Bunch Compression at the TESLA XFEL

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Integrated Modeling of the TESLA X-ray FEL

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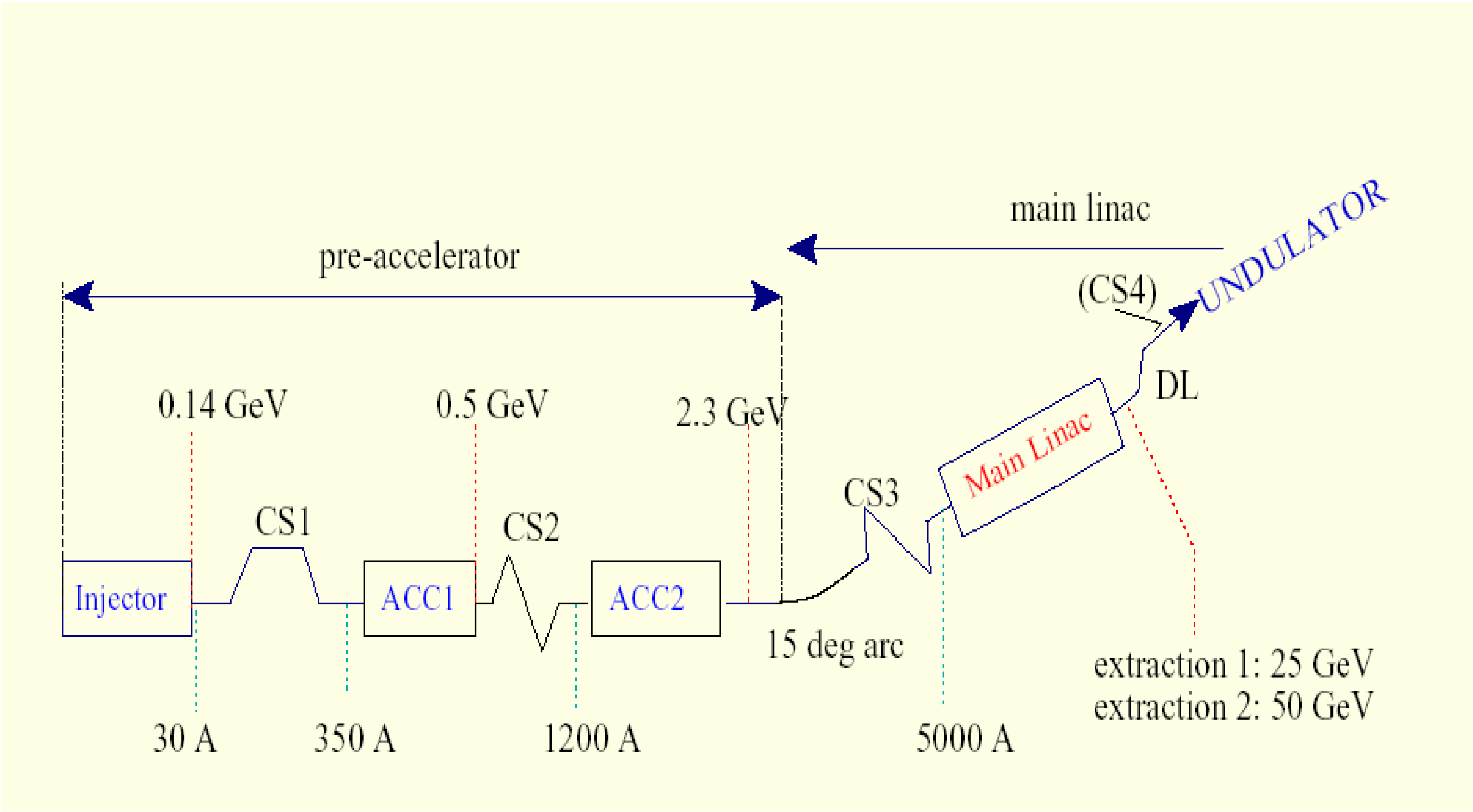
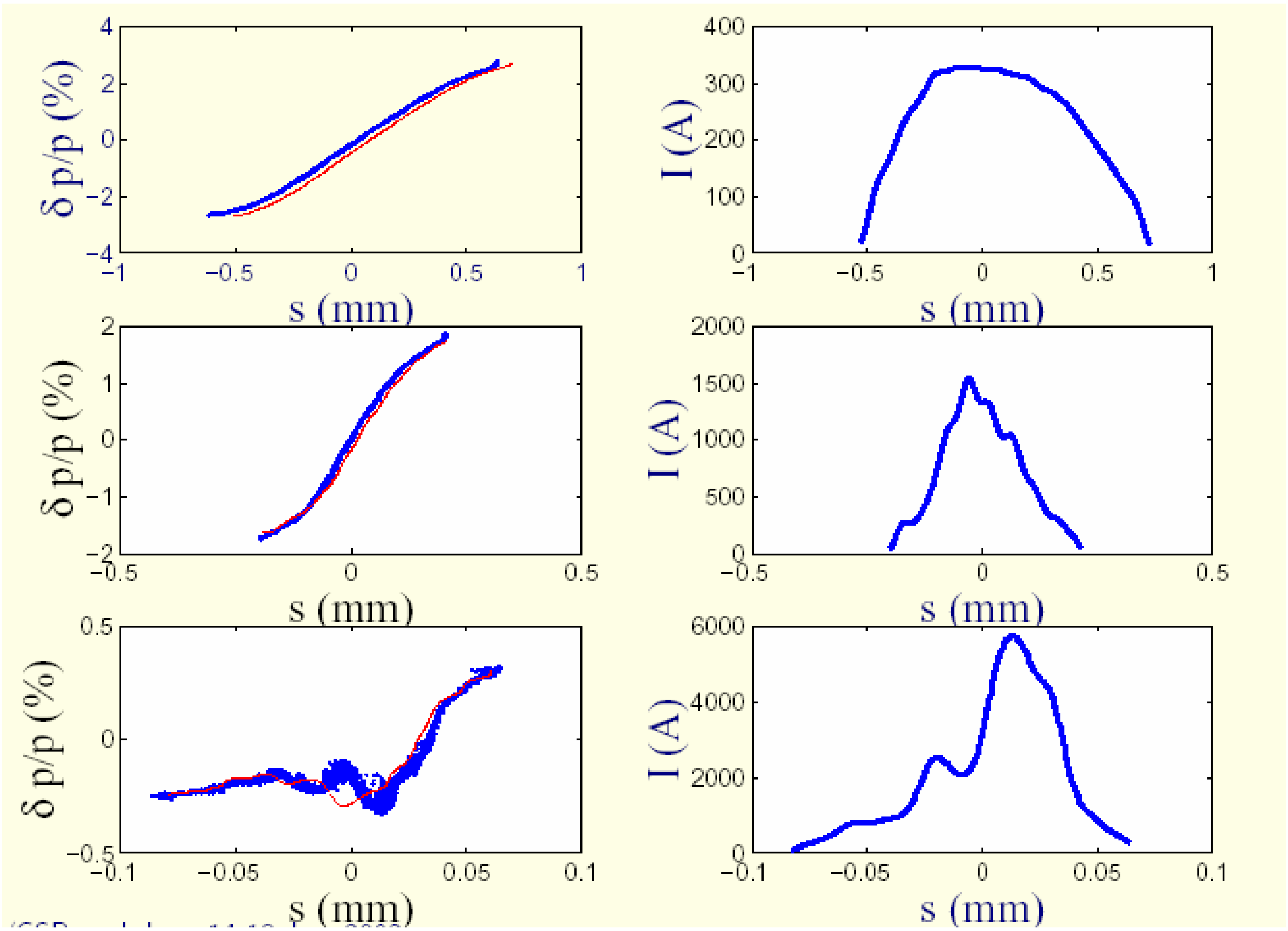
Proceedings of the 2001 Particle Accelerator Conference, Chicago



