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Optimization of Wire Scanner position for HINS Energy Spread Measurement

Task: introduce a dipole downstreams the MEBT line and find best place for measuring $(\Delta p/p)_{rms}$ through a Wire Scanner.

Eliana GIANFELICE

eliana@fnal.gov

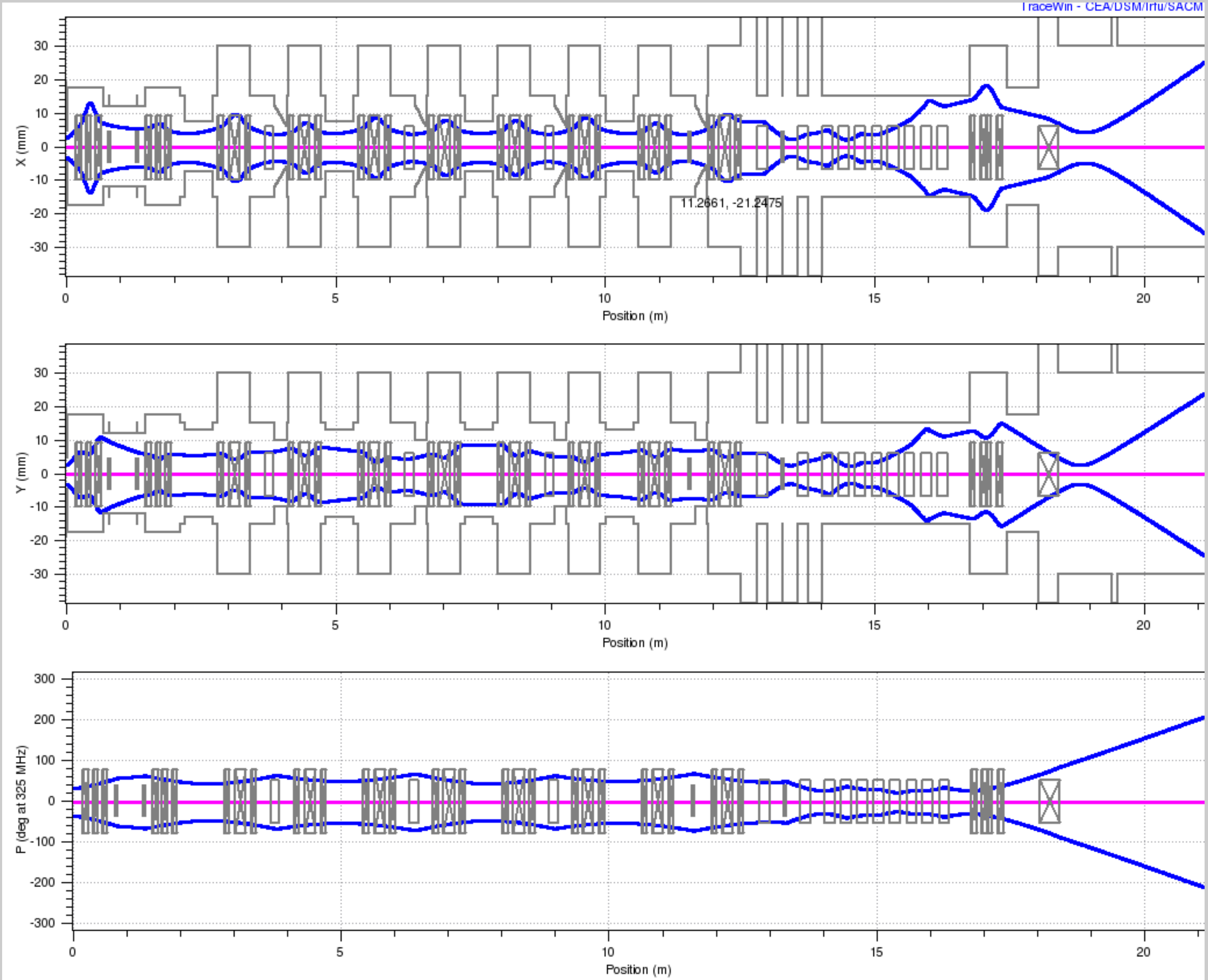
The beam size includes two terms

$$\boldsymbol{\sigma = \sqrt{\epsilon\beta + D^2 \left(\frac{\Delta p}{p}\right)^2}}$$

If a horizontal dipole is introduced downstream the beam line for creating horizontal dispersion the energy spread may be measured from the beam size.

The best location for the Wire Scanner should be a location with maximum $\boldsymbol{D_x/\beta_x}$.

