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PIP-II Process Cooling System Requirements

Maurice Ball

PIP-II Technical Meeting

22 September 2015

Agenda

- PXIE LCW Design – A Quick Review
- PIP-II LCW Cooling Needs
- Conclusions/Outstanding issues/Assumptions

A Quick Review – LCW for PXIE

- Requirements
- Piping Schematic Layout at CMTF
- LCW System Progress Status

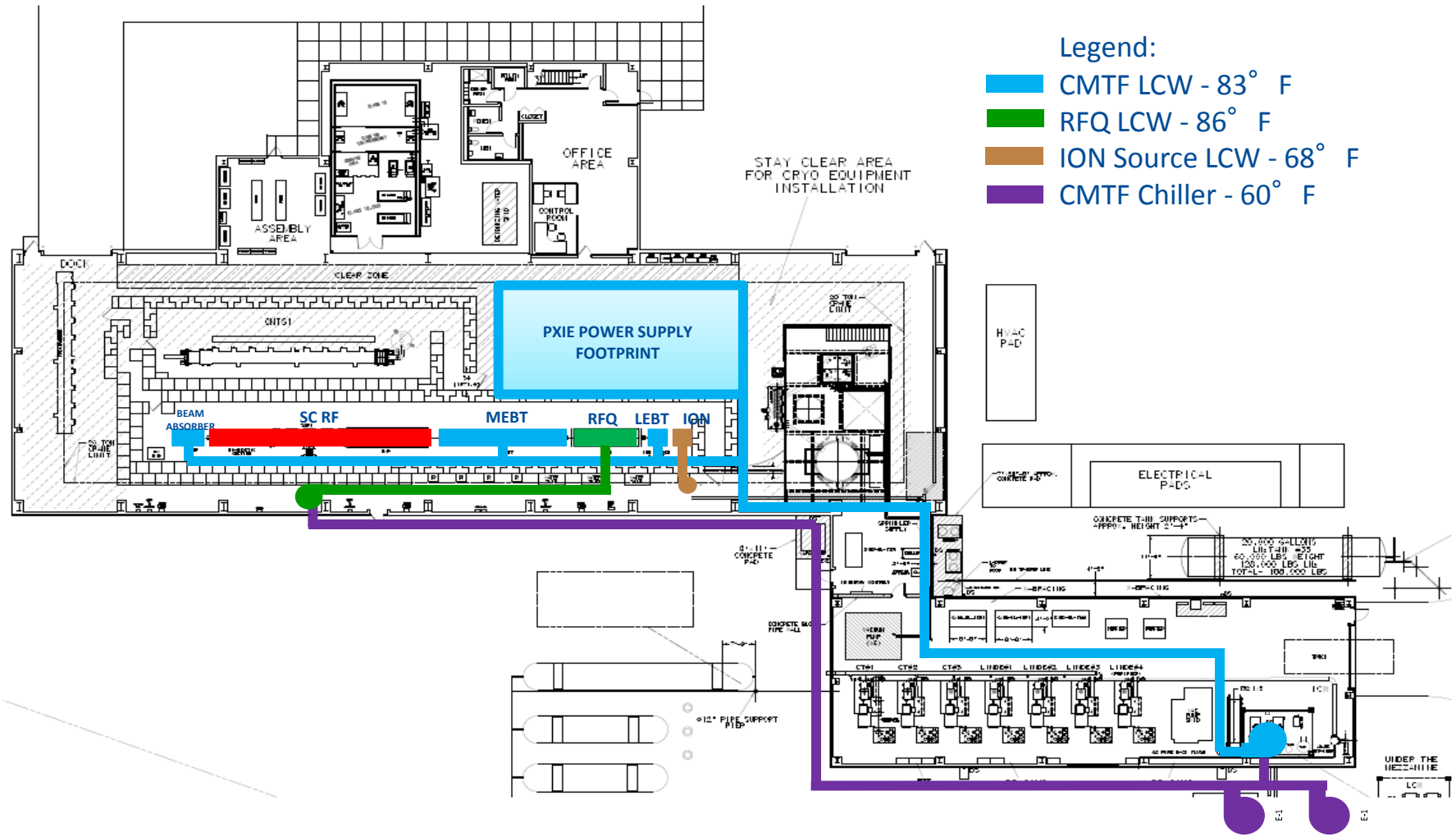
CMTF/PXIE LCW Requirements

PXIE LCW AT CMTF				
Equipment	Required Heat Load (KW)	Flow Rate (GPM)	Inlet T (°F)	
Ion Source[1]	7.4	6.2	68.0	
LEBT	24.9	12.0	83.0	
RFQ[2]	66.0	206.0	86.0	
RF Gallery[3]	569.2	303.0	**83.0**	Historical Default=90.0
MEBT	45.6	38.0	83.0	
Diagnostic Line	37.9	37.0	83.0	
OTHER LCW NEEDS AT CMTF				
CMTS1	125.0	48.0	83.0	

	(KW)	(GPM)	Tons of Refrigeration
PXIE LCW Total[1]	751.0	602.2	213.54
Other LCW Needs Total	125.0	48.0	35.54
Total LCW Cooling Needs at CMTF	876.0	650.2	249.09

Note:
1. Ion Source uses separate independent chiller skid.
2. RFQ cooling skid connects directly to CMTF chiller.
3. Critical Inlet (Supply) Temperature

