1.0.1 & 2.0.1 Recycler Upgrades

June 4-6, 2007

Paul Derwent

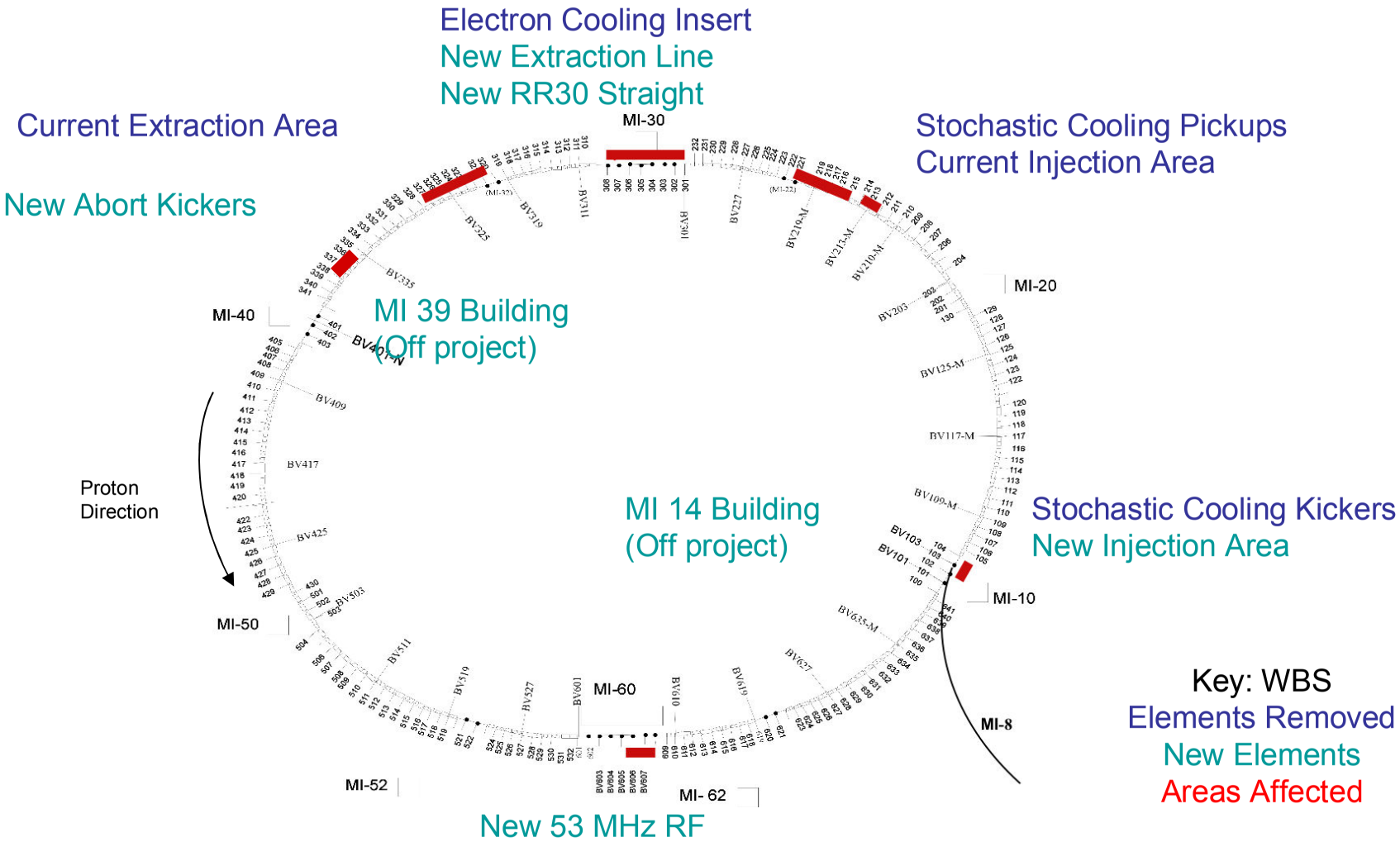
Recycler as Proton Injector

- Now: Recycler is the Tevatron Collider Antiproton Storage Bottle
  - Permanent magnet storage ring
  - Lifetime > 500 hours
  - Stochastic and electron Cooling
  - >4e12 circulating antiprotons (~1.2e13 protons)
    - Expect ~5e13 during Nova running
  - Good transverse and momentum acceptance
    - ~60π mm mr transverse acceptance
    - 1.5% momentum acceptance
- Future: Recycler as Proton Injector
  - Same size as MI: Single turn fill time (~11 μsec)
  - With good transverse and momentum acceptance
    - Slip stack to accumulate proton current

