

# Spallation Neutron Source (SNS) Magnet Systems Overview

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Magnet, Power Supply, Kicker, & Chopper Systems

Spallation Neutron Source

Oak Ridge National Lab

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

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# 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

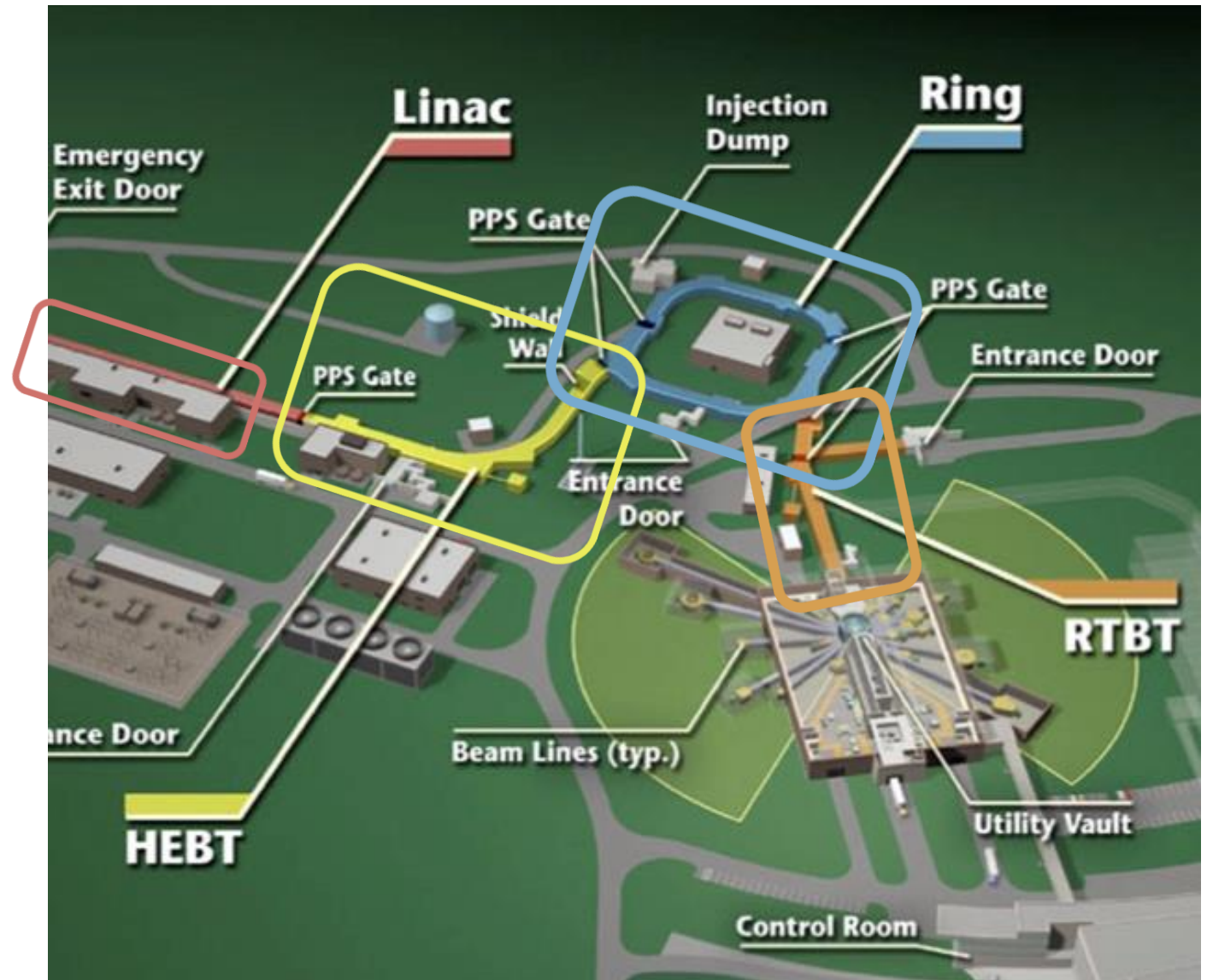


Produces high intensity pulsed neutrons for scientific research and industrial development

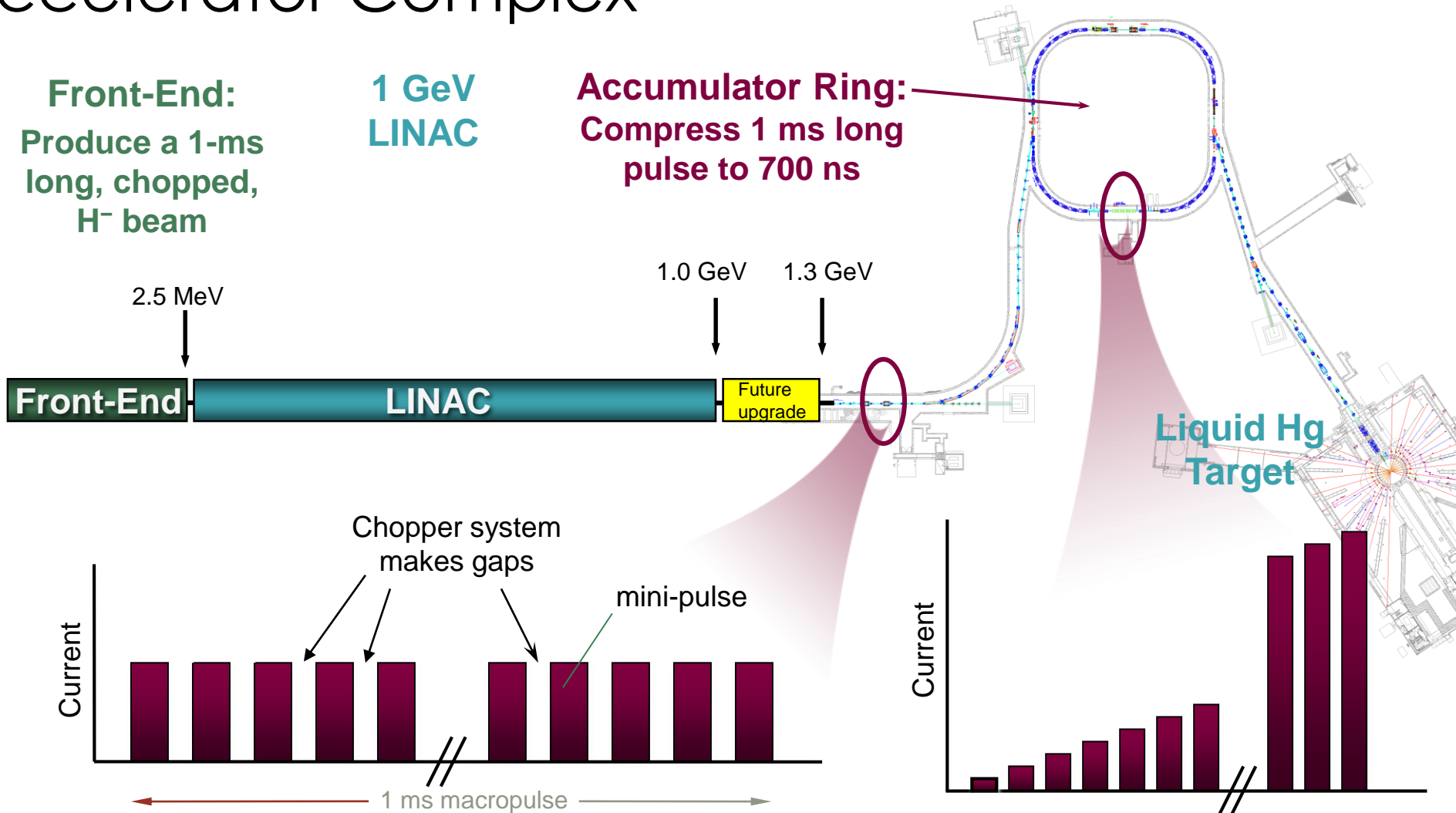
[neutrons.ornl.gov/sns](https://neutrons.ornl.gov/sns)

