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FEL UV Beam line for HKS Target Tests

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Abstract
An experiment has been approved for beam time in Hall C. These experiments require thin foil-type targets exposed to the CEBAF GeV electron beam. The electron beam currents and energy to be used have raised questions as to the structural integrity of the foil targets. The FEL electron beam could possibly be used and was proposed to be used to test the targets before placement into Hall C. This tech note examines the proposal and provides limits to the beam characteristics. Electron beam transport codes were used to establish the electron beam parameters for meeting the requirements of the Hall C Users collaboration.

Introduction & Requirements

The HKS collaboration has proposed a series of material science experiments using the electron beam of the FEL impinging on the targets the collaboration was to use in its Hall C experiment [1]. They wanted to conduct tests on an assortment of different target materials and thicknesses. The amount of high energy particles being kicked off the target by the electron beam wanted to be limited. The Hall C Users wanted to be extra careful to not put too powerful a beam through the target, because of possible destruction (equating to loss of time, resources).

Placement of the actual physical experimental equipment in relation to the Free Electron Laser (FEL) setup was discussed (See Figure 1). Initially, it was proposed to use the the straight ahead beam line so the electron beam could travel directly into that beam dump. The Hall C Users desired the tightest beam possible, approximately 200 microns rms, and it seemed this would be the best design.

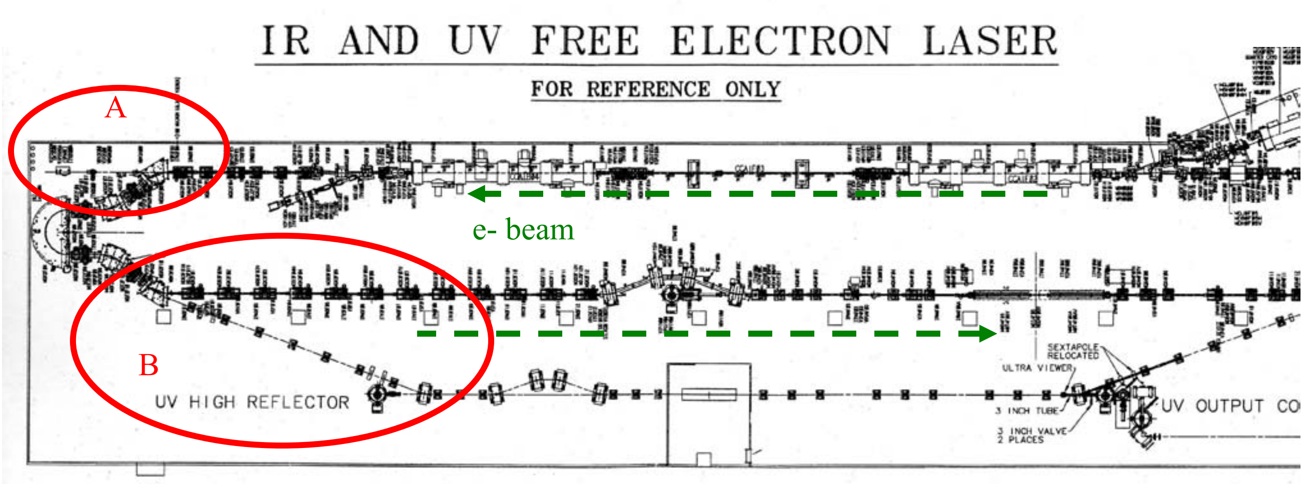


Figure 1: Layout of the FEL vault. Electrons travel in a counter clockwise direction. Ellipse A is the “straight ahead” area initially considered. Ellipse B shows the area finally chosen for these target tests and the beam studies of this Tech Note.

However, after further review, it was determined that it would be physically difficult to place the equipment at the end of the primary beam. At this point, there were designs for the UV beam line planned the line to branch off from the IR line at dipole MGX2F10. (ellipse B of Figure 1.) The electrons in the beam would be directed to slightly off the IR track as soon as they entered the magnet. The following are parametric values appropriate to use in this transport line.

