SS-6: Deuteron Observables Beyond Binding: Scope and Limits of the Base-to-Base Picture

600-Cell Standard Model Emergence Series

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Abstract

SS-5 derived the deuteron binding energy $B_d = 2.342$ MeV at leading order (+5.3%) from base-to-base bonding of hybrid-tetrahedral nucleons, along with concurrent predictions for ^{3}H, ^{3}He, and ^{4}He within 1.4%. A natural next question is whether the same bipyramid geometry predicts additional deuteron observables — the quadrupole moment Q_d, D-state admixture P_D, magnetic moment μ_d, matter radius r_d, and low-energy scattering parameters (a_{np}, r_0) — with comparable zero-parameter economy.

This paper reports a scoping exploration with one definitive negative finding and two quantitative consistency checks. The negative finding: the rigid bipyramid's *intrinsic* body-frame quadrupole is $Q_0^{\text{body}} = -0.22$ fm^2 (oblate), which converts to a lab-frame spectroscopic contribution of only ≈ -0.022 fm^2 — an order of magnitude smaller than and opposite in sign to the observed prolate $Q_d = +0.286$ fm^2. This is not a failure of the mechanism; it reveals that Q_d, r_d, P_D, and μ_d are dominated by the *orbital* deuteron wavefunction at $r \sim 2$ fm, not by the bipyramid at ~ 0.4 fm. The two consistency checks: (i) the universal Bethe-Peierls relation $a_{np} \approx 1/\kappa$ gives $a_{np} = 4.32$ fm from B_d alone (−20% vs observed 5.43 fm); this is standard two-body quantum mechanics, not a CPP-specific prediction. (ii) Inverting the effective-range expansion on the observed a_{np} and κ recovers the effective range to +0.8% ($r_0 = 1.76$ fm vs experimental 1.749 fm) — a notable consistency check indicating the deuteron's short-range potential is smooth and well-characterized by a single length scale.

We classify each deuteron observable into three categories: (A) bipyramid-geometric and hence computable at SS-5 precision (binding, spin-parity, isospin); (B) bipyramid-via-$V_{\text{SR}}(r)$ and hence computable once the short-range potential shape is derived (a_{np}, r_0, virtual singlet); (C) orbital-dominated and hence requiring the full deuteron wavefunction beyond the bipyramid core (Q_d, r_d, P_D, μ_d). Two new open problems are registered: OPEN-SS-20 (derive $V_{\text{SR}}(r)$ from CPP primitives) and OPEN-SS-21 (derive the deuteron orbital wavefunction in the CPP framework). This paper does not attempt to close either.

Keywords: deuteron quadrupole moment, scattering length, effective range, D-state admixture, magnetic moment, intrinsic vs orbital contributions, short-range potential, Bethe-Peierls relation, zero-range approximation, bipyramid geometry, base-to-base nucleon configuration, 600-cell lattice, Conscious Point Physics, scoping analysis.

Plain Language Summary: SS-5 showed that gluing two tetrahedral nucleons together face-to-face correctly predicts their binding energy. A natural follow-up question is whether the same glued-tetrahedron geometry predicts *other* deuteron properties — its shape (quadrupole moment), its size (matter radius), and its scattering behaviour. This paper reports what we find when we ask this: the geometry predicts the binding cleanly, and gives a rough first-guess for how slowly-moving neutrons scatter off protons, but it cannot by itself predict the deuteron's shape and size, because the deuteron spends most of its time with the two nucleons orbiting *around* each other at about 2 femtometres separation — much larger than the half-femtometre bipyramid core. So this paper is an honest scoping report: here is what the geometric picture predicts well, here is what it doesn't, and here are the new pieces we would need to derive to get the rest.

Contents

1 Introduction

SS-5 [1] derived four light-nuclei binding energies and three structural unboundness results from a single base-to-base bipyramid mechanism with zero fitted parameters. The question addressed here is whether the same mechanism predicts additional deuteron observables. If the bipyramid is a real geometric object and not a convenient mnemonic for the binding, then its charge distribution, spin structure, and coupling to external probes should produce definite predictions for Q_d, P_D, μ_d, r_d, a_{np}, and r_0 — all precisely measured.

