Accelerated Plasma Blocks Driven by Petawatt-Picosecond Laser Pulses for Igniting Near Solid Density DT

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Dedication

- This presentation is dedicated to the memory of Rose Hora, dedicated and loving wife of Heinz for many years.

Outline

- Review of prior volume ignition studies.
- Badziak effect and non-linear ion acceleration.
- Plasma block acceleration as an alternative to fast igniter electron beam ignition.
- Fusion regime involving 10-kJ input to produce 100 MJs or more output.

Introduction

- 30 years ago it was impossible to
  - ignite solid deuterium-tritium by pulsed laser irradiation
  - irradiation by ion beams had current densities of low magnitude
- This changed as improved drivers and targets were designed and the fast ignitor concept was introduced. However, very high compressions are still envisioned.
- Recently a method that avoids high compression was proposed by H. Hora et al.,based on an anomalous effect (block plasma acceleration) observed using PW-ps laser pulses

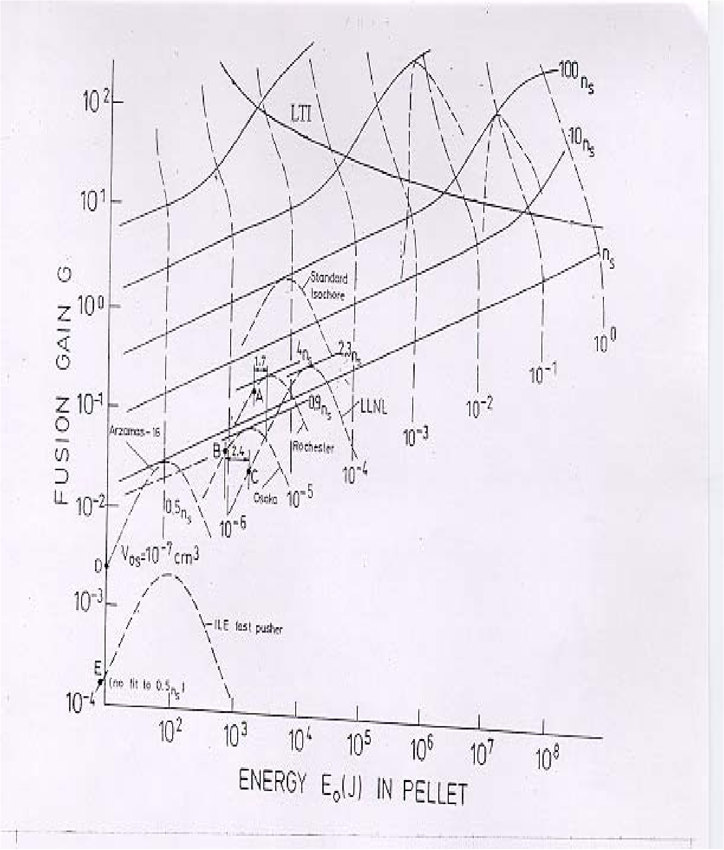
Basis

- Both experiments and theory conclude that suppression of prepulses by a factor 10^8 would
  - avoid relativistic self-focusing allowing broad area compression
  - gives directed 80-keV DT ion current densities in space- charge neutral plasma blocks of modest temperature. These blocks can reach parameters that allow them to produce fusion flame in the nearly uncompressed or solid DT target. The parameter that it can exceed are:
    - 10^{11} Amps/cm^2,
    - energy flux densities of 10^8 J/cm^2,
    - block thickness.
- Conditions for the energy flux are further relaxed by
  - considering interpenetration effects
  - the quantum modification of collisions
  - collective reduction of stopping power and double layer mechanisms

