Chapter 21.
Installation and Testing the Hardware

Revised March 1994

A workshop was held on March 10, 1994 on the work breakdown and schedule for installation and commissioning the hardware. A first pass schedule was done. Briefly, this schedule is as follows:

Commissioning the Storage Ring Magnet	November, 1994 - January, 1995
Shimming the Magnetic Field	January, 1995 - August, 1995
Installation of vacuum chambers, etc.	August,1995 - January, 1996
Commissioning with the beam begins	January, 1996

The detailed work breakdown presented at the workshop with schedule and leadership responsibility is shown in Appendix I. The calendar time is shown at level 3. The detailed time estimates are shown at lower levels. The detailed estimates may not add up to the calendar time, because some activities are in parallel, etc.

1.10	Installation & Testing	W. Morse
1.10.1	Commissioning Storage Ring Magnet - 11 weeks	W. Morse
1.10.1.1	Cool down - 2 wks	L. Jia
1.10.1.1.1	Cryo system evacuation - 1 week	
1.10.1.1.2	Cryo system set-up - 0.5 day	
1.10.1.1.3	Start refrigerator - 2 days	
1.10.1.1.4	Magnet system cool-down - 3 days	
1.10.1.1.2	Power to half nominal current - 2 weeks	G. Bunce
1.10.1.1.3	Magnetic measurements at half current -2 weeks	K. Woodle
1.10.1.1.4	Extract the energy with the quench protection circuit - 1 day	G. Bunce
1.10.1.1.5	Analyse the coil instrumentation data and compare with the quench analysis.	G. Bunce
1.10.1.1.6	Power to half current and repeat magnetic measurements - 1 week	K. Woodle
1.10.1.1.7	Study methods to "degauss" magnet to correct magnetic effects due to quench-back - 2 weeks	K. Woodle

1.10.1.1.8	Make decision on quench protection based on results of tests.	W. Morse
1.10.1.1.9	Power to full current - 1 day	G. Bunce
1.10.1.1.10	Make magnetic measurements and re-evaluate decision - 1 week	K. Woodle
1.10.2	Shim Magnetic Field - 27 weeks	K. Woodle
1.10.2.1	Install & Test Power Supply	J. Geller
1.10.2.1.1	Quench Protection	
1.10.2.1.2	NMR Feedback	
1.10.2.1.3	Transductor	
1.10.2.1.4	Reversing Switch	
1.10.2.1.5	Controls	
1.10.2.2	Install & Test Shim Trolley	I. Polk
1.10.2.2.1	Capacitec	S. Dhawan
1.10.2.2.2	Trolley NMR	R. Prigl
1.10.2.2.2.1	low-field NMR	
1.10.2.2.2.2	full-field NMR	
1.10.2.2.3	Drive	I. Polk
1.10.2.2.4	Azimuth Readout	J. Cullen
1.10.2.2.5	Computer Control	K. Woodle
1.10.2.3	Install & Test Shimming Fixed NMR	R. Prigl
1.10.2.3.1	low-field NMR	
1.10.2.3.2	full-field NMR	
1.10.2.4	Install & Test Radial Field Meas.	G. Danby
1.10.2.5	Install & Test Yoke Tilt Sensors	G. Danby
1.10.2.6	Yoke Corrections	I. Polk
1.10.2.7	Install Inflector Field Measurement	W. Meng
1.10.2.8	Map Field	R. Prigl
1.10.2.9	Map Radial Fiel	G. Danby
1.10.2.10	Survey Gap	S. Dhawan
1.10.2.11	Wedge Corrections	Z. Armoza
1.10.2.12	Rose Shim Corrections	Z. Armoza
1.10.2.13	Install & Test Pole-face windings	S. Dhawan
1.10.2.14	Pole-face Winding Corrections	S. Dhawan
1.10.3	Installation - 17 wks	W. Morse
1.10.3.1	Beam Vacuum Chamber	L. Snydstrup

