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Internal Beam Measurements and the Deflection Protons from the Gustaf Werner Institute Cyclotron

by

A. E. Taylor

The work described here was directed to the production of an external proton beam. However, before doing this, it was necessary to increase the internal beam current and then measure the internal energy spectrum of the protons which were to be deflected. It is convenient therefore to describe the work under three separate headings:- Beam intensity, Energy spectrum, and Deflection of Protons.

Beam Intensity.

For many of the experiments which were planned the external proton and neutron beams which could be obtained would have been of too low an intensity. The internal beam was about 0.1 μ amp mean current from a continuously run arc source of conventional design. The filament was a W rod, 2 mm in diameter bent in an arc and placed above a carbon hood in which a slot, 20 mm deep, was cut in the same arc. It was found that the beam current was very sensitive to the positioning of the filament above the carbon hood. In view of this and also of the low current the form of the filament, and slot in the carbon hood, was changed to rectangular dimensions. It was found that the dimensions which gave the greatest beam and least sensitivity to positioning was a rectangular hole in the carbon hood, 5 mm deep, 2·5 mm wide and 12 mm long, and a correspondingly ⊔ shaped filament. This gave a beam of about 0.4 μ amp. Also the maximum beam was obtained when the top of the carbon hood was level with the dee lip. A further increase, raising the beam to 0.6 μ amp was obtained by using a pulsed arc supply which allowed the filament to run at a higher peak temperature.

No attempt has yet been made to observe the effect of increased magnetic focussing at the centre of the cyclotron. Small soft iron cones are used at present, and it is known that their effect can be only small since the centre field is almost equal to the saturation value of the soft iron. Larger cones of cobalt iron alloy would improve the focussing and it is proposed in the near future to try them.

Internal Energy Spectrum.

The measurements of the internal proton energy spectra were made in order that the magnetic shielded channel could be designed to give the maximum external beam. However, the measurements were important for another reason, namely that they revealed the extent to which the internal energy spectrum was sensitive to cyclotron operating conditions. This in its turn has a direct bearing upon neutron experiments using a defined energy band, since the neutron spectrum from a given target is very closely related to the energy spectrum of the protons bombarding it.

The protons were scattered by a 1 mm thick U target and detected by the C^{11} activity produced in small pieces of graphite placed 180° away and below the dee edge. (Bloembergen and van Harden, 1951; Dickson and Salter, 1953). Since the peak of the activity was registered on pieces of graphite placed between 180 cm and 200 cm from the U scatterer, it was assumed that the energy spectrum was directly proportional to activity measured. Small corrections were applied for the variation in the C^{12}(p, pn) C^{11} cross section, which over the proton energies involved only amounted to a few per cent. The activity was measured, in a standard G.M. apparatus, and was shown to follow the 20.5 min half life of C^{11}.

For convenience the first measurements were made with the direction of the internal proton beam reversed. The dee height was limited to 20 mm so that using a 1 mm thick U target as the scatterer the effective number of traversal was only of the order 1.1. Corrections for this effect which would have been small, have not been applied. In all measurements the dee voltage was 6 KV and the same shape of carbon hood on the ion cource was used. The dee bias was normally 1 KV, only a small effect being obtained by reduction to 500 V (Fig. 1). Also a pulsed arc supply was used for most of the measurements although an appreciable difference was observed between pulsed and continuous arc supplies (Fig. 1).

A greater variation in the spectrum was observed however when the relative position of the arc source to the cyclotron centre was changed. This is illustrated in Fig. 2 where a change in position of 3.5 cm changed the spectrum from one peaked at 171 MeV, $12\frac{1}{2}$ MeV half width, to a rather broad and flat topped spectrum with the highest intensity at 167 MeV. Large changes in the spectrum were also observed between operation with strong and weak arcs. This is illustrated in Figs. 3 and 4 which were taken with the proton beam circulating in the direction normally used.

Since there seemed to be evidence of a double peak in some of the spectra, measurements were made of the pulse length for protons scattered out of the cyclotron. The protons were detected by a scintillation counter placed in the cyclotron hall and the pulses after suitable amplification were measured on a C.R.O. having a calibrated time base. The pulse length is related to the amplitude of the radial oscillations and rate of change of frequency. Variations of the pulse length with ion source conditions and position corresponded to the measurements made with the graphite detectors. Indeed it was even possible to see the presence of two peaks for the same position of ion source which produced the double hump in Fig. 4.

