ANU: Beam Physics

WBS 1.0.4

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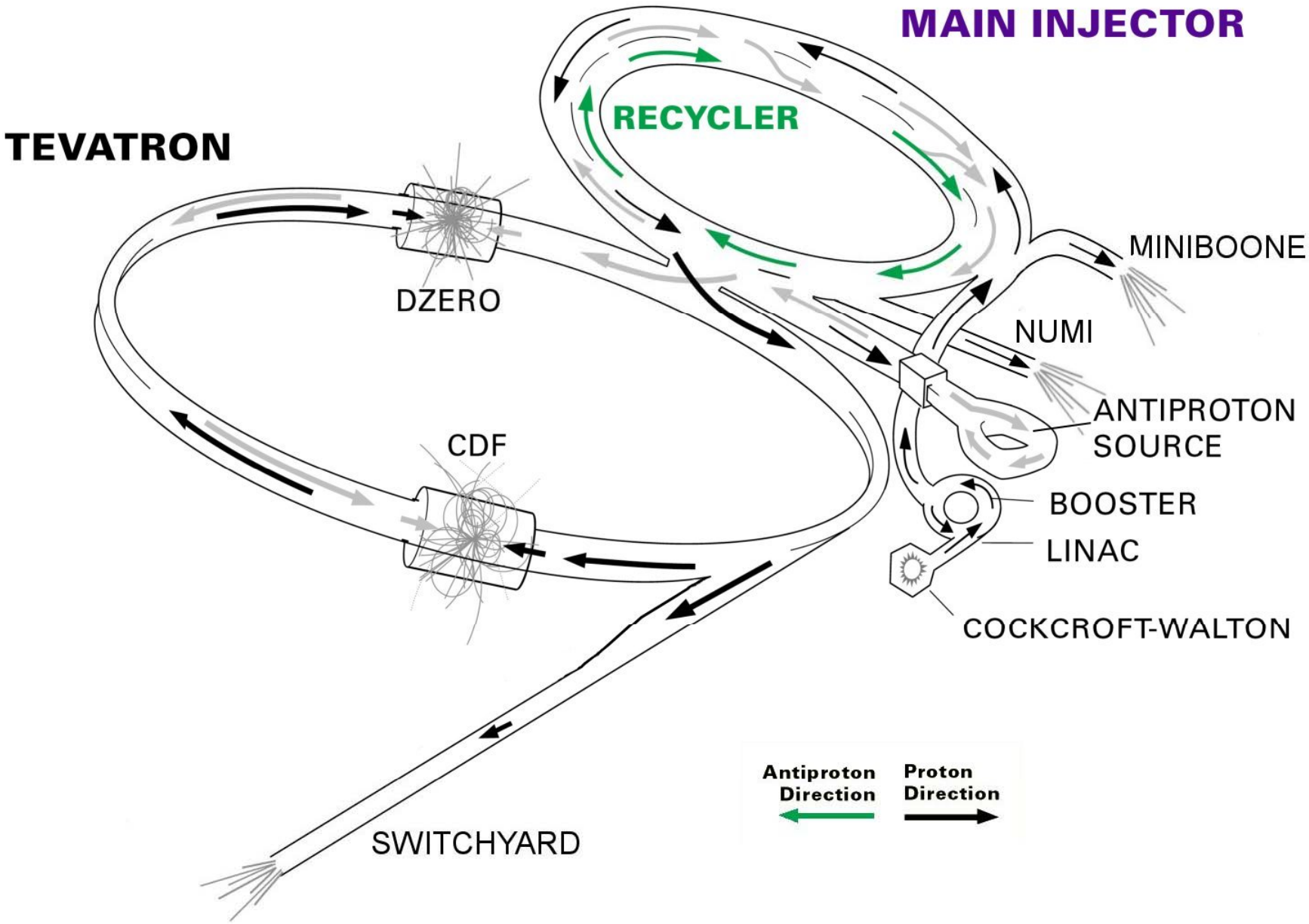
Overview

- Description of the ANU beam
  - Current Beam Operations
  - Proton Plan method
  - Integrating the Recycler
- NOvA-ANU beam physics effort
  - Proton Plan dependencies
  - Measurement, simulation, and analysis
  - Proton projections

