Emittance Exchange for Anisotropic Beams in the SPL

I Application of instability charts (idealized 2D theory) for realistic 3D linac (periodic focusing, bunched beam, multicell cavities)

- development of beam halo?

II Energy exchange for mismatched beams?

III What happens for different input emittances?

IV Considerations for the choice of lattice and emittance ratio.

test linac: first two superconducting sections (β=0.52, β=0.7) of the SPL

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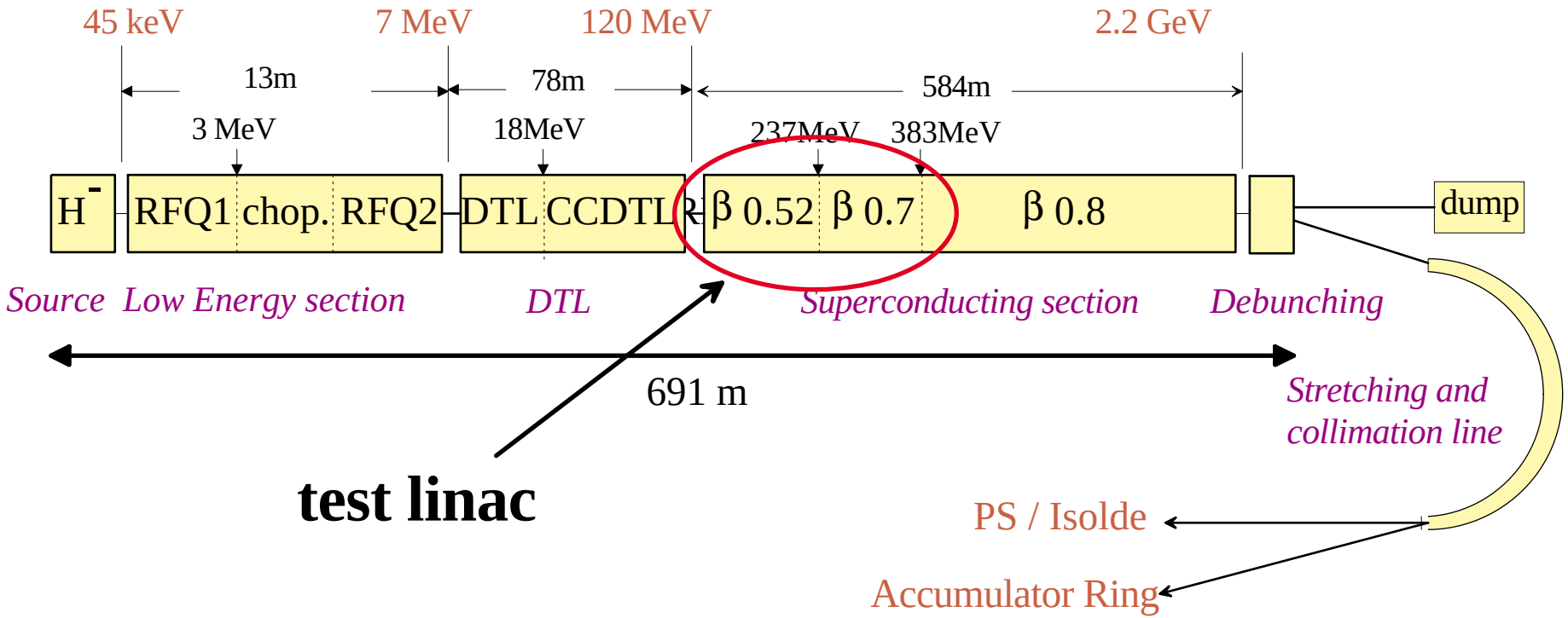
June 2001
CERN, PS/RF

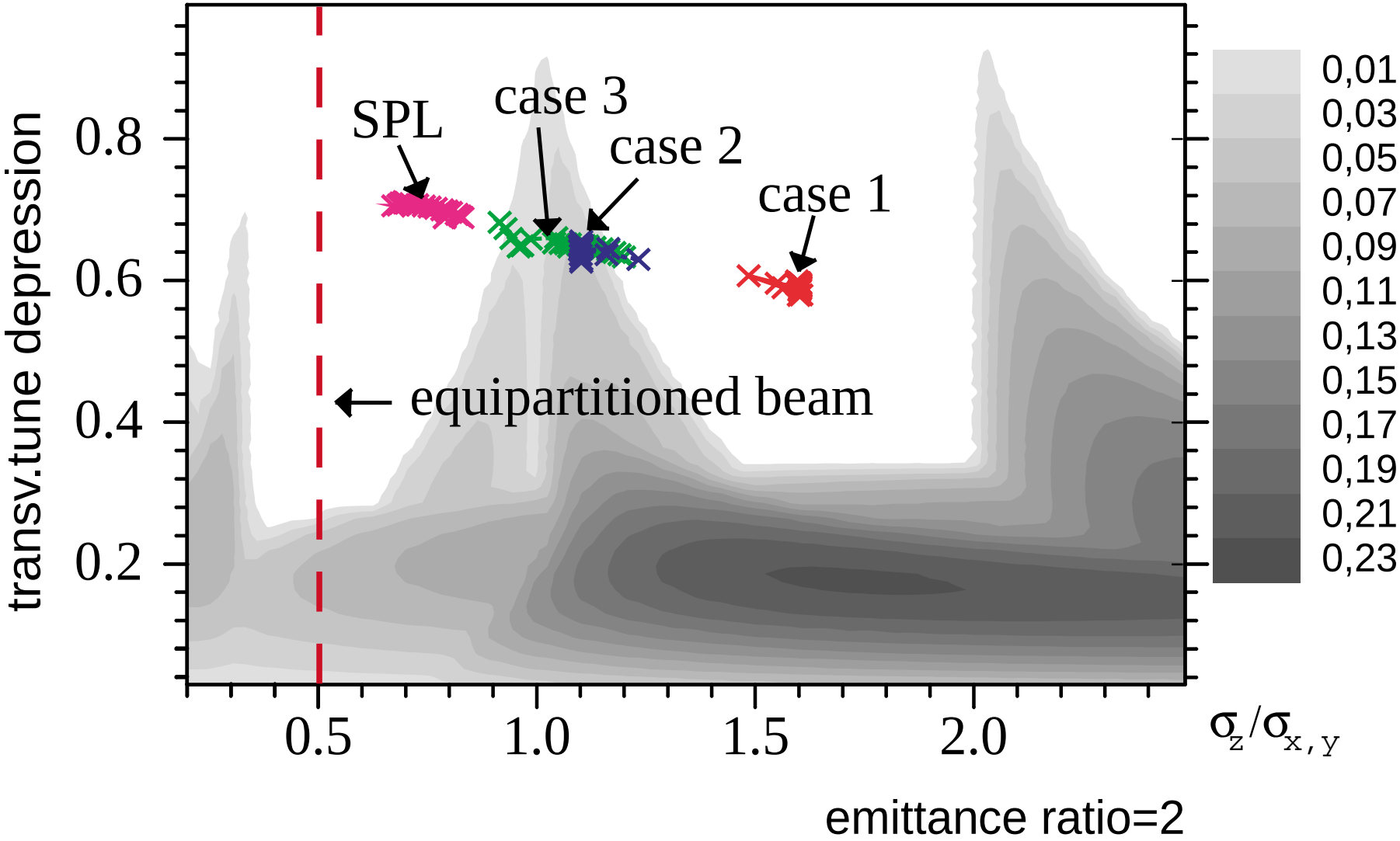
The SPL study at CERN: Superconducting Proton (H^-) Linac



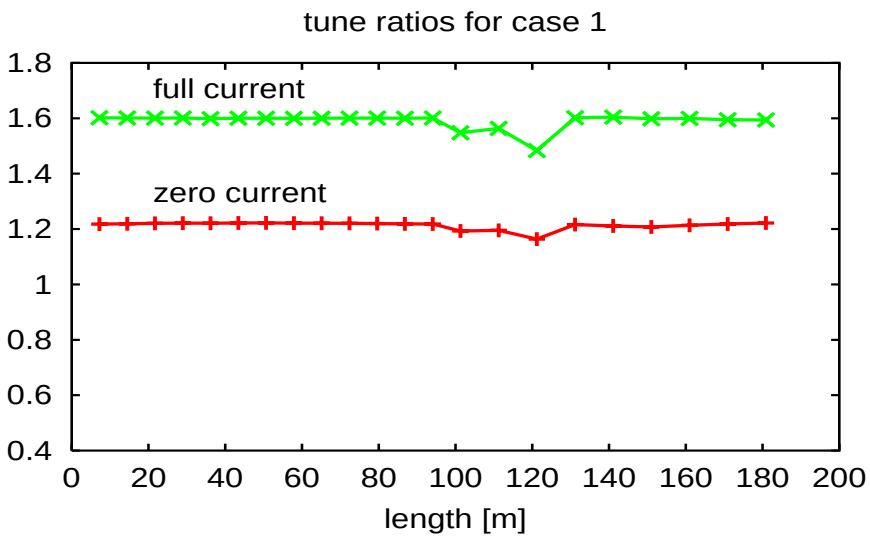
simulated structure:

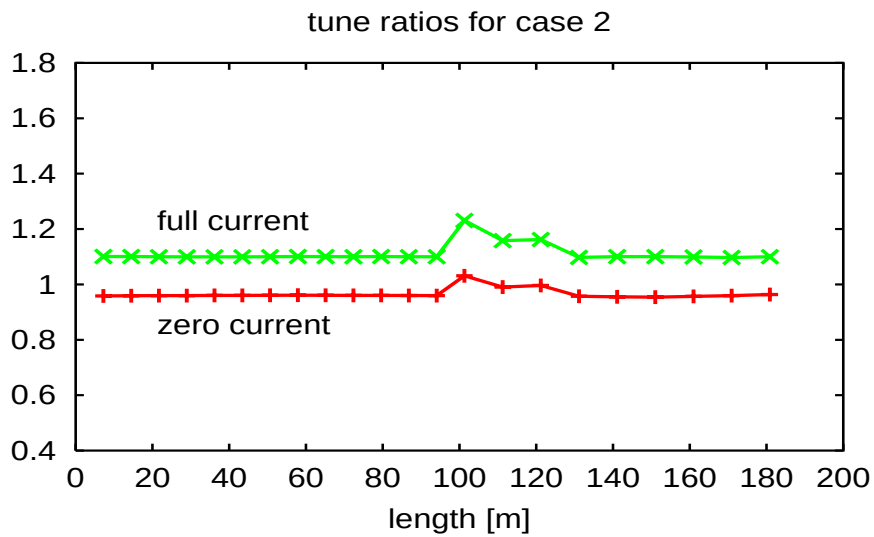
- Energy range: 120 - 383 MeV
- RF frequency: 352.2 MHz
- Max. bunch current: 22 mA
- Simulation current: 40 mA
- 22 focusing periods
- Doublet focusing

