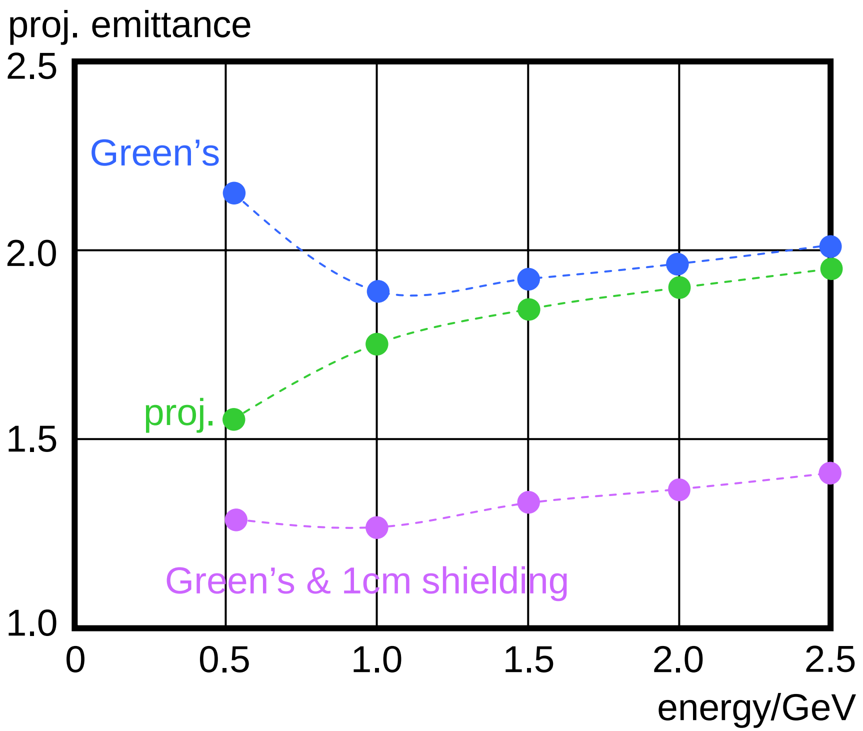
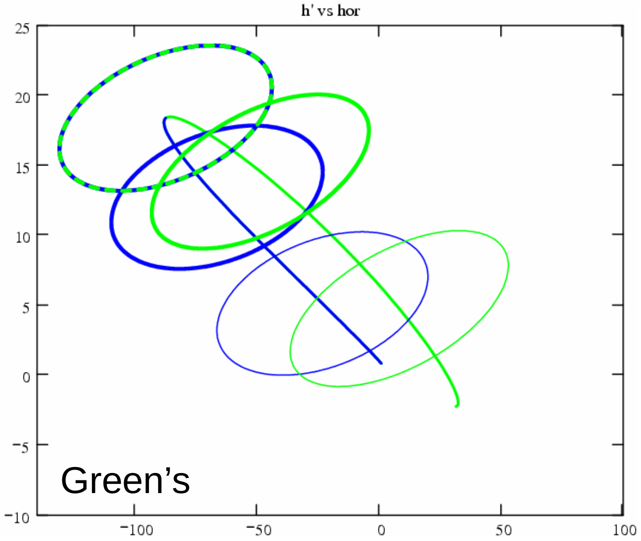
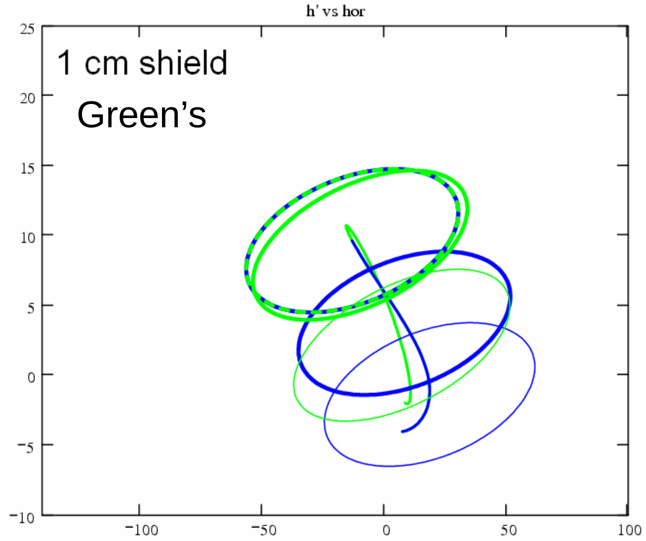
# XFEL-BC2 vs energy, absolute chirp = const




even if $\frac{h}{\sqrt[3]{R_0 \sigma^2}} >> 1$ : shielding effects may be important

2500 MeV




growth of projected emittance is essentially caused by offsets of the slice centroids

fast estimation by "projected method" but: shielding is not implemented → implementation for CSRtrack & ASTRA

resistive wall wakes not negligible but: no model for RWWs in BCs

# fast test environment

- define BC geometry $\rightarrow \; K(s)$
- calculate local bunch length (without self-effects) $\rightarrow \; \sigma(s)$
- calculate longitudinal field (unperturbed motion) $\rightarrow \; F_{\parallel}(s) \rightarrow \; \Delta E(s)$
- estimate centroid positions

$$x'' + \left(K^2 - n\right)x = \frac{K\Delta E + F_x}{E} \quad \rightarrow \quad x'' + K^2 x \approx \frac{K\Delta E}{E} \quad \rightarrow \quad \begin{matrix} x_c(s) \\ x'_c(s) \end{matrix}$$

- estimate projected emittance

$$\psi(x, x', y, y', ds, de, s) \approx \psi_h\left(x - x_c(s), x' - x'_c(s)\right) \cdot \psi_v(y, y') \cdot \eta\left(ds, \sigma(s)\right)$$