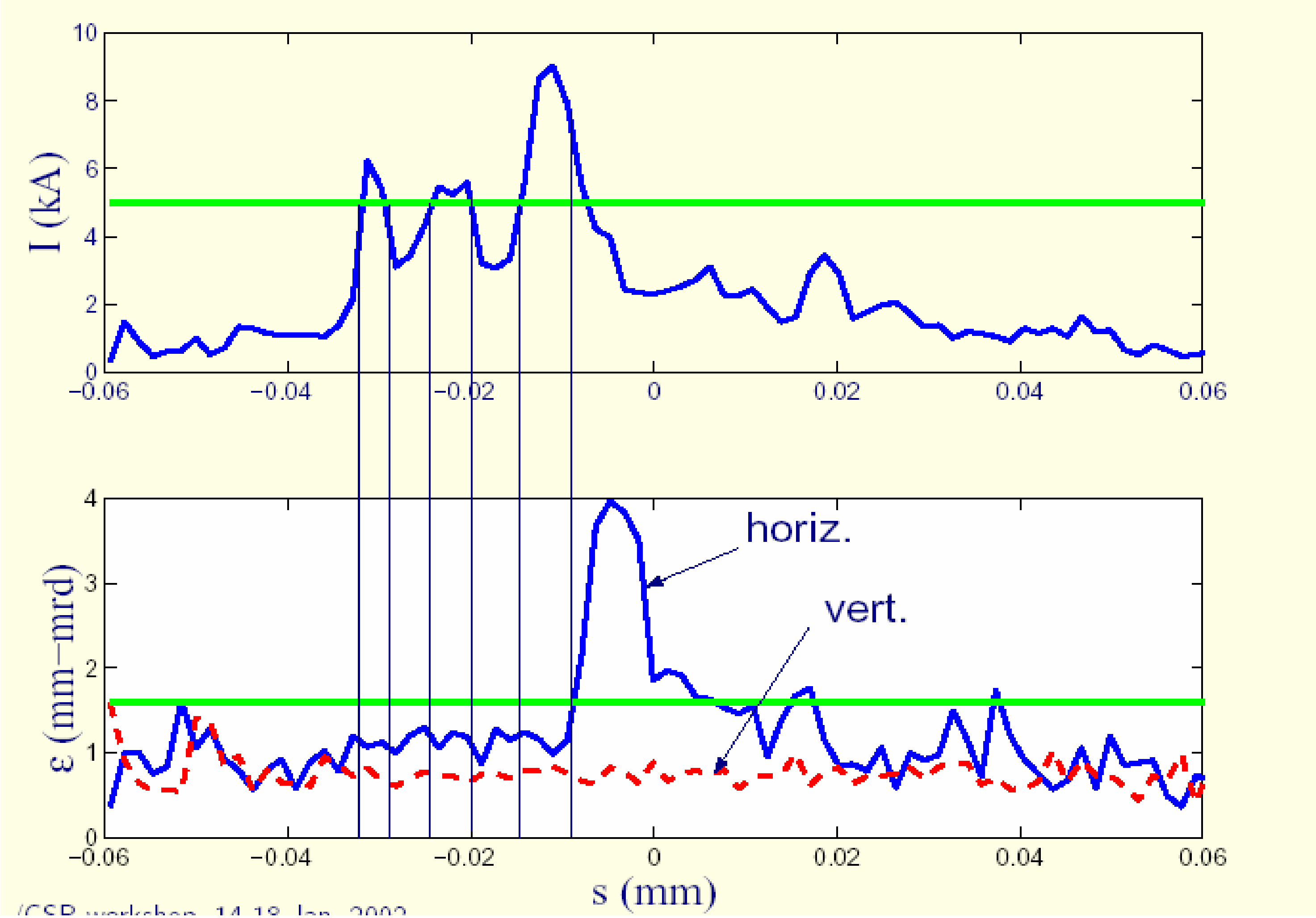
Simulation methodology

- Injector & space charge dominated sections:
  - Astra (cylindrically symmetric bunch; space charge computed using a cylindrical mesh). Point-like particles.
- Bending systems:
  - Gaussian macro-particles/point-like particles. Then TraFiC[4], now new code: CSRtrack (extended to Greens-function method).
- emittance-dominated transport:
  - Elegant (takes into account geometric (TESLA cavities & resistive wakes). Point-like particles.

