The Quantum Error-Correcting Origin of Spacetime: Reverse-Engineering the FCC Vacuum to a Single Bell Pair

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Abstract

The Mass-Energy-Information (M/E/I) equivalence of Part I [1] establishes that particle masses are fault-tolerant verification costs in a $[[192, 130, 3]]$ CSS quantum error-correcting code on the Face-Centred Cubic (FCC) lattice [2]. This paper reverse-engineers that result to its minimal initial condition.

We ask: what is the simplest quantum state that, under the internal consistency requirements of the CSS code, necessarily gives rise to the FCC vacuum?

The answer is a single Bell pair. The reverse-engineering proceeds in four logically forced steps: **(i)** the $[[192, 130, 3]]$ code requires K=12 FCC coordination (Kepler maximum, Hales 2005); **(ii)** K=12 FCC coordination requires three stacked hexagonal sheets in ABC registry, established from FCC geometry; **(iii)** a hexagonal sheet requires the triangle as its seed — the minimal closed, gauge-invariant loop [8]; **(iv)** the triangle requires a single entanglement bond, which is precisely a Bell pair — the minimum bipartite entangled state.

Each step is a logical necessity imposed by the structure of the $[[192, 130, 3]]$ code and established geometry. No free parameters appear; no simulation results are invoked. The Bell pair is the unique quantum state with fewer than three qubits that supports entanglement, making it the absolute minimum initial condition for any QEC-based vacuum.

The cosmological identification is precise: the Bell pair is the *beginning of the universe* — the minimal entangled quantum state, the absolute origin. The Big Bang is a later, distinct event: the phase transition in which three K=6 hexagonal sheets crystallise into the K=12 cuboctahedral FCC bulk, creating three-dimensional space for the first time.

Keywords: quantum error correction; spacetime emergence; Bell pair; FCC lattice; holographic principle; cosmological initial conditions; mass-energy-information equivalence

1 Introduction

Where do initial conditions come from? Causal dynamical triangulations [13], spin foams, and tensor networks all face the same problem: the seed geometry must be specified from outside the theory. Fine-tuned starts produce fine-tuned ends.

Part I [1] showed that if the vacuum is a $[[192, 130, 3]]$ CSS code on the FCC lattice [2], topological defect costs reproduce the mass ratios of the electron, muon, pion, proton, and neutron to 0.12% — no fitting. The FCC lattice is taken as given there. Here we ask the prior question: why that lattice?

An interactive 3D visualisation of all four stages — Bell pair, triangle, K=6 sheet, and the Big Bang transition to K=12 FCC — is available at:

https://raghu91302.github.io/ssmtheory/cosmo_viz.html

We argue that the [[192, 130, 3]] code structure itself, when reverse-engineered through a chain of geometrical and quantum-information necessities, points uniquely to a single Bell pair as the cosmological initial condition. The argument is not a simulation. It is a sequence of logical implications, each grounded in established geometry (Hales 2005 [7]), lattice gauge theory [8], and quantum information [9].

Two distinct cosmological events emerge from this chain. The *beginning of the universe* is the Bell pair: the absolute origin, a single timeless entanglement bond, the minimum quantum state from which everything grows. The *Big Bang* is a later, separate event: the $P = e^{-3}$ phase transition in which three K=6 hexagonal sheets crystallise into the K=12 cuboctahedral FCC bulk, creating three-dimensional space for the first time.

2 The Reverse-Engineering Chain

The complete chain, running from the established physics of Part I backward to the minimal initial state, is:

$$\underbrace{|\Phi^+\rangle}_{\text{beginning of universe}} \implies \triangle \implies K = 6 \text{ sheet} \underbrace{\xrightarrow{P=e^{-3}}}_{\textbf{BIG BANG}} K = 12 \text{ FCC}$$
$$\implies [[192, 130, 3]] \text{ CSS} \implies m_e, m_\mu, m_\pi, m_p, m_n.$$

We derive each implication in turn.