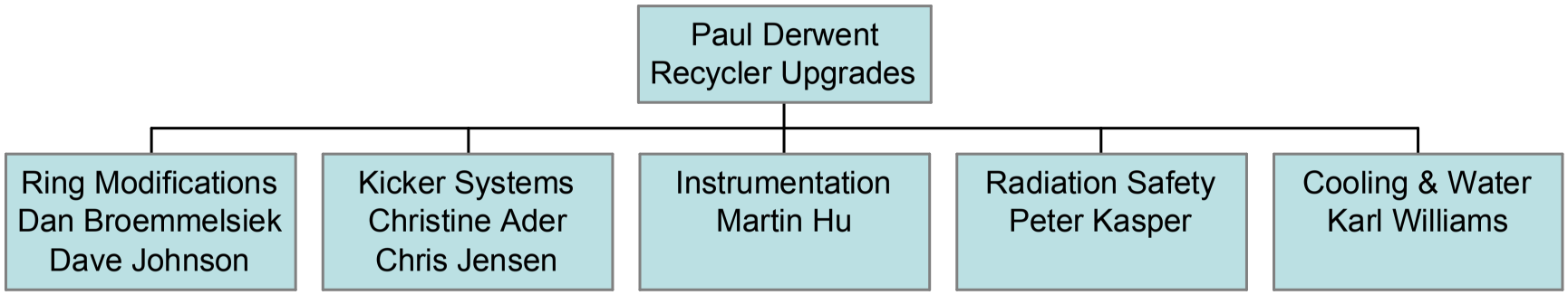
Conversion tasks

- Take antiproton specific devices out
  - Stochastic and electron cooling
- Build new transfer lines
  - Direct injection into RR
    - Currently only injection is through MI
    - Needs fast kicker!
  - New extraction line
    - Larger aperture (~20π protons vs ~5π antiprotons)
    - Needs 2 new full turn kickers
- 53 MHz RF system for slip stacking
- Instrumentation upgrades

Recycler Layout and Tasks



Recycler Upgrade Organizaton



1(2) .0.1.1: Recycler Ring Modifications Dan Broemmelsiek/Dave Johnson

- Decommission antiproton devices in Recycler
  - Dismantle stochastic cooling
  - Dismantle electron cooling insert and electron return line
    - Want to save for future use
    - 38 permanent magnet quads will be retuned and reused
  - Dismantle injection and extraction lines
    - Remove and reuse
      - Lambertsons
      - Instrumentation (multiwires, BPMs)
      - Vacuum components
      - Correction elements

Recycler Ring Modifications
Dan Broemmelsiek/Dave Johnson

- New Injection Line
  - Direct injection into the Recycler
    - Preserve 8 GeV injection into MI
    - Preserve 8 GeV Booster Neutrino Beam
  - Follow existing MI-8 Line
  - Vertical switcher magnet (at 848) inject at RR104
- New Extraction Line
  - Single turn extraction into MI
  - Kicker at RR230, extraction Lambertson at RR232
  - Injection Lambertson at MI306, Kicker at MI308
- Rework RR30 Straight Section
  - Removal of electron cooling
  - Rebuild as RR FODO

Refurbish permanent magnets (quads)
Refurbish bending magnets (switcher & major bends)
Build new mirror magnets and PDDs for injection line

