Accelerator Status and Plans

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Fermilab Physics Advisory Committee Meeting
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Fermilab Accelerator Complex

- Linac: MTA
- BNB: MicroBooNE
- NuMI: MINOS+, MINERvA, NOvA
- Fixed Target: SeaQuest, LArIAT, Test Beam Facility
- Muon: g-2, Mu2e (future)

Meeting experiments’ needs in FY16 and beyond requires running beam at 15 Hz in the Booster
Objectives for the next few years

• Ramp up beam power to 700 kW for NOvA, achieve performance metrics, and support full experimental program
• Achieve 15 Hz beam pulse repetition rate as soon as possible by carrying out Proton Improvement Plan
• Complete Muon Campus construction on budget and on schedule and commission g-2 experiment in FY17
• Make Booster Neutrino Beam operations more robust
  – Target and horn spares production and testing
  – Study of horn upgrade for Short Baseline Neutrino on-going
Accelerator performance for NuMI

- Started delivering protons to NuMI in 2005
  - $\sim 1.55 \times 10^{21}$ in 7 years; NOvA goal is $3.6 \times 10^{21}$
  - Most intense high energy neutrino beam in the world
Current high power operation and plans

- Commissioned slip-stacking in the Recycler
- Currently slip-stacking 2+6 batches, $3.1 \times 10^{13}$ ppp every 1.333 sec
  - Reconfigured Recycler transverse dampers
  - Commissioned MI collimators
  - Increased number of Booster turns
  - Beam power >450 kW (400 kW with SY120)

![Position in Recycler ring](image)

**Peak Power (Hour) to NuMI 481.3 kW**

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<th>Days since October 1</th>
<th>Peak Hour (kW)</th>
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- Fiscal Year 15
- Fiscal Year 14
- Fiscal Year 13
- Fiscal Year 12
- Fiscal Year 11
- Fiscal Year 10
- Fiscal Year 09
- Fiscal Year 08
- Fiscal Year 07
- Fiscal Year 06
- Fiscal Year 05

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6/23/2015
Current high power operation and plans

• Testing 4+6 operation (460 kW) prior to the summer shutdown with current Booster rep rate (7.5 Hz, no beam to BNB)

• Also would like to test low intensity beam at 15 Hz

• After shutdown will have
  - At least 18 refurbished Booster RF stations installed
  - New Booster shielding assessment taking into account use of Total Loss Monitors to allow higher flux in Booster

• Increase intensity with 4+6, commission beam at 15 Hz in Booster, commission 6+6

• Challenge is keeping losses low
Reduced Recycler losses by a factor a 4 by improving Recycler aperture
Current RR/MI Losses with 2+6 slip stacking

- Continuing to address Recycler misalignment and aperture issues to further reduce losses
Beam power in FY15 on track and increasing

- Goals for FY16 still under discussion, but think we can ~double POT to NuMI relative to FY15 goals
Excellent uptime in FY15

Main Injector bus ground fault and replacement
NuMI Target

- First NOvA target still healthy
  - MET-01 has integrated $6.1 \times 10^{20}$ protons
- Neutrinos experiments looked for deviations in neutrino rate
  - No changes observed which would indicate target degradation
  - Few percent changes are observed, but related to either slip-stacking or detector pile-up
- Muon monitors show consistent response
  - Variation of $\sim 0.5\%$ consistent with fluctuations in spot size and beam intensity
- First round of spares are ready, more are in production
  - Spare production has been impacted by redirection of effort to BNB
NuMI Horn Replacement

- Horn PH1-04 has severed stripline
  - First 700 kW capable horn, in service since Sept 2013, accumulated ~ 27 million pulses
  - Running in horn-off mode for 3 weeks prior to shutdown
  - Will replace during shutdown

- Spares of various condition are in hand
  - Under discussion which to use and which modifications to make

Location of severed stripline (outer stripline at first clamp)
MI/Recycler upgrades

• Recycler vacuum
  – Recycler titanium sublimation pump (TSP)-based vacuum system has exceeded design lifetime; not suitable for a proton machine
  – Plan for replacement of ~400 TSPs with ion pumps will take 3 long shutdowns (lots of cutting and welding)

• Replacing MI beam pipe in MI-30 collimation region with duplex stainless pipe with higher corrosion resistance

