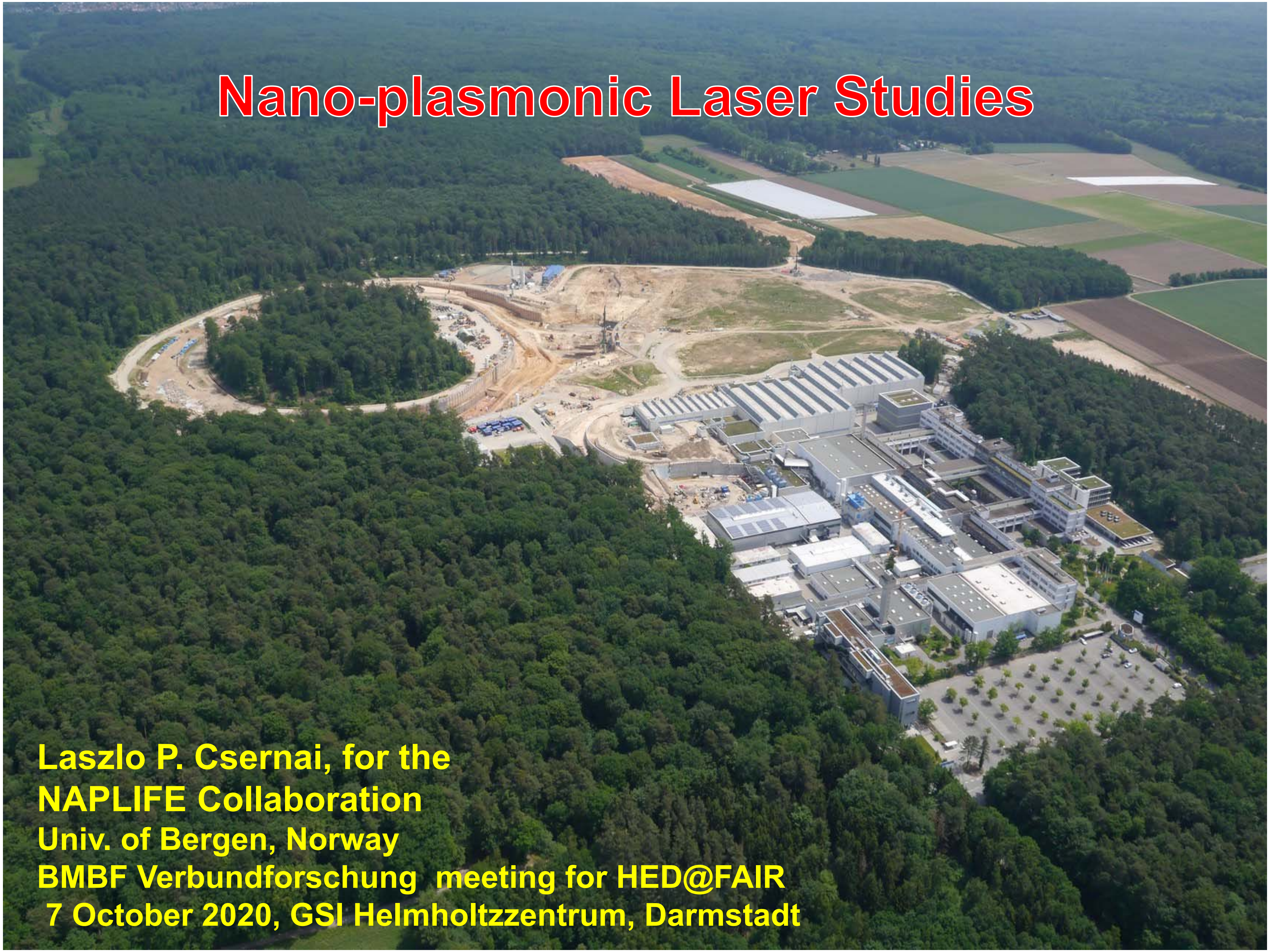
Nano-plasmonic Laser Studies



Laszlo P. Csernai, for the
NAPLIFE Collaboration
Univ. of Bergen, Norway
BMBF Verbundforschung meeting for HED@FAIR
7 October 2020, GSI Helmholtzzentrum, Darmstadt

Nano-Plasmonic Laser Inetial Fusion Experiment (NAPLIFE) Collaboration

Márk Aladi, Attila Bonyár, Alexandra Borok, Larissa Bravina, Maria Csete, Péter Dombi, Miklós Kedves, Péter Lévai, Igor N. Mishustin, Dénes Molnár, Anton Motornenko, István Papp, Péter Petrik, Péter Rácz, Béla Ráczkevi, Leonid M. Satarov, Horst Stöcker Daniel D. Strottman, Melinda Szalóki, András Szenes, Csaba Tóth, Dávid Vass, Miklós Veres, Tamás S. Biró, László P. Csernai , Norbert Kroó

* L.P. Csernai, M. Csete, I.N. Mishustin, A. Motornenko, I. Papp, L.M. Satarov, H. Stöcker & N. Kroo, Radiation Dominated Implosion with Flat Target, *Physics of Wave Phenomena*, **28** (3) 187-199 (2020), (arXiv:1903.10896v3).

