XFEL
X-Ray Free-Electron Laser

DESY

XFEL Bunch Compression System Tuning

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Setup Using 'Multiknobs'

- Make knobs to change independently the first, second and third derivative of the combined accelerating voltage of Injector Linac and 3rd harmonic RF, using linac and 3rd harmonic phase and 3rd harmonic amplitude.
  - $V(s) = V_1\cos(k_1 s+\varphi_1) + V_3\cos(k_3 s + \varphi_3)$

    $= \Delta V + g \cdot s + x_1 \cdot 10^{10} \cdot s^2 + x_2 \cdot 10^{12} \cdot s^3 + o(s^4)$

    Use gradient knob for peak current, 2nd derivative to balance beam distribution in the center region and 3rd derivative knob for adjusting the tails.

- Linac Amplitude is still used to keep beam energy constant.

First step XFEL: Adjust gradient knob to get Ip=0.5 kA @BC1 and use 2nd derivative knob to tune symmetry

XFEL X-Ray Free-Electron Laser

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Parabolic bunch
q=1 nC
I=50 A
Initial Energy: 4 MeV
Uncorr. Energy Spread: 5 keV

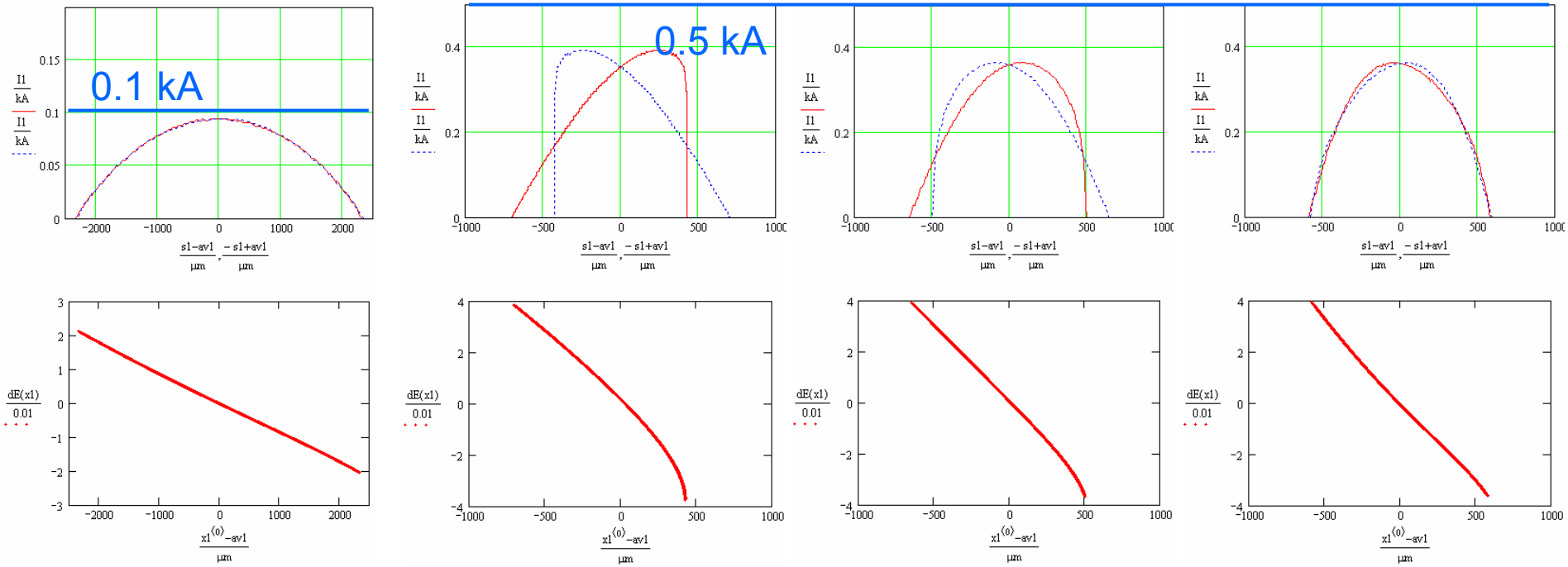
$$\begin{pmatrix} Ene1 \\ R1 \end{pmatrix} := \begin{pmatrix} 500\cdot MV \\ 4.0 \end{pmatrix} \qquad \begin{pmatrix} Ene2 \\ R2 \\ \phi 1b \end{pmatrix} := \begin{pmatrix} 2.4\cdot GV \\ 10.0 \\ 0\cdot deg \end{pmatrix}$$