$$\varepsilon_h \approx \sqrt{c_{xx} c_{x'x'} - c_{xx'}{}^2}$$

with $c_{ab} = f_{ab} + g_{ab}$

$f_{ab}$ = 2nd momenta of $\psi_h$

$g_{ab}$ = 2nd momenta of centroids

# after few minutes:

## original BC@2.5GeV

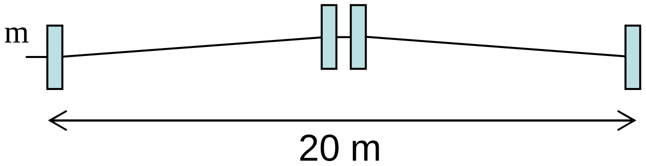
$r_{56} = -20.8\,\text{mm}$

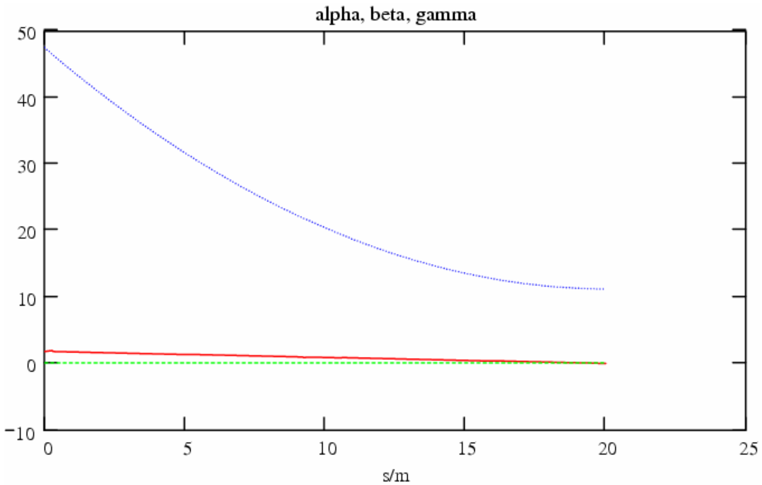
$\phi = 1.93^o$

$R = 8.890\,\text{m}$

$\beta = 47.5\,\text{m}$

$\alpha = 1.8$




## setup 2

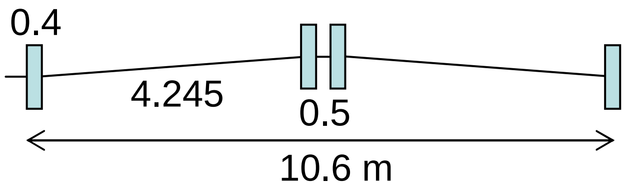
$r_{56} = -20.8\,\text{mm}$

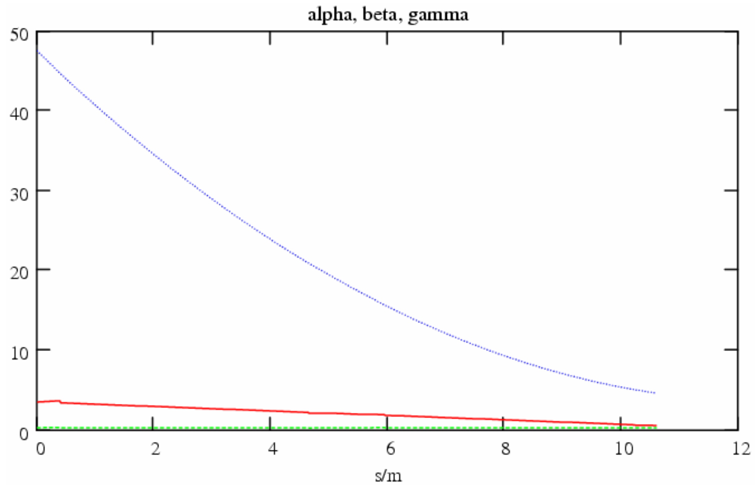
$\phi = 2.745^o$

$R = 8.353\,\text{m}$

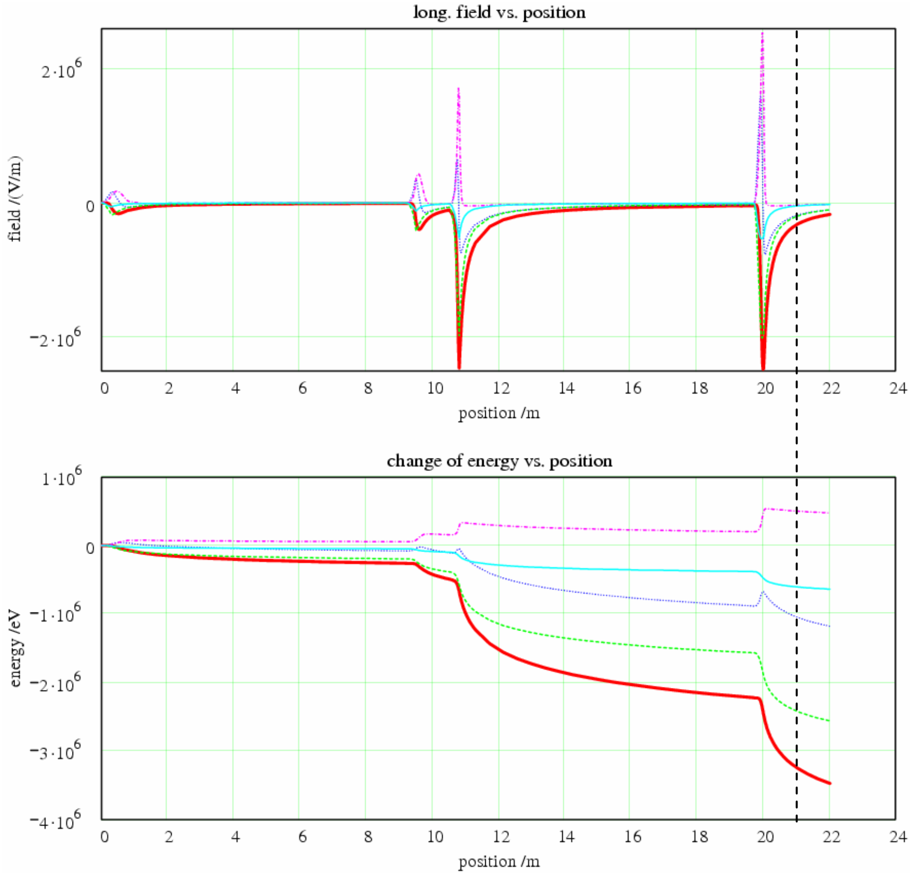
$\beta = 47.5\,\text{m}$

$\alpha = 3.5$



# original BC@2.5GeV




**Slice emittance:** $\sqrt{cxx \cdot cyy - cxy^2} \cdot \gamma = 1 \times 10^{-6}$

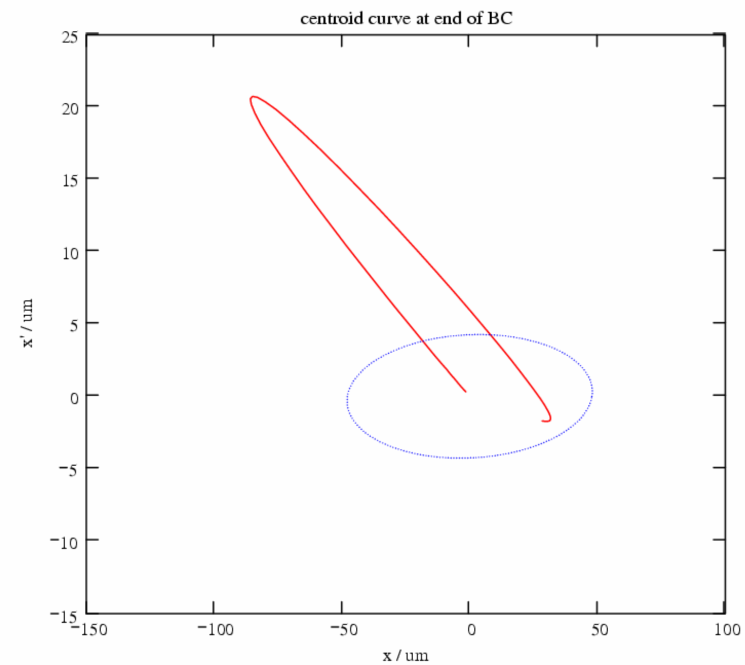
**Centroid emittance:** $\sqrt{dxx \cdot dyy - dxy^2} \cdot \gamma = 3.006 \times 10^{-7}$

