Spallation Neutron Source (SNS) Magnet Systems Overview

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Magnet, Power Supply, Kicker, & Chopper Systems

Spallation Neutron Source

Oak Ridge National Lab

POCA06 – Campinas, Brazil
September 24 - 26, 2018

Presentation Outline

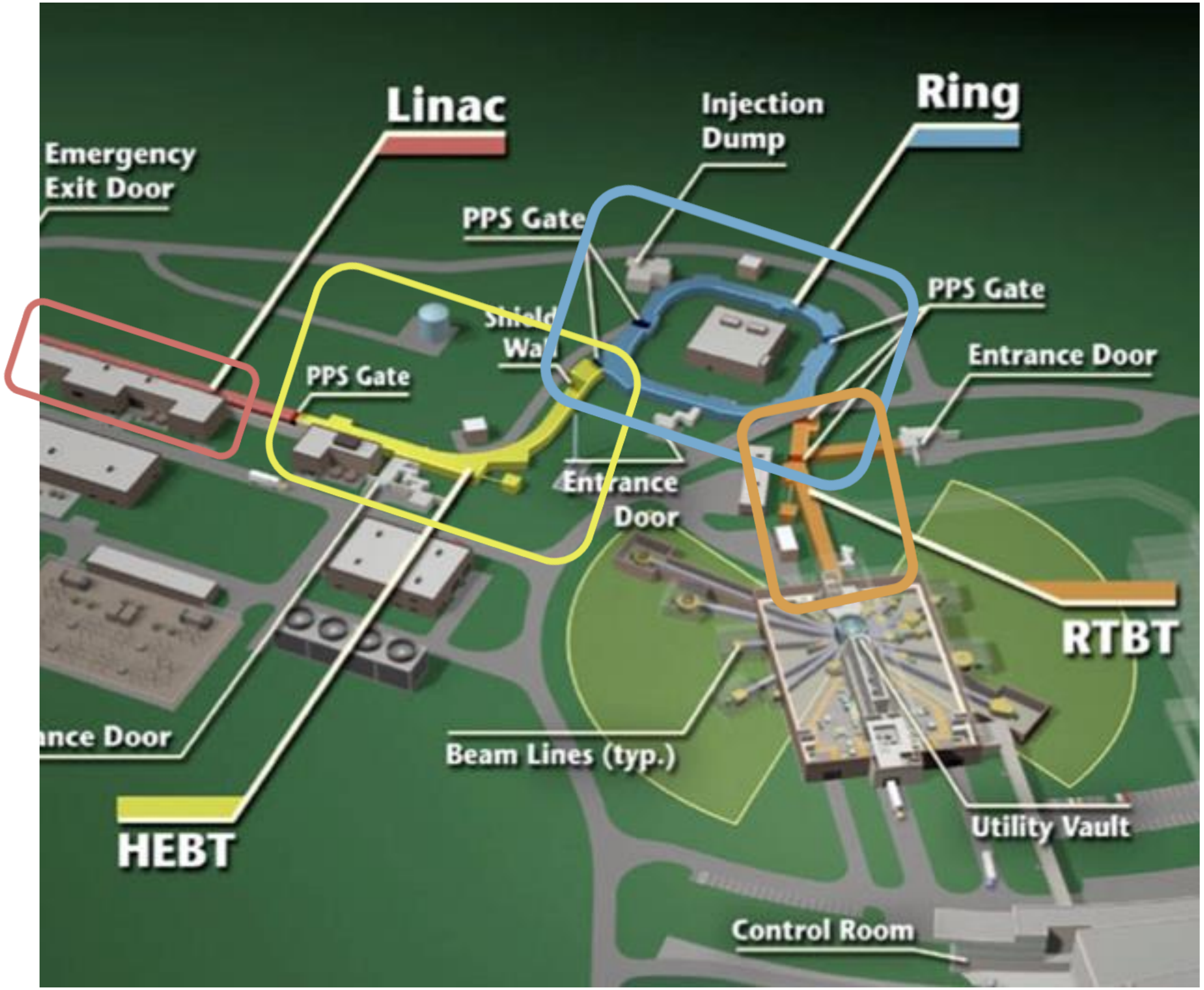
- SNS Site Overview
- Accelerator Magnet Systems
  - Linac
  - Accumulation Ring
  - Beam transport sections
- Two Major Accelerator Upgrade Projects are Funded
  - Proton Power Upgrade
  - Second Target Station

Spallation Neutron Source (SNS)Commissioned in 2006

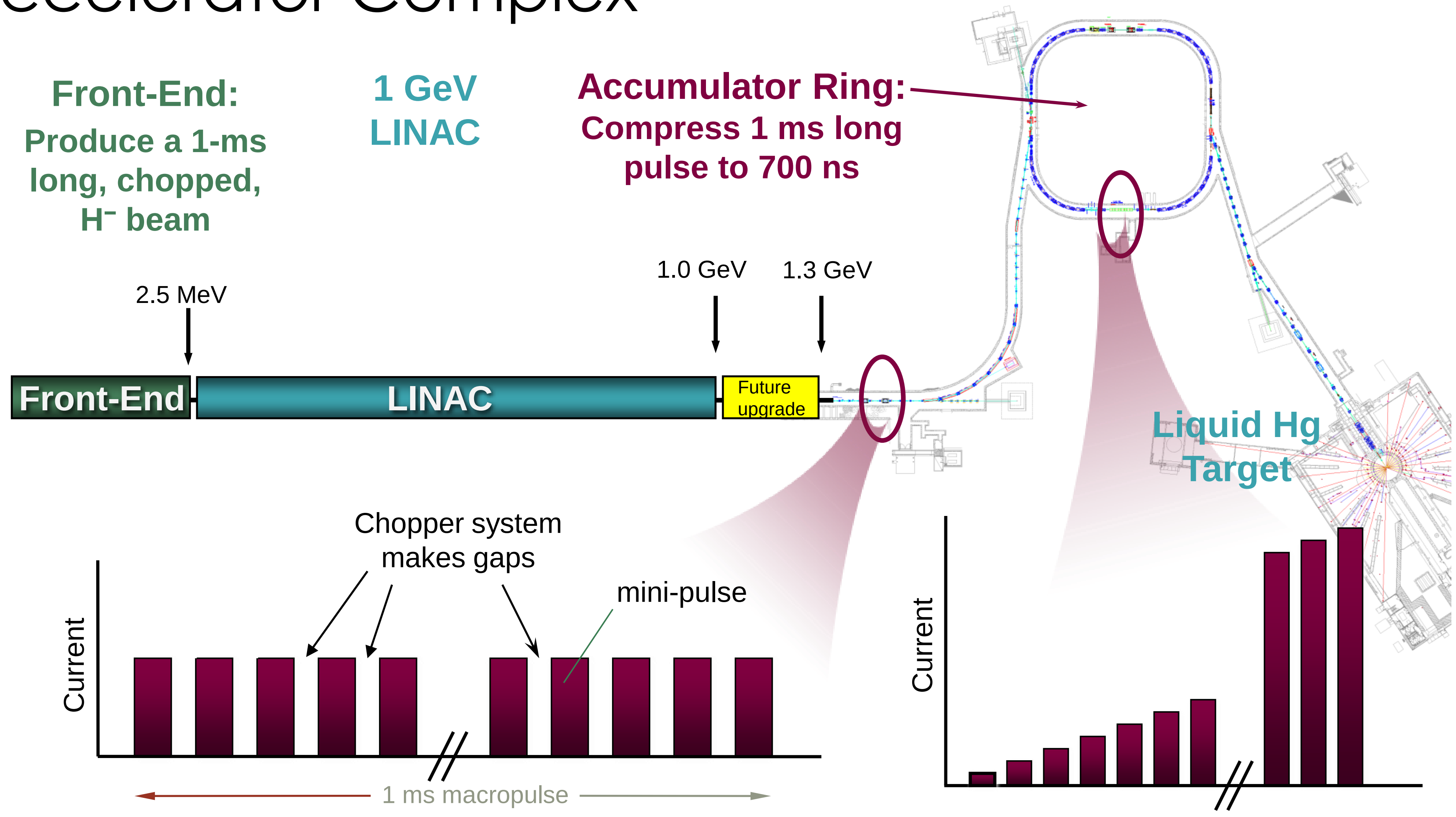
Produces high intensity pulsed neutrons for scientific research and industrial development
neutrons.ornl.gov/sns

Klystron Gallery, HEBT, RSB and RTBT Service Buildings

- Klystron Gallery
- Ring Service Building (RSB)
- High Energy Beam Transport Service Building(HEBT)
- Ring to Target Beam Transport Service Building (RTBT)



