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Fast ignition by laser driven particle beams of very high intensity

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Anomalous observations using the fast ignition for laser driven fusion energy are interpreted and experimental and theoretical results are reported which are in contrast to the very numerous effects usually observed at petawatt-picosecond laser interaction with plasmas. These anomalous mechanisms result in rather thin blocks (pistons) of these nonlinear (ponderomotive) force driven highly directed plasmas of modest temperatures. The blocks consist in space charge neutral plasmas with ion current densities above 10^{10} A/cm^2. For the needs of applications in laser driven fusion energy, much thicker blocks are required. This may be reached by a spherical configuration where a conical propagation may lead to thick blocks for interaction with targets. First results are reported in view of applications for the proton fast igniter and other laser-fusion energy schemes. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2748389]

I. INTRODUCTION

New aspects of laser driven fusion energy were opened since laser pulses in the order of picosecond duration and powers of terawatts (TW) up to few petawatts (PW) have been available. The aim is the fast ignition (FI) of deuterium-tritium (DT) fuel for controlled fusion. Initially, only the interaction of laser beams was considered for FI,[1] but modifications followed for using laser produced intense proton beams for fast ignition (PFI)[2] irradiating (DT) precompressed to about 1000 times the solid state. Using 10 TW-ps laser pulses for producing very high intensity 5 MeV electron beams, ignition of nearly uncompressed solid DT of larger volume controlled fusion reactions with gains above 10^4 may be possible.[3] We present here experimental and theoretical results how laser driven very high intensity DT ion beams[4] may strongly improve the PFI. This is applicable also when using the here considered *ion beam* ignition similar to the *electron beam ignition* scheme of Nuckolls *et al.*[3] based on space charge neutral plasma blocks[4] (plasma bunch or pistons[5]) with ultrahigh ion current densities.

The crucial new aspect with the space charge neutral ion beams of ultrahigh ion current densities[4] is given by an experimentally unexpected effect of skin-layer nonlinear-force acceleration of plasma blocks.[6–10] These drastically anomalous observations have long been expected theoretically,[7] but the conditions were buried under the enormously complex phenomena usually observed. In contrast, the rather unique few anomalous experiments permitted a transparent simplification of the facts. Since the acceleration of the ions is by the nonlinear force, the observed blocks (pistons) are highly directed and have a comparably low temperature. This may be of interest for fusion reactions in plasmas[11,12] at comparably low densities similar to the before mentioned fast ignition by electron beams.[3]

Attention should be given first to the very rich but nevertheless confusing results from TW-PW laser pulses of picosecond duration at interaction with plasmas. Laser intensities above 10^{19} W/cm^2 resulted in all kinds of relativistic effects,[13] producing beams of intense accelerated electron jets with energies up to several 100 MeV,[14] highly charged ions with energies in the GeV range,[15] gamma bursts with subsequent nuclear reactions—even for elimination of long-lived nuclear waste,[16] electron-positron pair production,[13] and other unexpected relativistic phenomena. A special observation is the generation of intense electron jets at oblique incidence on targets even with lower intensities with and without suppression of laser pre-pulses (one crucial point to be considered in the following),[17] also in view of the Nuckolls-Wood scheme.[3] The measured relativistic effects of intense laser produced electron beams were due to very high electric fields in the Debye layer as a double layer effect[18,19] and where the 10 MeV electrons were essential in particle-in-cell simulations.[20]

On the other hand, there are very transparent and not complicated observations at very wide focus interaction at

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lower laser intensities[21] as needed for direct drive laser interaction for conditions in the experiments of the National Ignition Facility (NIF). In contrast to this, however, at such low laser intensities below 10^{15} W/cm^2 at very wide focus interaction with rather smooth iodine laser beams, the generation of plasma jets could not be avoided.[22] Even then, the global observation of the ion-mass independent axial velocities indicated a nonlinear (ponderomotive) force acceleration, while the radial acceleration was definitely thermal, as seen from the strong mass dependence.[22]

