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AGS II*

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ABSTRACT

Interest in rare K decays, neutrino oscillations and other fields have generated an increasing demand for running, and improved intensity and duty cycle, at the AGS. Current projects include acceleration of polarized protons and light ions (up to mass 32). Future plans are for a booster to increase intensity and allow heavy ions (up to mass 200), and a stretcher to give 100% duty cycle. A later upgrade could yield an average current of 32 μ amps.

1. AGS PERFORMANCE

The AGS, a 30 GeV fixed target proton accelerator, has been operating now for more than 20 years, yet its performance and its physics program are by no means static. Both the average and the peak intensity in protons per pulse have been recently increased by approximately 60% (see Fig. 1b). This combined with an increased number of weeks of running per year has produced an even greater increase in the total number of protons accelerated per year (Fig. 1a). Perhaps more surprising, however, is the increase in the number of experimenters, institutions, and individual experiments that are currently running on the accelerator (see Fig. 2). These increases may reflect a lack of opportunities at other facilities, but also reflect a vital interest in the physics that can be done in this energy region. In an attempt to find out whether this was a long term trend implying a long term need for the AGS, the management asked the users organization to hold a user task force to study the question.

2. "AGS II" USER TASK FORCE

This task force met between November of 1983 and January of 1984, and produced a major report in February of 1984. The physics experiments both current and future at the machine were studied in great detail as well as possible improvements in the operation and in the facility. In the physics conclusion, special emphasis was given to the rare kaon decay experiments which were described as "an extraordinary opportunity for frontier physics". Neutrino interactions, oscillations and muon studies were described as offering a "unique opportunity for high quality forefront research". In addition, the report concluded that the intense hadron beams, polarized protons, and unique intermediate kaon beams at the AGS allowed "detailed studies of QCD, exploration of exotic atoms, dibaryons, and hypernuclei".

One may ask why the rare kaon decays were singled out for

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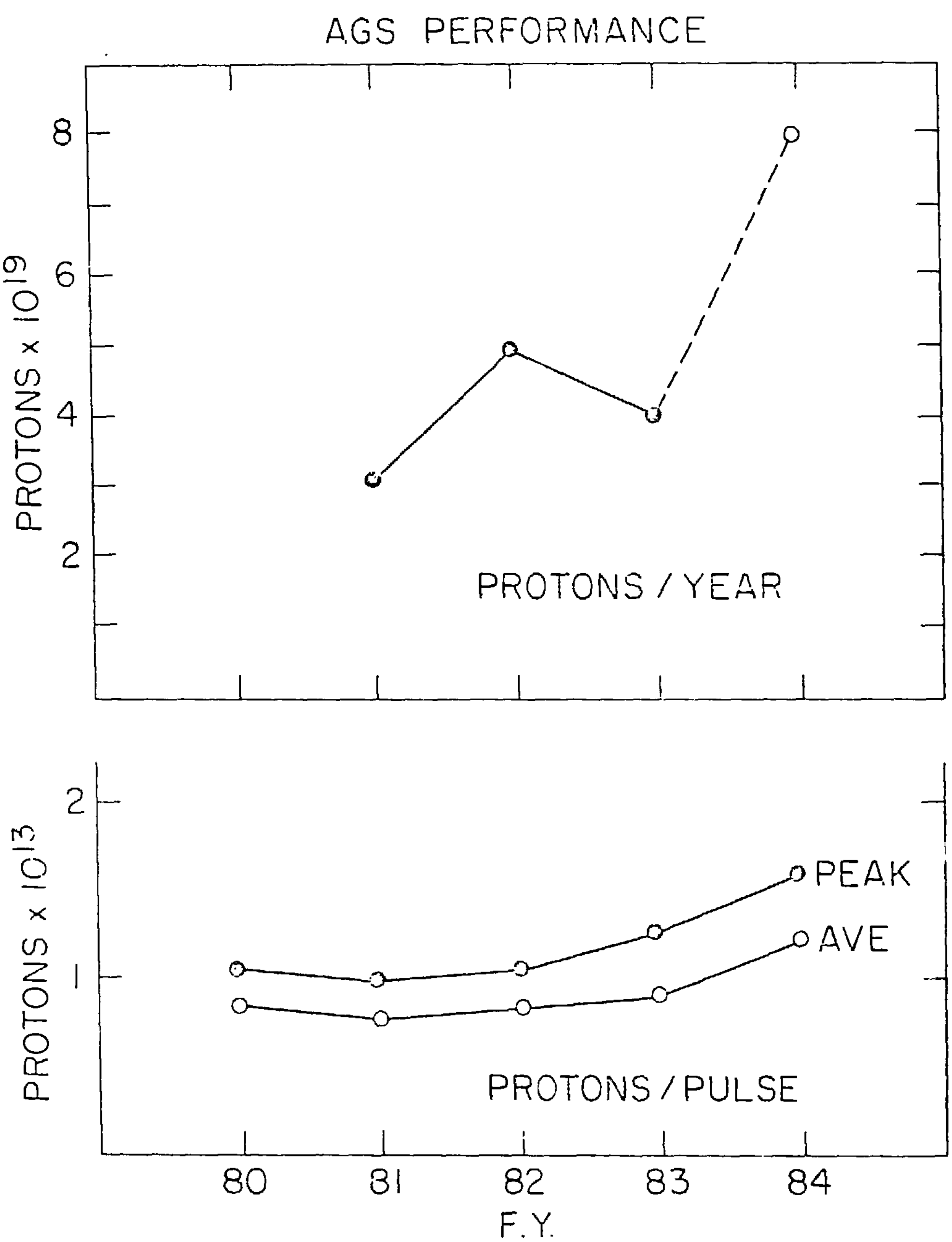