SNS Accelerator Complex



Design parameters: 60 Hz, 1.4 MW

Currently operating at 1.4 MW with >95% availability

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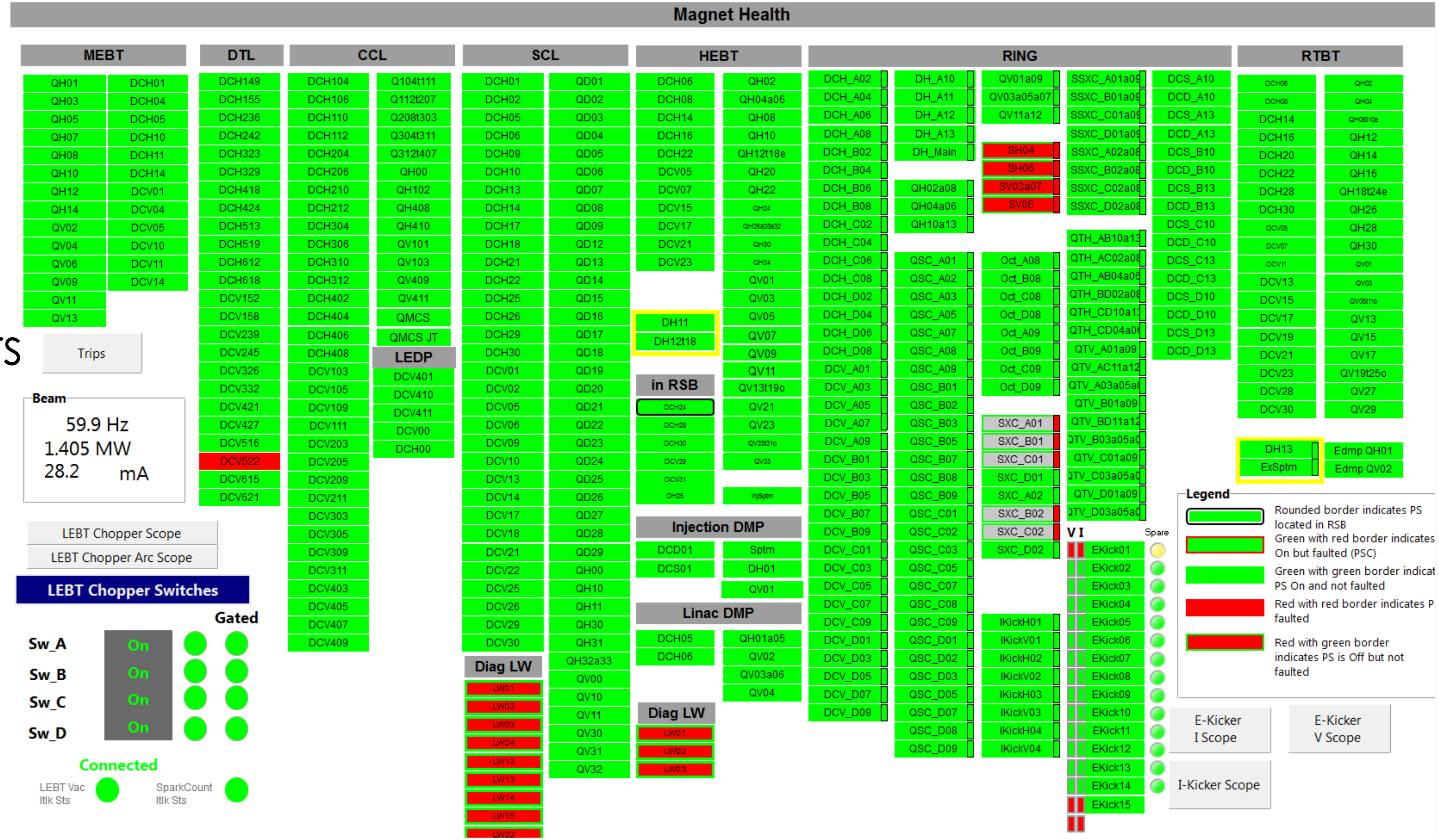
Magnet, Power Supply, Kicker and Chopper Systems

476 DC Magnets
4 LEBT Choppers
8 Injection Kickers
14 Extraction Kickers

Single "Green Screen" Magnet Status Page



Magnet Power Supply Systems

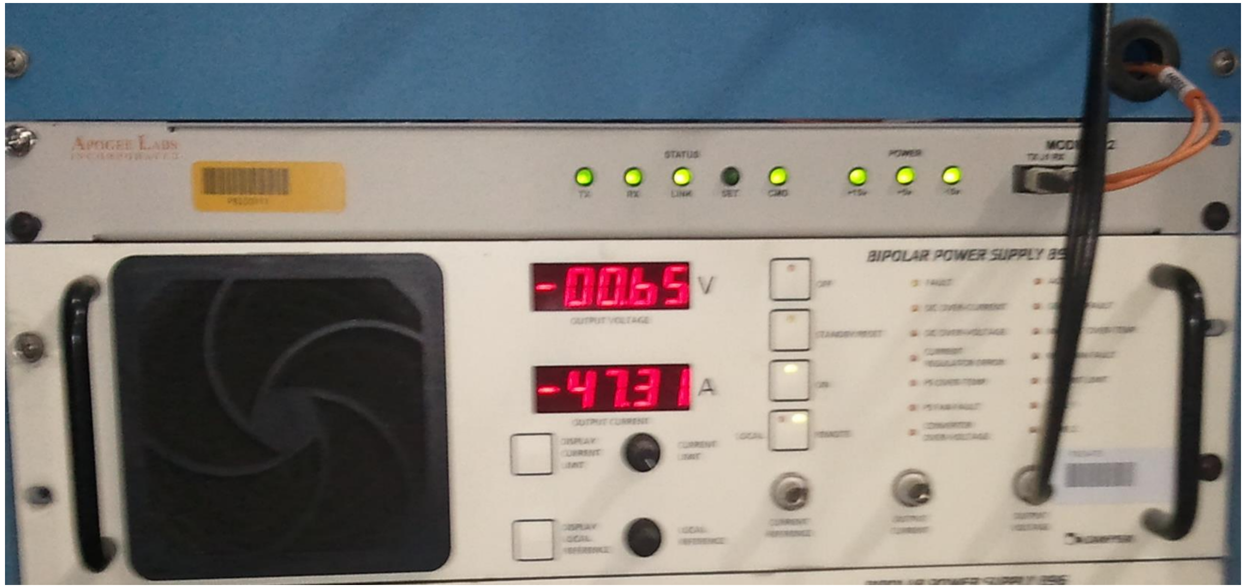
- 21 Types
- 6 Manufacturers
- 200 W to 2.6 MW power levels

4 Types of Controllers
- PSC/PSI
- Group 3
- PLC
- Serial

Manufacturer	Model	Voltage	Current	Power	Quantity
Kepco	BOP 20-10M	20	10	200	12
Danfysik	896	35	20	700	334
IE Power	UD185A27V	27	185	4995	3
IE Power	UD400A20V	18	400	7200	7
IE Power	UD390A24V	24	390	9360	16
Ametek	SGA20X500E	20	500	10000	14
IE Power	UD700A18V	18	700	12600	7
ALE	802L (Extraction Kicker Cap Charger)	50000	0.3	8000	14
IE Power	UD700A25V	25	700	17500	1
Alpha	625	35	525	18375	40
IE Power	UD375A80V	80	375	30000	6
IE Power	UD900A51V	51	900	45900	5
IE Power	UD4000A18V	18	4000	72000	5
IE Power	UD900A80V	80	900	72000	4
IE Power	UD5040A18V	18	5040	90720	1
IE Power	UD1300A95V	95	1300	123500	9
IE Power	UD2500A50V	50	2500	125000	2
IE Power	UD1300A125V	125	1300	162500	2
IE Power	UD1405A390V	390	1405	547950	7
IE Power	Injection Bump (pulsed)	+/-800	1400	320000	8
IE Power	UD6000A440V	440	6000	2640000	1
					498

Power Supply Control/Interface (PSC/PSI) System

Power Supply Controller (PSC) VME Module



Power Supply Interface (PSI) Module

Analog and Digital I/O
- 4 AI for readbacks
- 1 AO for set point
- 8 DO for control
- 16 DI for faults

- Designed for SNS by Bob Lambiase at BNL
- Still in use as originally designed
- Failures of Fiber Optic transceivers and capacitors
- 1 PSI per Power Supply
- 6 PSI per PSC
- 382 Installed

LINAC Quad Magnet Power Supplies

MEBT Steering:
Kepco
±20V, ±10A
G3 Controller

MEBT Quads:
Ametek
20V, 500A
Serial Control

CCL Quads:
IE Power Type II
20V, 400A
Type III
80V, 375A
PSI Controller

MEBT	MEBT	DTL	CCL	CCL	SCL	SCL
QH01	DCH01	DCH149	DCH104	Q104t111	DCH01	QD01
[illegible]	DCH04	DCH155	DCH106	Q112t207	DCH02	QD02
[illegible]	DCH05	DCH236	DCH110	Q208t303	DCH05	QD03
QH07a08	DCH10	DCH242	DCH112	Q304t311	DCH06	QD04
QH12	DCH11	DCH323	DCH204	Q312t407	DCH09	QD05
QH14	DCH14	DCH329	DCH206	QH00	DCH10	QD06
QV02	DCV01	DCH418	DCH210	QH102	DCH13	QD07
QV04	DCV04	DCH424	DCH212	QH408	DCH14	QD08
QV06a09	DCV05	DCH513	DCH304	QH410	DCH17	QD09
QV11	DCV10	DCH519	DCH306	QV101	DCH18	QD12
QV13	DCV11	DCH612	DCH310	QV103	DCH21	QD13
	DCV14	DCH618	DCH312	QV409	DCH22	QD14
		DCV152	DCH402	QV411	DCH25	QD15
		DCV158	DCH404		DCH26	QD16
		DCV239	DCH406		DCH29	QD17
		DCV245	DCH408		DCH30	QD18
		DCV326	[illegible]		DCV01	QD19
		DCV332	[illegible]		DCV02	QD20
		DCV421	DCV109		DCV05	QD21
		DCV427	DCV111		DCV06	QD22
		[illegible]	DCV203		DCV09	QD23
		[illegible]	DCV205		DCV10	QD24
		DCV615	DCV209		DCV13	QD25
		DCV621	DCV211		DCV14	QD26
			DCV303		DCV17	QD27
			DCV305		DCV18	QD28
			DCV309		DCV21	QD29
			DCV311		DCV22	QH00
			DCV403		DCV25	QH10
			DCV405		DCV26	QH11
			DCV407		DCV29	QH30
			DCH4109		DCV30	QH31
						QH32a33
						QV00
						QV10
						QV11
						QV30
						QV31
						QV32

