FLASH beam dynamic issues with 3rd harmonic system

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12. November 2009

MAC Meeting, DESY

FLASH & Methods

layout, some parameters, simulation methods

Rollover Compression

working point, longitudinal phase space

Compression with 3rd Harmonic System

working point and its stability, long. phase space

Transverse Dynamics

projected and slice emittance

Amplification of Microbunching

low and high energy part

FLASH layout

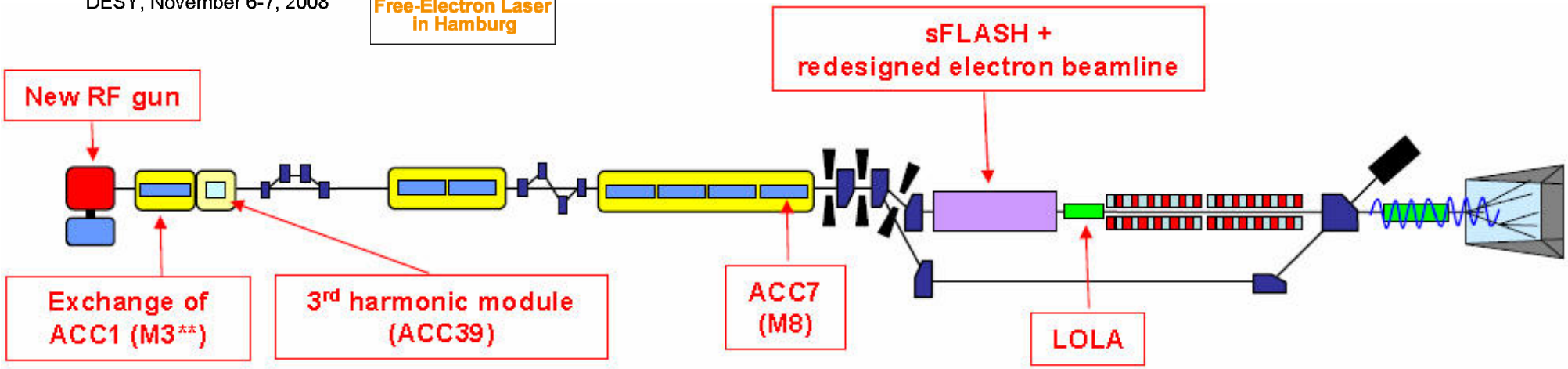
FLASH Upgrade 2009

Katja Honkavaara, DESY

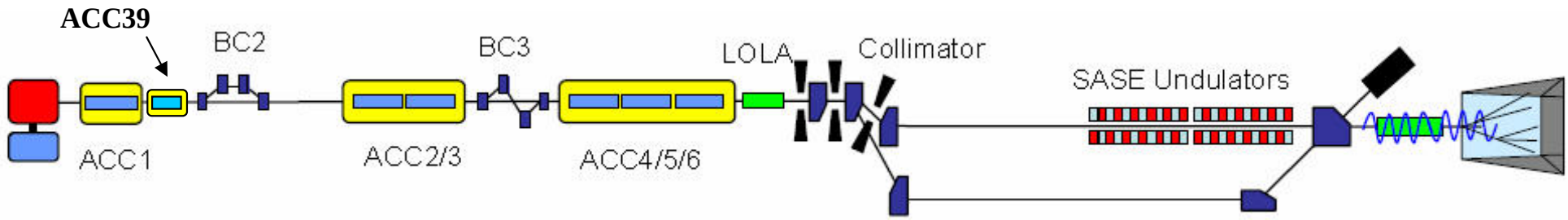
MAC Meeting

DESY, November 6-7, 2008

FLASH
Free-Electron Laser in Hamburg



present FLASH plus ACC39 is considered in the following (Dohlus & Zagorodnov)

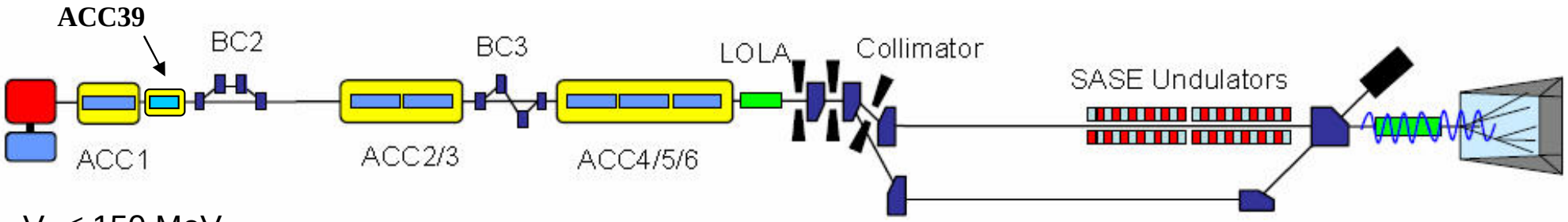


FLASH
some parameters

energy 1 GeV
radiation wavelength ~ 6.5 nm
this talk: simulation for 1 nC
next talk (I. Zagorodnov): 500 pC, 250 pC, 100 pC, 20 pC

E_1 = 130 MeV $\quad$ E_2 = 470 MeV $\quad$ E_3 = 1 GeV

$122 \le \frac{r_{56}}{\text{mm}} \le 250$ $\quad$ $10 \le \frac{r_{56}}{\text{mm}} \le 100$ $\quad$ $r_{56} \approx$ -0.56 mm

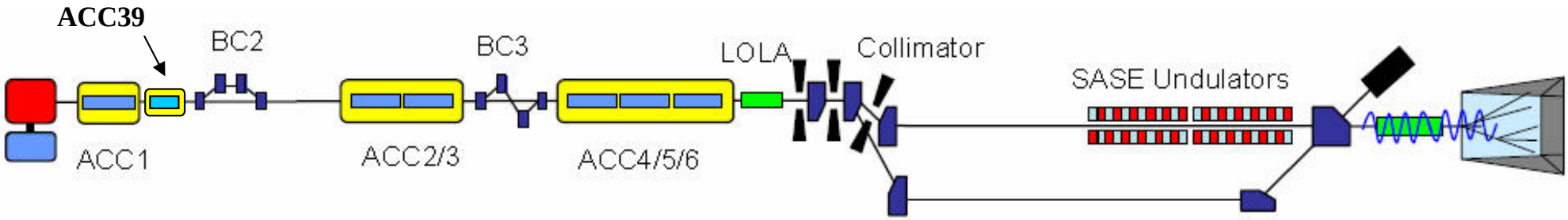


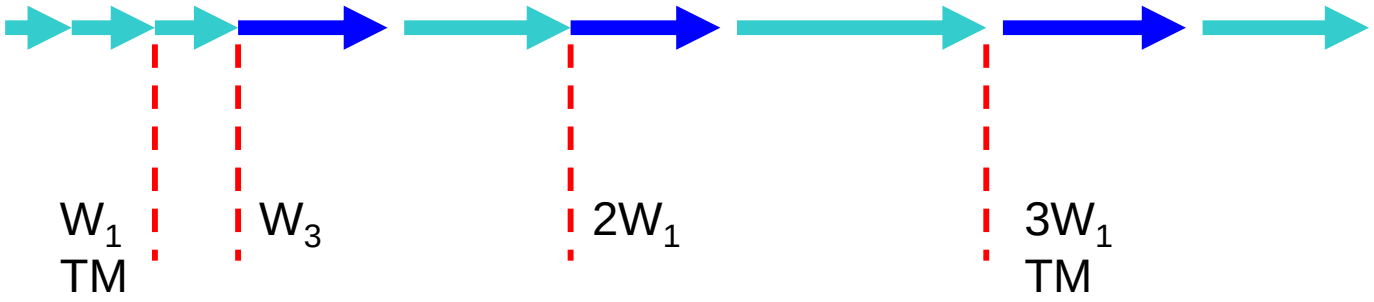
$V_1 \le 150$ MeV

$V_{39} \le 26$ MeV $\quad$ $V_{2\&3} \le 350$ (390) MeV

FLASH
3d simulation method

M. Krasilnikov - Input Desk for ASTRA gun simulations
N. Golubeva – MAD optics (V2, V2+) for 1 GeV





ASTRA

CSRtrack “projected” model
(sub-bunch approach)

W1 -TESLA cryomodule wake

W3 - ACC39 wake

TM- transverse matching to
design optics

FLASH
simulation methods

3d simulation method

~ 10 h
(46 cpu-s)

→ Astra

→ CSRtrack

1d simulation method

~ seconds
(1 cpu)

→ accelerator

$$E_1(s_1) = E_0(s_0) + V\cos(ks_0 + \varphi)$$
$$s_1 = s_0$$

→ compressor

$E_1(s_1) = E_0(s_0)$ and empirical self field model

$$s_1(s_0) = s_0 + \left(r_{56}\delta + t_{566}\delta^2 + u_{5666}\delta^3\right)$$

quasi 3d simulation method

~ 1 h
(1 cpu)

→ accelerator

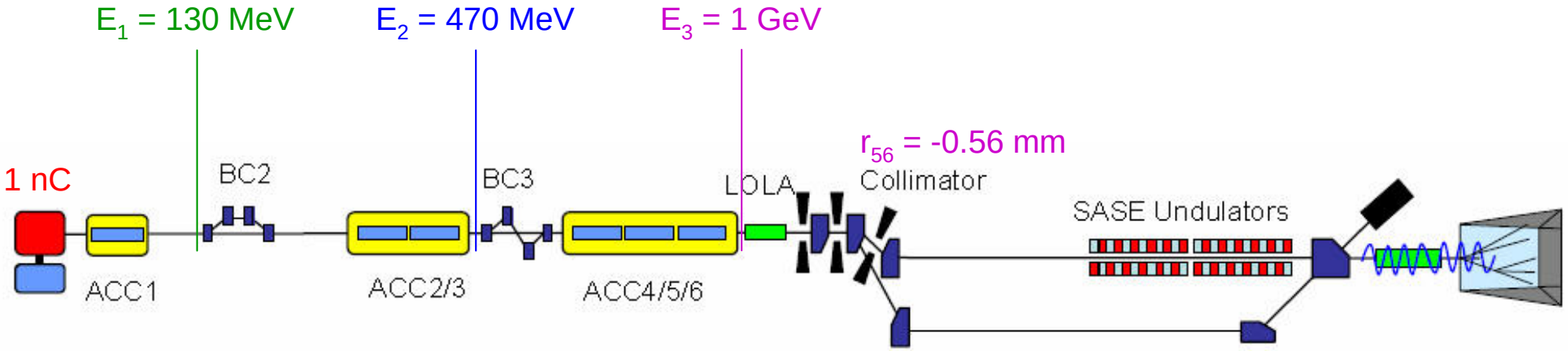
$$E_1(s_1) = E_0(s_0) + V\cos(ks_0 + \varphi)$$
$$s_1 = s_0$$

