Early time development of azimuthal anisotropies from small to large Knudsen numbers

Nicolas BORGHINI

with Marc BORRELL & Hendrik ROCH

(Universität Bielefeld)

Onset of azimuthal anisotropies

Is the development at early times of azimuthal anisotropies — in particular, of anisotropic transverse flow — universal across different classes of models for the fireball?

☞ May be relevant for anisotropic flow in smaller systems

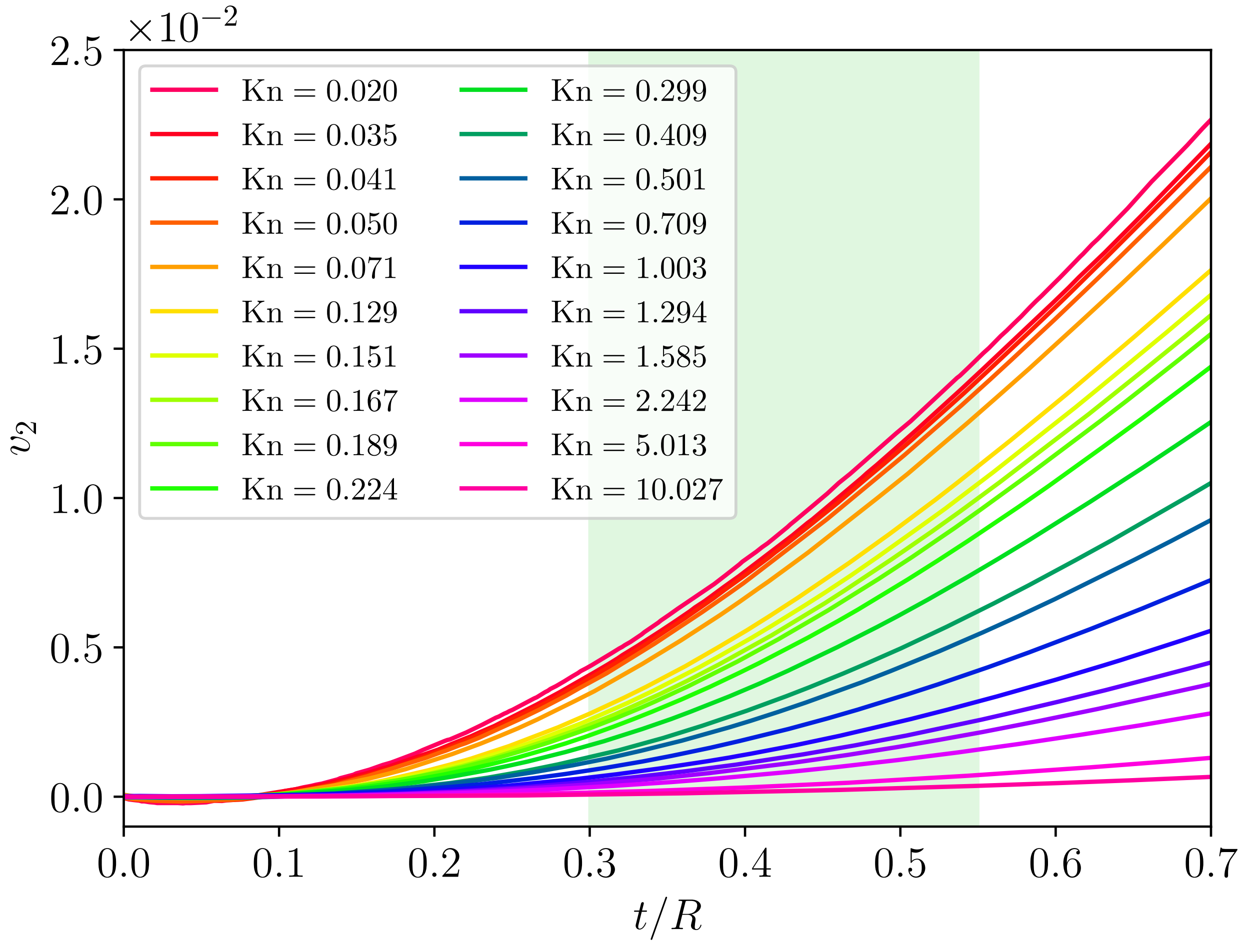
Investigations in kinetic transport theory (2D, massless particles, fixed semi-realistic initial geometry):

