SCUOLA
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SUPERIORE

Strongly Coupled Sectors in Inflation

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Scuola Normale Superiore, Pisa

Inflation 2025, Paris

Reference:

- 2503.17840: Strongly Coupled Sectors in Inflation: Gapless Theories and Unparticles; Guilherme L. Pimentel, CY
- 2512.xxxxx: Strongly Coupled Sectors in Inflation: Gapped Theories and Holography; Yikun Jiang, Guilherme L. Pimentel, CY
- 2507.06454: Dark Walker in the Early Universe: A Strongly Coupled Sector Model; CY

Why Strong Coupling?

UV Completion from Compositeness

EFT of Inflation   UV completion

Why Strong Coupling?

UV Completion from Compositeness

Time-translation

LSM with Symmetry Breaking

EFT of Inflation

UV completion

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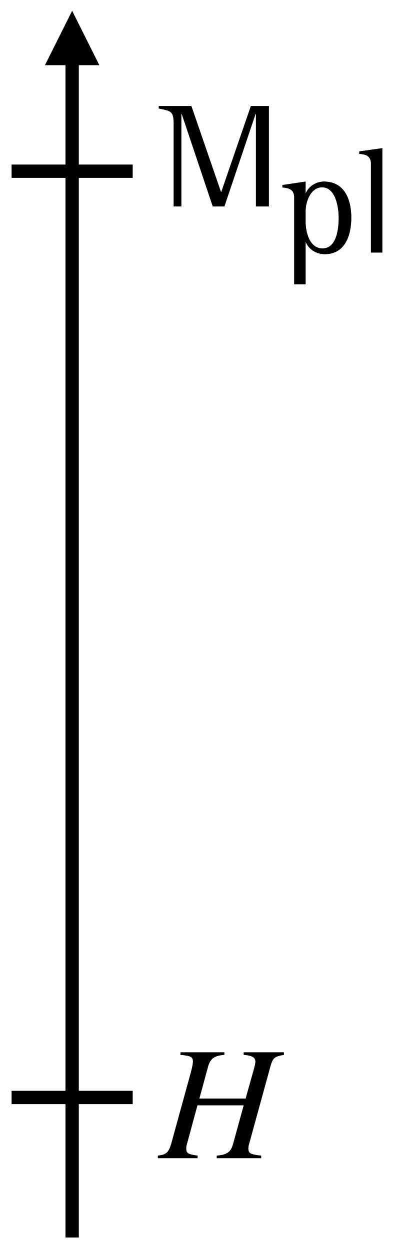
UV completion



Why Strong Coupling?

UV Completion from Compositeness

LSM with Symmetry Breaking

EFT of Inflation UV completion

Strongly Coupled Composites

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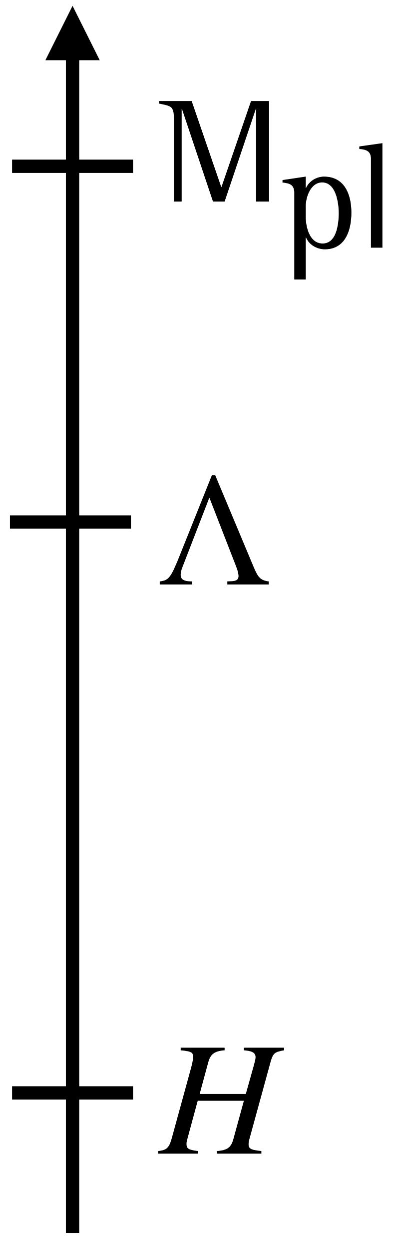
Strongly Coupled Composites



Why Strong Coupling?

UV Completion from Compositeness

LSM with Symmetry Breaking

EFT of Inflation

UV completion

Strongly Coupled Composites

Much Less Explored!

Setup

Unparticles and EFT of Inflation

IR Phases

Setup

Unparticles and EFT of Inflation

IR Phases $\longrightarrow$ Mass Gap

Setup

Unparticles and EFT of Inflation

$$
\begin{tikzcd}
\text{IR Phases} \arrow[r] \arrow[dr] & \text{Mass Gap} \\
& \text{Massless Modes}
\end{tikzcd}
$$

Setup

Unparticles and EFT of Inflation

$$\begin{tikzcd}
\text{IR Phases} \arrow[rr] \arrow[dr] \arrow[dd] & & \text{Mass Gap} \\
& \text{Massless Modes} & \\
\text{Scale-Invariant Theory} & &
\end{tikzcd}$$

Setup

Unparticles and EFT of Inflation

IR Phases $\longrightarrow$ Mass Gap

Massless Modes

Scale-Invariant Theory

$\Downarrow$

Conformal Field Theory

Setup

Unparticles and EFT of Inflation

$$\begin{tikzcd}
\text{IR Phases} \arrow[r] \arrow[dr] \arrow[dd] & \text{Mass Gap} \\
& \text{Massless Modes} \\
\text{Scale-Invariant Theory} \arrow[d] & \\
\text{Conformal Field Theory (Unparticle)} &
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Setup

Unparticles and EFT of Inflation

$$\begin{tikzcd}
\text{IR Phases} \arrow[r] \arrow[dr] \arrow[dd] & \text{Mass Gap} \\
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\text{Conformal Field Theory (Unparticle)} &
\end{tikzcd}$$

Conformal Field Theory (Unparticle)

Gapless

Setup

Unparticles and EFT of Inflation

Large Anomalous Dimension

IR Phases → Mass Gap

Massless Modes

Scale-Invariant Theory

Conformal Field Theory (Unparticle)

Gapless

Setup

Unparticles and EFT of Inflation

IR Phases

Mass Gap

Massless Modes

Scale-Invariant Theory

Conformal Field Theory (Unparticle)
Gapless

Large Anomalous Dimension

Strongly Coupled!

Setup

Unparticles and EFT of Inflation

IR Phases $\longrightarrow$ Mass Gap

Massless Modes

Scale-Invariant Theory

Conformal Field Theory (Unparticle)
Gapless

Large Anomalous Dimension

Strongly Coupled!

$$\langle \mathcal{O}_\Delta \mathcal{O}_\Delta \rangle = \frac{1}{|x_1 - x_2|^{2\Delta}}$$

Euclidean Flatspace

Setup

Unparticles and EFT of Inflation

IR Phases $\longrightarrow$ Mass Gap

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Scale-Invariant Theory

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Large Anomalous Dimension

Strongly Coupled!

$$\langle \mathcal{O}_\Delta \mathcal{O}_\Delta \rangle = \frac{1}{|x_1 - x_2|^{2\Delta}}$$

Euclidean Flatspace

Scaling Dimension

Setup

Unparticles and EFT of Inflation

Gapped Unparticles?

Setup
Unparticles and EFT of Inflation

Gapped Unparticles?

5D CFT on $\mathrm{dS}_4 \times S^1_R$

Setup

Unparticles and EFT of Inflation

Gapped Unparticles?

5D CFT on $\mathrm{dS}_4 \times S^1_R$

$\downarrow$ KK Reduction

Gapped Unparticles!

