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THE BNL AGS - A CONTEXT FOR KAON FACTORIES

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THE BNL AGS - A CONTEXT FOR KAON FACTORIES

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Figure 1 shows the Brookhaven site with the AGS-CBA complex highlighted. In this photograph the AGS is dwarfed by CBA and indeed during the past few years future plans for particle physics at BNL have been dominated by this enormous project. However, very recently interest in future physics use of the AGS has undergone a strong revival. Indeed, since the beginning of this year, two projects for augmenting the AGS have been proposed.^{1,2} Such projects could keep the AGS viable as a research machine for many years to come. In general such schemes will also improve the performance and increase the versatility of the CBA, and so are doubly valuable.

It should be kept in mind that in spite of the fact the AGS has been perhaps the most fruitful machine in the history of high energy physics,³ its full capacities have never been exploited. Even without improvements its usefulness as a source of new physics can be expected to continue for several years. At present it routinely produces 10^{13} protons/pulse in either slow extracted (one 1-sec spill every 2.4 seconds) or fast extracted (12 20-nsec bursts separated by 220 nsec every 1.5 seconds) mode. It is normally run at 28 GeV although its energy can be more or less continuously varied from 32 down to 1.5 GeV/c. In slow extracted mode the beam is shared by as many as 8 experiments and 2 test beams (see Figure 2). Table 1 lists the currently available beams. The capability for acceleration of polarized protons will soon be added. Table 2 gives a summary of the experiments serviced over the last few years. Table 3 gives a breakup by subject of recent and proposed experiments. These experiments constitute quite a rich and varied program. I will discuss some of them individually a little later on. First, I have a couple of points to make about the economics of operating an accelerator in this energy range. Figure 3 shows physics output of the AGS (measured in experiment-weeks) versus operating cost in constant dollars. Note, that in recent years, this has been in the region of \$30 M. This is a much higher figure than one often sees quoted as the operating cost of a kaon factory--which after all should be more expensive than the AGS to run. For \$10 M one gets no physics at all, and there is a break in the slope at about \$25 M. After this point one gets incrementally quite a bit more physics per dollar. Now although you and I think the sort of physics done at the AGS is exciting and important, someone influential has reservations because the most recent operating budgets have allowed < 50% utilization of the machine. This is true in spite of the fact that we are operating on the steep part of the curve, where your dollar buys you most.

Next I want to discuss how well the AGS is doing at the kind of physics one would build a kaon factory to pursue. The area in which

Fig. 1. Brookhaven site with AGS-CBA complex highlighted.

Fig. 2

Fig. 3. Physics output in experiment weeks vs ACS operating budget in FY 1983 dollars.

BNL BEAMS OPERATIONAL
January 1983

Separated Beams for General Use									
Beam	Gap/c	2ap/p (%)	Pred Angle	α (mrad)	θ^*	θ^*	θ^*	θ^*	Remarks
B4	1.5-6(K) 1.5-9(p)	3	3°	0.3	270	120	2×10^{-6}	100	Usually 2×10^{12} ppp; L = 81 m. Usually 2×10^{12} ppp; L = 15 m.
(22, C4)	≤ 1.1	2	10.5°	2.6	40	12	2×10^{-6}	2	Usually 2×10^{12} ppp; L = 15 m.
(56, C6)	≤ 0.8	2.5	5°	15.0	200	60	1.4×10^{-5}	14	Usually 2×10^{12} ppp; L = 15 m.

Separated Beams for Fixed Facilities (Same Characteristics as B4)									
Unseparated Charged Beams for General Use									
Beam	Gap/c	2ap/p (%)	Pred Angle	α (mrad)	θ^*	θ^*	θ^*	θ^*	Remarks
B1	5-24	3	0°	0.3	2500	700	1.5×10^{-5}	200	Usually 2×10^{12} ppp; L = 75 m.
C1	5-24	5	0°	0.8	900	400	3×10^{-5}	30	Usually 2×10^{12} ppp; L = 61 m.

