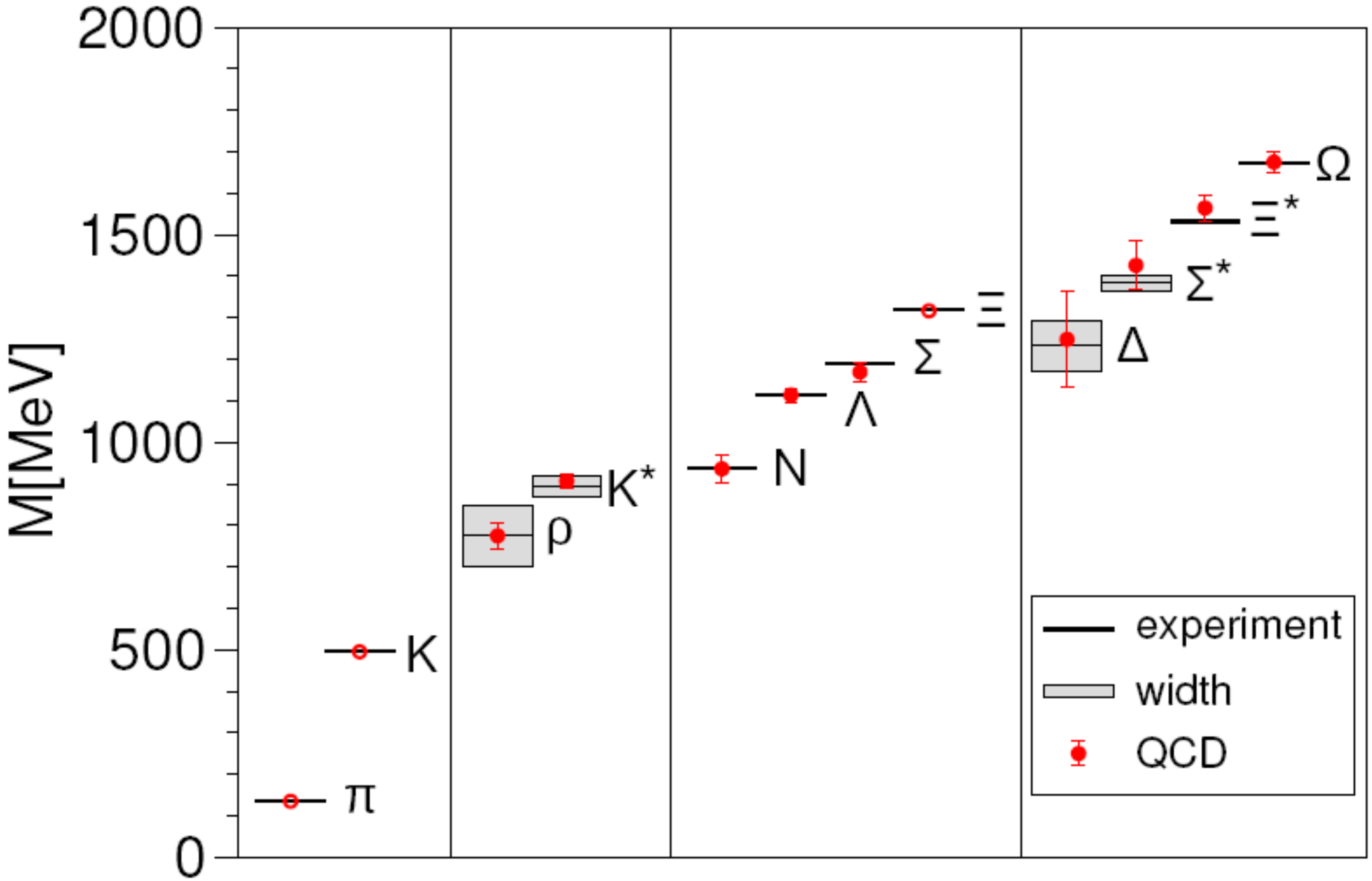
Low-lying Hadron Spectrum

Dürr, Fodor, Lippert et al., BMW Collaboration

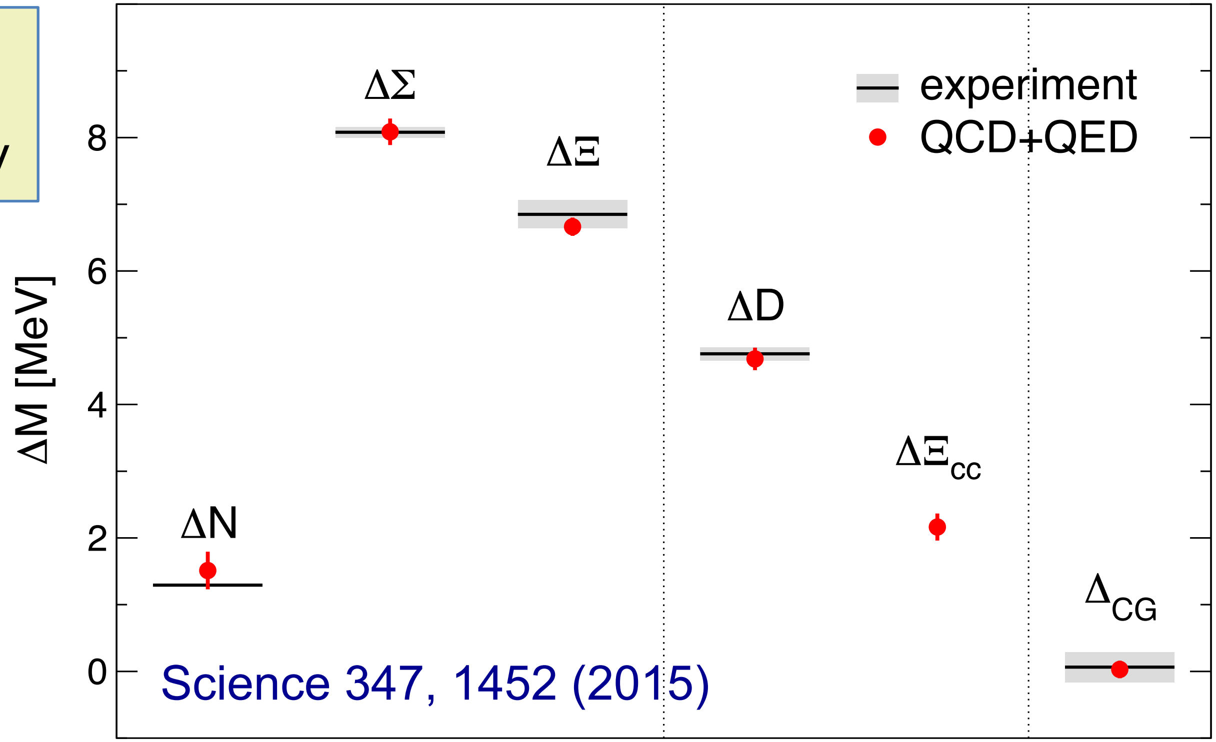
Science 322, 1224 (2008)

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
(ab initio calculation of the neutron-proton mass difference)

