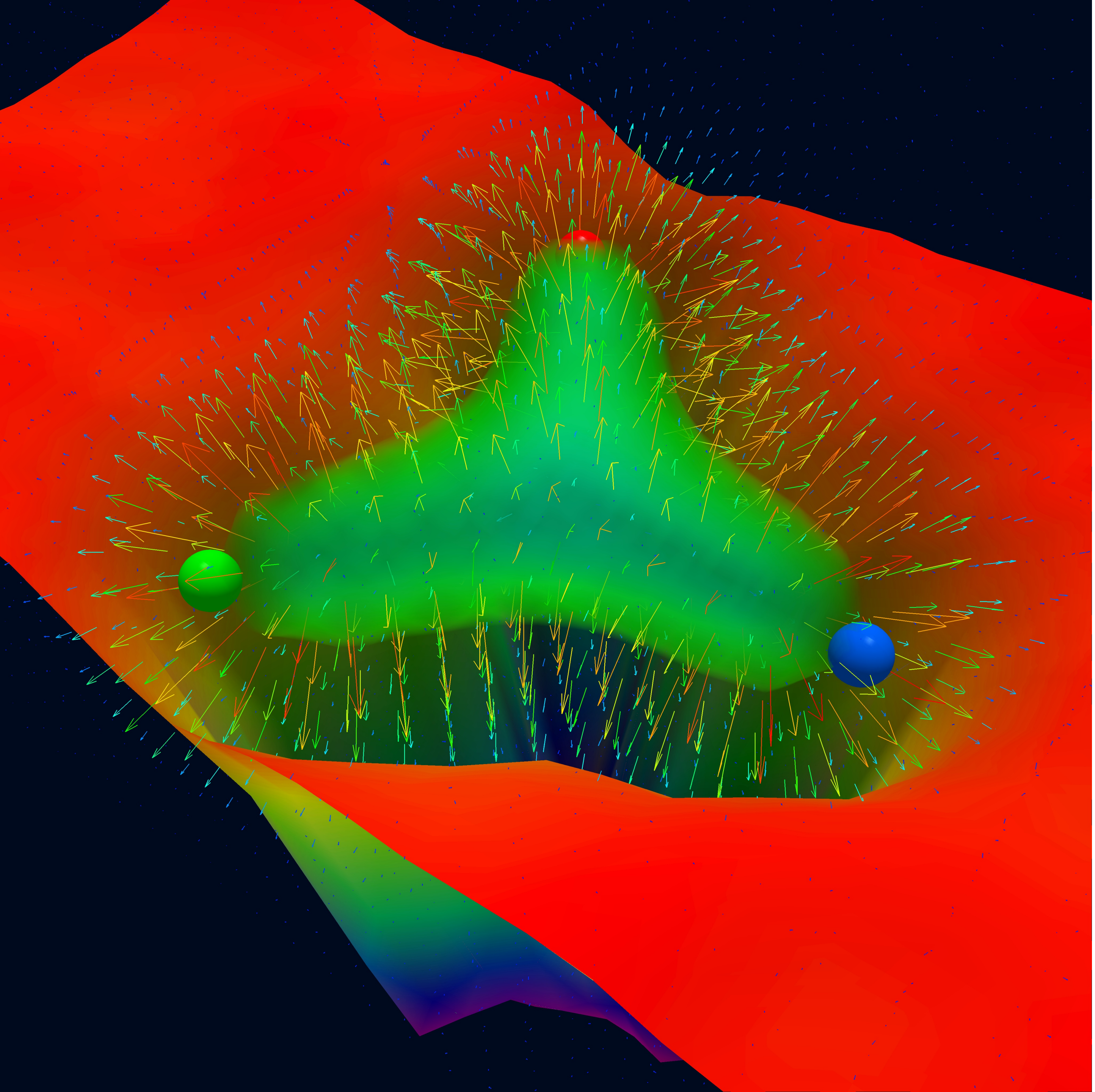
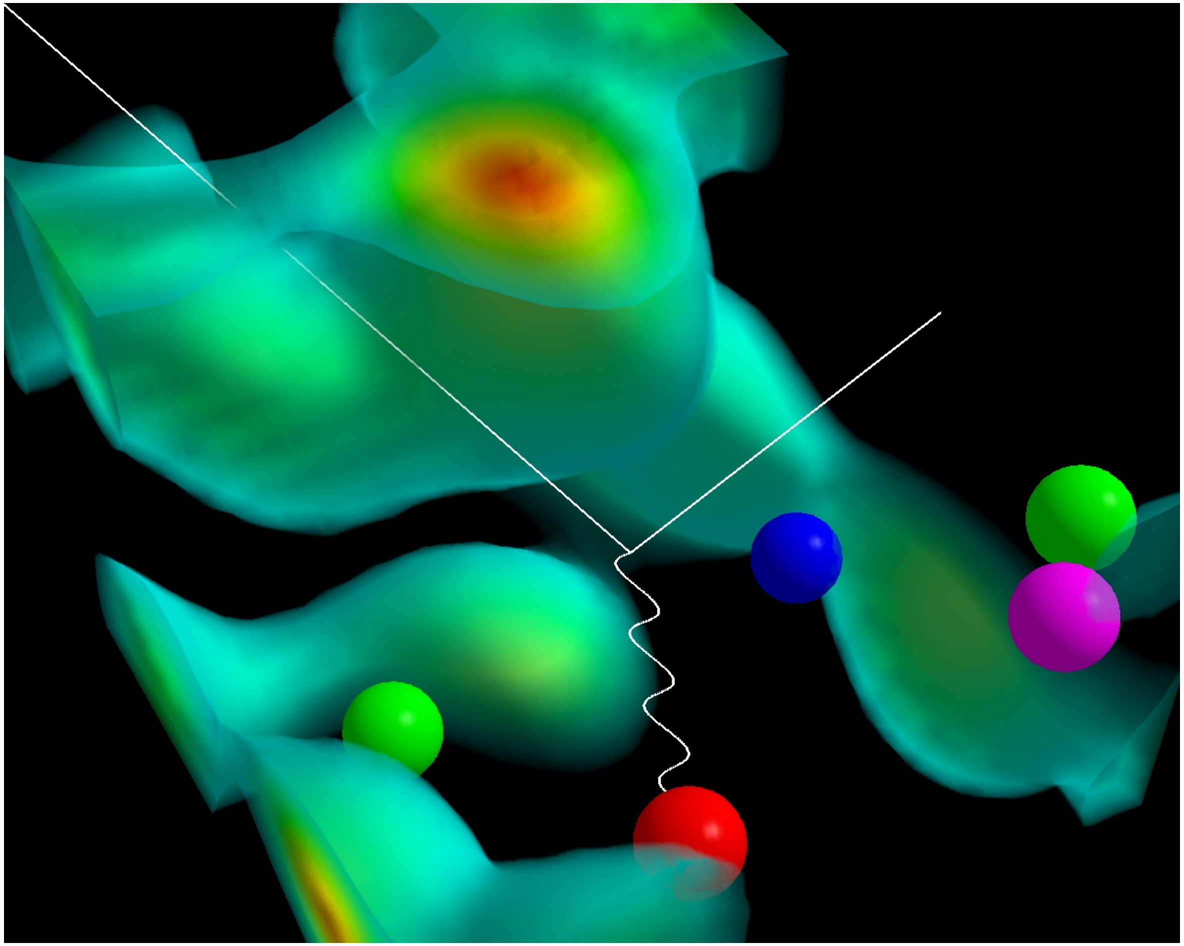


