Non-Gaussianity as a Particle Detector

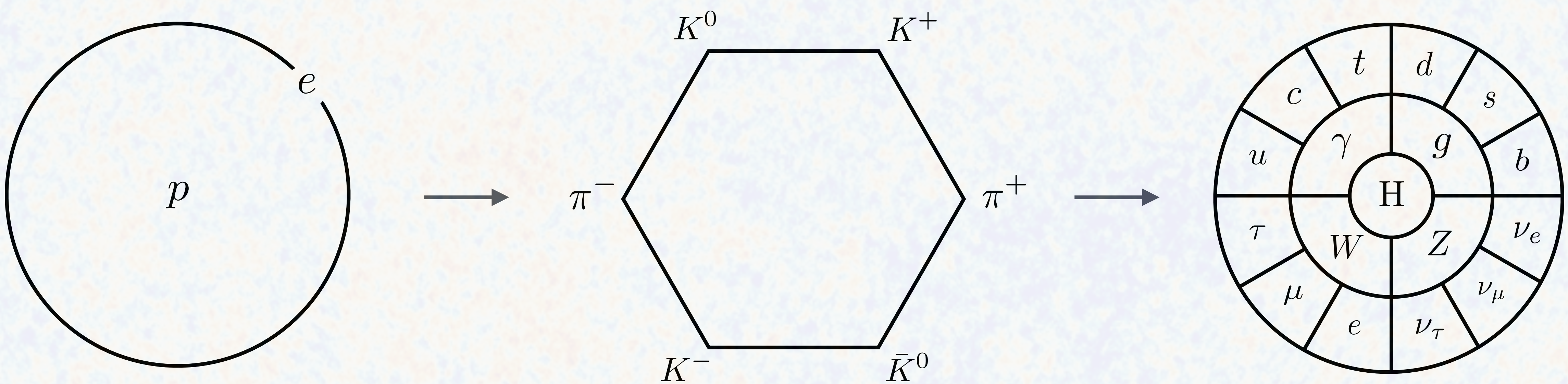
Hayden Lee

DAMTP, University of Cambridge

Based on JHEP 1612 040 [arXiv:1607.03735]
with Daniel Baumann and Guilherme Pimentel