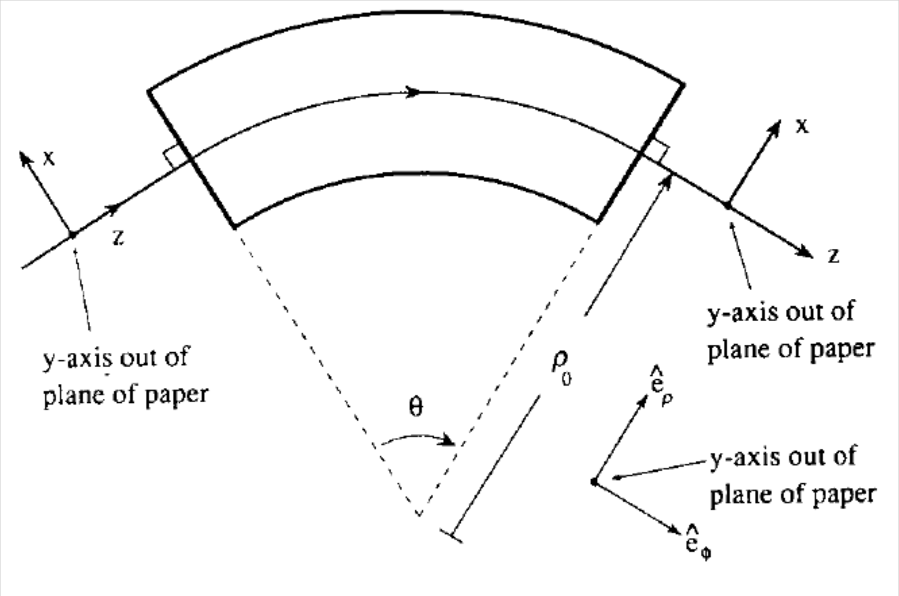
I used a TraceWin file from Nick Perunov containing chopper and 4 SSR0 cavities + 4 RT solenoids. The chopper is matched to the SSR0 section by 2 RT solenoids and a GAP. A large aperture triplet is used to control the beam size at the following 30 degrees dipole.


TraceWin - CEA/DSM/Irfu/SACM
X (mm)
Position (m)
11.2661, -21.2475
Y (mm)
Position (m)
P (deg at 325 MHz)
Position (m)

Try understanding what a dipole we are simulating.

Pitfalls:

- edge definition
- magnet length vs arc length



Sector magnet: beam enters and exits normal to the magnet face.
In the vertical plane it is equivalent to a drift.

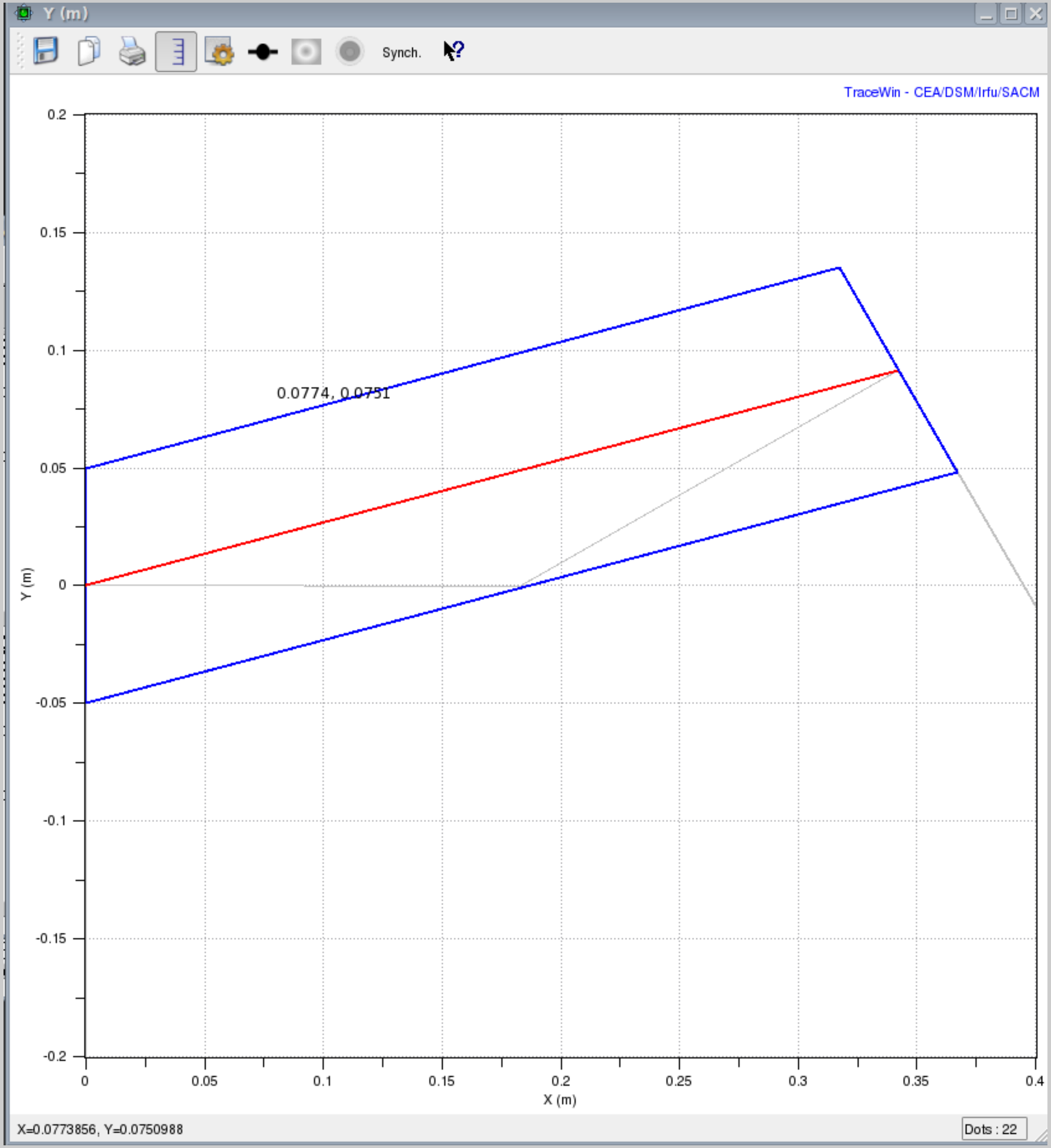
TraceWin description of a 30 degree sector bend