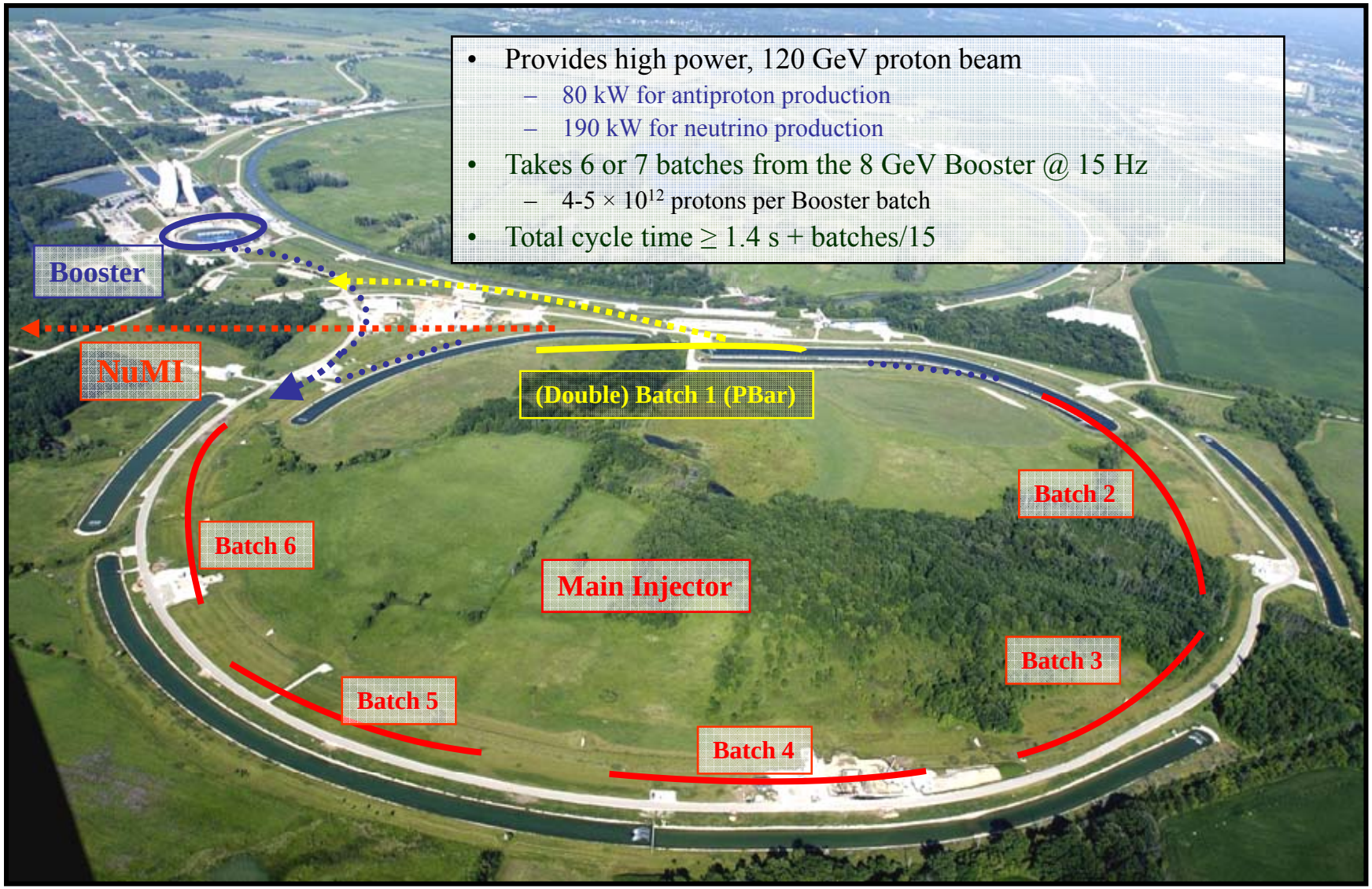
FERMILAB'S ACCELERATOR CHAIN



The ANU Beam

- The ANU beam builds upon existing machines:
  - The existing accelerator complex
    - Linac, Booster, Main Injector
  - The NuMI beamline
  - The Proton Plan
- ANU combines the above items and adds the Recycler, to increase proton beam power

