CONF-801111--6

LA-UR 80-2822

TITLE: ACCELERATOR DEVELOPMENT FOR HEAVY ION FUSION

MASTER

AUTHOR(S): W. L. Talbert, Jr., and G. A. Sawyer

SUBMITTED TO: Conference on the Application of Accelerators in Research and Industry - Denton, Texas, November 3, 4, 5, 1980.

University of California

DISCLAIMER

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

Form No. 836 R3
St. No. 2629
12/78

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

ACCELERATOR DEVELOPMENT FOR HEAVY ION FUSION

W. L. Talbert, Jr. and G. A. Sawyer
Los Alamos Scientific Laboratory
Los Alamos, N.M. 87545

Summary

Accelerator technology development is presented for heavy ion drivers used in inertial confinement fusion. The program includes construction of low-velocity "test bed" accelerator facilities, development of analytical and experimental techniques to characterize ion beam behavior, and the study of ion beam energy deposition.

Introduction

The role of technical management for the heavy ion fusion (HIF) program has recently been assigned to the Los Alamos Scientific Laboratory (LASL). In view of this new responsibility, we have reviewed the status of the HIF program in preparation for formulating a program plan for the coming years. We present here several elements included in the program which address developments in accelerator technology, and indicate additional areas of concern which need attention in future program directives.

Since the initial suggestions to consider heavy ion beams as drivers for inertial confinement fusion targets, four HIF workshops have been held,[1-4] at which various technical issues have been studied. At the last workshop, heald a year ago in Berkeley, the conclusions focused on continuing analytical studies regarding ion beam stabilities during acceleration and transport, with the development of hardware appropriate for HIF considered to be a secondary, albeit challenging, concern.

In presenting the accelerator requirements for HIF, one general type of accelerator is regarded as the prime candidate, the linear accelerator, or linac. Two approaches are being pursued for linacs, one being the conventional rf linac, and the other, the induction linac. In both approaches the ultimate beam power seems to be limited by conditions in the low-velocity portion of the linac (for example, beam quality, space charge effects); thus it is important to understand the low-velocity performance limits for each approach. The rf linac approach, which can achieve the necessary beam currents only by use of storage ring accumulation, has the additional concern of loss of beam quality during storage ring manipulations. The ultimate choice of which large linac, if any, will be built as a first HIF facility will result from efforts to understand these limits. For this reason, a rational program plan must include such studies and, in fact, funding realities associated with a newly emergent program such as HIF will preclude more ambitious projects until these studies have been made.

In the context of possible future large facilities and given the projected beam intensity requirements, development of non-destructive, indirect beam diagnostics is needed, and presents considerable challenge requiring more innovation rather than large resources. Additionally, analytical studies on beam stability during acceleration and transport, as well as for the beam-target interaction, have not yet resulted in a mature expectation of realistic beam performance at the power levels envisioned, and need futher effort.

The status of the program efforts in low-velocity linac development, in beam diagnostics, and in analytical studies is presented in the following sections, with comments included regarding the impact of funding limitations, where appropriate.

Low-Velocity Accelerator Development

The program to develop technology in low-velocity accelerators consists of several elements, with the two principal efforts at the Argonne National Laboratory (ANL) (to address issues in the rf linac) and Lawrence Berkeley Laboratory (LBL) (studying the induction linac approach). Additional programs are underway at LASL (the development of the radiofrequency quadrupole structure (RFQ), described elsewhere in this proceedings[5]), Brookhaven National Laboratory (BNL) (the MEQALAC concept, described elsewhere in this proceedings[6]), and Sandia National Laboratories (SLA) (the Pulselac concept[7]). The programs at ANL and LBL are configured toward the eventual construction of accelerator test beds which would be used for experimental study of the respective issues. The time to achieve these studies is presently limited by the available funds and would be difficult to be sooner than FY 1986.

ANL Test Bed

The ANL program includes construction of a "full-scale" front end of a heavy ion driver, consisting of ion source (Xe^{+1}), preaccelerator (a modified Dynamitron), low-velocity section (six independently phased cavities (IPC's)), 12.5-MHz Wideroe, stripper (to Xe^{+8}), 25-MHz Wideroe, two accumulator rings, and a final compression and transport line. The parameters of this accelerator are presented in Table I, and a schematic layout in the ANL ZGS accelerator complex is shown in figure 1.

