Powering of FRIB

POCPA3 Workshop Hamburg, Germany

May 22, 2012

Kent Holland
Power Supply Staff Engineer
MSU NSCL / FRIB
640 S. Shaw, Room 1300G
East Lansing, MI 48824
Phone: 517-908-7348
Fax: 517-908-7126

MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661.
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.

Outline

- National Superconducting Cyclotron Laboratory (NSCL) history
- Facility for Rare Isotope Beams (FRIB) history
- FRIB Overview
- Integration
- RF Systems Overview
- PS Systems Overview
- Path forward

NSCL History

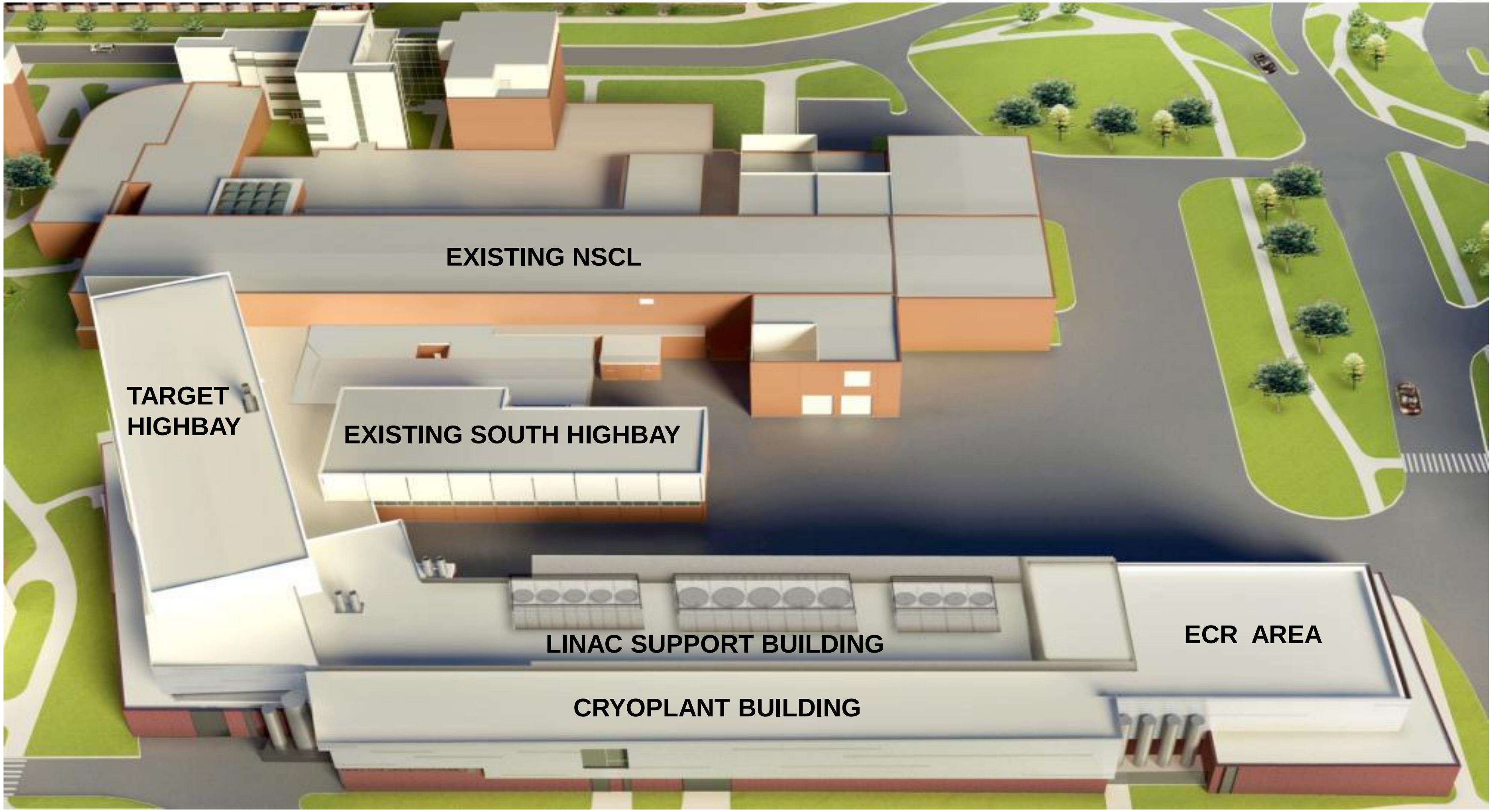
- **1954:** MSU receives funding to begin planning for a cyclotron-based nuclear research facility.
- **1961:** First National Science Foundation grant to build first 40 MeV cyclotron.
- **1965:** Because the device outperformed design, the 50 MeV, K-50 cyclotron is completed.
- **1975:** Funds for the superconducting magnet for the K-500 are awarded.
- **1977:** The superconducting magnet is completed and MSU is awarded the contract to build the cyclotron.
- **1981:** At 3:00 p.m. on Saturday, November 21, 1981, the world's first superconducting cyclotron was turned on.
- **1984:** The magnet for the second superconducting cyclotron is turned on.
- **1988:** The new cyclotron exceeds expectations and the K-800 is completed and renamed the K-1200.
- **1998:** Plans to couple the K-500 and K-1200 receive funding.
- **2000:** On October 1, the first beam of ions from the Coupled Cyclotron Facility is created.
- **2009:** Began construction of ReA3. ReA3 will provide world-unique low energy rare isotope beams produced by stopping fast, separated rare isotopes in a gas-stopper, and then reaccelerating them in a Linear Accelerator.

