Contributed to the Intl. Workshop on JHF Science (JHF98), High Energy Accelerator Research Organization (KEK), Tsukuba, Japan, March 4-7,1998

BNL- 65477

A Perspective from the AGS*

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Introduction

A working model for the proposed JHF project is the AGS facility at BNL. Research that is being planned at the JHF represent extensions of present AGS experiments. The AGS presently holds the record for beam intensity from a synchrotron. Experience gained and lessons learned over the years from operation of the AGS is invaluable to a new facility like JHF. Presented here is a brief description of the AGS facility with emphasis on the separated particle beam lines that are presently being used for studying strangeness -1 and -2 systems.

The AGS Complex

A schematic drawing of the AGS-RHIC complex is shown in Fig. 1. Beams from the AGS can be extracted either as a Fast Extracted Beam (FEB) or a Slow Extracted Beam (SEB). The AGS program includes over 900 scientists from 132 institutions. The experiments cover a wide range of topics including fundamental tests of the Standard Model, searches for exotic mesons, the quark gluon plasma, the H-particle, gluinos, double lambda hypernuclei, baryon spectroscopy studies, color transparency and other topics of interest to NASA, Basic Energy Science and DOE Defense Programs.

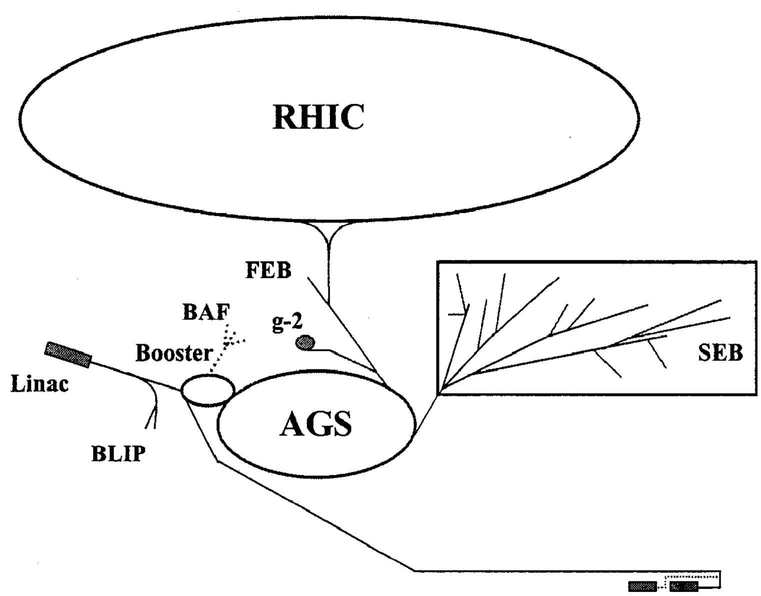

Fig. 1. The AGS RHIC Complex in 1998.

* Work performed under the auspice of the U. S. Dept. of Energy.

The AGS Separated Particle Beam Lines

Two of the three separated particle beam lines at the AGS have been and presently are being used for hypernuclear physics experiments. One is a low momentum (< 750 MeV/c) beam line, LESBII (Low Energy Separated Particle Beam) and is suitable for S = -1 studies. The second (2GeV) is a higher momentum (< 1.9 GeV/c) beam line uniquely suited for S = -2 studies. The third beam line, LESBIII, was constructed for and to date has only been used to deliver a K^+ beam to E787, the $K^+ \rightarrow \pi^+ \nu\nu^-$ rare kaon decay experiment.

LESBII

LESBII was commissioned in 1978 and was first used for hypernuclear physics experiments in 1987. This beam line has not performed to expectations. The beam line design incorporates optics corrected to second order and two short separators but only one mass slit and minimal beam collimation. A schematic of the beam line is shown in Fig. 2. Some of the beam line parameters are listed below.

