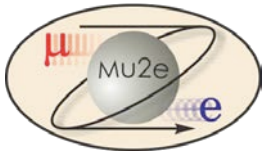
Fermilab

U.S. DEPARTMENT OF ENERGY Office of Science

475.04.06 Magnet Power Supply System



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AD E/E Support Electrical Engineer
7/8/2014

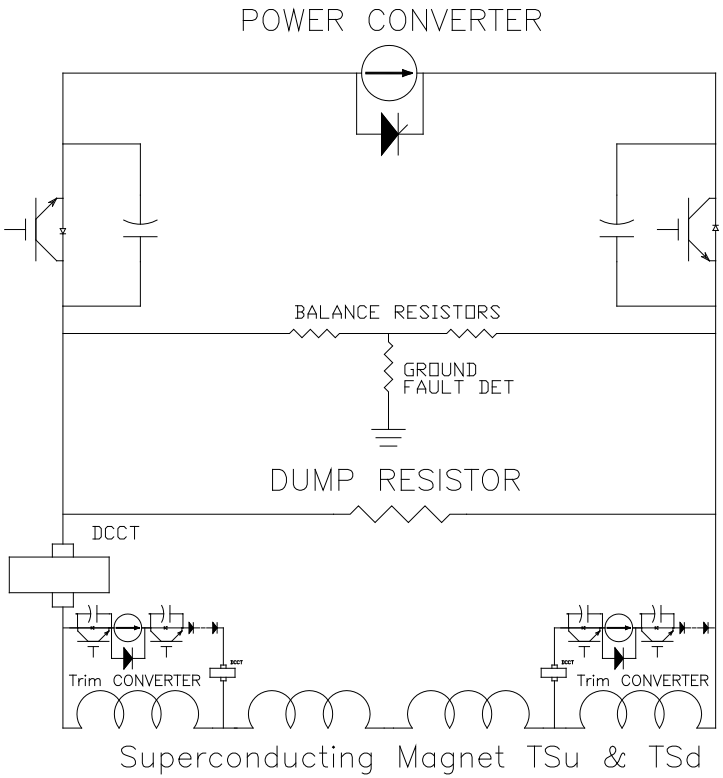
Requirements Magnet Systems

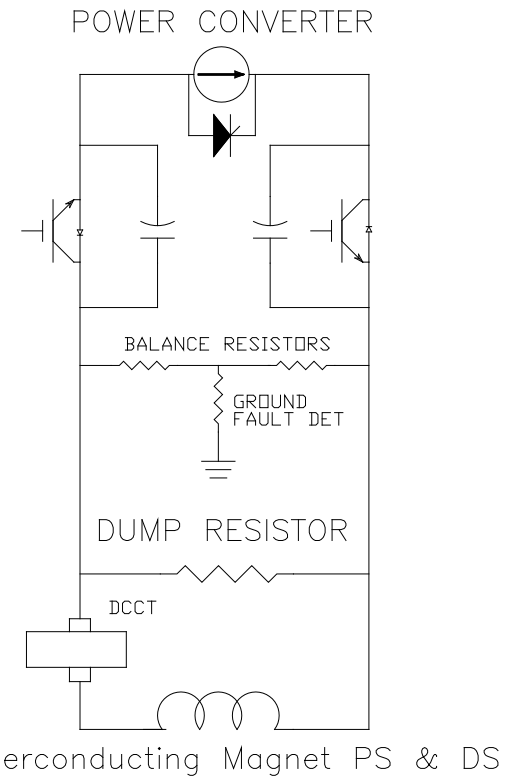
- Mu2e Power Supply Document 1237
  - Four main loops
  - Four trim loops, two on each TS magnet.
  - Energy Extraction on all main loops.

Parameter	Unit	PS	TSu	TSTU x2	TSd	TSTD x2	DS
Max. allowable conductor temperature	K	5.0	5.4		5.5		6.1
Nominal current	A	9200	1730	250	1730	250	6114
Peak field in coil	T	5.48	3.4		3.4		2.2
Current fraction along load line at 4.5 K	%	63	58		50		45
Inductance	H	1.58	4.77		3.79		1.40
Stored energy	MJ	66.8	7.1		5.7		26.1
Cold mass	tonnes	10.9	13		13		8
E/m	kJ/kg	7.31	0.8		0.7		3.6

Requirements Energy Extraction

- The TS magnet loops with two trim power supplies, one on each end.
  - The main Dump Switch disconnects the power supply from the magnet.
  - Two small switches will be installed on the trim power supplies to isolated them from the magnet during a Quench/Dump.