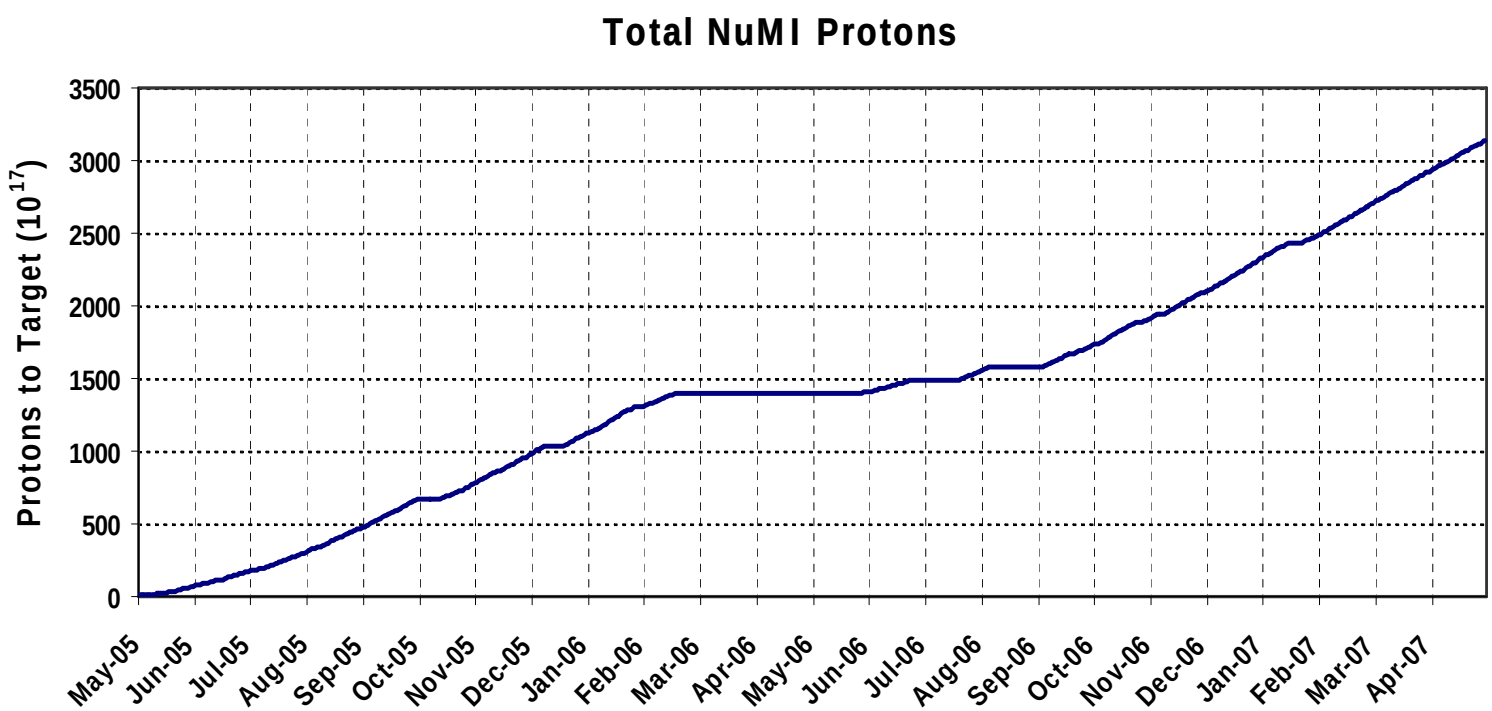
The Main Injector Today



- Provides high power, 120 GeV proton beam
  - 80 kW for antiproton production
  - 190 kW for neutrino production
- Takes 6 or 7 batches from the 8 GeV Booster @ 15 Hz
  - 4-5 × 10^{12} protons per Booster batch
- Total cycle time ≥ 1.4 s + batches/15

NuMI Operation

- Typical beam power of 190 kW
- Higher beam powers of ~ 270 kW without antiproton production
- Recent Achievements:
  - > 4 x 10^{13} protons in a pulse (exceeds design intensity)
  - 325 kW beam power

