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PHYSICISTS' COMMENTS ON THE SC IMPROVEMENT PROGRAMME

A collection of opinions, ideas and plans

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INTRODUCTION

Following the publication of the detailed proposal for the improvement of the CERN SC, the users of the SC who were present at CERN during August were invited to comment on the project. It was hoped that from these comments one would be able to prepare a summary statement assessing the need for improvements from the point of view of the community of research physicists.

So many of the physicists approached responded, there were so many different approaches, and there was such clear evidence of enthusiasm, that it did not seem appropriate to prepare a condensed impersonal document. The contributions received are thus given in full, ranging from comments on engineering aspects of the project, via descriptions of research programmes that would benefit considerably from the expected increase in intensity, to descriptions of ideas for studies that would become feasible only as a result of the planned improvements.

From 1970 until the Zurich meson factory becomes fully operational, the improved CERN SC would be a facility unique in Europe, the only one on which physicists would be able to learn how to use a high-intensity accelerator. But the enthusiasm shown by the contributors does not only stem from this. Because the high intensity will be available at a very high duty cycle, the machine will be an excellent tool for the investigation of rare phenomena as well as for many important systematic studies that would absorb too much machine time, or even all of it, if they were attempted with the SC in its present form. It is clear from the contributions that both elementary-particle physics and nuclear-structure research at energies below 600 MeV would receive a great stimulus if the improvement project were approved.

T.E.O.E.
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GENERAL REMARKS ON THE NEED TO IMPROVE THE SC

G. Phillips

Relationship to the Zurich 500-MeV IC-SIN

The expected advent of the IC-SIN machine about 1973, coming into full operation about 1975, poses several problems to the development of intermediate-energy physics in Europe. These may be summarized by noting that if the IC-SIN existed today it could not be effectively utilized. Specifically: 1) many problems, suitable for study with the meson factory, are at present poorly defined or unknown; 2) the experimental techniques for full utilization of the increased beam intensity, and beam quality, are not available at present; 3) scientists with suitable training, experience, and motivation to use the meson-factory facilities do not at present exist in sufficient quantity or quality. All of these points argue strongly for using the next six to eight years in order to be prepared for proper use of the new accelerator. The proposed improvement programme of the CERN SC accelerator should be considered partially in that context: to aid in defining problems of physical interest, developing new experimental techniques, and in training personnel.

It should be noted, finally, that there is no other accelerator in the world, as far as I know, that will have the improved SC capability during the period 1970 - 1973.

Technical comparison of the improved SC and IC-SIN

Two points need to be made: 1) the 600 MeV energy of the SC may allow more intense secondary beams than the 500 MeV of the IC-SIN in some cases; 2) the better duty cycle of the SC ($\sim 50\%$) with respect to IC-SIN ($\leq 10\%$) strongly mitigates the more favourable IC-to-SC beam ratios for many experiments. Thus it seems reasonable to expect that the SC, if improved, may be quite useful even after the IC-SIN is operational.

PERFORMANCE PARAMETERS FOR THE INTERMEDIATE-ENERGY PROTON ACCELERATORS EXPECTED TO BE IN OPERATION IN THE 1970's.

S. Kullander

It is likely that the intermediate-energy physics in the 1970's will be done by means of improved SC's and another class of circular and linear accelerators, which are now commonly called meson factories. Unimproved SC's will probably have difficulties in keeping up with this new generation of accelerators. Improved SC's, on the other hand, are expected not to be so inferior in intensity, and would benefit for a considerable time from the external beam facilities available. The continued use of internal targets would, thanks to multiple traversals, give a higher intensity of negative π mesons than when external targets, necessary in meson factories, are used.

Clearly, a comparison of the performance of machines as they will appear in the 1970's can be misleading, because published design data might be goals rather than verified figures. The following table has been compiled to the best of my knowledge from the information available in conference reports and proposals. The Intense Neutron Generator of Chalk River has been omitted, as this project is still too much in the planning stage. It should also be remembered that two intense electron linear accelerators in this energy range are being constructed at MIT and at Saclay. These machines will give intense low-energy pion beams with low duty cycles (1-4%).

As can be seen, some sort of improvement programme is carried out on all existing SC's in the range 400 to 800 MeV. At two laboratories (Carnegie and Columbia) the old machines will be modified to sector-focusing synchrocyclotrons. The improved CERN SC should not be inferior to these latter machines. The meson factories under construction in Zurich and Los Alamos will produce higher intensities than will the improved CERN SC, which, on the other hand, will have the best duty-cycle.

Accelerator	Energy (MeV)	Current (μA)		Duty cycle micr × macr %	Beam quality (mm × mrad)		Energy res. ΔE/E(%)	Secondary targets production I=Int. E=Ext.	Status	In Operatio
		Int.	Ext.		Hor.	Vert.				
Improved CERN SC	600	10	1	20 - 75	15	< 50	< 0.5	I, E	Proposal	1970
Dubna SC	680	2.4	0.05	2 - 30	-	-	0.9	I	Studies on improvements	Now
Berkeley SC	730	1-2	~ 0.08	10%	-	-	1.6	I	"	Now
Chicago SC	450	~ 1	0.002	10 - 20	-	-	< 0.5	I	"	Now
Williamsburg SC	600	~ 1	≈ 0.05	10 - 50	15	50	0.8	I, E	Machine newly completed	Now
Carnegie SFSC	500 - 600	5-50	5-40						Proposal	
Columbia SFSC	500 - 600	5-50	5-40						Constr.	1970
Zurich Ring SFC	510(520)	100	30-80	3 - 5(10)	10	10	0.3	I, E*	Constr.	1973-74**
Vancouver H^- SFC	200 - 500	20-100	20-100	2 - 25	5	5	0.3	E	Proposal	1972
Los Alamos Linac	200 - 800	1000	1000	6	30	30	0.4	E	Constr.	1970

Table of performance parameters (for comparison: present CERN SC ≈ Williamsburg SC)

* At reduced intensity.

** The years within which start of operation with reduced intensity is expected. Full intensity operation is estimated to begin one year later. The dates are still somewhat uncertain; they are expected to be fixed in the beginning of next year.

COMMENTS ON THE PROPOSED IMPROVEMENTS TO THE SC

(Document MSC-23/545)

S. Kullander

All previous failures to exceed the 1-μA intensity limit have recently been recognized as being due to space charge. Thus there is new hope for synchro-cyclotrons, as shown at the SC Conference in Williamsburg, 1964, summarized by R.T. Siegel in Physics Today, August 1964, p. 41.

The proposed fourfold increase of accelerating voltage will increase the limiting space charge by at least a factor of 4. Because of the high voltage the orbits can be kept under control from the moment of injection. In this way, small radial oscillation amplitudes can be obtained and the extraction system will be much more efficient. It is important to note that an increased voltage must be accompanied by an increased rate of change of frequency in order to prevent the particles from returning to the centre during the first phase oscillation. The demands on the voltage and frequency-time programmes are certainly the main motivations for a rotating capacitor. In the proposal, a careful design based on the equations of motion has made it possible to increase the present repetition frequency of 54 c/sec to 800-1000 c/sec.

The two improvements mentioned here, the increased RF voltage and the increase in repetition frequency, will give a much higher beam current, since more charge can be accelerated to full radius at an increased rate.

Therefore, considering the boundary conditions on page 2 of MSC-23/545, the SC improvement programme with a new rotating capacitor as main item appears to be the only way of getting a worth-while increase of the internal circulating current.

Some comments on the table on p. 2 of document MSC-23/545:

1) The current of 10 μA is the radiation limit. According to calculations the achievable currents are higher (p. 4).

2) The extraction efficiency of 10% is probably a conservative estimate. Calculations performed in Uppsala indicate that the extraction system could do better than that.

3) From these calculations one may expect a better energy resolution than 0.5%.

4) The vertical beam quality can probably be improved by means of a clipper at a small radius, since the achievable intensity is higher than that tolerated for radiation reasons.

IMPORTANT FEATURES OF THE IMPROVED SC

R. Meunier, M. Spighel and J.P. Stroot

The new RF system will increase the beam current by a factor of 10. This new intensity would make the SC closely comparable with other machines as regards this particular point. But this comparison alone would be incomplete when assessing the merits of the improved SC for its relevance as a tool for physics.

The maximum beam intensity is an important factor, but other important factors are:

1) Duty cycle, improved recently and expected to remain as good.
2) Acceleration in both directions, retained.
3) Provision for internal targets.
4) Maximum beam energy, 600 MeV at present.

1) Duty cycle

Recent improvements of the SC duty cycle on both the internal and external beams are of extreme importance for electronics experiments. The total duty cycle reaches around 50% in the best conditions, and is considerably better than it was a few years ago. Further improvements are expected, and the duty cycle would not lead to difficulties when there is an increase in intensity.

2) Acceleration in both directions

This is a nice feature of the SC that is kept in the proposed scheme. Secondary beams of both polarities are available in all channels whenever required.

3) Targets and pion beams

The internal targets are very important features of the SC. One has to consider their small size, resulting in good beam-image optics, high efficiency up to 5 to 10 traversals of the primary protons, good duty cycle, small conversion of γ rays from π^0 mesons and a correspondingly small contamination with electrons, and high efficiency of extraction of π^- as the main cyclotron field is used as an immersed optical element and allows particles produced at 0° to be used. Possibility of beam sharing between targets exists.

The drawback of a poor momentum spectrum and poor efficiency of extraction of π^+ produced at very large angles is removed with a target in the external proton beam. Some other machines rely mainly on this solution, but it is far from being a universal one. The proton-extraction efficiency has been very low so far (5%). The conversion efficiency is limited to one traversal. The target size is greater and longer. This means that generally only one user takes the secondaries at 0°.

