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MODIFICATION OF THE ARGONNE TANDEM

by

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MODIFICATION OF THE ARGONNE TANDEM

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If one wishes to do nuclear structure experiments with heavy ions, it is necessary to have ion energies in excess of 5 MeV per nucleon. Obviously, a FN tandem by itself cannot produce such energies for ions heavier than ^{19}F. It is therefore necessary to post accelerate the tandem heavy ion beam to attain the energies necessary for the experimental program. A Superconducting Linac post accelerator has been under development at Argonne for several years. The modification of the Argonne tandem was designed to make it a suitable ion source for the post accelerator.

The installation was directed by Peter Billquist, who also took care of the ion source development work. The terminal design and vacuum system modifications were the responsibility of Floyd Munson and Charles Heath. The installation of the 150 kV injector was largely done by Pat Den Hartog. The ion beam optics calculations were done by W. Mourad of NEC and John Erskine of ANL. We also had six technicians working on the installation and about 20 man days of assistance from National Electrostatic Corporation. The modification interrupted the research program for four months.

The linear accelerator is a pulsed machine operating at a frequency of about 97 MHz. It is clear that if one wishes to have an adequate beam of heavy ions to carry out an experimental program, it is necessary to bunch the heavy ion beam prior to injection into the FN tandem. This is immediately evident if one considers the intensity of Ca, Mg and Ti beams produced by present ion sources. The quality of the experimental data obtained in nuclear structure experiments with the tandem-linac system depends on the longitudinal emittance $\Delta E.\Delta t$ of the beam at the output of the system. If $\Delta E.\Delta t$ is small enough at its input, the linac will not deteriorate the longitudinal emittance. Therefore, the emittance and thereby the quality of the experimental program are determined essentially by the tandem and the purpose of the modifications was to achieve as good a preservation of the longitudinal $\Delta E.\Delta t$ and transverse (x,x',y,y') emittance during acceleration through the tandem as possible. According to Liouville's theorem, one cannot improve the emittance but it is certainly possible to deteriorate it. The emittance of the tandem beam is affected by the acceleration and by the ion source injection system.

The factors which affect the transit time through the accelerator are the terminal ripple, the voltage distributions along the accelerator and fluctuations in beam trajectory. The charging system of the Argonne tandem was changed from belt charging to Pelletron chains about 4 years ago. The terminal ripple is now normally ±200 volts with a main component of 0.6 Hz. The chains have been essentially trouble free for the past 4 years. Of course, the total upcharge to the terminal is only about 160 μa. The limited upcharge made it necessary to change the voltage distribution along the column structure from resistors to an independently pressurized closed corona system. This system has also worked very well after some initial teething problems. The lifetime of the corona needles is in excess of 10,000 hours. The total downcharge needed to run the machine is about 70 μa which leaves about 90 μa for the beam.

The transit time of heavy ions through the accelerator is of the order of a few microseconds. In order to successfuly operate the tandem-linac system, it is desirable to keep transit time fluctuations well below 1 nanosecond. Such transit time fluctuations are primarily caused by fluctuations of the voltage distribution along the accelerator. To keep such fluctuations to a minimum, it is necessary to match the injection to the acceptance of the accelerator, to minimize losses due to ionization of the insulating gas and to prevent ions from hitting the electrodes in the high energy section of the machine. It was our opinion that one could achieve these conditions more readily in an axially symmetric acceleration structure and this was one of the reasons why the National Electrostatic accelerator tubes were selected. The guaranteed terminal voltage for the NEC tubes was 8 MV. For a tandem-linac system, the terminal voltage is not very important as long as the linac has resonators with the appropriate values of β. It is however quite important that the accelerator be very stable at high heavy ion currents. In our case, we can readily produce 4 μa of $C\ell^{8+}$, O^{6+}, C^{4+} and 1.6 μa of $^{58}Ni^{10+}$ with the necessary stability. This is about an order of magnitude more current than targets used in nuclear structure experiments will usually be able to withstand without serious deterioration. The machine will operate with the needed stability at a terminal voltage of 8.5 MV and we expect eventually to achieve routine operations at 9 MV.

The arrangement of the accelerator tubes is shown in Fig. 1. It should be noted that tubes connecting the accelerator tube corona system are very close to the column electrodes and equipotential hoops. The potential difference between the column and the corona system can be as high as 100 kV and some care has to be exercised in the installation. The machine at this time is only equipped with foil stripping. The foil changer is a 230 foil NEC model. In order not to vent the accelerator tubes when changing foils, terminal valves similar to the ones developed by Weiser at ANU have been built and installed. This valve is shown in Fig. 2. These valves have worked very well and allow us to reload the foil changer and return to 8 MV operation in less than 24 hours. A view of the terminal is shown in Fig. 3. There are two mini Ti-Ball sublimator pumps in the terminal. However, since the pressure in the terminal is about the same as the pressure at the high energy end of the machine, approximately 2×10^{-8} torr, these pumps are not used in normal operation.