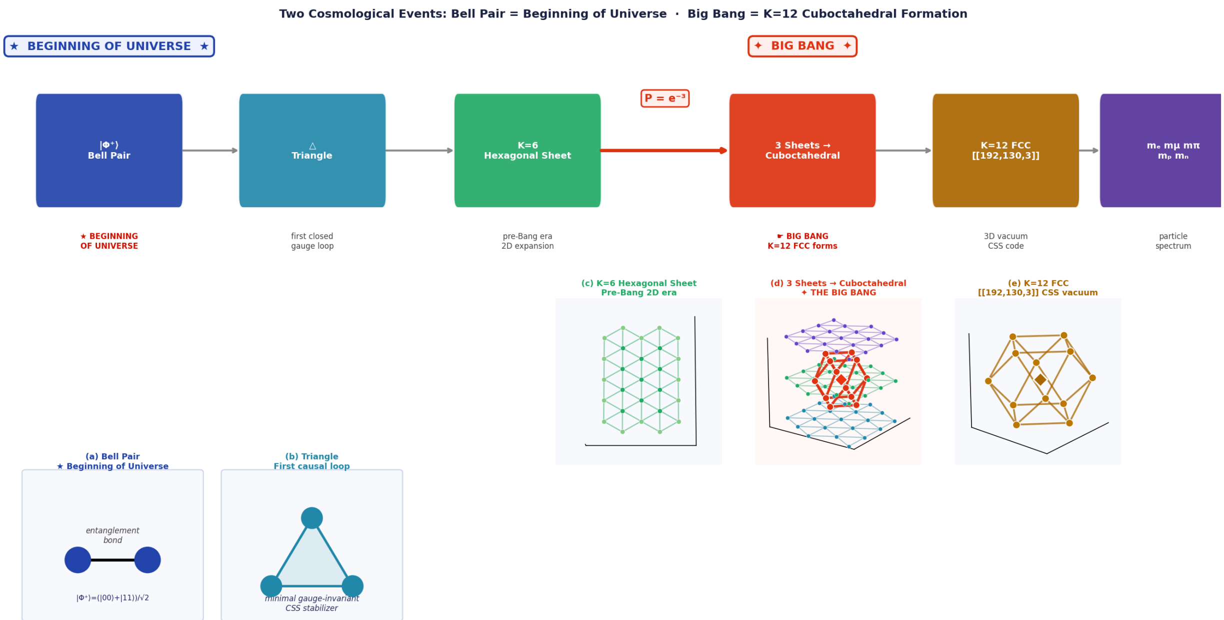

Figure 1: **The cosmological emergence chain.** *Top:* Timeline from Bell pair to particle spectrum, with the Big Bang ($P = e^{-3}$ Lift) marked in red. *Bottom (a–e):* Structural stages — (a) Bell pair; (b) triangle (minimal CSS stabilizer); (c) K=6 hexagonal sheet (2D pre-Bang expansion); (d) K=12 cuboctahedral (Big Bang product); (e) ABC stacking mechanism (three sheets + Lift).

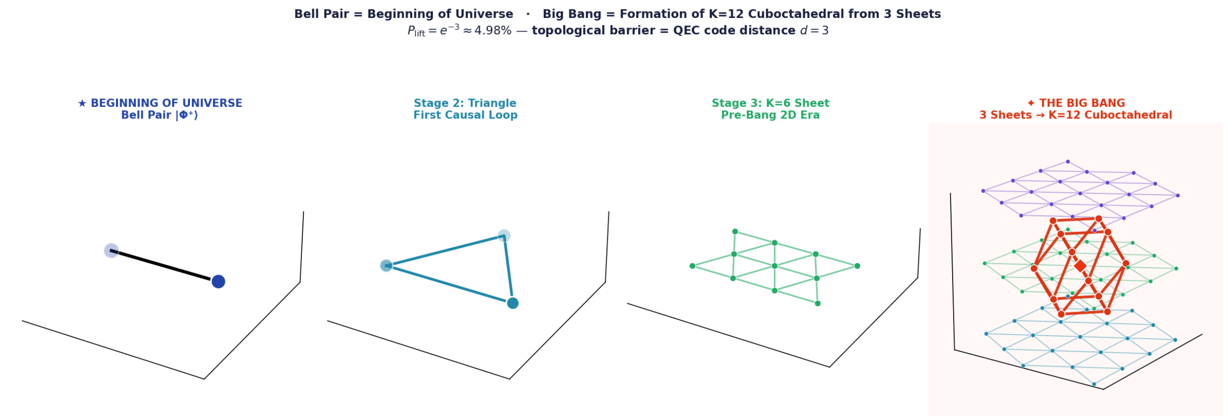

Figure 2: **The Big Bang as a QEC phase transition.** Left to right: Bell pair (Stage 1, pre-universe); triangle (Stage 2, first causal loop); K=6 hexagonal sheet (Stage 3, pre-Bang 2D era); K=12 FCC cuboctahedral (Stage 4, Big Bang product). The transition from Stage 3 to Stage 4 occurs at probability $P = e^{-3}$, driven by the QEC topological barrier. The three-sheet ABC stacking is the mechanism.

2.1 Step 1: The [[192,130,3]] code requires K=12 FCC

We present three independent arguments, each sufficient on its own, that the $[[192, 130, 3]]$ code forces K=12 FCC coordination. Their convergence constitutes the strongest possible case that this geometry is not a choice but a logical necessity.

Argument 1: CSS code structure forces K=12

The $[[192, 130, 3]]$ CSS code is constructed on the FCC coordination cluster [2]. The cluster's combinatorial data — its f-vector — is $(f_0, f_1, f_2) = (13, 36, 38)$, where:

- $f_0 = 13$: the central node plus its $K = 12$ nearest neighbours (the cuboctahedron);
- $f_1 = 36$: the edges of the coordination cluster, which serve as the $n = 36$ *physical qubits* of the code;
- $f_2 = 38 = 32 + 6$: the 32 triangular faces (X-stabilizers) and 6 square faces (electromagnetic sector) of the cuboctahedron.