It has been shown that the neutron spectrum from a thin Be target is closely related to the effective incident proton spectrum. These measurements of the internal proton spectrum suggest that small changes in the ion source conditions and position could appreciably alter the neutron spectrum. This has an important bearing in neutron experiments which attempt at a well defined energy resolution. If the monitor and detector do not have the same energy response, small changes of the ion source could alter the relative number of counts and produce misleading results.

It was also observed that in all the spectra there was a low energy tail. This tail was thought to be protons circulating with the cyclotron rather than low energy protons produced in the U target. There was only a slight difference between the peak characteristics of the neutron spectrum from a Be target and the effective incident proton spectrum, and the low energy tail in the neutron spectrum could also be explained if it was assumed that the low energy tail in the proton spectrum represented circulating protons. Again this is a point to bear in mind when irradiating targets in the cyclotron.

In an attempt to reduce the amplitude of the radial oscillations a W rod 2 mm in diam. was placed below the ion source (Chicago University). Only those protons with initial orbits around the rod could then be accelerated. This reduced the width of the spectrum by a factor two but also reduced the intensity to one per cent of its previous value. Although this may have applications for experiments using the internal beam, the reduction in intensity is too great for its use when extracting a proton beam.

With the information gathered it was then possible to proceed with the magnetic measurements required for the deflection of the proton beam.

Deflection of Protons.

The method used for the deflection of the protons has already been exploited at Berkeley and Harwell. It consists of scattering the internal beam at a thin U target. In order to take advantage of the much larger cross section at those small scattering angles where the protons oscillate about a stable orbit, a magnetic shielded channel must be provided. The efficiency of the deflector is governed therefore by how near the channel can be placed to the scattering target and the last orbit, and how well its disturbing effect can be shimmed out.

Preliminary tests were made of the amount of shielding which could be obtained and the effect of small shim plates. A comparable efficiency to that obtained at Harwell was sought, which meant that scattering angles greater than 5^{o} could not be tolerated. Further restrictions were imposed by mechanical considerations. It was required to remove the magnetic channel and the shimming through an air lock of given size, thus restricting the length of the channel to 40 cm.

The length of any addidional channel which might be placed outside the pole tips was also restricted since the probe carrying the neutron targets was placed close to the exit of the channel. It was also necessary to bring the beam cut in a given direction to pass through a hole in the concrete shielding wall 10 m away. There was thus little flexibility in the design of the channel. A further difficulty arose from the high field at the position of the channel, 20.5 KG, so that any ordinary soft iron would be nearly saturated.

With these restrictions of geometry and from the knowledge of the proton spectrum gained from the previous measurements, estimates of the amount of shielding required were made by the help of the graphical plotting method (Parkins and Crittenden 1946). If all the additional magnetic shielding which could be placed outside the pole tips was used, then the magnetic field in the main channel had to be at the most half that at the last orbit.

It was found that the dimensions required for soft iron bars forming the channel were 3 cm x 4 cm for the inside bar and 3.5 cm x 4 cm for the outside bar. The magnetic field inside the 1 cm gap between these bars was reduced to 50% of that at the last orbit. However, the disturbance 2.5 cm from leading edge was of the order of 2.6 K gauss. Tests with plates 10 cm x 6 cm x 0.1 cm separated by 6 cm indicated that their shimming effect was only about 120 gauss. The scattering angle with this size of bar would have been greater than the 5^{o} limit set, and it was doubtful whether the disturbance at the last orbit could have been shimmed away without producing over compensation at smaller radii. It was therefore decided to seek alternative magnetic material and a cobalt-iron alloy containing 35% cobalt was tried.

The magnetic field inside a channel formed of cobalt-iron bars 4 cm x 2 cm and 4 cm x 4 cm was reduced just below the 50% required. As a first order approximation to the orbit the channel was formed in three straight sections on the arc of a circle 200 cm radius. The centre of the entrance to the channel was placed at 105 cm radius and 53 cm away from the scattering target, which was to be placed at 101 cm radius. The maximum disturbance at this latter radius was just over

3 K gauss, whereas the maximum disturbance at 95 cm radius was 200 gauss. Attempts were made to shim out this disturbance using soft iron shims and allowing a 6 cm gap between upper and lower shims for the protons to circulate. It was found possible to shim out the disturbance for radii up to 100 cm leaving a variation less than ± 200 gauss. However, the amount of soft iron required for shimming out to 101 cm radius was so great that an over compensation of 1 K gauss was obtained at 100 cm and 99 cm. Large pieces of the same cobalt iron alloy which was used for the channel, were therefore used for the shimming at the azimuthial position of the greatest disturbance, the additional shimming still required being made with soft iron. By this means it was possible to shim out the disturbance up to radii of 100.5 cm to under ± 200 gauss, the disturbance at 101 cm being still about 750 gauss. It was therefore decided to place the target at 100.5 cm.

