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Progress on the NIF

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Progress on the National Ignition Facility

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ABSTRACT

The National Ignition Facility (NIF) is a 192 beam Nd-glass laser facility presently under construction at LLNL. When completed, NIF will produce 1.8 MJ, 500 TW of ultraviolet light making it the world's largest and most powerful laser system. NIF will be the world's preeminent facility for performing experiments for Inertial Confinement Fusion (ICF) and High Energy Density Science (HEDS). The Project, begun in 1995, is over 80% complete. The building and the beam path are essentially complete. Nearly all of the functionality of the laser subsystems has been demonstrated. NIF has demonstrated on a single beam basis that it meets its performance goals and shown the laser's precision and flexibility for pulse shaping, pointing, and timing. Beam conditioning techniques, important for target performance, were also demonstrated. The focal spot can be tailored to user specifications using phase plates. Temporal smoothing using smoothing by spectral dispersion (SSD) as well as polarization smoothing was demonstrated. The remaining work is mostly to complete the optics and install them in the beam path and complete the utilities. Presently, eight beams have been activated through the amplifiers and spatial filters to the switchyard wall. Over 150 kJ of 1ω light has been produced with just 4% of the NIF capacity activated. The Project is scheduled for completion in 2009 and plans have been developed to begin ignition experiments in 2010. This talk will provide NIF status, the plan to complete NIF, and the path to ignition.

Keywords: laser, ignition, experiments, facility

1. INTRODUCTION

The National Ignition Facility (NIF) is a large laser system presently under construction at Lawrence Livermore National Laboratory (LLNL). It consists of 192 high-powered Nd-glass laser beams that are converted to 0.35 μm light and focused on to sub-centimeter size targets. When completed in 2009, the laser will produce up to 1.8 MJ, 500 TW of ultraviolet light for target experiments. This is more than sixty times the energy presently available for target experiments. This will allow experiments studying high energy density science (HEDS) to access regimes of temperature, density, and pressure not previously achievable in the laboratory. These regimes of HEDS are of interest for understanding astrophysical and planetary phenomena as well as for weapons science. The preeminent mission of NIF is to achieve fusion ignition in the laboratory by Inertial Confinement Fusion ((ICF). The facility has been designed and specified to attain ignition by indirect drive although its construction does not to preclude ignition using the direct drive approach. Ignition will be the first step to using ignition for HEDS as well as demonstrating feasibility for fusion energy applications.

This paper reports on the progress on NIF and plans to begin ignition experiments. Section 2 presents a description of the facility, schedule for completion, and Project status. Section 3 discusses the performance of the system to date. Section 4 discusses the schedule and preparation for beginning ignition experiments in 2010.

2. NIF PROJECT STATUS

The NIF Project is the construction of the facility, laser equipment, and target area for performing HEDS experiments including ignition. The layout of the facility is shown in Figure 1. It consists of two laser bays, four capacitor areas, two laser switchyards, the target area, and the building core. In addition, there is an Optics Assembly Building and a Diagnostics Support Building. Details of the laser and building designs can be found elsewhere.[1,2] The laser is configured in four clusters of 48 beams, two in each laser bay. Each cluster has six sets of eight beams called a bundle that is the fundamental beam grouping in the laser bay. In the switchyard, each bundle is split into two sets of four beams, or a quad, with one quad from each bundle directed toward the top and bottom of the target chamber. The

