# Lattice QCD – realistic results on the horizon

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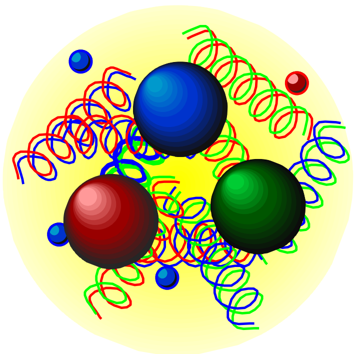
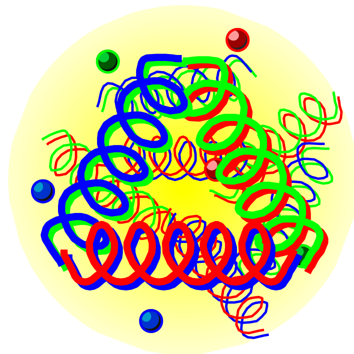
HPQCD (Glasgow, Cornell, OSU, SFU, FNAL) + MILC collaborations.

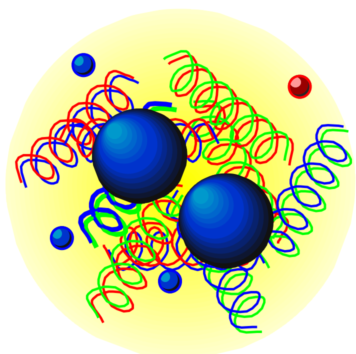
QCD describes strong interactions of quarks and gluons.



