WBS 3 - Cold Powering Overview

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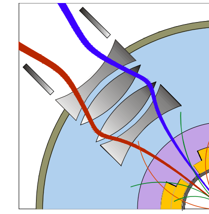
Fermilab

January 20th, 2010
DOE CD-1 Review of the APUL Project

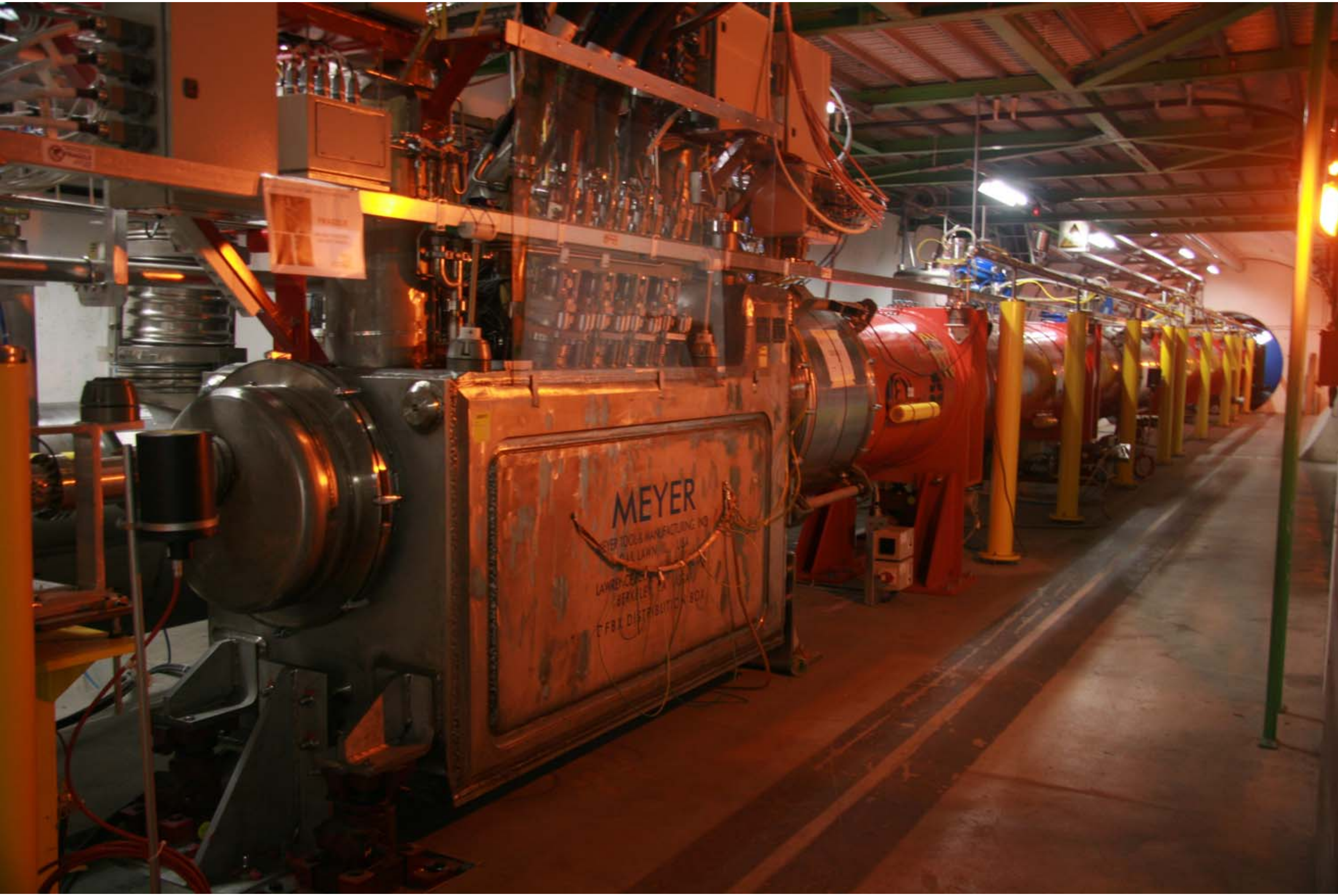


APUL Project WBS

- WBS - 1
  Project Management
- WBS - 2
  D1 magnets
  - WBS - 2.1
    D1 Design/Engineering
  - WBS - 2.2
    Tooling, D1 Magnet
  - WBS - 2.3
    Prototype, D1 Magnet
  - WBS - 2.4
    D1 Magnet Cold Mass Production
  - WBS - 2.5
    Testing
- WBS - 3
  Cold Powering
  - WBS - 3.1
    DFX
  - WBS - 3.2
    Current Leads
  - WBS - 3.3
    Sc Link
  - WBS - 3.4
    DFX, Lead, and Link Test

Outline of Presentation

- Technical Overview
  - Scope
  - Functional Specifications, Requirements
  - Codes And Standards
  - Concept/Design
  - Fabrication and Test
- WBS
- Project Team
- Cost & Schedule
  - Schedule/Critical Path analysis
  - Funding Profile/obligation profile
  - Labor Profile
- Risk Management
- Value Management
- ES&H/Quality assurance
- Configuration Management
- Summary
- Supporting Documents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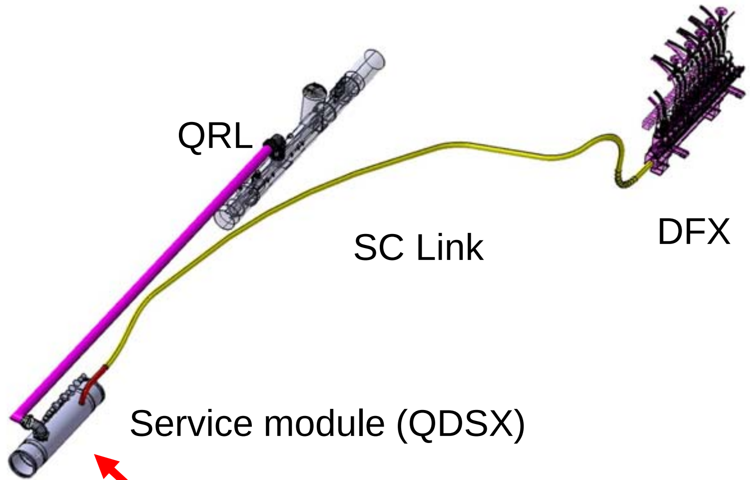
Cold Powering Scope



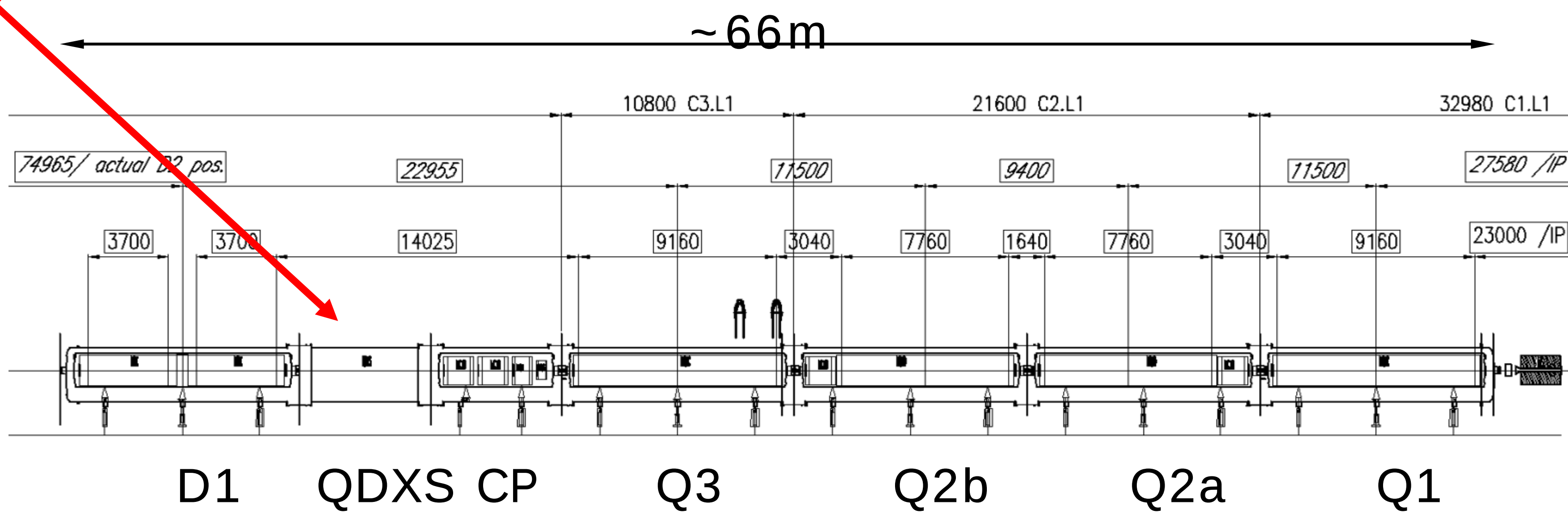
Fermilab will build:

DFX – warm cold transition for power; Current lead box

Superconducting Link – 30 -100m long superconducting NbTi buses

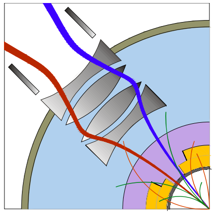
Four locations – ATLAS & CMS

1 Prototype (it will be used for the String Test/Spare)



Cold Powering Scope

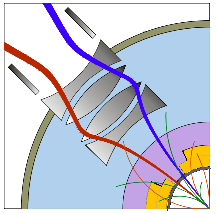
		Number
DFX		5 Identical
Current Leads per DFX	13 kA	4
	7 kA	2
	2.5 kA	8
	600 A	8
SC Link		5 (35m, 35m, 35m, 70m, 95m)



Performance Requirements and Specifications

- Related to magnet circuits:
  - Current ratings: PC spec, Magnet spec (maximum, operational)
  - Current ramp rate spec
  - Stored energy extraction; current decay as a function of time (quench integral)
  - Voltage rating; operational and voltage stand off
- Existing infrastructure specific:
  - Cooling requirements; cool down, stand by and under operation
  - Pressure rating; cool down, operational and upset conditions
  - Geometrical constraints: transportation, location
- Upgrade specific:
  - Radiation dose
  - Interface specifications; mechanical, electrical and thermal

➔ Details of the Performance requirements and Specifications can be found in the Functional Specifications Document (CERN doc: Cold Power Transfer System for the LHC IR UPgrade Phase-1) and in the CDR



Design Parameters
Codes and Standards

	Design pressure (bar abs)	Test pressure (bar abs)	Requirements, comments
5 K supply lines	20	25	ASME piping code (Fermilab ES&H Manual chapter 5031.1)
Helium vessel under current leads	20	25	ASME Pressure Vessel Code (depending on vessel size) (Fermilab ES&H Manual chapter 5031)
Current leads	20	25	
Thermal shield			Copper with stainless or copper trace piping
Thermal shield pipes	20	25	ASME piping code, stainless or copper pipe
Vacuum vessel	1.5	Leak check	Fermilab ES&H Manual chapter 5033 (Vacuum Vessel Standard)

Reference Documents

- Cold Power Transfer System for the LHC IR UPgrade Phase-1, EDMS 1046267, SLHC Project Doc Number SLHC-IRP1-D-ES-00001.
- LHC Project Report 1163, “Conceptual Design of the LHC Interaction Region Upgrade – Phase –I” (This is a fairly comprehensive report on the entire system by CERN.)
- Phase 1 upgrade website at CERN: http://slhc-irp1.web.cern.ch/slhc-irp1/
- LHC Project document No. LHC-DSL-CI-0001, “Technical Specification for the Supply, Assembly and Installation of Superconducting Links for the LHC”
- LHC Project Note 135 defines the pressures and temperatures for the cryogenic piping. Connections to these lines define the pressure requirements for our pipes.
- CERN-Fermilab agreements for US LHC project
  - Memorandum of Understanding between Fermilab and CERN (see http://sc-gs.web.cern.ch/sc-gs/gs_ms/TISUS/memorandum.htm)
  - Other documents such as those defining pressure standards
  - These are for reference until new agreements are made

Cold Powering Concept

- Conservative approach => existing technology
  - R&D ⇨ ~~R&~~**D**;
- Minimize risk: technical, cost and schedule;
- Value engineering from the very beginning of the alternative design selection;
- Overall design concept is stable since last summer and at this phase there are only a few design alternatives left to choose before reaching baseline.

SC Link (DSX) Concept

- Superconductor selection for the Bus strongly related to ⇔ Cooling conditions;
- Available: 3 bar and 4.7 K supercritical He fluid;
- Available maximum cooling rate is 10 g/sec;
- Cryogenic studies showed that if hard-piped system is used to make the cryostats less than 6.0 K at the DFX looks safely attainable;
- Above conditions made it possible to use NbTi as the superconductor;

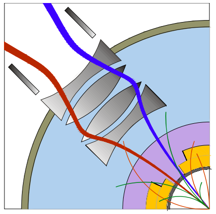
Bus Bar Conductor Selection

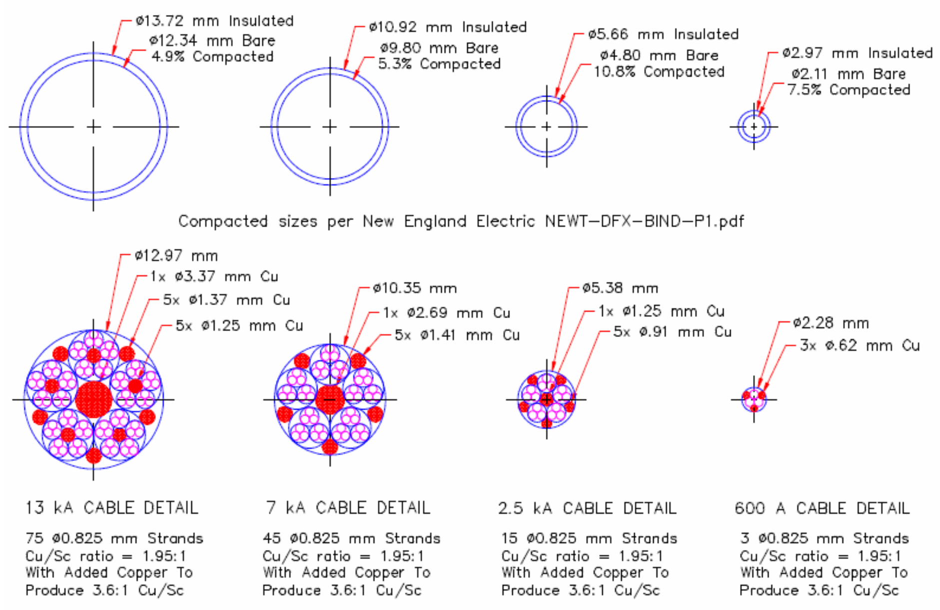
- Last year summer several different possibilities for conductor were examined:
  - Pure Aluminum => too heavy might be an option for short length;
  - HTS => too expensive IGC and Nexon have never given a quote;
  - Nb_3Sn => manufacturing process too complicated;
  - NbTi was the best choice based on the fact that cooling conditions can be met;
- Base line approach:
  - SC Link bus bar will be made from NbTi conductor;
  - SC Link cryostat will be based on solid piping - flexible cryostat sections as necessary;
  - 3bar, 4.7K supercritical helium for coolant.