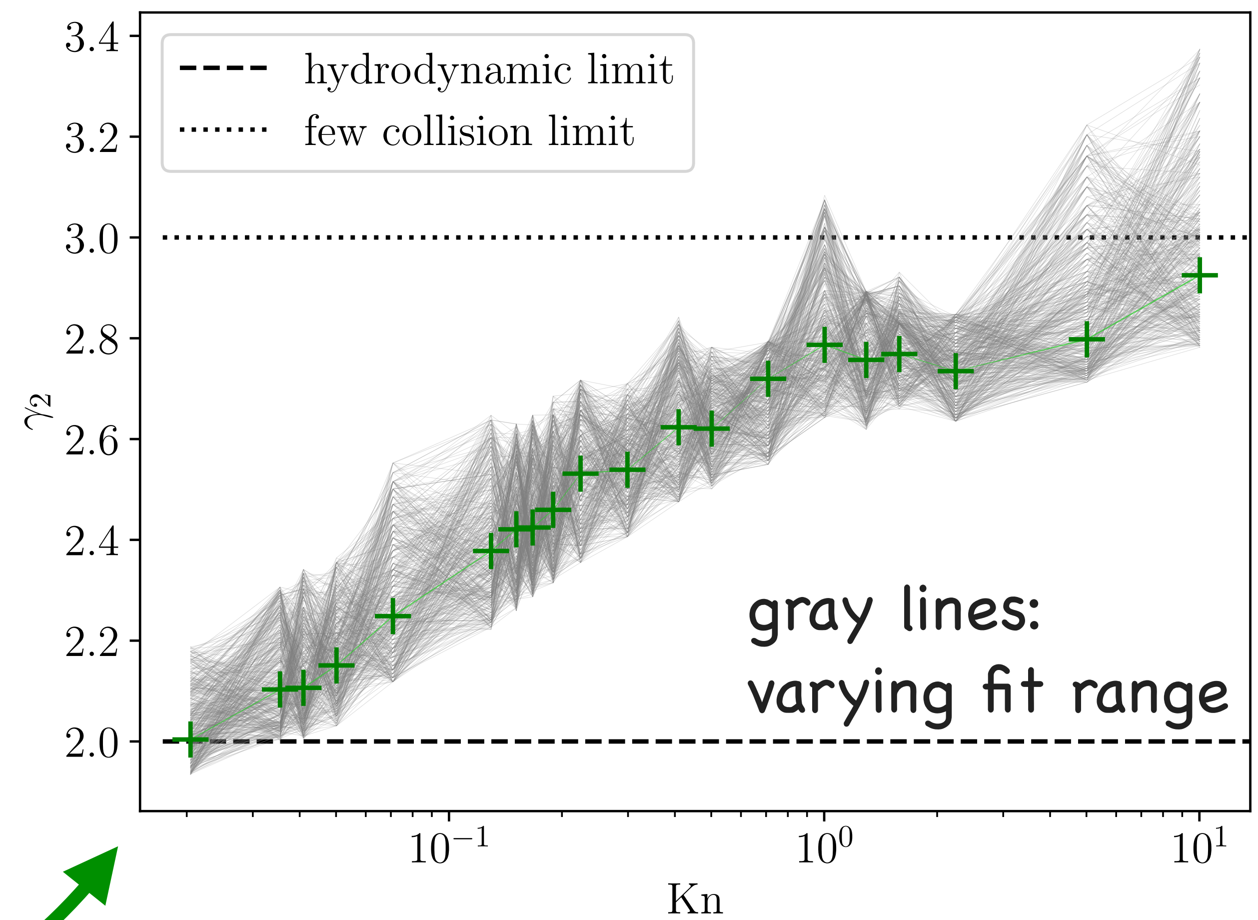
- Analytical calculations in the few-rescatterings regime (large Knudsen number Kn).
- Transport code simulations with tunable cross section: from few to many rescatterings ("hydro limit": small Kn) per particle.

arXiv:2109.15218 + arXiv:2201.13294

Early time development of v_2

Transport simulations:





fit

Ansatz $v_2(t) \propto t^{\gamma_2}$

Many ≠ few rescatterings!

