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HEAVY ION PULSES IN THE PICOSECOND RANGE

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Résumé. — On obtient une grande résolution en temps lors d'expériences de temps de vol avec des ions lourds avec une cavité de regroupeur fonctionnant à 108,48 MHz. On utilise un résonateur spiral à conduction normale pour regrouper des ions ^{32}S de 96 MeV. Le fonctionnement avec un faisceau injecté continu conduit à une durée d'impulsion de $\Delta t = 70$ ps (largeur à mi-hauteur). Lorsqu'on accorde la phase du regroupeur au système de pulsation à la nanoseconde du tandem MP on obtient des impulsions dans la forme des 170 ps. L'espacement des impulsions est de 147,5 ns avec un rapport impulsion sur bruit de fond de 10^5 . Les valeurs de $\Delta t/T$ obtenues permettent une résolution en masse $A < 1$, même pour les produits de réaction les plus lourds et pour des parcours de vol faible. En évitant les désavantages des détecteurs *start*, il est possible de mesurer des produits de faible énergie et aux angles faibles.

Abstract. — High mass resolution time of flight experiments with heavy ions can be performed by a rebuncher cavity operating at 108.48 MHz. A normal conducting spiral resonator has been used to bunch 96 MeV ^{32}S ions. Operation with an injected dc-beam yielded pulse widths of $\Delta t_{\text{FWHM}} = 70$ ps. When phase locking the rebuncher to the nanosecond beam pulsing system of the MP-Tandem pulses in the range of 170 ps were obtained. The pulse spacing is 147.5 ns with a pulse to background ratio of 10^5 . The $\Delta t/T$ values achieved allow a mass resolution of $\Delta A < 1$ even at heaviest reaction products with small flight paths. Avoiding the disadvantages of start detectors it is possible to measure reaction products at low energy and at small angles.

1. **Introduction.** — Using a spiral resonator as a *rebuncher* it is possible to perform heavy ion time-of-flight experiments with excellent mass resolution.

2. **Methods of time-of-flight experiments.** — A common experimental method in heavy ion physics is the detection of reaction products by means of a time-of-flight telescope. A thin detector defines the start time and the detection angle. In a distance of about one meter a second detector stops the particle and delivers the energy and the time of arrival. From the energy and the time of flight the mass of the particle can be deduced. Such telescopes have some disadvantages:

1. The time resolution of start detectors is limited to 250 ps with plastic scintillators or to 150 ps with a carbon foil and channel plate arrangement, necessitating relatively long flight paths and therefore large and fast detectors [1].

2. The multiple scattering of the particles in the start detector reduces the efficiency and resolution for slow particles.

3. It is difficult to measure at small scattering angles.

4. The use of several telescopes in coincidence is complicated.

An alternative method, which avoids these limita-

tions is the use of a pulsed beam. The start detector with its disadvantages is replaced by short ion bunches and the start signal is given by the pulsing system.

3. **Pulsing system and rebuncher.** — Such a pulsing system consists principally of a low energy buncher in front of the tandem, a high energy chopper behind the tandem and a rebuncher in front of the target [2]. The low energy buncher concentrates the dc-intensity into bunches. The chopper is a parallel plate capacitor in a resonant circuit, which is driven by a high frequency transmitter. The ions, which are traversing the plates, are deflected periodically with high velocity across an aperture perpendicular to the beam. Only in a short time interval the ion beam can pass the aperture and by this the chopper cuts out the intensity between the bunches. The typical pulse width, which has been achieved with the Heidelberg system is < 1 ns for ^{32}S [3]. In addition to the time structure the beam gets an energy modulation because of the different potentials at different beam diameters. This energy spread leads to an increase of the pulse width.

In order to produce very short pulses at the target position one uses a rebuncher some meters upstream the target. A buncher modulates the energy and thus the velocity of the beam. The modulation is usually

done by two gaps in a distance, which provides a correct phasing. After a drift length the pulsed beam has been compressed in time on the account of energy spread. By this the pulse width can be reduced considerably.

