CSR-IMMUNE ARC COMPRESSORS FOR RECIRCULATING ACCELERATORS DRIVING HIGH BRIGHTNESS ELECTRON BEAMS

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References:

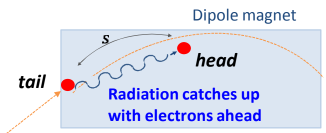
[1] S. Di Mitri, M. Cornacchia, Europhys. Letters 109, 62002 (2015).

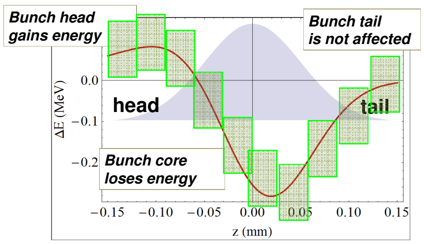
[2] S. Di Mitri, NIM A 806 (2016).

[3] S. Di Mitri, M. Cornacchia, and S. Spampinati, PRL 110, 014801 (2013).

The advent of short electron bunches in high bright-ness linear accelerators has raised the awareness of the accelerator community to the degradation of the beam transverse emittance by coherent synchrotron radiation (CSR) emitted in magnetic bunch length compressors, transfer lines and turnaround arcs. We reformulate the concept of CSR-driven beam optics balance, and apply it to the general case of varying bunch length in an achromatic cell. The dependence of the CSR-perturbed emittance to beam optics, mean energy, and bunch charge is shown. The analytical findings are compared with particle tracking results. Practical considerations on CSR-induced energy loss and nonlinear particle dynamics are included. As a result, we identify the range of parameters that allows feasibility of an arc compressor in a recirculating accelerator driving, for example, a free electron laser or a linear collider.

- CSR shows up a tail-head effect, in which photons emitted by trailing electrons catch up with leading electrons.





- **$\delta p_{z,CSR}$ is correlated with z along the bunch:**

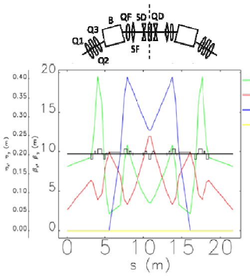
1. Different bunch slices are affected by different CSR-induced energy change;
2. Since it happens in a dispersive region, the energy change generates a change in the dispersive motion, thus in the betatron motion of the slices' centroid;
3. The emittance in the bending plane is increased.

RELATIVE ENERGY SPREAD of GAUSSIAN bunch, per DIPOLE:

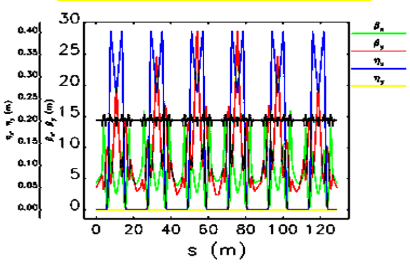
$$\sigma_{\delta,CSR} = 0.2459 \cdot r_e^{2}\frac{N\,\theta_B R^{1/3}}{\gamma\,\sigma_z^{4/3}}$$

CANCELLATION of CSR KICKS in an *ARC COMPRESSOR*:

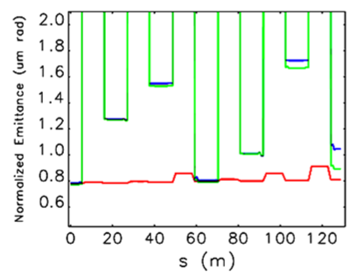
One DBA cell



180deg arc compressor (6 DBA cells)



Input beam			
Energy	2.4	2.4	GeV
Charge	100	500	pC
Bunch length, rms	300	900	µm
Peak current	30	45	A
Proj. norm. emittance, rms	0.20,0.20	0.80,0.80	µm rad
Uncorr. energy spread, rms	30	40	keV
Corr. energy spread, rms	0.14	0.42	%
Output beam			
Compression factor	45	45	
Peak current	1400	2000	A
Proj. norm. emittance, rms	0.34, 0.23	1.05, 0.82	µm rad
Slice energy spread, rms	≤1.6	≤2.0	MeV
CSR energy spread, rms	0.003	0.003	%



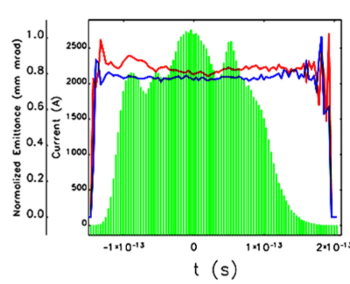
- The CSR-induced C-S invariant at the end of one DBA cell is:

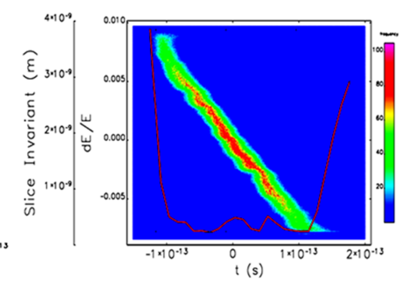
$$2J_3 = \beta_2 x_3'^2 + 2\alpha_2 x_3 x_3' + \left(\frac{1+\alpha_2^2}{\beta_2}\right)x_3^2 =$$

$$\cong \left(\frac{k_l \rho^{1/3}\theta^2}{2}\right)^2 \left\{\left[\sqrt{\beta_2}\left(C^{4/3}+1\right) - \frac{\alpha_2}{\sqrt{\beta_2}}\left(\frac{l_b}{6}\right)\left(C^{4/3}-1\right)\right]^2 + \left[\frac{1}{\sqrt{\beta_2}}\left(\frac{l_b}{6}\right)\left(C^{4/3}-1\right)\right]^2\right\}$$

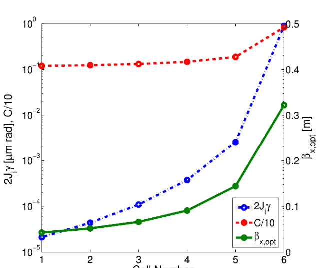
- The CSR effect on the emittance is minimized for an optimum betatron function in the dipoles, which depends in turn on the local compression factor:

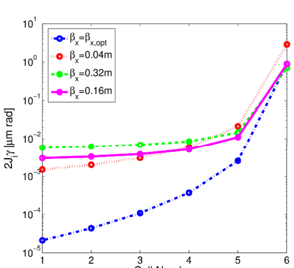
$$\beta_2 \cong \beta_{2,\min} = \frac{l_b}{6}\left(\frac{C^{4/3}-1}{C^{4/3}+1}\right)$$





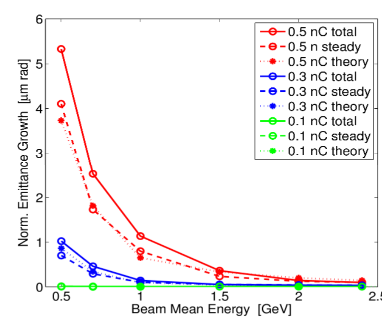
FEASIBILITY STUDY: OPTICS, CHARGE, ENERGY

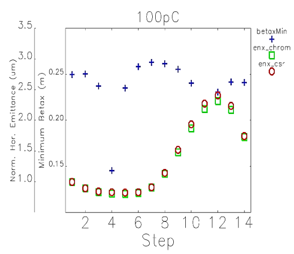


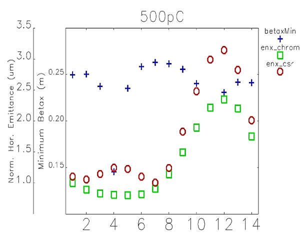


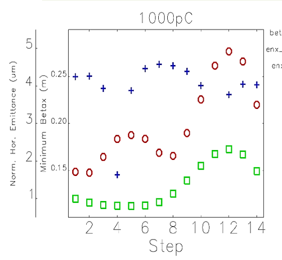
Left: local value of C/10 and of βx,opt in the dipoles vs. arc cell number. Right: the local value of the βx,opt is compared with its value evaluated for an identical βx value in all the dipoles.

Theoretical predictions (dotted lines) for steady-state CSR emission. Particle tracking results are for steady-state emission (dashed lines), and including transient CSR field at the dipoles' edges, and in drift sections (solid lines). The arc optics is the same for all beam charges and energies.









Horizontal projected emittance and minimum betatron function in the arc dipoles, at different simulation steps. Each step corresponds to a different periodic optics along the arc (Q1 strength is varied, see Fig.2). Emittance is computed with (enx_csr) and without CSR (enx_chrom).

CONCLUSIONS: **the capability of controlling CSR effects in a transfer line or an arc compressor (not necessarily constrained to a 180 deg total bending angle) – and thus to increase the beam peak current while preserving its 6-D normalized brightness – quite generally opens the door to new geometries in accelerator design and new schemes of beam longitudinal gymnastic.**

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