In contrast to this pluralism of observations, a few anomalous experiments appeared to be very different, with, however, clear and transparent properties. In this paper, the essential properties of this anomalous mechanism with its comparably uncomplicated results are clarified first. These can be transparently understood as the plasma block (piston) generation in contrast to the mentioned highly diffuse pluralism of the usual phenomena of PW-ps laser plasma interaction. Furthermore, for the application to fusion energy, it is of interest as to how these highly directed low temperature plasma blocks (pistons) may be transformed into blocks with a large thickness. This is evaluated for the first time by using the geometric convergence of laser driven spherical plasma shells. Indeed, this work about the skin layer acceleration by nonlinear forces (SLANF) is performed for the application to laser fusion. This nonlinear force acceleration follows mainly the scheme of plasma shells for fusion, where nearly all laser energy is converted into kinetic energy of directed motion of plasma,[23] to distinguish it from classical thermally determined ablation of plasma shells.[24] We focus then on the question of how these blocks can be transformed to such thicknesses that ion beam ignition for fusion[11,12] and a strong improvement of the proton fast ignition [2] may be achieved.

II. PLASMA BLOCK GENERATION

The new effect consists in the generation of plane geometry laser-plasma interaction,[7,25] in contrast to all the usual measurements where TW-ps laser pulses produced extreme relativistic effects in the irradiated plasmas.[13–20] Together with an interpretation of these differences, new theoretical and experimental facts are reported in preparation for further studies.

A. Sauerbrey's experiment with 300 fs-TW excimer laser pulses

This experiment by Sauerbrey[6] to measure the acceleration of plasma emitted against the laser light at irradiation of a solid target by the Doppler shift was rather unique. It was anomalous because nowhere before could such a Doppler shift have been detected in all usual experiments. The explanation of the measured acceleration by the nonlinear (ponderomotive) force is given here at the end of this subsection, with further details provided in the following subsections. The fact that such Doppler measurement was not possible before is simply due to the fact that in all usual interactions at sufficiently highly intense laser pules on a target, the unavoidable laser prepulse produced a plasma plume before the target where the relativistic dielectric interaction of the plasma with the laser front caused a bending of the front such that the beam was squeezed to a *diameter of about one wavelength*.[26] The laser beam reached such an extraordinary strong focusing which no optics system is able to achieve. The extreme intensity in the squeezed beam caused a nonlinear force[27] driven acceleration of the highly charged ions of MeV up to nearly GeV[28,29] energy moving into all directions, as explained in detail in Ref. 30.

The main difference in the experiments of Sauerbrey[6] was that the laser pulses he used were exceptionally clean, i.e., with a suppression of prepulses having a contrast ratio of 10^8 based on the Schäfer technique[31] using 300 fs dye laser pulses to be amplified in a laser pumped KrF medium to gain the TW pulse power. This was the first case in which the prepulses at target interaction with the usually following relativistic self-focusing was suppressed and a plane wave interaction of the laser beam of about 30 wavelength diameter with the target was possible. Only under these conditions, Sauerbrey measured an acceleration A_{exp} in a carbon plasma front by Doppler effect moving against the laser being produced by a 350 fs-TW KrF laser pulse at 3.5×10^{17} W/cm^2 of

$$A_{\text{exp}} = 10^{20}\ \text{cm/s}^2. \tag{1}$$

The laser intensity corresponds to an electric field

$$\mathbf{E}^2 = 2.9 \times 10^{15}\ \text{erg/cm}^3 \tag{2}$$

and a density $n_i m_i$ of the accelerated plasma layer of 5.4×10^{-3} g/cm^3 at the critical density is

$$n_i = 1.6 \times 10^{21}\ \text{cm}^{-3} \tag{3}$$

for C^{+6} ions at the krypton fluoride (KrF) laser frequency.