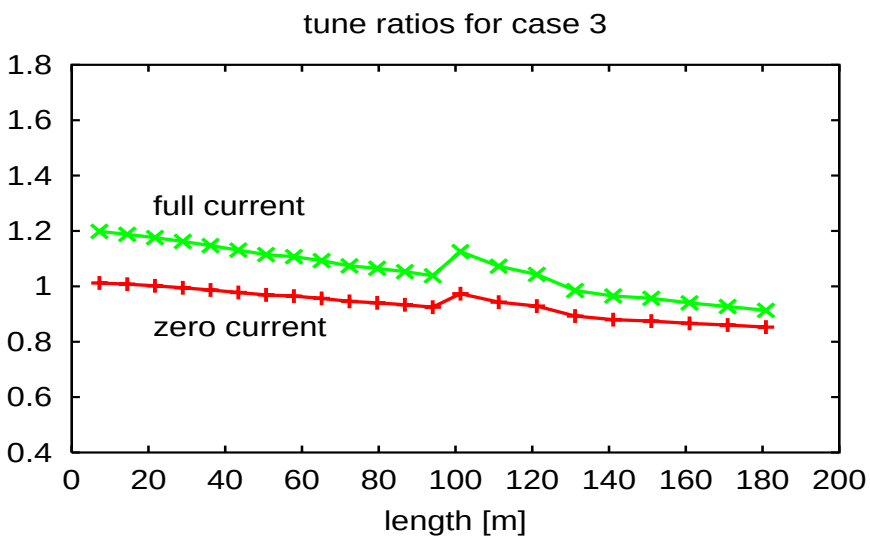
“Hofmann Chart” for the SPL with four test cases