R: typical initial system size

Rule of thumb: mean number of rescatterings per particle $\approx 0.5\,\mathrm{Kn}^{-1}$

Early evolution of the single-particle phase space density

Using the Boltzmann eq. $p^\mu \partial_\mu f(t,\vec{x},\vec{p}) = \mathcal{C}[f]$, the Taylor expansion of the phase space density at early times can be recast in the form

$$f(t,\vec{x},\vec{p}) = f_{\rm f.s.}(t,\vec{x},\vec{p}) + t\,\frac{\mathcal{C}[f]\big|_0}{E} + \frac{t^2}{2}\left(-\frac{\vec{p}}{E^2}\cdot\vec{\nabla}_x\mathcal{C}[f] + \frac{1}{E}\partial_t\mathcal{C}[f]\right)_0$$
$$+ \frac{t^3}{3!}\left(\frac{\big(\vec{p}\cdot\vec{\nabla}_x\big)^2}{E^3}\mathcal{C}[f] - \frac{\vec{p}}{E^2}\cdot\vec{\nabla}_x\partial_t\mathcal{C}[f] + \frac{1}{E}\partial_t^2\mathcal{C}[f]\right)_0 + \mathcal{O}(t^4)$$

↑ free-streaming with the same initial state

where the subscript 0 means that the quantities are evaluated in the initial state.

In the terms beyond free streaming, the collision kernel $\mathcal{C}[f]$ is linear in the cross section σ, $\partial_t\mathcal{C}[f]$ includes terms of order $\mathcal{O}(\sigma^2)$, and more generally $\partial_t^k\mathcal{C}[f]$ contains contributions $\mathcal{O}(\sigma^{k+1})$.

Early time development of v_2

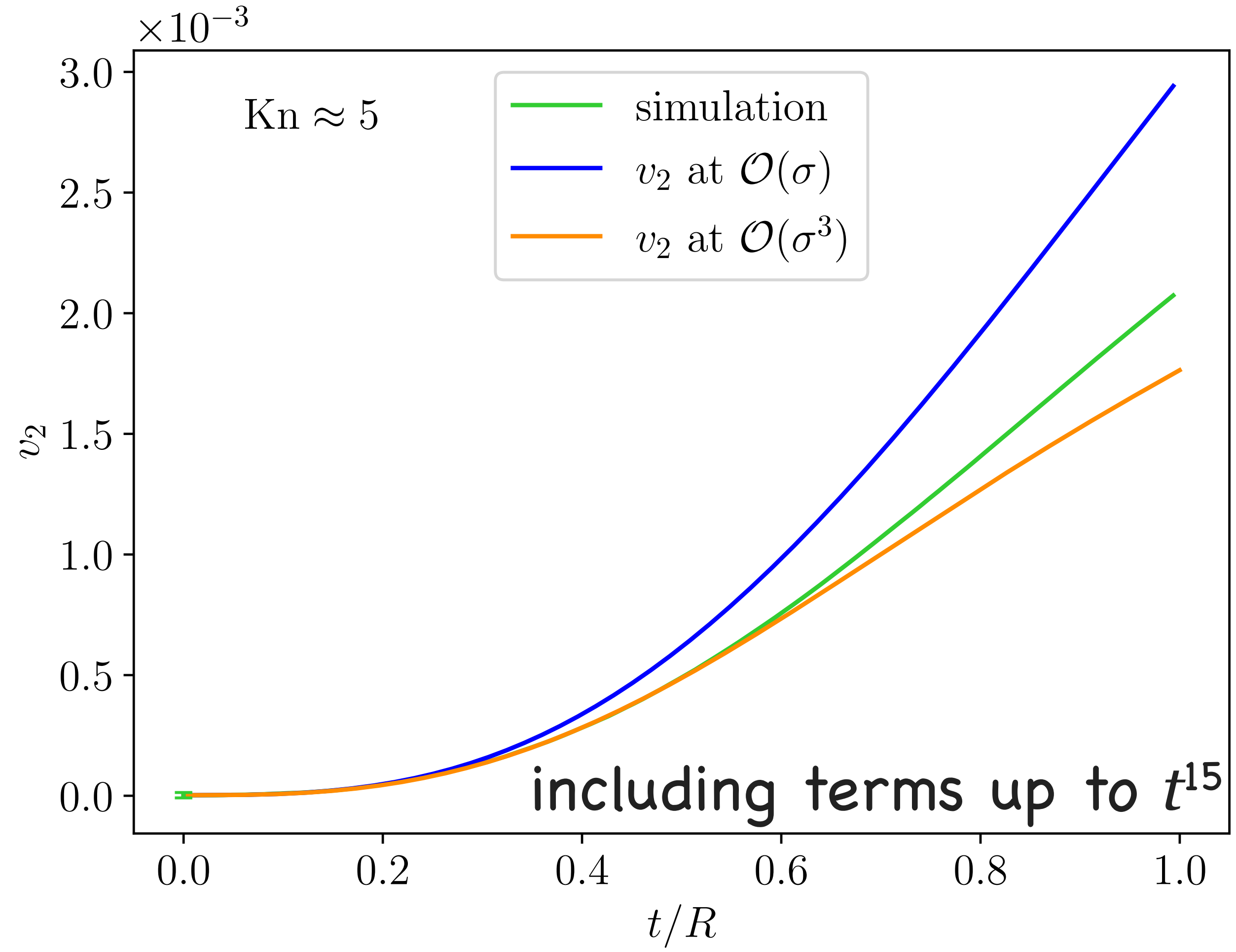
Invoking symmetry arguments (for an initial state without anisotropic flow), the early-time Taylor series yields