**Projected emittance:** $\sqrt{exx \cdot eyy - exy^2} \cdot \gamma = 2.01 \times 10^{-6}$

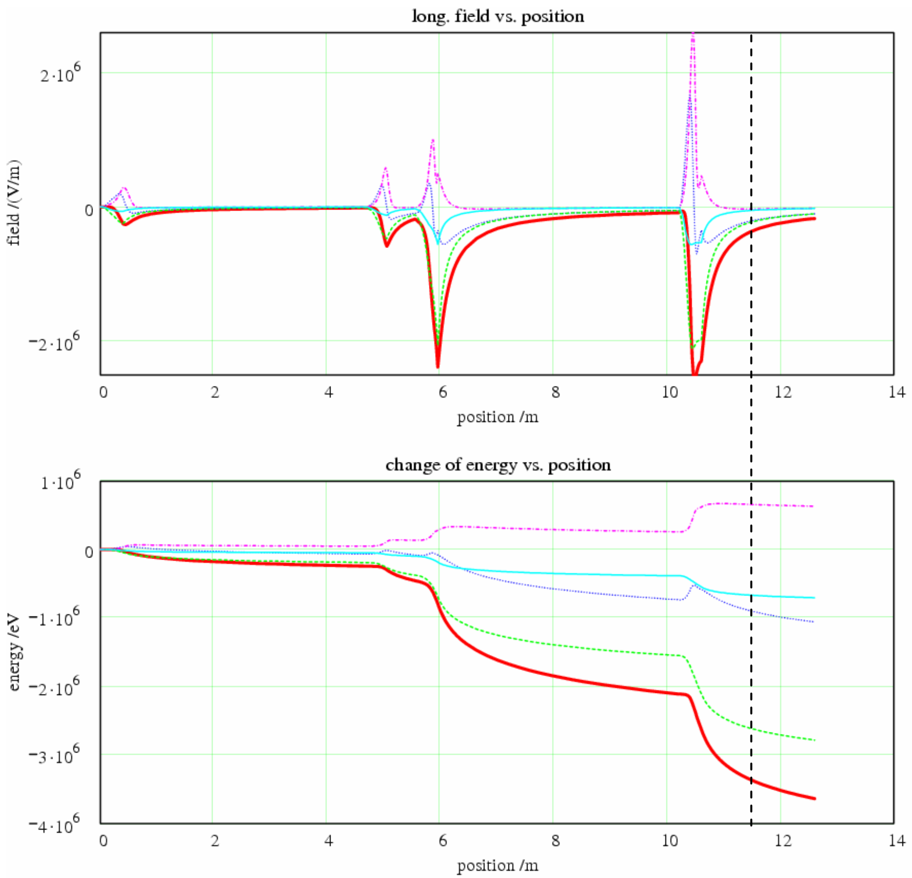
**Field in bending magnet:**

$B0 := 1.70447 \times 10^{-3} \cdot K0 \cdot \gamma \cdot \sqrt{1 - \gamma^{-2}}$

$B0 = 0.939$



# setup 2




**Slice emittance:** $\sqrt{cxx \cdot cyy - cxy^2} \cdot \gamma = 1 \times 10^{-6}$

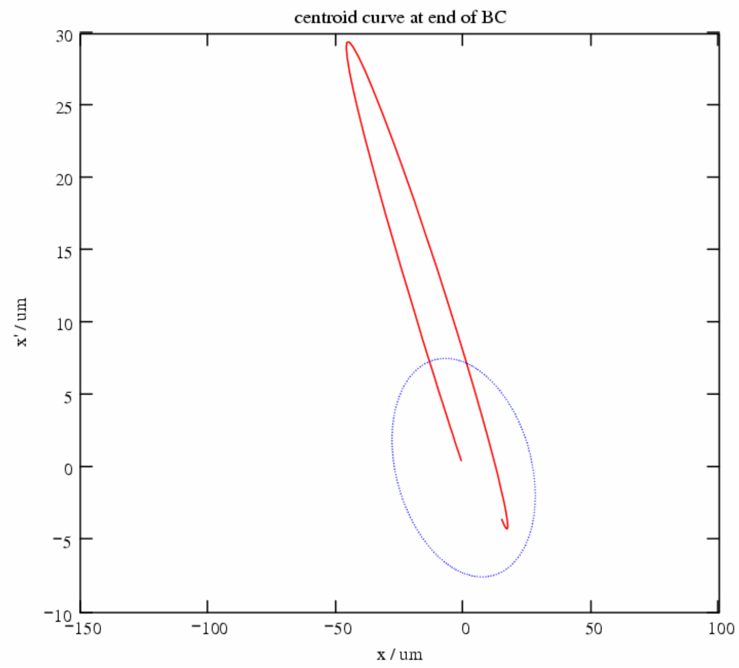
**Centroid emittance:** $\sqrt{dxx \cdot dyy - dxy^2} \cdot \gamma = 2.359 \times 10^{-7}$

**Projected emittance:** $\sqrt{exx \cdot eyy - exy^2} \cdot \gamma = 1.705 \times 10^{-6}$

**Field in bending magnet:**

$B0 := 1.70447 \times 10^{-3} \cdot K0 \cdot \gamma \cdot \sqrt{1 - \gamma^{-2}}$

$B0 = 1$



# with CSRtrack:

## original BC@2.5GeV

slice with I_peak:
length = 20.0 m
Green's projected

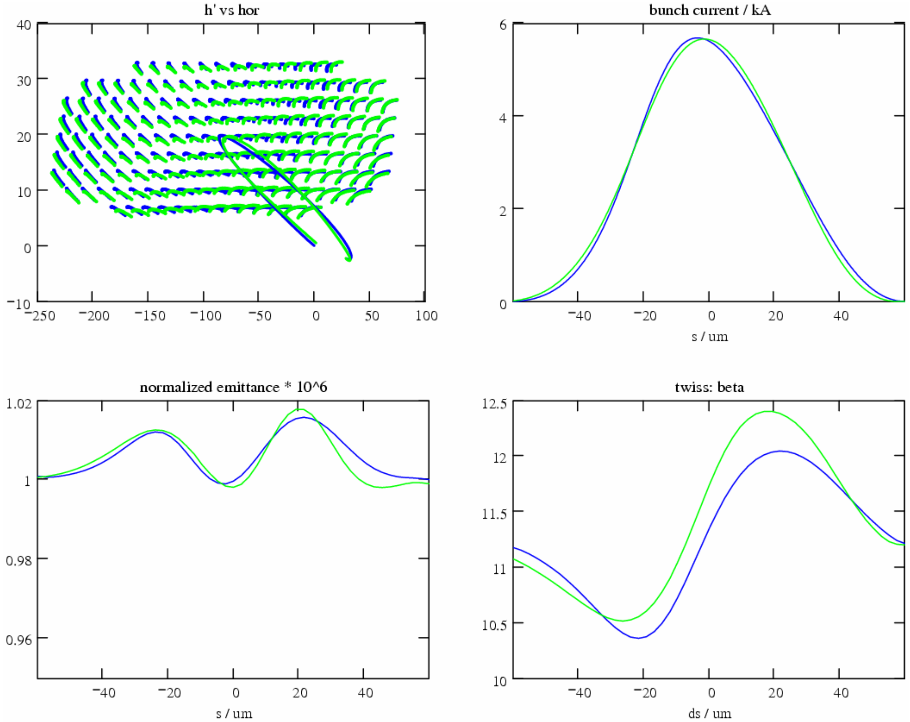
$\text{emittance}(x1) = 9.991 \times 10^{-7}$

