Production of Round Beams

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CONTENT OF THE TALK

Round Beams – Why?

„ A significant fraction of the beamline users at Swiss light source (SLS) prefer “round beam“ rather than flat beam, ...“, M. Aiba, et al., TUPJE045, IPAC2015, Richmond, VA, USA

What users really prefer most is a diffraction limited beam in all dimensions.

The low emittance will be spoiled from emittance growth due to Intra Beam Scattering (IBS) in case of too high particle density in the bunch – mitigated by longer bunches and round beams

II Radial Damping Wiggler Fields

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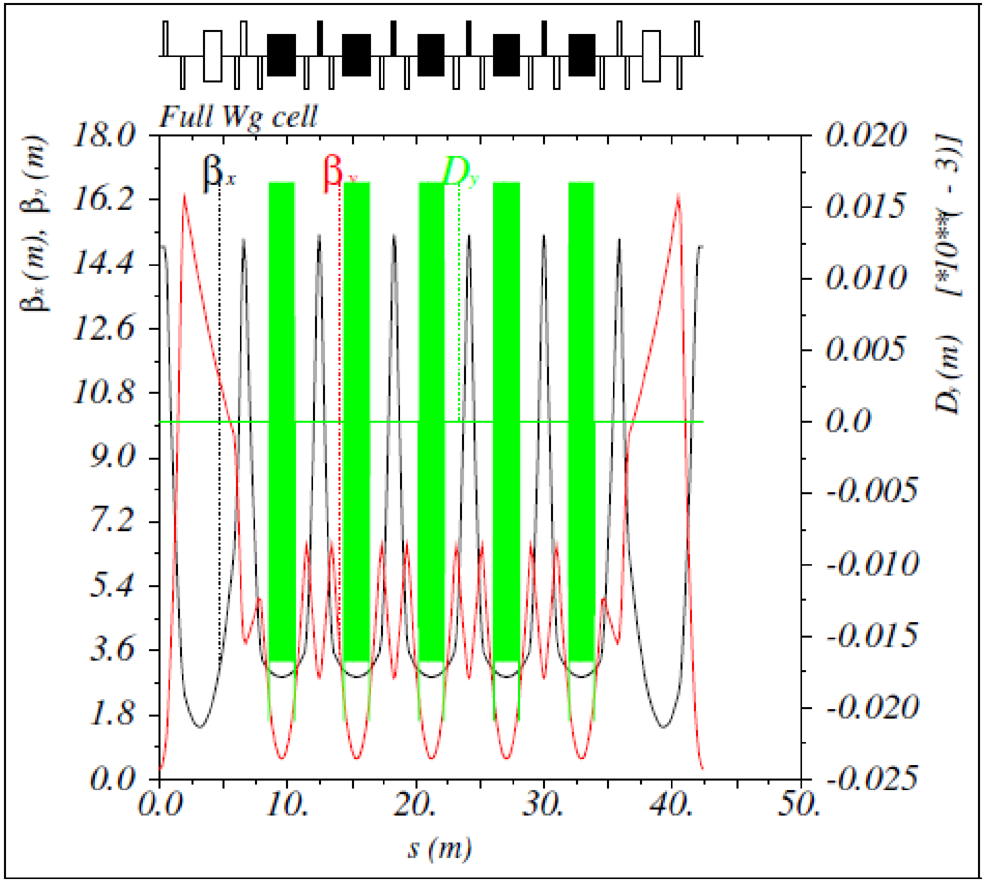
Straight section: damping wigglers with horizontal field



Wigglers with horizontal field:

$B = 2.3$ T

$\lambda = 4.8$ cm

$N_\lambda = 42$

$L_{wiggler} = 2.04$ m

$N_{total} = 20$

$L_{total} = 40.8$ m

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Parameters of the ring

$$Ring = 4 \times 6 \times \left[5 \times FiveCell + Straight\right]$$

20 straight are sections empty

4 straight sections are occupied by damping wigglers

	Wigg OFF	Wigg ON
Energy, GeV	3	
Circumference, m	1379	
Chromaticity h/v	-184/-251	
Betatron tunes h/v	84.52/91.772	
Horizontal Emittance, pm rad	64	3
Vertical Emittance, pm rad	0.6	8.6
Energy spread	4×10^{-4}	1.2×10^{-3}
Momentum compaction	7.8×10^{-5}	7.8×10^{-5}
Damping times h/v/s, msec	210/210/105	10/10/5
Wiggler field, T	0	2.33

