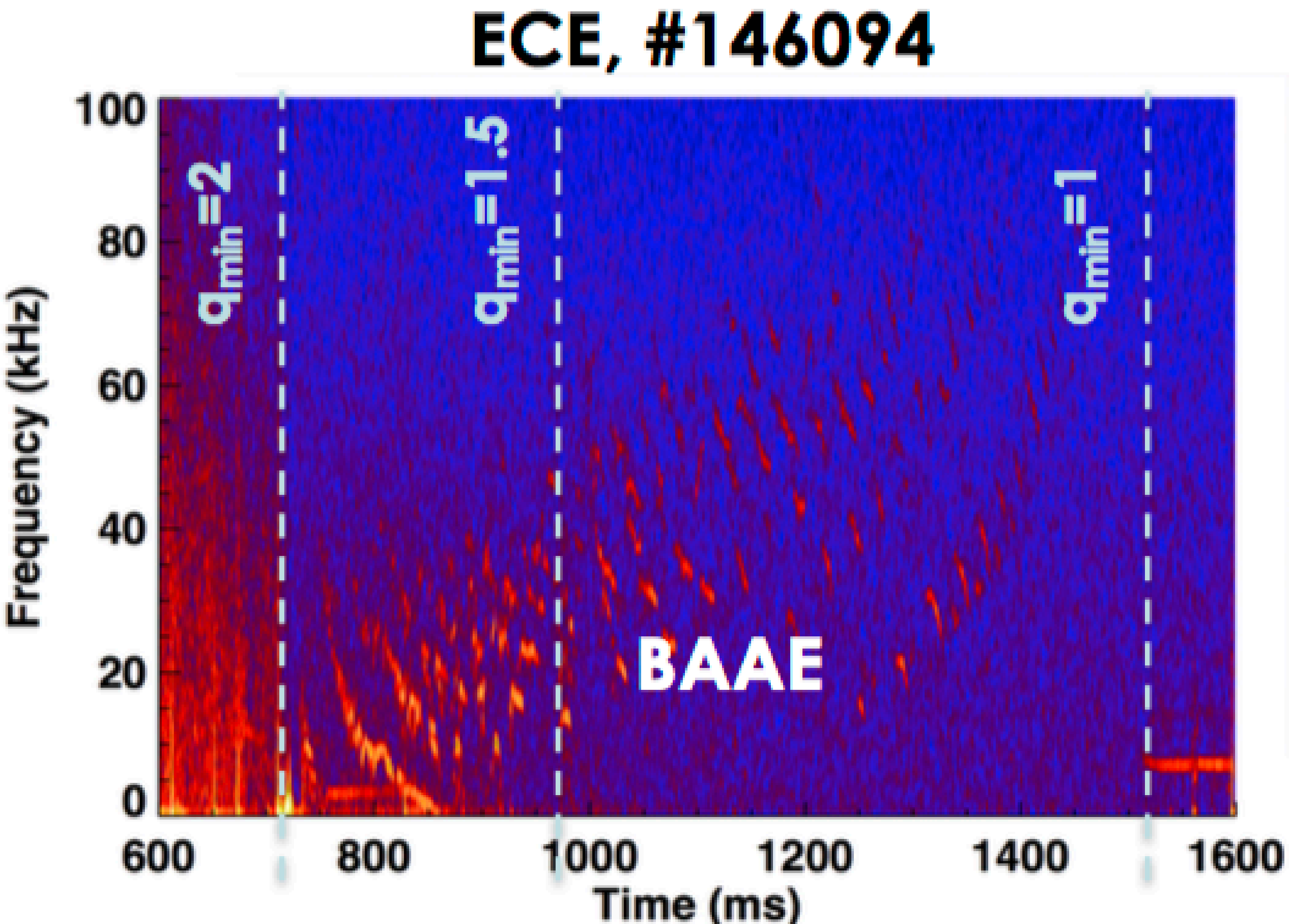
Low frequency EP driven modes in the BAE and BAAE frequency regime: DIII-D case
ITPA EP, Lisbon , September 2018

Ph. Lauber, IPP Garching
Z. Lu, X Wang, T. Hayward-Schneider

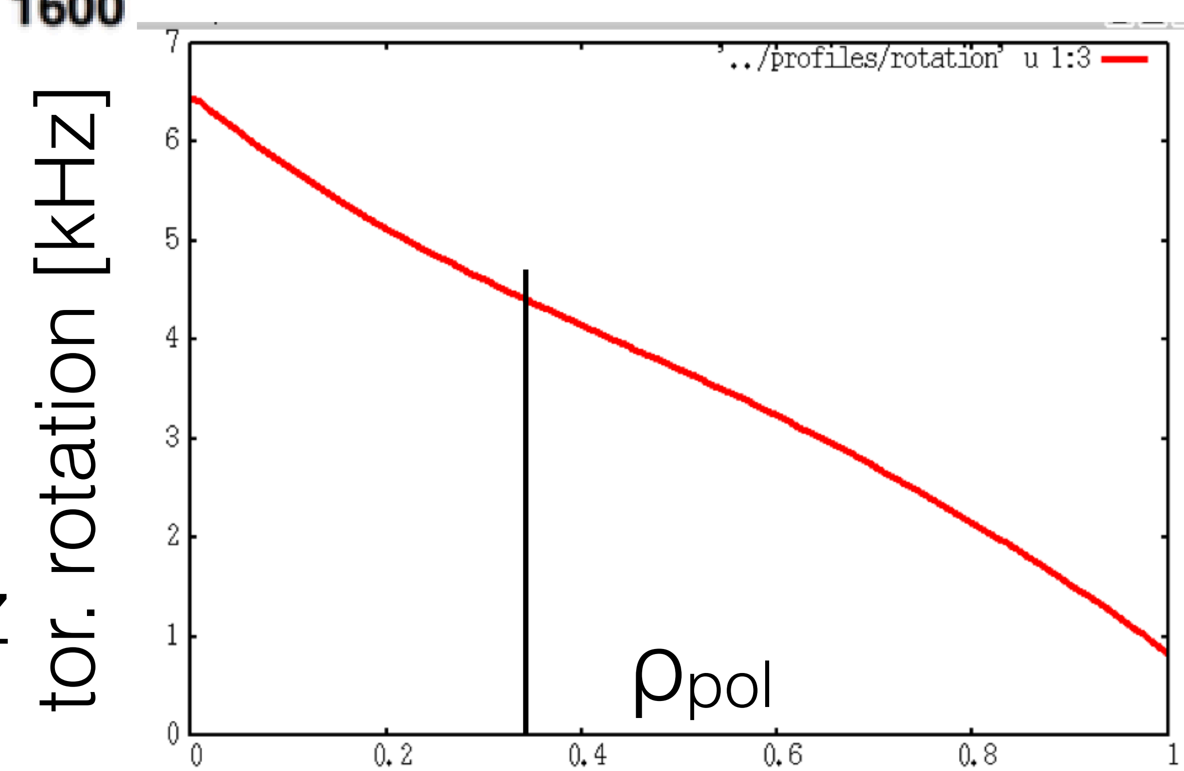
aim:

- local analysis: diamagnetic effects, multi-species, EPs
- global analysis:linear properties, polarisation
- discussion on benchmarks for ITER

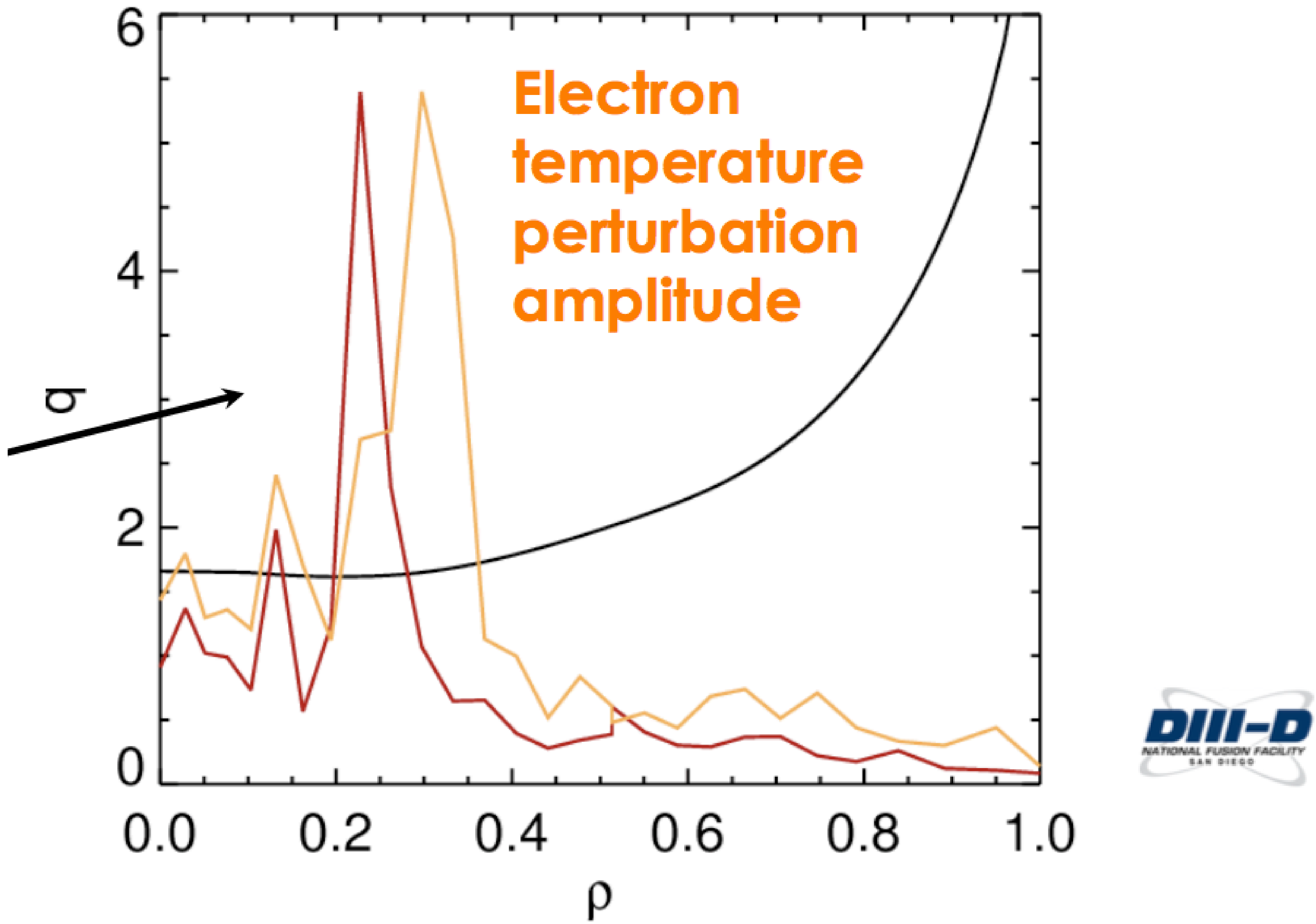
thanks to M. VanZeeland, D.Pace



- Discharge has clear BAAE activity – similar to previous cases
- Few observable RSAE in time range of interest

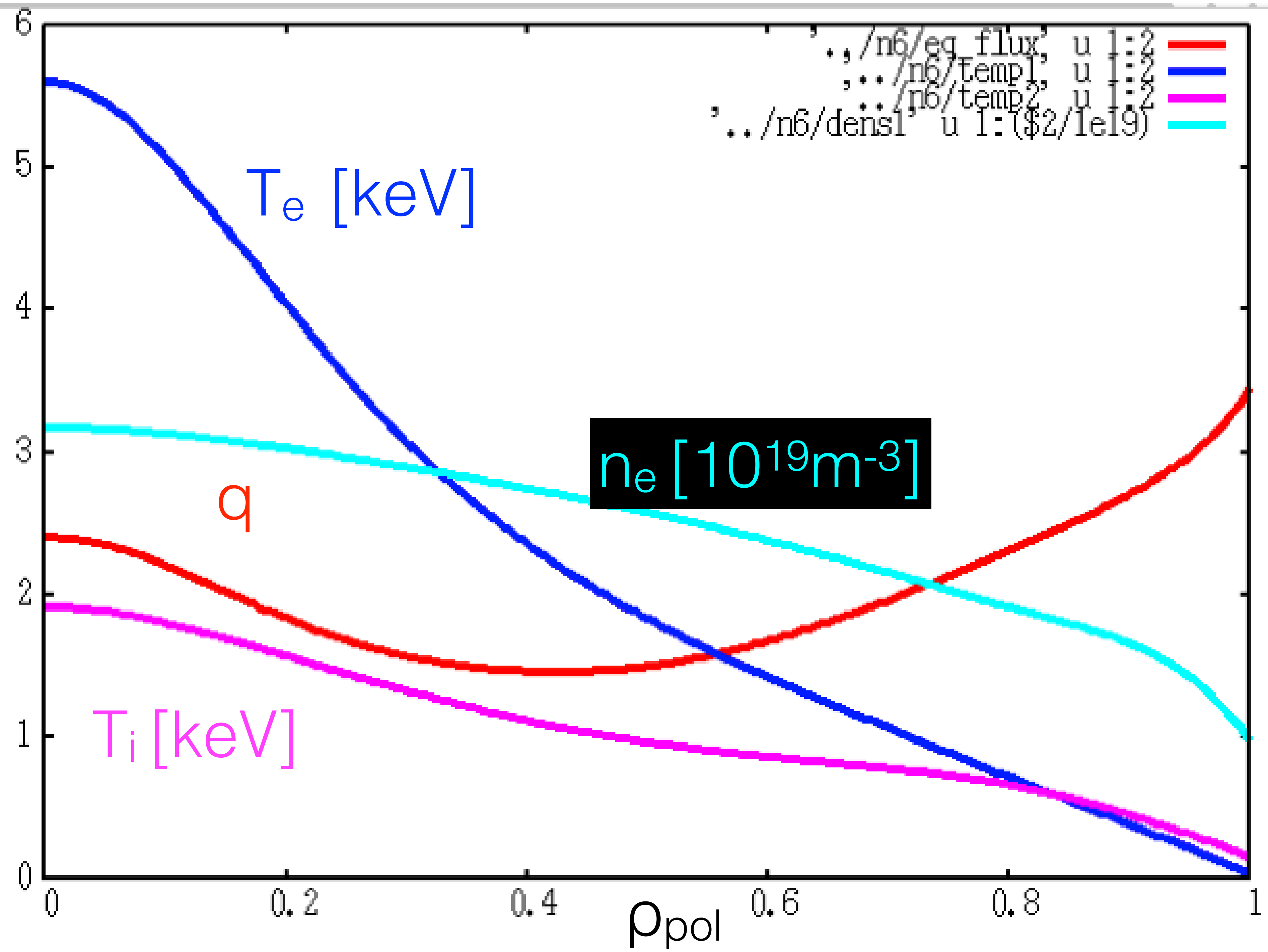


for n=6: subtract 6*4.5kHz=27kHz at rational surface nq-m=6*1.5-9 thanks to M. VanZeeland, D.Pace



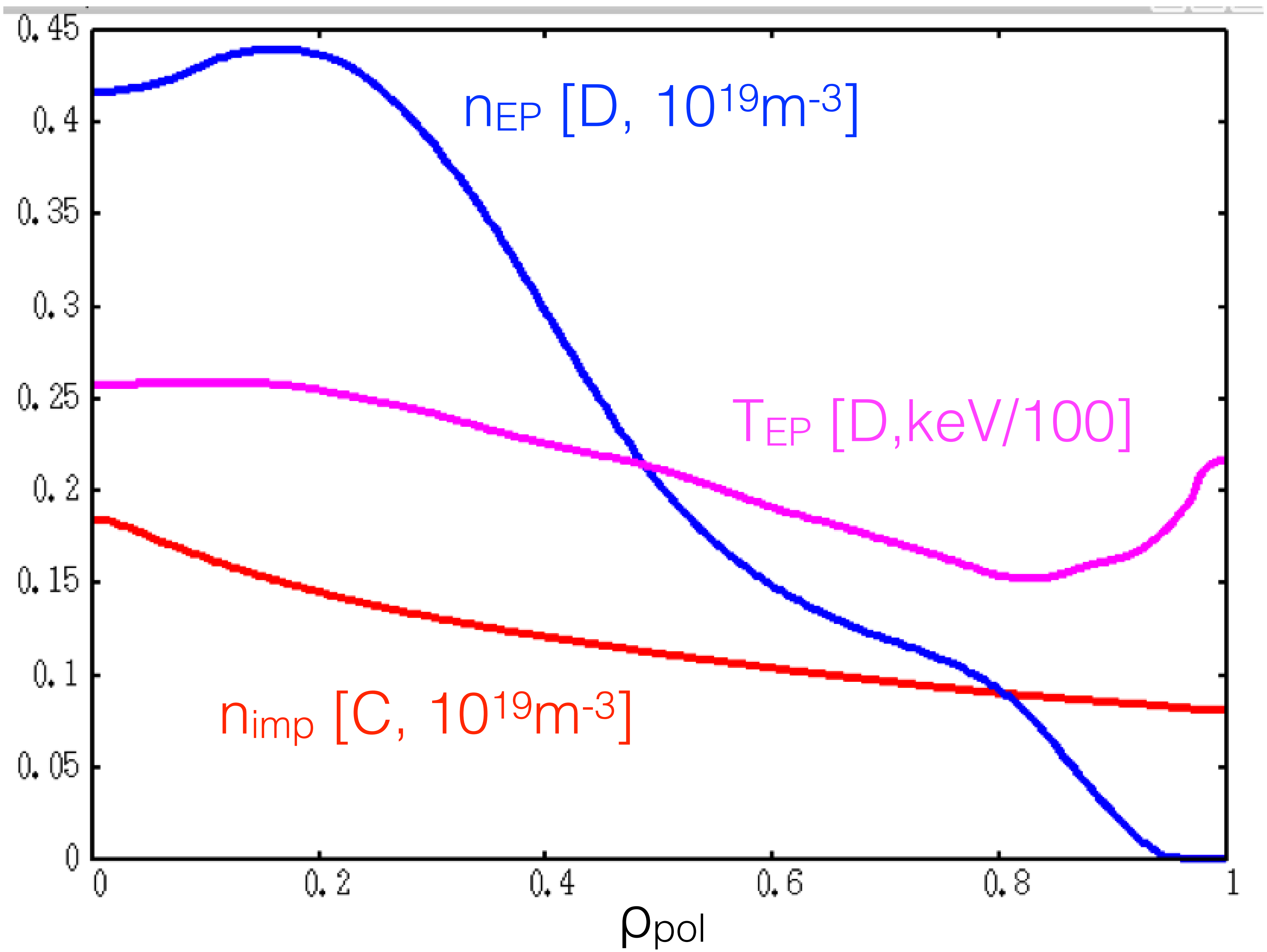
f_{mode}~10kHz

profiles: [M VanZeeland, D. Spong]