# 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

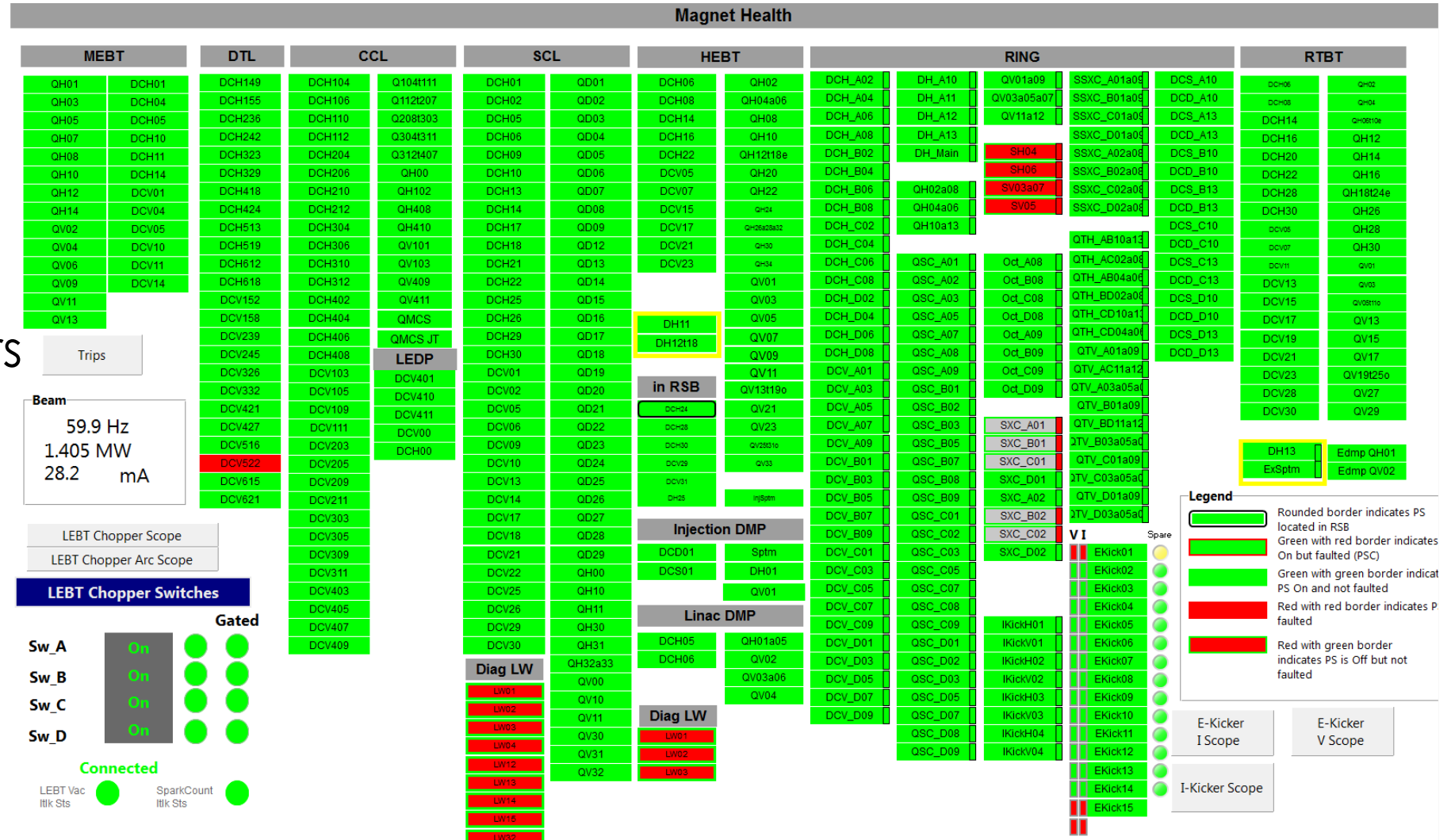
Currently operating at 1.4 MW with >95% availability

J. Tang SNS 2006

# Magnet, Power Supply, Kicker and Chopper Systems

## Single "Green Screen" Magnet Status Page

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



# Magnet Power Supply Systems

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

## 4 Types of Controllers

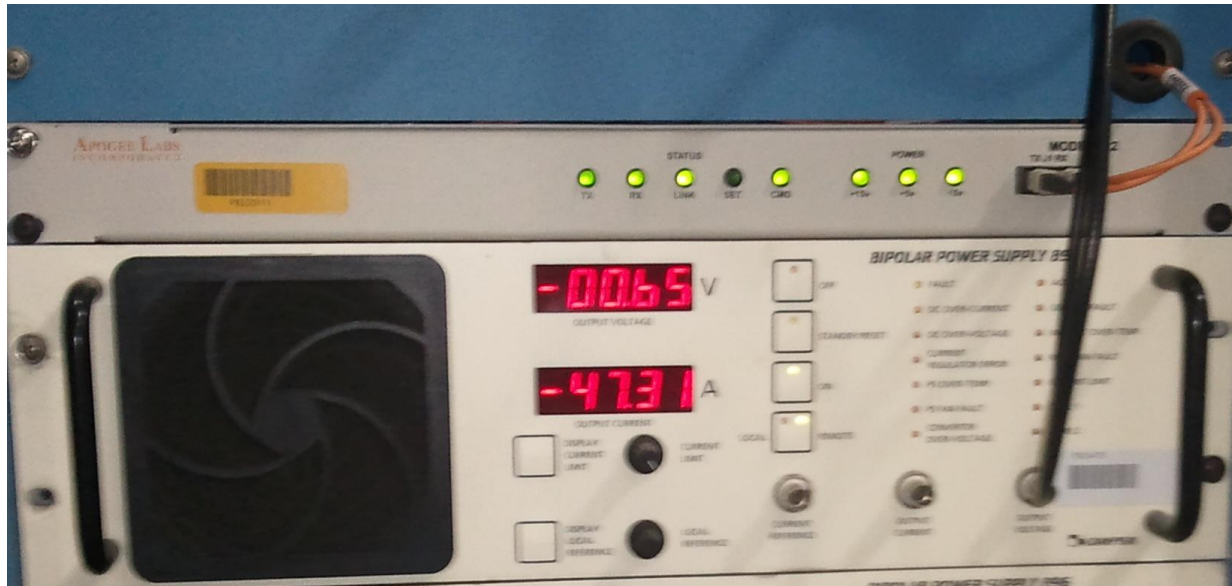
- PSC/PSI
- Group 3
- PLC
- Serial

Manufacturer	Model	Voltage	Current	Power	Quantity
Kepeco	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

# 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



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

MEBT		DTL	CCL		SCL	
QH01	DCH01	DCH149	DCH104	Q104111	DCH01	QD01
QH03	DCH04	DCH155	DCH106	Q1121207	DCH02	QD02
QH07a10	DCH05	DCH236	DCH110	Q2081303	DCH05	QD03
QH07a08	DCH10	DCH242	DCH112	Q3041311	DCH06	QD04
QH12	DCH11	DCH323	DCH204	Q3121407	DCH09	QD05
QH14	DCH14	DCH329	DCH206	QH00	DCH10	QD06
QV02	DCV01	DCH418	DCH210	QH102	DCH13	QD07
QV04	DCV04	DCH424	DCH212	QH408	DCH14	QD08
QV08a09	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	DCV105		DCV01	QD19
		DCV332	DCV109		DCV02	QD20
		DCV421	DCV111		DCV05	QD21
		DCV427	DCV203		DCV06	QD22
		DCV522	DCV205		DCV09	QD23
		DCV615	DCV209		DCV10	QD24
		DCV621	DCV211		DCV13	QD25
			DCV303		DCV14	QD26
			DCV305		DCV17	QD27
			DCV309		DCV18	QD28
			DCV311		DCV21	QD29
			DCV403		DCV22	QH00
			DCV405		DCV25	QH10
			DCV407		DCV26	QH11
			DCH4109		DCV29	QH30
					DCV30	QH31
						QH32a33
						QV00
						QV10
						QV11
						QV30
						QV31
						QV32

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

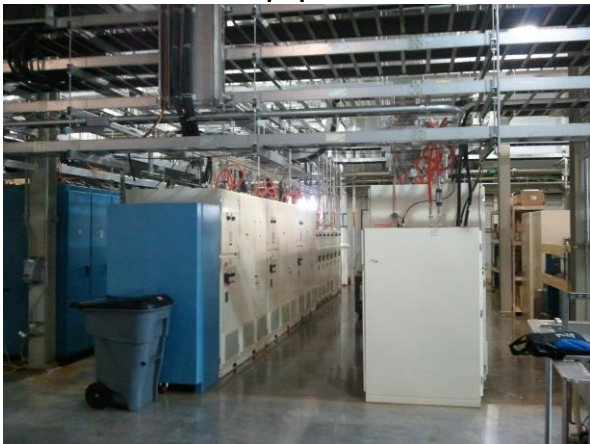
SCL Quads:  
Alpha Scientific  
35V, 525A,  
PSI Controller



# HEBT, RING, and RTBT Magnet Systems



HEBT Dipole and Quadrupole Magnet Power Supplies



High Power DC Supplies

Magnet Health									
HEBT			RING				RTBT		
DCH06	QH02	DCH_A02	DH_A10	QV01a09	SSXC_A01a09	DCS_A10	DCH06	QH02	
DCH08	QH04a06	DCH_A04	DH_A11	QV03a05a07	SSXC_B01a09	DCD_A10	DCH08	QH04	
DCH14	QH08	DCH_A06	DH_A12	QV11a12	SSXC_C01a09	DCS_A13	DCH14	QH0210e	
DCH16	QH10	DCH_A08	DH_A13		SSXC_D01a09	DCD_A13	DCH16	QH12	
DCH22	QH12118e	DCH_B02	DH_Main		SSXC_A02a09	DCS_B10	DCH20	QH14	
DCV05	QH20	DCH_B04			SSXC_B02a09	DCD_B10	DCH22	QH16	
DCV07	QH22	DCH_B06	QH02a08		SSXC_C02a09	DCS_B13	DCH28	QH18124e	
DCV15	QH24	DCH_B08	QH04a06		SSXC_D02a09	DCD_B13	DCH30	QH26	
DCV17	QH25a23a32	DCH_C02	QH10a13			DCS_C10	DCV05	QH28	
DCV21	QH30	DCH_C04			QTH_AB10a13	DCD_C10	DCV07	QH30	
DCV23	QH34	DCH_C06	QSC_A01	Ocd_A08	QTH_AC02a09	DCS_C13	DCV11	QH01	
	QV01	DCH_C08	QSC_A02	Ocd_B08	QTH_AB04a09	DCD_C13	DCV13	QH03	
	QV03	DCH_D02	QSC_A03	Ocd_C08	QTH_BD02a09	DCS_D10	DCV15	QH0211e	
	QV05	DCH_D04	QSC_A05	Ocd_D08	QTH_CD10a11	DCD_D10	DCV17	QH13	
	QV07	DCH_D06	QSC_A07	Ocd_A09	QTH_CD04a09	DCS_D13	DCV19	QH15	
	QV09	DCH_D08	QSC_A08	Ocd_B09	QTV_A01a09	DCD_D13	DCV21	QH17	
	QV11	DCV_A01	QSC_A09	Ocd_C09	QTV_AC11a12		DCV23	QH19t25e	
	QV13t19e	DCV_A03	QSC_B01	Ocd_D09	QTV_A03a05a9		DCV28	QH27	
	QV21	DCV_A05	QSC_B02		QTV_B01a09		DCV30	QH29	
	QV23	DCV_A07	QSC_B03	SXC_A01	QTV_BD11a12				
	QV25t31e	DCV_A09	QSC_B05	SXC_B01	QTV_B03a05a9				
	QV33	DCV_B01	QSC_B07	SXC_C01	QTV_C01a09				
	injS01	DCV_B03	QSC_B08	SXC_D01	QTV_C03a05a9				
	injS02m	DCV_B05	QSC_B09	SXC_A02	QTV_D01a09				
		DCV_B07	QSC_C01	SXC_B02	QTV_D03a05a9				
		DCV_B09	QSC_C02	SXC_C02					
		DCV_C01	QSC_C03						
		DCV_C03	QSC_C05						
		DCV_C05	QSC_C07						
		DCV_C07	QSC_C08						
		DCV_C09	QSC_C09						
		DCV_D01	QSC_D01	IKickH01	EKick01				
		DCV_D03	QSC_D02	IKickV01	EKick02				
		DCV_D05	QSC_D03	IKickH02	EKick03				
		DCV_D07	QSC_D05	IKickV02	EKick04				
		DCV_D09	QSC_D07	IKickH03	EKick05				
			QSC_D08	IKickV03	EKick06				
			QSC_D09	IKickH04	EKick07				
				IKickV04	EKick08				
					EKick09				
					EKick10				
					EKick11				
					EKick12				
					EKick13				
					EKick14				
					EKick15				