With an external target, the π^- flux is a factor 10 to 100 down from the flux of internally produced π^-. The π^+ flux is comparable to or even greater than the best π^- flux, but is peaked by the production mechanism $p + p \to \pi^+ + d$ at a relatively high energy.

Taking into account the primary and secondary beams slowing down, the π^+ spectrum is peaked near 200-280 MeV at the SC. This peak energy cannot be decreased in an efficient and easy way, but that is nevertheless the best π^+ beam. In comparison, the beams produced internally are continuously variable in energy, at present between 150 and 250 MeV within a factor of 2 in intensity for π^-. But clearly, though the external proton beam is in itself a powerful tool, it cannot produce all the best secondary beams.

4) Maximum beam energy

A magnet reshimming is not presented in the new scheme, but it has very small financial implications. It is worth mentioning because of its interest for physics.

The present energy, 600 MeV, may be slightly increased (5%) as the recent measurements of the main magnetic field revealed pronounced effects of the shims which bring the $n = 0.2$ region near 224 cm, when the pole-tip radius is 250 cm. These shims have never been modified since the original design 10 years ago, and the field at which the machine operates is above the original design value. It seems logical to take advantage of the installation of the new dee to try to smooth out the magnetic-field irregularities and obtain a corresponding increase in the maximum proton energy. Even a 5% increase of the good field region would have considerable consequences and interest.

The coils remaining the same and the target being pushed outwards by 5%, the secondary particles would "see" a much lower value of the integrated fringing field $= \int B ds$. This would decrease the low-momentum cut-off of the secondary π^- mesons below the present 75 MeV making it possible to have much better stopped beams. It would also extend the π^+ momentum spectrum and intensity.

On the high-energy side, the π^- momentum spectrum is limited by the proton energy. We can define an upper limit of the useful secondary π^- beams:

- the 600 MeV SC has a practical limit near 280 MeV π^- with 20% of the flux;
- the present NEVIS cyclotron of 385 MeV has a practical limit of 70 MeV;
- the DUBNA machine of 660 MeV has a practical limit of 335 MeV.

All these figures are consistent with the empirical formula: Maximum useful π^- beam energy $\sim$ E-320 MeV. This gains importance when we consider that the pion physics at the SC is exactly in the range of the $(^3/_2, ^3/_2)$ resonance. This resonance lies at 195 MeV for free protons and shows variations on nuclei. It is a broad resonance, 150 MeV wide. In order to study interference effects which change sign across it, a useful energy spectrum of pions extending at least up to the present SC limit is required. A machine of energy lower than 600 MeV cannot cope with experiments in the resonance region and probably would be used most profitably with stopped particles. So a slight increase in the maximum useful radius of the SC would extend the momentum spectrum on both sides in a very significant manner, for an extended range means much more comprehensive study in this important region.

Conclusion

The improved SC would not only provide 10 times higher beam intensity, but in comparison with other similar machines it would also be in an excellent position for the coverage of physics because of its special features which are retained or even improved upon (extension of the range of momentum of useful π beams), and which are not provided in other machines. Its versatility would gain from the increase of intensity.

NOTES ON SC IMPROVEMENT

J. Domingo

The proposed improvements in the SC would greatly enhance its usefulness for carrying out the type of pion nucleon structure investigations in which the Oxford group is currently engaged. The expected increase by a factor of at least 20 in the extracted proton beam together with the improvement in the duty cycle and energy spread of the beam should enable us not only to undertake new types of experiments but, probably, more importantly to reduce the running time required for collecting sufficient pion scattering data for a given nucleus from days to hours. Thus within a reasonable amount of machine time one will be able to perform a systematic investigation of a given reaction over a range of nuclei rather than having to confine the study to a few chosen nuclei. Experience with nuclear-structure investigations at energies of a few MeV has shown the importance of such systematic investigations.

In addition the much higher intensity pion beams which will be available with the improved SC should allow us to regard correlation studies between the scattered pion and the knocked-out nucleons as a standard technique rather than a special method which can be used only in the case of an extremely favourable cross-section.

The large increase in the extracted proton beam should enable us to obtain high-resolution π^+ beams of reasonable intensity over a much wider range of energies than is possible with the present extracted beam. In addition we should be able to produce usable π^- beams over a sufficient energy range so that π^+/π^- comparisons can be made in the region of the 3-3 resonance with the same experimental set up. The failure to observe the predicted π^+/π^- ratio in our activation experiments shows the importance of making such comparisons.

Measurements such as the search for high-momentum components in the nuclear wave functions through the single nucleon pion absorption process viz. $^{16}O(\pi^+,p)^{15}O$ which are difficult with the present machine should become quite feasible with the pion beams obtainable from the improved SC.

INTEREST OF A CONTINUED STUDY OF WEAK INTERACTIONS AT LOW ENERGIES

N. Cabibbo

Here I can only sketch the reasons why a continued effort on experiments in weak interactions at low energy seems of great interest. More arguments in favour of such an effort, as well as feasibility considerations, are contained in the many experimental contributions to this document.

I will discuss briefly:

1) decay modes of the pion;
2) neutrino and muon physics (ideas for wild experiments);
3) muon capture;
4) other possibilities.

1) Decay modes of the pion (see also contribution by Soergel)

The most interesting problem here is that of a precise measurement of the rate for pion β decay, $\pi^+ \to \pi^0 + e^+ + \nu$.

On the basis of the CVC hypothesis and the SU(3) theory of leptonic decays, the amplitude for this decay should be G cos Θ, where G is the Fermi coupling constant, accurately determined by the muon lifetime, and cos Θ is a correction due to the sharing of the weak interactions between $\Delta S = 0$ and $\Delta S = 1$ processes. The correction is

$$1 - \cos\Theta \approx \frac{\Theta^2}{2} \approx 2.2\%.$$

Including electromagnetic corrections, the rate for this decay can be computed to an accuracy of less than 1%. The present experimental results confirm the prediction to $\approx 7\%$. This is gratifying, but not completely satisfactory, since the experiment is not sensitive to the fine points, i.e.:

a) The presence or not of the cos Θ correction, which is of paramount interest for the presently accepted theory of weak interactions.

b) Radiative corrections. These are becoming the subject of discussion between theoretical physicists. The issue is the mechanism by which a possible ultraviolet divergence in the corrections is avoided. According to the mechanism realized in nature (special structure of the current algebra, intermediate vector meson, etc.) the corrections could change by as much as 2%.

A measurement of the rate in the 1% range would help clarify these rather fundamental points.

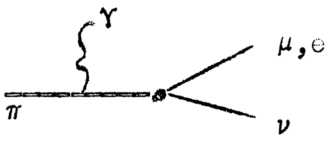
<u>Another interesting decay is $\pi \rightarrow e + \nu$.</u> The branching ratio $\pi \rightarrow e + \nu / \pi \rightarrow \mu + \nu$ is predicted to a very high accuracy under the following hypotheses:

i) the weak interaction is of V-A type;

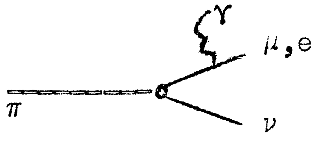
ii) the weak interactions of muon and electron are identical.

The prediction is now tested to 2%. In view of the very fundamental nature of these hypotheses, it would seem of great value to push the limit further.

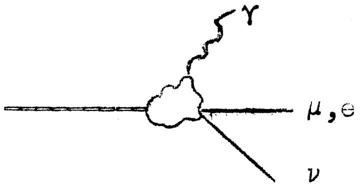
<u>The radiative decays $\pi^{+} \rightarrow e^{+} + \nu + \gamma$ and $\pi^{+} \rightarrow \mu^{+} + \nu + \gamma$</u> are also of great theoretical interest. Each of them has a contribution from the inner bremsstrahlung of the corresponding $\pi^{+} \rightarrow e^{+} + \nu$ and $\pi^{\mp} \rightarrow \mu^{\mp} + \nu$ decays [graphs (a) and (b)] and two direct contributions [graph (c)], one of them axial, the other vector.



a



b



c

The inner bremsstrahlung contribution can be computed in a straightforward way, while the two direct contributions are very interesting. The vector contribution is related by CVC to the $\pi^{0} \rightarrow 2\gamma$ decay. Its determination would then constitute a new and independent test of one of the cornerstones of the present theory of weak interactions. The axial contribution is also predicted in different models. Its sign is related to the mechanism of cancellation of divergences in the radiative corrections to π-β decay, and is therefore very interesting. Experiments to determine these contributions involve the measurement of lepton and γ spectra and correlations. Experiments on $\pi^+ \to e^+ + \nu + \gamma$ have been done at CERN, while the only experiment of $\pi \to \mu + \nu + \gamma$ which I remember is ten years old.

The possibilities of repeating the $\pi^+ \to e^+ + \nu + \gamma$ experiments are discussed in Soergel's note. It seems that with the improved SC one could tackle the interesting problems.

An interesting possibility is that of testing T-invariance in $\pi^+ \to \mu^+ + \nu + \gamma$, as discussed by Zavattini.

2) Muon number versus muon parity (ideas for wild experiments)

The main problem which could be attacked with neutrino experiments at the improved SC regards the nature of the muon and electron neutrinos. From the high-energy neutrino experiments, we know that the muon-neutrino, produced in $\pi^+ \to \mu^+ + \nu_\mu$, and the electron neutrino, produced in beta decay, are different particles. The strict association of each lepton with its neutrino is interpreted in terms of an additive quantum number, called muonic number. A possible attribution is

Particle	Muonic number	Leptonic number
μ^-, ν_μ	+1	+1
$\mu^+, \bar{\nu}_\mu$	-1	-1
e^-, ν_e	-1	+1
$e^+, \bar{\nu}_e$	+1	-1
hadrons	0	0

If we accept the conservation of such an additive number, together with lepton number, the neutrinos emitted in muon decay are

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu .$$

Although the existence of an additive muon number explains the known facts, it is not the only possibility. One could assume, instead, a multiplicative muon number, i.e. a sort of "muon parity", attributed as follows:

Particle	Muon parity
$\mu^\pm, \nu_\mu, \bar{\nu}_\mu$	-1
$e^\pm, \nu_e, \bar{\nu}_e$	+1
hadrons	+1

The "muon parity" conservation would still forbid $\pi^+ \to \mu^+ + \nu_e$ or $n \to p + e + \nu_\mu$ processes in which it changes from +1 to -1.

