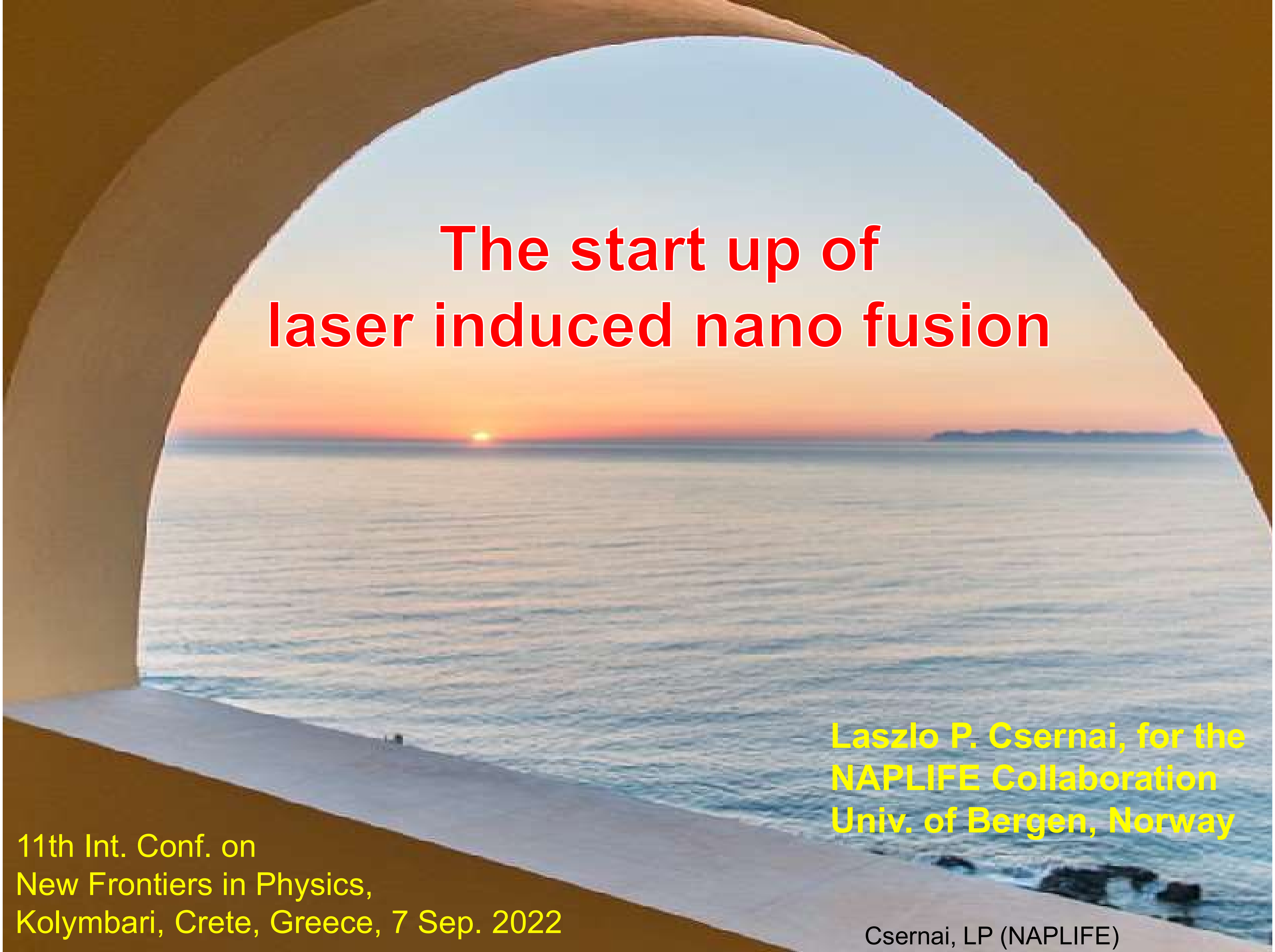


The start up of laser induced nano fusion

Laszlo P. Csernai, for the
NAPLIFE Collaboration
Univ. of Bergen, Norway

11th Int. Conf. on
New Frontiers in Physics,
Kolymbari, Crete, Greece, 7 Sep. 2022

NAPLIFE Collaboration – Participants - ELKH, National Res. Lab.