Longitudinal Phase Space after each compression stage

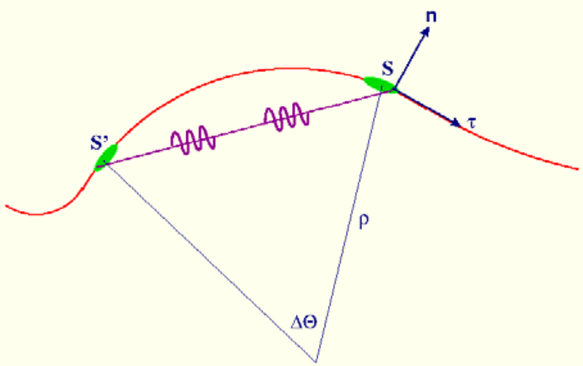


Peak current and emittance along the bunch



`Overtaking Fields´

Background (CNT'D)



- radiation emitted at a retarded time can interact with e- ahead in the bunch.

S e- bunch at present time

S' e- bunch at retarded time

- interaction effective if bunch travel on a curved path for a distance $> L_o \simeq (24\sigma_z\rho)^{1/3}$ self-interaction via field component with $\lambda \sim \sigma_z$.

- NA: TTF1, ρ=1.6 m, $\sigma_z = 250\mu$m, $L_o \sim 0.25\mu$m so $L_o >$ path length in bend.

Calculation of CSR Fields

- First analytically calculated for a line charge on a circular orbit (Shiltsev, Derbenev). Later a textbook example for the longitudinal force dating back to the beginning of the century was rediscovered.
- Gaussian line charge (later 3-D) on arbitrary orbit (transients etc.) numerically solved by M. Dohlus in 3-D space for longitudinal and transverse fields

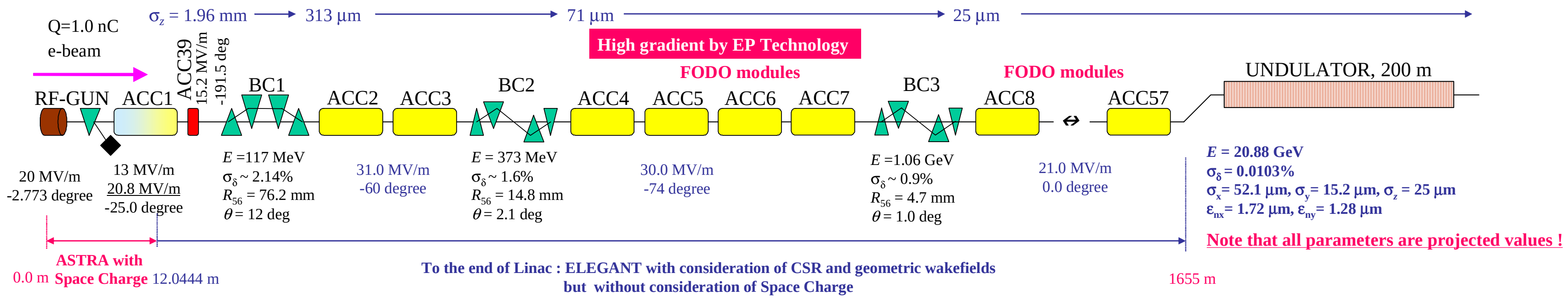
  => TraFiC4 and CSRtrack
- Analytic 1-D solution for drift – bend – drift system by Saldin, Schneidmiller and Yurkov

  => Matlab code (P. Emma and G. Stupakov)

  => elegant (M. Borland)
- Macro-Particle based algorithms: R. Li (2-D)

  Tredi (3-D)

Lattice for Benchmarking of TESLA XFEL



S2E calculation results: www.desy.de/s2e

‘Randbedingungen’ for Bunch Compression Optimization

- Will not get initial bunch length of less than 2 mm
  (for good transverse emittance out of L-band gun)
- Will have a 3rd order harmonic RF system available
- 1‰ projected energy spread @ 20 GeV
- Use simple chicanes (R566 = -3/2*R56); S-chicanes should not be too different
- Projected RMS energy spread should never exceed 2%
- More than 50% of the bunch above 2.5 kA peak current @ 20 GeV

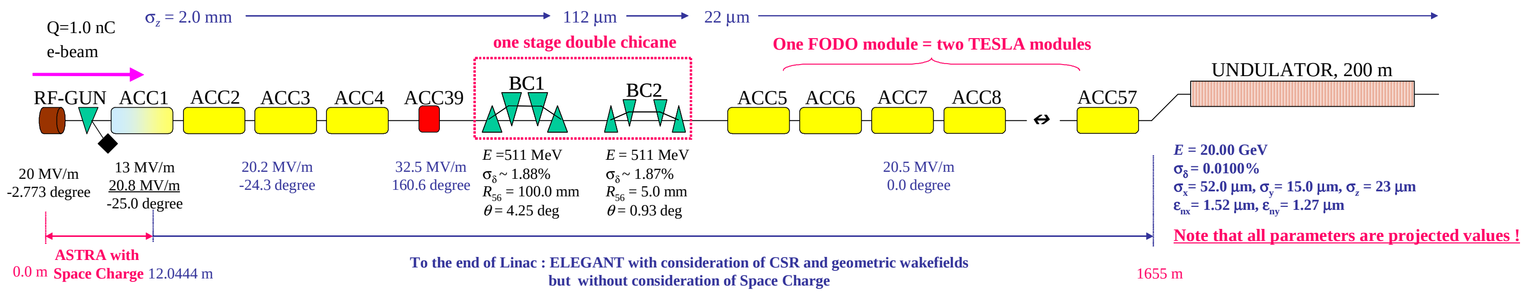
Further Considerations

- Compression less sensitive at higher beam energies if R56 and correlated relative energy spread are kept constant

