IUCF STATUS REPORT*

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Abstract

A report is presented on the status of the Indiana University Cyclotron Facility (IUCF) three years after first operation. The range of accelerator beam characteristics, the beam delivery record for research use and selected observations of unusual features of this facility will be given.

1. Introduction

The main ring cyclotron at IUCF came into operation[1] in the second half of 1975, with the first scheduled operation for research in December of that year. An account of the status after the first year of research operation is available.[2] The present report is made after more than 30 months of operation, in which some 55 experiments have received about 860 shifts (8 hours) of delivered beam. The beam energy and particle variability and the good beam quality have been exploited in a broad range of experimental applications.

The laboratory operates in a full "user mode" with beam available to all interested users on a common competitive basis. Twice yearly review of beam requests and a 10 week schedule cycle give fairly rapid access for new experiments. Groups from 41 laboratories in eight countries have been participants in IUCF experiments.

Within the past year a new 800 kV ion source platform has been completed, which will permit operation with polarized Z=1 beams, and with multiply-charged ion species for $Z \geq 2$. New experimental facilities for neutron and pion experiments are under construction.

2. Operating Record

In the 30 months beginning 1 January 1978, the IUCF accelerators have been scheduled for continuous operation except for short (2 shift or 2 day) maintenance intervals each week and longer (one to three week) construction shutdowns. The scheduled time has grown from 50% to more than 72% of the possible time over this period as the new installation and retrofitting workload has tapered off. The machine reliability (availability when scheduled) has continued at 80% over the period. Most of the unscheduled downtime is of very short duration (median repair time: 3 hours, in a 6 month sample analysis), so that visiting users almost never leave empty-handed. A small fraction (11%) of the beam available time continues to be invested in beam development studies for new beams and performance improvements. Because of the short duration of the typical IUCF experiment run (126 runs averaging 2.8 shifts in a recent typical 12 month sample), there is a substantial schedule component for energy, particle, room and experiment setup changes and for startup after weekly maintenance. Figure 1 shows the statistical summary for 30 months, while Figure 2 shows how the accumulating research beam delivery total has kept pace with approvals and beam time allocations following each meeting of our Program Advisory Committee. The "backlog" (pool of approved experiments awaiting scheduling) was deliberately increased last year to reduce the probability of having no experiment ready to run. At the present level the probability of turning down a scheduling request in the 10 week cycle for a given experiment is also small, i.e., the schedule pool is optimized so that experiments rarely wait for beam and the accelerators are rarely idle. In-house experiments and development tests are scheduled around the dates requested by visiting users.

In Tables 1 and 2 are shown data from our 1977 annual report giving a more detailed breakdown of the time required to change beams and the sources of unscheduled downtime. The latter are distributed among many subsystems.

3. Accelerator Performance

Most of the principal performance characteristics predicted for this cyclotron design have been confirmed in operation. The IUCF 3-stage accelerator system can deliver several ion species over a broad range of energies with good beam quality for experiments. Figure 3 shows the light ions used in experiments, including protons from 35 to 198 MeV and numerous ^{6}Li, deuteron and alpha energies. The threshold pion experiments have required a very large number of energies in the 130 to 155 MeV region.