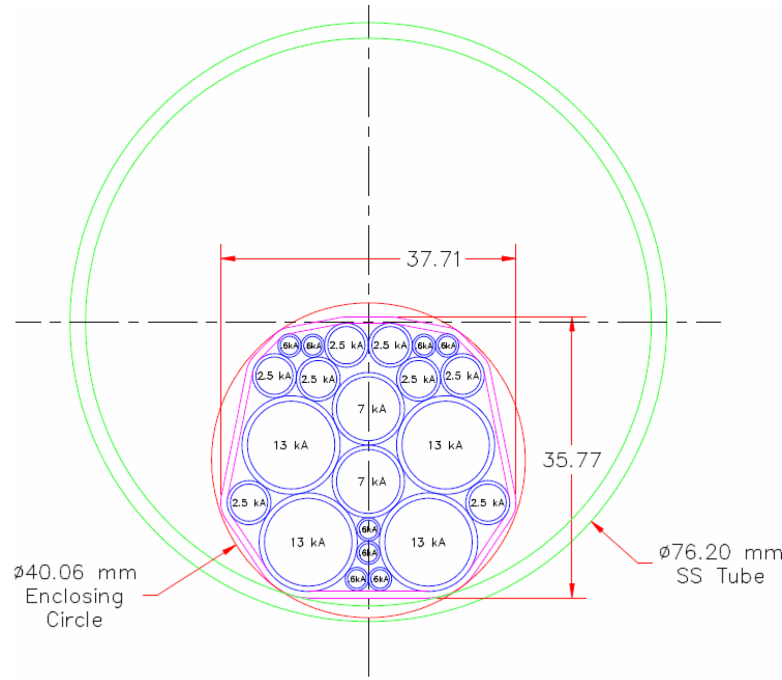
NbTi Bus

- Extensive study of the bus currently used in the IR magnets at LHC;
- Three TD notes and an IEEE publication about the LHC IR bus studies;
- Both modeling and experiments have been performed and compared.

Round Shape Bus Design





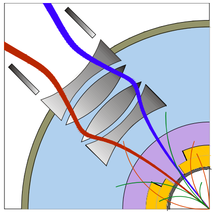


Round cable made from twisted strands:
- **Copper core**
- **Overall Cu/Sc=3.6**

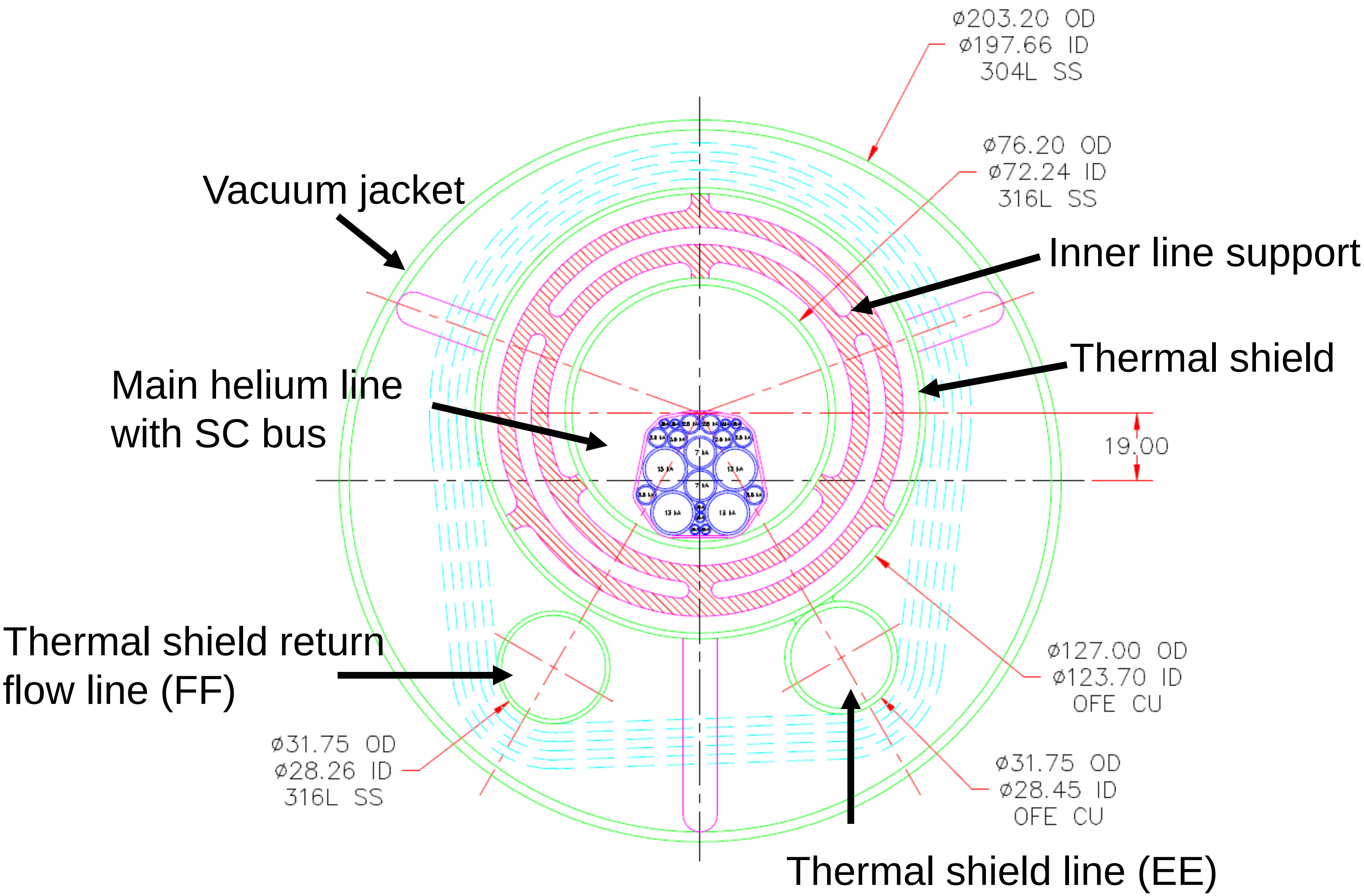
Round cross sections chosen to minimize the amount of conductor => bus bar cross section scales with the nominal current value.

Conductors grouped to improve cancellation of stray field.

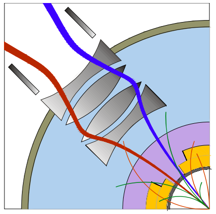
The support structure details are not yet worked out. We also looking at cable position stability for twisting the bundle.