- Emittance growth depends mainly on dispersion and bunch length in the 3^{rd} bend (4-bend chicane). So use at least two chicanes (weak one for final compression)

- Better linearization of longitudinal phase space if 3^{rd} harmonic cavity can compensate R566 of chicane(s) locally

New Lattice



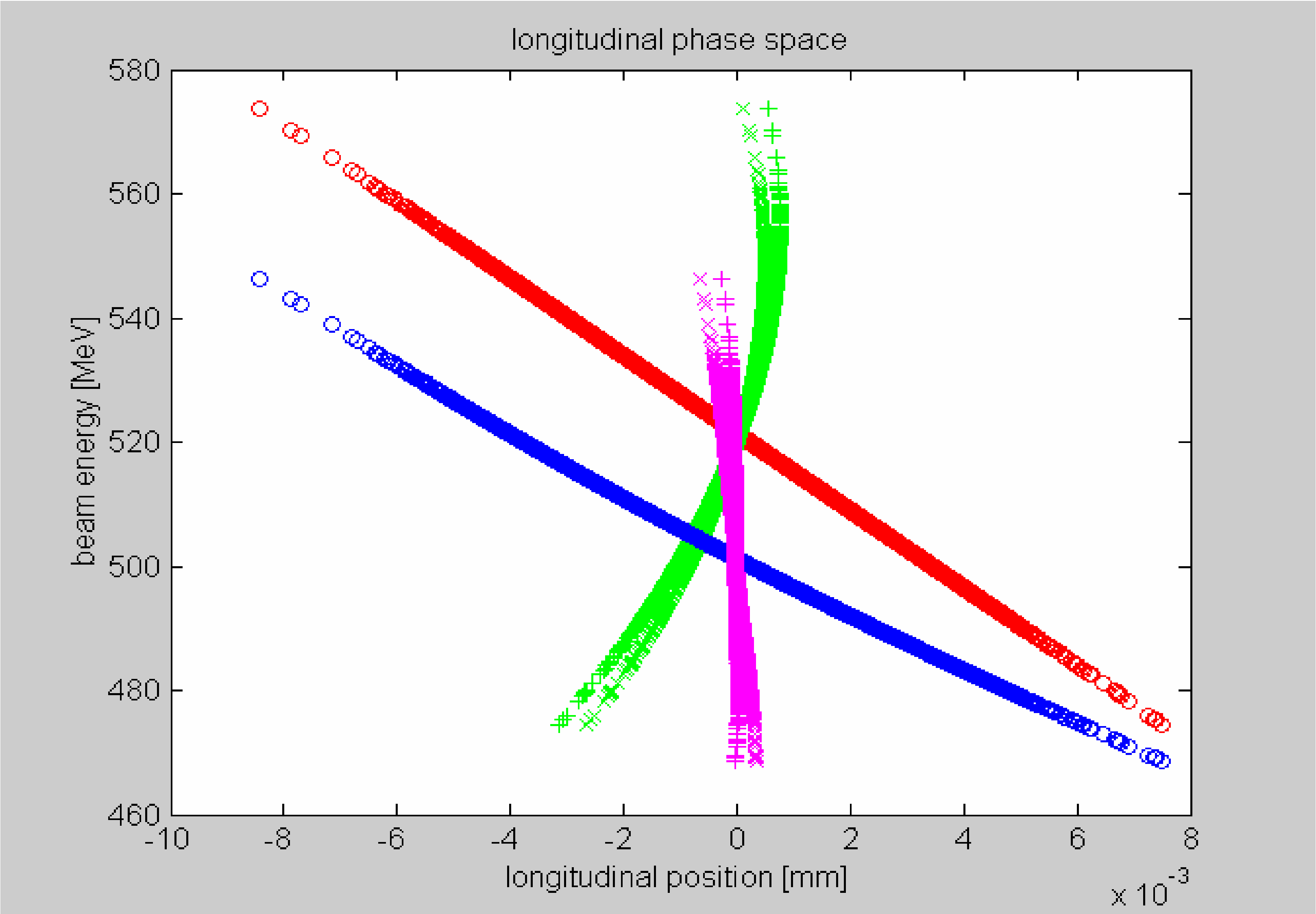
Elegant calculations: Yujong Kim

CSRtrack calculations: Martin Dohlus

