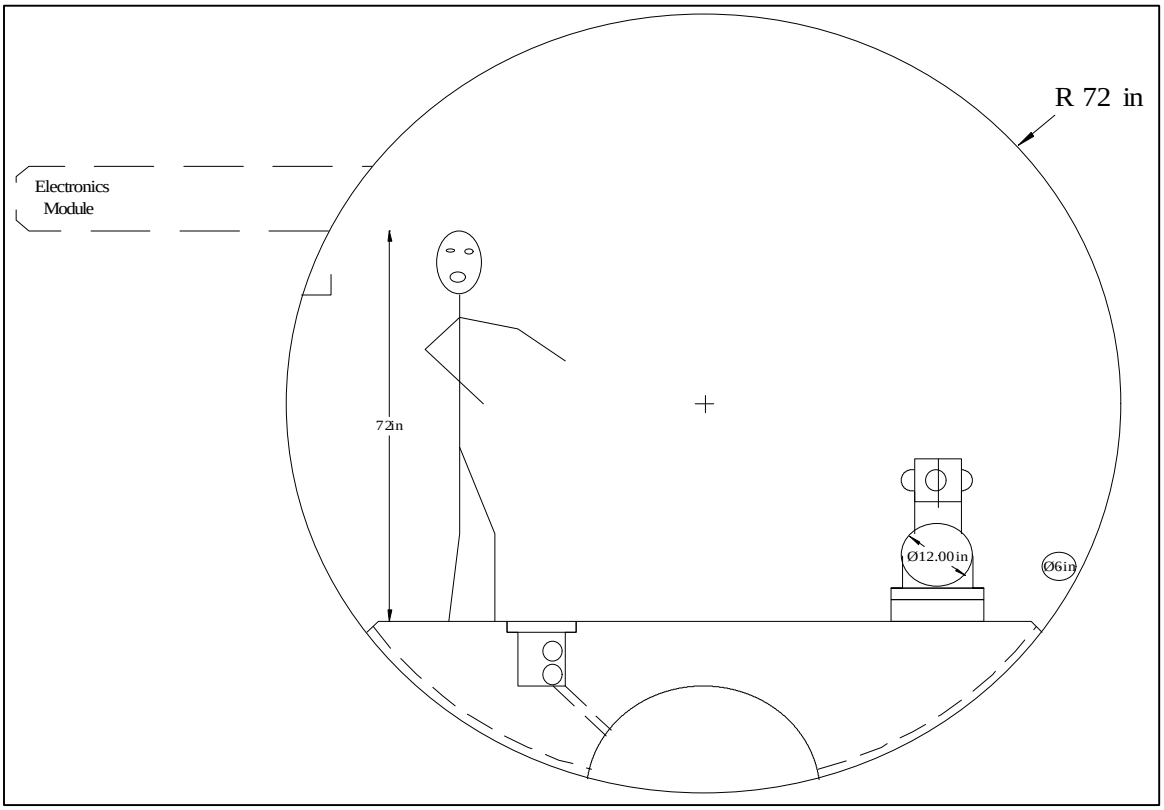
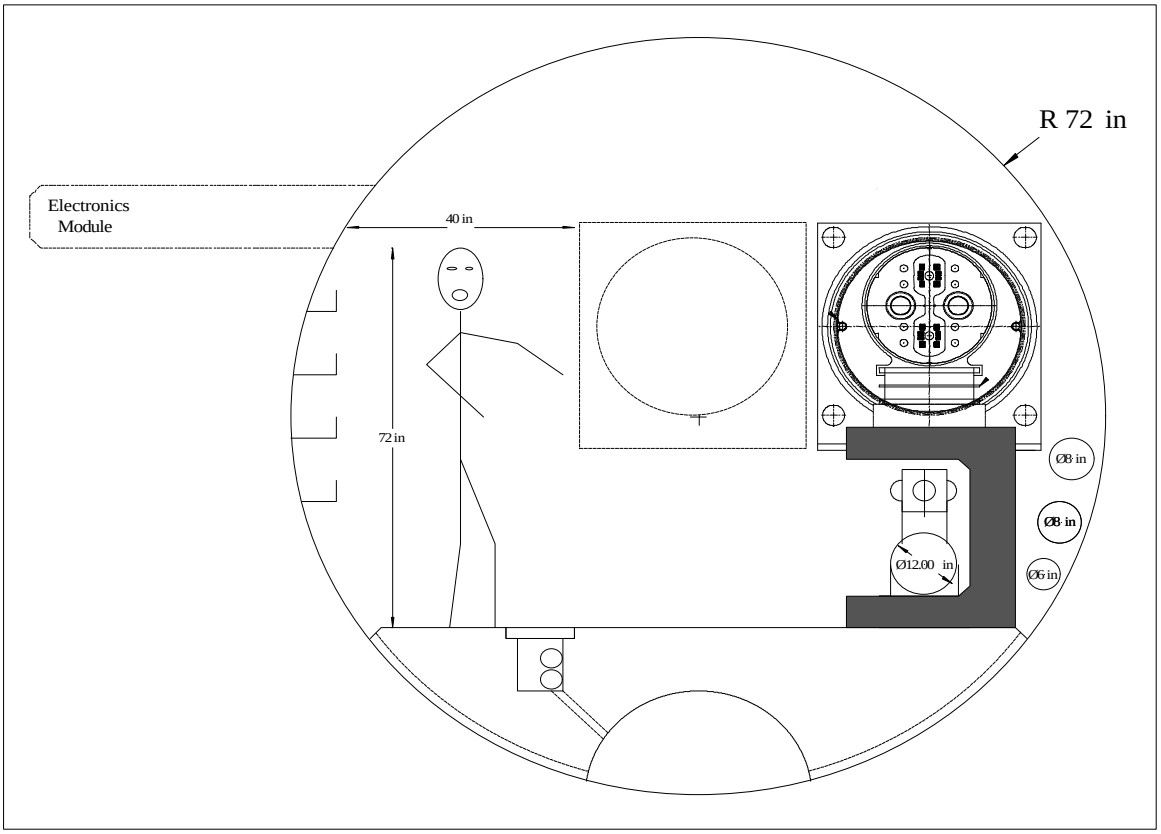
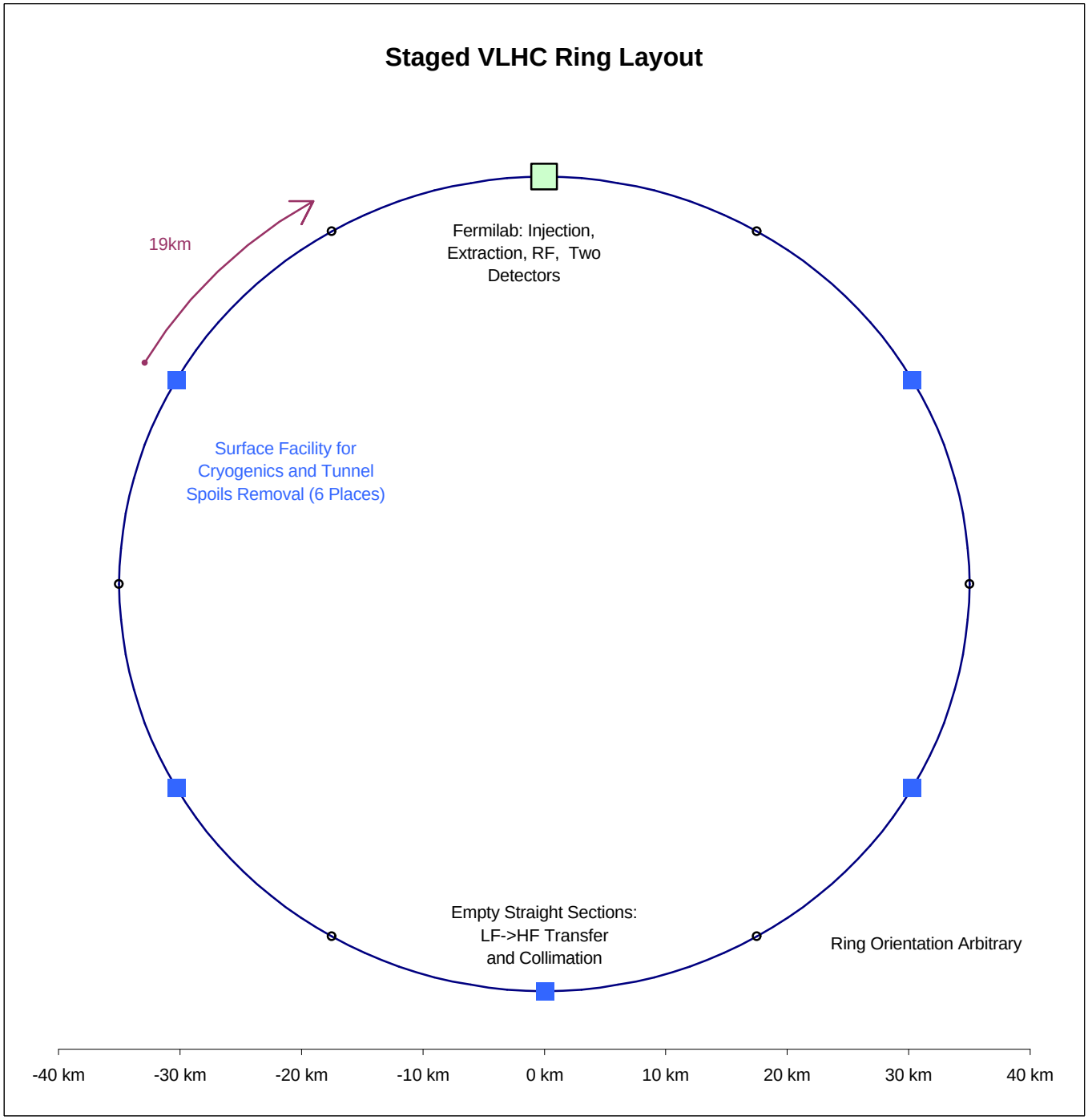
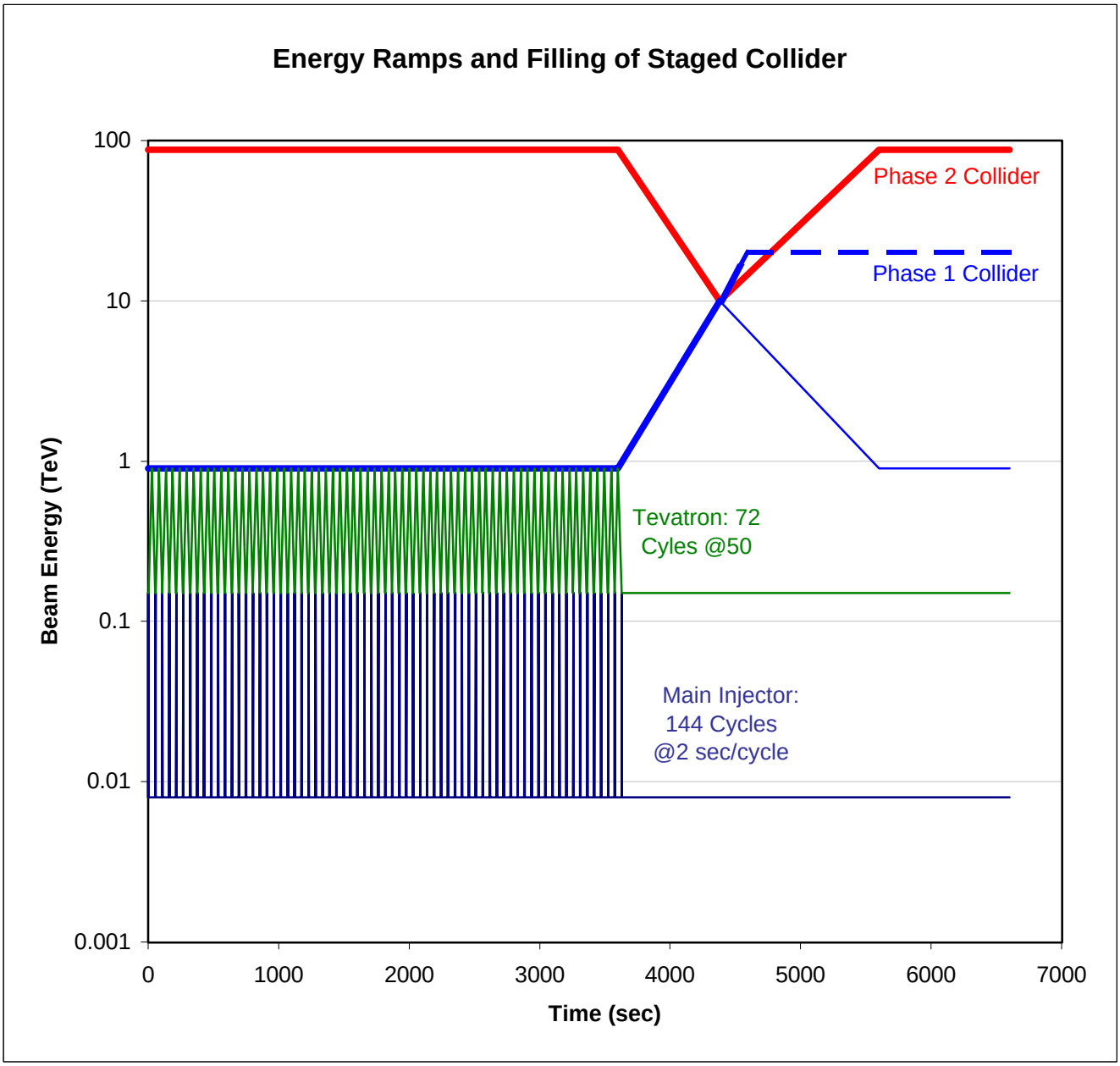

