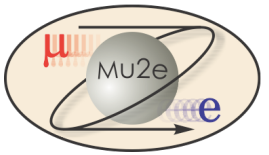
Fermilab

Delivery Ring RF 475.02.06
Mu2e DOE CD-2 Review



Joseph E. Dey
L3 Manager
10/21/2014

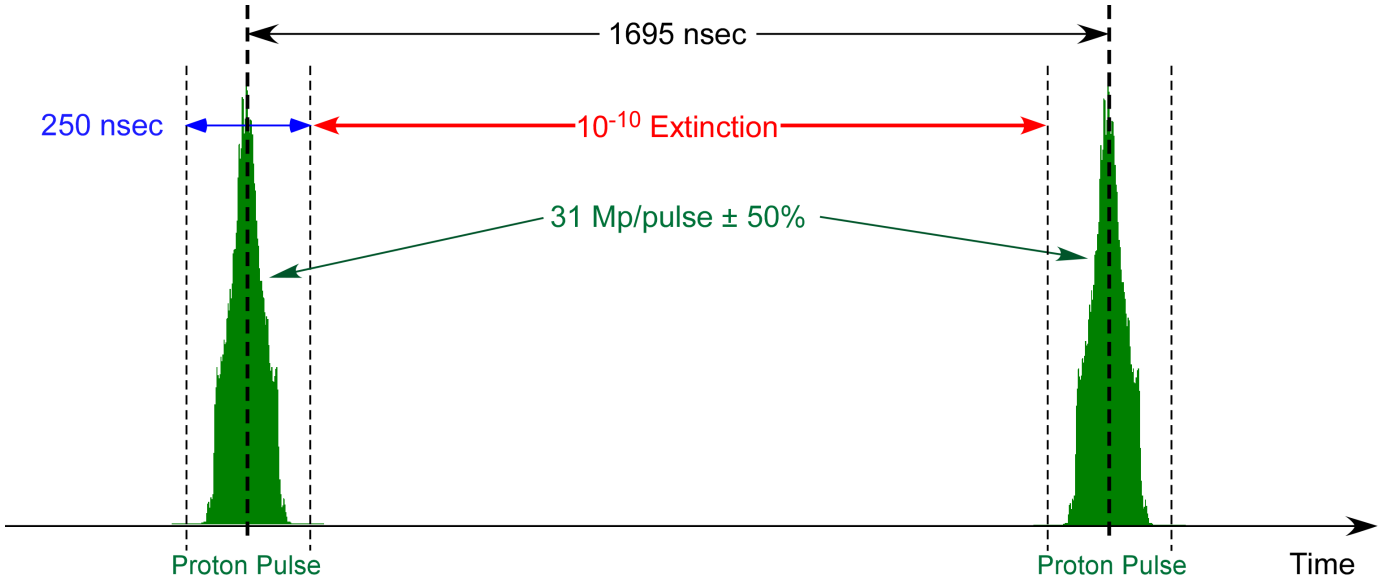
WBS 475.02.06 Delivery Ring RF

- The Delivery Ring's 2.4 MHz RF systems purpose is to produce an efficient transfer of beam from Recycler and to preserve a 250 ns bunch structure in the Delivery Ring.

Proton Beam Requirements

The bunch length requirement is primarily accomplished by the Recycler Ring 2.5 MHz RF system (Recycler AIP).

The function of the Delivery Ring 2.4 MHz RF system is to preserve the narrow bunch width received from the Recycler.

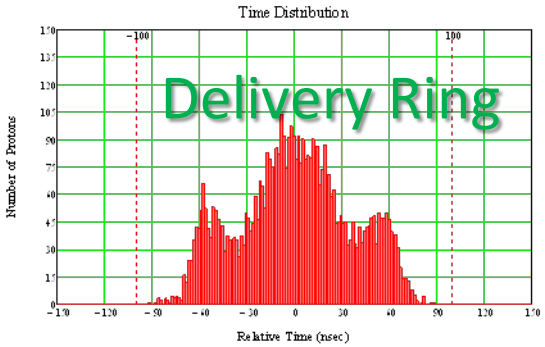


The g-2 experiment uses the same Recycler 2.5 MHz system for their bunch formation.

Since the g-2 requirements are more severe than those of Mu2e, the system will meet the needs of Mu2e.

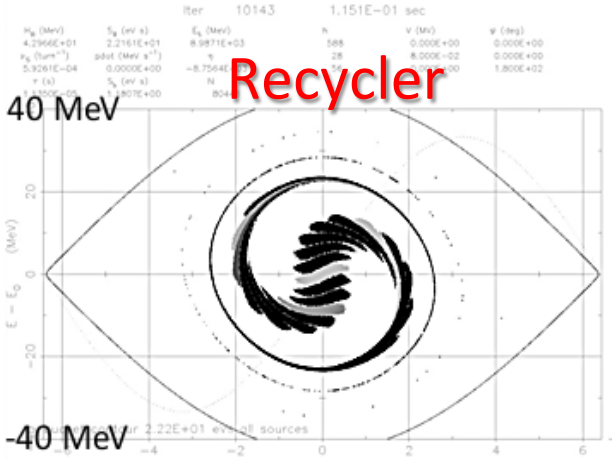
Bunch Length Requirements Full width	
Mu2e	g-2
250 nsec	149 nsec

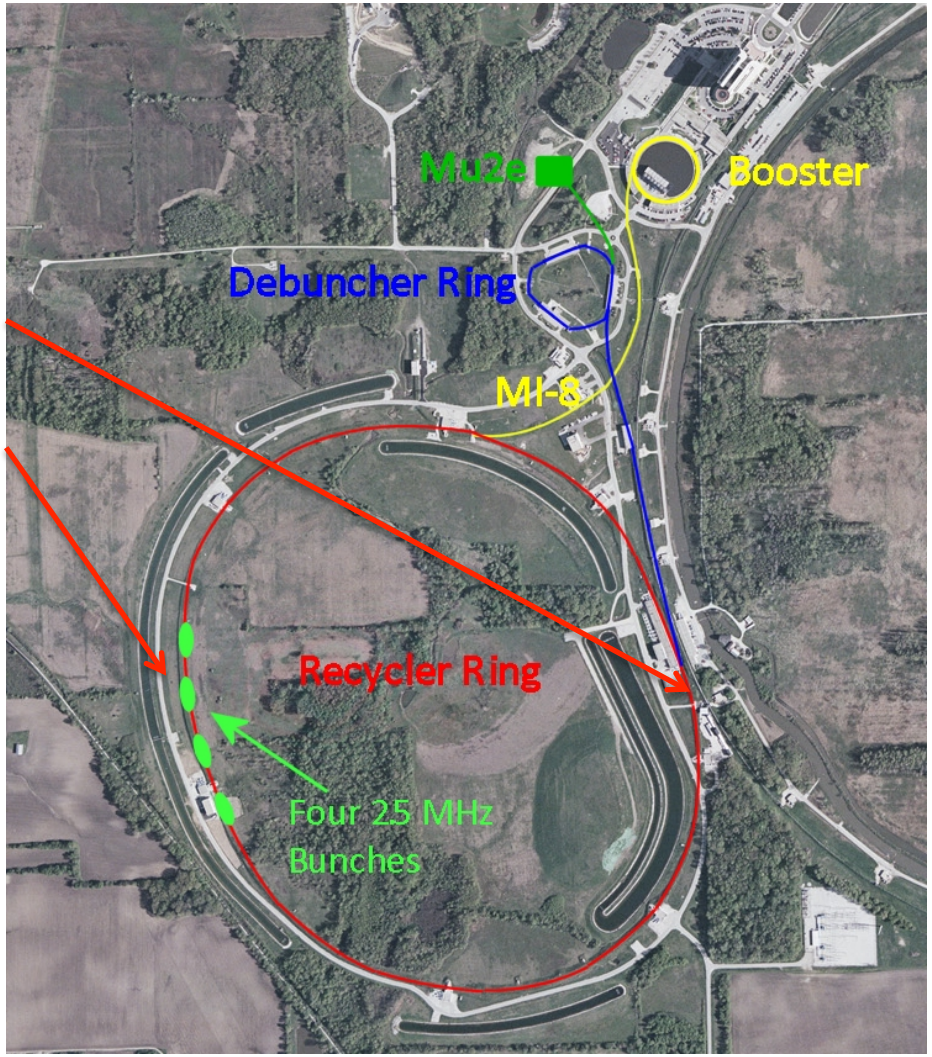
Big Picture Conceptual Design



Single bunch extraction

After bunch formation
(Δt_{FW} < 200 nsec)