$$\begin{pmatrix} V1a \\ \phi 1a \\ V3 \\ \phi 3 \end{pmatrix} := F\left(Ene1 - Ei\_av, g, x1\cdot 10^{10}, x2\cdot 10^{12}\right)$$

$$g\_est := \frac{(C-1)}{C\cdot r56\_est}\cdot Ene1$$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est\cdot 0.5 \\ 0 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est\cdot 0.9 \\ 0 \\ 0 \end{pmatrix}$$

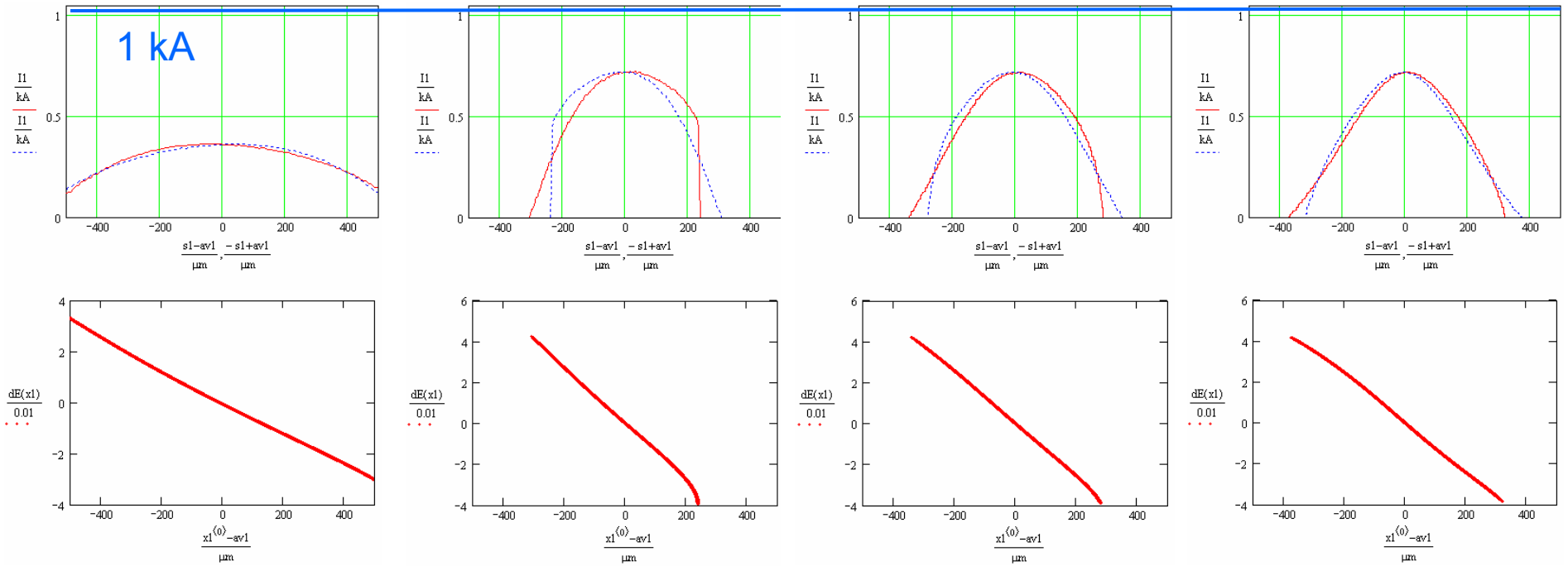
$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est\cdot 0.9 \\ 2 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est\cdot 0.9 \\ 4 \\ 0 \end{pmatrix}$$



