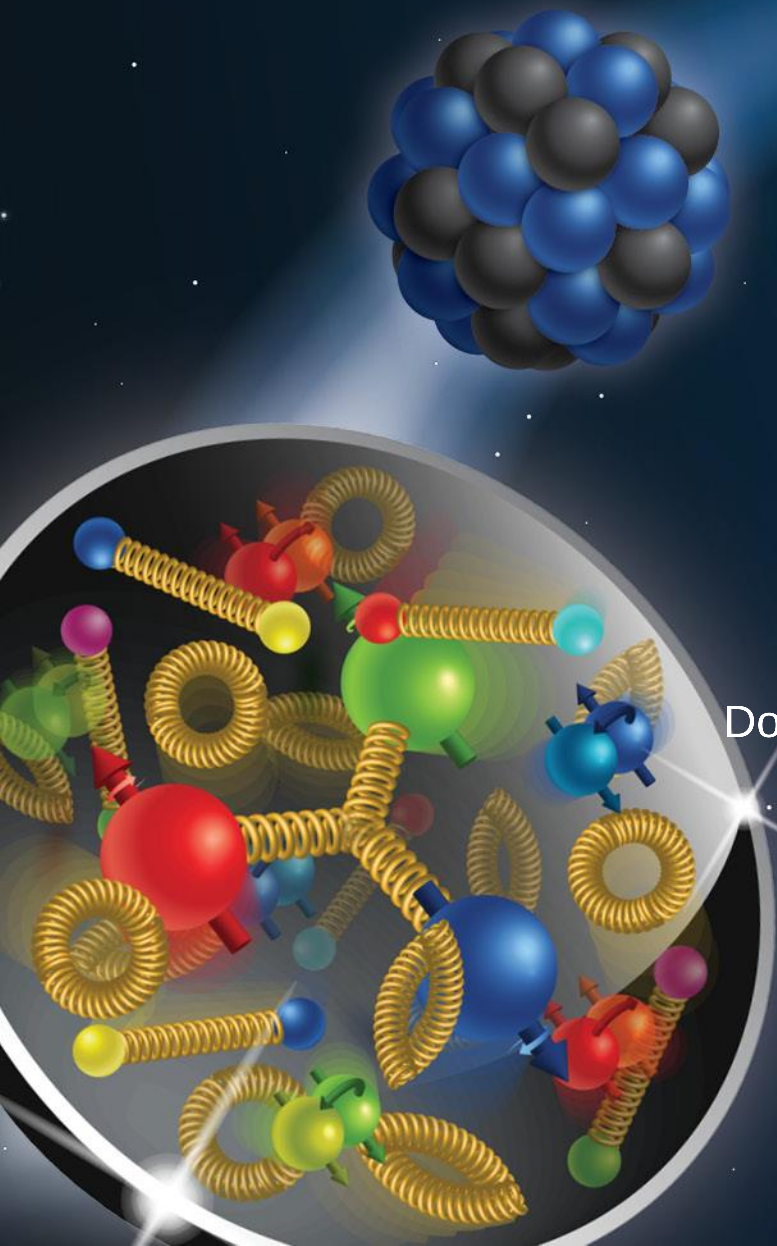


EIC Power Supplies
POCPA 2023

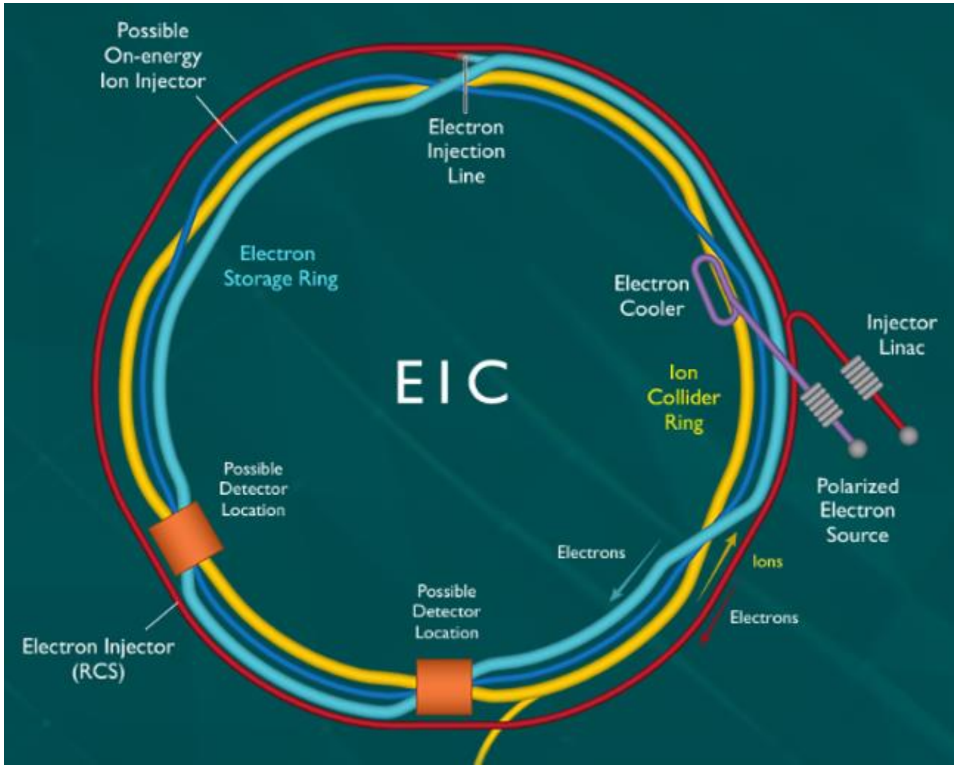
Don Bruno, Bob Lambiase, Ioannis Marneris, Ed Bajon

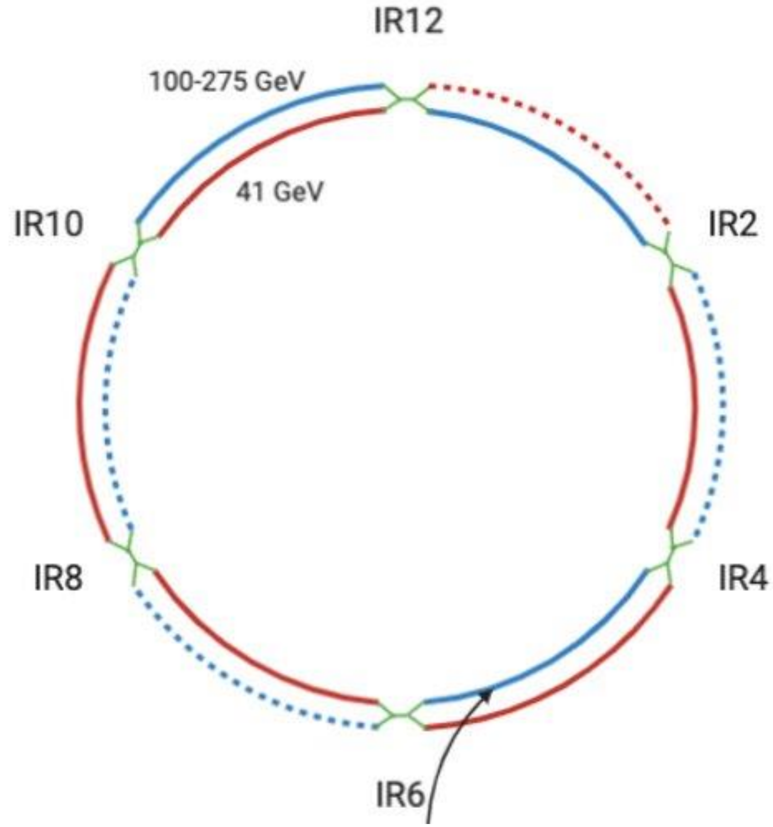
5/31/23 – 6/2/23

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY | Jefferson Lab | U.S. DEPARTMENT OF ENERGY | Office of Science

Scope Overview





Outline

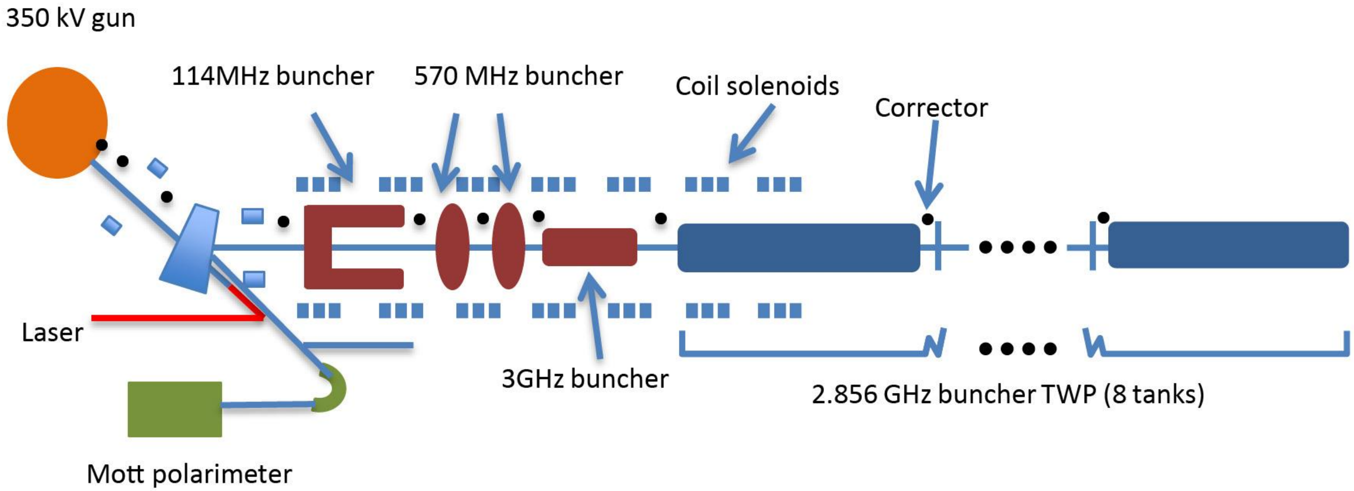
- PS Systems
  - 400MeV Injector –Gun to Linac PS's (Install 2028)
  - 400MeV Injector to (RCS) Rapid Cycling Synchrotron (Install 2028)
  - RCS (Install 2028)
  - RCS-ESR (Electron Storage Ring) (Install 2028)
  - ESR (Install 2029-2030)
  - Hadron Ring Modifications Injection (Install 2029-2031)
  - Hadron Ring Low Energy Bypass + (Install 2029-2031)
  - IR (Interaction Region) (Install 2032-2033)
  - SHC (Strong hadron Cooling) (Install 2033)
- Areas of Concern
- Conclusion

