About Micro Bunching
Investigation for DOGLEG with Longitudinal Dispersion

Remark: Micro Bunching in FLASH

LGM (= linear gain model using integral equation method)

XFEL bunch Compression System

DOGLEG without Sextupoles

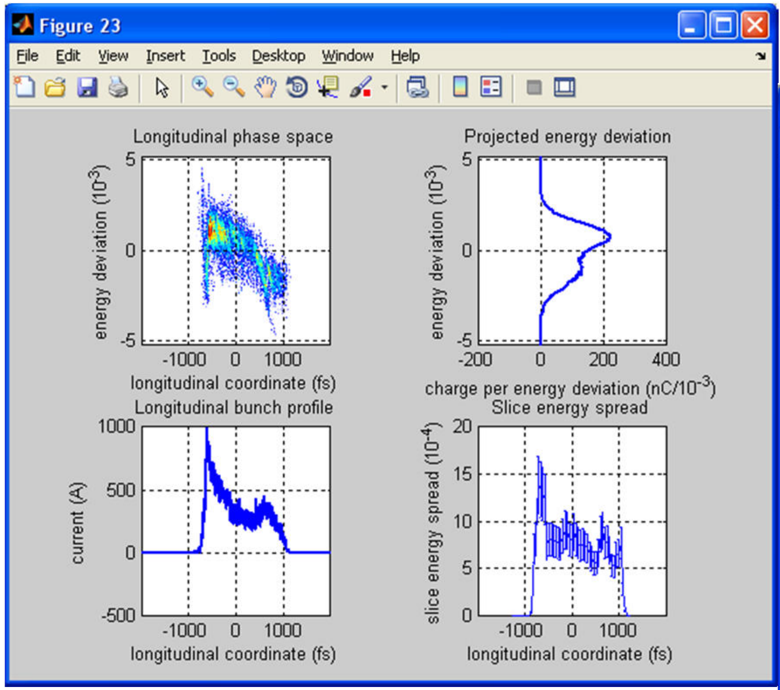
Working Points

Detailed Comparison for 0.1 nC Working Point

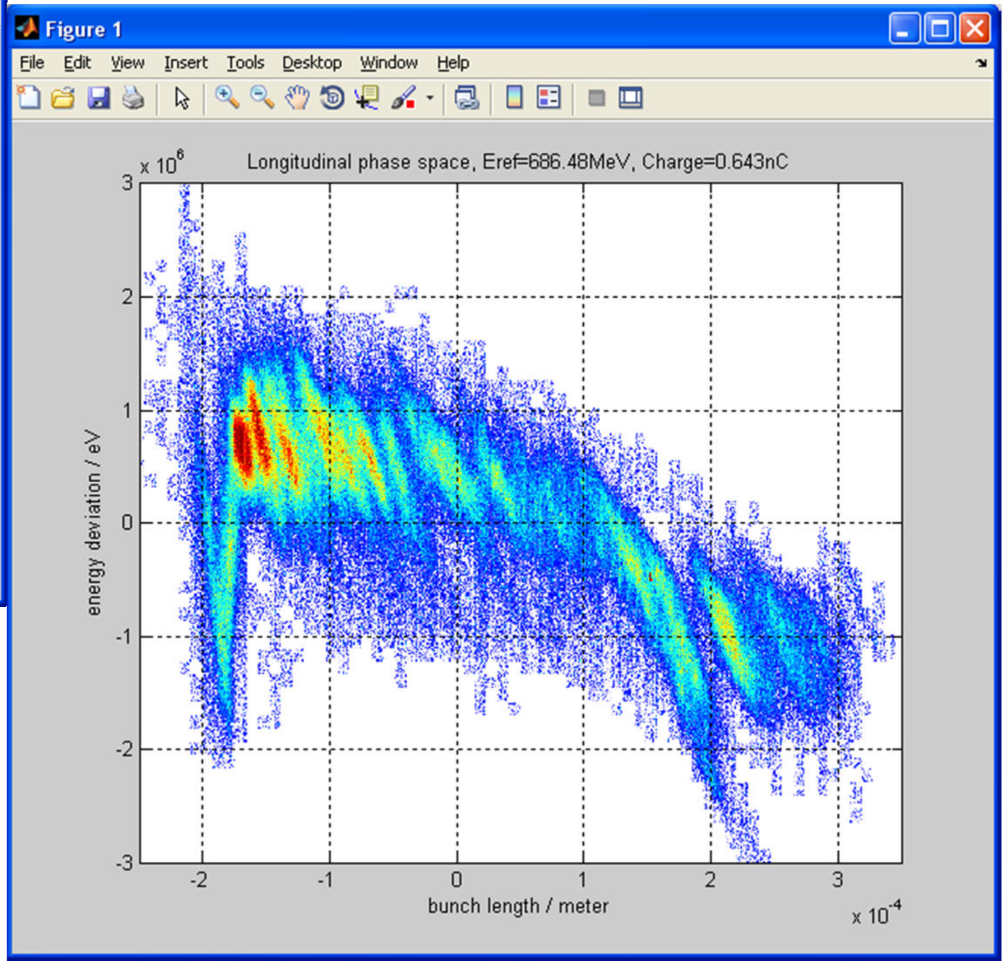
Results and Comparison

Remark: Micro Bunching in FLASH

f.i. 1st October 2010, 02:20



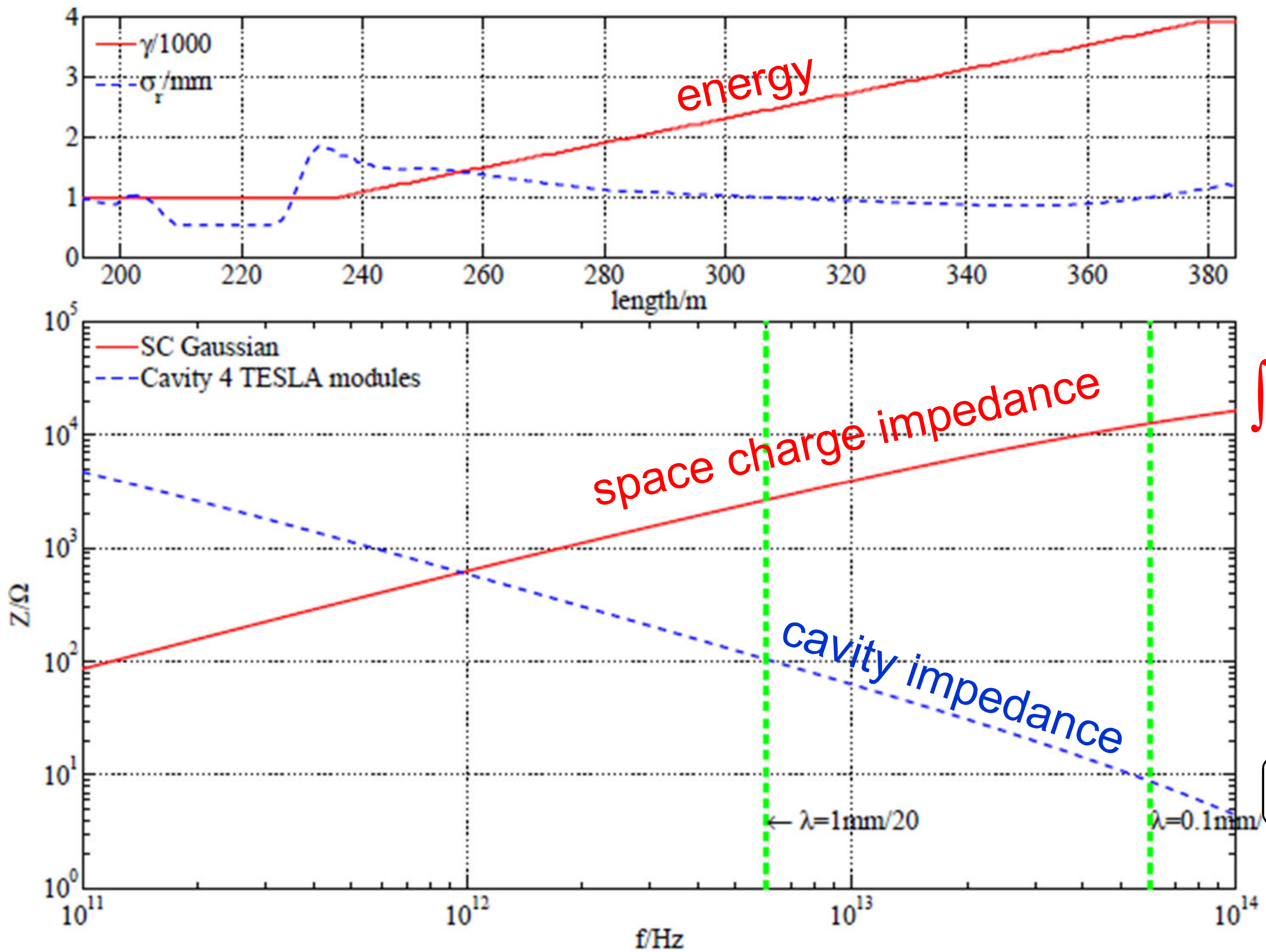
0.65nC



micro-bunching increases energy spread and affects emittance

example: energy spread $\delta E \approx e\tilde{I}\int Z' dz$

XFEL, from BC1 (@ 500 MeV) to BC2 (@ 2 GeV)



$\int Z' dz \sim 10\ \mathrm{k\Omega}$

100% of

$I \sim 500$ A

$\downarrow$

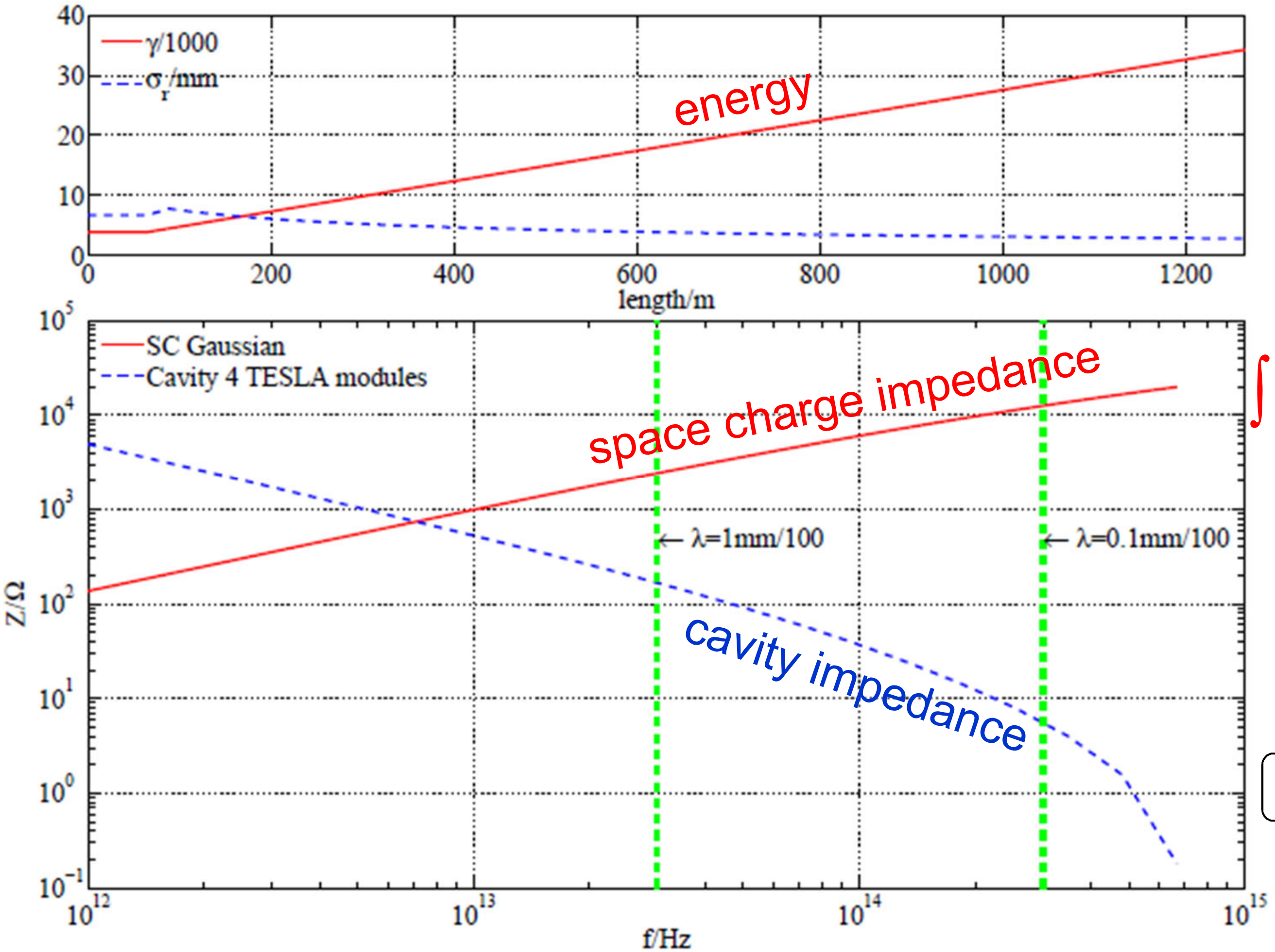
$\tilde{I} \sim 500$ A

$\downarrow$

$\delta E \sim 5$ MeV

