

121.3.16 Linac - Beam Instrumentation

Breakout Session: RF Systems, Controls, and Instrumentation

Victor Scarpine

PIP-II Director's Review

10-12 October 2017

In partnership with:

India Institutes Fermilab Collaboration

Istituto Nazionale di Fisica Nucleare

Science and Technology Facilities Council

Outline

- Requirements
- Conceptual Design, Maturity
- Scope/Deliverables
- Interfaces
- Technical Progress to Date
- ESH&Q
- Risk
- Cost
- Schedule
- Summary

About Me:

Victor Scarpine, PIP-II Beam Instrumentation, Level 3

- L3 Manager for PIP-II linac beam instrumentation
- Relevant experience
 - Physicist – Ph.D. 1992, University of Illinois
 - Member of Fermilab accelerator division beam instrumentation department as Application Physicist III
 - 15 years experience in development and operation of beam instrumentation
 - Development of HINS front-end beam instrumentation
 - Development of Fermilab RFQ commissioning beam instrumentation
 - Development of PIP2IT beam instrumentation

WBS L3 System Requirements

Charge #1

- Linac Beam Instrumentation shall measure, process, and record linac beam parameters required to verify and diagnose changes in beam quality and losses for commissioning and normal operation
 - Beam current monitors (BCM)
 - Measure current and intensity of the beam transported from the source thru the LEBT, MEBT, SC Linac, and transport sections.
 - Integration of beam current measurements into MPS
 - Measurement of MEBT chopper bunch-by-bunch extinction efficiency

WBS L3 System Requirements (cont)

Charge #1

- Beam phase and transverse position monitors (BPM)
 - Measurements of transverse position, phase and intensity via warm and cold BPMs
 - FRS ED0003675 – MEBT BPM
 - TRS ED0005680 – SSR1 BPM
- Beam loss monitors (BLM)
 - Measure of ionizing particles and neutrons
- Beam profile measurements
 - Transverse and longitudinal profiles
 - FRS ED0004340 – MEBT wire scanner
 - Transverse emittance
 - FRS ED0004080 – MEBT emittance scanner

Conceptual Design – Beam Current

Charge #1

- Production of 3 different types of primary Beam Current Monitor (BCM) systems
 - Toroids, Direct-Current Current Transformer (DCCT) and wall current monitors
- BCM plan is based on systems currently operating at Fermilab
 - Pick up signals are conditioned in a transition board, digitized and processed by a digitizer, and interfaces to the control system through a front-end
 - Resources will be applied to the design, programming, and testing of alternatives to the current front end standard during the R&D phase

Conceptual Design – Beam Position and Phase

Charge #1

- BPM system are based on 4-button BPM vacuum pickup design
 - Separate designs for warm and cold BPMs
- Electronics are based on analog transition cards and FPGA digitizer cards for signal analysis along with necessary FPGA firmware and front-end software
- Bunch-by-bunch capable BPM measurement system for four of the MEBT BPMs will utilize oscilloscopes for signal acquisition

Conceptual Design – Beam Loss

Charge #1

- BLM systems is based on a combination of ionization beam loss monitors, fast PMT-based beam loss monitors and neutron detectors
- Electronics are based on analog transition cards and VME-based FPGA digitizer cards for signal analysis along with necessary FPGA firmware and front-end software

Conceptual Design – Beam Profiles

- Transverse beam profiles
 - Wire-based transverse profile monitor
 - Two-wire secondary emission monitors
 - Linear motion actuators and FPGA-based signal processing electronics
 - Installed into warm MEBT and transfer beamline
 - Laser-based transverse beam profile monitor
 - Installed in cold section of SC linac
 - Single laser source located in a laser room, outside of the beam enclosure and near the ion source.
 - Enclosed line transports laser light from the laser room via fiber optics or free-space to each laser transverse profile monitor locations
 - Laser monitor will include a light-tight optics box with required optics and motion to provide the required laser scanning across the beam, as well as electron collection to measure the profile

Conceptual Design – Beam Profiles (cont)

Charge #1

- Transverse emittance monitor systems
 - LEBT - Allison-style emittance scanners
 - PC-based DAQ and controls
 - MEBT - Allison-style emittance scanner
 - PC-based DAQ and controls
 - Transfer line - laser-based emittance scanner
- Longitudinal beam profiles
 - MEBT – laser-based profiler
 - Part of transverse laser profiler system
 - Low-energy end of SC linac – laser-based profiler
 - High energy end of SC linac – requested but no conceptual design yet

Scope and Deliverables – Beam Current

Charge #1

- Deliverables:
 - Beam current monitors
 - Eight toroid-type monitors
 - Four DCCT monitors
 - Two wall current monitors
 - Signal processing electronics, crates and cables R&D prototyping at PIP2IT
 - Three toroid-type monitors, one DCCT, one wall current monitor