This question is motivated by the "more stars for better navigation" principle: a mechanism that predicts one observable cleanly but fails on others is partially wrong; a mechanism that predicts several observables concurrently within the same residual band is likely structural. SS-5's seven concurrent predictions (four quantitative bindings plus three unboundnesses) already constitute a strong test. Additional deuteron observables, if predicted at comparable precision from the same bipyramid, would further constrain the mechanism.

1.1 The finding, briefly

The result of this scoping is less triumphant than SS-5. Numerical exploration (§3) produces two clear outputs:

1. **The rigid bipyramid cannot produce the observed Q_d.** The three net-$+1/3$ EM charges in the base-to-base contact plane give a body-frame intrinsic quadrupole $Q_0^{\text{body}} = -0.22$ fm^2 (oblate), which converts for a $J = K = 1$ rigid rotor to a lab-frame spectroscopic contribution of only ≈ -0.022 fm^2. The observed $Q_d = +0.286$ fm^2 is ten times larger and opposite in sign. Interpreted correctly, this result *reveals* that the observed Q_d cannot arise from the bipyramid core; it must come from the *orbital* wavefunction at the deuteron's $\sim$2 fm scale, where the proton and neutron spend most of their time separated rather than in contact.
2. **The Bethe-Peierls relation places B_d and a_{np} in a universal consistency check.** For any shallow two-body bound state, $a_{np} \approx 1/\kappa$ with $\kappa = \sqrt{2\mu B_d}/\hbar c$. Using B_d alone gives $a_{np}^{(0)} = 4.32$ fm against the measured 5.43 fm (-20%). This is not a CPP-specific prediction; it is universal quantum scattering theory. What CPP *has* supplied is B_d; what it *owes* (OPEN-SS-20) is $V_{\text{SR}}(r)$, from which r_0 and the finite-range-corrected a_{np} follow.
3. **The effective-range expansion works to 0.8% at leading order.** Inverting the Bethe-Peierls relation on the observed $a_{np} = 5.425$ fm and $\kappa = 0.2316$ fm^{-1} gives $r_0 = 2(\kappa - 1/a_{np})/\kappa^2 = 1.76$ fm, against experimental $r_0^{\text{exp}} = 1.749$ fm. This $+0.8\%$ consistency is a notable positive finding: it indicates the deuteron's short-range potential is smooth and well-characterized by a single length scale r_0, which whatever $V_{\text{SR}}(r)$ CPP eventually derives must reproduce.

The upshot is a classification: some deuteron observables are bipyramid-computable; some require an additional CPP input (the $V_{\text{SR}}(r)$ shape); some require the orbital wavefunction and are beyond the present reach.

1.2 What SS-6 delivers

- A definitive structural finding: the observed deuteron quadrupole moment is orbital-dominated, not bipyramid-dominated. Rigid bipyramid alone predicts ≈ -0.022 fm^2

(oblate) in the lab frame; observation is $+0.286$ fm^2 (prolate).

- Two universal scattering-theory consistency checks: $a_{np} = 1/\kappa = 4.32$ fm from B_d alone (-20% vs measured 5.43 fm) and $r_0 = 1.76$ fm from effective-range inversion ($+0.8\%$ vs measured 1.749 fm).
- A three-category classification of deuteron observables by derivability from the bipyramid.
- Two new open problems: OPEN-SS-20 ($V_{\text{SR}}(r)$ shape) and OPEN-SS-21 (deuteron orbital wavefunction).

1.3 What SS-6 does not deliver

- No prediction of Q_d, P_D, μ_d, or r_d from CPP — these are orbital-dominated.
- No derivation of $V_{\text{SR}}(r)$ shape from CPP primitives.
- No numerical computation of r_0 or the effective-range-corrected a_{np}.
- No improvement to SS-5's B_d prediction.

This is a scoping paper, not a result paper. Its purpose is to sharpen the programme's claims by distinguishing what the bipyramid mechanism actually predicts from what requires additional CPP input.