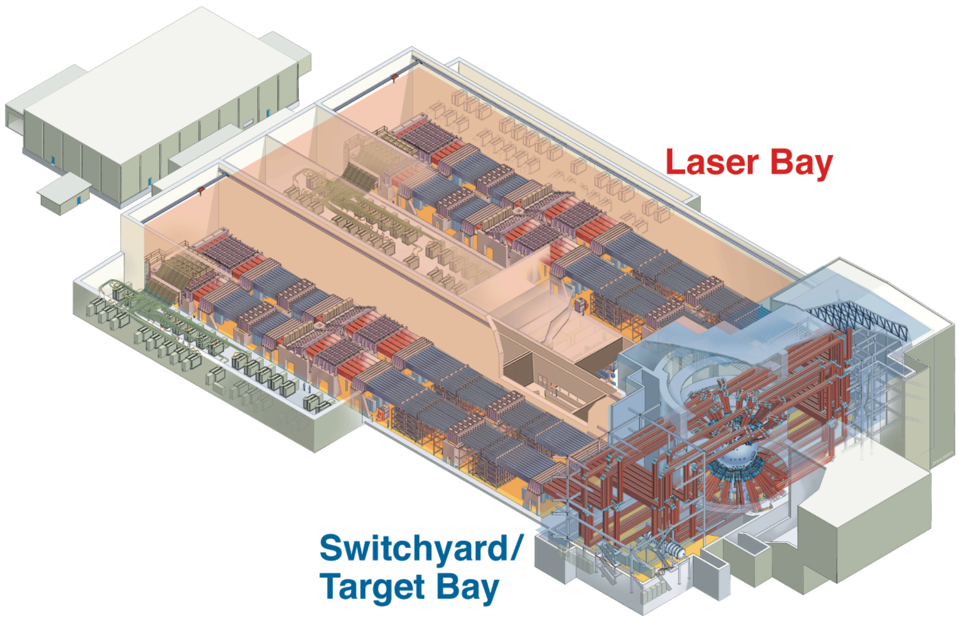
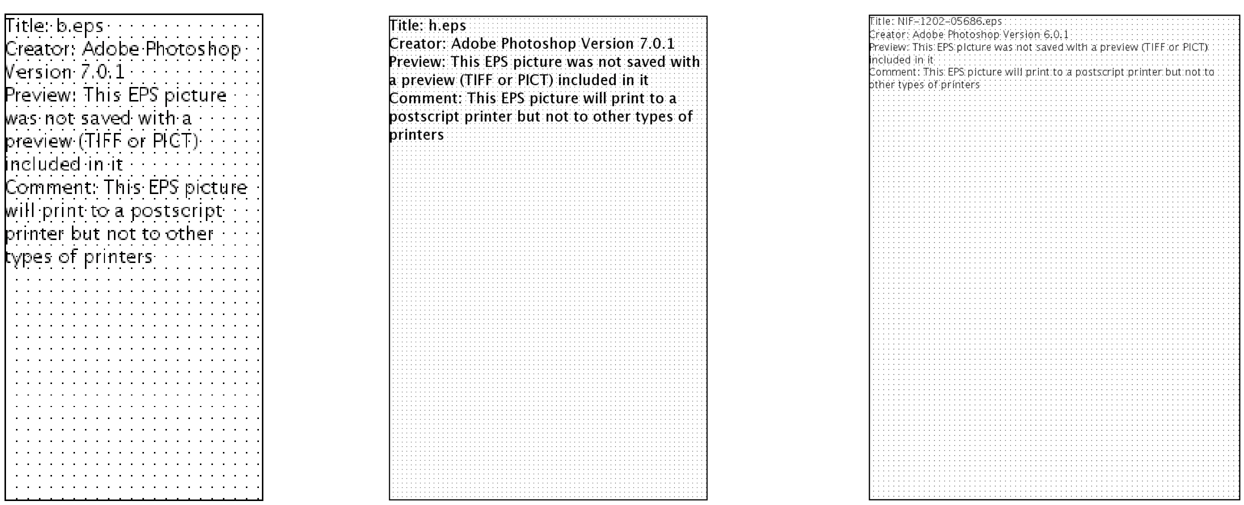


Figure 1: Layout of the National Ignition Facility

irradiation geometry for an indirect-drive target is 24 quads through the top laser entrance hole and 24 quads through the bottom laser entrance hole.

The Project began in 1995 and is scheduled for completion in 2009. The construction of the conventional facility was completed in 2001. The beam path structures that contain the optical equipment were completed in 2003. Presently, the optical and electronic equipment is being assembled and installed to complete the beam path. Initially, the equipment is being installed and activated to complete the 1ω beam path in the laser bay. Beginning in 2007, installation and activation will begin of the transport optics and final optics in the switchyard and target bay to complete the beam path through to conversion to 3ω and final focusing in the target chamber. At Project completion, the beam lines for all 192



(a) (b) (c)

Figure 2: Examples of optical LRUs.are (a) laser slabs, (b) flashlamp cassettes, and (c) plasma-electrode Pockels cell

beams will be installed and half of the laser will be operational producing 500 kJ of 0.35 μm light. The other half of the laser will become operational after Project completion.