- Maximum Momentum: 750 MeV/c
- Length: 15 meters
- Angular acceptance: 10 msr
- Momentum acceptance: 5% fwhm
- Beam Optics: Corrected to second order
- Movable Collimators
  - One Vertical Collimator (Mass Slit)
- Electrostatic Separators:
  - <625kV, 12.7 cm gap x 2.0 meter - #1
  - <560kV, 10.2 cm gap x 2.0 meter - #2
- Production Target
  - 9 cm long platinum electron beam welded to water cooled copper base
  - Maximum > 2×10^{13} per spill
  - Production Angle: 5 degrees
- Particle Flux (per 10^{13}, 24 GeV/c protons on target)
  - 700 MeV/c K^-, 3.3×10^4, 15% purity
  - 700 MeV/c K^+, 10^6 with 50% purity
  - 700 MeV/c $\pi^\pm$, 2×10^9 (limited to $<10^8$ due to area shielding)

The LESBII performance suffers from unexplained optics problems and from being located downstream of the C-primary target serving E787. The beam delivered to the LESBII C'-target must first pass through the 6 cm long Pt C-target. The scattered primary proton beam leads to a rather poor focus on the C'-production target serving LESBII. In addition, interactions of the primary proton beam on transport elements upstream of the C' target results in not only radiation damage but also secondary particle production that contribute to the relatively large π/K ratio. A new collimator is being installed (prior to the 1998-99 HEP run) just downstream of the C-target station. This collimator should help to minimize further radiation damage to downstream transport elements and may alleviate some of the background problems associated with the primary beam tune.

