WBS 1.0, 2.0 Accelerator and NuMI Upgrades (ANU)

June 4, 2007

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The Accelerator Complex

- Booster batches injected into the Main Injector at 15 Hz
  - Main Injector is 7 times the circumference of the Booster
  - Main Injector is a rapid cycling accelerator at 120 GeV
- Main Injector has to satisfy simultaneously the needs of the Collider program (anti-proton stacking and transfers to the Tevatron) and NuMI
  - Mixed-mode cycles: 1 slip-stacked batch to the antiproton source, 5 batches to NuMI
  - NuMI-only cycles: 6 to 7 batches to NuMI (11 slip-stacked in studies)
- Proton Plan
  - Current program to maximize protons to NuMI and MiniBoone during the Collider era through slip-stacking over multi-batches
  - Increase Booster repetition rate to 9 Hz ave. (15 Hz rate) & improve efficiency
  - Perform slip stacking in an efficient manner in the MI
    - RF improvements
    - Collimation
  - Achieve 320kW to NuMI, 80kW to anti-proton (400kW total)

NOνA: 700 kW
Recycler: 8 GeV Proton Pre-injector

- When Collider program concludes, use the Recycler as a proton pre-injector
  - Use the Recycler to accumulate protons from the Booster while MI is accelerating
  - Can save 0.4 s for each 6 Booster batches injected
- Recycler momentum aperture is large enough to allow slip-stacking operation in Recycler, for up to 12 Booster batches injected
  - 6 batches are slipped with respect to the other 6 and, at the time they line up, they are extracted to MI in a single turn and there re-captured and accelerated
  - Main Injector will run at its design acceleration rate of 240 GeV/s (1.3s cycle time) (operates at 204 GeV/s presently)
  - 4.3×10^{12} p/batch, 95% slip-stacking efficiency
  - 4.9×10^{13} ppp at 120 GeV every 1.333 s

  $\Rightarrow$ **700 kW**

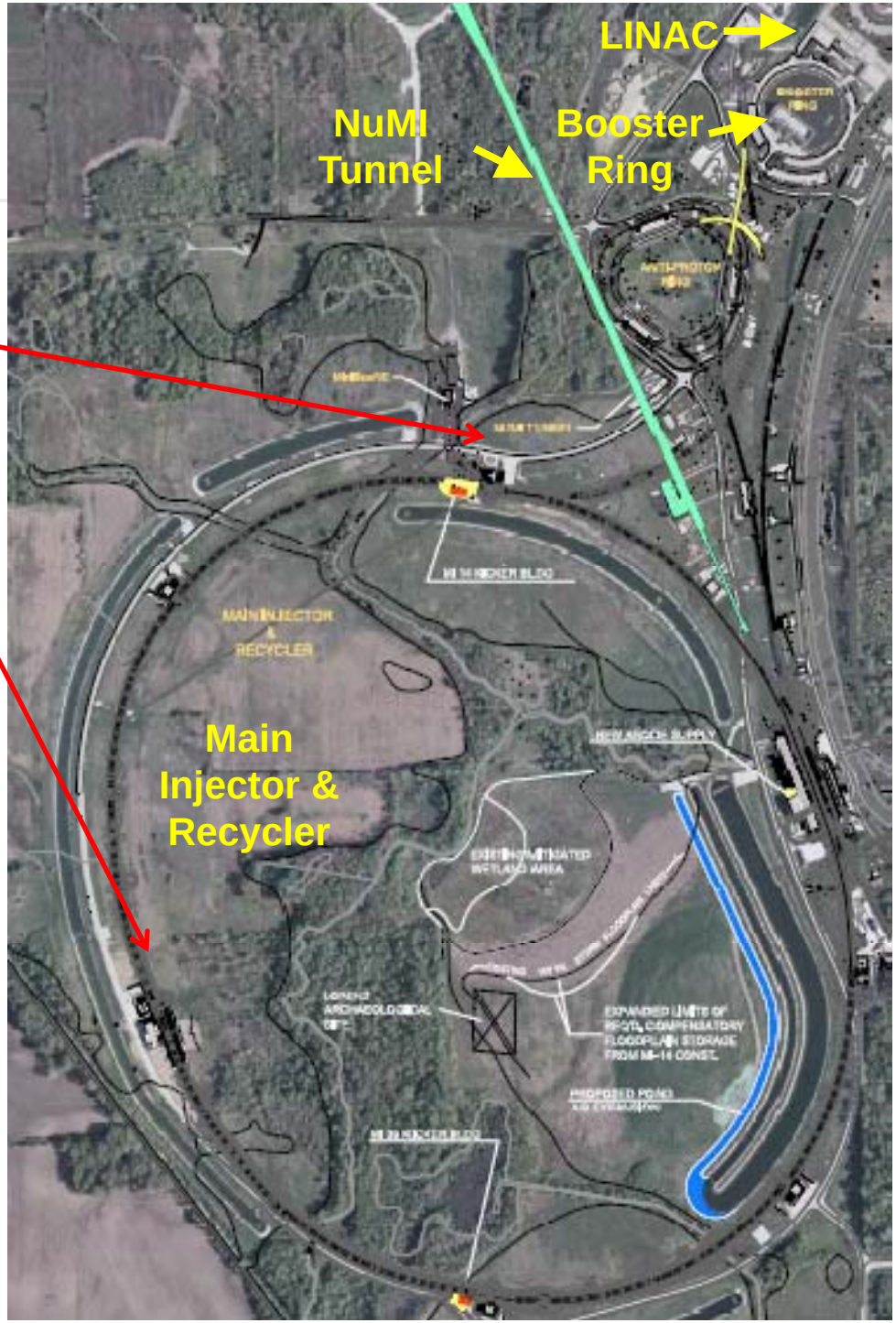
Present & Future Operating Scenarios

	Present Conditions Multi-batch slip-stacking in MI	Proton Plan Multi-batch slip-stacking in MI	NOνA Multi-batch slip-stacking in Recycler	SNuMI Momentum Stacking in the Accumulator, boxcar stacking in Recycler
Booster intensity (protons/batch)	$4.3\text{-}4.5\times10^{12}$	4.3×10^{12}	4.3×10^{12}	4.7×10^{12}
No. Booster batches	7 →	11 →	12 →	18
MI cycle time (s)	2.4 →	2.2 →	1.333 →	1.333
MI intensity (ppp)	3.3×10^{13}	4.5×10^{13}	4.9×10^{13}	8.3×10^{13}
To anti-proton source (ppp)	8.8×10^{12}	8.2×10^{12}	0	0
To NuMI (ppp)	2.45×10^{13}	3.7×10^{13}	4.9×10^{13}	8.3×10^{13}
NuMI beam power (kW)	192 →	320 →	700 →	1200
PoT/yr to NuMI	2×10^{20} →	3×10^{20} →	6×10^{20} →	10×10^{20}

SNuMI is a possible upgrade plan, not presently supported, NOνA design parameters in TDR Ch. 8, Details of PoT calculation in Beam Physics Breakout.

