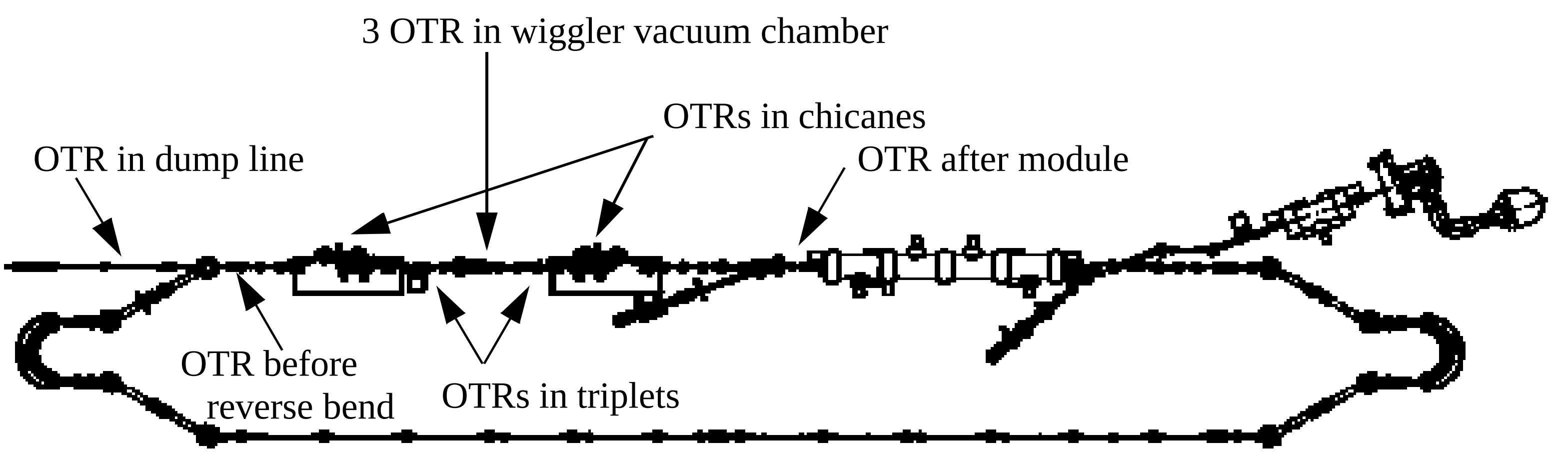
Emittance Measurements and Matching for First Light