However, muon decay could now go in two different ways which conserve μ parity, as well as lepton number:

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$

$$\mu^+ \to e^+ + \bar{\nu}_e + \nu_\mu .$$

A test of this possibility is discussed in Zavattini's note. The idea is to create a neutrino beam by stopping π^+ or μ^+.

Apart from muon neutrinos, which are anyway under threshold to interact, there would be electron-neutrinos. In the first alternative these would only be ν_e, while in the second alternative ("muon parity") they could be a mixture of ν_e and $\bar{\nu}_e$. In this case one could observe reactions such as

$$\bar{\nu}_e + \text{Nucleus} \to \text{Nucleus}' + e^+$$

which are absent in the first case.

A different approach to tackle the same problem lies in attempting to observe a transition

$$\text{muonium} \leftrightarrow \text{antimuonium},$$

i.e.

$$\mu^+ + e^- \leftrightarrow \mu^- + e^+.$$

The two sides of the proposed reaction (also discussed by Zavattini) have the same lepton number, equal to zero, but opposite "muon number". If the rule of conservation of muons is additive, this transition would be forbidden. In the "muon parity" case, the transition is allowed.

Both experiments discussed in this section are very difficult, very speculative, but of fundamental interest. Experimental thinking on them would lead to feasible projects.

3) Muon capture

The fundamental interest in muon capture is twofold:

i) to check muon-electron universality, i.e. the identity of muon and electron weak interactions;

ii) assuming (i), to study the structure of the hadronic weak current.

The most interesting case is capture on protons, i.e.

$$\mu^- + p \rightarrow \nu_\mu + n,$$

which is free of nuclear-structure problems. The theory is now tested to about 10% by capture experiments in liquid and gaseous hydrogen. This checks (i) to the stated precision, but leaves many theoretical possibilities untested. In particular, it fails to prove or disprove the existence of first forbidden contributions to the hadronic current, contributions which cannot be observed in beta decay because of the low Q values. These contributions ("second class" currents) could contribute few per cent to the capture rate, so that experiments in the 1-2% range would be very valuable.

Of particular value would be an attempt to measure even roughly the capture rate in the triplet state, which is predicted to be very small because of a critical cancellation between vector and axial contribution, and experimentally is essentially unknown. A rough determination could be obtained by combining capture in liquid and gaseous ^2H, both to 1-2% accuracy. For complex nuclei, starting with ^3He, the situation is reversed, in that the comparison between experimental and theoretical capture rates is at present limited by theoretical uncertainties on nuclear structure. A lot of very interesting work remains to be done on aspects different from the total capture rate:

a) Asymmetry of recoil neutrons of the capture of polarized muons from complex nuclei. The data existing at present are in conflict with the accepted theory. This is a sore point in the situation, which should be clarified.

b) Capture yielding special states (ground or excited) of the final nucleus. These processes are of especially simple theoretical interpretation. Among the interesting cases, I may mention the $0^+ \rightarrow 0^-$ transition in $^{16}O \rightarrow {}^{16}N$ especially sensitive to the induced pseudoscalar coupling.

c) Same as (b), but with measurement of recoil asymmetry. This is again interesting since in different cases it tests for different combinations of coupling constants.

d) Radiative muon capture (see note by Di Lella). This process,

$$\mu^- + p \rightarrow n + \nu_\mu + \gamma$$

is especially sensitive to the induced pseudoscalar coupling. It has been observed in ^{40}Ca, yielding $g_P = (13.3 \pm 2.7)\ g_A$, against a prediction of $g_P = 7\ g_A$. This kind of work could be pushed to lower-Z nuclei, such as ^{12}C, perhaps ^3He, or even hydrogen (this would be very difficult, though).

e) Polarization of recoil neutrons. Again a very interesting problem, on which little information exists.

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f) More imaginative experiments. The list given here does not exhaust what could be done with an intense machine allowing for elaborate experiments. As an example, radiative capture of polarized muons with coincident detection of the neutron and γ ray could provide a test of time reversal.

To sum up this section, muon capture is still an open field, with a large range of feasible and interesting experiments.

4) Other possibilities

There are many, such as:

a) Improving the accuracy in μ-decay parameters. These, in particular the Michel parameter ρ, are now known to somewhat better than 1%, but any experiments which could improve on this would be of high interest, since these are quantities directly related to the more fundamental ideas in the theory of weak interactions.

b) Experiments on baryon-baryonic weak interactions, such as Σ and Λ production by protons on nuclei. Little is known about these, except for the scant and indirect information from hyperfragment decays.

5) Conclusions

A continued experimental effort on weak interactions at SC energies could be rich in fundamentally interesting results, and attract the activity of first-class experimental groups. The theoretical interest in such a programme is very high, as attested by the continued production of good papers on the subject, both at CERN and at other centres.

INTERACTIONS OF μ MESONS AND NEUTRINOS

E. Zavattini

A) Absorption of μ^- mesons in hydrogen

In the course of the experimental activities of our group we have considered a number of experiments which, whilst difficult also for many other reasons, were dropped because of the limited beam intensity available at the CERN SC. These were the following:

1) The reaction $\mu^- + p \rightarrow n + \nu$.

It is now known how to obtain this reaction in such a way that the initial state of the $\mu^- p$ system is a singlet. The measurements in this condition done so far have a precision of about 10%. The aim here is to reach a measurement accuracy of $\leq$ 2%.

The initial state of the $\mu^- p$ system can also be a triplet and measurement in this condition is nowadays considered to be impossible, the rate being almost 50 times smaller than the rate obtained when the initial state is singlet. A beam of μ^-, 10 times more intense, would certainly make them possible, though still difficult. A measurement even at a level of 10 to 15% in the triplet initial condition, together with a precision of a few per cent in the singlet study, would represent a source of information from which the fundamental coupling constants of the weak interactions can be deduced, i.e.:

- the induced pseudoscalar coupling constant,
- the ratio g_ν/g_a.

2) The reaction $\mu^- + p \rightarrow n + \nu_\mu + \gamma$.

This process cross-section ($\sim 10^{-4}$ times smaller than for non-radiative capture) would be a very important one to study when higher intensity becomes available; it has never been detected in hydrogen.

3) Measurement of the angular distribution of the tritium, with respect to the spin direction of the stopping μ^-, in the reaction

$$\mu^- + {}^3\mathrm{He} \rightarrow {}^3\mathrm{H} + \nu_\mu . \qquad (1)$$

Theoretical calculations show that a measurement of the asymmetry parameter to within 20% gives the value of g_p (induced pseudoscalar coupling constant) to about 20%. The fraction of μ^- which undergo reaction (1) is ~ 2‰. Here the **main problem** is to stop enough μ^- in the gas; hence the improvement programme would change this experiment from possible-impossible, as it is now, to a possible and very important one (since good precision can be reached).

B) Interactions of ν_e produced by the SC

Through the process of μ^+ decay the SC can be a strong source of pure electron neutrinos. Very interesting reactions to study are:

$$\begin{array}{l} \bar{\nu}_e + p \rightarrow n + e^+ \\ \nu_e + n \rightarrow p + e^- \end{array} \qquad (2)$$

The detection (and measurement of the cross-section of either) can act as analyser of the kind of neutrinos emitted in the decay of the μ^+. In fact, according to the "additive lepton-conservation law"*), $\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$, whereas for a multiplicative one it is also possible to have $\mu^+ \rightarrow e^+ + \bar{\nu}_e + \nu_\mu$. With the aid of reactions (2), one can therefore distinguish between the two laws. Moreover, the comparison of the cross-sections involved in (2) with the results from the capture experiment gives one of the strongest tests for universality (which, so far, is based on reactions involving μ mesons and electrons at a rather different momentum transfer). At present the intensity calculated, under conservative hypothesis, is one event every five to ten days.

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*) The lepton number assignments for e^-, μ^-, ν_e, and ν_μ are +1, -1, +1, and -1, respectively.

C) Muonium-antimuonium conversion

This process, like the previous one, provides a test as to whether the lepton-conservation law is of a multiplicative or additive type. Since this conversion can be detected only when the μ^+e^- is in a medium of very low density (~ 10^{-3} mm Hg of a gas like argon1)) it is clear that one of the main difficulties is represented by the intensity of the μ^+ beam.

Assuming universality for this weak process, the fraction of muonium → antimuonium conversion is $\sim 2 \times 10^{-5}$ when muonium is formed in a gas at about 10^{-4} atm (higher pressure cannot be allowed since the transition is then quenched).

Combining this figure with the present available μ^- beam and experimental techniques, one realizes that nowadays it is possible to obtain one muonium → antimuonium conversion every ten to twenty days.

D) Time-reversal test in weak interactions

Analysing the decay products of

$$\begin{array}{l} \pi^+ \to \mu^+ + \gamma + \nu_\mu \\ \qquad\ \ \llcorner\!\!\longrightarrow e^+ + \nu_e + \bar{\nu}_\mu \end{array} \tag{3}$$

one can detect the presence of time-reversal-violating terms in the weak Hamiltonian governing process (3). The experiment must look at the polarization of the μ^+ produced with respect to the plane defined by the three final particles.

Unfortunately, the test is effective only in the region where the γ and the μ^- are almost in line. The useful region represents about 10^{-7} or 10^{-8} part of the π^+ decay: hence it is again clear that the problem is the intensity of the π^+ beam one can stop.

