Strong Mixing at the Cosmological Collider:

A glimpse of quantum particle production in cosmological data

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Outline

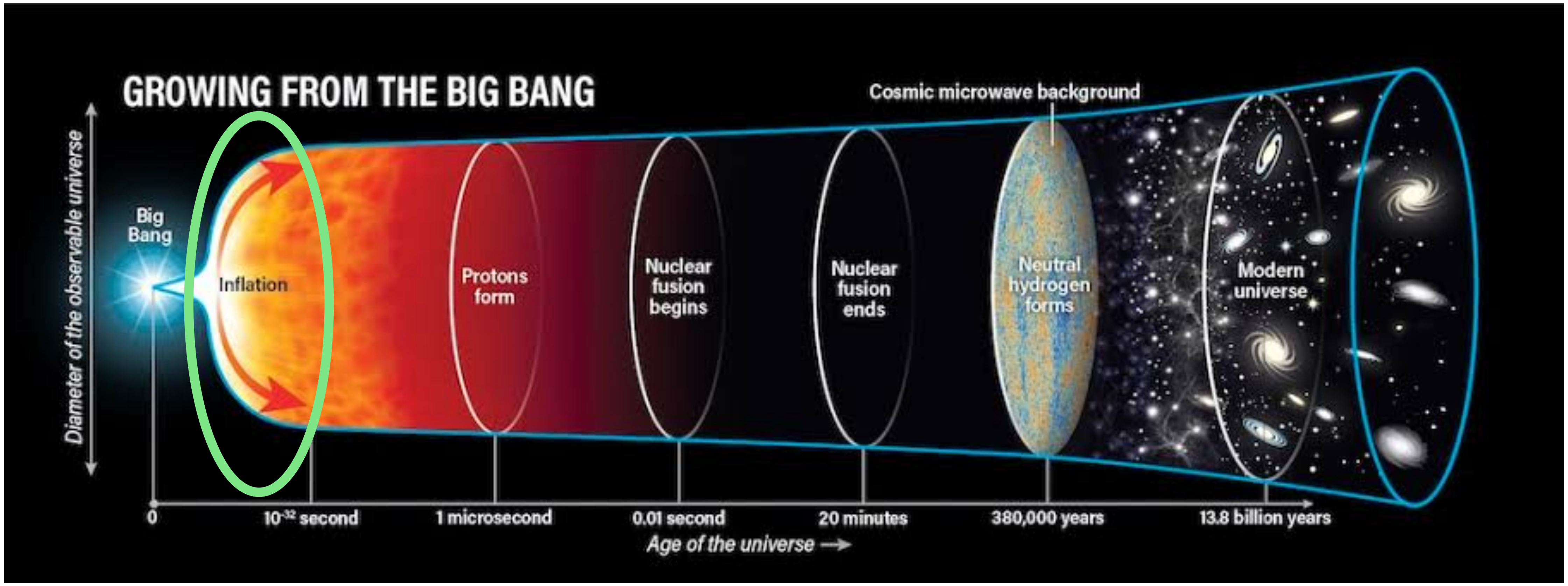
- Inflation can probe the physics at high energies.

- Cosmological Collider Phenomenon: quantum particle production.

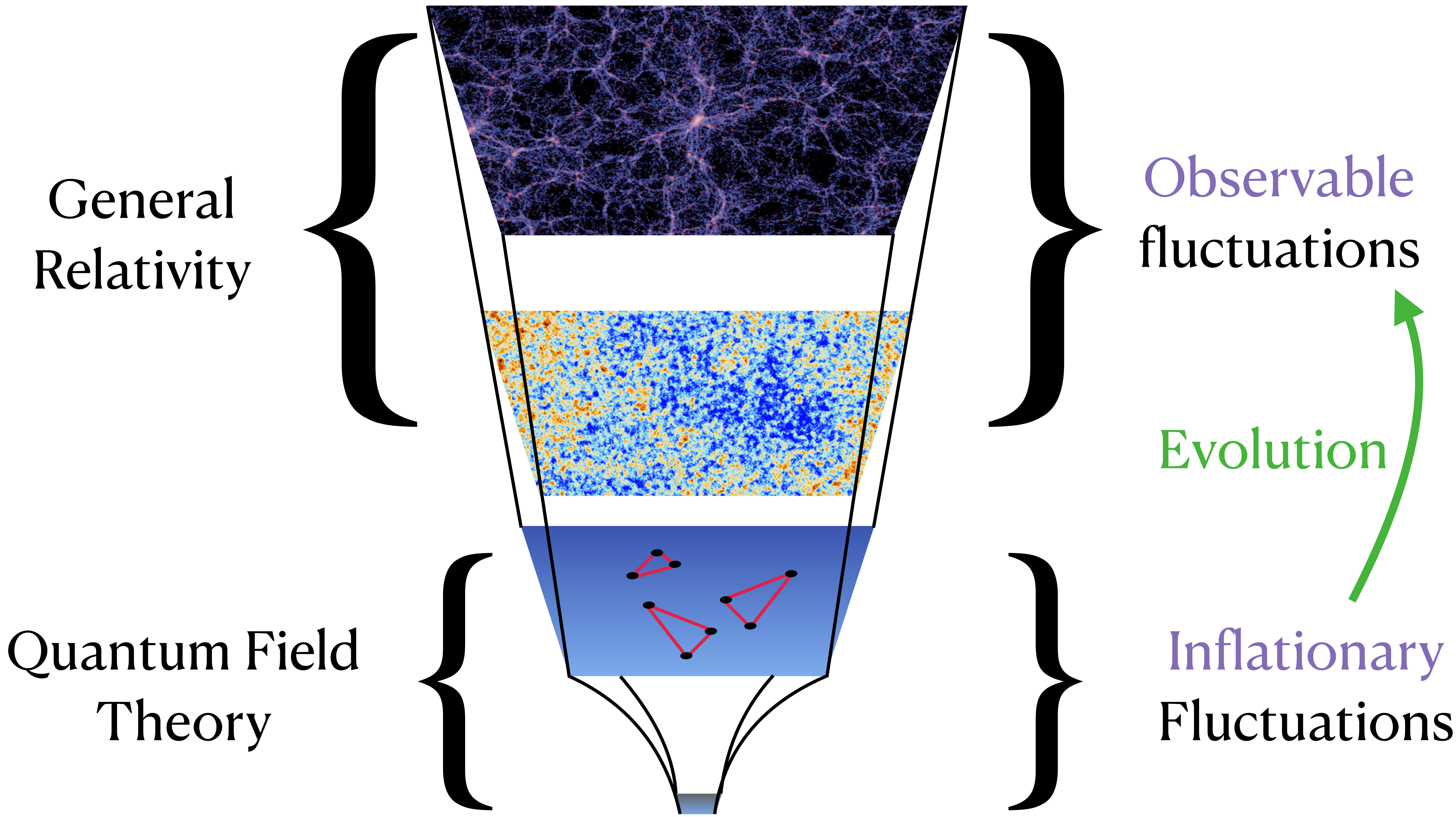
- Cosmological Collider at Strong Mixing

Cosmology: History of the Universe

- Universe is approximately homogeneous and isotropic.
- Inflation: accelerated phase of expansion after the big bang.
- Study of density fluctuations: seeded by inflation.