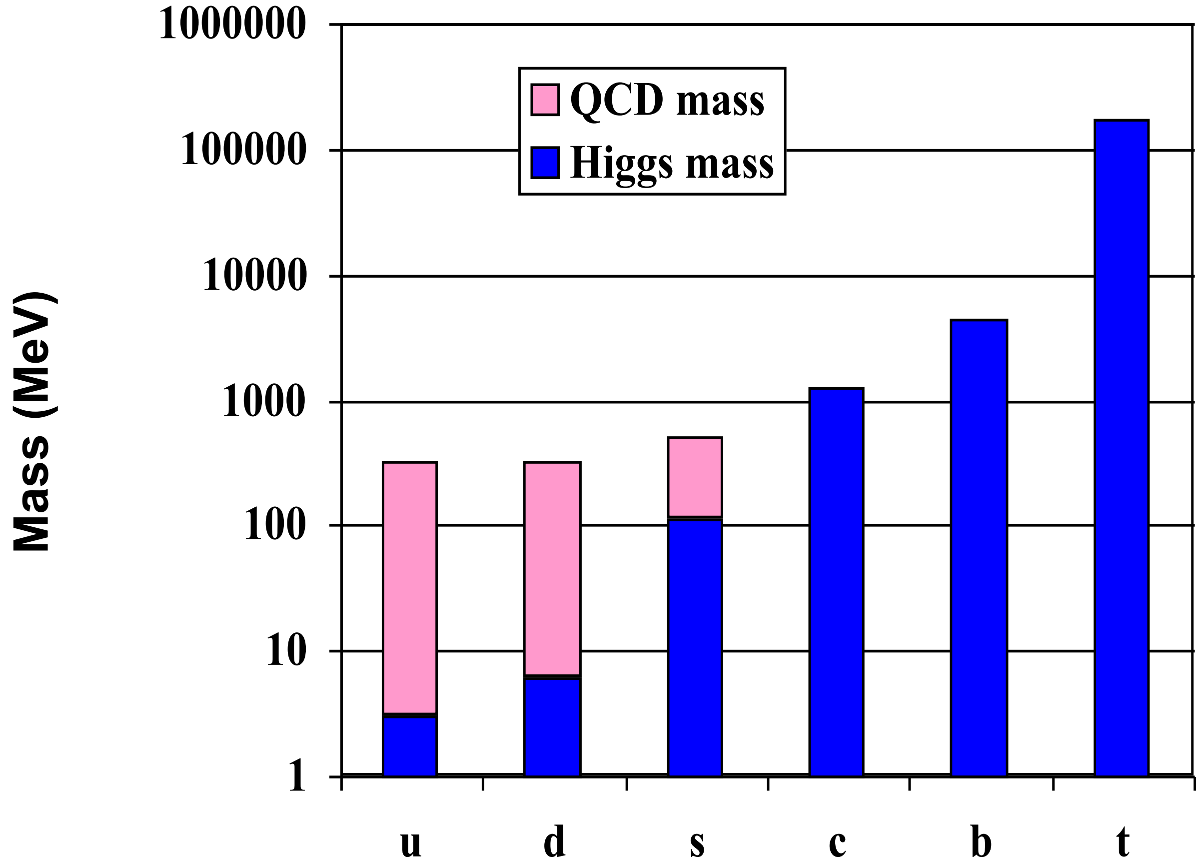
The positions of the three quarks composing the proton are illustrated by the colored spheres. The surface plot illustrates the reduction of the vacuum action density in a plane passing through the centers of the quarks. The vector field illustrates the gradient of this reduction. The positions in space where the vacuum action is maximally expelled from the interior of the proton are also illustrated by the tube-like structures, exposing the presence of flux tubes. A key point of interest is the distance at which the flux-tube formation occurs. The animation indicates that the transition to flux-tube formation occurs when the distance of the quarks from the center of the triangle is greater than 0.5 fm. Again, the diameter of the flux tubes remains approximately constant as the quarks move to large separations.