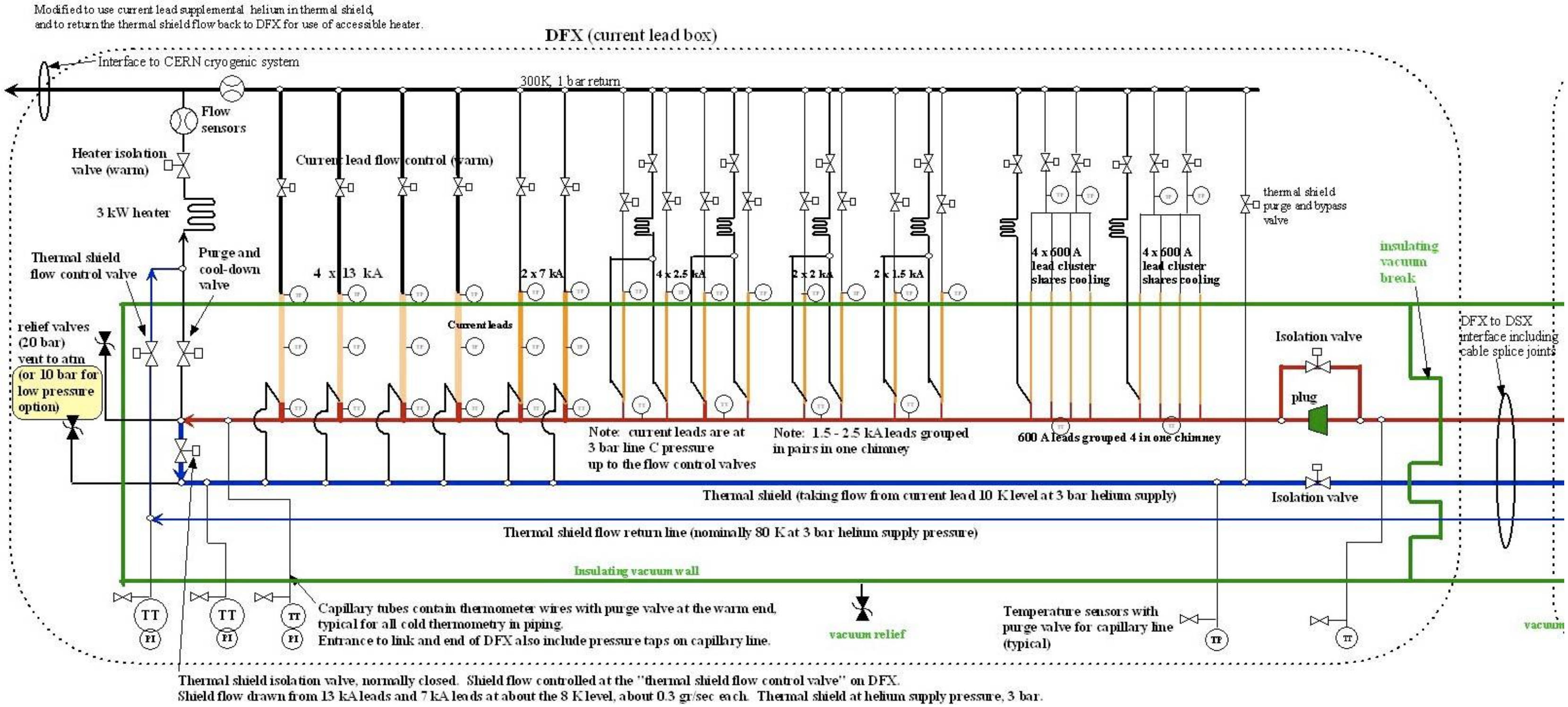


SC Bus Within the Link Cryostat



DFX Concept



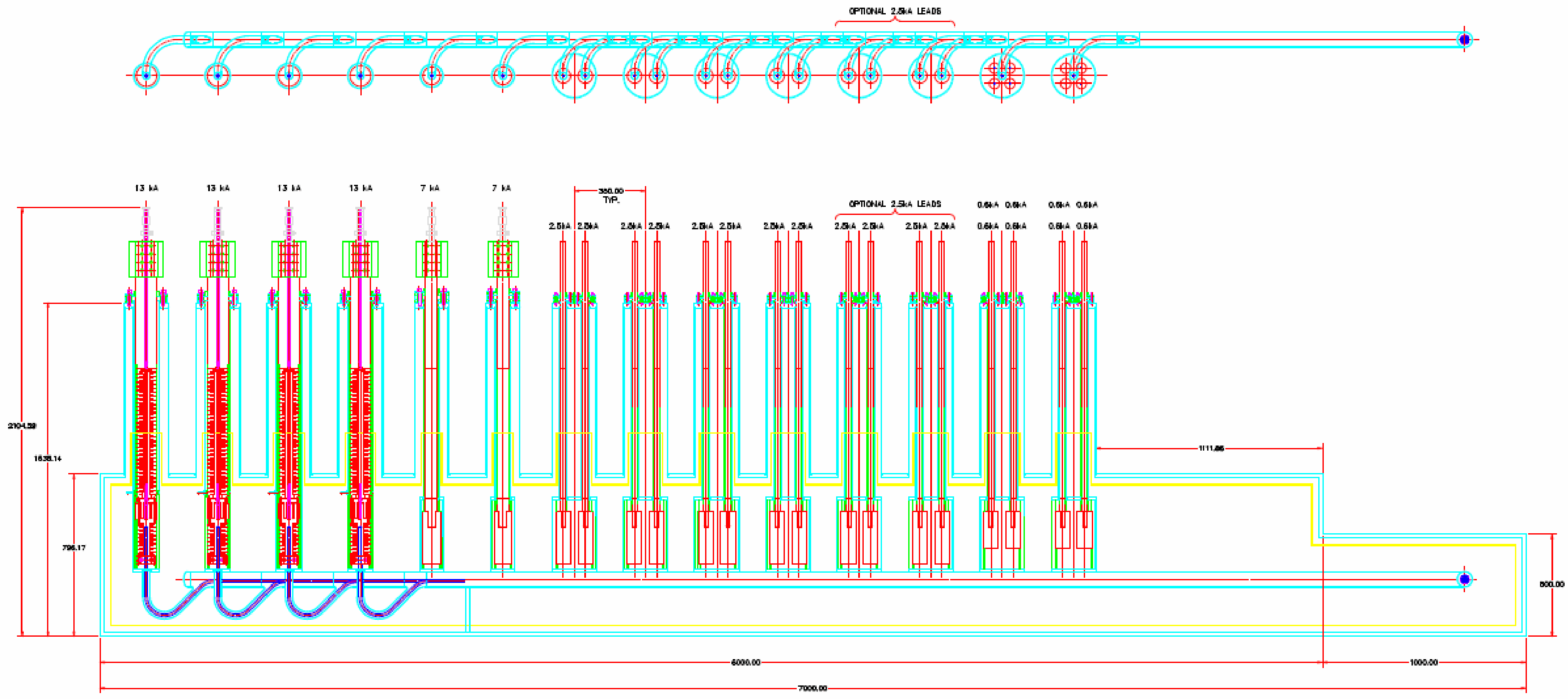


- Current leads in a row
- Flow to highest current last
- No liquid helium (3 atm supercritical)

4 identical boxes plus spare
All leads about same height (<2 m)
Box about 7 m long

DFX Concept Based on DFB

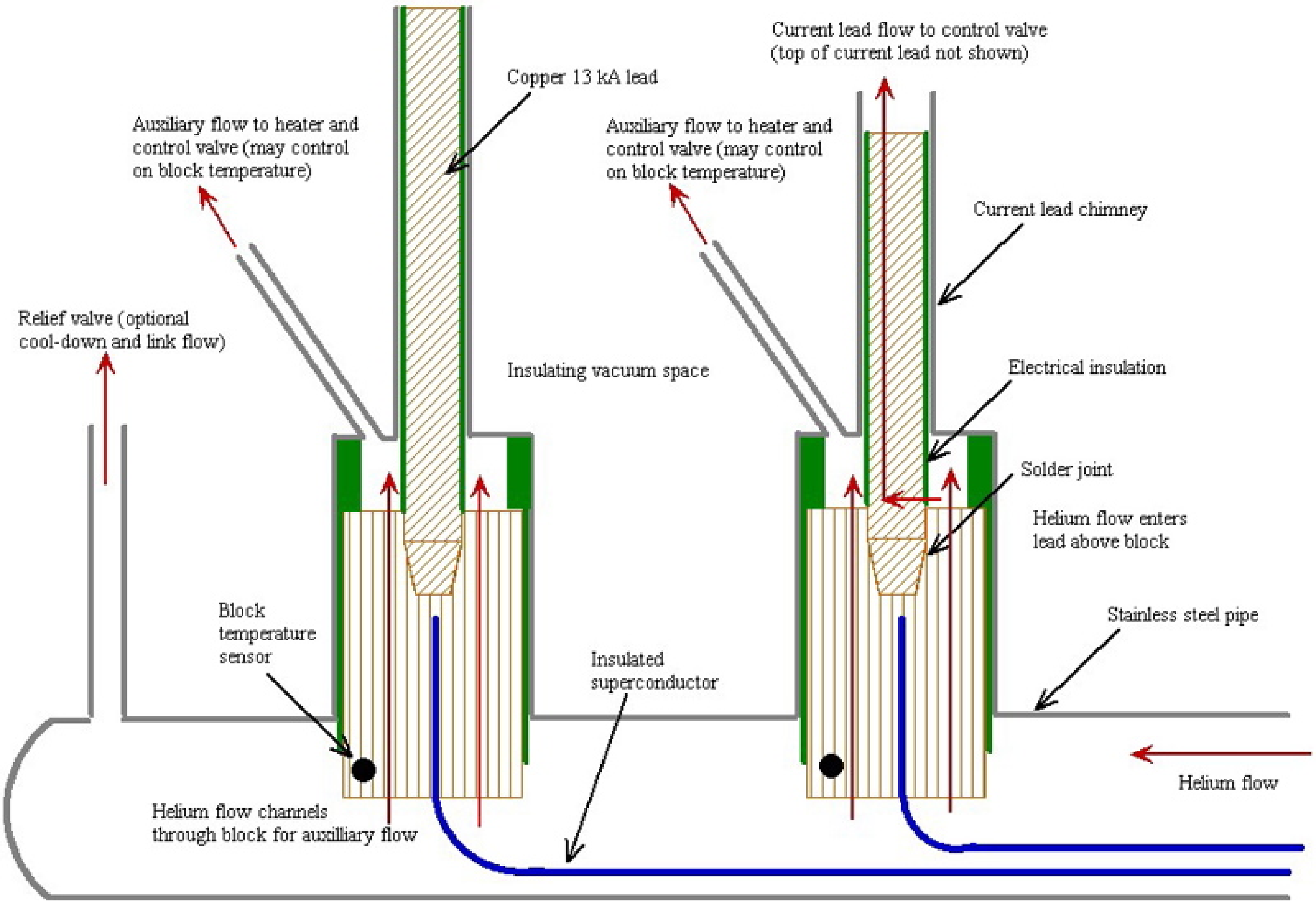
- Current lead chimneys arranged linearly;
- Helium supply pipe with connections to current leads to accommodate thermal contractions.