In the Möbius Accelerator transverse particle coordinates are exchanged every turn by a set of skew quadrupole magnets sharing the natural emittance equally among the two planes. (R. Talman, PRL 74, 1590 (1995) and M. Aiba, et al., TUPJE045, IPAC2015, Richmond, VA, USA)

Off-axis injection impossible with this really strong coupling of the horizontal and vertical plane.

Comparison of these two techniques:

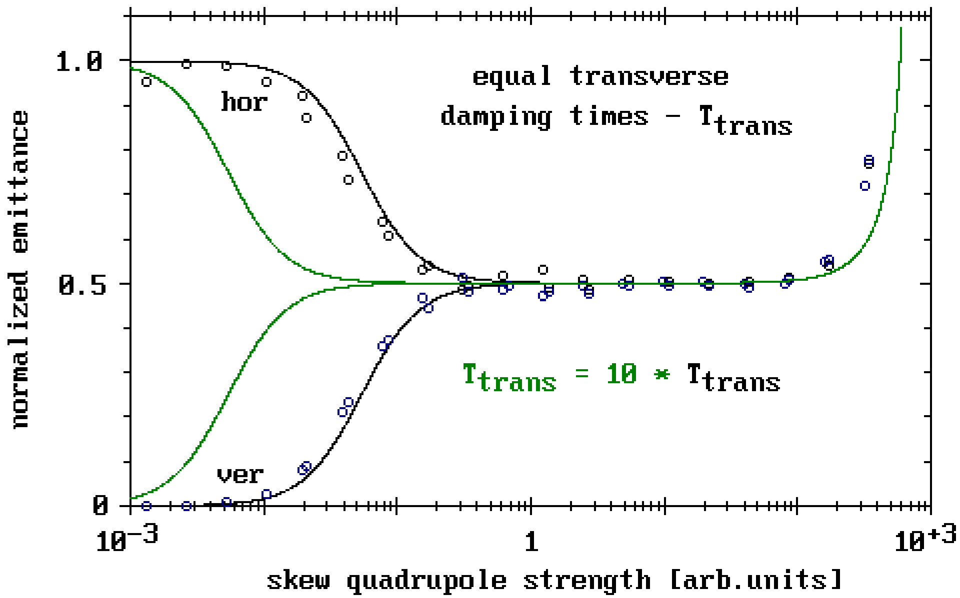
Technical Approach	**Injection**	**Emittance control**	**Complexity**
Radial Damping Wiggler	Off-axis	yes	large
Möbius Accelerator	On-axis	no	moderate

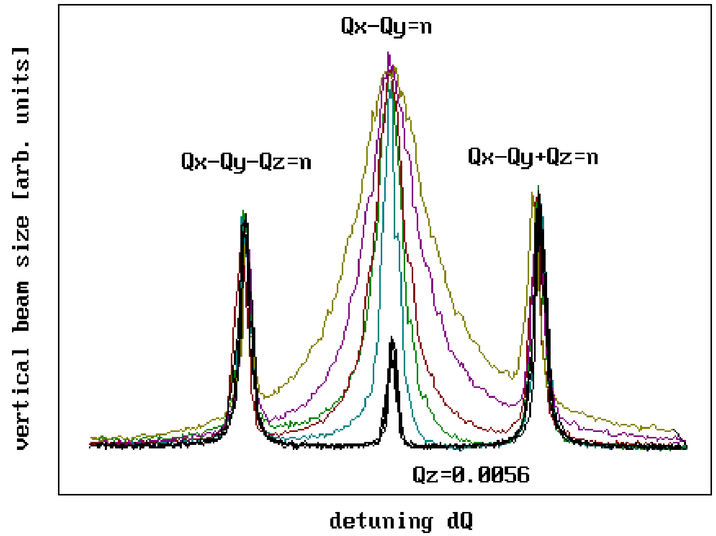
linear coupling due to skew quadrupole gradient:

