



Accelerator Systems (121.03)

Paul Derwent

PIP-II Independent Project Review

4-6 December 2018

In partnership with:

India/DAE

Italy/INFN

UK/STFC

France/CEA/Irfu, CNRS/IN2P3

Outline

- Scope/Deliverables
- Requirements
- Interfaces
- Preliminary Design, Maturity
- Design Review Plan
- Technical Progress to Date
- Milestone Schedule
- Organization
- Steps to CD-2
- ESH&Q
- Risks and Mitigations
- Responses to CD-1 recommendations
- Breakout Session topics
- Summary

About Me:

- Paul Derwent
 - Role: L2 Manager for Accelerator Systems
 - Relevant Experience:
 - Accelerator Division Department Head: Recycler (2006-2009), PIP-II (2014-2018)
 - Deputy Project Manager, PIP-II (2014-2017)
 - Accelerator Division Associate Head for Projects (2013-2014)
 - Associate Project Manager for Accelerator & NuMI Upgrades, NOvA (2009-2014)
 - 2014 CD-4
 - 2015 U.S. DOE Secretary's Award for Excellence
 - Antiproton source: design, fabrication, installation, commissioning of Accumulator stacktail stochastic cooling system

121.03 L2 System Scope

Charge #1

- Labor, materials, travel, and other costs associated with the management, design, procurement, fabrication, and testing of various accelerator system hardware and software including High Power RF, RF distribution, Low Level RF, Magnets, Power Supplies, Vacuum, Controls, Safety Systems, and Instrumentation. Also includes Accelerator Physics.

WBS Dictionary : pip2-docdb #599

L3 Scope and Deliverables

Charge #1

- L3 systems
 - 121.03.02 Accelerator Physics
 - Linac Lattice & Optics
 - 121.03.03 High Power RF
 - Linac Amplifiers & Distribution
 - 121.03.04 Low Level RF
 - Linac RF Stations & Interlocks
 - Resonance Control
 - 121.03.05 Magnets & Power Supplies
 - Superconducting Linac and Beam Transfer line
 - Warm Magnets
 - Cold & Warm Magnet Power Supplies
- L3 systems
 - 121.03.06 Vacuum
 - Cryomodule Insulating Vacuum
 - Linac and Transfer Line Beam vacuum
 - 121.03.07 Controls
 - Timing, Machine Protection
 - Infrastructure
 - 121.03.08 Safety Systems
 - Electrical, Radiation, ODH
 - Interlocks and Monitoring
 - 121.03.09 Instrumentation
 - Linac and Beam Transfer Line
 - Beam diagnostics
 - Electronics

WBS Dictionary : pip2-docdb #599

L3 Scope and Deliverables

Charge #1

- Linac and Beam Transfer Line Tunnel Components
 - Beam Pipe
 - Vacuum Pumps, Gauges
 - Dipoles, Quadrupoles
 - Beam Position Monitors, Beam Loss Monitors, Toroids, DCCT
 - Profile Monitors
 - RF Distribution
 - Cables
 - Interlocks & Enclosure gates
 - Timing Reference Line
- Test Stands
 - Cavity and Cryomodules
 - HPRF, LLRF
 - Vacuum
 - Power Supplies
- Shielding Assessments
 - Linac and Booster

Gallery Components

- RF Amplifiers & Distribution
- LLRF Stations
- Power Supplies
- Electronics
 - Diagnostics
 - Machine Protection
 - Controls
- Infrastructure
 - Ethernet, DataLoggers, Programmable Logic Controllers
- Software and firmware deliverables are associated with many systems

- 121.03.03 RF Power Amplifiers for:
 - SSR1 (325 MHz, 7 kW)
 - SSR2 (325 MHz, 20 kW)
 - LB650 (650 MHz, 40 kW)
 - HB650 (650 MHz, 70 kW)
- 121.03.04 LLRF and RF Protection Interlocks (RFPI) for test stands
- 121.03.05 Warm magnets
 - SC Linac Quadrupoles and dipole correctors

121.03 L2 System Requirements

Charge #1

- 121.03 Systems Function and Configuration Document:
 - **TC ED0008104**
 - Accelerator Systems tie together main pieces of the Linac configuration. The various aspects of this level 2 structure provide for the overall physics design, for RF power and control of the accelerating cavities in the Linac, for magnets and associated power supplies to focus the H-beam, for beam and insulating vacuum systems, for instrumentation to measure beam characteristics, for safety systems to protect personnel, and for control and user interface to all the various components. They also contribute systems to the various test stands necessary to test prototype and production components.