energy spread $\delta E \approx e\tilde{I}\int Z' dz$

XFEL, from BC2 (@ 2 GeV) to 17.5 GeV



$\int Z' dz \sim 10\ \mathrm{k\Omega}$

10% of

$I \sim 5\ \mathrm{kA}$

↓

$\tilde{I} \sim 500\ \mathrm{A}$

↓

$\delta E \sim 5\ \mathrm{MeV}$

LGM (= linear gain model using integral equation method)

$$G(B) = G^{(0)}(B) + \int_0^B K(B,S)G(S)\,dS$$

$$G^{(0)}(B) = H(kL(B))$$

(local) current

$$K(B,S) = -jq_{B\leftarrow S}^{(56)}k(B)\frac{I(S)Z'(S)}{E_{\mathrm{ref}}(S)/e}H(k(L(B)-L(S)))$$

emittance

$$Z'(\omega,S) = Z'(\omega,\, parameters(S))$$

optics

longitudinal impedance

compression: $C(S) = \dfrac{1}{1 + c_h q_{S\leftarrow 0}^{(56)}}$

chirp

$$H(V) = \int dx_0\, dx_0'\, d\eta_0^{(\mathrm{u})} \times \psi_\perp(x_0, x_0')\,\psi_\eta(\eta_0^{(\mathrm{u})})\exp\left(jV^t\begin{pmatrix} x_0 \\ x_0' \\ \eta_0^{(\mathrm{u})}\end{pmatrix}\right)$$