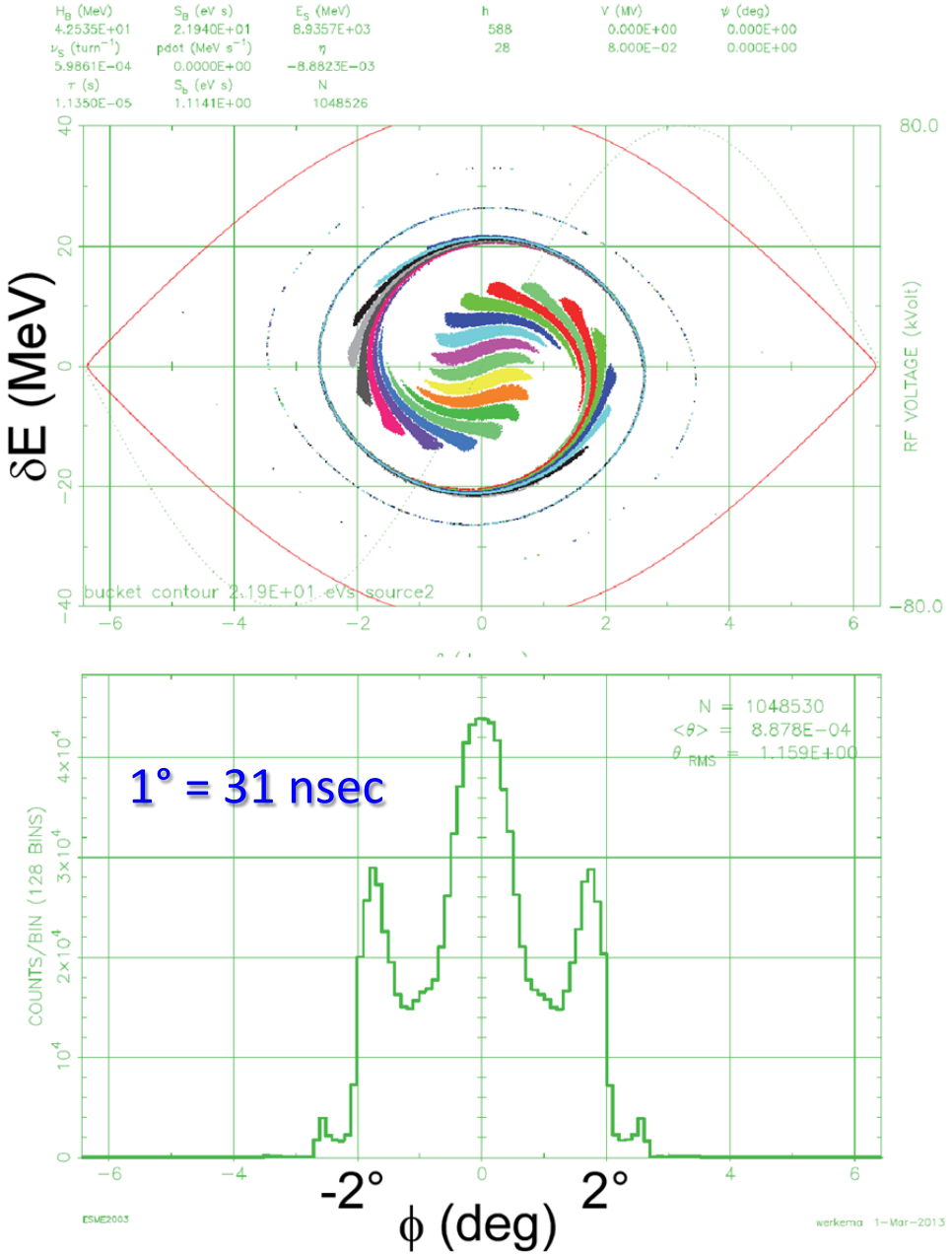
Recycler Bunch Formation

Recycler bunch shape

The 53 MHz bunched beam from the Booster Synchrotron is re-bunched with the 2.5 MHz RF system in the Recycler.

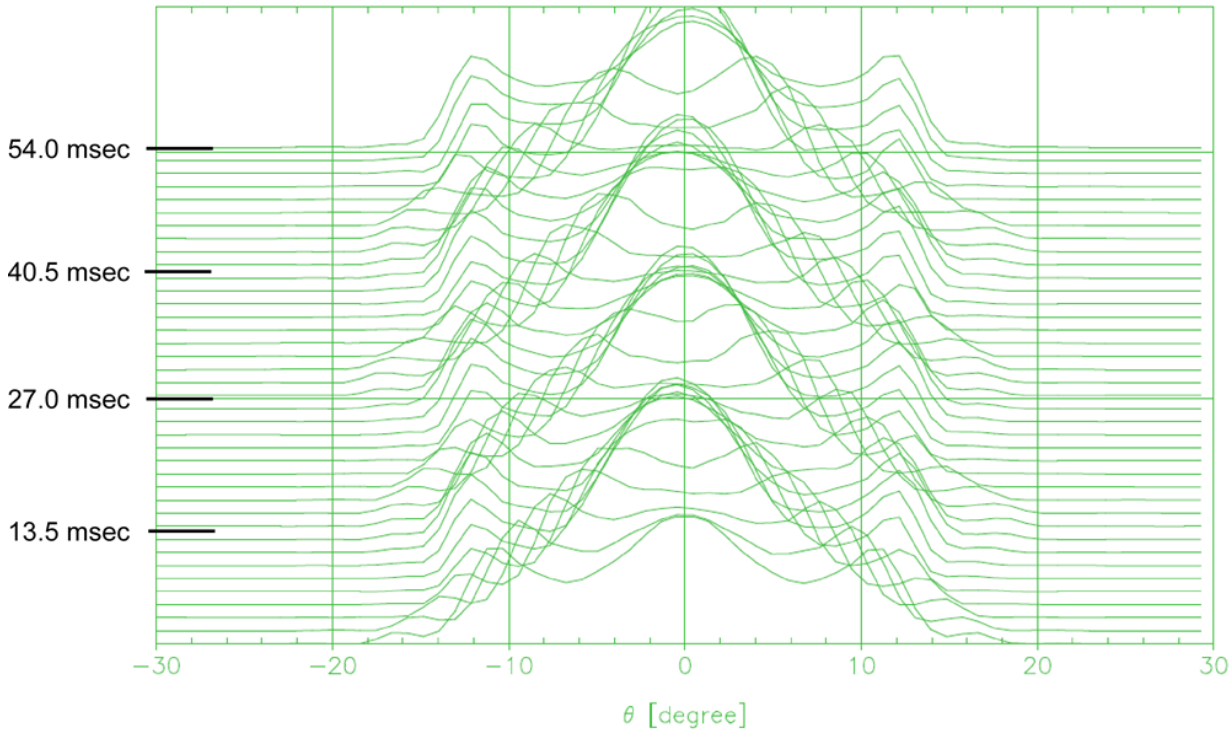
This re-bunching cycle requires 90 msec. At the end of this time, the Recycler beam consists of four bunches that occupy 1/7 of the circumference of the Recycler Ring.

This beam is extracted one bunch at a time to the Delivery Ring.