* L.P. Csernai, N. Kroo, & I. Papp, Radiation-Dominated Implosion with Nano-Plasmonics, *Laser and Particle Beams* **36,** 171 (2018), (arXiv:1710.10954)

* I. Papp, L. Bravina, M. Csete, I.N. Mishustin, D. Molnár, A. Motornenko, L.M. Satarov, H. Stöcker, D.D. Strottman, A. Szenes, D. Vass, T.S. Biró, L.P. Csernai, N. Kroó, Laser Wake Field Collider, *t.b.p*. (arXiv: 2009.00000)

* L.P. Csernai, N. Kroó, I. Papp, D.D. Strottman, Nano-plasmonic Laser Fusion, *Laser and Particle Beams, i.p.* (arXiv:2008.09847)

[A.H. Taub (1948)]

PHYSICAL REVIEW VOLUME 74, NUMBER 3 AUGUST 1, 1948

Relativistic Rankine-Hugoniot Equations

A. H. TAUB
*University of Illinois, Urbana, Illinois and Institute for Advanced Study, Princeton University, Princeton, New Jersey**

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

$$\lambda_\alpha \lambda^\alpha = 1, \quad \sum_{i=1}^{3} \Lambda_i{}^2 = 1,$$

we have

$$\lambda_i = \Lambda_i \quad \text{and} \quad \lambda_4 = 0.$$

Hence Eqs. (7.1) and (7.2) become, as ϵ goes to zero,

$$[\rho^0 u^i \Lambda_i] = 0, \qquad (7.3)$$

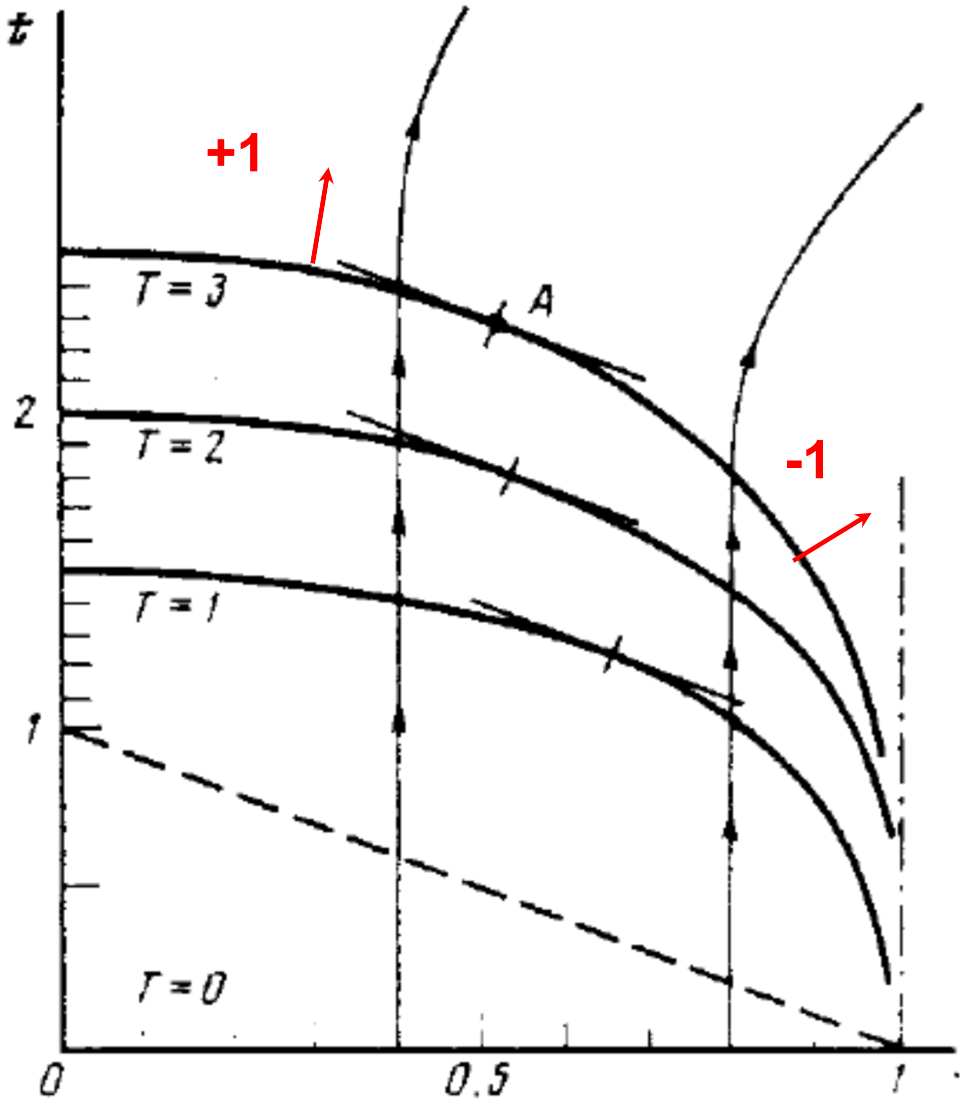
$$[T^{\alpha i} \Lambda_i] = 0, \qquad (7.4)$$

where

$$[f] = f_+ - f_-$$

Taub assumed that (physically) only slow space-like shocks or discontinuities may occur (with space-like normal, λ_4=0).

