CSR Effects in Collimator and Beamlines TD1, TD20

1 Geometry

2 CSRtrack calculation for ideal gaussian bunch

- 2.1 Collimator
- 2.2 TD1
- 2.3 TD20

3 Attempts to avoid/reduce longitudinal effects

- 3.1 Shielding
- 3.2 Magnet lengths and splitted arcs
- 3.3 In principle

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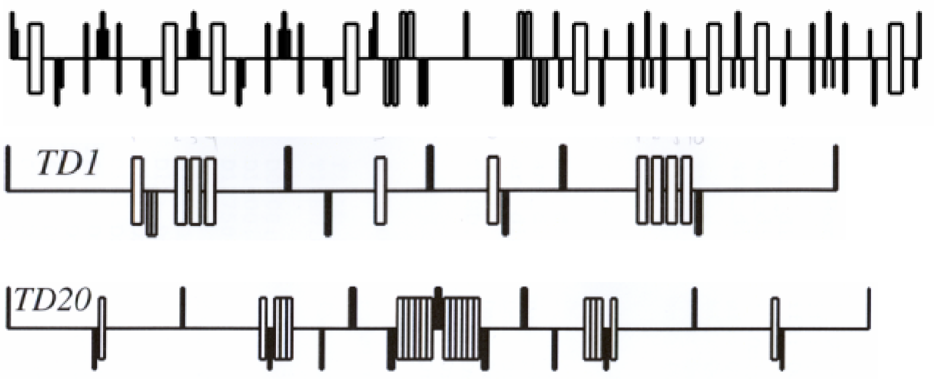
- 4.1 1D simulation
- 4.2 Collimator {impedance model, CSRtrack with distributed imp.}
- 4.3 TD1 and TD20

5 Summary / Conclusion

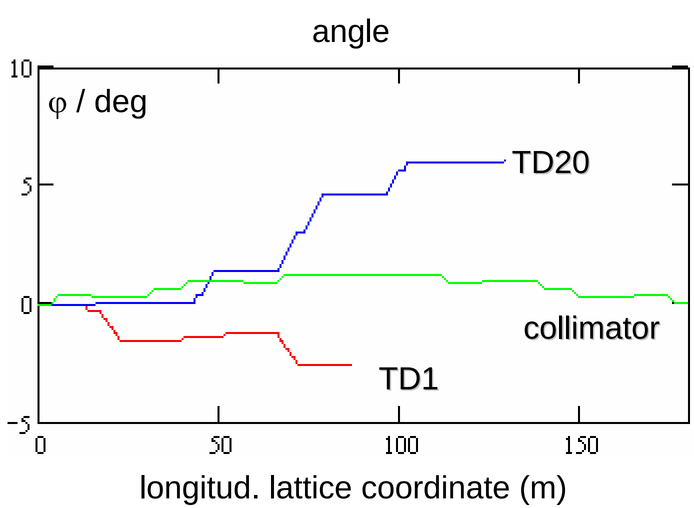
1 Geometry

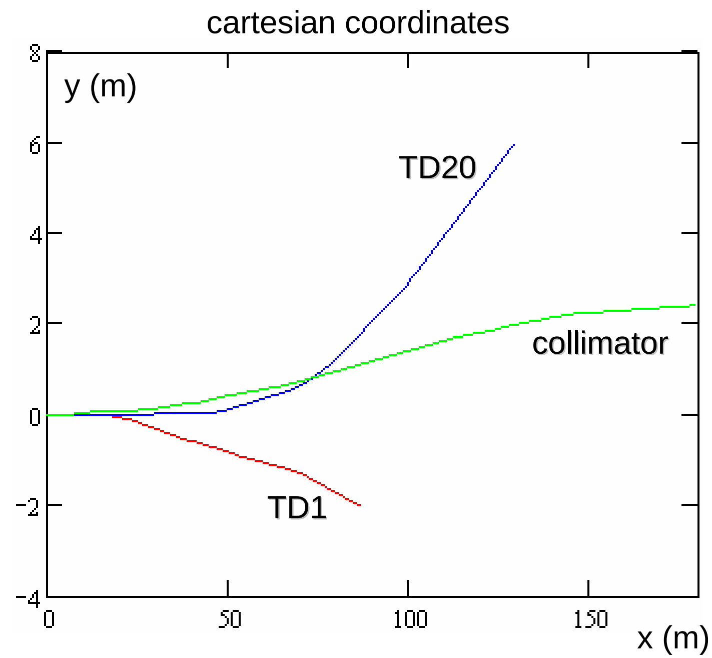


Collimation section: L = 180 m

TD1: L = 85.56 m φ = 2.25 deg

TD20: L = 147.62 m φ = 6.68 deg





5 Summary / Conclusion

2 CSRtrack calculation for ideal gaussian bunch (ε=1µm)

Collimator	emittance growth <1 %, energy spread 2.6 MeV
TD1	emittance growth 40 %, energy spread 2.0 MeV
TD20	emittance growth 41 %, energy spread 3.5 MeV, compression effects

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3 Attempts to avoid/reduce longitudinal effects

no shielding effects can be used

weak influence of magnet length on rms energy spread

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4 Realistic model for longitudinal phase space + collimator impedance model

after BC2	energy spread 2.9 MeV	
after collimator	energy spread 15.2 MeV	emittance growth ≈ 8 %
	significant (non-CSR collimator impedance) → 12 MeV rms spread	
after colli+TD1	energy spread 15.2 MeV	emittance growth 27 % **
after colli+TD20	over-compression due to uncompensated r56	

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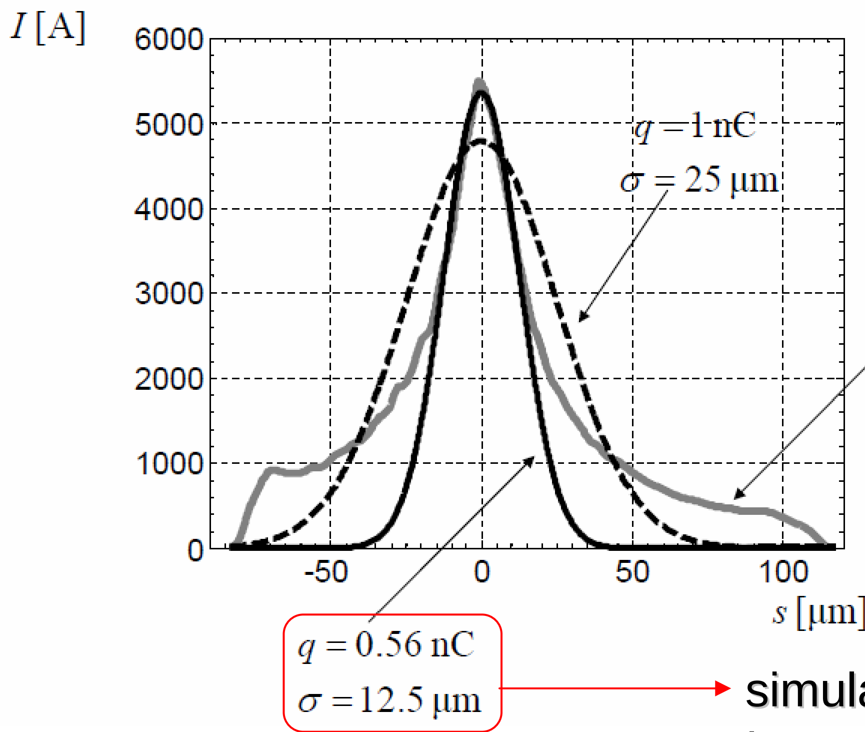
it is difficult to avoid CSR induced energy spread

emittance growth due to centroid shift can be controlled / compensated

Gaussian fit of the bunch shape from S2E simulations

(Igor Zagorodnov)



Bunch shape from S2E simulations by Martin Dohlus

simulation with gaussian bunch

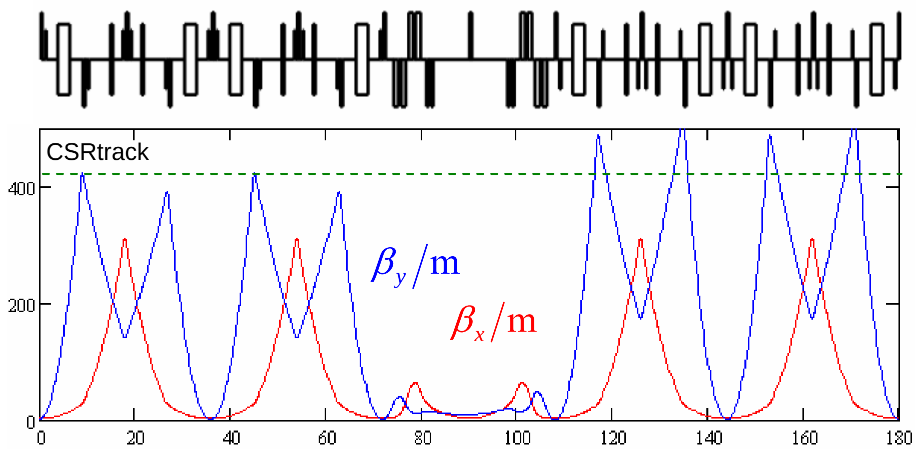
I_peak = 5 kA, q = 0.5 nC (→ σ = 12.5 µm)