Review Of Prior Volume Ignition Studies

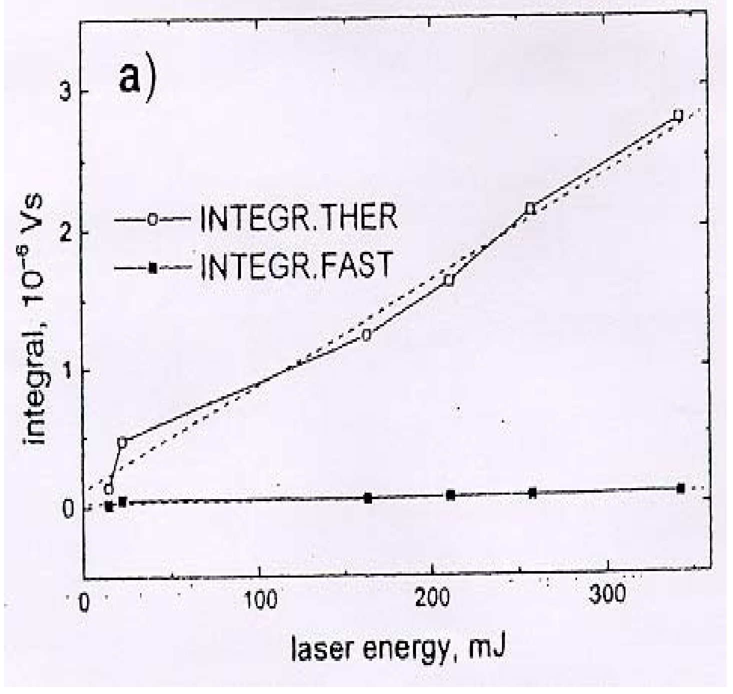
- Prior measurements at Rochester, Osaka, LLNL and Arzamas-16 agree with isotropic burn model.
- When radiation trapping and alpha reheat are included high gains occur with volume ignition above the threshold energy input.
- Optimized volume ignition requires high density and mass targets than does spark ignition,but is much simpler to implement.
- Block ignition allows use of lower density, greatly simplifying operation.

Experiments Agree Well with Isentropic Burn Model



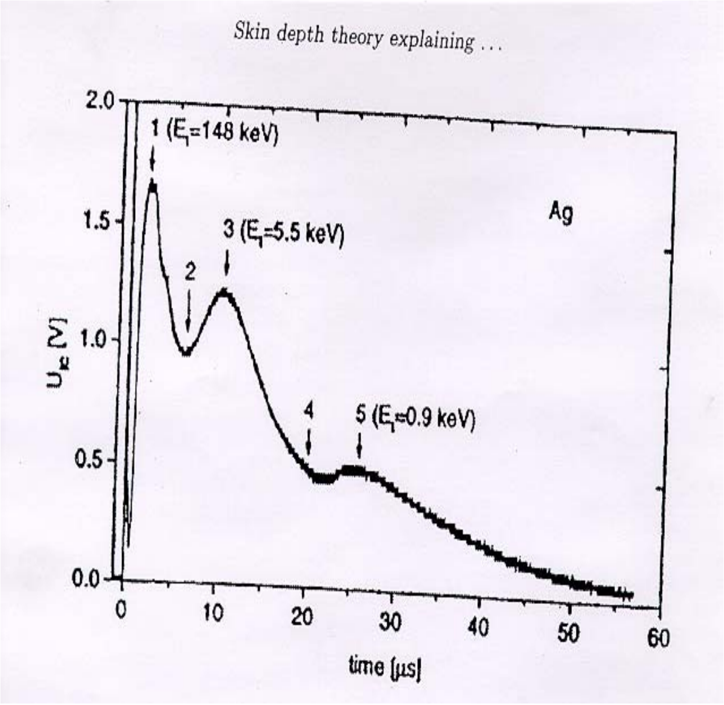
- Optimized core G (*full lines*) for 3-D self-similar volume comp. and simple burn (G<8) (~ quenching:1995) and volume ignition for G>8 with low T ignition above LTE line. Measurement at Rochester (*A*), Osaka (*B*), LLNL (*C*) and Arzamas-16 (*D*) agree with isentropic volume burn model, while the earlier fast pusher (*E*) with strong shocks does not.

