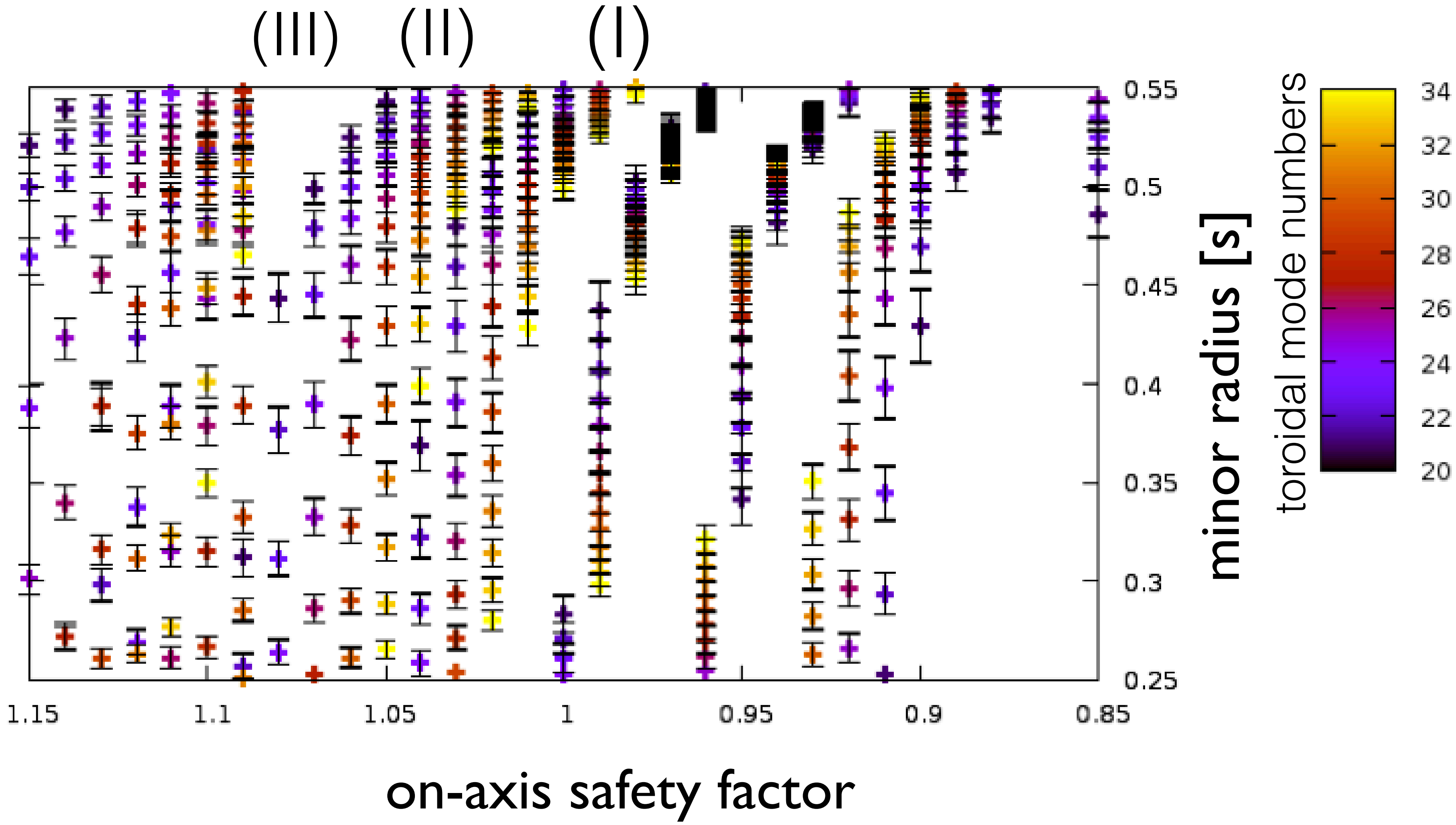
ITER example classifying AE-EP transport scenarios: workflow L1 for standard 15 MA scenario

[Polevoi, 2002]

- degree of (non-linear) Alfven eigenmode (AE) resonance overlap will determine the nature of EP transport [Berk 1995] in ITER and DEMO

example: 15MA ITER scenario: linear TAE-α resonances depend strongly on q0: strongly overlapping (I), intermediate (II) and scarce (III) TAEs spectra can exist here: only linearly unstable modes are shown

