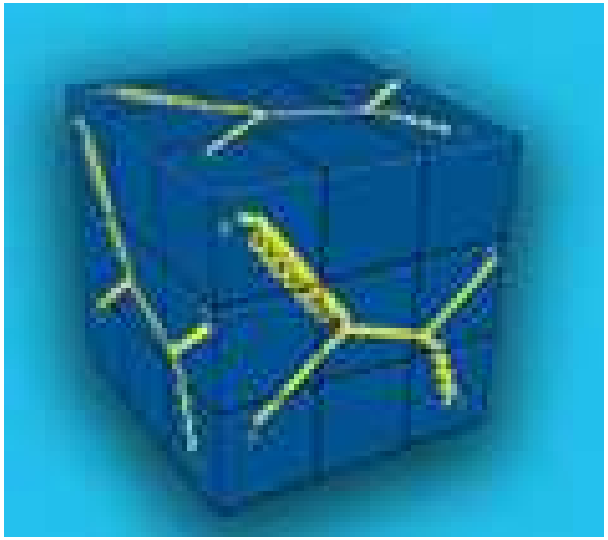
WP10: LatticeQCD

Spokesperson

G. Schierholz

Deutsches Elektronen-Synchrotron DESY

HadronPhysics3

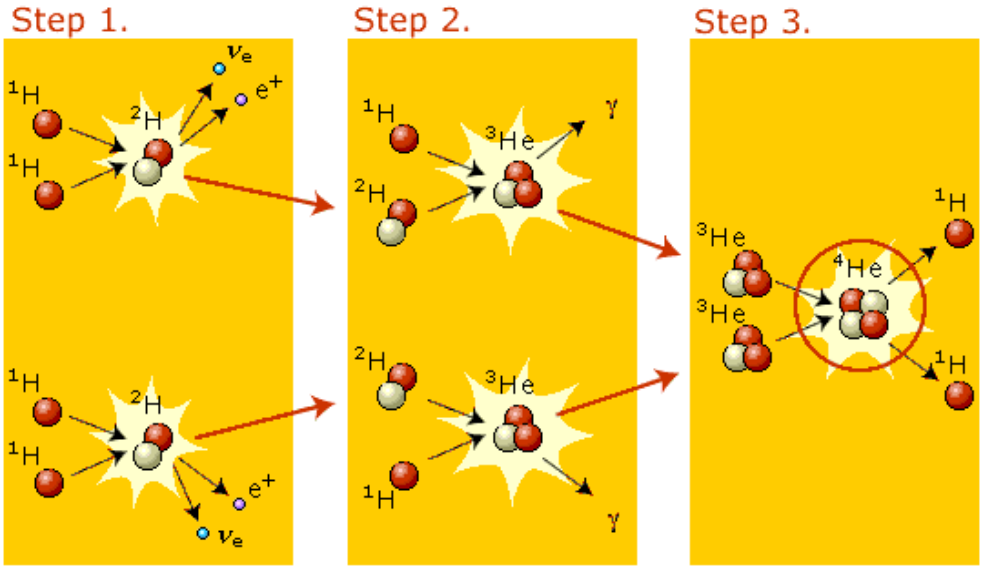


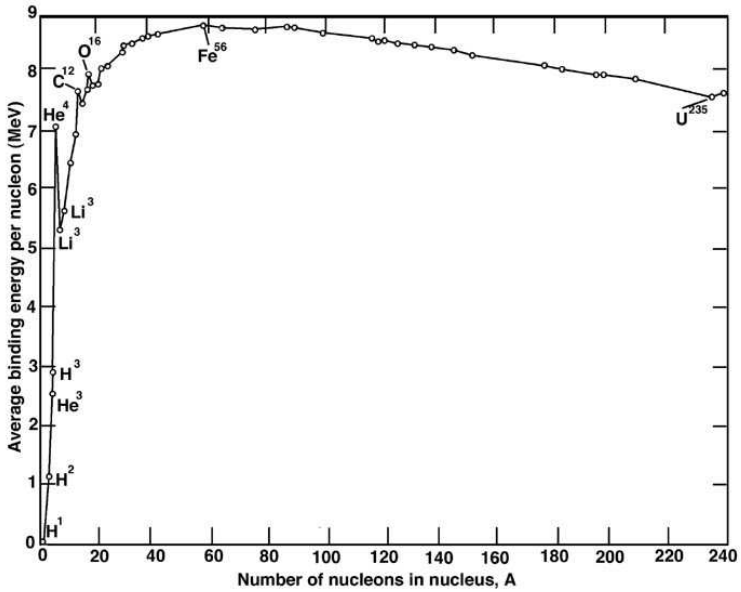
LatticeQCD

Challenge

	QCD	QED	Exp
$M_n - M_p$	$3.1(3)$ MeV	$-1.3(5)$ MeV	1.3 MeV

$m_d/m_u \approx 2$





QCD + QED parameters fine-tuned

Infrared fixed point?

Participating Institutions

1	DESY	Germany
2	U Bielefeld	Germany
3	U Wuppertal	Germany
4	U Edinburgh	UK
5	U Graz	Austria
6	U Liverpool	UK
7	U Swansea	UK
8	CNRS	France
9	INFN†	Italy
10	GSI	Germany
11	TUM München†	Germany
12	U Münster	Germany
13	U Regensburg†	Germany
14	ZIB Berlin†	Germany
15	TU Wien	Austria
16	U Bern	Switzerland
17	ETH Zürich	Switzerland
18	U Cyprus	Cyprus
19	U Valencia	Spain
20	U Helsinki	Finland
21	Eötvös U Budapest	Hungary
22	Trinity College	Ireland
23	NUI Maynooth	Ireland
24	U Ljubljana	Slovenia
25	Academia Swietokrzyska	Poland
26	ITEP Moscow	Russia
27	IHEP Protvino	Russia
28	U Oxford	UK
29	U Southampton	UK
30	U Cambridge	UK
31	U Glasgow†	UK
32	U Plymouth	UK
33	ECT* Trento	Italy
34	U Leipzig	Germany
35	HU Berlin	Germany