Fig. 1. ACS performance during the period 1980-1984.

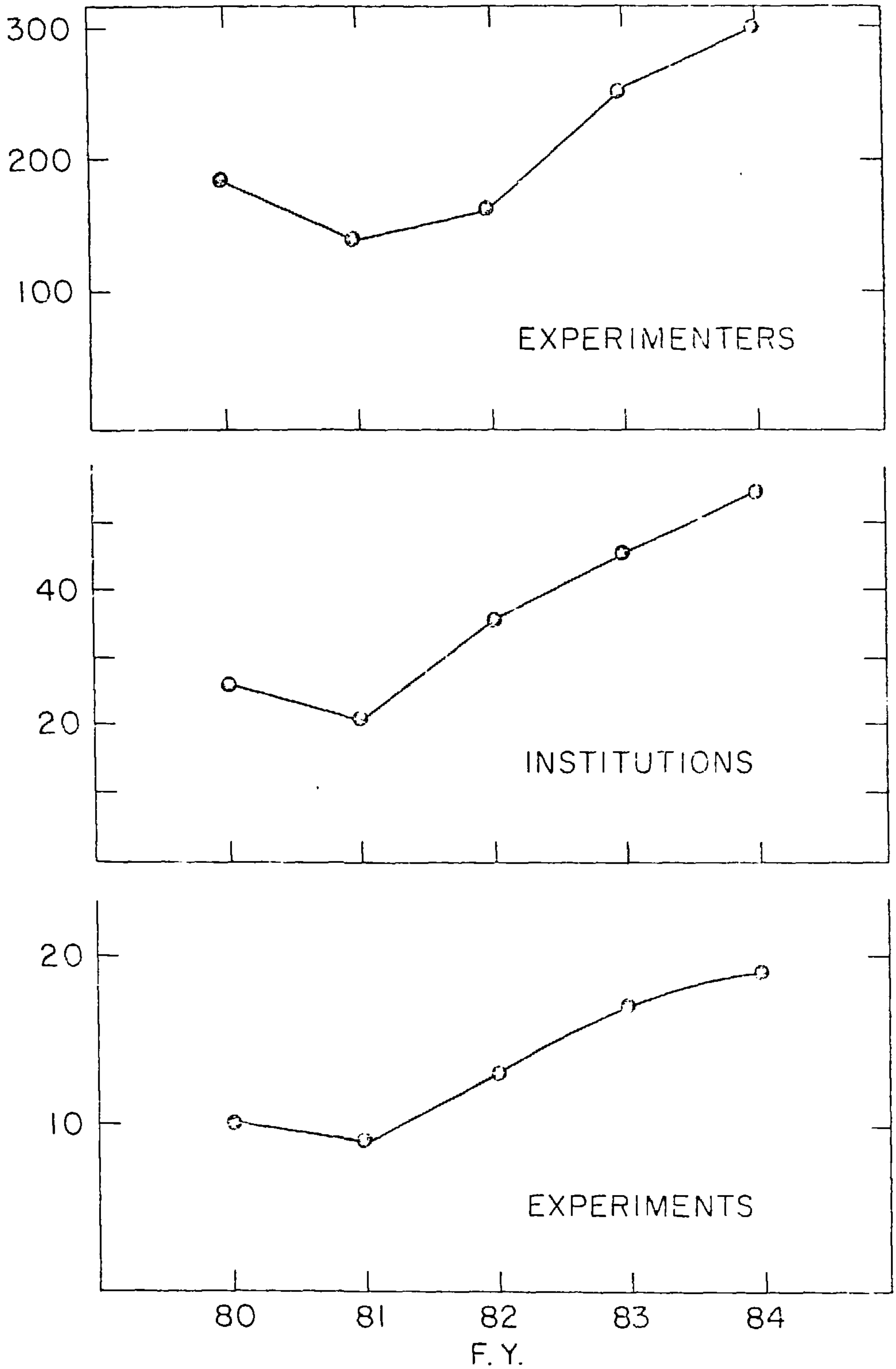

Fig. 2. ACS use during the period 1980-1984.

special mention. Kaons have been known and their decays studied for a long time. Nevertheless a recent strong interest in the search for particularly rare decays has arisen. Various decays were discussed in the Task Force Report (see Table I). In each case, the decay is either strongly suppressed or forbidden by some particular selection rule. And again in each case, the decay might be expected to proceed at a higher rate if some new physics were present. A new technicolor particle that coupled quark flavor changing currents with lepton flavor changing currents could have a mass as high as 100 TeV and still produce forbidden decays at a rate of the order of 10^{11}. In the Table the approximate exponent of the current branching ratio limit is given for each decay, together with the exponent that might be reached with currently proposed experiments and also the exponent that could be reached with upgraded experiments and AGS intensity, finally the approximate standard model prediction is given. It is seen that the current generation of experiments at the AGS should be able to lower the branching ratio limit by a factor of about 10^3 and that future experiments could increase this to 10^5. These searches could reveal a wide range of new physics as indicated in the table.

Table I. Rare K Decays

		BR = 10^{-N}			
		Now	Proposed	Possible	Standard Model
$K_L^0 \to \pi^0 e^+ e^-$	CP Test K-M	5	9	12	11
$K^+ \to \mu^+ \nu_H$	Heavy ν	6	7	10	–
$K^+ \to \pi^+ X^0$	Axion Higgs Familon				– – –
$K^+ \to \pi^+ \nu\bar{\nu}$	2nd order weak new flavors	7	9	11	10
$K_L^0 \to \mu e$	Technicolor	8	11	13	–
$K^+ \to \pi^+ \mu^+ e^-$	Technicolor	8	11	13	–