The ion source arrangement is shown in Fig. 4. There are three ion source positions — one is occupied by the direct extraction duoplasmatron, one by the Li exchange source, and one by the 150 kV preacceleration system, which normally uses the Chapman source. The ion optics for the 150 kV injection is shown in Fig. 5. The source is followed by einzellens L_1. The three preacceleration tubes A_1 A_2 A_3 are NEC multi-purpose tubes. These tubes can operate at 75 kV each. In our arrangment, the tube A_1 is at 1/3 the voltage gradient of A_2 and A_3 to allow formation of an object with 0.7 mm radius at W_1. The magnet M has a mass energy product of 20 for 40° injection. The buncher B is the single gap pretandem buncher developed by Bollinger, Lewis, Lynch and Henning. The beam is focussed by an electrostatic quadrupole to form the object for the accelerator tube with a radius of 1 mm at W_2, about 43 cm. from the accelerator tubes entrance. The corona tube of the first section of accelerator tube in the machine is arranged to give half the voltage gradient of the subsequent accelerator tube sections and the column structure corona in its first 8 sections from the low energy base has a similar arrangement. This is done to move the cross over point further away from the machine in order to produce a small enough beam spot, at the terminal. The beam diameter at the terminal is about 4 mm. The system was intended to be a constant Q system. However, in practice, it is not operated that way. It is much easier to achieve good matching of the ion source emittance with the accelerator tube acceptance with the axially symmetric accelerator tube than with the previous inclined field tube. For 150 kV injection at 9 MV on the terminal, the inclined field vertical waist would have been at 49.3 cm and the horizontal waist at 91.5 cm from the accelerator tube entrance. The layout of the elements between the injection magnet and the accelerator tube is shown in Fig. 6. The Ultek cryopump is attached to the housing of the first steerer. In normal operation, it pumps the magnet chamber to pressures in the low 10^{-8} torr range. The 1 inch valve is an all-metal NEC straight through valve. The einzellens located just before the tank wall was installed to allow injection of the 40 kV He^- beam. The quadrupole triplet would produce too large an object for the accelerator tubes for the lower voltage. The einzellens housing is connected to a 400 ℓ. Ultek DI pump through a 4 inch right angle all-metal valve. To reduce contamination problems, the DI pump will be replaced by a Granville Philips pump. The main purpose of the 4-jaw slit is to improve the mass resolution of the injection system. We expect that a mass resolution of about 1 part in 75 will be achieved. The waists of the ion beam are approximately in the center of the second section of the deflection plates X_2 Y_2 and this does reduce the effectiveness of the 4-jaw slit somewhat.

The 150 kV injection system is shown, with the source developed by Ken Chapman in Fig. 7. The beam line between the preaccelerator tubes and the injection magnet is shown in Fig. 8. Besides the einzellens L_2, it shows the location of the selectable aperture. Four apertures ranging from 3 mm diameter to 19 mm diameter are available. They are used primarily to attenuate the beam from the ion source when the experimentally desired beam intensity changes. The ion source einzellens and extraction supplies are similar to the ones of O'Dacre at Chalk River and allow operation from the control room.

To allow successful operation of the tandem-linac system, the energy spread of the beam at the buncher should be less than about 30 eV out of 132 keV. The 150 kV acceleration supply is a HVEC Deltatron with very low ripple and high stability.

Some of the problems which may occur in a tandem-linac system are best illustrated by some results obtained with the bunching system. Figure 9 shows the time spectrum from the 56 MeV O^{6+} beam from the sputter source with the prebuncher and the chopper using the phase stabilization system described in the paper by Lewis. This is obviously a very good bunched beam. If one now looks at the time spectrum obtained with this bunched beam after rebunching by the superconducting buncher at a point far past the time cross over point, one obtains the spectra labelled $\phi \neq 20°$ and $\phi = 0°$ in Fig. 10. Obviously there is some fine structure in the beam. Such a fine structure can be caused by a component of the 132 kV O^- beam with perhaps 100 eV less energy. Such components are readily introduced in O beam from sputter sources because one gets O^- beams from everywhere. Such a lower energy component cannot be resolved by the 90° analyzing magnet because the energy difference is only about one part in 500,000. However, the slow component arrives too late at the superconducting buncher and therefore gets a net energy gain greater than its energy deficiency and gives a high energy tail to the pulsed beam.

The adjustments made by Billquist to the ion source were an increase in the oxygen gas flow and selection of a smaller aperture in the variable aperture box. The low energy and retuning is essentially a touching up of the parameters required by the change in aperture. The improvements are obvious in the third spectrum. The energy spread of ions from the direct extraction source is too large to permit use of this source for the tandem-linac system as shown in Fig. 11.

In summary, the Argonne tandem has been improved as an injector for the superconducting linear post accelerator and is now the determining factor for the quality of data obtainable in nuclear structure experiments with the tandem-linac system. The intensity and stability of heavy ion beams has been substantially improved. The transmission of Ni beams is improved by a factor of 8. As a stand alone tandem, it has now a somewhat lower terminal voltage. However, it is quite likely that with increased operating experience, the terminal voltage will exceed 9 MV.

Fig. 1. NEC Accelerator tubes and corona systems mounted in the FN tandem.

Fig. 2. Terminal all metal valve.

Fig. 3. View of the terminal with portable vacuum unit

Fig. 4. Ion source area.

Fig. 5. Ion optics for 150 kv injection system.

Fig. 6. Low energy beam line elements.

Fig. 7. 150 kv injection system with FSU source.

Fig. 8. 150 kv beam line between source and injection magnet.

Fig. 9. Time spectrum of bunched tandem beam for 56 MeV O^{6+} with phase detector stabilization using sputtering source.

Fig. 10. The beam of fig. 9 rebunched by the superconducting buncher with the spectra taken far away from the time cross over point.

