry, Introduction to String Theory, QFT on the lattice, Physics at the LHC: Recent Results etc.)
- Soft Skills Course: Scientific Presentation, HGS / HU Berlin, 11/2010
- Soft Skills Course: Advanced Scientific Presentation, HGS / HU Berlin, 09/2011
- Participation in 5 Spring- and Autumn- Block Courses of GK

## Contact Details and further Information


**PhD student:** Marina Marinkovic, mmarina@physik.hu-berlin.de
**PhD advisors:** Prof. Dr. Ulrich Wolff, Prof. Dr. Hermann Kolanoski


January 16, 2013


Supported by DFG Deutsche Forschungsgemeinschaft