PIP-II Linac Beam parameters and Intrabeam Stripping

Fundamental constants

$m_p := 938.256 \cdot 10^6$ eV $\quad M_p := 1.6725 \cdot 10^{-24}$ $\quad m_e := 0.511006 \cdot 10^6$ eV $\quad M_e := 9.109081 \cdot 10^{-28}$ $\quad e_{SI} := 1.602 \cdot 10^{-19}$

$m_\mu := 105.658 \cdot 10^6$ eV $\quad m_\pi := 139.57 \cdot 10^6$ eV $\quad e_{conv} := 299.7925$ $\quad e_{SGS} := 4.802981 \cdot 10^{-10}$

$\tau_\mu := 2.197 \cdot 10^{-6}$ s $\quad \tau_\pi := 2.603 \cdot 10^{-8}$ s $\quad r_p := \frac{e_{SGS} \cdot e_{conv}}{m_p}$ $\quad r_e := \frac{e_{SGS} \cdot e_{conv}}{m_e}$

$c := 2.997925 \cdot 10^{10}$ cm/c $\quad Z_0 := 377$ Ω

$h_P := 1.054491 \cdot 10^{-27}$ $\quad k_B := 1.380541 \cdot 10^{-16}$ $\quad \alpha_{FS} := \frac{e_{SGS}^2}{h_P \cdot c}$ $\quad a_0 := \frac{h_P^2}{M_e \cdot e_{SGS}^2}$

Data reading from TraceWin simulations

position gam-1 rms_size(x,x',y,y',z,dp/p,z',phase,time,energie) centroid position(x,x',y,y',z,dp/p,z',phase,time,energy) (dispX,dispY,betX,betY) unit(m,rad,deg,s,MeV)

$M :=$ ...\envelope_data.txt $\quad N := \text{rows}(M)$ $\quad i := 0..N-1$ $\quad N = 2.917 \times 10^4$

$s_i := 100 \cdot M_{i,0}$ $\quad En_i := M_{i,1} \cdot m_p$ $\quad \sigma x_i := 100 \cdot M_{i,2}$ $\quad \theta x_i := M_{i,3}$ $\quad \sigma y_i := 100 \cdot M_{i,4}$ $\quad \theta y_i := M_{i,5}$ $\quad \sigma s_i := 100 \cdot M_{i,6}$ $\quad \Delta p_i := M_{i,7}$

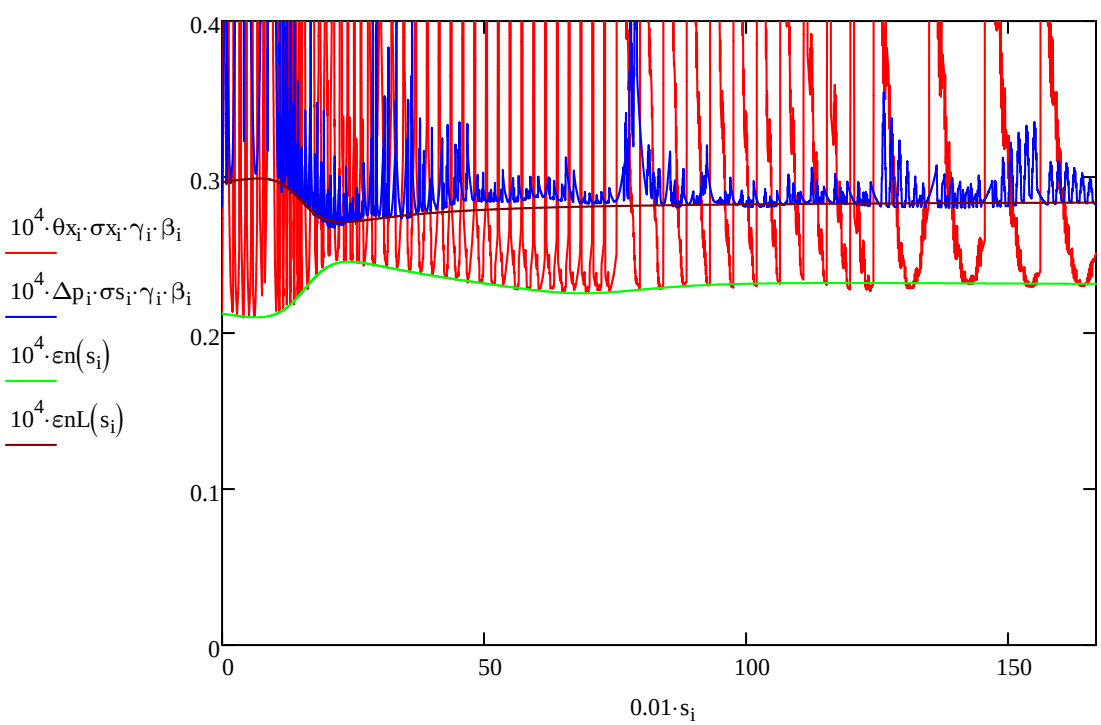
$s_0 := 1600$ $\quad a := 900$ $\quad a_1 := 2000$ $\quad s_1 := 7000$ $\quad \gamma_i := M_{i,1} + 1$ $\quad \beta_i := \sqrt{1 - \frac{1}{(\gamma_i)^2}}$