The calculations of the trajectory through this channel were checked by simulating the proton path by a current carrying under tension. Both suggested that a small extra channel outside the pole tips was required if the mean energy of the external proton beam was to be 165 MeV. From the spectrum measurements and the known energy loss in U this figure was chosen as giving reasonable intensity without reducing the energy by too great an amount.

X-ray films placed outside the cyclotron vacuum chamber showed that the proton beam emerged in the expected direction and with the characteristic cross section. Films placed inside the channel showed that the beam was fairly central. Estimates of the external current were made by exposing an Al plate out to the size of the beam and then counting the Na^{24} activity. This gave a current of 10^7 proton per sec on first switching on and later adjustment have lead to improvements.

References.

Bloembergen and van Heerden. P.R. 23, 561, 1951.
Dickson and Salter. Brit.J.App. Phys. 4, 175, 1953.

Fig 1

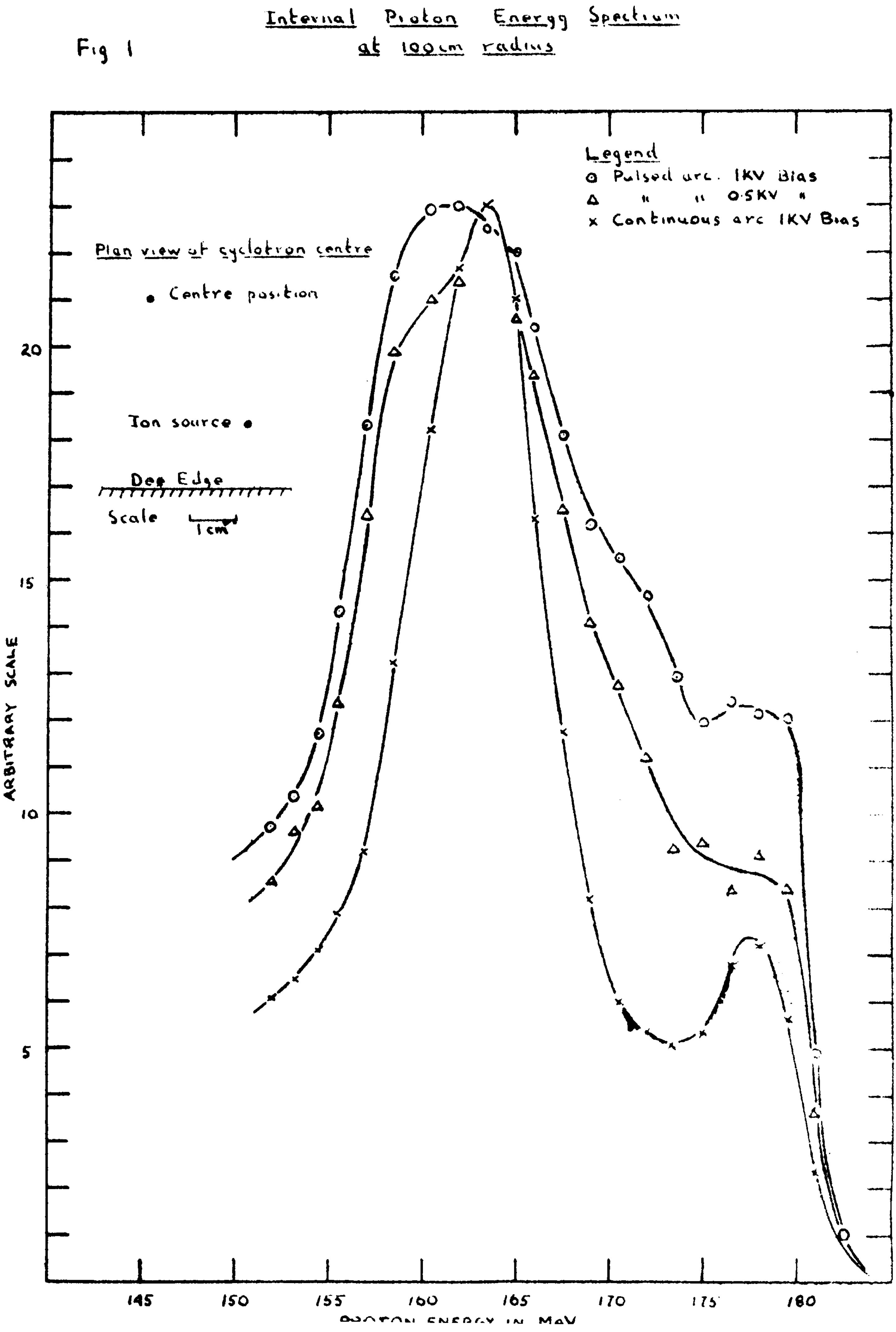
Internal Proton Energy Spectrum
at 100cm radius
Legend
Pulsed arc. 1KV Bias
" " 0.5KV "
Continuous arc 1KV Bias
Plan view of cyclotron centre
Centre position
Ion source
Dee Edge
Scale
1cm
20
15
10
5
ARBITRARY SCALE
145
150
155
160
165
170
175
180
PROTON ENERGY IN MeV