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



[L. P. Csernai, Zh. Eksp. Teor. Fiz. 92, 379-386 (**1987**) & Sov. Phys. JETP 65, 216-220 (1987)]

corrected the work of [**A. Taub**, Phys. Rev. 74, 328 (**1948**)]

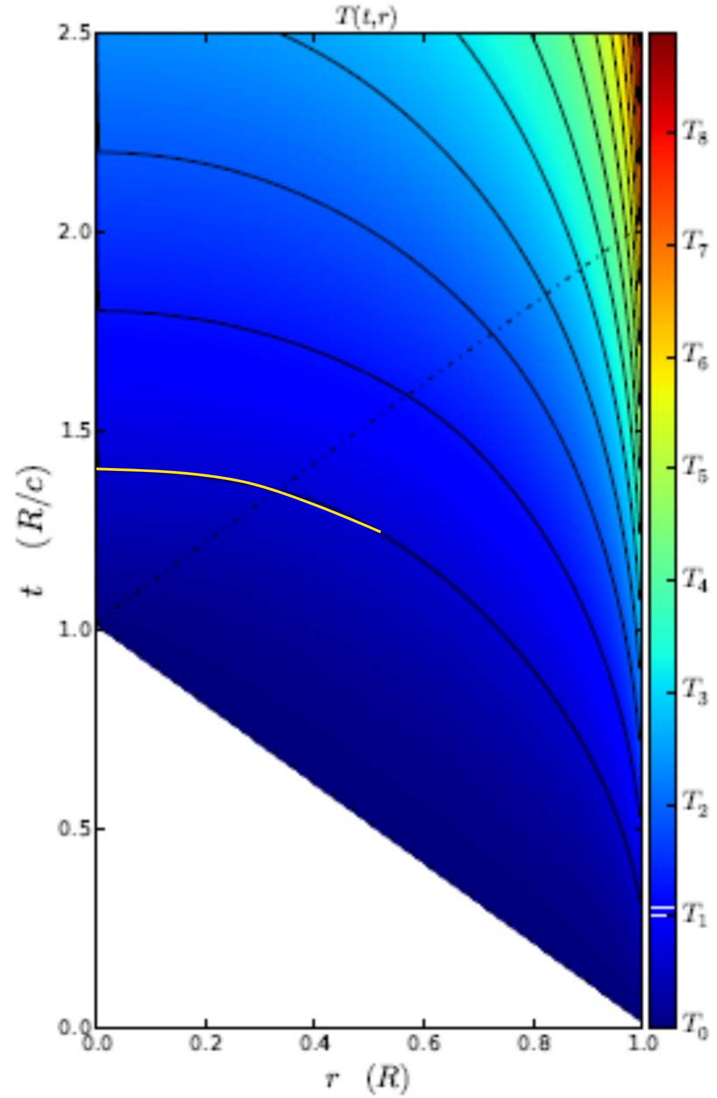
$$\lambda_\alpha \lambda^\alpha = \pm 1$$

Л. П. Чернаи

ДЕТОНАЦИЯ НА ВРЕМЕНИПОДОБНОМ ФРОНТЕ ДЛЯ РЕЛЯТИВИСТСКИХ СИСТЕМ

Журнал экспериментальной и теоретической физики

1987



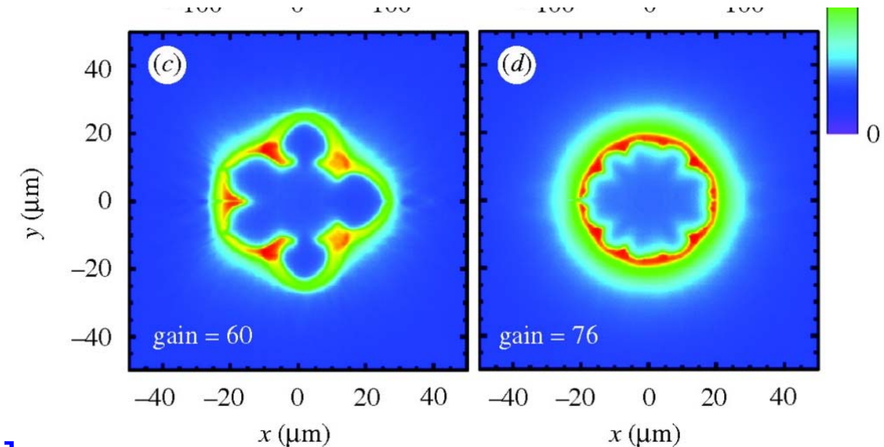
Fusion reaction:

D + T ➔ n(14.1 MeV) + 4He (3.5 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:



[L.P. Csernai & D.D. Strottman,
Laser and Particle Beams 33, 279 (2015).]

Can we achieve larger volume ignition (II-nd)

Two ideas are combined by

L.P. Csernai, N. Kroo, I. Papp **[Patent # P1700278/3](*)**

(2017)

- **Heat the system uniformly by radiation with RFD**
- **Achieve uniform heating by Nano-Technology**

Uniform, **4π radiation** should heat the target to ignition within the light penetration time (i.e. ~ 10-20 ps). This follows from RFD!

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

LPB, 36(2), (2018) 171-178.
Laser and Particle Beams

cambridge.org/lpb

Radiation dominated implosion with nano-plasmonics

L.P. Csernai[1], N. Kroo[2,3] and I. Papp[4]

[1]Department of Physics and Technology, University of Bergen, Bergen, Norway; [2]Hungarian Academy of Sciences, Budapest, Hungary; [3]Wigner Research Centre for Physics, Budapest, Hungary and [4]Department of Physics, Babes-Bolyai University, Cluj, Romania

Research Article

Cite this article: Csernai LP, Kroo N, Papp I (2018). Radiation dominated implosion with nano-plasmonics. *Laser and Particle Beams* 1–8. https://doi.org/10.1017/S0263034618000149

Received: 28 November 2017
Revised: 14 March 2018
Accepted: 3 April 2018

Key words:
Inertial confinement fusion; nano-shells; relativistic fluid dynamics; time-like detonation