Neutron = 939.56563 MeV
Proton = 938.27231 MeV
Electron = 0.51099906 MeV

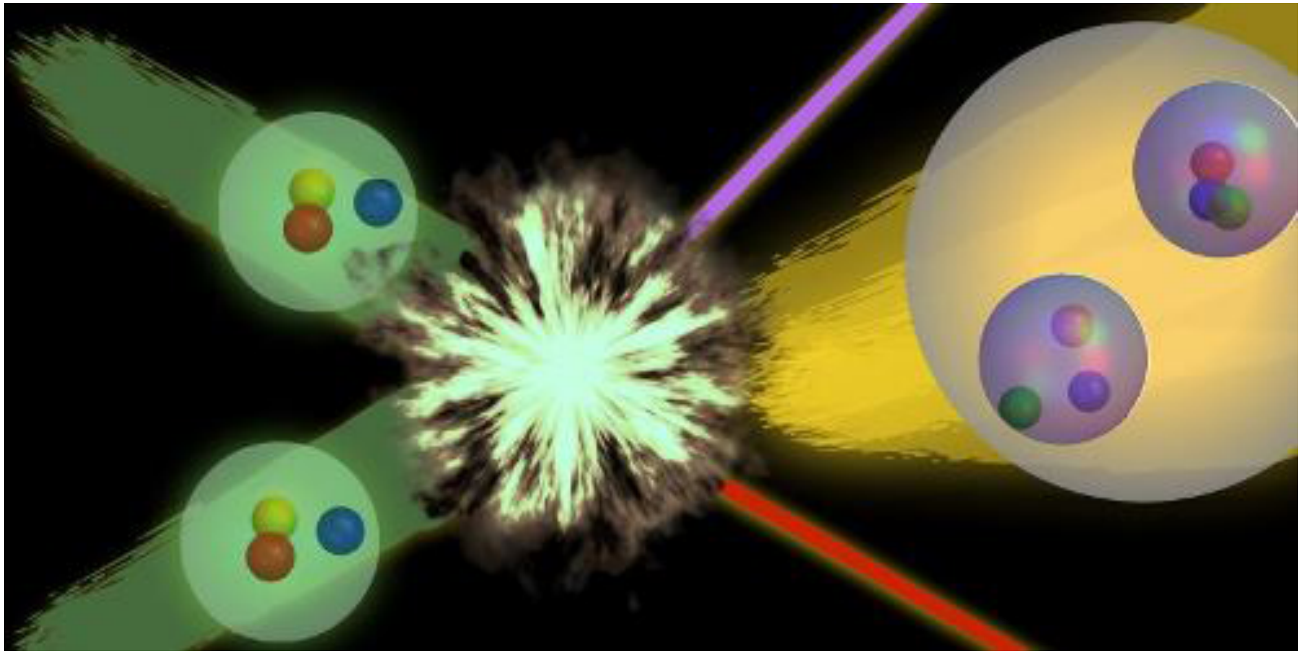


	mass splitting [MeV]	QCD [MeV]	QED [MeV]
$\Delta N = n - p$	1.51(16)(23)	2.52(17)(24)	-1.00(07)(14)
$\Delta\Sigma = \Sigma^- - \Sigma^+$	8.09(16)(11)	8.09(16)(11)	0
$\Delta\Xi = \Xi^- - \Xi^0$	6.66(11)(09)	5.53(17)(17)	1.14(16)(09)

"The neutron–proton mass difference, one of the most consequential parameters of physics, has now been calculated from fundamental theories. This landmark calculation portends revolutionary progress in nuclear physics." Wilczek, Nature 520, 303 (2015)

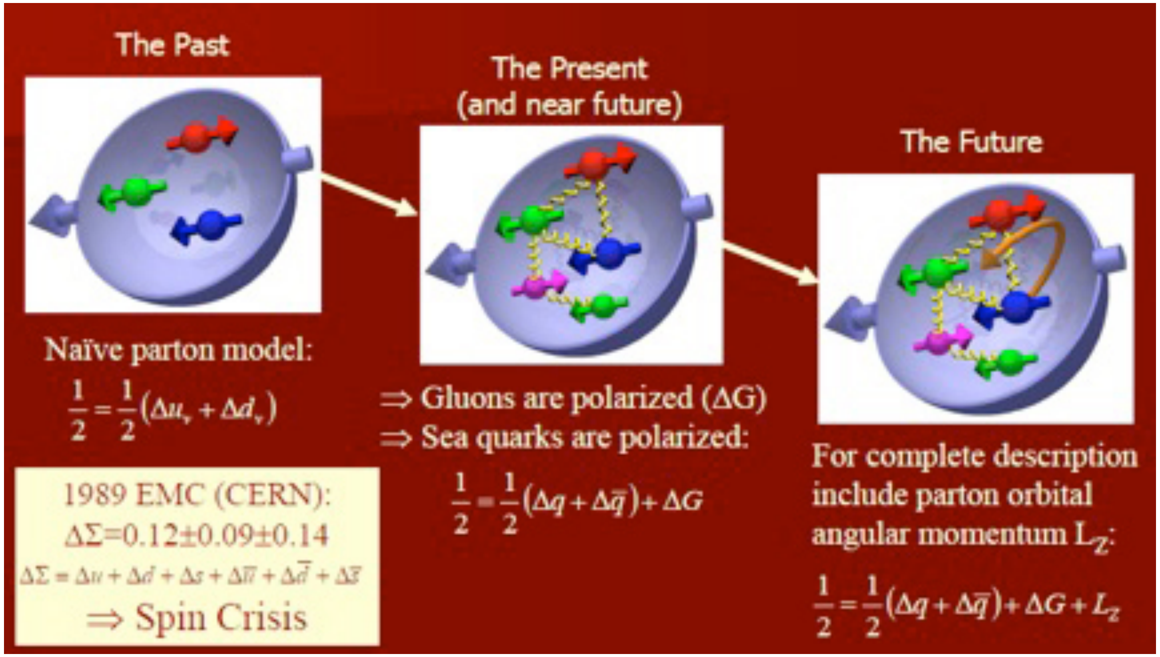
Synopsis: Strong Force Model for Weak Force Reactions