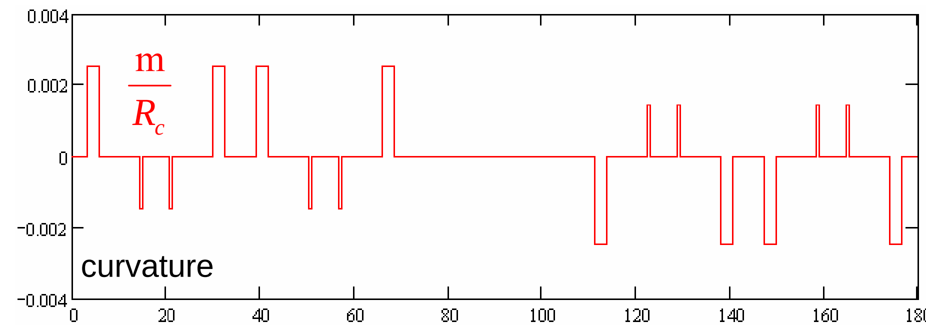
normalized transv. emittance = 1 µm

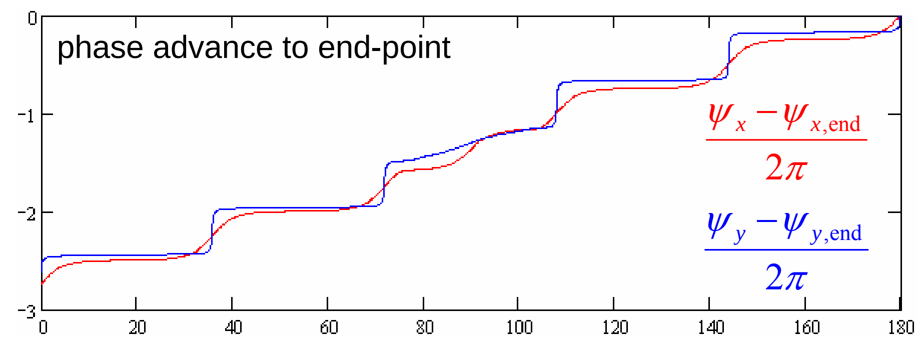
2.1 Collimator

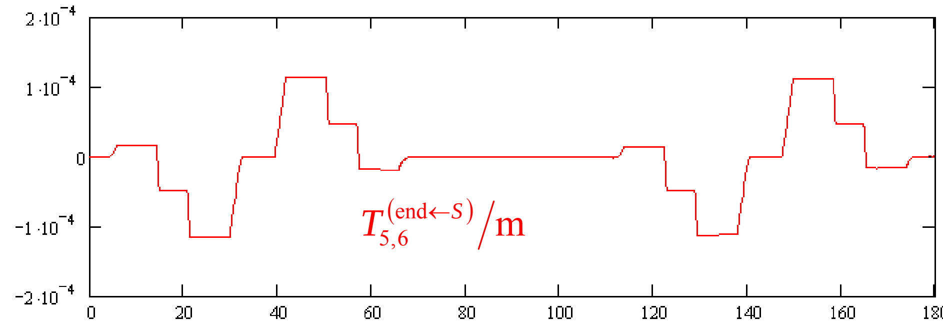
without self effects

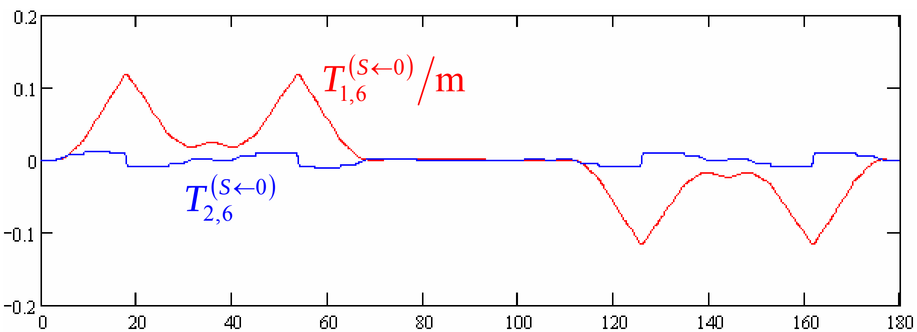
L = 180 m, mode A

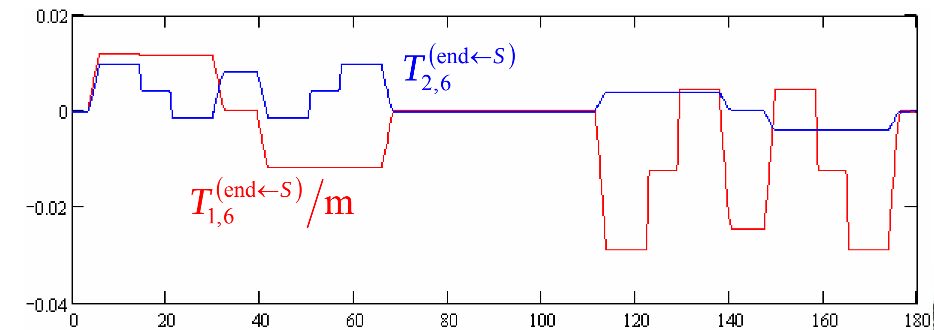






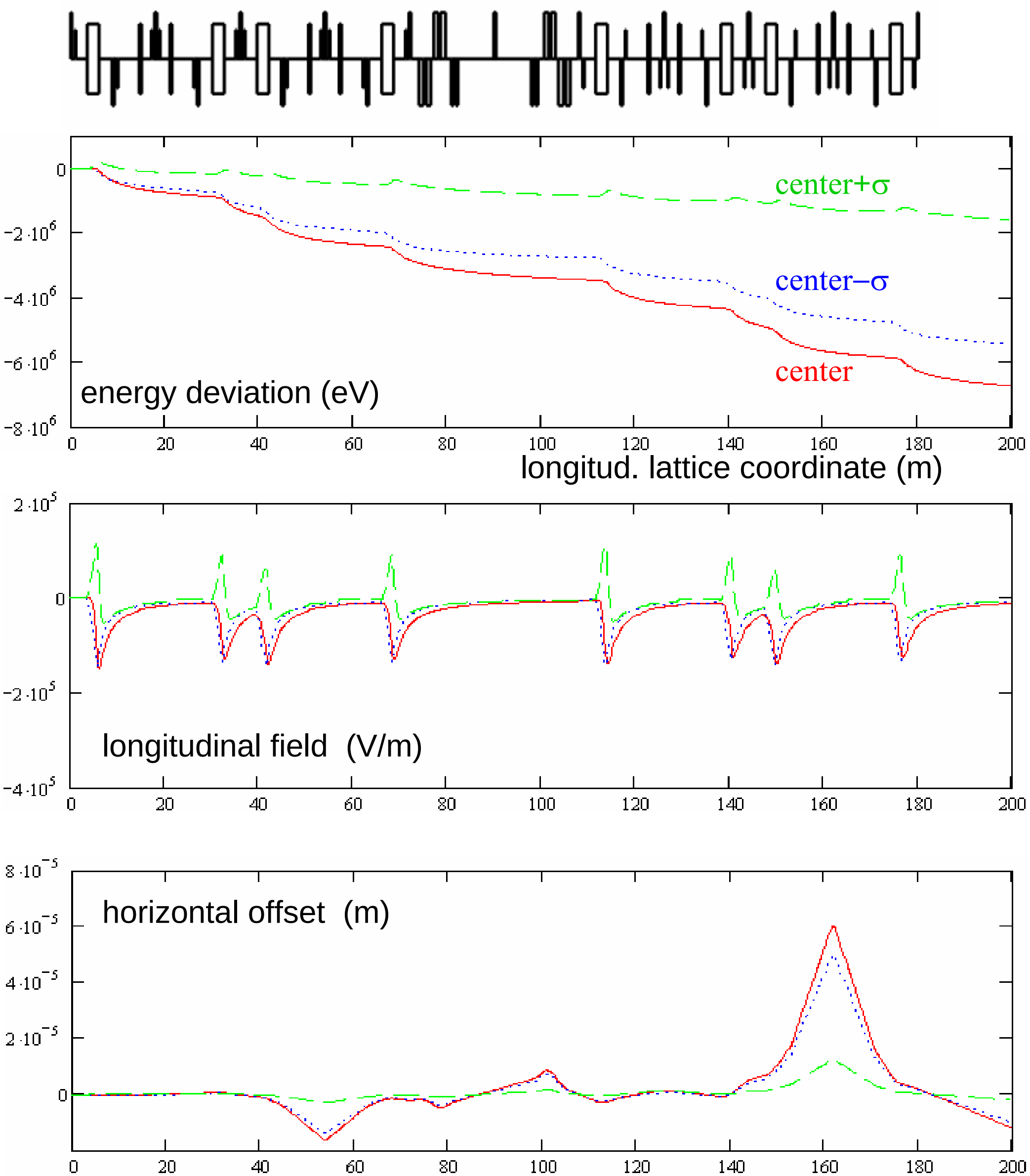


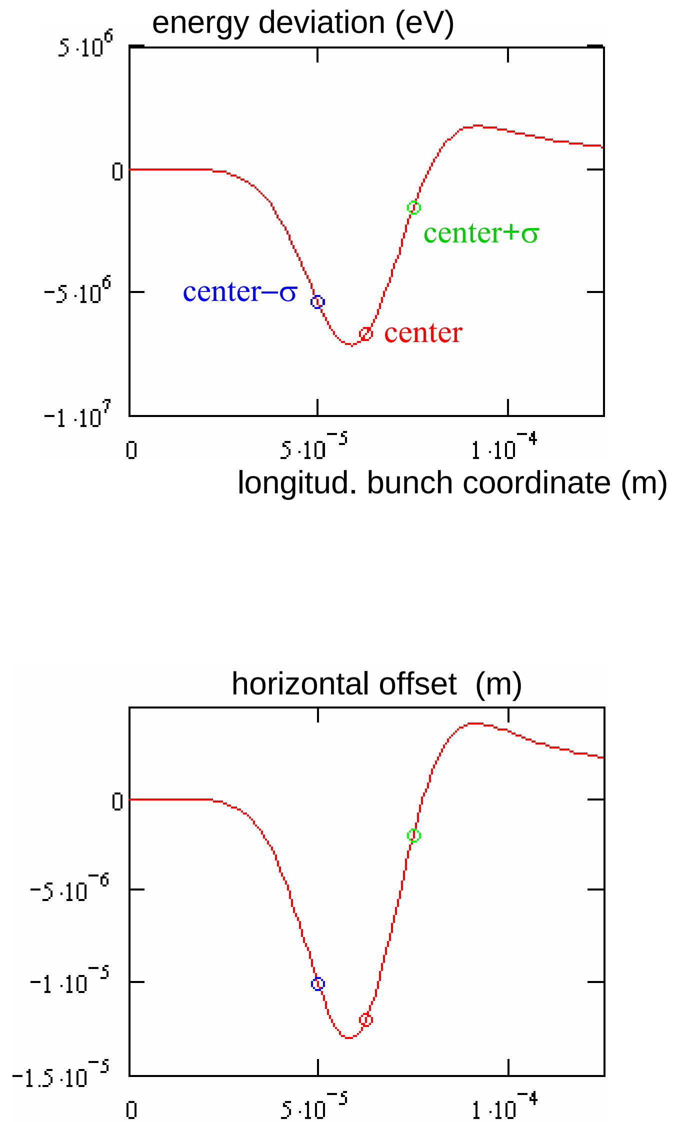




XFEL collimation section, mode A

self effects, 1d CSR model
centroid properties of a gaussian bunch 1nC, Ipeak=5kA
no chirp





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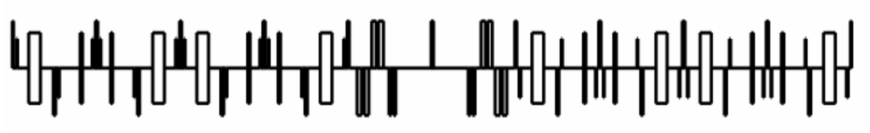
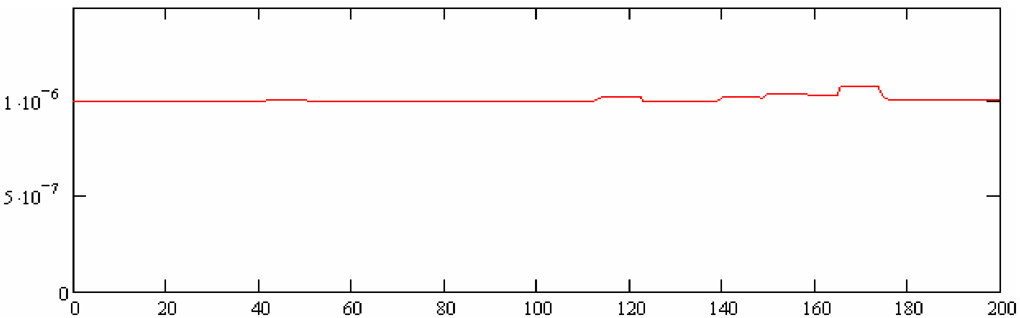


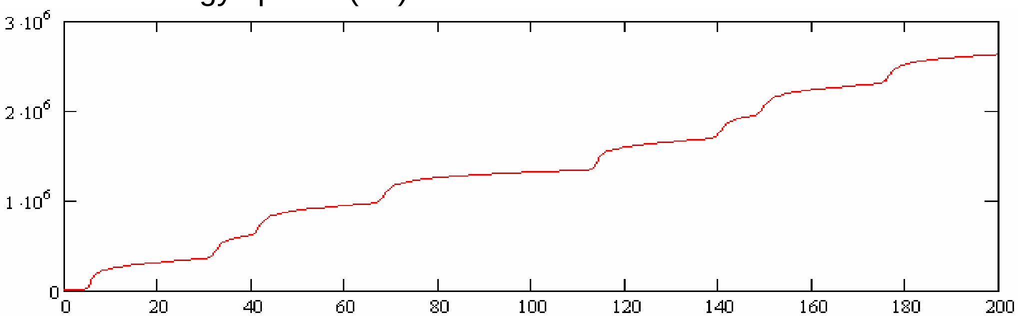
normalized horizontal emittance (m)



1.008

longitud. lattice coordinate (m)

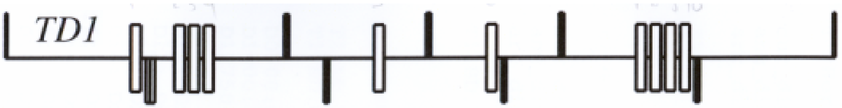
rms energy spread (eV)



