Injection System for SLS 2.0 Based on Non-Linear Injection Kicker and Efficient Emittance Exchange

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Seminar Talk PSI, September 26, 2023

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II. NLK Based Injection Scheme

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V. Summary

I. Injection System for SLS 2.0

Profits from the long straight and the low emittance booster/emittance exchange

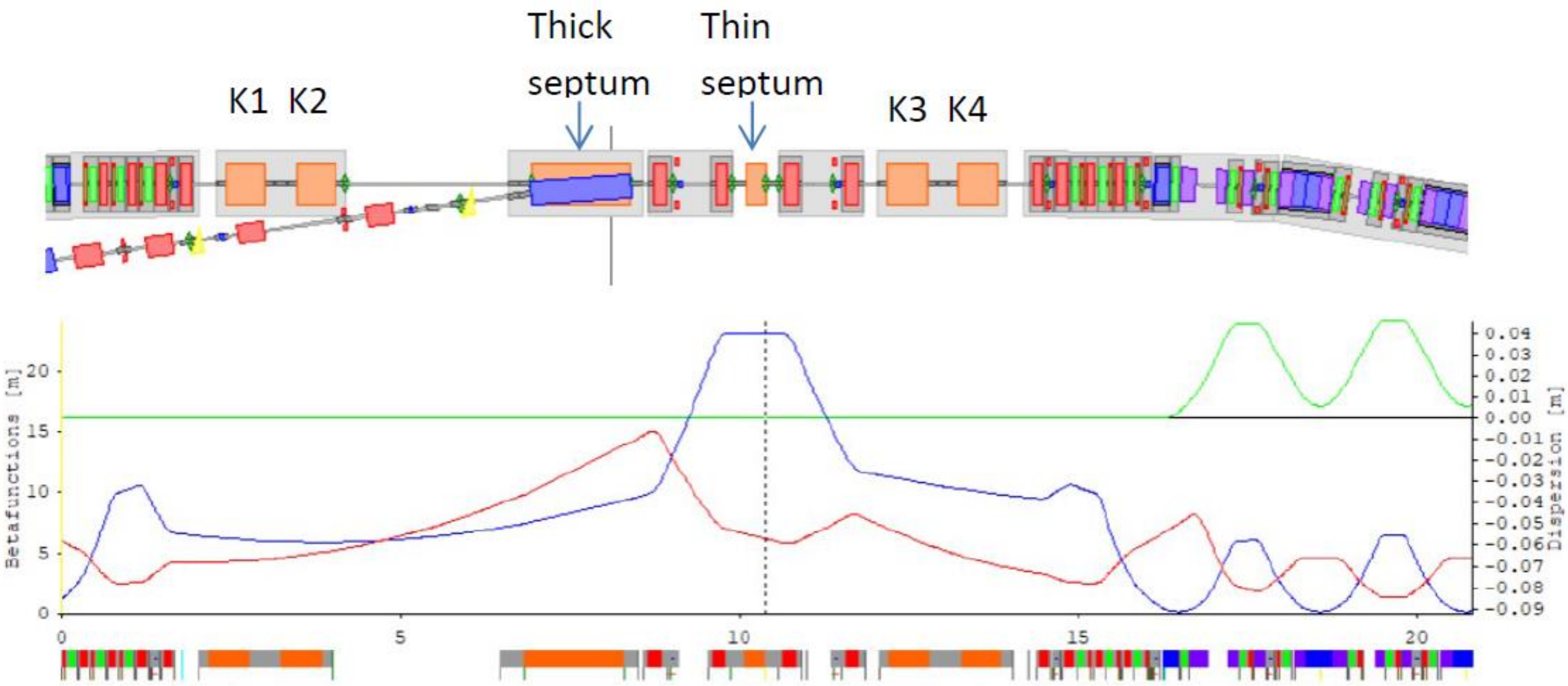


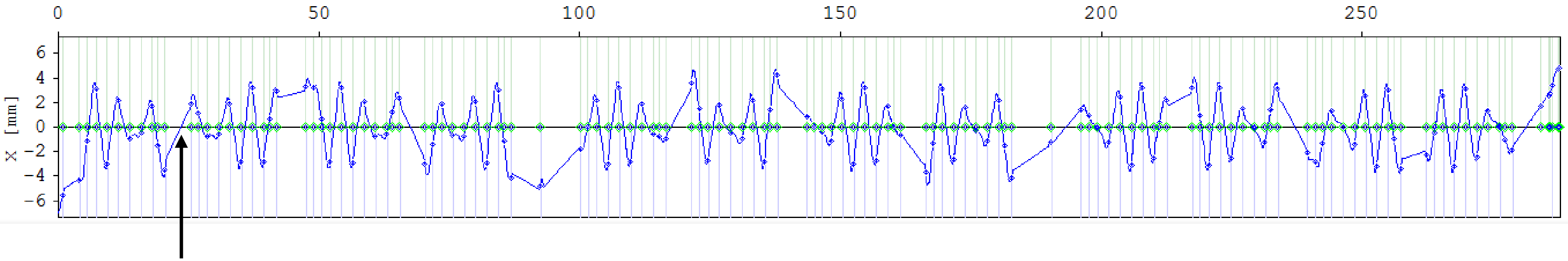
Figure 3. Layout of injection straight and optical functions.

PAUL SCHERRER INSTITUT PSI	Projekt / Project: SLS 2.0
Titel / Title: SLS 2.0 injection and injection straight layout	Dokument Nummer / Document Identification: SLS2-AM81-003-4
Autor(en) / Author(s): Masamitsu Aiba and Andreas Streun	Datum / Datee: 11.03.2021

+ space for fast kicker magnets in the following straight

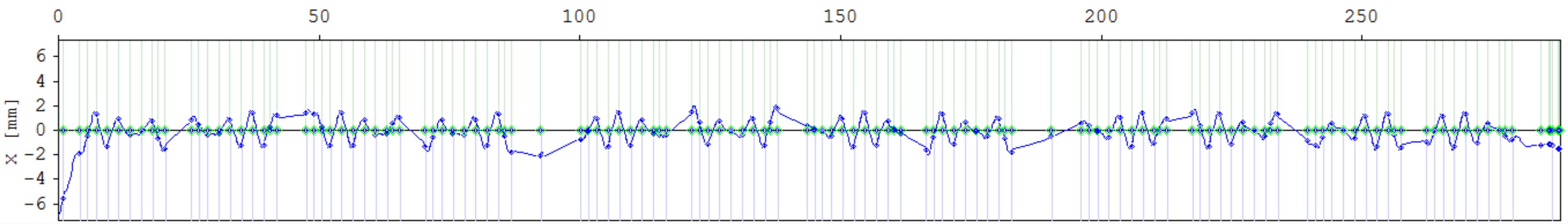
many thanks to Masamitsu Aiba for providing additional information

I. Injection System for SLS 2.0



fast kicker

Aperture sharing – stored and injected beam oscillate inside the acceptance, without injection bump



Injection bump active – hor. oscillation could even be smaller with support of fast kicker

Future kicker developments could lead to near transparent injection with just one bunch being kicked or longitudinal on-axis injection, with even faster kickers and shorter injected bunches

I. Injection System for SLS 2.0

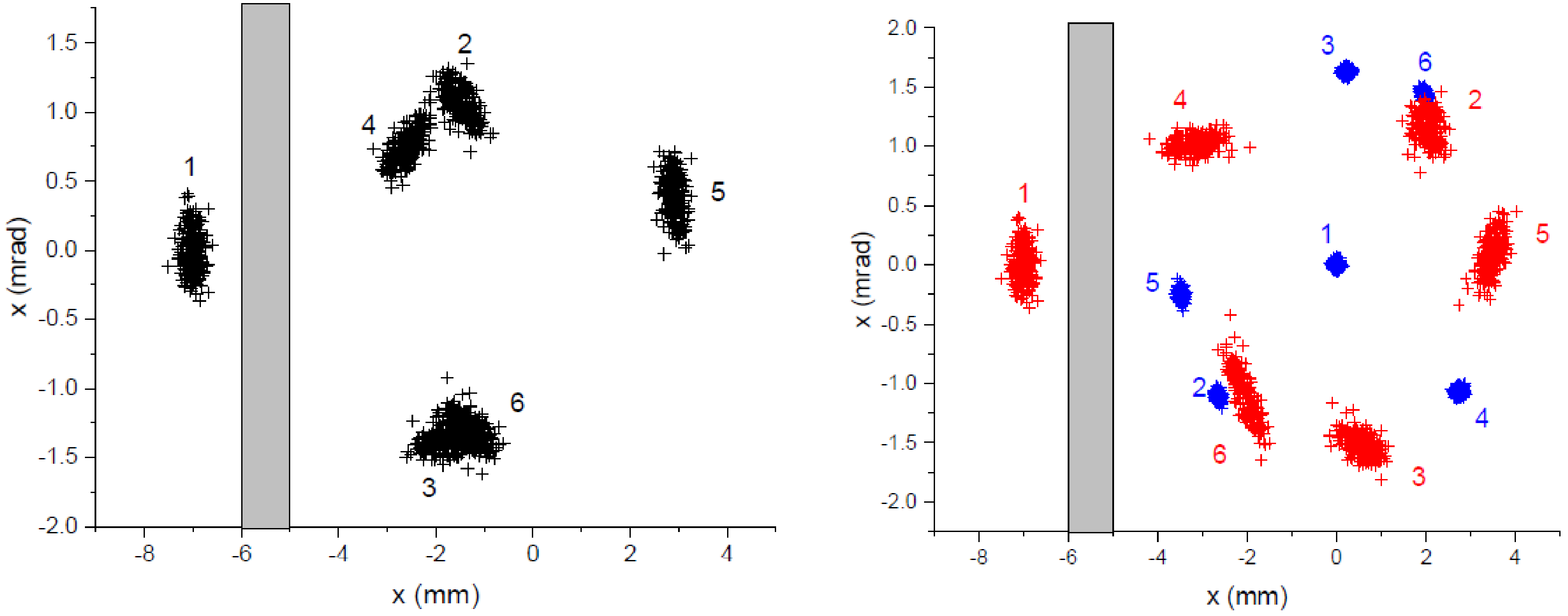


Figure 4. Tracking results for the conventional injection scheme (left) and the aperture sharing (right). The integer numbers indicate the number of turn after the injection. The red plots are for the injection beam and blue ones are for the stored beam in case of the aperture sharing. **Thanks to the low emittance SLS booster and emittance exchange, injection bump plus fast kicker could lead to rather small amplitudes in the straights**