The second area of physics picked out by the Task Force for special mention was that of neutrino interactions, oscillations, and muon studies. The neutrino oscillation studies are in fact somewhat complimentary to the rare K decay: $K \to \mu e$. In both cases the fundamental concept of mixing between the lepton flavors is being investigated. In Fig. 3 we examine one particular case: that of muon neutrinos mixing into electron neutrinos. The relevant parameters are the mass difference between the two neutrinos which might be expected to be of the order of an electron volt, and the $\sin^2$ of the mixing angle θ, which if it were similar to those encountered in quark mixing might be expected to be of the order of 10^{-2}. The figure shows the current limits together with an estimation of what might be possible with an improved AGS. As in the case of the rare K decays, a large improvement is seen to be possible.

As a result of the consideration of these physics topics and the many others that were studied, the Task Force came up with recommendations for improvement of the AGS facilities.

1) It was implicit that the Task Force concluded that a useful physics program should extend beyond five years unless and until an alternative facility in this energy range is built.

2) The Task Force concluded that the operating reliability of the AGS should be improved.

3) The Task Force concluded that the intensity of the AGS should be improved by a combination of a stretcher, which would allow a higher repetition rate, and a booster, which would increase the number of protons per pulse.

4) They concluded that the duty cycle should be improved both by attention to the operation of the slow extracted beam and by the construction of a stretcher ring in the AGS tunnel.

(In fact the Task Force suggested that a stretcher might be constructed first, followed by a booster and AGS improvements).

In response to these Task Force conclusions, Brookhaven management has come up with a long term plan for the AGS. This plan follows in spirit the AGS users task force although it differs in detail partly in response to the needs of the heavy ion program (not covered by the Task Force), and partly as a result of more detailed technical study of the booster possibility.

