K4-K10 PROJECT. TREBLe: TWO RING EXOTIC BEAM LABORATORY

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ABSTRACT
The concept of the Dubna project of two coupled storage rings intended to provide cooled beams of short lived exotic nuclei is briefly described and the evaluated luminosity values are presented. As the first stage of the project the construction of one of the rings is proposed. Due to the high peak beam intensity of the injector cyclotron U400M this ring will give high luminosity exotic beams.

1. DESCRIPTION OF THE PROJECT

TREBLe is a modification of the Dubna project of the heavy ion storage ring complex K4-K10 [1, 2, 3]. The specific feature of this modification is to provide high precision beams of exotic nuclei with mass numbers of $A<50$ in the energy range from few MeV to about 200 MeV/amu. We preserve the principal concept of the K4-K10 project (see Fig.1). The first ring is intended to accumulate the primary heavy ion beam from the JINR sector focusing cyclotron U400M, to cool this beam and to increase the energy up to about 120-170 MeV/amu. The primary beam obtained as a result of fast extraction from the first ring is used to produce the exotic beam which, after separation by an energy loss achromat, is injected into the second ring. The nuclei with the lifetime of ≥ 1 s can be cooled and accumulated on the ring orbit and their beam energy can be controlled. For the short lived nuclei ($T_{1/2}<1$ s), a target irradiation will be preferable immediately after cooling. The cooling time in the second ring will be of the order of 50 ms. This very short cooling time can be obtained due to a low initial phase space of the secondary beam. The small transverse emittance is resulted from the fact that the secondary beam is produced after focusing the high quality primary beam onto a very small target spot of less than 1 mm in diameter. The longitudinal emittance of the secondary beam is also considerably reduced due to the possibility to extract from the first ring the high quality primary beam in the form of very short (20 ns) bunches.

2. INJECTOR CYCLOTRON U400M

The sector focusing cyclotron U400M is a new machine which being tested during the 1993 commissioning cycle proved its ability to produce, with a PIG ion source, high intensity beams of ions ranging

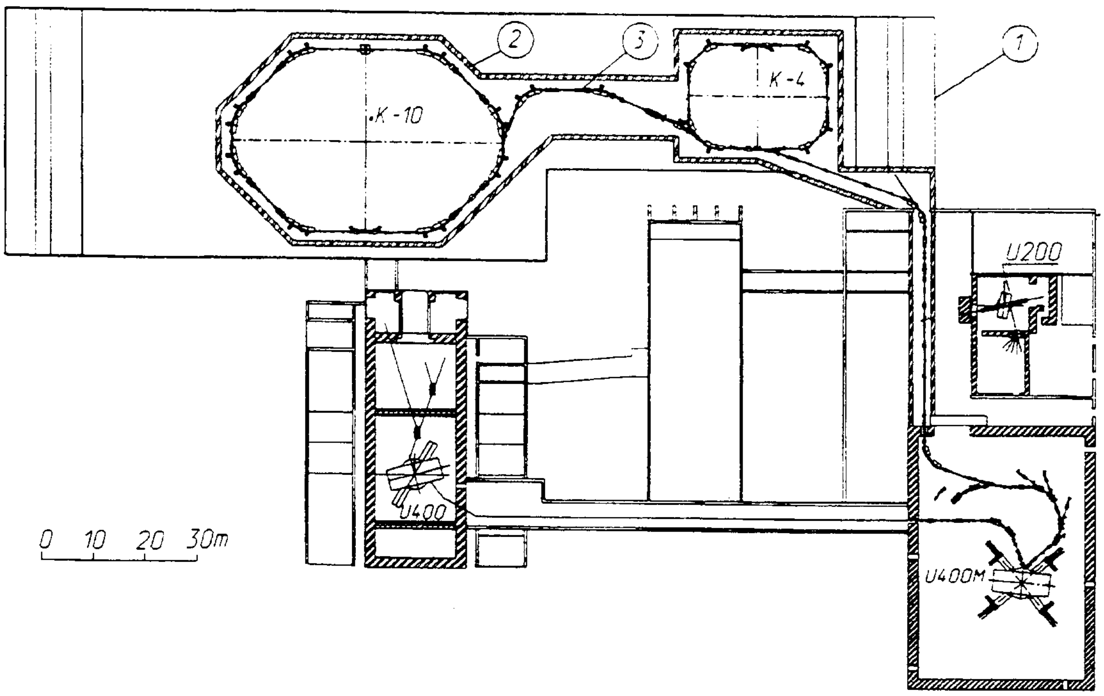

Fig.1 - Diagram of the complex K4-K10.
1-injection beam line, 2- production target, 3-separation channel.

from carbon to neon. Table 1 gives the intensities of some of the beams in terms of the number of ions which will be produced by the cyclotron within one microsecond, i.e. the time interval of the order of one period of beam revolution on a ring orbit. The data for the ECR ion source are from literature [4]. The numbers for the laser plasma ion source are obtained in experiments carried out at the sector focusing cyclotron U200 [5]. The program of installation of an ECR ion source is running in 1993 as an essential part of the funded U400M project. The routine operation of the cyclotron with this ion source will begin in 1994. Specially for the project TREBLe the work on a new version of the laser ion source for U400M is carried out in 1993. The tests are planned for 1994.