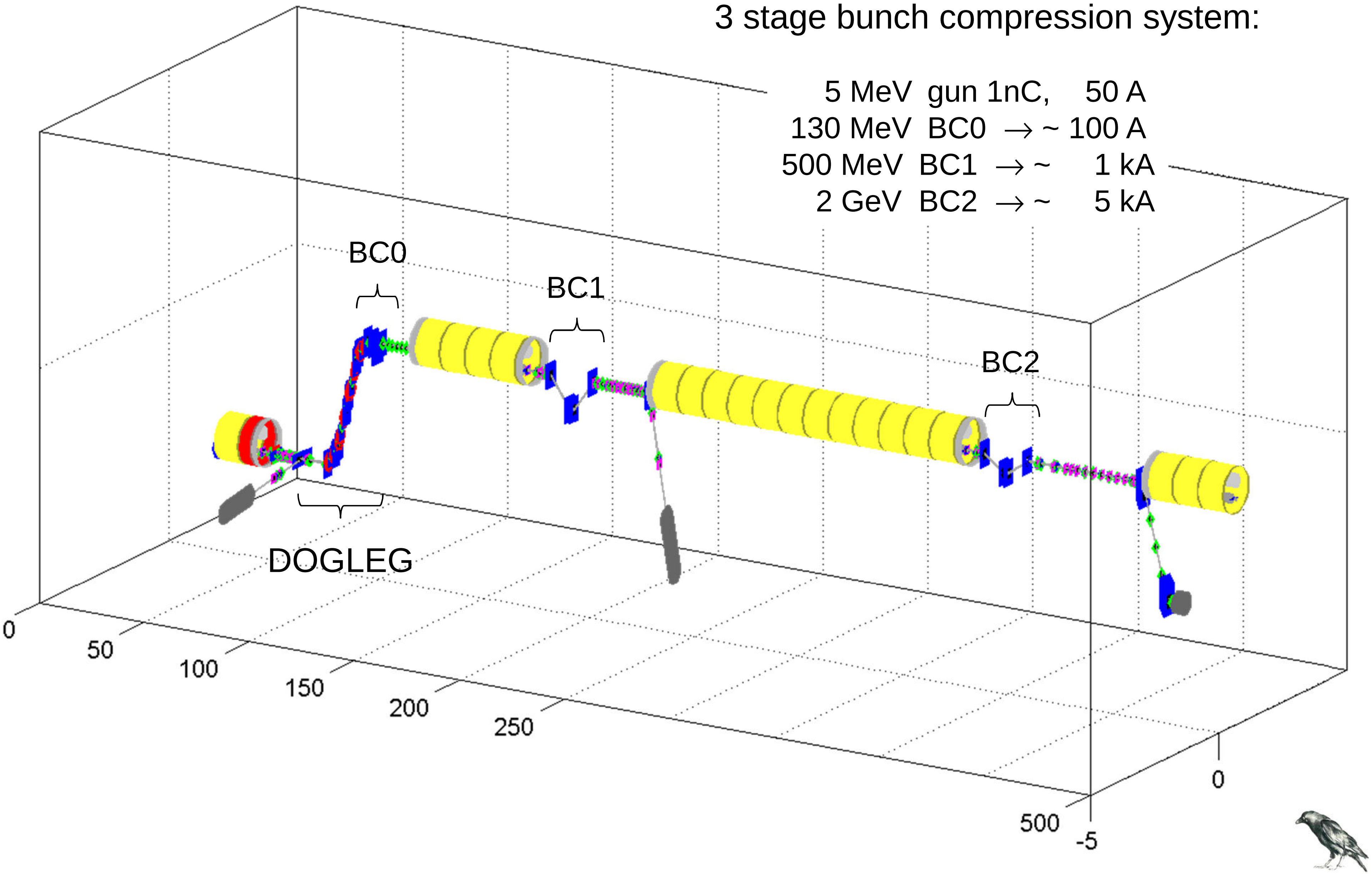
transverse phase space

longitudinal phase space ← laser heater

XFEL Bunch Compression System

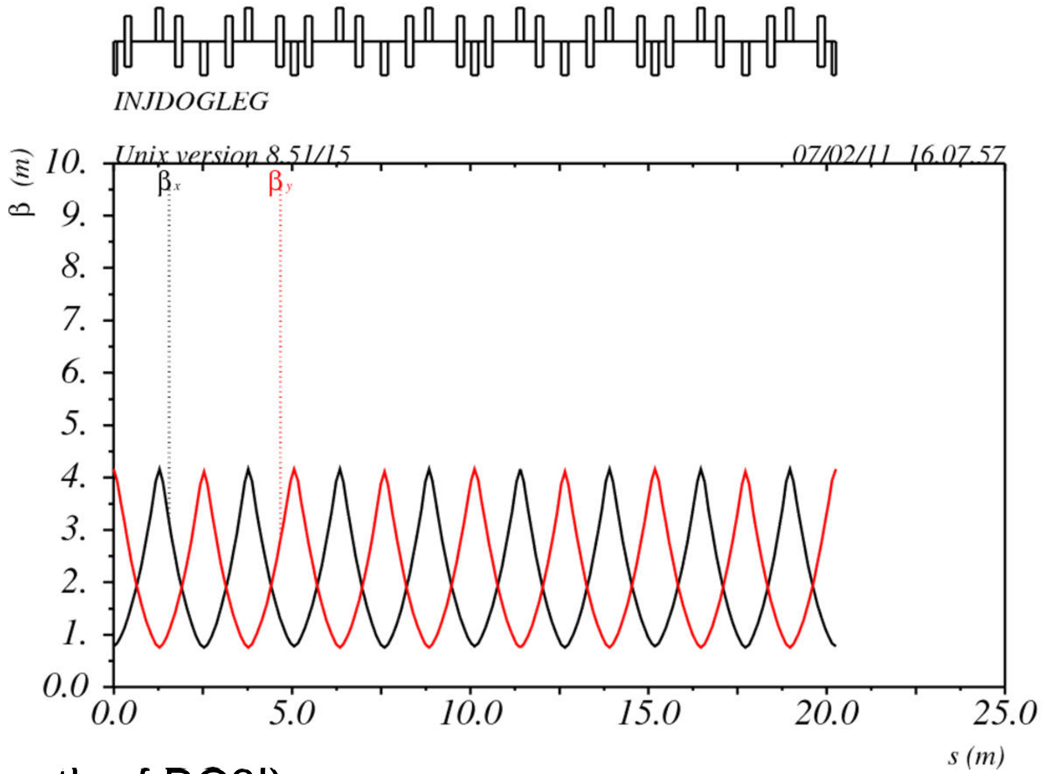
3 stage bunch compression system:

5 MeV gun 1nC, 50 A
130 MeV BC0 $\rightarrow$ ~ 100 A
500 MeV BC1 $\rightarrow$ ~ 1 kA
2 GeV BC2 $\rightarrow$ ~ 5 kA



DOGLEG without Sextupoles

```
!//  *******************************************************
!//  *        XFEL Injector Dogleg as two FRFR arcs:       *
!//  *-----------------------------------------------------*
!//  *  20 m length along linac axis, 2.75 m beam offset,  *
!//  *  20.253 m lenght along reference orbit and r56 = 0. *
!//  *-----------------------------------------------------*
!//  *   Created: 08 February 2011 (without sextupoles)    *
!//  *******************************************************
```



no sextupoles
16 bending magnets
16 quadrupoles
r56/mm = 30 (reduce strength of BC0!)

