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RECOMMISSIONING AN UPGRADED POLARIZED BEAM FACILITY

L. G. Ratner

November 1990

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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Accelerator Division
Technical Note

AGS/AD/Tech. Note No. 345

RECOMMISSIONING AN UPGRADED POLARIZED BEAM FACILITY

L.G. Ratner

November 1, 1990

Summary

We envision a three-phase project beginning with the immediate construction of a partial "Siberian Snake" and culminating with 24.8 GeV/c injected polarized proton beams in RHIC.

Phase 1

Construct and install a partial snake. Appendix 7 is an AIP proposal at a cost of $124,000, which starts January, 1991 and finishes October, 1992. Concurrently, maintenance and repair of the fast quad modulators (Appendix 2) at a hardware cost of $25,000 is accomplished. Depending on power supply availability, we would expect to test at energies between 10 and 22 GeV.

Phase 2

Reconfigure the fast quad modulator system to be able to reach RHIC injection energy at a hardware cost of $44,000 (Appendix 5). For tests of polarization survival, AGS extraction and transfer to RHIC, we will require some instrumentation and a polarimeter at the end of the transfer line. Could be scheduled for testing in AGS by October, 1993.

Phase 3

Installation of RHIC snakes and polarimeter at a cost of $4.8M (Appendix 6). Booster commissioning to reach higher polarized proton intensities if not already accomplished. Will also need the polarized proton tune quad power supplies. Appendix 3 is an AIP proposal for these quad power supplies at a cost of $301,000 which could be done as part of Phase 2 or Phase 3. To go from P_f/P_i = 40-50% to P_f/P_i = 90-100% will require a new power supply (12.6 kA, 230V) similar to the MPS supply (16 kA, 260V). This supply has not been included in the cost of the project.

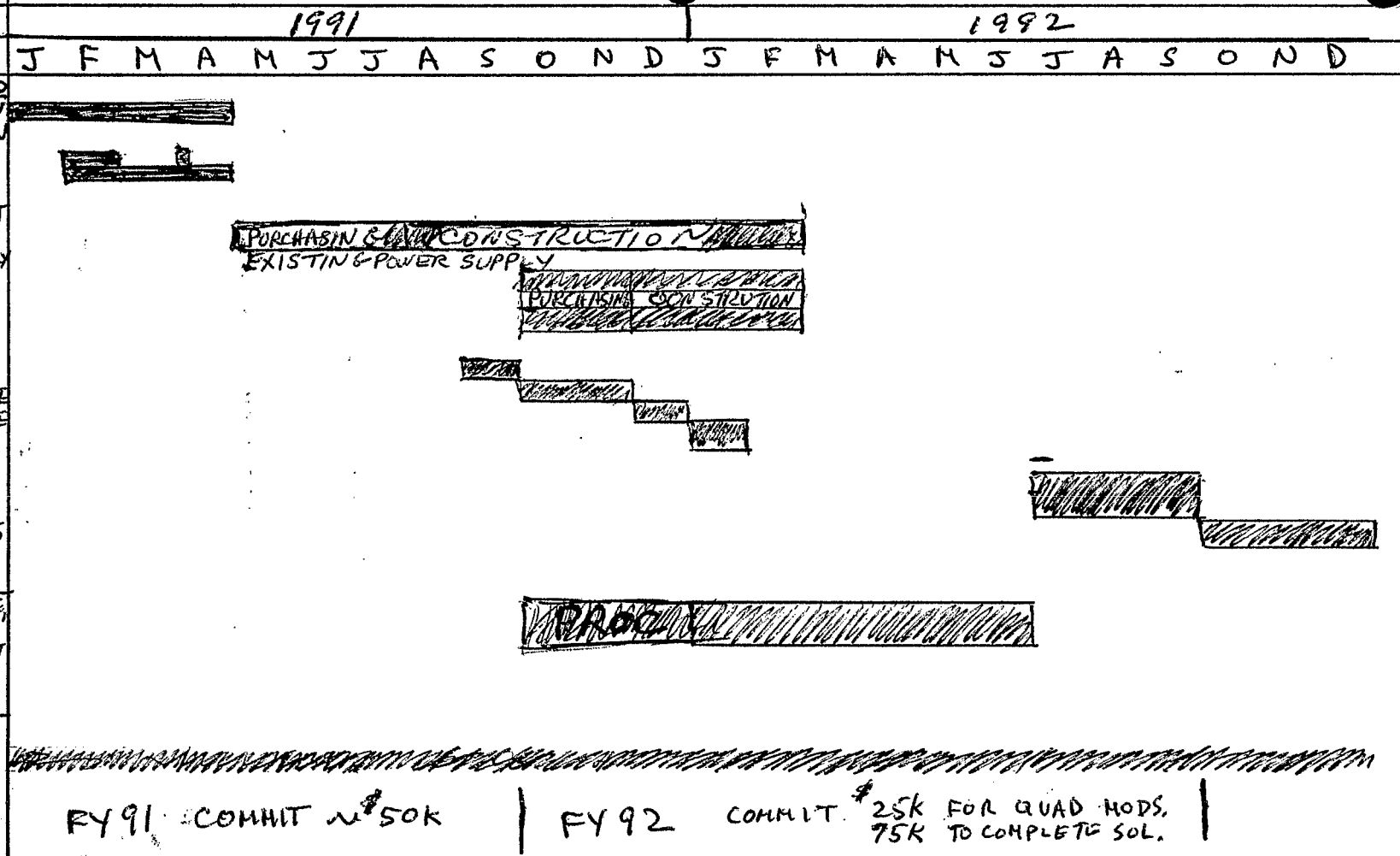
	COST	READY FOR AGS/RHIC TESTS
Phase 1	$149K	Oct. 1992 (FY91 $50K; FY92 $100K)
Phase 2	$44K or $345K	Oct. 1993 (FY93 $345K)
Phase 3	$4.8M or $5.1M	Oct. 1996 (FY94 $2M; FY95 $1.9M; FY96 $0.9 M)

