Strong Mixing At the Cosmological Collider

Quantum Particle Production in cosmological data

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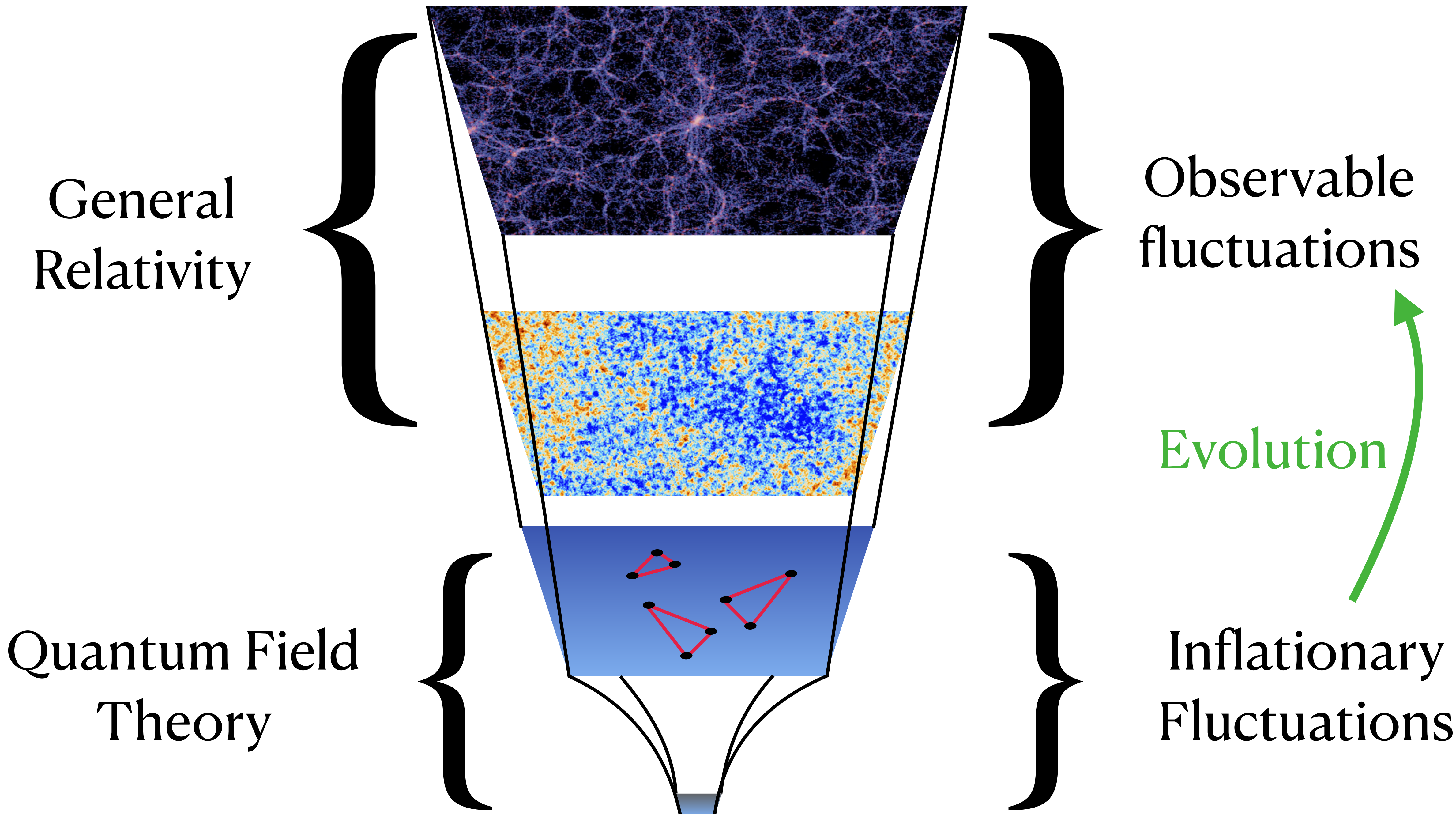
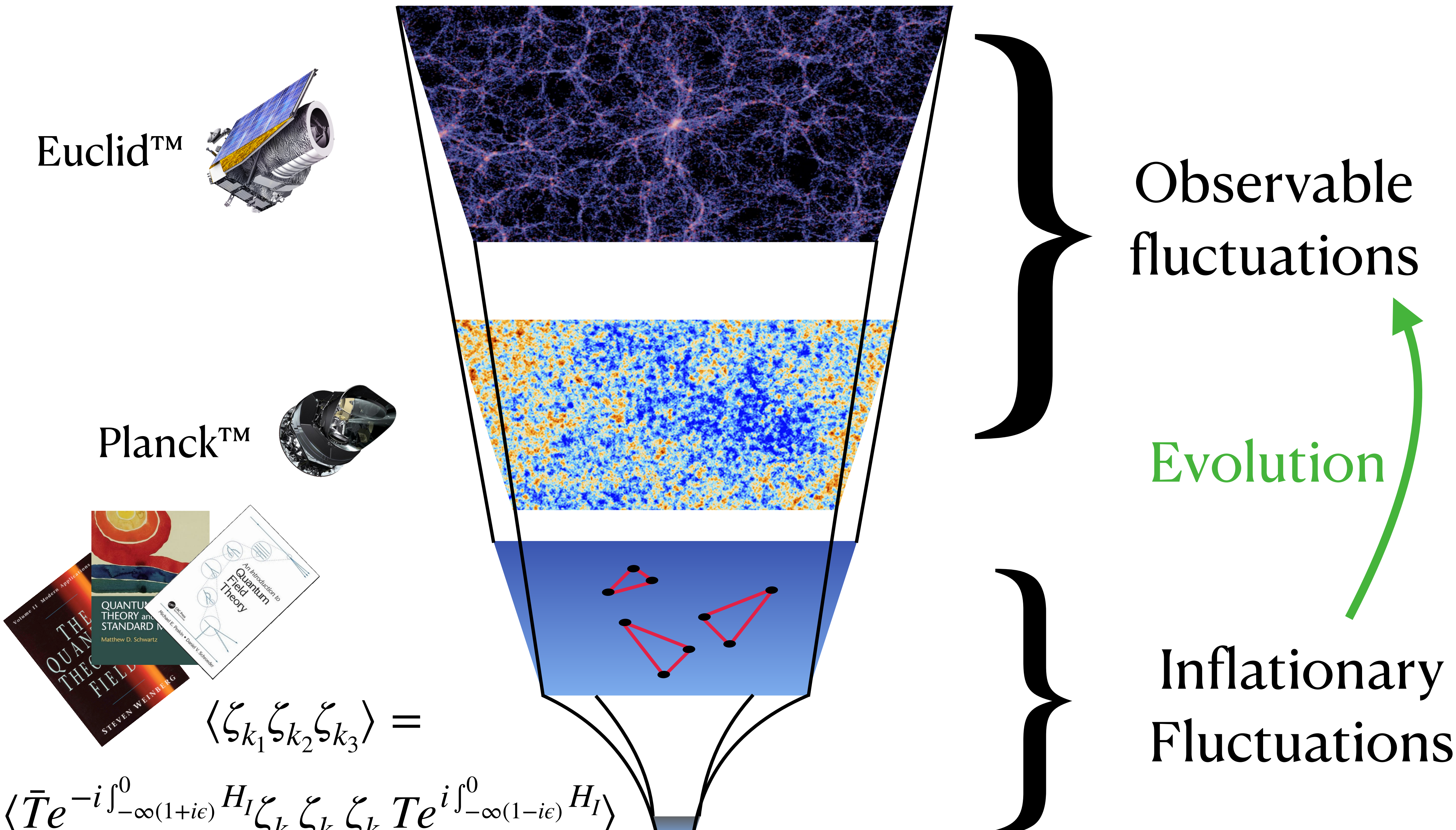
Inflation As Origine of Structures



