EMITTANCE ADAPTER FOR A LOCAL REDUCTION OF THE HORIZONTAL EMITTANCE IN A RING

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- This scheme could greatly relax the emittance requirements for a diffraction limited synchrotron light source.
- The lattice derivation and design are described.

- **This possibility has been extensively studied in the past few years.**
- **The theory is well established.**

[1] Y. Derbenev, Michigan Univ. Report No. 91-2 (1991); UM HE 93-20 (1993); Workshop on Round Beams and Related Concepts in Beam Dynamics, Fermilab (1996).
[2] Y. Derbenev, Michigan Univ. Report UM HE 98-04 (1998).
[3] A. Burov and V. Danilov, FNAL Report No. TM-2040 (1998); FNAL Report TM-2043 (1998).
[4] R. Brinkmann, Y. Derbenev, and K. Floettmann, Phys. Rev. Special Topics – Accel. & Beams, Vol. 4, 053501 (2001).
[5] A. Burov, S. Nagaitsev, and Ysroslov Derbenev, Phys. Rev. E 66, 016503 (2002).
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[8] D. Edwards et al., Proc. 2001 Part. Accel. Conf., Chicago, IL (IEEE, Piscataway, NJ, 2001), p. 73.
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[11] E.D. Courant, H.S. Snyder, Ann. Phys. 3, 1 (1958).

- **Several experiments have been successfully carried out, e.g to go from round to flat emittances**

THE FLAT BEAM EXPERIMENT AT THE FNAL PHOTOINJECTOR

D. Edwards, H. Edwards, N. Holtkamp, S. Nagaitsev, J. Santucci, FNAL*
R. Brinkmann, K. Desler, K. Flöttmann, DESY-Hamburg
I. Bohnet, DESY-Zeuthen, M. Ferrario, INFN-Frascati

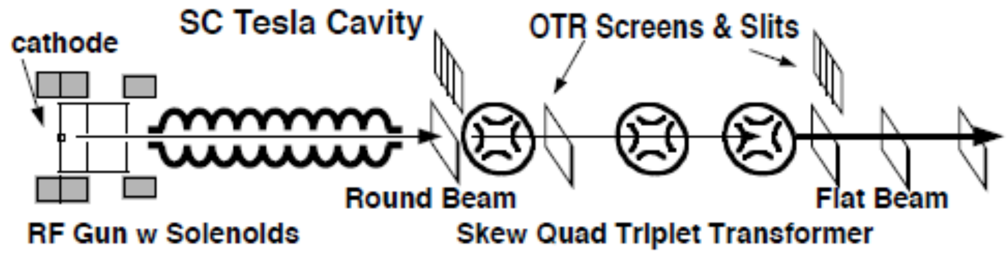

Figure 1: Very schematic rendition of the layout at Fermilab related to this experiment.

Flat Beam generation from a round cathode

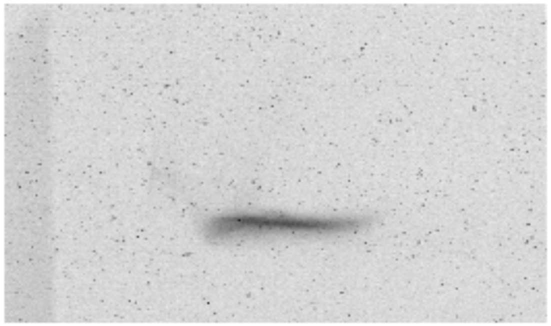

Figure 2: Beam profile on OTR screen 1.2 m downstrear of the third skew quadrupole.

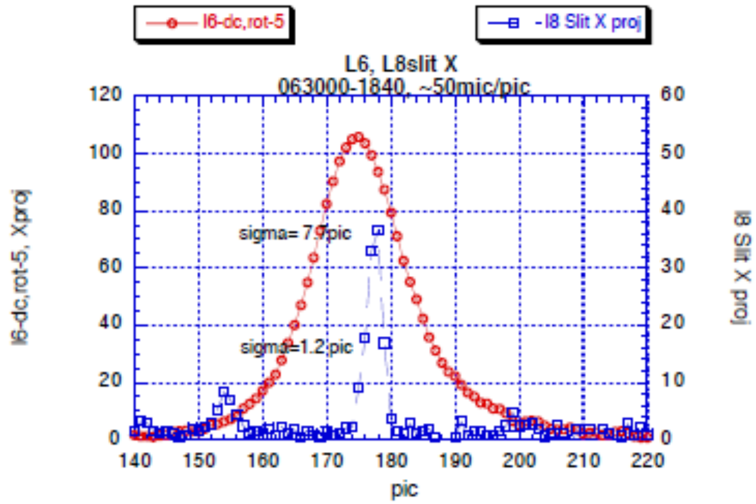

Figure 4: Projection of images used in emittance measurement at slit location and downstream of slit system.

