SEPTEMBER, 2016

- Laser trailer: The trailer was re-installed at its nominal location now atop a solid 50-ton steel base. The laser trailer floor was modified to allow the optical table's support legs to connect directly to this stable base (to decouple the optical table from the floor of the laser trailer). A new optical table has been relocated in the trailer. Design work is underway for rack layouts and additional shelving.

- Laser transport: The overall layout was finalized. Engineering designs for the in-vacuum transport and custom mirror supports were completed. The bore through the RHIC shield wall is underway. The concrete supports and shield blocks for the relay and gun tables are on hand and await surveying of the end-to-end optical path. These tables have been received.

- Laser development in laser R&D lab: The renovation to the bldg. 912 laser room was completed. The laser oscillator, amplifier and frequency doubling were reestablished on the newly installed 5' by 13' by 2' optical table (property transfer from the BNL SDL lab). Beam pointing instability measurements were completed (~ 5 microns over ~ 20 minutes for both 100 W and 180 W in the infrared). Design IR (160 W) and green (120 W) were demonstrated. Efforts are underway to coordinate a conduit from Industrial Laser Systems (Germany) to allow adjustment in the laser amplifier temperature setpoint to allow higher power operation for determination of performance limits.

- Laser transport development: A temporary test area, located in the clean room near the laser R&D lab, with borrowed optical table and newly installed networking infrastructure was realized. A cross-correlator was designed, set up and aligned. Testing of motion controllers for translation of optical devices was completed and decisions reached on types of controllers to implement for high reliability operation. A mock-up of the optical transport from the gun table to cathode to laser exit port was established. Two axes of mirror motion control (for mapping of the cathode quantum efficiency) were successfully tested using the RHIC controls system environment. Images of the spatially shaped laser beam were acquired over the intended range of spot sizes at the cathode (2-6mm diameter).

OCTOBER, 2016

- Laser trailer: The electrical power circuits and outlets both on the new optical table and in the anteroom for the relocated chillers were installed. The trailer was thoroughly cleaned in preparation for the laser relocation to this trailer. Vibration measurements are underway.

- Laser transport: The bore through the RHIC shield wall was completed. The optical table near the electron gun has been pre-positioned atop its concrete support in the tunnel.

- Laser development: Measurements of laser properties in the R&D lab were completed:

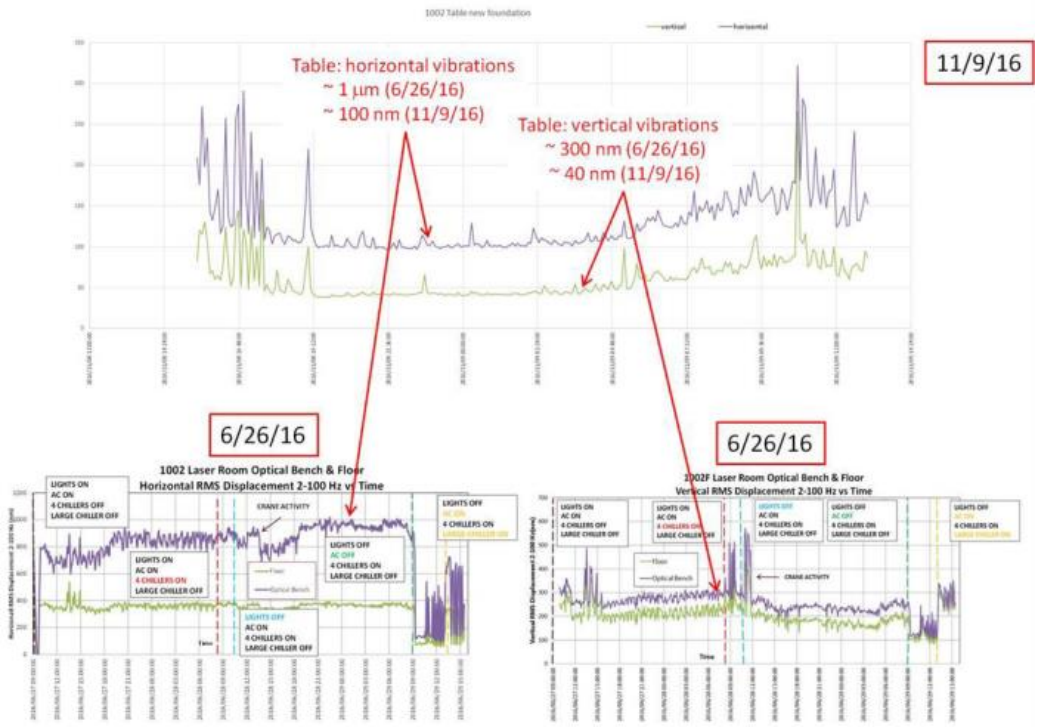
    - Laser power IR: 160 W design, 270 W achieved
    - Laser power green: 120 W design, 180 W achieved
    - RMS time jitter: <500 fs design, ~ 240 fs (between 1 Hz and 1 MHz) achieved
    - Spatial profile: M^2<1.2 design, 1.09 achieved
    - Pointing instability: 10 μm rms design, < 10 μm rms at 180 W (IR),
    - RMS laser power stability: 0.12% (IR, 180 W), 0.5% (green, 100W)

