

APS-U MAGNET POWER SUPPLY SYSTEMS STATUS

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POCPA 2023 – Austria

May 31st - June 2nd 2023



POCPA 2018 Summary

- **The Magnet Power Supply System has a numerous components:**
 - Two large AC/DC power supplies for L-bend (M1/M2) dipole magnet strings
 - 1000 unipolar 10-ppm stability-class commercial DC/DC power supplies
 - 921 slow +/-15A bipolar power supplies
 - 322 fast +/-15A bipolar power supplies
 - 200 unipolar power supply controllers
 - 200 bipolar power supply controllers
 - Magnet TC Monitoring System
- **CD-2 – October 10 -12, 2018 (Performance Baseline)**
- **CD-3 – Spring 2019 (Procurement Begins)**
- **Construction Starts in April 2022**

Pause

<https://www.nytimes.com/interactive/2021/12/05/business/economy/supply-chain.html>

COVID-19 pandemic

The **COVID-19 pandemic**, also known as the **coronavirus pandemic**, is an ongoing global pandemic of **coronavirus disease 2019** (COVID-19) caused by **severe acute respiratory syndrome coronavirus 2** (SARS-CoV-2). The **novel virus** was first identified in an outbreak in the Chinese city of **Wuhan** in December 2019. Attempts to contain it there failed, allowing the virus to spread to other areas of Asia and later **worldwide**. The **World Health Organization** (WHO) declared the outbreak a **public health emergency of international concern** on 30 January 2020, and a pandemic on 11 March 2020. As of 1 February 2023, the pandemic had caused **more than 670 million cases** and **6.83 million confirmed deaths**, making it one of the **deadliest in history**.

APS-U Measures:

- Pay Premium - \$78 for \$4 Chip
- Use DPAS

The New York Times



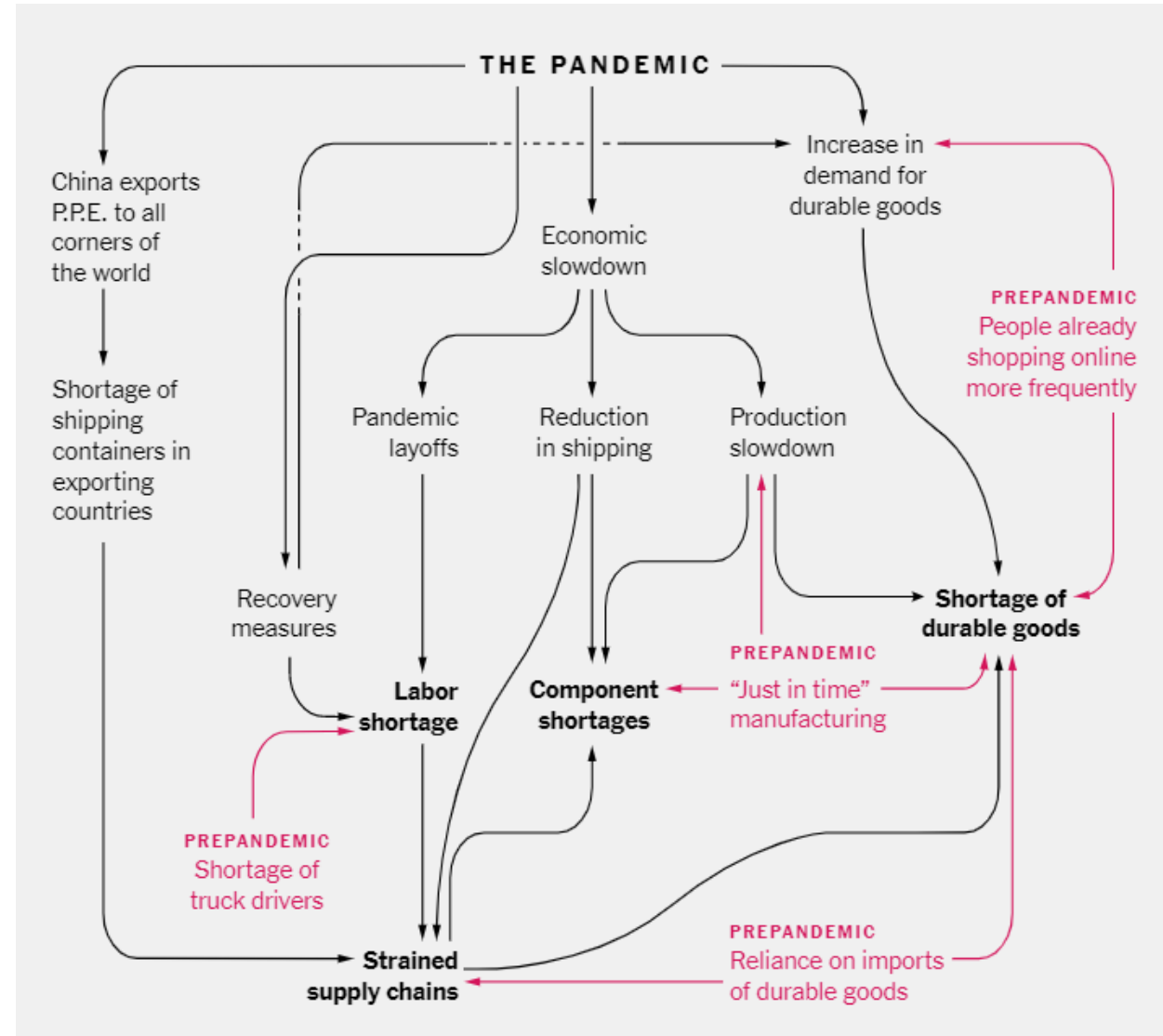
How the Supply Chain Crisis Unfolded

By [Lazaro Gamio](#) and [Peter S. Goodman](#) Dec. 5, 2021

Ships stuck at sea, warehouses overflowing, trucks without drivers: The highly intricate and interconnected global supply chain is in upheaval, with little end in sight.

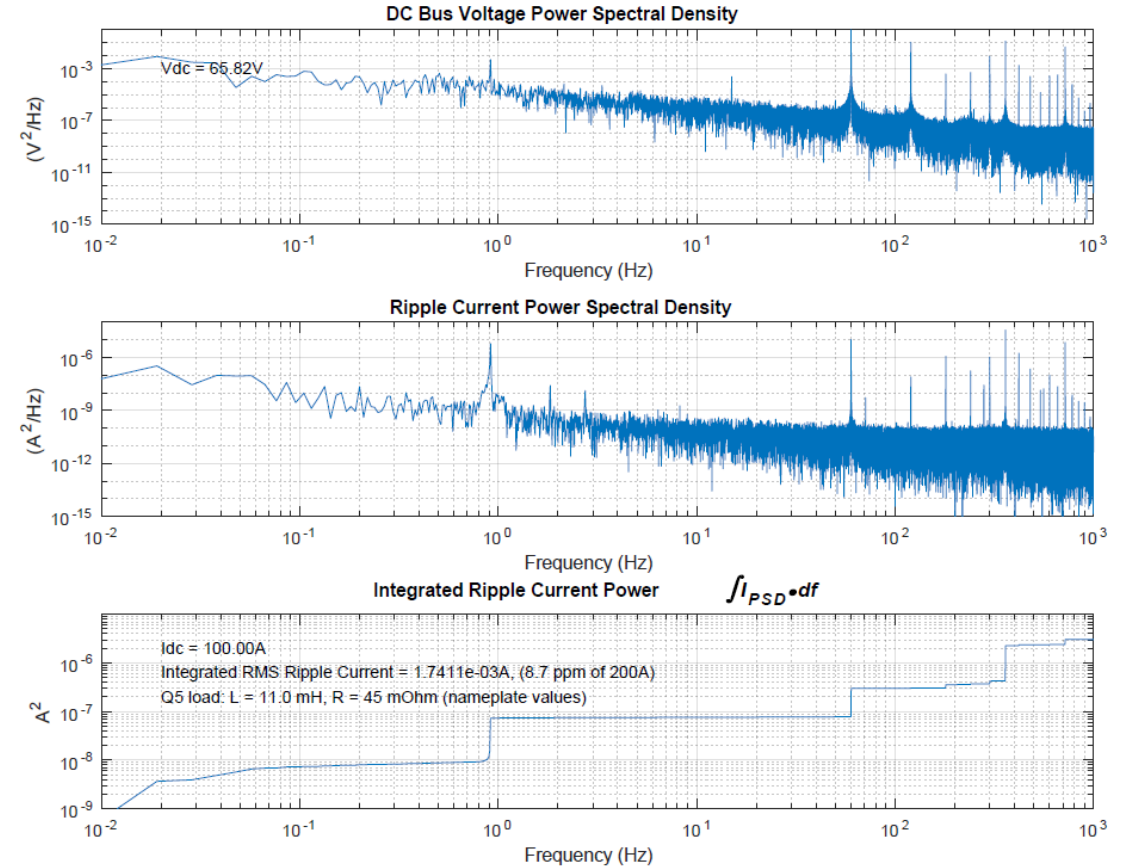
The turmoil has revealed how the need to ship surgical masks to West Africa from China can have a cascading effect on Ford's ability to put back-up cameras on its cars at factories in Ohio and delay the arrival of Amazon Prime orders in Florida in time for the holidays.