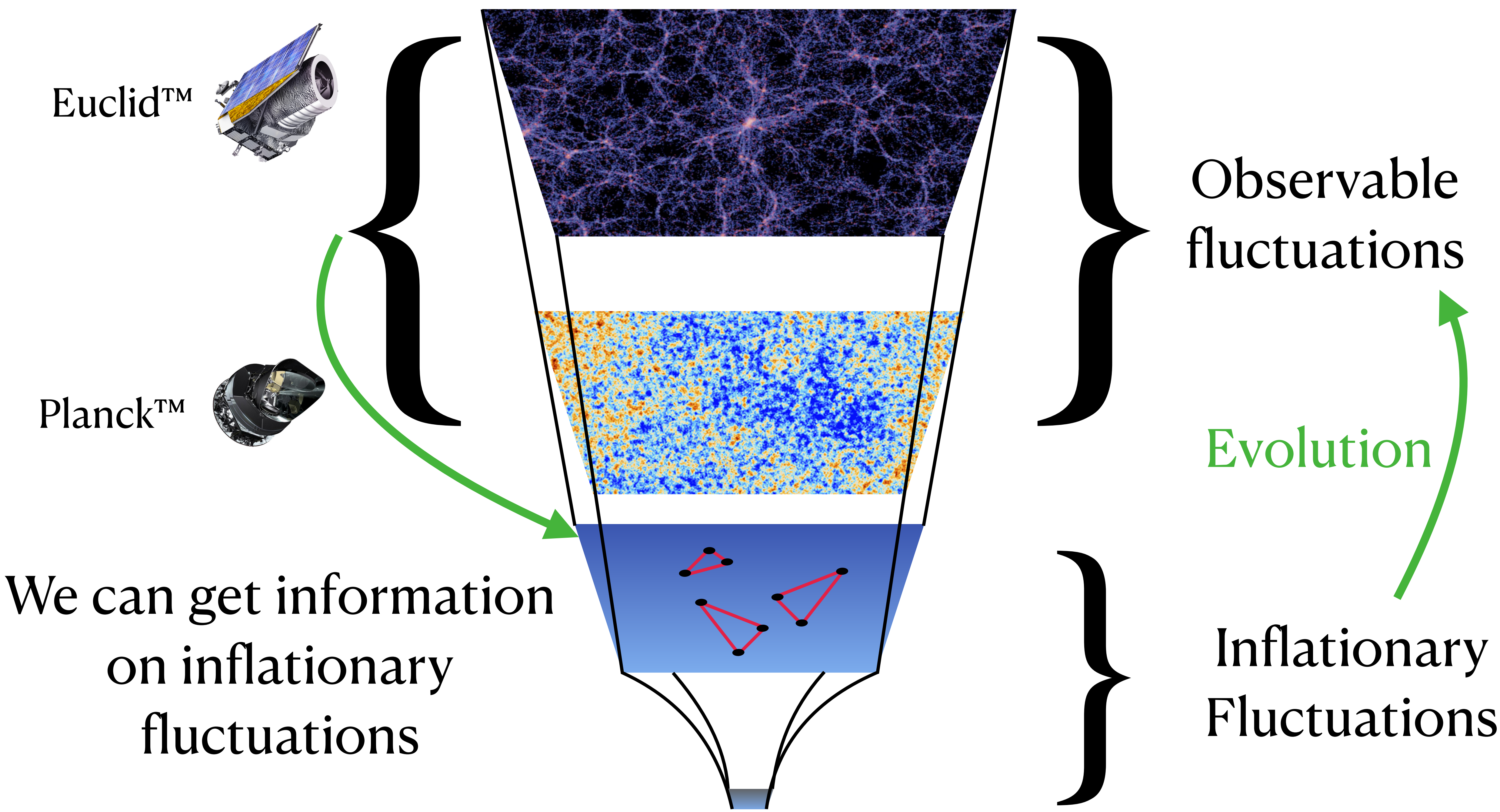
Inflation As Origine of Structures



$$\langle \zeta_{k_1}\zeta_{k_2}\zeta_{k_3}\rangle =$$

$$\langle \bar{T}e^{-i\int_{-\infty(1+i\epsilon)}^{0} H_I}\zeta_{k_1}\zeta_{k_2}\zeta_{k_3} T e^{i\int_{-\infty(1-i\epsilon)}^{0} H_I}\rangle$$

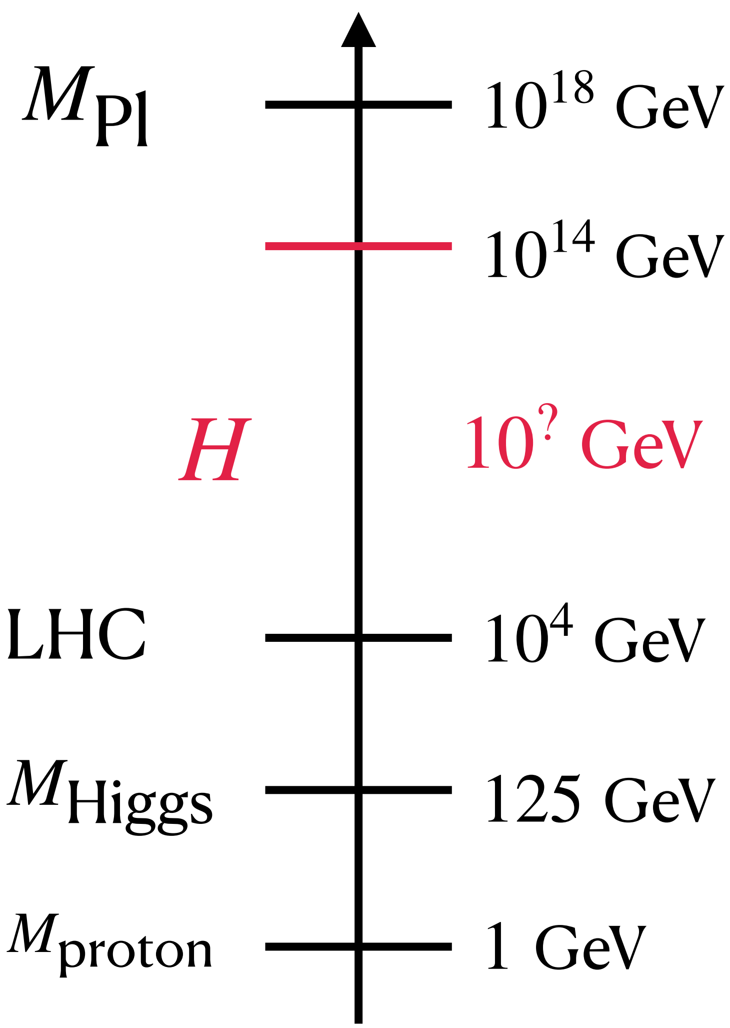
Inflation As Origine of Structures



Inflationary physics left imprints in cosmological data.

Energy Scales

- Inflationary physics = Very High energy scales.

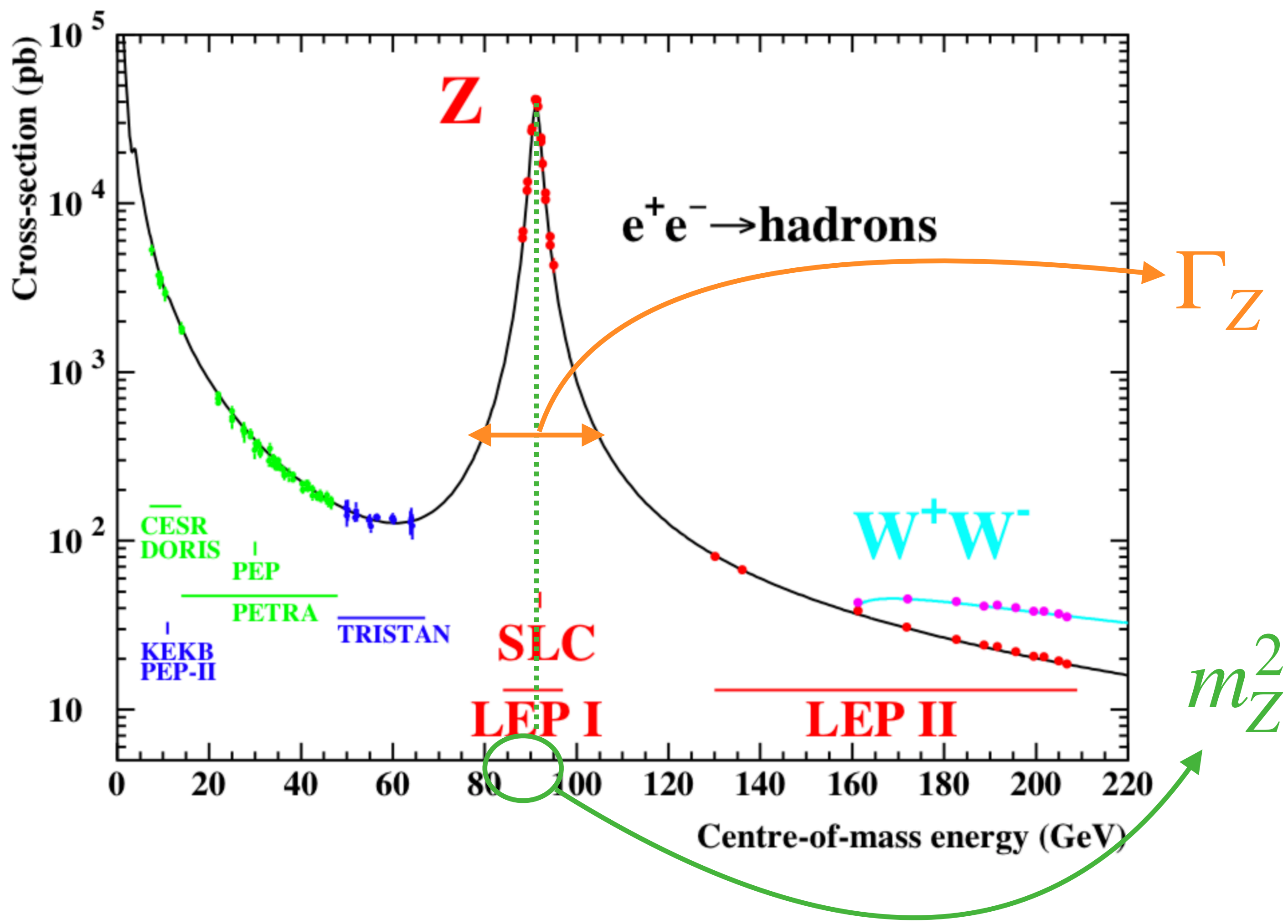


- PLANCK constraints: $H \lesssim 10^{14}$GeV
- **Energy Conservation**: we cannot produce on-shell particles heavier than 10^{4}GeV at the LHC.
- High-energy theories: often rely on the existence of very massive particles.

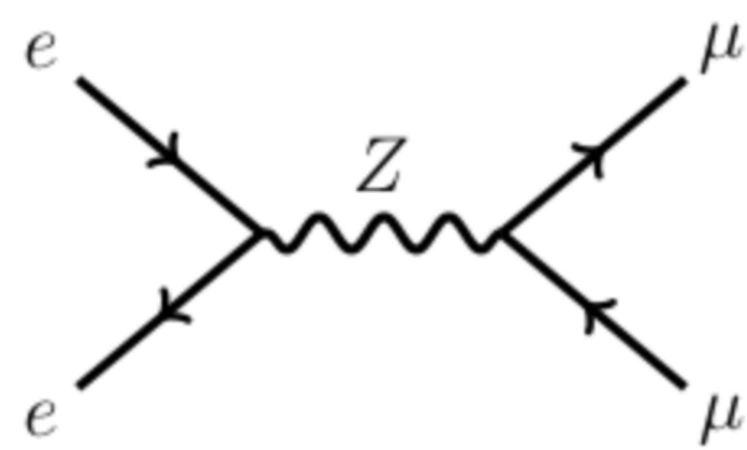
Idea: Use Inflation as a **Cosmological Collider**

How Do we detect new Particles?

- **Breit-Wigner Resonance**: mass/lifetime of exchanged particles.



Exchange of a massive boson after the e^+e^- collision.