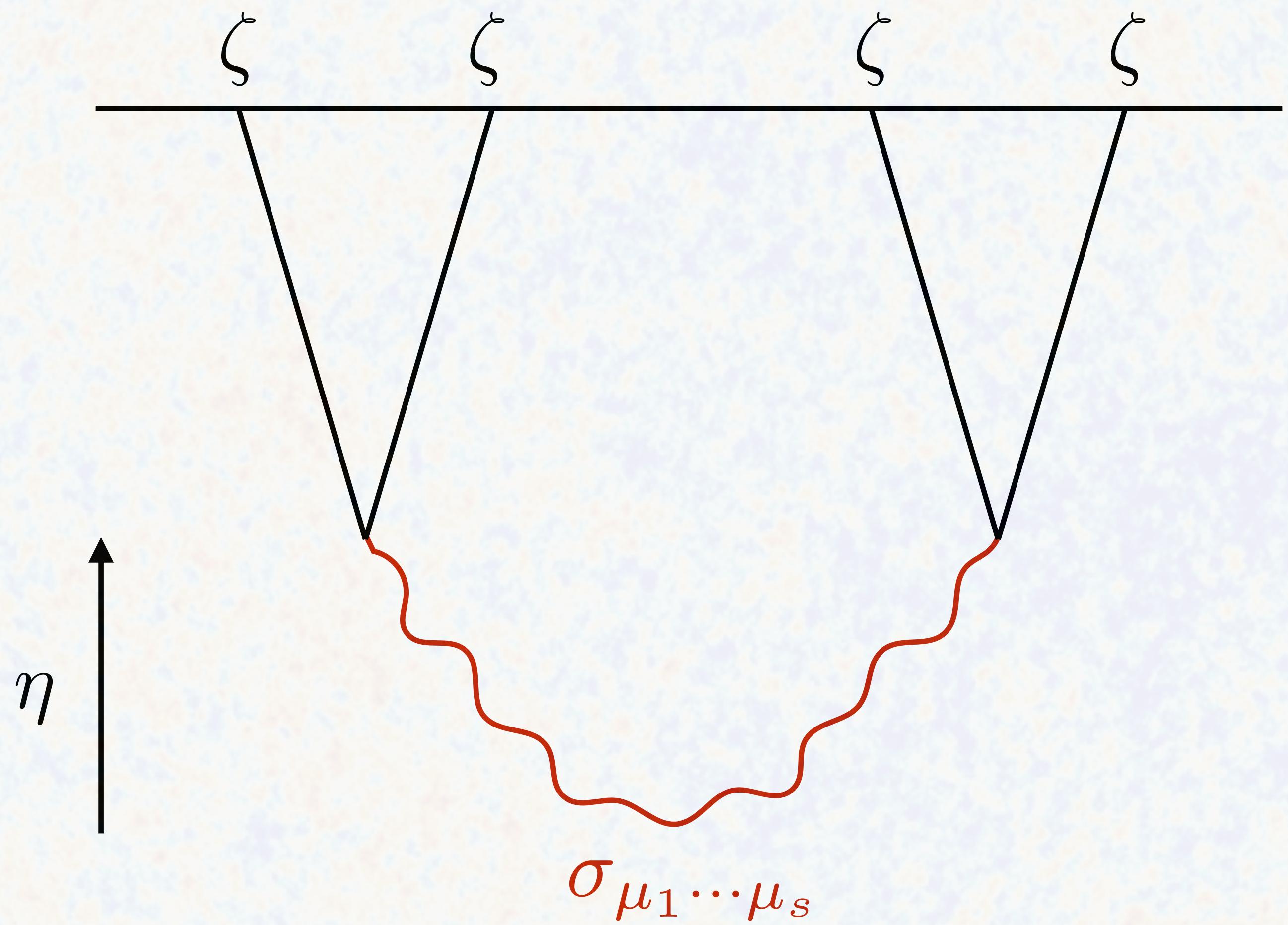
PASCOS, 20 June 2017

In particle physics, the discovery of new particles has revealed the fundamental laws of nature.



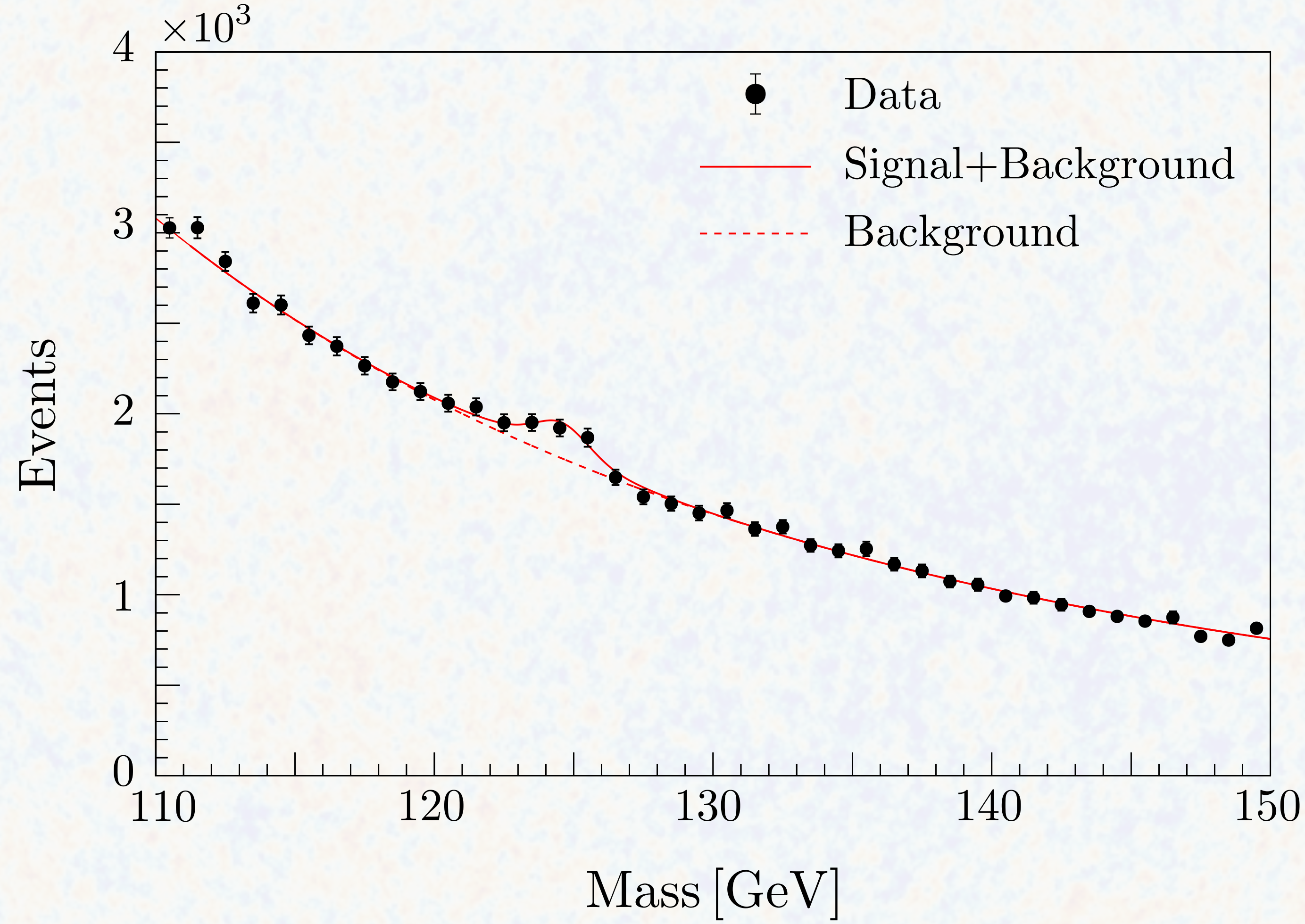
In cosmology, massive particles are important probes of the very early universe.