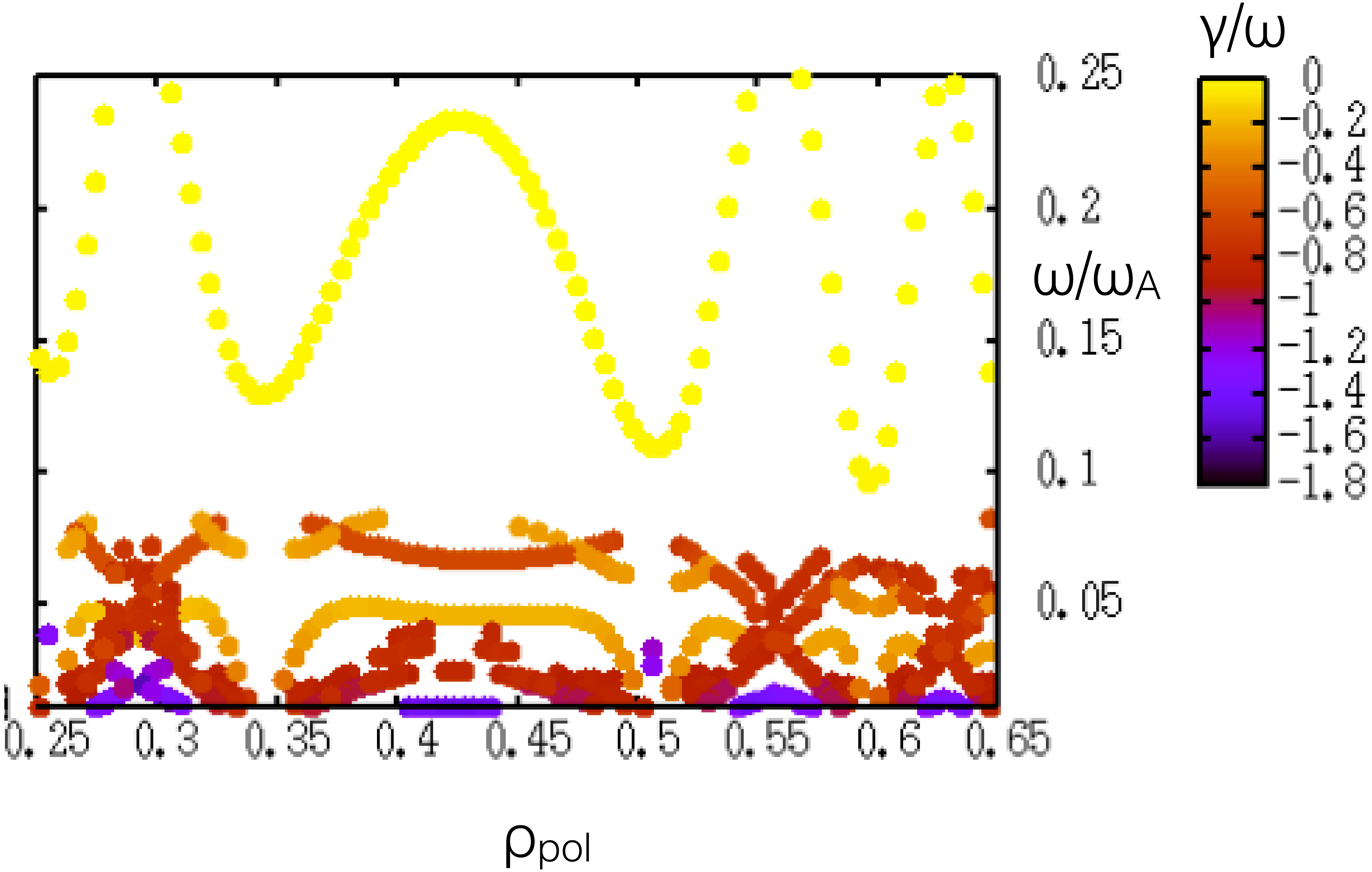
f_{A0}=516kHz

profiles: [M VanZeeland, D. Spong]

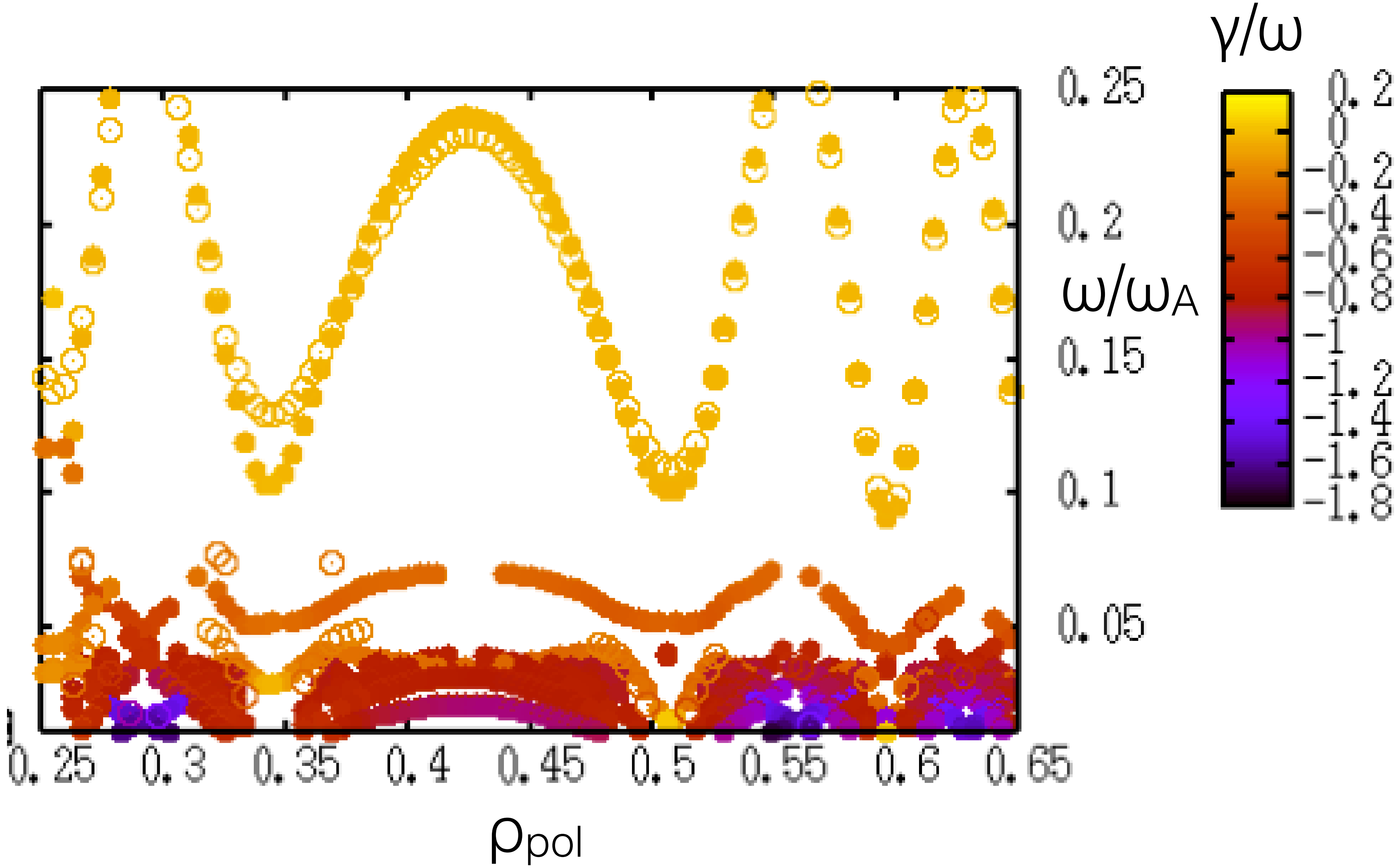


Kinetic continuum: n=6, 2 species (el,D), no ω*, no EPs

[LIGKA, Lauber PLREP 2013, Bierwage&Lauber 2017]

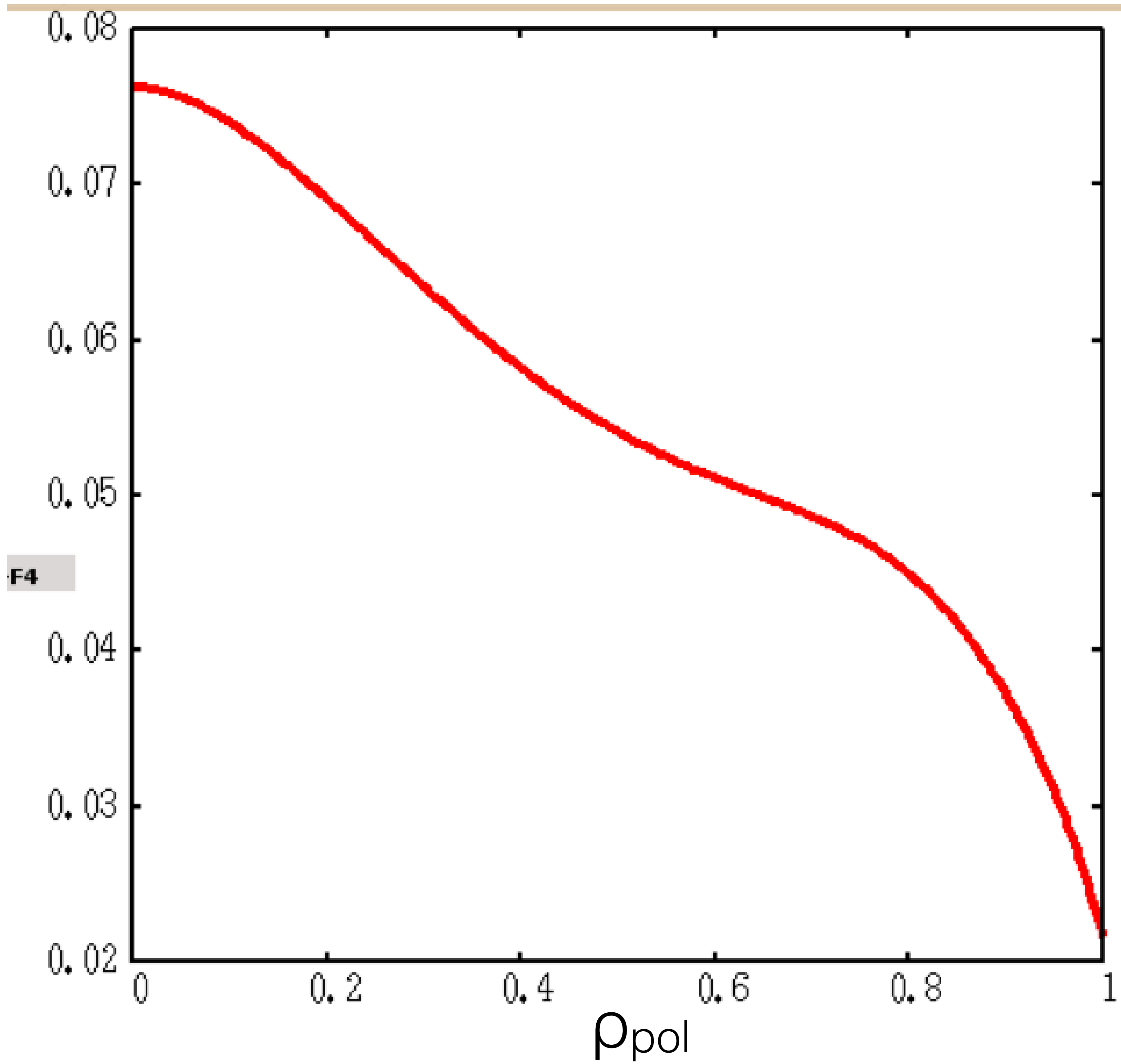


Kinetic continuum: n=6, 2 species (el,D), with (●) and without (○) ω*, no EPs

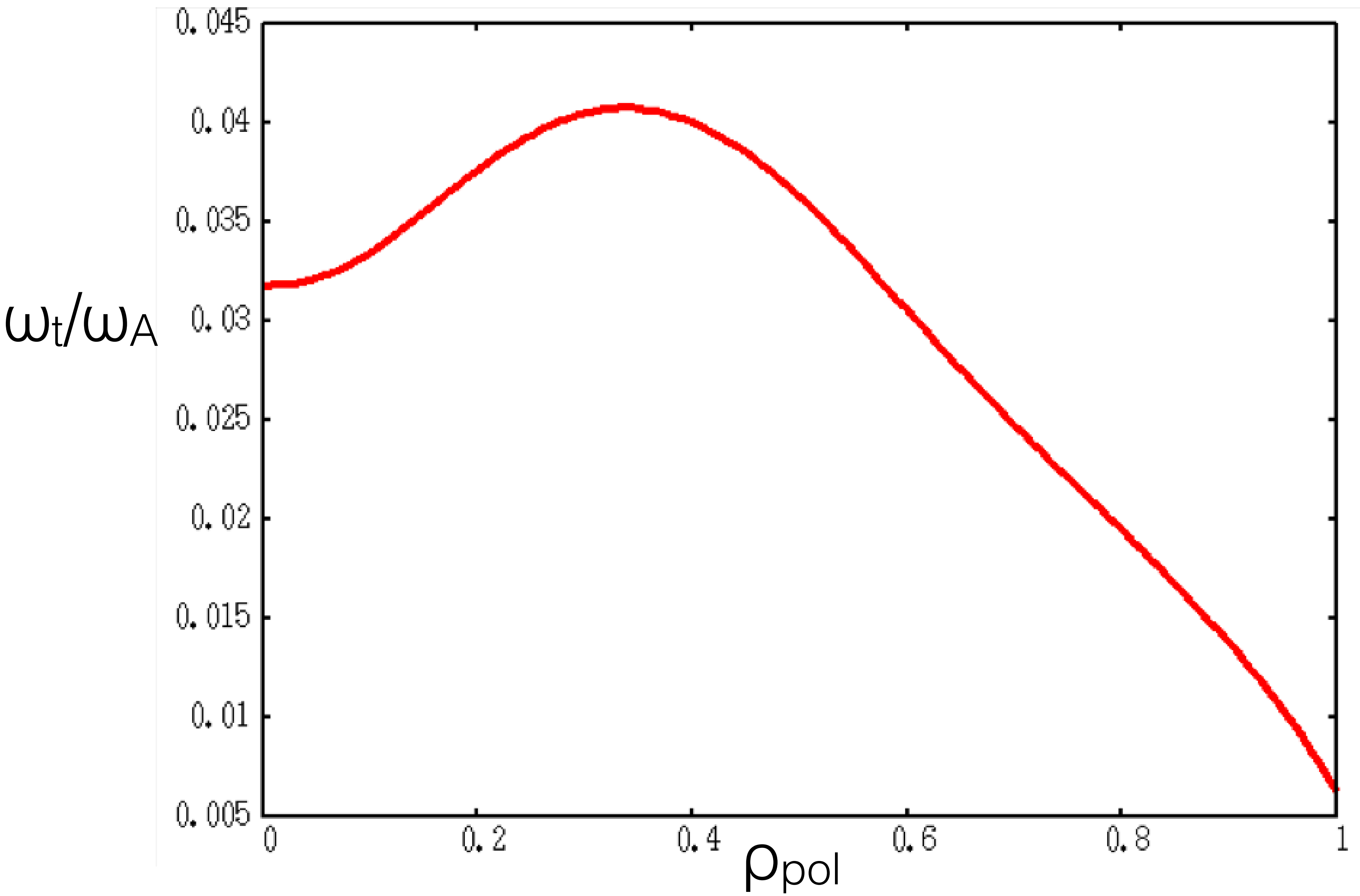


usual upshift of RSAE/TAE,
downshift of BAE accumulation points

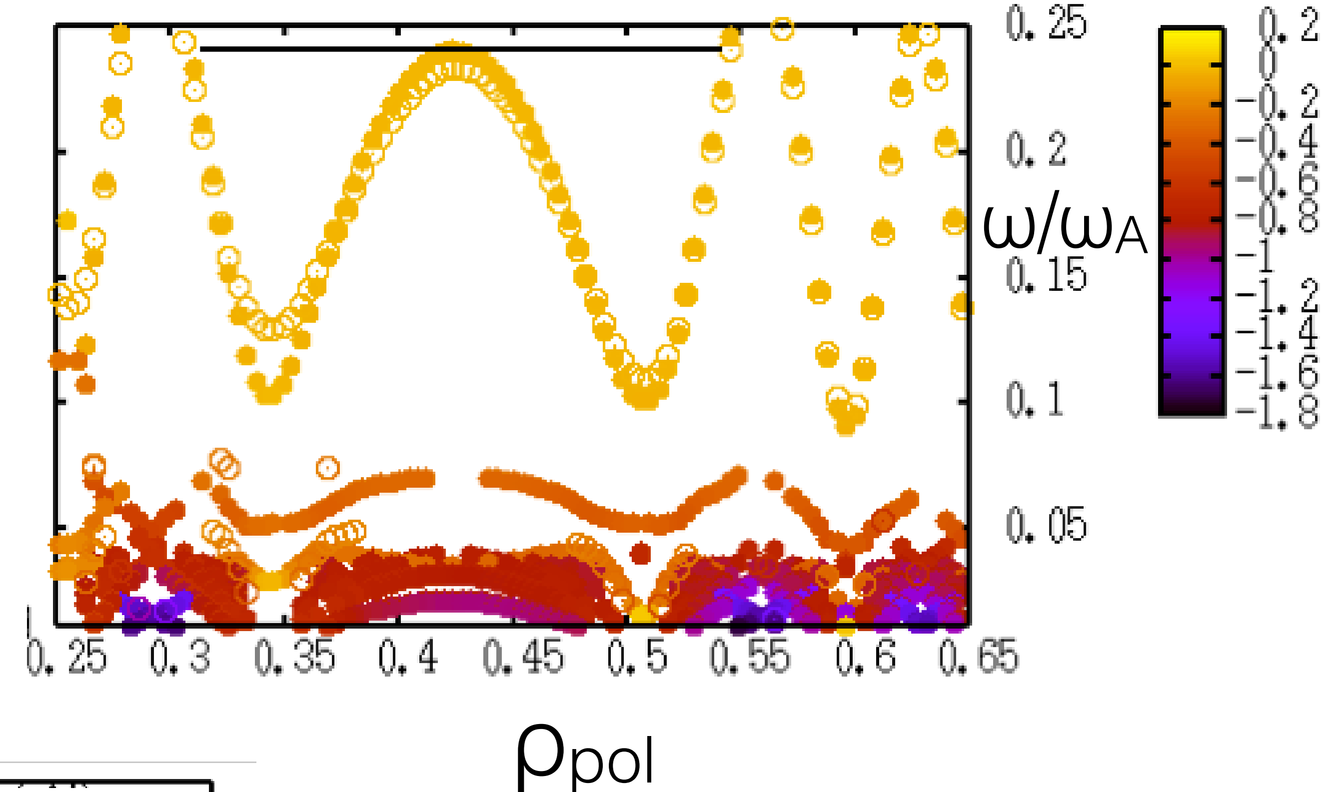
thermal ion sound frequency: $(v_{th}/R)/\omega_A$

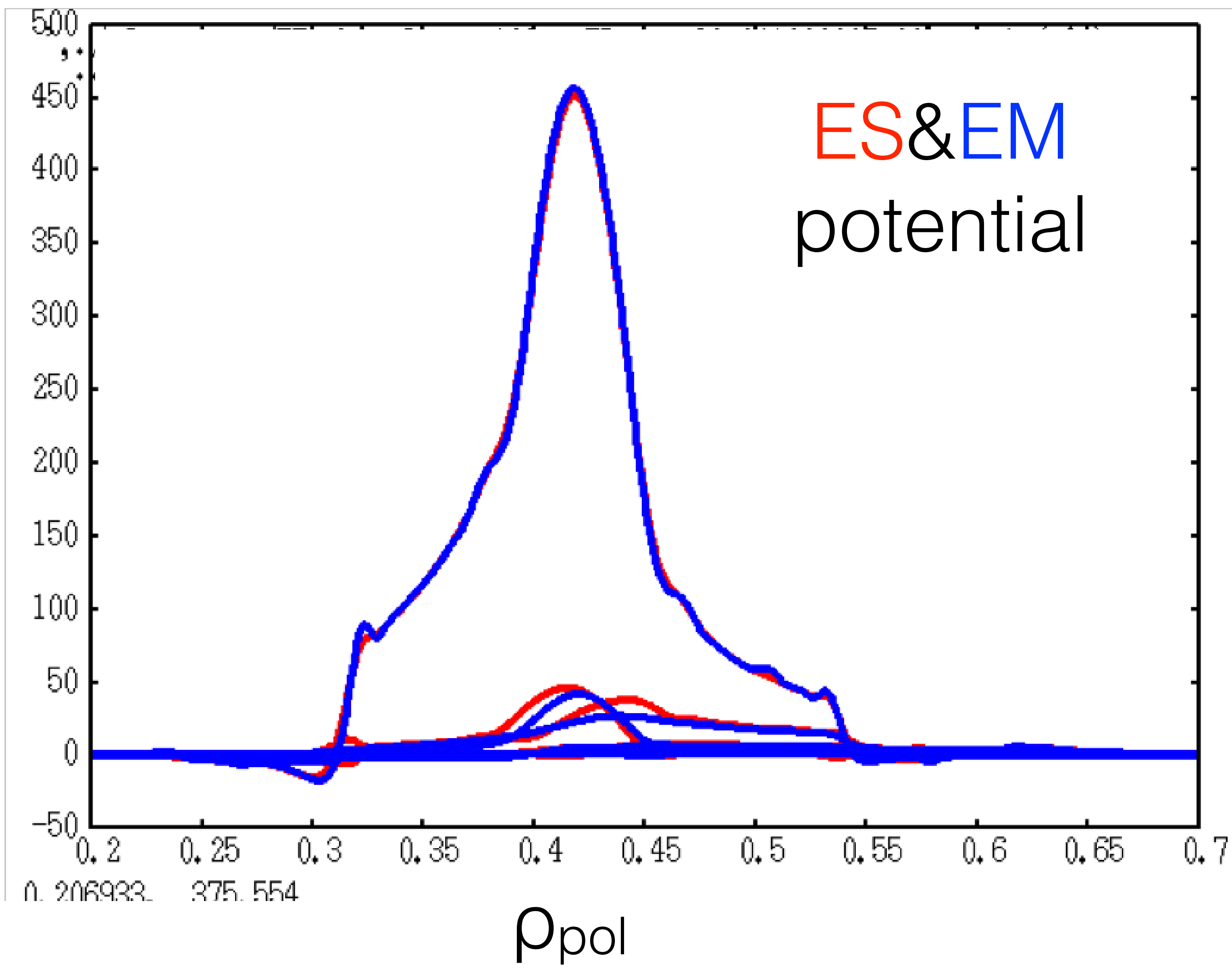


themal ion transit frequency: $(v_{th}/(qR))/\omega_A$



for reference: n=6 RSAE





RSAE: 0.241 ω_A

f=124kHz+rot

damping: -3.9%

(2 species,with ω*, no EPs)