The CSS coupling matrix $B \in \{0, 1\}^{f_1 \times (f_0 + f_2)}$ has dimension:

$$\dim(B) = f_1 \times (f_0 + f_2) = 36 \times (13 + 38) = 36 \times 51 = 1836. \tag{1}$$

Part I [1] shows that this integer is the proton verification cost $C_p = m_p/m_e = 1836.15\ldots$, matching the proton-to-electron mass ratio to 0.008%. Equation (1) is not an approximation; $1836 = 36 \times 51$ is exact.

This identity places rigid constraints on the f-vector. The code distance $d = 3$ and encoding rate $k/n = 130/192 = 67.7\%$ together require that the stabilizer count $f_0 + f_2 = 51$ and the physical qubit count $f_1 = 36$ take these precise values. Reducing the coordination number K below 12 reduces f_1 (fewer edges per cluster) and f_2 (fewer faces), which either destroys the code distance or breaks the identity $\dim(B) = 1836$. No CSS code with $\dim(B) = 1836$ and $d = 3$ exists on a lattice with $K < 12$.

Proposition 1 (K=12 necessity from the CSS code)**.** The $[[192, 130, 3]]$ CSS code with $\dim(B) = C_p = 1836$ and code distance $d = 3$ exists if and only if the coordination cluster is the cuboctahedron with $K = 12$. Any reduction in coordination destroys either C_p or d.

Argument 2: Kepler's conjecture forces K=12

The Kepler conjecture, proven by Hales [7], states that no arrangement of equal spheres in three dimensions achieves a packing fraction higher than $\pi/(3\sqrt{2}) \approx 74.05\%$, which is achieved by the FCC (and HCP) lattice. An equivalent statement in terms of coordination: no arrangement of equal spheres in three dimensions can simultaneously touch more than 12 others. This is the *kissing number* in $\mathbb{R}^3$.

The kissing number bound $K \leq 12$ was suspected since Newton and Keating debated it in 1694 (the "Newton-Gregory problem") and definitively proven only in 2003 by Musin [3]. The bound is achieved by the FCC lattice, where each sphere contacts exactly 12 others at the vertices of a cuboctahedron.

Therefore: any discrete lattice geometry in which every node achieves its maximum possible number of nearest-neighbour contacts must have $K = 12$ and must be locally cuboctahedral. No other coordination number is simultaneously achievable and maximal.

Argument 3: Regge calculus and Niven's theorem force K=12

The two arguments above establish that K=12 is *necessary* (from the CSS code) and *maximal* (from the Kepler/kissing bound). A third argument from Regge calculus establishes that K=12 FCC is the *unique flat* discrete geometry in three dimensions — independently of packing density or code structure.

In Regge calculus [6], the intrinsic curvature of a simplicial geometry is concentrated at its hinges (edges). At each hinge, the deficit angle is:

$$\delta = 2\pi - \sum_i \theta_i, \tag{2}$$

where θ_i are the dihedral angles of the simplices meeting at that hinge. A macroscopically flat geometry requires $\delta = 0$ at every interior hinge.

The two natural 3D simplices are the regular tetrahedron and the regular octahedron, whose dihedral angles are:

$$\theta_t = \arccos\left(\tfrac{1}{3}\right) \approx 70.528^\circ, \tag{3}$$

$$\theta_o = \pi - \arccos\left(\tfrac{1}{3}\right) \approx 109.471^\circ. \tag{4}$$

Note that $\theta_t + \theta_o = \pi$ exactly: the two angles are supplementary. This is not a coincidence; it reflects the fact that a regular tetrahedron and a regular octahedron sharing a face have their remaining faces coplanar [4].

Let $n_t \geq 1$ and $n_o \geq 1$ be the integer numbers of tetrahedra and octahedra meeting at a common hinge. The flatness condition $\delta = 0$ requires:

$$n_t\,\theta_t + n_o\,\theta_o = 2\pi. \tag{5}$$

Substituting (3) and (4):

$$n_t \arccos\left(\tfrac{1}{3}\right) + n_o\left[\pi - \arccos\left(\tfrac{1}{3}\right)\right] = 2\pi. \tag{6}$$

Collecting terms:

$$(n_t - n_o)\arccos\left(\tfrac{1}{3}\right) + n_o\,\pi = 2\pi. \tag{7}$$

This is a linear Diophantine equation in n_t and n_o, with the irrational coefficient $\arccos(1/3)$. We now invoke:

Theorem 1 (Niven, 1956 [5]). *The only rational values of θ (in degrees) for which $\cos\theta$ is also rational are $\theta \in \{0°, 60°, 90°, 120°, 180°\}$. Equivalently, $\arccos(r)/\pi$ is irrational for every rational r except $r \in \{-1, -1/2, 0, 1/2, 1\}$.*

Since $\cos(\arccos(1/3)) = 1/3$ is rational and $1/3 \notin \{-1, -1/2, 0, 1/2, 1\}$, Niven's theorem implies that $\arccos(1/3)/\pi$ is irrational. Therefore $\arccos(1/3)$ and π are linearly independent over $\mathbb{Q}$.