Prof. Dr. Peter J. Lévai, Prof. Dr. Laszlo P. Csernai, Prof. Dr. Norbert Kroó, Prof. Dr. Tamás S. Biró, Dr. Márk Aladi, Dr. Roman Holomb, Dr. Miklós Kedves, **Dr. Archana Kumari, Dr. István Papp**, Dr. Péter Petrik, Dr. Péter Rácz, Dr. Béla Ráczkevi, Dr. István Rigó**, Dr. Miklós Veres**, Anett Szeledi, **Ágnes Nagyné Szokol**; Prof. Gábor Galbács, Dr. Balázs Bánhelyi, Dr. Mária Csete, Dr. Attila Czirják, Olivér Antal Fekete, Péter Földi, Emese Tóth, András Szenes, Dávid Vass; Prof. Dr. Attila Bonyár, **Dr. Judit Kámán**, Alexandra Borók; Zsolt Fogarassy, Kolos Molnár, Dr. Péter Dombi Dr. Melinda Szalóki, Laura Juhász; Prof. Dr. Horst Stoecker, Dr. Leonid Satarov, Dr. Anton Motornenko; Prof. Dr. Larissa Bravina, Dr. Evgeny E. Zabrodin; Prof. Dr. Igor N.Mishustin, Prof. Dr. Daniel D. Strottman, Dr. Csaba Tóth, Prof. Dr. Dénes Molnár, Shereen Zangana (~> 40)

How to remedy the problems of present Laser Fusion trials of NIF@Livermore & OMEGA@Rochester

Two ideas are combined by L.P. Csernai, N. Kroo, I. Papp:

[Patent # P1700278/3] (2017)

Problems:

- Rayleigh-Taylor (RT) 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]