Phase 3 costs do not include experimental detectors nor any new experimental facilities, but does include a polarimeter in RHIC.

The AGS could be used for HEP experiments with polarized beam as soon as the partial snake is commissioned. This could be accomplished by December, 1992.

The following bar charts represent a doable scenario. Phase 1 is rather solid, Phase 2 requires further consideration of RHIC transfer line instrumentation, and Phase 3 requires much more work and probably more money for a complete operating system. The given time frame, however, does seem adequate.

PHASE I

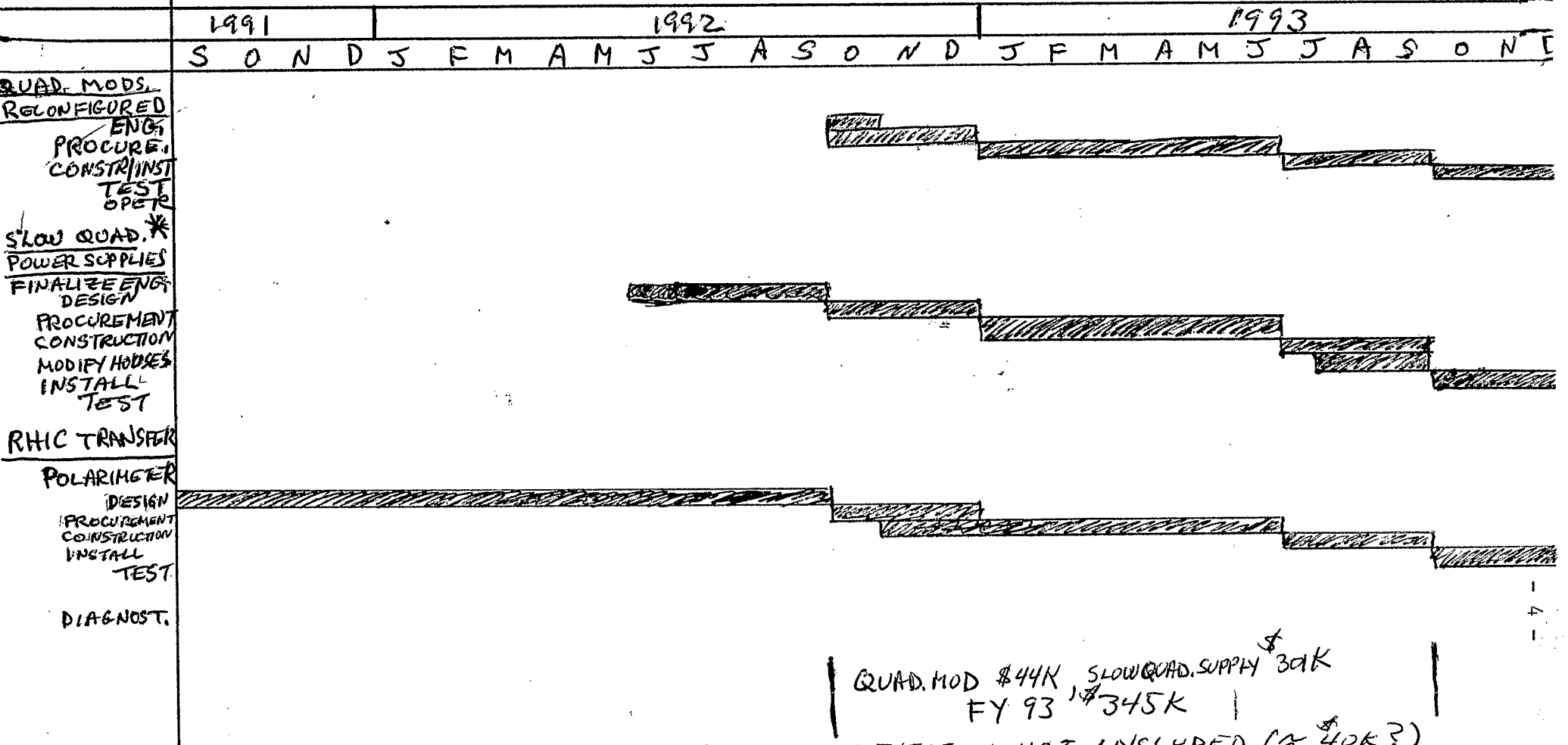


FY 91 : COMMIT #50K | FY 92 COMMIT #25K FOR QUAD MODS, 75K TO COMPLETE SOL.

