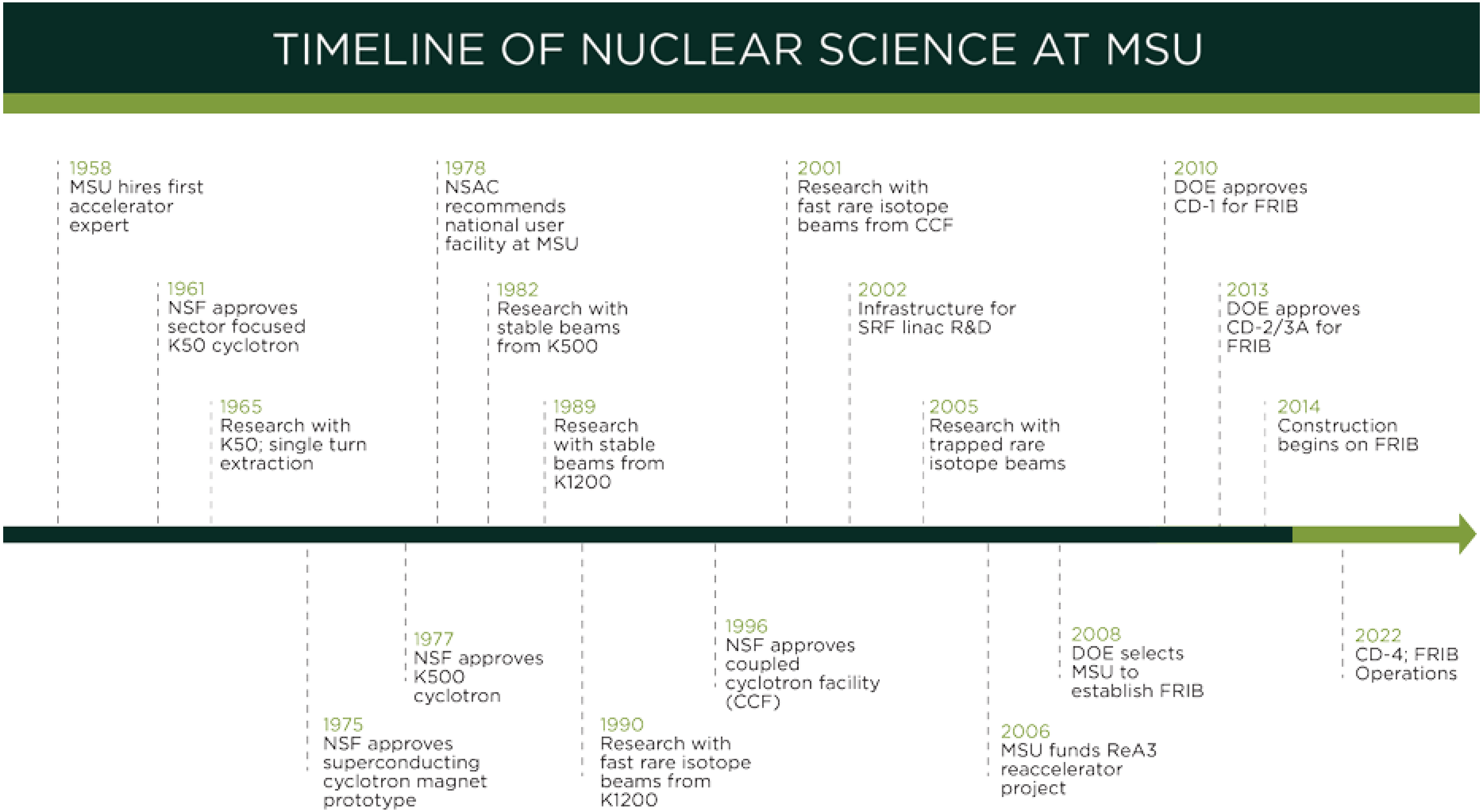
NSCL/FRIB Power Supplies Overview, Integration, And Project Status

Kent Holland

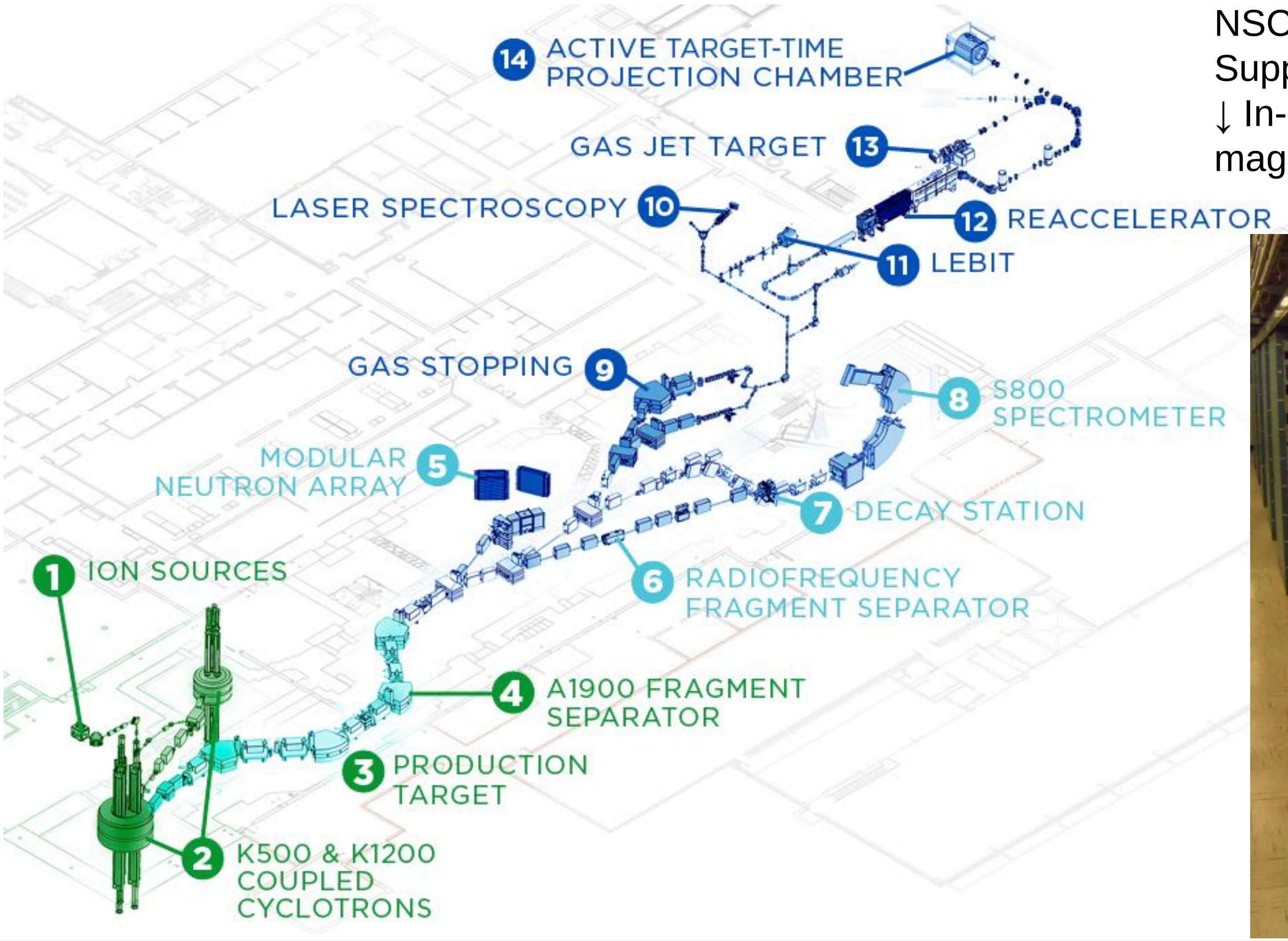
Power Supplies Staff Engineer
Control Account Manager
Power Supplies Group Leader

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

NSCL History



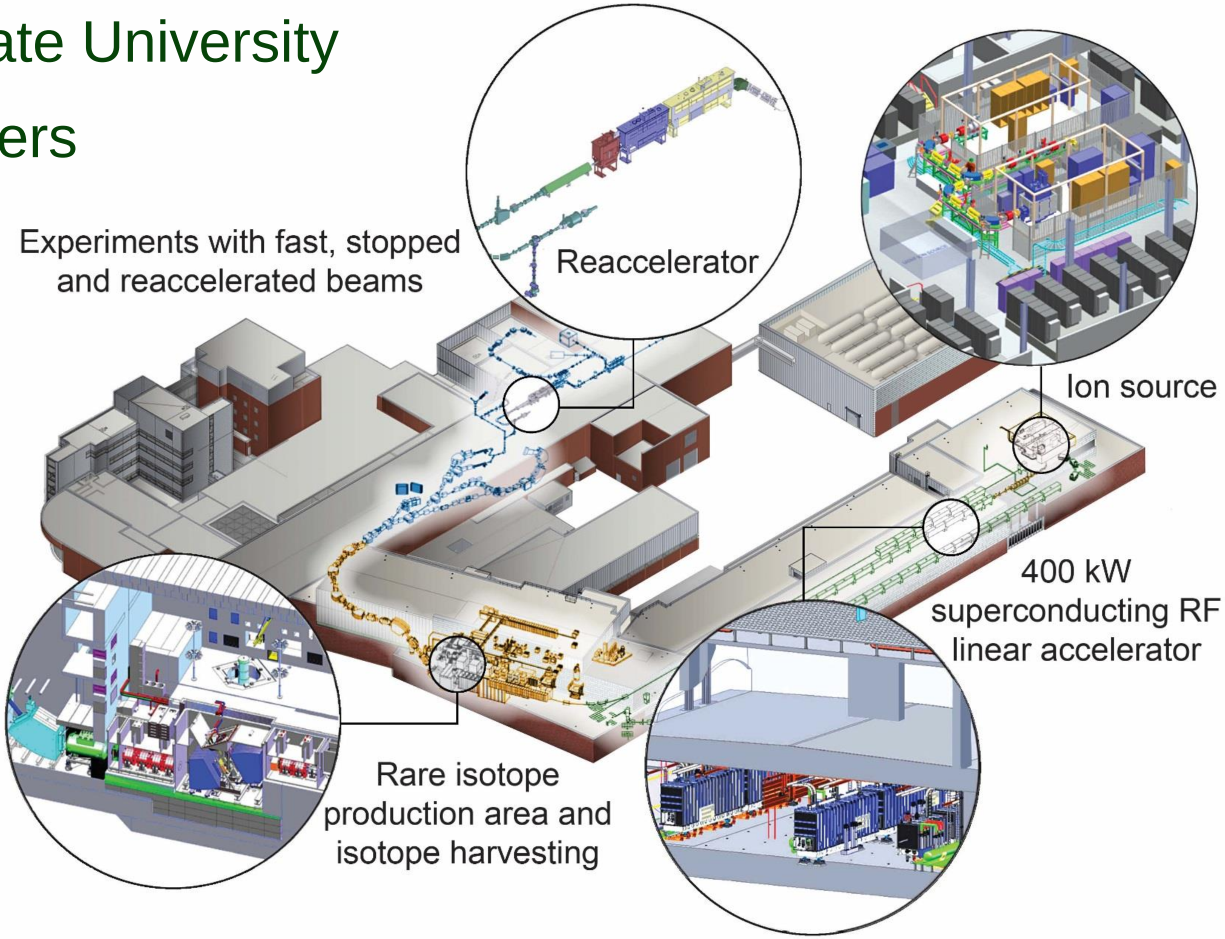
Existing NSCL Facility



NSCL has over 1100 Power Supplies (PS) in operations
↓ In-house superconducting magnet (SCM) PS

Facility for Rare Isotope Beams
A Future DOE-SC National User Facility

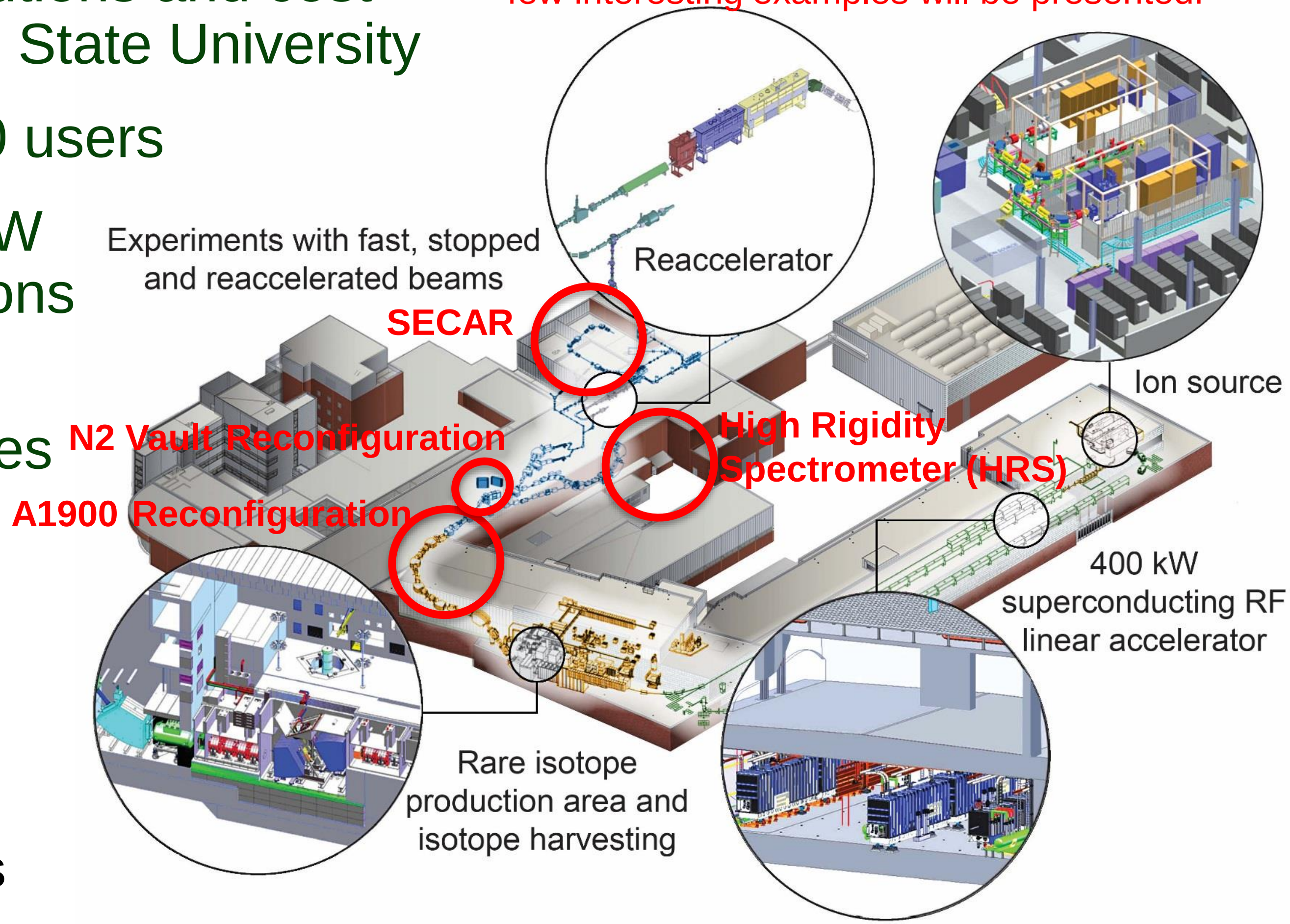
- Funded by DOE–SC Office of Nuclear Physics with contributions and cost share from Michigan State University
- Serving nearly 1,350 users
- Key feature is 400 kW beam power for all ions (e.g. 5×10^{13} ^{238}U/s)
- Separation of isotopes in-flight provides
  - Fast development time for any isotope
  - All elements and short half-lives
  - Fast, stopped, and reaccelerated beams



Facility for Rare Isotope Beams
A Future DOE-SC National User Facility

- Funded by DOE–SC Office of Nuclear Physics with contributions and cost share from Michigan State University
- Serving nearly 1,350 users
- Key feature is 400 kW beam power for all ions (e.g. 5×10^{13} ^{238}U/s)
- Separation of isotopes in-flight provides
  - Fast development time for any isotope
  - All elements and short half-lives
  - Fast, stopped, and reaccelerated beams