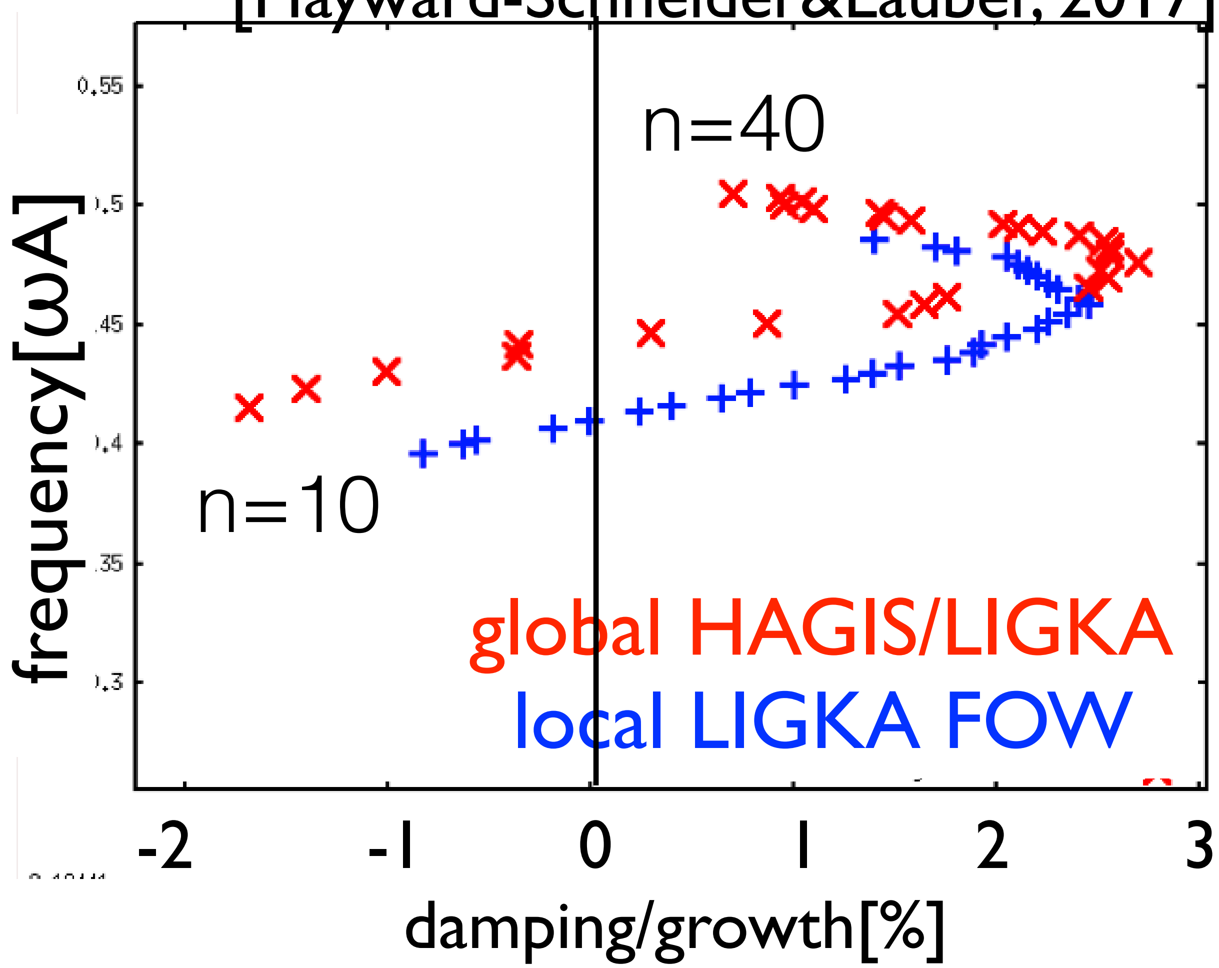
(N.B: for small particle orbits, Pφ and s are similar, thus the radial mode overlap is a proxy for resonance overlap)



automated HAGIS/LIGKA workflow L2/L3/L4 for ITER 15 MA including FLR/FOW

including some global information (kr,k⊥) in local model:

[Hayward-Schneider&Lauber, 2017]