1.4 Open problems addressed

- **OPEN-SS-10** (Nuclear binding $V(r)$): partially clarified — the integrated binding at A=2,3,4 was resolved in SS-5; the short-range shape of $V_{\text{SR}}(r)$ is now separately registered as OPEN-SS-20.
- **New OPEN-SS-20**: derive the shape of $V_{\text{SR}}(r)$ as a function of inter-nucleon separation from CPP primitives. Controls a_{np}, r_0, and the singlet virtual state.
- **New OPEN-SS-21**: derive the deuteron orbital wavefunction at ∼2 fm from CPP in a framework that connects to the bipyramid core at ∼0.4 fm. Controls Q_d, r_d, P_D, μ_d.
- **New PROP-SS-6-1**: the rigid bipyramid's body-frame $Q_0^{\text{body}} = -0.22$ fm^2 is oblate, lab-frame contribution ≈ -0.022 fm^2; observed prolate $Q_d = +0.286$ fm^2 is orbital-dominated.
- **New PROP-SS-6-2**: universal Bethe-Peierls gives $a_{np} = 1/\kappa = 4.32$ fm (-20%) from B_d; effective-range inversion additionally gives $r_0 = 1.76$ fm ($+0.8\%$).

2 Setup: The Bipyramid from SS-5

2.1 Geometric summary

In SS-5, the deuteron is the face-to-face contact of two hybrid-tetrahedral nucleons. Each nucleon (per SS-2) has:

- three quarks at the vertices of a triangular base face,
- one "open" vertex opposite the base carrying net polarity (+ for proton, − for neutron) but no additional electromagnetic charge,

- isosceles base geometry: u-u edge stretched to $r_{uu} = (1+\varepsilon_{\text{cage}})l_{\text{edge}} = 1.07$ fm with $\varepsilon_{\text{cage}} = 1.94$; u-d edges at $r_{ud} = 0.62$ fm (SS-2 [2]).

In the base-to-base deuteron configuration, the proton base $\{u, u, d\}$ contacts the neutron base $\{d, d, u\}$ with the three charge-opposite vertex pairs aligned, forming a K_3 contact face. Three quark-quark DP chains span the contact, with K_3 collective mode reducing the three oscillators to one effective binding mode at $B_{\text{pair}} = M_0/\varphi = 2.342$ MeV (LO).

The open vertices of the two nucleons point *outward* along the symmetry axis: proton's + vertex at $z = +h$, neutron's − vertex at $z = -h$, with h the apex-to-base distance of a single cage. The resulting compound object is a *bipyramid*: two tetrahedral cages joined at a common triangular base, apices pointing outward.

2.2 Key geometric lengths

For the numerical scale of the bipyramid core, SS-2 [2] and SM-8 [3] give:

$$\begin{aligned}
l_{\text{edge}} &= 0.364 \text{ fm},\\
l_{\text{unit}} &= \hbar c/\Lambda_{\text{QCD}} = 0.589 \text{ fm},\\
r_{uu} &= 1.07 \text{ fm} \quad \text{(proton u-u edge)},\\
r_{ud} &= 0.62 \text{ fm} \quad \text{(u-d edges)},\\
h &\approx 0.63 \text{ fm} \quad \text{(apex-to-base; equivalent-regular-tet estimate)}.
\end{aligned}$$

The apex-to-apex long axis of the bipyramid is $2h \approx 1.26$ fm. The equatorial extent is set by $r_{uu} = 1.07$ fm. The bipyramid is mildly prolate, aspect ratio $\sim$1.18.

These scales are all $\lesssim$1.3 fm — substantially smaller than the observed deuteron matter radius $r_d = 1.9753$ fm and charge radius $r_c = 2.1413$ fm.

2.3 The separation of scales

A crucial physical fact: in the deuteron, the proton and neutron are *not* locked in the contact bipyramid geometry. They orbit at an rms separation of $\sim$4 fm (inferred from $r_d^2 = \langle r_{np}^2\rangle/4$, giving $\langle r_{np}^2\rangle^{1/2} \approx 3.95$ fm). This is $\sim 10\times$ the bipyramid's internal scale and $\sim 4\times$ the bipyramid's apex-to-apex dimension.

This separation of scales is not a CPP issue — it is a standard feature of the deuteron recognized in all nuclear-physics treatments. The deuteron is a *loosely-bound* state: $B_d = 2.22$ MeV, kinetic energy $T \sim 33$ MeV, potential depth $V \sim 35$ MeV (standard textbook values), giving a binding $B = V - T \approx 2$ MeV that is the difference of two large, nearly-cancelling energies. The wavefunction extends far outside the attractive-potential range. The asymptotic behaviour $\psi(r) \sim e^{-\kappa r}/r$ with $1/\kappa = 4.32$ fm sets the observed size.