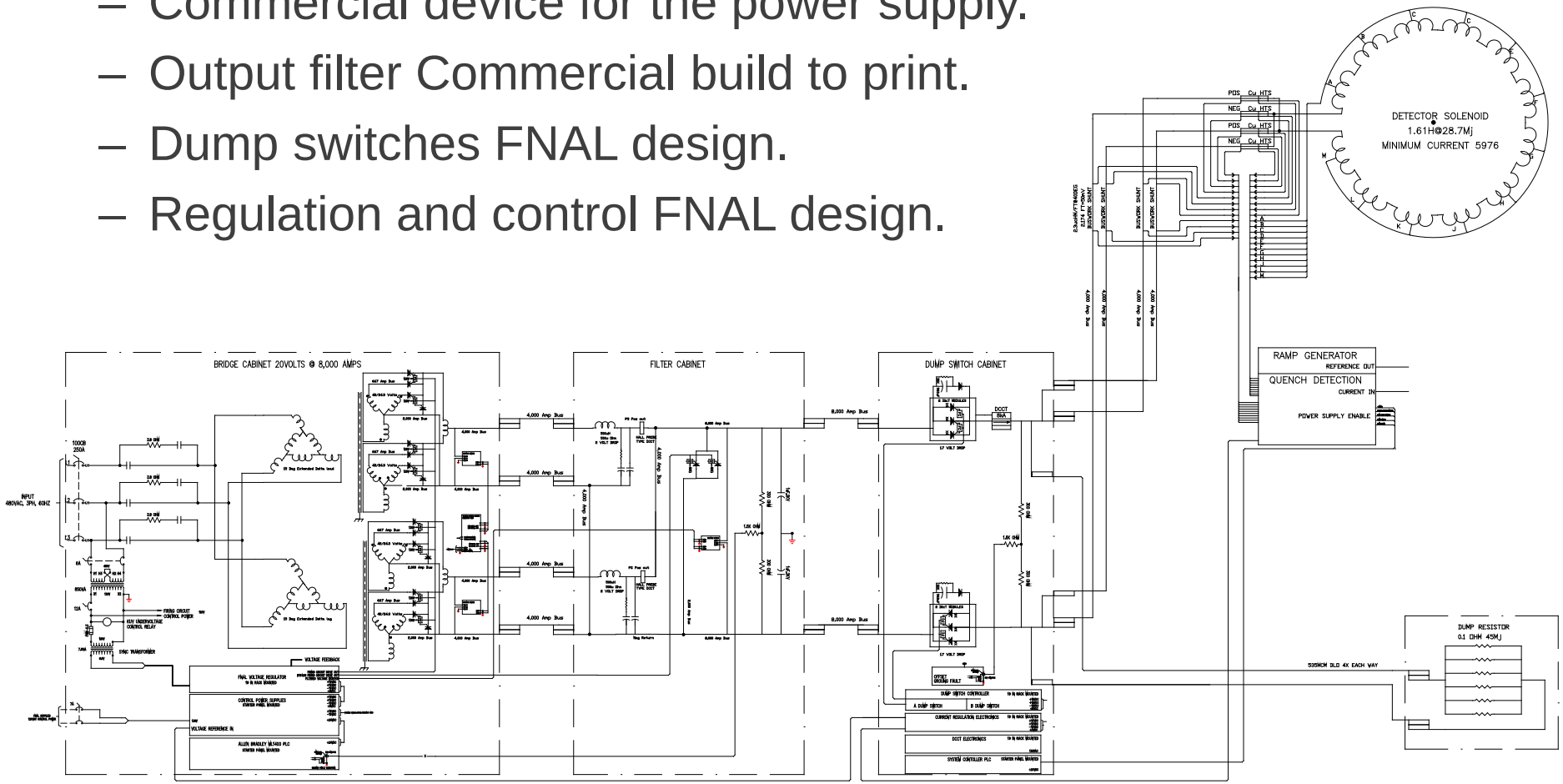


Requirements Regulation and Quench Response

- **FUNCTIONS OF THE POWER SUPPLY SYSTEM**
  - Stand by – Startup - Allow for system check before high current.
  - Ramping - All loops track to +/-10^{-3} of FS while ramping.
  - Steady State - Ramp to current and regulate to +/-10^{-4} of full scale.
  - Field Adjustments - +/- current changes as needed.
    - The speed will be limited by the available voltage, More ramp down voltage than up because of bus and semiconductor voltage drops.
    - To provide this the power supplies will need to be two quadrant, +/- Voltage and will need minor modifications to enable.
- **Magnet Protection**
  - Normal Discharge - Use the power supply to remove the magnet energy.
  - Minor Faults - Turn Off the supply and decay using bus work.
  - Emergency Discharge – Dump into a resistor, most passive mode.