$$v_2(t) = \mathcal{O}(\sigma)t^3 + \mathcal{O}(\sigma^2)t^4 + \big[\mathcal{O}(\sigma) + \mathcal{O}(\sigma^3)\big]t^5 + \cdots$$

☞ systematic (but tedious…) approach!

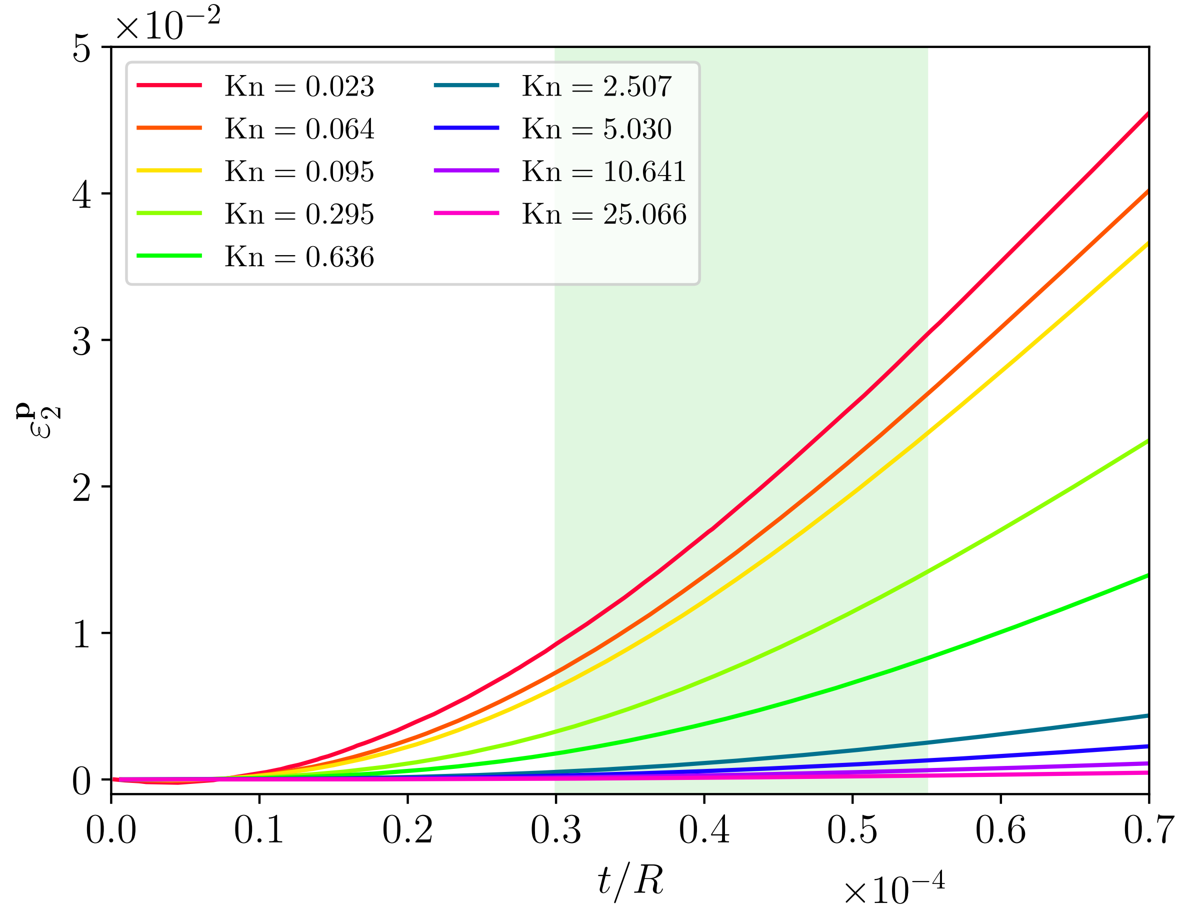
$v_2(t) \propto t^3$

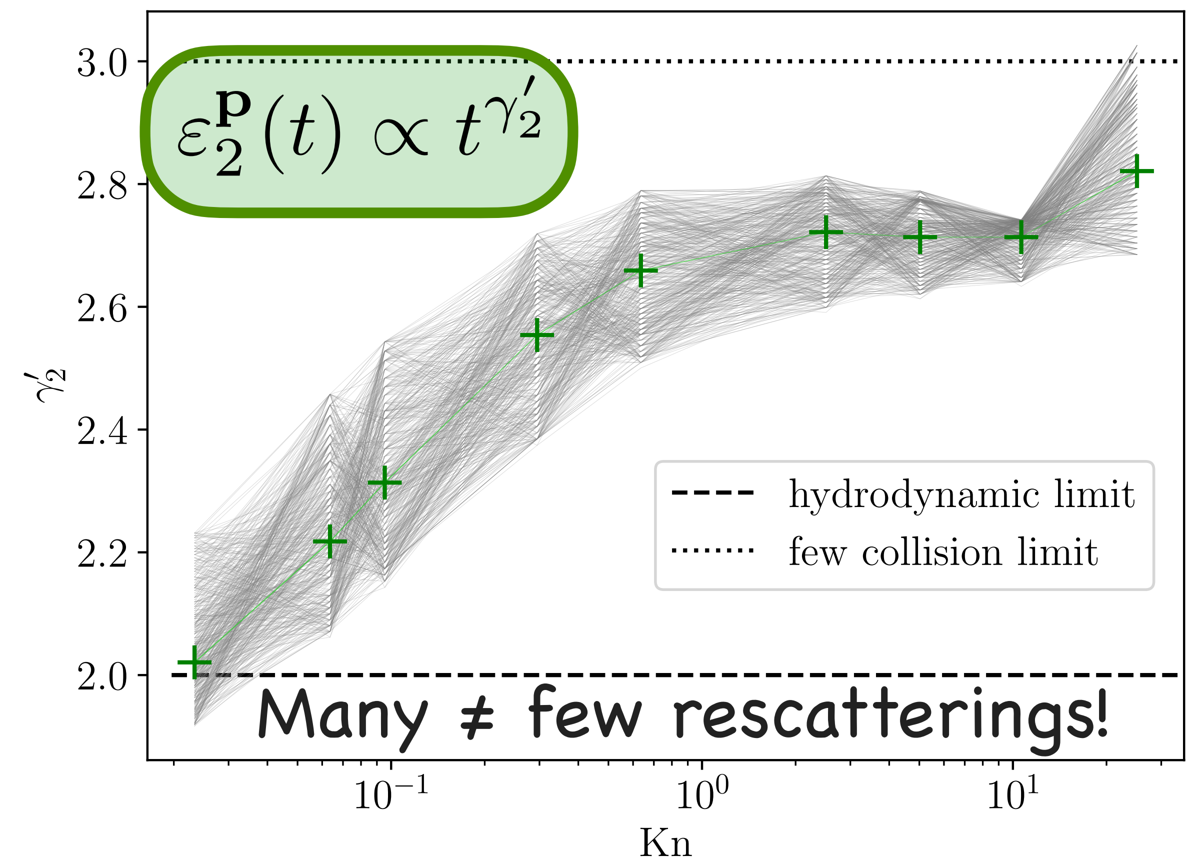
at early times!