$s_2 := 1500$ $\quad a_2 := 800$

$$\varepsilon n(s) := 10^{-4} \cdot \left[0.229 + 0.044 \frac{a \cdot (s - s_0)}{(s - s_0)^2 + a^2} \cdot \left[1 - \frac{1.5}{1 + \left(\frac{s - s_1}{a_1} \right)^2} \right] \right]$$

$$\varepsilon nL(s) := 10^{-4} \cdot \left[0.285 - 0.028 \frac{a_2 \cdot (s - s_2)}{(s - s_2)^2 + a_2^2} \right]$$

$\sigma_{\theta x_i} := \frac{\varepsilon n(s_i)}{\beta_i \cdot \gamma_i \cdot \sigma x_i}$ $\quad \sigma_{\theta y_i} := \frac{\varepsilon n(s_i)}{\beta_i \cdot \gamma_i \cdot \sigma y_i}$ $\quad \sigma_{p_i} := \frac{\varepsilon nL(s_i)}{\beta_i \cdot \gamma_i \cdot \sigma s_i}$ $\quad \beta x_i := \frac{(\sigma x_i)^2 \cdot (\beta_i \cdot \gamma_i)}{\varepsilon n(s_i)}$ $\quad \beta y_i := \frac{(\sigma y_i)^2 \cdot (\beta_i \cdot \gamma_i)}{\varepsilon n(s_i)}$ $\quad \beta s_i := \frac{(\sigma s_i)^2 \cdot (\beta_i \cdot \gamma_i)}{\varepsilon nL(s_i)}$



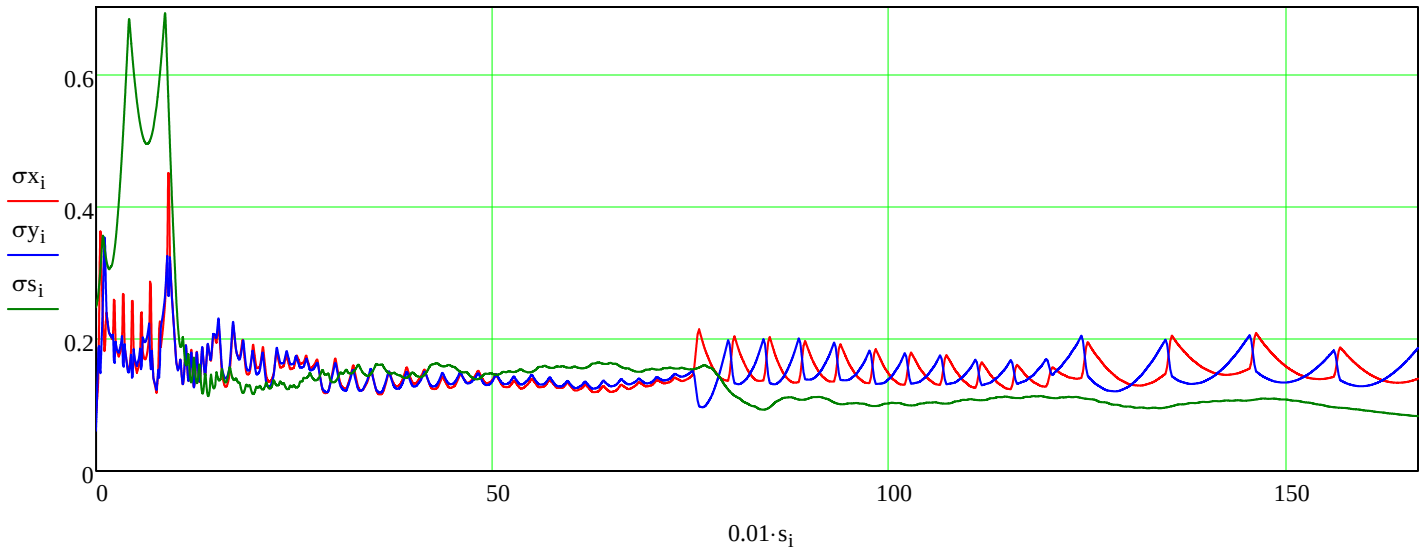
$j := 0..N-2$

$$\alpha x_j := \frac{1}{2} \cdot \frac{\beta x_j - \beta x_{j+1}}{s_{j+1} - s_j + 10^{-8}}$$