Fig. 11. Bunched beam from direct extraction duoplasmotron.

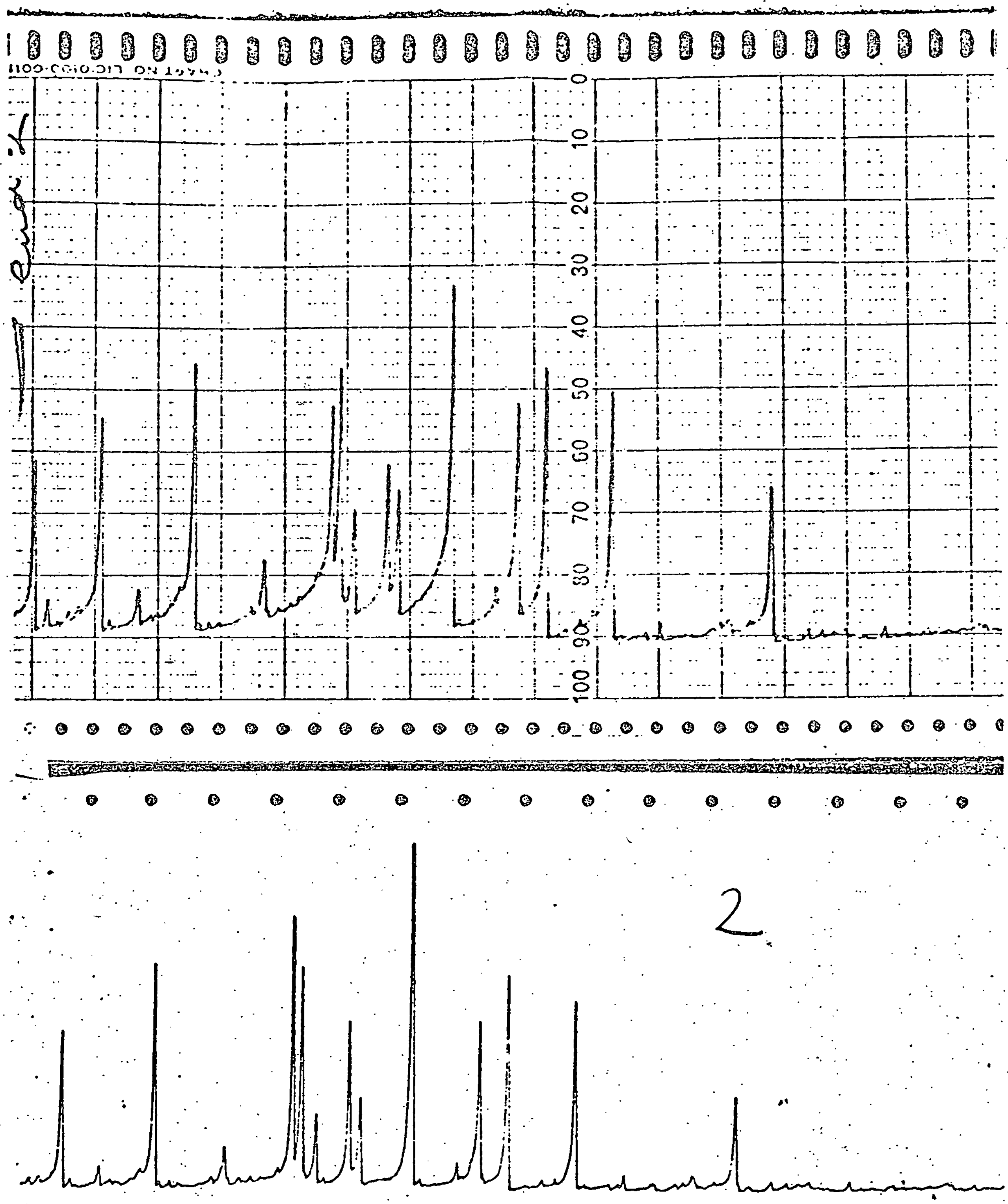


Figure 1

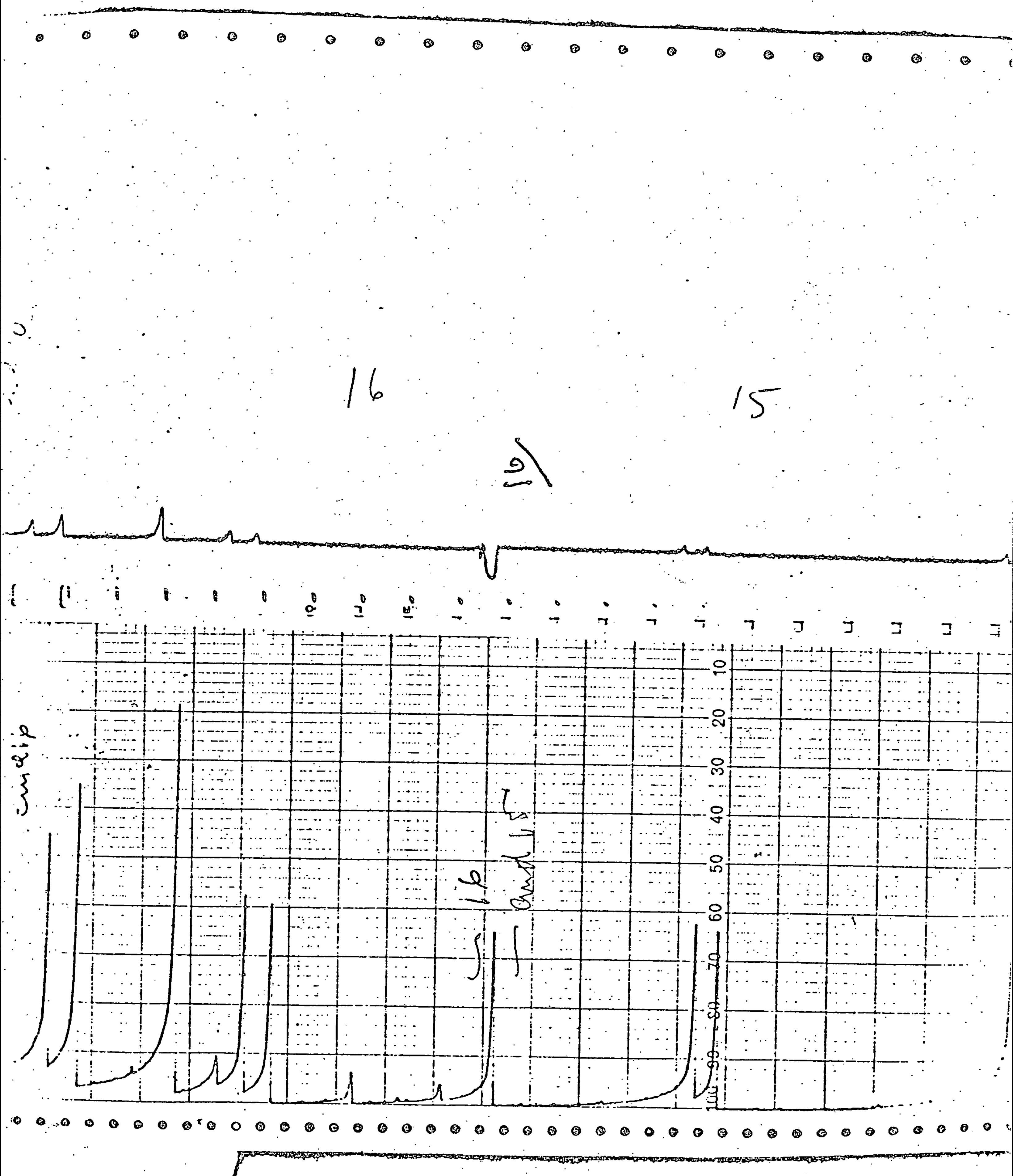