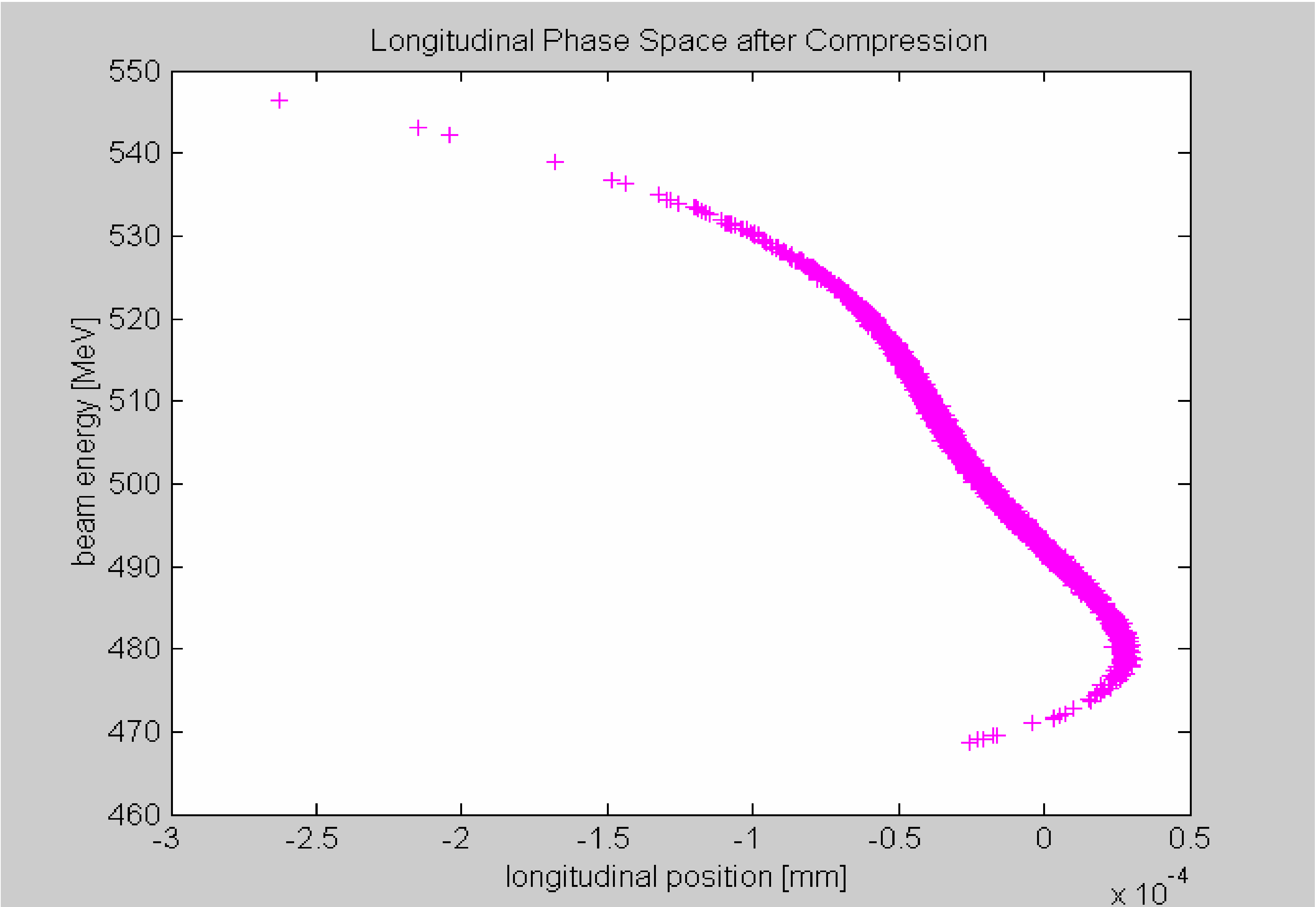
Longitudinal Phase Space

red and green: before and after compression using the 3rd harmonic RF to linearize upstream of the compressor

blue and magenta: using the 3rd harmonic RF to compensate R566 of chicanes

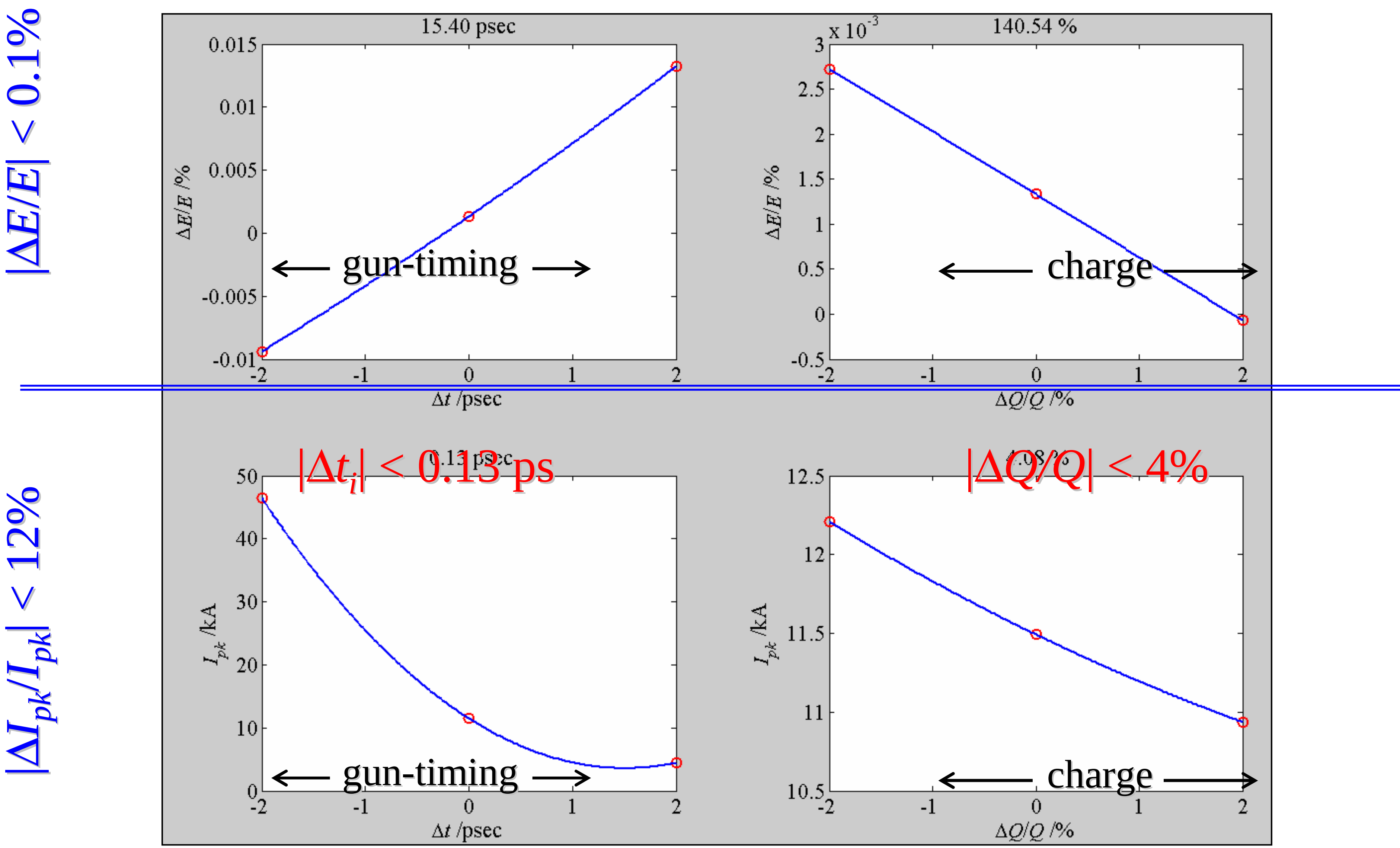


Final Longitudinal Phase Space



P. Emma Jitter Analysis:

Scan gun-laser timing and charge, monitoring energy and peak current, do 2nd order fit