Design DS shown, typical of all loops.

- BASIC POWER SUPPLY DESIGN
  - Commercial device for the power supply.
  - Output filter Commercial build to print.
  - Dump switches FNAL design.
  - Regulation and control FNAL design.



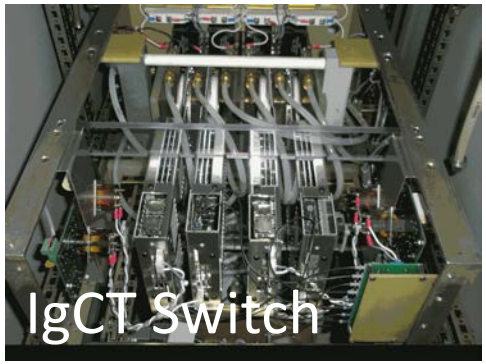
Changes since CD-1

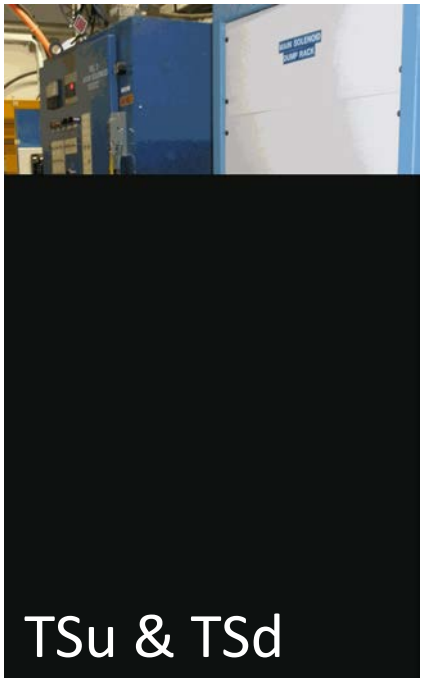
- Updated the requirements document to clarify and better detail the minimum requirements of the power system.
  - Updated operating currents
  - Removed the Trim power supply requirement from the PS coil
  - Increased the number of Trim power supplies for the Tsu and TSd magnets to two each.
  - Improved the wording for the Power Supply Function definition.

Value Engineering since CD-1 mu2e-Docdb 2423

- The Solenoid Power Supply Systems are very much like the TeV Low Beta Quad systems and TEL Solenoid. Because they are a very good match we have a Value Engineering agreement with Accelerator Division to reuse these power supplies.


PS & DS


IgCT Switch


TSu & TSd

- Will need new dump resistors for all systems.
- Trim Power Supplies will all be new.

Performance

- The requirements for the power supply system is required to track at 10^{-3} and regulate at 10^{-4}, the Low Beta Quad System in the TeV operated at 10^{-5} .
- We can only be as accurate as the current measurement we make, The use of DCCTs allows us to regulate to these levels.

Remaining work before CD-3

- Detailed Control Cable Drawings
- Detailed building layout
- Detailed design work the common controls

Quality Assurance

- The equipment being reused was part of the TeV in collider operation and maintained at a very high level so they are still valuable and usable.
- We will replace components that have limited life times
- Some modifications need to be done to the supplies to make them operate in two quadrant mode (+/- Voltage)

Risks

- The risk for reusing the type of equipment is reasonable and low and not included in the risk registry.
- We will be constructing new Dump Switches but they will be copies of a proven design used in the TeV.
- The trim power supplies are a new design but similar to other system used in the TeV.
- Magnetic coupling issues will need to be addressed during the detail design.

ES&H

- All of this equipment will require written Lock Out Tage Out “LOTO”s because we have multiple input power sources and large stored energy in the magnets.
- The Power Supply, Filter and Dump Racks are all separate cabinets that will require interlocking in addition to the written LOTOs.