Tasks

Algorithms and machines	
Stochastic techniques	✓
Renormalization and improvement	
Hadron spectrum	✓
Hadron structure	
Flavor singlet matrix elements	✓
Constraining effective field theory	
Heavy quark physics	✓
Physics beyond the Standard Model	
Fundamental symmetries	✓
QCD phase diagram	
Equation of state	
Screening phenomena	
Spectral properties	
Quantum number fluctuations	✓
QCD vacuum	

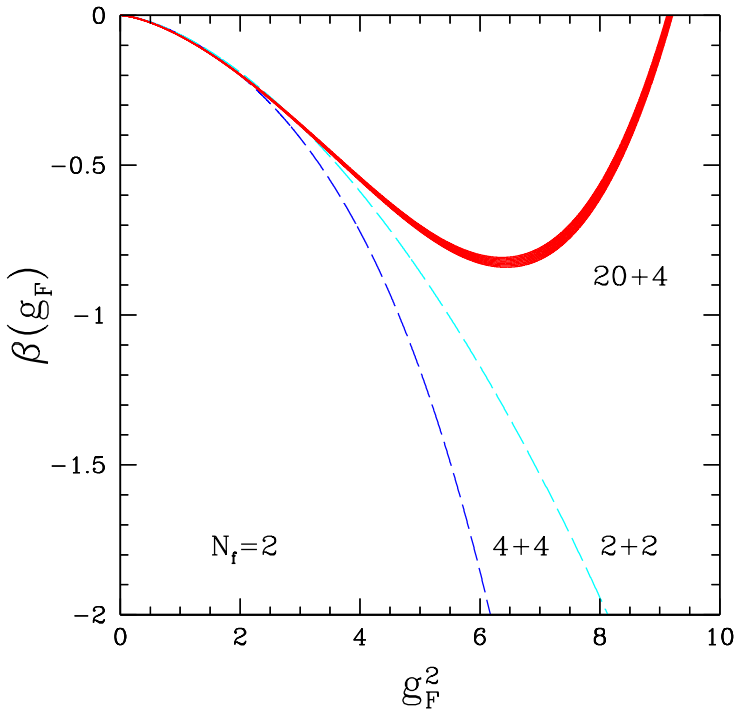
Peer Reviewed Publications

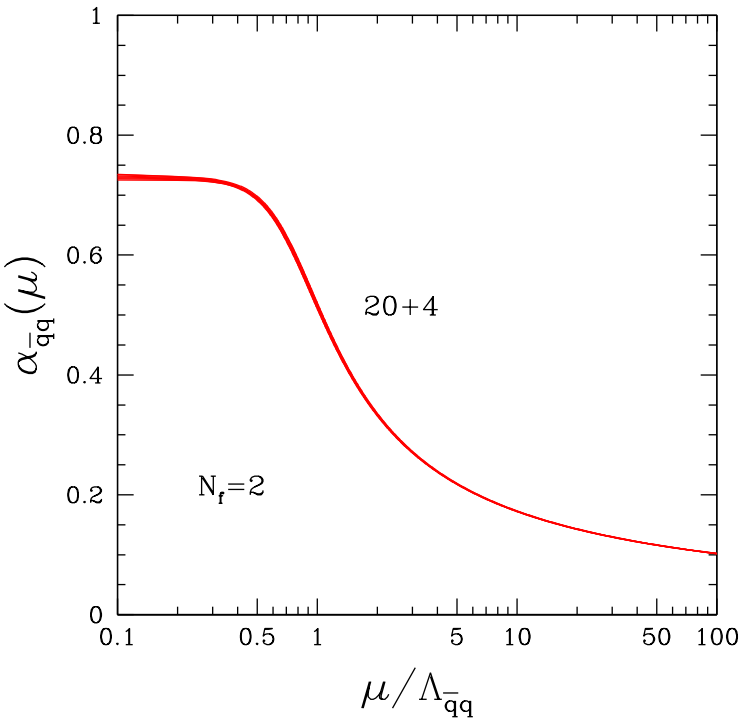
Phys. Rev. Lett.	5
Phys. Rev. D	43
Phys. Lett. B	9
Nucl. Phys. B	10
JHEP	21
Eur. Phys. J. C	2
Rev. Mod. Phys.	1
Conf. Proc.	47