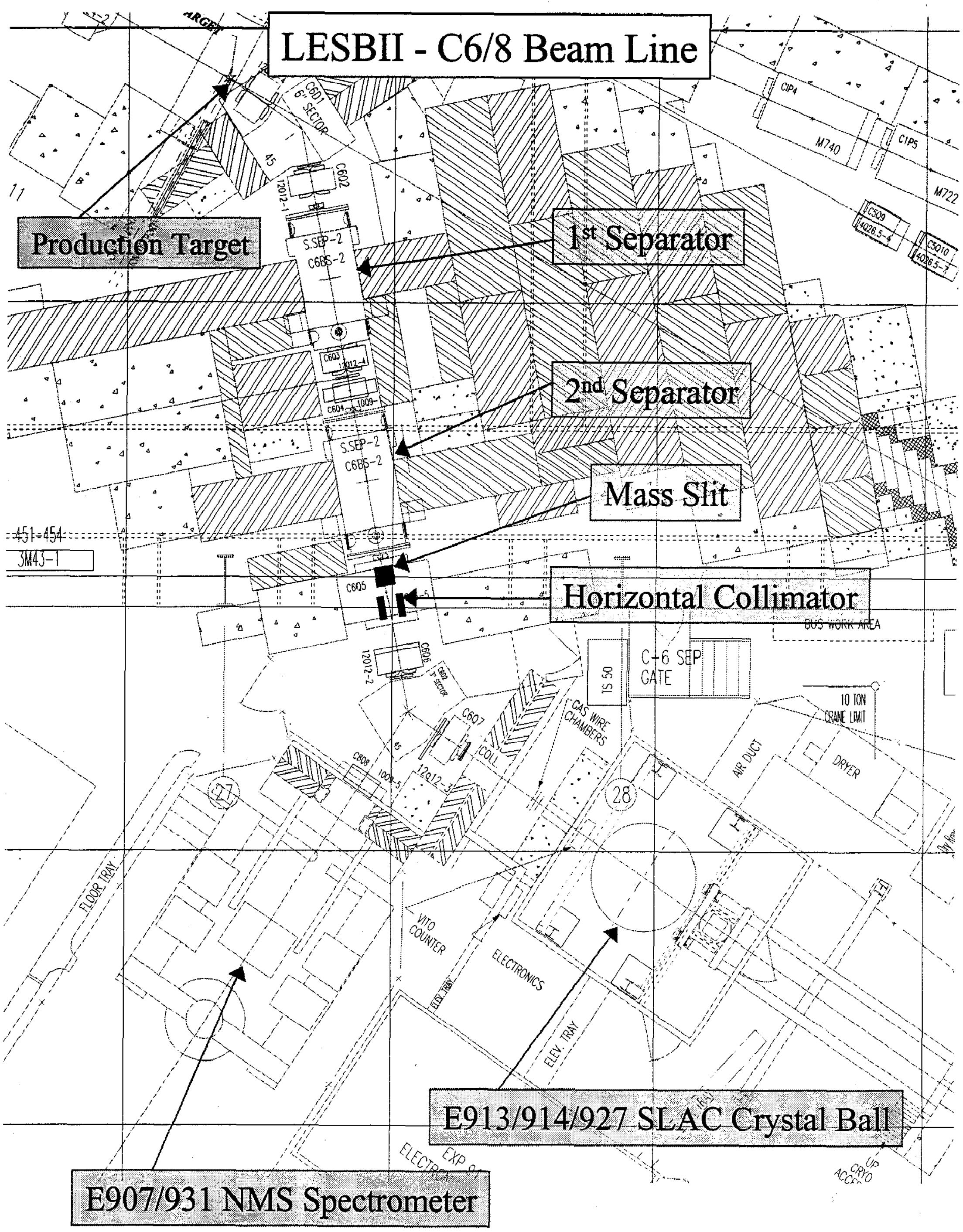

Fig. 2. The LESBII Beam Line as configured in 1998.

2GeV

The 2GeV beam line[1] was commissioned in 1991 for E813, an H-particle search experiment. This beam line was designed to deliver an intense, clean beam for studying S = -2 systems. Some of the beam line parameters are listed below.

- Maximum Momentum: 1900 MeV/c
- Length: 31.6 meters
- Angular acceptance: 1.6 msr
- Momentum acceptance: 6% fwhm
- Beam Optics: Corrected to third order
- Movable Collimators:
  - 4Jaw θ-φ Collimator
  - Horizontal Momentum Collimator
  - Two Vertical Collimators (Mass Slits)
- Electrostatic Separators:
  - Two Stage Separation
  - <750kV, 10.2 cm gap x 4.5 meter length separators
- Radiation Hardening - First dipole coils are mineral insulated.
- Production Target
  - 9 cm long platinum electron beam welded to water cooled copper base
  - Maximum ~2 x 10^{13} protons per spill (limited by area shielding)
  - Production Angle: 5 degrees
- Particle Flux (per 10^{13}, 24 GeV/c protons on target)
  - 1800 MeV/c K^-, 2.2 x 10^6 with 51% purity
  - 1400 MeV/c K^-, 3.8 x 10^5 with 72% purity
  - 1800 MeV/c antiprotons - 1.3 x 10^6 with 92% purity

The performance of this beam line meets expectations. A schematic of the beam line is shown in Fig. 3. below. This beam line incorporates state-of-the-art electrostatic separators whose design was based on pioneering work at KEK[2]. The beam line design includes two stages of separation together with two mass slits. In addition, a 4-jaw collimator was inserted downstream of the first bend. This collimator is designed to eliminate unwanted particles that originate from the production target that, would otherwise reach the final focus. The beam at this location is approximately parallel with a strong correlation between angle at the production target and x-y position at the collimator. The 4-jaw collimator serves to reduce the θ-φ phase space at the production target. This collimator has little effect on reducing background from extended sources (hyperon and meson decays, pole tip scattering, etc.).

The front end dipole of this beam line is equipped with mineral insulated coils so should not be seriously affected by radiation damage. However, the first quadrupole downstream of the target has conventional epoxy coils. The 25 degree first dipole bend coupled with a 5 degree secondary beam production angle allow the quadrupole coils to be no closer than 10 degrees to the incident beam direction. Even so the useful lifetime of this quadrupole would only be about 10,000 hours with a 10^{14} per spill JHF beam. It would therefore be advisable to equip this quadrupole with radiation hardened coils if this beam line design were chosen for JHF.