Fig 2

Internal Proton Energy Spectrum
at 100 cm radius
Variation with ion source position
Pulsed arc. Dee Bias 1 KV

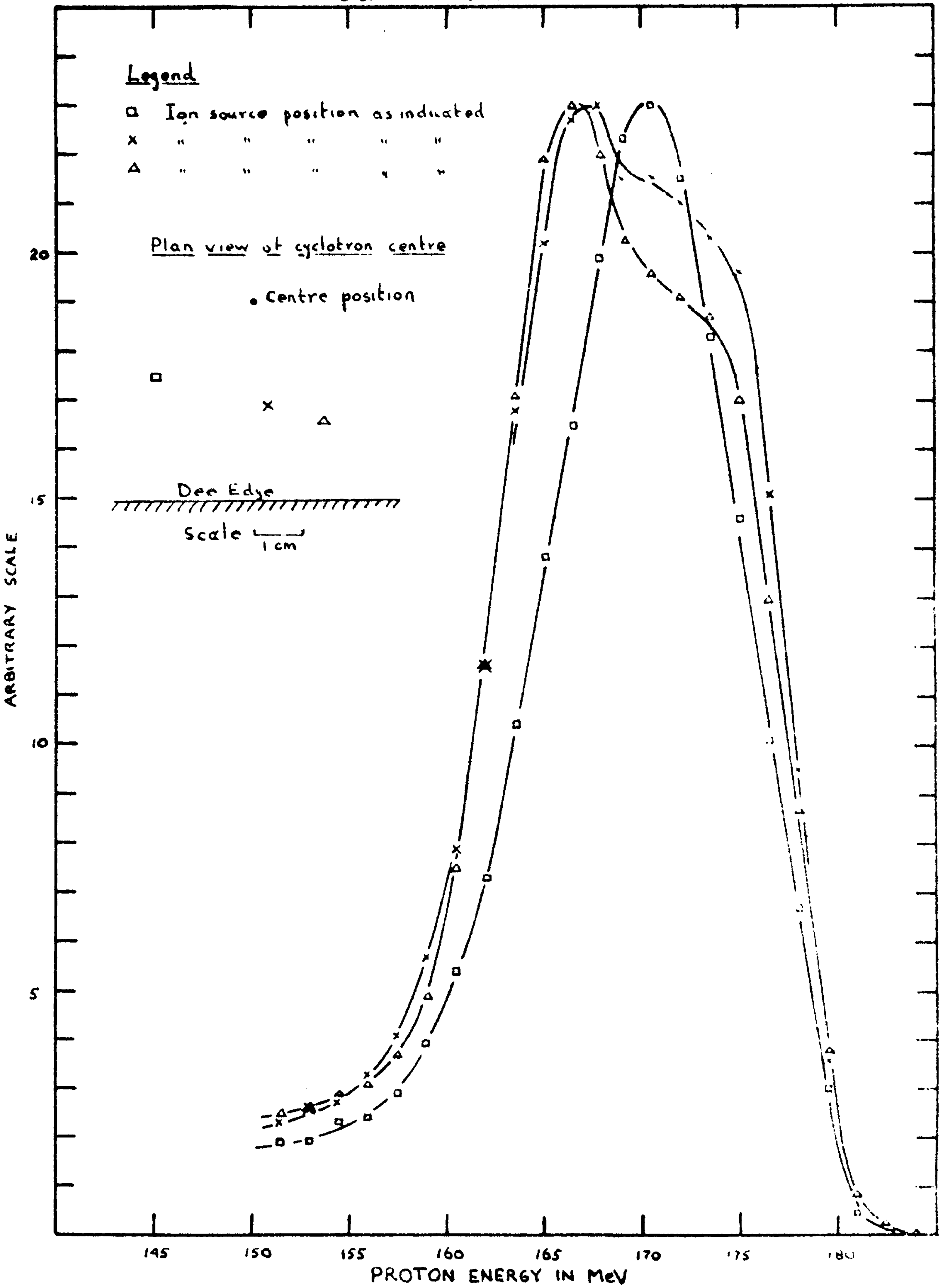

Fig 3

Internal Proton Energy Spectrum
at 100 cm radius
Variation with strength of arc
Ion source position, centre Dee Bias 1 KV