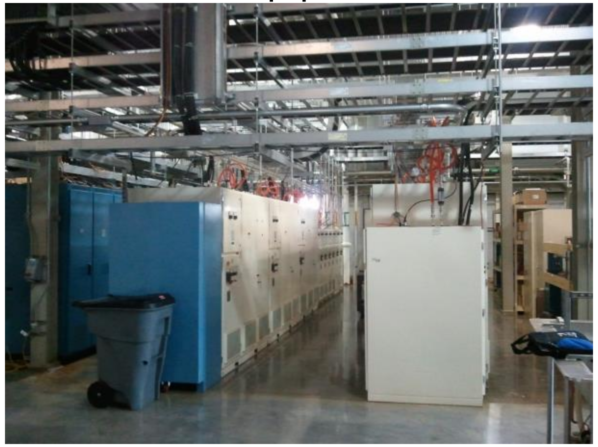
MEBT: 14
CCL: 8
SCL: 39
Total: 61

SCL Quads:
Alpha Scientific
35V, 525A,
PSI Controller

Linac Correctors:
Danfysik
±35V, ±20A
PSI Controller

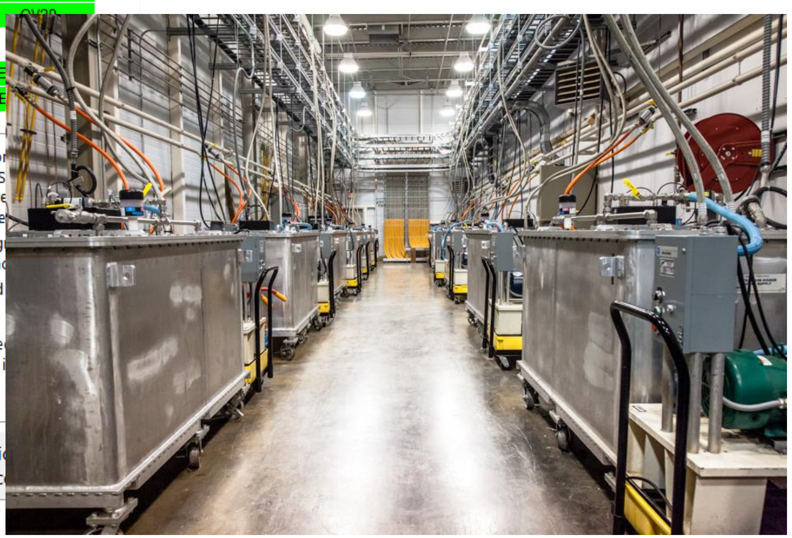
HEBT, RING, and RTBT Magnet Systems

HEBT Dipole and Quadrupole Magnet Power Supplies



High Power DC Supplies

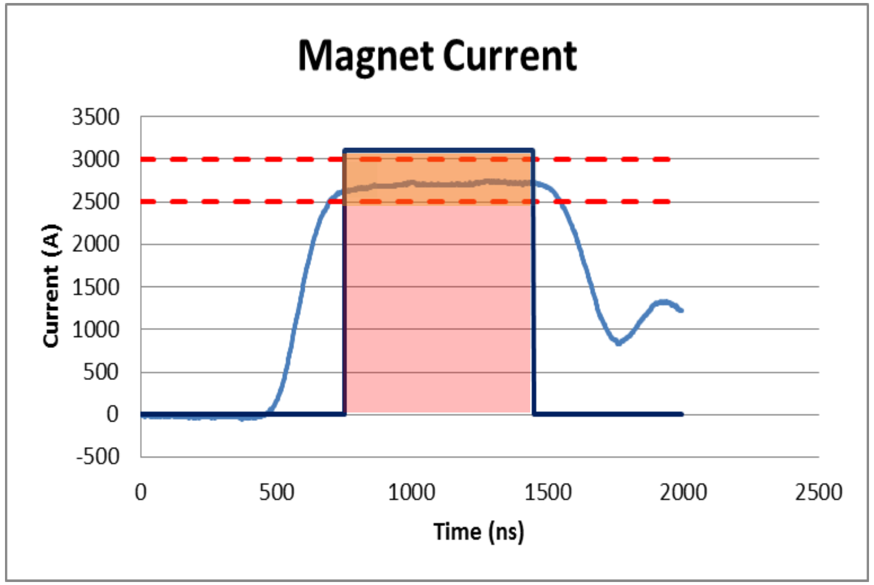
Corrector Power Supplies

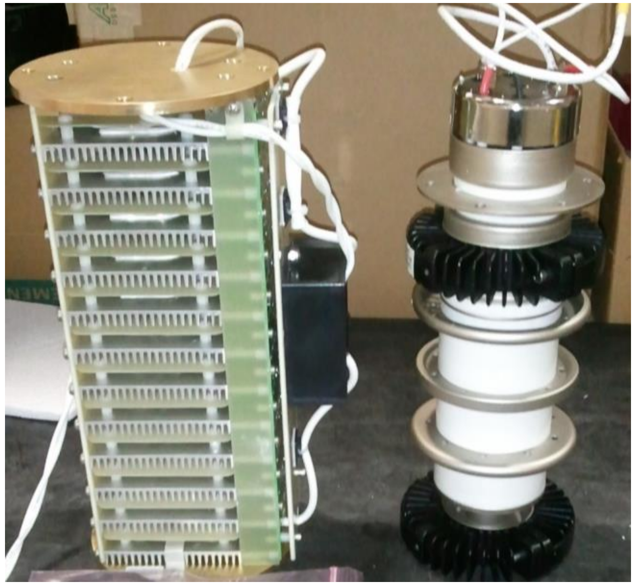


14 Extraction PFNs - Replacing Thyratrons with Solid-State Switches

New Extraction Kicker PLC, Pulse Monitoring System, and Solid-State Switch

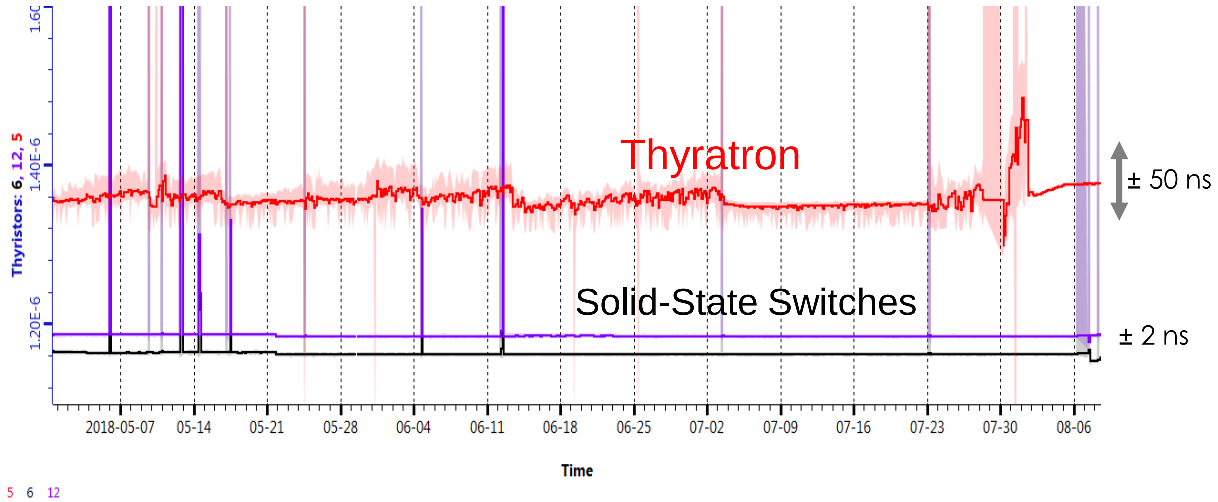
- Combined V & I monitor system
- Send Charge Voltage and Current Pulse "Fault" signals to MPS only when detected





Thyristor Thyratron

Thyratron & Solid-State Switch Jitter/Delay over 100 days

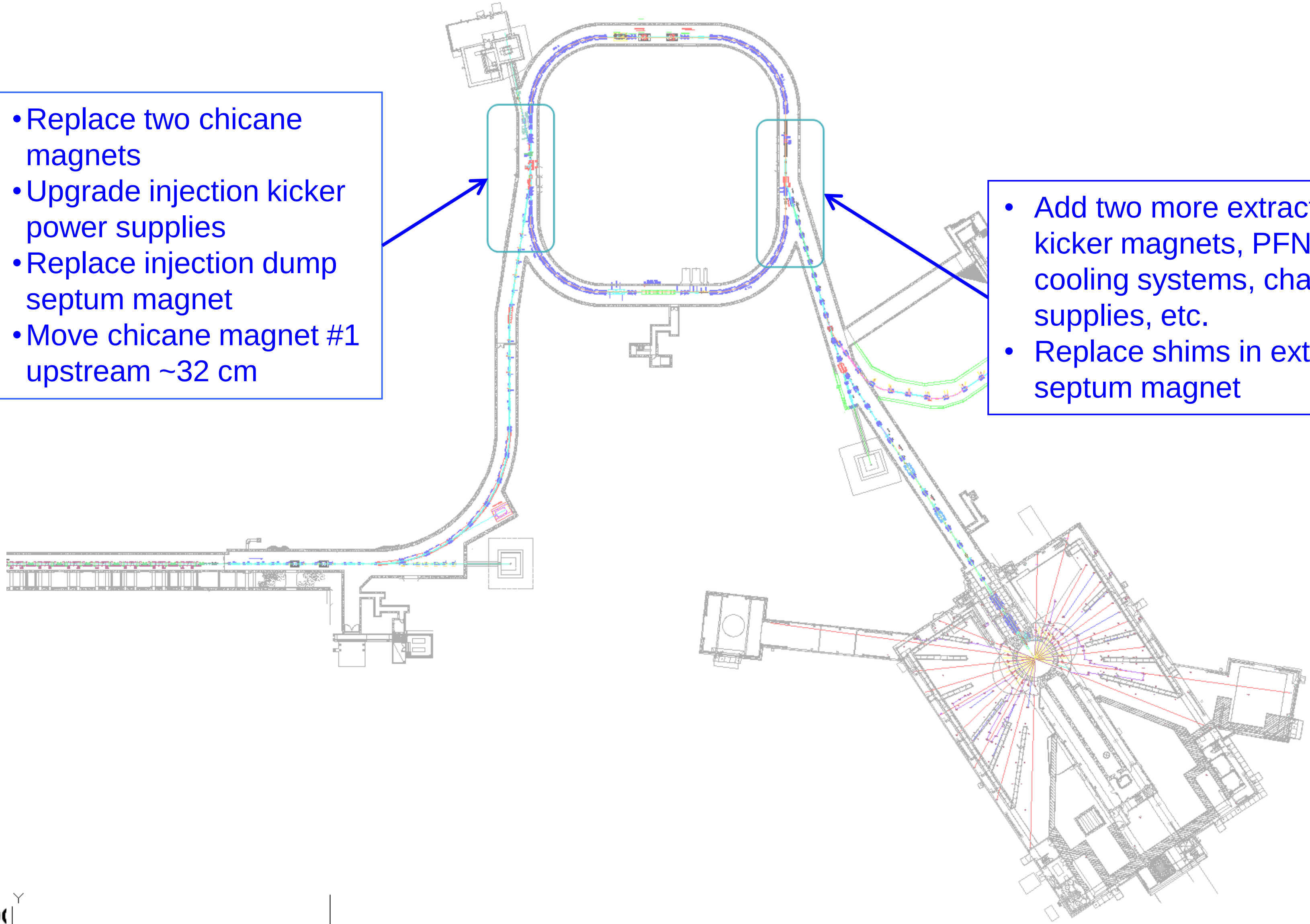


Major Accelerator Upgrades in Planning

- Proton Power Upgrade (PPU)
  - Increases the beam energy from 1.0 GeV to 1.3 GeV
  - Requires magnet currents to increase by 20%
  - All magnet power supplies were designed for this except the Injection and Extraction Kickers
  - Detailed cost and schedule with preliminary design plans by Fall 2019
  - Commissioning in 2023
- Second Target Station (STS)
  - New magnet systems for deflecting and transporting beam from ring to the second target
  - Initial cost and schedule Fall 2019
  - Commissioning in 2025