Bend Radius: 2.4 meters
Bend Angle: 23.1374996°
Entrance Angle: 2°
Exit Angle: -18.24606538°

(The negative exit angle merely represents a chosen orientation of magnetic fields)

The new UV line was designed to include a series of quadrupole magnets and drifts which simply acted as spacers between the magnets. The beam size determined by the specific magnets would stay reasonably consistent through the length of the drift. The drift length was predetermined to be 1.4428482 meters. Figures 2 and 3 illustrate the initial concept for using the FEL UV beam line.

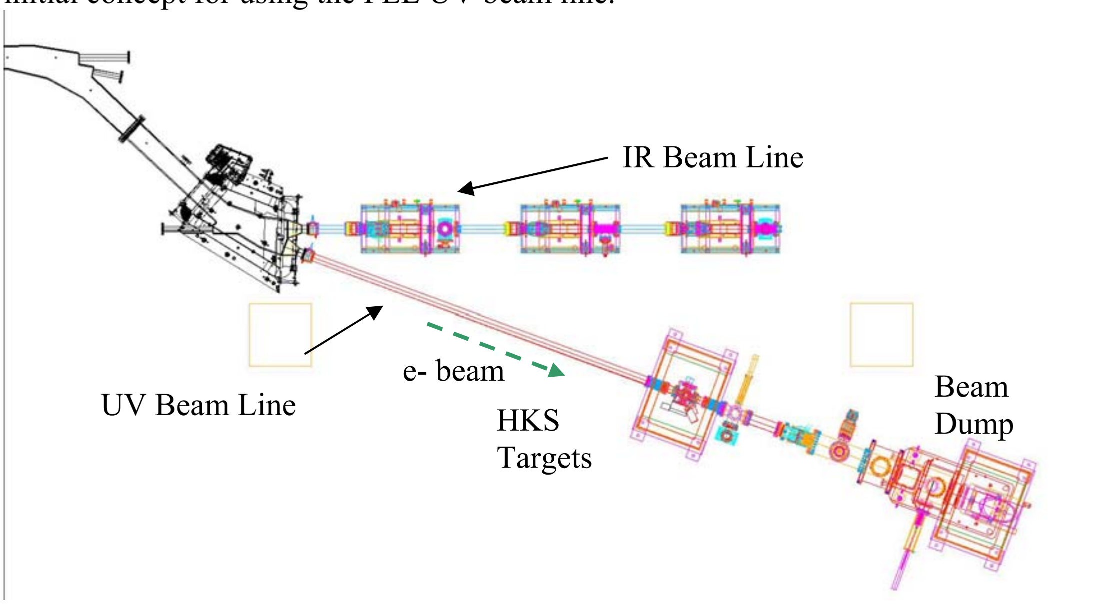


Figure 2. Plan view layout of the FEL UV beam line region showing the HKS targets assembly and electron beam dump. Not shown are the quadupoles QX3F01-7, upstream from the HKS targets assembly, that were the focus of this study.

