

THE NELSON-BARR RELAXION AND THE HIERARCHION

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OD, R. S. Gupta, Prof. G. Perez, D. Redigolo, and A. Shalit ([1711.00858](#), [1806.08791](#))

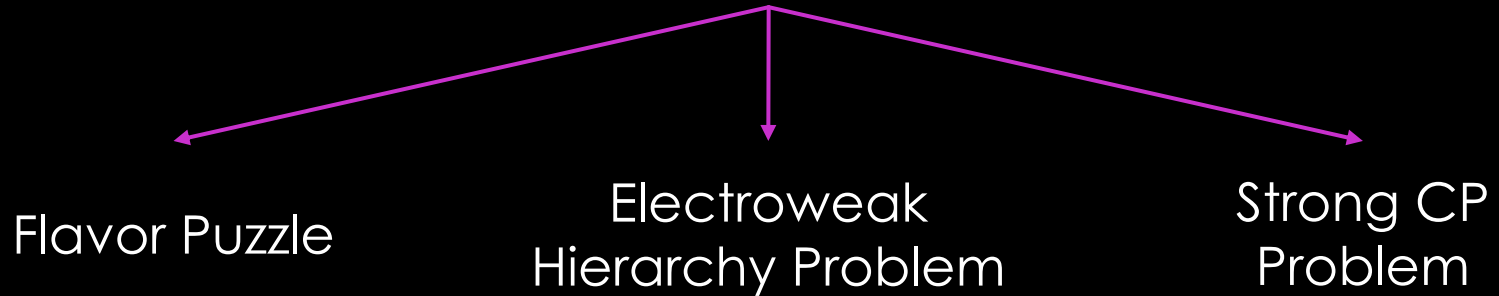
The Problems and Their Possible Solutions

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Three Hierarchy Problems in the Standard Model

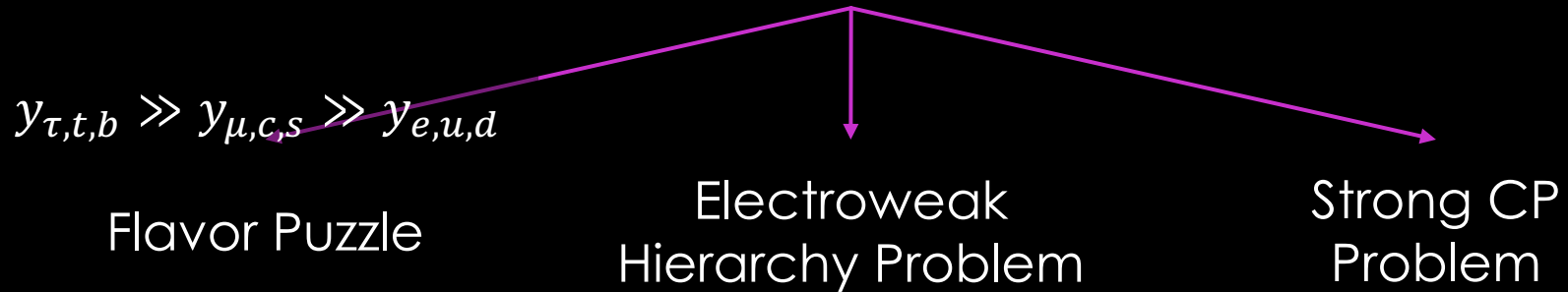
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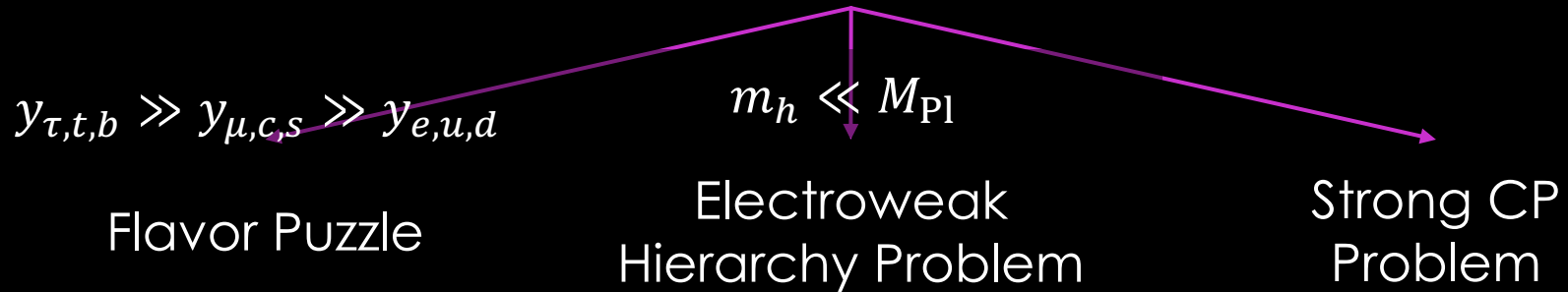
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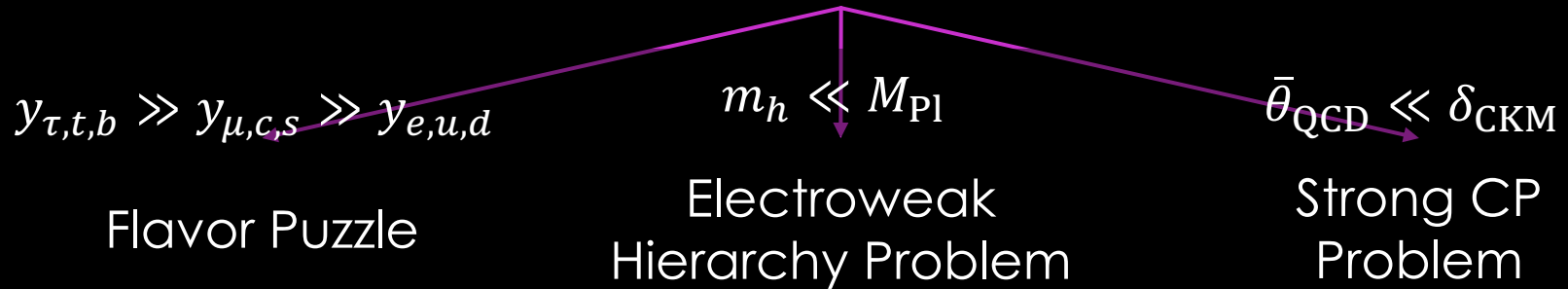
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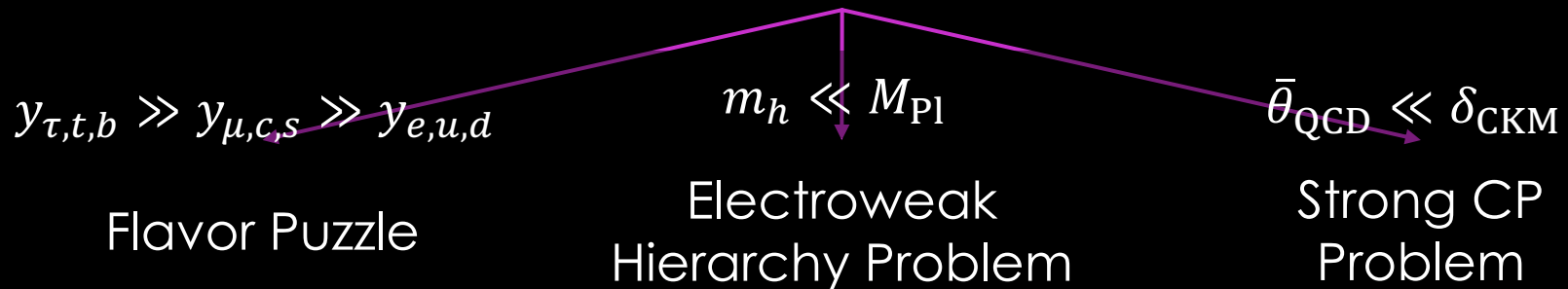
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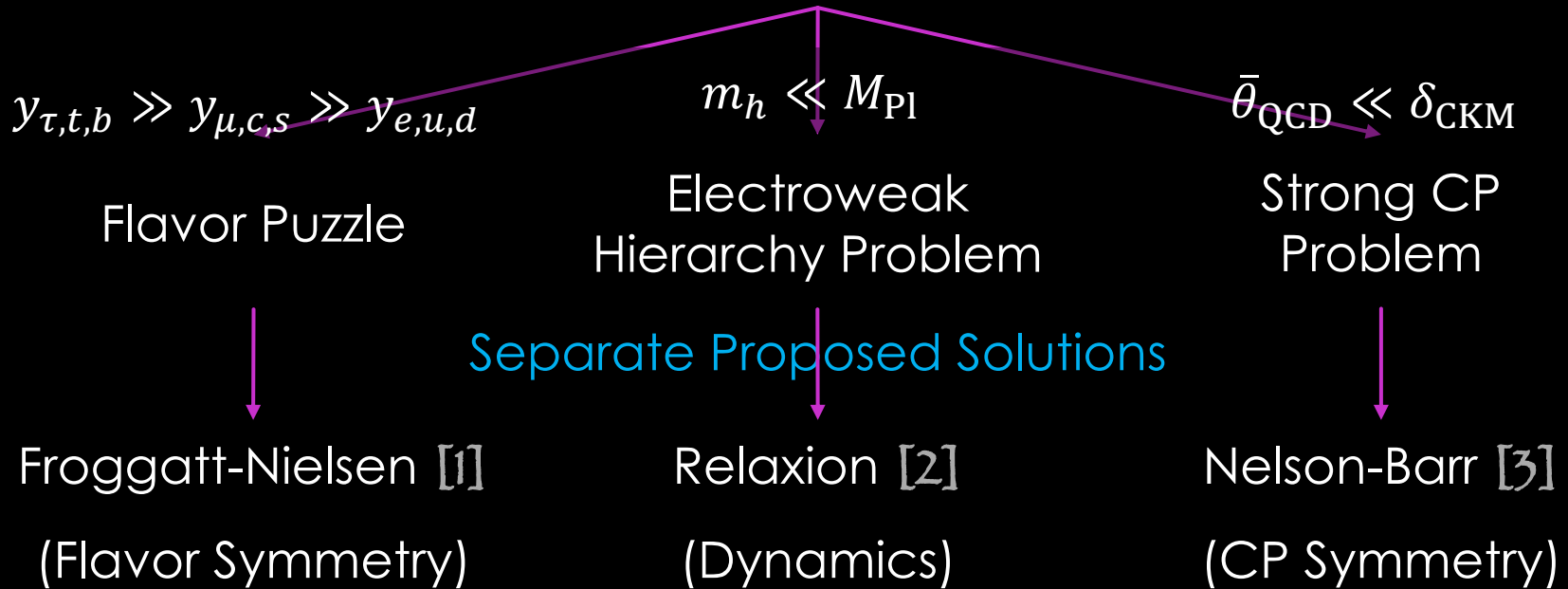
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Separate Proposed Solutions