Highlights

Stochastic perturbation theory

$20 + 4$ loops





Fixed point

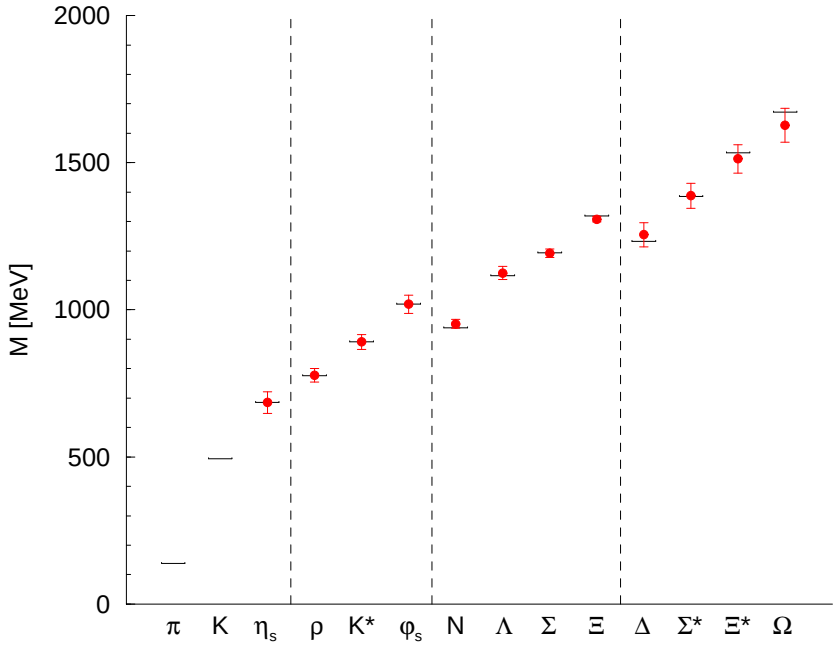
Conformal window

↓

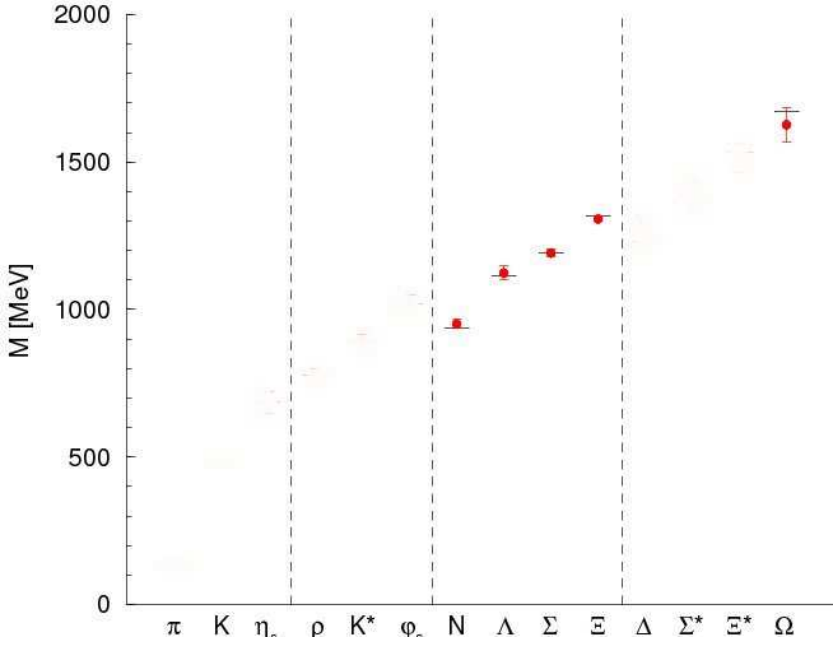
AdS/CFT correspondence

Holographic QCD

Hadron spectrum



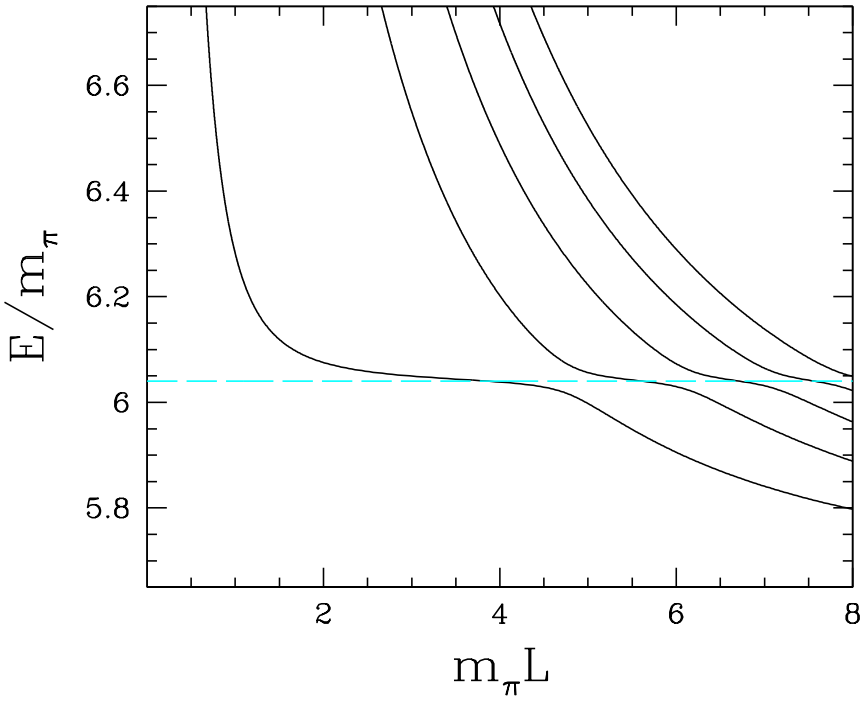
QCDSF

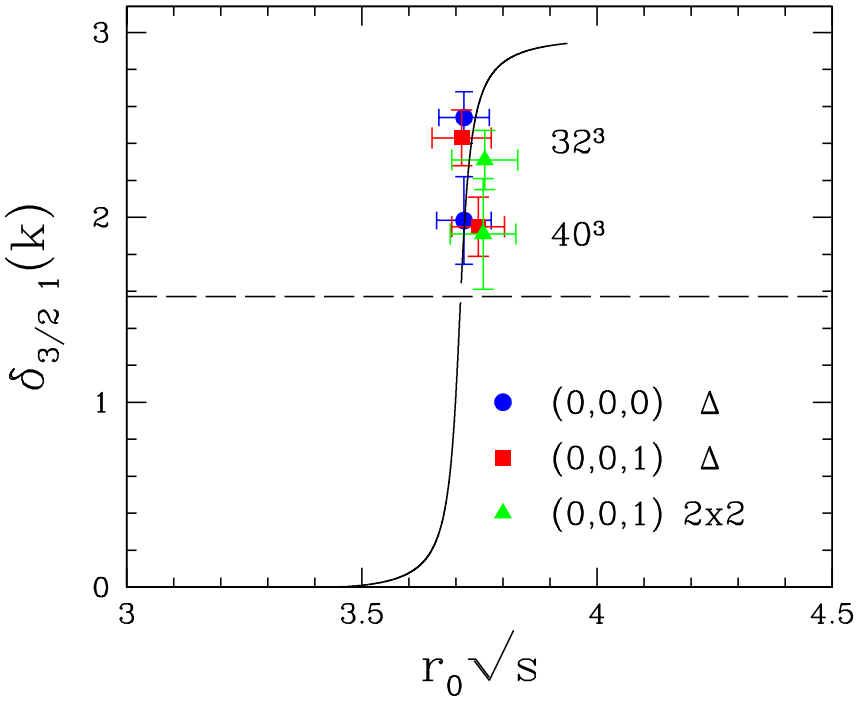