$\text{emittance}(x2) = 9.984 \times 10^{-7}$

$E0 = 2.5 \times 10^{9}$

$\text{emittance}(X1) = 1.937 \times 10^{-6}$

$\text{emittance}(X2) = 1.987 \times 10^{-6}$




## setup 2

slice with I_peak:
length = 10.6m
Green's projected

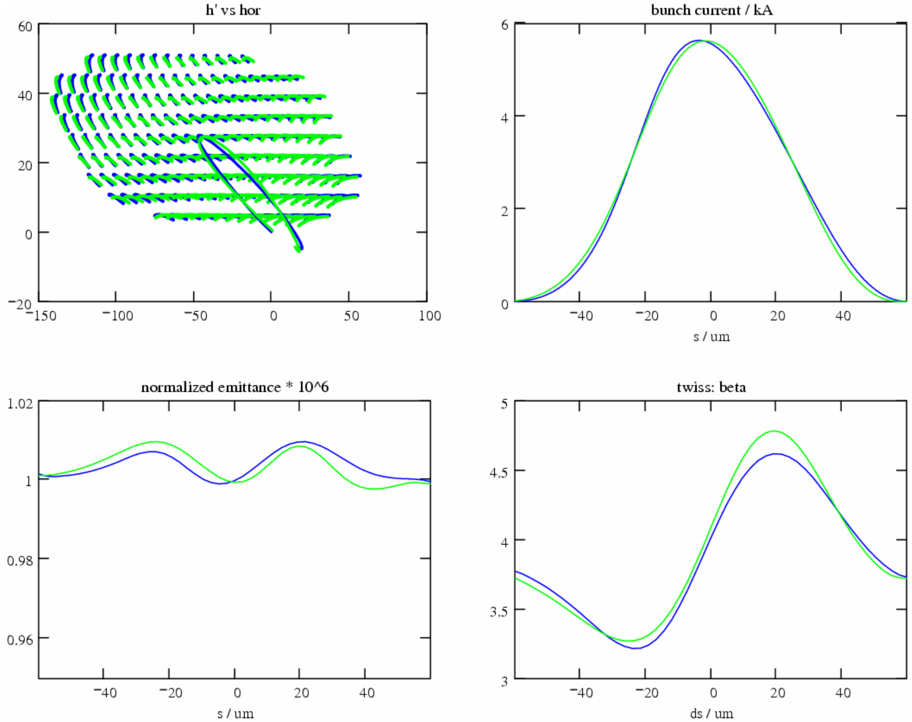
$\text{emittance}(x1) = 9.993 \times 10^{-7}$

$\text{emittance}(x2) = 9.997 \times 10^{-7}$

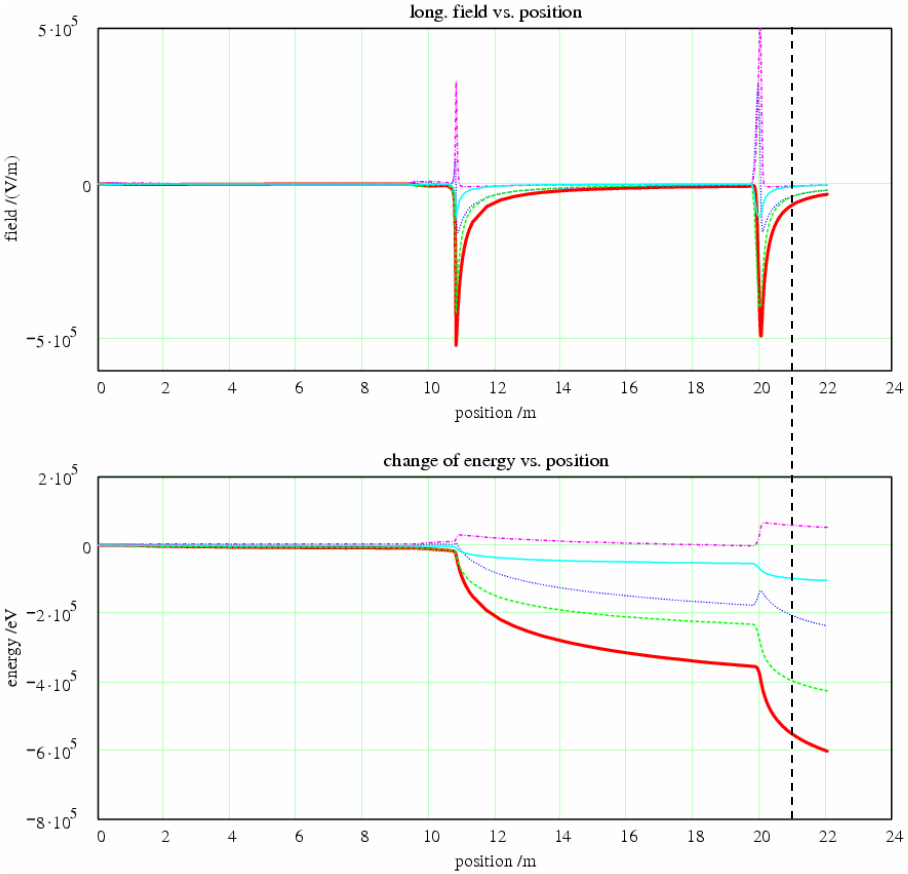
$E0 = 2.5 \times 10^{9}$

$\text{emittance}(X1) = 1.664 \times 10^{-6}$

$\text{emittance}(X2) = 1.704 \times 10^{-6}$



# original BC1
(511 MeV)




**Slice emittance:** $\sqrt{cxx \cdot cyy - cxy^2} \cdot \gamma = 1 \times 10^{-6}$

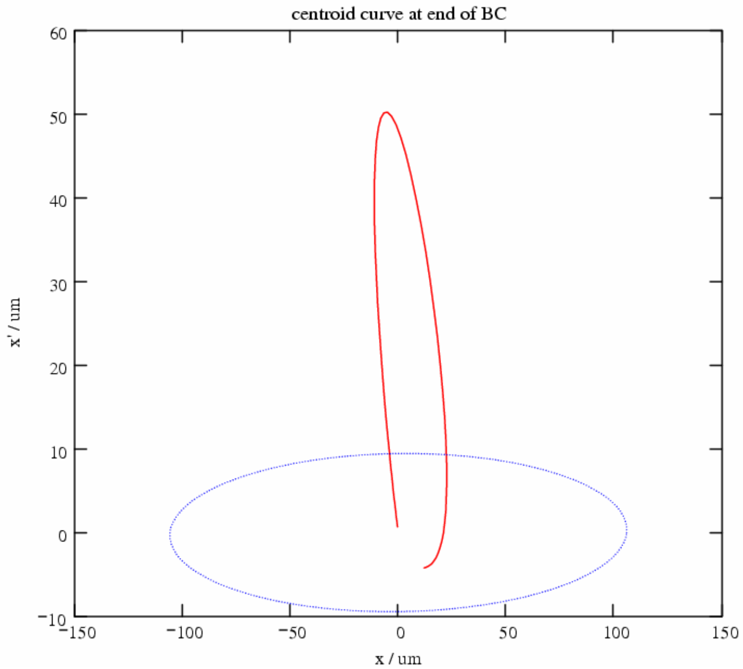
**Centroid emittance:** $\sqrt{dxx \cdot dyy - dxy^2} \cdot \gamma = 1.447 \times 10^{-7}$

**Projected emittance:** $\sqrt{exx \cdot eyy - exy^2} \cdot \gamma = 1.903 \times 10^{-6}$

**Field in bending magnet:**

$B0 := 1.70447 \times 10^{-3} \cdot K0 \cdot \gamma \cdot \sqrt{1 - \gamma^{-2}}$