Main Items: ANU

- Recycler Ring, RR (WBS x.0.1)
  - New injection line into RR
  - New extraction line from RR
  - New 53 MHz RF system
- Main Injector (WBS x.0.2)
  - Two 53 MHz cavities
  - Quad Power Supply Upgrade
  - RR Low Level RF System
- NuMI (WBS x.0.3)
  - Change to medium energy ν beam configuration
  - Cooling & power supply upgrades
- Beam Physics (WBS x.0.4)
  - Beam Simulations & Evaluation of Proton Plan
- Commissioning not included on NOvA



ANU Org Chart

1. 0, 2.0 ANU
Nancy Grossman
Elaine McCluskey, Deputy
Robert Reilly, ANU ME
Robert Ducar, ANU EE
Michael Andrews ANU ES&H/QA Coordinator

1.0.1, 2.0.1 Recycler Upgrades
Paul Derwent

- **1, 2.0.1.1 Recycler Ring Modifications**
  Daniel Broemmelsiek
  David Johnson, Deputy
- **1, 2.0.1.2 Recycler Kicker Systems**
  Christine Ader
  Chris Jensen, Deputy
- **1, 2.0.1.3 Recycler Instrumentation**
  Martin Hu
- **1, 2.0.1.4 Recycler Radiation Safety**
  Peter Kasper

1.0.2, 2.0.2 Main Injector Upgrades
Ioanis Kourbanis

- **1, 2.0.2.1 Main Injector Modifications**
  David Capista
- **1, 2.0.2.2 Main Injector RF Cavities**
  Joseph Dey
- **1, 2.0.2.3 Main Injector Radiation Safety**
  Peter Kasper

1.0.3, 2.0.3 NuMI Upgrades
Michael Martens
Kamran Vaziri (RSC)

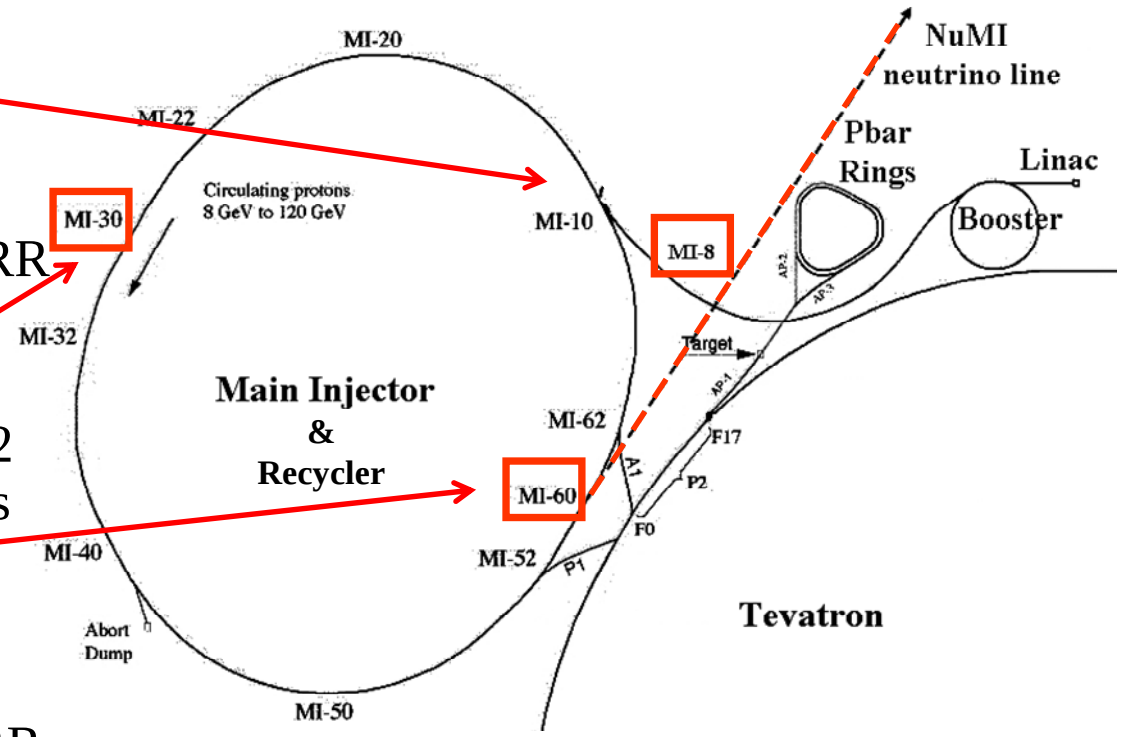
- **1, 2.0.3.1 NuMI Primary Proton Beam**
  Samuel Childress
- **1, 2.0.3.2 NuMI Technical Components**
  James Hylen
  Thomas Kobilarcik, Deputy
- **1, 2.0.3.3 NuMI Infrastructure**
  Salman Tariq
- **1, 2.0.3.4 NuMI Decay Pipe, Hadron Absorber & Utilities**
  Karlton Williams

1.0.4 Beam Physics
Robert Zwaska

Notes:
1. The individuals shown with responsibility on subprojects are matrixed to the NOvA Project.
2. Line management for safety is through the subproject departments within AD and TD.
3. RSC: Radiation Safety Coordinator

Main Items: Recycler Ring Upgrades

- Decommissioning of anti-proton specific devices
- Design, build & install:
  - New injection line connecting MI-8 (from the Booster) into the Recycler
  - New extraction line from RR to MI at RR-30 straight section (near MI-30)
  - 53 MHz RF system using 2 new RF cavities w/controls & power in MI-60
  - Five new kicker systems (RR Injection, RR Extraction, MI Injection, RR Abort and Gap Clearing)



Linac, Booster, MI, RR and NuMI Line

- Upgrade Recycler instrumentation (new beam position monitors, new intensity measuring devices, and new dampers)