Working Points (from Beam Dynamics Homepage, Jan 2010)

Choosing of machine parameters

Macro-parameters

Charge Q, nC	Momentum compaction factor in BC_1 $R_{56,1}$, [mm]	Compr. in BC_1 C_1	Momentum compaction factor in BC_2 $R_{56,2}$, [mm]	Compr. in BC_2 C_2	Momentum compaction factor in BC_3 $R_{56,3}$, [mm]	Total compr. C	First derivative Z', [m^{-1}]	Second derivative Z'', [m^{-2}]
1	-100	3.5	-54	8	-20	121	0	2000
0.5	-89	3.5	-50	8	-20	217	0	1000
0.25	-78	3.5	-50	8	-20	385	0	1000
0.1	-71	3.5	-50	8	-20	870	0	1000
0.02	-67	3.5	-50	8	-20	4237	0	500

$E_1 = 130\,\text{MeV}$ $E_2 = 700\,\text{MeV}$ $E_3 = 2400\,\text{MeV}$

Detailed Comparison for 0.1 nC Working Point

initial current $I = \dfrac{5\ \mathrm{kA}}{C_{tot}}$ (0.1 nC $\rightarrow C_{tot} = 870$)

normalized emittance $\varepsilon_n = 1\,\mu\mathrm{m}\sqrt{\dfrac{\mathrm{q}}{1\,\mathrm{nC}}}$

initial RMS energy spread $\delta E(q) = 2\,\mathrm{keV}\,\dfrac{q}{1\,\mathrm{nC}}$ gaussian / parabula

laser heater: perfect match of particle and optical beam

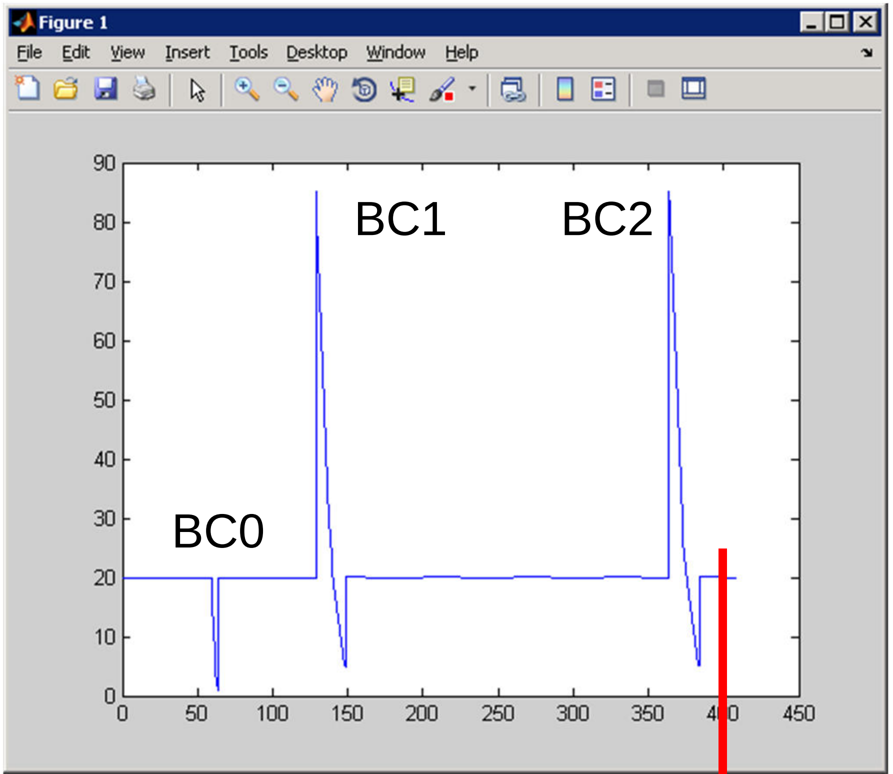
1) adjust laser amplitude for $\delta E_{\mathrm{end}} = \delta E \times C_{\mathrm{tot}} = 1\,\mathrm{MeV}$

2) adjust laser amplitude for $\max\{G(\omega, S)\} = 100 \rightarrow \delta E_{\mathrm{end}}$

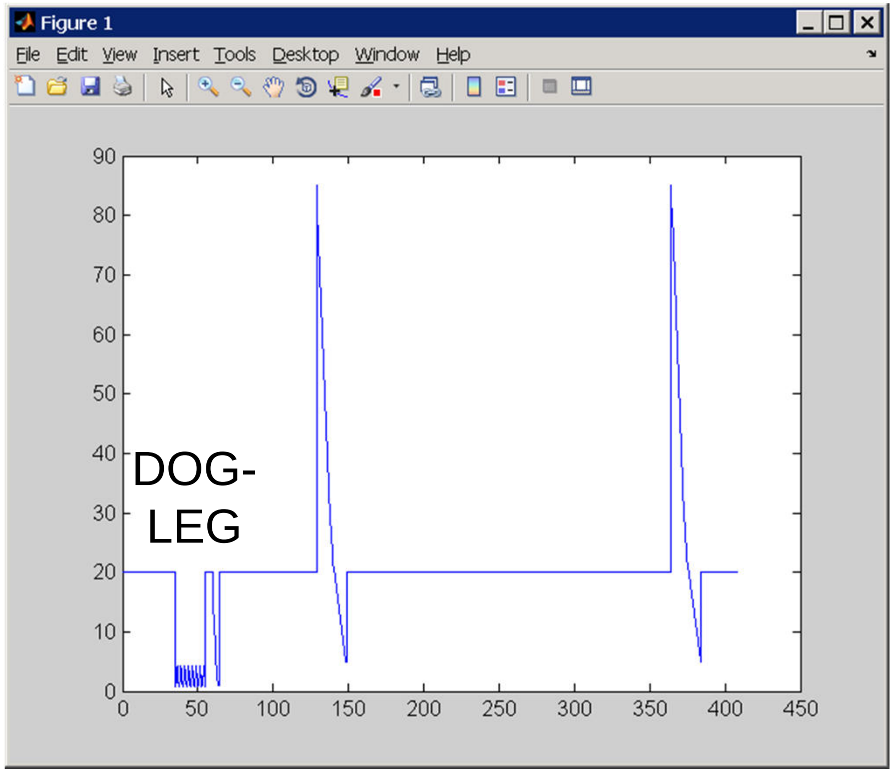
Detailed Comparison for 0.1 nC Working Point

