Femtoscopcy for the NAPLIFE nano-fusion project?

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Two ideas are combined by L.P. Csernai, N. Kroo, I. Papp: [ Patent # P1700278/3 ] (2017)

Problems:
• Rayleigh-Taylor instability
• Slow propagation of burning from central hot-spot

Solution:
• Heat the system uniformly by radiation with RFD (1)
• Achieve uniform heating by Nano-Technology (2)

[ L.P. Csernai, N. Kroo, I. Papp, Laser and Particle Beams, LPB, 36(2), (2018) 171-178. ]
https://doi.org/10.1017/S0263034618000149

But let us go back in history ➔
Rayleigh-Taylor Instability
The target is compressed to density $\sim 700 \text{ g/cm}^3$.

But, although an ablator layer is used, only $\sim 10\%$-of the target is ignited. Elsewhere the surface protruded as “potato from the potato press”: RT-instability.
How can we prevent it
Idea - #1
A.H. Taub assumed that (physically) only slow space-like shocks or discontinuities may occur (with space-like normal, $\lambda_4=0$).

This was then taken as standard, since then (e.g. LL 1954-)

Next we suppose that the three-dimensional volume is a shell of thickness $\epsilon$ enclosing a surface of discontinuity $\Sigma$ whose three-dimensional normal vector is $\Lambda_i$. If we choose our coordinate system so that the discontinuity is at rest, then since

$$\lambda_a \lambda^a = 1, \quad \sum_{i=1}^{3} \Lambda_i^2 = 1,$$

we have

$$\lambda_i = \Lambda_i \quad \text{and} \quad \lambda_4 = 0.$$
corrected the work of

\[ \lambda_a \lambda^a = \pm 1 \]
@ CERN in High energy heavy ion collisions

[ Stefan Floerchinger and Urs Achim Wiedemann, Phys. Rev. C 89, 034914 (2014) ]
Femtoscopy in heavy ion collisions: Wherefore, Whence, & Whither?

Mike Lisa
Ohio State University

- Wherefore (=“why?”)
  - motivation & (basic) formalism
- Whence (=“from where?”)
  - systematics over 2 decades
- Whither (=“to where?”)
  - or “wither”...?

http://www-rne.lbl.gov/TBS

MAL, Pratt, Soltz, Wiedemann
Fusion reaction:
\[ D + T \rightarrow n(14.1 \text{ MeV}) + 4\text{He} (3.5 \text{ MeV}) \]

Constant absorptivity,
Spherical irradiation
Ignition temperature = T1

Simultaneous, volume ignition up to 0.5 \( R \) (i.e. 12% of the volume).

Not too good, but better than:

How can we realize it
Idea - #2
Golden Nano-Shells – Resonant Light Absorption

Csernai, L.P. [NAPLIFE]
The absorption coefficient is **linearly** changing with the radius: In the center, \( r = 0, \ \alpha_K = 30 \text{ cm}^{-1} \) while at the outside edge \( \alpha_K = 8 \text{ cm}^{-1} \).

The temperature is measured in units of \( T_1 = 272 \text{ keV}, \) and \( T_n = n T_1. \)

Simultaneous, volume ignition is up to 0.9 \( R \), so **73% of the fuel target!**
TEM Photo of ~uniformly implanted 85x25 nm nanorod antennas in UDMA target polymer. The density is 9-20 / μm³

[Judit Kámán, A. Bonyár et al. (NAPLIFE Collab.)], Gold nanorods …, 10th ICNFP 2021, Kolymbari, Crete, Greece, 30 August 2021.]
Layered target with variable light absorption

Representative uniform & Gaussian number density distributions of (d) 70 oriented nanorods, in a $1 \times 1 \times 21$ µm$^3$ supercell of UDMA polymer target, with random location distribution.

Validation tests ➔

Laser Induced Fusion with Nanoantennas
Deuterium production (PRELIMINARY !)

Two step process (average of 20 shots):

\[ p + e^* \rightarrow n + \nu \ \text{electron capture } (-1.24 \text{ MeV}) \]
\[ n + p \rightarrow d + \gamma \ \text{neutron capture } (+2.22 \text{ MeV}) \]

Electron capture may happen spontaneously in heavy nuclei, here laser light and resonant nanorods act similarly, high \( \Theta \) density UDMA (470: H38, C23, O8, N2)

5-12% \( \text{D} \) + 88-95% \( \text{H} \)

\(~ 10^{17} \text{ D} / \text{pulse} \) (10Hz)

100% \( \text{H} \)

Balmer-\( \alpha \) line

[ P. Rácz, A. Kumar et al. 2021 ICNFP, Kolymbari ]
With Nanorods (Au2) at 25 mJ laser pulse ~4 times increased D production, compared to 1 mJ pulse

Csernai, L.P. [NAPLIFE]
J. Kámán, Á. Nagyné Szokol et al., 11th Int. Conf. on New Frontiers in Physics 2022, Kolymbari, Crete
Theoretical analysis of Crater & Deuterium production

With nanorods $V$ grows non-linearly. Increasing energy deposition. Several types of targets are considered: Au1 and Au2 with implanted nano-rod antennas, and Au0 without implantation. The mass concentrations of implanted particles in UDMA are 0.126% and 0.182% for targets Au1 and Au2, respectively.