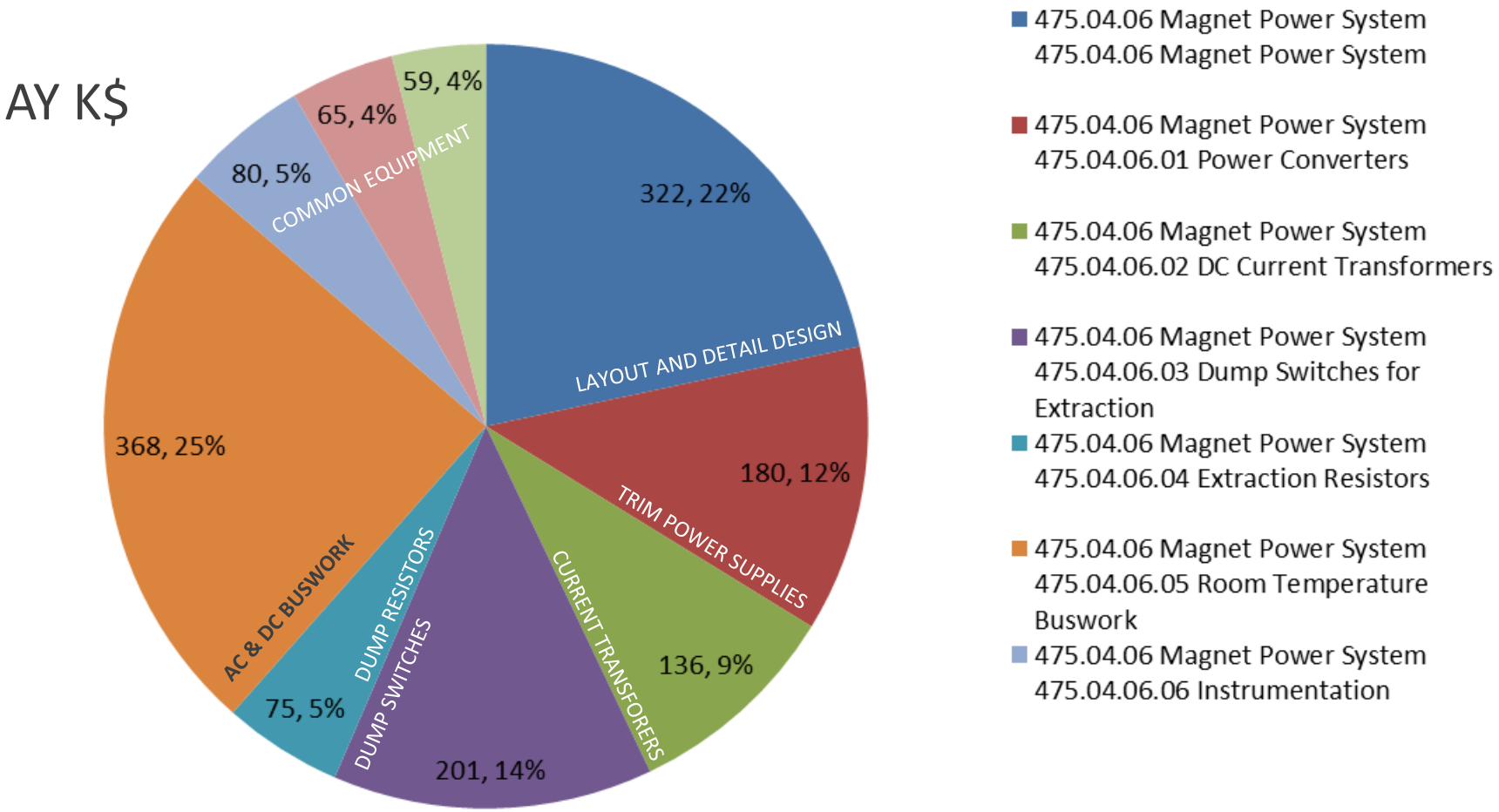
Cost Table

- Most of the labor consumed doing detailed design because we have equipment on hand and the new construction of equipment will be based on existing designs.

	Base Cost (AY k$)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining costs)	% Contingency on ETC	Total Cost
475.04 Solenoids						
475.04.06 Magnet Power System						
475.04.06 Magnet Power System Management	25	297	322	30	53%	352
475.04.06.01 Power Converters	90	90	180	63	35%	243
475.04.06.02 DC Current Transformers	113	23	136	40	29%	176
475.04.06.03 Dump Switches for Extraction	160	41	201	80	40%	281
475.04.06.04 Extraction Resistors	53	22	75	24	31%	99
475.04.06.05 Room Temperature Buswork	306	62	368	85	23%	453
475.04.06.06 Instrumentation	39	40	80	27	34%	107
475.04.06.07 Common Instrumentation	53	12	65	20	31%	86
475.04.06.08 VAC Transformer Relocation	50	9	59	14	23%	73
Grand Total	890	597	1,487	383	31%	1,870