Setup

Unparticles and EFT of Inflation

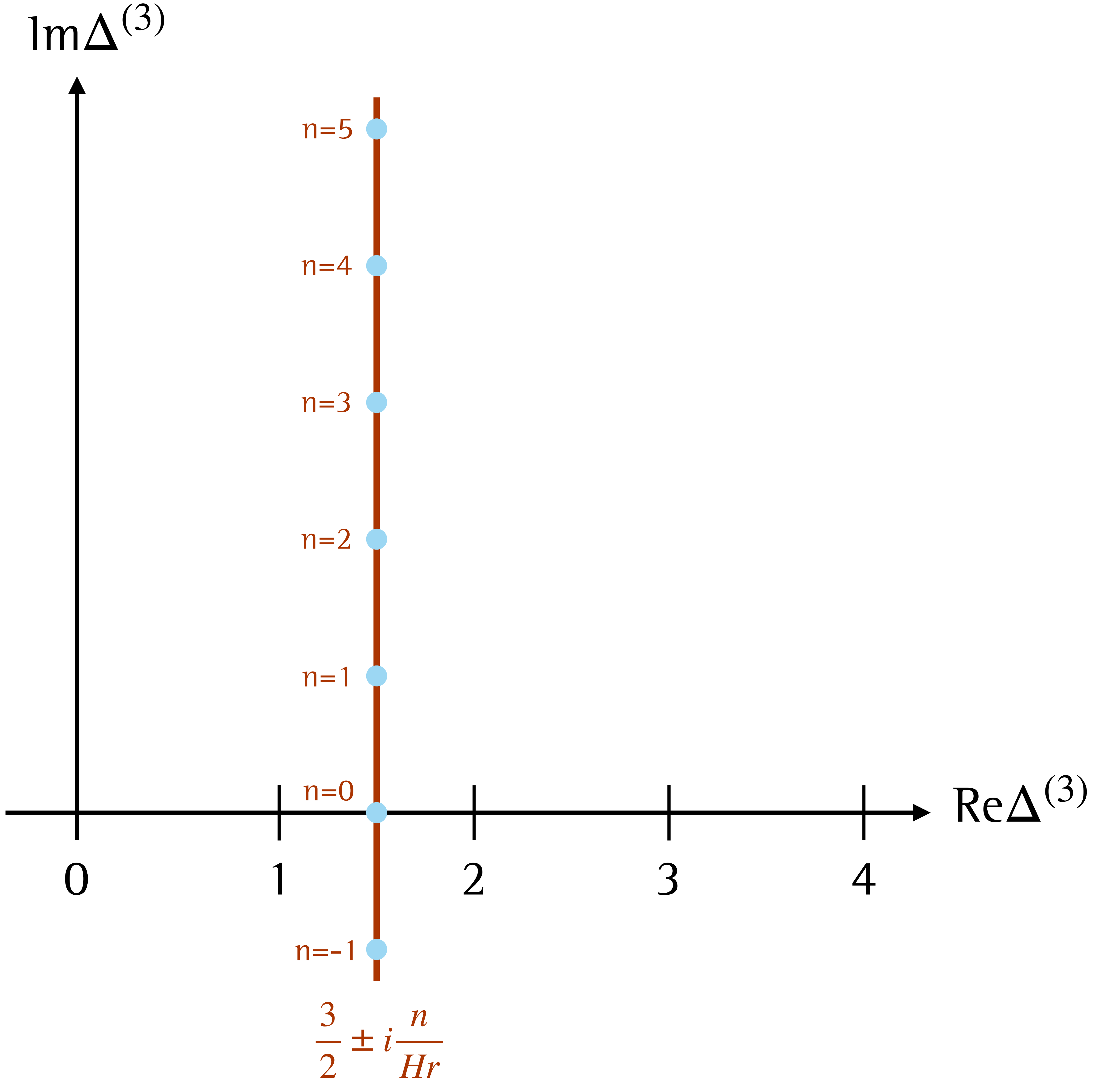
Gapped Unparticles?

5D CFT on $\mathrm{dS}_4 \times S^1_R$

KK Reduction

Gapped Unparticles!

5D Conformally Coupled Scalars



Setup

Unparticles and EFT of Inflation

(Gapped) Unparticles

$$\mathcal{O}_\Delta$$

Setup

Unparticles and EFT of Inflation

(Gapped) Unparticles

$\mathcal{O}_\Delta$

Scalar Perturbations

π

Setup

Unparticles and EFT of Inflation

(Gapped) Unparticles

$\mathcal{O}_\Delta$

Scalar Perturbations

π

$$\mathcal{L}_{\pi\mathcal{O}} = \lambda^{4-\Delta}\mathcal{O}_\Delta(\delta g^{00})$$

Setup

Unparticles and EFT of Inflation

(Gapped) Unparticles

$\mathcal{O}_\Delta$

Scalar Perturbations

π

$$\mathscr{L}_{\pi\mathcal{O}} = \lambda^{4-\Delta}\mathcal{O}_\Delta(\delta g^{00})$$
$$= \lambda^{4-\Delta}\left(-2\dot{\pi}\mathcal{O}_\Delta + (\nabla_\mu \pi)^2 \mathcal{O}_\Delta \right)$$

Setup

Unparticles and EFT of Inflation

(Gapped) Unparticles

$\mathcal{O}_\Delta$

Scalar Perturbations

π

$$\begin{aligned}\mathscr{L}_{\pi\mathcal{O}} &= \lambda^{4-\Delta}\mathcal{O}_\Delta(\delta g^{00}) \\ &= \lambda^{4-\Delta}\left(-2\dot{\pi}\mathcal{O}_\Delta + \underline{(\nabla_\mu \pi)^2 \mathcal{O}_\Delta}\right)\end{aligned}$$

Strategy

Weight-Shifting

Massless Inflaton

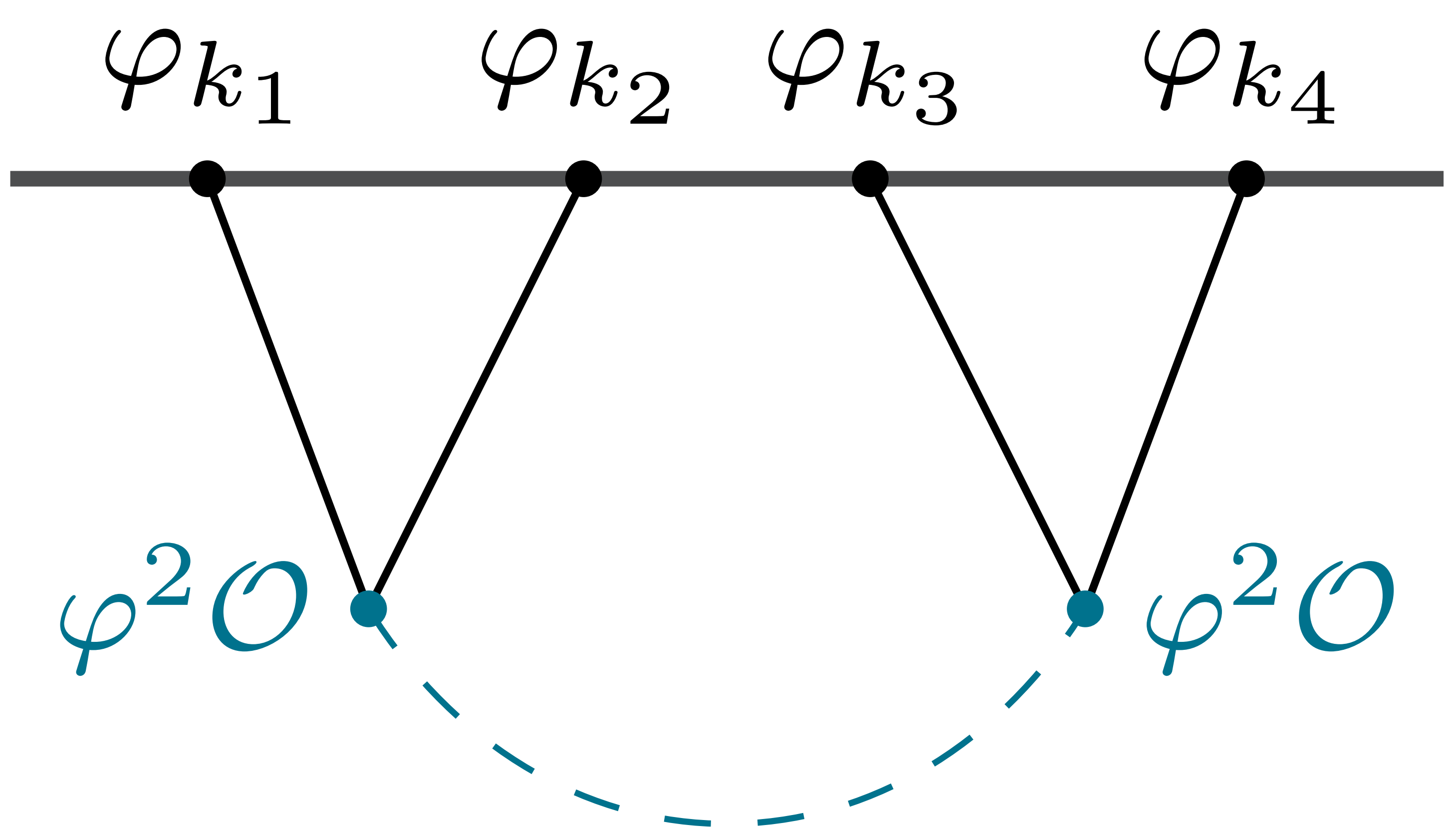
$$\phi_k = (1 + ik\eta)e^{-ik\eta + i\vec{k}\cdot\vec{x}}$$

