Computer Models to Optimise the Setting of the MAMI Double Sided Microtron*

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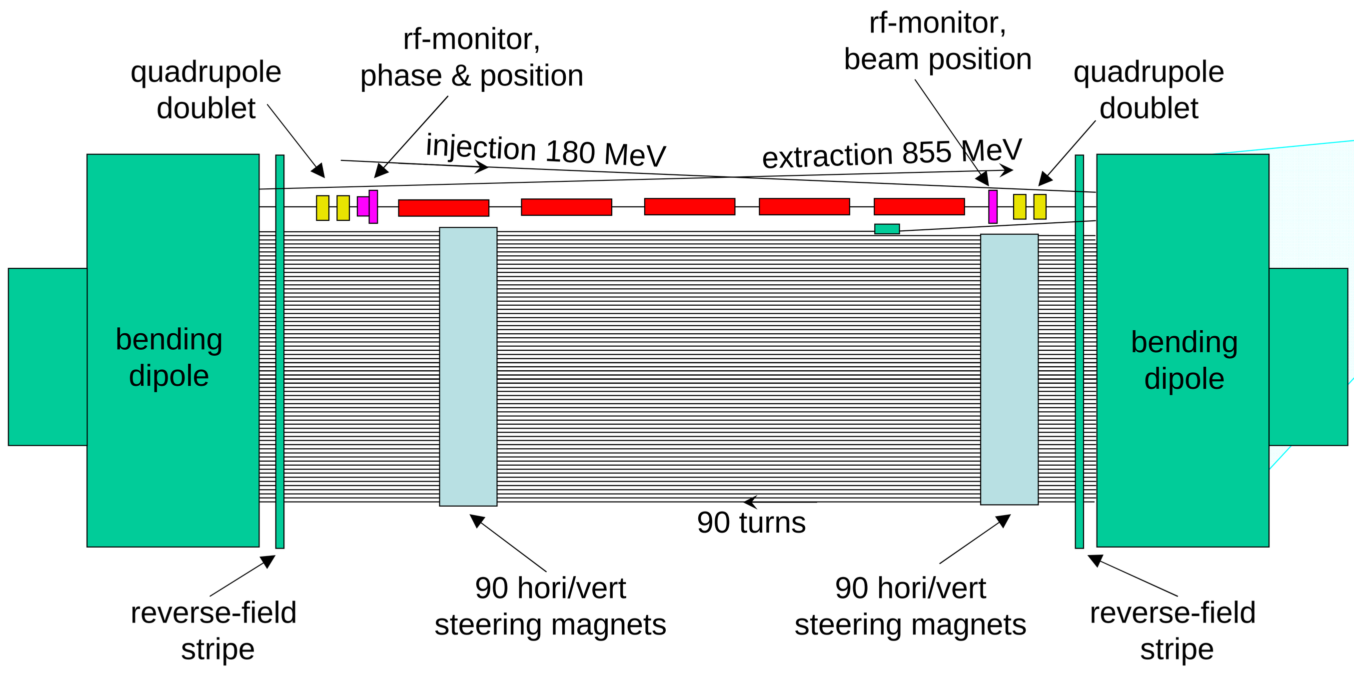
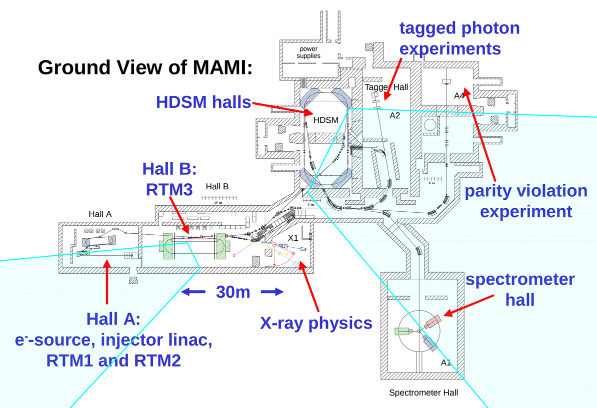
The Race Track Microtron (RTM)