PXIE LCW Cooling Layout at CMTF



PXIE LCW System Status

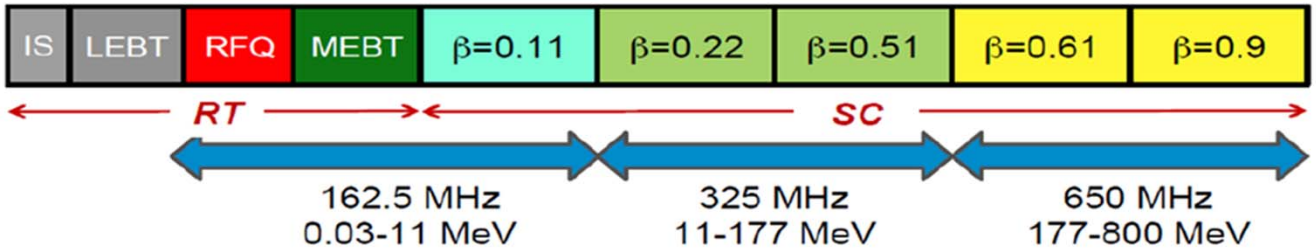
- Piping installation complete (CMTF)
- 315 ton chiller(s) installed
- Commissioned/operational August, 2015
- Piping insulation, final system tweaks remain

Review of PIP-II LCW Cooling Needs

- PIP-II LCW Requirements - Review each cooling circuit
- Process Piping Schematic Layout Scheme
- Temperature set point discussion
- Transport beamline cooling needs (i.e. warm magnets)

PIP-II LINAC Technology Map

PIP-II LINAC Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-11	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	11-38	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.51)	325	38-177	35/21/7	SSR, solenoid
LB 650 (β_G=0.61)	650	177-480	30/20/5	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	480-800	24/10/4	5-cell elliptical, doublet

All components CW-capable ***First HWR cavity recently tested at ANL***

Credit: P. Derwent Neutrino Beams &Instrumentation Workshop Presentation

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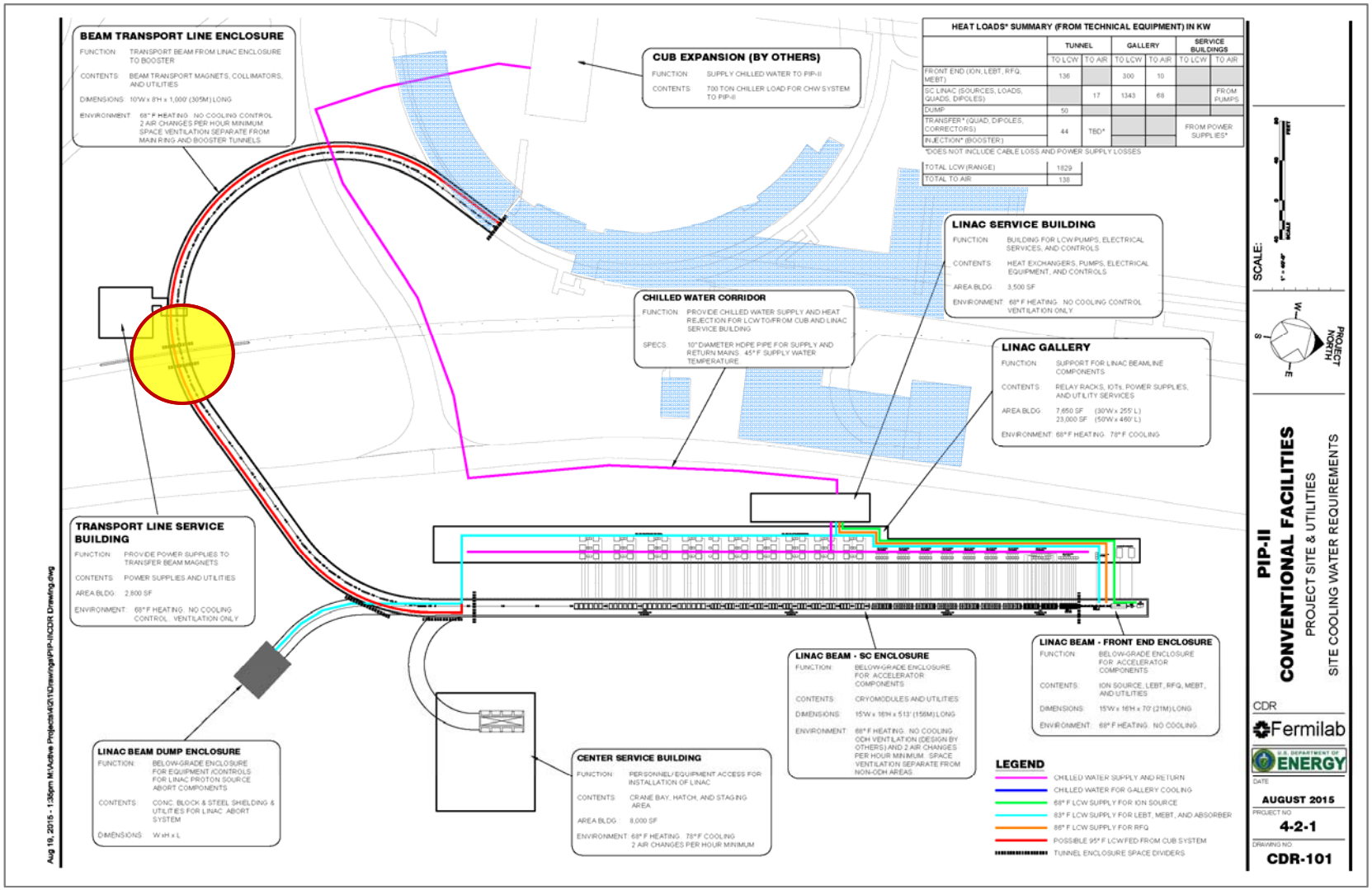
Cooling Requirements