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[1] P.H. Pile et.al., Nucl. Instr. & Meth. A321 (1992) 48.

[2] A. Yamamoto et.al., Nucl. Instr. And Meth. 203 (1982) 35.

2 GeV (D6) Beam Line

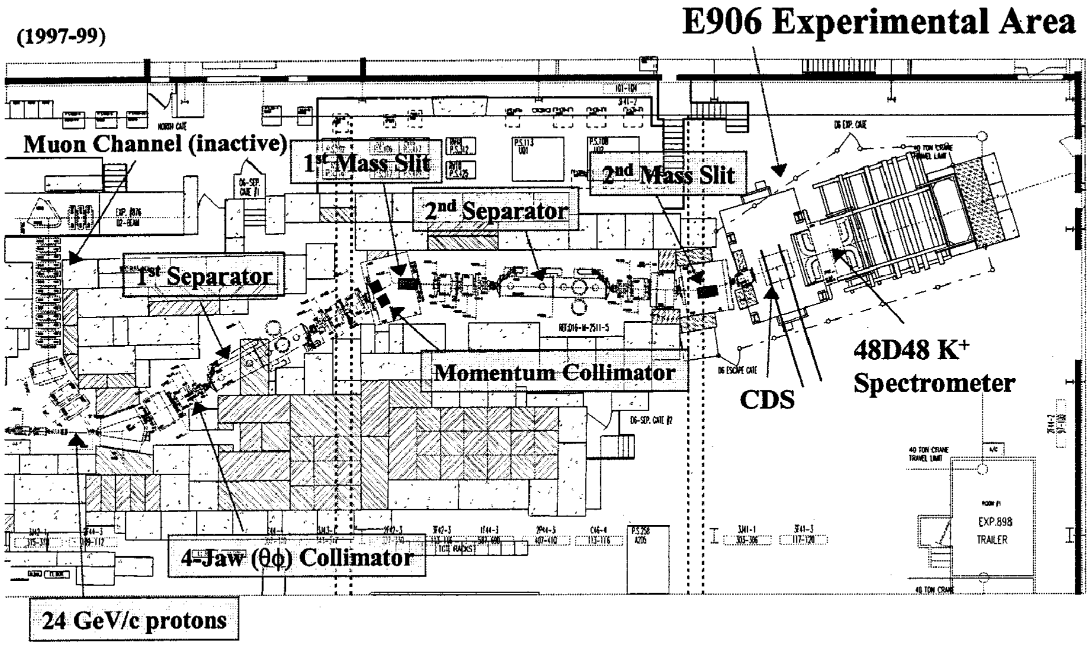

Fig. 3. D6 beam line and experimental area, 1998

LESBIII

Even though this beam line has not been available for general use, a few remarks concerning its design will be made. The design of LESBIII beam line was the result of a joint effort between BNL and Triumf. A schematic layout of the beam line is shown in Fig. 4. The design incorporates many of the features found in the 2GeV beam line discussed above. This includes 2 stage separation, optics corrected to third order and radiation resistant front end elements. The LESBIII design advanced the state-of-the-art for separated particle beam lines with the inclusion of an adjustable small opening horizontal collimator positioned at an achromatic focus just downstream of the second mass slit. The added collimator proved to virtually eliminate pions from extended sources. New kaon beam line designs for JHF should, if possible, incorporate such a slit. LESBIII was designed for optimum operation at 800 MeV/c.

