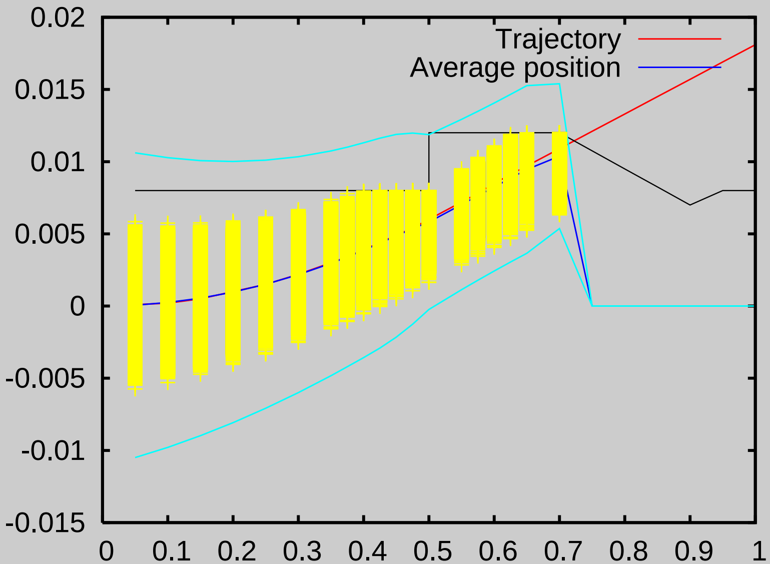
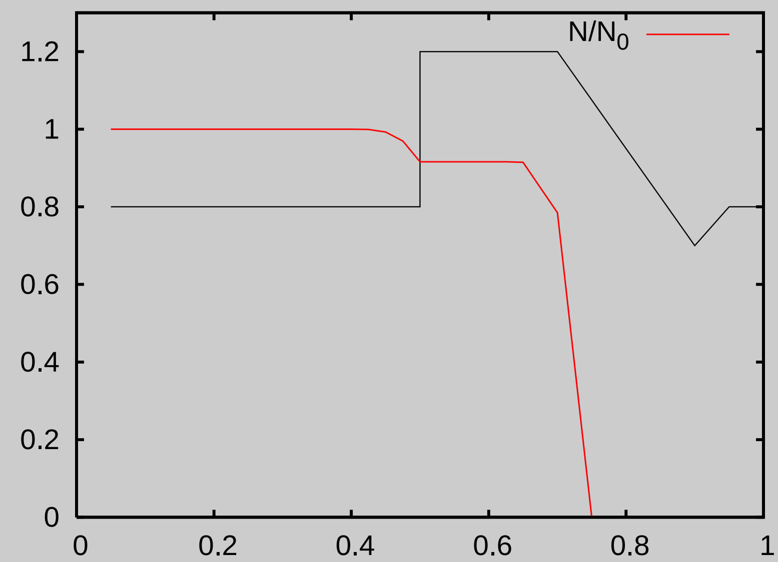
Simulating the chopper

Waiting for Brahim chopper file, I used MAD8 and I tracked the particle distribution at the entrance of the chopper as given by TRACK (50000 particles simulating 30 mA). No space charge in MAD8, of course. Aperture limit simulated by introducing collimators (where beam is shown). Chopper parameters: L=0.5 m at 14 cm from solenoid exit, gap=16 mm, ΔV=4.8 kV $\times$ 0.8 ("reduction factor").