System Configuration



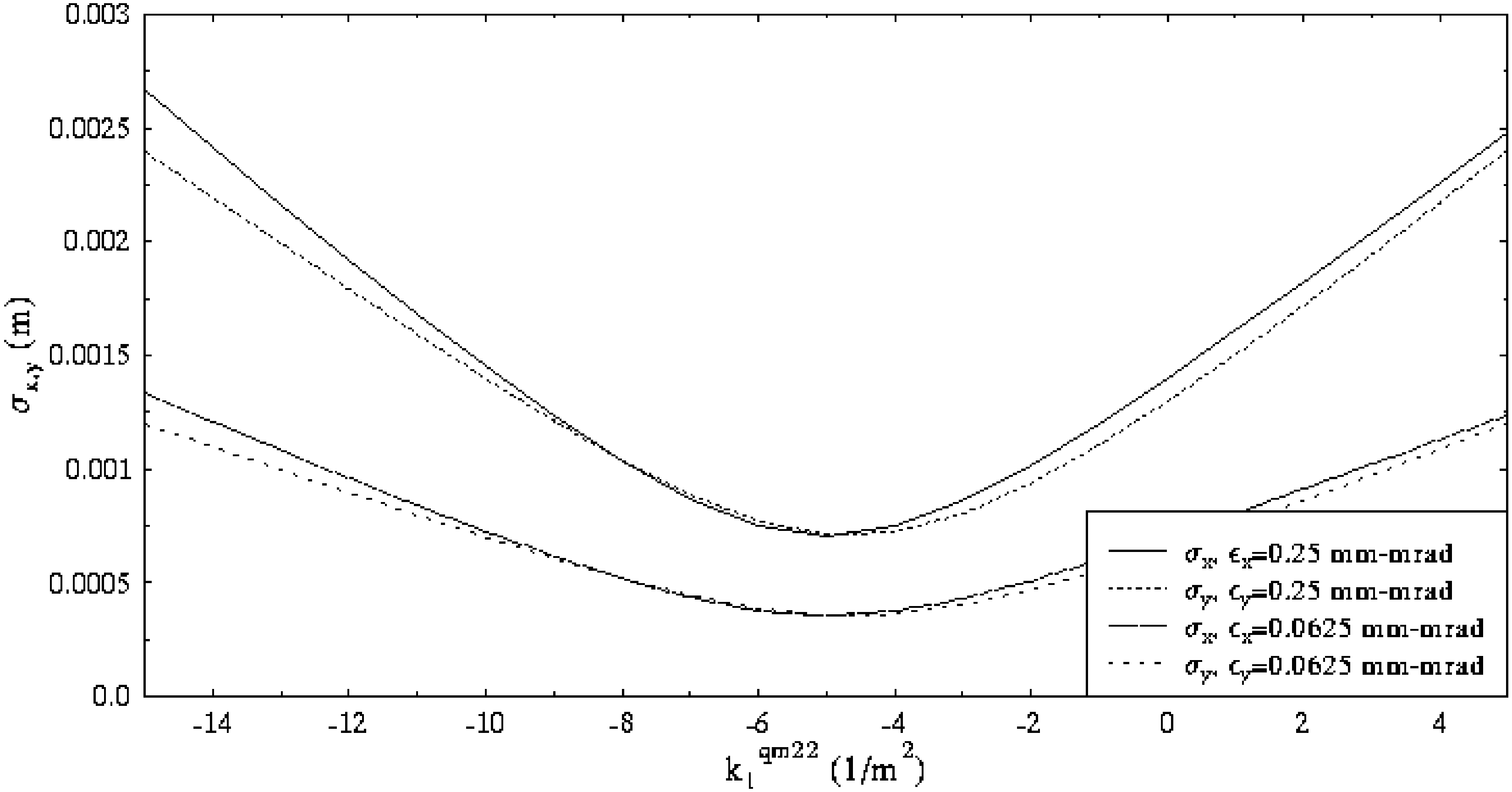
Prior to Wiggler Installation

- Use as “calibration” of systems, debugging of transport
- Make multiple measurements of emittances and cross-correlate

Procedure

1. Measure emittance at wiggler insertion:
   a. using quad/monitor at monitor in triplet upstream of wiggler slot,
   b. using 3 monitors in wiggler vacuum chamber, and
   c. using quad monitor at monitor in triplet downstream of wiggler slot.
2. Measure emittance at entrance to arc:
   a. using quad/monitor at monitor in triplet upstream of reverse bend, and
   b. using quad/monitor at monitor in first light dump.
3. Back propagate results of each measurement to module:
   a. check for consistency amongst measurements and with observed results at each OTR, including OTR following module and those in optical cavity chicanes, and
   b. seek out and correct sources of inconsistency.
4. Measure momentum spread using emittance results and horizontal profile measurements in optical cavity chicanes.
5. Recompute match to wiggler insertion and to arc, download, and repeat measurements. Check for and resolve sources of inconsistency, iterate as needed.

Simulation of Measurement (at entrance to reverse bend)



0.003
0.0025
0.002
0.0015
0.001
0.0005
0.0
$\sigma_{x,y}$ (m)
-14
-12
-10
-8
-6
-4
-2
0
2
4
k_1^{qm22} ($1/m^2$)
σ_x, ϵ_x=0.25 mm-mrad
σ_y, ϵ_y=0.25 mm-mrad
σ_x, ϵ_x=0.0625 mm-mrad
σ_y, ϵ_y=0.0625 mm-mrad

After Wiggler Installation

- Use as “reproducibility check” of system (now presumably calibrated/commissioned in previous step)

<u>Procedure</u>

1. Measure emittance at wiggler insertion using 3 monitors in wiggler vacuum chamber, and
2. Measure emittance at entrance to arc:
    a. using quad/monitor at monitor in triplet upstream of reverse bend, and
    b. using quad/monitor at monitor in first light dump.
3. Back propagate results of each measurement to module:
    a. check for consistency amongst measurements and with observed results at each OTR, including OTR following module, in triplets adjacent to wiggler, and those in optical cavity chicanes, and
    b. seek out and correct sources of inconsistency.
4. Measure momentum spread using emittance results and horizontal profile measurements in optical cavity chicanes.
5. Recompute match to wiggler and to arc, download, and repeat measurements. Check for and resolve sources of inconsistency, iterate as needed.