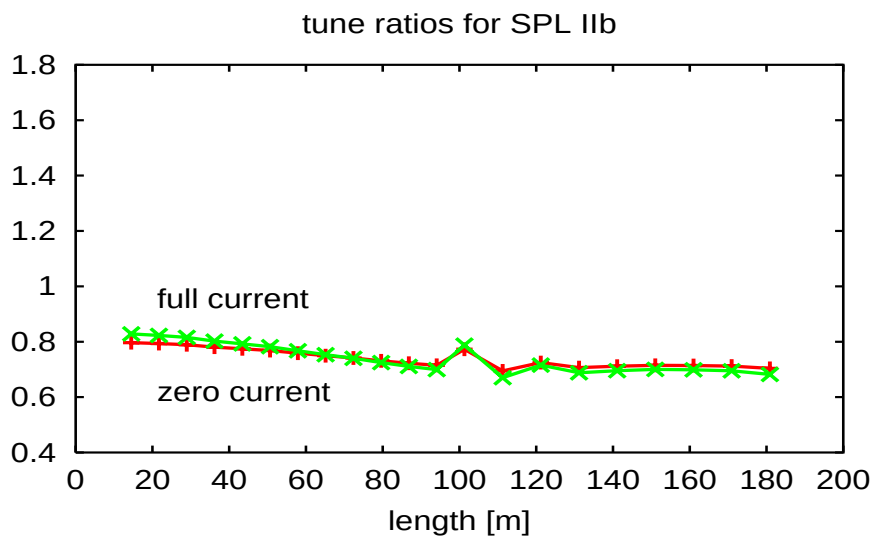


Full and zero current tune ratios $\sigma_z/\sigma_{x,y}$

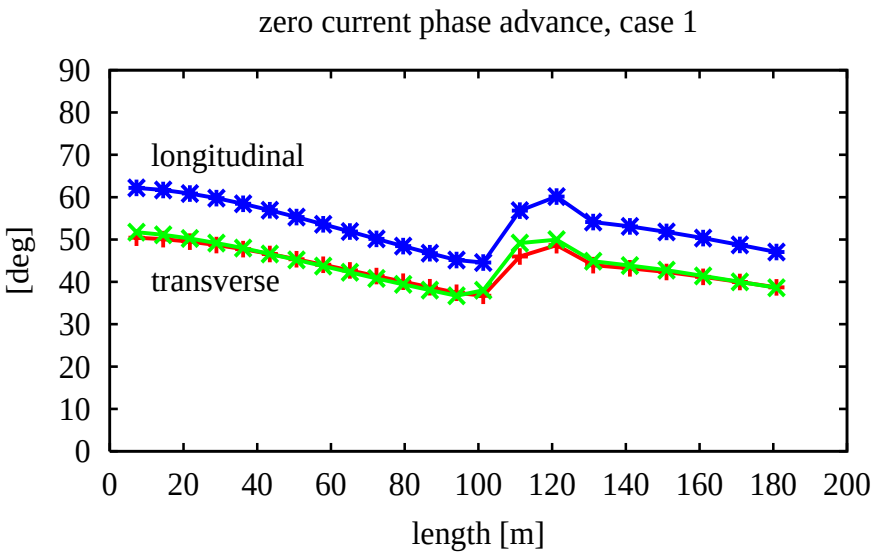


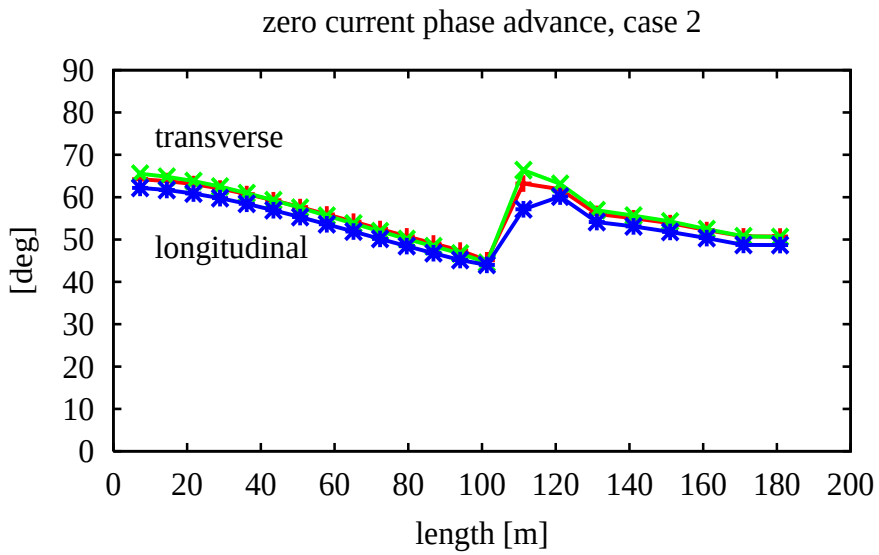


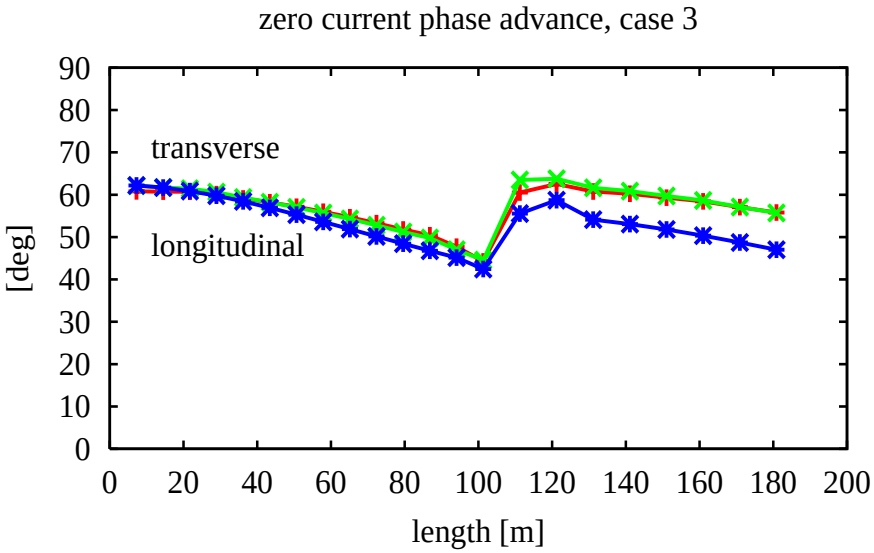


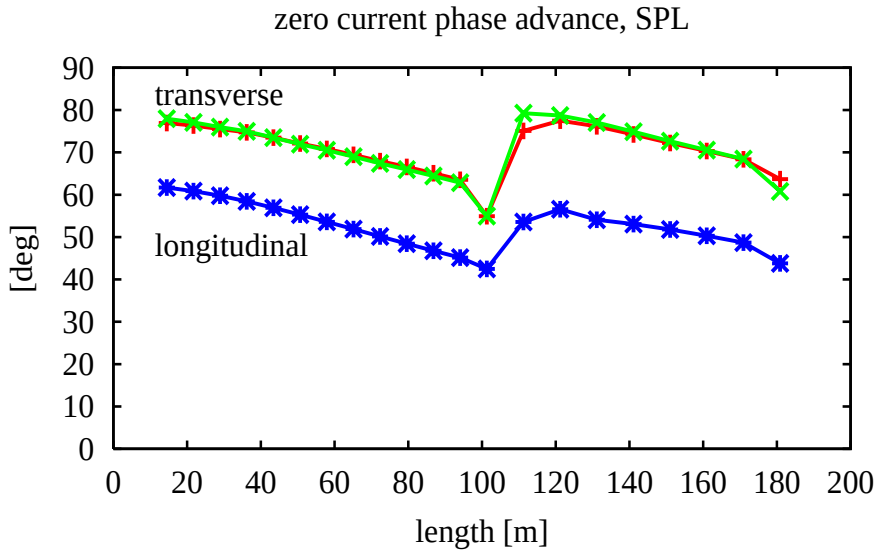


Zero current phase advance per period

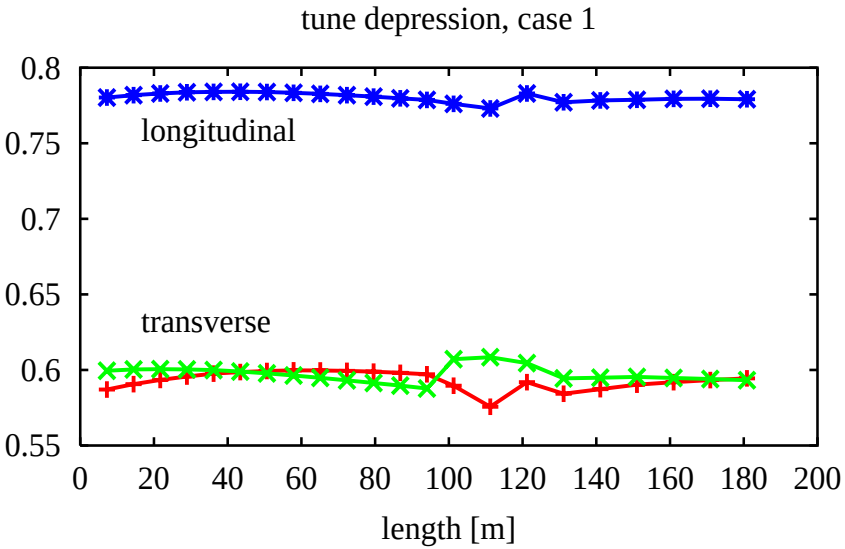


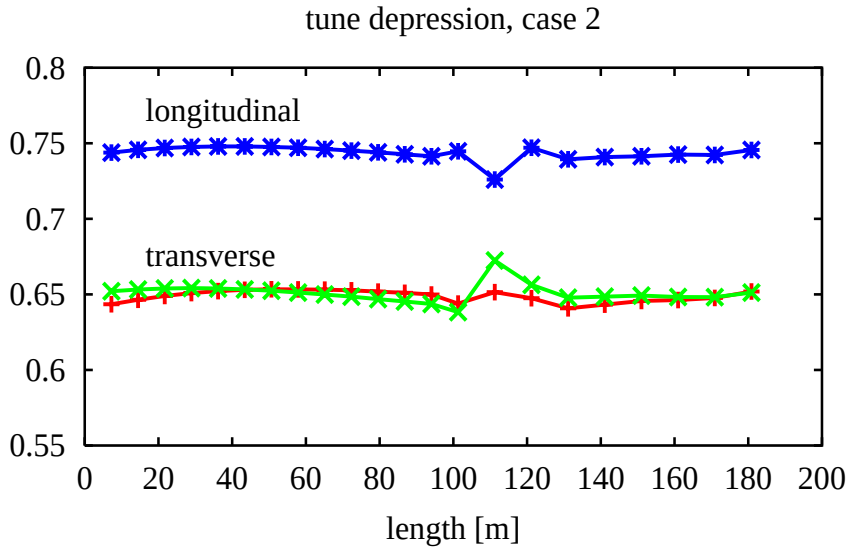


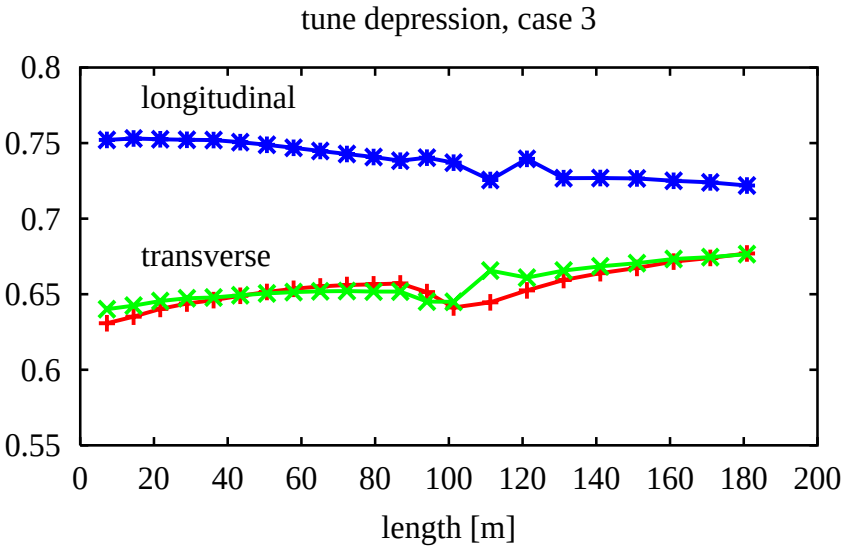


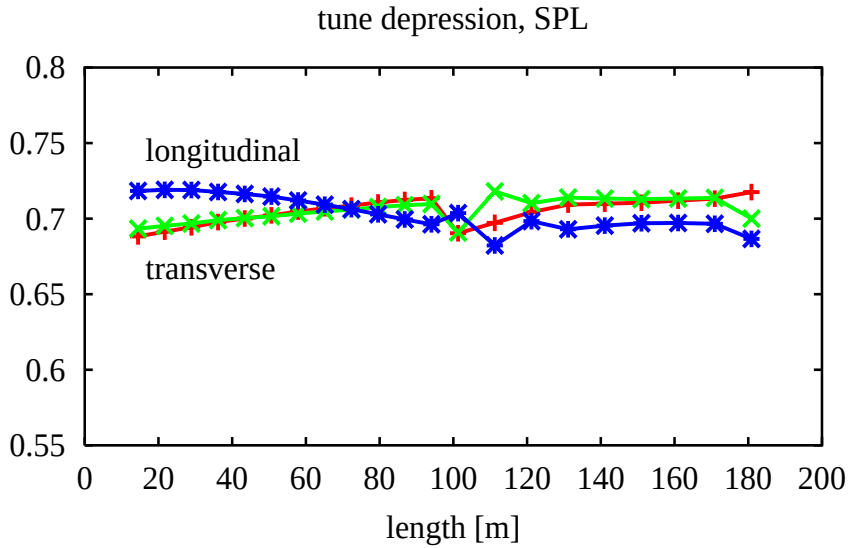


Tune depression