121.03 L2 System Requirements

- Necessary to achieve 4 Objective Key Performance Parameters
 - Necessary for beam KPPs
 - Controls interface for Cryogenic systems

#	Description of Scope	Threshold KPP	Objective KPP
1	SRF Linac Beam Energy	600 MeV	800 MeV
2	Linac Beam	Beam delivered to the Beamline Dump	5.4E12 particles per pulse (H-) at 20 Hz beam delivered to the Beamline Dump
3	Booster/Recycler/Main Injector upgrades	Booster injection region, Recycler RF upgrades, and Main Injector RF upgrades, hardware installed and tested without beam in respective machines.	Linac beam injected and circulated in the Booster
4	Cryogenic Infrastructure	Cryogenic plant and associated distribution system are installed and capable to support cavities operation at 2 K	Cryogenic system installed and is capable to support Linac operation in the CW mode

121.03 L3 Functional Requirement Specifications

Charge #1

WBS #	L3 System	TeamCenter ED#
121.03.02	Accelerator Physics	8103
121.03.03	High Power RF	8023
121.03.04	Low Level RF	4194
121.03.05	Magnets & Power Supplies	8059
121.03.06	Vacuum	8216
121.03.07	Controls	8101
121.03.08	Safety Systems	8061
121.03.09	Beam Instrumentation	8303

121.03 L3 Interface Control Documents

Charge #1

WBS #	L3 System	TeamCenter ED#
121.03.02	Accelerator Physics	7696
121.03.03	High Power RF	7688
121.03.04	Low Level RF	7689
121.03.05	Magnets & Power Supplies	7690
121.03.06	Vacuum	7691
121.03.07	Controls	7692
121.03.08	Safety Systems	7693
121.03.09	Beam Instrumentation	7694

Preliminary Design and Design Maturity

Charge #1

- 121.03.02 Accelerator Physics
 - Preliminary Shielding Assessment for Cryo Plant Building
 - November 30, 2018
 - Plan for executing Linac and Booster Shielding Assessment
 - Awaiting CD2 and definition of baseline design
- 121.03.03 HPRF
 - 325 MHz 7 kW Preliminary Design Review (PDR) Oct 23 2017 **TC ED0004290**
 - Existing Functional Requirement Specification (FRS), Technical Requirement Specification (TRS), and acceptance criteria for India Institutes Fermilab Collaboration (IIFC) Joint R&D deliverables
- 121.03.04 LLRF
 - Existing FRS, TRS, and acceptance criteria for IIFC Joint R&D deliverables
 - Prototype design reviews for boards, distribution, software architecture within context of the IIFC
 - Building prototype systems
 - Electronics designs as late as possible to match technology development
- 121.03.05 Magnets & Power Supplies
 - Final Design Review (FDR) and PRR for PIP2IT Quench Protection Monitors (QPM) **TC ED0008375**
 - PDR for 650 Warm Quadrupole Magnets
 - Possible solution for the Beam Transfer Line Quadrupoles
 - Preliminary designs exist for all beam transfer line magnets and power supplies
 - Using commercial devices and mature Fermilab designs
 - Specialty systems may require additional prototype development to validate design

Preliminary Design and Design Maturity

Charge #1

- 121.03.06 Vacuum
 - PIP2IT Warm vacuum section and Warm to Cold vacuum transition installed and tested
 - Superconducting RF section preliminary design under development
 - Beam Transfer line based on existing transfer line designs
- 121.03.07 Controls
 - Machine Protection System (MPS) prototype development at PIP2IT
 - Timing System prototype development at PIP2IT
- 121.03.08 Safety Systems
 - Mature and based on existing laboratory technology
 - Linac and Transport enclosures will be sectioned into four radiological enclosures based upon operational needs
 - ODH Monitoring system for Linac enclosure and cryo building
- 121.03.09 Beam Instrumentation
 - Operating systems at PIP2IT
 - BPMs, Current Monitors, Emittance Scanners
 - Preliminary Design reviews concentrate on System Architecture
 - Electronics designs as late as possible to match technology