DH11  
DH12118

in RSB

DCH24  
DCH28  
DCH30  
DCV29  
DCV31  
DH25

Injection DMP

DCD01  
DCS01  
QV01

Linac DMP

DCH05  
DCH06  
QV02  
QV03a06  
QV04

Diag LW

LW01  
LW02  
LW03

**Legend**

- Rounded box located in RSB
- Green with red border indicates PS On but faulted
- Green with green border indicates PS On and not faulted
- Red with red border indicates PS faulted
- Red with green border indicates PS faulted
- E-Kicker
- I Scope
- I-Kicker Scope
- Spare



Corrector Power Supplies

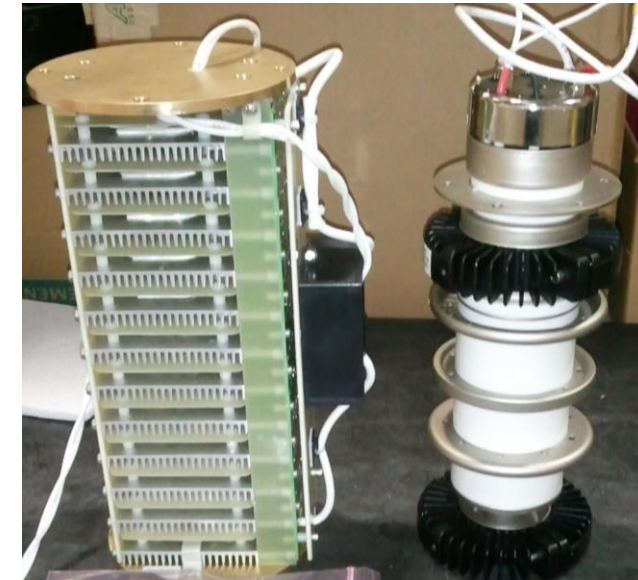
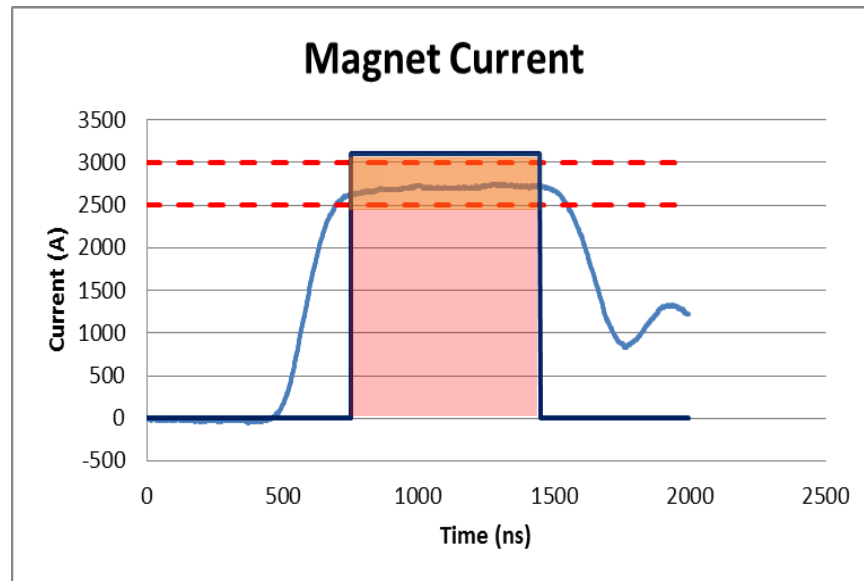


14 Extraction PFNs - Replacing Thyratrons with Solid-State Switches

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



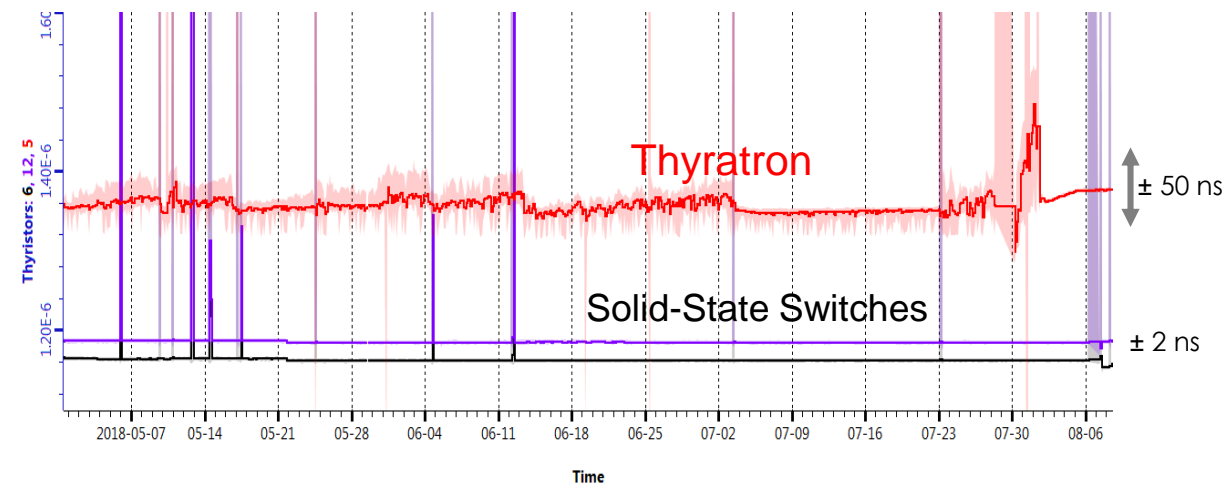
- Combined V & I monitor system
- Send Charge Voltage and Current Pulse "Fault" signals to MPS only when detected



Thyristor

Thyratron

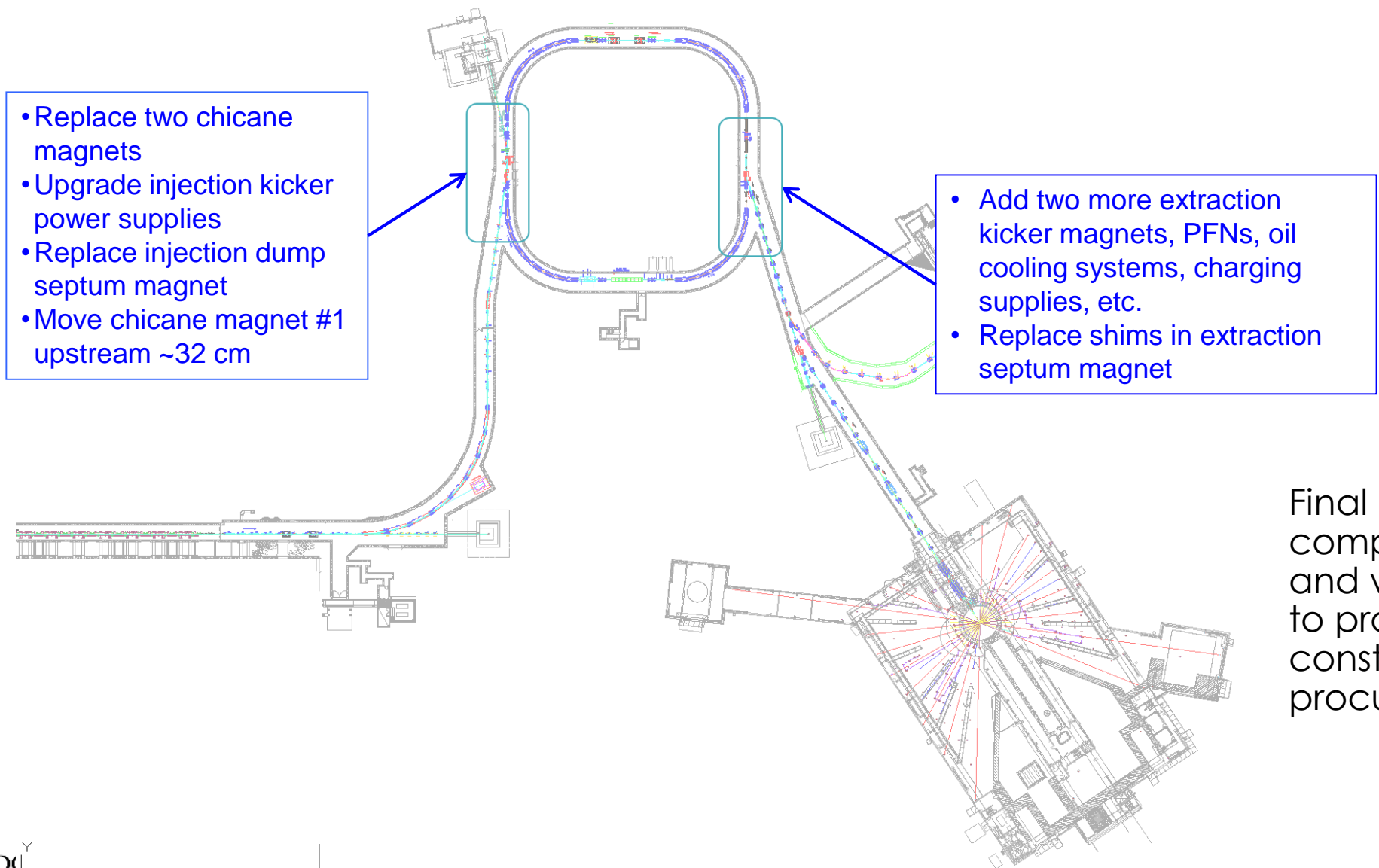
Thyratron & Solid-State Switch Jitter/Delay over 100 days