Then form 'jitter budget' based on uncorrelated jitter: $\sqrt{\sum_{i=1}^{n}\left(\frac{p_{\text{tol}}}{p_{\text{sen}}}\right)_i^2} < 1$

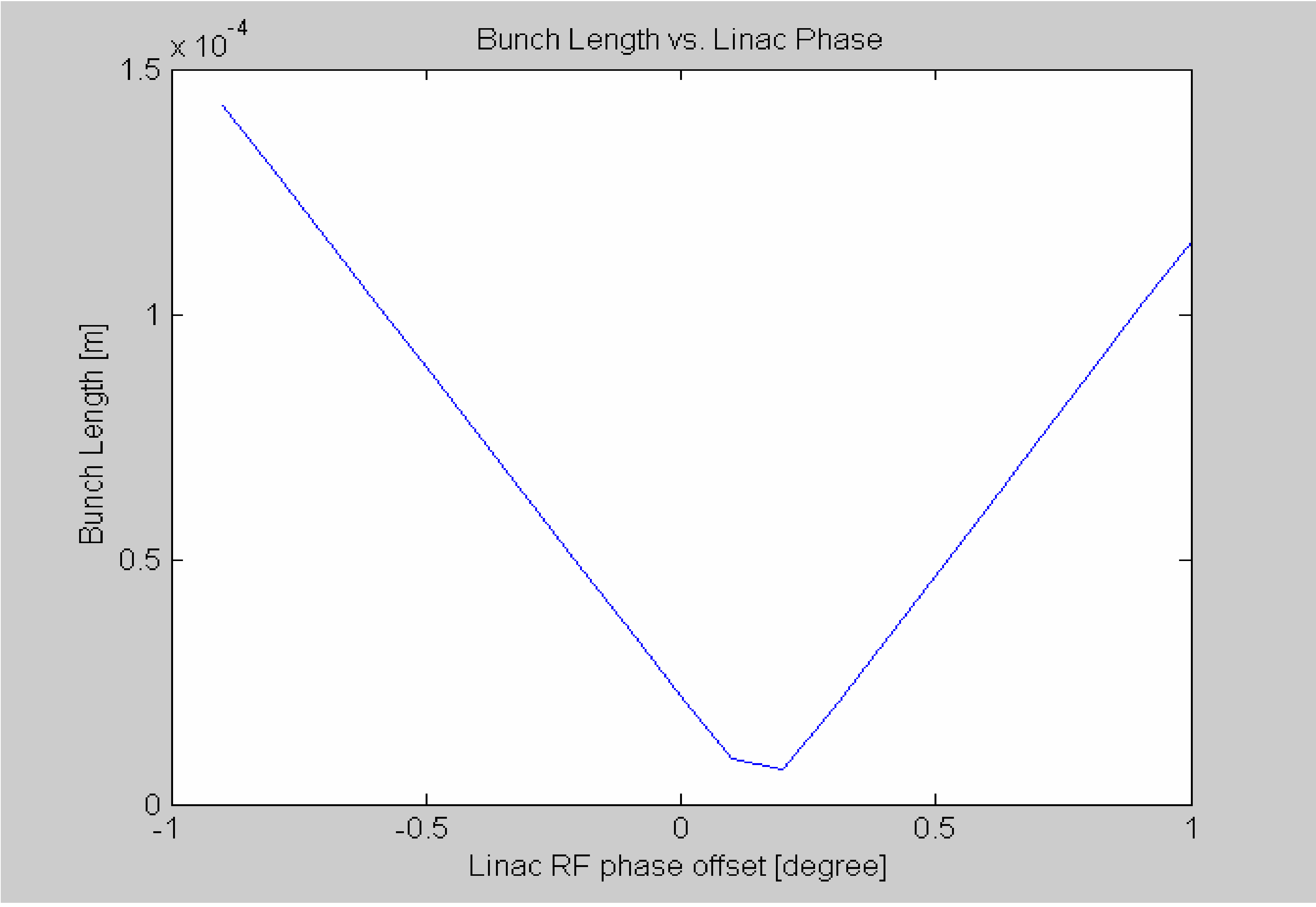
Table 2. A possible longitudinal jitter tolerance budget for LCLS and TESLA-XFEL.