Unseparated Charged Beams for Fixed Facilities									
Beam	Gap/c	2ap/p (%)	Pred Angle	α (mrad)	θ^*	θ^*	θ^*	θ^*	Remarks
A1	5-24	1.5	0°	0.2					ppp; L = 130 m; 10^{12} ppp; 25 cm beam target

Neutral Beams for General Use									
Beam	Gap/c	2ap/p (%)	Pred Angle	α (mrad)	θ^*	θ^*	θ^*	θ^*	Remarks
A3	1-28		0°	0.0035				2000	$< 10^{12}$ ppp; alternates with A1; L = 8 m; design intensity 10^{16} ppp typical; L = 2.6 m; design intensity
B5	1-28		0°	0.01				3 $\times 10^5$	
Non Channel									
D2, D4	1-2.5 (c) 0.05-0.15 (u)		9 (c) 55 (u)	30 (c)				2000	Flux in 100 cm^2 with $40/p$ = $\pm 2\%$; design intensity
Neutral Beams for General Purpose use									
D									Fast emitt., flux avg. over 0.7 m^2 typical, peaks at 1.5 GeV/c

4A3 has been converted to a neutral beam for FY 1982.

TABLE I

TABLE 2

	FY80	FY81	FY82	FY83
AGS MANTEARS	359	314	278	270
AGS WEEKS	26	24	23	21
EXPERIMENTS SERVICED	10	9	13	17
NO. OF EXPERIMENTERS	181	142	168	251
NO. OF INSTITUTIONS	26	21	36	46

TABLE 3

EXPERIMENTAL TOPICS	
HADRON SPECTROSCOPY	13
HADRON DYNAMICS	7
SYMMETRY TESTS	7
DETAILED ELECTRO-WEAK INTS	6
HYPERNUCLEI	7
OTHER	3

the full capability of the AGS is most nearly exploited is that of ν physics. The entire internal beam is dumped on the ν target and the resulting horp-focussed decay beam impinges on a sophisticated 200 ton detector. This consists of a series of alternating layers of liquid scintillator hodoscopes and proportional drift tube banks (see Fig. 4 and Table 4). Aiming primarily at the processes

$\nu_\mu + e^- \rightarrow e^- + \nu_\mu$ and $\bar{\nu}_\mu + e^- \rightarrow e^- + \bar{\nu}_\mu$ its designers took pains to keep the fraction of inactive material in the detector to an absolute minimum. In this way they hope to be able to distinguish electron showers from the far more copious γ showers resulting from processes like $\nu_\mu + A \rightarrow \nu_\mu + \pi^0 + X$. How well this worked is illustrated dramatically by Figure 5 which gives the θ^2 distribution of events identified as electrons versus those identified as photons. There is a clear peak at $\theta^2 = 0$ in the 'electron' events as expected for νe elastic scatters, whereas the 'photon' events have no such structure.

Next we move on to a pair of recently approved K decay proposals. I will be brief about these since proponents of each of them are present at the conference and are available to discuss them in detail. Both experiments search for possible lepton flavor violations: E780⁶ will probe $K_L^0 \rightarrow \mu e$ to $< 10^{-10}$ and E777⁷ will probe $K^+ \rightarrow \pi^+ e^+ \mu^+$ to 10^{-11} . The E780 apparatus is shown schematically in Figure 6. A beam of 2×10^7 K_L^0 (and 6×10^8 neutrons) impinges on a drift chamber spectrometer. About 1% of the K_L^0 decay in the drift zone and about 10% of the two body decays are accepted by the spectrometer. In a 1000 hr experiment this allows them to get beyond 10^{-10} in statistical sensitivity. Of course, to justify this, the background rejection must be commensurate. Electrons are identified by a segmented hydrogen Cerenkov counter and a lead glass hodoscope. Muons are distinguished from π 's by means of a hadron filter. In this experiment particle identification is of limited value because the main background arises from $K_L^0 \rightarrow \pi e \nu$ decay in which the π subsequently decays to a μ somewhere in the apparatus. Although the the apparatus has been made as short as possible to minimize this, once such a decay has occurred the only recourse is to kinematics. Therefore, great stress is placed upon resolution. The $K_L^0 \rightarrow \mu e$ is generally a 3-c fit since one knows the incoming K_L^0 direction. In addition there is a vertex constraint and consistency checks given by redundant chambers. Since one is shooting for a unique point in the parameter space given by the kinematic, vertex, and other constraints, whereas the background is smoothly distributed in this space, the better the resolution, the smaller the target region and consequently the smaller the contamination. Crudely one tends to gain as a power $n > 2$ of the spatial resolution of the chambers. However, at a certain point, multiple Coulomb scattering in the chambers make further gains in resolution almost impossible. This point seems to be reached at a contamination level of about 10^{-11} according to the proponents of E780.⁸ As their spectrometer will be operating with very nearly this optimal

Fig. 4. The BNL ν detector.

