

A decorative graphic consisting of a series of spheres of varying sizes and colors (red, orange, yellow, green, grey) arranged in a parabolic arc that opens downwards. The spheres are positioned around the main title.

# bnl 2AGS 2000+

**BROOKHAVEN**  
NATIONAL LABORATORY

**A DEVELOPMENT PLAN FOR THE  
AGS MAIN EXPERIMENTAL HALL**

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# Alternating Gradient Synchrotron

## AGS2000<sup>+</sup>

A Development Plan for the Main Experimental Area

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## INTRODUCTION

Despite the fact that the first priority of the AGS will be as an injector to RHIC, for the years of 2000 and beyond, the AGS will continue to be useful as an accelerator of unique capabilities in terms of intensity and versatility. These capabilities can provide exciting opportunities. In addition to the particle and nuclear physics experiments of AGS 2000, new facilities for Basic Energy Science and national accelerator development are included for AGS 2000+.

The Fast Extracted Beam (FEB) area to the north will be heavily utilized in its dual role as a proton beam to the g-2 experiment and as an injector to RHIC.

The program for the main experimental halls in Building 912, however, is largely undefined. In order to have a coherent plan for future development of this area, we of the Experimental Planning and Support Division\* of the AGS have undertaken a study with members of the Accelerator Division and representatives of the experimental community. We have considered all the proposals and major initiatives for the area, and developed siting plans, shielding designs, and beam optics. The plans are designed to allow re-deployment of the area nearly independent of the order in which particular experiments or facilities are funded.

Following this introduction, there is an overall floor layout (see Figure 1), then a table of required beam parameters (see Table 1), and a description on pages of beam operations. There are also written descriptions and floor layouts of each of the experiments and facilities.

A particular feature of AGS 2000+ is the development of a fast extracted beam into the "A" and "C" lines for muon collider developments and neutron spallation studies. The development of a fast extracted beam into this traditionally slow extracted beam (SEB) area will allow installation of facilities for targeting studies which can run nearly independent of the heavy use in the north area.

The thrust of this report is a feasibility study. This is not a finished plan. We wish only to show that there are no major technical difficulties to developing a program of this size. There is always room for creative ideas, and we look forward to developing this plan further with input from the user community.

\* Soon to be Experimental Support and Facilities Division of the Collider Accelerator Department.

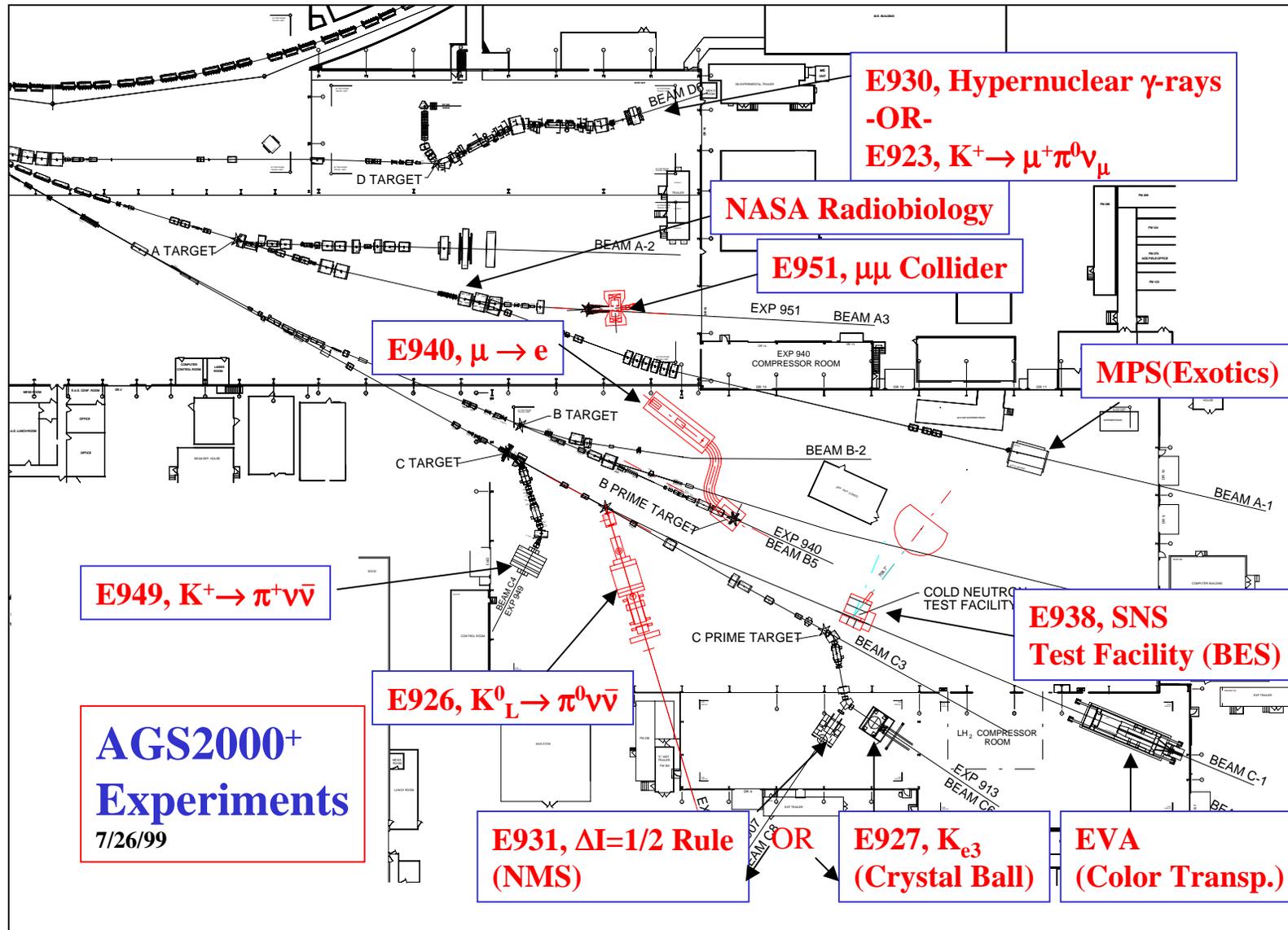


Figure 1: AGS2000+ Main Experimental Area

**Figure 1:** [AGS2000<sup>+</sup> Main Experimental Area](#)

<i>Primary Beam Requirements for AGS 2000<sup>+</sup> Experiments</i>			
<i>E923</i>	20-30 TP	24 GeV	Debunched
<i>E926</i>	50 – 100 TP	24 GeV	40 nsec structure
<i>E940</i>	40 TP	< 8 GeV	2 microsec structure
<i>E949</i>	50 – 100 TP	24 GeV	Debunched
<i>Crystal Ball</i>	5 – 20 TP	24 GeV	Debunched
<i>Test Beam</i>	1 –2 TP	24 GeV	Debunched
<i>Muon Collider</i>	50 TP	24 GeV	FEB
	2 TP for secondary beam	24 GeV	Debunched
<i>Neutron Spallation</i>	50 –100 TP	24 GeV	FEB
	lower intensities	< 24 GeV	FEB
<i>NASA Biology</i>		~ 1 GeV/A	Heavy Ions

