# Design Considerations for the IR FEL Upgrade

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## Abstract

Issues relevant to the IR FEL upgrade to ~80 MeV are discussed.

## Baseline Lattice

The baseline design of 16 May 1996 [1] comprises a single cryomodule, followed by a matching telescope, the FEL, a second matching telescope, and the energy recovery transport (Figure 1).

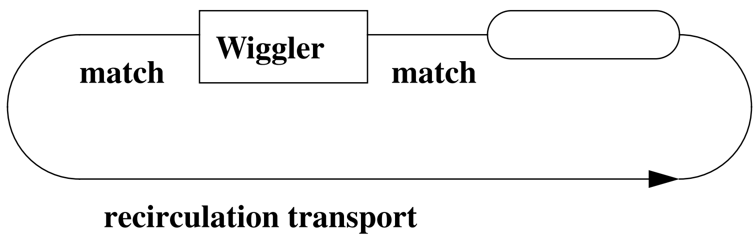


Figure 1: Baseline lattice concept at 42 MeV

We note that cavity focussing is used to confine the beam during acceleration and energy recovery, and that space charge effects are significant, at least at the low energy ends of the operation cycle.

## Design Issues

Issues to be considered when planning the IR FEL upgrade are as follows:

- space charge - what is the impact during acceleration and energy recovery of space charge on beam performance?
- cavity focussing - what role is to be played by cavity focussing, which rolls rapidly at higher energy, but is used to provide all focussing during acceleration and energy recovery in the baseline scenario?
- CSR - what performance limitations are imposed by coherent synchrotron radiation?
- dynamic range - what are the injection and final energies, the dynamic range of the machine, and the range of injection to final energies?
- cost schedule optimization - what is the most cost effective scenario for upgrading from 42 to ~80 MeV; what are the schedule implications of each scenario?

## Upgrade Scenarios

### A. Forward Engineering - from 42 to ~80 MeV

If the intent is to build a 42 MeV driver that can be upgraded to ~80 MeV, two upgrade scenarios may be examined.

Case A.1: CSR Relevant - If CSR is an issue, a layout such as that in Figure 2 will be needed. The 42 MeV machine must become longer and space for additional focussing (to compensate the rolloff in cavity focussing at higher final energy) will be needed. This upgrade scheme requires a modest redesign of the baseline system and moderate reinstallation of components.

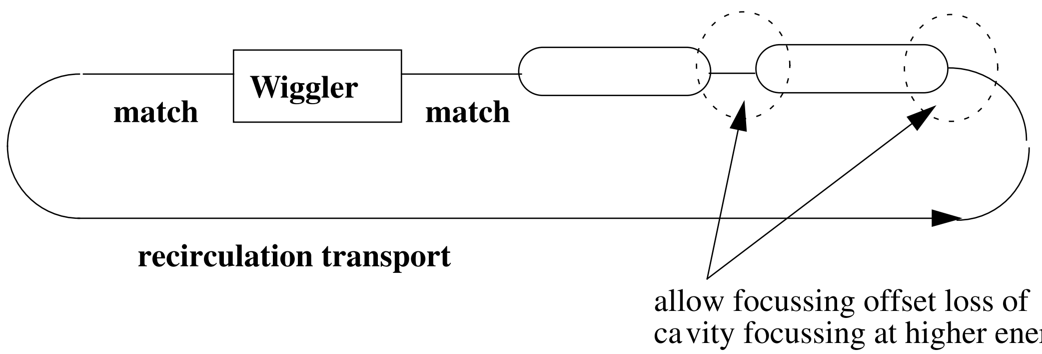


Figure 2 - downstream wiggler layout

Case A.2: CSR Irrelevant - If CSR is not an issue, a layout such as that in Figure 3 can be used. The machine may not increase in length at all; there is probably sufficient space in the baseline to accommodate not only the second cryomodule but also the additional focussing required on the linac axis to compensate for the rolloff of cavity focussing. This upgrade scheme requires significant redesign of the baseline system and significant reinstallation of components.

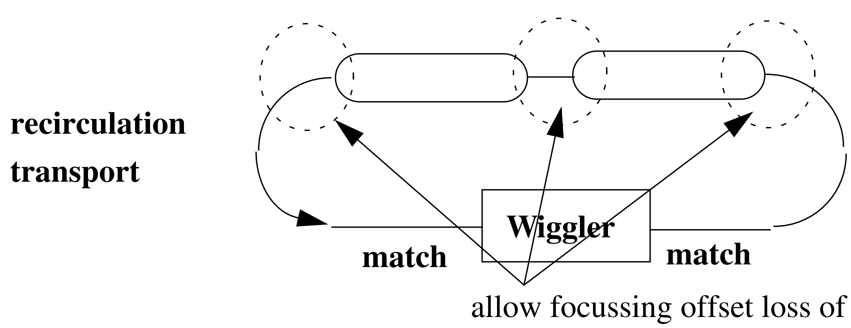


Figure 3 - wiggler in backleg option

**B. Reverse Engineering - to ~80 MeV *via* 42 MeV**

If the intent is to build an ~80 MeV driver that will undergo phased construction and preliminary operation at 42 MeV, two schemes may be proposed.