PPU Magnet Systems - Commissioning 2023

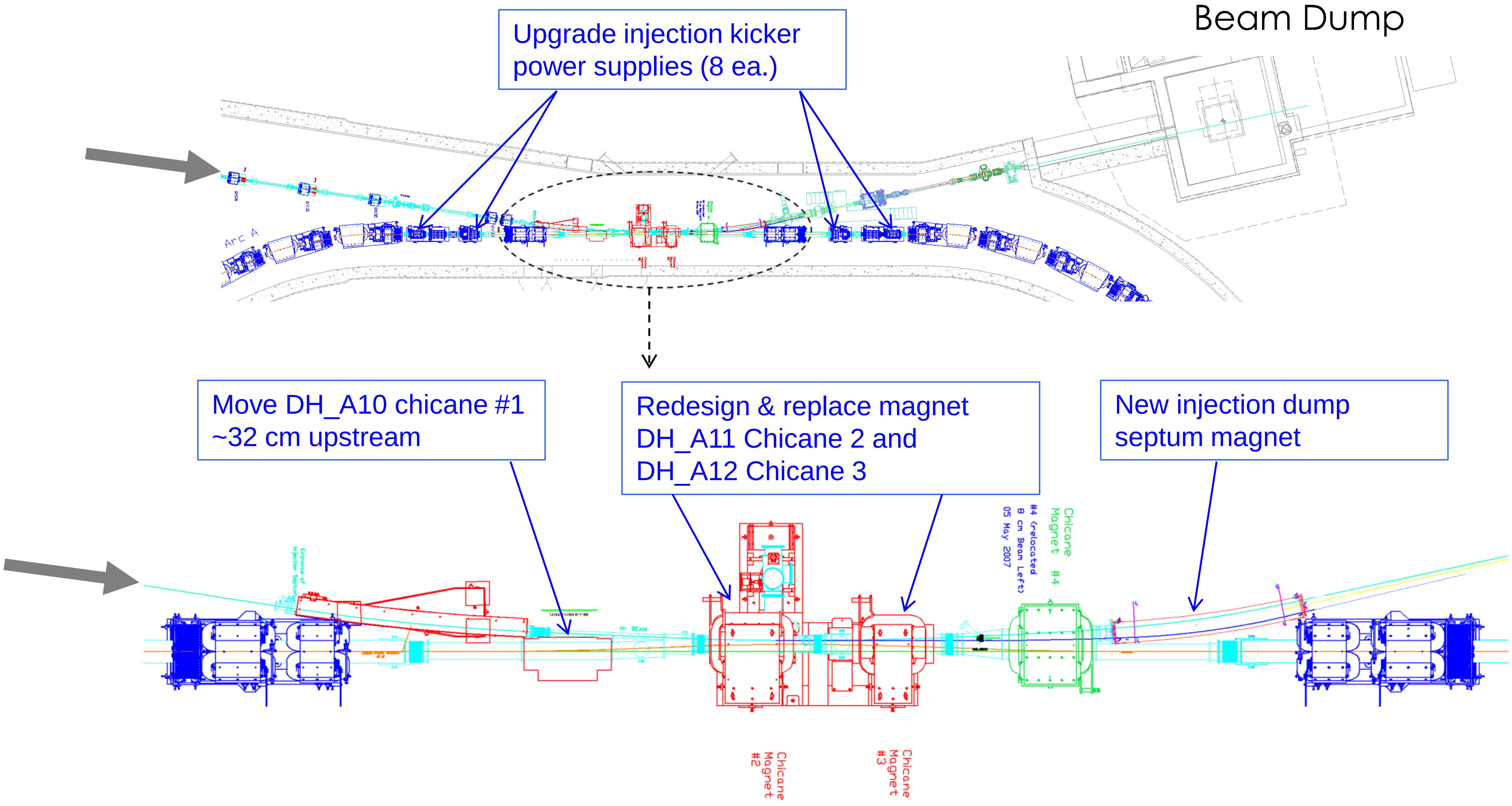
- Replace two chicane magnets
- Upgrade injection kicker power supplies
- Replace injection dump septum magnet
- Move chicane magnet #1 upstream ~32 cm



- Add two more extraction kicker magnets, PFNs, oil cooling systems, charging supplies, etc.
- Replace shims in extraction septum magnet

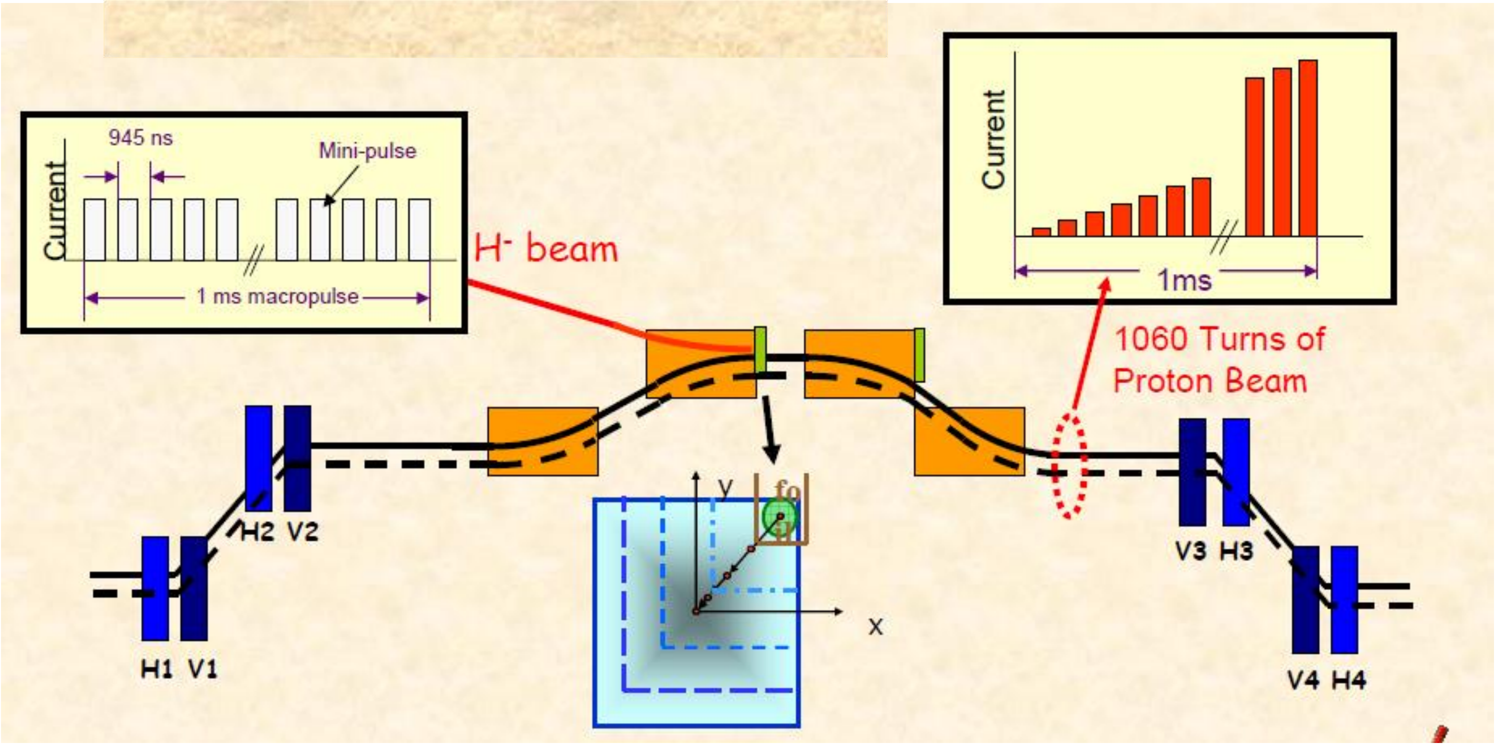
Final designs will be complete in 2020 and willl be ready to proceed to construction and procurements.

PPU Ring Injection Scope Detail



SNS Injection Painting Process

- 4 horizontal & 4 vertical kickers
- Produces a controlled dynamic deflection of the beam during the 1ms injection time.