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Three Hierarchy Problems in the Standard Model



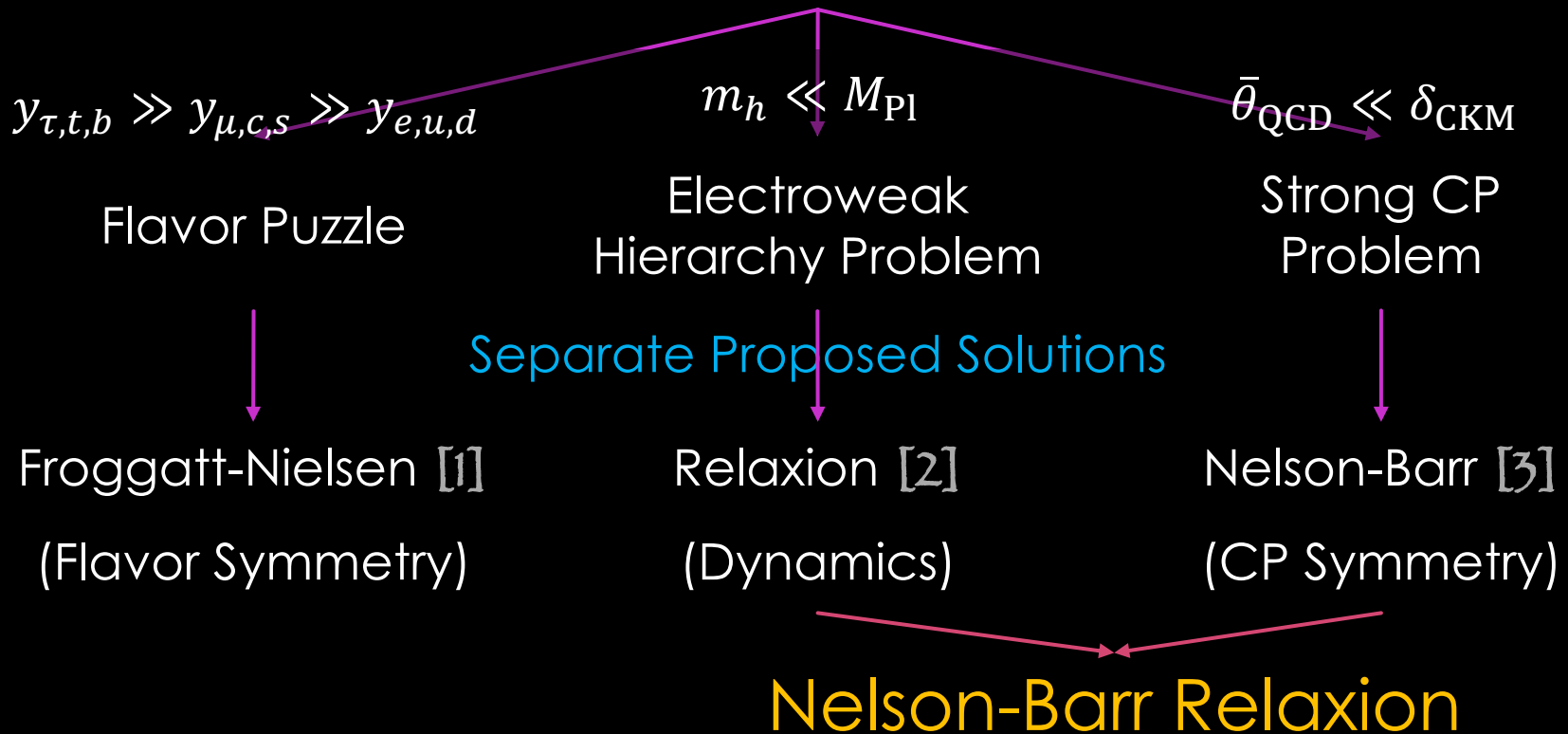
[1] C. D. Froggatt, and H. B. Nielsen (DOI: [10.1016/0550-3213\(79\)90316-X](https://doi.org/10.1016/0550-3213(79)90316-X))