Scope and Deliverables – Beam Position

Charge #1

- Deliverables:
 - Beam position monitor pickups
 - 89 warm 4-button pickups
 - 37 cold 4-plate pickups in HWR, SSR1 and SSR2
 - Signal processing electronics, crates and cables
 - Fermilab provides all cold BPMs
 - Fermilab provides 12 MEBT 4-button BPMs
 - IIFC to provide R&D prototype signal processing electronics
 - IIFC provides 78 4-button warm BPM for construction
 - IIFC provides 512 channels of analog and digital electronics for construction

Scope and Deliverables – Beam Loss

- Deliverables:
 - Beam loss monitor pickups
 - 115 ionization chamber pickups
 - 115 PMT-based scintillator pickups
 - 25 neutron detectors
 - Signal processing electronics, crates and cables
 - IIFC provides
 - 115 assembled and tested ionization loss monitor detectors
 - 115 assembled and tested PMT-based fast loss monitor detectors
 - 25 assembled and tested neutron detectors
 - Analog and digital DAQ electronics, electronic crates and software to support basic operation of above loss monitor detectors
 - HV power supplies to operate above list of loss monitor detectors

Scope and Deliverables – Beam Profile

Charge #1

- Deliverables:
 - Beam profile monitors
 - 20 laser-wire transverse profile monitors
 - 4 wire scanner transverse profile monitors
 - 4 transverse emittance scanners
 - Signal processing electronics, crates and cables
 - Fermilab provides all beam profile monitors
 - Fermilab testing LEBT and MEBT Allison emittance scanner at PIP2IT
 - Fermilab prototyping wire profile monitor and laser wire profile monitor at PIP2IT
 - Fermilab prototyping MEBT laser-based longitudinal profile monitor at PIP2IT

Interfaces

Charge #1

	Warm Front End WBS 121.3.3	HWR WBS 121.3.4	SSR1 WBS 121.3.5	SSR2 WBS 121.3.6	LB650 WBS 121.3.7	HB650 WBS 121.3.8	RF Power WBS 121.3.9	RF Integration WBS 121.3.10	Cryo Systems WBS 121.3.11	Warm Units WBS 121.3.12	Magnet PS WBS 121.3.13	Beam Trans. Line WBS 121.3.14	Beam Absorber WBS 121.3.15	Beam Instrum. WBS 121.3.16	Control Sys. WBS 121.3.17	Vacuum WBS 121.3.18	General Supt. Serv. WBS 121.3.19	Safety Systems WBS 121.3.20	Test Infrastructure WBS 121.3.21	Instal., Integ., Com. WBS 121.3.22	Booster WBS 121.4.1	RR/MI WBS 121.4.2	Conv. Facilities WBS 121.5	
Warm Front End WBS 121.3.3																								
HWR WBS 121.3.4	ED0002529																							
SSR1 WBS 121.3.5																								
SSR2 WBS 121.3.6																								
LB650 WBS 121.3.7																								
HB650 WBS 121.3.8																								
RF Power WBS 121.3.9	Y	ED0002529	ED0004129																					
RF Integration WBS 121.3.10	Y		ED0004129					ED0004290 ED0005489																
Cryo Systems WBS 121.3.11		ED0002529	ED0004129	Y	Y	Y																		
Warm Units WBS 121.3.12					ED0003441	ED0003441																		
Magnet PS WBS 121.3.13		ED0002529	ED0004129	Y																				
Beam Transfer Line WBS 121.3.14																								
Beam Absorber WBS 121.3.15																								
Beam Instrum. WBS 121.3.16	Y	ED0002529	ED0004129					Y	Y			ED0003441												
Control Sys. WBS 121.3.17	Y	Y	Y	Y	Y	Y	Y	ED0005489	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Vacuum WBS 121.3.18	Y	ED0002529	ED0004129	Y	Y	Y						Y	Y									Y	Y	Y
General Supt. Serv. WBS 121.3.19																								
Safety Systems WBS 121.3.20	Y																							Y
Test Infrastructure WBS 121.3.21		ED0002529	ED0004129		Y	Y	Y	Y																Y
Instal., Integ., Com. WBS 121.3.22		ED0002529 F10051442	ED0004129 F10051442	F10051442	F10051442	F10051442						Y	ED0003441											Y
Booster WBS 121.4.1																								Y
RR/MI WBS 121.4.2																								Y
Conv. Facilities WBS 121.5	Y	ED0002529 F10051442	ED0004129 F10051442	F10051442	F10051442	F10051442	F10051442																	Y