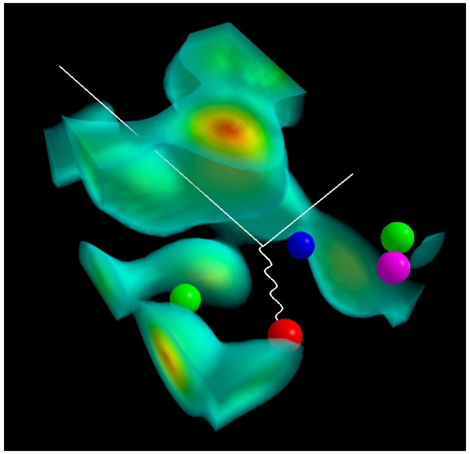
- Three quarks indicated by red, green and blue spheres (lower left) are localized by the gluon field.
- A quark-antiquark pair created from the gluon field is illustrated by the green-antigreen (magenta) quark pair on the right. These quark pairs give rise to a meson cloud around the proton.

http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/index.html



Nucl. Phys. A750, 84 (2005)





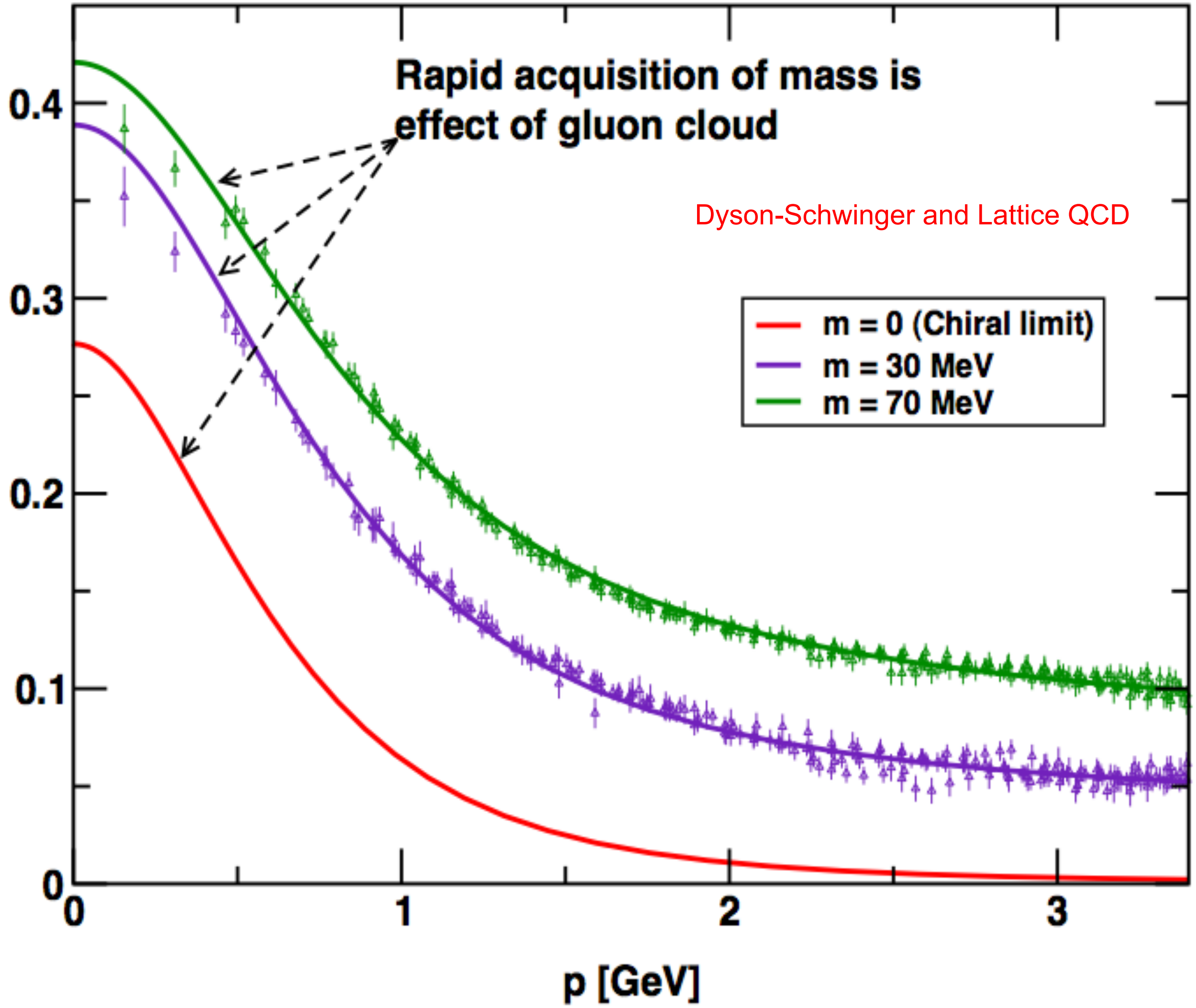
u + u + d = proton

mass: 0.003 + 0.003 + 0.006 ≠ 0.938 GeV

HOW does the rest of the proton mass arise?