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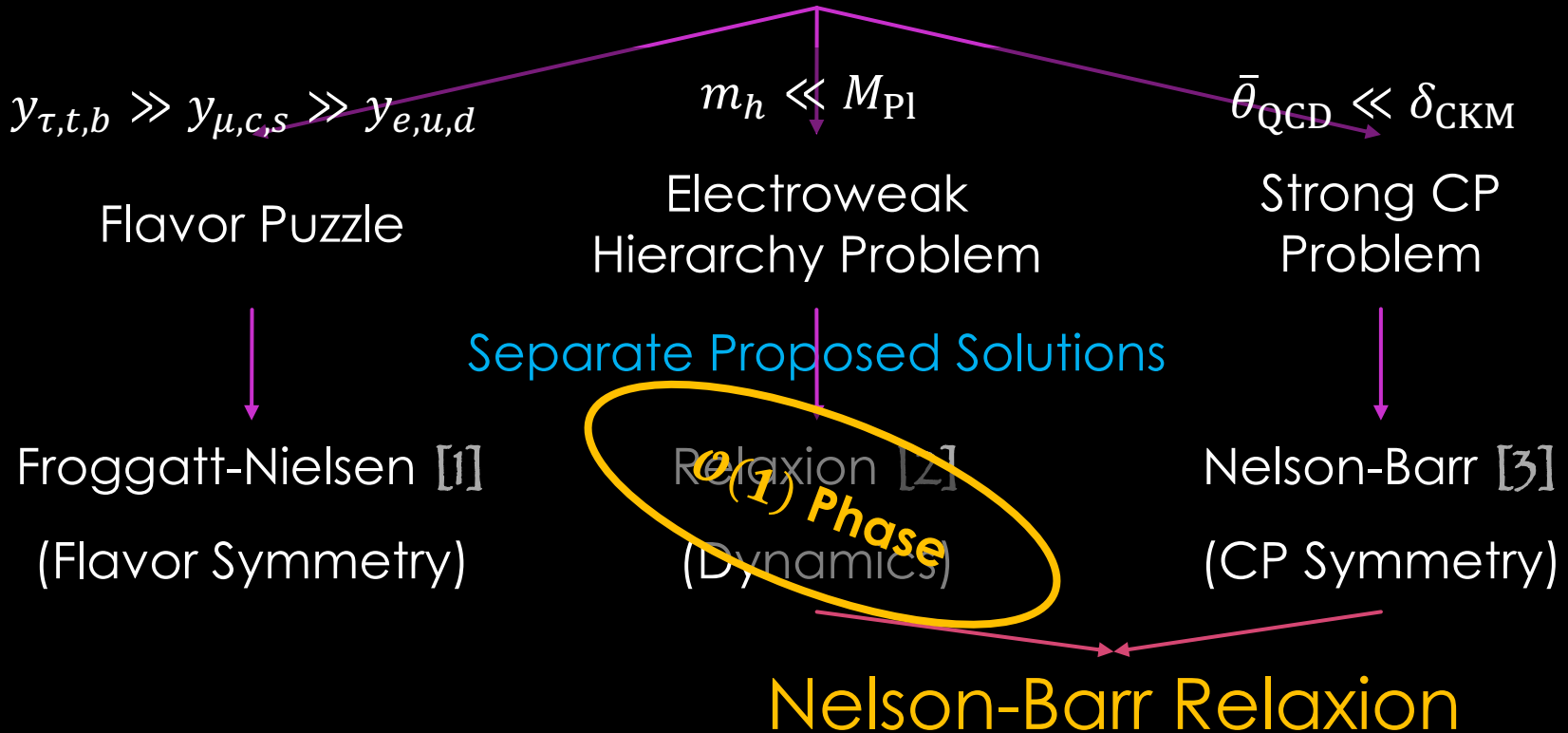
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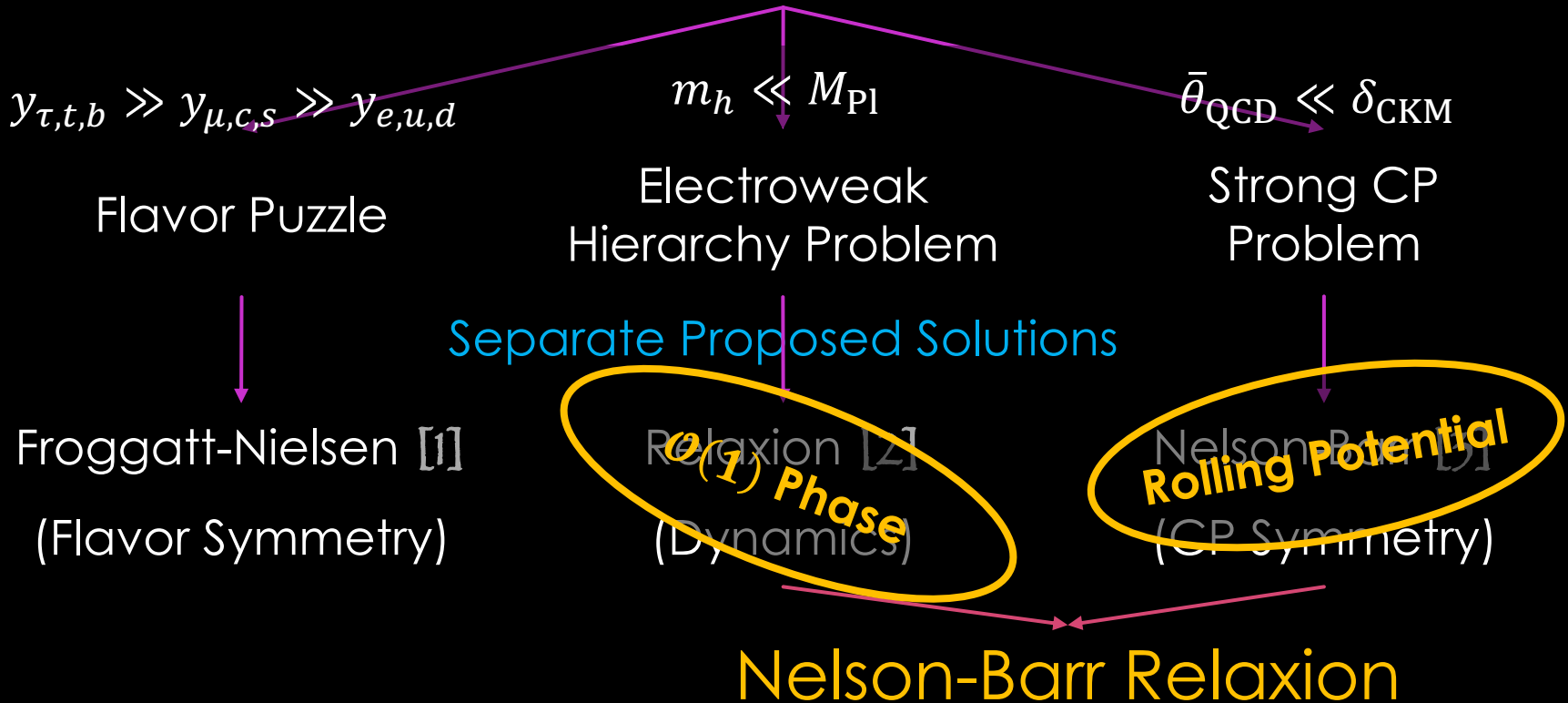
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