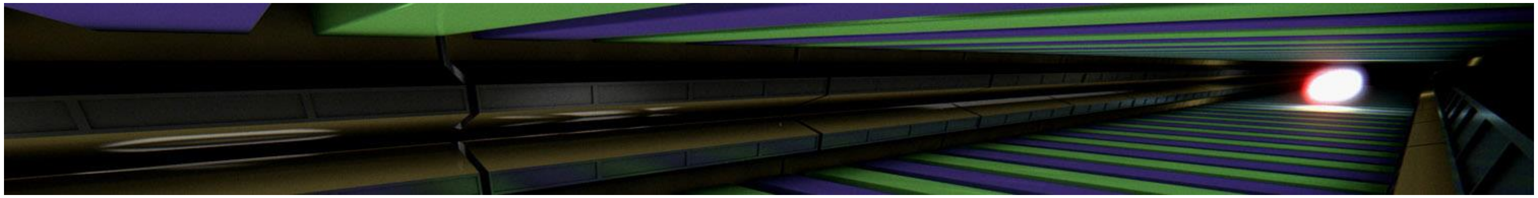

Analysis of linear taper scans and comparison with energy loss measurments

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DESY Beam Dynamics Meeting

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Standard scaling

$$\lambda = \frac{\lambda_{\mathrm{w}}(1+K^2)}{2\gamma^2}$$

$$\hat{C} = \left(k_{\mathrm{w}} - \frac{\omega(1+K^2)}{2c\gamma^2}\right)\Gamma^{-1}$$ detuning parameter

$$\hat{z} = \Gamma z$$ normalized longitudinal coordinate

$$\Gamma = 4\pi\rho/\lambda_{\mathrm{w}}$$ gain parameter (≈inverse gain length at resonance)

Now let K be linear function of z:

$$\hat{C}(\hat{z}) = \beta\hat{z}$$

$$\beta = -\frac{\lambda_{\mathrm{w}}}{4\pi\rho^2}\frac{K(0)}{1+K(0)^2}\frac{dK}{dz}$$

Energy loss

- Spontaneous undulator radiation (can be precisely calculated)

$$dE/dz = 2r_e^2\gamma^2 H(z)^2/3$$

- Wakefields (depend on how we compress the bunch)

$$\beta = -\frac{\lambda_{\mathrm{w}}}{4\pi\rho^2}\left[\frac{K(0)}{1+K(0)^2}\frac{dK}{dz} - \frac{1}{\gamma(0)}\frac{d\gamma}{dz}\right]$$