In one way or another, much of the crisis can be traced to the outbreak of Covid-19.



APSU Magnet Power Supplies Scope

- U.U2.03.03.03	Magnet Power Supply Systems
+ U.U2.03.03.03.01	L-Bend Dipole Magnet Power Supply System
+ U.U2.03.03.03.02	Unipolar Power Supply System
+ U.U2.03.03.03.03	DC Trim Bipolar Power Supply System
+ U.U2.03.03.03.04	Fast Corrector Bipolar Power Supply System
+ U.U2.03.03.03.05	CTL Power Supply Controllers
+ U.U2.03.03.03.06	TMS Magnet TC Monitoring System
+ U.U2.03.03.03.07	Test Power Supply Pre-Installation Testing



Parameters*	Q1-8	Q-Bend	L-Bend	Sextupoles	Bi-Trim	Bi-Fast	Unit
Current (range)	135 - 250	230 - 254	245 - 441	62 - 88	+/-15	+/-15	A
Current Stability	10	10	10	10	100	100	ppm
Quantity	640	120	2	240	921	322	2245

May 2023 - Procurement Dashboard

WBS	Quantities Ordered	Quantities Received	ETC	Notes
U2.03.03.03.01 – L-Bend Power Supply System				
M1 and M2 Power Supplies	2	2	Complete	
Stripline Bus (Number of Segments)	5	5	Complete	
U2.03.03.03.02 – Unipolar Power Supply System				
DC-to-DC Converters	1,030	1,030	Complete	
DLO Cables	80,000'	80,000'	Complete	
Interlock Cables	40,000'	40,000'	Complete	
U2.03.03.03.03 – Bipolar Power Supply System				
Power Supplies	1020	1020	Complete	
Relay Racks	200	200	Complete	
U2.03.03.03.03 – Fast Correctors Power Supply System	332	332	Complete	
U2.03.03.03.05.01.01 – Unipolar Controller System	205	205	Complete	May/23
U2.03.03.03.05.01.02 – Unipolar Ext. Meas. System				
DCCTs	1,024	1,024	Complete	
Interface	205	205	Complete	
Cables	1024	1024	Complete	
U2.03.03.03.05.02.01 – Bipolar Controller System	205	205	Complete	
U2.03.03.03.05.02.02 – Bipolar Ext. Meas. System	205	205	Complete	

L- Bend Power Supply System

■ M1 and M2 Power Supply Load Specification

Parameters	DCL-475	DC-220	Unit
Rated output DC current	475	220	A
Rated output voltage	1500	1000	Vdc
Rated output power	750	220	kW
Input AC voltage range ($\pm 10\%$)	480	480	Vrms
Minimum efficiency at full rating	90	90	%
Total Load resistance (R)*	2.660	3.906	Ω
Total Load inductance (L)	0.216	0.704	H
Load time constant (L/R)	0.083	0.180	s



■ M2 Stripline Bus (1.1 km)

Deliverable	Quantity	Document #
M2 L-Bend DC Power Supply <u>Stripline</u> #1	41	A141-DCL008
M2 L-Bend DC Power Supply <u>Stripline</u> #2	41	A141-DCL009
M2 L-Bend DC Power Supply <u>Stripline</u> #3	41	A141-DCL010
M2 L-Bend DC Power Supply <u>Stripline</u> #4	41	A141-DCL011
M2 L-Bend DC Power Supply <u>Stripline</u> #5	41	A141-DCL012



Unipolar Power Supply System

Unipolar Power Supplies Load Specification

Parameters	DCU-100	DCU-200	DCU-300	Unit
Rated output DC current	100	200	300	A
Rated output voltage	15.0	15.0	45.0	V
Rated output power	1.50	3.0	13.5	kW
Minimum efficiency at full rating	90	90	90	%
Load resistance**	110 – 130	45 – 72	60 – 204	mΩ
Load inductance**	19.5 – 21.8	11.0 – 18.0	18.9 – 106	mH
Load time constant (L/R)	0.17 – 0.18	0.25 – 0.31	0.23 – 0.78	s

Unipolar Power Supplies Cables

Type	Length	Packaging
444 MCM DLO (BLACK)	30,750	82 reels with 375' minimum
4/0 DLO (BLACK)	27,300	42 reels with 650' minimum
#2 AWG DLO (BLACK)	17,640	42 reels with 420' minimum



Production Quantities

	100 A	200 A	300 A
Evaluation	2	2	2
1 st Article	10	10	10
Production	240	320	440



Bipolar Power Supply System

- Bipolar Power Supply System Requirements
 - 1,020 Bipolar Power Supplies Built to print

Magnet Windings	R (Ω)	L (mH)
M3T	1.63	90.0
M4T	1.28	62.0
Q4T	2.57	37.0
Q5T	1.71	20.0
Q7H	4.14	50.0
Q7V	3.85	41.7
Q8T	5.28	51.1
Q8V	5.48	65.2
S1H/S3H*	2.17	10.0
S1V/S3V*	1.14	4.0
S2H*	2.47	11.6
S2V*	1.28	4.8



Fast Correctors Power Supply System

- Fast Correctors Power Supply Requirements
 - 332 Bipolar Power Supplies

Parameters:	Units	H Dipole	V Dipole
Max. operating current	A	±15	±15
Max. power	W	67.5	67.5
Magnet resistance	Ω	0.30	0.30
Magnet inductance	mH	17	17