beta function: typical = 20 m, real optic for DOGLEG, BC0 ... BC2

optics without DOGLEG



optics with DOGLEG



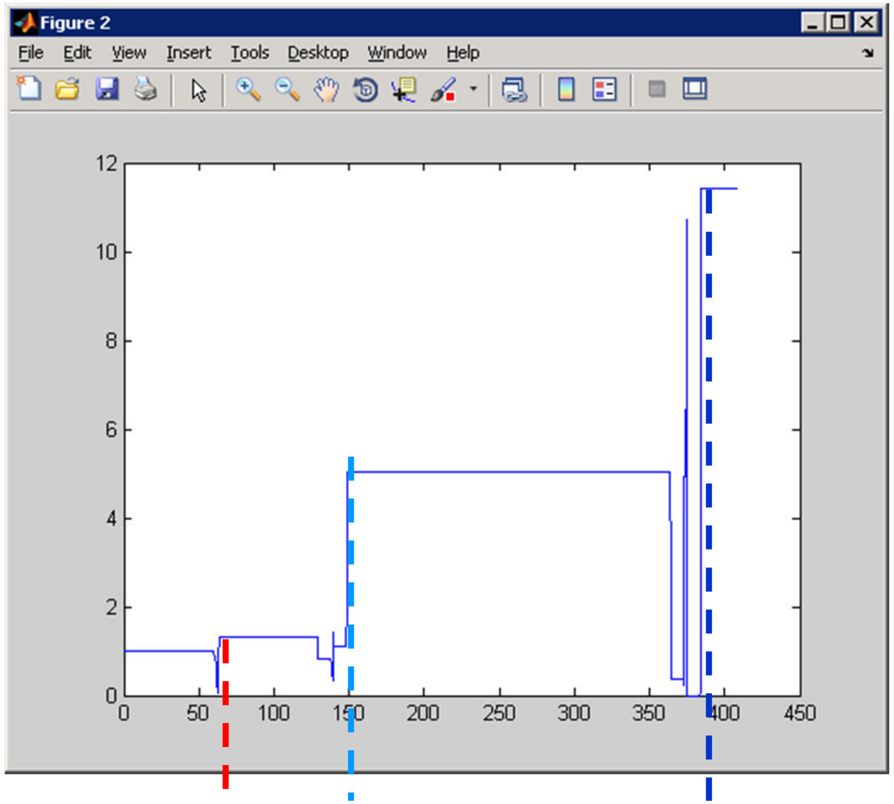
calculation ends after BC2
(or no longitudinal dispersion beyond that is)

Detailed Comparison for 0.1 nC Working Point

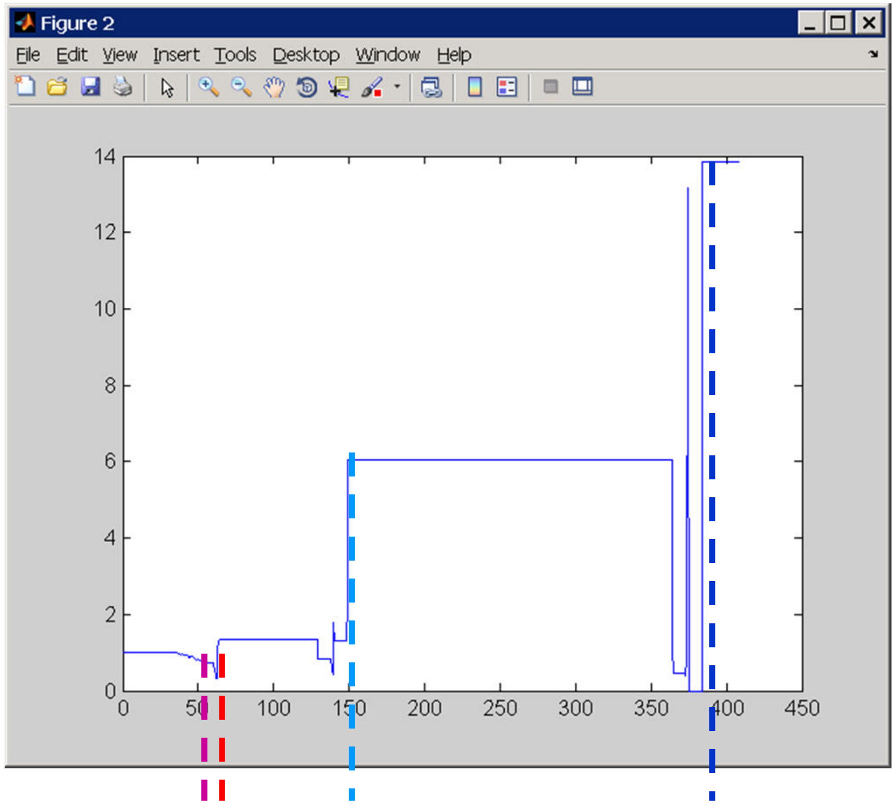
adjust laser amplitude for $\delta E_{\mathrm{end}} = \delta E \times C_{\mathrm{tot}} = 1\,\mathrm{MeV}$