Important notice

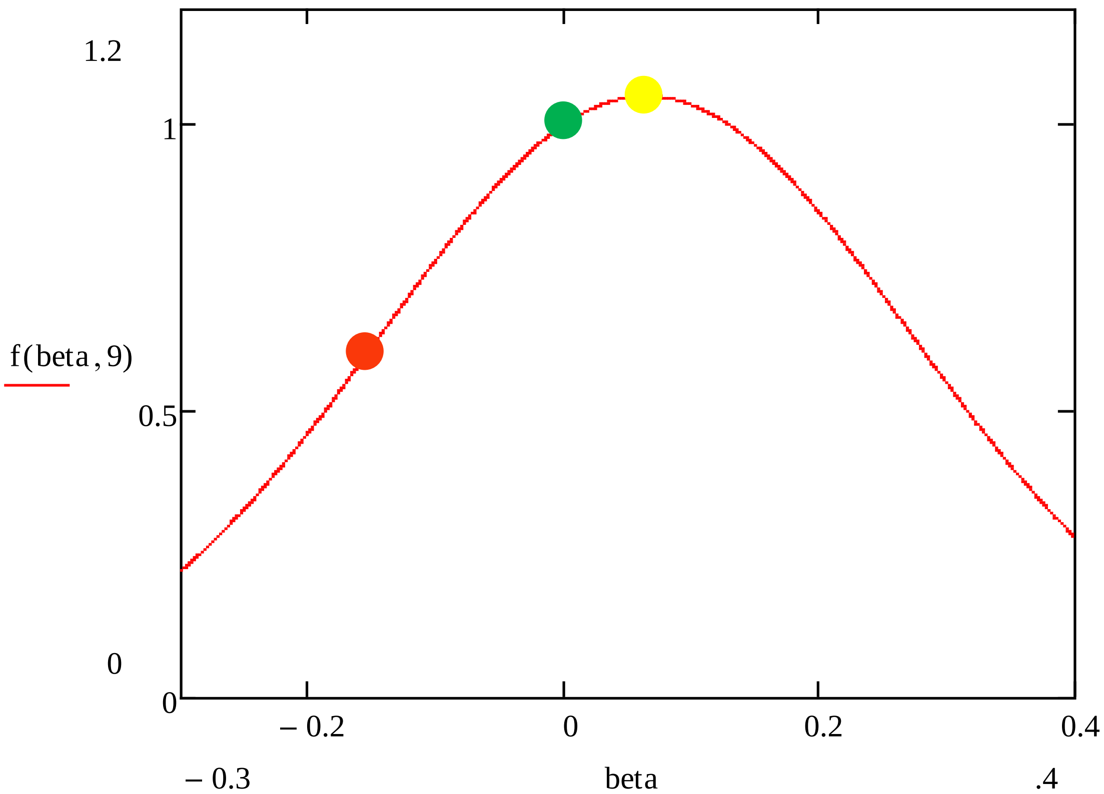
- One can observe some confusion in the logbook: sometimes relative energy loss is understood as relative change of K required for compensation.
- However, there is a coefficient (here again K is rms value):

$$\frac{\Delta K}{K} = \frac{1+K^2}{K^2}\frac{\Delta\gamma}{\gamma}$$

- For 14 GeV and 9 keV we have: K_peak = 2.88, then K = 2.04 and

$$\frac{\Delta K}{K} = 1.24\frac{\Delta\gamma}{\gamma}$$

Exponential gain regime



- maximum
- full compensation
- zero taper (uncompensated energy loss)

$$< \hat{\eta} > \simeq \frac{\exp\left\{\sqrt{3}\hat{z}\left[1-(\beta\hat{z}/6)^2/3\right]+\beta\hat{z}/6\right\}}{3^{5/4}\sqrt{\pi\hat{z}}N_c}$$

First obtained (with an error):

Z. Huang and G. Stupakov, Phys. Rev. ST-AB, **8**(2005)040702

Error corrected:

E. Saldin, E. Schneidmiller, M. Yurkov, Phys. Rev. ST-AB 9(2006)050702

Method

- Linear taper scan should be done at the level of ~ 30 uJ (for 250 pC and ~ 10 keV) in a sufficiently wide range of taper values (typically from -10 to +30 in a step of 2, in units of 1E-5 per cell for K value).
- For the fitting formula use the value z=9 (this corresponds to 7.8 field gain lengths) to get rid of extra parameter. It was checked that changing z by plus minus one gives few per cent correction to final result.
- Fitting formula:

$$y = a \exp\left(b(x - x_0) - 7.8b(x - x_0)^2\right)$$

- Find the point of full compensation by comparison of the fit result with the theoretical curve (the simplest algorithm: multiply maximum value of the fit by 0.95 and find the corresponding point on the left side).
- Note that no assumptions on beam parameters and number of undulator segments are made