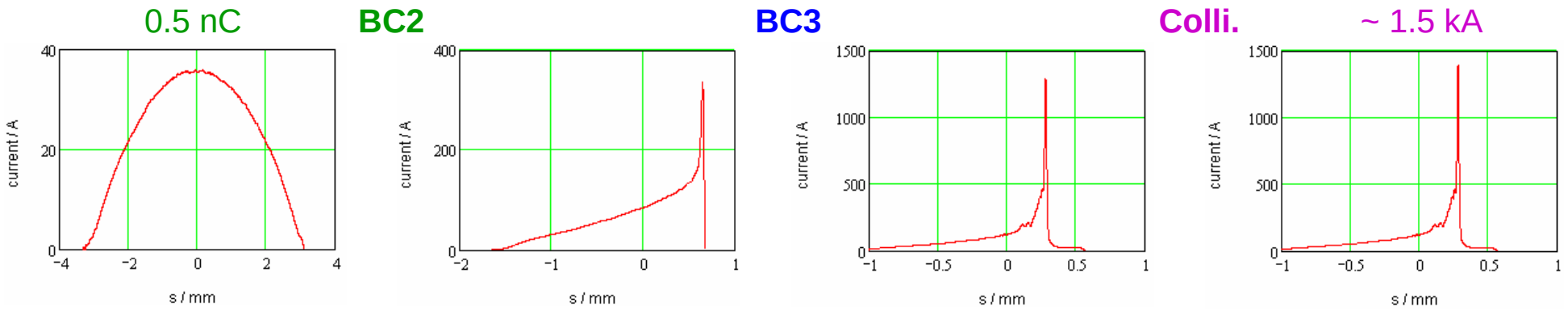
matrix transport for x & y

→ CSRtrack

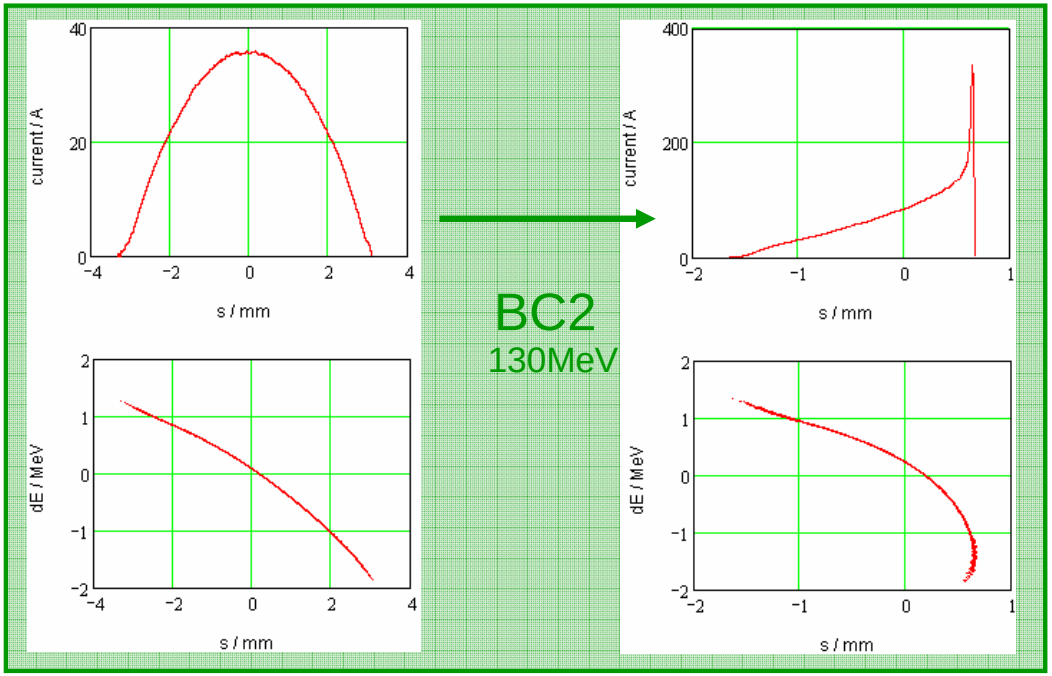
Rollover Compression working point

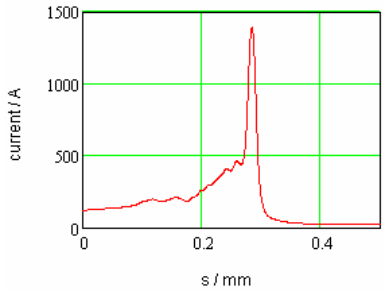
no 3rd harmonic system

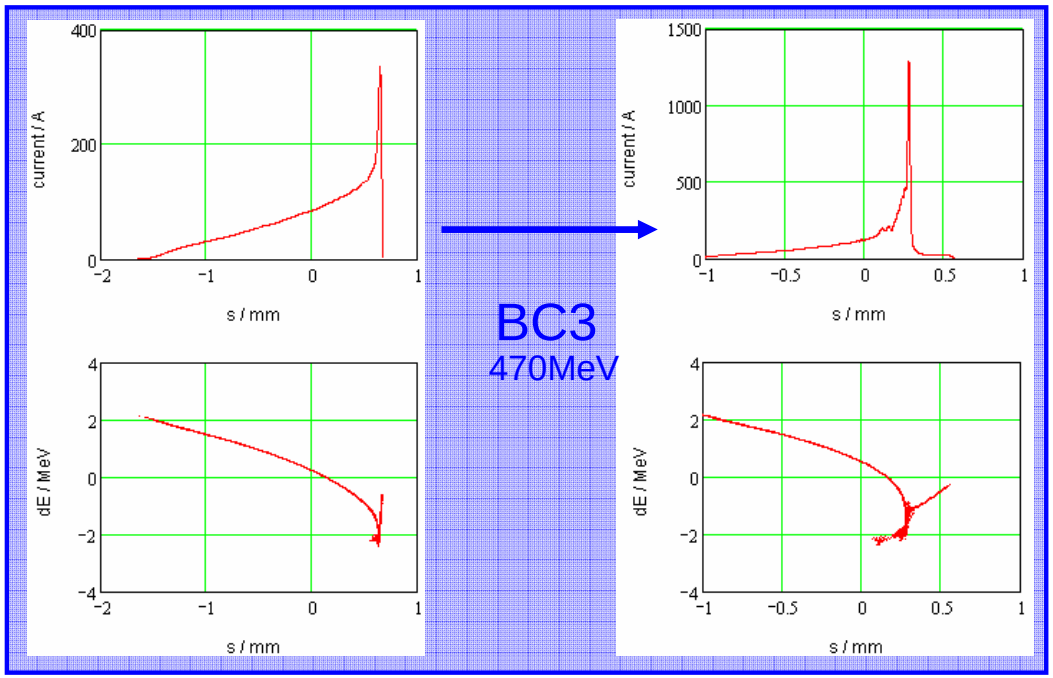


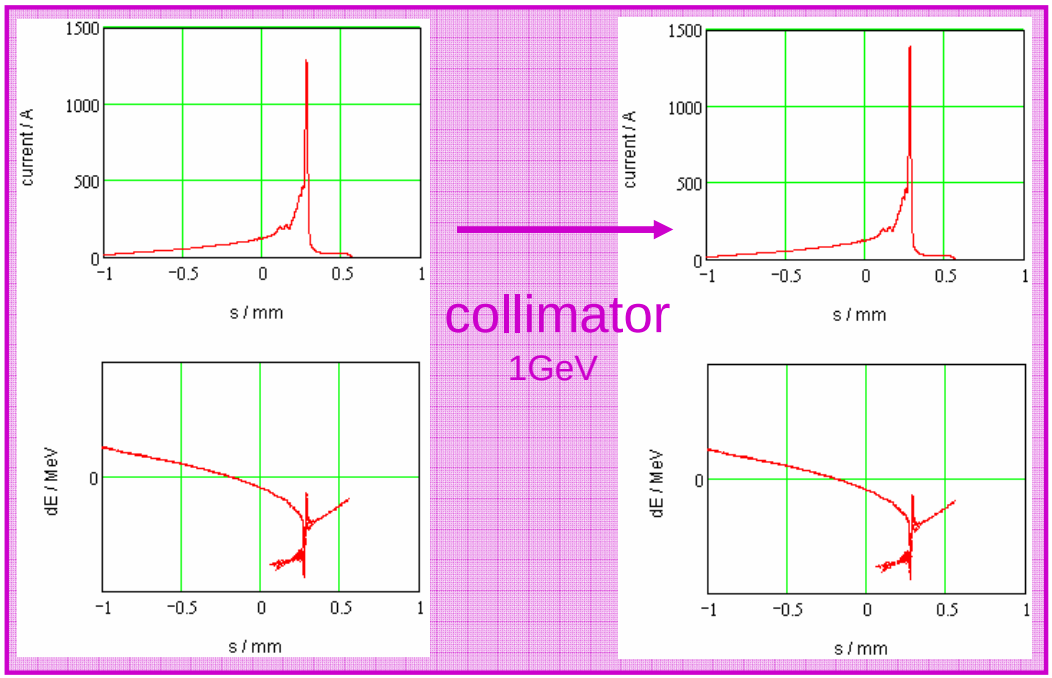


Rollover Compression
longitudinal phase space



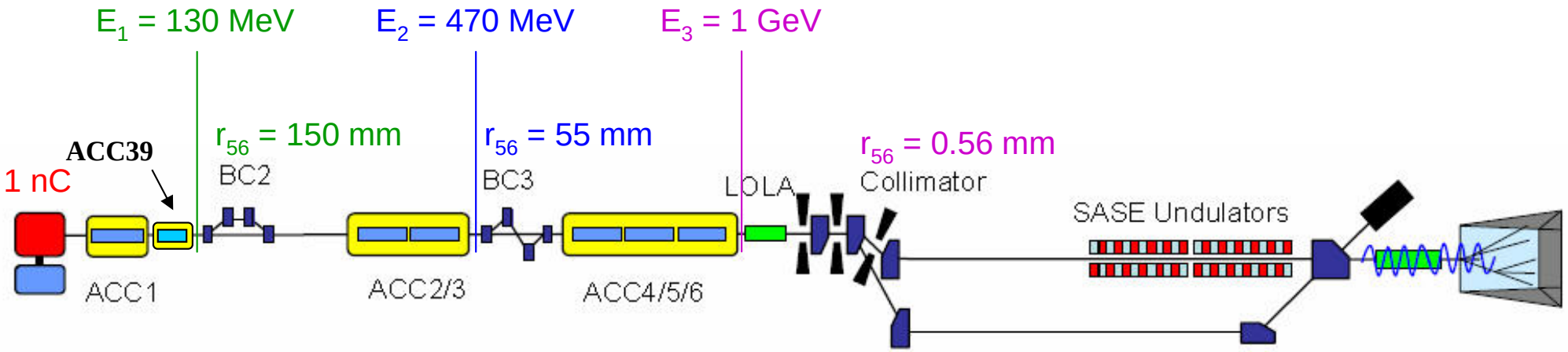






Compression with 3rd harmonic System working point