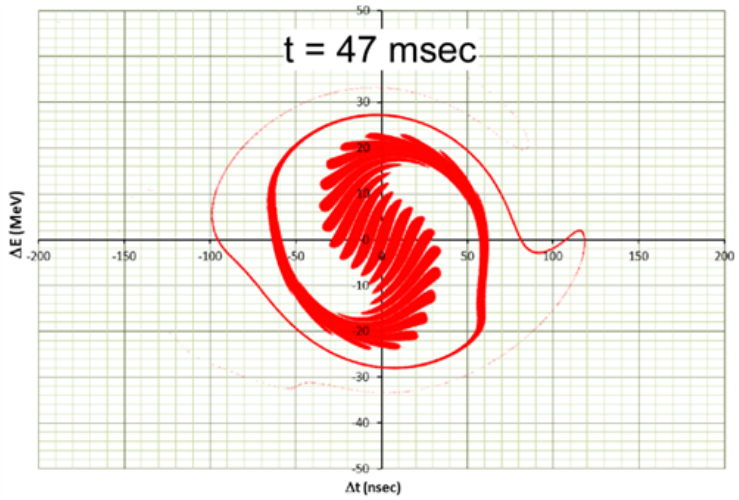
Bunch Shape Time Variation

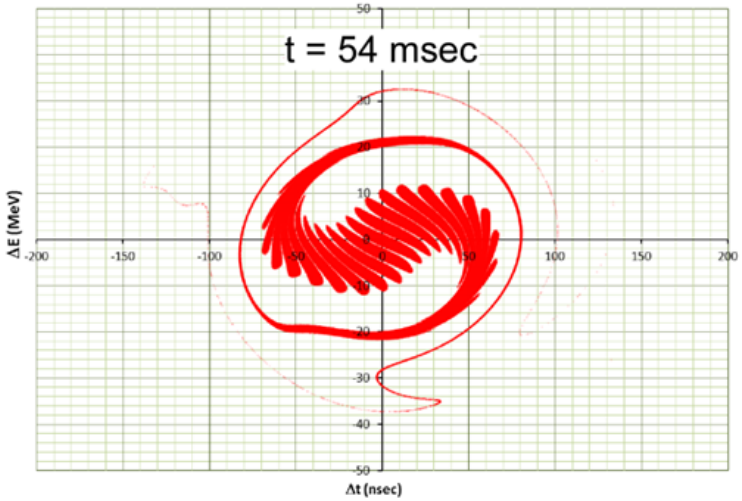
The re-bunched beam from the Recycler is poorly matched to the 2.4 MHz RF bucket in the Delivery Ring. Thus, the beam tumbles in the bucket. The bunch shape changes at twice the synchrotron frequency (T_{synch} = 25.6 msec).



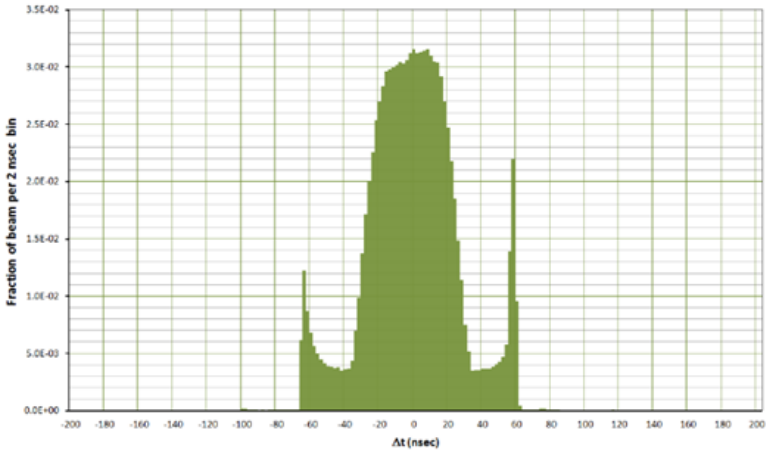
Waterfall display of the variation of the proton bunch time profile as the bunch rotates in the 2.4 MHz RF bucket. A trace is plotted every 1.35 msec over the course of the spill. The vertical axis is time relative to the start of the spill. The horizontal axis is Delivery Ring phase (1° = 4.708 nsec).