R 72 in
Electronics
Module
72in
Ø12.00in
Ø6in


R 72 in
Electronics
Module
40 in
72 in
Ø8 in
Ø8 in
Ø12.00 in
Ø6 in


Staged VLHC Ring Layout
19km
Fermilab: Injection, Extraction, RF, Two Detectors
Surface Facility for Cryogenics and Tunnel Spoils Removal (6 Places)
Empty Straight Sections: LF->HF Transfer and Collimation
Ring Orientation Arbitrary
-40 km
-30 km
-20 km
-10 km
0 km
10 km
20 km
30 km
40 km

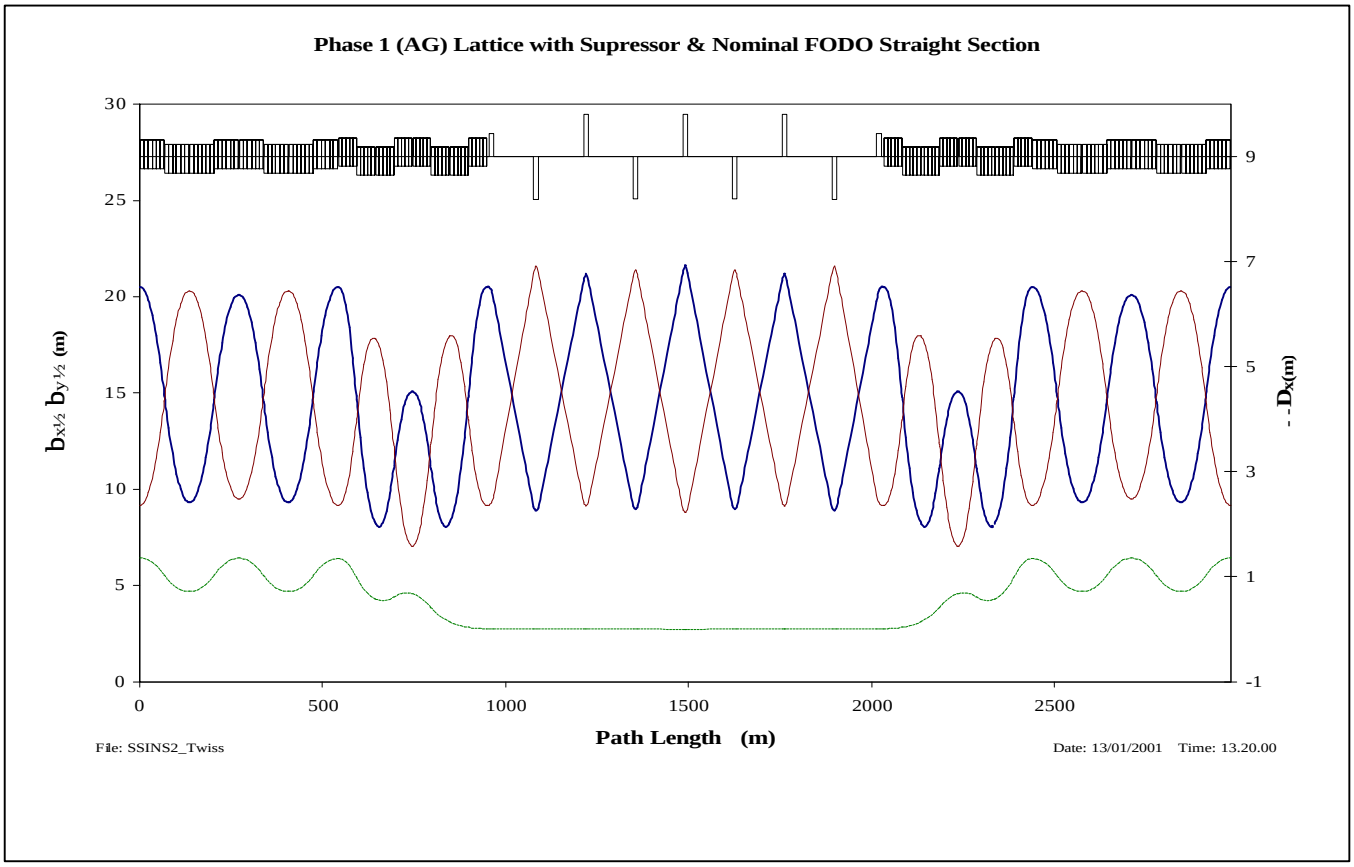
*Staged VLHC Parameter List - **DRAFT** Version 0.4 2/23/01*