Massive particles are produced by the expanding spacetime.



During inflation, their masses can be as high as 10^{14} GeV.

In particle colliders, we identify particles through resonances.



What are the signatures of new particles in the cosmic collider?

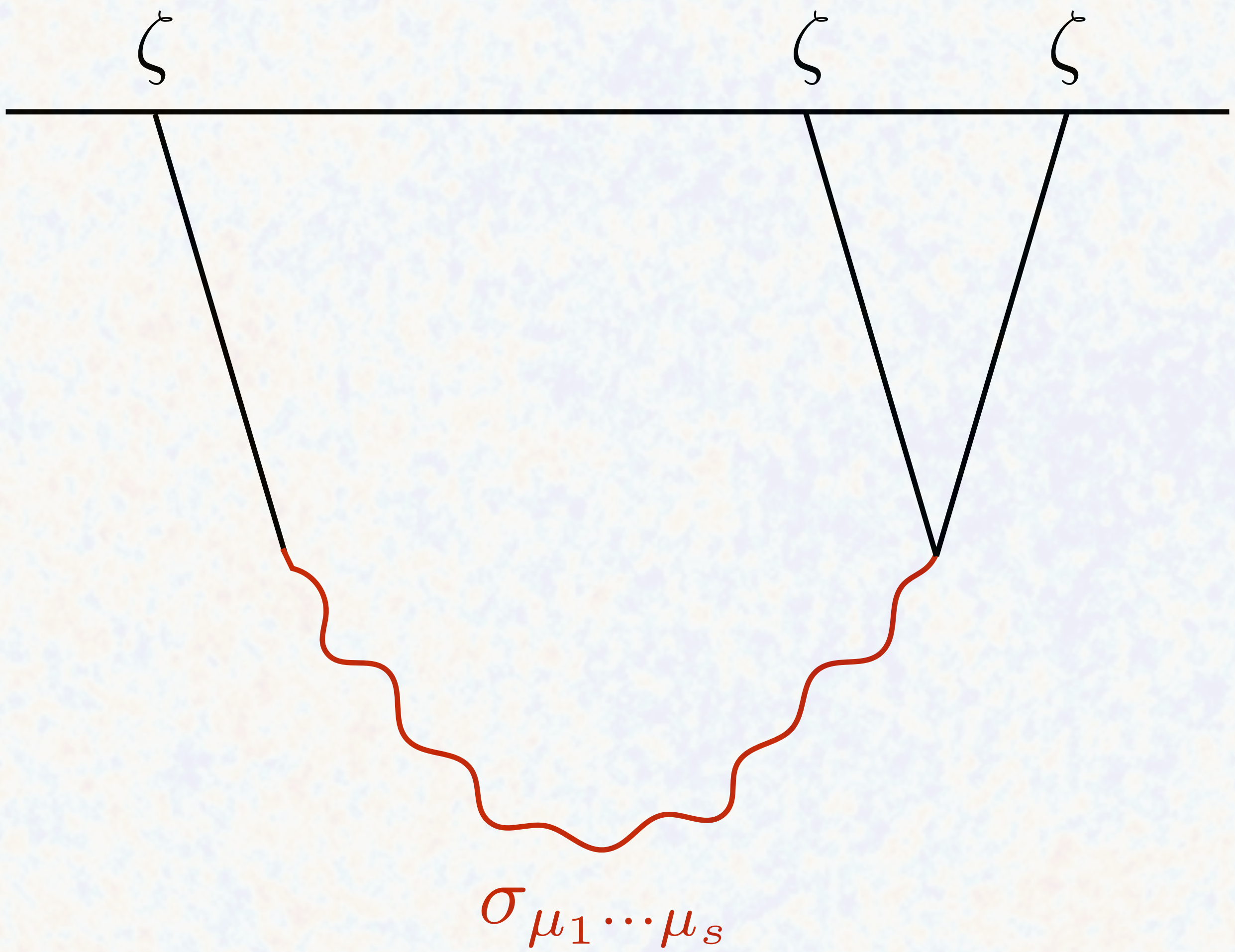
ATLAS, CMS Collaborations [2012]