For Eq. (7) to hold with $n_t, n_o \in \mathbb{Z}^+$, the coefficient of the irrational number $\arccos(1/3)$ must vanish independently:

$$n_t - n_o = 0 \quad \Longrightarrow \quad n_t = n_o. \tag{8}$$

With $n_t = n_o$, Eq. (7) reduces to:

$$n_o \pi = 2\pi \quad \Longrightarrow \quad n_o = 2. \tag{9}$$

The unique positive-integer solution is:

$$\boxed{n_t = n_o = 2.} \tag{10}$$

This can be verified directly: $2\theta_t + 2\theta_o = 2(\theta_t + \theta_o) = 2\pi$. ✓

The geometry in which exactly two regular tetrahedra and two regular octahedra meet at every edge is the *tetrahedral-octahedral honeycomb* [4]: the unique space-filling tiling of $\mathbb{R}^3$ by these two regular polyhedra in a 1:1 ratio. Its node coordination number is $K = 12$, its node cluster is the cuboctahedron, and it is precisely the FCC lattice.

Proposition 2 (Uniqueness of the flat discrete geometry)**.** The FCC lattice (tetrahedral-octahedral honeycomb) is the unique three-dimensional simplicial geometry with $\delta = 0$ at every interior hinge. Any other combination of regular polyhedra at a hinge has $\delta \neq 0$, introducing either positive curvature (five tetrahedra: $\delta \approx 7.36° > 0$, negative curvature: three octahedra give $\delta < 0$).

Convergence of three independent arguments

The three arguments are logically independent — each relies on a different mathematical framework — yet all point to the same geometry:

Argument	Framework	Conclusion
CSS code + $C_p = 1836$	Quantum information	K=12 is *necessary*
Hales + Musin (2003/2005)	Sphere packing	K=12 is *maximal*
Regge + Niven (1956/1961)	Discrete geometry	K=12 is *unique flat*

No other coordination number satisfies all three simultaneously. The FCC lattice is not an assumption of the M/E/I framework; it is the unique geometry forced by the internal consistency of a quantum error-correcting vacuum with $C_p = 1836$.

2.2 Step 2: K=12 FCC requires three stacked hexagonal sheets

The K=12 coordination of the FCC lattice decomposes uniquely as:

$$K = 6_{\text{in-plane}} + 3_{\text{above}} + 3_{\text{below}} = 12, \tag{11}$$

where the 6 in-plane bonds connect to nearest neighbours within a single hexagonal (triangular) layer, and the 3+3 bonds connect to the two adjacent layers above and below [2].

This decomposition is geometrically unique: the ABC stacking of three hexagonal sheets at inter-layer spacing $h = \sqrt{2/3}\,L \approx 0.8165\,L$ (the regular tetrahedron altitude) is the only way to achieve Eq. (11) with equal bond lengths L throughout.

The three-sheet structure also maps precisely onto the f-vector of the coordination cluster:

- 1-sheet (single hexagonal layer): $(f_0, f_1, f_2) = (5, 4, 0)$ — the electron sector, $C_e = 1 \times 1 = 1$ [1].
- 2-sheet (two coupled layers): $(f_0, f_1, f_2) = (9, 16, 10)$ — the pion sector, $C_\pi = 16 \times 17 + 1 = 273$.
- 3-sheet (full cuboctahedron): $(f_0, f_1, f_2) = (13, 36, 38)$ — the proton/neutron sector, $C_p = 36 \times 51 = 1836$.

The particle spectrum of Part I is therefore directly encoded in the layered structure of the FCC lattice: one sheet gives the electron, two sheets give the pion, three sheets give the proton. K=12 FCC is not just a convenient geometry — it is the unique geometry that simultaneously generates all five particles.

2.3 Step 3: The hexagonal sheet requires the triangle

A hexagonal (triangular) sheet is composed entirely of equilateral triangles: it is the unique 2D tiling by a single regular polygon with coordination K=6. The triangle is both the minimal unit of the sheet and the minimal closed, gauge-invariant loop in a lattice gauge theory.

In Wilson's formulation of lattice gauge theory [8], physical observables must be gauge-invariant. An open link (two nodes connected by one bond) transforms under gauge transformations at both endpoints and carries no gauge-invariant content in isolation. The minimal gauge-invariant structure on a simplicial complex is the plaquette: a closed loop enclosing minimal area. On a triangular lattice, this is the triangle.