Taken from Cooling Requirements Drawing

PIP-II LCW Requirements

Equipment	Required Heat Load (KW)	Flow Rate (GPM)	Inlet T (°F)
LINAC ENCLOSURE (Front End)[7]			
Ion Source[1]	15.8	3.9	68.0
LEBT	24.9	7.5	83.0
RFQ[2]	66.0	173.8	86.0
MEBT	36.5	38.9	83.0
TRANSFER LINE ENCLOSURE			
Magnets (Quads, Dipoles)[4,5]	65.0	25.1	95.0
Beam Dump	50.0	20.0	95.0
LINAC GALLERY (SC LINAC)[3,7]			
RFQ (162.5 MHz)	302.0	158.8	**83.0**
HWR (162.5 MHz)	106.0	159.3	**83.0**
SSR1 (325 MHz)	135.3	288.6	**83.0**
SSR2 (325 MHz)	228.0	604.0	**83.0**
LOW BETA (LB-650 MHz)	420.0	644.0	**83.0**
HIGH BETA (HB-325 MHz)	522.0	549.5	**83.0**

Note:
1. Ion Source cooling skid connects directly to facility chill water source (CHW).
2. RFQ cooling skid connects directly to facility chill water source (CHW).
3. Critical Inlet (Supply) Temperature - Historical Default = 90° F
4. Transfer Line magnet lattice optics data provided by A. Vivoli, V. Lebedev
5. Transfer line magnet flow data assume a 17° F temperature rise.
6. Transfer line magnet power supplies are estimates based on V. Lebedev.
7. LINAC equipment allowable operating temperature rise is limited by absolute flow rate requirements.

	(KW)	(GPM)	
LINAC Enclosure SubTotal[1]	143.2	224.1	**Tons of Refrigeration**
LINAC Gallery SubTotal	1713.3	2404.2	
LINAC (Enclosure and Gallery) Total	**1856.5**	**2628.3**	**527.89**
TRANSFER LINE (Enclosure and Gallery) Total	**115.0**	**45.1**	**32.70**

Temperature Set Point

- Circulators led the way
- Design constraints at original set temperature not achievable
- Achievable at 83ºF
- Chill Water (CHW) needed
- Pond Water (PW) and Industrial Cooling Water (ICW) ➔
  - 95ºF+ preferred
  - 90ºF borderline

Ion Source (1/2)

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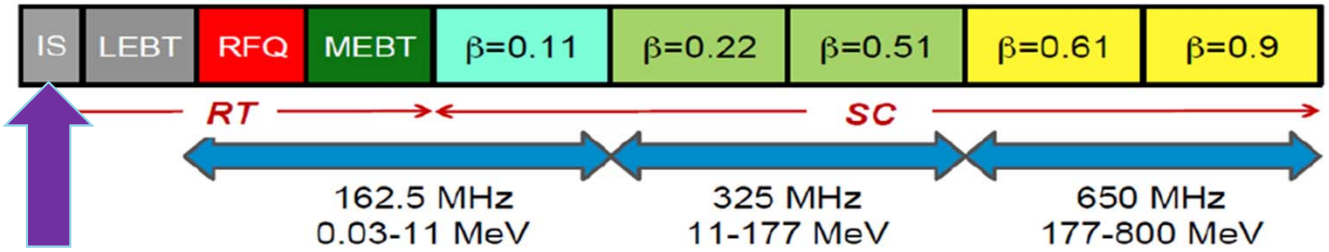
PIP-II LINAC Technology Map



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All components CW-capable ***First HWR cavity recently tested at ANL***

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Ion Source (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
Ion Source								
Source Body	1.0	3.9	2.2	49.0	90	60.0	68.0	80.0
Filament	1.0	0.5	0.3	49.0	90	60.0	68.0	80.0
Backplate	1.0	0.7	0.4	49.0	90	60.0	68.0	80.0
Plasma and Extraction Lens	1.0	1.8	1.0	49.0	90	60.0	68.0	80.0
Dipole Magnets	1.0	0.5	0.3	49.0	90	60.0	68.0	80.0
Open		8.4	4.8					
Subtotal		**15.8**	**9.0**					

LEBT (1/2)