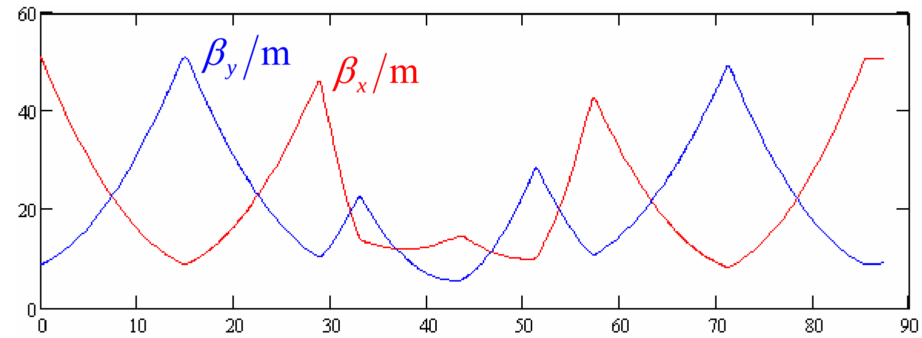
2.62E6

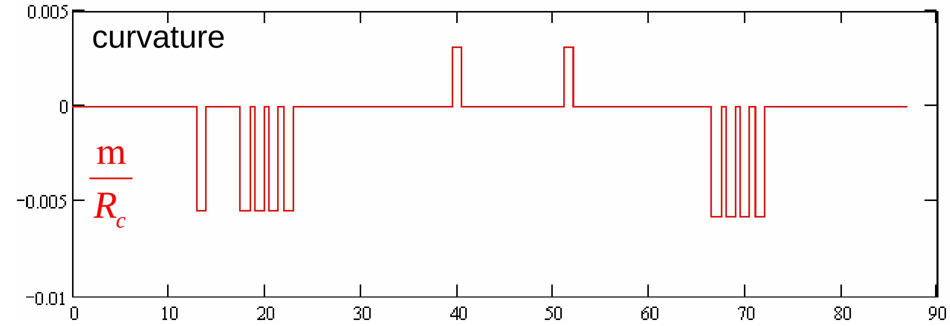
2.2 TD1

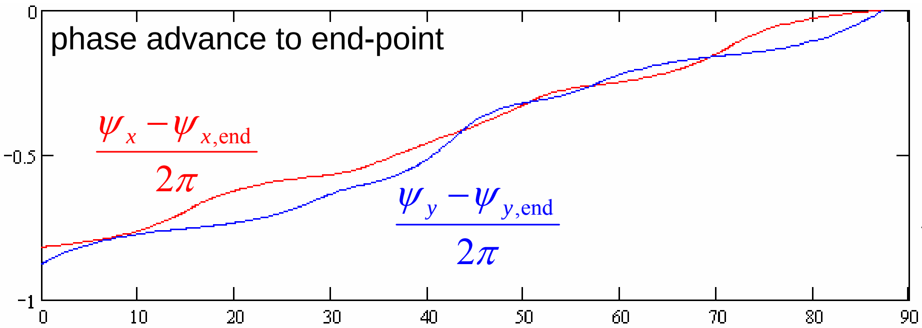
without self effects

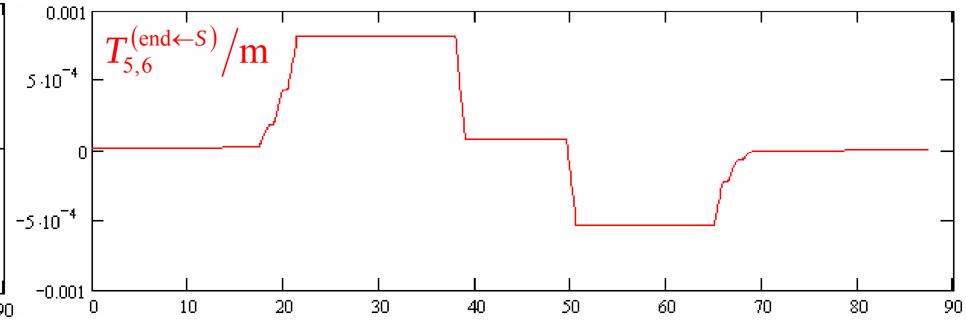


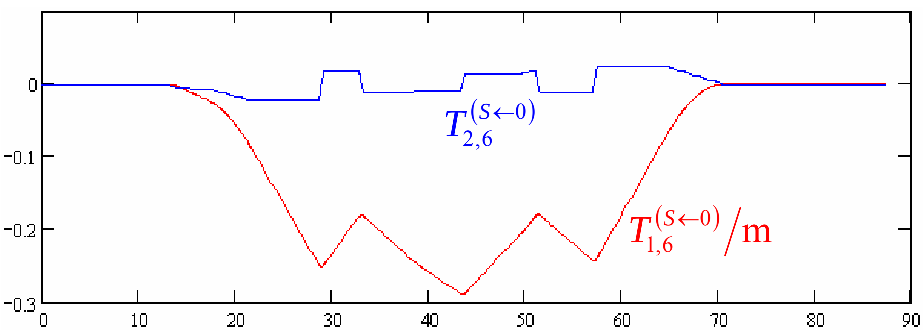
L = 85.56 m φ = 2.25 deg

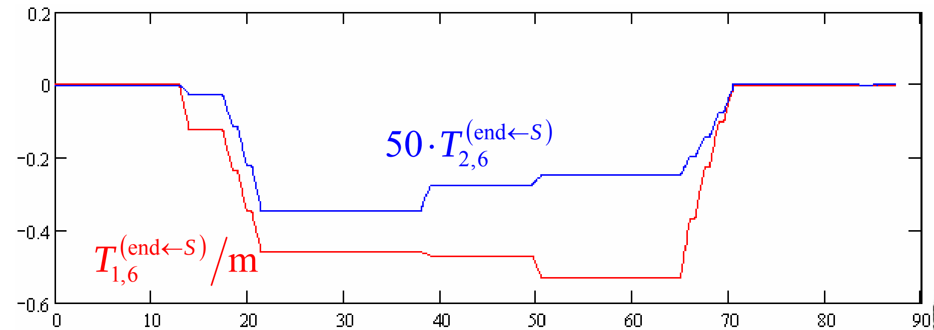






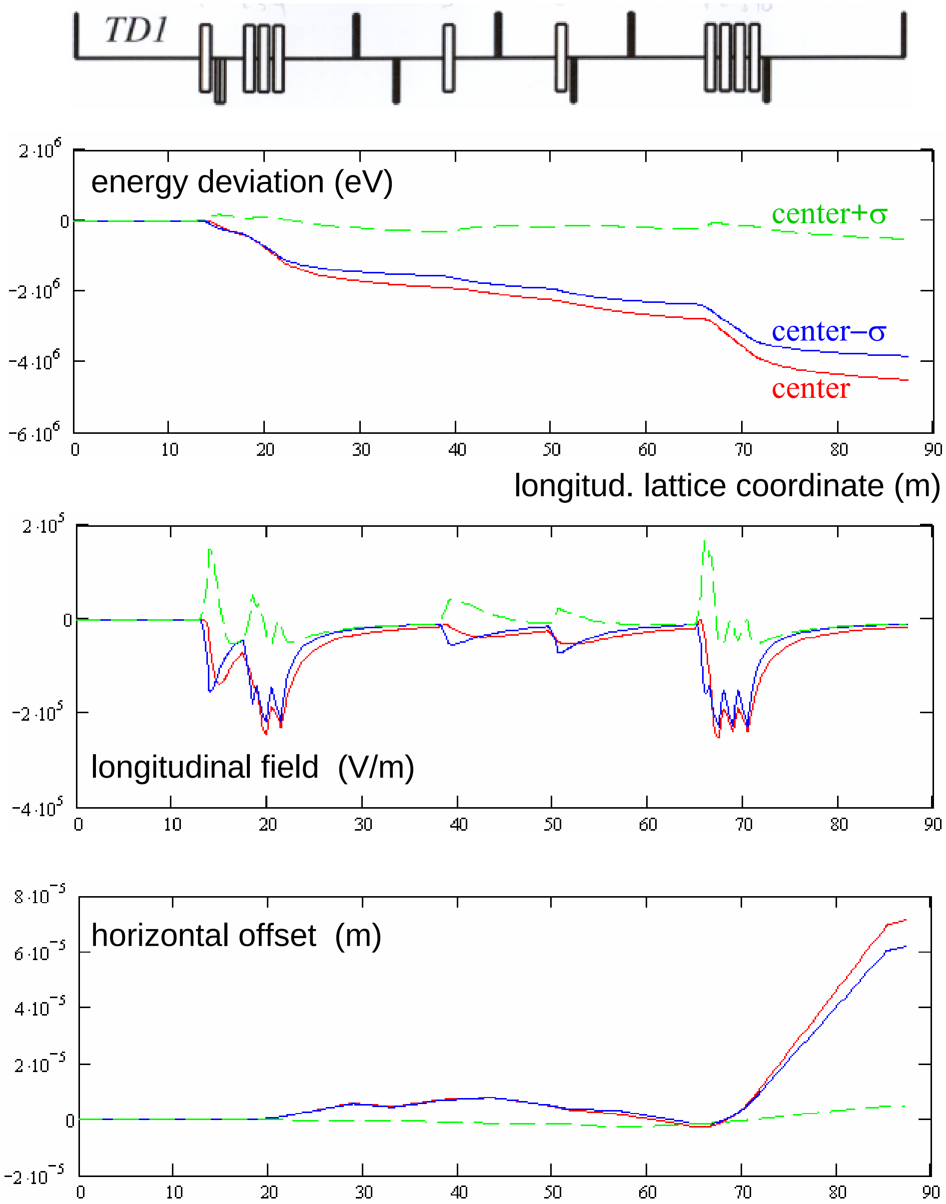


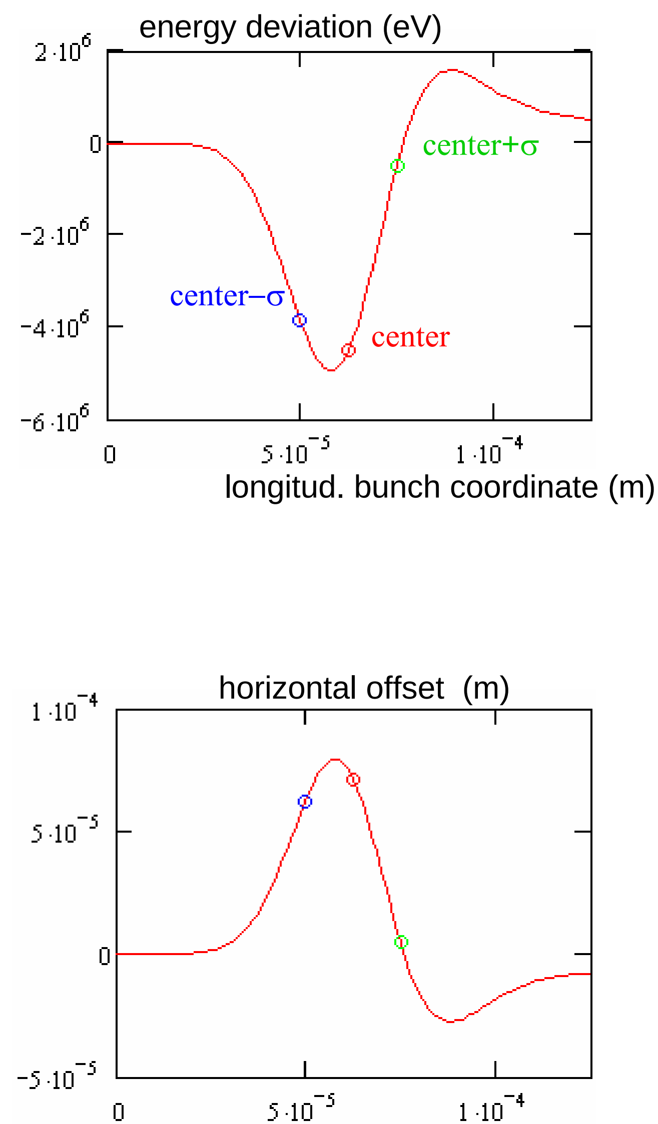




TD1; L = 85.56 m φ = 2.25 deg

self effects, 1d CSR model
centroid properties of a gaussian bunch 1nC, Ipeak=5kA
no chirp





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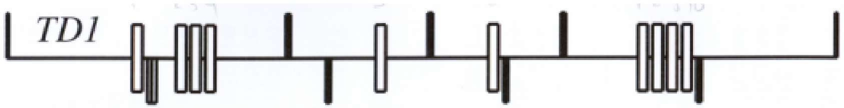
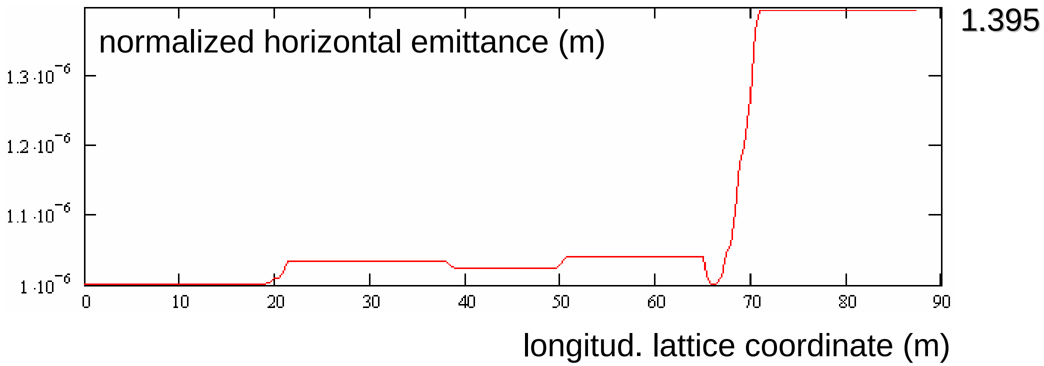
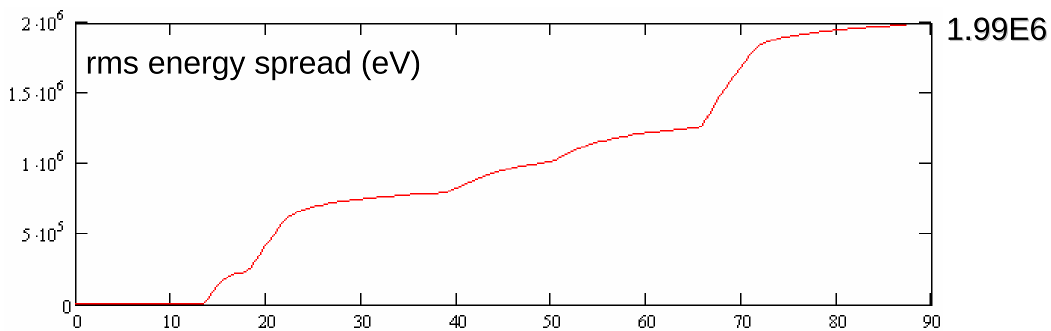
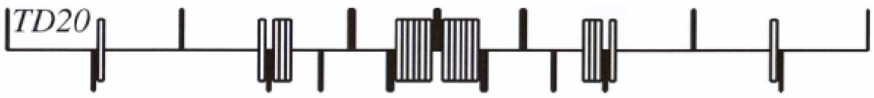