NOTE 1 : MISC. MATERIAL FOR SOLENOID INCLUDES STANDS, FITTINGS PLUMBING, ELECT. CONNECTIONS, VACUUM CHAMBER & FLANGES

NOTE 2 : THE INTERNAL POLARIMETER SHOULD BE REVIEWED AND EITHER REINSTALLED OR REDESIGNED, IT WOULD BE ADVANTAGEOUS TO ADD A P_H ARM (TO MEASURE POLARIZATION IN THE HORIZONTAL PLANE).

PHASE 2

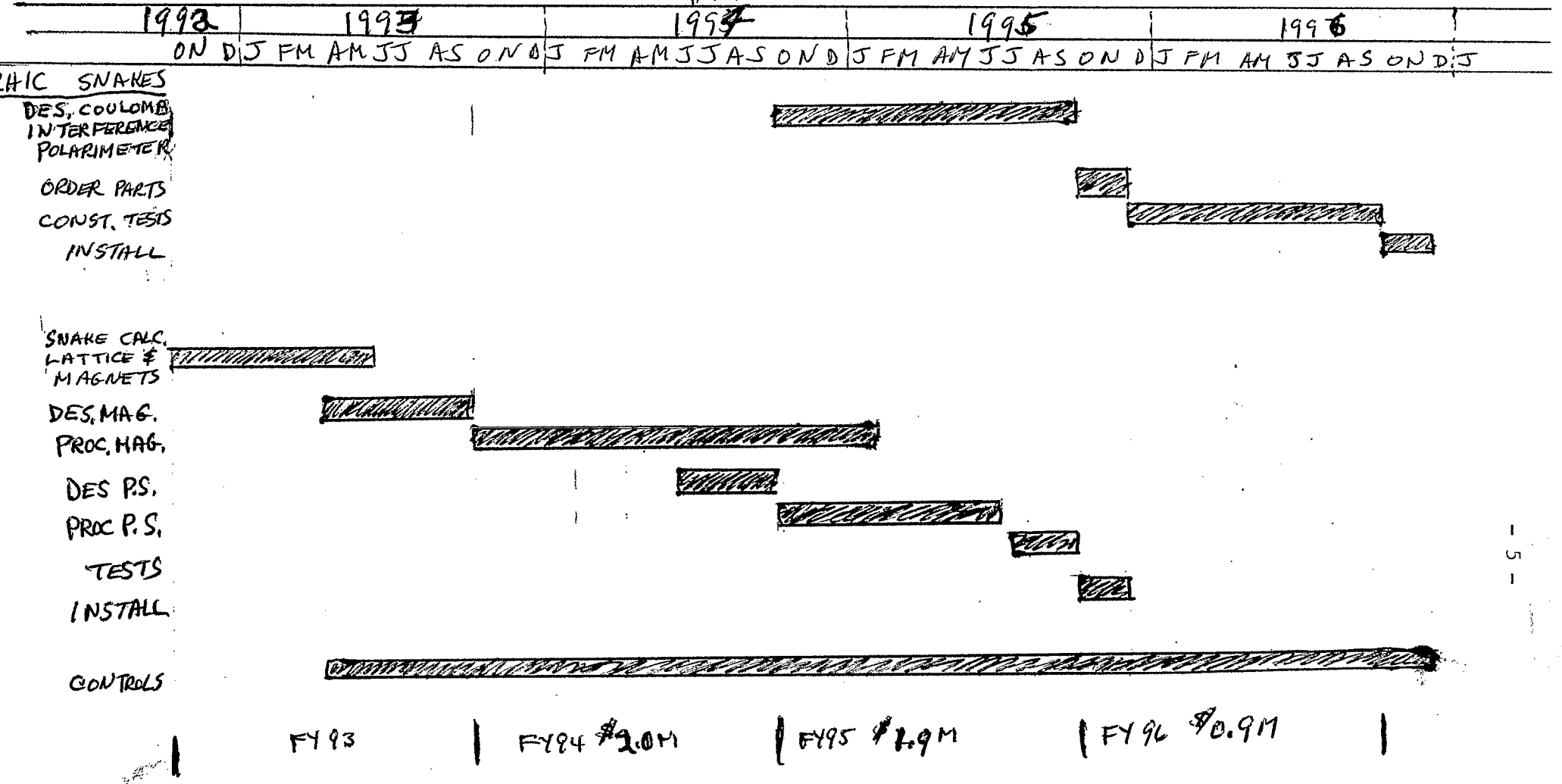


QUAD. MOD $44K, SLOW QUAD. SUPPLY $301K
FY 93 ≈ $345K

NOTE: COSTS FOR RHIC TRANSFER INSTRUMENTATION NOT INCLUDED (≈ $40K?)

