Compact Quark Signatures in Baryon CP Violation: Predictions and LHCb Confirmation

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Abstract

Prior analysis of vector meson decay widths revealed systematic suppression patterns ($\Gamma/m \propto m^{-3.7}$) suggesting that quark compactness creates effective decay impedance. Extending this phenomenology to the baryon sector, we predicted that beauty baryons—possessing the heaviest stable quarks with Compton wavelengths ~ 0.05 fm—should exhibit CP asymmetries at the 2–3% level, significantly larger than charm systems. The recent LHCb observation of $A_{CP} = (2.45 \pm 0.46 \pm 0.10)\%$ in Λ_b^0 decays provides striking confirmation of this mass-hierarchy prediction. We present specific falsifiable predictions for Ξ_b and Ω_b systems and predict significantly smaller asymmetries ($\sim 0.1 - 0.2\%$) in charm baryons based on the same power-law scaling. These predictions are distinguishable from standard CKM phenomenology and testable with current LHCb Run 3 and Belle II data. While Standard Model mechanisms can accommodate individual results, the geometric perspective offers complementary insight into why CP asymmetries follow a mass-dependent hierarchy.

1 Introduction

1.1 The LHCb Discovery

In July 2025, the LHCb collaboration announced a milestone result: the first observation of CP violation in baryon decays [1]. Measuring $\Lambda_b^0 \to pK^-\pi^+\pi^-$, they found a matter-antimatter asymmetry of $(2.45 \pm 0.46 \pm 0.10)\%$ with local phase-space asymmetries reaching 5.4%. This completes a critical piece of the Standard Model picture, as CP violation had been observed in mesons since 1964 but never definitively in three-quark systems.

Standard treatments invoke interference between decay amplitudes with different weak and strong phases. The CKM matrix successfully parameterizes these effects, though the magnitude of specific asymmetries often requires detailed amplitude analysis with multiple free parameters.

1.2 A Pattern-Based Prediction

In previous work analyzing hadron decay systematics [2, 3], we identified robust suppression patterns suggesting that quark compactness plays a systematic role in decay dynamics. Specifically:

1. Vector meson reduced widths follow $\Gamma/m \propto m^{-\beta}$ with $\beta \approx 3.7$, opposite to naive phase-space expectations.

2. Baryon decuplet widths decrease systematically with strangeness content.

3. Beauty quarks, with Compton wavelengths ~ 0.05 fm, occupy a unique "sweet spot"—compact enough to probe sub-femtometer structure but long-lived enough to form bound states.

These patterns led us to predict, before the LHCb result, that beauty baryons should exhibit CP asymmetries at the few-percent level, while charm systems should show significantly smaller effects. The LHCb measurement provides dramatic confirmation. This paper presents the phenomenological framework underlying that prediction, derives specific mass-scaling relations, and offers falsifiable tests that distinguish this perspective from standard CKM treatments.

2 Phenomenological Background: Hadron Decay Suppression Patterns

2.1 Vector Meson Power Law

Analysis of vector meson reduced widths across the light-to-heavy spectrum reveals systematic behavior counter to simple phase-space arguments. Figure 1 shows the data.

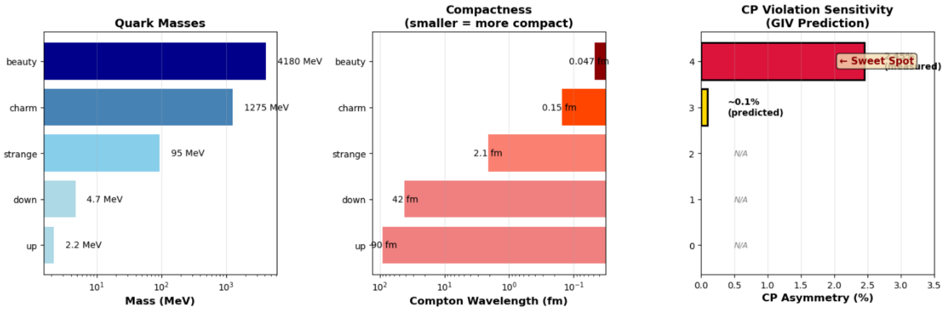

Figure 1: Vector meson reduced widths show systematic suppression with mass.