Preliminary Design and Design Maturity

Charge #1

- Systems are still in preliminary design stage
 - Cost estimates based on
 - Previous similar systems at the lab
 - Prototype development at PIP2IT
 - Estimate uncertainty appropriate for the design maturity
- Have completed 14 Design Reviews
 - HPRF, LLRF, Magnets & PS
- Have 10 scheduled Preliminary Design Reviews
 - LLRF and Vacuum to be scheduled
- Plan 3 PDRs complete by CD2 (June 2019)
 - Accelerator Physics: lattice design
 - Magnets & PS: Beam Transfer line Magnets & PS design
 - Magnets & PS: 650 Warm Unit Magnets

Design Review Plan : Completed Reviews

Charge #2

Review Class	Key Design Elements Reviewed / Activity Name	Review Date	Teamcenter ED#
Conceptual Design Review	LLRF System	9-Jul-15	none
Conceptual Design Review	RF Distribution System	11-Aug-15	ED0008501
Preliminary Design Review	RFPI Prototype	19-Sep-16	ED0007434
Preliminary Design Review	Up/Down Converter (Prototype stage) (India/Fermilab review)	5-Dec-16	ED0008506
Preliminary Design Review	RF Distribution System	5-May-17	ED0008502
Production Readiness Review	Digitizer Board Prototype	25-Jan-18	ED0008252
Requirements Review	Prototype RFPI FRS	8-Feb-18	ED0005729
Final Design Review	Up/Down Converter - (Prototype stage) (Fermilab Peer review)	28-Mar-18	ED0008504
Conceptual Design Review	Firmware software Architecture review (Fermilab peer review)	9-Jul-18	ED0008505
Requirements Review	Prototype RFPI TRS	18-Jul-18	ED0006125
Production Readiness Review	FPGA Board Prototype	26-Jul-18	ED0008253
Production Readiness Review	Stepper Board Prototype	16-Aug-18	ED0008251
FDR/PRR	QPM	4-Oct-18	ED0008375
Preliminary Design Review	Warm Unit Quads 650 MHz section	19-Oct-18	ED0008430

- Updates to the Linac optics
 - Changes in locations : fabrication requirements, diagnostic inserts
- Preliminary Shielding Assessment for Cryo Plant Building
 - Necessary condition in Fermilab Rad Control Manual before going for construction bids
 - ES&H Presentation from John Anderson
 - November 30, 2018
- Resonance Control algorithms
 - Testing with SSR1 cavities at the Spoke Test Cryostat and lessons from LCLS-II testing
- Preparations for HWR and SSR1 CM at PIP2IT
 - Amplifiers, circulators, LLRF stations, Instrumentation electronics, vacuum, controls, QPMs, power supplies, Oxygen Deficiency Hazard (ODH) and Rad Safety interlocks
 - Every L3 has had to advance design, interfaces, procurements to support these operations

Progress to date: Hardware & Prototypes

Charge #1, 2

- Hardware demonstration (many at PIP2IT)
 - HPRF
 - RFQ, buncher cavities
 - Coupler test stands (325 & 650 MHz at STC)
 - LLRF
 - RFQ, buncher cavities
 - Beam pattern generator for Medium Energy Beam Transport (MEBT) chopper
 - Beam diagnostics
 - BPMs, Time of Flight
 - Beam Current Monitors
 - Emittance Scanners
 - Low Power Laser Profile monitor
 - Vacuum
 - Warm to cold vacuum transition performance tested
 - Magnets and Power Supplies
 - Quench Protection Monitor prototype with SSR1 solenoid

Progress to Date: RF development

- Test stands at STC
 - Couplers at 325 MHz and 650 MHz
 - 650 MHz Inductive Output Tube (IOT) Amplifier and power distribution
 - Preparations for the Horizontal Tests of 650 MHz cavities