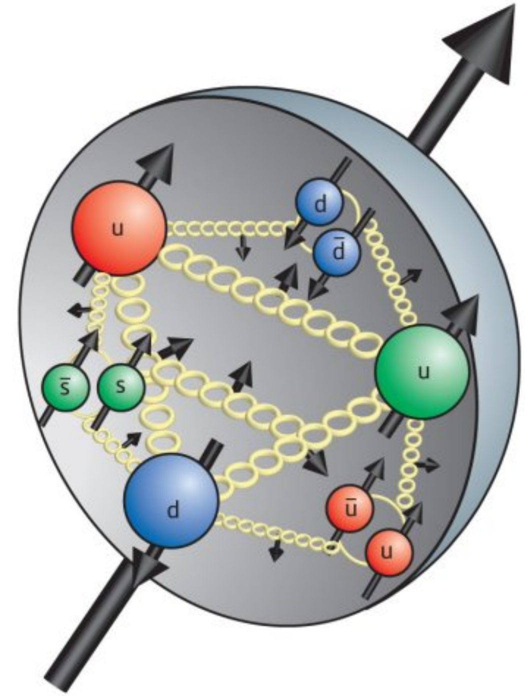
https://physics.aps.org/synopsis-for/10.1103/PhysRevLett.119.062002



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

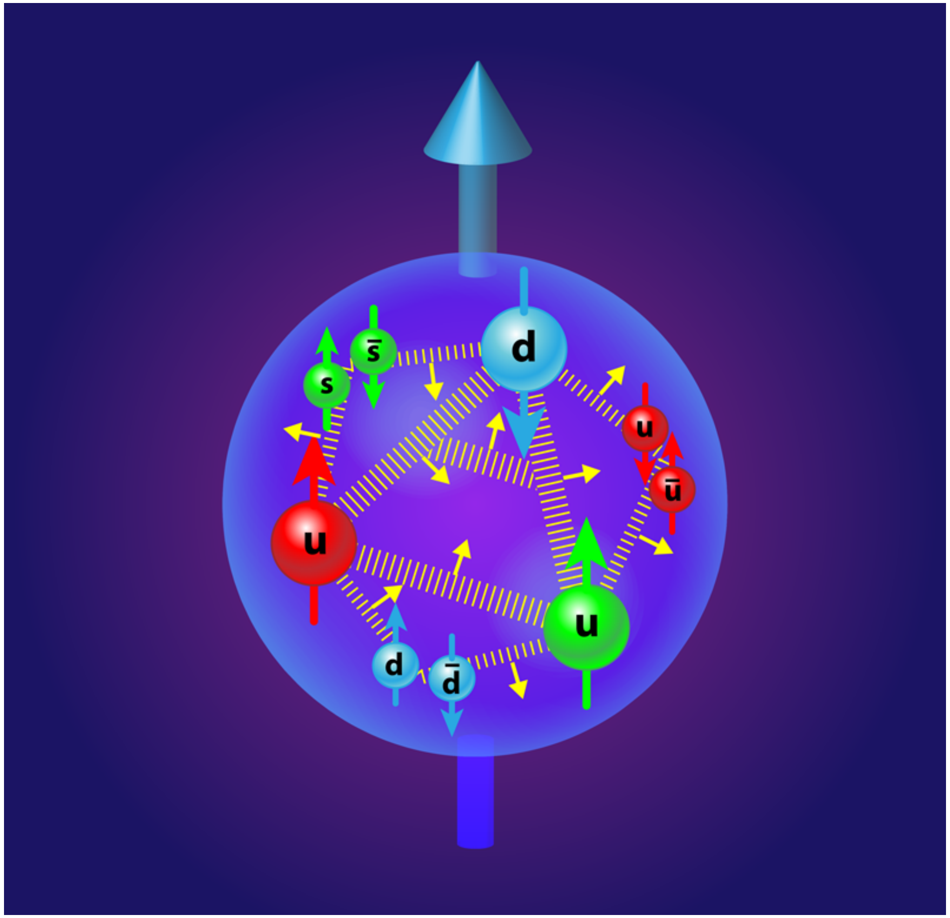
http://www.scientificamerican.com/article/proton-spin-mystery-gains-a-new-clue1/