Inflation As Origine of Structure



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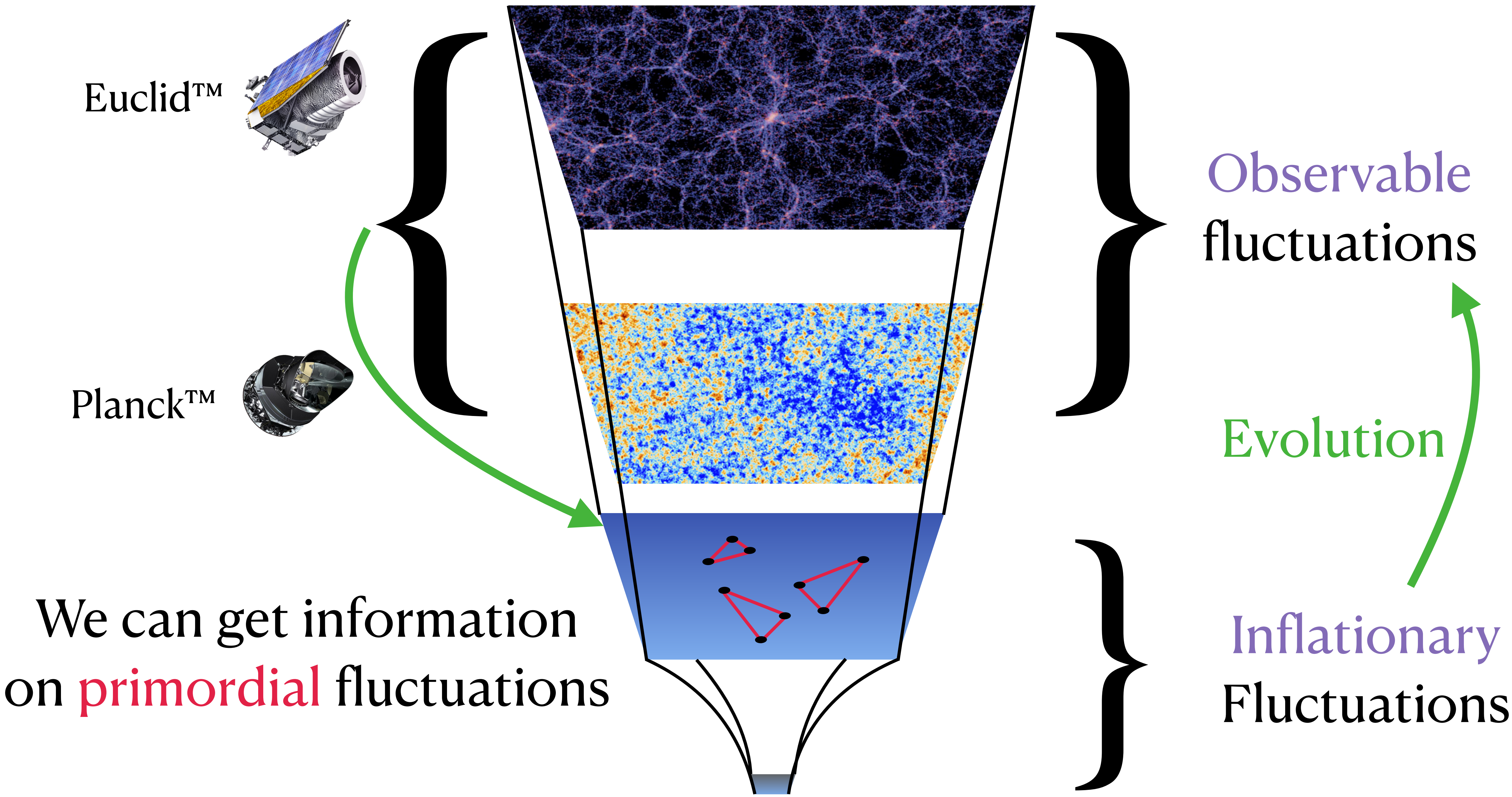
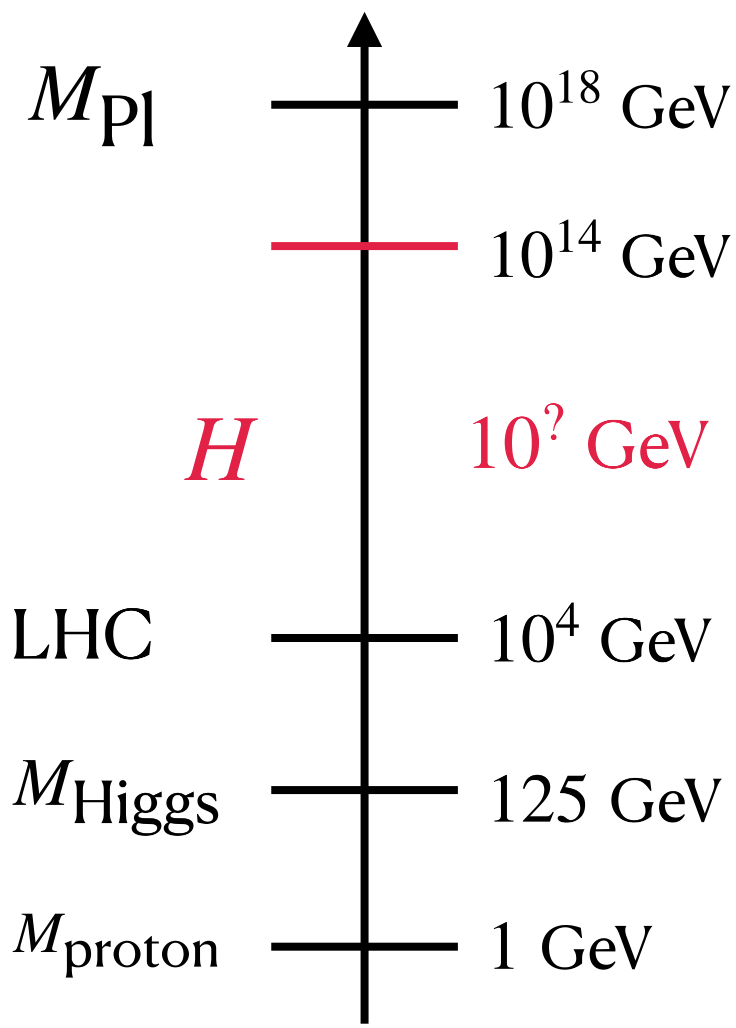


Inflationary physics left imprints in cosmological data.

Energy Scales

- **Inflation** = Very High energy scales.



- **PLANCK** constraints: $H \lesssim 10^{14}$GeV

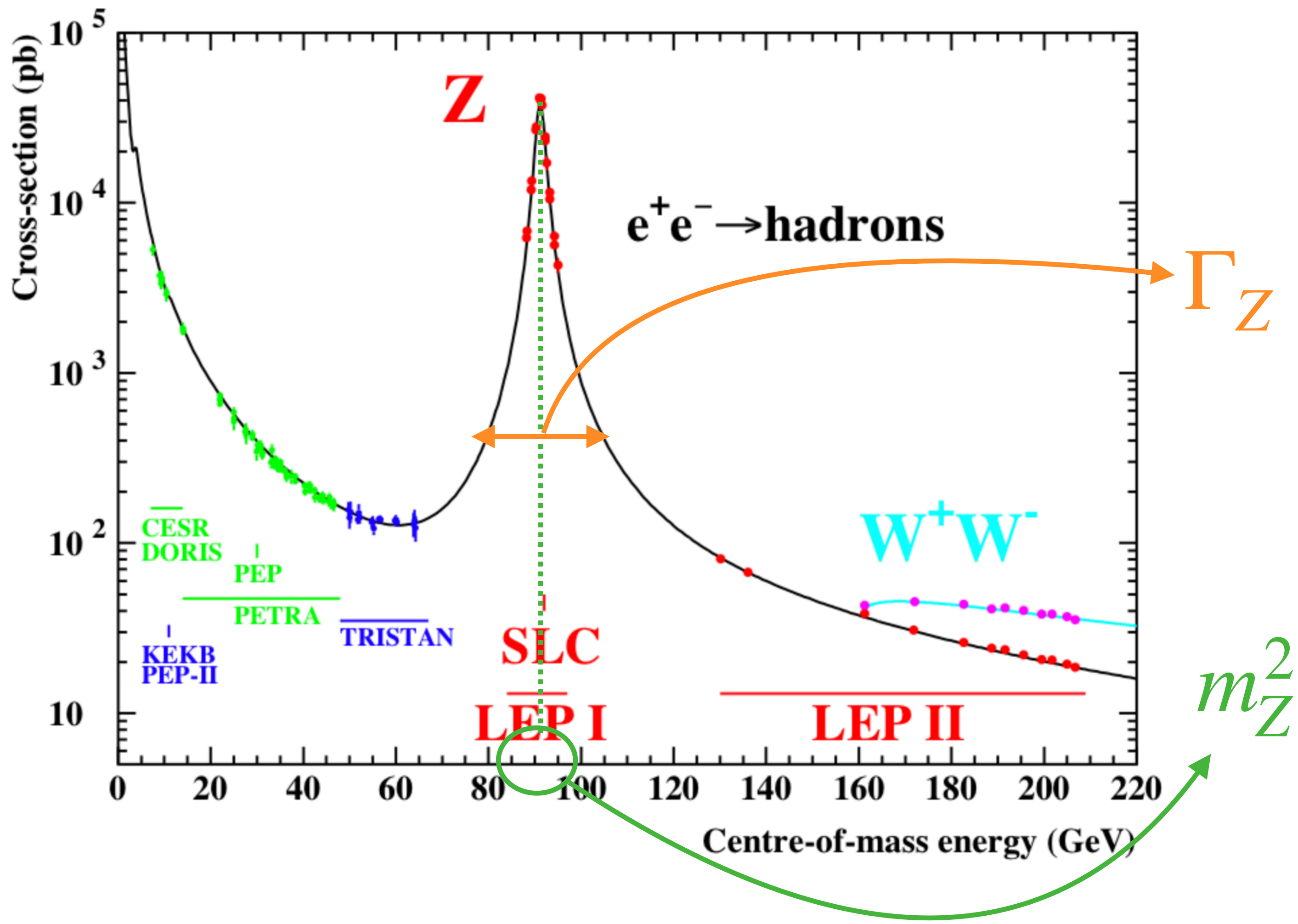
- **Energy Conservation**: we cannot produce on-shell particles heavier than 10^4GeV at the LHC.

- **High-energy theories:** often rely on the existence of very massive particles.