650 MHz LLRF
Station for
Horizontal Tests

SC1-Chase

Charge #1, 2



650 MHz Coupler
Test Stand

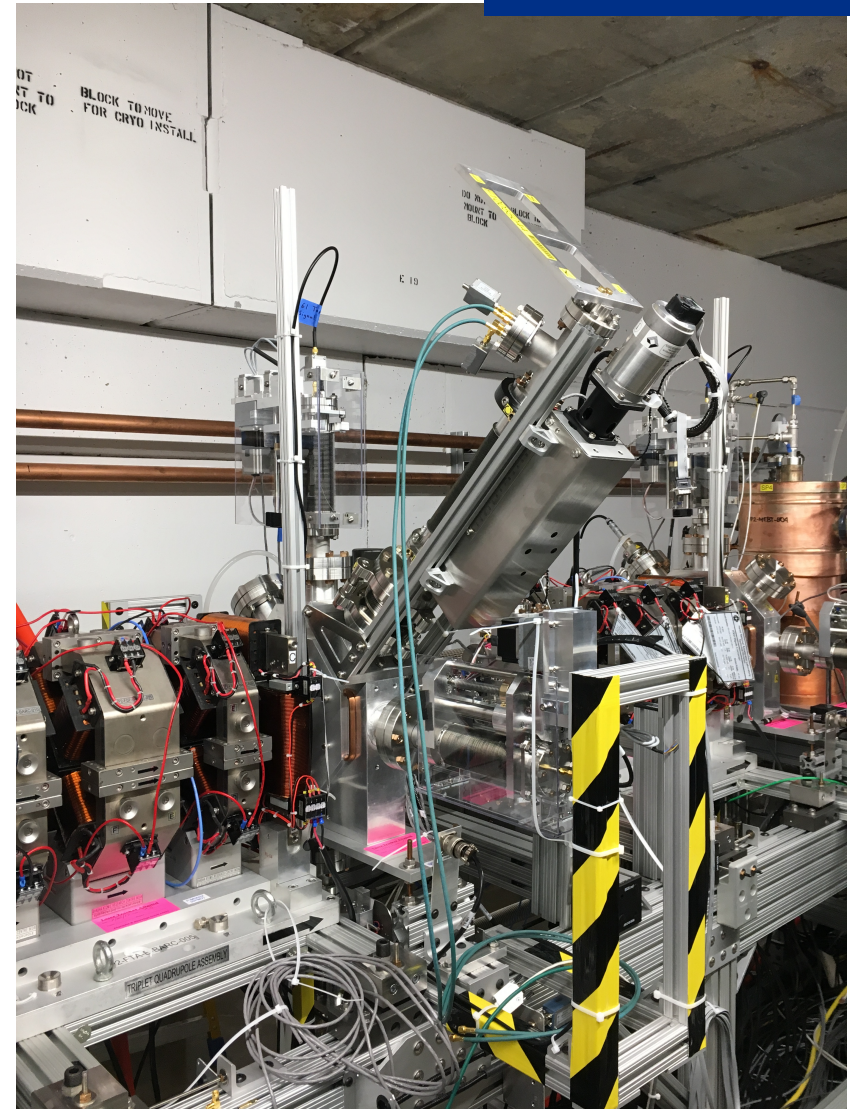
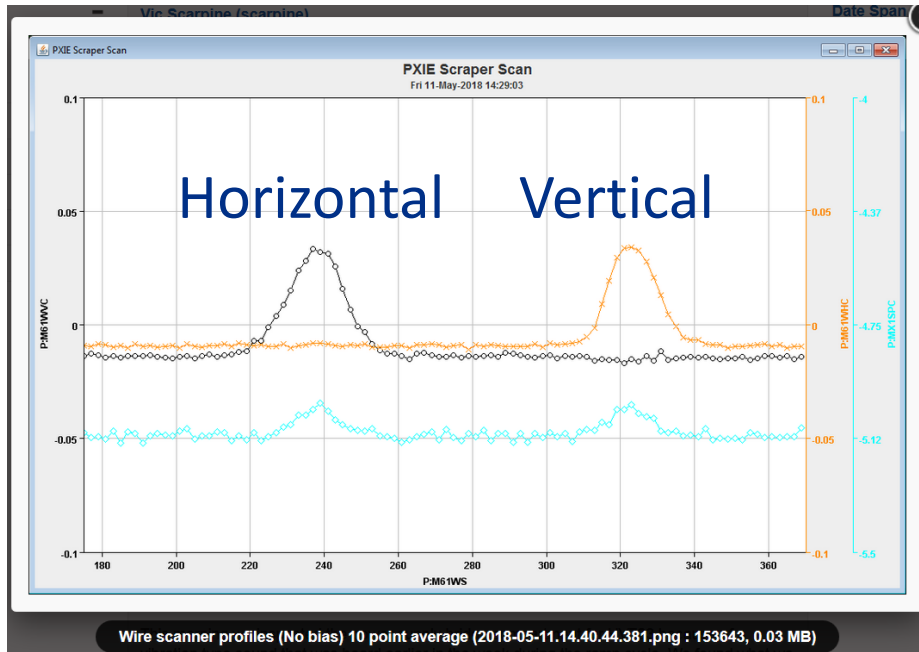
SC1-Steimel