In the following, we will compare these results with the theoretically expected acceleration by the nonlinear (ponderomotive) force for the simplified plane geometry,[32] which implies the more transparent formulation of force densities as gradients of energy density that is identical to the simplified case with ponderomotive force density:[27,28,32]

$$\begin{aligned} f_{\text{NL}} &= -(\partial/\partial x)(\mathbf{E}^2 + \mathbf{H}^2)/(8\pi) = n_i m_i A \\ &= -(1/16\pi)(\omega_p/\omega)^2 (d/dx)\mathbf{E}^2. \end{aligned} \tag{4}$$

Assuming, for simplification, $dx = \Delta x = 10\ \mu$m and a swelling $S=2$ (the experiments at similar conditions later by Badziak *et al.*[7,9,25] for picosecond pulses resulted in $S=3.5$), we find the theoretical value in agreement with Sauerbrey's[6] measurement (1)

$$A_{\text{NL}} = 1.06 \times 10^{20}\ \text{cm/s}^2. \tag{5}$$

Applying this result to the accelerated plasma blocks of DT with a critical density at for $n_e = 10^{21}$ cm^{-3} and ion velocity above 10^8 cm/s, shows that the accelerated plasma block moving against the laser lights has an ion current density above

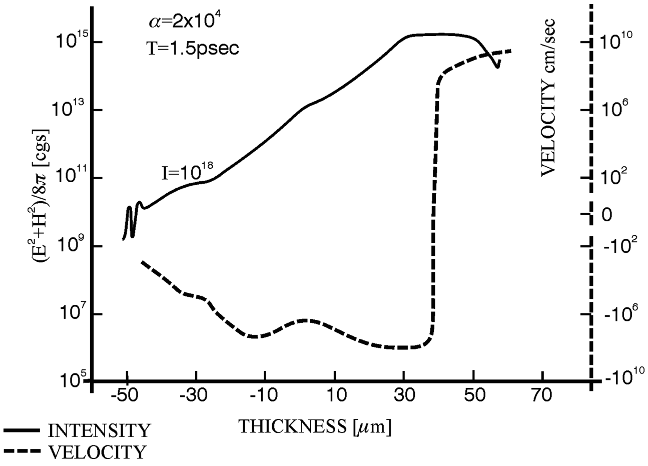

FIG. 1. Generation of blocks of deuterium plasma moving against the neodymium glass laser light (positive velocities v to the right) and moving into the plasma interior (negative velocities) at irradiation by a neodymium glass laser of 10^{18} W/cm^2 intensity onto an initially 100 eV hot and 100 μm thick bi-Rayleigh profile (see Fig. 10.17 of Ref. 32) with minimum internal reflection. The electromagnetic energy density $(\boldsymbol{E}^2+\boldsymbol{H}^2)/(8\pi)$ is shown at the time of 1.5 ps after the start of the constant irradiation for comparison with the results of Ref. 33.

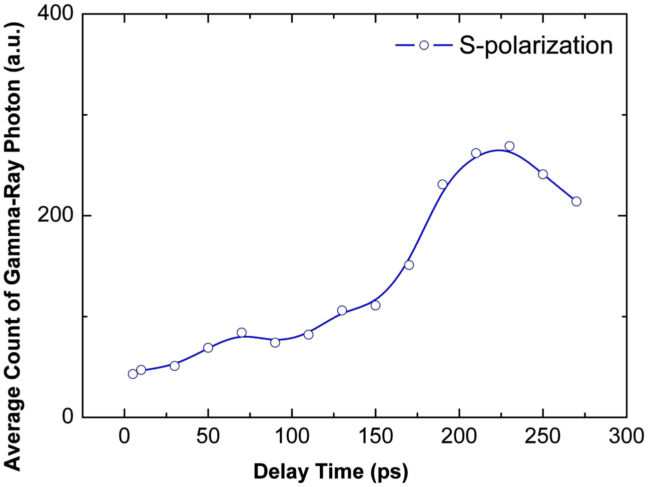

FIG. 2. (Color online) Emission of x rays by 10^{16} W/cm^2 irradiation of 300 fs Ti:sapphire laser pulses of contrast ratio 10^8 from a target at 45° incidence at s-polarization depending on the pre-irradiation by a time t_p of a similar lower power prepulse. At t_p of 200 fs, the generated plasma plume is dense enough to produce relativistic self-focusing with considerably high laser intensities in the target to increase the x-ray emission. At perpendicular incidence (Ref. 8), the sufficiently dense plume was established at 70 fs under the same conditions.

$$j = 10^{10}\ \text{A/cm}^2. \tag{6}$$

The plasma block is space charge neutral since the effective Debye length[32] is sufficiently smaller than the block thickness.