$|\langle\Delta E/E_0\rangle| < 0.1\%$ **and** $|\Delta I/I_0| < 12\%$

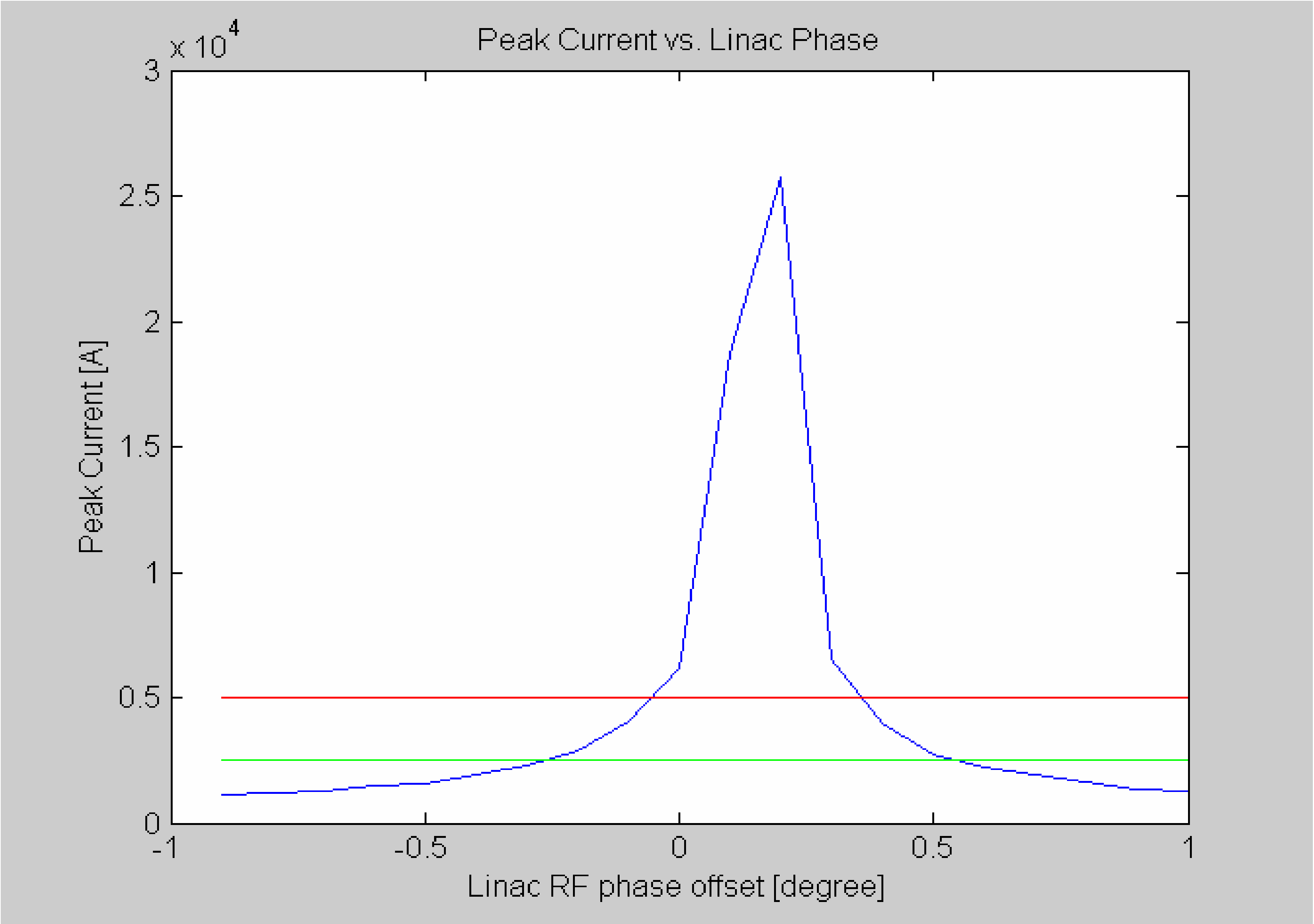
Parameter	Symbol	LCLS	$XFEL_2$	Unit
Gun timing jitter	Δt_0	0.80	1.5	psec
Initial bunch charge	$\Delta Q/Q_0$	2.0	10	%
mean L0 rf phase	φ_0	0.10	0.05	deg
mean L1 rf phase	φ_1	0.10	0.08	deg
mean L*h* rf phase (3.9-GHz & X-band)	φ_h	0.50	0.07	*h*-deg
mean L2 rf phase	φ_2	0.07	0.10	deg
mean L3 rf phase	φ_3	0.15	1.0	deg
mean L0 rf voltage	$\Delta V_0/V_0$	0.10	0.08	%
mean L1 rf voltage	$\Delta V_1/V_1$	0.10	0.20	%
mean L*h* rf voltage	$\Delta V_h/V_h$	0.25	0.30	%
mean L2 rf voltage	$\Delta V_2/V_2$	0.10	0.20	%
mean L3 rf voltage	$\Delta V_3/V_3$	0.08	0.09	%