This separation of scales is the dominant physics controlling Q_d, r_d, P_D, and μ_d. It is *not* controlled by the bipyramid core.

3 The Observables

We work through the non-binding deuteron observables in turn, identifying what the bipyramid can and cannot say.

3.1 Spin, isospin, parity

Already addressed in SS-5 §7 at the bipyramid level: $J^P = 1^+$, $I = 0$. These are geometric consequences of the base-to-base K_3 alignment and the S-wave relative motion. No additional work required. **Category A (bipyramid-geometric).**

3.2 Quadrupole moment Q_d

3.2.1 Intrinsic bipyramid quadrupole (body frame)

Consider the bipyramid at rigid contact ($s = 0$ gap between the two bases). The three quark-quark DP chains span the contact with opposite-charge pairs superposed at identical (x, y) positions on the $z = 0$ contact plane:

- vertex 1: proton u ($+2/3$) superposed with neutron d ($-1/3$), net charge $+1/3$ at $(-r_{uu}/2, 0, 0)$;
- vertex 2: proton u ($+2/3$) superposed with neutron d ($-1/3$), net charge $+1/3$ at $(+r_{uu}/2, 0, 0)$;
- vertex 3: proton d ($-1/3$) superposed with neutron u ($+2/3$), net charge $+1/3$ at $(0, y_3, 0)$,

where $y_3 = \sqrt{r_{ud}^2 - (r_{uu}/2)^2} = 0.313$ fm is the base-triangle height from the u-u edge to the d vertex. Total net charge is $3 \times (+1/3) = +1$, the deuteron charge.

The apices at $z = \pm h$ carry polarity (one extra qCP each), not electromagnetic charge. They do not contribute to the intrinsic charge quadrupole.

In the *body frame* (bipyramid symmetry axis aligned with z), with charges at positions $\vec{r}_i$ and values q_i, the intrinsic quadrupole moment is

$$Q_0^{\text{body}} = \sum_i q_i(3z_i^2 - r_i^2).$$

With all three charges at $z_i = 0$, the formula reduces to

$$Q_0^{\text{body}} = -\sum_i q_i(x_i^2 + y_i^2) = -\frac{1}{3}\left[2 \cdot \frac{r_{uu}^2}{4} + y_3^2\right] = -\frac{1}{3}\left[\frac{(1.07)^2}{2} + (0.313)^2\right] = -0.224 \text{ fm}^2.$$

The negative sign indicates an *oblate* intrinsic charge distribution: charge concentrated equatorially, neutral poles axially.

3.2.2 Conversion to lab-frame spectroscopic quadrupole

The observed deuteron quadrupole $Q_d = +0.286$ fm^2 [4] is the *spectroscopic* quadrupole in the $J = 1, M = \pm 1$ stretched state. For a rigid rotor with symmetry axis $K = J$, the conversion from body-frame intrinsic Q_0^{body} to lab-frame spectroscopic Q is standard [6]:

$$Q = Q_0^{\text{body}} \cdot \frac{J(2J - 1)}{(J + 1)(2J + 3)}.$$

For $J = K = 1$: $Q = Q_0^{\text{body}}/10$. Applying this to the bipyramid's $Q_0^{\text{body}} = -0.224$ fm^2 gives the spectroscopic value one would observe *if the bipyramid dominated the deuteron's charge distribution*:

$$Q^{\text{bipyramid−only}} = \frac{-0.224}{10} \approx -0.022 \text{ fm}^2.$$

Finding 3.1 (Bipyramid cannot produce the observed Q_d)**.** *If the rigid base-to-base bipyramid dominated the deuteron's charge distribution, the predicted lab-frame quadrupole would be* $Q^{\text{bipyramid}-\text{only}} \approx -0.022$ *fm*^{2}*: an order of magnitude smaller than the measured* $Q_d = +0.286$ *fm*^{2}*,* and *the opposite sign. The bipyramid's equatorial-charge / neutral-pole geometry is intrinsically oblate; the observed deuteron charge distribution is prolate. This two-way mismatch cannot be closed by finite corrections to the bipyramid geometry.*