Table 1 – Primary Beam Requirements for the Proposed Program in the AGS Main Experimental Hall. 1 TP = 10<sup>12</sup> Protons

## EXTRACTED BEAMS FOR THE MAIN EXPERIMENTAL AREA

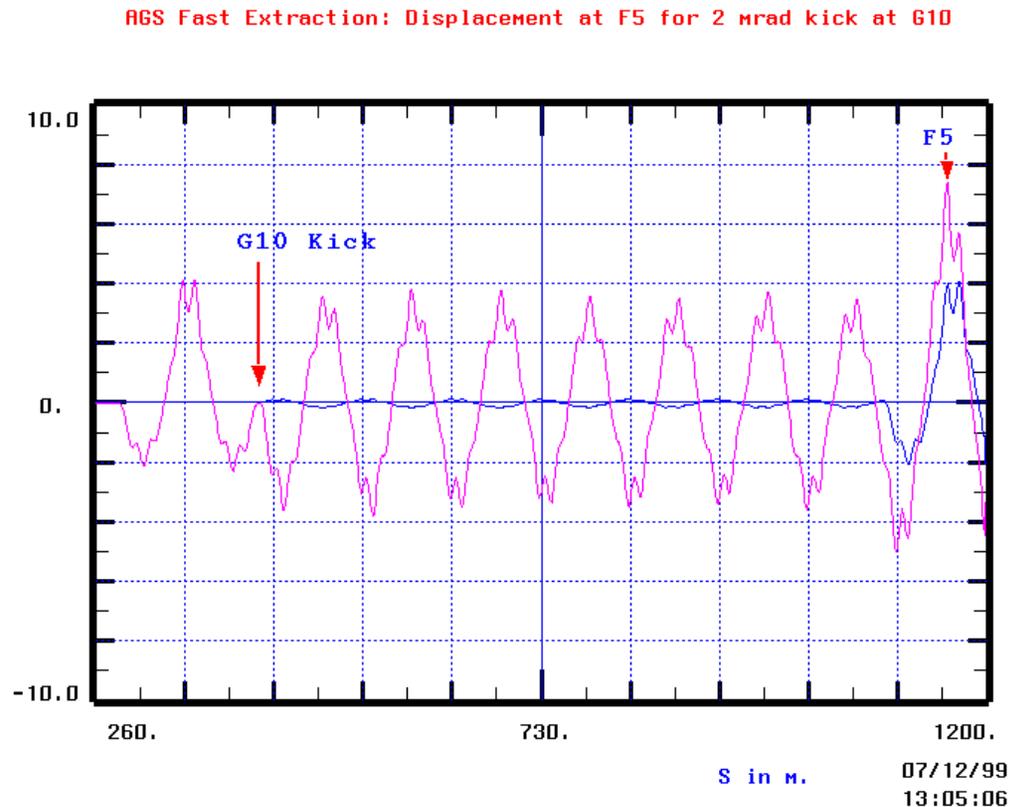
The AGS has had a program of third integer resonant extraction (also known as slow extracted beam – or SEB) in place for over two decades. During this time the beam intensities at the AGS have increased from the order of  $1 \times 10^{13}$  to well over  $7 \times 10^{13}$  protons per cycle. The most significant increase in intensities came along when the AGS Booster was made operational. Some operating parameters are shown in Table 2. In order to accommodate the even higher intensity beams and, in addition, to provide fast beam pulses through the SEB channel, improvements and changes need to be made to current SEB equipment and beam lines. The necessary changes outlined below include a new extraction septum magnet, improvements in instrumentation, and the addition of elements to provide beam characteristics required by experiments. What is outlined here are changes needed to achieve the first phase of the AGS 2000+ program.

Table 2: Recent AGS SEB Systems Parameters		
<i>Parameter</i>	<i>Value</i>	<i>Unit</i>
AGS Radius (aver.)	128.4525	m
AGS Mag. Bend Radius	85.3785	M
No. AGS Super Periods	12	
Max. Rigidity*	100	Tm
Max. Prot. Intensity	72	$\times 10^{12}$ ppp
SEB Eff.	98	%
Spill Length	2.8	second
Rep. Period	5	second
FEB Eff. **	>99	%
* corresponding to about 30 GeV/c protons.		
** predicted		