- Maximum Momentum: 830 MeV/c
- Length: 19.6 meters
- Angular acceptance: 12 msr
- Momentum acceptance: 4% fwhm
- Beam Optics: Corrected to third order
- Movable Collimators
  - 4Jaw θ-φ Collimator

  - Horizontal momentum collimator
  - Two vertical collimators (Mass Slits)
  - Second horizontal collimator at achromatic focus
- Electrostatic Separators:
  - Two Stage Separation
  - <625kV, 12.7 cm gap x 2.0 meter - #1
  - <560kV, 10.2 cm gap x 2.0 meter - #2
- Radiation Hardening
  - Quad doublet downstream of the target , kapton wrapping with conventional epoxy
  - Dipole downstream of production target, polyimide insulated coils good to about 10^9 Gy
- Target
  - 6 cm long platinum silver soldered to a water cooled copper base
  - Maximum ~3 x 10^{13} per spill
- Production Angle: 0 degrees
- Particle Flux (per 10^{13}, 24 GeV/c protons on target):
  - 800 MeV/c positive kaons - 4.8 x 10^6 with 71% purity
  - Stopped positive kaons ~10^6

LESBIII is the best low energy separated beam in the world in terms of both kaon flux and beam purity. The front end beam elements, however, have a limited lifetime due to radiation damage to their coils. Although the quadrupoles downstream of the production target have radiation resistant kapton wrapped coils, conventional epoxy is used for final insulation (developed by the Tesla corporation). The tensile strength of conventional epoxy approaches zero with a radiation dose of about 5 x 10^7 Gy. Kapton is much more radiation resistant than conventional epoxy so may allow the coils to run past this conventional epoxy "lifetime". The C-target has seen a fluence of about 1 x 10^{20} protons since LESBIII was commissioned in 1992. This translates into a radiation dose to the coils of about 5-6 x 10^7 Gy[3]. The first two quadrupoles have therefore reached (or exceeded) their conventional epoxy lifetime.

If this beam line were replicated for use at the JHF particular attention must be paid to coil construction for the front end quadrupoles and first dipole. Polyimide (Tokin Corporation) insulation is expected to allow about a factor of 10-20 longer lifetime than conventional epoxy. The quadrupole coils will receive a dose of about 10^9 Gy (tensile strength for polyimide approaches zero with this dose) in 10-20,000 hours of running with 1 x 10^{14} proton per spill (half the JHF beam).

Front end magnets for high intensity beam lines at JHF must be designed to allow quick replacement with a reasonable radiation burden to personnel and/or be designed with more radiation resistant coils. Mineral insulated coils such as used in the past at LAMPF, TRIUMF and PSI (and first used at BNL for the 2GeV beam line front end dipole) are known to be very radiation resistant. This type of coil, however, cannot presently be made the same current density capability as conventional epoxy coils and procurement is problematic. High current densities are necessary to achieve large solid angle acceptances for beam lines. Alternative designs that preserve conventional coil current densities (hard anodized aluminum clad to copper, copper with ceramic spacers etc.) need to be developed.

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[3] D.Beavis,A.S.Carroll,W.Leonhardt,J.Mills,A.Pendzick,E.Schwaner, *High Intensity Target Station Study:PhaseI*, AGS/EP&S Technical Note 131 (1988).