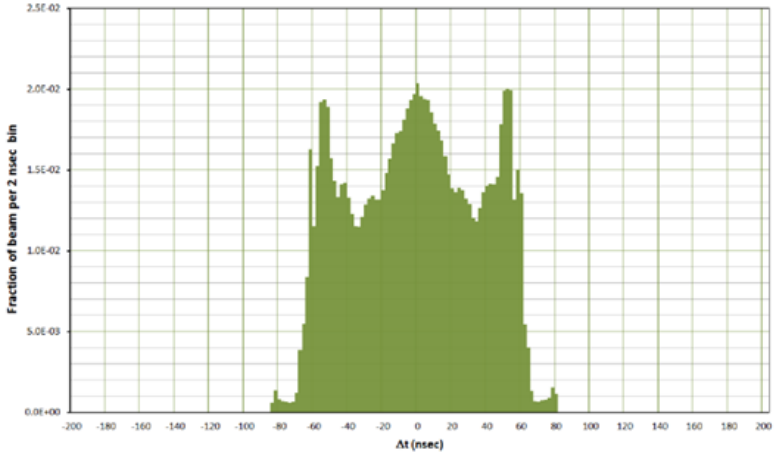
Bunch Shape Time Variation





ΔE vs. Δt



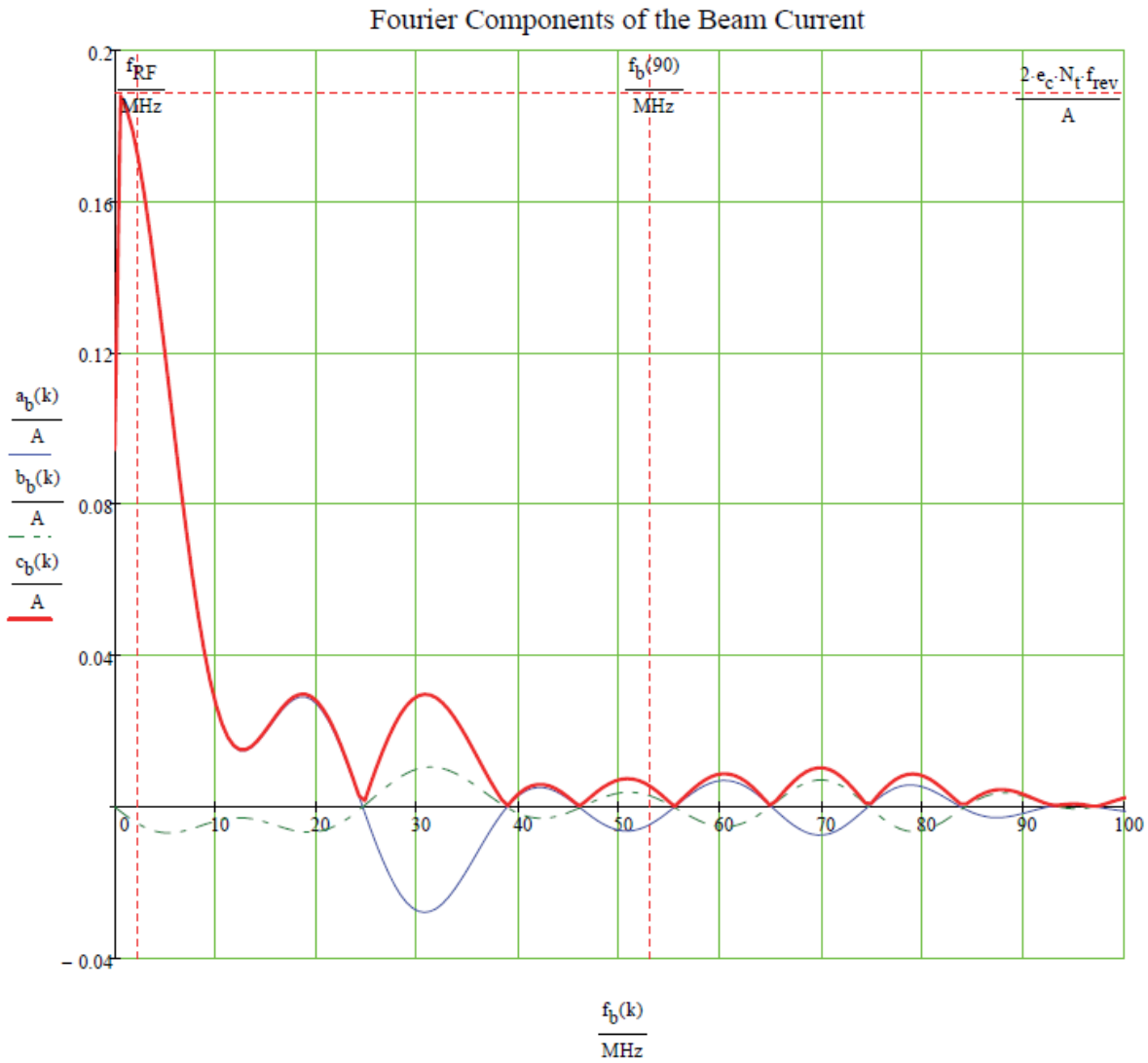


Bunch time distribution

Fourier Components of the Beam

1×10^{12} protons
Single Bunch
ESME Simulation

$a_b(k)$ = cosine amplitudes
$b_b(k)$ = sine amplitudes
$c_b(k)$ = overall magnitude



Requirements

Parameter	Value	Units
Harmonic Number	4	
Frequency	2.360	MHz
Peak Total Voltage	10	kV
Number of Cavities	1	
R/Q	400	Ω
Q	125	
Duty Factor	100	%

Requirements

Beam Current (Ip) = 178.564×10^{-3} A

Number of Cavities = 1

R/Q = 400 Ω

Q = 125

Cavity Voltage = 10.0 kV

Cavity Power Loss per Cavity = $1. \times 10^{3}$ W

Total Apparent Power = 1.04858×10^{3} VA ∠ 17.5089 degrees

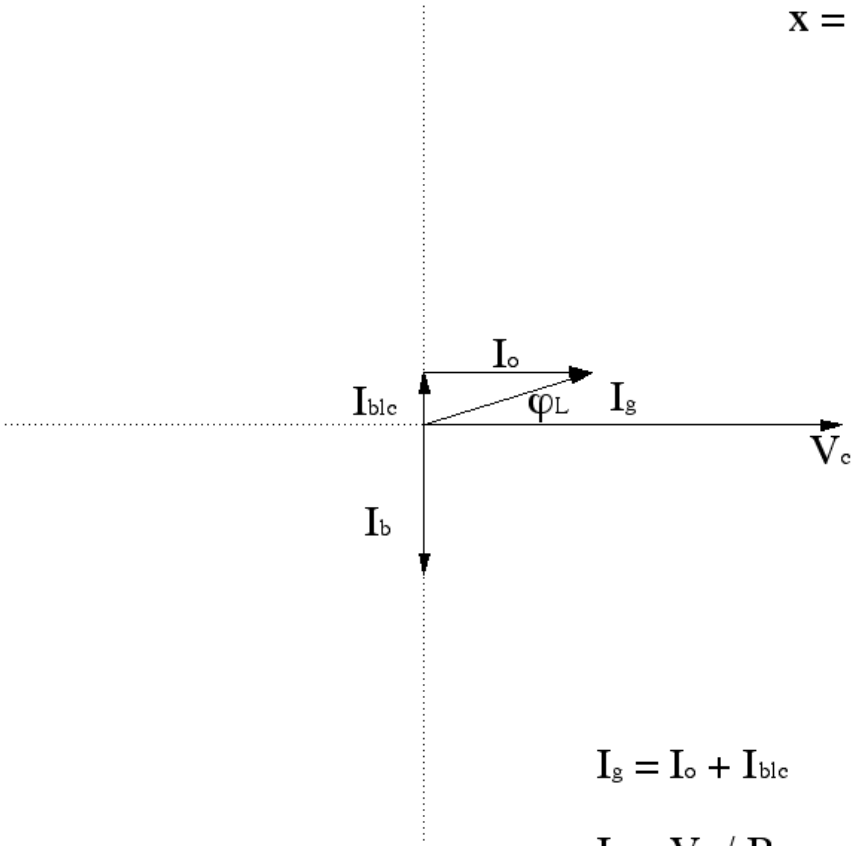
Total Current = 209.716×10^{-3} A ∠ 17.5089 degrees

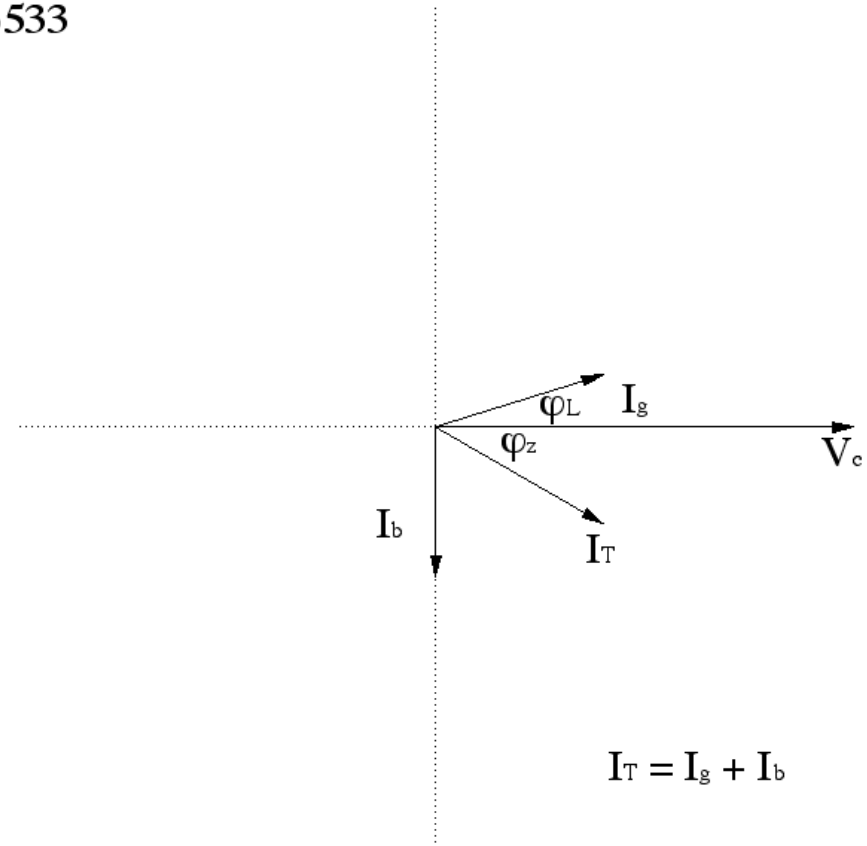
Percent of Induced Mode Compensated = 3.78649 dB = 35.3341 %

Robinson Stable = 4.