The issues to be studied by ANL for the rf linac/storage ring approach are broadly stated in Table II. While this list of studies is expected to lead to a resolution of more present concerns in accelerator technology for the rf linac and/or storage ring manipulations, some of the points may be addressed in a scalable manner using existing facilities before the test bed is available. One possible approach is to study injection into and extraction from a non-ramped synchrotron ring, for example the rapid cycling synchrotron at ANL. The results of such pre-test-bed experiments may be useful in optimizing the test bed configuration for the issues remaining.

The ANL test bed represents a natural extension of the current program at ANL. The injector and preaccelerator sections are allready at hand or under construction, and beam tests are underway. It can be regarded that the completion of the test bed may represent only a plateau in ANL capabilities. Conversion of one of the storage rings to a synchrotron (and perhaps addition of a second injector and low-velocity section) would allow significantly higher beam energy (perhaps as high as 3 kJ) to be achieved for a relatively modest additional investment. Thus, the ANL facility constructed for studying accelerator technology issues could conceivably be upgraded to allow physics studies of beam-target interactions.

LBL Test Bed

The program at LBL is designed for the short-term goal of constructing a facility to study the most pressing issues confronting the induction linac approach. The parameters of the LBL Test Bed, which consists of a source, low-velocity section, and flexible main section of induction modules, are presented in Table I, and a schematic outline of the accelerator is shown in figure 2.

Since the main concerns of the induction linac approach are associated with low-velocity performance, the ultimate beam kinetic energy need not be as high as for the rf linac test bed. The studies of accelerator performance will include the items presented in Table II, and should provide a confident basis for the design of a complete driver of the induction linac type.

The LBL facility can also be upgraded in the future to provide capabilities for physics studies of beam-target interactions, but a multi-kJ beam energy may require a substantial additional investment. More likely, should the induction linac approach be preferable to the conception of a large HIF facility, a totally new design may be undertaken rather than a simple extension of the test bed.

Diagnostics developments ——>

The requirement to make precision studies of beam quality in the test bed facilities, and anticipated conditions where direct beam probes are unsuitable in a larger HIF facility, dictate that non-destructive diagnostics be available for high current heavy ion beams. Possible approaches to non-destructive beam position, profile, velocity spread, and charge distribution are being evaluated at both ANL and LBL.

The position and profile system (PAPS) developed at ANL[8] has been used to measure the emittance of the ANL heavy ion source and preaccelerator. The details are presented in figure 3. The PAPS device makes use of electron generation by an ion beam in background gas, and is essentially a passive array of electron collection strips at one end of an imposed (transverse) electric field. As can be seen in the figure, this technique can be used for intense heavy ion beams, at least for the beginning stages of a heavy ion driver.

Development of two diagnostic devices is underway at LBL, one to characterize velocity distributions in an ion beam and the other to sense position and charge cross-section of an ion beam. The former, as presently conceived, employs resonant laser scattering and senses the velocity distribution in a beam by means of doppler broadening measurements, as illustrated in figure 4. The latter system can be used to infer spatial and charge density characteristics by inverting beam direction. A schematic of this approach is shown in figure 5.

Although the above examples of non-destructive ion beam diagnostics may not yield the precision required for a heavy ion driver, they illustrate the type of development needed in the future. It is also possible that these examples will evolve into devices which respond to the eventual requirements.

Other problem areas →

The promise of HIF is based on two considerations: the development of heavy ion drivers (including beam transport) represents reasonable extension of current technology, and the beam-target interaction is expected to be classical and to yield confident target designs. We have indicated above that a resolution of some of the concerns in accelerator development may be possible with the pending test bed programs. Accompanying the pending studies should be an effort devoted to assessing means be which heavy ion driver costs can be minimized. At the present time, cost estimates for heavy ion drivers exceed those for other drivers up to about the 1 MJ energy level. We must attempt to reduce present cost estimates to a more economically attractive level if the HIF program is to graduate above a modest technology assessment level.