The optical equipment is being installed as line replaceable units (LRU). The optics are installed in their assembly hardware, aligned, and characterized before being installed in the beam path. Once installed, the LRU is ready to be activated for use. Examples of optical LRUs are shown in Figure 2. Optical LRUs can be over two meters tall and weigh over 100 kg. They are installed using robotic transporters. Initial installation and activation is the same process as is planned for maintaining the facility for operations. There are over 5700 optical and electronic LRUs in NIF. Presently, over 1000 LRUs, or nearly 20%, have been installed.

3. LASER PERFORMANCE

Although NIF will not be completed until 2009, four of the NIF beams were activated to the target chamber in 2002 as NIF early light (NEL) and operated for experiments into 2004. Target experiments were performed in four areas: hydrodynamics, equation of state, laser- plasma beam propagation, and hohlraum physics.[3,4,5,6] One of the beams could also be directed to the Precision Diagnostic System (PDS) for laser performance experiments at full aperture and energy. NEL allowed the functionality and operability of the system to be tested from the master oscillator to the final optics and target irradiation. Over 400 system shots were performed during NEL.

Laser performance tests explored the entire operating range of the system. The laser demonstrated that it could meet all of its functional requirements and primary criteria on a beamline basis. The energy versus power parameter space explored for both 3ω (0.35 μm) and 2ω (0.53 μm) operation is shown in Figure 3. In square pulse experiments, up to 10.4 kJ of 3ω light was produced in a 3.5 ns pulse. 11.4 kJ of 2ω light was produced in a 5 ns pulse. For the full NIF at 192 beams this would extrapolate to 2.0 MJ and 2.2 MJ of 3ω and 2ω light, respectively, exceeding the NIF design requirement. Beam quality in these experiments was demonstrated to be very good with the intensity distribution in the near field shown to be uniform to better than 80%. At short pulses, peak power of 4 TW was demonstrated in a 200 ps Gaussian pulse at 3ω light.

Ignition experiments require a highly shaped pulse with stringent pointing and timing requirements. Pulses with contrast ratios of greater than 100:1 were demonstrated exceeding the 50:1 requirement. An example of the pulse shaping capability is shown in Figure 4. This pulse is an example of an ignition design pulse by Haan, et al.[7] The 3ω pulse is 21