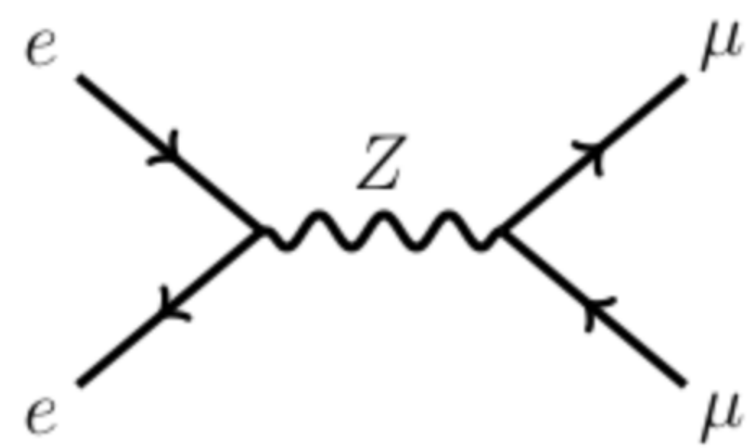
Idea: Use Inflation as a **Cosmological Collider**

High Energy Physics on Earth

- New physics at high energy usually means new massive particles.
- **Collider Resonance**: mass/lifetime of exchanged particles.



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

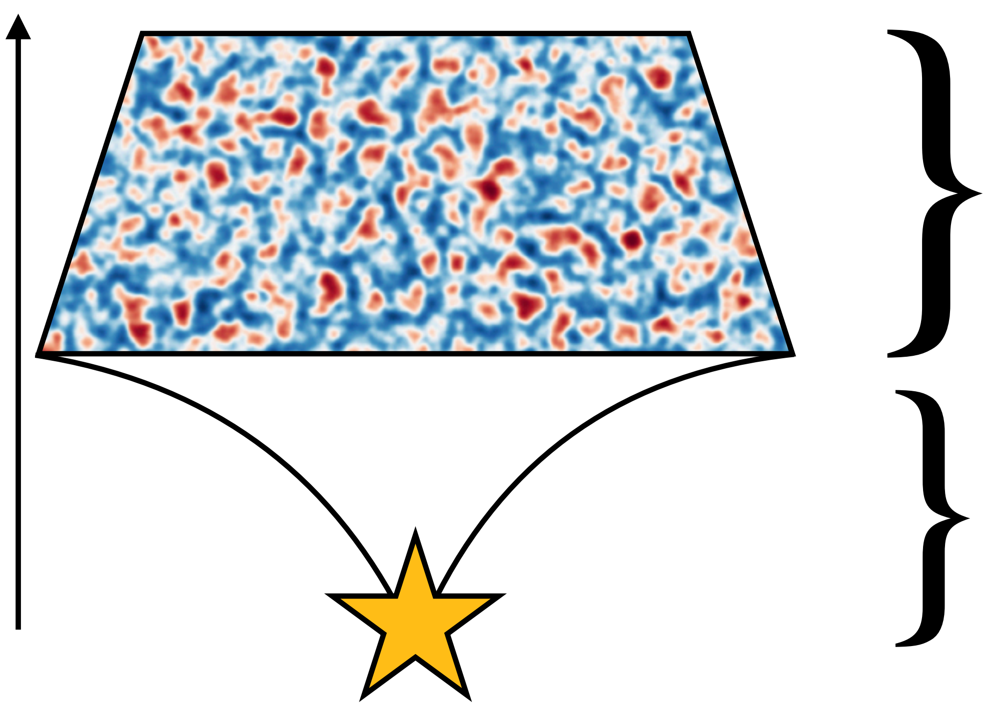


Is there an inflationary equivalent ?

Which Observable in Cosmology?

- We observe the primordial density fluctuations.

« Observable Surface »



Quasi-Gaussian

- We predict their distribution $\mathbb{P}(\delta\rho_k)$

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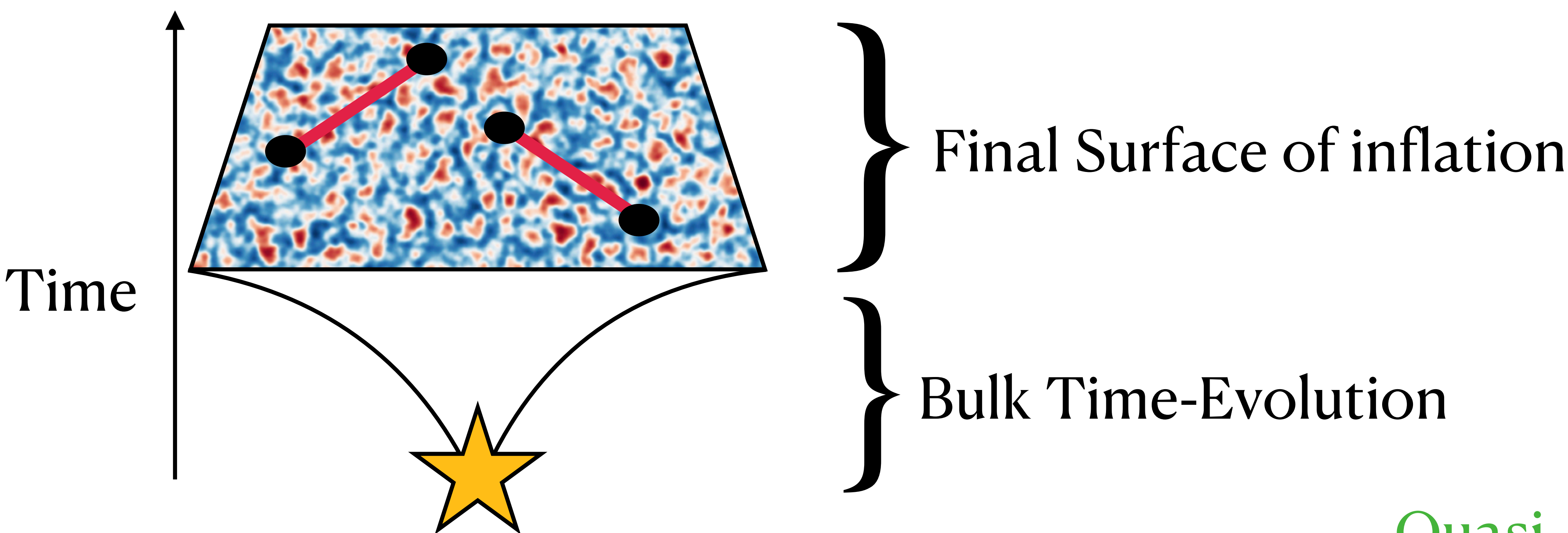

Quasi-Gaussian

- We predict their distribution $\mathbb{P}(\delta\rho_k)$
- Characterised by the two-point correlations.

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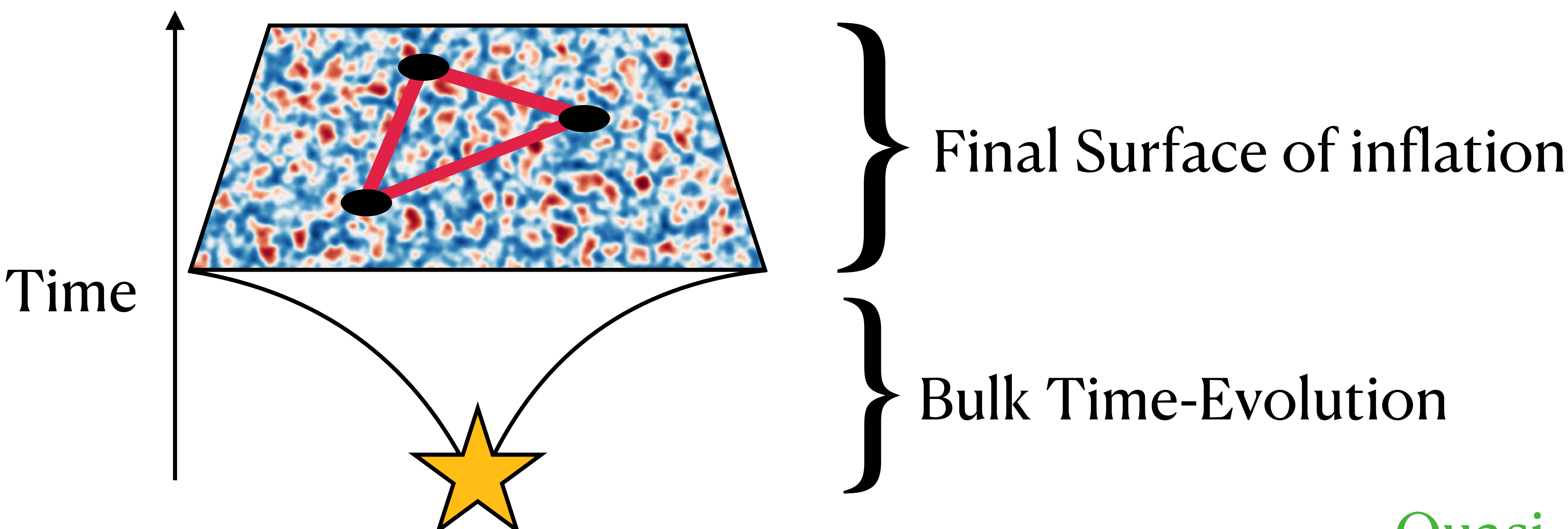


Quasi-Gaussian

- We predict their distribution $\mathbb{P}(\delta\rho_k)$
- The physics we want = encoded in the higher point correlators:

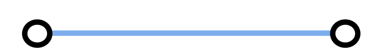
The Non-Gaussianities.