1nC → 2.5 kA

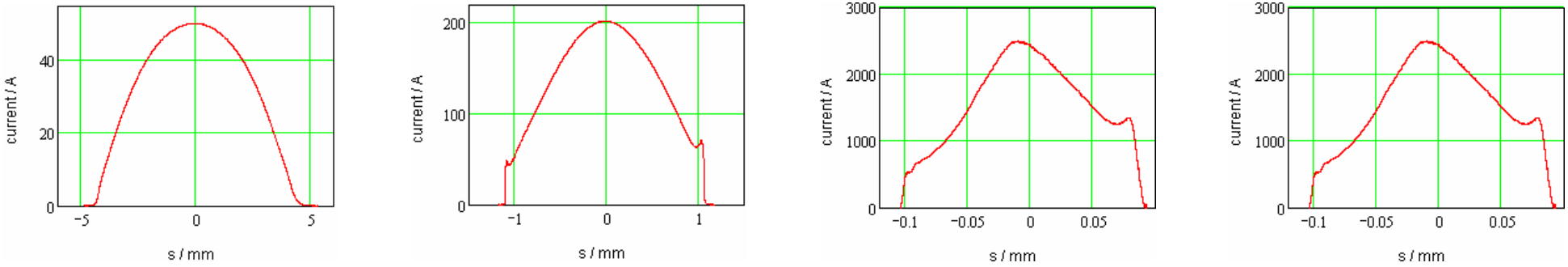


ACC1+Gun: 147 MV, -5 deg
ACC39: 21 MV, 142 deg

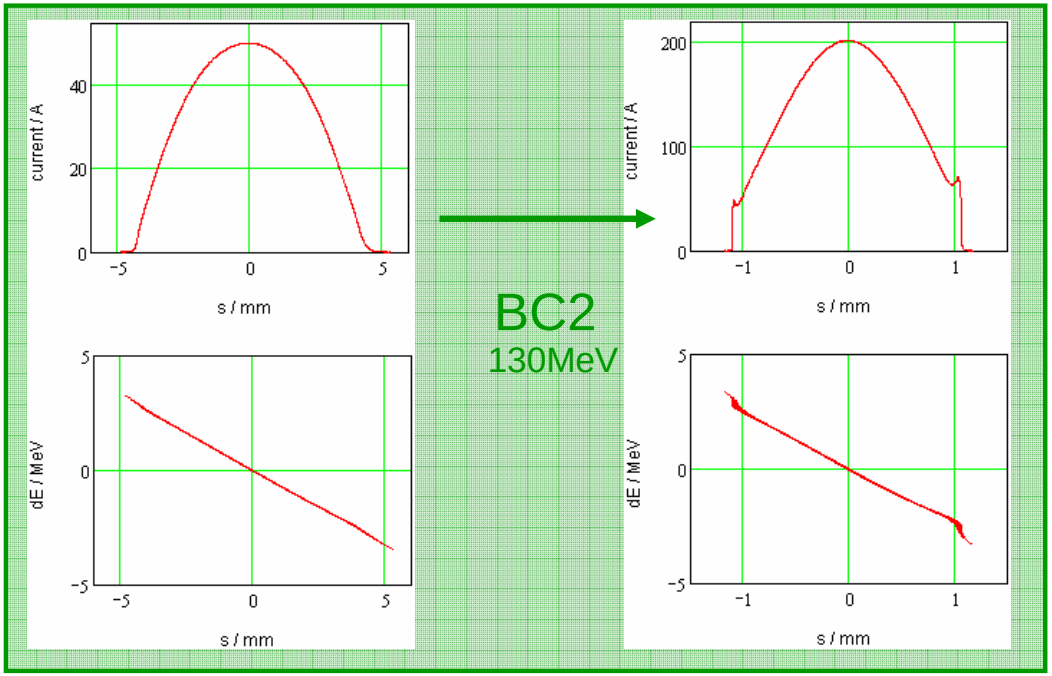
ACC2/3: 390 MV, 30 deg

ACC4/5/6: 530 MV

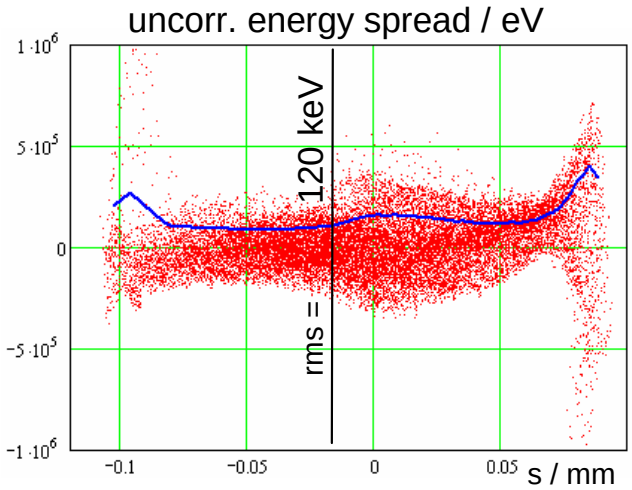
50 A × **4** 200 A × **12.5** 2.5 kA 2.43 kA

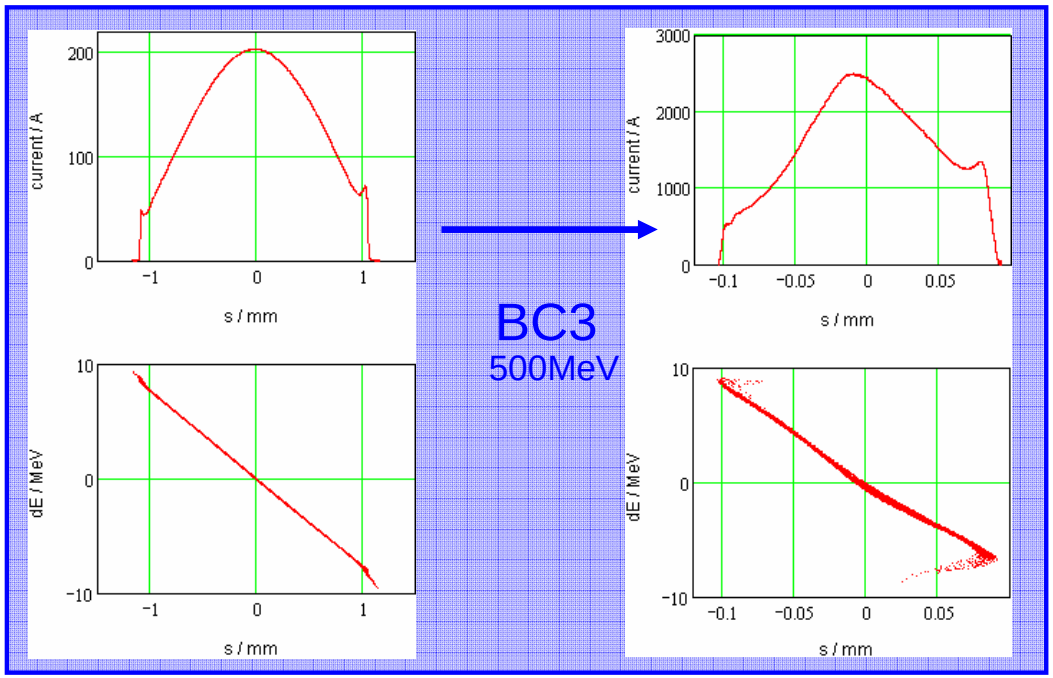


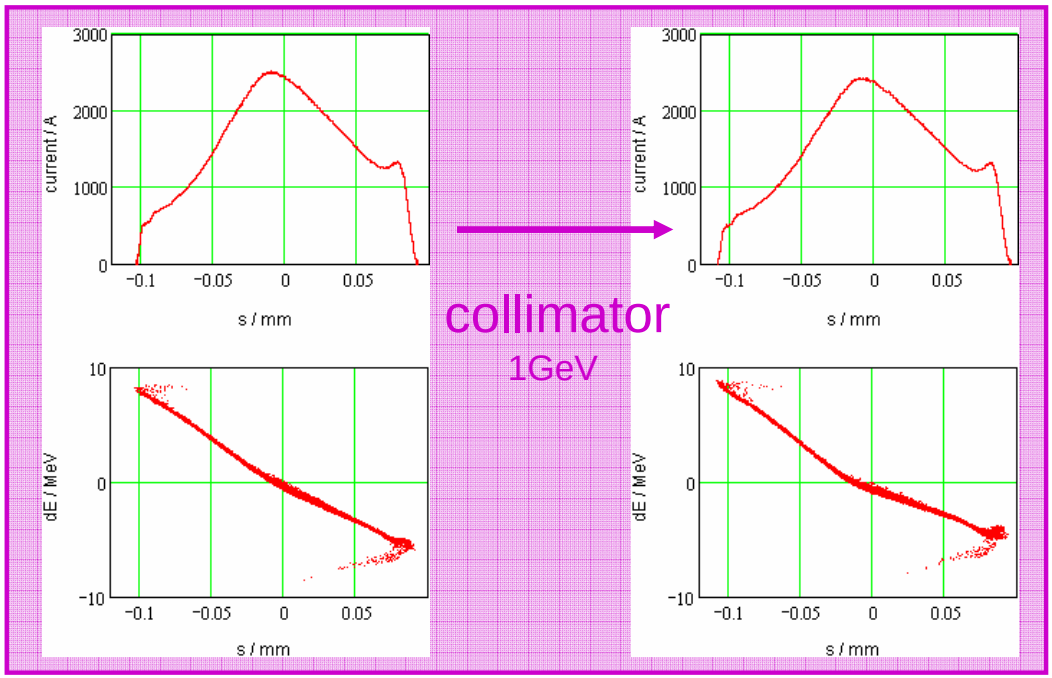
Compression with 3rd harmonic System longitudinal phase space