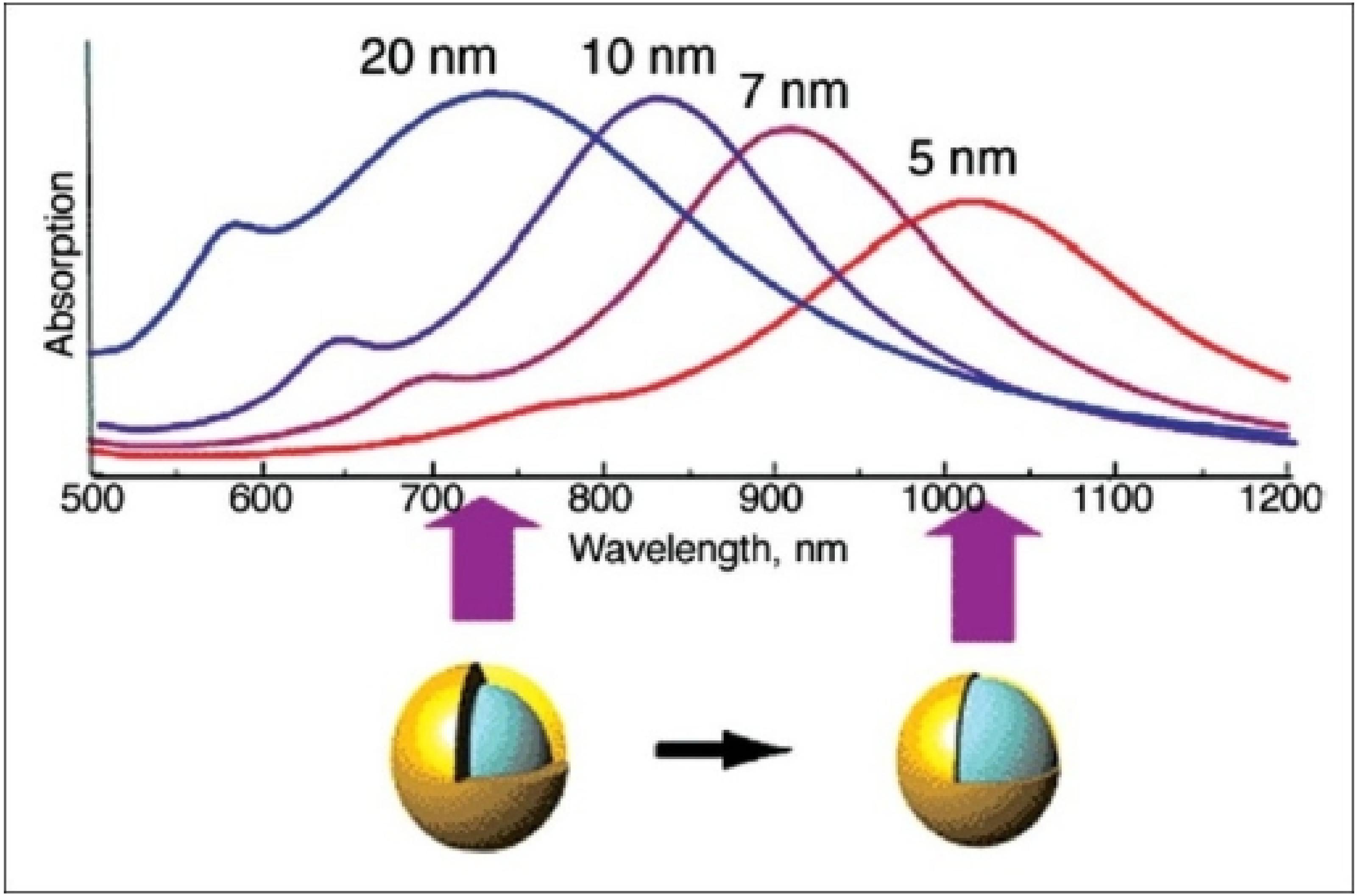
Author for correspondence:
L.P. Csernai, Department of Physics and Technology, University of Bergen, Bergen, Norway. E-mail: Laszlo.Csernai@uib.no