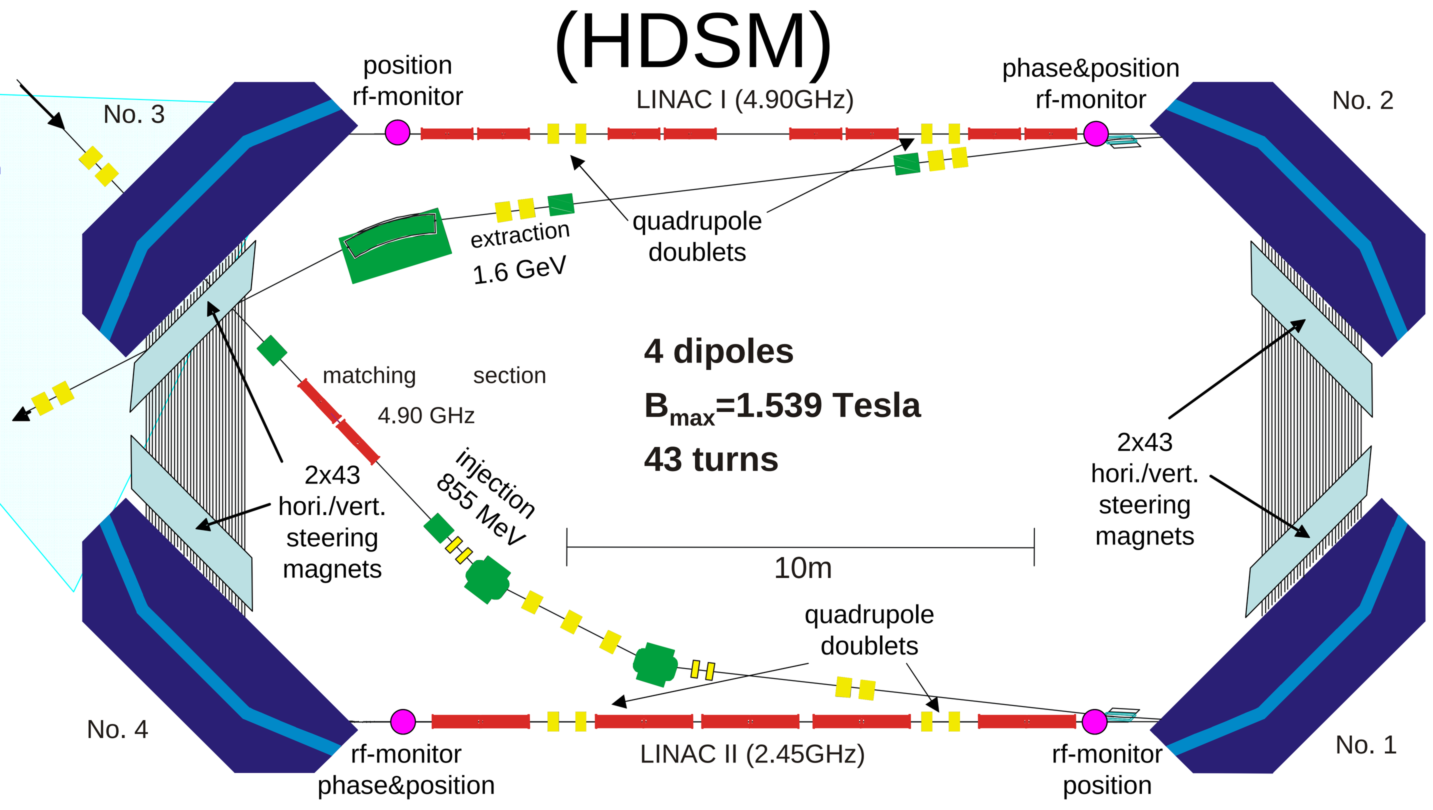


The 3rd RTM stage with an output energy of 855 MeV is in operation since 1990 and serves now as injector for the HDSM.



The MAMI (Mainz Microtron) facility is a normal conducting machine, consisting of a pre-accelerator equipped with a polarised and a thermal electron gun, a cascade of four microtrons and beam-lines to four experimental areas. The output of the accelerator is a c.w. electron beam with 1.5 GeV @ 100 μA maximum.

