Light hybrid baryons

in the constituent model of QCD

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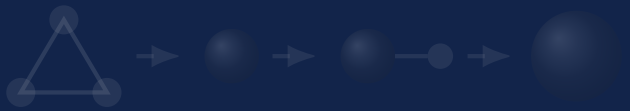
https://arxiv.org/abs/2606.14451



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What do we mean by constituent picture ?

Constituent picture: hadrons = color neutral bound states of colored quarks and gluons.
Example:

$$3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10.$$

$\hookrightarrow$ Our model:

- $\rightarrow$ Interactions modeled by phenomenological QCD-inspired potentials.
- $\rightarrow$ Spectra obtained by solving a Schrödinger-like equation:

$$H|\Psi\rangle = E|\Psi\rangle, \text{ with } H = T + V.$$

Why the name of hybrid?

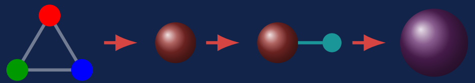
- Conventional baryons: three quarks, gluons only *mediate* the interactions.
- QCD allows more: baryons where a gluonic excitation is an active dynamical degree of freedom.
- In the constituent picture:

$$3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10$$
$$\hookrightarrow 8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \overline{10} \oplus 27.$$

→ Presently: 4−body problem where a constituent gluon interacts with the three quarks.

The core-gluon idea

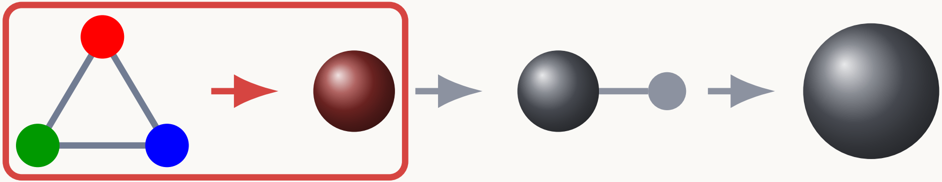
When a complex four-body problem becomes two easier ones



Divide and conquer

4−body quantum system + helicity degrees of freedom → a mess... ☹

↪ Core-gluon approximation, from [1].



- Group the three quarks into an effective quark core.
- The core carries a definite J^P and an octet colour charge.

[1] Cimino et al., Phys. Rev. D 110 (2024) 034032

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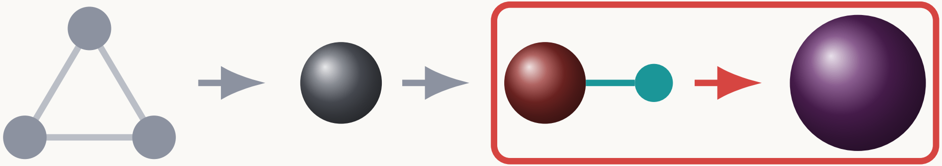


- Quark core + constituent gluon → effective 2-body system.
- Construct the hybrid baryon states within the two-body helicity formalism.

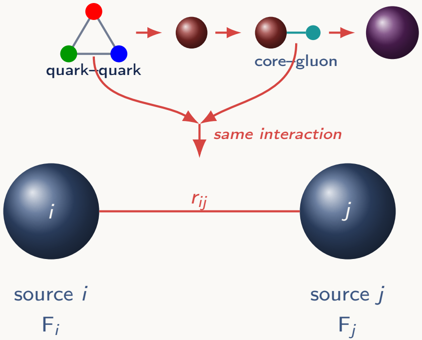
Echoes the quark-diquark picture of conventional baryons [2].

[1] Cimino et al., Phys. Rev. D 110 (2024) 034032 [2] Tourbez et al., Eur. Phys. J. A 62 (2026) 101

Which interaction to use ?

- Working hypothesis: universality of colour interactions

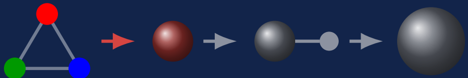
$$V(r) = \underbrace{\sigma\, r + \mathrm{F}_i \cdot \mathrm{F}_j\, \frac{\alpha_s}{r} + V_0}_{\text{Cornell-like}}$$
$$\underbrace{- \mathrm{F}_i \cdot \mathrm{F}_j\, \frac{8\alpha_{ss}\Lambda^3}{3\sqrt{\pi}\, m_1 m_2}\, e^{-\Lambda^2 r^2}\, \mathrm{s}_i \cdot \mathrm{s}_j}_{\text{regularised hyperfine}}$$



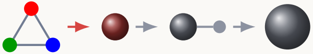
Same Cornell-type potential everywhere – only the colour factor $\mathrm{F}_i \cdot \mathrm{F}_j$ and the parameters change between quark-quark and core-gluon interactions.