HOW does the rest of the proton spin (magnetic moment,…), arise?

Mass from nothing



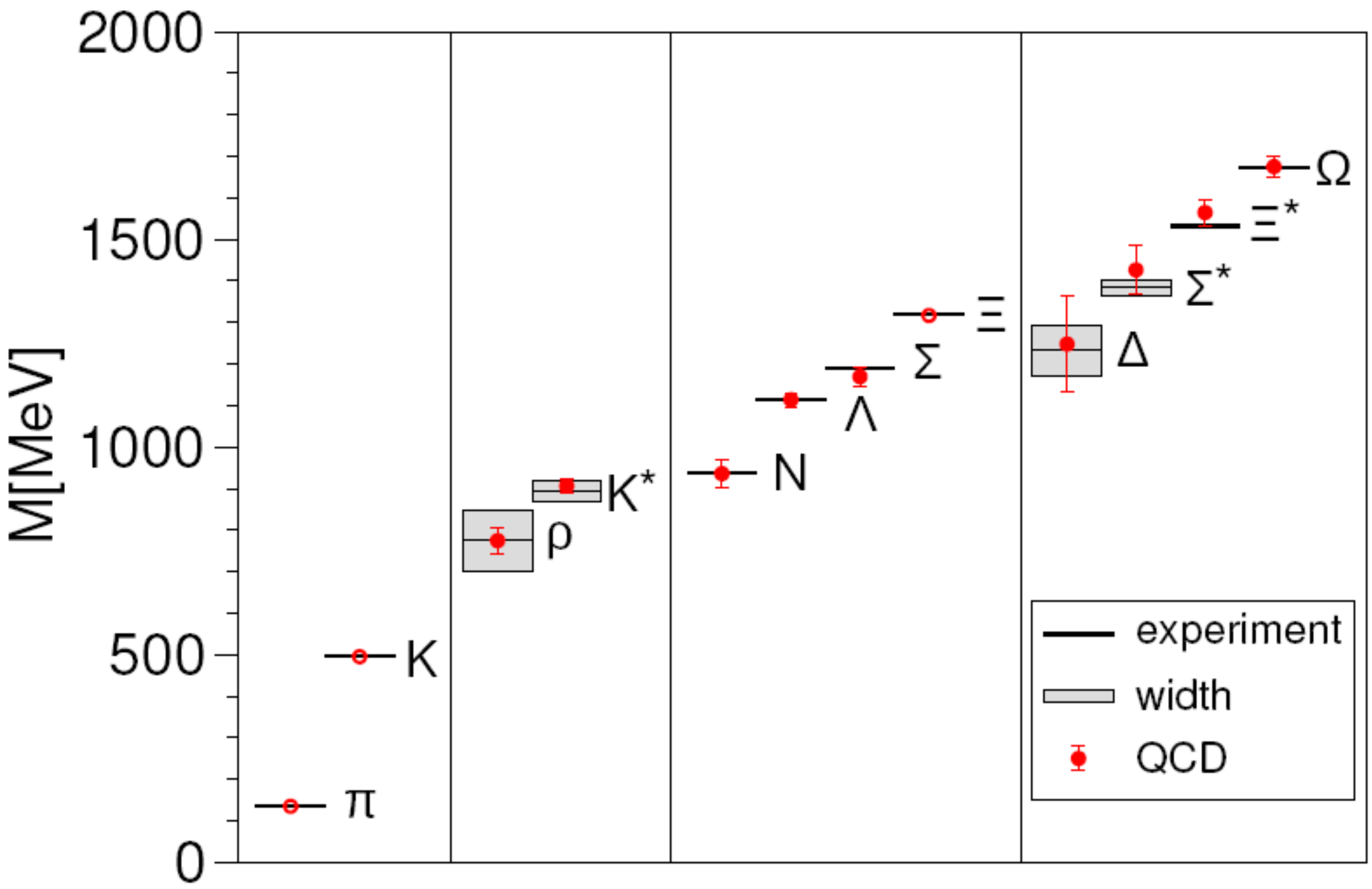
It is known that the dynamical chiral symmetry breaking; namely, the generation of mass *from nothing,* does take place in QCD. It arises primarily because a dense cloud of gluons comes to clothe a low- momentum quark. The vast bulk of the constituent-mass of a light quark is contained in a cloud of gluons, which are dragged along by the quark as it propagates. In this way, a quark that appears to be absolutely massless at high energies acquires a large constituent mass at low energies.