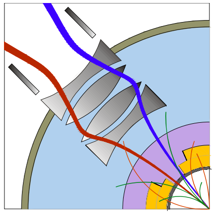


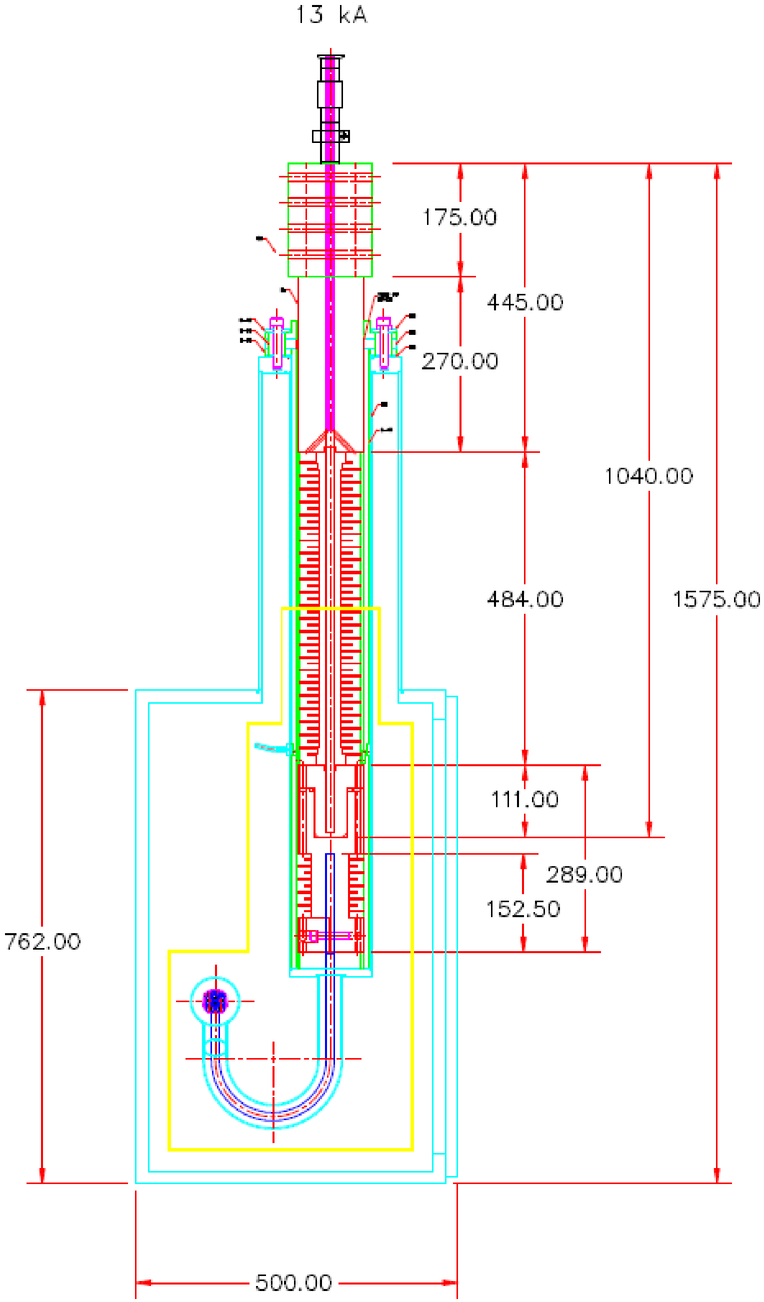
Current Lead Cooling

- Supercritical flow (not a liquid bath)
  - Tevatron current leads successfully operate in single-phase helium (no liquid bath);
  - SSC test stand current leads at Fermilab all operated in 4 bar, 5 K helium;
  - Enhanced heat transfer at base of current lead replaces isothermal nature of bath as insurance that superconductor is well cooled.
- This design incorporates adjustable additional flow at base of current lead
  - Utilize extra link flow for lead cooling;
  - This extra flow may be determined during testing and set with a fixed orifice for operation in LHC.

Single-Phase Flow
With Auxiliary Stream



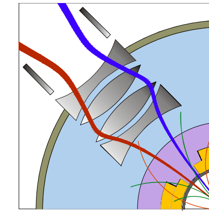




Start of a current lead layout. Concept is to use LHC copper heat exchanger design with custom designed top and bottom.

Remote Current Lead Soldering

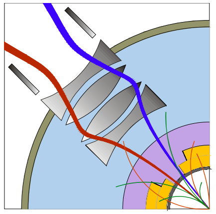
- IGC and Fermilab developed a removable current lead
  - Final solder joint with 52:48 InSn solder, melts at 118 C;
  - Non-corrosive Indalloy fluxes;
  - 4 x 100 W heater cartridges were permanently embedded within the receiver cup;
  - Two thermocouples measured temperature for soldering lead.
- Built one lead box, installed in the Tevatron and operated successfully for 9 years