Power Supply Machine Sections

Hadron Storage Ring, HR Injection, Low Energy Bypass

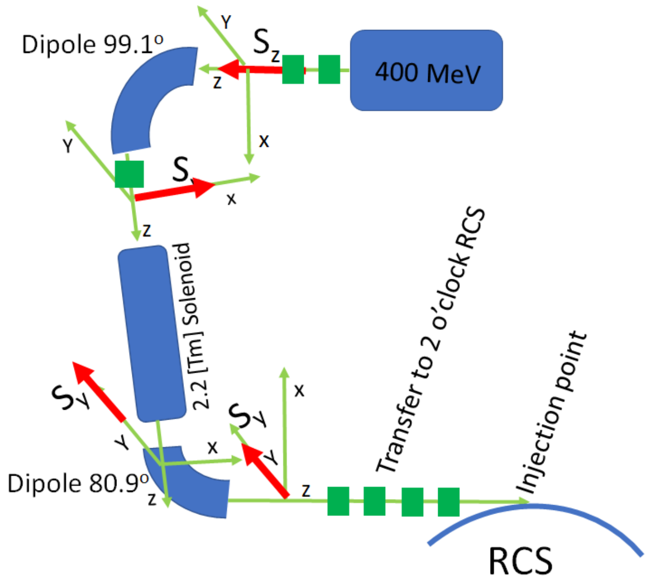
- The Hadron Storage Ring (old yellow ring) will use the existing RHIC Power Supplies – except for the RHIC Main Dipole and Quad PS's- New PS's will be purchased for RHIC Yellow Mains
  - IR ps's
  - Sextupole ps's
  - Corrector ps's
  - Gamma-T ps's
- The inner arc (old blue) for HR Injection Transport, the Low Energy bypass and between 10:00 and 12:00, and between 2:00 and 12:00 will still be using some of the RHIC Power Supplies
  - IR ps's
  - Sextupole ps's
  - Corrector ps's
- Warm Injection line - must jump over the yellow arc to get to the the blue arc
  - Old Warm Injection line ps's + new ps's
- These have been maintained and some have been upgraded

Gun to 400MeV Linac – DC Supplies



400MeV Injector PS	Manufacturer	Power	Qty	Topology
High Voltage Gun PS	Glassman	5.4kW	1	COTS SwMode Voltage Multiplier
Dipole, Solenoid and Quad	Lambda	1.5kW-15kW	66	COTS SwMode, DCCT FWD Chassis
Medium Corrector PS	CAEN FAST-PS	200W-400W	72	Custom SwMode Bulk DC, 4 Chan
Small Corrector PS	Cbeta Sigma Phi	24W	13	Custom SwMode Bulk DC, 12 Chan
Helmholtz Coil PS	kepco	1kw-2kw	3	COTS Single Channel SwMode
		Total	**155**	

400MeV Injector to RCS Transfer line- DC Supplies



400MeV-RCS	Manufacturer	Power	Qty	Topology
Quads and Dipoles	Lambda	2kW-8kW	16	COTS SwMode, DCCT FWD Chassis
Correctors	CAENS	64W	14	Custom SwMode Bulk DC, 4 Chan
Solenoid	Not This Scope			
		Total	**30**	

RCS Waveform

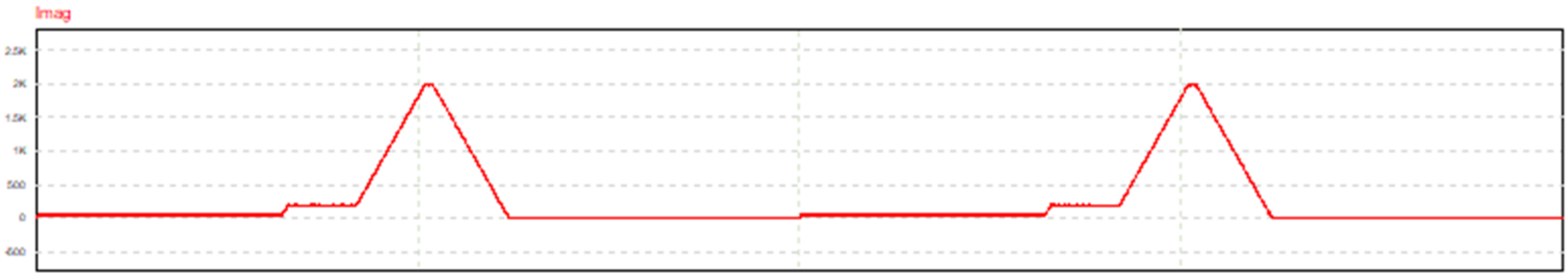
All these supplies will produce pulsed current with rise and fall times of 100 msec.

- Flattop of 20 msec, for 18GeV
- Flattop of 270 msec for 5 GeV.

There will be two front porches in the current of every power supply.

- The first front porch will at 400 MeV for 320 msec.
- The second front porch will be at 1.8GeV for 90 msec.

The repetition rate will be 1 Hz.



RCS Reference: Ioannis Marneris

RCS PS Types

All power supplies will be switch mode four quadrant.

The topology of all of the RCS power supplies is still being investigated

- Interleaved H bridge?
- Multi level Converter?

Each RCS power supply will have a capacitor bank from where energy is drawn from when the magnets are pulsing.

Possibility of a front-end power regulator which will maintain the input average power constant and will stop charging the capacitor bank when the required capacitor voltage is reached.

See Ed Bajon talk for more details.

RCS Power Supplies

100 msec rise time, copper cable, 18 GeV 2 Dipole supplies						
		Power	**PS**	**PS**	**Cap**	**Cap Bank**
Power supply name	**Magnets/ps**	**supplies**	**AMPS**	**VOLTS(+/-)**	**Bank (F)**	**Volts**
Dipole1	192.00	**1.00**	2000	1800	0.3	2300
Dipole2	192.00	**1.00**	2000	1800	0.3	2300
QD	180.00	**1.00**	1100	2300	0.3	2600
QF	174.00	**1.00**	1100	2300	0.3	2600
QD0 to QD8	8.00	**9.00**	1100	500	0.15	700
QDI0 to QDI8	4.00	**9.00**	1100	300	0.15	500
QF1 to QF7	8.00	**7.00**	1100	500	0.15	700
QFI1 to QFI7	4.00	**7.00**	1100	300	0.15	500
QF8	4.00	**1.00**	1100	500	0.15	700
QDI9	2.00	**1.00**	1100	300	0.15	500
SX1, SX2, SX3, SX4	90.00	**4.00**	720	600	0.2	700
CH1 to CH276, CV1 to CV552	1.00	**828.00**	10	50	0.1	140
Total power supplies	**869.00**					
Total Dipole magnets	**192.00**					
Total Quad magnets	**546.00**					
Total Sextuple magnets	**360.00**	Circumferance of RHIC 2.4606 miles or 3.96 Km				
Total Correction magnets	**558**	1 mile is 5280 feet				

RCS Reference: Ioannis Marneris

RCS-SR transfer line

RCS-SR	Manufacturer	Power	Qty	Topology
Quads	Lambda	5kW	14	COTS SwMode, DCCT FWD Chassis
Small Dipole String	Lambda	10kW	2	COTS SwMode, DCCT FWD Chassis
Large Dipole String	APS	28kW	1	Custom Interleaved H-bridge
H,V Correctors	CAEN	600	20	COTS SwMode 1 Chan
		Total	**37**	

ESR ps's - overall ps's

ESR	Manufacturer	Power	Qty	Topology
D1/D3	APS	3.64MW	1	Custom Interleaved H-bridge
D2	APS	5.6MW	1	Custom Interleaved H-bridge
Arc Quads, Arc Sext	APS	30kW-176kW	24	Custom Interleaved H-bridge
Straight Quads, Sext	Lambda	2.7kW-10kW	186	COTS SwMode, DCCT FWD Chassis
Slow, Fast Correctors	CAEN	150W-200W	452	Custom SwMode Bulk DC, 4 Chan
		Total	**664**	

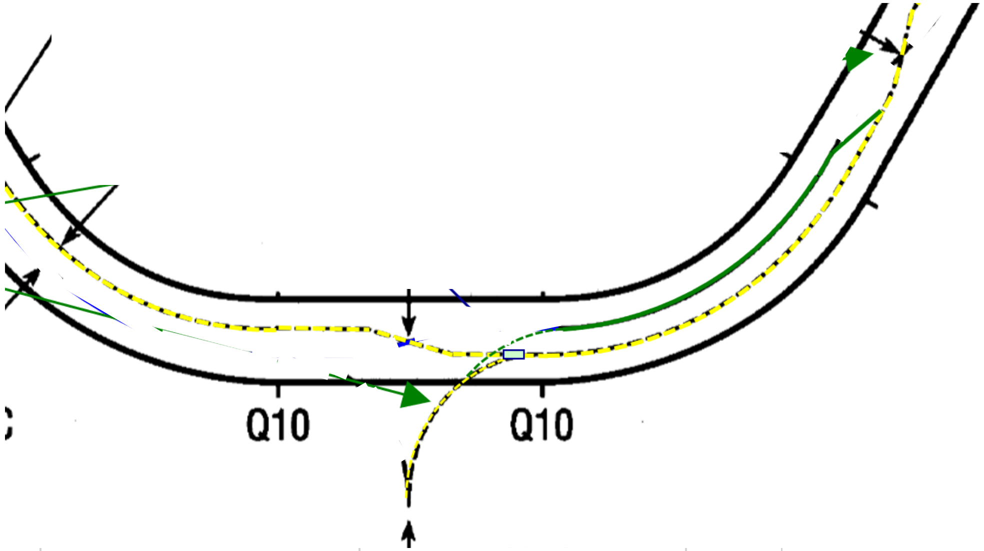
The Electron Storage Ring (SR) – Main Dipoles

The storage ring (SR) is operated DC. The main dipoles in the SR are implemented as 252 triplets. The outer dipoles, D1 and D3, are connected in series throughout the entire ring, and operates at 5,200A. The inner dipoles, D2, are also operated in series throughout the ring, and operates at 7,027A. D2 must also be bipolar, but this is not a burden for the proposed technology (interleaved H-bridge).

Unlike RHIC, where the main currents are distributed around the ring using superconductor, these warm magnets will be powered with warm conductors. To keep the power in the bus to about 3 MW for each circuit, water cooled copper bus, with area 6.25 in^2 is chosen.

The ring is about 4km around or 8km round trip. Because this bus must go around the experimental areas and up to the equipment house, 10.5km is used.

Injection Transport – 6:00 Side of 4/5 – Warm Line



Injection Transport	Manufacturer	Power	Qty	Topology
Quad, Dipoles	Lambda	5kW-25kW	6	COTS SwMode, DCCT, FWD Chassis
Dipoles	APS	38.5kW	2	Custom Interleaved H-bridge
Correctors	CAEN	600W	6	COTS SwMode 1 Chan
		Total	**14**	

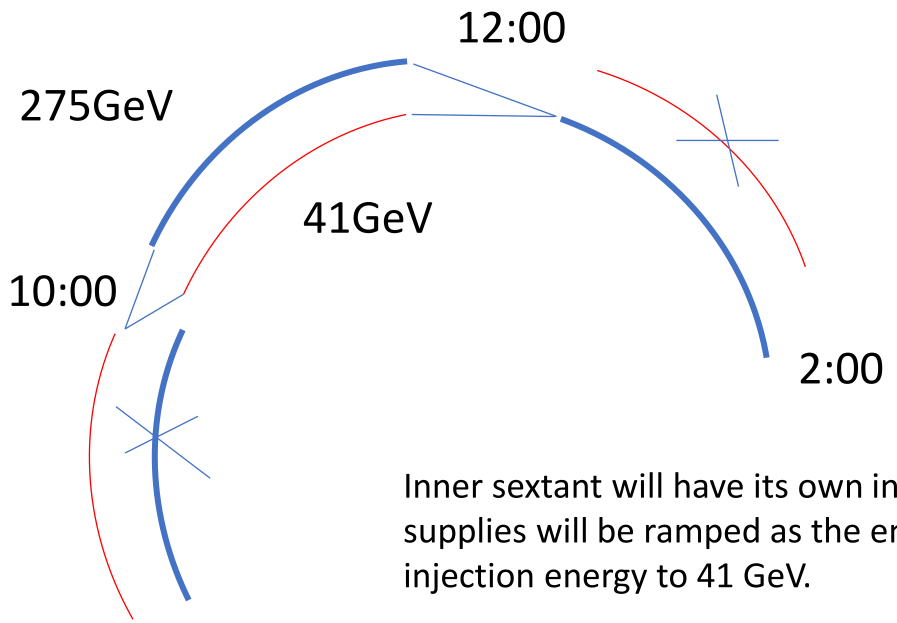
Main Dipole & Quad	APS	12kW	2	Custom Interleaved H-bridge
H/V Offset	kepco	1kW	1	COTS Single Channel SwMode
		Total	**3**	

Injection Transport – 4:00 Side of 4/5 – Warm Line

The beam is transferred from the outer ring to the inner ring in a warm transfer line. The power supplies for that line are shown below. The fast kicker magnets are not part of this scope.