* THIS CAN BE DONE EARLIER IN FY92 OR CAN WAIT UNTIL PHASE 3 ($301K)

PHASE 3



NOTE: THIS SCHEDULE ONLY REQUIRES THE TOTAL FUNDING. IT IS NOT TOO IMPORTANT HOW WE SPEND PER YEAR EXCEPT TO INSURE THAT THE LONGEST LEAD ITEM (MAGNETS) IS COMMITED SOON ENOUGH

RECOMMISSIONING AN UPGRADED POLARIZED BEAM FACILITY

As evidenced by the activities of some dozen laboratories around the world, there is a great deal of interest in spin physics. Basically, we see that spin physics experiments are producing challenges to PQCD that have as yet not been answered. Spin may indeed lead to a more complete theory, just a it was an essential ingredient in QED, a calculable theory with unsurpassed success. Today, we have no theoretical explanation of hyperon polarization, no convincing picture of the spin structure of the nucleon, and no ideas of why the analyzing power in proton-proton elastic scattering should be large at high energy and high transverse momentum. These are only a few of the items that are being further explored by on-going experiments. It is also thought that spin in the proposed higher energy machines will provide important tests of standard model predictions as well as giving distinctive signatures for new physics. Physics ideas of exploiting spin to study the strong and weak interactions will be explored at the November, 1990, Polarized Collider Workshop at Pennsylvania State University. Clearly, the first collider available for such tests is RHIC.

The recent history of spin physics is closely tied to the state-of-the-art accelerator physics with the resonance-jumping tests developed for the ZGS and AGS and the development of Siberian Snakes, first tried at IUCF. The AGS is the next logical place after the Indiana University Cyclotron Facility to continue the study of Siberian Snakes. At IUCF, we demonstrated that one could use a snake to cross both an imperfection and an intrinsic resonance. The AGS will allow us to study the behavior of snakes in crossing many resonances as well as other aspects which should be demonstrated before such devices are incorporated into accelerators like the SSC.

It, therefore, seems appropriate that we again prepare to accelerate polarized protons in the AGS with a snake and prepare the AGS to be a suitable injector for RHIC. We view this program as a sequence of several phases that will culminate with a successful injector and a polarized beam capability in RHIC.

The steps necessary to arrive at polarized protons in RHIC have become clear:

1. The Booster/Accumulator provides a high polarized proton luminosity for the AGS and RHIC.

2. A partial Siberian Snake in the AGS will maintain polarization up to RHIC injection energy.

3. An injection momentum of 24.8 GeV/c avoids a spin resonance in the transfer line and is above RHIC transition energy.

4. Two Siberian Snakes per ring will be needed in RHIC; these snakes can be distributed around intersection regions to provide the dual function of maintaining the polarization and preparing longitudinal spins for experiments.

5. By box-car stacking the polarized protons in RHIC, alternate bunches can have opposite polarization. This will largely eliminate systematic errors for the experiments.

Phase 1

In this phase, we address the major problem of the long tune-up time needed to run polarized protons in the AGS. From

past experience, it would take two to three weeks to obtain a high energy polarized beam. This can be reduced to 2-3 days by the use of a Siberian Snake. Based on the experiments at the Indiana University Cyclotron Facility Cooler Ring and on our calculations of the effects in the AGS, we have a conceptual design for a Partial Snake solenoid (Appendix 2) that can give us a polarized beam up to the RHIC injection energy of 24.84 GeV/c ($G\gamma$ = 47-1/2, which is an energy that preserves polarization in going through the RHIC transfer line).

This phase then consists of the following steps:

1. Engineering design and construction of a partial snake solenoid. Installation with a power supply suitable for initial testing.

2. Perform the necessary maintenance for the fast pulsed quadrupole power supplies. The necessary effort is outlined in Appendix 2.

3. Reinstall the 200 MeV and internal polarimeters and check operation and communications to the Main Control Room.

4. Plan to use the normal tune quads and bipolar supplies for a slow tune shift until we obtain suitable power supplies for the new polarized proton slow tune quads (Appendix 3).

5. Install a suitable power supply for the snake. A choice can be made from the table in Appendix 4. There are 2.4 kA, 4.8 kA supplies in the AGS inventory. 9.5 kA can be reached with two 4.8 kA supplies in parallel. Power supplies for RHIC physics operation will probably have to be procured.

With these steps completed, we would begin machine studies of a few days (3-4) at a time addressing the effects of adiabatic turn-on and turn-off of the snake, the efficiency in passing through imperfection resonances, the interaction, if any, with the fast tune corrections and with transition, and to study the stable spin direction in the AGS. As in the past, new phenomena may occur. Phase 1 could proceed in stages of increasing current availability to the snake solenoid by starting with 2.4 kA and then to 4.8 kA and 9.6 kA. This would give momentum limits of about 10, 18, and 22-1/2 GeV/c for the three ranges.

Phase 2

This phase prepares the AGS to reach RHIC injection energy. Tests of the AGS extraction and transfer to RHIC can also be made. The essential steps and hardware are as follows:

1. The fast quad power supply system must be re-arranged so that we can provide a pulse to cross the $36 + \nu$ intrinsic resonance. The effort and cost are in Appendix 5.