3.2.3 Interpretation

This is not a failure of the bipyramid mechanism. It is a diagnostic. The observed Q_d is well-known in conventional nuclear physics to arise from the D-wave ($L = 2$) component of the deuteron wavefunction at orbital separation $r_{np} \sim 2$ fm. The relationship (standard [6]):

$$Q_d \approx \frac{\sqrt{2}}{10}\int_0^\infty u(r)w(r)r^2\,dr - \frac{1}{20}\int_0^\infty w(r)^2 r^2\,dr,$$

where $u(r)$ is the S-wave radial wavefunction and $w(r)$ is the D-wave wavefunction, weights Q_d heavily with the large-r structure of the wavefunction. With $\langle r^2\rangle \approx 15$ fm^2 for the deuteron, the dominant contribution to Q_d comes from $r \gtrsim 2$ fm, far outside the $\lesssim$1 fm bipyramid core.

The bipyramid's lab-frame spectroscopic contribution is ≈ -0.022 fm^2 (oblate, small). The orbital wavefunction must therefore supply the entire observed $+0.286$ fm^2 plus a small compensating $+0.022$ fm^2 to cancel the bipyramid's intrinsic oblateness — a total orbital contribution of $\approx +0.308$ fm^2. The bipyramid contribution is only $\sim$7% of the orbital contribution by magnitude; this is why the orbital regime dominates Q_d observationally.

Proposition 3.2 (PROP-SS-6-1: Q_d is orbital-dominated)**.** *The rigid base-to-base bipyramid produces an oblate body-frame* $Q_0^{\text{body}} = -0.22$ *fm*^{2}*, converting to a lab-frame spectroscopic contribution* ≈ -0.022 *fm*^{2} *— an order of magnitude smaller than and opposite in sign to the observed prolate* $Q_d = +0.286$ *fm*^{2}*. The observed quadrupole therefore cannot arise from the bipyramid core alone; it is dominated by the orbital-scale (*$r \gtrsim 2$ *fm) D-wave wavefunction. Quantitative prediction of* Q_d *from CPP requires OPEN-SS-21 (orbital wavefunction), not bipyramid geometry alone.*

Category C (orbital-dominated).

3.3 Matter and charge radii r_d, r_c

$r_d = 1.975$ fm and $r_c = 2.141$ fm are both significantly larger than the bipyramid extent ($\lesssim 1.3$ fm). In standard nuclear physics, $r_d^2 = \frac{1}{4}\langle r_{np}^2\rangle + \frac{1}{2}(r_p^2 + r_n^2)$, with the first term (relative-motion) dominating.

The relative-motion contribution is controlled by the asymptotic form $\psi(r) \propto e^{-\kappa r}/r$ with $1/\kappa \approx 4.32$ fm. The size of the deuteron is essentially the size of this exponential tail, not the bipyramid core. **Category C (orbital-dominated).**

3.4 D-state admixture P_D and magnetic moment μ_d

The D-state admixture is the fractional weight of the $L = 2$ component of the deuteron wavefunction. Modern NN-potential extractions give $P_D = 4.5$–5.8% (Argonne v18 [7]: 5.76%; CD-Bonn: 4.85%; chiral N^{3}LO [8]: 4.5–4.9%). The D-wave extends throughout the orbital region; its weight is fixed by the full wavefunction, not by the bipyramid's intrinsic angular structure.

The magnetic moment μ_d follows from P_D via standard spin algebra:

$$\mu_d = \mu_p + \mu_n - \frac{3}{2} P_D (\mu_p + \mu_n - \tfrac{1}{2}),$$

with $\mu_p = 2.793\mu_N$, $\mu_n = -1.913\mu_N$ [4]. The experimental $\mu_d = 0.8574\mu_N$ implies $P_D \approx 3.9\%$ from this relation (slightly below the NN-potential extraction range, with the discrepancy attributed to meson-exchange and relativistic corrections).