Badziak Effect Results In Large Number Of Fast & Thermal Ions



- Badziak et al type anomalous ion emission: No. of fast and thermal ions emitted from a copper target at Nd glass laser irradiation of (1.2 ps) focused to 30 wave length dia. with pre-pulse suppression of 10^8 for <0.1 ns before the main pulse.

Ion Energy Groups Observed During Irradiation



- TOF signal from a flat ion collector with a silver target irradiated by an iodine second harmonic laser pulse of 14 J and 0.35 ns. Three groups of ions appear! The fastest ions (*1*), the second fastest ions (*3*) and the slow thermal ions (*5*).

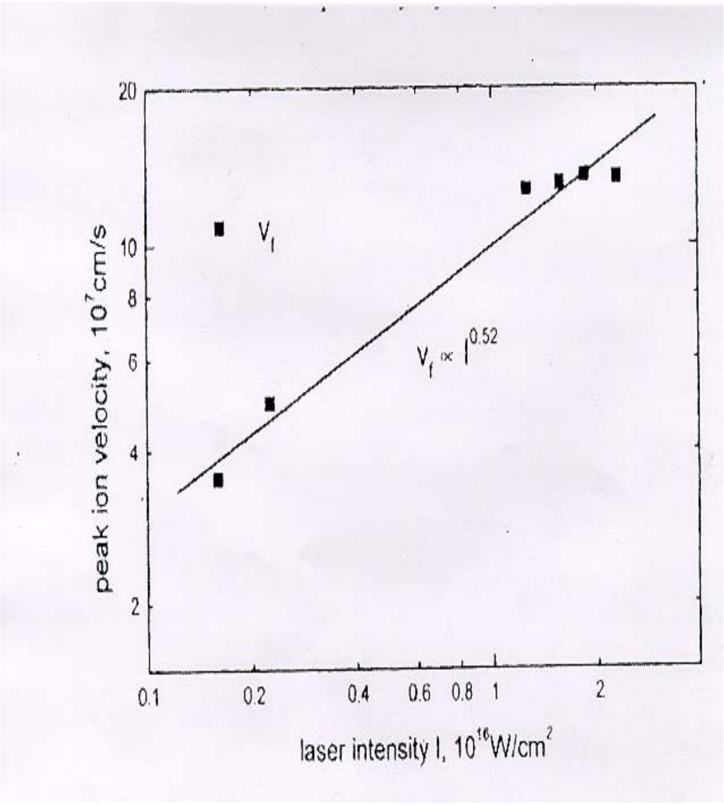
Badziak Effect & Non-Linear Ion Acceleration

- 5 energy groups of Ions observed for irradiation of a copper target during 1.2 ps Nd glass laser.
- Fast ions attributed to relativistic self focusing of laser beam.
- Slow ions characteristic of non-linear force acceleration.
- Analysis suggests plasma block acceleration, driven by non-linear forces, occured.

Other observations favorable to block formation

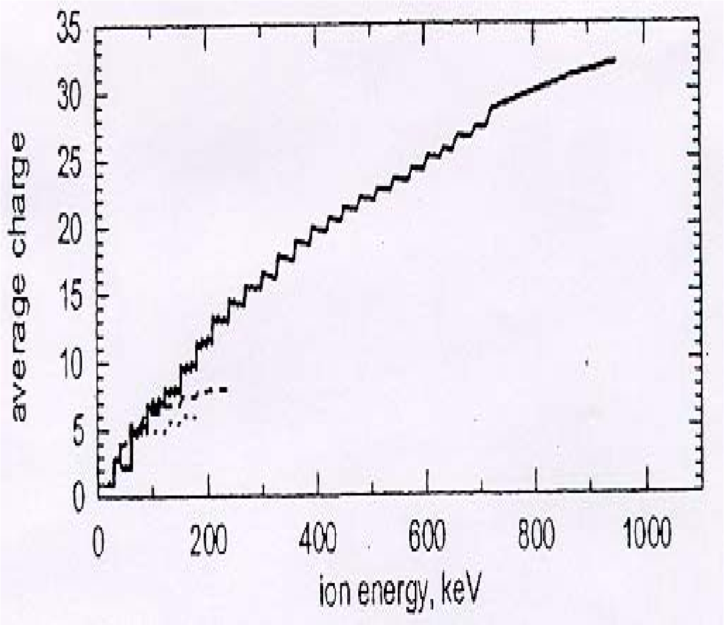
- Fast Ion Velocity Scales as $\sim I^{1/2}$
- Average Charge of Emitted Ions Depends Strongly
- Shorter Laser Pulses Lower the Average Charge