Most hadrons are resonances

Cannot be identified with a single energy level of the lattice Hamiltonian

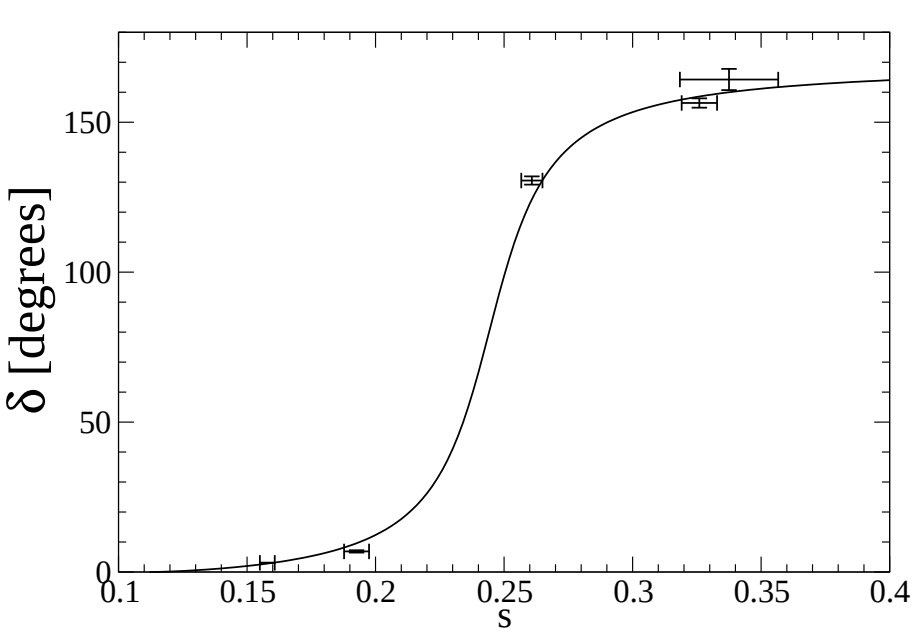
$\Delta(1232)$

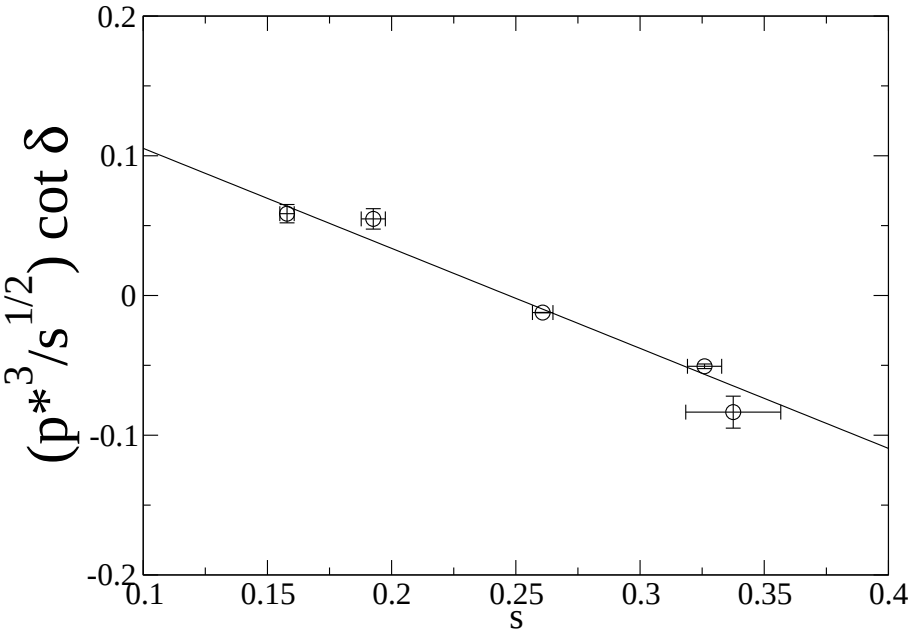




QCDSF–Bonn

$\rho(770)$





$m_\rho = 792 \pm 10$ MeV

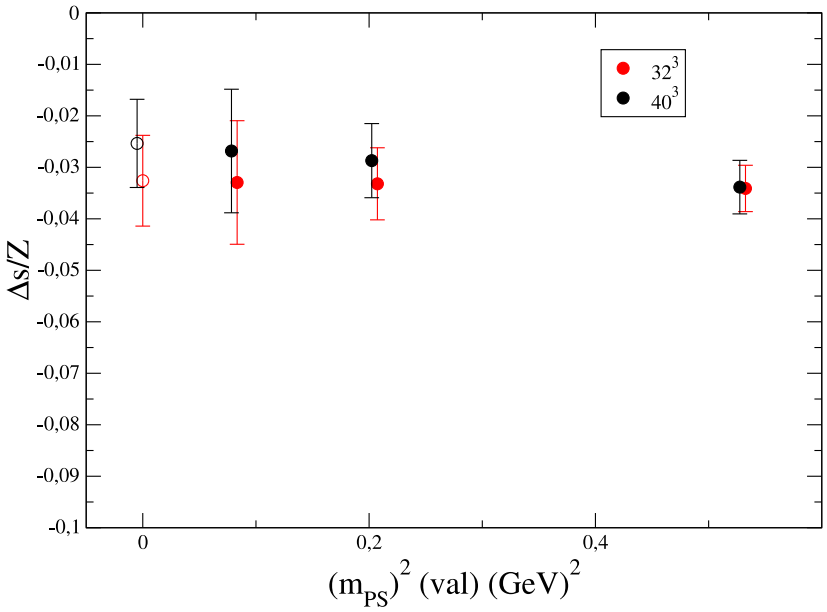
$g_{\rho\pi\pi} = 5.13 \pm 20$

Prelovsek et al.