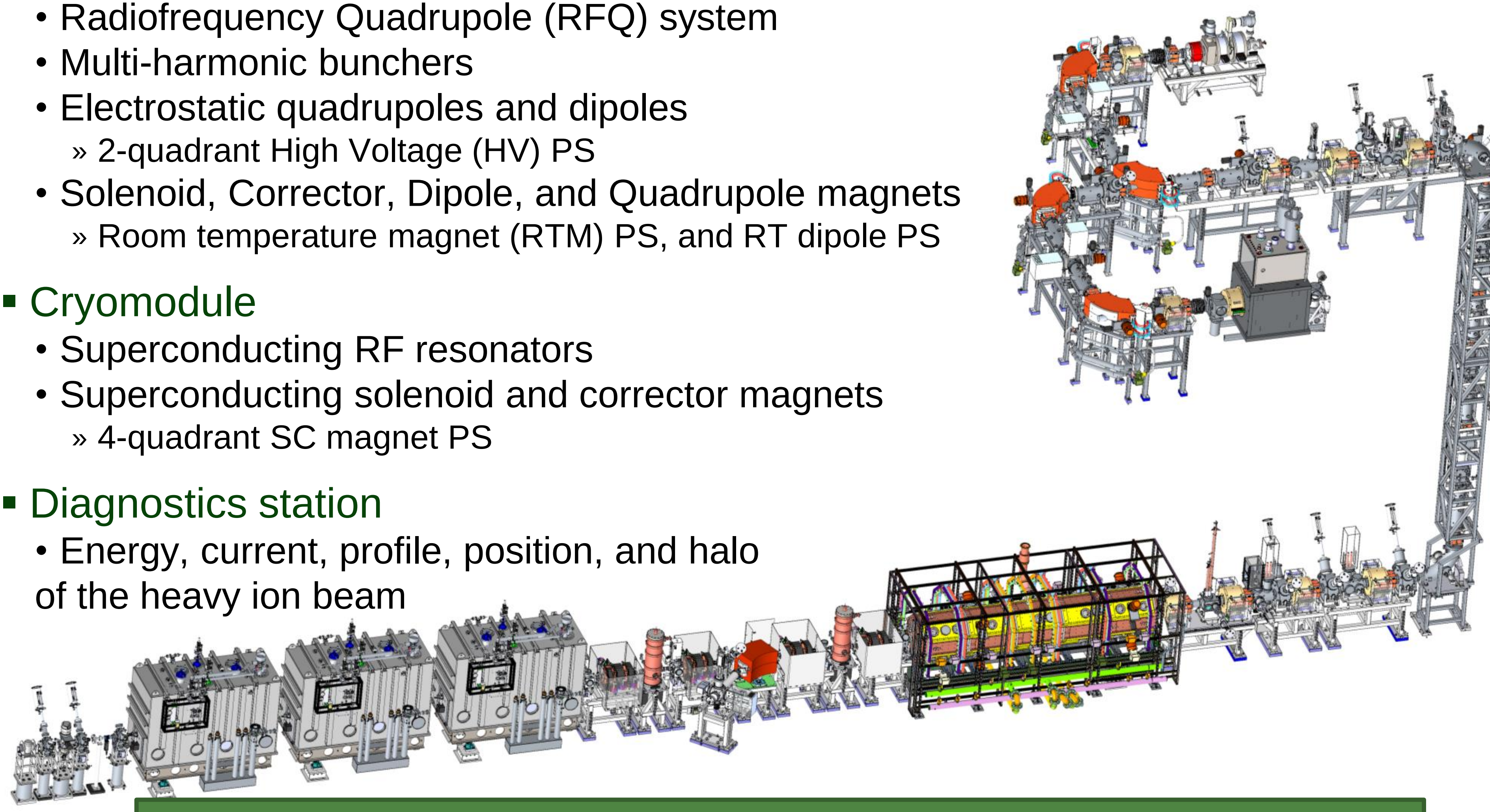
In addition to operating NSCL and building FRIB there are always multiple projects in parallel. A few interesting examples will be presented:



Present Stage of FRIB Beam Commissioning

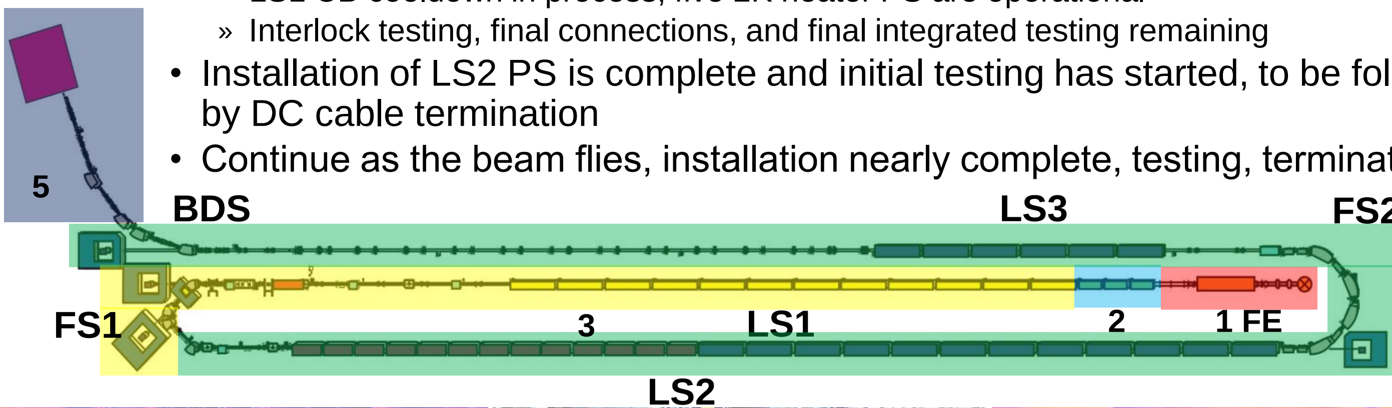
Front End, Cryomodule 1 – 3, Diagnostics Station

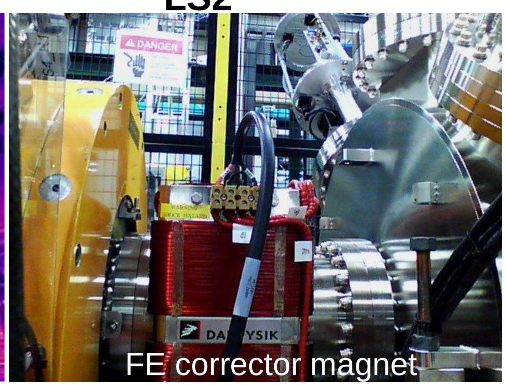
- Front End
  - Electron Cyclotron Resonance Ion Source
  - Radiofrequency Quadrupole (RFQ) system
  - Multi-harmonic bunchers
  - Electrostatic quadrupoles and dipoles
    - » 2-quadrant High Voltage (HV) PS
  - Solenoid, Corrector, Dipole, and Quadrupole magnets
    - » Room temperature magnet (RTM) PS, and RT dipole PS
- Cryomodule
  - Superconducting RF resonators
  - Superconducting solenoid and corrector magnets
    - » 4-quadrant SC magnet PS
- Diagnostics station
  - Energy, current, profile, position, and halo of the heavy ion beam

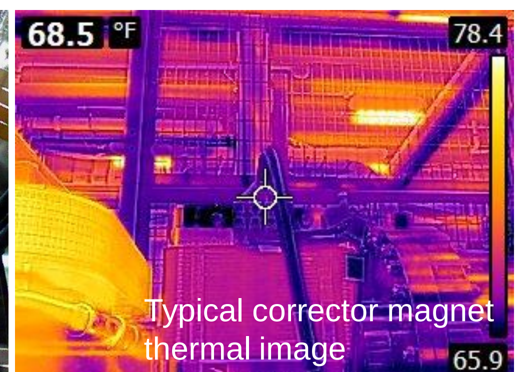


FRIB Power Supplies (PS) Scope and Status

- 728 PS are installed for FRIB, installation and commissioning status;
  - Front End (red) and CA (blue) Beam Commissioning Successful
  - Next commission CB (yellow) and to the first 2 beam dumps (yellow) early 2019
    - » Initial testing complete for remaining LS1 and FS1 PS
    - » LS1 DC cabling complete, FS1 nearly complete
    - » LS1 CB cooldown in process, five 2K heater PS are operational
    - » Interlock testing, final connections, and final integrated testing remaining
  - Installation of LS2 PS is complete and initial testing has started, to be followed by DC cable termination
  - Continue as the beam flies, installation nearly complete, testing, terminations…





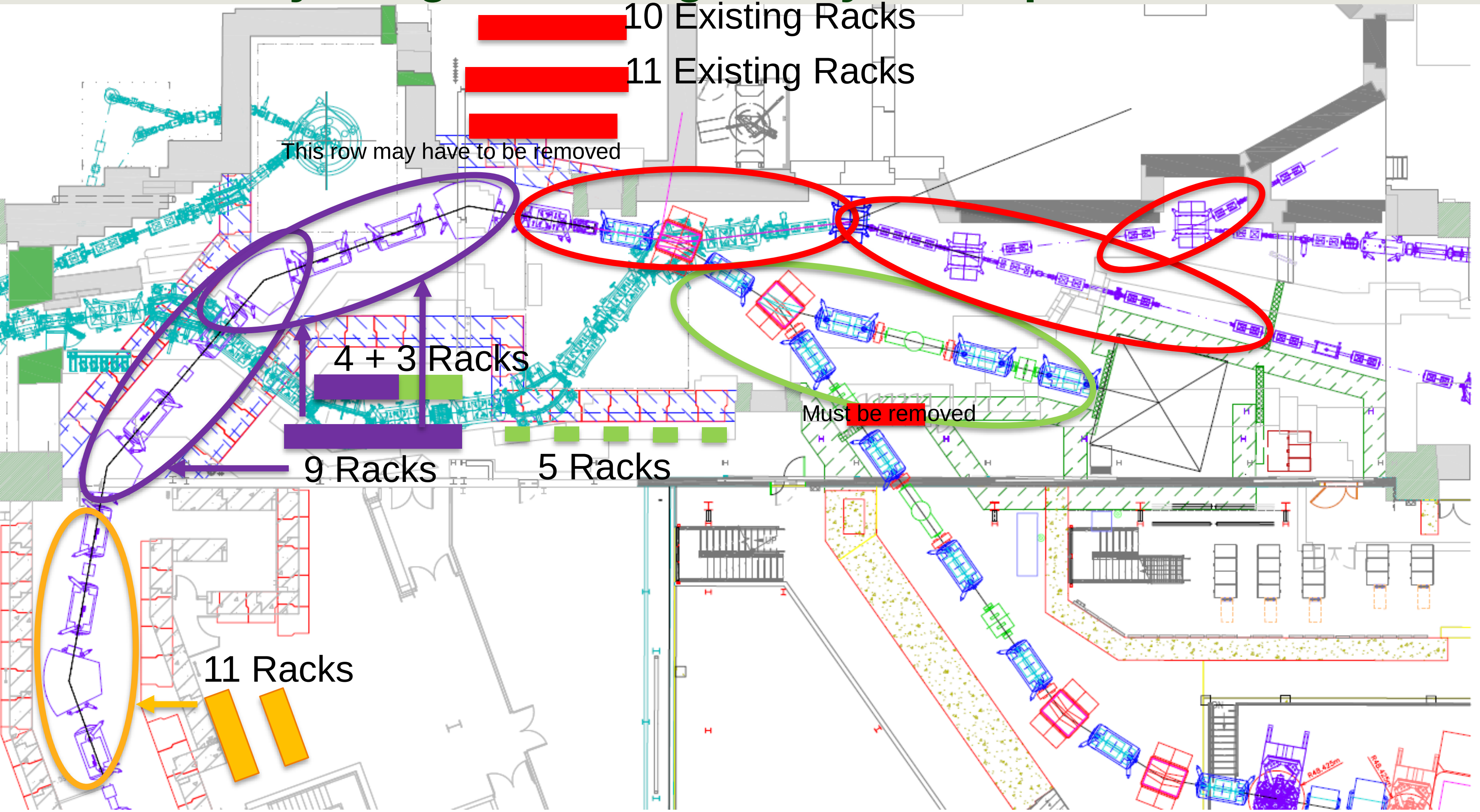


Connection issue found using thermal imager during final integrated testing

FRIB SC Magnet PS

A1900 Reconfiguration Planning

Early Integration Stage - Physical Space Claim



Possible PS / Rack Locations

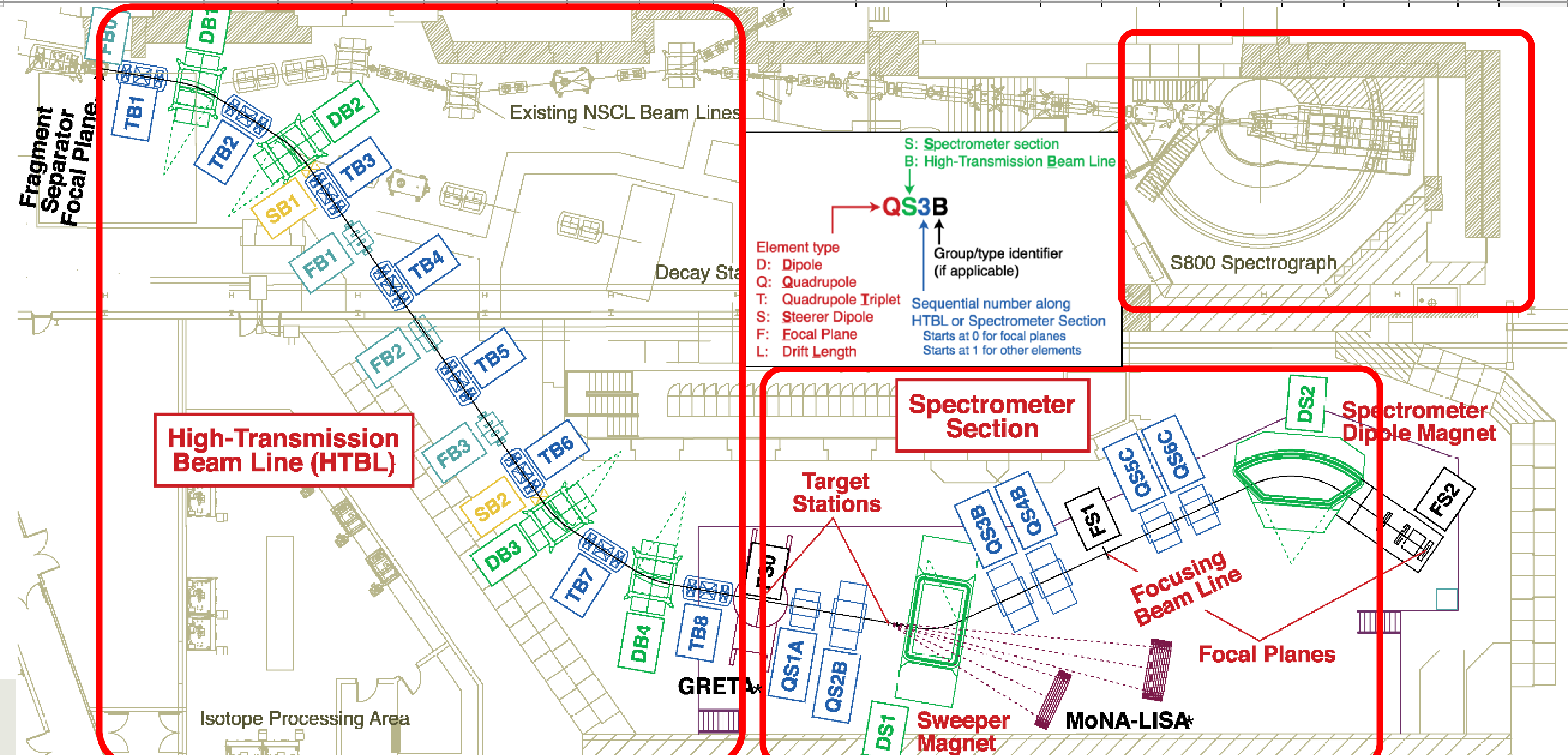
HRS

Scope of HRS PS

96 SC magnet PS, 2 RT corrector PS

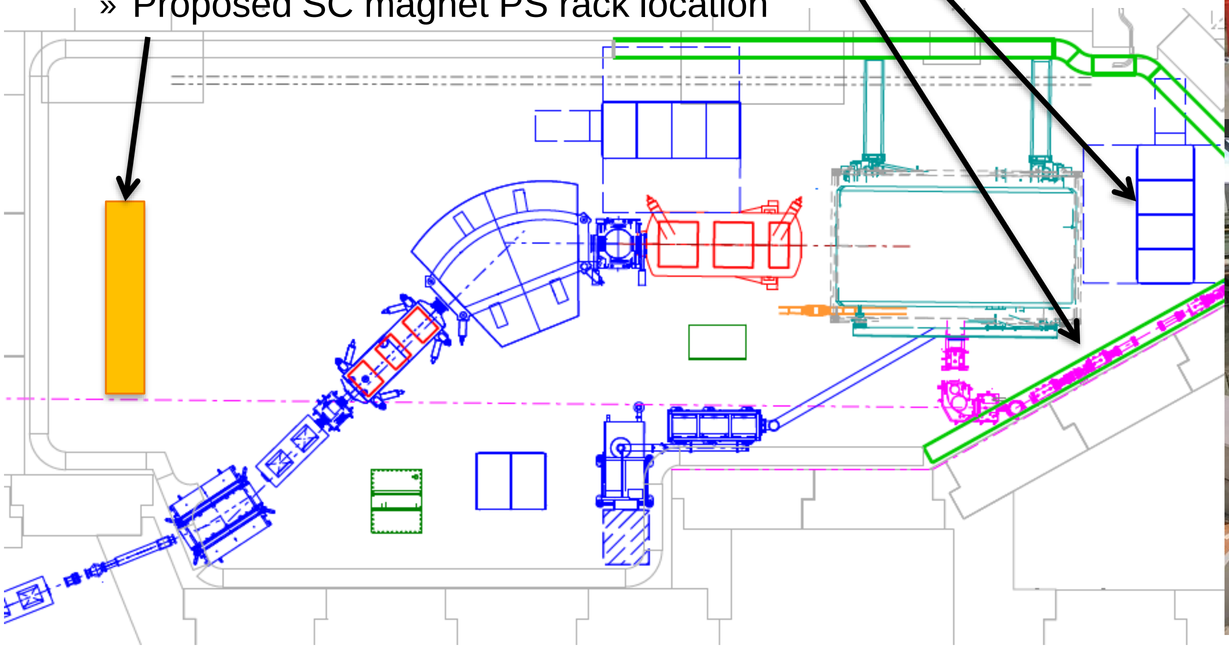
- A new spectrometer for in-flight reactions providing sensitive tests of nuclear models

HRS + HTB Magnet	QSA(Q)	QSA(S)	QSA(O)	QSB(Q)	QSB(S)	QSB(O)	QSC(Q)	QSC(S)	QSC(O)	Dipole-D1	Dipole-D2	QB(Q)	QB(S)	QB(O)	QD(Q)	QD(S)	QD(O)	B1	C1	Totals
Quantity	1	1	1	3	3	3	2	2	2	1	1	16	16	16	8	8	8	4	2	98
Imax	500	100	100	750	100	100	500	100	100	1250	1250	100	100	20	100	100	20	500	70	
Vmax	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	12	