- The laser will be moved from the R&D lab to the laser trailer (1002F) starting this week.

- Laser integration: Laser state tables for the LEReC Gun Test machine protection system were defined. The Standard Operating Procedure (SOP) for the LEReC (and CeC) lasers was updated and reviewed by safety experts (A. Etkins, C-AD ES&H Coordinator and C. Weilandics, BNL laser safety officer); a few installation-specific details will be incorporated into the document as that information becomes available. Laser failure possibilities and their impact are being evaluated.

NOVEMBER, 2016

- Laser trailer: Vibration measurements were completed (T. Tallerico, S.V. Badea) showing significant improvement



- Laser trailer, continued: Trailer was re-keyed; the through-port for the optical transport line was completed; the move of laser from Bldg. 912 R&D area started

- Laser transport:

  - The optical table just inside the RHIC tunnel (relay table) has been installed and grouted
  - The optical table near the electron gun (gun table) has been pre-positioned atop its concrete support
  - The design for cathode imaging (exit table) was completed
  - The laser transport pipes have been cleaned and cut (Vacuum Group) and sent to Central Shops for welding; the in-tunnel optical table enclosures have been designed

- Laser integration: reviewed remote control diagnostics requirements, continued coordination with Controls Group on implementation specifics (signal types, frequencies, levels, etc.); continued coordination on laser-related aspects to Machine Protection System (Z. Altinbas leading)

- The Laser System Development presented at the DOE review in Germantown (16-17 Nov, 2016)

DECEMBER, 2016

- Laser trailer: Infrastructure – additional electrical power outlets, relocation of air conditioning, ante-room shelving, cleaning etc. completed (D. Phillips et al), custom shelving for new laser table with incorporated racks designed and ordered (B. Streckenbach), laser safety interlock cable connects upgraded

- Laser development: 80% of the laser equipment was moved back from the Laser R&D area (Bldg. 912) to the laser trailer, the pump diodes and chillers are operational, work is underway to restore operation of the fiber laser in the laser trailer and then to setup the two pulse pickers used for establishing the temporal structure of the laser beam.

- Laser integration, laser trailer: design started for integration of Pockel cell with timing and MPS (K. Mernick, M. Costanzo, J. Jamilkowski et al)

- Laser transport:

    - The optical table near the electron gun (gun table) has been grouted (so now both the relay and gun tables are in their final positions)
    - The laser transport pipes were welded at Central Shops; the pipes (trailer to relay table, relay table to gun table) were installed (D. Lehn et al) and vacuum established (M. Mapes et al)
    - The in-tunnel optical table (relay and gun) enclosures were designed and fabrication is underway, design of the exit table enclosure is starting.
    - The optics and motion controllers for the relay, gun and exit tables are in storage and ready for final installation.
    - Two of three mirror lift/mounts have been received from Central Shops.
    - Concerning in-vacuum laser transport, four stainless steel mirrors - of which two are required - were received (S. Nayak); pre-bake measurements of the surface roughness and profile, to characterize laser halo, were completed.

laser transport between laser trailer and RHIC tunnel:

laser transport from relay to gun table:

- Laser integration, transport line: addressing late request for online scans of quantum efficiency with low power, small cross-sectional area laser beam (using either flip mirror or an on-order filter wheel)

JANUARY, 2017

- Laser trailer infrastructure completed; new 5’ by 12’ custom shelving for laser table installed (design by B. Streckenbach)

- Laser development:

  - finished relocating laser equipment from Laser R&D area (Bldg. 912) to the laser trailer
  - laser construction underway to restore operation of fiber laser
  - developed the ultrafast pulse picker needed to produce 9 MHz modulation with 10-30 optical pulses per macro-bunch and demonstrated a signal-to-noise ratio exceeding 40 dB; control chassis for Pockel Cell laser/bunch intensity control with interface to timing system and MPS fabricated and under test (K. Mernick, M. Costanzo, J. Jamilkowski et al)

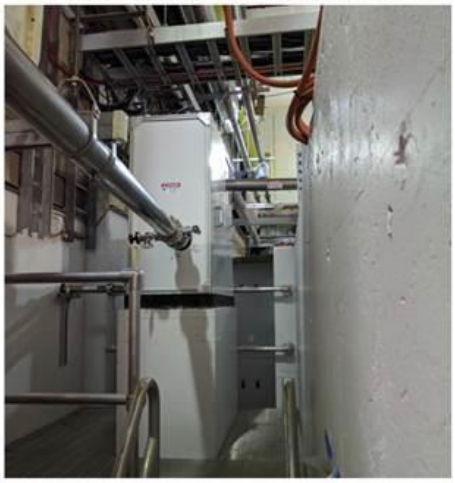
- Laser integration:
  - prepared VME crate (cfe-2f-laser) for the 1002F laser trailer (R. Schoenfeld) and completed associated initial ADO configuration (J. Jamilkowski)
  - procured a filter wheel with solid steel scanning apertures to address late request for online measurements of the cathode quantum efficiency, developed associated ADO manager (A. Sukhanov)
  - all laser system cables and laser-related cables have been pulled and installed at the appropriate locations: 1002F laser trailer, in buildings 1002D, 1002B and at relay table, gun table and exit table; starting cable terminations

- Laser transport:

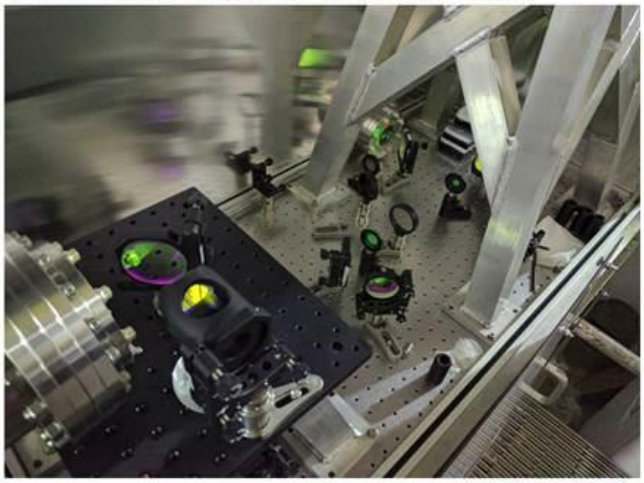
  - secured into final position the transport tube through the RHIC wall (T. Shrey, Survey Group)
  - installed work platform at relay table (D. Phillips et al)
  - installed the relay and gun optical table enclosures
  - laser exit table enclosure fabrication in progress
  - received and installed all custom mirror mounts (from Central Shops, design by S. Bellavia and B. Meier)
  - completed relay table optics setup (including that for CeC laser)
  - completed optics setup on gun table
  - completed laser alignment (using low-power diode laser) from the laser trailer to the gun table
  - dressed in cables for laser control (still need to terminate)
  - starting hookup of devices for laser control (mirror motion control, power meters, cameras etc.) to the network
  - laser remaining laser transport tube between gun table and gun-to-booster vacuum chamber to be installed when cleanroom area is opened and work area is accessible
  - final laser alignment (into gun-to-booster vacuum chamber to cathode then to laser exit table) to be completed thereafter and after vacuum gate valve opened

1002F laser table shelving during construction

Relay table enclosure with laser transport pipes to LEReC and CeC



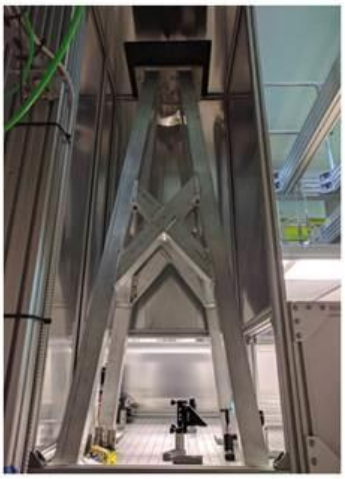
View inside relay table enclosure during LEReC and CeC laser alignment using diode lasers