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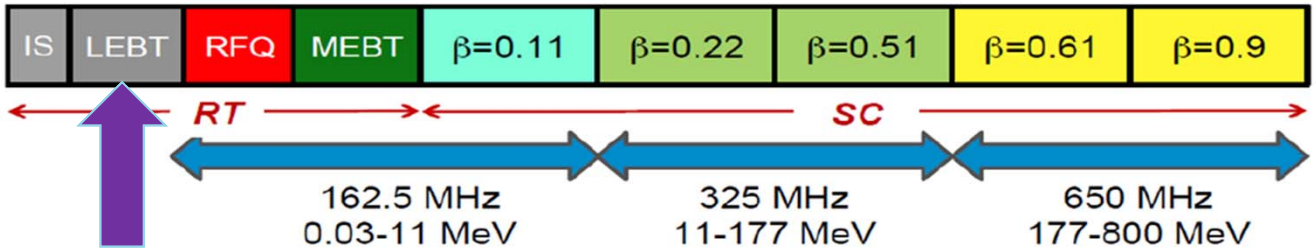
PIP-II LINAC Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-11	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	11-38	16/8/ 2	SSR, solenoid
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LEBT (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
LEBT								
Solenoids	3.0	22.5	4.2	60.0	90	30.0	83.0	119.0
Beam Absorber/Chopper	1.0	0.3	0.1	70.0	90	20.0	83.0	119.0
Scrappers	3.0	0.9	0.2	70.0	90	20.0	83.0	119.0
Faraday Cup/Temp. Dump	1.0	0.3	1.5	70.0	90	20.0	83.0	84.4
Allison Scanner	1.0	0.6	1.5	70.0	90	20.0	83.0	85.7
Movable Scraper	1.0	0.3	0.1	70.0	90	20.0	83.0	119.0
Subtotal		**24.9**	**7.5**					

RFQ and RF Gallery (1/3)

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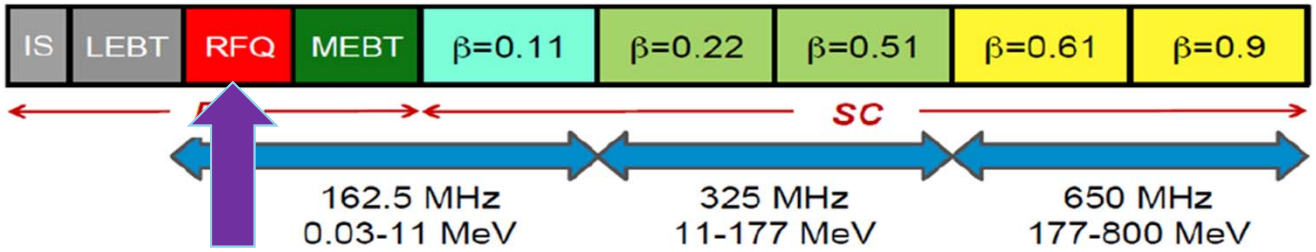
PIP-II LINAC Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-11	8/8/1	HWR, solenoid
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LB 650 (β_G=0.61)	650	177-480	30/20/5	5-cell elliptical, doublet
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RFQ and RF Gallery (2/3) – Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
RFQ								
Vanes (.1°C to.5°C)	16.0	31.0	37.5	70.0	90	20.0	86.0	91.6
Wall	32.0	29.5	133.1	70.0	90	20.0	86.0	87.5
PI-mode Rods (.1°C to.5°C)	32.0	5.5	3.2	70.0	90	20.0	86.0	97.7
Subtotal		**66.0**	**173.78**					

RFQ and RF Gallery (3/3) – Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
RF Gallery								
RFQ RF Source	2.0	300.0	112.8	70.0	90	20.0	83.0	101.0
RFQ Circulators (±1°F)	2.0		16.0		90	20.0	83.0	83.3
RFQ Circulator Loads	2.0		30.0		90	20.0	83.0	117.3
Ancillary Power		2.0						
Subtotal		**302.0**	**158.8**					

MEBT (1/2)

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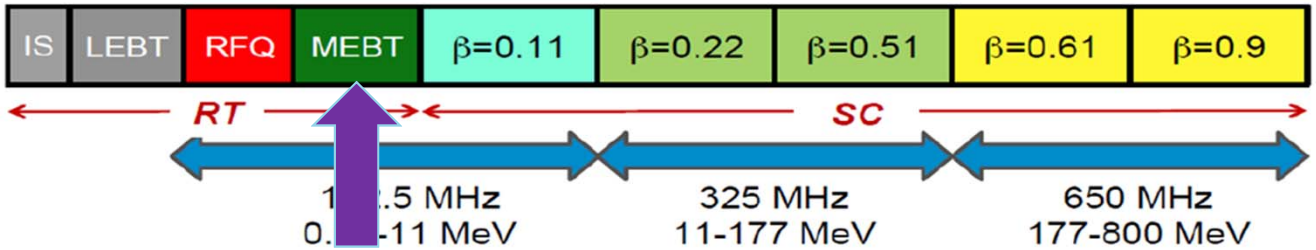
PIP-II LINAC Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-11	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	11-38	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.51)	325	38-177	35/21/7	SSR, solenoid
LB 650 (β_G=0.61)	650	177-480	30/20/5	5-cell elliptical, doublet
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All components CW-capable ***First HWR cavity recently tested at ANL***

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MEBT (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
MEBT								
Buncher Cavities (.1°C to .5°C)	3.0	18.0	33.8	70.0	90	20.0	83.0	86.6
Diagnostics (Slit Scanner)	1.0	10.5	3.9	70.0	90	20.0	83.0	101.0
50 Ohm Pulser	1.0	0.4	0.2		90	20.0	83.0	101.0
Quads (air cooled)	25.0	7.5						
200 Ohm Kicker System	2.0	0.1	1.0		90	20.0	83.0	101.0
Subtotal		**36.5**	**38.9**					