This scheme has all features needed for injecting into a 4th generation light source and offers good chances for improvements in the future

More comments

- **Transparent injection? Closure of the 4 kicker bump?**
  alternatively a non-linear kicker could be used
- **Pulse-to-pulse jitter of the septum magnets – will add to the "emittance budget" of the injected beam**
  better emittance exchange could improve the performance if jitter is approaching the 10^{-5}-level
- **What would be the smallest acceptance for off-axis injection – in the "ideal" case (state of the art)**
  updated graph from an overview of injection systems which I showed a few years ago

MAXIV Injection Scheme - Results

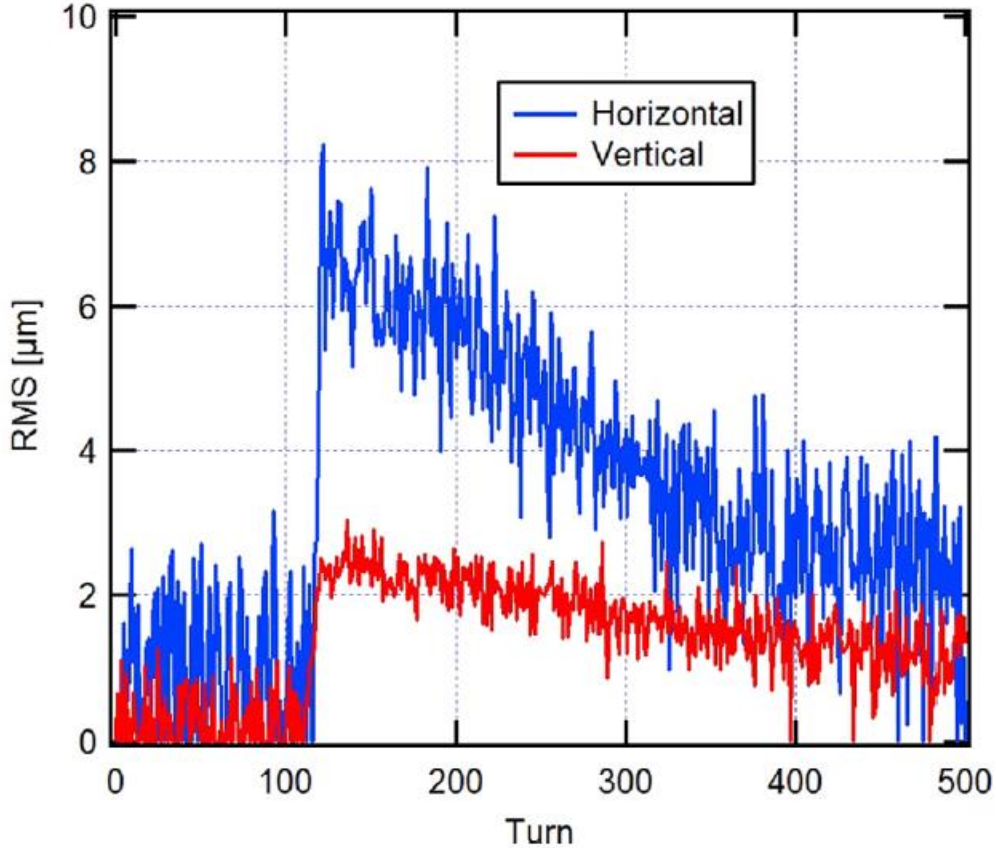


Fig. 21. Measured horizontal and vertical RMS turn-by-turn beam position. Values are scaled to the centre of the long straight. The stored beam is at the nominal transverse position at the MIK.

Injection efficiency > 90%, with in-vac. ID closed to 4.4 mm full gap

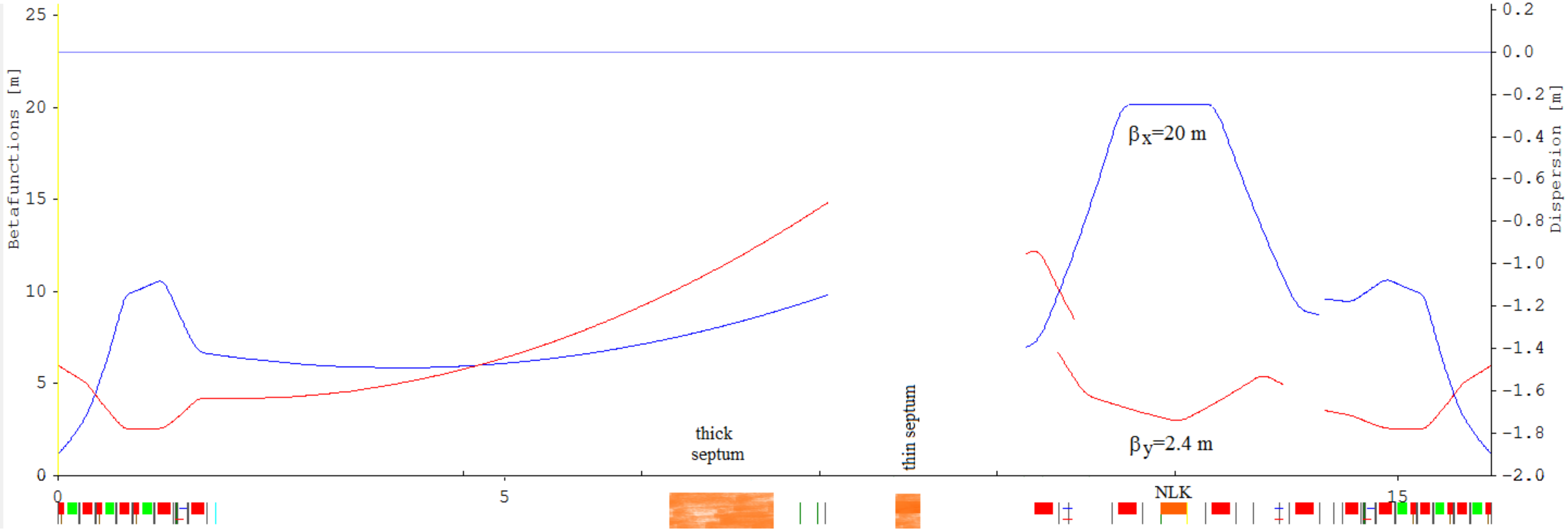
Beam size variation:
$\Delta\sigma_x = 0.3 \pm 0.6\ \mu m$
$\Delta\sigma_y = 0.6 \pm 0.3\ \mu m$

Orbit distortion:
$X_{rms} = 7 \pm 1\ \mu m$
$Y_{rms} = 2 \pm 0.5\ \mu m$

Not yet fully transparent injection, perturbation level hard to reach with other injection schemes

P. Alexandre, R.B.E. Fekih, A. Letrésor et al.
Nuclear Inst. and Methods in Physics Research, A 986 (2021) 164739

II. NLK Based Injection Scheme



remove 4 kicker magnets, shift ß-bump further downstream where the NLK is placed
$ß_y$ chosen for vertical aperture ±2mm, $ß_x$ as large as possible – could be impossible with the given phase advance constraints in all straights at SLS 2.0

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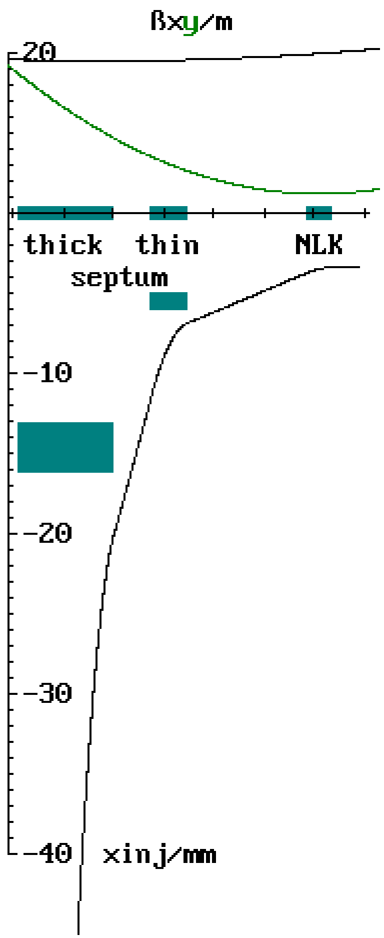