Fig. 5. Preliminary data from Experiment 734. Distributions in the quantity θ^2 for single shower events: a) Events in which the shower was identified as an electron, b) events in which the shower was identified as a photon, c) control sample photon events.

TABLE 4

BROOKHAVEN NEUTRINO DETECTOR

LOCATION	Brookhaven National Laboratory, Upton, NY 11973
INCIDENT BEAM	Neutrino, Horn Focussed from 28 GeV Protons 110m from proton target
ASSEMBLY	Modular construction; each module consisting of a plane of calorimeter and two planes (x,y) of tracking proportional drift tubes 112 Modules + γ-Catcher + Spectrometer Weight 172 + 30 metric tons

MODULE PROPERTIES

CALORIMETER (LIQUID SCINTILLATOR)

Active Area $4.22 \times 4.09 \text{ m}^2$ Thickness 7.9 cm
Weight (Liquid & Acrylic) 1.35 metric tons
16 cells/module 2 Amperex 2212A phototubes/cell
1 Pulse Height Measurement/2 Time Measurements Per Tube Readout

PROPORTIONAL TUBES (PDT)

Active Area $4.2 \times 4.2 \text{ m}^2$
Thickness (x and y) 7.6 cm 54 x wires 54 y wires
1 Pulse Height Measurement/2 Time Measurements Per Wire Readout

GAMMA CATCHER 10 standard calorimeter modules with 1 radiation length of lead between each module
30 metric tons target mass.

MUON SPECTROMETER

2m x 2m Aperture Muon Spectrometer

$\langle \beta \text{ Bdl} \rangle = 70 \text{ MeV/c}$

$(\Delta p/p)^2 = (.10^2 + (.067p)^2) p \text{ in GeV/c}$

resolution they expect to reach the 10^{-10} level fairly easily. The experiment is also sensitive to $K_L^0 \rightarrow \mu^+\mu^-$ and e^+e^- at about this level.

The E777 apparatus is shown in Figure 7. An unseparated 6 GeV/c beam is incident on a PWC spectrometer. There are again about 20 million K^+ , this time accompanied by $2.5 \times 10^8 \pi^+$, and 1.2×10^8 protons per spill. At the front end of the spectrometer is a pitching magnet to bend the K^+ decay products out of the intense beam and to separate them by charge. On the negative track side electrons are identified and heavy particles rejected by two H_2 Cerenkov counters and a lead glass hodoscope. On the positive side electrons will be rejected by two CO_2 or N_2 Cerenkov counters and more lead glass, whereas muons will be distinguished from pions via a hadron filter. This heavy artillery is motivated by the fact that in this experiment, unlike $K_L^0 \rightarrow \mu e$, a large background suppression through particle identification is possible. However, once again the final recourse is to kinematics so that good resolution is also essential. About 10% of the K^+ decay is in the drift region, and the acceptance for $K^+ \rightarrow \pi^+e^+\mu^+$ is about 10%. This yields an overall statistical sensitivity of 1 per 2×10^{11} in 10^6 pulses. Residual backgrounds are estimated to be at the few $\times 10^{-12}$ level, making a sensitivity of $\sim 10^{-11}$ feasible. The experiment may also be able to look at $K^+ \rightarrow \pi^+e^+\mu^+$, $\pi^0 \rightarrow e^+e^-$ and other interesting processes.

A third interesting K decay mode is $K^+ \rightarrow \pi^+\nu\bar{\nu}$. Although no proposal has been submitted, an experiment sensitive to this mode at the 10^{-9} level is being planned. A possible detector is sketched in Figure 8. One would attempt to stop about $10^5 K^+$ /pulse in a highly segmented 20 cm target. The full beam rate through this target would then be roughly a megacycle (mainly π^+). Charged decay products are momentum analyzed in a cylindrical drift chamber system inside a superconducting solenoid. Range and energy of the daughters are measured in a cylindrical scintillator array. Thus pions can be distinguished from muons by comparing range and momentum. In addition one detects the $\pi \rightarrow \mu e$ decay chain in the scintillator array. The main backgrounds come from the dominant $K^+ \rightarrow \mu\nu$ and $\pi^+\pi^0$ modes and from $K^+ \rightarrow \mu\nu\gamma$. Photon vetos surround the entire apparatus in an effort to suppress the latter two backgrounds. Since there is no unique kinematic signature for $K^+ \rightarrow \pi^+\nu\bar{\nu}$, background rejection is absolutely crucial. Two body decays such as $K^+ \rightarrow \pi^+ + \text{Familon}$ as proposed by Wilczek⁹ are quite a bit easier to detect. Although the apparatus as shown has a geometrical acceptance of $\sim 50\%$, and accepts 50% of the π^+ momentum spectrum, the overall detection efficiency is only $\sim 2\%$. This is due to a number of individually small or moderate losses (e.g., pions interacting before ranging out, pulse height and timing cuts on decaying particles etc.). Thus for 10^6 pulses at $10^5 K^+$ stops/pulse one gets to the 10^{-9} level. One could also study $K^+ \rightarrow \pi^+\gamma\gamma$, $K^+ \rightarrow \nu\bar{\nu}\text{heavy}$, etc., with this apparatus.