Next: iterate, use 3rd derivative knob for precision adjustment

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.9 \\ 4 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.97 \\ 4 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.97 \\ 4 \\ 2 \end{pmatrix} \qquad \begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.97 \\ 4 \\ 4 \end{pmatrix}$$



2nd Iteration

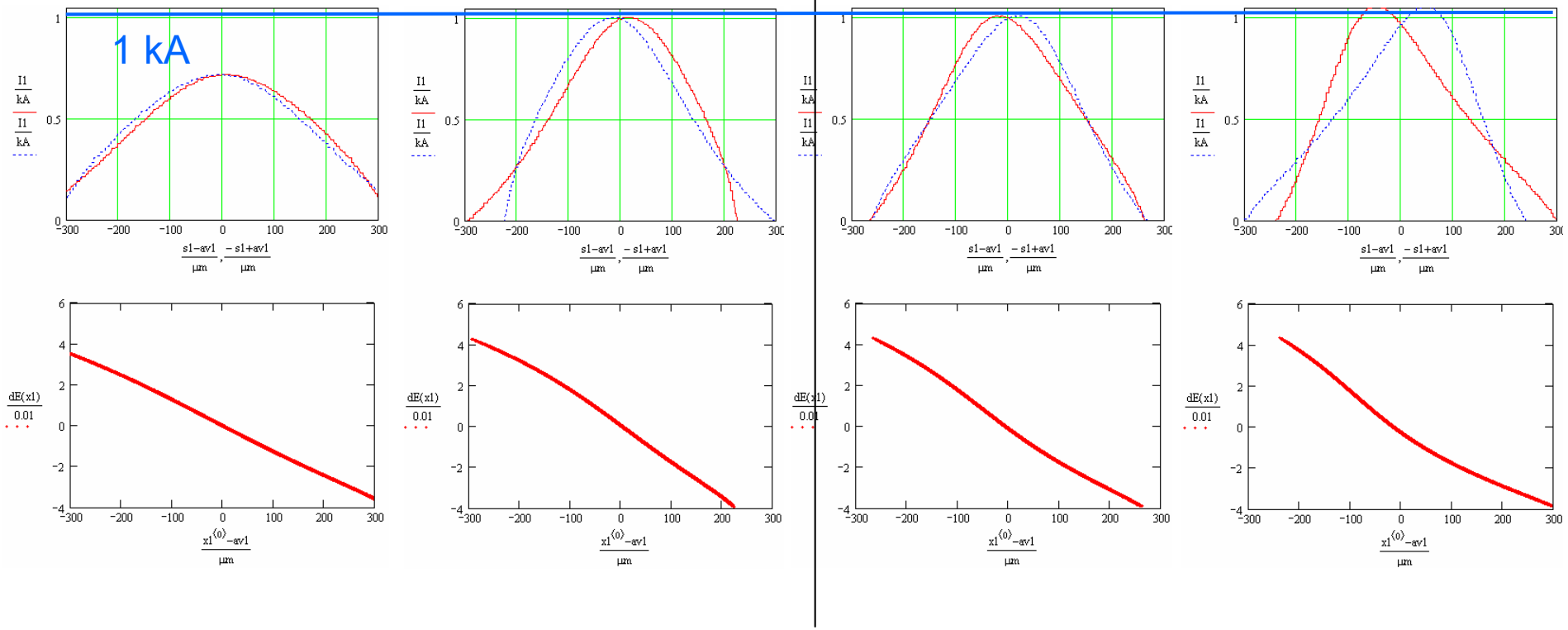
$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 4.5 \\ 4 \end{pmatrix}$$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.97 \\ 4 \\ 4 \end{pmatrix}$$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 4 \\ 4 \end{pmatrix}$$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 5 \\ 4 \end{pmatrix}$$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 6 \\ 4 \end{pmatrix}$$