Computations of this type of a plane, one-dimensional plasma block motion at the laser intensities used by Sauerbrey[6] for laser pulses in the range of picoseconds was numerically calculated long before the experiment (see a combination of Figs. 10.18a and 10.18b of Ref. 32 for a neodymium glass laser intensity of 10^{18} W/cm^2 in deuterium plasma, and Fig. 1 here). A comparison with experiments was never possible before the experiments of Sauerbrey since all the other numerous experiments had no suppression of the prepulse to avoid relativistic self-focusing, and therefore no plane interaction fronts. The just given comparison of the measurement with theory, however, was possible only after the knowledge about the anomalous conditions realized after the results described in the following.[7]

B. Anomalously low x-ray emission measured by Zhang *et al.*

The next indication of a new effect was the anomaly in the measurement of x-ray emision by Zhang *et al.*[8] at interaction of TW-ps laser pulses. Usually it was observed in all the experiments of high intensity laser-plasma interaction, that high intensity x rays were emitted due to the relativistically squeezed extremely intense laser beam in the plasma[26] (see Chaps. 12.2 and 12.6 of Ref. 32). A necessary condition is that some prepulse of the laser produces a plasma plum in front of the target of at least one to two times the diameter. This even happens if the laser beam is defocused to a very large diameter.[22] The very high laser intensity in the shrunken beam causes not only the emission of MeV to GeV highly charged ions with remarkable angular dependence but also high intensity hard x rays.

The surprise was[8] that the interaction of the few TW-ps laser pulses focused to more than 20 wavelength diameter at a target did not produce the high x-ray emission as usual. The reason was that the laser beam had an enormous quality thanks to the techniques applied by Zhang *et al.*[8] Similar to the Schäfer[31] method used by Sauerbrey for the picosecond laser pulses,[6] the usually applied chirped pulse amplification method used by Zhang *et al.*[8] had a suppression of the prepulse by a contrast ratio of more than 10^8. In order to demonstrate this, Zhang *et al.*[8] separated a laser pulse of less than few percent power from the main pulse to be fired as pre-irradiation at varying times t_p to the target before the main pulse arrived. If t_p was 10 ps, nothing changed; the x-ray emission stayed on the low level. The same occurred for longer times up to 70 ps, but from then on suddenly the well known high x-ray emission has usually appeared.

It can be simply estimated that during the prepulse at 70 ps before the main pulse, a plasma plume with a depth of about two times the interaction diameter on the target was produced. This is just sufficient at critical density that the relativistic shrinking of the laser occurred.[26] What was discovered by Zhang *et al.*[8] was that the strong suppression of *the prepulse prevented the relativistic self-focusing* similar to the case of Sauerbrey,[6] but this was not explicitly realized before 2001. New measurements confirm the result[8] as seen in Figs. 2 and 3. In this case, comparable laser intensities of 10^{16} W/cm^2 similar to Ref. 8 were irradiated after a prepulse at varying times t_p was incident before the main pulse. Due to the needs of other experimental applications, the angle of incidence was not normal, but 45°, and the generation of the plasma plume due to the prepulse was similar to that in Ref. 8 because the generated plasma and electrons emitted from

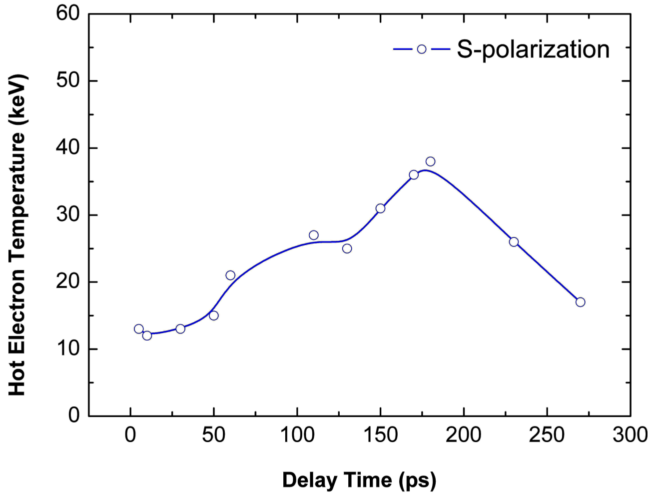

FIG. 3. (Color online) Measurements of the hot electron temperature on t_p as in the case of Fig. 2 with an increase at 200 fs.

