NUMI: towards 700kW

Phil Schlabach, Fermilab/AD/external beams

- overview of NUMI history and beamline
- upgrades for 700kW
- commissioning and 1st year of NOVAera operations
- shutdown plans
- NUMI component spares status
- towards 700kW

a brief history of NUMI

- 1st protons Dec. 2004
 - beam for experiments spring 2005
 - 120 GeV protons
 - booster \rightarrow MI \rightarrow NUMI
 - max power ~350kW
- shutdown May, 2012 for 700kW upgrades
- 1st beam early Aug., 2013, beam for experiments, early Sept., 2013
- shutdown 5 Sept. (beam useful to experiments returns 31 Oct.)

NUMI beamline

- kick beam in MI up into lambertsons
- bend up and away
- slip out between MI and RR into the stub
- bend down, go through acquifer
- bend back up to point at target and exp'ts
- final focus quads, then 8m of drift to target



Upgrades for NOVA 700kW

	NuMI Design	NOvA
Beam Power (kW)	400	700
Energy Spectrum	Low Energy	Medium Energy
Cycle time (s)	1.87	1.33
Intensity (ppp)	4.0×1013	4.9×1013
Spot Size (mm)	1.0	1.3



700kW upgrades: MI/RR

- Turn RR from pbar to proton machine
 - decommission/remove pbar stuff
 - inject from booster into RR while MI ramps down, extract to MI, accelerate, extract to NUMI
 - injection and extraction lines w. associated kickers and instrumentation
 - 53 MHz RF
- shorten MI cycle to 1.33s
 - RF/power supply upgrades

700kW upgrades: NUMI beamline

- Primary beamline
 - kicker power supply upgrade for faster rep rate
 - reconfigure dipole PS (same)
 - 5 highest current quads upgraded to directly-water cooled coil versions
 - upgrade profile monitors (see G. Tassotto talk)
- Water systems
 - increase cooling capacity for kicker flourinert, LCW and RAW
- Monitors: replaced hadron monitor (modified design) and 4th muon monitor added

700kW upgrades: NUMI beamline

- Upgrade NUMI target and horns for increased power
 - new medium energy target (see P. Hurh talk)
 - horn 1 gets a thinner outer conductor and improved cooling $(1" \rightarrow 0.6")$
 - no changes to horn 2
- Reconfigure target hall for desired neutrino flux and energy
 - horn 2 moves downstream to "medium energy" position
 - shield pile reconfigured to accommodate move

700kW upgrades: target



700kW upgrades: Target hall



700kW upgrades: Target hall

prepping for horn 2 move

horn 1 coming out



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Commissioning and 1st year of operations

- 1st beam to NUMI early Aug. 2013, beam for experiments, early Sept. 2013
- Dec. 2013, MI running at 1.67s rep rate, 26e12 POT/spill
- Mar. 2014 start RR commissioning
 - 1 or 2 consecutive RR pulses mixed in timeline (possibly multiple times per 60s supercycle)
 - first 1.67s rep rate for RR pulses, then 1.33
 - started with low intensity then ramped it up

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Commissioning and 1st year of operations

- July: 1.33s all RR timeline
 - booster \rightarrow RR \rightarrow MI \rightarrow NUMI 1.33s cycle
 - power approaching 300kW
- July-August: intensity increases
 - 24-25e12 POT/spill, 320-330kW normal running
 - maximum power 370kW (no switchyard)
- shutdown 5 Sept.: 3.3e20 POT delivered
 - beam useful to experiments returns 31 Oct.



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NUMI experience during commissioning



3.3e20 POT Sep 6, 2013 at 15:00 – Sep 5, 2014

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NUMI operations

- (surprisingly) little NUMI required downtime
 - July 2013: 3 days to replace a main dipole in the V108 string
 - Feb. 2014: 1-1.5 shifts to fix a vacuum leak caused by a mis-steered pulse
 - 65 million beam pulses before this first damaging one
 - various < 1 shift: e.g. horn, horn PS, evaporators
 - we did implement some upgrades during the shutdown that allowed us to do remotely what we shut off to do in the past; also added redundancy (e.g. water system)

bad magnet



July 2013 B2 magnet replacement ~3 days

mis-steered pulse

- extracted with magnets at the wrong currents
 - simulated trajectory with US bends on down ramp shows beam coming out of the beam pipe exactly where vacuum seal was damaged (next slide)
 - 8-40 amps low on multiple magnets

tightened beam permit limits for bends and moved sampling closer to extraction; would catch this instance now