Progress to Date: Wire Scanner for Transverse Profiles

Charge #1, 2

- Prototype wire scanner for transverse profiles
 - Horizontal and Vertical
 - Installed and Tested at PIP2IT
 - For use in MEBT and Beam Transfer Line

SC1 Scarpine



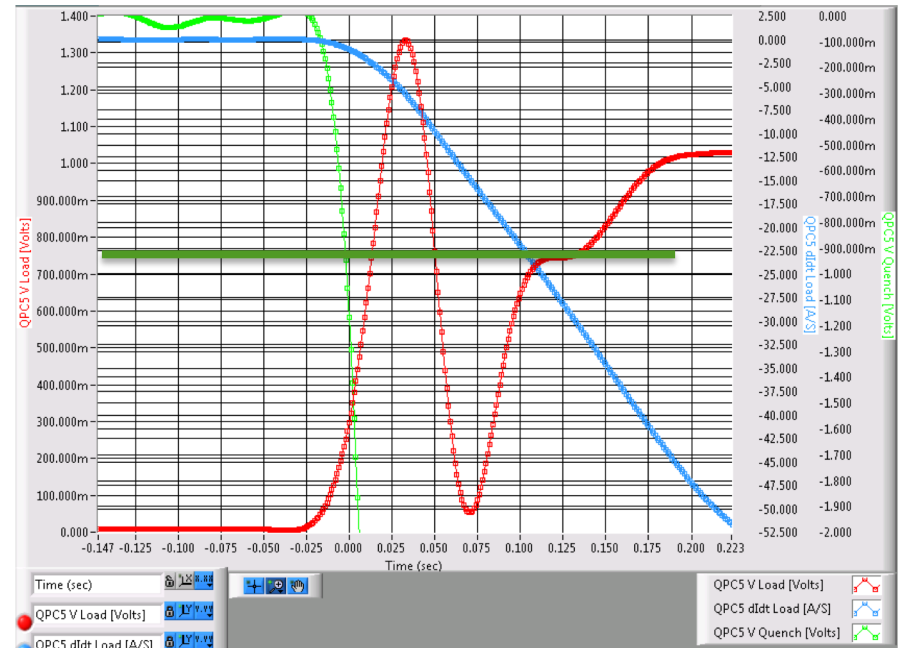
Progress to date: QPM Prototype Test

Charge #1, 2

- HWR and SSR CMs contain superconducting magnets
 - Quench Protection Monitor hardware to:
 - Detect quench
 - Remove power from magnets
 - Complete Prototype system designed and tested in VTS
 - Drove systems to quench with heaters
 - 121.03.05 Magnets & PS
 - Breakout presentation

SC1-Hanna

- Design Review: Sept 27 2018
 - TC ED0008375
- Procurement of QPMs to support HWR and SSR1 at PIP2IT