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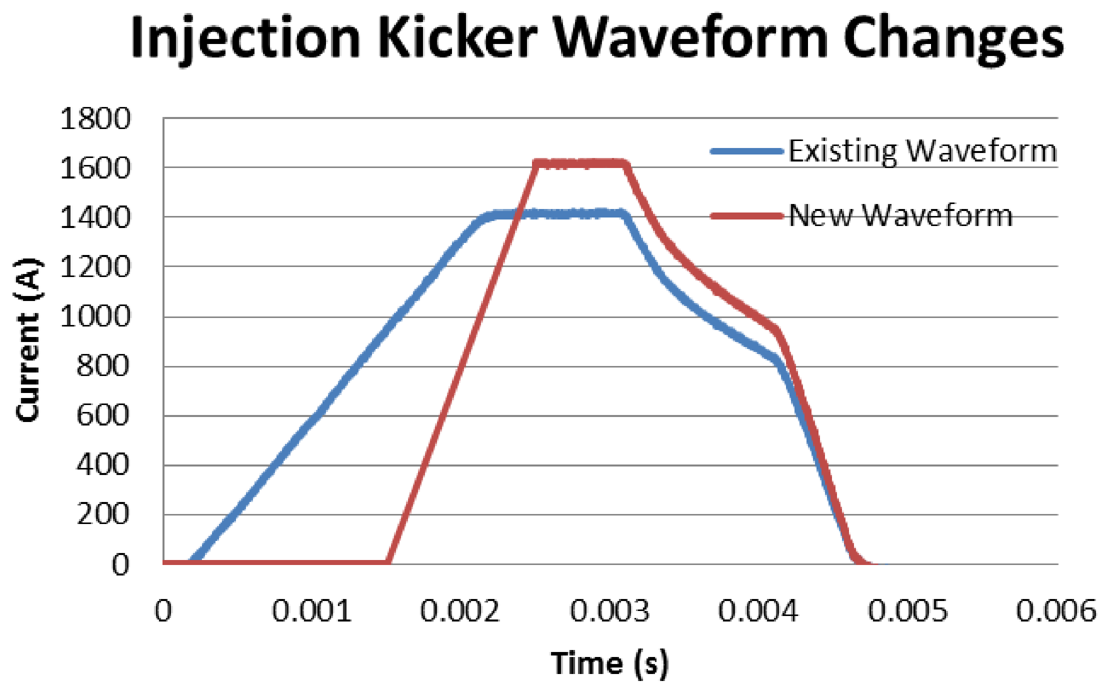
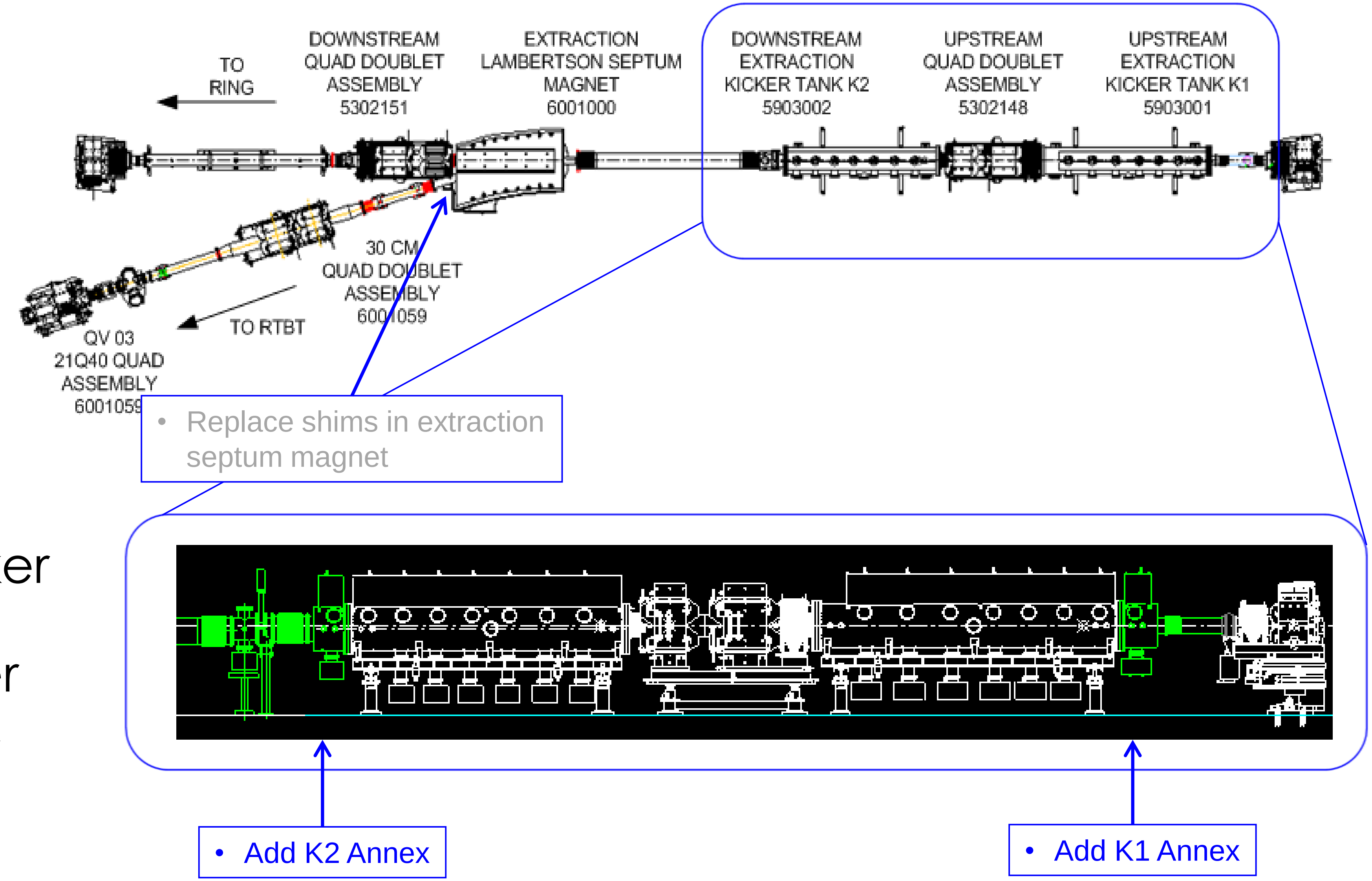
Injection Kicker Power Supply Upgrade Requirements



- 8 Identical Power Supplies
- Arbitrary Waveform
- Max di/dt is 1.6 A/μs
- Large signal response time is 2 kHz
- Switching Frequency 108 kHz
- Increase current from 1400 to 1600 A
- Waveforms modified to maintain same average power
- Magnet Load is 160 μH, 13 mΩ
- Bipolar voltage output ± 800 V

- Original Manufacturer had a design change that can meet the higher current requirements but has since gone out of business.
- We are reverse engineering the design to determine path forward.

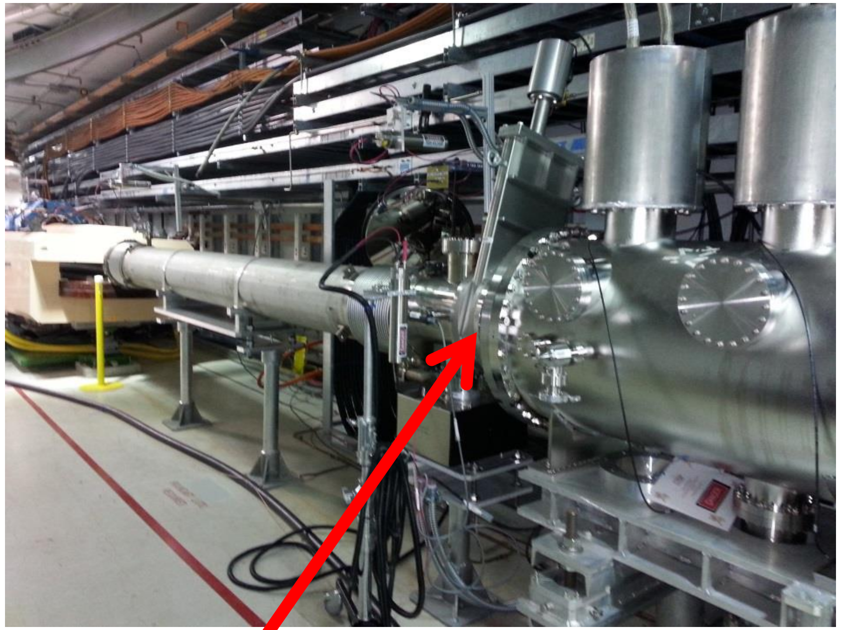
Ring Extraction Region PPU Scope Detail

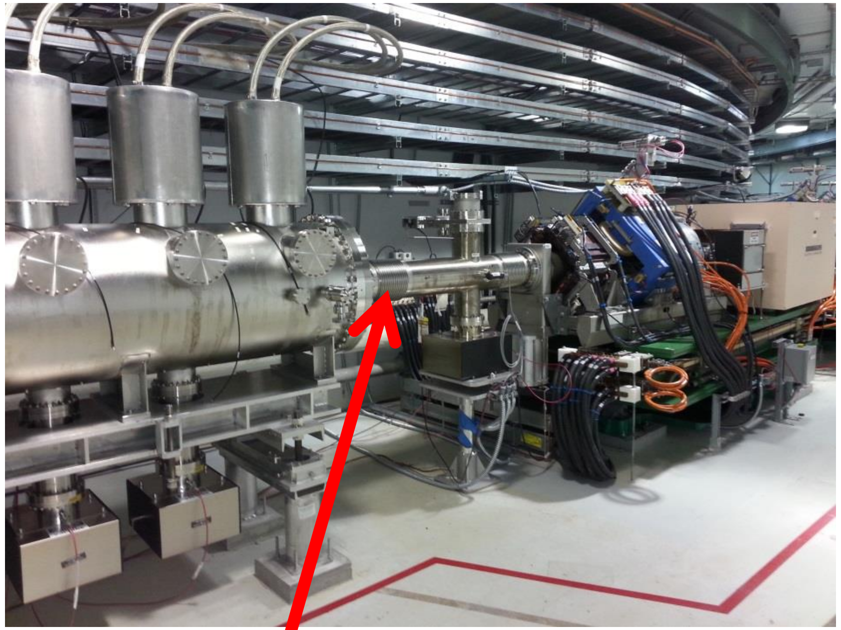


- Two addition kicker magnets and associated power supplies, controls, vacuum, cooling

