The Pointing Stabilization Algorithm for the Coherent Electron Cooling Laser Transport at RHIC*

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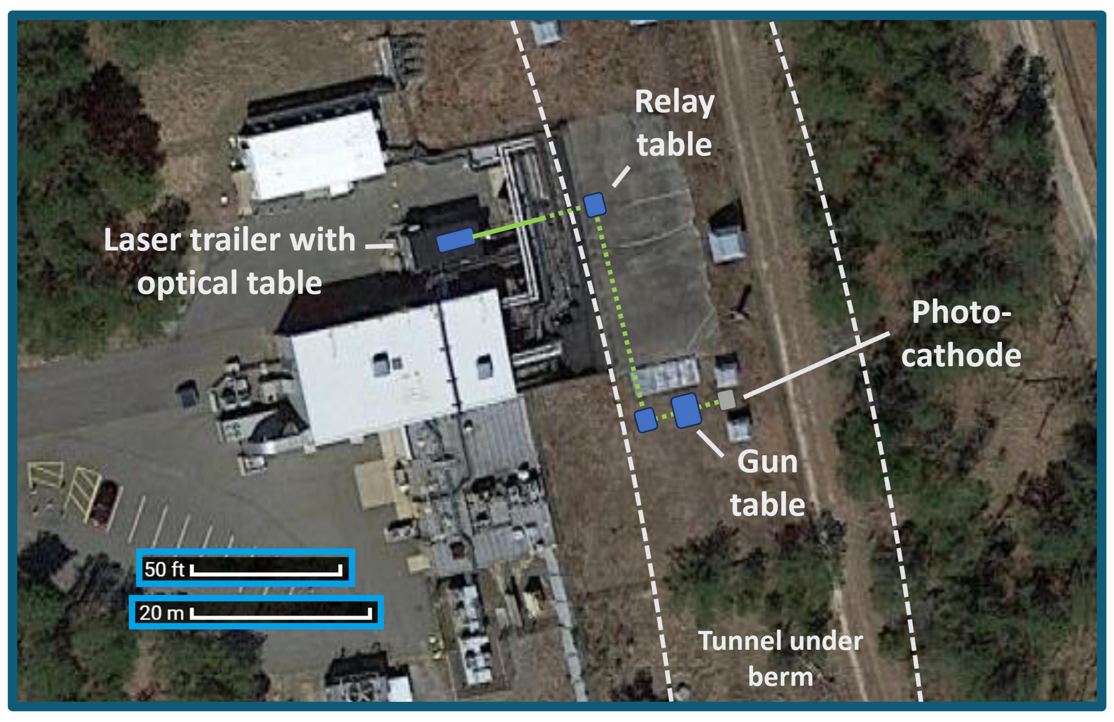
Abstract

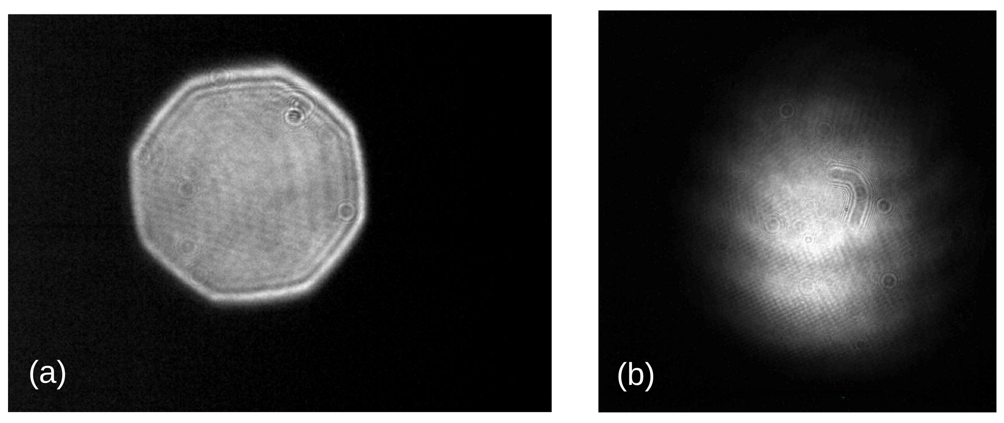
Coherent electron cooling (CeC) is a novel cooling technique being studied in the Relativistic Heavy Ion Collider (RHIC) as a candidate for strong hadron cooling in the Electron-Ion Collider (EIC). The electron beam used for cooling is generated by laser light illuminating a photocathode after that light has traveled approximately 40 m from the laser output. This propagation is facilitated by three independent optical tables that move relative to one another in response to changes in time of day, weather, and season. The alignment drifts induced by these environmental changes, if left uncorrected, eventually render the electron beam useless for cooling. They are therefore mitigated by an active "slow" pointing stabilization system found along the length of the transport, copied from the system that transversely stabilized the Low Energy RHIC electron Cooling (LEReC) laser beam during the 2020 and 2021 RHIC runs. However, the system-specific optical configuration and laser operating conditions of the CeC experiment required an adapted algorithm to address inadequate beam position data and achieve greater dynamic range. The resulting algorithm was successfully demonstrated during the 2022 run of the CeC experiment and will continue to stabilize the laser transport for the upcoming run. A summary of the algorithm is provided.