view from above

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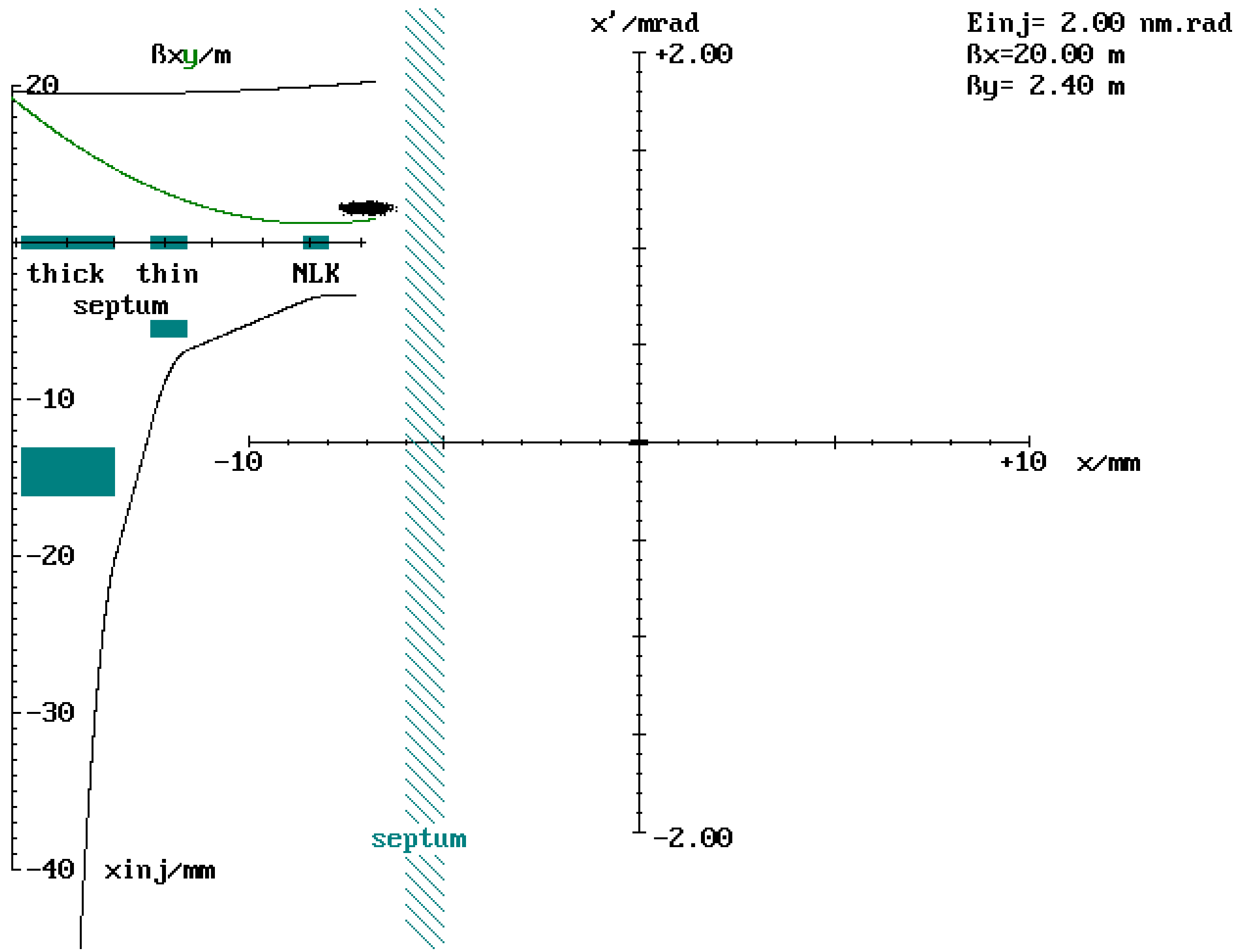

view from above

horizontal phase space behind thin septum

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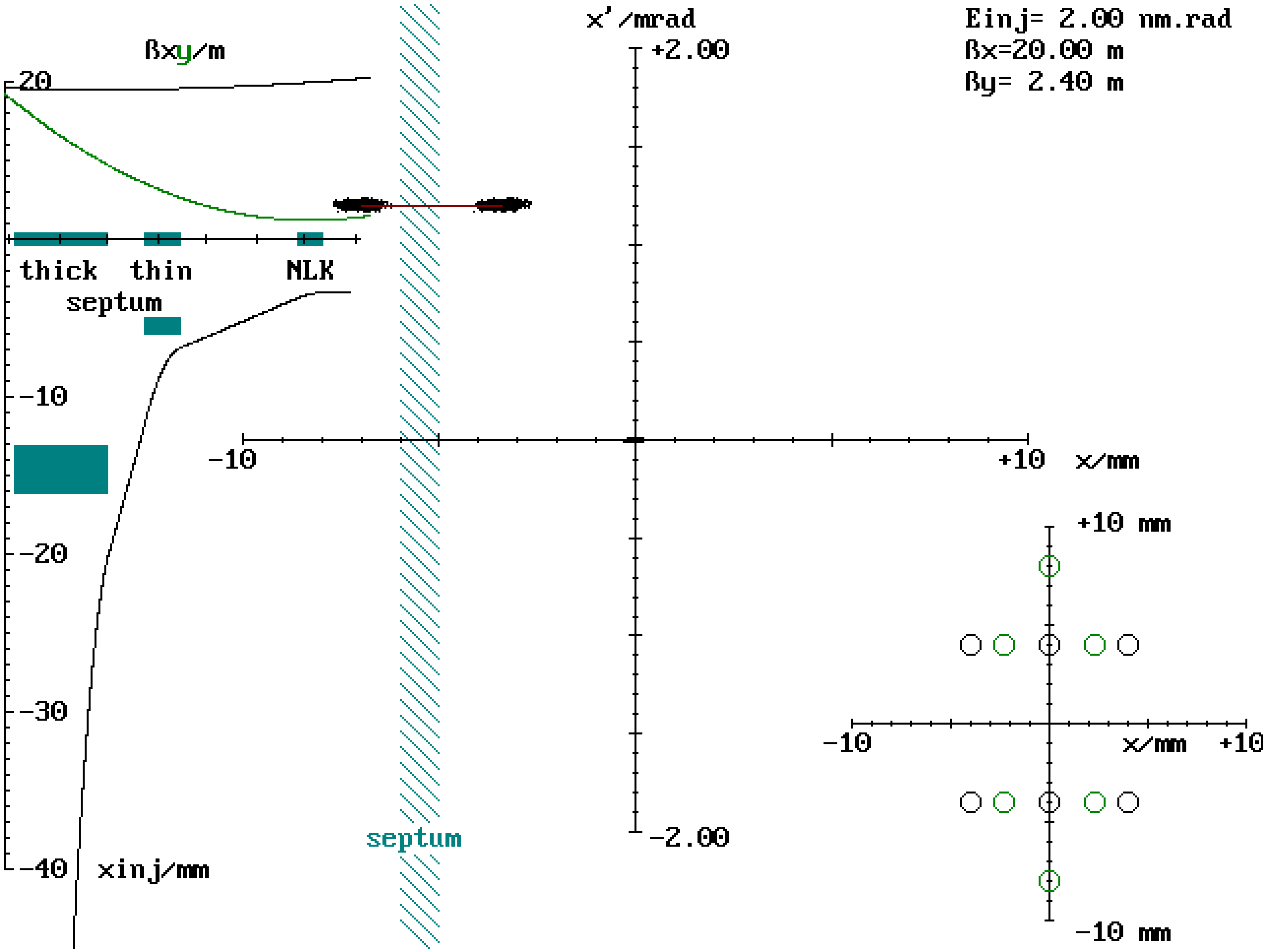

view from above

horizontal phase space at NLK

cross section of NLK (Soleil design)

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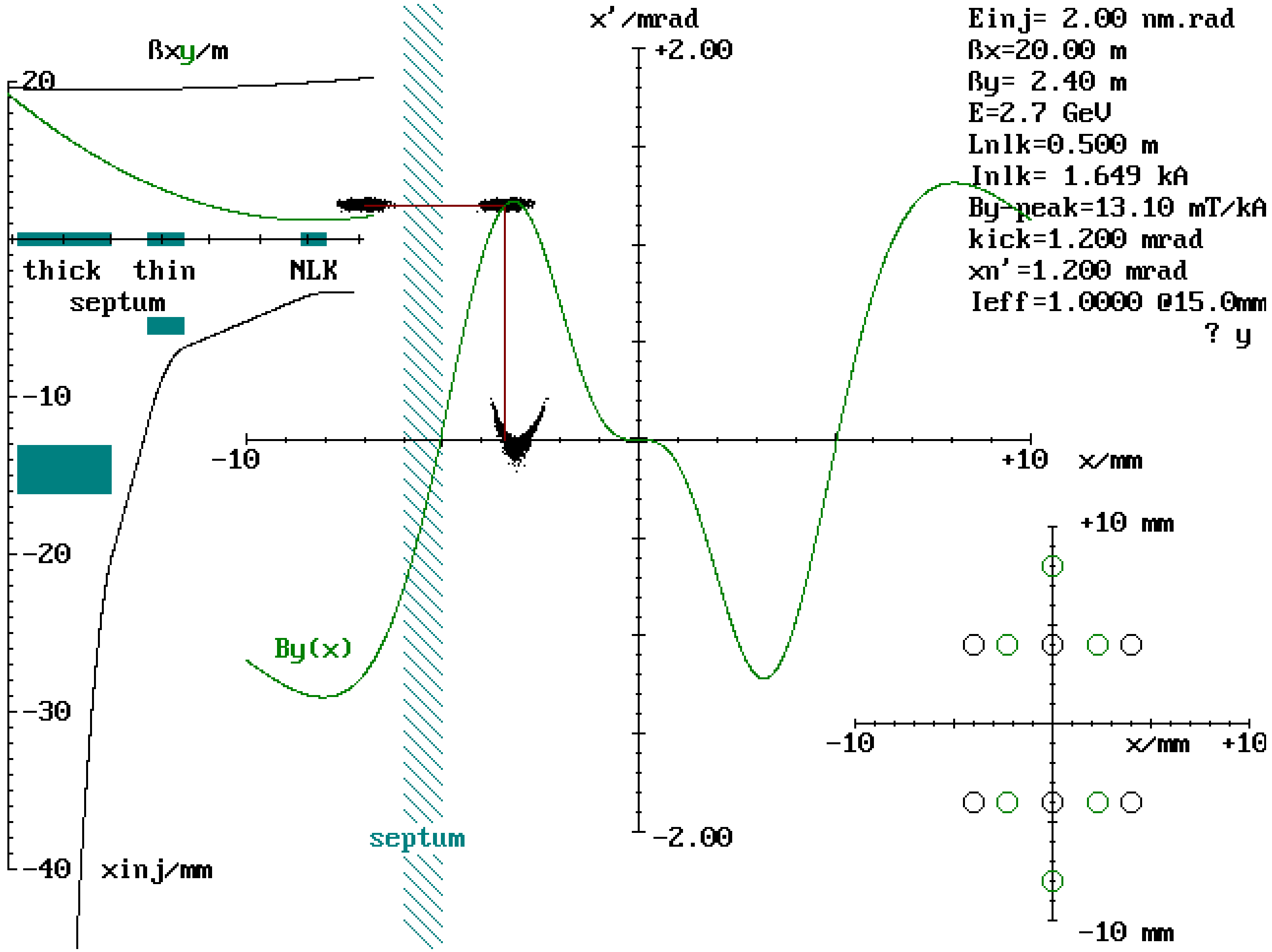

view from above

horizontal phase space behind NLK

cross section of NLK (Soleil design)