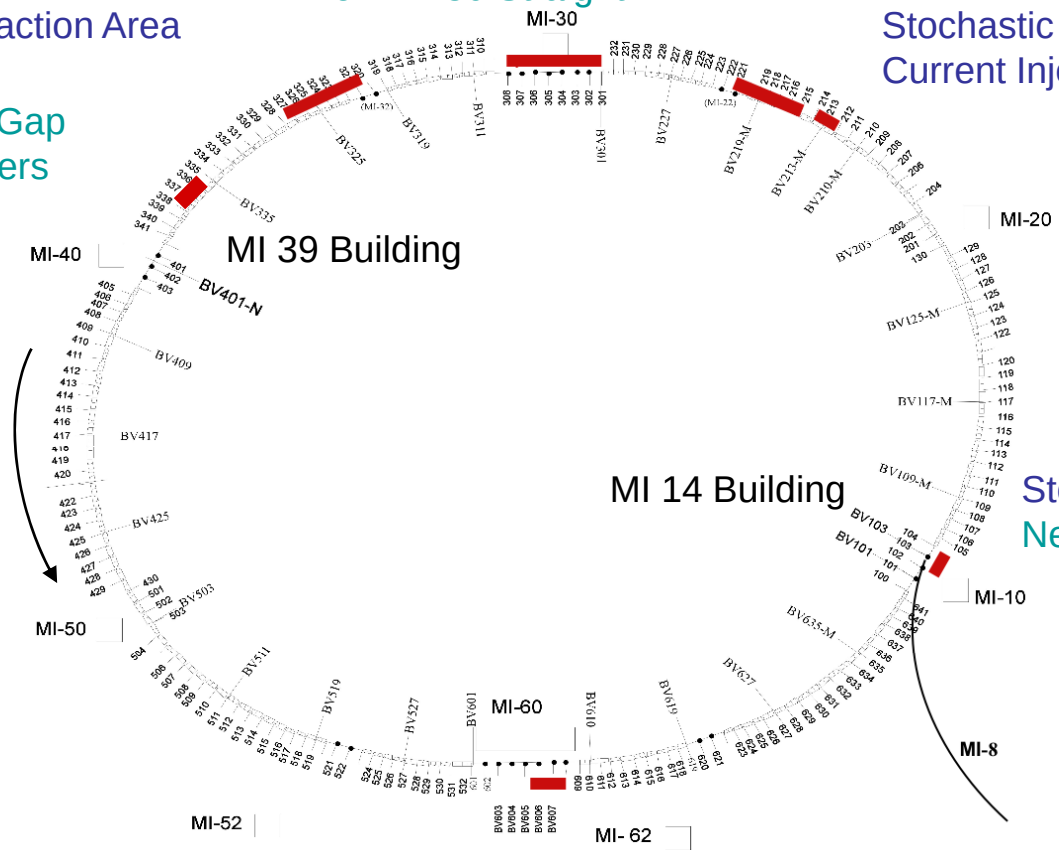
Main Items:
Recycler Ring Upgrades

Electron Cooling Insert
New Extraction Line
New RR30 Straight

Current Extraction Area

Stochastic Cooling Pickups
Current Injection Area

New Abort & Gap
Clearing Kickers



Proton
Direction

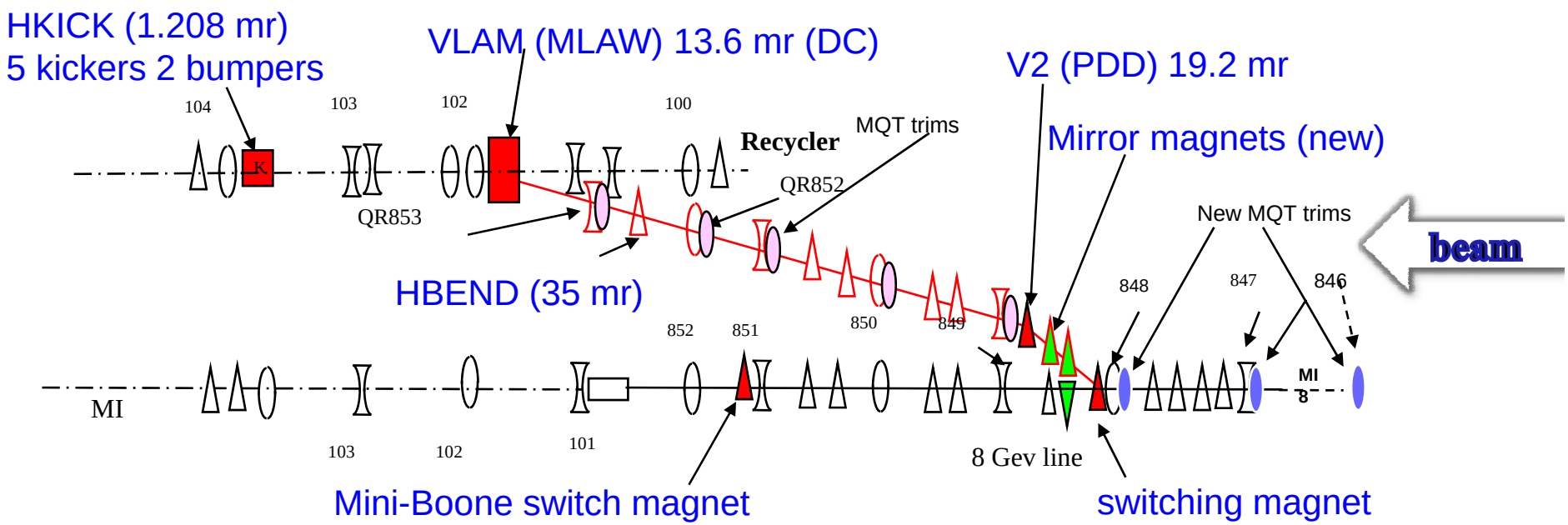
Stochastic Cooling Kickers
New Injection Area

Key: WBS
Elements Removed
New Elements
Areas Affected

New 53 MHz RF

Recycler /MI Ring

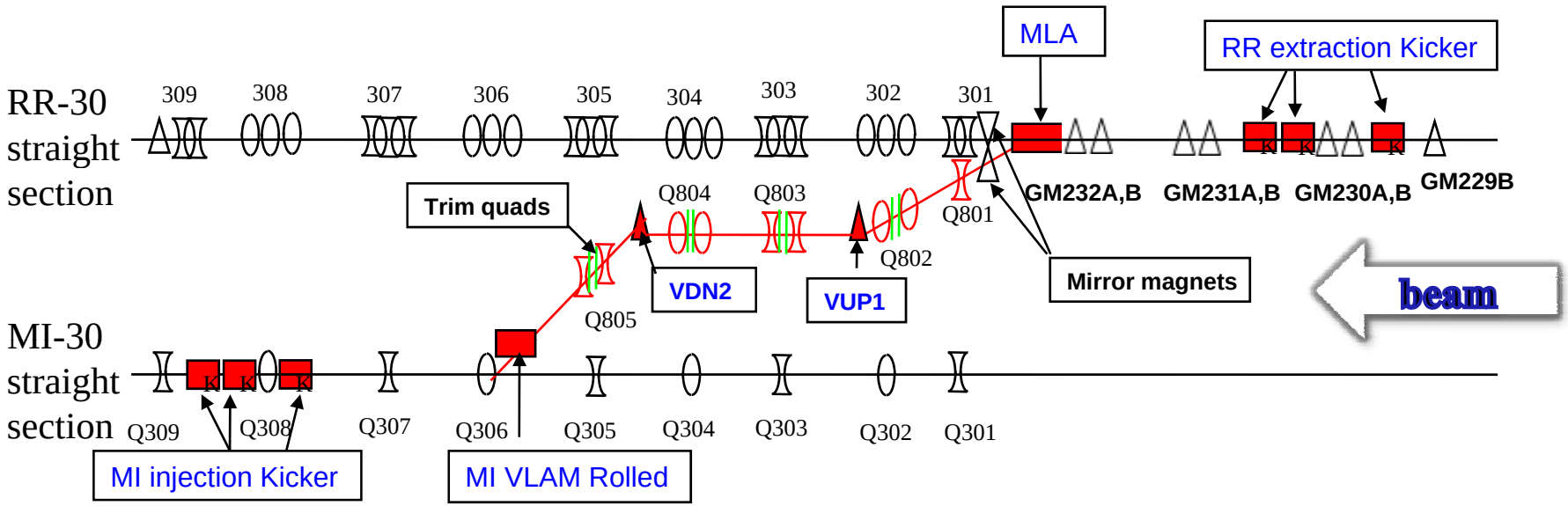
Recycler Ring Injection Line



- Keep ability to transfer from MI-8 into MI and MiniBoone
- Vertical switching magnet
- Mirror dipoles – permanent magnets
- Keep AC magnetic fields away from RR
- MLA vertical injection Lambertson – cancels vertical dispersion from switching magnet
- Injection kicker – horizontal

  Required kick implies 5 kicker magnets and 2 bumper magnets

Recycler Ring Extraction Line



- Extraction line redesigned to reduce required kicker strength by extending the whole line by a cell.
- 8GeV Lamberston used for initial vertical bend.
- Apertures at Lambertsons and Kickers fit 20pi-10sigma beam envelope.