Case B.1 <u>CSR Relevant</u> - The wiggler must remain downstream of the linac. In this case, a slot for the second cryomodule can be introduced by lengthening the *entire* machine, putting the “upgrade slot” either before (Figure 4a) or after (Figure 4b) the FEL, and introducing appropriate linac focussing to accommodate the roll-off of cavity focussing at higher energy. For 42 MeV, the “upgrade slot” would contain a M=-I or M=I quad telescope.

<u>Slot before FEL</u>: The mechanically simplest scenario would be that of Figure 4a, in which the 42 MeV beam is taken through the upgrade slot *before* the FEL. This would upgrade to the concept of Case A.1 by replacing the quad telescope by the second module. This, however, is risky for at least three reasons. Firstly, the “direct upgrade” of Figure 4a requires transport of the “space-charge dominated” beam over a long distance. Secondly, the upgrade slot quad telescope is operationally difficult to implement due to the betatron mismatch inherent when imaging a round beam (such at that cryomodule exit) to a round beam (such as that at the wiggler). Finally, the details of dumping the energy recovered beam are not transparent at 42 MeV - is it done just after the module, or after the quad telescope/upgrade slot? If done just after the module, the dump must be shuffled around during upgrade, with associated changes in optics, while after the telescope, 42 MeV operation requires transport of a low energy space charge dominated beam with huge momentum spread.

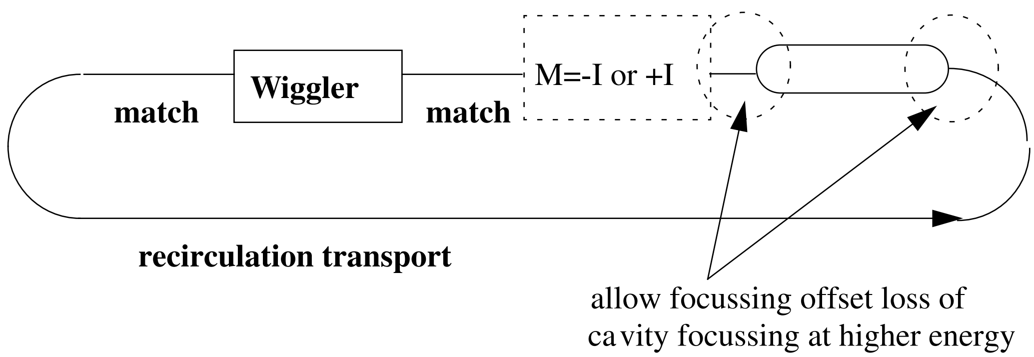


Figure 4a - “Direct Upgrade” Concept for IR FEL at 42 Mev

This scheme involves significant redesign of the baseline system (because of the space charge and dump/upgrade slot telescope optics issues involved), but needs only modest reinstallation during upgrade.

<u>Slot after FEL</u>: A less risky, operationally simpler concept is shown in Figure 4b. Here, the FEL is positioned just as in the baseline 42 MeV machine, and a M=-I or

M=I telescope is introduced between the matching telescope following the wiggler and the energy recovery recirculation. This scheme has the advantage of minimizing the transport distance for space charge dominated beam prior to lasing or during energy recovery. In addition, it provides utility space following the second matching telescope that could be used for diagnostic or other operational/recreational purposes. This beam transport concept has been successfully employed in the spreader/extraction region/arc matches of the nuclear physics accelerator; a very preliminary examination of the concept with DIMAD suggests the performance is not drastically worse than that of the baseline. Approximately 10 m is added to the overall machine footprint; at least 4 additional quadrupoles and correctors and 2 additional positional diagnostics would be required.

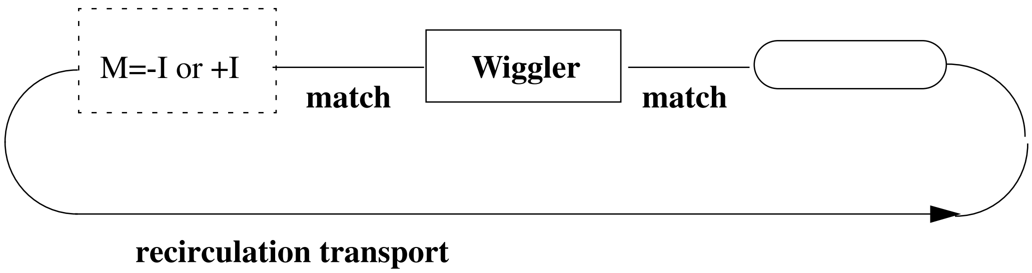


Figure 4b: “Indirect Upgrade” Concept for IR FEL at 42 MeV

An upgrade to ~80 MeV can be accomplished by removing the quad telescope, moving the matching telescopes and FEL to the left, and installing the second cyromodule. The overall machine footprint remains fixed; the resulting device is the same as in Case A.1. This scheme requires little redesign of the baseline system, but entails moderate reinstallation for the upgrade.