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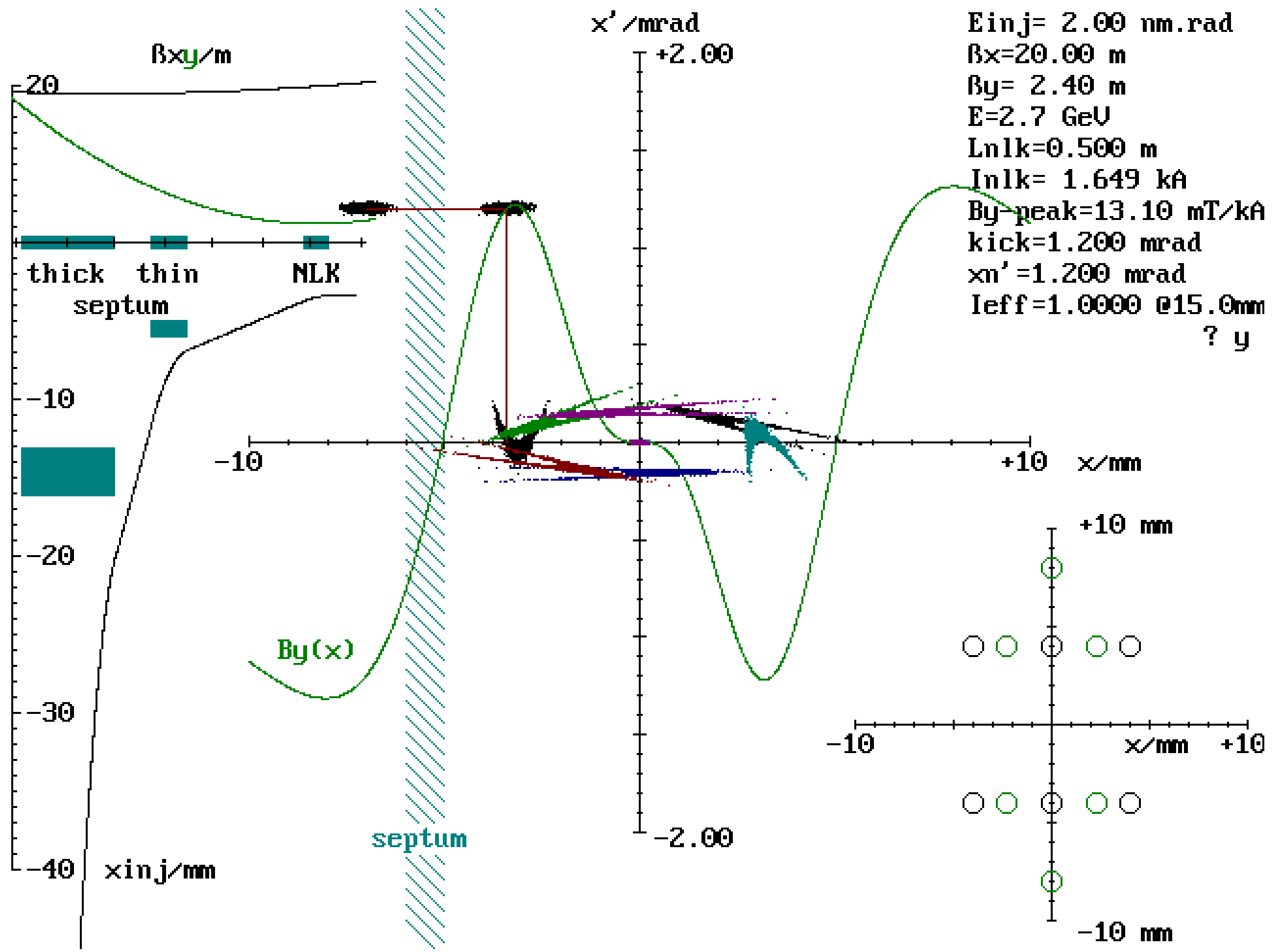


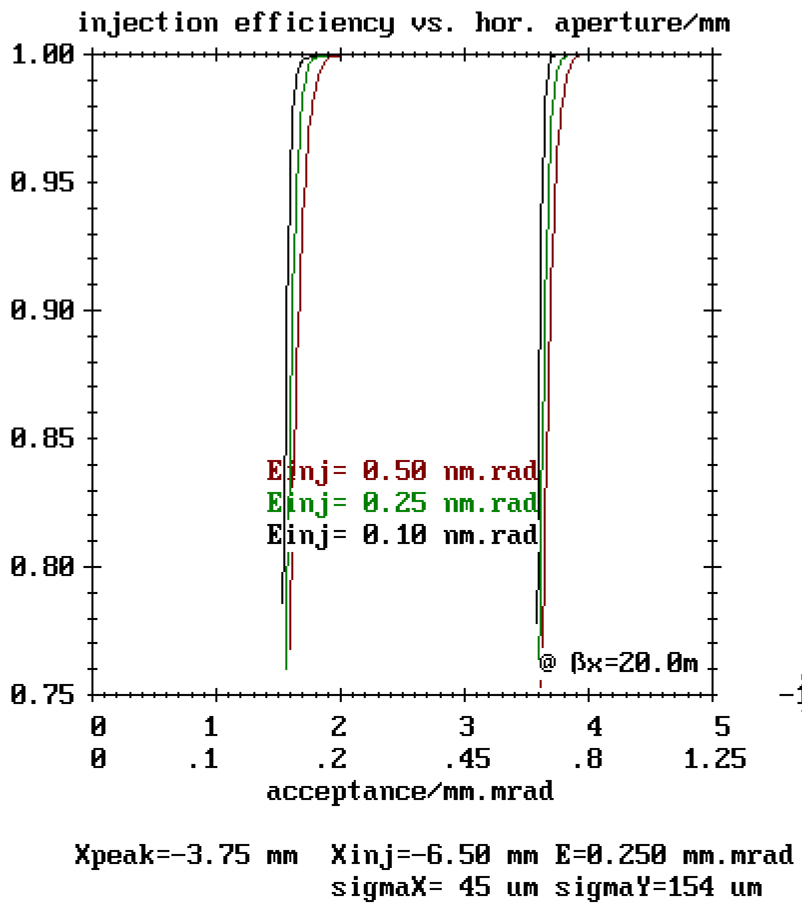
view from above

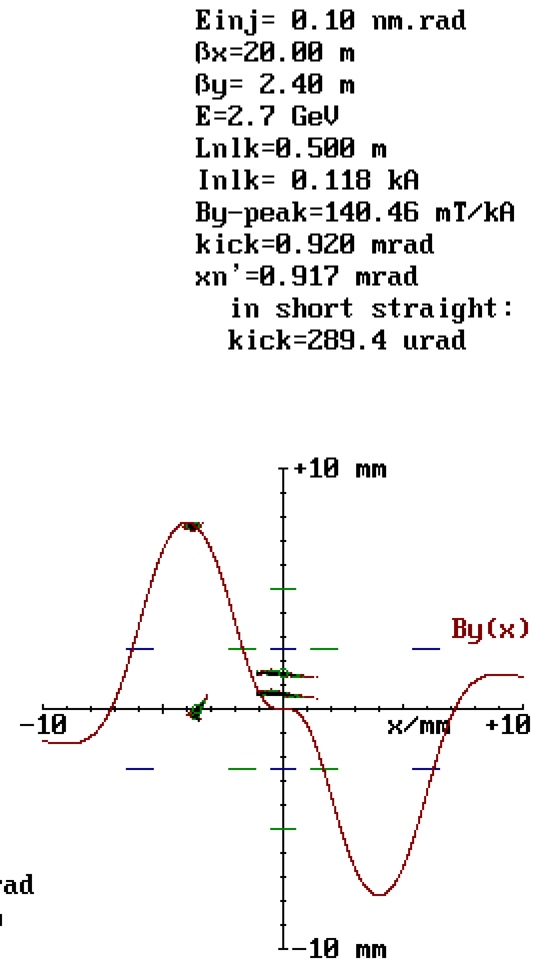
horizontal phase space behind NLK

cross section of NLK (Soleil design)

II. NLK Based Injection Scheme

- pulse-to-pulse jitter $2 \cdot 10^{-5}$ of septum magnets
- injected beam shifted 0.5 mm closer to the thin septum
- aperture sharing with acceptance of 0.25 mm·rad for stored beam
- NLK with ±2 mm vertical aperture →120 A, based on printed circuit boards?