4. **Experimental set-up.** — In our experiments we used a spiral resonator (Fig. 1) as a buncher, which has been constructed as an accelerating cavity for the Heidelberg post accelerator [4]. The cavity consists of a $\lambda/4$ — resonator wound as a spiral in a cylindrical tank. At the end of the spiral a drift tube is attached, which is aligned between the ground tubes in the tank walls on the beam axis. In this way two gaps are formed.

FIG. 1. — Open resonator showing spiral, coupling loop and tuning plate. Tank inner diameter is 35 cm.

The resonator is powered by a commercial 20 kW radio transmitter at 108.48 MHz in continuous wave mode. This cavity provides an effective accelerating voltage of 320 kV for ions with the design velocity $\beta_0 = v_0/c = 0.06$.

In our test arrangement the ions hit a gold target after a drift path of about 3.4 m. Elastically scattered particles are detected at a distance of 17 cm at an angle of 10° by a solid state detector. The best detectors for both, good time and good energy resolution, are thin totally depleted silicon surface barrier detectors. They are overbiased by a factor of 4 to decrease

the pulse rise time [5]. We used a fast voltage preamplifier (rise time 0.9 ns) and a constant fraction discriminator to derive the time signal. In parallel a charge sensitive preamplifier for the energy proportional signal was used. The time difference to the RF-phase and the energy of the particle in coincidence were fed to a multichannel analyzer.

FIG. 2. — $\Delta E, \Delta t$ phase space density distribution of a bunched 96 MeV $^{32}\text{S}^{13+}$ dc-beam.

5. **Experimental results.** — Figure 2 shows a two dimensional $E-t$ spectrum. In this experiment we used a dc-beam of 96 MeV $^{32}\text{S}^{13+}$, which was bunched with the spiral resonator. The RF power was 4 kW, which produces an energy modulation of ± 1.91 MeV.

FIG. 3. — Time spectrum generated by projecting the distribution of figure 2 onto the time axis.

Figure 3 shows the projection of this spectrum onto the time axis. The FWHM of the peaks is 70 ps including all effects of the beam energy spread and emittance and of the detector and the electronics. The pulse spacing of this bunched dc-beam is 9.2 ns. About one half of the particles is concentrated in the

short pulses. This beam is of course not usable for time-of-flight experiments because of the high background and because of the high repetition rate. Therefore in a further experiment the rebuncher cavity was phase locked to the nanosecond pulsing system (Fig. 4).

FIG. 4. — $\Delta E \cdot \Delta t$ phase space density distribution similar to figure 2 for a 1 ns-pulsed $^{32}\text{S}^{13+}$ 96 MeV beam with the spiral resonator phase locked to the ns-pulsing system.

The pulse spacing is now 147.5 ns at a peak to background ratio of 10^5 . The intensity corresponds to 25 % of the dc-beam current. The measured pulse width is 170 ps. The increase was due to at that time unsolved phase jitter problems between chopper and rebuncher (*). The little peaks between the main ones can be cut out if a prechopper is used.

6. Conclusion. — Ray-tracing calculations, which included the finite phase space showed that an overall pulse width of 100 ps in phase locked mode with the chopper can be achieved. This rebuncher now has been installed in the normal beam line and it will be used with heavy ion experiments. With a time resolution of 100 ps the flight path from target to detector can be reduced to 25 cm maintaining a mass resolution of $\Delta A < 1$ up to mass 80. Such a spiral resonator, which is a standard section of the Heidelberg post accelerator, also will be used as a rebuncher to match the heavy ion beam to the longitudinal acceptance of $\pm 5^\circ$ of the post accelerator as well as to rebunch or debunch according to the experimental requirements [6].

(*) *Note added in proof* : Improved timing and phasing electronics resulted in $\Delta t_{\text{FWHM}} = 90$ ps for a prepulsed ^{32}S beam.

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