Fig. 6. Schematic of E780 apparatus.

APPARATUS - PLAN VIEW

Fig. 7. Schematic of E770 apparatus.

Fig. 8. Possible detector for $K^+ + \pi^+ \nu \bar{\nu}$.

Now I'd like to take up the subject of how far these sort of experiments might be taken at the AGS. It seems hard to increase the number of ν_μ events without increasing the primary beam intensity. In principle, with enough money and no competition from the slow beam program, one could run four or five times longer than has been the case in recent years. One could also think about making the detector larger (or adding more detectors). However, the present detector cost \$6 M and its builders feel that it is already large enough to have realized most of the possible economies of scale. Thus, to price a larger detector of comparable quality just multiply \$6 M by the ratio of tonnage. Of course, special purpose detectors of more limited usefulness could cost less per ton (one has already been approved for a ν oscillation experiment¹⁰). It's somewhat daunting to note that the present beam-apparatus combination is not all that far from being rate limited (for ν_μ). Although the experimenters make very good use of the time structure of the beam to reduce background (see Figure 9), the in-time rate approaches 1/spill. Since the apparatus is constantly sensitive (triggerless) it tends to get confused by more than a few events/spill. Thus one can imagine using perhaps another order of magnitude but not much more in such an apparatus. By contrast, almost unlimited increases in flux would be welcome to study ν_e

and $\bar{\nu}_e$ interactions, or to be traded in for ν energy determination by making a narrow band beam.

As mentioned above E780 is not expected to be background limited. Thus if the mini-drift chambers are not overloaded, such an experiment could use more beam. Unfortunately, because of the dearth of experience with $0^0 K_L^0$ beams, one doesn't yet know the ultimate K_L^0 intensity and purity obtainable at the AGS. In fact, the proponents of E780 are now carrying out a CP violation experiment¹¹ in such a beam and will soon settle the issue. In the meantime one must rely on calculation and extrapolation from other data. This turns out to be rather difficult because data near 30 GeV is sparse and of fair quality at best. Data near 200 GeV is better but the extrapolation is a long one. Secondly, most experimental results are off H_2 and so need to be corrected for A dependence in order to predict the yield of a production target. There are also corrections for multiple interactions, beam attenuation etc., which are not entirely cut and dried. Two recent attempts^{6, 12} to calculate the flux disagree by a factor 2 or 3. If the more optimistic estimate⁶ is right, the n/K ratio in the beam will be around 30; if the more pessimistic is correct, it will be more like 100. Figure 10 shows the flux vs production angle for the pessimistic calculation. Using these conservative numbers, one could get 6.5×10^5 usable $K_L^0/10^{12}$ p/usr. As much as 4×10^{12} ppp have been delivered to targets at the AGS in the past, and solid angles up to ~ 250 usr have been used. (E780 will use $\sim 10^{12}$ protons and $\Delta\Omega = 15$ usr). This would yield at least $6.5 \times 10^8 K_L^0$ pulse. For a decay tank of length .03 Λ_K and an apparatus of

Fig. 9. Time distribution of ν events from E734.

Fig. 10. K_L^0 flux per 10^{12} protons on target per μsr vs production angle for various p_K ranges (from Ref. 12). Assumes 28.5 GeV/c protons and one interaction length Be target.