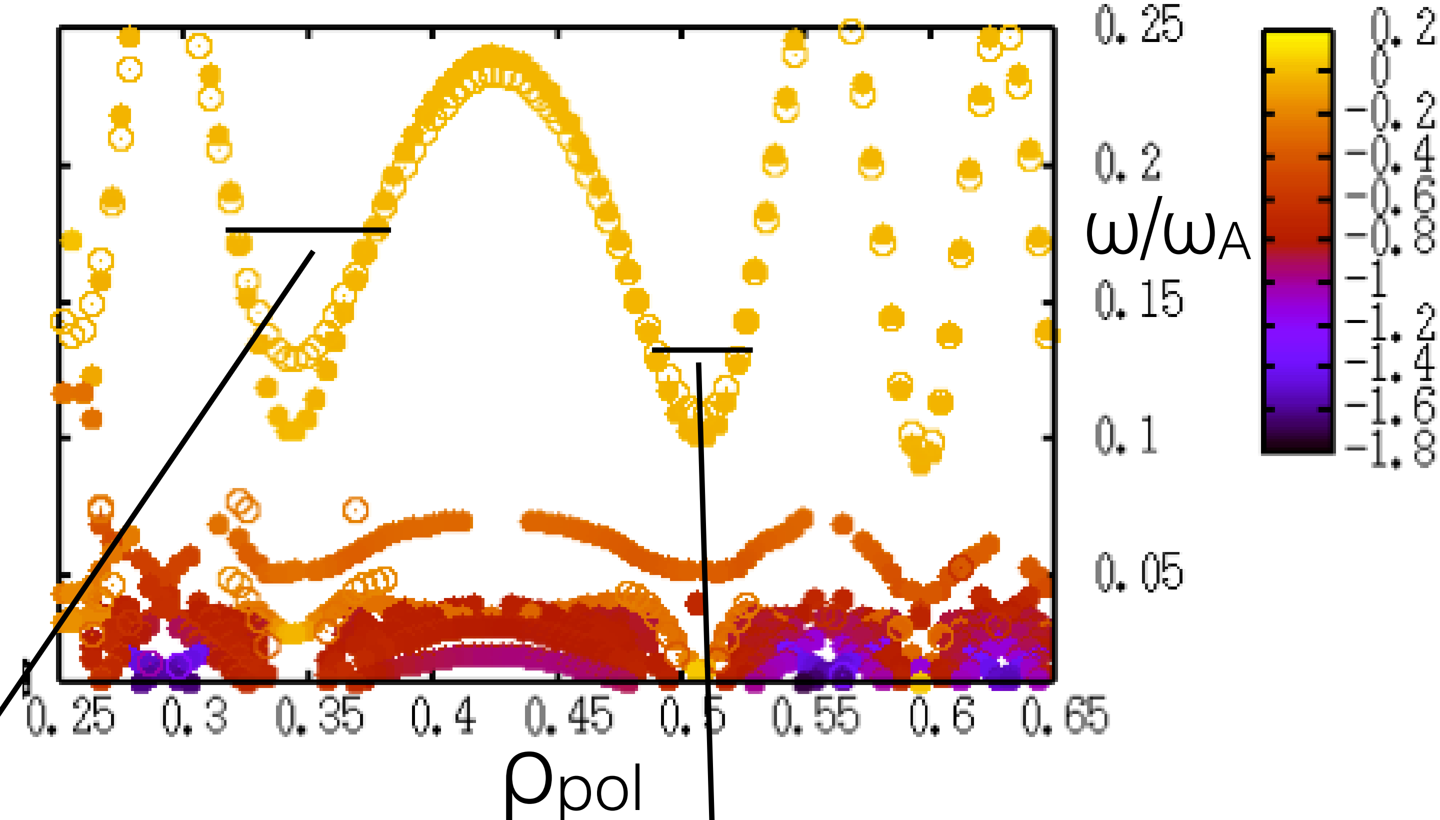
with C impurity:

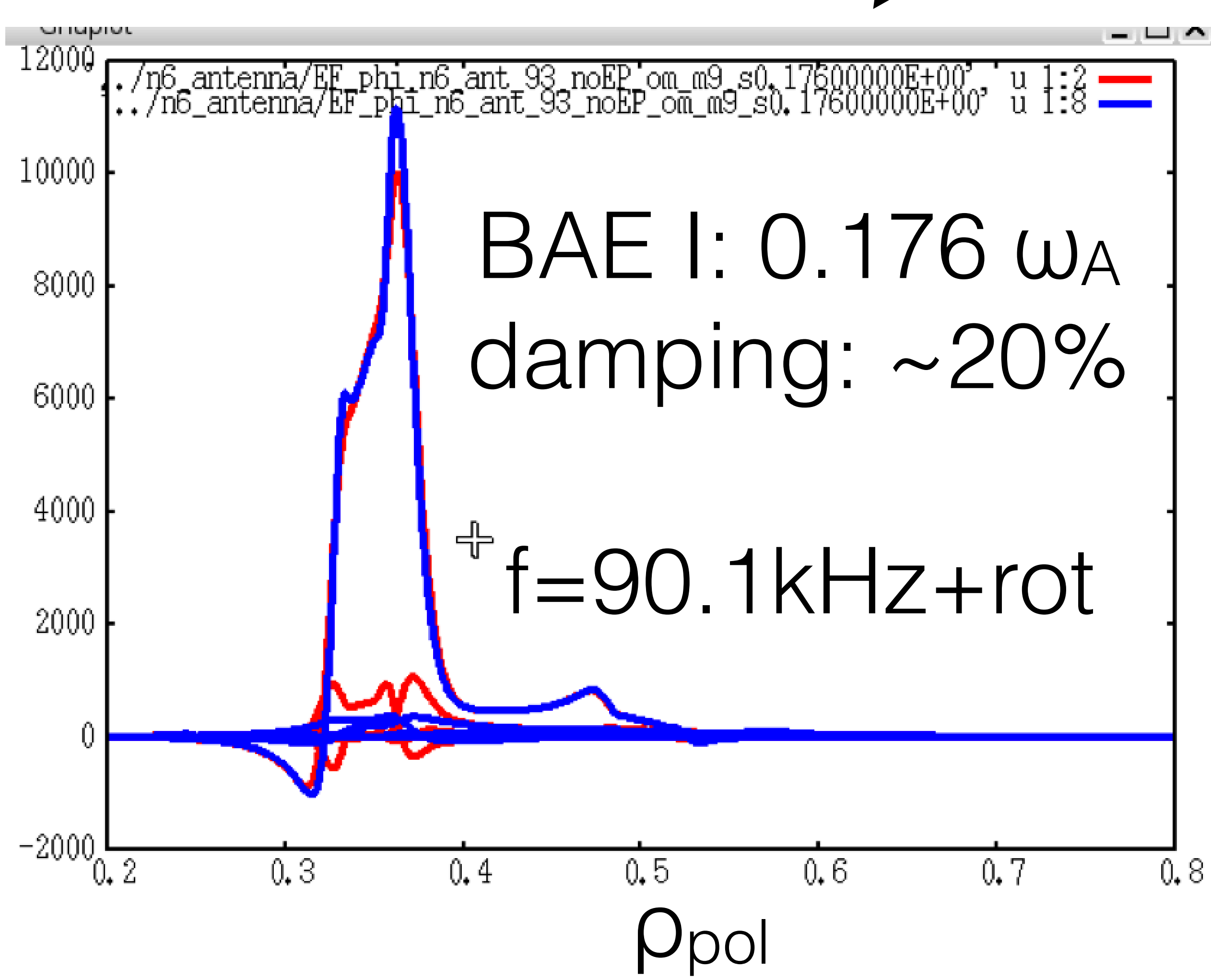
RSAE: 0.231 ω_A

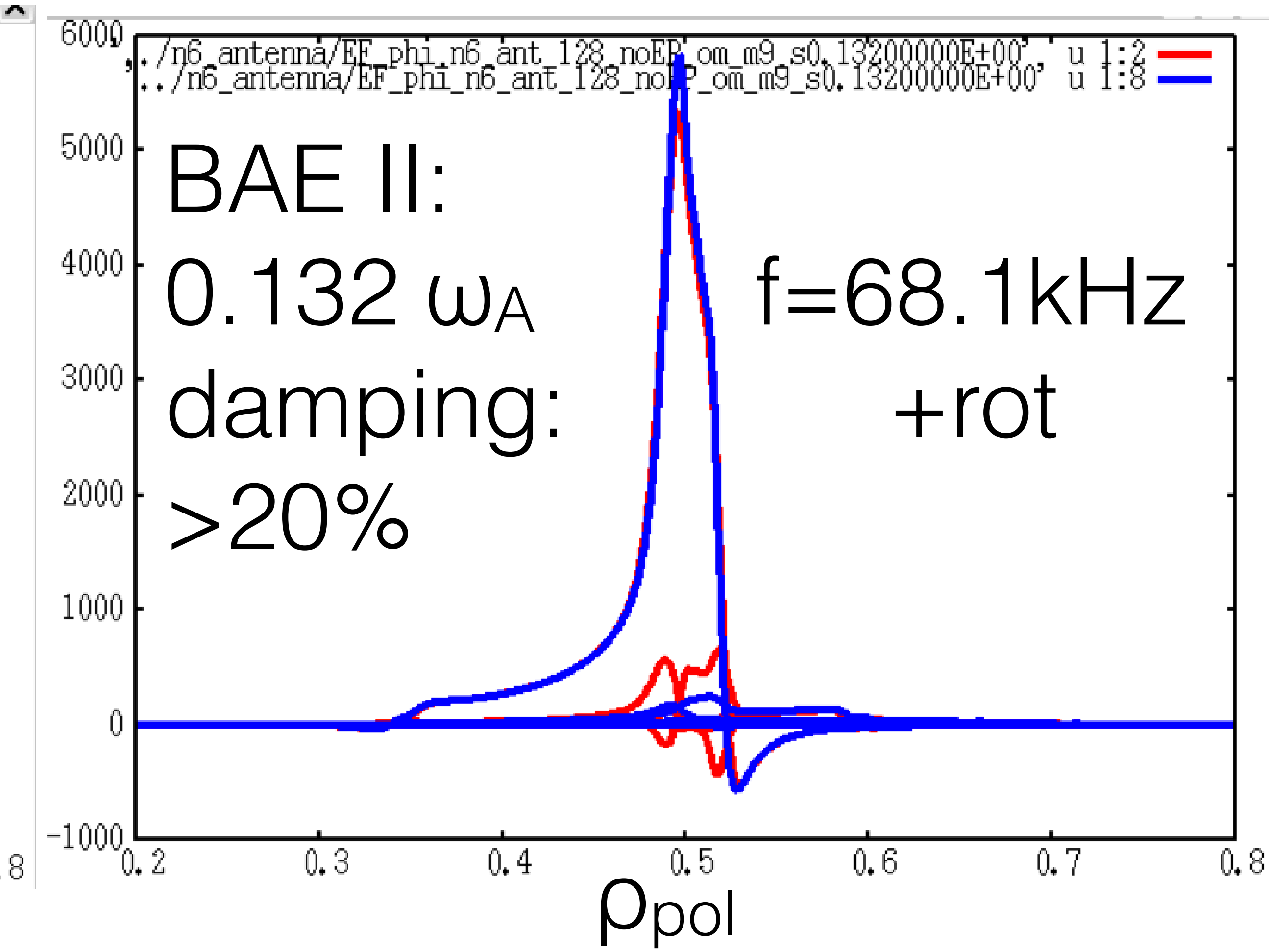
damping: -5%

(no mode structure chances)

for reference: n=6 BAEs



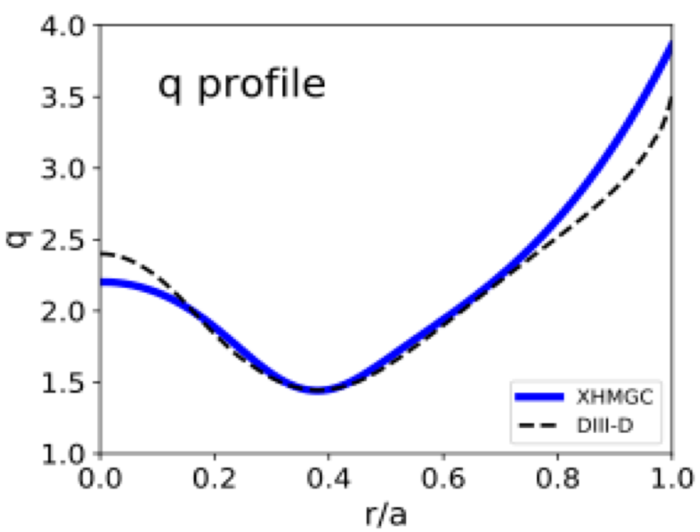




[see talk Xin. Wang]

Updates of XHMGC results to the BAE/BAAE benchmark activity

XHMGC Inputs



Parameters/simplifications:

(1) $q_{min} = 1.44$

(2) Inverse aspect ratio $\epsilon = 0.1$

(3) Shifted circular surfaces

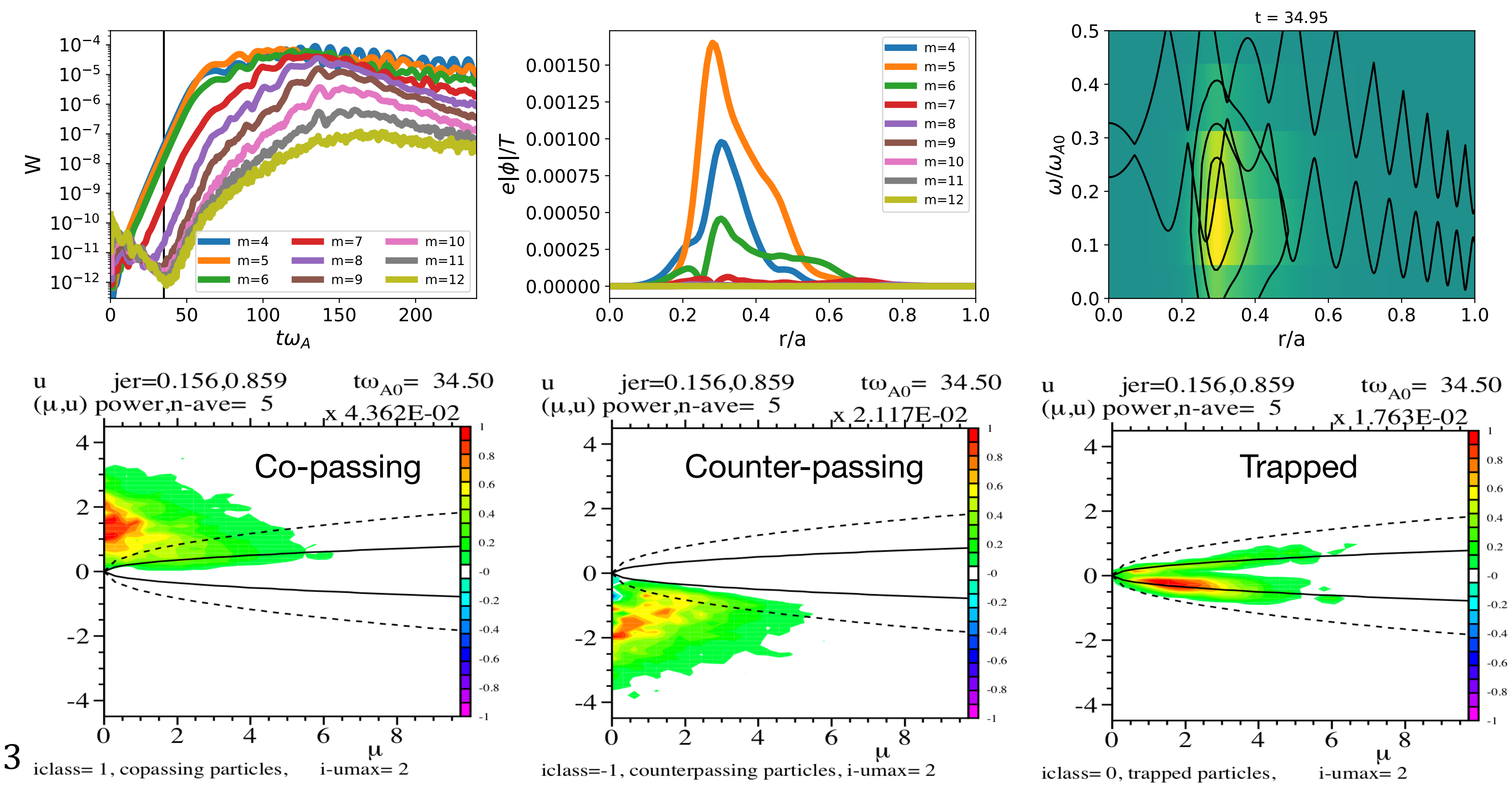
(4) $\frac{n_{H0}}{n_{th0}} = 0.1$

(5) single toroidal mode number $n = 3$

(6) Isotropic Maxwellian distribution

(7) EP contribution is limited in the range from 0.1 to 0.85 of r/a

XHMGC Results



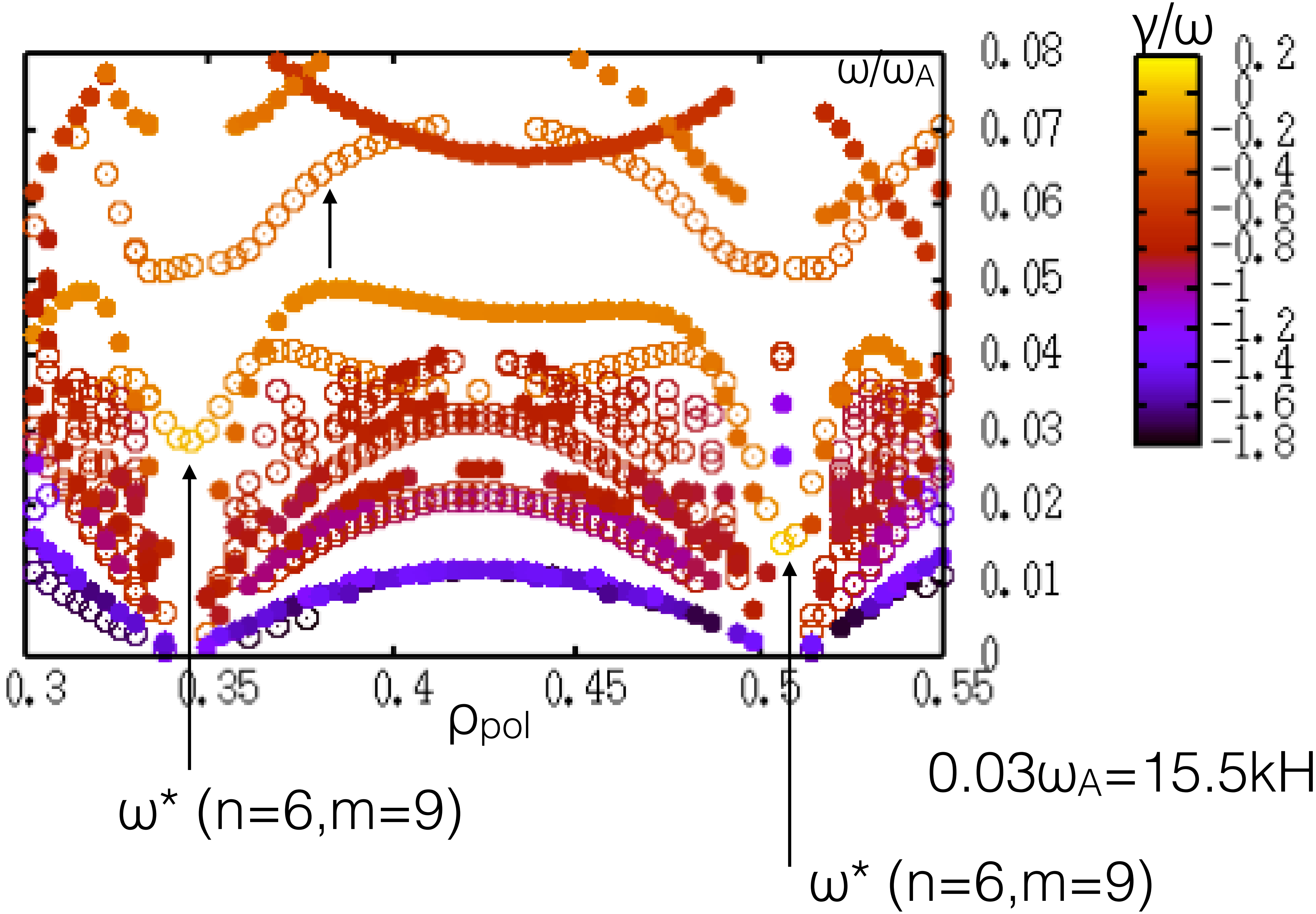
(1) The dominant mode is m = 5.