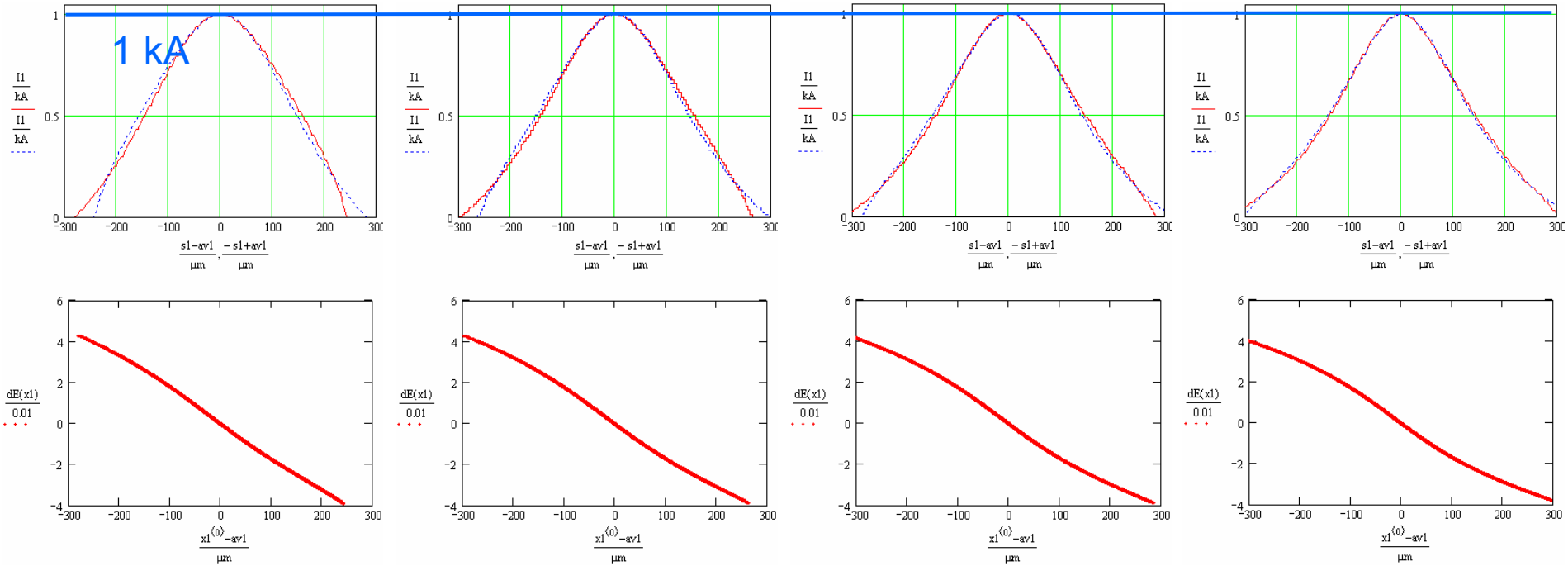


Reaching perfection with 3rd derivative knob…
(not essential for usable beam after 2nd chicane)

$\frac{V1a}{MV} = 573.157$	$\frac{\phi 1a}{deg} = 0.971$	$\frac{V1a}{MV} = 573.714$	$\frac{\phi 1a}{deg} = -2.705$
$\frac{V3}{MV} = 94.19$	$\frac{\phi 3}{deg} = -215.086$	$\frac{V3}{MV} = 101.735$	$\frac{\phi 3}{deg} = -220.746$

$\frac{V1a}{MV} = 576.622$	$\frac{\phi 1a}{deg} = -6.358$
$\frac{V3}{MV} = 110.131$	$\frac{\phi 3}{deg} = -225.585$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 4.5 \\ 4 \end{pmatrix} \qquad \begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 4.5 \\ 5 \end{pmatrix} \qquad \begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 4.5 \\ 6 \end{pmatrix} \qquad \begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 4.5 \\ 7 \end{pmatrix}$$