Table 1 - Peak Beam Intensities of U400M

ION	NUMBER OF IONS PER 1μS			ENERGY MeV/amu
	ECR	Laser source	PIG	
$^{14}C^{+4}$		10^{9}	$5*10^{8}$	43
$^{15}N^{+5}$	$4*10^{9}$		10^{7}	56
$^{18}O^{+6}$	$3*10^{8}$	10^{8}		56
$^{20}Ne^{+7}$	$2*10^{8}$			59
$^{30}Si^{+7}$		$8*10^{8}$		31
$^{36}S^{+8}$		10^{9}		29
$^{40}Ar^{+10}$	10^{8}			35
$^{46}Ti^{+12}$		$3*10^{8}$		38
$^{48}Ca^{+10}$	$4*10^{7}$	$3*10^{8}$		27

3. COOLER RINGS

The ring K4 described in [1] meets the conditions imposed on the first ring in TREBLe. Its basic parameters are listed in Table 2. Two beam injection schemes foreseen for this ring are considered in detail in our previous papers [1, 2, 3]. Both schemes, the injection by ion stripping and multiple single turn injection, provide for the fast primary beam accumulation and cooling. This can be accomplished

Table 2 - Basic Parameters of the Ring K4

Ring	K4
$B\rho_{max}$, T*m	4
Circumference , m	83.11
Acceptance $\mathcal{E}_{\perp}$, π*mm*mrad	35
$(\Delta p/p)_{max}$, %	1.0
Cooling electron maximum energy , keV	100
Length of the cooling section , m	3
Electron maximum current , A	5
Cathode diameter , cm	3
RF amplitude, kV	14
Range of the RF frequency , MHz	0.5–3.4
Vacuum, Pa	10^{-8}

Table 3 - Some exotic beams attinable at TREBLe

BEAMS	$T_{1/2}$ (sec)	$\lvert N-N_{drip}\rvert$	E inj. (MeV/amu)	E max. (MeV/amu)	NUMBER OF IONS ON ORBIT	LUMINOSITY ($s^{-1}cm^{-2}$)
^{6}He	0.808	2	105	175	10^{7}	10^{27}
^{8}He	0.122	0	110	120	10^{5}	10^{25}
^{9}Li	0.178	2	110	175	10^{7}	10^{27}
^{11}Li	0.009	0	110	120	10^{4}	10^{24}
^{11}Be	13.8	3	125	210	10^{7}	10^{27}
^{14}Be	0.05	0	120	130	10^{2}	10^{22}
^{12}B	0.02	5	85	265	10^{8}	10^{28}
^{17}B	0.006	0	120	140	10^{2}	10^{22}
^{16}C	0.75	6	115	220	10^{6}	10^{26}
^{18}C	0.1	4	120	175	10^{3}	10^{23}
^{14}O	70.6	2	110	455	10^{8}	10^{28}
^{22}O	0.76	2	120	210	10^{4}	10^{24}
^{24}Ne	225	8	125	265	10^{8}	10^{28}
^{28}Ne	0.014	2	120	200	10^{3}	10^{23}
^{44m}Sc ($J^{P}=6^{+}$)	$2*10^{5}$	9	110	335	10^{10}	10^{30}

within 100 ms for 10^{11} and 10^{10} ions of carbon and calcium, respectively, accumulated and cooled on the orbit of the ring. Formation of 20 ns bunches on the K4 orbit will cause some increase of the beam momentum spread while it does not affect the small transverse emittance of the cooled beam. A beam having the transverse emittance of 1 π mm*mrad and momentum spread of $\pm 0.2\%$ will be easily focused onto a production (beryllium) target of a diameter of 0.8 mm. The beam of exotic nuclei produced on this target will be separated and focused by the ion optical system of the fragment separator shown in Fig.1. The separator is designed to manage, for the injection into the second ring, with the exotic beam having the momentum spread of $\pm 0.5\%$ and emerging from the target within a solid angle of about 3 msr. The maximum magnetic rigidity of the second ring is not specified at this stage. Other essential parameters can be borrowed from the K10 ring described in [1]. In Table 3 we show, for some exotic nuclei, the evaluated numbers of ions on the orbit of the second ring and the luminosity values which will be attainable in experiments carried out with internal ring targets. We assumed that a long term irradiation will be possible in the case when the thickness of the target does not exceed 10^{14} atoms per cm^{2} and that the beam accumulation time of up to 1000 s will be possible for the long lived nuclei.

4. FIRST STAGE OF THE PROJECT

We determine the first stage of the project realization which implies the building of the first ring K4. The peak primary beam intensities presented in Table 1 give us favorable conditions to produce the beams of exotic nuclei suitable for accumulating and cooling in the ring K4. Immediately after splitting (see Fig.2), the beam is focused on a target (diameter of 1 mm), and secondary beams are produced.