In this talk, I will describe the signatures of

massive particles with arbitrary spin *during inflation.*

Scalar Non-Gaussianity

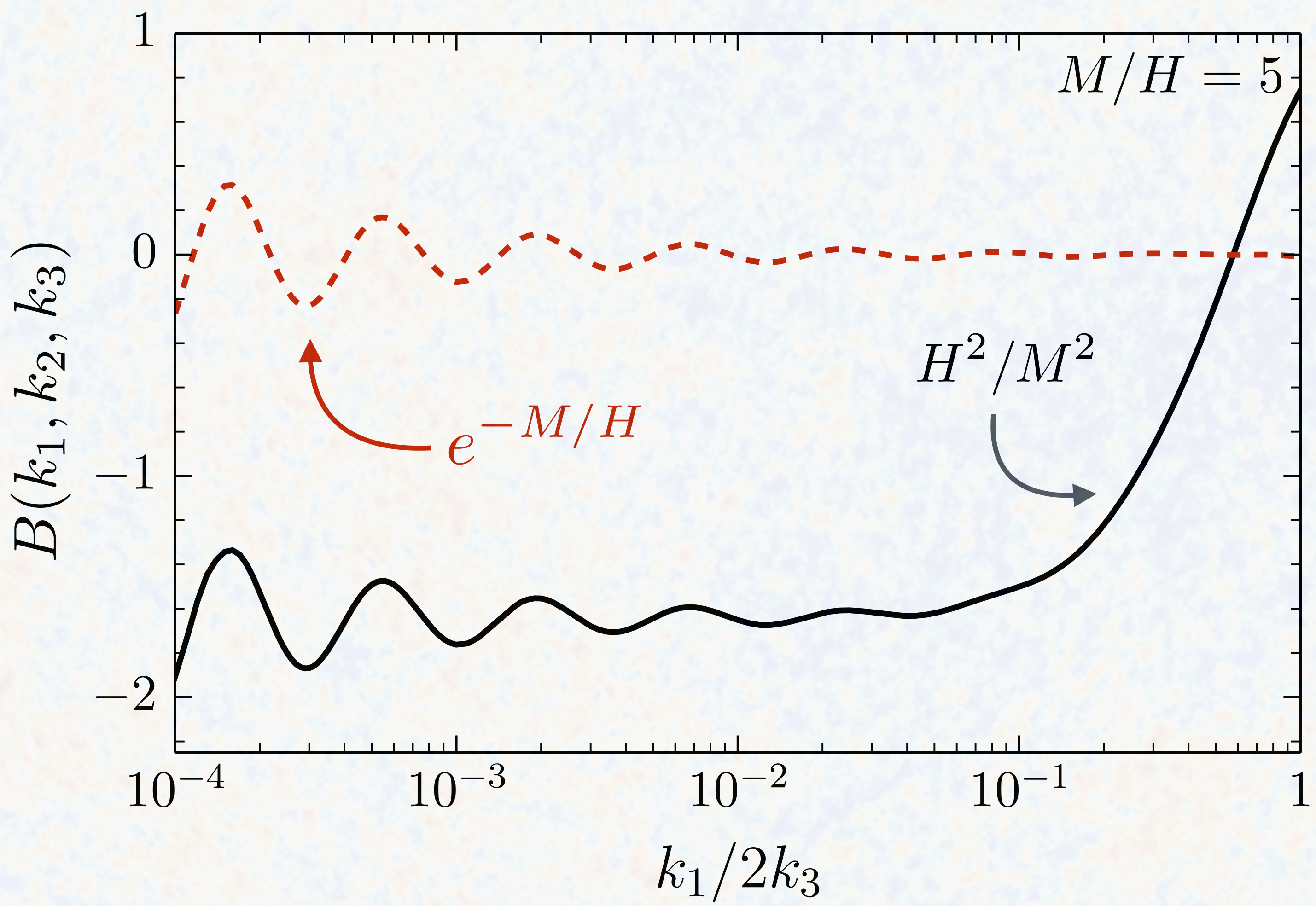
The leading diagnostic for primordial NG is the **bispectrum.**



The shape of NG depends on three factors: **mass, spin, sound speed**.

Mass Dependence

$$\lim_{k_1 \ll k_3} \langle \zeta_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \zeta_{\mathbf{k}_3} \rangle' \propto \left(\frac{k_1}{k_3}\right)^{3/2} \cos\left[\frac{M}{H} \ln \frac{k_1}{k_3} + \delta\right] P_s(\cos\theta)$$