HWR β = 0.11 (1/2)

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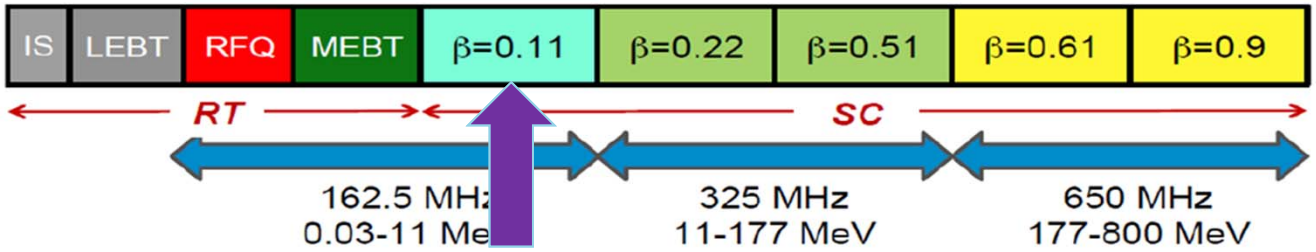
PIP-II LINAC Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
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HWR (β_{opt}=0.11)	162.5	2.1-11	8/8/1	HWR, solenoid
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All components CW-capable ***First HWR cavity recently tested at ANL***

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HWR β = 0.11 (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
HWR Gallery								
162.5 MHz Source	1	6	2.3	70	90	20	83.0	101
162.5 MHz Sources	7.0	98.0	37	70	90	20.0	83.0	101
162.5 MHZ Loads	8.0		120.0	70	90	20.0	84.3	121.8
Ancillary Power		2.0						
Subtotal		**106.0**	**159.3**					

SSR1 β = 0.22 (1/2)

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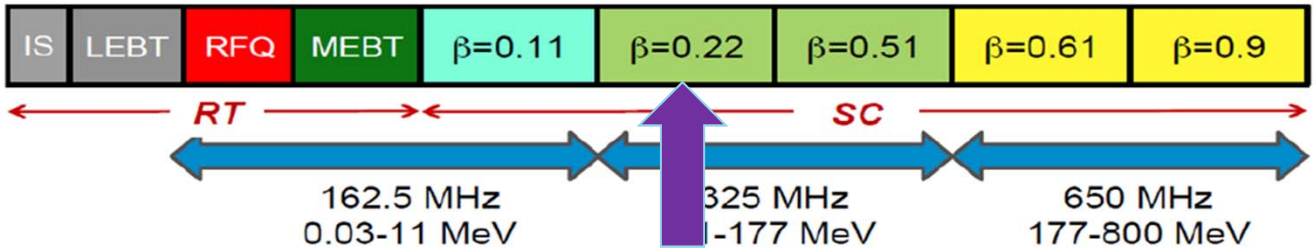

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All components CW-capable ***First HWR cavity recently tested at ANL***

Credit: P. Derwent Neutrino Beams &Instrumentation Workshop Presentation

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SSR1 β = 0.22 (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
SSR1 Gallery								
325 MHz Sources (duty 100%)	8.0	112.5	42.3	63	90	17.0	83.0	101
325 MHz Sources (duty 15%)	8.0	16.8	6.3	63	90	17.0	83.0	101
325 MHZ Loads	16.0		240.0	63	90	17.0	84.3	118.4
Ancillary Power		6.0						
Subtotal		**135.3**	**288.6**					

SSR2 β = 0.51 (1/2)

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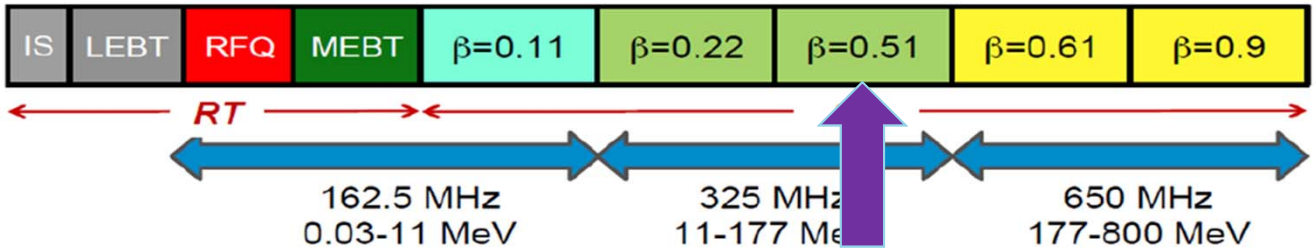
PIP-II LINAC Technology Map



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All components CW-capable ***First HWR cavity recently tested at ANL***

Credit: P. Derwent Neutrino Beams &Instrumentation Workshop Presentation

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SSR2 β = 0.51 (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
SSR2 Gallery								
325 MHz Sources (20kW 15% duty)	35.0	210.0	78.9729	70	90	17	83	101
325 MHZ Loads	35.0		525	70	90	17	84.3	118.4
Ancillary Power		18.0						
Subtotal		**228.0**	**603.9729**					

Low Beta 650 β = 0.61 (1/2)