PRIMARY PARAMETERS	Stage 1		Stage 2	
Machine Type	Proton-Proton Collider		Proton-Proton Collider	
Beam Energy	20	TeV	87.5	TeV
Luminosity	1.0E+34	s-1cm-2	2.0E+34	s-1cm-2
Dipole Field	1.96	Tesla	10	Tesla
Circumfrence	232	km	232	km
Injection Energy	0.9	TeV	10	TeV
Injector	Tevatron		Stage 1 Machine	
Filling Time	60	mins	< 30	sec
Acceleration Time	1000	sec	2000	sec
Detectors	Two, on-site @FNAL		Upgrade at same sites	
Power Consumption	TBD	MW	TBD	MW
BEAM PARAMETERS				
Transverse Emittance (RMS norm)	1.67	Pi um-rad	1.5	Pi um-rad
(95% norm)	10.0	Pi um-rad	9	Pi um-rad
Beam Size at Injection (@beta=400m)	0.8	mm RMS	0.2	mm RMS
Revolution Frequency	1294	Hz	1294	Hz
Bunch Frequency	53.1	MHz	53.1	MHz
Bunch Spacing	18.8	ns	18.8	ns
Number of Buckets	41048		41048	
Bunch Filling Fraction	0.9		0.9	
Number of Bunches	36943		36943	
Bunch Intensity	2.48	x1E10	2.06	x1E10
Protons/Beam	9.17	x1e14	7.60	x1e14
Beam Current	190	mA	175	mA
Stored Energy/beam	2.94	GJ	10.64	GJ
COLLISION PARAMETERS				
Beta*	0.3	m	0.5	m
Head-on BB Tune Shift	0.002		0.002	
Crossing Geometry	Horizontal		Vertical	
Crossing Angle	TBD	urad	TBD	urad
Inelastic Cross Section	130	mbarns	150	mbarns
Interactions/crossing	25.8		59.6	int/xing
Interactions/cm	1.97	#/cm	6.56	#/cm
IR Power from Collision Debris	3.9	kW	39.8	kW
SYNCHROTRON RADIATION				
Synchrotron Radiation Loss/turn	0.03	MeV	12.37	MeV
Synchrotron Radiation Power/beam	6	kW	2,161	kW
Synchrotron Radiation Power/meter/beam	0.029	W/m	9.827	W/m
Longitudinal Damping Time	inf.		1.4	hours


Energy Ramps and Filling of Staged Collider
Beam Energy (TeV)
100
10
1
0.1
0.01
0.001
0
1000
2000
3000
4000
5000
6000
7000
Time (sec)
Phase 2 Collider
Phase 1 Collider
Tevatron: 72
Cyles @50
Main Injector:
144 Cycles
@2 sec/cycle

*Staged VLHC Parameter List - **DRAFT** Version 0.4 2/23/01*

LATTICE	**Stage 1**		**Stage 2**	
Magnet Type	Combined Function		Separated Function	
Bore Separation in Arcs	15	cm	18-29	cm TBD
# of Half-cells	1710		1710	
Integer Tune	214	nu	214	nu
Fractional Tune	TBD		TBD	
Slip Factor Eta	2.19	x1e-5	2.19	x1e-5
Average Beta	233	m	270	m
Avg. Dipole Field in Arcs	1.90	Tesla	8.33	Tesla
Dipole Filling Factor (Arcs)	97%		83%	
ARC CELLS				
Number of half-cells in Arcs	1568		1568	
Half Cell Length	135.5	m	135.5	m
Phase Advance/cell	90	deg	90	deg
Dipoles Per Halfcell	2		7	
Dipole Length (magnetic)	65.75	m	16.1	m
Bend Angle per halfcell	3.9	mrad	3.9	mrad
Sagitta in Halfcell	6.5	cm	6.5	cm
Beta Max	412	m	460	m
Beta Min	87	m	81	m
Beta Avg	233	m	270	m
Dispersion Max	1.35	m	1.4	m
Dispersion Avg.	1.03	m	1.1	m
SUPPRESSOR CELLS				
Number of 1/2 Cells	80		80	
Half Cell Length	101.6	m	101.6	m
Phase Advance/cell	90	deg	90	deg
Dipoles Per Halfcell	2		5	
Dipole Length (magnetic)	48.8	m	16.1	m
Bend Angle per halfcell	2.6	mrad	2.6	mrad
Sagitta in Halfcell	2.5	cm	2.5	cm
Beta Max	412	m	460	m
Beta Min	50	m	40	m
Beta Avg	231	m	250	m
Dispersion Max	1.35	m	1.4	m
Dispersion Avg.	0.675	m	0.7	m
STRAIGHT SECTION CELLS (Nominal FODO)				
Number of 1/2 Cells	80	TBD	80	
Half Cell Length	135.5	m	135.5	m
Phase Advance/cell	90	deg	90	deg
Beta Max	460	m	460	m
Beta Min	81	m	81	m
Beta Avg	270	m	270	m



Stage 2 (Separated Function) Lattice

		Stage 1		Stage 2	
BEAM SIZES AND ACCEPTANCE					
Design Emittance		1.7 pi (RMS norm)		1.5 pi (RMS norm)	
		10.0 pi (95% norm)		9.0 pi (95% norm)	
Beam Size at Injection (@Betamax=400m in arcs)					
	Sigma	0.8	mm	0.2	mm
	95%	2.04	mm	0.58	mm
Beam Size at Full Energy (@Betamax=400m)					
	Sigma	0.18	mm	0.08	mm
	95%	0.43	mm	0.20	mm
Physical Aperture (arc magnets)					
Nominal Physical full-Aperture		28 x 18	mm (H x V)	20	mm diam
Min Radial Aperture w/misalignments		7.5	mm	7.5	mm
Acceptance of Phys. Apert. @injection		9.0	sigma	31.6	sigma
		135 pi RMS norm		1499 pi RMS norm	
		810 pi (95% norm)		8995 pi (95% norm)	
(ref: Acceptance of Main Injector)		40 pi (95% norm)			
Beam Scraping Radius		6	sigma	6	sigma
Dynamic Aperture at Injection (Tracking Target for Arc Magnets only)					
Tracking Target (Avg over seeds)		13	sigma	13	sigma
	target amplitude at beta=400m	10.8	mm	3.1	mm
	Acceptance of Dynap. Target	282 pi (RMS norm)		254 pi (RMS norm)	
		1690 pi (95% norm)		1521 pi (95% norm)	

UNDERGROUND CONSTRUCTION

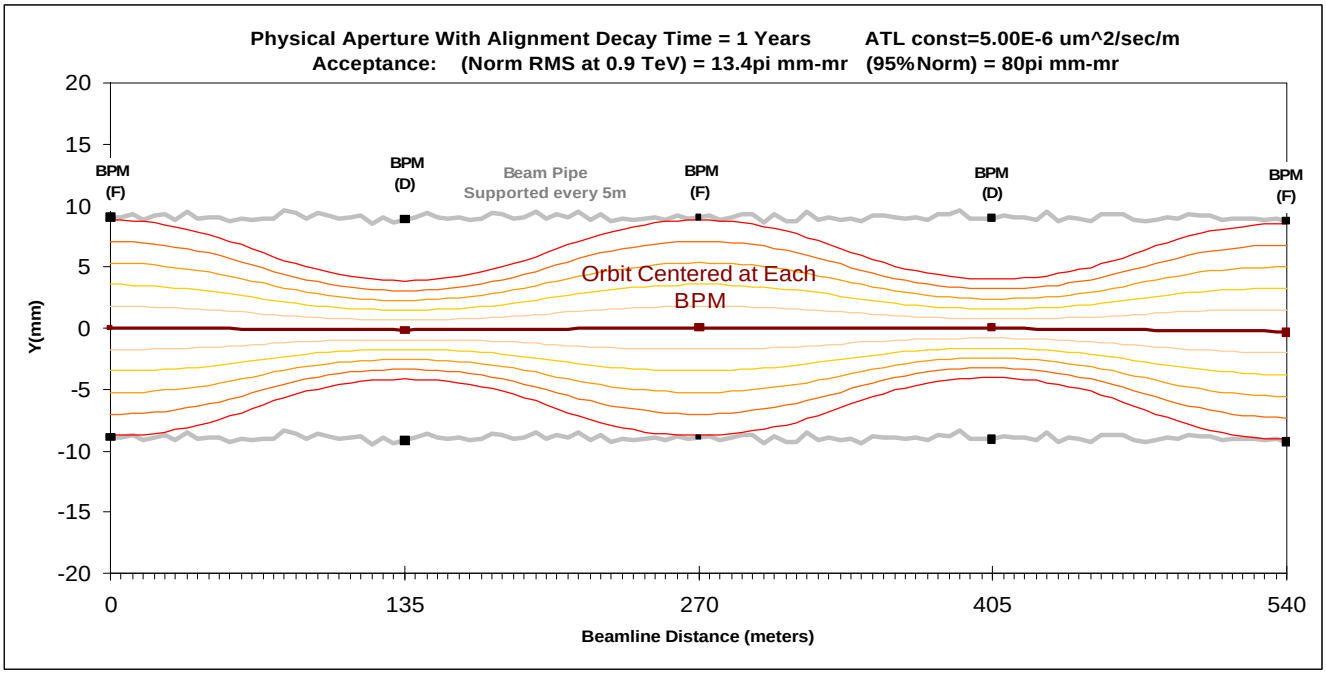
Collider Tunnel				
Tunnel Depth (Avg.)	120	m		
Finished Diameter	3.65	m	(= 12 ft.)	
Arc Radius of Curvature R_Arc	35	km		
Arc Circumference	220	km		
Straight Sections (number)	10			
Straight Section (Total length)	12	km		
Circumference overall	232	km		
Maximum Line-of-sight in Tunnel	1011	m		
Number of Muck removal Sites	6			
Distance Between Mucking Sites	38	km	(= 23.6	mi)
Tunnel Drive Lengths	19	km	(= 11.8	mi)
Emergency Egress for Construction	4.75	km TBD	(= 3.0	mi TBD)
Emergency Egress for Operations	9.5	km TBD	(= 5.9	mi TBD)
Excavated Volume per Site	397,612	m^3	(= 19,881	Truckloads)
Tunnelling Schedule (Target)	**Stage 1**		**Stage 2**	
Arc Tunnel Construction time	5	yr		
Number of Simultaneous TBM Sites	4		1	Bypass Line
Site Prep and Shaft Excavation	0.5	yr	0.5	yr
TBM Setup & Boring (first Drive)	1.5	yr	0.5	yr
TBM Setup & Boring (2nd Drive)	1.5	yr	0.5	yr
Demobilization	0.25	yr	0.25	yr
Total Time at One Site	3.75	yr	1.75	yr
On-Site Underground Construction				
Transfer Line Length (CW+CCW)	7	km	-	
Abort Line Length	2x3	km	-	
Bypass Line Length	(stub only)		6	km
Number of On-site Shafts	TBD		TBD	
Detector Cavern Dimensions (2)	30x40x80	m	30x40x80	m
Beam Absorber Hall Dimensions	16x16x40	m	16x16x40	m
RF Klystron Gallery Dimensions	4x5x20	m	4x5x20	m
Power Supply Room Dimensions	4x5x20	m	4x5x20	m
Power Dump Resistor Room (@20km)	TBD		TBD	
Transfer Lines / Equipment Ramps				
Number	2			
Length	3	km		
Location	FNAL	on site		
Occupancy with Tevatron Running	unlimited			
Max. Slope	4	%		
Minimum Radius of Curvature	1	km		