The triangle is also the minimal CSS stabilizer: in the $[[192, 130, 3]]$ code, the X-stabilizers are exactly the triangular faces of the lattice [2]. A two-node open link is not a stabilizer. The triangle is the minimal structure that participates in the fault-tolerant verification machinery of the code.

Proposition 3 (Triangle as minimal seed)**.** The triangle is the unique minimal structure that is simultaneously: (i) gauge-invariant (closed plaquette); (ii) a valid CSS stabilizer; (iii) the seed of the hexagonal tiling. No simpler structure satisfies all three conditions.

2.4 Step 4: The triangle requires a Bell pair

A triangle has three edges. Each edge is a bond between two nodes — a unit of entanglement. Before the triangle can close, the first entanglement bond must exist: a connection between two initially separate nodes.

Definition 1 (Bell pair)**.** A Bell pair $|\Phi^+\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$ is the unique maximally entangled state of two qubits. It corresponds to the $[[2, 0, 2]]$ error-detecting code — two physical qubits, zero logical qubits, distance 2. It is the minimum bipartite entangled state: no entangled state on fewer than two qubits exists.

The first bond of the triangle is precisely a Bell pair: two nodes connected by one maximally entangled link. The remaining two edges of the triangle are generated by adding a third node equidistant from the original two, at the apex of the equilateral triangle. This third node closes the gauge-invariant loop, converting the open Bell-pair bond into a CSS stabilizer.

The Bell pair is therefore not merely the simplest possible initial condition — it is the *only* possible initial condition at minimal qubit count. A single qubit cannot be entangled with anything. Two unentangled qubits carry no non-local correlations. The Bell pair is the boundary of the possible.

3 The Complete Reverse-Engineering

Combining the four steps:

Theorem 2 (Cosmological initial condition)**.** *The* $[[192, 130, 3]]$ *CSS code of Part I [1] requires, by logical necessity through four steps of established geometry and quantum information:*

1. *K=12 FCC coordination (Kepler maximum, Hales 2005 [7]);*
2. *three hexagonal sheets in ABC stacking (FCC geometry);*
3. *the triangle as minimal gauge-invariant seed (Wilson 1974 [8]);*
4. *a single Bell pair as the unique minimal initial entanglement.*

No quantum state with fewer degrees of freedom supports entanglement. The Bell pair is the unique minimal cosmological initial condition consistent with the FCC vacuum.

The particle spectrum that follows from Part I is therefore not merely consistent with a Bell-pair origin — it *requires* it, as the backward chain shows. The forward and backward implications together constitute a complete logical closure:

A Bell pair, under the internal consistency requirements of a CSS code on a maximally coordinated 3D lattice, inevitably produces the observed particle mass spectrum.

4 The Role of QEC in Each Transition

Each step of the forward chain (Bell pair $\to$ FCC) is driven by a QEC consistency requirement, not an external rule.

Bond $\to$ triangle (gauge closure). An open bond (Bell pair) is a CSS half-stabilizer: it detects errors at one endpoint but provides no redundant verification for the other. The QEC requirement of fault tolerance [10, 11] demands that every physical qubit participates in at least $d+1=4$ independent stabilizer checks. A node on an open bond participates in zero checks. Closure into a triangle gives each node participation in 3 checks; further lateral growth into the sheet interior raises this to 6 (first hop) and beyond (compound detection paths), exceeding the $d+1=4$ threshold.

Triangle $\to$ hexagonal sheet. Once the triangle exists, lateral expansion (adding nodes equidistant from existing edges) is the path of least resistance: it requires satisfying 2 distance constraints (1D solution manifold), versus the 3 constraints required for out-of-plane growth (0D). The sheet-interior nodes achieve $t \gg d+1$ triangle membership and are fault-tolerant stable.

Hexagonal sheet $\to$ three sheets (dimensional emergence). A single K=6 sheet uses only half the Kepler bonding capacity. The out-of-plane Lift is suppressed by a topological barrier. We derive its magnitude via two independent routes that converge on the same value.

Derivation 1: Coleman bounce action. In Coleman's framework [12], the tunneling rate from a false vacuum ϕ_f to a true vacuum ϕ_t is $P \sim A\, e^{-S_\mathrm{bounce}}$, where the Euclidean bounce action is:

$$S_\mathrm{bounce} = \int_{-\infty}^{\infty} d\tau \left[\tfrac{1}{2}\left(\frac{d\phi}{d\tau}\right)^2 + V(\phi) \right], \tag{12}$$

the classical action of the $O(4)$-symmetric instanton connecting the two vacua in Euclidean time τ. Applying the on-shell identity $\frac{1}{2}(\dot{\phi})^2 = V(\phi)$, Eq. (12) reduces to the WKB form:

$$S_\mathrm{bounce} = \int_{\phi_\mathrm{f}}^{\phi_\mathrm{t}} \sqrt{2V(\phi)}\, d\phi. \tag{13}$$

We now evaluate this for the Lift.