While it seems inappropriate to question the validity of the assumptions on beam-target interactions, in view of the apparently well-established body of data and theory regarding energy loss processes, there are recent data on ion stopping powers[9] that deviate considerably from the reference tabulations of Northcliffe and Schilling.[10] Because these deviations could possibly impact target designs resulting in changes in input energy requirements, it is important to benchmark the ion energy deposition models. A sensitivity study of the beam-target interaction for various energy deposition model parameters is underway at LASL and may result in the definition of experiments that can be carried out at existing heavy ion facilities to test deposition model realism.

Associated with the beam-target interaction is the realistic appraisal of beam transport and final focus in bringing the beam into the target in reactor conditions. At the present time, analytical approaches to this issue must be used, and simulation techniques for analysis of intense charged particle beams are being developed to identify transport system parameter ranges that would result in achievement of the required beam focus at the target.

To conclude, the national effort in HIF includes broad-based studies of accelerator technology and ion beam physics. At the present level of funding, analytical work is required to prepare for, and justify, the experiments planned for test bed facilities to be constructed at a pace limited by actual funding.

We would like to thank D. Keefe and S. Rosenblum of LBL, R. Martin and R. Arnold of ANL, and S. Humphries of SLA for kindly providing us with information on their programs.

References →

1. ERDA Summer Study of Heavy Ions for Inertial Fusion, July 19-30, 1976, Report LBL-5543.
2. Proceedings of the Heavy Ion Fusion Workshop, October 17-21, 1977, Report BNL-50769.
3. Proceedings of the Heavy Ion Fusion Workshop, September 19-26, 1978, Report ANL-79-41.
4. Proceedings of the Heavy Ion Fusion Accelerator Study, October 29 - November 9, 1979, Report LBL-10301.
5. T. P. Wangler and R. H. Stokes, these proceedings.
6. R. M. Mobley, these proceedings.
7. S. Humphries, Jr., G. W. Kuswa, C. W. Mendel, and J. W. Poukey, IEEE Trans. Nucl. Sci. NS-26, 4220 (1979).
8. J. M. Bogaty, IEEE Trans. Nucl. Sci. NS-26, 3349 (1979).
9. R. Bimbot, D. Gardes, H. Geissel, T. Kitahara, P. Armbruster, A. Fleury, and F. Hubert, GSI annual report, 1979.
10. L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables A7, 233 (1970).

TEST BED ACCELERATOR PARAMETERS

	ANL	LBL
ION SPECIES	$Xe^{+1,+8}$	Cs^{+1}
INJECTOR/PREACCEL.		
SOURCE	Xe^{+1} PENNING WITH EXTRACTION	CONTACT IONIZATION WITH PIERCE EXTRACTION
STRUCTURE	MODIFIED DYNAMITRON	5 PULSED DRIFT TUBES
ENERGY OUTPUT	1.5 MeV	3 MeV
CURRENT	40 mA	1 A
PULSE DURATION	100 μsec	5 μsec
ACCELERATOR SECTION		
TYPE/ENERGY	6 IPC's FOLLOWED BY 12.5-MHz WIDEROE, 1.5 TO 20 MeV. BEAM STRIPPED TO Xe^{+8}. 25-MHz WIDEROE, 20 TO 220 MeV.	47 INDUCTION MODULES, 320 kV MAXIMUM EACH, 3 TO 10 MeV.
OUTPUT CURRENT	5 mA	3.1 A (1.6 μsec PULSE)
STORAGE RINGS	TWO, 4x4 STACKING COMBINED WITH INTER-RING PHASE ROTATION. 0.4 A OUTPUT CURRENT.	N.A.
COMPRESSION	x20, 8 A OUTPUT AT FINAL FOCUS.	N.A.
FINAL BEAM ENERGY	180 J	50 J

TABLE I

TEST BED ACCELERATOR PARAMETERS

	ANL	LBL
ION SPECIES	$Xe^{+1,+8}$	Cs^{+1}
INJECTOR/PREACCEL. SOURCE	Xe^{+1} PENNING WITH EXTRACTION	CONTACT IONIZATION WITH PIERCE EXTRACTION
STRUCTURE	MODIFIED DYNAMITRON	5 PULSED DRIFT TUBES
ENERGY OUTPUT	1.5 MeV	3 MeV
CURRENT	40 mA	1 A
PULSE DURATION	100 μsec	5 μsec
ACCELERATOR SECTION TYPE/ENERGY	6 IPC's FOLLOWED BY 12.5-MHz WIDEROE, 1.5 TO 20 MeV. BEAM STRIPPED TO Xe^{+3}. 25-MHz WIDEROE, 20 TO 220 MeV.	47 INDUCTION MODULES, 320 kV MAXIMUM EACH. 3 TO 10 MeV.
OUTPUT CURRENT	5 pmA	3.1 A (1.6 μsec PULSE)
STORAGE RINGS	TWO. 4x4 STACKING COMBINED WITH INTER-RING PHASE ROTATION. 0.4 pA OUTPUT CURRENT.	N.A.
COMPRESSION	x20. 9 pA OUTPUT AT FINAL FOCUS.	N.A.
FINAL BEAM ENERGY	180 J	50 J