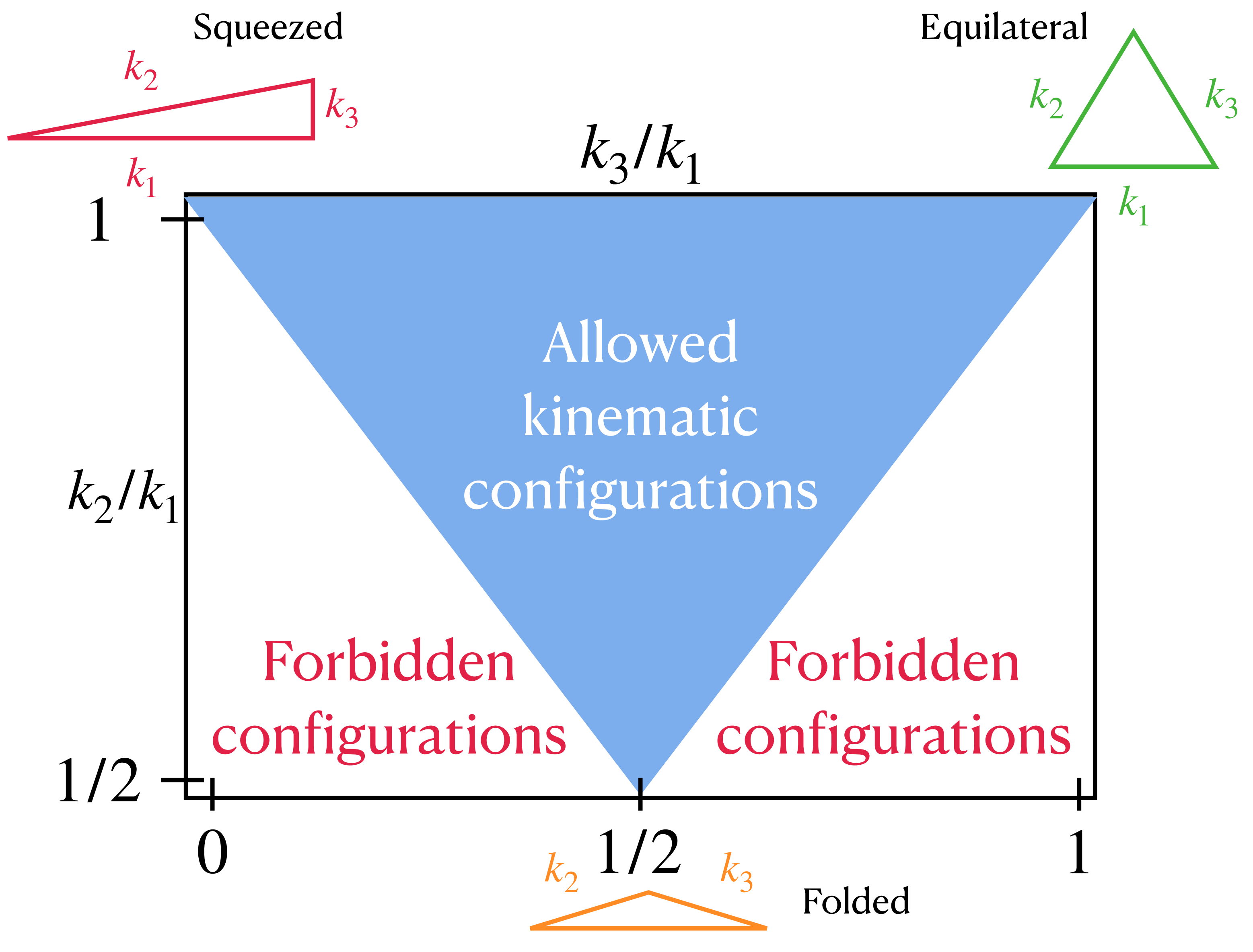


Idea: Build an equivalent for inflation !

Observable: Bispectrum

- Simplest non-gaussian signal.
- Homogeneity of space imposes triangular configurations.

$$\langle (\delta\rho/\bar{\rho})^3 \rangle = (2\pi)^3 \delta^{(3)}(\vec{k}_1 + \vec{k}_2 + \vec{k}_3) B(k_1, k_2, k_3)$$

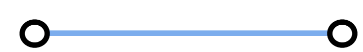


Particle Physics In Inflation

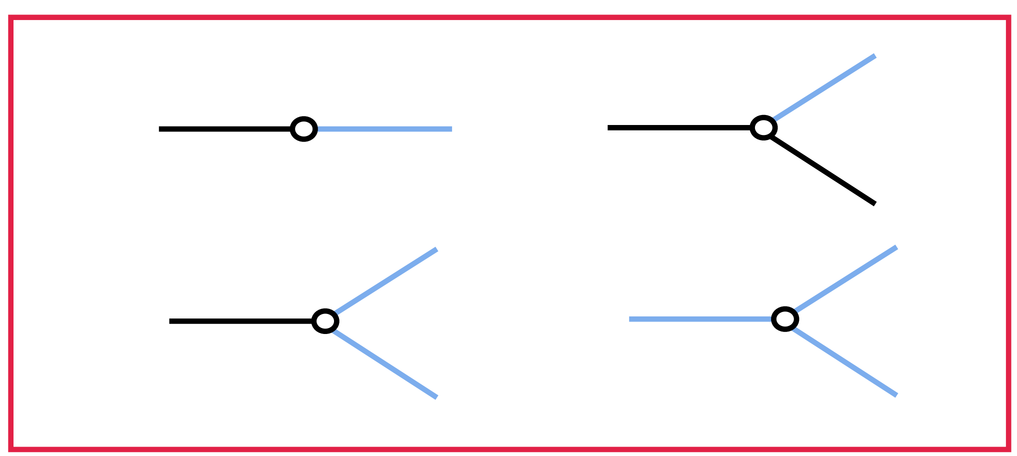
- We can build a general theory of inflationary fluctuation:

Inflaton fluctuations = massless particle

- We can build the most generic interaction with some massive particle.



- Here is the list of ALL the possible interactions patterns:



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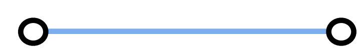

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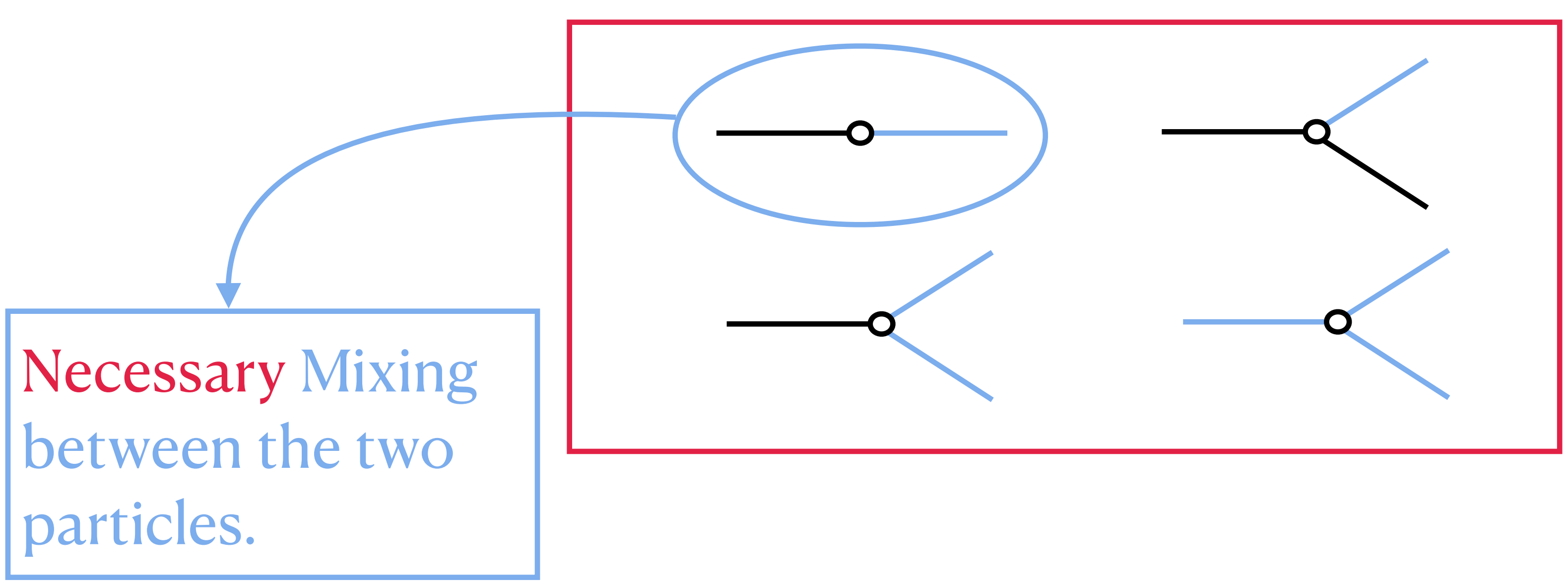
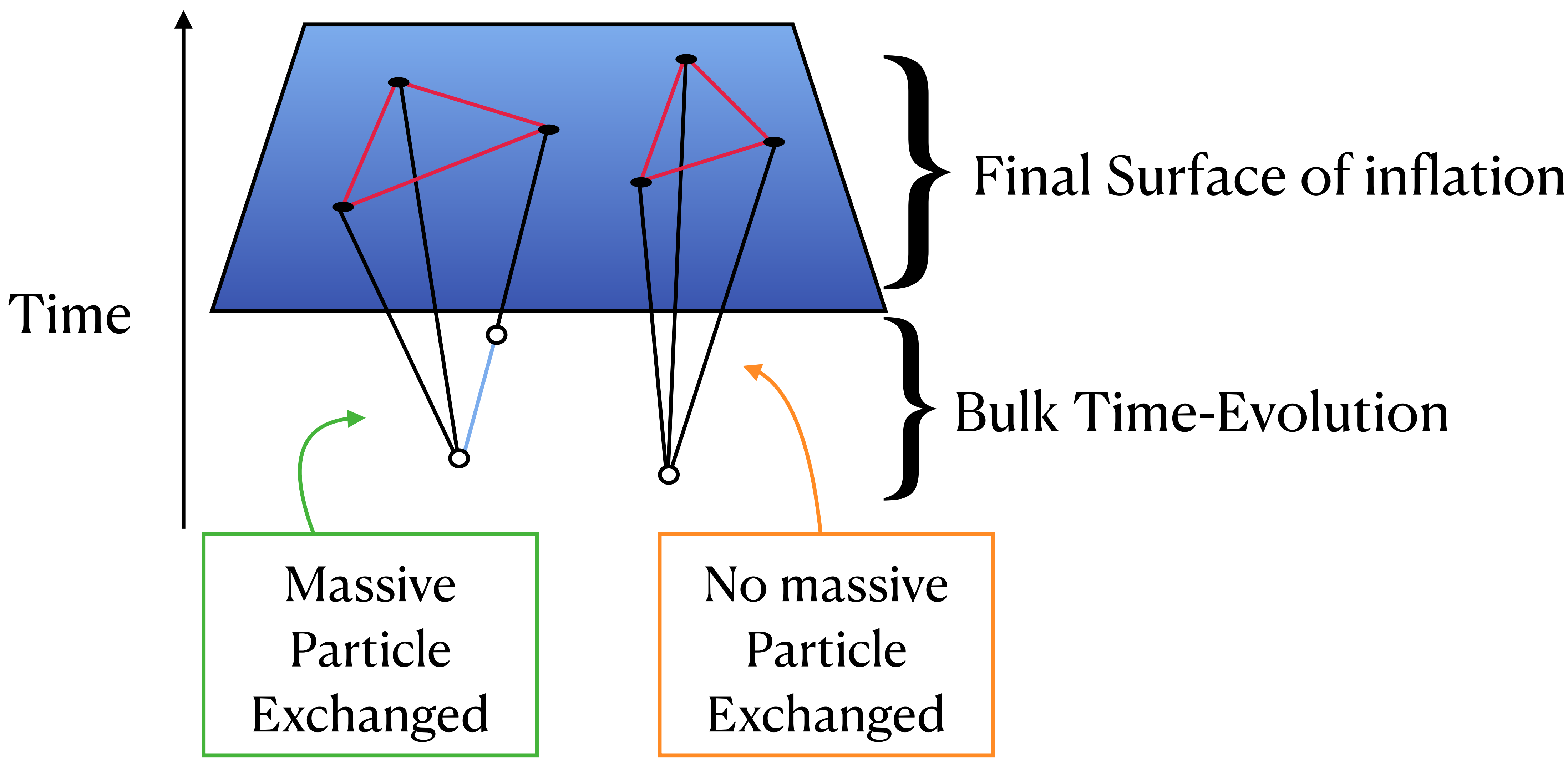