3. AGS PLANS

Ongoing

Presently nearing completion are the modifications to the AGS to allow polarized protons to be injected and accelerated to of the order of 20 GeV. This program is nearing completion with successful operation of the polarized proton source, the RFQ, acceleration through the linac, injection into the AGS and resonance jumping during acceleration up to about 12 GeV. This program should be completed this summer.

A project currently just starting is to construct a transfer line from the Tandem Van de Graaff to the AGS which will allow the injection and acceleration of heavy ions of mass up to 32 (sulphur) in the AGS. This project should be completed in fiscal year 1986.

Planned

The new long term construction plan would envisage building a booster in the 1986 and 1987 fiscal years, and following this with the construction of a stretcher in the fiscal years 1988 and 1989. The booster envisaged in this plan has a somewhat reduced capability compared with that proposed in the task force, but would be expected to increase the proton intensity per pulse from its current value of around $1.2\ 10^{13}$ to $5\ 10^{13}$. Such an increase should not require any modification to the AGS vacuum or rf systems.

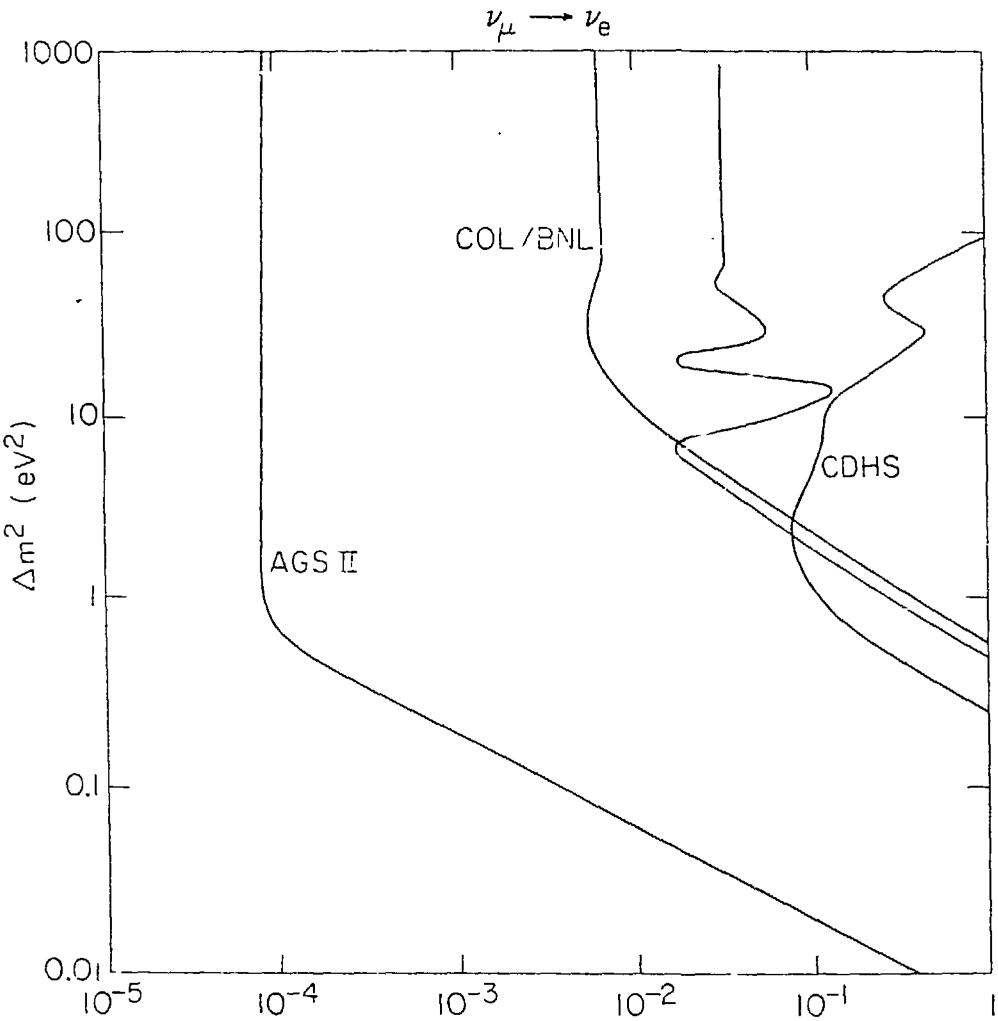

Fig. 3. Limits on the ν mass difference and mixing angles for $\nu_\mu \to \nu_e$ oscillations.