Why 5 Kicker Systems?

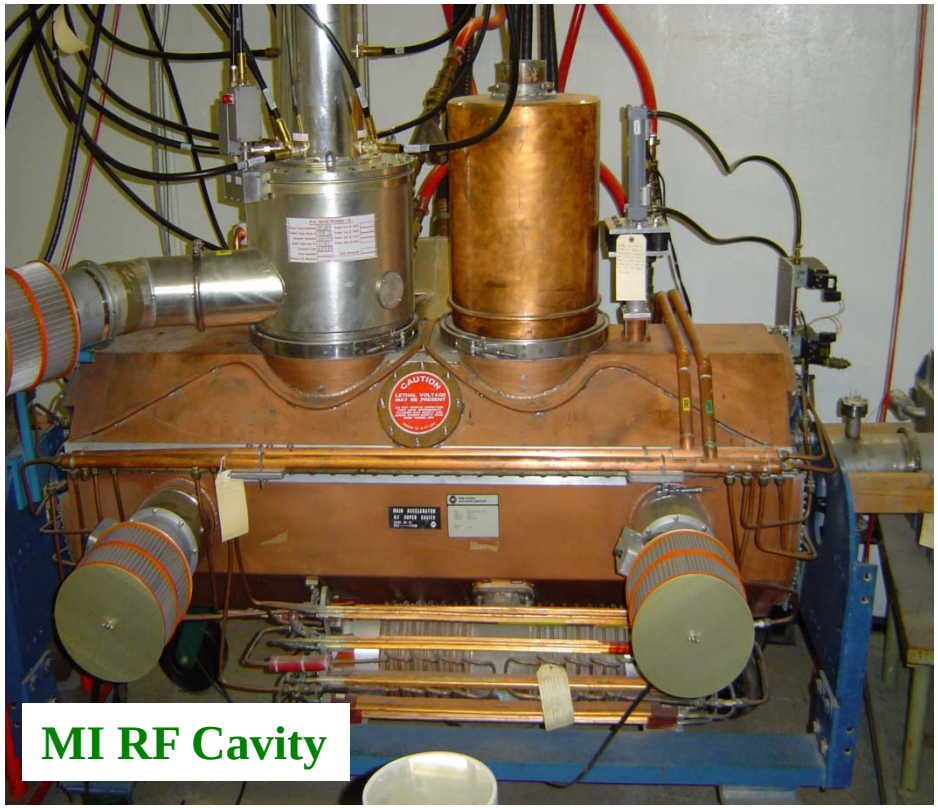
- Recycler has injection & extraction kickers for pbars, why do we need new ones?
  - RR Injection Kicker: existing one not fast enough for slip-stacking
    - Magnet defines rise time, power supply defines fall time
    - New magnet and new power supply
    - What about MI 10 Injection kicker (Booster -> MI) design?
      - Vertical kick, RR Injection & Gap Clearing require horizontal kick
      - Design would be difficult to make meet specs & difficult to build
      - Different ceramic beam tube (now all NOvA kickers use the same)
  - Gap Clearing Kicker: doesn't exist, for loss mitigation (same as RR Inj.)
    - Clears the gap that the 1st of the second 6 batches is injected into
  - RR Extraction Kicker: flattop length too short (1.6 μsec vs. 9.5μsec)
    - Use existing kicker magnet, with added cooling because of duty factor (9 times per day for pbars vs 0.75 Hz for NOvA)
    - New power supply (Pulse Forming Line and thyratron switch) for flattop length

Why 5 New Kicker Systems?

- Recycler has injection and extraction kickers for pbars, why do we need new ones?
  - MI Injection Kicker: flattop length too short (1.6 μsec vs. 9.5μsec)
    - New magnet with modifications to existing design (no more left to refurbish & need bigger beam tube), with added cooling because of duty factor (9/day vs 0.75 Hz)
    - New power supply (Pulse Forming Line and thyratron switch) for flattop length
  - RR Abort Kicker: flattop length too short (1.6 μsec vs. 9.5μsec)
    - Use existing kicker magnet, with added cooling because of duty factor (9/day)
    - New power supply (Pulse Forming Line and thyratron switch) for flattop length

Main Items:
Main Injector Upgrades

- Accelerating only 10% more proton intensity
- Beam power out of the MI much larger since the cycle time will be reduced from 2.2 seconds to 1.33 seconds.
  - Using the Recycler Ring for stacking, MI cycle time reduced to 1.5 sec
  - Reduce to 1.33 seconds by increasing the maximum acceleration rate from 204 GeV/sec to 240 GeV/sec.
- Requires an upgrade to one of the quad power supplies.
- 2 additional RF cavities need to be installed (18 stations now)
- Also included in this WBS is the Recycler Ring Low Level RF (RR LLRF) since it is a minor upgrade to the existing MI LLRF – used for slip-stacking in the RR for NOνA

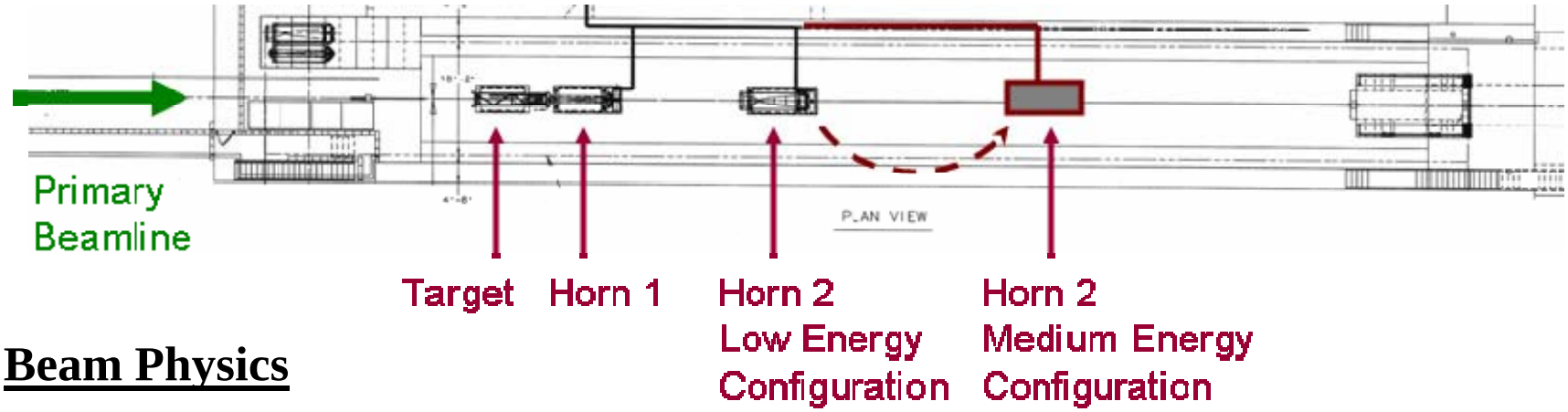


MI RF Cavity

Main Items:
NuMI Upgrades and Beam Physics

NuMI - designed for 4E13 ppp every 1.87 s (400 kW beam power)