Location of Magnet Annex Tanks in Ring Tunnel

Space required for new annex tanks already exists



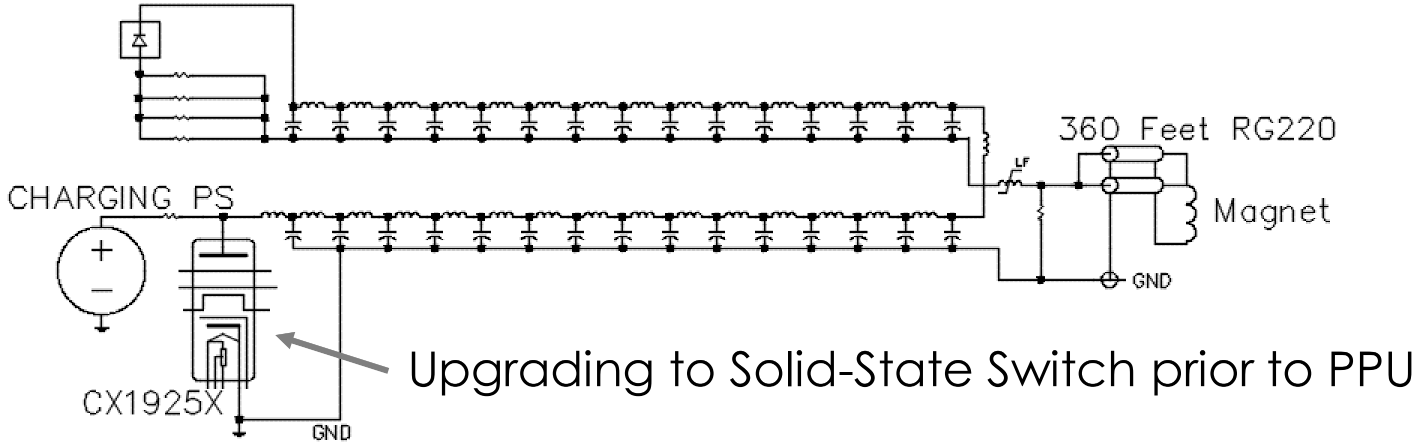


Downstream tank
Annex K2X-1

Upstream tank
Annex K1X-1

Alternative to adding two PFN kicker systems

- $3.2M cost of 2 additional systems
- Increase the current in each of the existing fourteen magnets by 20% to achieve the same deflection at 1.3 GeV as at 1.0 GeV.
  - Increase operational setpoint from 32 kV to 38.4 kV (45 kV for design margin.)
  - Existing power supply cannot charge to 45 kV in 13 ms.
  - A new Resonant Charging Power Supply (RCPS) is being developed.
  - Projected cost savings of $2M.



30 Stages
Z = 6.25 Ω
L = 195 nH
C = 5 nF
flat top PW = 750 ns
t_r = 200 ns (1-95%)
flat top +/- 2.5%
I_{amp} = 3.2kA @ 45 kV
L_{magnet} = 700nH

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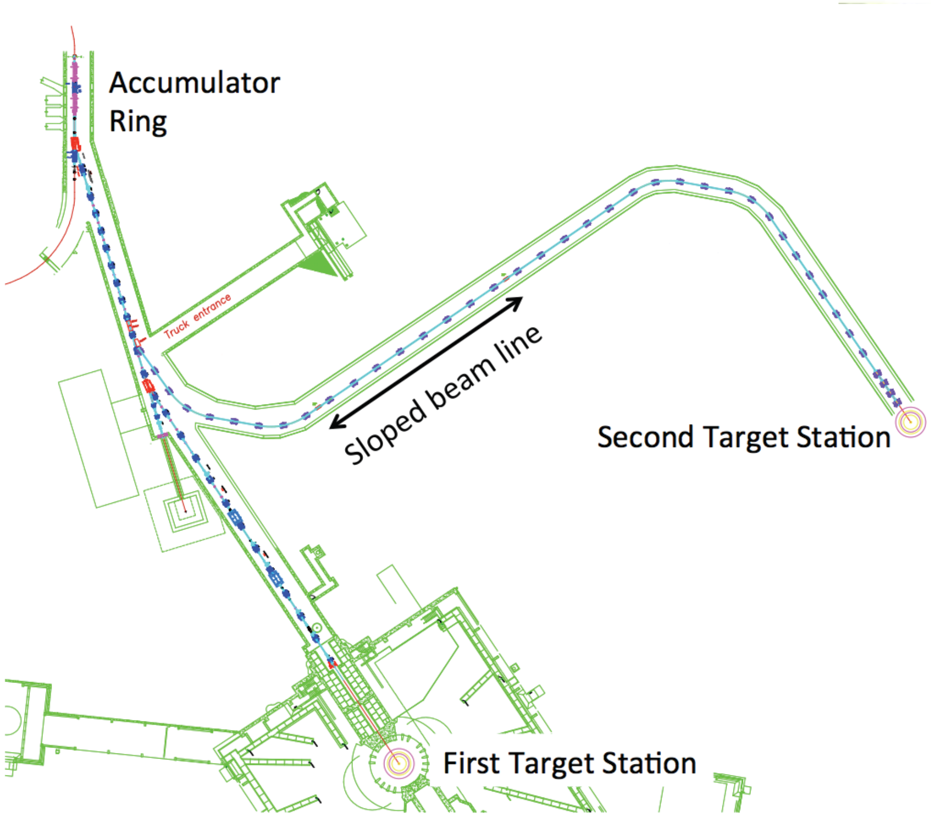
Second Target Station Project CD-1 Fall 2019



- 69 New Magnets Quadrupoles, Dipoles, Kicker, Septum, Correctors
- 51 New Power Supplies
- Commissioning 2026

Conclusion

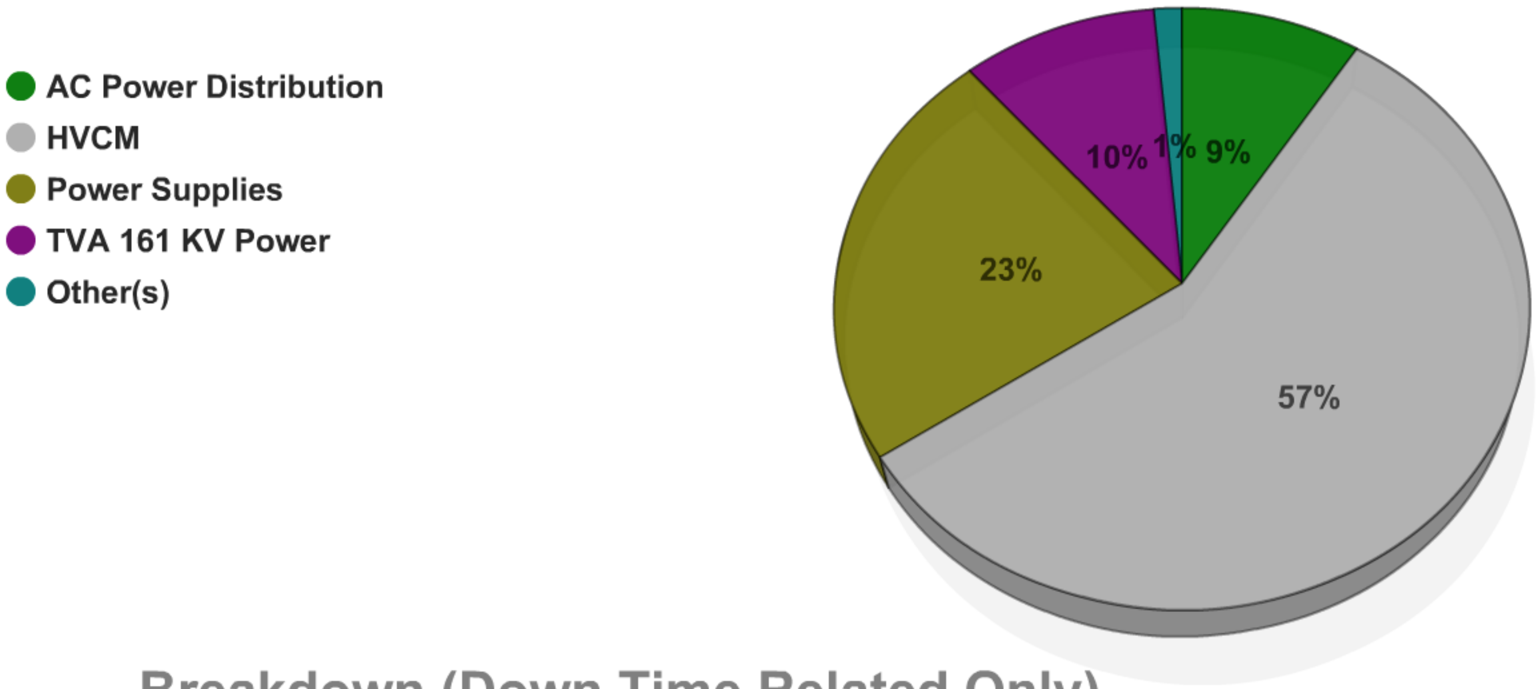
- Questions?

- We have multiple openings for Electrical and RF Engineers
  - Power Electronics Engineer / NB50684392
    - https://neutrons.ornl.gov/careers
    - Listed as a junior engineer level but will consider upgrading for well qualified applicants.
    - This position is open to all domestic and foreign applicants.
    - ORNL is an equal opportunity employer. All qualified applicants, including individuals with disabilities and protected veterans, are encouraged to apply.