Low-lying Hadron Spectrum

Dürr, Fodor, Lippert et al., BMW Collaboration

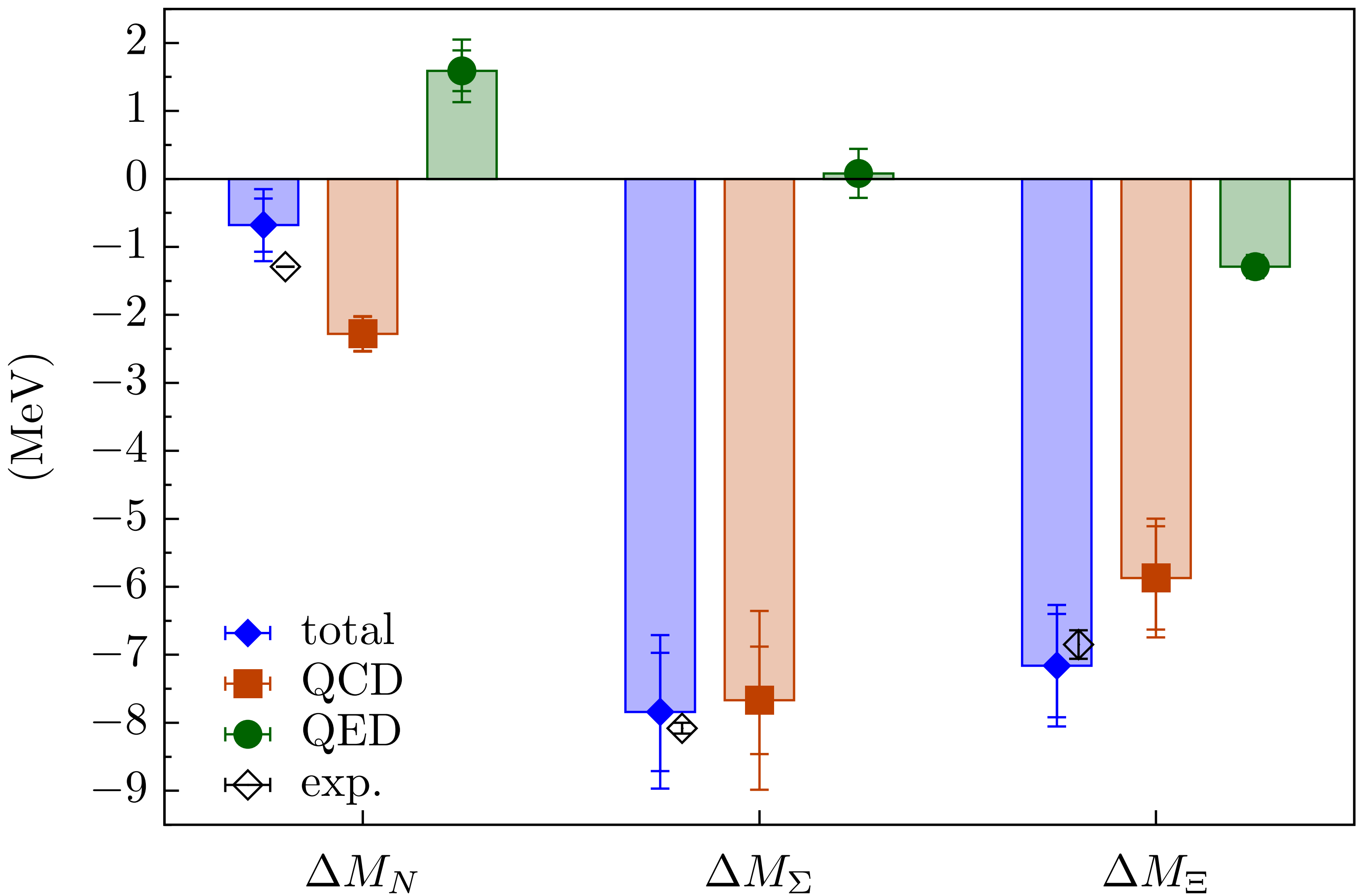
Science 322, 1224 (2008)