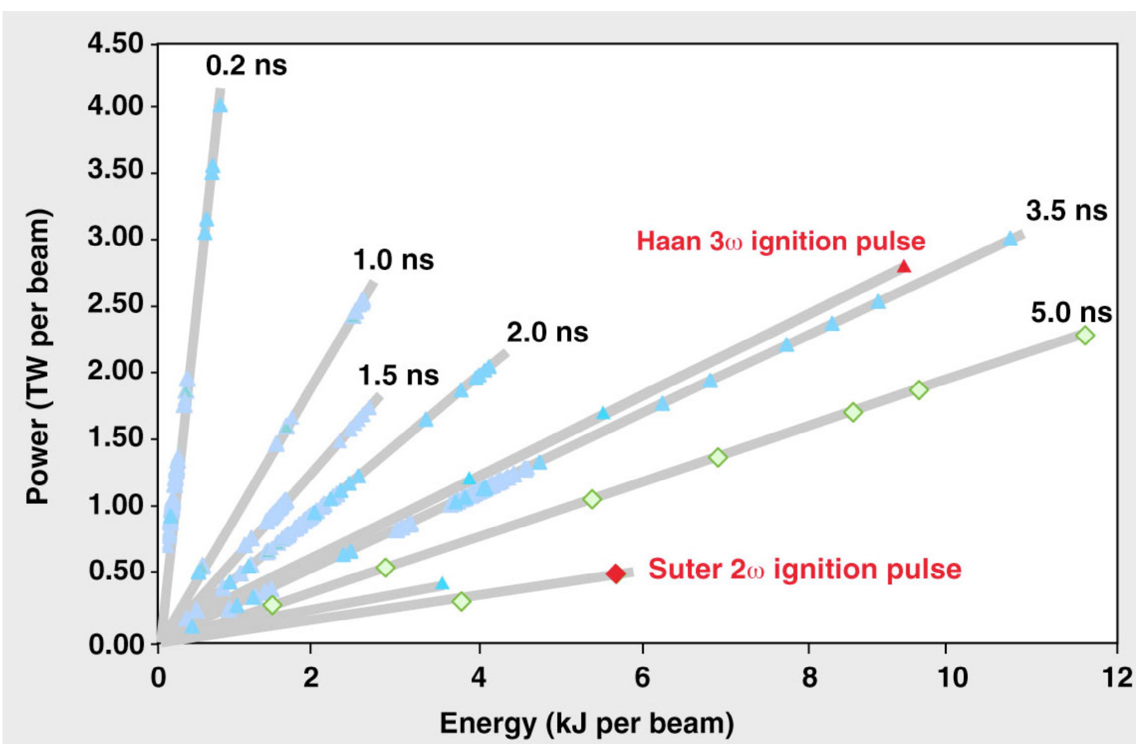


Figure 3: NIF beamline performance at 3ω (triangle) and 2ω (diamond) for square pulses from 1 ns to 5ns, Gaussian pulses at 200 ps and ignition design shaped pulses

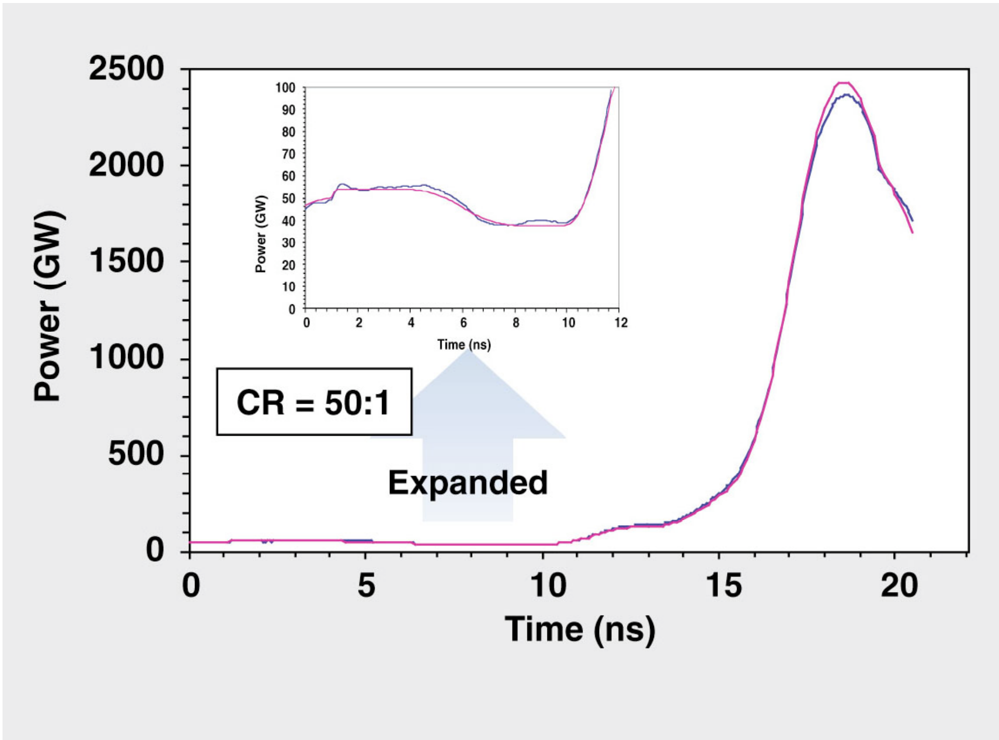


Figure 4:Example of a shaped ignition pulse with a 50:1 contrast ratio. The red curve is the predicted pulse shape and the blue curve is the measured output pulse in PDS.

ns long and has a contrast ratio of 50:1. Similarly, a 2ω pulse from an ignition design by Suter, et al.[8] was also demonstrated. In Figure 4, the predicted pulse shape is plotted along with the measured pulse shape for the Haan ignition pulse. The difference between the predicted and measured pulse shape is better than 8% RMS averaged over 2 ns indicating NIF can meet its beam balance specification. NEL experiments also showed beams can be timed to better than 10 ps and pointing to 30 µm accuracy, both better than NIF design specification.