Proton



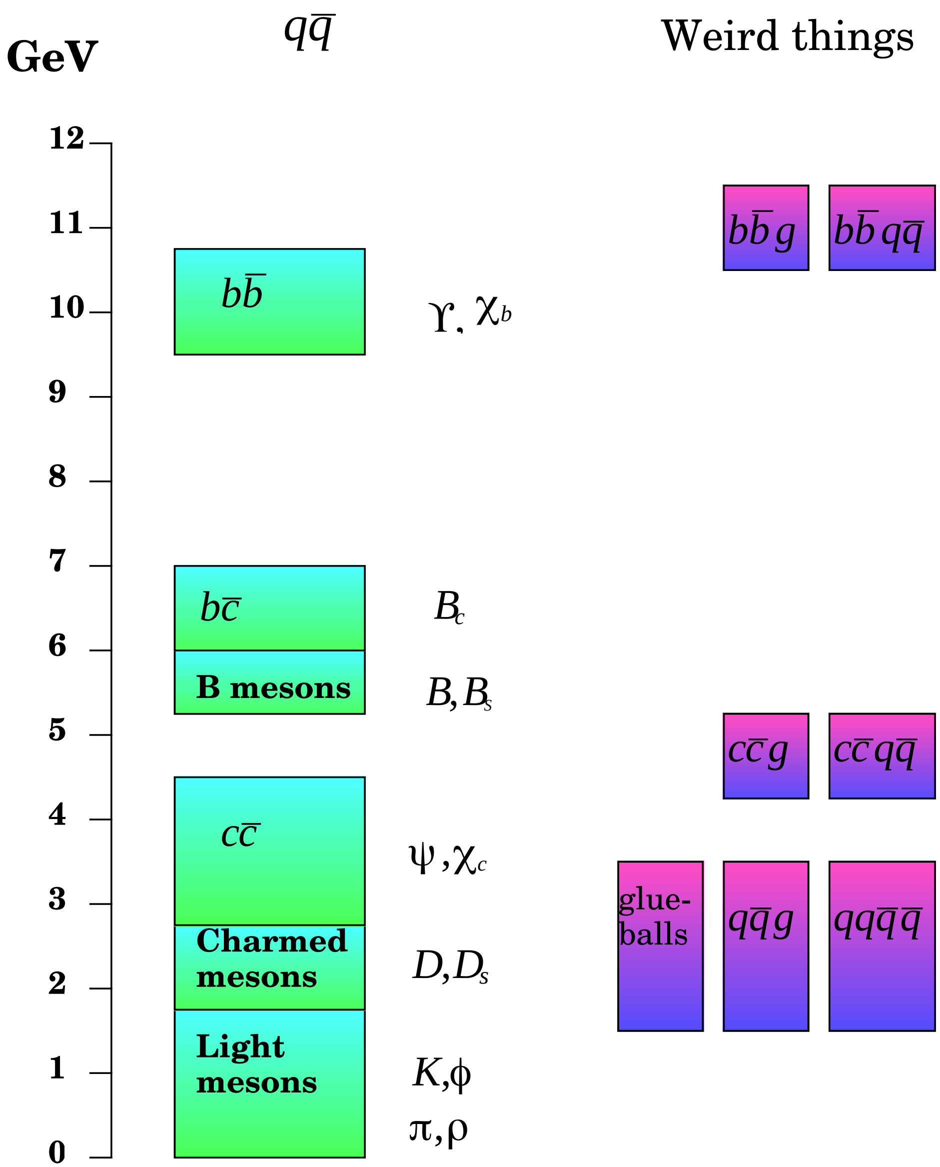
Glueball



Pion

QCD is confining

Quarks and gluons are bound into hadrons. Need numerical methods to solve QCD in this regime.



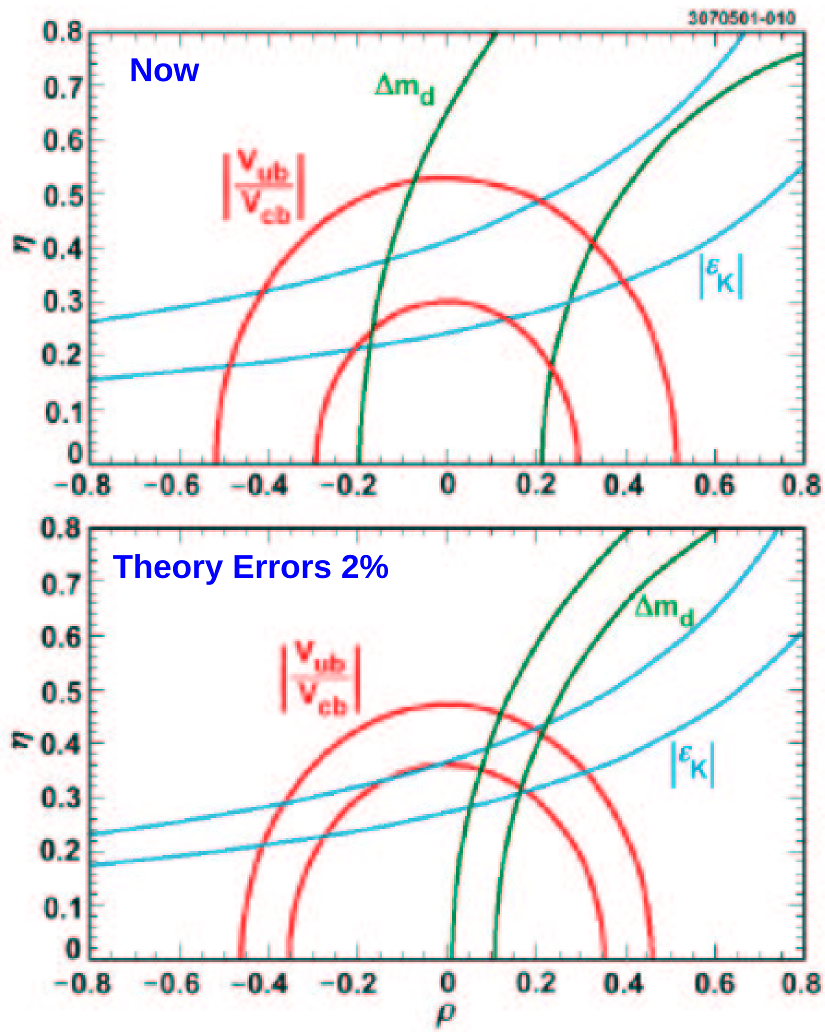
The Meson Spectrum

Spectrum of hadronic states made from $u, d, s, c, b$ quarks is very rich.

Spectrum is predicted by QCD and we would like to calculate it from the theory.

Hadrons made from the heavy $c, b$ quarks turn out to be particularly good ones to look at, both heavy-heavy and heavy-light.