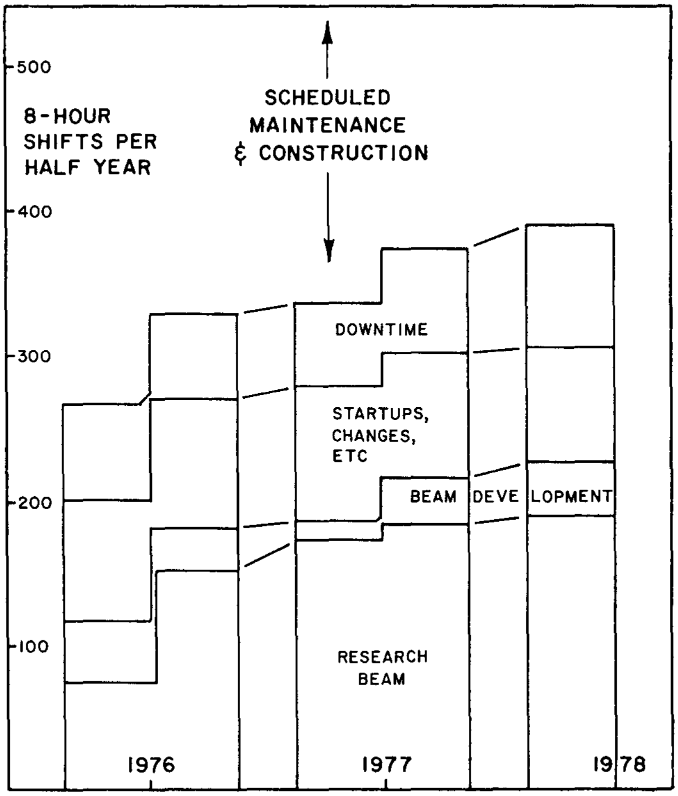

Figure 1. *The first 30 months. Research time is for beam on target and charged to an experiment.*

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Table 1

A. Unscheduled Downtime Summary

(6 month sample, July-Dec. 77)

Shifts Lost	Vac.	rf	p.s.	ctrl	HV	other	total	#
Ion Source and BL1	0.9	2.3	5.4	2.7	2.5	0.5	14.3	26
Injector and BL2	1.6	2.8	1.3	0.1	5.4	2.6	13.8	26
Cyclotron and BL3	13.8	5.1	6.5	0.4	10.4	0.0	36.2	52
Expt. and misc.	3.2	0.1	0.7	0.3	0.0	2.1	6.4	15
Total	19.5	10.3	13.9	3.5	18.3	5.2	70.7	
# Events	22	22	25	13	23	13		118

B. Duration of Loss

	#	Shifts
0 - ½ shift	67	17.2
½ - 1 shift	35	22.2
1 - 2	11	15.4
More than 2	5	15.9
Totals	118	70.7

C. Repair Time

Mean Repair time	5 hrs.	Mean time between failures	24 hrs.
Median Repair time	3 hrs.		

Table 1. An analysis of sources of downtime and of their duration.

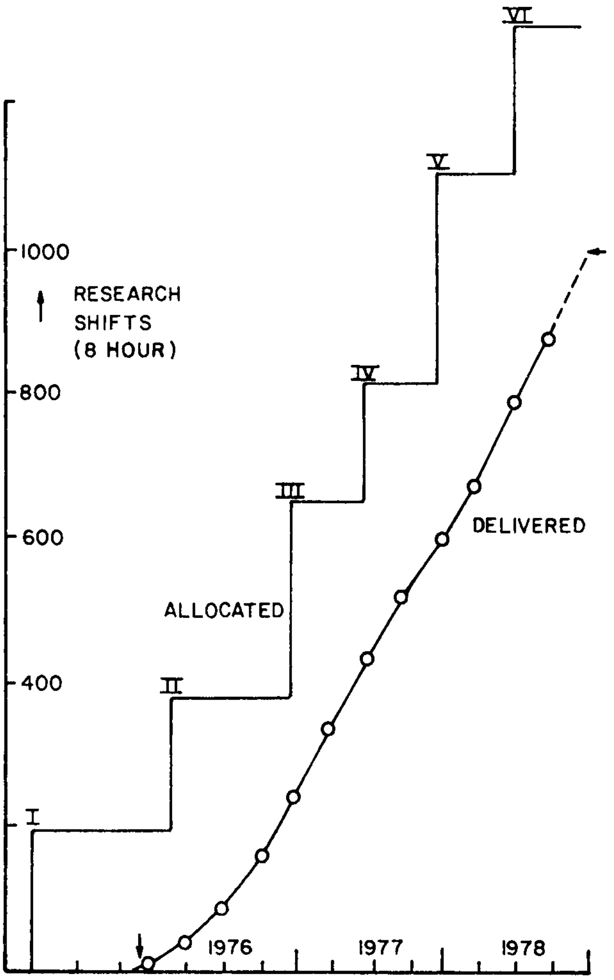

Figure 2. Beam delivery for research will pass 1000 shifts by the end of 1978. Time is allocated at each PAC meeting (PAC I - VI shown).