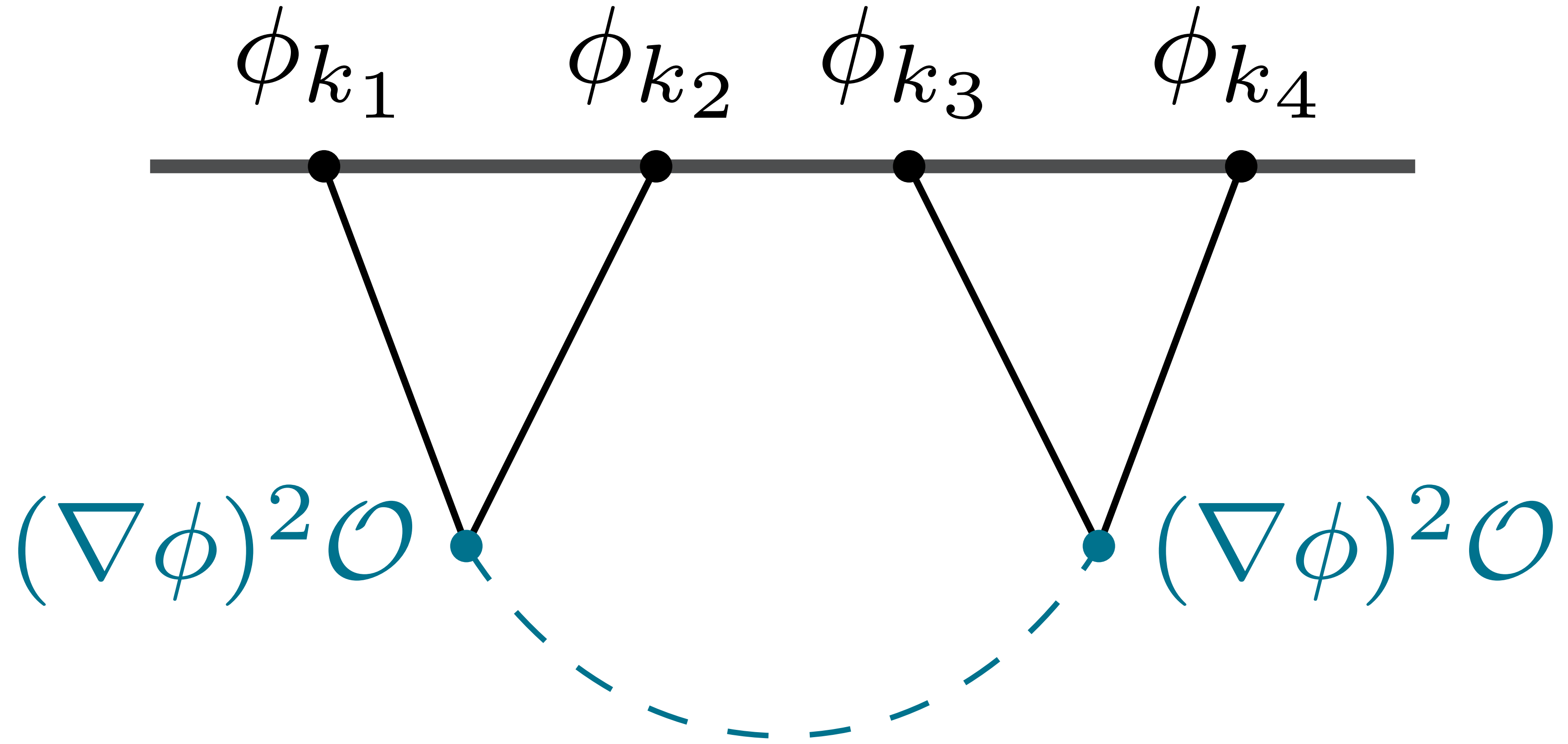
Conformally Coupled Scalar

$$\varphi_k = \eta e^{-ik\eta + i\vec{k}\cdot\vec{x}}$$

Strategy

Weight-Shifting

$U_{12}U_{34}$ 

$=$ 

Strategy

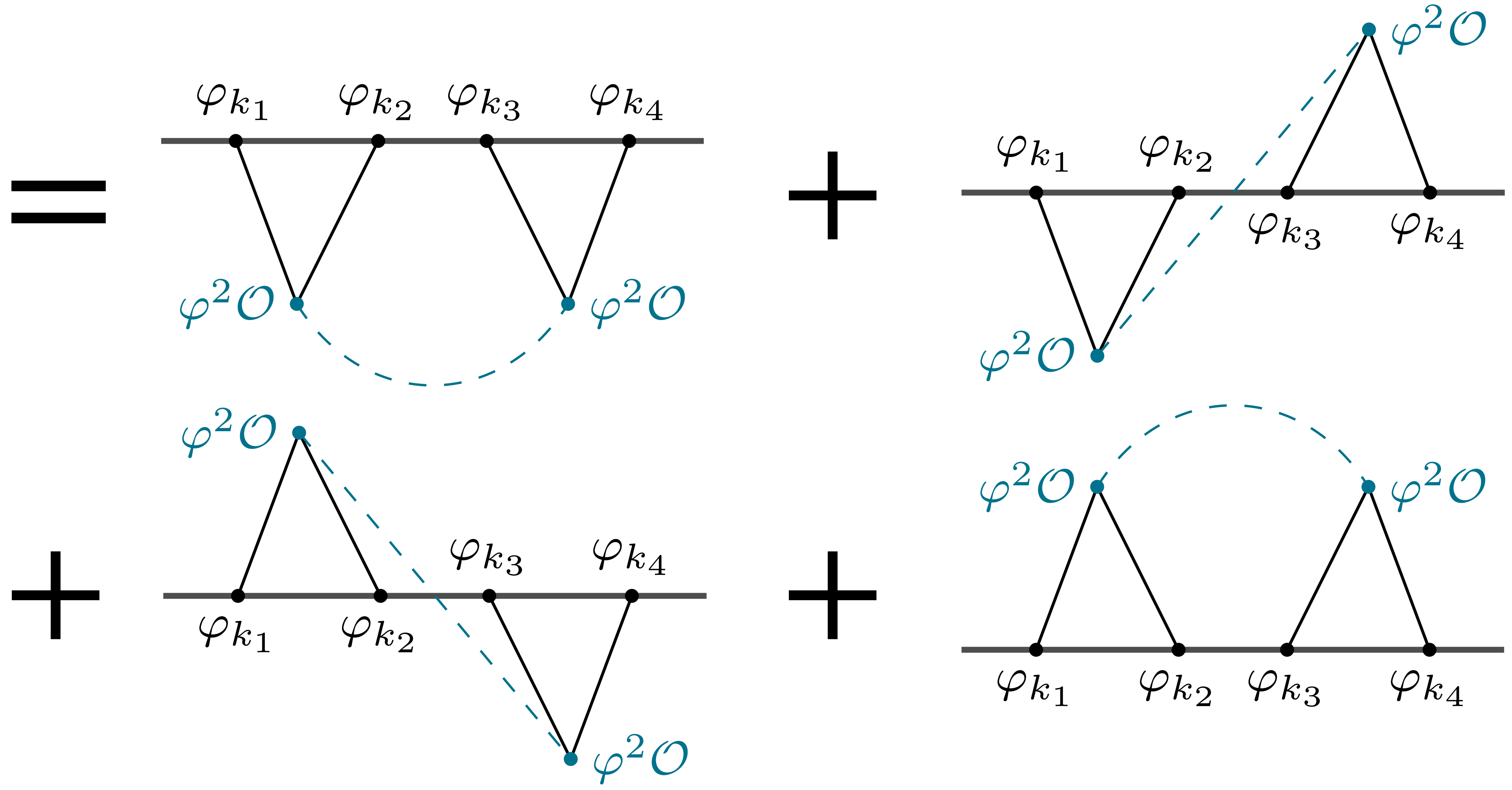
Weight-Shifting

$$\varphi^2 \mathcal{O}_\Delta \quad \rightarrow \quad (\nabla_\mu \phi)^2 \mathcal{O}_\Delta$$

Analytic Result

Gapless Unparticles with Mellin-Barnes Integration

$$\langle \varphi_{k_1}\varphi_{k_2}\varphi_{k_3}\varphi_{k_4}\rangle' =$$



Analytic Result

$$a_\varphi \equiv \frac{g^2 2^2 \Lambda^{4-2\Delta} H^{2\Delta} \eta_0^4}{16 k_1 k_2 k_3 k_4} \quad u = \frac{k}{k_1 + k_2} \quad v = \frac{k}{k_3 + k_4}$$

Gapless Unparticles with Mellin-Barnes Integration

Analytic Result

$$a_\varphi \equiv \frac{g^2 2^2 \Lambda^{4-2\Delta} H^{2\Delta} \eta_0^4}{16 k_1 k_2 k_3 k_4} \quad u = \frac{k}{k_1 + k_2} \quad v = \frac{k}{k_3 + k_4}$$