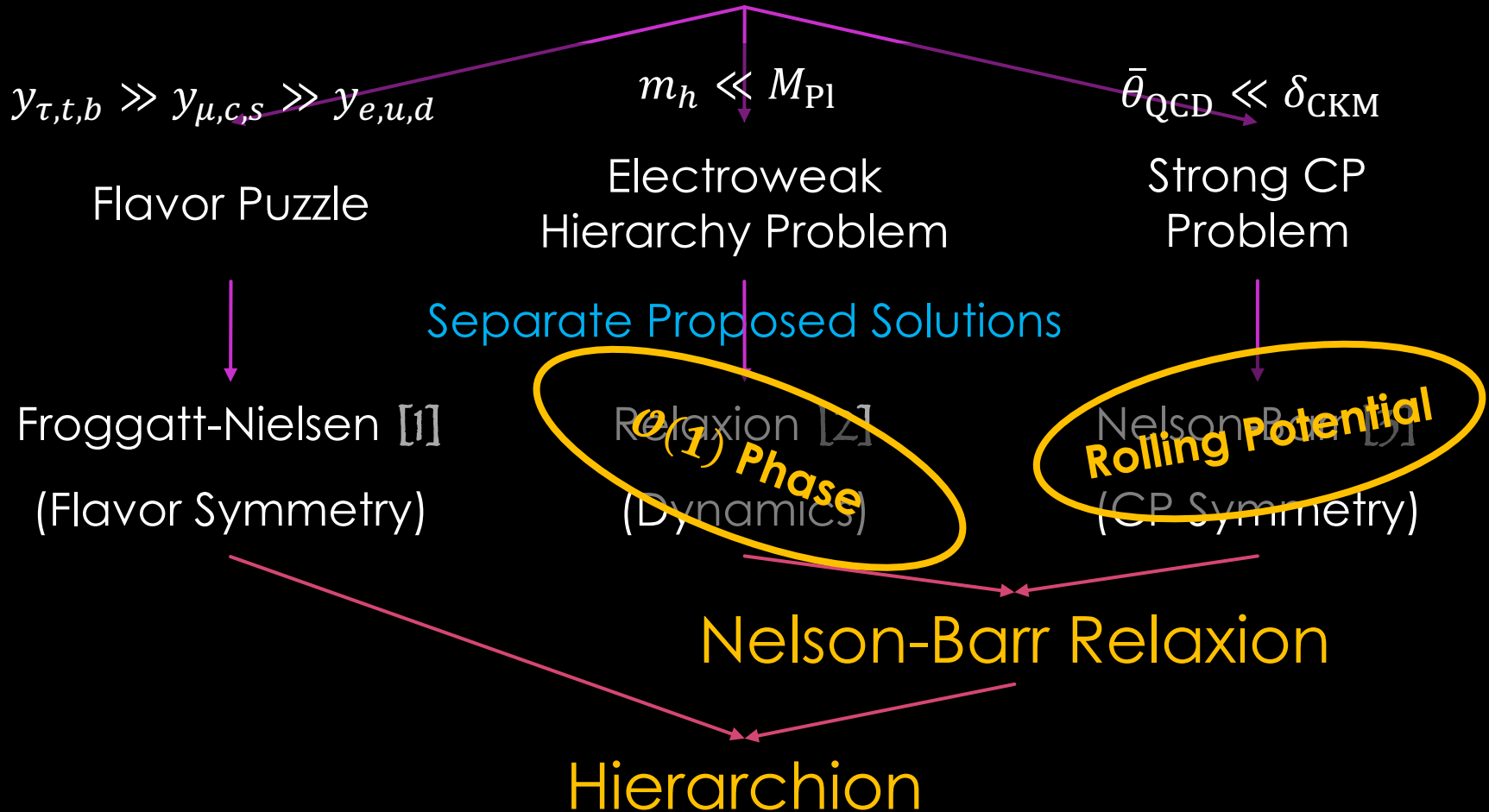
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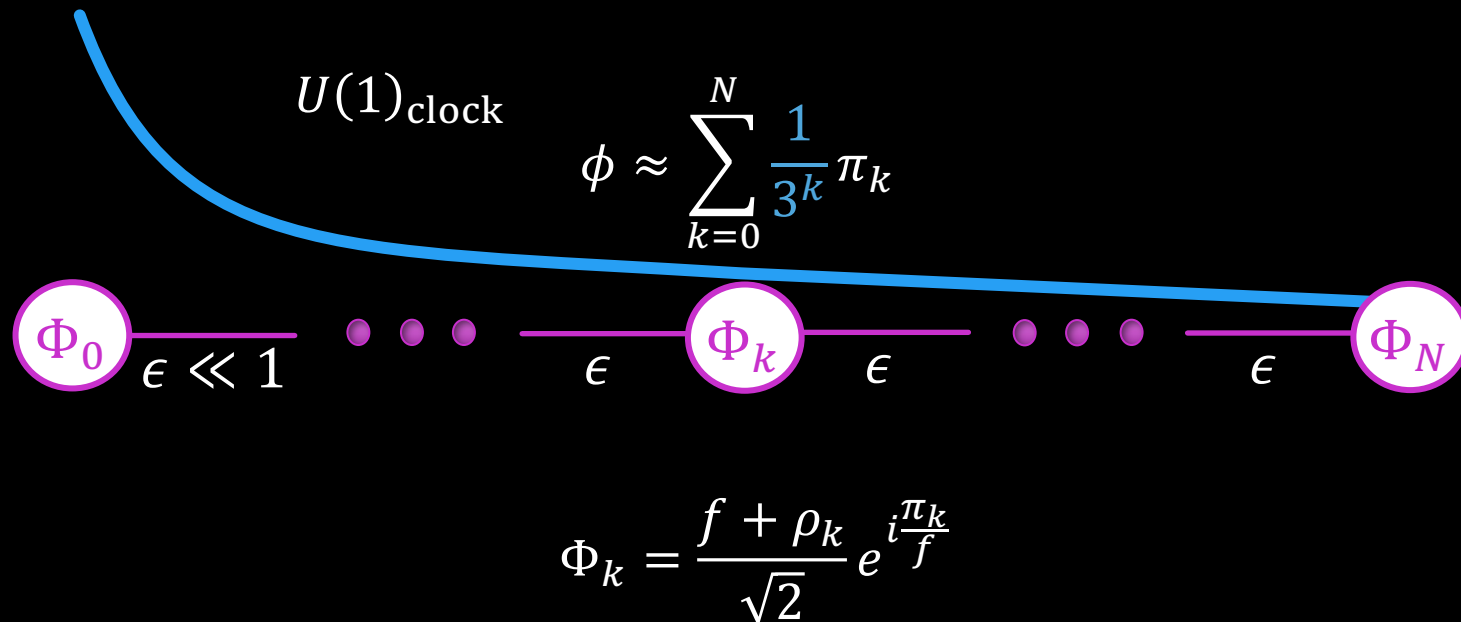
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Construct Overview

