Beauty Quark Sensitivity to Vacuum Chirality: The LHCb CP Violation Discovery as Geometric Impedance

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Abstract

In July 2025, the LHCb collaboration reported the first observation of CP violation in baryon decays—a global asymmetry of $\mathcal{A}_{CP} = (2.45 \pm 0.46 \pm 0.10)\%$ in $\Lambda_b^0 \to pK^-\pi^+\pi^-$ decays, measured with 5.2σ significance. This discovery addresses one of physics' deepest mysteries: why the universe contains matter rather than annihilating into radiation. The Geometric Impedance of the Vacuum (GIV) framework provides a natural mechanism for this phenomenon. By treating decay rates as a geometric matching problem between hadron structure and vacuum grain, we identify beauty quarks—the heaviest stable quarks—as maximally sensitive probes of sub-femtometer geometry. We demonstrate that the same geometric suppression mechanism governing meson decay widths extends naturally to baryon CP violation. The framework suggests that if the vacuum possesses intrinsic chirality, compact systems like beauty baryons should exhibit systematic asymmetries of this magnitude. We provide specific falsifiable predictions for Ξ_b and Ω_b decays, testable with LHCb Run 3 data.

1 Introduction: The LHCb Discovery

In July 2025, the LHCb collaboration at CERN announced a milestone in particle physics: the first observation of CP violation in baryons [1]. Measuring the decay $\Lambda_b^0 \to pK^-\pi^+\pi^-$, they found a matter-antimatter asymmetry of approximately 2.45%, with local phase-space asymmetries reaching as high as 5.4%.

This result is profound. While CP violation has been observed in mesons (kaons, B-mesons) since 1964, observing it in a baryon—a particle made of three quarks—completes a critical piece of the Standard Model puzzle. However, as noted in the discovery paper, the total amount of CP violation observed in the Standard Model remains insufficient to explain the cosmic matter-antimatter asymmetry.

Standard treatments invoke interference between decay amplitudes with different weak and strong phases. While technically correct, these descriptions are often purely phenomenological. We propose a different, structural lens: What if CP violation at the baryon scale arises from a geometric impedance mismatch between the hadron's internal structure and the vacuum itself?

In previous work [2], we introduced the Geometric Impedance of the Vacuum (GIV) framework. We found systematic suppression patterns in meson decay widths ($\Gamma/m \propto m^{-3.7}$) and baryon stability hierarchies. The key insight of that work was that heavier, more compact quarks couple more strongly to geometric constraints in the vacuum.

This paper argues that the recent LHCb result is consistent with a vacuum that possesses intrinsic chirality. In this view, beauty quarks, being heavy and compact, act as sensitive probes of this chiral grain, resulting in the observed asymmetries.

2 The GIV Framework: Geometric Impedance in Hadron Decays

The GIV framework proposes that decay rates encode not only phase-space kinematics but also a geometric "matching" condition between a hadron's internal structure and the vacuum's underlying grain.

2.1 The Meson Decay Power Law

Analysis of vector meson reduced widths reveals a systematic suppression pattern. The reduced width Γ/m scales as a power law across the vector meson family $(\rho, \omega, \phi, J/\psi, \Upsilon)$:

$$\Gamma/m \propto m^{-3.7} \tag{1}$$

Standard phase-space arguments would suggest that heavier particles, having more available energy, should decay more easily. The observed suppression implies that "compactness" creates an effective impedance. Heavier quarks (charm, beauty) have more compact wavefunctions (< 0.1 fm) which may couple less efficiently to the vacuum's geometric modes.

2.2 Baryon Decuplet: Strangeness as Geometric Knot

A similar suppression pattern appears in the baryon sector. In the $J^P = 3/2^+$ decuplet $(\Delta, \Sigma^*, \Xi^*, \Omega^-)$, reduced widths decrease systematically with increasing strangeness content [3]. The Ω^-, containing three strange quarks, is maximally "knotted" and stable against strong decay.