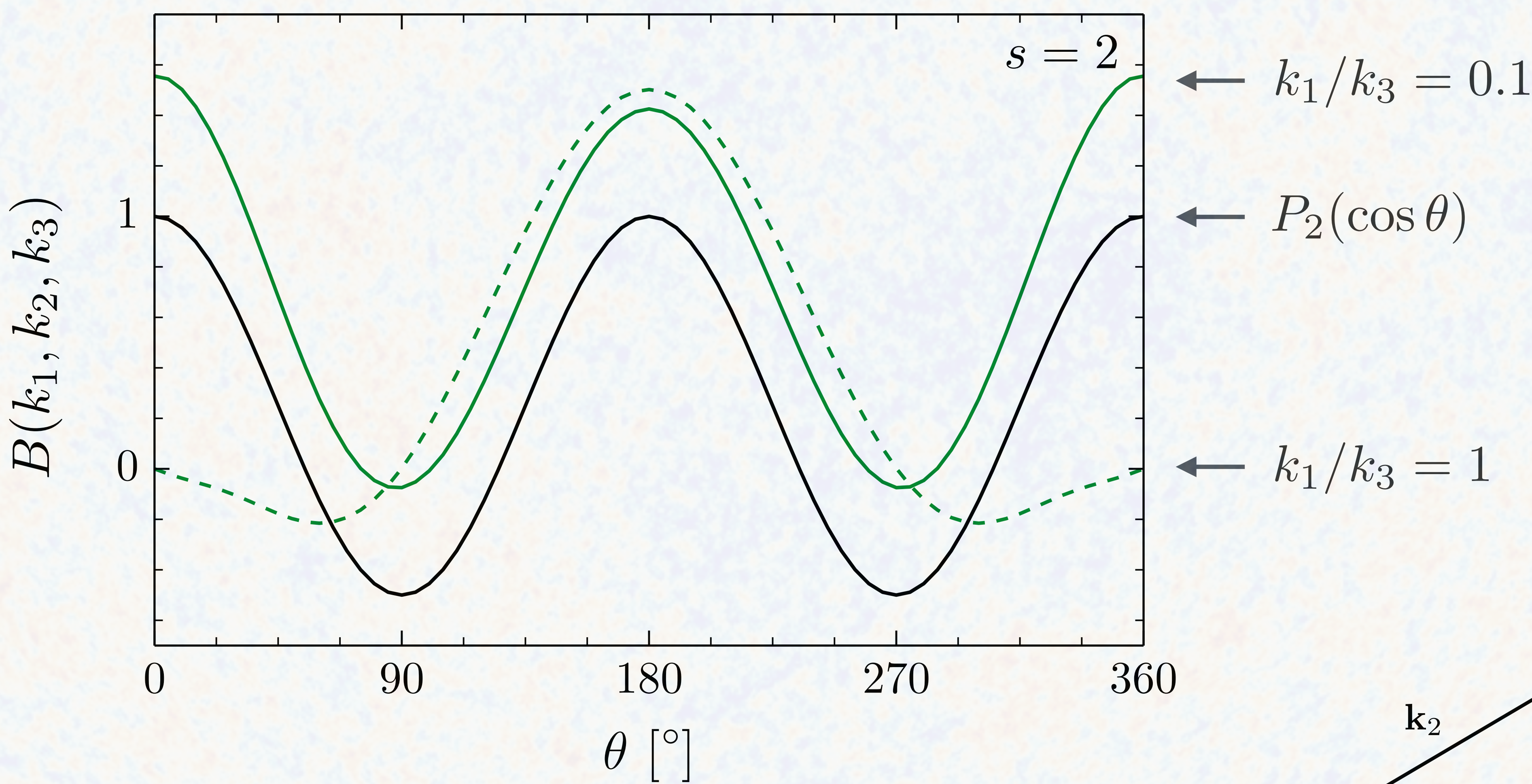


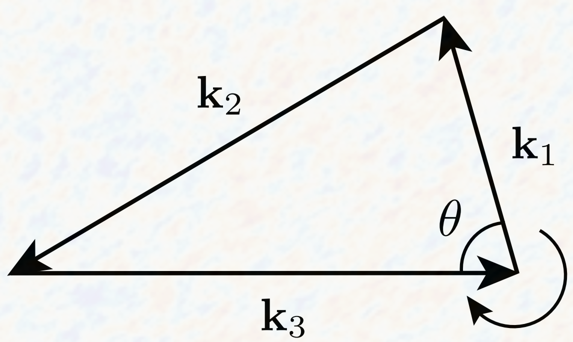
Oscillations determine the **mass** of the particle.

Arkani-Hamed, Maldacena [2015]
HL, Baumann, Pimentel [2016]

Spin Dependence

$$\lim_{k_1 \ll k_3} \langle \zeta_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \zeta_{\mathbf{k}_3} \rangle' \propto \left(\frac{k_1}{k_3}\right)^{3/2} \cos\left[\frac{M}{H} \ln \frac{k_1}{k_3} + \delta\right] P_s(\cos\theta)$$





Angular dependence determines the **spin** of the particle.