1.10.3.1.1	Vacuum Chamber Sectors - 11 wks	L. Snydstrup
1.10.3.1.1.1	Clean/Bakeout - 440 hrs	D. Hseuh
1.10.3.1.1.2	Vacuum Test - 360 hrs	D. Hseuh
1.10.3.1.2	Bellow Adapters - 4 wks	L. Snydstrup
1.10.3.1.2.1	Clean Parts - 24 hrs	“
1.10.3.1.2.2	Assemble Rails/Scrapers - 104 hrs	“
1.10.3.1.2.3	Vacuum Test - 48 hrs.	D. Hseuh
1.10.3.1.3	Standard Support Frames - 8 wks	L. Snydstrup
1.10.3.1.3.1	Clean/Assemble/Align Frame - 110 hrs	“
1.10.3.1.3.2	Clean/Polish Quad Elec/Leads - 224 hrs	“
1.10.3.1.3.3	Assy/Align Quad Elec/Insul/Leads - 224 hrs	“
1.10.3.1.4	Special Support Frames (5) - 4 wks	L. Snydstrup
1.10.3.1.4.1	Clean/Assy/Align Trolley Gar Frame - 24 hrs	“
1.10.3.1.4.2	Clean/Assy Trolley Drive Frame - 24 hrs	“
1.10.3.1.4.3	Clean/Assy Inflector Frame - 64 hrs	“
1.10.3.1.4.4	Clean/Assy Fiber Monitor/PU Elec Frame - 72 hrs	“
1.10.3.1.5	Assemble/Align Vac Chbr Sectors/Sup Frm - 8 wks	L. Snydstrup
1.10.3.1.5.1	Assy/Align - 216 hrs “	
1.10.3.1.5.2	Vacuum Test - 384 hrs	D. Hseuh
1.10.3.1.5.3	Electrical Test (Quads)	Y. Semertzizidis
1.10.3.1.6	Vacuum Ring Assy - 17 wks	L.Snydstrup
1.10.3.1.6.1	Install/Align Inflector Chbr in Magnet - 240 hrs	C. Pai
1.10.3.1.6.2	Test/Shim Inflector	W. Meng
1.10.3.1.6.3	Assemble/Align Vac Chbrs/Belllows in Ring (include NMR fixed probes) -960 hrs	L. Snydstrup
1.10.3.1.6.4	Install NMR Plunge Probe, Fiber Monitor, Calibrate Position - 160 hrs	L. Snydstrup
1.10.3.1.6.5	Test/Checkout NMR Plunge Probe	S. Dhawan
1.10.3.1.6.6	Test/Checkout Fiber Monitor	Y. Mizumachi
1.10.3.1.6.7	Test/Checkout Quad Electrodes	Y. Semertzizidis
1.10.3.1.6.8	Install/Test/Checkout Trolley System	R. Prigl
1.10.3.2	Beam Vacuum System - 2 months	D. Hseuh
1.10.3.2.1	Gate Valves, Pumps, Gauges - 12 man-days	D. Hseuh
1.10.3.2.2	Utilities (Air, N2 Vent.) - 4 man-days	D. Hseuh
1.10.3.2.3	Instrumentation and Cabling - 15 man-days	J. Geller
1.10.3.2.4	Vacuum PLC and CPU - 10 man-days	J. Geller