	Stage 1		Stage 2	
TUNNEL UTILITIES				
Collider Tunnel				
Nominal Finished Diameter	3.6	m	12	ft
Guaranteed Clear ID WRT ideal		m		
Floor Elevation		m		
Floor Width		m		
Electrical Power				
Cryoplant Power Feed	from surface grid		from surface grid	
Ramping Power Supplies	FNAL on-site		from surface grid	
Welding Supplies	on Installation Vehicles		on Installation Vehicles	
Work Lighting	on Installation Vehicles		on Installation Vehicles	
Emergency Lighting	at quad locations		at quad locations	
HVAC	TBD			
Arc Instrumentation Power including Correctors				
nominal avg	1.6	kW/quad		
installed	4	kW/quad		
Average Power in Tunnel	12	W/m		
Tunnel Air Circulation				
De-Watering				
contractual maximum water inflow				
nominal water inflow				
sumping method				
spacing				
locations				
AC power for sumps (nominal)				
emergency sump volume				
max time of power loss without flooding				
Emergency Lighting				
location			at quad locations	
type			battery backup fluorescent	
recharging			arc instrumentation power	
time of installation			BOD	
Fire Detection				
method	MI-style Waxed cable			
readout spacing				
time of installation				
ODH detection				
method				
readout spacing				
time of installation				

TUNNEL ALIGNMET AND SURVEY

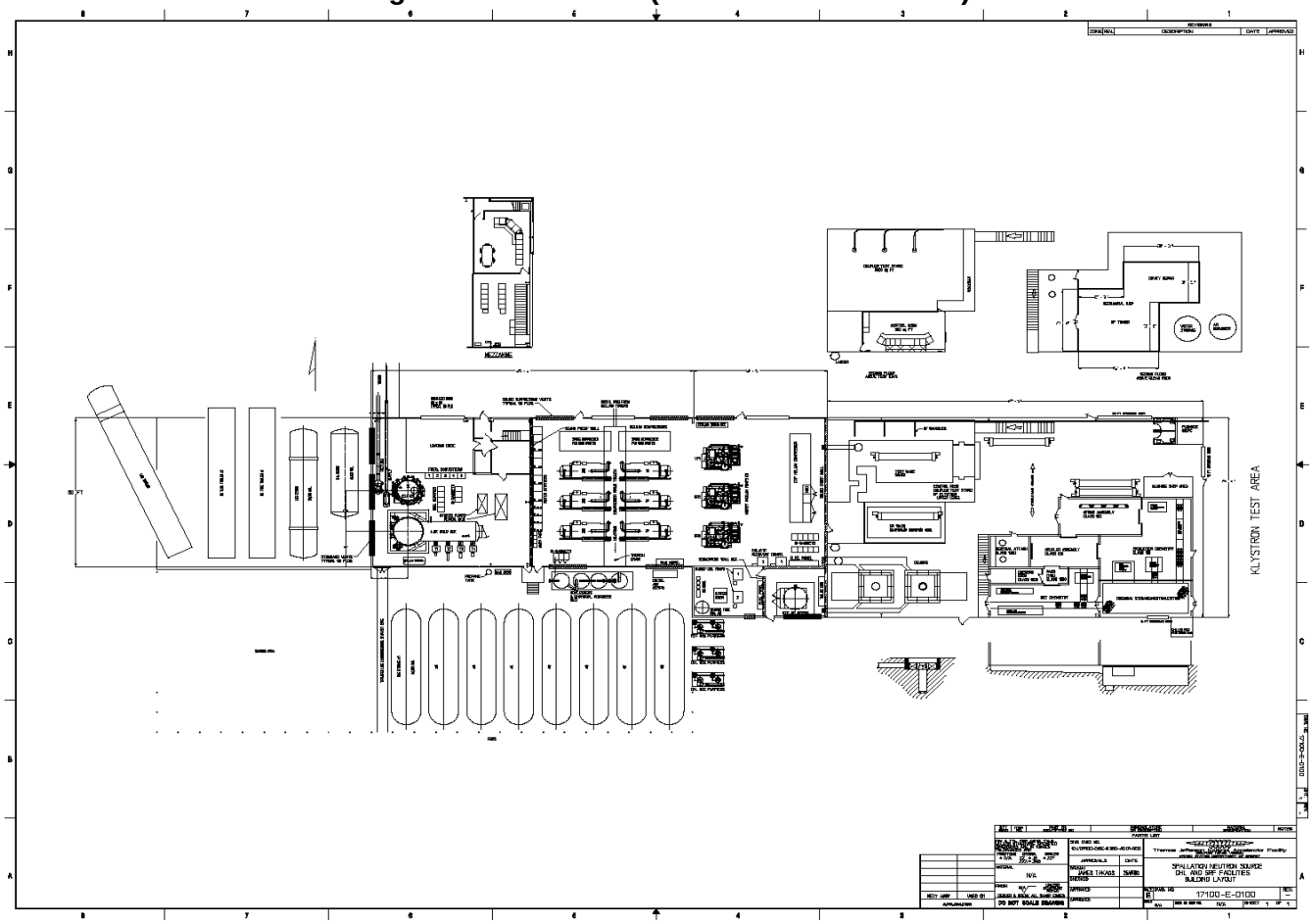
Accuracy of Bored Tunnel		
Over 1km Distance Scale	10	cm
Over 20km Distance	20	cm
Global Accuracy (before settling)	30	cm
Site Risers		
site riser spacing (during construction)	5	km
site riser spacing (after construction)	10	km
minimum diameter of line-of-sight	1	m
Survey Monuments		
Number of monuments	2	per cell
	1710	per ring
Monument Spacing	65.5	m
Monument Accuracy (transverse)		
over 1km length	0.25	mm RMS
over 10km length	2	mm RMS
ring-wide	20	mm RMS
Monument Accuracy (station)		
over 1km length	2	mm RMS
over 10km length	10	mm RMS
ring-wide	20	mm RMS

MAGNET ALIGNMENT	Stage 1		Stage 2	
Dipole Alignment				
Dipole Magnet Length (mechanical)	65.5	m	17	m
Number of alignment feet per magnet	11		2	
Coordinates Per Alignment Foot	3 (x,y,roll)		4 (x,y,Station,roll)	
Spacing of alignment feet	6	m	10	m
Spacing of Magnet Fiducials	6	m	10	m
Alignment of Fiducials to Monuments	0.25	mm	0.25	mm
Fiducialization	Grooves in Laminations		TBD	
Accuracy of Fiducialization to Bore	0.1	mm	0.5	mm
Magnet Straightness between supports	0.25	mm	0.5	mm
Loss of Aperture due to misalignments	1	mm	1	mm
Quad Alignment	TBD		TBD	
Alignment Decay				
ATL Decay Constant	5.00E-06	um^2/sec/m		
Number of Magnets needing realignment	5	per year		