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beam line trajectory



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NUMI experience during commissioning

- few problems with faster rep rates
 - \rightarrow 1.67s: logging issues from legacy settings
 - \rightarrow 1.33s: on the 2nd of 2 consecutive RR pulses, NUMI toroids missed the pulse
 - caught quickly, and timing card reprogrammed, experimental triggers had the same problem and were fixed
- mixed MI/RR pulses
 - small (~0.1mm) differences in the position at the target BPM for RR pulses
 - all RR time line is easier

NUMI shutdown plans

- schedule has placeholder for target replacement
 - no degradation, no replacement
 - MET-02 w. 3 test Be/47 regular graphite fins goes in next
- remove dead B2 dipole from NUMI stub, stage good one (requires removing/replacing a MI dipole to get it in)
- add 2 new style button BPMs in drift space at the end of primary beamline+fix 1 that's there
 - redundancy of measurements in targeting region
- replace one profile monitor that won't move into the beam
- routine (periodic) maintenance of systems

status of NUMI spares

- targets:
 - MET-01 shows no signs of degradation w. 3.3e20 POT
 - MET-03 (new, ready)
 - MET-02 (w. 3 Be fins) would go in next (new, ready)
 - 2 MET under construction
 - 2 NT-xx viable (400kW)
- spare hadron monitor of modified design

• horns:

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- PH1-04 installed
- 2 PH1-xx (400kW)
- PH1-05: field map done, attaching water tank
- PH1-06 (early FY16)
- PH2-02 (remains in place)
- PH2-03 (new, ready)
- PH2-04 (May '15)
- PH2-05 (FY16)

NUMI at 700kW: what remains?

- ran since Sept. 2013 with ~1.1mm beam spot
 - 1.1 at 26e12 (intensity dependent)
 - measured at the last profile monitor, ~8m upstream of target
 - for 700kW want 1.3mm at target
 - spread beam out to reduce target stress
 - w.o. having too much halo miss
 - also need to understand the translation from profile monitor to target

NUMI at 700kW

- performed a series of studies with experts
 - validate the model
 - extrapolate from end of line to target
 - find final focus quad settings for 1.3mm
 - analysis ongoing
 - implement 1.3mm coming out of shutdown?
 - up to experiments as we'd still be ok in intensity on target for a while
- otherwise ready to go

Towards 700kW: what's next?

- RR
 - instability threshold above present intensities (24-25e12)
 - not understood, although e-cloud gets mentioned a lot
 - needs to be figured out, could be multiple things, probably doesn't hinder slip stacking
 - aperture really tight in the "300" region
 - physical restriction? or dynamics? or something else
 - alignment being checked/improved during shutdown

Towards 700kW: what's next?

- RR, con't
 - slip stacking demonstrated
 - needs to work at operational intensities
 - prior to shutdown were trying to put in 6, move them out of the way, put in 2 more without success
 - will try the opposite when we get beam again
 - will start up as we finished up
 - 6 batches, no slip stacking, 1.33s RR pulses
 - operational slip stacking (other things the same) would give us
 - 24e12*8/6 = 32e12 POT
 - 320kW*8/6 = 430kW

Towards 700kW: what's next?

- RR, con't
 - solve the instability, aperture: could perhaps accept a bit more intensity out of the booster (5%?)
 - 4+6 would require the booster rep rate to increase (although not to 15Hz)
 - 530kW
 - full 6+6 requires 15Hz (all booster cavities refurbished, 15Hz commissioned)

- see K. Gollwitzer talk

>400kW in the next year, possibly >500

Summary

- 1.33s, booster \rightarrow RR \rightarrow MI \rightarrow NUMI commissioned
 - 3.3e20 POT for this run
 - 0.2 MW-year of accumulated beam power
 - power routinely 320-330 kW (max 370)
 - next step: slip stacking 2+6 batches in the RR
 - ~430kW for normal operation
 - ME target showing no degradation
- NUMI upgrades for 700kW commissioned
- minimal NUMI downtime
- NUMI shutdown work not extensive
- NUMI spares status excellent