4:00 Warm Line	Manufacturer	Power	Qty	Topology
Quads, Dipole	Lambda	10kW	4	COTS SwMode, DCCT, FWD Chassis
Septum-DC	APS	235kW	1	Custom Interleaved H-bridge
		Total	**5**	

Low Energy Bypass - Overview



Red = Yellow

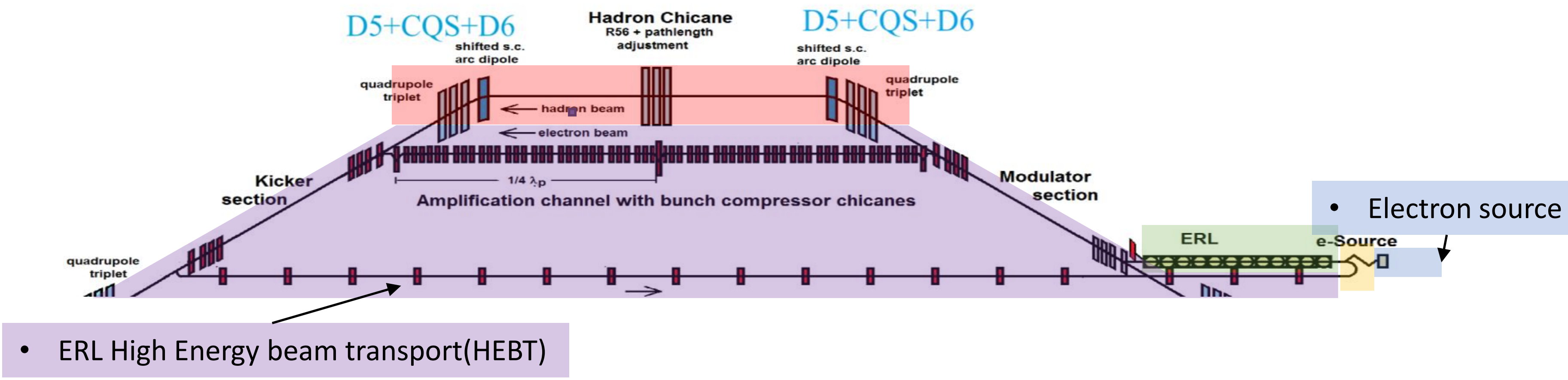
Inner sextant will have its own independent set of power supplies. The power supplies will be ramped as the energy in the sextant is accelerated from injection energy to 41 GeV.

DX magnets are removed, the SC D0 magnets will be removed and replaced with Warm D0 magnets which are independently powered.

Cold diode reversal is required in order to protect a quenching magnet since the current flow has been reversed through the magnets of the inner ring for 41GeV

Low Energy Bypass	Manufacturer	Power	Qty	Topology
Main Dipole & Quad	APS	336kW	2	Custom Interleaved H-bridge
H/V Offset	CAEN	4.3kW	1	COTS Single Channel SwMode
Switching Magnet	APS	60kW	2	Custom Interleaved H-bridge
		Total	**5**	

SHC layout



SHC	Manufacturer	Power	Qty	Topology
Sol, Chicane, Dipole, Quad	Lambda	2.7kW-15kW	118	COTS SwMode, DCCT FWD Chassis
Corrector, Trims	CAEN	200W	156	Custom SwMode Bulk DC, 4 Chan
Hi V DC Gun		90kW	1	Cockroft Walton Voltage Multiplier
		Total	**275**	

High Voltage Power Supply - reviewing RFP now

Nominal Output Voltage Vout	600kV
Nominal Output Current Iout	150mA
Voltage Accuracy	1% V out
Voltage Stability (long term)	0.1 % pp V out
Risetime	Voltage rise slow (not critical), Current rise immediate @ Vout
Overshoot	1% Vout (no load only)
Ripple Voltage	0.1 % pp Vout
Energy into Arc	<10 J
Operation Mode	CW
Efficiency	80%
Power Factor	> 0.9
Gas	SF6 Gas Isolation
Load	Electron gun that acts as a current sink
Location	Brookhaven National Laboratory, NY, USA
Mains supply voltage	3 phase 480Vrms
Frequency	60Hz
Cooling	Air and or water
Water Cooling Pressure inlet	100psi-200psi
Water Cooling T inlet	35C
Water Cooling T outlet	55C max
Area available	L=15ft, W=15ft, H=15ft
Site Location	Indoor, Building
Manufacturer Testing	No load and full load testing required, Factory Testing and accecptance
On site requirements	Require the manufacturer to assist with onsite installation and testing
Remote Interface	Ethernet, Alternates will be considered

6:00 IR PS and Quench Protection

Both the electrons and hadrons will use superconducting magnets at IR6. Each magnet load is independently powered.

- High current, high energy – There are four magnets which will be powered at the 12-15kA level with energies in the MJ range. These will require quench protection and energy extraction resistors. These are 1.2kA paralleled switchode ps.
- Low current, medium energy – There are five magnets that will be powered in the 100-500A level with energies up to 120kJ.
- Low current, low energy – There are eight magnets that will be powered in the 35-500A level with low stored energy. These will be protected with overvoltage sensing and clamping, as is done with the RHIC correctors.

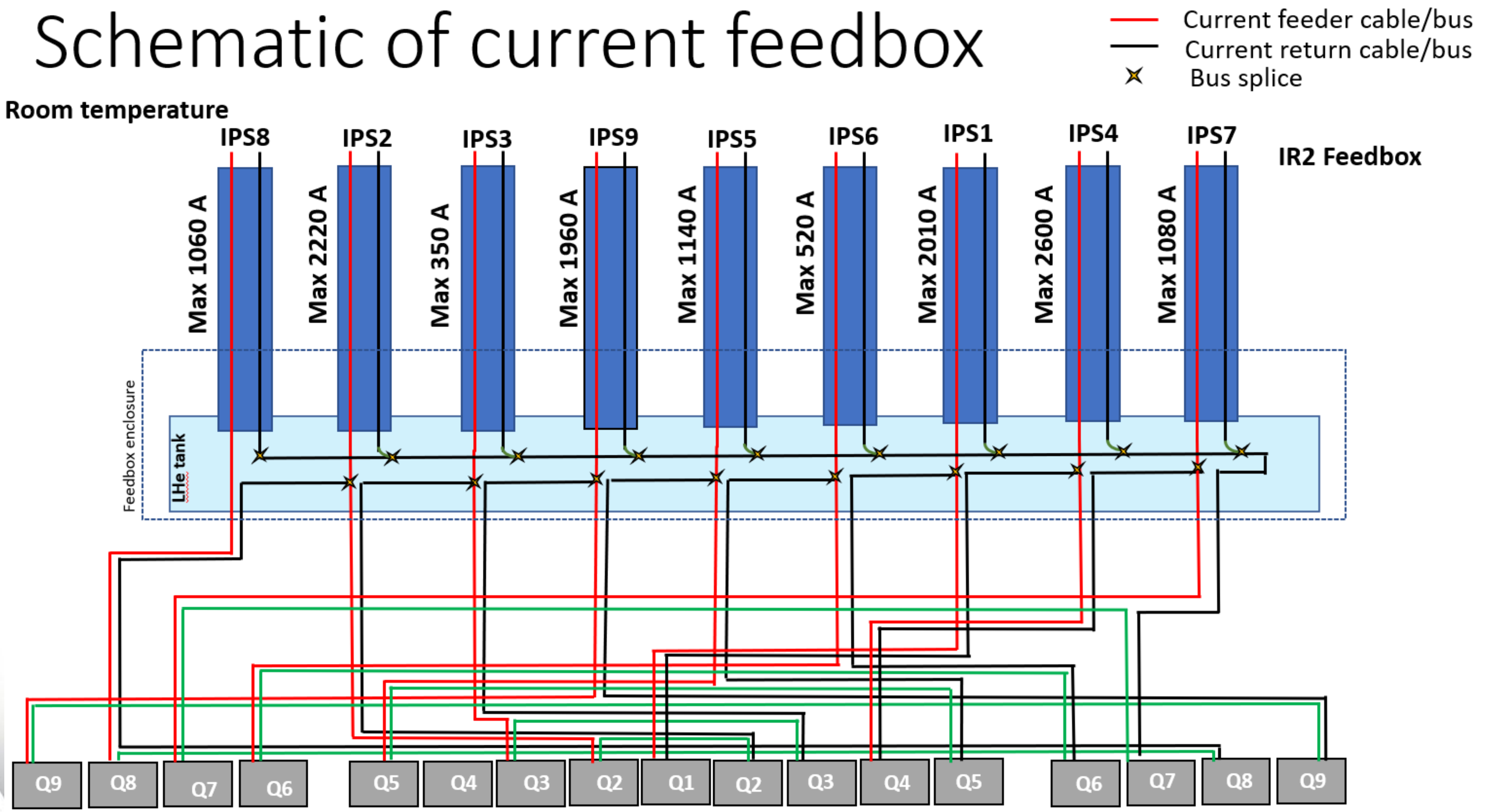
Power to all of these magnet loads will be by copper cables or water cooled bus.