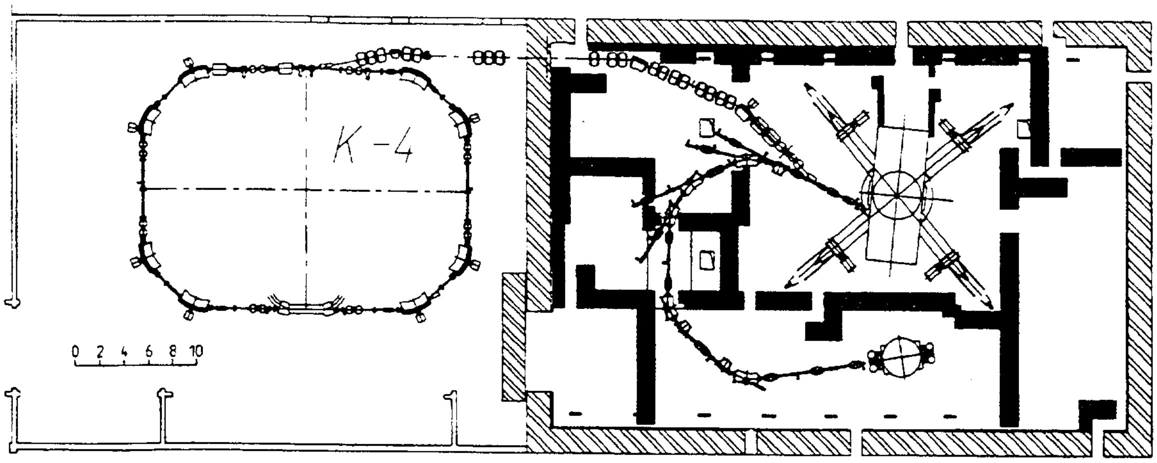

Fig.2 - First stage of TREBLe.

The secondary beam emerging from the target within the solid angle of 3.5 msr will be captured by this separation channel and injected into the K4 ring. To widen the accessible momentum range of the beam accumulated in the ring a beam debunching (see Fig.3) will be provided before the injection. This reduces, by a factor of about ten, the initial momentum spread (±1.0%) of the secondary beam. In Table 4 we give the parameters of some exotic beams which will be obtained after the completion of the project first stage.

Table 4 - Exotic Beams in K4.

BEAMS	$T_{1/2}$ (sec)	$\|N-N_{drip}\|$	E inj. (MeV/amu)	E max. (MeV/amu)	NUMBER OF IONS ON ORBIT	L ($s^{-1} cm^{-2}$)
^{6}He	0.808	2	42	80	10^4	10^{24}
^{8}He	0.122	0	43	50	10^2	10^{22}
^{8}Li	0.84	3	41	105	10^4	10^{24}
^{9}Li	0.178	2	44	80	10^3	10^{23}
^{11}Be	13.8	3	44	100	10^5	10^{25}
^{12}B	0.02	5	40	125	10^5	10^{25}
^{16}C	0.75	6	42	105	10^3	10^{23}
^{14}O	70.6	2	36	225	10^5	10^{25}
^{24}Ne	225	8	20	125	10^6	10^{26}
^{28}Mg	$7*10^4$	12	20	130	10^7	10^{27}
^{38}S	$1*10^4$	14	17	130	10^7	10^{27}
^{44m}Sc ($J^P=6^+$)	$2*10^5$	9	22	160	10^8	10^{28}

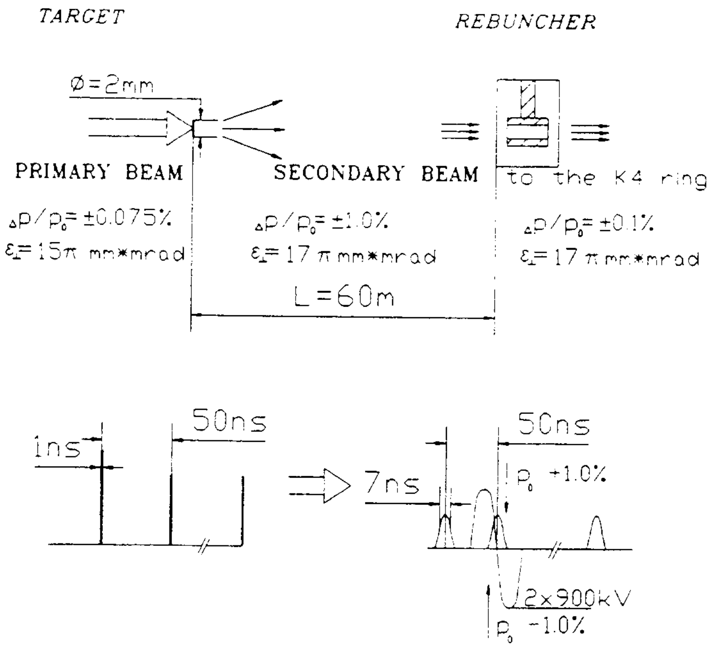

Fig.3 - Schematic diagram illustrating the production and debunching of a secondary beam.

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