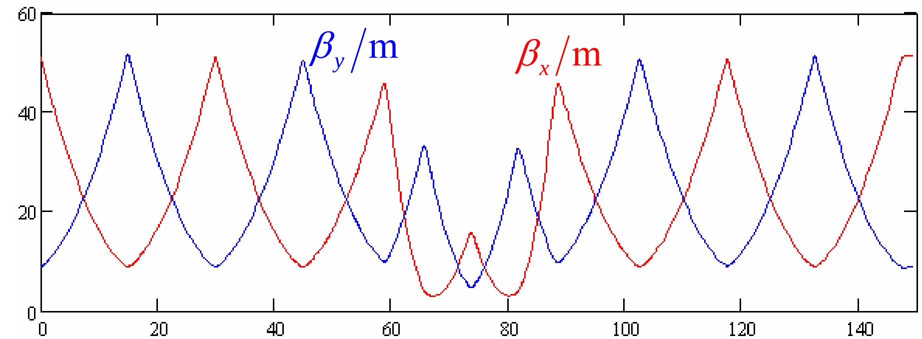


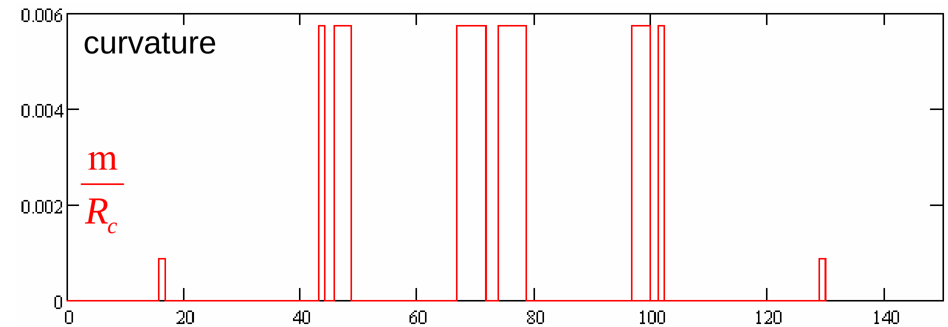
2.3 TD20

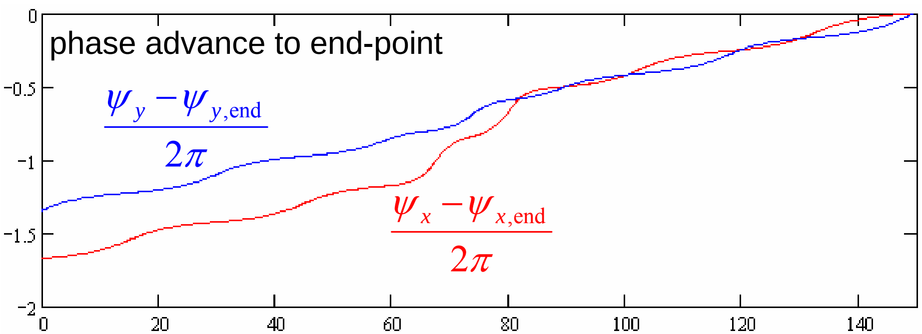
without self effects

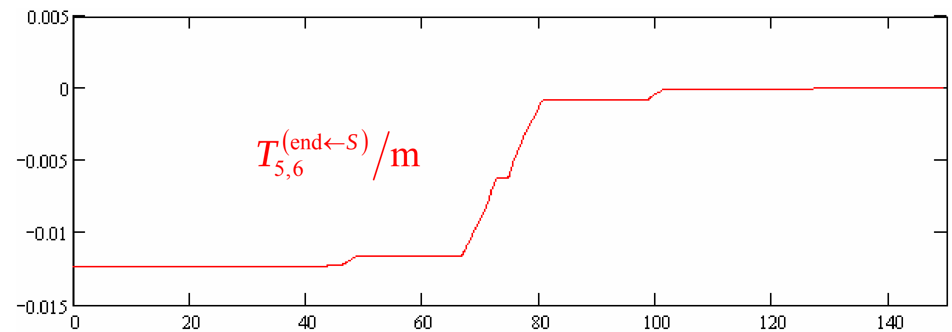


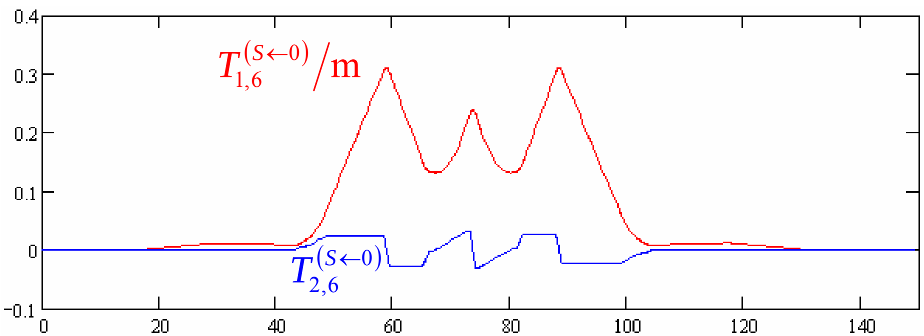
L = 147.62 m φ = 6.68 deg

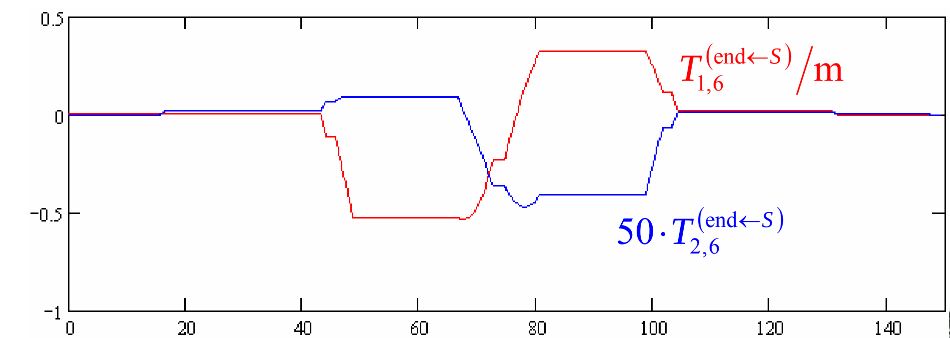






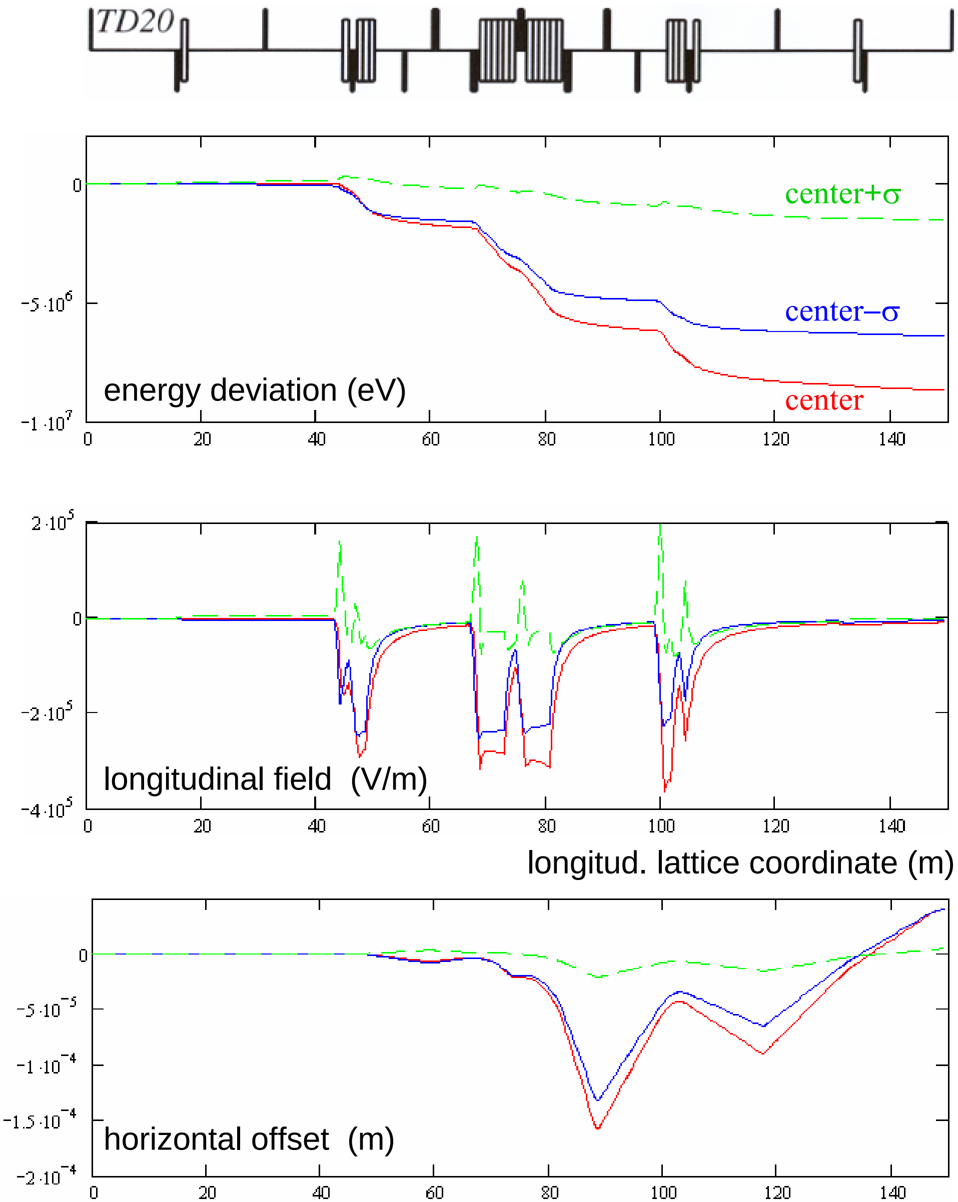


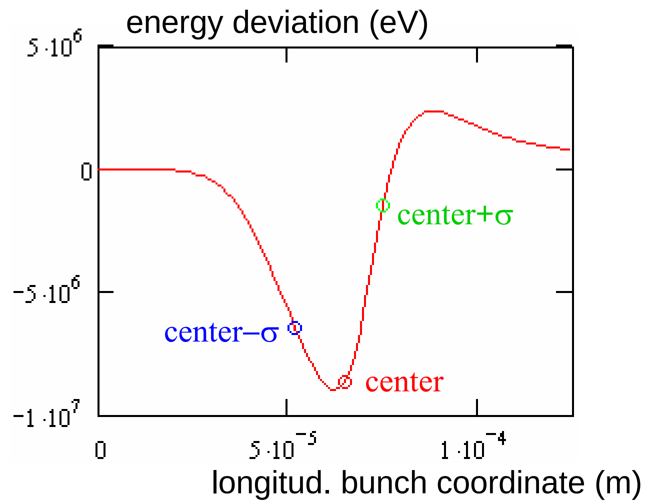


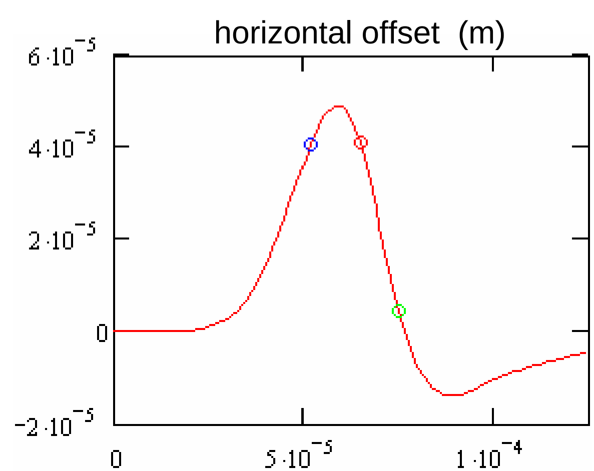


TD20; L = 147.62 m φ = 6.68 deg

self effects, 1d CSR model
centroid properties of a gaussian bunch 1nC, Ipeak=5kA
no chirp

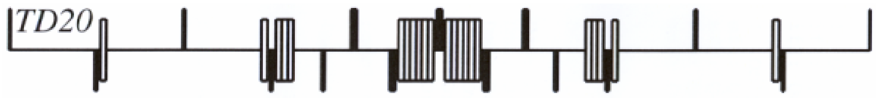


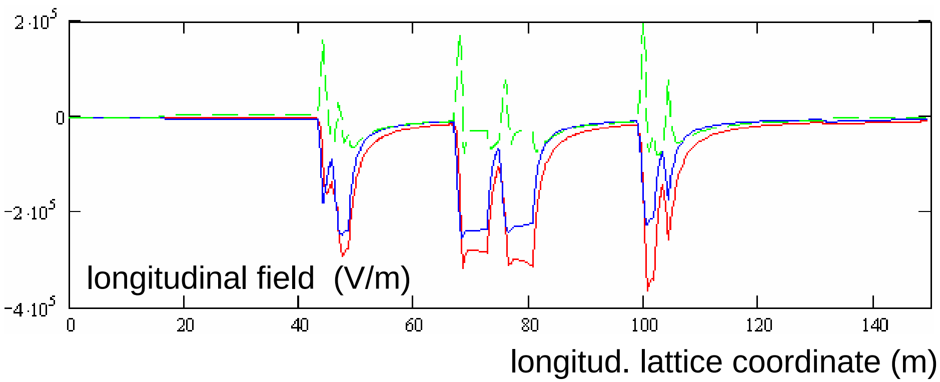


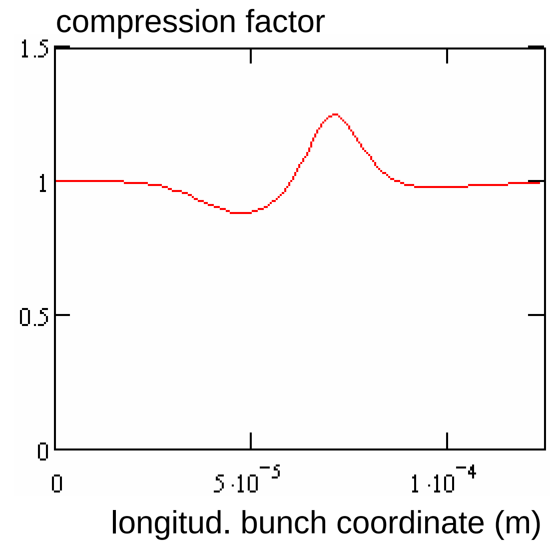


TD20; L = 147.62 m φ = 6.68 deg

self effects, 1d CSR model
centroid properties of a gaussian bunch 1nC, Ipeak=5kA
no initial chirp







TD20; L = 147.62 m φ = 6.68 deg

self effects, 1d CSR model
centroid properties of a gaussian bunch 1nC, Ipeak=5kA
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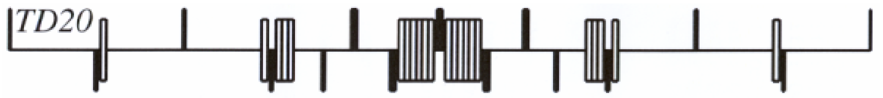

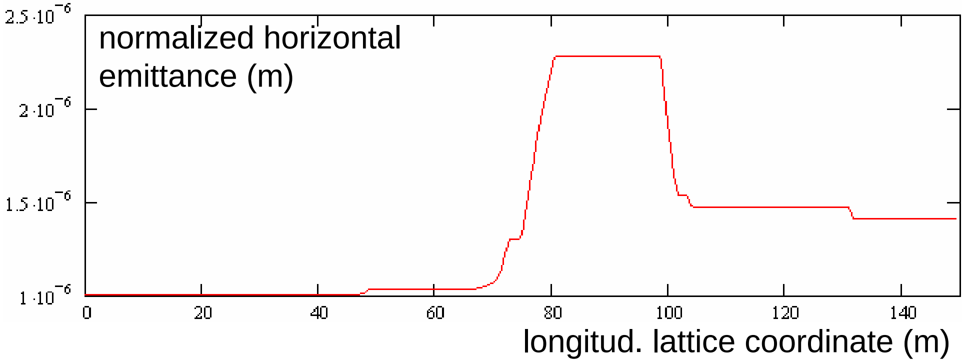

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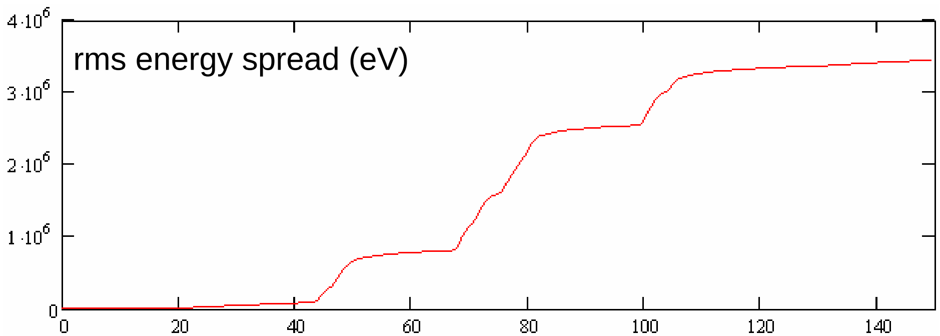
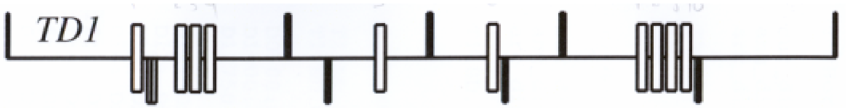
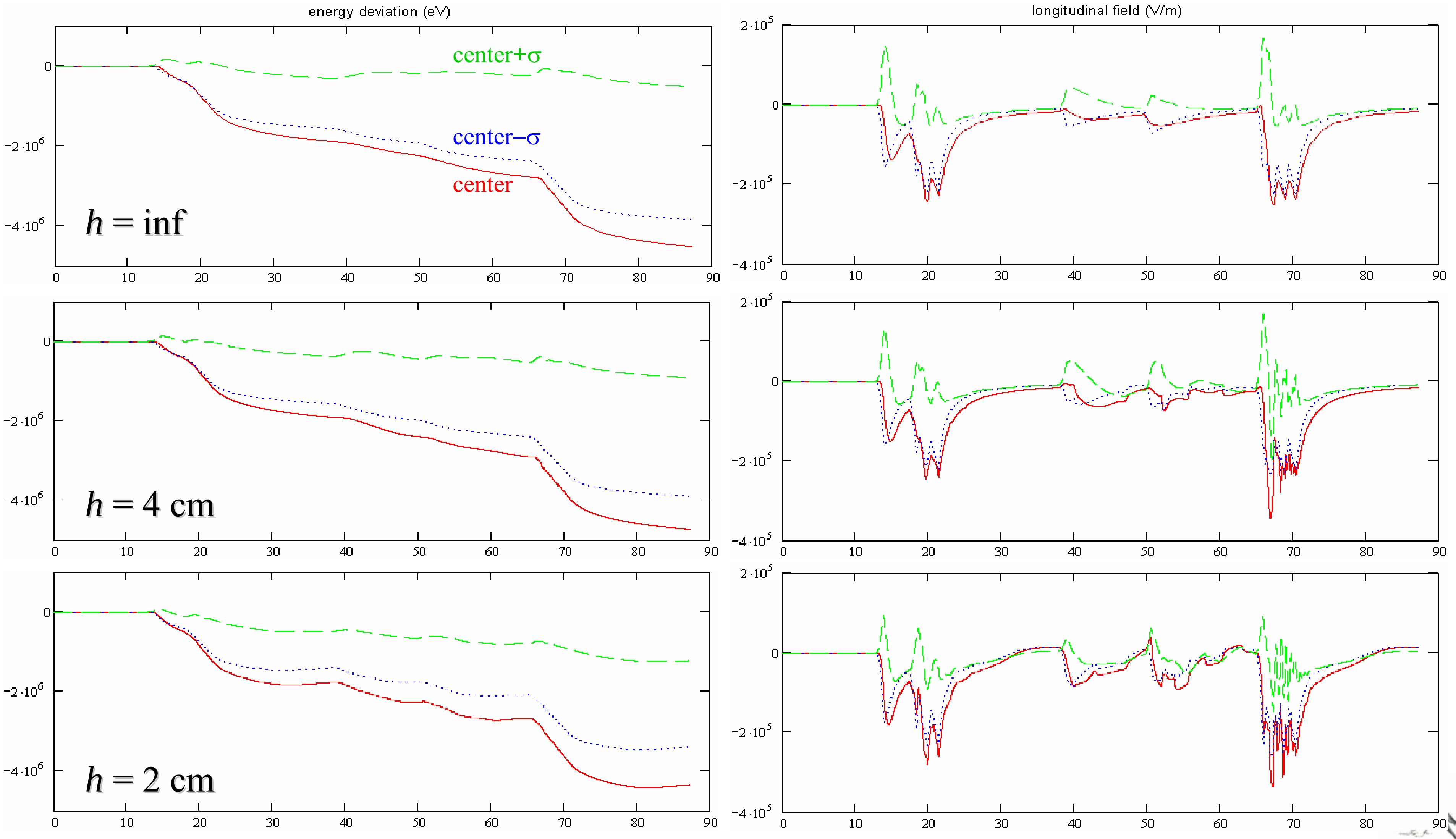