IR	Manufacturer	Power	Qty	Topology
High Current, High Energy	OCEM	120kW	4	1.2kA Paralled Switchmode
Low Current, Med Energy	Lambda	5kW	5	COTS SwMode, DCCT FWD Chassis
Low Current, Low Energy	Lambda	5kW	8	COTS SwMode, DCCT FWD Chassis
Spin Rotator	Lambda	2.4kW	16	COTS SwMode, DCCT FWD Chassis
		Total	**33**	

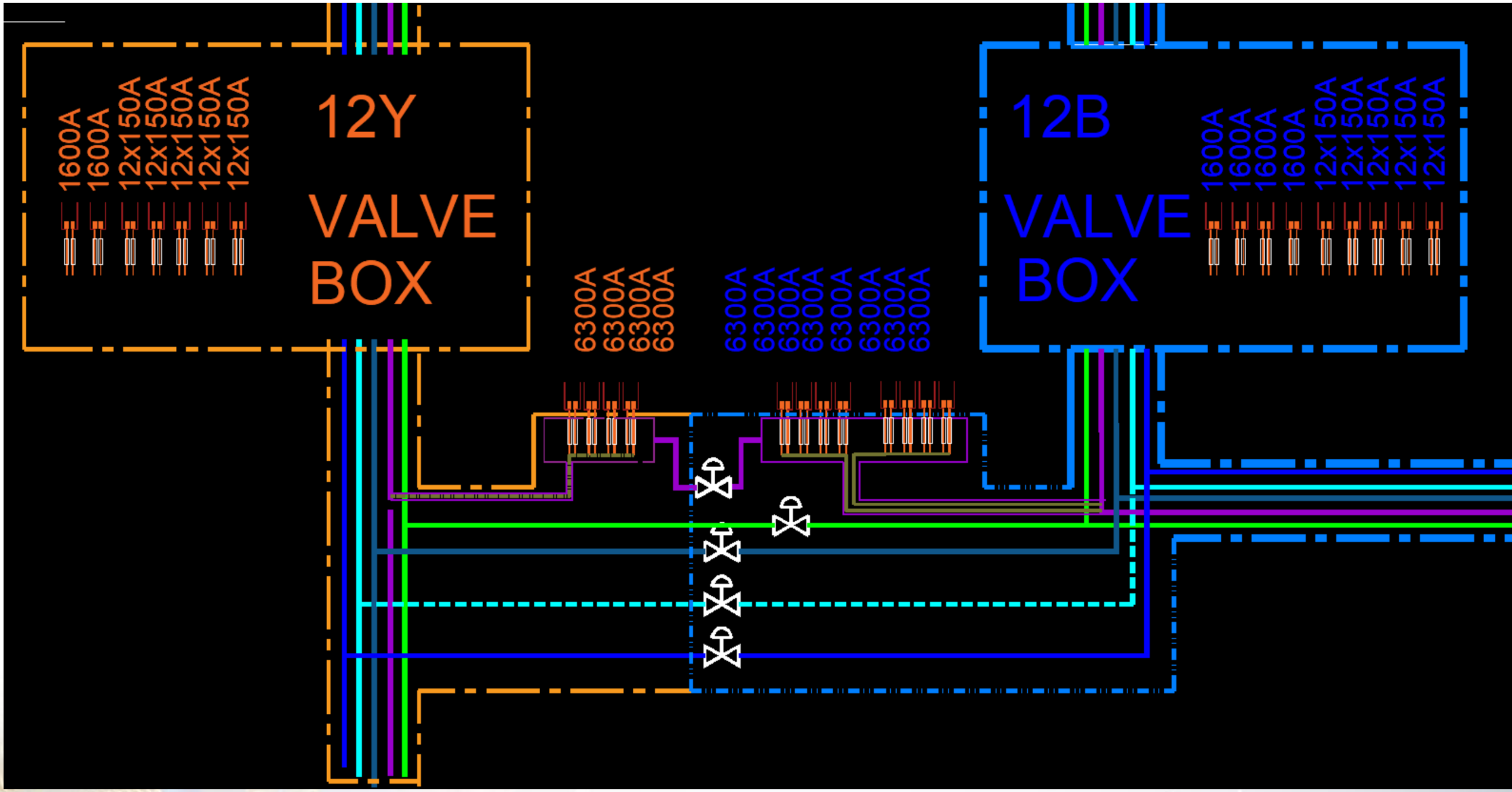
Hadron Ring – Cold Crossing Bus Elements

The two CCB cables (one dipole, one quad) start at the valve boxes in the equipment houses outside the ring. They are pulled through the VJ piping, which enters the ring through access openings.

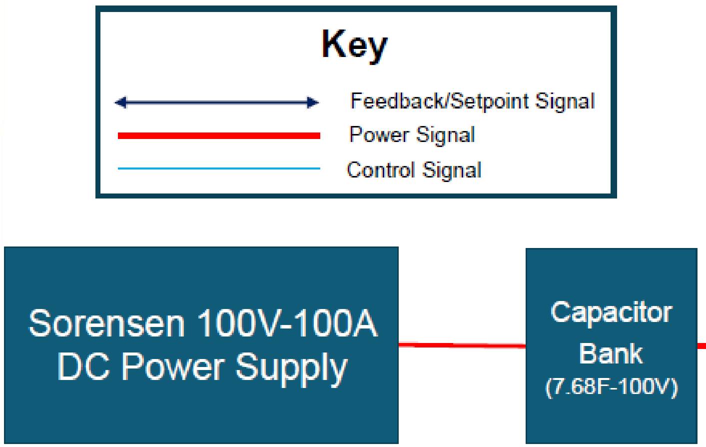
1002 IR New Lead Pot

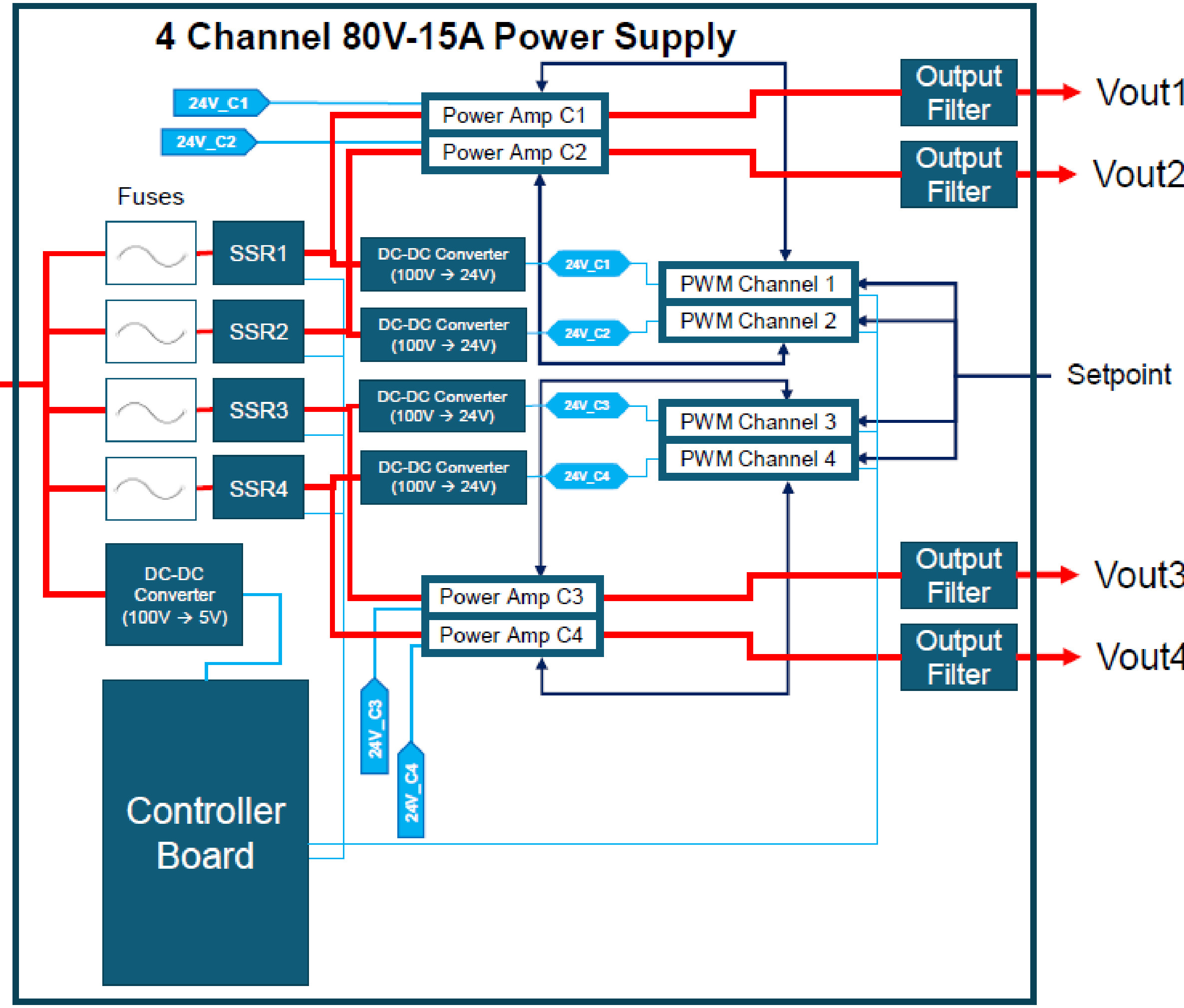


1012A Valve Box Crossover



Block Diagram (external cap bank_V2)





Capacitor Bank Specifications:

- From PSIM model: 60mF needed per magnet load
- 240mF needed per power supply
- 128 correctors per building and 4 correctors powered per power supply
- 128/4 = 32, 4 channel power supply chassis needed per building
- 240mF * 32 = 7.68F external capacitance needed

Splitting into two cap banks:

- Two separate cap banks connected to 16 supplies each
- 240mF * 16 = 3.84F external capacitance needed

Reference: Zachary Zapata

Areas of Concern

- Requirements (still waiting), Staffing, Late start for PS's
- Retirement of staff with extensive knowledge of PS's and the machines
- Low current ripple requirement of ESR (0.5ppm)
- Will the Warm DC Cables, cable tray and magnets fit in the tunnel?
- Large number of power supplies
- Limited Vendors
- Environmental control of buildings
- Building size
- Quench Detection, Quench Protection
- Hadron Ring work extensive

Conclusion

- ~2100 EIC PS's + 600 RHIC PS's
- DC PS's and Pulsed PS's, one special High Voltage
- Collaboration with the BNL LSII PS engineers for PS's and Power Supply Controllers
- Build to Prints will help with limited vendor base but more work for us
- Possible use of Electrolytic capacitors will help reduce the size of the RCS ps's
- We will need all the time and help we can get

END

Staffing

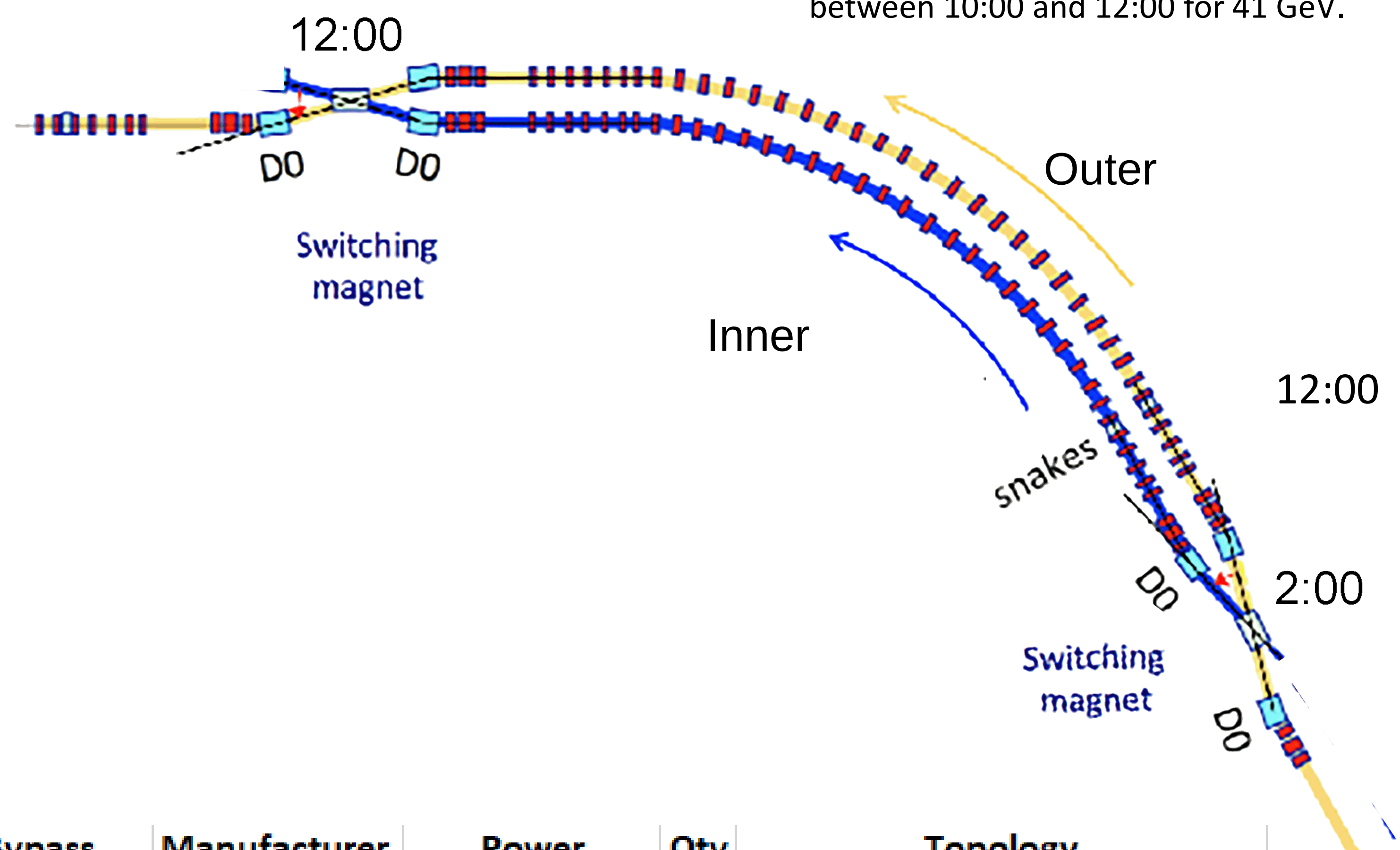
- Don Bruno 80% EIC 20% AD
- Bob Lambiase 60% EIC 40% CAD
- Ioannis Marneris 20% EIC 80% CAD
- Entry level engineers
  - Zachary Zapata, started 12/22/23
  - Albert Labrada, started 5/15/23
  - Dominic Prevosto, starts 6/5/23
  - Kiran Pandy, starts 6/26/23
- Looking to hire 3 more experienced engineers
- RHIC PS Group
  - 3 experienced engineers
  - 12 techncians