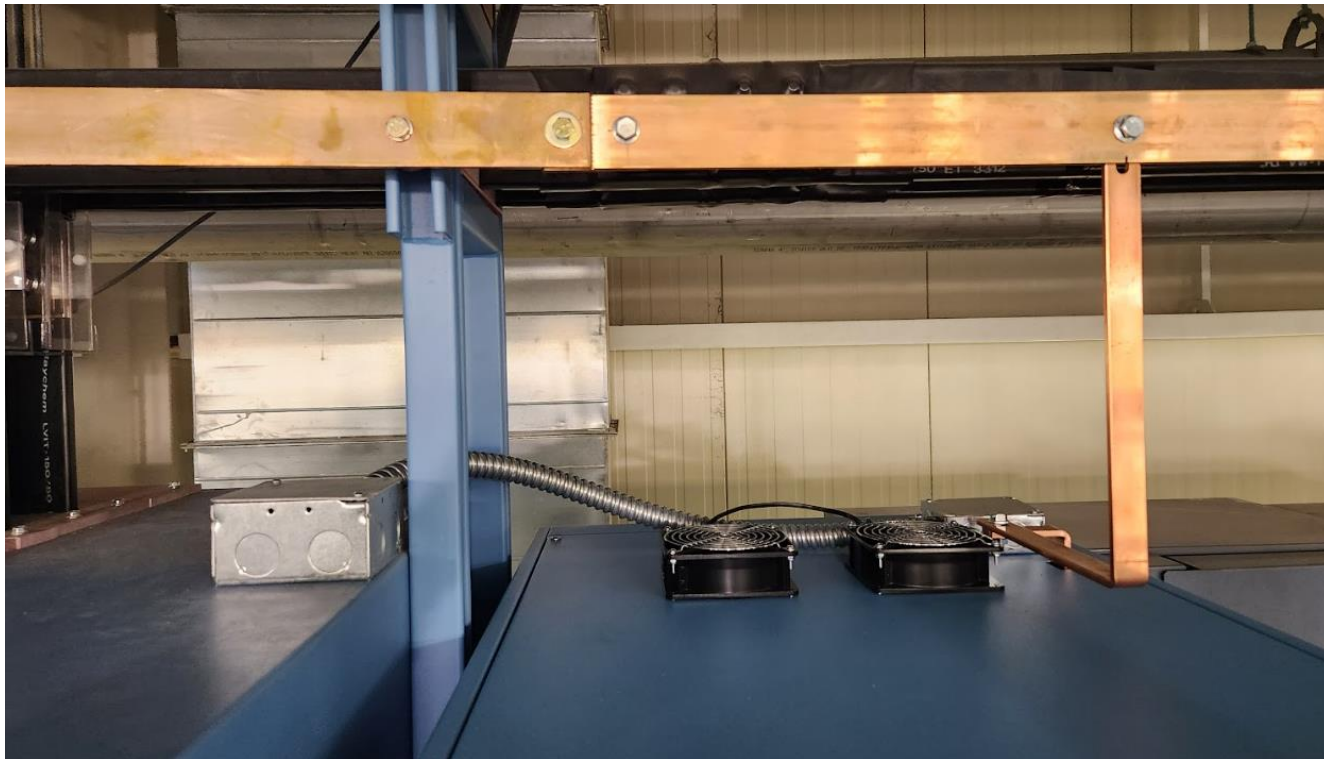
- Fast Correctors Power Supply Specifications

Parameter	Value	Units
Polarity:	Bipolar	-
Maximum operating current:	±15	A
Maximum output voltage:	±36 V	V
Small signal bandwidth (< 1%):	10	kHz
Initial accuracy after installation:	100	ppm
Repeatability (supply to supply):	100	ppm
Reproducibility after shutdown:	100	ppm
Output current stability:	100	ppm
Output current ripple (RMS) 0.01 to 1000 Hz	100	ppm

- DC Trim and Fast Correctors Power Supply Cables
 - 49,000', 14 AWG, 2 conductor EPDM, 300V Portable Cord in 1000 feet spool.

Bipolar Power Supply Relays Racks

- 2 First Articles
- 200 Production Relays Racks
 - 40 RU (74.50 inches) tall with a 19" wide panel opening and 36" depth
 - 3" C-channel shall be mounted on the base of the cabinet.
- 120 Vac Modification:



Power Supply Controllers System

Unipolar PS Controller



Bipolar Power Supply Controller



UPS External measurement System



BPS External Measurement System



Unipolar Power Supply Controller

- Unipolar Power Supply Controller – 205 ordered and received

EPICS IOC Interface

Parameter	Requirement
Protocol	UDP/IP over Ethernet
Link Speed	1 Gbit/s
Connector	RG-45 or Small-Form Pluggable
Location	Front Panel

FOFB/DAQ Interface

Parameter	Requirement
Protocol	UDP/IP over Ethernet
Link Speed	1 Gbit/s
Connector	RG-45 or Small-Form Pluggable

Parameter	Requirement
Location	Front Panel
Rate	22.6 kHz (determined by FBC)

Precision Current Measurement Status and Control

- Output current (out-of-loop precision DC measurement)
- Internal temperatures
- Temperature regulation status
- Calibration command
- Module serial number

BULK DATA INTERFACE

Parameter	Requirement
Protocol	UDP/IP over Ethernet
Link Speed	1 Gbit/s
Connector	RG-45 or Small-Form Pluggable



Power Supply Status and Control

- ON/OFF command
- Reset command
- ON/OFF status
- Remote status
- Fault status
- Output current (in-loop measurement)
- Output voltage
- Input voltage
- Internal temperatures
- Internal logic supply
- Output current set value
- Regulation status
- Power supply serial number
- Communication error counts
- Internal temperatures
- Firmware build date
- Firmware revision
- Controller serial number

Bipolar Power Supply Controller

■ Bipolar Power Supply Controller Requirements

- 205 Unipolar Power Supplies Controller Built to print
- Setpoints will be sent via UDP over Ethernet to the local controllers.
- Setpoint messages may be sent on-demand via EPICS or synchronously from the fast orbit feedback system.
- A setpoint message coming from the fast orbit feedback system may contain setpoints for many bipolar supplies (up to 62 for a double sector), and the local controllers must extract relevant setpoints for the power supplies that it controls.
- Setpoint messages will be sent out synchronously nominally every 44.1 microseconds.
- The latency budget for transmitting and distributing new setpoints from the fast orbit feedback system to the power supply controllers is 10 μ s.

Table 2.16: Bipolar DC-DC converter specifications

Parameter	DCB-15	FCB-15	Units
Rated output DC current	+/-15	+/-15	A
Rated output voltage	36 ^(c)	36 ^(c)	V
Setpoint resolution	≥ 16	≥ 16	bits
RMS current ripple+noise ^(b)	<100	<100	ppm ^(a)
Small-signal bandwidth	N/A	10	kHz

^a With respect to rated current

^b Integrated over the frequency band 0.01 – 1000 Hz

^c Constrained by maximum available input voltage of 40V



Magnet TC Monitoring System

- Magnet TC Monitoring System Requirements

Parameter	Value	Units
Range	20 ~ 45	degreeC
Sensor	K-type	thermocouple
Accuracy	3	degreeC
Channel per sector*	74	Per Sector
Communication	EtherNet/IP	RJ45, 10/100M
Repeatability (supply to supply):	100	ppm
Reproducibility after shutdown:	100	ppm
Output current stability:	100	ppm
Output current ripple (RMS) 0.01 to 1000 Hz	100	ppm

- Additional Scope added to support Diagnostics, Vacuum and Insertion Devices Temperature Monitoring, the installation to be completed during the Darktime.