Table 2. Overhead summary for the 12 month period from 1 February 1977 to 31 January 1978

48 startups @ 7.7 hours	46 shifts	
24 retunes @ 2.3	21	
18 miscellaneous @ 1.8	4	
not attributed	8	
Subtotal operational causes		79
51 energy changes @ 6.0	38	
27 particle changes @ 9.1	31	
34 room changes @ 1.7	7	
16 user not ready @ 5.5	11	
4 early shutdown (no user)	9	
Subtotal research schedule related		96
272 occurrences @ 5 hrs.	175	175

For example, 22 different proton energies were delivered in a recent two-week period for excitation function studies. By changing only one trim coil current at large radius in the main stage, it has been found possible to change beam energy in 0.2 MeV steps in about 10 minutes/step over a range of about 1 MeV centered on the isochronous condition. Figure 4 shows a sample experimental curve of a π^0 threshold determination (IUCF Expt. #29) with seven proton energies in a two shift run.

The beam energy resolution before analysis is typically 0.10 to 0.15%. With dispersion matching on the spectrograph target, overall resolutions of 0.035% to 0.05% can be obtained ($\Delta E/E$, fwhm). The beam time resolution is typically 0.5 to 0.7 nsec fwhm, somewhat broadened by slow time drifts in the magnetic fields during extended runs. The time resolution is improved by the phase compression[3] arising from the increasing dee voltage with radius in the IUCF main cyclotron. Figure 5 shows an example of an isochronism study in which the field is made isochronous to ± 6^0 in rf phase for h=13, nh ∿ 2000 operation with 75 MeV $^6Li^{3+}$. The phase difference between injector and main cyclotron is then changed by a discrete amount (in this case ± 40^0) and the accelerated beam is seen to move toward the unperturbed phase in such a way that the product of energy gain and the sine of the phase is invarient.

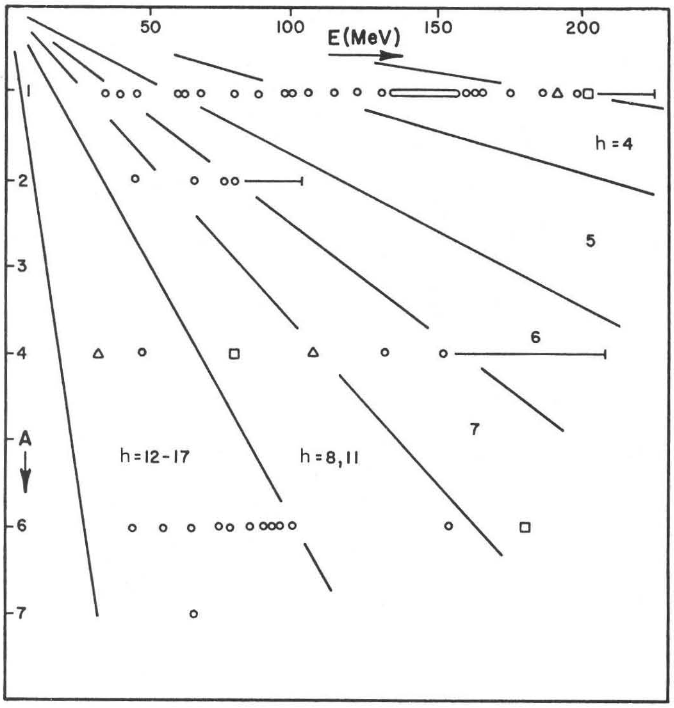

Figure 3. The circles give beams used for research. The squares are beams through the first two accelerators only. The triangles are developed but not used. Harmonic numbers h=3-8 and 12-17 have been used.