Exchange Process in Inflation

- End of Inflation = Initial Condition for Large Scale Structures.
- Different process in the bulk leads to different correlations.



Cosmological Collider Signal

- Exchange of massive particles leads to oscillating behavior in the squeezed limit:

$$B(k_1, k_2, k_3) \sim \left(\frac{k_3}{k_2}\right)^{1/2} e^{-\pi m/H} \cos(m/H \log(k_3/k_1) + \varphi)$$

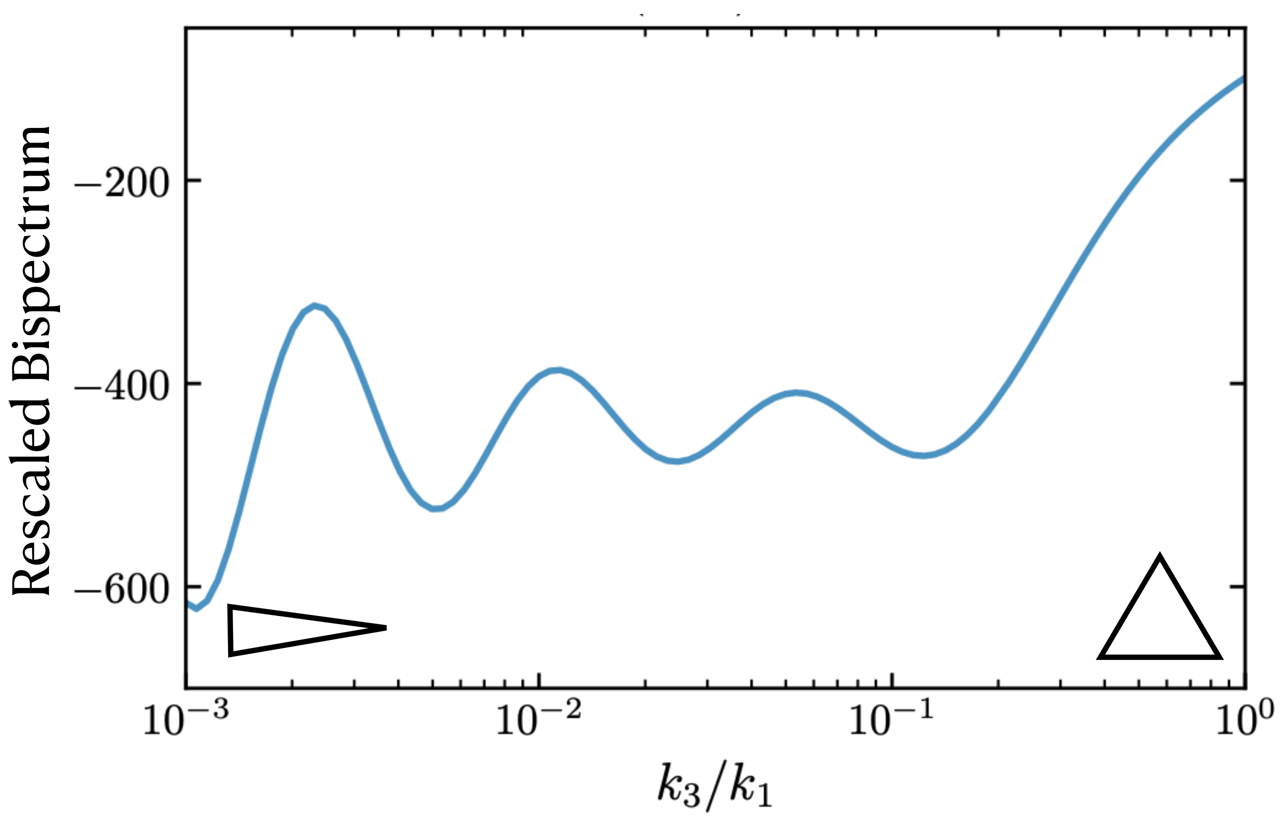


Figure from Werth, Pinol, Renaux-Petel, 2312.06559
Using CosmoFlow™

- Oscillation in $\log(k_3/k_1)$.
- Frequency = mass of the new particle.
- Amplitude suppressed by the mass $\Longrightarrow$ Small signal

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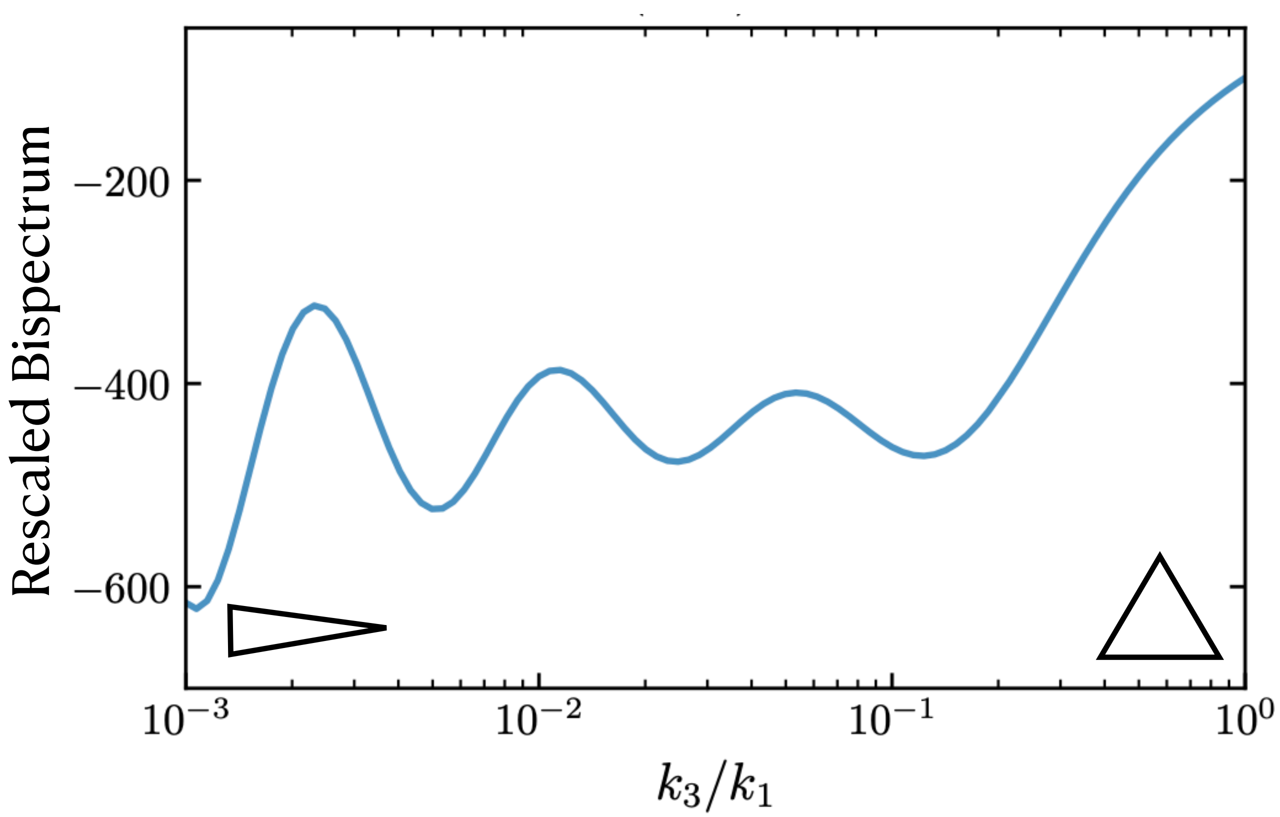