Particle Physics In Inflation

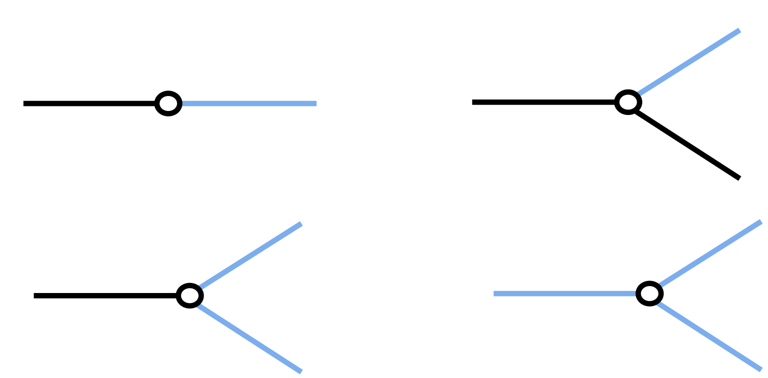
- We can build a general theory of inflationary fluctuation:

Density fluctuations = massless particle

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



- Here is the list of ALL the possible interactions:

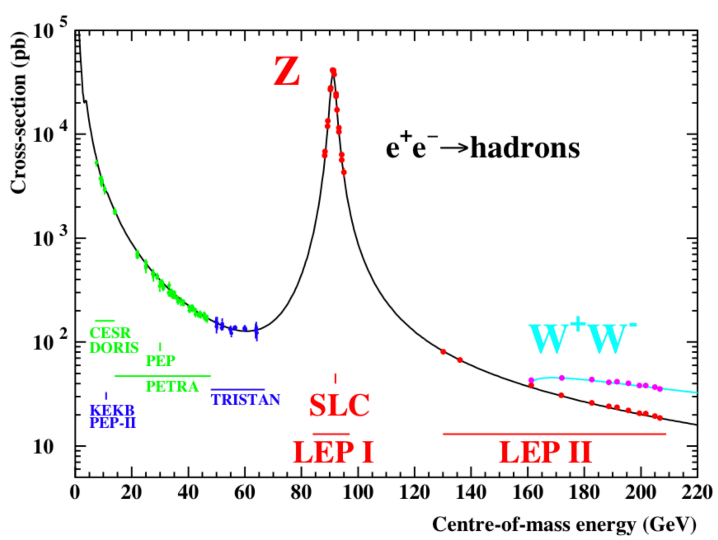


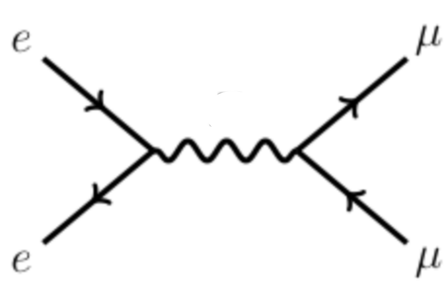
A Cosmological Collider?

- Sign of new physics: exchange of massive particles.

Particle Colliders

Observable = Scattering Amplitudes





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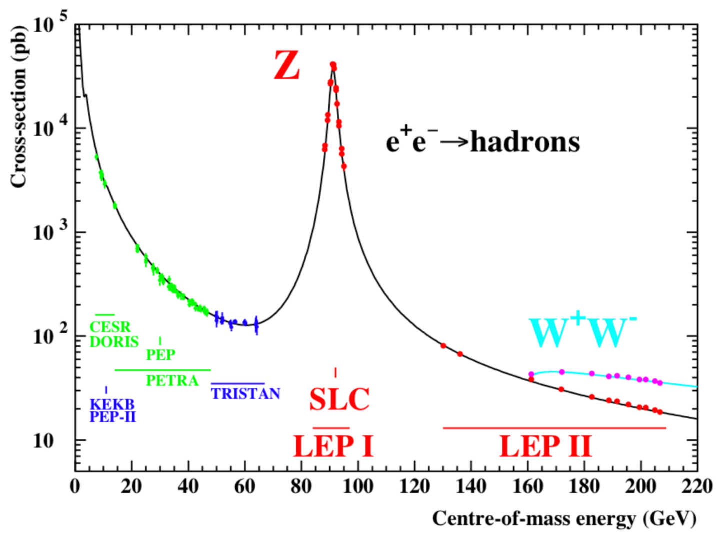

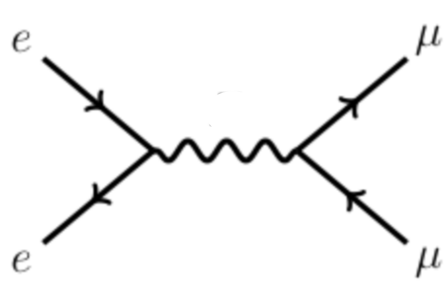

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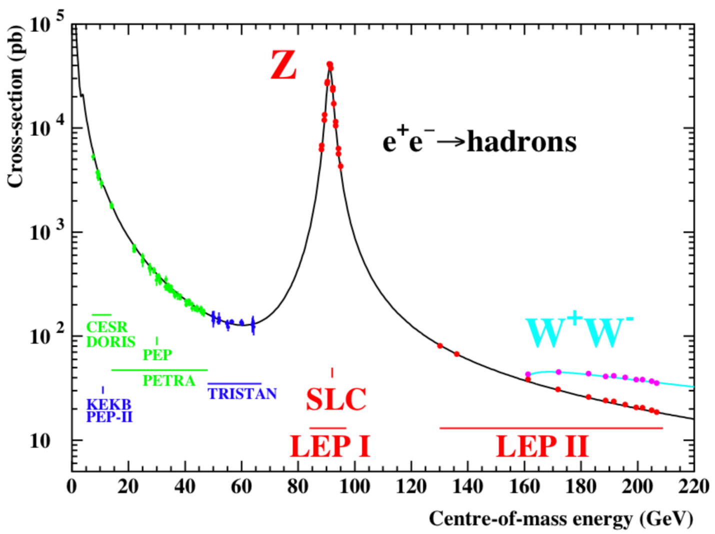

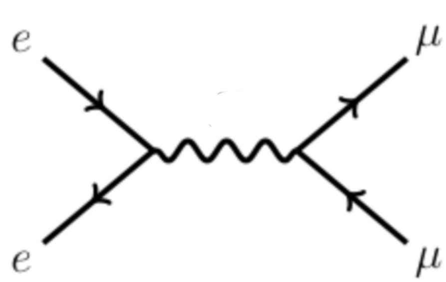

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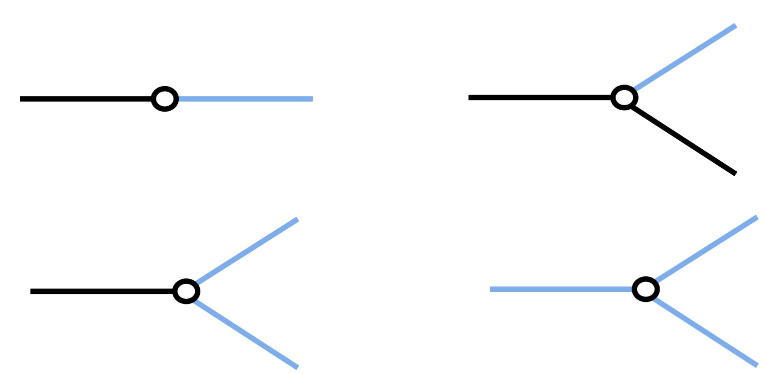

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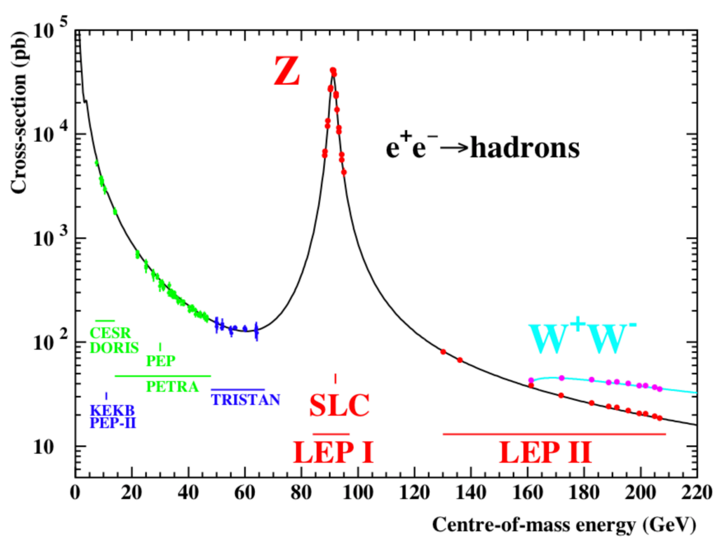