# Major Accelerator Upgrades in Planning

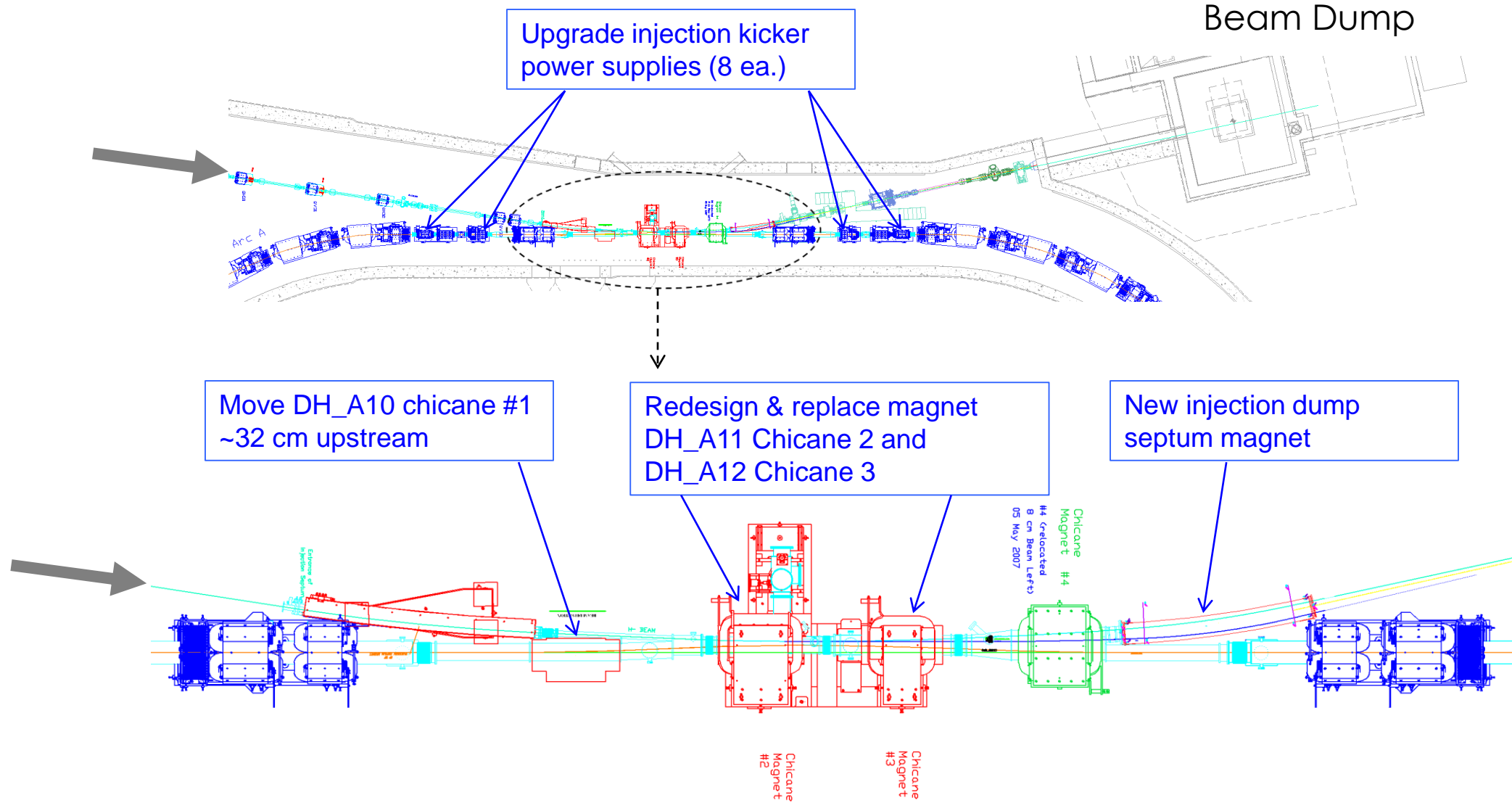
- Proton Power Upgrade (PPU)
  - Increases the beam energy from 1.0 GeV to 1.3 GeV
  - Requires magnet currents to increase by 20%
  - All magnet power supplies were designed for this except the Injection and Extraction Kickers
  - Detailed cost and schedule with preliminary design plans by Fall 2019
  - 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



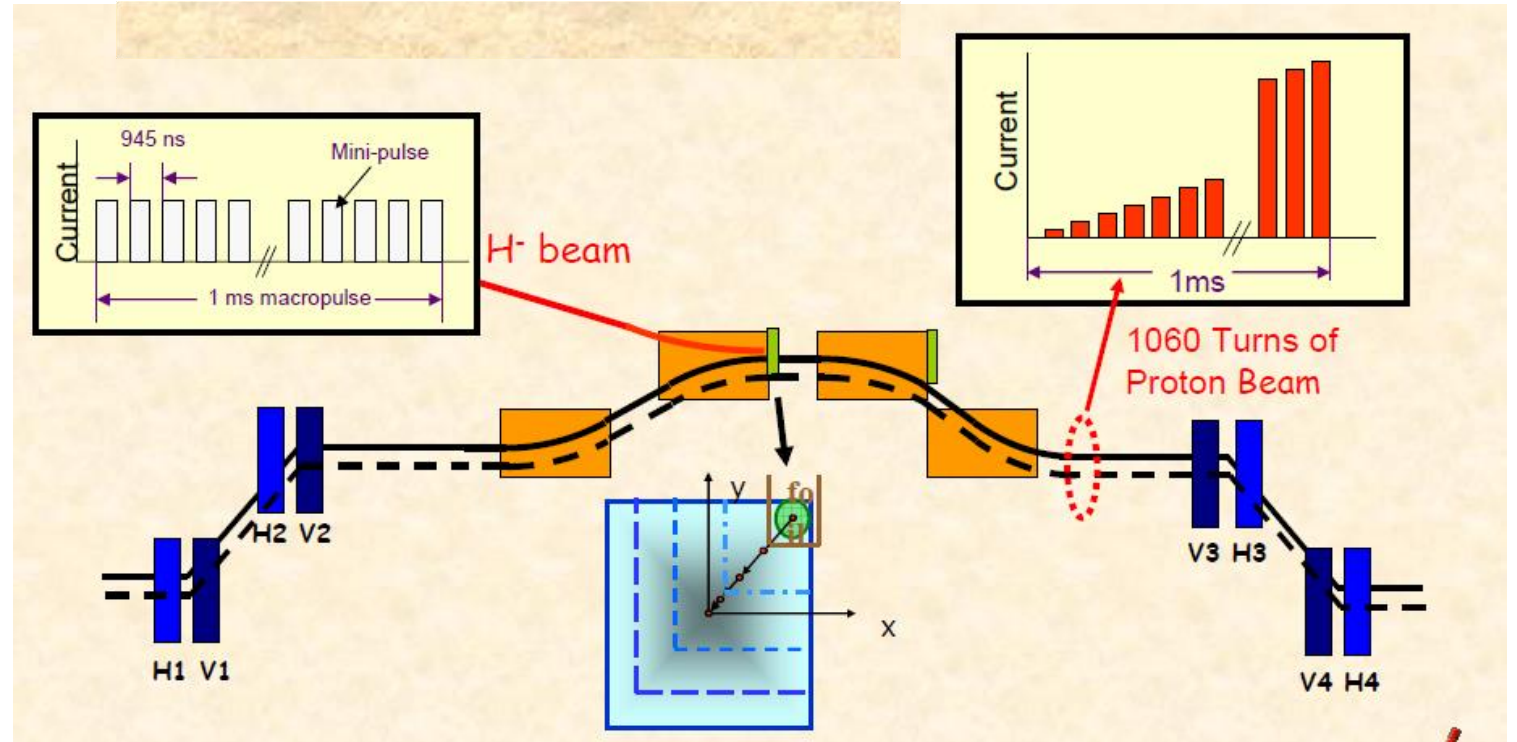
Final designs will be complete in 2020 and will be ready to proceed to construction and procurements.

