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URANIUM BEAMS IN RHIC: FOUR MEVVA-BASED PREINJECTION APPROACHES

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by

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There is physics justification for eventually colliding uranium beams in RHIC. The tandem preinjector is quite adequate and reliable for the Au+Au collision program, but the tandems are not expected to produce sufficient beam currents for U+U experiments at RHIC. Evaluated here are four viable uranium preinjection schemes, which are all based on variations of the Metal Vapor Vacuum Arc (MEVVA) ion source. The analysis is based on experimentally achieved performance and conservative estimates of enhanced capabilities. The first approach is based on a conventional MEVVA and two LINACS. The second option combines an EMEVVA (electron-beam injected MEVVA) with a small low β LINAC, similar to the one used in the Positive-Ion Injector (PII) for ATLAS at ANL. Either of these first two schemes can allow for multi-pulse single turn injection of U^{42+} ions into the Booster with sufficient beam currents (many particle microamps) to satisfy future RHIC requirements. Integration into the Booster-AGS-RHIC complex would require minimal (if any) new source or accelerator development. Two upgrade options, which would require some additional research and development, are based on a MEVVA and a plasma stripper or a combined EMEVVA and plasma stripper (EMEVVAPS). We estimate that, if properly developed, an EMEVVAPS could produce ***two particle milliamps*** of U^{42+} ions for injection into the Booster, AGS, and RHIC.

of heavy ions with moderate charge states was very poor. The 1986 committee concluded that low charge-state heavy-ion sources, like the Penning ionization gauge (PIG), Metal Vapor Vacuum Arc (MEVVA), and various sputter sources did not warrant serious consideration as a basis for a preinjector (other than their potential for providing primary ions to an advanced source).

Since 1986 a number of significant new developments have occurred, which strongly suggest that other approaches deserve more serious consideration. Specifically, the discovery of the afterglow mode in an ECR ion source in GANIL [3] enhanced the yield of higher charge states by more than a factor of four. Recently, GANIL supplied CERN with such a source for the lead program at the SPS [4]. The ECR injector performance is excellent in terms of reliability and reproducibility. Its yield is three particle microamps (3 pμA) of Pb^{+27}. To be viable for RHIC an ECR approach must be enhanced by a smaller factor than an EBIS-based preinjector must be scaled up (50% in length, and a factor of 20 in electron beam current). However, since the ECR afterglow mode was a lucky breakthrough, there is no assurance that an ECR preinjector could be made viable for RHIC. Other, very important achievements are the success of the Positive Ion Injector (PII) low β LINAC for ATLAS [5], great improvements in MEVVA sources [6], and the development of the electron-beam injected EMEVVA ion source [7,8]. The latter generated large currents (in the mA range) of metallic ions like Cu^{+21} and U^{+20}. These recent developments indicate that MEVVA-based approaches should be viable for future RHIC preinjectors.

In addition, a vacuum-atmosphere interface (recently developed at BNL [9]) could be used as a separator of high and low vacuua to facilitate the use of plasma strippers and lenses in a RHIC preinjector. The physics of ionization and focusing in a current carrying plasma anode, a suppressor, and a three-grid extractor. Triggering of the vacuum arc is accomplished by applying a short high voltage pulse between the trigger electrode and the cathode across an insulating surface. Discharge occurs due to formation of *cathode spots*, which are micron-sized spots on the cathode surface characterized by extremely high current densities. Cathode material is vaporized and ionized, producing a plasma plume.

MEVVA ion sources vary in size and extracted current. The usual range of arc or discharge currents is from 20-200 A, depending on the source size and intended application. The beam extraction area ranges from 0.05 to 2000 cm^2. The maximum extracted ion current varies from 10 mA to 3.5 A. Although dc operation is possible, the typical MEVVA output beam has a pulse length of about 0.1 to 3 msec. Figure 2 shows a micro-MEVVA which was fabricated and operated at BNL [12]. In spite of its small dimensions, this MEVVA generated 10 mA uranium ion beams with pulse lengths of 0.1 to 1 msec.

Most MEVVA ion sources have solid cathodes that are shaped like rods. However, at least two have hollow cathodes. These two are used by the groups of Marrs at LLNL and Batalin at ITEP, Moscow. The LLNL source operates with a higher reliability than a conventional MEVVA (it fires every shot) and generates various metallic ions including uranium. A good general reference on the MEVVA is the review by Ian Brown [13].