acceptance 5%, one would reach a statistical sensitivity of $\sim 10^{12}$ in a 1000 hr experiment. The optimistic estimate of K_L^0 flux would yield $\sim 3 \times 10^{-13}$. The K^+ situation is similar. Here we have a measured number of about $2 \times 10^5 K^+/10^{12} p/\mu\text{sr}$ at 4 GeV/c with $\Delta p/p \sim 10\%$. For $\Delta\Omega = 500 \mu\text{sr}$ and 4×10^{12} on target one would get $4 \times 10^6 K^+$ /pulse accompanied by 20 times more p's and π 's. Then the statistical sensitivity attainable is similar to that of the K^0 case. Now these are formidable sensitivities and we must ask what barriers, other than raw K flux, stand in the way of achieving them. First the question of rates in the detectors. If we adopt the criteria developed in discussions of high luminosity detectors for CERN we must satisfy: 1) rate/wire $< 2 \text{ MHz}$; 2) no more than 1 or 2 pile-up events per signal event. For a 2m chamber with 2mm wire spacing the first limit translates to 2×10^9 hits/sec. The K_L^0 's in the hot beam discussed above will provide only $\sim 3 \times 10^7$. Thus one is within the above limit if the hits due to n interactions are less than ~ 30 times those due to K decays. Now this may seem quite safe, since we are assuming no more than 100 n/K, and only a small fraction of these (certainly not 1/3!) can be expected to cause chamber hits, but one must be a little cautious. For one thing the high energy n interactions will tend to be concentrated in the wires near the beam, for another it is quite common in actual fact to have ten times the chamber rates that one calculates in advance. As for pile-up, with a drift time of say 50 nsec, the average K decay event will be accompanied by .6 accidental event which satisfies criterion 2. In principle, triggers can also be made at these rates in the sense that triggering devices e.g., multi-element C counters and electronics are fast enough, but the problem of making the trigger for e.g., $K + \nu e$ sufficiently selective is non-trivial. Events with an e and apparent ν from $K e3$ decay will impinge on the detector at a rate of $> 10^5/\text{sec}$. Kinematic qualities of the events will have to be exploited at rates like these. This seems at least possible, if not easy.

Finally, we come to limitations due to intrinsic physics background. In the case of $K_L^0 + \nu e$, according to the proponents of E780, one can improve the background rejection by reducing the chamber resolution down to about 150 μ , at which point MCS in the planes dominates. At this point one has about one background event/ 10^{11} sensitivity. Now this is not the limit of course. With enough statistics one can see a signal above quite a large background. However, to be generally accepted a history making result, such as the observation of $K_L^0 + \nu e$, would be required to be of very high quality, certainly a $> 5\sigma$ effect. Assuming the above background, even with a statistical sensitivity of 3×10^{-13} then, one could not claim a signal much less than ~ 28 events ($= 8.5 \times 10^{-12}$) i.e., about the background level. If one had an order of magnitude more K's, this limit would only go down to 2.7×10^{-12} . This illustrates the general point that once a background is present, one tends to gain only as the square-root of the increase in statistical sensitivity.

The situation is similar for $K^+ + \pi^+e^-p^+$. Assuming 10% of decays occur within the fiducial region and a detection efficiency for these of 10%, in 1000 hours one could reach a statistical sensitivity level of 2.5×10^{-13} . In E777 the proposed sensitivity is limited by a desire to keep the chamber rates from $K^+ + \pi^+p^+$ decays below a few megacycles. Compared with what we have discussed above this is very conservative indeed. In spite of the fact that the PWC resolution is nowhere near the state of the art, the expected residual background is at the 10^{-12} level. Thus it does not seem impossible that the background could ultimately be brought down to the 2.5×10^{-13} level of the statistical sensitivity. This would allow one to pull out a convincing signal at the 10^{-12} level. I should inject a note of realism here and point out that both these ultimate experiments would be massive undertakings involving techniques that are somewhat beyond the present state of the art. It would take several years of unrelenting effort to reach the target sensitivity levels, even if no anticipated sources of background or other impediments were to show up. Elsewhere¹⁴ I have discussed at length the sort of unexpected problems that can plague rare K decay experiments.

Thus both $K_L^0 \rightarrow \mu e$ and $K^+ + \pi^+e^-p^+$ experiments could probably use the maximum flux available at the AGS. This may not be true of $K^+ + \pi^+p^+$ which is more likely to be background limited. A recent test in the LESB 1¹⁵ has shown that at $p_K^+ = 710$ MeV/c one can stop well over $200,000 K^+/4 \times 10^{12}$ protons on target. This number of protons/pulses has been routinely delivered to the C target for some time now. The π/K ratio in the beam was ~ 3 -4 to 1 and about 40% of the beam K^+ were stopped in a lucite target 10 cm in diameter and 20 cm long. Raising the beam momentum to 750 MeV/c increased the yield of stopped K^+ /proton on target by a factor 1.7 without significantly degrading the transverse stopping distribution. The time available for the test ran out before the $p_K^+ = 800$ MeV/c setting could be optimized, but it was clear that another large increment in stopping K^+ /proton on target could be realized. At about this point one would probably start compromising beam properties (longer and wider stopping target necessary, more beam π^+ /stopping K^+ etc.). However, it seems clear that one could obtain upwards of 500,000 K^+ per pulse under reasonable beam conditions. Presumably one could stop even more K^+ in the LESB II,¹⁶ albeit under worse conditions. Since the present BNL beams are surely not the ultimate one could design, it does not seem fantastical that one could eventually stop ~ 1 M K^+ /pulse in good conditions at the AGS.