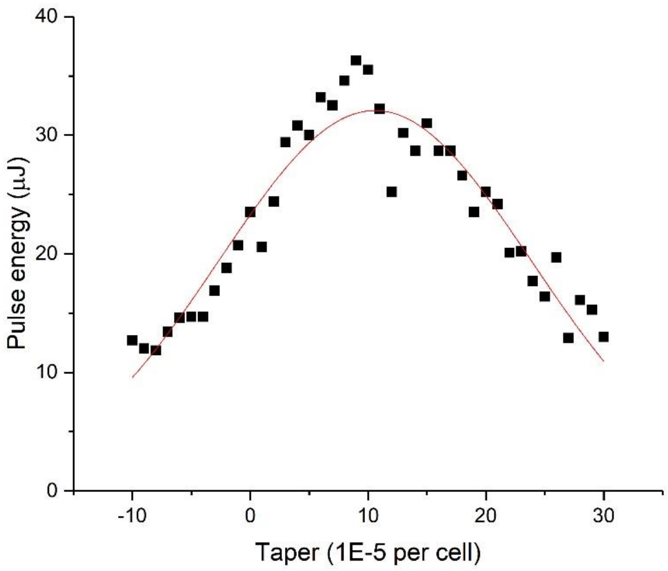
Practical considerations

- Scans were done last week in the range ~ 10-100 uJ. However, for ~ 100 uJ at 250 pC we enter nonlinear regime. At ~ 10 uJ the XGMs are at the limit. For studies the screens (or maybe integrated HIREX?) can be used. For routine scans one can try to subtract background from XGM (like Winni did with gain curve) or use HAMP?
- First measurments indicate that probably working in the range 30-100 uJ should be ok.
- Finding a position of maximum is relatively robust operation, it weakly depends on backgrounds, offsets etc. Correction towards "green dot" depends on curvature that might be influenced by background (but error in correction is not big in absolute sense).
- More tests are needed to find a comfortable and reliable regime.