(2) Mode frequency is $\omega{\sim}0.125$, where $\omega_{BAE}{\sim}0.10$

(3) The resonant structures in phase space for co-passing, counter-passing and trapped particles are shown, the dominant species are co-passing particles.

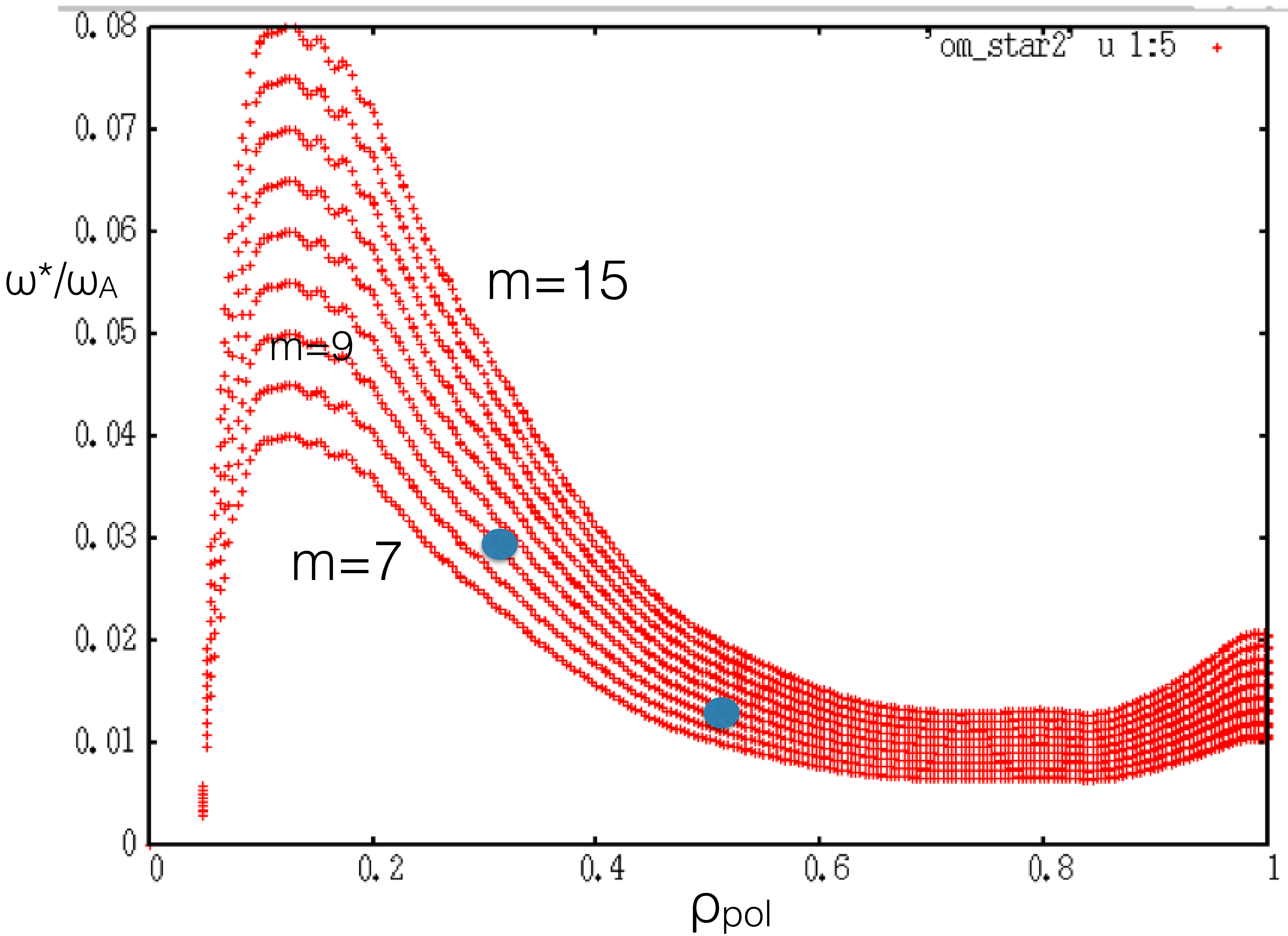
note: here n=3… comparison to be done, but similar features of BAE found: localisation, upshift wrt BAE accumulation point…

Kinetic continuum: n=6 (low frequency part), 2 species (el,D), without (●) and with (○) ω*, no EPs

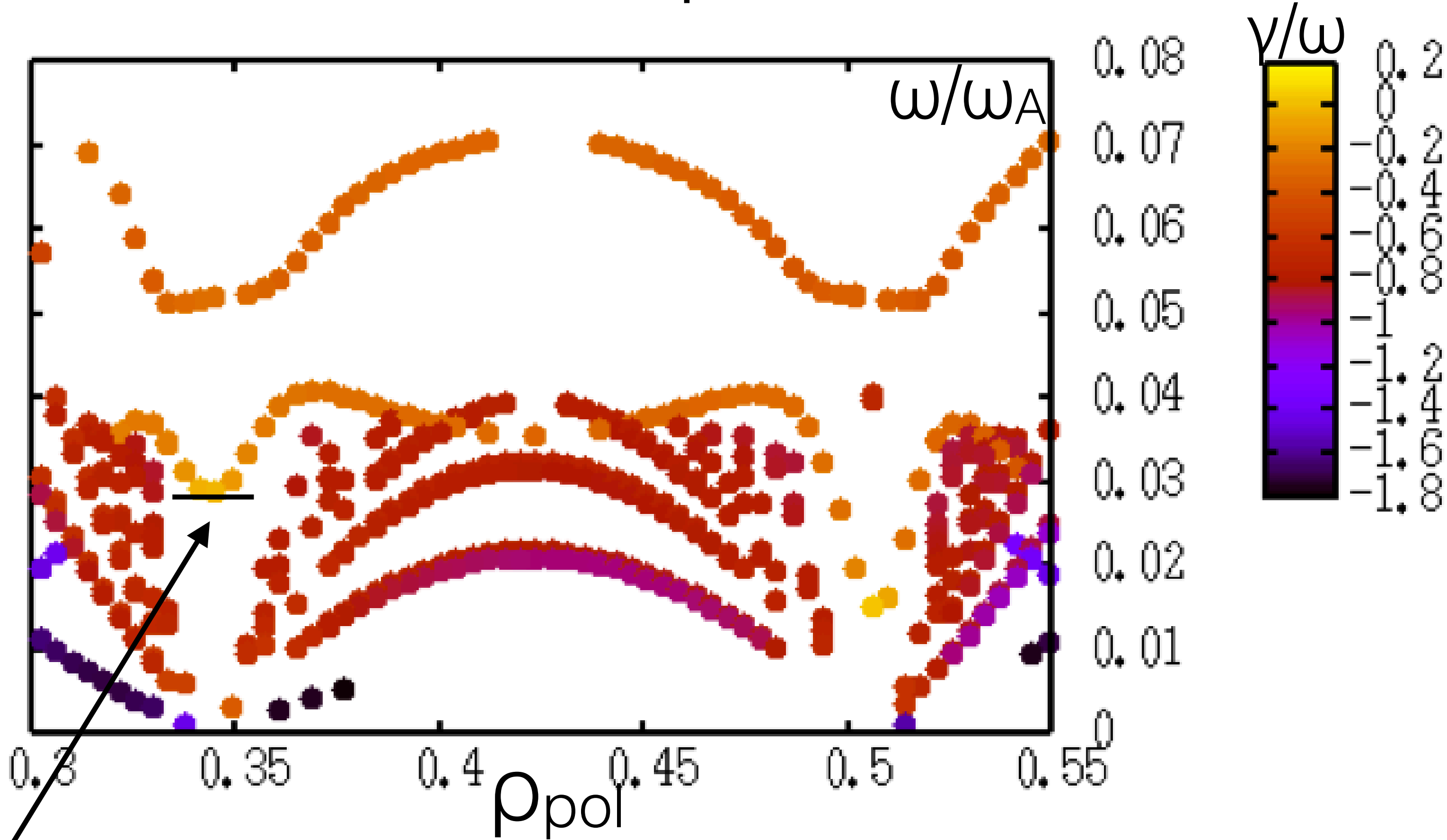


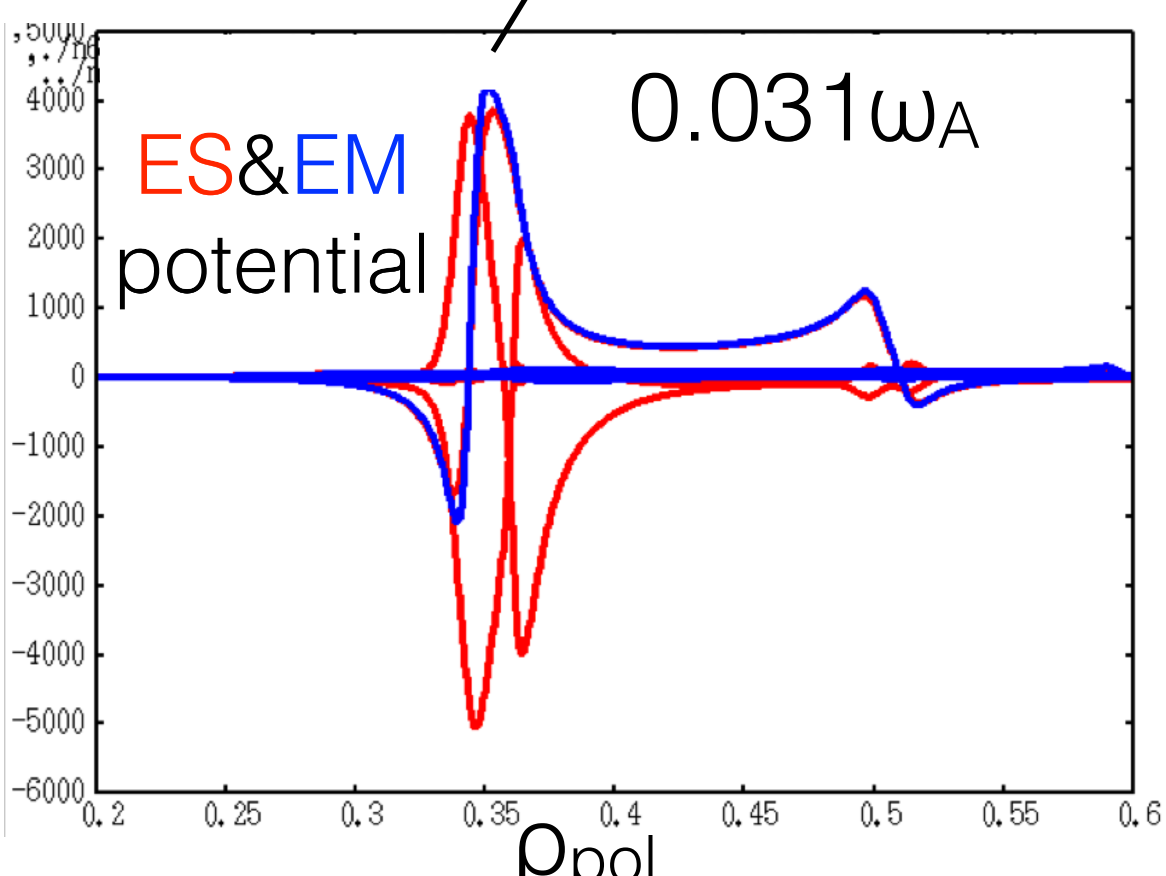
$0.03\omega_A = 15.5 kHz$

diamagnetic frequency $\omega^* = \omega_n^*(1+\eta)$



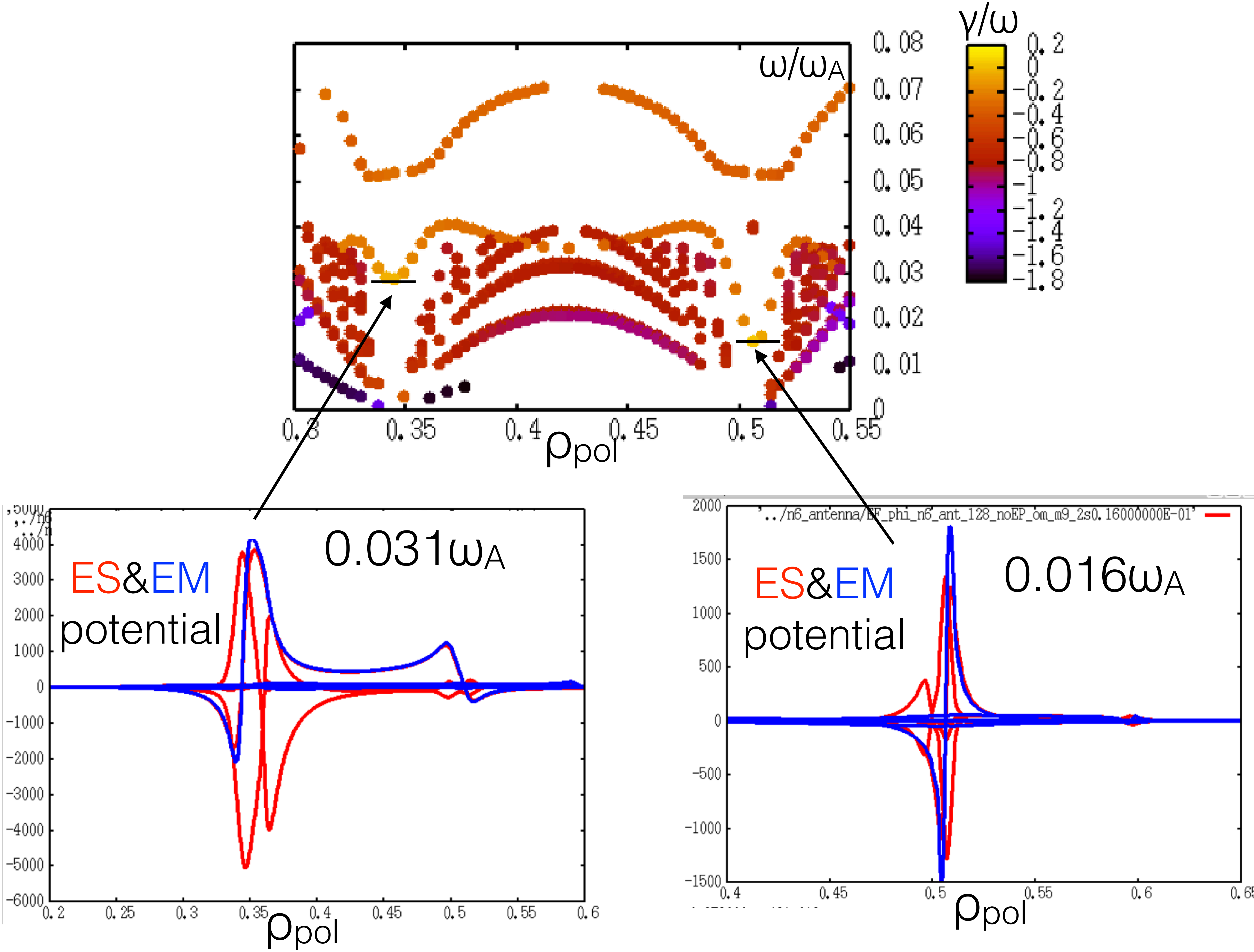
global antenna solutions: 2 species, with ω*, no EPs