the target were directed perpendicular to the plasma surface, as expected from the nonlinear force interaction process (see Chap. 8.2 of Ref. 32). Figures 2 and 3 are the results for s-polarization since the case of p-polarization is modified by resonance absorption (please note the effect of collisions; see Chap. 11.2 of Ref. 32) and is not comparable to the conditions of Ref. 8.

In Figs. 2 and 3, the high values of x-ray emission as well as of the high temperature of the hot electrons is reached at a pre-irradiation time of about 200 ps and not at 70 ps as at perpendicular incidence.[8] The reason is in the fact that the lateral plasma density in the plume is lower at 45° than in the perpendicular direction such that the relativistic generation of the self-focusing channel needs a longer time. It should be mentioned that the relativistic self-focusing within one to two times the beam diameter works at plasmas of nearly critical density occurs at laser intensities more than thousand times less than the relativistic threshold (see Fig. 12.4 of Ref. 32).

C. Anomalously low energies of emitted ions measured by Badziak *et al.* and skin layer acceleration

Measurements of the energy of the ions emitted against the laser beam from a target at irradiation of TW-ps laser pulses resulted—against all usual observations—in surprisingly low energies.[9] At the conditions of this experiment, copper ions of 22 MeV maximum energy would have been the result when relativistic self-focusing occurred as in all usual experiments. Instead, the ion energy was half the number of MeV only showing again the drastic anomaly of the effect. In order to compare with the usual observations, Badziak *et al.*[9] measured the ion emission at very same experimental conditions with 0.5 ns laser pulses, where the detailed results showed the usual behavior.

Again, it has to be underlined that Badziak *et al.*[9] had very clean picosecond laser pulses where in retrospect it can confirmed that the contrast ratio could be estimated to be 10^8 at least until less than 50 ps before the main pulse hit the target. A further anomaly was the observation that the *number of the fast ions* did not change when the laser power P varied by a factor 30. Well the energy of the fast ion was linear on P at constant focus conditions and laser pulse lengths.

These results were a final indication that there was a laser-plasma interaction over the whole plane of the focus area at the target of about 30 wavelengths diameter and the usually happening relativistic self-focusing was avoided. The suppression of the prepulse avoided the generation of a plasma plume before the target. This fact led to the conclusion that the laser interacted only in the constant volume of the skin layer of the plane plasma generated within some picoseconds at the beginning of the main pulse. On top, the measured velocities of the fast ions could only be produced by nonlinear force acceleration as known from the computations of this plane geometry shown in Fig. 1.[7]

This result of this skin layer acceleration by nonlinear forces (SLANF), was then in retrospect the confirmation of the measurements by Sauerbrey,[6] Zhang *et al.*[8] and that of Badziak *et al.*[9]

Further experiments were performed to confirm this conclusion parallel to detailed numerical simulations.[25] It was shown that the SLANF mechanism resulted in measured highly directed plasma fast ions, in clear contrast to the wide-angle ion emission at the usual relativistic self-focusing. SLANF generates a directed plasma block against the laser light and another block in the direction of the laser light into the target, as expected theoretically and numerically in all details. This was experimentally confirmed by irradiation of thin foils where the plasma block in the direction of the laser beam could be demonstrated. Comparison with SLANF for gold ions of various charges Z and long pulse laser irradiation at simultaneous x-ray emission could be used to confirm analytically a dielectric swelling of the laser field in the plasma corona within the skin layer by a factor of 3. This was, then, consistent with very detailed numerical calculations with very general genuine *two-fluid hydrodynamic codes* (see Fig. 4 as an example).[25,33] The most significant result was that the fast ions were only one group of plasma ions apart from the thermal of ions in contrast to all the numerous fast ions groups following those from relativistic self-focusing as that is due to hot electron ambipolar acceleration[7,29] and other mechanisms. As expected, the fast plane plasma moving against the laser (see Fig. 5), *did not show the usual beam divergence in the experiment* apart from a minor spreading due to some minor unavoidable thermal effects during the dominant nonlinear force acceleration.