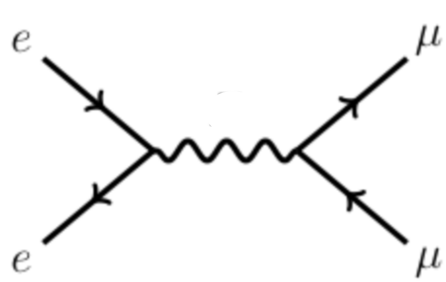

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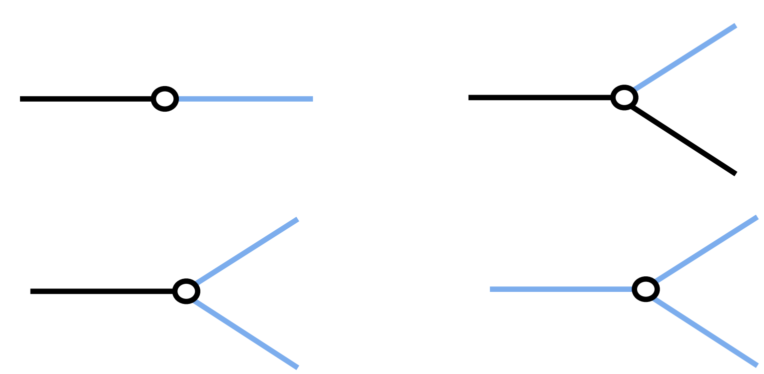

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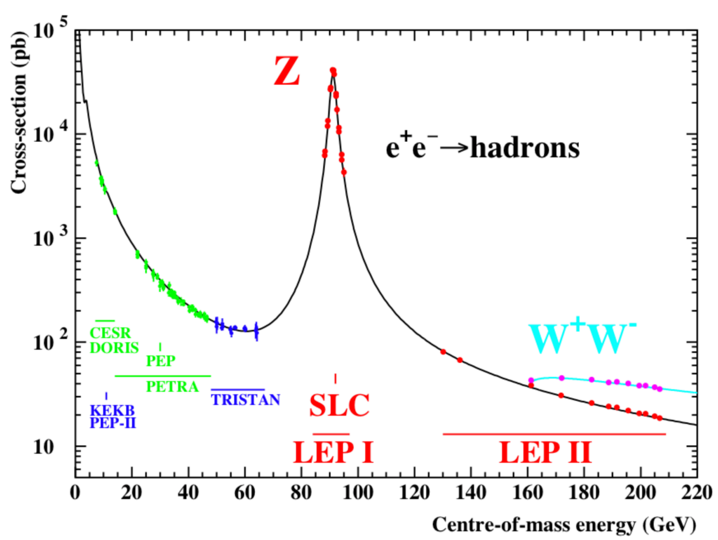

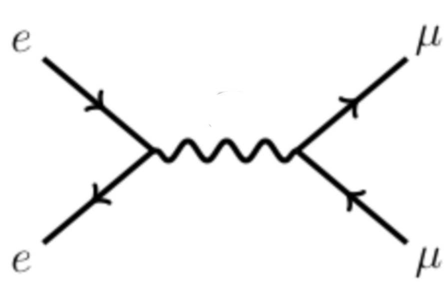

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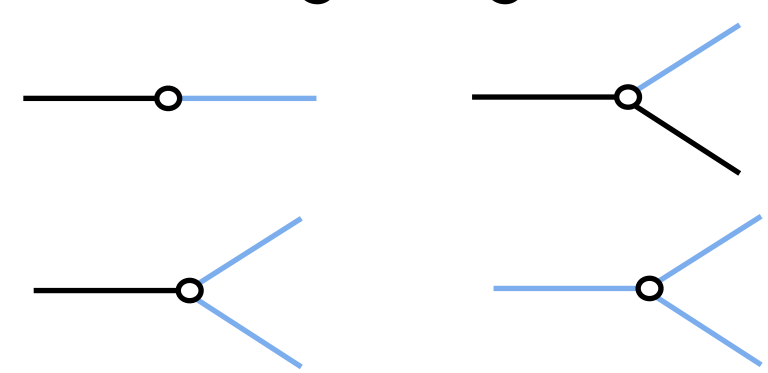

Which process???

Spontaneous Particle Production

- Expansion = time dependent background: No energy conservation.
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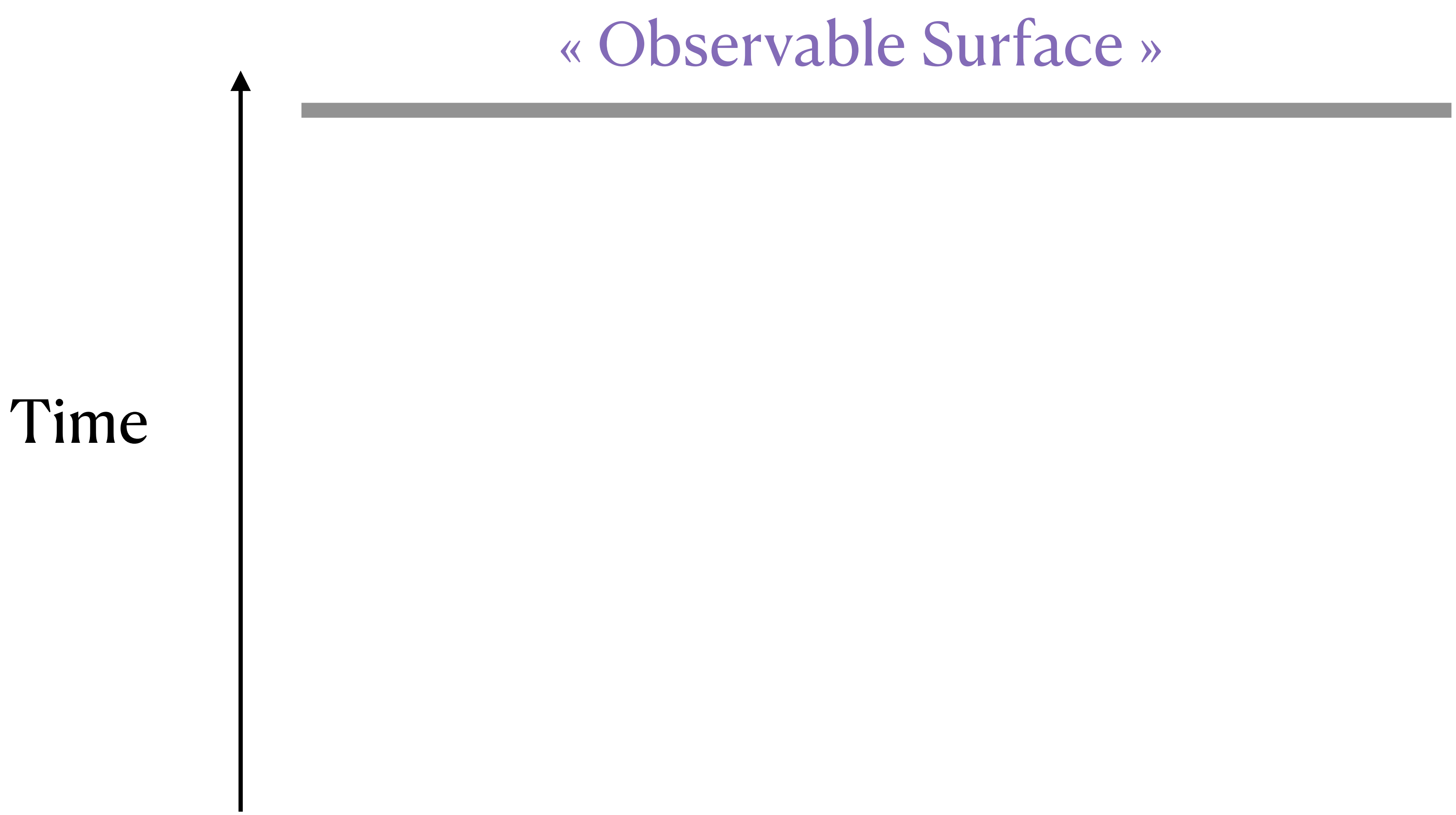