Bend magnet

	angle	ρ	gradient	aperture	plane flag
BEND	30	684.3	0	50	0

must be preceeded and followed by an EDGE element

	face rotation	ρ	gap	fringe field	factors	aperture	plane flag
EDGE	0	684.3	100	1e-8	1e-8	50	0



TraceWin "Synoptic" knob: geometry looks correct.

For finding the optimum position for the wire scanner I need an output with dispersion and β vs position.

TraceWin writes the beam size and the emittances on file.

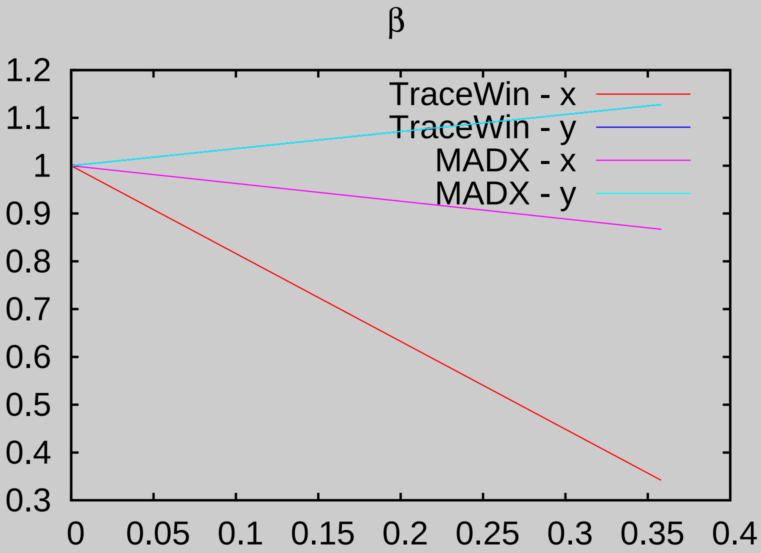
The beam size includes two terms

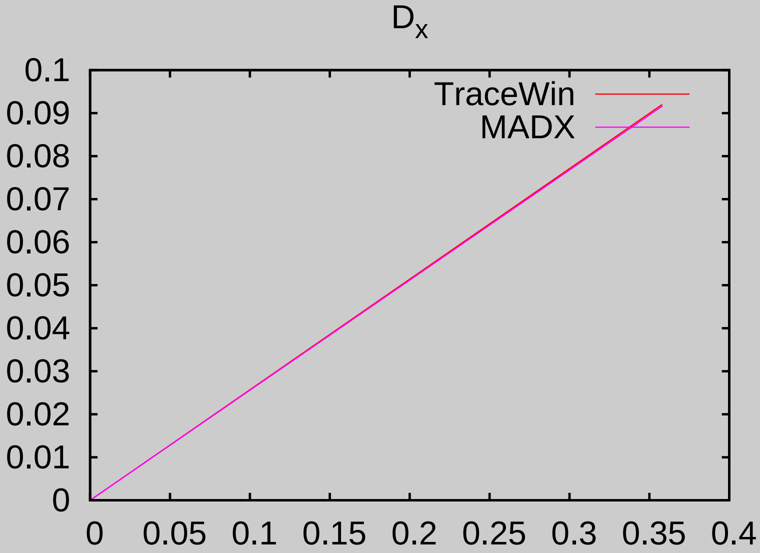
$$\boldsymbol{\sigma_x = \sqrt{\epsilon_x \beta_x + D_x^2 \left(\frac{\Delta p}{p}\right)^2}}$$

Giving a small energy offset to the beam, one can compute the dispersion from the trajectory, subtract the term $\boldsymbol{D_x \Delta p/p}$ from the beam size and get the *usual* β once the emittance is known.

