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# Novel schemes for inertial confinement fusion (ICF): fast ignition and shock ignition

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## Abstract

1. **Basic principles of ICF** (recall): spherical shell target, implosion and central spot ignition. Disadvantage – high shell implosion velocity, excitation of the Rayleigh-Taylor instability (RTI). Characteristic figures for laser and target parameters.

2. **Alternative ignition schemes** – separation of ignition and implosion. Advantage – lower implosion velocity, better control of RTI. Problem: smaller power amplification, higher laser intensity, nonlinear LPI, energy transport by energetic (non-thermal) particles. Two possible solutions: either off-center isochoric (fast) ignition with electron or ion beams, or central shock-driven non-isobaric ignition with a minor power amplification. Reference to the Nuclear Fusion issue 2014.

3. **Fast ignition** – off center hot spot. Basic principles, hole boring and energy transfer to energetic particles. Main issues: efficient laser-particle beam conversion – energy and angular distribution, beam transport – collimation and controlled energy deposition. The electron beam conversion is efficient, but the transport is very difficult to control. In contrast, for ions the transport is easier to control but the conversion efficiency is low and required laser power and intensity could be very high (> few PW and > $10^{19}$ – $10^{21}$ W/cm$^2$).

   *Electron fast ignition*: the ignition criterion in terms of the target and beam parameters – the compressed core density and the ignition areal density, the electron stopping range and energy (1-2 MeV), the beam energy needed for ignition (~ 20 kJ) and the time available.

   Mechanisms of electron acceleration with relativistic laser pulses (JxB acceleration dominates) bunching of accelerated electrons, energy distribution. Physical mechanisms of strong electron divergence and utilization of self-generated and external magnetic fields for electron collimation. Where we are now – summary of the experimental data.

   *Ion fast ignition*: main problem is the energy conversion efficiency. Mechanisms of ion acceleration – TNSA and RPA, possibility of ion focusing in the core, using carbon ions and low density targets. Examples of recent experimental achievements and plans.

4. **Central spot ignition driven by a strong shock**. Advantage – accessible power (< 500 TW): possibility to use existent lasers, the power amplification technique and the existent and partially formed hot spot. Major issue – high shock pressure implies too high laser intensities, nonlinear LPI, control of the hot electron preheat.

   Three phases: launch of the shock with a laser spike, propagation of the igniting shock in the shell – pressure amplification and collision with the primary shock, hot spot ignition with a shock. Ignition criterion in a converging shock. Definition of the temporal window for ignition and required laser intensity.

   Numerical (PIC) simulations of LPI in the extended hot corona corresponding to shock ignition: SRS and SBS, competition with the TPD, suppression of strong back scattering and cavitation. Generation of hot electrons with SRS. Hot electron characteristics.

Ablation pressure generation with a hot electron beam. Comparison with the laser-driven ablation pressure. Time of shock formation and its strength, energetic efficiency. Comparison of a mono-energetic and broad energy distribution.

Experiments on the strong shock excitation and the planar and spherical geometry. Demonstration of the correlation SRS and hot electrons, hot electron temperature and energy repartition. Formation of a strong shock by a combination of the laser and electron energy deposition. Maximal achieved pressure and perspectives for the Gbar pressures for material studies.

Toward integrated shock ignition simulations – multiscale modeling. Insufficiency of the ray tracing model for the laser energy absorption. The thick ray model for nonlinear LPI, equation for the ray curvature, implementation of RPP and temporal smoothing technique with Gaussian beamlets. Cross beam energy transfer with thick rays. Implementation of the hot electron generation due to the resonance absorption, SRS and TPD. Comparison with the experiments. Example of an integrated modeling of shock ignition: absorption repartition, hot electron energy deposition, role of hot electrons in the shock generation and preheat.