Requirements

Robinson Stable = 4.00
35.33% Beam Loading Compensation
x = 0.3533





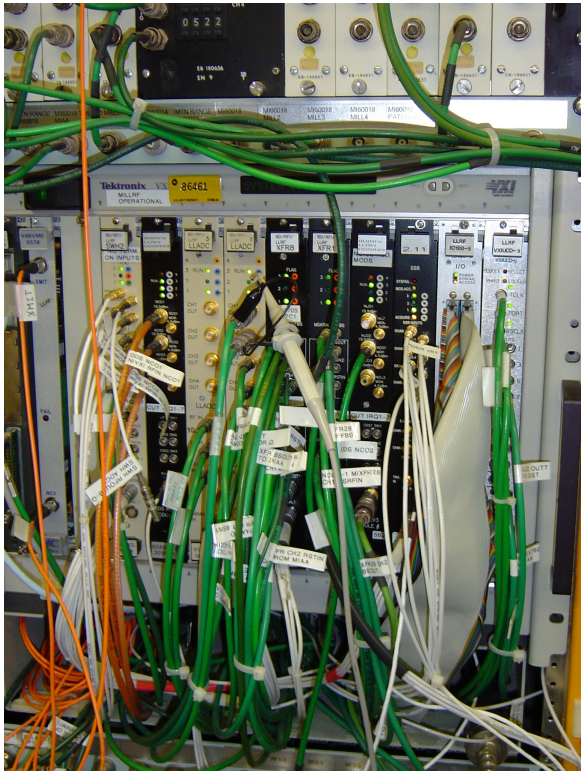
$I_g = I_o + I_{blc}$

$I_o = V_c / R$

$I_{blc} = j \times I_b$

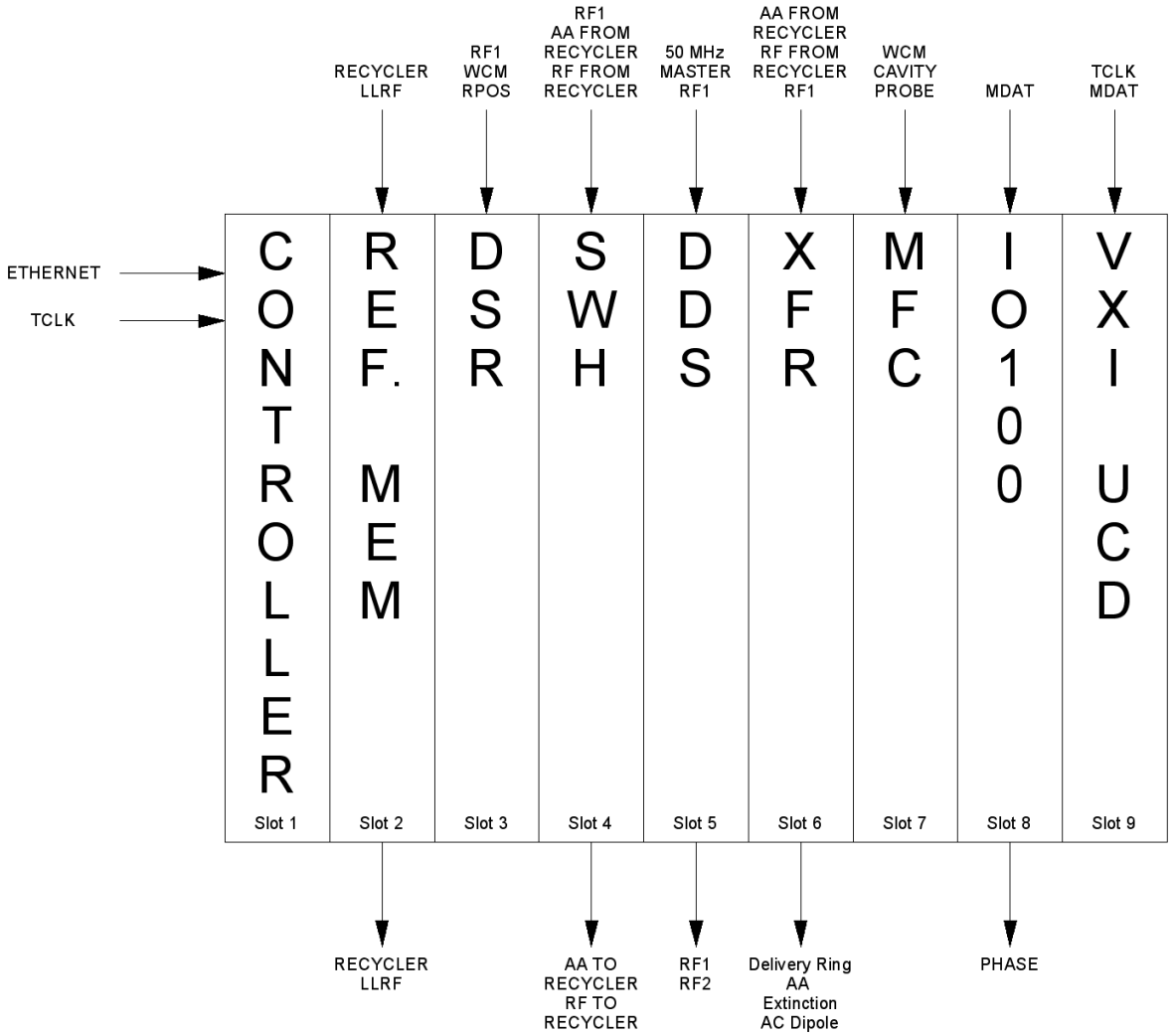
$I_T = I_g + I_b$

Design – Low Level RF System



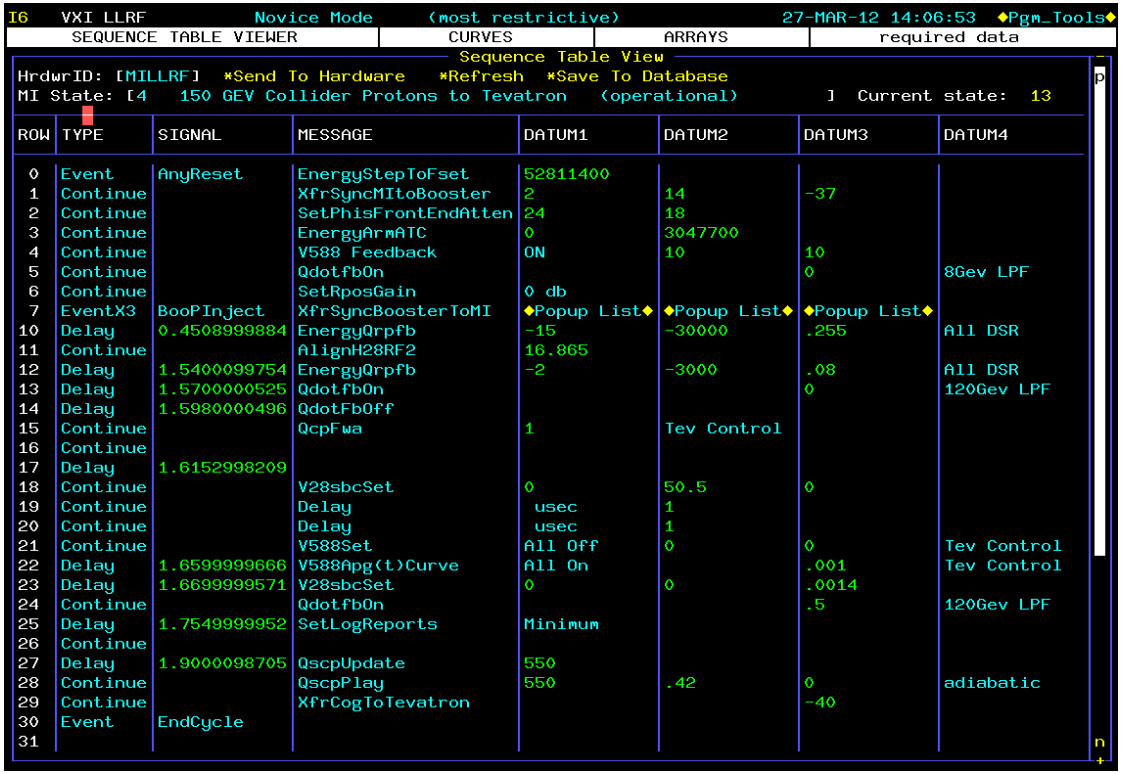
Main Injector VXI Controlled
Low Level RF

Design – Low Level RF System



VXI Crate Block Diagram

Design – Low Level RF System



I6 VXI LLRF Novice Mode (most restrictive) 27-MAR-12 14:06:53 ◆Pgm_Tools◆

SEQUENCE TABLE VIEWER | CURVES | ARRAYS | required data

Sequence Table View

HrdwrID: [MILLRF] *Send To Hardware *Refresh *Save To Database

MI State: [4 150 GEV Collider Protons to Tevatron (operational)] Current state: 13