# CP violation

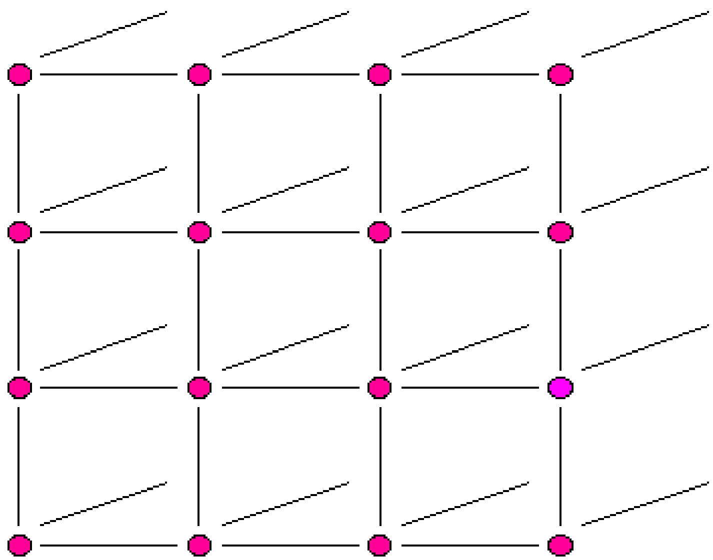



Weak and e.m. decay rates of hadrons important for e.g. understanding CP violation in the SM at B factories.

Theory needed is lattice QCD. Aim for 2% error, tested against experimentally known quantities.

Precise determination of quark masses, $\alpha_s$ also needs lattice QCD.

# Lattice QCD calculations =

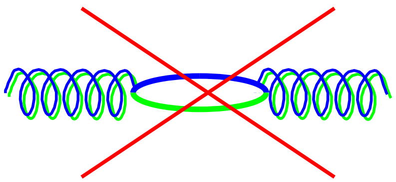


Box of Euclidean space-time $\rightarrow$ lattice + $\mathcal{L}_{QCD}$(discretised)

Generate 'vacuum snapshots' (configurations) by Monte Carlo. Calcs on these $\equiv$ to evaluating Feynman Path Integral.

Major problem is: QUARKS. Fermions $\rightarrow$ integrate by hand. Result is determinant of a huge matrix. Cost of including this is enormous.

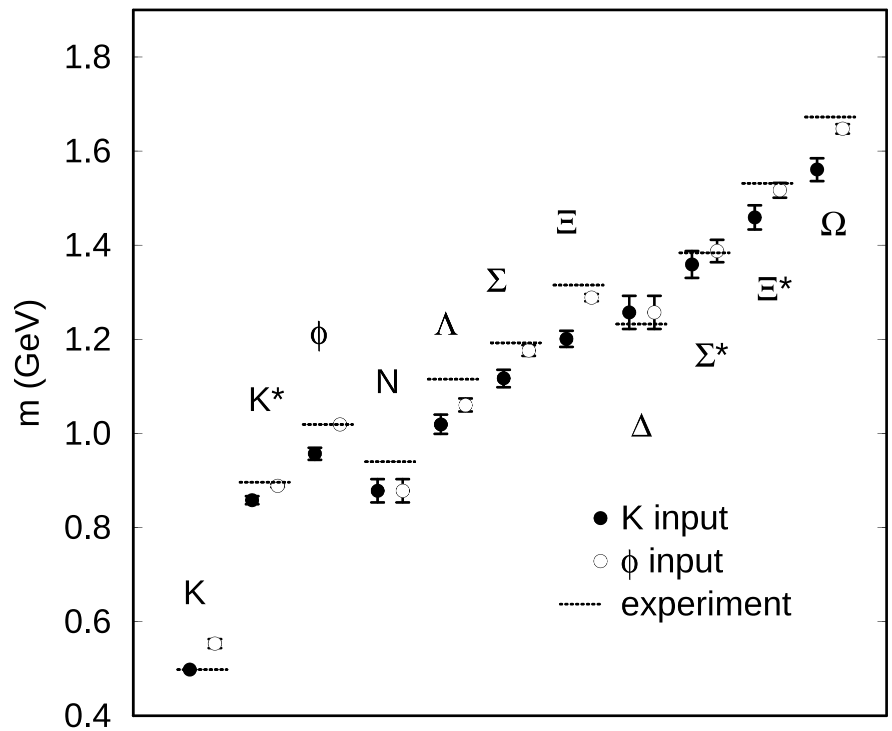
Missing out quark det. $=$ ‘Quenched Approximation’.