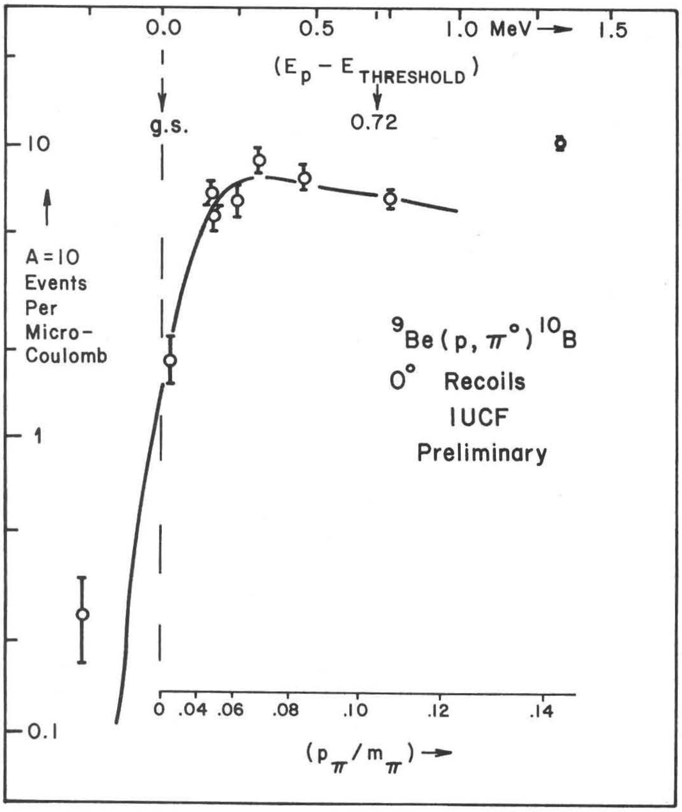

Figure 4. An excitation function for a π^0 production reaction near threshold obtained with the rapid energy change method (see text).