Both P_D and μ_d are downstream consequences of the orbital wavefunction. **Category C.**

3.5 Scattering length a_{np} and effective range r_0

Low-energy np scattering in the triplet channel is described by the effective-range expansion

$$k \cot \delta_0 = -\frac{1}{a_{np}} + \frac{1}{2} r_0 k^2 + \dots$$

For a loosely-bound two-body state, the Bethe-Peierls relation connects a_{np} to the bound-state wavenumber $\kappa = \sqrt{2\mu B_d}/\hbar c$:

$$\frac{1}{a_{np}} = \kappa - \frac{1}{2} r_0 \kappa^2 + \dots,$$

so that

$$a_{np} = \frac{1}{\kappa} \left(1 + \frac{r_0 \kappa}{2} + \dots\right).$$

With $B_d = 2.2246$ MeV [5] and reduced mass $\mu = m_N/2 = 469.45$ MeV:

$$\kappa = \frac{\sqrt{2\mu B_d}}{\hbar c} = 0.2316 \text{ fm}^{-1}, \quad \frac{1}{\kappa} = 4.318 \text{ fm}.$$

Proposition 3.3 (PROP-SS-6-2: Zero-range scattering length follows from B_d via universal two-body theory)**.** *For any shallow two-body bound state, the Bethe-Peierls zero-range limit gives*

$$a_{np}^{(0)} = \frac{1}{\kappa} = 4.318 \textit{ fm}$$

using B_d as the only input. This is not a CPP-specific prediction — it is universal two-body quantum-mechanical scattering theory applied to any theory that correctly predicts B_d. The measured value is $a_{np} = 5.425$ fm [9], giving a zero-range error of -20.4% that is the well-known finite-range shortfall of the deuteron.

3.5.1 What CPP owes, and what CPP has already supplied

CPP's path to a precision a_{np} prediction is structural: CPP supplies B_d (done in SS-5); two-body scattering theory supplies $a_{np}^{(0)} = 1/\kappa$ automatically (universal); and CPP must additionally supply $V_{\text{SR}}(r)$ (OPEN-SS-20) to reach r_0 and the finite-range-corrected a_{np}.

The 20% zero-range residual is therefore not a "CPP error" at all; it is the distance any theory must travel from zero-range approximation to finite-range precision. What CPP *has* supplied — via B_d — is the scale on which the whole construction rests.

Inverting the Bethe-Peierls relation $1/a_{np} = \kappa - r_0\kappa^2/2 + \dots$ using measured $a_{np} = 5.425$ fm and $\kappa = 0.2316$ fm^{-1}:

$$r_0 = \frac{2(\kappa - 1/a_{np})}{\kappa^2} = \frac{2(0.2316 - 0.1843)}{(0.2316)^2} = 1.76 \text{ fm}.$$

The experimental effective range is $r_0^{\rm exp} = 1.749$ fm [10], so the leading-order effective-range expansion reproduces r_0 to +0.8% using only B_d and a_{np} as inputs. This is a notable consistency check: the deuteron is loosely enough bound that the effective-range expansion converges well at leading order, suggesting the underlying potential $V_{\rm SR}(r)$ is smooth and reasonably characterized by the single length scale r_0. Whatever CPP eventually derives for $V_{\rm SR}(r)$ must be consistent with this observation.

Category B (bipyramid-via-$V_{\rm SR}$).

3.6 Singlet virtual state

The $^1S_0$ np scattering channel has a virtual state near threshold: $E_v = +66$ keV above threshold (standard value). Analogously to the triplet, it is governed by the singlet channel $V_{\rm SR}^{(s)}(r)$ which in base-to-base CPP corresponds to the K_3 face under orientation misalignment (SS-5 §**??** discussion). Quantitative prediction again requires $V_{\rm SR}^{(s)}(r)$. **Category B.**

4 Three-Category Classification

Table 1 summarizes the classification for all deuteron observables considered.

Table 1: Classification of deuteron observables by CPP derivability.

Observable	**Measured**	**CPP category**	**Status**
Binding energy B_d	2.2246 MeV	A (bipyramid)	**Derived** in SS-5 at +5.3%
Spin $J^P = 1^+$	1^+	A (bipyramid)	Derived in SS-5
Isospin $I = 0$	0	A (bipyramid)	Derived in SS-5
Scattering length a_{np}	5.425 fm	B (via $V_{\rm SR}$)	Zero-range: 4.32 fm (−20%)
Effective range r_0	1.749 fm	B (via $V_{\rm SR}$)	Inverted from a_{np}, κ: 1.76 fm (+0.8%)
Singlet virtual state	+66 keV	B (via $V_{\rm SR}^{(s)}$)	Requires singlet $V_{\rm SR}$
Quadrupole Q_d	+0.286 fm^2	C (orbital)	Bipyramid lab-frame −0.022 fm^2: wrong sign, 10× too small
Matter radius r_d	1.975 fm	C (orbital)	Orbital-scale
Charge radius r_c	2.141 fm	C (orbital)	Orbital-scale
D-state admix P_D	4.5–5.8%	C (orbital)	Requires orbital WF
Magnetic moment μ_d	$0.857\mu_N$	C (orbital, via P_D)	Requires orbital WF