Arkani-Hamed, Maldacena [2015]
HL, Baumann, Pimentel [2016]

c_s Dependence

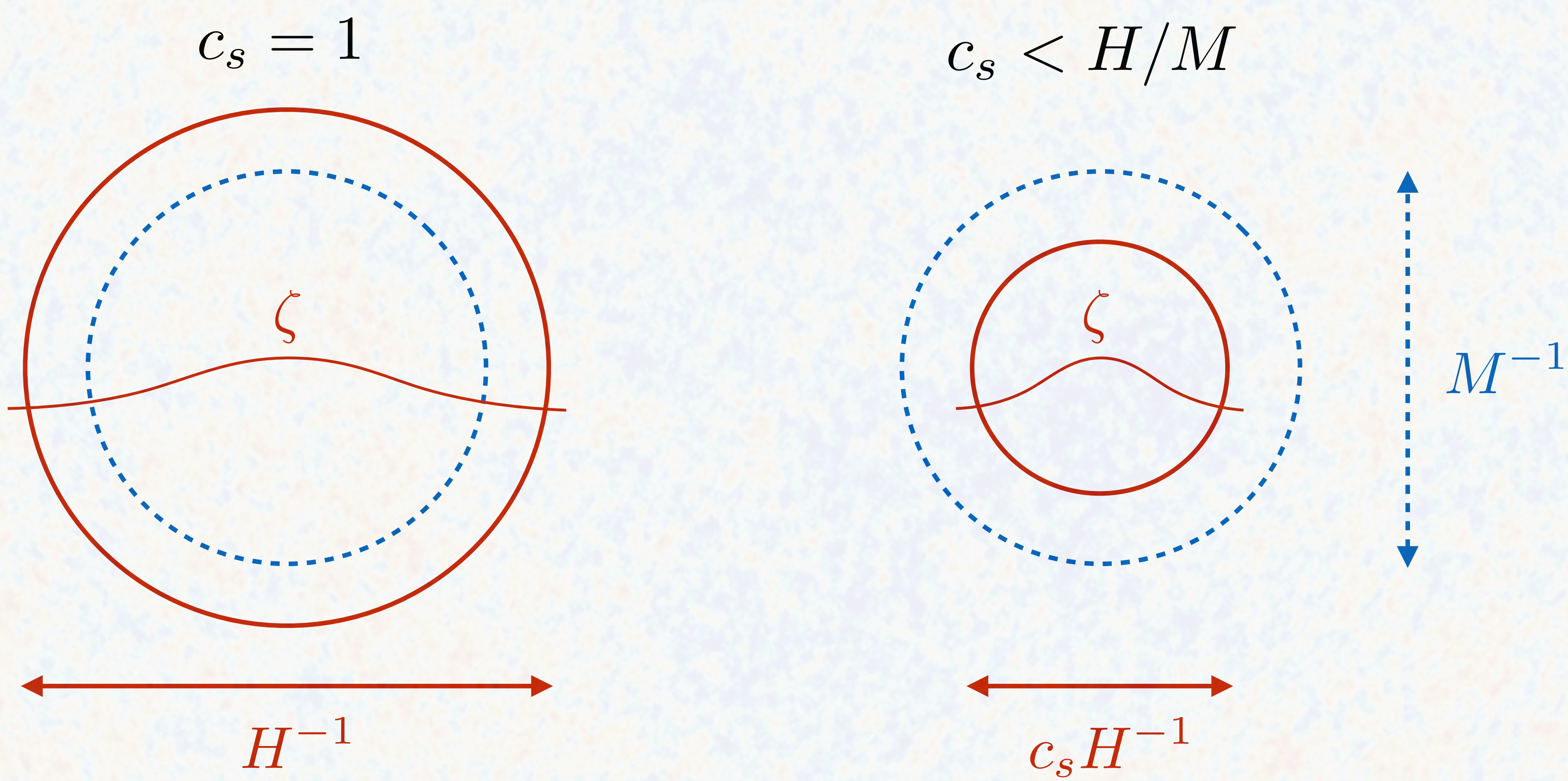
A small sound speed ***enhances*** *the size of non-Gaussianity:*

$$c_s < H/M \;\Rightarrow\; e^{-M/H} \to e^{-M/2H}$$

HL, Baumann, Pimentel [2016]

c_s Dependence

There are **two time scales** in the problem:



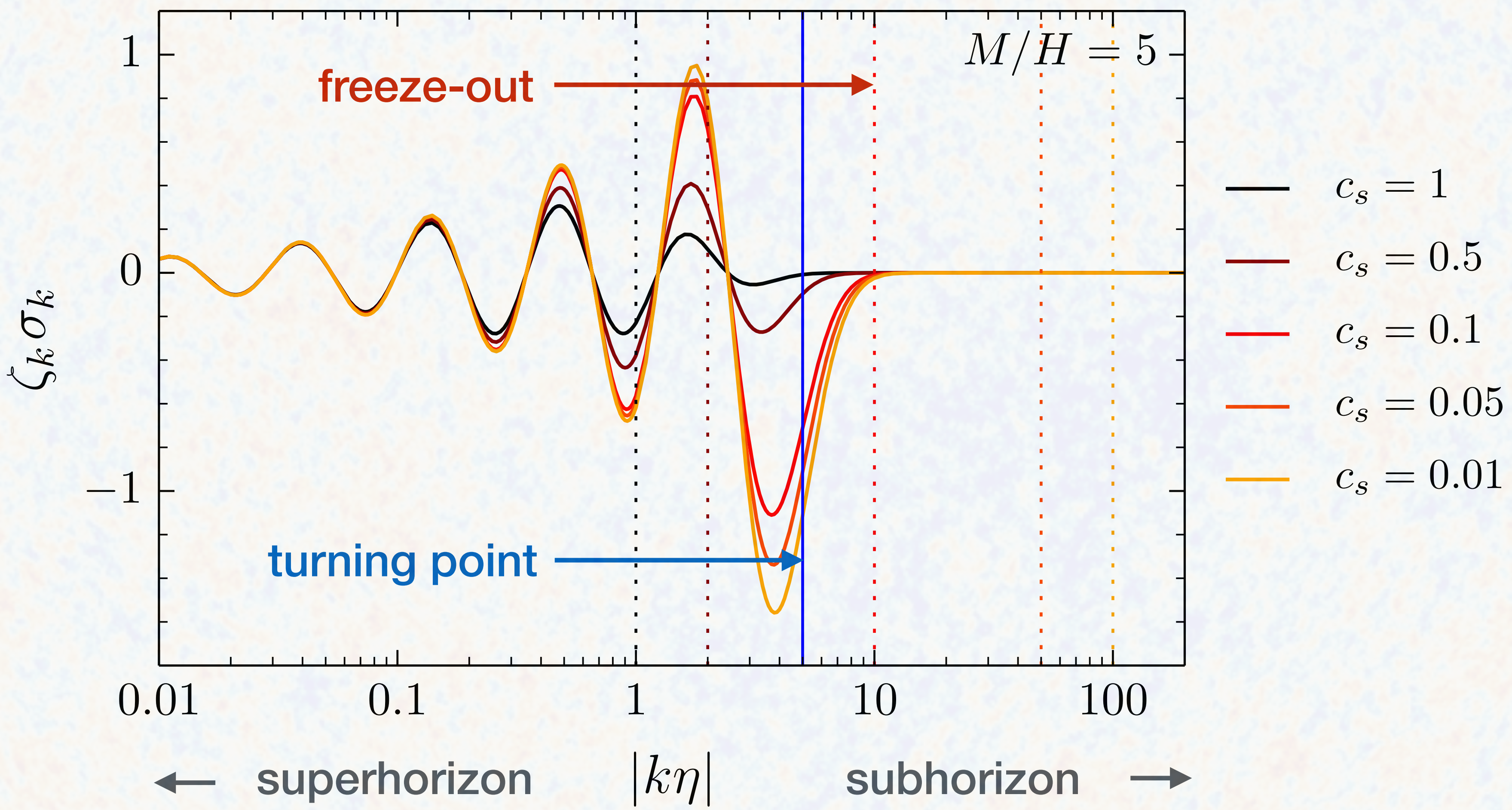
At the **sound horizon crossing**, the curvature perturbation **freezes** out.

At the **turning point**, the massive particle starts to **decay**.

HL, Baumann, Pimentel [2016]

c_s Dependence

A small **sound speed** enhances **mixing** near the turning point.



$$c_s < H/M \;\Rightarrow\; e^{-M/H} \to e^{-M/2H}$$

HL, Baumann, Pimentel [2016]

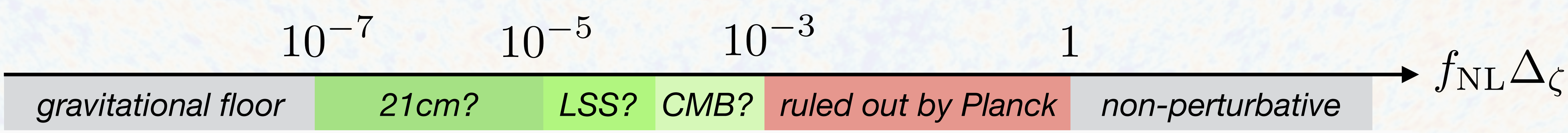
Detectability

The amplitude of the **non-analytic** signal is

$$f_{\rm NL} \sim \underset{<1}{\lambda}\,\underset{10^5}{\Delta_\zeta^{-1}} \times \begin{cases} e^{-M/H} & c_s = 1 \\ e^{-M/2H} & c_s < H/M \end{cases}$$

Observable NG requires small mass: $f_{\rm NL} \gtrsim 1 \;\Rightarrow\; M \lesssim \mathcal{O}(10H)$