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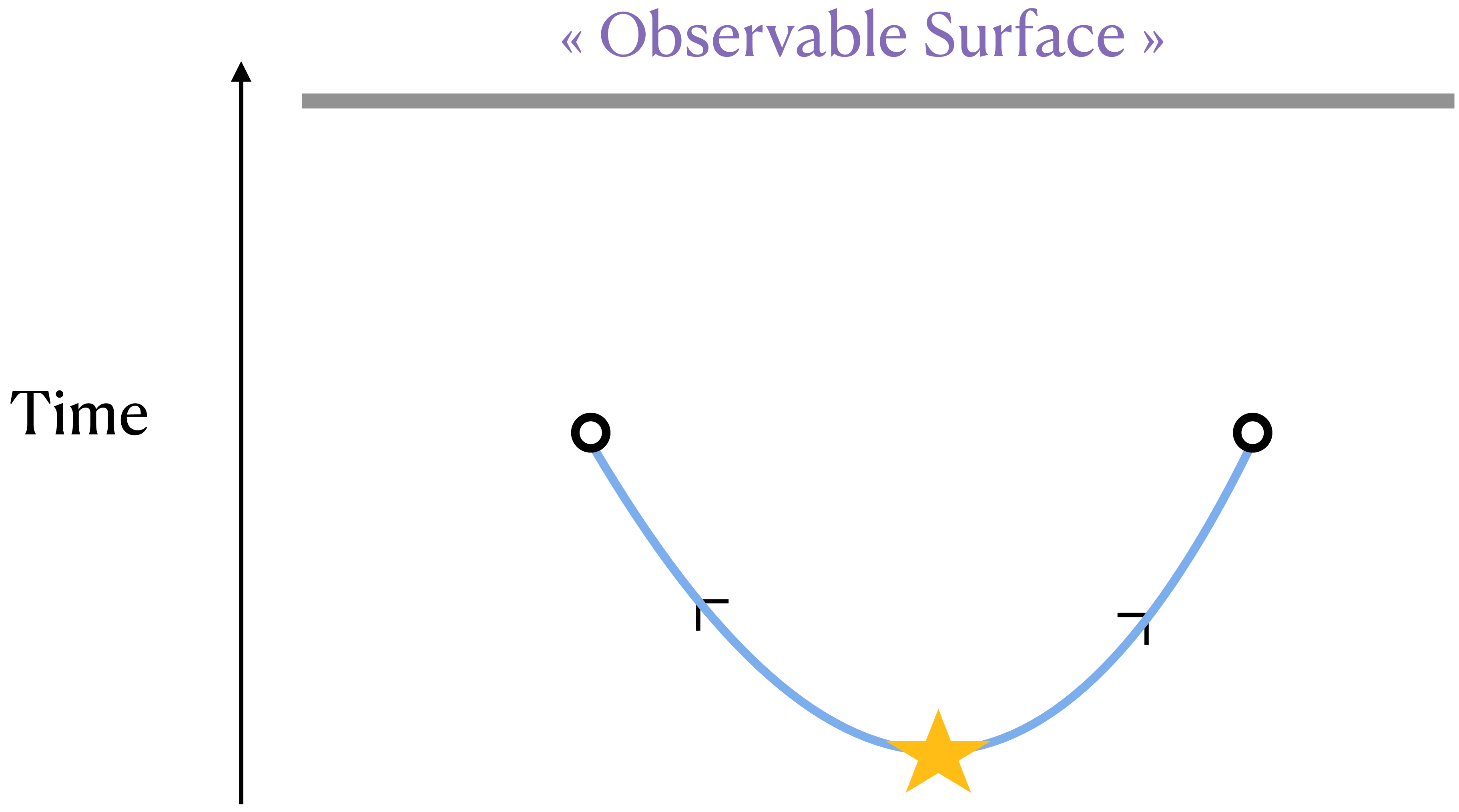

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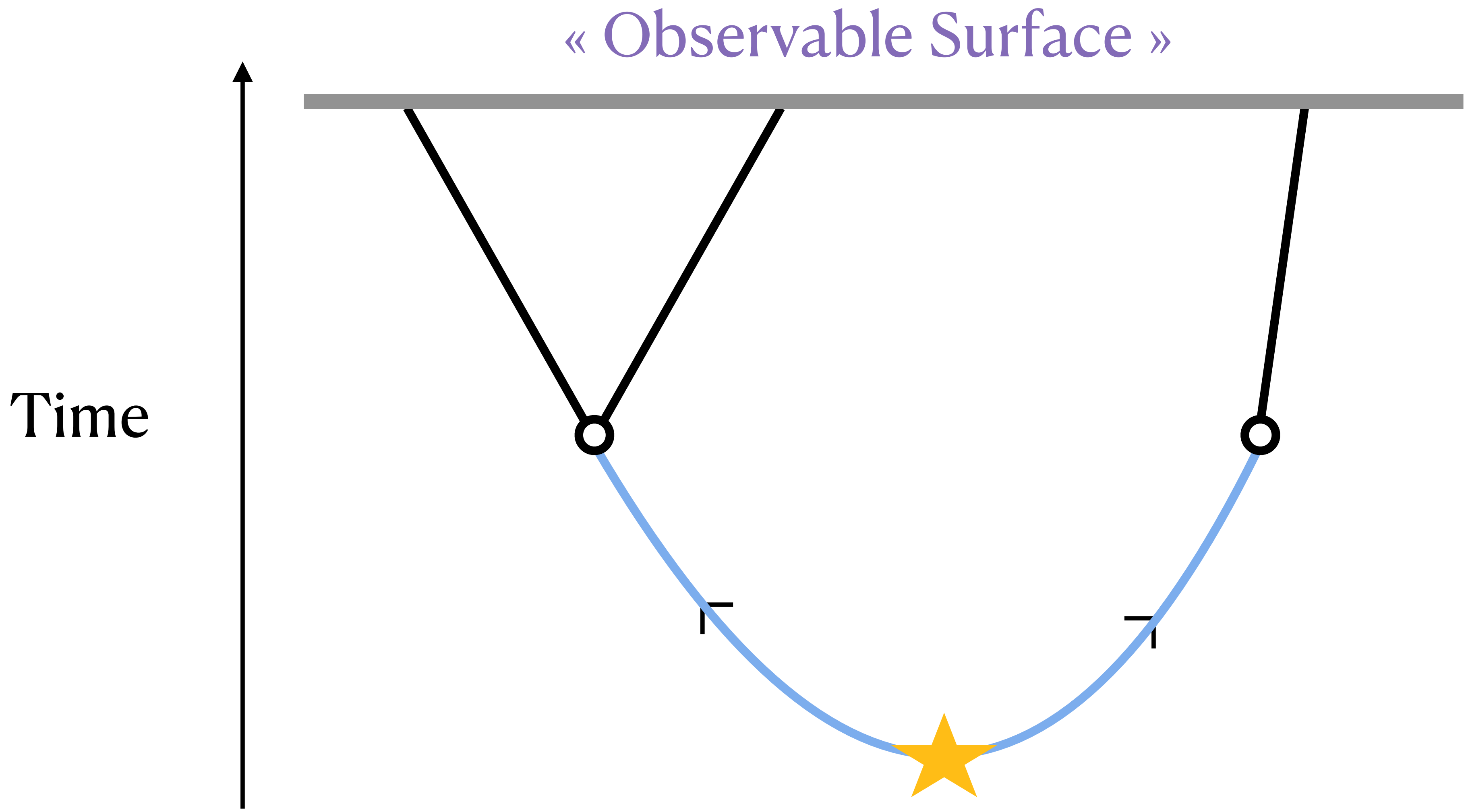
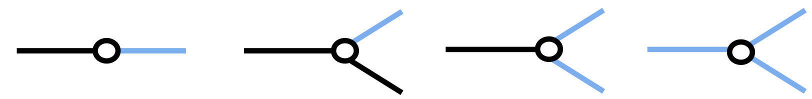
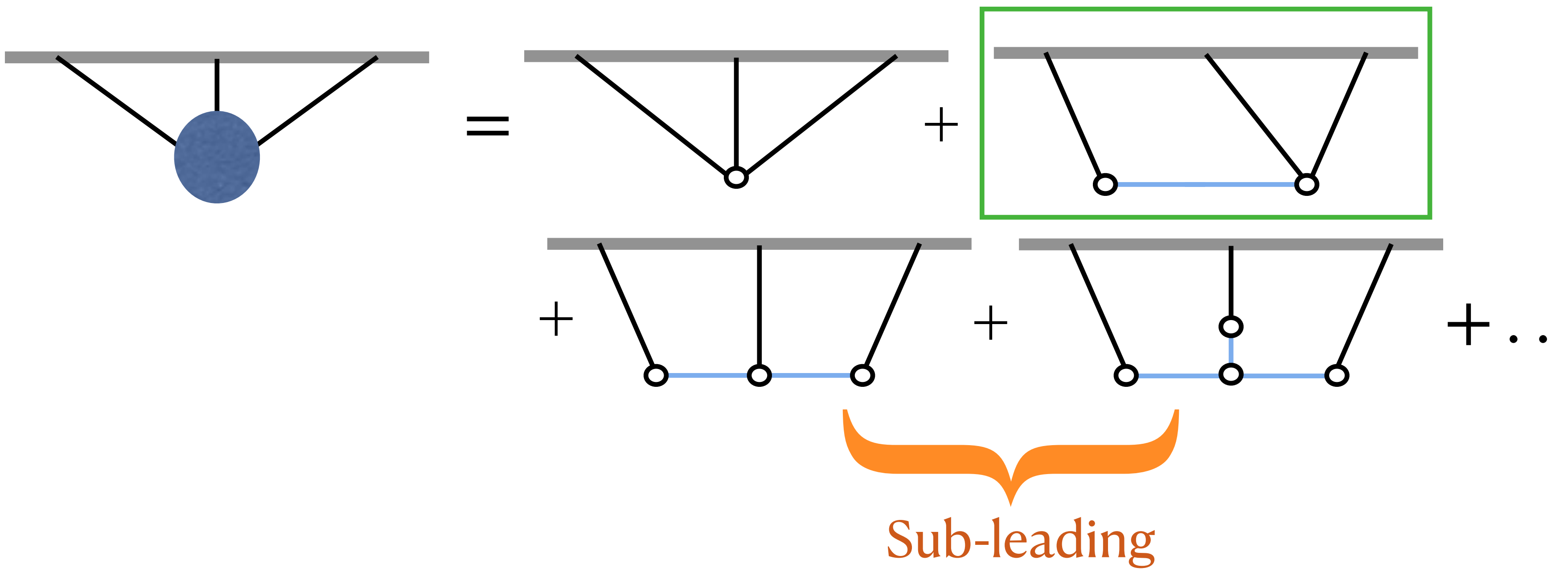
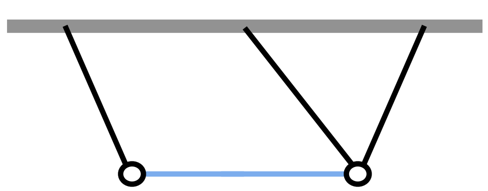