- Design, build, install a new medium energy target/carrier/baffle
- Reconfigure shielding & move horn 2 to the medium energy location & extend the stripline
- Upgrade cooling & power supplies for increased power and rep. rate

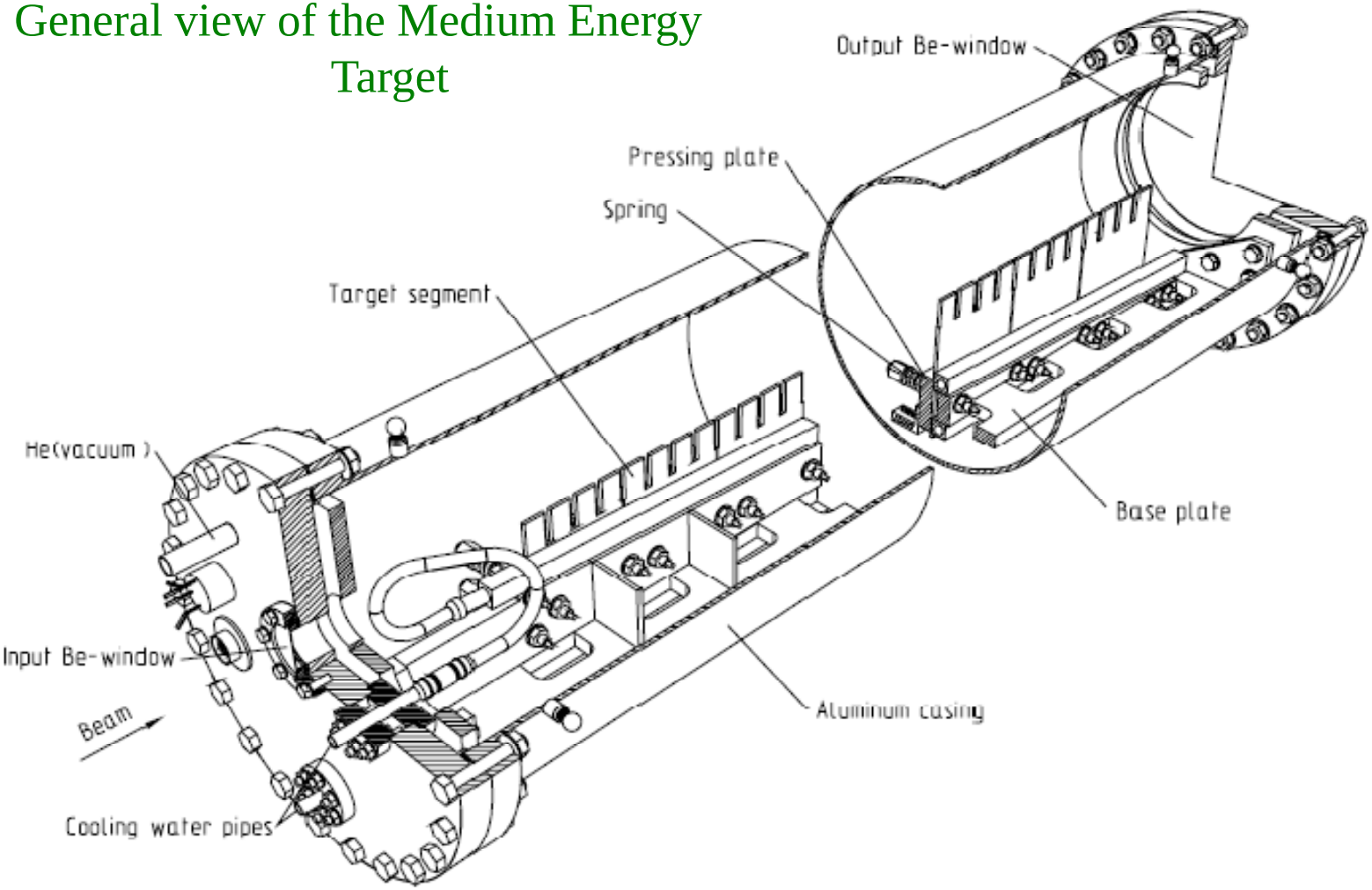


Beam Physics

- Analyze improvements implemented by the Proton Plan
- Machine and process analysis: collection of theoretical, experimental and simulation studies on the existing machines
- Provide a method for predicting realistic proton projections to NOνA

Main Items: NuMI Upgrades

General view of the Medium Energy Target



Environment, Safety & Health and Quality Assurance

- Mike Andrews is the ANU ES&H/QA Coordinator
  - Very experienced, was NuMI/MINOS ES&H/QA Coordinator
  - Hazard Assessments, Integrated Safety Management similar to NuMI/MINOS
- Radiation safety is a major issue for installation and operation for NOvA
  - Appointed P. Kasper for Accelerator complex and K. Vaziri for NuMI
- Set up ES&H Reviews in same manner as NuMI/MINOS
  - ES&H Review Committee
- Design reviews before major acquisitions
  - Depts. have internal design review process that is followed
  - Drawings are reviewed and signed off
  - Have design reviews in the RLS before every major procurement with design risk
    - Size and make-up of review committee for these design reviews will be determined using the graded approach, determined by the appropriate manager
- More details in the NOvA QMP and ISM Plan

Value Management

- Main Value Engineering changes since November 2006 (SNuMI Review):
  - Injection line design changed
    - Simplified installation & to minimized the number of powered elements near the Recycler Ring.
  - Extraction line design changed
    - Now can use same ceramic beam tube and magnet for MI Injection kicker as for RR extraction and abort kickers
    - Eliminating a separate design for both the ceramic beam tube and the magnet.
  - Decided to accept 81 Booster bunches per Booster batch instead of 82.
    - This change loosens the kicker rise/fall time specifications from 38 nsec to 57 nsec with ~1% loss of protons to the NuMI target.