ISSUES TO BE STUDIED WITH TEST BEDS

ANL - 1. PERFORMANCE OF FULL-SCALE FRONT END OF A HEAVY ION DRIVER:

A. BEAM CAPTURE AT FULL CURRENT.
B. EMITTANCE GROWTH IN EARLY STAGES OF LINAC.

2. STORAGE RING MANIPULATION:

A. EFFICIENCY AND EMITTANCE GROWTH DURING INJECTION TO SPACE CHARGE LIMIT INTO STACKING RING.
B. BEAM TRANSFER WITH PHASE ROTATION FROM STACKING RING TO STORAGE BEAM.
C. EFFICIENCY AND EMITTANCE GROWTH IN EXTRACTION FROM BOTH RINGS.

3. FINAL COMPRESSION, TRANSPORT, AND FOCUSING OF BEAM.

LBL - 1. BEAM QUALITY:

A. PREPARE AND LAUNCH A SIGNIFICANT BEAM INTO INDUCTION LINAC STRUCTURE.
B. BUNCH BY PULSE COMPRESSION IN STRUCTURE.
C. EXPLORE STABILITY LIMITS.
D. REALISTICALLY EVALUATE EFFECTS OF IMPERFECT OPERATION OF MULTI-ELEMENT SYSTEM.

2. BEAM EXPERIMENTS:

A. GAINS FROM NEUTRALIZATION.
B. STRONG FOCUSING ELEMENTS IN DRIFT TUBES.
C. BEAM SPLITTING.
D. ACCELERATION OF OTHER ION SPECIES.

3. ENGINEERING:

A. COMPONENT DEVELOPMENT - COST OPTIMIZATION.
B. OPERATIONAL EXPERIENCE - MACHINE SENSITIVITIES.

Fig. II

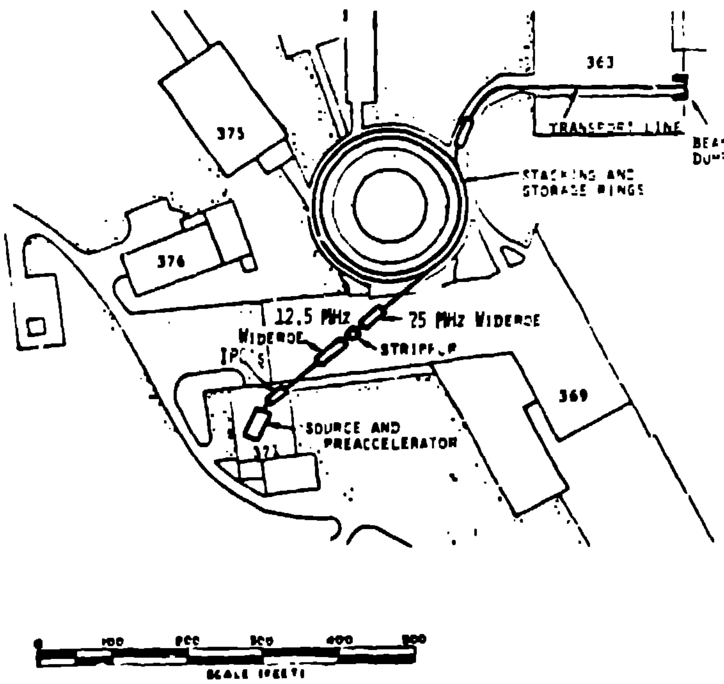
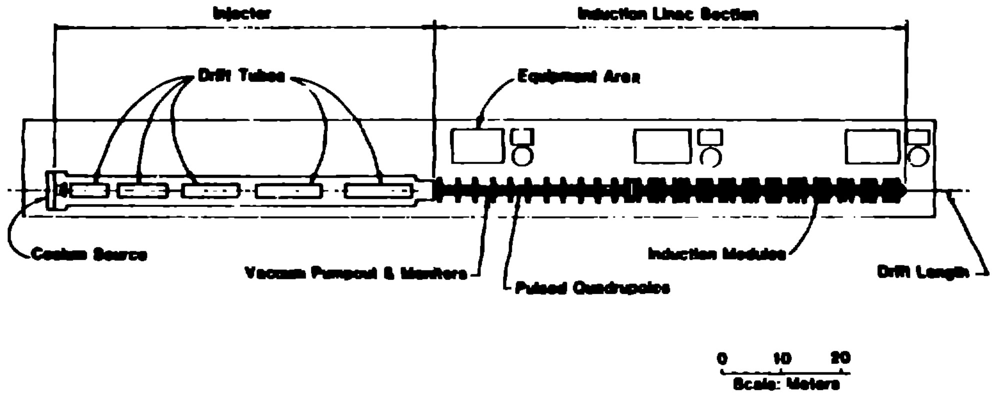