Q_x-Q_y=n, n=integer

on resonance emittance sharing - $\varepsilon_x=\varepsilon_y=\varepsilon_0/2$

with equal damping times in both planes





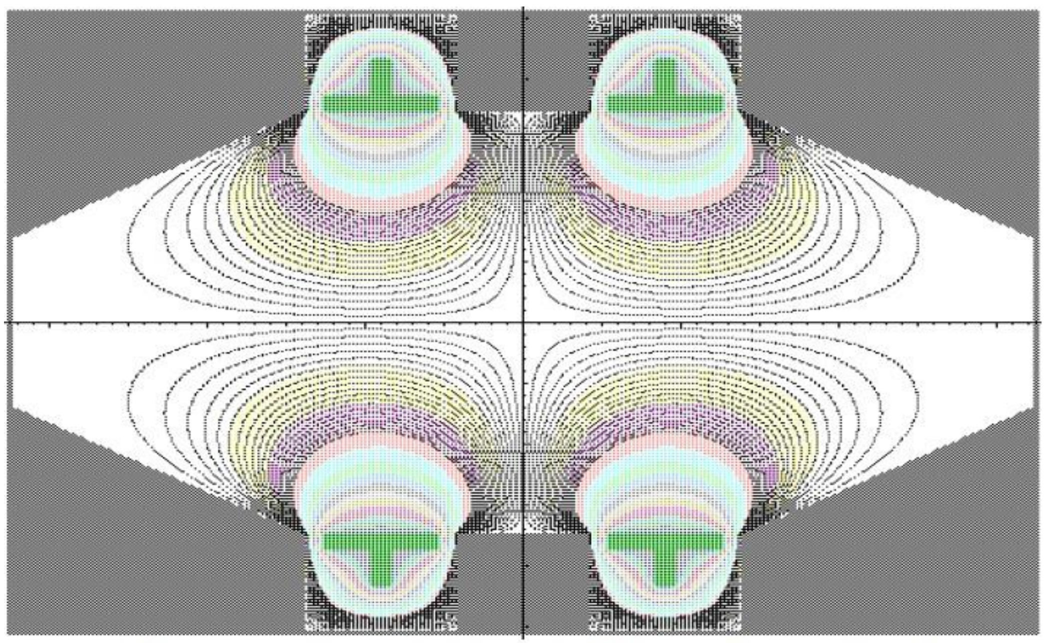
Compensation of the coupling resonance in the BESSY II storage ring – as expected: damping dominates for very small coupling coefficients, and width depends on coupling strength. „power broadening", will be helpful later on

Comparison of solutions from multi particle tracking and first modeling attempts with analytical solutions based on moment mapping.

For better control of the coupling and in case the storage ring can not be operated at the coupling resonance the resonance can be excited artificially. With a time dependent sinusoidal varying skew gradient the resonance condition is:

$$Q_x – Q_y = n \pm F_{sq}/F_0,$$

with the revolution frequency, F_0, and of the skew gradient, F_{sq}.



Skew quadrupole-like field distribution in the centre of the stripline arrangement.

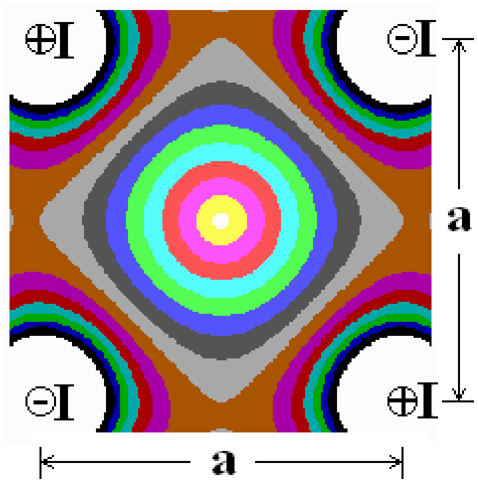
Neighboring currents in opposite directions.

Full coupling and emittance sharing achievable – little power broadening, sensitivity to tune jitter.