Requirements on System

1. OTR profile measurement hardware/software with at least 25µm resolution (implies ~1 cm field of view for 400x400 pixel area) and profile analysis

2. Model server allowing
    a. evaluation of emittance, envelopes from captured OTR data
    b. forward- and back-propagation of beam envelopes
    c. rematching
3. Procedures for measurement, matching to wiggler, matching to arc
4. Beam transport tunings giving adequate resolution (~1 m minimum beam envelopes at OTRs used in monitor/quad method, factor of 2 variation in beam envelopes at OTRs used in multiple monitor method)

Measurement of CSR-Driven Emittance Growth in the

Jefferson Lab IR-FEL Driver

System Configuration

The conceptually relevant portions of the Jefferson Lab IR-FEL Driver are presented in Figure 1. A small (42 MeV) SRF CW accelerator delivers beam to an IR-FEL through an achromatic bunch compressor/betatron matching telescope. Following the FEL, an achromatic bunch decompressor/betatron matching telescope matches the beam to an achromatic, large-acceptance transport system with variable momentum compaction. This beam line can in principle reinject beam into the SRF accelerator for energy recovery. For the purposes of this study, this will not be done. Rather, a plungable tune-up beam dump will be inserted upstream of the final arc to provide “parking” for the beam; this avoids the need to transport the beam through energy recovery following possibly disruptive emittance related measurements.

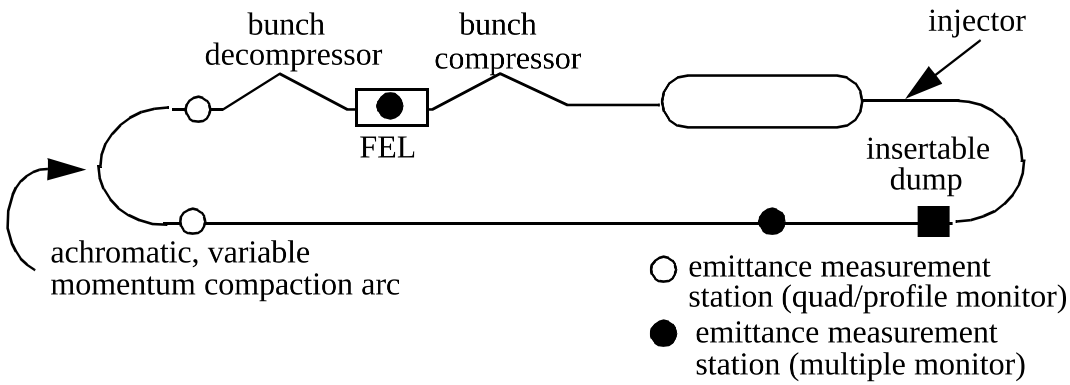


Figure 1: Conceptual layout of IR-FEL Driver, showing location of emittance measurement systems.

Experimental Plan

The purposes of this investigation are to

1. certify that CSR-driven emittance growth is not intolerably large for FEL operation, particularly in the case of potential system upgrades, with FEL systems located in the accelerator backleg transport, and to
2. investigate the parametric dependences of CSR-driven emittance growth.

These purposes in mind, the initial phase of the experiment is designed to measure beam emittances using the available diagnostics in as many locations as possible. the evolution of the emittance through the system will then be characterized for the baseline operating parameters of the accelerator. At the present time, the emittance will be measurable at three locations. These are:

1. at the location of the FEL proper, downstream of the bunch compressor. To simplify interpretation of the results, it is recommended that the wiggler be removed during this experiment.
2. downstream of the bunch decompressor (which is identical in geometry to the bunch compressor upstream of the FEL)
3. in the backleg, where multiple emittance measurement systems are available.

Determination of beam emittances at each of these three locations will allow conclusions regarding the operational impact of CSR to be drawn.

Parametric Investigations

Subsequent to initial investigation of CSR and certification of its impact during operation under nominal Driver parameters, exploration of the parametric dependences of CSR-driven effects may be made. The following parameters are readily and more or less orthogonally varied through each of the relevant bending regions:

- bunch current (60pC, 135pC being nominal operating points)
- bunch transverse size through any particular bending region, through use of upstream quadrupole matching telescopes
- bunch momentum spread, through adjustment of injector parameters and RF phase during acceleration
- bunch length - in the compressor/decompressor through adjustment of incident momentum spread, in the arc through adjustment of the momentum compaction

With additional injector operations experience, it may additionally be possible to adjust incident emittance independently of other parameters.

By measuring beam emittance growth as a function of each of these parameters, a sensitivity matrix can be developed which can then be compared to the predictions of theory and employed to predict the operability of various upgrade scenarios for the Jefferson Lab FEL.