Injection line area

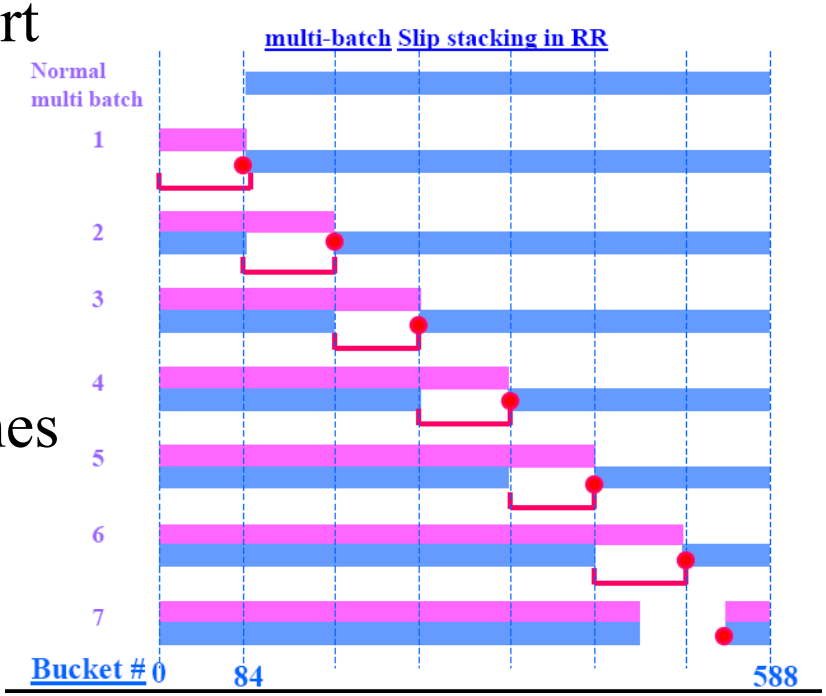
MI 8

MI 8 and Main Injector

MI and Recycler and Utilities

Recycler Ring Modifications
Dan Broemmelsiek/Dave Johnson

- Beam Abort Modifications
  - Installation of new full turn abort kicker
  - Installation of new gap clearing 1.6 μsec kicker
- 53 MHz RF System
  - Slip stacking 6+6 Booster batches
  - 52.809 MHz ± 1300 Hz
  - 2 + (hot spare) cavities
- Constraints on kicker rise and fall times



Recycler 53 MHz RF

- f_o = 52.809 MHz +/- 1.3 kHz necessary
  - Tunable over +/- 5 kHz range using fast (4 turns) garnet phase shifters developed for the Proton Driver
- V_{rf} = 2 X 150 kV_{peak} for slip-stacking
- Fast cavity tuning for Beam Loading Compensation
- HOM dampers for 3rd & 5th harmonics on Cavities
- Recycle Tev RF power amps (200kW)
  - Place amps in tunnel
  - Tetrode anode dissipation with 1 Adc beam current and no detuning = 130 KW (tube rated for 150 kW)
- Recycle Tev Modulators
- Anode Supply
  - Build new supply south of existing MIRF APS1 (off project)

1(2) .0.1.2: Recycler Kicker Systems Christine Ader/Chris Jensen

- Injection & Gap Clearing Magnets & Power Supplies
  - Injection
    - Fast rise (3 52.809 Buckets -- 57 nsec)
    - Fast fall (3 52.809 Buckets -- 57 nsec)
    - New design: Prototype stage
  - Gap clearing
    - Clear the injection gap of any beam lost in slip stacking process
- Prototyping and Production stage
- Issues
  - All Recycler kickers will use same ceramic beam tube aperture
    - Long lead time item
  - Rise and fall times drive magnet size
  - Desired kick drives number of magnets and number of tubes
  - Fall time drives need for bumper magnets -- investigating with MI

Recycler Kicker Systems
Christine Ader/Chris Jensen

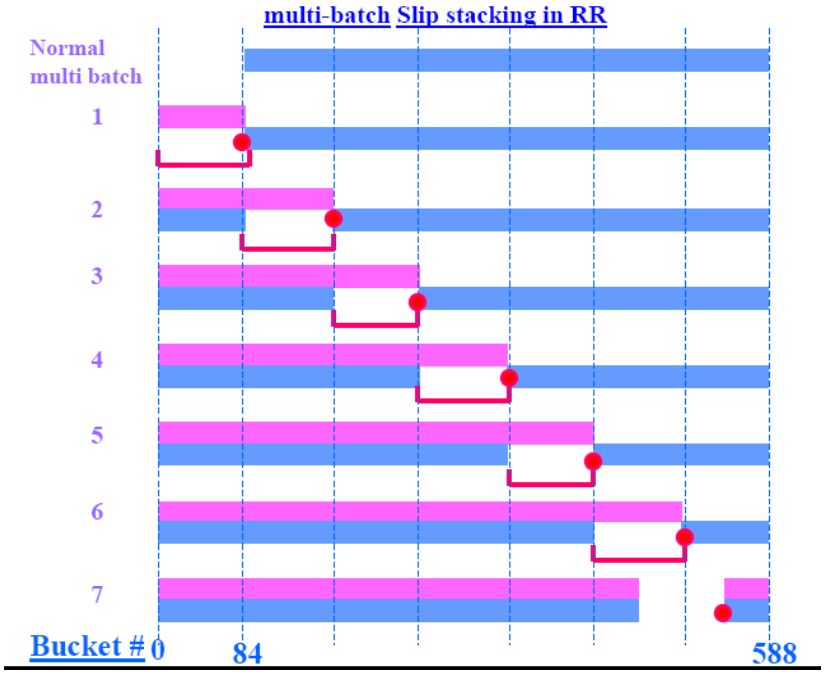
- Recycler Extraction Magnets & Power Supplies
  - RR extraction:
    - Existing magnet design, add fluorinert cooling
    - Longer power supply flattop
      - New PFL
  - MI injection:
    - Revise existing magnet design, add fluorinert cooling
    - Longer power supply flattop
      - New PFL
- Recycler Beam Abort Magnets & Power Supplies
  - Full turn abort
  - Existing magnet design, add fluorinert cooling
  - Longer power supply flattop
    - New PFL