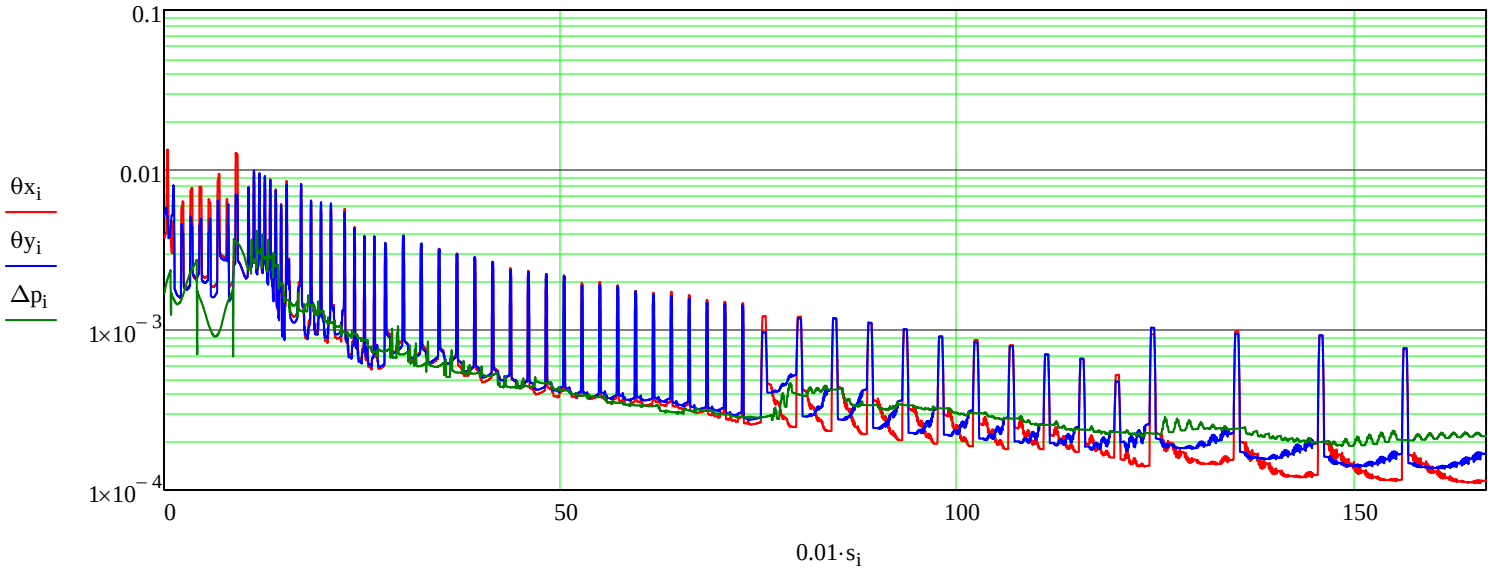
$$\alpha y_j := \frac{1}{2} \cdot \frac{\beta y_j - \beta y_{j+1}}{s_{j+1} - s_j + 10^{-8}}$$

$$\alpha s_j := \frac{1}{2} \cdot \frac{\beta s_j - \beta s_{j+1}}{s_{j+1} - s_j + 10^{-8}}$$

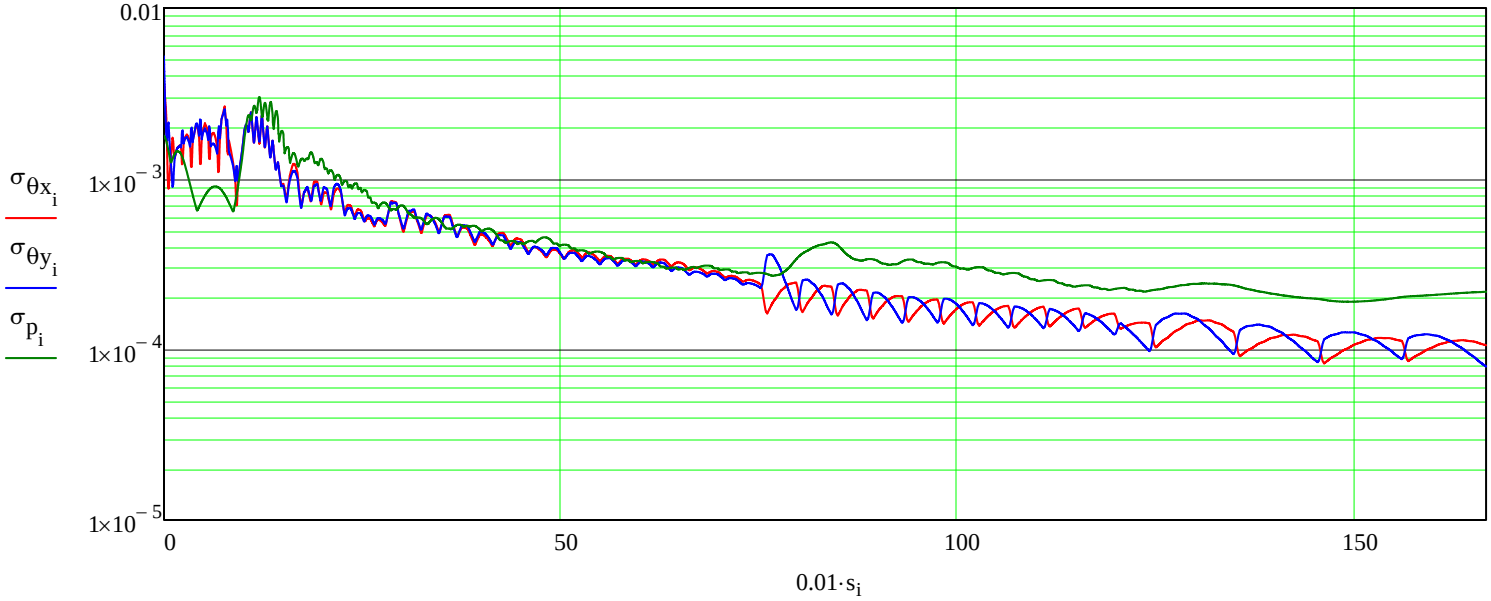
Rms beam sizes [cm]