More than 99% of the mass of the visible universe is made up of protons and neutrons. Both particles are much heavier than their quark and gluon constituents, and the Standard Model of particle physics should explain this difference. We present a full ab initio calculation of the masses of protons, neutrons, and other light hadrons, using lattice quantum chromodynamics. Pion masses down to 190 mega–electron volts are used to extrapolate to the physical point, with lattice sizes of approximately four times the inverse pion mass. Three lattice spacings are used for a continuum extrapolation. Our results completely agree with experimental observations and represent a quantitative confirmation of this aspect of the Standard Model with fully controlled uncertainties



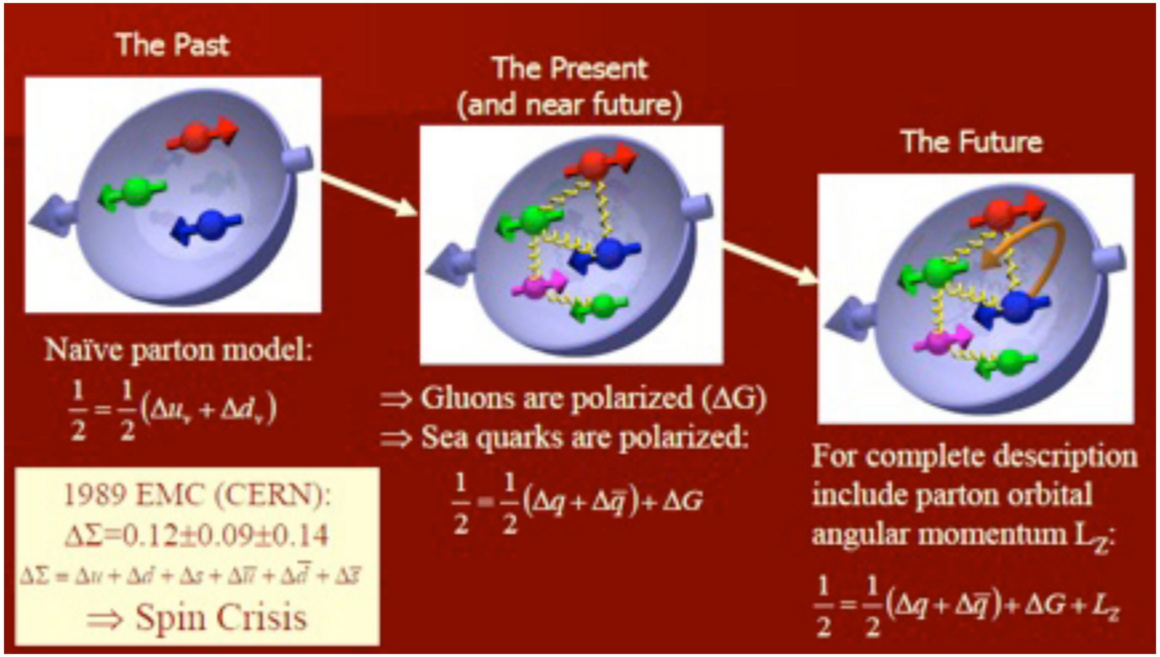
Isospin Splittings in the Light-Baryon Octet from Lattice QCD and QED

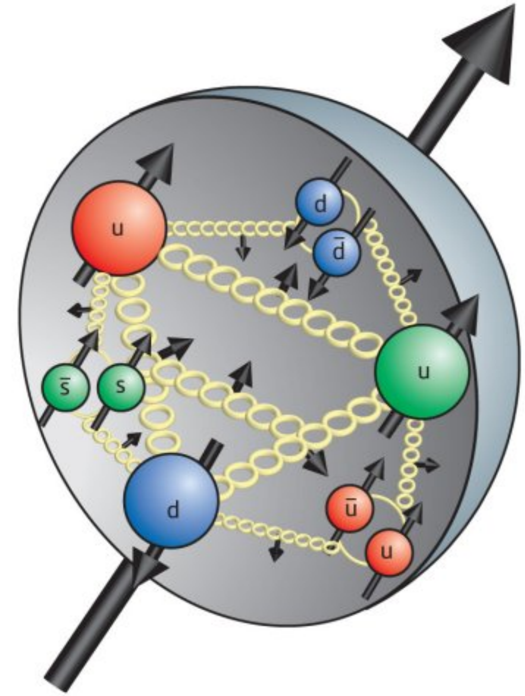
Phys. Rev. Lett. 111, 252001 (2013)