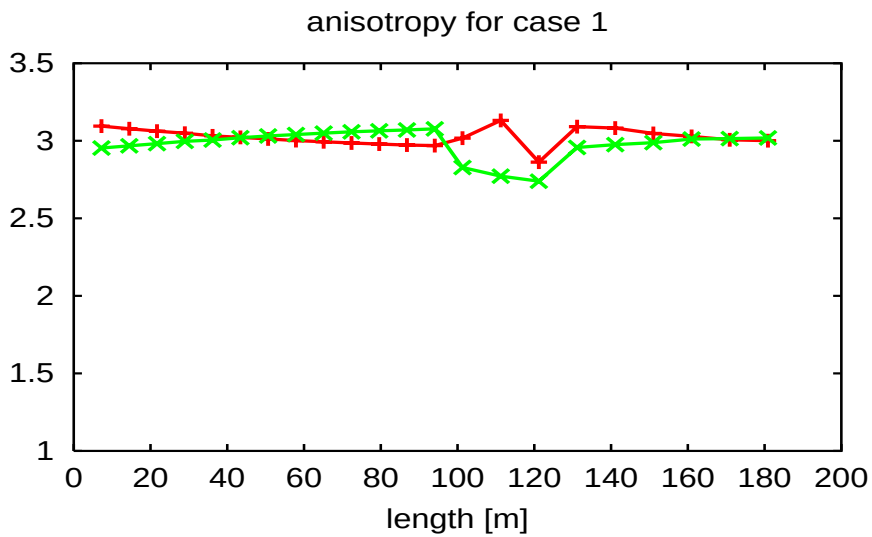


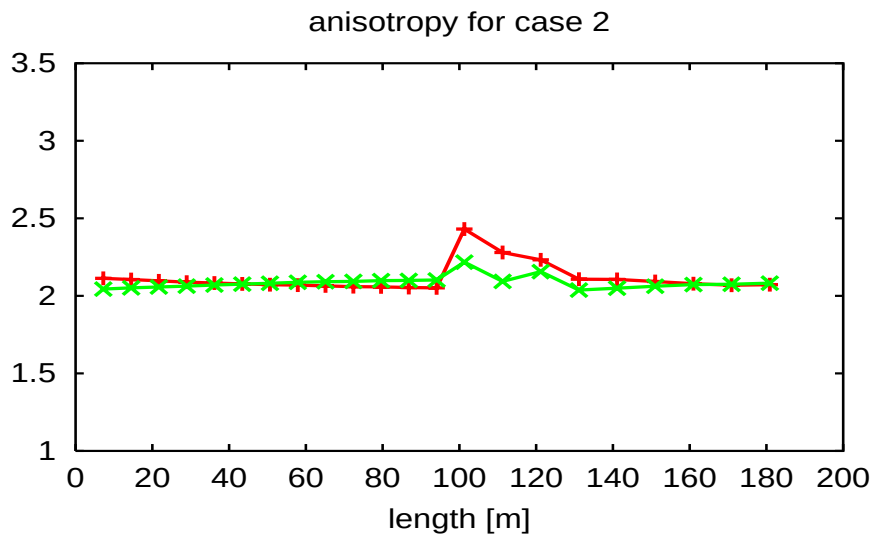


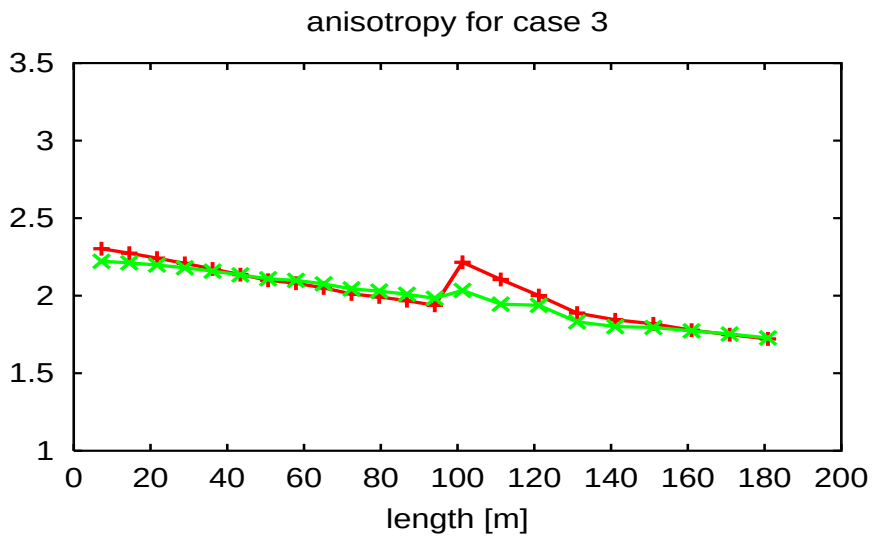


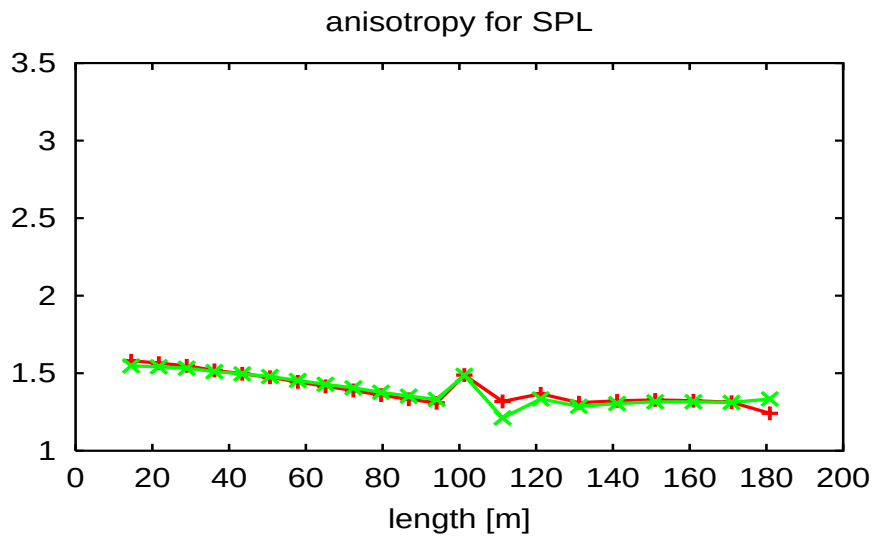


Anisotropy: $\varepsilon_l\sigma_l/\varepsilon_t\sigma_t$

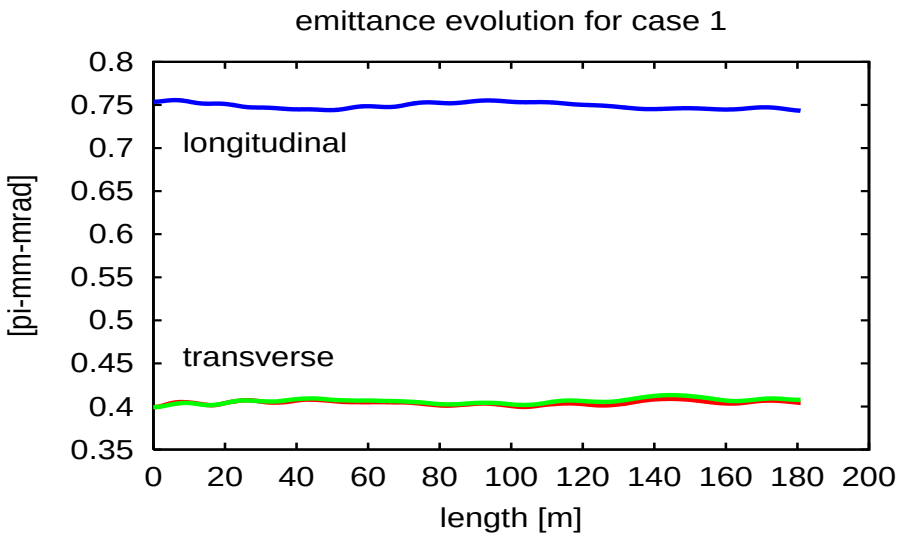


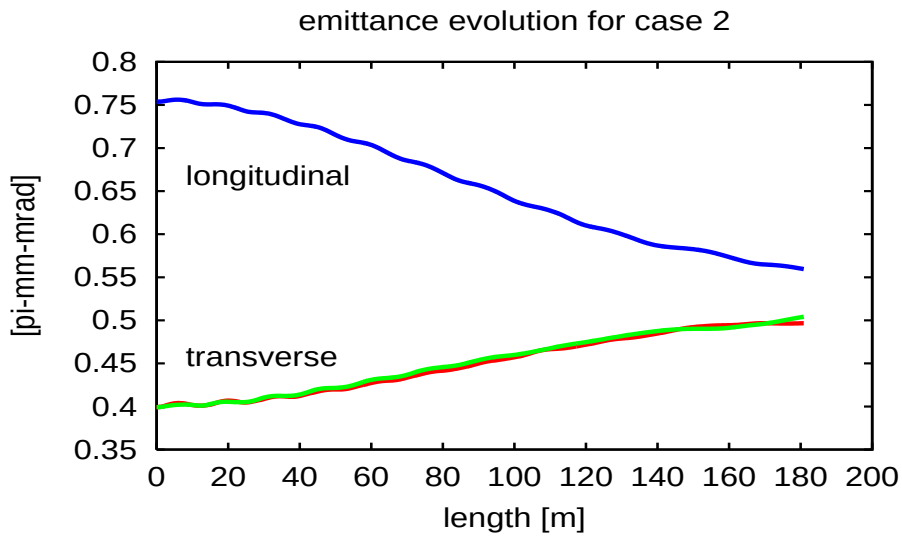


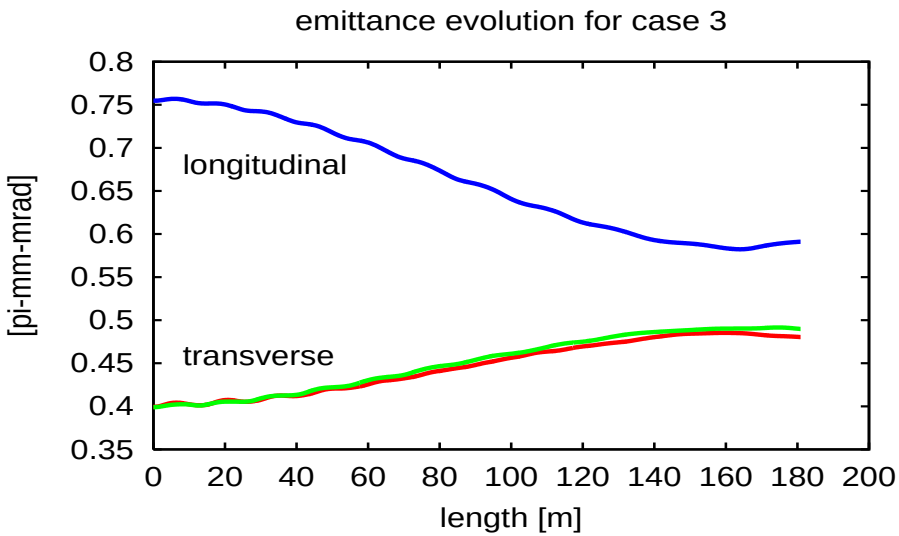


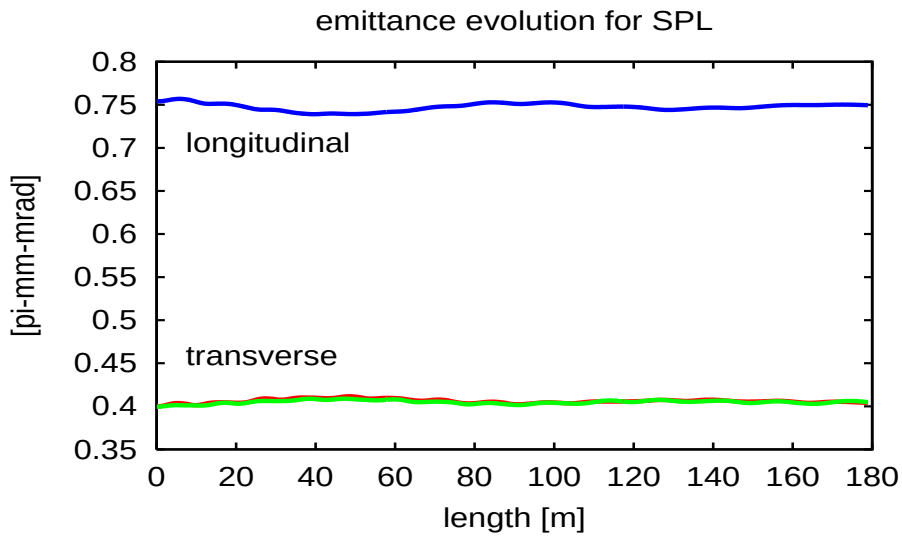


R.m.s. emittance

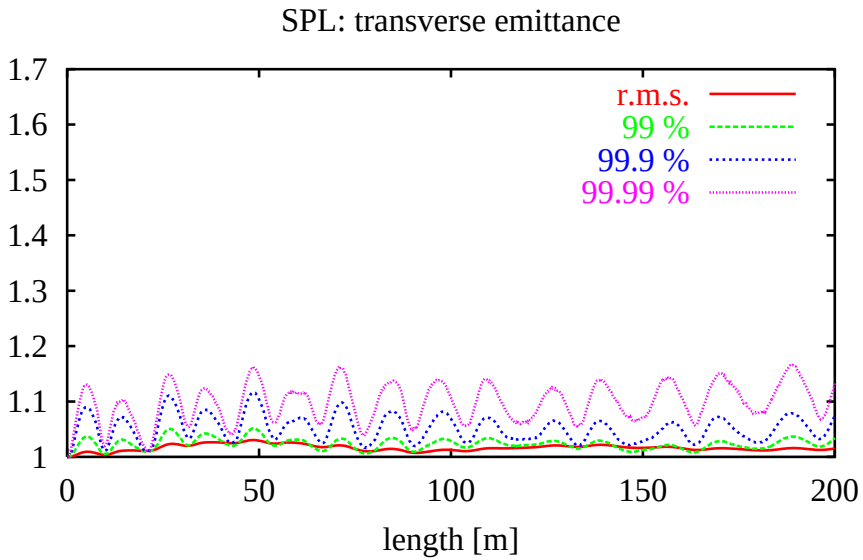


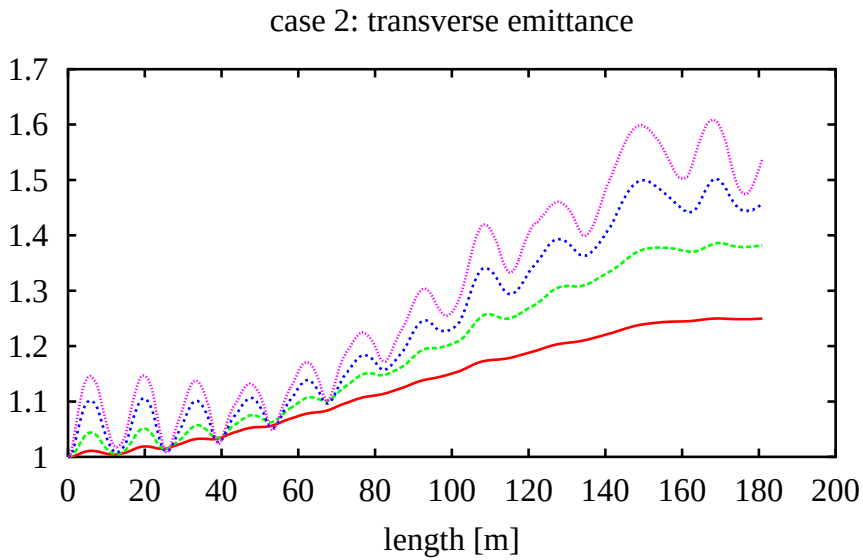


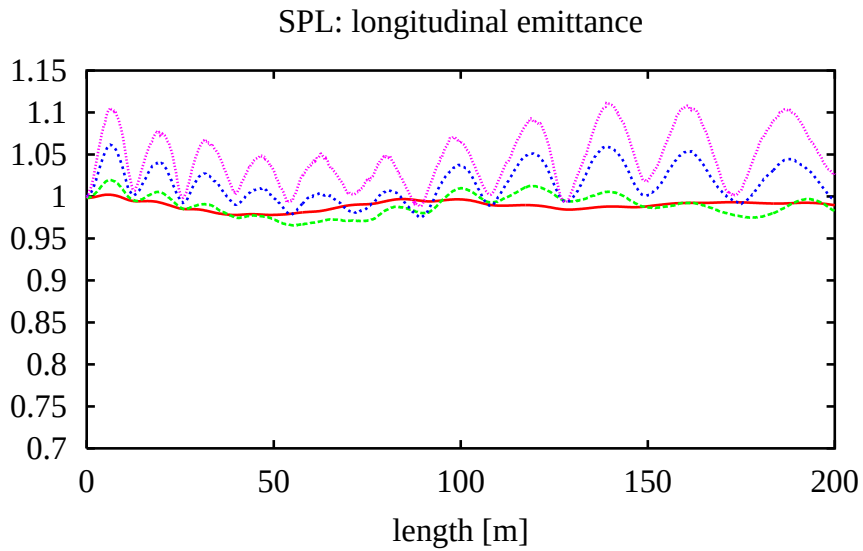