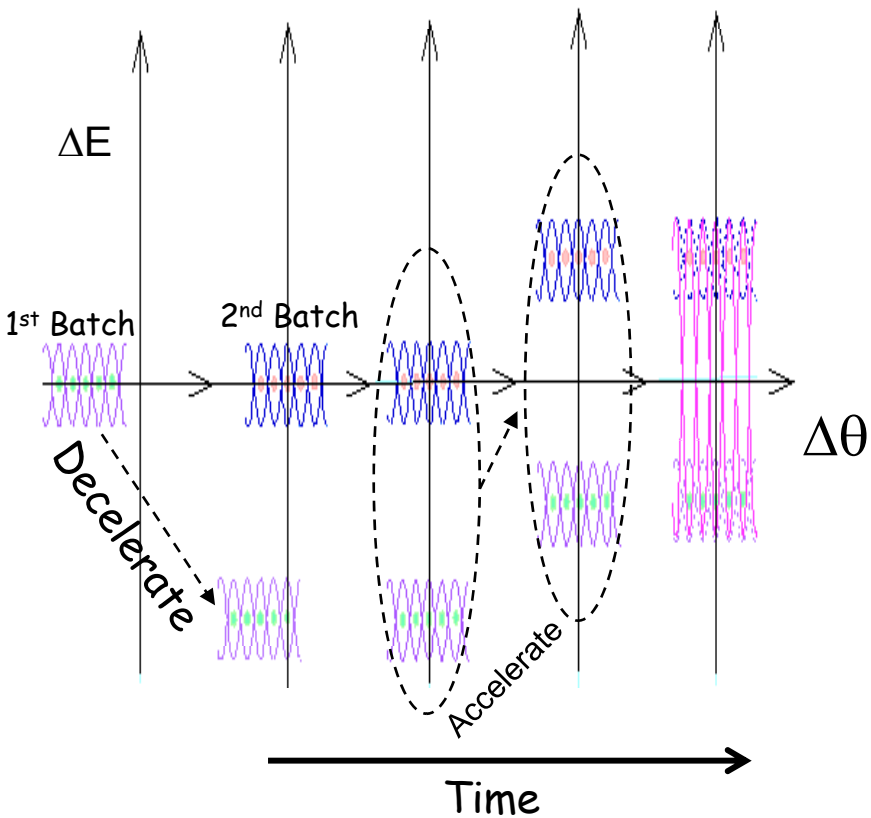


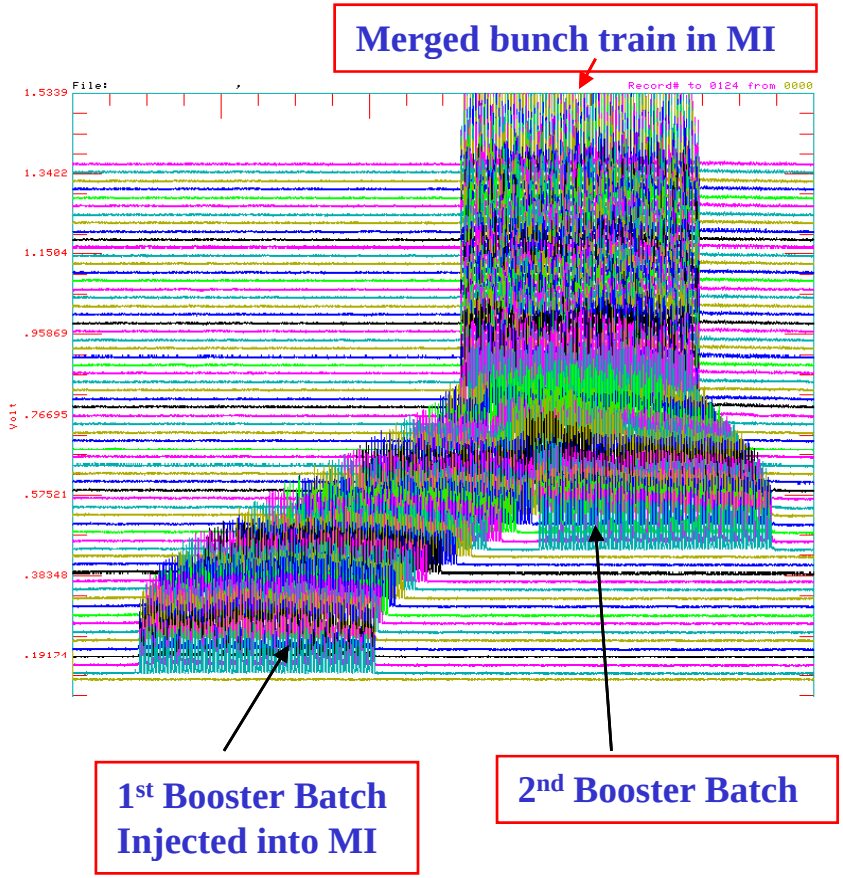
The Proton Plan

- Increase 8 and 120 GeV proton production (underway)
  - Precedes and is necessary for ANU
- Implementation of slip stacking of 9 batches (11 total) to NuMI in the Main Injector
  - Increase NuMI intensity to 3.7×10^{13} protons to NuMI per 2.2 second cycle or about 3×10^{20} p/yr. (~320 kW)
  - Increases by ~30% if antiproton production is not needed. (~400 kW)
- Proton Plan primary elements
  - Increase Booster repetition rate to 9 Hz ave. (15 Hz rate), and improve efficiency
  - Perform slip stacking in an efficient manner in the MI
    - RF improvements
    - Collimation