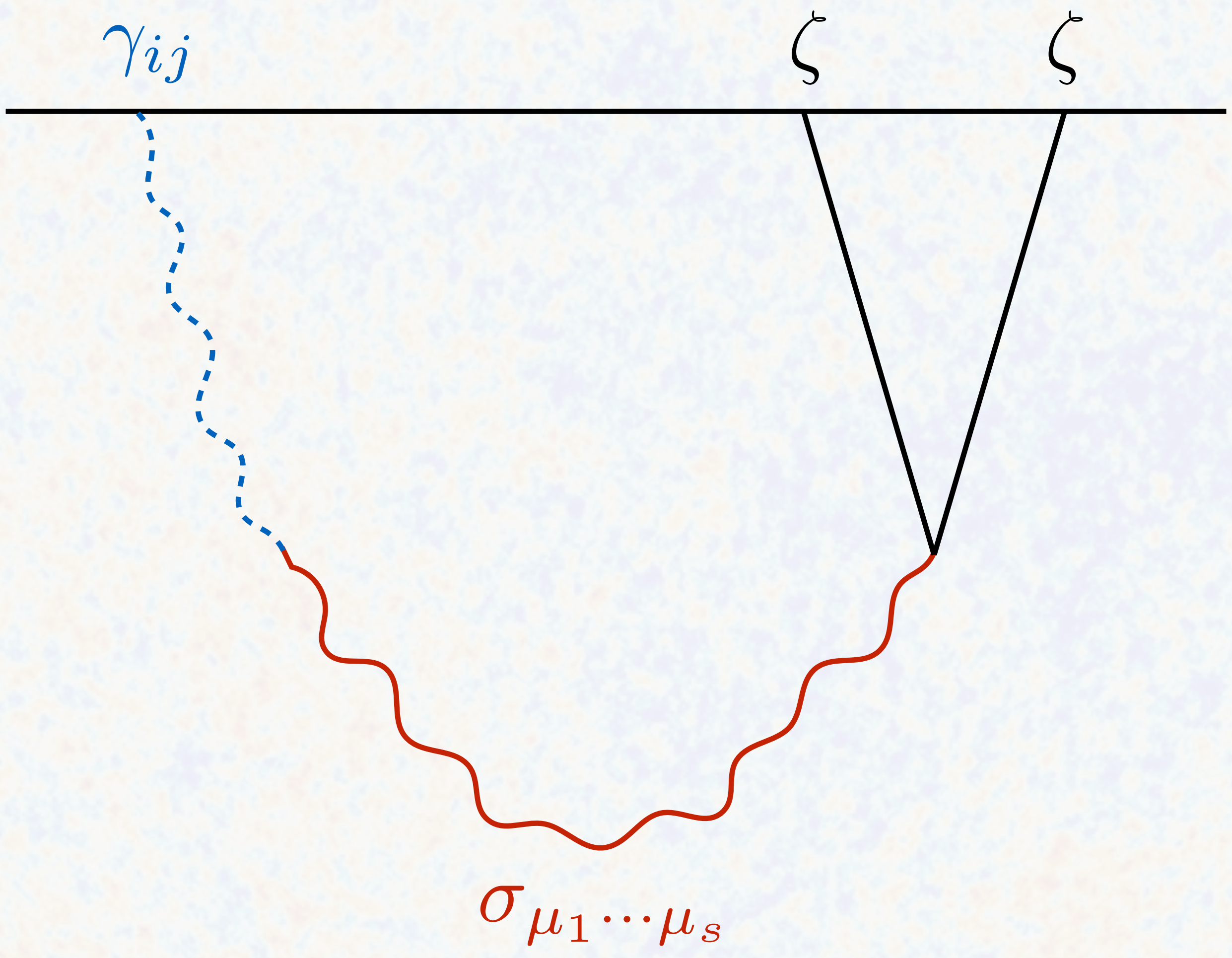
Current and future constraints on primordial NG:



HL, Baumann, Pimentel [2016]

Tensor Non-Gaussianity

Mixing with the graviton leads to a **tensor-scalar-scalar correlator.**



This is only non-vanishing for **higher-spin particles** with **s ≥ 2.**

HL, Baumann, Pimentel [2016]

Tensor Non-Gaussianity

The tensor NG has an **extra angular dependence**: HL, Baumann, Pimentel [2016]

$$\lim_{k_1 \ll k_3} \langle \gamma^h_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \zeta_{\mathbf{k}_3} \rangle' \propto \left(\frac{k_1}{k_3} \right)^{3/2} \cos\left[\frac{M}{H} \ln \frac{k_1}{k_3} + \delta \right] k_1^i k_1^j \varepsilon^h_{ij}(\hat{k}_3) P^h_s(\cos\theta)$$

The **non-analytic** signal can be larger than the slow-roll prediction:

$$f_{\rm NL}^{\gamma\zeta\zeta} \sim (\lambda \Delta_\zeta^{-1} e^{-M/H}) \sqrt{r} \overset{?}{>} \underbrace{\sqrt{r}}_{\text{single-field slow-roll}}$$

The signal can show up in $\langle BTT \rangle$.

Meerburg et al. [2016]
CMB Stage-IV [2016]

Conclusions

- Non-Gaussianity allows us to determine particle's
  - **mass** from oscillations (*squeezed limit*)
  - **spin** from angular dependence (*general configurations*)

- These signatures might be observable if the
  - mass is close to the Hubble scale (*reduced exponential suppression*)
  - **sound speed** is small (*enhanced mixing efficiency*)

- New signatures in the **tensor bispectrum**.
  - Detection channel for stringy effects ($\langle BTT \rangle$)