$B0 = 0.422$




only BC1: ε = 1.9

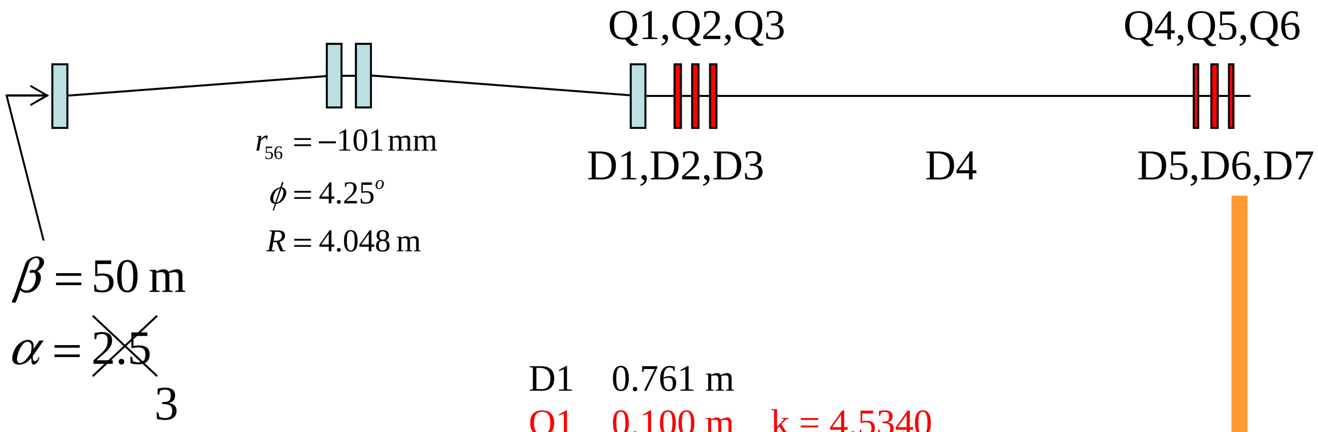
only BC2: ε = 2.0

BC1 + BC2: ε = 1.5 compensation of centroid offsets !!!

not new:
P. Emma
Loulergue & Mosnier

# both BCs

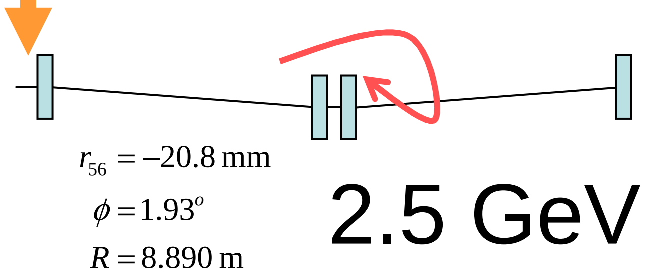
1st CSRtrack run




511 MeV

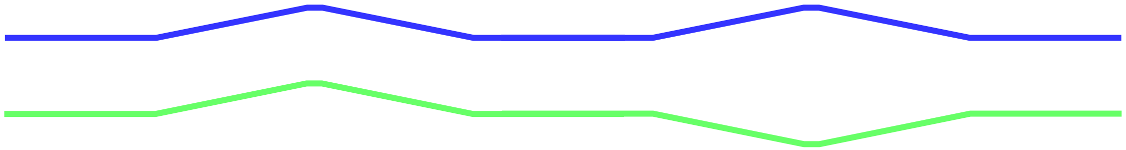
particles scaled
to 2.5 GeV
no cavity wakes

| | | |
|---|---|---|
| D1 | 0.761 m | |
| Q1 | 0.100 m | k = 4.5340 |
| D2 | 0.300 m | |
| Q2 | 0.100 m | k = –6.8347 |
| D3 | 0.300 m | |
| Q3 | 0.100 m | k = 2.5442 |
| D4 | 20.100 m | |
| Q4 | 0.050 m | k = –3.7623 |
| D5 | 0.600 m | |
| Q5 | 0.100 m | k = 5.2225 |
| D6 | 0.600 m | |
| Q6 | 0.100 m | k = ~~–6.9480~~ –7.2259 |
| D7 | 0.200 m | |




2.5 GeV

2nd CSRtrack run



slice with I_peak:
cf=100 1nC em=1
a30 a30_b

slice

$\text{emittance}(x1) = 1.002 \times 10^{-6}$

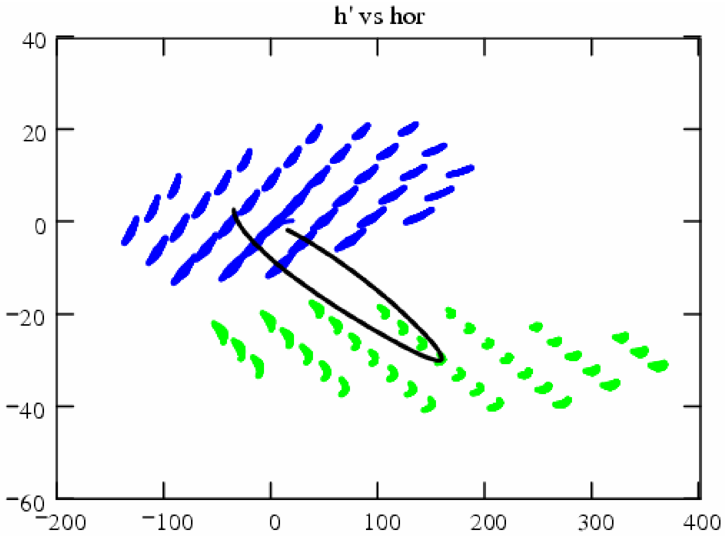
$\text{emittance}(x2) = 1.005 \times 10^{-6}$

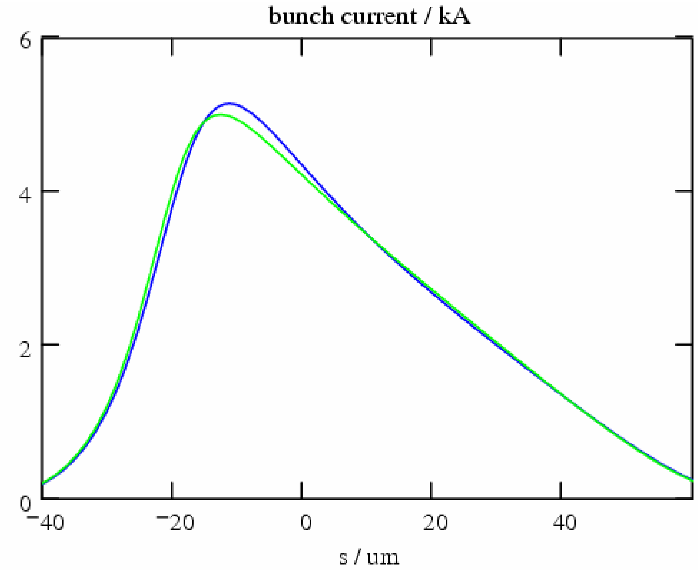
$E0 = 2.5 \times 10^{9}$

projected

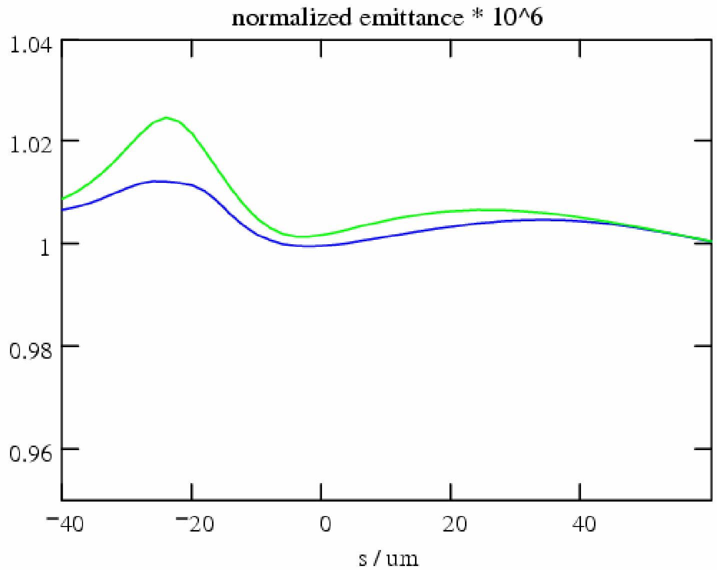
$\text{emittance}(X1) = 1.38 \times 10^{-6}$