Slip Stacking

- **Merge two booster batches through RF manipulations**

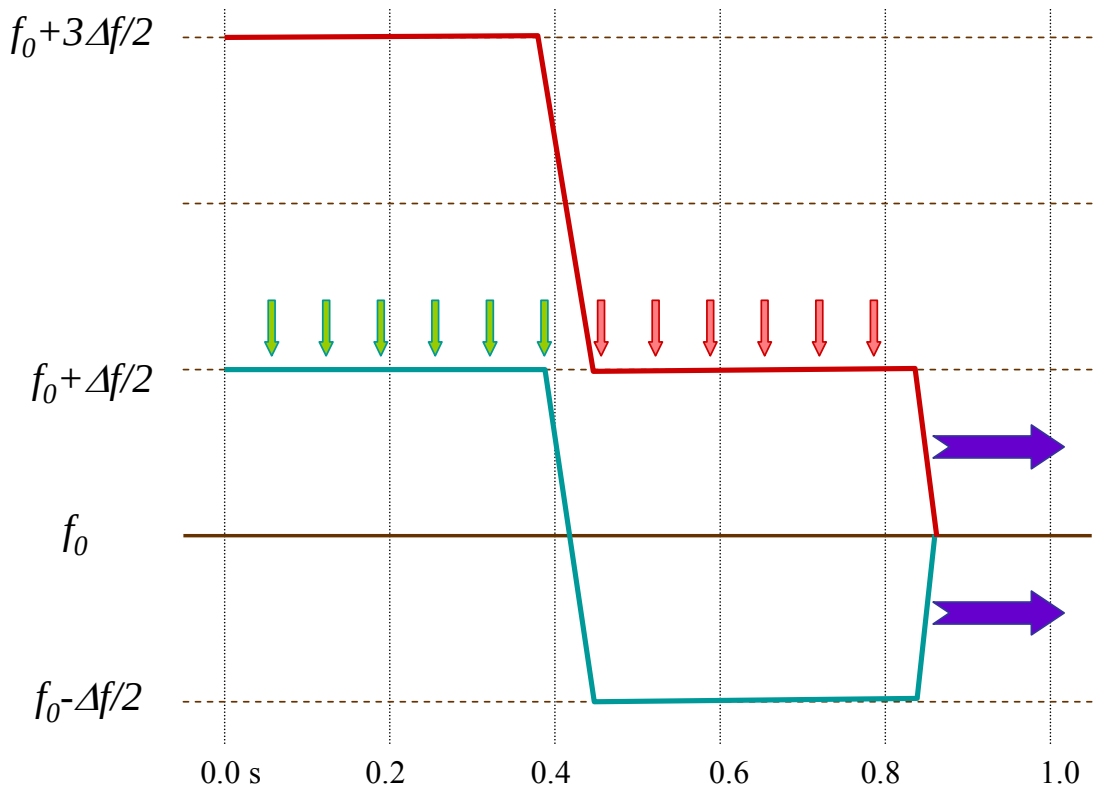




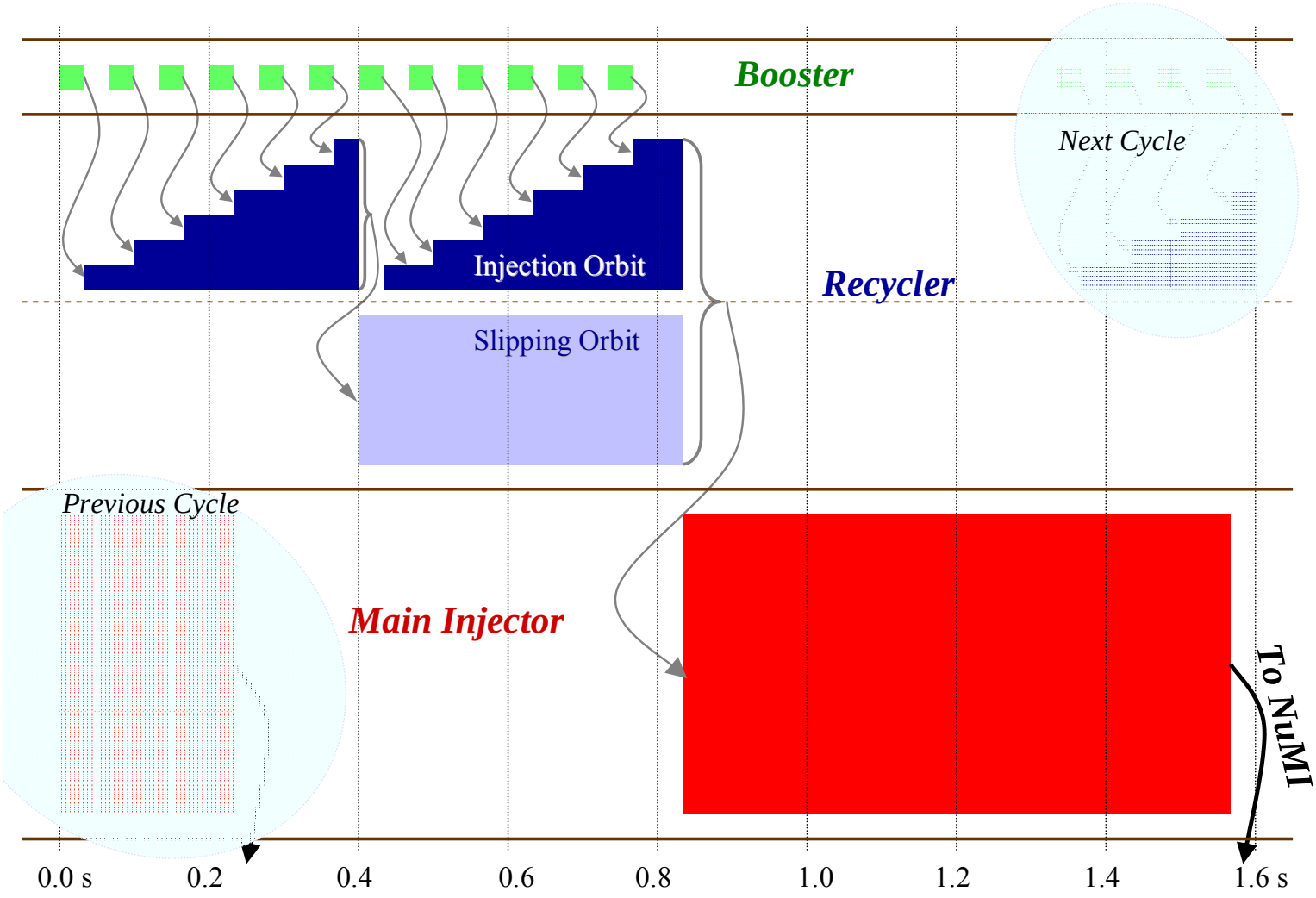
➢ **Doubles the azimuthal charge**

ANU Slip Stacking

- 12 batches injected
  - All injections on the same orbit
  - Six batches moved to slipping orbit during later injections
- Extracted in a single turn to MI