III. ULTRAHIGH ION CURRENTS POSSIBLY USED FOR A FUSION FLAME

It was underlined at the time of the discovery of the laser that it was envisaged by Nuckolls in 1960[34] that a use of radiation ignition for fusion reactions may be considered when applying laser radiation. From the knowledge of radiation driven reactions, it was interesting to be aware that the laser intensity of 10^{17} W/cm^2 is the intensity of Planck radiation of a temperature of 1 keV. Based on this fact, it was

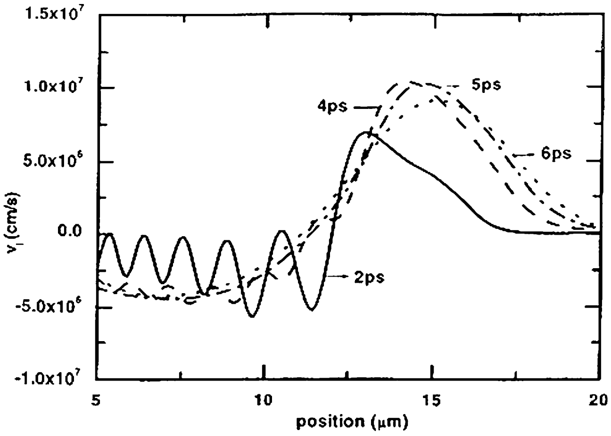

FIG. 4. Ion velocities computed for a one-dimensional 3×10^{15} W/cm^2 neodymium glass 4 ps laser pulse on an initially linearly increasing deuterium plasma ramp with critical density at a depth of 12 μm at different times. The ripple in the plasma corona (negative velocities for motion against the laser light) is due to the partially standing waves washed out after the end of the laser pulse showing the blocks of plasma of many wavelength thickness (Ref. 33).

nevertheless a question as to whether the monochromatic long wave laser radiation can be compared with the Planck radiation of the same intensity to ignite fusion fuel.

This question of directly igniting solid DT by a laser pulse was studied by Bobin,[11] resulting in practically impossible conditions wherein the fusion flame needs to have an energy flux density of

$$F > F^* = 10^8 \text{ J/cm}^2 \tag{7}$$

or to have an irradiation corresponding to an ion current density

$$j > j^* = 10^{10} \text{ A/cm}^2. \tag{8}$$

The condition for beam fusion (8) was by more than five orders of magnitude out of the possibilities for using particle beams as drivers. For achieving condition (7), Nuckolls deduced the spark or central core ignition where the laser radiation (or after conversion into x rays as "indirect drive," summarized by Lindl[35]) compresses the DT in such a very sophisticated way, first producing isobaric a very hot but low density central core. Its fusion reaction ignites then a very high gain fusion detonation wave (see Fig. 4 of Ref. 36) into a surrounding low temperature high density mantle. The reaction in the core was shown to be an ideal volume ignition[36–38] and the energy flux density for driving the fusion detonation wave was in the range of $F=7\times10^8$ J/cm^2 fulfilling condition (7).