Figure 2

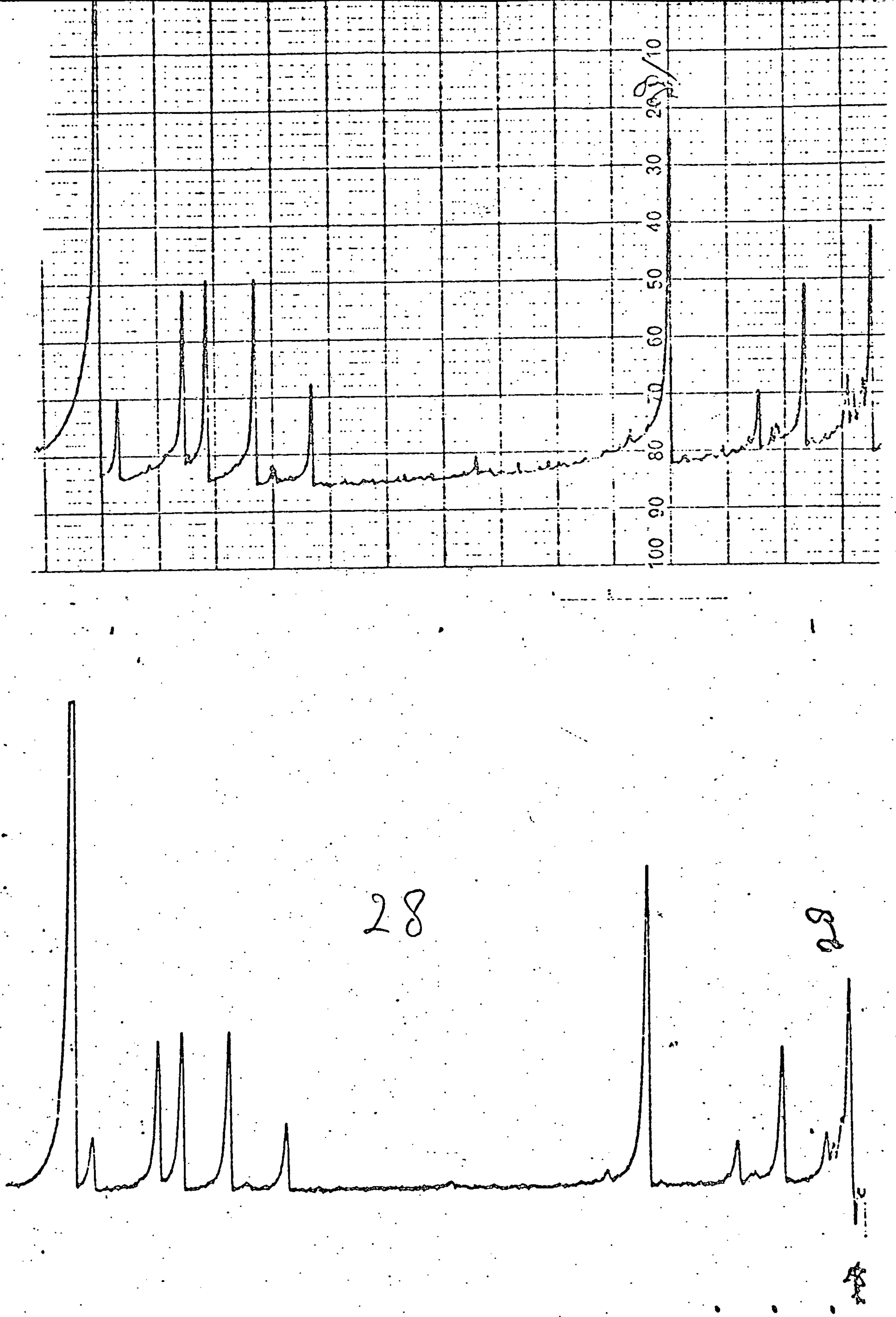


Figure 3