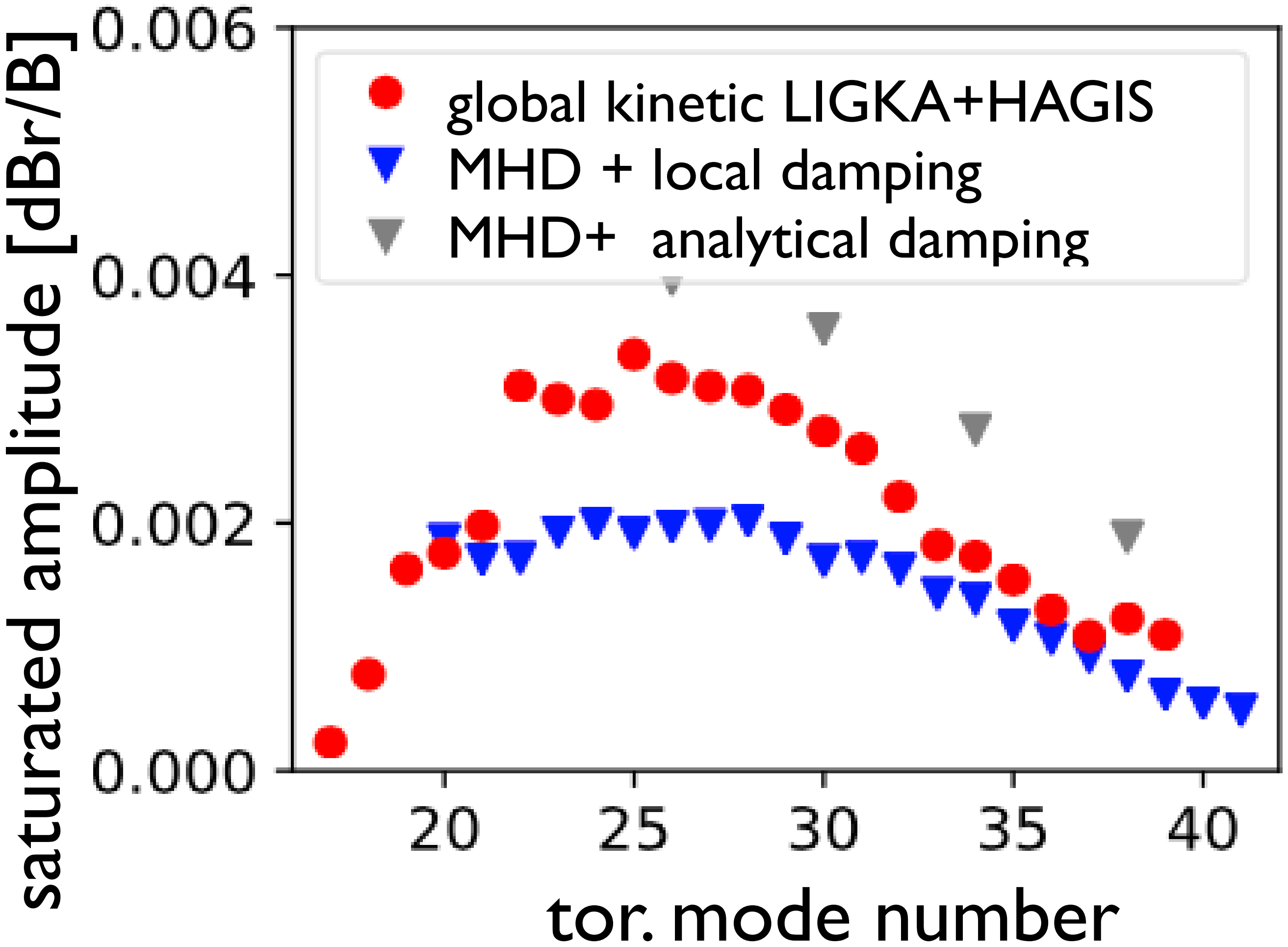


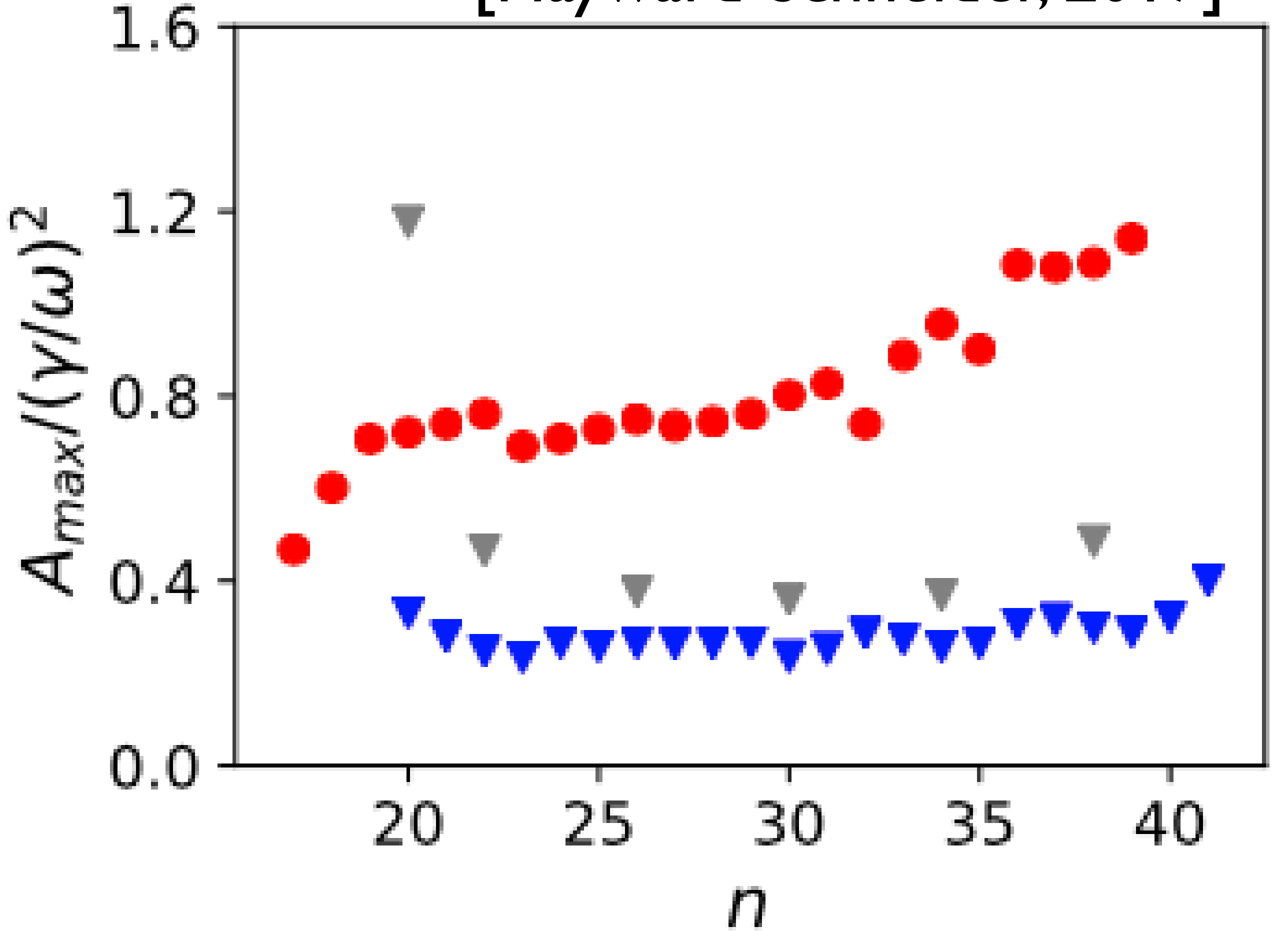
10-100 times faster than global solver: analytical finite orbit width version of LIGKA based on analytical theories [Zonca 1996/98]; benchmarked in relevant limit [Lauber 2018]:

reasonable agreement for intermediate and high mode numbers

automated HAGIS/LIGKA workflow H1 including FLR/FOW

[Hayward-Schneider, 2017]





runtime: minutes - few hours

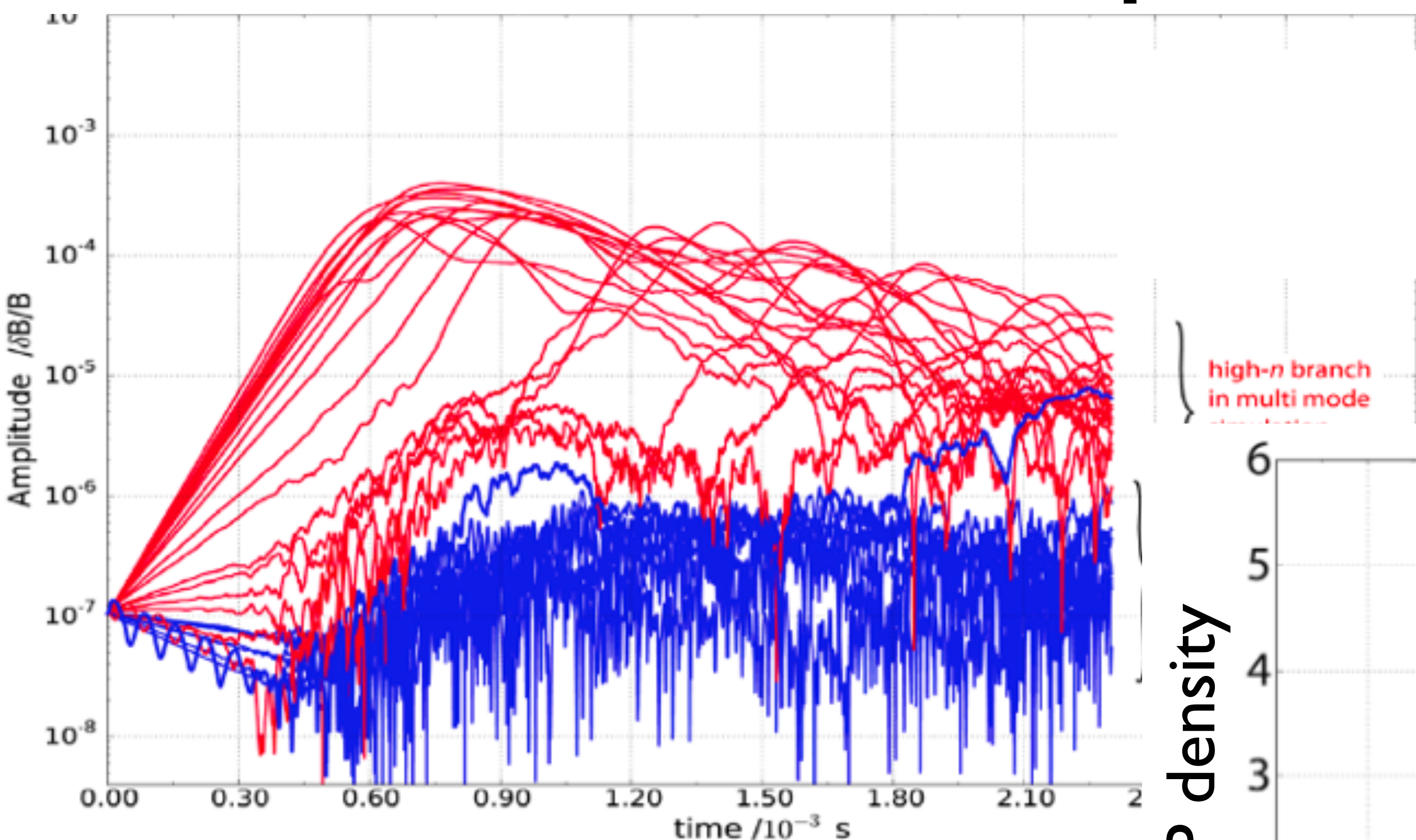
for whole range of mode numbers

global effects crucial, non-perturbative features observed;