Many MEVVA ion sources are operational world wide. At pulse lengths of 100 μsec, a MEVVA uranium cathode can generate 10^5 pulses. A uranium multi-cathode ion source, incorporating 16 cathodes that could be changed without breaking vacuum simply by rotating an external control knob, operated very reliably [6]. MEVVA sources have produced uranium ion beams with large electrical currents (exceeding 100 mA) and with low emittances ranging from 0.15 to 0.3 π mm-mrad [14]. The dominant charge state (more regarded as provisional until repeated elsewhere or documented with more detailed descriptions of achieved performance.

III. Conservative Preinjector Options

Initially, the BNL Tandem Van de Graaff facility will be the RHIC preinjector for heavy ions up to gold (A=197). For the heavier element uranium (A=238) the negative ion sources compatible with tandem operation produce beam currents which are two or three orders of magnitude less intense than for gold beams. Therefore, it is prudent to consider alternative preinjector schemes to deliver useable uranium ion beams into the Booster at injection energies of 1 – 3 MeV/u. The most promising approach identified in 1986 was the EBIS-RFQ-LINAC preinjector, which features ions with $q/m \geq 0.17$ entering the RFQ with $\beta = 0.0043$, and single turn injection into the Booster. However, the EBIS state of the art yield of the desired ions is more than a factor of 30 below what is needed for RHIC.

Alternative sources of uranium ions with lower q/m are worth considering for RHIC, if both (1) the ion yield is sufficiently high, and (2) an appropriate preinjection scheme is developed. EMEVVA, yielding 3 mA of U^{+17} in 20 μsec long pulses [7,8], and MEVVA yielding hundreds of mA of U^{+3} ions satisfy the first requirement, while ATLAS [5] has provided at least one feasibility demonstration for the second. Furthermore, successful acceleration of 5 mA of U^{+3} ions was achieved, more than ten years ago, in an RFQ to an energy of 4.76 MeV [14].

Figure 3 shows two conservative preinjector options, which are based on previously demonstrated performance. For these two approaches (and the two upgrade options discussed below) we assume that the booster is filled with four single turn, 13.6 μsec long pulses of uranium ions. The pulse length is determined by the energy at which the beams are

B. EMEVVA / LINAC

Figure 3 also illustrates Option 2, which is based on an *EMEVVA / LINAC* combination. The low- β LINAC used in the Positive Ion Injector (PII) at ATLAS can accelerate beams with a starting β as low as 0.009 [5]. Therefore, U^{+17} ions from an EMEVVA could be easily injected into such a LINAC from a high voltage platform or an RFQ. With some small modifications, such a LINAC could accelerate these ions to 293 MeV. At this energy, uranium ions complete a single turn in 13.6 μsec. Since our interest is in multi pass single turn injection into the booster, only 13.6 μsec of the EMEVVA pulse length can be used. Therefore, a 3 mA beam of U^{+17} ions for 13.6 μsec, yields $1.5x10^{10}$ ions per pulse (it is $1.2x10^{10}$ for U^{+20}). These ions can be injected into and accelerated by a LINAC similar to PII, to an energy of 1.23 MeV/u, after which, they are stripped to U+42.

The transmission and bunching efficiency of the PII is 63%. In the HILAC I stripping stage of the Bevalac facility at LBL U^{+13} was stripped to U^{+40} at an energy of 1.2 MeV/u with a factor of 4.2 in beam loss. Combining this result with the PII efficiency, yields a prediction that at least 2.2×10^9 U^{+42} ions per pulse would be available for injection into the RHIC Booster. Four such pulses can be stacked into the Booster with transverse stacking for a total of about 8.8×10^9 U^{+42} ions. Although the ***EMEVVA / LINAC*** approach has a lower yield than ***BEVALAC Revisited***, only one LINAC is required. Furthermore, the expected output is an order of magnitude higher than achievements to date with any alternative approach, and improvements in EMEVVA performance are highly likely, because development is still in infancy.

IV. Upgrade Options using Plasma Strippers

Finally, low energy heavy ions are not likely to be stopped in plasma strippers, because the plasma can be made arbitrarily *thin*. Unlike foils, plasmas do not break. For example, in the ***EMEVVA / LINAC*** approach described above, which is based on a 100 mA U^{+3} ion source, the first stripping stage must endure 2.7 x 10^{12} ions per pulse. Foil lifetimes could be very short, but the beam current will not adversely affect performance of the plasma stripper.