Case B.2 <u>CSR Negligible</u> - Redesigning the 42 MeV machine to accommodate upgrades to 80 MeV can be accomplished by pursuing the scenario of Case A.2, above. Two choices are available.

1. We can initially build the 42 MeV machine with the wiggler in the backleg, with sufficient length on the linac axis (and appropriate linac axis focussing) to allow a “drop-in upgrade”. This requires significant changes to the current design.
2. We can build the machine as in the current baseline, and simply move the wiggler to the backleg when the module becomes available, introducing linac axis focussing as appropriate to compensate the rolloff of rf focussing. This requires little change in the current design, but significant reinstallation during upgrades.

We note either approach entails some (and possibly significant) risk; the relevance of

CSR has not been empirically verified and the impact of space charge, particularly with bending to a wiggler in the backleg, is not completely understood.

## Comments

1. At present, the design intent during upgrade is to *avoid* changing the recirculation arcs. If betatron acceptance problems arise, they could probably be cured by changing only the reverse bends, not the large π-bend. We would, even then, attempt to maintain the transverse footprint, so as not to affect the backleg layout.
2. The principle optics problem during upgrade will be the loss of rf cavity focussing at higher energy. As a consequence, we must include some additional focussing on the linac axis and/or matching into/out of the linac. Both are avoided at 42 MeV through judicious use of cavity focussing.
3. When the upgrade is done, the two cryomodules would preferentially run at the same gradient, so that the beam energy is the same at the middle of the linac during acceleration and energy recovery. This avoids energy/focussing mismatch, which would limit the effective focussing that can be applied (note well the reinjection issues in the CEBA North Linac front end!). Specifications on the allowable asymmetry require detailed computation of beam envelopes at various energy mismatches and focussing strengths.
4. The complexity, difficulty, and cost of the upgrade is dependent primarily on CSR.If this is important, the machine is harder, larger, and more complex. If it is not important, the machine size and complexity would probably change little from the baseline, but a fair amount of redesign and reinstallation (to move the FEL to the backleg) would need to be done. CSR conclusions should be made before the upgrade path is fixed!
5. The upgrade planning must realistically cope with details of the machine that will change or constrain operation. For example, if the final energy goes from 42 to ~80 MeV while the injection energy remains at 10 MeV, the extraction and reinjection chicanes must be rebuilt. Similarly, the energy range of the machine is at issue; the baseline is designed for ~34 to ~45 MeV. If we upgrade to ~80 MeV, will the lower limit still be 34 MeV? Will the injection energy be raised? These have significant implications on magnet dynamic range.

## Summary and Conclusions

Before detailed planning for an IR FEL driver energy upgrade can commence, certain questions must be answered. The two driving issues are as follows:

1. Are collective effects important (space charge and/or CSR)
2. Is the baseline machine a 42 MeV machine that is to be upgraded to ~80 MeV, or is it an ~80 MeV machine that is to be constructed in stages and initially operated at 42 MeV

These drive the general configuration of the machine that is to be installed on a ~1 year time scale. Because of this schedule limitation, we conclude that whatever is installed, it will be more or less based on the baseline design of 16 May 1996. The path to ~80 MeV is then set by the answers to the above questions; the recommendations of this author are summarized in Table 1

**Table 1: Recommendation Matrix**

| Energy Scenario | Are collective effects important? | |
|---|---|---|
| | No | Yes |
| 42 MeV with upgrade to ~80 MeV | build baseline (to verify collective effects assumption), then upgrade to wiggler in backleg (Case A.2, Figure 3) | build baseline (to verify collective effects assumption) then split and stretch machine to add cryomodule (Case A.1, Figure 2) |
| ~80 MeV *via* 42 MeV | build baseline (to verify collective effects assumption), then upgrade to wiggler in backleg (Case A.2, Figure 3) | Build "stretched baseline" (Case B.1 with "indirect upgrade", Figure 4b); when upgrade cryomodule becomes available, move wiggler and insert module. |

Other issues also need resolution. Machine parameters such as injection energy, ratio of injection to final energy, and energy range (? to ~80 MeV) must be specified. The baseline design was developed within the "42 with upgrade to 80/CSR matters" scenario. Design tolerances for components must be reevaluated if the machine dynamic range changes. If a significant change occurs in the machine performance goals, there will be some schedule impact; this must be evaluated.

## References

[1] D. Douglas, "Baseline Design for the 42 MeV IR FEL Driver", CEBAF-TN in progress. D. Douglas "Engineering Design Specifications for IRFEL Driver Transport System", CEBAF-TN-96-026, 6 June 1996.