Power Supply Pre-Installation Testing

QA, Infant Mortality Testing and Calibration

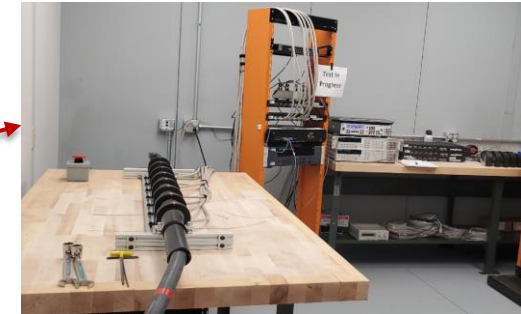
- Receiving Area
- Inspection Area (Not Pictured)
- Raw Power Supplies
- Temperature Elevate Room
- Calibration Room
- Magnet load area



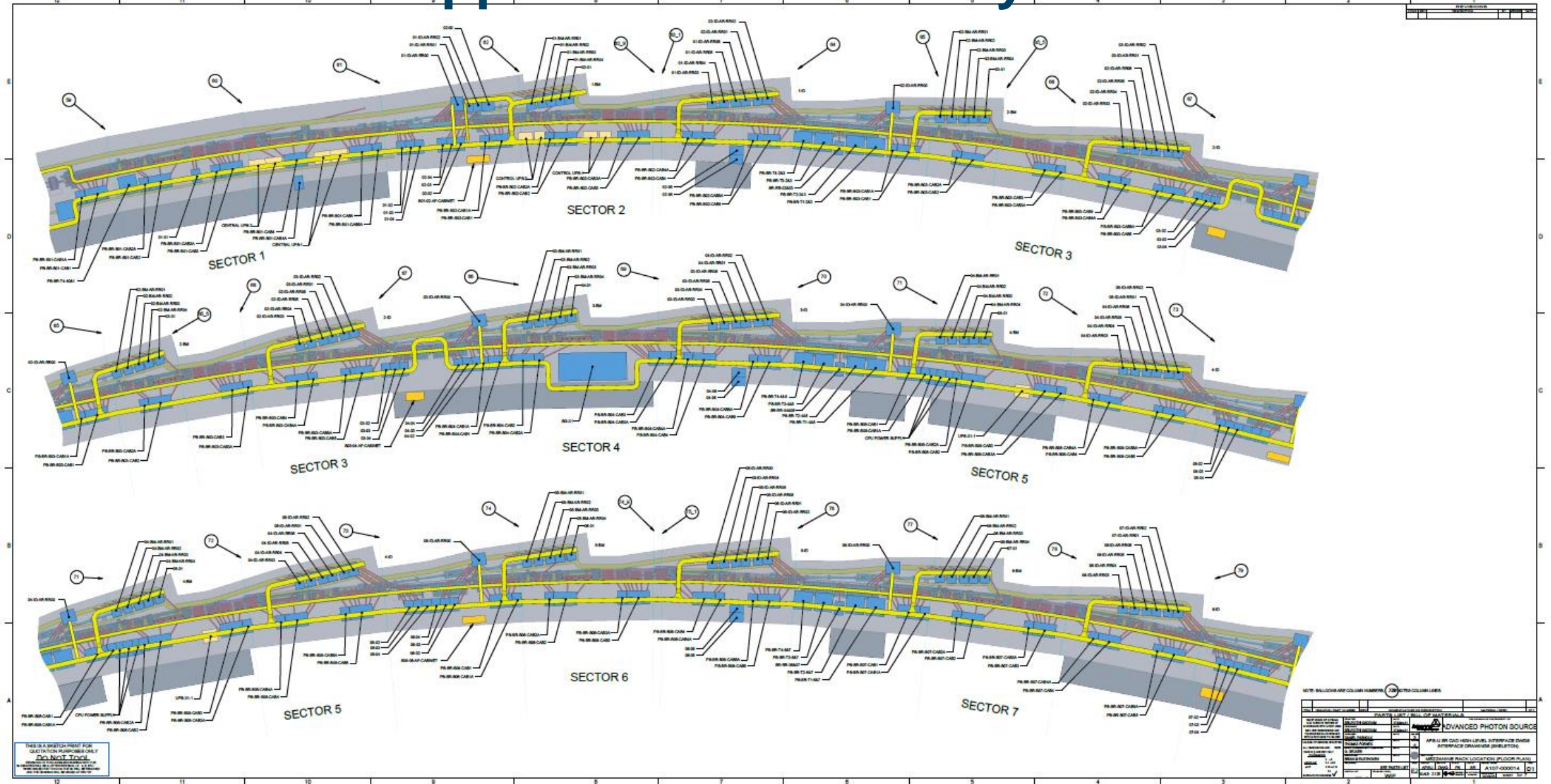
Inside of the Elevate Temperature Room



Raw Power Supplies and Loads

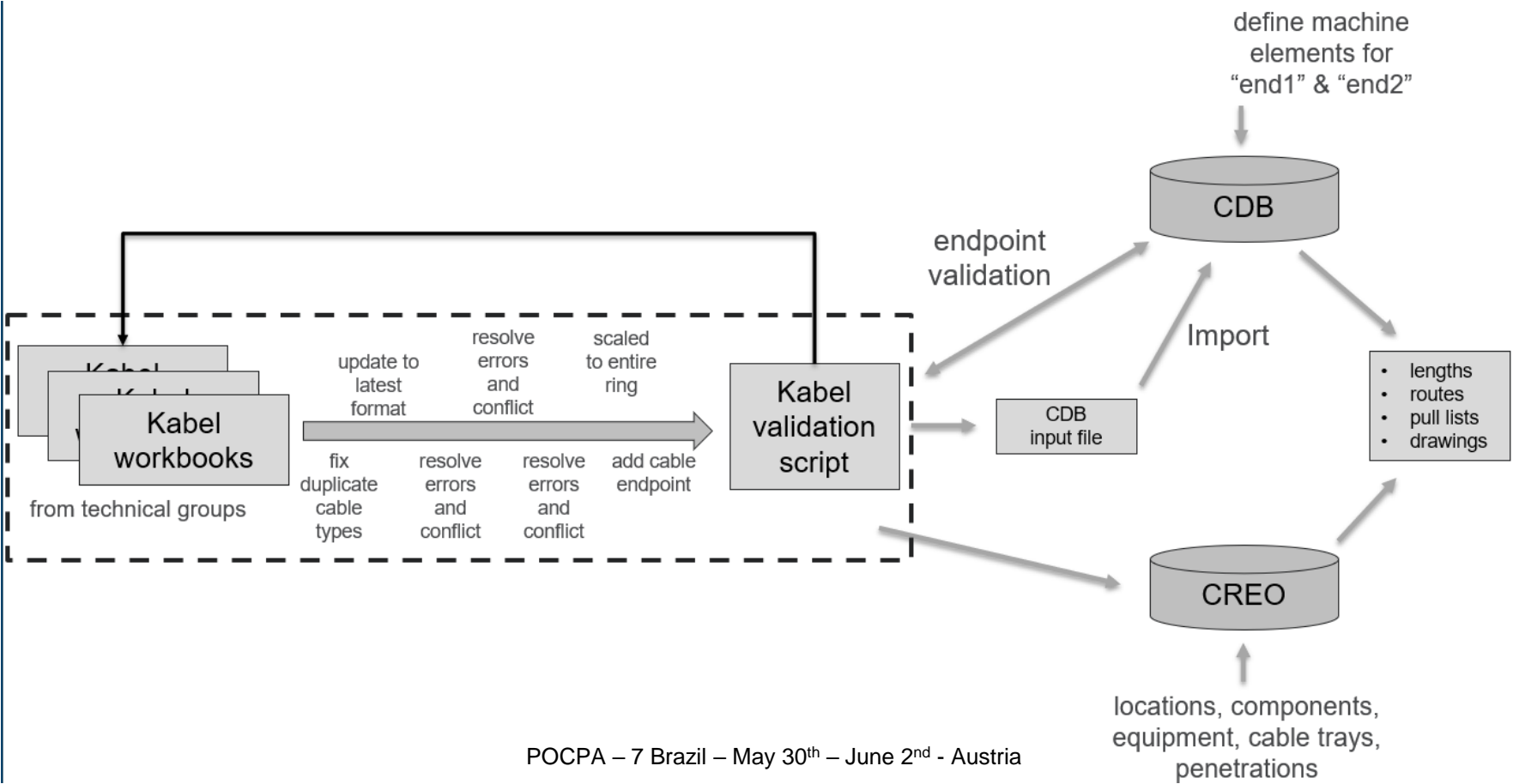


Installation Support - Mezzanine Layout – S01 – S40



Cable Plant Management System

- Cable installation requires data about the facility, as well as information specific to installation
- The APS-U Component Database (CDB) is the universal repository for data about the APS-U facility design, inventory, etc.
- Additional information, needed to describe the installation process, is obtained from the technical groups and maintained by R&I
- An automated process for combining CDB data with other installation data has been determined



Cable Tags identification

The cable number shall follow the following format.