Backup

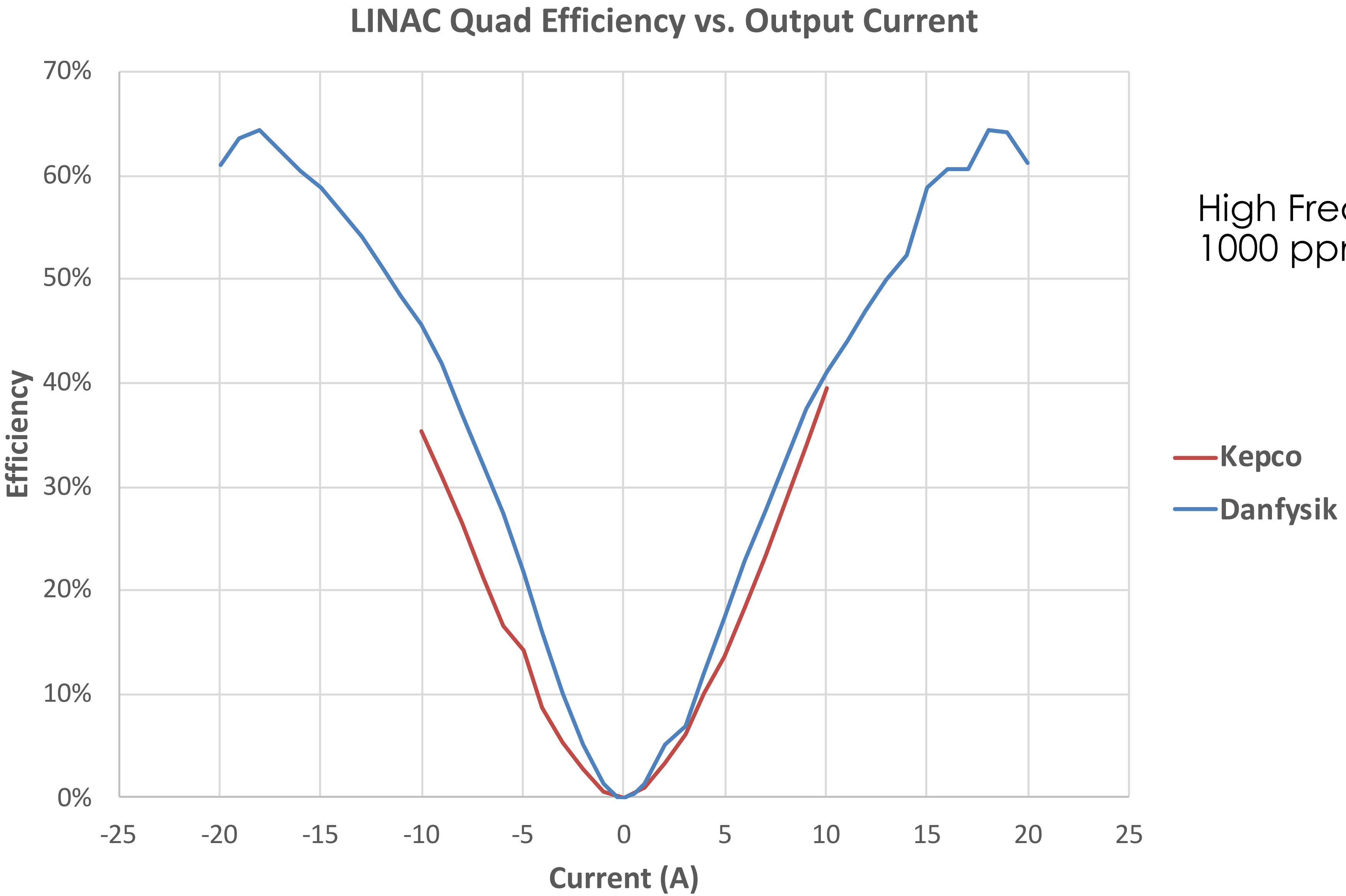
Machine Availability and Electrical Systems Downtime

	Last 24 hrs.	Last 7 days	FY18-3	FY18
NP availability for:	100.0%	94.1%	97.0%	94.5%
MWhr:	2.8	180.2	694.0	4040.8
Avg MWhr/day:	33.6	31.8	30.7	31.7
NP Hrs. delivered:	2.0	128.0	525.8	2888.1



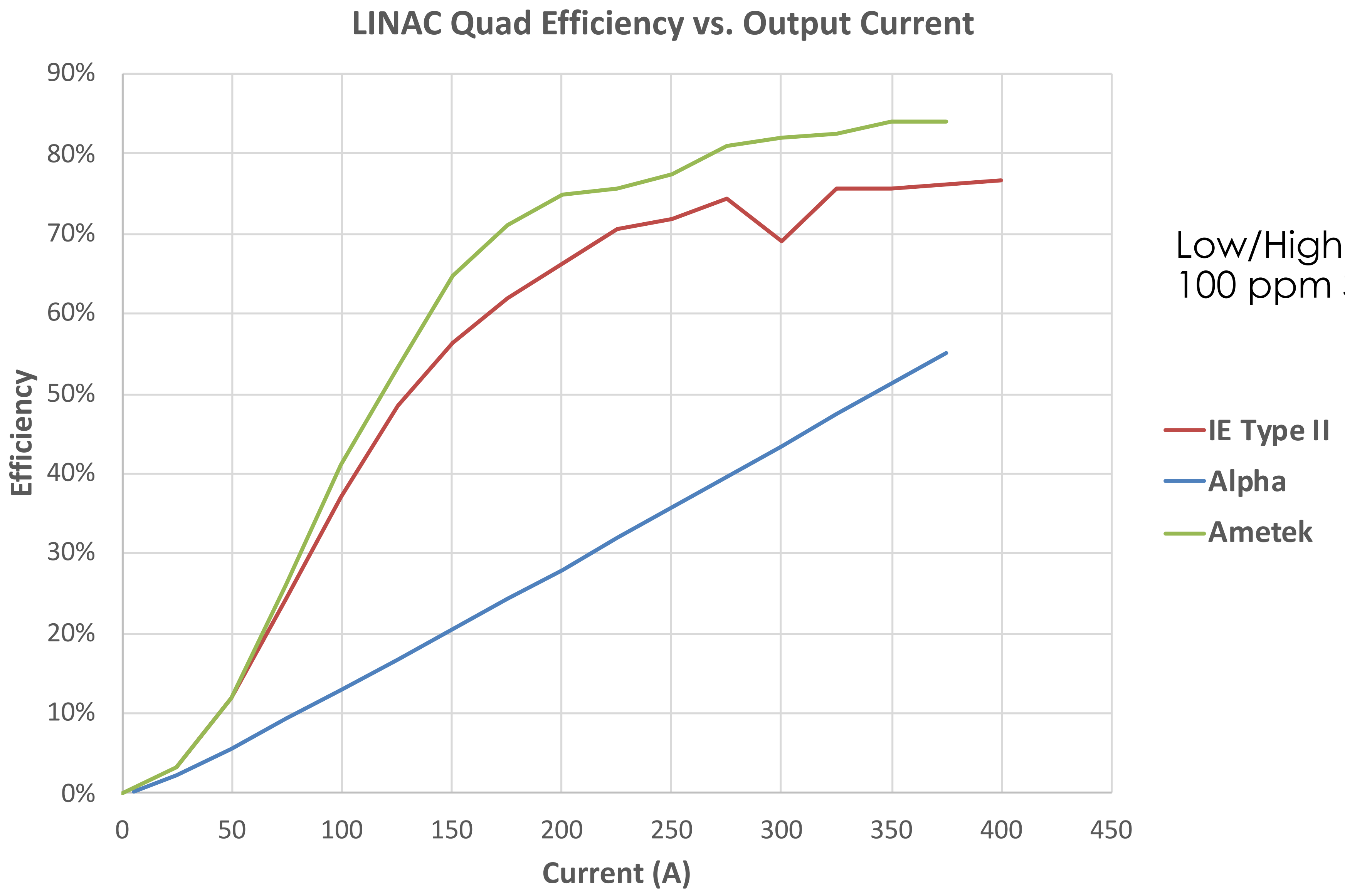
Breakdown (Down Time Related Only)

MEBT Steerer and Accelerator Corrector Efficiency



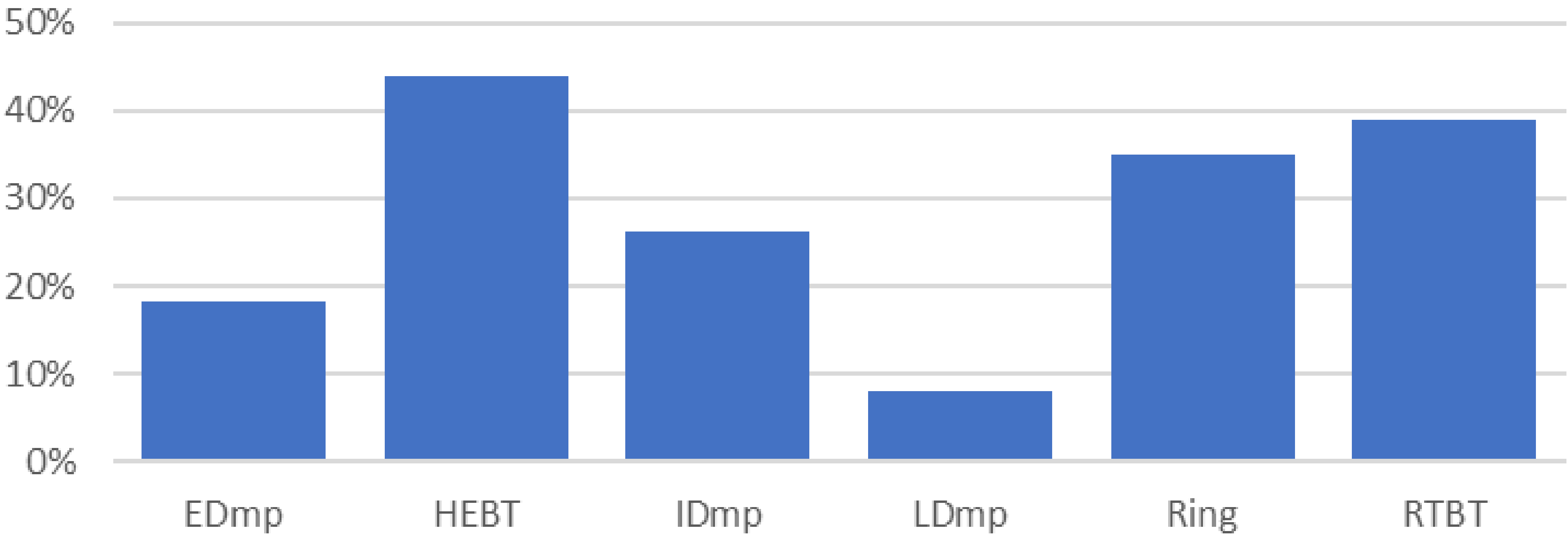
High Frequency Switching
1000 ppm Stability