1.5 THz (initial wavelength 0.2 mm)

gain(S) without DOGLEG

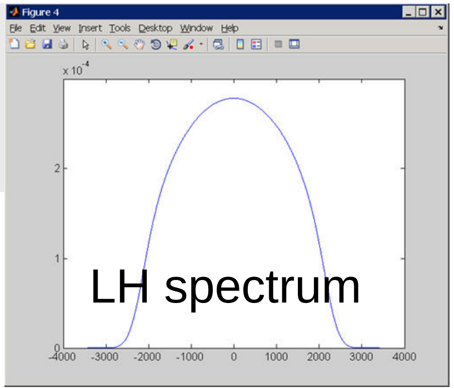


gain(S) with DOGLEG



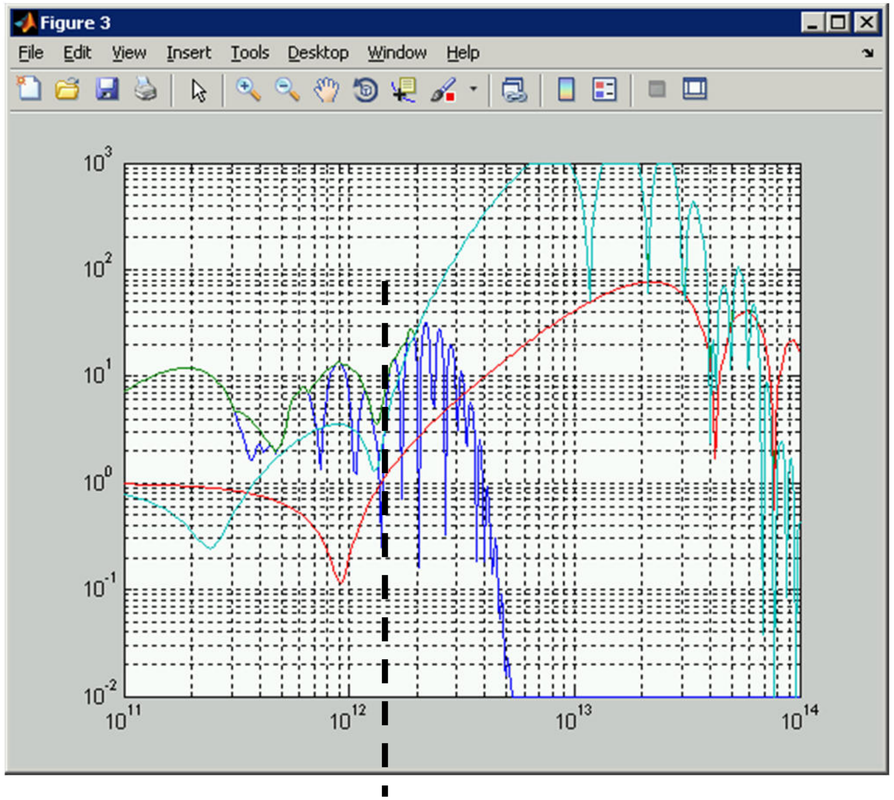
after DOGLEG, BC0, BC1, BC2

Detailed Comparison for 0.1 nC Working Point



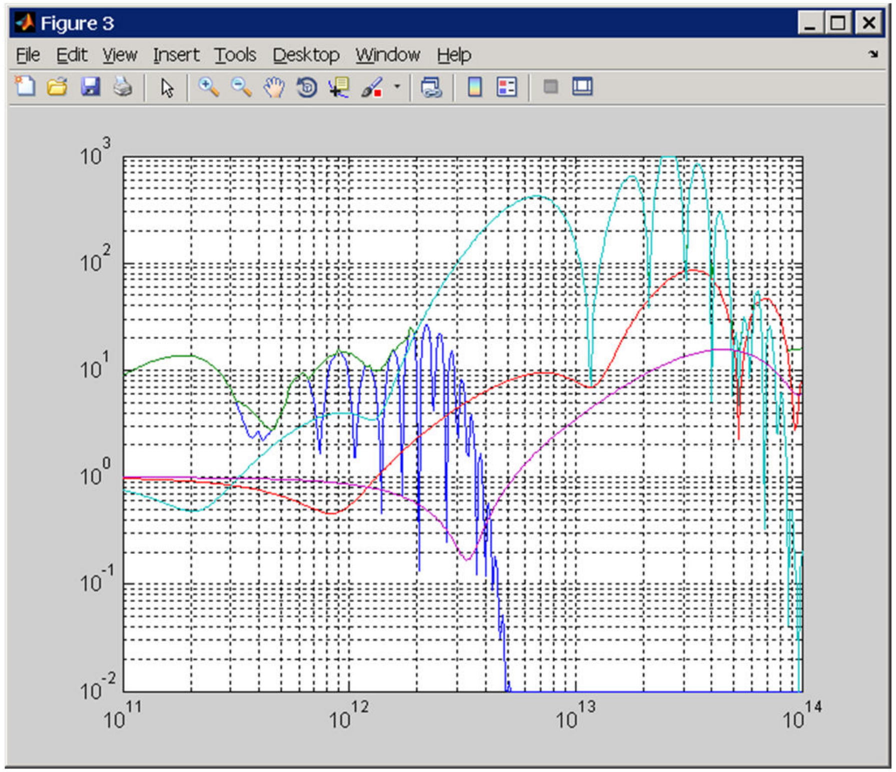
adjust laser amplitude for $\delta E_{\text{end}} = \delta E \times C_{\text{tot}} = 1\,\text{MeV}$

gain(f) without DOGLEG



1.5 THz

gain(f) with DOGLEG



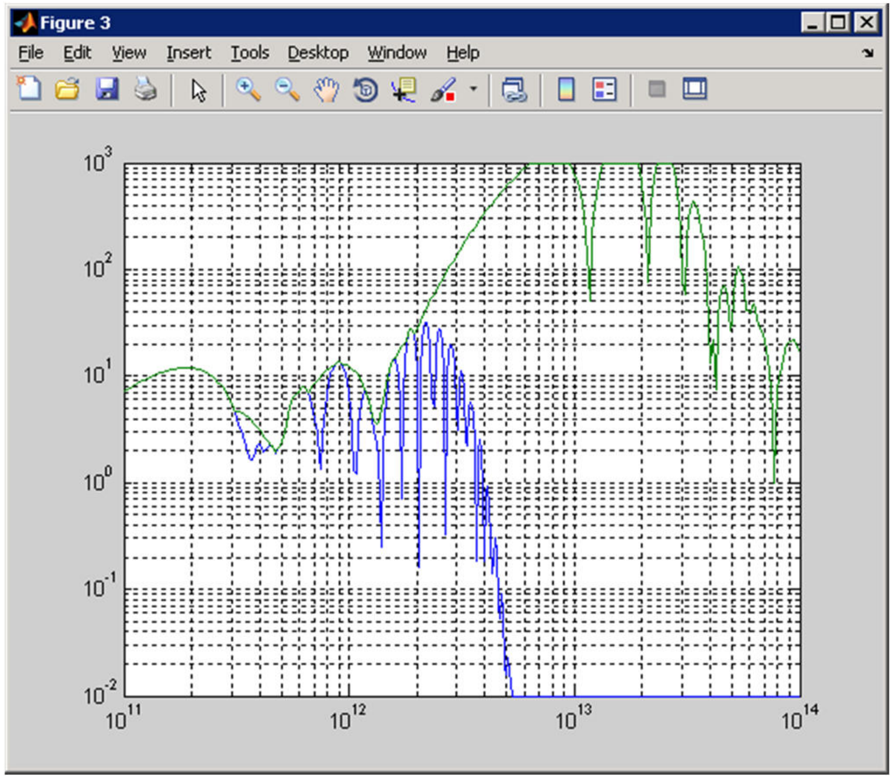
after DOGLEG, BC0, BC1, BC2, maximum

too many curves →

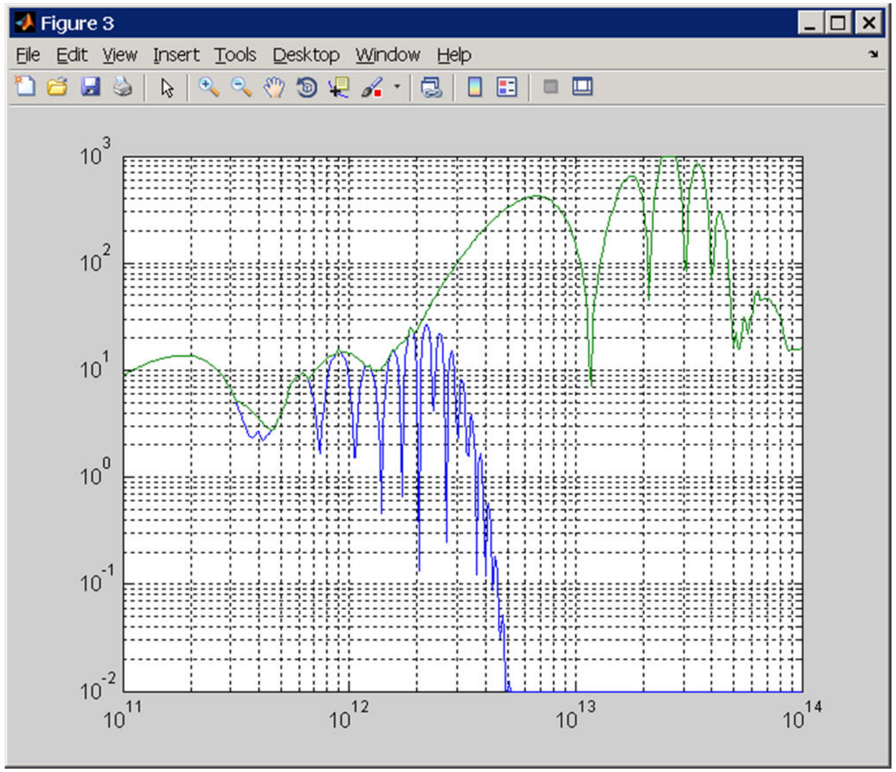
Detailed Comparison for 0.1 nC Working Point

adjust laser amplitude for $\delta E_{\mathrm{end}} = \delta E \times C_{\mathrm{tot}} = 1\,\mathrm{MeV}$