FRIB History

- **2004:** The Department of Energy puts out a call for proposals for a $1 billion projected dubbed the Rare Isotope Accelerator (RIA). However, the project is shelved.
- **2007:** The Department of Energy puts out a new, scaled-down call for proposals for the Facility for Rare Isotope Beams (FRIB).
- **2008:** On December 11, the Department of Energy announced that MSU will host the new FRIB project.
- **2010** and beyond: Plans for the $615 million FRIB facility continue to move forward. Current estimations predict construction to begin in 2013 with a completion date in 2020, and a potential early completion date in 2018.
- **2012** Conventional facilities have completed final design, technical groups starting final design May, 2012.
- http://www.nscl.msu.edu/
- http://www.nscl.msu.edu/interactivemap.html
- http://www.frib.msu.edu/

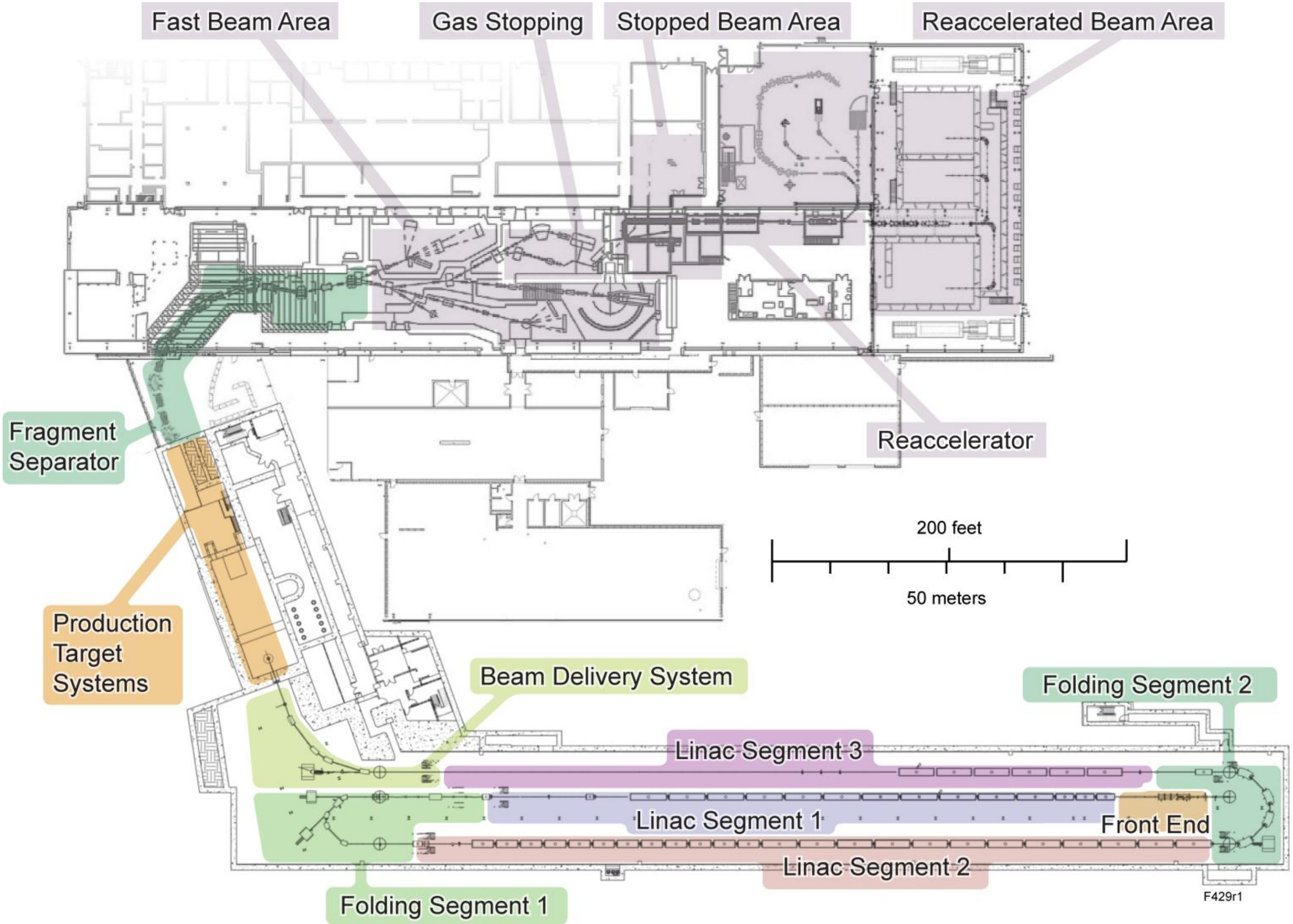
FRIB overview

Site Layout



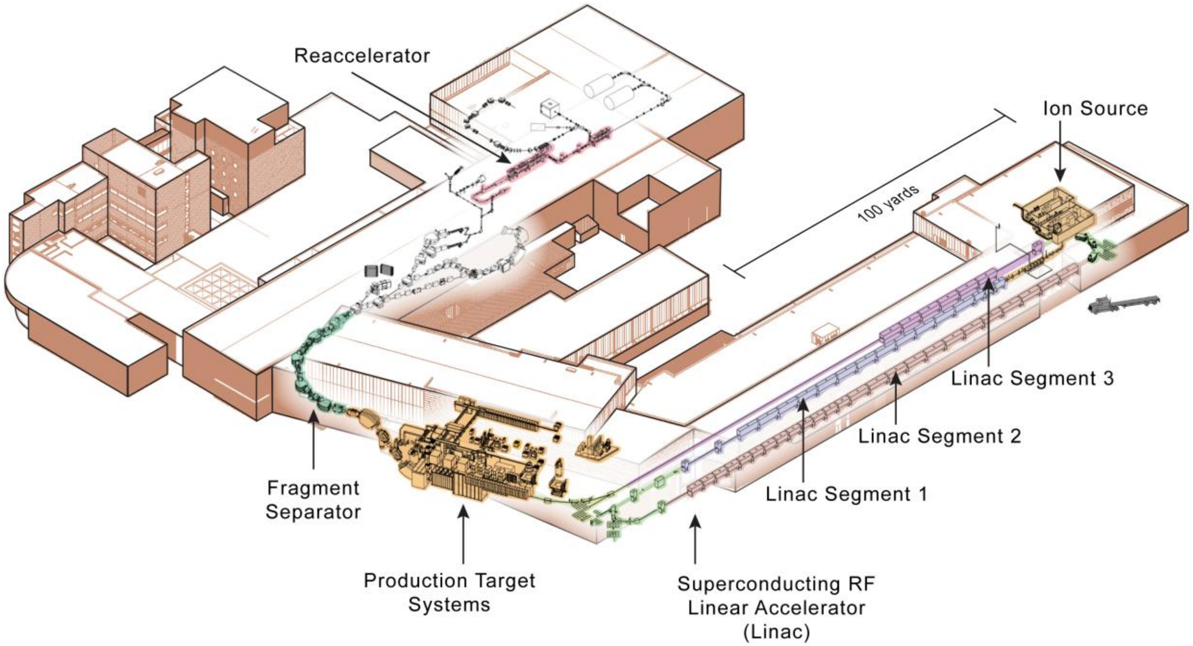
FRIB overview