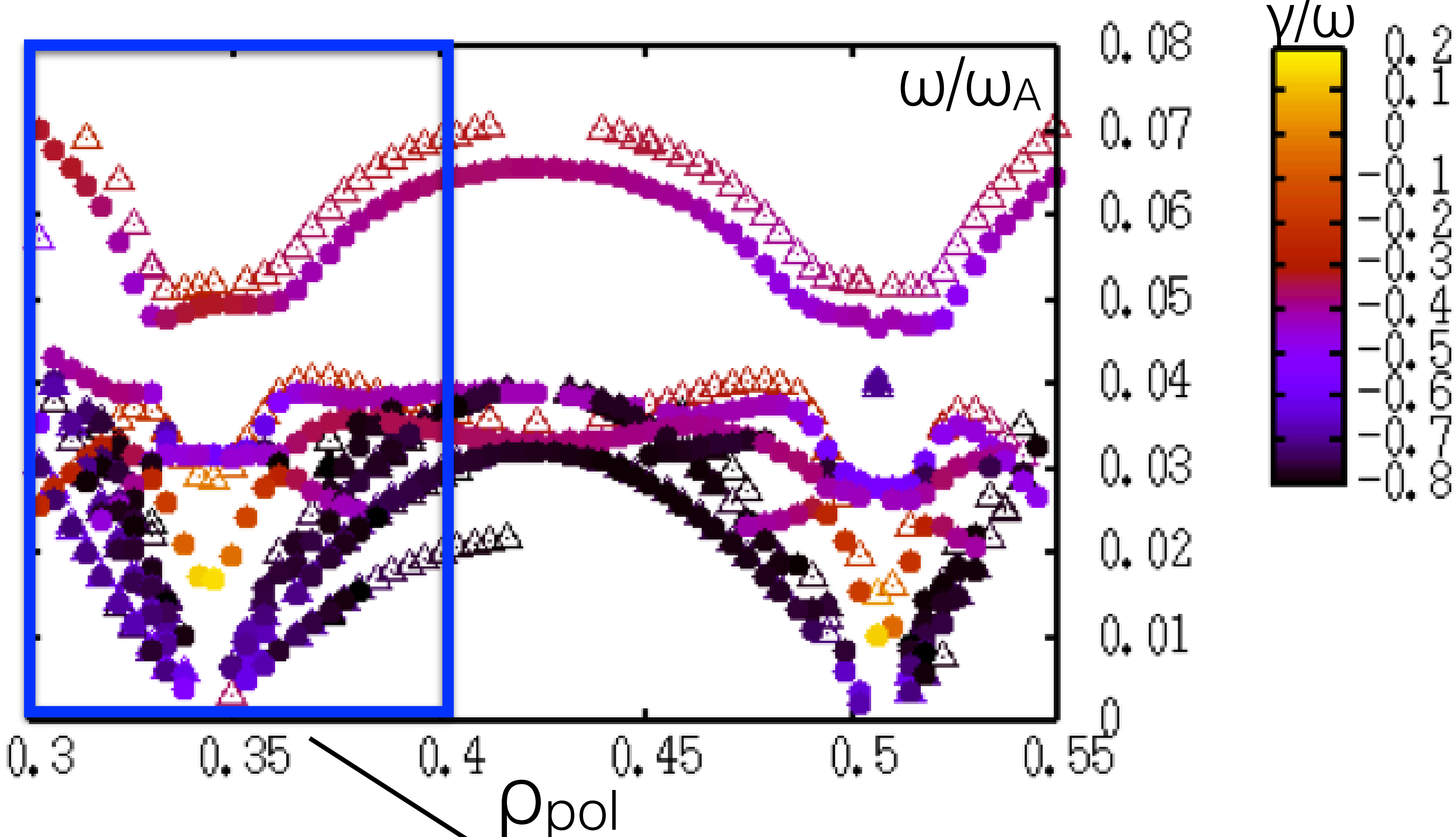


m=9: ES ≈EM potential:
mainly Alfvénic polarisation;
ES sidebands differ

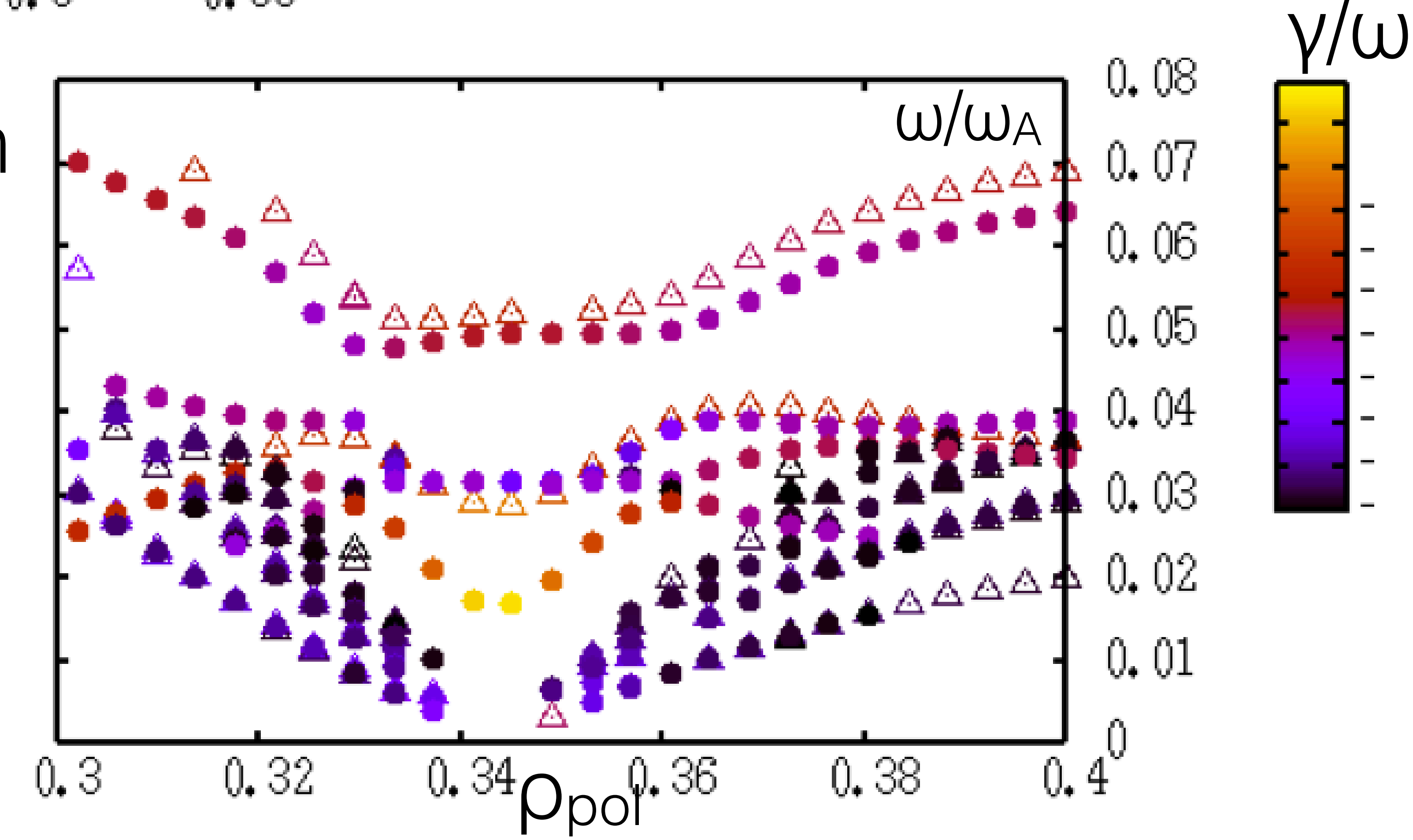
global antenna solutions: 2 species, with ω*, no EPs



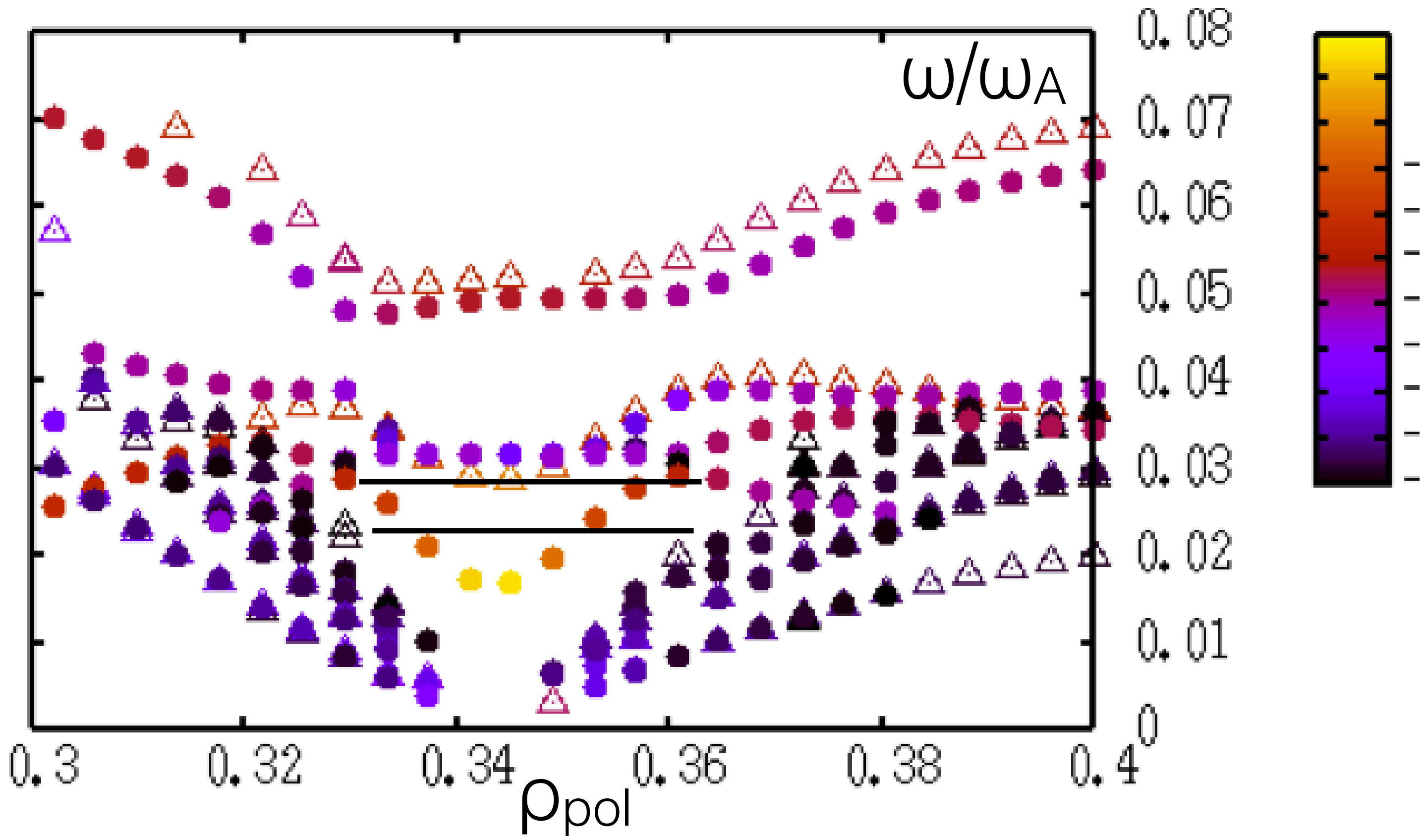
comparison: 2 species (el,D) △ - 3 species (el,D,C)•



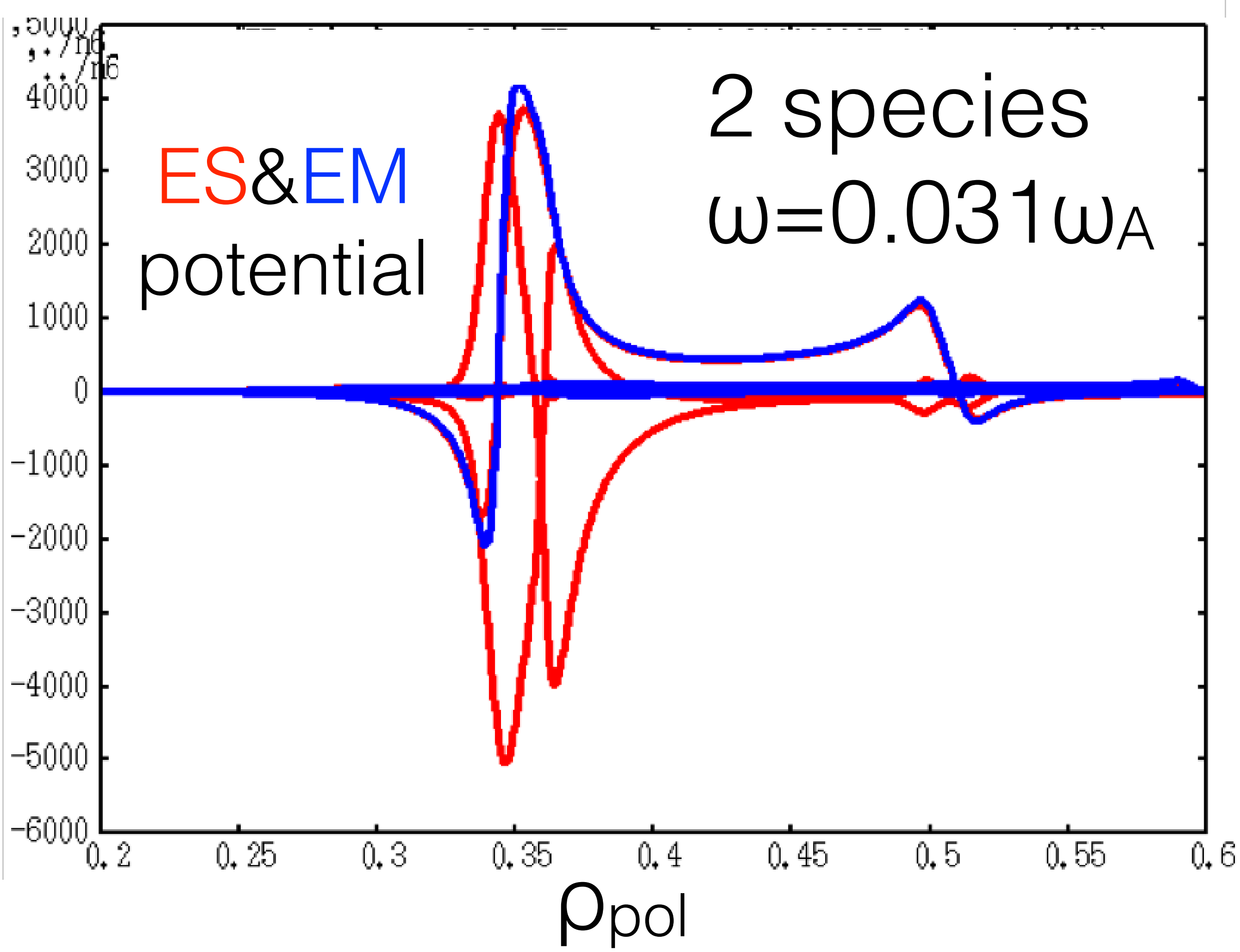
zoom



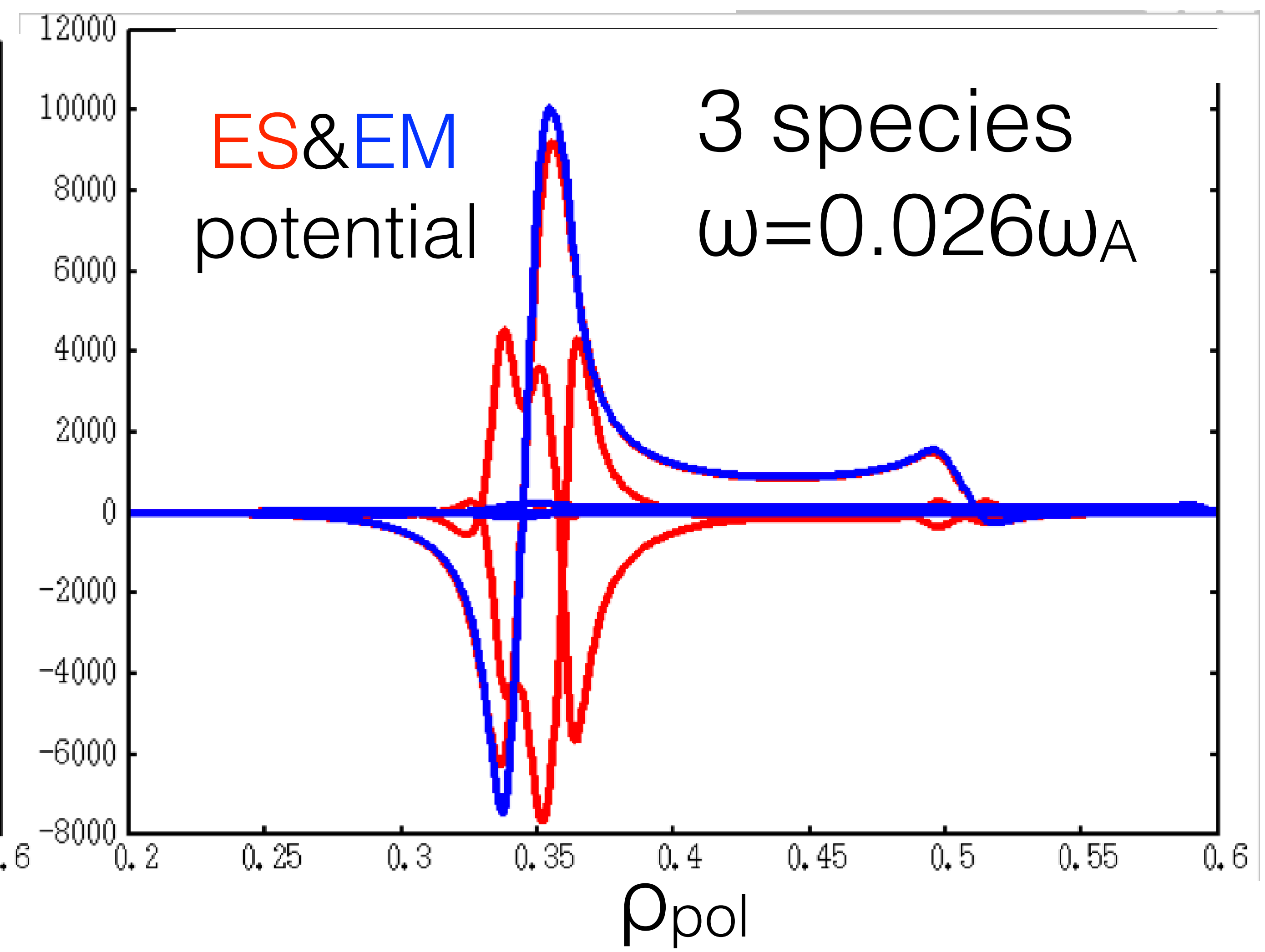
C impurity (10% ne) introduces new branches



ω/ωA
0. 08
0. 07
0. 06
0. 05
0. 04
0. 03
0. 02
0. 01
0
0. 3
0. 32
0. 34
0. 36
0. 38
0. 4
ρpol

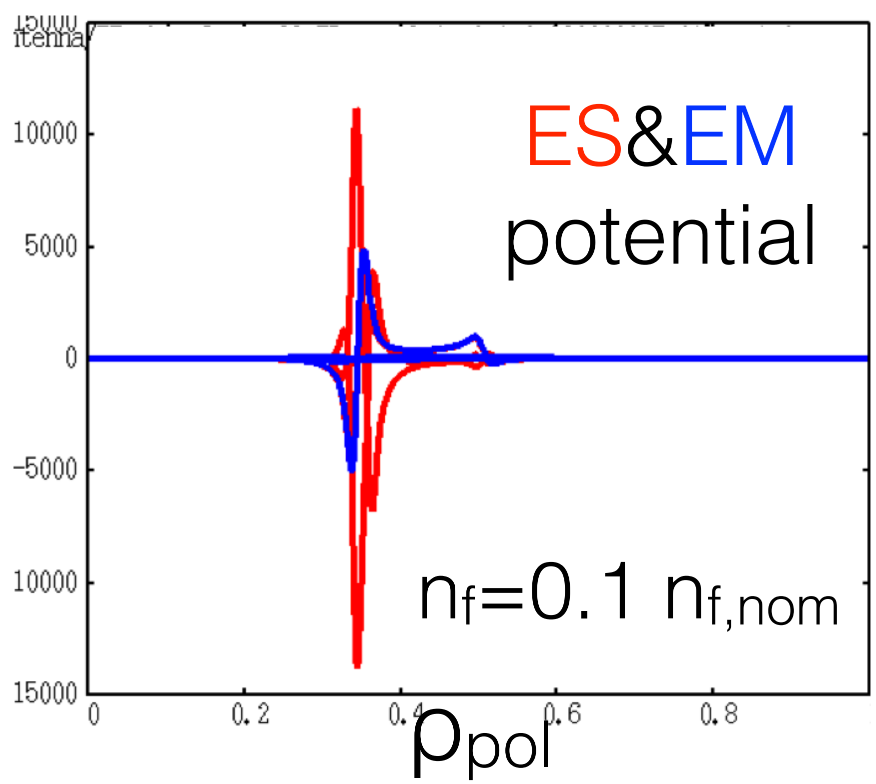


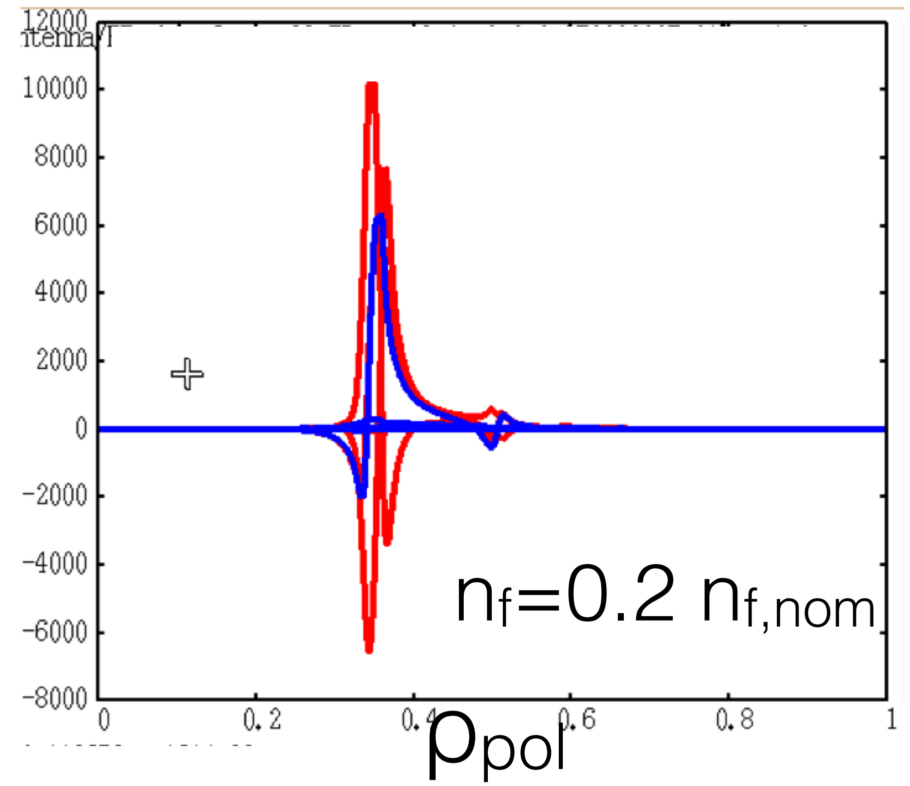
ES&EM
potential
2 species
ω=0.031ωA
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
0. 2
0. 25
0. 3
0. 35
0. 4
0. 45
0. 5
0. 55
0. 6
ρpol