No feedback between quark and gluon sectors $\Rightarrow$ no ‘screening’ of charge, $\alpha_s$ running wrong.

Internally inconsistent because no single scale.

Errors $\mathcal{O}$(10-20%)




(CP-PACS collaboration)

Cost of DYNAMICAL QUARKS limits physics reach of calculations

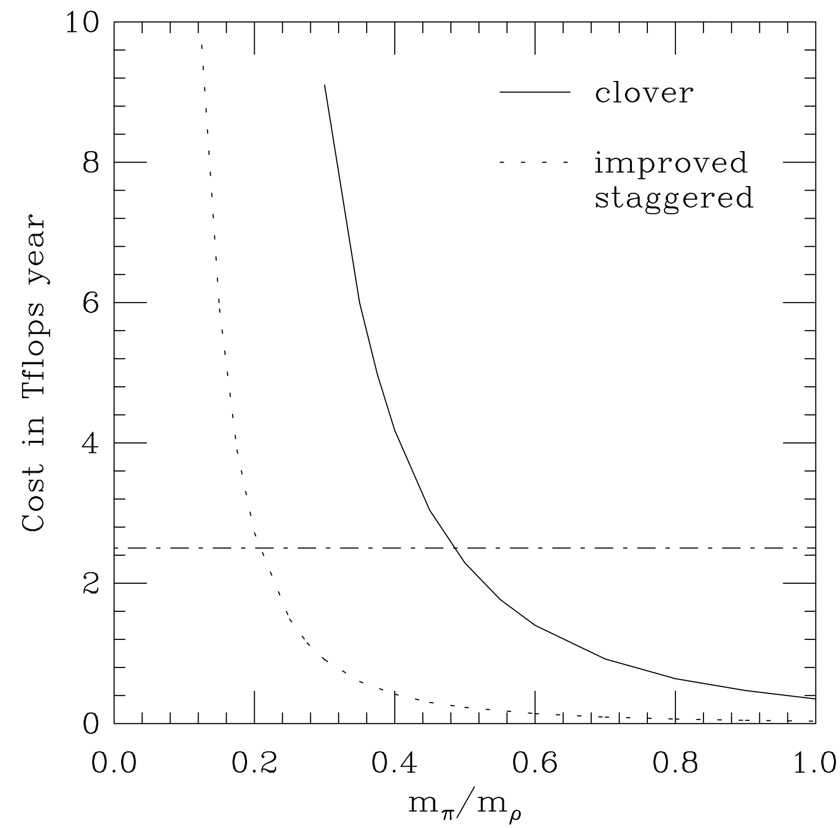
Cost is $\mathcal{O}$(Teraflop years).

Grows as $m_q \to 0$ but most important are light $u, d$ ones.

Depends on formalism used for quarks.

$\Rightarrow$ Enter the cheaper improved staggered formalism.

Warning: all technical details suppressed.



# RESULTS with improved staggered quarks.

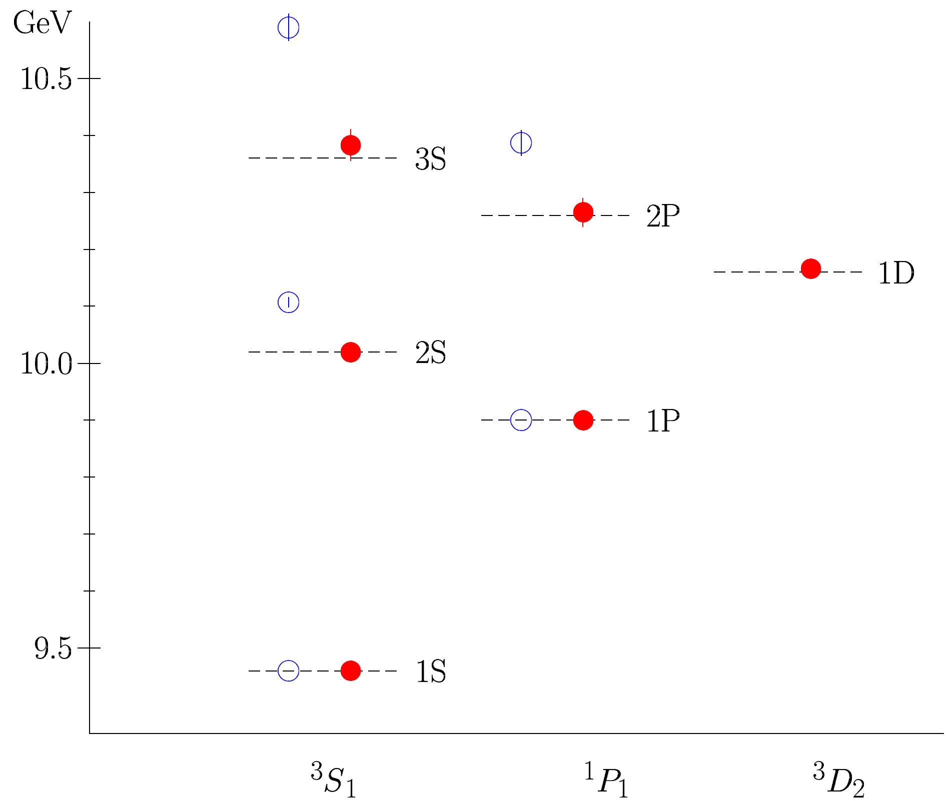
MILC have used improved staggered formalism to generate ensembles of configurations including the effect of 2+1 flavours of dynamical quarks for the first time. Sustained computing power = 0.25 Tflops.