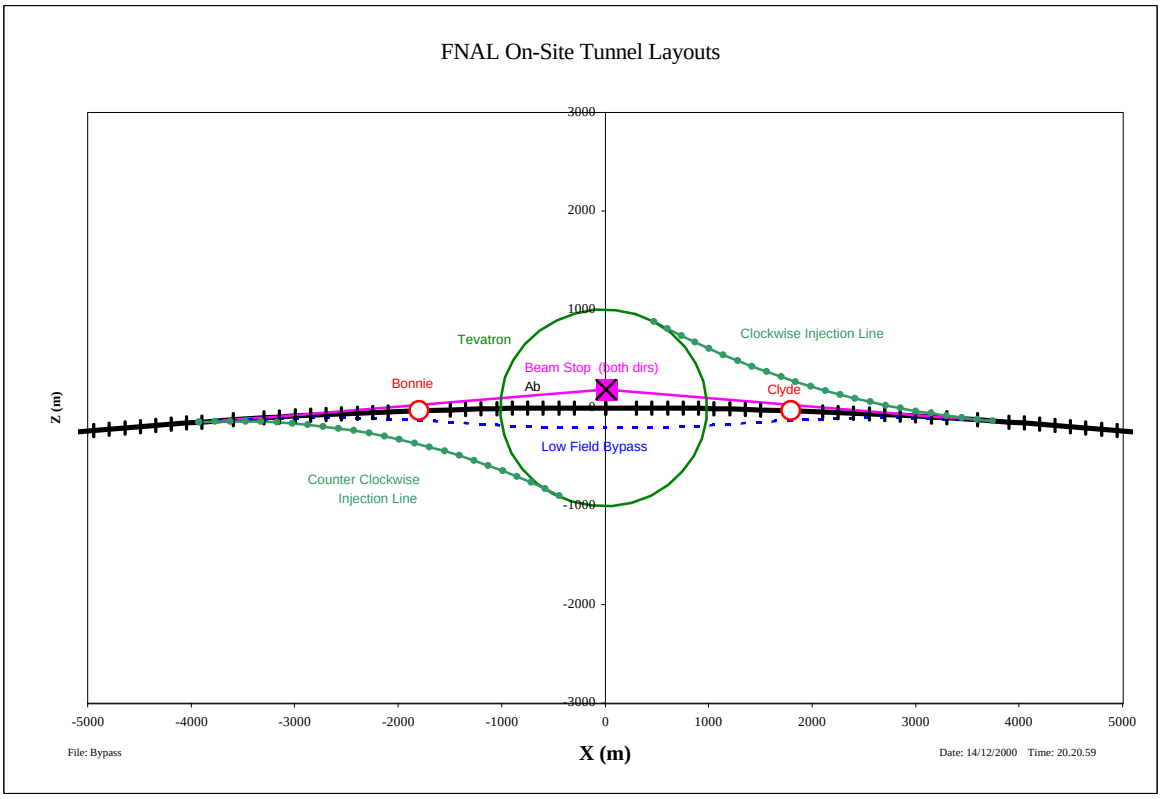


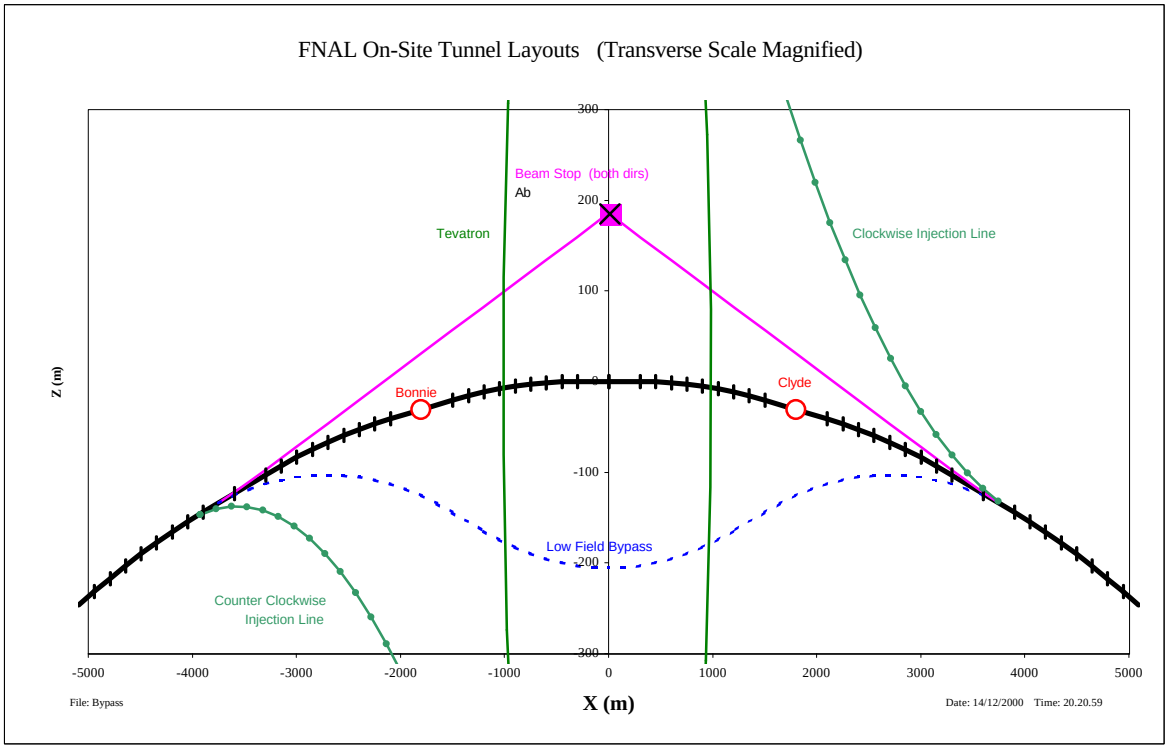
OFF-SITE FACILITIES	**Stage 1**		**Stage 2**	
Number of Off-site Surface Facilities	5		5	
Off-Site Surface Facility Footprint	50	acres	50	acres
Buildings	1	cryoplant	5	cryoplant
Sq. ft. Total	12,000	sq. ft.	162,000	sq. ft.
Number of Access Shafts	2	TBD	2	
Equipment Access Shaft Diameter	20	m TBD	20	m TBD
Manned Access Shaft Diameter	3	m TBD	3	m TBD
AC Power per Site	4	MW	25?	MW
Cooling Ponds	4	acres	25?	Acres
Cryo Tank Farms	TBD	25k gal tanks	TBD	25k gal tanks

Stage 1 CRYOPLANT (Placeholder from SNS)



ON-SITE FACILITIES	Stage 1		Stage 2	
Detector Surface Assembly Halls				
Number of Detectors	2			
Assembly / Crane Bldg sq. ft.	10,000	sq. ft		
Collaboration Offices Occupancy	200			
Parking Lot Size	100	cars		
Magnet Assembly Building / Ramp Headhouse				
Location	CW Transfer Line ramp			
Dimensions	TBD			
Auxiliary Installation Ramp Headhouse				
Location	CCW Transfer Line ramp			
Dimensions	TBD			
On-Site Cryo/Power Headhouse				
Location	Beam Crossover			
Dimensions	TBD			
Number of Access Shafts	2			
Equipment Access Shaft Diameter	20	m TBD		
Manned Access Shaft Diameter	3	m TBD		
Beam Absorber Shaft Headhouse				
Location	Shaft Above Beam Absorber			
Dimensions	TBD			
Number of Access Shafts	2			
Equipment Access Shaft Diameter	20	m TBD		
Manned Access Shaft Diameter	3	m TBD		
Utility Straight Shaft Headhouse				
Number	2			
Locations	Above Utility Straight on site boundary			
Dimensions	TBD			
Number of Access Shafts	2			
Equipment Access Shaft Diameter	20	m TBD		
Manned Access Shaft Diameter	3	m TBD		
Bypass Line Headhouse (Phase 2)				
Location			Midpoint of Bypass Line	
Dimensions			TBD	
Number of Access Shafts			2	
Equipment Access Shaft Diameter			20	m TBD
Manned Access Shaft Diameter			3	m TBD


FNAL On-Site Tunnel Layouts
Tevatron
Clockwise Injection Line
Beam Stop (both dirs)
Ab
Bonnie
Clyde
Low Field Bypass
Counter Clockwise
Injection Line
Z (m)
X (m)
File: Bypass
Date: 14/12/2000 Time: 20.20.59


FNAL On-Site Tunnel Layouts (Transverse Scale Magnified)
Beam Stop (both dirs)
Ab
Tevatron
Clockwise Injection Line
Bonnie
Clyde
Low Field Bypass
Counter Clockwise
Injection Line
Z (m)
X (m)
File: Bypass
Date: 14/12/2000 Time: 20.20.59

DIPOLE MAGNETS	Stage 1		Stage 2	
ARC DIPOLE MAGNETS				
Number of Magnets in Ring	3136		10976	
Nominal Bend Field	1.96	Tesla	10	Tesla
Arc Dipole Physical Length	67.75	m	16.1	m
Arc Dipole Magnetic Length	65.75	m	17	m
Gradient	+/-9.3	T/m	0	T/m
Sextupole	+20/-155	T/m^2	0	T/m^2
Magnetic Aperture (H x V)	30 x 20	mm	30 x 30	mm
Physical Aperture (H x V)	28 x 18	mm	20 x 20	mm
Operating Current	100	kA	23.5	kA
Number of Turns(both Bores)	1		2 x 58	
Inductance (both Bores)	2.9	uH/m	3000	uH/m
	0.19	mH/magnet	51	mH/magnet
Stored Energy at nominal field (both bore	15	kJ/m	828	kJ/m
	0.95	MJ/magnet	14.08	MJ/magnet
DISPERSION SUPPRESSOR DIPOLE MAGNETS				
Number of Magnets in Ring	160		400	
Bend Field	1.76	Tesla	10	Tesla
Gradient	+/-16.7	T/m	0	T/m
Sextupole	0	T/m^2	0	T/m^2
Dispersion Suppressor Magnet Length	48.8	m	16	m
Magnetic Aperture (H x V)	30 x 20	mm	30 x 30	mm
Physical Aperture (H x V)	28 x 18	mm	20 x 20	mm
Operating Current	100	kA	23.5	kA
Number of Turns(both Bores)	1		2 x 58	
Inductance (both Bores)	2.9	uH/m	3000	uH/m
	0.14	mH/magnet	48.00	mH/magnet
Stored Energy (both bores)	15	kJ/m	828	kJ/m
	0.71	MJ/magnet	13.25	MJ/magnet