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Using CosmoFlow™

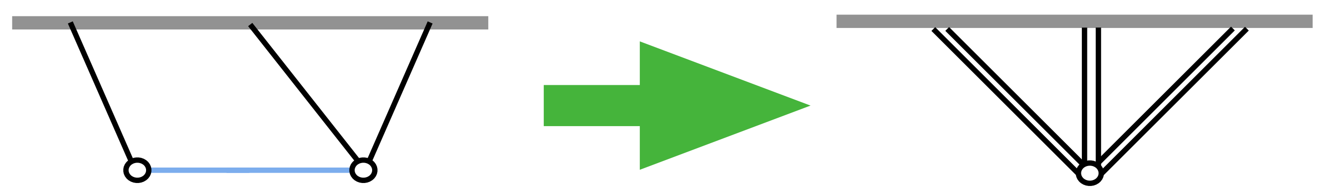
- Physically: property of massive field propagation if $m \gg H$:

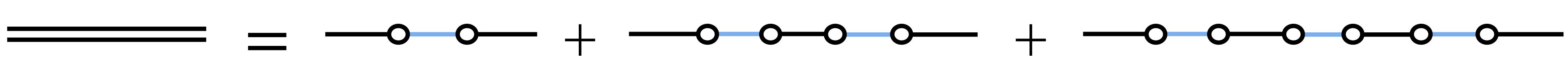
$$X'' - \frac{2}{\tau}X' + \left(k^2 + \frac{m^2}{\tau^2 H^2}\right)X = 0$$

$$\implies X \sim (k\tau)^{\frac{3}{2} \pm \Delta}, \Delta = \sqrt{\frac{9}{4} - \frac{m^2}{H^2}}$$

Strong Mixing

- Strong Mixing:  gives a strong contribution.
- We cannot rely on the simpler diagrams!





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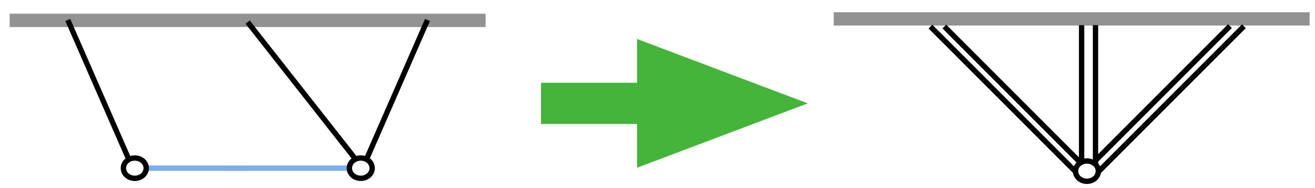
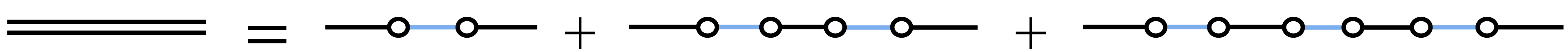
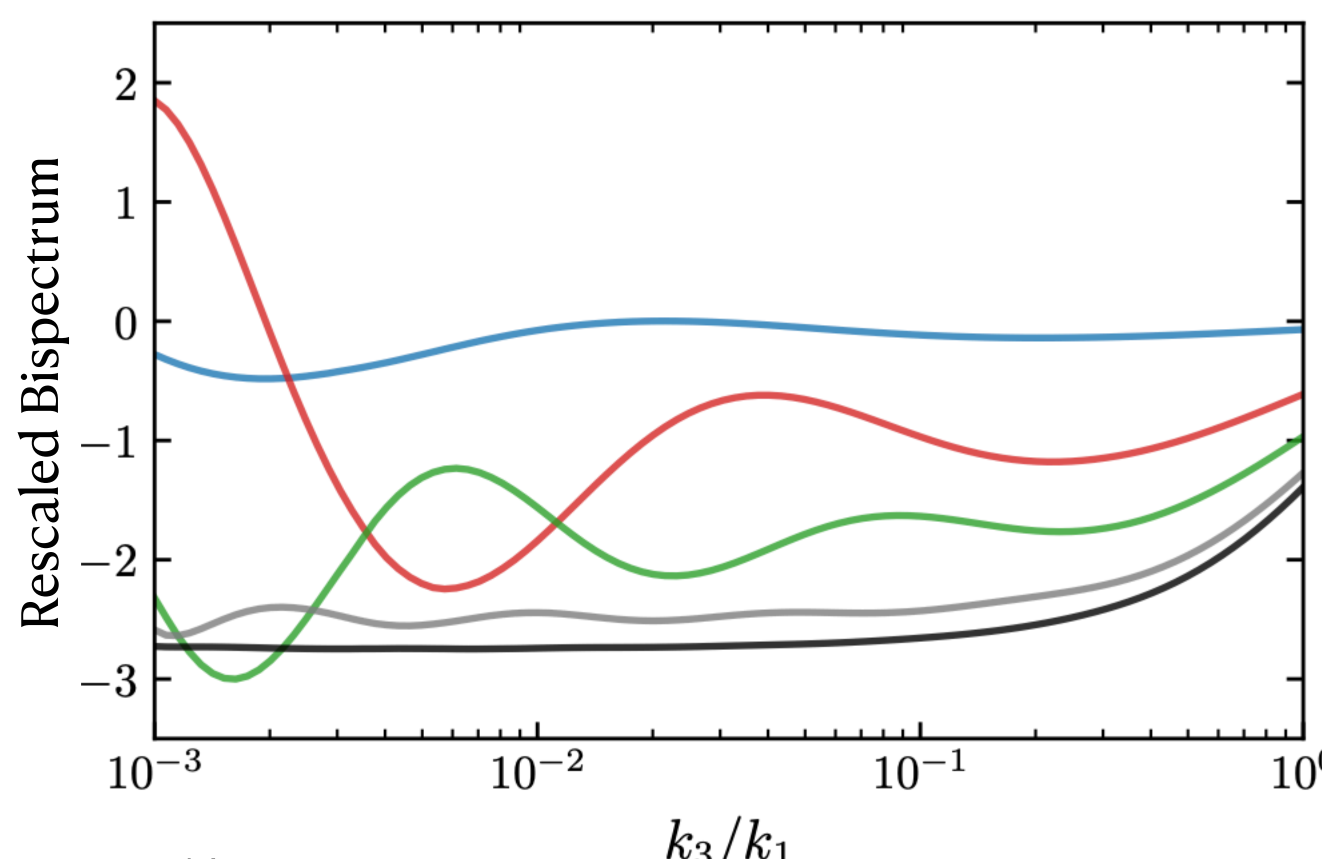




CosmoFlow™

- Lack of analytic understanding.
- Numerically: it can lead to larger signals!



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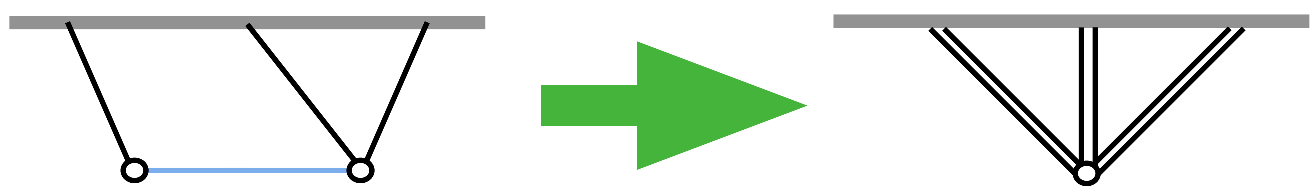

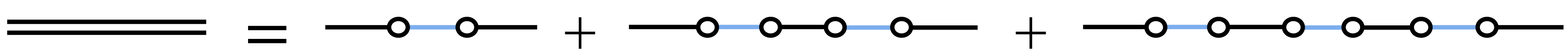

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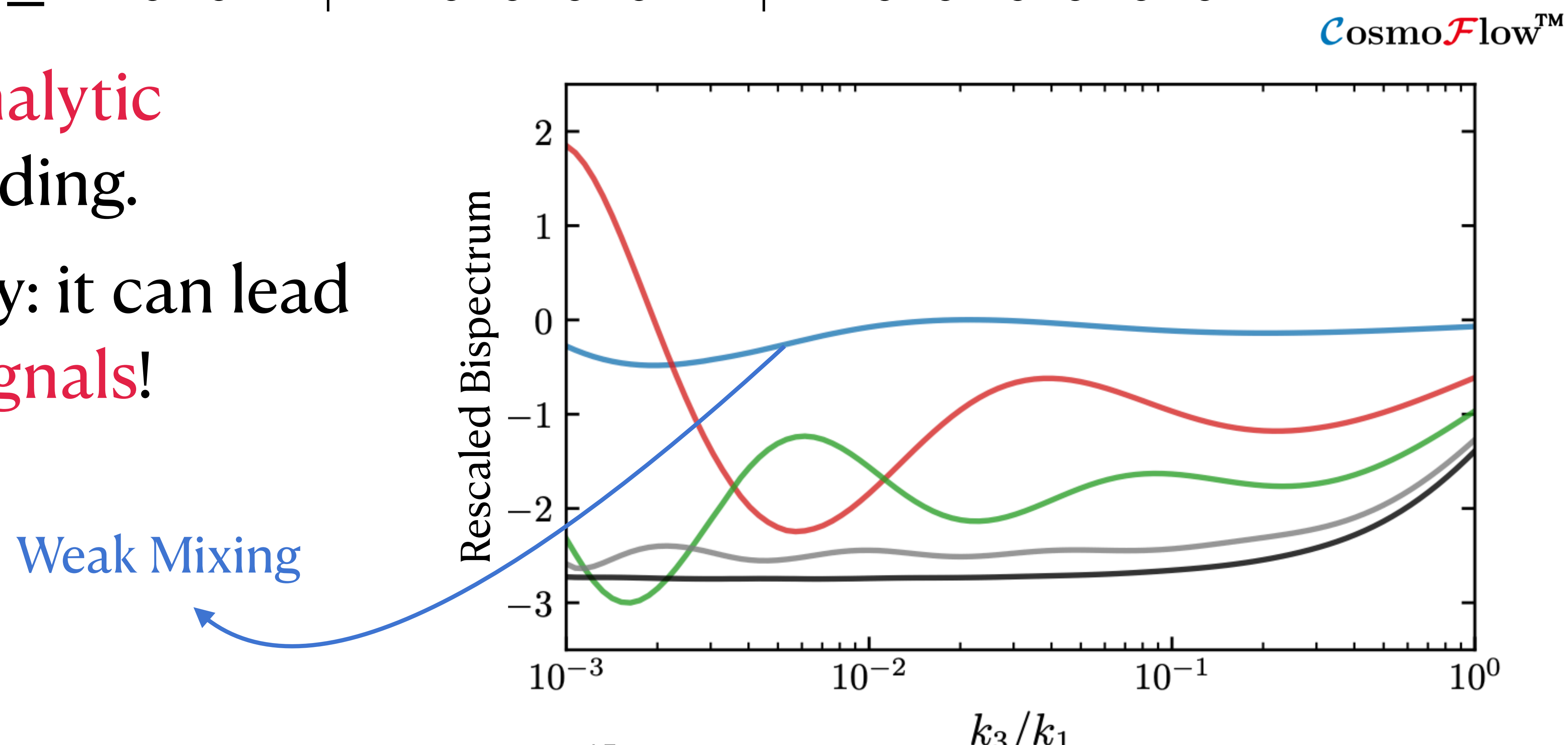