- **Category A (bipyramid-geometric, 3 observables):** binding, J^P, I. All derived in SS-5.
- **Category B (bipyramid-via-$V_{\rm SR}$, 3 observables):** a_{np}, r_0, singlet virtual state. Derivable once OPEN-SS-20 is solved.
- **Category C (orbital-dominated, 5 observables):** Q_d, r_d, r_c, P_D, μ_d. Derivable once OPEN-SS-21 is solved.

The classification is substantive: it tells a would-be critic that the bipyramid mechanism makes *no* claim about Q_d, r_d, P_D, or μ_d without additional CPP input. The Q_d-sign finding (Finding 3.1) *supports* this classification — the bipyramid actively predicts the wrong sign for Q_d if one were to apply it naively, which reveals that a different physical mechanism must dominate.

5 Open Problems

Open Problem 1 (OPEN-SS-20: Derive $V_{\mathrm{SR}}(r)$ shape from CPP primitives)**.** *Starting from the base-to-base K_3 face structure of SS-5, derive the shape of the short-range np potential $V_{\mathrm{SR}}(r)$ as a function of inter-nucleon separation r. Constraints:*

- $V_{\mathrm{SR}}(0) = -B_{\mathrm{pair}} = -2.342$ *MeV (LO, rigid contact).*
- $V_{\mathrm{SR}}(r) \to 0$ *as* $r \to \infty$*.*
- *Range scale:* $l_{\mathrm{edge}} = 0.364$ *fm (natural CPP scale).*

Candidate functional forms: Coulombic $V_{\mathrm{SR}}(r) \propto -l_{\mathrm{edge}}/\sqrt{l_{\mathrm{edge}}^2 + r^2}$*; Yukawa-like* $V_{\mathrm{SR}}(r) \propto -\exp(-r/l_{\mathrm{edge}})$*; smooth cutoff* $V_{\mathrm{SR}}(r) \propto -l_{\mathrm{edge}}/(l_{\mathrm{edge}} + r)$*. Each gives different numerical predictions for* r_0*. The correct form must be selected by a CPP-structural argument, not a fit. Once derived, resolution gives:*

- a_{np} *beyond zero range,*
- r_0 *from first principles,*
- *singlet-channel* $V_{\mathrm{SR}}^{(s)}(r)$ *and virtual-state energy,*
- *np phase shifts at low energy.*

Open Problem 2 (OPEN-SS-21: Deuteron orbital wavefunction from CPP)**.** *Derive the deuteron relative-motion wavefunction* $\psi_{np}(r)$ *in the CPP framework, connecting the bipyramid core at* $r \lesssim 1$ *fm to the orbital extension at* $r \sim 2$*–*4 *fm. This is a multi-scale problem: at short range the* K_3 *face dynamics dominate; at long range the wavefunction is governed by the attractive potential tail plus the kinetic-energy balance appropriate for a loosely-bound state. Once resolved, yields:*

- r_d*,* r_c *from* $\langle r_{np}^2 \rangle$*,*
- P_D *from* $|w(r)|^2$ *integrated weight,*
- Q_d *from standard quadrupole integrals including both intrinsic bipyramid contribution and orbital D-wave contribution,*
- μ_d *via the* P_D*-dependent magnetic-moment relation.*

The central unresolved question is how the CPP K_3 *collective mode extends from the rigid-contact limit to finite inter-nucleon separation in a way compatible with the observed orbital size.*

6 Discussion

6.1 Why the negative finding is useful

The Q_d-sign result (Finding 3.1) is not a failure of CPP; it is a clarification. Three points:

(i) It sharpens the mechanism's claims. SS-5 establishes that the bipyramid predicts binding; SS-6 establishes that the bipyramid does *not* predict quadrupole. This is a falsifiable, testable distinction that any competing mechanism also has to navigate — if an alternative theory claims to predict both B_d and Q_d from the same rigid geometric object, that theory is suspect.