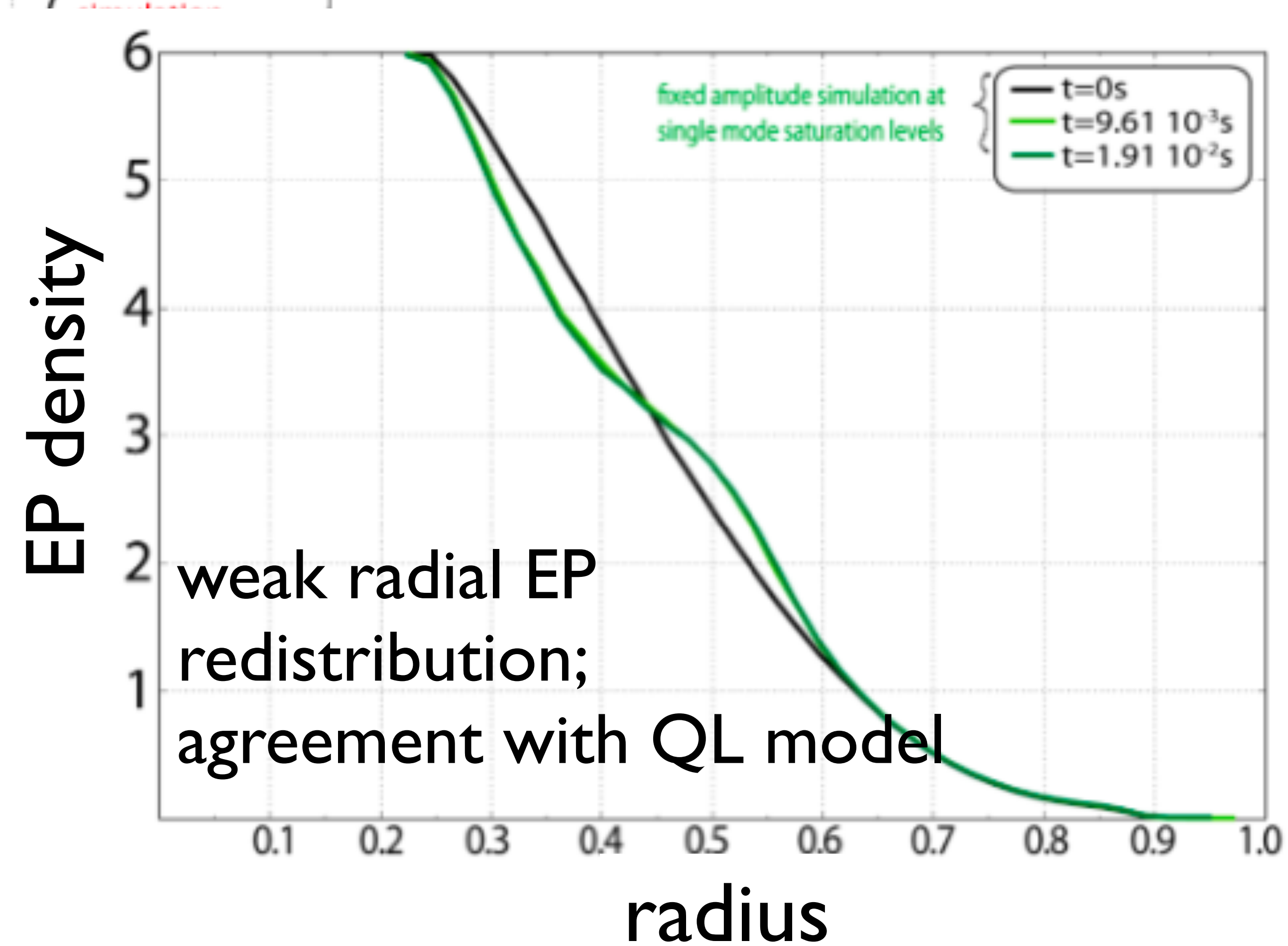
no constant between $A\sim(\gamma/w)^2$

automated HAGIS/LIGKA workflow H2 including FLR/FOW

HAGIS/LIGKA model, ITER 15 MA TAEs [Schneller, 2015]



'sea' of weakly unstable TAEs expected with small EP transport; agreement with QL estimates



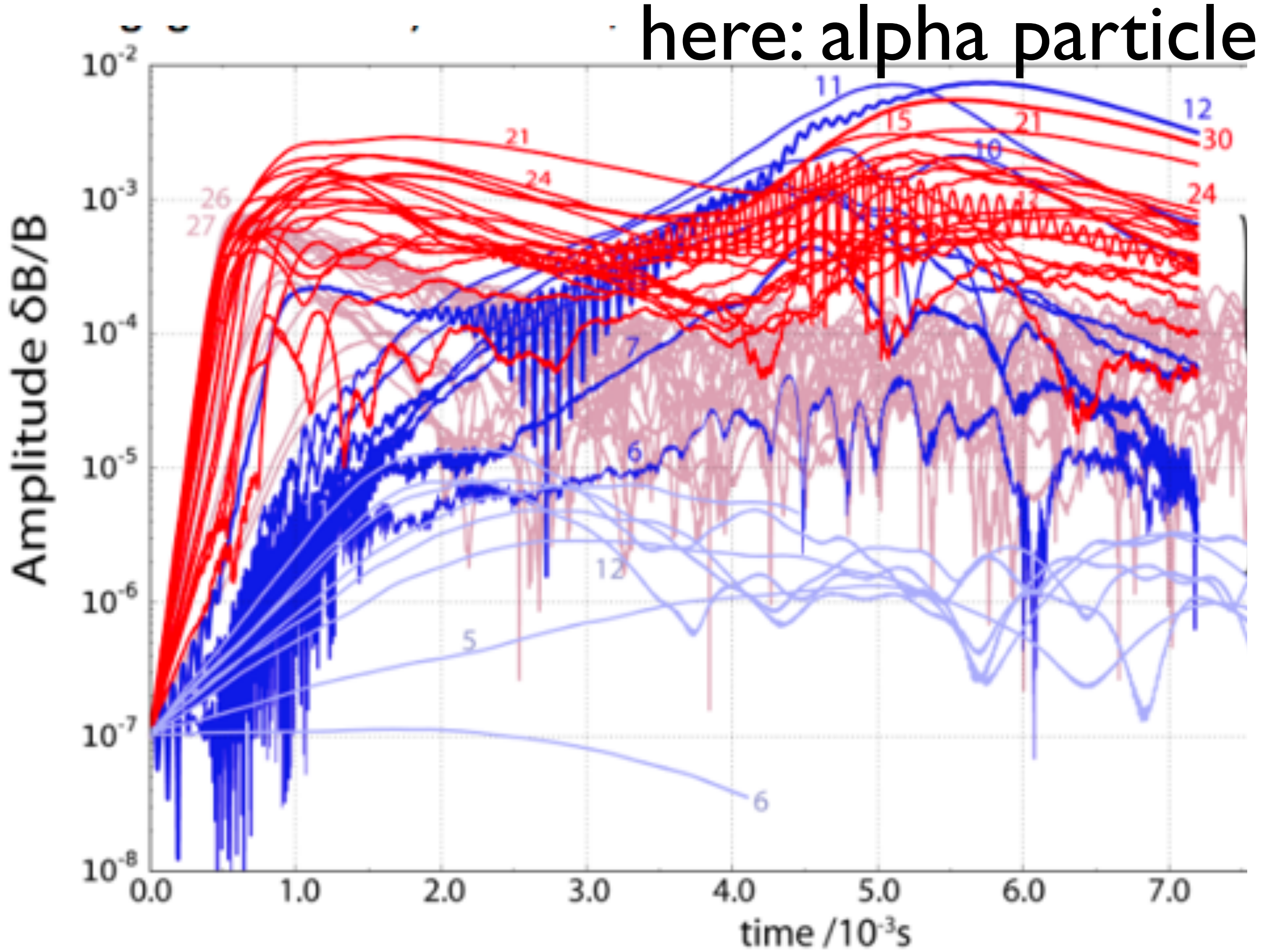
weak radial EP redistribution; agreement with QL model