The spin structure of the nucleon

Rev. Mod. Phys. 85, 655 (2013)



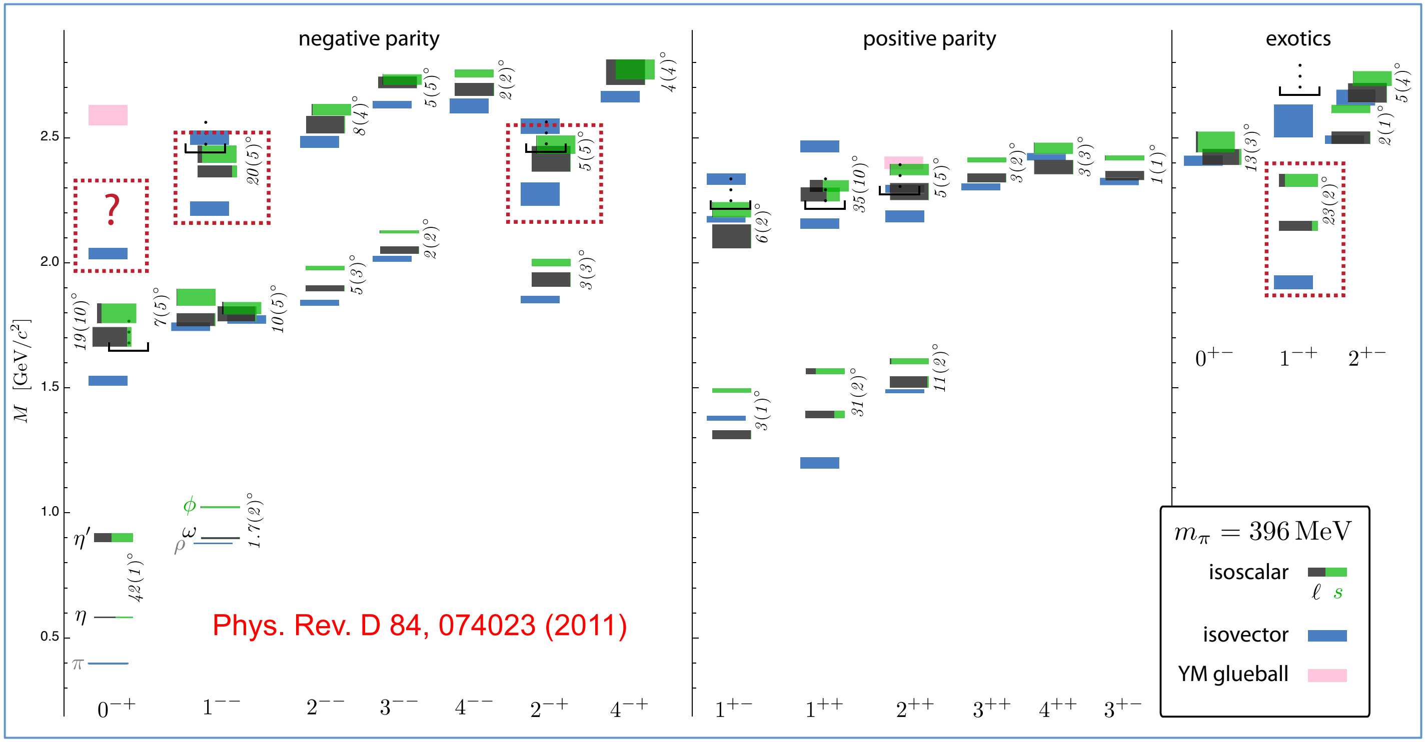


How do the proton's various constituents contribute to its overall spin? As illustrated by the diagram, the quarks, antiquarks, and gluons are all believed to have their own intrinsic spins, and these must contribute. But so also must the relative orbital motions of the quarks and gluons inside the proton. The first measurements of the proton's spin substructure have been made recently, employing the technique of deep inelastic scattering with spin-polarized beams bombarding spin-polarized targets. By combining these measurements with constraints from other data, one can infer the fraction of the proton's spin carried by the intrinsic spin of quarks (and antiquarks) of different flavors. The results of experiments performed at CERN, SLAC, and DESY, summarized in the graph, point to an unexpected outcome: all the quarks and antiquarks together account for **no more than one-third of the total spin**. More direct probes of the spin alignment of different flavors of quarks, separation of the contributions from quarks and antiquarks, and extraction of information on the gluon spin contributions are goals of ongoing and planned second-generation experiments.