A. MEVVA / Plasma Stripper

Figure 4 illustrates Option 3, which is based on using the fast electrons in a plasma stripper or a high current electron beam to strip slow uranium ions (75 keV) from a MEVVA. To reach U^{+20} a $j\tau$ equal to 0.8 and an electron energy exceeding 900 eV are needed (see Fig. 1). These requirements can be satisfied with a 1 meter long 200 kA Z discharge with a 1 cm^2 cross section. A 75 keV uranium ions transits 1 meter in about 4.2 μsec; hence $j\tau$ = 0.84. One concern is attenuation of the uranium beam, which is dominated by interactions with thermal plasma electrons. Crude calculations indicate that attenuation will not be severe, but further research and development is needed to demonstrate that attenuation is not a problem. If attenuation is not serious, then the ***MEVVA / Plasma Stripper*** approach is estimated to produce 0.13 pmA of U^{+42} ions.

B. EMEVVA / Plasma Stripper

Figure 4 also illustrates Option 4, which is based on the use of a metal vapor plasma cathode. In this approach the plasma stripper is essentially a high intensity electron beam, which is produced either by the plasma expanding from the MEVVA or by a metal vapor cathode located at the end of a drift channel. The latter option reduces the needed current density to 45 A/cm^2, because the uranium ions move with thermal velocity. MEVVA current

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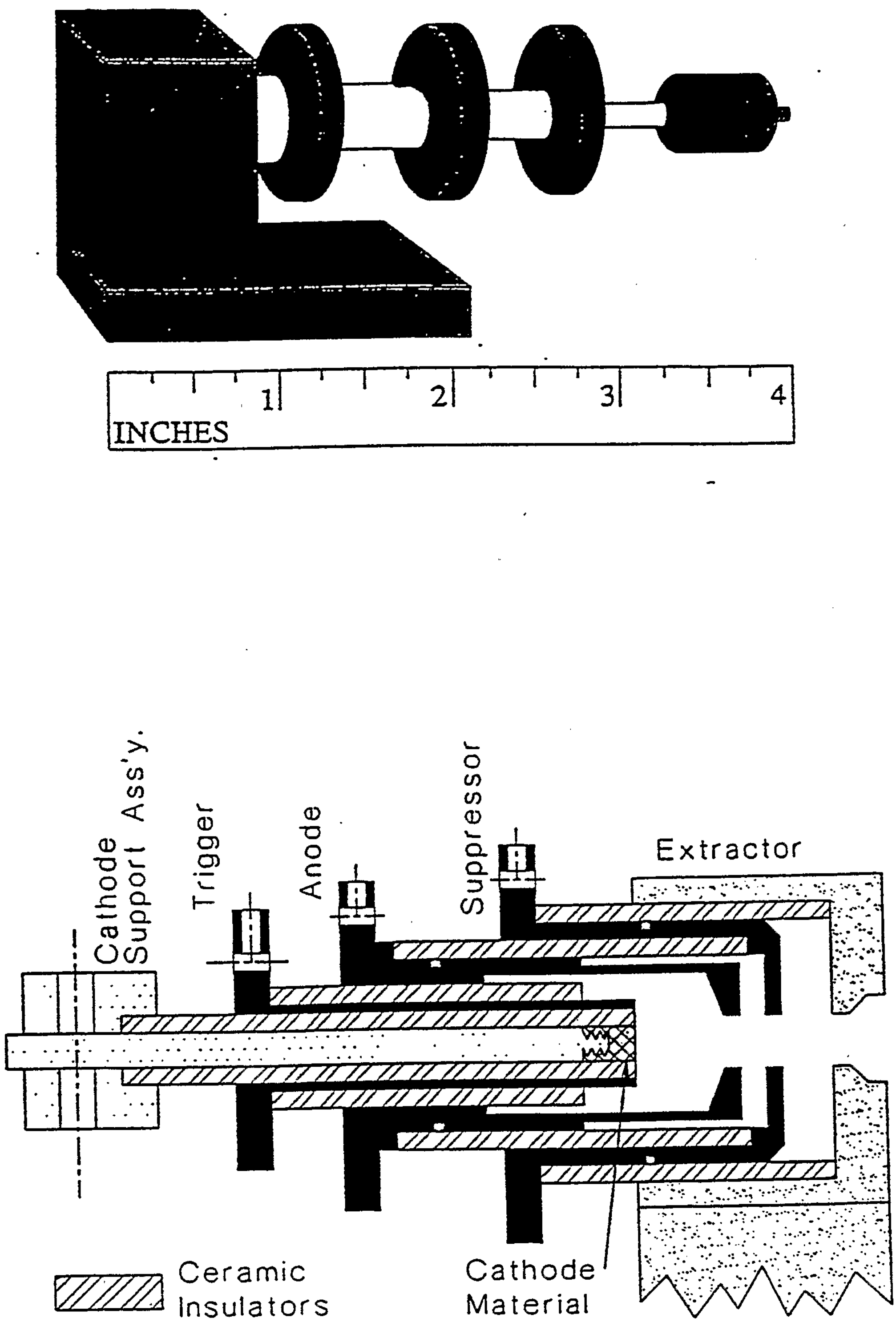

Figure 2. Schematic of a micro-MEVVA, which was fabricated and operated at BNL [12].