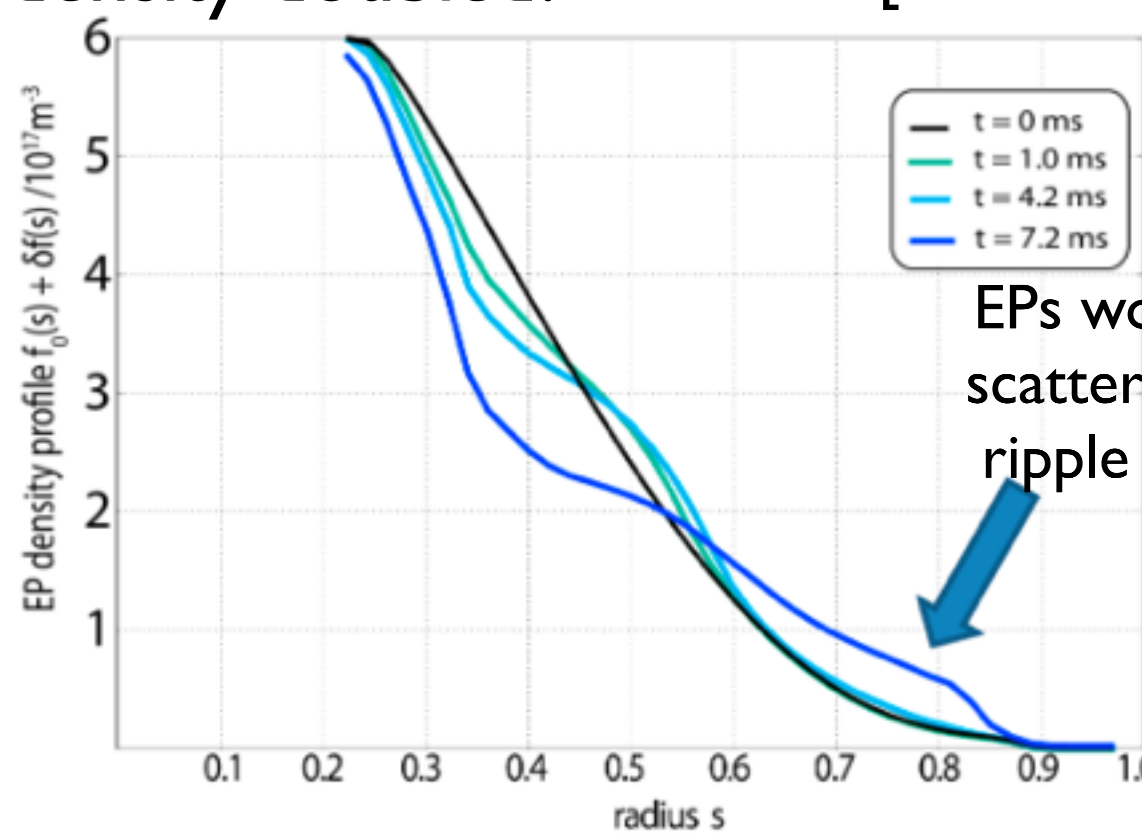
check QL linear resonance broadening models [Berk, 1995]
and reduced descriptions 1d beam plasma model [Carlevaro, 2015-17]

automated HAGIS/LIGKA workflow H2 including FLR/FOW

here: alpha particle density doubled!