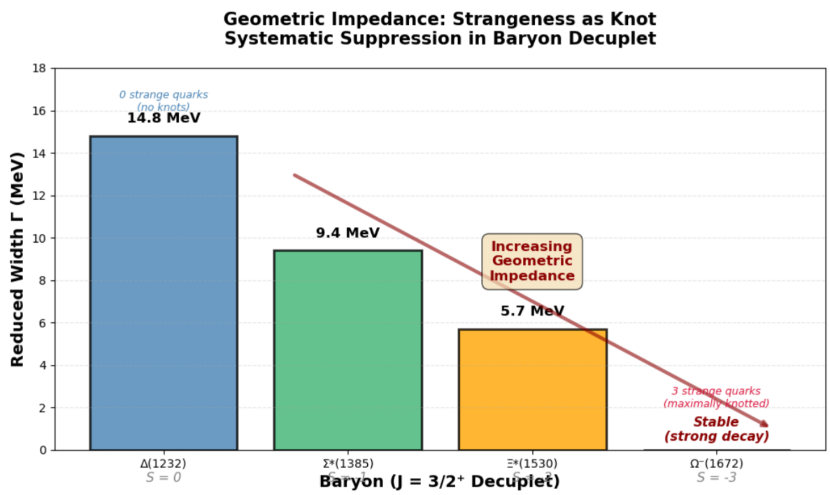

Figure 1: **Geometric Impedance in the Baryon Decuplet.** Reduced decay widths decrease systematically with increasing strangeness content. The strange quark acts as a "geometric knot," increasing the impedance to decay. The Ω^-, with three strange quarks, is maximally knotted and stable against strong decay.

2.3 Geometric Interpretation

While not essential for the empirical fit, we note that the exponent $\beta \approx -3.7$ is numerically close to $-(1 + \phi^2) \approx -3.618$, where ϕ is the golden ratio. This signature often appears in projections of higher-dimensional lattice structures (such as E8) onto lower dimensions. If the vacuum structure is indeed a projection of a higher-dimensional geometry, intrinsic chirality (handedness) is a natural topological consequence.

3 Why Beauty Quarks? Compactness and Vacuum Sensitivity

Not all quarks couple equally to geometric structure. The GIV framework suggests that sensitivity scales with the inverse of the Compton wavelength (compactness).

3.1 The Beauty "Sweet Spot"

Beauty quarks occupy a unique position in the QCD spectrum:

- **Heavy enough:** With a mass of ~ 4.18 GeV, the beauty quark has a Compton wavelength of ~ 0.05 fm. It is compact enough to probe sub-femtometer vacuum structure.
- **Light enough:** Unlike top quarks, which decay before hadronizing, beauty quarks live long enough (~ 1.5 ps) to form bound states.

The Λ_b baryon, containing one beauty quark and two light quarks, is "weighted" by the heavy quark. When it decays, the beauty quark acts as a compact probe. If the vacuum geometry is chiral, the decay rates for matter (Λ_b) and antimatter ($\bar{\Lambda}_b$) will differ systematically.