3.45E6

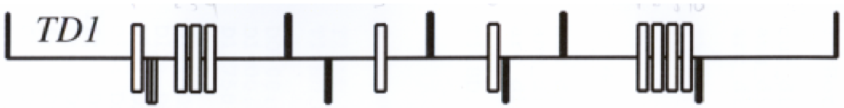
3 Attempts to avoid/reduce longitudinal effects
3.1 Shielding



self effects, 1d CSR model
centroid properties of a gaussian bunch 1nC, Ipeak=5kA
no chirp



3.2 Magnet lengths and splitted arcs



self effects, 1d CSR model
centroid properties of a gaussian bunch 1nC, Ipeak=5kA
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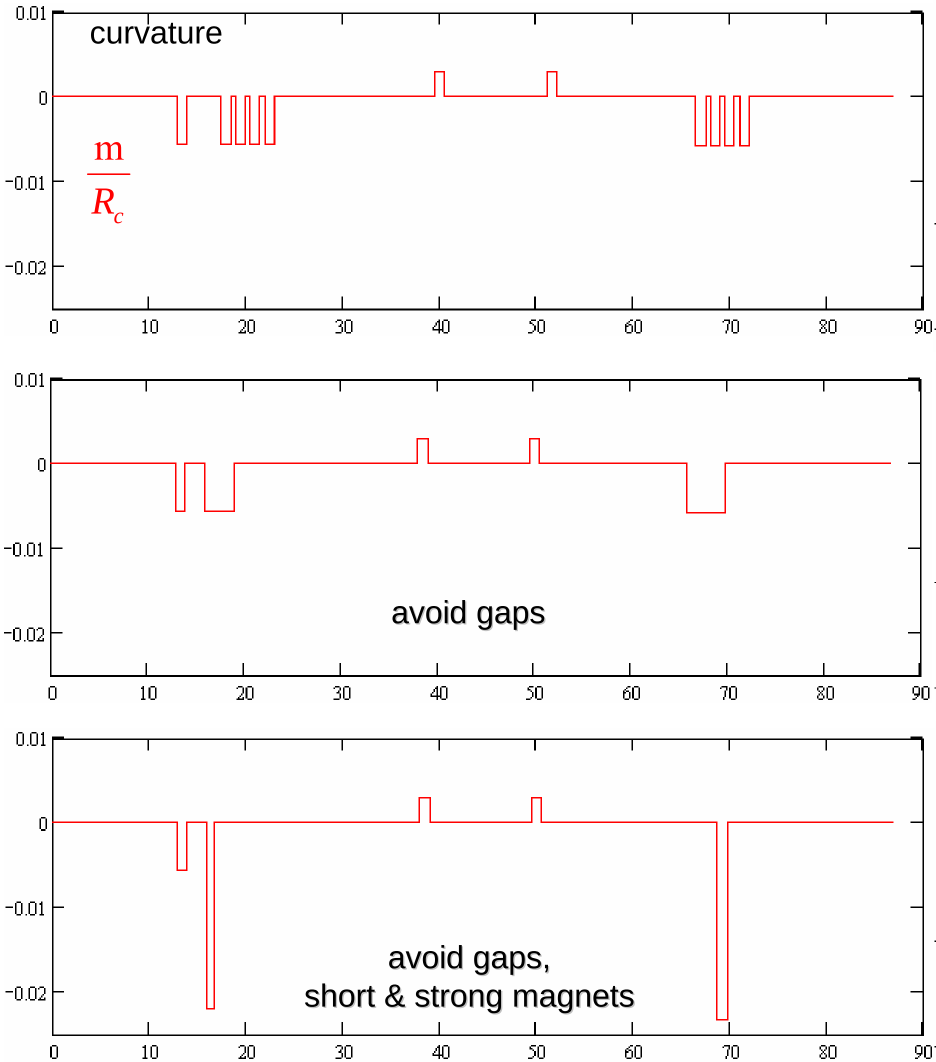
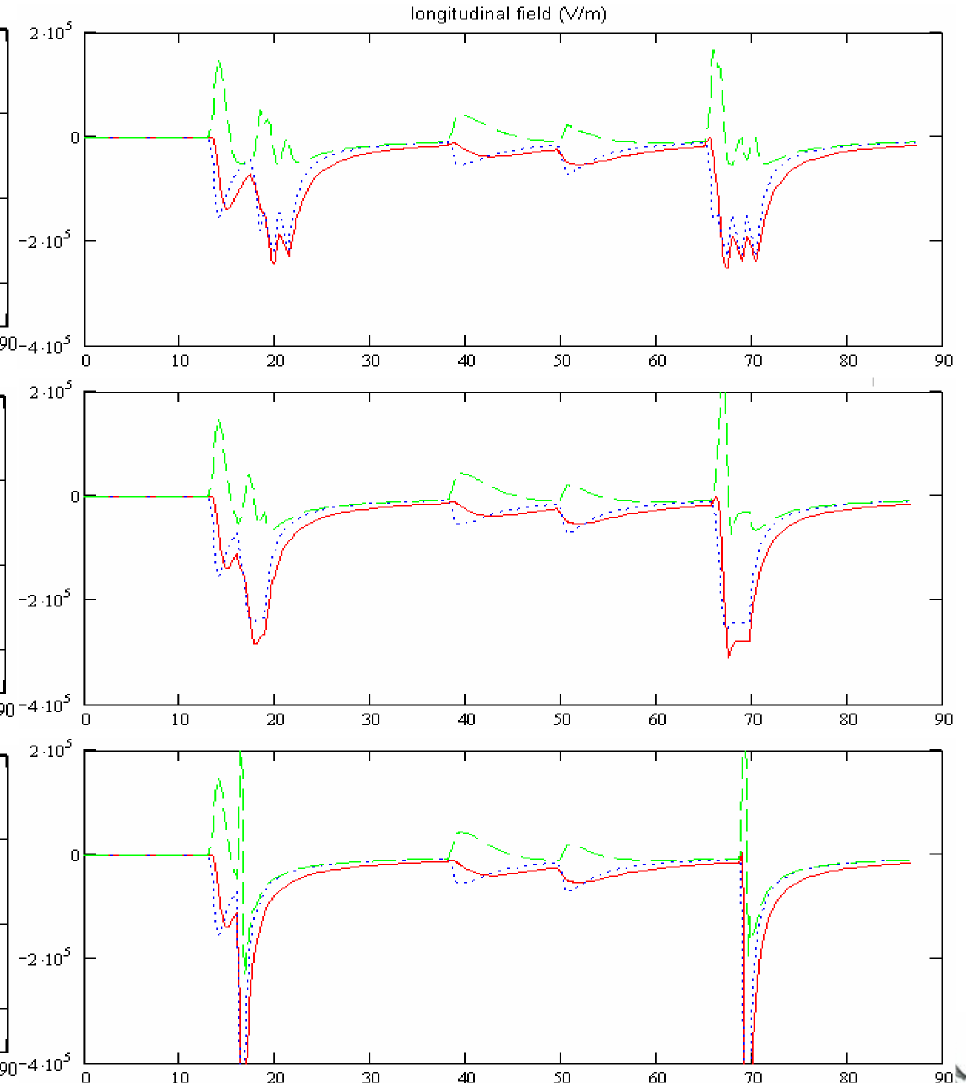
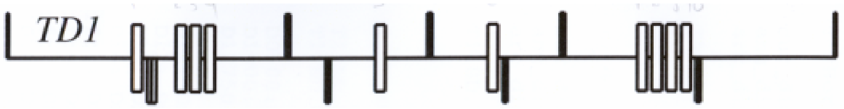




magnet lengths and splitted arcs



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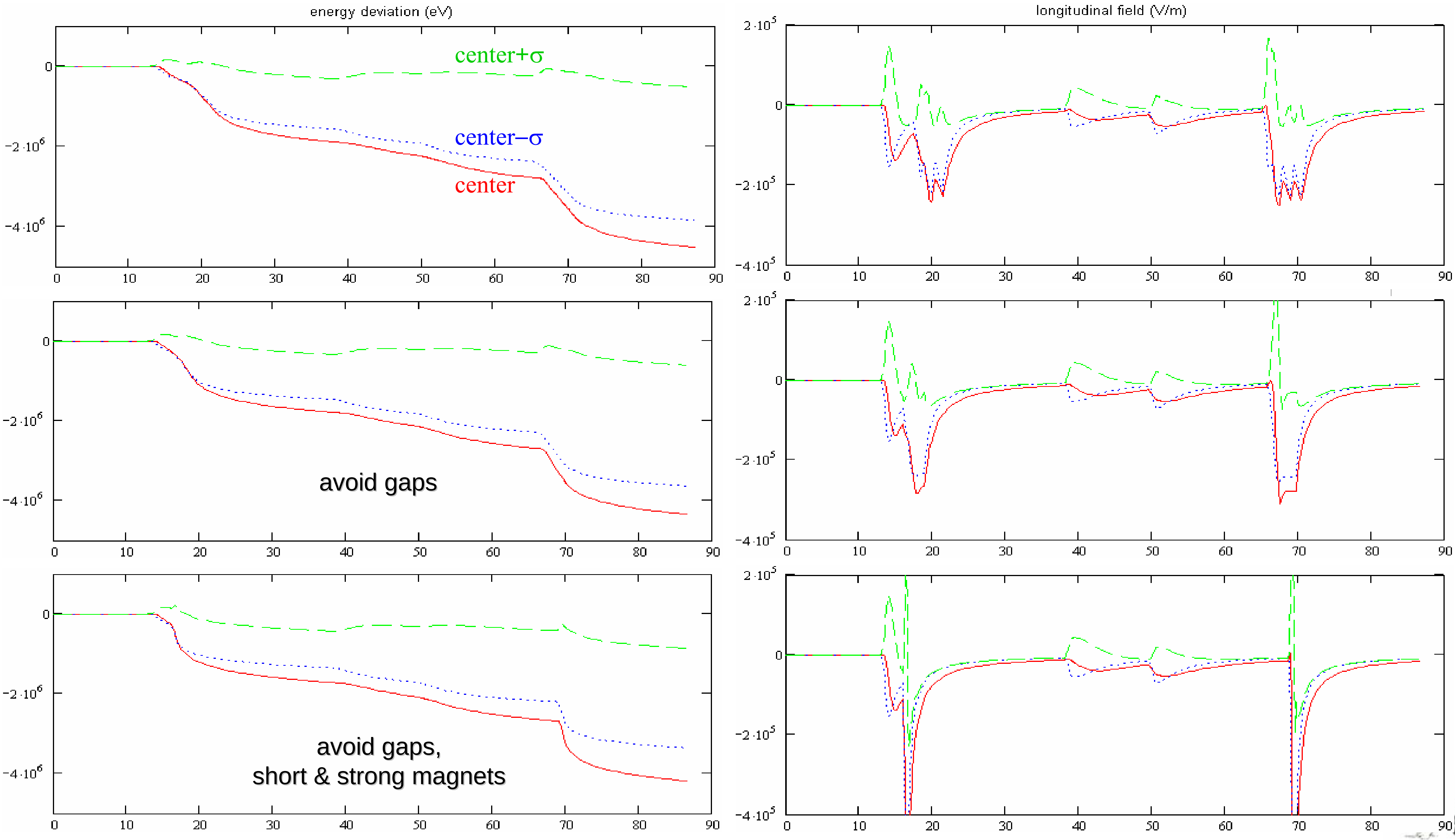
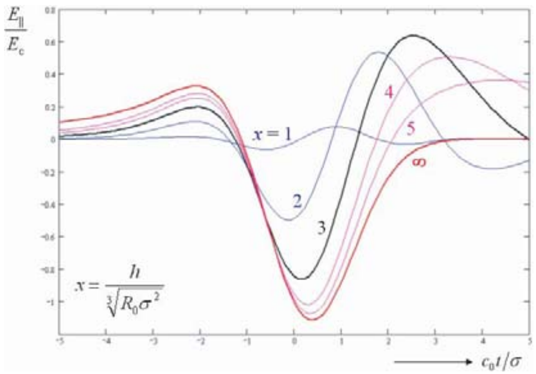


3.3 In principle

shielding by horizontal planes

circular motion: shielding parameter x << 3



$$R_{bend} \approx 100 \text{ m}$$
$$\sigma \approx 12.5 \text{ µm}$$

$$h << 3\sqrt[3]{R_{\text{bend}}\sigma^2} \approx 7.5 \text{ mm}$$

but $2R_{\text{pipe}} \approx 40 \text{ mm}$

transients: shielding by dispersion in waveguide

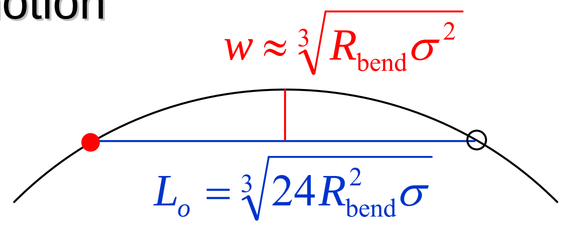
$$\frac{L}{v_{\text{ph}}(\omega_{\text{rms}})} - \frac{L}{c} >> \frac{\sigma}{c}$$

$$L >> \frac{2}{\sigma}\left(\frac{c}{\omega_{\text{cutoff}}}\right)^2 \qquad L >> \frac{2}{\pi^2}\frac{h^2}{\sigma} \qquad h \approx 40 \text{ mm} \rightarrow L >> 26 \text{ m}$$