[Schneller, 2015]





EPs would be scattered into ripple region

above simulations are 'worst case':
reduced amplitudes found when zonal flow dynamics is included (forced excitation)!
[Todo, 2011, Biancalani, 2016, Vlad 2017]

recently: similar behaviour found using global ORB5 [T. Hayward-Schneider, 2019]
(in contrast to other studies [M. Fiztgerald, 2015] not observing this transition)

the LIGKA model equations

can be evaluated numerically or analytically

$$0 = \sum_a e_a \int \mathrm{d}^2 v \, \{J_0 f\}_a + \nabla_\perp \cdot \frac{m_i n_i \nabla_\perp \phi}{B^2}$$

QN

$$-\frac{\partial}{\partial t}\left[\nabla \cdot \frac{1}{v_A^2} \nabla_\perp \phi\right] + \boldsymbol{B} \cdot \nabla \frac{\nabla \times (\nabla \times (\frac{\nabla \psi}{i\omega})_\parallel \boldsymbol{b})}{B} + (\boldsymbol{b} \times \nabla (\frac{\nabla \psi}{i\omega})_\parallel \boldsymbol{b}) \cdot \nabla \frac{\mu_0 j_\parallel}{B}$$

$$= -\sum_a \mu_0 \int \mathrm{d}^2 v \, e_a \{\boldsymbol{v}_\mathrm{d} \cdot \nabla J_0 f\}_a + \sum_a \left[\boldsymbol{b} \times \nabla \left(\frac{\beta_{a\perp}}{2\Omega_a}\right)\right] \cdot \nabla \nabla_\perp^2 \phi$$

$$+ \sum_a \frac{3 v_{th,a}^2}{8 v_A^2 \Omega_a^2} \nabla_\perp^4 \frac{\partial \phi}{\partial t} + \boldsymbol{B} \cdot \nabla \frac{1}{B} \sum_a \frac{\beta_a}{4} \nabla_\perp^2 (\frac{\nabla \psi}{i\omega})_\parallel \boldsymbol{b}$$

