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OSC of Electron Beams While Cooling Protons

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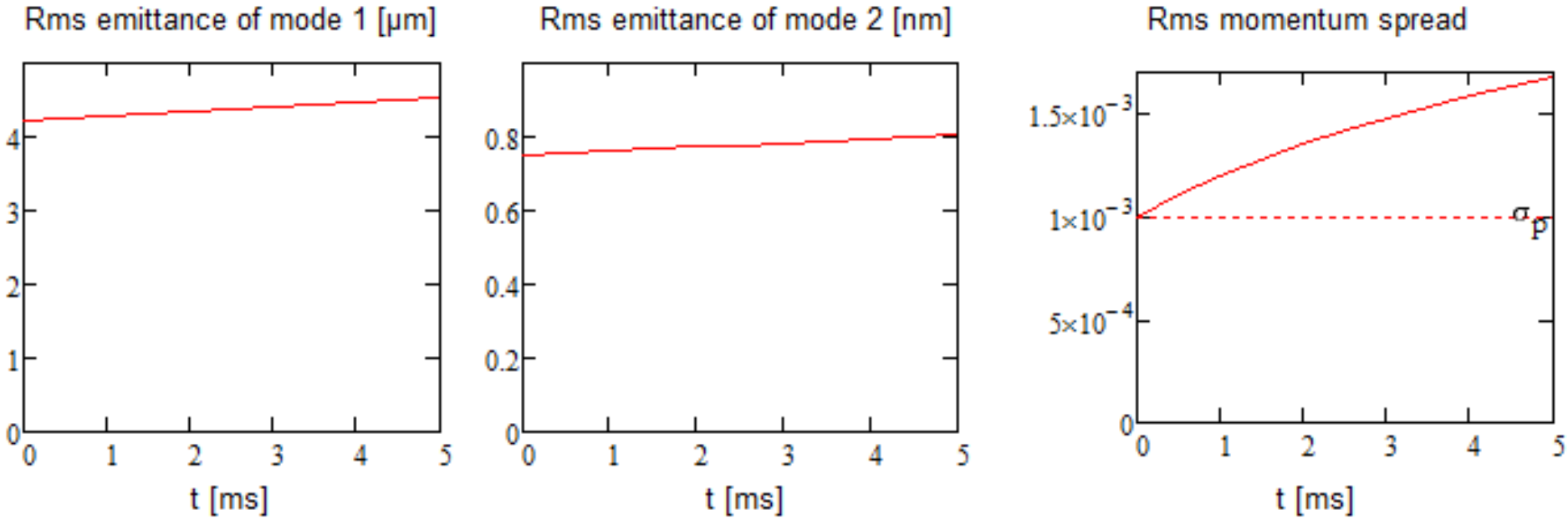
Objectives

- Emittance growth driven by IBS sets the repetition rate in the ring based electron cooling
  - That determines the total power of the induction linac required to support continuous electron cooling



Dependencies of rms mode emittances and momentum spread on time for 100 A electron beam for perturbed optics.

- The IBS emittance growth rates are: (τ_1, τ_2, τ_s)=(56, 82, 2.2) ms
- || heating strongly dominates => we suggest to use only || OSC
  - $\perp$ cooling is greatly complicated by large difference of $\perp$ emittances