Check TraceWin results for a dipole with MAD-X with starting conditions

$\beta_x^{(0)} = \beta_y^{(0)} = 1$
$\alpha_x^{(0)} = \alpha_y^{(0)} = 0$
$D_x^{(0)} = D_x'^{(0)} = 0$





The resulting β_y [a] and D_x are in perfect agreement with MADX, but β_x not (?) [b].

[a] it is indeed as for a drift

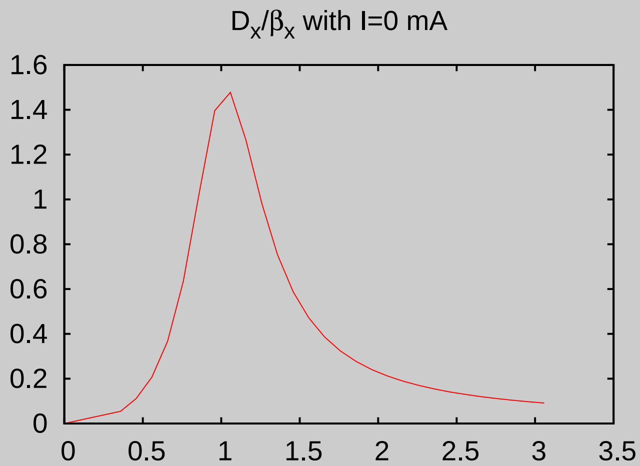
[b] nb: only entrance and exit computed, straight line connects just two points!

What else is wrong? Why, although I corrected $\boldsymbol{\sigma_x}$, is $\boldsymbol{\beta_x}$ still wrong?

The point is that also the emittance[a] itself is "wrong" because contains the part due to the energy spread. To get the right $\boldsymbol{\beta_x}$ the emittance too must be corrected. For this one needs $< \boldsymbol{D^2} >$, $< \boldsymbol{DD'} >$ and $< \boldsymbol{D'^2} >$ which are *not* available.

Trick: run with an artificially small longitudinal emittance (a factor $10^{\mathbf{3}}$). At least w/o space charge it should be possible. But if no space charge may be considered also MAD-X can make the job...

[a] $\boldsymbol{\epsilon_x^2 =< (x - \bar{x})^2 >< (x' - \bar{x}')^2 > - < xx' >^2}$



distances from dipole entrance (18.049 m from RFQ exit)
dipole is 0.358 m long
distance between triplet exit and dipole entrance is 0.6 m

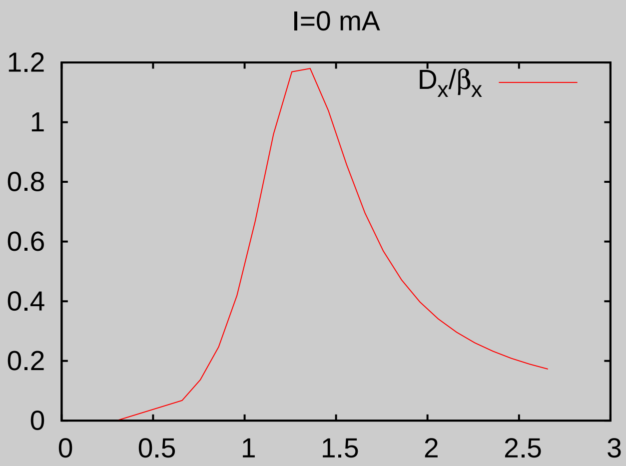
The ratio is maximum at about 1.058 m. For $\boldsymbol{I}$=0 the expected $(\boldsymbol{\Delta p/p})_{\boldsymbol{rms}}$ at this location is 3.2×10$^{\boldsymbol{-3}}$, [a] $\boldsymbol{\beta_x}$ = 0.2806 m and $\boldsymbol{D_x}$ = 0.441 m. Thus ($\boldsymbol{\beta\gamma}$=0.079)

$$\boldsymbol{\beta_x \epsilon_x = 0.2806 \times \frac{0.25}{0.079} \times 10^{-6} = 0.888 \times 10^{-6}} \text{ m}^2$$

$$\boldsymbol{\left[D_x \frac{\Delta p}{p}\right]^2 = \left[0.441 \times 3.2 \times 10^{-3}\right]^2 = 2 \times 10^{-6}} \text{ m}^2$$

The ratio may be improved by shortening the dipole, introducing focusing edges, increasing the bending angle. In all cases the optimum position moves towards the dipole.