Risk Management

Risk Registry for all risks is in WelcomRisk® (92 Risks with mitigations)

- 18 are high NOvA risks & are in the NOvA Risk Registry
  - 12 related to the kicker ceramic beam tubes not meeting specifications (NOvA-doc-#1444)
    - Work with vendors, order extra, look for backup vendors etc.
  - 5 related to insufficient manpower available to do the work as scheduled (NOvA-doc-#1446)
    - Leveled resources (still need to do a bit more), work with all FNAL divisions, look to contract out work, look to hire AD people
  - 1 related to Installation taking longer than planned (NOvA-doc-#1964)
    - Work hard on planning and taking advantages of earlier shutdowns to plan work and or perhaps start some work if possible.
- 33 middle priority
- 41 low priority

Recommendations from SNuMI Review (11/2006)

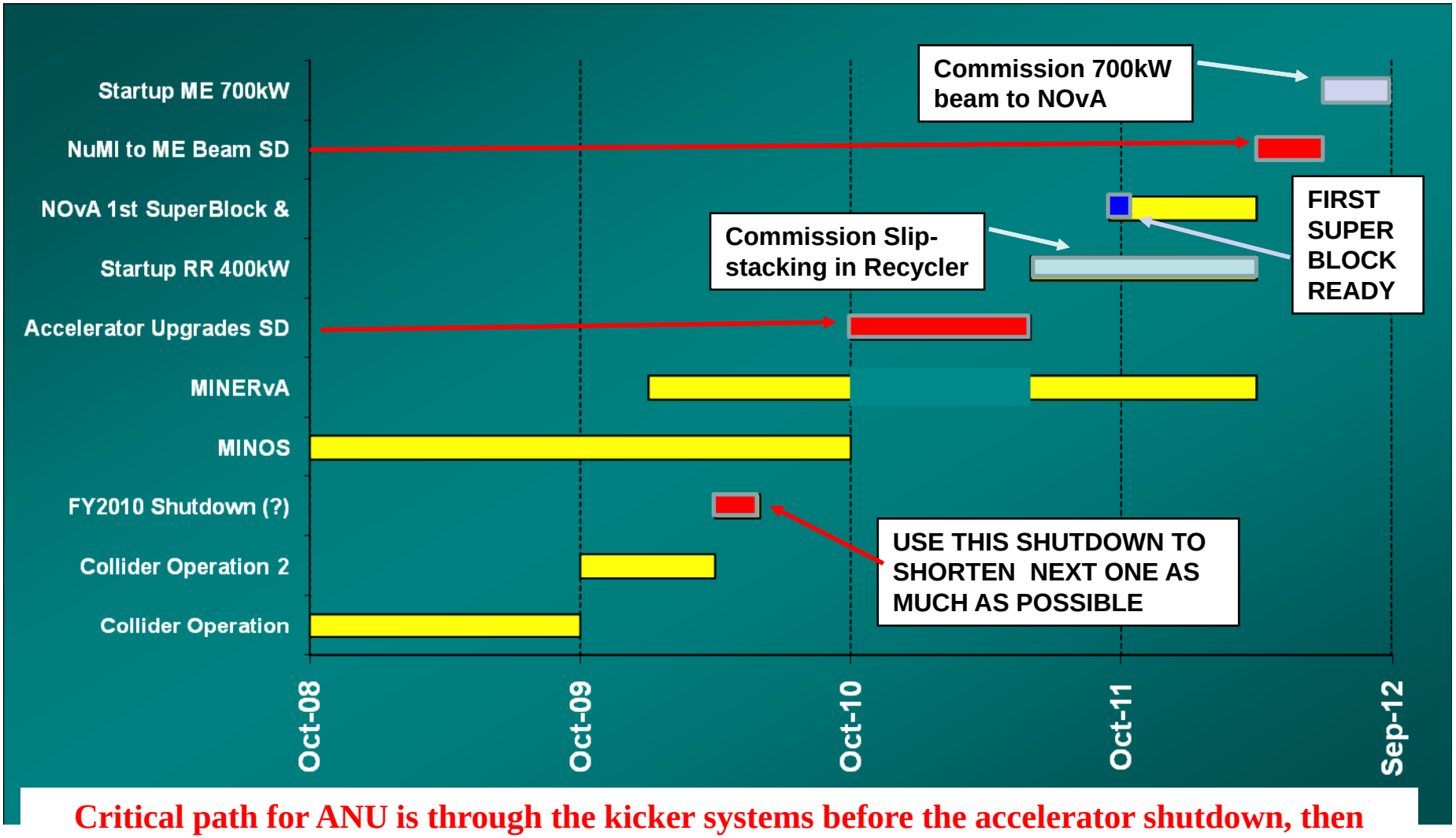
- 20 recommendations related NOvA Accelerator and NuMI Upgrades
- More details in NOvA-doc-1668, review web page and in breakout talks

Recommendation	Number On NOvA Project	Comments
Recycler Upgrades	5	kickers, slip stacking simulations and tests, shutdown planning
MI Upgrades	1	MI collimators
NuMI Upgrades	6	cooling, target, beam permit, radiation issues
Cost	3	BOEs, Risk assessment
Schedule	1	scrub schedule, costs
Management	4	PMG meetings, funding, labor

Shutdown Plan

- Accelerator Upgrades Shutdown, 8 months long, 10/1/10 to 6/1/11
  - MI modifications and installation of 2 additional RF cavities
  - RR modifications and installation of new injection & extraction lines
  - NuMI begins preparation for 700 kW
    - Upgrade Target Pile air cooling, RAW systems & Primary beam
    - Extend Stripline to medium energy (ME) location
    - Reconfigure shielding and install dummy horn module in medium energy location (allows quicker change to ME next shutdown)
- Commissioning of Recycler then NOvA first super block ready (fall 2011)with slip-stacking at 400kW (due to low energy target) for 3 months
- Several months of beam to NOvA before the..
- NuMI to ME Beam Shutdown, 3 months, 4/1/12 to 7/1/12
  - NuMI completes preparation for 700 kW
    - Horn 2 relocation
    - Replace low energy target with medium energy target

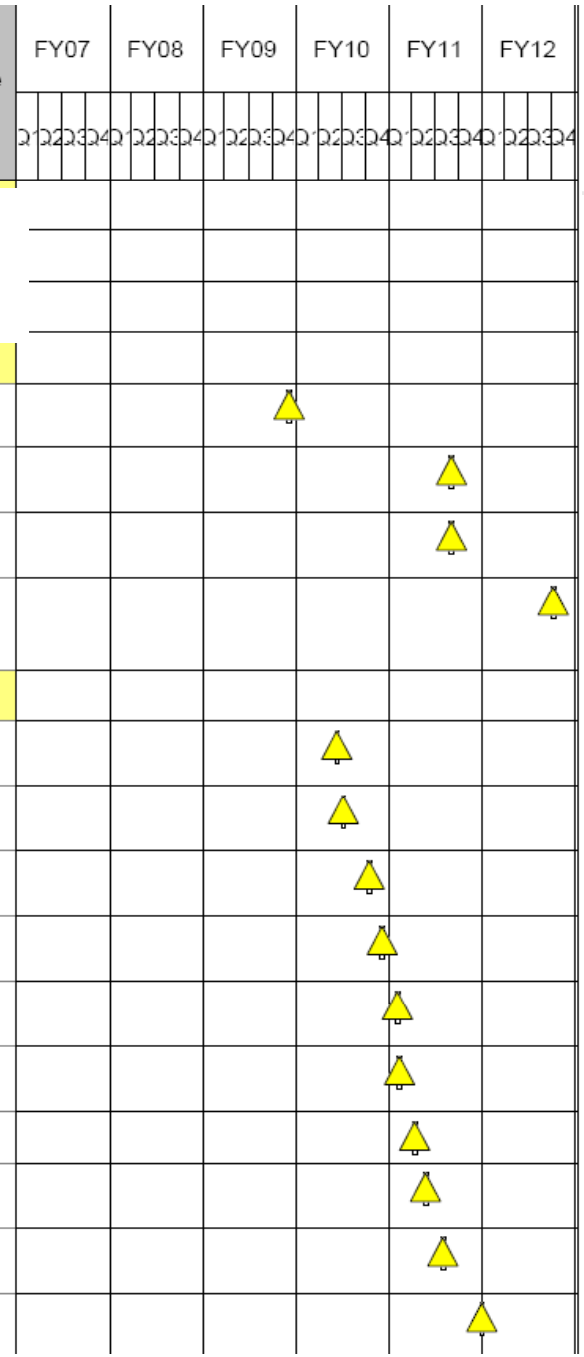
ANU Schedule Overview



Critical path for ANU is through the kicker systems before the accelerator shutdown, then moves to magnets that need to be removed, refurbished and re-installed, then to NuMI