• Reminder of the principle….(idealized)

We can track a parallel beam X_{in} from inside the solenoid through the Its exit.

Then we have a triplet with 90deg phase advance difference in the two planes.

We obtain a flat beam X_{out} tilted 45deg w.r.t. the normal axis.

$$X_{in} = \begin{pmatrix} x_0 \\ 0 \\ y_0 \\ 0 \end{pmatrix}; \qquad Sol_{exit} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & -k_s/2 & 0 \\ 0 & 0 & 1 & 0 \\ k_s/2 & 0 & 0 & 1 \end{bmatrix}$$

$$Triplet = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \beta \\ 0 & 0 & 1/\beta & 0 \end{bmatrix}; \qquad \beta = 2/k_s; \qquad X_{out} = \begin{pmatrix} x_0 \\ -k_s/2 \cdot y_0 \\ x_0 \\ -k_s/2 \cdot y_0 \end{pmatrix}$$

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Changing the triplet in a skew (45deg tilt) channel, will generate a flat beam:

$$X_{flat} = \begin{pmatrix} \sqrt{2} \cdot x_0 \\ -k_s/\sqrt{2} \cdot y_0 \\ 0 \\ 0 \end{pmatrix}$$

- Application in a ring….

We start from a beam with $\beta_x=\beta_y$ and $\alpha_x=\alpha_y=0$:

$$\Sigma_0 = \begin{bmatrix} \beta_x\varepsilon_x & 0 & 0 & 0 \\ 0 & \varepsilon_x/\beta_x & 0 & 0 \\ 0 & 0 & \beta_x\varepsilon_y & 0 \\ 0 & 0 & 0 & \varepsilon_y/\beta_x \end{bmatrix}$$

Then we have a triplet (skewed) with :
(V with triplet not rotated)

$$V = \begin{bmatrix} \cos(\varphi+\frac{\pi}{4}) & \beta_x\sin(\varphi+\frac{\pi}{4}) & 0 & 0 \\ -\frac{1}{\beta_x}\sin(\varphi+\frac{\pi}{4}) & \cos(\varphi+\frac{\pi}{4}) & 0 & 0 \\ 0 & 0 & \cos(\varphi-\frac{\pi}{4}) & \beta_x\sin(\varphi-\frac{\pi}{4}) \\ 0 & 0 & -\frac{1}{\beta_x}\sin(\varphi-\frac{\pi}{4}) & \cos(\varphi-\frac{\pi}{4}) \end{bmatrix}$$

Then a solenoid with $K_s=2/\beta_x$.

Inside the solenoid we will have:

$$\Sigma_{sol} = \begin{bmatrix} (\varepsilon_x+\varepsilon_y)/k_s & 0 & 0 & \varepsilon_y \\ 0 & \varepsilon_y k_s & -\varepsilon_y & 0 \\ 0 & -\varepsilon_y & (\varepsilon_x+\varepsilon_y)/k_s & 0 \\ \varepsilon_y & 0 & 0 & \varepsilon_y k_s \end{bmatrix}$$