Gun table enclosure

Gun table enclosure

Gun table mirror mount



FEBRUARY, 2017

- Administration:

  - Standard Operating Procedure (SOP) for LEReC and CeC lasers completed (reference: http://www.c-ad.bnl.gov/esshq/snd/opm/Ch23/23-07.PDF)
  - laser interlock test in 1002F completed
  - laser-related ASSRC checkoff list items completed

- Laser development:

  - completed construction of laser amplifier (main amplifier and all pre-amplifiers)
  - completed development of 1002F laser diagnostics including measurements of
    - pulse train duration using an ultrafast diode and scope
    - optical spectrum of the laser beam (around the central wavelength) using an optical spectrum analyzer
    - rf spectrum to characterize the mode-locked signal and its 704 MHz sideband using an ultrafast diode, RF amplifier and RF spectrum analyzer
    - laser pulse duration using autocorrelator
  - nearing completion of the high-power Pockels cell, intensity control and crystal pulse shaping setups

- Laser transport:

  - awaiting final laser alignment (into gun-to-booster vacuum chamber to cathode then to laser exit table) to be performed after bake-out and vacuum gate valve opened
  - began measurements of long-term laser pointing stability between 1002F trailer and gun table, 1002F trailer and relay table

- Laser integration:

  - continuing cable terminations for remote control and diagnostics (mirror motion control, power meters, cameras etc.)
  - continuing hookup of laser control and diagnostics devices to the network
  - developing associated pet pages for online viewing, control and logging
  - preparing for system test of timing control and connection to LEReC MPS system

MARCH, 2017

- Laser development: completed construction of laser proper including integration of the Pockels cell, intensity control and temporal shaping crystals

- Laser transport:

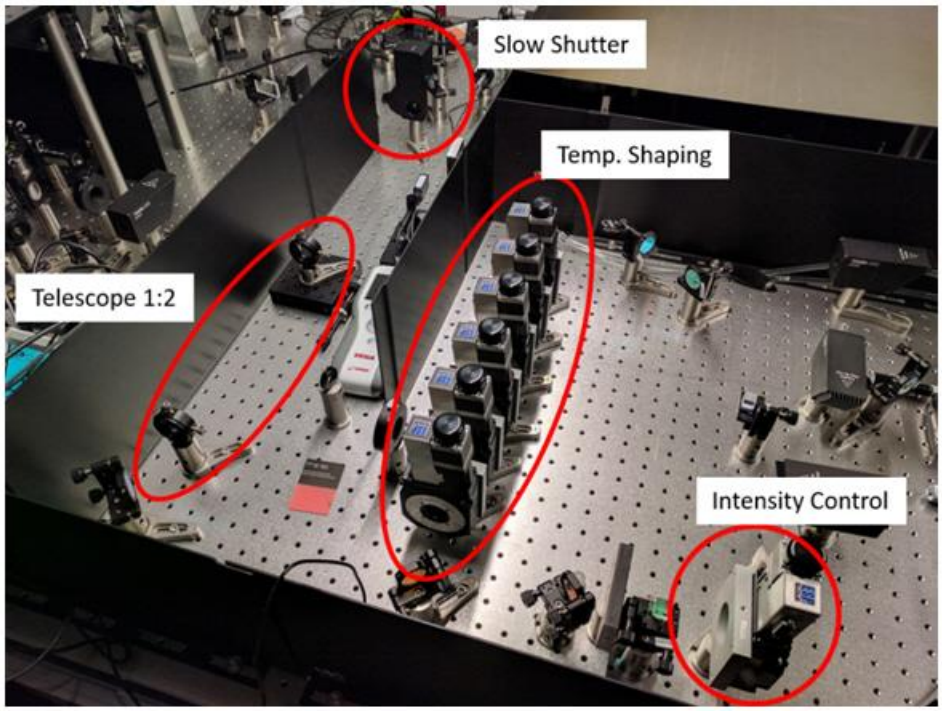
  - completed laser transport installation (final transport pipe between gun table and LEReC beamline)
  - installed and commissioned laser exit table
  - performed laser alignment (03/09/17) from laser trailer→ relay table → gun table → in-vacuum entrance mirror → puck in cathode holder → in-vacuum exit mirror → laser exit table first with a (low power) alignment laser, then with the green fiber laser. At next opportunity (04/05/17), verified alignment after including a telescope to control the fiber laser divergence to produce a small (~ 3 mm) laser spot diameter at the vacuum window