Viewpoint: Spinning Gluons in the Proton

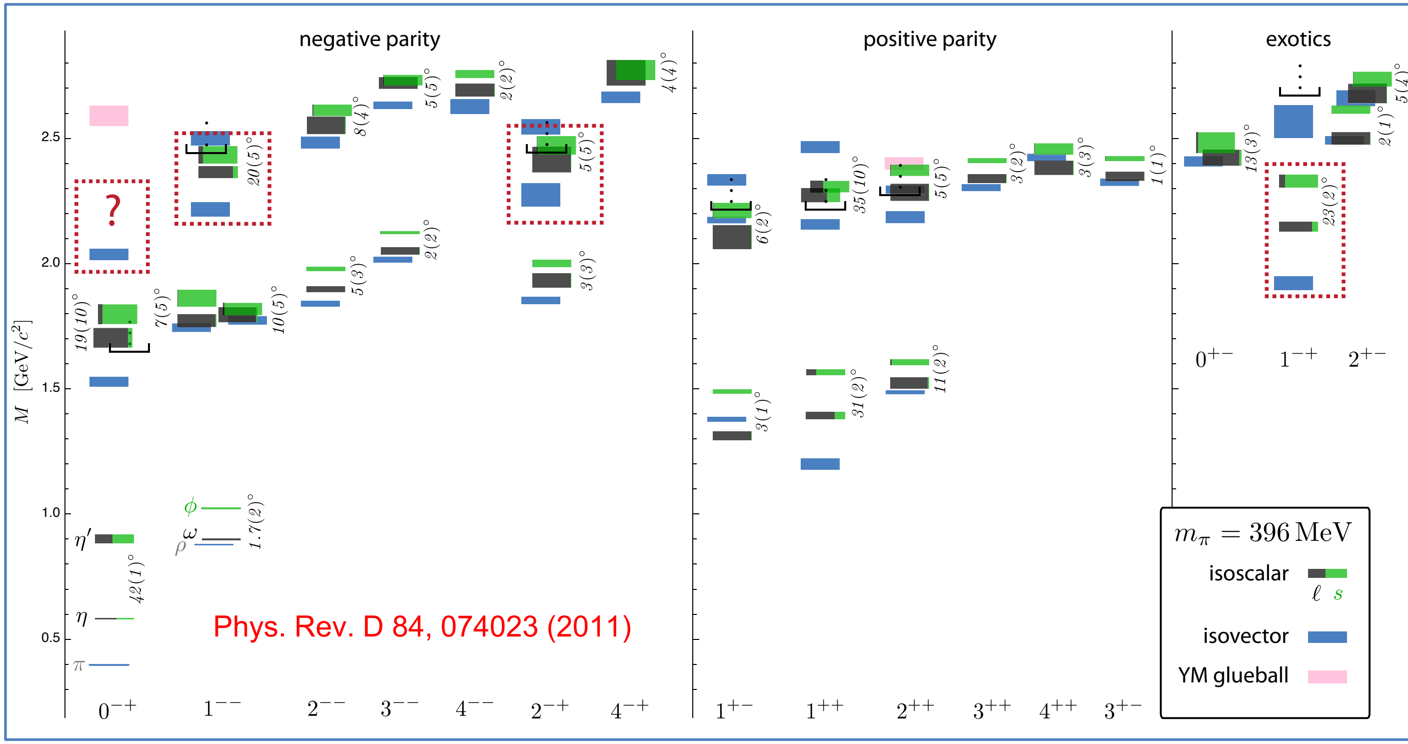
http://physics.aps.org/articles/v10/23

Computer simulations indicate that about 50% of the proton’s spin comes from the spin of the gluons that bind its quark constituents

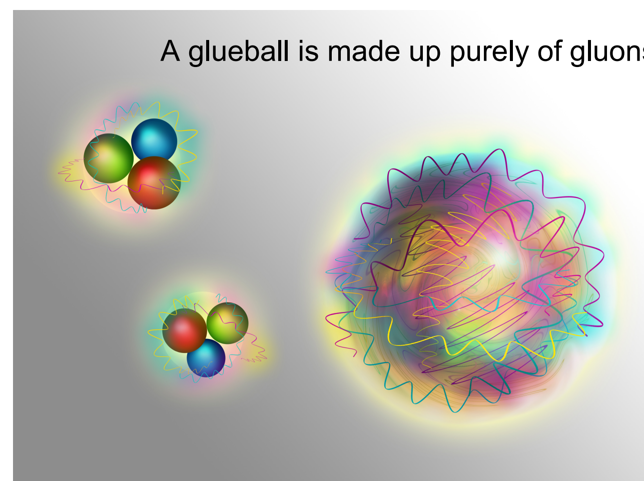
Phys. Rev. Lett. 118, 102001 (2017)



Where is the glue? Search for exotic particle



http://www.gluex.org