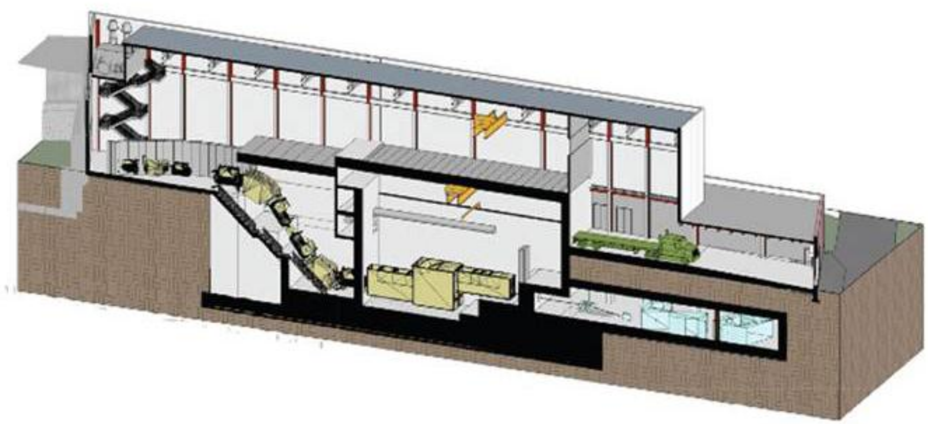
Facility Layout

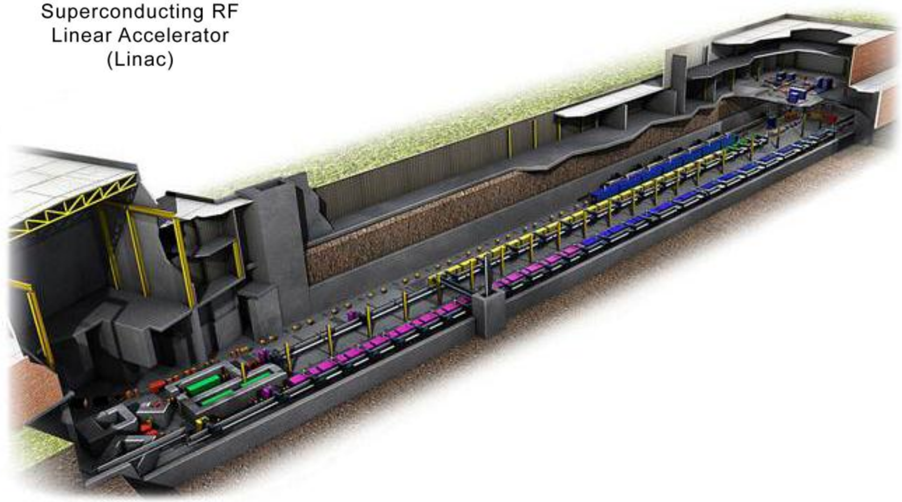


FRIB overview

Facility Layout



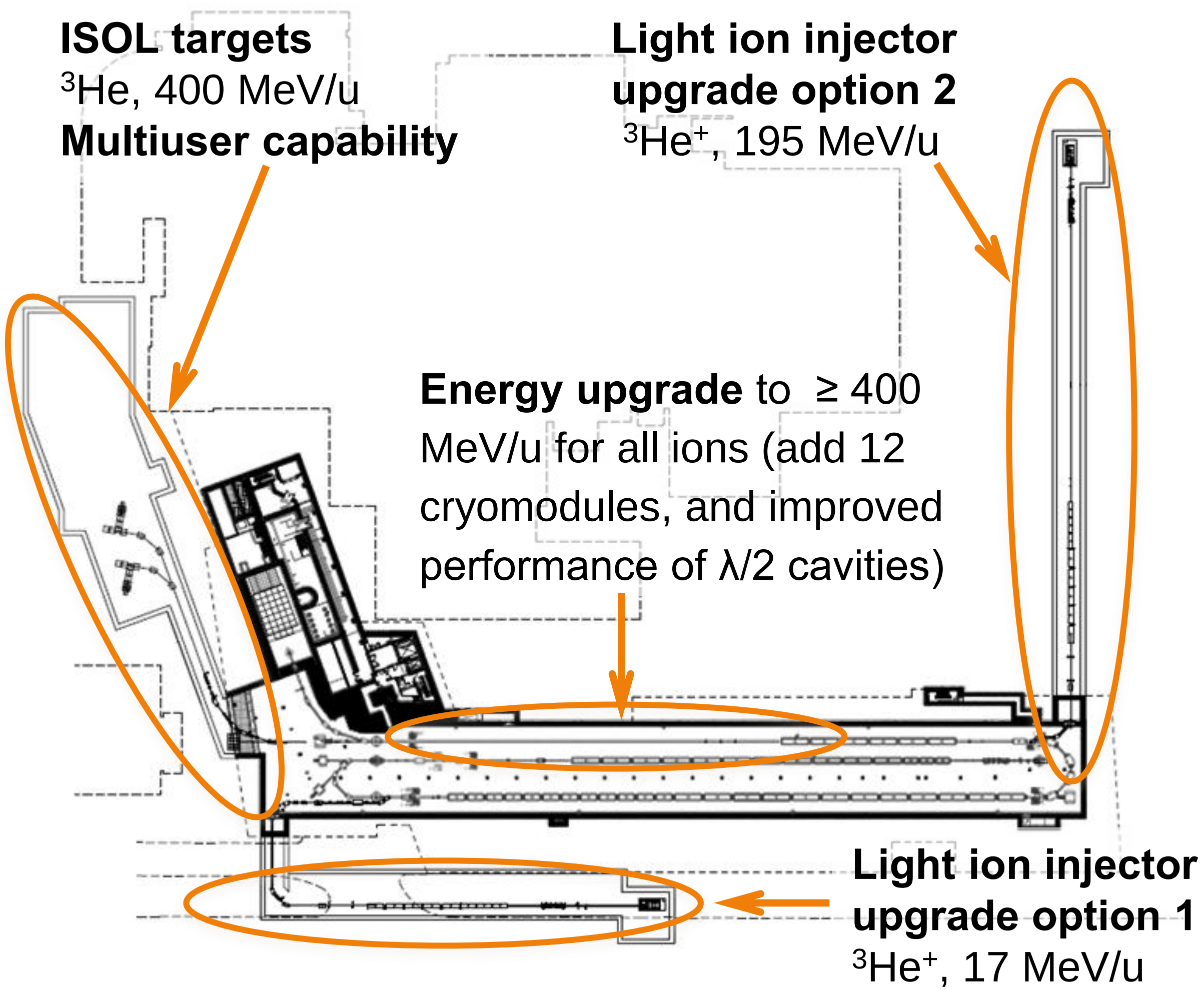




FRIB overview

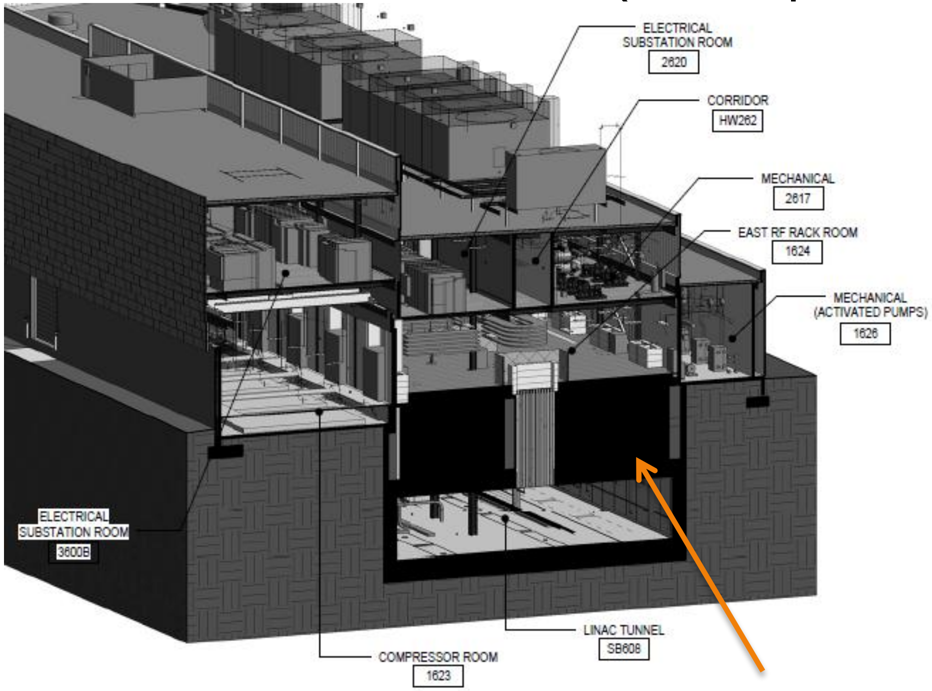
Future Upgrade Opportunities

- Space available for various upgrade options
  - Higher energy
  - ISOL targets
  - Light ion injector (17 or 200 MeV/u)
  - Multi-user simultaneous operation
- Tunnel penetration locations identified in facility design