Above: Aerial view showing a rough layout of the CeC laser transport.

Environment and Setup

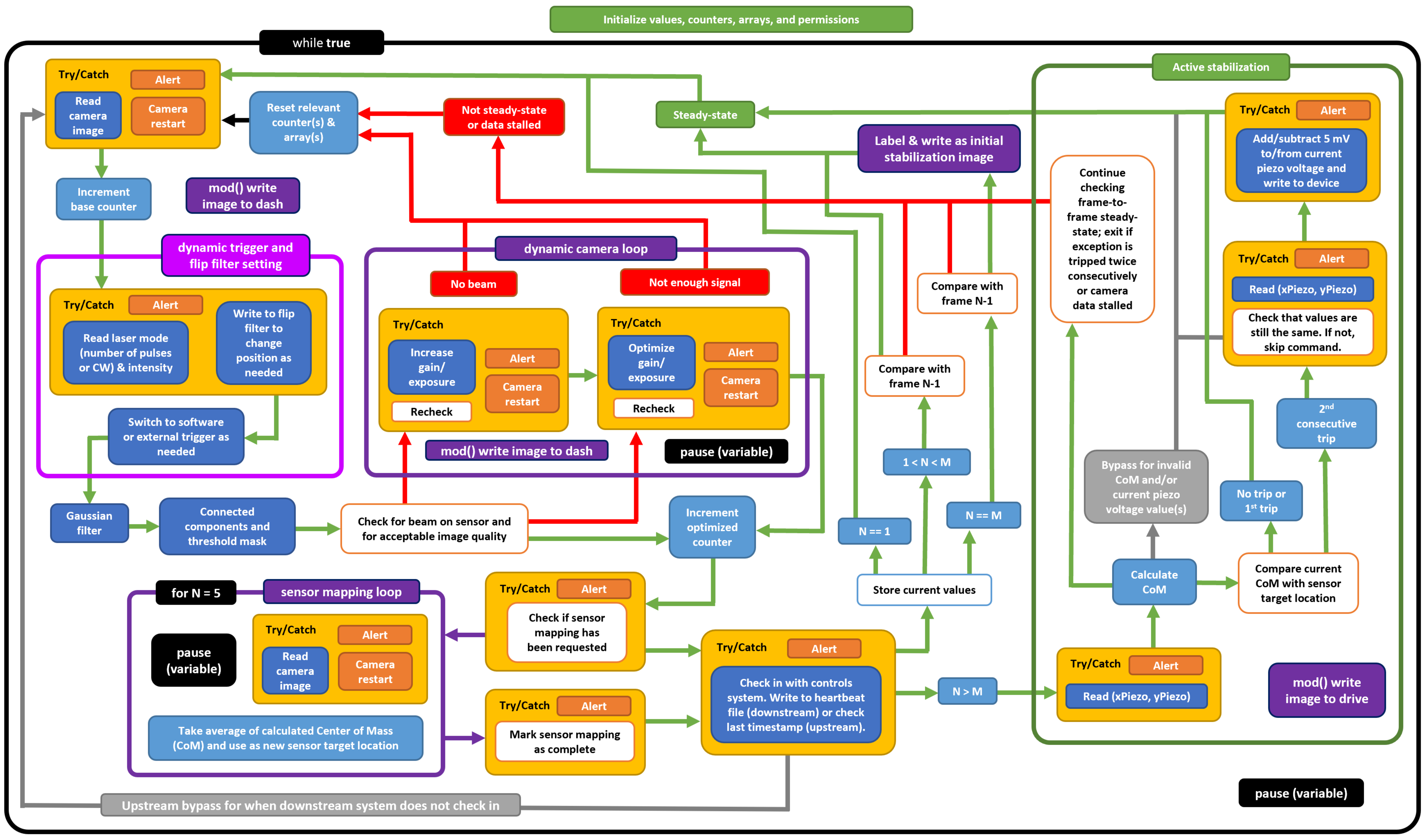
- Laser beam is generated in the laser trailer. **First piezo steering mirror is located here.**
- Beam travels through evacuated tube to reach the relay table, just inside tunnel. **First camera, with flip filter, is located here.** Then, also on the relay table, **second piezo steering mirror is located here.**
- Beam travels down another evacuated tube to reach the gun table. **Second camera, with flip filter, is located here.** Beam then proceeds to photocathode. Total propagation distance is about 40 meters.
- A dedicated camera system is used instead of the Operations cameras due to issues with valid center of mass and dynamic range.
- A MATLAB script creates a feedback loop between the trailer piezo mirror and the relay table camera (relay system). Another creates a feedback loop between the relay table piezo mirror and the gun table camera (gun system).