Now the question is whether one could begin to use such a flux in an experiment like $K^+ + \pi^+p^+$. Since at least one detector for this reaction with a 20% acceptance has been proposed¹⁷ at CERN, one can imagine statistical sensitivities in the 10^{-11} ballpark. But will the backgrounds permit this level to be realized? Take the decay $K^+ + \pi^+p^+$ which occurs at about 3×10^{-3} in the kinematic

region of interest. One would need to reject this by at least 10^{-3} to reach the sensitivity for $K^+ + \pi^+p^+$ discussed above. One can probably get $> 10^{-3}$ rejection of μ 's by comparing energy and range. The experiment¹⁸ which established the present limit of

$BR(K^+ + \pi^+p^+) < 1.4 \times 10^{-7}$ used the observation of the $\pi^+ \rightarrow e$ decay chain to reject μ 's by about 10^3 to 1. How well this technique works depends entirely on the accidental rate in the π range stack. Since the beam rate in the previous experiment was ~ 300 KHz, while that of a 1 MHz stopping K^+ beam would be more like 15 MHz, to get an equally good result one would need to increase the detector granularity by a factor 50. This might well be prohibitively expensive,¹⁹ and still might not work—it was valuable in the previous experiment to veto any apparent decays which occurred within about 50 nsec of a subsequent beam track. Since the particles in a 15 MHz beam come every 70 nsec or so, it seems impossible in the case being considered here. Thus I'd guess one would be lucky to get a μ rejection factor of 10^3 by waiting for the $\pi \rightarrow \mu$ decay only. One then needs something like a 10^3 rejection of photons to reach the necessary suppression of $K^+ + \pi^+p^+$. Since at low energy the photon attenuation length is about twice the radiation length, about 14 radiation lengths of veto detector are necessary to achieve this. Even then, any cracks, dead spaces or inactive absorber undermine this rejection. What's more, at the beam rate under discussion, random vetoing is liable to induce unacceptable downtime unless the veto device is extremely fast. Other backgrounds produce equally daunting problems at these rates. Thus 10^{-11} seems like the hairy edge for this process at the AGS.

Now although I concluded that each of the K decay experiments considered above could be pursued at the AGS to about the point that intrinsic backgrounds allow, each would be a massive undertaking, tending to dominate the AGS program. It's hard to see how all three plus the other interesting physics of the energy range could be pursued simultaneously. To alleviate these problems one may rightly ask whether the AGS intensity could be increased.

This brings us to the subject of AGS future plans. As mentioned above a program allowing the acceleration of polarized protons is under way at the AGS. The initial intensity is anticipated to be around 10^{10} protons/pulse. Although this is adequate for most polarized proton experiments, such an intensity would, in general, be useless to unpolarized beam experiments. In addition the most interesting uses of polarized protons in CEA require the full luminosity. Thus to avoid program conflicts it would be desirable eventually to raise the polarized proton intensity to 10^{13} protons/pulse. To accomplish this one probably needs both a greatly improved ion source and an accumulator ring. A proposal² to build such a ring has recently appeared. Figure 11 shows the layout of the ring which would be situated between the present 200 MeV LINAC and the old 50 MeV LINAC building. The parameters of the ring are given in Table 5. Twenty 200 MeV LINAC

Fig. 11. Layout of the proposed BNL Accumulator/Booster.

TABLE 5

Accumulator/Booster Parameters

Energy

Injection	200 MeV
Maximum	1000 MeV

Lattice

Circumference	134.52 m (1/6 AGS)
Periodicity	18
Number of Cells	18 FODO
Cell Length	7.473 m
Phase Adv/Cell	94°
$v_x - v_y$	4.7
E_{max}/E_{min}	12/2 m
v_{max}	2 m
γ_T	4.55

RF System

Number of Stations	1
Harmonic Number	2
Peak RF Voltage	18 kV
Synchronous Phase Angle	
Capture	0°
Transfer	5°
Acceleration (future)	30°

Dipole

Number	18
Length (iron)	75"/78.25" (199 cm)
Gap	3.25"
Good Field Region	> 7"
Field (Inj/Max.)	3.73 kG/9.82 kG

Quadrupole

Number	36
Length (iron)	20"
Aperture	8" ϕ
Pole Tip Field	3.75 kG

TABLE 5 cont'd.