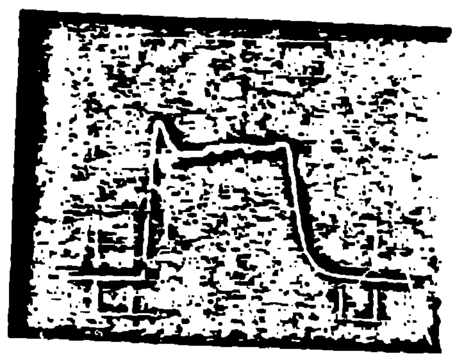
Figure 1 - Schematic



10 MeV Cs^{+1} 50 JOULE ION INDUCTION LINAC LAYOUT

XBL 804-9315

Xe^{+1} SOURCE EMITTANCE MEASUREMENT

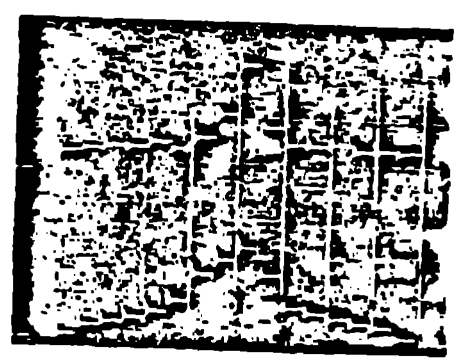


1 MeV Xe^{+1}
40 mA
200 μs PULSE

PAPS MEASUREMENT MIDWAY IN PULSE WITH 10 μs WINDOW

FORM ROUND WAIST AT PAPS 1
R_0 = 0.95 CM

BEAM DRIFTS Z = 254 CM TO PAPS 2
R = 1.6 CM

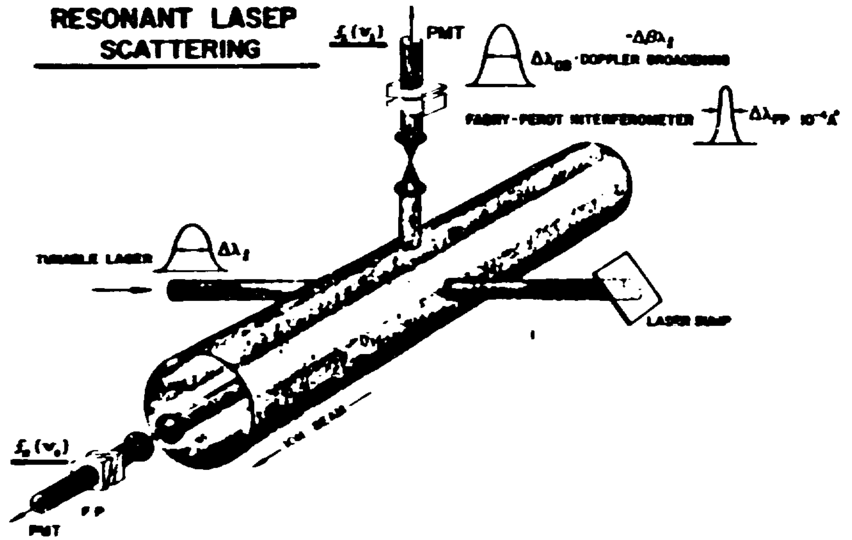


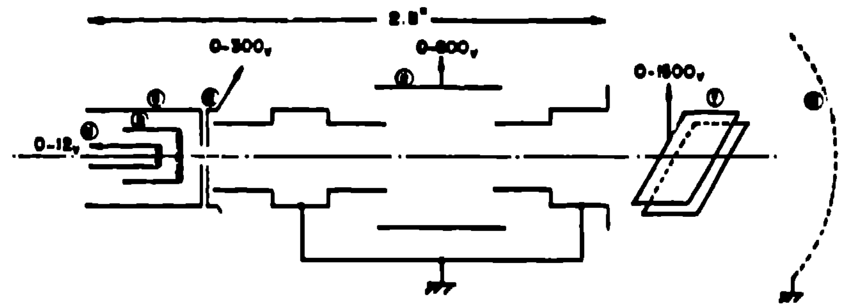