Approximate Dates Will be delayed

RCS PS - Preliminary Design	134 days	Mon 7/3/23	Thu 1/4/24
RCS PS - Final Design	42 days	Fri 1/5/24	Mon 3/4/24
RCS PS Specifciations and procurement efforts	305 days	Mon 3/4/24	Fri 5/2/25
RCS PS Award Contracts	83 days	Fri 5/2/25	Tue 8/26/25
RCS PS Delivery	314 days	Sat 12/26/26	Wed 3/8/28
RCS PS Install	219 days	Sat 1/1/28	Wed 11/1/28
Transfer Line PS System Preliminary Design	176 days	Sat 7/1/23	Fri 3/1/24
Transfer Line PS System Final Design	43 days	Fri 3/1/24	Tue 4/30/24
Transfer Line PS Award Contracts	524 days	Tue 2/25/25	Fri 2/26/27
Transfer line PS Delivery	268 days	Wed 10/29/25	Fri 11/6/26
Transfer Line PS Install	219 days	Sat 1/1/28	Wed 11/1/28
400 MeV Gun to Linac PS's - Preliminary System Design	133 days	Wed 7/3/24	Fri 1/3/25
400 MeV Gun to Linac PS's - Final System Design	43 days	Wed 1/3/24	Fri 3/1/24
400 MeV Gun to Linac PS's - Award Contracts	22 days	Fri 5/2/25	Mon 6/2/25
400 MeV Gun to Linac PS's - Delivery	222 days	Mon 4/20/26	Tue 2/23/27
400Mev Gun to Linac PS Install	219 days	Sat 1/1/28	Wed 11/1/28
eSR PS - Preliminary System Design	175 days	Mon 7/3/23	Fri 3/1/24
eSR PS - Final System Design	44 days	Fri 3/1/24	Wed 5/1/24
eSR PS - Award Contracts	133 days	Thu 5/1/25	Sat 11/1/25
eSR PS Delivery	125 days	Mon 5/18/26	Fri 11/6/26
eSR PS Install	262 days	Mon 1/1/29	Tue 1/1/30
HR Strt Sect Mods PS - System Preliminary Design	175 days	Mon 7/3/23	Fri 3/1/24
HR Strt Sect Mods PS - System Final Design	44 days	Fri 3/1/24	Wed 5/1/24
HR Strt Sect Mods PS - Award Contracts			
HR Strt Sect Mods PS - Delivery	311 days	Tue 5/19/26	Tue 7/27/27
HR Strt Sect Mods PS Install	522 days	Mon 1/1/29	Tue 12/31/30
HR Injection Preliminary System Design	262 days	Wed 3/8/23	Fri 3/8/24
HR Injection Final System Design	47 days	Fri 3/8/24	Sat 5/11/24
HR Injection Award Contracts	67 days	Sun 5/25/25	Mon 8/25/25
HR Injection Delivery	358 days	Fri 3/13/26	Tue 7/27/27
HR Injection PS Install	522 days	Mon 1/1/29	Tue 12/31/30
SHC PS Preliminary System Design	45 days	Mon 1/1/24	Fri 3/1/24
SHC PS Final System DesignSystem Design	22 days	Fri 3/1/24	Mon 4/1/24
SHC PS Award Contracts	24 days	Mon 5/5/25	Thu 6/5/25
SHC PS Delivery	166 days	Mon 5/18/26	Sat 1/2/27
SHC PS Install	263 days	Thu 1/1/32	Sat 1/1/33
IR Power Supplies - System Preliminary Design	135 days	Mon 1/1/24	Fri 7/5/24
IR Power Supplies - System Final Design Design	63 days	Fri 7/5/24	Tue 10/1/24
IR Power Supplies Award Contract	24 days	Mon 5/5/25	Thu 6/5/25
IR Power Supplies Delivery	170 days	Tue 6/16/26	Mon 2/8/27
IR PS Install	262 days	Wed 1/1/31	Thu 1/1/32
SHC DC Gun 600kV PS Procurement + Delivery	577 days	Fri 3/17/23	Sun 6/1/25

Low Energy Bypass - Overview

Warm switching magnets are added to change the path of the hadrons to the inner sextant between 10:00 and 12:00 for 41 GeV.



Low Energy Bypass	Manufacturer	Power	Qty	Topology
Main Dipole & Quad	APS	336kW	2	Custom Interleaved H-bridge
H/V Offset	CAEN	4.3kW	1	COTS Single Channel SwMode
Switching Magnet	APS	60kW	2	Custom Interleaved H-bridge
		Total	**5**	

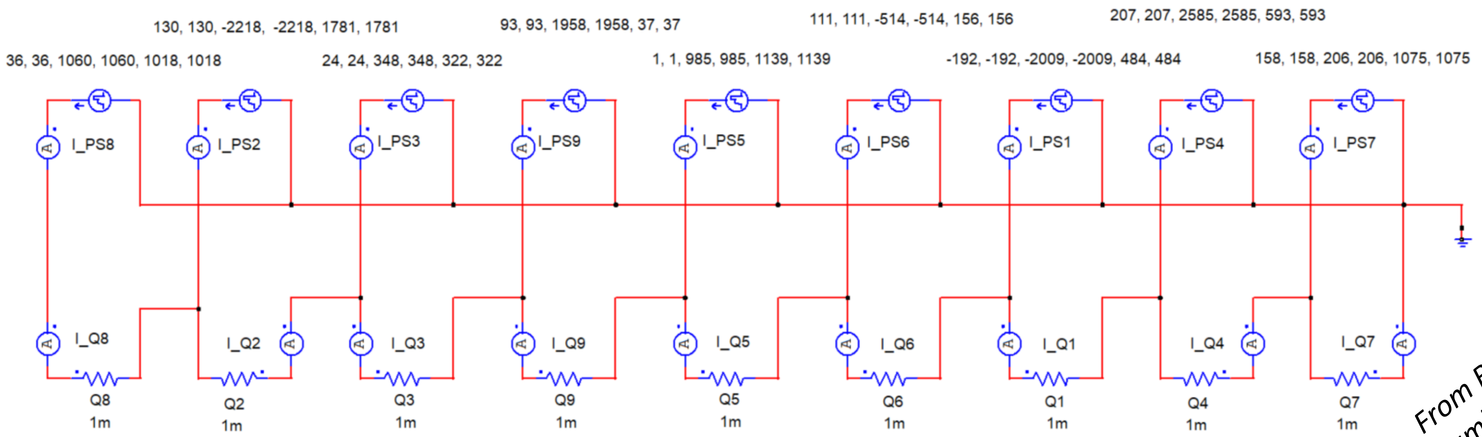
Powering the SHC chicane quads

Based on the required magnet current from the lattice design (see table), Bob has designed a cascade shunting circuit (below).

This minimizes the power supply rating and the current passed through the feedthroughs.

There is not enough space in the valve box to take all these feedthroughs. They will need to be located in the tunnel.

	Injection	100 GeV	275 GeV	Injection	100 GeV	275 GeV	Magnet max current (A)
I bus ave	446	1,876	5,160	446	1,876	5,160	5160
Q9	283	276	2,913	283	1,148	3,158	3158
Q8	36	262	721	36	1,060	1,018	1060
Q7	-568	-2,402	-6,606	-568	-2,111	-6,489	6606
Q6	395	1,032	4,274	395	1,619	4,453	4453
Q5	284	1,511	4,166	284	2,133	4,297	4297
Q4	-410	-2,196	-5,531	-410	-1,238	-5,404	5531
Q3	190	-810	2,352	190	-154	3,121	3121
Q2	-166	835	-2,799	-166	1,158	-2,315	2799
Q1	203	-390	3,803	203	77	4,937	4937
						Total current (A)	41122
						Total Q5-Q5 (A)	36433
						Total Q6-Q9 (A)	15277
						Total lead current IP2 (A)	**66987**



From Bob Lambiase

RHIC

CCB from Sector 11 - Blue - Outer					CCB from Sector 12 - Blue - Inner
Main Dipole (Return)	6300			6300	Main Dipole (Return)
Main Dipole (Source)	6300			6300	Main Dipole (Source)
D0 Bypass	6300	600		6300	D0 Bypass
DX Bypass	6300	2,000		6300	DX Bypass
D6 Bypass	450	NC		450	D6 Bypass
Spare	450			450	Spare
QT6+	150	+/- 150	+/- 150	150	QT6+
QT6-	150			150	QT6-
QT5+	150	+/- 150	+/- 150	150	QT5+
QT5-	150			150	QT5-
QT4+	150	+/- 150	+/- 150	150	QT4+
QT4-	150			150	QT4-
Spare	150			150	Spare
Spare	150			150	Spare
Main Quad (Defocus)	6300			6300	Main Quad (Defocus)
Main Quad (Focus)	6300			6300	Main Quad (Focus)
Q9 Bypass	6300		±300	6300	Q9 Bypass
Q7 Bypass	6300		600	6300	Q7 Bypass
H/V Bypass	450			450	H/V Bypass
Q6 Bypass	450		450	450	Q6 Bypass
Q3 Bypass	450	300	300	450	Q3 Bypass
Q8 Bypass	150	200	200	150	Q8 Bypass
Spare	150			150	Spare
Spare	150			150	Spare
Q2 Bypass	150	±150	± 150	150	Q2 Bypass
Q1 Bypass	150	200	200	150	Q1 Bypass
Spare	150			150	Spare
Spare	150			150	Spare
Spare	150			150	Spare