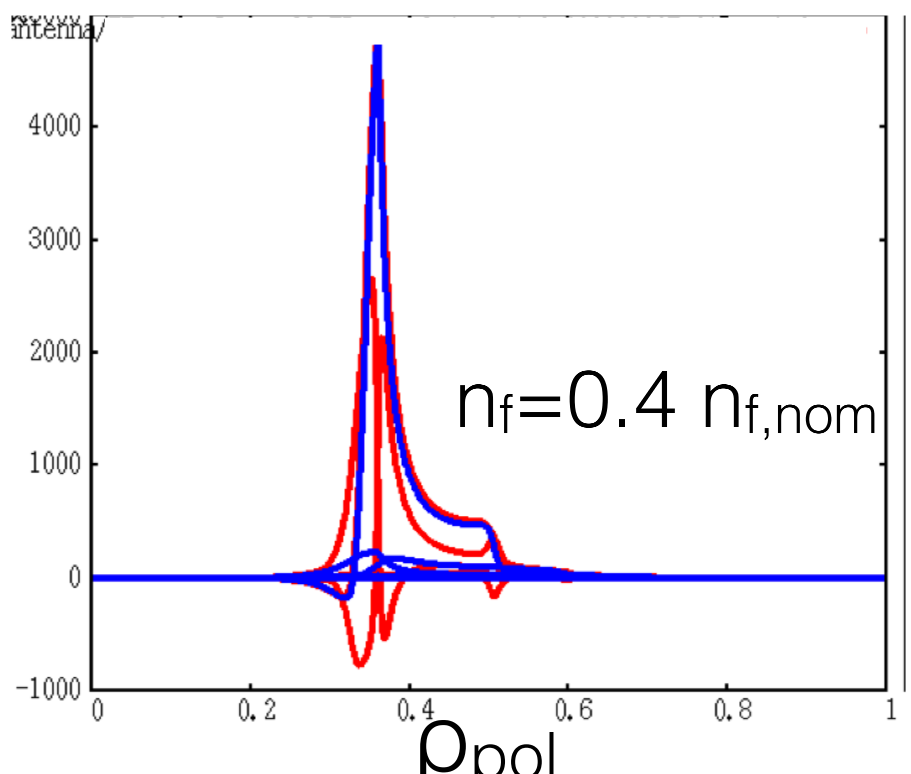


ES&EM
potential
3 species
ω=0.026ωA
12000
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
0. 2
0. 25
0. 3
0. 35
0. 4
0. 45
0. 5
0. 55
0. 6
ρpol

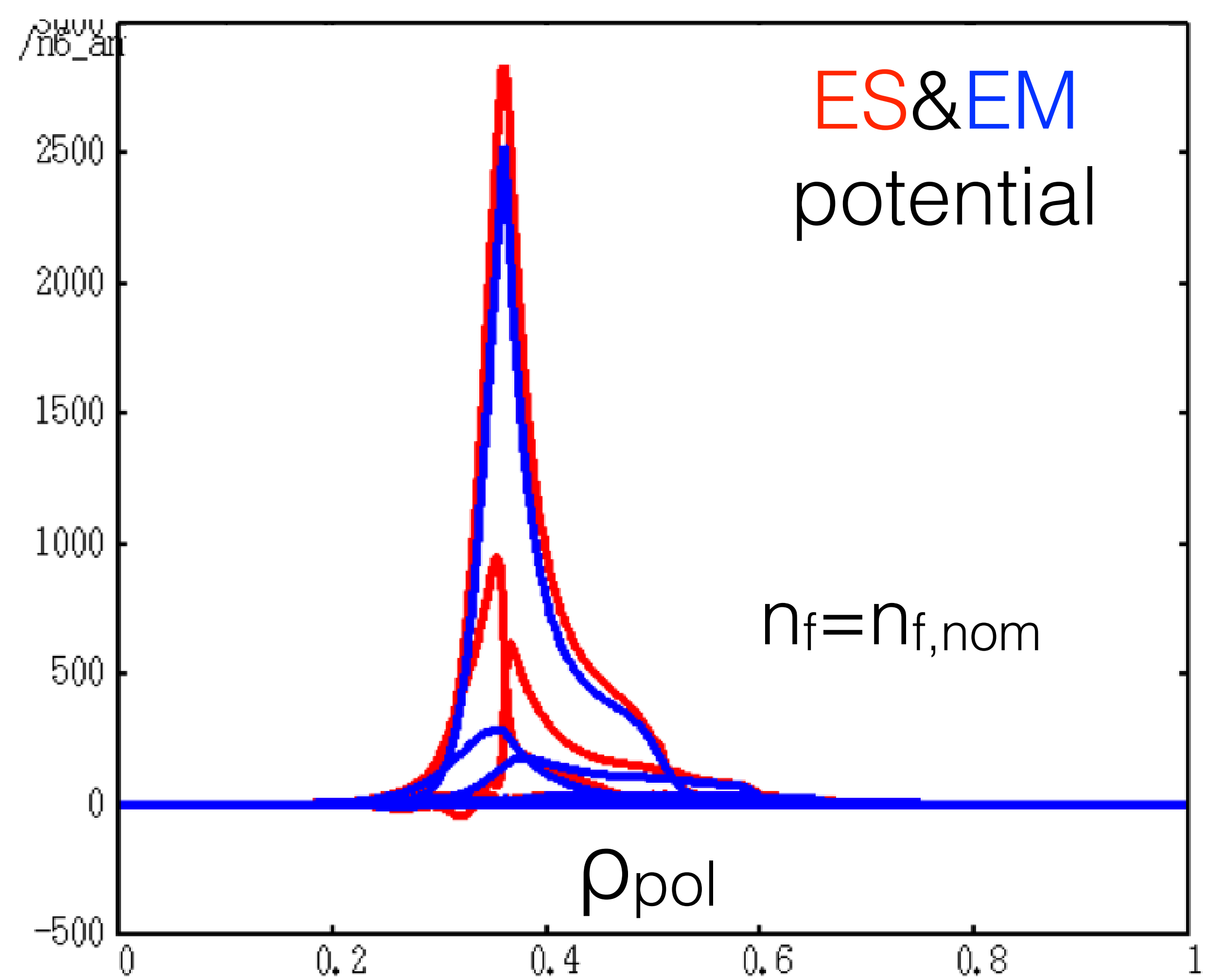
with EPs: 4 species (el,D,C,fast D): antenna results







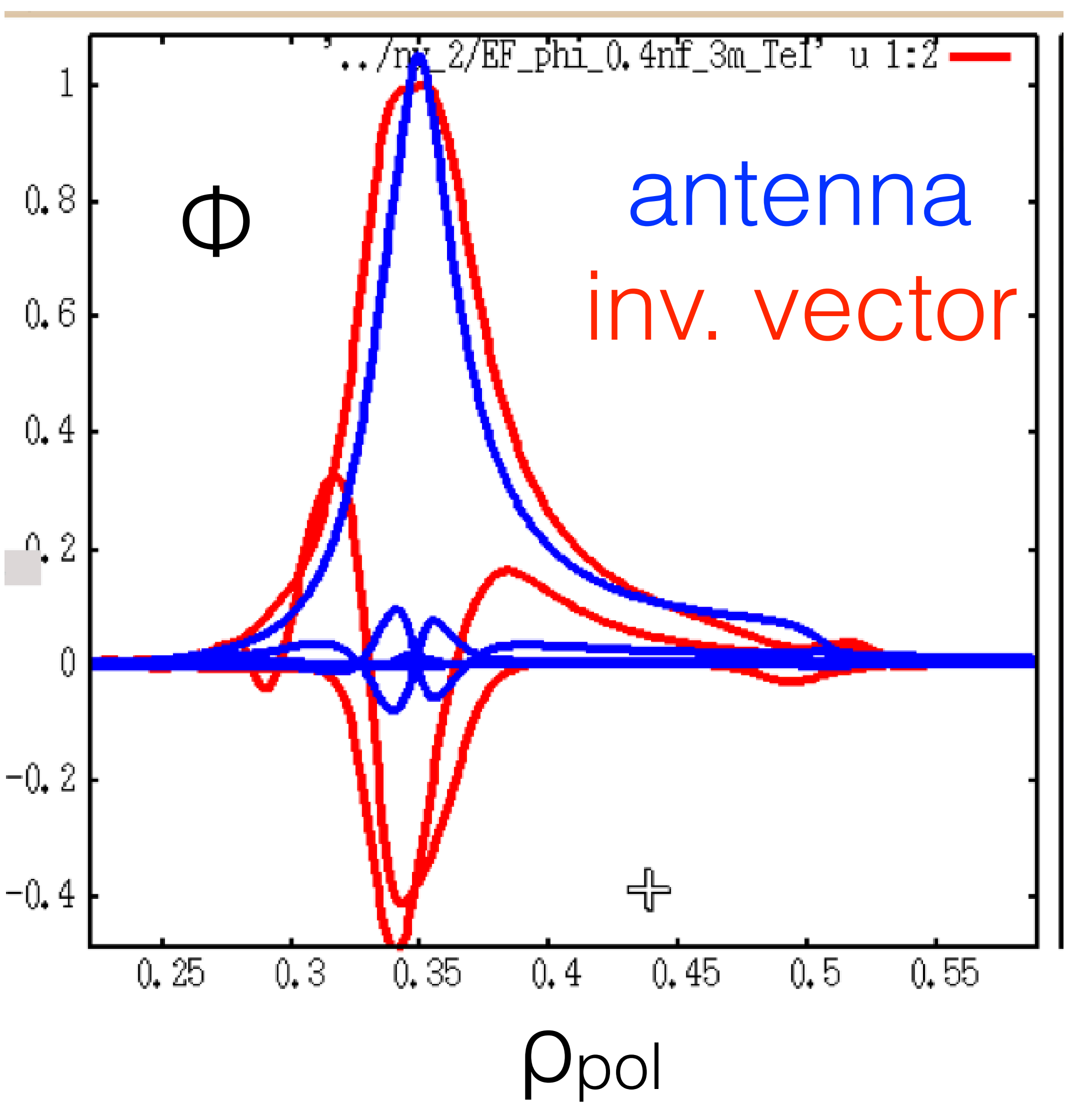
EPM -type mode emerges with increasing n_f

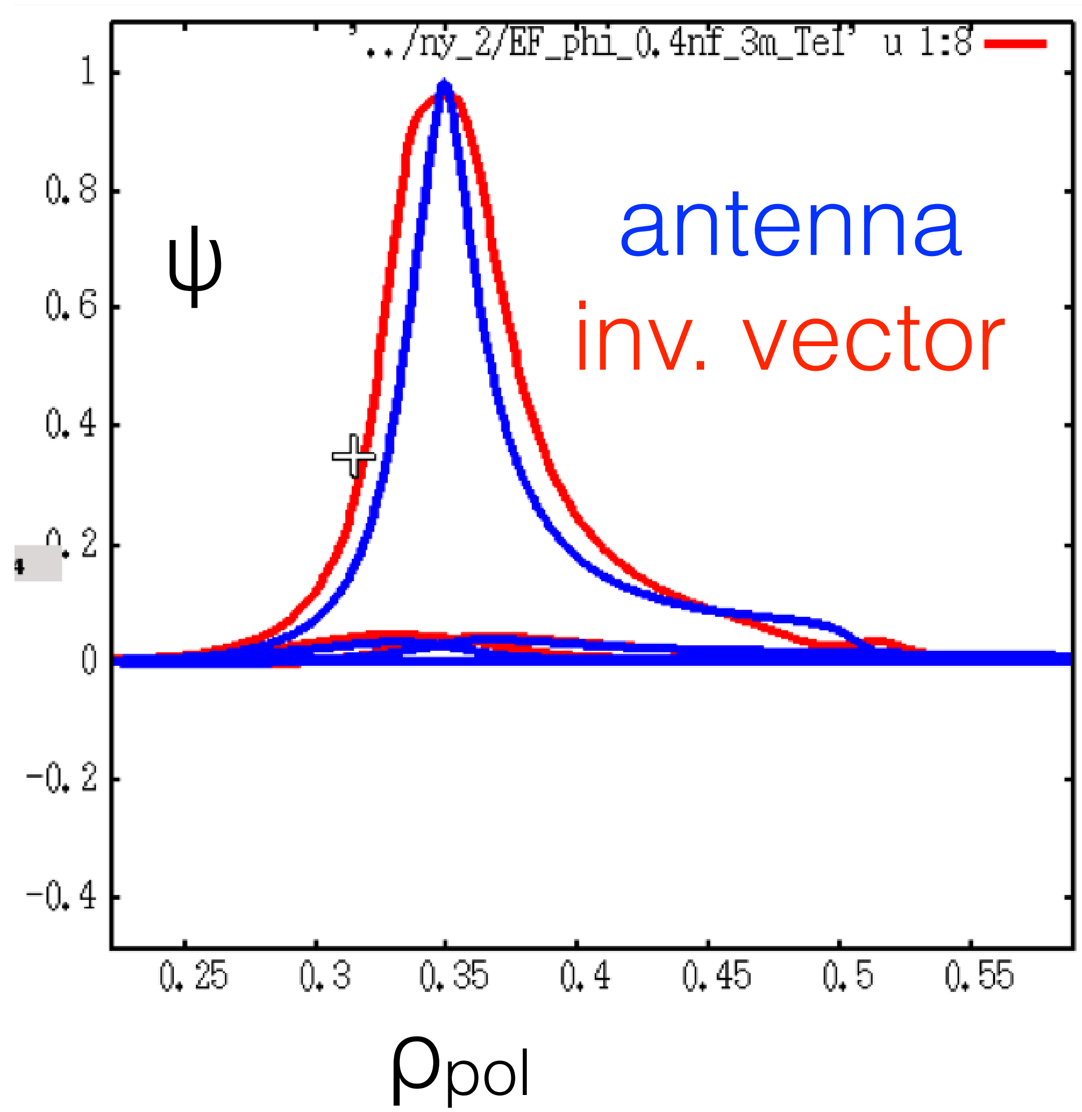


perturbative character: check antenna results with inverse vector iteration solver:

n_f=0.4n_f

f=22,8kHz

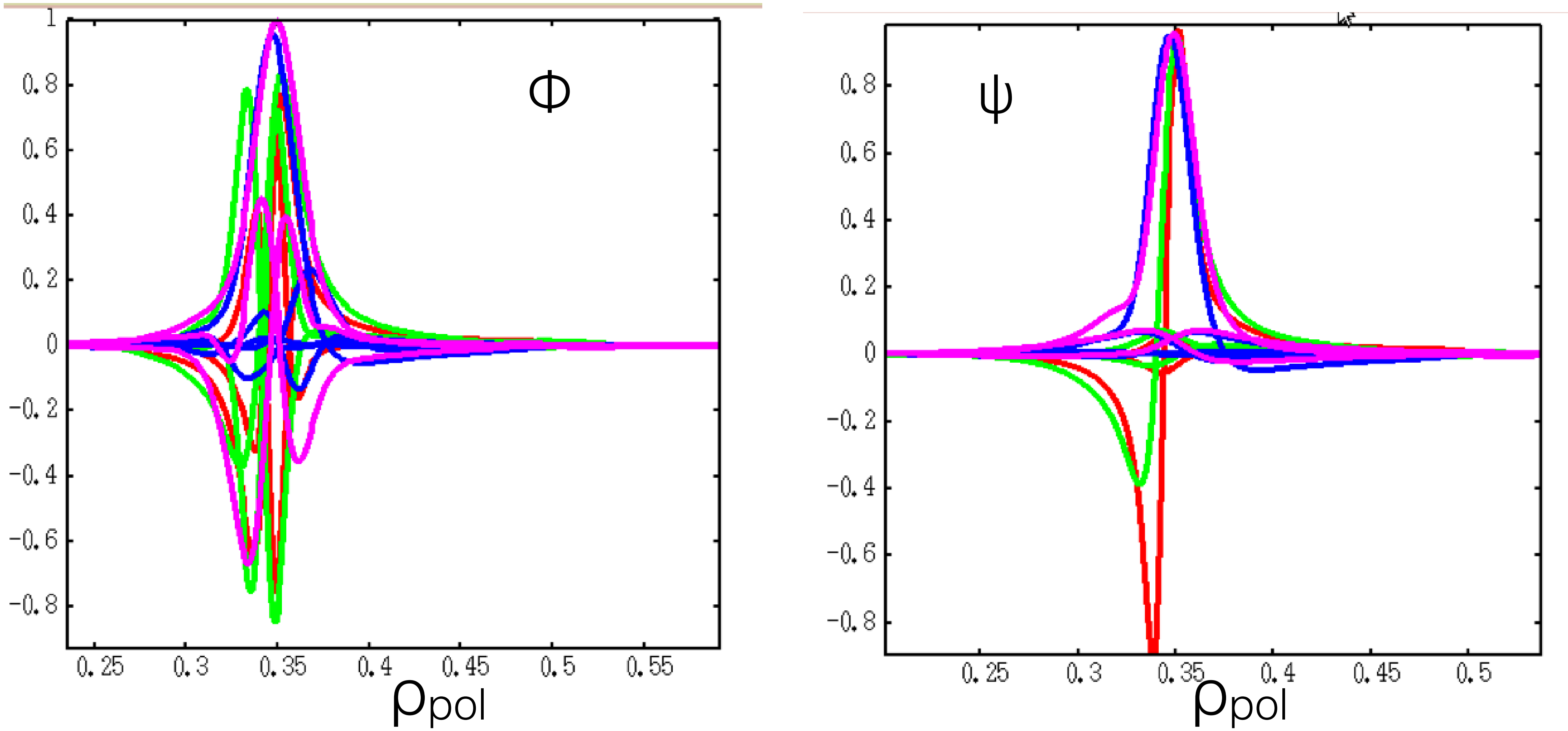




in all cases checked so far, good match for f and γ, mode structure slightly narrower for antenna version

3 ·Te: EPs change mode structure, especially of EM potential ψ: vector iteration solver

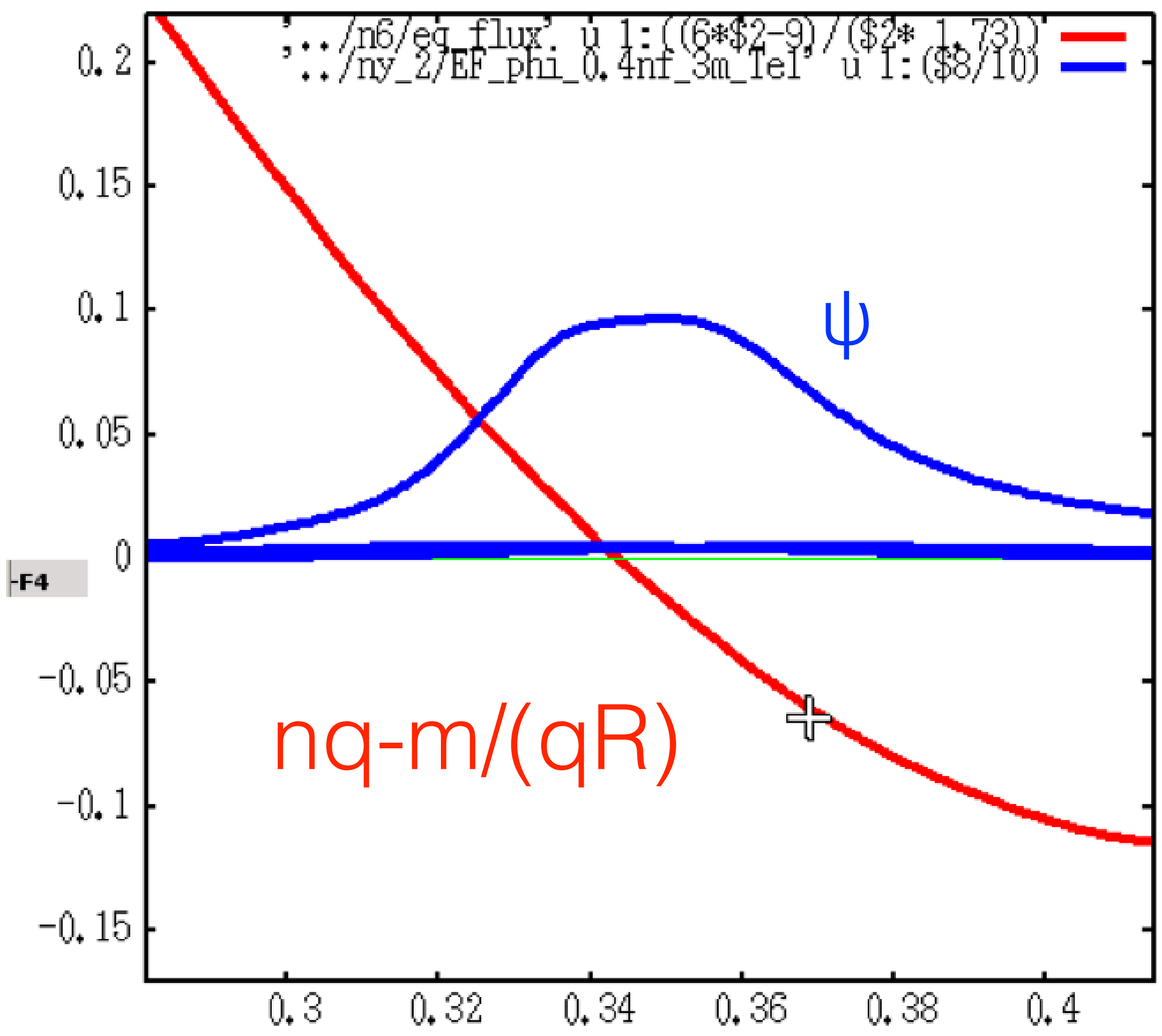
$$i\omega A_{\|} = (\nabla\psi)_{\|}$$



$n_f=0.01n_f$ $n_f=0.1n_f$ $n_f=0.2n_f$ $n_f=0.4n_f$

modes are peaked slighlty off rational surface:

modes are peaked slightly off rational surface and are asymmetric with respect to rational surface