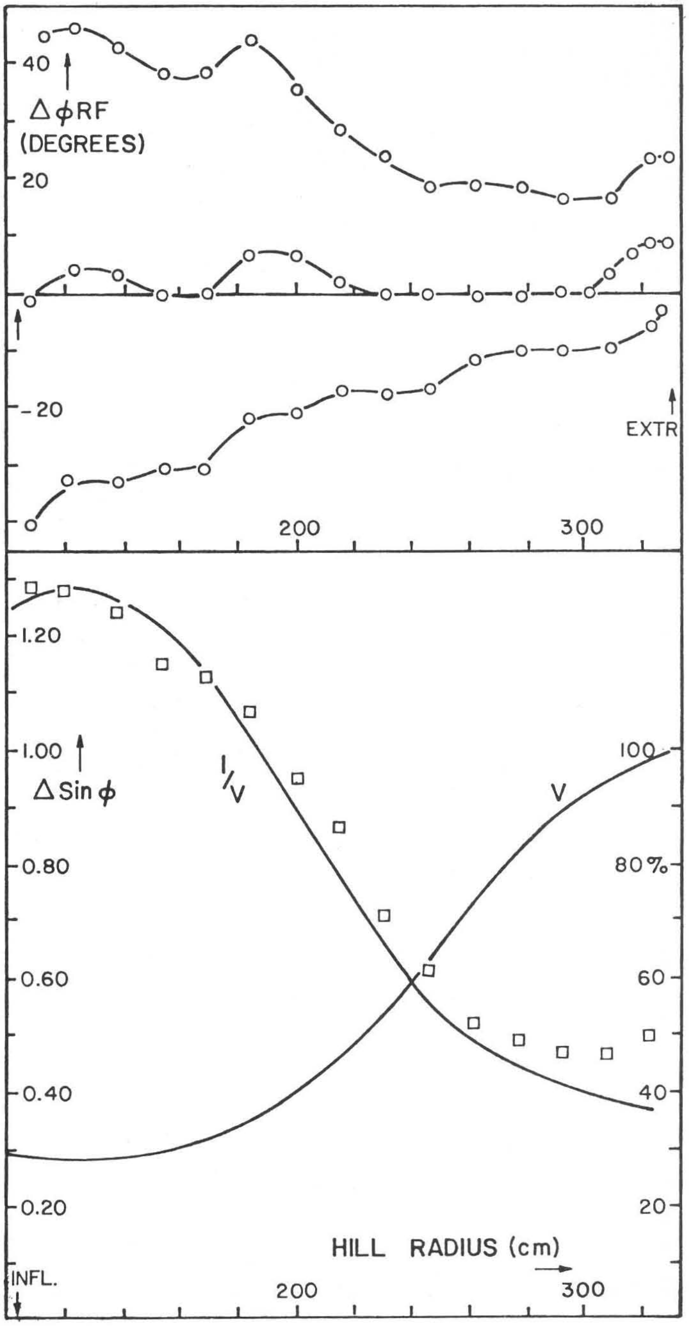

Figure 5. The phase compression effect for an isochronous field, illustrated for 3 phase groups differing in initial phase. The dee voltage profile was obtained in a full scale rf model.

The beam time structure can be modified to increase the separation between beam bursts. On a microscopic scale this is accomplished by beam chopping at a rational submultiple of the rf frequency (e.g., chop at 3/4 of the rf frequency to obtain one pulse in four). The rejection ratio can be several thousand to one for extended runs if the rejection ratio agrees with the harmonic number. Incommensurate ratios have been used (e.g., one pulse in 5 while operating on seventh harmonic) and the resulting pulse suppression is a sensitive test for clean single turn extraction. A slow chopper has been developed for muon decay experiments which can, for example, provide 1 μsec on/14 μsec off, with an on/off ratio of about 75,000 maintained for one-hour runs. This device is installed between the two cyclotrons and has been used to measure time delay in the main stage acceleration as a dee voltage calibration. Because the main cyclotron will operate with either of the two rf systems shut down, the dee voltage balance can be checked by switching off one side at a time for a direct comparison.

The beam intensity used in experiments is typically 50 to 250 nA. The shielding of the experimental areas permits higher levels only for brief tests. Figure 6 shows two intensity profiles of the complete system from source to target at the microamp level. This figure shows clearly the principal loss during chopping and bunching on the low energy beam line, and subsequent smaller losses at the point of matching each cyclotron into its beam line. The inflection and extraction in the cyclotrons proper is usually a less significant contributor to the overall transmission efficiency. Using a spill monitor near the injector cyclotron extraction system, an extraction efficiency of (97.5 ± 0.2)% has been measured. Some of the loss in the transfer beam line (beam line 2 on the figure) is attributable to additional phase selection by the dispersive elements of this line. A factor of two of the transfer loss is not predicted and should be recoverable in subsequent development and optical modification of the beam line. Further intensity increases are possible with more elaborate bunching procedures than are now employed.