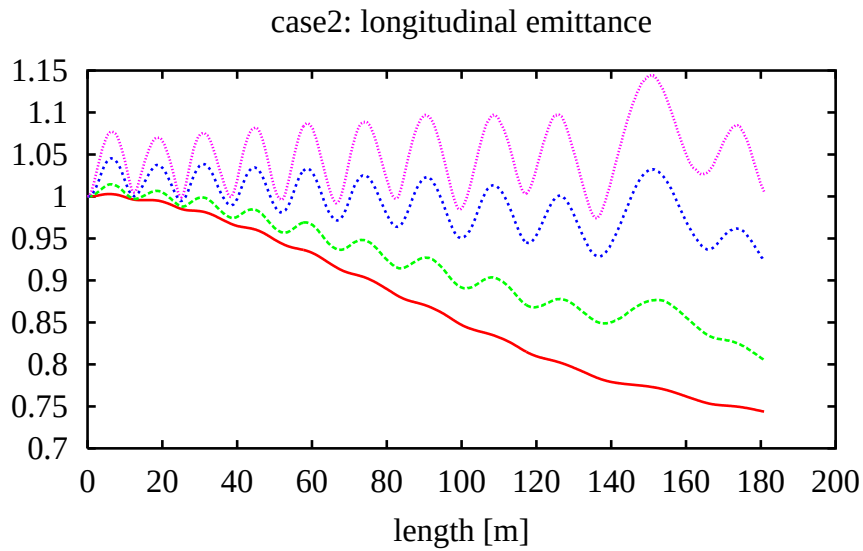


Fractional normalized emittances for case 2 and the SPL





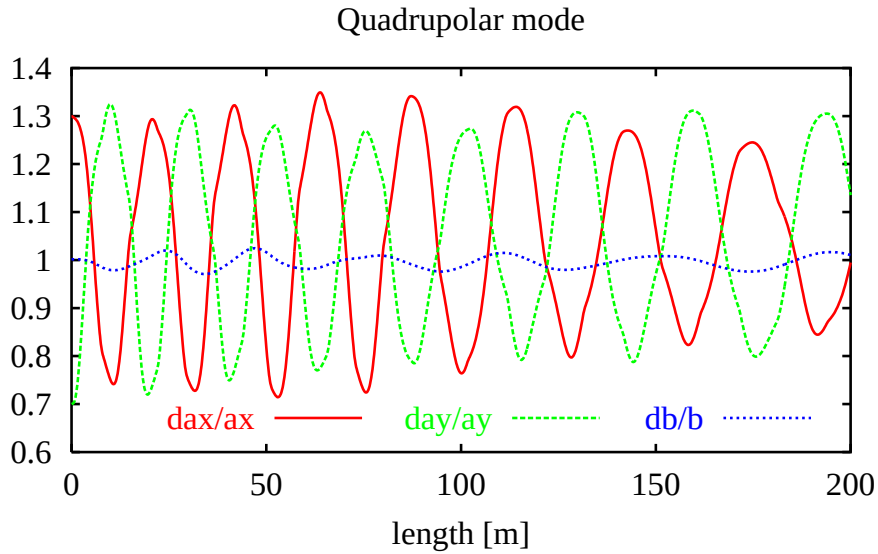




Excitation of mismatch modes with an amplitude of 1.3

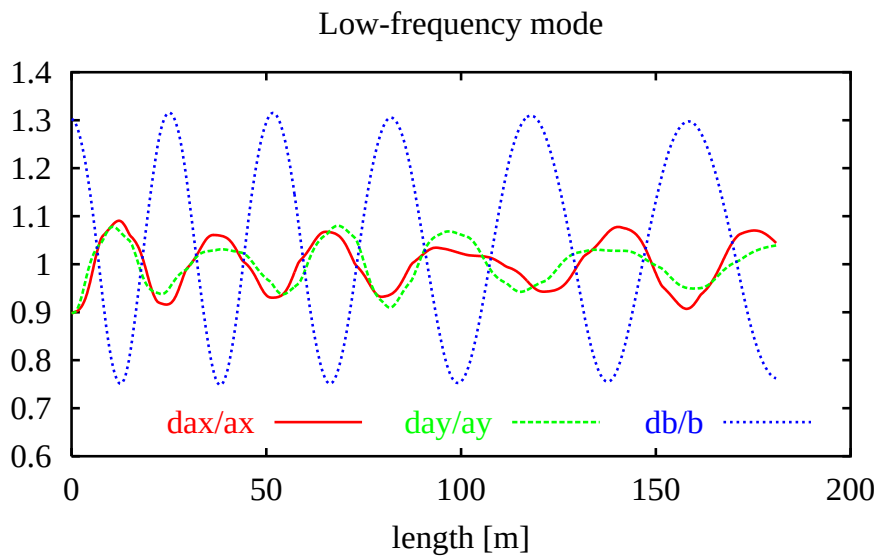
Quadrupolar mode:

$$\frac{\Delta a_x}{a_{x0}} = -\frac{\Delta a_y}{a_{y0}}, \quad \frac{\Delta b}{b_0} = 0$$



High-/Low mode:

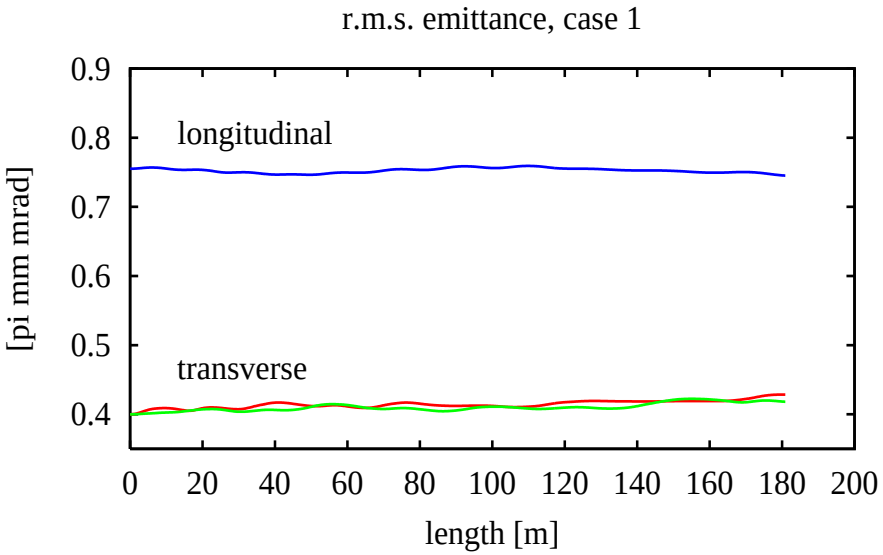
$$\frac{\Delta a_x}{a_{x0}} = \frac{\Delta a_y}{a_{y0}} = g_{H/L}\frac{\Delta b}{b_0}$$