Fast Ion Velocity Scales As $I^{0.52}$



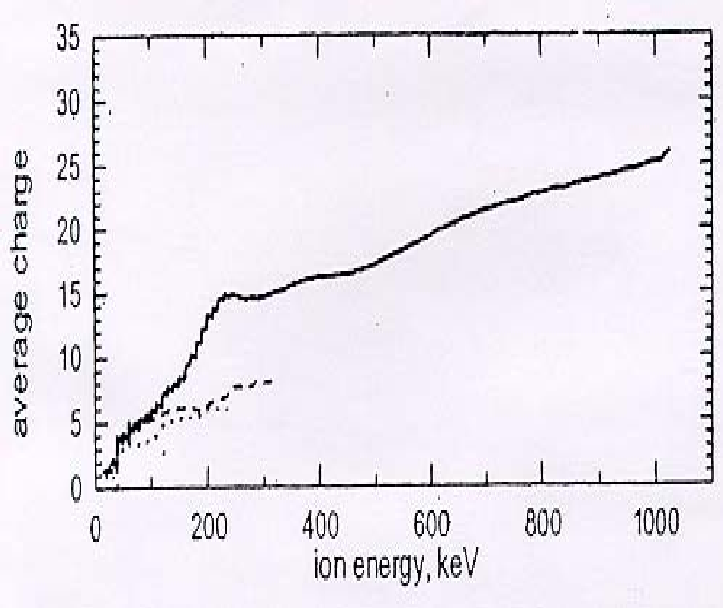
- Velocity of the fast ions measured by TOF.

Average Charge of Emitted Ions Depends Strongly on Their Energy



- Measured Charge and energy of fast ions (gold target, 0.5 ns Nd glass laser 0.7 J, dia. of 30um) plus emitted O (*dashed line*), C (*dotted line*) and H ions.

Shorter Laser Pulses Lead to a Lowering Of the Average Charge

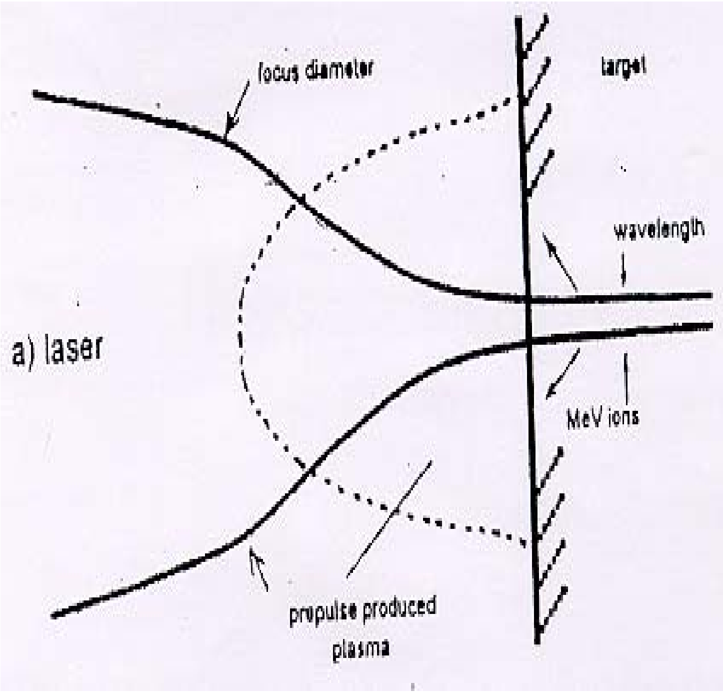


- Same as prior Slide but 1.2 ps –0.7 J laser pulses.