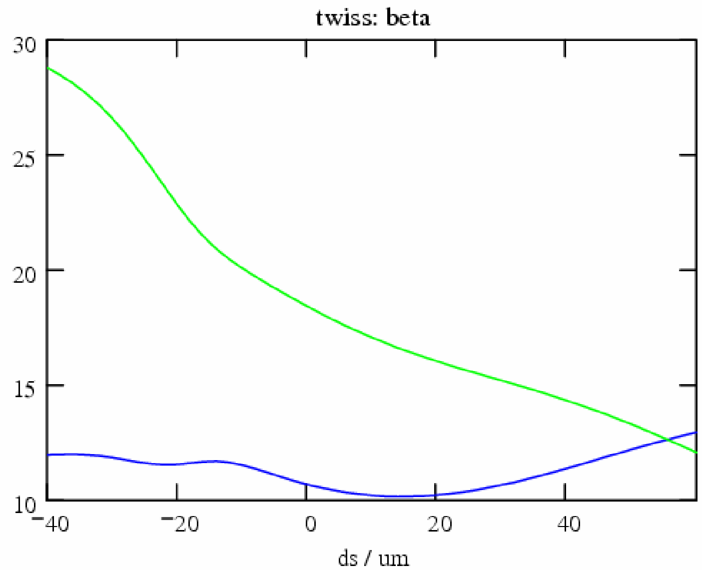
$\text{emittance}(X2) = 3.135 \times 10^{-6}$




CSRtrack, projected



# fast double BC optimization

**BC1**

- define BC geometry $\rightarrow K(s)$
- calculate local bunch length (without self-effects) $\rightarrow \sigma(s)$
- calculate longitudinal field (unperturbed motion) $\rightarrow F_{\parallel}(s) \rightarrow \Delta E(s)$
- estimate centroid positions $\rightarrow x_c(s)$, $x'_c(s)$

- BC1 out $\rightarrow$ BC2 in
  transport matrix

$$(\alpha,\beta)^{(\mathrm{bc1\,out})} \xrightarrow[\mu]{} (\alpha,\beta)^{(\mathrm{bc2\,in})}$$

**BC2**

- define BC geometry $\rightarrow K(s)$
- calculate local bunch length (without self-effects) $\rightarrow \sigma(s)$
- $\Delta E^{(\mathrm{bc2\,in})} \rightarrow$ calculate longitudinal field (unperturbed motion) $\rightarrow F_{\parallel}(s) \rightarrow \Delta E(s)$
- $x_c^{(\mathrm{bc2\,in})}$, $x_c'^{(\mathrm{bc2\,in})} \rightarrow$ estimate centroid positions $\rightarrow x_c(s)$, $x'_c(s)$

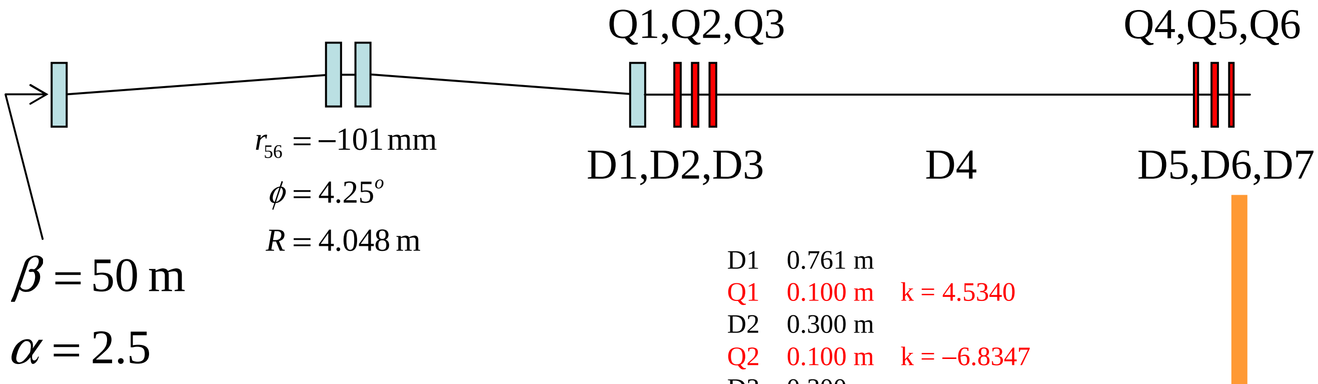
- estimate projected emittance

$$\varepsilon_h \approx \sqrt{c_{xx}c_{x'x'} - c_{xx'}{}^2} \quad \text{with} \quad c_{ab} = f_{ab} + g_{ab}$$

...

# after few minutes:

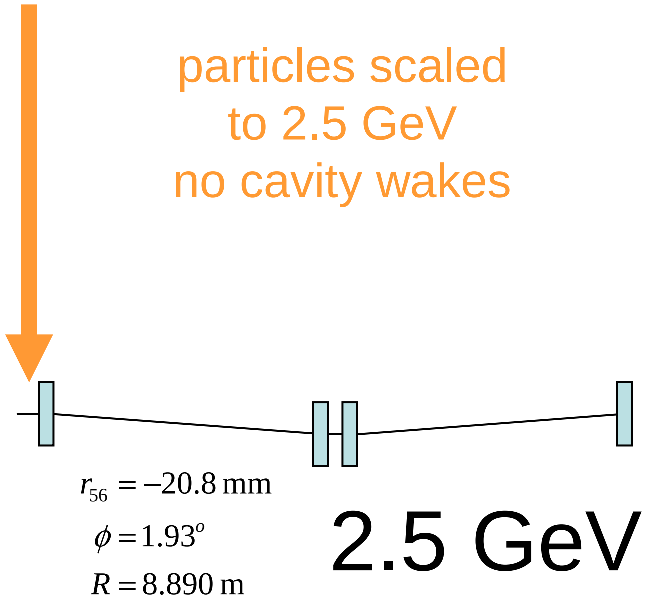
$$T = \begin{pmatrix} -1.149 & 18.949 \\ 8.289 \times 10^{-3} & -1.007 \end{pmatrix}$$




