proton radial charge distribution
from polarized electron scattering (JLAB)
neutron radial charge distribution
from polarized electron scattering (JLAB)

Note that neutron charge density contains regions of both positive and negative charge, a clear hint for sub-structure.

\[ \text{neutron} = (u \ d \ d) \]

up quark has \(q=+\frac{2}{3}\),
down quark has \(q=-\frac{1}{3}\).
Root mean square (rms) - radii for proton and neutron

The mean square radius can be obtained from the measured density distribution

\[ \langle r^2 \rangle = \int r^2 \rho(r) d^3r = \int 4\pi r^4 \rho(r)dr \]

The root mean square (rms) radius is defined as

\[ R_{rms} = \sqrt{\langle r^2 \rangle} \]

For both proton and neutron one finds rms radii of about 0.8 fm
Standard model of elementary particle physics
Quark sub-structure of nucleon and meson
Ref: National Research Council Report, 1999
Nucleon-nucleon interaction in quark picture / baryon-meson picture
Ref: National Research Council Report, 1999
Nucleon-nucleon interaction in baryon-meson picture and in quark picture

Feynman diagram of one-pion exchange (pointlike p, n, π).
Baryon-meson quantum Field theory

Feynman diagram in quark picture
Nucleon-nucleon interaction in potential picture

At low energies, the two nucleons “see” each other as structure-less point particles (large de Broglie – wavelength, see section 1.4). The N-N interaction can be adequately described by an interaction potential which depends on the positions, momenta, spins, and isospins of the two nucleons:

\[ V_{NN} = V_{NN}(\vec{r}_1, \vec{p}_1, s_{z1}, t_{z1}; \vec{r}_2, \vec{p}_2, s_{z2}, t_{z2}) \]

The N-N interaction potential can be derived from quantum field theory of baryons interacting via virtual meson exchange; the potential is obtained from the T-matrix in the static limit.

Ref: Bjorken & Drell, Relativistic quantum mechanics
From quarks to nuclei
Ref: RIA Physics White Paper 2000

Figure 1: From QCD vacuum to heavy nuclei: the intellectual connection between the hadronic many-body problem (quark-gluon description of a nucleon) and the nucleonic many-body problem (nucleus as a system of Z protons and N neutrons). The bridges illustrate major physics challenges: the mechanism of quark confinement, the understanding of the bare nucleon-nucleon interaction in terms of the quark-gluon dynamics, and the understanding of the effective interactions in heavy nuclei in terms of the bare force.