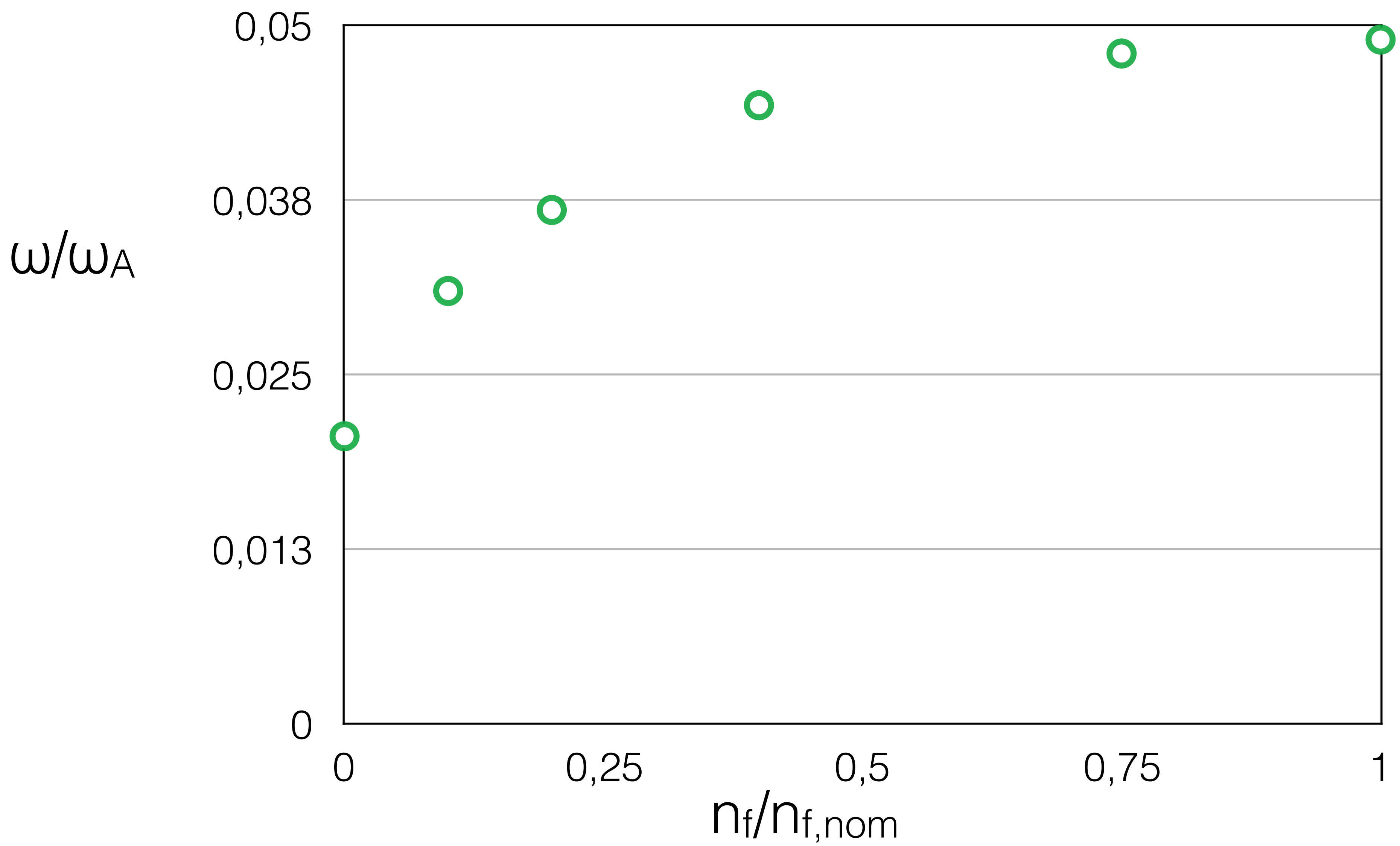
peak $k_\parallel$ and $\langle k_\parallel \rangle$ (all modes are slightly asymmetric around rational surface) are not 0, but finite! [similar to Z. Lu, POP 2017/NF 2018]

resonance condition: ω-(nq-m)/(qR) $v_{th,fast}$ for fast ions can be fulfilled!

assume: $k_\parallel=0$, sideband resonance at ω-1/(qR)v_{th} -> $v_{th}=0.11v_A$ ($\omega=0.044\omega_A$) ($v_{th,D}=0.058v_A$, $v_{th,fast}=0.27v_A$): no efficient drive possible!

mode 'chooses' finite $k_\parallel$ to avoid effective thermal ion damping and facilitate EP drive: estimate $\langle k_\parallel \rangle \lesssim 0.1$, $v_{th,res} \gtrsim 0.4v_A$ - typical beam particle energy!

with EPs: 4 species (el,D,C,fast D)



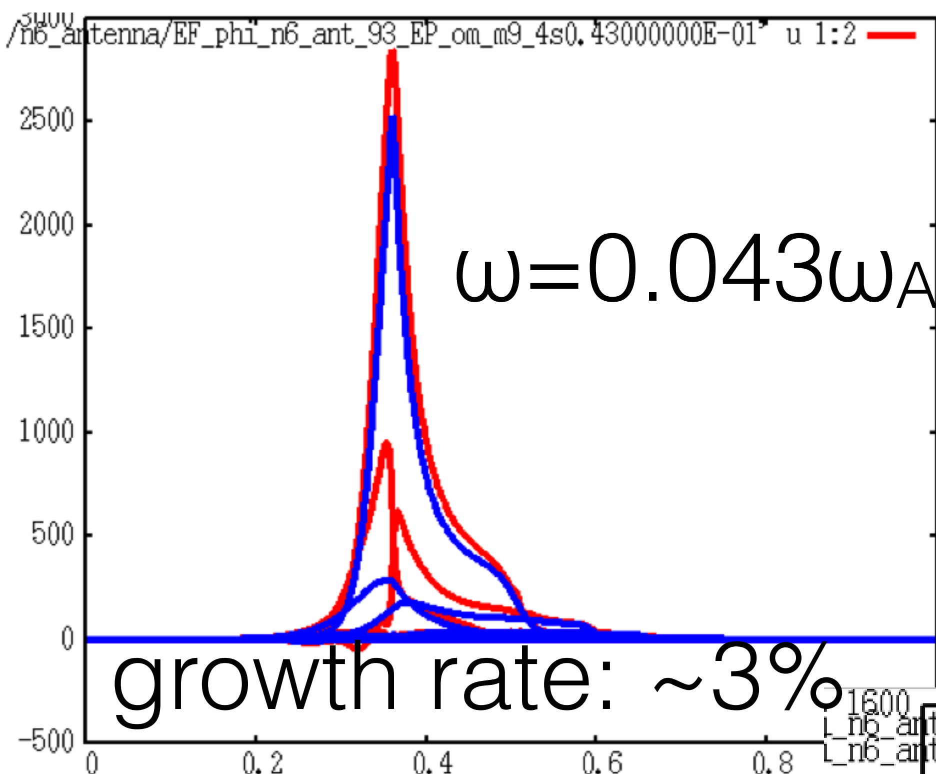
f_mode=10,6kHz-25kHz,
strongly dependent on F_{EP}

many other roots in that frequency rage (radial harmonics in Φ)

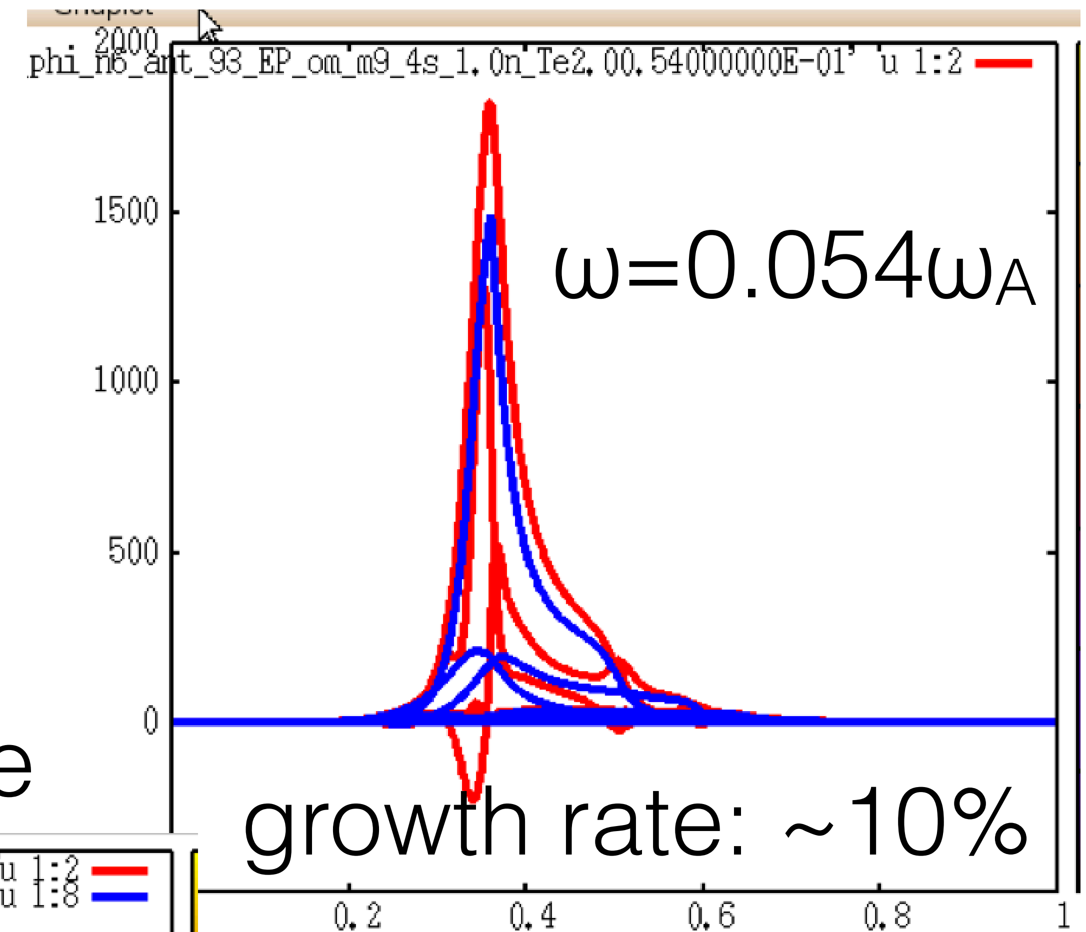
Te scan: with EPs: 4 species (el,D,C,fast D)?

Te=Te/2~Ti: no mode!