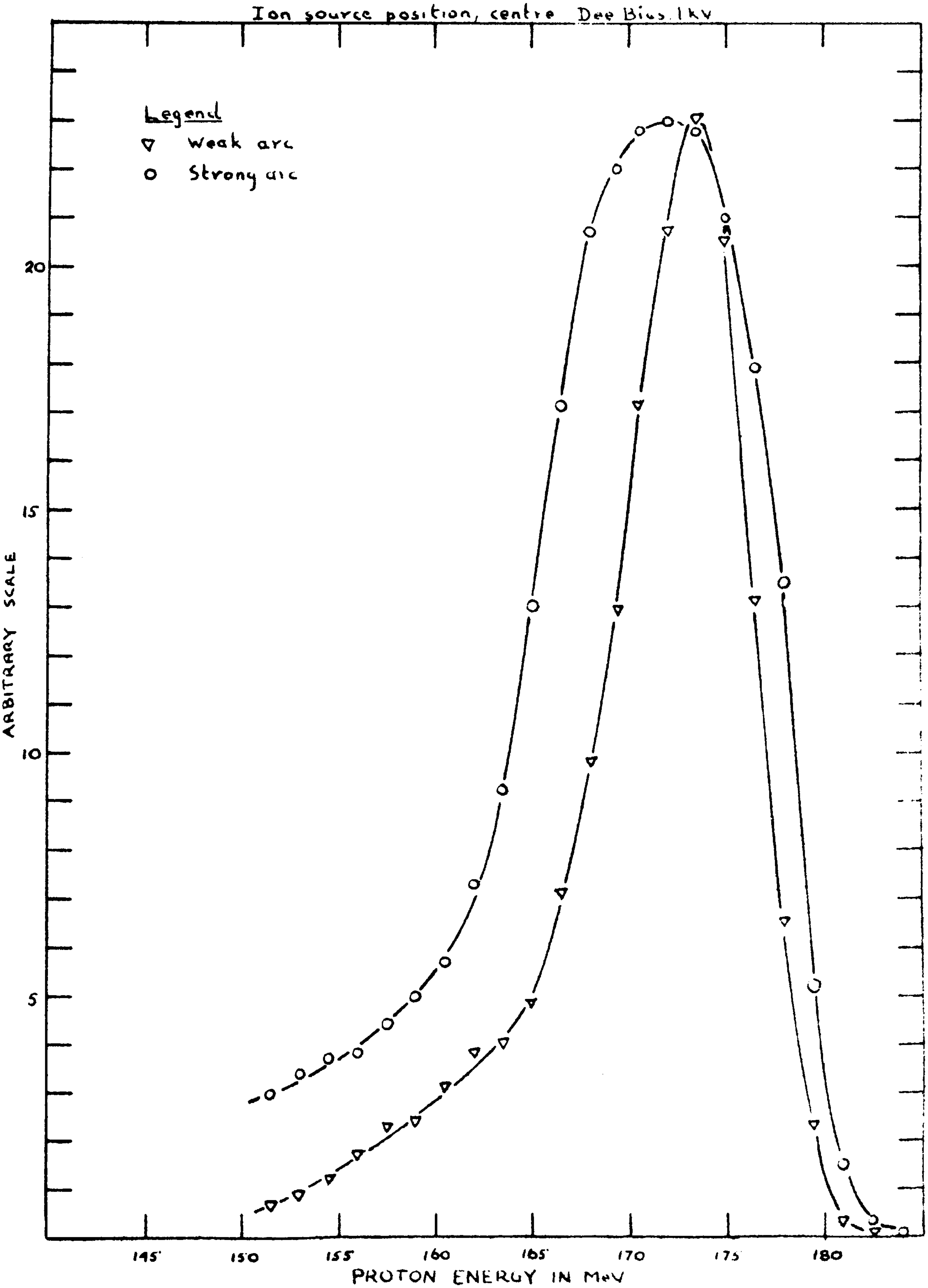

Fig 4

Internal Proton Energy Spectrum
at 100 cm radius
Variation with strength of arc