RADIATIVE MUON CAPTURE

L. Di Lella

The process $\mu^- + p \rightarrow n + \nu_\mu + \gamma$ was studied in 1963 at the SC by Conversi et al., using a ^{40}Ca target in which about 6000 μ^-/sec were stopped. 400 events were recorded in the high-energy part of the spectrum ($60 \leq E_\gamma \leq 100$ MeV) in two weeks of effective data taking. The experiment has yielded a value for the induced pseudoscalar coupling constant

$$g_p = (13.3 \pm 2.7)\ g_a$$

and a branching ratio of $\sim 3 \times 10^{-4}$ of the radiative relative to the normal μ^- capture. The value of g_p is affected by several theoretical uncertainties coming from the fact that the experiment was done in complex nuclei. A study of such a process in several lighter nuclei, especially ^{16}O, as pointed out by Luyten et al., would considerably reduce these uncertainties. In ^{16}O the rate is, however, five times lower, needing more intense beams. A study of the above reaction with polarized muons would give very important information. The angular distribution of the γ's with respect to the muon polarization is

$$\frac{dN_\gamma}{d\vartheta} \propto 1 + P_\mu\ \alpha \cos \vartheta,$$

where $P_\mu \sim 15\%$ in ^{40}Ca and α would be ≈ -1 in case of A-V interaction, +1 in case of S-T. The only information available today is that the interaction responsible for μ^- capture is of the F-GT type: so it could be A-V, as suggested by universality, or S-T, or a mixture of the two as well. With the intensities available at present, such an experiment would require about 100 days of continuous data taking to collect about 2000 events, which would give α within a relative error of $\sim 20\%$.

Also, with an increase in intensity by a factor 10 it may become possible to study the radiative muon capture in liquid H_2, which would, of course, eliminate all the uncertainties due to the nuclear structure in the interpretation of μ^- capture in complex nuclei.

ON THE POSSIBILITY TO STUDY RARE DECAY MODES OF THE PION WITH AN IMPROVED CERN SC

V. Soergel

The available pion fluxes limit, at the moment, the experimental precision on two interesting rare decay modes of the charged pion: the pion beta decay, $\pi^+ \to \pi^0 + e^+ + \nu$, and the radiative decay $\pi^+ \to e^+ + \nu + \gamma$.

A measurement of the pion beta-decay rate allows a direct test of the conserved-vector-current (CVC) hypothesis, which is the fundamental concept of present-day weak-interaction theory. The decay rate predicted by the CVC theory is $\lambda_{\pi^+\pi^0} = (0.393 \pm 0.002)\ \mathrm{sec}^{-1}$.

With $\tau_{\pi^+} = 26.02$ nsec, this gives a branching ratio:

$$R\left(\frac{\pi^+ \to \pi^0 e\nu}{\pi^+ \to \mu\nu}\right) = (1.035 \pm 0.005) \times 10^{-8} .$$

Any even very small deviation from this number would have a similar consequence for the weak interactions, as would have a difference in the charge of the electron and proton for the electromagnetic interactions. It is therefore highly desirable and, as will be shown, probably possible with the improved SC, to measure $\lambda_{\pi^+\pi^0}$ with an uncertainty of 1 to 2%, which is close to the uncertainty in the predicted number.

The best experimental number available at the moment

$$\lambda_{\pi^+\pi^0}(\mathrm{exp}) = (0.38 \, {}^{+0.03}_{-0.04})\ \mathrm{sec}^{-1},$$

is furnished by a CERN experiment, in which 332 ± 10 beta decays were collected.

With the improved SC and an apparatus similar to the one used earlier which had a detection efficiency of ~ 25%, 60 to 75 beta decays can be collected per day. A data-taking period of ~ 100 days (which was also used for the earlier experiment), would give ~ 6000 events and bring the statistical error to 1.3%.

The experience gained in the old experiment shows that the detection efficiency can probably be determined with the required precision.

The radiative decay has also a branching ratio of the order of 10^{-8}, as determined by an earlier CERN experiment. The vector interaction and the axial-vector interaction can, in principle, contribute to this decay mode. The vector matrix element is, through CVC, related to the π^0 lifetime and can be calculated. On the axial-vector matrix element, there is not such direct theoretical information. Its knowledge is of great interest to test, e.g. quark-model theories or current-algebra considerations on pion decay. A precise rate measurement and a measurement of the electron and γ spectra could give the required information. The improved SC would allow one to do simultaneously the two experiments discussed with the same set-up and during the same running time. It is understood that the good duty cycle obtained at our machine is absolutely essential for this kind of work, in particular at such high pion fluxes.

The Physics Institute of the University of Heidelberg is strongly interested in carrying out these experiments, if the SC is to be improved.

TWO EXPERIMENTS IN THE ISOLDE EXTRACTED PROTON BEAM

P. Waloschek

The improvement of the ISOLDE beam would make various interesting experiments easier or possible, such as the two indicated below. I do not consider myself to be the author of these ideas, nor do I wish to propose them at present, but I am convinces they alone would be a major justification of the SC improvement programme, and I am certain that someone will do them.

1) The reaction $p + d \leftrightarrows {}^3\mathrm{He} + \gamma$

This reaction provides a check of time reversal. The (${}^3\mathrm{He} + \gamma$) reaction is being measured at Frascati. The ($p + d$) reaction can be measured at the SC at a c.m.s. energy also obtained at Frascati. The cross-sections are of the order of several μb. Details of the experiment (time of flight of the ${}^3\mathrm{He}$) make it desirable to use a thin target and therefore to increase the incident proton-beam intensity (ISOLDE).

2) Reactions violating strangeness conservation

The present intensity of the ISOLDE beam would already allow one to obtain some hyperon-production events per day via the reactions $p + n \rightarrow \Lambda + p$ and $p + p \rightarrow p + \Sigma^+$. The proposed improvement of the ISOLDE beam is obviously welcome.

DISCUSSION OF NUCLEON-NUCLEON EXPERIMENTS AT THE SC WITH MORE INTENSE BEAMS

D.F. Measday

Summary

A more intense external proton beam at the SC will make it possible to tackle experiments that will eventually lead to a complete determination of the nucleon-nucleon scattering matrix at 600 MeV. Because intensity is lost when the beam is degraded to lower energies, a greater initial intensity would extend the energy range over which data may be obtained, and would make for a more efficient use of complicated experimental equipment. One can expect that the present poor accuracy of intermediate energy (200-1000 MeV) proton-proton phase-shifts would be remedied, and one can hope that a unique set of neutron-proton phase-shifts would soon be established at 600 MeV.

Introduction

A major aim of nucleon-nucleon experiments is the reliable determination of the scattering matrix at each energy. For energies below 1 GeV, it has been normal for the problem to be tackled by making phase-shift analyses. At the recent nucleon-nucleon conference (University of Florida, March 1967) the whole subject was thoroughly discussed. Reviewing this conference, MacGregor drew the following conclusions:

a) Below 400 MeV the proton-proton phase shifts are reliably known but the neutron-proton phase shifts are only qualitatively known, even when charge independence is assumed.

b) Around 660 MeV, proton-proton phase shifts can be just about determined if the pion-production channels are handled phenomenologically by means of a model [e.g. the Mandelstam model which assumes the dominance of the ($\frac{3}{2}$, $\frac{3}{2}$) resonance]. However, the neutron-proton data at 660 MeV are not yet sufficient for a determination of the $I = 0$ scattering matrix.

Below 300 MeV, where there is no pion production, it is possible to determine the proton-proton scattering matrix at one energy if five experiments are done at all angles; another five are needed for the neutron-proton scattering matrix. These five could be, for example, σ, P, C_{NN}, D, and R. Above pion threshold it is found that nine elastic-scattering experiments at one angle can determine the scattering matrix. In phase-shift analyses one must use complex phase parameters. Thus more experiments are needed above 300 MeV than below, but unfortunately at present there are less. Furthermore, all these discussions assume that the experimental results are reliable; it is more prudent to have some redundancy, and so more than the minimum numbers of experiments should be done at a few energies.

Elastic-scattering experiments

For most proton-proton scattering experiments the present intensity of the machine is sufficient at 600 MeV; however, it is more sensible to use the same equipment at various energies. At the Berkeley synchro-cyclotron it is found that on reducing the beam energy from 700 to 400 MeV, the intensity drops by a factor of 300. Because of this, triple-scattering experiments over a range of energies are impossible at present, but become feasible with more intense polarized proton beams.

For neutron-proton scattering experiments only the basic experiments can be done, even at 600 MeV. At present there are very few neutron-proton triple-scattering experiments at any energy; the only published experiment at 600 MeV is a measurement of R at two angles by Kazarinov et al. The rate at which data are collected is so slow that very few checks can be made. One should note that a polarization measurement, made at the same time by Kazarinov et al., gave results which are quite different from those of Cheng. It is clear that higher beam intensities are required for reliable triple-scattering experiments.

All intermediate-energy neutron-proton triple-scattering experiments have used polarized protons and a deuterium target. (There are a few free-neutron-proton triple-scattering experiments at 130 MeV.) Now Breit, in his recent phase-shift analyses, has rejected almost all neutron-proton data that were obtained with deuterium targets. Unfortunately, polarized neutron beams have very low intensity (7×10^4 neutrons/sec at CERN) compared to polarized proton beams (10^6 to 10^7 protons/sec). With a factor of 10 or 20 increase in intensity in the available beams, free-neutron-proton triple-scattering experiments become possible though still difficult. Correlation experiments using a polarized proton target also become marginally possible.