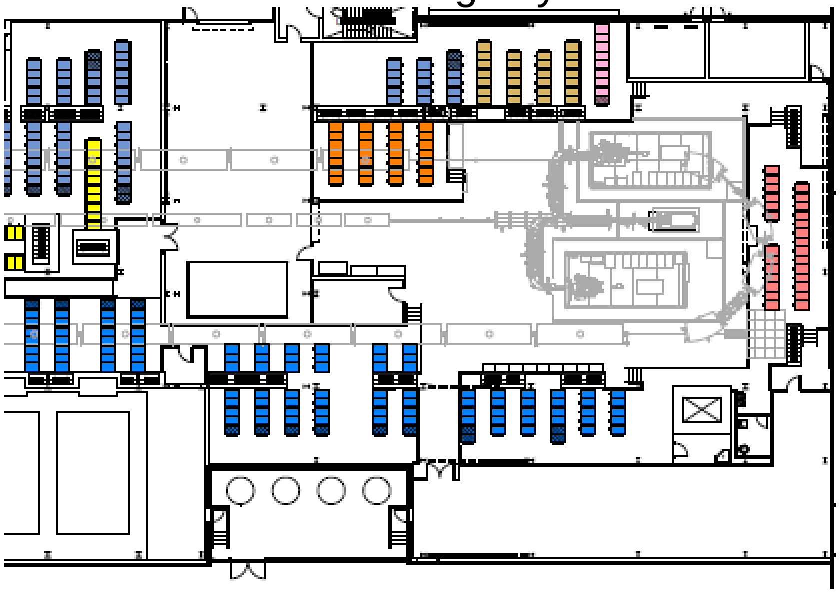


Integration:
Service Building and Linac Tunnel

- Baseline 767 racks for Accelerator Systems and Experimental Systems technical systems
(RF amplifiers, power supplies, vacuum controls, diagnostics, etc.)
  - Connect to tunnel lattice elements
  - Determine overall loads (water, power, air cooling) and distribution



Service Building Layout

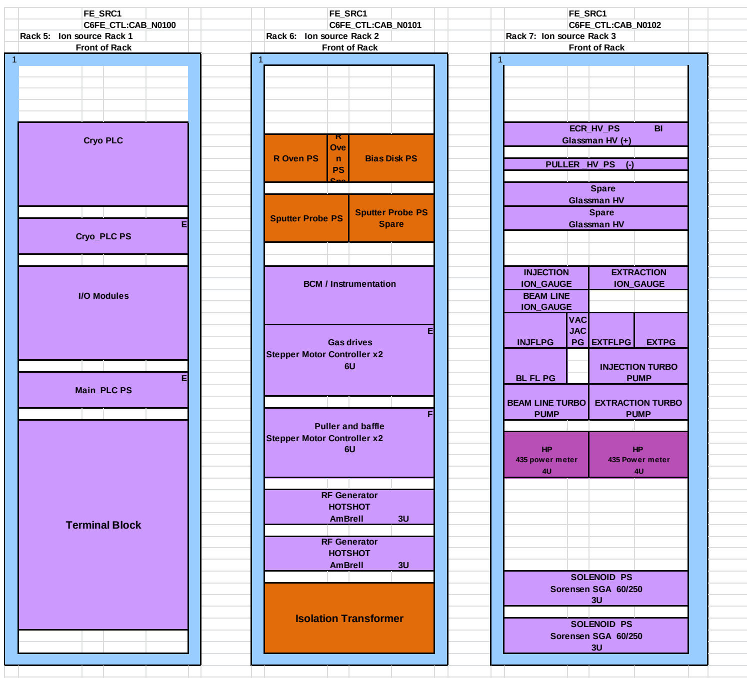


20 feet of concrete & soil

Integration:
Service Building and Linac Tunnel

Lattice Element and Power Supply counts in Parameter List

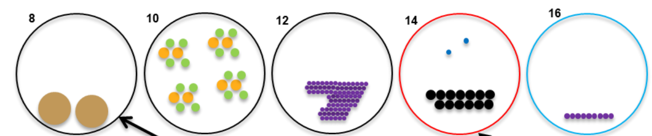
Rack layout



Total Power Consumption

Rack Installed?		Yes
120Vac	20A	2
120V Backup	20A	0
120V Clean	20A	0
208Vac 1P	30A	0
208Vac 1P	50A	0
208Vac 3P	20A	0
208Vac 3P	30A	1
480Vac 3P	20A	0
480Vac 3P	30A	2
480Vac 3P	40A	0
480Vac 3P	60A	2
480Vac 3P	80A	0
LCW	0	gpm
Fans	2	825 CFM
HVAC	2.8	Tons

Conduits



Safety conduit

- 0.250 " OD Diagnostics cable
- 0.375 " OD Diagnostics cable
- 0.2" OD Controls cable