The stretcher would not increase the number of protons per pulse, but would allow a nearly continuous slow beam while the AGS is used only to accelerate and transfer particles into the stretcher. In this way the AGS would be able to cycle at least a factor of 2 faster and with some electrical modifications possibly a factor of 3 faster, thus increasing the proton intensity per second by a factor of 2 or 3.

Possibility

The Lab will keep in mind the possibility of upgrading the booster to allow injection at 2.5 GeV instead of 1 GeV which would allow the injection of up to 1.4 10^{14} protons per pulse into the AGS. In order to accelerate this number of protons, significant modifications would be required in the AGS vacuum, rf systems, and beam shielding. These modifications would be expensive and no immediate plans have been made to propose them. They are presented here primarily because the resulting proton current of 32 microamps is comparable to the currents in proposed kaon factories. The cost of implementing such an upgrade, although high, is certainly less than that to construct a new factory.

4. THE BOOSTER

Table II gives the main parameters of the proposed booster. Its circumference is one quarter of the AGS. As a booster, its magnets would cycle at a 10 Hz repetition rate up to a peak field of 4 kG corresponding to a proton energy of 1000 MeV. For heavy ions, the repetition rate would be lowered to 1 Hz, but the field would rise to 12 kG.

Table II. Accumulator/Booster Cost Summary

		($1986) x 1000
Conventional Construction		1,730
Accelerator Systems		11,500
Magnets	4,720	
Vacuum	1,790	
Cooling & Bussing	150	
Controls	1,640	
Rf	1,950	
Power Supply	1,250	
EDIA (15% Conventional, 20% Technical		2,560
Contingency (15% Overall)		2,370
Total		18,160

This booster has 3 purposes and 3 corresponding modes of operation.

1) To boost the AGS proton intensity.

By injecting into the AGS at 1 GeV instead of 200 MeV the space charge limit in the AGS should be reached with four times the number of protons, i.e. at 5 10^{13}. The space charge limit of the booster at injection into the booster is approximately twice that of the AGS. Thus two cycles of the booster would be required to attain the factor of 4 in overall current capability. In fact as many as four cycles will probably be used.

2) Heavy ion injection. To allow the stripping and acceleration of ions up to mass 200 in the AGS. Using the Van de Graaff energy, the highest mass that can be fully stripped is approximately 32 (sulfur). Higher masses such as gold are only approximately 50% stripped at this energy. Such partially stripped ions cannot be accelerated in the relatively poor vacuum of the AGS, but can be collected and stacked in the booster ring and subsequently accelerated to the booster ring maximum field. At this energy full stripping is performed and the particles are injected and subsequent accelerated in the AGS.

3) Polarized proton intensity improvement.

Stacking in the AGS of more than one linac pulse of polarized protons is not possible because of vacuum considerations. The booster, however, with its superior vacuum would allow multi pulse stacking up to say 20 pulses with a resulting 20 fold intensity increase.

The cost of the booster is summarized in Table II and is seen to total approximately $18M. It may be noted that this cost could be reduced by approximately $5M if the heavy ion option were not included. Figures 4 and 5 show the booster layout and a cross section of one dipole magnet.

We note that the currently approved experiments on the AGS if running simultaneously would require of the order of 3 10^{13} protons per pulse compared with the current average of 1.2 10^{13}. Further experiments will increase this beam requirement as new techniques allow the use of other beams. The need for the booster is thus urgent for even for the present program and its implementation will allow a significant range of new experimentation.

5. STRETCHER AND REPETITION RATE MODIFICATIONS

The stretcher would be a small aperture ring of fixed field magnets in the AGS tunnel placed somewhat higher than the present main AGS ring. Since with the stretcher the AGS would not be required to have a flat top, a modification can be made in the power supply wiring to allow a faster ramp of the main ring magnets. The design of the stretcher ring is only currently in the conceptual stage. As stated before it should allow a duty cycle of 100% and a repetition rate increase of approximately a factor of 3 coming from a reduction in the cycle time from 2.5 seconds to approximately .8 seconds. The intensity per second would thus be increased by this factor of 3. The cost estimate given by the Task Force is of the order of $20M, a