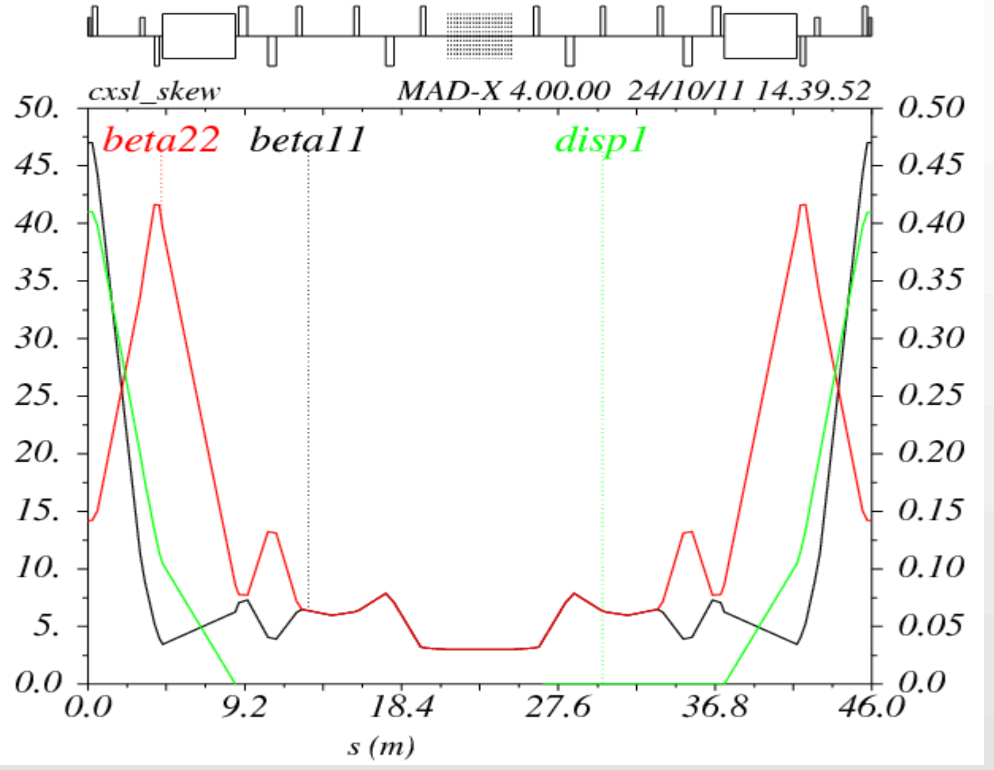
After the solenoid there is an identical triplet and the beam returns uncoupled

We have to remark that the x and y emittances in the canonical coordinates (x,p_x,y,p_y) are larger. They are the average of the two, as shown by the Sigma matrix expressed in canonical coordinates:

$$\Sigma_{can} = \begin{bmatrix} \frac{\varepsilon_x + \varepsilon_y}{k_s} & 0 & 0 & -\frac{1}{2}(\varepsilon_x - \varepsilon_y) \\ 0 & \frac{k_s}{4}(\varepsilon_x + \varepsilon_y) & \frac{1}{2}(\varepsilon_x - \varepsilon_y) & 0 \\ 0 & \frac{1}{2}(\varepsilon_x - \varepsilon_y) & \frac{\varepsilon_x + \varepsilon_y}{k_s} & 0 \\ -\frac{1}{2}(\varepsilon_x - \varepsilon_y) & 0 & 0 & \frac{k_s}{4}(\varepsilon_x + \varepsilon_y) \end{bmatrix}$$

Fortunately the beam properties of interest are determined by the mechanical momenta, so the effective X and Y emittances in the solenoid are roughly:

$$\sqrt{\varepsilon_x \varepsilon_y}$$

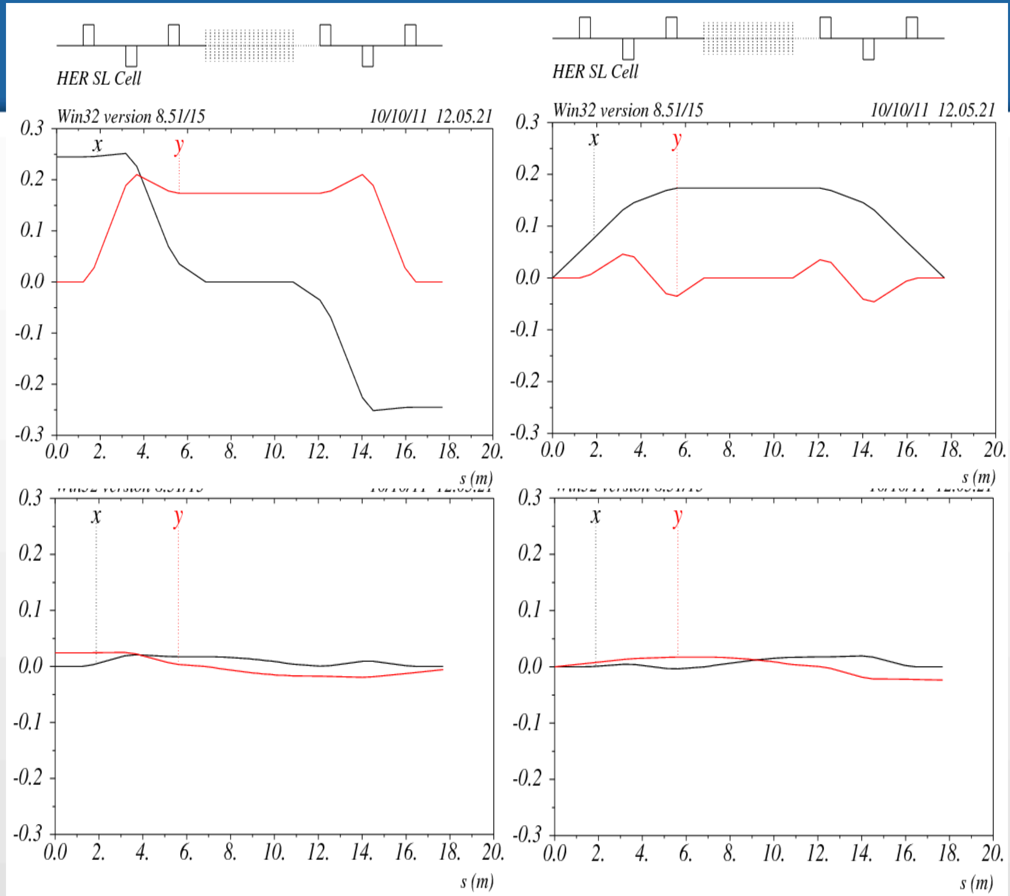


- An example of an insertion. After the Dispersion suppressor a triplet makes $\beta_x=\beta_y$= 6m and $\alpha_x=\alpha_y=0$ at the entrance of the emittance adapter.
- The adapter consists of the solenoid and two skew-triplets on each side. The solenoid has: $k_s = 2/\beta_x = 0.333/m$ (4.2T for a 6GeV beam)
- K values for the skew-quads (50cm long) are around 1

Skew triplet transport matrix (in the upright configuration) is:

$$V = \begin{bmatrix} \cos(\varphi+\frac{\pi}{4}) & \beta_x \sin(\varphi+\frac{\pi}{4}) & 0 & 0 \\ -\frac{1}{\beta_x}\sin(\varphi+\frac{\pi}{4}) & \cos(\varphi+\frac{\pi}{4}) & 0 & 0 \\ 0 & 0 & \cos(\varphi-\frac{\pi}{4}) & \beta_x \sin(\varphi-\frac{\pi}{4}) \\ 0 & 0 & -\frac{1}{\beta_x}\sin(\varphi-\frac{\pi}{4}) & \cos(\varphi-\frac{\pi}{4}) \end{bmatrix}$$

We have set $\varphi = \pi/2$ as an example, but its value is arbitrary. In general the incoming parameters β and α in the adapter section are arbitrary as well, provided that they are equal in the two planes.
For lower values of φ the quads become weaker and the section less chromatic.



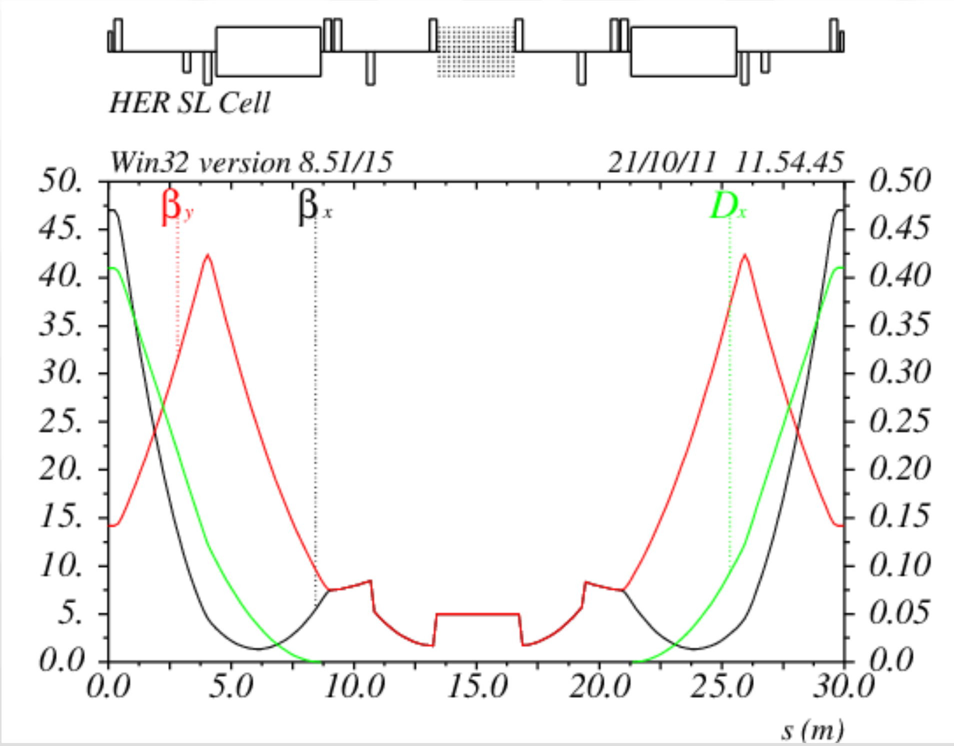
Tracking through the adapter for incoming beam displacements (ε_x = 10 nm, $\varepsilon_y = 10^{-2}\varepsilon_x$):