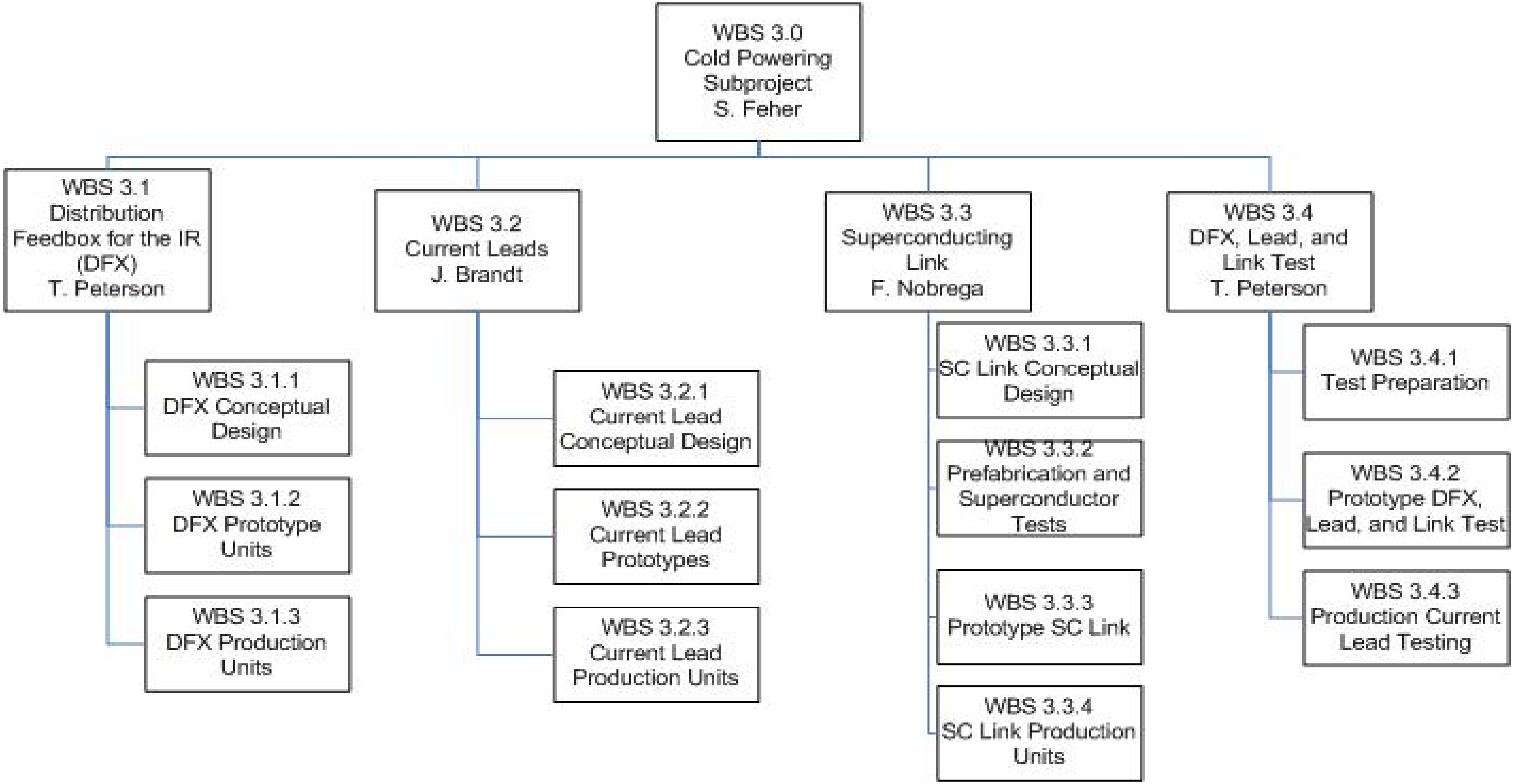
Test and Fabrication Plan

- First full sized DFX box and prototype link are used to test all current leads (no other prototype box nor other lead test box);
- Cold testing in IB1 (Fermilab's magnet test facility);
- First cold test is the first full sized DFX box with one complete set of current leads;
- Design and fabrication of the rest of the leads follows the test of first set of prototype leads;
- Design and fabrication of the rest of the DFX boxes and links follows the test of the first set of prototype leads.
- All current leads (except last set remaining in DFX test box) are shipped to DFX vendor after testing;
- The four production DFX boxes have leads installed at the vendor;

Test and Fabrication Plan (more)



- The four production DFX boxes with leads and links are shipped to CERN as a final shipment after completion of all boxes;
  - Current leads were cold-tested;
  - Production DFX boxes were not cold-tested;
  - Production link sections were not cold-tested.
- Shipment of the DFX test box and test link follows the completion of all current lead testing (shipped with last set of tested leads);
- Strength of plan
  - Full-scale system, hence fully integrated design, is tested repeatedly while used as current lead test facility;
  - Production of DFX boxes, leads, and links come after full prototype tests;
  - Current leads all tested in operational configuration (not just in a dewar).



- Defines the total scope of CP
- Deliverable oriented
- Description is in the WBS dictionary

APUL Cold Powering Team at FNAL

Project Manager: Sandor Feher

Lead Technical Engineer: Tom Peterson

Current Leads

Jeff Brandt

Eng/Phys (test)

Designer (as needed)

Technicians (assembly, test)

DFX

Tom Peterson

Eng/phys (test)

Experienced designer

Technicians (assembly, test)

SC Link

Fred Nobrega

Eng/phys (SC expert, test)

Experienced designer

Technicians (assembly, test)

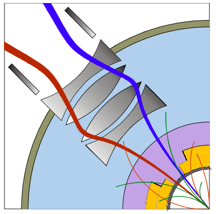
Test:
IB1 personnel

SC experts:
Rodger Bossert
Vadim Kashikhin
Emanuela Barzi

Cold Powering Team

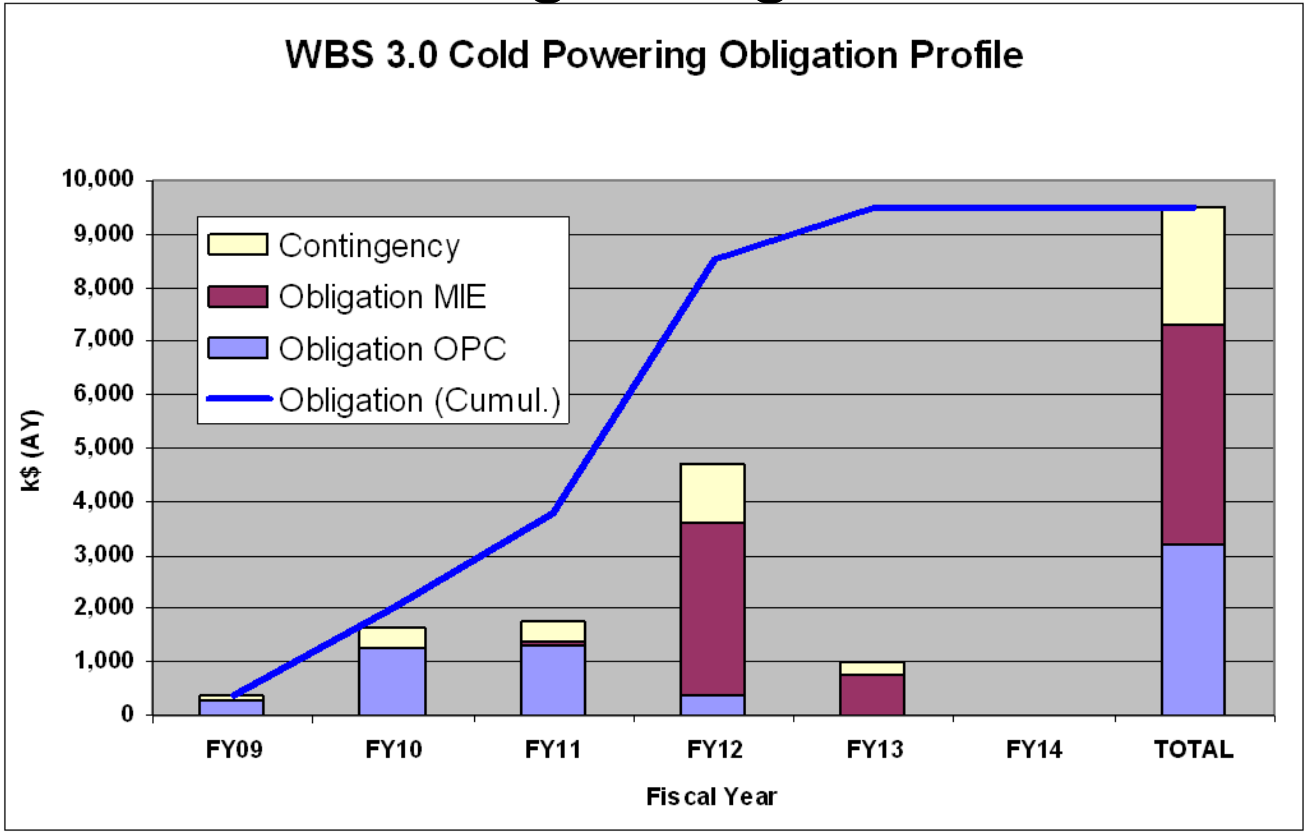
- Tom Peterson – Cryogenic expert:
  - US LHC; DFBX work;
  - RF cryo module design and Fabrication activity;
  - Developing and operating Magnet test stands;
  - Cryogenic systems development work for the Tevatron;
  - Cryogenic transfer line development at Magnet Test Facility.
- Jeff Brandt – Mechanical engineer:
  - Tevatron Spool box design;
  - Retrofitting Spool boxes with HTS current leads;
  - Cryo module design work.
- Fred Nobrega – Mechanical Engineer:
  - US LHC; Magnet design work;
  - LARP; Magnet design work