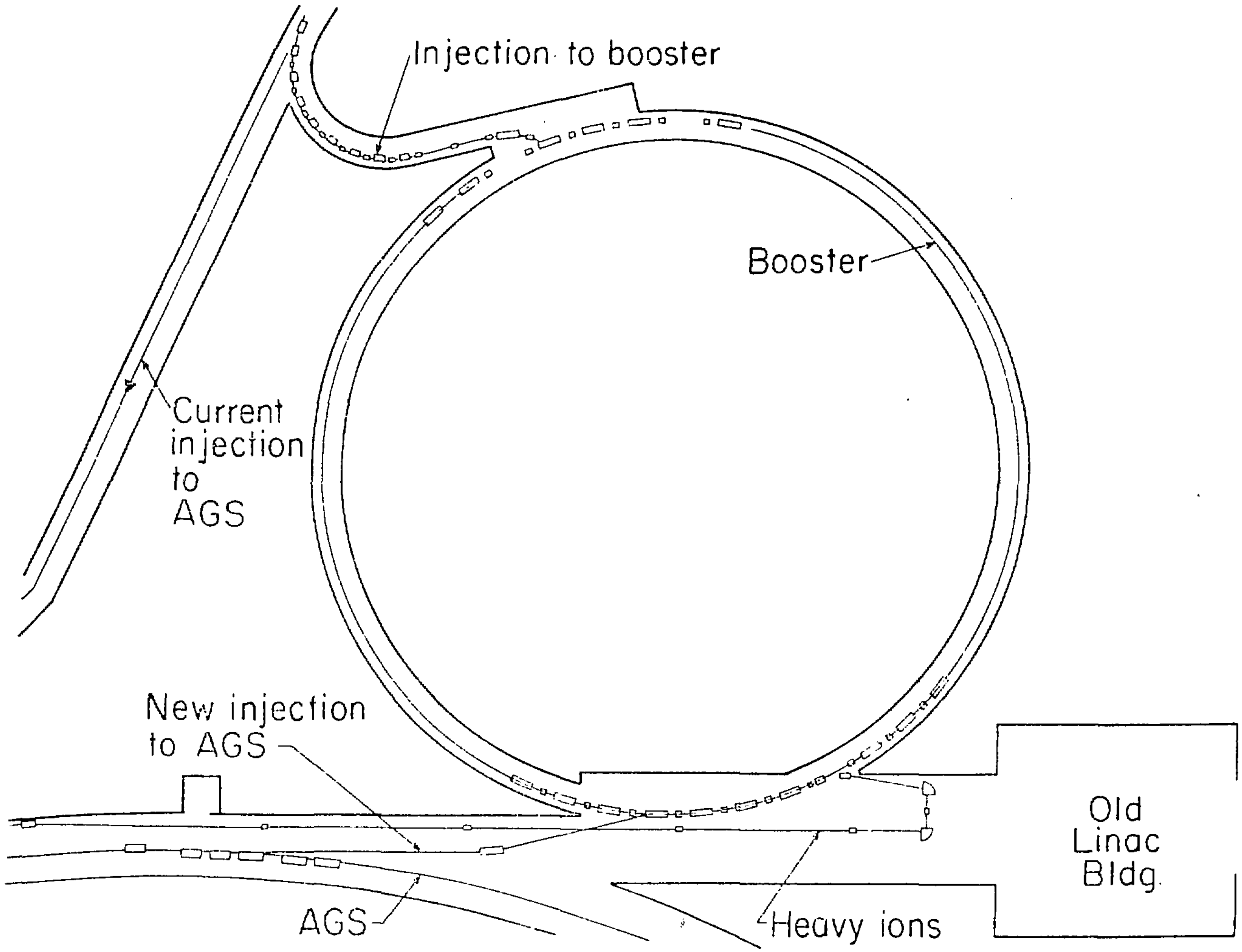

Fig. 4. Booster layout.