5σ envelop



Losses

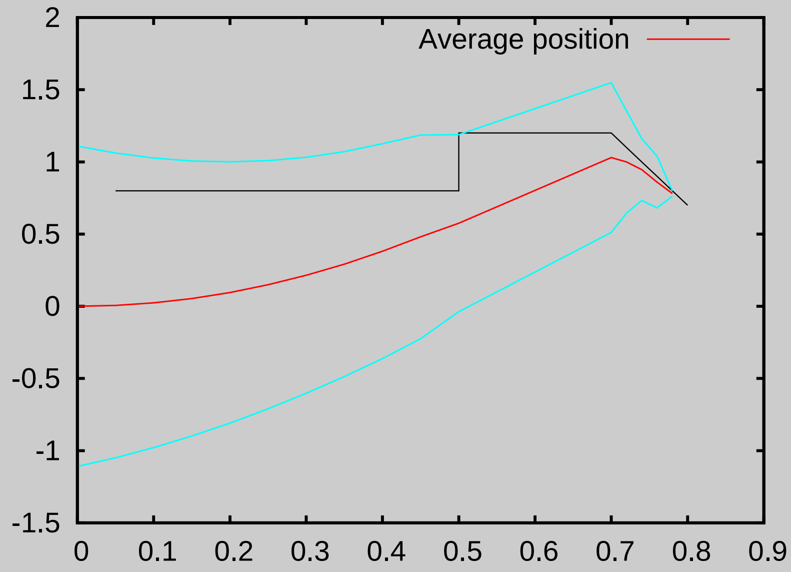


About 10% of the particles is lost on the upper chopper plate.

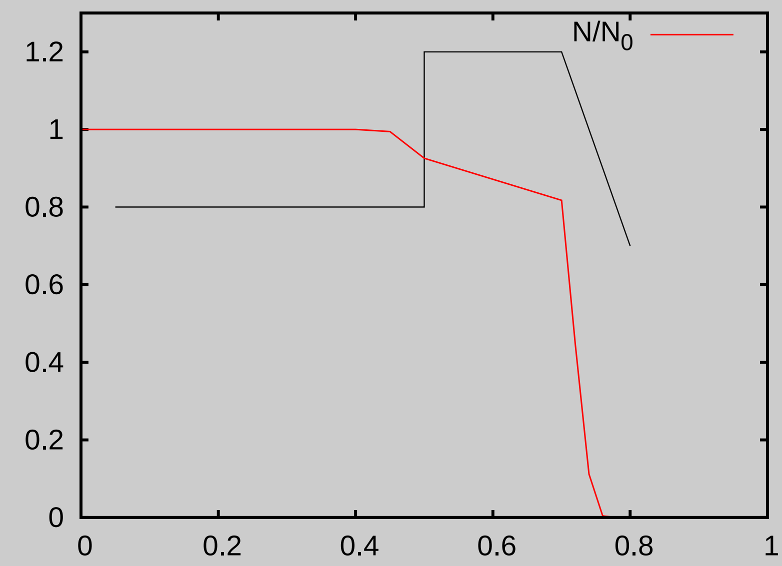
A new version of TRACK can read (only) ascii files. It has been used with a "hard-edge" chopper file provided by Brahim (3D Field Map Electrostatic Quadrupole). 50000 particles tracked, starting distribution at chopper entrance obtained by using the binary files and 50000 particles to simulate 30 mA (starting distribution at beginning of Linac from Jean-Paul).