The lattice vacua. Let $\phi \equiv z$ denote the height of the candidate node above the base triangle. The false vacuum is $\phi_\mathrm{f} = 0$ (in-plane); the true vacuum is $\phi_\mathrm{t} = h = \sqrt{2/3}\, L$ (the unique tetrahedral apex equidistant from all three base nodes).

The constraint potential. The Lift requires the new node to be equidistant from all three base nodes: $|\mathbf{r} - \mathbf{b}_i| = L$, $i = 1, 2, 3$. Each constraint defines a sphere $\mathcal{S}_i$ of radius L. By dimension counting:

$$\begin{aligned} \dim(\mathcal{S}_1) &= 2, \\ \dim(\mathcal{S}_1 \cap \mathcal{S}_2) &= 1, \\ \dim(\mathcal{S}_1 \cap \mathcal{S}_2 \cap \mathcal{S}_3) &= 0. \end{aligned} \tag{14}$$

The three constraints reduce the solution manifold from 3D to a discrete set of two points (the two tetrahedral apices, $\pm h$). Crucially, all three constraints are satisfied *simultaneously* at $z = h$; there is no trajectory that satisfies them sequentially. The potential $V(\phi)$ therefore encodes a single composite barrier at ϕ_t, with three independent constraint directions.

In the natural units of the CSS code (unit coupling per stabilizer, unit lattice spacing $L = 1$), each constraint direction contributes one unit to the WKB integral (13):

$$S_\mathrm{bounce} = \underbrace{\int_{\phi_\mathrm{f}}^{\phi_\mathrm{t}} \sqrt{2V(\phi)}\, d\phi}_{\text{3 constraint directions}} = 3 \times 1 = 3. \tag{15}$$

The codimension of the solution manifold (Eq. 14) equals the bounce action in natural units: $S_\mathrm{bounce} = \mathrm{codim}(\mathcal{S}_1 \cap \mathcal{S}_2 \cap \mathcal{S}_3) = 3$. This gives:

$$P^{(1)}_\mathrm{lift} = e^{-S_\mathrm{bounce}} = e^{-3} \approx 4.98\%. \tag{16}$$

Derivation 2: QEC survival threshold. For a CSS code of distance d, the threshold theorem [19] states that logical error rates are suppressed below the fault-tolerance threshold when the number of independent stabilizer checks t on a defect exceeds $d + 1$. Below threshold, the survival probability scales as:

$$P_\mathrm{survive}(t) = \begin{cases} 1 & t \geq d + 1 \\ e^{-(d+1-t)} & t < d + 1, \end{cases} \tag{17}$$

where the exponential form reflects the fact that each missing stabilizer check leaves one undetected error mode [2]. A node placed by the Lift at the tetrahedral apex participates in exactly $t = 1$ triangular stabilizer (its single parent triangle). There is no second independent check: the apex is a topological peninsula. At code distance $d = 3$:

$$P^{(2)}_\mathrm{lift} = e^{-(d+1-t)}\big|_{d=3,\, t=1} = e^{-(3+1-1)} = e^{-3}. \tag{18}$$

Convergence. Both derivations give $P_\mathrm{lift} = e^{-3}$. The mathematical identity linking them is:

$$S_\mathrm{bounce} = \mathrm{codim}(\mathcal{S}_1 \cap \mathcal{S}_2 \cap \mathcal{S}_3) = d + 1 - t = 3. \tag{19}$$

The left side is the Euclidean bounce action (Coleman, field theory). The right side is the QEC syndrome deficit (threshold theorem). Both count the same quantity: the number of independent constraints separating the 2D false vacuum from the 3D true vacuum. The dimensional barrier and the error-correction barrier are identical. The rare but inevitable Lift stacks sheets until K=12 is reached, after which the Kepler maximum terminates further growth.

Three sheets → K=12 FCC. The inter-layer proximity bonding (nodes within $1.05\,L$ bind automatically) converts the stacked sheets into the cuboctahedral K=12 structure. No tuning is required: the bond radius $1.05\,L$ is set by the Regge deficit angle ($\delta \approx 7.36°$) of the regular tetrahedron [2].

5 The Big Bang as the K=6 → K=12 Phase Transition

The precise cosmological identification that emerges from the reverse chain is:

The Big Bang is the $P = e^{-3}$ Lift event — the moment when the 2D hexagonal sheets undergo a phase transition into the 3D FCC bulk, creating three-dimensional space.

The Bell pair is the *beginning of the universe*: the absolute origin, a single entanglement bond, the minimum quantum state consistent with non-trivial correlation. It is not the Big Bang — it precedes the Big Bang. The triangle is the first causal structure: the first closed loop, the first gauge-invariant plaquette, the first moment of time. The K=6 hexagonal sheet is the pre-Bang era: rapid 2D lateral expansion, a flat planar universe with no volume.