Scans in SASE1

M. Scholz, 14.07.20 (night shift)

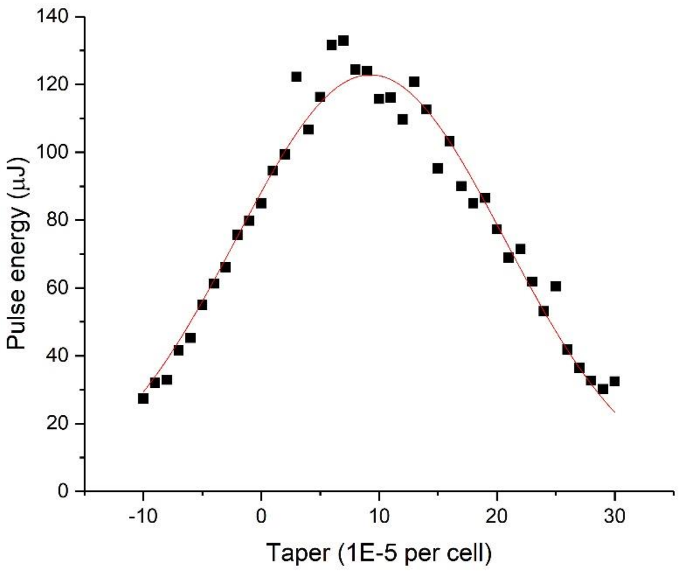
XGM, 30 uJ



6.4E-5

the same for HAMP

XGM, 120 uJ

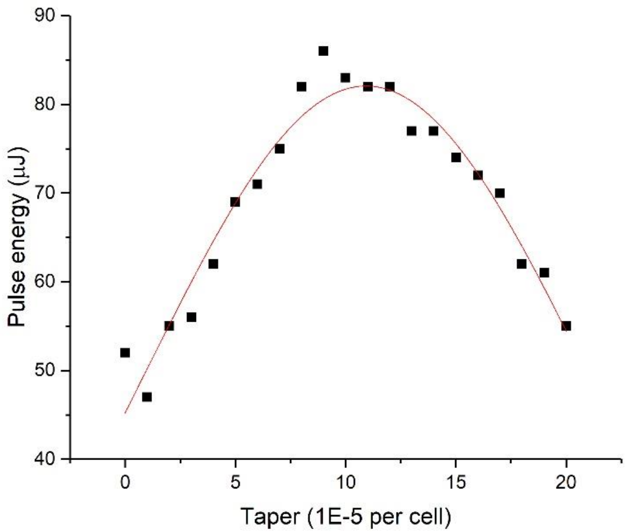


5.6E-5

Scans in SASE2

F. Brinker, O. Koschig
14.07.20 (afternoon shift)

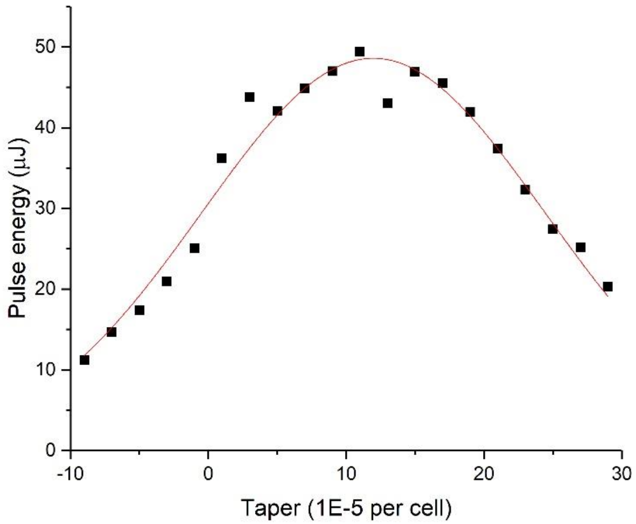
XGM, 80 uJ



7.8E-5

M. Scholz
14.07.20 (night shift)

XGM, 50 uJ



8.0E-5

Summary of taper scans

SASE1

Measurement device	Pulse energy, uJ	Point of full compensation (1E-5)
XGM	30	6.4
HAMP	30	6.4
XGM	120	5.6

SASE2

Measurement device	Pulse energy, uJ	Point of full compensation (1E-5)
XGM	50	8.0
XGM	80	7.8

Energy loss estimates

Undulator	dK/K per cell (1E-5)	dE/E per cell (1E-5)	dE per cell (keV)	SR loss per cell (keV)	Wakefield loss per cell (keV)	Comments
SASE1	6.4	5.2	720	370	350	Phase shifters not adjusted
SASE2	8.0	6.4	900	370	530	Phase shifters adjusted (K-mono)

SR loss was unchecked in the undulator server for all scans

Standard tool for the control room?

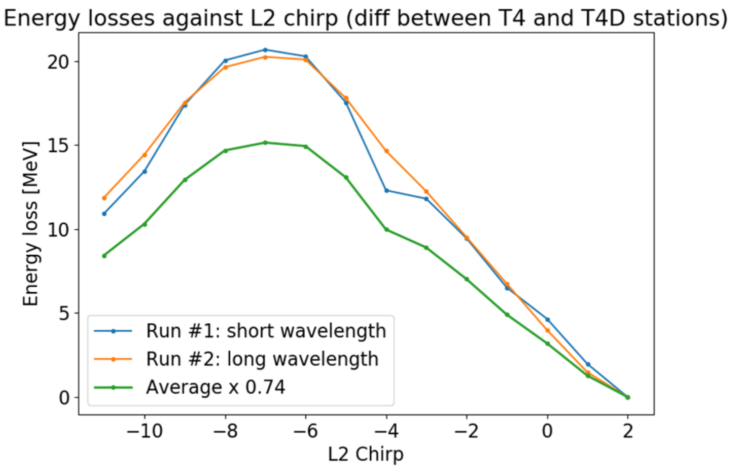
- Write a simple script doing scans and fitting the results; can be a standard tool for the control room (takes about 10 min per scan);
- Do extensive checks (repeat several times and find the spread, try different intensity levels, different photon energies, compression etc.);
- The tool is supposed not only to find compensation of energy loss in lasing part of the bunch but also to take away systematic offsets of phase shifters (and undulator gaps if remain). Can be especially useful for change of photon energy.
- Choice between full compensation point (green dot) and the maximum (yellow dot) will practically not affect FEL performance. One may need to slightly adjust start and/or coefficient of quadratic taper. Any point between yellow and green would be ok.