Quench Detector V
threshold -1 V

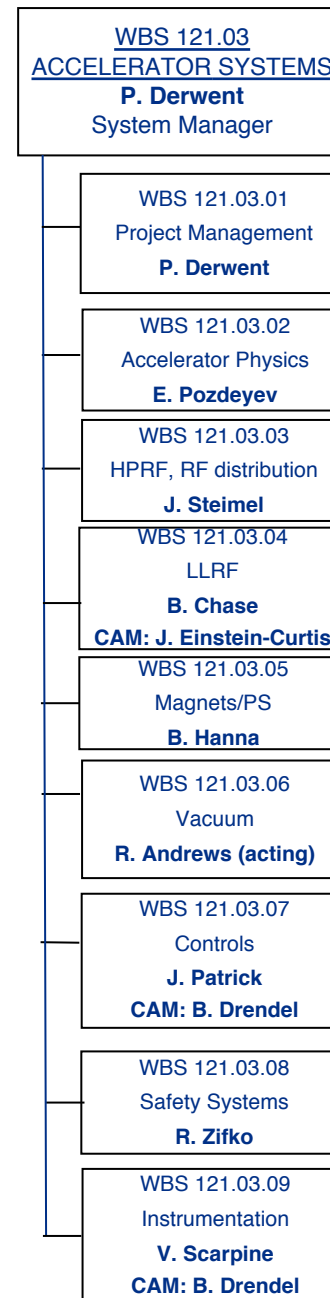
Magnet Load Voltage
dI/dt

T5 Milestones – Accelerator Systems

L3	T5 Milestone	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027
Safety Systems	PIP2IT Radiation Safety Interlock System Validated										
Safety Systems	PIP2IT Electrical Safety System Validated										
Accelerator Physics	PIP-II Preliminary CryoPlant Building Assessment Complete										
Safety Systems	PIP2IT Oxygen Deficiency Hazard Monitoring System Validated										
High Power Radio Frequency	Couplers Test Stand 30kW RF System tested										
High Power Radio Frequency	Spoke Test Cryostat 10kW RF System tested										
Accelerator Physics	PIP2IT Assessment Proposed										
Magnets and Power Supplies	PIP2IT Coupler bias ready for RF test of HWR and SSR1										
Low Level Radio Frequency	PIP2IT HWR Low Level Radio Frequency Hardware Ready for RF										
Low Level Radio Frequency	PIP2IT HWR RF Protection Interlocks Ready for RF										
High Power Radio Frequency	HWR 7kW RF System ready for RF Test before HWR RF tests start										
Low Level Radio Frequency	PIP2IT SSR Hardware Ready for RF										
Low Level Radio Frequency	PIP2IT SSR RF Protection Interlocks Ready for RF										
Magnets and Power Supplies	PIP2IT Ready to test HWR and SSR1 CryoModule 1 (before full power RF test)										
Accelerator Physics	Preliminary Shielding design for CD-2 Complete										
High Power Radio Frequency	SSR1 7kW RF ready for RF test in PIP2IT										
High Power Radio Frequency	SSR1 7kW RF System tested completed in PIP2IT										
Beam Instrumentation	Beam Instrumentation Ready for Beam Commissioning of HWR and SSR1 at PIP2IT										
Low Level Radio Frequency	LLRF SSR1 Successful Generator Driven Resonator operation demonstrated in CW for all 8 cavities										
Low Level Radio Frequency	PIP2IT Beam Pattern Generator Prototype ready for installation										
Low Level Radio Frequency	Pulsed Mode Development Complete										
Beam Instrumentation	Longitudinal Profile Monitor System Ready for TRS beam commissioning at PIP2IT										
Accelerator Physics	Documentation and Reports for for CD-3 Complete										
Accelerator Physics	PIP-II Preliminary Assessment Ready										
Accelerator Physics	Booster Preliminary Assessment Proposed										
Magnets and Power Supplies	Magnets and Power Supplies Test Infrastructure ready for installation										
High Power Radio Frequency	HTS-2 40kW RF System tested before Test Infrastructure HTS-2 Commissioning										
Safety Systems	Cryo Building Oxygen Deficiency Hazard Monitoring System Validated										
High Power Radio Frequency	PIP2IT 40kW RF System tested										
High Power Radio Frequency	SSR2 20kW RF System tested in PIP2IT										
Magnets and Power Supplies	PIP2IT Coupler bias ready for RF Test of SSR1 Cryomodule 1 Production and SSR2										
Magnets and Power Supplies	BTL Magnets and Power Supplies Ready for Installation (Before BO of BTL)										
High Power Radio Frequency	SSR1 7kW 325 MHz RF System fabrication and tests of components complete										
Accelerator Physics	PIP-II Final Assessment Ready for Review										
High Power Radio Frequency	SSR2 20kW 325 MHz RF System fabrication and tests of components complete										
Safety Systems	Linac Oxygen Deficiency Hazard Monitoring System Validated										
Safety Systems	Beam Transferline-Beam Absorber Line Radiation Safety Interlock System Validated										
Safety Systems	Linac Electrical Safety System Validated										
Safety Systems	Beam Transferline-Beam Absorber Line Electrical Safety System Validated										
Magnets and Power Supplies	Warm Magnets and Power Supplies Ready for Installation										
Safety Systems	Linac Radiation Safety Interlock System Validated										
Magnets and Power Supplies	PIP-II Quench Protection Monitors and Power Supply system ready for final install - SSR1										
High Power Radio Frequency	LB650 40kW 650 MHz RF System fabrication and tests of components complete										
High Power Radio Frequency	HB650 70kW 650 MHz RF System fabrication and tests of components complete										
Magnets and Power Supplies	PIP-II Quench Protection Monitors and Power Supply system ready for final install - SSR2										
Accelerator Physics	Booster Final Assessment Ready for Review										
Low Level Radio Frequency	PIP-II Low Level Radio Frequency Ready for Installation and commissioning										