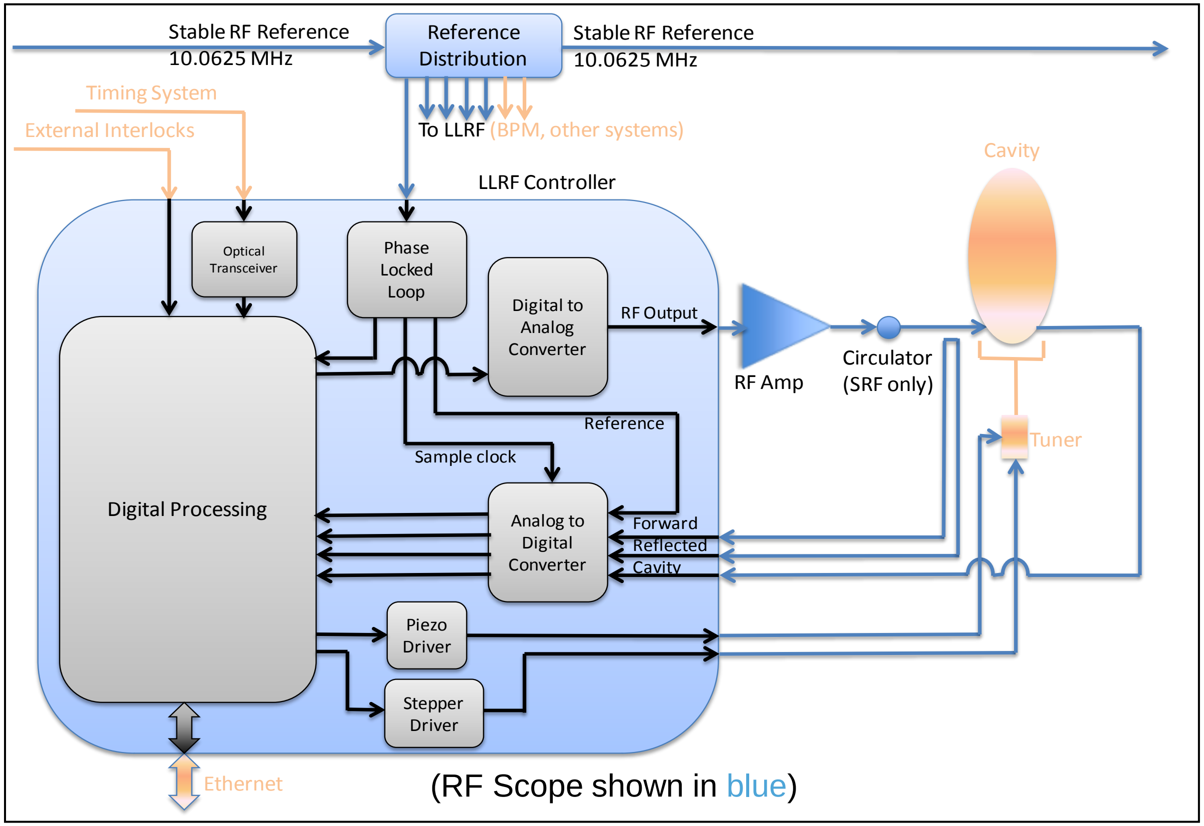
Rack counts

C6SB Racks Overview						
	400MeV LINAC					
T.3	# Systems	# Racks ea	# Racks	# Racks	space reserved (# PS Racks)	sq ft
Linac Segment 1						
beta = 0.041 QWR 4.2	3	7	21	21		
beta = 0.085 QWR 8.3	14	10	140	130		
beta = 0.285 HWR 2.0	1	6	6	6		
PS			2	4		
Diag			2	0		
Ctl			6	6		

= logical link

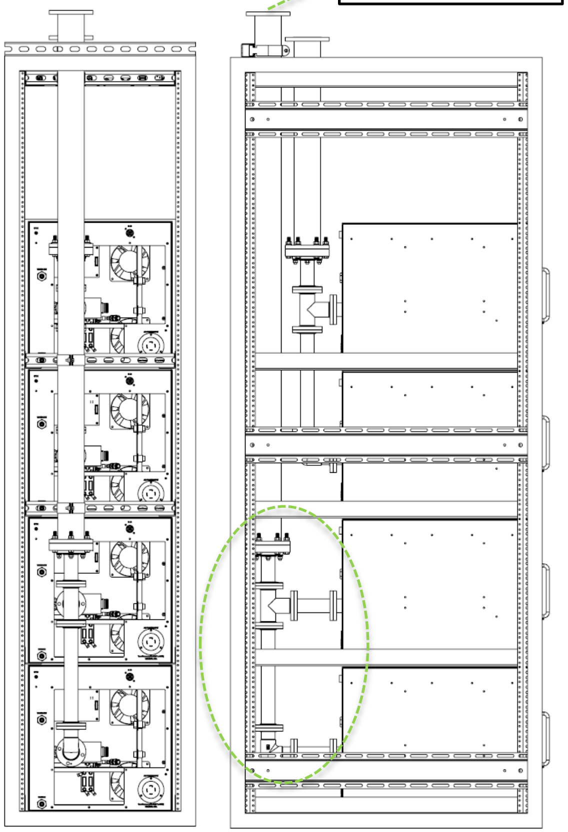
RF Systems Overview

- RF system provides the phase reference signal and regulates the cavity amplitude and phase, which accelerate the ions.
  - Total of 337 RF systems



(RF Scope shown in blue)

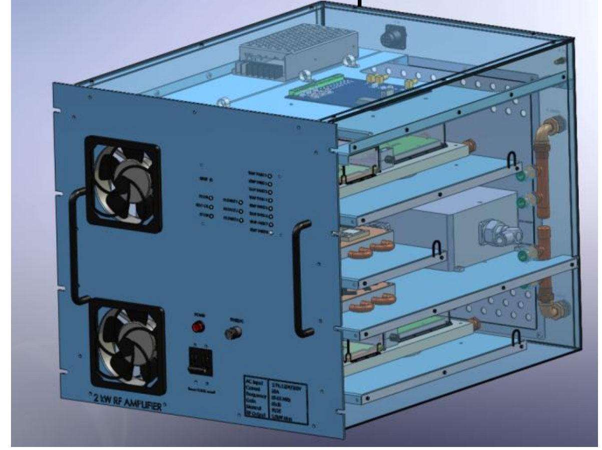
4 kW Output



2-way Power Combiner

RF Systems Overview

2 kW Amplifier



New FRIB LLRF Controller

PS Systems Overview

- Power supplies (PS) are needed for FRIB ion sources, optical elements in the FRIB driver linac beam line, and in the FRIB experimental system
- PS provide regulated DC current to magnets which focus, and/or steer the ions.
- PS can be segregated into 3 PS family types
  - Room Temperature Magnet Power Supplies (RTM PS)
  - Superconducting Magnet Power Supplies (SCM PS)
  - High Voltage Power Supplies (HV PS)
- Many commercial off the shelf (COTS) PS are available, which will meet system requirements
- High reliability, stability, and availability of the FRIB PS systems with a reasonable price is a key for the success of the project.