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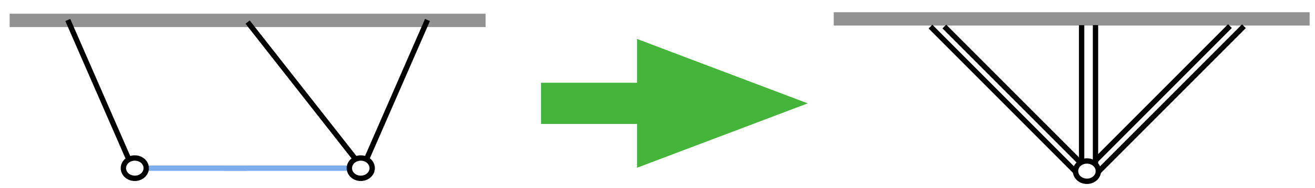

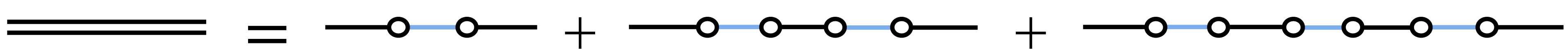

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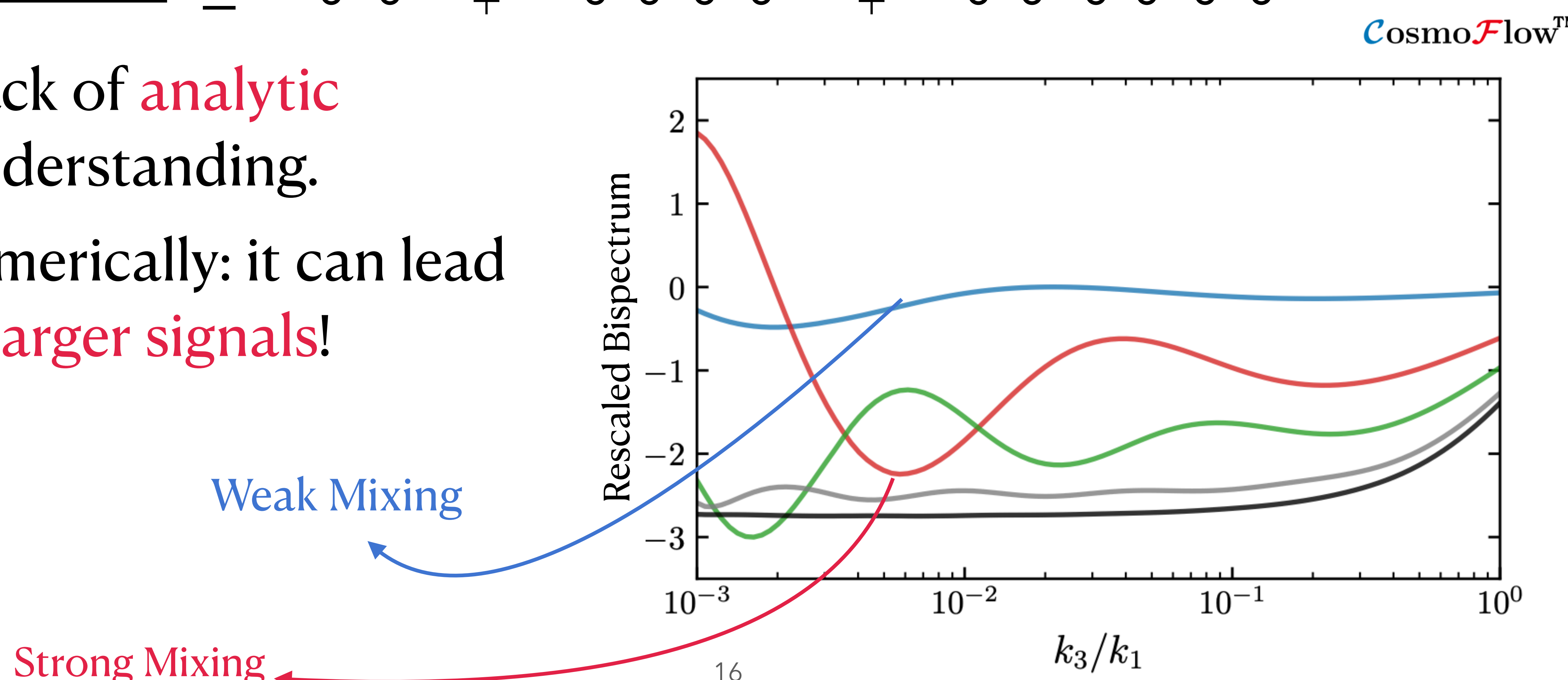

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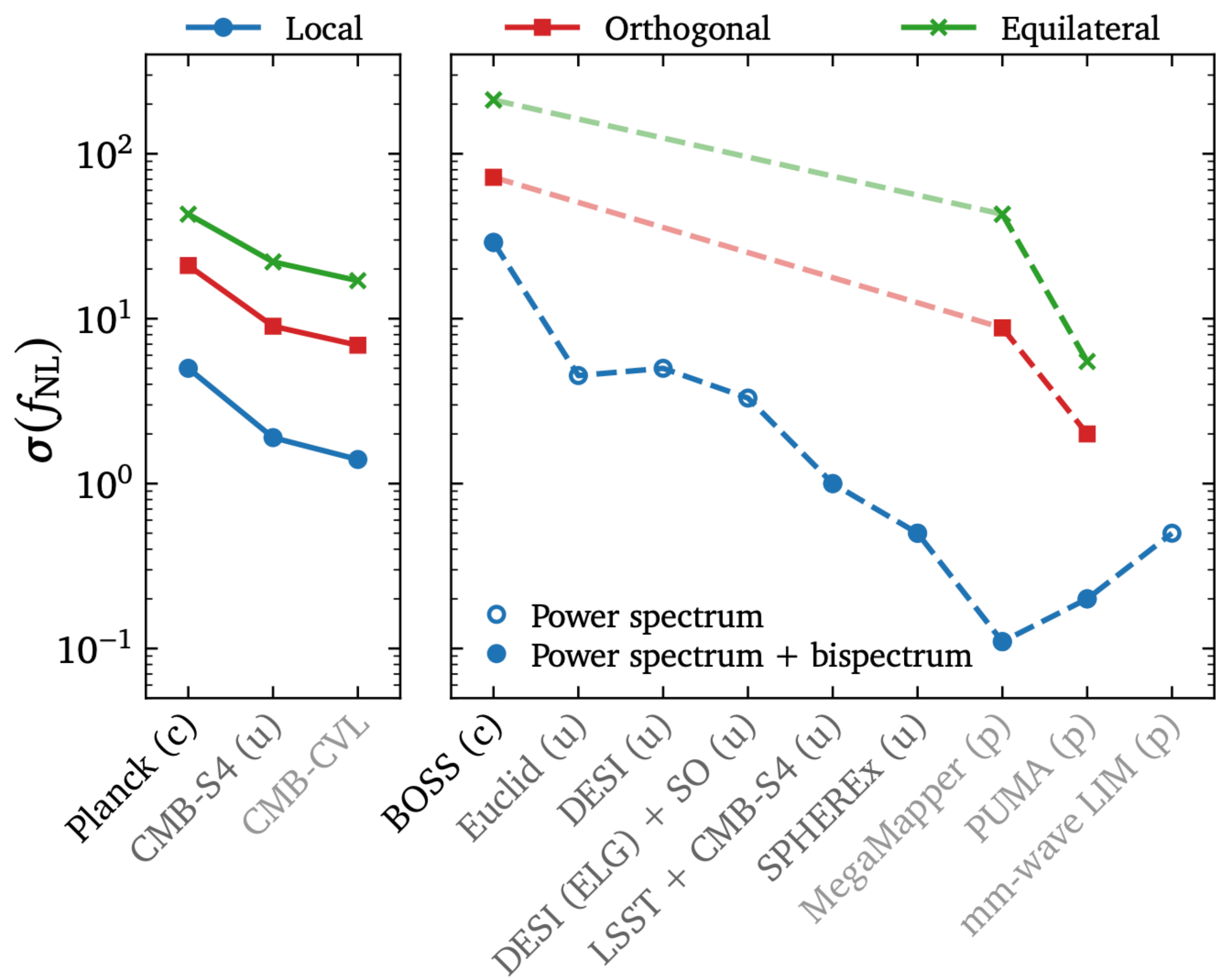
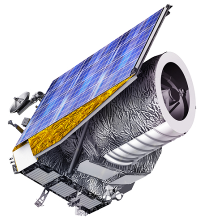
What about observations?