2 = $u, d$ with masses down to $m_s/5$
1 = $s$

2 sets, $a \approx$ 0.12 fm and $a \approx$ 0.08 fm. Most results on coarse set, hep-lat/0104002.

# $\Upsilon(b\bar{b})$ spectrum

$\Upsilon$ is a good system since no valence light quarks. Radial and orbital excitations precisely calculated. Errors from QA are removed.

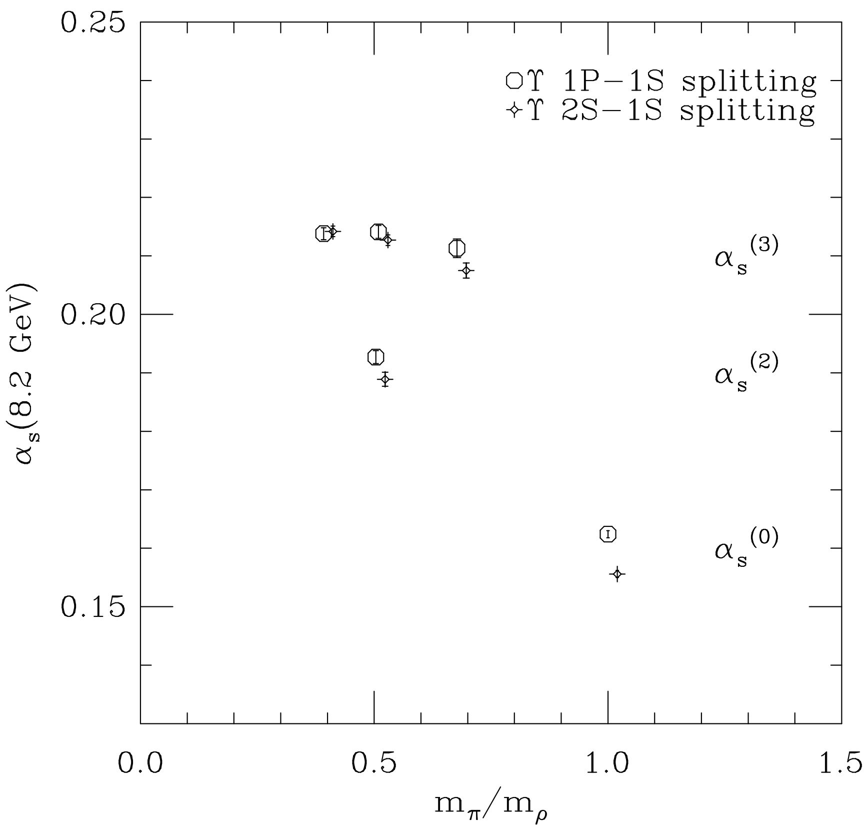



--- : Experiment

○ : Quenched MILC

● : 2+1 flavors MILC with $m_{u,d} = m_s/5$.