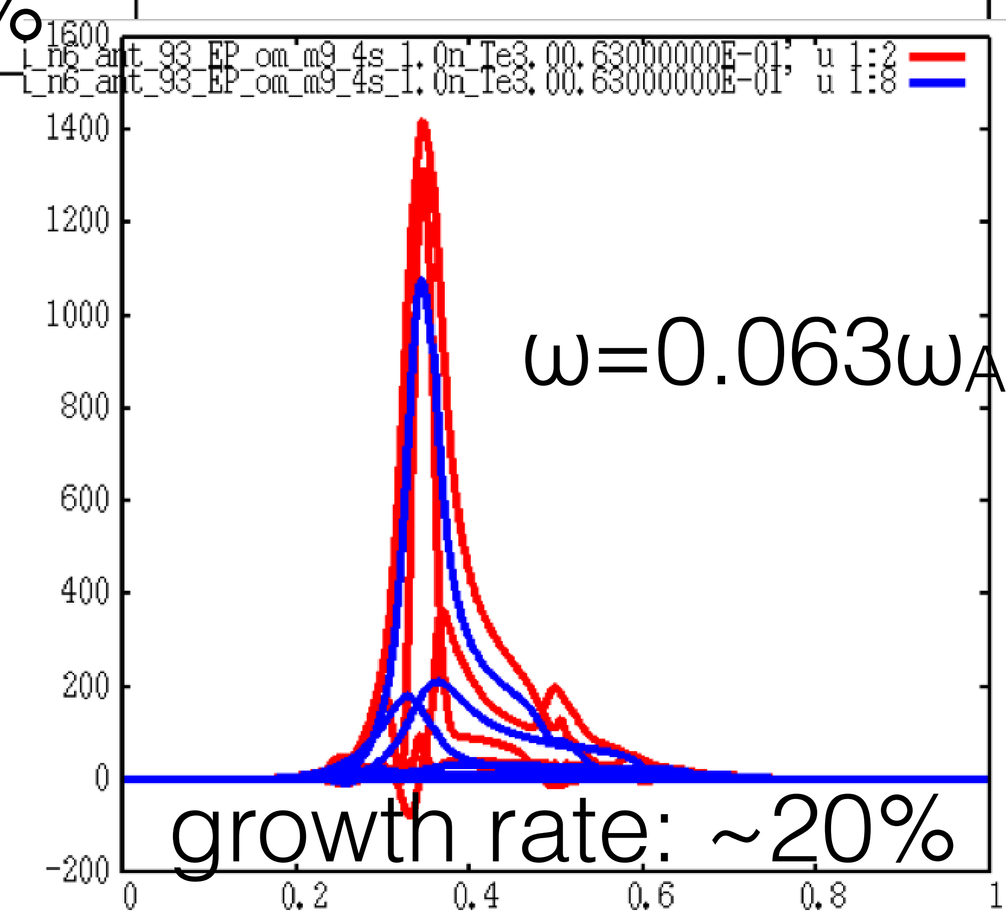
nominal Te



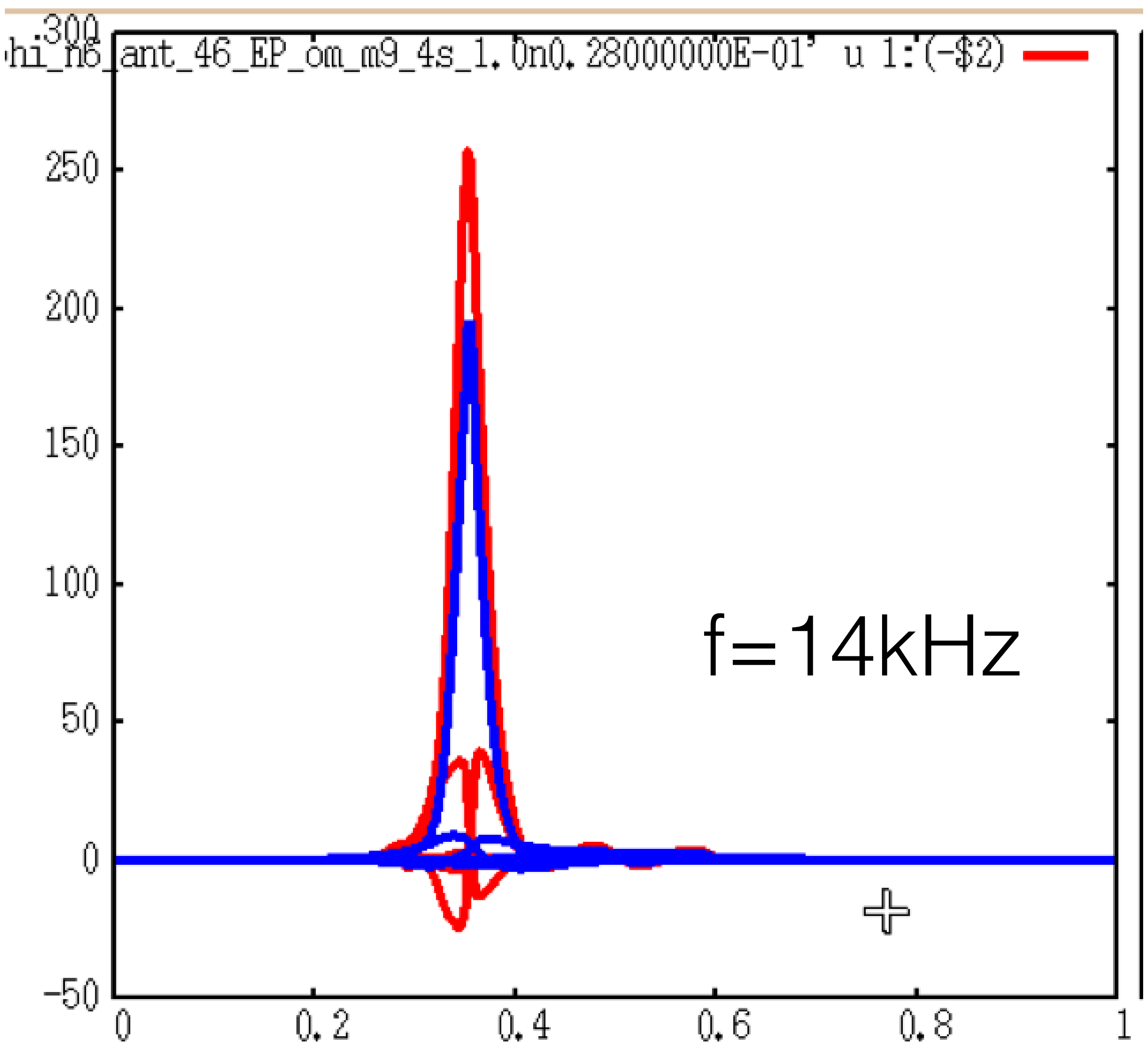
2* nominal Te

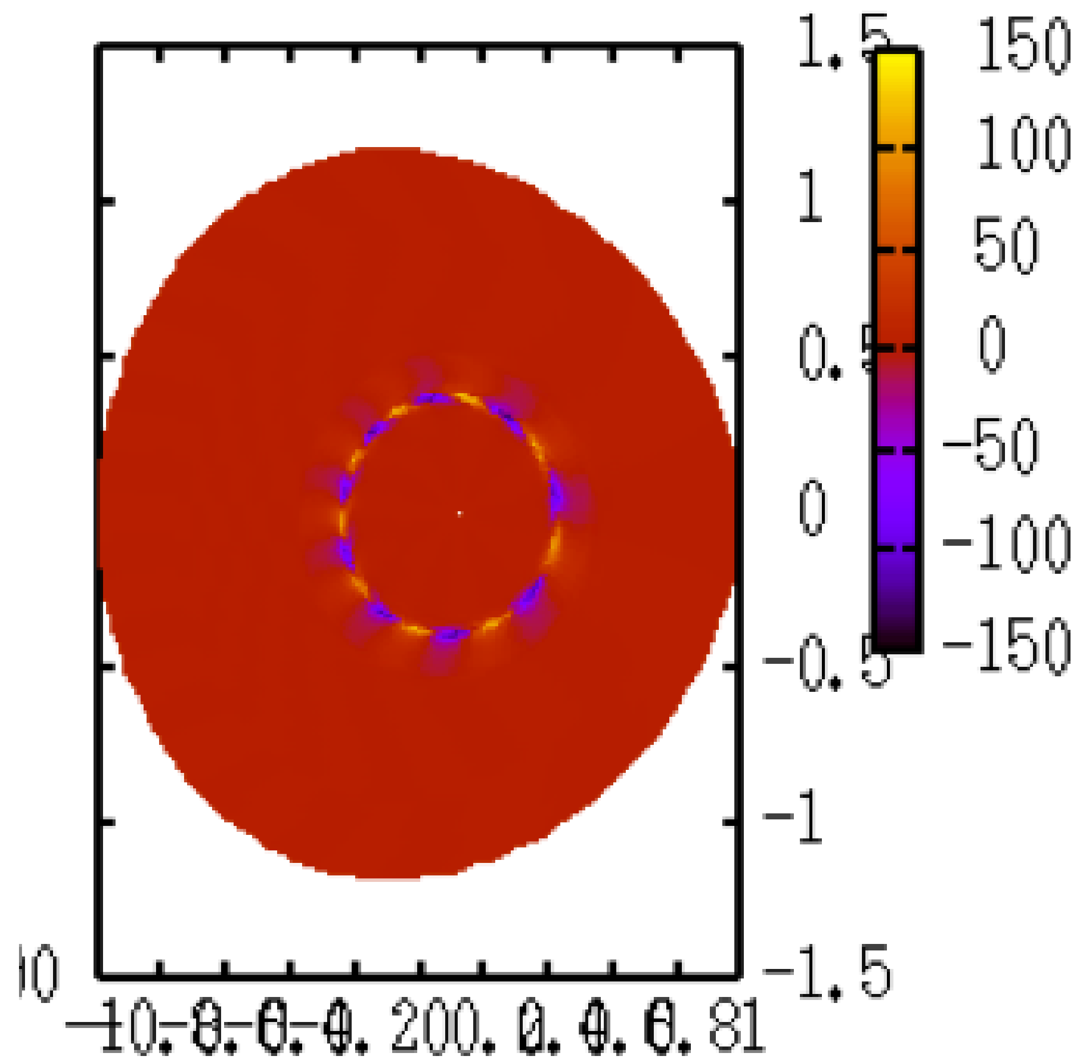


3* nominal Te



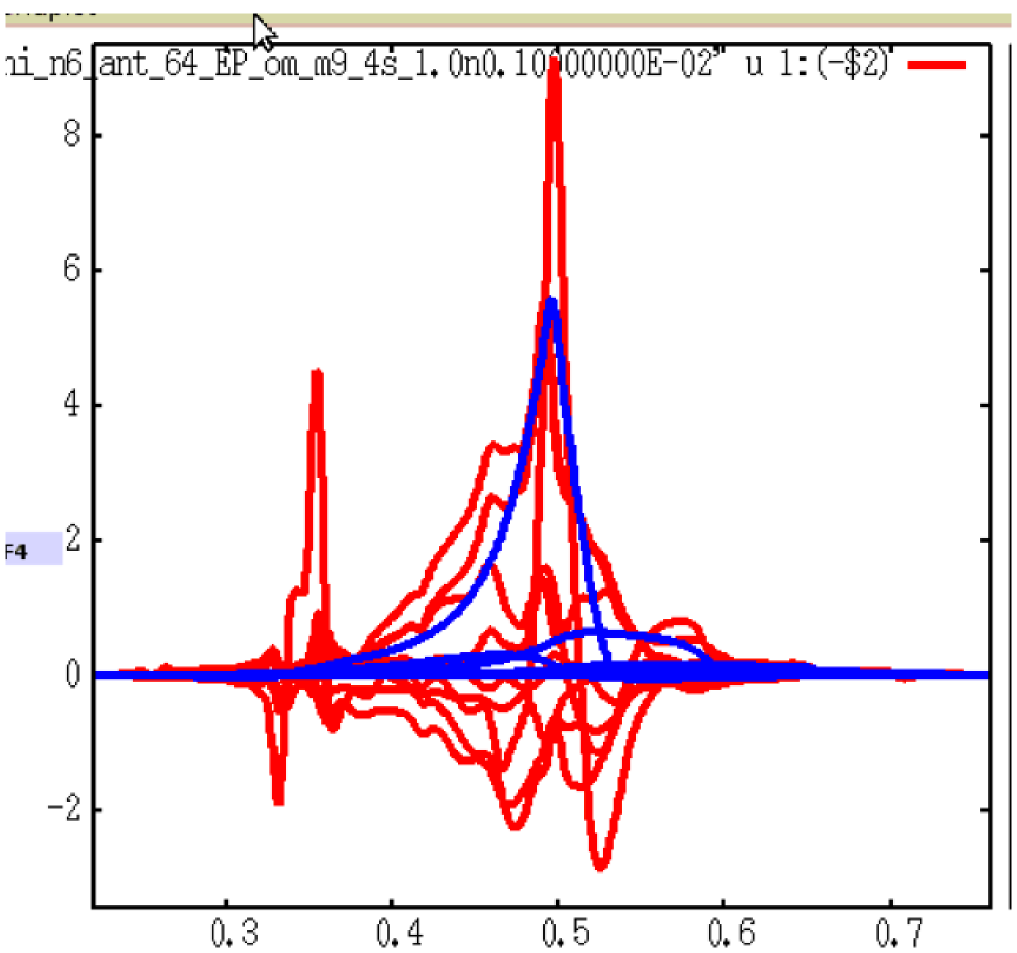
with EPs, adding trapped particles, finite parallel velocity (HAGIS orbits)
4 species (el,D,C,fast D), inner rational surface



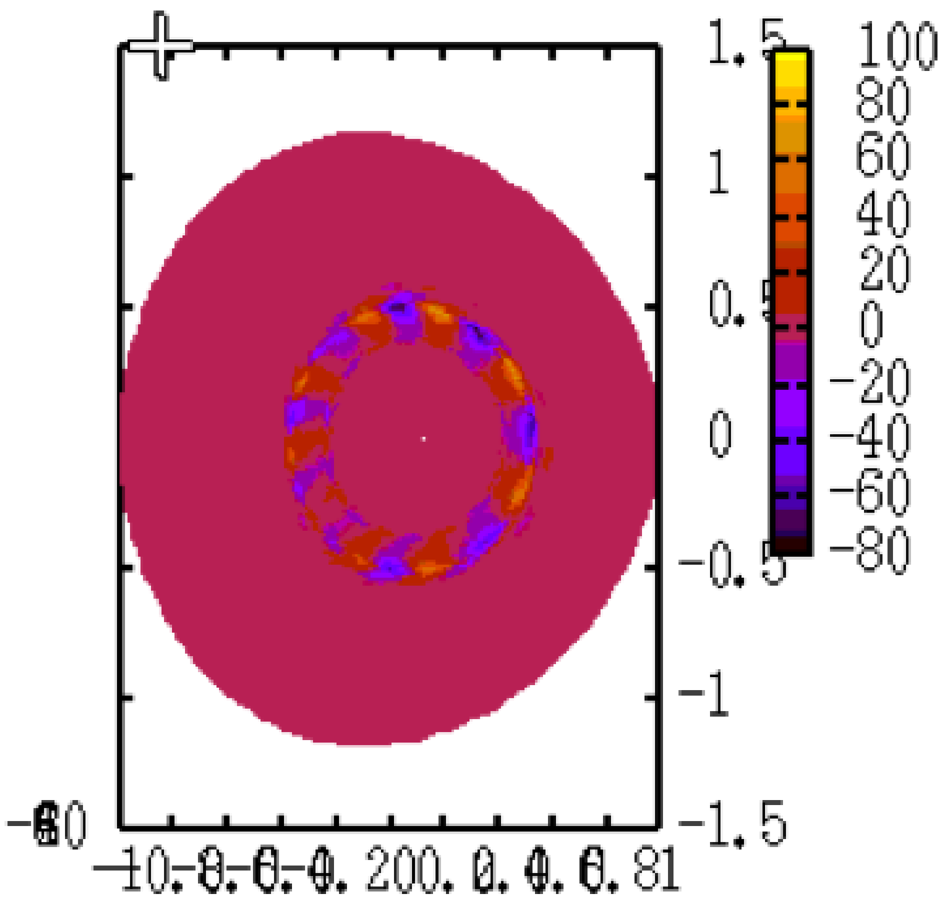


smaller f, mode more symmetric, i.e. smaller $k_\parallel$

with EPs, adding trapped particles, finite parallel velocity (HAGIS orbits)
4 species (el,D,C,fast D): outer rational surface: coupling to other rational surfaces seen

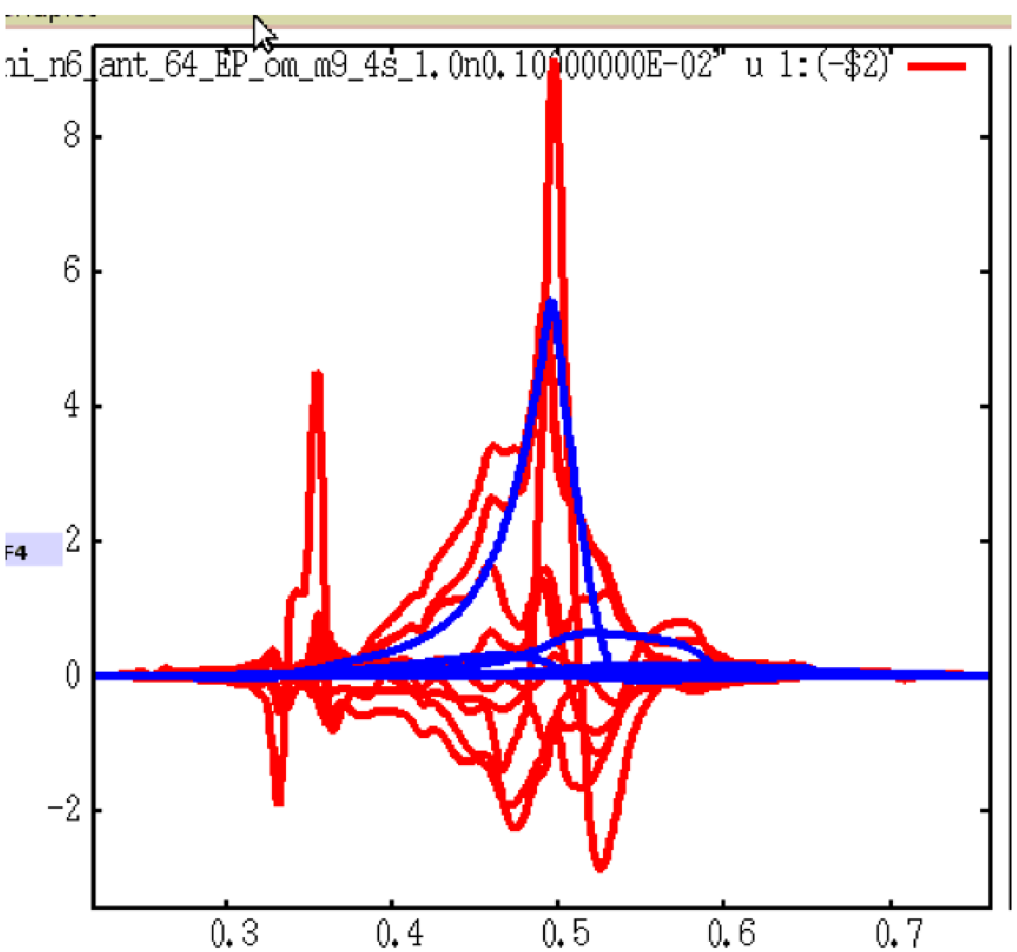


f=8kHz

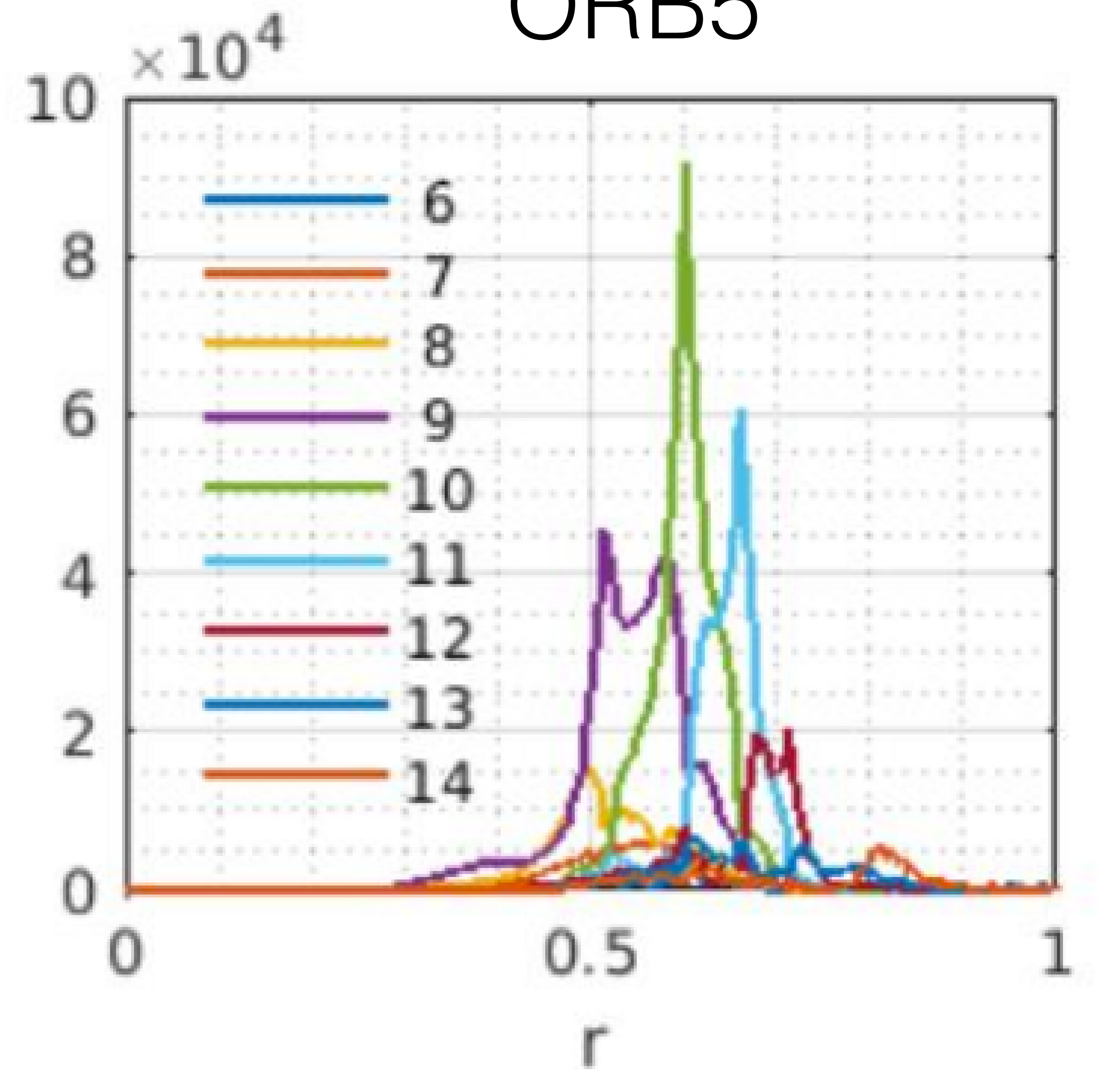


other modes found by ORB5 (see talk by Z Lu):
lower f range and electrostatic polarisation
to be found by LIGKA (search in even lower f-range)

LIGKA



ORB5



preliminary conclusions:

- mode found is of EPM-type
- it has Alfvénic polarisation with ES sidebands;
- the relative magnitude of the sidebands depends on Te: 0.5·Te~Ti suppresses the mode, 2-3·Te increases mode frequency and ES sidebands: large Te/Ti reduces sound wave and ES drift wave damping
- two modes with ~6kHz splitting can be related to two different rational surfaces with the same n and m
- frequency well below local sound frequency: emerges form drift Alfvén branch
- somewhat similar to GTC results [Zhang 2010,Liu 2017] (however, GTC group considered different case) and in line with analytical work [Chen&Zonca2017]
- to do: other mode numbers, ω^* scans of electrons and ions; anisotropic F_{EP}

update needed because:

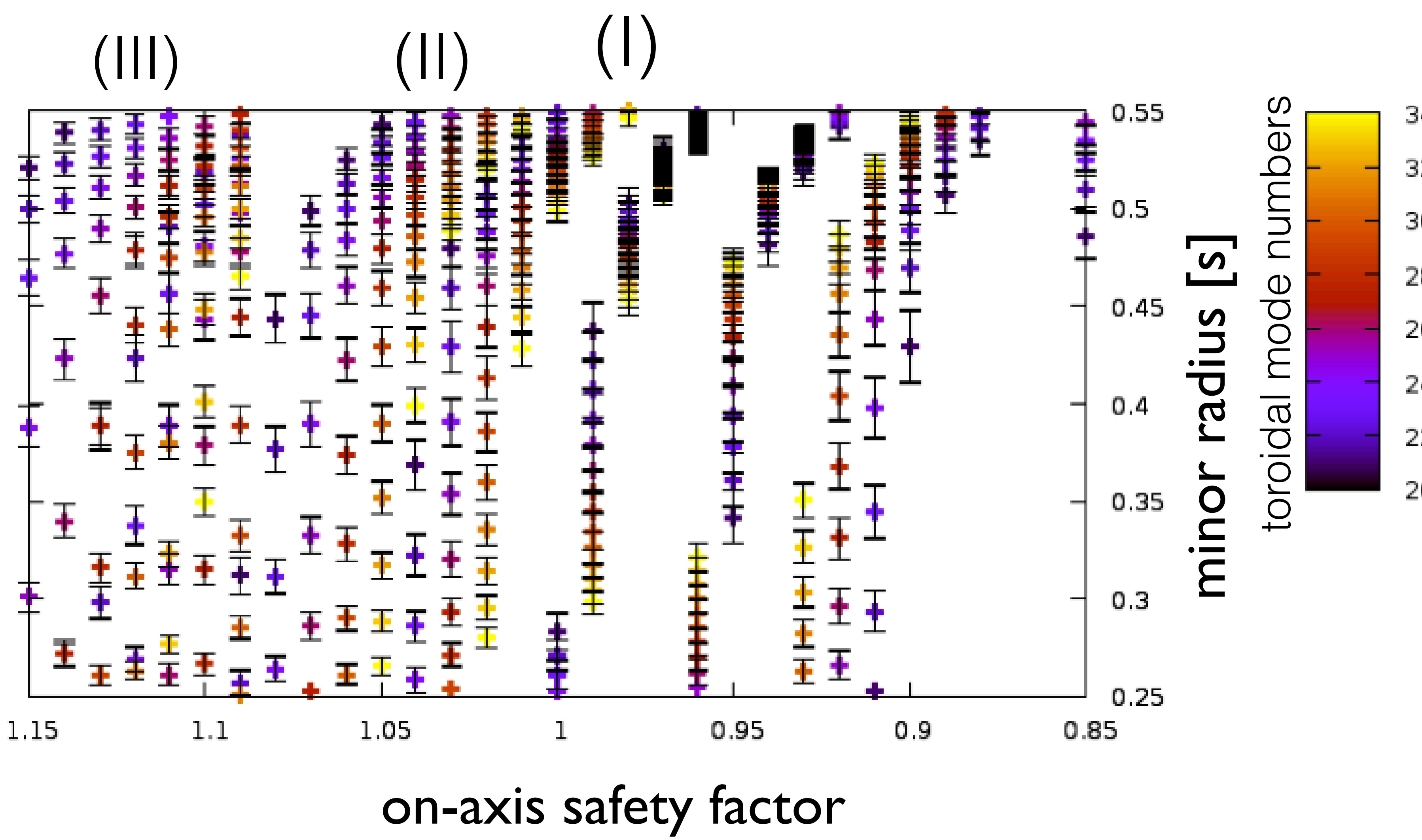
- q=1 surface makes it difficult to benchmark case for kinetic MHD codes due to kink/fishbone instabilities
- unless we define/simulate a 'sawtooth cycle' and study the influence of AEs on sawtooth stabilisation…
- different q-profiles might lead to scenarios without strong AE resonance overlap (see next slide) - different AE transport regime
- several transport groups predict peaked density profiles: since also α-particle profile will be more peaked, the AE stability might be decreased
- action item: who will provide updated (q0>1) hybrid scenario data?

classifying AE-EP transport scenarios:

- 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)



[LIGKA: automated, fast local model including multi species, EPs, FLR;FOW Ph. Lauber, T. Hayward-Schneider]

discussion on BAE/BAAE benchmark
[Ph. Lauber]

BAE/BAAE benchmarks

- so far not satisfactory: different modes (BAE/BAAE/EPMs) with different mode numbers were studied
- no agreement on neither f, γ or mode structures/polarisation
- confirms that mode is difficult to simulate
- some similarities but also differences between LIGKA and (old, different discharge) GTC results: exact comparison to be done
- non-perturbative EP effects seem to be crucial
- no modes for Ti~Te

- further steps: DIII-D: focus on one mode number: n=6, vary n_{EP}
- DIII-D mode structures to be uploaded on ITPA web-site (caveat: this is a theoretical study that should not be stopped when finding ‘something similar’ compared to the experiment…)
- work on quantitative analytical theory comparisons/dispersion relation
- ITER: update scenario to hybrid (q0>1) with peaked density profile before starting further AE analysis (TAE/BAE/BAAE)