The Harmonic Double Sided Microtron (HDSM)



The 4th stage, boosting the energy from 0.855 GeV to 1.6 GeV, was built in parallel to regular operation of the first 3 RTMs. Its commissioning started in Dec 2006 and since Feb 2007 it is in routine operation for nuclear physics experiments.

Longitudinal Dynamics

RTM

The synchronous accelerating phase is constant, that means synchrotron frequency does not depend on turn number.

Parameters to optimise:

- rf-amplitude of the linac
- injection beam phase and energy

Optimisation procedure for an RTM:

1. tune rf-amplitude till the synchrotron frequency is as desired (typically for a phase angle of 16°)
2. vary injection beam phase and energy until synchrotron oscillation cancels

This procedure is quite simple and up to now there was no need for a more sophisticated one.

HDSM

The synchronous phase is not constant. This is due to the special field profile of the bending dipoles to compensate for vertical defocusing by the 45° beam entrance/exit. The longitudinal focusing increases with the turn number.

Parameters to optimise:

- rf-amplitude in each of the linacs
- phase relation among the linacs, i.e. starting beam phase on each linac
- injection beam energy

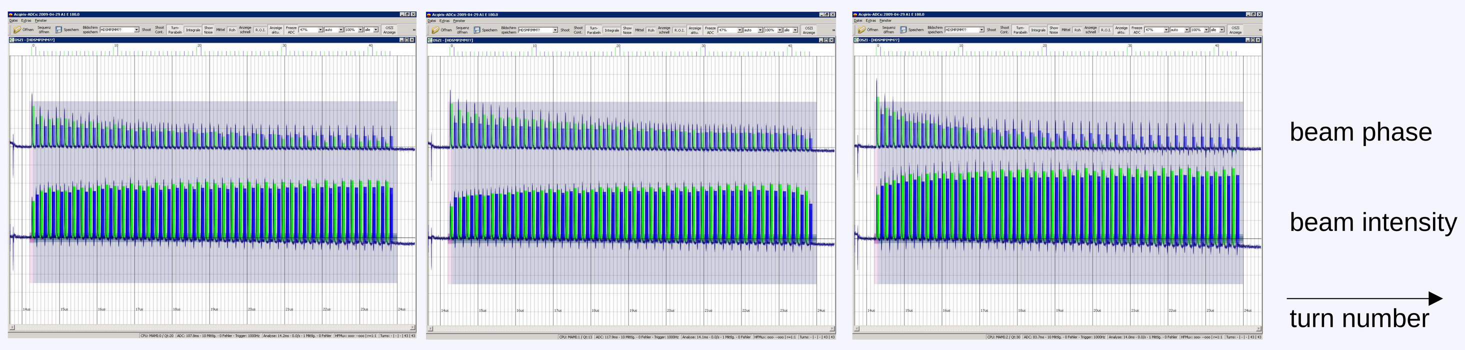
Having a smooth phase advance (no synchrotron oscillations) is not a sufficient criterion!

Optimisation procedure for a HDSM:

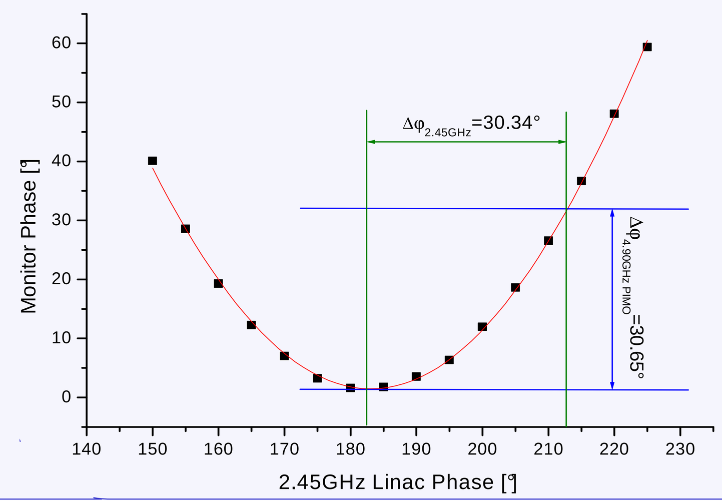
1. find the beam phase angles of the first passage through each linac by measuring the flight time through the following bending system
2. scan the HDSM acceptance phase-space by varying injection beam phase and energy