# Determination of $\alpha_s$



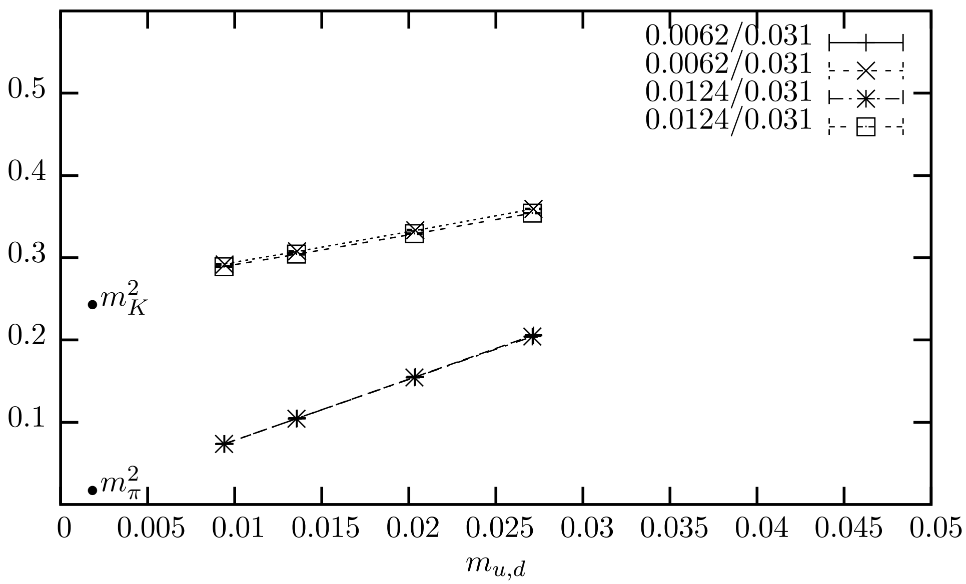

Use a gluonic matrix element measured on lattice + lattice perturbation theory to obtain $\alpha_s$.

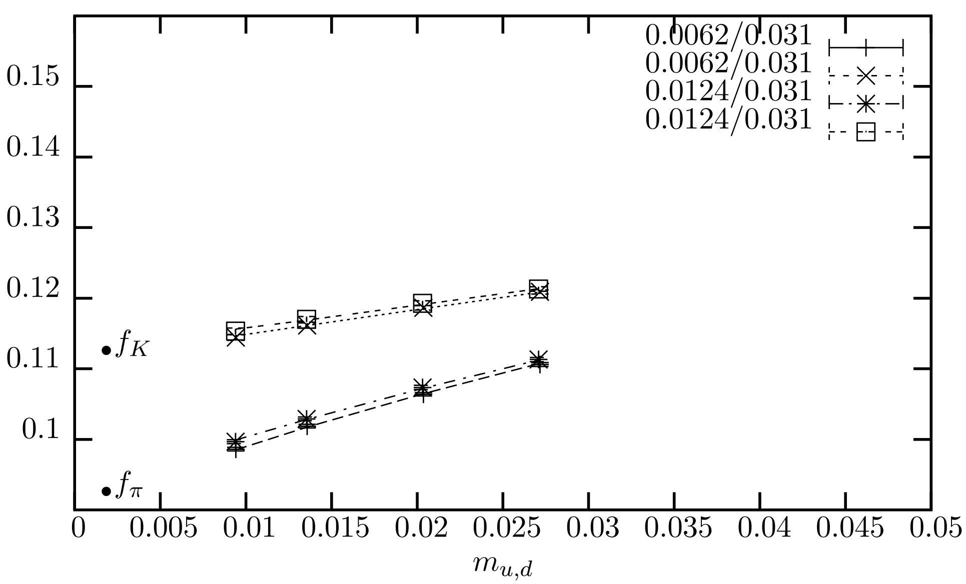
Fix scale from e.g. $1P - 1S$ splitting of $\Upsilon$.