$$x = 10^{-4}\sqrt{\beta_x}\,;x' = 10^{-4}/\sqrt{\beta_x}\,;y = 10^{-5}\sqrt{\beta_x}\,;y' = 10^{-5}/\sqrt{\beta_x}$$

For this particular phase x_{in} becomes pure y in the solenoid and x'_{in} pure x.

Only the vertical emittance contributes to $\sigma_{x'}$ and $\sigma_{y'}$ in the solenoid

Simplified Insertion



A more optimized matching (shorter section and fewer magnets), can be realized if we just require $\beta_x=\beta_y$ and $\alpha_x=\alpha_y$.

The first two quads in the straight (one upright and one skew) could be further replaced by just a single quad properly rotated.

Match the beam with the undulator:

- The beam angular divergences in the undulator are:

$$\sigma_{x'} = \sigma_{y'} = \sqrt{\varepsilon_y k_s}$$

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In order not to spoil the potential gain in brightness we need:

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3) the radiation wave length as short as possible

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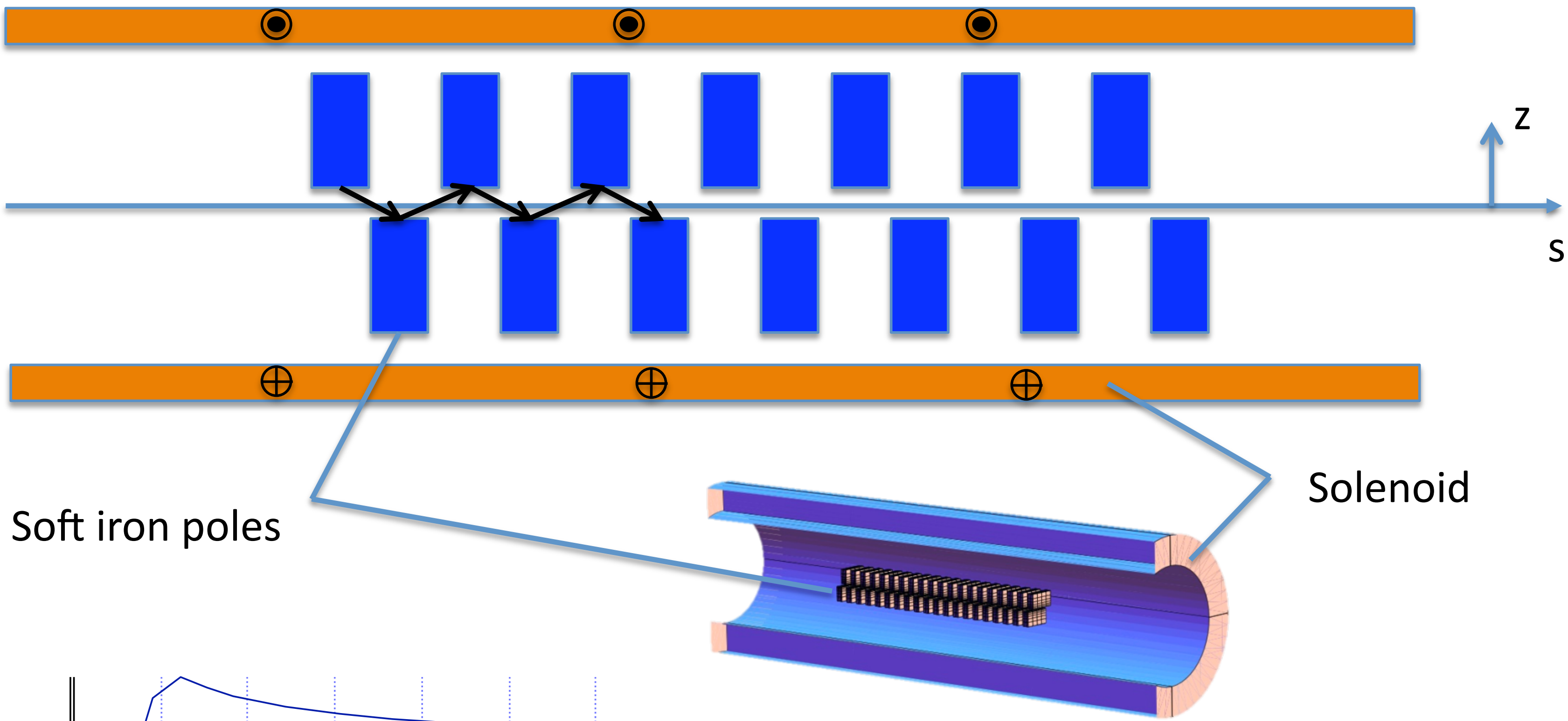