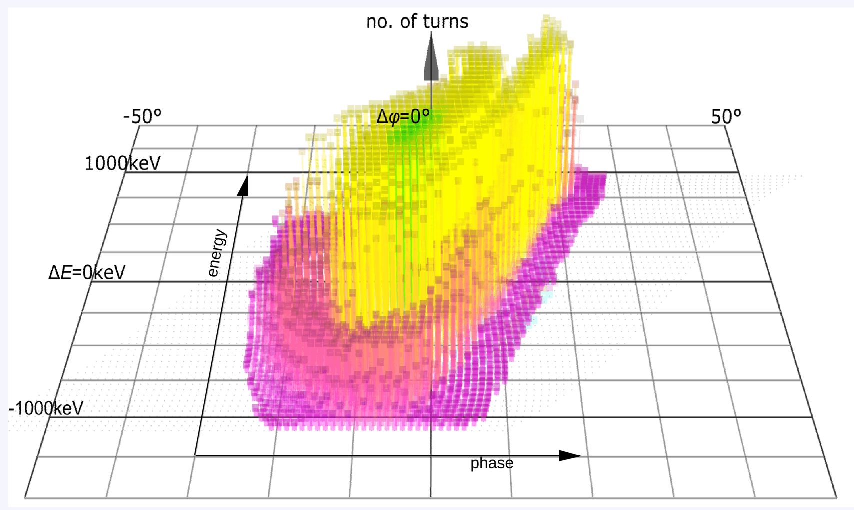
A longitudinal beam optics simulation is in work to speed up the optimisation procedure.

Three different rf settings with smooth phase advance:



Even for an experienced operator it is hard to estimate which phase advance is the best, and it is particularly difficult to adjust a special one !





Transversal Beam Optics

RTM

Requirement: Centre the beam on the linac axis for all turns.
To accomplish this, beam steerers on each of the return paths and the beam position monitors on the linac axis are used.

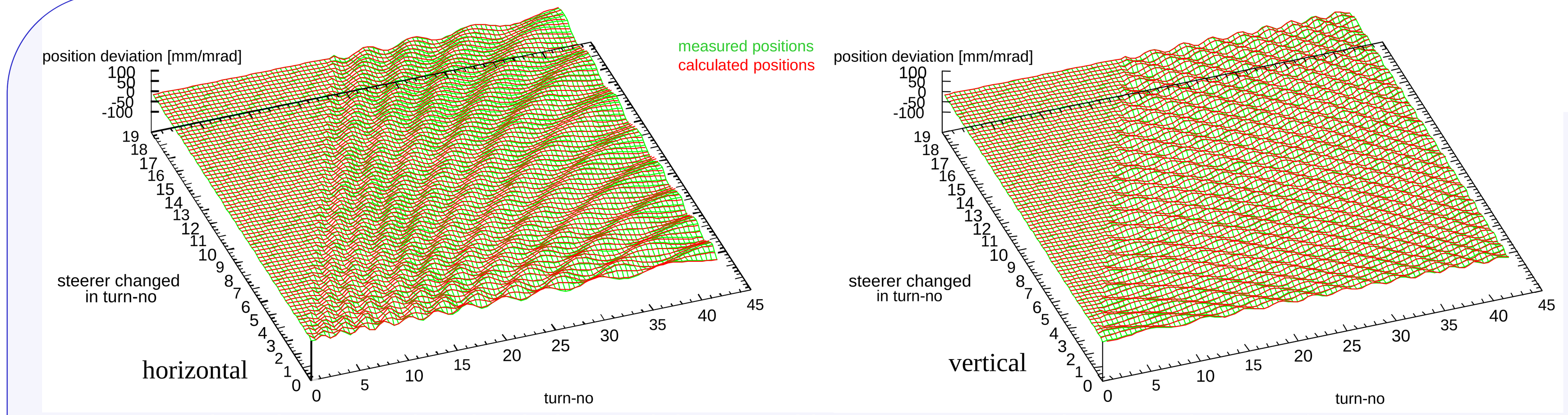
To achieve fast and effective optimisation, transversal beam optics is calculated using a parameterised first order simulation:

$$\Delta x = S \cdot \Delta w \quad ,$$

where Δw contains the changes of steerer kicks in all turns and Δx the resulting changes of all beam positions in both planes. S is a triangular-like matrix depending on beam optic parameters. The model is fitted for describing the betatron-oscillation excited by one steerer. The parameters used in an RTM are:

- the sensitivity of the beam position monitors (4 parameters)
- the focal strength of the quadrupole doublets on axis (2 parameters)
- the focal strength of the reverse-field (only in vertical plane) (1 parameter)

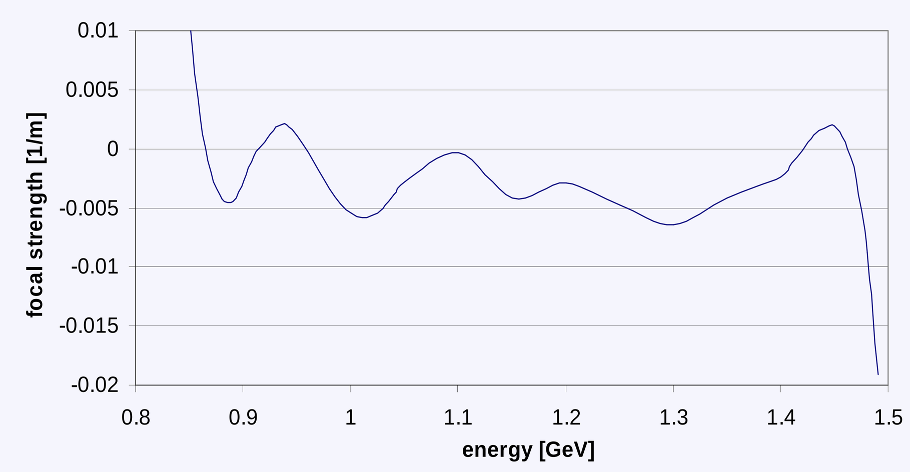
Though the resulting parameters do not reflect the actual settings of the quads resp. reverse-field amplitude, the model is sufficient to provide for proper operation of the automatic steerer optimisation.



Comparison between the simulation and the actual beam responses due to a change of one steerer kick at a time in the first 19 turns. The right axis denotes the turn number in the HDSM, the upright axis the beam position variations due to a change of one steerer, whose position (in turn-no) is noted at the left axis (there are 4 steerers in each turn). The green lines show the measured beam position deviations, the red ones the deviations calculated by the adapted HDSM simulation.

HDSM

A HDSM has two linac axes and accordingly 4 quadrupole doublets. The special field profile in the bending dipoles additionally complicates the optics. To cope with this situation, the optics of the bending dipoles was determined with a ray-trace simulation for each energy yielding transfer matrices with appropriate focal lengths:



Vertical focal strength of the first dipole against beam energy.

A linear model, represented by the triangular-like matrix S as in an RTM, should describe the beam responds to changes in the steerer kicks. As parameters were chosen:

- the sensivities in both directions of each of the 4 beam position monitors (8 parameters)
- the quadrupole strengths of the 8 quadrupoles (4 doublets) (8 parameters)

To have a larger data pool for the considerable greater number of parameters, a large set of steerer-kick changes and beam responses is used.

The fits with only these parameters failed. Therefore two additional parameters had to be introduced:

- a defocusing horizontal lens in the upper turns (>20)
- an energy independent lens in the vertical plane taking into account errors in the bending dipole focusing.

These additional parameters may be explained by a slight magnet field decay in the bending dipoles parallel to the pole face, respectively by a not ideal field shape perpendicular to the pole face.

The adapted model enables a fast automatic optimisation of the beam steerers in the HDSM in the same way as it is done in the RTMs. The remaining work is to better understand discrepancies of the fitted model parameters to their settings in the real microtron.

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