energy spread = 3.0 MeV







Compression with 3rd harmonic System stability of working point

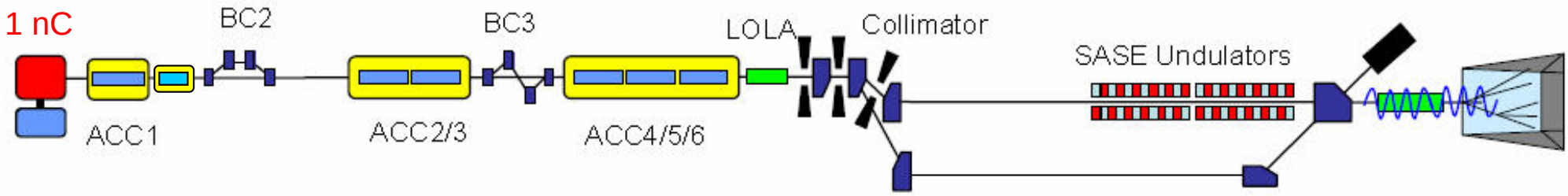
147 MV
-5 deg

21 MV
142 deg

390 MV
30 deg

530 MV

← with self effects (wakes, SC, CSR)



$$\left|\frac{\Delta V}{V}\right| =$$ 0.1 0.04 0.05

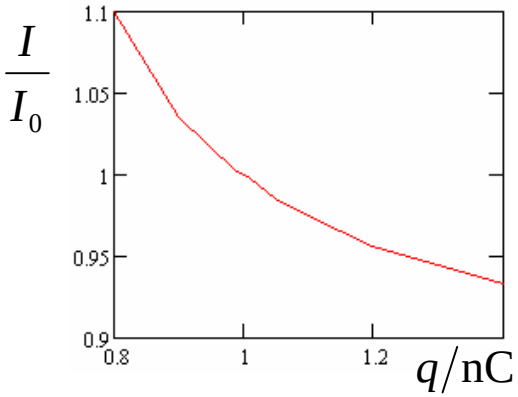
← working point without self effects

0.0015
0.055 deg

0.005
0.14 deg

0.01
0.7 deg

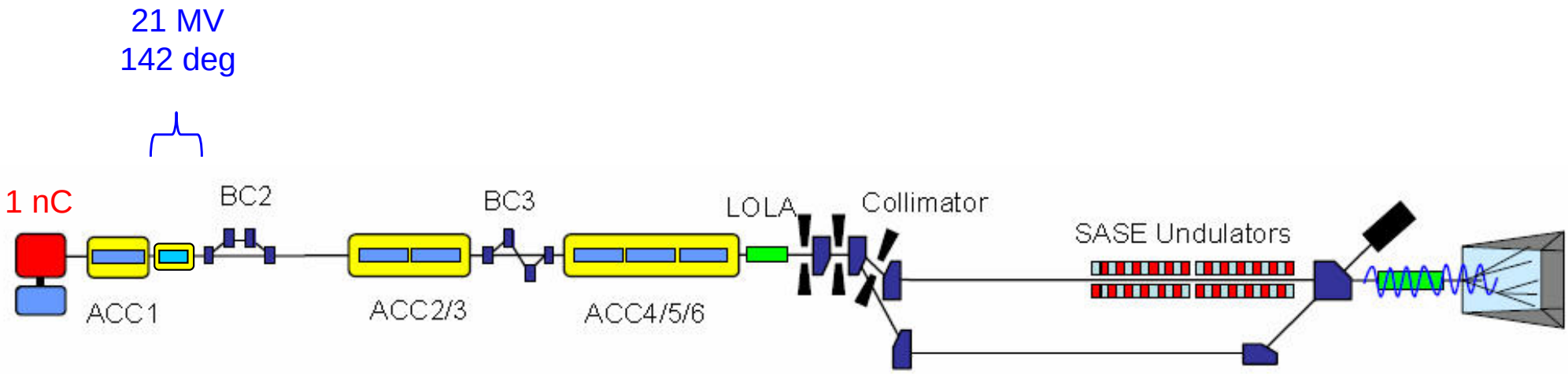
← tolerance (10% change of current)



← bunch charge (gun)

self stabilization
(over compensation!)

Compression with 3rd harmonic System stability of working point

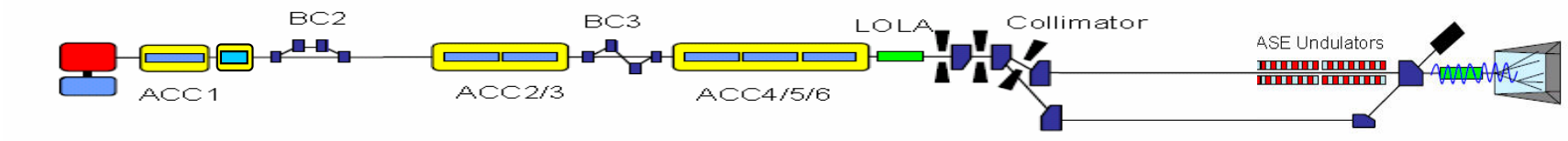


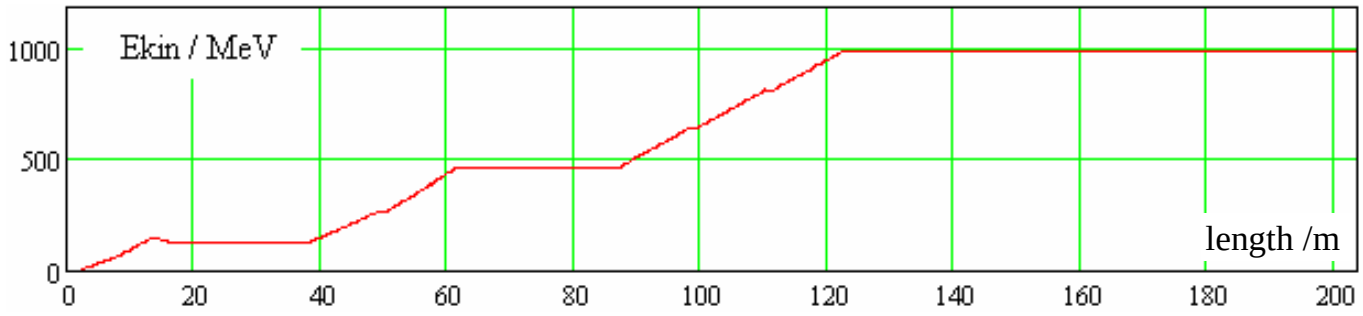
0.05 MV ← tolerance (phase)

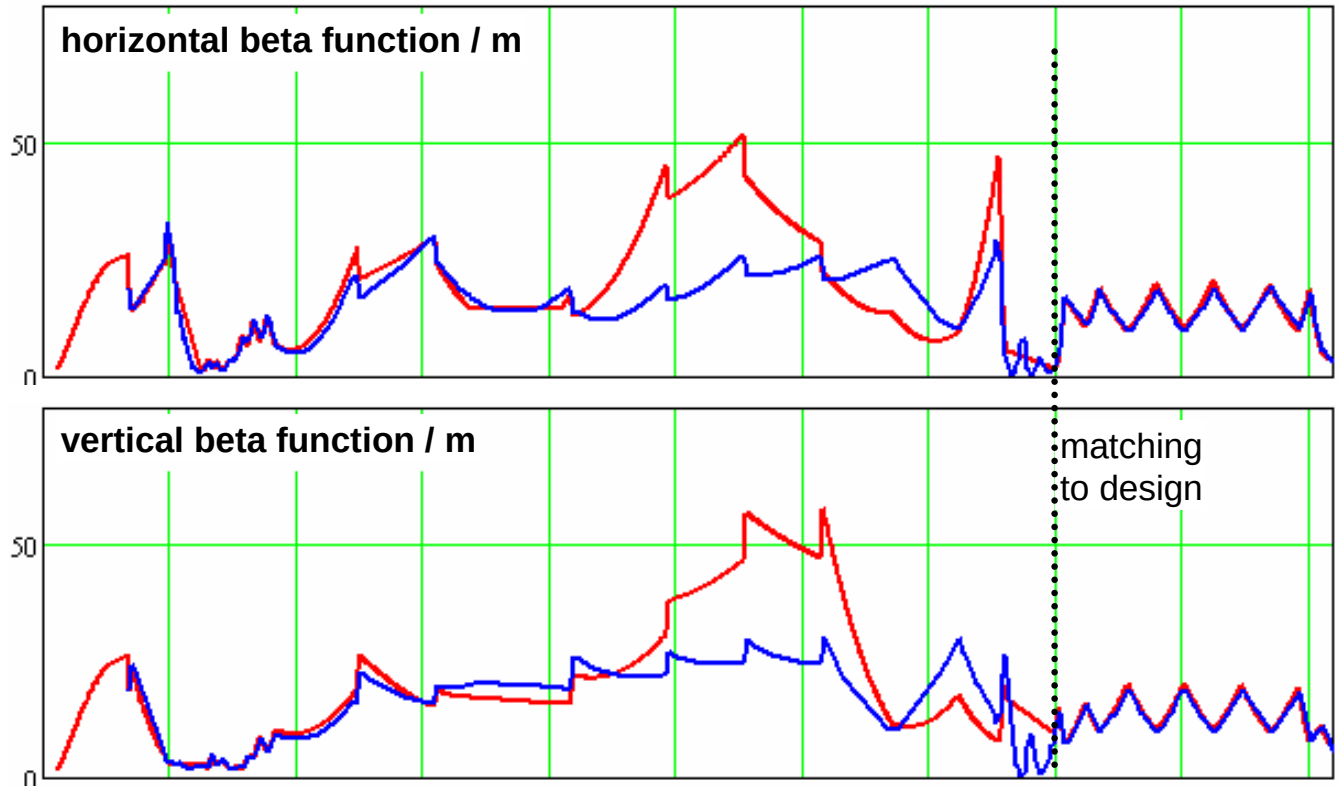
3.1 MV ← beam loading (1 mA = 1 nC & 1 MHz)