Right: (a) Laser beam profile on the gun table as viewed by the Operations camera. The beam is greatly expanded to provide as uniform a profile as possible on the aperture; thus, center of mass does not provide enough information about movement behind the aperture. (b) Laser beam profile on the gun table as viewed by stabilization camera.

Script

- Written in MATLAB
- Relay (upstream) system and gun (downstream) system operate independently and on different bandwidths. Gun system is configured to be at least twice as fast as relay system.
- Values are read from Controls System over a network connection except for heartbeat file, which is located on the computer hard drive
- mod() write means only certain iterations perform stated action
- The dash is an internet-based viewer for the stabilization system cameras, which are on a local network
- The dynamic camera loop detects whether or not there is a beam on the sensor and then optimizes the image quality if it is; increasing exposure time is preferred over increasing gain due to noise characteristics
- Script automatically switches between external trigger (achieves camera minimum of ~50 μsecs of exposure time) to software trigger (implements up to 5 secs) to handle different laser operating modes
- Dynamic range is further extended by presence of flip filter (~1.5OD) whose position is controlled by the script

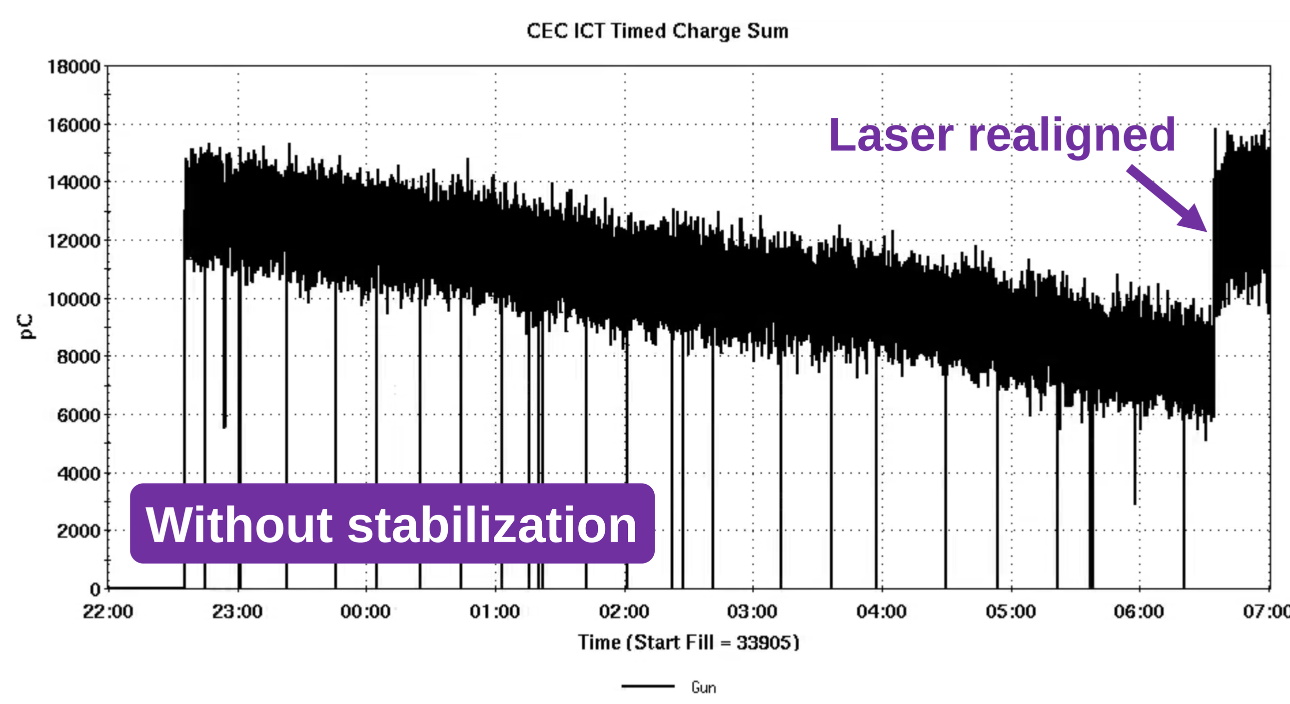