No space charge

5σ envelop



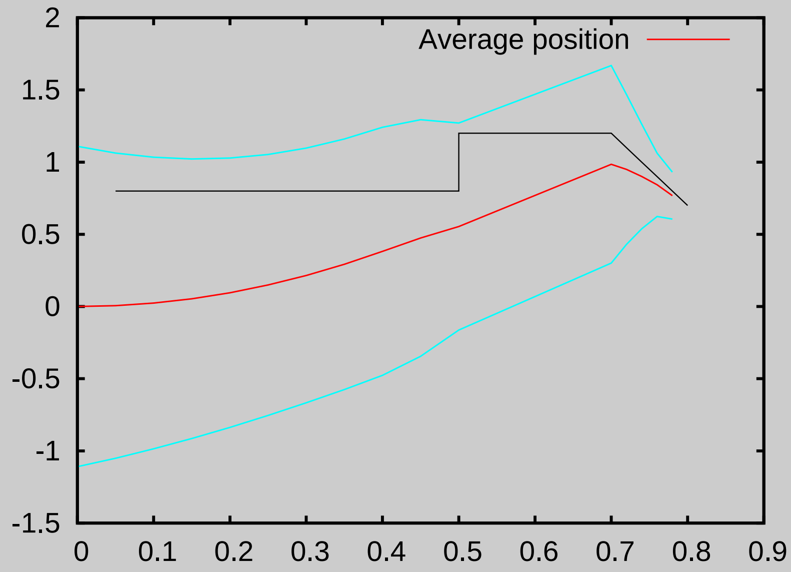
Losses



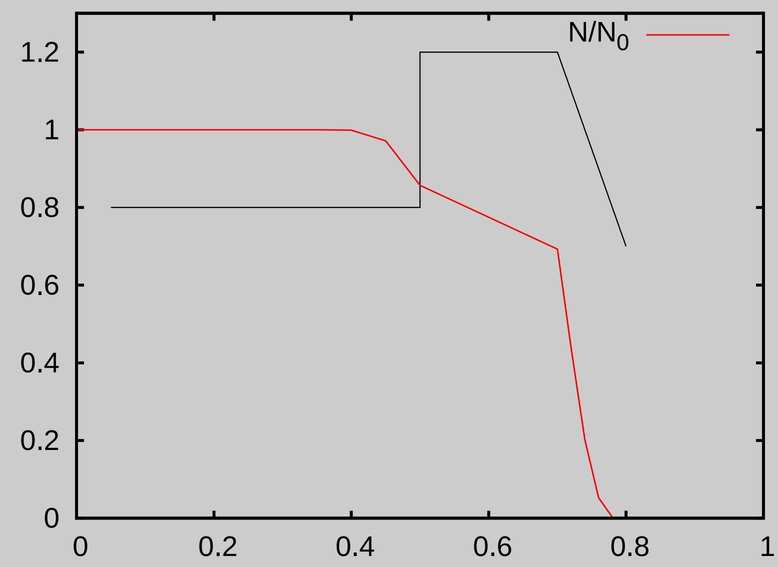
Good agreement with MAD8 results.

30 mA

5σ envelop



Losses



About 15% of the particles is lost on the upper chopper plate.

Solenoids and coupling

Solenoid transfer matrix

$$M = \frac{1}{2}\begin{pmatrix} 1+\cos\chi & 2\frac{\sin\chi}{K_s} & -\sin\chi & -2\frac{(1-\cos\chi)}{K_s} \\ -\frac{K_s}{2}\sin\chi & 1+\cos\chi & \frac{K_s}{2}(1-\cos\chi) & -\sin\chi \\ \sin\chi & 2\frac{(1-\cos\chi)}{K_s} & 1+\cos\chi & 2\frac{\sin\chi}{K_s} \\ -\frac{K_s}{2}(1-\cos\chi) & \sin\chi & -\frac{K_s}{2}\sin\chi & 1+\cos\chi \end{pmatrix}$$

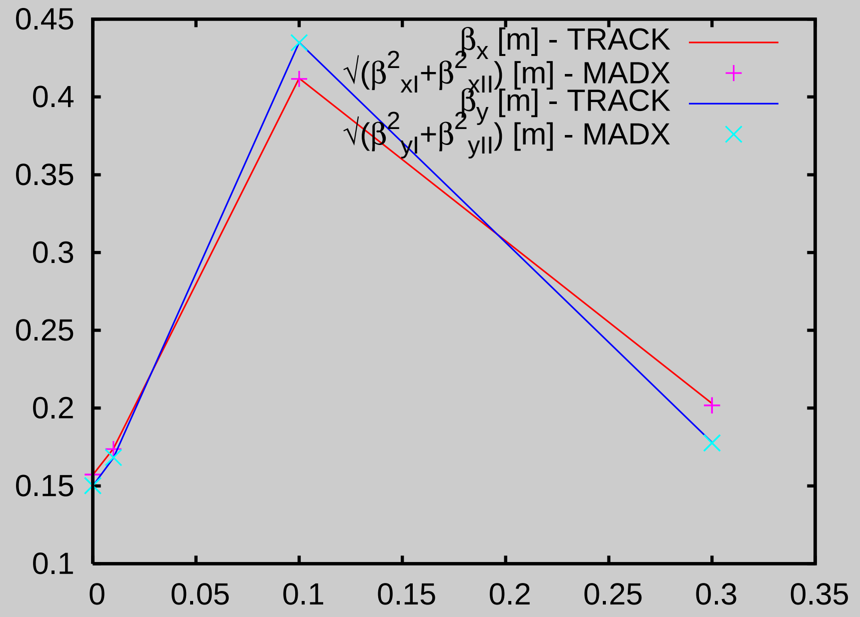
with

$$K_s \equiv \frac{e}{p}B_s \qquad \chi \equiv K_s \ell_s$$

Solenoids introduce coupling. Optics codes use two different approaches for computing the Twiss functions: Edwards-Teng or Mais-Ripken parameterization.