QUADRUPOLE MAGNETS	Stage 1		Stage 2	
NORMAL QUADRUPOLE MAGNETS				
Number of Magnets in Ring	160		1568	
Magnet Type	warm iron/copper		2-in-1 Cos-2Theta SC	
Gradient	70	T/m	400	T/m
Quadrupole Magnet Length	6.0	m (typ)	9.16	m
Magnetic Aperture (coil/pole tip diam)	20	mm	30	mm
Physical Aperture	22	mm(star pipe)	20	mm
Operating Current	283	A	27.2	kA
Operating Voltage	50.1	V	2 x 52	
Number of Turns per pole	12			
DC Power / Cryogenic Heat load	14.2	kW		W@4.5K
LCW Consumption		GPM		
Inductance	5.3	mH/m	1.13	uH/m
			10.4	mH/magnet
Stored Energy	0.212	kJ/m	418	kJ/m
			3.83	MJ/magnet
LARGE APERTURE QUADRUPOLE MAGNETS (for Beam Injection / Extraction)				
Number of Magnets in Ring	10		TBD	
Magnet Type	warm iron/copper			
Gradient	45	T/m		
Quadrupole Magnet Length	10.0	m		
Magnetic Aperture (coil/pole tip diam)	40	mm		
Physical Aperture	45	mm(star pipe)		
Operating Current	625	A		
Operating Voltage	120.0	V		
Number of Turns per pole	12			
DC Power	73.6	kW		
LCW Consumption		GPM		
Inductance	5.6	mH/m		
Stored Energy	1.094	kJ/m		

CORRECTOR SYSTEM	**Stage 1**		**Stage 2**	
# Magnets at each F/D loc (both bores)	6		6	
Dipole Correctors at each F/D Location	1	per Bore	1	per Bore
Quad Correctors at each F/D Location	1	per Bore	1	per Bore
6-Pole Correctors at each F/D Location	1	per Bore	1	per Bore
Multipole Correctors	TBD		TBD	
Total Corrector Magnets	10260		10260	
Power Dissipation (max)				
Dipole Correctors	400	W/magnet	0	W
Quad Correctors	140	W/magnet	0	W
6-pole Correctors	176	W/magnet	0	W
Total Power at Quad Location (max)	1432	W		
Total Corrector Magnet Power (max)	2.4	MW		
Power Supply Redundancy	2	fold		
Redundancy Method	live load sharing			
Avg Power at Quad Location	1000	W		
Avg Corrector Power in Tunnel	7.4	W/m		
Avg Corrector Power in Tunnel (Total)	1.7	MW		

DIPOLE CORRECTORS	**Stage 1**		**Stage 2**	
Location (one per half-cell each bore)	(H/V) at (F/D) quad locs		(H/V) at (F/D) quad locs	
Number per Ring (both bores)	3420		3420	
Magnet Type	Warm Iron/Copper		Nb3Sn Superconducting	
Configuration	C-Magnet		Cos-Theta	
Bend Field (max)	1.0	T	3.9	T
Magnetic Length	0.5	m	1.0	m
Physical (slot) Length	0.7	m	1.2	m
Integrated Bend Strength	0.5	T-m	3.9	T-m
Bore	warm aluminum pipe		70K beam screen	
Magnetic Aperture (magnet gap/coil diam)	20 x 30	mm	40	mm
Physical Aperture	18x28	mm	20	mm
Max Bend Angle				
at injection	166.7	urad	117.0	urad
at max energy	7.5	urad	13.4	urad
Max Orbit Deflection (2-bump)				
at injection	68.7	mm	53.8	mm
at max energy	3.1	mm	6.2	mm
Equivalent Quad Displacement				
at injection	15.4	mm	10.8	mm
at max energy	0.7	mm	1.2	mm
Core Weight	220	kg	10?	kg
Coil Weight	170	kg	20?	kg
Magnet Weight	390	kg		kg
Operating Current (max)	3	Amp	80	Amp
Coil Resistance incl. Leads	44	Ohm	0.0025	Ohm
Ohmic Voltage (max)	133	V	0.2	V
Ohmic Power (max) incl. Leads	400	W	16	W
Ohmic Power (average for ring)	80	W	3.2	W
Coil Inductance		H	3	H
Min Ramping Time 0-100%		sec	200	sec
Max Inductive Voltage		V	1.16	V
Inductive Stored Energy @max current		J	9280	J
Quench Detection	-		individual VT on PS	
Quench Protection	-		individual	
Overheating Protection	Series Klixon		TBD	
Coolant	Air		5K Helium	
Power Supply Location	Each Quad location		Each Quad location	
Currrent Lead Location	-		Spool Piece at Each Quad	
Current Lead Type	-		HTS, conduction cooled	

QUADRUPOLE CORRECTORS	Stage 1		Stage 2	
Location	Each Quad location		all half-cells	
Number per halfcell	1	per bore	1	per bore
Number per Ring (both bores)	3136		3420	
Magnet Type	Warm Iron/Copper		Nb3Sn Cos-2Theta	
Gradient	29.0	T/m	141	T/m
Field at 1cm radius	0.29	T	1.41	T
Magnetic Length	0.50	m	0.6	m
Physical (slot) Length	0.7	m	0.65	m
Integrated Quad Strength	14.5	T-m/m	84.6	T-m/m
Bore	warm aluminum pipe		70K beam screen	
Magnetic Aperture (poletip/coil diam)	20.0	mm	40	mm
Physical Aperture	22.0	mm(star pipe)	20	mm
Tune Adjustment (single corrector)				
at injection	0.158	nu	0.093	nu
at max energy	0.007	nu	0.011	nu
Tune Adjustment (all correctors in ring)				
at injection	124.2	nu	72.8	nu
at max energy	5.6	nu	8.3	nu
Beta Wave Generation/Trim (per corrector, fractional tune 0.3)				
at injection	106	%	62	%
at max energy	5	%	7	%
Maximum Correctable Gradient Error in Dipoles				
at injection	+/-156	units@1cm	+/-82	units@1cm
at max energy	+/-7	units@1cm	+/-9	units@1cm
Magnet Weight	66.0	kG	25?	kG
Coil Weight	38.0	kG	20?	kG
Operating Current (max)	1	Amp	90	Amp
Coil Resistance incl. Leads	140	Ohm	0.002	Ohm
Ohmic Voltage (max)	140	V	0.2	V
Ohmic Power (max) incl. Leads	140	W	18	W
Coil Inductance		H	0.78	H
Min Ramping Time 0-100%	20	sec	100	sec
Max Inductive Voltage		V	0.702	V
Inductive Stored Energy		J	3159	J
Quench Detection	-		individual VT on PS	
Quench Protection	-		individual	
Coolant	Tunnel Air Flow		5K Helium	
Overheating Protection	Klixon Interlock		TBD	
Power Supply Location	Each Quad location		Each Quad location	
Currrent Lead Location	-		Spool Piece at Each Quad	
Current Lead Type	-		HTS, conduction cooled	

SEXTUPOLE CORRECTORS	**Stage 1**		**Stage 2**	
Location	each halfcell in arcs		each halfcell in arcs	
Number per halfcell	1	per bore	1	per bore
Number per Ring (both bores)	3136		3136	
Magnet Type	Warm Iron/Copper		NbTi Cos-3Theta	
Sextupole Strength (field at 1cm)	0.18	T @1cm	0.58	T @1cm
d2By/dy2	3528	T/m^2	11600	T/m^2
Magnetic Length	0.8	m	1	m
Physical (slot) Length	1.0	m	1.1	m
Integrated Sextupole Strength	0.14	T-m@1cm	0.6	T-m/cm^2
Bore	warm aluminum pipe		70K beam screen	
Magnetic Aperture (pole tip/coil diam)	23.0	mm	40	mm
Physical Aperture (diameter)	21.0	mm	20	mm
Chromaticity Adjustment (single corrector)				
at injection				
at max energy				
Maximum Correctable Sextupole Error in Dipoles				
at injection	+/-122	units@1cm		units@1cm
at max energy	+/-5	units@1cm		units@1cm
Magnet Weight	250.0	kG		kG
Coil Weight	100.0	kG		kG
Operating Current (max)	1.25	Amp	100	Amp
Coil Resistance incl. Leads	113	Ohm		Ohm
Ohmic Voltage (max)	141	V		V
Ohmic Power (max) incl. Leads	176	W		W
Coil Inductance		H	0.76	H
Min Ramping Time 0-100%		sec		sec
Max Inductive Voltage		V		V
Inductive Stored Energy		J	3800	J
Quench Detection	-		individual VT on PS	
Quench Protection	-		individual	
Coolant	Tunnel Air Flow		5K Helium	
Overheating Protection	Klixon Interlock		TBD	
Power Supply Location	Each Quad location		Each Quad location	
Currrent Lead Location	-		Spool Piece at Each Quad	
Current Lead Type	-		HTS, conduction cooled	

POWER CONSUMPTION	**Stage 1**		**Stage 2**	
Main Injector (5% Duty Cycle)	2	MW	2	MW
Tevatron (Cold standby)	10	MW	12	MW
Ring Cryoplants	9	MW	110	MW
Detectors & IR's incl. Cryo	5	MW	10	MW
Main Power Supplies (ramping)	5	MW	200	MW
Main Power Supplies (collision)	0.3	MW	2	MW
Straight-Section Quads (collision)	3.2	MW		
Arc Correctors	1.7	MW		
RF(ramping)	20	MW TBD	40	MW
RF(collision)	10	MW TBD	20	MW
Tunnel HVAC	TBD	MW	TBD	MW
Tunnel Sumps, etc.	TBD	MW	TBD	MW
Peak Ramping Power	TBD	MW	TBD	MW
Avg. Power During Collisions	TBD	MW	TBD	MW