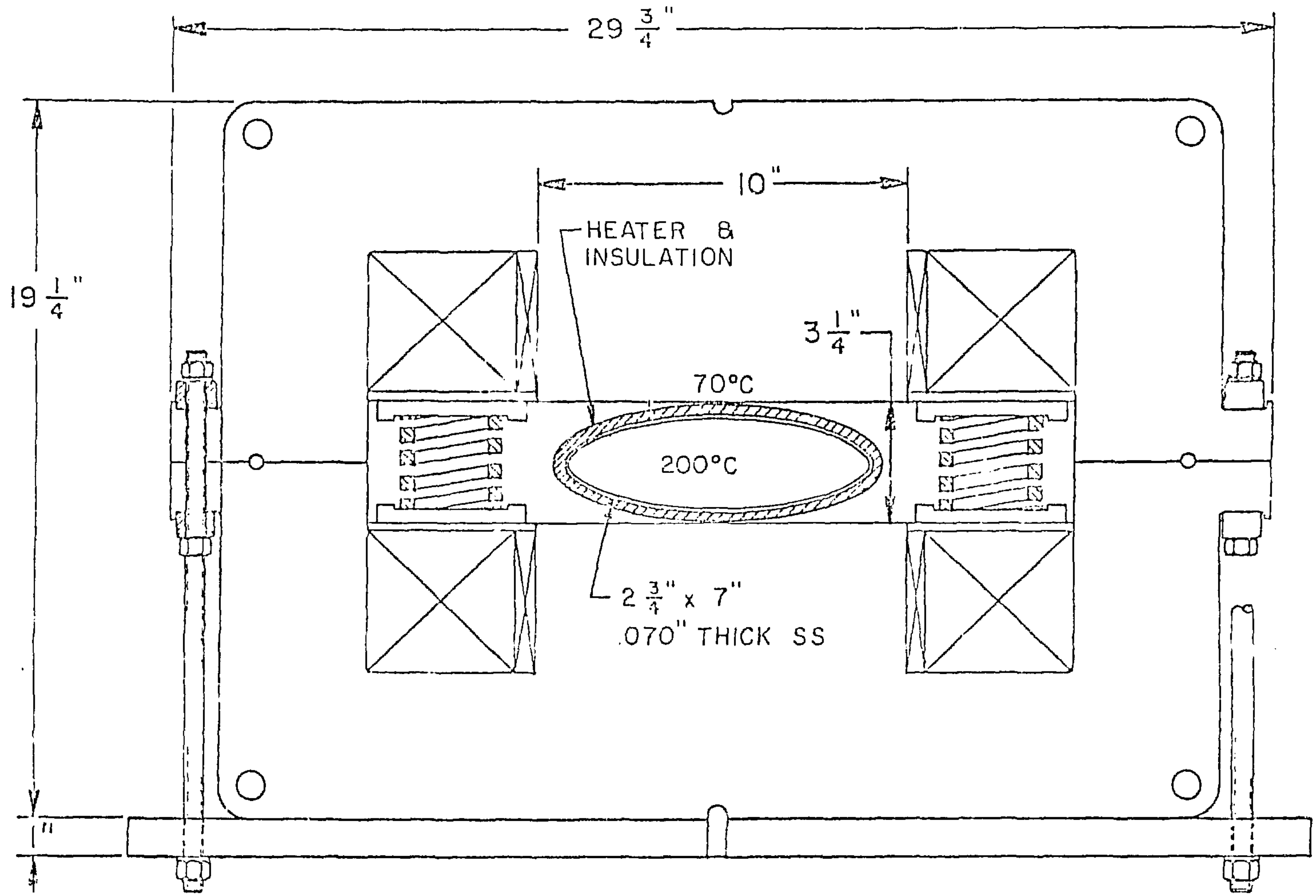

Fig. 5. Booster dipole magnet cross section.

a BNL estimate has not yet been made.

The need for a better duty cycle has been strongly stressed by the rare K decay experimentalists, and it appears likely that the ultimate limit in the rare K decay branching ratios may be set by the duty cycle. The stretcher is thus clearly desirable.

6. BOOSTER UPGRADE

As stated above, this is presented as a possibility and not as part of the AGS plans. The upgrade of the booster would involve an increase in the power supply to allow ten cycle operation to the full field and also an increase in the rf system to allow a more rapid acceleration of the high currents. The booster would then be operated to an energy of 2.5 GeV at which value the space charge limit in the AGS would be reached at eleven times the present current, or approximately 1.4 10^{14} protons per pulse. The cost estimate for these modifications is fairly well known at approximately $6M including EDIA and contingency.

In addition, however, improvements would be required to the AGS rf system and vacuum in order to handle the high current. The cost estimate for these modifications given by the Task Force is approximately $32M.

In addition the high currents would require significant upgrading of beam lines and extraction equipment the cost of which has not been estimated but is likely to be of the order of $50M.

If this final modification was made, the proton intensity would average 2 10^{14} per second or 32 microamps. Such a current would allow a full range of nuclear and medium energy physics as outlined in the various kaon factory proposals.