III. Efficient Emittance Exchange

Makes sense if

- **Emittance of the injected beam is dominating the required aperture for injection**
- **Vertical acceptance ≥ ±5 natural horizontal emittance of the beam**
- **Vertical emittance in the booster can be made as small as desirable**

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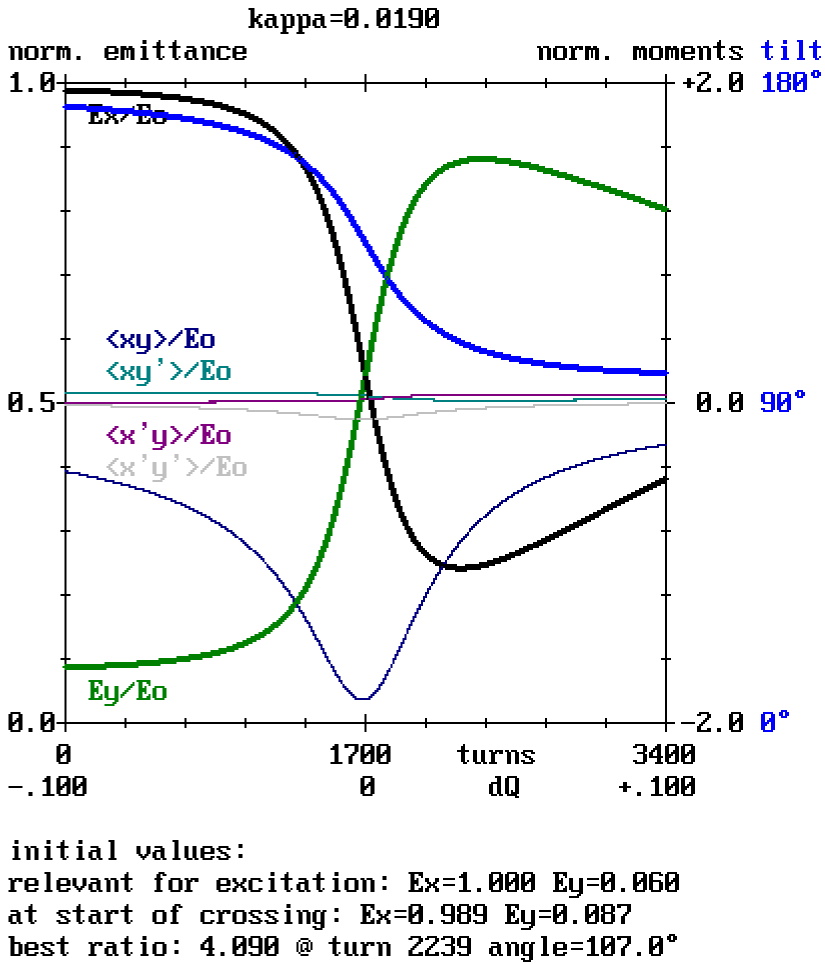
The ultimate exchange ratio can be achieved by employing a pulsed rotated quadrupole magnet, simultaneously producing a normal and a skew gradient.

The normal component forces the tunes to cross the coupling resonance, Q_x-Q_y, and the skew component creates the coupling needed for an emittance exchange.

The beam is extracted as soon as the optimum exchange is reached. This is a fast process and much faster than the transverse damping times which plays a rhole if the crossing is created by changing the ramp of a quadrupole PS.

Strength of the pulsed quadrupole magnet, initial distance to the coupling resonance, and the extraction time determine the performance of this scheme.

First SLS experiments on emittance exchange



Jonas and Masamitsu suggested a scaling parameter, S, which should be

$$S = \frac{\dot{\Delta}}{|C|^2} < 3 \text{ per turn}$$

$$|C| = coupling\ constant, \kappa$$

$$\dot{\Delta} = \frac{\Delta(Q_x - Q_y)}{\Delta t}\,[\text{turn}^{-1}]$$

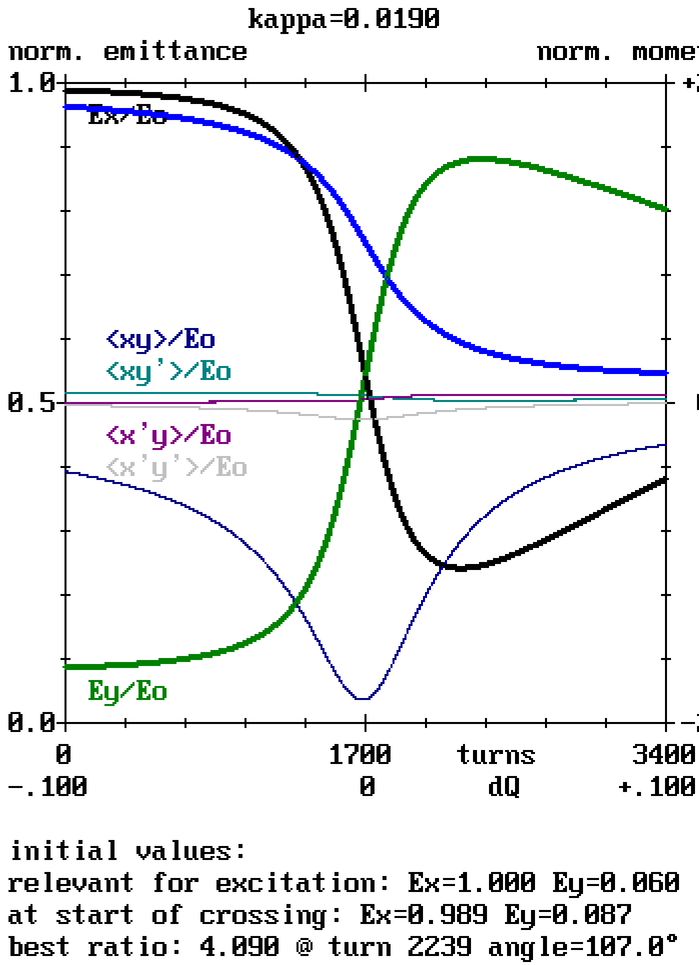
Emittance ratio: 4.1, only partly due to initial vertical emittance from vertical dispersion

limited by the ramping speed of PS/magnet

simulation based on moment mapping

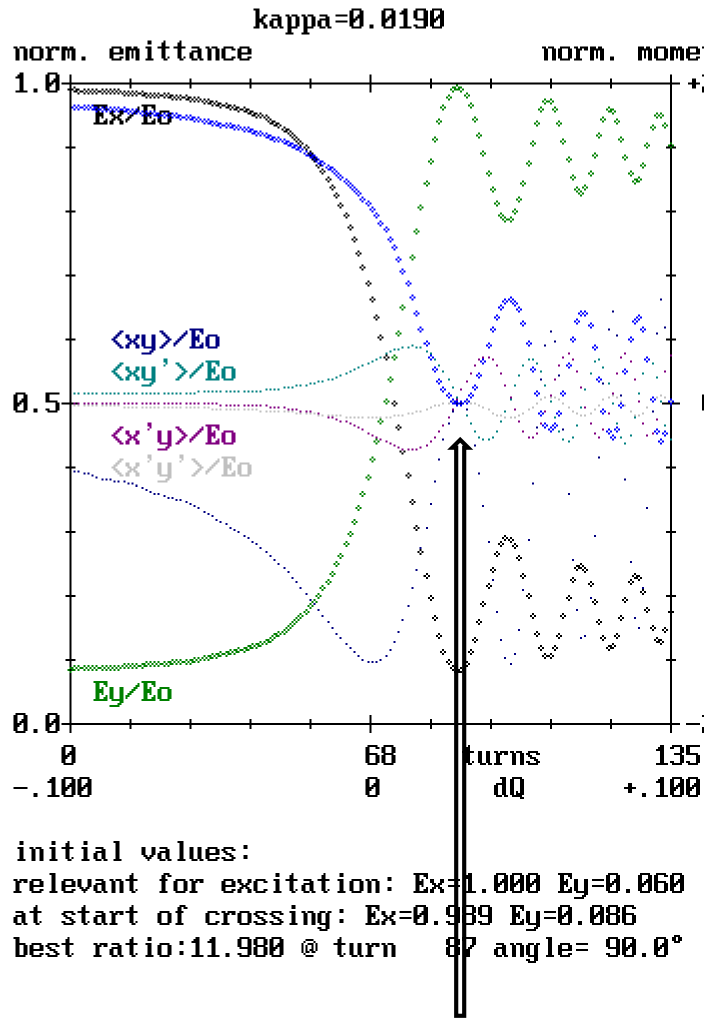
III. Efficient Emittance Exchange

First SLS experiments on emittance exchange



simulation based on moment mapping

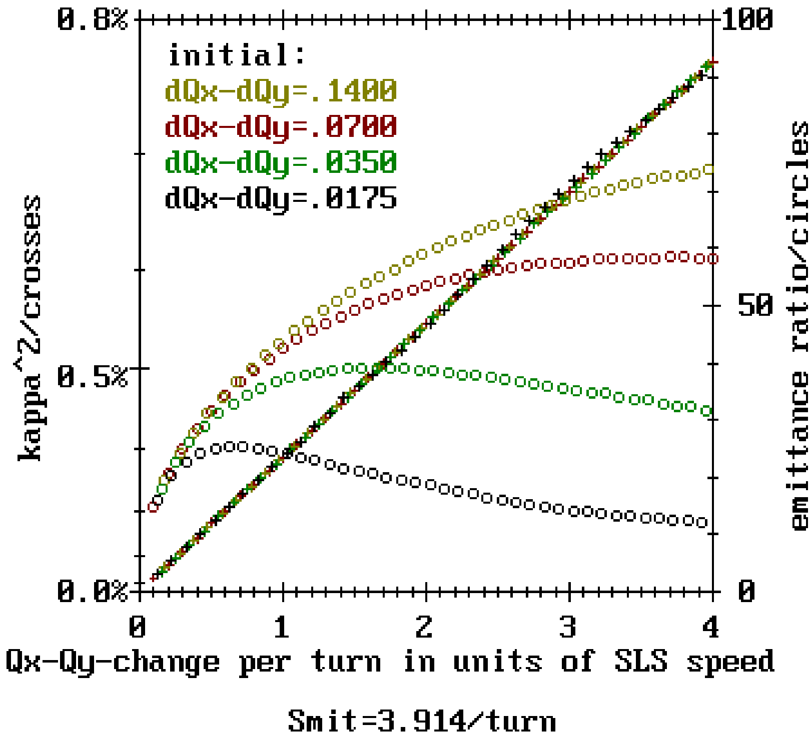
25 times higher resonance crossing speed leads to much better emittance exchange