### Extraction Subprocesses into the SEB channel

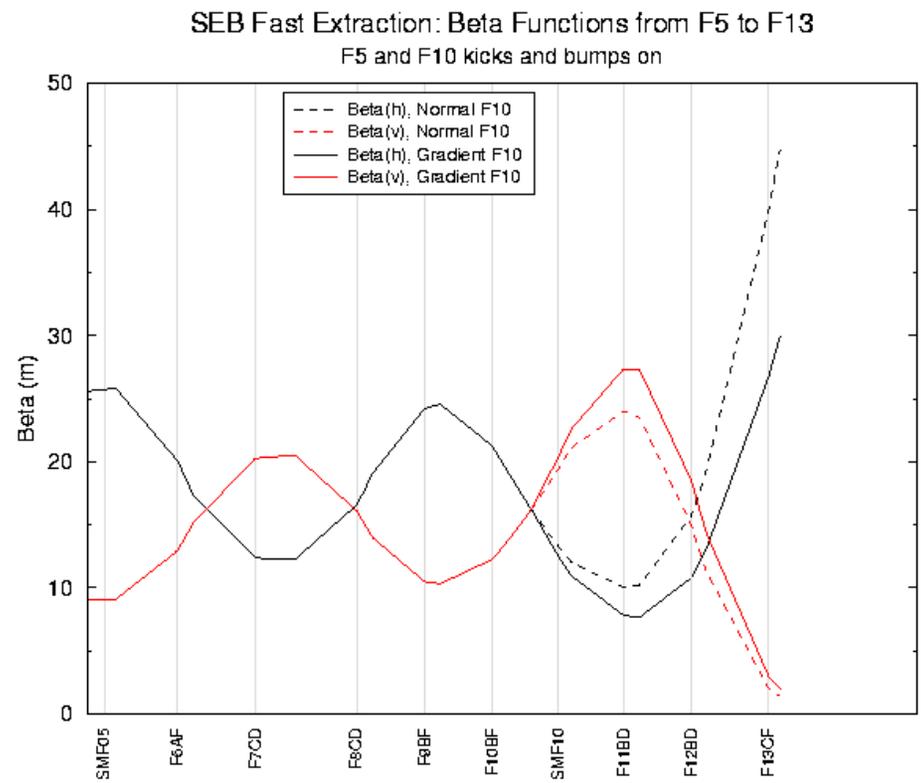
Resonant extraction from the AGS is performed on a third integer resonance created by four sextupoles in the AGS lattice. The efficiency of resonant extraction is determined primarily by the number of particles which intercept the electrostatic wire septum located in AGS straight section H20. This efficiency is typically of the order of 98%. At high intensity the efficiency is potentially affected by instabilities potentially in the 6 dimensional phase space (that is, all planes of motion can be affected). The degree of modulation of the extracted beam current is minimized through a number of techniques. Typically we can keep the modulation as low as 20% and usually not worse than 35-40%. The modulation has proved to be intensity dependent and so at higher intensities it is

more difficult to control. To bring the modulation back down we employ a 100 MHz RF cavity to filter the DC beam through, prior to entering resonance. This technique has been very effective.



**Figure 2: Orbit for a 2 mrad kick at G10 (vertical axis in cm)**

Currently we employ a multiple single bunch fast extraction system. Fast extraction is performed by exciting a fast open c-magnet ferrite kicker to give a single bunch a 1-2 mrad kick. The magnet is not full aperture, so the beam must be moved into the acceptance of the magnet after acceleration. This is done using slow bumps. The kicked beam trajectory then allows for the bunch to pass into the acceptance of a thicker septum magnet. For the current FEB program (g-2, transfer to RHIC, etc.), the thick septum magnet is located in the H10 AGS straight section. For fast extraction into the SEB channel we need not make any modifications. The phase advance from the fast kicker to the SEB F5 thin septum magnet is correct to put the kicked beam into the F5 acceptance. Operationally we would simply run without any bump at the H10 septum magnet, but instead turn on the bump at F5. Studies need to be performed to verify this operationally. Figure 2 shows a model of the fast extracted beam orbit and the displacement at the F5 thin septum magnet.



**Figure 3: Beta Functions from F5 to F13, with and without gradient F10 magnet**

## AGS MODIFICATIONS

### Extraction Subsystem Improvements

In order to accept  $\epsilon_{95\%}^N = 100 \pi$  mm-mrad beams the beam optics in the extraction channel between the thick septum extraction magnet and the first matching quadrupoles in the SEB beam line need to be improved. The main problem is the beam is highly focused vertically and gets fairly large horizontally. Figure 3 shows the beta functions from the F5 thin septum magnet through to the point where beam has fully exited the AGS lattice. By putting a modest gradient on the thick septum magnet we get a better behaved beam, changed only slightly in the vertical, but significantly improved in the horizontal. Figure 3 will allow the  $100 \pi$  mm-mrad beams to be more easily transported into the SEB beam lines.

### SEB Subsystems Modifications

The switchyard consists of four matching quadrupoles at the beginning of the line followed by three electrostatic splitters. For each splitter there is a thin Lamertson magnet (vertical steering). The combination provides efficient splitting of the beam into four parts, and sets the trajectory of those four parts down each of the main beam lines. The first four quadrupoles match to the beam characteristics of the extracted beam and are set to make the beam size constant through the splitting/Lambertson sections. Each of the beam lines has quadrupoles for fixing the final beam characteristics on the targets, and some additional quadrupoles for containing the beam in the apertures. The general behaviour of the optics is to keep the beam size more or less constant for most of the transport. Final focus quadrupoles are set to provide both horizontal and vertical focus at the target. Figures 3 and 4 show the beam sizes for the A line and C line, in which the upstream optics are defined in the canonical way.

To get the final focus required for the Muon Collider experiment in A Line requires the addition of two or three quadrupoles. The current solution uses 2 8Q48's and one 3Q36. The 8Q48's could be replaced with either a single 5" quad, or a pair. Figure 4 shows the beam size for a  $120 \pi$  mm-mrad particle with desired beam sizes on the  $\mu$ -collider target.

Figure 5 shows the respective beam sizes for beam transported to the spallation target. No modifications are required to the C/C3 optics to achieve the desired beam sizes.