- Amplitude of three-point function $B \sim f_{NL}$.
- Current constraints, PLANCK 2018: $f_{NL} \lesssim \mathcal{O}(10)$



- Improved sensitivity from next surveys.

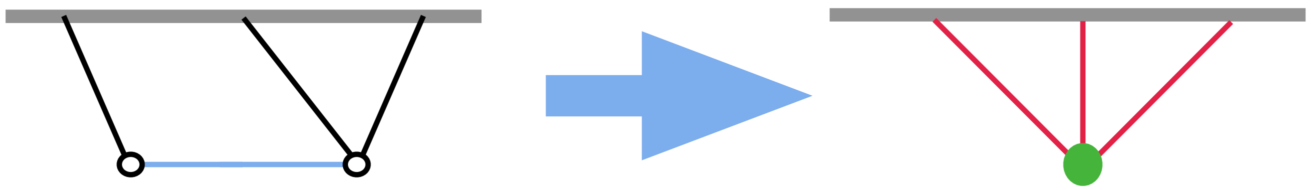


- **Weak Mixing**: smaller signal

- Need for analytical templates for **strong mixing**.

Effective Field Theory

- At low energy, any two-field system can be approximated by a single-field effective theory.



Replace heavy field σ by a low energy version $\sigma_{\text{eff}}(\pi)$

- Very accurate for small momentum ratios, even at strong mixing.

- Neglects the propagation of the heavy field: misses the cosmological collider physics!

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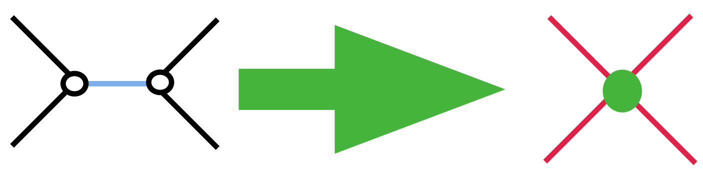
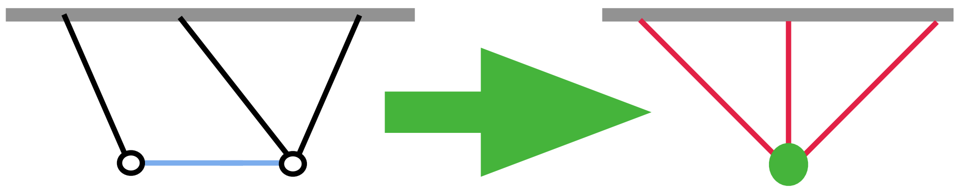


VS



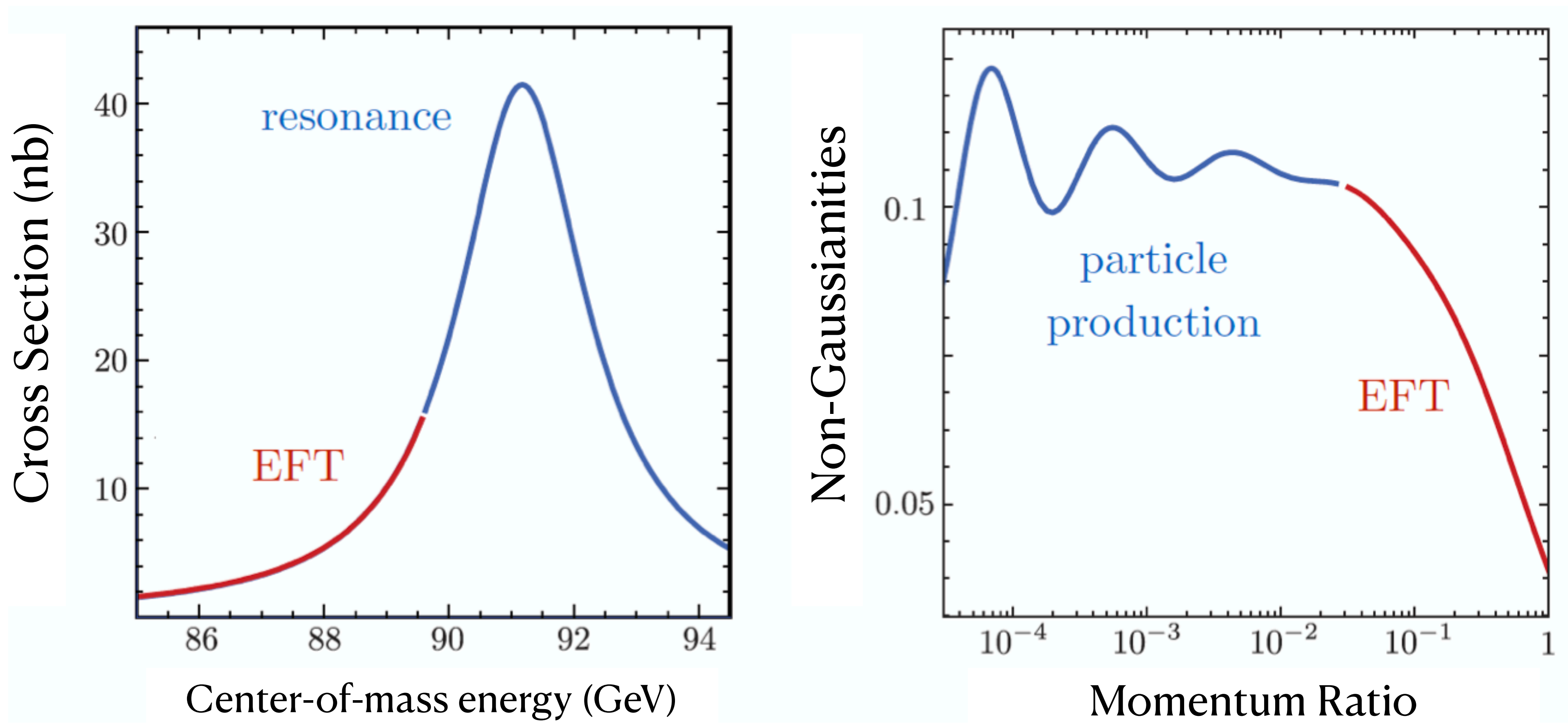
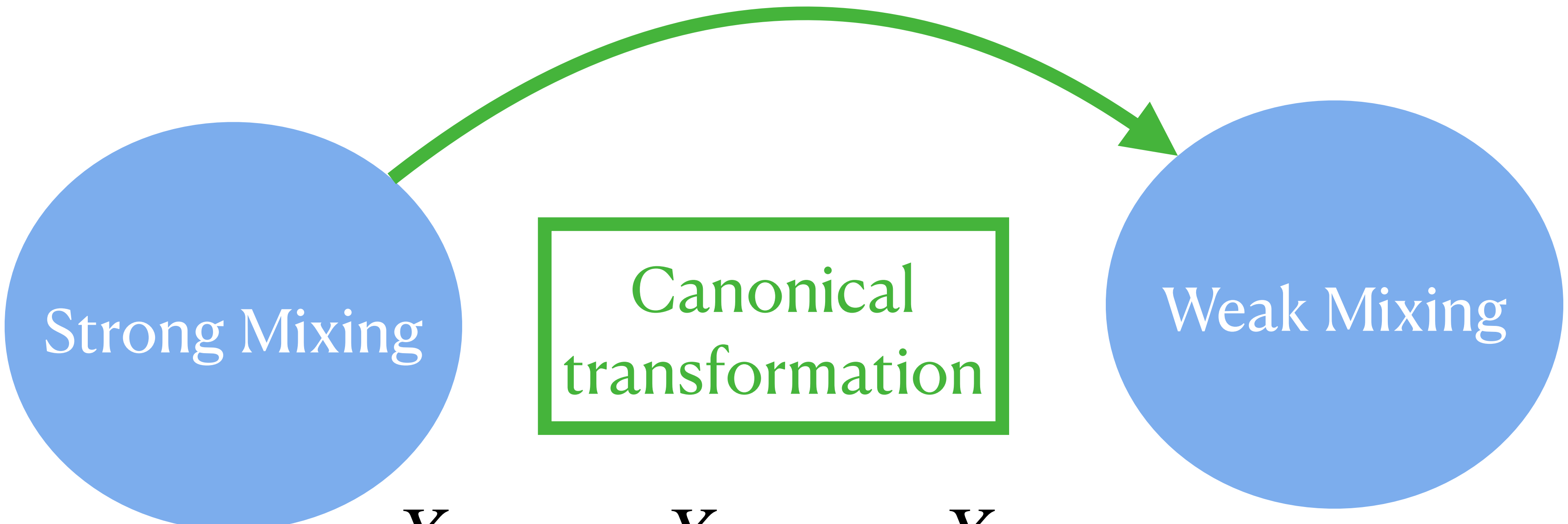


Figure from Arkani-Hamed and al. 1811.00024

A Flavor of the idea

- We use the EFT to parametrize a field redefinition.