Gapless Unparticles with Mellin-Barnes Integration

$$\langle \varphi_{k_1} \varphi_{k_2} \varphi_{k_3} \varphi_{k_4} \rangle'$$

$$= a_\varphi \frac{4^{-\Delta}}{k} \frac{2}{\Delta - 1} \Bigg(\left(\frac{2uv}{u+v}\right) \frac{1}{2-\Delta} F_1\left(1; 2-\Delta, 2-\Delta; 3-\Delta; \frac{u(1-v)}{u+v}, \frac{u(1+v)}{u+v}\right)$$

$$+ \left(\frac{2uv}{u+v}\right) \frac{1}{2-\Delta} F_1\left(1; 2-\Delta, 2-\Delta; 3-\Delta; \frac{v(1-u)}{u+v}, \frac{v(1+u)}{u+v}\right)$$

$$- \left(\frac{2uv}{u+v}\right)^{2(\Delta-1)} \frac{1}{\Delta-1} F_1\left(1; \Delta-1, \Delta-1; \Delta; \frac{u(1-v)}{u+v}, \frac{u(1+v)}{u+v}\right)$$

$$- \left(\frac{2uv}{u+v}\right)^{2(\Delta-1)} \frac{1}{\Delta-1} F_1\left(1; \Delta-1, \Delta-1; \Delta; \frac{v(1-u)}{u+v}, \frac{v(1+u)}{u+v}\right)$$

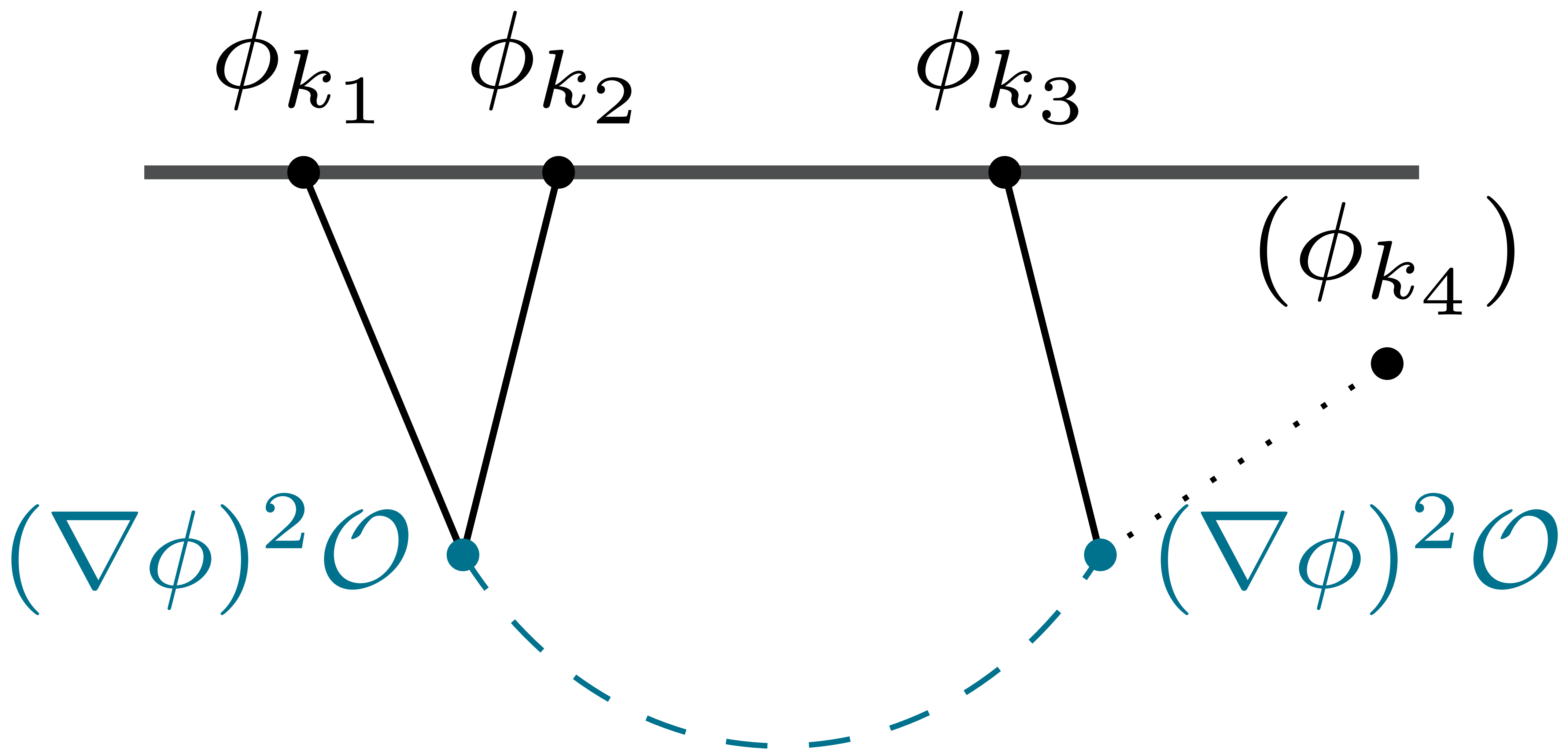
$$+ \frac{2}{\Delta-1} F_1\left(1; \Delta-1, \Delta-1; \Delta; \frac{u-1}{2u}, \frac{v-1}{2v}\right) \Bigg)$$

Analytic Result

Gapless Unparticles with Mellin-Barnes Integration

Full Result Obtained!

Bispectra from Trispectra



Bispectra

squeezed limit $k_3 \ll k_1$

Gapless Unparticles

Bispectra

squeezed limit $k_3 \ll k_1$

Gapless Unparticles

$$\Delta < 3/2$$

$$\Delta \geq 3/2$$

Bispectra

squeezed limit $k_3 \ll k_1$

Gapless Unparticles

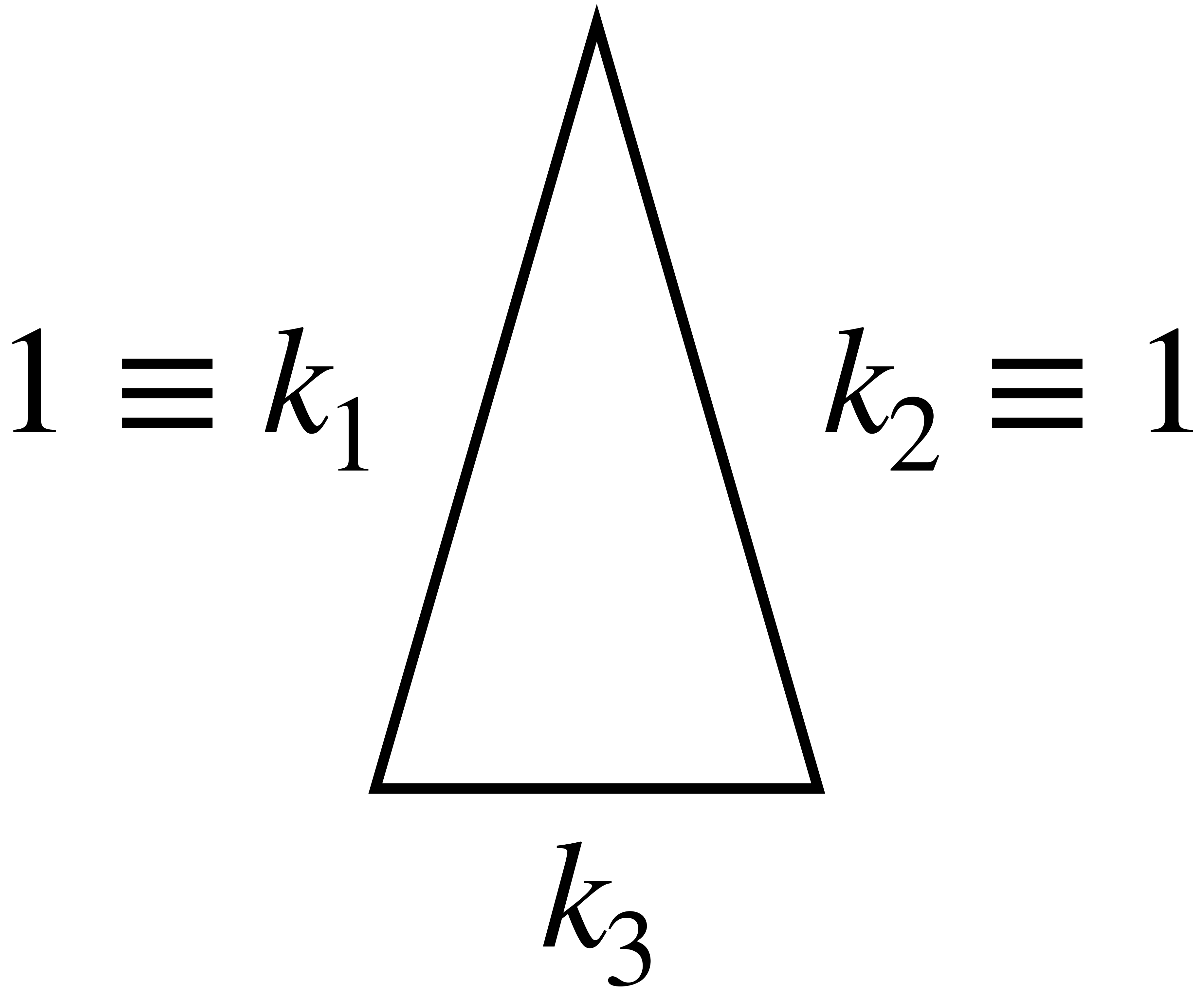
$\Delta < 3/2$ $$B_\phi \propto k_1^{-3} k_3^{-3} (k_3/k_1)^{2\Delta - 1}$$