TRACK tracks particles, find the ellipse contour in (x,x') and (y,y') and computes the Twiss functions from the ellipse parameters.

Comparison of TRACK and Mais-Ripken MADX-PTC Twiss functions for a hard-edge solenoid



Multiplying the transfer matrix of a solenoid by that of a solenoid having the same strength but *opposite* polarity the off-diagonal block elements vanish; the diagonal blocks elements do not depend on the field sign.

In the MEBT the two solenoids have not the same strength (3.5 and 2.7 T) and there is a cavity in between.

Track 4 particles with starting conditions

$$\vec{z}_1 = \begin{pmatrix} 1\,\mathrm{mm} \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad \vec{z}_2 = \begin{pmatrix} 0 \\ 10\,\mathrm{mrad} \\ 0 \\ 0 \end{pmatrix} \qquad \vec{z}_3 = \begin{pmatrix} 0 \\ 0 \\ 1\,\mathrm{mm} \\ 0 \end{pmatrix} \qquad \vec{z}_4 = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 10\,\mathrm{mrad} \end{pmatrix}$$

Particles coordinates at the exit of the 2th solenoid:

	#	x	x'	y	y'
same polarity	1	-0.412	-1.120	1.012	2.735
	2	0.702	-1.603	-1.717	3.812
	3	-1.012	-2.735	-0.412	-1.120
	4	1.717	-3.813	0.701	-1.603
opposite polarity	1	-1.078	-2.921	0.175	0.450
	2	1.828	-4.085	-0.314	0.644
	3	-0.175	-0.450	-1.078	-2.921
	4	0.314	-0.644	1.828	-4.085

Courant-Snyder invariant

$$\epsilon = \beta z'^2 + 2\alpha z z' + \gamma z^2$$

Ratio of Courant-Snyder invariant at the exit of the 2th solenoid (Twiss functions computed by TRACK for I=0)

	$\epsilon_y^1/\epsilon_x^1$	$\epsilon_y^2/\epsilon_x^2$	$\epsilon_x^3/\epsilon_y^3$	$\epsilon_x^4/\epsilon_y^4$
same polarity	6.1	5.8	5.9	5.6
opposite polarity	0.02	0.02	0.02	0.02

The coupling cancellation is not perfect, but still acceptable.

Solenoids and positioning errors

Exit (hard-edge) transfer matrix:

$$M(K_s) = \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & K_s/2 & 0 \\ 0 & 0 & 1 & 0 \\ -K_s/2 & 0 & 0 & 1 \end{pmatrix}$$

similar to a thin *skew* quadrupole[a]. The exit transfer matrix is $M(-K_s)$.

Trajectory kick due to a horizontal and vertical offset δ_x and δ_y

$$\begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & K_s/2 & 0 \\ 0 & 0 & 1 & 0 \\ -K_s/2 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} -\delta_x \\ 0 \\ -\delta_y \\ 0 \end{pmatrix} = \begin{pmatrix} -\delta_x \\ -K_s\delta_y/2 \\ -\delta_y \\ K_s\delta_x/2 \end{pmatrix}$$

That is $\Delta x' = -K_s\delta_y/2$ and $\Delta y' = K_s\delta_x/2$

[a] but $M_{41} = -M_{23}$

The kick due to the exit cancels with the kick due to the entrance of the next solenoids if they have opposite polarity and opposite offsets. Therefore using alternate polarities is convenient for *random* positioning errors.

Orthogonal steering through the solenoid

$$\vec{z}_e = M\vec{z}_i = M(x_i, x'_i, y_i, y'_i)^T$$

M being the solenoid transport matrix. Using one horizontal and one vertical corrector upstream, it is possible to avoid moving simoultanously the horizontal and vertical position at the solenoid exit. Coordinates at solenoid entrance

$$x_i = X_{ij}\Theta^x_j \quad x'_i = X'_{ij}\Theta^x_j \quad y_i = Y_{il}\Theta^y_l \quad y'_i = Y'_{il}\Theta^y_l$$

Requiring for instance $x_e = \bar{x}$ and y_e=0 one has two equations for the two corrector strengths, Θ^x_j and Θ^y_l, but the vertical position will change downstream the solenoid because $y'_e \neq 0$. To avoid this it is needed a third corrector upstream.