• Designing collimation system for Recycler
Proton Improvement Plan

• Increase the beam repetition rate from the present ~7.5 to 15 Hz
  – Need at least 9 Hz for NOvA 12-batch slip-stacking
  – Requires refurbishment of Booster RF cavities
• Eliminate major vulnerabilities and maintain reliability at present levels (>85%) at the full repetition rate
• Eliminate major obsolescence issues
• Increase the proton source throughput, with a goal of reaching >2x10^{17} protons/hour
  – Presently operating at <1x10^{17} protons/hour
• Ensure a useful operating life of the proton source through at least 2030 (PIP-II)
• Main challenge: keep beam losses at present level while increasing protons on target
Booster loss and Linac laser notch

- Doubling the beam repetition rate so need to cut the losses per Booster cycle in half
- Addressing each of the three main areas of Booster beam loss:
  - Injection
  - Notching the beam to create a gap for extraction kickers to fire
  - Transition, related to RF during acceleration
- Phased improvements to notch creation
  - Most recent was new cogging system which allowed notching at 400 MeV instead of 700 MeV → lower energy losses
  - Final phase is to install laser notcher in Linac PreAcc during shutdown

Successful test of Linac notch
Dec 2014

Optical cavity (attached end of RFQ)
PIP recent progress

• Linac replacement high-voltage modulator for RF power amplifier prototype assembly in progress
• Booster replacement RF anode power supplies
  – Had trouble finding vendor that can meet specifications but progressing
  – Hope to install during shutdown
• Booster RF bias supplies being upgraded for reliable 15-Hz operation; expect complete early FY16
• Booster new RF cavity tuners
  – Vendor has now met specs for ferrites; Tech Division producing new tuners
• Preparing new Booster shielding assessment w/ Total Loss Monitors
Booster RF cavity refurbishment

- Expect to have at least 18 cavities certified to run at 15Hz when start up after summer shutdown
  - Installed 17th ahead of schedule
  - Ran at 15 Hz for 6 h
    - A cavity developed tuner problems and was no longer certified; another developed a vacuum leak
    - Had similar issues when first started running east gallery at 15 Hz
      - Hope to try again before shutdown
- Many tuners still have dings and dents that will likely leak at later time
  - TD making new tuners
Booster Neutrino Beam

- Preparing to run to MicroBooNE
- Replaced horn which lasted ten years and >400M pulses
  - Expected lifetime was about one year and 100M pulses
  - Had to also redesign and replace adjustor platform and horn extraction mechanism (was not designed to last this long)

- Looking into requests for upgrades for Short Baseline Neutrino program but limited resources
Modifications to allow beam to BNB during MI access

- Install new gates and safety system FY15 shutdown
- Fabricate new beam stops and install FY16 shutdown
- Estimate $1.5 \times 10^{18}$ POT/day assuming 5 Hz operation
SY120 (120 GeV fixed target program)

- Delivering beam to Fixed Target Test Beam Facility as needed (the facility is fully subscribed)
- Supporting a second test beam for LArIAT (repurposed ArgoNeuT liquid argon time projection chamber)
- Modified primary beamline to allow clean transport of higher intensity beam to SeaQuest
Muon Campus construction

• New beamline enclosure for connection from Delivery Ring (former antiproton rings) to g-2 and Mu2e experiments nearing completion
Pbar to Muon reconfiguration for Muon Campus / g-2 / Mu2e

- Remove existing magnets
- Reconfigure cables, cooling water, electrical bus, lighting
- Install injection and extraction lines
- Reinstall Delivery Ring magnets

5/8/14 start of decommissioning

3/23/15

reconfiguration of new injection/extraction region
Muon Campus Recycler modifications

Recycler Ring

Beam Transport and Delivery Ring

Muon Campus

g-2 Target Station

Assembling new RF cavities to install in FY16

New connection from RR to P1-line to be installed this summer (Drives the length of the shutdown)
Protons to Muon Campus

- In Recycler, use 2.5 MHz RF to rebunch Booster batch of $4 \times 10^{12}$ protons into 4 bunches of $10^{12}$ protons to Muon Campus experiments.