Ignition experiments also require laser beam conditioning to control laser-plasma interactions and beam propagation. Beam conditioning performance specified by the users was also been demonstrated in PDS experiments. Figure 5 shows the measured change in the far field beam spot when smoothing by spectral dispersion (SSD) is implemented.[9] A NIF beam without beam conditioning is shown in Figure 5(a). Most of the energy is contained within a 200 µm diameter spot. The structure in the beam is the speckle pattern of a nearly diffraction limited beam. Adding a continuous phase plate (CPP) to the beam broadens the spot producing a more uniform central region as shown in Figure 5(b).[10] The spot size can be designed to produce spot sizes desired by the user including oval spots to minimize intensities through laser entrance holes. When bandwidth is added using SSD, the speckle pattern is modulated as shown in Figure 5(c). PDS experiments on NEL demonstrated SSD performance with bandwidth specified by users for control of laser plasma interactions. In addition, beam conditioning by polarization smoothing[11] is being implemented at NIF by adding polarization rotation on two of the beams in each Quad.

After completion of NEL, the laser production equipment is being installed in the laser bay to complete the 1ω portion of the laser to the switchyard wall calorimeters. The operation of a bundle of eight beams has been demonstrated. During the operations tests of this bundle, over 150 kJ of 1ω light was produced on one shot. This is the highest energy produced from a pulsed laser system using only 4% of the NIF capability.

4. PLANS FOR IGNITION

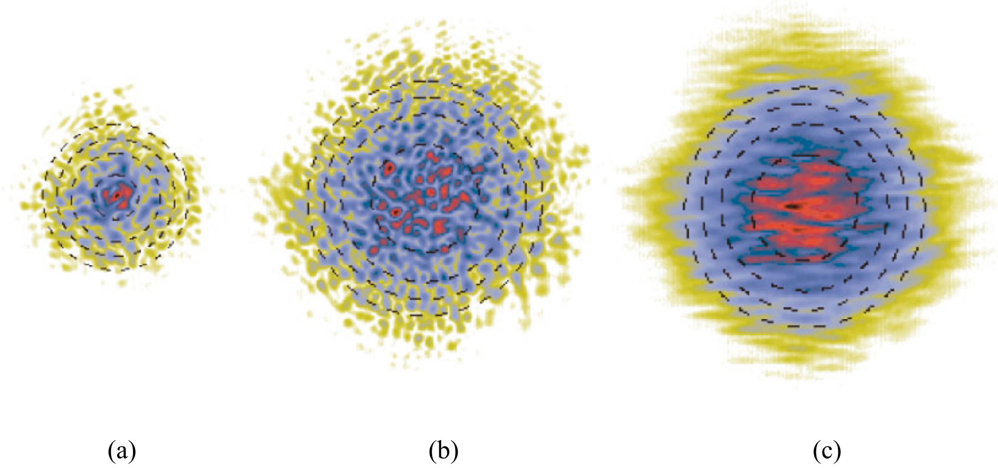


Figure 5: Effect of beam smoothing on far field distribution with the unconditioned spot (a), spot with CPP (b), and spot with CPP and SSD (in horizontal direction) (c).

Significant progress has been made in understanding the physics and improving target designs since the NIF Project began in 1995. The original NIF ignition design calculated to ignite and produce 10-15 MJ of yield with 1.8 MJ of laser energy.[12] The design balanced risk between laser-plasma interactions and hydrodynamic instabilities and had an adequate safety margin above ignition threshold. Presently, target designs are predicted to ignite and produce similar yields with 1 MJ of laser energy. A schematic of the present design is shown in Figure 6. The capsule is Be, or CH, with a graded doping. The hohlraum is made of a mixture of materials and has laser entrance hole shields. The lower energy and beam smoothing has reduced the expected losses from laser-plasma interactions. These changes, as well as improved physics modeling, have enabled target designs to be developed at the lower energy. In addition, the targets now use fill tubes for filling with liquid DT. This results in an easier and less expensive target fielding strategy.