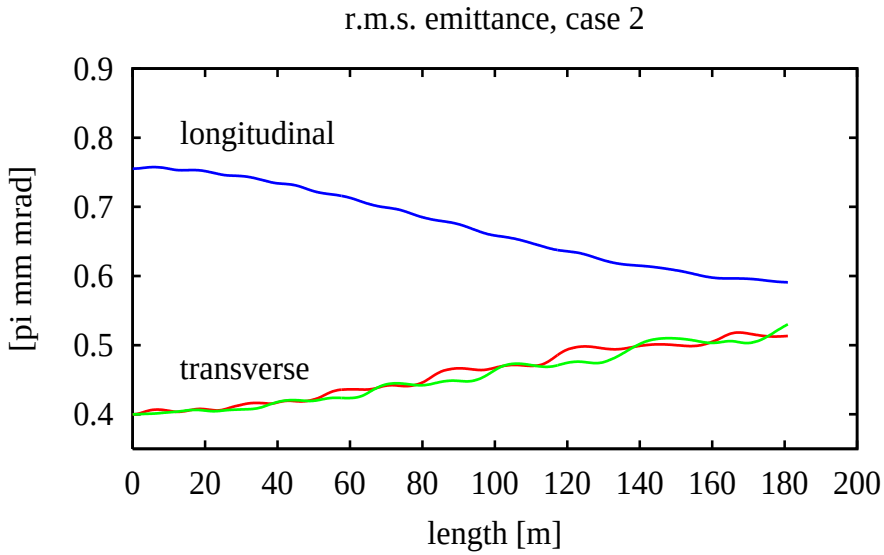


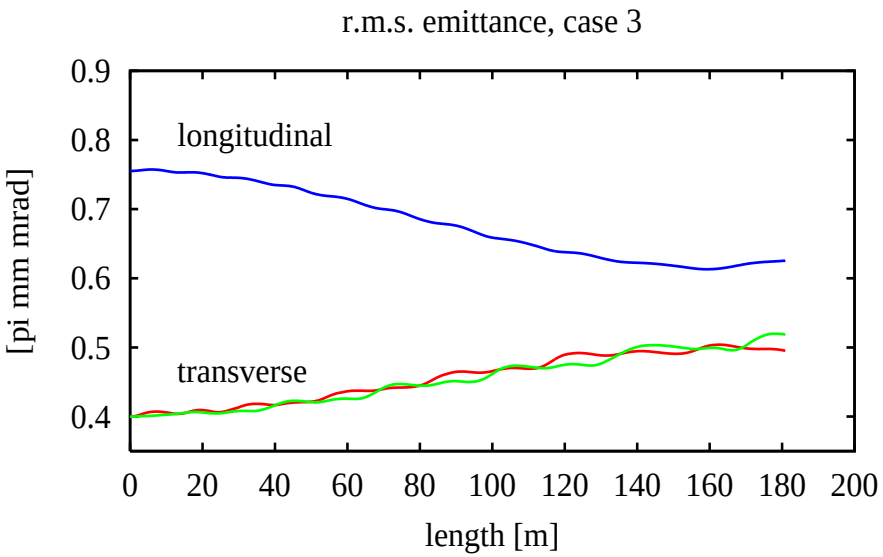
Form factors:

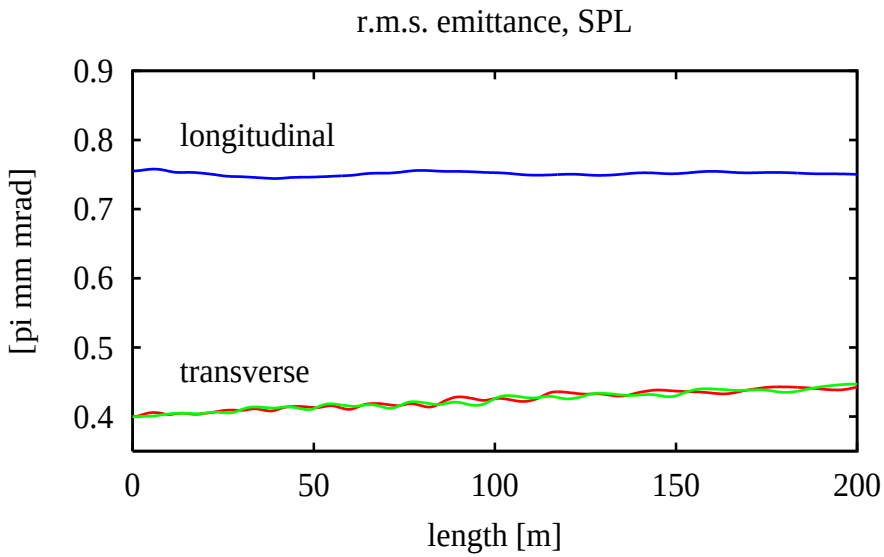
$$g_{H/L} = f(\sigma_{l0}, \sigma_l, \sigma_{t0}, \sigma_t)$$

R.m.s. emittances for 30% quadrupolar mismatch

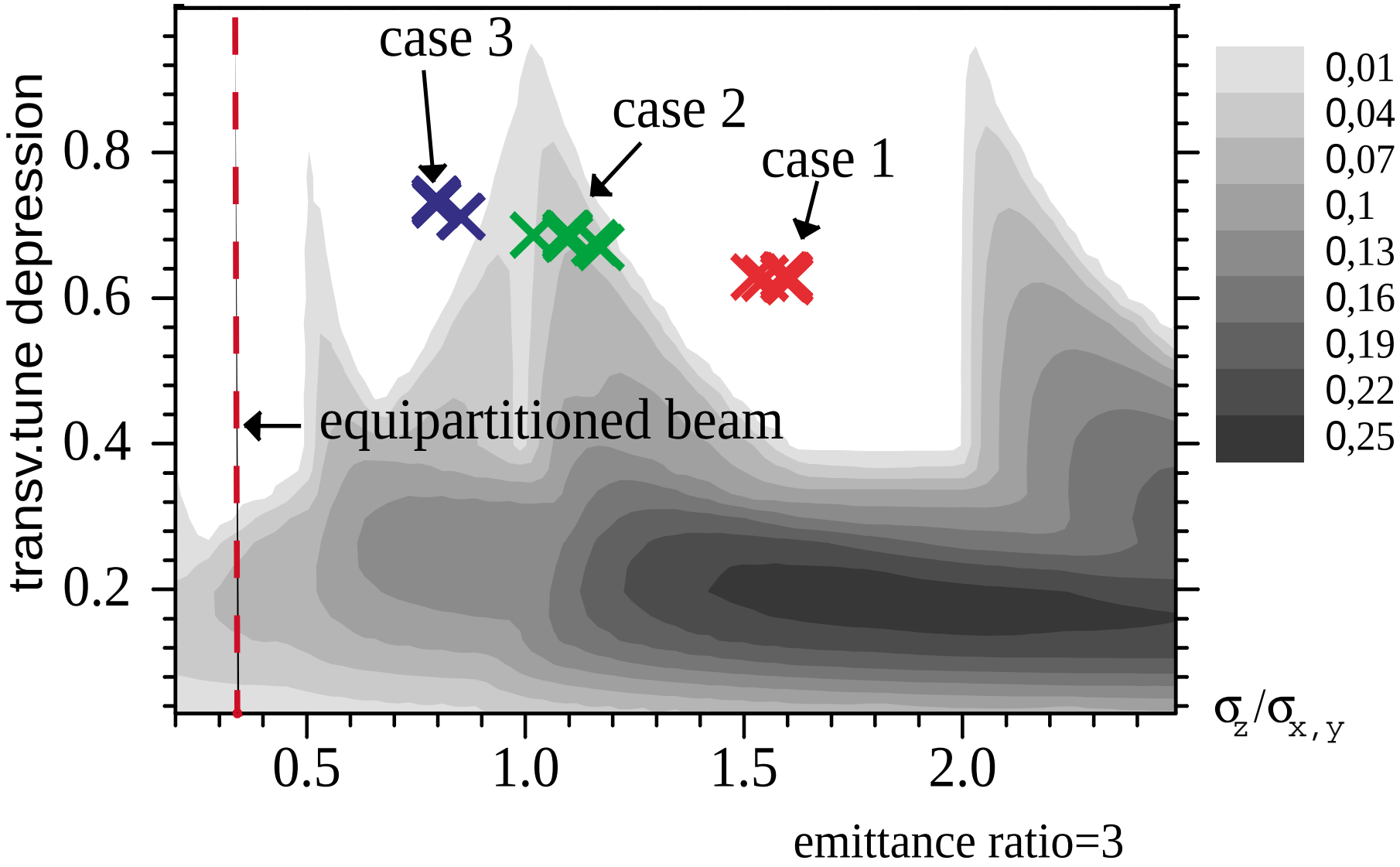




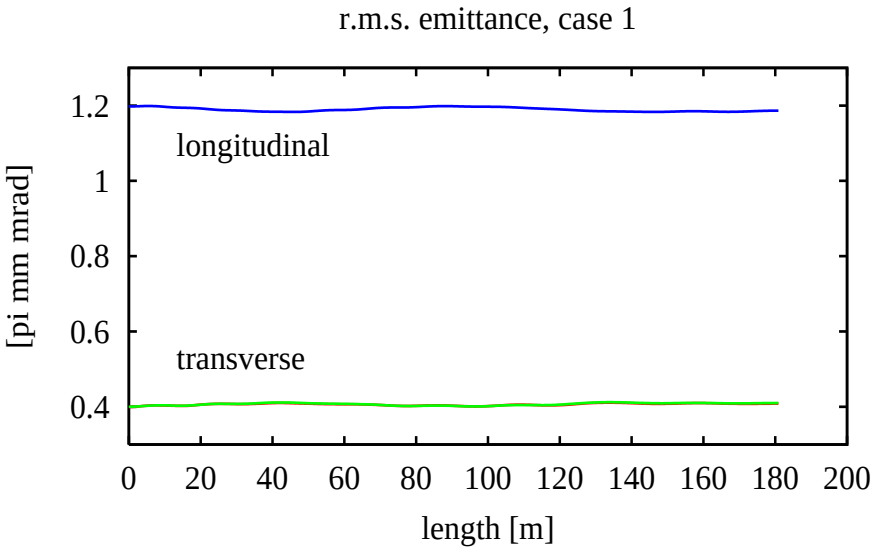




“Hofmann Chart” for the SPL with 50% higher longitudinal emittance



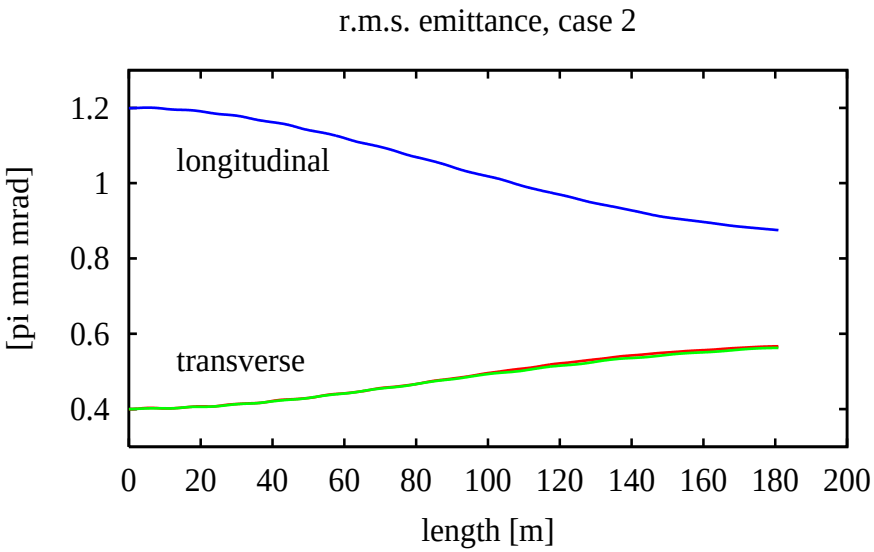
R.m.s. emittance evolution (emittance ratio = 3)