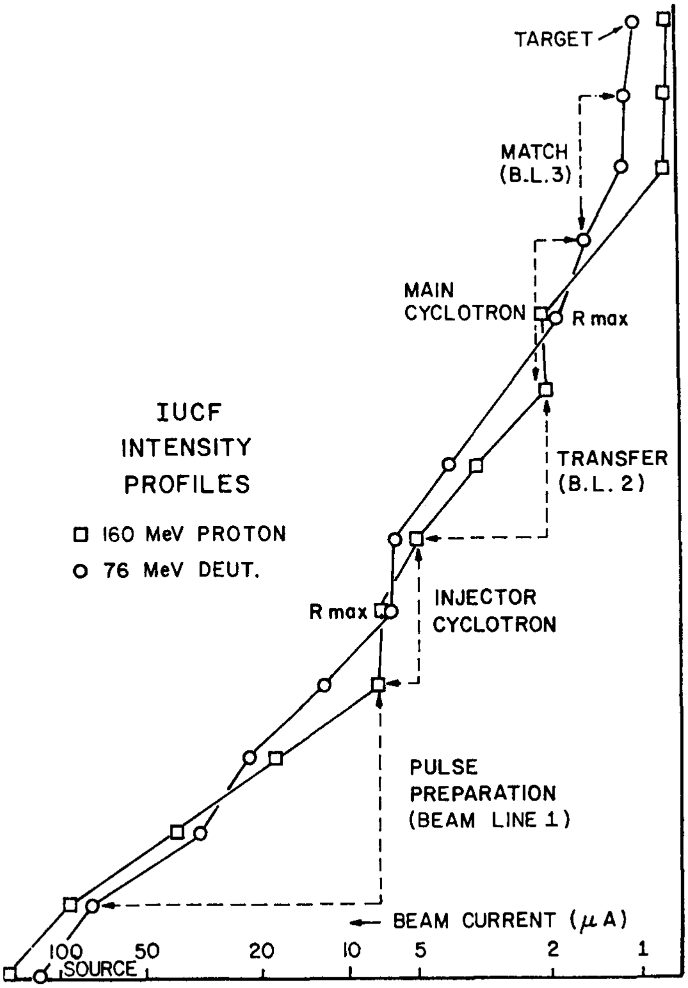

Figure 6. The beam intensity as measured in various stops and probes between source and target. The preparation of subnanosecond pulses from the DC source is the cause of the principal losses.

4. Work in Progress

A polarized source for $\vec{p}$ and $\vec{d}$ beam has been installed in the second 800 kV ion source terminal during the summer of 1978. It has passed its final acceptance tests and will be used for experiments in the next month. Intensity of the polarized beam, based on known source emittance and intensity, will be 5% of the existing unpolarized beams. The neutron flight paths are being rearranged to allow up to 200 meter fixed paths at 0° and 25° with shorter paths at 50°, 75° and 100°. Intermediate angles are to be obtained by changing the incident angle on target with a 3-magnet "swinger" system. A 35 msr QQDD spectrometer for pion measurements will be installed later in 1978. Beam development work at the moment is concentrated on better diagnostic feedback for more reproducible setup and faster change of beam between experiments.

As a final example of recent operation, Figure 7 shows a $^{12}C(p,\pi^+)^{13}C$ spectrum taken at 198 MeV in which the 180 keV doublet at 3.8 MeV is clearly resolved.

5. Summary

The IUCF accelerators are now in routine use for research and the basic soundness of the design principles has been demonstrated. Enhanced performance may be expected to follow from work in progress.

References

1) "Status Report on the Indiana University Cyclotron Facility," R.E. Pollock, Proc. 7th Int'l Conf. on Cyclotrons and their Applications, ed. by W. Yoho, 27 (Birkhäuser, Verlag, Basel and Stuttgart, 1975).

2) "Indiana University Cyclotron Facility - The First Year of Operation," R.E. Pollock, IEEE Trans. Nucl. Sci. 24, 1505 (1977).

3) W. Yoho, Particle Accelerators 6, 41 (1974).

