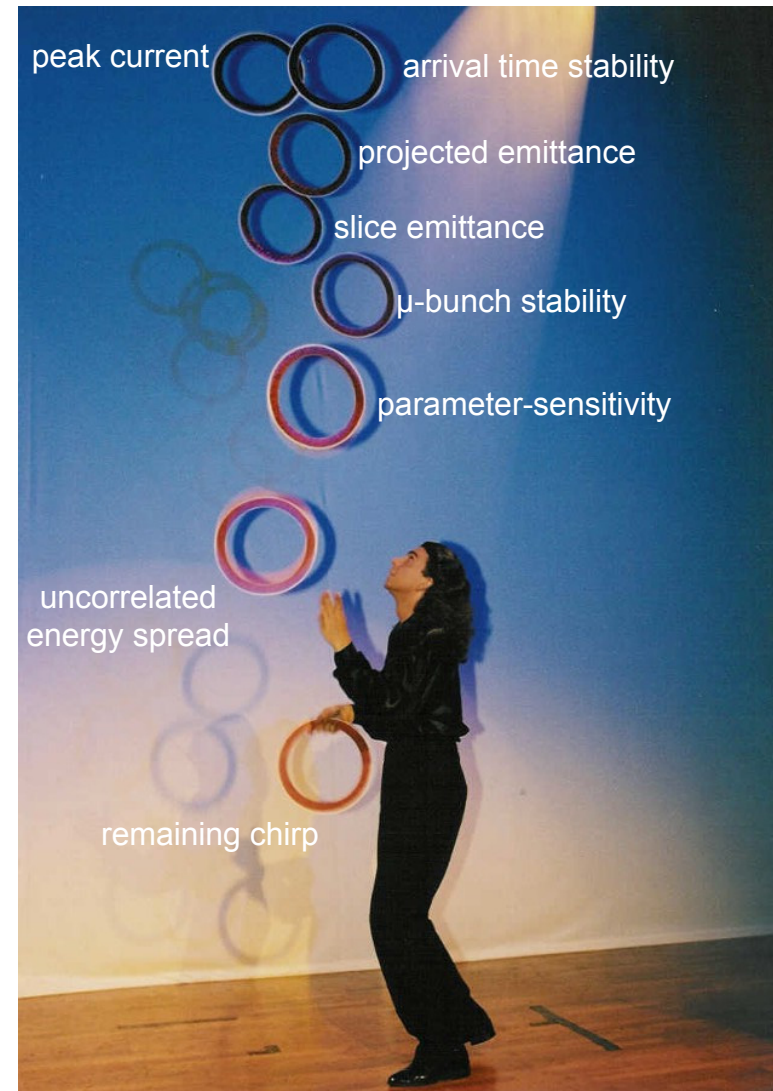


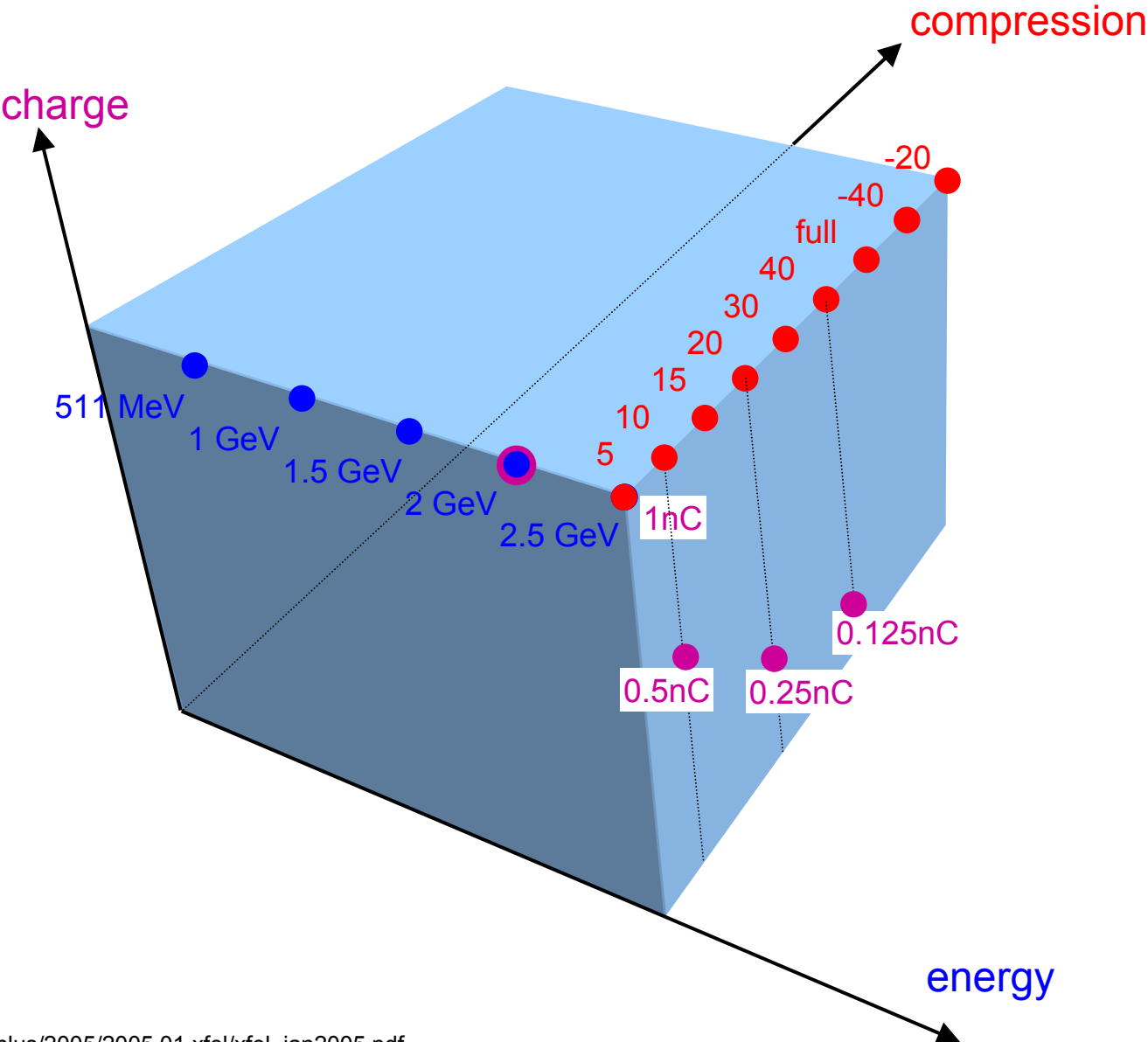


BC System – Review Options

- BC2 working point (energy-charge-compr.)
- 2BC (rf-rf-bc-rf-bc-rf)
- table: 2BC (rf-rf-bc-rf-bc-rf)
 - dogleg + 2BC (rf-dog-rf-rf-bc-rf-bc-rf)
 - n3BC (rf-bc-rf-rf-bc-rf-bc-rf)
 - 3BC (rf-rf-bc-rf-rf-bc-rf-bc-rf)
 - rollover compression
- laser heater
- cases in detail