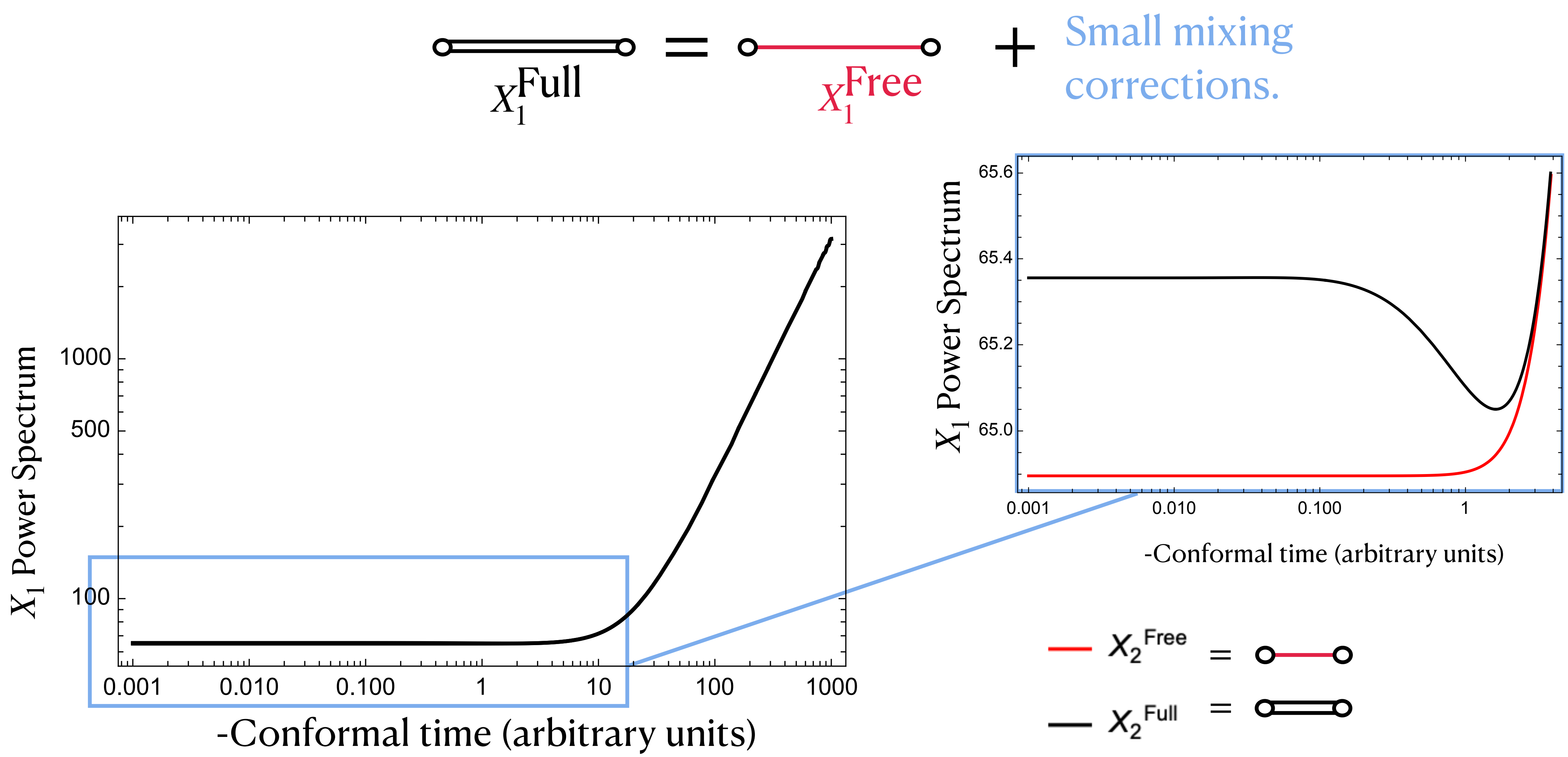
$$X_{\rm new} = X_{\rm old} - X_{\rm EFT}$$

- New Variables = what the EFT is missing

- Two-field description: we cannot miss the Cosmic Collider signal.

It works!

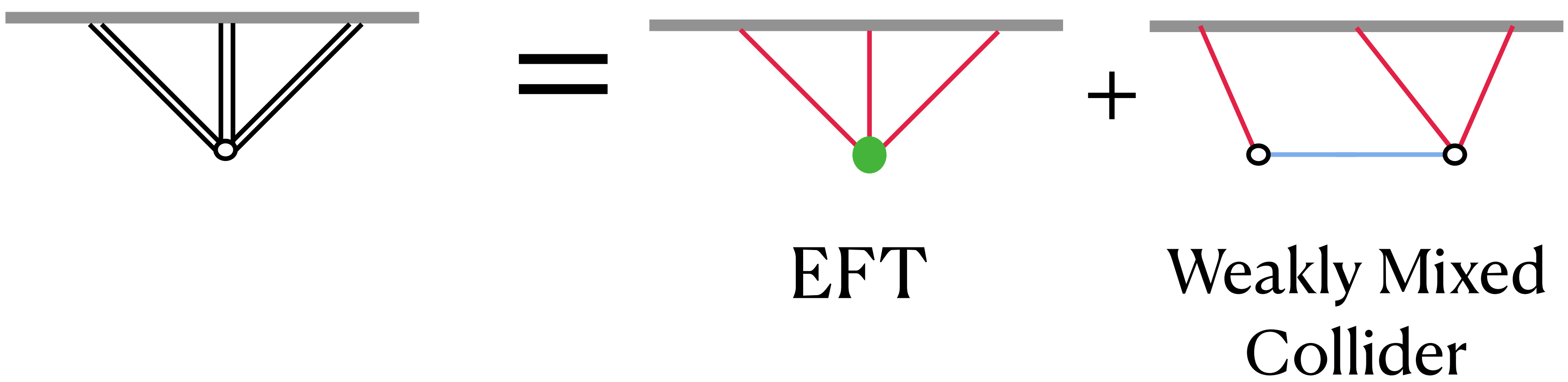
- Power Spectrum in the new massless field $X1$:



- The effect of the strong mixing is included in the EFT description: its impact on the new variables is weak!

Consequence

- We can apply the standard computation technics.

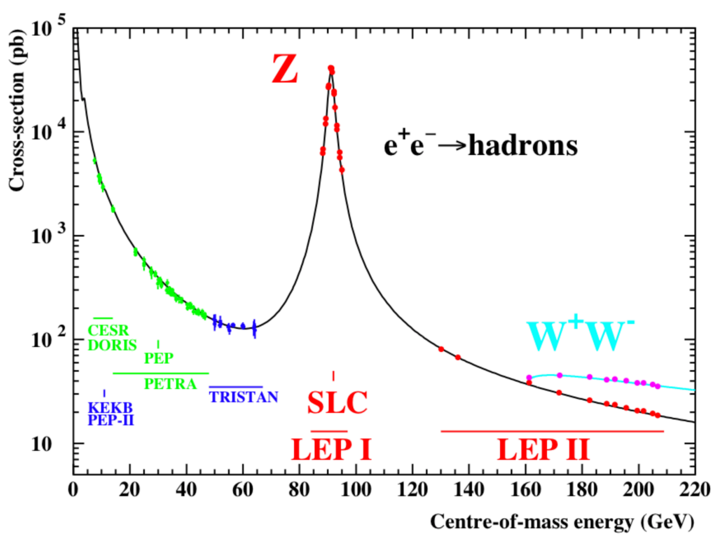


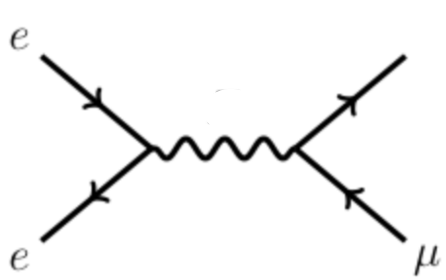
- Generic extension of the EFT techniques.

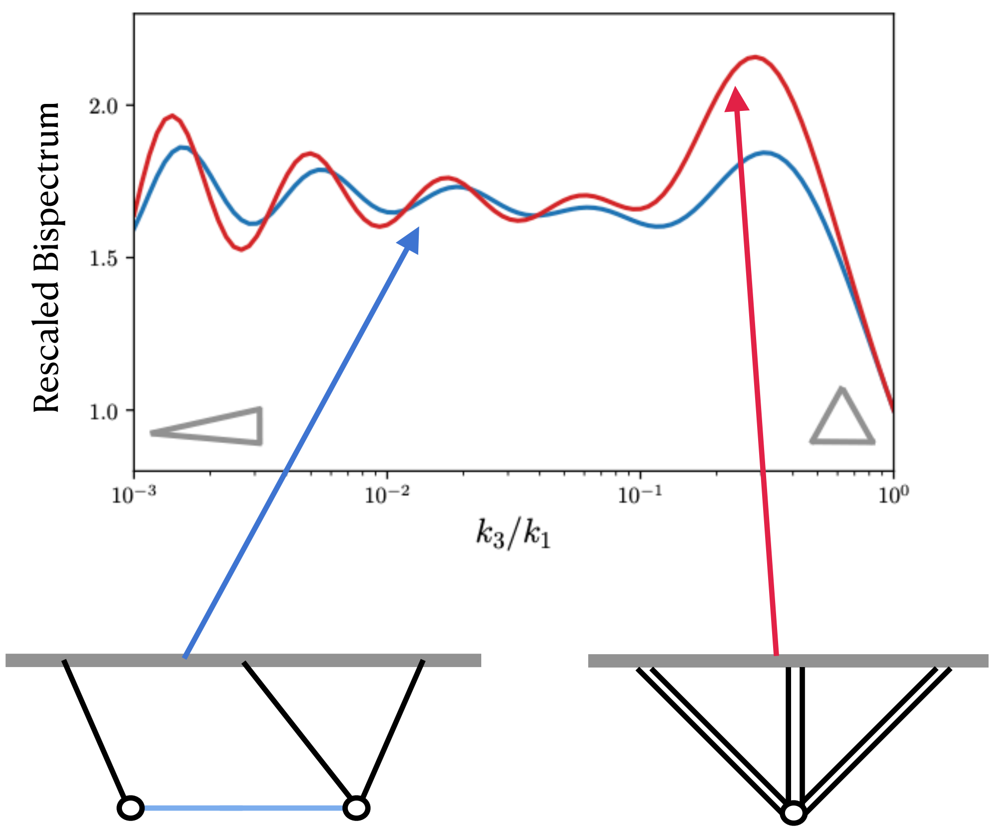
Conclusion

- Particles of mass $m \gg E_{LHC}$ can be produced on-shell in inflation.

- Exchange of massive particles leave distinctive imprints in non-gaussianities: **Cosmological Collider Signal**.







- **Strong Mixing** leads to a larger signal which can be understood by extending EFT techniques.

- Very promising way of probing high-energy physics!