An integrated plan has been developed for fielding ignition experiments including the physics, technology development,

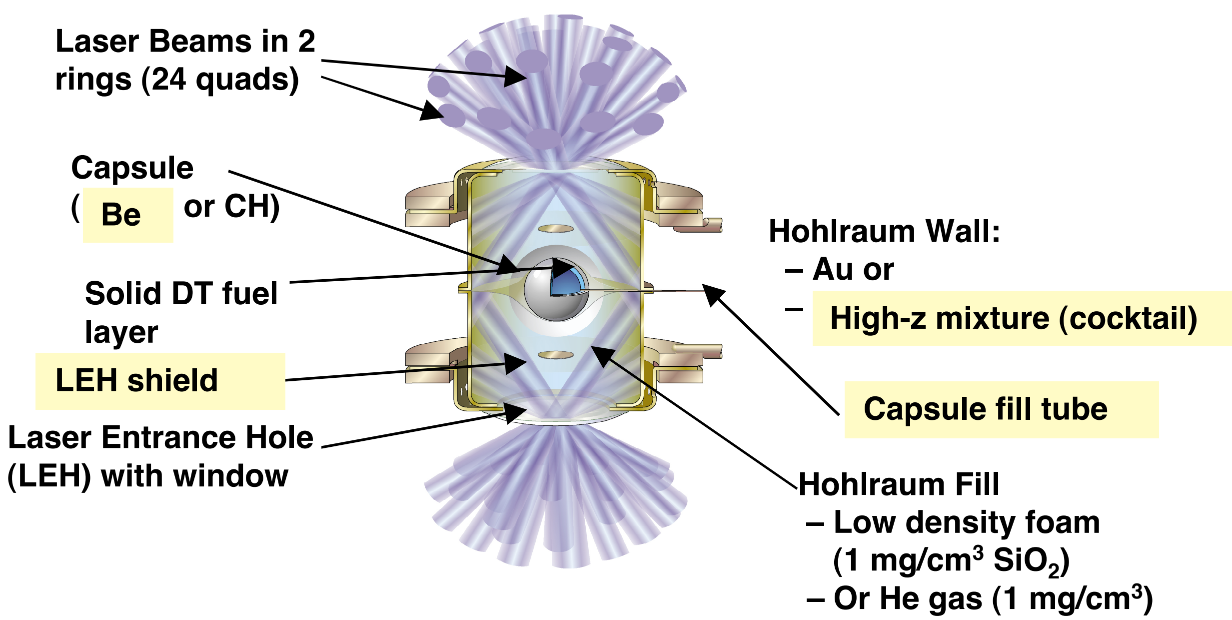


Figure 6: Schematic of an ignition target

and user equipment. The goal of the plan is to begin ignition experiments in 2010. In addition to the target physics, the major elements of the plan are diagnostics, user optics, target fabrication, cryogenic target fielding, personnel and equipment protection systems (PEPS), and preparation for operations. The plan, called the NIF Ignition Campaign (NIC), has a scope, schedule, and budget integrating all of these elements. The NIC is a national effort with participation by Los Alamos National Laboratory, University of Rochester's Laboratory for Laser Energetics, General Atomics, and Sandia National Laboratories as well as LLNL. A top level schedule for the NIC is shown in Figure 7.

The experimental plan is an aggressive campaign to begin ignition experiments by September 2010. The initial ignition experiments will be testing the 1 MJ design. The 1 MJ design is consistent with the Project completion criterion and activation plan that will be completed in 2009. Tuning campaigns are planned before beginning ignition experiments to optimize the radiation drive, radiation symmetry, ablator design, and shock timing. It is expected that these campaigns will require around 100 system shots. As laser operations are refined the energy can be increased allowing ignition experiments at higher energy in the following years.

The NIC schedule shows the plans of a number of subsystems and hardware in the areas of targets, cryogenics, user optics, diagnostics and PEPS that are required for ignition experiments. Targets develop the production capability for ignition targets as well as targets for the tuning campaigns. This includes the capsules, hohlraums, and other features required for the experiments. Both Be and CH capsules are being developed with surface smoothness meeting ignition design requirements. Hohlraums having high Z mixtures are also being developed. Cryogenics are the cryogenic systems needed to field cryogenic DT layered targets. The systems include the DT filling system, the layering and characterization system, and the cryogenic manipulator in the target chamber. User optics are the optics to deliver the conditioned beam with the desired focal properties. These include the user requested CCPs, plates for polarization smoothing, and disposable debris shields for protecting optics from target debris. Diagnostics are the diagnostics needed for the ignition experiment as well as the tuning campaign. A number of these diagnostics have already been fielded on NEL experiments. New diagnostics include the implosion diagnostics and new imaging capabilities. A plan is being developed for managing the diagnostics and other target area systems in the yield environment of ignition experiments. PEPS are the equipment to manage contaminated waste from beryllium, tritium, uranium, and other materials. It also includes management of neutron yield through monitoring and shielding. Although most of the above subsystems use