gain(f) without DOGLEG



gain(f) with DOGLEG

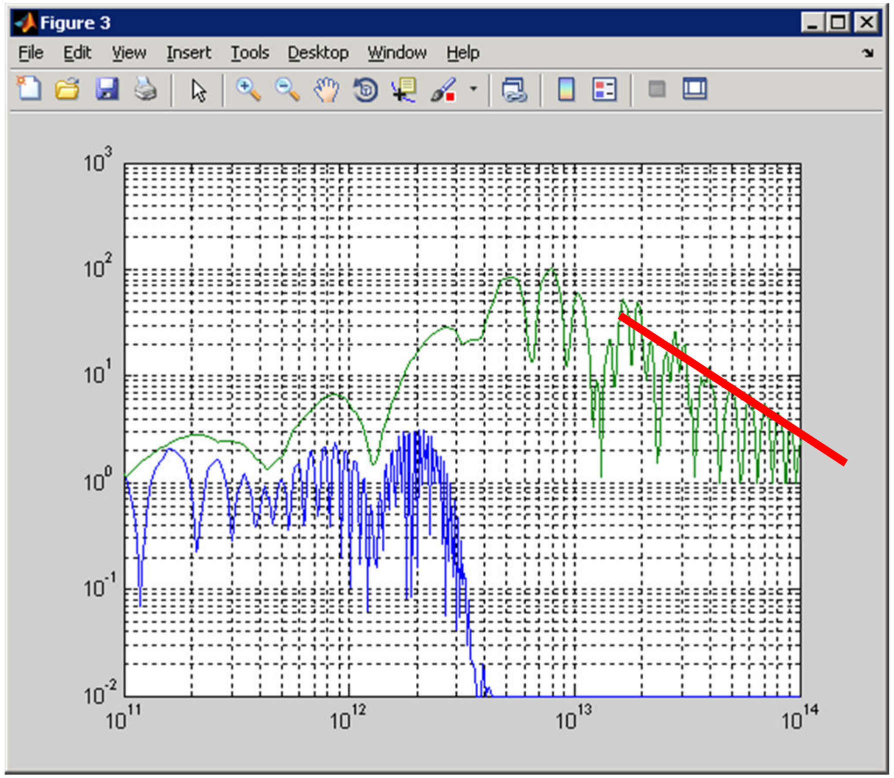


after BC2, maximum

Detailed Comparison for 0.1 nC Working Point

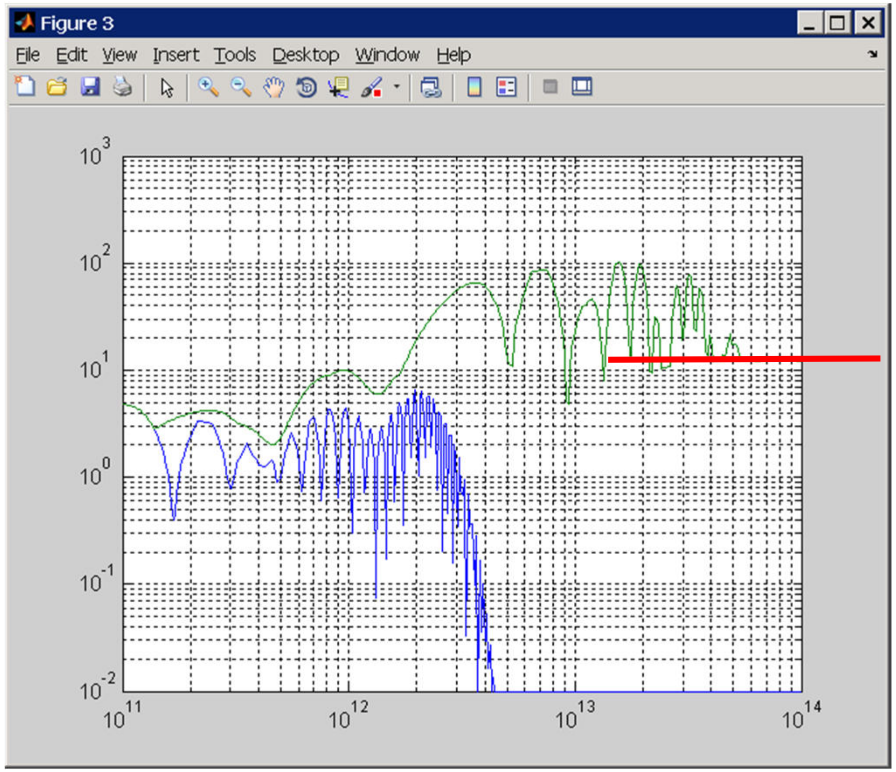
adjust laser amplitude for $\max\{G(\omega,S)\}=100 \rightarrow \delta E_{\mathrm{end}}$