BC2 working point



details; see:
http://www.desy.de/~dohlus/2005/2005.01.xfel/xfel_jan2005.pdf



2BC (rf-rf-bc-rf-bc-rf)

compression

r56 knobs

factors

rf knobs

$$BC_S1 = \begin{pmatrix} 3 \times 10^8 & -0.103298 & 2 \\ 2 \times 10^8 & -0.0173908 & 100 \end{pmatrix}$$

$$QT = \begin{pmatrix} 1 & 0 \\ 0.39 & 2.943 \end{pmatrix}$$

lrcx1 = 30

lrcx2 = 30

lrcx3 = 1×10^3

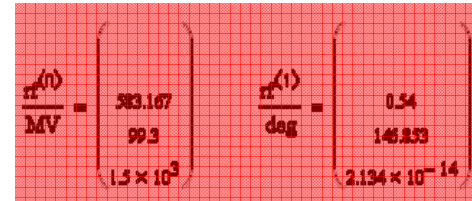
lrcx4 = 3000

$$\frac{\Delta\phi \cdot BC_S1_{2,0}}{MV} = -10.942$$

$\Delta\phi 2 = 0$ chirp

$\Delta\phi 3 = -0.022$

$\Delta\phi 4 = -5.471 \times 10^{-2}$



absolute tolerances
(amplitude & phase_deg)

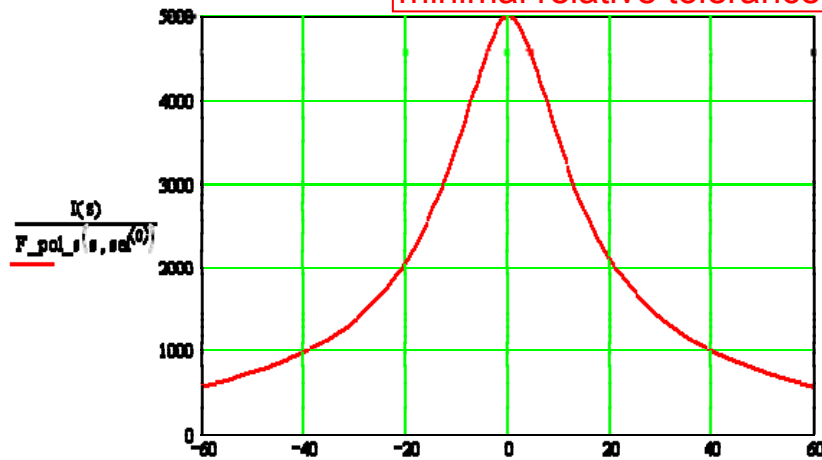
$$MV3 = \begin{pmatrix} 0.198 & -1 \\ -0.161 & 1 \end{pmatrix} \quad \text{deg3} = \begin{pmatrix} 0.015 & 1 \\ -0.018 & -1 \end{pmatrix}$$

$$MV4 = \begin{pmatrix} 0.039 & 1 \\ -0.08 & -1 \end{pmatrix} \quad \text{deg4} = \begin{pmatrix} 0.035 & 1 \\ -0.044 & 1 \end{pmatrix}$$

$$MV5 = \begin{pmatrix} 18.526 & -1 \\ -15.148 & 1 \end{pmatrix} \quad \text{deg5} = \begin{pmatrix} 2.613 & 1 \\ -4.406 & -1 \end{pmatrix}$$

$\min(\text{stack}(am, ph)) = 2.912 \times 10^{-4}$

$\min(am) = 3.079 \times 10^{-4} \quad \min(ph) = 2.912 \times 10^{-4}$
minimal relative tolerances



shot noise due to μ -bunching gain

$$I_{\text{noise,rms}} \approx \sqrt{\frac{eI}{\pi} \int_{\omega>0} |G|^2 d\omega}$$