Convert to $\overline{MS}$, run :

$\alpha^{(5)}_{\overline{MS}}(M_Z) = 0.121(3)$

# Light hadron results

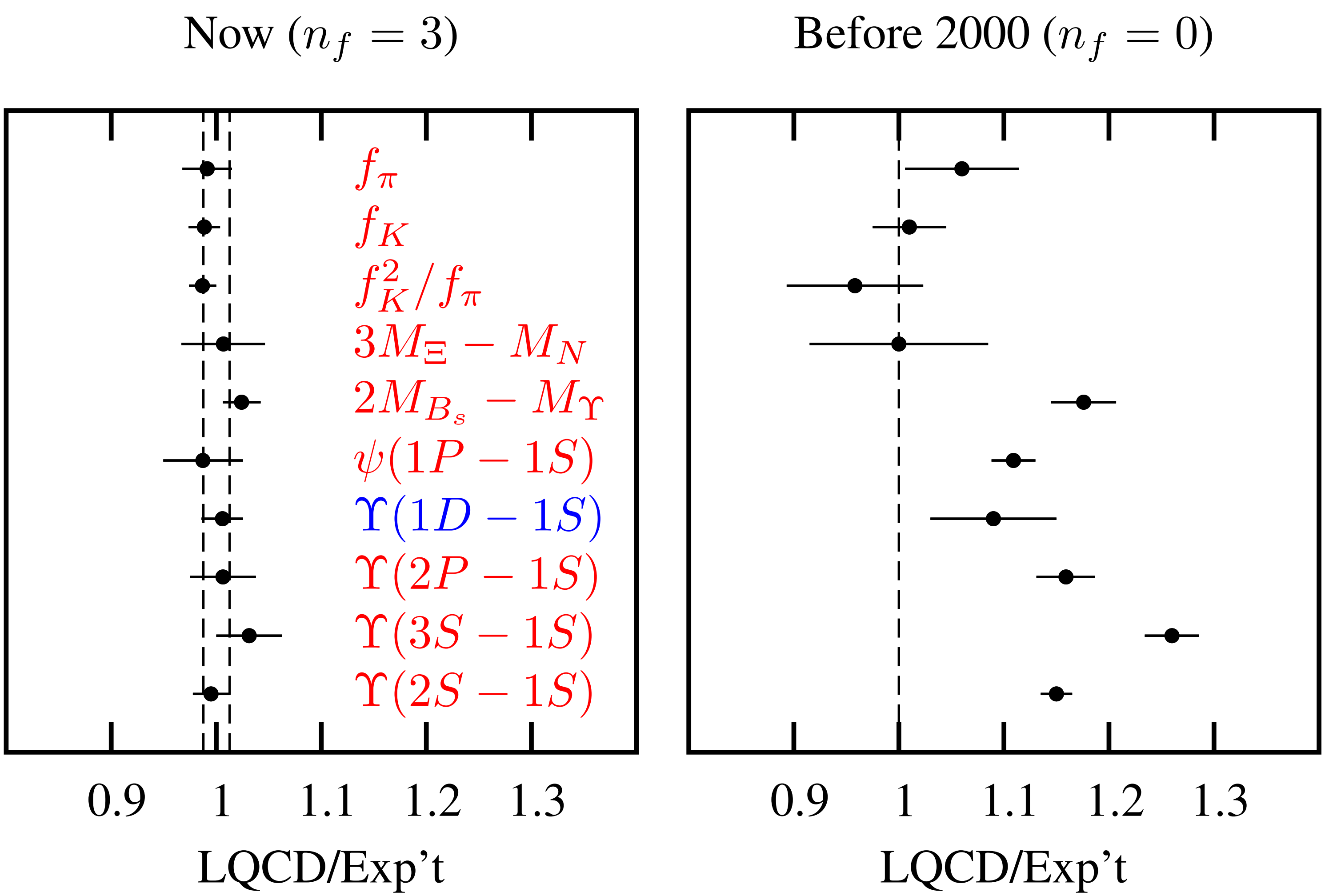



Light hadron masses must be extrapolated to the real world, 'chiral limit' using chiral pert. th.

Use to fix $m_{u,d}, m_s$, predict decay constants, $f_\pi, f_K$, amplitude for leptonic decay.

# Putting it all together




Inconsistencies of quenched approximation disappear!

# Future lattice calculations

With 5 Tflops machine (UKQCD 2003) can make ensembles with finer lattice spacing and 2+1 dynamical quarks with smaller $u/d$ mass using improved staggered formulation.

Study harder matrix elements and hadron masses (glueballs, hybrids).

- $\Upsilon$ radiative decays and leptonic widths
- $B$, $D$, leptonic and semi-leptonic decays and mixing
- Nucleon structure function moments
- $K \to \pi\pi$ decays