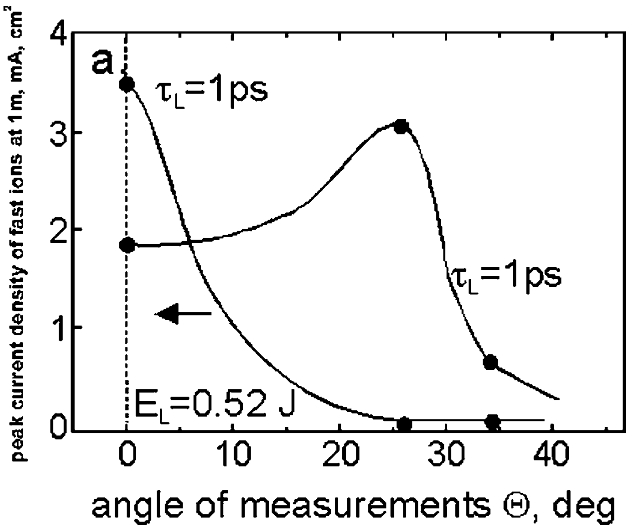

FIG. 5. Measurement of ion emission direction depending on the angle to the laser beam. For long (0.5 ns) pulses, the ions are emitted under wide angles, while the emission of the blocks at high aspect ratio have very directed ion emission against the laser.

The result (6) reached with SLANF of space charge neutral plasma blocks provides the necessary high ion current densities (8) for igniting a fusion flame. However, there are still further problems discussed in the following section such that more extensive studies will have first to be performed before a use of this scheme for laser induced fusion energy can be considered. A rather much closer result from SLANF is the application to a modification of the fast igniter scheme[1] for a spark ignition using 5 MeV intense ion beams for energy deposition into the pre-compressed center of the DT fuel.[2] It has been shown that the SLANF mechanism can provide 1000 times higher ion current densities[25,39] than those achieved under the previous conditions,[2] such that there is a support for nearly certainty that this scheme[2] may work though it needs fuel precompression of DT to more than 1000 times solid. The preference of double shell targets for the volume ignition in the experiments by Amend *et al.*[38] has to be especially underlined.

IV. COMPARISON WITH MODIFIED FAST IGNITER SCHEMES

The result (6) that the plasma block (piston) represents a fully directed space charge neutral DT ion beam of more than 10^{10} A/cm^2 with preferably 80 keV ion energy, provides a necessary condition for *ignition of a fusion flame in uncompressed solid DT*.[11] For the condition (7) of the energy flux density of the block, it was estimated that even for the pessimistic values of condition (7) may be reached.[12] The question is whether sufficient thermonuclear energy is produced to ignite the DT and whether the nonlinear force driven plasma block (or called piston plasma bunch[5] or impact fast ignition[24]) has not a too low mass per area such that *it will blow apart* before enough thermonuclear energy is generated. The question is how to correlate the results with the that of ignition of 12 times solid state density DT by the relativistic electron beam from a 10 PW-ps laser pulse,[3] and how an even lower DT density may be possible.

Taking the case of Storm *et al.* for spark ignition (see Fig. 4 of Ref. 36), the evaluation arrived at the volume ignition of the plasma core of a temperature of 12 keV of 200 times solid state density containing 430 kJ to ignite a fusion flame into the surrounding high density mantle for producing a gain of 100 of fusion energy per input total laser energy. A mechanism for a sufficiently thick plasma block to avoid that the piston[5] is blowing apart, may be reached by using a spherical irradiation geometry (Fig. 6). This spherical

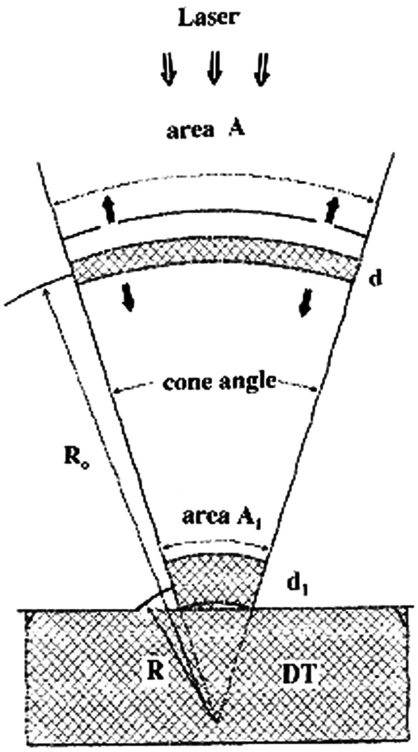

FIG. 6. Schematic description of spherical laser irradiation on a DT layer (upper part) to generate a plasma block moving into a cone. The thermal broadening of the block, while having a highly directed 80 keV ion energy for moving into a DT target, leads to an isochoric volume of very much higher thickness of the block.

geometry[39] was first aimed to improve the proton fast ignition scheme of Roth *et al.*[2] by a factor of 1000 by using the plasma block generation, but the same geometry can also be used for generation of a thicker piston.