RING CRYOGENICS		**Stage 1**		**Stage 2**	
Superconductor Temperature		4.5-6	K	4.5-5.5	K
Shield Temperature		40-60K	K	40-60K	K
Beam Screen Temperature		(Warm bore)		75-85	K
Refrigeration (4.5K equiv)	(nominal)		kW		kW
	(Installed)		kW		kW
AC Power (nominal)			MW		
Cryo Plant Efficiency (fraction of Carnot)		0.3		0.3	
Cold Mass (5K)					
Cold Mass (50K)					
Helium Inventory					
Cool Down Time					
Number of Ring Cryoplants		6		24	
Number of Cryoplant locations		6		6	
Number of Cryoplants per location		1		4	
Cryoplant Size (4.5K equivalent)		8	kW	25	kW
Ring Cryogenic System Totals					
Nominal Cryogenic Load (4.5K equivalent		48	kW	600	kW
Nomnal AC Power for Cryogenics		10.7	MW	133.3	MW
Efficiency (% of Carnot)		30%		30%	
AC Power Per Location		1.8			
Cryoplant					
Contingency + Overhead Factor				1.5	
Nominal Cryogenic Power			kW@4.5K equiv		
Nominal Refrigeration Power			kW@4.5K equi	150	kW@4.5K eq
5K Flow System					
Coolant		Supercritical He			
Operating Temperature		4.5-6	K		
Operating Pressure		2.5-5	Bar		
Heat Inflow					
Shield Flow System					
Beam Screen Flow System					

IR CRYOGENICS	**Stage 1**	**Stage 2**

	Stage 1		Stage 2	
POWER SUPPLIES				
Magnetic Stored Energy	3.1	GJ/ring	151.8	GJ/ring
Ramping Time	1000	sec	2000	sec
Ramping Power per Ring	3	MVA/ring	76	MVA/ring
ARC DIPOLE POWER SUPPLY				
Number of Supply Locations	1	at FNAL	6	at cryoplants
Number of Supplies Per Location	1		4	
Total Number of Supplies	1		24	
Ramping Power per Supply	3.1	MVA	3.2	MVA
Power Supply Voltage	62	volts	269	volts
Power Supply Current	100	kA	23.5	kA
Holding Voltage per Supply	4.69	V	4.67	V
Current Leads	0.18	V	0.1	V
Series Pass SCR's	2	V	2	V
Bus Work & Filters	1	V	1	
Holding Supply Internal Losses	1.5	V	1.5	V
SC Splice Drops	0.013	V	0.067	
Holding Power Per Ring	469	kW	2632	kW
ARC QUADRUPOLE POWER SUPPLY				
Magnetic Stored Energy	-		10.0	GJ/ring
Ramping Time	-		2000	sec
Ramping Power/ring	-		5.0	MVA
Number of Supply Locations	-		6	at cryoplants
Number of Supplies Per Location	-		4	
Number of Supplies	-		24	
Ramping Power per Supply	-		0.4	MVA
Power Supply Voltage	-		17	volts
Power Supply Current	-		30	kA
Corrector Magnet Supplies				

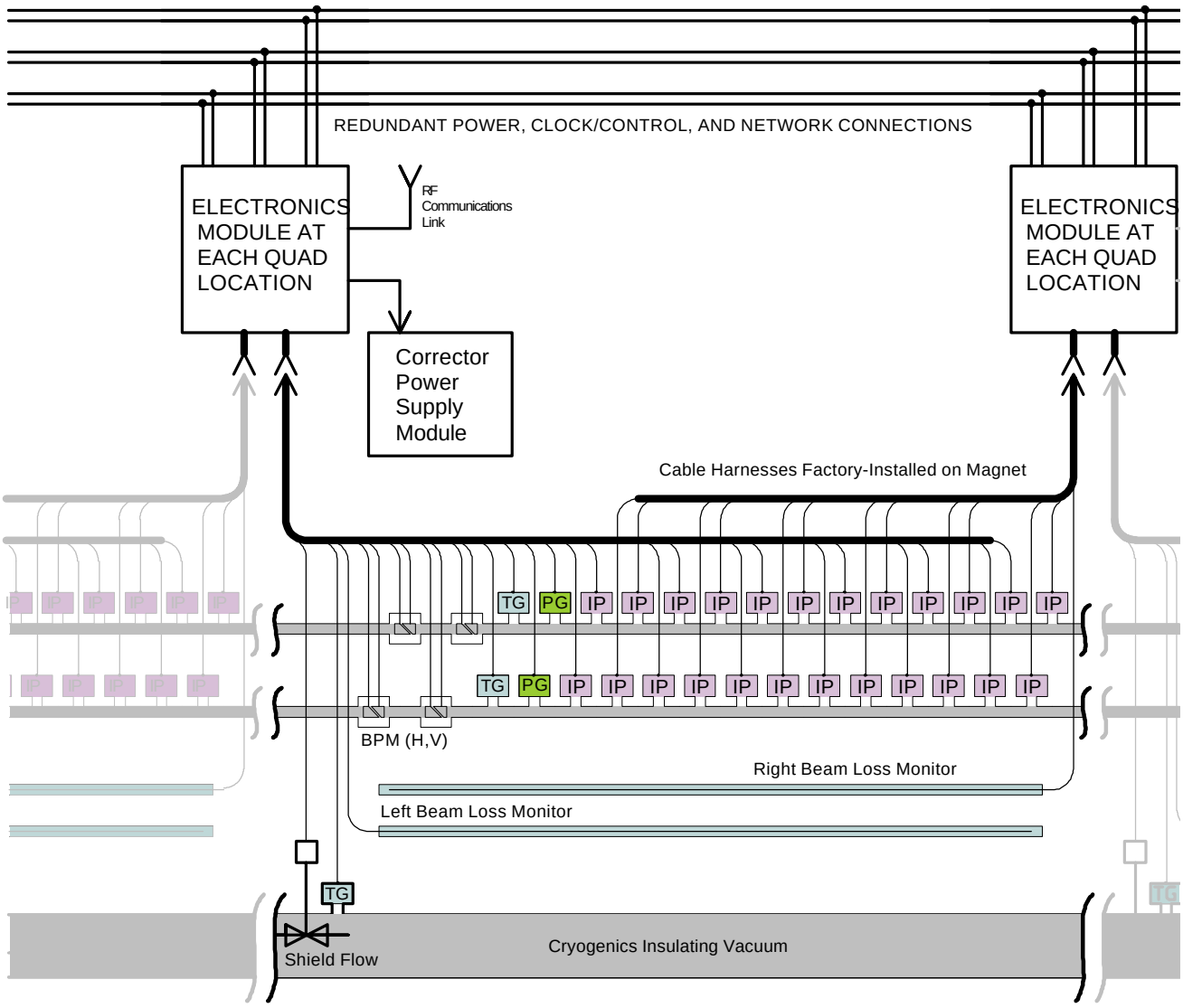
	Stage 1		Stage 2	
BEAM VACUUM SYSTEM				
Vacuum Requirements for Initial Operations				
Beam Lifetime from Vacuum	20	hrs	20	hrs
Luminosity Lifetime from Vacuum	10	hr	10	hr
Operating Current	100%	of design	100%	of design
Fraction of Beam Loss Power into 5K	5%		100%	
Cryogenic Heat Load into 5K	0.02	W/m	TBD	W/m
Fraction of 5K Cryo Load from Beam Loss	25%		TBD	
Vacuum Requirements after 6 Months				
Beam Lifetime	200	hr	TBD	hr
Luminosity Lifetime from Vacuum	100	hr	TBD	hr
Operating Current	100%	of design	TBD	of design
Fraction of Beam Loss Power into 5K	5%		TBD	
Cryogenic Heat Load into 5K	0.002	W/m	TBD	W/m
Fraction of 5K Cryo Load from Beam Loss	4%		TBD	
Beam Pipe				
Operating Temperature				
Contiunuous Pumping Method				
pumping speed		liters/sec/m		
Distributed Pumping				
Spacing				
Speed				
Photodesorbtion				
critical energy				
photon flux				
synch rad power				
		l/sec/m N2 equiv		

	Stage 1		Stage 2	
QUENCH PROTECTION				
Length of Quench Protection Cell	Whole Ring		19	km
Quench Heaters	at Dump Resistors		on each magnet	
Peak Temperature in Quench	270	degK	400	degK
Voltage to Ground	+/-2.5	kV to ground	< 1	kV to ground
Peak Pressure in Quench	30	Bar	< 25	Bar
System Relief Pressure	40	Bar	TBD	Bar
Recovery Time	2	hours	TBD	Hours
QUENCH DETECTION				
Quench Detection Method	Voltage Balance		Voltage Balance	
Quench Detection Locations	One, at Power Supply		Each Halfcell	
Redundancy	3	fold	2	fold
Number of Circuits	3	per Ring	3136	per ring
Quench Detection Threshold	1	V	0.3	V
Inductive Bucking Voltage	62	V	2.0	V
Response Time	0.1	sec	0.05	sec
ENERGY DUMP RESISTORS				
Number of Dump Resistors	24		48 (Dipole) + 48 (Quads)	
Location	Every 10km in arcs		Every 20km in arcs	
Energy Per Dump	129	MJ	3163	MJ
Inductance per dump	0.03	H	60	H
Dump Voltage	+/-2.5	kV to ground	+/- 1	kV to ground
Dump Time	1	sec	250	sec
Dump Switch Type	Cryogenic (quench switch)		Room Temp SCR Switch	
Dump Resistor Coolant	Helium		Water Cooled	
Forward Voltage Drop	10	uV	2	V
CURRENT LEADS (ARC MAGNETS)				
Number of Lead Pairs	1		48 (Dipole) + 48 (Quads)	
Operating Current	100	kA	23.5	kA
Total Superconducting Leads	100	kA-pair	2256	kA-pair
Lead Type	Normal		HTS	
LHe Consumption/kA	2	l/hr/kA-pair	0.25	
LHe Consumption (all leads)	200	liters/hr	564	liters/hr