http://physicsworld.com/cws/article/news/2014/jul/11/gluons-get-in-on-proton-spin

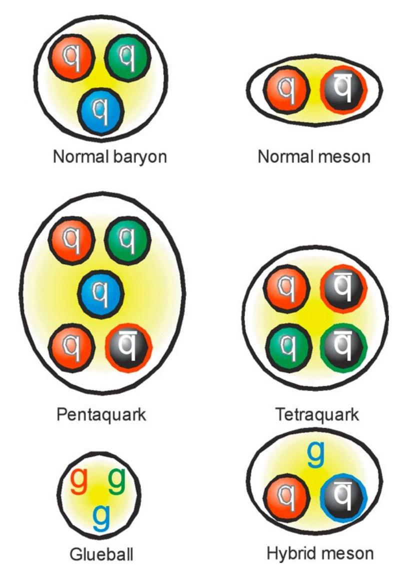
http://www.scientificamerican.com/article/proton-spin-mystery-gains-a-new-clue1/

Where is the glue? Search for exotic particle



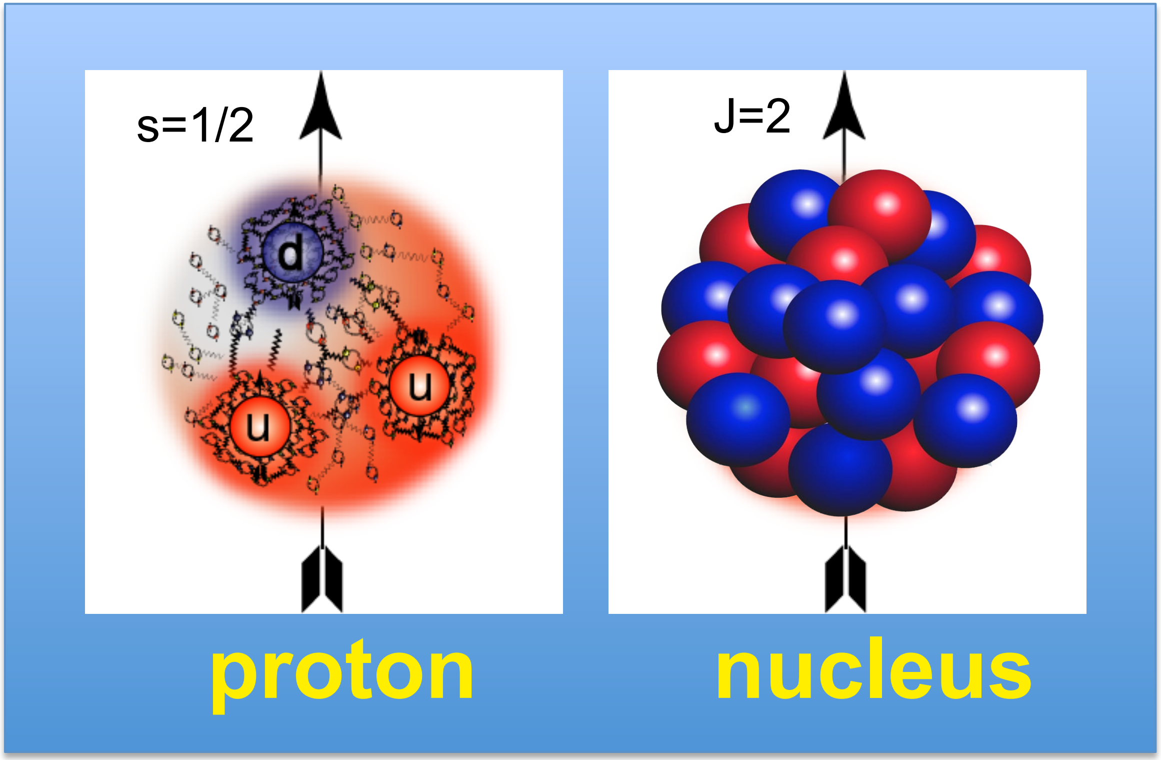
http://www.gluex.org

- Non-quark model mesons include exotic mesons, which have quantum numbers not possible for mesons in the quark model;
- glueballs or gluonium, which have no valence quarks at all;
- tetraquarks, which have two valence quark-antiquark pairs;
- hybrid mesons, which contain a valence quark-antiquark pair and one or more gluons.



http://www.symmetrymagazine.org/article/september-2006/the-rise-and-fall-of-the-pentaquark

The Structure



hadron spectroscopy

The origin of confinement
The origin of mass, spin
Quantum numbers and symmetries

nuclear spectroscopy

The origin of nuclear force
The origin of binding, spin
Quantum numbers and symmetries