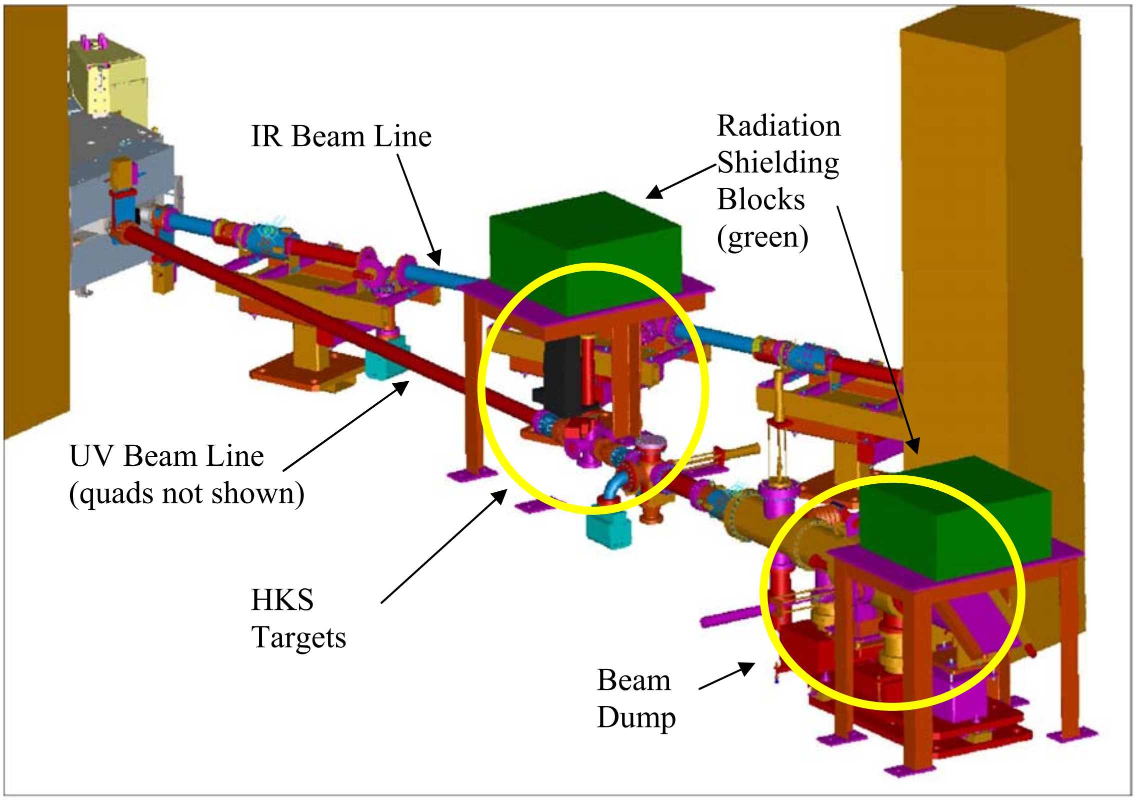


Figure 3. Concept layout of HKS target testing assembly and the electron beam dump.

