K-band lineariser
from a beam-dynamics perspective

Andrea Latina (CERN)

XLS First Midterm Review - Trieste, 19-20 June 2018

Target parameters and machine schematics

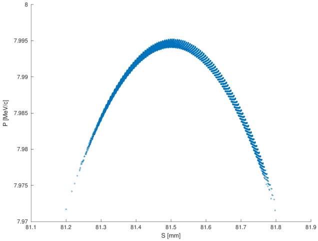
	σ_z	$\langle E \rangle$
Initial	131.3 μm	8 MeV
After K-band	-	160 MeV
After BC1	64 μm	-
After Linac1	-	1.6 GeV
After BC2	8 μm	-
After Linac2	-	4.6 GeV

Machine schematics:

$$\text{Gun} \Rightarrow \underbrace{\text{X0}}_{\text{X band}} \Rightarrow \underbrace{\text{K}}_{\text{K band}} \Rightarrow \text{BC1} \Rightarrow \underbrace{\text{X1}}_{\text{X band}} \Rightarrow \text{BC2} \Rightarrow \underbrace{\text{X2}}_{\text{X band}}$$

Initial particle distribution

From an X-band gun, particle distribution courtesy of Avni Aksoy:



Characterisation of the particle distribution:

$$P \text{ [MeV/c]} = m\,(S \text{ [mm]})^2 + nS \text{ [mm]} + P_{\text{max}} \text{ [MeV/c]}$$

gives:

$$\begin{aligned} m &= -0.253291 \ \mathrm{MeV/c/mm^2} \\ n &= 0 \ \mathrm{MeV/c/mm} \\ P_{\text{max}} &= 7.9945 \ \mathrm{MeV/c} \end{aligned}$$

$Q = 250$ pC; $\sigma_z = 131.3\ \mu$m; $\sigma_{P_{\text{uncorrelated}}} = 0.3$ keV/c.

Optimisation procedure

Multivariate non-linear optimisation, tracking performed using a dedicated 1-D tracking code that implements

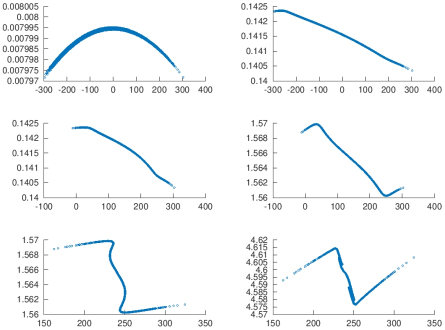
- Acceleration
$$E \Leftarrow E + eV_{RF}\cos\left(\phi_{RF} - K_{RF}z\right) - \Delta E_{\text{long wakes}}$$
- Longitudinal wakefields
$$\Delta E_{\text{long wakes}} = Ne^2 L_{\text{RF}} \int_z^{\infty} W_{\parallel}\left(z' - z\right)\rho\left(z'\right)dz'$$
- $W_{\parallel}\left(z' - z\right)$ = Karl Bane's formulæ, with aperture a, gap length g, and cell length l:
    - X-band (Frascati structure):
    $$a = 3.20 \text{ mm}; \quad g = 6.495 \text{ mm}; \quad l = 8.32 \text{ mm}$$
    - K-band:
    $$a = 10 \text{ mm, or } 2.5 \text{ mm}; \quad g = g_{X\text{-band}}/3; \quad l = l_{X\text{-band}}/3$$
    86 cells
- Magnetic compressors: $R_{56} \neq 0$. [For now I assumed $T_{566} = 0$ (spoiler alert: all solutions seem to favour arcs, rather than chicanes)]

X-band and K-band wakefields

X0_phase = 8.7481 deg
X1_phase = 4.7167 deg
X2_phase = 25.724 deg
K_phase = 292.57 deg
K_voltage = 10.290 MV
R0_56 = 0.020104 m
R1_56 = 0.031820 m
X0_voltage = 0.13179 GV
X1_voltage = 1.4316 GV
X2_voltage = 3.2947 GV

Plot legend:

after gun	after k-band
after BC1	after X1
after BC2	after X2



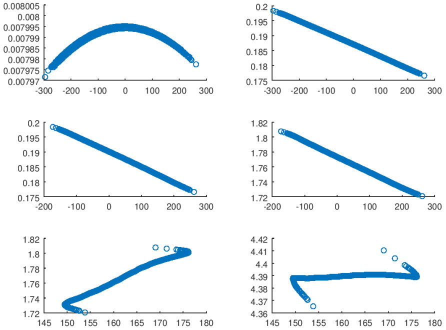
Final peak-to-peak energy spread $=-0.4\%..0.4\%$

X-band and K-band wakefields $a_K = 10$ mm

XLS.X0_phase = -32.77 deg
XLS.X0_voltage = (200.0) MV
XLS.K_phase = 313 deg
XLS.K_voltage = (17.7) MV
XLS.BC1_R56 = 0.001; m
XLS.X1_phase = -16.82; deg
XLS.X1_voltage = 1.661; GV
XLS.BC2_R56 = 0.009; m
XLS.X2_phase = -49; deg
XLS.X2_voltage = 4.237; GV

Plot legend:

after gun	after k-band
after BC1	after X1
after BC2	after X2



Final relative energy spread =0.04%

Effects of wakefields

Short-range wakefields scale as

$$W_{\parallel}(s) \approx \frac{Z_0 c}{\pi a \sqrt{a^2 + 8.6 s \lambda_{\mathrm{rf}}}}$$

$$W_{\perp}(s) \approx \frac{2 Z_0 c s}{\pi a^2 \left(a^2 + s \lambda_{\mathrm{rf}}\right)}$$

over the range $s < a/4$ and $0.1 < a/\lambda_{\mathrm{rf}} < 0.2$ (A.Chao, Handbook of Acc. Physics). compating 10 mm and 2.5 mm apertures:

$$W_{\perp,\ 2.5\ \mathrm{mm}} \approx 256 \times W_{\perp,\ 10\ \mathrm{mm}}$$

Impact of longitudinal wakefields:

- correlated energy spread (induce energy chirp)

Impact of transverse wakefields:

- beam-breakup: cured with autophasing (or BNS damping)
- emittance growth due to misalignments

$$\Delta(\gamma\epsilon) \propto \sigma^2_{acc\ mis} \left[N W_{\perp}(2\sigma_z)\right]^2 \langle\beta\rangle \frac{L_{acc}}{2\alpha G} \left[\left(\frac{E_f}{E_i}\right)^{\alpha} - 1\right]$$

α = lattice parameter.

- jitter amplification
  - Cured with strong focusing, tight misalignment tolerances

Summary

- We are in a wakefield-dominated machine (X-band)
- The K-band lineariser helps with the longitudinal phase space, but it dangerously harm the transverse one
  - 2.5 mm aperture has ≈ 256 times $W_\perp$ effect than 10 mm
  - impact on the transverse emittance goes with the square of $W_\perp$
- Numerical simulations will have be performed to check the models, at both 2.5 mm and 10 mm, as these models do not fully apply ($a/\lambda_{\mathrm{rf}} \approx 0.3$ at 2.5 mm, and $a/\lambda_{\mathrm{rf}} \approx 1.16$ at 10 mm)