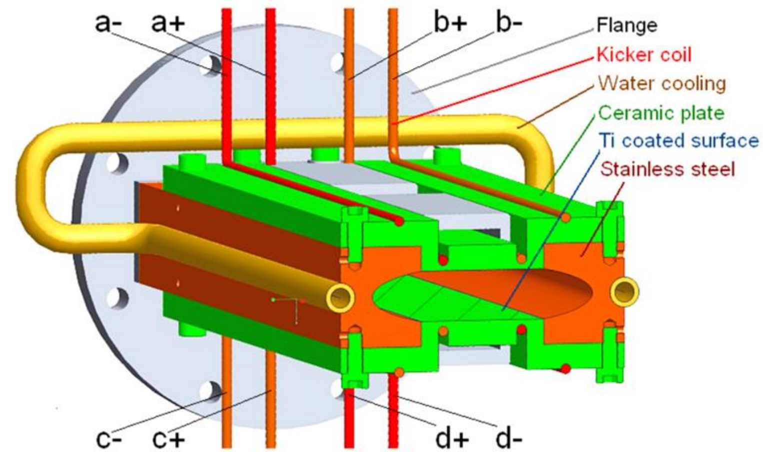
P. Kuske, R. Görgen, EPAC 2002, WEPLE015

The required frequency, F_q, for the skew quadrupole is on the order of 100 kHz. Striplines are not really required. Simpler design could look like this:

skew quadrupole with four wire arrangement and currents flowing in alternating directions



$$\left|\frac{\partial B_x}{\partial x}\right| = \frac{4\cdot\mu\cdot I}{\pi\cdot a^2} = \frac{1.6\cdot 10^{-6}\cdot I[A]}{a^2[m^2]}\ [T/m]$$