PS Systems Overview
Parameter List

Linac Segment 1 Parameter List

Date 8/29/2011 Based on the FRIB_V12R4 lattice

T.3.06

WBS	Parameter	Qty or Type	Unit	Comments
	Segment One Length	103.097	m	
	Uranium Acceleration			
	Charge states (2)	33+/34+		
	Input Energy	0.5	MeV/u	
	Output Energy	16.6	MeV/u	
	Energy gain	16.1	MeV/u	
	Acceptance (Nominal)			
	Transverse (beam size/aperture)	60	%	24 mm max. beam size,40 mm aperture
	Longitudinal	30	π.keV/u.ns	
T.3.06.02	**Cavity & Cryomodule Configuration**			
	λ/4 , βopt 0.041 **(LS1_CA)**			
	Number of cryomodules	3		Based on 500 keV/u RFQ
	Number of cavities/cryomodule	4		
	Number of solenoids/cryomodule	2		
	Number of cavities	12		
	Number of gate valves	6		2 per cryomodule
	Number of solenoids (type S1)	6		Superconducting with integrated steerers
	Dipole correctors	12		One in each plane per solenoid
	Cavity Data			
	RF Frequency	80.5	MHz	
	Flange to flange length	0.1755	m	
	Aperture	30	mm	
	Epk (numerical calculation)	30	MV/m	peak surface electric field
	Bpk (numerical calculation)	53	mT	peak surface magnetic field
	Va	0.81	MV	accelerating voltage design goal (includes transit time factor, at beta = beta_opt)
	R/Q (numerical calculation)	433	Ω	shunt impedance/Q (linac definition)
	G (numerical calculation)	15	Ω	geometry factor
	U	3.0	J	Average stored energy
	T	2	K	operating temperature

Type of PS and qty defined

PS Systems Overview

Example Power Supply Requirements for Electrostatic / HV PS

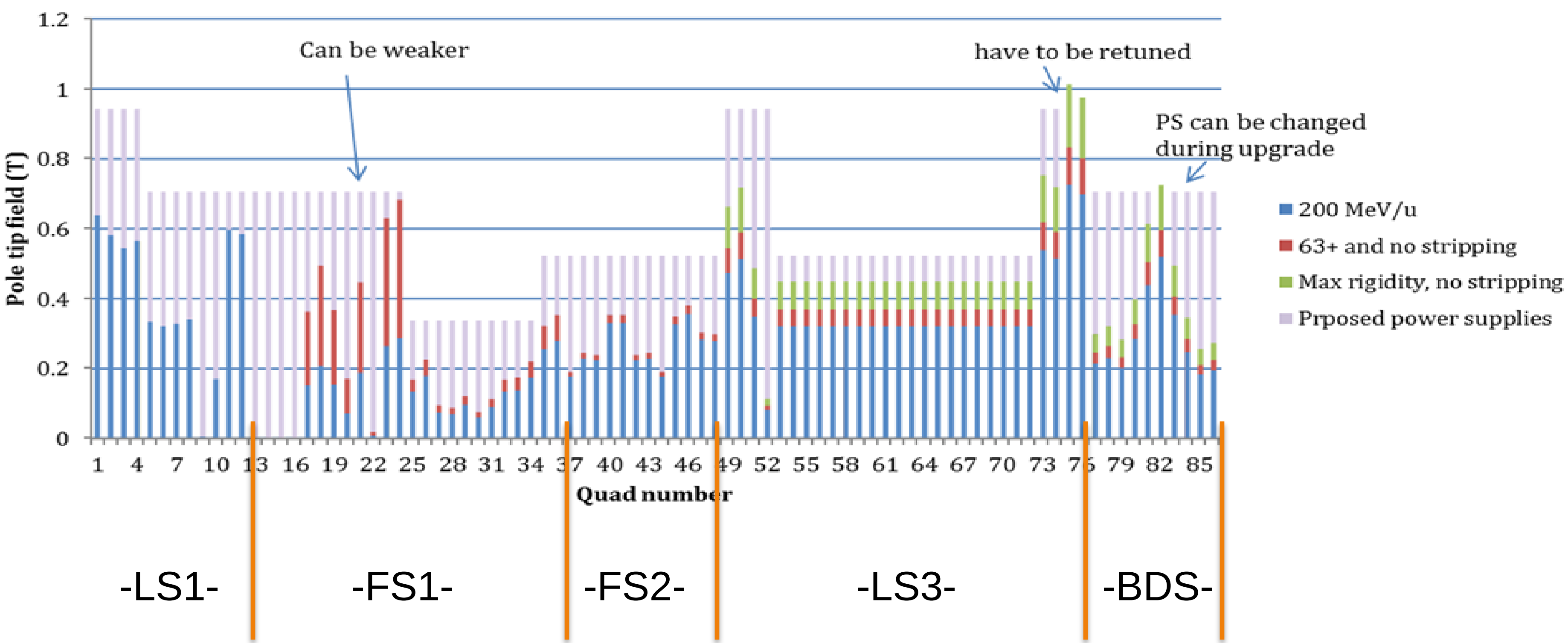
Name	**PSED1a**
Parameter list description	**RT E-Dipole ED1 (+)**
V required maximum (kilovolts)	20
I required maximum (Amps)	0.006
Field contingency % (included in V/I requirements)	30%
Range (Volts)	6 to 15
Polarity	Positive
Voltage stability – long term - % of Full Scale	±0.01%
Voltage ripple – short term - % of Full Scale (rms)	0.01%
Voltage set-point accuracy/precision - % of Full Scale	0.1% of rated +0.5% of setting
Voltage read-back accuracy/precision - % of Full Scale	0.1% of rated +0.5% of setting
Current read-back accuracy/precision - % of Full Scale	0.1% of rated +0.5% of setting
Voltage set-point resolution - % of Full Scale	0.05%
Voltage read-back resolution - % of Full Scale	0.05%
Current read-back resolution - % of Full Scale	0.05%
Voltage repeatability/reproducibility	±0.01%
Number of quadrants	1
Temperature Coefficient %/°C of of Full Scale Current	0.01%
Sampling rate Hz (note 3) (needs verification)	3-10
Magnet maximum voltage rating	
Magnet capacitance	200pF
Lead Capactance (100ft 30pF/ft)	3nF