7. CONCLUSION

Figure 6 shows the AGS intensity per second as a function of fiscal year if all of the proposed plans were carried out. Such a plan shows a steady improvement in the available current and would allow a full exploration of the new fields of rare K decays, of the neutrino physics of oscillations, and of the wide range of nuclear and medium energy physics for which the AGS is unique in its energy range.

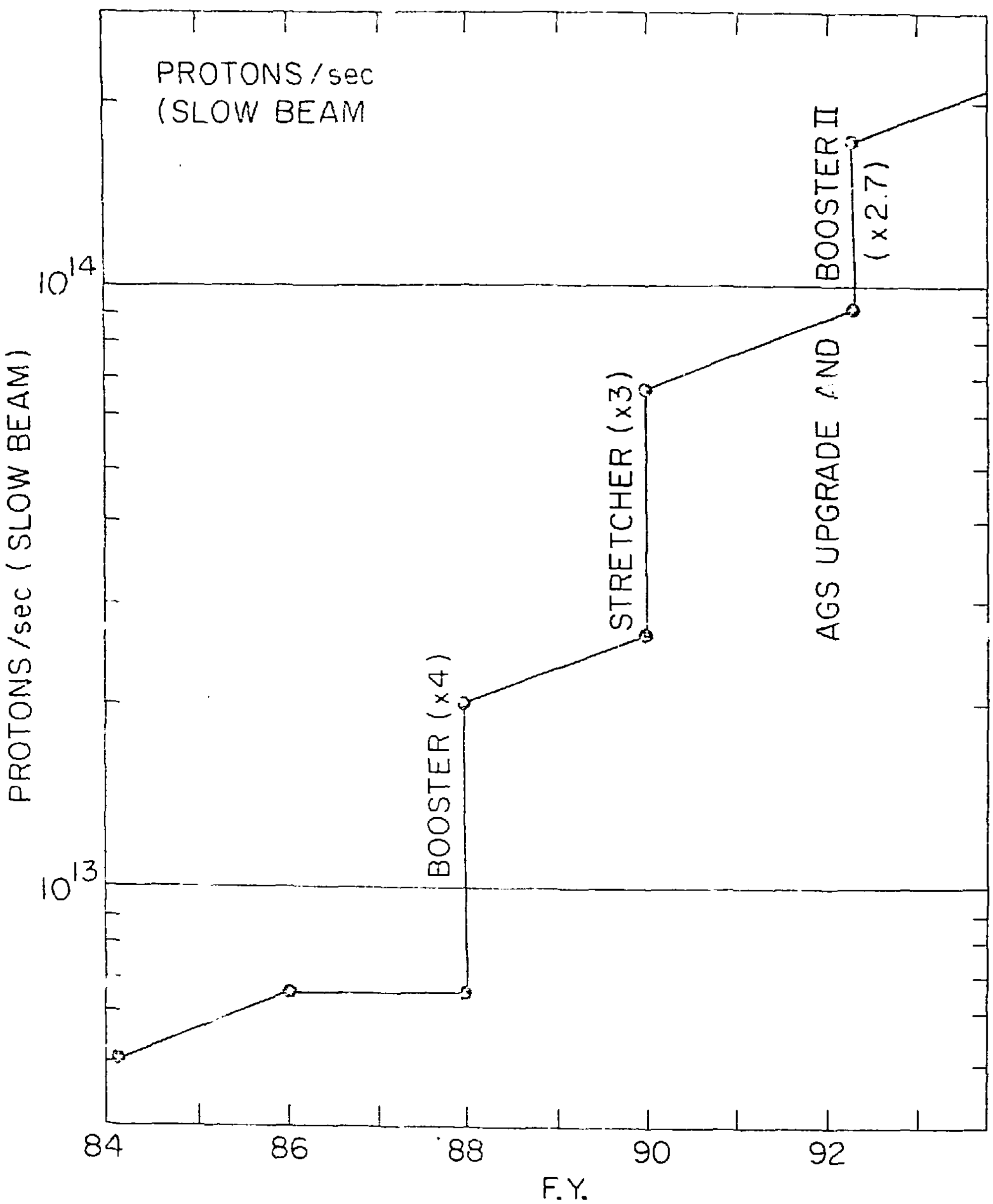

Fig. 6. AGS intensity as function of time if all plans were carried out.