# PPU Ring Injection Scope Detail



# SNS Injection Painting Process

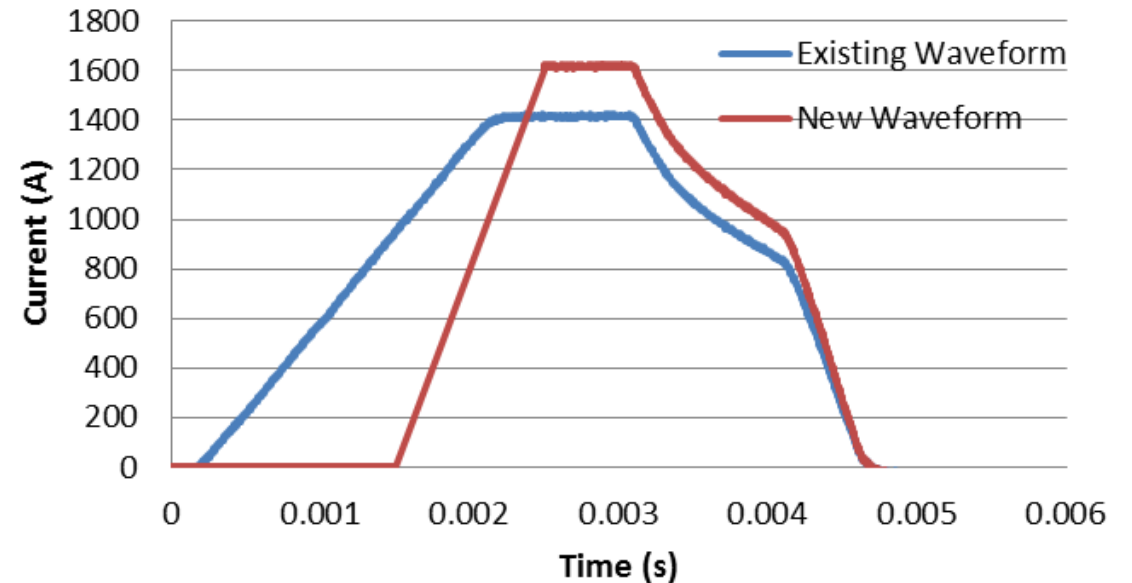
- 4 horizontal & 4 vertical kickers
- Produces a controlled dynamic deflection of the beam during the 1ms injection time.



# Injection Kicker Power Supply Upgrade Requirements

- 8 Identical Power Supplies
- Arbitrary Waveform
- Max  $di/dt$  is  $1.6 \text{ A}/\mu\text{s}$
- 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  $160 \mu\text{H}$ ,  $13 \text{ m}\Omega$
- Bipolar voltage output  $\pm 800 \text{ V}$

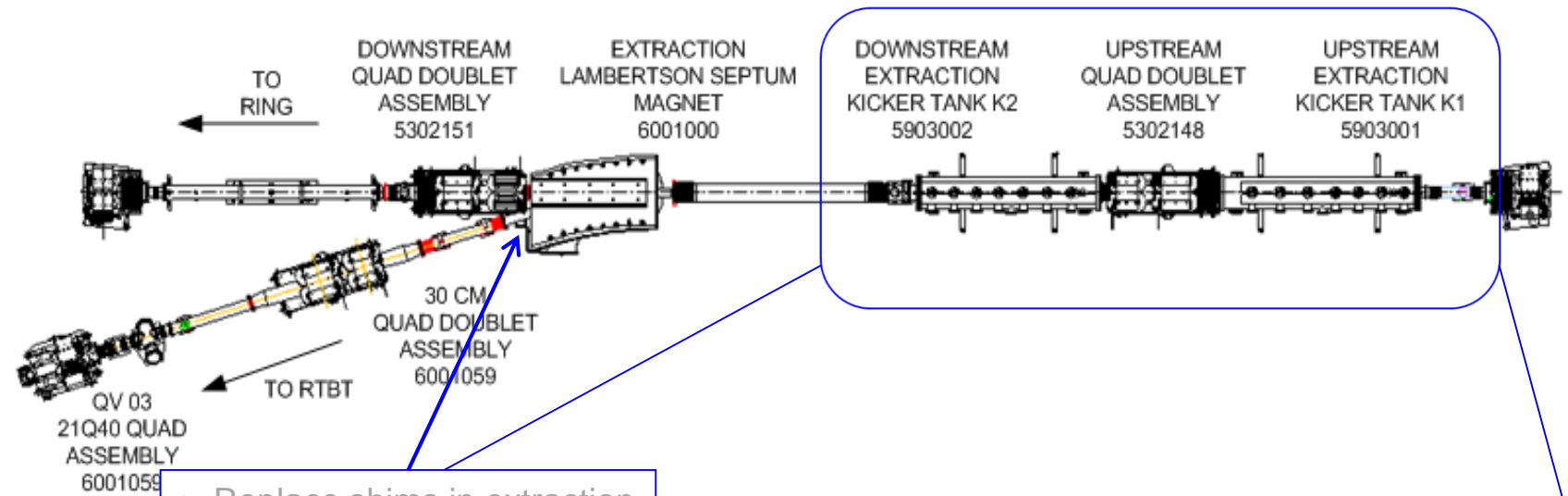
## Injection Kicker Waveform Changes



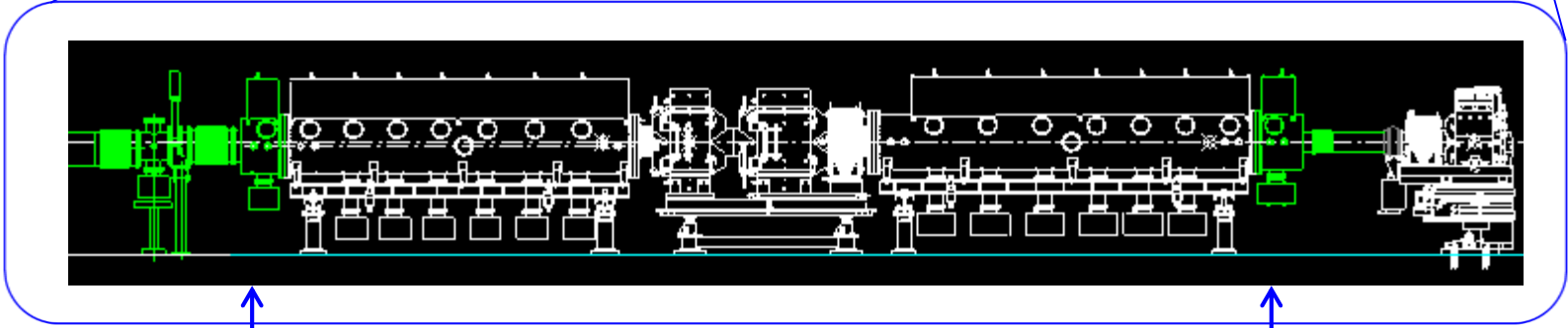
- Original Manufacturer had a design change that can meet the higher current requirements but has since gone out of business.
- We are reverse engineering the design to determine path forward.



# Ring Extraction Region PPU Scope Detail



• Replace shims in extraction septum magnet



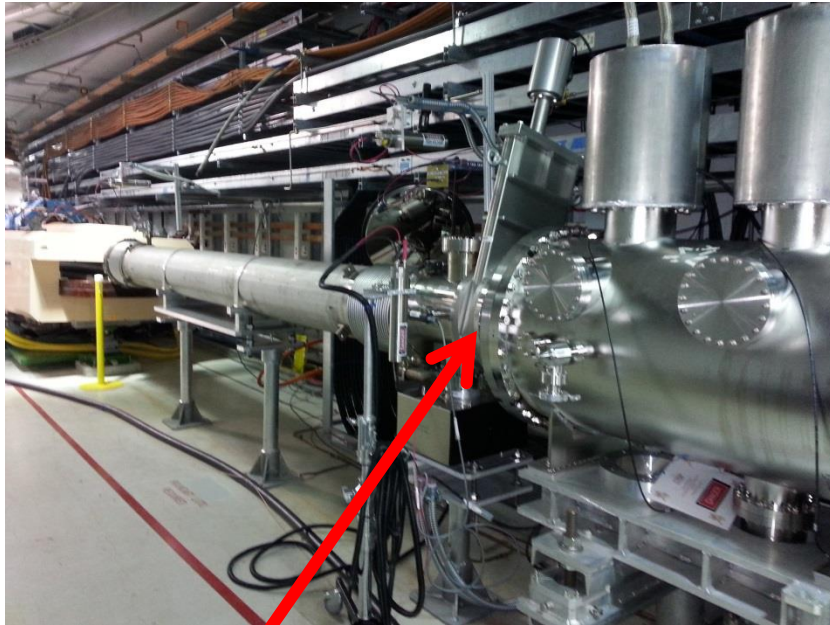
• Add K2 Annex

• Add K1 Annex

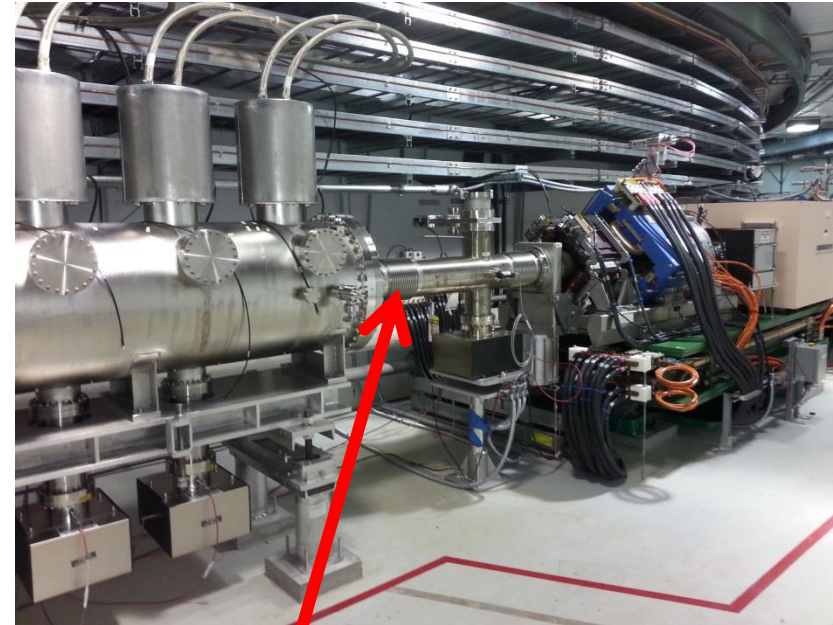
- Two addition kicker magnets and associated power supplies, controls, vacuum, cooling