ROW	TYPE	SIGNAL	MESSAGE	DATUM1	DATUM2	DATUM3	DATUM4
0	Event	AnyReset	EnergyStepToFset	52811400			
1	Continue		XfrSyncMItoBooster	2	14	-37	
2	Continue		SetPhisFrontEndAtten	24	18		
3	Continue		EnergyArmATC	0	3047700		
4	Continue		V588 Feedback	ON	10	10	
5	Continue		QdotfbOn			0	8Gev LPF
6	Continue		SetRposGain	0 db			
7	EventX3	BooPInject	XfrSyncBoosterToMI	◆Popup List◆	◆Popup List◆	◆Popup List◆	
10	Delay	0.4508999884	EnergyQrpfb	-15	-30000	.255	All DSR
11	Continue		AlignH28RF2	16.865			
12	Delay	1.5400099754	EnergyQrpfb	-2	-3000	.08	All DSR
13	Delay	1.5700000525	QdotfbOn			0	120Gev LPF
14	Delay	1.5980000496	QdotFbOff				
15	Continue		QcpFwa	1	Tev Control		
16	Continue						
17	Delay	1.6152998209					
18	Continue		V28sbcSet	0	50.5	0	
19	Continue		Delay	usec	1		
20	Continue		Delay	usec	1		
21	Continue		V588Set	All Off	0	0	Tev Control
22	Delay	1.6599999666	V588Apg(t)Curve	All On		.001	Tev Control
23	Delay	1.6699999571	V28sbcSet	0	0	.0014	
24	Continue		QdotfbOn			.5	120Gev LPF
25	Delay	1.7549999952	SetLogReports	Minimum			
26	Continue						
27	Delay	1.9000098705	QscpUpdate	550			
28	Continue		QscpPlay	550	.42	0	adiabatic
29	Continue		XfrCogToTevatron			-40	
30	Event	EndCycle					
31							

Main Injector VXI Low Level RF
Console Application

Performance – Low Level RF System

- In using an embedded system LLRF, we will be able easily accommodate studies and modify operations as needed.
- The LLRF system will be very similar to the existing Main Injector and Recycler LLRF systems.
- In using a Console Application, one will be able to access the Delivery Ring RF from any Console onsite.
- State of the art embedded systems hardware will be used for this design.

Changes since CD-1

- BOE, 475.02.06.03 Delivery Ring RF Cooling System, was moved off Project to Recycler RF AIP.
- BOE, 475.02.06.04 Delivery Ring 2.4 MHz RF, Cavity Installation and 8 kW 2.4 MHz Solid State Driver Items were moved off Project to Recycler RF AIP.

Organizational Breakdown

- Low Level RF System – 475.02.06.01
  Engineers – Brian Chase, Ed Cullerton, Philip Varghes
  Technician – Dan Klepec

- Delivery Ring RF Studies & Tuning – 475.02.06.02
  Steve Werkema, Dave Peterson,
  Dave Vander Meulen and Joe Dey

- Delivery Ring 2.4 MHz RF -475.02.06.04
  Physicist – Steve Werkema

Quality Assurance

- Low Level RF System – Will have been completely bench tested and documented before being released to the project.

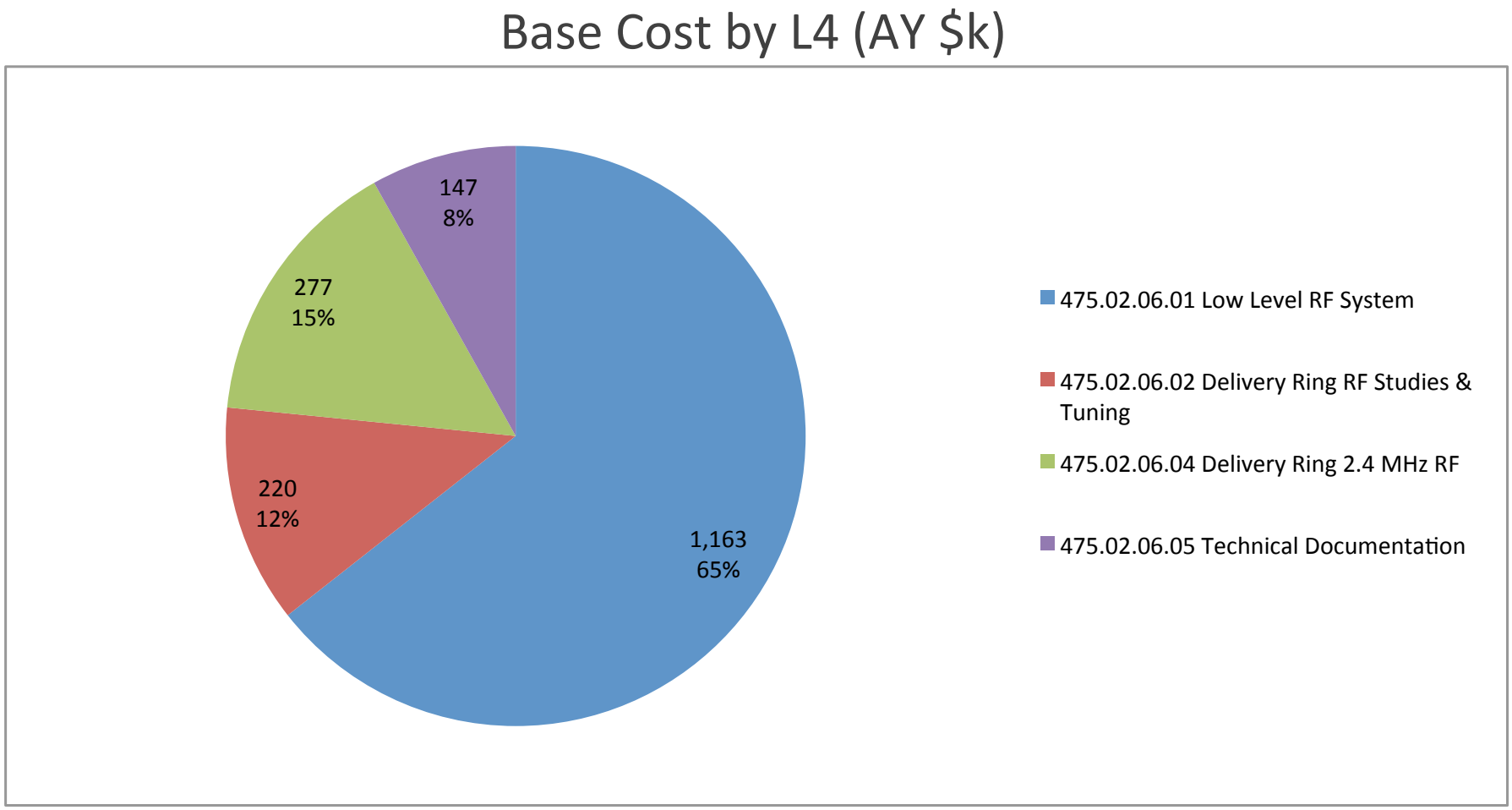
Risks

- Risks from TDR
- Low Level RF System – No risks are noted here.
- Delivery Ring RF Studies & Tuning – No risks are noted here.