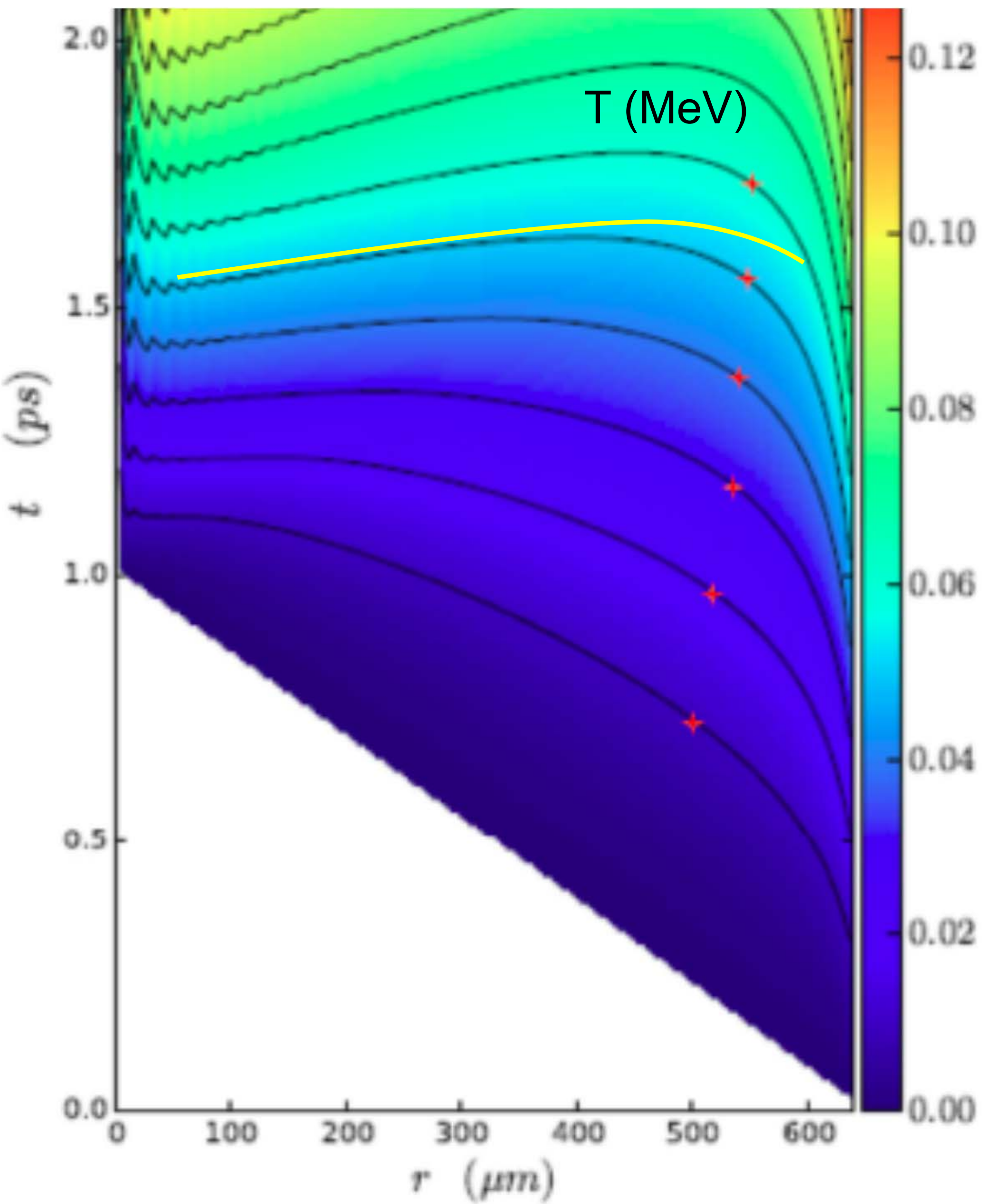
Abstract

Inertial Confinement Fusion is a promising option to provide massive, clean, and affordable energy for mankind in the future. The present status of research and development is hindered by hydrodynamical instabilities occurring at the intense compression of the target fuel by energetic laser beams. A recent patent combines advances in two fields: Detonations in relativistic fluid dynamics (RFD) and radiative energy deposition by plasmonic nano-shells. The initial compression of the target pellet can be decreased, not to reach the Rayleigh–Taylor or other instabilities, and rapid volume ignition can be achieved by a final and more energetic laser pulse, which can be as short as the penetration time of the light across the pellet. The reflectivity of the target can be made negligible as in the present direct drive and indirect drive experiments, and the absorptivity can be increased by one or two orders of magnitude by plasmonic nano-shells embedded in the target fuel. Thus, higher ignition temperature and radiation dominated dynamics can be achieved with the limited initial compression. Here, we propose that a short final light pulse can heat the target so that most of the interior will reach the ignition temperature simultaneously based on the results of RFD. This makes the development of any kind of instability impossible, which would prevent complete ignition of the target.

… and 35th Hirschegg Int. Workshop on High Energy Density Physics, Jan. 25-30, 2015

Golden Nano-Shells – Resonant Light Absorption





The absorption coefficient is **linearly** changing with the radius: In the center,

r = 0, $\alpha_K = 30\ \mathrm{cm}^{-1}$ while at the outside

edge $\alpha_K = 8\ \mathrm{cm}^{-1}$.

The temperature is measured in units of $T_1 = 272$ keV, and $T_n = n\,T_1$.