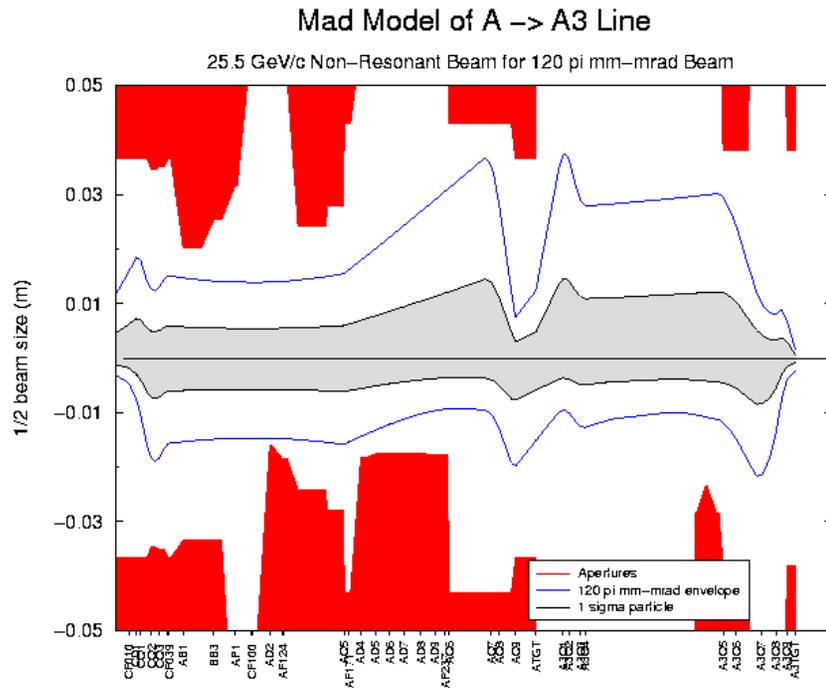


Figure 4: Beam Sizes in A line

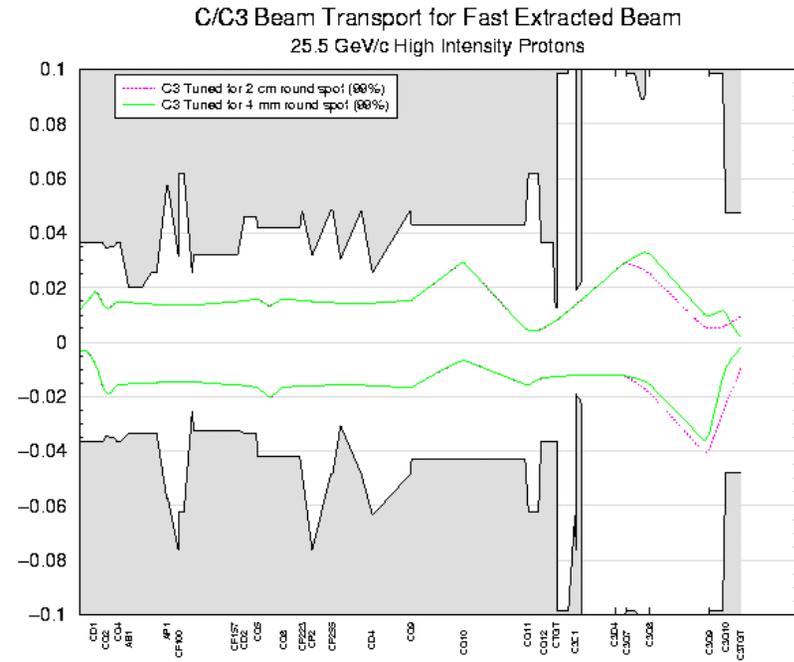


Figure 5: Beam Sizes in C and C1 lines

### Instrumentation

Currently the SEB lines are instrumented for slow extracted beam only. Fast extracted beam would use most of the same instrumentation, but some additions are needed. In particular, current transformers at the beginning of the SEB and at target stations where fast beam will be taken will be needed (3 total). Profile instruments (phosphor or SWICS) are also needed together with some additional loss monitors, to cover areas poorly covered for primary beam.

## References:

1. L. A. Ahrens, et al., “High intensity performance of the Brookhaven AGS”, proceedings of the 1999 Particle Accelerator Conference, <http://pac99.bnl.gov>
2. J. W. Glenn, et al., “AGS slow extraction improvements”, IEEE NS26, No. 3, 3167 (1979)
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## **E938 - COLD NEUTRON TEST FACILITY**

### **Goals of Experiment**

The goals of the Cold Neutron Facility, to be funded by Basic Energy Sciences, are to provide the location for testing targets, moderators and shields for future neutron spallation sources in the United States, Europe and Japan. These targets are expected to be up to 1.5 meters in length. A fast extracted proton beam of the highest possible intensity will be brought to this location. Initially the extraction will be single bunch, but full-turn extraction will be provided later. Some prototype neutron experiments may also be included.

### **Beam Requirements**

The Cold Neutron Facility will use the C primary and C1 beam lines to deliver up to  $10^{14}$  protons from a single AGS turn at 24 GeV. Initially there will be single bunch extraction, but full turn extraction will be added. Beam spots of 1 cm diameter are required. Beams of lesser intensity of any energy down to 1 GeV will be available.

### **Location and Shielding**

The C1 location was chosen for ease of bringing the fast extracted beam to a well shielded area and to allow continued operation of the LESB II from the C' target. The beam stop for the spallation target will integrate a new stop with the present C3 stop.

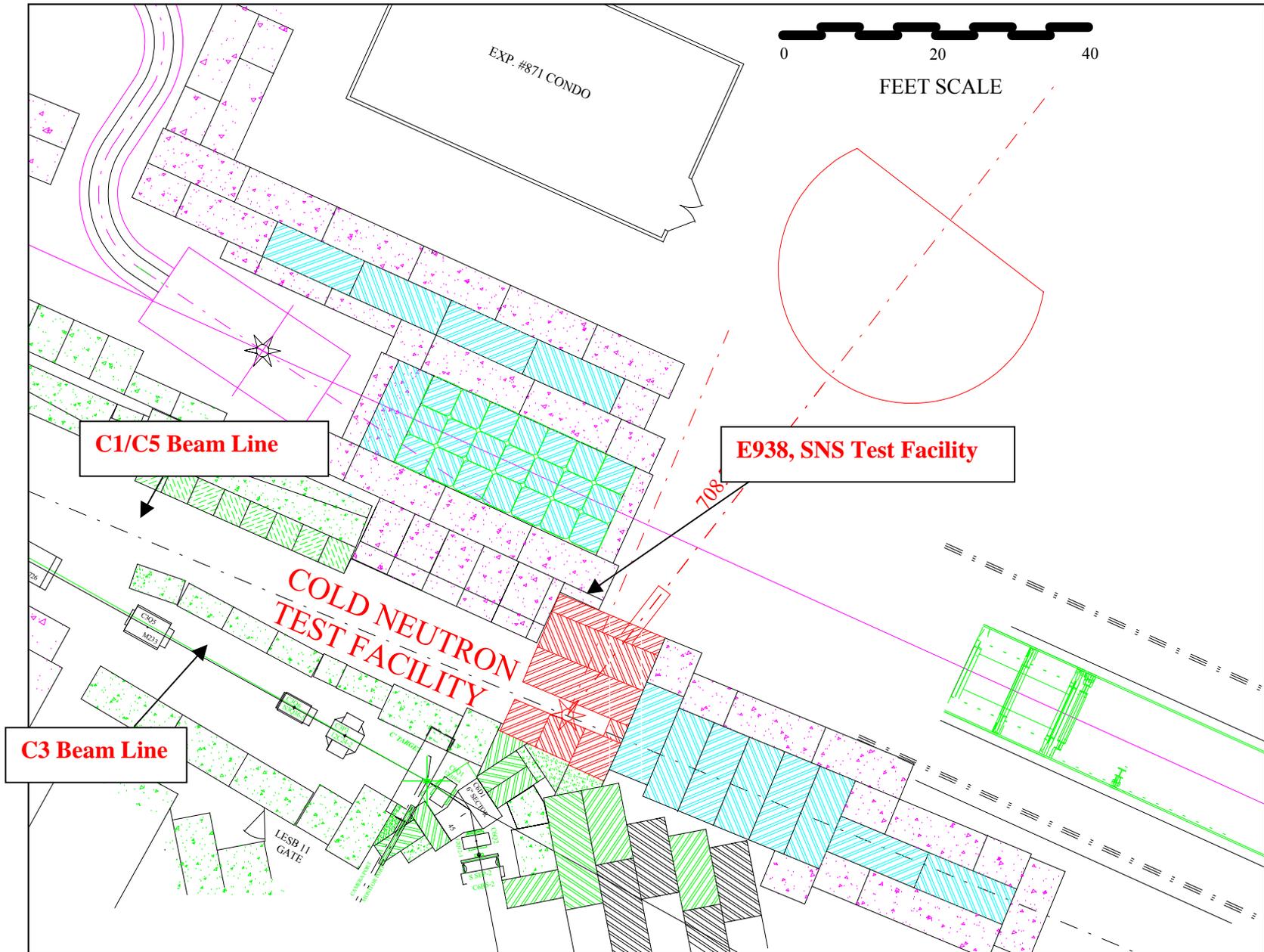
The beam stop for the C3 line will be re-utilized to provide a beam stop beyond the spallation target. A steel cave for containing the targets and moderators will be built. The targets and perhaps the moderators will be hung from a top shielding plate to provide acceptable handling for materials with high activation levels.