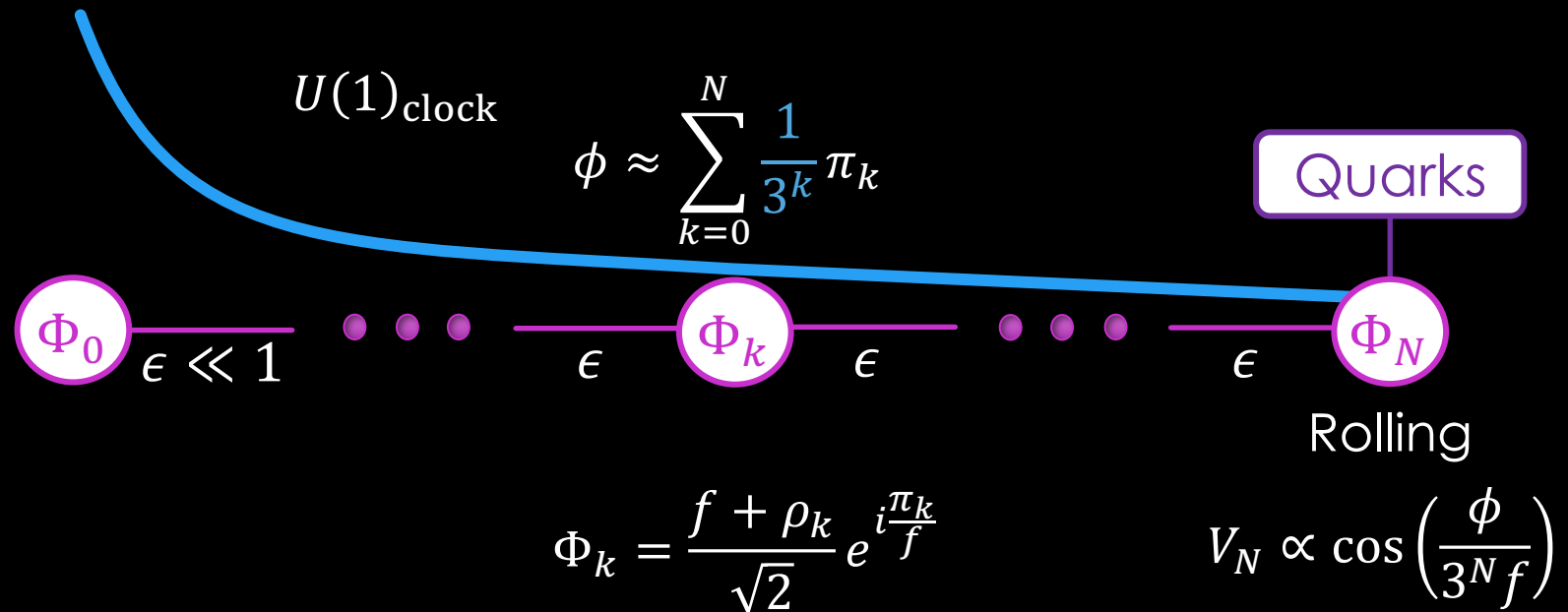
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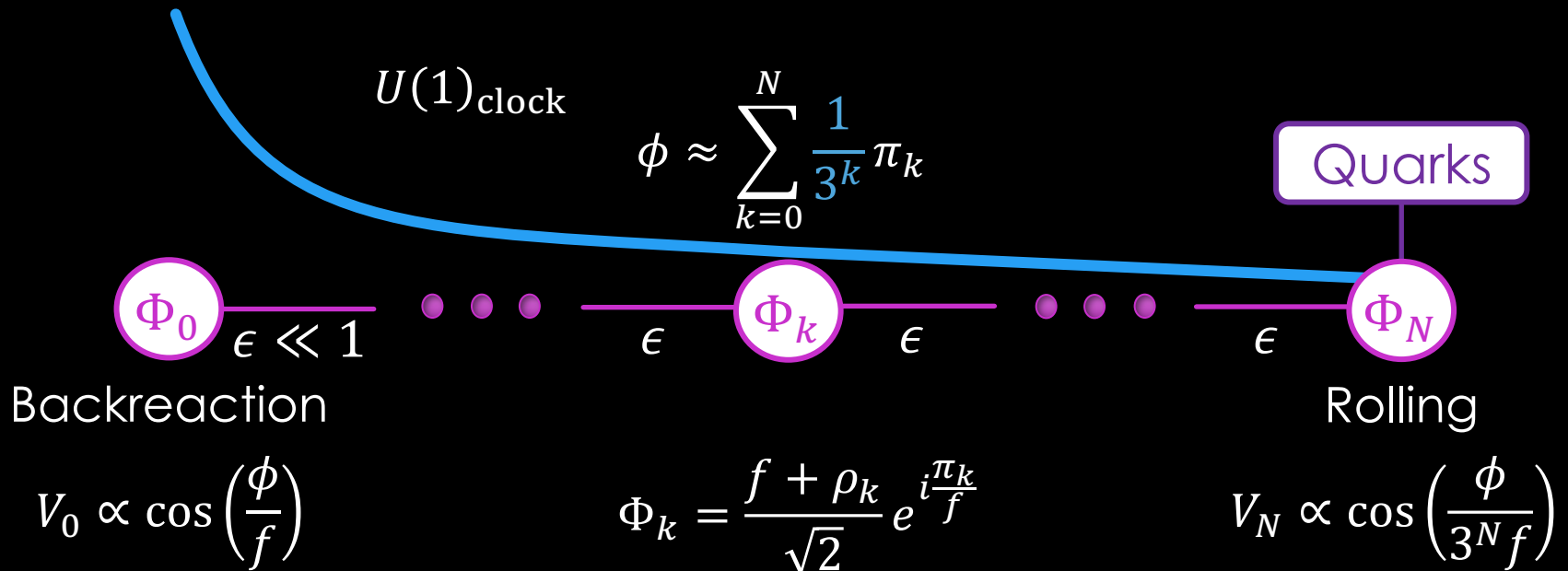
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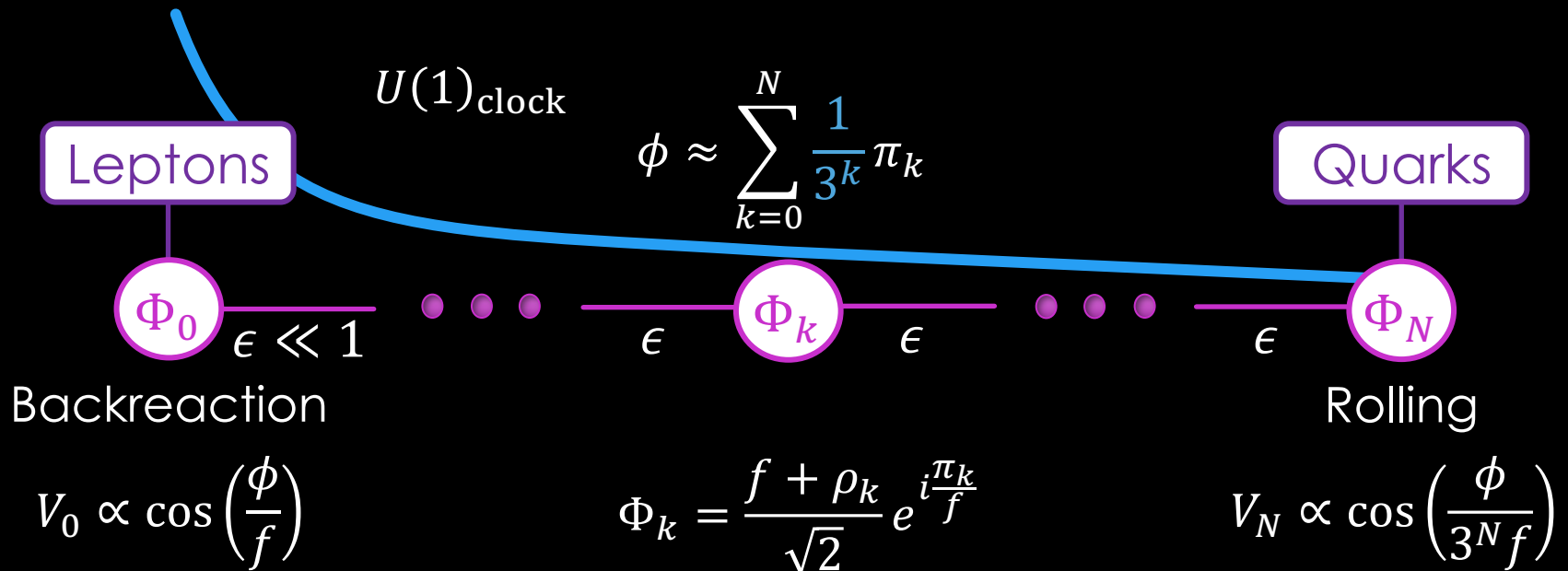