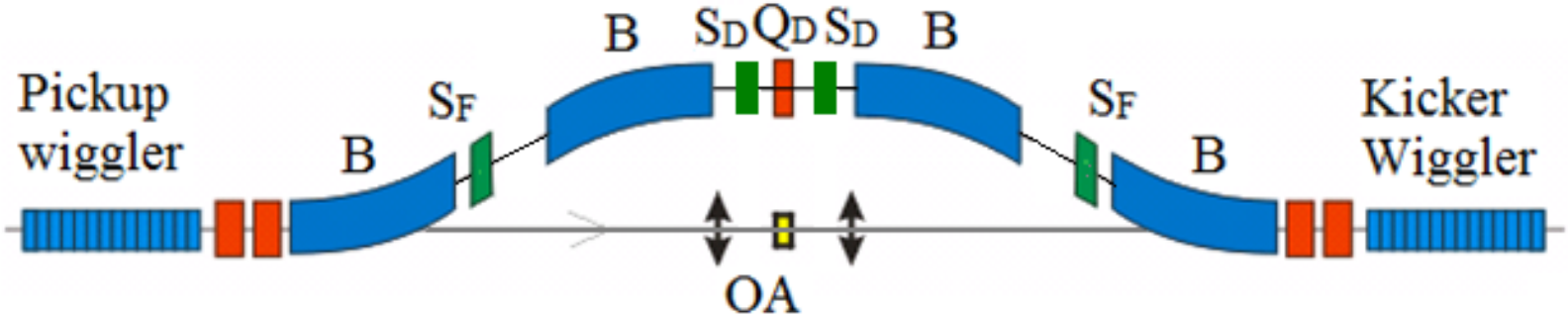
Major Parameters of the OSC

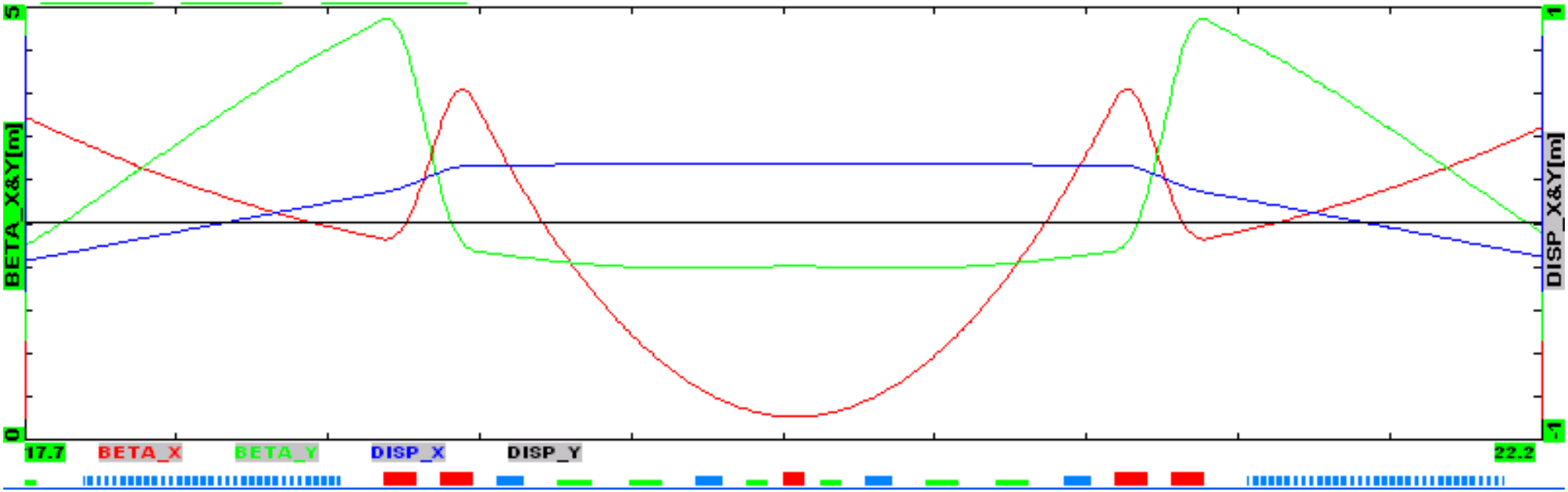
Electron beam energy	75 MeV
Electron beam current	100 A
Electron ring circumference	114 m
Longitudinal OSC acceptance (3σ)	$\pm 3 \cdot 10^{-3}$
Undulator period	23 mm
Number of periods per undulator, n_{per}	43
Undulator length	1 m
Undulator parameter, K	1.0
Peak undulator magnetic field	4.6 kG
Wavelength for forward radiation	0.8 μm
Effective bandwidth of OSC, $(3\mu_{11}^2/n_\sigma^2)\, c/(\lambda_0 n_{per})$	42 THz (11%)
Bandwidth of optical amplifier	20%
Angular acceptance for the radiation, θ_0	3.7 mrad
Optical amplifier gain	32 dB
Optical amplifier power	10 kW

- Beam energy was increased from 50 to 75 MeV to obtain reasonably large undulator period
- Vertical focusing of undulators of ~0.6 m must be accounted in the ring lattice