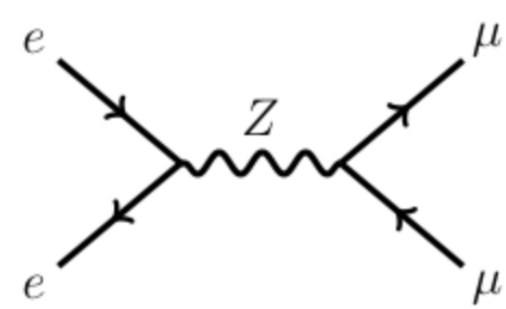
Inflationary 3-Points Function

- Allowed Interactions: 





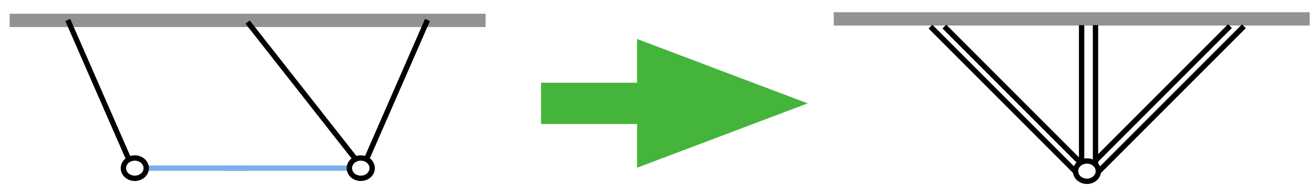
= Analog of

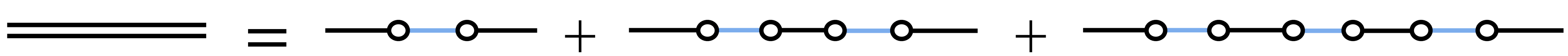


Cosmological Collider Signal!

Strong Mixing: Current Project

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





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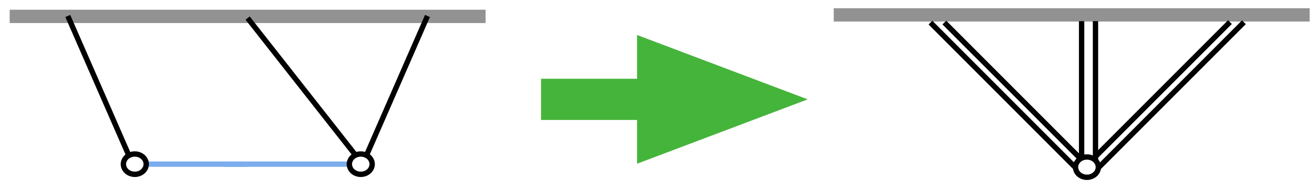

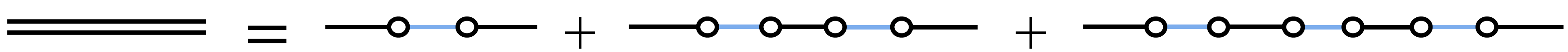

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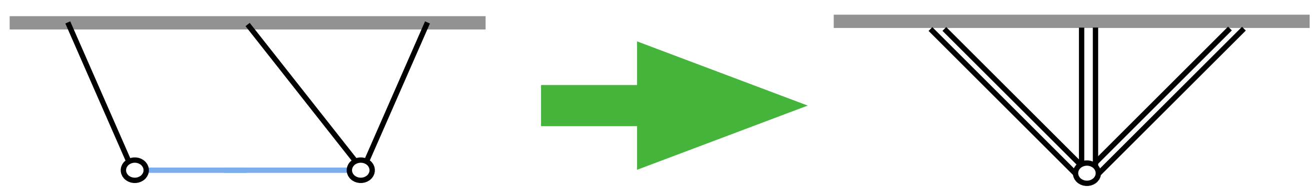

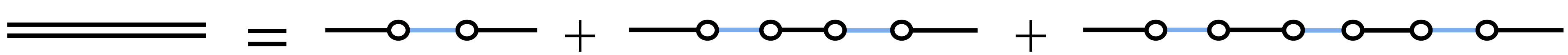

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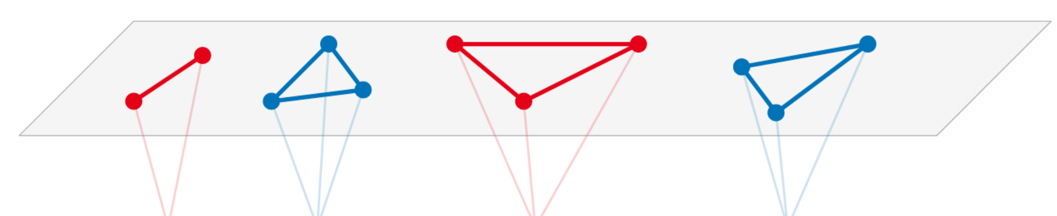
- Can be computed numerically:

CosmoFlow™

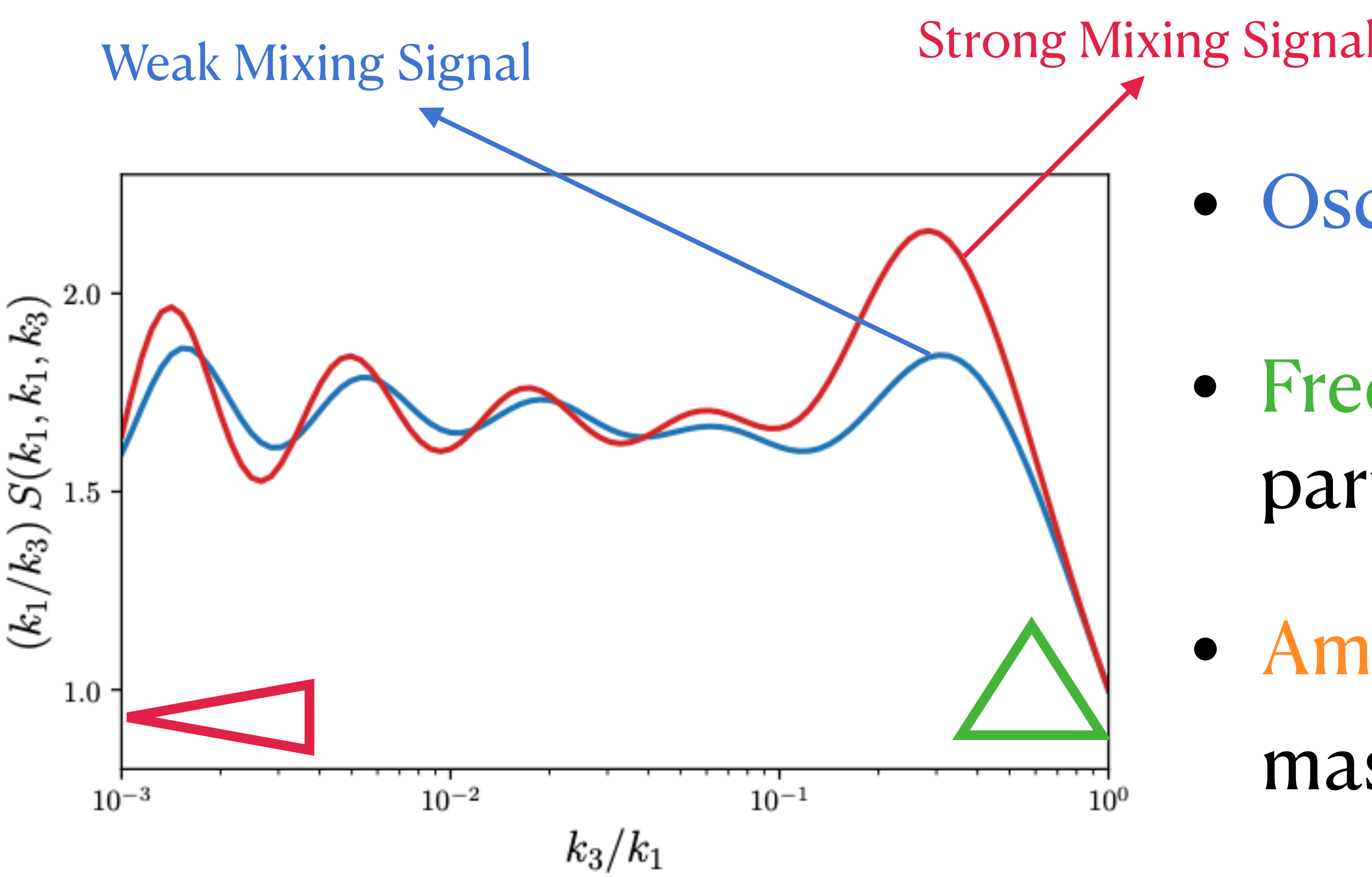
Python Package for Cosmological Correlators