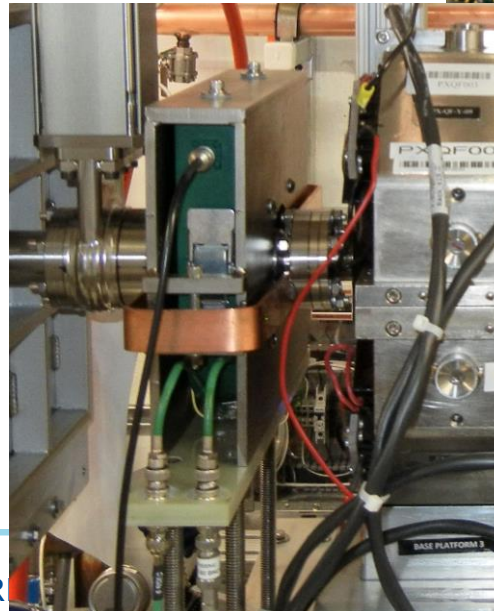
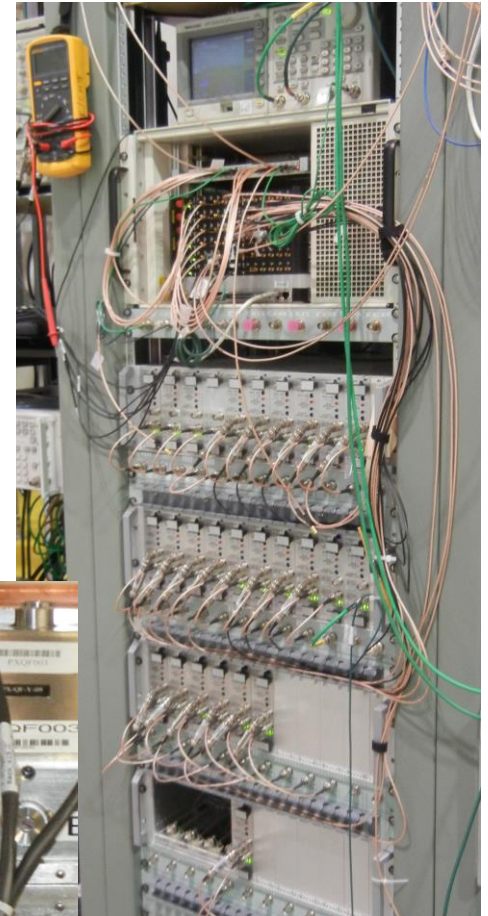


Interfaces

- Two primary interfaces for Instrumentation systems:
 1. Controls system
 - Data acquisition through ACNET
 - Timing and event distribution
 - Machine protection
 2. All beamline components for beam measurements
 - LEBT, MEBT, HWR, SSR1, SSR2, LB650, HB650, transport line
 - Mechanical installation of instrumentation detectors
 - Signal and HV cabling connections and distribution

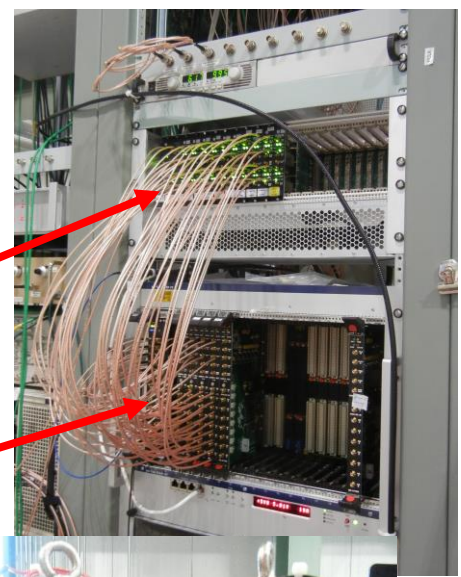
Progress to date – Beam Current

- Installation and testing of current measurements at PIP2IT
 - PIP2IT LEBT – DCCT and Toroid
 - PIP2IT MEBT – Toroids, Faraday cup dump, ring pickups, wall current monitor and EIP(scrapers)
- Utilize FPGA-based 8-channel, 125 MHz, 14 bit digitizer cards
 - Integrates with MPS
- Analog transition/bias cards
 - Bias up to +100 volts