$I_{\text{rms}} = 260.71$

$r56_total(BC_S1) \cdot \frac{E_{rms}}{E_{e01}} = 8.608 \times 10^{-6}$

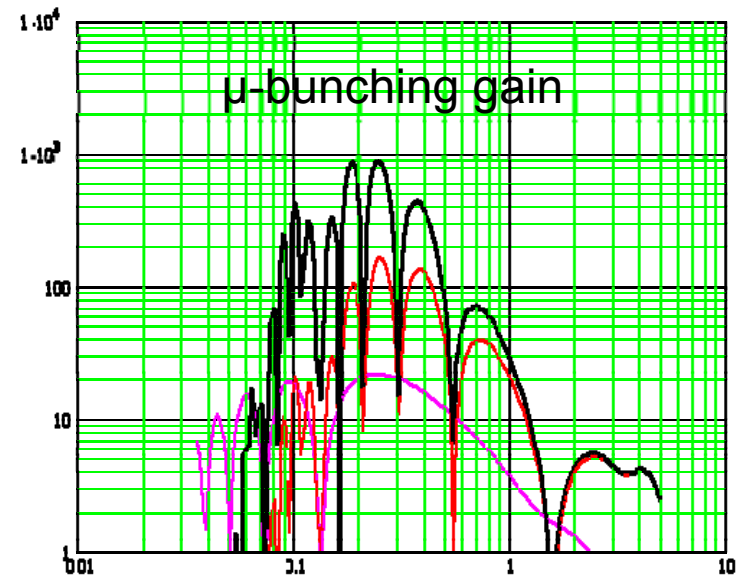
$\frac{E_{e03}}{MV} = 1.75 \times 10^4$

$\frac{r56_3}{0.501} = 0.84$

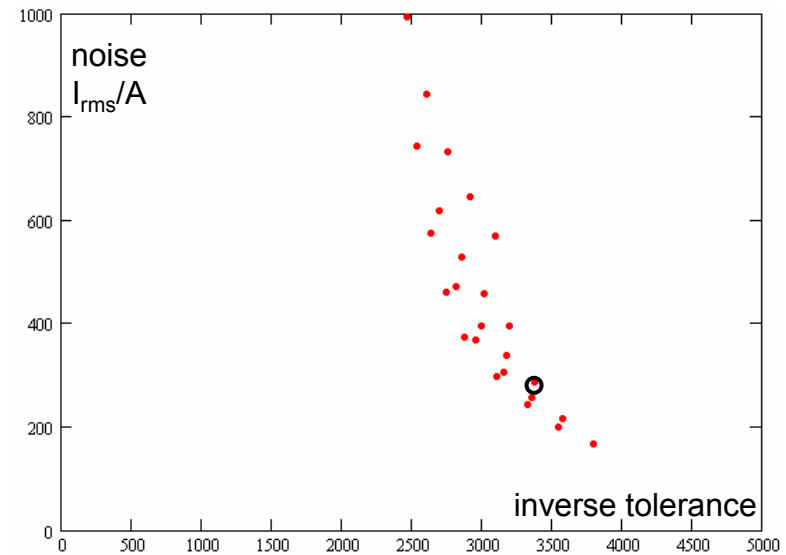
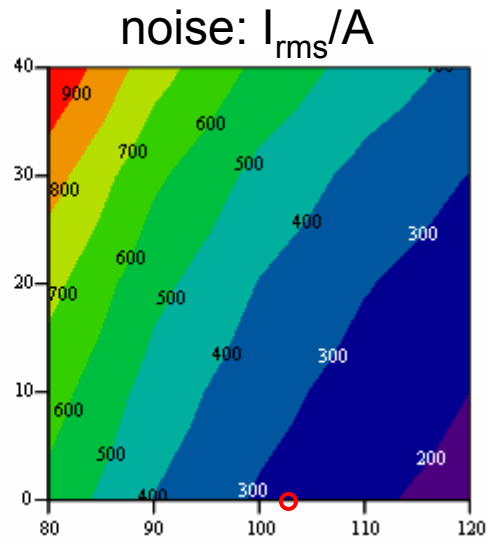
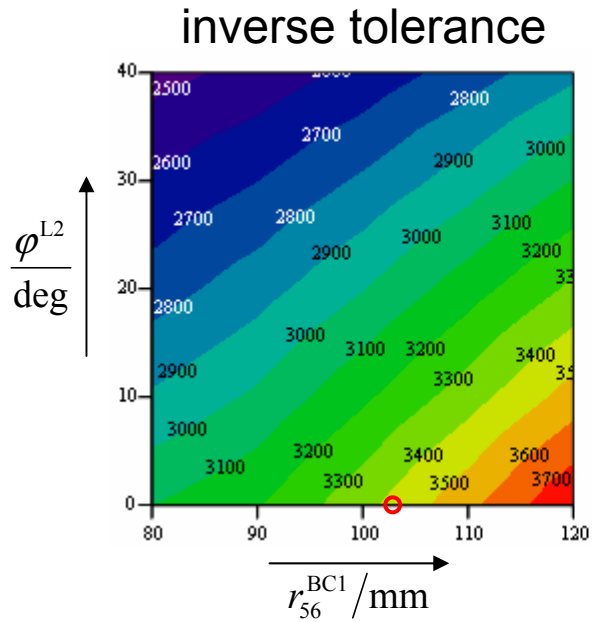
$C3 = 0.9784$

$E_{rms} = 1 \times 10^4$

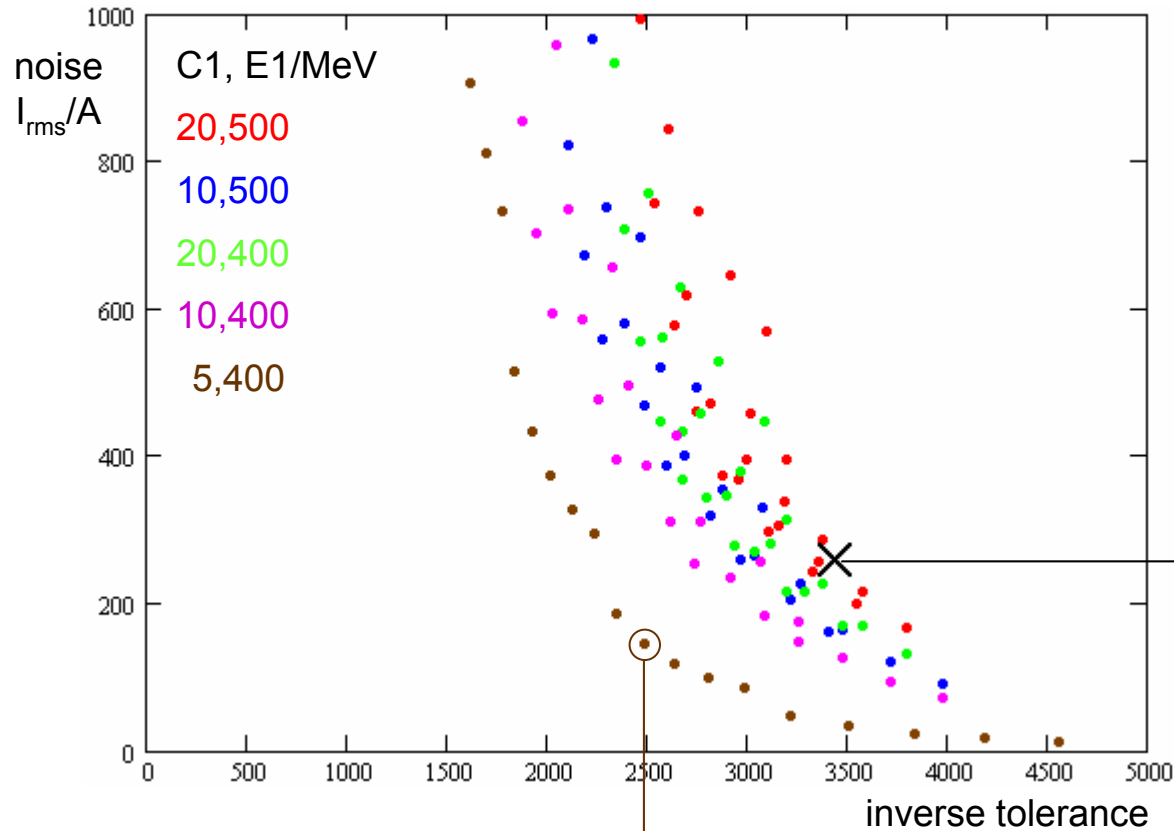
$C_{tot} \cdot E_{rms} = 1 \times 10^6$



const.: E1, E2, E2'', E2''', r56^{coll}, C1, C1*C2
 tuned: E1', E2', r56^{BC2}, parameter: r56^{BC1}, ϕ^{L2}



const.: (E1), E2, E2'', E2''', r56^{coll}, (C1), C1*C2
 tuned: E1', E2', r56^{BC2}, parameter: r56^{BC1}, ϕ^{L2}



min(phas_tol) = 0.016 deg
 noise: $I_{rms} = 260 A$

E1 = 400 MeV
 r56BC1 = 90mm, C1=5
 r56BC2 = 75mm, C2=20
 $\phi^{L2} = 10 \text{ deg}$
 min(ampl_tol) = 0.1%
 min(phas_tol) = 0.023 deg
 noise: $I_{rms} = 147 A$