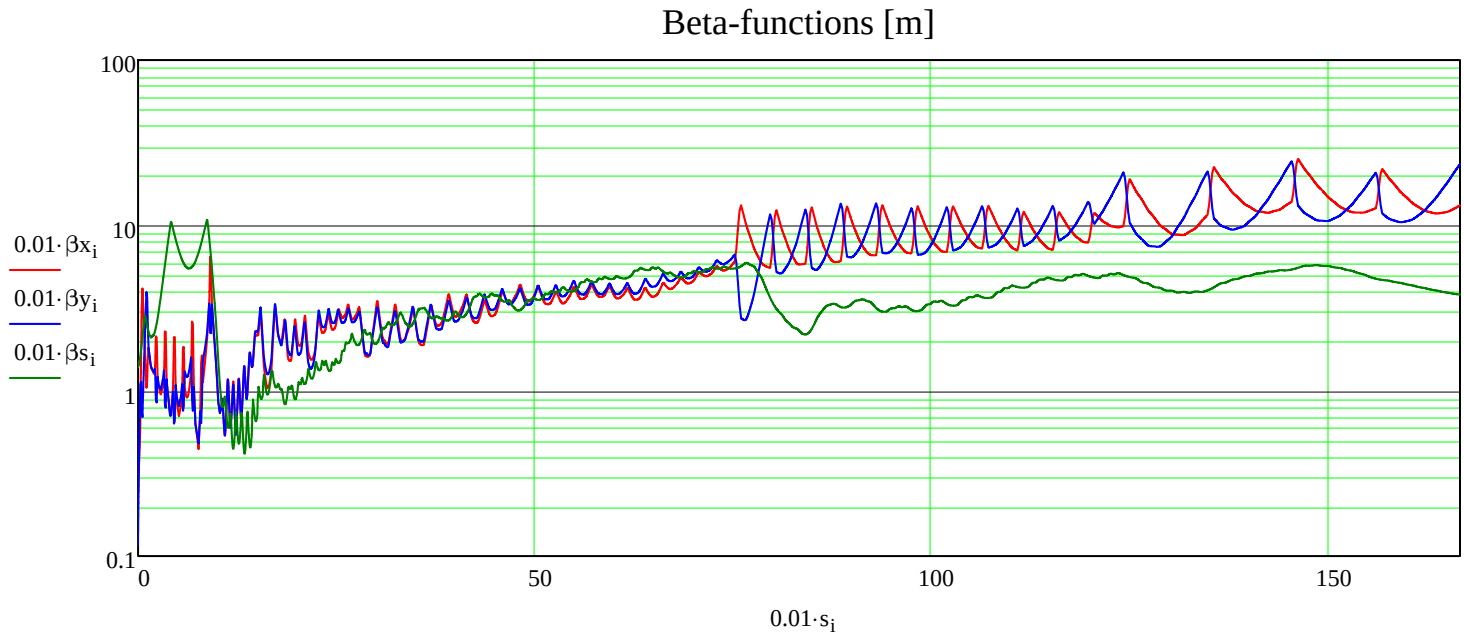


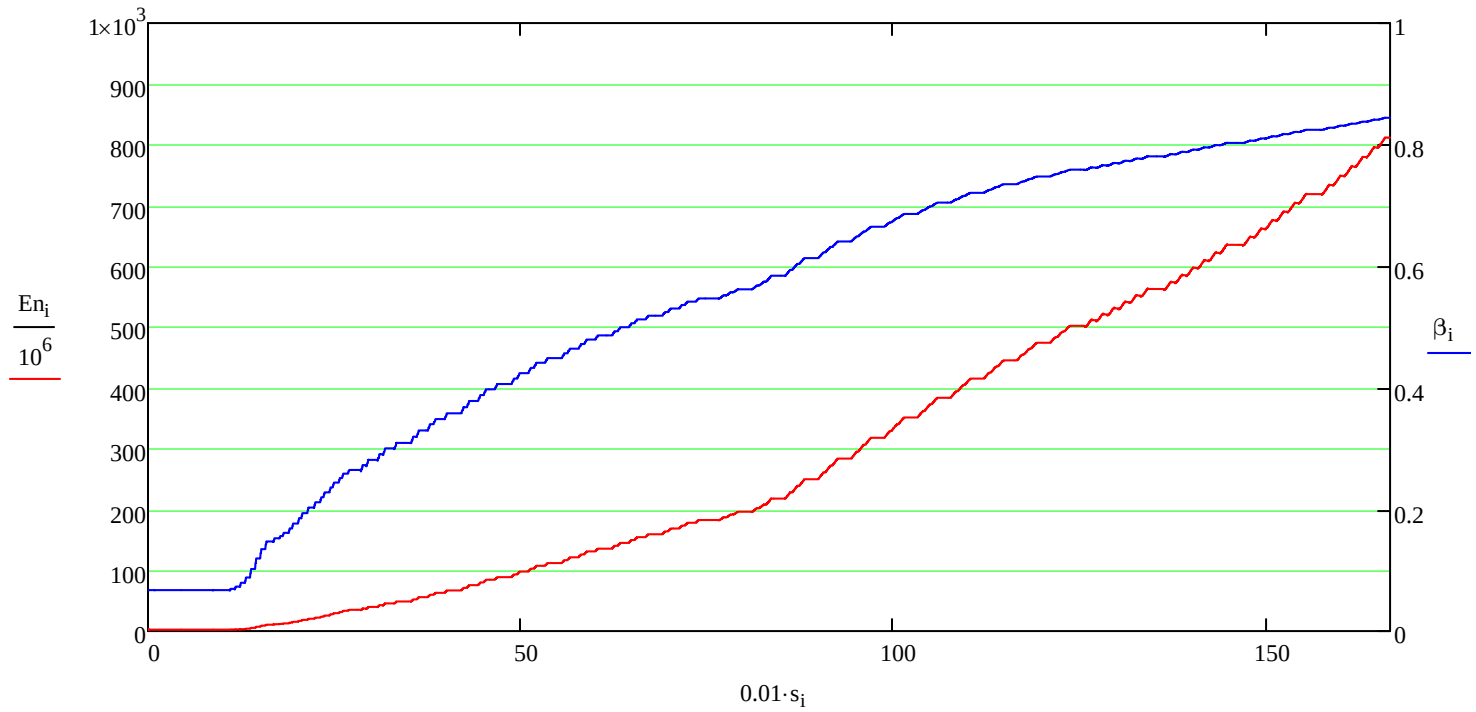
Relative rms momentum spreads

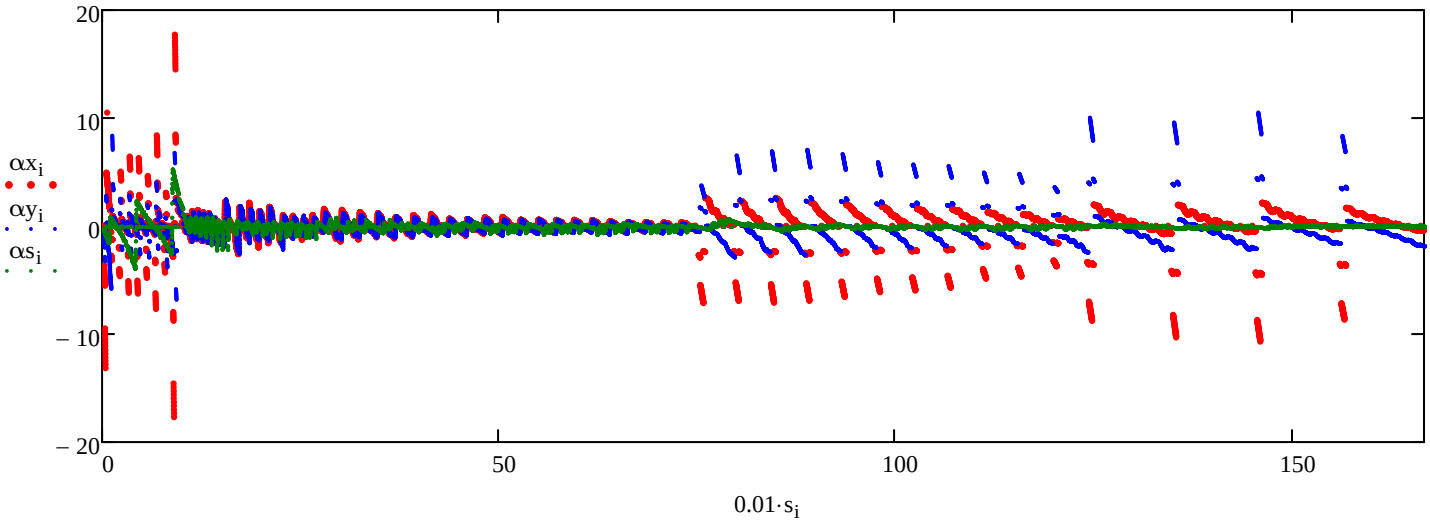


Relative local rms momentum spreads




Beta-functions [m]
100
10
1
0.1
0.01·βx_i
0.01·βy_i
0.01·βs_i
0
50
100
150
0.01·s_i


1×10^3
900
800
700
600
500
400
300
200
100
0
En_i / 10^6
1
0.8
0.6
0.4
0.2
0
β_i
0
50
100
150
0.01·s_i