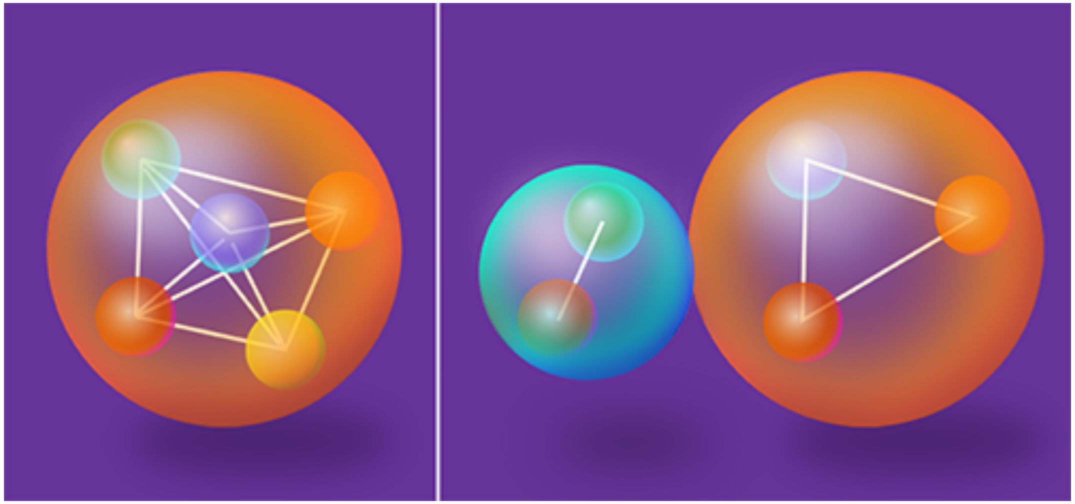


- Non-quark model mesons include exotic mesons, which have quantum numbers not possible for mesons in the quark model;
- glueballs or gluonium, which have no valence quarks at all;
- tetraquarks, which have two valence quark-antiquark pairs;
- hybrid mesons, which contain a valence quark-antiquark pair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