Flavor singlet (disconnected) matrix elements

Stochastically

Spin content of the nucleon Δs



$$\Delta s = -0.020(10)(2)$$

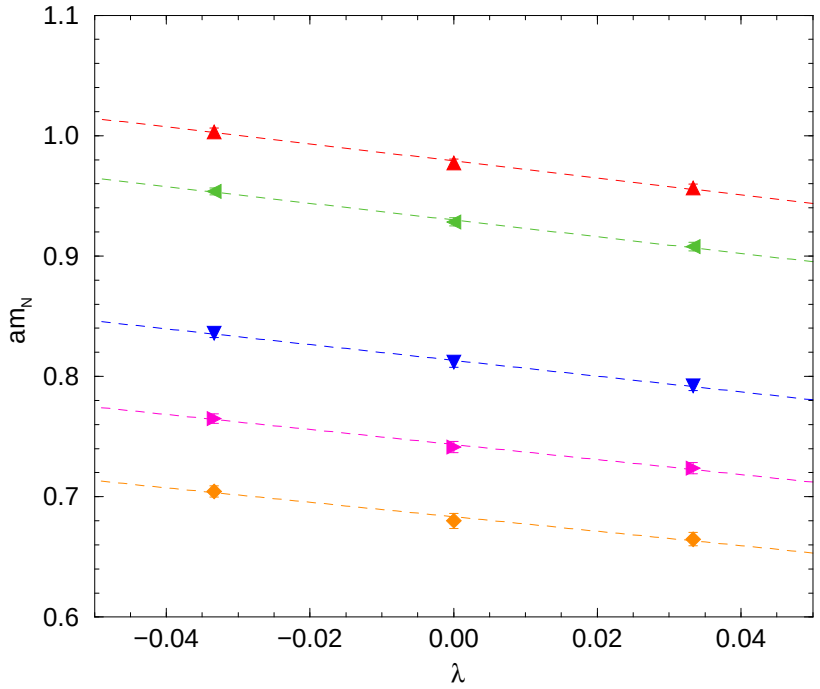
QCDSF

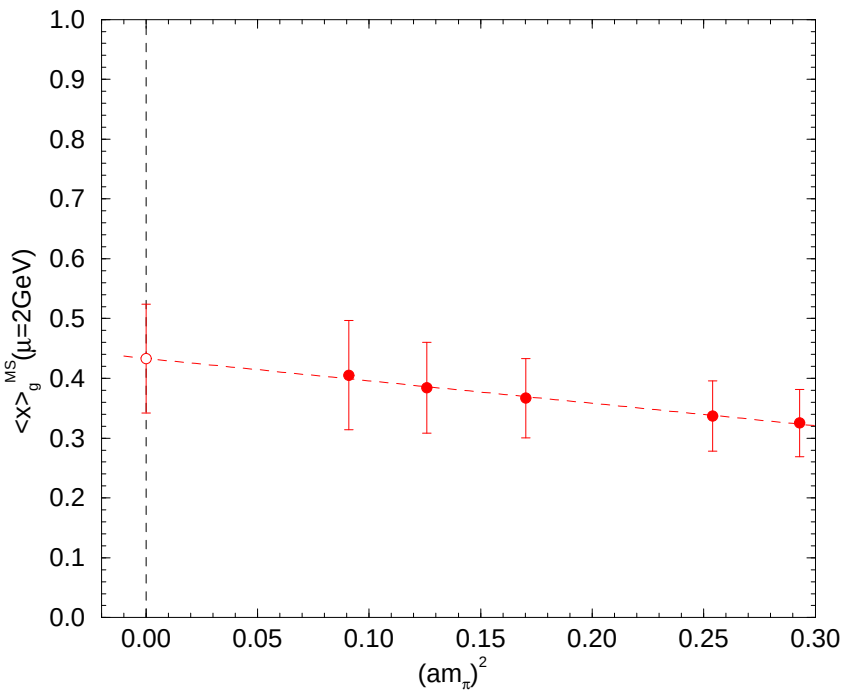
New approach: Feynman-Hellmann

$$S \to S + \lambda \mathcal{O}\,, \quad \left.\frac{\partial E_H}{\partial \lambda}\right|_{\lambda=0} = \langle \mathbf{p}, s | \mathcal{O} | \mathbf{p}, s \rangle$$

$$\mathcal{O} = \mathrm{Tr}\left(\mathbf{E}^2 - \mathbf{B}^2\right)$$

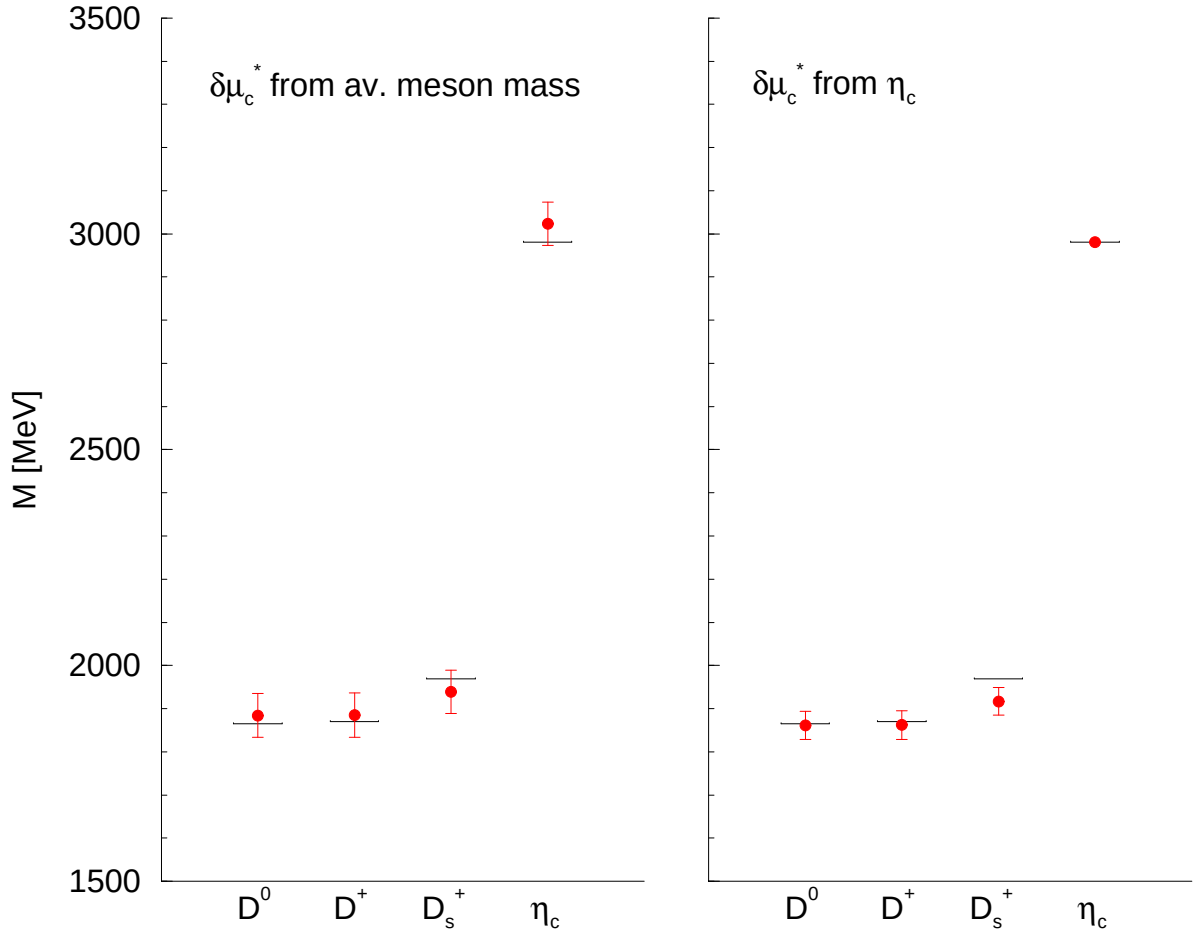
Gluon content of the nucleon $\langle x \rangle_g$