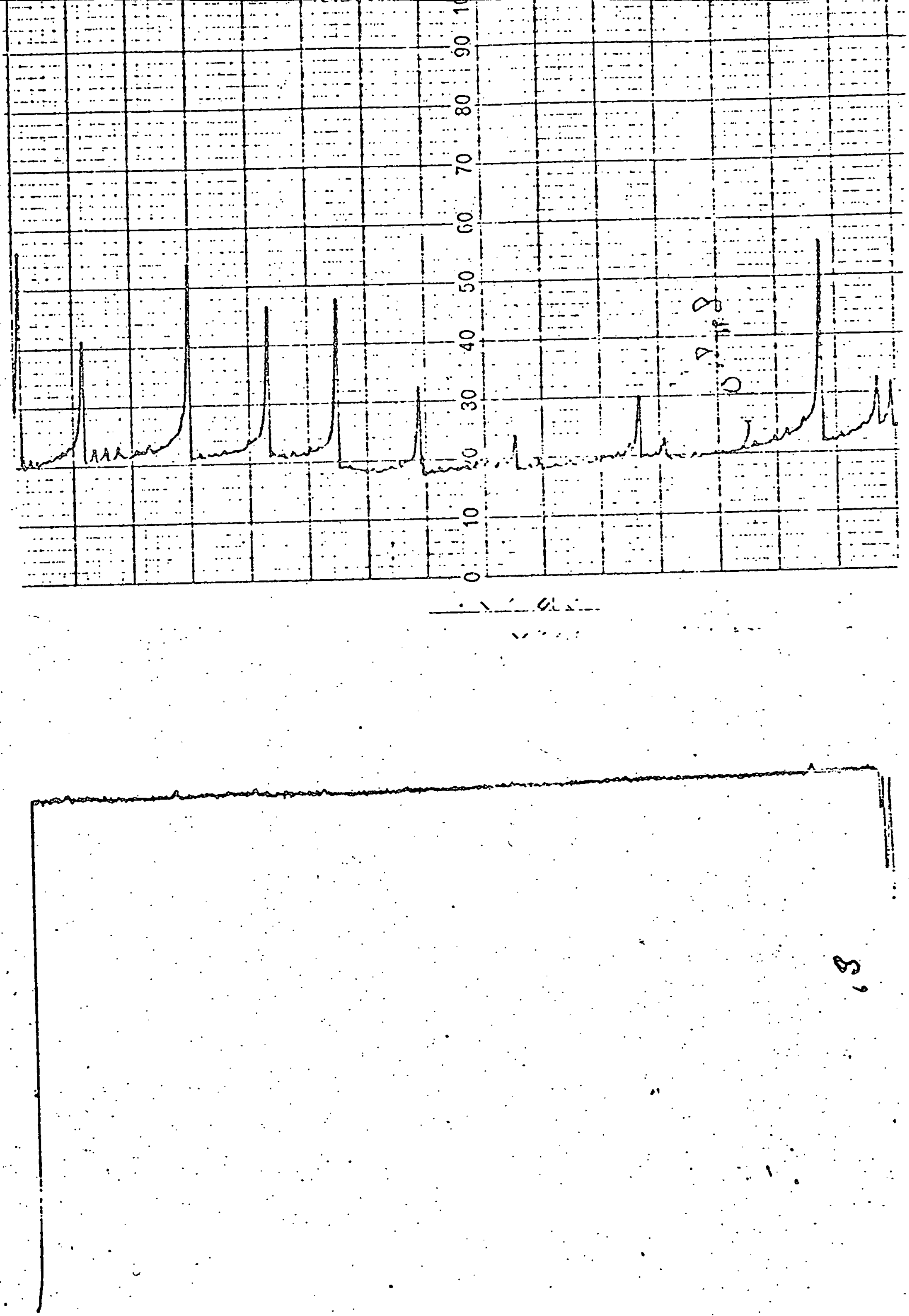
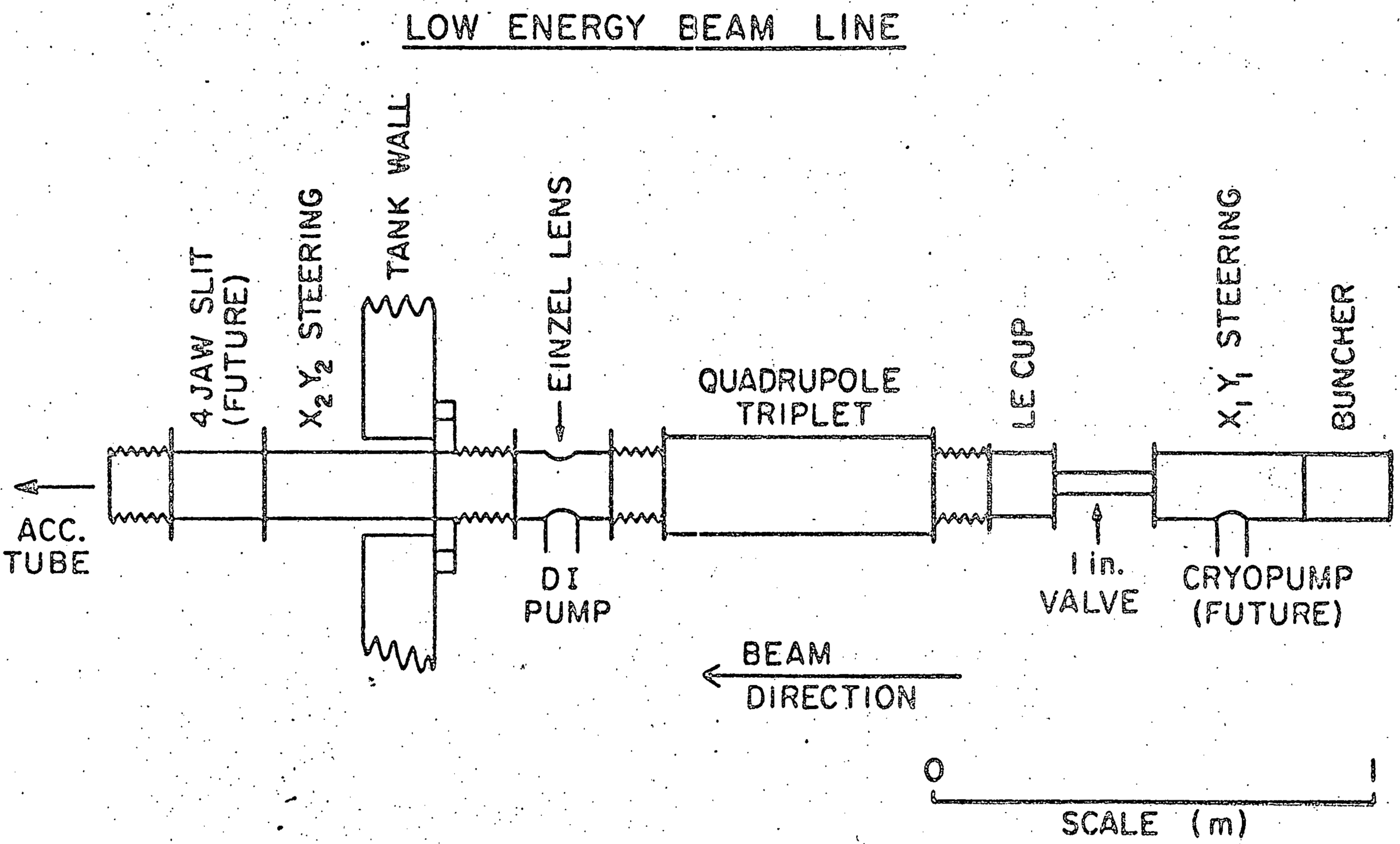