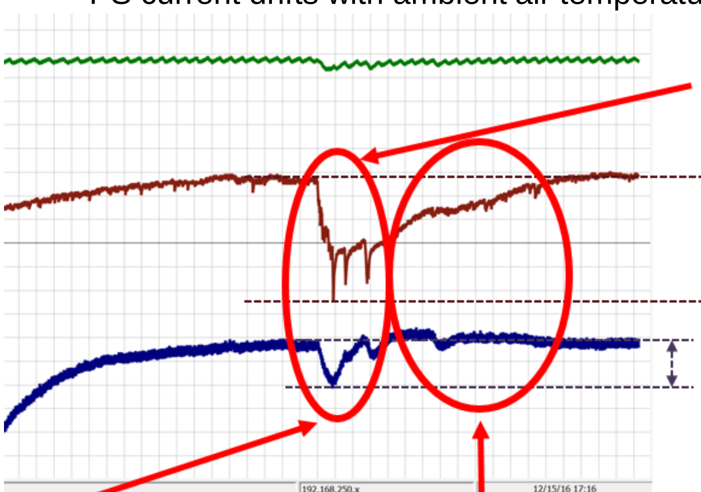
N2 Vault Cyclotron Stopper Reconfiguration

- Cyclotron (Cyc) stopper for intense thermalized beams
- The SC Cyc stopper has been commissioned and is being moved into the N2 Vault
  - Cyc stopper floating on top of 60 kV HV DC PS
    - Including the cyc stopper SC magnet PS
  - Electrostatic beamline requires HV PS
  - Using existing SC beamline magnets
    - Proposed SC magnet PS rack location



SECAR Project Status

- Magnet Power Supply (PS) procurement – working with supplier to resolve quality issues
  - 9 failures out of 30 PS! 5 Failure modes.
    - (4) DC Under-voltage, supplier investigating root cause and corrective action
      - (2) blown power module fuses, (1) bad FET, (1) bad cap
      - (1) tripped at 40 A intermittent, no longer occurring
      - (1) trips at 100 A
    - (2) AC Phase Detection – loose connection resolved on all 30
    - (1) Blank panel – wrong standoffs from subcontractor resolved on all 30
    - (1) No communication to controller – resolved swapped front panel
    - (1) Ripple at 90% current – proposed to resolve by adding series resistor
- Power supplies installation and testing status →
- Air temperature stability risk reduced by testing
  - PS current drifts with ambient air temperature change

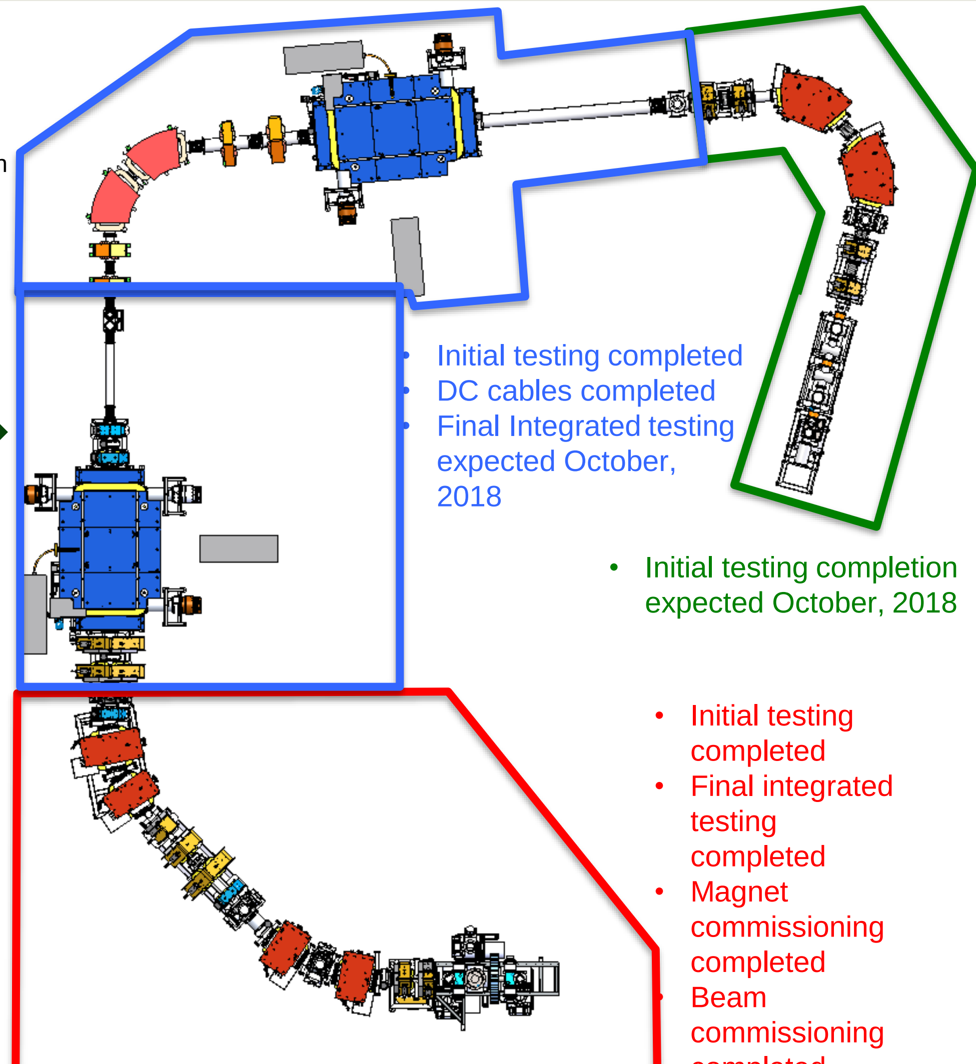


Receiving door opened for 10 minutes on a ~15 F day

5.5°C air temperature

PS current ±9.4 ppm-fs Within ±17.5 ppr specification

- Example of fast temperature transient, PS temperature control loop cant keep up with fast change
- Example of slow temperature transient, PS temperature control loop keeps up with change



- Initial testing completed
- DC cables completed
- Final Integrated testing expected October, 2018

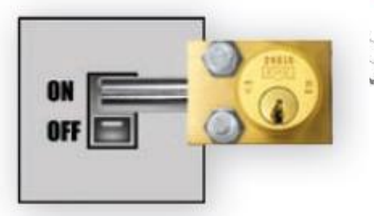
- Initial testing completion expected October, 2018

- Initial testing completed
- Final integrated testing completed
- Magnet commissioning completed
- Beam commissioning completed

PS Safety Integrated into Designs

- Front End Ion Source HV Platforms, exposed HV mitigated by
  - High Voltage Lockout Tagout Procedure
  - Mandatory - Lock-Out Tag-Out (LOTO) to isolate energy source and verify isolation, ground bar and ground stick to ensure zero stored energy state
  - Engineering controls – Kirk keys, force the sequence to be performed in the proper order
  - Defense in depth – door switches, control box, and high voltage shorting relays automatically isolate energy source and ground the HV platform
- Standard industrial hazards are known and mitigated
  - Mitigate by following standard industrial practices such as LOTO, covers, etc.
  - Magnet and PS connections will be covered, PS racks will be locked, signs posted, and a tool and LOTO procedures are required to unlock rack or remove covers
    - » Signage
      - Example magnet cover hazard signage
      - Example rack safety instruction signage (In addition to rack hazard signage)

LOTO



Kirk key

SAFETY INSTRUCTIONS

RACK 7
Following FRIB-T31209-PR-000448
The following breakers must be locked prior to opening rack:

Control Name	Breaker Panel	Breaker Number	Breaker V/A Rating	Equipment Owner
REA_BTS33:PSQ_D1388	REA3/L-Line EXT	35	480V/30A	Power Supply Group
REA_BTS33:PSQ_D1395	REA3/L-Line EXT	30	480V/30A	Power Supply Group
REA_BTS33:PSQ_D1411	REA3/L-Line EXT	31	480V/30A	Power Supply Group
REA_BTS33:PSQ_D1415	REA3/L-Line EXT	33	480V/30A	Power Supply Group

Magnet Cover

Walkthrough of Interface Tracker

- The FRIB interface tracker spreadsheet tracks Interface Requirements Documents between systems
- Interface tracker
- ESD Interface tracker shown →

Legend	
O	ICD not required
Y	ICD required, not yet in DCC
T	Link to ICD(s), but details T.B.D. in ICD
V	Link to ICD(s)

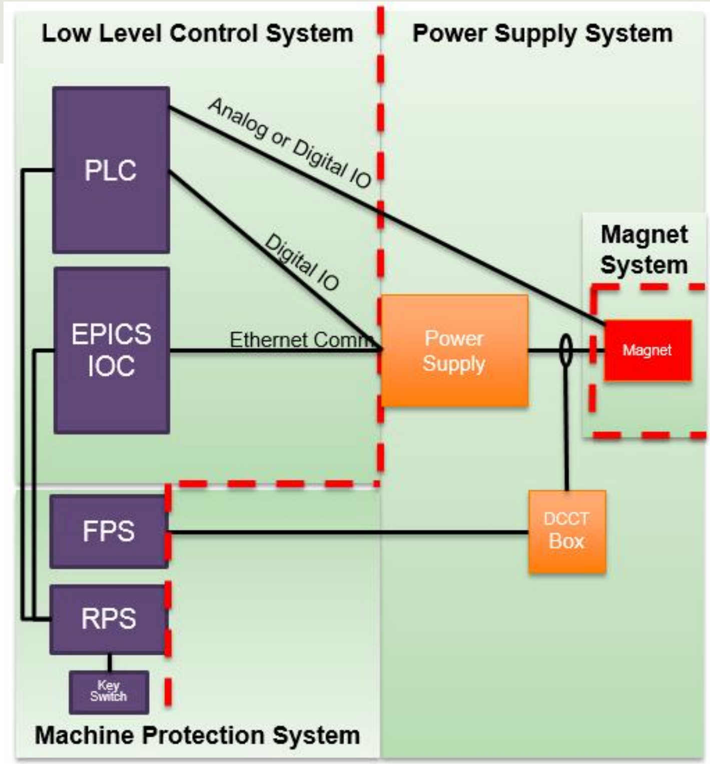
Acronyms	
ASD	Accelerator Systems Division
CFD	Conventional Facilities Division
ESD	Experimental Systems Division

Avg.% 49

%avail.			Cryogenic Systems T.3.02	Target Area Utilities T.4.02.01	Target Area Remote Handling T.4.02.02	Target Area Non-Conv. Utilities T.4.02.03	Frag. Sep. Beam Physics T.4.03.01	Diagnostics T.4.03.02	Preseparator Magnets T.4.03.03	Preseparator Mechanical Systems T.4.03.04	A 1900 Reconfiguration T.4.03.05	Power Supplies T.4.03.06
63	Cryogenic Systems	T.3.02	O									
29	Target Area Utilities	T.4.02.01	O	O								
33	Target Area Remote Handling	T.4.02.02	O	O	O							
11	Target Area Non-Conv. Utilities	T.4.02.03	Y	Y	Y	O						
100	Frag. Sep. Beam Physics	T.4.03.01	O	O	O	O	O					
18	Diagnostics	T.4.03.02	O	Y	Y	O	V	O				
64	Preseparator Magnets	T.4.03.03	V	Y	V	Y	V	O	O			
27	Preseparator Mechanical Syst.	T.4.03.04	Y	Y	Y	Y	O	Y	Y	O		
63	A1900 Reconfiguration	T.4.03.05	V	O	O	O	O	Y	O	O	O	
100	Power Supplies	T.4.03.06	V	V	O	O	O	O	V	V	V	O
89	Vacuum Systems	T.4.03.07	O	V	V	O	O	O	V	V	V	O
46	Low Level Controls	T.4.03.08	Y	O	O	Y	O	Y	V	Y	V	V
0	Target and Material Physics	T.4.03.09	O	O	O	O	O	O	O	Y	O	O
100	Machine Protection System	T.4.06	O	O	O	V	O	V	O	V	O	V
25	Global Timing System	T.3.04.02	O	O	O	O	O	Y	O	O	O	O
20	Central Control Systems	T.3.13.01	O	O	O	Y	O	Y	Y	O	O	V
43	Alignment Systems	T.3.13.03	O	O	Y	O	O	Y	V	Y	V	O
40	Personnel Protection Systems	T.3.13.04	V	O	Y	O	O	O	O	Y	O	V
	ASD Beam Delivery System	T.3.11	O	O	Y	O	O	O	O	V	O	O
	CFD	T.2	V	Y	V	Y	O	Y	O	Y	Y	V
	NSCL	NA	O	O	O	O	O	O	O	O	Y	O

Magnet / Controls / PS Interface Defined

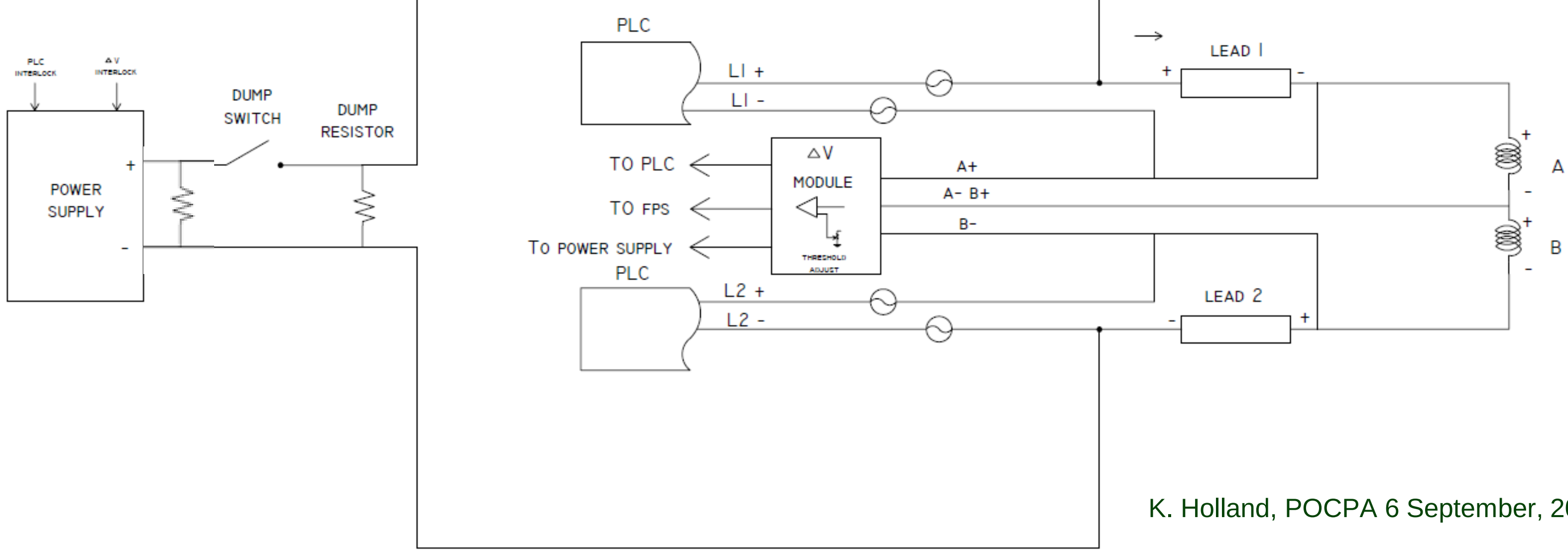
- The magnet group provides
  - Terminal block to attach the DC leads
  - Wiring between terminal block and magnet, strain relief for cables, safety covers, polarity labels and testing
- Controls monitors magnets via PLC
  - Example RT magnet - water flow and coil temperature
- Controls provides a failsafe hardwired digital output
  - 0 V / disconnected = PS disabled
  - 24 V = PS enabled
- The table below lists the conditions which will cause interlock (immediate shutdown) of PS for typical self protecting SC magnets



Interlocked Device	Interlocked State	Interlocking Device Description	Signal/Limit	Delay
Solenoid Power Supplies Vertical Corrector Power Supplies Horizontal Corrector Power Supplies	0 – "OFF"	Solenoid Power Supply Lead Voltage Drops Vertical Corrector Power Supply Lead Voltage Drops Horizontal Corrector Power Supply Lead Voltage Drops	>±100 mV	None
		Helium header level	<25% full	Ramp
		Helium header pressure	>12 PSIG	None
		PS Rack row water flow	<17 GPM	None

Magnet Quench Protection Interfaces Defined

- Quench detection
  - Self protecting SC magnets require only slow dump resistors
    - » No special quench detection is required other than helium level, pressure, and lead drop interlocks
  - For magnets requiring fast dump resistors
    - » Lead drop
      - Lead voltage drop >60 mV, ramp the PS to 0 A
      - Lead voltage drop >100 mV, shut off the PS
    - » Delta V - quench detected by the voltage difference between coils
      - Controls provides the delta V module that monitors the voltage on both coils, if the voltage exceeds a threshold (50 mV) the PS is shut off and the dump switch is opened