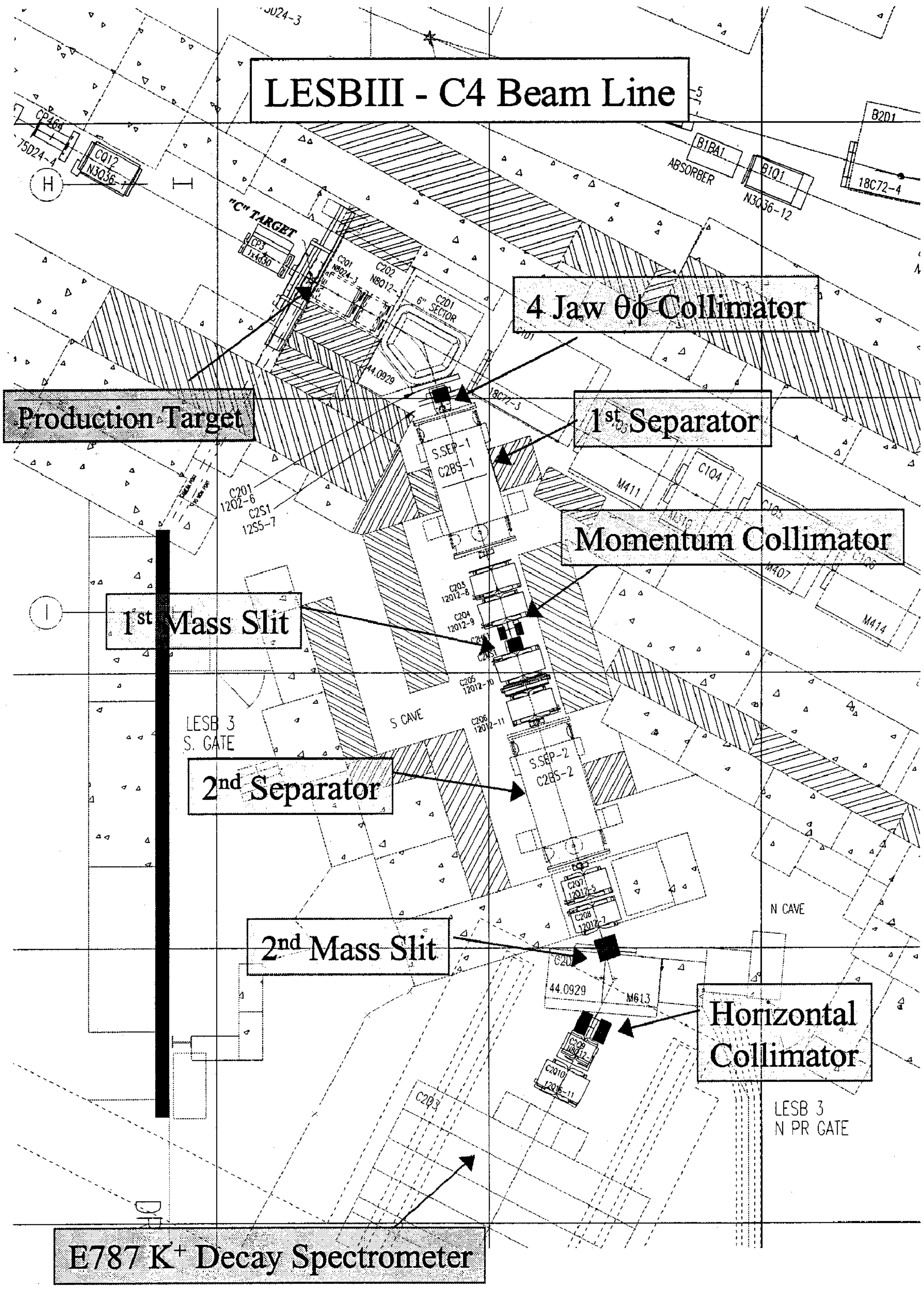

Fig. 4. LESBIII as configured in 1998

Possible Problem Areas for JHF

The following concerns are based on operational experience at the AGS facility. The AGS facility grew from an accelerator that could accelerate only a small fraction of today's beam intensity. As a result, radiation damage to beam transport elements, activation of magnet cooling water, general radiation levels on the floor etc. have become problematic. The construction of a new facility like JHF should take into consideration from the beginning probable beam intensity upgrades. In addition, sufficient floor space should be available to allow first round experiments to expand and allow new beam lines and experiments to be built with minimal radiation burden to personnel involved in the construction.

1) The proposed experimental area for JHF is about 1/3 the size of the present AGS experimental floor, yet the envisioned experimental program is comparable in scope to the present AGS program. Too many experiments are being planned for such a small area. The logistical problems of servicing beam lines and experimental areas will be difficult to handle.