The shielding needs to be designed for an instantaneous rate of  $10^{14}$  protons per pulse. Initially the integrated intensity could be limited to  $10^{16}$  per hour (~100 pulses at high intensity), but if this facility were operated as a prototype spallation facility, the number of protons could rise to about  $2 \times 10^{17}$ /hour.

### **Safety and Environmental Concerns**

The target assembly would need to have secondary and perhaps some tertiary containment for both solid and liquid metal targets. The secondary containment would be an integral part of the target assembly. Any tertiary containment would seal the floor to prevent migration of materials out of the cave.

Storage caves adequate for shielding the activated targets would be used to hold targets not in use.



**E938**: Spallation Neutron Source Test Facility (Basic Energy Science)

## **E926 - MEASUREMENT OF $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$**

### **Goals of Experiment**

Experiment 926 is a search for the decay  $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$  which is expected to proceed primarily through direct CP violation at the branching ratio level of  $(3 \pm 2) \times 10^{-11}$ . The main problems are the poor signature with a neutral particle decaying to three particles of which only the  $\pi^0$  is manifest by its decay to a pair of photons and the large branching ratios for other decays with  $\pi^0$ 's and photons in the final state. Microbunching the primary proton beam makes determination of the  $K_L^0$  momentum by time of flight with good timing and vertex determination in the detector which consists of a pre-shower array followed by a highly segmented calorimeter with the entire experiment enclosed by gamma veto detectors.

### **Beam Requirements**

The beam requirements call for a 80 TP per AGS cycle on the production target with a time structure of a train of  $< 200$  pico sec bunches every 40 nsec for 2-3 seconds. The secondary beam be centered on a production angle of  $40^\circ$  will require a vacuum below  $10^{-6}$  mm Hg with massive collimation in the upstream section and two large sweeping magnets to remove charged particles from the beam. The large production angle results in the neutral kaon and neutron spectra peaking below 1 GeV/c which is necessary for the time of flight determination. Shielding requirements for the secondary beam and detector area are therefore not great in contrast to those for the target station.

### **Location and Shielding Considerations**

The present best locations for the experiment would be in the C line just downstream of E787 or with the production target at the present B5 target location and the neutral beam at  $40^\circ$  to the west. The latter location has the advantage of the B5 counting House being well located for fast electronics and the B1 Counting House as the main experimental habitation.

### **Safety and Environmental Concerns**

The principal safety concern will be the large volume vacuum decay box.



## **E949 – Measurement of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$**

### **Goals of Experiment**

E949 is a continuation of the previous experiment, E787. It will measure the  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  branching ratio. This strangeness changing neutral current decay has a branching ratio of  $\sim 1 \times 10^{-10}$  in the Standard Model. In the 1995 data set, one event was observed. This corresponds to a branching ratio of  $4.2 \times 10^{-10}$ . E949 plans to take the full AGS beam on the C target and run for 6000 hours. It was rated “must do” by the PAC (Program Advisory Committee) in 1998, and was approved to run by BNL management. The experiment is upgraded from E787 through the addition of a barrel veto liner, more photon vetos along the beam direction, and upgrades to several existing detector systems, including: target, drift chamber, range stack, trigger and DAQ. The experiment is expected to reach  $(8-15) \times 10^{-12}$  sensitivity, an order of magnitude below the standard model prediction of  $\sim 1 \times 10^{-10}$ .

### **Beam Requirements**

E949 will take the entire slow extracted beam from AGS on the C target. For 65 TP extracted beam, the expected spill length will be 4.1 seconds every 6.4 seconds. The 6cm C target will be continuously monitored and interlocked with a temperature monitor to prevent overheating of the Platinum. In addition, there will be an instantaneous intensity monitor to abort extraction if the rate is greater than 100 TP/Sec (with  $\sim 100$  msec time delay). To prevent shut down due to components failures due to long term radiation damage, the water cooled Platinum target will be replaced ( $15 \times 10^{19}$  protons from 1995-1999). Radiation hard spares will be made for the upstream magnets, C4Q1, C4Q2 and C4D1. The beam line instrumentation (SEC, SWIC) were badly damaged by proton beam and will need to be replaced.