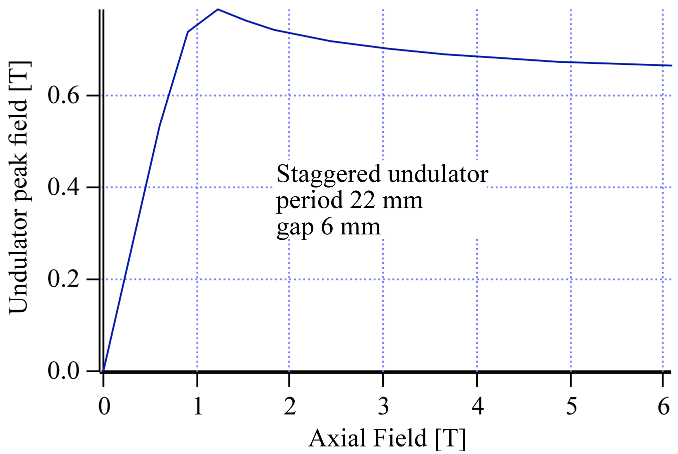
These requirements are very hard to achieve.

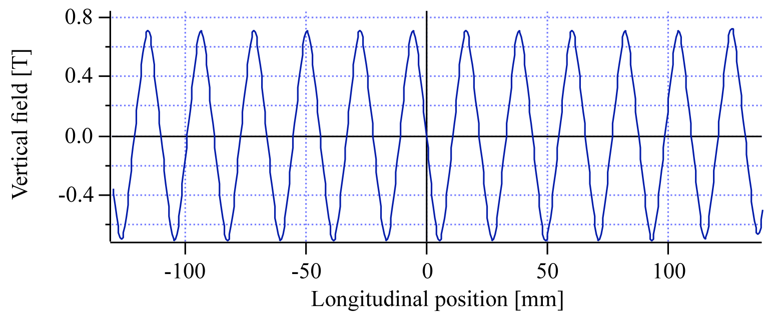
It is not going to be easy to find a suitable solution for the existing rings.

The key element is the realization of an Undulator in a very powerful SC Solenoid with very large k and short period…

Possible undulator scheme: Staggered undulator [1] (J.Chavanne)







Field along beam axis

[1] A. H. Ho, R. H. Pantell, J. Feinstein, B. Tice, Nucl. Instrum. Methods A296, 631 (1990)

Conclusions

- The emittance adapter has the potential to lower the horizontal emittance in the Insertion Devices.
- The optics requirements for the transport line are easy to meet with the present technology.
- However the requirements for the Undulator+Solenoid are very challenging.

- If some feasible solution is found:

Present facilities could improve their performance on some dedicated ID.

Future Light Sources could relax some requirements on their parameters or further boost their performance.