2BC rf ⁽¹⁺³⁾ -bc-rf-bc-rf-c	dogleg+2BC rf-d- rf ⁽¹⁺³⁾ -bc-rf-bc-rf-c	n3BC rf-bc- rf ⁽¹⁺³⁾ -bc-rf-bc-rf-c	3BC rf ⁽¹⁺³⁾ -bc- rf ⁽¹⁺³⁾ -bc-rf-bc-rf-c	rollover compr. rf ⁽¹⁺³⁾ -bc-rf-bc-rf-c
E=400MeV 2GeV 17.5GeV	E=130MeV 400MeV 2GeV 17.5GeV	E=130MeV 400MeV 2GeV 17.5GeV	E=130MeV 500MeV 2GeV 17.5GeV	E=500MeV 2GeV 17.5GeV
C=5 20 0.98	C=1.2 4.17 20 0.98	C=1.25 4 20 0.98	C=1.45 6.90 10 0.98	C=10 10 0.98
r56=-90mm -75mm 0.84mm	r56=40mm -90mm -87.2mm 0.84mm	r56=30mm -80mm -83.7mm 0.84mm	r56=-30mm -90mm -45.0mm 0.84mm	r56=-100mm -200mm 0.84mm
ampl_tol=0.1% ph_tol=0.023deg noise= 147 A	ampl_tol=0.11% ph_tol=0.040deg noise= 270 A	ampl_tol=0.11% ph_tol=0.045deg noise= 93 A	ampl_tol=0.09% ph_tol=0.048deg noise= 95 A	ampl_tol=0.2% ph_tol=0.055deg small
$\phi^{L2} = 10 \text{ deg}$	e'=1%@ 130MeV $\phi^{L2} = 10 \text{ deg}$ t566_dog=1m	e'=1.6%@ 130MeV $\phi^{L2} = 10 \text{ deg}$ t566_dog=1m	e'=2.5%@ 130MeV $\phi^{L2} = 10 \text{ deg}$	$\phi^{L2} = 40.5 \text{ deg}$



laser heater

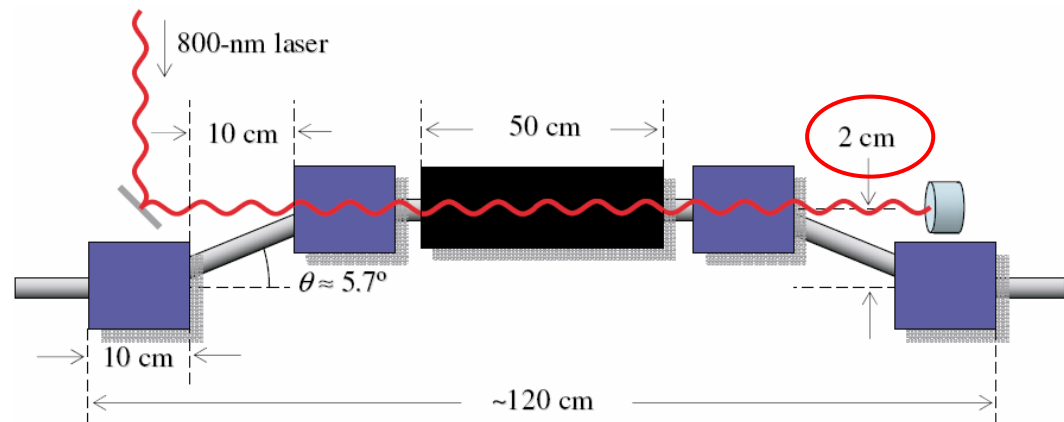
Suppression of Microbunching Instability in the Linac Coherent Light Source*

SLAC-PUB-10334

Z. Huang, M. Borland, P. Emma, J. Wu, C. Limborg, G. Stupakov, J. Welch

TABLE II: Main parameters for the LCLS laser heater.

Parameter	Symbol	Value
electron energy	$\gamma_0 mc^2$	135 MeV
average beta function	$\beta_{x,y}$	10 m
transverse rms beam size	$\sigma_{x,y}$	190 μm
undulator period	λ_u	0.05 m
undulator field	B	0.33 T
undulator parameter	K	1.56
undulator length	L_u	0.5 m
laser wavelength	λ_L	800 nm
laser rms spot size	σ_r	1.5 mm (175 μm)
laser peak power	P_L	37 MW (1.2 MW)
Rayleigh range	Z_R	44 m (0.6 m)
maximum energy modulation	$\Delta\gamma_L(0)mc^2$	55 keV (80 keV)
rms local energy spread	$\sigma_{\gamma_L} mc^2$	40 keV



1% energy offset \leftrightarrow transv. rms beam size

overlap of electron and laser beam !!!



cases in detail

- 2BC (rf-rf-bc-rf-bc-rf)
- dogleg + 2BC (rf-dog-rf-rf-bc-rf-bc-rf)
- n3BC (rf-bc-rf-rf-bc-rf-bc-rf)
- 3BC (rf-rf-bc-rf-rf-bc-rf-bc-rf)
- rollover compression



2BC (rf-rf-bc-rf-bc-rf)

compression with BC1 and BC2

$$BC_S1 = \begin{pmatrix} 0 & -1 \times 10^{-5} & 1 \\ 4 \times 10^8 & -0.09 & 5 \\ 2 \times 10^9 & -0.074554 & 100 \end{pmatrix}$$

$$\frac{rf^{(0)}}{MV} = \begin{pmatrix} 0 \\ 0 \\ 465.626 \\ 78.804 \\ 1.625 \times 10^3 \end{pmatrix} \quad \frac{rf^{(1)}}{\text{deg}} = \begin{pmatrix} 0 \\ 0 \\ -0.09 \\ 146.385 \\ 10 \end{pmatrix}$$

$$QT = \begin{pmatrix} 0 & 0 \\ 0.313 & 2.943 \end{pmatrix}$$

$$Imax1 = 50$$

$$MV1 = 0$$

$$deg1 = 0$$

$$Imax2 = 50 \quad \Delta e2 = 0$$

$$MV2 = 0$$

$$deg2 = 0$$

$$Imax3 = 250.002 \quad \Delta e3 = -0.021$$

$$MV3 = \begin{pmatrix} 0.547 & -1 \\ -0.431 & 1 \end{pmatrix} \quad deg3 = \begin{pmatrix} 0.021 & 1 \\ -0.025 & -1 \end{pmatrix}$$

$$Imax4 = 5000 \quad \Delta e4 = -6.134 \times 10^{-3}$$

$$MV4 = \begin{pmatrix} 0.083 & 1 \\ -0.105 & -1 \end{pmatrix} \quad deg4 = \begin{pmatrix} 0.066 & -1 \\ -0.053 & 1 \end{pmatrix}$$