PS Systems Overview
Value Engineering Performed

- RT correction magnet PS, eliminated the need for an external reversing switch, and reduced PS power, greatly reducing PS costs
- Q1 magnet/PS optimization reduced cost by ~$250k, PSQ1 average power was reduced to ~5 kW from 10 kW. Details shown on next slide.
- Front End solenoid power supplies scaled with power. Similar to Q1, although due to the low quantity the cost reductions were much less.
- Request for procurement (RFP) in process for SC magnet PS
- High PS efficiency and power factor are key considerations in choosing suppliers
- Provisions made to allow future capability enhancements
  - Rack space, conduits, utilities planned for upgrade from 200 MeV to 400 MeV
  - Rack space, conduits, utilities planned for upgrade to Cable in Conduit (CICC) magnets in hot cell

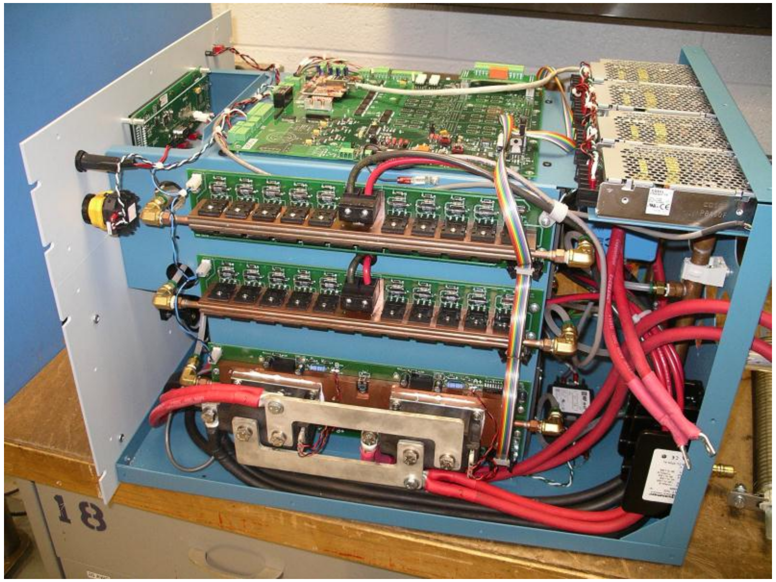
PS Systems Overview
Q1 Power Supplies Optimized by Location

- Q1 magnet/PS optimization reduced cost by ~$250k, PSQ1 average power was reduced to ~5 kW from 10 kW



PS Systems Overview
Cost Basis, SC Magnet PS

- SCM PS Basis of Estimates (BOE) costs are based on previous experience at NSCL to build, install, and test
  - All material costs are captured in Bill of Materials (BOM)
  - Labor estimates are based on previous workorders to build, install, and test SCM PS at NSCL
    - » Built 2 identical 10V 250A SCM PS for the cyclotron stopper
    - » Built 1 identical 10V 750A “Modular” SCM PS for a spare S800 dipole PS
    - » Built 50+ identical SCM PS for ReA3 and N4 vault reconfiguration, 20V 25A, 10V 40A, 10V 125A, 10V 250A.
    - » Built 4 prototype “Modular” SCM PS that have been in service since 2007
    - » 100+ SCM PS built at NSCL in 2001 in service
    - » 20+ SCM PS built at NSCL in 1990 in service
  - Supporting Items/systems captured in BOE
    - » Network connection
    - » Digital I/O
    - » AC power requirement specified
    - » LCW connection
  - Usage dependant costs captured in BOE
    - » DC lead – based on length



PS Systems Overview
Cost Basis, RT Magnet PS & HV PS

- RTM PS, and HV PS BOE costs are based on recent quotes from Ametek, TDK-Lambda, Glassman HV, etc.
  - Labor estimates are based on previous workorders to install RTM PS at NSCL
  - Supporting Items/systems captured in BOE
    - » Network connection
    - » Digital I/O
    - » AC power requirement specified
  - Usage dependant costs captured in BOE
    - » DC lead – based on length of path between PS and magnet

PS Systems Overview
Schedule Basis

- Installation time allowance, from BOEs, is 2 days per power supply, including final testing, plus DC lead time allowance depending on quantity, type, and length of leads
- Sufficient temporary labor will be available, and good instruction and oversight will be provided
- Install and test power supplies initially independent of magnet schedule
- Pull cables from racks to equipment locations (relatively) independent of status of equipment at each end

Path Forward

- Final Design, completed by Nov, 2013
  - Detailed acquisition and installation plans
  - Detailed acceptance and verification plans
  - RFP's for RT magnet PS and HV PS
  - SCM PS make vs. buy decision, manufacturing plan if make chosen
  - Finalize integration details
    - » Machine protection system
    - » Personnel protection system
    - » Grounding
    - » Cable routing
- Technical equipment installation beginning 2015
- Commissioning beginning 2018
- Early completion 2020