Linac Quadrupole Power Supply Efficiency



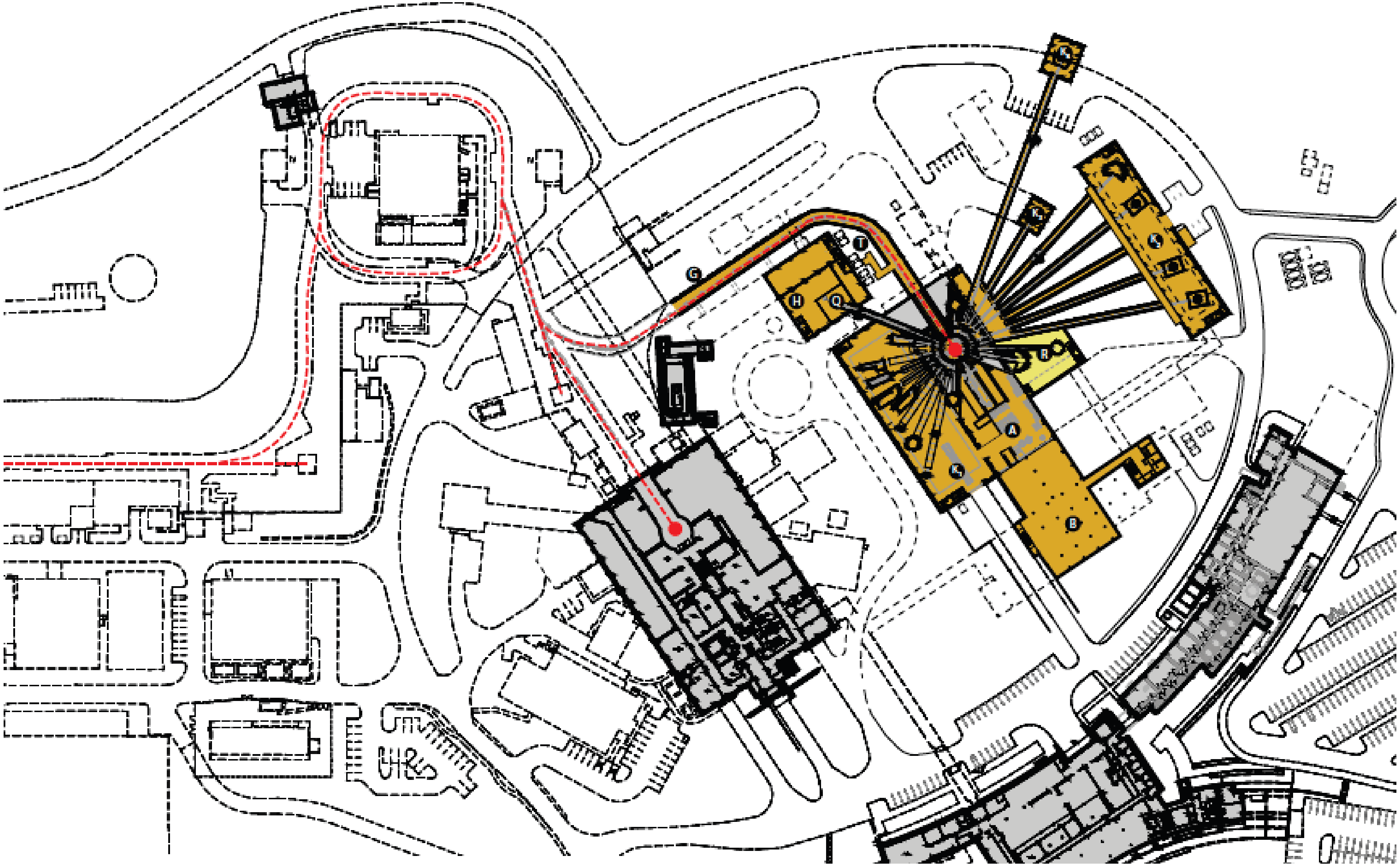
Low/High frequency Switching
100 ppm Stability

SCR Based Switching High Power Supplies Average Efficiency By Accelerator Section



100 ppm stability requirement

Plan View STS



Linac Corrector and Quadrupole Power Supply Systems

SCL Quads:
Alpha Scientific
35V, 525A,
PSI Controller

Linac Correctors:
Danfysik
PSI Controller

CCL Quads:
IE Power Type II and III
20V-400A, 80V-375A
PSI Controller

HEBT Service Building Power Supplies

Four PPS Controlled Power Supplies
1 in HEBT, 2 in RSB, and 1 in RTBT

Dipole and Quadrupole Magnet Power Supplies

Ring Service Building Power Supplies

14 Extraction PFNs - Replacing
Thyratrons with Solid-State Switches

129 Corrector Power Supplies

Power Supply Block Diagram

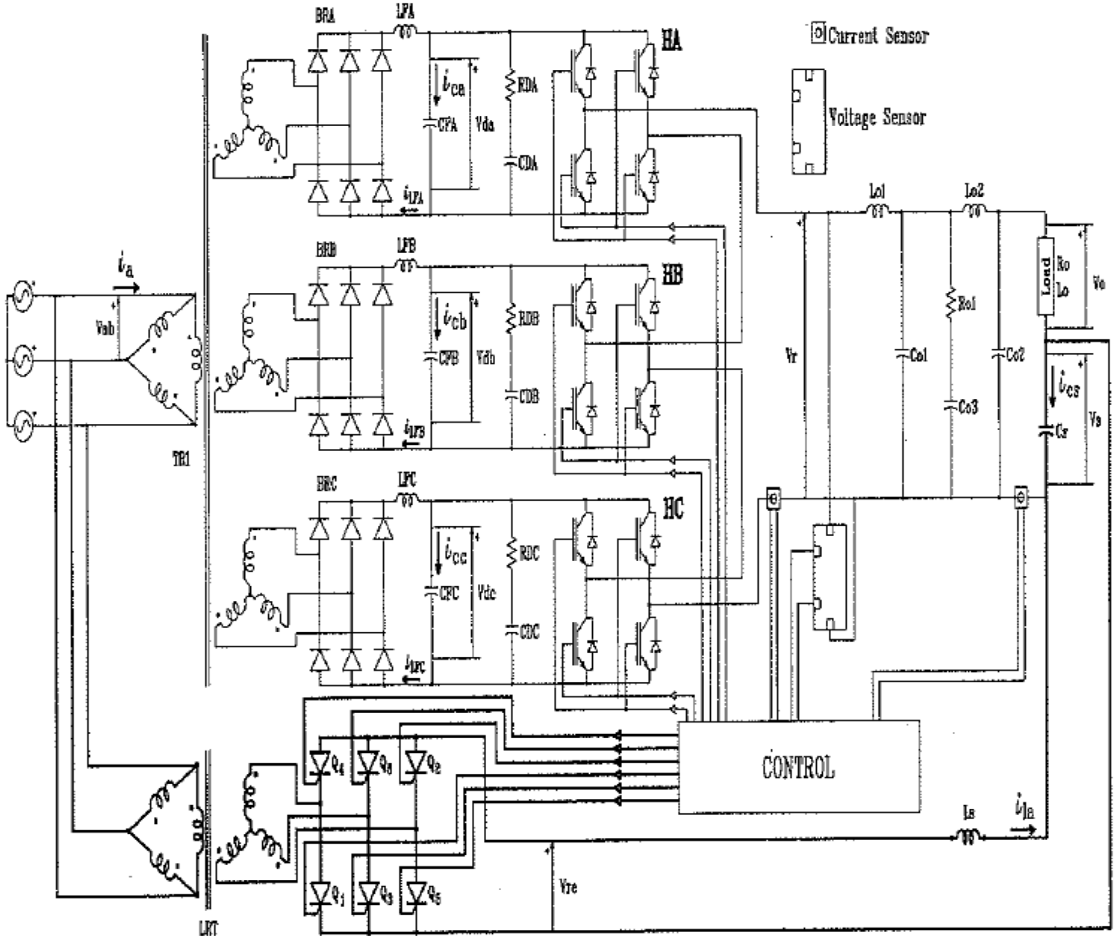
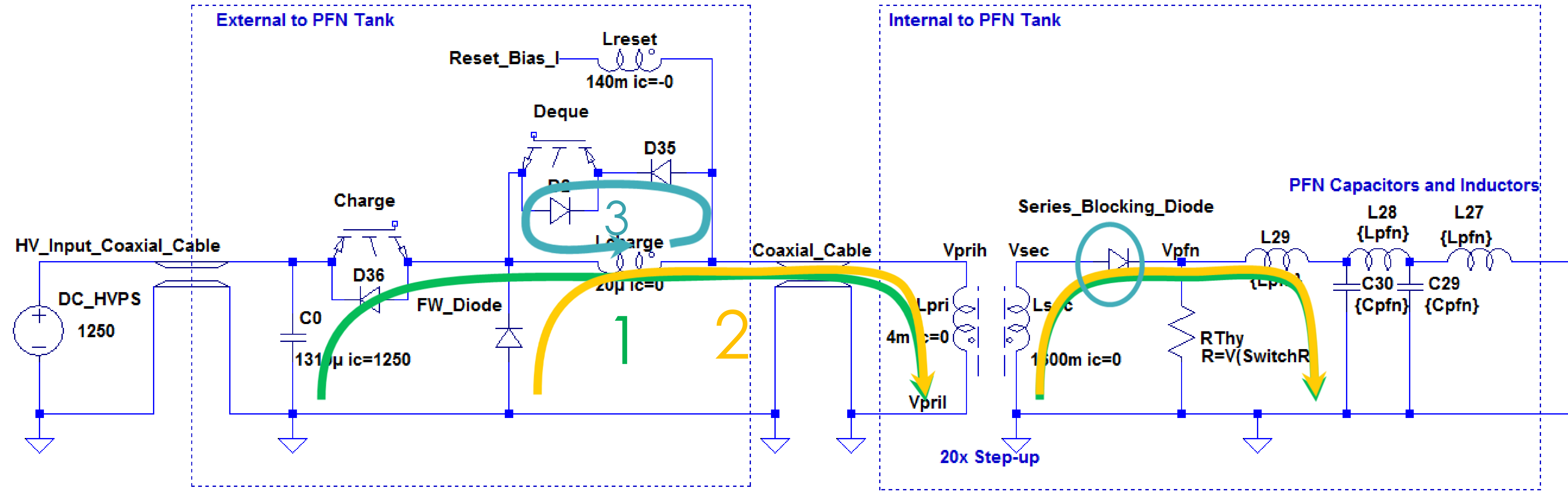


Figure 1 Basic 1,400A, ±900V Converter System with Energy Storage Capacitor CS and Six Pulse SCR Rectifier

Resonant Charging Scheme



Timing Sequence: C0 is always Charged to 1250Vdc

1. Charge IGBT closes, Current resonantly charges the PFN through L_{charge}
2. When the energy in L_{charge} and C_{pfn} equals the final energy the Charge IGBT opens
3. The current continues to charge C_{pfn} through the freewheel diode
4. When the voltage on C_{pfn} is equal to the set point the Deque IGBT closes and stops the charge
5. The series diode keeps the voltage from discharging back through the transformer