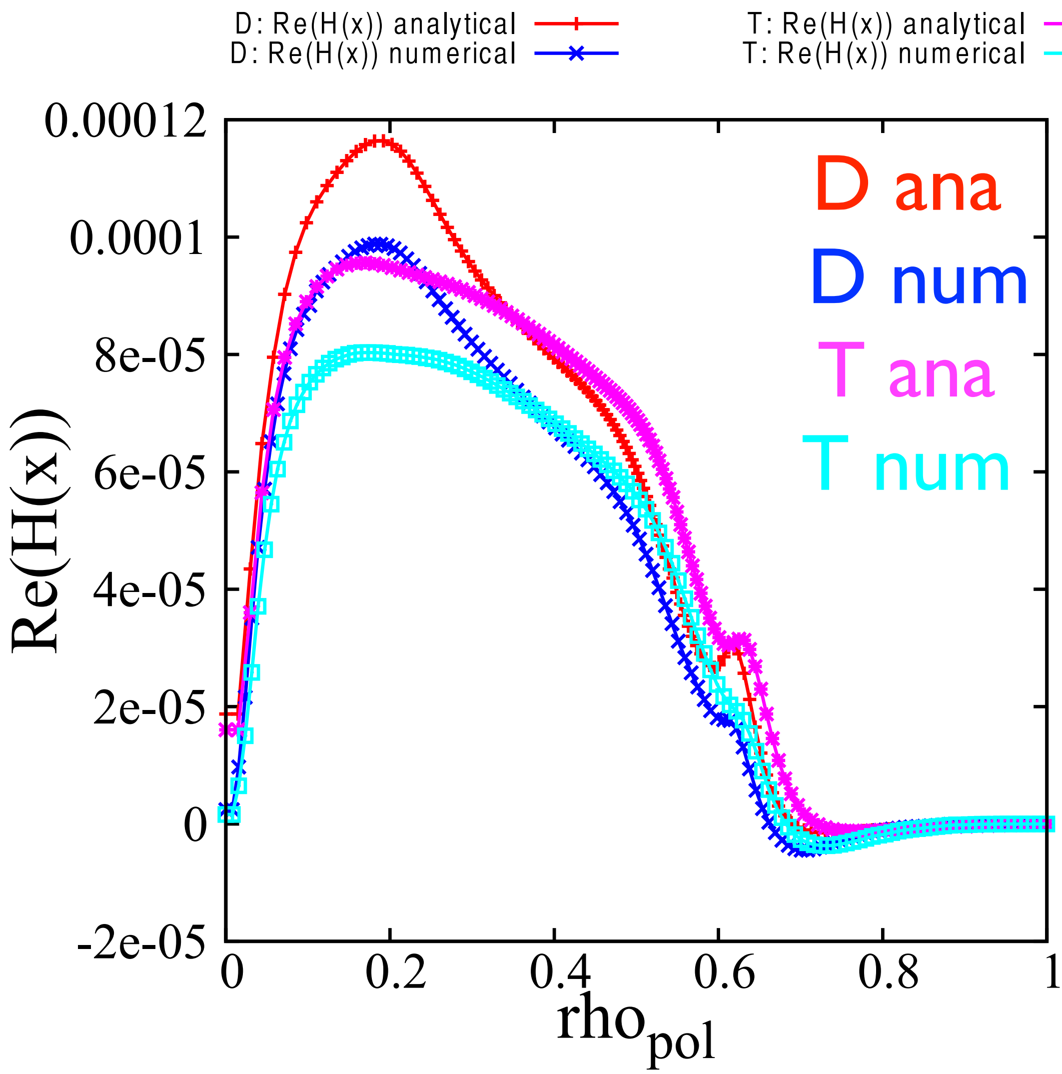
GKM

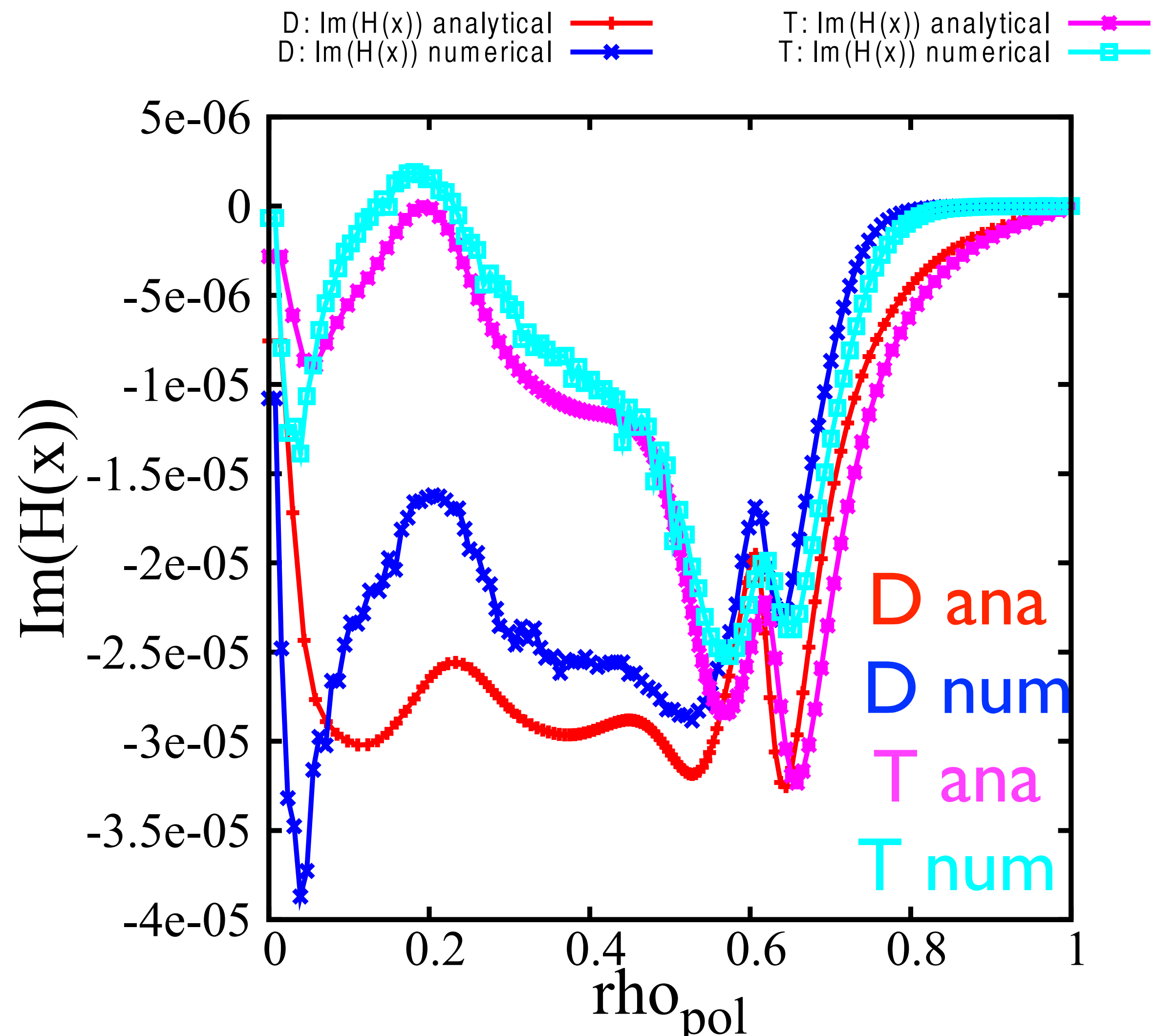
$$\hat{h} = ie \sum_m \int_{-\infty}^{t} dt' e^{i[n(\varphi'-\varphi) - m(\theta'-\theta) - \omega(t'-t)]} e^{-im\theta}$$
$$\frac{\partial F_0}{\partial E} [\omega - \omega_*] J_0(k_\perp \varrho_i) \left[\phi_m(r') - (1 - \frac{\omega_d(r', \theta')}{\omega}) \psi_m(r')\right]$$

GKE

$$f = h + H_1 \frac{\partial F_0}{\partial E} - [e \frac{\partial F_0}{\partial E} - \frac{c \nabla F_0}{i\omega B} \cdot (\mathbf{b} \times \nabla)] J_0 \psi,$$

comparison analytical theory - numerical integration; can be calculated including FLR/FOW effects (100 times faster!)





- similar dependence for analytical expression vs numerical result
- D and T damping differ - exponential dependence of ion LD!
- numerical damping is typically smaller than analytical expression (assumption $v=v_{//}$)

$v_{th,e}/v_{A0}$	~ 13
$v_{th,D}/v_{A0}$	~ 0.2
$v_{th,T}/v_{A0}$	~ 0.16
$v_{th,He}/v_{A0}$	~ 0.14
$v_{th,Be}/v_{A0}$	~ 0.09