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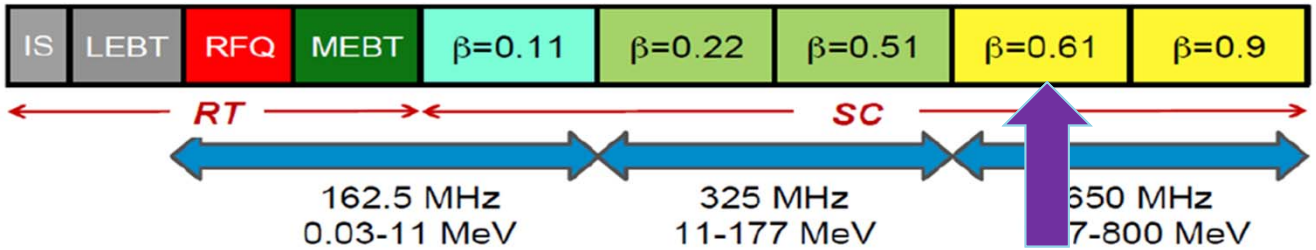

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Low Beta 650 β = 0.61 (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
LB 650								
Quad	22.0	6.6	2.2	70	90	17	83	101
Dipoles	11.0	5.5	3.3	70	90	17	83	101
Subtotal		**12.1**	**5.5**					
LB 650 Gallery								
650 MHz Sources (40kW 15%duty)	33	396	148.9203	70	90	17	83	101
650 MHz Loads	33		495	70	90	17	84.3	118.4
Ancillary Power		24						
Subtotal		**420**	**643.9203**					

High Beta 650 β = 0.9 (1/2)

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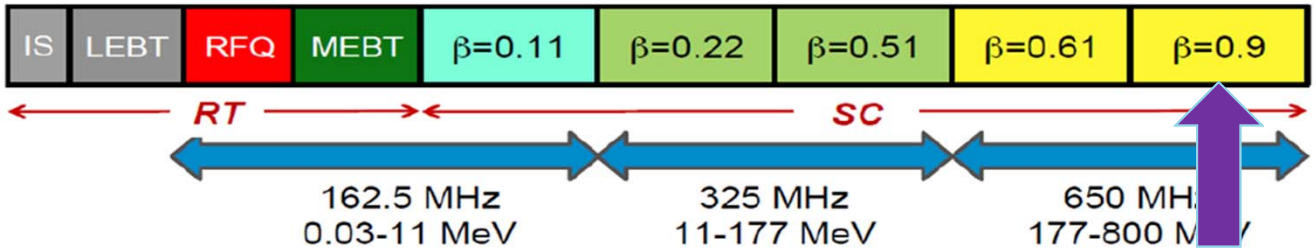

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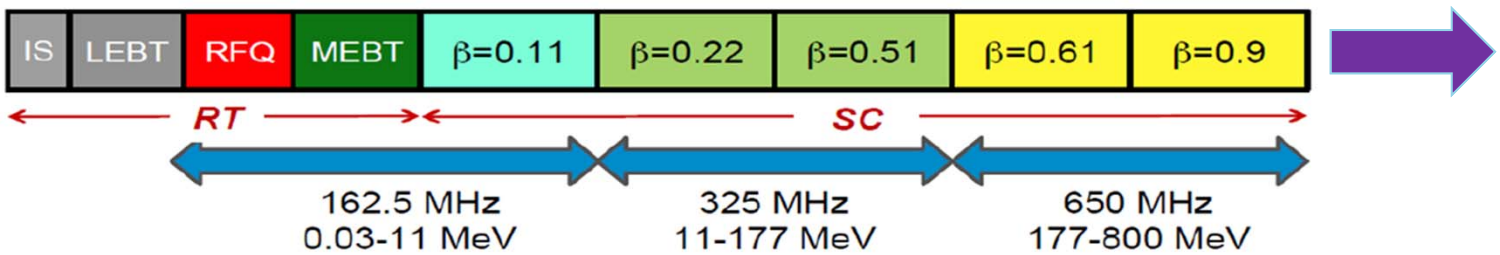
High Beta 650 β = 0.9 (2/2) - Table

Equipment	Quantity	Required Heat Load (kW)	Flow Rate (gpm) total	Pressure Drop (psid)	Inlet Pressure (psig)	Outlet Pressure (psig)	Inlet T (°F)	Outlet T (°F)
HB 650								
Quads	8	2.4	0.902547	70	90	17	83	101
Dipoles	4	2	0.752123	70	90	17	83	101
Subtotal		**4.4**	**1.65467**					
HB 650 Gallery								
650 MHz Sources (70kW 15%duty)	24	504	189.535	70	90	17	83	101
650 MHz Loads	24		360	70	90	17	84.3	118.4
Ancillary Power		18						
Subtotal		**522**	**549.535**					

Transport Beamline (1/4)

PIP-II

PIP-II LINAC Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-11	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	11-38	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.51)	325	38-177	35/21/7	SSR, solenoid
LB 650 (β_G=0.61)	650	177-480	30/20/5	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	480-800	24/10/4	5-cell elliptical, doublet