1.10.3.3	Quad High Voltage System - 3 weeks	Y. Semertzidis
1.10.3.3.1	Install Ac Power to 4 Rack stations	3 days 6-95
1.10.3.3.2	Install 4 high voltage racks	4 " -
1.10.3.3.3	Install 8 high voltage conduits	4 " -
1.10.3.3.4	Install Dielectric gas system	2 " -
1.10.3.3.5	Install Quad pulsing controls	1 " -
1.10.3.3.6	Install High voltage Protection system	3 " -
1.10.3.3.7	Connect to Slow Controls	1 " -
1.10.3.3.8	Connect to Vacuum Inhibit Line	1 " -
1.10.3.3.9	High Voltage Test	1 " -
1.10.3.4	Detectors - 4 months	J. Miller
1.10.3.4.1	Install 1 or two complete stations w/electronics calibration May,1995	D. Hertzog
1.10.3.4.2	Install all detectors 1 mo Sept. 1-Oct 1, 1995	D. Hertzog
1.10.3.4.3	Install all electronics 1 mo Oct 1-Nov 1, 1995	R. Carey
1.10.3.4.4	Install cables 1 week Sept 1995	D. Hertzog
1.10.3.4.5	Wire in, shake down, calibrate electronics 2 months Oct-Dec, 1995	R. Carey
1.10.3.5	DAQ & Control - 13 months	P. Cushman
1.10.3.5.1	Purchase Host Computer 8/94	Timmermans
1.10.3.5.2	Occupy Control Room 9/94	Timmermans
1.10.3.5.3	Cold Test(Slow Control integration on Host)10-11/94	Stillman/Lopati
1.10.3.5.4	Install test beam VME crate4-5/95	Hertzog/Timmerman
1.10.3.5.4.1	supply Temporary host	
1.10.3.5.4.2	hook up CPU and ethernet	
1.10.3.5.4.3	Install and test WFD, MTDC	
1.10.3.5.4.4	Install and connect CAMAC	
1.10.3.5.5	Install Flight Simulator and Host interface 6/95	Hertzog
1.10.3.5.6	Install event-builder VME crate 5/95	Timmermans
1.10.3.5.6.1	Connect ethernet to host and test	
1.10.3.5.6.2	Install and connect fast CAMAC	
1.10.3.5.6.3	Set up Tape Drive and diff'l SCSI	
1.10.3.5.7	Install 2 VME stations in Ring 6/95	Carey/Worstell
1.10.3.5.7.1	Connect MXI interconnect to central crate	

1.10.3.5.7.2	Test WFD, MTDC readout to tape and host monitoring	
1.10.3.5.8	Flight Simulator Run on 2 stations 7/95	Hertzog
1.10.3.5.9	Install and test 4 more VME stations as calorimeters	Carey/Worstell
become ready.	7/95-10/95	
1.10.3.5.10	Transfer testbeam crate to Cont Rm as spare.10/95	Timmermans
1.10.3.5.11	Full Flight Simulator Run 11/95-12/95	Hertzog
1.10.3.5.12	Data taking 1/96–¿	Everyone
1.10.3.6	Magnetic Field Control	S. Dhawan
1.10.3.6.1	DCC	TBA
1.10.3.6.1.1	Installation of 72 coils - 2 hrs ea = 140 hrs	
1.10.3.6.1.2	Cabling from DCC to control rack 1 hr ea = 72 hrs	
1.10.3.6.1.3	Installation of DCC Power Supply Rack and control system - 3 days	
1.10.3.6.2	Surface Coils	TBA
1.10.3.6.2.1	Installation of 72 coils - 2 hrs each = 144 hrs	
1.10.3.6.2.2	Cabling from coils to control rack 300 cables @ 1/2 hr each = 150 hours	
1.10.3.6.2.3	Installation of DCC Power Supply Rack and Control systems = 5 days	
1.10.3.6.3	NMR	TBA
1.10.3.6.3.1	Control Electrons and VME = 5 days	
1.10.3.6.3.2	Fix probes 300 @ 1/6 hours = 50 hours	
1.10.3.6.3.3	Plunging Probes 10 @ 4 = 40 hours	
1.10.3.6.3.4	Calibraton Probe = 10 hours	
1.10.3.6.3.5	Cabling = 5 days	
1.10.3.7	Inflector	W. Meng
1.10.3.7.1	Cryostat installation	C. Pai
1.10.3.7.2	Power Sypply installation	J. Sandberg
1.10.3.7.3	Leads and He Transfer Line	L. Jia
1.10.3.7.4	Instrumentation & Control	A. Stillman
1.10.3.8	Beam Monitors - Oct. 94-Dec.95	L. Roberts
1.10.4	Testing - 4 weeks	W. Morse