2) One of the two primary beam lines serving the K-Arena provides beam to two target stations in succession. Each target station serves at least one separated particle beam line. Optimum running for these beam lines require dense, 50-100% interaction length targets. Interaction products as well as the multiple scattered primary beam from the first target will present activation/radiation damage problems for downstream transport magnets. AGS operational experience suggests that only one high density/intensity target station is desirable per primary transport beam line. If two target stations in succession are deemed necessary then the 1.8 GeV beam line target station should incorporate a low Z target or a short, high Z target with a collimation system downstream. Advertised secondary beam fluxes for this beam line should then be appropriately reduced.

3) The presently envisioned 1.8 GeV/c beam line for hypernuclear research does not allow room for providing an alternate (momentum dispersed) branch. A dispersed beam would allow an experiment the possibility of making a beam momentum measurement to a few tenths of a percent without having to track the beam through the last half of the beam line (as is presently done in the D6 beam line at the AGS). In addition, one could take advantage of the natural correlation between the position at the final focus and the first focus just downstream of the first mass slit, leading to less ambiguity in particle tracking downstream of the first mass slit (a beam rate issue). An alternate branch would also allow two experiments to be simultaneously setup in the beam line. The final design for the JHF 1.8 GeV beam line should allow sufficient clearance between the end of the beam line and the primary beam shielding so that a dispersed beam experiment could be setup.

4) One of the present AGS platinum targets (C-target station) used for separated particle beam lines has demonstrated the ability to withstand greater than 3×10^{13} protons per spill. This target is shown in Fig. 5. It is constructed by silver soldering a platinum bar (0.6 x 0.5 x 6 cm) to a water cooled copper base and then slotting the target into 6 longitudinal segments for stress relief. A plot of platinum maximum temperature vs beam intensity[4] is shown in Fig. 6. The melting point of platinum is 1772 °C, therefore the absolute beam intensity limit with this design is about 80 TP. The practical limit will of course be less (around 60 TP). In addition, stress on the target material due to the temperature differences will limit the maximum beam intensity and lifetime of the target.

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[4] I-H.Chiang,J.Geller,C-I.Pai,C.Pearson,A.Pendzick,E.Zitvogel, *Water Cooled Platinum C Target*, AGS/EP&S Technical Note 153 (1998) .

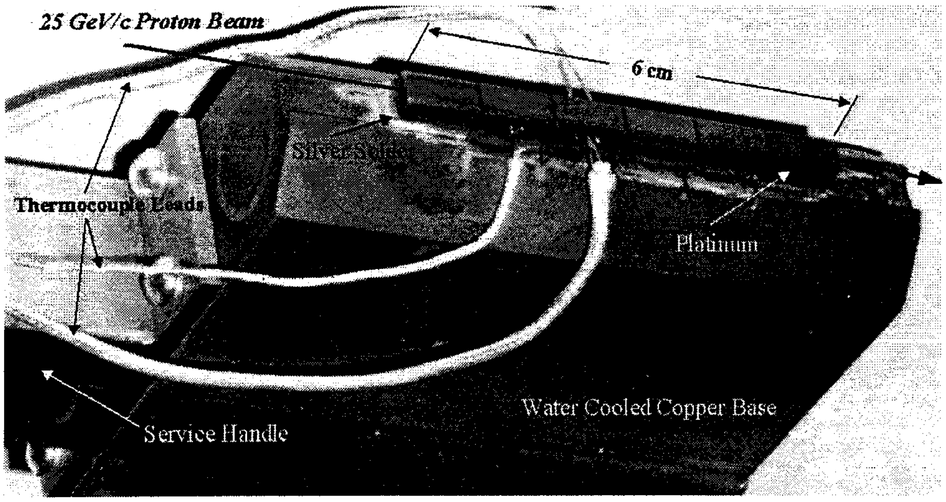

Fig. 5. The C-target, 1996-98.