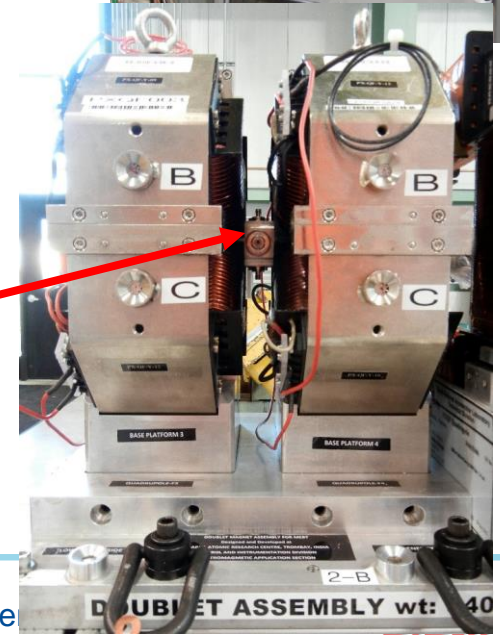
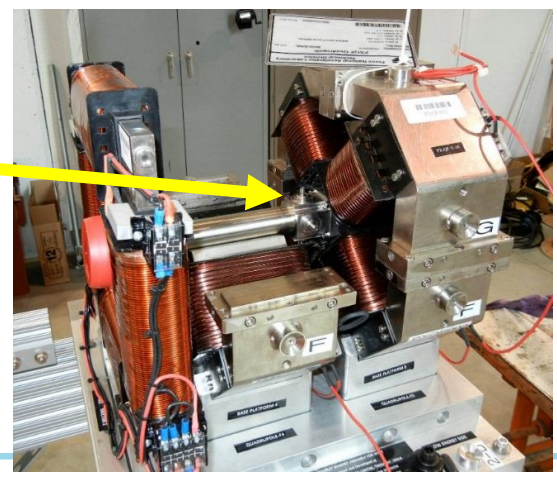
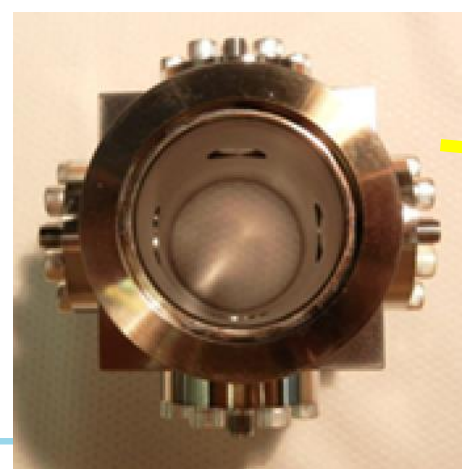


Progress to date – BPM Development

- Installation and testing of BPMs in PIP2IT MEBT
 - 4-button BPMs attached to quad magnet
 - DAQ with FPGA-based electronics for CW and pulsed beam
 - Analog filter & amp boards
 - 8 channel, 14 bit, 125 MSPS boards



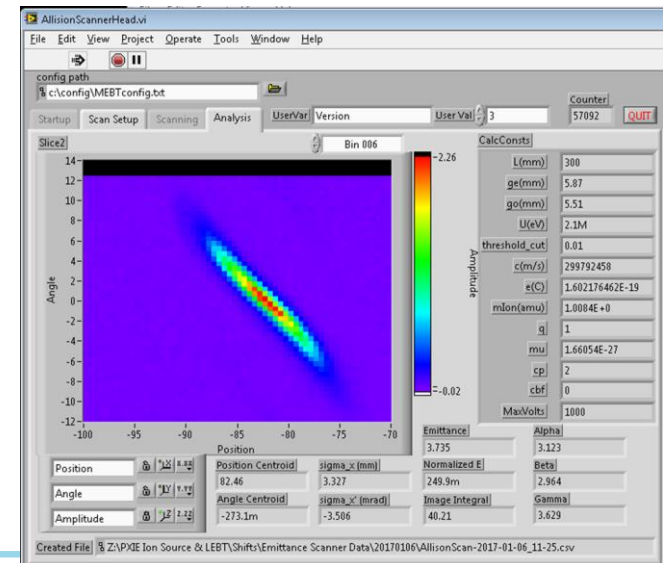
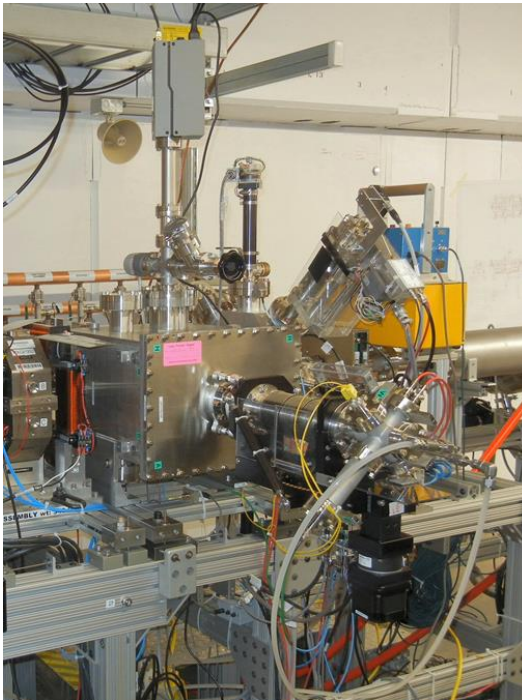
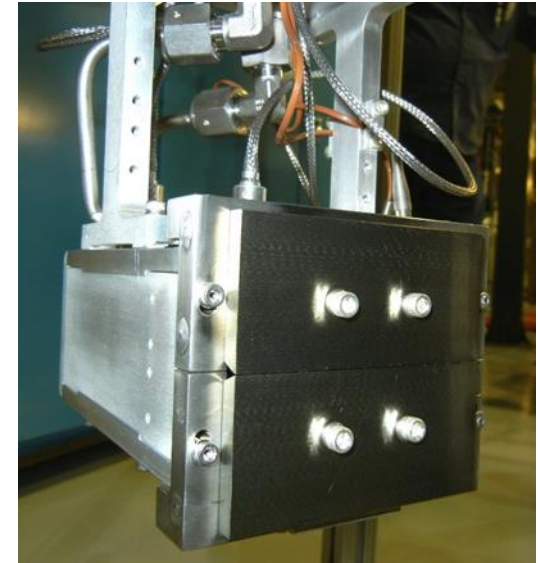
4-button BPM