Based on preceding detailed numerical evaluation with genuine two-fluid hydrodynamic codes including collisions, thermal equipartition, the general nonlinear force, temporally and spatially varying optical constants with complete numerical solution of the laser field, we find the following case for increasing the block thickness by spherical dynamics (Fig. 6). Several simplifications are still included as the losses by bremsstrahlung radiation and the conductive losses between the fast moving plasma block and the confining solid state cone based on the fact that there is a double layer to eliminate electron thermal conduction and the ion thermal energy transfer is reduced due to the grazing incidence in the double layer by the fast moving directed 80 keV ions.

Figure 4 described a case where the initial plasma density was a linear ramp into the overdense plasma where nevertheless the swelling, the increase of the effective wavelength near the critical density and the generation of a block of several wavelength thickness moving in the direction of the laser beam was confirmed. Here we shall use the perpendicular laser irradiation on a thin layer of solid DT similar to the case of Fig. 1, as discussed generally in a spherical compression scheme of plasma shells where the shells are mostly accelerated by the nonlinear force converting most of the optical laser energy into directed kinetic energy of shell motion with a comparably low loss of unavoidable collisional electron heating,[40,41] in contrast to the usual ablation process.[24]

The DT shell (upper part of Fig. 6) is irradiated by a laser pulse of 20 PW power and 2 ps duration with a spherical geometry of focusing a uniform neodymium glass laser beam to the area A with a diameter of $D = 1.668$ mm diameter. The plasma block moving with ion energies of 80 keV in the conical direction has an estimated thickness of 18 μm due to a swelling factor of 4 and a spread of the layer similar to Fig. 1. The heating of the electron up to 1 keV temperature is then comparably low. Following up a isochoric motion of the block, there is a reduction of the width of the layer simply due to the spherical direction of the layer in a ballistic way after being pushed by the nonlinear force. On the other hand, the heated electrons cause a thermal increase of the thickness of the layer. With a cone angle α of 3.7°, an initial radius $R_0 = 3.7$ cm, the layer reaches a thickness of 1 mm at an upper radius of $R = 1.4$ mm and a diameter D' $= 240$ μm, hitting a fusion target at a radius of 0.4 mm.

The numbers for the very intense ion driven fast ignition are a first illustration—apart from several simplifications—as to how a spherical skin layer acceleration by nonlinear forces (SLANF) mechanism in conical geometry can lead to a comparably thick plasma block or piston. The processes controlling how such a plasma bock interacts with a solid state or slightly precompressed DT target are not followed up in this paper. Indeed, there are several modified mechanism to be clarified, such as the strong inhibition of lateral thermal conduction due to double layer effects including anomalous resistivity,[32,41–48] modified stopping power, and the interpenetration process[43] with at least a relaxation of the condition (7).

V. CONCLUSION

In conclusion, the interaction of TW-ps laser pulses with plasma results in a skin layer mechanism for nonlinear (ponderomotive) force driven two-dimensional plasma blocks (pistons). This mechanism relies on a high contrast ratio for suppression of relativistic self-focusing.[7] Space charge neutral plasma blocks are obtained with ion current densities larger than 10^{10} $\mathrm{A/cm^2}$. Using ions in the MeV range results in 1000 times higher proton or DT current densities than the proposed proton fast igniter requires.[2] This should result in better conditions of this fast ignitor scheme.[39] The ballistic focusing of the generated plasma blocks and then short time thermal expansion increases their thickness but keeps the high ion current densities. As shown here, this approach then provides conditions that are very favorable for efficient fast ignition of a fusion target. If successful, this approach to fast ignition could significantly simplify operation of an inertial fusion energy plant, allowing very attractive energy production costs (Ref. 12; see also Hora 2003 in Ref. 7).

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