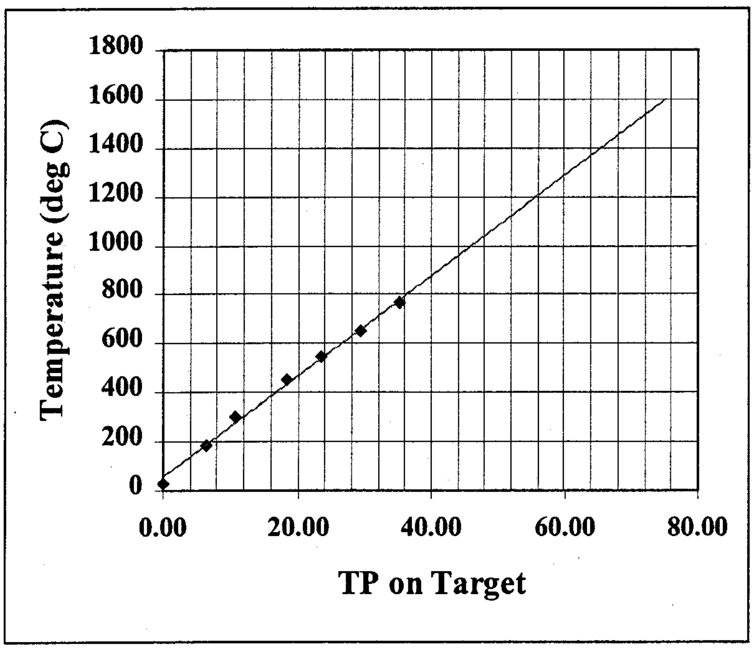

Fig. 6. The C-target, Temperature vs beam intensity (24 GeV protons,TP for 1.6 sec spill, 3.6 sec repetition time).

5) The planned 0.7 seconds maximum flat top (1.4 seconds at 30 GeV) with 3.42 second repetition time (20% duty factor) at 50 GeV will present many experiments with rate limit problems at beam intensities well below the 100 μA expectation. The AGS experience is that experiments (rare K decay experiments in particular) opt for longer spills as more beam intensity becomes available. This is generally due to experiments being instantaneous rate limited and

increased beam intensity can only be efficiently utilized by lengthening the beam spill time. The gain in events per unit time as a result of an increase in beam intensity is reflected in the duty factor improvement, not in the increase in beam intensity. As a reference point, AGS experiment E787 is presently instantaneous rate limited with about 2.5×10^{13} 24 GeV protons per 1.6 second spill (3.6 second repetition time, 1.8 μA,). If this experiment were allocated all the beam available from the AGS (6×10^{13} per spill) the spill length would need to be increased from 1.6 to $1.6 \times (6/2.5) = 3.8$ seconds in order to keep the experiment optimized. This is presently possible with the AGS, in fact spill lengths up to 5 seconds have been demonstrated. During the upcoming HEP run a new AGS Barrier Bucket Cavity system will be commissioned. This is expected to result in a substantial increase (up to $\sim 1 \times 10^{14}$ per spill) in available beam.

Concluding Remarks

Many proponents of the JHF are collaborators (or in some cases spokespersons) for AGS high energy and nuclear physics experiments. The AGS future role (>1999) will primarily be as the injector for RHIC, however the DOE High Energy Physics Program Office is expected to supply incremental funding to support important high energy physics experiments that are uniquely suited to the AGS. Continued support for AGS medium energy (nuclear physics) experiments, however, is in jeopardy. These experiments represent a significant part of the experimental program presently envisioned for the JHF. These are the AGS experiments that enjoy the greatest participation by Japanese scientists. The potential loss of the AGS for conducting these experiments (hypernuclear physics, baryon and meson spectroscopy, hyperon scattering etc.) is recognized as a problem for this community. If operation of the AGS for these experiments does not continue beyond 1999, the proponents of these experiments will effectively be without access to an operating accelerator during a large part of the 5 year JHF construction period. The scientific vitality of the field is therefore at risk.