Progress to date – Transverse Emittance

Charge #1

- Installation and testing of emittance scanners in PIP2IT LEBT and MEBT
 - Water-cooled Allison-style scanners
 - PC-based DAQ and motion control



ESH&Q

- Electrical hazards associated with these systems are covered under the codes below:
 - National Electrical Code, NFPA 70
 - OSHA 29 CFR, Part 1910, Subpart S, Electrical
 - Fermilab ESH&Q Manual, Fermilab Electrical Safety Program
- Domestically procured electrical equipment will be National Recognized Testing Lab (NRTL) certified.
- Lasers present a unique hazard for PIP-II profile instrumentation. These systems are covered under safety documents:
 - Fermilab FESHM 4260 – Lasers
 - ANSI Z136.1 – Safe Use of Lasers

Risk: Instrumentation

- Beam current measurements for long pulse or CW operation
- Integration of instrumentation into MPS
- Choice of laser profiling technology

Title	Probability	Probability Score	Impact Score - Cos	Impact Score - Schedu	Risk Rank	P * Impact (k\$)	P * Impact (months)
Beam current measurements for long pulse or CW operation	50.00%	4 (H)	2 (M)	3 (H)	3 (High)	125	9.0
Integration of instrumentation into MPS	50.00%	4 (H)	2 (M)	3 (H)	3 (High)	0	3.0
Choice of laser profiling technology	25.00%	3 (M)	2 (M)	3 (H)	3 (High)	50	1.5

Cost Summary

Charge #2

WBS Element (BI)	Hours	Labor (\$000)	M&S (\$000)	Est. Uncertainty (\$000)		Total Cost Incl. Uncrty.
	P6 Hours	P6 Base Cost	P6 Base Cost	Total	% of Base	
121.3.16.2 - Linac - BI - Project Management and Coordination	5,602	\$ 1,212.9	\$ 51.2	\$ 126.4	10.0%	\$ 1,390.4
121.3.16.3 - Linac - BI - Beam Position Monitor System	9,919	\$ 1,338.9	\$ 870.2	\$ 753.1	34.1%	\$ 2,962.1
121.3.16.4 - Linac - BI - Beam Current Monitor System	8,900	\$ 1,344.6	\$ 1,644.1	\$ 1,031.1	34.5%	\$ 4,019.7
121.3.16.5 - Linac - BI - Beam Loss Monitor System	7,842	\$ 1,164.6	\$ 144.3	\$ 392.7	30.0%	\$ 1,701.6
121.3.16.6 - Linac - BI - Beam Profile Monitor Systems (BProMS)	8,400	\$ 1,157.3	\$ 1,897.5	\$ 1,221.9	40.0%	\$ 4,276.7
Grand Total	40,663	\$ 6,218.3	\$ 4,607.1	\$ 3,525.1	32.6%	\$ 14,350.5
Note: P6 base cost = BOE + overheads and escalation						

- Note: As stated earlier, IIFC will provide a large portion of the BPM system and also the BLM system and are not included in this cost summary.

BOE Summary

Charge #2

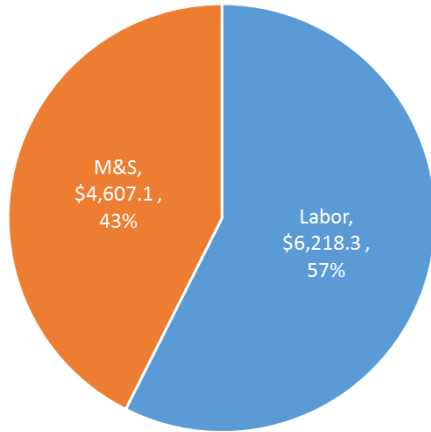
WBS Number	Title	Docdb #
121.3.16.2	Linac - BI - Project Management and Coordination	650-v4
121.3.16.3	Linac - BI - Beam Position Monitor System	653-v6
121.3.16.4	Linac - BI - Beam Current Monitor System	656-v7
121.3.16.5	Linac - BI - Beam Loss Monitor System	659-v4
121.3.16.6.1	Linac - BI - BProMS - Transverse Profile Monitor System	662-v4
121.3.16.6.3	Linac - BI - BProMS - Transverse Emittance Monitor System	668-v4