gain(f) without DOGLEG



$\delta E_{\mathrm{end}}/MeV = 3.2$

gain(f) with DOGLEG



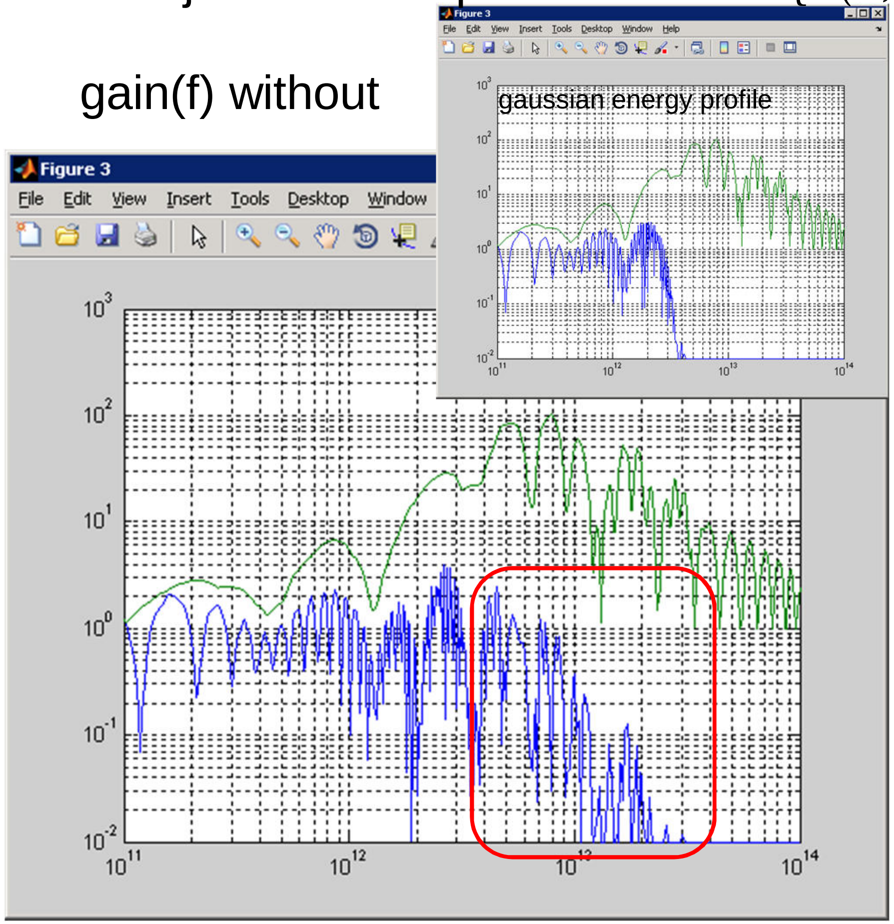
$\delta E_{\mathrm{end}}/MeV = 2.2$

Detailed Comparison for 0.1 nC Working Point

parabola energy profile before LH

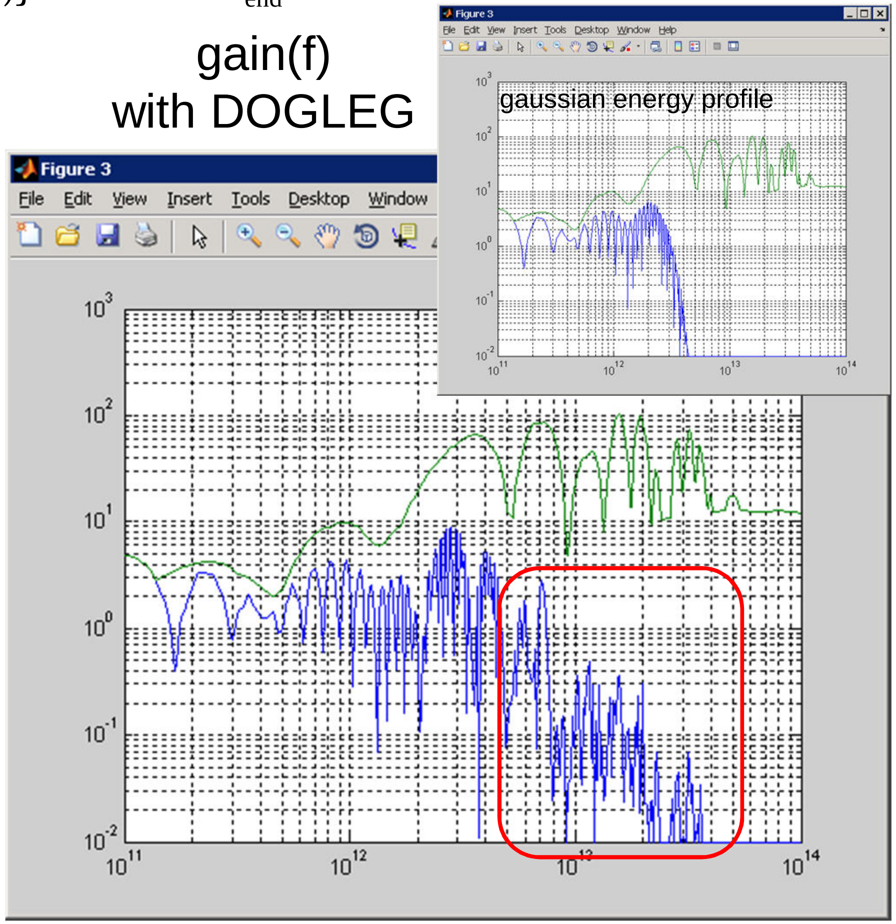
adjust laser amplitude for $\max\{G(\omega,S)\}=100 \rightarrow \delta E_{\text{end}}$

gain(f) without



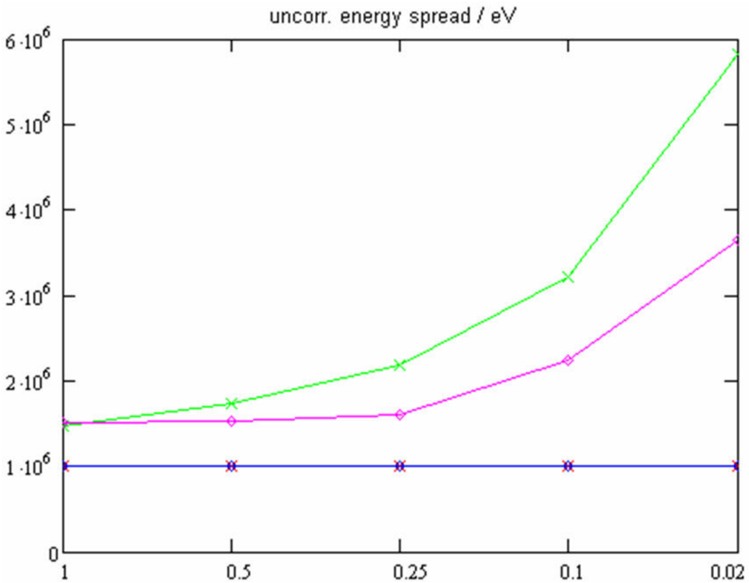
$\delta E_{\text{end}} / MeV = 3.2$

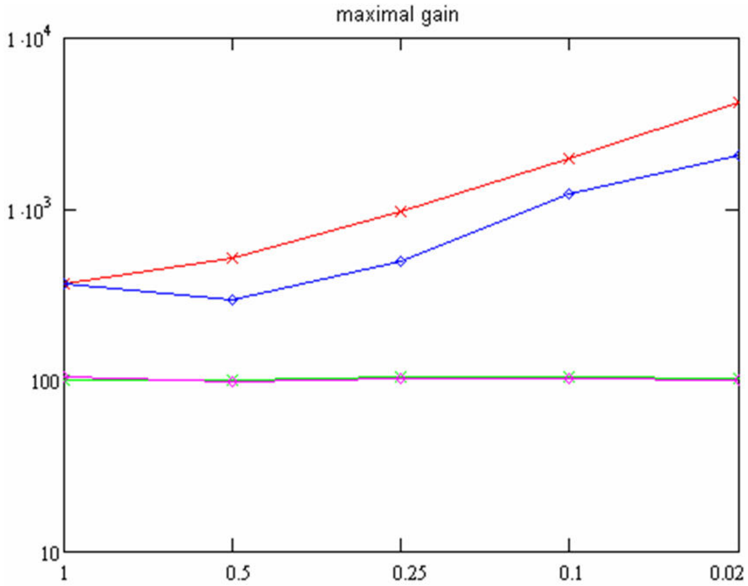
gain(f)
with DOGLEG

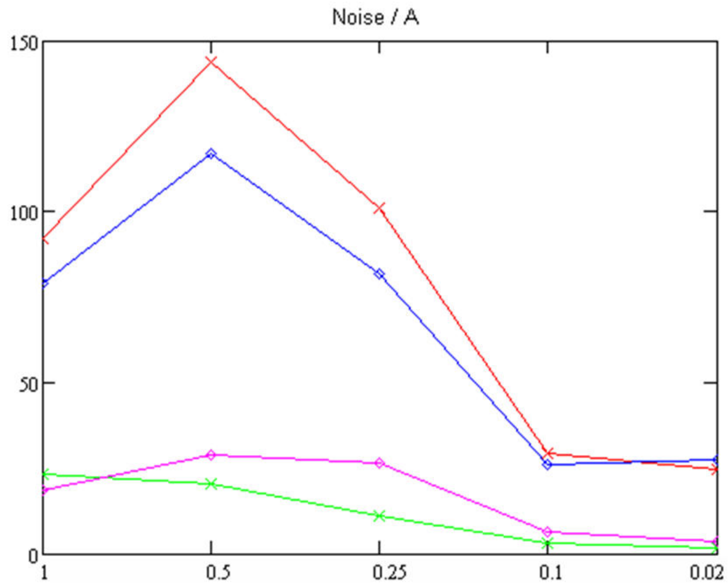


$\delta E_{\text{end}} / MeV = 2.2$

Results and Comparison







without dogleg δE = 1MeV

without dogleg Gmax = 100

with dogleg δE = 1MeV

with dogleg Gmax = 100

$$I_{rms} = \sqrt{\frac{eI_2}{\pi} \int_0^\infty \left| G(\omega_2) \right|^2 d\omega_2}$$