Cable Number – **SF-XXXXXX** where:

SF = System Function (*also identifies the group that owns and is responsible for the cable*)

Examples of the system function identifier are:

PS = Power Supplies **RF** = Radio Frequency **VA** = Vacuum **WA** = Water **IT** = IT

SI = Safety Interlocks **CC** = Controls **DG** = Diagnostics **ID** = Insertion Devices

CT = Controls *Will add more at group requests*

XXXXXX = Number (Sequenced Number, intelligent number, characters or a hybrid)

Number format should be developed by the group owning the system

Number can just be a generated number with no intelligence built in (sequential)

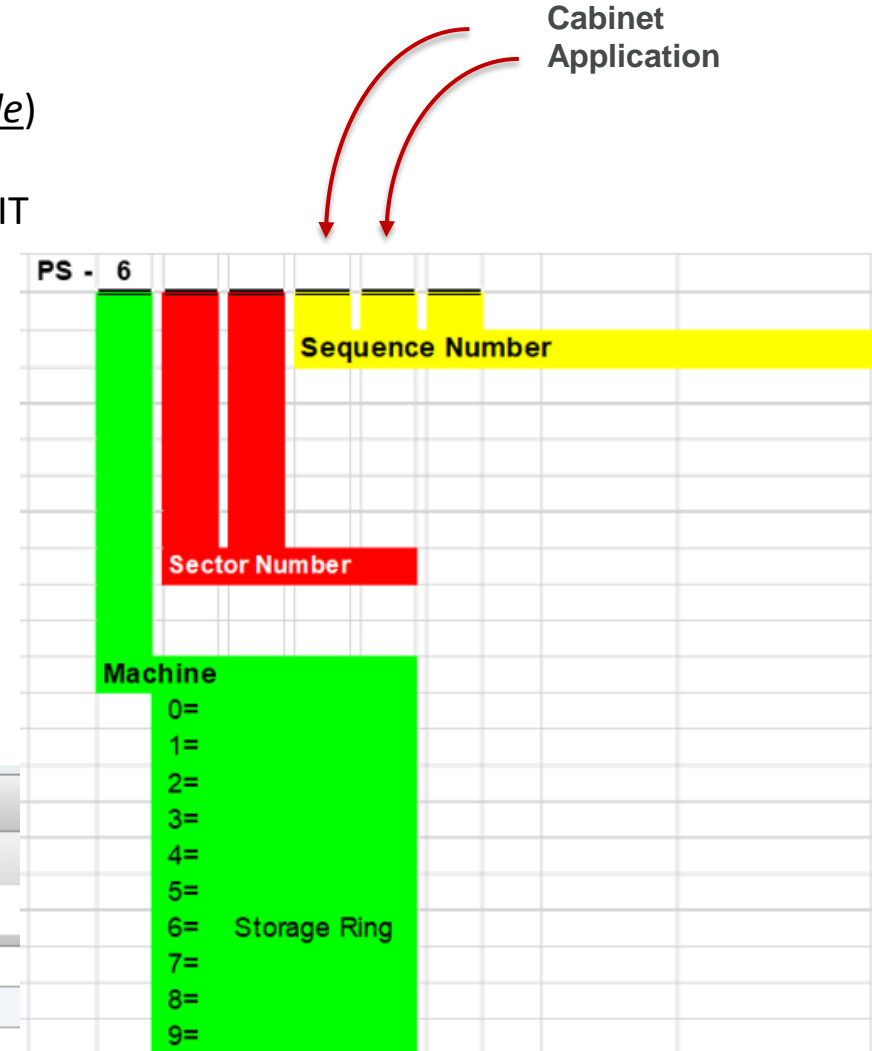
000001, 000002, 000003 or could use the Import Cable ID number

Group specific intelligent number can have logistical meaning to it.

640001, 231054, S40002, 40-004, etc.

Care must be taken to assure legacy numbers are not used

Cabinet Application



Name ↑↓	Primary Image	Technical System ↑↓	Description ↑↓	Endpoints ↑↓
ps-60111		Power Systems		
PS-601111		Power Systems		S01A:S2:PS S01A:S2
PS-601118		Power Systems		S01A:Q1:PS S01A:Q1
PS-601116		Power Systems		S01A:Q2:PS S01A:Q2

Cable Inventory

Argonne NATIONAL LABORATORY Component Database Portal

Username: frafel
Role: User
Reset Session
Jump to: CDB
View: Testbed

Browse Catalog Inventory Design MAARC Search Supplemental Settings Logout About

Cable Design List

★ Display Mode: All

Export

Name	Primary Image	Technical System	Cable Type	Installation Status	End1 Primary Device	End2 Primary Device	Laying	Route	Total Required Cable Length (ft)	End1 Route	End2 Route	Actions
VA-091306		Vacuum	2-9872-150 (Televac CC/QS SR/ID)		S09-TP5:VGC1	S09-TP5:TP1:CCG1	M	09-C59 CT-509-VA . CCG1		09-C59	CT-509-VA . CCG1	
VA-151305		Vacuum	2-9824-150 (Televac Convection SR/ID)		S15-TP5:VGC1	S15-TP5:TP1:CVG1	M	15-C59		15-C59		

Tracked in CDB - Inventory

Cable Inventory Item List

★ Display Mode: All

Export Create Multiple Items Edit Multiple Items

More Info	Cable Catalog Item	Group	Tag	QrId	Serial Number	Primary Image	Location	Housing	Status	Length	Actions
>		VAC	Unit: 0013	000 019 764	SN 406081 STA.1		Pallet-00410	Vacuum Gauge Controller- Televac MX200 - [5788]	Ready For Use		
>		VAC	Unit: 0021	000 019 772	SN 406091 STA.1		Pallet-00410	Vacuum Gauge Controller- Televac MX200 - [5792]	Ready For Use		
>		VAC	Unit: 0005	000 019 756	SN 406077 STA.1		Pallet-00410	Vacuum Gauge Controller- Televac MX200 - [5784]	Ready For Use		
>		VAC	Unit: 0065	000 019 816	SN 406917 STA.1				Ready For Use		
>		VAC	Unit: 0073	000 019 824	SN 407003 STA.1				Ready For Use		
>		VAC	Unit: 0033	000 019 784	SN 406097 STA.1		Pallet-00412	Vacuum Gauge Controller- Televac MX200 - [5798]	Ready For Use		
>		VAC	Unit: 0081	000 019 832	SN 407008 STA.1				Ready For Use		
>		VAC	Unit: 0041	000 019 792	SN 406317 STA.1		Pallet-00223	Vacuum Gauge Controller- Televac MX200 - [6083]	Ready For Use		
>		VAC	Unit: 0049	000 019 800	SN 406460 STA.1		Pallet-00223	Vacuum Gauge Controller- Televac MX200 - [6087]	Ready For Use		
>		VAC	Unit: 0057	000 019 808	SN 406888 STA.1				Ready For Use		
>		VAC	Unit: 0006	000 019 757	SN 406077 STA.2		Pallet-00410	Vacuum Gauge Controller- Televac MX200 - [5784]	Ready For Use		
>		VAC	Unit: 0014	000 019 765	SN 406081 STA.2		Pallet-00410	Vacuum Gauge Controller- Televac MX200 - [5788]	Ready For Use		
>	150' 4A Rad Resist Cable	VAC	Unit: 0022	000 019 773	SN 406091 STA.2		Pallet-00410	Vacuum Gauge Controller- Televac MX200 - [5792]	Ready For Use		
>		VAC	Unit: 0066	000 019 817	SN 406917 STA.2				Ready For Use		