Sweet spot – highest emittance ratio, all mixed coordinate moments close to zero

Sweet spot dependencies:

- **The ultimate emittance exchange ratio is achieved for S~3.91/turn**
- **Higher resonance crossing speeds lead to better emittance exchange**



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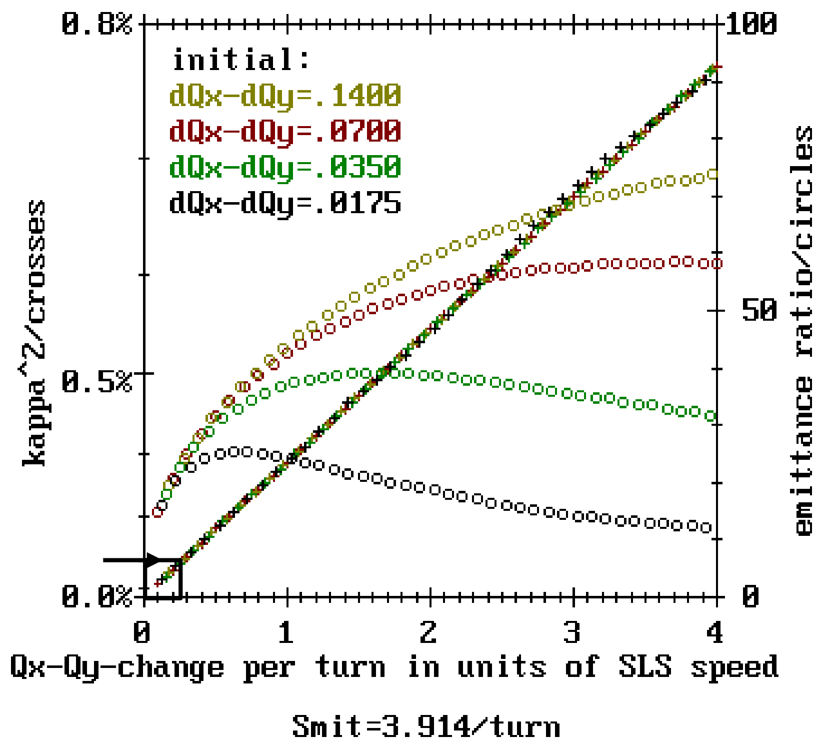
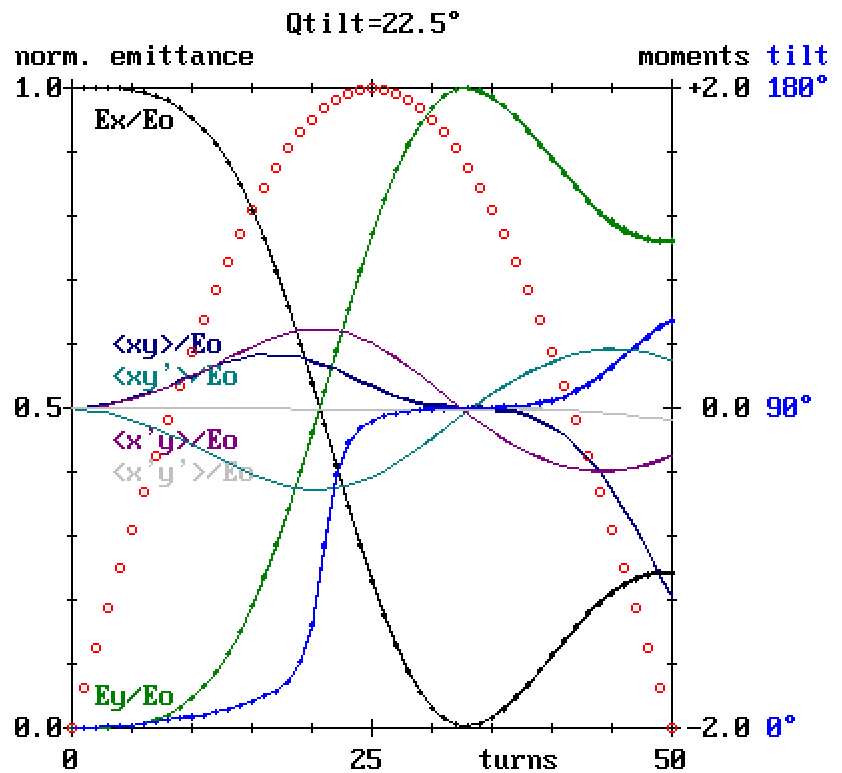


With reduced coupling (0.2%, IPAC 2021, MOPAB020) **the ultimate performance would require a reduction of the ramping speed by a factor of ~4**

III. Efficient Emittance Exchange

How to cross the resonance faster?

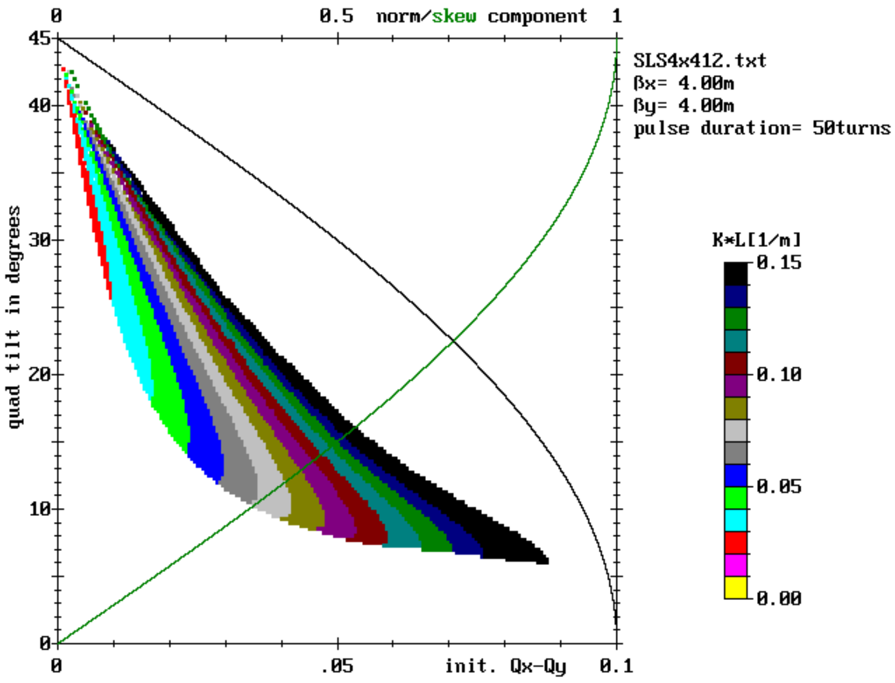
- **Emittance exchange occurs also for non-linear time dependend crossing and coupling**
- **Half-sine pulsed tilted quadrupole magnet under 22.5 degrees – equal skew and normal component –** shown as red circles, pulse duration 45 µs
- **Initial tune difference and strength chosen for the sweet spot of ultimate emittance exchange –** all mixed coordinate second order moments close to zero
- **Extraction when optimum is reached** and beam ellipse upright (90°)



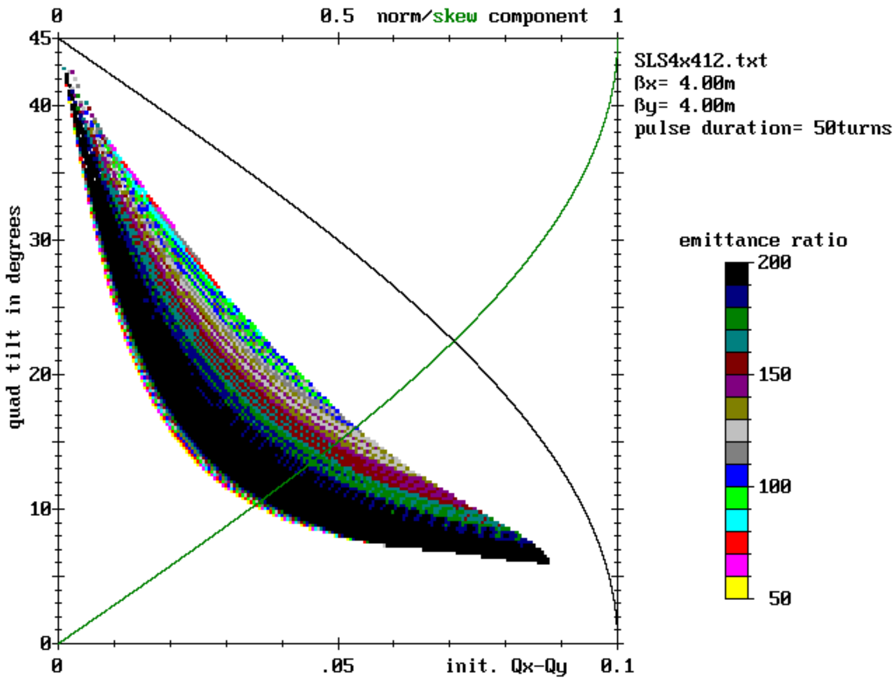
initial values: Qx=12.3590 Qy=8.3410 dQ=0.01800
relevant for excitation: Ex=1.000 Ey=0.000
best hor. emittance ratio:219.64 @ turn 33
int. K-value= 0.046640/m angle= 90.0°

III. Efficient Emittance Exchange

Numerical scan of the sweet spot as a function of tilt angle of the pulsed quadrupole magnet, its strength, and the initial detuning from resonance