Simultaneous, volume ignition is up to 0.9 R, so **73% of the fuel target!**

Thick Coin like target - New Developments

L.P. Csernai, N. Kroo, I. Papp

x

Thickness of the target is: h

h depends on pulse energy, ignition energy, target mass, …

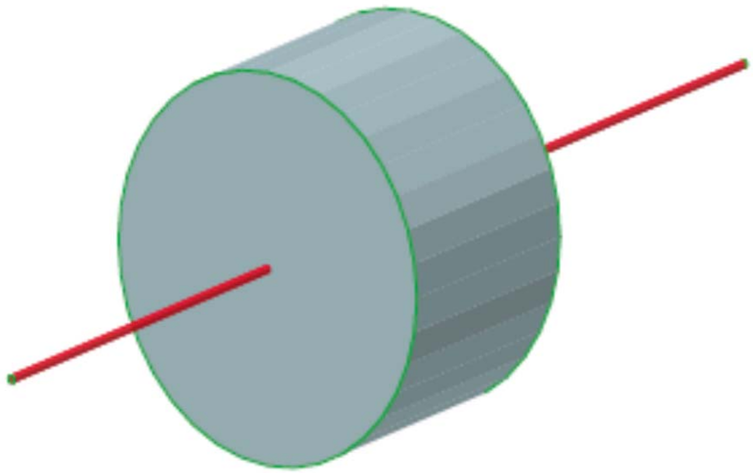
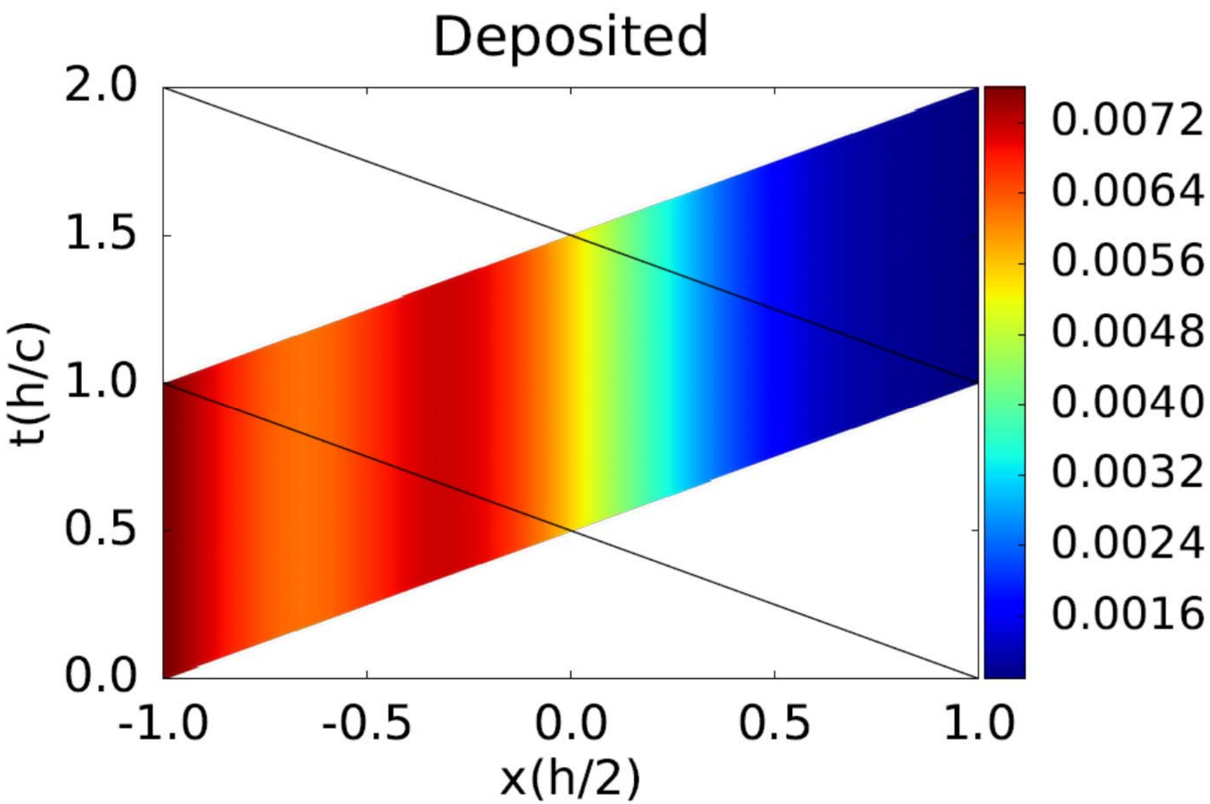


Figure 1: (color online) The target still should be compact to minimize the surface effects. The irradiation is performed along the x−axis from both sides towards the target. The laser beam should be uniform hitting the whole face of the coin shaped target.



With nano antennas

The absorptivity is increased towards the center, due to the implanted nano antennas.

The deposited energy from laser irradiation from one side only. The absorption is modified by nano antennas so that the absorptivity is increasing towards the middle, so that the deposited energy is constant up to the middle. Then the absorptivity is decreasing, but hardly any energy is left in the irradiation front. Thus again only a negligibly small energy reaches the opposite end of the target.