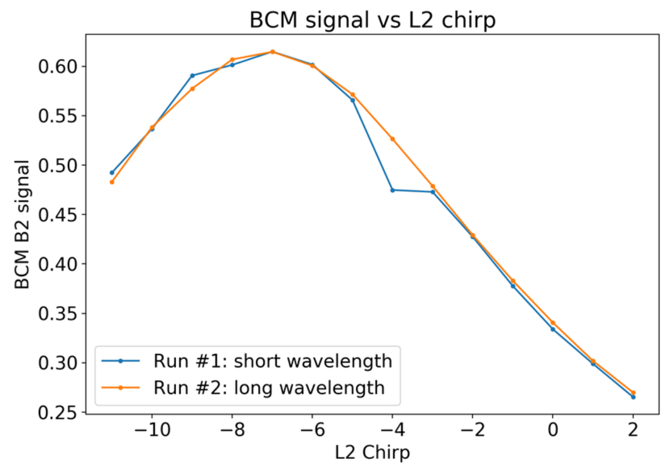
Comparison with other measurements

Calibrated energy measurement (T4D)

- Energy measurement in T4D was calibrated using SR loss in SASE3
- Energy feedback was used to keep a given energy in T4 during scans
- Corrected energy change in T4D gives wakevield loss in SASE3 vs L2 chirp

Wakefields energy loss measurement. LH atten. 1200.