150' 4A Rad Resist Cable - [Unit: 0013]

Tag Unit: 0013

QR Id 000 019 764

Cable Catalog Item [150' 4A Rad Resist Cable](#)

Serial Number SN 406081 STA.1

Project APS-U Production

Description Storage Ring

Location

- Pallet-00410
 - 981-S5-G-11-D2
 - 981-S5-G-11-D
 - 981-S5-G-11
 - 981-S5-G
 - 981-Racks
 - 981

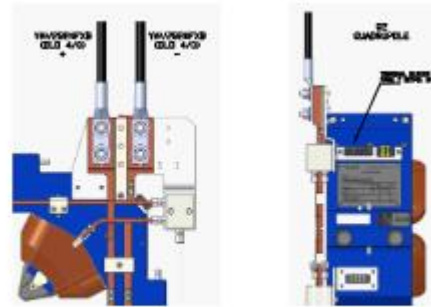
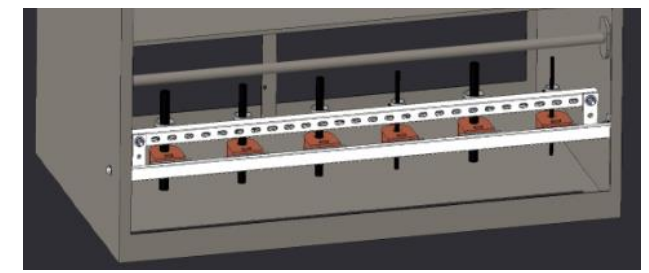
Location Details Assigned to assembly

Housing [Vacuum Gauge Controller- Televac MX200](#)

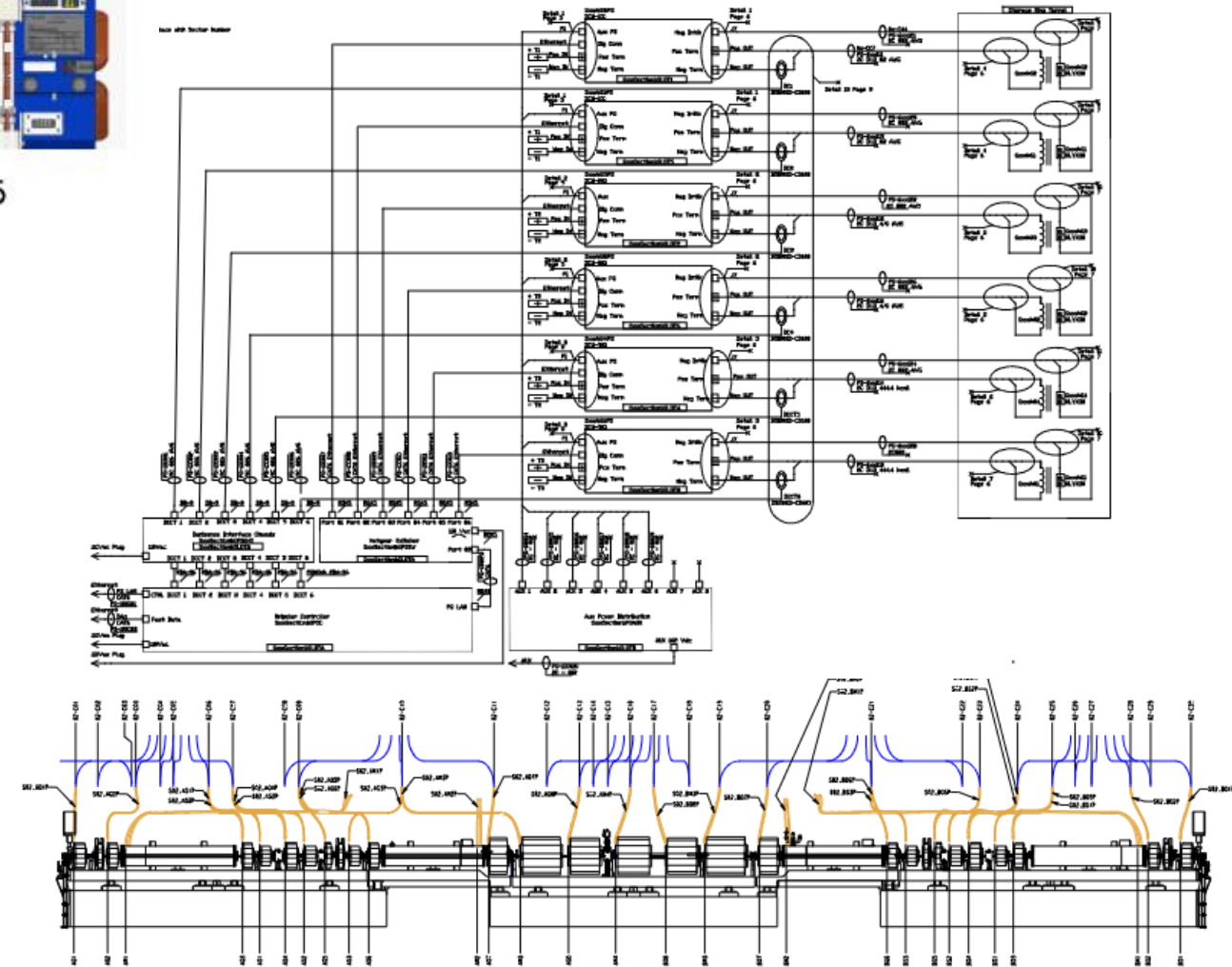
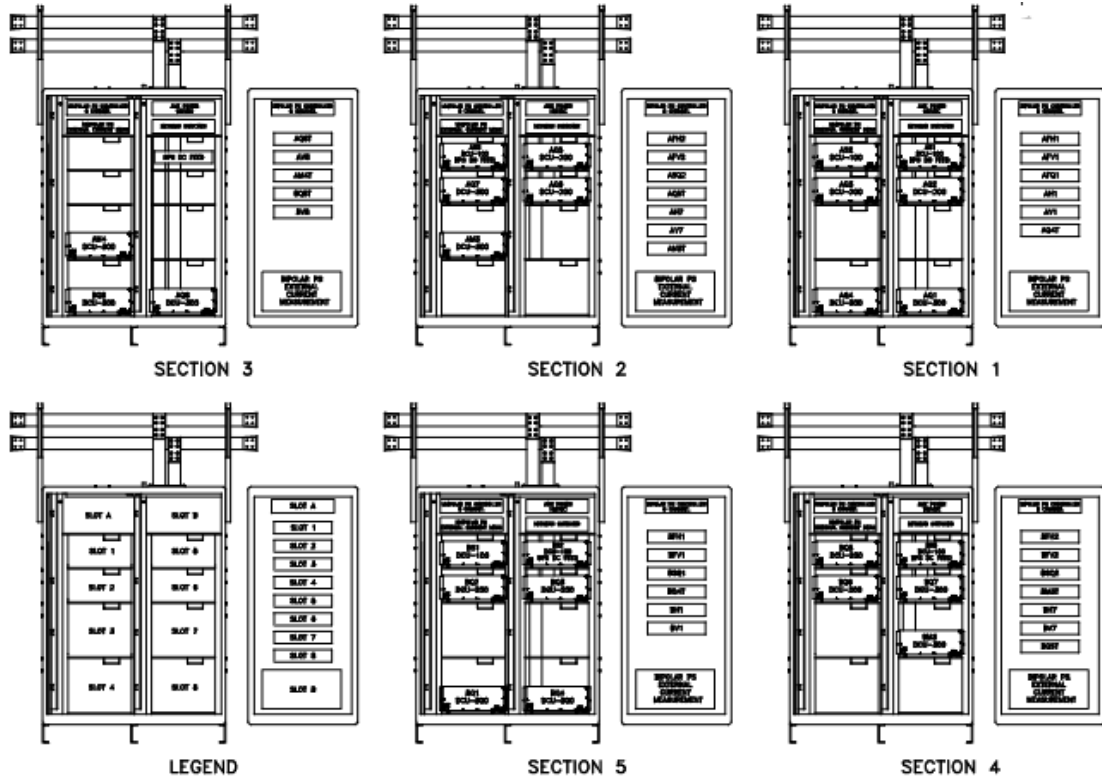
Status Ready For Use