Example Quench Protection Circuit

Reduces quench voltage by Forcing both coils to quench simultaneously

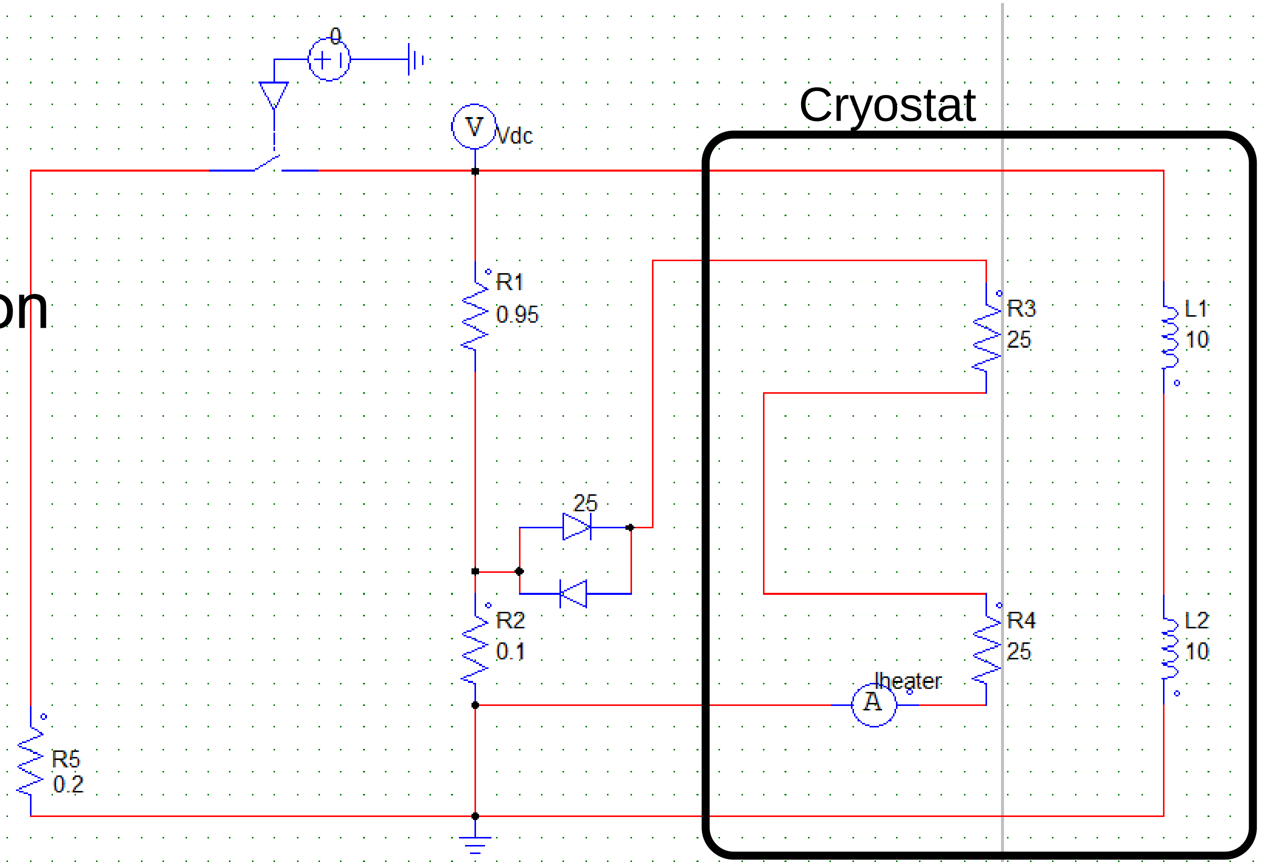
Specification:

Coil: IL=500A max, 350A min

Slow dump ~80 V
Heaters don't turn on

Fast dump ~500 V

Heater 1 W each at 350 V, shut down at 250 V



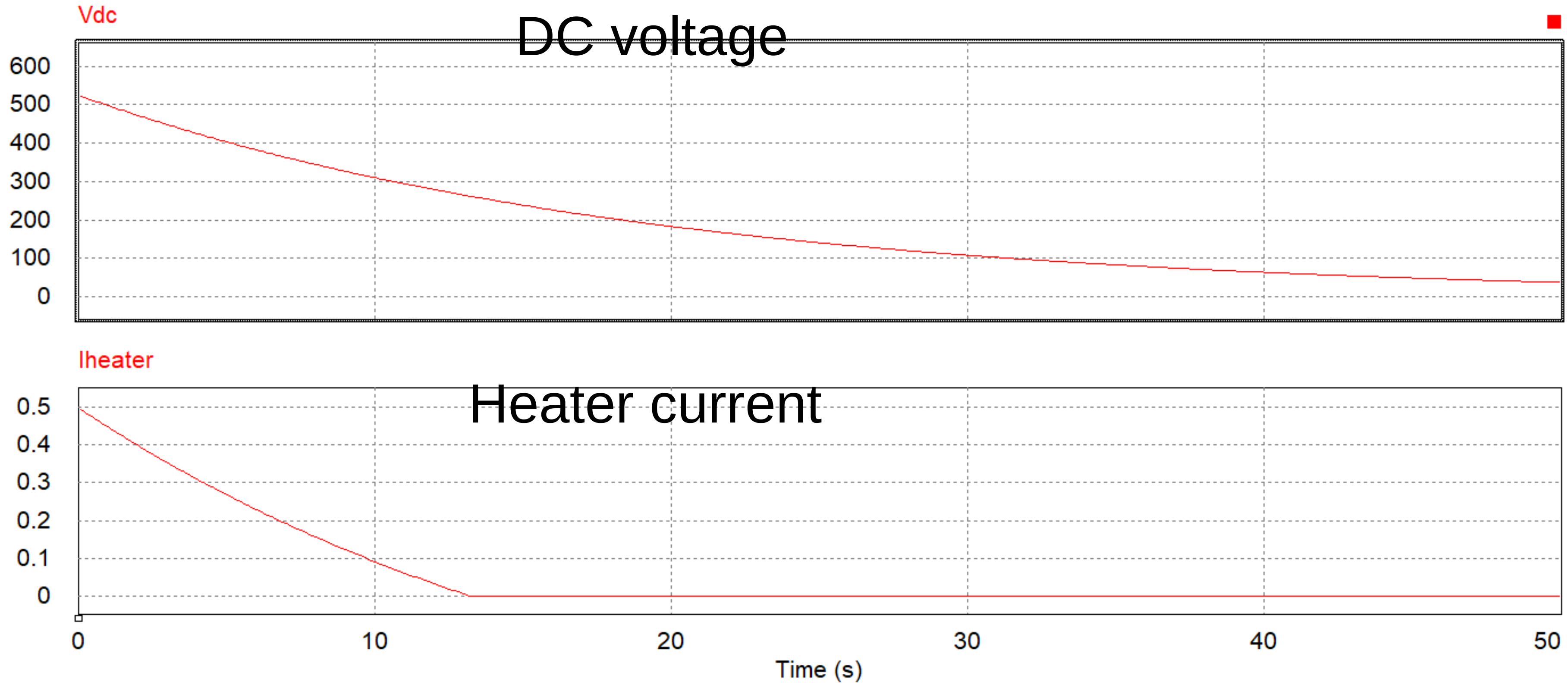
R2 >=0.1 Ohm (per manufacturer)

Quench Protection Circuit [2]

Fast dump waveforms (switch off@500A):

Note: Simulations do not include increased magnet resistance during the forced quench, magnet current will drop very quickly after current flows in heater resistors

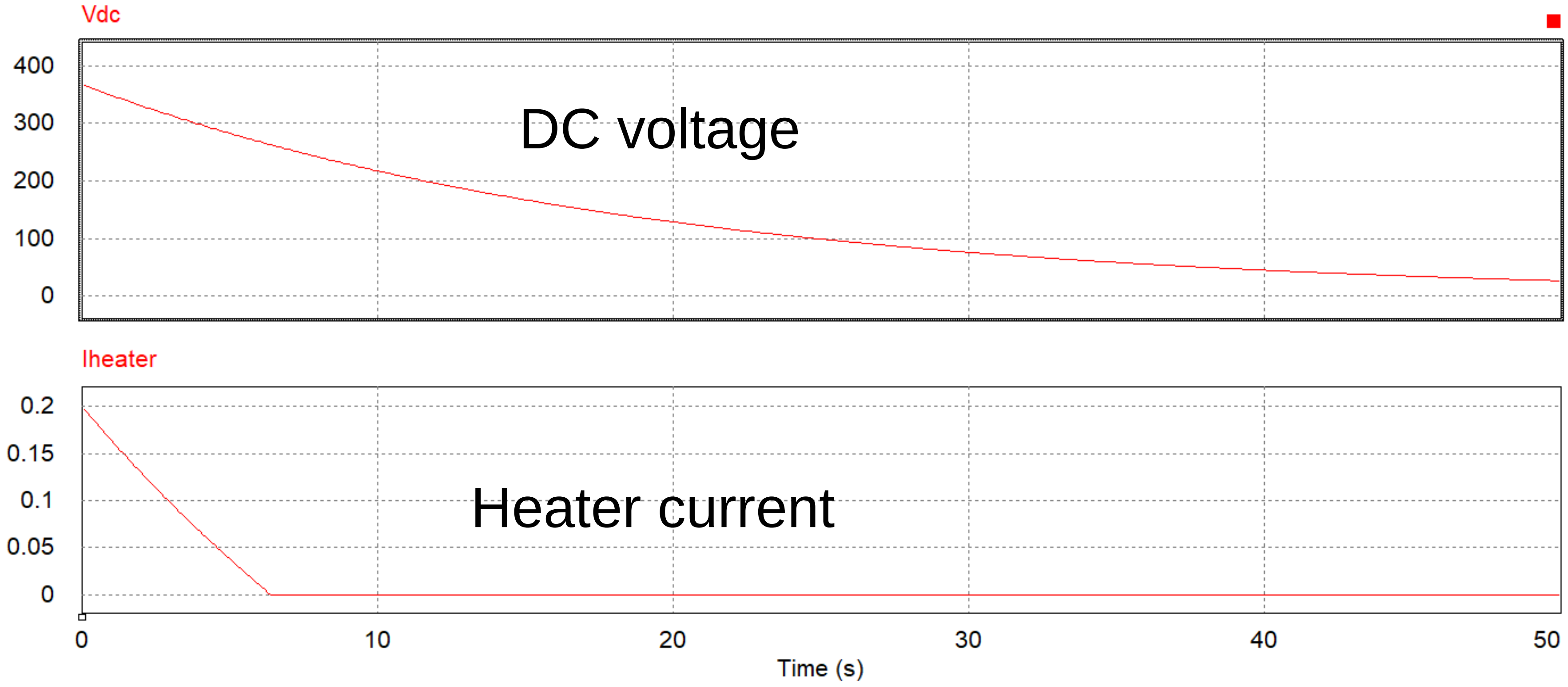
Heater power 6.25 W each



Quench Protection Circuit [3]

Fast dump waveforms (switch off@350A):

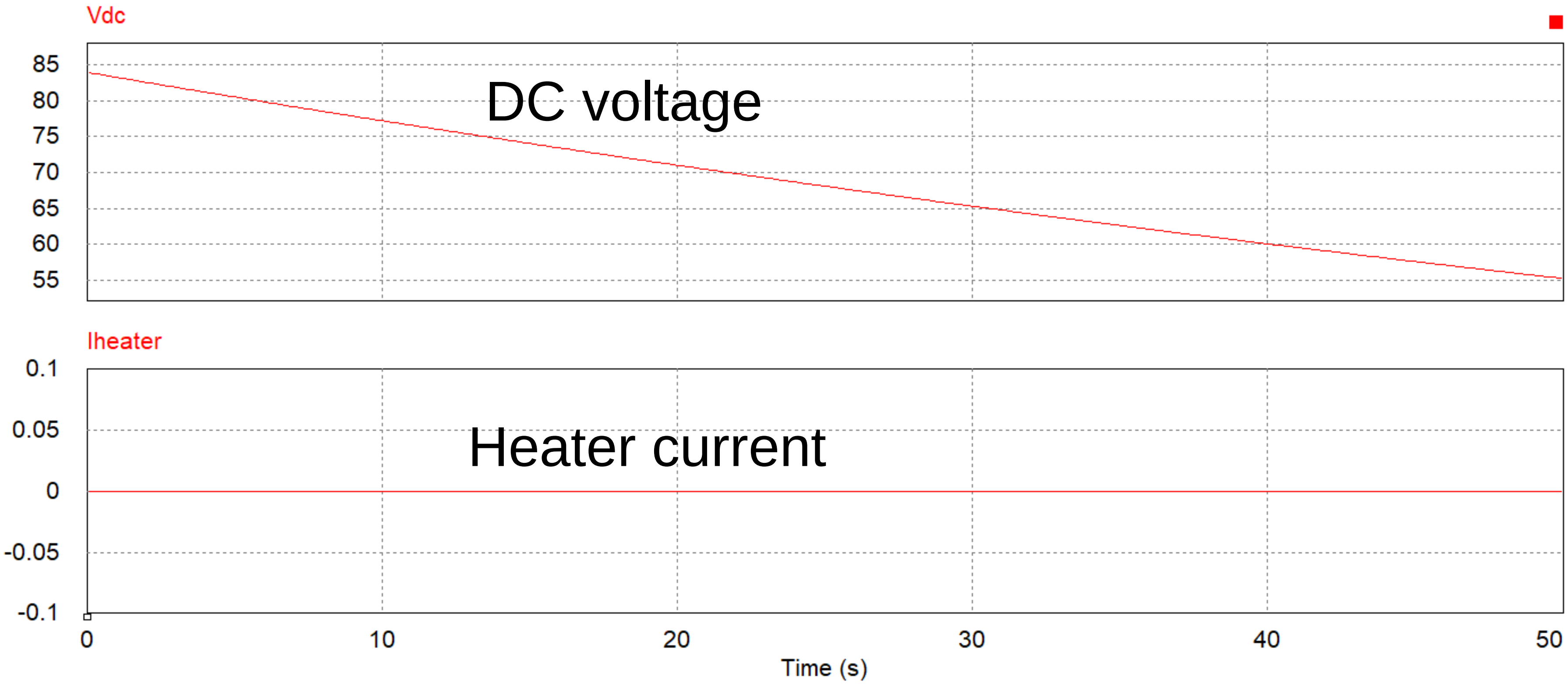
Heater power 1 W each



Quench Protection Circuit [4]

Slow dump waveforms (switch on@500A):

Heater power 0 W each



Requirements Example: Magnets and Power Supplies Direct Correlation

Magnet Counts in Parameter List

Optical Elements

Date 4/2/2012

T.3		FE-RT	FE-SC	LS1-RT	FS1-RT	FS2-RT	FS2-SC	LS3-RT	BDS-RT	
		WBS	WBS	WBS	WBS	WBS	WBS	WBS	WBS	
Name*	Element description	T.3.05.02	T.3.05.03	T.3.06.07	T.3.07.02	T.3.09.02	T.3.09.03	T.3.10.02	T.3.11.02	TOTALS
D1	RT Dipole 5 Deg				8					8
D2	RT Dipole 45 Deg				4					4
D3	SC Dipole 45 Deg						4			4
D4	RT Dipole 17.5 Deg								4	4
D5	RT Dipole 90 Deg	4								4
D6	RT Dipole 45 Deg	1								1
Q1	RT Quad 25 cm 50 mm			12	28	14		28	12	94
Q2	RT Quad 26 cm 75 mm								2	2
Q3	RT Quad 40 cm 75 mm								1	1
QS1	RT Quad-Sextupole 25 cm 140 mm				4					4
QS2	RT Quad-Sextupole 50 cm 100 mm					2				2
QS3	RT Quad-Sextupole 40 cm 100 mm					4			4	8
C1	RT HE Corr-14				2					2
C2	RT HE Corr-5			6	13	7		14	6	46
C3	RT HE Corr-10					3			3	6
C4	FE LEBT Corrector	19								19
S3	SC Solenoid FE_MEBT		4							4
S4	RT Solenoid FE_LEBT	11								11
S5	RT Solenoid FE_SCS									0
ED1	RT E-Dipole	2								2
EQ1	RT E-Quad	30								30
	TOTALS	67	4	18	59	30	4	42	32	256

PS Counts in Parameter List

T.3 Beam line			FE-RT	FE-SC	LS1-RT	LS1-SC	FS1-RT	LS2-SC	FS2-RT	FS2-SC	LS3-RT	LS3-SC	BDS-RT	
			WBS	WBS	WBS	WBS	WBS	WBS	WBS	WBS	WBS	WBS	WBS	
Optical Element*	PS type**	# of PS/element	T.3.05.07	T.3.05.07	T.3.06.04	T.3.06.04	T.3.07.08	T.3.08.05	T.3.09.07	T.3.09.07	T.3.10.05	T.3.10.05	T.3.11.05	TOTALS
D1	PSD1	1					8							8
D2	PSD2	1					4							4
D3	PSD3	1								4				4
D4	PSD4	1											4	4
D5	PSD5	1	4											4
D6	PSD6	1												0
Q1	PSQ1	1			8		24		12		28		10	82
Q2	PSQ2	1											2	2
Q3	PSQ3	1											1	1
QS1 (quad)	PSQS1a	1					4							4
QS1 (sxt1)	PSQS1b	1					4							4
QS1 (sxt2)	PSQS1c	1					4							4
QS2 (quad)	PSQS2a	1							2					2
QS2 (sxt1)	PSQS2b	1							2					2
QS2 (sxt2)	PSQS2c	1							2					2
QS3 (quad)	PSQS3a	1							4				4	8
QS3 (sxt1)	PSQS3b	1							4				4	8
QS3 (sxt2)	PSQS3c	1							4				4	8
C1	PSC1	2					4							4
C2	PSC2	2			8		26		14		28		12	88
C3	PSC3	2							6				6	12
C4	PSC4	2												0
S1 (solenoid)	PSS1a	1				6								6
S1 (correctors)	PSS1b	2				12								12
S2 (solenoid)	PSS2a	1				36		25				6		67
S2 (correctors)	PSS2b	2				72		50				12		134
S3 (solenoid)	PSS3a	1		4										4
S3 (correctors)	PSS3b	2		8										8
S4	PSS4a	1	7											7
S4	PSS4b	1												0
S4	PSS4c	1												0
S4	PSS4d	1												0
S5	PSS5	1	4											4
S6	PSS6	1												0
ED1 (+)	PSED1a	1	2											2
ED1 (-)	PSED1b	1	2											2
EQ1 (+)	PSEQ1a	1	32											32
EQ1 (-)	PSEQ1b	1	32											32
		TOTALS	83	12	16	126	78	75	50	4	56	18	47	565

*Names as listed in the requirements document T31201-SP-000019

**Names as listed in the requirements document T31201-SP-000033

Rack Layout & Power Consumption Sheets

→ = logical link

Design Integration with Civil
Example: Power Supply (PS) Rack Layouts and Conduits

PS Counts in Parameter List

Rack Installed?		Yes
120Vac	20A	3
120V Backup	20A	0
120V Clean	20A	0
208Vac 1P	30A	0
208Vac 1P	50A	0
208Vac 3P	10A	0
208Vac 3P	15A	0
208Vac 3P	20A	0
208Vac 3P	25A	0
208Vac 3P	35A	0
208Vac 3P	45A	4
208Vac 3P	55A	0
208Vac 3P	65A	0
208Vac 3P	90A	0
208Vac 3P	110A	0
208Vac 3P	130A	0
LCW	0	gpm
LCW Upgrade	0	gpm
HVAC	1.3	Tons
HVAC Upgrade		Tons
Standard 120 W	3586	
Back up 120 W		
Expected 208 W	42442	
Expected 208 W Upgrade		