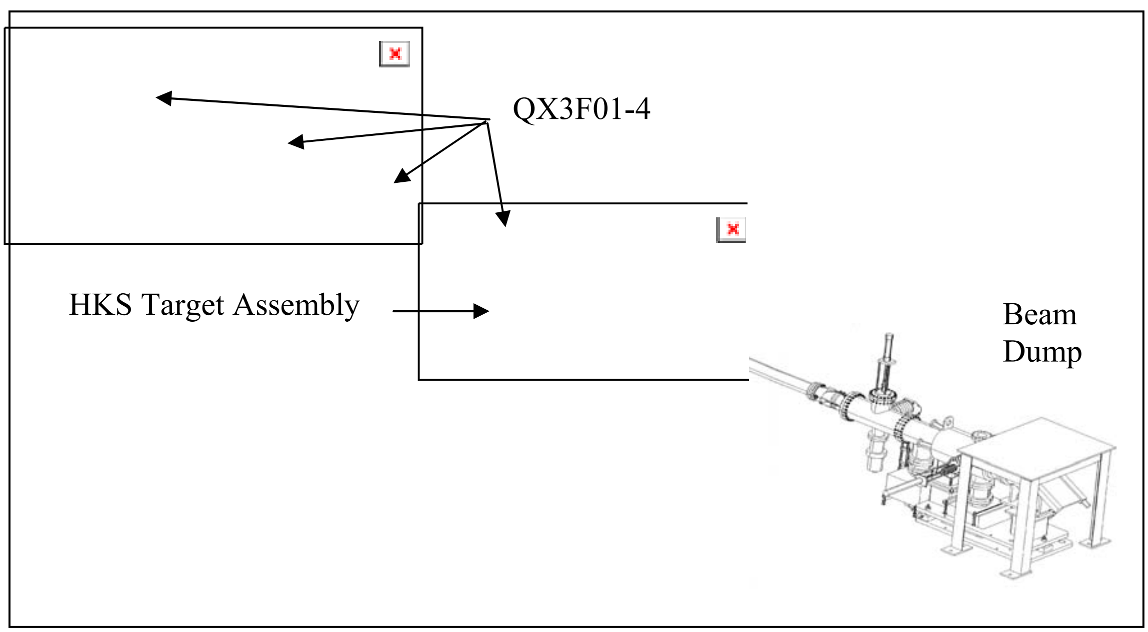


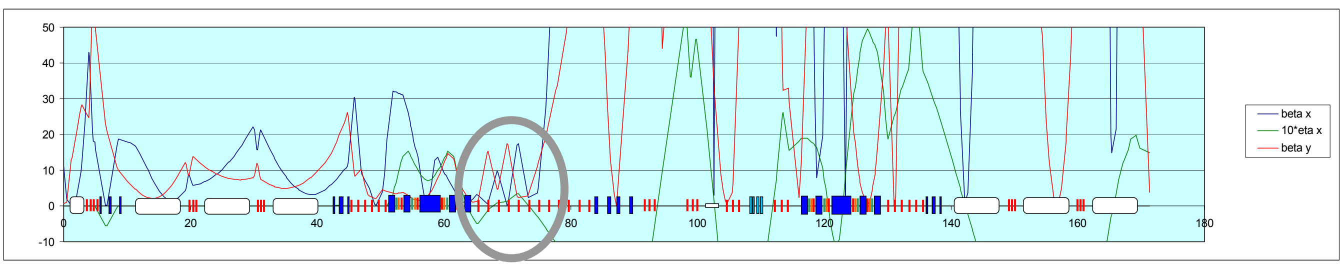
Figure 4. Layout showing the location of the quadrupoles, HKS target assembly, and beam dump.

Calculations & Discussion

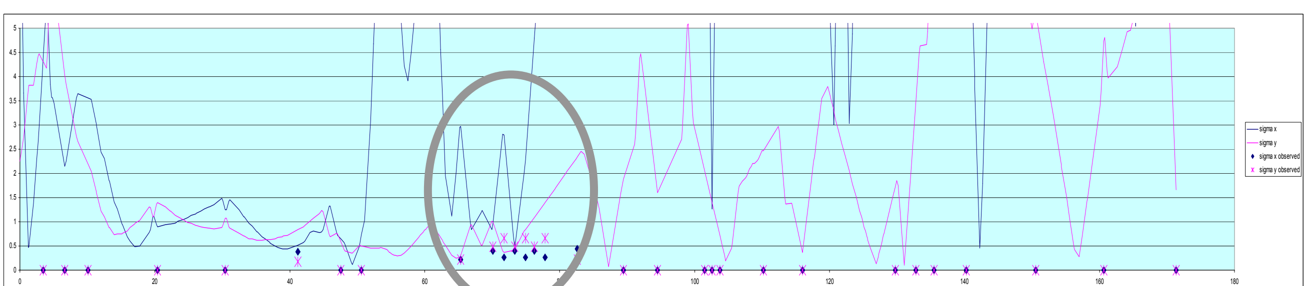
The goal of this exercise was to control the size of the electron beam using the quadrupole magnets to provide the user a small, controlled, tight beam of high-intensity light. Ideally, only 4 quadrupole magnets would be needed – thus reducing costs and the time of installation. A mobile container holding the test target would be positioned at the point determined to have the optimal light conditions. The target was planned to be inserted from the side because of space requirements. Figure 4 illustrates the location of the quadrupoles, target assemply, and beam dump.

A computer simulation model implemented through Microsoft Excel was used to determine the exact settings needed to supply the tightest beam possible. The model included two graphs, each dealing with the size of the electron beam.

- The first graph depicted the beta functions, beta x and beta y, whose magnitudes could be taken and used to determine the diameter of the beam. The beta functions are not physically observable. Also, on this graph was the momentum spread which shows the beam's inclination to spread, becoming less tight, as it moves through the line. The graph's scale was in meters. The region of interest is inside the ellipse.



- The second graph depicted the sigma functions, sigma x (horizontal, blue) and sigma y (vertical, red), whose magnitudes directly represented the spot size of the beam. The sigma functions are physically observable. The graph illustrated the beam spot size through the length of the line, scaled by the root mean square, measured in millimeters.



The first step was to examine how the beam could best be directed into and around the large dipole at left end of the FEL track to make sure the beam was more easily controlled into the UV line. This was done by controlling a series of 6 quadruple magnets labeled: QX2F01, QX2F02, QX2F03, QX2F04, QX2F05, QX2F06. As soon as the fields in the dipole MGX2F10 direct the beam into the UV line the quadrupole magnets take over. Quads QX3F01, QX3F02, QX3F03, QX3F04 were controlled along with the 2F quads to provide a beam that had beta function magnitudes of no larger than 20-30 meters and had a spot size of under 0.5 millimeters. Ideally the momentum spread was zero on the beta function graph at the spot size.