$P_f \approx 27$ kW
$P_r \approx 44$ kW
← forward & reflected power at 3rd harmonic cavities with beam

Transverse Dynamics







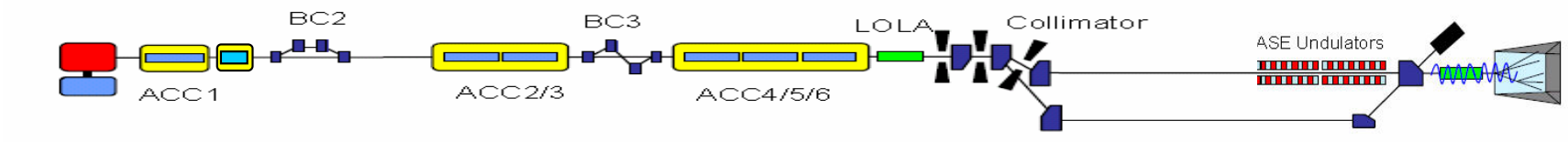
s2e calculation

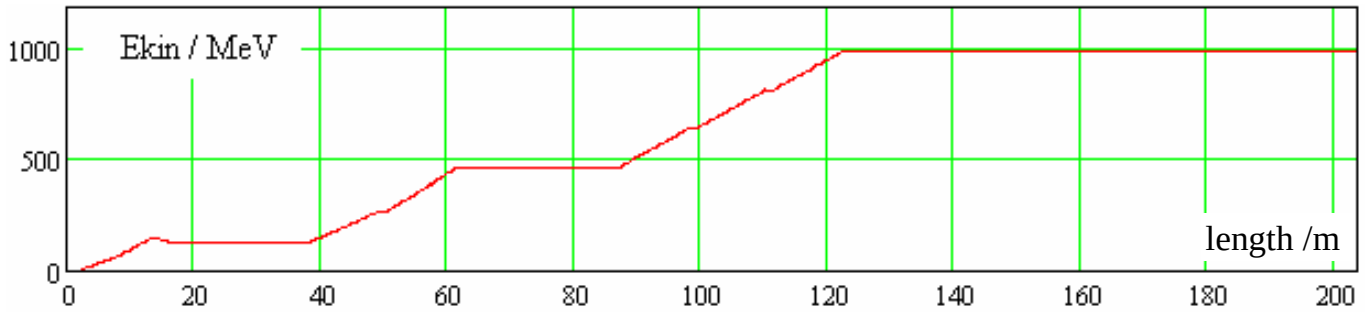
ASTRA

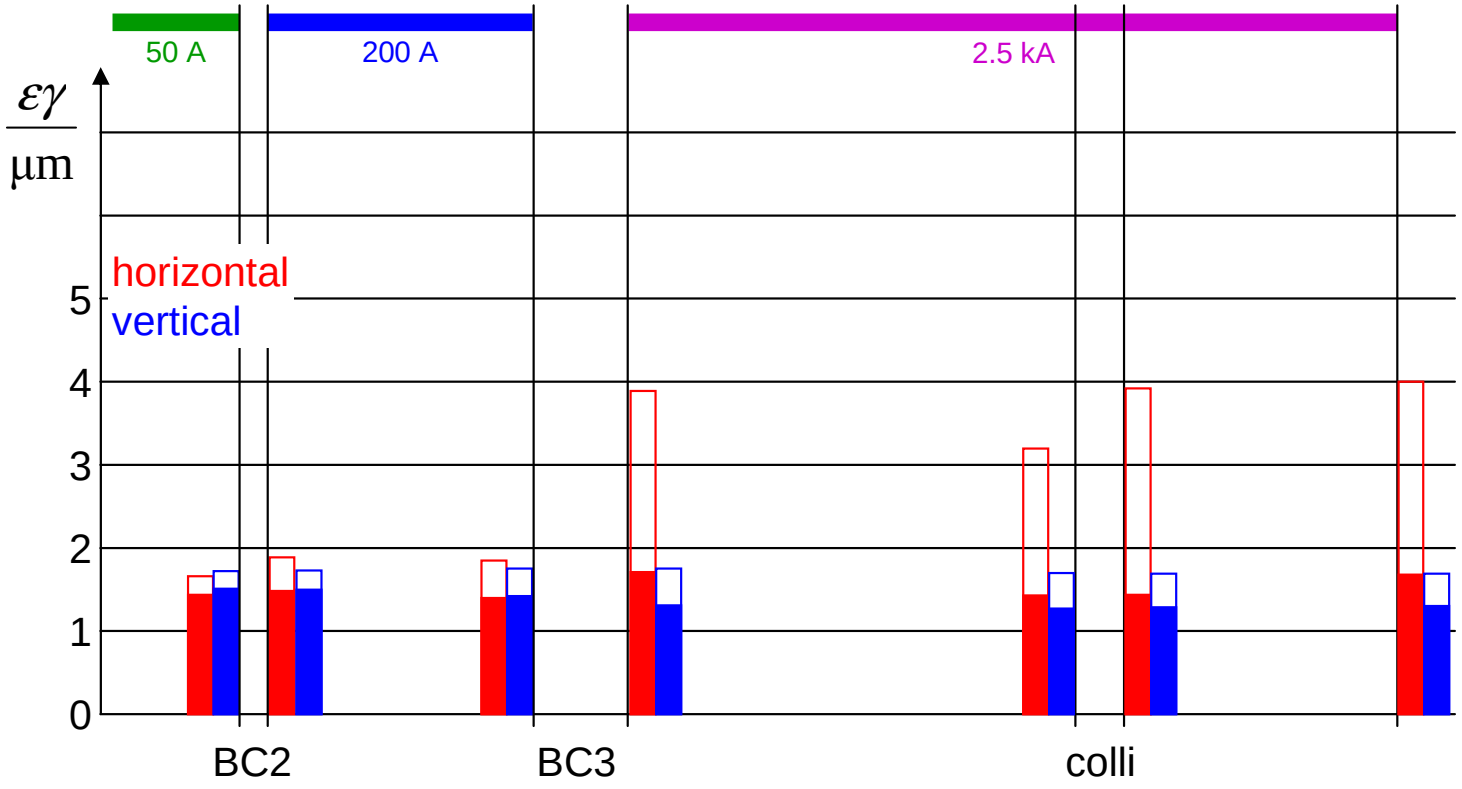
CSRtrack 1d (3d)

design optic (2+)

Transverse Dynamics
projected emittance – no coupler kicks

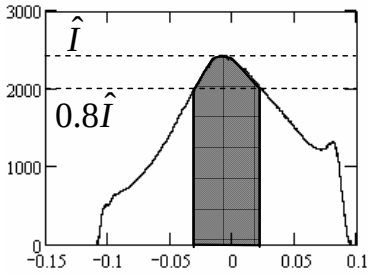


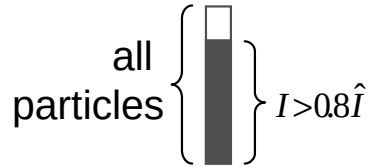




$\gamma\varepsilon_x^{(0.8)} = 1.67\ \mu\text{m}$

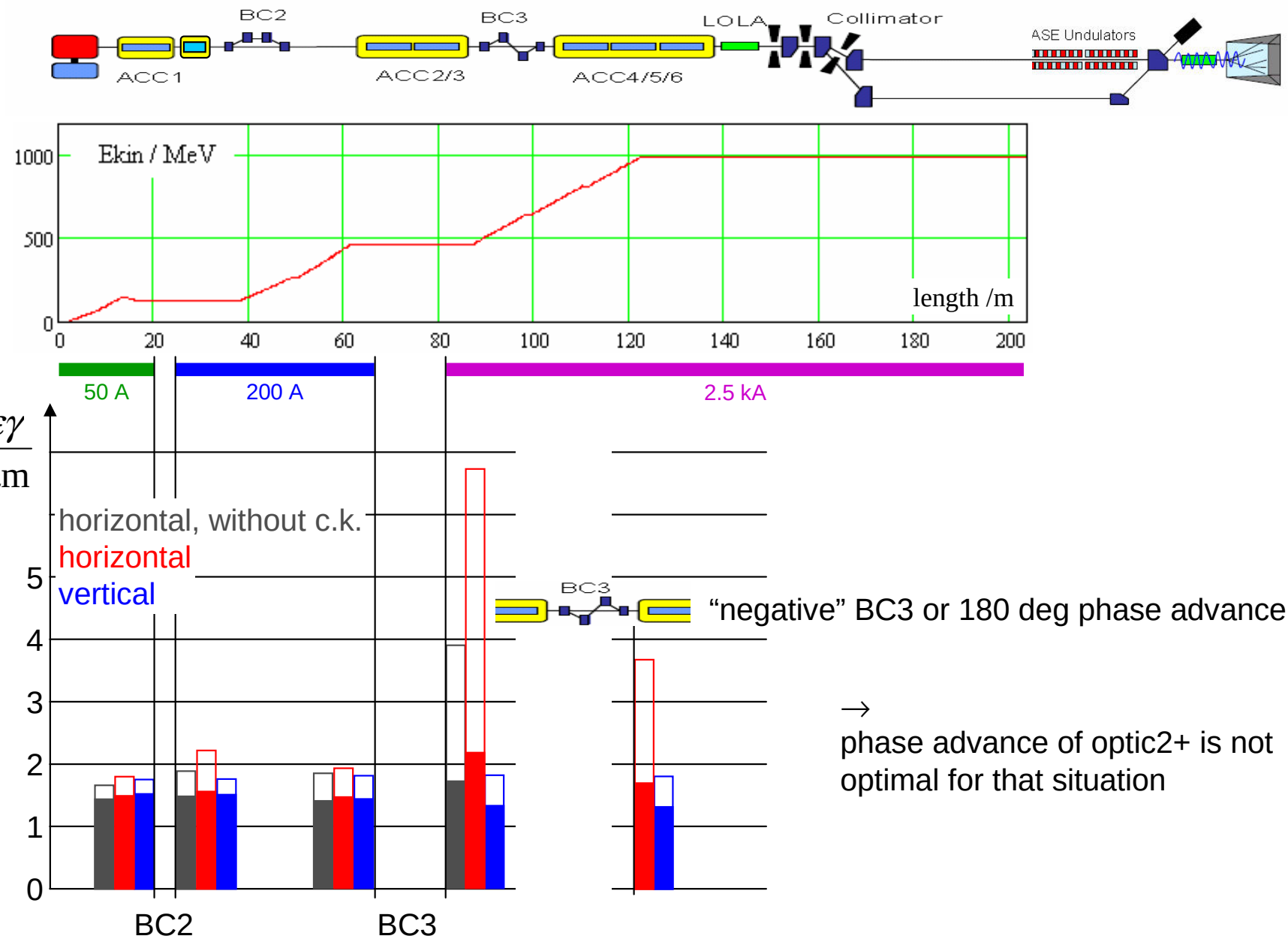
$\gamma\varepsilon_y^{(0.8)} = 1.30\ \mu\text{m}$