### **Location and Shielding**

E949 will remain in the same location as E787. At the expected running condition (65 TP per spill, 6.4 second cycle time and 4.1 second spill length) the average beam intensity is  $\sim 10$  TP/second. E787 has run as high as 8.6 TP/second during 1998-1999 run. The radiation level in the area has been acceptable. To further reduce the radiation in the area, the cooling water to the C target, C4Q1, Q2 and D1 will be rerouted to reduce the general radiation level in the area near the C target area.

## **E940 - Muon Electron Conversion**

### **Goals of Experiment**

The goal of Experiment 940 is to search for the lepton flavor violation (LFV) process,  $\mu^-(A,Z) \rightarrow e^-(A,Z)$ , with a single event sensitivity of about  $2 \times 10^{-17}$ . The sensitivity is almost four orders of magnitude below existing measurements. In order to analyze a very large number of muons stopped on an aluminum target, the high intensity of the AGS is combined with a very special beam structure.

### **Beam Requirements**

This proposed plan for the proton structure in the AGS is 2 bunches accelerated to yield a 0.74 MHz time structure at the energy of 8 GeV or below. A critical feature of this structure is an extinction rate of at least  $10^{-9}$  between bunches with a goal of  $10^{-10}$ . For a  $4 \times 10^{13}$  per pulse intensity, a spill length of 0.5 second, a repetition rate of 1.5 second will supply the proper yield of  $\mu^-$  from the radiation cooled titanium target. The curved solenoid will select and transport the  $\mu^-$  to the aluminum stopping target.

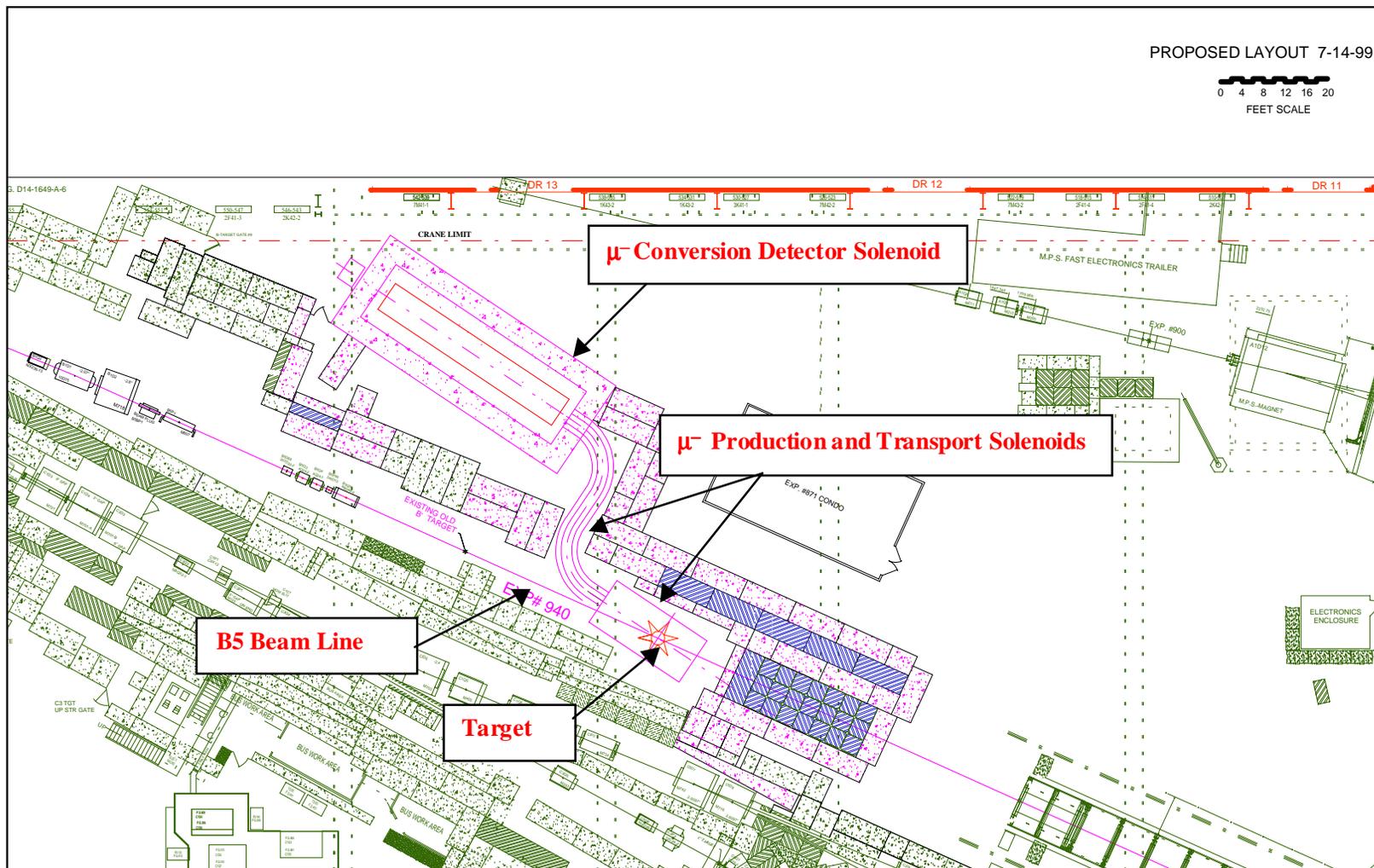
### **Location and Shielding Considerations**

The B5 line location was chosen to accommodate large experimental equipment (3 super conducting solenoid magnets), with relatively less impact to the other AGS beam lines. E940 target is located 10 meters down stream of the old B5 target.

Based on required beam intensity (40 TP), the shielding design is similar to the existing C target area. There is eight feet (thickness) of heavy concrete side shielding with a narrow aperture between the production and detector solenoids. This reduces the amount of shielding required for the production target and reduces the length of the roof spans. The roof shielding thickness varies from 12 feet (above the production solenoid) to 4 feet (above the detector solenoid).

### **Safety and Environmental Concerns**

The three large superconducting magnets will require a large cryogenic system. Such systems present hazards from extreme cold, possible high pressures, and oxygen deficiency. Also, regions of high magnetic fringe field will have to be carefully delineated.