All components CW-capable ***First HWR cavity recently tested at ANL***

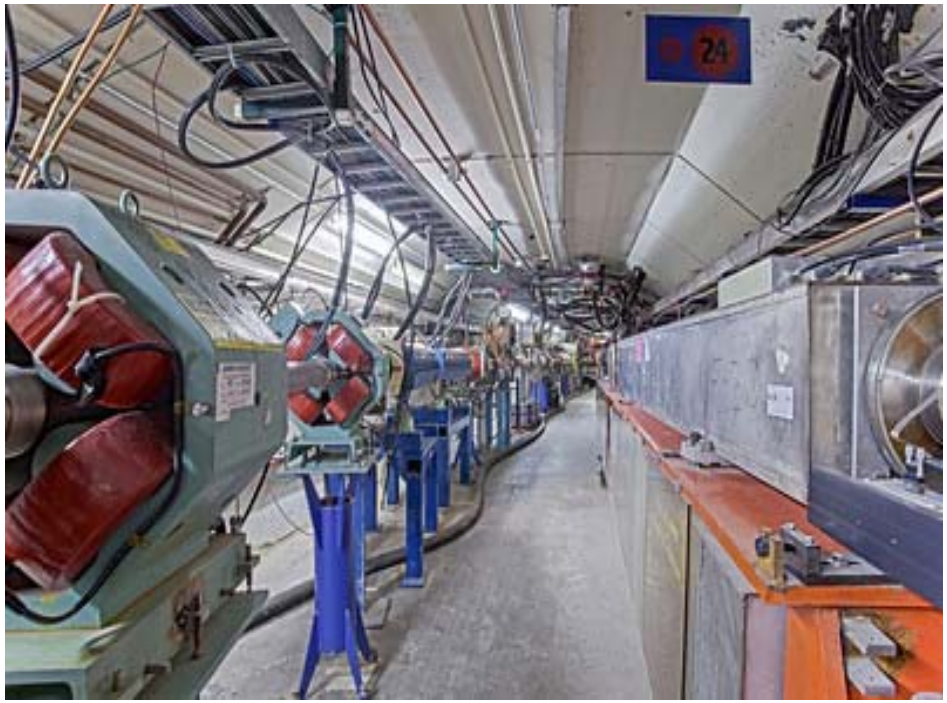
Credit: P. Derwent Neutrino Beams &Instrumentation Workshop Presentation

9 **PIP-II Meeting, December 16, 2014** Fermilab

Fermilab

Transport Beamline (2/4) - Notes of consideration

- Total cooling needs
- Est. ~100 KW
- Est. min ~ 40 GPM total
- Depends on final transport beamline arrangement – (CFS-Dixon)
- Actual flowrates could be much higher ~ 100+ GPM total
- Reasons?



Transport Beamline (3/4) - Notes of consideration

- Magnet Design - meeting cooling needs are important
- Equally important! - Specifying flow parameters
  - Avoid cooling inefficiencies (i.e. CuO, lost heat transfer efficiency)
  - To insure reliable consistent flowrates to meet those needs
  - High velocities (V), high Reynolds(Re), complete turbulence
  - Differential pressure (DP) between inlet and outlet
  - Reliable magnet connection, non-spliced cooling lines

Transport Beamline (4/4) - Specification

- Male Pipe Thread (MPT) connections preferred
- Flow paths - ¼” or larger, inner diameter (larger ID, the better)
- High DP ≥ 50 PSID
- High velocity, V ≥ 6 ft/sec (~1.8 m/sec)
- High Reynolds no, Re ≥1 X 10^5

PIP-II LCW Requirements

Equipment	Required Heat Load (KW)	Flow Rate (GPM)	Inlet T (°F)
LINAC ENCLOSURE (Front End)[7]			
Ion Source[1]	15.8	3.9	68.0
LEBT	24.9	7.5	83.0
RFQ[2]	66.0	173.8	86.0
MEBT	36.5	38.9	83.0
TRANSFER LINE ENCLOSURE			
Magnets (Quads, Dipoles)[4,5]	65.0	25.1	95.0
Beam Dump	50.0	20.0	95.0
LINAC GALLERY (SC LINAC)[3,7]			
RFQ (162.5 MHz)	302.0	158.8	**83.0**
HWR (162.5 MHz)	106.0	159.3	**83.0**
SSR1 (325 MHz)	135.3	288.6	**83.0**
SSR2 (325 MHz)	228.0	604.0	**83.0**
LOW BETA (LB-650 MHz)	420.0	644.0	**83.0**
HIGH BETA (HB-325 MHz)	522.0	549.5	**83.0**

Note:
1. Ion Source cooling skid connects directly to facility chill water source (CHW).
2. RFQ cooling skid connects directly to facility chill water source (CHW).
3. Critical Inlet (Supply) Temperature - Historical Default = 90° F
4. Transfer Line magnet lattice optics data provided by A. Vivoli, V. Lebedev
5. Transfer line magnet flow data assume a 17° F temperature rise.
6. Transfer line magnet power supplies are estimates based on V. Lebedev.
7. LINAC equipment allowable operating temperature rise is limited by absolute flow rate requirements.