Plasma Block Acceleration As an Alternative to Fast Igniter Electron Beam Ignition

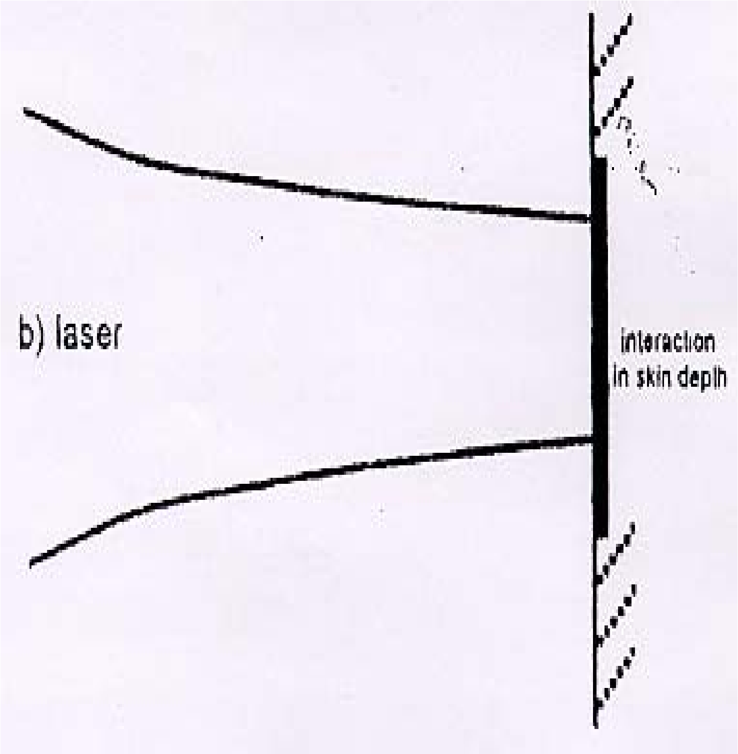
- Block acceleration requires pre-pulse suppression to prevent plasma self focusing.
- Using studies from light ion beam fusion volume ignition with a ion current of 10^{10} Amp/cm^2 from 10-kJ pulses, calculations predict high gain volume ignition is possible.

Pre-generated Plasma Causes Self-focusing



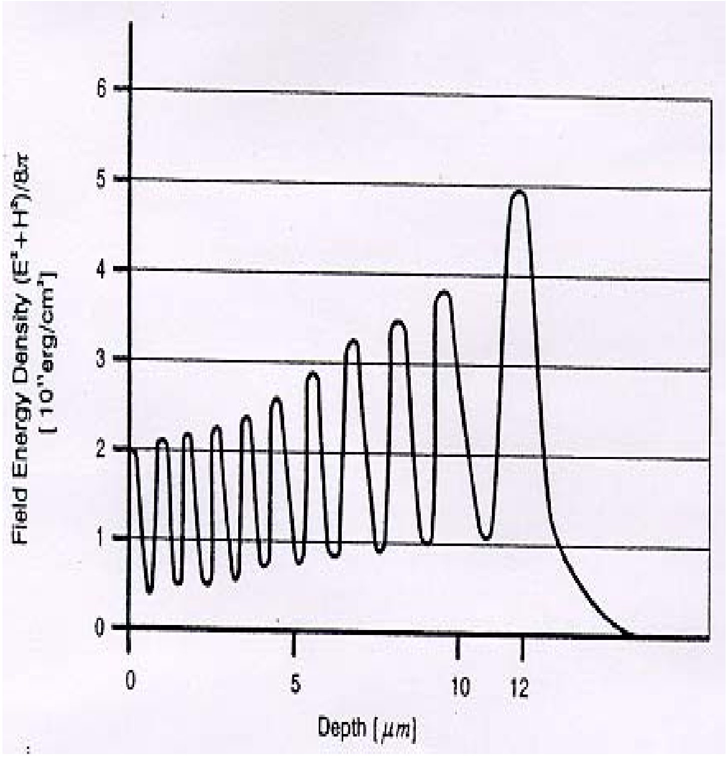
- Geometry for subsequent volume-forced nonlinear electron acceleration with separation by the ion charge Z. The pre-generated plasma before the target causes relativistic self focusing of the laser beam to less than a wave length dia. and very high acceleration due to the strong gradient of laser field density.