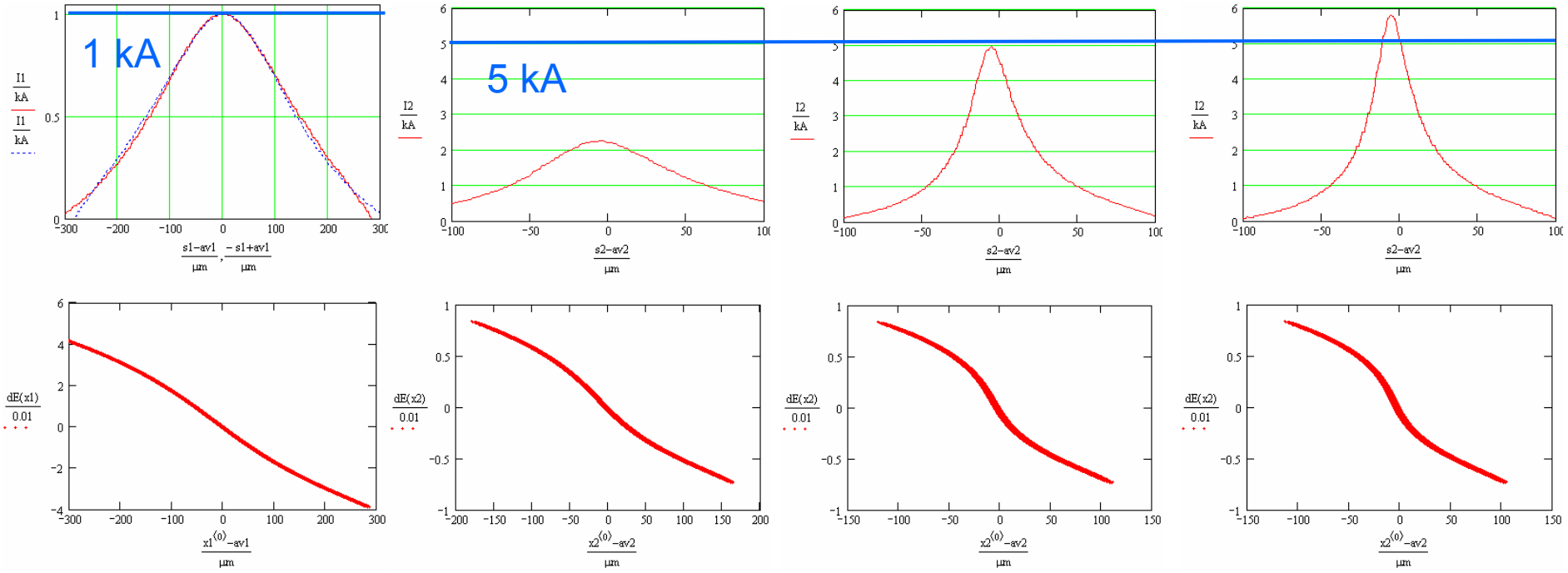
Increase R56 of 2nd Chicane to achieve 5 kA peak current

$$\frac{V1a}{MV} = 573.714 \qquad \frac{\phi 1a}{deg} = -2.705$$

$$\frac{V3}{MV} = 101.735 \qquad \frac{\phi 3}{deg} = -220.746$$

$$\begin{pmatrix} g \\ x1 \\ x2 \end{pmatrix} := \begin{pmatrix} g\_est \cdot 0.99 \\ 4.5 \\ 6 \end{pmatrix} \qquad \begin{pmatrix} Ene2 \\ R2 \\ \phi 1b \end{pmatrix} := \begin{pmatrix} 2.4 \cdot GV \\ 10.0 \\ 0 \cdot deg \end{pmatrix}$$

$$\begin{pmatrix} Ene2 \\ \phi 1b \\ R1 \\ R2 \end{pmatrix} := \begin{pmatrix} 2.4 \cdot GV \\ 0 \cdot deg \\ 4.0 \\ 8.35 \end{pmatrix} \qquad \begin{pmatrix} Ene2 \\ \phi 1b \\ R1 \\ R2 \end{pmatrix} := \begin{pmatrix} 2.4 \cdot GV \\ 0 \cdot deg \\ 4.0 \\ 8.2 \end{pmatrix}$$



Things to Do

- Practical design of multi-knobs for FLASH
- Prepare detailed tuning scheme for FLASH
- Test it and learn…