**Experiment 940:** Search for  $\mu^-(A,Z) \rightarrow e^-(A,Z)$  with Sensitivity Below  $10^{-17}$

## **E951 - Muon-Collider Targetry and Capture in the A3 line**

### **Goals of Experiment**

Experiment 951, "An R&D Program for Targetry and Capture at a Muon-Collider Source" aims to address several critical technical questions associated with the production target and capture of the pions for a muon collider. To achieve a good capture efficiency, the target has to be inside a magnet with a field strength of about 20T. Also, it has to have a small radius to avoid absorption of the production pions spiraling in the magnetic field. This favors a pulsed jet of liquid metal such as Hg.

In a first stage, this experiment plans to study the operation of a free liquid jet target in a magnetic field. The AGS is the only existing machine capable of providing peak intensities of up to  $10^{14}$  protons/pulse at 16-24 GeV, about required proton driver intensity for a first muon collider.

The second part of the proposal addresses the capture of the pions produced in the target. Pions over a wide momentum range have to be collected requiring the use of low frequency rf cavities for acceleration very close to the target and inside of solenoid magnets. The operation of such cavities in the vicinity of a high intensity production target and the achievable capture efficiencies will be studied once the targetry R&D has been completed.

### **Beam Requirements**

For most of the planned studies, the experiment requires a fast extracted beam at the highest intensity available, i.e.  $10^{14}$  protons/pulse at 24 GeV kinetic energy. For the characterization of the pion yield downstream of the first rf cavity, a slow extracted beam of about  $10^6$  protons/sec is requested. The RMS beam-spot size should be about 1mm.

### **Location and Shielding Considerations**

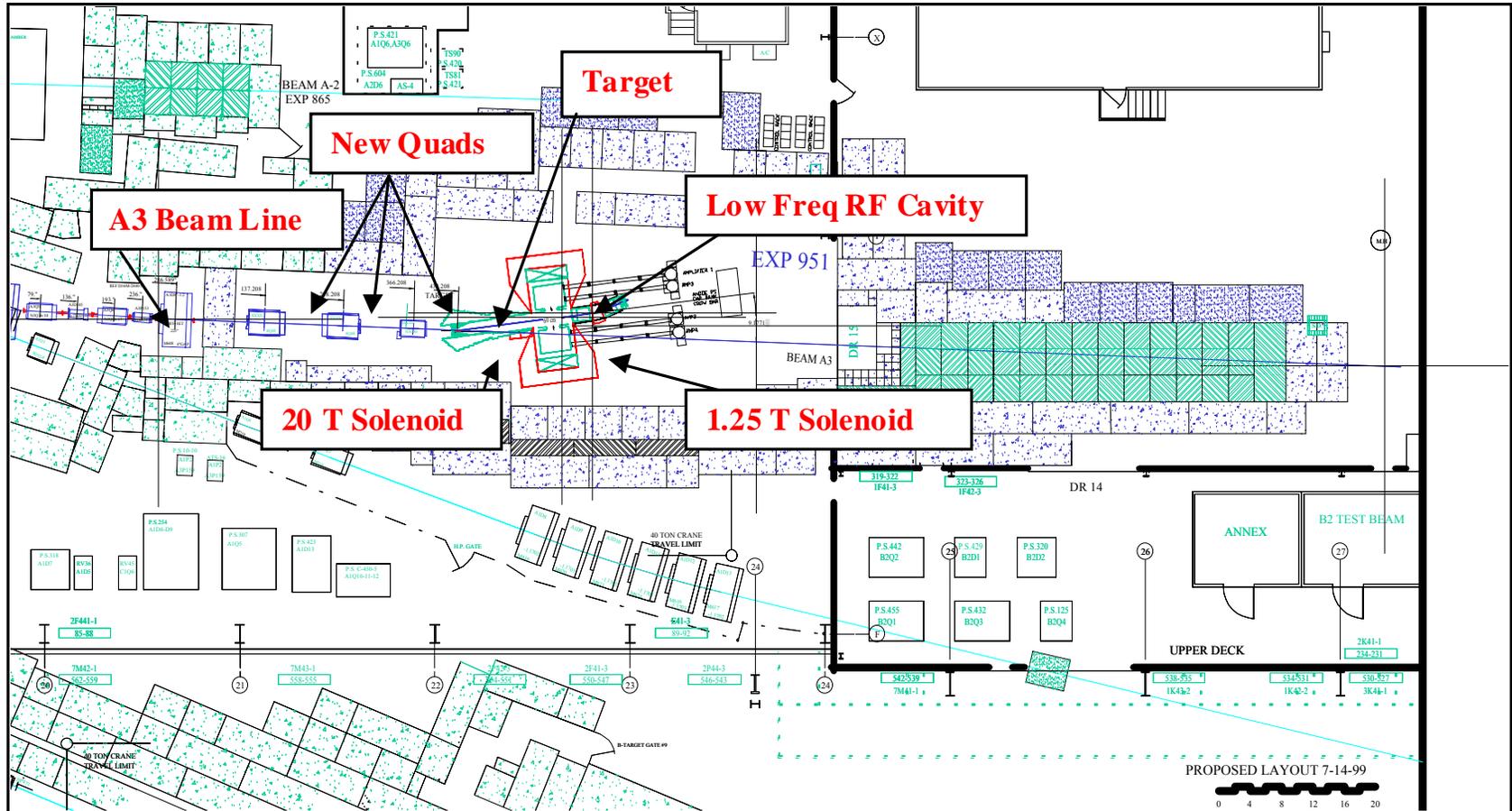
Given the capability of fast extracted beam to the old SEB beamlines, which is addressed somewhere else, the choice fell on the A3 line the size of the present A3 cave roughly matches the needs of this experiment, and there is no interference with other experiments running or proposed. The small beam spot required can be achieved with the addition of two or three quadrupole magnets for final focussing.

Due to the high intensities requested, the shielding of the area and its beam dump has to be upgraded substantially. The design goal is to allow continuous tuning at  $10^{13}$  p/pulse (up to 1000 pulses per hour) or at full intensity ( $10^{14}$  p/pulse) for up to 100 pulses per hour.

### **Safety and Environmental Concerns**

The main safety and environmental concerns are associated with the operation of the liquid target. A liquid mercury target may turn out to be the best choice. The targets may be violently dispersed by the incident beam and carefully designed primary and secondary containment vessels are required. The rf cavity for phase two is a potential x-ray source and needs to be shielded during operation.

Mechanical safety issues are associated with the operation of high field magnets, possibly including one cryogenic magnet. For the pion yield studies at low intensities, the use of a TCP operated with pure iso-butane is proposed.