Milestones

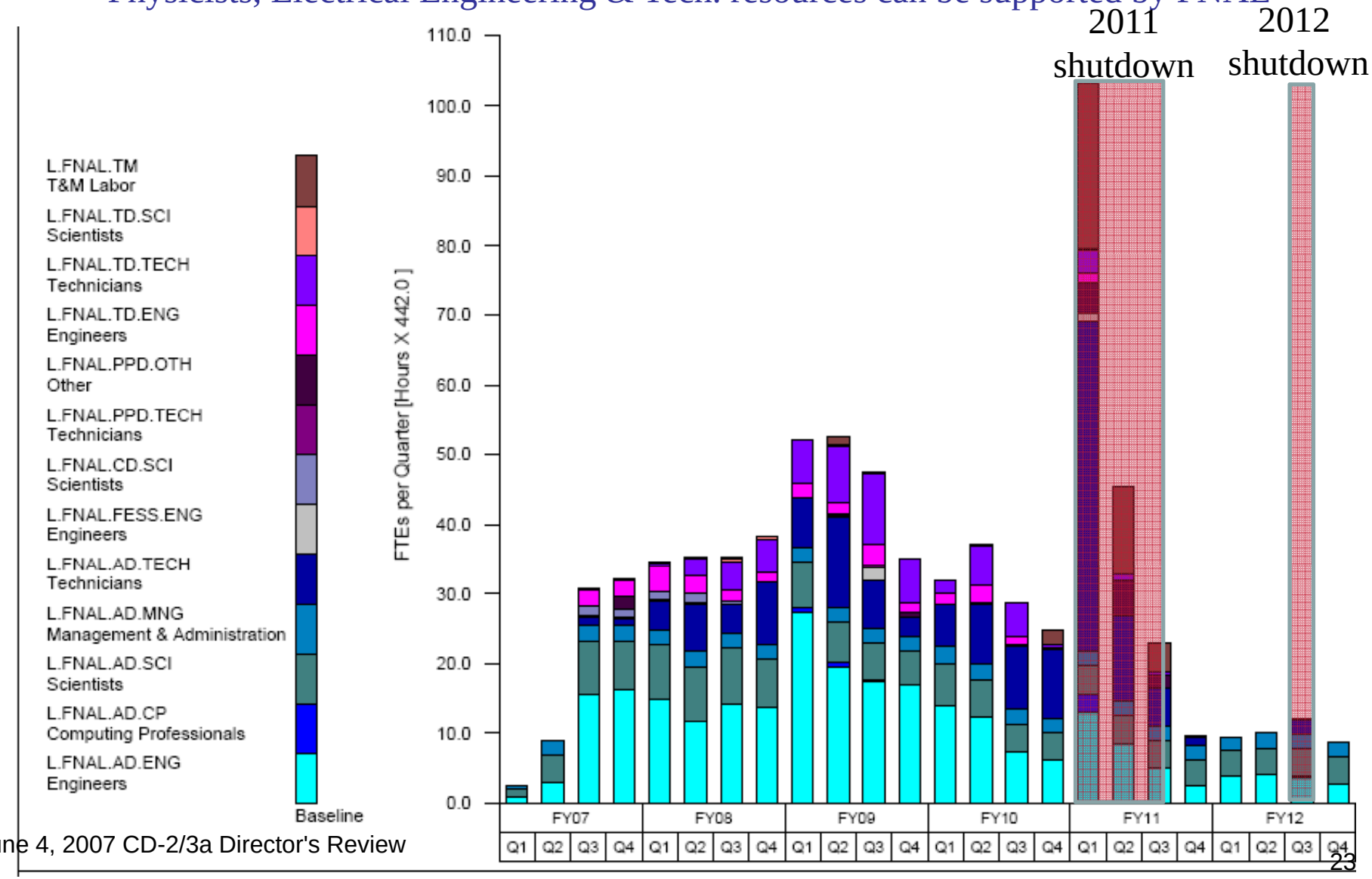
Activity ID	Activity Desc.	Date	Late Finish	Total Float	Milestone Tier
T.2 -- DOE-FSO Milestone					
2.0.1.2.8.1	RR Ready to start Final Procurement for Kicker Magnets	02Sep09	17Jun10	196d	T.2
2.0.4.3.14	MI Ring Modifications Ready for Beam Transport	26May11	02Jul12	276d	T.2
2.0.4.3.15	RR Modifications Ready for Beam Transport	26May11	31May11	2d	T.2
2.0.4.3.17	Ready to Commission Upgrades with Medium Energy Neutrino Beam	02Jul12	02Jul12	0	T.2
T.3 -- Fermilab Director or NOVA Management Milestone					
2.0.4.3.12	ANU Shielding Assessment Updates Complete	05Mar10	05Oct10	148d	T.3
2.0.4.3.13	Ready for Shutdown to Install Accelerator Upgrades	31Mar10	01Oct10	128d	T.3
2.0.3.3.4.1	NuMI Shielding Blocks, Dummy Module & Carriage Complete	09Jul10	07Apr11	186d	T.3
2.0.3.3.4.3	NuMI Stripline Assembly Complete	30Aug10	05Oct10	24d	T.3
2.0.2.1.4.1	MI Vertical Quad Bus Upgrade Complete	02Nov10	31May11	143d	T.3
2.0.2.2.5.4	MI RF Cavities (2) Installation & Testing Complete	11Nov10	31May11	136d	T.3
2.0.1.1.5.1	RR 53 Mhz RF Ready for Beam	04Jan11	31May11	103d	T.3
2.0.3.1.5.2	NuMI Primary Beamline Ready for Faster Cycle Time	21Feb11	31May11	70d	T.3
2.0.1.2.8.5	RR All Kicker Systems Ready for Beam	29Apr11	31May11	21d	T.3
2.0.3.2.3.3	NuMI ME Target/Carrier/Baffle Assembly Complete	26Sep11	02Apr12	127d	T.3