Inelastic-scattering experiments

Although pion production in proton-proton collisions can be studied at present, the use of polarized beams for such work has hardly started. The few studies which have been made show that there are important effects to be elucidated; for example, the reaction $p + p \rightarrow \pi^+ + d$ has a strong asymmetry. Another important point is that this same reaction has recently been found to have a strong s-wave production at threshold. This calls into question the Mandelstam model which has been so frequently used as a basis for phase-shift analyses above 300 MeV. Intense polarized beams of variable energy will simplify a full investigation of such problems, and should make it possible for there to be a model-independent analysis of pion production to 1 GeV.

Data on pion production in neutron-proton collisions are in a very sorry state. Very little is known, and the cross-sections which have been published are in only marginal agreement. Intense monokinetic neutron beams of variable energy should settle these problems.

Nucleon-nucleon bremsstrahlung has recently been quite widely discussed. Proton-proton bremsstrahlung has been studied at Rochester with a polarized beam of 2×10^7 protons/sec; at times even this beam was too intense, so that at 600 MeV where the cross-section is larger, the major worry will not be the beam intensity but the separation of the background caused by π^0 production. This separation, however, will be facilitated by the hoped-for improved energy resolution in the external proton beam.

Neutron-proton bremsstrahlung has been studied so far using proton-deuteron collisions, which is clearly unsatisfactory. Since the cross-section is 50 times larger than for proton-proton bremsstrahlung, it could be that more intense monokinetic neutron beams will make possible the study of bremsstrahlung from free-neutron-proton collisions.

THEORETICAL REMARKS ON THE NEED FOR STUDIES OF π-NUCLEON INTERACTIONS

A. Donnachie

A) Pion-nucleon scattering

1) A much better determination of the pion-nucleon coupling constant is required (this is not nearly so well known as is generally supposed, the answer being strongly dependent on the process involved and the method of extraction used).

2) A much better determination of the pion-nucleon scattering lengths is required (as for the coupling constant, there are considerable inconsistencies among the results obtained by different approaches).

3) It is a convenient system in which to study inner and outer Coulomb corrections and the general question of how to include Coulomb scattering in the framework of a relativistic strongly-interacting system.

4) At what point does charge independence break down in pion-nucleon interactions (i.e. apart from direct Coulomb effects)? Is the pion-nucleon coupling constant charge-independent or not?

5) Indirect (but, in principle, accurate and detailed) information may be obtained on the π-π interaction.

B) Pion-nucleon radiative scattering

(linked with A.3)

The information obtainable from electromagnetic off-mass-shell effects is extremely relevant to current algebras and three-particle theories.

C) π^--p radiative capture

(in association with photo-pion production)

1) Separation of isoscalar and isovector transition amplitudes and a more precise test of dispersion relations (the ambiguities involved in extracting this information from photoproduction on deuterium make this latter process of doubtful value).

2) With the Panofsky ratio, it is related directly to A.2 (at present the available data do not all tie together).

3) Indirect (but, in principle, accurate and detailed) information on $\rho\pi\gamma$ coupling.

4) Study T-invariance in electromagnetic interactions by detailed comparison of the multipole phases with the corresponding π, N scattering phases.

THE REACTION $\pi^- + p \rightarrow n + \gamma$

Č. Župančič

The theoretical interest of measuring this process has recently been stressed by Donnachie and by Shaw. At one pion energy (72 MeV) and one angle (90° c.m.) about 500 events due to this process were measured at CERN six years ago. Since then, both the measuring techniques and the performance of the SC have been improved. A conservative estimate of counting rates possible at present indicates about 20 events/hour. Since a normal-sized experiment at the SC may use 50 data-taking shifts, about 8000 events could be collected altogether. Their distribution among different energies and angles is a matter of detailed experimental and theoretical considerations. Some interesting problems, such as the general correctness of Donnachie's calculations and the SU_3 assignment of the Roper resonance could probably be elucidated in an experiment with the present intensity. Others, such as the testing of the $\Delta I \leq 1$ rule of electromagnetic interactions, will probably only become accessible with counting rates an order of magnitude larger, i.e. with an improved SC.

PION-NUCLEON SCATTERING

P. Waloschek

There is a definite need for a substantial improvement in the knowledge of pion-nucleon scattering parameters at low energy. Arguments for this necessity arise from many fields: nuclear physics, electromagnetic interactions, backward dispersion relations, time reversal (Λ^0 decay), and others.

At the energies accessible to the CERN SC, a "second generation" of data taking is going on at present: one aims at determinations of differential cross-sections with accuracy of about 1% at energy intervals around 10 MeV (between 20 and 300 MeV). It is expected (and hoped by many theoreticians) that this programme will be completed during the next five to eight years. The amount of work to be done is such that most of the existing (and planned) medium-energy accelerators should contribute in the best possible conditions.

Data from the CERN SC are expected particularly in the π energy region from 50 to 300 MeV, as one can see from the attached table. An improvement of the intensity and duty cycle of the SC would accelerate the data-taking process and, in some difficult cases, make it feasible to obtain the required accuracy. A parallel programme to develop better beam facilities and machine controls is also essential.

Reaction	Energy MeV (± 20)	$d\sigma/d\Omega$ mb/sr.	Beam at SC	Improved SC
$\pi^+ + p \rightarrow \pi^+ + p$	120 - 260	$\gtrsim 10$	extr. protons $(p + p \rightarrow d + \pi^+)$	not indispensable
	40 - 120	1 - 10	int. target ev. slow-down	very convenient
	0(?) - 40	< 1	ISOLDE	? may make some experiments possible
$\pi^- + p \rightarrow \pi^- + p$	100 - 300	$\gtrsim 1$	int. target	quite useful
	40 - 100	< 1	int. target ev. slow-down	very useful
	0(?) - 40	<< 1	? int. targ. + slow-down	? may make some experiments possible
$\pi^- + p \rightarrow \pi^0 + n$	100 - 300	$\gtrsim 3$	int. target	useful
	40 - 100	< 3	int. target ev. slow-down	very useful
	0(?) - 40	< 1	? int. target + slow-down	? may make some experiments possible
$\pi^- + p \rightarrow \gamma + n$	60 - 300	< 0.1	int. target	extremely useful
	0(?) - 60	< 0.1	? int. target + slow-down	? may make some experiments possible
$\pi + p \rightarrow \pi + N + \gamma$	60 - 300	<< 0.1	various	extremely useful
	0(?) - 60	<< 0.1	various	?

Summary of comments on experimental conditions at improved SC (pion-nucleon scattering).

SOME THEORETICAL ASPECTS OF NUCLEAR STRUCTURE PHYSICS AT SC ENERGIES

T.E.O. Ericson

1. Electromagnetic interactions (μ-mesic atoms, μ scattering)

Mesic atoms are a very important tool for investigating nuclear charge and current distributions. Present research is directed towards detailed comparisons of the distributions between neighbouring nuclei and between states in the same nucleus. For example:

i) How is the charge distribution affected by adding neutrons to the nucleus? Are the protons diluted uniformly over the full mass distribution or not, and to what extent (isotope effect)?

ii) How does the charge distribution vary with the detailed structure and configuration of the nuclear state? In particular, how much does the charge distribution change between two rotational states of different spin? Or between two shell-model states (isomer effects)?

iii) What is the nuclear quadrupole distribution? Is it just a uniform deformation of the entire charge distribution or is indeed also the nuclear surface thickness asymmetric in space (hyperfine effect)?

iv) How different are nuclear quadrupole moments in the ground state and the excited states, and, in deformed nuclei, how different are the diagonal and non-diagonal matrix elements? In a deformed nucleus, how much is the centrifugal stretching (hyperfine effects)?

v) Is the magnetic-moment distribution (in closed shell ± 1 nucleon) carried by the odd nucleon or not (1s hyperfine structure)?

Isolated problems in these categories can presently be attacked in favourable cases (and have been so). However, it is extremely frequent that target samples of the theoretically most interesting nuclei are unavailable isotopically pure in sufficient quantity. Smaller targets imply fewer stopped muons, which makes a more intense muon beam highly desirable. In this way, weak transitions can also be studied. The improved SC would mean a greatly increased flexibility to the whole field of μ-mesic atoms. In view of the maturity of the field, there is every reason to expect important scientific results as a consequence of improvements.

Experiments on μ scattering are marginal at present, but should become possible with a tenfold increase of intensity, though not for systematic applications. In heavy nuclei, sizeable form-factor effects in elastic scattering occur with cross-sections in the region from several mb/sr to several tens of mb/sr. The basic interest in μ-meson scattering is the small radiative tail, and the small systematic errors in comparison with electron-scattering experiments. This largely compensates for the huge difference in intensity.

2. Strong interactions

2.1 Protons

So far the proton beam at the SC has hardly been used for nuclear physics because of inadequate resolution for resolving nuclear states. The intrinsic advantage of 600 MeV protons is:

i) short wavelength allowing exploration of details of the nuclear shape;

ii) the rather small total NN cross-section at this energy, leading to good transparency which is favourable for the analysis of experiments in terms of multiple-scattering theory.

The exploratory experiments at the Brookhaven Cosmotron shortly before its shutdown (at momentum 1.7 GeV/c compared to 1.2 GeV/c at the SC) indicated that simple high-energy approximations are valid at these energies (Glauber theory) with great simplifications in analysis.

Questions naturally coming under study are:

a) Has the high-energy limit for multiple-scattering theory been obtained quantitatively?

b) If so, one can study elastic and inelastic form factors for the nuclear matter distribution. Do the neutron and proton distributions differ in light N = Z nuclei? How neutron-rich is the surface of a heavy nucleus quantitatively?

c) Can the nuclear pair-correlation function be studied at short distances using sum rules for inelastic scattering?

d) Must nuclear matter distributions be described more accurately than by the Fermi shape? In particular, is the central region of the nucleus one of uniform density or not?

e) What fraction of nuclei consists of d, t, ^{3}He, and α substructures?

All of these questions are very important to nuclear-structure physics; the improved CERN SC seems to be the best machine available for the purpose for a period of several years.