$\Delta \geq 3/2$ $$B_\phi \propto k_1^{-3} k_3^{-3} (k_3/k_1)^{2}$$

Bispectra

Gapless Unparticles

Three Typical Shapes

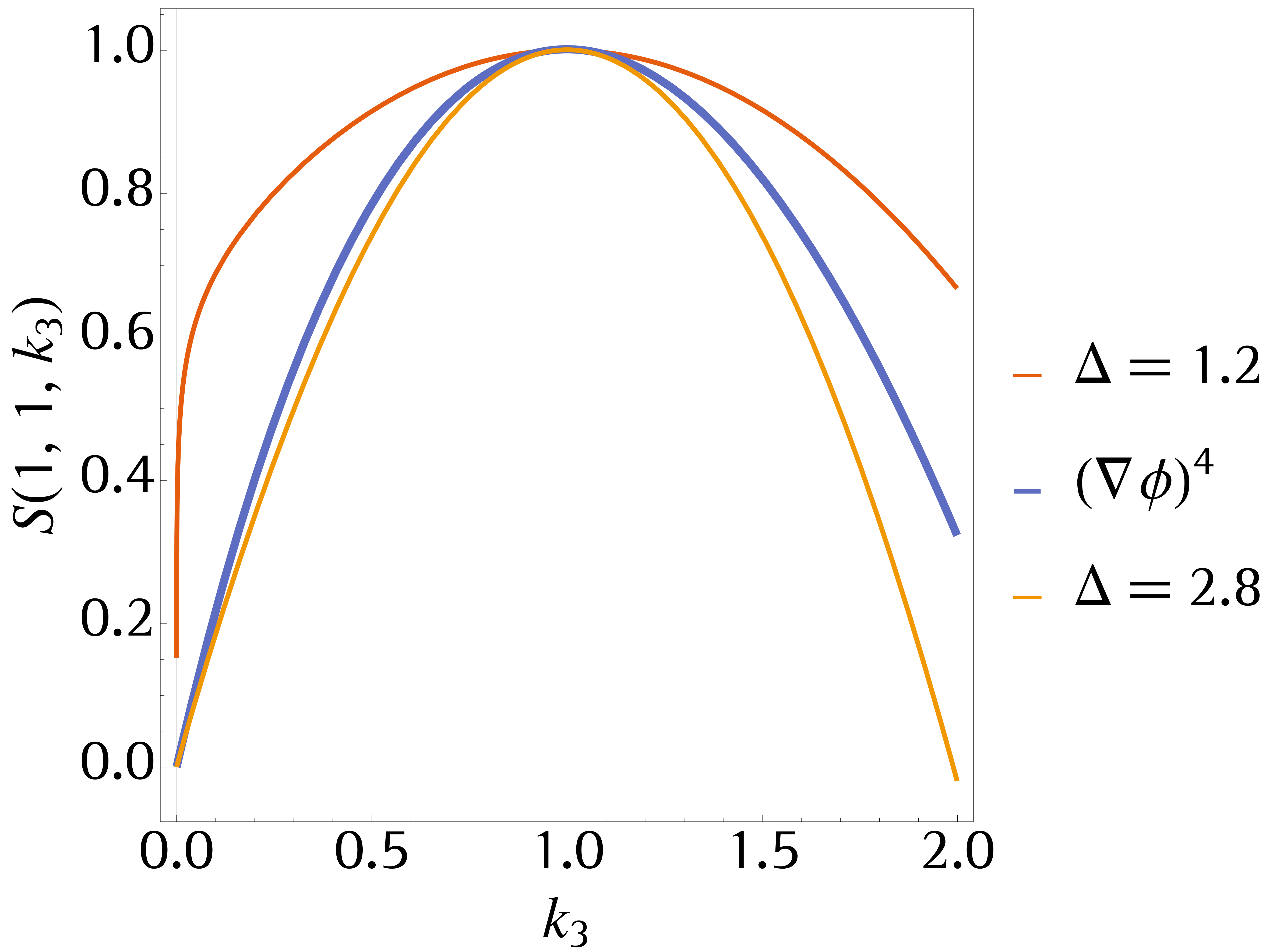


Bispectra

Gapless Unparticles

Three Typical Shapes

Equilateral-like

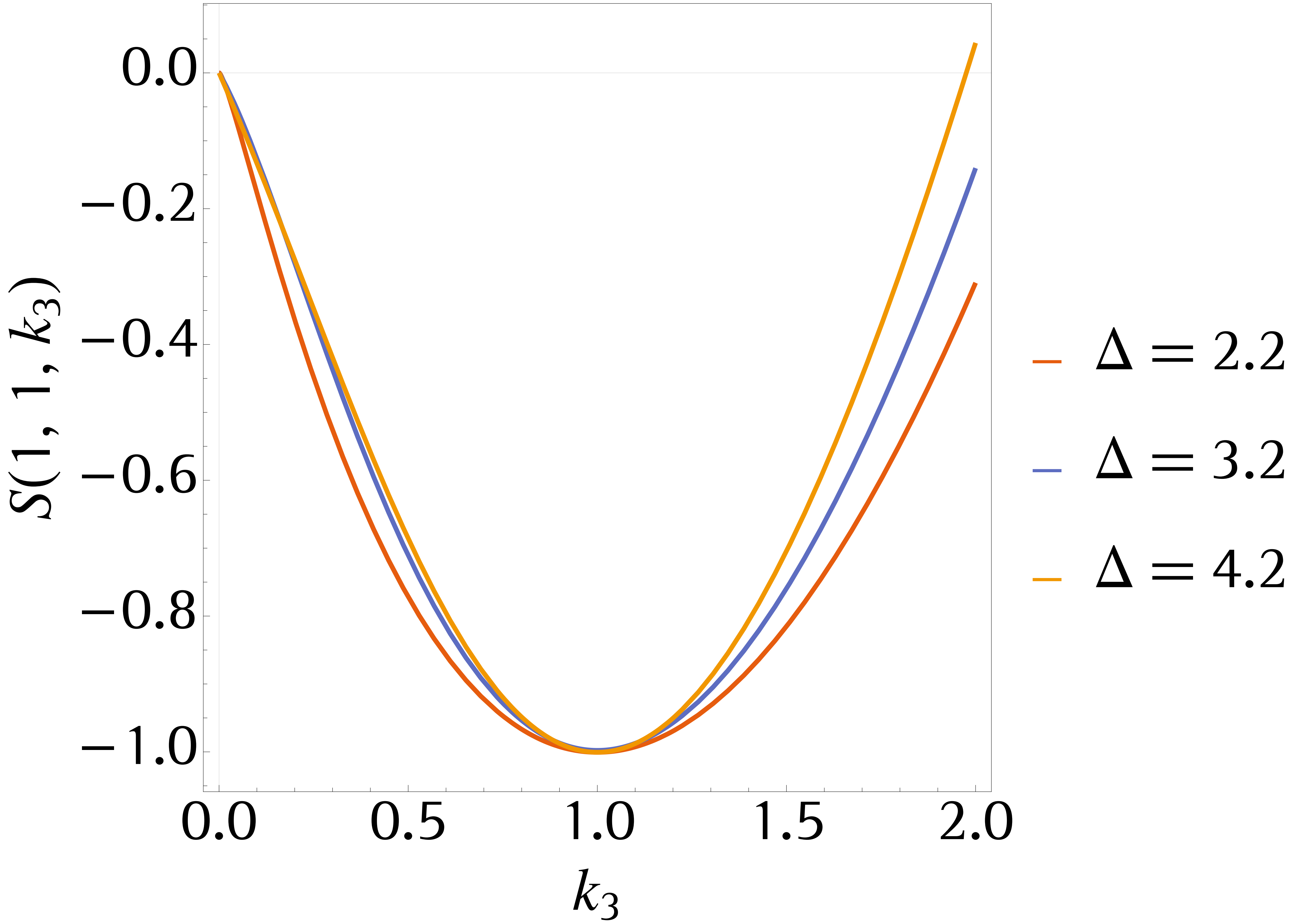


Bispectra

Gapless Unparticles

Three Typical Shapes