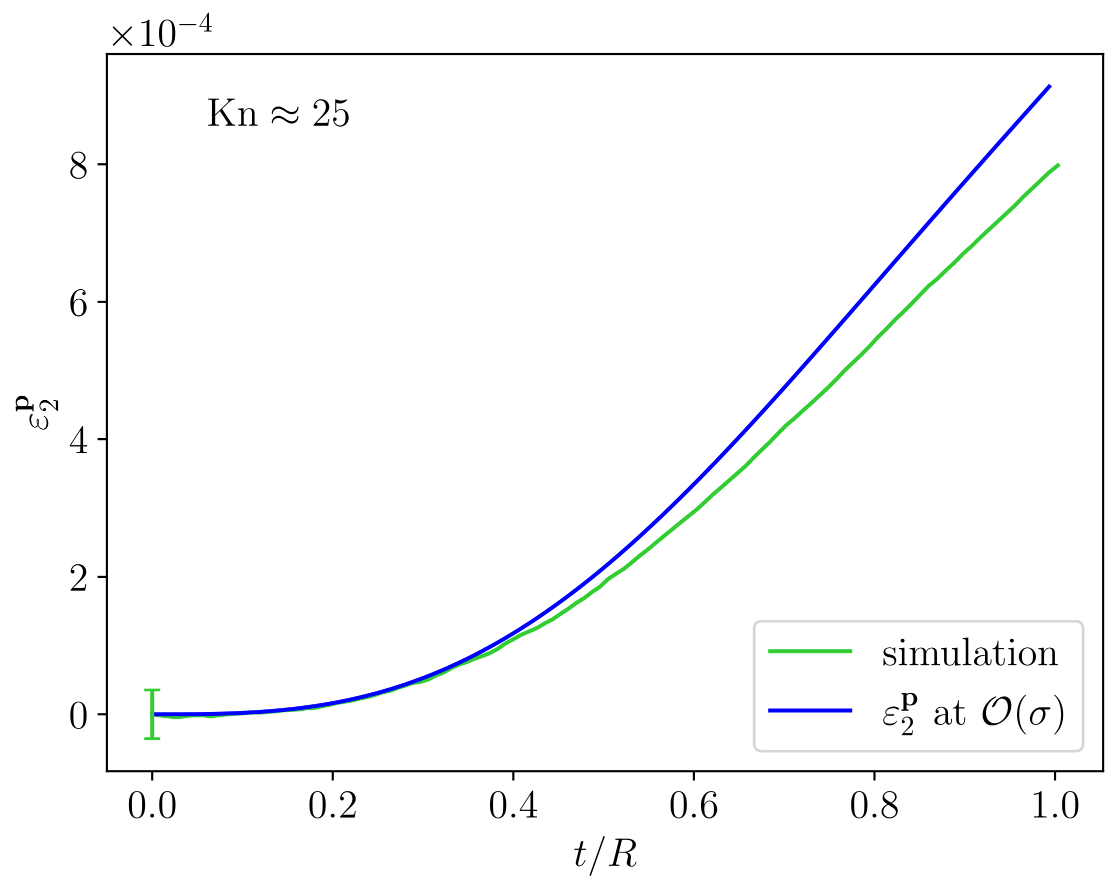


including terms up to t^{15}

An alternative measure of elliptic flow





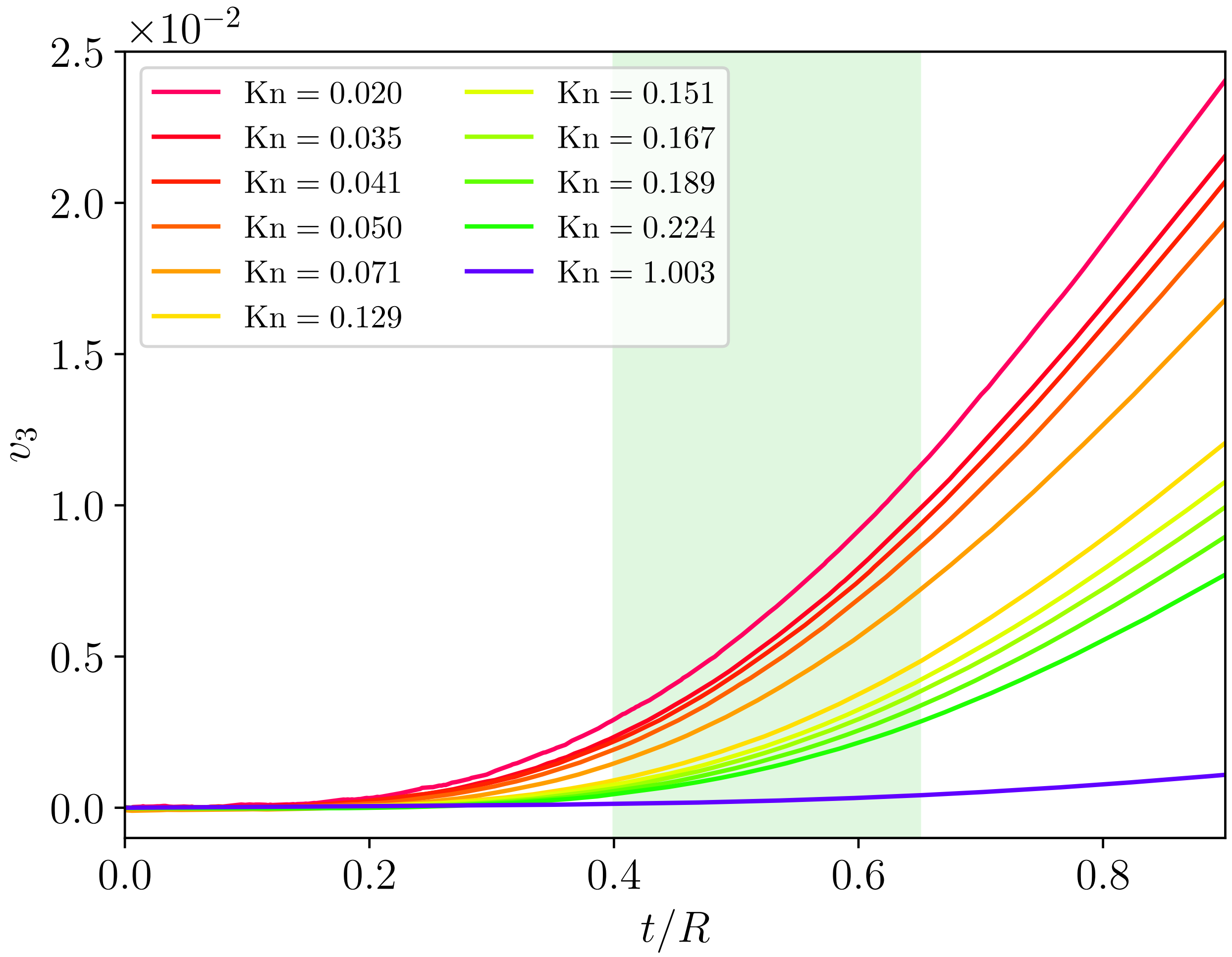