1(2) .0.1.3: Recycler Instrumentation Martin Hu

- BPMs
  - New cable installation for 53 MHz system
  - Duplicates existing MI BPM hardware & software
- DCCT / Toroids
  - New intensity regime: 5e13
  - Decision:
    - In house (as in MI DCCT)
    - Bergozs (as in RR DCCT): costed this choice
- Dampers
  - Instabilities
    - Longitudinal and transverse
  - Injection oscillations
  - Based on existing designs
    - MI & RR
    - Use existing pickups and kickers
    - More power amplifiers

Performance Specifications

- 6 + 6 Batch injection for slip stacking
  - 53 MHz RF
  - Fast kickers
  - Upgrade instrumentation
- Booster Neutrino Beam Program
  - Switching magnet at injection
  - Dipole mirror magnets
- Minimize loss in tunnel
  - Gap clearing kicker



Value Engineering

Value Engineering/Management:

- Magnets:
  - Refurbish existing dipoles and quadrupoles
    - ADCs for switching and major bends in transfer lines
    - Permanent Magnet Quads in transfer lines
  - Refurbish kicker magnets, add cooling (RR extraction, RR abort)
  - Build new magnets using existing designs
    - Permanent Dipoles (PDD) in RR injection line
  - Reuse powered trim and quad correctors from transfer lines
- Power Supplies:
  - Copy BNB switcher magnet (MBEX) for switching magnet
  - Reuse corrector packages from transfer lines
- Instrumentation:
  - Existing BPM plates & digitzer boards (Echotek)
  - Reuse BPMs/multiwires/toroids in transfer lines

Risks

Risk Management:

- Injection & gap clearing kicker
  - Rise & fall time specifications (Nova-docdb #1445)
  - Schedule (Nova-docdb #1446)
    - Resource restrictions
- Ceramic beam tubes (Nova-docdb #1444)
  - Need a lot of tubes
    - Procurement schedule
    - Handling
- Installation Schedule (Nova-docdb #1964)
  - Lots of work in overlapping areas
- Mitigated by Contingency estimates in Schedule and Cost, planning tasks for the installation and many other items listed in the NOvA documents listed above.

Relevant Recommendations from SNuMI Review 11/2006

2.1.2 Recycler Upgrades Recommendation	Response
Concerning the kicker modules, their impedance and the danger of electron cloud, the committee recommends reconsidering the inside coating of the ceramics in terms of resistivity and SEY (Ti, TiN, …).	Calculations determined that coating is not required. See NOVA-doc-2116.
There seems to be a trade-off between the number of bunches "notched" out in the booster and the stringent requirements on rise- and fall-time of the injection and gap clearing kickers – the specified 38 ns are based on 2 missing bunches. The committee recommends evaluating this trade-off and to prepare for a different number of "notched" bunches as a fall-back solution.	Decided to set number of bunches at 81 (of 84) and change kicker specifications accordingly
Since slip-stacking to full intensity cannot be tested early in the RR, the committee recommends continuation of tests in the MI.	Agree, will continue aggressively.
Due to the envisaged completely new type of operation of the RR without the possibility of relevant tests before the end of the Tevatron run, the committee recommends to consider at least fully simulating this new operation, including longitudinal and transverse beam dynamics.	Will address as many aspects as possible with simulations.
Concerning the change of BPM cables, the committee recommends: Assign a coordinator now who will manage the 2009 shutdown activities. Develop the installation plan, and examine what activities could be done in earlier shutdowns to ease conflicts due to multiple personnel working in the same areas and tunnel blockages. (Cables pulls and LCW pipe relocation are two obvious candidates for doing early.)	A shutdown coordinator will be assigned in a timely way for the FY2011 shutdown. Planning tasks for this shutdown are in the resource loaded schedule. A shutdown plan and detailed schedule will be made.