**Experiment 951:** An R&D Program for Targetry and Capture at a Muon-Collider

## Additional Experiments for the AGS Main Experimental Hall

In addition to the experiments previously described, there are several experiments still in place or new experiments which could utilize existing beam lines and/or detectors. These are indicated on Figure 1 and described briefly here.

1. NASA Radiobiology: This small facility will remain in the A3 line to study the effects of heavy ion irradiation of biological specimens. The NASA program runs for about ten days once or twice a year in a stand-alone mode with energies of about 1 GeV/nucleon.
2. E927 and E931 are approved experiments for the LESB II separated beam (C6 and C8 branches).
  - a. The finely tuned “Crystal Ball” detector will be used for a precision measurement of the  $K^+ \rightarrow e^+ \pi^0 \nu$  decay rate. The LESBII beam line will supply a large flux of stopping  $K^+$ .
  - b. The Neutral Meson Spectrometer in the C8 branch will make precise measurements of the nature and validity of the  $\Delta I = \frac{1}{2}$  rule in weak decay processes involving Helium 4  $\Lambda$  hypernuclei.
3. E923 and E930 are approved experiments for the 2GeV separated beam from the D target station.
  - a. E923 is designed to measure the Time Reversal Violating transverse muon polarization from  $K^+ \rightarrow \mu^+ \pi^0 \nu$  decays. The separated beam provides a high rate of 1.9 GeV  $K^+$  for the study of in-flight decays. A modest, but carefully designed polarimeter will allow asymmetries with statistical and systematic errors as small as  $10^{-4}$  to be determined.
  - b. Initial data with the Hyperball of E930 are very promising. The precision gamma ray spectroscopy with this detector should provide a complete characterization of the  $\Lambda N$  interaction in light nuclei. Again, the purity and flux of Kaons from the separated beam allows a unique set of measurements.

4. The Multi-Particle Spectrometer is located in the A1 line, and is instrumented to detect charged and neutral decays of mesonic states produced by beams in the 10 to 22 GeV region. Of particular interest is the study of “exotic states” outside the three quark model.
5. The EVA spectrometer is located in the C1 line and has been carrying out a program of nuclear studies at high momentum transfers corresponding to angles near  $90^\circ$  in the center of mass. These measurements include the transmission of hadrons through nuclei (“color transparency”) and nucleon-nucleon correlations.
6. The B1 and B2 test beams will be available until E940 in the B5 line construction is started whenever there is slow beam extraction from the AGS.
7. A 6 GeV/c test beam utilizing the A2 line can be easily developed. There are two intermediate foci in the present A2 line intended to reduce muon halo, but these are not required for a test beam. The simplest (no effort) test beam can be obtained by turning off all quadrupoles but Q7-Q9 which limits the intensity to about  $10^6$  positive particles per TP on the A target. At 6 GeV/c, the beam power with all quadrupoles at their nominal value is 2 MW. With Q1-Q6 off it would drop to 0.5 MW.

Credit is offered here to institutions and persons  
involved in these current experiments  
(Spokespersons indicated in italics)

**Experiment 926:**

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Japan Atomic Energy Research Institute – *N. Watanabe*

Los Alamos National Laboratory – G. Russell

Oak Ridge National Laboratory – *J. Haines*

Paul Scherrer Institute – *G. Bauer*

### **Experiment 940:**

Institute for Nuclear Research - R. M. Djikibaev, V. M. Lobashev, A. N. Toropin

New York University - A. Mincer, P. Nemethy, J. Sculli

Purdue University - S. Carabello, D. Koltick

University of California at Irvine - M. Bachman, G. Kagel, R. Lee, T. J. Liu, *W. Molzon*, M. Overlin

University of Houston - A. Empl, E. V. Hungerford, K. J. Lan, B. W. Mayes, L. S. Pinsky, J. Wilson, M. Youn

University of Pennsylvania - W. D. Wales

## **Experiment 949:**

**Brookhaven National Laboratory** - M. S. Atiya, I-H. Chiang, M. V. Diwan, J.S. Frank, J. S. Haggerty, V. Jain, *S. H. Kettell*,  
T. F. Kycia, K. K. Li, L. S. Littengerg, G. Redlinger, R. C. Strand, C. Witzig

**Centre for Subatomic Research-U. Alberta** - P. Kitching, H-S. Ng

**Fukui University** - M. Miyajima, J. Nishide, K. Shimada, T. Shimoyama, Y. Tamagawa

**Inst. for Nuclear Research** – M. M. Khabibullins, A. N. Khotjantsev, Y. G. Kudenko, O. V. Mineev

**KEK** - T. Inagaki, S. Kabe, M. Kobayashi, Y. Kuno, T. Sato, T. Shinkawa, Y. Yoshimura

**KEK Tanashi** - T. K. Komatsubara, N. Muramatsu, K. Omata, *S. Sugimoto*

**Osaka Univrsity** - T. Nakano, M. Nomachi

**TRIUMF** - P. C. Bergbusch, E. W. Blackmore, *D. A. Bryman*, S. Chn, A. Konaka, J. A. Macdonald, J. Mildenberger, T. Numao,  
J-M. Poutissou, R. Poutissou,

**University of New Mexico** – B. Bassalleck, D. E. Fields, J. Lowe, T.L. Thomas

## **Experiment 951:**

**Argonne National Laboratory** – A. Hassanein, J. H. Norem, C. Reed, D. L. Smith

**Brookhaven National Laboratory** – J. Alessi, R. C. Fernow, J.C. Gallardo, J. Hastings, S. A. Kahn, B. J. King, H.G. Kirk,  
V. LoDestro, R. B. Palmer, T. Roser, Y. Torun, H. Wang, R. Weggel, Y. Zhao

**CERN** – C. Johnson,

**Fermi National Laboratory** – P. Lebrun, N. V. Mokhov, A. van Ginneken

**Lawrence Berkeley National Laboratory** – J. Corlett, Y. Fukui, M. A. Green, R. M. Scanlan,

**Oak Ridge National Laboratory** – D. D. Earl, T. A. Gabriel, J. R. Haines,

**Joseph Henry Laboratories, Princeton U.** – C. Lu, *K. T. McDonald*, E. J. Prebys

**SUNY Stony Brook** – Y. Torun