Step 1 – the quark core

a core to rule them all



The quark-core Hamiltonian



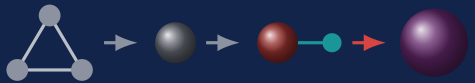
$$H_C = \sum_{i=1}^{3} \sqrt{p_i^2 + m_i^2} + \sum_{i<j} \left[\sigma\, r_{ij} + \mathrm{F}_i \cdot \mathrm{F}_j \, \frac{\alpha_s}{r_{ij}} + V_0 - \mathrm{F}_i \cdot \mathrm{F}_j \, \frac{8 \alpha_{ss} \Lambda^3}{3 \sqrt{\pi} m_i m_j} e^{-\Lambda^2 r_{ij}^2} \, \mathrm{s}_i \cdot \mathrm{s}_j \right]$$

- Same Hamiltonian as for conventional baryons [1].
- Parameters fixed on the experimental masses of the nucleon and the Δ.
- Resolution with the oscillator-basis expansion method [2].
  - $\rightarrow$ No orbital excitation: $L_C = 0$.
  - $\rightarrow$ The mass spectrum + eigenfunctions will be used in step 2.

[1] Theußl et al., Eur. Phys. J. A 12 (2001) 91–101
[2] Chevalier and Khodja, Few Body Syst. 65 (2024) 86

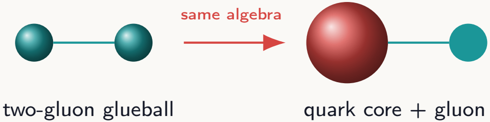
Step 2 – the core-gluon system

a two-body problem, with a twist: finite core size



A useful analogy: two-gluon glueballs

- Core (octet) + gluon (octet) $\rightarrow$ singlet.
- Formally the same colour algebra as a two-gluon glueball.
- Core-gluon potential parameters: fitted on the LQCD glueball spectrum [1,2].
- The gluon has a constituent mass m_g and $J^P = 1^-$.



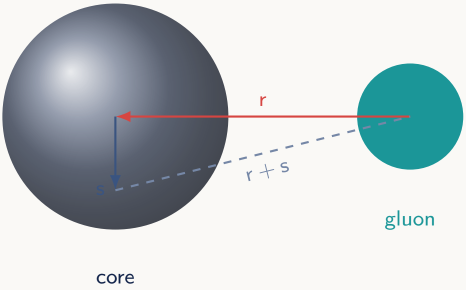
$$V_{Cg}(r) = \sigma_{Cg}\, r - 3\,\frac{\alpha_{s_{Cg}}}{r} + \frac{8\alpha_{ss_{Cg}}\Lambda_{Cg}^3}{\sqrt{\pi}\, m_C\, m_g}\, e^{-\Lambda_{Cg}^2 r^2}\, \mathbf{s}_C \cdot \mathbf{s}_g .$$

[1] Meyer and Teper, Phys. Lett. B 605 (2005) 344
[2] Chen et al., Phys. Rev. D 73 (2006) 014516

The core is not point-like

- Naive potential $V_{Cg}(r)$: depends on core-gluon distance only.
- Real interaction: gluon feels every quark inside the core.
- Fix: convolute V_{Cg} with the core's own quark density ρ, computed from the 3-body wave function.

$$\tilde{V}_{Cg}(r) = \int d^3s \, \frac{\rho(\mathrm{s})}{3} \, V_{Cg}(|\mathrm{r} + \mathrm{s}|)$$



The constituent gluon: spin or helicity ?

- Constituent gluons with two helicity degrees of freedom.

  $\hookrightarrow$ Better reproduce LQCD results for two-gluon glueballs [1].

- Core-gluon system $\leftrightarrow$ two-gluon glueball.

  $\Rightarrow$ Even with a mass, the gluon keeps $\lambda_g = \pm 1$.

  $\rightarrow$ The physical states $|\Psi, J^P\rangle$ must be build using the helicity formalism [2].

[1] Mathieu et al., Phys. Rev. D 77 (2008) 114022

[2] Chevalier and Mathieu, Phys. Rev. D 112 (2025) 014015

Getting the mass spectrum

Solve the eigenvalue equation

$$H_{HB}|\Psi, J^P\rangle = M|\Psi, J^P\rangle$$

with

$$H_{HB} = \sqrt{\boldsymbol{p}^2 + m_C} + \sqrt{\boldsymbol{p}^2 + m_g} + \tilde{V}_{Cg}\,.$$

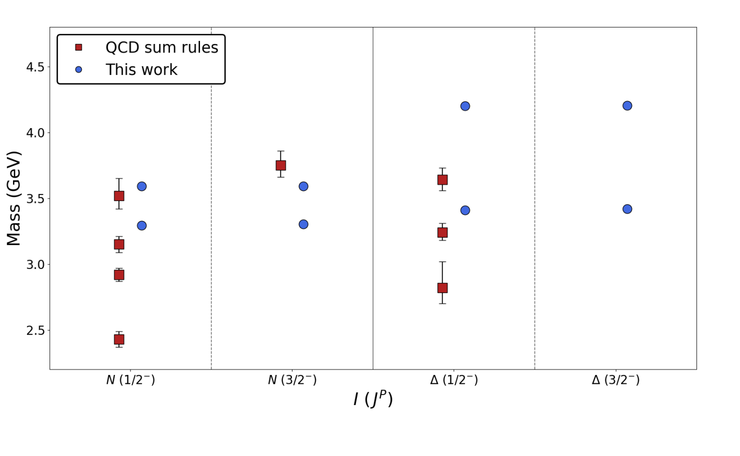
$\rightarrow$ Lagrange mesh method: quasi-variational method based on a mesh made of the roots of some Lagrange functions [1].
$\hookrightarrow$ Fast and precise for two-body systems.