Analysis of experiments like those above will require a good knowledge of the NN scattering matrix at about 600 MeV. While considerable work has been done at Dubna, it seems likely that additional experiments on nucleon-nucleon scattering at 600 MeV will be necessary at some stage of such studies.

2.2 Pions

Only recently have pion beams achieved a resolution sufficient to clearly resolve nuclear ground states from excited states for light elements. Further, pion beams are intrinsically weak. As a consequence nuclear-structure work with pions is still largely exploratory. Thus only processes with rather large cross-sections can be attacked; further systematic studies both on single elements as a function of energy and for a class of nuclei can be done only in a limited way due to serious time-restrictions. An exception is π-mesic X rays for which systematic studies are already possible.

The intrinsic interest in the pion stems from the fact that:

a) it is the only strongly interacting elementary particle besides the nucleon available in reasonable abundance for systematic studies of nuclei;

b) its spin, charge states and isospin are quite different from the nucleon and, in addition, it is a boson;

c) its force range is short compared to its Compton wavelength, which makes the connection between πN and π-nuclear interaction considerably more transparent than for nucleons;

d) the πN interaction resonates at 180 MeV.

Present work should therefore in part be looked at as defining fields of research on future or improved machines. A large part of the theoretical effort up to now has gone into the elastic interactions, since the understanding of these is a prerequisite for a proper understanding and analysis of most other processes involving pions.

2.2.1 Nuclear matter

Recently a semiquantative connection between πN scattering, π production and π-nuclear interactions has been obtained below the πN resonance energy using multiple-scattering theory. Numerous questions remain to be elucidated in this context.

i) Can pair-correlation effects beyond Pauli correlations be seen?

ii) Can the important isospin effects expected in heavy elements be demonstrated?

iii) Is there an observable strong hyperfine effect in π-mesic atoms, and if so, how is it related to πN interactions?

iv) How does the πN resonance modify the properties of the nuclear medium at energies close to 180 MeV? Is there a resonance in the nuclear refractive index, and if so, is this a global property of the medium regarded as a pion source or is it due to the individual nuclear constituents resonating? At what energy does the resonance occur? What are the isospin properties of the resonance if it is a π-nuclear resonance?

v) Since π^+ and π^- scattering on a T = 0 nucleus are identical, the difference in $\pi^\pm$ scattering on N = Z nuclei depends on isospin isolation and is hence sensitive to the difference between neutron and proton distributions.

The elementary-particle input data into π-nuclear physics are in part unsatisfactory. In particular, improved πN S-wave phase shifts as well as the extremely badly known cross-section for $n + p \rightarrow \pi^- + p + p$ are urgently needed as input data in the low-energy multiple-scattering theory.

2.2.2 Nuclei as elementary particles

The π-nuclear interactions provide a meeting place for concepts, ideas, and techniques of both high-energy physics and nuclear-structure physics. It is thus ideal for exchanges between the fields. For example:

1) Elastic interactions with T = 0, J = 0 targets (even-even nuclei) depend on one single amplitude. This simplifies forward dispersion relations which are being explored with indications of at least qualitative success. Can dispersion techniques in practice be applied also to non-forward angles with nuclear binding, size (anomalous thresholds) and absorption effects included? How is this approach related to multiple-scattering theory?

2) Low-energy theorems on π-scattering and ($\pi\gamma$) amplitudes. How true is it that the nucleus can just be considered as an extended source of the pion field?

Both 2.2.1 and 2.2.2 imply that it is proper to regard pion interactions with nuclei as a whole over a wide range of energies starting from the bound pions in π-mesic atoms. The present experimental situation is unsatisfactory from this point of view. Not even for standard reference nuclei like ^{4}He, ^{12}C, and ^{16}O do there exist satisfactory data on basic quantities like total, absorption, and elastic cross-sections as a function of energy. This is a constant nuisance in theoretical work, since they are needed as input or comparison data.

Beams of appropriate energy resolution and with the higher envisaged intensity would be of enormous help. It is now possible to barry out most of these experiments at one energy or in one nucleus (although small cross-sections have to be avoided), but the limited information obtained in this way also limits the theoretical use. Finally, it is indispensable for a proper study of the resonance region to dispose of good pion beams up to at least near 300 MeV.

2.2.3 Nuclear states

1) The axial-vector transitions in ($\pi\gamma$) reactions would lead dominantly and selectively to members of Wigner supermultiplet levels (charge independence of nuclear forces), difficult to reach otherwise. The theory is closely analogous to that of μ-capture in nuclei. How well does this description hold? What splittings, shifts and distribution of transition strength result in the multiplet from violation effects?

2) What are the high-momentum components in nuclear wave functions and how do they differ from those of the shell model? [Reactions (π^+,p) require high momentum transfer and are hence sensitive to source components.]

In particular the important group of (π,γ) reactions which present very crude experiments already show to be highly selective in population of nuclear states, should become fully accessible for investigations with an order-of-magnitude increase in intensity.

EXPERIMENTS ON MESIC X RAYS

G. Backenstoss

Investigations on pionic and muonic atoms are rapidly expanding in many directions and will certainly remain an attractive field of research for the years to come. At present the situation may be characterized by the fact that measurements are performed which exploit the general behaviour throughout the periodic system. The muonic measurements provide -- except for light nuclei with $Z < 10$ -- the most sensitive method for the determination of the charge radius in spherical nuclei and of the charge distribution in deformed nuclei. Pionic X rays are used to investigate the strong π^--nucleus interaction which can be related to the π-N and the π-2N interaction (N = nucleon).

These effects must now be studied in greater detail. That means:

1) Separated isotopes, frequently very expensive and available in only small quantities, must be investigated. Therefore high specific stop rates (stop rate per gramme of material), i.e. high beam intensities, are needed.

2) Detailed examination of the spectra requires that also weak lines are measured with sufficient accuracy, which implies high beam intensity.

3) In order to disentangle the many effects which can be observed, a large amount of accurate experimental data is needed. Therefore, one thorough measurement of one particular isotope will not be sufficient.

The following effects or quantities can be studied:

A) Muons

1) Charge distribution in spherical nuclei.
2) Charge distribution in deformed nuclei, including quadrupole moment in even-even nuclei.
3) Isotopic shift.
4) Distribution of the nuclear magnetic moments.
5) Nuclear excitation by the muon.
6) Check of vacuum polarization of the muon.
7) Cascade process of the muon in the atom.
8) γ rays after capture of the muon in the nucleus.
9) Effects in condensed matter.

1) The number of parameters of the charge distribution which can be obtained equals the number of X-ray transitions which are sufficiently sensitive to the charge distribution. For light nuclei ($Z < 20$) this is at present done only for a 1s level measured by the 2p-1s transition, because only the 1s orbit is sufficiently close to the nucleus. The 2s level is more sensitive to finite-size effects than the 2p level. Therefore observation of transitions such as 3p-2s or 2s-2p which are 10 to 100 times less frequent than the 2p-1s transition and only in some cases just observable at present could contribute essentially to a more detailed knowledge of the charge distribution.

2) In deformed nuclei the muonic spectra are much more complex. Additional parameters are necessary to define the charge distribution, and excited states of the nucleus are important. Already now the study of muonic spectra providesthe best method to measure quadrupole moments and charge distributions in deformed nuclei. For a unique interpretation of these spectra, the exact energies and relative intensities also of the weak transitions in separated isotopes will be needed requiring high resolution and high intensities [see also under 3)].

3) Measurements on separated isotopes to study the isotopic shift, known from atomic spectra, can be interpreted more directly in the muonic atom. The small amounts in which these isotopes are usually available need very high specific Coulomb capture rates. They can be achieved if the muons are stopped in gaseous H_2 from which they are transferred to the isotope in the form of a gaseous admixture to the H_2. 10^{-3} to 10^{-4} grammes of the isotope per gramme of H_2 should be sufficient. To stop in 10^{-1} g/cm^2 H_2 (10 cm at a pressure of 100 kg/cm^2) a number of muons equal to that in conventional targets, a beam intensity increased by a factor of 10 is needed.

4) Magnetic-moment hyperfine splitting which is small due to the small magnetic moment of the muon can be observed with high-resolution detectors. Very good statistics are needed in order to draw conclusions about the distribution of the nuclear magnetic moment.

5) The excitation of nuclear γ rays by the muon cascading down is an interesting phenomenon. A measured energy shift of the γ line is related to the change in the nuclear-charge radius in the excited state. Nuclear polarization by the muon may be studied. So far only strongly excited γ rays related to rotational levels have been observed. High muon intensities are needed to investigate weak excitation, e.g. levels in spherical nuclei.

6-9) These processes could be studied at present muon intensities, but such work is very tedious -- such as the check on the vacuum polarization of the muon, which is very important. The knowledge of the cascade process of the muon is necessary for the measurement of transition intensities in pionic atoms. The capture γ rays yield information on how the excited nucleus decays. The investigation of the X rays in various chemical compounds will open a new field in the physics of condensed matter. All these studies will very soon come to a point where higher intensities are essential.

B) π mesons

1) π-nucleus interaction.
2) Nuclear-structure effects, pair correlations.
3) Hyperfine effects.
4) Excitation of the nucleus after pion capture.

Pionic atoms have been much less investigated than muonic atoms.

1) The study of the π-nucleus interaction involves measurements of energy shifts, widths and yields of pionic transitions. Since the transitions with low yields show the greatest shifts and widths, it is clear that high beam intensities will facilitate accurate measurements, particularly when separated isotopes are needed.

2) The strong π-nucleus interaction is sensitive to the nucleon distribution and particularly to the pair correlation of nucleons in the nucleus. Individual nuclei should be studied (isotopes).

3) Hyperfine splitting in deformed nuclei may be observed and compared to the electric quadrupole splitting. In this case the highest possible resolution is necessary. Since small Ge detectors have better resolution than larger ones but, of course, a smaller detection efficiency, a higher beam intensity is definitely needed.