511 MeV

| | | |
|---|---|---|
| D1 | 0.761 m | |
| Q1 | 0.100 m | k = 4.5340 |
| D2 | 0.300 m | |
| Q2 | 0.100 m | k = –6.8347 |
| D3 | 0.300 m | |
| Q3 | 0.100 m | k = 2.5442 |
| D4 | 20.100 m | |
| Q4 | 0.050 m | k = –3.7623 |
| D5 | 0.600 m | |
| Q5 | 0.100 m | k = 5.2225 |
| D6 | 0.600 m | |
| Q6 | 0.100 m | k = –6.9480 |
| D7 | 0.200 m | |

particles scaled
to 2.5 GeV
no cavity wakes




2.5 GeV

## after BC1 (511 MeV)

**Slice emittance:** $\sqrt{cxx \cdot cyy - cxy^2} \cdot \gamma = 1 \times 10^{-6}$

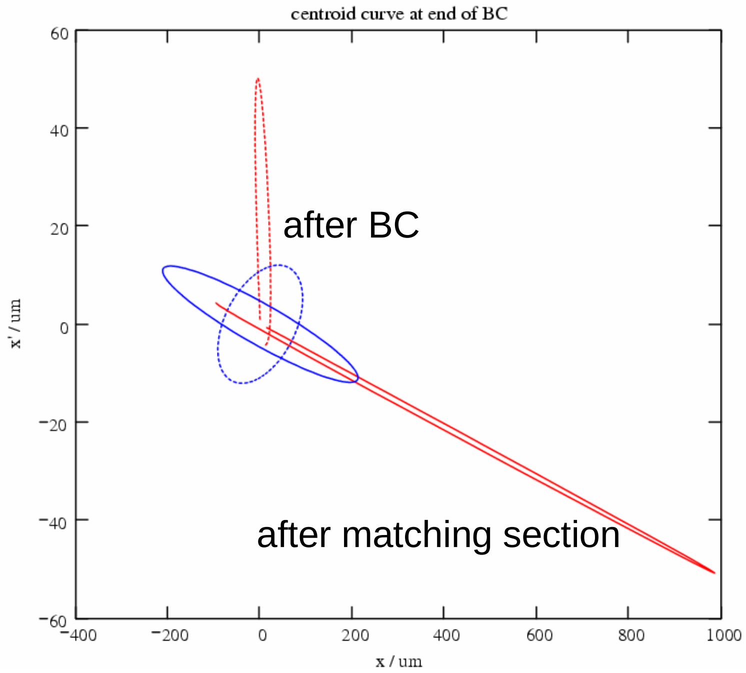
**Centroid emittance:** $\sqrt{dxx \cdot dyy - dxy^2} \cdot \gamma = 1.447 \times 10^{-7}$

**Projected emittance:** $\sqrt{exx \cdot eyy - exy^2} \cdot \gamma = 1.758 \times 10^{-6}$

**Field in bending magnet:**

$B0 := 1.70447 \times 10^{-3} \cdot K0 \cdot \gamma \cdot \sqrt{1 - \gamma^{-2}}$

$B0 = 0.422$




## after BC2 (2.5 GeV)

**Slice emittance:** $\sqrt{cxx \cdot cyy - cxy^2} \cdot \gamma = 1 \times 10^{-6}$

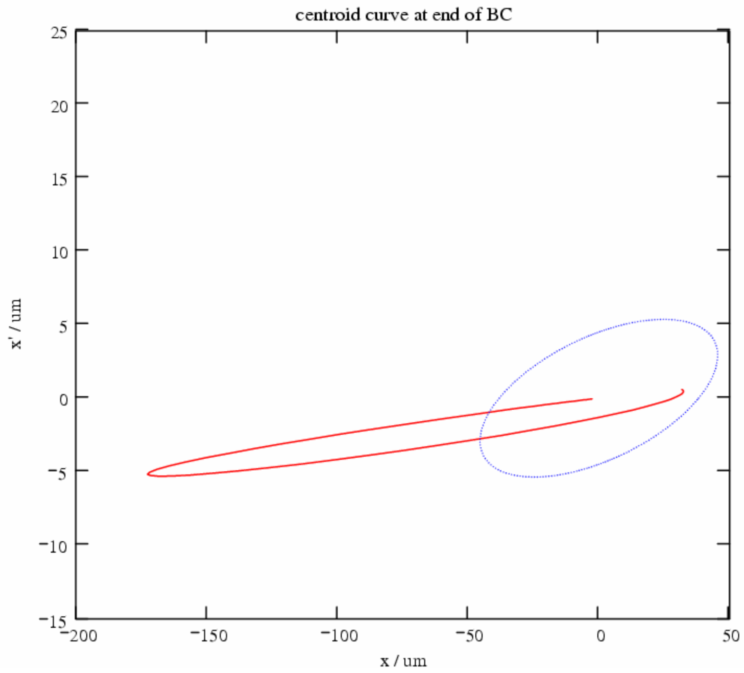
**Centroid emittance:** $\sqrt{dxx \cdot dyy - dxy^2} \cdot \gamma = 1.748 \times 10^{-7}$

**Projected emittance:** $\sqrt{exx \cdot eyy - exy^2} \cdot \gamma = 1.704 \times 10^{-6}$

**Field in bending magnet:**

$B0 := 1.70447 \times 10^{-3} \cdot K0 \cdot \gamma \cdot \sqrt{1 - \gamma^{-2}}$

$B0 = 0.939$



it is possible to optimize the matching section for better compensation:

$$(\alpha,\beta)^{(\mathrm{bc1in})} = (\alpha,\beta)^{(\mathrm{bc1in})} = (1.8, 47.5\,\mathrm{m})$$

$$\mu = 1.4$$

**Slice emittance:** $\sqrt{cxx\cdot cyy - cxy^2}\cdot\gamma = 1\times 10^{-6}$

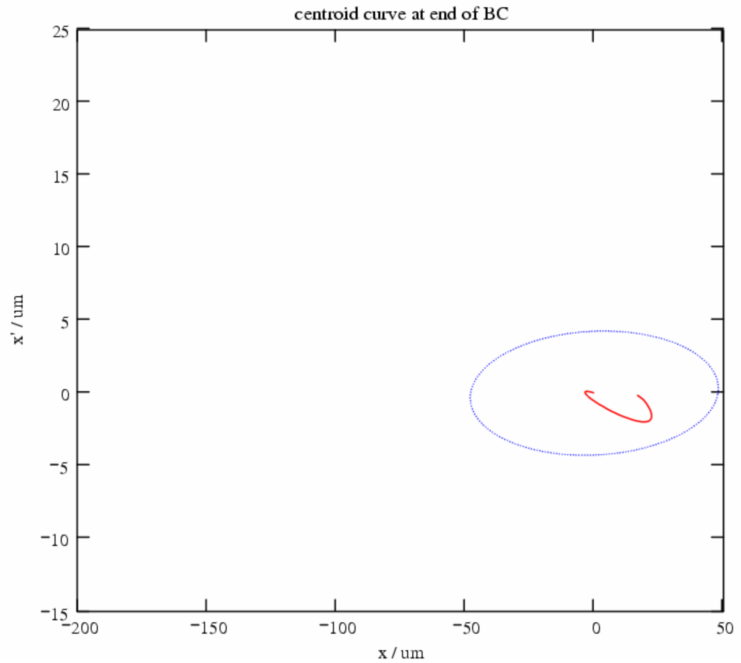
**Centroid emittance:** $\sqrt{dxx\cdot dyy - dxy^2}\cdot\gamma = 1.449\times 10^{-8}$

**Projected emittance:** $\sqrt{exx\cdot eyy - exy^2}\cdot\gamma = 1.035\times 10^{-6}$

**Field in bending magnet:**

$B0 := 1.70447\times 10^{-3}\cdot K0\cdot\gamma\cdot\sqrt{1-\gamma^{-2}}$

$B0 = 0.939$



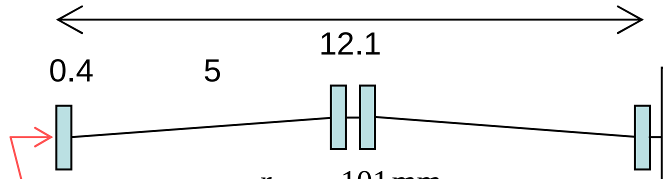

improved working point is confirmed by CSRtrack $\rightarrow \varepsilon < 1.4$

small improvement: old working point ($\mu = 2.18$) nearly perfect

that is luck: other working points are much worse !