# Location of Magnet Annex Tanks in Ring Tunnel

Space required for new annex tanks already exists



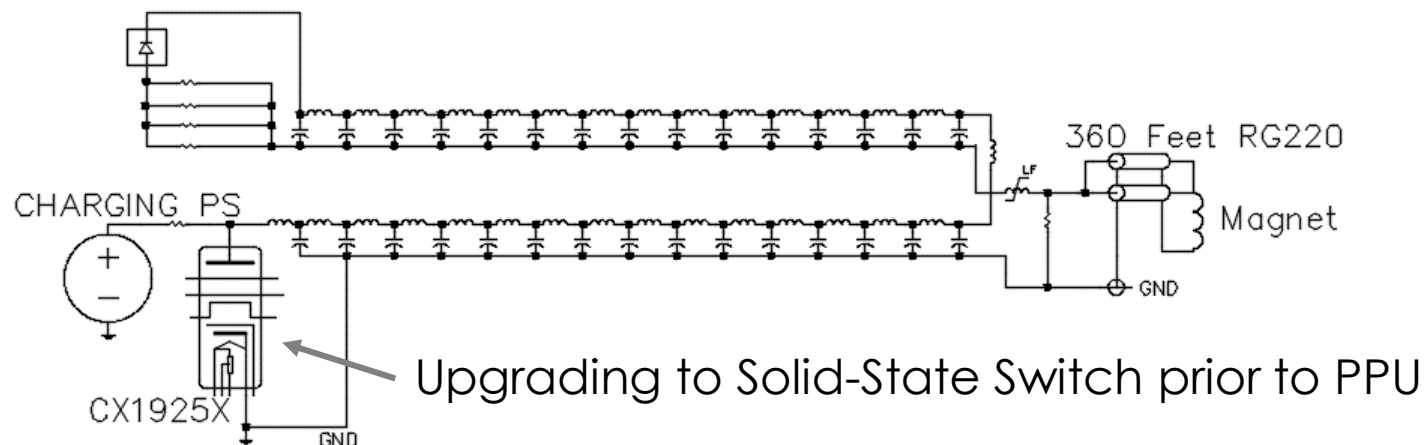
Downstream tank  
Annex K2X-1



Upstream tank  
Annex K1X-1

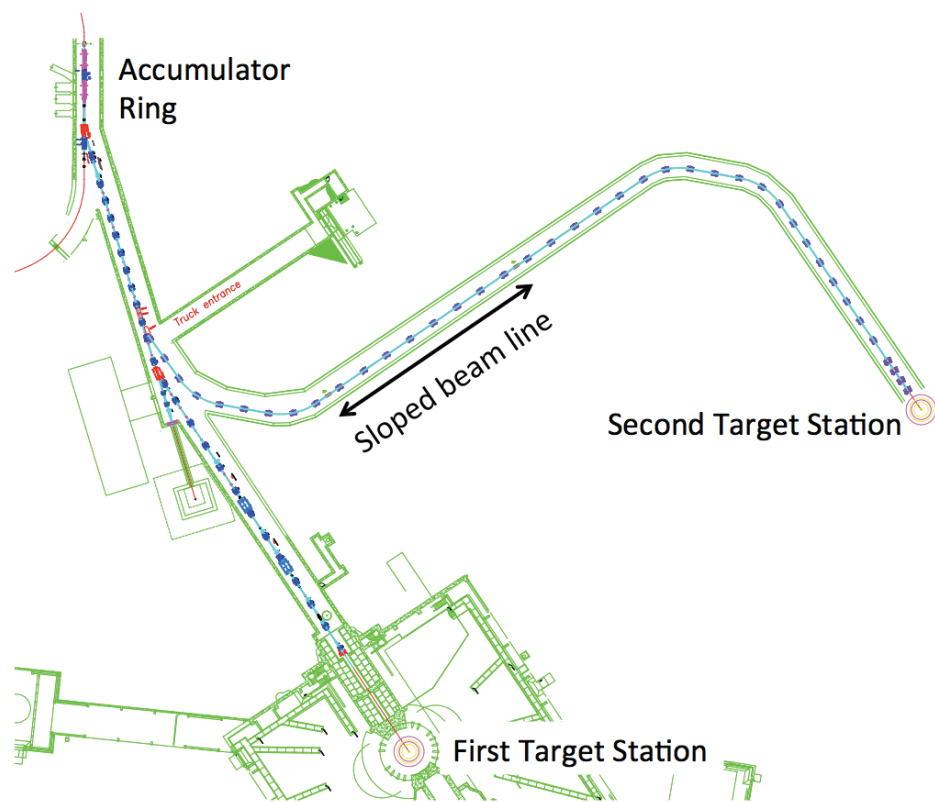
# Alternative to adding two PFN kicker systems

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

# Second Target Station Project CD-1 Fall 2019



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

# Conclusion

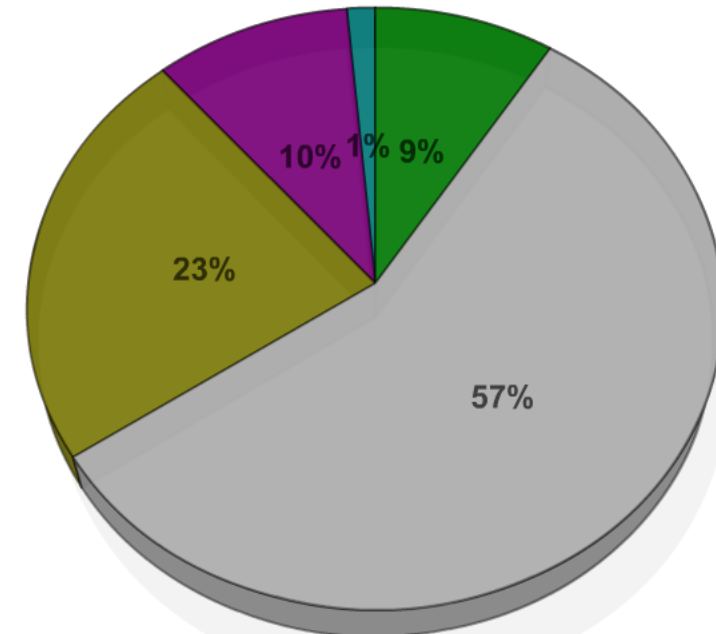
- Questions?
  
- We have multiple openings for Electrical and RF Engineers
  - Power Electronics Engineer / NB50684392
    - <https://neutrons.ornl.gov/careers>
    - Listed as a junior engineer level but will consider upgrading for well qualified applicants.
    - This position is open to all domestic 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%
MW hr:	2.8	180.2	694.0	4040.8
Avg MW hr/day:	33.6	31.8	30.7	31.7
NP Hrs. delivered:	2.0	128.0	525.8	2888.1