(ii) It matches conventional nuclear physics. In the deuteron, Q_d is well-known to arise from the D-wave orbital tail, not from a short-range "shape." CPP joining this understanding, rather than claiming to predict Q_d from the bipyramid, is consistent with known physics.

(iii) It redirects programme effort. Instead of trying to squeeze Q_d, r_d, and P_D out of the bipyramid, the programme now has a sharply defined open problem (OPEN-SS-21) — derive the orbital wavefunction — which is the right target for the next serious theoretical effort.

6.2 The zero-range scattering length as a consistency check

The $a_{np} = 1/\kappa = 4.32$ fm zero-range prediction is not a CPP-specific result. Any theory that correctly predicts B_d automatically gets this zero-range prediction right at the same precision, via the Bethe-Peierls relation. What CPP must do is *go beyond* zero range by supplying $V_{\mathrm{SR}}(r)$. The 20% zero-range residual is therefore a measure of how far CPP has to travel to claim a precision prediction for a_{np}.

6.3 Comparison with the SS-5 strategy

SS-5's strength is a single mechanism giving seven concurrent independent predictions. SS-6's contribution is a single mechanism giving *one* concurrent clarification: the bipyramid's active prediction of an oblate intrinsic Q_d (wrong sign) reveals the orbital-dominance of the observed value. Compared to SS-5, this is a smaller paper with lower epistemic density, but it closes the easy avenue ("just predict more deuteron observables from the bipyramid") cleanly and redirects effort toward the real open problems.

7 Conclusion

Applied to deuteron observables beyond the binding energy, the SS-5 base-to-base bipyramid mechanism yields three categories:

- **A (bipyramid-geometric):** binding, spin, isospin, parity — derived in SS-5.
- **B (bipyramid-via-$V_{\mathrm{SR}}(r)$):** a_{np}, r_0, singlet virtual state — await $V_{\mathrm{SR}}(r)$ derivation (OPEN-SS-20).
- **C (orbital-dominated):** Q_d, r_d, P_D, μ_d — await orbital wavefunction (OPEN-SS-21).

The rigid-bipyramid body-frame quadrupole is oblate, and its lab-frame contribution (-0.022 fm^2) is ten times smaller and opposite in sign to the measured $Q_d = +0.286$ fm^2 — a diagnostic revealing that the observed Q_d is orbital-dominated. Two universal scattering-theory consistency checks from B_d alone: zero-range $a_{np} = 1/\kappa = 4.32$ fm (-20% vs 5.43 fm), and effective-range inversion $r_0 = 2(\kappa - 1/a_{np})/\kappa^2 = 1.76$ fm ($+0.8\%$ vs 1.749 fm). The 0.8% r_0 match is not a CPP-specific prediction but a notable consistency indicating the deuteron's short-range potential is smooth and well-characterized by a single length scale.

This paper does not close either of its two new open problems. Its contribution is scope clarification: it maps out which deuteron observables are downstream of the bipyramid (SS-5's territory), which require one further CPP input (OPEN-SS-20), and which require a new CPP framework for the orbital regime (OPEN-SS-21). The programme gains two sharp open problems and one definitive negative finding in exchange for an honest assessment of what the base-to-base mechanism actually claims.

7.1 Problem status after this paper

- OPEN-SS-10 (nuclear $V(r)$): clarified — integrated binding at A=2,3,4 done in SS-5; short-range shape now separately OPEN-SS-20.
- NEW OPEN-SS-20 ($V_{\mathrm{SR}}(r)$ shape): OPEN.
- NEW OPEN-SS-21 (orbital wavefunction): OPEN.
- NEW PROP-SS-6-1 (Q_d orbital-dominated; bipyramid lab-frame contribution 10× smaller and wrong sign): SUPPORTED by explicit body-frame and lab-frame calculations.
- NEW PROP-SS-6-2 (universal Bethe-Peierls $a_{np} = 1/\kappa$ plus effective-range inversion): DERIVED from standard two-body theory. Zero-range $a_{np} = 4.32$ fm (-20%); inverted $r_0 = 1.76$ fm ($+0.8\%$).

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