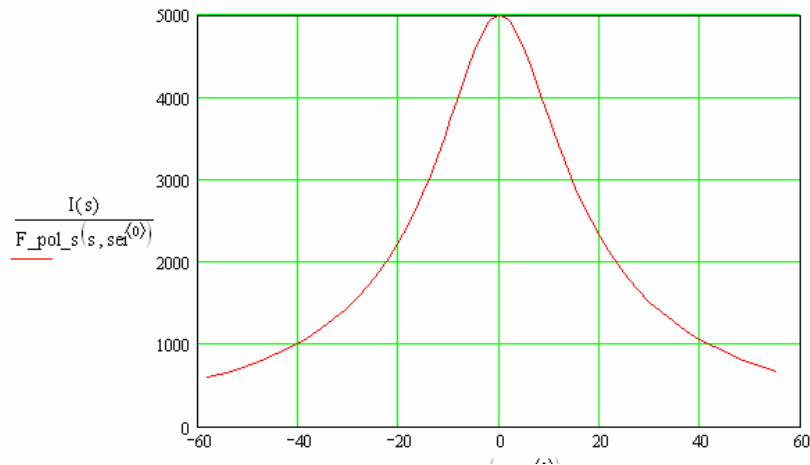
$$\frac{\Delta e4 \cdot BC_S1_{2,0}}{MV} = -12.269$$

$$MV5 = \begin{pmatrix} 4.575 & -1 \\ -3.665 & 1 \end{pmatrix} \quad deg5 = \begin{pmatrix} 0.09 & 1 \\ -0.192 & -1 \end{pmatrix}$$

$$\min(\text{stack}(\text{am}, \text{ph})) = 4.026 \times 10^{-4}$$

$$\min(\text{am}) = 1.051 \times 10^{-3}$$

$$\min(\text{ph}) = 4.026 \times 10^{-4}$$



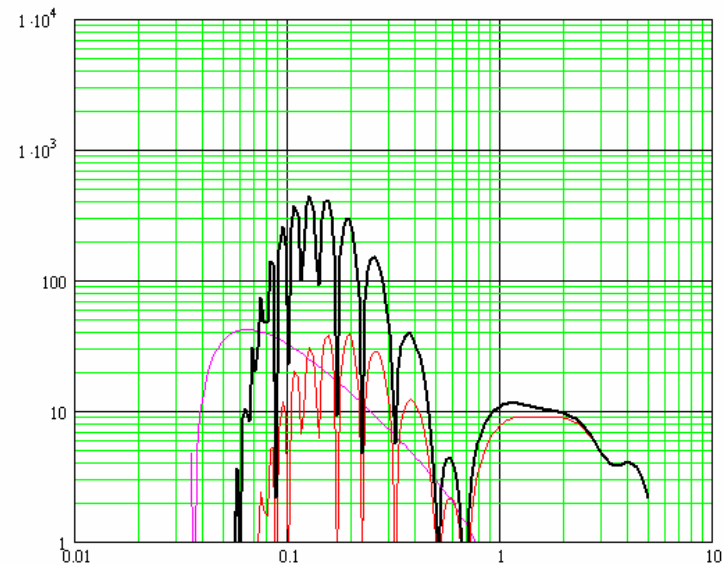
Z(BC1 to BC2) is scaled with $(500\text{MeV} / E_{BC1})^{**2}$
 Z(BC2 to ...) is scaled with $(2000\text{MeV} / E_{BC2})^{**2}$

$$r56_total(BC_S1) \cdot \frac{E_{rms}}{E_{e1}} = 9.882 \times 10^{-6} \quad I_{rms} = 146.726$$

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$$\frac{E_{ne3}}{MV} = 1.75 \times 10^4 \quad \frac{r56_3}{0.001} = 0.84 \quad C3 = 0.97612$$

$$E_{rms} = 1 \times 10^4 \quad C_{tot} \cdot E_{rms} = 1 \times 10^6$$



dogleg + 2BC (rf-dog-rf-rf-bc-rf-bc-rf)

compression with Dog (t566=1m), BC1, BC2

$$BC_S1 = \begin{pmatrix} 1.3 \times 10^8 & 0.04 & 1.2 \\ 4 \times 10^8 & -0.09 & 4.1666667 \\ 2 \times 10^9 & -0.0872313 & 100 \end{pmatrix} \quad \frac{rf^{(0)}}{MV} = \begin{pmatrix} 131.503 \\ 0 \\ 347.222 \\ 99.994 \\ 1.625 \times 10^3 \end{pmatrix} \quad \frac{rf^{(1)}}{\text{deg}} = \begin{pmatrix} -8.672 \\ 0 \\ -10.224 \\ 135.818 \\ 10 \end{pmatrix}$$

$$QT = \begin{pmatrix} 0 & 0 \\ 0.759 & 4.55 \end{pmatrix}$$

$$Imax1 = 50$$

$$MV1 = \begin{pmatrix} 0.708 & 1 \\ -0.246 & 1 \end{pmatrix} \quad \text{deg1} = \begin{pmatrix} 0.066 & 1 \\ -0.082 & -1 \end{pmatrix}$$

$$Imax2 = 60.005 \quad \Delta e2 = 9.966 \times 10^{-3}$$

$$MV2 = 0 \quad \text{deg2} = 0$$

$$Imax3 = 250.001 \quad \Delta e3 = -0.017$$

$$Imax4 = 5000 \quad \Delta e4 = -5.343 \times 10^{-3}$$

$$MV3 = \begin{pmatrix} 0.855 & -1 \\ -0.638 & 1 \end{pmatrix} \quad \text{deg3} = \begin{pmatrix} 0.036 & 1 \\ -0.044 & -1 \end{pmatrix}$$

$$\frac{\Delta e4_BC_S1_{2,0}}{MV} = -10.686$$

$$MV4 = \begin{pmatrix} 0.094 & 1 \\ -0.117 & -1 \end{pmatrix} \quad \text{deg4} = \begin{pmatrix} 0.071 & -1 \\ -0.058 & 1 \end{pmatrix}$$

$$MV5 = \begin{pmatrix} 4.686 & -1 \\ -3.757 & 1 \end{pmatrix} \quad \text{deg5} = \begin{pmatrix} 0.073 & 1 \\ -0.175 & -1 \end{pmatrix}$$

$$\min(\text{stack}(\text{am}, \text{ph})) = 6.896 \times 10^{-4}$$

$$\min(\text{am}) = 1.054 \times 10^{-3} \quad \min(\text{ph}) = 6.896 \times 10^{-4}$$