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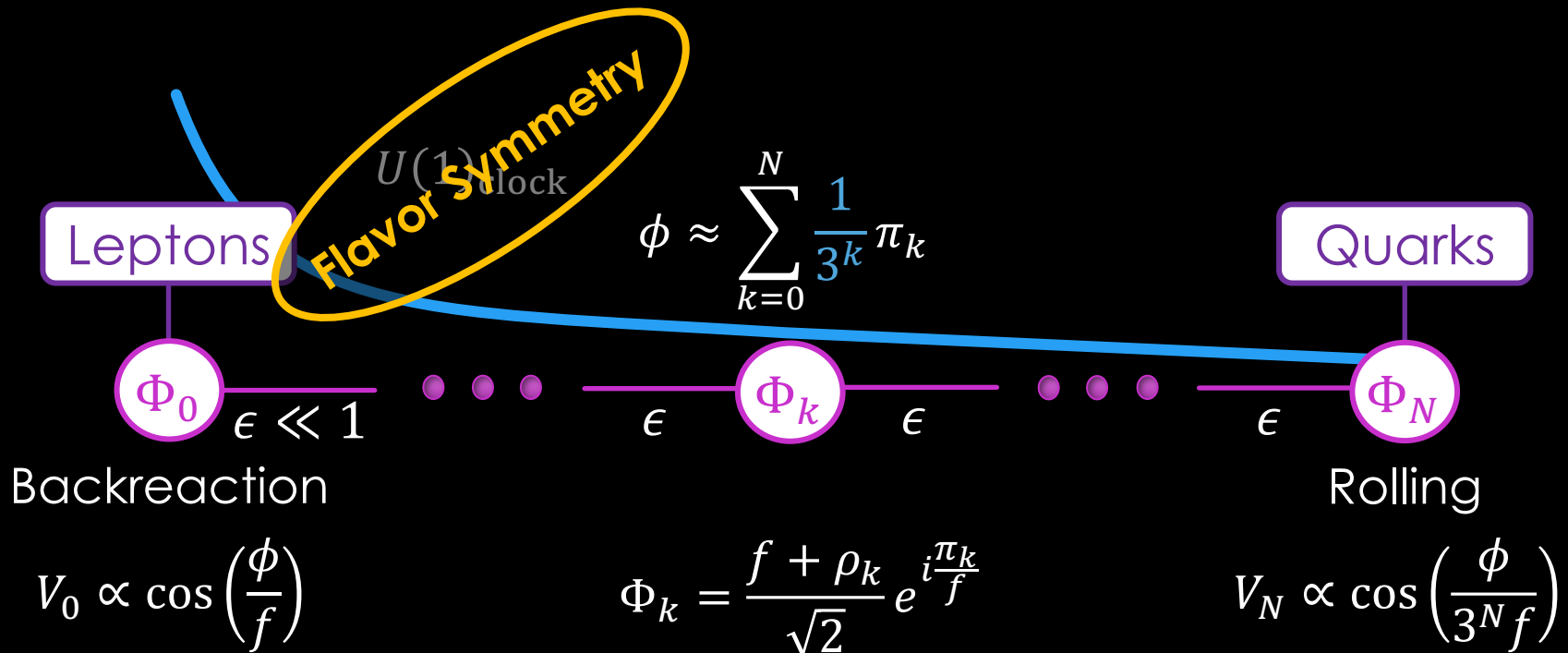
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Model Building Challenges