Orthogonal-like

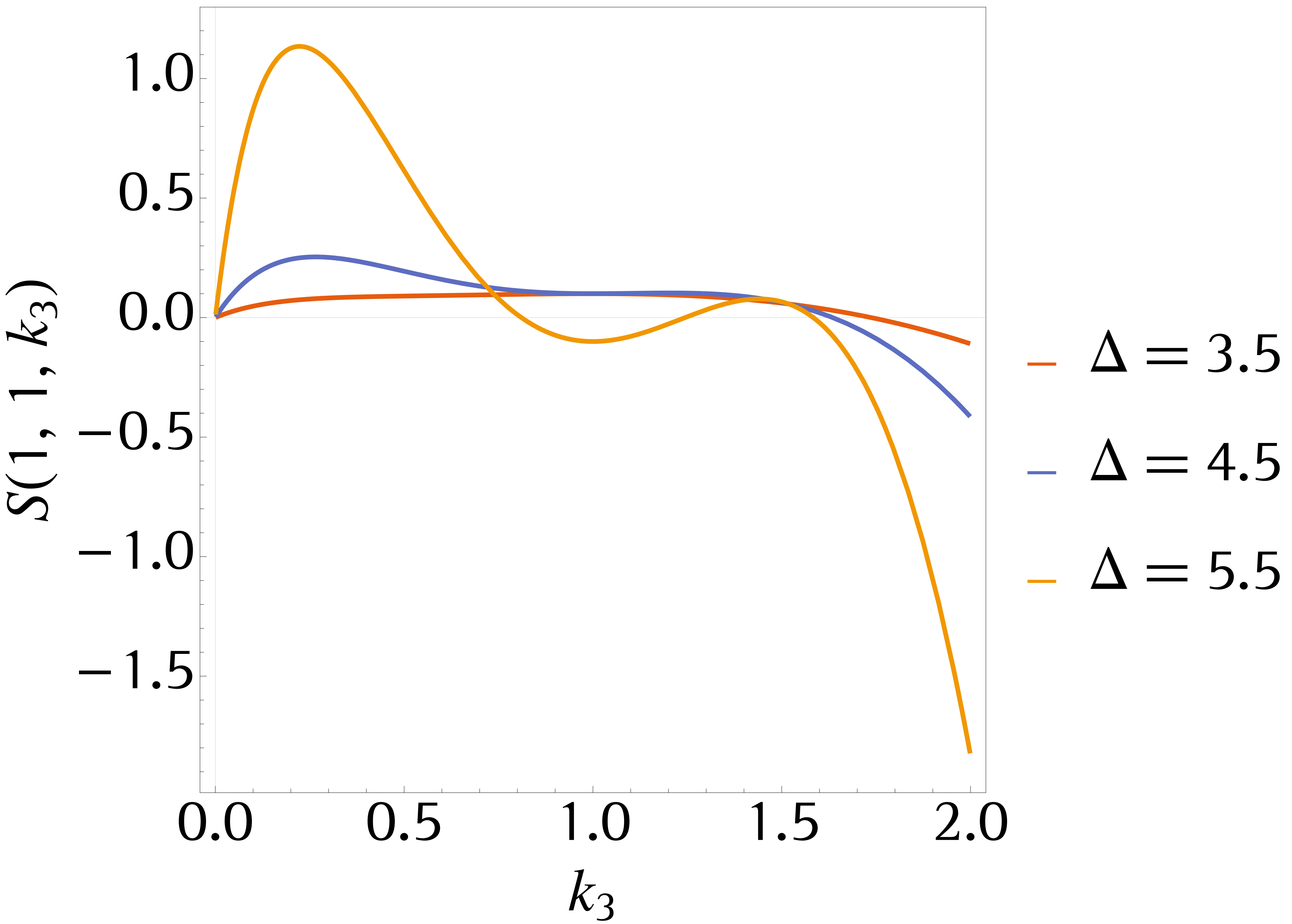


Bispectra

Gapless Unparticles

Three Typical Shapes

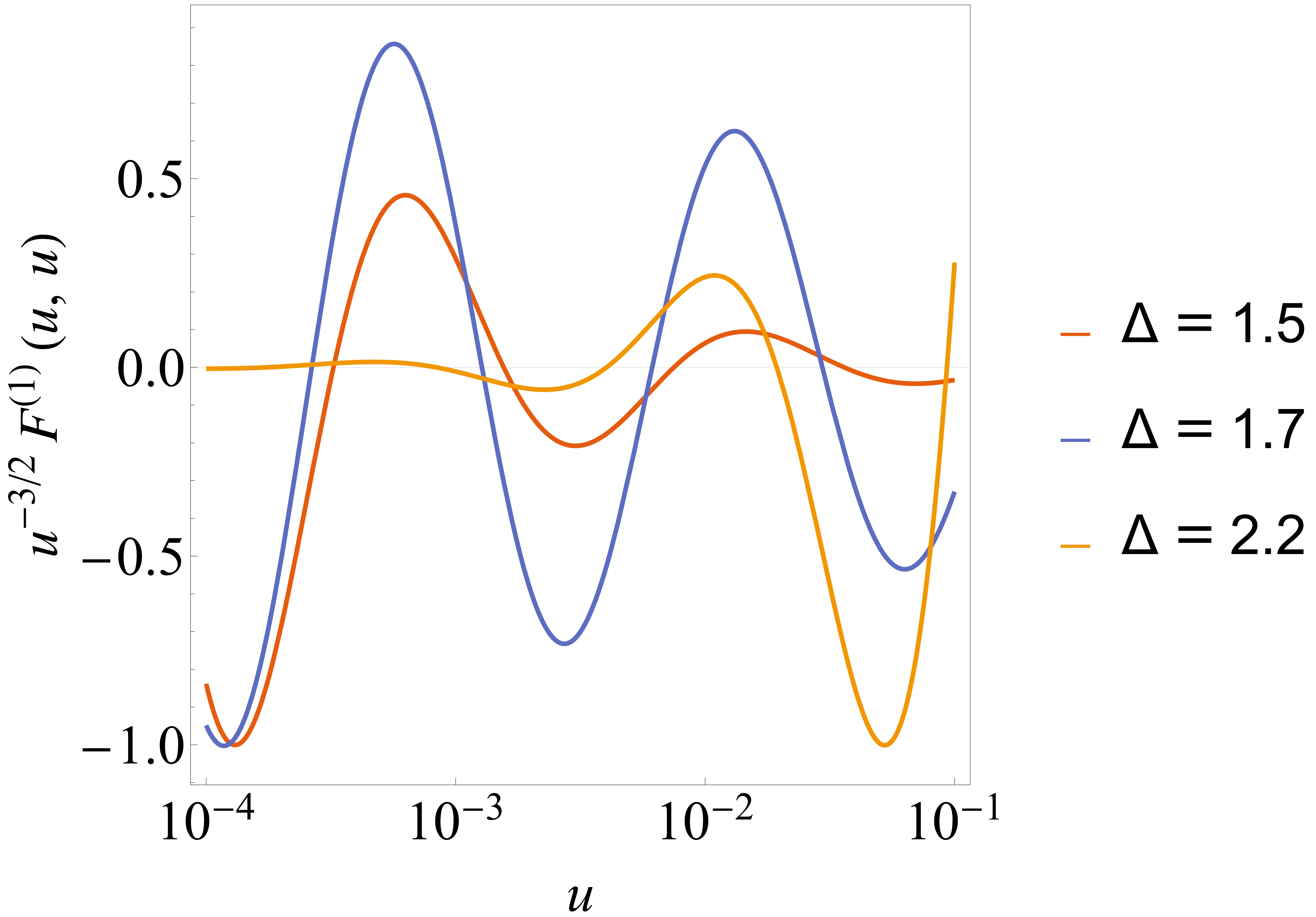
Novel Shape



Trispectra
before weight-shifting

Gapped Unparticles

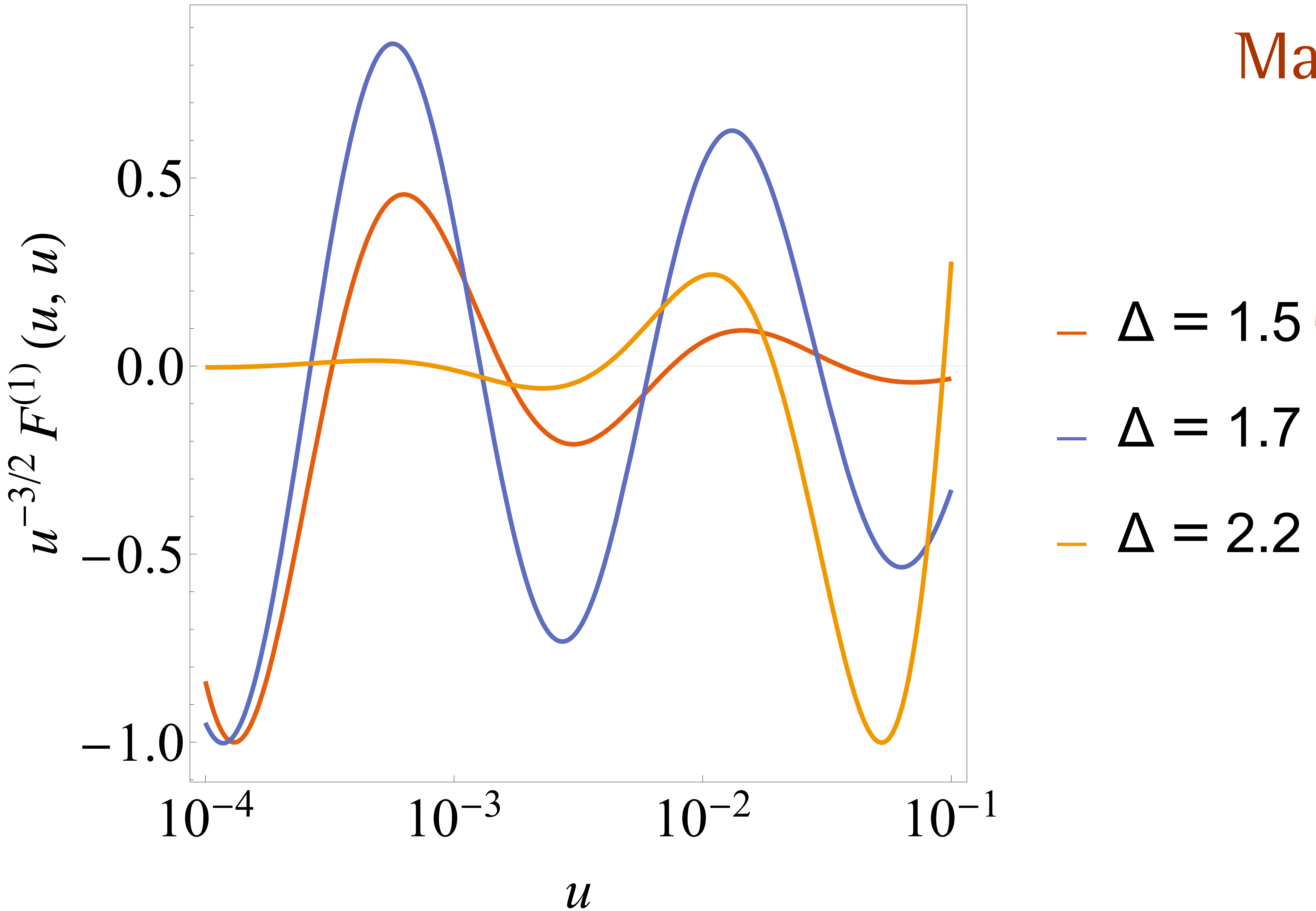
Different Envelopes



Trispectra
before weight-shifting

Gapped Unparticles