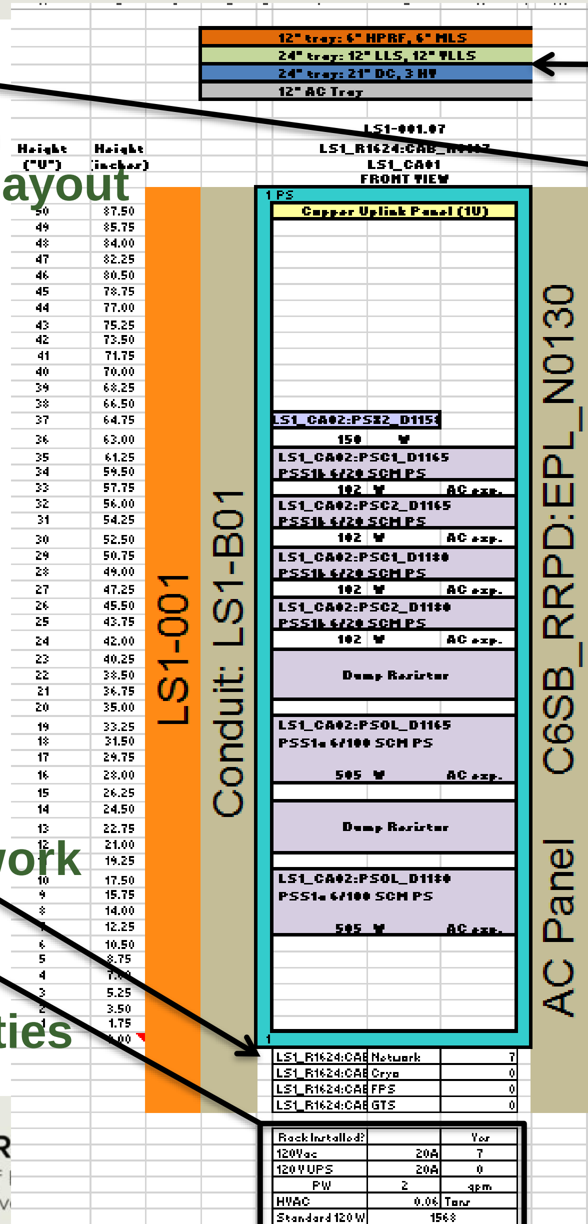
Rack layout

Cable tray

Power Consumption Sheets (next slide) and "power tree"

Network

Utilities



Rack Counts

200MeV LINAC						
T.3	# Systems	# Racks ea	# Racks	# Racks	sq ft	comments
FE (incl. ECR platforms)			Expected	Actual		
PS			17	17		
RF			6	6		
Diag			4	4		
Ctl			13	13		
RFQ					16' x 16'	includes 3' keepout all around
Linac Segment 1						
beta = 0.041 QWR 4.2	3	7	21	21		
beta = 0.085 QWR 8.3	12	10	120	120		
beta = 0.285 HWR 2.0	1	6	6	6		
PS			2	2		
Diag			2	2		
Ctl			1	1		
Folding Segment 1						
beta = 0.085 QWR 2.0	2	6	12	12		
beta = 0.285 HWR 2.0	1	6	6	6		
PS			10	10		
Diag			4	4		
Ctl			11	11		
Linac Segment 2						
beta = 0.285 HWR 6.1	13	8	104	104		
beta = 0.53 HWR 8.1	12	14	168	168		
Folding Segment 2						
beta = 0.53 HWR 3.0	1	8	8	8		
PS			7	7		
Diag			2	2		
Ctl			9	9		
Linac Segment 3						
beta = 0.53 HWR 8.1	6	14	84	84		
PS			12	12		
Diag			3	3		
Ctl			2	2		
BDS						
PS			7	7		
Diag			4	4		
Ctl			10	10		
		Total	655	655		

Fragment Separator						
T.4	# Systems	# Racks ea	# Racks	# Racks	sq ft	comments
PS			25	25		
Ctl			9	9		
		Total	34	34		

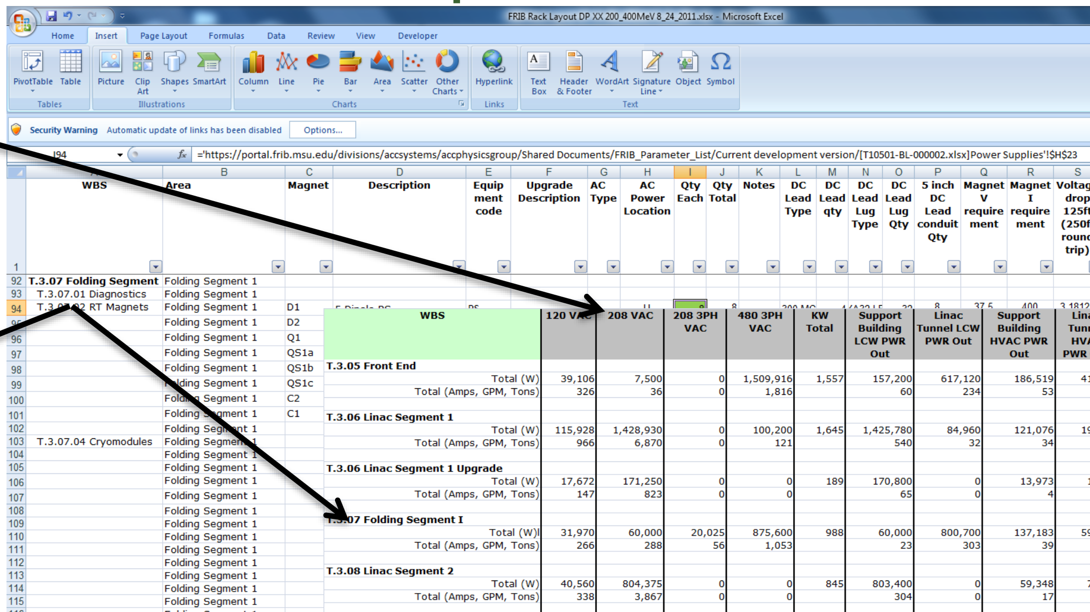
Design Integration
Example: Conduits/Alternating Current (AC) Power Requirements

→ = logical link

PS Counts in Parameter List

- Utilities by Linac segment
- AC, cooling water, and HVAC, in service building and tunnel
- Information fed forward to CF

Power Consumption Sheets



WBS	120 VAC	208 VAC	208 3PH VAC	480 3PH VAC	KW Total	Support Building LCW PWR Out	Linac Tunnel LCW PWR Out	Support Building HVAC PWR Out	Linac Tunnel HVAC PWR Out
T.3.05 Front End									
Total (W)	39,106	7,500	0	1,509,916	1,557	157,200	617,120	186,519	41,945
Total (Amps, GPM, Tons)	326	36	0	1,816		60	234	53	12
T.3.06 Linac Segment 1									
Total (W)	115,928	1,428,930	0	100,200	1,645	1,425,780	84,960	121,076	19,115
Total (Amps, GPM, Tons)	966	6,870	0	121		540	32	34	5
T.3.06 Linac Segment 1 Upgrade									
Total (W)	17,672	171,250	0	0	189	170,800	0	13,973	1,876
Total (Amps, GPM, Tons)	147	823	0	0		65	0	4	1
T.3.07 Folding Segment I									
Total (W)	31,970	60,000	20,025	875,600	988	60,000	800,700	137,183	59,589
Total (Amps, GPM, Tons)	266	288	56	1,053		23	303	39	17
T.3.08 Linac Segment 2									
Total (W)	40,560	804,375	0	0	845	803,400	0	59,348	7,541
Total (Amps, GPM, Tons)	338	3,867	0	0		304	0	17	2
T.3.09 Folding Segment 2									
Total (W)	27,683	91,875	0	375,300	495	67,200	333,590	67,573	26,595
Total (Amps, GPM, Tons)	231	442	0	451		25	126	19	8
T.3.10 Linac Segment 3									
Total (W)	40,440	971,250	0	350,700	1,362	970,800	297,360	117,379	29,158
Total (Amps, GPM, Tons)	337	4,669	0	422		368	113	33	8
T.3.10 Linac Segment 3 Upgrade									
Total (W)	38,000	1,942,500	0	0	1,981	1,941,600	0	115,483	7,255
Total (Amps, GPM, Tons)	317	9,339	0	0		735	0	33	2
T.3.11 BDS									
Total (W)	21,395	11,250	0	462,500	495	0	394,900	67,997	27,923
Total (Amps, GPM, Tons)	178	54	0	556		0	150	19	8
T.4 Target Area									
Total (W)	19,556	180,000	0	880,250	1,080	94,500	100,200	61,649	26,594
Total (Amps, GPM, Tons)	163	865	0	1,059		36	38	18	8
T.4 Target Area CICC Upgrade									
Total (W)	0	0	0	983,333	983	590,000	0	194,700	88,500
Total (Amps, GPM, Tons)	0	0	0	1,183		223	0	55	25
Total (W) w/upgrade	**392,309**	**5,668,930**	**20,025**	**5,537,800**	**11,619**	**6,281,280**	**2,628,830**	**1,142,880**	**336,093**
Total (Amps, GPM, Tons)	**3,269**	**27,254**	**56**	**6,661**		**2,379**	**996**	**325**	**96**
Total (W) wo/upgrade	**336,637**	**3,555,180**	**20,025**	**4,554,466**	**8,466**	**3,578,880**	**2,628,830**	**818,724**	**238,461**
Total (Amps, GPM, Tons)	**2,805**	**17,092**	**56**	**5,478**		**1,356**	**996**	**233**	**68**

Conduits

Component (each)	Qty DPXX	RF Drive 400MeV	RF Signal	Controls	Diagnostics	PS	Total
		5.5 inch conduits each					
Front End							
Magnets				5	5	18	28
RF Bunchers	2	1	1				4
RFQ	1	2	1				3
Linac Segment 1							
Magnets				1		9	10
beta = 0.041 QWR 4.2	3	2	1	2	2	2	27
beta = 0.085 QWR 8.3	14	4	1	2	2	3	168
beta = 0.285 HWR 2.0	1	2	1	2	2	0	7
Folding Segment 1							
Magnet				5		53	58
beta = 0.285 HWR 2.0	1	2	1	2	2	0	7
beta = 0.085 QWR 2.0	2	2	1	2	2	0	14
Stripper	1			2	2	3	7
Linac Segment 2							
beta = 0.285 HWR 6.1	13	6	2	2	2	1	169
beta = 0.53 HWR 8.1	12	8	3	2	2	1	192
Folding Segment 2							
Magnet				5		29	34
beta = 0.53 HWR 3.0	1	3	1	2	2	0	8
Linac Segment 3							
Magnet				3		30	33
beta = 0.53 HWR 8.1	6	8	3	2	2	1	96
Linac Segment 3 Upgrade							
Magnet				3		30	-33
beta = 0.53 HWR 8.1	12	8	3	2	2	1	192
BDS	1			36	18	24	78
Minimum Conduits		395	141	168	150	205	**1102**

Design Example: Magnets

- We will look at the front end Low Energy Beam Transport (LEBT) solenoids in the accelerator tunnel
  - 4 of the 11 S4 solenoids are located prior to the Radio Frequency Quadrupole (RFQ)

Optical Elements

Date 4/2/2012

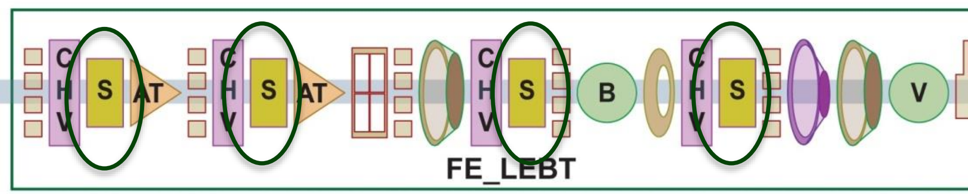
T.3

Name*	Element description	FE-RT WBS T.3.05.02	FE-SC WBS T.3.05.03	LS1-RT WBS T.3.06.07	FS1-RT WBS T.3.07.02	FS2-RT WBS T.3.09.02	FS2-SC WBS T.3.09.03	LS3-R WBS T.3.10		
D1	RT Dipole 5 Deg				8					
D2	RT Dipole 45 Deg				4					
D3	SC Dipole 45 Deg						4			
D4	RT Dipole 17.5 Deg									
D5	RT Dipole 90 Deg	4								
D6	RT Dipole 45 Deg	1								
Q1	RT Quad 25 cm 50 mm			12	28	14				
Q2	RT Quad 26 cm 75 mm									
Q3	RT Quad 40 cm 75 mm									
QS1	RT Quad-Sextupole 25 cm 140 mm				4					
QS2	RT Quad-Sextupole 50 cm 100 mm					2				
QS3	RT Quad-Sextupole 40 cm 100 mm					4				
C1	RT HE Corr-14				2					
C2	RT HE Corr-5			6	13	7				
C3	RT HE Corr-10					3			3	6
C4	FE LEBT Corrector	19								19
S3	SC Solenoid FE_MEBT		4							4
S4	RT Solenoid FE_LEBT	11								11
S5	RT Solenoid FE_SCS									0
ED1	RT E-Dipole	2								2
EQ1	RT E-Quad	30								30
	TOTALS	67	4	18	59	30	4	42	32	256