2. We must have at least the 9.5 kA power supply to reach 24.8 GeV/c ($P_f/P_i \approx 40$-50%).

3. A polarimeter at the RHIC end of the transfer line would be desirable, but not absolutely necessary at this stage. Should probably measure both P_H and P_V.

4. Again, one would expect better polarization survival if the power supplies of Appendix 3 were available, but again not absolutely necessary.

5. Some instrumentation in the RHIC transfer line.

With the above in place, we again would need periods of a few days to achieve 24.8 GeV/c, extract, and transfer to RHIC.

Phase 3

This phase covers RHIC operation. Given that all of the above steps are completed, this stage requires:

1. A power supply capable of reaching 11.2 or 12.5 kA giving a P_f/P_i of 80-90% (including anticipated intrinsic resonance depolarization).

2. Design, construction, installation, and tests of RHIC snakes (Appendix 6).

3. A RHIC polarimeter that can measure P_V and P_H.

4. Commissioning of Booster to reach higher P↑ intensity. This could be done during any phase.

Studies can then be made in RHIC on snake behavior, spin rotation, polarization reversal, and polarization survival.

Acknowledgment

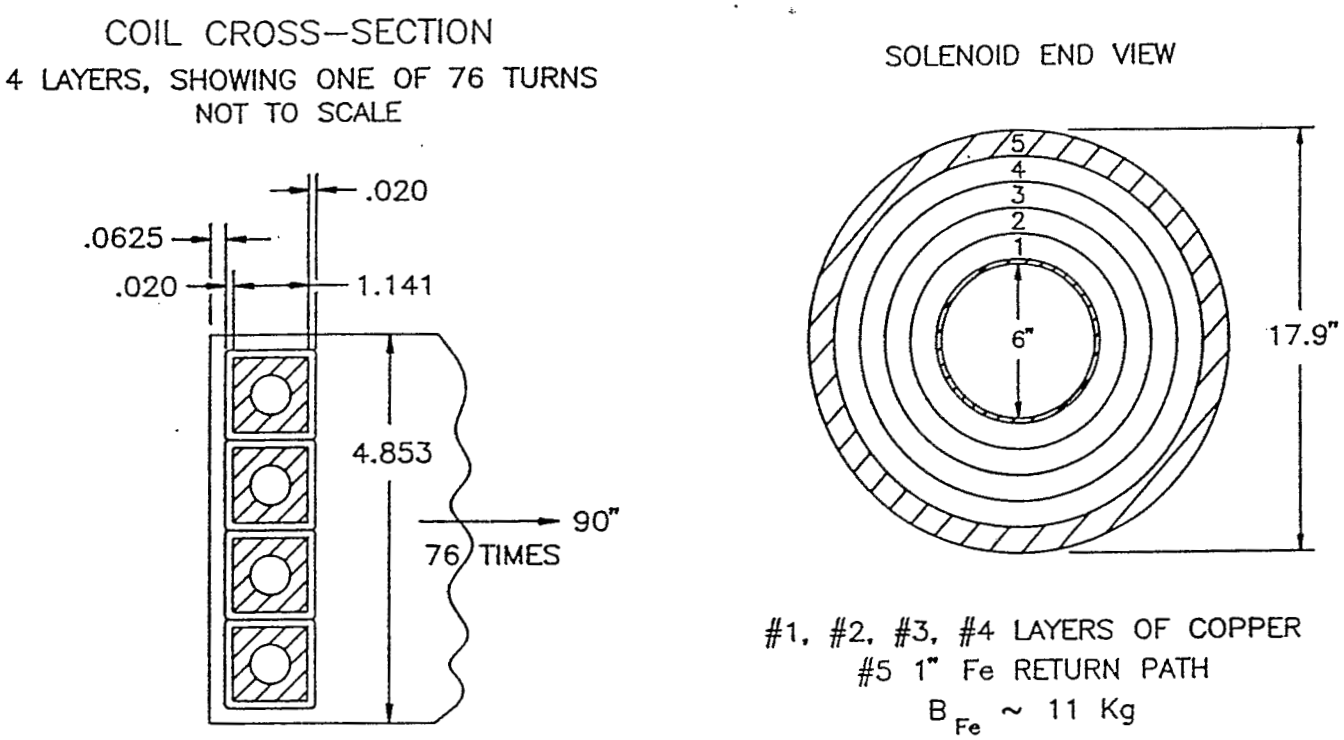
I would like to thank Leif Ahrens and Gerry Bunce for their valuable comments.

APPENDIX 1

PARTIAL SNAKE SOLENOID DESIGN

This version uses 15% more current than the design in BNL-44886 but does not invalidate any conclusions from the previous calculations.

Using OTOKUMPO METALS #6810 29 mm x 29 mm x 16.2ϕ with 0.02" insulation wrap, we can get 76 turns per layer in 90". Use four layers, 304 turns.



Schematic of coil and end view--not to scale.