ANU Scheme


Booster
Next Cycle
Injection Orbit
Recycler
Slipping Orbit
Previous Cycle
Main Injector
To NuMI
0.0 s
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6 s

ANU Beam Physics Notes

- Booster proton demands are similar to Proton Plan's base goals
  - Booster must be able to provide pulses at the ANU rate
  - Recycler is used for an entirely new type of beam
  - Recycler similar to MI in lattice and circumference
  - 53 MHz RF must be added for slip stacking
  - Instability damping of MI will need to be reproduced in Recycler
  - Beam cleaning introduced to control losses
- MI in ANU will accelerate about the same intensity as in Proton Plan
  - Increase ramp rate of MI to allow faster cycling (needs more RF voltage)
- Beam loss management throughout is necessary for achieving goals
  - Take advantage of Proton Plan improvements
  - Add beam cleaning system (gap clearing kicker) in the Recycler

Beam Physics WBS Description

- Goals of the Beam Physics Effort:

  1.5.1: Verify that the Proton Plan achieves performance for ANU and prescribe augmentation, if necessary

  - ANU performance relies on parts of the Proton Plan

  1.5.2: Further characterization of the machines and processes involved with ANU

  - e.g. Recycler must be understood in terms of high-intensity, 53MHz proton beams
  - Provide input toward upgrade designs, and verify the specifications

  1.5.3: Maintaining Proton Projections for NOvA

  - Develop an operational model and measure efficiencies

Cost Overview Beam Physics

(Fully Burdened FY07 $)

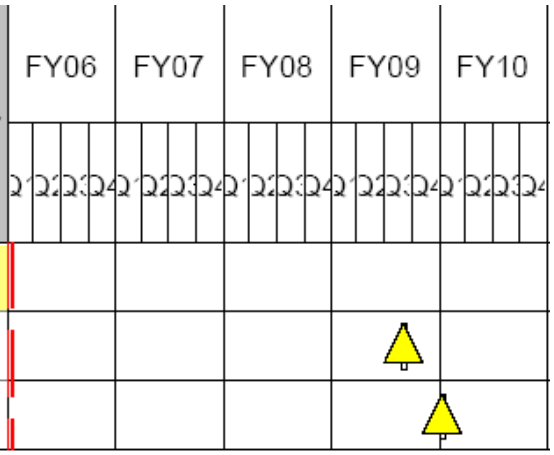
		ANU Beam Physics Upgrades Cost Estimate $K (FY07$)						
		Estimated Cost (w/Indirects)			Contingency %			Total Project Cost
WBS	Name	M&S	Labor	Total	M&S Cont %	Labor Cont %	Total Cont %	
1.0.4	**Beam Physics Planning, Engineering & Design**	**$41**	**$38**	**$78**	**40%**	**40%**	**40%**	**$109**
1.0.4.1	ANU Demands on Proton Plan	$0	$9	$9	0%	40%	40%	$12
1.0.4.2	Machine & Process Analysis	$41	$29	$69	40%	40%	40%	$97
1.0.4.3	Proton Plan Projections	$0	$0	$0	0%	0%	0%	$0

- Most of the labor is physicist (thus labor costs are low) directed towards measurement and simulation
  - We assume that parallel efforts are ongoing in support of the Proton Plan and regular department operation
- M&S costs are for electronics and instrumentation in the Recycler

Beam Physics Milestones

- 1.0.4.4.1: Analysis of Proton Plan performance (May 29, 2009)
  - Depends on progress of Proton Plan
  - Will document progress to that point, even if incomplete
- 1.0.4.4.2: Preparative analyses for commissioning and operation (Oct. 29, 2009
  - Documentation and one instrument
  - Set in scope – will only change if project design changes substantially

Activity ID	Activity Desc.	Date	Milestone Tier
L.2 -- WBS L2 Manager's Milestone			
1.0.4.4.1	Estimate Limits of Proton Plan Performance	29May09	L.2
1.0.4.4.2	Beam Physics Preparative Analysis Complete	09Oct09	L.2



Beam Physics Risk

- Risk Registry for all risks is in WelcomRisk®
  - 15 Risks entered with mitigations for this WBS
    - 0 high, 4 moderate, 11 low
  - Top risks for this WBS