quite similar to our non-linear injection kicker magnet

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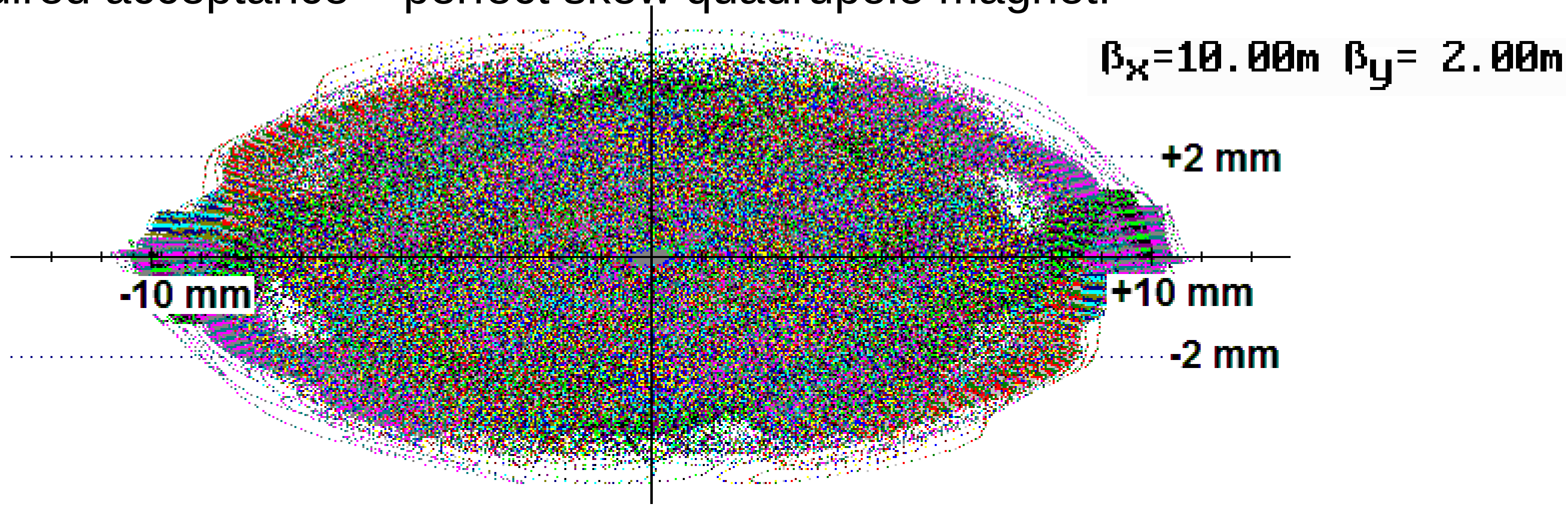
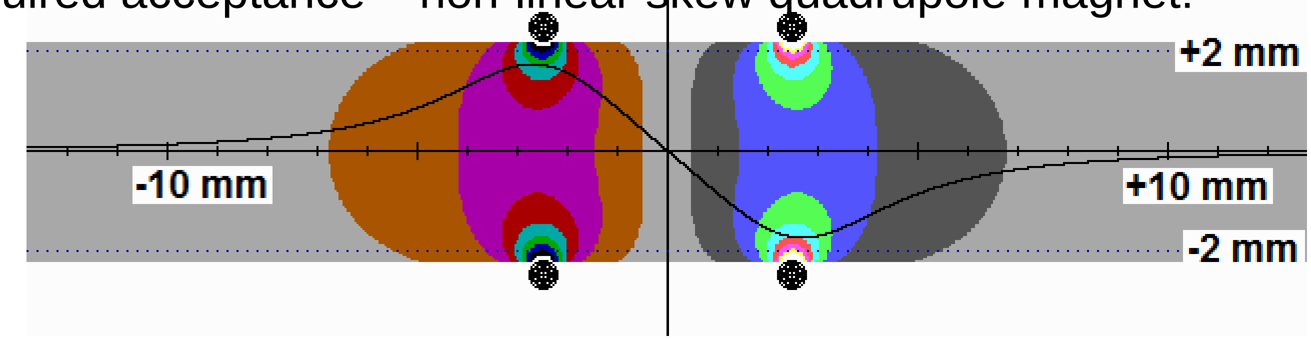
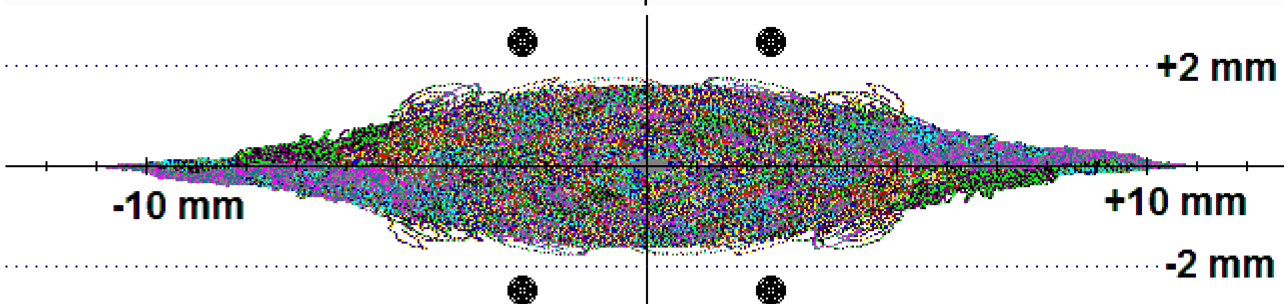
Required acceptance – perfect skew quadrupole magnet:

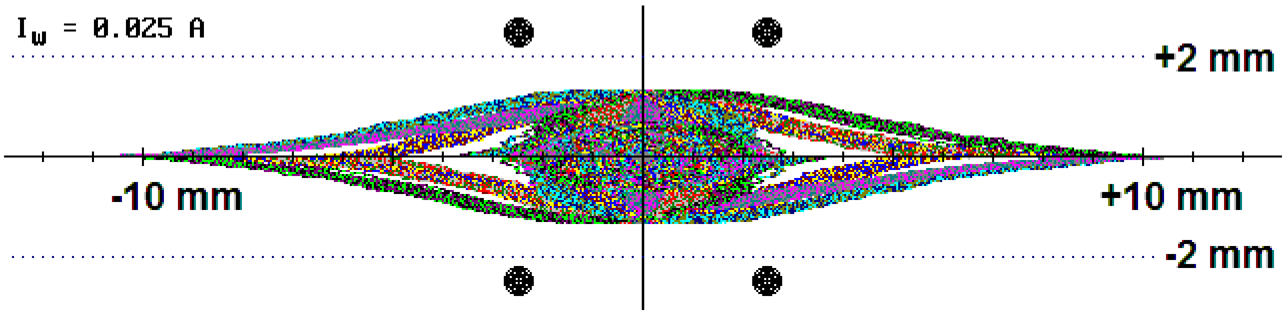


Required acceptance – non-linear skew quadrupole magnet:

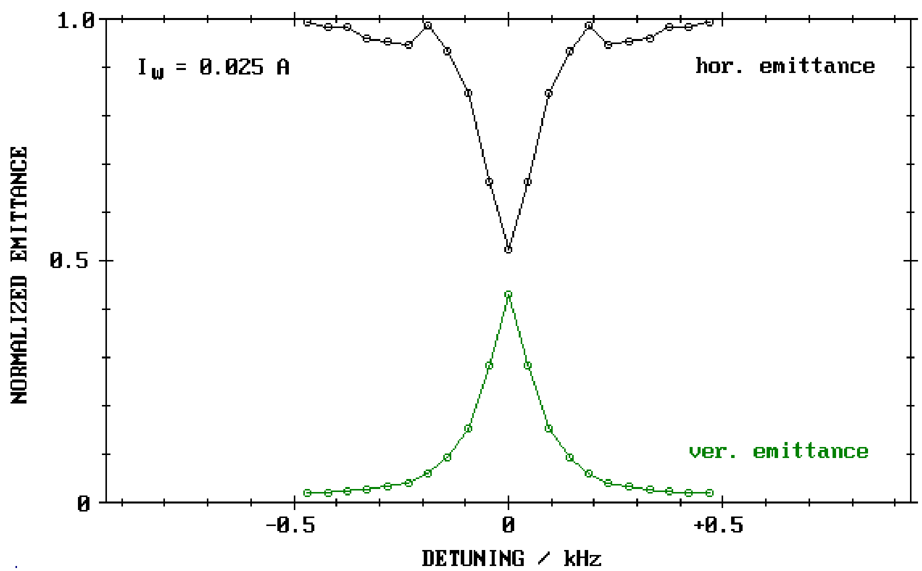




Level of excitation as large as not to cause injection losses



Level of excitation will still be too small to broaden the coupling resonance
Small resonance width – stability of the tunes sufficient?
→ active tune stabilization



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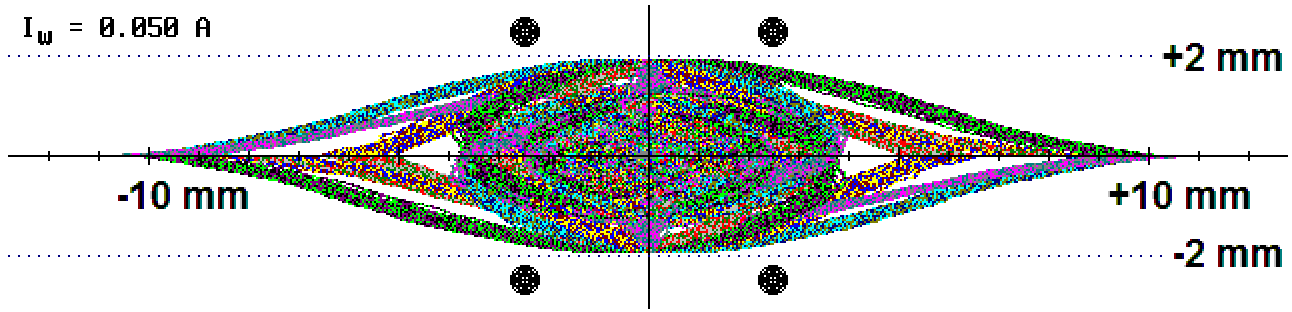