Power Supplies Installation Drawings

- Mechanicals (Tunnel)
- Rack Layouts (Mezzanine)
- Interconnect Diagrams
- Detail Installation Instructions



DETAIL 5



Checkouts - A-priori component testing

- All power supply components undergoes extensive testing prior to installation
- Functionality and performance are verified during acceptance testing

Procurement model	Components	Component testing
Procured to spec	<ul style="list-style-type: none"> • L-bend power supplies • Unipolar power supplies • Unipolar PS external monitoring 	<ul style="list-style-type: none"> • Functionality and performance are verified during factory acceptance testing prior to shipping and then confirmed during site acceptance and extended duration tests in 400A
In-house design, built to print by outside fabrication house	<ul style="list-style-type: none"> • Fast corrector bipolar supplies • Slow DC trim bipolar supplies • Bipolar PS controllers • Unipolar PS controllers • Bipolar PS external monitoring 	<ul style="list-style-type: none"> • Functionality and performance are verified in-house during testing of prototype units and confirmed during production acceptance tests in 400A PS test area
In-house controls application development	<ul style="list-style-type: none"> • Controls IOCs, medm screens • PS DAQ • High-level apps 	<ul style="list-style-type: none"> • New controls apps are test on the accelerator simulation server ('Weed')

Framework for integrated checkout of unipolar PS in a double sector

Components that make up the subject of the test

Elements that must be in place to perform each step of the checkout

		Checkout sequence						
		Configure controllers	Checkout PS electronics	EPICS/controls interfaces	Validate ps interlocks	Checkout PS with magnet	Check magnet polarities	24-hr Full-power test
Magnet PS Components	Unipolar ps	Control power energized	Control power energized	Control power energized		Running at lower current	Running at lower current	Running at full current
	PS Raw supplies					Energized	Energized	Energized
	Unipolar ps controller	Required	Required	Required		Required	Required	Required
	PS External monitoring		Required	Required		Required	Required	Required
	PS interlocks PLC				Required for checkout	Made up - with jumpers as needed	Made up - with jumpers as needed	Made up - with jumpers as needed
IT	IT networks / computing	Aceelerator networks	Aceelerator networks	Aceelerator networks		Aceelerator networks	Aceelerator networks	Aceelerator networks
	EPICS infrastructure			Required		Required	Required	Required
Controls	PS IOCs			Required		Required	Required	Required
	Controls DAQ / PS aggregator							Requested
	Controls data logging							Required
FMS	AC POWER (120/208V)	Required on mezzanine	Required on mezzanine	Required on mezzanine	Required on mezzanine	Required on mezzanine	Required on mezzanine	Required on mezzanine
	AC POWER (480V 3ph)					480v power to PS Raws	480v power to PS Raws	480v power to PS Raws
MOM	Mezz. cooling					Capacity to handle nominal heat load	Capacity to handle nominal heat load	Capacity to handle full heat load
	In-tunnel cooling					Capacity to handle nominal heat load	Capacity to handle nominal heat load	Capacity to handle full heat load
	Magnets				Klixons	Required	Required	Required
MCR	SR tunnel access					Restricted access to areas under test	Restricted access to areas under test	Restricted access to areas under test

Required components/systems and ownership

120V AC power only
 Testing on mezzanine only, tunnel open
 480V 3-ph AC power
 Tunnel (partially) closed
 POCPA – 7 Brazil – May 30th – June 2nd - Austria

Framework for integrated checkout of unipolar PS in a double sector



ts/systems and ownership

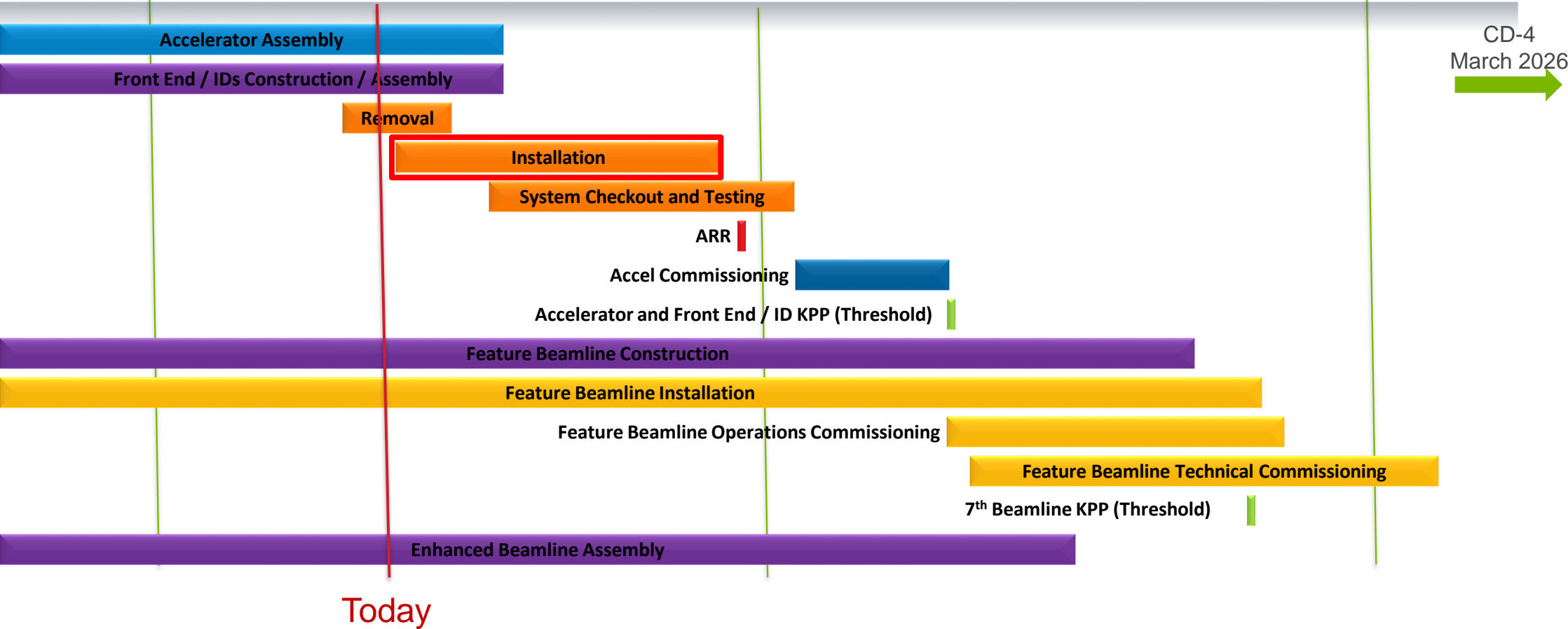
		Configure controllers	Checkout PS electronics	EPICS/controls interfaces	Validate ps interlocks	Checkout PS with magnet	Check magnet polarities	24-hr Full-power test
Magnet PS Components	Unipolar ps	Control power energized	Control power energized	Control power energized		Running at lower current	Running at lower current	Running at full current
	PS Raw supplies					Energized	Energized	Energized
	Unipolar ps controller	Required	Required	Required		Required	Required	Required
	PS External monitoring		Required	Required		Required	Required	Required
	PS interlocks PLC				Required for checkout	Made up - with jumpers as needed	Made up - with jumpers as needed	Made up - with jumpers as needed
IT	IT networks / computing	Aceelerator networks	Aceelerator networks	Aceelerator networks		Aceelerator networks	Aceelerator networks	Aceelerator networks
PLS	EPICS infrastructure			Required		Required	Required	Required
	PS IOCs			Required		Required	Required	Required