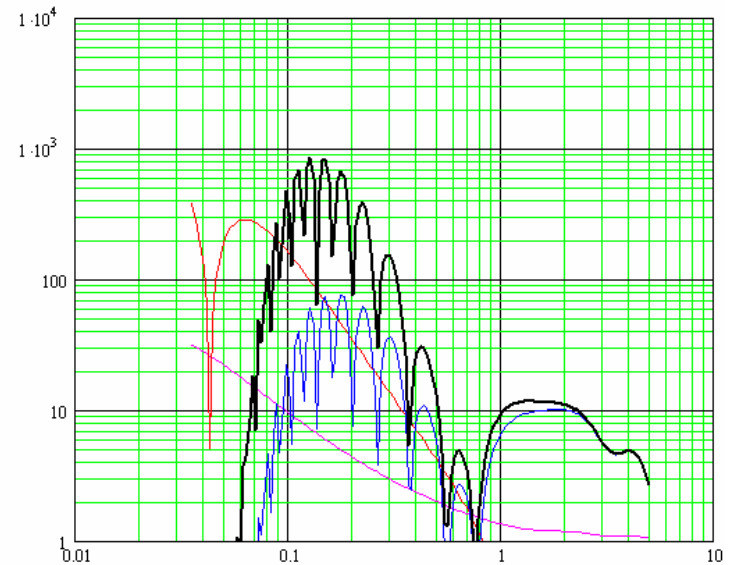
Z(BC1 to BC2) is scaled with $(500\text{MeV} / E_BC1)^{**2}$
 Z(BC2 to ...) is scaled with $(2000\text{MeV} / E_BC2)^{**2}$

$$T_S1(BC_S1) \cdot \begin{pmatrix} 0 \\ E_{\text{rms}} \end{pmatrix} = \begin{pmatrix} 2.279 \times 10^{-6} \\ 7.275 \times 10^3 \end{pmatrix} \quad I_{\text{rms}} = 273.255$$

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$$\frac{E_{ne4}}{MV} = 1.75 \times 10^4 \quad \frac{r56_4}{0.001} = 0.84 \quad C4 = 0.97952$$

$$E_{\text{rms}} = 1 \times 10^4 \quad C_{\text{tot}} \cdot E_{\text{rms}} = 1 \times 10^6$$



n3BC (rf-bc-rf-rf-bc-rf-bc-rf)

compression with Dog (t566=1m), BC1, BC2

$$BC_S1 = \begin{pmatrix} 1.3 \times 10^8 & -0.03 & 1.25 \\ 4 \times 10^8 & -0.08 & 4 \\ 2 \times 10^9 & -0.0836743 & 100 \end{pmatrix}$$

$$\frac{rf^{(0)}}{MV} = \begin{pmatrix} 133.815 \\ 0 \\ 374.44 \\ 111.601 \\ 1.625 \times 10^3 \end{pmatrix}$$

$$\frac{rf^{(1)}}{deg} = \begin{pmatrix} 13.714 \\ 0 \\ -18.318 \\ 139.98 \\ 10 \end{pmatrix}$$

$$QT = \begin{pmatrix} 0 & 0 \\ 1.034 & 4.55 \end{pmatrix}$$

$$Imax1 = 50$$

$$MV1 = \begin{pmatrix} 0.164 & -1 \\ -0.13 & 1 \end{pmatrix} \quad deg1 = \begin{pmatrix} 0.049 & 1 \\ -0.06 & -1 \end{pmatrix}$$

$$Imax2 = 62.698 \quad \Delta e2 = -0.016$$

$$MV2 = 0 \quad deg2 = 0$$

$$Imax3 = 250.557 \quad \Delta e3 = -0.018$$

$$Imax4 = 5000 \quad \Delta e4 = -5.442 \times 10^{-3}$$

$$MV3 = \begin{pmatrix} 0.549 & -1 \\ -0.432 & 1 \end{pmatrix} \quad deg3 = \begin{pmatrix} 0.041 & 1 \\ -0.05 & -1 \end{pmatrix}$$

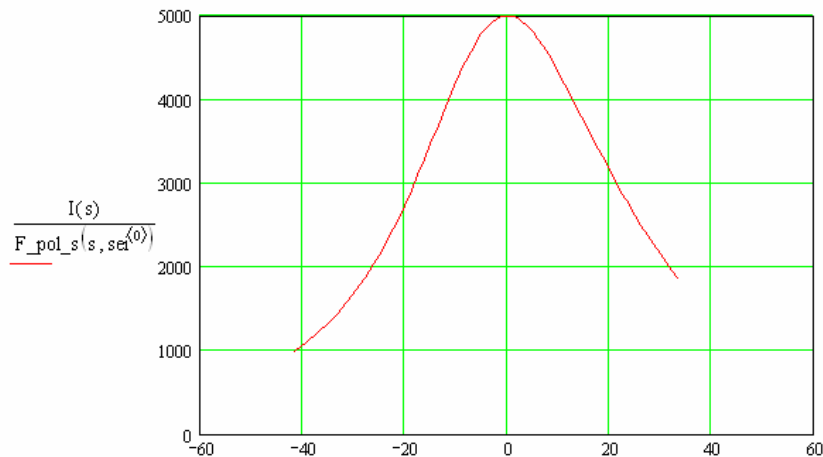
$$\frac{\Delta e4 \cdot BC_S1_{2,0}}{MV} = -10.883$$

$$MV4 = \begin{pmatrix} 0.11 & 1 \\ -0.138 & -1 \end{pmatrix} \quad deg4 = \begin{pmatrix} 0.069 & -1 \\ -0.056 & 1 \end{pmatrix}$$

$$MV5 = \begin{pmatrix} 4.655 & -1 \\ -3.73 & 1 \end{pmatrix} \quad deg5 = \begin{pmatrix} 0.078 & 1 \\ -0.179 & -1 \end{pmatrix}$$

$$\min(\text{stack}(\text{am}, \text{ph})) = 7.936 \times 10^{-4}$$

$$\min(\text{am}) = 1.096 \times 10^{-3} \quad \min(\text{ph}) = 7.936 \times 10^{-4}$$



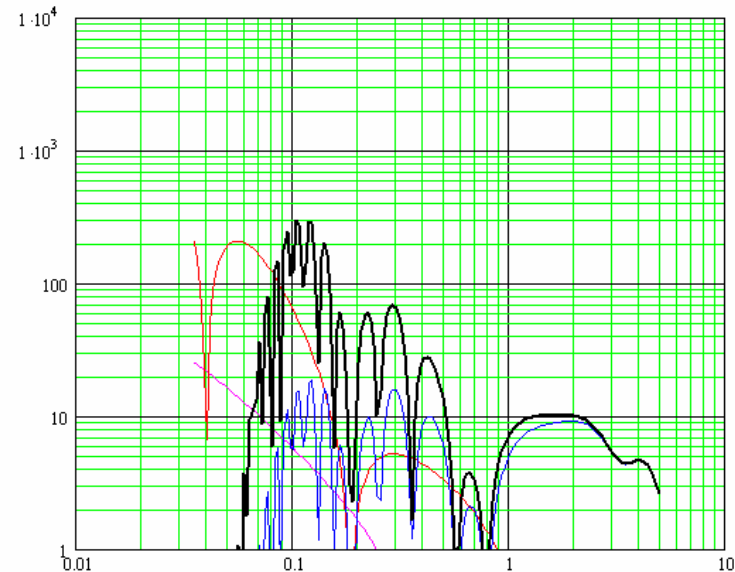
Z(BC1 to BC2) is scaled with $(500\text{MeV} / E_{BC1})^{**2}$
 Z(BC2 to ...) is scaled with $(2000\text{MeV} / E_{BC2})^{**2}$

$$T_S1(BC_S1) \cdot \begin{pmatrix} 0 \\ E_{rms} \end{pmatrix} = \begin{pmatrix} 2.246 \times 10^{-6} \\ -1.987 \times 10^4 \end{pmatrix} \quad Irms = 93.423$$