ARC INSTRUMENTATION	Stage 1		Stage 2	
Arc Instrumentation Modules				
Location	Each "quad location"		Each "quad location"	
Spacing	135.5	m	135.5	m
Number in Ring (including straights)	1648		1648	
Packaging	Module in Hole-in-Wall		Module in Hole-in-Wall	
Hole Diameter	0.4	m	0.4	m
Hole Depth	2	m	2	m
Module Length	0.8	m	0.8	m
Module Power Dissipation	200	W max	200	W max
Cooling	Tunnel Air		Tunnel Air	
Module Power Consumption (incl load)	1200	W max	500	W max
Maintenance Method	"Black Box"		"Black Box"	
Fault Tolerance	Ring OK if module dead		Ring OK if module dead	
Cable Plant				
Location	on Magnet		Cable Trays	
Harness Fabrication	Commercial Vendor		In Tunnel	
Installation & Test	at Factory		In Tunnel	
Beam Position Monitor				
Pickup Type	X-Y Buttons		X-Y Buttons	
Beam RF Structure	53 MHz Burst/DC		53 MHz Burst/DC	
First Turn Capability	Yes		Yes	
Number of Channels	4 (+/-X, +/-Y)		4 (+/-X, +/-Y)	
in-situ Calibration	60dB all channels		60dB all channels	
Cable Length to Electronics	5	m	5	m
Technology	Log Amp		Log Amp	
Readout	Sum & Difference of logs		Sum & Difference of logs	
Resolution	12	bits	12	bits
	0.01	dB	0.01	dB
	50	microns	50	microns
Input Filter Bandwidth	40-60	MHz	40-60	MHz
Triggering	Ext. Synch or self-triggered		Ext. Synch or self-triggered	
Input Impedance	50	Ohms	50	Ohms
Input Protection/clamping	TBD	V	TBD	V
Beam Loss Monitor				
Technology	Ionization Chamber		Ionization Chamber	
Operating gas	Ar, permanently sealed		Ar, permanently sealed	
Operating HV	2.5	kV	2.5	kV
Mechanical	Alum. Wall Coax Cable		Tevatron (bulb) Style	
Location	Full Length of Magnet		Quad Locations	
Number per Quad Location	2	(1/bore)	1	
Redundant Readout from F/D Quads	yes, x2		no (magnet quenches)	
Readout	resettable integrator		resettable integrator	
Adjustable Gain	x10,x100		x10,x100	
Max Digitization Rate	53	MHz	53	MHz

ARC INSTRUM. (cont'd)	Stage 1		Stage 2
Ion Pump HV			
Voltage	3.5	kV	-
Number of Channels	12		-
Bulk Supply Current	150	mA	-
Power during Startup	100W to 5 pumps		-
Power during Operation (all channels)	~0.5	W	-
Shutdown (HV Reed relay)	independent per pump		-
Current Readback	independent per pump		-
Full Scale Current	100	mA	-
Resolution (LSB)	1	uA	-
Redundancy	link to adjacent halfcell		-
Beam Vacuum Monitoring			
TC Gauge	2 per halfcell		2 per halfcell
Ion Gauge	2 per halfcell		2 per halfcell
Insulating Vacuum Monitoring			
TC Gauge (magnet pipe)	1 per halfcell		1 per halfcell
TC Gauge (cryo service pipe)	1 per halfcell		1 per halfcell
Cryo Temperature Monitors			
Temperature Measurement	1 per halfcell		10 (2 per dipole)
Location	Shield Flow outlet		SR absorbers
Cryo Valve Controls			
Location	every other halfcell		10 (2 per dipole)
Function	shield flow control		SR Absorber Flow
Stepping Motor Control			
Function			SR absorber positioning
Number of Channels			10 (2 per dipole)
Limit switches and/or LVDT readback			10 (2 per dipole)
DAQ/Signal timing Functions			
Beam Extraction Synch on same cable?			
Modules individually addressable w/ redundant network links			
DAQ data collection of BPM/BLM following each beam transfer (every 30 seconds)			
Miscellaneous functions:			
Tunnel Temperature readout			
RF Link for Tunnel Communications			
Microphone/speaker			
Integrated radiation dose readout	0-10	Mrad	
uncommitted digital A/D I/O?	TBD		
expandability	daughter card		

ELECTRONICS MODULE AT EACH ARC HALF-CELL (~1



RADIO FREQUENCY SYSTEM PARAMETERS

	Stage 1		Stage 2	
Long Emittance eLrms	2	eV-sec	2	eV-sec
RF Multiple of 53MHz	9		9	
RF Frequency fRF	477	MHz	477	MHz
RF Harmonic Number hRF	3.69E+05		3.69E+05	
Acceleration Voltage/turn	15.5	MV/turn	33.8	MV/turn
Acceleration Power (both beams)	5.9	MW	11.8	MW
Synchronous Phase		deg		deg
RF at Injection				
RF Voltage VRFinj	50	MV	50	MV
Synch Tune NuSynchInj	8.45	x10-3	2.53	x10-3
Synch Freq fSynchInj	10.93	Hz	3.28	Hz
Bucket Area AbucketInj	5.0	eV-S	16.8	eV-S
Bunch Length SigmaSinj	14.2	cm	7.8	cm
Momentum Spread dPPinj	149	x1e-5	24	x1e-5
RF at Collision				
RF Voltage VRF	50	MV	50	MV
Synch Tune NuSynch	1.79	x10-3	0.86	x10-3
Synch Freq fSynch	2.32	Hz	1.11	Hz
Bucket Area Abucket	23.7	eV-S	49.6	eV-S
Bunch Length SigmaS	6.6	cm	4.5	cm
Momentum Spread dPP	15	x1e-5	5	x1e-5
Synchrotron Power (both beams)	13	kW	4322	kW

INJECTION LINES	**Stage 1**	**Stage 2**
Tevatron Acceleration Mode	Bipolar (CW & CCW)	Bipolar (CW & CCW)
Number of Injection Lines	2	
Beam Line Length (each line)	3 km	

BEAM ABORT	**Stage 1**		**Stage 2**
Number of abort Lines	2		
Number of Beam Absorbers	1	(shared)	
Beam Line Length (each line)	3	km	
Beam Absorber Location	on site at FNAL		
Beam Absorber Depth Underground	120	m	
Maximum Stored Energy Per Beam	2.9	GJ	
Minimum Beam Emittance (RMS norm)	1.0	pi mm-mr	
Recovery Time at full energy	2.0	hr	
Power Extracted During Recovery	0.4	MW	
Typical (Decelerated) Beam Energy	0.1	GJ	
Typical Rep Rate (shots per day)	6		
Average Beam Power	10	kW	
Absorber Configuration	Main Injector Style		
	Two absorber cores in shared shield		
Overall Sarcaphagus Dimensions	10x10x25	m	
Enclosure Inside Dimensions	16x16x40	m	
Enclosure Concrete Wall Thickness	1	m	
Beam Sweeper			
Pattern	circular fixed radius		
Number of Sweepers	2	X+Y	
Angular Kick	0.3	mrad	
Sweep Radius at Absorber	1	m	
Sweep ratio	2	sweeps/rev	
Sweep Frequency	2587.194	Hz	
Sweep Speed on Dump	16256	m/s	
Sweep Radius at Beam Window	0.05	m	
Tesla-meters	20		
Sweeper Bend Field at Full Energy	1	Tesla	
Number of Modules	10		
Module Length	2	m	
Redundancy	8 of 10 modules OK		
Sacrificial Plug for Sweeper Failure			
Material	pyrolytic Graphite		
Distance Downstream of Sweeper	160	m	
Sweep radius Around Plug	80	mm	
Plug Diameter	50	mm	
Plug Length along Beamline	10	m	

	Stage 1		Stage 2
BEAM ABORT (cont'd)			
Beam Window			
Distance Downstream of Sweeper	150	m	
Sweep radius at Window	45	mm	
Beam Spot Size at Window	0.5	mm	
Material	Inconel		
Peak Temperature Rise	TBD		
Result of Sweeper Failure	hole <5mm		
Vacuum Protection Backup	redundant automatic gate Valve		
Absorber Core			
Material	pyrolytic Graphite		
Radius	1.5	m	
Length	10	m	
Peak Temperature Rise	TBD	degC	
Absorber Shield Iron Thickness	1.5	m	
Concrete Thickness	2	m	
Heat Exchanger Loop			
Location	inside enclosure		
Water Flow Rate	TBD	GPM	
Water Volume	TBD	Gal.	
Environmental & Monitoring Systems			
groundwater			
Chilled Water			
Tunnel Air			
Air Hold Time After Full-Energy Dump		mins	

	Stage 1		Stage 2	
BEAM STABILITY				
TMCI				
Pipe Half-size aPipe	9	mm	9	mm
TMCI Threshold (Inj)	1.80	x1e10	3.84	x1e10
TMCI Safety Factor(inj)	0.7		1.9	
TMCI Threshold (flattop)	5.77	x1e10	8.67	x1e10
TMCI Safety Factor	2.3		4.2	

Non-Negotiable

Proton Mass mp	938	Mev
Electric Charge	1.60E-19	Coulomb
Classical Radius Proton	1.53E-18	m