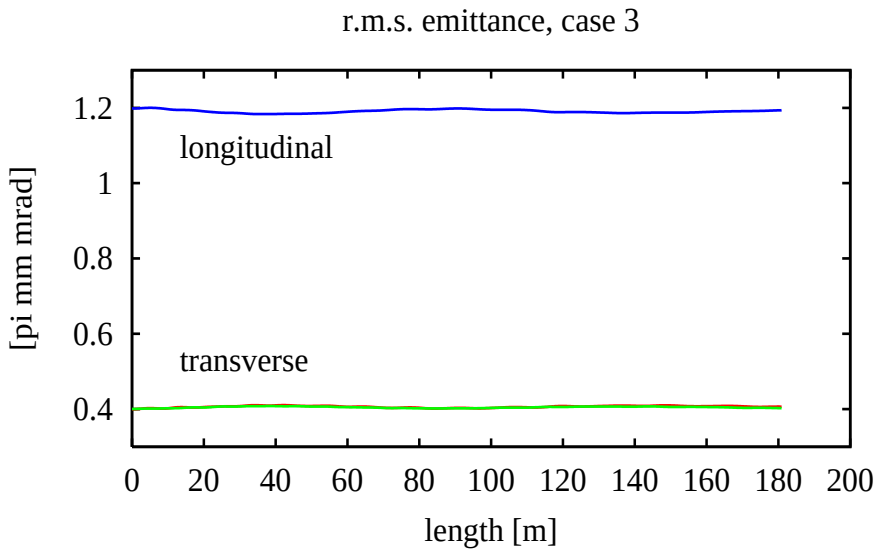


- anisotropy: 2.3 - 4.9
- tr. phase advance: < 85°

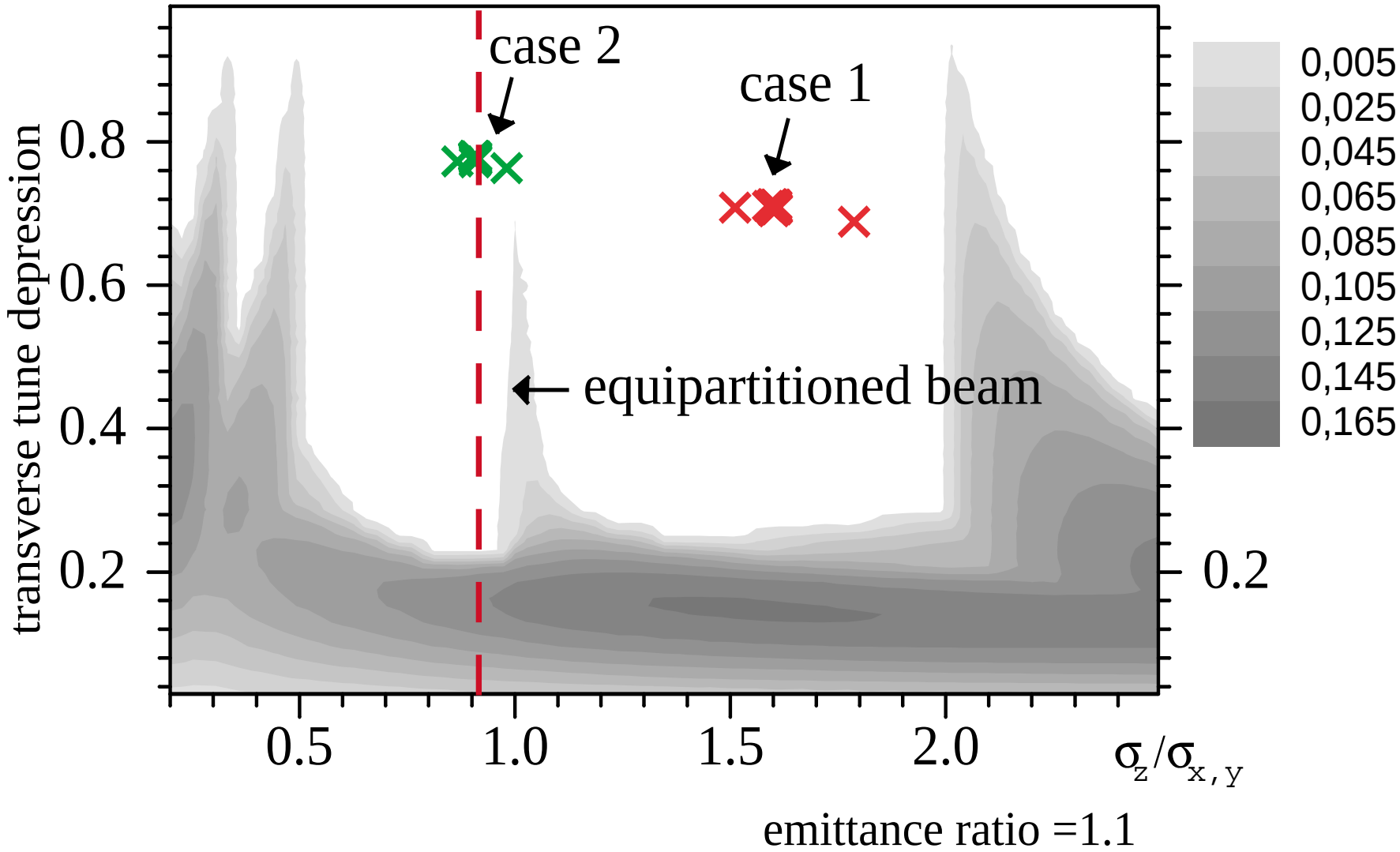
➔ good agreement between chart and simulation

➔ stable operation is possible

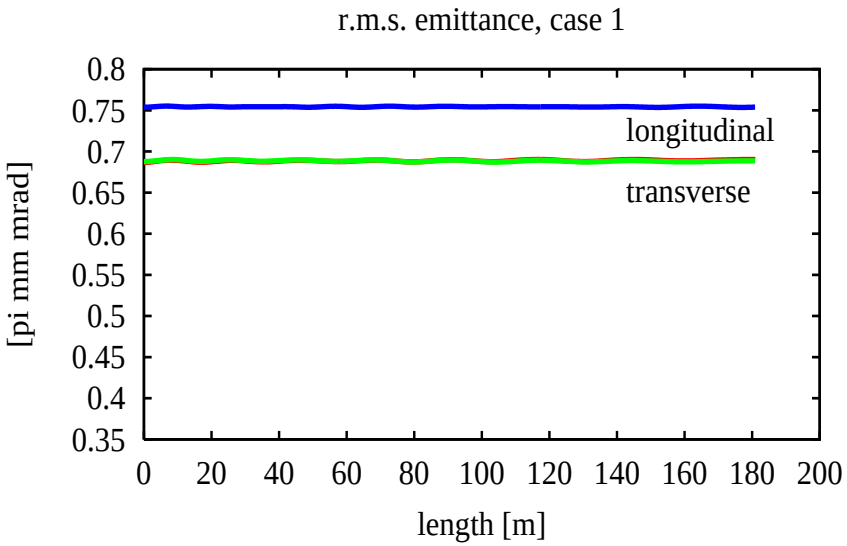


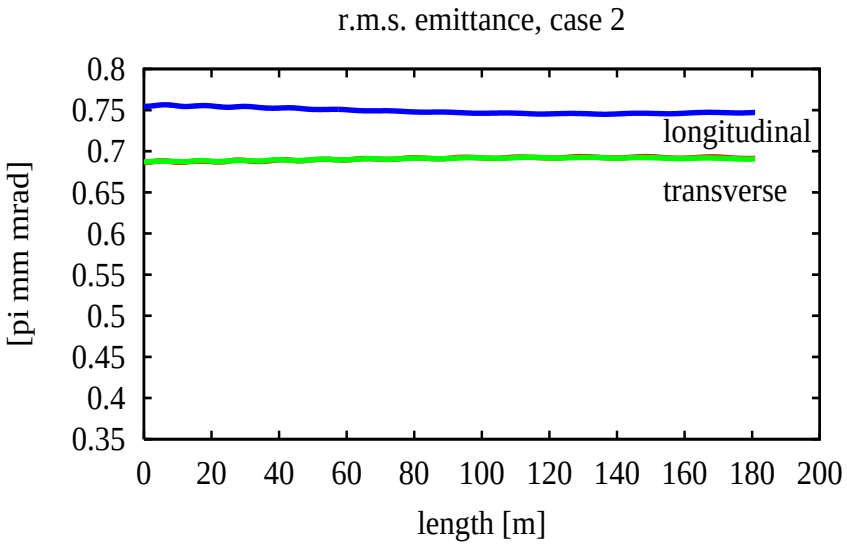


“Hofmann Chart” for the SPL with 70% higher transverse emittance



R.m.s. emittance evolution (emittance ratio = 1.1)





- case 2 is almost perfectly equipartitioned
- anisotropy: 0.95 - 1.9
- transverse zero current phase advance: < 68°

→ good agreement between chart and simulation

→ largest stable area of all cases

What can we learn up to now?