The *Big Bang* is the formation of the cuboctahedral structure from three hexagonal sheets.

The Big Bang — the creation of three-dimensional space — is the Lift. It occurs at probability $P = e^{-3} \approx 4.98\%$ per unit time, independently derived from (i) the topological action $S = 3$ for satisfying three simultaneous distance constraints [12], and (ii) the code distance $d = 3$ of the $[[192, 130, 3]]$ code [2]. Once the Lift occurs, three hexagonal sheets stack in ABC registry, proximity bonding produces K=12 coordination, and the Kepler maximum terminates further growth. The 3D FCC vacuum crystallises.

This picture predicts that the pre-Bang era was purely 2D: a K=6 hexagonal sheet expanding without volume. The flatness problem of standard cosmology — why is the universe so flat? — is resolved naturally: the pre-Bang universe *was* flat, because it was a 2D sheet. The inflationary era is the K=6 sheet expansion. The end of inflation is the Lift.

6 Cosmological Implications

6.1 Why the spatial dimension is 3

The $[[192, 130, 3]]$ code has distance $d = 3$. The number of constraints for tetrahedral (out-of-plane) node placement is $S = 3$. The spatial dimension of the resulting lattice is $D = 3$. The triple coincidence $d = S = D = 3$ is not accidental in this framework: the code distance sets the barrier to dimensional projection, and that barrier is surmounted exactly d times (once per spatial dimension) before the Kepler maximum terminates growth. The result is a $D = d = 3$-dimensional vacuum.

If the code distance were $d = 2$, the suppression e^{-2} would be less severe, and the lattice would stabilise in 2D (a triangular lattice, K=6, no third dimension). If $d = 4$, the suppression e^{-4} would require more sheet stacking events and might produce a 4D lattice. The observation that our universe is 3-dimensional is therefore encoded in the code distance $d = 3$ of the vacuum QEC code.

6.2 Lorentz invariance as a consequence of the Big Bang

The K=12 cuboctahedral structure produced by the Big Bang (the three-sheet crystallisation) carries Lorentz invariance as a geometric consequence, established in Part I [1]. We reproduce the key results here since they apply directly to the emergent geometry of this paper.

Spatial isotropy. The K=12 FCC has 12 nearest-neighbour bond vectors:

$$\mathbf{n}_j \in \big\{(\pm1, \pm1, 0),\ (\pm1, 0, \pm1),\ (0, \pm1, \pm1)\big\}/\sqrt{2}.$$

The rank-2 structure tensor $S_{\mu\nu} \equiv \sum_{j=1}^{12} n_j^\mu n_j^\nu$ satisfies (by explicit enumeration):

$$S_{\mu\nu} = 4\,\delta_{\mu\nu}. \tag{20}$$

This exact isotropy is a direct consequence of the cuboctahedral K=12 geometry: no other coordination number or bond geometry achieves $S_{\mu\nu} \propto \delta_{\mu\nu}$ in 3D. The odd-rank tensor $T_{\mu\nu\lambda} \equiv$

$\sum_j n_j^\mu n_j^\nu n_j^\lambda = 0$ exactly (by inversion symmetry of the FCC bond set), eliminating any preferred direction and any linear term in the dispersion.

Isotropic dispersion. For a scalar field on the FCC lattice, the long-wavelength dispersion (expanding $\omega^2(\mathbf{k}) = \kappa \sum_j [1 - \cos(\mathbf{k} \cdot \mathbf{n}_j a)]$ to second order) gives:

$$\omega^2 \approx \frac{\kappa a^2}{2} k_\mu k_\nu S_{\mu\nu} = 2\kappa a^2 |\mathbf{k}|^2, \tag{21}$$

so $\omega = c_{\text{lat}}|\mathbf{k}|$ with $c_{\text{lat}} = a\sqrt{2\kappa}$. The dispersion is exactly isotropic by Eq. (20); this is not an approximation but an algebraic identity. Corrections appear only at $O(k^4 a^4) \sim (E/M_P)^4$.

Emergent Lorentz boosts. The two tensor identities (20) and $T_{\mu\nu\lambda} = 0$, together with the isotropic linear dispersion (21), are sufficient for Lorentz boosts to emerge in the standard continuum limit [1]. A lattice Hamiltonian with isotropic linear dispersion gives a relativistic effective field theory in the continuum limit. The lattice breaks Lorentz symmetry only at the cutoff scale $1/a$ (the Planck scale $M_P \sim 10^{19}$ GeV), with violations suppressed by $(E/M_P)^2$ — consistent with all current bounds [18] of $\lesssim 10^{-20}$–10^{-40}.

The significance for the present paper is that Lorentz invariance is not an assumption: it is a theorem of the K=12 cuboctahedral geometry that the Big Bang produces. Before the Big Bang (in the K=6 sheet era), the universe was 2D and Lorentz invariance in 3D did not exist. The Big Bang created both 3D space and 3D Lorentz invariance simultaneously.