20
10
0
− 10
− 20
αx_i
αy_i
αs_i
0
50
100
150
0.01·s_i

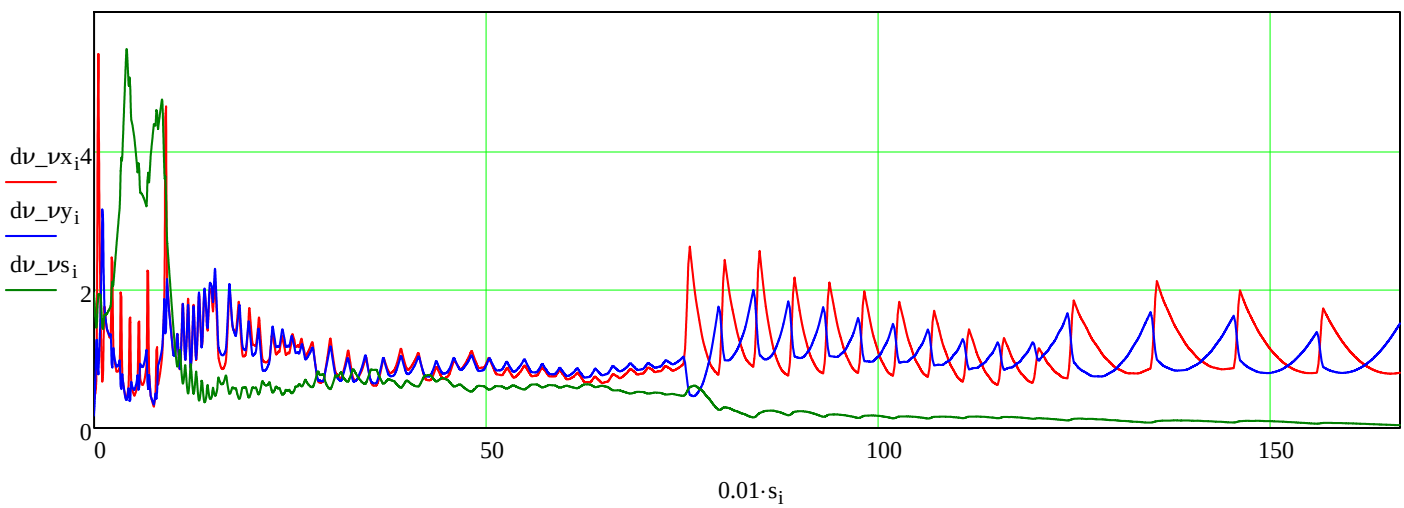
Tune shifts due to beam space charge

$I_b := 5\cdot 10^{-3}\,A$ $\qquad f_b := 162.5\cdot 10^{6}\,Hz$ $\qquad N_p := \dfrac{I_b}{e_{SI}\cdot f_b}$ $\qquad N_p = 1.921\times 10^{8}$

$$dEz_dz(\sigma_x,\sigma_y,\sigma_z) := \frac{4}{\sqrt{\pi}}\cdot\int_0^{\infty}\frac{t^2}{\sqrt{\left(1+2\cdot\sigma_x^{\,2}\,t^2\right)}\cdot\sqrt{\left(1+2\cdot\sigma_y^{\,2}\cdot t^2\right)}\cdot\left[\sqrt{\left(1+2\cdot\sigma_z^{\,2}\cdot t^2\right)}\right]^3}\,dt$$

Transverse tune shifts: $d\nu_\nu x_i := \dfrac{1}{2}\cdot\dfrac{r_p\cdot N_p\cdot(\beta x_i)^2}{(\beta_i)^2\cdot(\gamma_i)^2}\cdot dEz_dz(\gamma_i\cdot\sigma s_i,\sigma y_i,\sigma x_i)$ $\qquad d\nu_\nu y_i := \dfrac{1}{2}\cdot\dfrac{r_p\cdot N_p\cdot(\beta y_i)^2}{(\beta_i)^2\cdot(\gamma_i)^2}\cdot dEz_dz(\gamma_i\cdot\sigma s_i,\sigma y_i,\sigma y_i)$

Longitudinal tune shift: $d\nu_\nu s_i := \dfrac{1}{2}\cdot\dfrac{r_p\cdot N_p\cdot(\beta s_i)^2}{(\beta_i)^2\cdot(\gamma_i)^3}\cdot dEz_dz(\sigma s_i,\sigma y_i,\gamma_i\cdot\sigma s_i)$



Particle loss due to charge stripping intrabeam collisions

Results of numerical simulations from "Stripping H- in low energy collisions with Antiprotons", Phys. Rev. A., v33, N.3, p.33

$\beta_{rel} := \alpha_{FS}\cdot(0.015\ \ 0.02\ \ 0.03\ \ 0.05\ \ 0.1\ \ 0.2\ \ 0.4\ \ 0.6\ \ 1)^T$ $\qquad nh := 0..8$

$\sigma_{sim} := 10^{-16}\cdot(0.4\ \ 20.3\ \ 33.2\ \ 40\ \ 37.7\ \ 34.3\ \ 33.8\ \ 26.5\ \ 19.1)^T$