Cold Powering Cost Summary



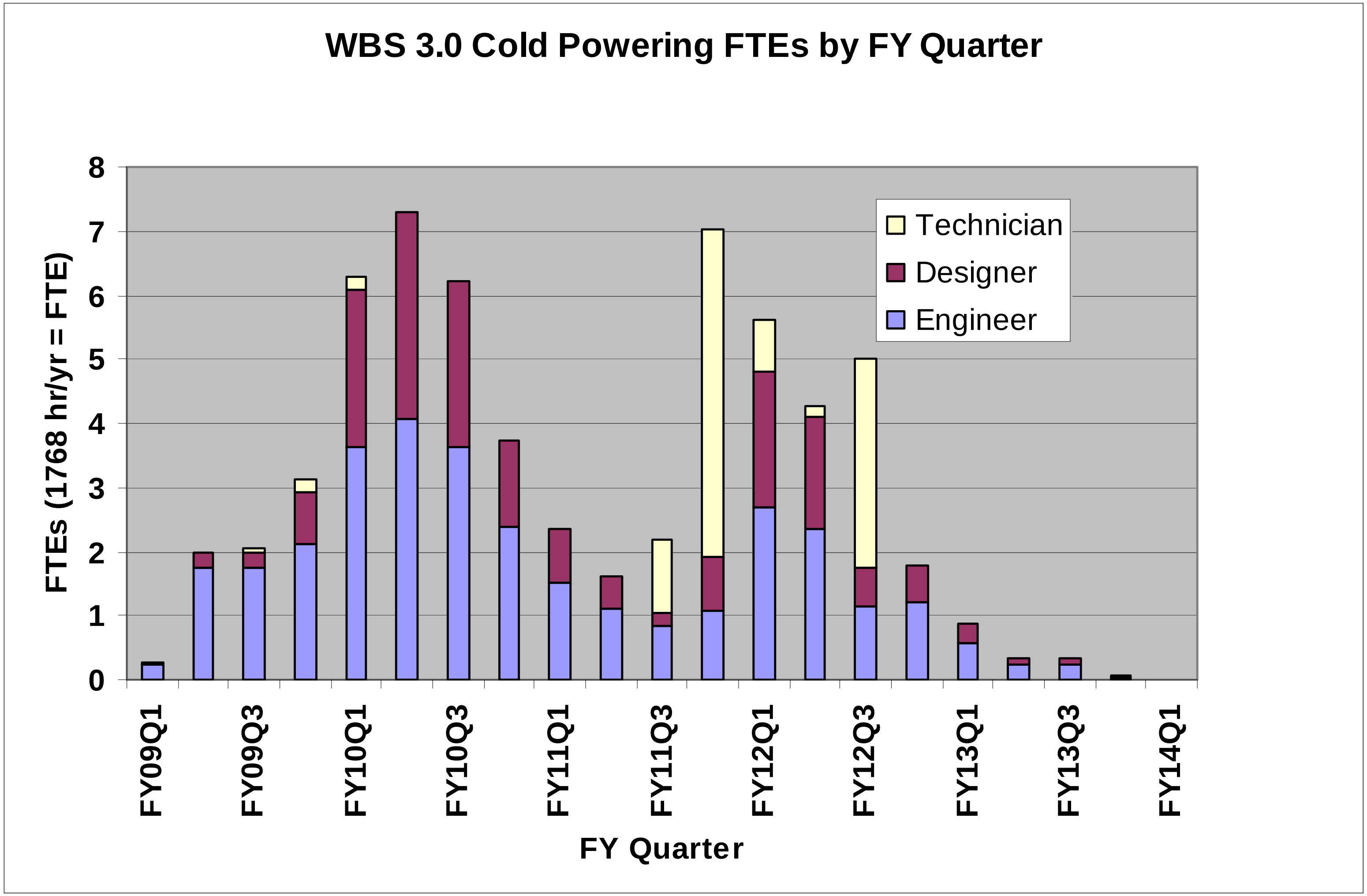
	WBS	Items	APUL WBS 3.0 Cost Estimate AY $K					
			Estimated Cost (AY$k with indirects)			Contingency		Total
			M&S	Labor	Total	Percent	Total	Cost (AY $k)
TEC	3	Cold Powering System						
TEC	3.1	Distribution Feedbox for the IR (DFX)	$ 1,768.6	$ 560.2	$ 2,328.8	29%	$ 674.3	$ 3,003.2
TEC	3.2	Current Leads	$ 625.0	$ 62.6	$ 687.7	35%	$ 239.2	$ 926.9
TEC	3.3	Superconducting Link	$ 545.4	$ 405.6	$ 951.0	34%	$ 326.1	$ 1,277.1
TEC	3.4	DFX, Lead, and Link test	$ -	$ 135.4	$ 135.4	30%	$ 40.6	$ 176.1
		Total TEC:	**$ 2,939.0**	**$ 1,163.9**	**$ 4,102.9**	**31%**	**$ 1,280.2**	**$ 5,383.2**
OPC	3	Cold Powering System						
OPC	3.1	Distribution Feedbox for the IR (DFX)	$ 488.2	$ 789.9	$ 1,278.1	28%	$ 360.3	$ 1,638.4
OPC	3.2	Current Leads	$ 179.0	$ 467.5	$ 646.5	33%	$ 212.6	$ 859.0
OPC	3.3	Superconducting Link	$ 177.1	$ 517.1	$ 694.2	32%	$ 220.0	$ 914.2
OPC	3.4	DFX, Lead, and Link test	$ 68.8	$ 499.3	$ 568.1	27%	$ 150.7	$ 718.8
		Total OPC:	**$ 913.1**	**$ 2,273.8**	**$ 3,186.9**	**30%**	**$ 943.6**	**$ 4,130.4**
		Total:	**$ 3,852.1**	**$ 3,437.7**	**$ 7,289.8**	**31%**	**$ 2,223.8**	**$ 9,513.6**