[a] it is 3.7×10$^{\boldsymbol{-3}}$ for 10 mA



shifting dipole by 0.4 m

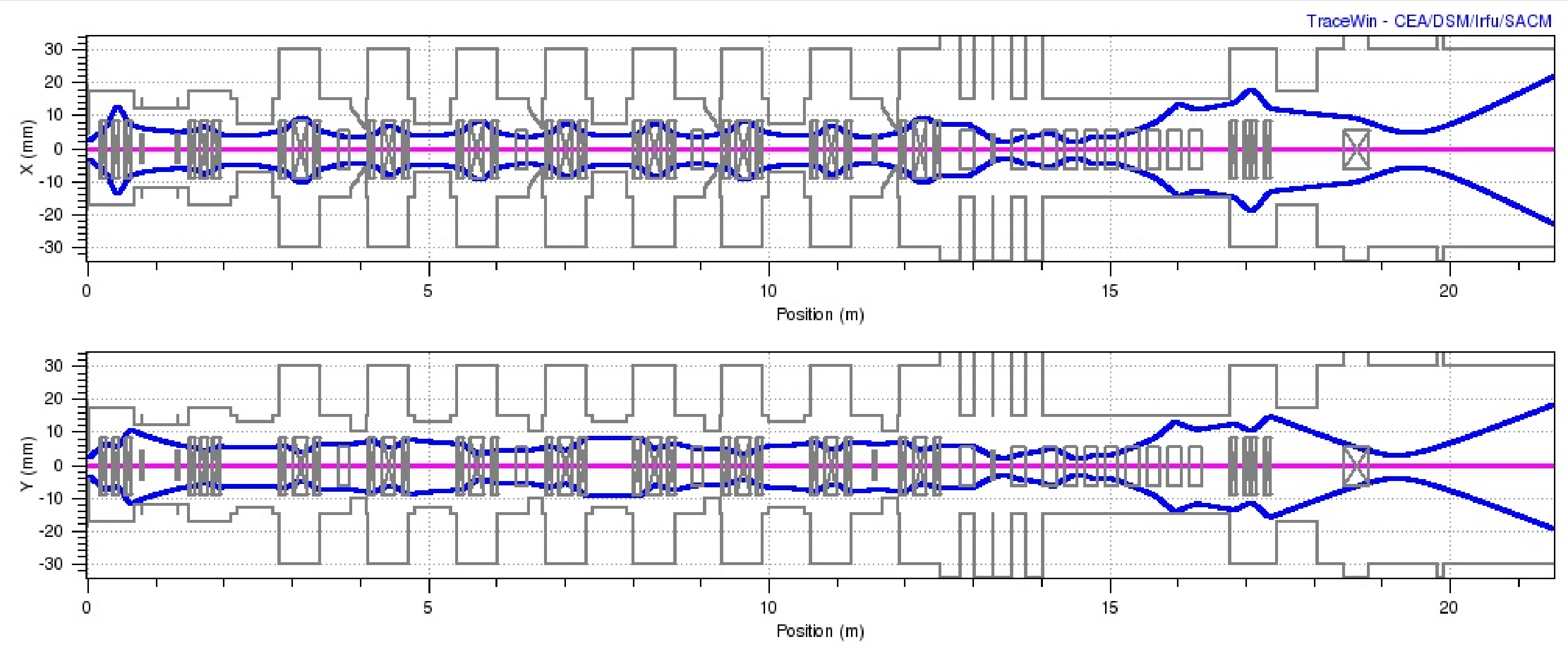
to increase space for diagnostics

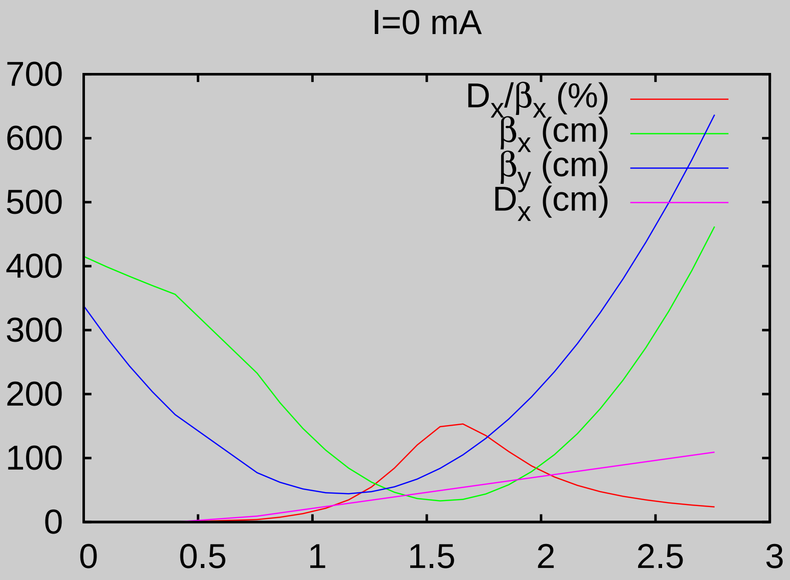
(ie distance between triplet exit and

dipole entrance is now 1 m)

