μ_k vanishes at the edges and takes the maximum value $\mu_k = q/2$, where $q = g^2(\hat{\phi}^2/4m_\phi^2)$. Thus the occupation number grows exponentially. The situation changes quite dramatically when one switches the expansion rate of the universe, the evolution of the scalar field during the first $10-50$ oscillations modifies to:

$$\phi(t) \simeq \frac{M_{\rm P}}{\sqrt{3\pi}}\frac{\cos\left(m_\phi t\right)}{m_\phi t}\,, \tag{381}$$

where t is the physical time. The presence of the t at the denominator shows the damping of the oscillations due to the expansion of the universe. During this period the *stochastic resonance* come into the picture [100], where there are resonance bands as well as decrease in the particle number due to quantum effects.

In either case (expanding or non-expanding background), based on initial VEV of σ there would be two distinct cases.

- $\underline{\sigma \ll h^2 M_{\rm P}}$:

  In this regime the $h^2\phi^2\chi^2$ term is dominant at the beginning of the inflaton oscillations. This case has been studied in detail in first two references of [99, 100]. For a nominal value of the inflaton mass, i.e. $m_\phi = 10^{13}$ GeV in chaotic inflation case, non-perturbative χ production during every oscillations of ϕ field, with a physical momentum, $k \lesssim \left(hm_\phi\hat{\phi}\right)^{1/2}$ (where $\hat{\phi} \sim M_{\rm P}$), takes place if $h > 10^{-6}$. Particle production is particularly efficient if $h > 3\times 10^{-4}$, and results in an explosive transfer of energy to χ quanta. The number density of χ_k quanta increases exponentially. The parametric resonance ends when re-scatterings destroy the inflaton condensate. The whole process happens over a time scale $\sim 150 m_\phi^{-1}$, which depends logarithmically on h [100, 102].

- $\underline{\sigma \gg h^2 M_{\rm P}}$:

  In this regime the cubic term $\sigma\phi\chi^2$ dominates. This case was recently considered in Refs. [103, 806], where the the χ field becomes tachyonic during half of each oscillation. For $\sigma > m_\phi^2/M_{\rm P}$ (which amounts to $\sigma > 10^7$ GeV for $m_\phi = 10^{13}$ GeV) this tachyonic instability transfers energy from the oscillating condensate very efficiently to the χ quanta with a physical momentum $k \lesssim \left(\sigma\hat{\phi}\right)^{1/2}$. Particle production ceases when the back-reaction from χ self-coupling induces a mass-squared $\gtrsim \sigma\hat{\phi}$. Depending on the size of λ, most of the energy density may or may not be in χ quanta by the time back reaction becomes important [807].