BI = Beam Instrumentation

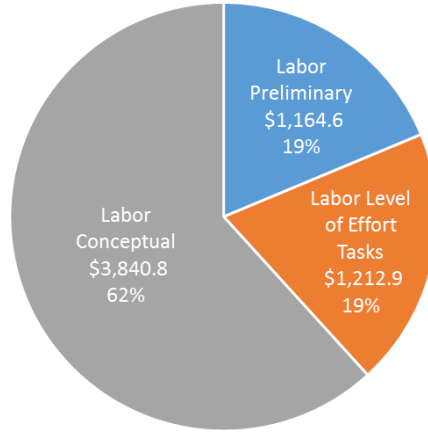
Cost Drivers and Estimate Maturity

Charge #2

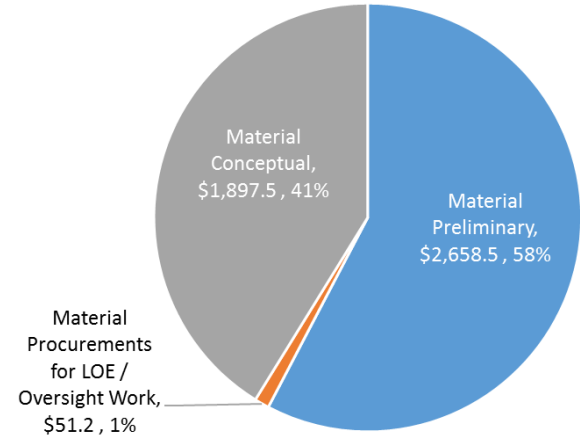
Cost Distribution - P6 Base Cost



Labor Cost Distribution - P6 Base Cost



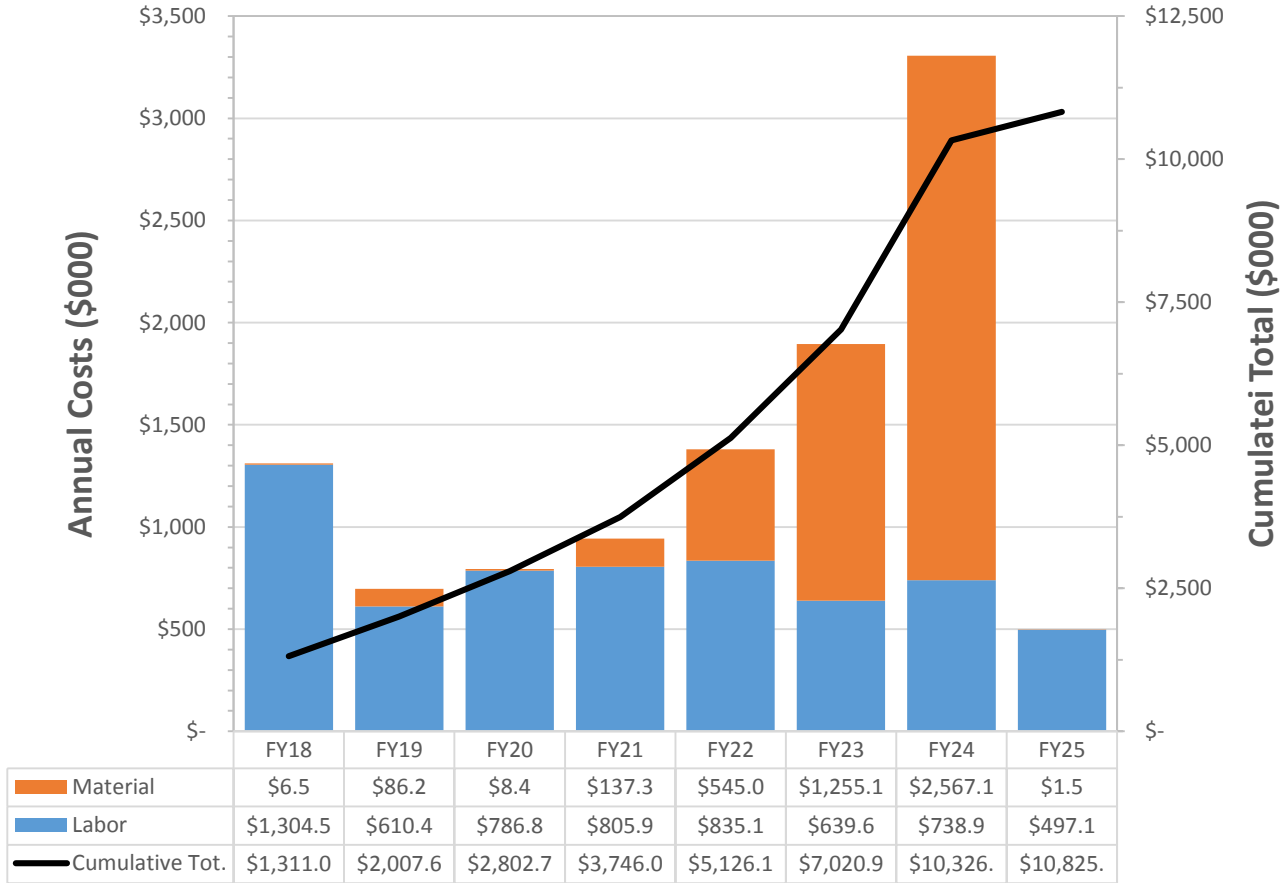
M&S Cost Distribution - P6 Base Cost



P6 Base Costs = BOE + Overheads + Escalation

Cost Profile – P6 Base Cost Only

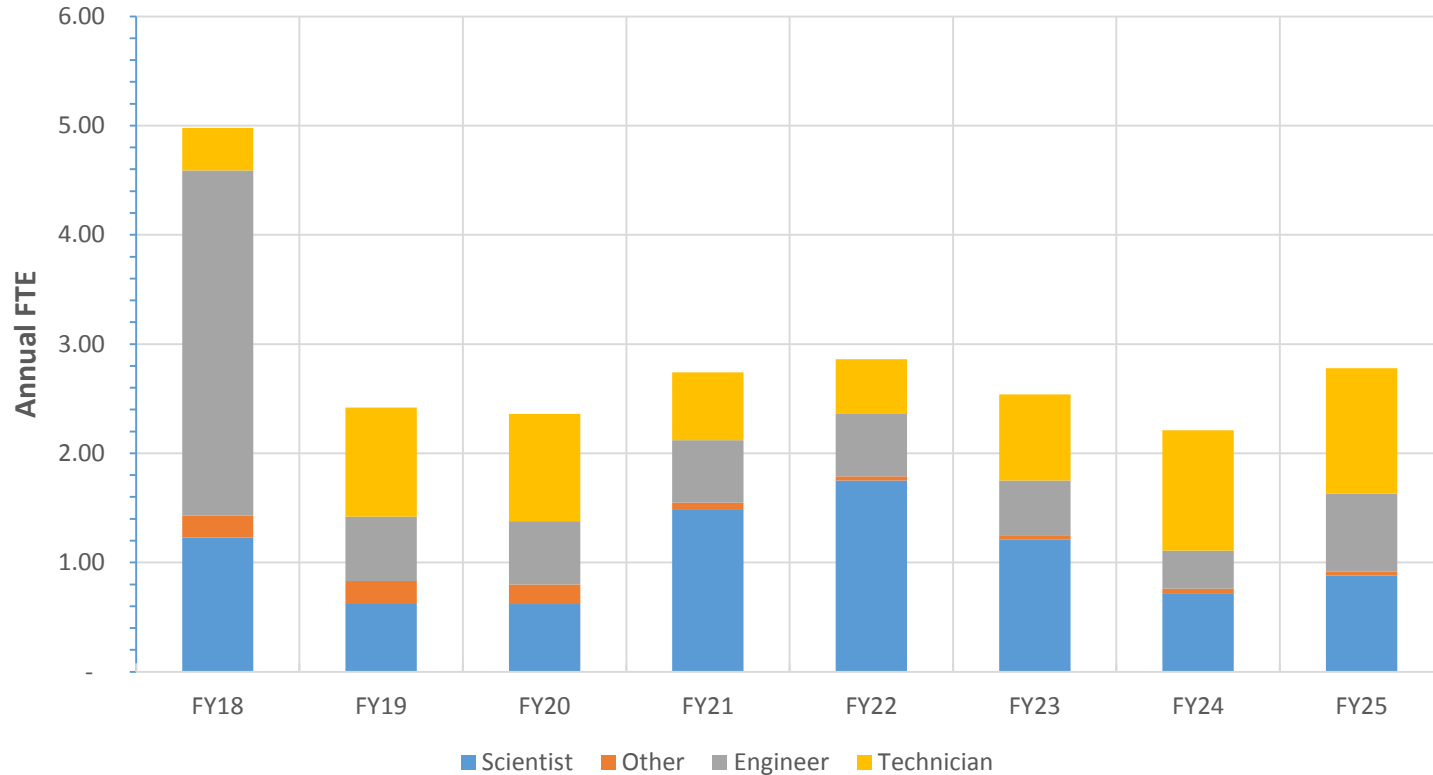
Charge #2



P6 Base Costs = BOE + Overheads + Escalation

Labor Profile – P6 Hours/FTE

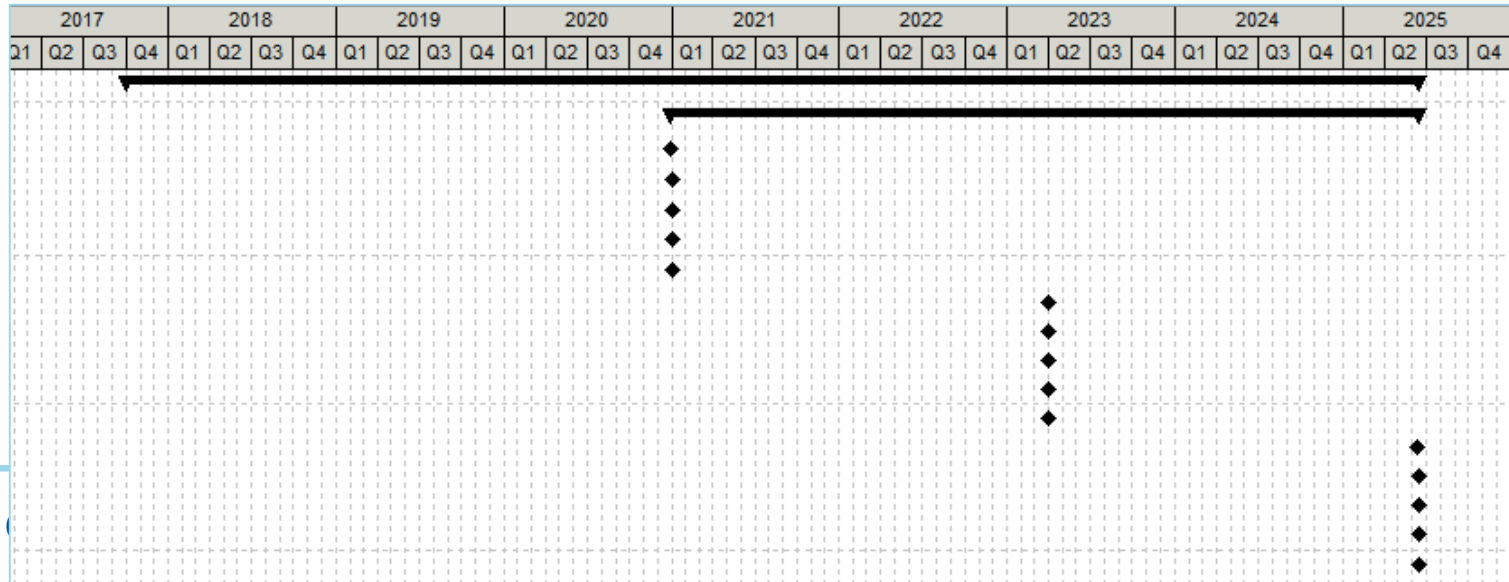
Charge #2



Schedule – Beam Instrumentation

Charge #2

Activity ID	Activity Name
[-] 121.3.16	Linac - Beam Instrumentation (BI)
[-] 121.3.16.1	Linac - BI - T4 Milestones
A17765300	Linac - BI - BLM - R&DPh: T4 MS - Accepted IFC Prot. BLM Detectors and Electr. (6 m after HWR/SSR1 RF tested in PIP2IT)
A17764390	Linac - BI - BPM - R&DPh: T4 MS - Accepted IFC Prot. BPM Detectors and Electr. (6 m after HWR/SSR1 RF tested in PIP2IT)