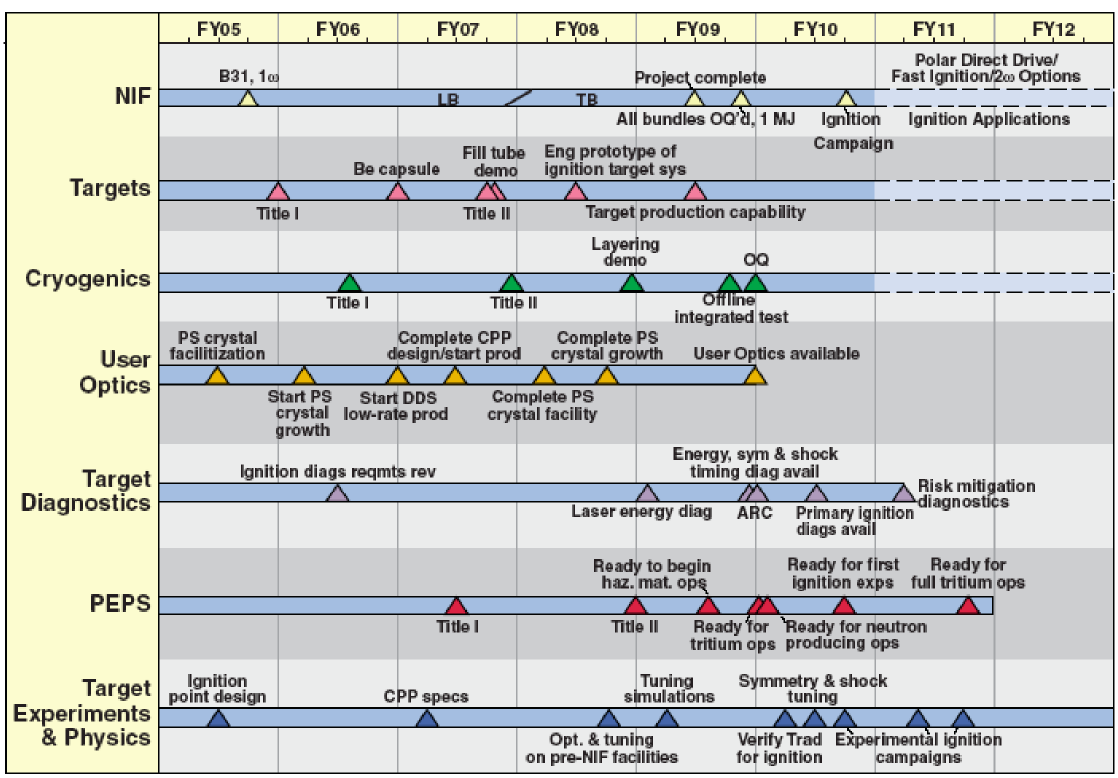


Figure 7: Top level schedule for the National Ignition Campaign showing the major elements of the plan.

developed technology, the challenge will be making them operational in the target area during Project completion and commissioning.

5. CONCLUSION

In conclusion, The NIF Project and Program are on track to begin ignition experiments in 2010. The Project is presently installing optical and electrical LRUs for completing the 192 beampaths. The first bundle of eight beams have been completed in the Laser Bay and produced over 150 kJ of 1ω light making NIF the world's most energetic pulsed laser system. Four of the beams have been operated to the target chamber for laser performance and user experiments. Over 400 system shots were done demonstrating NIF operability. The laser performance experiments demonstrated that NIF meets all of its functional requirements and primary criteria on a beamline basis. They also demonstrated NIF performance of user desired beam smoothing capability. The NIC campaign is in place that integrates all of the systems needed for ignition with a plan to begin ignition experiments in 2010.

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