Cost Breakdown

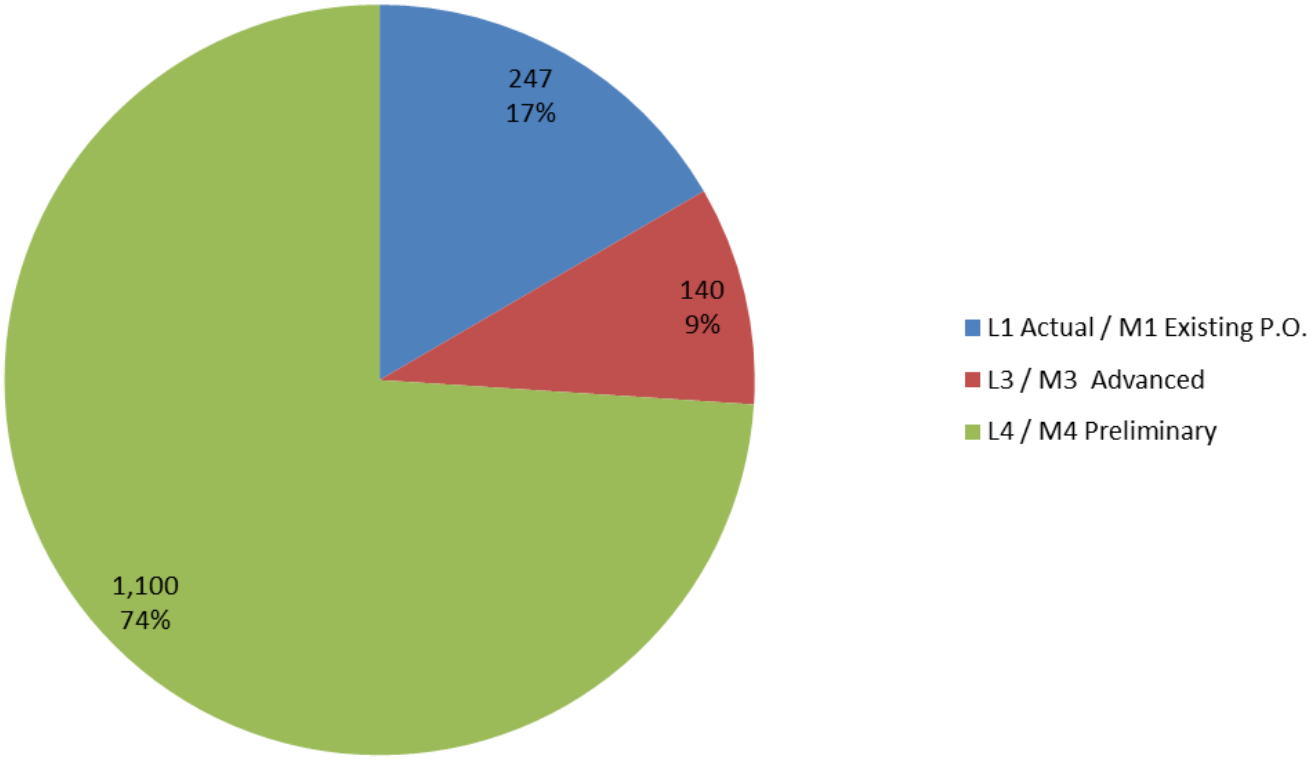
- AC&DC Copper Followed by design time



Quality of Estimate

- All equipment based on existing designs and equipment on hand but need final design