Different
Envelopes

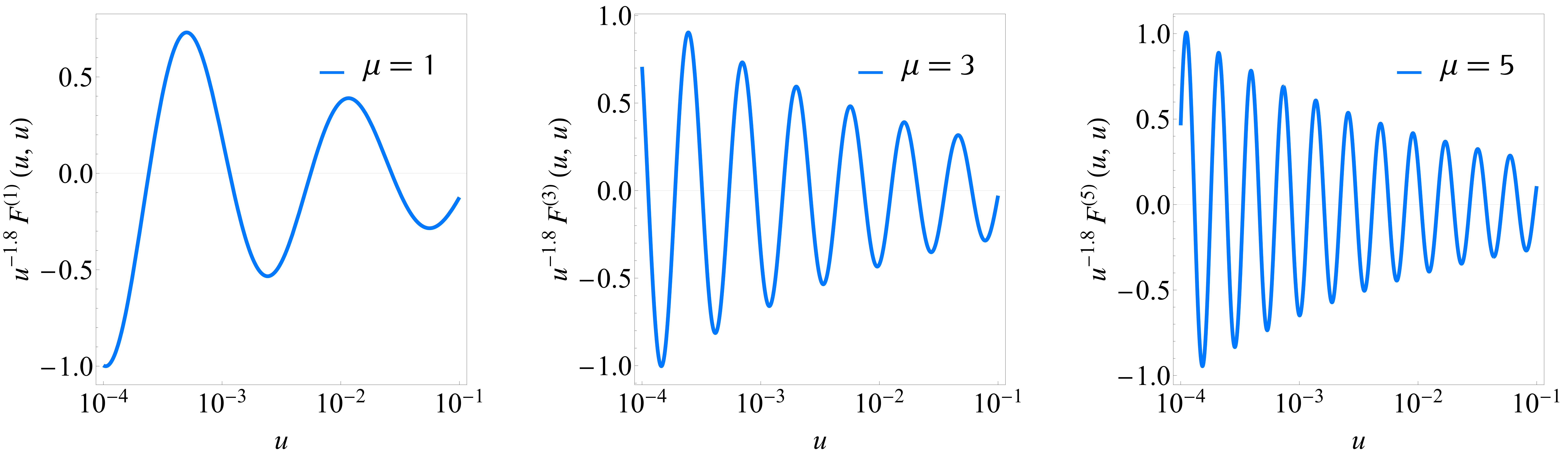


Massive Scalar

Trispectra

before weight-shifting

Gapped Unparticles



Different Frequencies

Take-Home Message

Precise Measurements

& Full Shape

Needed!

Model Building

A Story about the Dark Walker

Extra Taste!

Model Building

A Story about the Dark Walker

Extra Taste!