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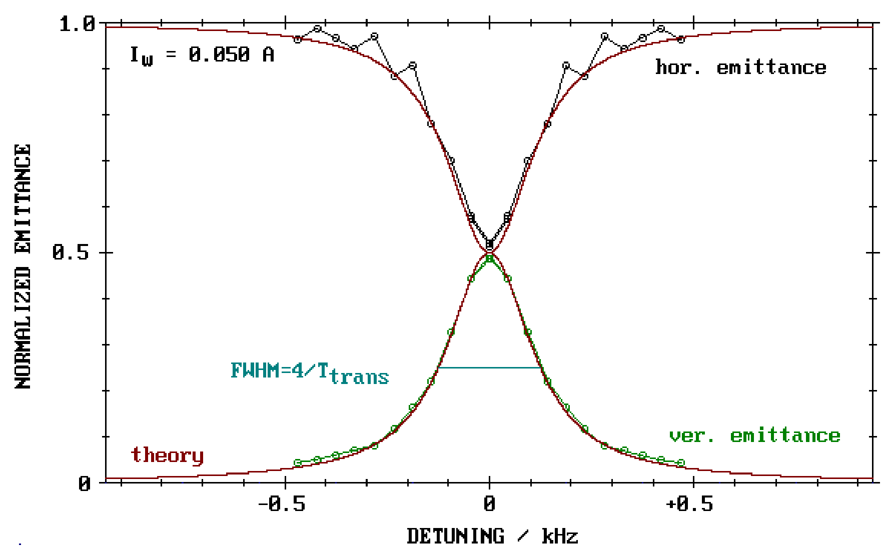
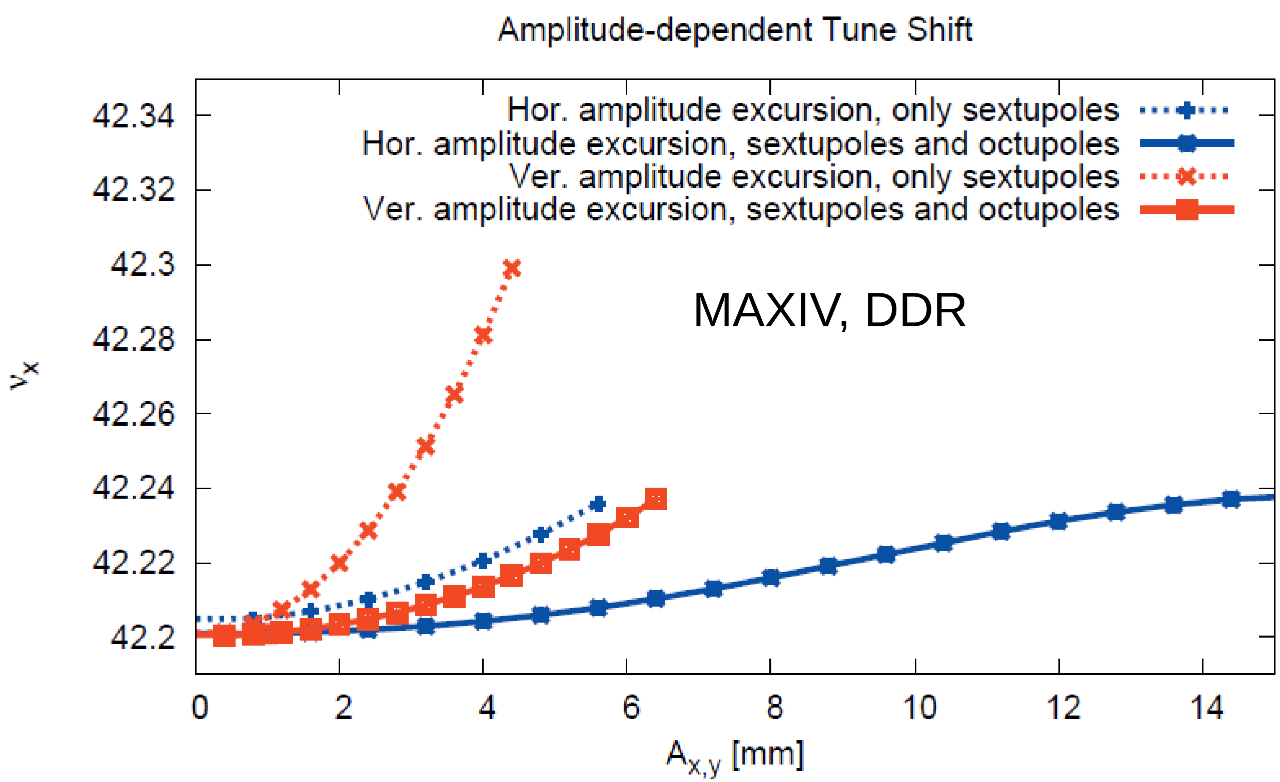