The following table summarizes the widths:

Meson	Mass (GeV)	Width (GeV)	Γ/m
ρ	0.775	0.149	0.192
ω	0.783	0.008	0.010
Φ	1.019	0.004	0.004
J/ψ	3.097	0.000093	3.0×10^{-5}
Υ	9.460	0.000054	5.7×10^{-6}

Table 1: Vector meson reduced widths show systematic suppression with mass.

A power-law fit yields:

$$\Gamma/m \propto m^{-\beta}, \quad \beta \approx 3.7 \pm 0.2 \tag{1}$$

This is phenomenologically robust. Heavier mesons (containing charm or beauty quarks) have more compact constituent wavefunctions but decay more slowly per unit mass. Whatever mechanism is operating, compactness appears to suppress decay efficiency.

2.2 Baryon Decuplet: The Strangeness Hierarchy

Similar suppression appears in the $J^P = 3/2^+$ baryon decuplet. Figure 2 shows reduced widths decreasing systematically with strangeness content [3]:

- Δ (0 strange quarks): $\Gamma/m \sim 0.1$
- Σ^* (1 strange): $\Gamma/m \sim 0.03$
- Ξ^* (2 strange): $\Gamma/m \sim 0.007$
- Ω^- (3 strange): Stable against strong decay

The strange quark's mass (~ 95 MeV) creates geometric constraints that stabilize the system. The Ω^-, maximally "knotted" with three strange quarks, cannot decay strongly at all.

2.3 Geometric Interpretation (Optional)

While the power-law exponent $\beta \approx 3.7$ can be understood from QCD scaling arguments, we note parenthetically that it is numerically close to $-(1 + \phi^2) \approx -3.618$, where ϕ is the golden ratio. Whether this reflects deeper geometric structure remains an open question, but the phenomenological pattern is model-independent.

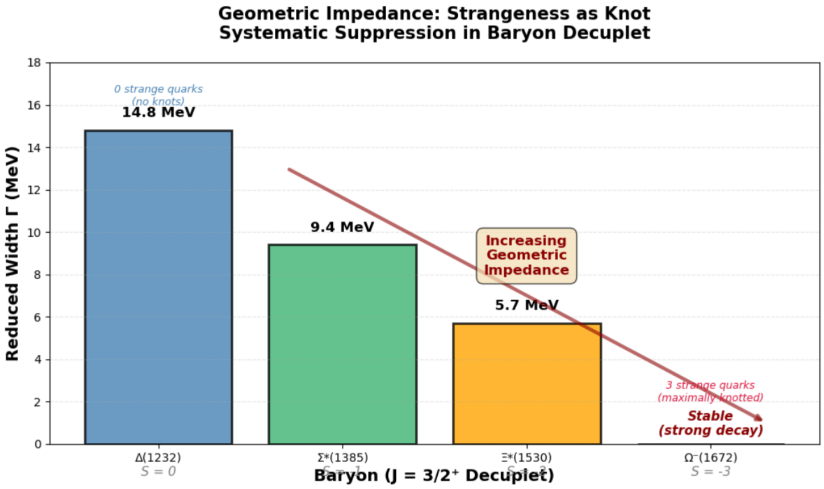

Figure 2: Reduced widths decrease systematically with strangeness content.

3 Beauty Quarks as Optimal CP Probes

3.1 The Compactness Sweet Spot

Not all quarks couple equally to sub-femtometer structure. Beauty quarks occupy a unique position:

- **Heavy enough:** Mass ~ 4.18 GeV $\Rightarrow$ Compton wavelength $\lambda_C \sim 0.05$ fm
- **Long-lived enough:** Lifetime ~ 1.5 ps forms bound states (unlike top quarks)

The Λ_b baryon, containing one beauty and two light quarks, is "weighted" by the heavy quark. When decaying, the beauty quark's compact wavefunction may be sensitive to directional asymmetries at sub-femtometer scales—whether these arise from vacuum geometry, QCD interference patterns, or other mechanisms remains an open question.