RHIC

CCB from Sector 11 - Yellow - Inner					CCB from Sector 12 - Yellow - Outer
Main Dipole (Return)	6300			6300	Main Dipole (Return)
Main Dipole (Source)	6300			6300	Main Dipole (Source)
D0 Bypass	6300	600		6300	D0 Bypass
DX Bypass	6300	2000		6300	DX Bypass
D6 Bypass	450	NC		450	D6 Bypass
Spare	450			450	Spare
QT6+	150	+/- 150	+/- 150	150	QT6+
QT6-	150			150	QT6-
QT5+	150	+/- 150	+/- 150	150	QT5+
QT5-	150			150	QT5-
QT4+	150	+/- 150	+/- 150	150	QT4+
QT4-	150			150	QT4-
Spare	150			150	Spare
Spare	150			150	Spare
Main Quad (Defocus)	6300			6300	Main Quad (Defocus)
Main Quad (Focus)	6300			6300	Main Quad (Focus)
Q9 Bypass	6300		±300	6300	Q9 Bypass
Q7 Bypass	6300		600	6300	Q7 Bypass
H/V Bypass	450			450	H/V Bypass
Q6 Bypass	450		450	450	Q6 Bypass
Q3 Bypass	450	300	300	450	Q3 Bypass
Q8 Bypass	150	200	200	150	Q8 Bypass
Spare	150			150	Spare
Spare	150			150	Spare
Q2 Bypass	150	±150	±150	150	Q2 Bypass
Q1 Bypass	150	200	200	150	Q1 Bypass

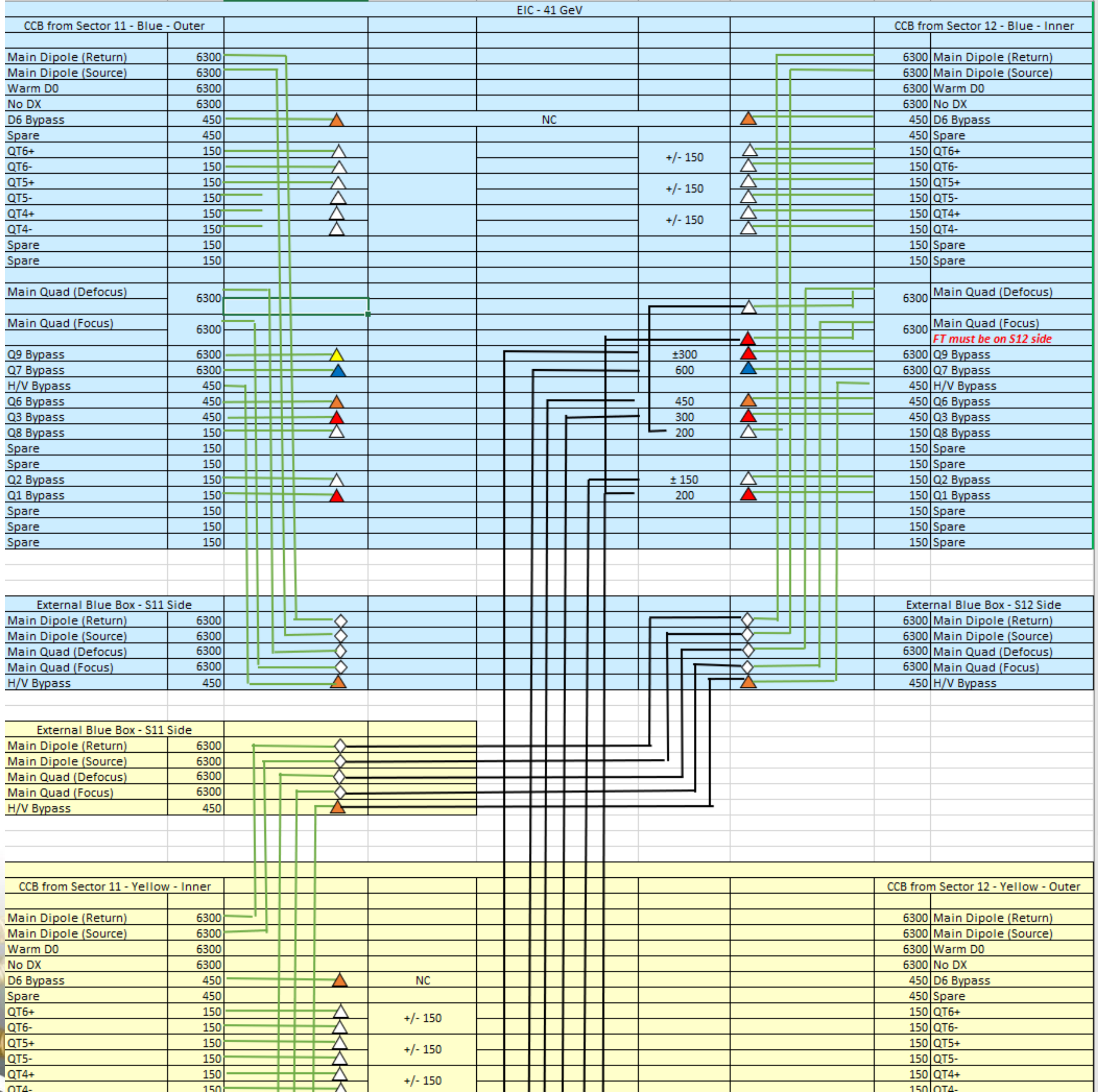
EIC - 275 GeV Blue VB

CCB from Sector 11 - Blue - Outer					CCB from Sector 12 - Blue - Inner
Main Dipole (Return)	6300			6300	Main Dipole (Return)
Main Dipole (Source)	6300			6300	Main Dipole (Source)
Warm D0	6300			6300	Warm D0
No DX	6300			6300	No DX
D6 Bypass	450		NC	450	D6 Bypass
Spare	450			450	Spare
QT6+	150	+/- 150	+/- 150	150	QT6+
QT6-	150			150	QT6-
QT5+	150	+/- 150	+/- 150	150	QT5+
QT5-	150			150	QT5-
QT4+	150	+/- 150	+/- 150	150	QT4+
QT4-	150			150	QT4-
Spare	150			150	Spare
Spare	150			150	Spare
Main Quad (Defocus)	6300			6300	Main Quad (Defocus)
Main Quad (Focus)	6300			6300	Main Quad (Focus) *FT must be on S12 side*
Q9 Bypass	6300		±300	6300	Q9 Bypass
Q7 Bypass	6300		600	6300	Q7 Bypass
H/V Bypass	450			450	H/V Bypass
Q6 Bypass	450		450	450	Q6 Bypass
Q3 Bypass	450	300	300	450	Q3 Bypass
Q8 Bypass	150	200	200	150	Q8 Bypass
Spare	150			150	Spare
Spare	150			150	Spare
Q2 Bypass	150	±150	± 150	150	Q2 Bypass
Q1 Bypass	150	200	200	150	Q1 Bypass
Spare	150			150	Spare
Spare	150			150	Spare
Spare	150			150	Spare

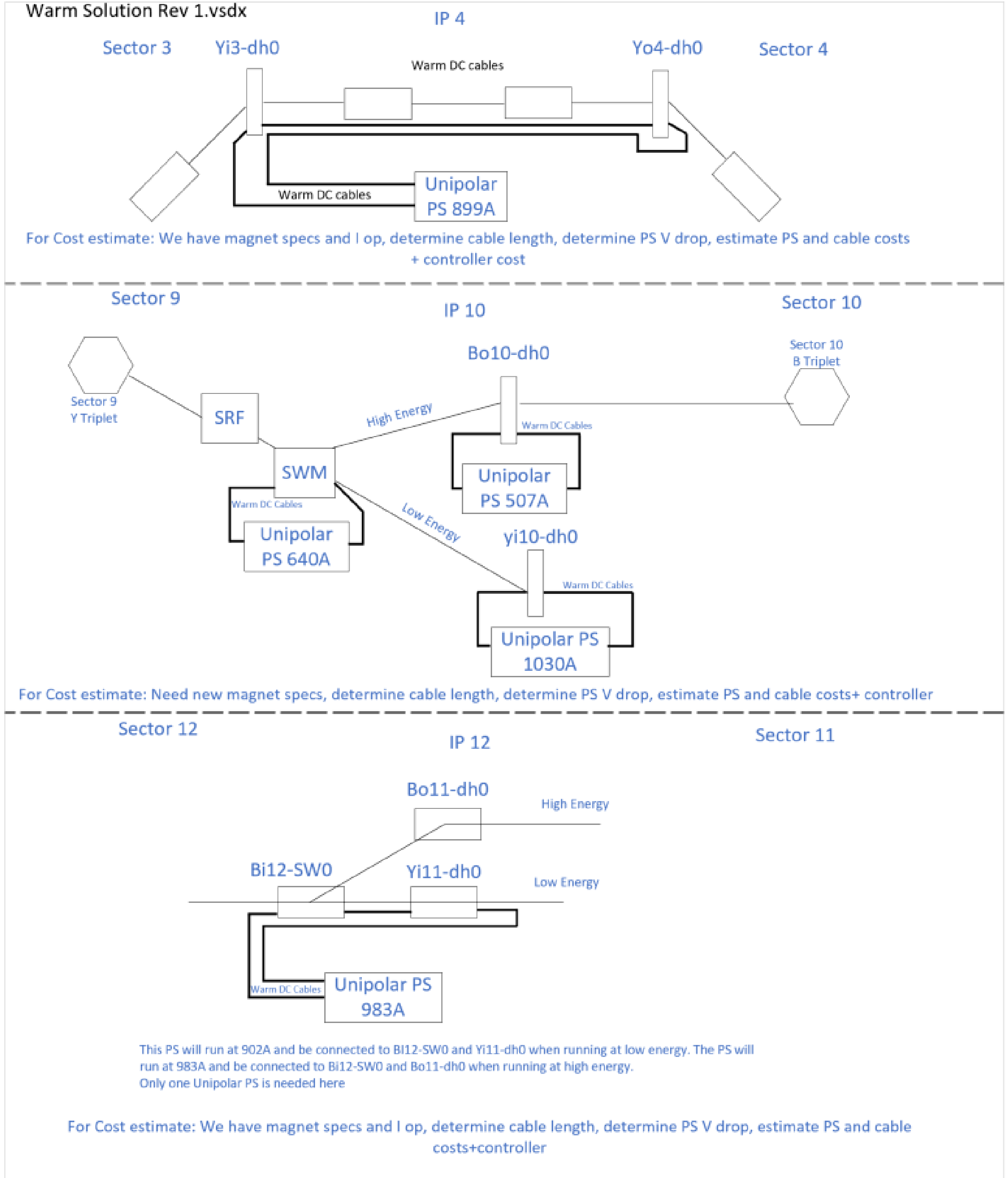
External Blue Box - S11 Side			External Blue Box - S12 Side
Main Dipole (Return)	6300	6300	Main Dipole (Return)
Main Dipole (Source)	6300	6300	Main Dipole (Source)
Main Quad (Defocus)	6300	6300	Main Quad (Defocus)
Main Quad (Focus)	6300	6300	Main Quad (Focus)
H/V Bypass	450	450	H/V Bypass

External Blue Box - S11 Side	
Main Dipole (Return)	6300
Main Dipole (Source)	6300
Main Quad (Defocus)	6300
Main Quad (Focus)	6300
H/V Bypass	450