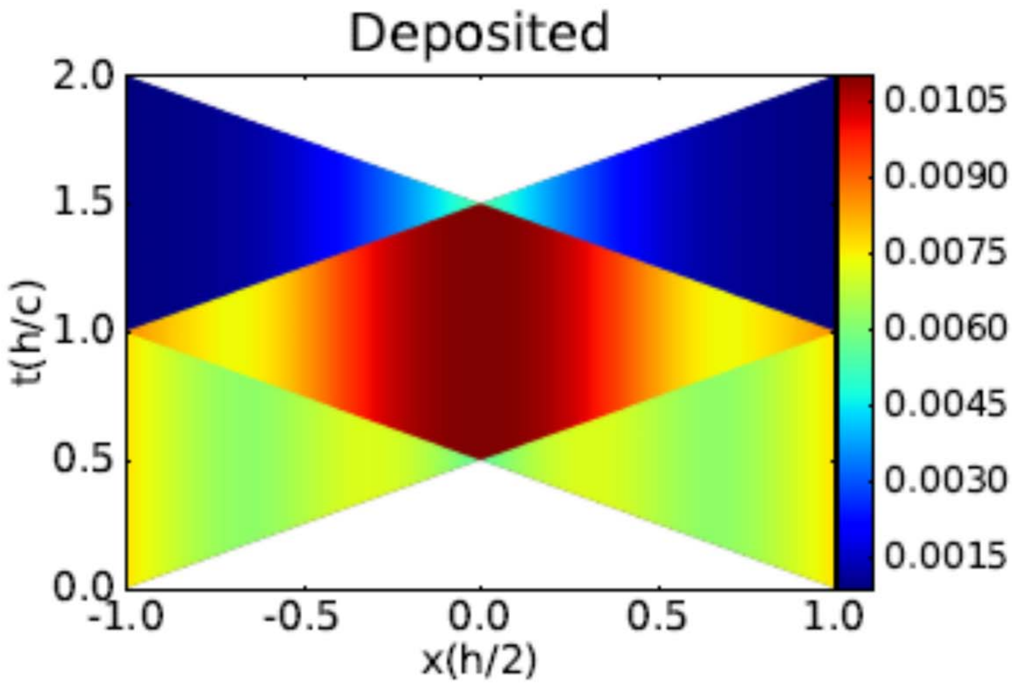


Figure 2: (color online) Deposited energy per unit time in the space-time across the depth, h, of the flat target. The time is measured in units of (h/c), where c is the speed of light in the material of the target. The irradiation lasts for a period of $\Delta t = h/c$ the time needed to cross the target. The irradiated energy during this time period is Q from one side, so it is $2Q$ from both sides together.
The color code indicates the deposited energy per unit time and unit cross section (a.u.). The deposited length is $\Delta x = c\Delta t$. Note! The absorptivity in this case $\alpha_K \neq$ const. For more details please see Appendix B.

With nano antennas

Irradiation from both sides.

Ignition energy is: Q_i/m
e.g. for DT target: $Q_i/m = 27$ kJ/g
➔ if we have $Q = 100$ J , then we can have a target mass:
$m_{DT} = Q / Q_i$ g $= 3.703$ mg.

Then with m_{DT} and ρ_{DT} given we get the DT-target's volume, V_{DT} and $h_{DT} = 2.67$ mm .

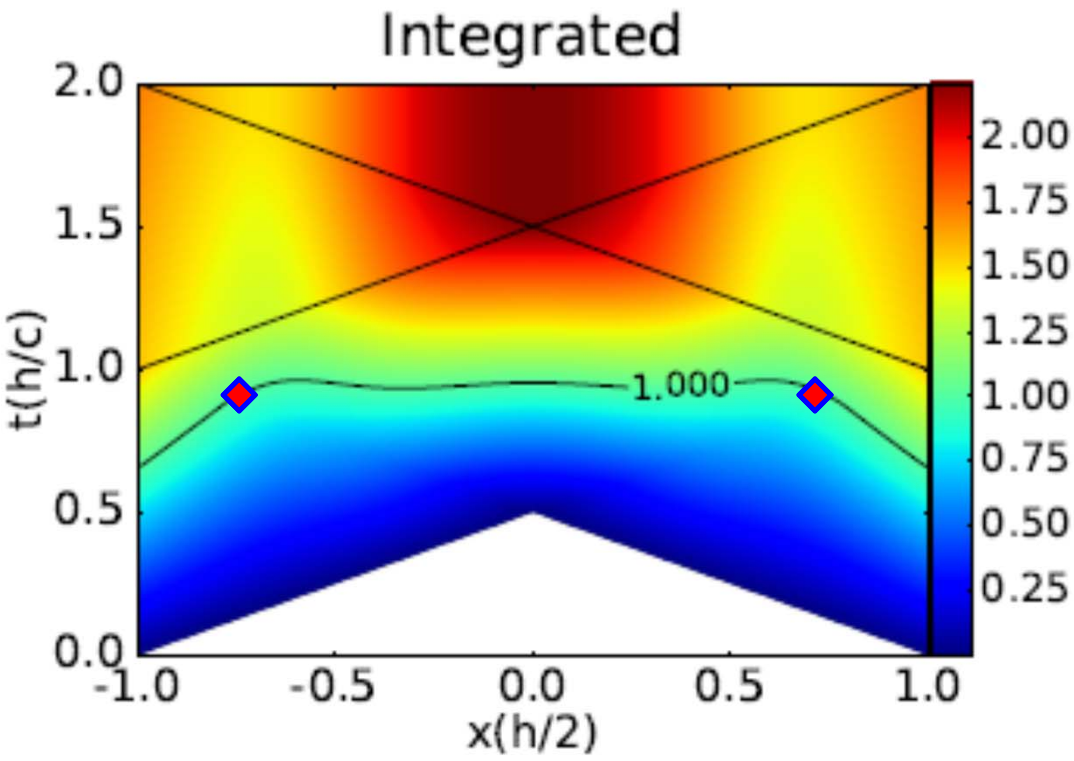


Figure 3: (color online) Integrated energy up to a given time in the space-time across the depth, h, of the flat target. The color code indicates the temperature, T, reached in a given space-time point, in units of the critical temperature, (T_c). The contour line $T = 1$, indicates the critical temperature, T_c where the phase transition or the ignition in the target is reached. This contour line is almost at a constant time, indicating simultaneous whole volume transition or ignition. The irradiated energy, Q is chosen so that, $1Q$ irradiation will achieve the critical temperature.

With nano antennas

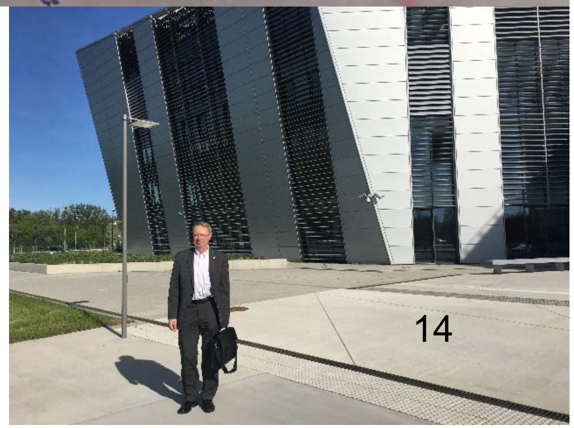
Ignition is reached at contour line $Q = 1$.