ratio decreases

Final triplet changed to improve ratio





distance between triplet exit and dipole entrance is 1 m (careful to the units!)

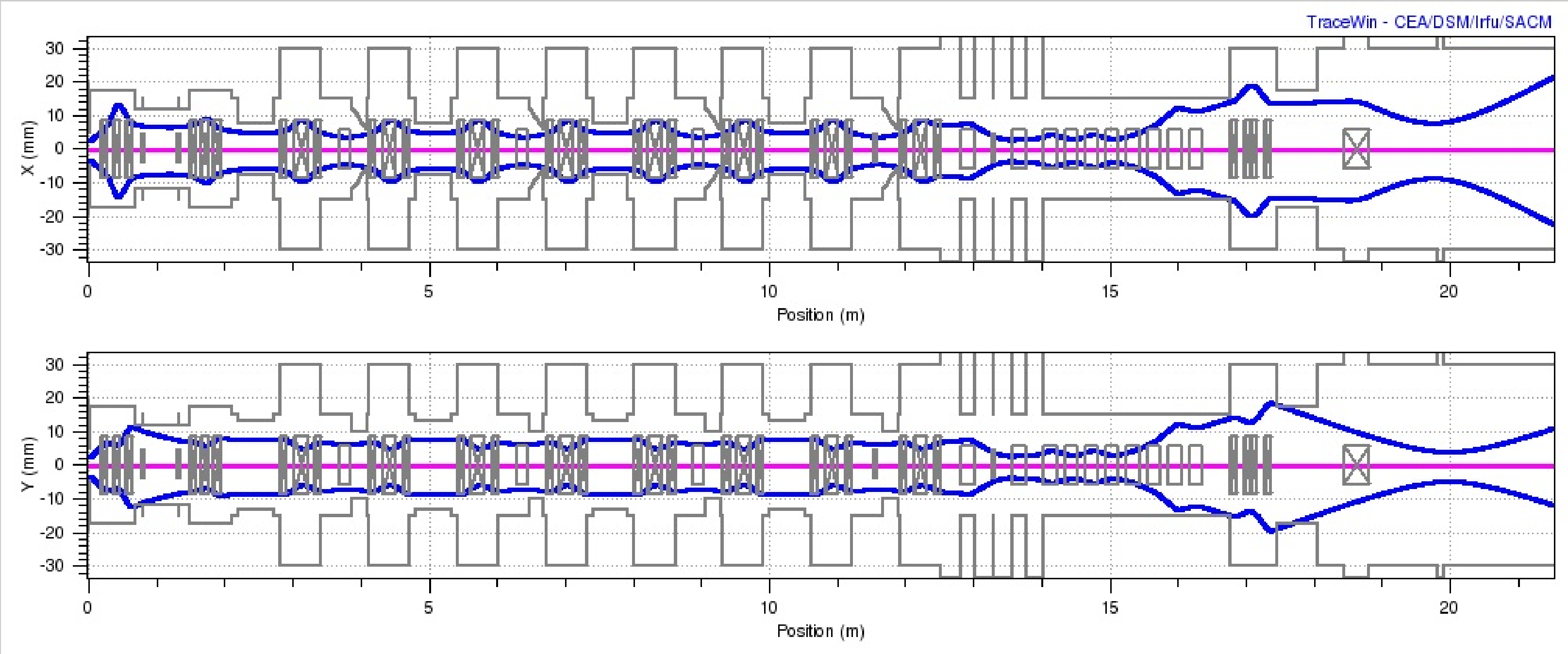
ratio may be increased if we go to the $\hat{\beta}_y$ limit.