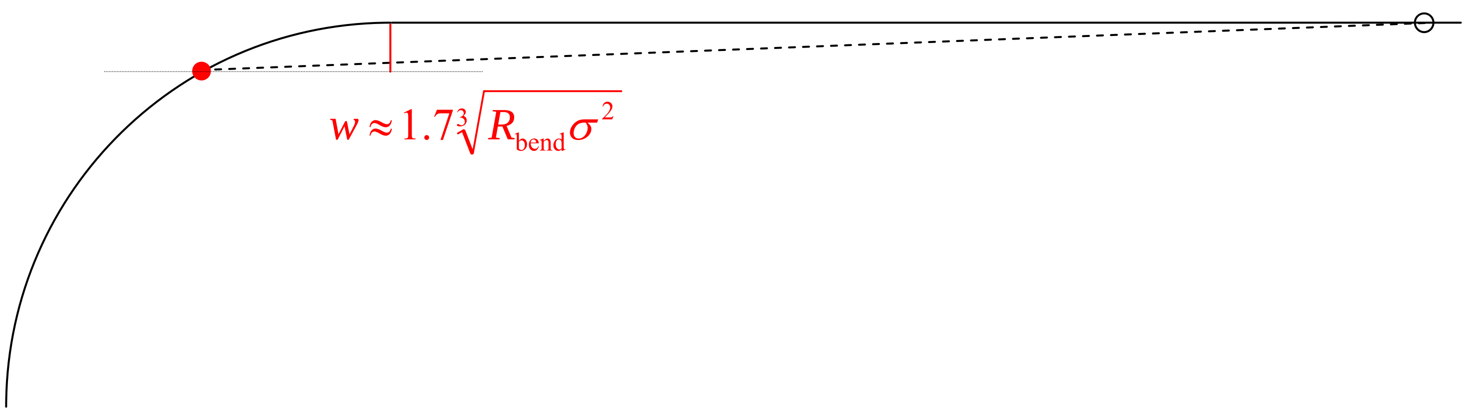
remark: kicker $R = 1 \text{ cm}$

shielding by horizontal obstacles

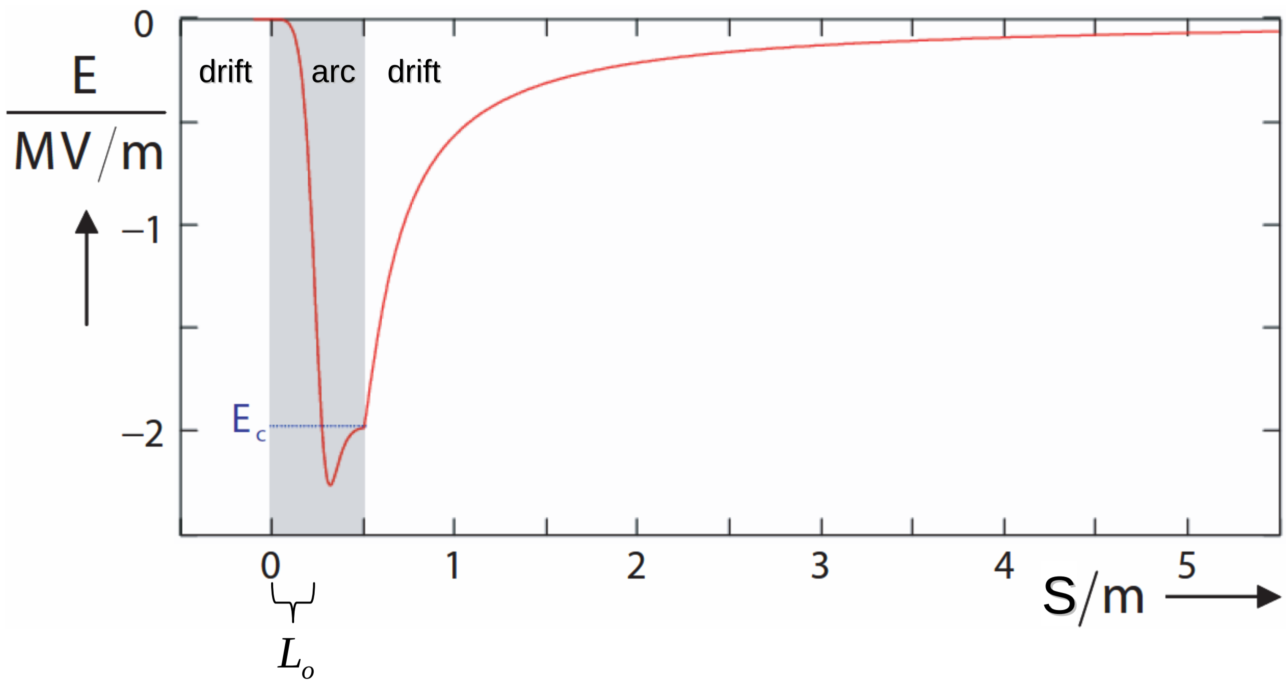
circular motion



transient (exit, case ‘long magnet”, β=1)



steady state and transient longitudinal CSR field



steady state in arc $\left|E\right| \propto E_c = \dfrac{1}{\pi}\dfrac{Z_0 \hat{I}}{L_o}$

asymptotic after arc $E \approx -\dfrac{1}{2\pi}\dfrac{Z_0 I(s)}{(0.5L_o + \Delta S)}$

rough estimation for energy loss or energy spread

steady state in arc $$|E| \propto E_c = \frac{1}{\pi}\frac{Z_0 \hat{I}}{L_o}$$

asymptotic after arc $$E \approx -\frac{1}{2\pi}\frac{Z_0 I(s)}{(0.5L_o + \Delta S)}$$

$$E = \int_0^{L_{\mathrm{bend}}+\Delta S} E dS \propto E_c\left(L_{\mathrm{bend}} + 0.5L_0 \ln\left(1 + 2\Delta S / L_o\right)\right)$$ with

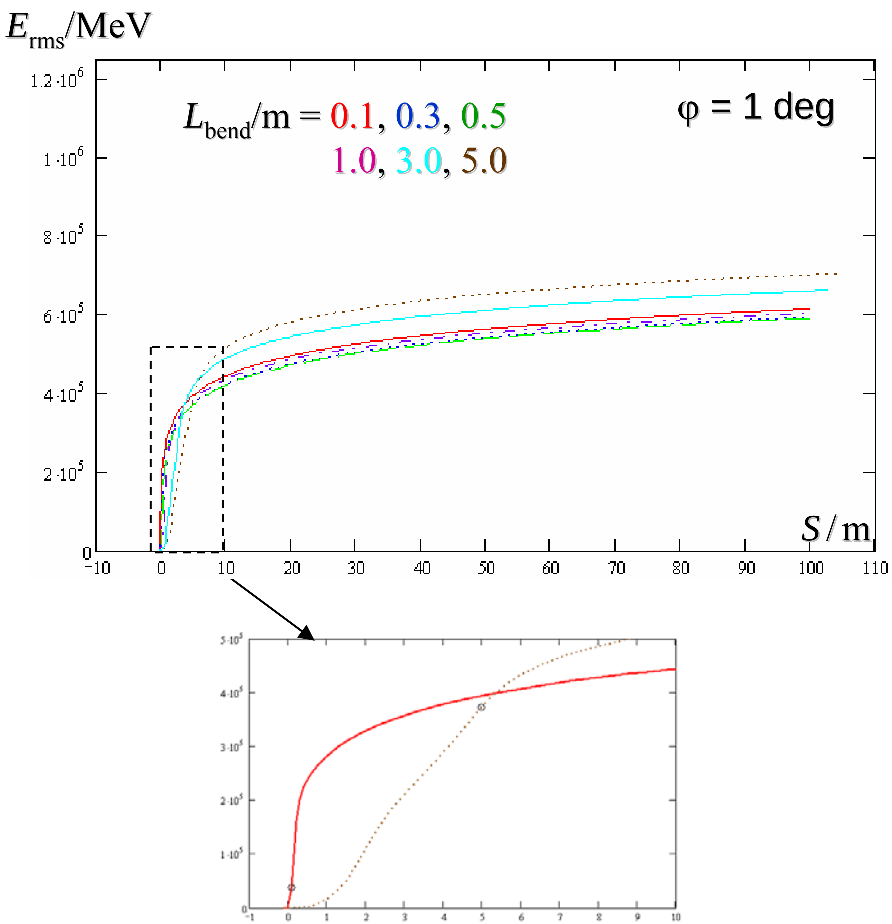
$$L_o = \sqrt[3]{24 R_{\mathrm{bend}}^2 \sigma}$$

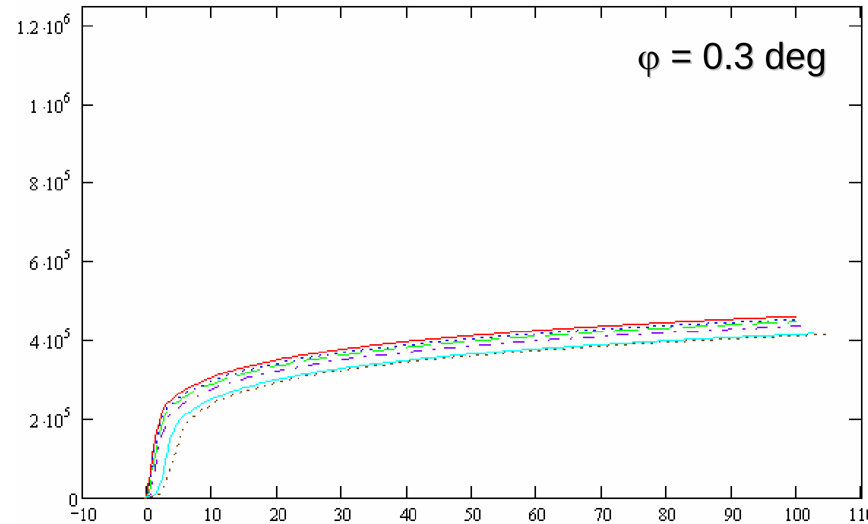
$$\varphi_{\mathrm{bend}} = \frac{L_{\mathrm{bend}}}{R_{\mathrm{bend}}}$$

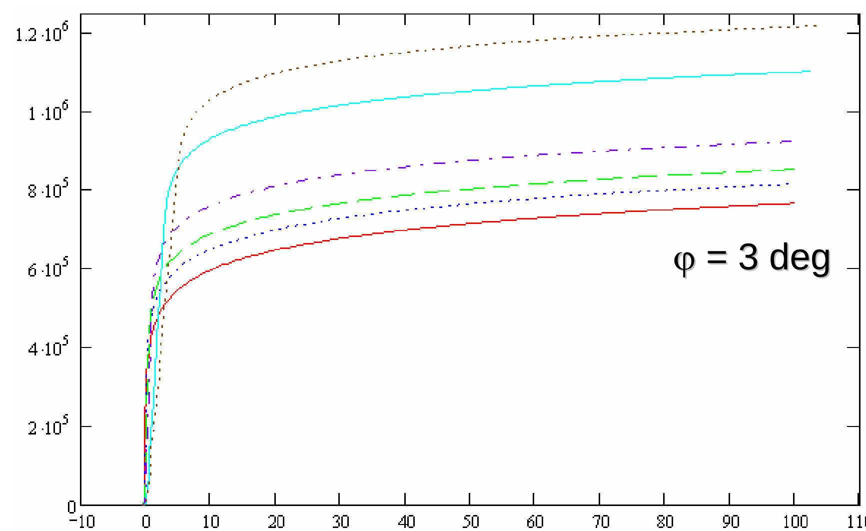
$\Delta S = \min\{\sigma/(1-\beta),$
shielding length,
next element$\}$

$$E \propto \frac{Z_0 \hat{I}}{2\pi}\left(\varphi_{\mathrm{bend}}\sqrt[3]{\frac{R_{\mathrm{bend}}}{3\sigma}} + \ln\left(1 + \frac{\Delta S}{\sqrt[3]{3R_{\mathrm{bend}}^2 \sigma}}\right)\right)$$

example: (CSRtrack – projected)
rms energy spread for bend + drift
(I_{peak} = 5 kA, σ = 12.5 μm)



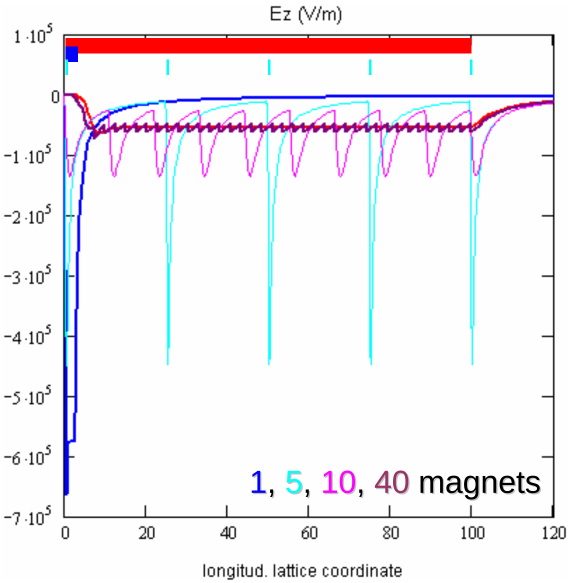




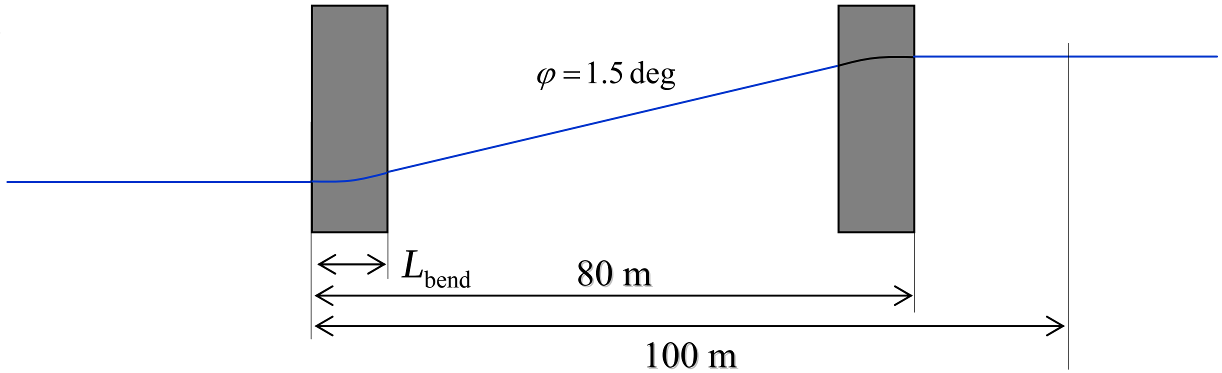
example: (CSRtrack – projected)