Schedule – Look Ahead to Completion

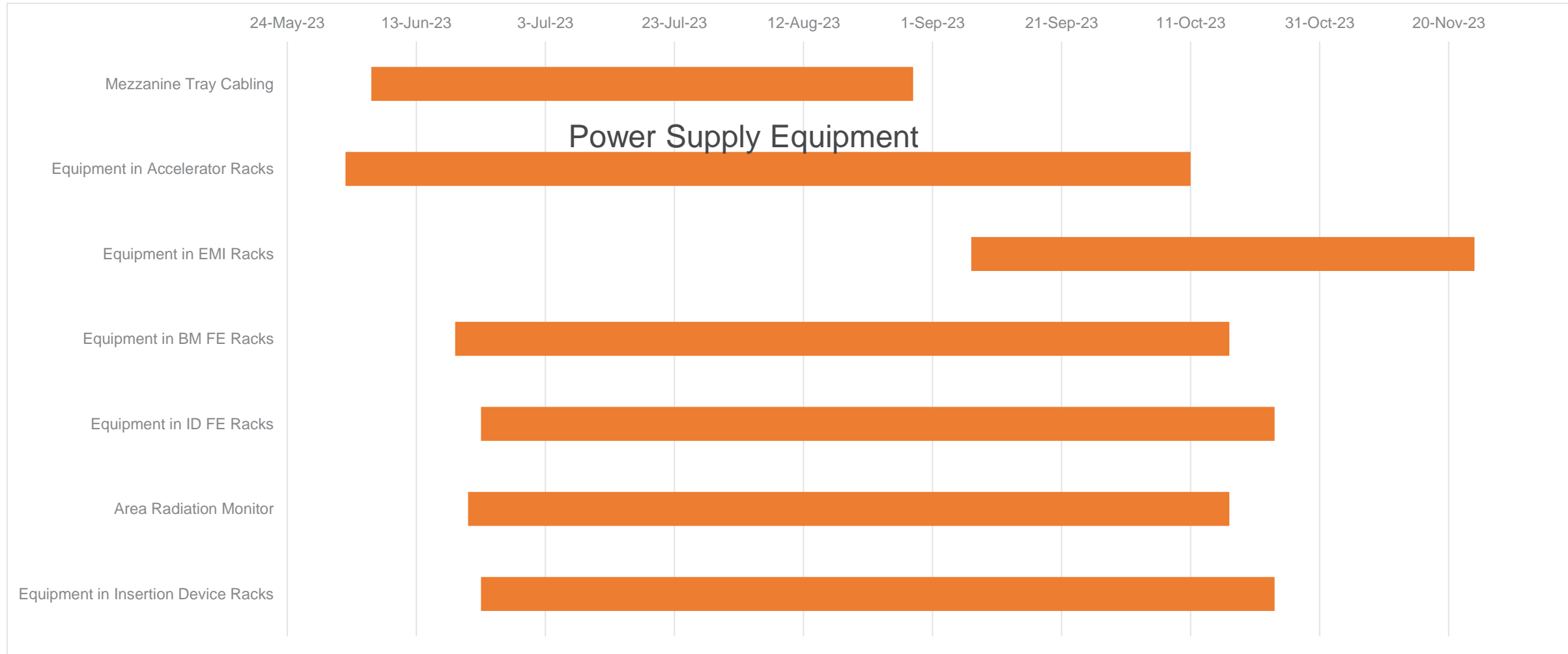
2022

2025

Oct 2023 | Apr 2023 | Jul 2023 | Oct 2023 | Oct 2024 | Apr 2024 | Jul 2024 | Oct 2024 | Oct 2025

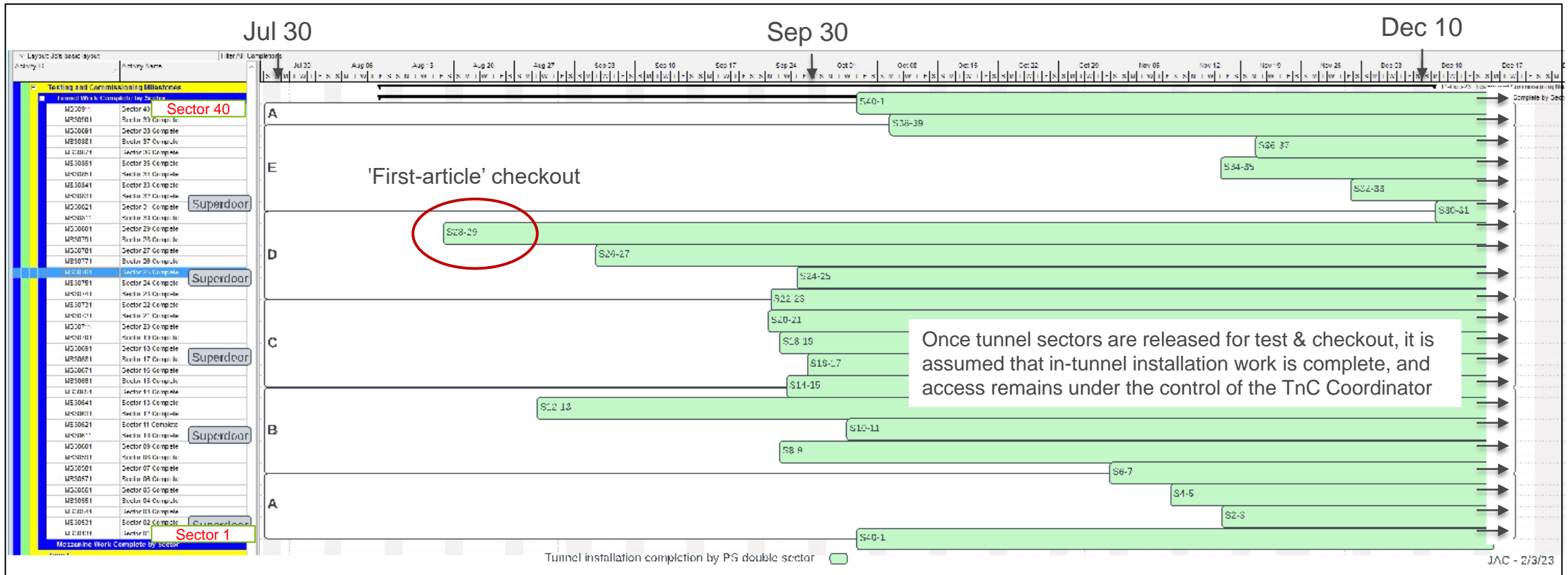


Mezzanine Schedule



SR tunnel double-sector availability for test & checkout

- Green bars indicate periods when in-tunnel work will be complete for each power supply double-sector pair and they can be released for test & checkout.
- Access to the sectors under test will be restricted using barricades, warning lights, and signage



Dates from R&I P6 (2/1/23)

Lessons Learned

- Mix performance from Contractors/Vendors
 - Some Vendors will delay deliveries intentionally to force you to accept their product as is
 - Pay special attention when ordering components from offshore companies (line voltage and frequency)
- Order as many components as possible during LLP
 - Procurement get very slow as project moves to acquisition phase
- Our engineers are not trained/qualified for mass production design
 - Get a good Vendor involved in the early design phase.
- Safety
- Test Acceptance

APS Power Supply Group



Backup Slides