Cosmological Collider Signal

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

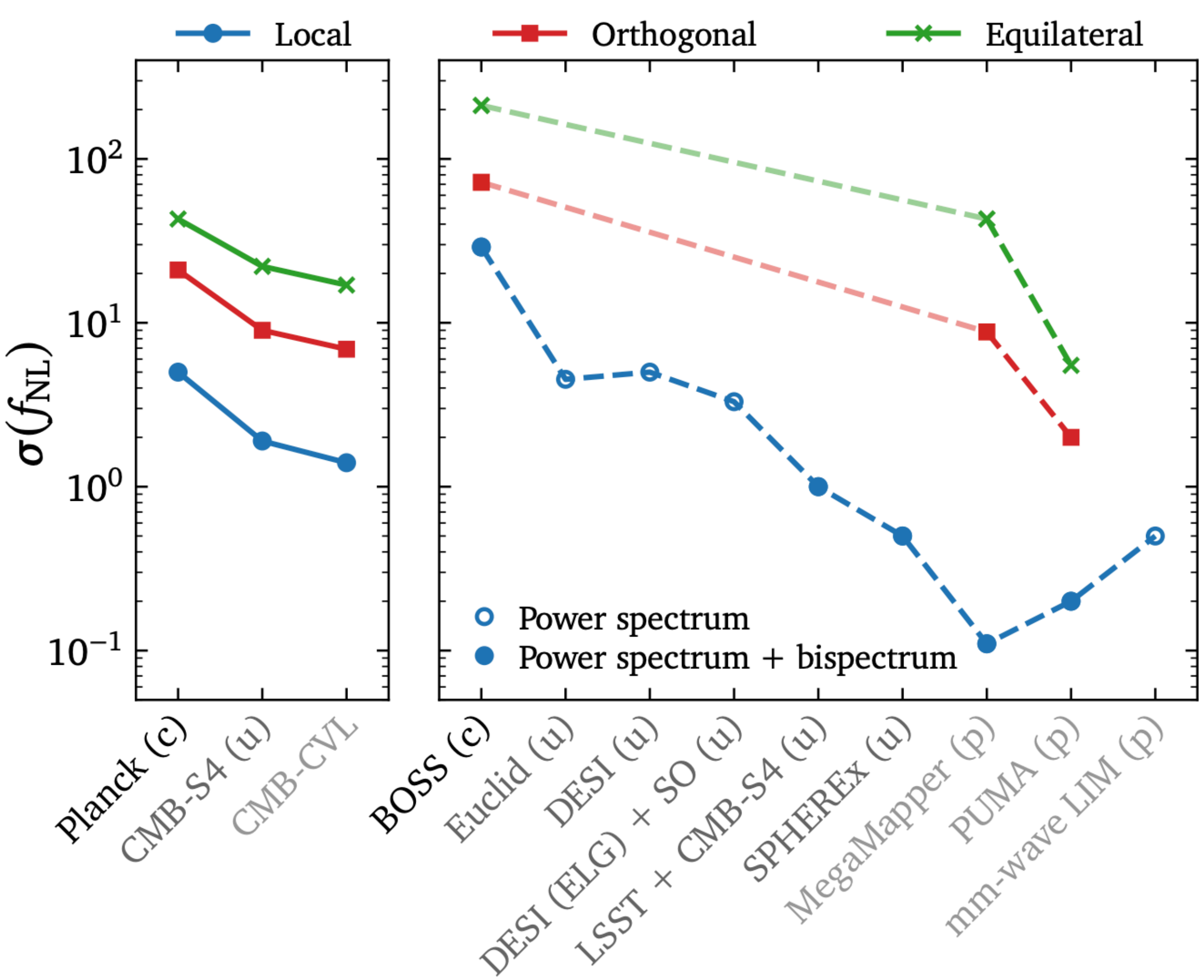
$$B(k_1, k_2, k_3) \sim \left(\frac{k_3}{k_2}\right)^{1/2} e^{-\pi m/H} \cos(m/H \log(k_3/k_1) + \varphi)$$



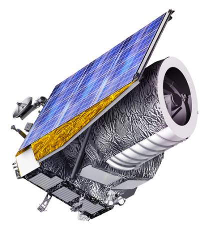
- Oscillation in $\log(k_3/k_1)$.
- Frequency = mass of the new particle.
- Amplitude suppressed by the mass $\Longrightarrow$ Small signal

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.



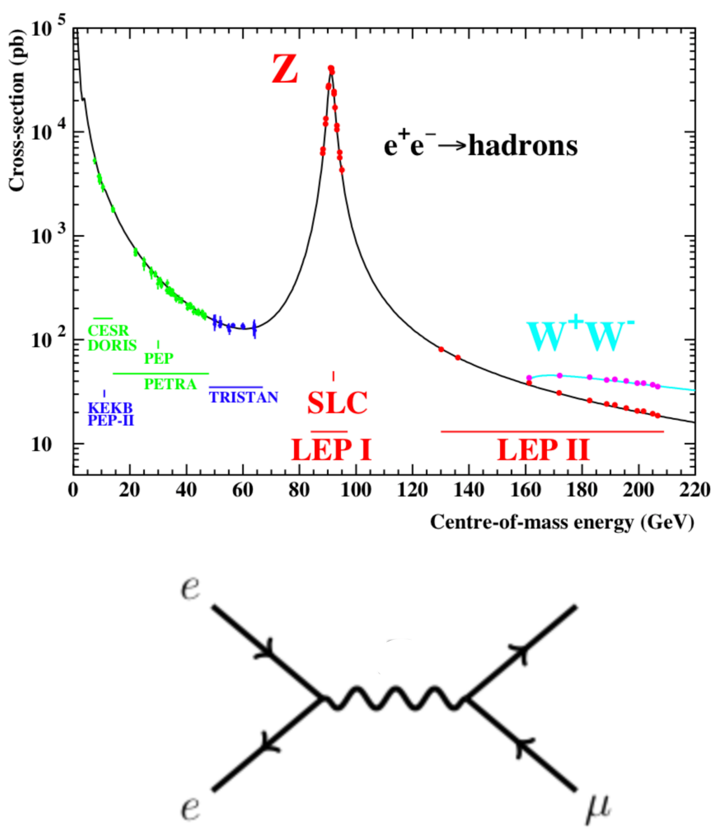
- **Weak Mixing**: smaller signal

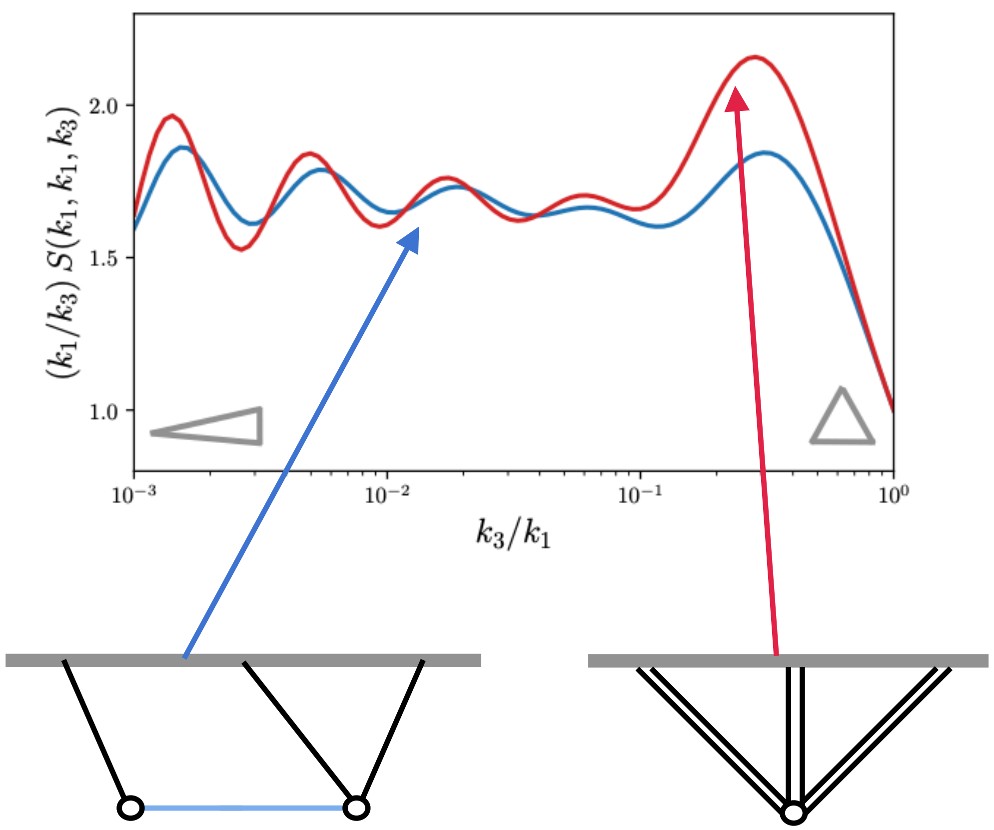
- Need for analytical templates for **strong mixing**.

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: needs to be understood!

- Very promising way of probing high-energy physics!