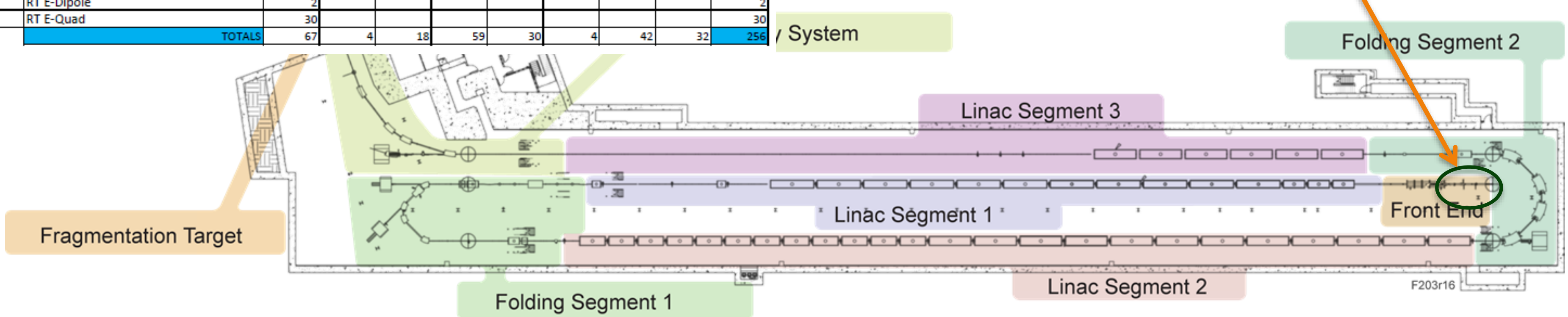
Front End Linac Tunnel

Parameter list

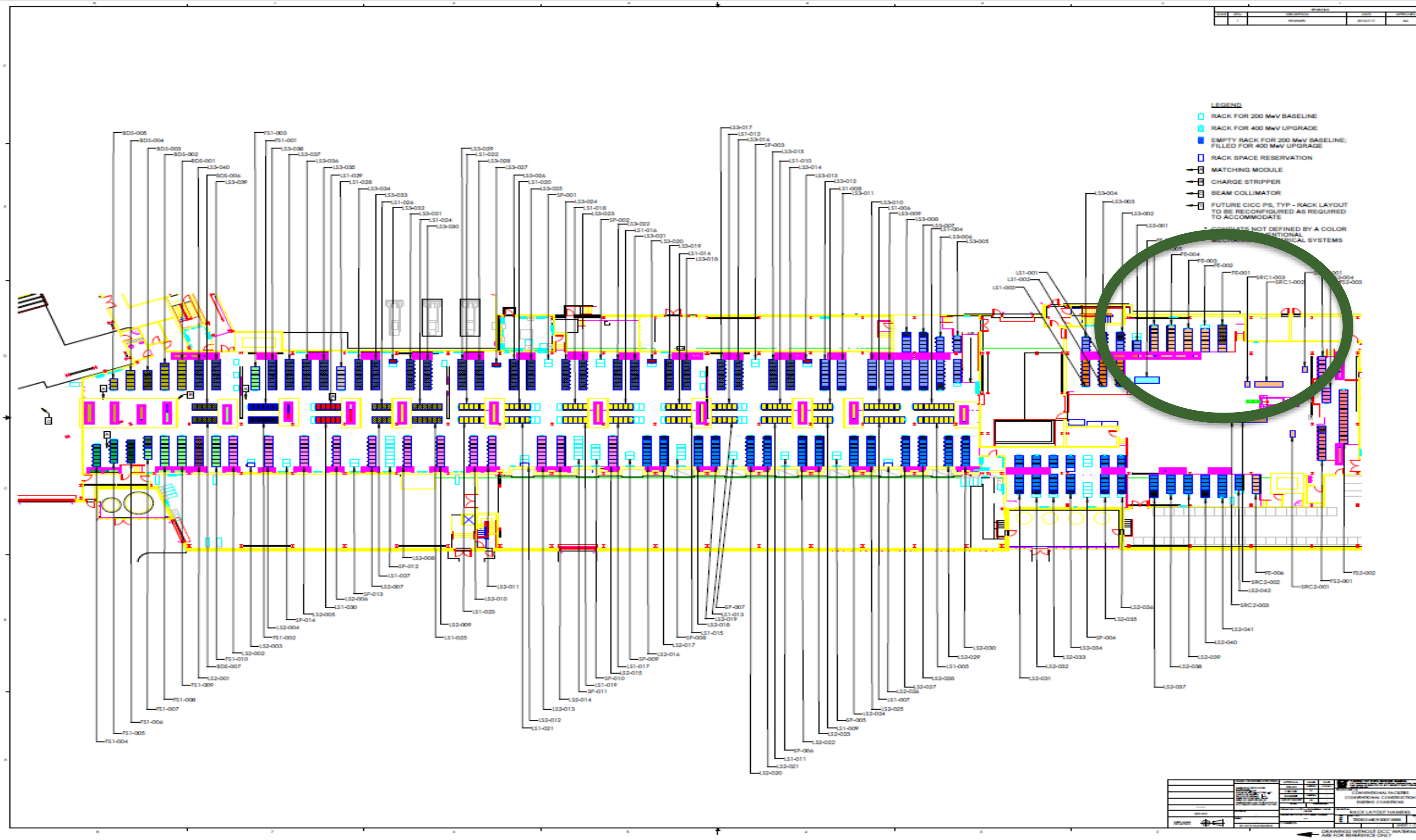
From Vertical Drop



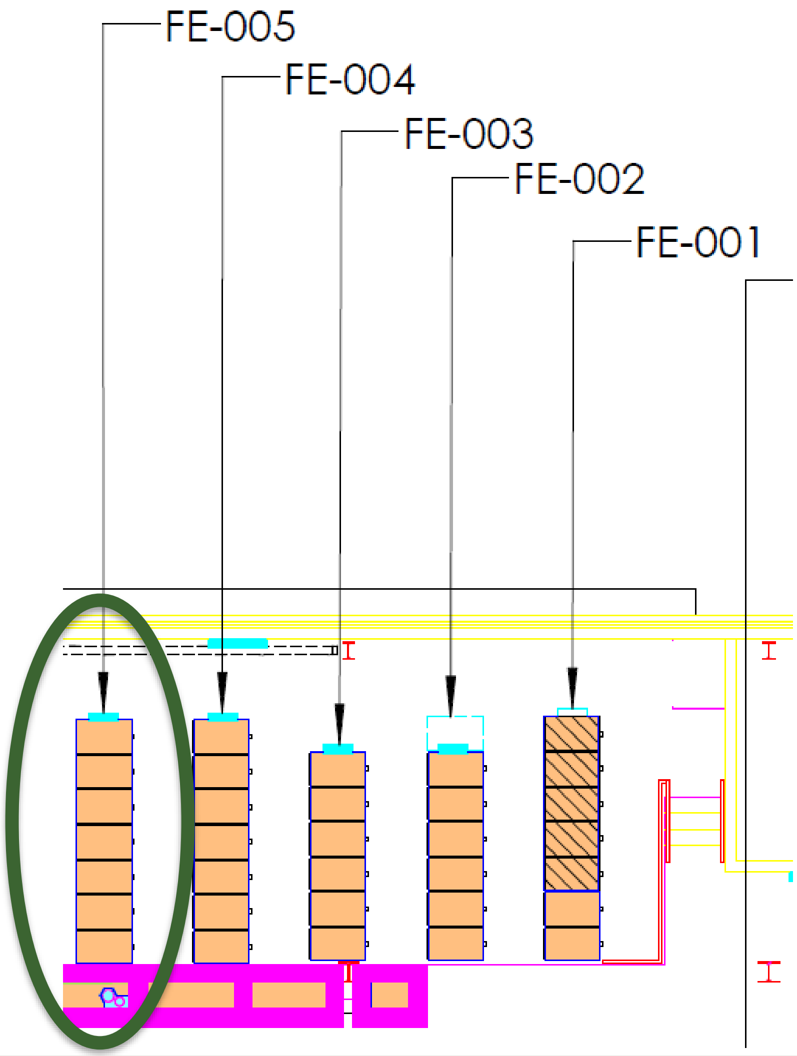
Located



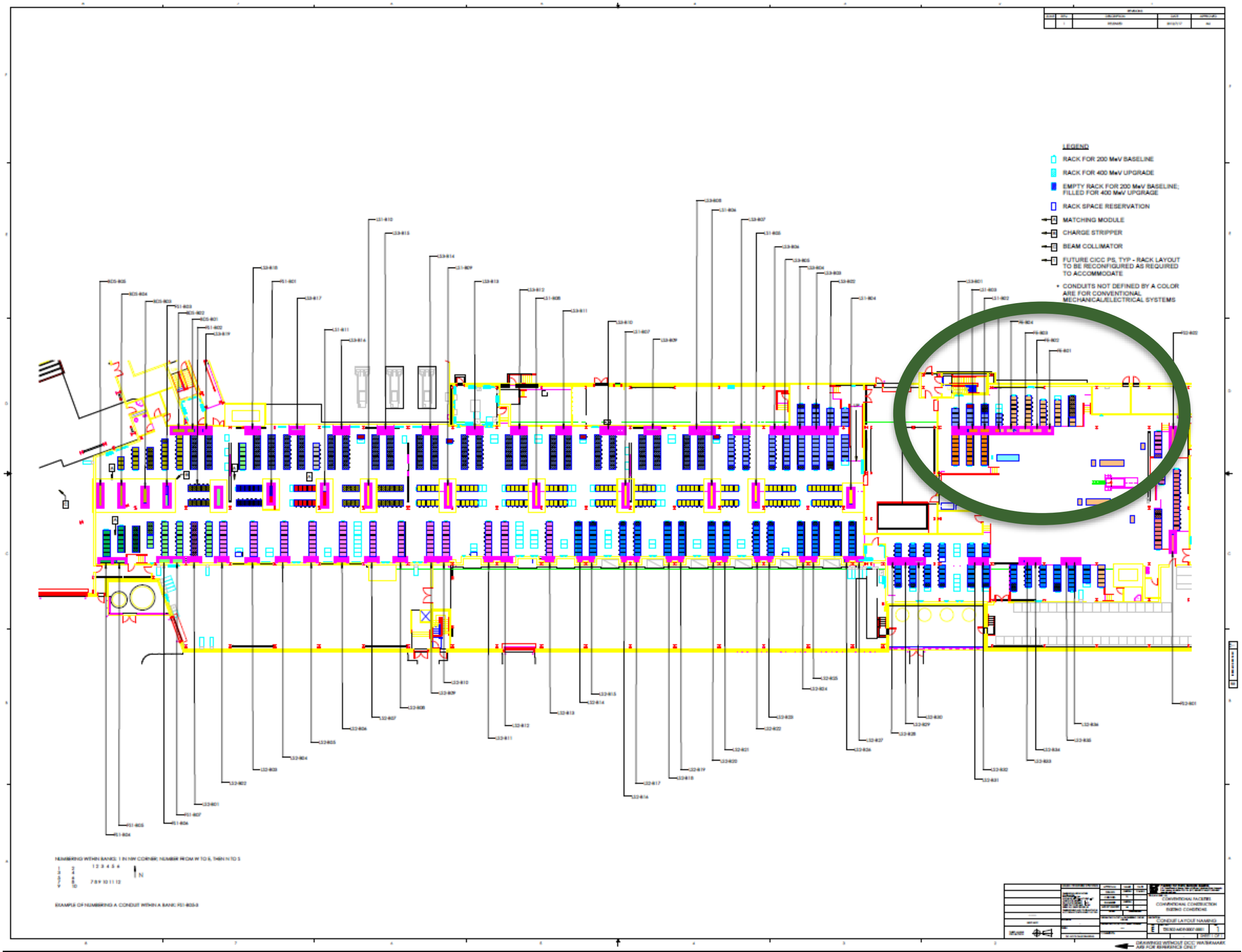
Service Building Rack Row Naming



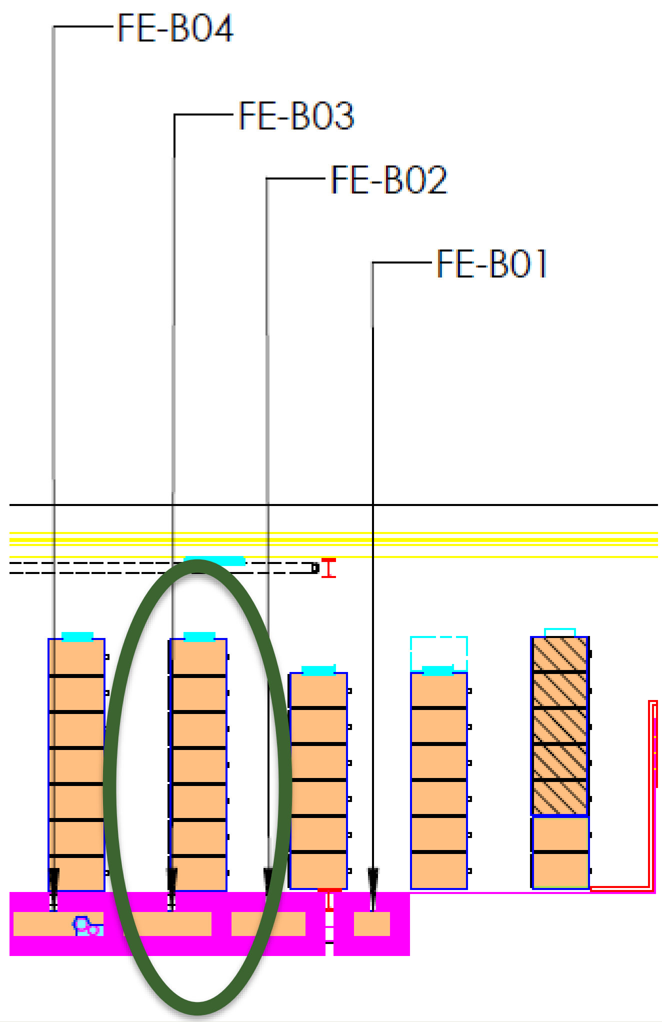
Front End Rack Row Naming



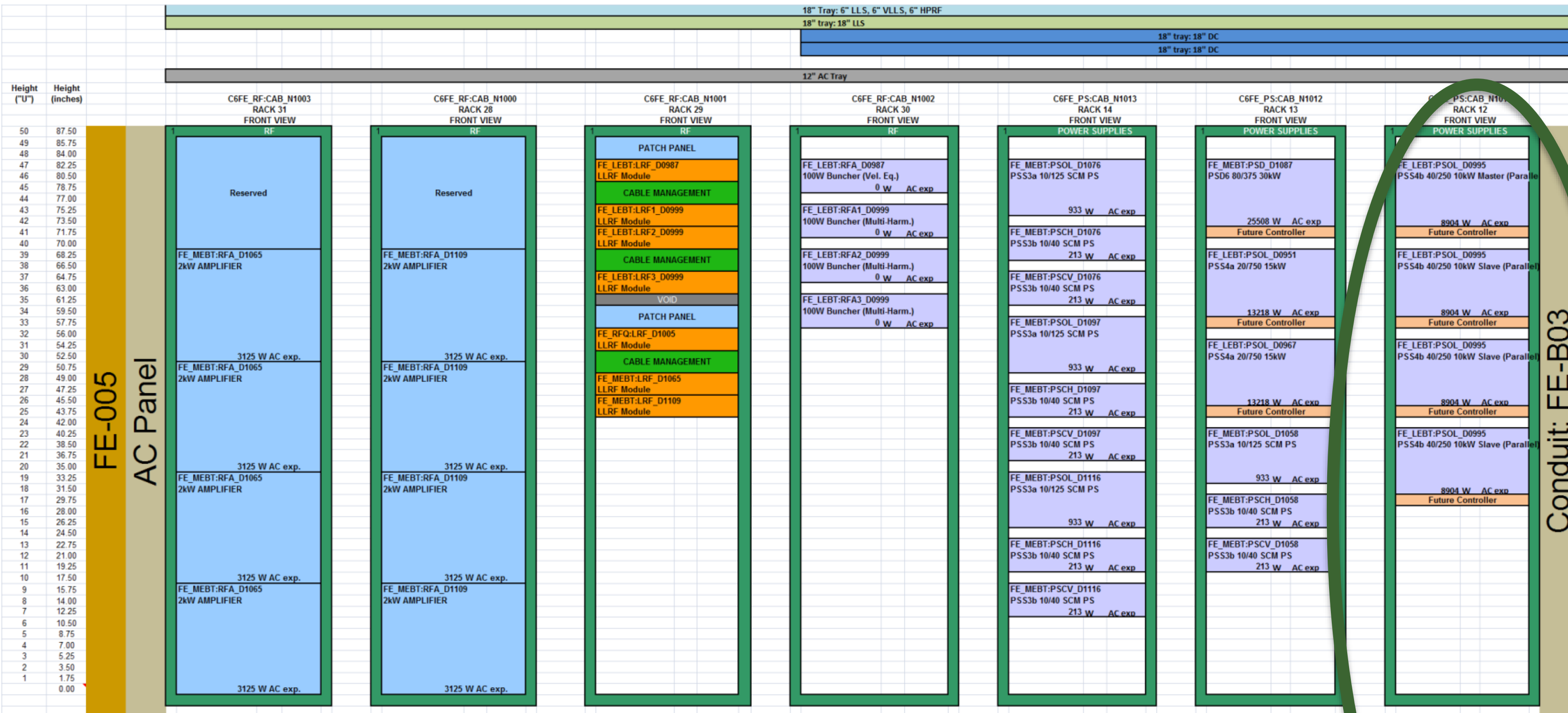
Service Building Conduit Bank Naming



Front End Conduit Bank Naming

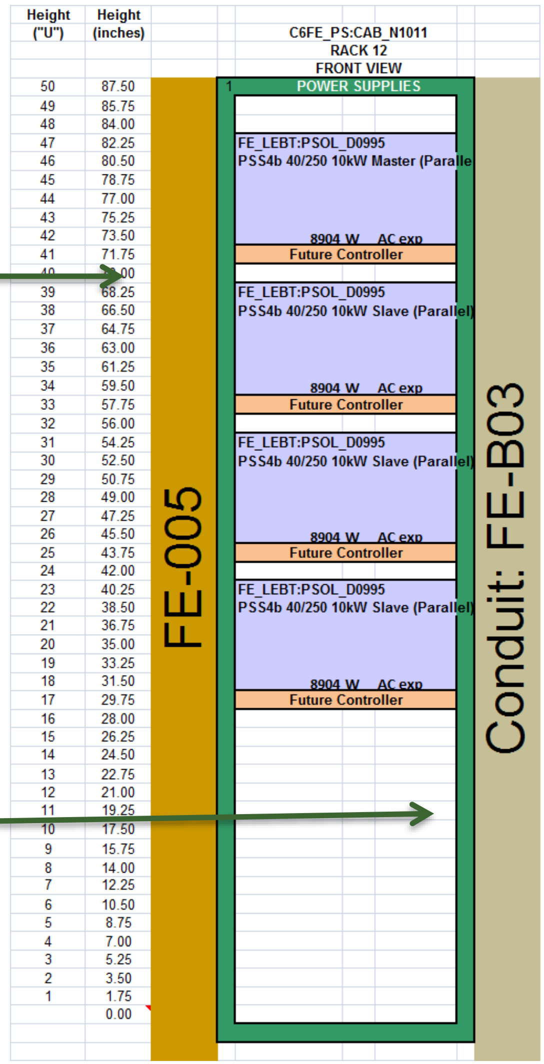


Rack Row Layout



Item	Rating / Unit	Rack 31	Rack 28	Rack 29	Rack 30	Rack 14	Rack 13	Rack 12
Rack Installed?		Yes	Yes	Yes	Yes	Yes	Yes	Yes
120Vac	20A	1	1	1	1	1	1	1
120V Backup	20A	0	1	0	0	0	0	0
120V Clean	20A	0	0	0	0	0	0	0
208Vac 1P	30A	4	4	0	0	9	3	0
208Vac 1P	50A	0	0	0	0	0	0	0
208Vac 3P	10A	0	0	0	0	0	0	0
208Vac 3P	15A	0	0	0	0	0	0	0
208Vac 3P	20A	0	0	0	0	0	0	0
208Vac 3P	25A	0	0	0	0	0	0	0
208Vac 3P	35A	0	0	0	0	0	2	0
208Vac 3P	45A	0	0	0	0	0	0	4
208Vac 3P	55A	0	0	0	0	0	0	0
208Vac 3P	65A	0	0	0	0	0	0	0
208Vac 3P	90A	0	0	0	0	0	0	0
208Vac 3P	110A	0	0	0	0	0	0	0
208Vac 3P	130A	0	0	0	0	0	1	[illegible]
LCW	gpm	0	0	0	0	0	0	0
Fans	825 CFM	0	0	0	0	1	1	1
HVAC	Tons	0.356	0.36	0	0	0.15	2	[illegible]
Expected 120 W						1277	426	
Expected 208 W		12500	12500			2800	52877	35618

Rack Layout



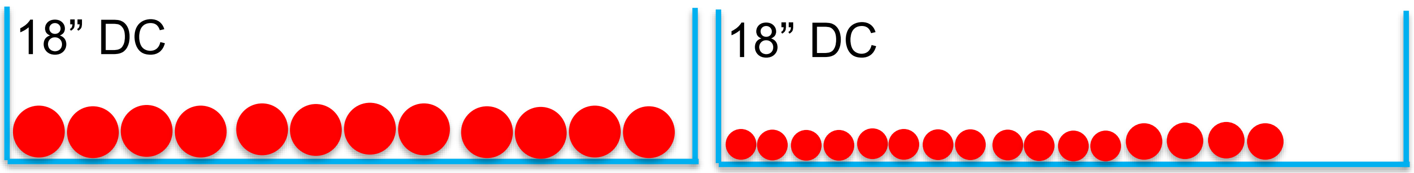
Rack Row Name and Conduit Name Match Drawings