Integrated strength of pulsed quadrupole magnet

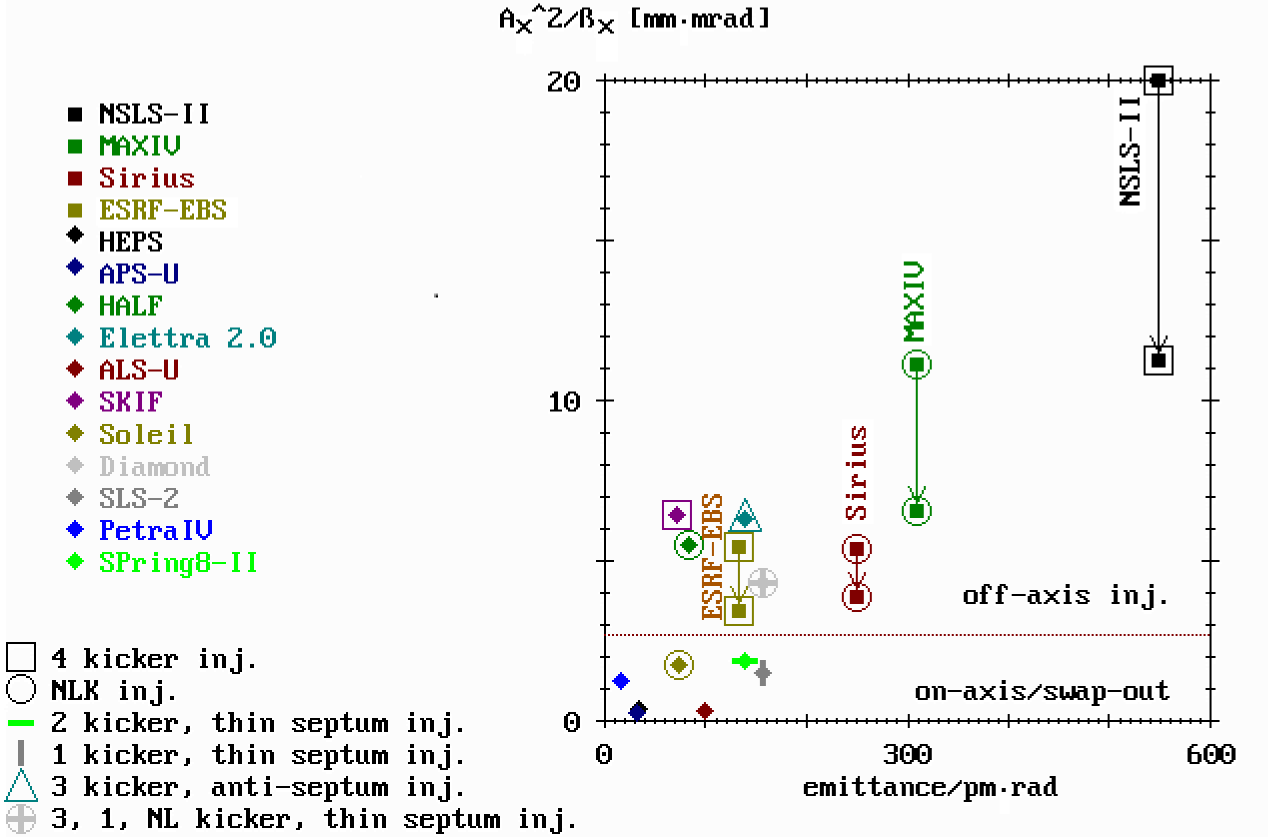


Emittance ratio for zero initial vertical emittance

With vanishingly small initial vertical emittance (reduction of ß-tron coupling + suppression of vertical dispersion) **the horizontal emittance after the exchange reaches the percent level.**

For off-energy or off-momentum injection a LINAC will still be required.

2nd RULε Topical Workshop on Injection and Injection Systems



4 kicker injection NSLS-II, ESRF-EBS and SKIF

Non-linear kicker injection: successfully done at MAXVI, Sirius, and planned for Soleil , HALF

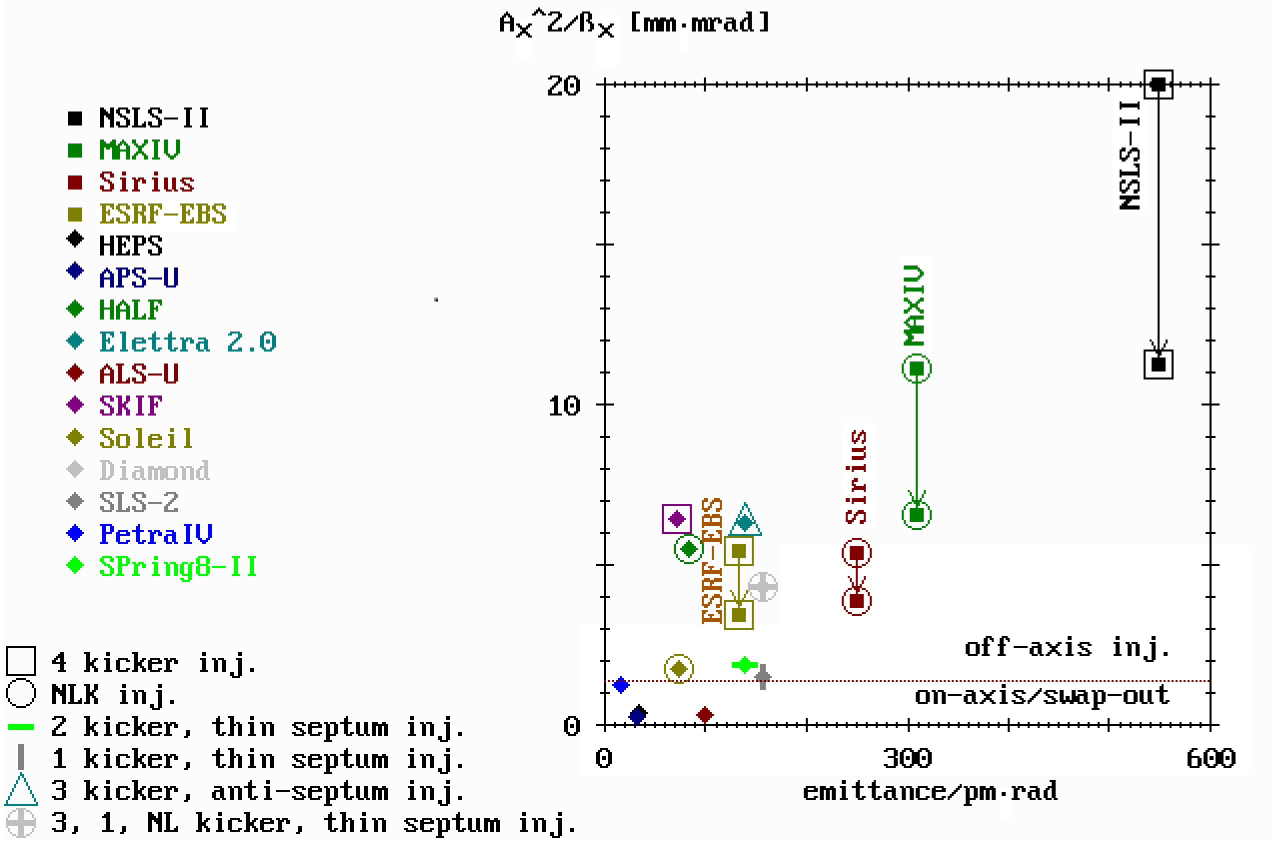
Two kicker, π-bump injection: SPring8-II

Single kicker, acceptance sharing, and maybe even longitudinal injection: SLS-2

3 kicker bump with anti-septum: Elettra 2.0

3 kicker bump, single kicker, NLK ... Diamond

IV. Acceptance vs. Emittance (8th LER, Frascati, 2020)



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On-axis swap-out / longitudinal injection: ALS-U, APS-U, HEPS / Soleil, SLS-2?

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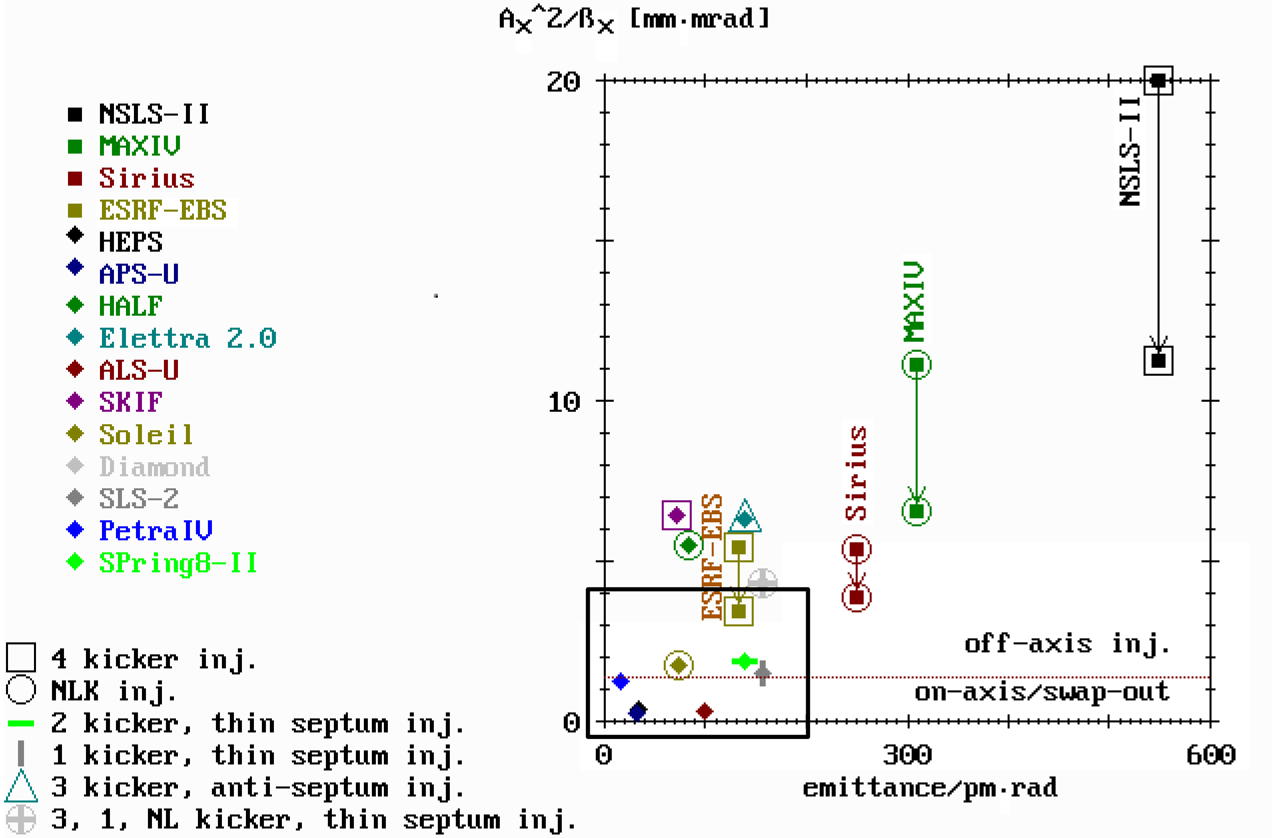