6.3 Relation to holography and ER=EPR

The reverse chain formalises several conjectured correspondences:

Van Raamsdonk (2010) [14]: "Entanglement builds spacetime." Here this is literal: the Bell pair is one unit of entanglement, and the FCC lattice is the spacetime it builds.

ER = EPR (Maldacena–Susskind 2013 [15]): The Bell pair is the ER bridge at one quantum of length. The triangle is the minimal wormhole that is gauge-invariant. The FCC lattice is the thermodynamically stable wormhole network.

Holography ('t Hooft [16], Susskind [17]): The 2D hexagonal sheet is the holographic boundary; the e^{-3} projection generates the 3D bulk. The encoding rate $k/n = 67.7\%$ of the $[[192, 130, 3]]$ code is the fraction of boundary degrees of freedom that carry bulk logical information.

6.4 The Bell pair as the beginning of spacetime

The cosmological picture that emerges separates two distinct events. The Bell pair is the *beginning of spacetime* — the absolute origin, the minimum entangled quantum state, preceding space, time, and dimension. No external initial conditions are required: the Bell pair is the unique boundary of the possible, and the QEC rules of the $[[192, 130, 3]]$ code drive the rest without further input. The Big Bang is a separate, later event: the K=6 $\to$ K=12 phase transition in which three hexagonal sheets crystallise into the FCC cuboctahedral bulk, creating three-dimensional space.

The Hartle–Hawking no-boundary proposal [20] states the universe has no boundary in imaginary time. The Bell pair is consistent with this: it has no temporal extent. It is a single entanglement bond between two qubits, timeless. The triangle then introduces the first closed loop — the first moment from which causal structure can grow.

7 Discussion and Open Questions

7.1 What the argument does not claim

The reverse-engineering is logical, not dynamical: it shows that the Bell pair is a *necessary* precursor to the FCC vacuum, not that it is the *unique* predecessor of all possible vacua. A different QEC code with different distance and f-vector would give a different particle spectrum and possibly a different initial condition. The claim is: *given* the $[[192, 130, 3]]$ code (which gives the observed particle masses), the initial condition is uniquely a Bell pair.

7.2 The triple coincidence $d = S = D = 3$

Whether the coincidence of code distance, constraint dimension, and spatial dimension is a structural identity (the only self-consistent 3D QEC vacuum has distance $d = 3$) or a numerical coincidence for $d = 3$ specifically is an open question. An extension to $d = 4$ would predict a 4D lattice with e^{-4} dimensional projection rate and a different particle spectrum; testing whether such a code self-consistently supports a particle spectrum analogous to Part I would either confirm the structural identity or reveal it as coincidental.

7.3 Deriving α and δ from the Bell pair

Part I requires two inputs from nuclear data: the volume coefficient $\alpha = 4.5$ MeV/bond and the pairing coefficient $\delta = 12$ MeV. The reverse-engineering chain does not yet derive these from the Bell-pair initial condition. Deriving α from the Bell-pair entanglement energy and δ from the Bell-pair correlation structure are identified as the two remaining open problems in the M/E/I programme.

8 Conclusion

The [[192, 130, 3]] CSS code of Part I [1] has a unique minimal cosmological precursor: a single Bell pair. No quantum state with fewer qubits supports entanglement. The chain is forced at every step:

$$\begin{aligned}
[[192, 130, 3]] \text{ (particle masses)} \;&\Longleftarrow\; K = 12 \text{ FCC (Kepler maximum)} \\
&\Longleftarrow\; 3 \times K = 6 \text{ (ABC sheet stacking)} \\
&\Longleftarrow\; K = 6 \text{ sheet (minimal QEC-stable 2D)} \\
&\Longleftarrow\; \triangle \text{ (minimal gauge-invariant loop)} \\
&\Longleftarrow\; |\Phi^+\rangle \text{ (Bell pair: minimum entanglement).}
\end{aligned}$$

Each implication is forced by established geometry (Hales 2005), lattice gauge theory (Wilson 1974), or quantum information. No simulation results are invoked. No free parameters appear.

The triple coincidence $d = S = D = 3$ — code distance, constraint dimension, and spatial dimension all equal to three — sits at the heart of why the universe has three spatial dimensions, not two or four.

The cosmological identification is precise and falsifiable. The *beginning of the universe* is the Bell pair: the absolute origin, the minimum entangled quantum state. The *Big Bang* is the formation of the K=12 cuboctahedral structure from three K=6 hexagonal sheets at probability $P = e^{-3}$: a phase transition, not the origin. These are two distinct events separated by the pre-Bang 2D era. If the [[192, 130, 3]] code correctly describes the physical vacuum (as the 0.12% mass-ratio accuracy of Part I suggests), both identifications follow by logical necessity.

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