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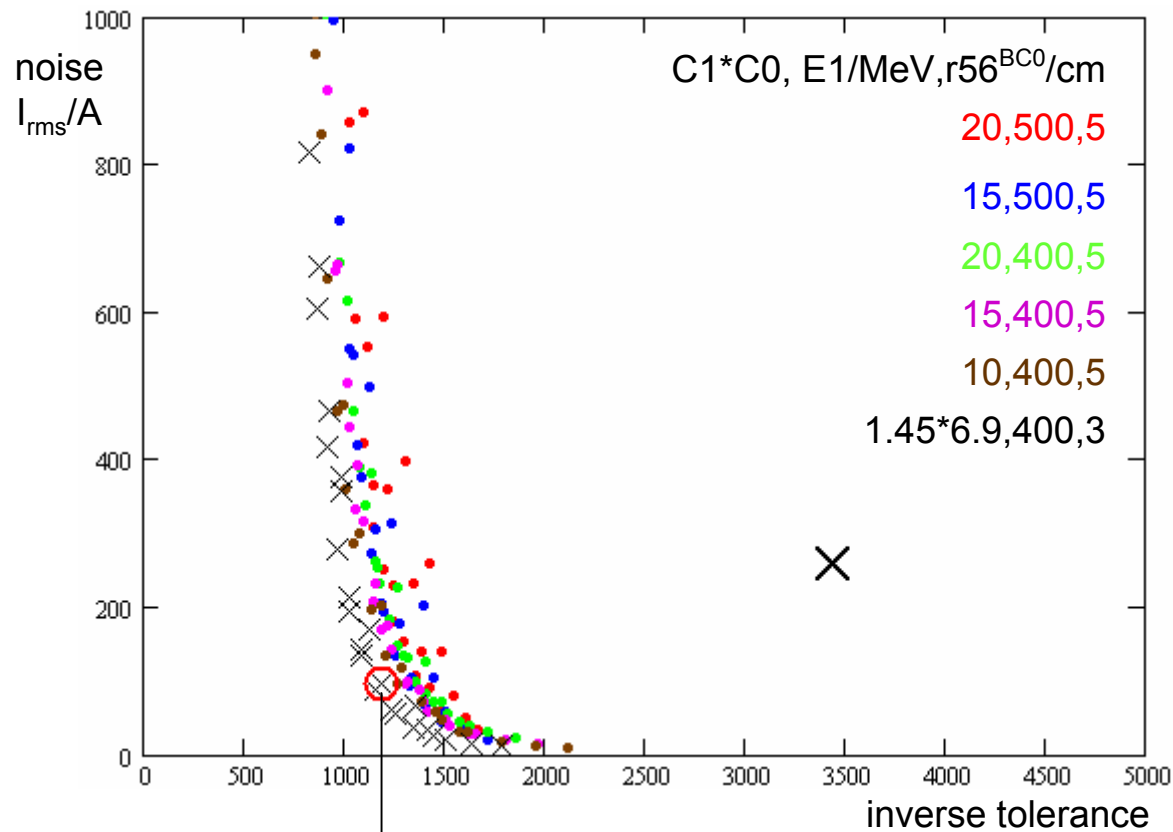
$$\frac{Ene4}{MV} = 1.75 \times 10^4 \quad \frac{r56_4}{0.001} = 0.84 \quad C4 = 0.97867$$

$$E_{rms} = 1 \times 10^4 \quad C_{tot} \cdot E_{rms} = 1 \times 10^6$$



3BC (rf-rf-bc-rf-rf-bc-rf-bc-rf)

const.: $E_0=130\text{MeV}$, E_0'' , E_0''' , (E_1) , E_2 , E_2'' , E_2''' , r_{56}^{coll} , $C_0=1.5$, (C_1) , $C_1 \cdot C_2$
 tuned: E_1' , E_2' , $r_{56}^{\text{BC}2}$, parameter: $r_{56}^{\text{BC}1}$, $\varphi^{\text{L}2}$



$E_1 = 400 \text{ MeV}$
 $r_{56\text{BC}0} = 30\text{mm}$, $C_0=1.45$
 $r_{56\text{BC}1} = 90\text{mm}$, $C_1=6.9$
 $r_{56\text{BC}2} = 45\text{mm}$, $C_2=10$
 $\varphi^{\text{L}2} = 10 \text{ deg}$
 $\text{min}(\text{ampl_tol}) = 0.088\%$
 $\text{min}(\text{phas_tol}) = 0.048 \text{ deg}$
 noise: $I_{\text{rms}} = 97 \text{ A}$



compression with BC1 ... BC3

$$BC_S1 = \begin{pmatrix} 1.3 \times 10^8 & -0.03 & 1.45 \\ 5 \times 10^8 & -0.09 & 6.8965517 \\ 2 \times 10^9 & -0.045018 & 100 \end{pmatrix} \quad \frac{rf^{(0)}}{MV} = \begin{pmatrix} 169.7 \\ 30.478 \\ 403.515 \\ 58.608 \\ 1.523 \times 10^3 \end{pmatrix} \quad \frac{rf^{(1)}}{deg} = \begin{pmatrix} 19.047 \\ -176.141 \\ -6.716 \\ 121.642 \\ 10 \end{pmatrix}$$

$$QT = \begin{pmatrix} 0.871 & 0 \\ -0.248 & 2.6 \end{pmatrix}$$

$$Imax1 = 50 \quad MV1 = \begin{pmatrix} 0.416 & 1 \\ -0.485 & -1 \end{pmatrix} \quad deg1 = \begin{pmatrix} 0.047 & 1 \\ -0.057 & -1 \end{pmatrix}$$