Maximum ratio is at 0.9 m from dipole exit where σ_x^{tot}=1.8 mm, $\beta_x = 0.3533$ m and $D_x = 0.542$ m. Expected sizes are

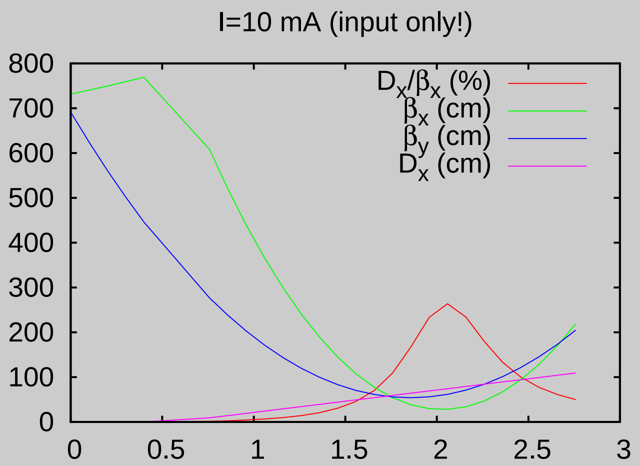
$$\beta_x \epsilon_x = 0.3533 \times \frac{0.25}{0.079} \times 10^{-6} = 1.118 \times 10^{-6} \text{ m}^2$$

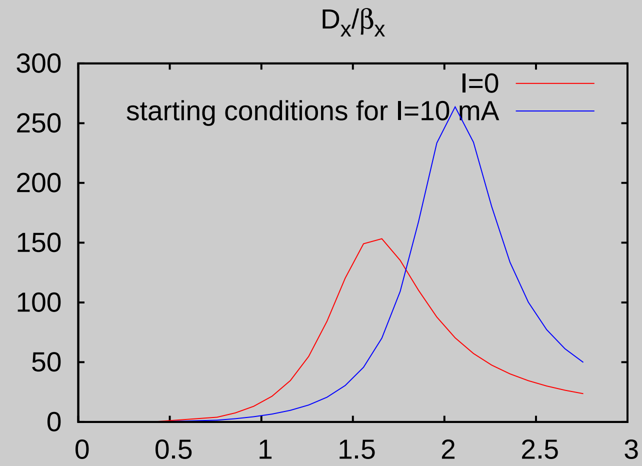
$$\left[D_x \frac{\Delta p}{p}\right]^2 = \left[0.542 \times 3.2 \times 10^{-3}\right]^2 = 3.0 \times 10^{-6} \text{ m}^2$$

TraceWin Envelopes with I=10 mA



Use starting values upstream dipole obtained by TraceWin with $\boldsymbol{I}$=10 mA and compute optics with MADX (*no* space charge).

