Gamma Bang Time/Reaction History Diagnostics for the National Ignition Facility (NIF) Using 90º Off-axis Parabolic Mirrors

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Gas Cherenkov detectors (GCD) have been used to convert fusion gamma into photons to achieve gamma bang time (GBT) and reaction history measurements. The GCD designed for Omega used Cassegrain reflector optics in order to fit inside a ten-inch manipulator. A novel design for the National Ignition Facility (NIF) using 90º Off-Axis Parabolic (OAP) mirrors will increase light collection efficiency from fusion gammas and achieve minimum time dispersion. The broadband Cherenkov light (from 200 to 800 nm) is relayed into a high-speed detector using three parabolic mirrors. Because light is collected from many source planes throughout the CO2 gas volume, the detector is positioned at the stop position rather than an image position. The stop diameter and its position are independent of the light-generation location along the gas cell. The current design collects light from a 100-mm diameter by 500-mm-long gas volume. Optical ray tracings demonstrate how light can be collected from different angled trajectories of the Compton electrons as they fly through the CO2 gas volume. A cluster of four channels will allow for increased dynamic range as well as different gamma energy threshold sensitivities.

52.70.La, 29.40.Ka, 42.15.Eq, 07.60.-j, 07.85.-m

1. Introduction

A CO2 gas Cherenkov detector was built for the OMEGA laser system to record high-energy gamma rays emitted during deuterium-tritium experiments.1,2 A new optical model has been created to optimize the Cherenkov light collection from these Cherenkov gamma ray detectors. For broadband light sources, reflective optics are preferred because of chromatic aberrations. OAP mirrors can relay broadband Cherenkov light; however, using parabolic mirrors with imaging applications have advantages and limitations3. Because the Cherenkov light is emitted from many source planes within the gas volume, the corresponding intermediate images also span a long range. However, the stop position does not change. Thus, the final detector is placed at a stop and not at an image plane. As a result, we are using the parabolic mirrors as a nonimaging system.

Figure 1 shows gamma rays emitted from a point at the Target Chamber Center (TCC) located 5800 mm away from our Be converter. Some of the gammas produce Compton electrons within a converter, here shown leaving the converter with an angular spread of ±2 degrees. With enough gas pressure and enough energy, an electron track will produce Cherenkov photons, here shown leaving the moving electron with an angular spread of ±1 degrees. The optical system is optimized with a ±3-degree acceptance cone. The chief ray of the Cherenkov photon cone does not follow the electron trajectory. Instead the chief ray is aimed at the center of the detector. Thus, as the electron travels and produces Cherenkov light, slightly different cones of light are collected by the detector. For this optical model, the stop for the gammas and the Compton electrons is at TCC, whereas the stop for the Cherenkov light is at the detector.

The OAP system is being designed to improve the gamma sensitivity over prior GCD systems and to allow better shielding of the detector (e.g., photomultiplier tube) to reduce sensitivity to direct line-of-sight gammas. The layout of three OAP mirrors also delays the Cherenkov light for a longer time, enabling the detector to recover from other gammas and electrons that hit it.
Scattering is a concern with reflective optics used for ultraviolet light. The higher the angle of reflection (e.g., grazing incidence), the lower the scatter losses will be. Surface figure is not critical, but a special post-polishing treatment will be necessary to reduce surface roughness.

2. Optical design constraints

When using relay optics (mirrors or lenses) one must be aware that as the object position moves, the image position also moves, but the stop position never moves. In addition, the stop diameter does not change because it is related to the full angle cone of source light. Therefore, the stop position is the best place to locate the high-speed detector that is collecting light from many source planes. The object range over which relay optics can transfer the light is limited. Too much object range can cause the intermediate image to move to undesirable locations (on the wrong side of an optical element). The stop is tilted by 60 degrees, and the amount of image plane tilt (≤60 degrees) depends on the OAP mirror rotations.

The ±3 degrees acceptance cone causes the first stop position to be too large for the high-speed detector. So, another pair of OAP mirrors is used to relay and demagnify the stop diameter into the detector. The optical model uses four OAP mirrors to optimize performance. However, the last OAP is not shown (Figure 1) since it is located after the detector position.

The Lagrange optical invariant defines the system light throughput. Working backwards through this system, the high-speed detector has a diameter of 1 cm. The detector’s collection angle is artificially limited to ±30 degrees, because later a streak camera that is limited to a 30-degree acceptance angle will replace the detector. We wish to collect light from a 10-cm-diameter converter, so the acceptance angle of Cherenkov light is 3 degrees within the gas.

GCD-1 provided our first recording of gammas at the Omega laser facility. Ray trace analysis shows that the GCD-1 and the OAP system have almost identical light collection efficiencies at the same distance from TCC. The OAP system collects over a 500 mm long gas volume, whereas the GCD-1 collects light over 900 mm.
3. Complete NIF GBT diagnostic

Figure 2 shows a package of four OAP systems. By varying the gas pressure, different gamma energy thresholds will be measured. Several optical fibers (each with different time delays) will add extra signals to the data record. These fibers introduce their signals at the first stop position.

![Diagram of NIF GBT diagnostic](image)

**Figure 2.** The complete NIF Gamma Bang Time diagnostic will consist of four channels, each at a different gas pressure. Two fibers add time delayed signals to the data record. Other fibers (not shown) bring calibration and dry run signals into the first Stop position.

We are still improving on the quad design to gather more light. Specifically, we are designing the next version to allow light collection up to 60 degrees at the photomultiplier tube (PMT) and to capture >±3-degree acceptance cone. The flexibility of the quad design allows for maximum shielding of the PMT and its Mach-Zehnder modulator for conversion to an optical signal to be transmitted down an optical fiber. For calibrations and dry run operations, the system accommodates two fiber optic calibration light sources at the first stop position; one source sends light to be reflected off the converter and the other to the detector. A variable aperture is placed at the intermediate image plane so that dynamic range studies can be done without affecting the spatial uniformity of the light hitting the detector’s surface. All data are sent to a remote recording station by optical fibers that mitigate issues with electromagnetic interference produced during a NIF experiment. The fibers also preserve signal bandwidth.

References