After the best beam model was calculated an additional quadrupole in the 3F region was used, in hopes of creating a tighter beam. Quads QX3F05, QX3F06, QX3F07 were added one at a time, each providing improvements on the beam quality.

Because of the nature of the quadrupoles, the beam is constantly focused and defocused, causing the controls to be rather tricky. The beam is quite sensitive to some quads and almost unresponsive to others.

The priority in the quadrupole controls was the magnets from the (1) 3F region 01-04, (2) 2F region 01-06, (3) 3F region 05-07.

Conclusions

In conclusion, the experiments proposed by the HKS collaboration in regards to target testing using various materials and material thicknesses was evaluated. It was determined that if operation of the 6 quadruple magnets (QX2F01, QX2F02, QX2F03, QX2F04, QX2F05, QX2F06) is allowed, a 0.2 mm rms spot size is possible. This value is within the established limits of the Hall C Users and would provide the necessary beam characteristics required for a meaningful and worthwhile engineering experiment. As a result, testing could be done in an effectively and timely manner.

N.B. Due to scheduling difficulties with both the FEL and CEBAF, this effort was not completed. It was decided to incorporate target testing in situ in Hall C prior to the HKS experiments.

References

[1] Notes documenting meetings about this effort are in the possession of the second author. Here, we draw on information from the 21 October, 2004 discussion.

Appendix A: Parameter specifications for FEL HKS Target Tests

Meeting note for the HKS target study at FEL (SNN), Thursday, Oct. 21, 2004.

Review and establish the minimum requirements for beam:

- Spot size
  - Desirable : sigma 100um
  - How small is possible? a few mm : corresp. rastering / Possibly 250 is OK
- Energy
  - 80 MeV is OK.
- Current
  - Dump is for 2kW? -> 2kW/80MeV = Max 25μA..
- Rep Rates
  - Rep rate is not important if it is fast enough comparing the thermal conduction time constant. (<< 1 sec)
- Power density
  - @HallC 1.8GeV electron beam passes through 100mg/cm2 target
    Energy deposit is about 2MeV/(g/cm2).
    So, 2 [MeV/g/cm2] * 0.1 [g/cm2] * 30[uA] = 6 [W]
  - Power density on the target is :
    6[W]/(0.1*0.1*3.14) ~ 200 W/mm2

Safety requirements - especially radiation and shielding.

- From target: 0.2 MeV * 25 uA = 5 W (5/2000 = 0.25% of the beamdump) Shielding around dump.
- Can we send the target to the chemical composition study?
  (eg. CH2 target)
- We would like to study the target after irradiation.
  Target cracking, stress, etc. OK for on site.

Vacuum Beam Line components (e.g., 6-way cross, vac valves, physical clearance spaces, cables, video cameras, etc.)

- Required Monitor:
  - Beam spot size
  - Beam current (accuracy from Kevin Jordan)
  - Target temperature (themocouple, color pyrometer?) (optional)
  - Target viewer (video camera?)
- Target :
  - CH2 (several thickness/condition) @
  - Li (6Li, 7Li metal) (not high priority) 50mg/cm2) disposal
  - Be (metal)
  - B (sintered powder)
  - C (foil)
  - Si (natural, enriched 28Si, melted and solidification / sinter)
  - V (metal foil)
  - Y (metal foil)

Determine what needs to be designed, if anything.

- Target holder : Hall C one is too large.
- Target vac. chamber
- Easy mechanism to change target?

Schedule.

- E01-011 installation start from next January
- We would like to have FEL test before Christmas

Account code to which work is charged.

- Vac. Chamber : fabricate in US or Japan?
  - Japan : Tohoku Univ. can pay
  - USA : Tohoku Univ. direct contract?
    : EXPHYP account (Hall-C Rolf)

Periodical meeting might be required (eg. in every two weeks?)

- Sumihama : Local contact, Tohoku Univ. ex.5324
- Nue : 8-13 Nov., Beginning of December
- Jim : FEL contact ex. 7513

Need: Video camera

@ Issue: Poly in the beam line.
: Target disposal.
: Radiation + MPS
250 : Pumping (Do we have enough?)