With nanorods, Au2, deposited energy into the crater increases non-linearly (?!)

Origin of this extra energy (?!)

[ LP. Csernai et al., Phys. Rev. E, 108(2) 025205 (2023) ]
Laser pulse energy: 25 mJ

Dependence of crater volume on laser energy for copper. (532 nm, 6 ns)
Calculational Box (CB) 
(530 nm)$^3$

Nano-rod antenna
(~ 85x25 nm)

Ey Ffield

laser

Csernai, L.P. [NAPLIFE]
$I = 4 \cdot 10^{17} \text{ W/cm}^2 \quad V \sim 7.1 \cdot 10^{12} \text{ V/m}$

$I = 4 \cdot 10^{15} \text{ W/cm}^2 \quad V \sim 2.6 \cdot 10^{12} \text{ V/m}$

[I. Papp et al., arXiv: 2306.13445]
I = 4 \cdot 10^{17} \text{ W/cm}^2
\quad \text{dV} \sim 8 \cdot 10^{12} \text{ V/m}

\text{Dipole } L = 85 \text{ nm}

\text{dV} \sim 1 \cdot 10^6 \text{ V/m}
\quad \text{Dipole } L \sim 16 \text{ cm}

Neighboring protons are accelerated (100-200 nm)
Laser wake field acceleration mechanism =>

BUT
Proton amplitudes & speeds are smaller
Number of 1-2 MeV protons is about 1-100
=> small number of Deuterium
One-sided irradiation

\[ C(p_1, p_2) = \frac{P_2(p_1, p_2)}{P_1(p_1)P_1(p_2)}, \]

\[ C(k, q) = 1 + \frac{R(k, q)}{\left| \int d^4x S(x, k) \right|^2}, \]

\[ R(k, q) = \int d^4x_1 d^4x_2 \cos[q(x_1 - x_2)] \times \]
\[ S(x_1, k + q/2) S(x_2, k - q/2). \]

Two-sided irradiation

\[ J(k, q) = \int d^4x S(x, k + q/2) \exp(iq x) \]
\[ R(k, q) = Re \left[ J(k, q) J^*(k, -q) \right]. \]

\[ f^J(x, p) = \frac{n(x)}{C_\pi (2\pi \hbar)^3} \exp \left( \frac{-p^\mu u_\mu(x)}{T(x)} \right) \]

\[ f_{CJ} = \frac{\Theta(p^\mu d_\sigma_\mu) n(x)}{C_\pi (2\pi \hbar)^3} \times \]
\[ \left( \exp \frac{-p^\mu u^R_\mu}{T} - \exp \frac{-p^\mu u^L_\mu}{T} \right) \]
Fluid elements [s] can be represented by Cancelling Jüttner distributions, i.e. Cells are not in thermal equilibrium. (protons are accelerated by the nanorods

Then standard procedure like for a spherical, thermal cell.

\[
C(k, q) = 1 + \exp \left( -\frac{(\Delta\tau)^2(\hat{\sigma}^\mu q_\mu)^2 - R^2 q^2}{2R^2} \right)
\]

\[
C(k, q) = 1 + \exp \left( -R^2 q^2 \right)
\]

For a single spherical source:

[L.P. Csernai, S. Velle, and D.J. Wang
PHYSICAL REVIEW C 89, 034916 (2014)]
New fusion mechanism

Traditionally (NIF) after ignition, DT burning is spreading by *alpha particle self heating*. This turns out to be slower than expansion after extreme compression and extreme pressure.

**HINT:**
Here after simultaneous (time-like) ignition attraction of large number of electrons *collectively accelerate* protons, which can induce nuclear reaction (e.g. transmutation).

We try to verify this mechanism by the Hanbury-Brown and Twiss effect to determine the deuteron and alpha source size, after a laser shot.
High Energy, Short Pulse Laser, unique at ELI – ALPS Szeged
European Laser Infrastructure – Szeged, HU

ELI-ALPS Szeged:
EU Extr. Light Infrastructure
Attosec. Light Pulse Source

2PW High Field laser
10 Hz, <10fs, 20 J