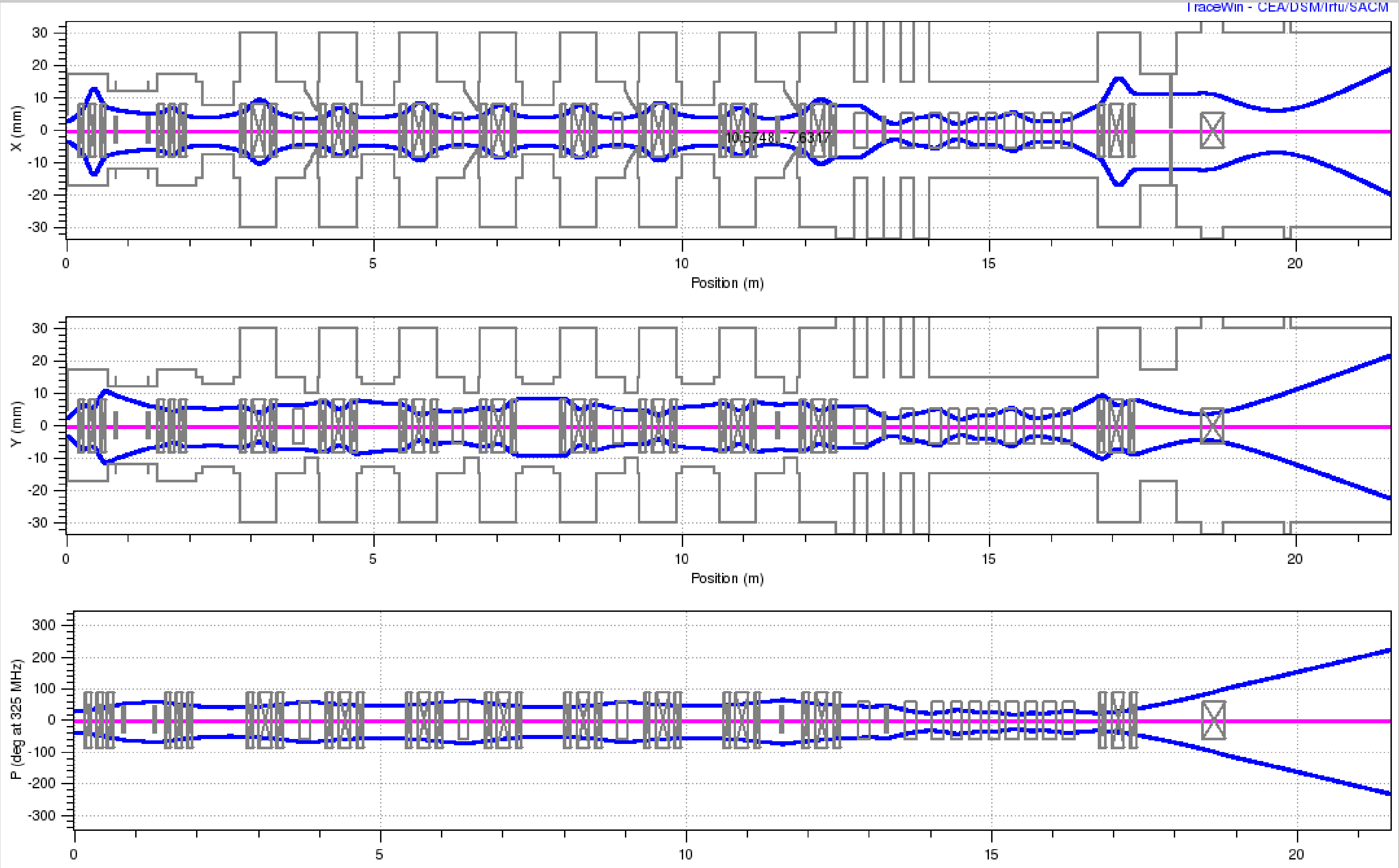


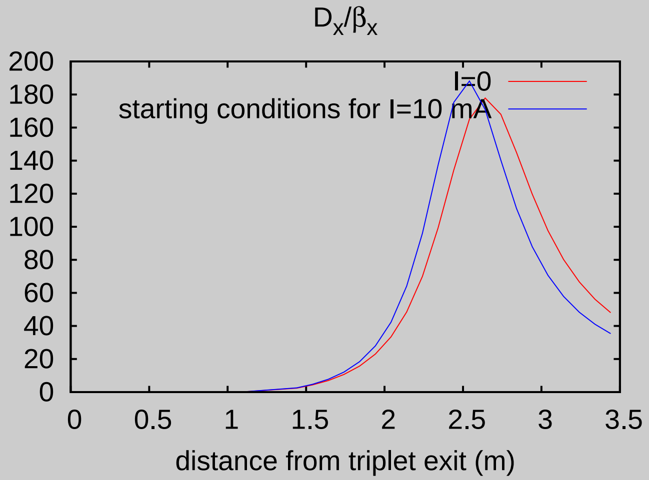


With the new starting conditions the maximum ratio increases but the *position* moved by about 0.3 m ($\boldsymbol{\sigma_x^{tot}}$=2.8 mm).

Where should the Wire Scanner be located??

The 3th solenoid in cryostat was off. This caused some losses by tracking with space charge. Switch on and re-optimize triplet to move focal point far downstream dipole so that the dispersion may grow.





Starting conditions are for I=10 mA but D_x and β_x are computed by MADX w/o space charge. The best wire scanner location (19.8661 m from RFQ, 2.5 m from triplet exit and 1.0586 m from dipole exit) is *insensitive* to current.

From MADX data with I=0 mA starting conditions, at optimum location it is σ_x^{tot}= 2.3 mm, β_x = 0.404 m and D_x = 0.621 m. Expected sizes are

$$\beta_x \epsilon_x = 0.404 \times \frac{0.25}{0.079} \times 10^{-6} = 1.278 \times 10^{-6} \text{ m}^2$$

$$\left[D_x \frac{\Delta p}{p}\right]^2 = \left[0.621 \times 3.2 \times 10^{-3}\right]^2 = 3.949 \times 10^{-6} \text{ m}^2$$

If we neglect the betatron contribution in the previuos formula, from the total size one get $(\Delta p/p)_{rms} = 3.7\times10^{-3}$ (ie 16% error). If the emittance could be reduced by a factor 10, the error would be 1.6%.

Idea: insert a slit before the dipole to reduce horizontal emittance.

Check idea through tracking: 2×10^4 particle starting conditions are extracted from a 6D ellipsoid and tracked from RFQ to slit entrance with $I = 10$ mA. The new distribution is tracked through the slit to the wire scanner optimum position.

Results

ϵ_x^N (mm mrad)	I (mA)	σ_x (mm)	$(\Delta p/p)_{rms}$ (%)	σ_x/D_x (%)	error (%)
0.009	0	2.55	0.378	0.411	9
0.009	10	2.58	0.371	0.415	12
0.026	0	2.59	0.378	0.418	10
0.026	10	2.69	0.366	0.433	12

There is an *intrinsic* error which seems not strongly related to space charge.