Differences to the IOTA OSC: Beam Optics

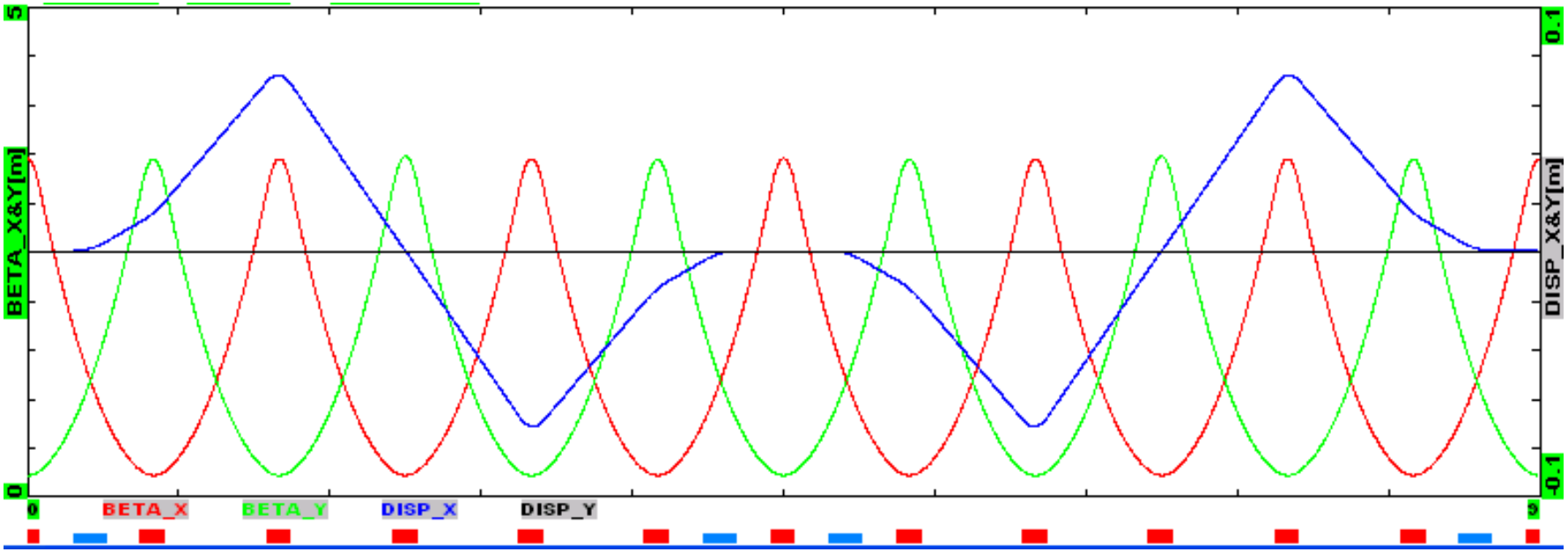
- The wave length is quite close to the IOTA OSC
- Limited space in IOTA for OSC
  - Only simple chicane fits into available space
    - ⇨ Rigid limitation on the optical amplifier delay





Differences to the IOTA OSC: Beam Optics

- Ecool ring has much larger space available for OSC
  - OSC chicane may be built with much larger delay using ideas used for construction of isochronous lines
    - Chicane length: 2m -> 9 m
    - Number of quads: 1 -> 11
      - Optics type: FODO – ~120 deg/cell
    - Optical delay: 0.65 mm -> 6 mm
    - Chicane offset: 20 mm -> 150 mm



Ultimate Cooling Rate

- In IOTA OSC as well as in the original proposal ⊥ size of e-beam is smaller than ⊥ size of radiation
- Then the effective bandwidth of OSC is

$$W = \frac{3\mu_{11}^{\ 2}}{n_\sigma^{\ 2}} \frac{c}{\lambda_0 n_{per}}, \quad \mu_{11} \approx 3.832...$$

and the corresponding maximum emittance cooling rate (at the optimal gain) is

$$\lambda_s \equiv \frac{1}{\sigma_p^{\ 2}} \frac{d}{dt} \sigma_p^{\ 2} = \frac{W}{N}$$

For n_σ=3, λ_0=0.8 μm, n_{per}=43 and the beam current of 100 A we obtain: W = 43 THz, λ_s = 0.18 s^{-1}.
That is much less than the required 200 s^{-1}.

- However, with appropriate focusing the transverse size of the electron beam in both undulators can be set to be much larger than the size of the radiation spot (0.18 mm FWHM).

Ultimate Cooling Rate (continue)

- An increase the transverse rms cross-section of e-beam in undulators to $\sigma_x\sigma_y$=25 mm greatly reduces the number of particles in the sample and enables an achievement of desired cooling rate
  - Vertical focusing in undulator limits further increase of the electron beam size

Conclusions

- Presently, transverse OSC of electron beam in e-cool ring looks unfeasible, due to too large difference of transverse emittances
- However, longitudinal cooling looks feasible and it can reduce the required power of the induction linac by almost an order of magnitude
- OSC for Ecool ring implies significant step forward in OSC experimental techniques
  - The sizes of transverse sample in OSC has to be much smaller than the transverse size of the electron beam in the undulators
  - Significant increase of length of OSC region allows one to achieve much larger delay to be used in the optical amplifier which makes it feasible.
    - That is achieved by almost isochronous optics in the OSC chicane. However, such choice greatly increases difficulties of || particle displacement control on the way from pickup- to kicker-undulator.