- Laser integration:

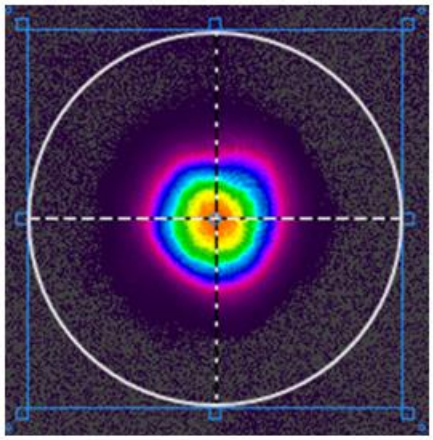
  - fabricated and installed feedthrough panels for relay and gun tables
  - continued cable terminations for remote control and diagnostics (mirror motion control, power meters, cameras etc.)
  - continued hookup of laser control and diagnostics devices to the network
  - continued development of associated pet pages for online viewing, control and logging
  - completed fabrication and started testing of EOM and Pockels cell driver chasses
  - executed partial system test of timing control and connection to LEReC MPS system (slow shutter control)
  - coordinating work in laser trailer with CeC operations (class IIIB CeC laser is located in same trailer)

- Published "Generation of 180 W average green power from a frequency-doubled picosecond rod fiber amplifier", Z. Zhao et al in Optics Express, Vol. 25, Issue 7, pp. 8138-8143 (2017), https://doi.org/10.1364/OE.25.008138

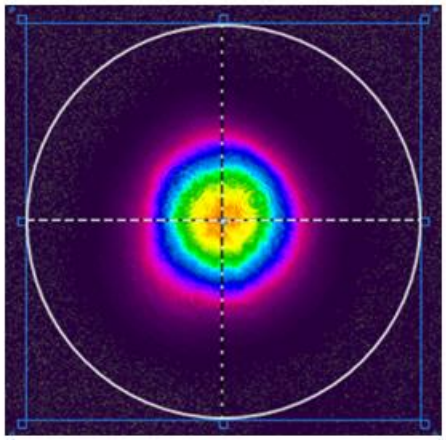
Final laser components added on optical table in laser trailer



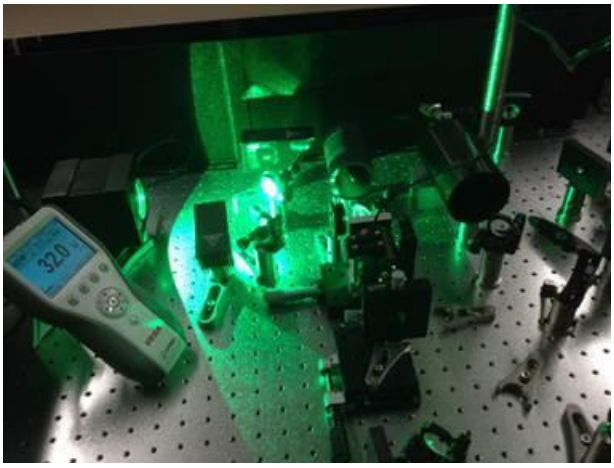
Laser image after crystal stacking



Laser image after telescope



Photograph of (small portion of fiber laser installation) operating at conditions for first LEReC electron beams.



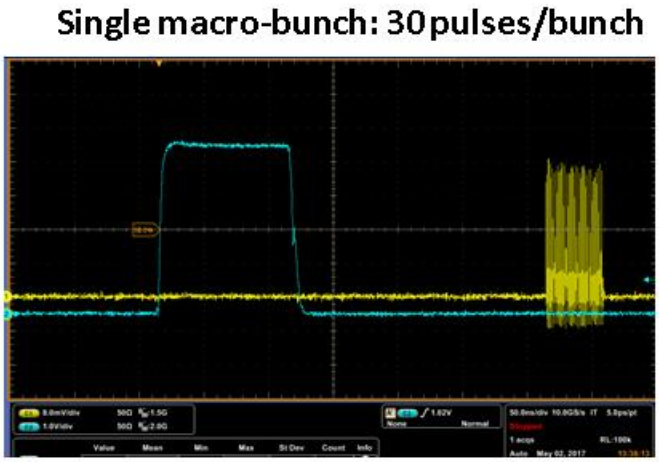
Photograph of fiber laser exiting vacuum chamber at location of laser exit window.