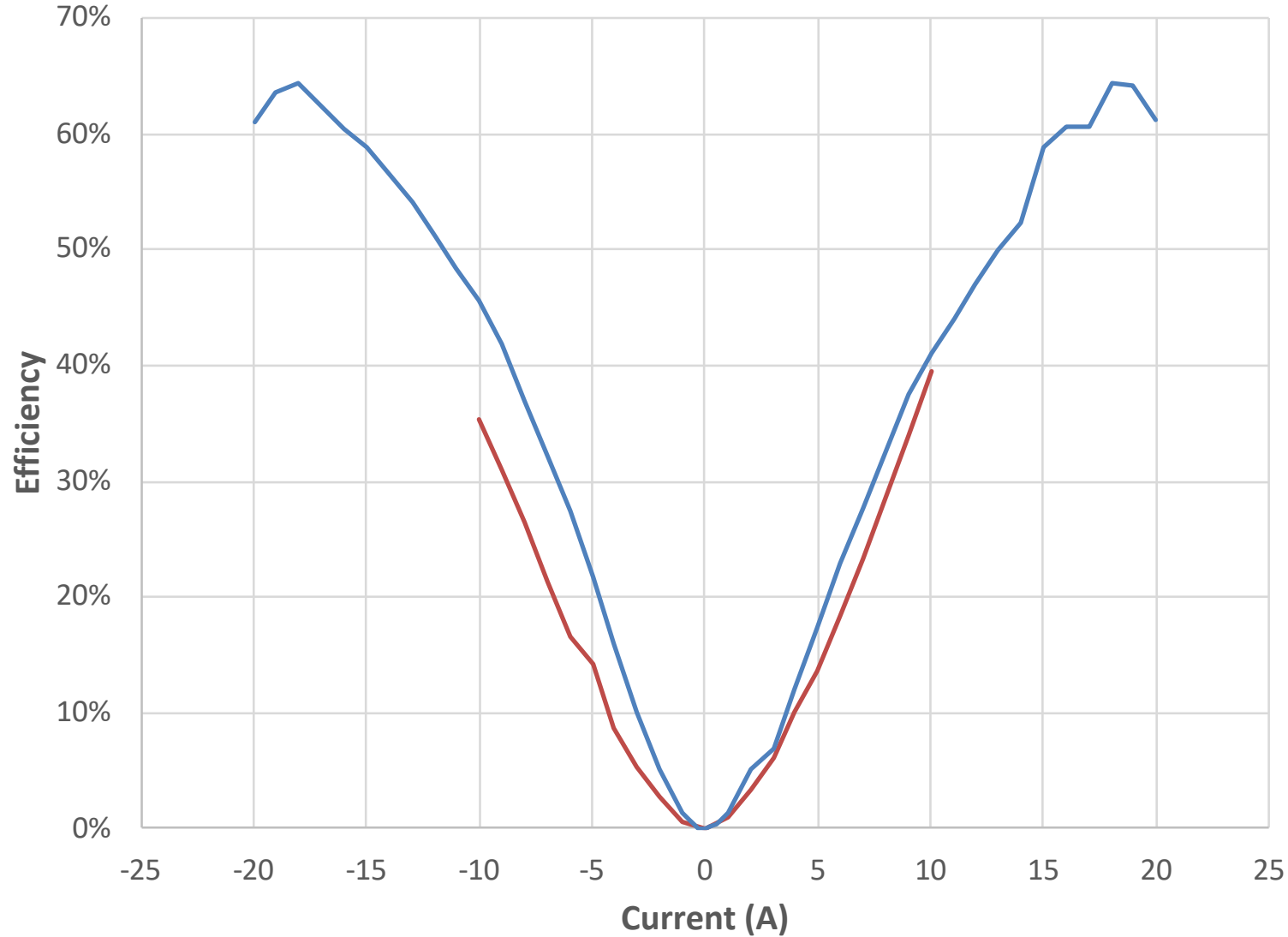
- AC Power Distribution
- HVCM
- Power Supplies
- TVA 161 KV Power
- Other(s)



Breakdown (Down Time Related Only)

# MEBT Steerer and Accelerator Corrector Efficiency

## LINAC Quad Efficiency vs. Output Current



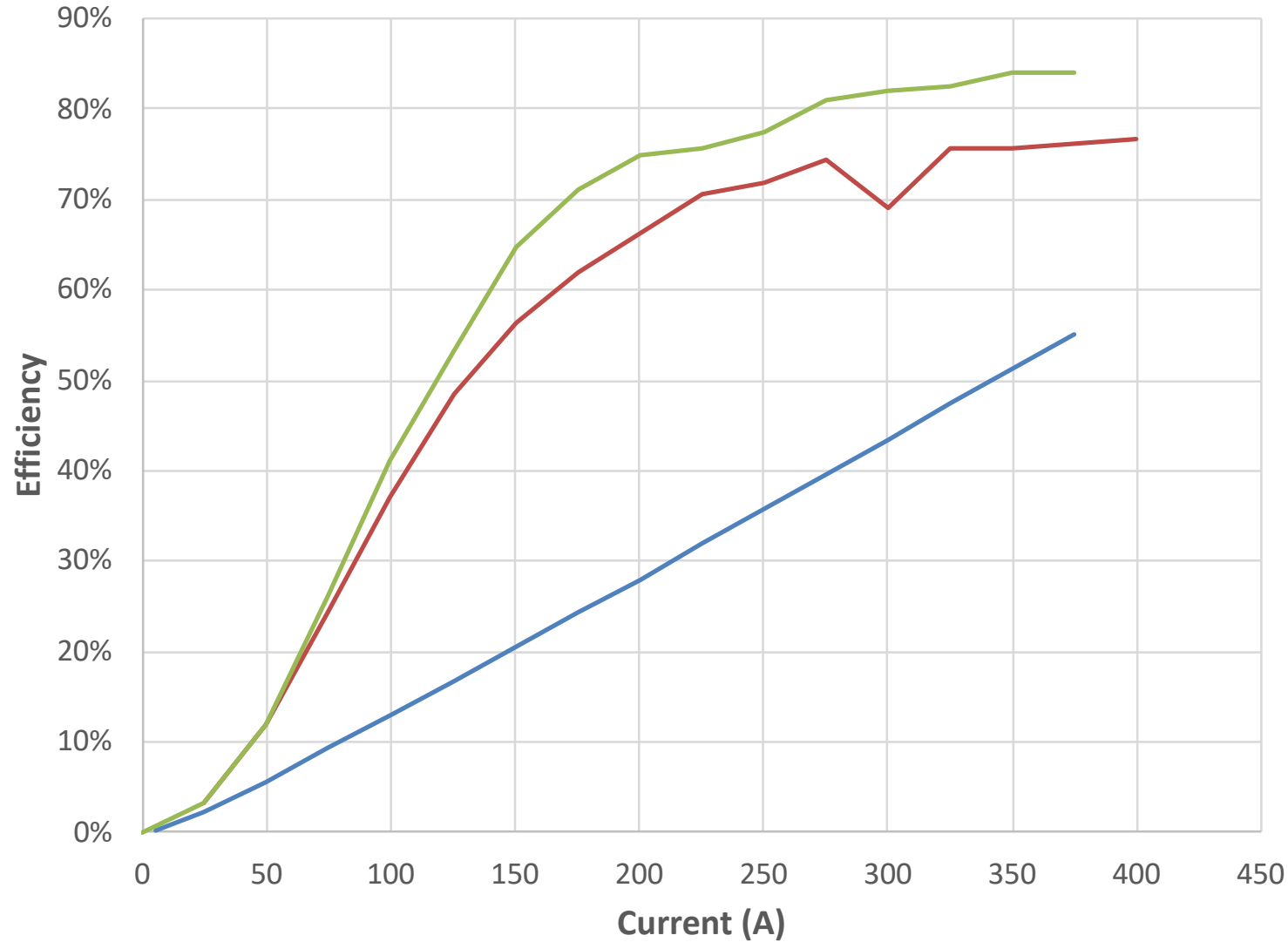
High Frequency Switching  
1000 ppm Stability

— Kepeco  
— Danfysik



# Linac Quadrupole Power Supply Efficiency

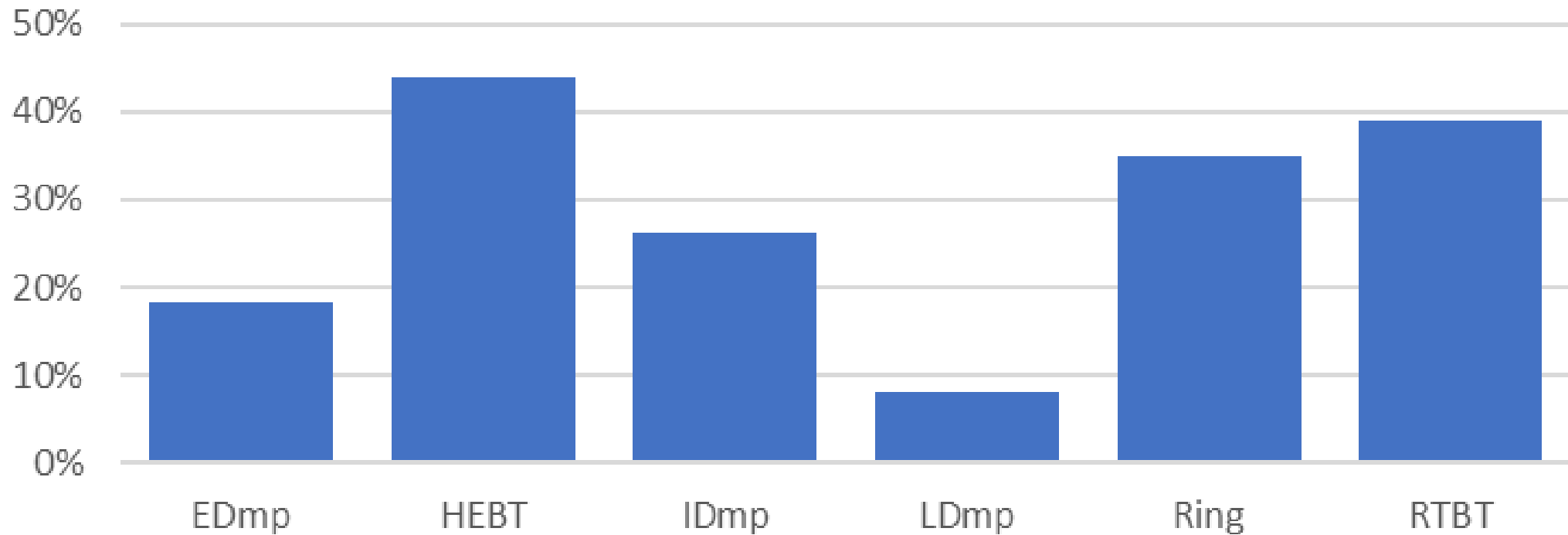
LINAC Quad Efficiency vs. Output Current