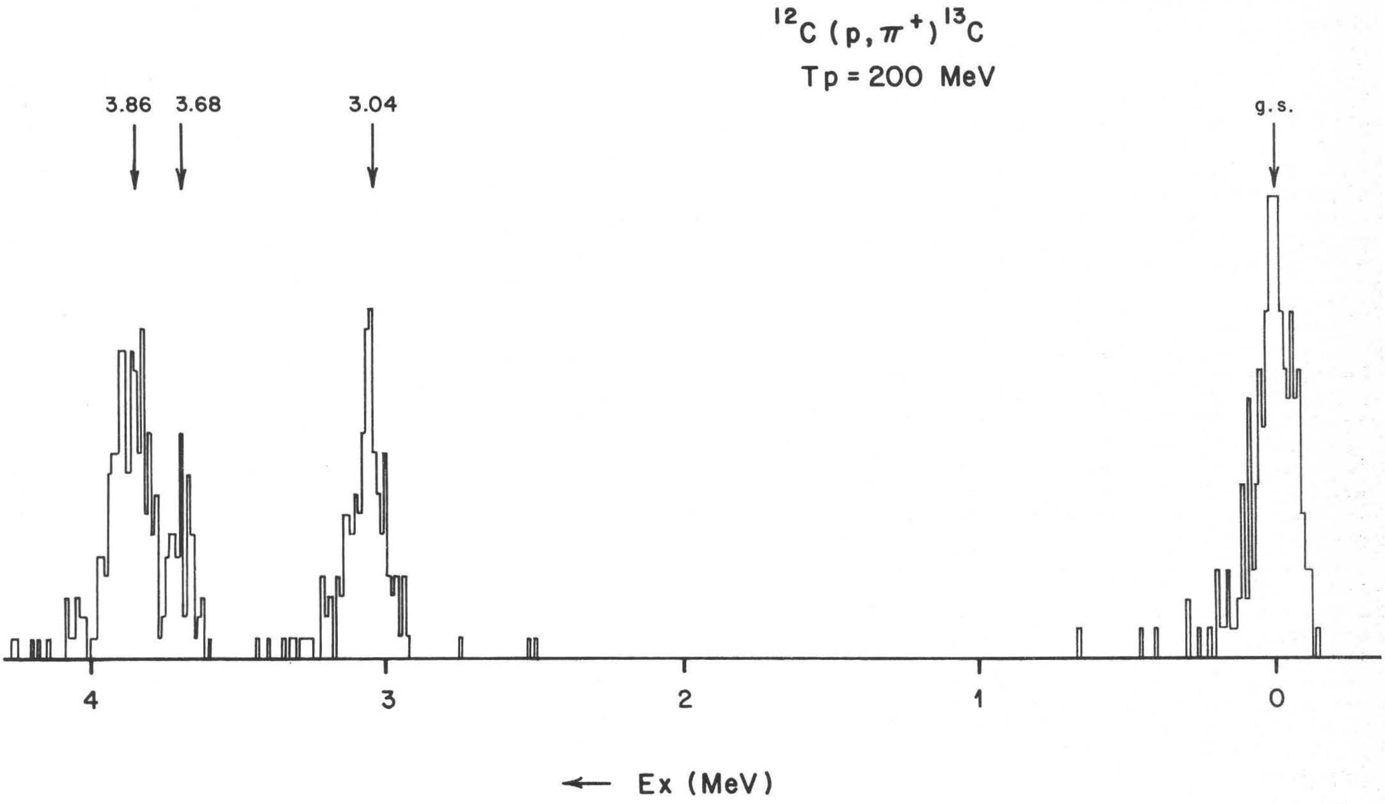

Figure 7. Composite spectrum for $^{12}C(p,\pi^+)^{13}C$ at Ep=200 MeV showing ground state and three resolved excited states in ^{13}C. This is the IUCF design maximum energy. The peak shape shows a Landau tail indicating that much of the peak width arises from target thickness. The QDDM spectrograph used in this work will give resolution better than 100 keV fwhm for other reactions at this energy.

** DISCUSSION **

H. SCHREUDER: How much time is needed for producing a new beam on target?

R. POLLOCK: We make very little distinction in scheduling between new beams and old beams which have been developed before. In each case we allow about eight hours for start-up. Most energies have, in fact, been run only a few times. The accelerators interpolate well, so a new energy between two existing tunes can be expected to work well with little development.

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