[L. P. Csernai, M. Csete, I. N. Mishustin, A. Motornenko, I. Papp, L. M. Satarov, H. Stöcker, N. Kroo, ***arXiv***:1903.10896, ***Submitted to MRE***]

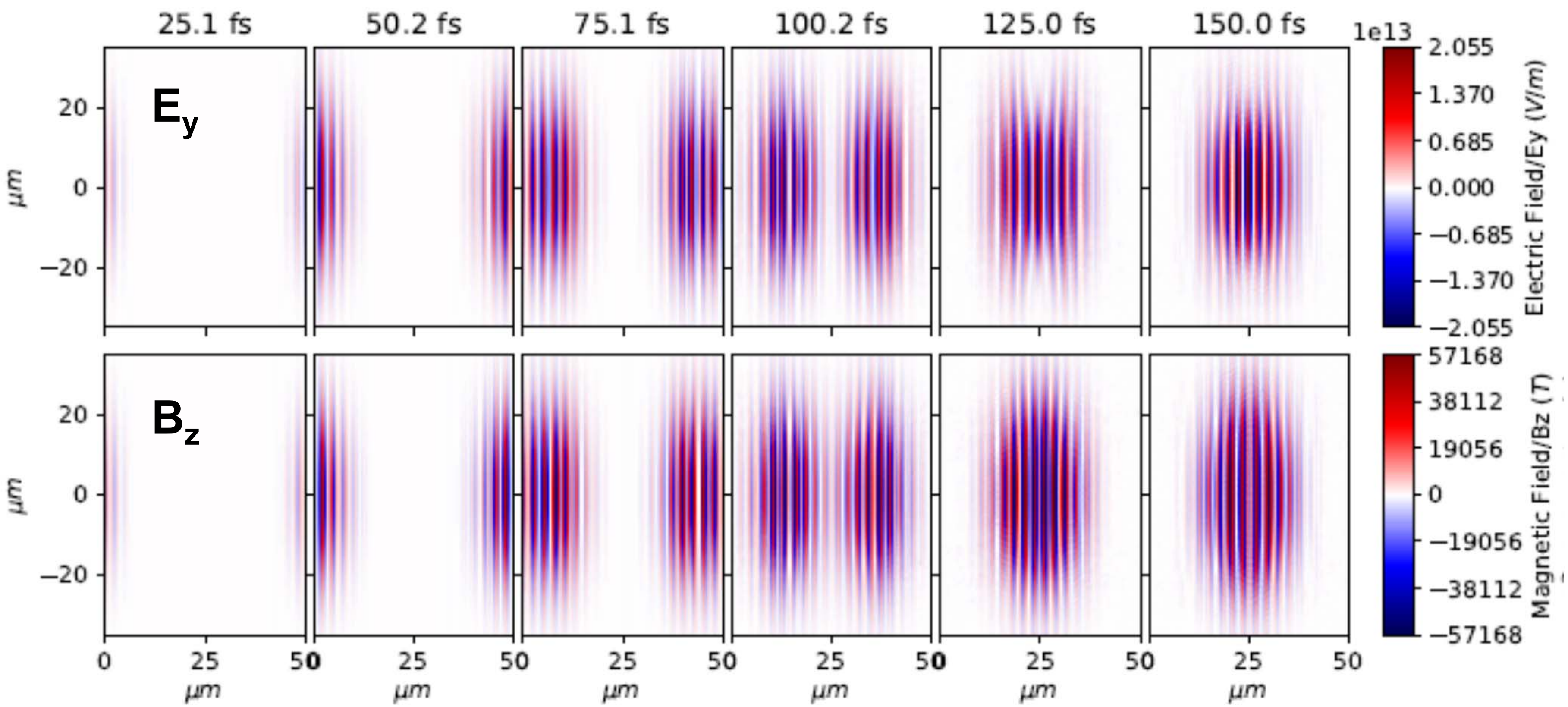
European Laser Infrastructure – Szeged, HU

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

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



Laser Wake Field Collider



The electric field, E_y (top) and magnetic field, B_z (bottom) in a Laser Wake Field (LWF) wave formed by irradiation from the $\pm$x- direction. The rest number density of the H target is n_H = 2.13 10^{25}/m^3 = 2.13 10^{19}/cm^3. The laser beam wavelength is λ = 1μm. The LWF wavelength is about 20 λ. **Pulse energy is 19.6 J**

[Papp, I., et al., NAPLIFE Collaboration, arXiv-2009.03686]

Validation tests – Target manufacturing

Two basic principles are tested on non-fusion material targets at low energies

- **Multilayer targets**
- **Implanted with nano-antennas**
- **Absorption diagnostics at Wigner RCP**

- **Other diagnostic methods at GSI/PHELIX for material technology**
- **Using different material targets w/wo implanted with nano-antennas**
- **Rapid volume transitions in various materials**
- **Connected with FIAS (Project partner) & Wigner RCP – theory.**

Thus, ultra-relativistic heavy ion physics lead to discovery Quark Gluon Plasma (QGP), but also to advances in **(i)** relativistic fluid dynamics (RFD).

With **(ii)** nano technology this may revolutionize in a simple, and **(iii)** affordable 1D geometry the technological development of ➔

Nanoplasmonic Laser Inertialconfinement Fusion Experiment (NAPLIFE)

*****