APRIL, 2017

- Laser development:

- synchronized laser oscillator to new externally supplied 704 MHz timing reference from Control System, as needed to synchronize generated electron beams with instrumentation and RHIC beams
- commissioned electro-optic modulator (EOM) using newly supplied externally 9 MHz reference signals for macro-pulse generation / 704 MHz pulse suppression
- commissioned Pockels Cell, including on/off controls, to allow selection of desired number of macro-pulses

- Laser development: demonstrated diverse pulse structures (example photo, left) and as required for first electron beam generation (photo, right) consisting of ~30 pulses:



- Laser development: continued laser characterization measurements, demonstrated extinction ratio of 1: 2E5 (5E-6), began sensitivity studies - started logging of environmental factors – temperature and humidity – in the laser trailer and in all optical enclosures comprising the laser transport

- Laser transport: done

- Laser integration:

  - commissioned EOM and Pockels cell driver chasses (designed and fabricated by K. Mernick and M. Costanzo)
  - commissioned fast shutter (for leakage current suppression) and slow shutter (for suppressing laser beam on demand)
  - continued cable terminations for remote control and diagnostics located at the gun and relay tables and in the laser trailer (laser exit table completed earlier)

- completed installations and developed Controls interfaces for gun table motion control including 4 linear actuators for mirror positions (horizontal, vertical, pitch and yaw), 1 linear actuator for laser spot size control in the final-focusing telescope
- developed associated pet pages for online viewing, control and logging

- planned installations in progress (gun table): camera for virtual cathode, local laser power measurement including flip mirror, filter and aperture wheels
- planned installations in progress (relay table): camera for laser alignment monitoring, local laser power measurement
- planned installations pending (laser trailer): intensity control (half-wave plate), flip mirror (for power measurements, expert-only motion controls (such as for rotational adjustments in the crystal stacking used in producing the 80 ps long micropulses)
- planned installation pending: laser position feedback with measurements on the gun table, actuators in the laser trailer

- Worked with BNL Media and Communications Office on a press release to accompany publication ("Generation of 180 W average green power from a frequency-doubled picosecond rod fiber amplifier", Z. Zhao et al in Optics Express, Vol. 25, Issue 7, pp. 8138-8143 (2017), https://doi.org/10.1364/OE.25.008138) and for a DOE NP Highlight article

MAY, 2017

- Laser operation:

- generated first electron beams using green fiber laser on 5/5/17
- commissioned laser-related inputs to machine protection system
- supported routine operation 09:00 – 21:00 weekdays starting 5/12/17
- resolved minor commissioning issues (underrated chiller fuse, communications issue with local laptop)
- delivered 10 W to cathode, ~ 15 pC/bunch and up to 100 macropulses

Laser and electron beam measurements, 6/2/17
pink: photodiode (PD) measurement of laser pulses (~ 80 ps of ~ 700 MHz pulses delivered in 9 MHz packets) measured on the laser table in the laser trailer
green: PD measurement showing pulses delivered to the cathode - also measured in the laser trailer
yellow: fast current transformer (FCT) measurements at the DC gun
blue: FCT measurements at the electron beam dump

- Laser integration:

- installed at the gun table: camera for virtual cathode, local laser power measurement including flip mirror, filter and aperture wheels
- installations at the relay table: camera for laser alignment monitoring

- installed in the laser trailer: intensity control (half-wave plate), flip mirror (for power measurements)
- developed associated pet pages for online viewing, control and logging

- planned installations pending (laser trailer): expert-only motion controls (such as for rotational adjustments in the crystal stacking used in producing the 80 ps long micropulses)
- planned installation pending: laser position feedback with measurements on the gun table, actuators in the laser trailer
- planned evaluation pending: use operating experience to determine if cascaded position feedback is required (e.g. laser trailer to relay table + relay table to gun table)

- Continuing summer shutdown planning for laser-related work including:

  - completion of installations for remote diagnostics (if not already done)
  - development and delivery of improved temperature control in laser trailer; continue evaluation of component temperature coefficients
  - laser trailer improvements (class 1 laser table enclosure with slow N2 or dry air purge, additional temperature and humidity monitors)
  - development of laser MPS (including remote monitoring of chiller flow and power)
  - development of measurement-based alarms and integration of alarms, with response instructions, into Main Control Room's AlarmDisplay
  - evaluation of spares inventory (oscillator, chillers, etc.)