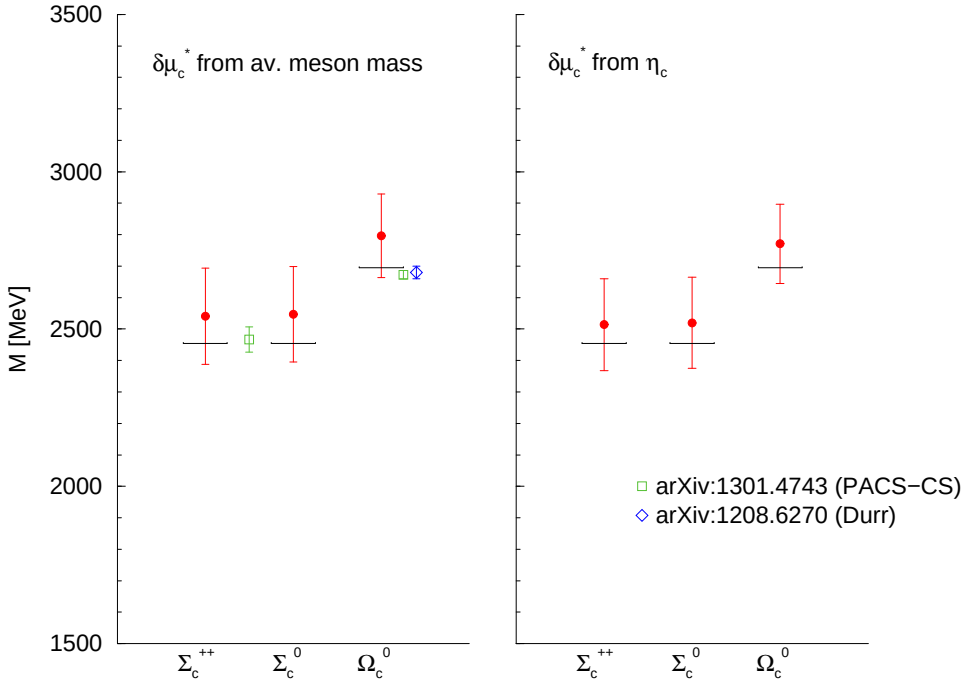
Heavy quark physics

Single charmed mesons

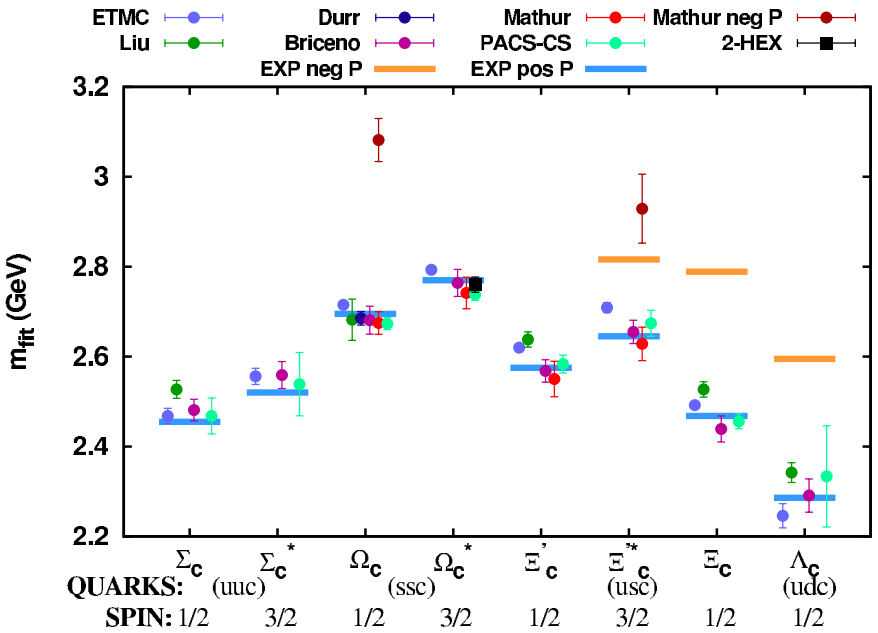


QCDSF

Single charmed baryons

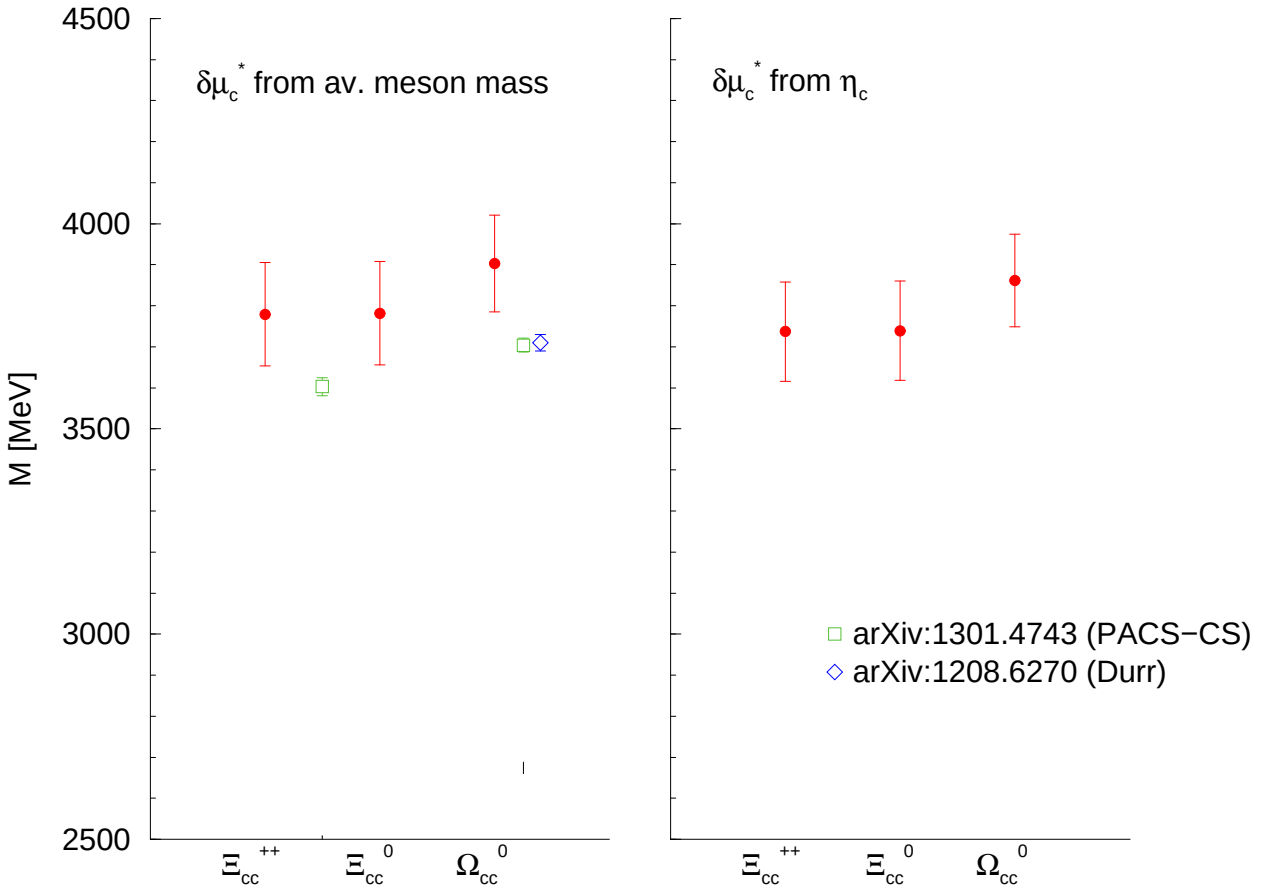


QCDSF



ETMC, Wuppertal, · · ·

Double charmed baryons



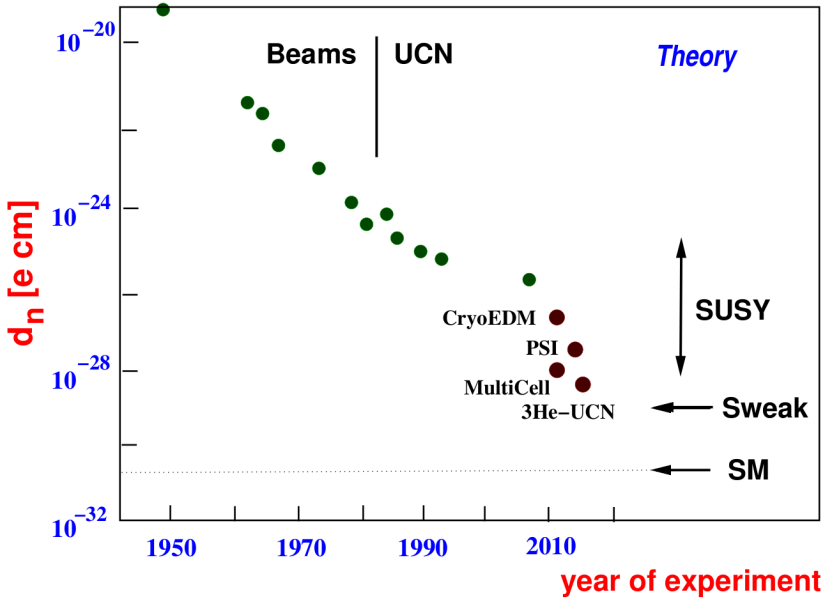
QCDSF

Fundamental symmetries

Electric dipole moment

$$\mathbf{d} = \int d^4x\, \mathbf{x}\, \rho(x) \qquad \mathbf{d}\cdot\mu \to -\,\mathbf{d}\cdot\mu$$

CP



QCD

$$S_\theta = S + i\theta Q\,, \quad Q = \frac{1}{32\pi^2}\int d^4x\, \mathbf{E}\cdot\mathbf{B}$$