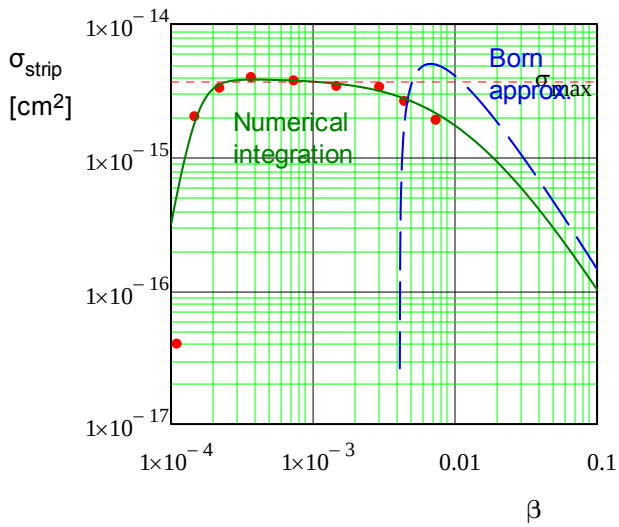
Fitting formulas

$$\sigma_{strip}(\beta, Z) := 152.2\cdot a_0^2\cdot Z^2\cdot\left(\frac{\alpha_{FS}}{\beta}\right)^2\cdot\ln\left[\frac{3.2}{Z}\cdot\left(\frac{\beta}{\alpha_{FS}}\right)^2\right]$$

Theoretical result obtained in born approximation from Нейтрализация ионов H- в столкновениях с быстрыми многозарядными ионами", ЖТФ, 1999, т. 69, в. 7

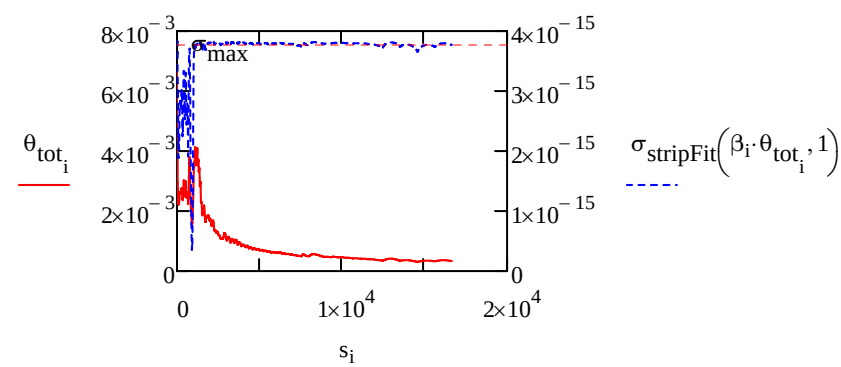
$$\sigma_{stripFit}(\beta, Z) := 120\cdot a_0^2\cdot Z^2\cdot\left(\frac{\alpha_{FS}}{\beta+\alpha_{FS}}\right)^2\cdot\frac{\beta^6}{\left(1.5\cdot10^{-4}\right)^6+\beta^6}\cdot\ln\left[\frac{3.2}{Z}\cdot\left(\frac{\beta+\alpha_{FS}}{\alpha_{FS}}\right)^2\right]$$

$$\sigma_{max} := 135\cdot a_0^2$$



$$\theta_{tot_i} := \sqrt{\left(\sigma_{p_i}\right)^2+\left(\sigma_{\theta x_i}\cdot\gamma_i\right)^2+\left(\sigma_{\theta y_i}\cdot\gamma_i\right)^2}$$

$$\lambda_{L_i} := \frac{N_p\cdot\sigma_{stripFit}\left(\beta_i\cdot\theta_{tot_i},1\right)}{8\cdot\pi^2\cdot\sigma x_i\cdot\sigma y_i\cdot\sigma s_i\cdot\left(\gamma_i\right)^2}\cdot\theta_{tot_i}$$



$j := 0..N-2$

$loss_0 := 0 \qquad loss_{j+1} := loss_j + \lambda_{L_j}\cdot\left(s_{j+1}-s_j\right)$

$I_{BeamAv} := 2\cdot10^{-3}A \qquad Ploss_0 := 0 \qquad Ploss_{j+1} := Ploss_j + \lambda_{L_j}\cdot\left(s_{j+1}-s_j\right)\cdot En_j\cdot I_{BeamAv}$