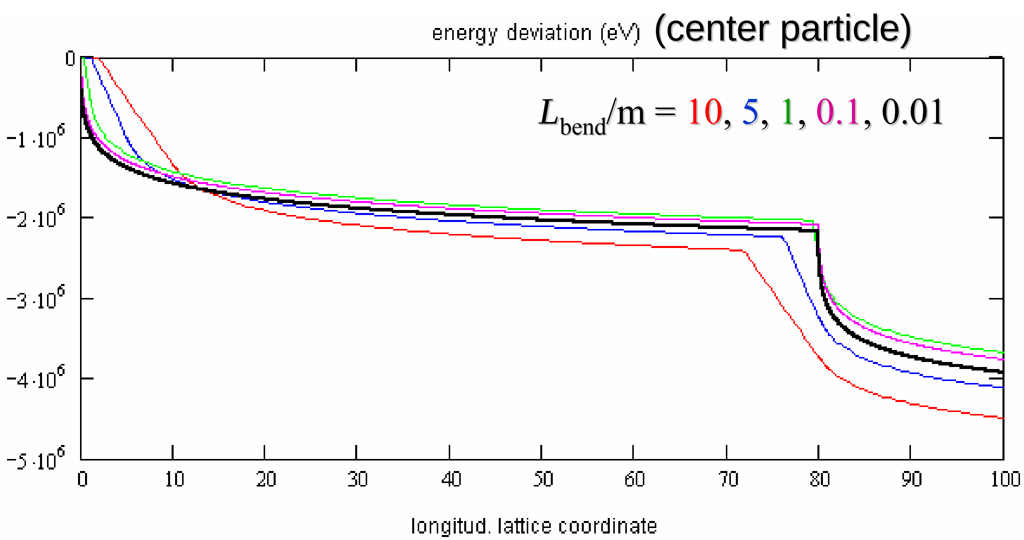
L = 100 m φ = 3.00 deg

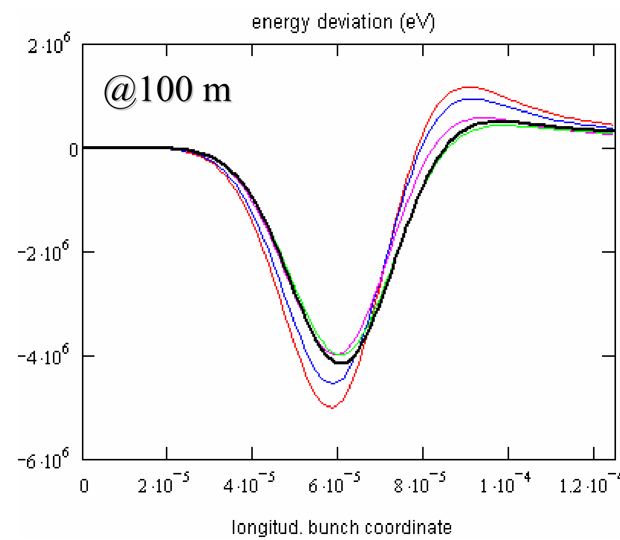
long weak magnet $\rightarrow$ many short strong magnets



example: (CSRtrack – projected)
dogleg with 2 magnets







E_{rms}/MeV = 1.854, 1.631, 1.323, 1.233, 1.305

4 Realistic model for longitudinal phase space
+ collimator impedance model (from database)

4.1 1D simulation

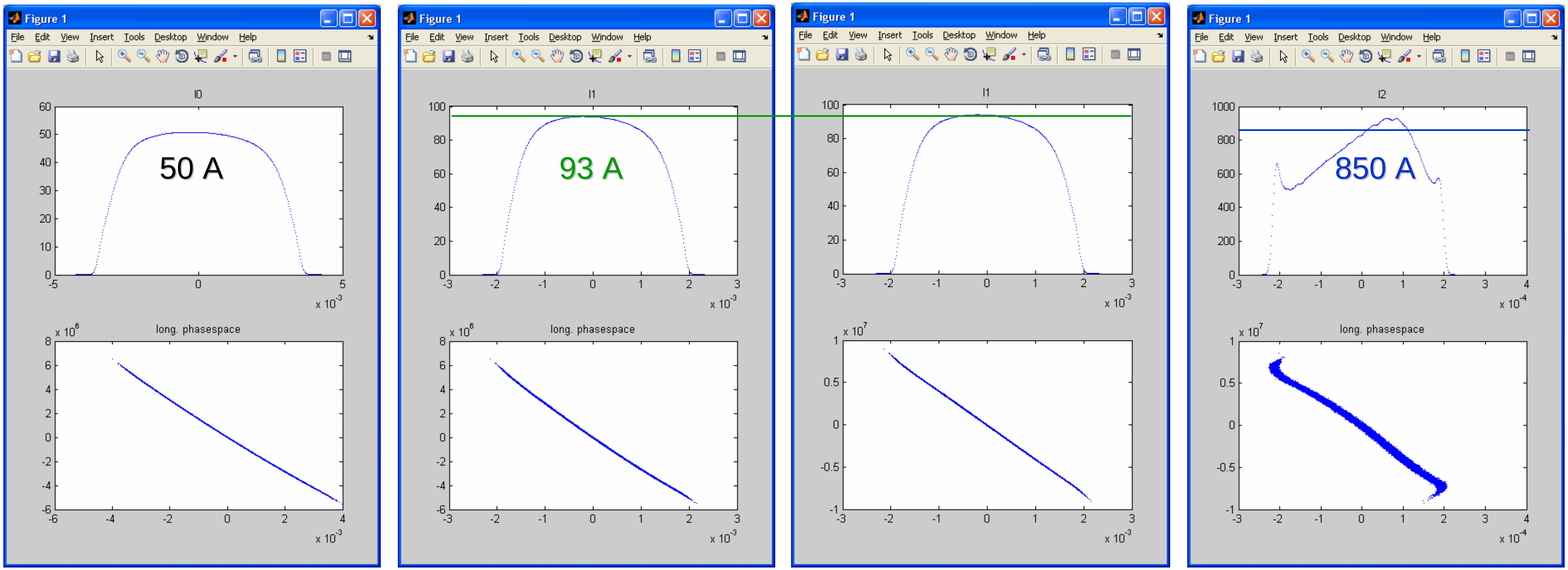
(ideal transverse phase space $\varepsilon\gamma$ = 1µm), working point “0”

BC0
130MeV

L0→1

BC1
500MeV

L1→2



cavity wake
space charge

1D-CSR

cavity wake
space charge

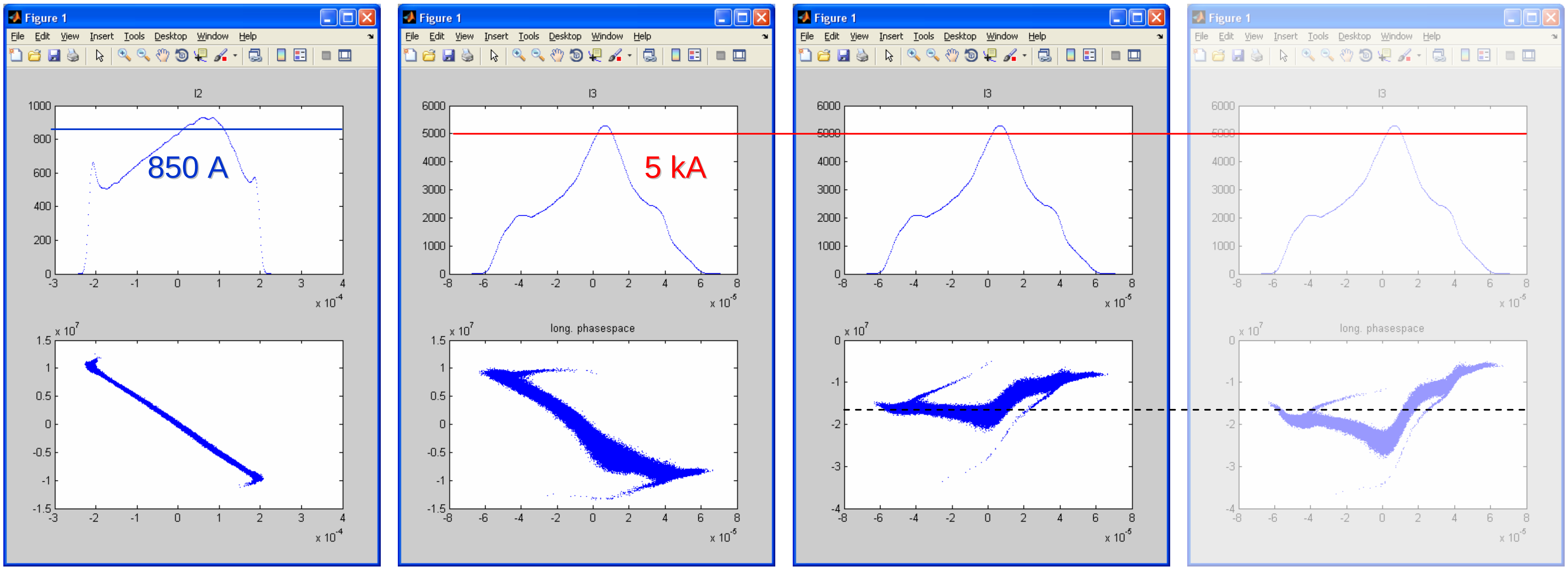
1D-CSR

cavity wake
space charge

L1→2

BC2
2GeV

main
LINAC 17.5 GeV



cavity wake
space charge

1D-CSR

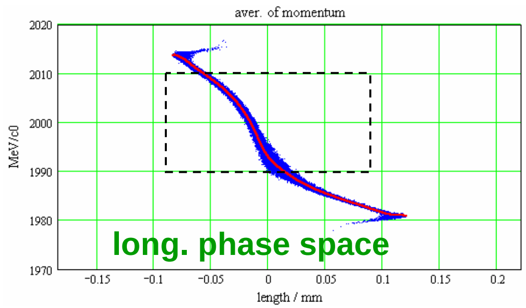
cavity wake
space charge

1D-CSR
in collimator

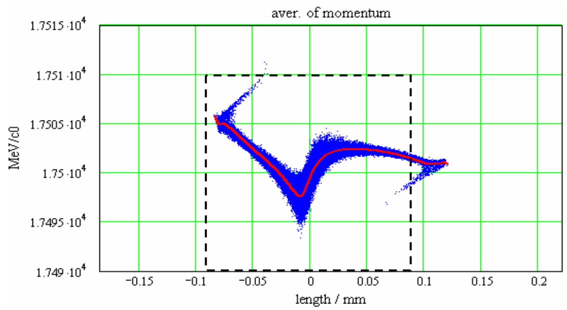
main LINAC

old design “2BC”

after BC2

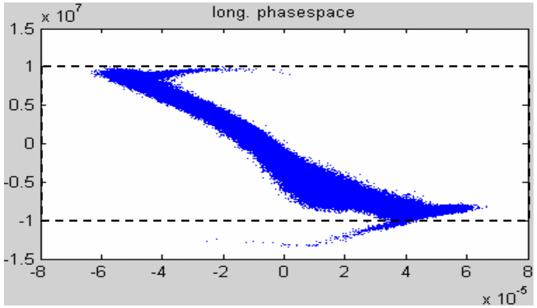


cavity wakes + SC



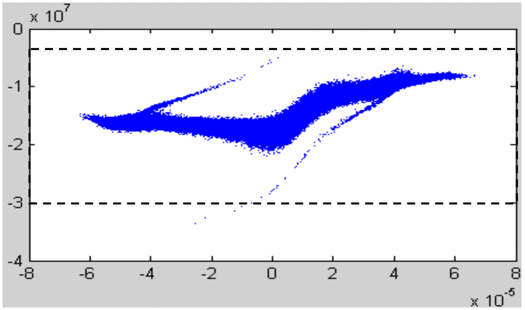
100 modules

new design “3BC” (V0)