Cost Overview Recycler Upgrades

(Fully Burdened: FY07$)

		ANU Recycler Upgrades Cost Estimate $K (FY07$)						
		Estimated Cost (w/Indirects)			Contingency %			Total Project Cost
WBS	Name	M&S	Labor	Total	M&S Cont %	Labor Cont %	Total Cont %	
	Recycler Upgrades	**$10,515**	**$12,535**	**$23,049**	**31%**	**34%**	**33%**	**$30,558**
1.0.1	**Recycler Upgrades Planning, Engineering & Design**	**$1,390**	**$4,382**	**$5,772**	**26%**	**32%**	**31%**	**$7,559**
1.0.1.1	Recycler Ring Modifications	$79	$1,896	$1,975	36%	35%	35%	$2,674
1.0.1.2	Recycler Kicker Systems	$1,299	$2,470	$3,769	26%	30%	29%	$4,849
1.0.1.3	Recycler Instrumentation	$0	$7	$7		20%	20%	$8
1.0.1.4	Recycler Radiation Safety	$12	$11	$22	25%	20%	23%	$27
2.0.1	**Recycler Upgrades Construction**	**$9,125**	**$8,152**	**$17,277**	**32%**	**34%**	**33%**	**$22,999**
2.0.1.1	Recycler Ring Modifications	$1,889	$3,704	$5,593	36%	36%	36%	$7,598
2.0.1.2	Recycler Kicker Systems	$6,108	$4,214	$10,321	32%	33%	33%	$13,706
2.0.1.3	Recycler Instrumentation	$1,128	$235	$1,363	23%	29%	24%	$1,694

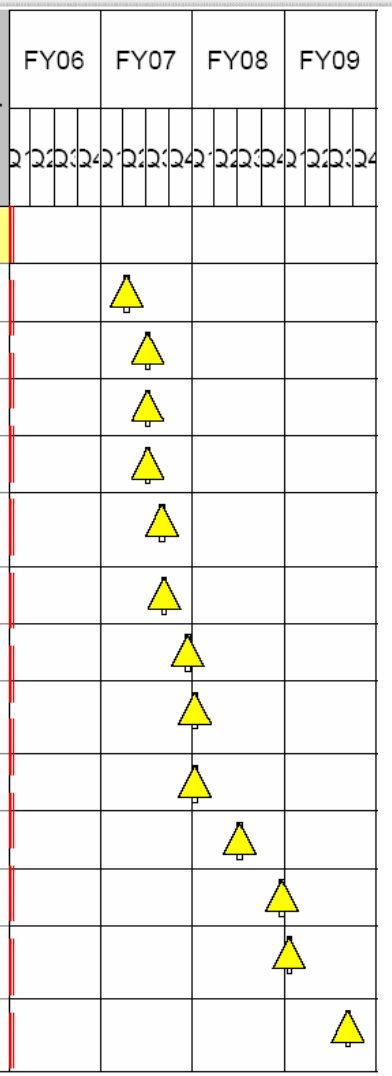
Cost Drivers for Each Level 4 System

- Ring Modifications:
  - 53 MHz RF cavities
- Kicker Systems:
  - Injection & gap clearing kicker power supplies
- Instrumentation:
  - Cabling for 53 MHz BPM system

- Need Items in next 6 months:
  - Parts for prototype kicker magnet construction
  - Order ceramic beam tubes (on TD inventory)