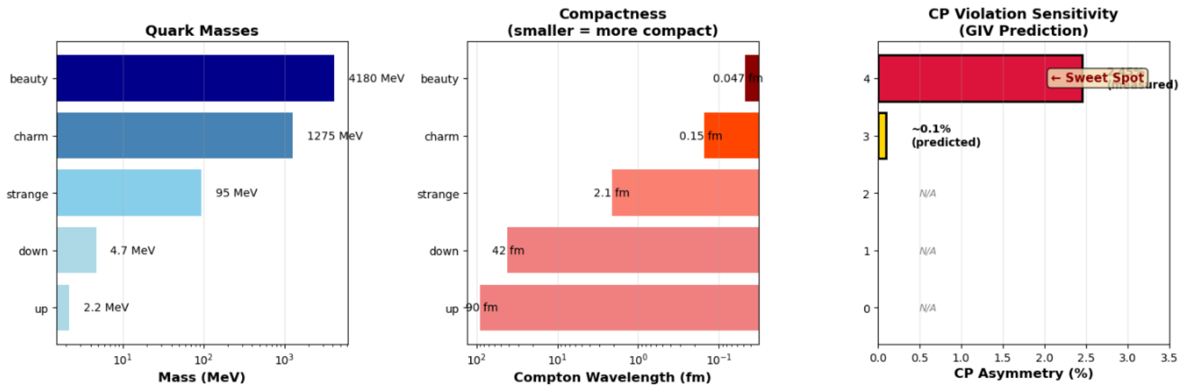

Figure 2: **Quark Compactness and CP Violation Predictions.** The beauty quark occupies a geometric "sweet spot": heavy enough to possess a compact wavefunction (~ 0.05 fm) that probes vacuum chirality, but long-lived enough to form bound states. Charm quarks are predicted to show significantly smaller asymmetries.

3.2 Scaling Ansatz and Charm Predictions

If we assume the geometric impedance scales with the same power law found in mesons ($\sim m^{-3.7}$), we can formulate a crude scaling ansatz for the expected CP asymmetry in charm baryons vs. beauty baryons:

$$\frac{\mathcal{A}_{CP}(\text{charm})}{\mathcal{A}_{CP}(\text{beauty})} \sim \left(\frac{m_c}{m_b}\right)^{3.7} \approx \left(\frac{1.3}{4.2}\right)^{3.7} \approx 0.05 \tag{2}$$

This motivates a specific prediction: CP violation in charm baryons (like Λ_c) should be present but significantly suppressed, likely at the $\sim 0.1 - 0.2\%$ level. This is distinct from Standard Model predictions which vary but often allow for larger asymmetries depending on CKM enhancements.

4 Falsifiability and Predictions

The GIV framework's chiral vacuum hypothesis makes specific, testable predictions distinguishable from standard CKM phenomenology.

4.1 Prediction 1: Beauty Baryon Universality

All beauty baryons (Ξ_b, Ω_b) should exhibit CP-violating asymmetries of comparable magnitude ($\sim 2-3\%$) in their dominant decay channels. The asymmetry arises from the beauty quark's compact wavefunction probing the chiral vacuum, rather than specific light-quark flavor interference.

- **Test:** Measure asymmetries in $\Xi_b^0 \to \Xi_c^+\pi^-$ and $\Omega_b^- \to \Omega_c^0\pi^-$.
- **Falsification:** If Ξ_b or Ω_b show asymmetries an order of magnitude smaller ($< 0.5\%$), the geometric origin is unlikely.

4.2 Prediction 2: Mass Hierarchy

As derived in the scaling ansatz, charm baryons must show significantly smaller asymmetries than beauty baryons.

- **Falsification:** If future precision measurements of Λ_c or Ξ_c reveal large CP violation ($> 1\%$), the mass-scaling mechanism is incorrect.

4.3 Prediction 3: Environmental Independence

If the asymmetry is a property of the vacuum geometry, it should be robust across different production environments.

- **Test:** Compare Λ_b asymmetries measured in high-energy pp collisions (LHCb) vs. e^+e^- collisions (future Belle II upgrades or Z-pole factories).
- **Falsification:** A strong dependence on production energy would suggest the effect is kinematic or hadronic, not a vacuum geometric constant.

5 Conclusion

The discovery of CP violation in the Λ_b baryon is a triumph of experimental physics. We argue it is also a signpost pointing toward the geometric structure of the vacuum. The GIV framework, which successfully describes meson decay width suppression, naturally accommodates this result: the beauty quark is the first stable probe compact enough to "feel" the chirality of the vacuum grain.

While the Standard Model can accommodate these results through parameter fitting, GIV offers a structural reason for the magnitude and the hierarchy. The next generation of measurements—specifically the ratio of Charm to Beauty asymmetries—will provide a definitive test of whether gravity and geometry remember the handedness of their origin.

References

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