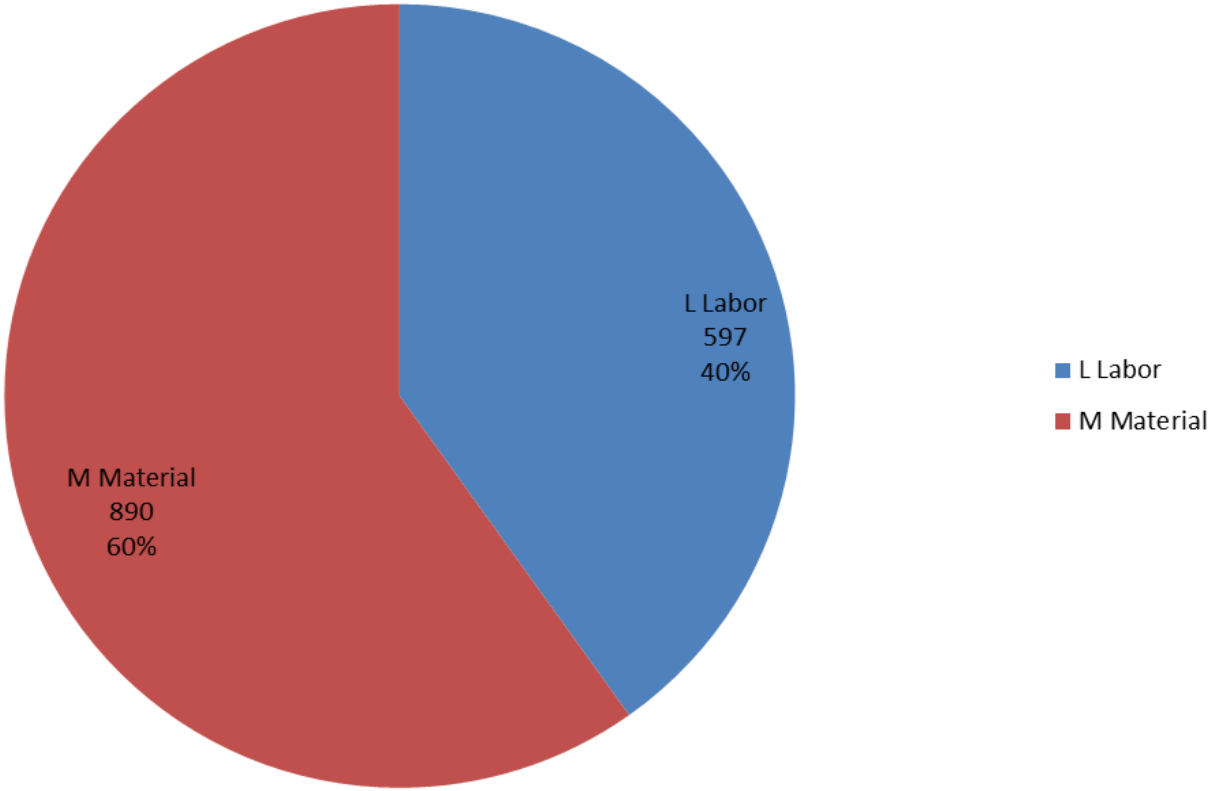
AY K$



Resource Type

- Material Cost driven by two large items: Copper & Dumps
- Labor driven by detail design and Dump Switch Construction