design optic (2+)

Transverse Dynamics
projected emittance – **with** coupler kicks

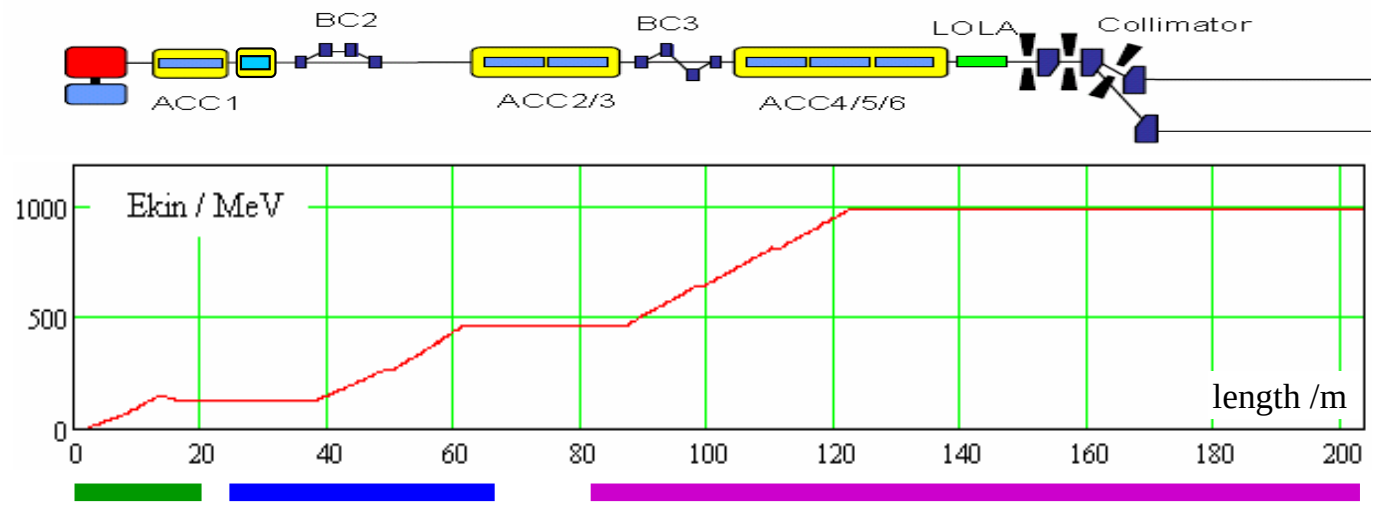


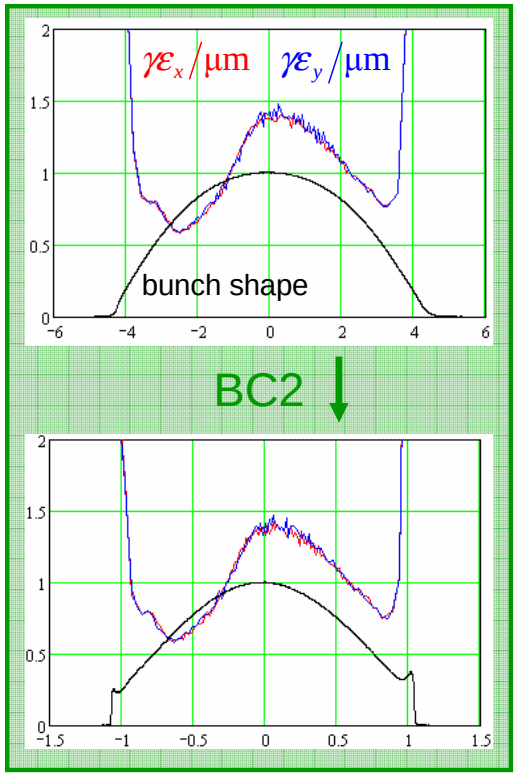
“negative” BC3 or 180 deg phase advance

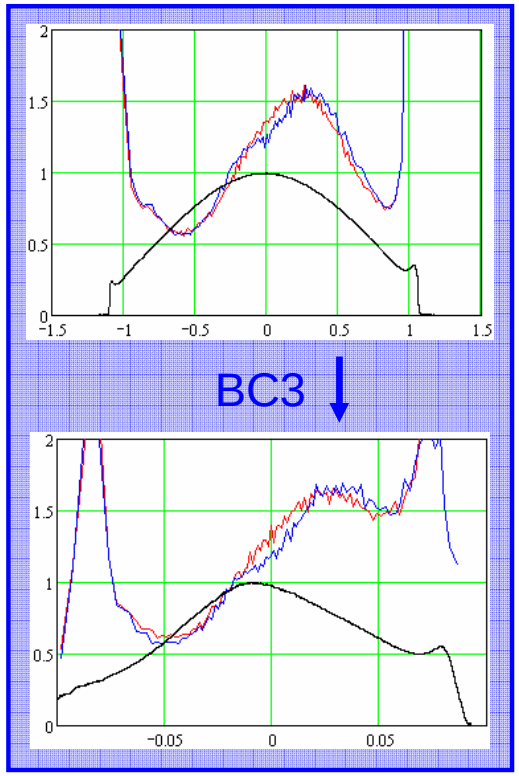
→
phase advance of optic2+ is not optimal for that situation

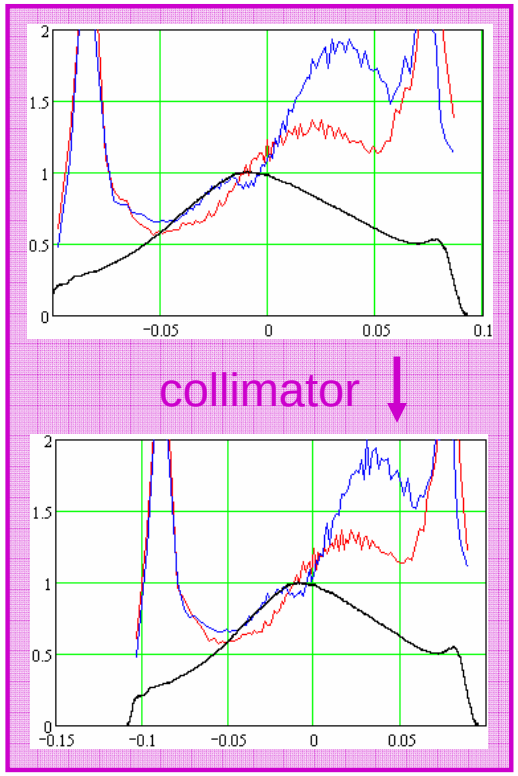
design optic (2+)

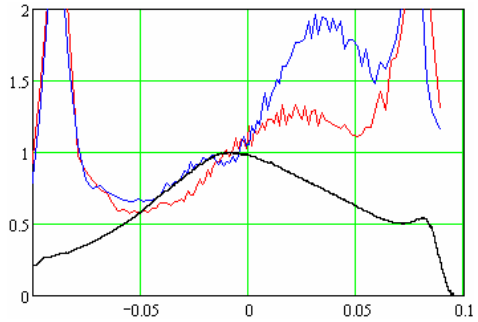
Transverse Dynamics
slice emittance











undulator-start

$$\gamma\varepsilon_{x/y}^{(0.8)} = 0.5\ldots1.5\,\mu\mathrm{m}$$

design optic (2+)

CSR approach: “projected” vs. “sub-bunches”

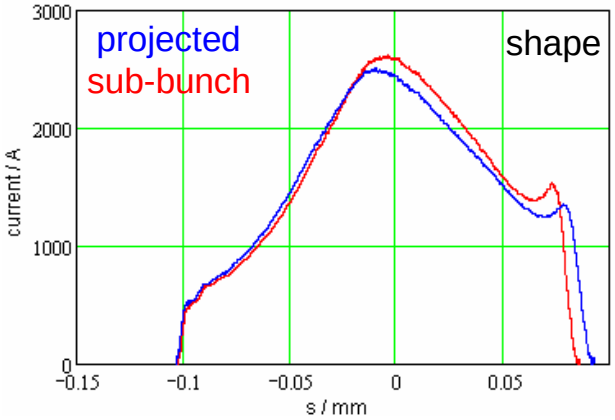
CSR model, type = “projected”