A17764920	Linac - BI - BCM - R&DPh: T4 MS - Accepted Prot. BCM System (6 m after HWR/SSR1 RF tested in PIP2IT)
A17765330	Linac - BI - BProfM - TransvProf - R&DPh: T4 MS - Accept. Prot. Tr. Pr. M Syst. (6 m after HWR/SSR1 RF tested in PIP2IT)
A17765360	Linac - BI - BProfM - TransvEmitt - R&DPh: T4 MS - Acc. Prot. Tr. Em. M. System (6 m after HWR/SSR1 RF tested in PIP2IT)
A17765310	Linac - BI - BLM - ConstrPh: T4 MS - BLM System / Ready For Installation
A17764750	Linac - BI - BPM - ConstrPh: T4 MS - BPM System / Ready For Installation
A17765340	Linac - BI - BProfM - TransvProf - ConstrPh: T4 MS - Transv. Prof. Monitor System / Ready For Installation
A17765370	Linac - BI - BProfM - TransvEmitt - ConstrPh: T4 MS - Transv. Emitt. Monitor System / Ready For Installation
A17764930	Linac - BI - BCM - ConstrPh: T4 MS - BCM System / Ready For Installation
A17765320	Linac - BI - BLM - ConstrPh: T4 MS - BLM Stations Ready For Integration (before Linac colddown)
A17764810	Linac - BI - BPM - ConstrPh: T4 MS - BPM Stations Ready For Integration (before Linac colddown)
A17764940	Linac - BI - BCM - ConstrPh: T4 MS - BCM Stations Ready For Integration (before Linac colddown)
A17765350	Linac - BI - BProfM - TransvProf - ConstrPh: T4 MS - Tr. Prof. M. Stations Ready For Integration (before Linac colddown)
A17765380	Linac - BI - BProfM - TransvEmitt - ConstrPh: T4 MS - Tr. Em. M. Stations Ready For Integration (before Linac colddown)



Summary

- Instrumentation plan for PIP-II proceeding
- Most systems are in conceptual design
- Most conceptual designs based on well tested technology
- Conceptual design to final design appears fairly straight forward
- Many instrumentation systems being tested at PIP2IT
 - Testing at PIP2IT invaluable to instrumentation development
 - Risk items being addressed at PIP2IT
- We are ready for CD-1

END