http://phys.org/news/2015-10-particle-purely-nuclear.html

The rise and fall (and rise) of the pentaquark

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



http://physics.aps.org/articles/v8/77

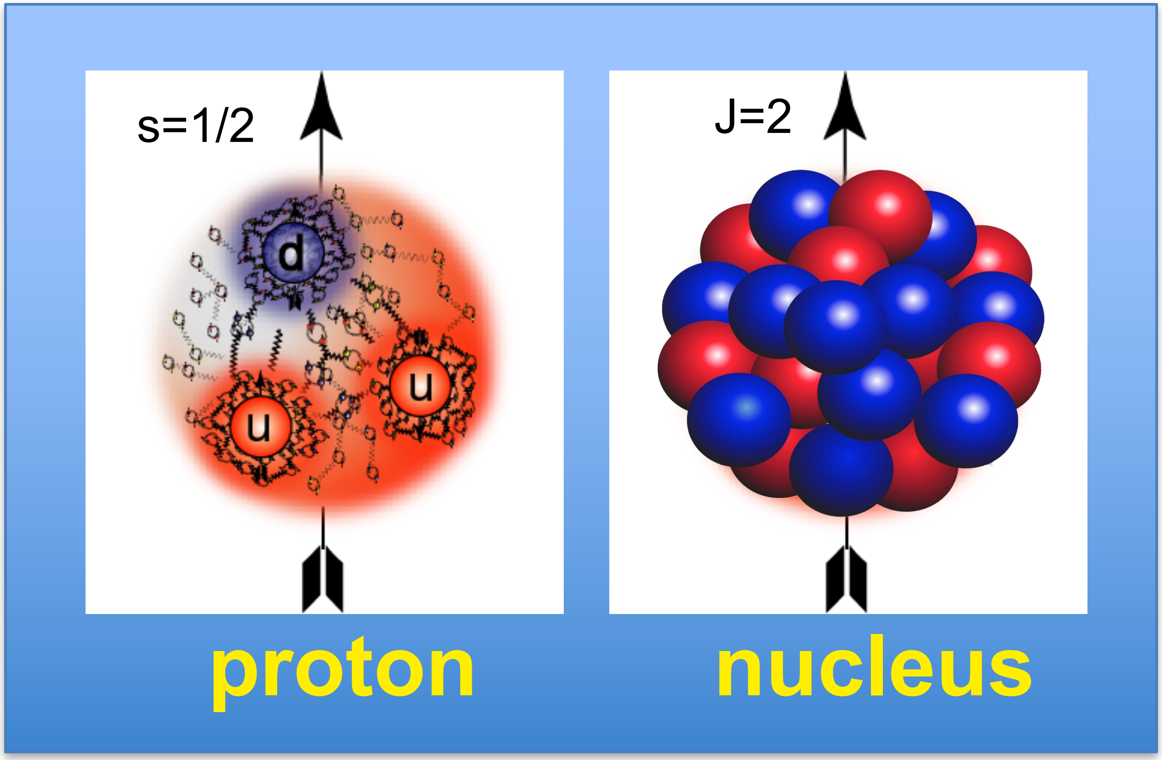
LHCb produces charmonium pentaquarks: Phys. Rev. Lett. 115, 072001 (2015)

http://physics.aps.org/articles/v8/77
http://phys.org/news/2015-07-cern-lhcb-exotic-pentaquark-particles.html
http://www.sciencedaily.com/releases/2015/07/150714082858.htm

http://physicsworld.com/cws/article/news/2016/feb/29/fermilab-bags-a-tetraquark
http://physicsworld.com/cws/article/news/2016/mar/21/cern-fails-to-confirm-fermilab-tetraquark-discovery

http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.117.082003 Confirmed!

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