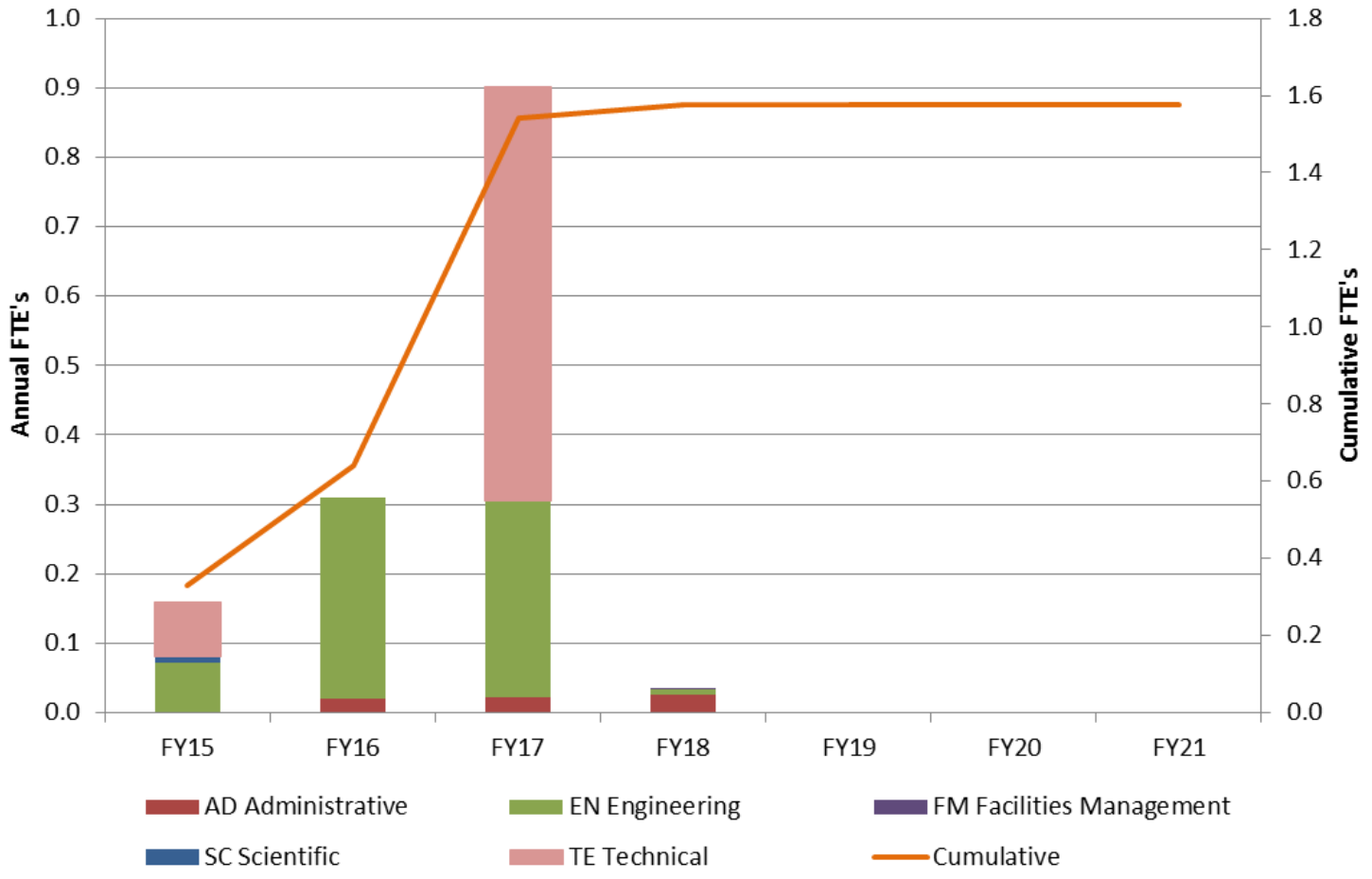
AY K$



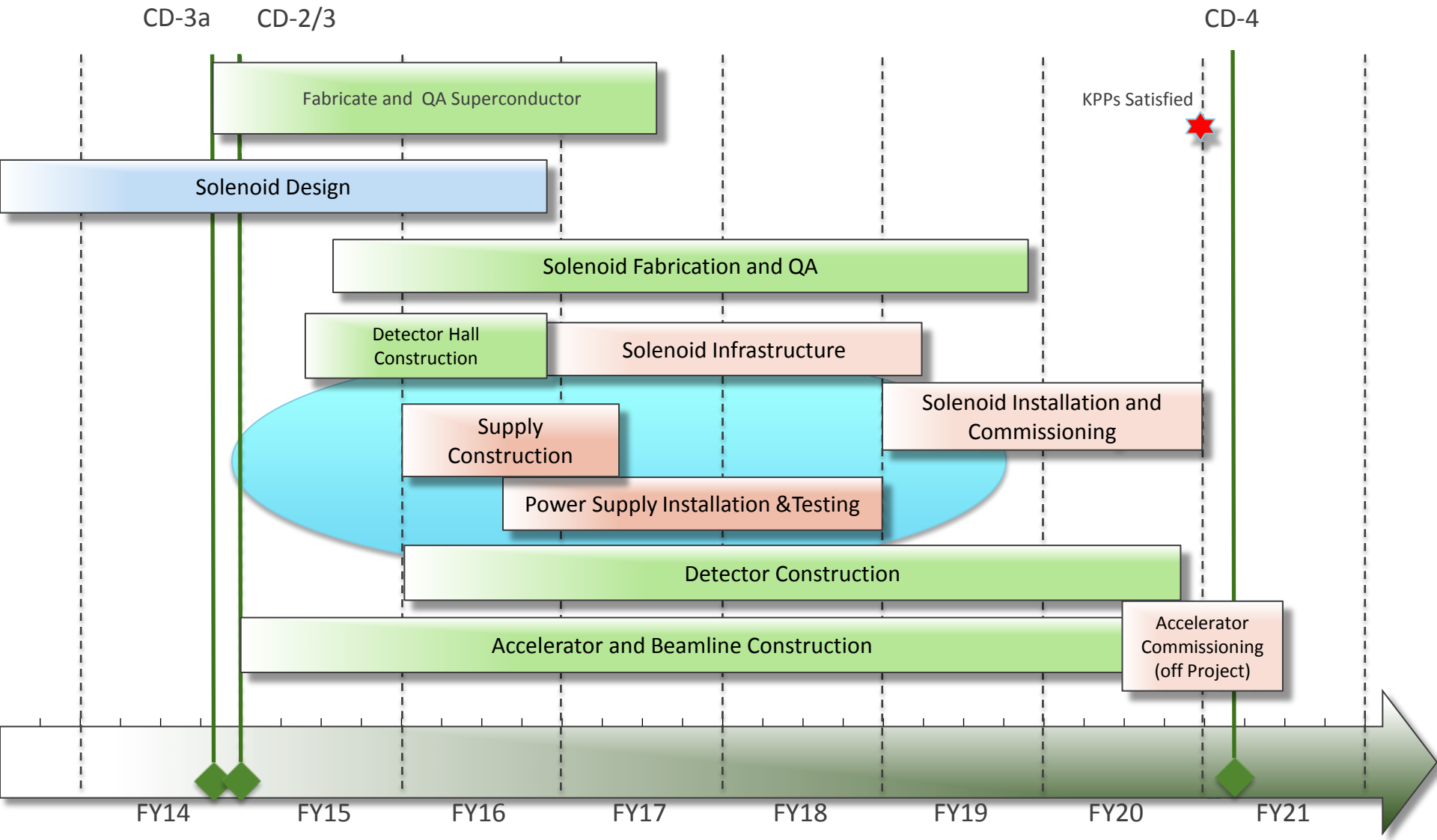
FTE's by Discipline

- Detailed design first followed by construction

AY K$



Schedule


CD-3a
CD-2/3
CD-4
Fabricate and QA Superconductor
KPPs Satisfied
Solenoid Design
Solenoid Fabrication and QA
Detector Hall Construction
Solenoid Infrastructure
Solenoid Installation and Commissioning
Supply Construction
Power Supply Installation &Testing
Detector Construction
Accelerator and Beamline Construction
Accelerator Commissioning (off Project)
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- By reusing existing power supplies most of the large dollar and long lead time items are on hand.
  - We will not be able to move equipment until we have the service building constructed.
  - We will need to coordinate the installation in the building with other large equipment being installed.
- The major cost in both M&S and Labor will be spend on constructing new Dump Switches and Bus work.
- We are ready to move forward on the final design.

- end

Remaining work before CD-3 extra detail

- Detailed Control Cable Drawings
  - Power Supply to Regulator/Controller
  - Regulator/Controller to Quench Protection
  - Dump Controller to Quench Protection
- Detailed building layout
  - Power Supply, Filter and Dump Switch floor plan
  - Cable tray routing
  - Bus Work routing
- Detailed design work the common controls
  - Water monitoring system that is common to all magnet loops.
  - Independent overcurrent monitors for all loops.
  - UPS system monitors.

Quality Assurance extra detail

- The equipment being reused was part of the TeV in collider operation and maintained at a very high level so they are still valuable and usable.
  - All regulation and control circuits were replaced with FNAL designs to improve the reliability early in operation.
- We will replace components that have limited life times
  - Electrolytic Capacitors in all control circuits