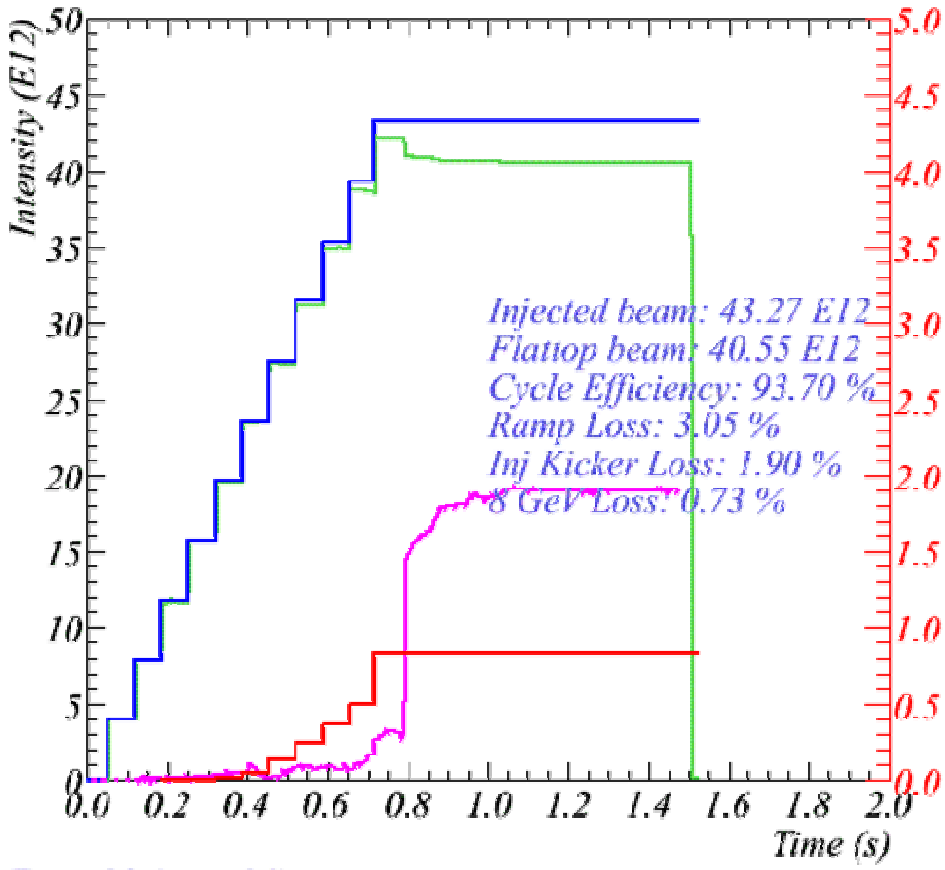
    <u>Top Moderate ones:</u>
    - Can't make electron cloud measurements in MI/RR
      - Integrate installation into other RR jobs. Some contingency and float in this task to mitigate.
    - Beam cleaning analysis not completed
      - Use different codes and teams for analysis. Some contingency and float in this task to mitigate.
    - Poor beam quality and/or losses in the Booster
      - Closely watching the Proton Plan is to mitigate this early is necessary.
      - Loss requirements are nearly met at this point in time and beam quality is close to what is needed for ANU.

Proton Plan Details

- Proton Plan increases proton throughput to 13-19x10^{16} /hour
  - ANU demand will be 14x10^{16} hour
  - Throughput increased by improved efficiency (not intensity)
- Longitudinal emittance and bunch rotation must be controlled
  - Slip stacking performance depends strongly on these parameters for Proton Plan and ANU
  - Maintain emittance of 0.08 eV·s, momentum spread of ± 8 MeV/c
- Collimation in transfer line and MI controls losses
  - Similar loss control will be used in ANU
- RF control (Beam Loading Compensation) for slip stacking
  - ANU will use same system, but split among Recycler and MI

Proton Plan: Beam Records

- 11 batch slip stacking produces > 4 x10^{13} protons
  - Approaching ANU goals
- Higher intensity comes at lost efficiency
  - 98 -> 93%
  - Loss management limits further advancement
- May be operational later this year
  - Requires collimators



Beam Physics Analyses

- Produce a beam Physics sourcebook
  - Document design decisions and calculations
  - Provide background that will be necessary for installation, commissioning, operation
- Particular items:
  - Beam dynamics simulations
  - Electron Cloud simulation and instrumentation
  - Analyses of lattices and losses

Making Proton Projections

- Proton Projections is a work item in the NOvA-ANU Project
  - Goal is to have a more systematic approach for realistic projections
  - Maintain scope expectations of the project
  - Design and measure performance statistics of the present complex
    - Extrapolate to NOvA

- Making projections doesn't increase number of protons, but:
  - Allows reasonable expectation of experimental reach
  - Gives guidance on where improvement can be found
  - And, people always ask about it

Estimation Method

- "Design" scenario is the goal for ANU involving reasonable predictions of performance
- "Base" scenario is based on a set of parameters assuming lower intensities or efficiencies than expected of the ANU upgrades

- ANU is what is described in this review: use of the Recycler
  - Accelerates 12 Booster batches at once to 120 GeV
- SNuMI is the proposed use of Accumulator
  - Accelerates 18 Booster batches to 120 GeV
  - Not part of this project
  - Included for comparison