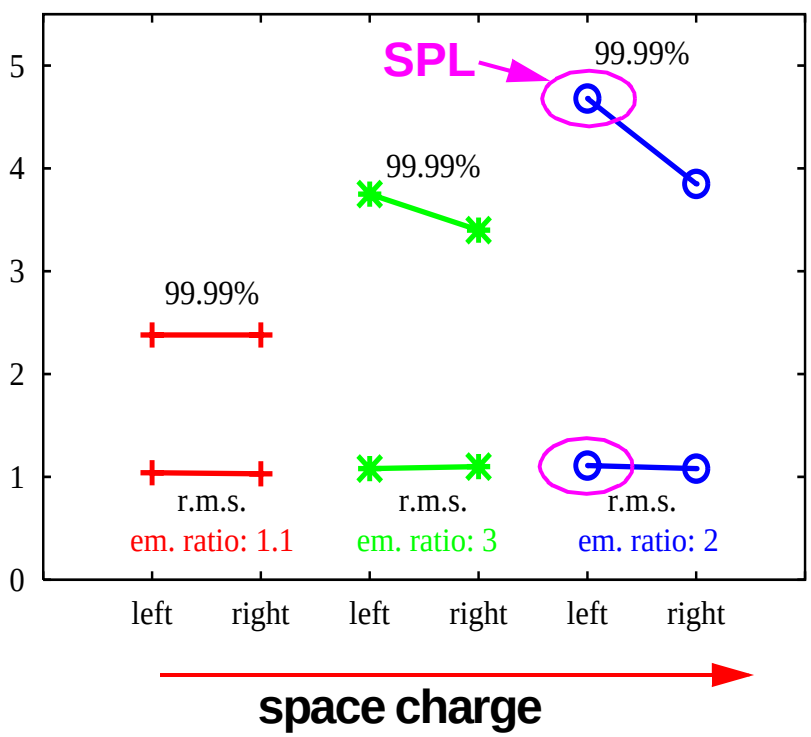
- good agreement between the charts, derived from linearized 2D theory, and 3D PIC simulations of a realistic linac,
- emittance exchange affects r.m.s. quantities, outer particles migrate into a diffused halo,
- the exchange mechanism seems to be insensitive to mismatch,
- stable machine operation with high anisotropy is possible (for moderate tune depression),
- equipartitioned beams have the largest stable area, and
- the SPL can be operated even with emittance blow-up in previous sections.

Which area should be chosen?
(left or right from the instable region)
Which emittance ratio is preferable?

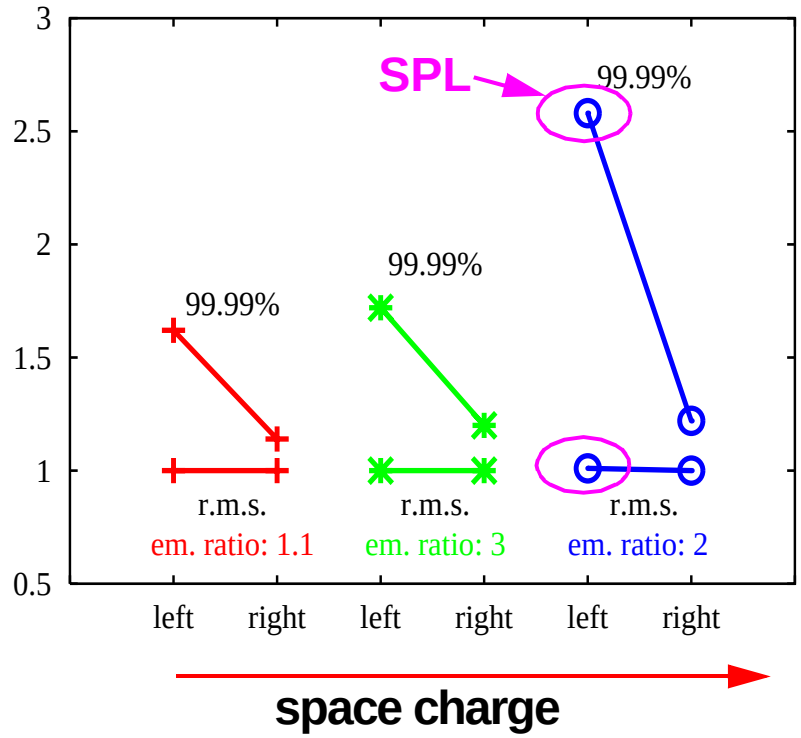
	left	right
transverse effects	higher phase advance ➔ higher focusing forces ➔ weaker tune depression ➔ lower space charge forces ➔ smaller beam radius	lower phase advance ➔ lower focusing forces ➔ stronger tune depression ➔ higher space charge forces ➔ bigger beam radius
longitudinal effects	equal focusing forces ➔ higher space charge forces ➔ higher longitudinal emittance growth in case of mismatch	➔ lower space charge forces ➔ lower longitudinal emittance growth in case of mismatch when accelerating to higher energies the longitudinal phase advance goes down ➔ crossing of unstable region

Max. emittance growth rates for the 3 different emittance ratios when exciting the 3 mismatch modes

transverse:



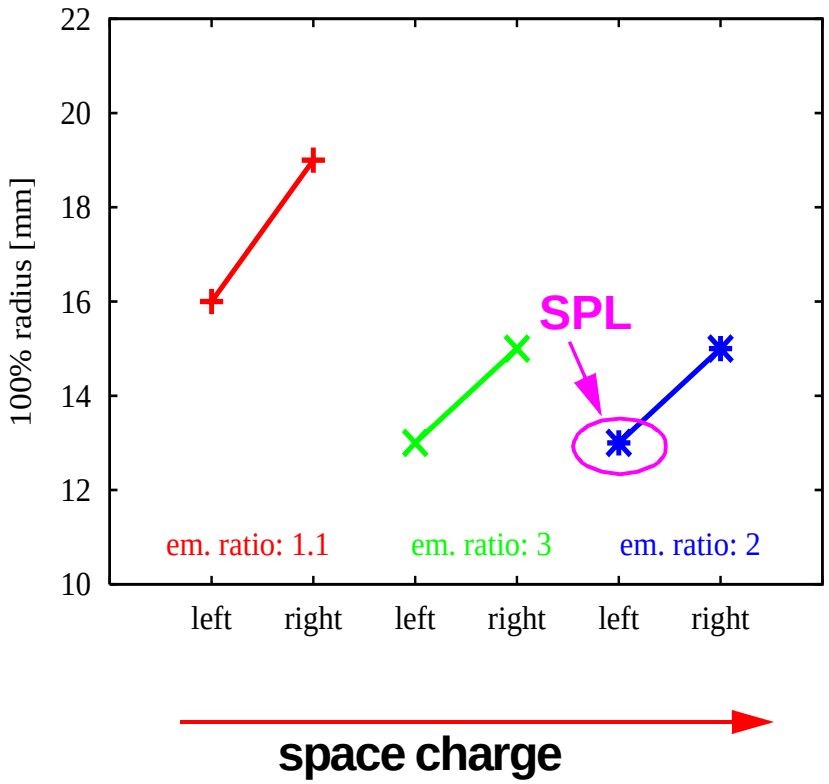
longitudinal:



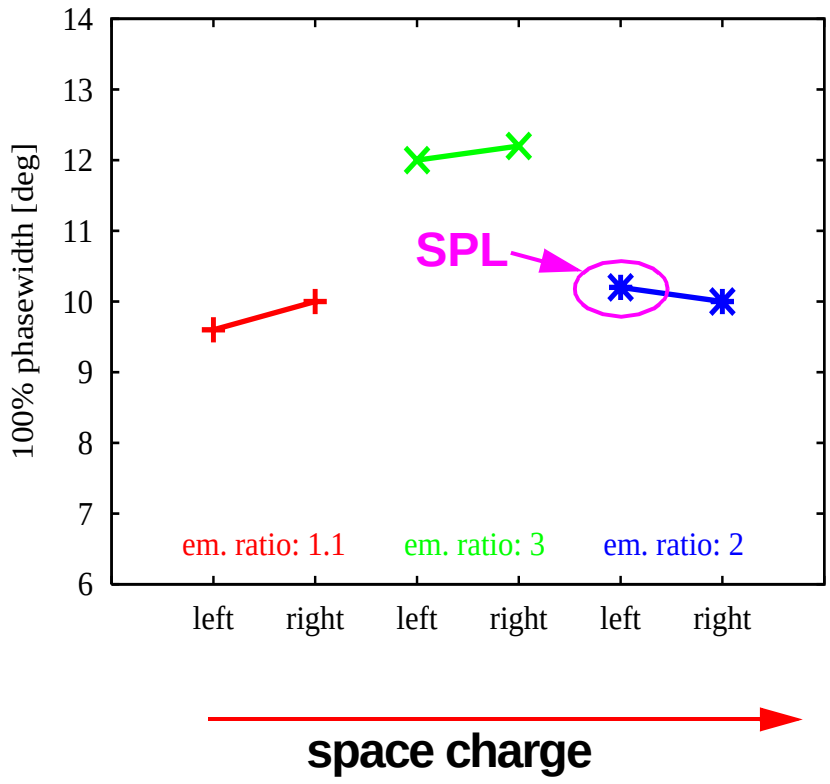
SPL parameters yield the highest emittance growth rates, but ....

Max. beam radii for the 3 different emittance ratios when exciting the 3 mismatch modes

transverse:



longitudinal:



... yield the smallest beam radii, even in the case of mismatch!

more conclusions and outlook

- Two sections of the SPL have been simulated with different transverse settings but identical longitudinal settings for: different emittance ratios, with matched and mismatched beams
- anisotropic beams in unstable areas exchange energy with a tendency towards equipartitioning,
- 2D “Hofmann Charts” provide a useful guideline for the lattice layout,
- outside of the “unstable regions” emittance growth and halo formation is induced by mismatch and increased by high space charge forces,
- emittance growth rates for mismatched beams in the charts are slightly lower for the “right stable area” than for “left” due to the slightly lower space charge forces, but the transverse beam radius is higher due to smaller phase advance.
- Linac 2 at CERN shall be used as test bench to further investigate: the reasons for emittance growth and the reliability of simulation codes (IMPACT).