Low/High frequency Switching  
100 ppm Stability

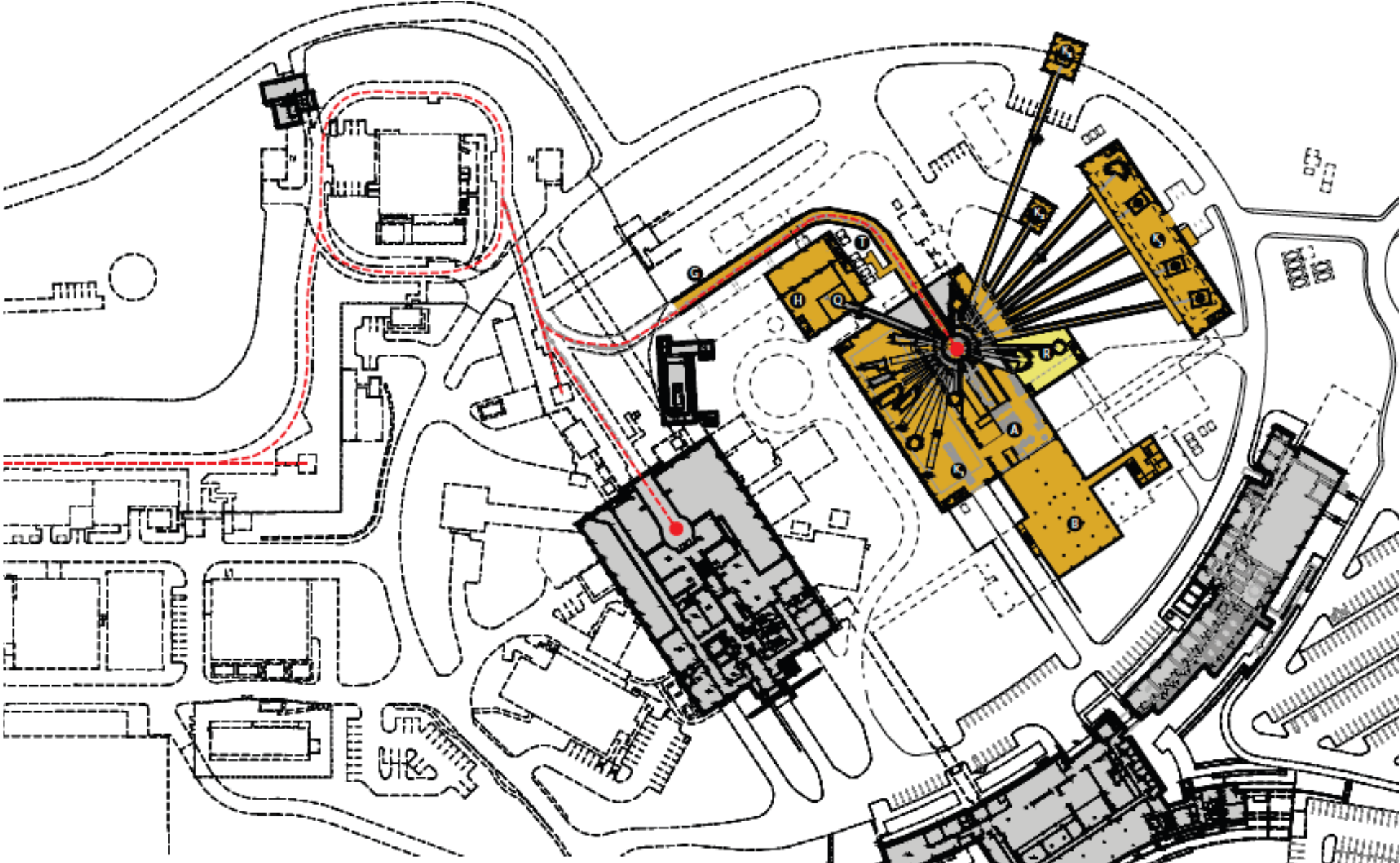
- IE Type II
- Alpha
- Ametek

# 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



Linac Correctors:  
Danfysik  
PSI Controller



SCL Quads:  
Alpha Scientific  
35V, 525A,  
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

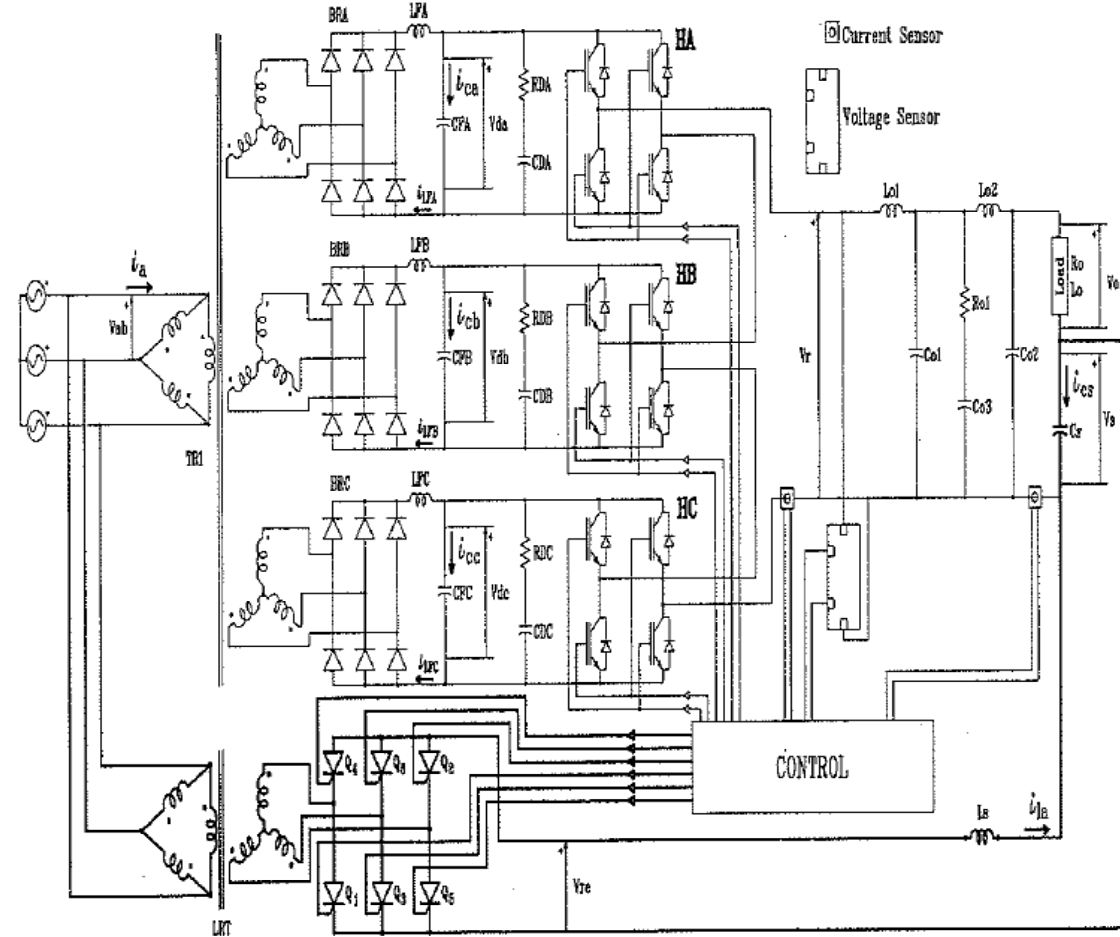
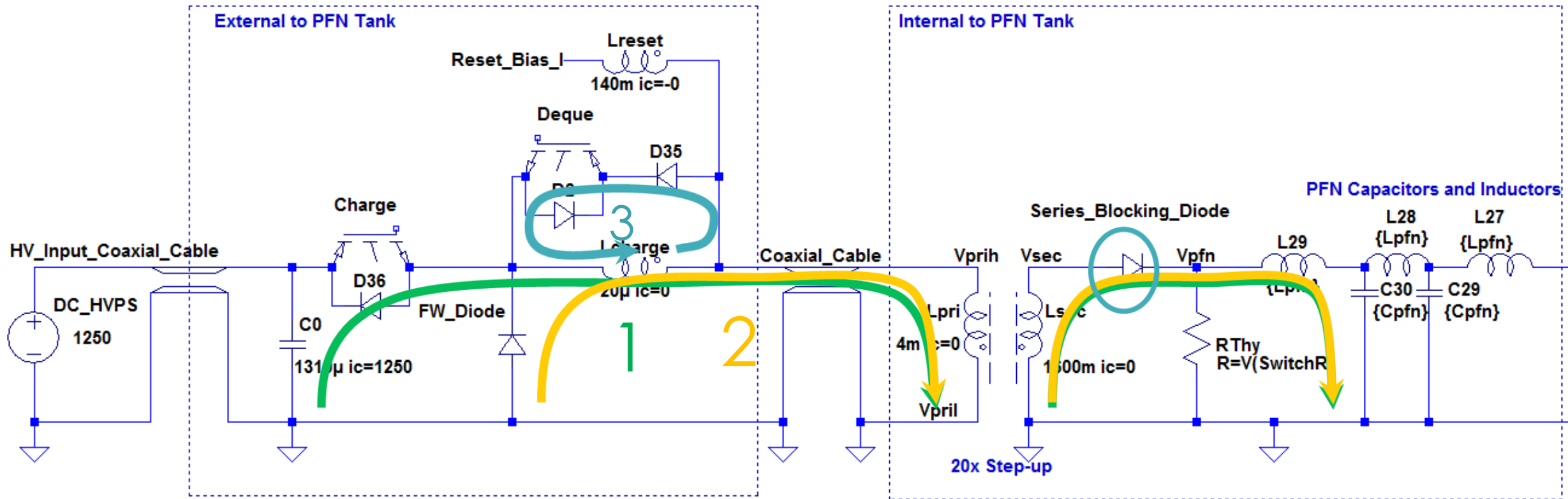


Figure 1 Basic 1,400A, ±900V Converter System with Energy Storage Capacitor CS and Six Pulse SCR Rectifier

# 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