# shorter double BC
(few minutes tuning)

1st CSRtrack run




$r_{56} = -101\,\mathrm{mm}$

$\phi = 5.57^o$

$R = 4.11\,\mathrm{m}$

$\beta = 47.5\,\mathrm{m}$

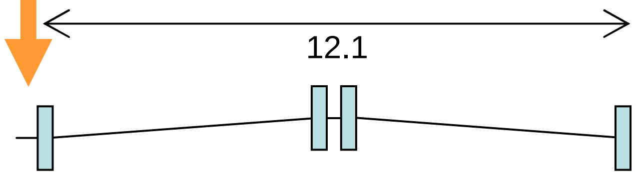
$\alpha = 3.6$

| | | |
|---|---|---|
| $\beta_1 = 3.4\,\mathrm{m}$ | $\mu = 1.4$ | $\beta_2 = 47.5\,\mathrm{m}$ |
| $\alpha_1 = 0.014$ | | $\alpha_2 = 2.8$ |

$$T = \frac{\gamma_1}{\gamma_2}\begin{bmatrix} \sqrt{\beta_2/\beta_1}(\cos\mu + \alpha_1 \sin\mu) & \sqrt{\beta_1\beta_2}\sin\mu \\ \dfrac{\{\alpha_2 - \alpha_1\}\cos\mu + \{1+\alpha_1\alpha_2\}\sin\mu}{-\sqrt{\beta_1\beta_2}} & \sqrt{\beta_1/\beta_2}(\cos\mu - \alpha_2\sin\mu) \end{bmatrix}$$

511 MeV

particles scaled
to 2.5 GeV
no cavity wakes




$r_{56} = -20.8\,\mathrm{mm}$

$\phi = 2.54^o$

$R = 9.023\,\mathrm{m}$

2.5 GeV

2nd CSRtrack run

# not worse than the old solution:

## CSRtrack: green's, projected

slice with I_peak:
cf=100  1nC  2.5GeV, em=1
gm  pr

$\text{emittance}(x1) = 1.012 \times 10^{-6}$

$\text{emittance}(x2) = 1.011 \times 10^{-6}$

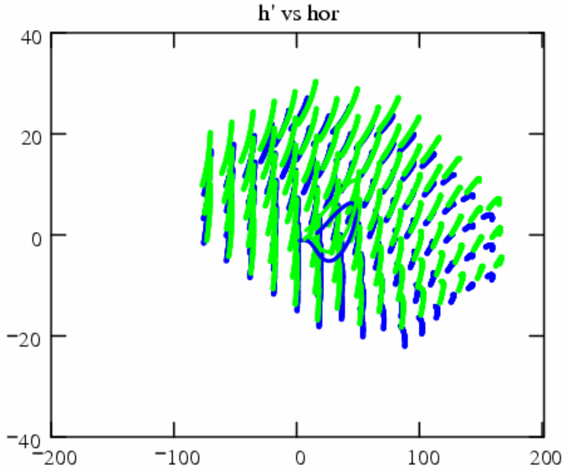
slice

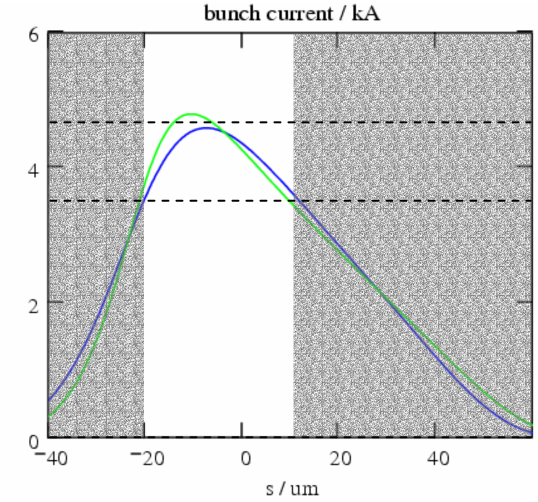
$E0 = 2.5 \times 10^{9}$

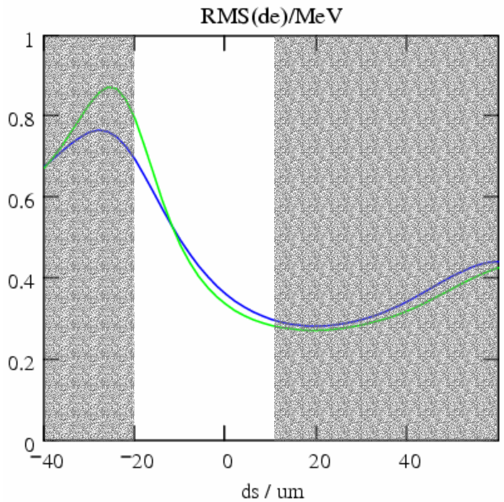
$\text{emittance}(X1) = 1.317 \times 10^{-6}$

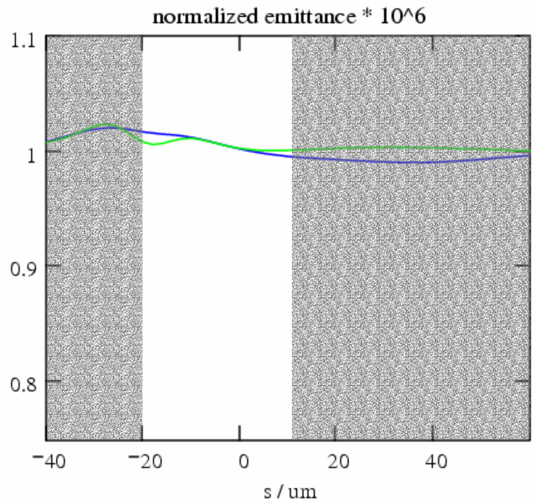
$\text{emittance}(X2) = 1.46 \times 10^{-6}$

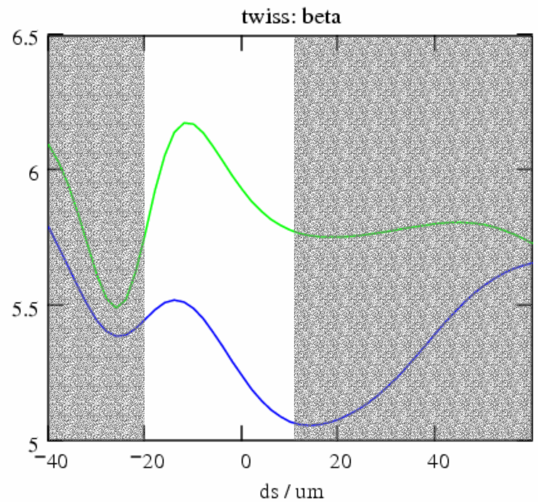
full



# summary

- double BC uses compensation mechanism
- without shielding:
  - working point (optics, matching) of present BC close to optimum
  - is the geometry optimal?
- strategy “no shielding”:
  - use large gap
  - “simple computation”
- strategy “shielding”:
  - could help to reduce projected emittance
  - complicated optimization (compensation of effects in both BCs vs. resistive wall wakes)
  - no method available for the calculation of resistive wall wakes

- still to be done: projected method with PEC shielding