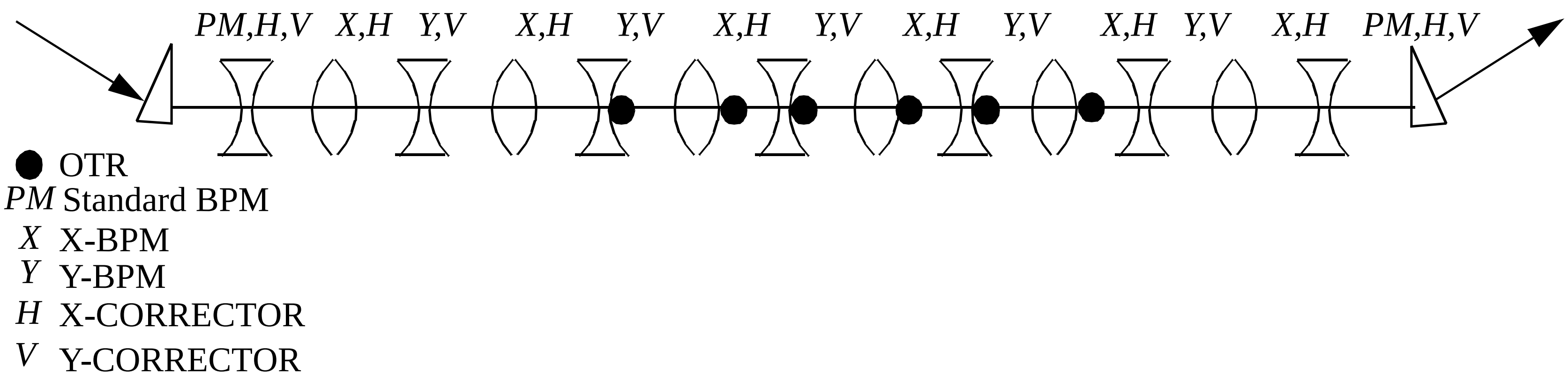
Requirements

At the present time, the following requirements must be met:

1. Detailed experimental design must be completed. This should include
   a. quantitative analysis and modeling of the measurements, and
   b. error propagation and characterization of experimental resolution, so as to determine if the measurement can provide significant results, given the anticipated machine and diagnostic performance.

   Preliminary scaling from CEBAF injector measurements indicates the available experimental resolution is adequate. In the CEBAF injector, emittances below 1 mm-mrad (normalized) are routinely measured at 45 MeV with relative errors of order 20-40%, using a moving-wire based profile monitor (harp) with a minimum resolution of order 25 µm. Typically, rms spot sizes in excess of 100-200 µm are measured at locations with minimum beam envelopes of a few meters, with a relative resolution of 10-20%. This leads to the stated emittance resolution of 20-40%. In the IR-FEL driver, we will measure normalized emittances of order 10 mm-mrad at 42 MeV using an optical transition radiation based monitor (OTR) with resolution similar to that of the harp, though in a system with potentially smaller beam envelopes. In the worst case, spots with rms sizes as small as ~350 μm will be measured at points with 1 m beam envelope function with a resolution of 25 μm (a relative resolution of 7%). This implies, pessimistically, a relative emittance resolution of order 15%, which is adequate to observe growths of ~50% theoretically anticipated through the arcs in this system, but at or beyond the resolution limit required for growth through the optical cavity chicanes. It is, however, realistic to expect minimum beam envelopes two to three times larger to be available. In this case, the minimum rms spot size would be in excess of 500-600 μm and the relative resolution would drop to below ~5%. This leads to an emittance resolution of better than ~10%, which is adequate to observe the CSR-driven emittance growth expected in the compressor/decompressor.

The backleg diagnostic hardware and correction system configuration is shown below. This distribution allows the use of a four quadrupole match to the first profile monitor for the purpose of a quad/monitor emittance measurement, and provides three monitors at points of high beam envelope function in each plane for the purpose of multi-monitor emittance measurements. The latter method requires reduction of the backleg phase advance from 90^o/FODO cell to 60^o/FODO cell.



Scheduled task completion - Summer, 1997

2. Experimental procedures must be generated and documented

   Scheduled task completion - Early Fall, 1997

3. Data acquisition and analysis software must be specified, developed, debugged, and commissioned.

   Scheduled task completion - Late Fall, 1997

4. Driver construction must be completed, the machine initially commissioned, and the transport and diagnostics

system hardware adequately characterized to allow the experimental resolution established in Requirement 1.

Scheduled task completion - Winter, 1998