$\ell_{\text{longest layer}} = 260.4'$, $\ell_{\text{shortest layer}} = 174.9'$,

$\bar{\ell} = 204.15'$, $\ell_{\text{total}} = 4 \times 204.15 = 817'$

$R_{\text{longest layer}} = 2.2\ m\Omega$, $R_{\text{shortest layer}} = 1.28\ m\Omega$

$\bar{R} = 1.76\ m\Omega$, $R_{\text{total}} = 7.04\ m\Omega$

$$L = \frac{0.32\ a^2\ n^2}{6a + 9b + 10c}\ \mu H,$$ where a = 13.943 cm; n =304 turns; b = 228.5 cm; c = 12.327 cm

$L = 5.65\ mH$

An 8° snake would use 11.2 kA and a 9° snake 12.6 kA at 24.8 GeV/c. We will check the electrical and cooling performance for 12.6 kA.

1. Cooling Requirements

   Ramp power supply in 0.6 sec to 12.6 kA

   ∴ Average current ~ 6.3 kA
   $\text{Voltage}_{\text{longest turn}} = 14.2\ V$
   Duty cycle is 0.6 sec/3 sec = 0.2

   ∴ $\text{Power}_{\text{longest turn}} = 6.3 \times 14.2 \times 0.2 = 89.46 \times 0.2 \approx$ 18 KW.

   Keep temperature rise to 10°, requires 6.8 GPM. Total length of four layers = 817' with d = 0.638". Pressure required for 6.8 GPM is

$$\Delta P = \frac{817}{100} \times 4.84 \times 10^{-2} \frac{6.8^{1.85}}{0.638^{4.8655}} = 122 \text{ PSI.}$$

Total average power $\bar{R}_T \bar{I}^2 \times 0.2 = 7.04 \times 6.3 \times 0.2$.

$\bar{P}_{total} \approx 57$ KW $\Rightarrow \Delta T = 31°C$ in whole magnet.

2. Voltages required are shown in Appendix 4.

These requirements are certainly feasible.

APPENDIX 2

FAST QUAD MODULATOR REPAIR AND UPGRADE

Task Description	Man Hours
New Ceramic Tube Cap Assemblies	30
Inspect/Repair Carborundum Resistor Assemblies	38
Repair/Calibrate Hillman Chassis	160
Inspect KV71 Trigger Tubes	15
New BNC Test Points on KV17/71 Chassis	75
Complete Automatic Current Adjust (PEIs)	80
	398 Hrs.

@ 25 hours/week ⇒ 16 man weeks

SPARE PARTS REQUIRED

20 Trigger Thyratron Tubes	$ 6,000
2 Power Thyratrons	4,000
5 Ignitrons	10,000
5 Resistor Assemblies	500
Misc. Components	5,000
Total	$25,500

Procurement and work accomplished between October, 1991 and July, 1992.

APPENDIX 3
(Phase 2 or 3)

BROOKHAVEN NATIONAL LABORATORY
PROPOSAL FOR ACCELERATOR IMPROVEMENTS

Polarized Proton tune Quad Power Supplies

1. Basis

The AGS accelerator requires a larger tune shift than is normally acceptable in order to pass through the intrinsic depolarizing resonances. In order to accomplish this, the power supplies in this project allow a slow shift in the opposite direction to compensate for the fast shift.

2. Description

The twelve correction quadrupoles located in the #3 straight sections will be powered in pairs by six power supplies located in the equipment houses at ground level. Cables for each pair will come down the #18 straight section conduit and feed to the #3 straight sections on either side. Each power supply will be a 60 Amp, 300 V dc unit which will charge a fast capacitive discharge circuit to give a fast rise time of 3 milliseconds. The system will be interfaced to the Apollo control system and will be similar to the system designed for the fast gamma transition jump.

3. Justification

The large fast tune shift would blow up the beam in the AGS. It, therefore, becomes necessary to limit it to a value of 0.2 or less which is accomplished by the above described power supplies.

4. Analysis of Safety and Pollution

There are no potential pollution problems or explosion risks associated with this project, other than those common to high power electrical equipment installation. Fire hazards are also limited to the usual risks inherent with electrical cables and equipment. The electrical installation will be designed and installed to meet or exceed the current national standards and safety codes.

All work will be in accordance with DOE Order 5480.1B "Environmental Protection, Safety and Health Protection Standards", DOE 6430.1A, General Design Criteria Manual, and BNL's Safety Manual.

5. Cost Estimate

A.	Engineering @ approx. 10% of Procurements, Assembly, Installation & Testing		$ 24,000
B.	Procurements		$162,000
	Power Supplies	$40,000	
	Cables	30,000	
	Controls	18,000	
	Bridges	74,000	
C.	Assembly, Installation, and Testing		$ 80,000
D.	Quality Assurance @ 3% of Project Cost		$ 8,000
E.	Contingency @ 10% of Project Cost		$ 27,000
	TOTAL PROJECT COST		$301,000

Estimate is based on the latest manufacturers catalogue prices and engineering estimates using current costs for labor and material.