CCB from Sector 11 - Yellow - Inner			CCB from Sector 12 - Yellow - Outer		
Main Dipole (Return)	6300		6300	Main Dipole (Return)
Main Dipole (Source)	6300		6300	Main Dipole (Source)
Warm D0	6300		6300	Warm D0
No DX	6300		6300	No DX
D6 Bypass	450	NC	450	D6 Bypass
Spare	450		450	Spare
QT6+	150	+/- 150	150	QT6+
QT6-	150		150	QT6-
QT5+	150	+/- 150	150	QT5+
QT5-	150		150	QT5-
QT4+	150	+/- 150	150	QT4+
QT4-	150		150	QT4-


EIC - 41 GeV
CCB from Sector 11 - Blue - Outer
CCB from Sector 12 - Blue - Inner
Main Dipole (Return) 6300
Main Dipole (Source) 6300
Warm D0 6300
No DX 6300
D6 Bypass 450
NC
Spare 450
QT6+ 150
QT6- 150
QT5+ 150
QT5- 150
QT4+ 150
QT4- 150
+/- 150
+/- 150
+/- 150
Spare 150
Spare 150
Main Quad (Defocus) 6300
Main Quad (Focus) 6300
FT must be on S12 side
Q9 Bypass 6300
Q7 Bypass 6300
H/V Bypass 450
Q6 Bypass 450
Q3 Bypass 450
Q8 Bypass 150
Spare 150
Spare 150
Q2 Bypass 150
Q1 Bypass 150
Spare 150
Spare 150
Spare 150
±300
600
450
300
200
± 150
200
External Blue Box - S11 Side
External Blue Box - S12 Side
Main Dipole (Return) 6300
Main Dipole (Source) 6300
Main Quad (Defocus) 6300
Main Quad (Focus) 6300
H/V Bypass 450
External Blue Box - S11 Side
Main Dipole (Return) 6300
Main Dipole (Source) 6300
Main Quad (Defocus) 6300
Main Quad (Focus) 6300
H/V Bypass 450
CCB from Sector 11 - Yellow - Inner
CCB from Sector 12 - Yellow - Outer
Main Dipole (Return) 6300
Main Dipole (Source) 6300
Warm D0 6300
No DX 6300
D6 Bypass 450
NC
Spare 450
QT6+ 150
QT6- 150
QT5+ 150
QT5- 150
QT4+ 150
QT4- 150
+/- 150
+/- 150
+/- 150

eRHIC

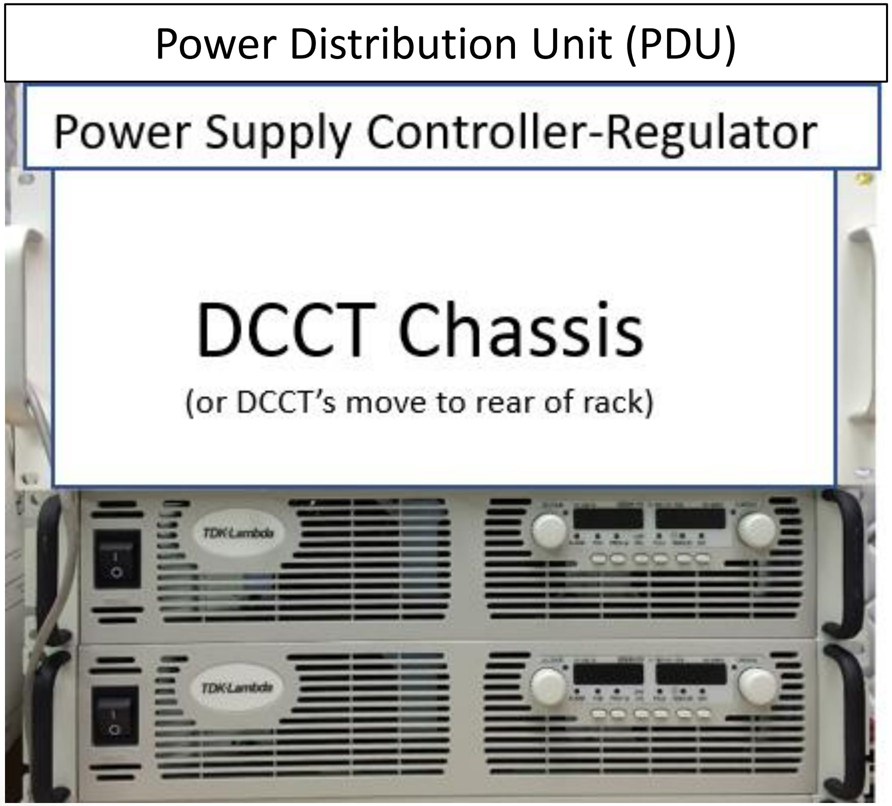

Warm Solution Rev 1.vsdx
IP 4
Sector 3
Yi3-dh0
Yo4-dh0
Sector 4
Warm DC cables
Warm DC cables
Unipolar PS 899A
For Cost estimate: We have magnet specs and I op, determine cable length, determine PS V drop, estimate PS and cable costs + controller cost
Sector 9
IP 10
Sector 10
Bo10-dh0
Sector 10 B Triplet
Sector 9 Y Triplet
SRF
High Energy
Warm DC Cables
SWM
Unipolar PS 507A
Warm DC Cables
Unipolar PS 640A
Low Energy
yi10-dh0
Warm DC Cables
Unipolar PS 1030A
For Cost estimate: Need new magnet specs, determine cable length, determine PS V drop, estimate PS and cable costs+ controller
Sector 12
IP 12
Sector 11
Bo11-dh0
High Energy
Bi12-SW0
Yi11-dh0
Low Energy
Warm DC Cables
Unipolar PS 983A
This PS will run at 902A and be connected to Bi12-SW0 and Yi11-dh0 when running at low energy. The PS will run at 983A and be connected to Bi12-SW0 and Bo11-dh0 when running at high energy.
Only one Unipolar PS is needed here
For Cost estimate: We have magnet specs and I op, determine cable length, determine PS V drop, estimate PS and cable costs+controller

Mid Range Power DC Supplies

Polarity:	Unipolar
Current Sensor:	DCCT
Stability:	100ppm of max current
Regulation:	Current regulation
Efficiency:	85%
Frequency:	60hz
Cooling:	Air
19" Rack Monunted:	Yes
Remote Interface:	Ethernet, Alternates considered
Free Wheeling Diode:	Included

Voltage	Current	Power (W)	Quantity
10	265	2650	16
10	500	5000	13
30	170	5100	1
30	500	15000	18
30	510	15300	2
40	65	2600	5
40	68	2720	36
40	85	3400	104
40	125	5000	22
40	250	10000	18
40	625	25000	1
60	25	1500	21
60	45	2700	3
60	56	3360	10
60	85	5100	7
60	170	10200	120
80	65	5200	39
80	195	15600	1
Total			437

Mid Range Power PS's (3kW-25kW)



When high precision is needed for DC unipolar power supplies with ratings of 25kW or less, it is most economical to use standard switch mode power supplies.

The units shown to the left are a good example of this. The lower portion contains three units rated 110A @ 30V, which are set in the voltage mode. Above it is a BNL built DCCT chassis (which also contains the freewheeling diodes), and above that is the PSC. The controllers take an Ethernet command and deliver a regulated current to the magnets.

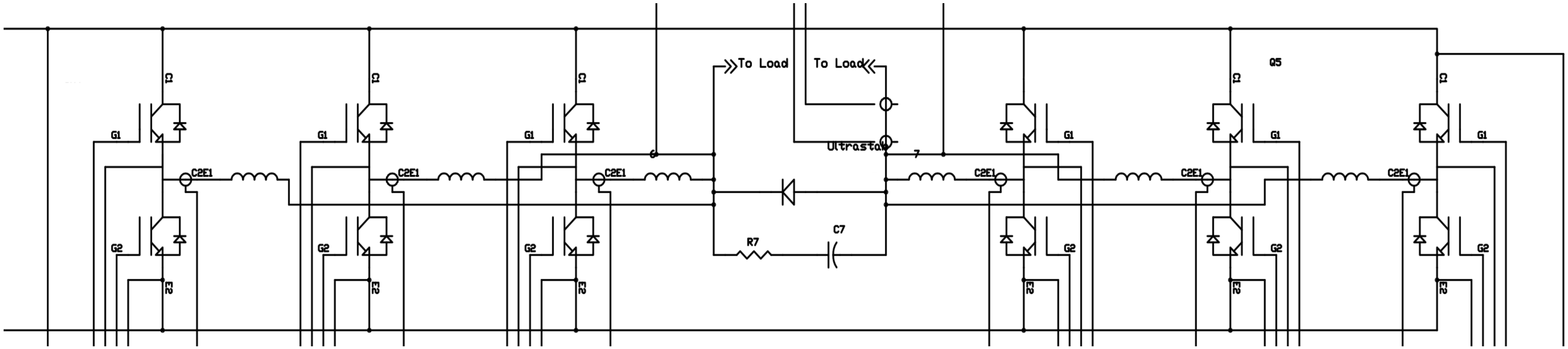
3kW-25kW, unipolar, DC, COTS sw mode ps, 2 Ch or 4Ch PSC based on ALS-U PSC and a PDU based on the ALS-U design

Correctors DC Supplies

Polarity:	Bipolar		
Current Sensor:	DCCT		
Stability:	100ppm of max current		
Regulation:	Current regulation		
Efficiency:	85%		
Frequency:	60hz		
Cooling:	Air		
19" Rack Monunted:	Yes		
Remote Interface:	Ethernet, SFP, Alternates considered		

Voltage (V)	**Current (A)**	**Power (W)**	**Quantity**
40	5	200	8
40	10	400	64
20	10	200	628
60	10	600	10
60	10	600	10
30	5	150	222
30	20	600	6
95	45	4,275	1
50	20	1,000	1
40	50	2,000	2
20	50	1,000	1
8	3	24	13
		Total	966

ESR Arc Dipoles, Other Large EIC PSs (Applied Power Systems)



Custom, Will use PSC for control

The design shown above is a three phase interleaved H-bridge design. The three phase switched output triples the ripple frequency as compared to one bridge.

This design has been used at C-AD for the e-Lens solenoids just above the 1kA level, the EBIS pulsed quads, and more recently for Linac Bending Magnet 1.

This design is that this design is scalable, as these outputs parallel easily

It can also be bipolar in both voltage and current

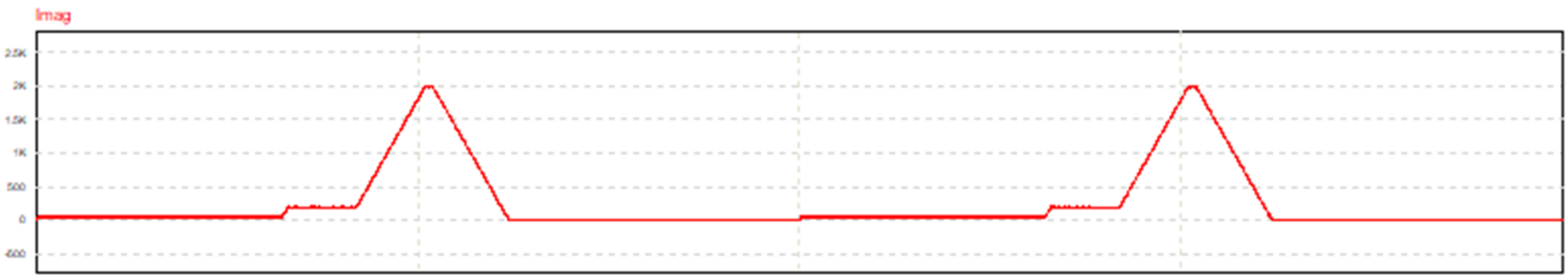
One Application is the ESR, D1/D3 is 5.2kA and D2 is 7kA.