$d_N^n = -0.016(1)\,[e\,\theta\,\text{fm}]$

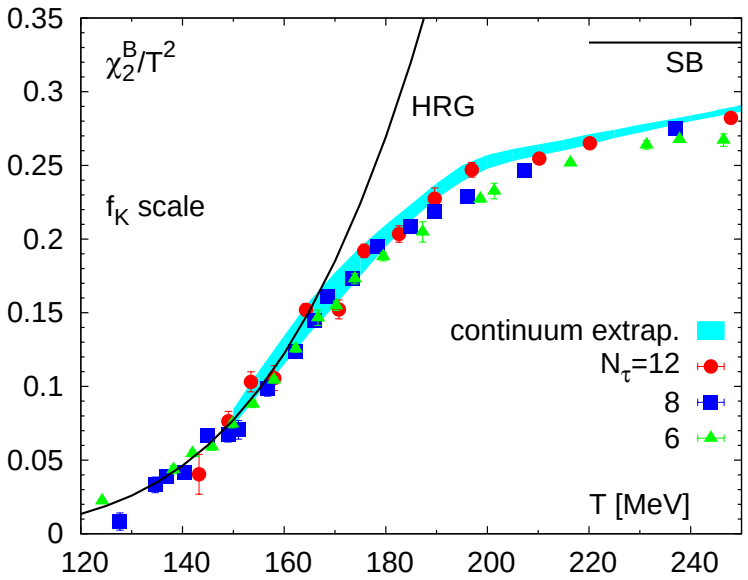
$|\theta| \leq 1.8 \times 10^{-11}$

QCDSF

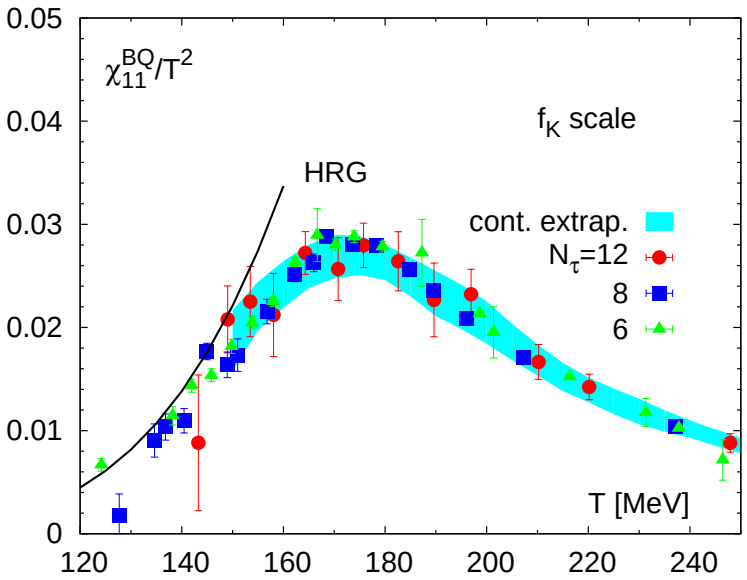
Quantum number fluctuations

Baryon number/electric charge fluctuations

B



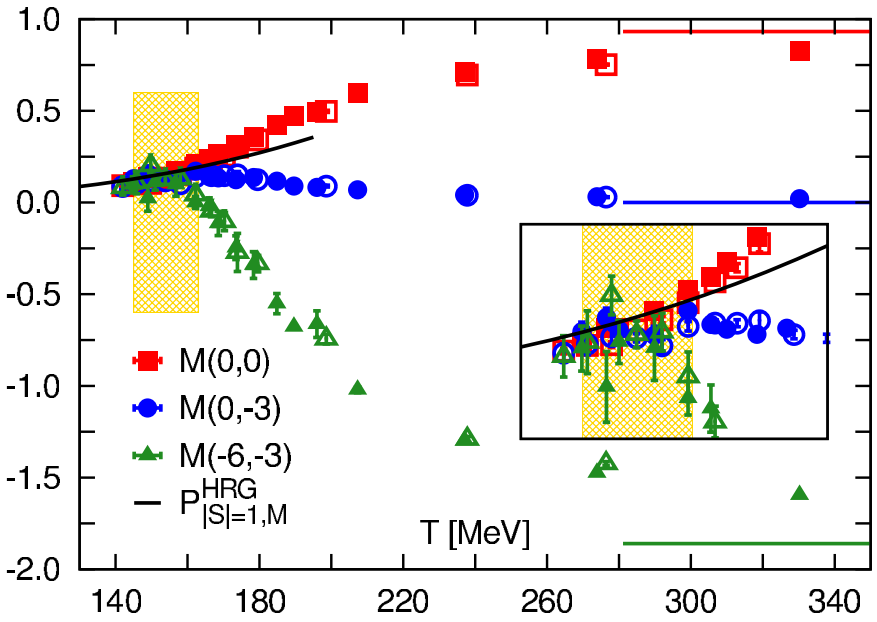
B×Q

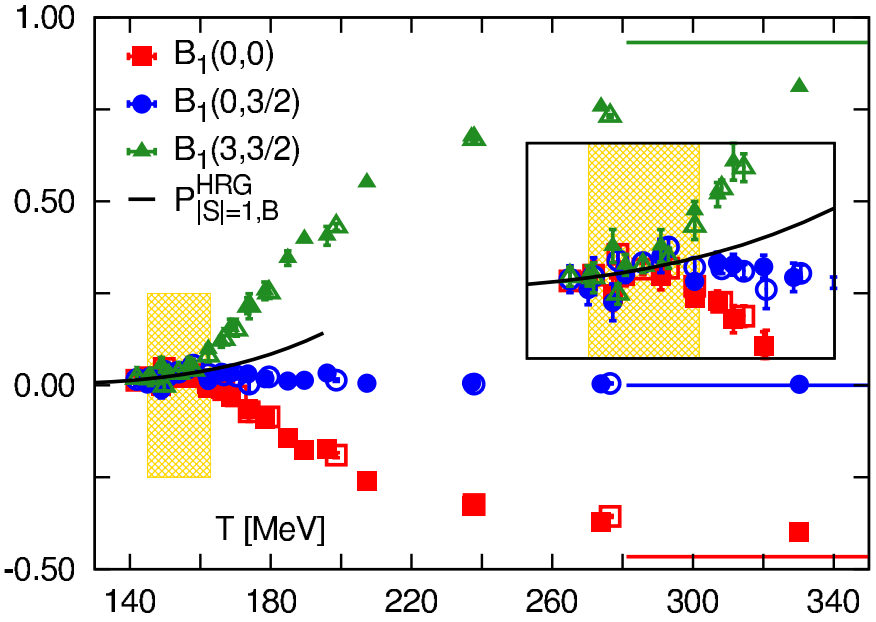


$$\chi_2^B = \frac{\langle (N - \bar{N})^2 \rangle}{V\, T^3}$$

HotQCD

Strangeness fluctuations





$$M(0,0) = \chi_2^S - \chi_{11}^{BS}$$

$$B_1(0,0) = \frac{1}{2}\left(\chi_4^S - \chi_2^S + 5\chi_{13}^{BS} + 7\chi_{22}^{BS}\right)$$

Strangeness becomes liberated from hadronic bound states at $T \gtrsim T_c$.
Approach to an ideal gas is slow though

HotQCD

Lattice Quantum Chromodynamics and Hadron Physics

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Summary/Outlook

- Calculations are done at JSC (Jülich), Cineca (Bologna), Dirac (Edinburgh), LRZ (Munich), HLRN (Berlin and Hannover), QPACE (Jülich and Wuppertal), $\cdots$
- Landscape of computing has changed in favor of open access supercomputer centers (like JSC, Cineca, $\cdots$) due to massive investment in computer hardware
- Investigations are progressing steadily and are on target, with minor adjustments with respect to focus and techniques
- The European Lattice QCD community is still very fragmented. Perhaps a pan-European network EUQCD (the counterpart of USQCD) might change that
- My personal to do/wish list: baryon resonances, QCD $\cup$ QED, flavor symmetry, $(g-2)_\mu$, nucleon electric dipole moment EDM, studies of baryon decays for CKM unitarity, nucleon matrx elements for dark matter searches, $\cdots$

$\longrightarrow$ discovery potential