6. Method of Accomplishment

The engineering, procurement and quality assurance (at $24,000, $162,000, and $8,000, respectively) will be accomplished by BNL. The procurement of materials and components will be accomplished with multiple orders of the fixed-price competitive type wherever possible. Installation and assembly will be carried out at the job site by BNL personnel. The work is considered "non-covered" work, not subject to the Davis-Bacon Act, Ref., DEAR 970-2273 (a)(3) (Research machinery and equipment, assembly, modifications, rearrangement and setup).

7. Schedule

	Start	Complete
Engineering	June, 1992	October, 1992
Procurement	October, 1992	July, 1993
Assembly, Installation, and Testing	July, 1993	December, 1993

APPENDIX 4

Power Supply	Beam Momentum	Snake* Angle θp	% Snake	P_f/P_i	Comment
2.4 kA	7.5 GeV/c	6°	3.3	100%	Cross $G\gamma=7-14, 0+\nu$
@40 V	8.9	5°	2.8	93	Cross $G\gamma=7-17$, transition
	10.0	4.5°	2.5	80	$G\gamma=24-\nu, 0+\nu$; good choice to start machine physics
4.8 kA	12.9 GeV/c	7°	3.9	100%	Cross additional
@80 V	15.0	6°	3.3	99.5	resonances. Study $G\gamma=27$ &
	18.0	5°	2.8	83	$36-\nu$ interference. A
	18.5	4.5°	2.5	56	possible physics run at 18.5 GeV/c with about 40% polarization.
9.5 kA	22.5	7°	3.9	100%	Machine studies. Physics
@120 V					run. 1.0 sec rise time instead of 0.6 sec. at 7°
7.1 kA		6°	3.3	100	and back to 0.6 sec. at
6.5 kA		5.5°	3.1	93	5.5°.

To go 24.8 GeV/c we need system upgrade to get $36+\nu$ correction pulse (Appendix 5).

9.5 kA @ 120 V	24.8	7°	3.9	50%	RHIC injection energy. Study transfer, extraction and RHIC 1.4, sec rise time.
11.2 kA @184 V	24.8	8°	4.4	90%	RHIC Operation with sufficient voltage for 0.6 sec. rise time.
12.5 kA @205 V	24.8	9°	5.0	100%	

*Note: 100% snake is a precession angle $\theta p = 180°$.

There are 2.4 kA and 4.8 kA supplies in the AGS inventory. Two (2) 4.8 kA supplies in parallel can be used for 9.5 kA. New supplies probably needed for RHIC operation.

APPENDIX 5

$G\gamma = 36 + \nu$ CORRECTION PULSE

Because of the phased start-up for the initial polarized beam facility, we configured our fast quad systems to reach only 23 GeV/c. We did not set up for the $36 + \nu$ resonance correction. We, therefore, now have to reconfigure our equipment so we can cross $G\gamma = 36 + \nu$ and reach RHIC injection energy. The following table lists the shuffling that is needed where "OLD" is our original set up and "NEW" is what is necessary now.

Fast Quad Modulator Upgrade

Present and Possible Phase 2 or 3 Configuration

P1 New Spare	1000A	1.2 ms	LV1 7.5A	600 μf	500 μh	0.75 Ohm
P4 Old 24+v	1000A	1.2 ms	LV5 7.5A	600 μf	500 μh	0.75 Ohm
N1 New 0+v	550A	3.0 ms	LV2 5A	800 μf	1500 μh	2.0 Ohm
N1 Old Spare	500A	3.5 ms	LV --	800 μf	1500 μh	2.0 Ohm
P2 New Spare	24-v		LV3 15A	100 μf	1000 μh	4.4 Ohm
P2 Old Spare	200A	1.0 ms	LV ---	100 μf	100 μh	4.4 Ohm
N2 New 13+v	1300A	3.0 ms	LV 15A	1700 μf	500 μh	1 Ohm
N2 Old 48-v	1100A	3.0 ms	LV6 15A	1700 μf	500 μh	1 Ohm
P3 New 36-v	2250A	3.0 ms	LV5 25A	2000 μf	500 μh	0.75 Ohm
P3 Old 0+v	1400A	3.5 ms	LV1 15A	2000 μf	500 μh	0.75 Ohm
N3 New 24+v	1000A	3.0 ms	LV6 15A	1700 μf	500 μh	1 Ohm
N3 Old 24-v	600A	1.0 ms	LV2 5A	300 μf	350 μh	2 Ohm
P4 New 48-v	1200A	3.0 ms	LV7 15A	2000 μf	500 μh	0.75 Ohm
P1 Old 12+v	1400A	3.5 ms	LV3 15A	2000 μf	500 μh	0.75 Ohm
N4 New 36+v	2250A	3.5 ms	LV8 25A	2000 μf	500 μh	0.75 Ohm
N4 Old 36-v	2250A	3.5 ms	LV4 25A	2000 μf	500 μh	0.75 Ohm

MANPOWER REQUIREMENTS

Reconfigure power supplies and cables in E-10 House:

1 Week, 2 Technicians = 2 Man Weeks

Reconfigure pulses in 10 houses, change on ignitron, and add one ignitron

3 Weeks /hs, 2 Technicians = 60 Man Weeks

HARDWARE REQUIREMENTS

	Unit Price	Total
50 One Ohm Resistors	$ 30	$ 1,500
100 Resistor Clamps	$ 10	$ 1,000
11 500 μH Inductors	$ 300	$ 3,300
12 500 μf Capacitors	$ 800	$ 9,600
24 100 μf Capacitors	$ 300	$ 7,200
12 Ignitrons	$1,500	$18,000
Misc. Cables/Clamps	$ 200/hs	$ 2,000
Ignitron Mounting Hardware	$ 100/hs	$ 1,000
		$43,600

This allows us to get to P = 26.4 GeV/c which was the original design goal for the AGS and, of course, to inject at RHIC energy of 24.87 GeV/c.