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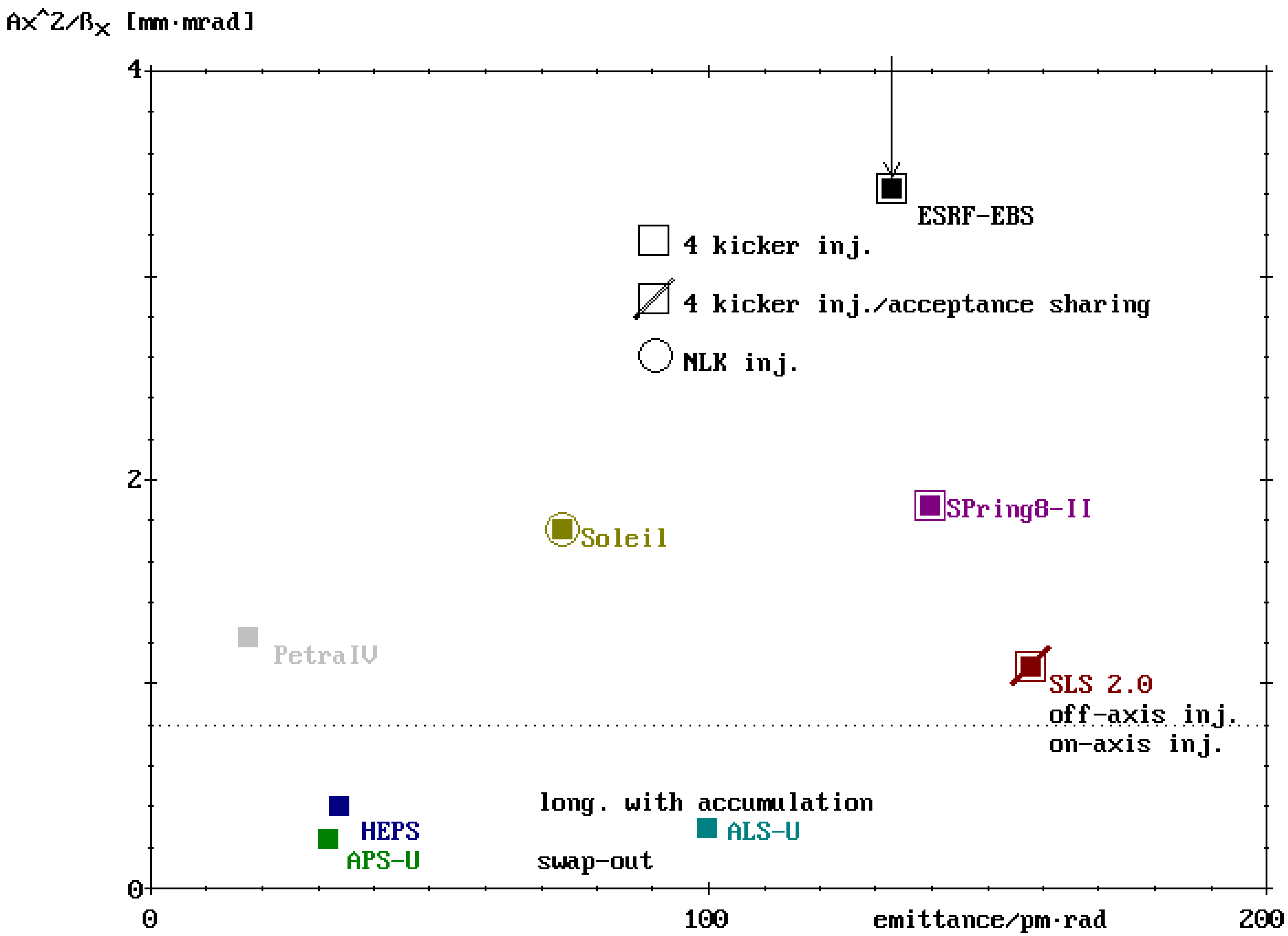

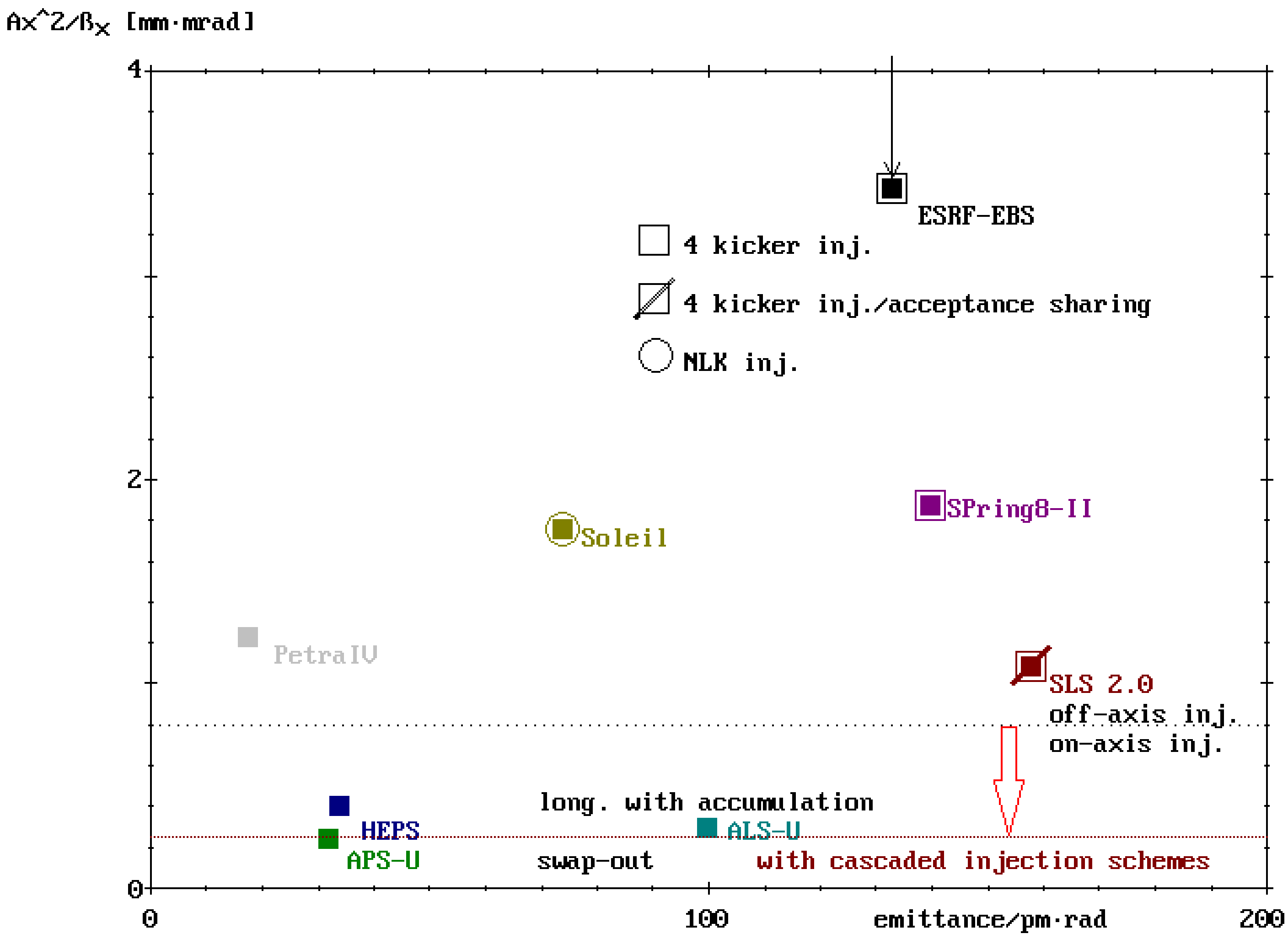

Cascaded injection schemes – the combination of off-axis injection with aperture sharing (or off-phase/off-momentum injection with very fast kicker magnets) drastically reduces the dynamic aperture needed for efficient injection and offers quite transparent injections.

Injection scheme for the SLS 2.0

- **has all features needed for injecting into a 4th generation light source and**
- **offers good chances for improvements in the future**

Transparent injections might be easier to realize with a non-linear kicker

Emittance exchange by crossing the coupling resonance can be improved

Cascading two injection principles opens the path for injection and accumulation in lattices with even more challenging dynamic apertures

Thanks for your attention

Thanks to Felix and PSI for inviting us
Thanks to Masamitsu for the information on the SLS 2.0 injection scheme