	(KW)	(GPM)	
LINAC Enclosure SubTotal[1]	143.2	224.1	**Tons of Refrigeration**
LINAC Gallery SubTotal	1713.3	2404.2	
LINAC (Enclosure and Gallery) Total	**1856.5**	**2628.3**	**527.89**
TRANSFER LINE (Enclosure and Gallery) Total	**115.0**	**45.1**	**32.70**

Subtotals (1/2) – Concluding remarks

- SC LINAC gallery has the largest cooling needs requirements throughout the PIP-II footprint.
- HB 650 largest heat load and water flow requirement (522kW) and 550 GPM respectively.
- Most temperature sensitive device: Circulator within the RFQ section.
- Cooling requirements table is still a fluid task. Living and breathing document

Outstanding Issues/Assumptions

- Unknown cooling heat loads remain
  - LINAC Gallery, Enclosure
  - Heat to air – 20%, conservative estimate in most locations
- Transport Beamline configuration decision will impact overall cooling needs totals

Acknowldegements

- Christopher Cameron
- Steve Dixon
- Emil Huedem
- Jonathan Hunt
- Valerie Lebedev
- Alessandro Vivoli

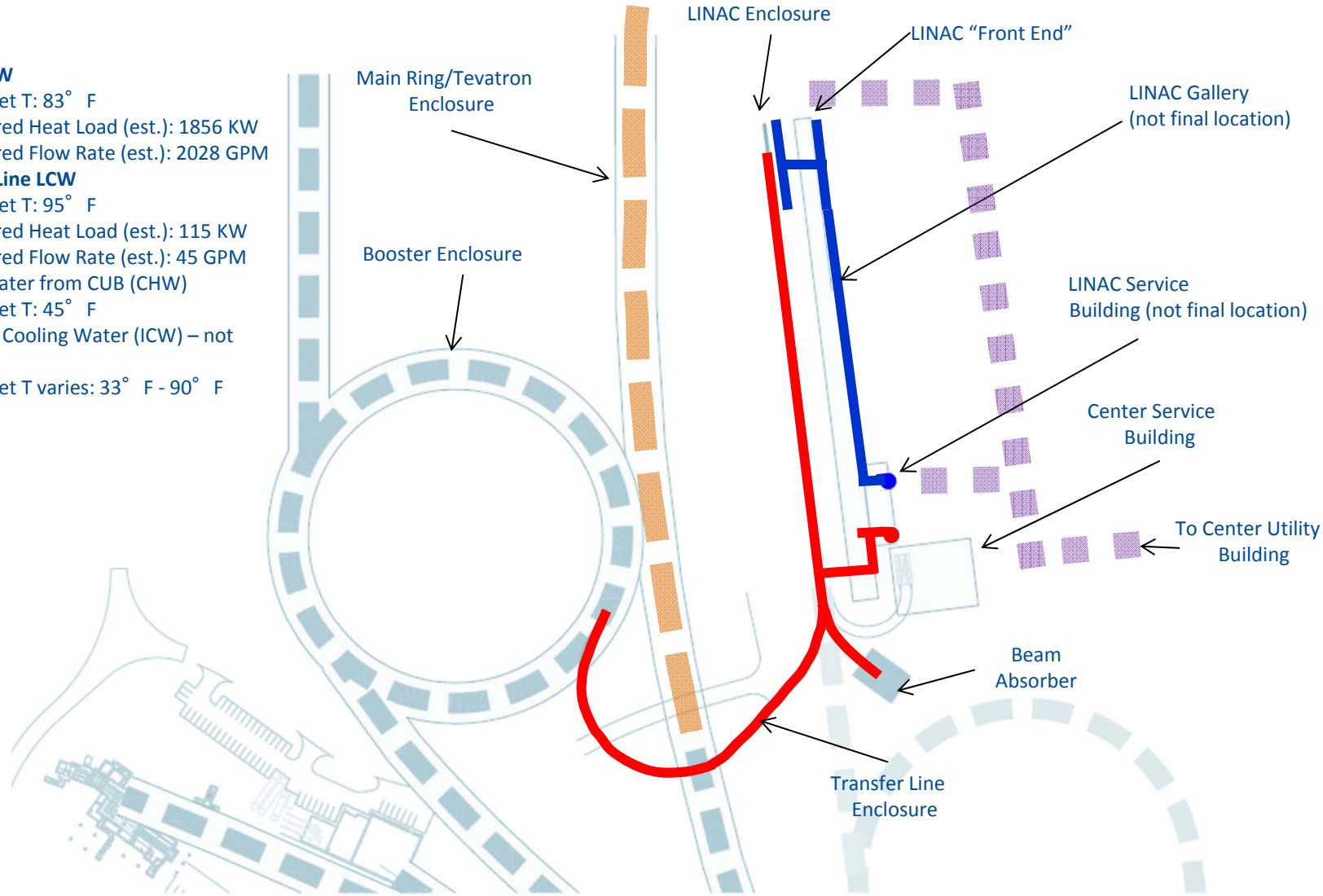
Appendix – Backup Slides

Study Scenario – PIP-II LCW Circuit LINAC Gallery East (not final location)

Legend:

LINAC LCW
- Set Inlet T: 83° F
- Required Heat Load (est.): 1856 KW
- Required Flow Rate (est.): 2028 GPM

Transfer Line LCW
- Set Inlet T: 95° F
- Required Heat Load (est.): 115 KW
- Required Flow Rate (est.): 45 GPM

Chilled Water from CUB (CHW)
- Set Inlet T: 45° F

Industrial Cooling Water (ICW) – not shown
- Set Inlet T varies: 33° F - 90° F