Figure 4



LOW ENERGY BEAM LINE
ACC. TUBE
4 JAW SLIT (FUTURE)
$X_2 Y_2$ STEERING
TANK WALL
EINZEL LENS
DI PUMP
QUADRUPOLE TRIPLET
LE CUP
1 in. VALVE
$X_1 Y_1$ STEERING
CRYOPUMP (FUTURE)
BUNCHER
BEAM DIRECTION
0
1
SCALE (m)

Figure 6

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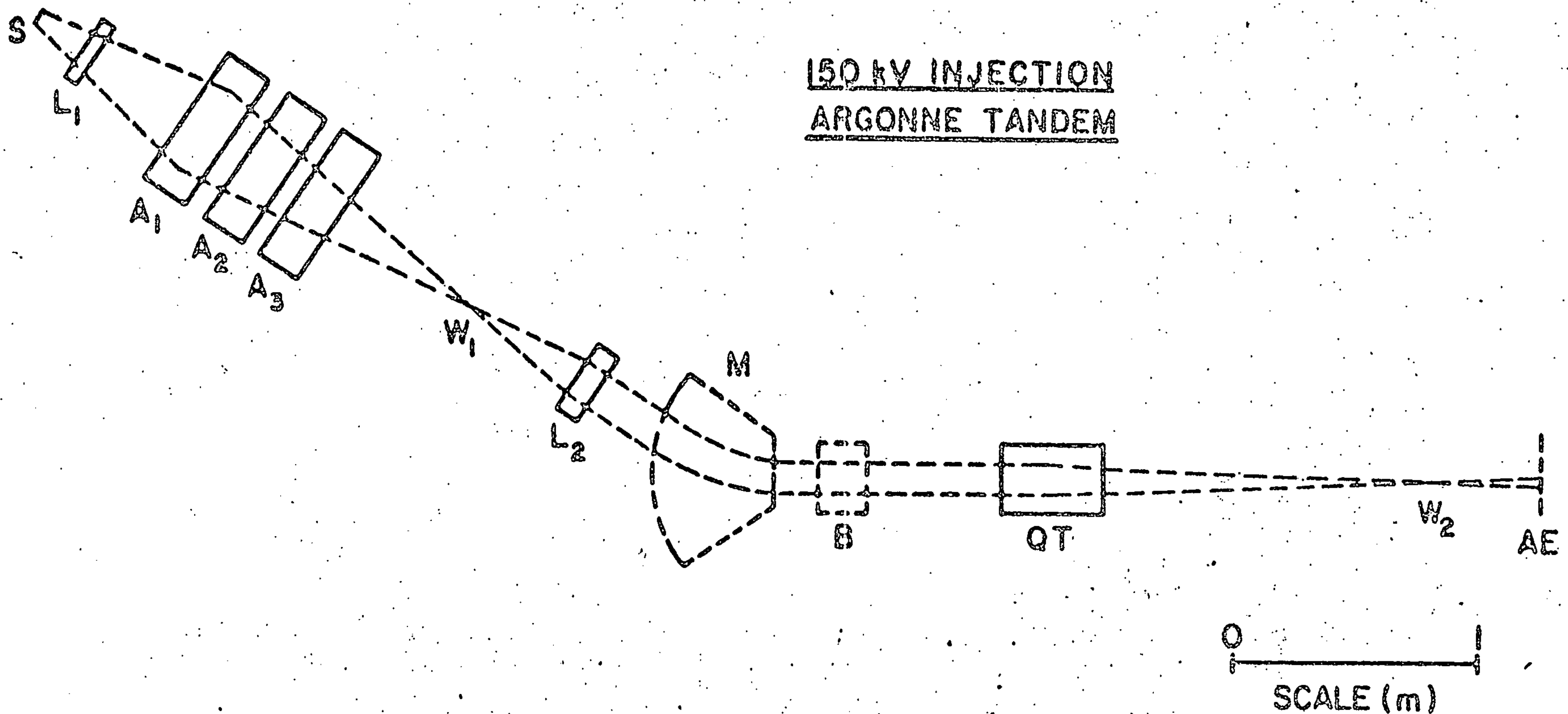
150 kV INJECTION
ARGONNE TANDEM
S
L1
A1
A2
A3
W1
L2
M
B
QT
W2
AE
O
SCALE (m)

Figure 8

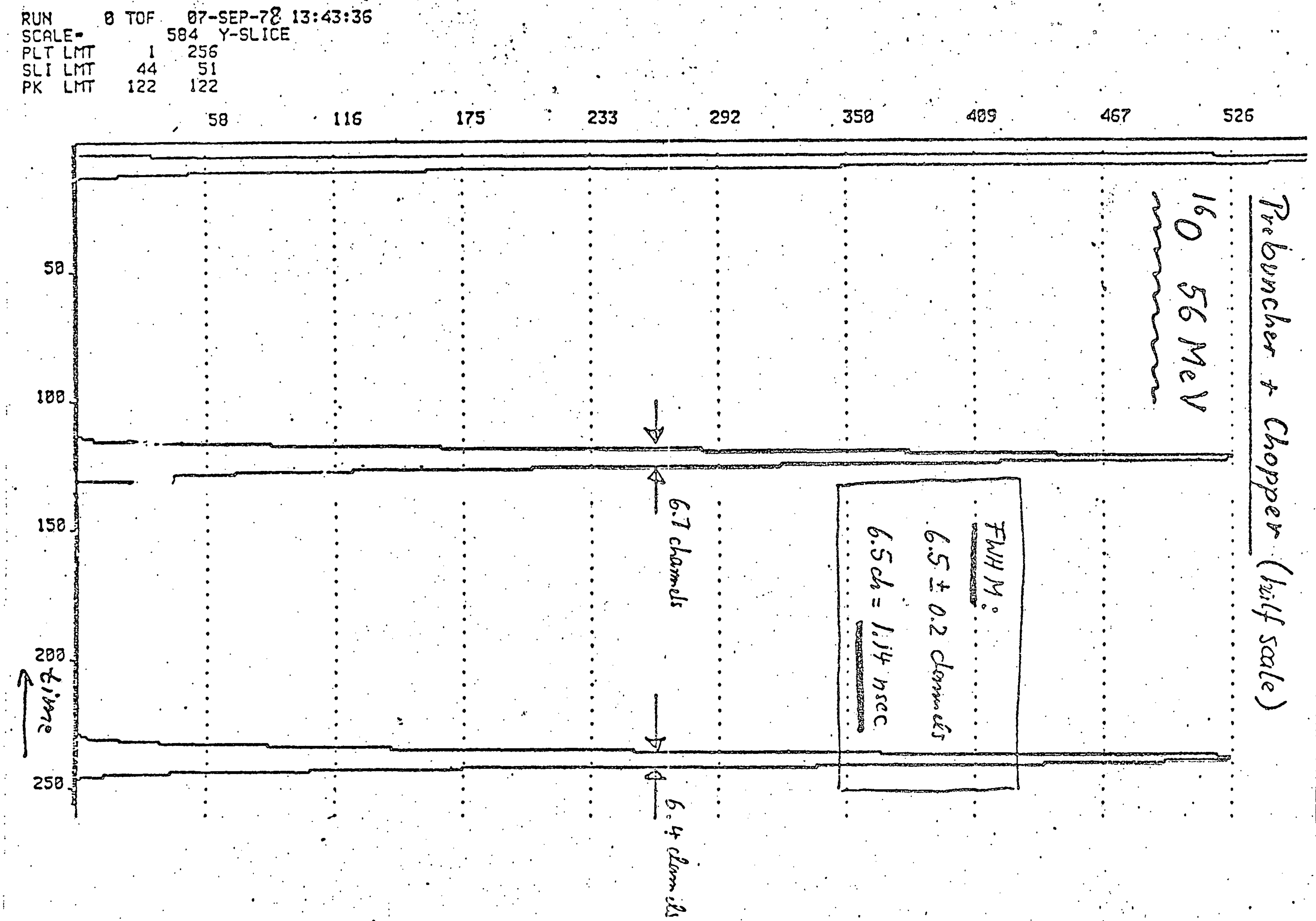
RUN 8 TOF 07-SEP-78 13:43:36
SCALE= 584 Y-SLICE
PLT LMT 1 256
SLI LMT 44 51
PK LMT 122 122
58
116
175
233
292
350
409
467
526
50
100
150
200
250
Prebuncher + Chopper (half scale)
16O 56 MeV
6.7 channels
6.4 channels
FWHM: 6.5 ± 0.2 channels
6.5 ch = 1.14 nsec
time