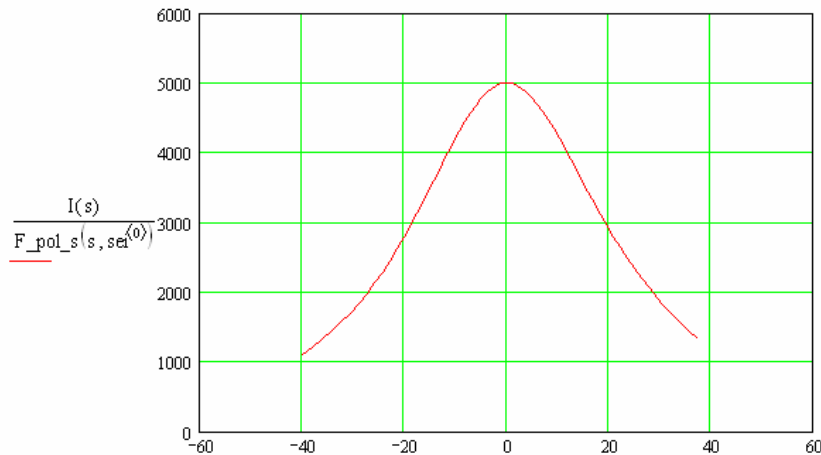
$$Imax2 = 72.542 \quad \Delta e2 = -0.025 \quad MV2 = \begin{pmatrix} 1.098 & -1 \\ -0.583 & 1 \end{pmatrix} \quad deg2 = \begin{pmatrix} 0.101 & -1 \\ -0.082 & 1 \end{pmatrix}$$

$$Imax3 = 500.046 \quad \Delta e3 = -0.016 \quad MV3 = \begin{pmatrix} 0.394 & -1 \\ -0.32 & 1 \end{pmatrix} \quad deg3 = \begin{pmatrix} 0.044 & 1 \\ -0.053 & -1 \end{pmatrix}$$

$$Imax4 = 5000 \quad \Delta e4 = -4.802 \times 10^{-3} \quad MV4 = \begin{pmatrix} 0.094 & 1 \\ -0.117 & -1 \end{pmatrix} \quad deg4 = \begin{pmatrix} 0.356 & -1 \\ -0.294 & 1 \end{pmatrix}$$

$$\frac{\Delta e4 \cdot BC_S1_{2,0}}{MV} = -9.604 \quad MV5 = \begin{pmatrix} 9.079 & -1 \\ -7.412 & 1 \end{pmatrix} \quad deg5 = \begin{pmatrix} 0.394 & 1 \\ -0.502 & -1 \end{pmatrix}$$

$$\min(\text{stack}(\text{am}, \text{ph})) = 8.477 \times 10^{-4} \quad \min(\text{am}) = 8.836 \times 10^{-4} \quad \min(\text{ph}) = 8.477 \times 10^{-4}$$



$$Ene1 = 1.3 \times 10^8$$

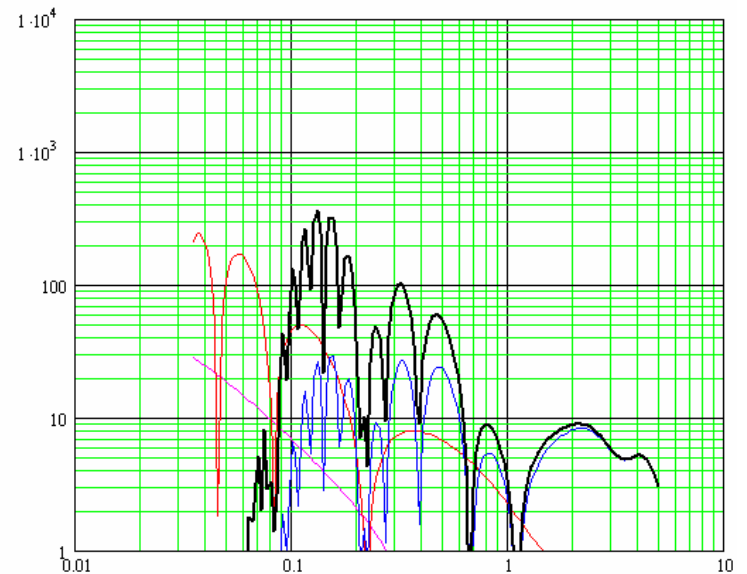
Z(BC1 to BC2) is scaled with $(500\text{MeV} / E_BC1)^{**2}$
 Z(BC2 to ...) is scaled with $(2000\text{MeV} / E_BC2)^{**2}$

$$T_S1(BC_S1) \cdot \begin{pmatrix} 0 \\ E_{rms} \end{pmatrix} = \begin{pmatrix} 2.545 \times 10^{-6} \\ -1.774 \times 10^4 \end{pmatrix} \quad Irms = 95.371$$

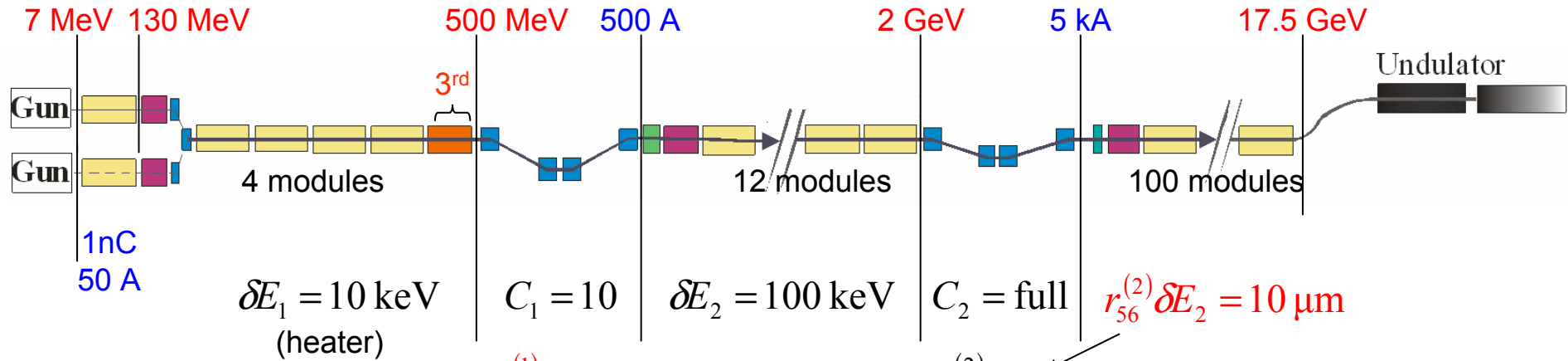
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$$\frac{Ene4}{MV} = 1.75 \times 10^4 \quad \frac{r56_4}{0.001} = 0.84 \quad C4 = 0.98117$$

$$E_{rms} = 1 \times 10^4 \quad C_{tot} \cdot E_{rms} = 1 \times 10^6$$



rollover compression



$$r_{56}^{(1)} = -0.1 \text{ m}$$

$$e'_1 = \frac{-9}{\text{m}} \xrightarrow{(500 \text{ MeV})} e' = \frac{-90}{\text{m}}$$

$$r_{56}^{(2)} = -0.2 \text{ m}$$

$$e' = \frac{-22.5}{\text{m}} + e'_{L2} = \frac{1}{r_{56}^{(2)}}$$

$$e'_{L2} = \frac{+17.5}{\text{m}} = \frac{1.5 \text{ GeV}}{2 \text{ GeV}} k \tan \varphi_{L2}$$

$$\varphi_{L2} = 40.5 \text{ deg}$$

$$U_{L2} = 1.973 \text{ GV}$$

min(phas_tol) = 0.055 deg