[1] Viseur and Chevalier, Eur. Phys. J. A 62 (2026) 34

Results

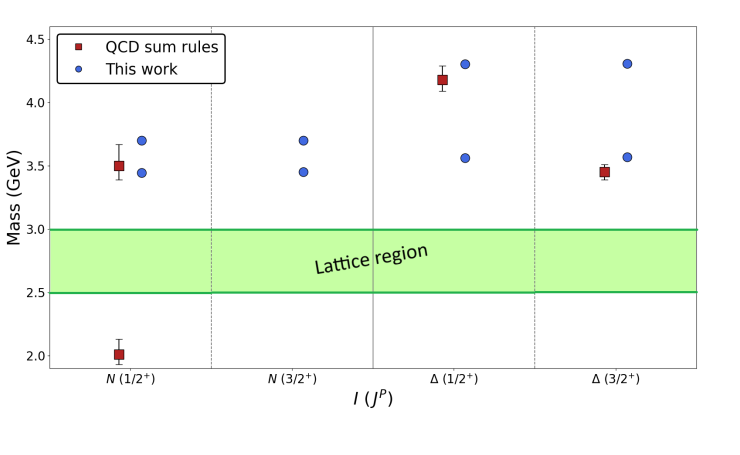
the light hybrid baryon spectrum

The light hybrid baryon spectrum



Negative parity
QCD Sum Rules results from Wang et al., Phys. Rev. D 113 (2026) 014033.

The light hybrid baryon spectrum



Positive parity
QCD Sum Rules results from Wang et al., Phys. Rev. D 113 (2026) 014033. Lattice results from Dudek and Edward, Phys. Rev. D 85 (2012) 054016.

Outlook

It is just the beginning

Next on the list

- Compute decay properties – essential for experimental searches.
- Polarisation of the quark core by the gluon (cf. atomic core polarisation).
- Extend to mixed-flavour baryons.

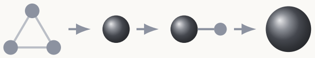
decays properties

core polarisation

mixed-flavour baryons

Take-home message

- A four-body problem, tamed as 3-body core + 2-body core-gluon.
- Full light hybrid baryon spectrum: lightest states above $\sim$3.3 GeV, negative parity favoured.
- Qualitative agreement with LQCD and QCD sum rules; hybrid baryon states should lie above 2 Gev.



Thank you

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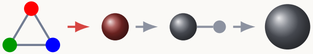
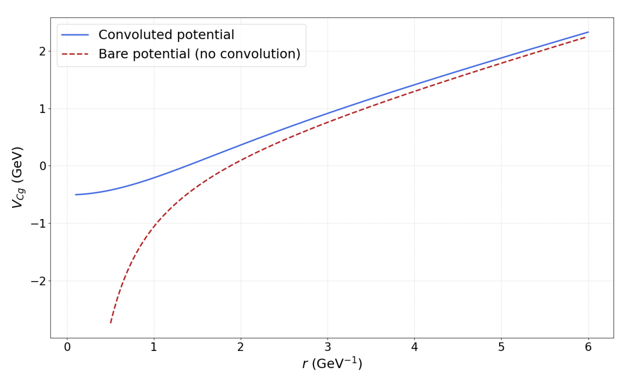
Back up slides

The core is heavier than an ordinary baryon 

J_C^P	I_C	ordinary baryon (GeV)	**octet quark core** (GeV)
$\frac{1}{2}^+$	$\frac{1}{2}$	0.941 (N)	1.481
	$\frac{3}{2}$		1.615
$\frac{3}{2}^+$	$\frac{1}{2}$		1.562
	$\frac{3}{2}$	1.232 (Δ)	2.228

- Same Hamiltonian shape, different colour representation $\Rightarrow$ heavier spectrum.
- Richer symmetry structure of the octet core $\Rightarrow$ twice as many accessible states as for an ordinary baryon at $L_C = 0$.
- These masses become the mass parameter m_C of the two-body problem next.

Effect of the convolution



Comparison of the convoluted and non-convoluted Cornell part of the core-gluon potential,for $L_C = 0, I_C = 1/2, J_C = S_C = 1/2$.

short range: regularized by the finite core size • *long range: the core looks point-like*