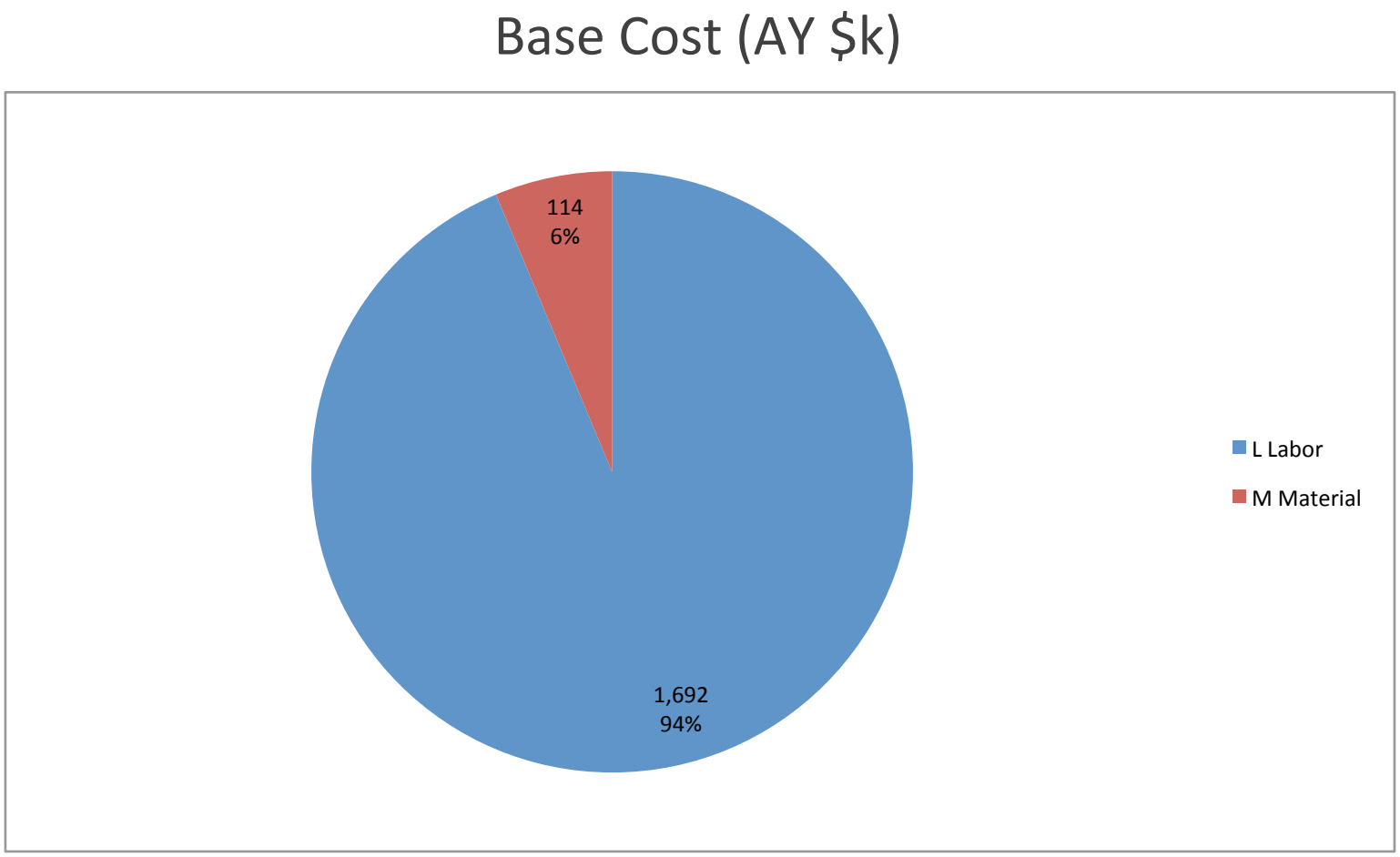
ES&H

- LOTO procedures will be written for the Operation of the Delivery Ring High Level RF and for the Delivery Ring RF Cooling System.