  - Electrolytic Capacitors in Filter bank
  - Internal low level control power supplies
- Some modifications need to be done to the supplies to make them operate in two quadrant mode (+/- Voltage)
  - We will install new proven design firing circuits for all the SCRs in the high current supplies to add the Bypass device.
    - We will replace the existing 3 circuit boards with new four circuit boards.
- High current testing will be done in AD lab before installation.

Risks extra detail

- The risk for reusing the type of equipment is reasonable and low and not included in the risk registry.
  - The Low Beta Systems operated at very close to the same level as they will in the experiment.
  - The 375kW power supplies are designed to operate at 7,500 amps each and we will only use them at 6,114 for DS and 4,600 for PS (two in parallel).
  - The TSx supplies will be 50kW supplies that are designed for 2,500 amp operation and will be used at 1,730 amps.
- We will be constructing new Dump Switches but they will be copies of a proven design used in the TeV.
- The trim power supplies are a new design but similar to other system used in the TeV. Magnetic coupling issues will need to be addressed during the detail design.

ES&H Extra Details

- All of this equipment will require written Lock Out Tage Out “LOTO”s because we have multiple input power sources and stored energy in the magnets.
- The Power Supply, Filter and Dump Racks are all separate cabinets that will require interlocking in addition to the written LOTOs.
  - These LOTOs will be written by AD E/E Support and be part of the department training and qualification process.
  - On large Super Conducting load we normally manage access using a registered Key system to ensure that the systems are turned Off in a controlled way. This Key system will defined by E/E support but issued by the Main Control Room in conjunction with Experiment Control Room.