Elimination of Plasma Prevents Self-focusing



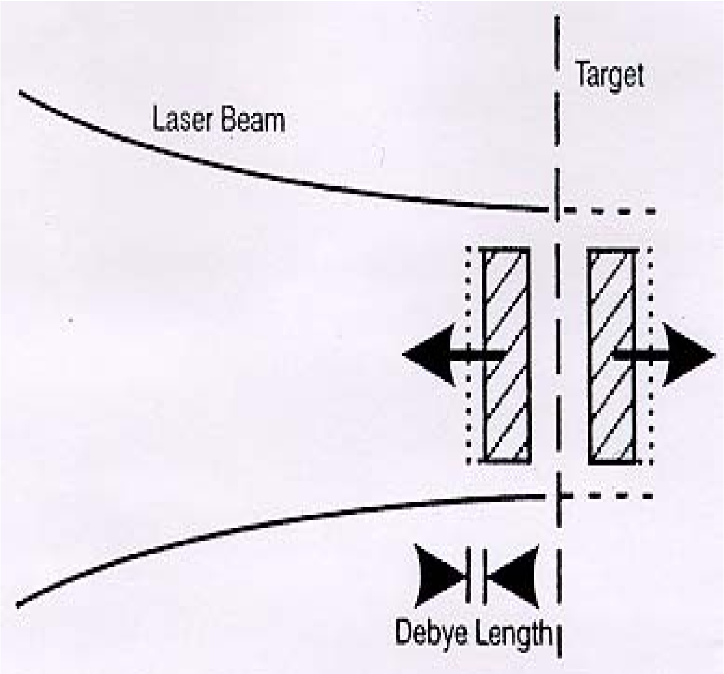
- The very thin plasma does not produce self-focusing, hence lower ion energies. This ideal geometry has frequently been assumed in prior studies.

Nonlinear Force Effects Create High Electric Field Amplitudes



- Two fluid calculation of the electromagnetic energy density Nd glass laser 10^{16} W/cm^2 after n_e~ 5×10^{20} cm^{-3} is reached at 12um from the surface. The maximum corresponds $\mathcal{E}$~3.1 times higher than vacuum due to dielectric swelling.

Plasma Block Acceleration By Non-Linear Force



- Skin depth laser interaction: nonlinear force accelerates a plasma block against the laser light and another block towards the target interior. Election clouds form with a thickness of the effective Debye length.

Block Ignition Targets

- Design point-generation of reaction front with interpenetrating ion energies ~ 100 keV.
- Use high aspect ratio ps pulse defocused to large cross section.
- PW pulses with final intensity of few 10^{17} W/cm^2 – gives swelling of 2-3x.
- Resulting ion current density of 10^{10} Amp/cm^{2,} giving 10^6 J/cm^2.

Ignition Criteria

- Collective interaction of ions determines stopping power.
- Ignition condition for fusion reaction wave reduces to minimum energy density E_{min} for DT of E_{min} = $10^6 J/cm^2$.
- Reaction wave of high intensity ion beam of minimum current density j_{min} = 10^{10} A/cm^2.

Conclusions

- This new approach overcomes the DT compression issues and electron beam issues of the fast ignitor
- Plasma block ignition,10-kJ laser pulses produce 100-MJs of fusion energy
- Simplified and Lower Cost Energy Production

Thank you

If you have any questions, please

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