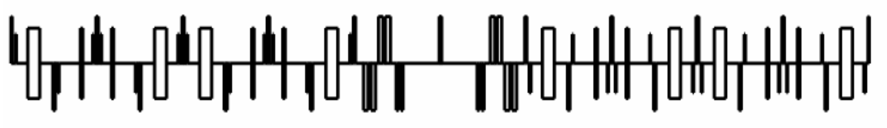
reduced remaining chirp

cavity wakes + SC



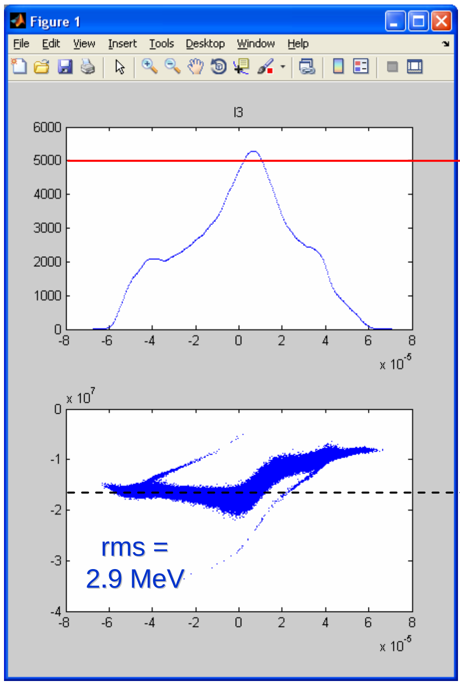
84 modules

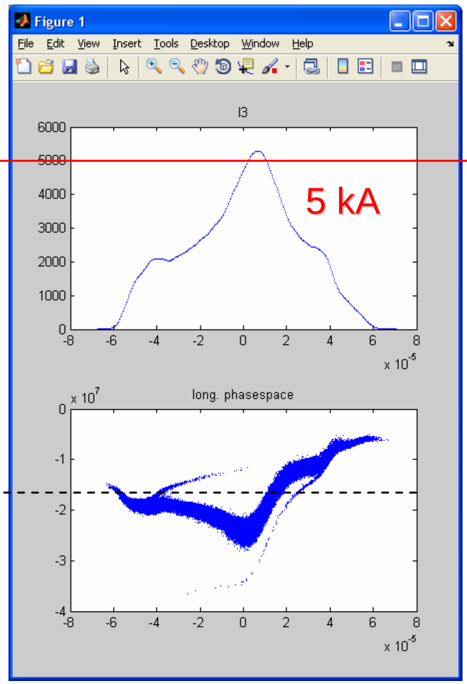
4.2 Collimator

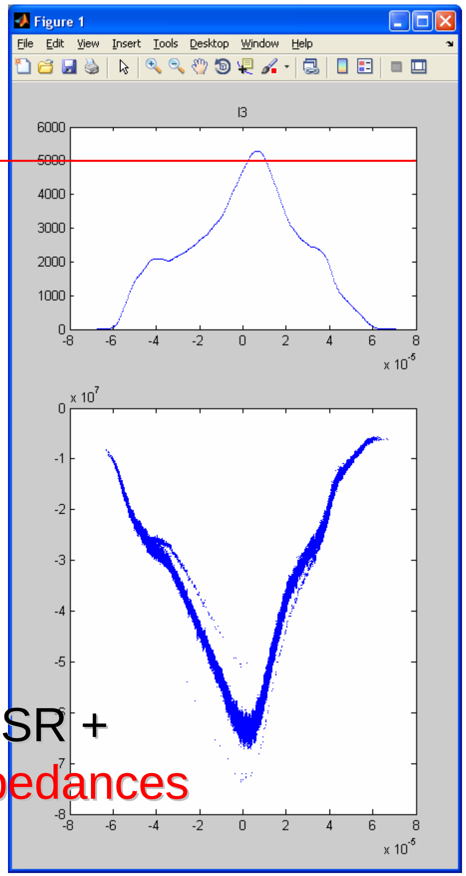


L = 180 m

main LINAC   collimator







1D-CSR
in collimator

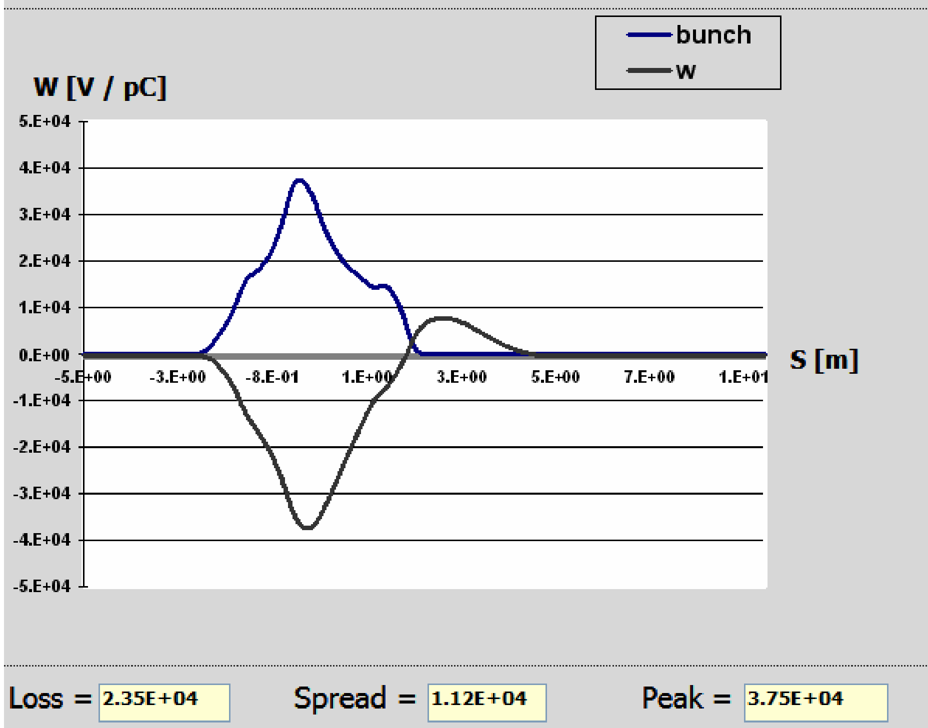
1D-CSR +
other impedances

collimator – impedance budget (Olga Zagorodnova)

Impedance budget

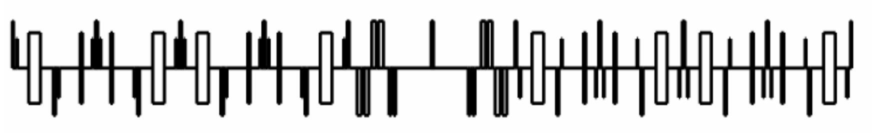
Section	*El. type*	*Num.*	*Loss (kV/nC)*	*%*	*Spread(kV/nC)*	*%*	*Peak(kV/nC)*	*%*
CL								
	PUMCL	78	5.75E+02	2	2.18E+02	2	7.66E+02	2
	PIP20	1	4.54E+03	19	4.32E+03	38	9.26E+03	25
	KICK	4	4.61E+03	20	1.87E+03	17	6.78E+03	18
	FLANG	500	1.36E+03	6	5.16E+02	5	1.82E+03	5
	COLL	4	5.20E+03	22	2.69E+03	24	8.69E+03	23
	BPMCL	12	7.16E+03	31	2.73E+03	24	1.11E+04	30
			2.35E+04	100	1.12E+04	100	3.75E+04	100
			2.35E+04	100	1.12E+04	100	3.75E+04	100

rms energy spread ≈ 11.2 MeV



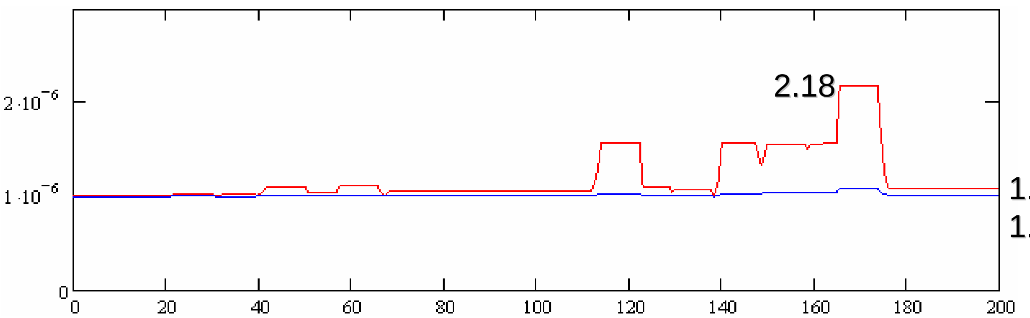
pessimistic estimation
BPMCL = 12 cavity BPMs
KICK = 4 kickers (4x10m, r=1cm, κ=2E6 S/m)

CSRtrack calculation with distributed collimator impedance



XFEL collimation section, mode A
ideal gaussian bunch
“realistic model” (transversely ideal)

normalized horizontal emittance (m)

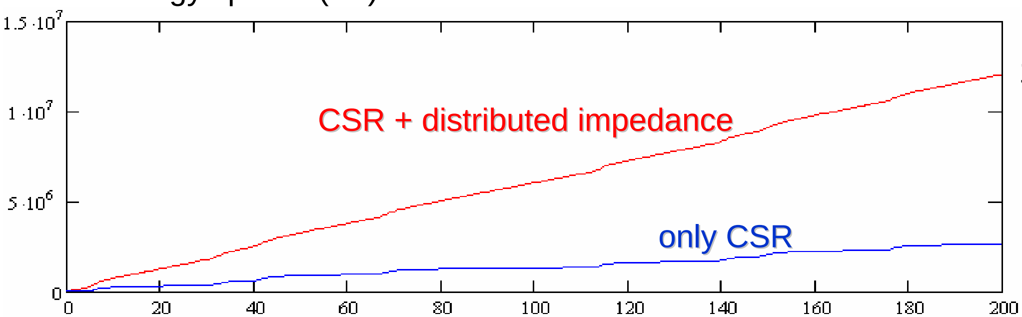


1.091 1.082
1.008

longitud. lattice coordinate (m)

remark: kicker after collimator dog leg is “distributed”

rms energy spread (eV)



12.02 MeV

2.62 MeV

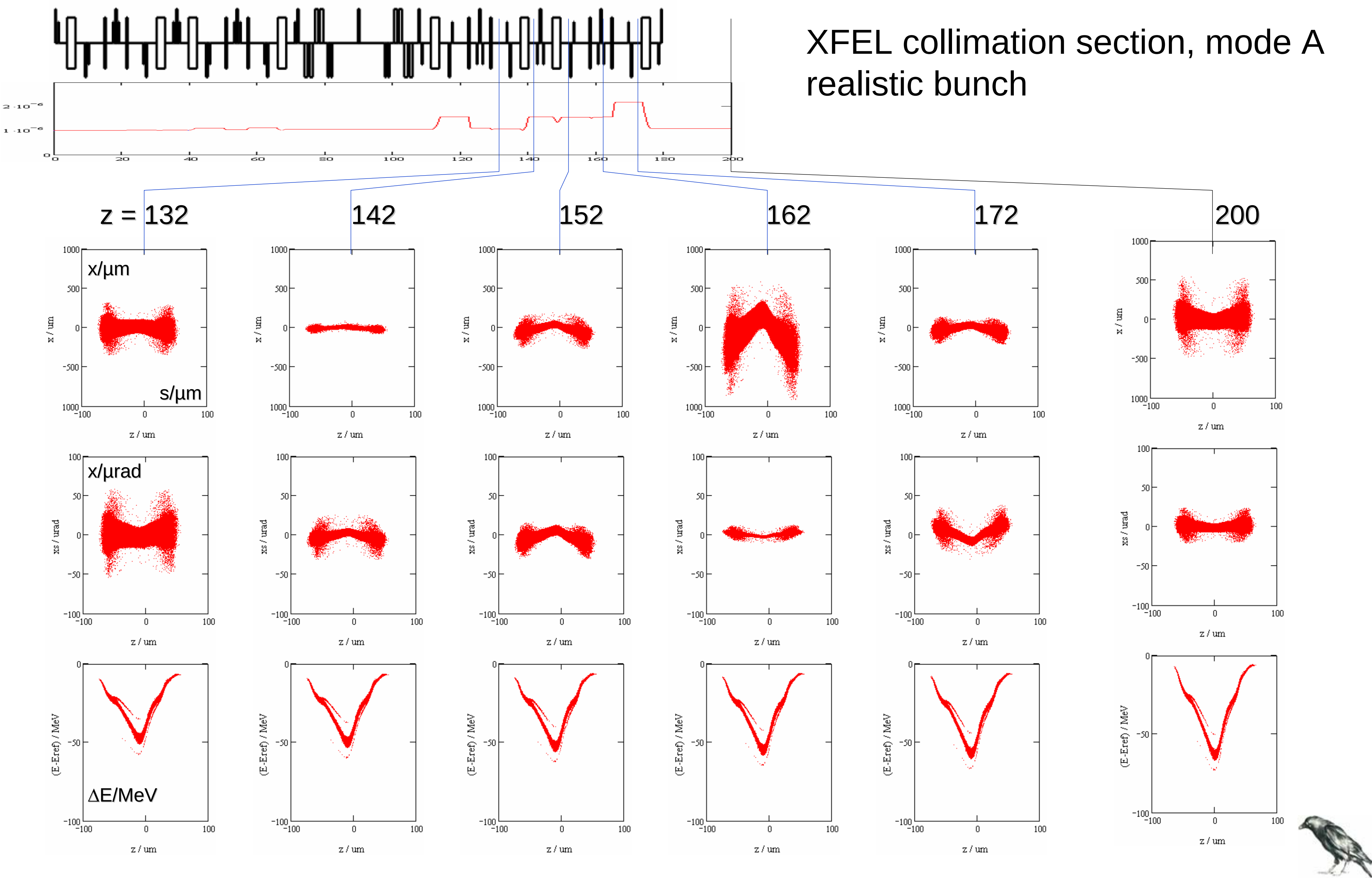
before collimator 0.0 MeV
after collimator 12.0 MeV

before collimator 2.9 MeV
after collimator 15.2 MeV

only collimator 12 MeV

CSRtrack calculation with distributed collimator impedance

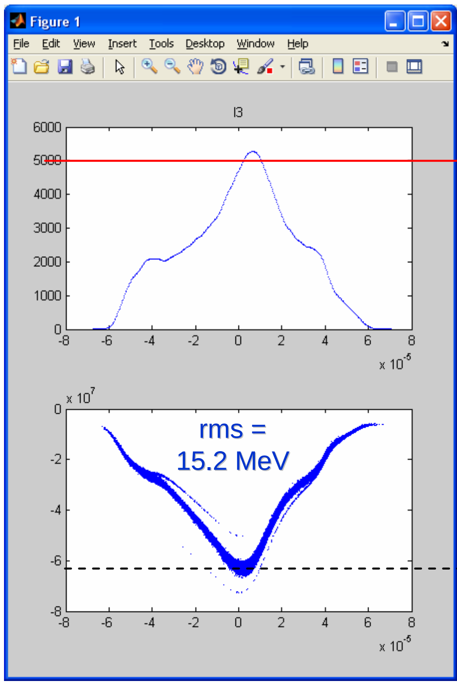
XFEL collimation section, mode A
realistic bunch



4.3 TD1 and TD20

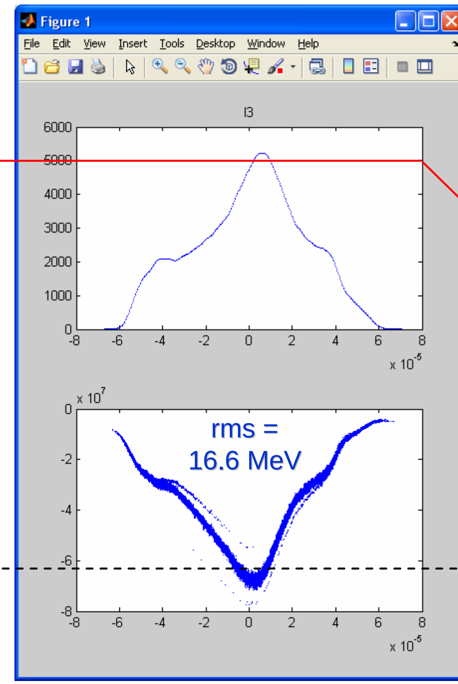
1D-CSR, no other impedances

collimator

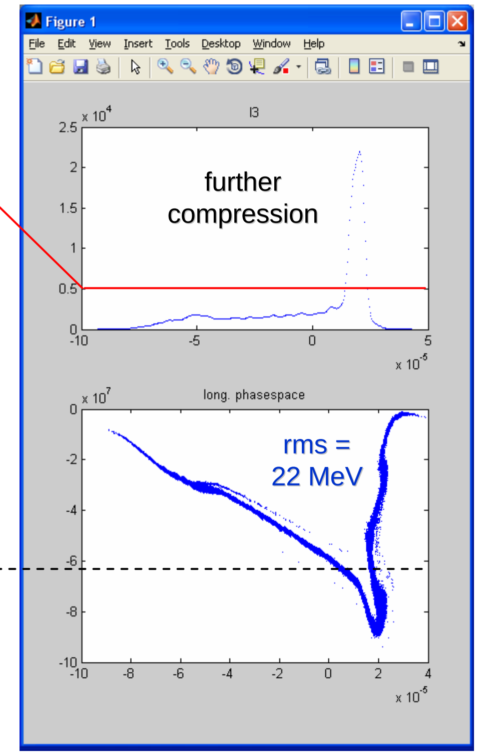


5 kA

collimator & TD1



collimator & TD20



ε = 1.008 µm *

* only colli.

ε = 1.27 µm **

** only TD1

5 Summary / Conclusion

2 CSRtrack calculation for ideal gaussian bunch (ε=1µm)

Collimator emittance growth <1 %, energy spread 2.6 MeV

TD1 emittance growth 40 %, energy spread 2.0 MeV

TD20 emittance growth 41 %, energy spread 3.5 MeV, compression effects

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3 Attempts to avoid/reduce longitudinal effects

no shielding effects can be used

weak influence of magnet length on rms energy spread

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4 Realistic model for longitudinal phase space + collimator impedance model

after BC2 energy spread 2.9 MeV

after collimator energy spread 15.2 MeV emittance growth $\approx$ 8 %

significant (non-CSR collimator impedance) $\rightarrow$ 12 MeV rms spread

after colli+TD1 energy spread 15.2 MeV emittance growth 27 % **

after colli+TD20 over-compression due to uncompensated r56

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it is difficult to avoid CSR induced energy spread

emittance growth due to centroid shift can be controlled / compensated