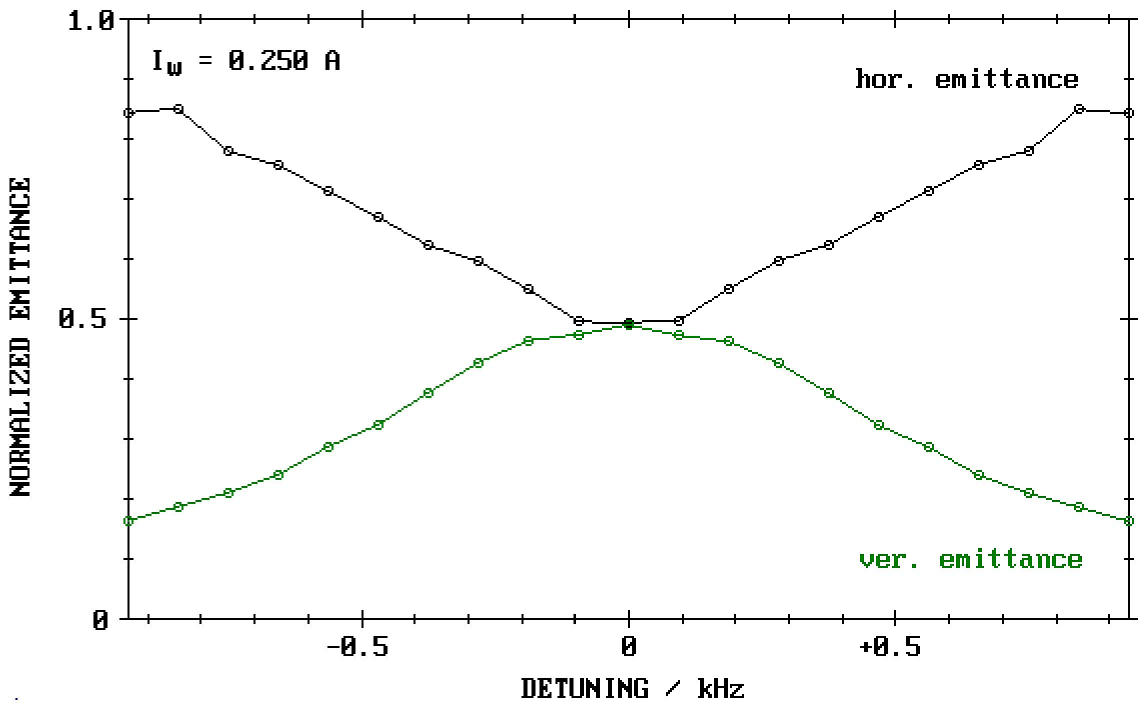
VI. EXCITING THE COUPLING RESONANCE – OPERATIONAL ASPECTS

Tune shift with amplitude would help – resonance condition only fulfilled for small amplitudes, stronger excitation could be used



$\Delta\nu$ =0.02 → ΔF =11.4 kHz – much larger than the natural resonance width $\cong 4/\tau_{trans}$ or width due to non-linear chromatic effects

The resonant coupling sets in for small horizontal oscillation amplitude. Stronger skew gradients will not cause losses of injected particles and the “power broadening” can be made as large as desirable.



This could be tried out with the tune of the ring set to the coupling resonance. The resonance would be excited by the skew gradient errors – compensated for as much as required for a small resonance width.

Four techniques for the production of round beams have been presented:

- Radial wiggler fields
- The Möbius accelerator
- Artificial excitation of the coupling resonance with a special magnet
- Sitting on the intrinsic coupling resonance and taking advantage of the tune shift with amplitude
- These techniques require careful tune stabilization or adjustment of excitation frequency and strength of skew components

Technical Approach	Injection	Emittance control	Complexity
Radial Damping Wigglers	off-axis	yes	large
Möbius Accelerator	on-axis	no	moderate
Resonance Excitation	off-axis	(no)	moderate
On Coupling Resonance	off-axis, tune shift with ampl.	(no)	trivial