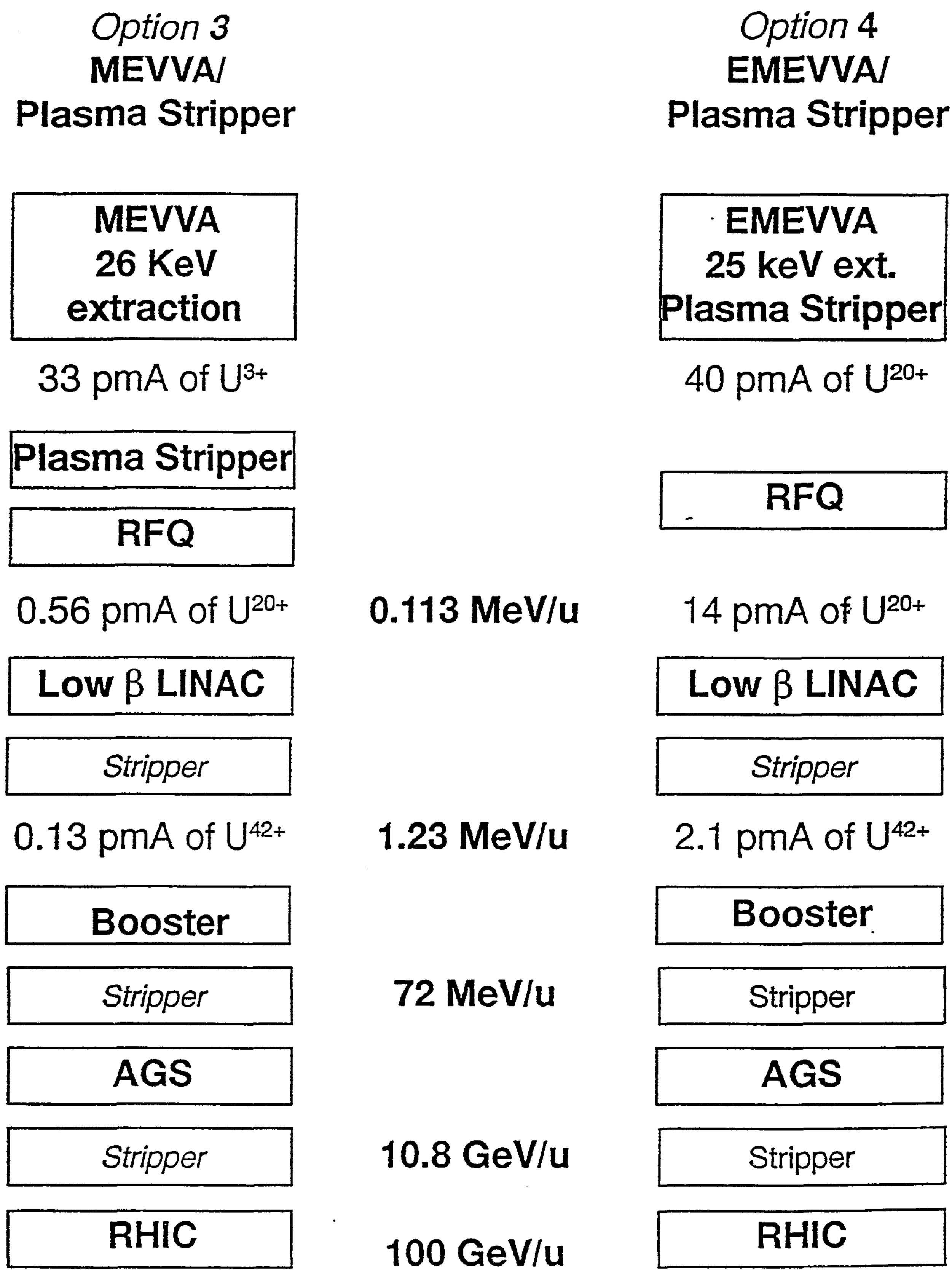

Figure 4. Illustrations of two possible upgrade options using plasma strippers. Beam current estimates are based on previously demonstrated performance and projections of future development.