APPENDIX 6

COST "GUESSTIMATE" FOR RHIC

SNAKES AND POLARIMETERS

E.D. Courant and S.Y. Lee have presented a design for a split Siberian Snake which can also function as a spin rotator and thus reduce the number of magnets necessary to preserve and rotate polarization in RHIC. Using split snakes then requires only two such devices per ring or 32 magnets for RHIC. A conceptual design of room-temperature magnets for such snakes has been made. A 2 M long picture frame magnet at 13.75 KG with a 1" V x 5" H gap costs out at $50,000/magnet. These are long magnets and 1/2 M or 1 M superconducting magnets should be considered. An estimate for a 1/2 M, 3" diameter, 5.4T magnet has recently been made for the 200 GeV SSC booster. This came to about $50,000. A 5" diameter for RHIC would be more expensive, but power supplies would be cheaper. Costs appear to be competitive between room temperature and SC magnet systems. Available straight section length might be a decisive factor. There will be additional costs besides these to get an operational system.

4 Snakes (32 magnets)	$1.6 M
Cabling & Controls	0.8 M
Power Supplies	0.7 M
	$3.1 M
Coulomb-Nuclear Interference Polarimeter	$0.8 M
	$3.9 M
Contingency, Engineering, Quality Control	$0.9 M
TOTAL	$4.8 M

APPENDIX 7

PROPOSAL FOR ACCELERATOR IMPROVEMENTS

PARTIAL SIBERIAN SNAKE

1. Basis

The AGS accelerator must overcome depolarizing resonances in order to accelerate a polarized proton beam. The Siberian snake of this project allows this to be done in a very efficient manner.

2. Description

The partial Siberian snake for this project will be a 4 T-M room-temperature solenoid which will be built and installed in a 10-foot long AGS straight section. It will be connected to various existing power supplies which will supply currents from approximately 2 kA to 9.6 kA at 125 V or less as desired for various tests and programs. These will ramp the solenoid field currents synchronously with the AGS. The solenoid current will then be discharged through a bridge circuit on flattop in about 100 msec. The entire system will be interfaced to the Apollo control system in a similar manner to our existing pulsed magnets.

3. Justification

The AGS accelerator presently requires 2-3 weeks of dedicated tune-up time in order to operate with an accelerated polarized proton beam. The partial Siberian snake should allow this time to be reduced to 2-3 days and also to provide a beam with a much higher polarization for AGS experiments, as well as for injection into RHIC. A phased procedure allows the initial use of smaller power supplies which will extend the scope of accelerator research on snakes from the recent work at the Indiana University Cyclotron Facility. This research will be directly applicable to snakes in RHIC and SSC.

4. Analysis of Safety and Pollution

There are no potential pollution problems or explosion risks associated with this project, other than those common to high power electrical equipment installation. Fire hazards are also limited to the usual risks inherent with electrical cables and equipment. The electrical installation will be designed and installed to meet or exceed the current national standards and safety codes.

All work will be in accordance with DOE Order 5480.1B "Environmental Protection, Safety and Health Protection Standards", DOE 6430.1A, General Design Criteria Manual, and BNL's Safety Manual.

5. Cost Estimate

A. Engineering @ approximately 10% of Procurements, Assembly, Installation, and Testing		$ 10,000
B. Procurements		
Copper	$30,000	
Steel	1,000	
Fixtures + Central Tube	20,000	
Misc.	5,000	
Cables	5,000	
Controls	10,000	
Bridge Circuit	10,000	$ 81,000
C. Assembly, Installation, Testing		$ 20,000
D. Quality Assurance @ 3% of Project Cost		$ 3,300
E. Contingency @ 10% of Project Cost		$ 10,000
TOTAL PROJECT COST		$124,300

6. Method of Accomplishment

The engineering, procurement and quality assurance (at $10,000, $81,000, and $3,300, respectively) will be accomplished by BNL. The procurement of materials and components will be accomplished with multiple orders of the fixed-price competitive-type wherever possible. Installation and assembly will be carried out at the job site by BNL personnel. The work is considered "non-covered" work, not subject to the Davis-Bacon Act, Ref. DEAR 970-2273 (a)(3). (Research machinery and equipment, assembly, modifications, rearrangement and setup).

7. Schedule

	Start	Complete
Engineering	Jan. 1991	May 1991
Procurement	May 1991	March 1992
Assembly, Installation, Testing	July 1992	December 1992