Also have 63 Level 2 Milestones which are monitored by the L2 Manager

Physicists, Engineers & Technicians

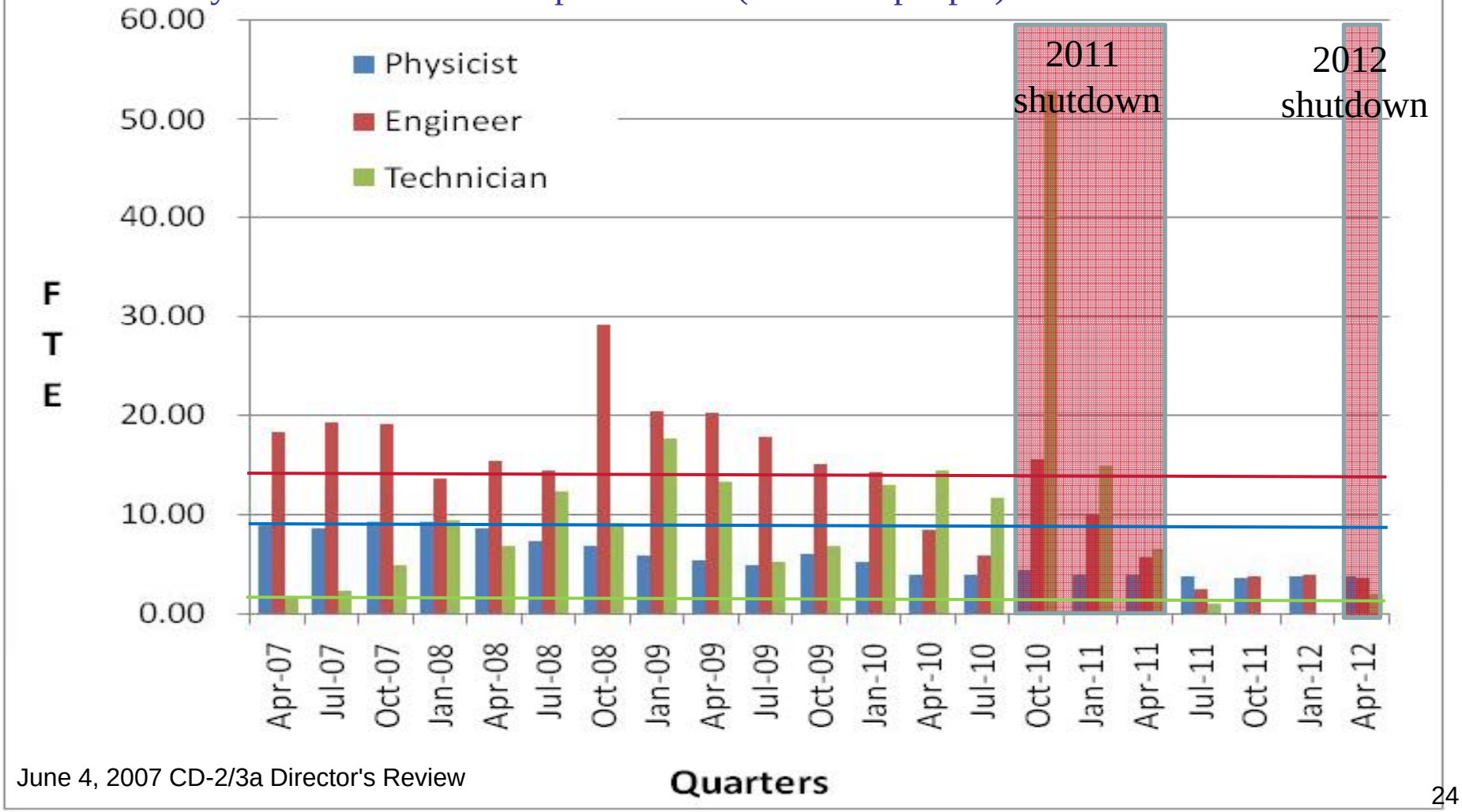
- Physicists, Electrical Engineering & Tech. resources can be supported by FNAL



Physicists, Engineers & Technicians

(lines show present effort)

- Physicists, Electrical Engineering & Tech. resources can be supported by FNAL
- Mechanical Engineering/Drafting is tight, need to start work on construction in early FY08 in order to keep resources (short 3-4 people)



Costs Overview

- Basis of Estimates for Costs in DocDB, DocDB number in Open Plan schedule
- Technical Requirements are listed in the TDR, specifications documents are listed in DocDB as they are written
- Have design reviews before major procurements with significant design work for example, all listed at Level 5 for each WBS:

  Recycler Ring Modifications Reviews

  - 1.0.1.1.5.1 53 Mhz RF System Design Review
  - 1.0.1.1.5.2 Recycler Transfer Lines Review
  - 1.0.1.1.5.3 Recycler Cooling Systems Initial Design Review
  - 1.0.1.1.5.4 Recycler Cooling System Engineering Design Review

- WBS 1.0 and 2.0 have ~500 lines each in the schedule
- Details of the kickers systems work processes are well thought out
  - Critical path for this sub-project
  - Highest cost main item
  - Highest risk main item

Cost Overview (Fully Burdened: FB)

WBS x.0 Accelerator & NuMI Upgrades	Estimated Cost (AY $M)	Contingency Estimate (AY $M)	Contingency (%)	Total Cost (AY $M)
Construction w indirects				
M&S	13.2	4.4	34%	17.6
Labor[1]	20.5	6.5	32%	27.1
Construction total:	33.7	11.0	33%	44.7
Operating (Part of Planning, Engineering & Design)				
M&S	0.2	0.1	36%	0.2
Labor[1]	1.2	0.6	51%	1.8
Operating total:	1.3	0.7	49%	2.0
R&D - Accelerator (Part of Planning, Engineering & Design)				
M&S	1.4	0.4	30%	1.8
Labor[1]	7.8	3.0	38%	10.8
R&D total:	9.3	3.4	37%	12.7

[1] Labor costs presented here include all project labor from Fermilab, other DOE facilities, and Universities.

- Cost Drivers (total is $59.4M including 34% contingency)
  - Recycler upgrades ~50% (Kicker systems ~2/3 of Recycler Upgrades)
  - NuMI Upgrades ~25%
- High contingency for NuMI upgrades, since design least progressed of all
- More details in 'ANU More Details' break out talk

CD-3a Items for ANU

- For CD-3a, need "advanced technical design" at the 90 – 95% level
- Need to procure these items to keep the present labor force working and to minimize labor crunch in FY09 – for kickers it is the critical path.
- Costs include manpower for preparing reqs., receiving items and some assembly
- ANU CD-3a justification table on web page (NOvA-doc-2114)

	Cost Fully Burdened w/Cont. ($K)	Design Status
Magnet Tooling, Lambertson Magnet Parts, Injection Line PDD Magnet parts	$347	Design items relating to the M&S purchase is at least 90% complete
Kickers: Resistors, cables, parts for HV Pulsers, cooling skids, PFL frames and rebuilding some magnets	$2099	NOvA-doc-2114 for details
MI RF Cavity Ferrite Bias Supplies	$140	complete
NuMI PS regulation system parts	$71	complete

Summary

- Accelerator and NuMI Upgrades (ANU) subproject relies on reconfiguration of existing machines
  - Technically achievable, reuses as much as possible existing components, designs and processes and experience
- Overall Cost $59M, average contingency 34%
- Schedule
  - Present schedule best matches experimental needs, including schedule contingency for the shutdown of the Tevatron
  - Allows for commissioning of the recycler with slip-stacking several months before the first NOvA superblock.
- CD-3a items are listed in with cost and risk on the web page, main ones:
  - Various parts for kicker systems $2.1M (labor issue & critical path)
  - Parts to start magnet work in Technical Division while labor is available