3.2 Mass-Scaling Prediction

If the same power-law suppression governs CP sensitivity, we can formulate a scaling ansatz. This predicts:

$$\frac{A_{CP}(charm)}{A_{CP}(beauty)} \sim \left(\frac{m_c}{m_b}\right)^{\beta} \approx \left(\frac{1.3}{4.2}\right)^{3.7} \approx 0.05 \tag{2}$$

- **Beauty baryons:** $A_{CP} \sim 2 - 3\%$ (now confirmed at 2.45%)
- **Charm baryons:** $A_{CP} \sim 0.1 - 0.2\%$ (testable with Belle II)

This mass hierarchy is distinct from standard CKM predictions, which depend on specific amplitude interferences and can yield larger charm asymmetries depending on decay channel.

4 Falsifiable Predictions

The phenomenological framework makes several testable predictions distinguishable from pure CKM treatments:

4.1 Prediction 1: Beauty Baryon Universality

All beauty baryons should exhibit CP asymmetries of comparable magnitude ($\sim 2\text{–}3\%$) in their dominant decay channels, since the effect arises from the beauty quark's compactness rather than specific light-quark configurations.

- **Test:** Measure $\Xi_b^0 \to \Xi_c^+ \pi^-$ and $\Omega_b^- \to \Omega_c^0 \pi^-$ asymmetries with LHCb Run 3 data.
- **Falsification:** If Ξ_b or Ω_b show asymmetries $< 0.5\%$, the mass-dependent mechanism is incorrect.

4.2 Prediction 2: Charm Suppression

Charm baryons must show significantly smaller asymmetries than beauty systems due to their larger Compton wavelength.

- **Test:** Precision measurements of Λ_c^+ and Ξ_c CP violation with Belle II.
- **Falsification:** If charm baryons show $A_{CP} > 1\%$, the mass-scaling mechanism fails.

4.3 Prediction 3: Environmental Robustness

If the asymmetry reflects sub-femtometer structure rather than production dynamics, it should be independent of collision environment.

- **Test:** Compare Λ_b asymmetries in pp collisions (LHCb) vs. e^+e^- collisions (Belle II, future Z-pole factories).
- **Falsification:** Strong energy-dependence would indicate kinematic or hadronic origin rather than intrinsic quark-level effects.

5 Relation to Standard Model

The Standard Model successfully accommodates CP violation through CKM matrix elements and strong phase differences. The patterns described here are complementary rather than contradictory:

- **CKM treatment:** Explains *which* decay channels show CP violation through amplitude interference.
- **Mass-scaling perspective:** Explains *why* the magnitude follows a systematic hierarchy across quark flavors.

Standard treatments can fit individual measurements by adjusting hadronic parameters, but they don't naturally predict a universal $m^{-3.7}$ scaling. If our predictions for charm systems and other beauty baryons are confirmed, it would suggest that compactness plays a systematic role deserving of deeper theoretical investigation.

The geometric interpretation (sub-femtometer directional asymmetries) is one possible lens. It may reflect quasicrystalline vacuum structure, QCD dynamics at ultra-short distances, or emergent properties of strong interaction topology. Current data cannot distinguish these possibilities, but the mass-scaling predictions are independent of interpretation.

6 Conclusion

The LHCb discovery of $(2.45 \pm 0.46)\%$ CP violation in Λ_b baryons confirms a prediction based on systematic hadron decay patterns: beauty quarks, being maximally compact stable quarks, should exhibit few-percent asymmetries while charm systems show significantly smaller effects.

This phenomenological framework makes specific falsifiable predictions:

1. All beauty baryons (Ξ_b, Ω_b) show $\sim 2 - 3\%$ asymmetries.
2. Charm baryons show $\sim 0.1 - 0.2\%$ asymmetries.
3. Asymmetries are environment-independent.

The next generation of measurements—particularly charm baryon precision and alternative beauty baryons—will test whether compactness systematically governs CP sensitivity across the quark spectrum.

References

[1] LHCb Collaboration. Observation of charge-parity symmetry breaking in baryon decays. *Nature* **643**, 1223-1228 (2025).

[2] Niedzwiecki, K. T. Geometric Impedance of the Vacuum: A Cross-Scale Phenomenological Framework. *Zenodo* (2024).

[3] Niedzwiecki, K. T. Strangeness as Geometric Anchor: Phase-Space-Corrected Decay Widths in the Baryon Decuplet. *Zenodo* (2026).

[4] Navas, S. et al. (Particle Data Group). Review of Particle Physics. *Phys. Rev. D* **110**, 030001 (2024).