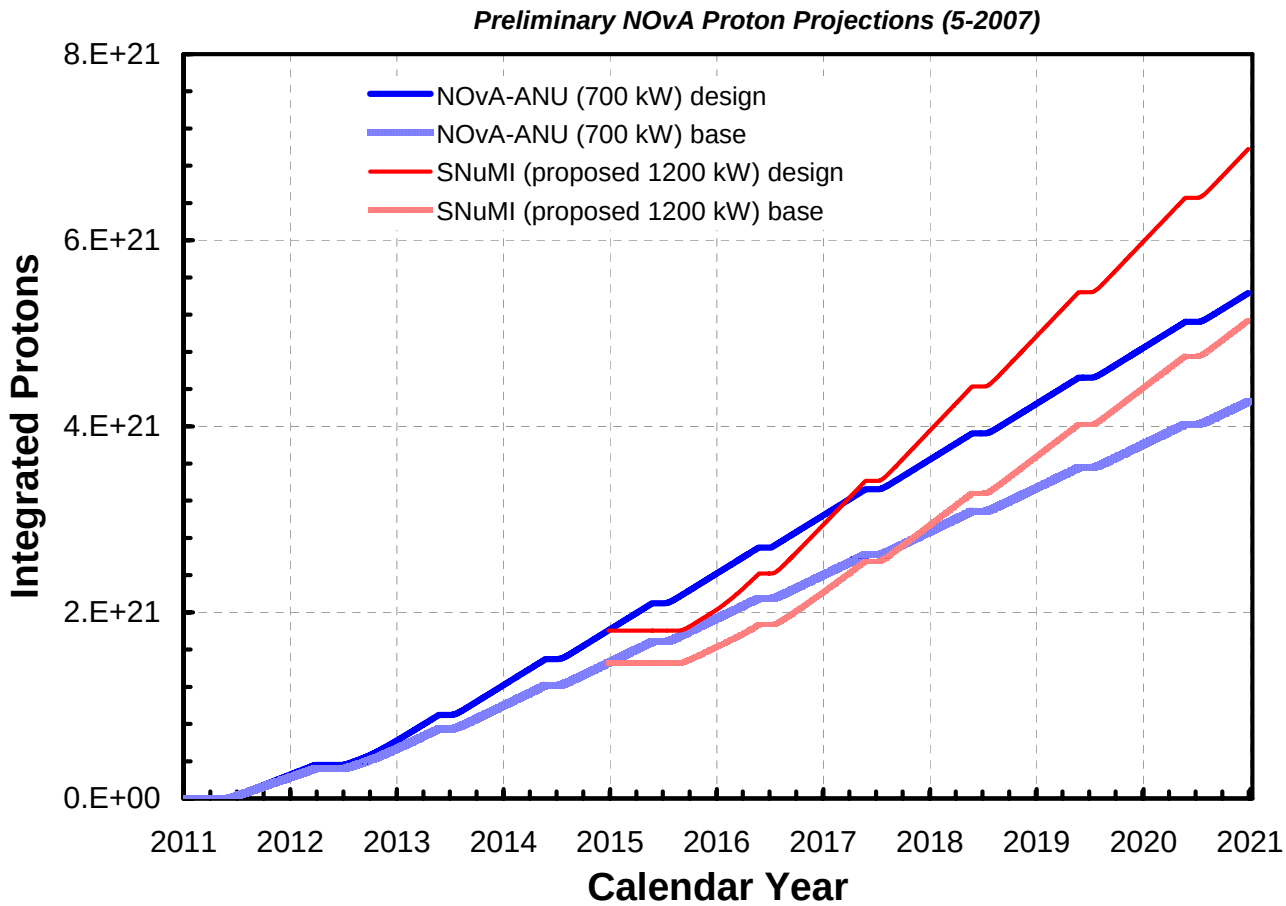
Annual Proton Production

- Apply efficiencies derived from Proton Plan estimations
  - Accelerator & NuMI uptimes and operation details
- These are long term numbers, expected once commissioning is complete
  - Also with 44 weeks of regular running per year

	ANU		SNuMI		
	Design	Base	Design	Base	
Booster Batch Intensity	4.3×10^{12}	4.0×10^{12}	4.7×10^{12}	4.3×10^{12}	protons
MI Cycle Efficiency	0.95	0.9	0.98	0.95	
MI Cycle Time	1.333	1.333	1.333	1.333	seconds
Peak Beam Power	707	623	1196	1060	kW
Complex Uptime	85%	85%	85%	80%	
Avg-to-peak	90%	90%	90%	90%	
NuMI Uptime	80%	70%	80%	70%	
Operating Eff.	61%	54%	61%	50%	
Annual Running Time	44	44	44	44	weeks/yr
Annual Protons	**6.0×10^{20}**	**4.6×10^{20}**	**10.1×10^{20}**	**7.4×10^{20}**	**p/yr.**

Long Term Projections

- ANU shutdowns from schedule
  - Anticipate a commissioning curve
- SNuMI shutdowns are arbitrary



Summary

- The Beam Physics effort is well-defined, as ANU is based on established machines and techniques
  - Slip stacking is operating in Main Injector, is being expanded
  - The primary risk to ANU is whether the Proton Plan will meet its performance goals; will be an area of study in ANU

- ANU is predicted to deliver 6 x 10^{20} 120 GeV protons per year, once fully commissioned
  - Without major downtime/competition from other programs