WBS 121.03 Accelerator Systems

- Experienced team with both operational and project expertise, both on the technical and management side
 - NOvA
 - LCLS-II
 - LBNF
 - Mu2e
 - g-2
 - FRIB



Next Steps toward CD-2/3a

- Complete the details for the RLS
 - FY19 & FY20 in P6
 - Vacuum, Controls, LLRF
 - Detailing the out years
 - BOE documents need to be completed and validated
 - Start executing the monthly reporting cycle
- Advance Design to Preliminary Stage
 - Design Review Plan as previously presented
 - Advanced far enough to understand the cost with appropriate level of estimate uncertainty
- Complete Prototypes necessary to understand performance, cost, & schedule
 - Low Power Laser Profile Monitor at PIP2IT
 - LLRF Station to support HWR and SSR1 at PIP2IT
 - Resonance Control
 - Protection Interlocks
 - 325 MHz 7 kW amplifier test at Bhabha Atomic Research Center (BARC) Mumbai
- No 3a scope in this L2 section

- Personnel Safety and environmental and equipment protection are the highest priorities in the PIP-II Project.
 - included in all work via Safety By Design Assessment
- Specific hazards in Hazard Analysis Report *pip2-docdb #140*
- All activities will be in full compliance with the PIP-II Integrated ESH Management program *pip2-docdb #141*
 - Laboratory and DOE standards and practices
 - Fermi ES&H Manual, Radiological Control Manual, etc
 - Division/Area specific Hazards Analyses and Training
 - Appropriate National / International Codes
 - For example, Power Amplifiers
 - National Electrical Code, NFPA 70
 - OSHA 29 CFR, Part 1910, Subpart S, Electrical
 - International Electrotechnical Commission (IEC) standard IEC 61010-1

- Quality Assurance and Control
 - PIP-II Project Quality Assurance Plan *pip2-docdb #142*
 - Quality is integrated into the design process
 - Requirements, Interfaces, Manufacturing plans, Acceptance Criteria
 - Responsibility with L3s
 - Integrate Quality into the technical design
 - Example: QPM boards
 - follow existing Division and Department procedures
 - ADDP-EE-2003 Maintenance and Quality Control Guidelines
 - ADDP-EE-2004 Quality Control and Maintenance Considerations in Equipment Design
 - Define acceptance criteria for procurements / in-kind contributions
 - Example: 325 MHz 7 kW power amplifiers from BARC
 - Criteria are defined in the amplifier testing procedures
 - *TC ED0006507, TC ED0006484*

Accelerator Systems Risks

- High Risks: **2**
- Medium Risks: **8**
- Low Risks: **4**

High Risks

RI-ID	Title
RT-121-03-002	RF Power Amplifiers have technical issues
RT-121-03-003	High Power Circulator fails

High Risks are performance related

- Director's CD-1 Review (October 2017)
 - 4 Recommendations
 - 3 closed
 - 1 open: Action plan with scheduled completion in 2020

- DOE CD-1 IPR (December 2017)
 - 6 recommendations
 - 1 closed
 - 5 open
 - 1 to be closed by December 2018
 - 4 to be closed by CD-2, 3 with existing action plans

Breakout Presentations

Breakout Presentations		
SC1 Accelerator Systems		
121.03.02	Linac Beam Dynamics	A Saini
121.03.03	High Power RF and RF Distribution	J Steimel
121.03.04	Low Level RF	B Chase
121.03.05	Magnets and Power Supplies	B Hanna
121.03.07	Controls	J Patrick
121.03.09	Instrumentation	V Scarpine

Summary

- L2 and L3 requirements for Accelerator Systems are defined in L2 SFCD and L3 FRS.
- Preliminary designs in hand, many have been/will be validated in PIP2IT.
- Project Processes are in place and functioning
- Risk Management, ES&H, Quality Management, Reviews
 - PIP2IT and Test Stands important for risk mitigation activities
- Path to completing the RLS is understood
- We are on track for CD-2 and look forward to your feedback
- Thank you for your attention

END