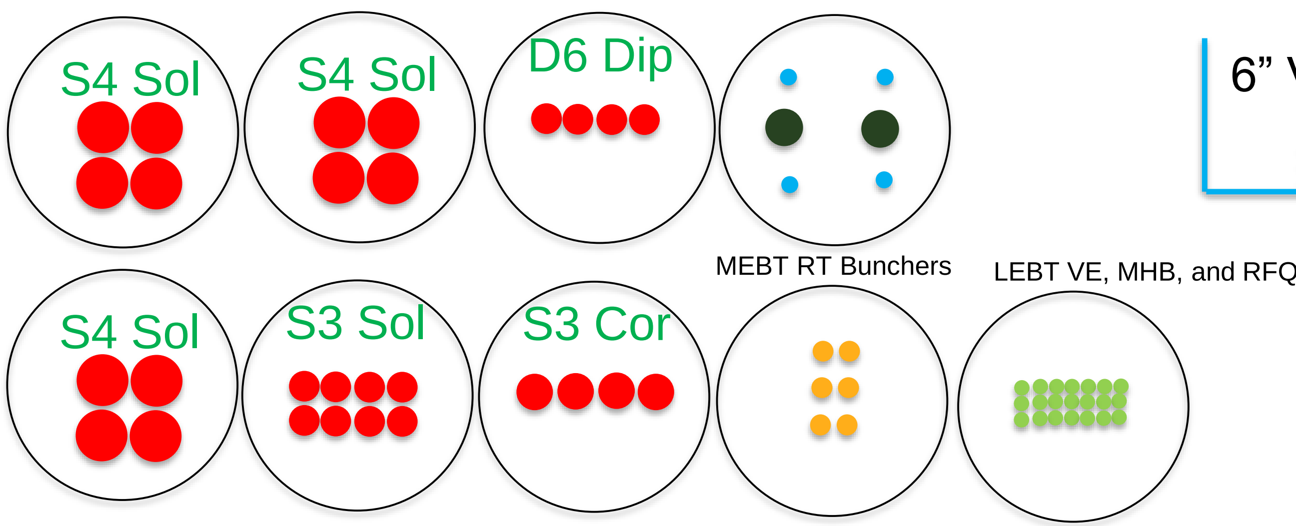
Utilities Captured Here

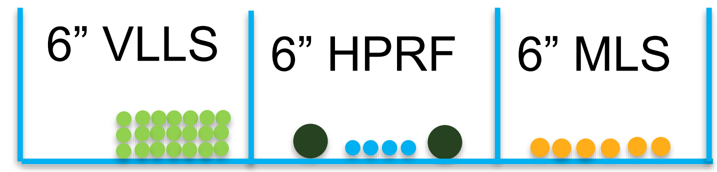
Rack Installed?		Yes
120Vac	20A	1
120V Backup	20A	0
120V Clean	20A	0
208Vac 1P	30A	0
208Vac 1P	50A	0
208Vac 3P	10A	0
208Vac 3P	15A	0
208Vac 3P	20A	0
208Vac 3P	25A	0
208Vac 3P	35A	0
208Vac 3P	45A	4
208Vac 3P	55A	0
208Vac 3P	65A	0
208Vac 3P	90A	0
208Vac 3P	110A	0
208Vac 3P	130A	0
LCW	0	gpm
Fans	1	825 CFM
HVAC	1.3	Tons
Expected 120 W		
Expected 208 W	35618	

Cable Trays for Rack Row FE-005, 3 Trays

18”(w) x 4”(d) assumed (with and without divider)







Conduits:

Available*: 4 in LS1-B04
10 in FE-B04

Needed: 9

Spares: 5

*could use more in FE-B03

1.37” OD PS cable

.95” OD PS cable

.83” OD PS cable

1/2” OD LLRF RF control

3/8” OD LLRF RF signal

3/8” OD HPRF RF cable

7/8” OD HPRF cable

Rack row FE-005

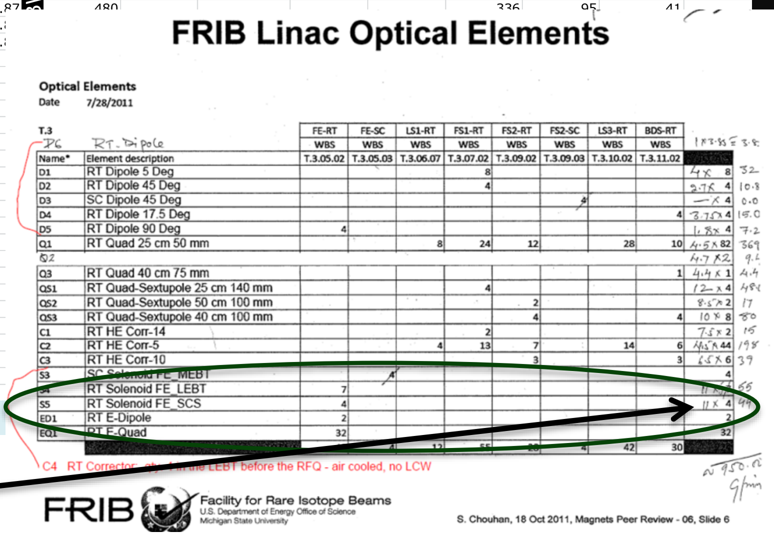
3x4x1.37	for S4 solenoids
4x2x0.83	for S3 solenoids
4x2x0.5x0.95	for S3 corr.
1x4x0.83	for D6 dipoles
RF Bunchers, RFQ RF signals	

ASD Tunnel Utility Requirements

- Loads and flows are from the Utility Spreadsheet and the Magnet Requirements document

WBS	Area	Magnet	Description	Equipment code	Qty Each	Qty Total	Notes	Magnet V requirement	Magnet I requirement	PS V	PS I	MAX PWR Each (W)	Expected PWR Each (W)	Efficiency
T.3.05 Front End	Front End													
T.3.05.01 Diagnostics	Front End													
T.3.05.02 RT Magnets	Front End	D5a	Dipoles (90 deg)	RTPS	2	2	No conduit	55	305	60	333	19980	17699	0.87
	Front End	D5b	Dipoles (90 deg)	RTPS	1	1	No conduit	36	200	40	250	10000	7680	0.87
	Front End	D5c	Dipoles (90 deg)	RTPS	1	1	No conduit	36	200	40	250	10000	7680	0.87
	Front End	D6	Dipoles (90 deg)	RTPS	1	1		66	320	80	375	30000	22192	0.87
	Front End	S4a	Solenoid	RTPS	3	3	3 in servic	16.8	600	20	750	15000	11499	0.87
	Front End	S4a	Solenoid	RTPS	2	2	3 in servic	16.8	600	20	750	15000	11499	0.87
	Front End	S4b	Solenoid	RTPS	2	2	2 in servic	28	1000	40	1000	40000	30988	0.87
	Front End	S4b	Solenoid	RTPS	2	2	2 in servic	28	1000	40	1000	40000	30988	0.87
	Front End	EQ1a	Electrostatic quadrupol	RTPS	30	30	2 PS/EQ,	10000	0.012	10000	0.01	120	120	0.87
	Front End	EQ1b	Electrostatic quadrupol	RTPS	30	30	2 PS/EQ,	10000	0.012	10000	0.01	120	120	0.87
	Front End	ED1a	Electrostatic dipoles	RTPS	2	2	2 PS/ED,	20000	0.006	20000	0.01	120	120	0.87
	Front End	ED1b	Electrostatic dipoles	RTPS	2	2	2 PS/ED,	20000	0.006	20000	0.01	120	120	0.87
	Front End	C4	Corrector Dipole	RTPS	38	38	4 quad, 2F	3	2	20	5	100	11	0.87
	Front End		PLC & IOC	CI	12.15	12.15						80	65.6	0.[illegible]
	Front End													0.[illegible]
T.3.05.03 SC Magnets	Front End	S3a	10V/100A PS	SCPS	4	4		6	100	10	125	1500	840	
	Front End	S3b	10V/40A PS	SCPS	8	8	2 PS/Soler	6	20	10	40	600	192	
	Front End		PLC & IOC	CI	8.05	8.05						80	65.6	
	Front End													
T.3.05.04 Sources	Front End		SC ECR Ion Source	MS	3	3	ECRs on					180000	147600	
	Front End		Vacuum Inst	VA	60	60						40	20	
	Front End		Diagnostics Inst	DI	6	6						300	246	
	Front End		ION Pumps	VA	7	7						80	24	
	Front End		Cryogenics CI	CI	2	2						120	98.4	
	Front End		Cryo PLC	CI	2	2						160	131.2	
	Front End		PLC & IOC	CI	3	3						2400	1968	
	Front End		Turbo Pump	VA	17	17						100	40	
	Front End		Turbo Pump (Large)	VA	1	1						200	80	
	Front End		Fast Valve	VA	1	1						100	82	
	Front End													
	Front End													
T.3.05.05 RF Systems	Front End		RFQ	RF	1	1						0	0	
	Front End		RFQ Amplifier	RF	1	1	Includes					350000	287000	
	Front End		100W Bunchers											
	Front End		8kW Bunchers	RF	2	2						20000	12500	
	Front End		PLC & IOC	CI	1.87	1.87						80	65.6	
Total														
Total (Amps, GPM, Tons)														

Magnet	120 VAC (W) w/ BW	208 VAC (W) w/ BW	208 3PH VAC (W) w/ BW	480 3PH VAC (W) w/ BW	Service Building LCW PWR Out (W) w/ BW	Linac Tunnel LCW PWR Out (W) w/ BW	Service Building HVAC PWR Out (W) w/ BW	Linac Tunnel HVAC PWR Out (W) w/ BW	Total EQPT KW w/ BW
	Expected Capacity w/BW								
D5a			40688		35399		6016		
D5b			8828		7680		1302		
D5c			8828		7680		1302		
D6			25508			20304	3404	1369	
S4a			39653		34498		7171		
S4a			26435			20058	4184	1747	
S4b			71236		61975		13032		
S4b			71236			53901	11373	4757	
EQ1a	4138						468		
EQ1b	4138						468		
ED1a	276						31		
ED1b	276						31		
C4	480					336	95	41	



FRIB Linac Optical Elements

Optical Elements

Date 7/28/2011

T.3

D6 RT-Dipole

Name*	Element description	FE-RT WBS T.3.05.02	FE-SC WBS T.3.05.03	LS1-RT WBS T.3.06.07	FS1-RT WBS T.3.07.02	FS2-RT WBS T.3.09.02	FS2-SC WBS T.3.09.03	LS3-RT WBS T.3.10.02	BDS-RT WBS T.3.11.02	[illegible]
D1	RT Dipole 5 Deg				8					8
D2	RT Dipole 45 Deg				4					4
D3	SC Dipole 45 Deg						4			4
D4	RT Dipole 17.5 Deg								4	4
D5	RT Dipole 90 Deg	4								4
Q1	RT Quad 25 cm 50 mm			8	24	12		28	10	82
Q2										
Q3	RT Quad 40 cm 75 mm								1	1
QS1	RT Quad-Sextupole 25 cm 140 mm				4					4
QS2	RT Quad-Sextupole 50 cm 100 mm					2				2
QS3	RT Quad-Sextupole 40 cm 100 mm					4			4	8
C1	RT HE Corr-14				2					2
C2	RT HE Corr-5			4	13	7		14	6	44
C3	RT HE Corr-10					3			3	6
S3	SC Solenoid FE_MEBT		4							4
S4	RT Solenoid FE_LEBT	7								[illegible]
S5	RT Solenoid FE_SCS	4								4
ED1	RT E-Dipole	2								2
EQ1	RT E-Quad	32								32
		[illegible]	4	12	55	20	4	42	30	

C4 RT Corrector: qty 4 in the LEBT before the RFQ - air cooled, no LCW

~950.0 G/min

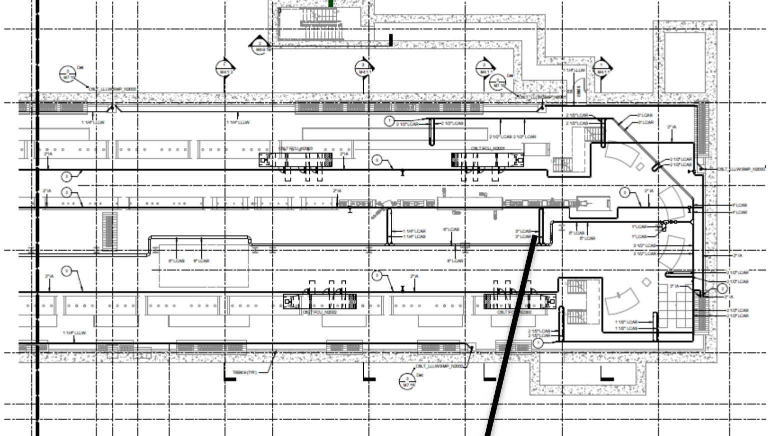
FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

S. Chouhan, 18 Oct 2011, Magnets Peer Review - 06, Slide 6

11 gallons per minute (gpm) each magnet

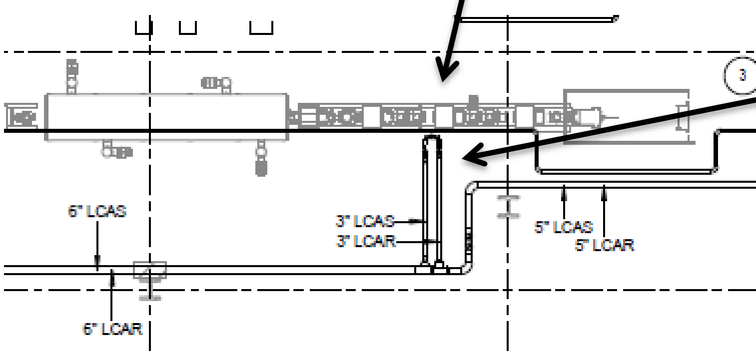
ASD Magnet Water Needs Met by CF Design

- All CF scope verified to meet requirements during design reviews
  - Racks, AC power, cooling water, HVAC, Cable tray, conduits
- LCW example