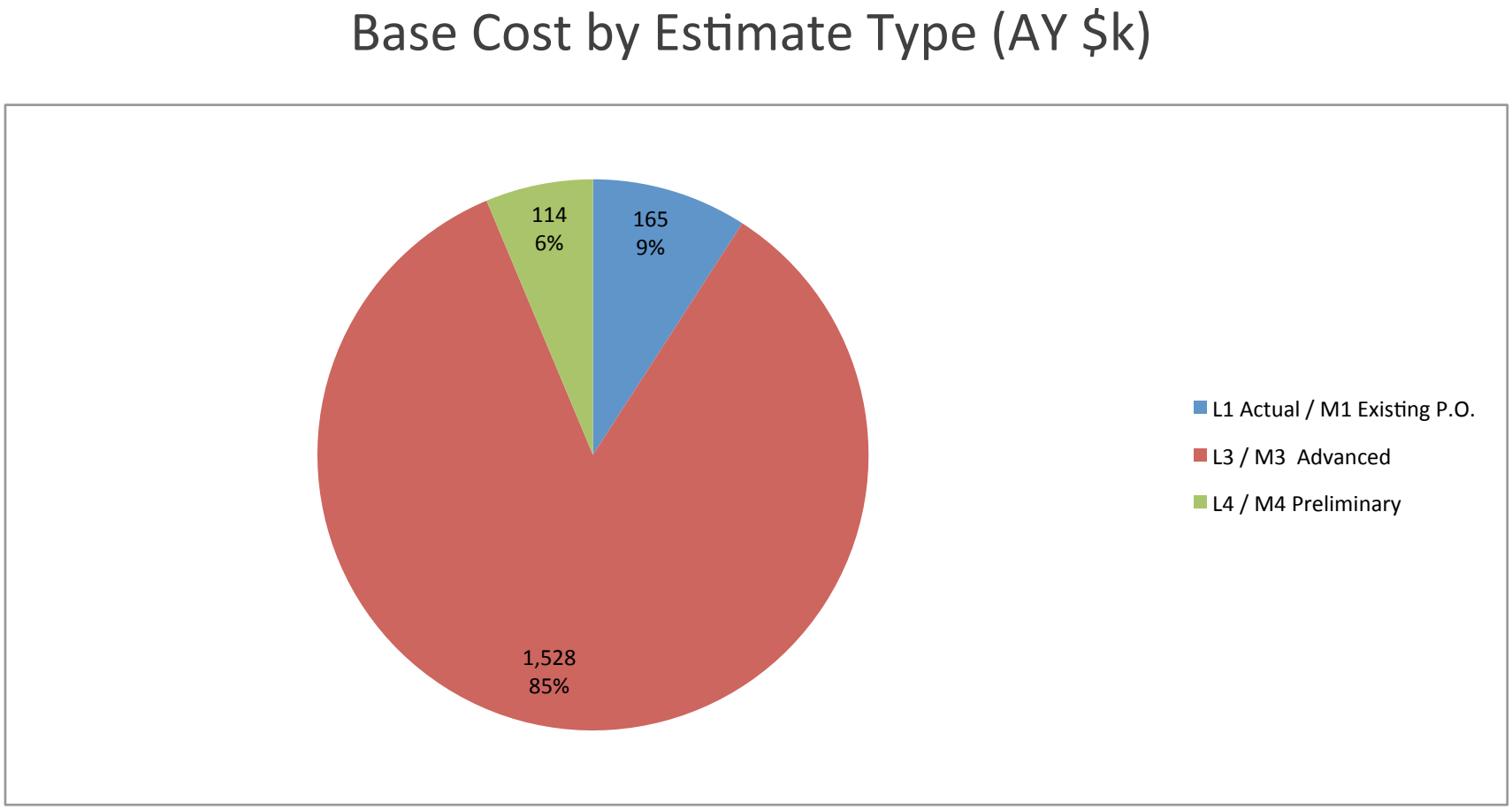
Cost Distribution by L4



Cost Distribution by Resource Type



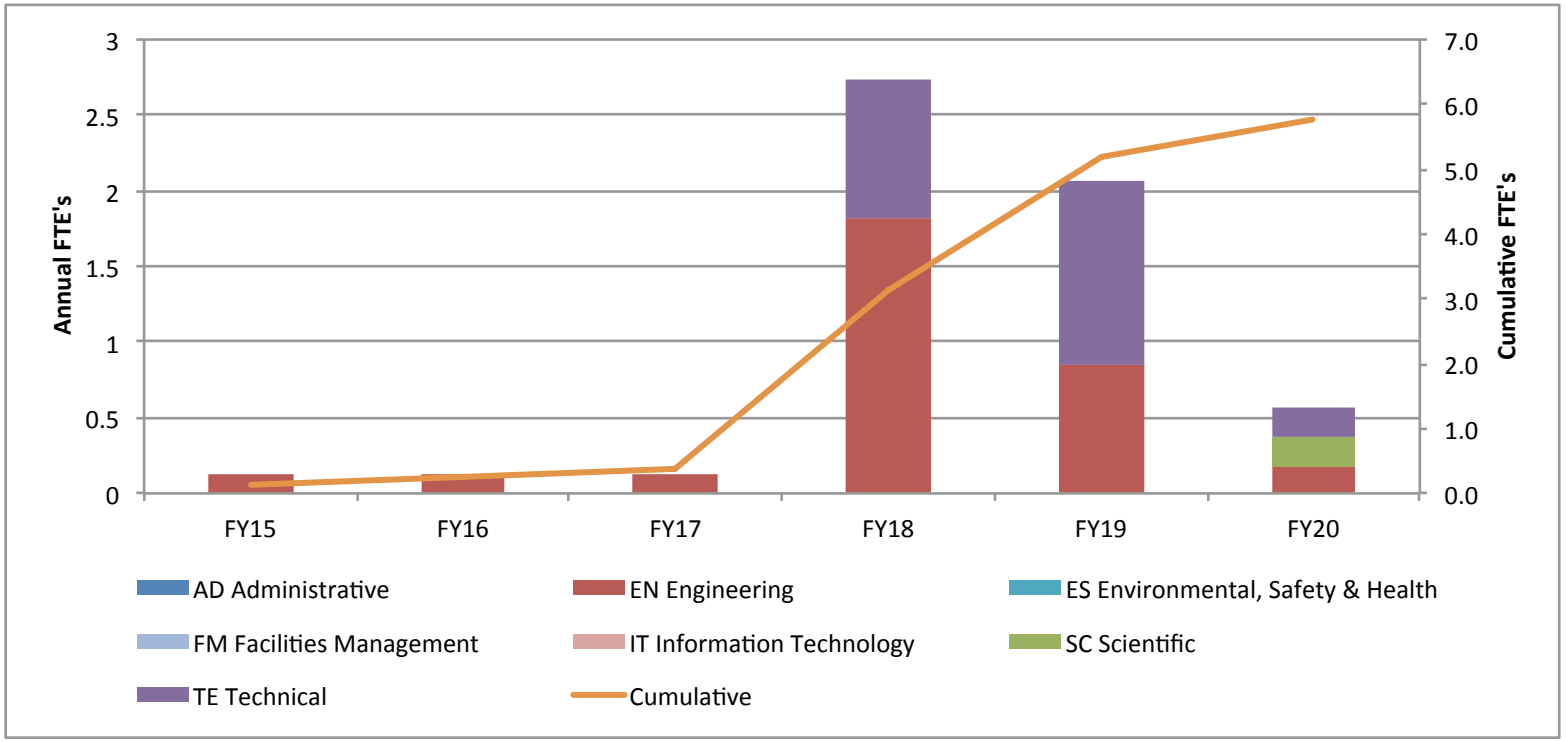
Quality of Estimate



Quality of Estimate of Preliminary or Better is 100%

Labor Resources

FTEs by Discipline



Cost Table

WBS 2.6 Delivery Ring RF

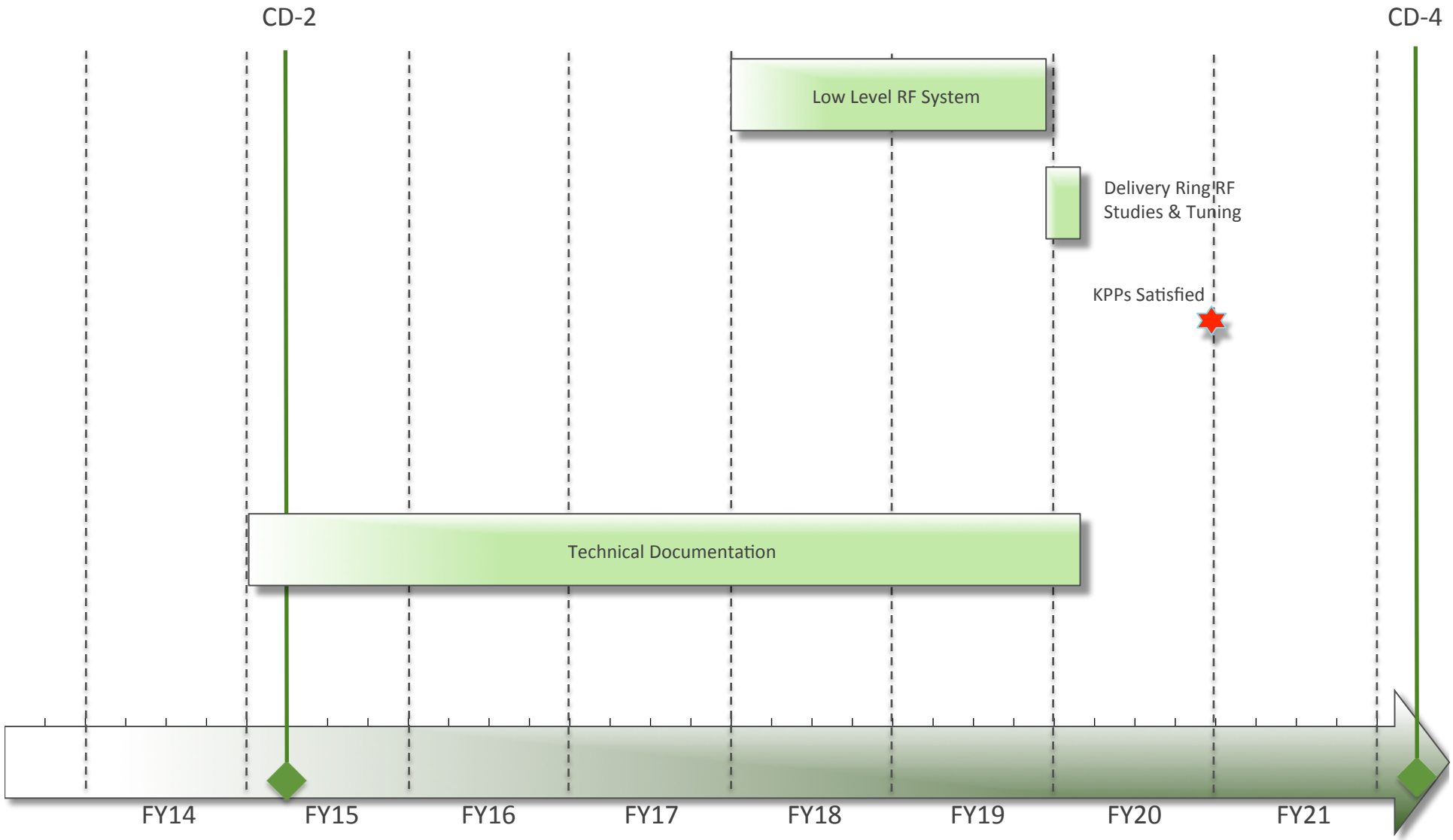
Costs are fully burdened in AY $k

	M&S	Labor	Total	Estimate Uncertainty (on remaining budget)	% Contingency on (on remaining budget)	Total Cost
475.02.06.01 Low Level RF System	114	1,049	1,163	297	25%	1,460
475.02.06.02 Delivery Ring RF Studies & Tuning		220	220	55	25%	275
475.02.06.04 Delivery Ring 2.4 MHz RF		277	277	1	-	278
475.02.06.05 Technical Documentation		147	147	36	22%	183
Grand Total	114	1,692	1,806	389	25%	2,195

Major Milestones

Activity ID	Milestone Name	Milestone Start Date	Milestone Finish Date
47502.06.01.000500	T5 - Start Low Level RF System Procurements	3-Oct-16	
47502.06.001030	T5 - RF Cavity installed in Delivery Ring		21-Sep-18
47502.06.01.001220	T5 - Delivery Ring LLRF System Complete		5-Sep-19
47502.06.02.001040	T5 - Delivery Ring RF Studies Complete		2-Dec-19
47502.06.001020	T5 - Delivery Ring RF Implementation and Closeout Complete		2-Dec-19

Schedule


CD-2
CD-4
Low Level RF System
Delivery Ring RF
Studies & Tuning
KPPs Satisfied
Technical Documentation
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- Our Final Design is complete and we are ready to Baseline the schedule.