High Power (RCS) Pulsed Supplies

Rapid Cycling Synchrotron (RCS) High Power Power Supplies	
Polarity:	Unipolar in current, bipolar in voltage
Current Sensor:	DCCT
Stability:	100ppm of max current
Regulation:	Current regulation
Efficiency:	85%
Frequency:	60hz
Cooling:	Water and Air
19" Rack Monunted:	No
Remote Interface:	Analog setpoint and analog readbacks of voltage, current setpoint and error
	PLC control for OFF, STANDBY and ON
These power supplies will be pulsed supplies. They will not be running DC	
A front end converter and energy storage capacitor bank is required to minimize the amplitude of the pulsing on the AC line	
All these supplies will produce pulsed current with rise and fall times of 100 msec.	
• Flattop of 20msec for 18GeV	
•Flattop of 270 msec for 5 GeV.	
There will be two front porches in the current of every power supply.	
•The first front porch will at 400 MeV for 320 msec.	
•The second front porch will be at 1.8GeV for 90 msec.	
The repetition rate will be 1 Hz.	

High Power (RCS) cont'd

Power supply name	Power supplies	AC Input Voltage (Vrms)	PS Output Current RMS (A)	Peak PS Output Current (A)	Peak PS Output Voltage (V)	Input Average Power/PS (KW)	Total Input Average Power (KW) All ps's
Dipole1, (Dipole1 and Dipole 2 are in series)	1.00	460.00	520.26	2000.00	1714.72	83.50	83.50
Dipole2, (Dipole1 and Dipole 2 are in series)	1.00	460.00	520.26	2000.00	1714.72	83.50	83.50
QD	1.00	460.00	260.13	1000.00	2060.97	57.09	57.09
QF	1.00	460.00	260.13	1000.00	2009.79	56.67	56.6704
QD0 to QD8	9.00	460.00	260.13	1000.00	399.07	28.55	256.9060
QDI0 to QDI8	9.00	460.00	260.13	1000.00	183.93	12.95	116.5724
QF1 to QF7	7.00	460.00	260.13	1000.00	399.07	28.55	199.8158
QFI1 to QFI7	7.00	460.00	260.13	1000.00	183.93	12.95	90.6674
QF8	1.00	460.00	260.13	1000.00	364.95	28.26	28.2643
QDI9	1.00	460.00	260.13	1000.00	166.87	12.81	12.8121
SX1, SX2, SX3, SX4	4.00	460.00	182.10	700.00	503.16	23.71	94.8546
Total	**42.00**						



Low Power Correctors (RCS) Pulsed Supplies

Rapid Cycling Synchrotron (RCS) Corrector Power Supplies

Polarity:	Bipolar
Current Sensor:	shunt or dcct
Stability:	1000ppm of max current
Regulation:	Current regulation
Efficiency:	85%
Frequency:	60hz
Cooling:	Air
19" Rack Monunted:	Yes
Remote Interface:	Analog setpoint and analog readbacks of voltage, current setpoint and error
	PLC control for OFF, STANDBY and ON

These power supplies will be pulsed supplies. They will not be running DC

A front end converter and energy storage capacitor bank is required to minimize the amplitude of the pulsing on the AC line

All these supplies will produce pulsed current with rise and fall times of 100 msec.

- Flattop of 20msec for 18GeV
- Flattop of 270 msec for 5 GeV.

There will be two front porches in the current of every power supply.

- The first front porch will at 400 MeV for 320 msec.
- The second front porch will be at 1.8GeV for 90 msec.

The repetition rate will be 1 Hz.

Power supply name	Power supplies	AC Input Voltage (Vrms)	PS Current RMS (A)	Peak PS Output Current (A)	Peak PS Output Voltage (V)	Input Average Power/PS (KW)	Total Input Average Power (KW) All ps's
CH1 to CH276, CV1 to CV552	828.00	120.00	2.80	10.00	43.83	0.0395	32.70

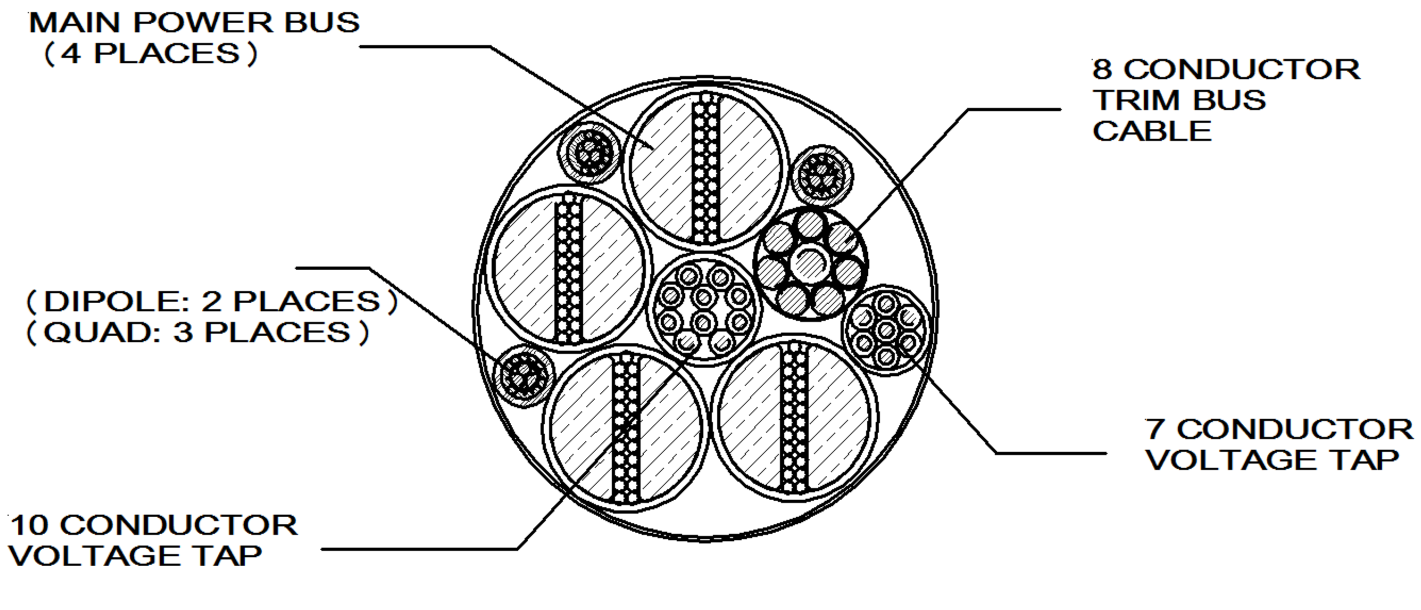
Hadron Storage Ring, HR Injection, Low Energy Bypass

- The Hadron Storage Ring (old yellow ring) will use the existing RHIC Power Supplies.
  - Except RHIC main dipole and quad ps's – will be purchased new
  - IR ps's
  - Sextupole ps's
  - Corrector ps's
  - Gamma-T ps's
- The inner arc (old blue) for HR Injection Transport and the Low Energy bypass will still be using some of the RHIC Power Supplies
  - IR ps's
  - Sextupole ps's
  - Corrector ps's
- Warm Injection line
  - Old Warm Injection line ps's + new ps's
- These have been maintained and some have been upgraded

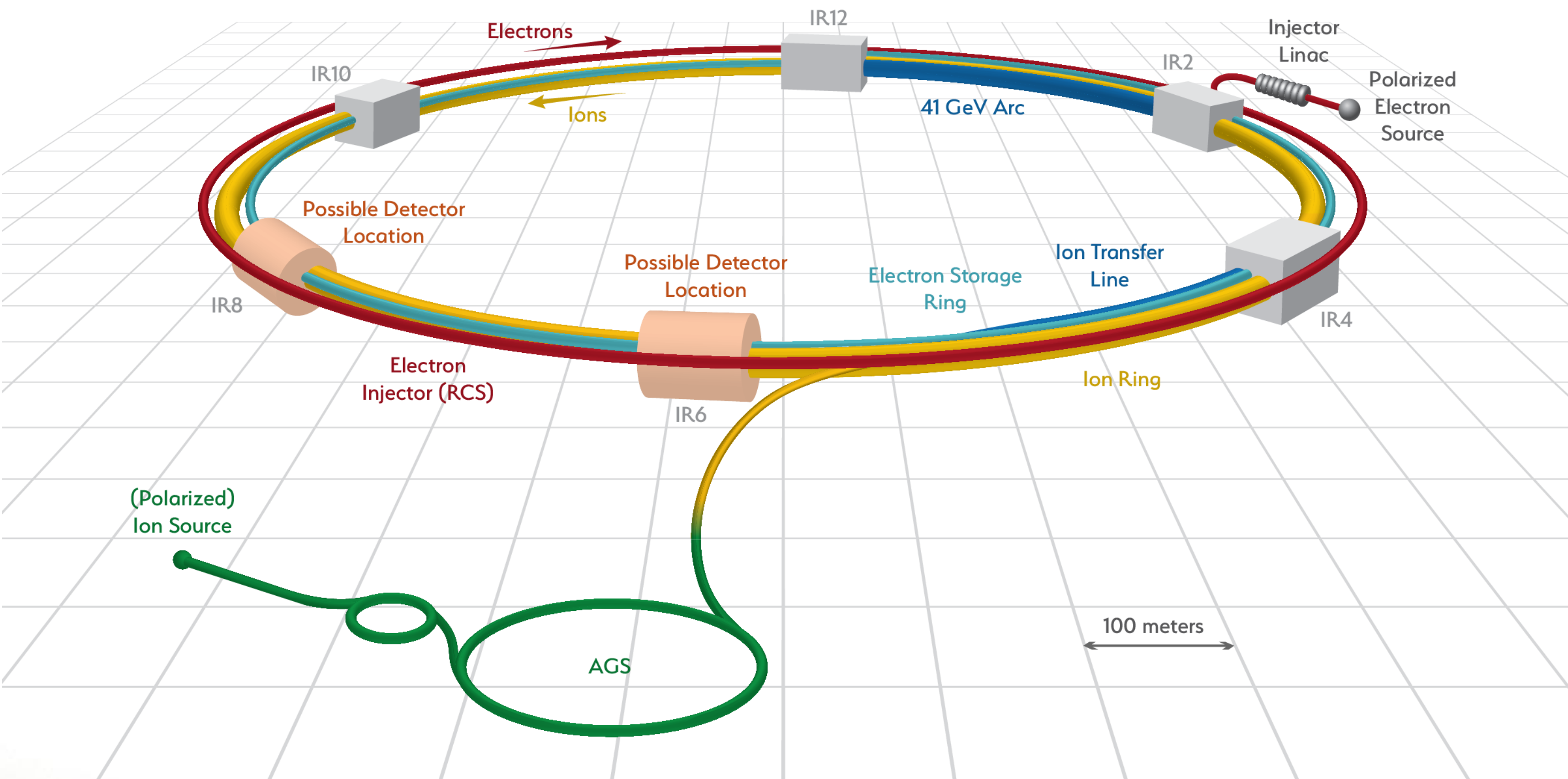
The Cold Crossing Bus (CCB)

The CCB is used to carry power between the valve boxes in the service buildings to the magnets in the ring, as well as to carry power over warm sections of within the ring. There are three types of superconductors – the main power bus rated 6,300 A, the dipole/quad cable rated 450 A, and the trim bus conductors rated 150 A.

The CCB is about an inch in diameter.



Scope Overview: The Big Picture



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The CCB is about an inch in diameter.