- Had a conceptual design which provided 16 bunches to g-2, 8 to Mu2e in a 1.33s NOvA cycle (12 Hz / 6 Hz, 3 Hz to BNB).
Detailed planning found some modifications needed to timing of bunches to Muon Campus and possibly to NOvA cycle.
Possible pulse schemes for protons to g-2 (late FY17)

75% rate to g-2
NOvA unaffected
(BNB 3.8 Hz)

100% rate to g-2
8% reduction in
NOvA intensity
(BNB 3.8 Hz)

95% rate to g-2
5% reduction in
NOvA rate
(BNB 3.6 Hz)

- Should be able to switch back and forth between these options if desired
Possible pulse schemes for protons to Mu2e (FY20)

- 20 tick, 12 to NOvA, 8 to Mu2e w/ 34ms spill
  - Booster events: 19, 19, 19, 19, 19, 19, 19, 19, 19, 19, 1D, 1C, 1D, 1C
  - Recycler events: E3
  - 50% rate to Mu2e
  - NOvA unaffected (BNB 3.8 Hz)

- 20 tick, 12 to NOvA, 8 to Mu2e w/ 54ms spill
  - Booster events: 19, 19, 19, 19, 19, 19, 19, 19, 19, 19, 1D, 1C, 1D, 1C
  - Recycler events: E3
  - 100% rate to Mu2e
  - 8% reduction in NOvA intensity (BNB 3.8 Hz)

- 20 tick, 11 to NOvA, 8 to Mu2e w/ 43ms spill
  - Booster events: 19, 19, 19, 19, 19, 19, 19, 19, 19, 19, 1D, 1C, 1D, 1C
  - Recycler events: E3
  - 95% rate to Mu2e
  - 5% reduction in NOvA rate (BNB 3.6 Hz)

- 21 tick, 12 to NOvA, 8 to Mu2e w/ 43ms spill
  - Booster events: 19, 19, 19, 19, 19, 19, 19, 19, 19, 19, 1D, 1C, 1D, 1C
  - Recycler events: E3
  - not enough time for Delivery Ring abort kicker to charge

50% rate to Mu2e
NOvA unaffected (BNB 3.8 Hz)

100% rate to Mu2e
8% reduction in NOvA intensity (BNB 3.8 Hz)

95% rate to Mu2e
5% reduction in NOvA rate (BNB 3.6 Hz)
Projections for FY16
FY16 NuMI POT Projections (Maximize Beam to NuMI)

Draft Projections for FY16 Integrated Beam to NuMI

Integrated Protons (1e18)

Oct-15  Nov-15  Jan-16  Mar-16  May-16  Jul-16  Sep-16

Design  Base
FY16 BNB POT Projections (Maximize Beam to NuMI)

Draft Projections for FY16 Integrated Beam to BNB

- Integrated Protons (1e18)
- Aug-15 to Oct-16
- Design and Base lines

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Possible to send more beam to BNB at expense of NuMI
Accelerator summer shutdowns

- 2015 shutdown begins July 6 (beam off July 4)
  - 13 weeks
  - First of three phases in Recycler TSP2IP project
  - Connection from Recycler to Muon Campus beamlines
  - General maintenance

- 2016 shutdown
  - Estimate 10-12 weeks
  - Complete phase two of TSP2IP project
  - Install 2.5-MHz Recycler RF cavities for beam to Muon Campus
  - Rework MI-30 extraction

- 2017 shutdown
  - Estimate 8-10 weeks
  - Complete phase three of TSP2IP project

- Shutdowns expected to occur July-Aug to optimize MI performance
Master Substation replacement

- Laboratory typically powered by two substations
  - Kautz Road Substation (KRSS)
    - Typically powers Main Injector and Recycler
  - Master Substation (MSS)
    - Typically powers the remainder of the site
- Successfully ran on Kautz Road Substation as a test from Nov 2014 – Apr 2015
- Will be ready for Master Substation to go offline in Sept 2015 for about one year for replacement
Impact of proposed CAPTAIN MINERvA experiment

- Requires only the usual maintenance and operation of the NuMI beamline and target system already being operated for beam to NOvA
Impact of LOI: Direct Search for Dark Photon and Dark Higgs Particles with the SeaQuest Spectrometer

- Requires the continued maintenance and operation of the Neutrino Muon beamline
- Impacts beam available from MI along with other SY120 experiments
Summary

• Running with high reliability with record beam power to NOvA
• Preparing to run beam at 15 Hz
• Increasing protons on target to NOvA with goal of 700 kW next spring
• Providing beam to SeaQuest, LArIAT, test beams
• Replaced BNB horn and will be ready to run beam to MicroBooNE
• Will be ready to run beam to Muon Campus in FY17