Injection Line

Number of Dipoles (angle)	8 (16-1/2°)
Edge	4° each end
Length (iron)	75"
Field	7 kG
Number of Quadrupoles	13
Aperture	8" ϕ
Length (iron)	24"
Field Gradient	1 kG/inch

Vacuum

Max. Pressure	10^{-8} Torr
Chamber Inside Dimensions	7" x 2.6" (in dipoles)

pulses would be accumulated in the ring (of circumference = 1/6 CAGS) and then injected into the AGS via a synchronous bucket to bucket transfer. As only one of ten LINAC pulses/sec is currently used by the AGS, the gain in intensity would be a factor 20. This project which includes some 18 dipoles and 36 quadrupoles is expected to cost about \$6M. Now of more immediate interest to this conference is the fact that for a modest additional investment this accumulator can be upgraded to a booster which would allow a ten-fold increase in the unpolarized AGS beam. This would, of course, directly benefit the type of physics I have been discussing and also offer the possibility of simplifying the CBA injection. In order to circumvent the present space charge limit in the AGS one needs to accelerate from 200 MeV to 1 GeV in the accumulator/booster. The booster would be cycled at 10 Hz with the resulting 1 GeV 10^{13} -proton bunches accumulated in the AGS. Now, of course, in order to accelerate, extract, and use such an intense beam there would need to be a number of other improvements and additions made to the AGS beyond the addition of the accumulator ring. The most important of these are included in the following list.

1. Add significant accelerating capability to the A/B RF system.
2. Modify A/B ring magnet power supplies to permit 10 Hz operation.
3. Modify the A/B extraction system magnet and power supply for 10 Hz operation.
4. Transfer line from A/B and AGS injection system must handle 1 GeV.
5. Upgrade AGS vacuum from 10^{-7} to 10^{-8} Torr, so that 1 second dwell time is possible.
6. New RF system to accelerate 10^{14} protons/pulse. Total RF (A/B + AGS) > 4 MW.
7. Radiation harden ring components, and add fast abort system.
8. Modification to beam lines and external areas.
9. Add a stretcher ring to ease extraction and raise duty cycle to 1.

The result of these efforts would be an AGS with 10 times higher average intensity than at present, with duty cycle of 1. As a side benefit the A/B would allow the construction of 1 GeV/c π test beam which could be available year round.

Finally I'll discuss briefly the heavy ion proposal¹ which advocates yoking the AGS to the BNL Tandem Van de Graaf via a cyclotron (see Figure 12). The cyclotron would be constructed from components of the SREL cyclotron which are already on the BNL site.²⁰ Eventually the Tandem (.008 A GeV) will feed the cyclotron (.15 A GeV) which in turn will feed the AGS yielding up to 15 A GeV for heavy ions. Ions up to A = 130 (iodine) can be fully stripped

Fig. 12. AGS heavy ion injection by the Tandem booster cyclotron.

yielding currents of 10^8 - 10^{10} particles/pulse. Many combinations and permutations are possible. For example, without the cyclotron one can inject and accelerate ions up to S^{32} in the AGS. Table 6 shows sample AGS currents with and without the cyclotron. Without the AGS the cyclotron can feed partially stripped ions as heavy as U^{238} back to the Tandem.

The project would take about four years and \$38M. The Tandem-AGS combination could be ready in 2 years. The cost of one new and one upgraded high energy detector are included in the above estimate. A 10 week AGS program is envisioned. It is anticipated that at the energy density attainable at this facility, the hypothesized QCD phase change will occur, converting the collection of colliding nucleons into a quark-gluon plasma. If this is true a whole new field of physics will be opened up.

Ultimately the heavy ions could be injected into the CBA. Figure 13 shows the energy vs mass range attainable by various stages of the project compared to that of the Bevelac.