- Reviewing laser-related safety protocols for different operational modes based on experience to date
- Updated JAFs (Job Assessment Forms) for Collider Accelerator Support staff and LEReC operators in preparation for future 24/7 laser operations

JUNE, 2017

- Laser operation: supported operations with typically ~ 10 W to cathode, 10-50 pC/bunch (max 130 pC/bunch) with ~ 80 bunches per macrobunch and increasing total current (number of macrobunches)

- Laser integration:
  - developed pet pages for relay table camera control to be used for remote alignment of high power laser
  - installed Piezo controllers in the laser trailer for remote alignment of laser using position measurements from gun table
  - commissioned high-power laser power meter and flip mirror
  - planned evaluation pending: determine if cascaded position feedback is required (e.g. laser-to-relay table + relay-to-gun table)
  - planned installations pending: motion controls for rotational adjustments in the crystal stacking for macropulse generation

- Laser developments:
  - installed high bandwidth photo diode to better resolve 704 MHz structure
  - for CW operation, developed laser intensity feedback and prepared its integration into the LEReC MPS system
  - for CW operation, evaluated possible failure modes - procured and installed flip mirror and laser beam dump (for event of failure of above-mentioned intensity feedback)
  - for CW operation, began characterization of high-power-related thermal lensing in the crystal stacking used to generate macropulses; simulated and evaluated alternative approaches to mitigate effects (of laser spot size variation with laser power)

- Developed and implemented enhanced laser-related safety protocols in preparation for CW laser operations

- Continued summer shutdown planning

- Coordinated with Access Controls group to automate effective laser lockout (integration into PASS) for future operations

- Started procurement of high priority spares

JULY, 2017

- Laser operation: supported pulsed beam operations with typically ~ 10 W to cathode, 10-50 pC/bunch (max 130 pC/bunch) with ~ 80 bunches per macrobunch and increasing total current (number of macrobunches); prepared for CW operations, supported beam operations with CW beams starting 08/01/17

- Laser developments for CW operation:
  - installed flip mirror and high power laser dump; integrated flip mirror control into LEReC machine protection system (MPS)
  - installed half-wave plate needed for changing between pulsed and CW operation
  - installed EOM (including HV driver); established initial turn-on and intensity control procedures; integrated EOM HV driver input from MPS
  - installed thermal lensing compensation (telescope installed between stacking crystals); demonstrated 3W at gun table with 80% transport
  - enabled remote control via pet pages for the above (flip mirror, half-wave plate, telescope)

- Laser integration:
  - started integration of LEReC laser controls into LEReC timing manager
  - continued trouble-shooting environmental problems with repeatability of mirror actuators (which had tested fine, long-term in bench tests earlier)
  - planned evaluation pending: cascaded position feedback, rotational control of stacking crystals

- Completed one-on-one training of CAS and LEReC operators involved in laser shutdown and LOTO procedure; continued laser safety related planning for the longer term (including integration of laser state into Access Controls) and IRR preparation (with ESSHQ)

- Continued procurement of laser system spares

AUGUST, 2017

- Laser operation: supported operations providing both pulsed and CW beams for up to 2 shifts per day through end of this year's commissioning run (08/11/17)
  - pulsed beam laser parameters: ~ 10 W to cathode, 10-50 pC/bunch (max 130 pC/bunch) with ~ 80 bunches per macrobunch and increasing total current (number of macrobunches) as before
  - CW beam laser parameters: ~ (3-4) W at gun table

- Laser integration:
  - resolved problem with repeatability of mirror actuators (identified influence of environmental noise at ~20 kHz on the limit switch control signals, implemented low-pass filters in signal processing), placed purchase orders for remaining systems
  - planned evaluation/installations pending: cascaded position feedback, rotation control of stacking crystals

- Shutdown activities
  - developed plan for laser-trailer air conditioning upgrade (will decouple optical and infrastructure support rooms and upgrade air conditioning systems for both areas)
  - started systematic measurements to characterize high-power CW laser operation
  - started development of laser intensity feedback (to compensate for QE-drift and temperature-related effects)
  - started development of rf-to-laser phase and laser phase monitors
  - prototyped laser MPS (chiller water temperature, water flow, etc.), placed purchase orders
  - continued procurement of laser system spares

- Laser safety
  - continued coordination with Access Controls for laser-related interlock extensions
  - coordinated with BNL LSO and C-AD ESSQ on upcoming DOE-IG "audit of lasers at selected sites"