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From QED atoms to QCD hadrons

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Hadrons have been the focus of much interest in the past 50 years. The challenges of Poincaré covariance and color confinement have been addressed by various methods, including QCD theory, numerical (lattice) and model approaches. We have considerable experience with atoms and molecules. Yet the bound state principles of Quantum Field Theory are not found in textbooks.

The bound state methods of QED are based on a perturbative expansion unlike that of the perturbative S-matrix. The expansion starts from a state (given, *e.g.*, by the Bethe-Salpeter or Schrödinger equation), whose wave function is non-polynomial in the coupling α. An instantaneous potential is generated by the gauge-fixing of the A^0 or A_L fields. In temporal gauge ($A^0 = 0$) there is a constraint on physical states which determines the instantaneous longitudinal electric field E_L.

Hadrons are strongly bound, yet their spectra are routinely classified as for atoms. The apparent dominance of the valence ($q\bar{q}$, qqq) components of QCD bound states is paradoxical: The strong gluon field would be expected to generate an abundance of quark and gluon constituents.

The hadronic scale $\Lambda_{QCD} \simeq 1$ fm^{-1} is not in the QCD action. Solving the constraint for E_L requires a boundary condition (scale) Λ, which need not vanish for QCD. $\Lambda \neq 0$ implies a linear $O(\alpha_s^0)$ potential $V(r) = \Lambda^2 r$ for $q\bar{q}$ states. The scale Λ is universal, and fully determines the confining potential also of other (globally) color singlet states $(qqq,\ q\bar{q}g,\ gg)$.

The $O(\alpha_s^0)$ states are bound by the instantaneous potential and define the lowest order of a formally exact expansion. Higher Fock states with transverse (propagating) gluons and $q\bar{q}$ pairs are generated as power corrections in α_s by the interaction terms of $\mathcal{H}_{QCD}$. The dynamics is simplified at $O(\alpha_s^0)$ but still non-trivial, with Poincar\'e covariance dynamically realized. Mesons lie on linear Regge trajectories (at small quark masses) and there are features of parton-hadron duality and quark hadronization as observed in experiments [1,2].

[1] Paul Hoyer, Journey to the Bound States, SpringerBriefs in Physics (Springer, 2021) arXiv:2101.06721 [hep-ph].
[2] Paul Hoyer, "QCD bound states in motion,"Phys. Rev. D 108, 034031 (2023), arXiv:2304.11903 [hep-ph].

Internet talk

Maybe

Is this an abstract from experimental collaboration?

No

Name of experiment and experimental site

N/A

Is the speaker for that presentation defined?

No

Details

N/A

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