1.10.4.1	Beam Vacuum - 4 weeks	D. Hseuh
1.10.4.1.1	Vacuum Testing, Conditioning - 10 man-days	D. Hseuh
1.10.4.1.2	Electrical - 10 man-days	J. Geller
1.10.4.1.3	PLC & Interlock - 10 man-days	J. Geller
1.10.4.2	Quads - 2 wks	Y. Semertzidis
1.10.4.2.1	Connect Quads to High Voltage system	4 days
1.10.4.2.2	High Voltage Commissioning, Magnet Off	2 "
1.10.4.2.3	High Voltage Commissioning, Magnet On	2 "
1.10.4.2.4	Run Quads in Beam Tuning Mode	1 "
1.10.4.2.5	Run Quads in Data Taking Mode	1 "
1.10.4.2.6	Test Slow Control and Run Controls	1 "
1.10.4.2.7	Test other interactive systems	1 "
1.10.4.3	Detectors	J. Miller
1.10.4.3.1	Detector calibration Spring and summer 1995 at a test beam	
1.10.4.3.2	Test 1 or 2 complete stations w/flight sim, calibration syst. in ring May 1995-Oct 1995	
1.10.4.3.3	Test all detectors and electronics Oct-Dec 1995.	
1.10.4.4	Magnetic Field Control - 5 weeks	S. Dhawan
1.10.4.4.1	DCC Tests = 1 week	
1.10.4.4.2	Surface Coil Tests = 1 week	
1.10.4.4.3	NMR Testing = 3 weeks	
1.10.4.5	Inflector	W. Meng
1.10.4.5.1	Cryostat Vacuum Test	C. Pai
1.10.4.5.2	Power Supply Test	J. Sandberg
1.10.4.5.3	Cryogenic Supply	L. Jia
1.10.4.5.4	Instrument Control	A. Stillman
1.10.4.6	Beam Monitors - no schedule	L. Roberts

Chapter 22.
Storage Ring Commissioning with Beam

Revised April 1994

22.1. Introduction

The muon $(g-2)$ storage ring is a unique storage ring which differs from conventional storage rings in several important aspects. There is no RF power, or cooling, so it is essentially a static device. The magnetic field value is fixed by the equilibrium radius and the magic momentum to be $\sim 1.45\ T$. The n value of 0.135 for the ring was chosen both to avoid resonances, and because it could be achieved with reasonable high voltages ($\pm 30\ kV$) and modest coverage of the storage region ($\sim 33\%$) with electrostatic quadrupoles. The quadrupole and vacuum system can be brought into operation before the beam is available, as can the superconducting inflector.

Furthermore, because of the finite muon lifetime ($64.4\ \mu s$ at the magic value of γ), and a cyclotron period of $149\ ns$, one has a maximum of approximately 4000 turns following injection. This means that the usual equilibrium of stable orbits is never reached and there will be particle losses during the entire storage time. These muon losses will be monitored during the storage time, and they have been studied with the tracking code.

The only parameters which can be "tuned" to optimize injection (besides the steering of the incident beam) are the inflector angle, and, in the case of pion injection, the incident beam momentum.

The only other parameter which can be changed is the high voltage on the electrostatic quadrupoles, as discussed in Chapter 5. Initially the quads will be powered asymmetrically, so that the beam is displaced sideways and vertically. After 100 turns, the lower voltage plates are brought up to full voltage over 50 turns, so that they are powered symmetrically, with a quadrupole field centered on the storage aperture. The scraping voltage can be varied, as can the final voltage which will change the average field index of the weak focussing ring.

Muon injection introduces an additional complication, since the fast kicker must be fired such that the full kick is there when the bunch enters, and then gone 149ns later. The beam momentum will be set at the "magic momentum", but there will need to be some optimization of the full aperture kicker, when it is brought on-line.