In summary, it looks like quite a busy future for the AGS. Even without improvements at least one generation of rare K decay experiments beyond those currently launched seems feasible. Beyond that a major effort at any of the experiments discussed above could take it to the point where it would be limited by intrinsic physics background. To pursue a full program of physics at this level one would want to increase the intensity of the AGS as described above. A ten-fold increase in K flux would remove such experiments from the category of all-out technological assaults and render them manageable by reasonably small groups of physicists. In addition, certain other, cleaner experiments, e.g., $K_L^0 \rightarrow e^+e^-$ or $e^+e^- \rightarrow K_L^0$, could be pushed to limits unobtainable at the present AGS. The increased flux would also be welcomed by the neutrino and hypernuclear physics programs. Even experiments which do not at present require higher fluxes would benefit through the availability of purer beams and cleaner conditions.

The advent of polarized beams and of heavy ion acceleration will open up new whole areas of physics at the AGS. A 52 week program will be hardly enough.

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Fig. 13. Energy/nucleon vs mass for the BNL heavy ion accelerator complex and the BEVALAC. Future possible CBA performance is indicated.

TABLE 6 Expected AGS Currents

	Tandem Only			Tandem-Cyclotron		
	Oxygen	Sulfur	Iron	Sulfur	Iron	Iron
Source	100 μ a	200 μ a	200 μ a	200 μ a	200 μ a	200 μ a
Pulsewidth	22 μ sec	22 μ sec	4.9 μ sec	4.9 μ sec	7.3 μ sec	7.3 μ sec
Duty Cycle	1.5×10^{-5}	1.5×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	1.6×10^{-4}	1.6×10^{-4}
Terminal Stripper Efficiency	40%	20%	20%	20%	20%	20%
Tandem 2nd Stripper Efficiency	—	25%	—	—	—	—
Tandem Transmission	75%	75%	75%	75%	75%	75%
Buncher Efficiency	—	—	—	60%	60%	60%
Cyclotron Stripper Efficiency	—	—	—	16%	16%	16%
Cyclotron Acceleration and Extraction Efficiency	—	—	—	70%	70%	70%
Transport to AGS	100%	100%	100%	100%	100%	100%
Stripping Efficiency at AGS	100%	6%	100%	100%	30%	30%
Number of Pulses Injected in AGS	10	10	33	33	33	33
AGS Current	3.9×10^{10} ppp	5.9×10^8 ppp	1.8×10^9 ppp	1.8×10^9 ppp	8.3×10^9 ppp	8.3×10^9 ppp
AGS Energy	14.6 A·GeV	14.6 A·GeV	14.6 A·GeV	14.6 A·GeV	12.0 A·GeV	12.0 A·GeV

REFERENCES

1. "Proposal for a 15A GeV Heavy Ion Facility at Brookhaven" BNL 32250, January 1983.
2. "Proposal for an Accumulator/Booster for the AGS", March 1983, BNL 32949.
3. "High Energy Physics Achievements at the AGS and Cosmotron", R.H. Phillips, BNL 1981. "AGS 20th Anniversary Celebration", N.V. Baggett, BNL 1980.
4. K.M. Terwilliger, et al., IEEE Trans. Nuc. Sci., NS-28, No. 3, June 1981.
5. AGS Proposal 734, BNL/Brown/Pennsylvania/KEK/Osaka/Stony Brook/Tokyo (INS).
6. R.C. Larsen, et al., AGS Proposal 780, 1982.
7. D.M. Lazarus, et al., AGS Proposal 777, 1981.
8. M.P. Schmidt, private communication.
9. F. Wilczek, Phys. Rev. Lett. 49, 1549 (1982).
10. G. Bozoki, et al., AGS Proposal 776, 1981.
11. R.C. Larsen, et al., AGS Proposal 749, 1981.
12. J. Greenhalgh "On Estimating the K^0_L Flux at BNL, 1982 (unpublished).
13. CBA Newsletter No. 5, April 1983.
14. L. Littenberg "Rare K Decays", Proceedings of the Second LAMPF II Workshop, Los Alamos, NM, July 1982, p. 728.
15. M.E. Zeller, et al., BNL Summer Study on AGS Utilization 1970, p. 193.
16. D.M. Lazarus, BNL-21728, 1976.
17. M. Ferro-Luzzi, et al., CERN/PSCC 82-24 and 82-95 (1982).
18. Y. Asano, et al., Phys. Lett. 107B, 159 (1981).
19. The transient digitizers used in the experiment of Ref. 17 cost ~ \$25,000 a channel! Although it's probable that a cheaper solution can be found, one cannot multiply these entities indefinitely.
20. Alternatively the A/B, if built, could serve as the heavy ion booster, see AGS Tech. Note 187.