degrees of X-band or 3.9-GHz

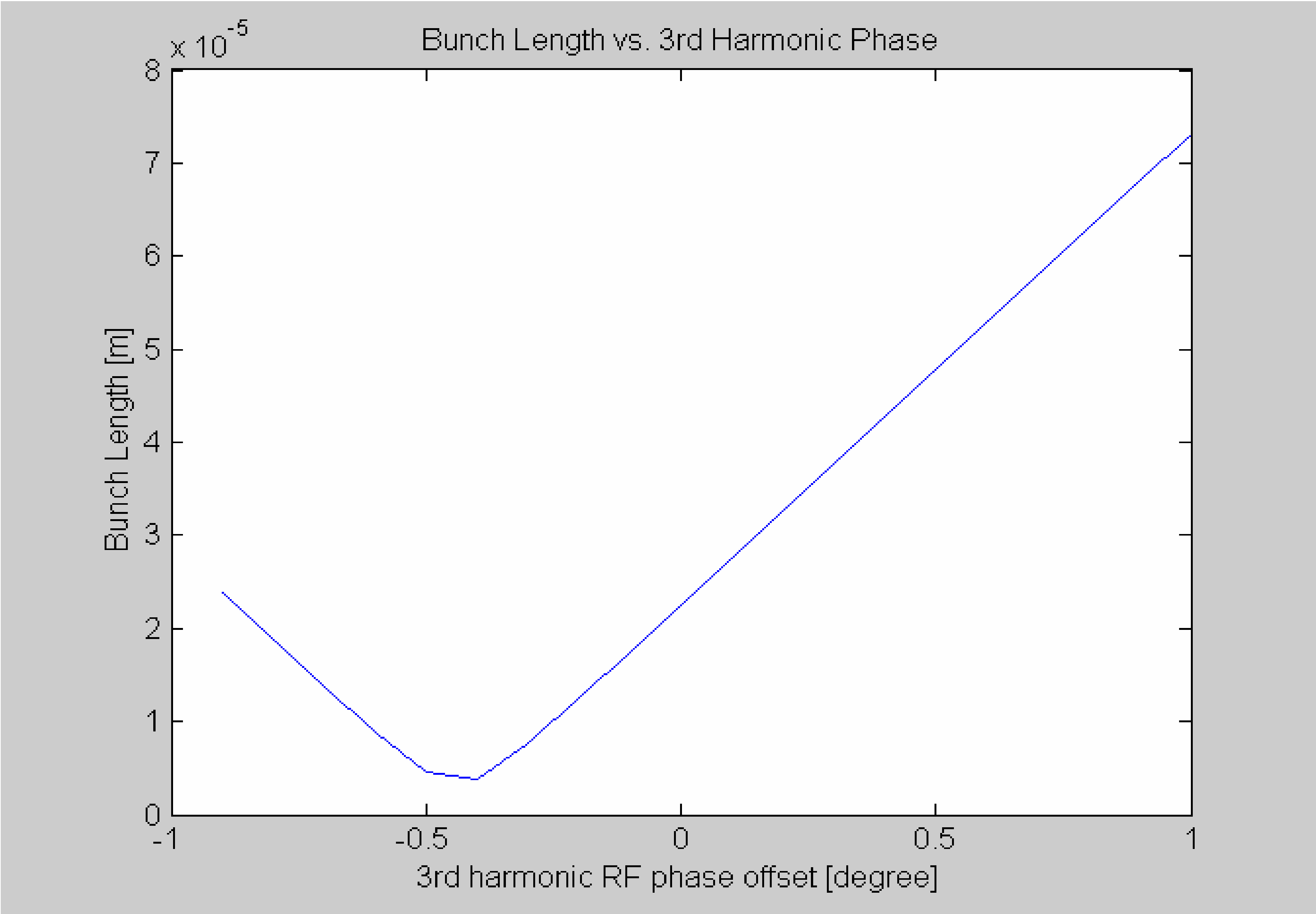
Varying the Linac RF Phase



Varying the Linac RF Phase



Varying the 3rd Harmonic RF Phase



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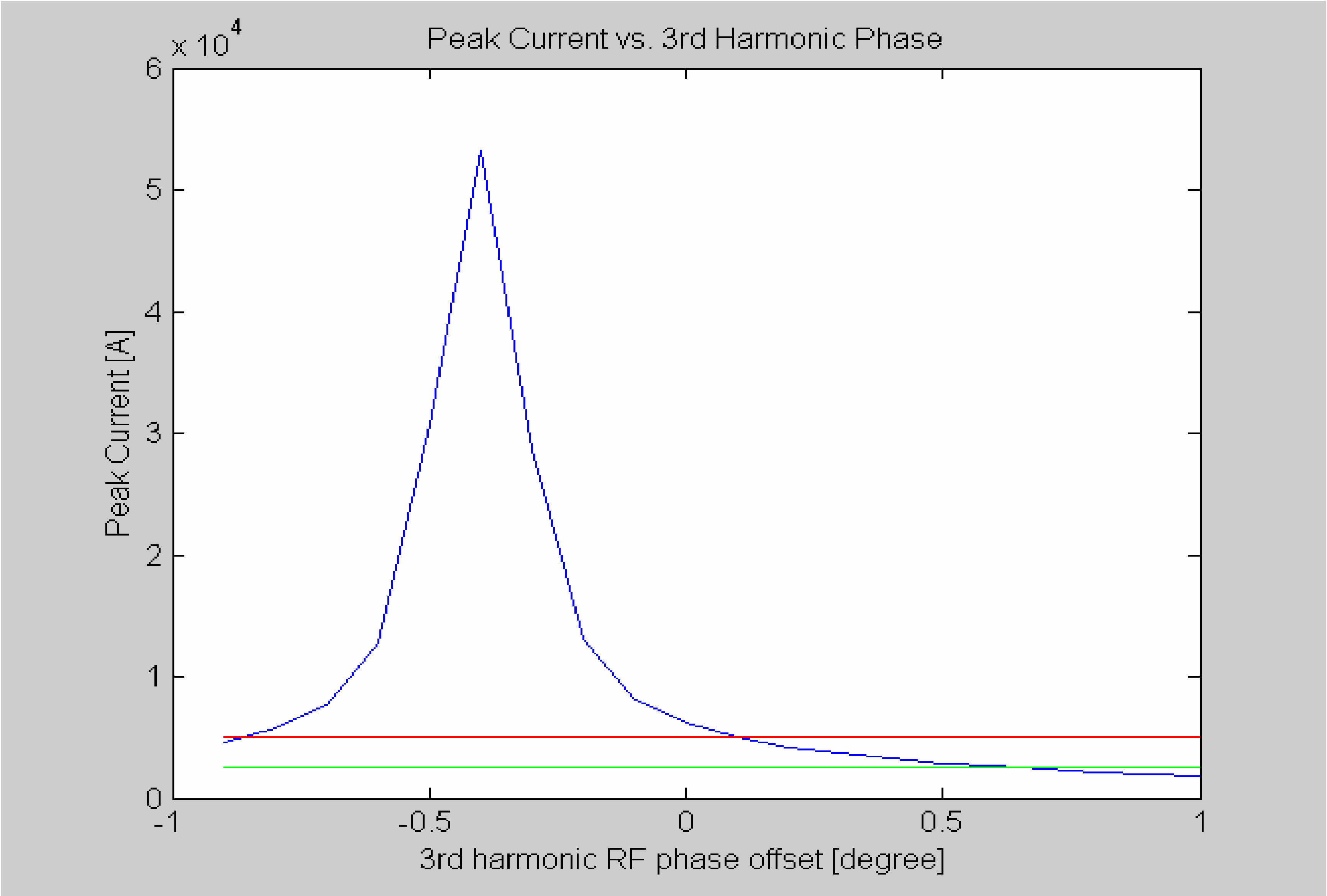

What´s next?

- Comparison Jitter-Sensitivity for different designs
- Do s2e for off-phase (off-amplitude) cases
- Remove last doubts about space-charge instabilities
- Study CSR optics sensitivities
- Detailed design