Gapless Unparticles

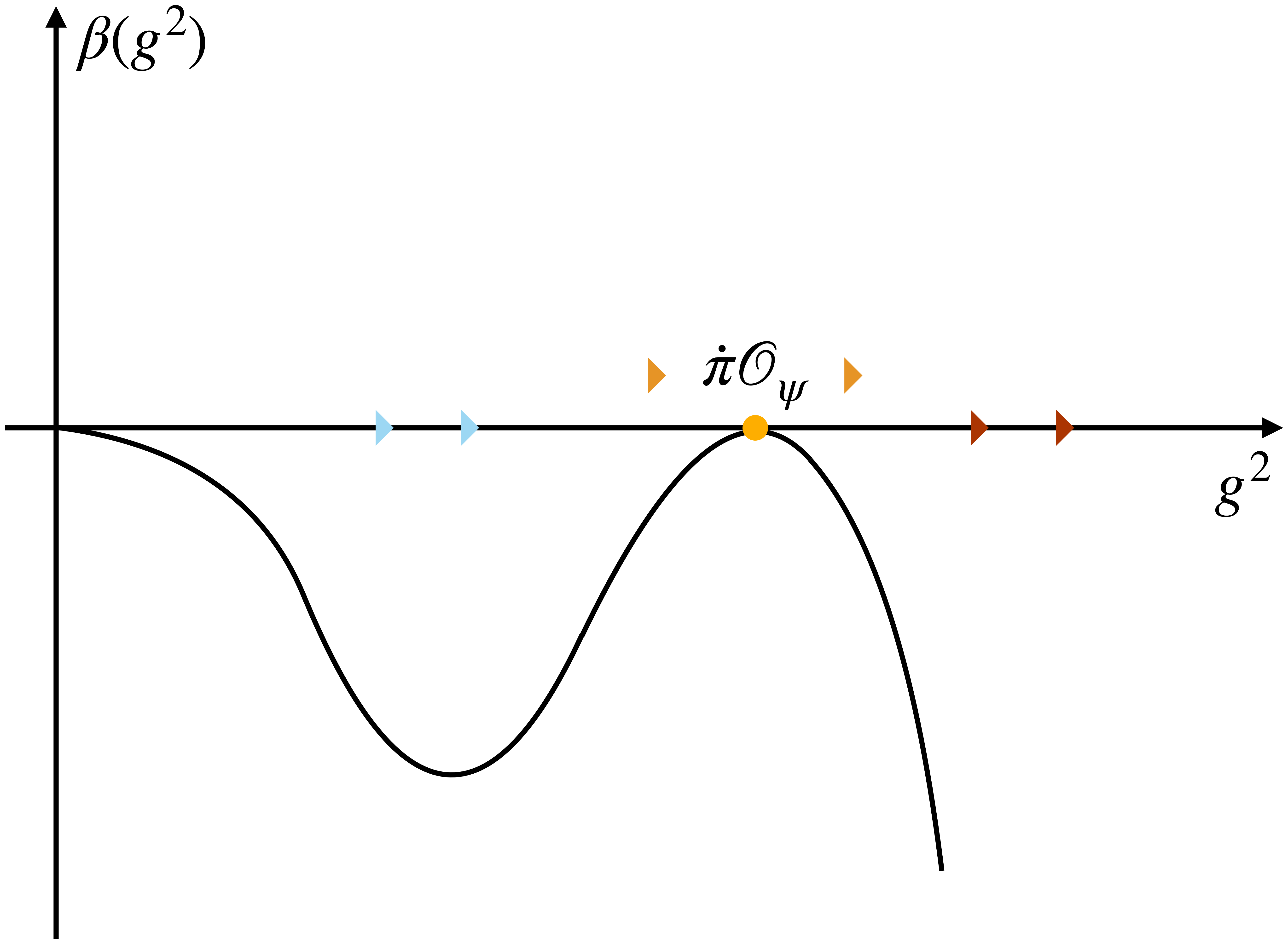
Model Building

A Story about the Dark Walker

$SU(3)$

with

$N_f = 8$



Model Building

A Story about the Dark Walker

$SU(3)$

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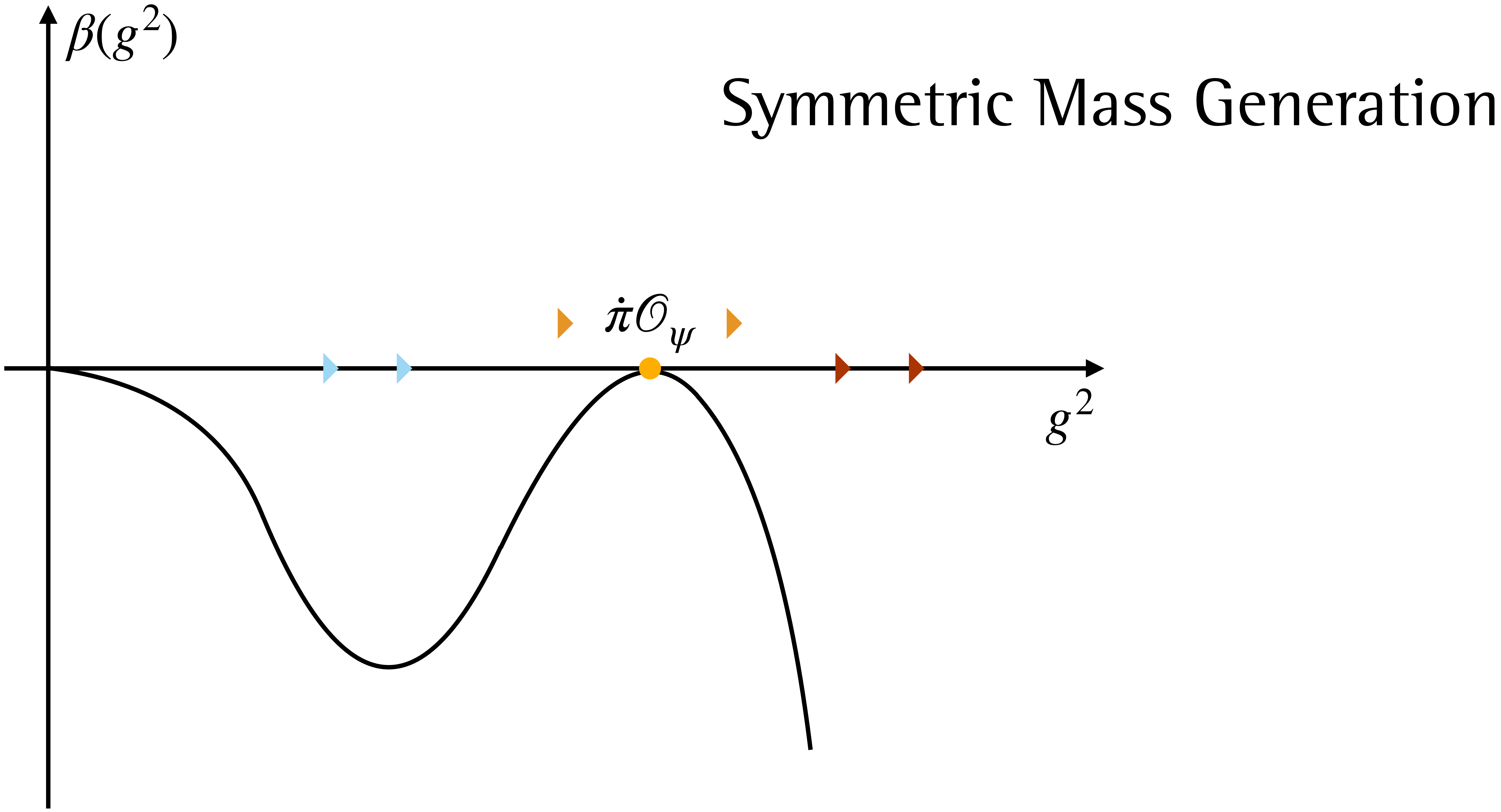
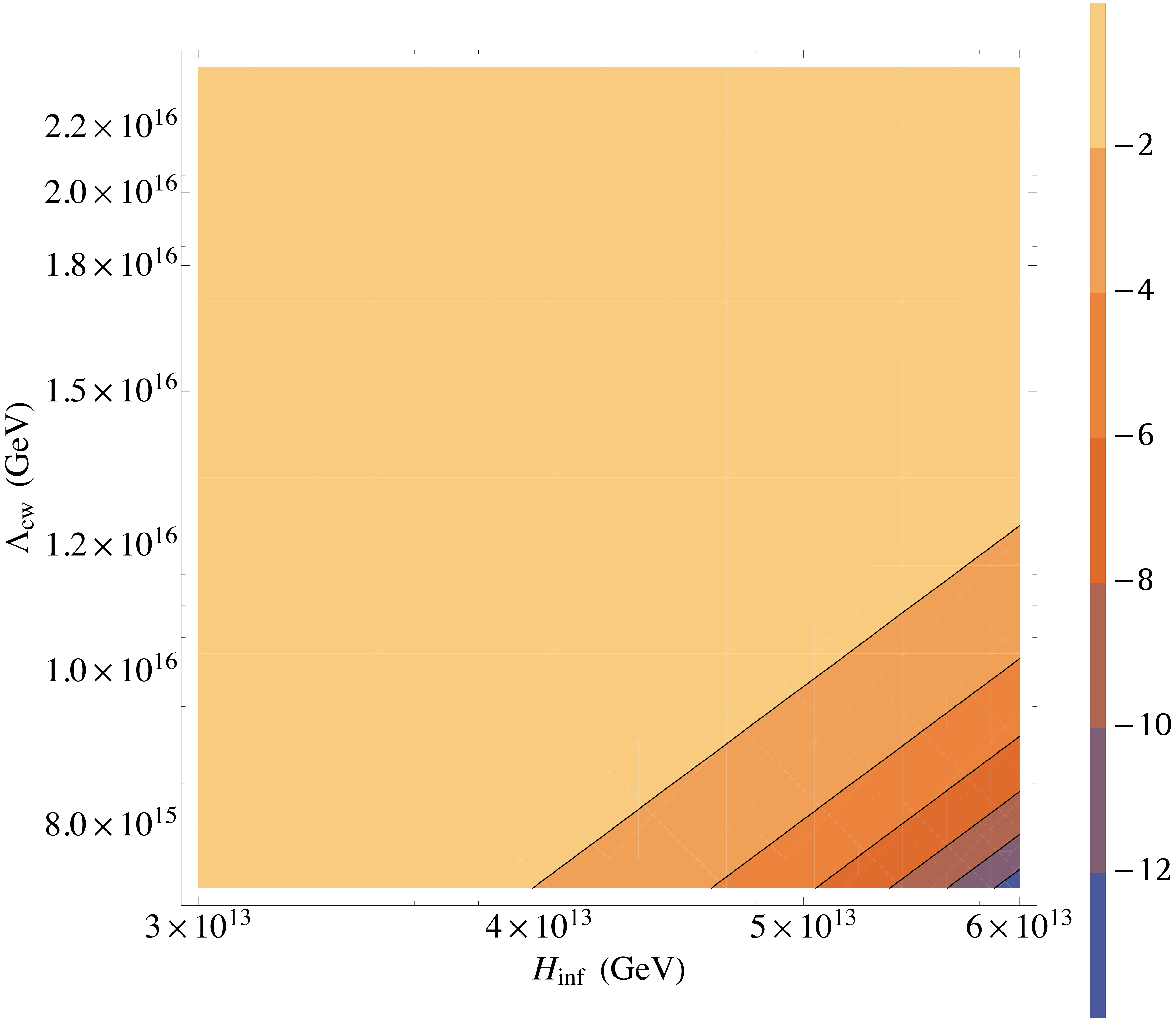


Model Building

A Story about the Dark Walker



Model Building

A Story about the Dark Walker