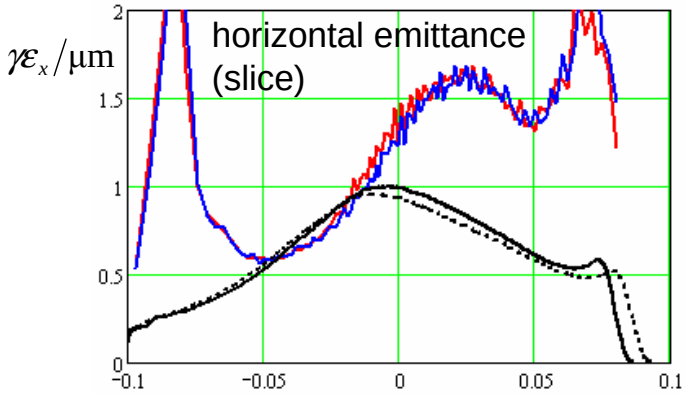
only radiation effects without SC
offset independent (= “projected”)
only longitudinal forces
bunch shape locally frozen

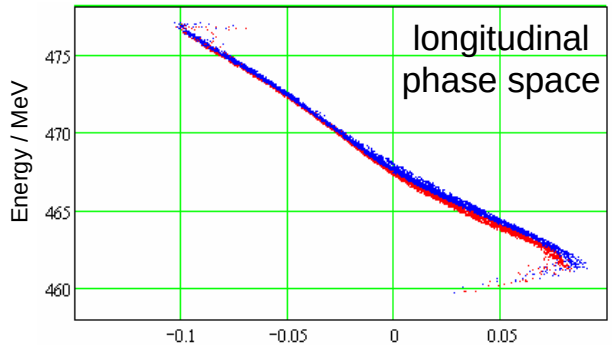
CSR sub-bunch approach

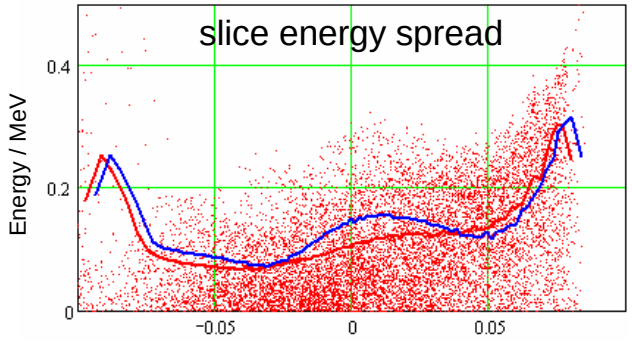
SC + CSR
includes transient shape deformation effects
xy forces

comparison for BC3:





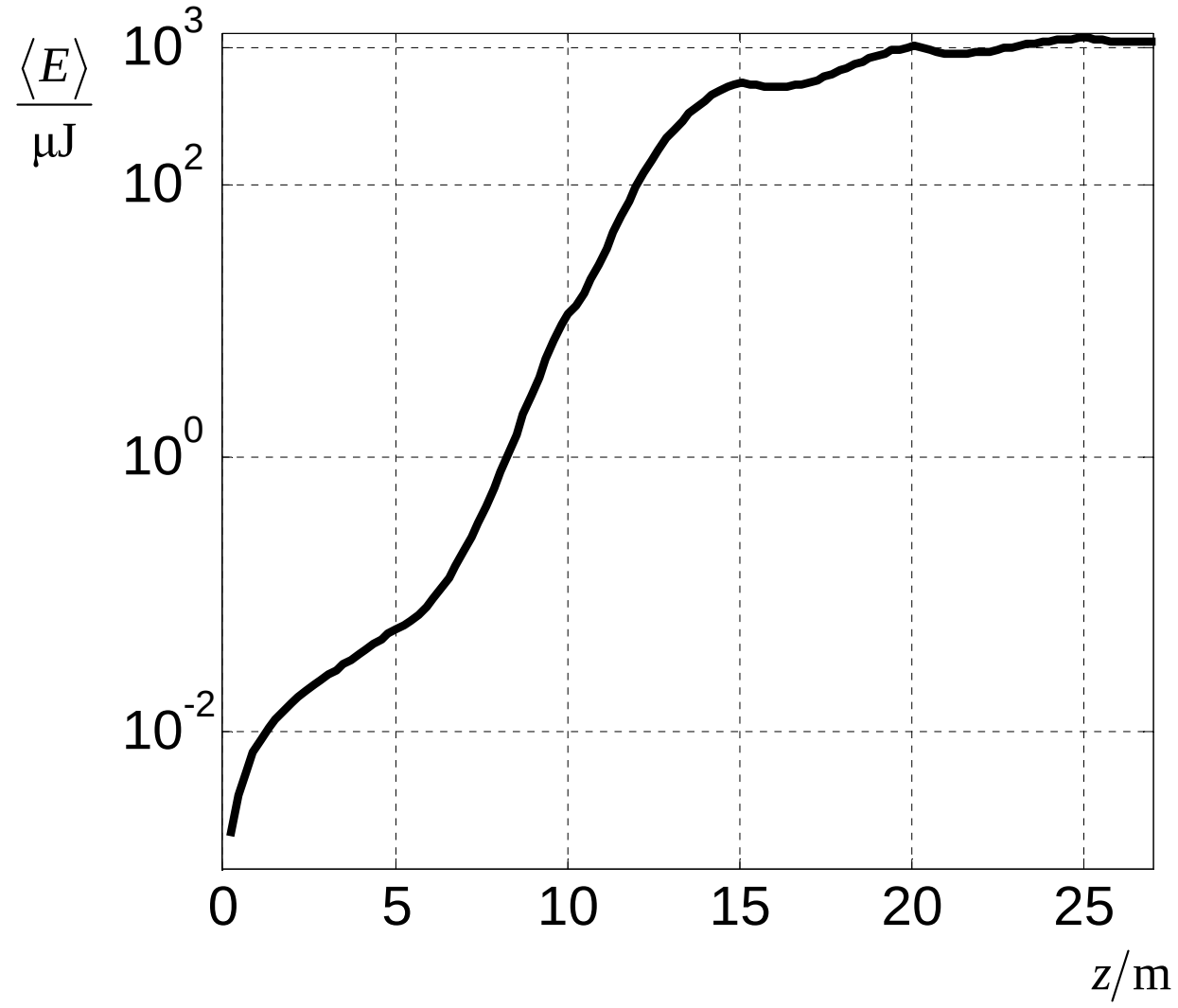




the “projected” model is sufficient for this application

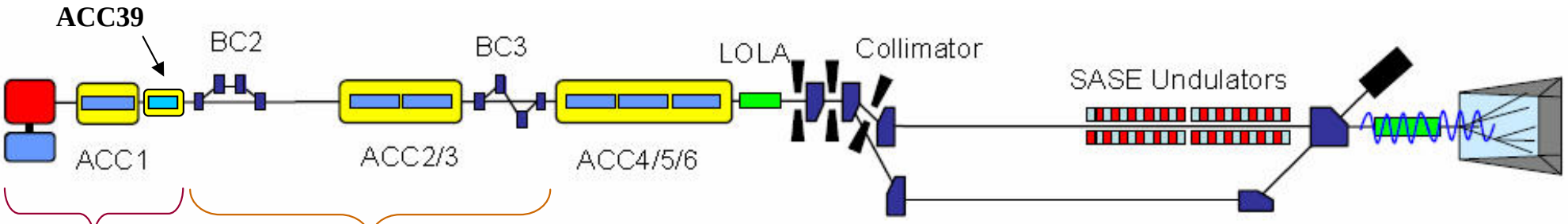
SASE simulation

mean energy



from I. Zagorodnov, see next talk for more

Amplification of Microbunching

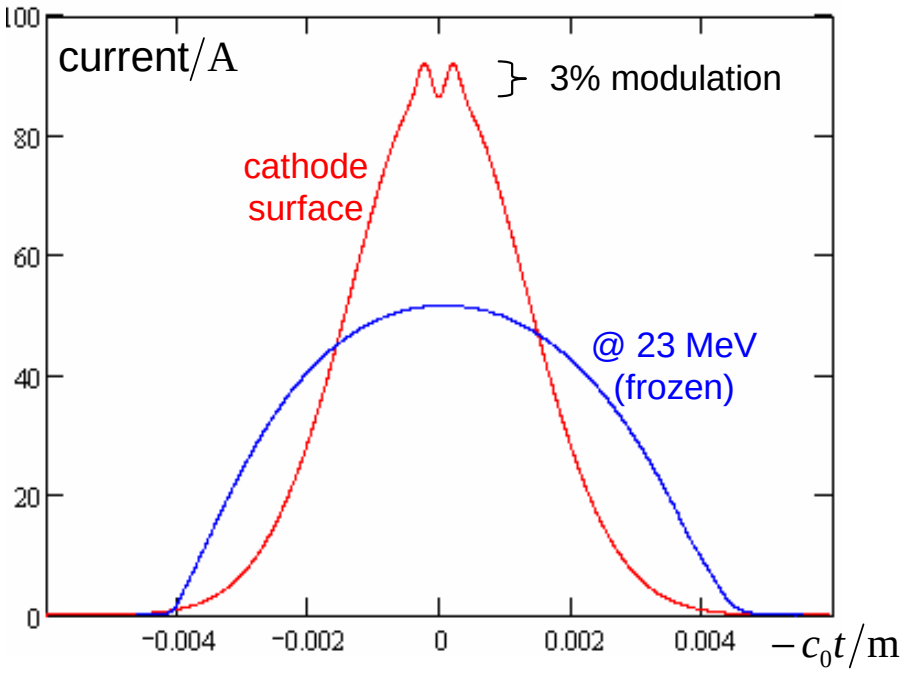


low energy part

high energy part
linear gain model
(integral equation)

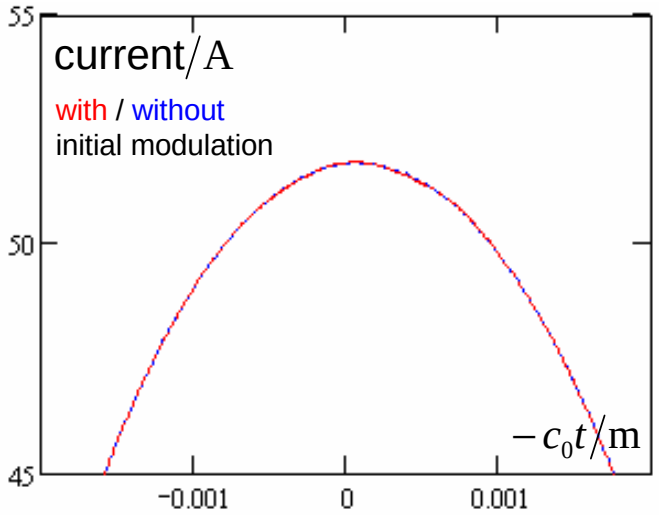
low energy part:

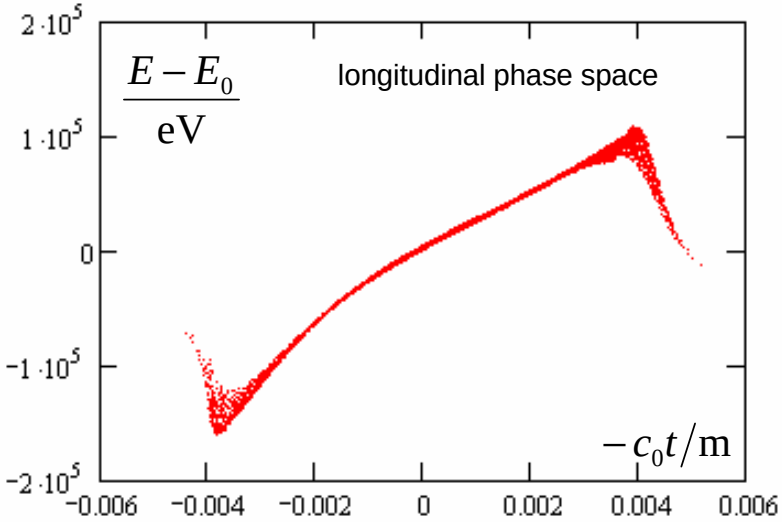
artificial µ-structure at cathode
particle tracking with Astra

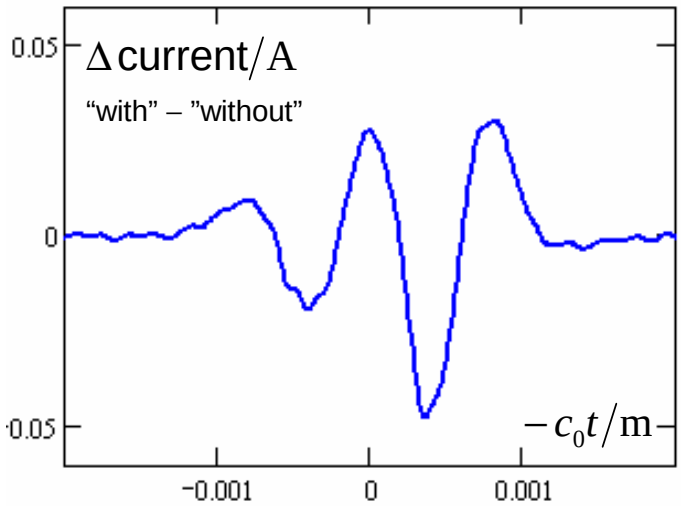


Amplification of Microbunching low energy part

after 1st cavity of ACC1 (@23MeV)



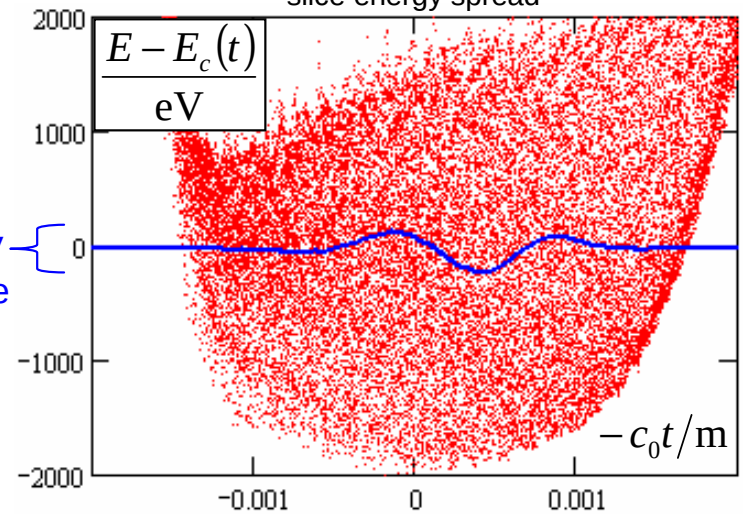




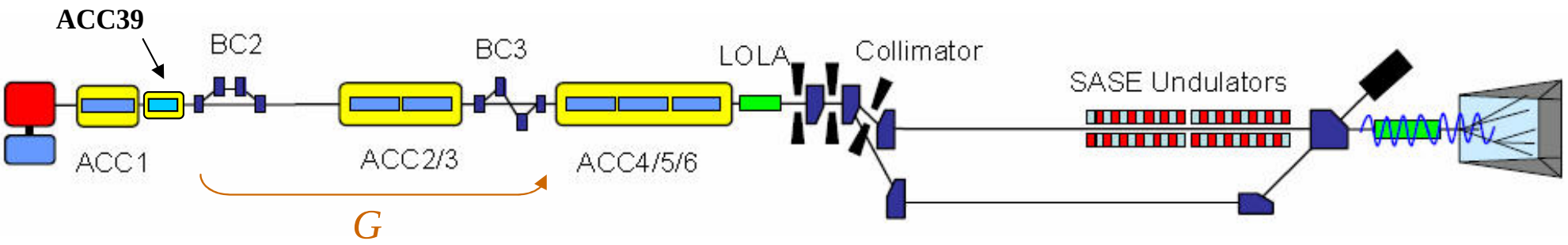
< 0.1% modulation

slice energy spread

≈ 200 eV amplitude

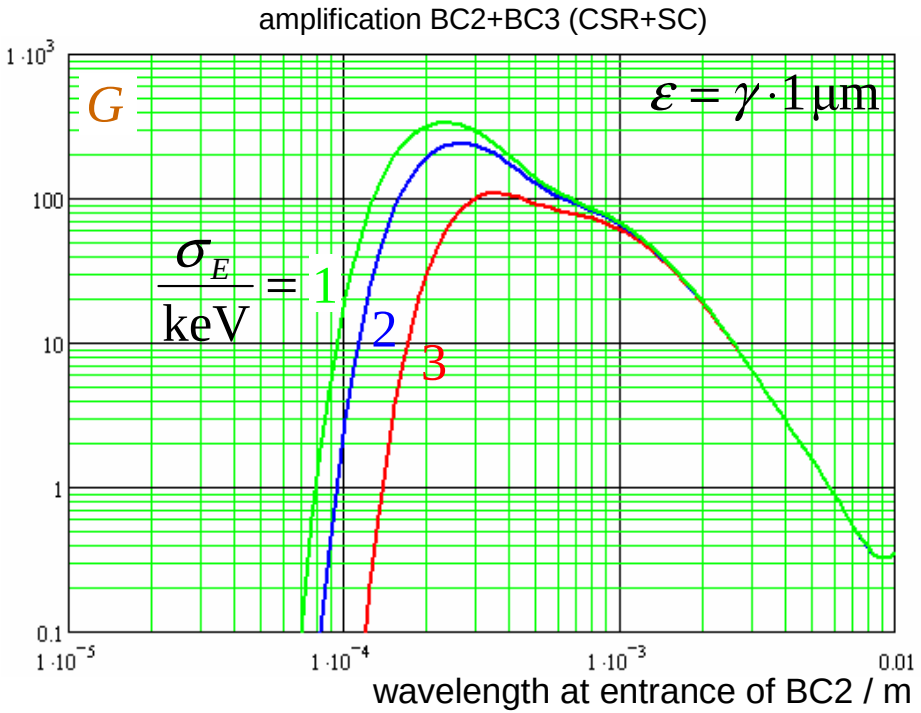


Amplification of Microbunching



high energy part:

linear gain model
(integral equation)

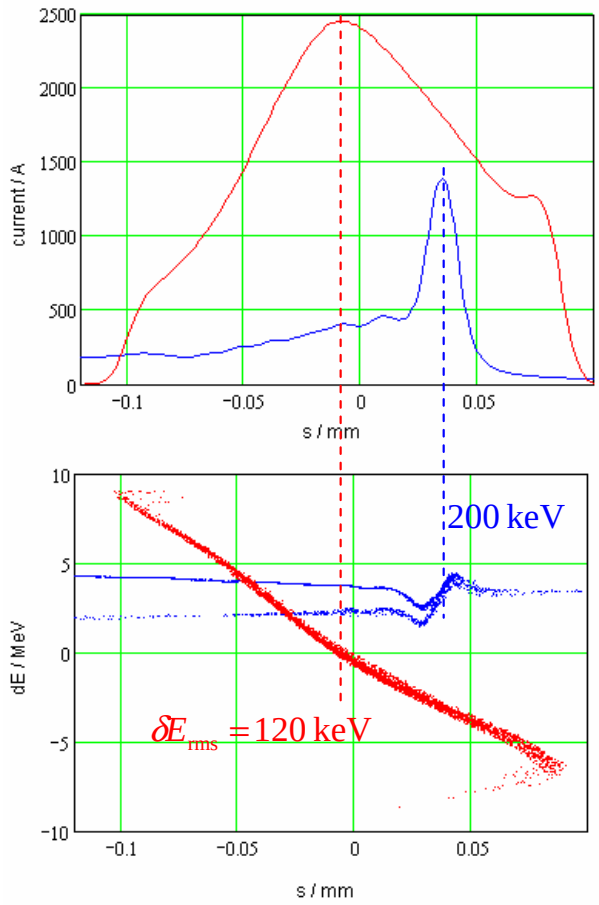


Summary

compression with 3rd harmonic cavity:

working point	1 nC, 2.5 kA
$I > 0.8\, I_{max}$	0.2 psec or 0.44 nC
rf tolerance	0.0015, 0.055 deg
insensitive to charge fluctuations:	self stabilization
total energy spread	3 MeV
projected emittance	increased by CSR and coupler kicks optic has to be improved < 1.7 µm for $I > 0.8\, I_{max}$
amplification of µ bunching	~ 1/30 @ low energy ~ 100 @ high energy

3rd harm. ↔ roll-over



slice emittance

0.5 … 1.5 µm ↔ > 2 µm