(Or “Why Should I Read the Hierarchion Paper?”)

- Standard charge assignment does not generally work in Nelson-Barr-Froggatt-Nielsen models.
 - Should be anomaly free.
 - The values of δ_{CKM} and $\bar{\theta}_{\text{QCD}}$ depend on the charges.
- Novel backreaction sector with no electroweak charged states around the electroweak scale.

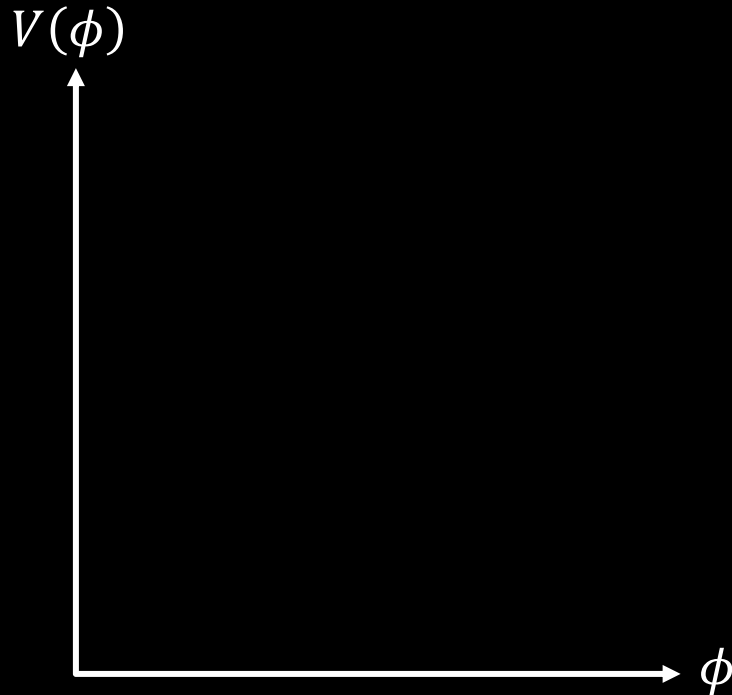
Additional Slides

The Relaxion Mechanism

$$V_H(H; \phi) = m_H^2(\phi)|H|^2 + \lambda_H|H|^4$$

$$m_H^2(\phi) = \Lambda_H^2 \left[\kappa - \cos\left(\frac{\phi}{F}\right) \right]$$

The Relaxion Mechanism

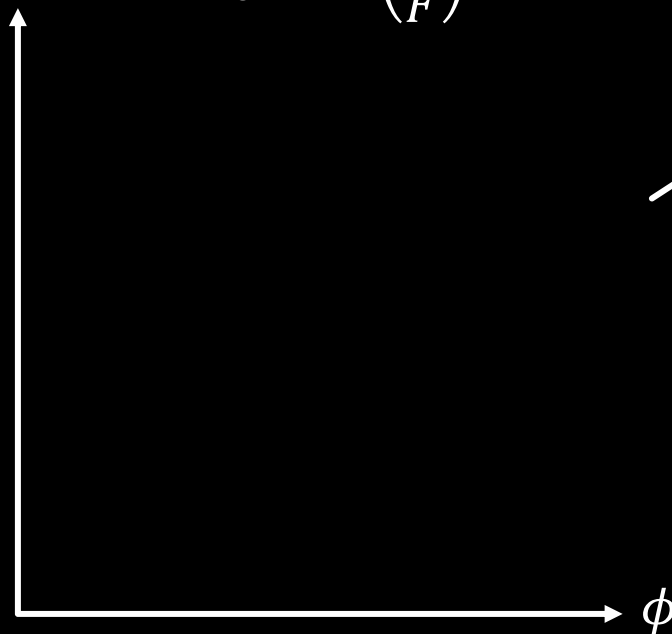


$$\langle \phi \rangle_+$$

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The Relaxion Mechanism

$$V(\phi) = -\Lambda_{\text{roll}}^4 \cos\left(\frac{\phi}{F}\right)$$


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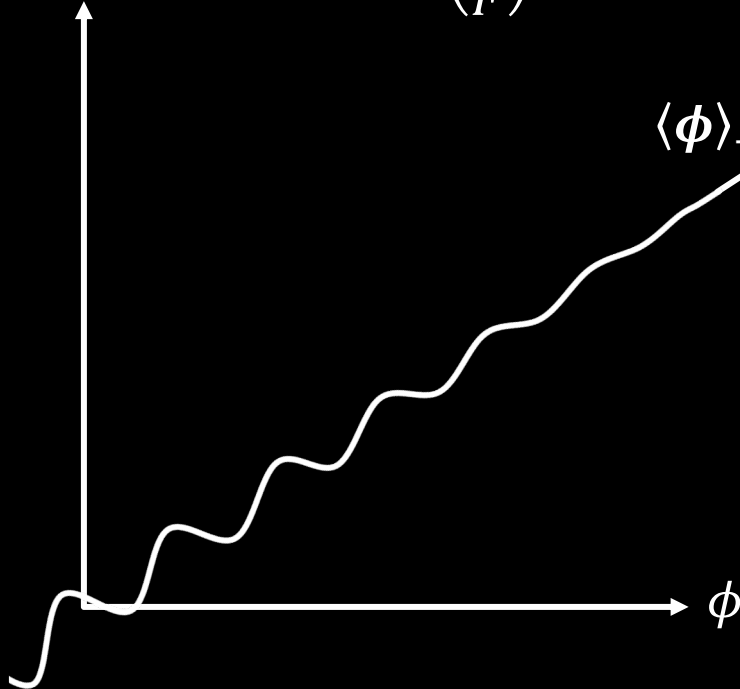
$\langle\phi\rangle_0$

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$$V(\phi) = -\Lambda_{\text{roll}}^4 \cos\left(\frac{\phi}{F}\right) + M_{\text{br}}^2 \langle |H| \rangle^2(\phi) \cos\left(\frac{\phi}{f}\right)$$