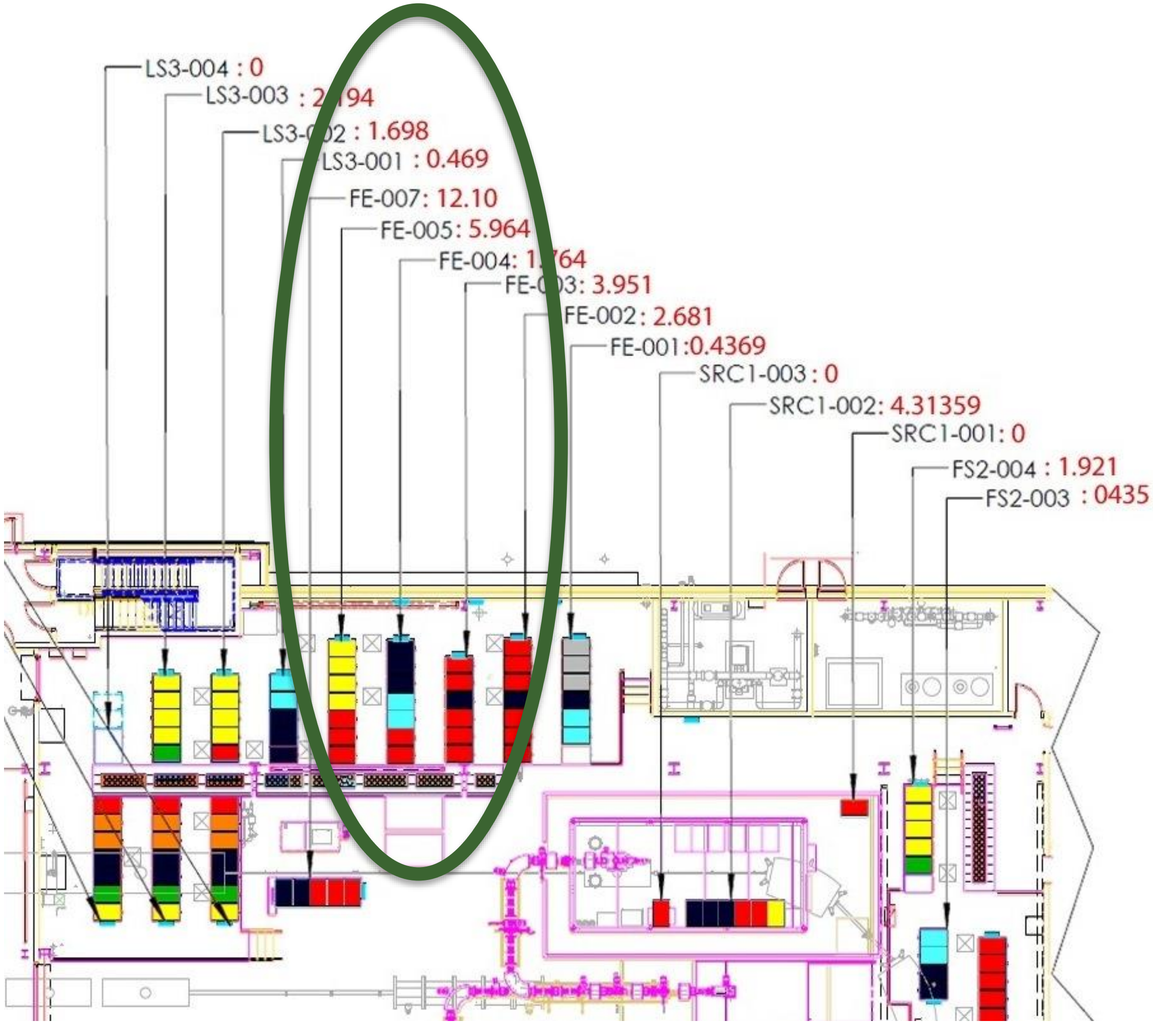


M1.1.A

3” header at ~ 3 ft/s velocity = ~ 70 gpm

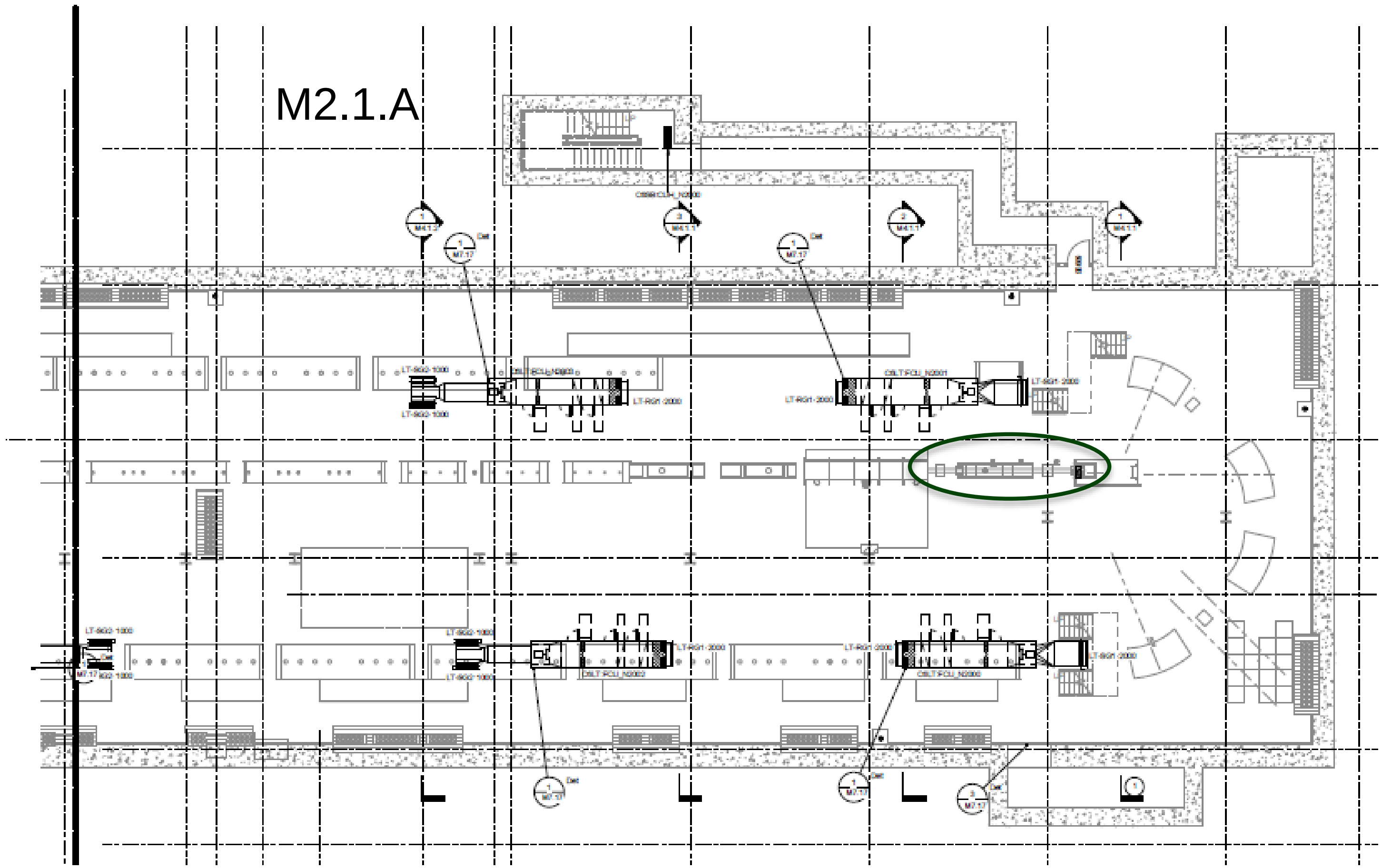


HVAC Requirements (Tons) by Rack Row

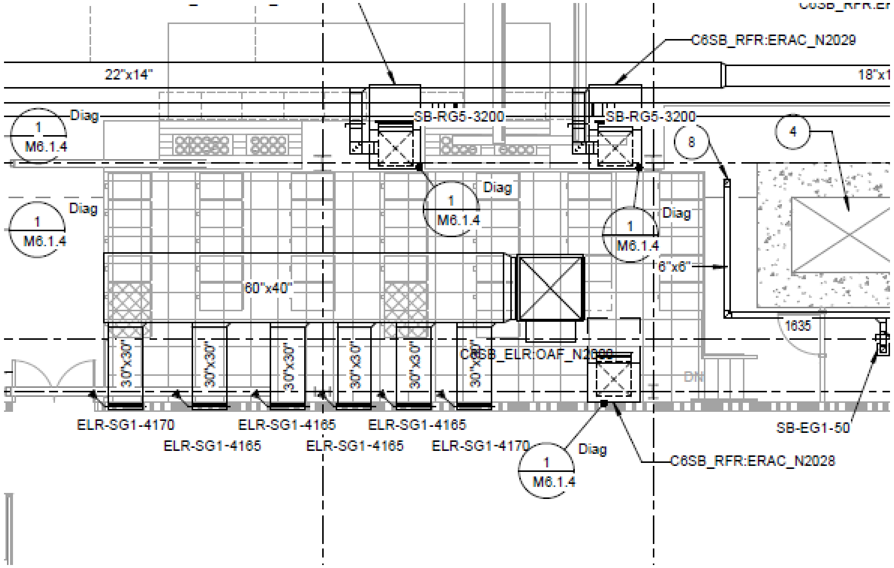


ASD Tunnel HVAC Needs Met by CF Design

- Load to HVAC is picked up by Fan Coil Units (FCU) in the area

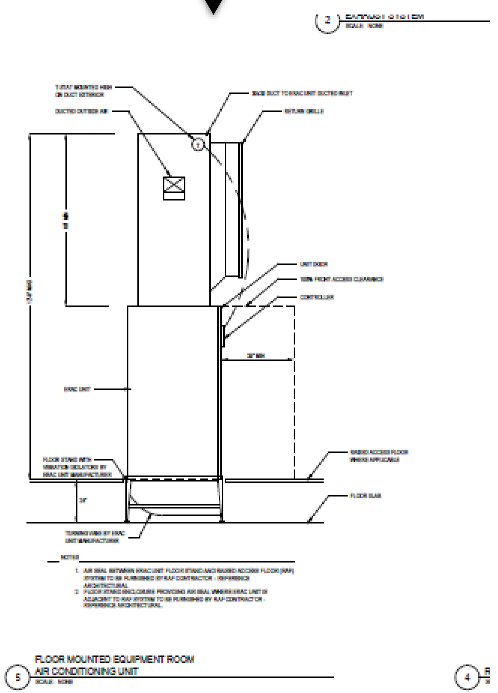


ASD Service Building HVAC Needs Met by CF Design (Ducting Detail)



M2.3.A Ducting Detail

M7.2 Air Handling Unit



Questions ?

- holland@frib.msu.edu
- Thank you POCPA community for you expert advice on many questions over the last several years!!!

Backup Slides

Quench Detection Fault Analysis Summary

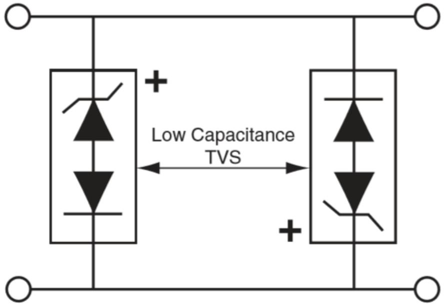
- Conclusions:
  - R1 short results in a very slow dump.
  - Wire from R2 to R3 should be rated for full current.
  - Heater resistor should be rated for the full stored energy.
  - R2 short will disable the heater system.

Quench Detection Component Selection [1]

Transient Voltage Suppressors (TVS) diode

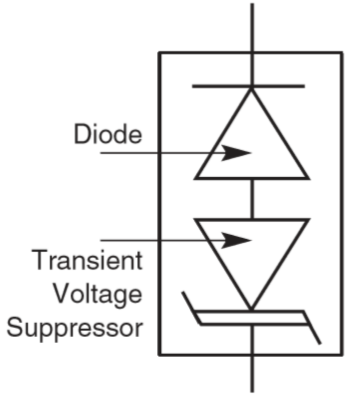
- Zener diode which is typically designed to fail in short
- Large peak pulse power capability
- Variety choices of break down voltage

PRIMARY CHARACTERISTICS	
V_{WM}	8.5 V to 188 V
V_{BR}	9.4 V to 231 V
P_{PPM}	5000 W
P_D	8.0 W
I_{FSM}	500 A
T_J max.	175 °C
Polarity	Uni-directional
Package	P600



Application Note: Device must be used with two units in parallel, opposite in polarity as shown in circuit for AC signal line protection.

Fig. 4 - AC Line Protection Application



Quench Detection Component Selection [2]

TVS diode pulse power handling

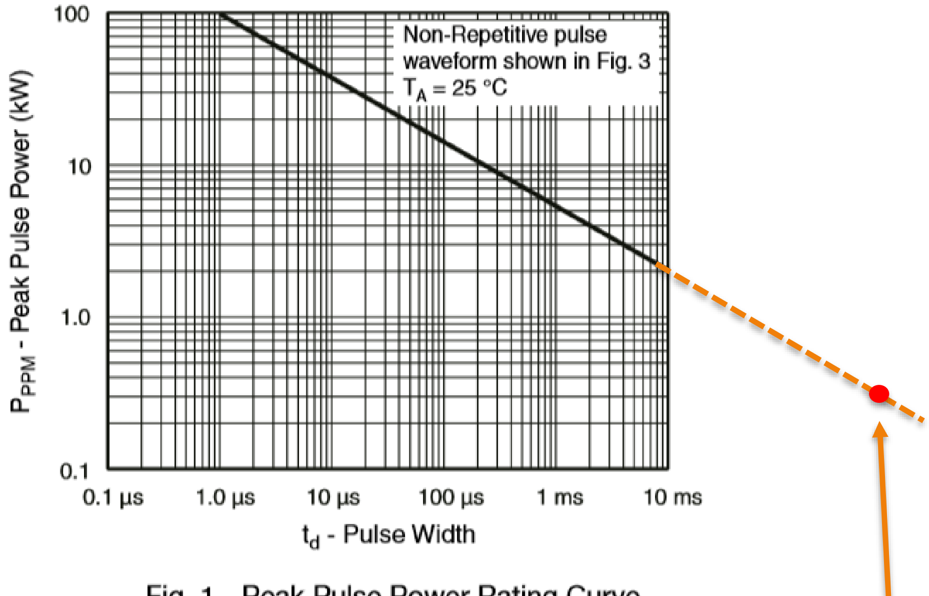


Fig. 1 - Peak Pulse Power Rating Curve

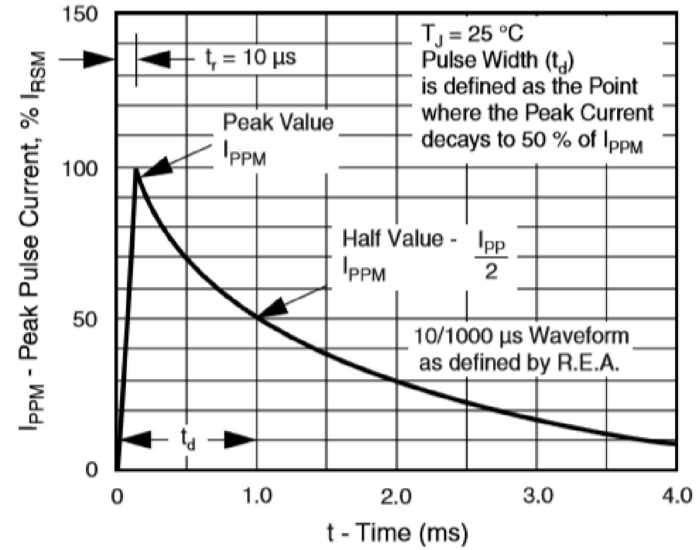


Fig. 3 - Pulse Waveform

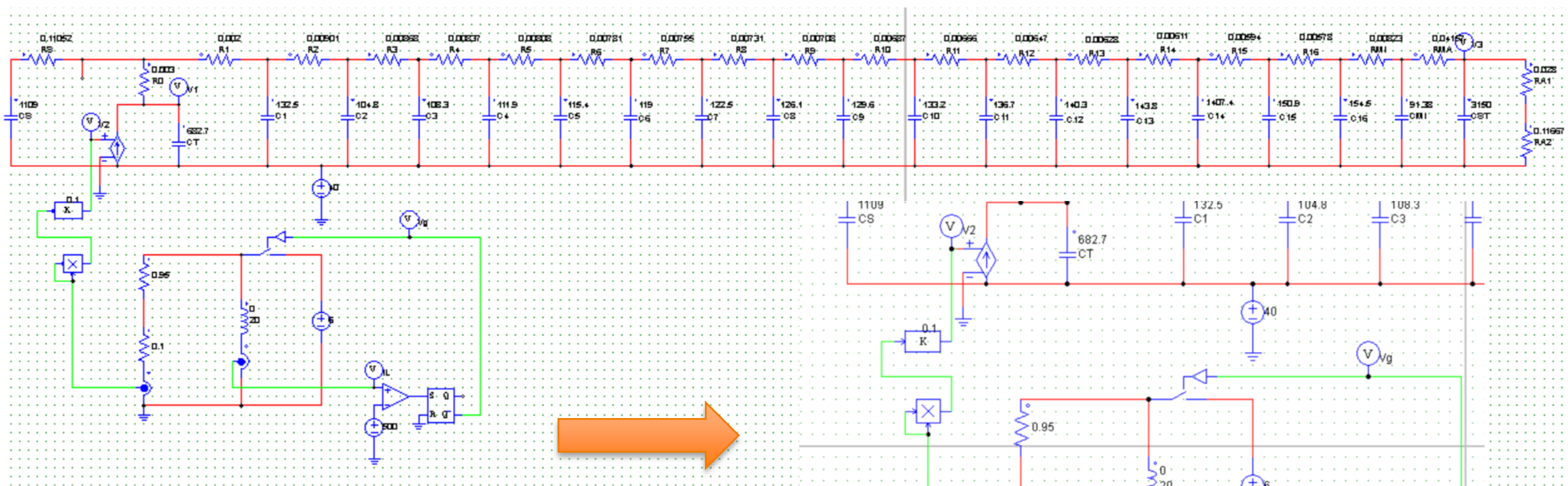
Our case: Ippm=0.5 A, Vd=25 V
Peak power=12.5 W
td= 5 s

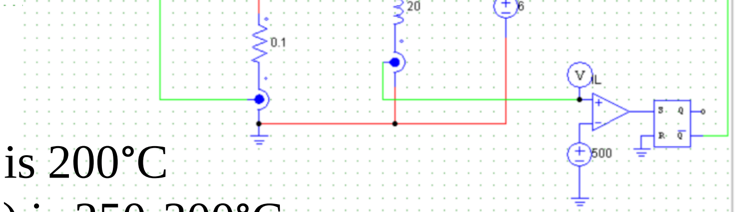
Limit:
Peak power=190 W
td= 4 s

Quench Detection Component Selection [3]

0.1 Ohm dump resistor

(manufacturer cannot guarantee 10% tolerance for resistor below 0.1 Ohm)





General comments to the simulation:

Max allowed wire temperature is 1000°C

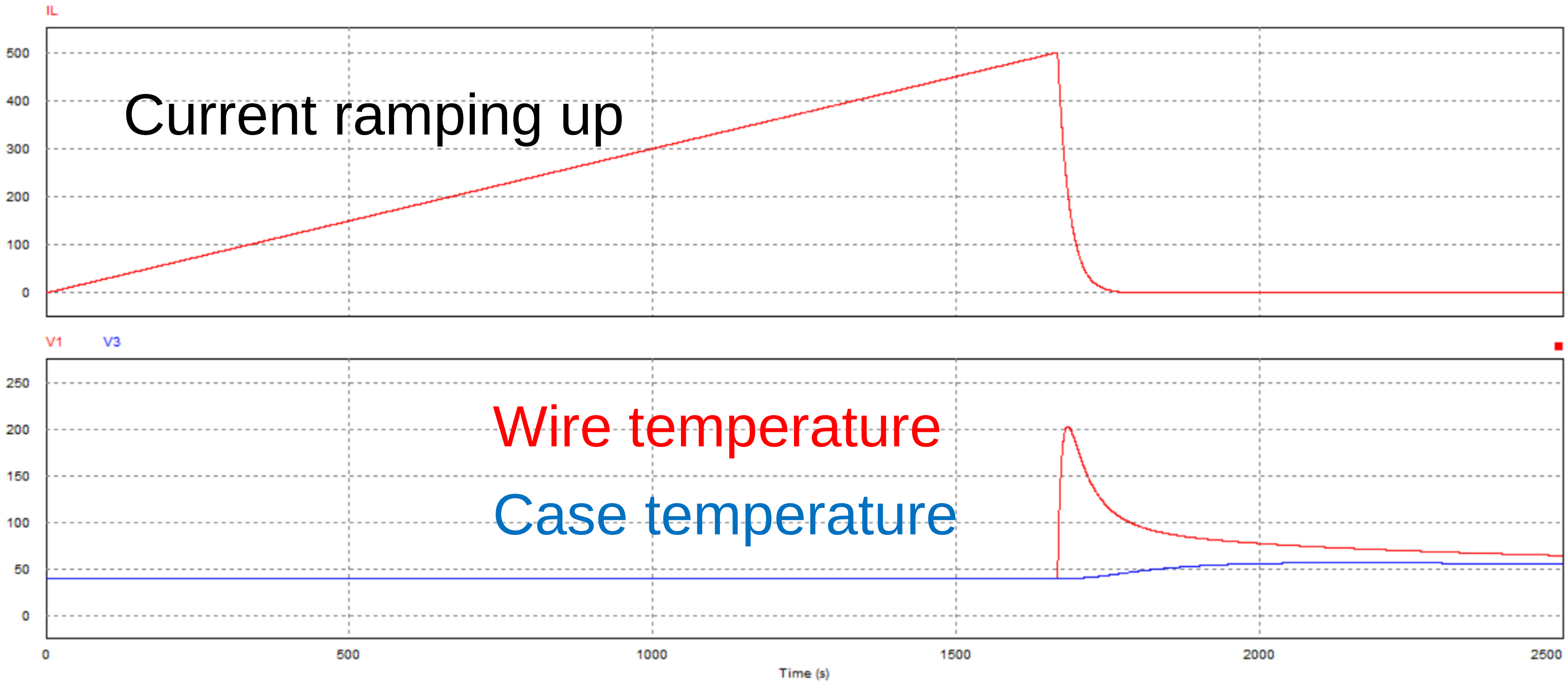
Max allowed housing temperature (cold end) is 200°C

Max allowed housing temperature (warm end) is 250-300°C

Ambient temperature: 40°C

Quench Detection Component Selection [4]

0.1 Ohm dump resistor



✓ Good