4) The γ rays emitted after pion capture may shed light on the π^- absorption process in nuclei. If the nuclear γ lines can be measured in coincidence with pionic X rays, information about the state from which the pion was captured is obtained. Such coincidence measurements need high intensities.

C) Conclusion

A number of important experiments, in particular those involving separated isotopes and weakly excited X or γ rays, are only feasible with higher intensities.

But also for the experiments which could be carried out at present intensities, the future programme on mesonic atoms will require machine times which cannot be provided by the CERN SC because of the demands made by many other experiments. Already now the machine time available for this field at four comparable cyclotrons in the United States is considerably higher than at CERN because of the lower pressure there.

It is hoped that the mesonic-atom programme will benefit strongly from the improvement of the SC facilities. These should provide not only the fully increased intensity for some experiments, but also a beam-sharing system giving partially increased intensity for longer running times in order to carry out a programme competitive with that at other laboratories.

STUDIES OF PIONIC X RAYS WITH A CRYSTAL SPECTROMETER

J. Rohlin

The main problem for pionic-X-ray studies by crystal diffraction is the inherently low efficiency of the diffraction spectrometer, which requires a large number of stopped pions per unit time.

The diffraction spectrometer built by the Chalmers team, Sweden, has a built-in flexibility which, to a certain extent, allows a choice of geometry according to the measuring conditions, i.e. essentially the beam geometry. The best solution with the present conditions at the SC seems to be to use the pion beam of the muon channel and the spectrometer in the Cauchois geometry (extended source, slit detector, favourable peak-to-background ratio). With this arrangement our tests with radioactive sources indicated that we require approximately a pion flux increased by a factor of thirty in order to be able to perform a good precision measurement (energy and line width) in a reasonable time (one transition in less than ten shifts). Another solution would be to increase the density of the present intensity (focusing the beam) by a factor of thirty over an area of about 10 × 80 (vertical) mm^2. An increase of the internal beam at the SC by a factor of ten would put us very close to acceptable measuring conditions at the muon channel; it might be possible to gain the remaining factor of 2 or 3 by a careful design of the measuring system -- shielding, collimators, crystals, etc. However, the experiment would still be a very marginal one.

An improved internal beam in connection with optimized secondary beams, as is indicated in the MSC proposal, might also give favourable measuring conditions at other beams in the neutron hall. The present difference between the channels does not seem to be very great, and a highly increased intensity together with a small momentum spread and good focusing properties may give good conditions for a diffraction spectrometer.

NUCLEAR-STRUCTURE STUDIES USING PROTONS AND OTHER PARTICLES AS PROBES

S. Kullander
G. Tibell

The recently completed nuclear-structure studies on the Brookhaven Cosmotron have clearly shown the usefulness of high-energy protons as probes of atomic nuclei. At lower energies, e.g. around 200 MeV, precision experiments yielding valuable results on nuclear structure have already been performed for some years. In connection with work at 1 GeV, new theories have been proposed by Glauber and others in order to explain the reaction mechanism. Since one knows already a great deal about the fundamental interaction (the nucleon-nucleon scattering amplitude), it is realistic to hope for very important information on purely nuclear effects from such experiments. In particular, it seems possible to learn more about nucleon correlations inside nuclei.

It is obvious that the extracted proton beam from the CERN SC would be an extremely powerful tool for nuclear-structure studies, if the accelerator were further improved according to the proposal submitted. With the high intensity, excellent duty cycle, and very good definition of geometry as well as energy it would be possible to perform precision experiments in a field which, so far, has been explored very little. It should also be noted that the external proton beam could be used for production of secondary beams of neutrons, pions, and muons. Beams of such particles would provide a very useful complementary means for probing nuclear structure.

Some examples of experiments will be given below, together with an indication of the particular importance in each case.

1) Nucleon-nucleon scattering experiments for more accurate data on the fundamental interaction.

2) Elastic and inelastic scattering of particles from complex nuclei. This class of experiments may lead to increased knowledge on nuclear correlation phenomena.

3) The study of knock-out reactions like (p,2p), $(\pi,\pi p)$, $(\mu,\mu p)$, etc. with simultaneous detection of both outgoing particles. At lower incoming particle energies one has already obtained very interesting results from such experiments. These results mainly concern shell-model aspects of nuclei, and with increasing energy of the incoming particle one would be able to penetrate more deeply into the nucleus for information on inner shells.

4) Studies of reactions like (p,pd) and $(p,p\alpha)$, where a nucleon cluster is knocked out by the incident particle. The results of such studies would yield information on clustering phenomena which is difficult to obtain at lower energies.

It is clear that the examples given above do not exhaust the list of important experiments which could be performed on an improved synchro-cyclotron. It should be stressed that the increase in beam intensity is vital for the success of such experiments, partly because of the low cross-sections for some of the reactions to be studied. Also, the high intensity would make it possible to improve on the precision in the determination of angle and energy.

BRIEF CONSIDERATIONS ON PROTON-NUCLEI MEASUREMENTS

P. Macq

The protons of the CERN SC have an associate wavelength of roughly 0.2 fermi. In elastic scattering one can obtain momentum transfers of several fermi^{-1}. We are thus typically in a clear region -- the one in which the Brookhaven Cosmotron worked during its last days -- where the probes used can explore the distribution of strongly-interacting matter (coherent scattering) and the nuclear structure (quasi-elastic scattering). A new impulse has been given to that kind of work by putting in parallel the Brookhaven results and the theoretical insights of Glauber.

A special effort in this kind of work is thus worth while and coupled with transfer reactions (p,X) could shed new light on the nuclear structure (shells $\rightleftarrows$ clusters $\rightleftarrows$ correlations, ...).

To be useful, such investigations have to explore a wide spectrum of nuclei and not only some "easy" cases. We must thus dispose of a high-resolution beam ($\Delta E/E < 1/600$), of high intensity to minimize multiple Coulomb scattering (thin target) and good angular definition: a good-quality beam is required.

Let us point out finally that the CERN SC is one of the very few machines in the world which could attack that kind of problems during the coming five years.

π-SCATTERING ON NUCLEI

R. Meunier, M. Spighel and J.P. Stroot

An improvement by a factor 10 of the SC internal beam current would help to start quantitative investigation of phenomena that have been barely explored. Double-charge-exchange scattering of pions is a particular example. Our first experiments on this process had to be made with a large momentum bite because of low intensity. It would now be desirable to measure individual $\Delta I = 2$ transitions, for instance, for which double charge exchange is a rather unique tool.

Nevertheless, intensity is not the only SC improvement relevant to π-nuclear scattering physics. Reshimming of the SC main magnet would not cost much and should bring the maximum energy of the protons to a higher value and decrease the fringing field to be traversed by particles emitted from an internal target. It would allow a more complete coverage of the $(3/2, 3/2)$ π-nucleon resonance energy range that will remain a unique feature of this machine in Europe. It also extends the range of π^+ energy in order to make possible the desirable π^- and π^+ scattering comparisons over as large a domain as possible. It would also decrease the low-momentum cut-off which would provide adequate coverage for comparison with results at other machines.

These two improvements, intensity and magnetic field, together with the best efforts to achieve a maximum duty cycle (a condition that becomes more and more stringent when intensity is increased) would extend considerably the scope of experiments being done at present. A quantitative study of elastic and inelastic scattering of π^- on light nuclei has just been started. Present conditions will permit a rather comprehensive survey of elastic scattering including the important features of Coulomb-nuclear interferences (to measure the real part of the scattering amplitude with the view to testing nuclear dispersion relations) and that of good measurement of the second maximum in elastic angular distributions. The field including inelastic scattering is so large that more intensity would, in any case, help data-taking. However, it is still almost impossible with the present conditions to study many individual processes in which it is desirable to measure more than one emitted particle, such as, for instance, when the excitation in the recoil nucleus is large enough for it to decay by particle emission. This is the case with possible I = 2 excited levels. Also some preliminary measurements of γ-ray spectra emitted from pion bombardment of light nuclei, made by us two years ago, are rich in unidentified transitions that should be investigated and identified for their interest for nuclear structure. Successful tests have also been accomplished with our set-up for the measurement of forward emitted protons in a CH_2 target. The peak of protons that corresponds to backward π scattering on the hydrogen nuclei is well identified. Similar quasi-elastic processes on the C nuclei, if present, need more beam intensity.

Finally, as mentioned earlier, one would try very much to make a detailed investigation of double charge exchange. With the proposed improvements it would nevertheless still only be possible to make a limited number of measurements due to the low cross-section for this process.

THE RADIATIVE CAPTURE OF STOPPED π^- MESONS IN NUCLEI

Č. Župančič

Delorme and Ericson have pointed out that the radiative capture of stopped π^- mesons in nuclei should feed the giant resonance supermultiplet by a theoretically rather well-understood mechanism. Therefore, the high-resolution study of high-energy γ spectra from stopped π^- mesons in nuclei should be of great interest for nuclear physics. Using NaI detectors, Davies, Muirhead and Woulds have measured these high-energy γ rays and determined that their yield was of the order of a few per cent per stopped π^-. Of course, their resolution was too poor to detect any details of the spectra.

Nowadays, magnetic pair spectrometers with an acceptance (including solid angle for γ rays) of the order of 10^{-5} and a resolution of the order of 1% can be built. With the present SC the measurement of a spectrum for one element with reasonable statistics (about 4000 events) would require of the order of ten data-taking shifts. For a reasonable survey, such as is desirable in nuclear physics, this seems prohibitive. An improved SC would enable the measurement of one element per shift and make a survey feasible. Also, in especially interesting cases, smaller quantities of separated isotopes could be used as targets.