Milestones - Design 1.0.1

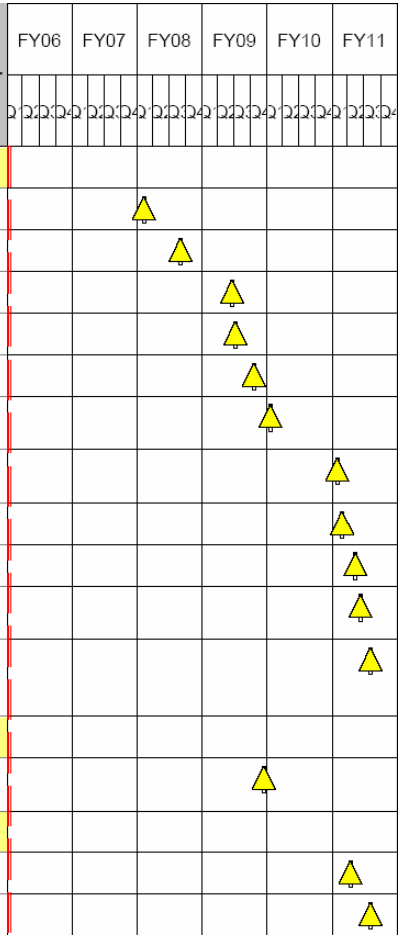
Activity ID	Activity Desc.	Date	Milestone Tier
L.2 -- WBS L2 Manager's Milestone			
1.0.1.1.6.1	RR All 3 ADC Magnets Found	03Jan07	L.2
1.0.1.1.6.2	RR Lattice Designs Complete	30Mar07	L.2
1.0.1.2.7.2	RR Ext/MI Inj Pulser Cables Finalized	02Apr07	L.2
1.0.1.2.7.1	RR Inj & Gap Clearing Pulser Cables Finalized	02Apr07	L.2
1.0.1.2.7.3	RR Existing Design for RR Injection Design Fluorinert System Confirmed	24May07	L.2
1.0.1.1.6.4	RR Vacuum Window to be Removed Finalized	01Jun07	L.2
1.0.1.1.6.6	RR Mirror Magnet Design Finalized	06Sep07	L.2
1.0.1.1.6.5	RR Beamline Modifications Design Review Complete	03Oct07	L.2
1.0.1.1.6.3	RR 53 Mhz RF Design Review Complete	09Oct07	L.2
1.0.1.4.3.1	RR Shielding Assessment Complete	28Mar08	L.2
1.0.1.2.7.5	RR Injection Line Prototype Kicker Complete	17Sep08	L.2
1.0.1.2.7.6	RR Ferrite Procurement or Re-design Finalized	16Oct08	L.2
1.0.1.2.7.4	RR Extraction MI Injection Kicker Prototype Pulser System Complete	03Jun09	L.2



All internal milestones for project

Milestones - Construction 2.0.1

Activity ID	Activity Desc.	Date	Milestone Tier
L.2 -- WBS L2 Manager's Milestone			
2.0.1.3.4.1	RR DCCT Order Finalized	29Oct07	L.2
2.0.1.1.5.3	RR Orders Placed for Copper for 53 Mhz RF	28May08	L.2
2.0.1.1.5.4	RR ADCW Magnet Refurbish Complete	12Mar09	L.2
2.0.1.3.4.3	RR DCCT Ready for Installation	01Apr09	L.2
2.0.1.3.4.5	RR BPM System Procurement Complete	15Jul09	L.2
2.0.1.3.4.6	RR BPM Transition Boards Ready for Installation	12Oct09	L.2
2.0.1.1.5.2	RR Permanent Magnet Quad Refurbished & Mapped	28Oct10	L.2
2.0.1.1.5.5	RR LCW System Mods Complete	23Nov10	L.2
2.0.1.2.8.3	RR Beam Abort Kicker Checkout Complete	07Feb11	L.2
2.0.1.2.8.2	RR Extraction MI Injection Line Kicker Checkout Complete	07Mar11	L.2
2.0.1.2.8.4	RR Injection & Gap Clearing Magnets & Fluorinert Piping in Tunnel Checkout Complete	29Apr11	L.2
T.2 -- DOE-FSO Milestone			
2.0.1.2.8.1	RR Ready to start Final Procurement for Kicker Magnets	02Sep09	T.2
T.3 -- Fermilab Director or NOVA Management Milestone			
2.0.1.1.5.1	RR 53 Mhz RF Ready for Beam	04Jan11	T.3
2.0.1.2.8.5	RR All Kicker Systems Ready for Beam	29Apr11	T.3



3 project milestones (2 T.3, 1 T.2)
Remaining internal milestones

Conclusions

- Convert the Recycler Ring from antiproton storage ring to proton injector
  - New transfer lines
  - New 53 MHz RF system
  - Upgraded instrumentation
  - Building on existing designs and knowledge
  - Reusing / refurbishing many components
- Overall Cost ($23.0M FB FY07$, no contingency)
  - Total contingency for system 33%
  - Largest Cost: kicker systems with 5 new kickers to build
- Schedule
  - Driven by kicker development
  - Critical path item for the shutdown readiness
  - Shutdown length driven by magnet refurbishing