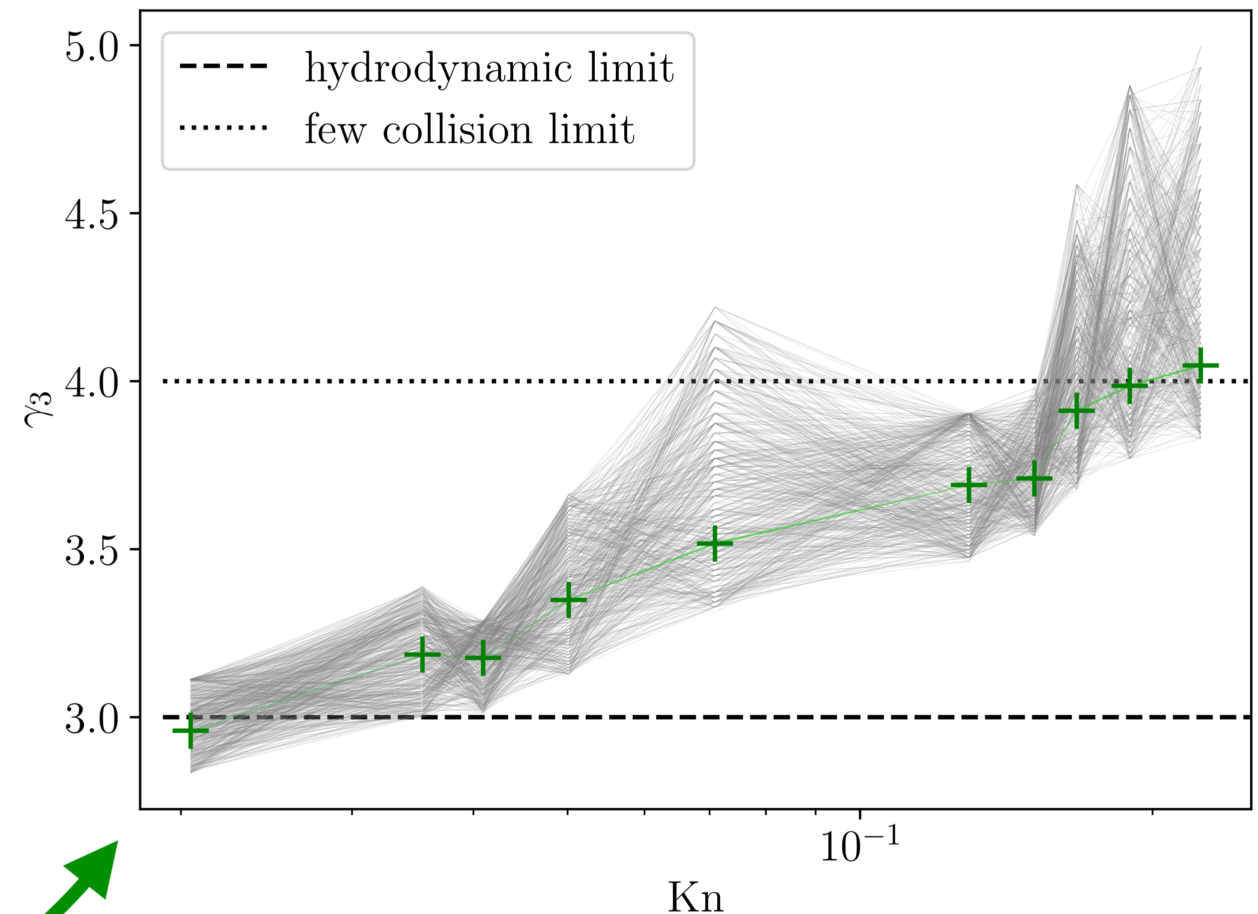
$$\varepsilon_2^{\mathbf{p}} \equiv \frac{\langle T^{xx} - T^{yy} \rangle}{\langle T^{xx} + T^{yy} \rangle}$$

Bonus slide

Early time development of v_3

Transport simulations:





fit

Ansatz $v_3(t) \propto t^{\gamma_3}$

Many ≠ few rescatterings!