Cold Powering Obligation Profile

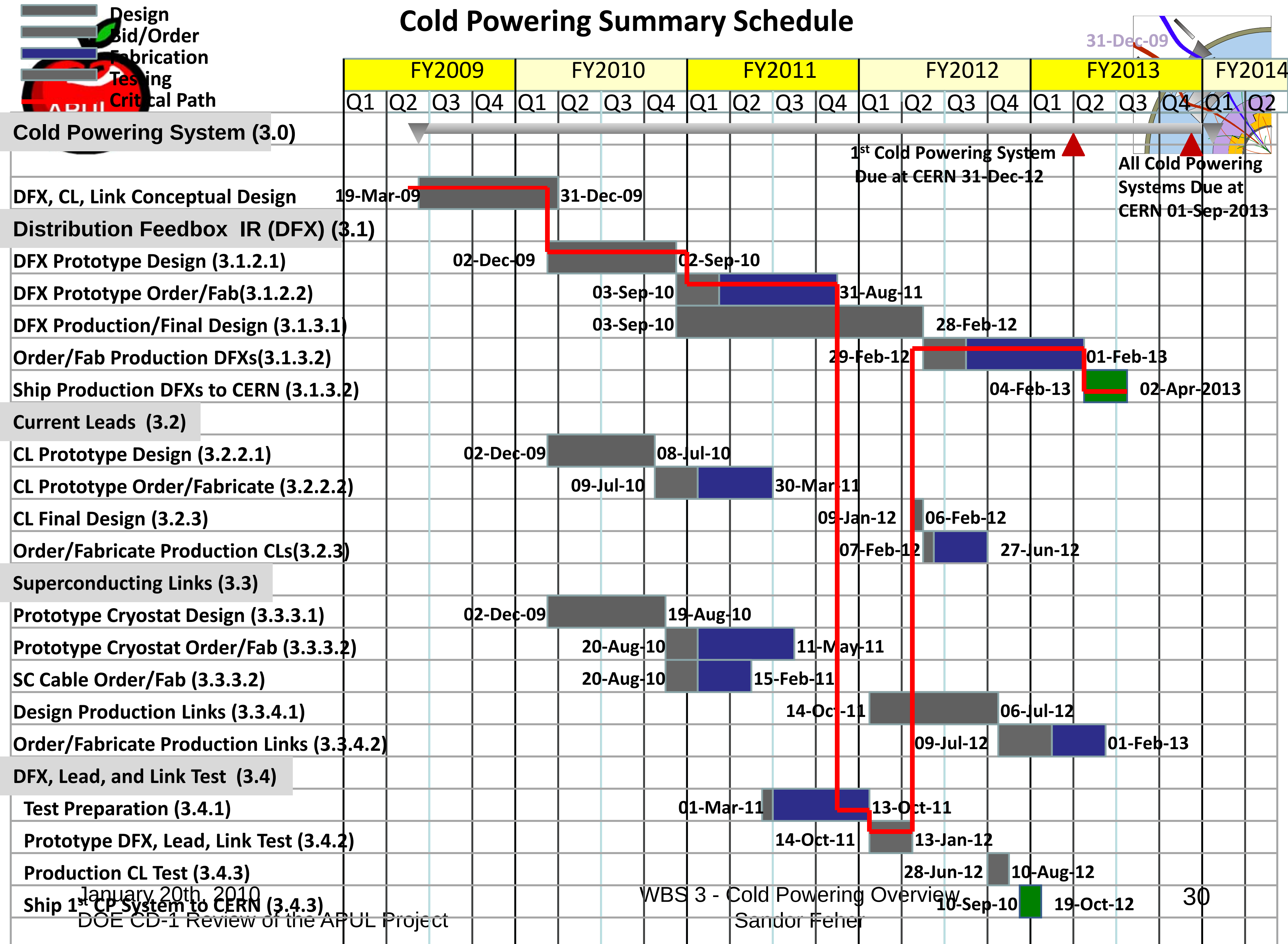


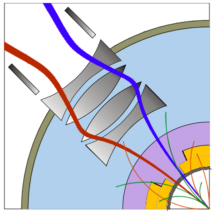
Costs in k$ (AY)	FY09	FY10	FY11	FY12	FY13	FY14	TOTAL
Obligation OPC	278	1,257	1,284	367	0	0	3,186
Obligation MIE	0	7	84	3,249	759	5	4,104
Contingency	85	386	417	1,103	232	2	2,224
Obligation TOTAL	**363**	**1,650**	**1,785**	**4,719**	**991**	**7**	**9,514**
Obligation (Cumul.)	**363**	**2,012**	**3,798**	**8,517**	**9,507**	**9,514**	**9,514**

Cold Powering FTEs



Cold Powering Summary Schedule

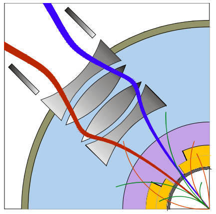




Risk Management
WBS 3 — Cold Powering System

Task	Risk Description	Prob.	Impact	O	ML	P	Assessed Risk ML	Mitigation
3.1.2.1-3 DFX Prototype Unit, Design Phase	Scope change, e.g. fewer or more correctors than planned, due to CERN need.	0.40	Cost	$0	$50	$100	$20	MOU documenting scope between US and CERN should be developed prior to CD-2. In the unlikely event that this occurs, the cost impact will be less than $100k for extra DFX ports and current leads.
			Schedule	0.0	1.0	2.0	0.4	
			Technical	0	0	0	0	
3.1.2.2-1 DFX Prototype Unit, Procurement Activities	High/low bid, e.g. due to labor or material cost increase, or lack of competitive bids.	0.20	Cost	$0	$100	$200	$20	The contingency applied in the Basis of Estimate provides what APUL considers a ceiling on likely bid amounts. Therefore no additional contingency was added. Lack of competitive bids is unlikely as several known qualified vendors exist. For DFX, the labor cost is likely to dominate over materials such as stainless steel. APUL plans to commission an "engineering study" whereby a budgetary cost survey is generated based on preliminary drawings prior to CD-2.
			Schedule	0.0	0.0	0.0	0.0	
			Technical	0	0	0	0	

Probability = Probability of Event; **Cost** = Current Cost Impact Estimates (Use $K);
Schedule = Schedule Impact (Use time in months); **Technical** = Technical Impact (Use performance degradation in %);
O = Optimistic; **ML** = Most Likely; **P** = Pessimistic;



Value Management

- Utilize previous experience from FNAL engineers and designers involved previously in DFBX, Current Leads, Cryogenic transfer lines and similar work.
- Perform engineering study to obtain feedback from vendors on manufacturability issues and to improve accuracy of cost estimate.
- Adapt existing DFBX and CERN DFB design elements into design of DFX including the lead design.
- Procure all units on a single purchase order utilizing options to reduce FNAL overhead/burdening.
- Utilize competitive bidding process for optimizing purchase price. Qualified bidders are largely known from previous experience.
- Work with CERN to define electrical, mechanical, and cryogenic interfaces early in the design process

Safety, Hazard Analysis

- Existing Integrated Safety Management at FNAL
  - APUL involves routine operations
  - FNAL Technical Division have ISM systems and a Safety Representative assigned to APUL
    - FNAL – Rich Ruthe
- Hazard Analysis documents for FNAL (DocDB#53). Documents include:
  - APUL Safety Policy
  - Hazard Analysis for work at FNAL

A NEPA Categorical Exclusion was granted for APUL by BHSO in May 2009.

Quality Assurance

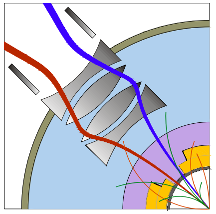
- QA plan for the FNAL work (DocDB#54)
- Elements of QA are the same as those for US-LHC DFBX work
  - Use of travelers
  - Documenting Nonconformance
  - Drawing/model control
  - Requirement that vendors provide QA plan addressing elements of APUL’s QA

Configuration Management

- APUL is comprised of a relatively small team and work at BNL and FNAL is technically independent, making configuration management less challenging than in a large, fractured collaboration with several hardware interfaces.
- Mapping of ANSI/EIA-649 standard to APUL exists in Configuration Management Program document (DocDB#3).
- DocDB used for management and technical documents, existing drawing systems at BNL and FNAL used for drawing version control.
- No software development or specialized computing on APUL
- APUL PMG serves as the Change Control Board.

Supporting Documents

- Conceptual Design Report, APUL-doc-6
- Value Management, APUL-doc-44
- FNAL QA Plan, APUL-doc-54
- Risk Management Plan, APUL-doc-2
- Risk Registry, APUL-doc-49
- Preliminary Hazard Analysis, APUL-doc-53
- Configuration Management Program, APUL-doc-3
- Key Assumption Document, APUL-doc-56
- WBS Dictionary, APUL-doc-60
- NEPA Categorical Exclusion, APUL-doc-50
- Preliminary Project Management Plan, APUL-doc-1
- Preliminary Project Execution Plan, APUL-doc-58
- Acquisition Strategy, APUL-doc-62



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