INTRABEAM SCATTERING IN HIGH BRIGHTNESS ELECTRON LINACS

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Reference: S. Di Mitri, Phys. Rev. ST – Accel. Beams, 17, 074401 (2014).

Intra-beam scattering (IBS) of a high brightness electron beam in a linac has been studied analytically, and the expectations found to be in reasonable agreement with particle tracking results from the Elegant code. It comes out that, under standard conditions for a linac driving a free electron laser, IBS plays no significant role in the development of microbunching instability. A partial damping of the instability is envisaged, however, when IBS is enhanced either with dedicated magnetic insertions, or in the presence of an electron beam charge density at least 4 times larger than that produced by present photo-injectors.

- Multiple Coulomb scattering tends to redistribute the beam momenta from the transverse degree of freedom to the longitudinal one. This process is called IntraBeam Scattering (IBS) and its longitudinal growth rate may be comparable to the beam damping time in low emittance electron storage rings:

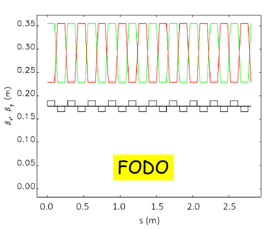
$$\frac{1}{\sigma_\delta}\frac{d\sigma_\delta}{dt} \approx \frac{r_e^2 cN}{8\gamma^2 \varepsilon_{n,x}\sigma_x\sigma_z\sigma_\delta^2}\ln\left(\frac{\Delta\gamma_{\max}}{\Delta\gamma_{\min}}\right) \quad (1)$$

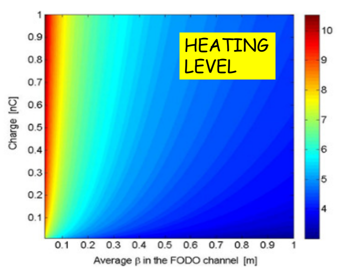
- Eq.1 can be integrated and it yields to the final fractional rms energy spread in the presence of IBS cumulated over the distance Δs

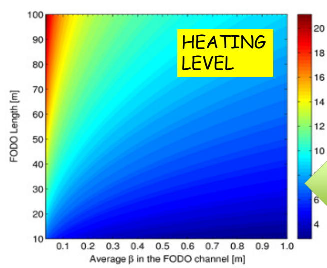
$$\sigma_\delta \approx \sqrt{\sigma_{\delta,0}^2 + \frac{2r_e^2 N}{\gamma^2 \varepsilon_{n,x}\sigma_x\sigma_z}\Delta s} \equiv \sqrt{\sigma_{\delta,0}^2 + \sigma_{\delta,IBS}^2}, \quad (2)$$

LOW-β FODO CHANNEL as an alternative to a LASER HEATER:

- The idea of using IBS to increase the energy spread of an electron bunch traveling in a dedicated FODO channel seems to be attractive for the following reasons:
  - i) IBS heats the beam by avoiding cost, complexities and maintenance of a laser heater system;
  - ii) the heating level is tunable with the quadrupoles' focusing strength;
  - iii) it provides longitudinally uncorrelated energy spread, thus avoiding any side effect associated to the energy modulation induced in a LH at the infrared laser wavelength (e.g., the so-called trickle heating)







ANALYTICAL ESTIMATION:

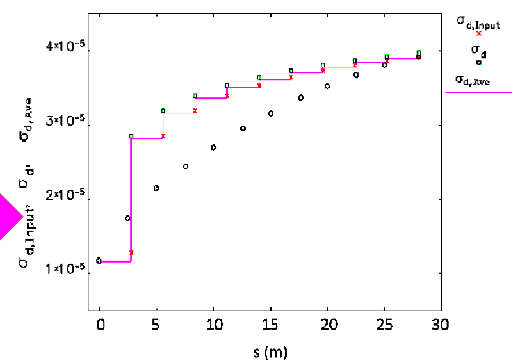
- IBS-induced rms energy spread in keV, in the (β,Q) space for L = 30 m (left), and in the (β,L) space for Q = 500 pC. Both plots are for a beam energy of 150 MeV.
- The beam transverse emittances and the bunch duration are scaled with Q in order to keep the 3-D charge density constant.

Charge	500	pC
Bunch duration, rms	2.5	ps
Norm. slice emittance, rms	0.6	µm
Incoherent energy spread, rms	2.0	keV
Mean energy	150	MeV
FODO length	30	m
Average betatron function in FODO	0.3	m
IBS-induced energy spread, rms (Eq.3)	6.0	keV

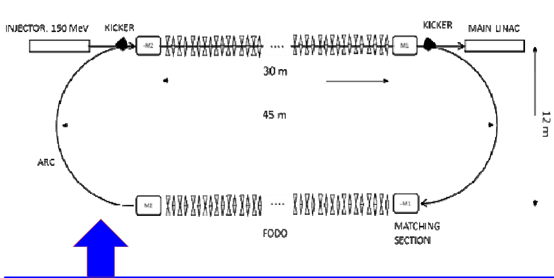
PARTICLE TRACKING (Elegant code):

- Slice rms fractional energy spread along the FODO channel in the presence of IBS (see Tab.1). In the legend:
  - "$\sigma_{d,Input}$" is the energy spread at the entrance of each "IBS module" depicted in ELEGANT;
  - "σ_d" is the energy spread at the exit of each IBS module,
  - "$\sigma_{d,Ave}$" is the rms fractional energy spread, averaged over all bunch slices.

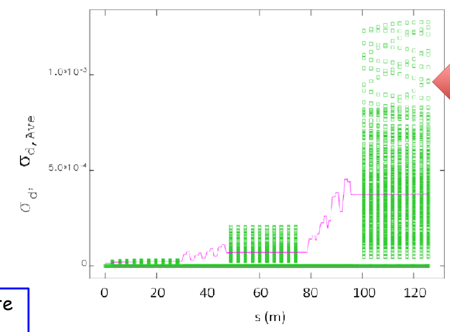
  The rms fractional energy spread estimated with Eq.2 is also shown (circles).



INTRABEAM SCATTERING in RECIRCULATION:

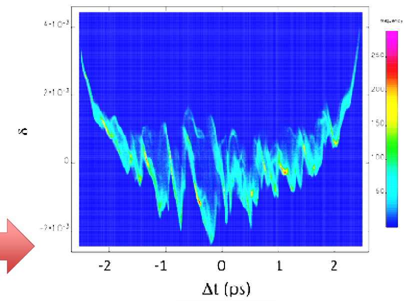


- A recirculating IBS beam line (RIBS) could be used to cumulate a larger $\sigma_{E,IBS}$ and to minimize the impact on the total linac length. The two arcs are achromatic and quasi-isochronous. An ultra-relativistic bunch takes approximately 360 ns to make one turn in the RIBS. Kickers with rise and fall time pulse duration of a few tens of nanosecond are therefore adequate for our purposes.



- The number of turns in RIBS should be a compromise between the amount of desired $\sigma_{\delta,IBS}$ and the tolerable degradation of the beam 6-D emittance due to chromatic aberrations and CSR instability.

- Unfortunately, the CSR instability in the arcs, driven by the high charge density and the low beam rigidity, deeply modulates the beam longitudinal phase space after only one turn.



CONCLUSIONS: **a relatively compact single-pass low-beta FODO channel at the linac injection could almost double the incoherent energy spread of high brightness beams with charge in the range 100–500pC. A beam heating above the 10 keV rms level is envisaged at the end of the FODO channel for charge densities at least 4 times higher than generated by state-of-the-art photo-injectors.**

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