EFFECT OF AN INTENSITY INCREASE ON (π, 2N) REACTIONS

G. Charpak

1) The (π^+,2p) reactions

Our recent work on (π^+,2p) reactions in ^{12}C, ^{14}N, and ^{16}O has shown that nuclear-structure effects play a major role in the relative population of the excited levels of the residual nuclei. The attached figure shows the comparison of our results (experimental points) with the theoretical predictions of Kopaleishvili et al., when we fold our resolution of ~ 5 MeV into the predicted level scheme.

It is clear that for the (π^+,2p) reactions to become useful for a check of the refined theory it is essential to bring the resolution to the level of 1 MeV. This is obtained routinely in the (p,2p) experiments where the energy of the protons is measured with magnetic spectrometers. With large volumes of magnetic fields and wire chambers, magnetic analysis of the spectra would also be possible now, but the higher the intensity, the smaller can be the acceptance, the smaller and cheaper the magnets.

2) The (π^-,pn) and (π^-,nn) reactions

When neutrons are produced, the energy is measured by time-of-flight techniques. An increase by a factor 10 of the intensities allows an increase by a factor of 3 in the path length and an improvement by the same factor in the resolution. The resolutions reached up till now by Cernigoi (~ 10 MeV) do not allow any precise comparison with the theoretical predictions for most of the light nuclei.

THE ISOLDE ISOTOPE-SEPARATOR PROJECT

A. Kjelberg

The ISOLDE project will investigate a large number of neutron-deficient nuclides (half-life well below 1 hour), hitherto not accessible for studies. The project has encountered great interest, and the accommodation of ISOLDE-type experiments is being considered in Dubna (both for the SC and the heavy-ion accelerator), and for the meson factories in Zurich and at Los Alamos.

The ISOLDE project was initiated assuming the availability of an external proton beam of about 0.1 μA at the target position. It was estimated that if the production cross-section was not far below 1 mb, isotopically pure samples could be obtained, strong enough to allow sophisticated spectroscopic studies, at least of nuclides having half-lives of a minute or more. This would, however, require the use of quite large amounts of target material.

As the facility is still some time from operation, we have only the results of off-line studies and the experience from the Orsay group's on-line studies with the 150-MeV SC as a base for our present judgement, namely that there will be a considerable number of nuclides accessible, and also that the limitation for the facility will primarily be low cross-sections for nuclides very far from stability, and not short half-lives. In principle, this can be overcome in two ways: in some cases by using higher energy; but more generally through higher intensity of the proton beam. Higher intensity will not only give better statistics when studying the nuclides farthest from stability (i.e. those with the lowest cross-sections and shortest half-lives), but also the purity of the samples may be improved by various means, one of which is a reduction in the target size.

A reduction of the target size automatically takes care of the worry expressed by Brianti (MSC/25/545, p. 12) that activation of the ISOLDE target would become a problem with the planned increase of intensity of the external beam. A considerable effort has already been made to reduce the radiation exposure of personnel by building remote-controlled handling equipment for the exposed ISOLDE target, possibly enough to handle this problem also in the future.

The ISOLDE facility integrates the proton flux because the diffusion time of the product in general is much larger than the repetition rate of the SC. Special beam qualities, except for intensity and focalization properties, are therefore of little importance. Energy resolution will also be rather unimportant. We do not at present expect that the increased repetition rate will inconvenience us.

Evidently an increase in proton-beam intensity makes available for study nuclides farther away from stability. This is important for the following problems:

a) Nuclear mass surface: Knowledge of the mass surface is of primary interest in a variety of problems, such as nuclear-reaction theories and astrophysical applications. At present, such knowledge is limited to regions close to stability, which necessitates extrapolations via mass formulae.

b) Delayed neutron emission: The regions of delayed proton emission and of delayed α emission are far out on the neutron-deficient side of stability. At present very little information is available on cross-sections and properties of such nuclei in the medium-mass ($A \approx 100$) region, but even now the most favourable cases should be marginally observable with ISOLDE.

c) Deformed nuclei: A new region of deformed nuclides has recently been predicted between the 50 and 82 nucleon shells, on the neutron-deficient side of the beta stability line. Only a few of these nuclides have been accessible for study so far.

d) Source of doubly magic nuclides $^{56}_{28}$Ni and $^{100}_{50}$Sn: Levels in ^{56}Ni have never been obtained, and ^{100}Sn has not even been identified. Cases like these have great theoretical interest, and a considerable effort will be made to study them.

Particular reasons for having stronger samples, i.e. a proton beam of higher intensity, are:

a) All measurements will in general benefit from an increase in the source strength, as we expect that this will directly increase the signal-to-noise ratio.

b) New techniques could be feasible. A much-discussed example is the attachment of atomic-beam magnetic-resonance equipment for direct measurements of spins of radioactive nuclides. It has been estimated that an increase of the proton-beam intensity by a factor of 10 will be sufficient in favourable cases. Results of such measurements would be very welcome as calibration points for general spin assignments of nuclear levels.

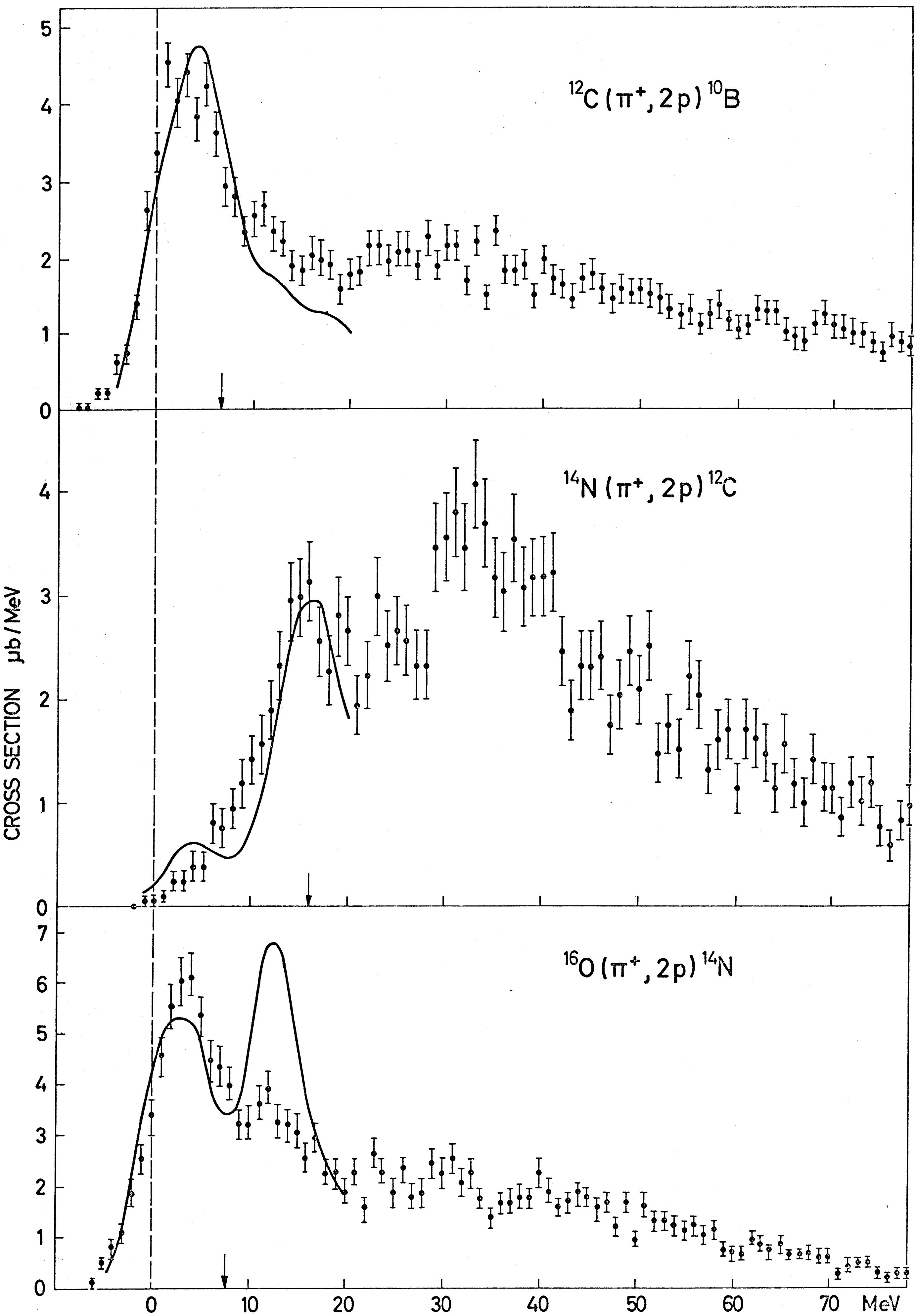
Complementary programme and general nuclear-chemistry irradiations

A considerable amount of the SC time used by the NC group and its visitors is for the complementary programme, i.e. for nuclear-spectroscopy studies off-line with the equipment available in the NC group, and with ISOLDE equipment in general. This spectroscopy work generally requires stronger samples than nuclear-reaction studies, and an increase of the internal beam will therefore be very valuable.

An increased external-beam intensity will also benefit nuclear-reaction studies where counter techniques are used. Specific projects, such as angular-distribution studies of fragmentation products, have been mentioned by outside users.

Conclusion

From the point of view of the ISOLDE project an increase of the intensity of the external beam would be strongly encouraged, as it will generally increase the fields of study where the instrumentation is suitable. We should gladly accept the inconvenience of a six-month shut-down in 1970 as a price to pay.


$^{12}C(\pi^+,2p)^{10}B$
$^{14}N(\pi^+,2p)^{12}C$
$^{16}O(\pi^+,2p)^{14}N$
CROSS SECTION μb / MeV
EXCITATION ENERGY
0
10
20
30
40
50
60
70
MeV
0
1
2
3
4
5
6
7

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