ASSUME UPRIGHT ELLIPSE, $\epsilon_N = \beta\gamma \frac{R_0^2}{Z}\left[\frac{R^2}{R_0^2} - 1\right]^{1/2} = \beta\gamma R R'$

$\epsilon_{NX} = \epsilon_{NY} = 0.0040 \times 4.7 = 0.019$ CM-MRAD

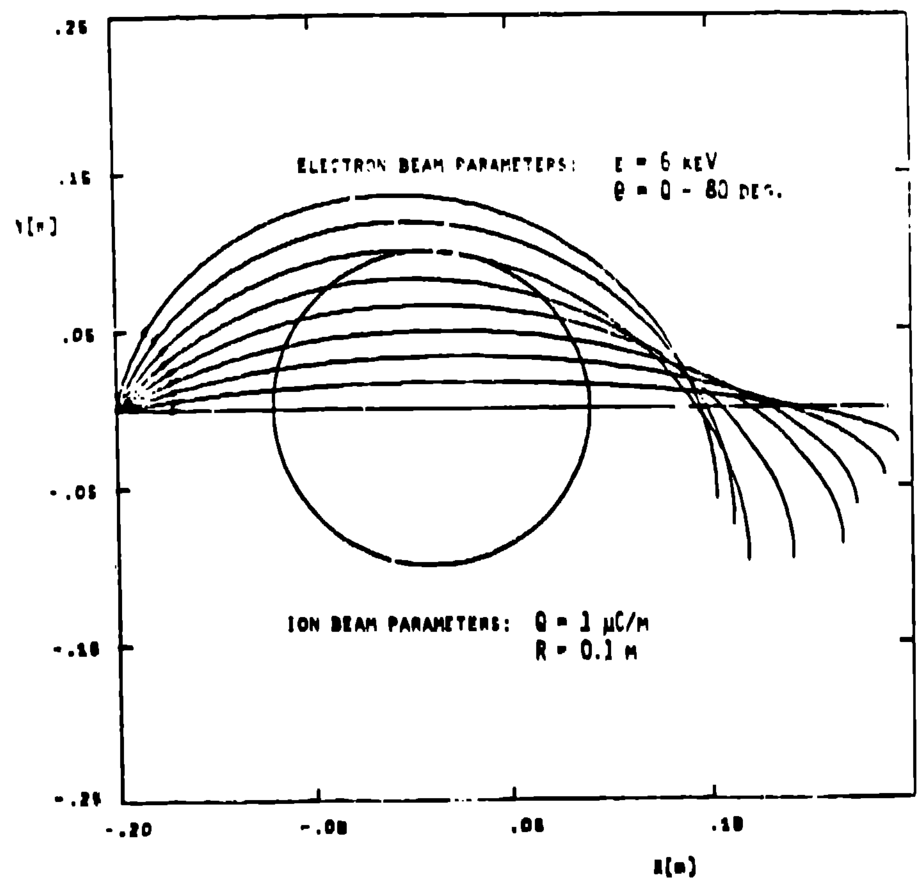
Figure 3. Emittance measurement of ANL injector beam.

RESONANT LASEP SCATTERING





a. Filament
b. Cathode
c. Grid
d. Anode
e. Electrostatic lens
f. Deflection plates
g. Accelerator grid



[illegible]