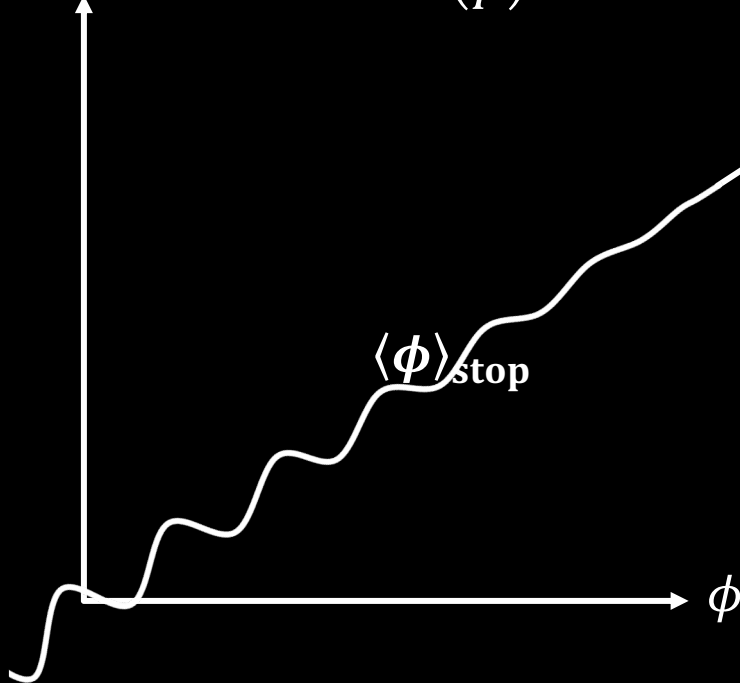


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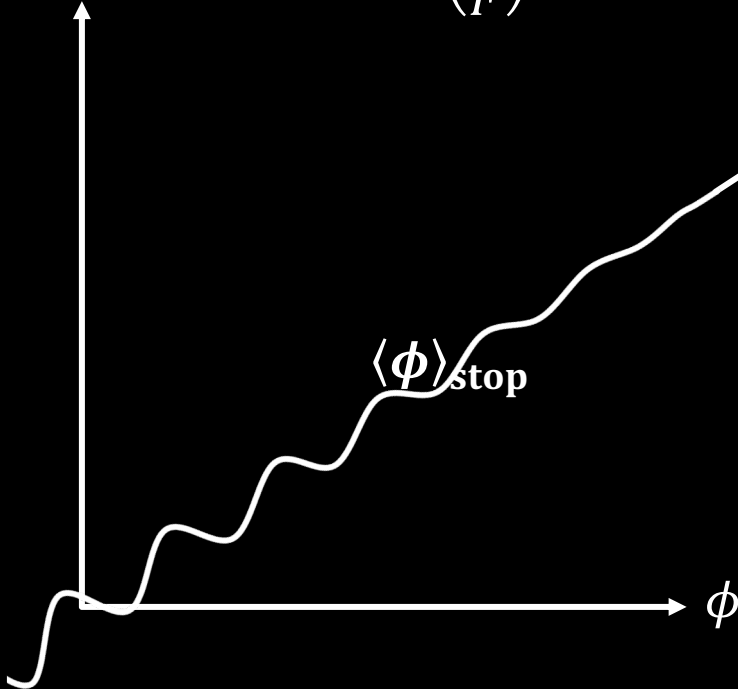
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$$\frac{\langle \phi \rangle_{\text{stop}}}{F} \equiv \mathcal{O}(1)$$

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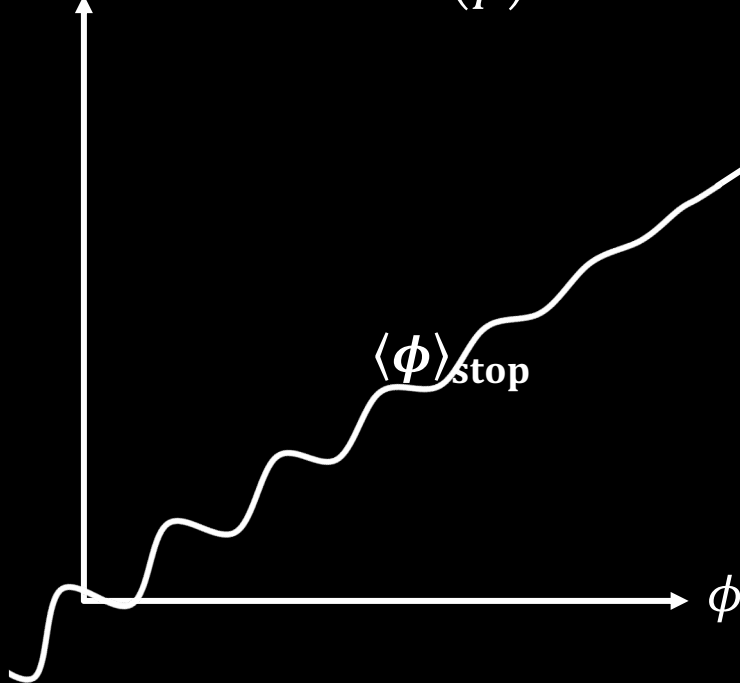
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Nelson-Barr Relaxion

$$\frac{\langle \phi \rangle_{\text{stop}}}{F} \equiv \mathcal{O}(1)$$



Relaxion

δ_{CKM}

Rolling Potential

Nelson-Barr

CLOCKWORK CONSTRUCTION

- The clockwork potential is

$$V_{\text{clock}} = \sum_{k=0}^N \left(-m_k^2 |\Phi_k|^2 + \lambda_k^2 |\Phi_k|^4 \right)$$

- Connecting nearest neighbors

$$\Delta V_{\text{clock}} = - \sum_{k=0}^{N-1} \epsilon_k \left(\Phi_k^\dagger \Phi_{k+1} + \text{H. c.} \right)$$

- Taking $m_k = m_{\text{clock}} > 0$, $\lambda_k = \lambda_{\text{clock}}$, and $\epsilon_k = \epsilon \ll \lambda_{\text{clock}}^2$, the clockwork fields obtain a VEV

$$\sqrt{2} |\Phi_k| = f = m_{\text{clock}} / \lambda_{\text{clock}}$$

CLOCKWORK CONSTRUCTION (CONT.)

- Expanding around the VEV

$$\Phi_k = \frac{f + \rho_k}{\sqrt{2}} e^{i\frac{\pi_k}{f}}$$

the potential for the angular modes is

$$\Delta V_{\text{clock}} \supset -\frac{\epsilon f^4}{4} \sum_{k=0}^{N-1} \cos\left(\frac{3\pi_{k+1} - \pi_k}{f}\right)$$

- N pseudo-Nambu-Goldstone bosons with mass $\sim \sqrt{\epsilon}f$.
- One Nambu-Goldstone boson

$$\phi \equiv \mathcal{N} \sum_{k=0}^N \frac{\pi_k}{3^k} \quad \mathcal{N} = \left(\sum_{k=0}^N 3^{-2k} \right)^{\frac{1}{2}}$$