Figure 9

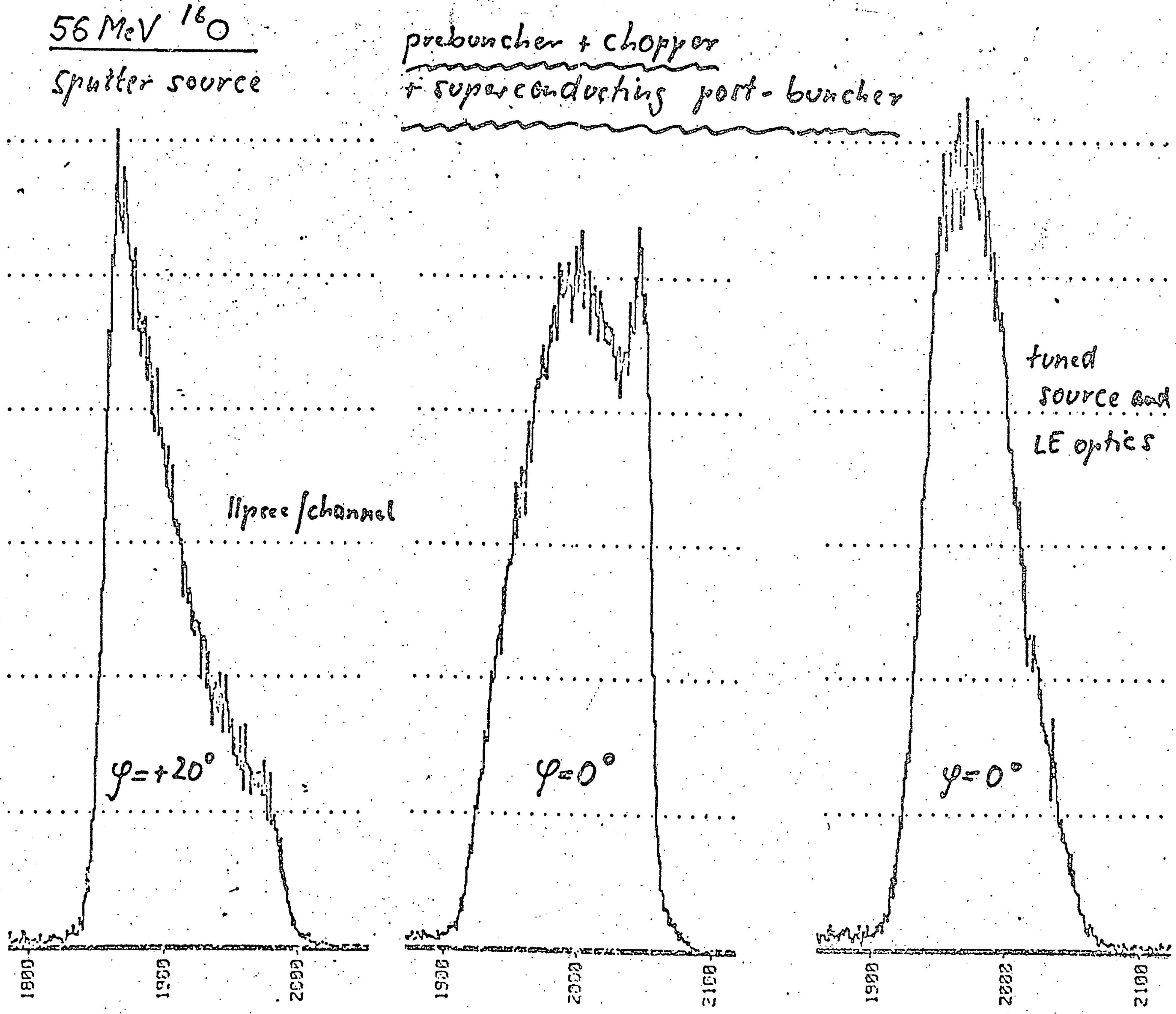
56 MeV ^{16}O
Sputter source
prebuncher + chopper
+ superconducting post-buncher
11psec/channel
tuned source and LE optics
φ=+20°
φ=0°
φ=0°
1800
1900
2000
1900
2000
2100
1900
2000
2100
← time

Figure 10

16 MeV protons

DE source

Prebuncher spectra