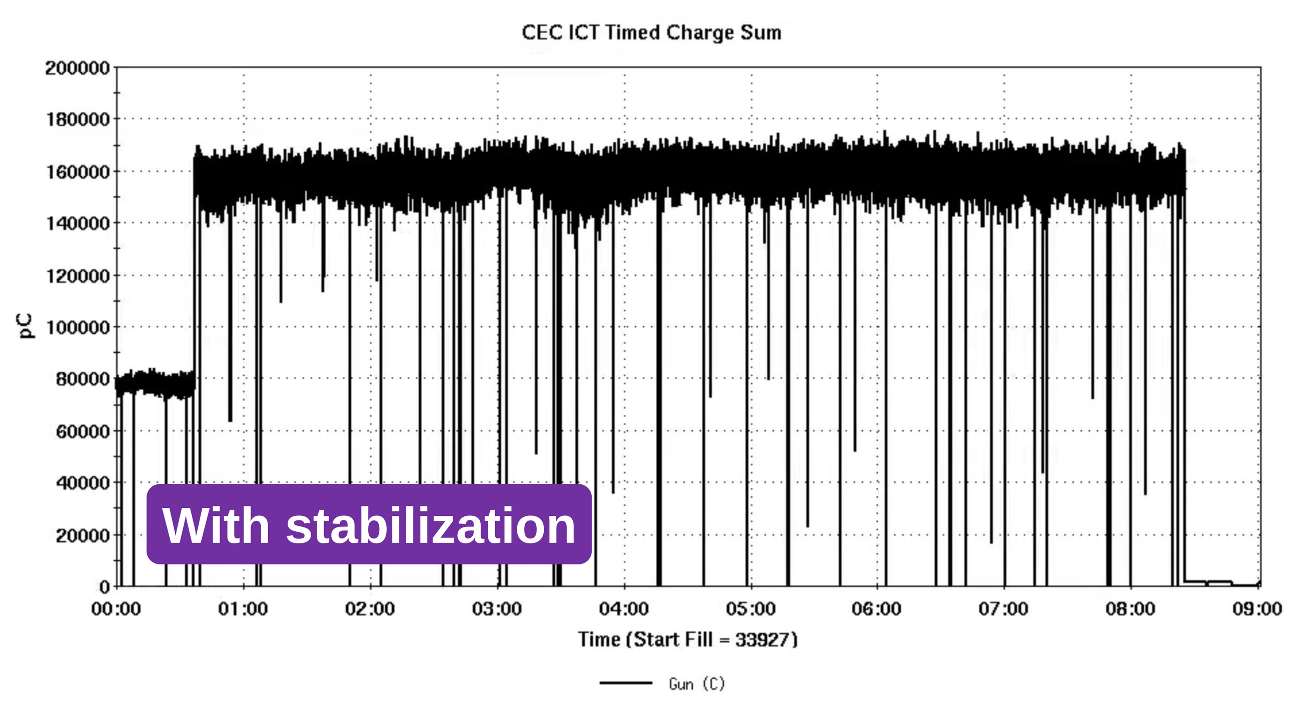
- Once camera image quality and steady-state conditions are met, script automatically enters active stabilization
- System adds/subtracts 5-mV to/from existing piezo settings if excursion threshold is tripped twice consecutively
- MATLAB's weighted centroid function (Image Processing Toolbox) is used for the calculation
- Stabilization automatically disengages when exception thresholds are met
- Pause length is not allowed to drop below 1.5 seconds for the gun system. This forces the bandwidth of the overall system, and it only responds to slow drifts in the laser trajectory.

Above: Flowchart for both relay and gun system scripts (differences noted where appropriate).

Results

Since center of mass information from Operations cameras does not reflect laser beam movement well, electron beam charge stability is the main metric for laser position stability on the photocathode. Without the systems on (left), there was a 60% drop in summed charge over 8 hours. With the systems on (right), stability was maintained to within ±10% for 8 hours. However, since measured charge depends on many factors, such as quantum efficiency variations, this only puts an upper bound on the laser spot instability.





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* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.
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