Properties of particle passage through iron

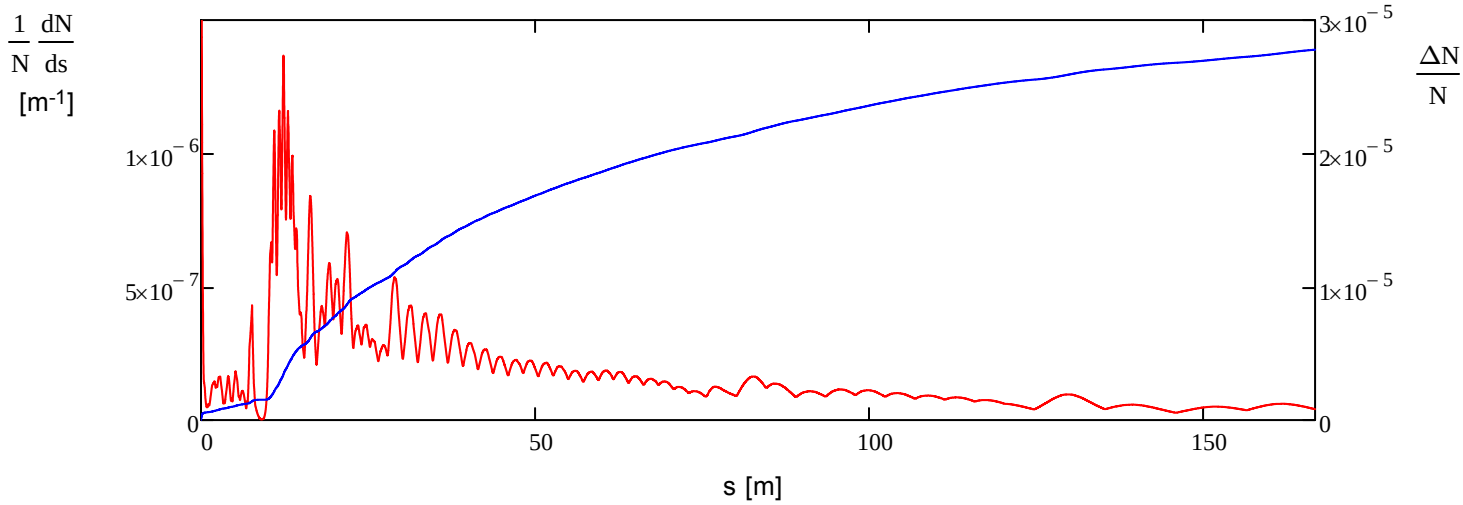
$dEdx_0 := 1.45\cdot10^6$ MeV/(g/cm2) $\qquad \gamma_p := \frac{1}{m_p}\cdot dEdx_0$

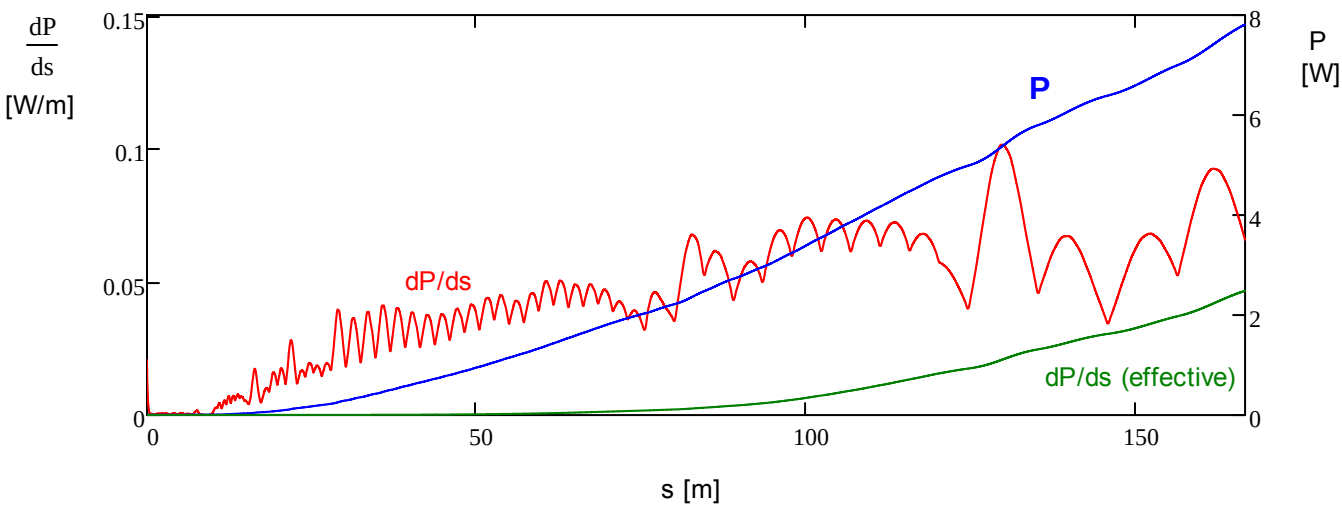
$L_{nucl} := 132$ g/cm2

$$F_p(\gamma) := 1-\frac{1}{\left[1+\frac{1}{5}\cdot\left(\frac{\gamma-1}{\gamma_p\cdot L_{nucl}}\right)^2\right]^{0.69}}$$

$PlossEf_0 := 0$

$$PlossEf_{j+1} := PlossEf_j + F_p\left(\frac{En_j}{m_p}+1\right)\cdot\lambda_{L_j}\cdot\left(s_{j+1}-s_j\right)\cdot En_j\cdot I_{BeamAv}$$


1/N dN/ds [m-1]
ΔN/N
1×10−6
5×10−7
0
3×10−5
2×10−5
1×10−5
0
0
50
100
150
s [m]


dP/ds [W/m]
P [W]
0.15
0.1
0.05
0
8
6
4
2
0
P
dP/ds
dP/ds (effective)
0
50
100
150
s [m]