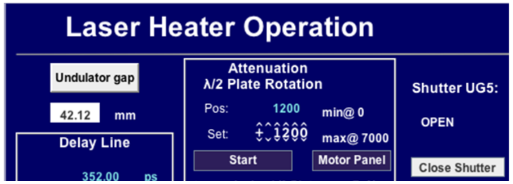




S. Tomin

11.07.20

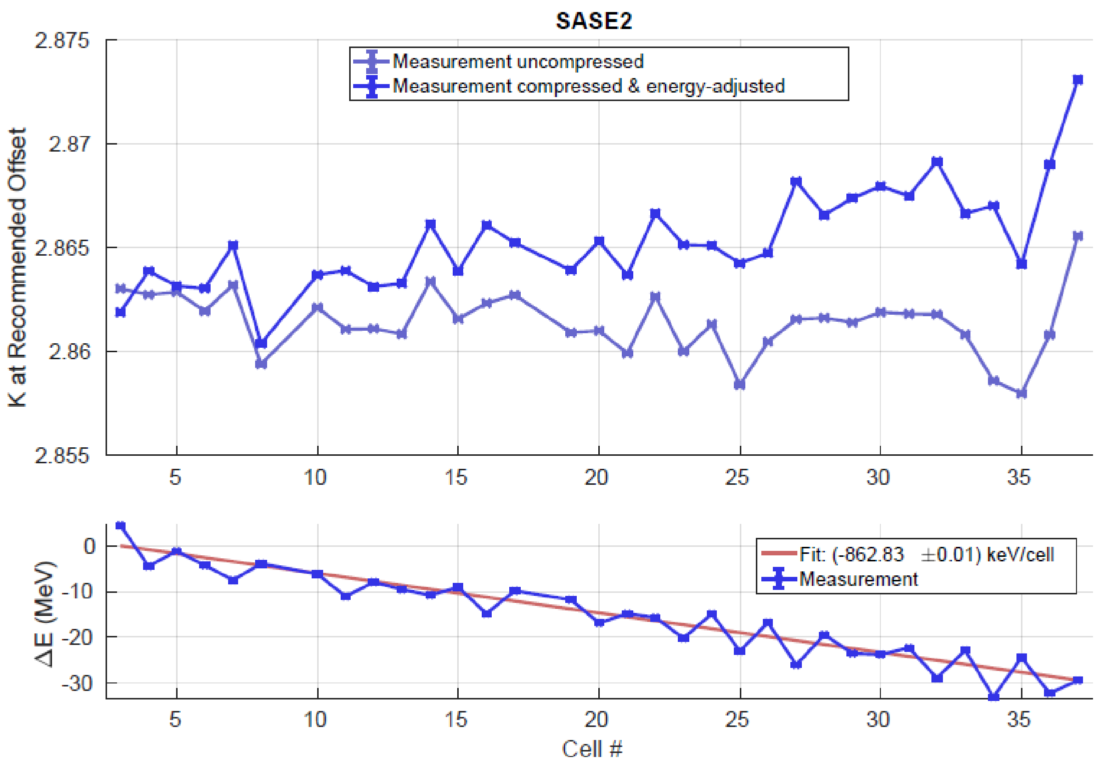
Presented last week at BDM



Taking into account calibration factor = 0.83,
Maximum energy loss is 16.6 MeV.

K-mono measurement

- K-values of all segments are measured for compressed and uncompressed beams
- Initial offset is removed and the difference is fitted with a straight line and converted to energy change



L. Fröhlich
W. Freund
12.07.20

Some remarks before comparison

- Measurements were done for different machine settings so that direct comparison is impossible; next time it should be done for the same machine!
- Speculation: wakefield loss might be correlated with BC2 pyro (at least for the North branch) independently of machine settings (LH, chirps etc.) but this should be studied next time;
- Taper scans can give inaccurate estimate for enery loss if the undulator is not properly tuned (systematic offsets of gaps and phase shifters remain). SASE2 was tuned by Frank with K-mono (the part where measurements were done), SASE1 not;
- Taper scans give average energy loss of the lasing part, two other methods – of the whole bunch.

Comparison of the three measurements

South branch

Method	Energy loss per cell due to wakefields	BC2 pyro	Date	Comments
K-mono	860 keV	0.5	12.07.20	Average loss; lasing conditions
Taper scans	530 keV	0.53	14.07.20	Energy loss of lasing part; phase shifters adjusted with K-mono

North branch

Method	Energy loss per cell due to wakefields	BC2 pyro	Date	Comments
K-mono	660 keV	0.5	12.07.20	SASE1; average loss; lasing conditions
Taper scans	350 keV	0.53	14.07.20	SASE1; energy loss of lasing part; phase shifters not adjusted
SR calibrated energy measurement	~ 400 keV	0.5	11.07.20	SASE3; average loss; non-lasing conditions; rough estimate from Sergey's plots

Effects in T1 arc?

- Maybe it is too early to discuss, we need more measurements to be sure. However, it seems (from two independent measurements) that wakefield losses are higher in SASE2 than in SASE1 for the same compression settings.
- Speculation 1: compression in the arc

Ideally, the R56 is zero. Can it be sufficiently large for additional compression in a non-ideal case (dispersion is out of control)?

- Speculation 2: CSR microbunching

Change of macroscopic shape of the bunch due to CSR in the arc is practically impossible (in an ideal case), but how about CSR induced microbunching instability? If there is a gain, microbunching can be stronger in the South branch. Can this lead to enhanced wakefield loss that is measurable? Do we have a sufficient impedance for that?

Some remarks for future studies

- Improve the methods. For example, for K-mono the calibration of energy measurements in T4D or T5D vs SR from undulators is desirable (then energy drifts would be properly accounted for). Also, direct check of the method using SR in upstream segments would be nice;
- Do all measurements for the same machine settings;
- Repeat them for different compression regimes (but the same in both branches);
- Extract as much information as possible about the machine (pyros, CRISP, TDS, LH induced energy spread ...) and SASE (taper scans at different positions, gain curves, different detectors incl. screens and HIREX ...);
- Do extensive simulations and end up with a conclusive picture;
- Igor is supposed to coordinate this according to Torsten‘s list.