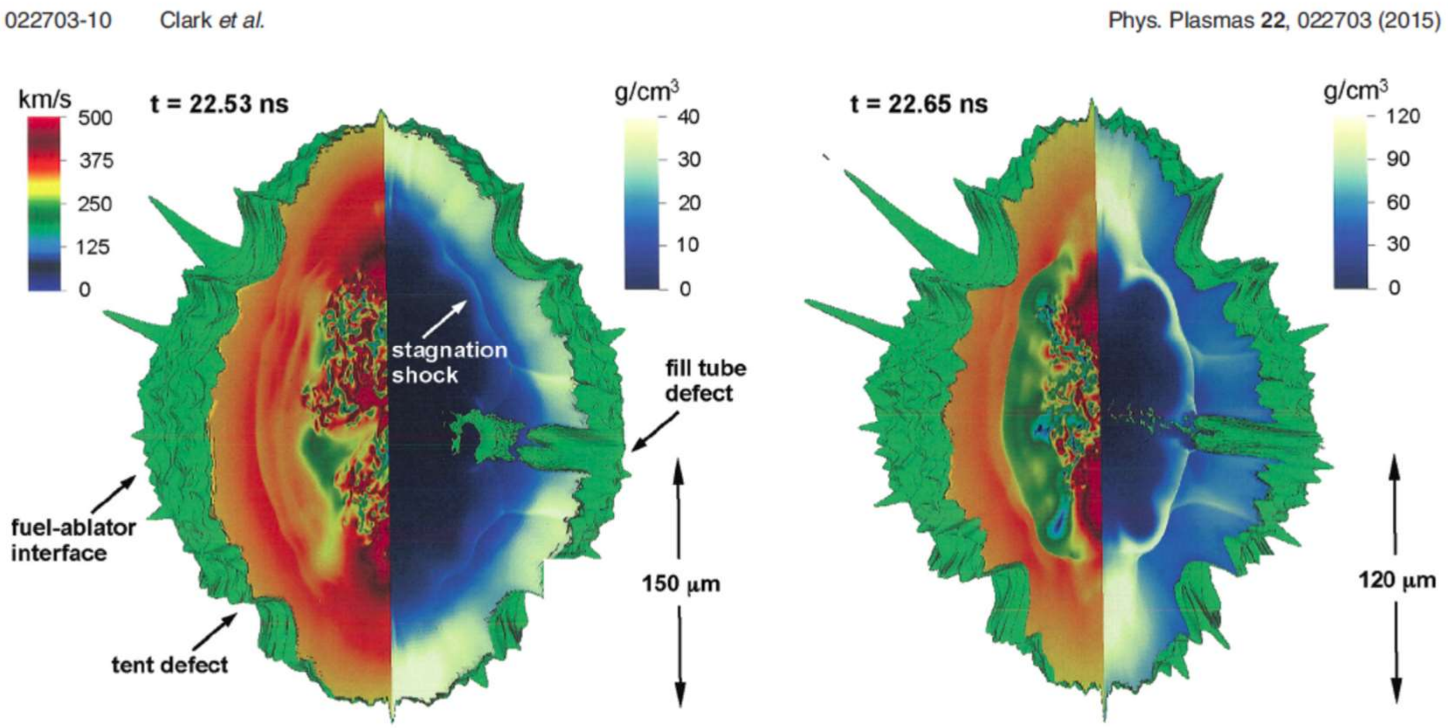
But let us go back in history →

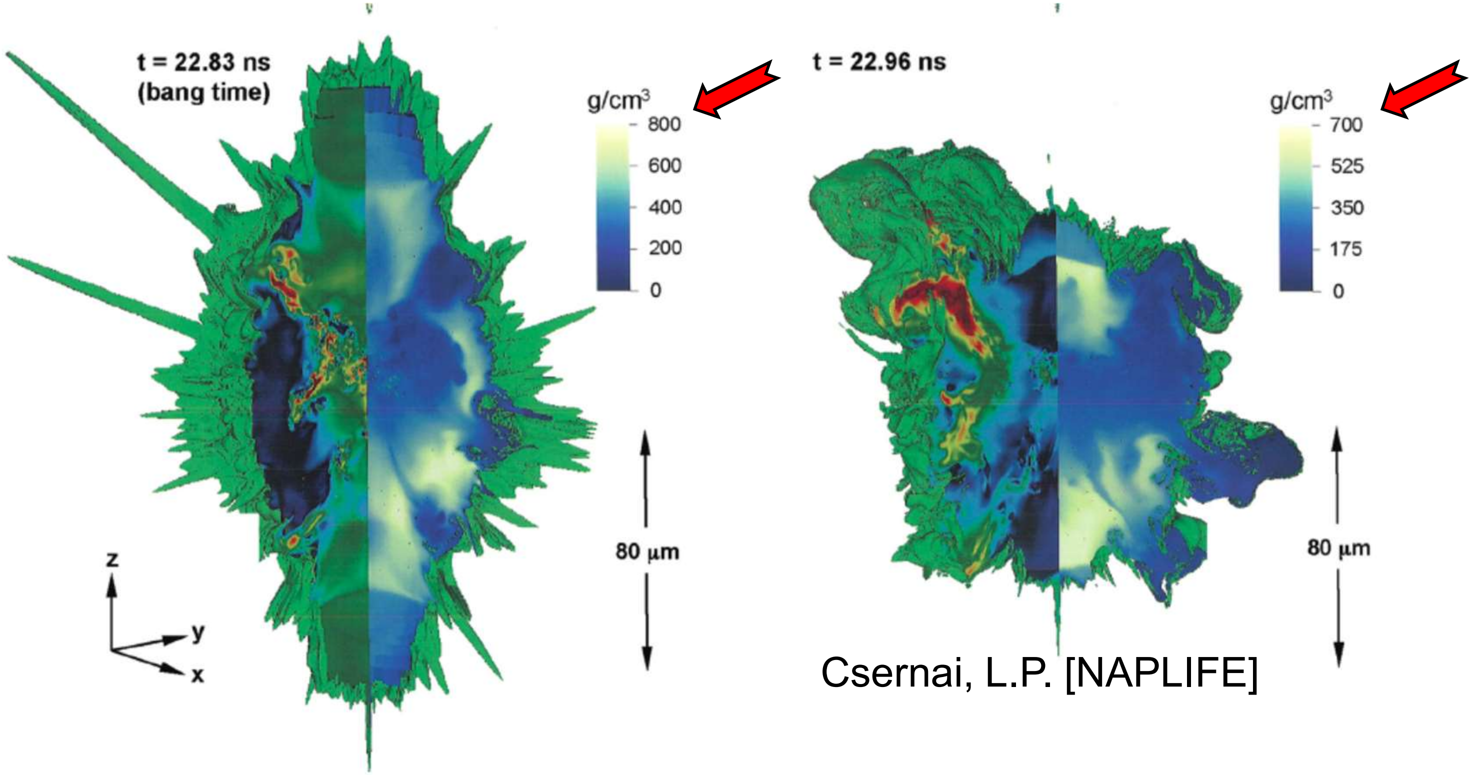
Kőszeg, September 14**, 2019** - Int. Workshop on Collectivity
First meeting on the NAPLIFE project (12 people)

Rayleigh-Taylor Instability

[Clark et al., Phys. Plasmas, **22**, 022703 (2015).]

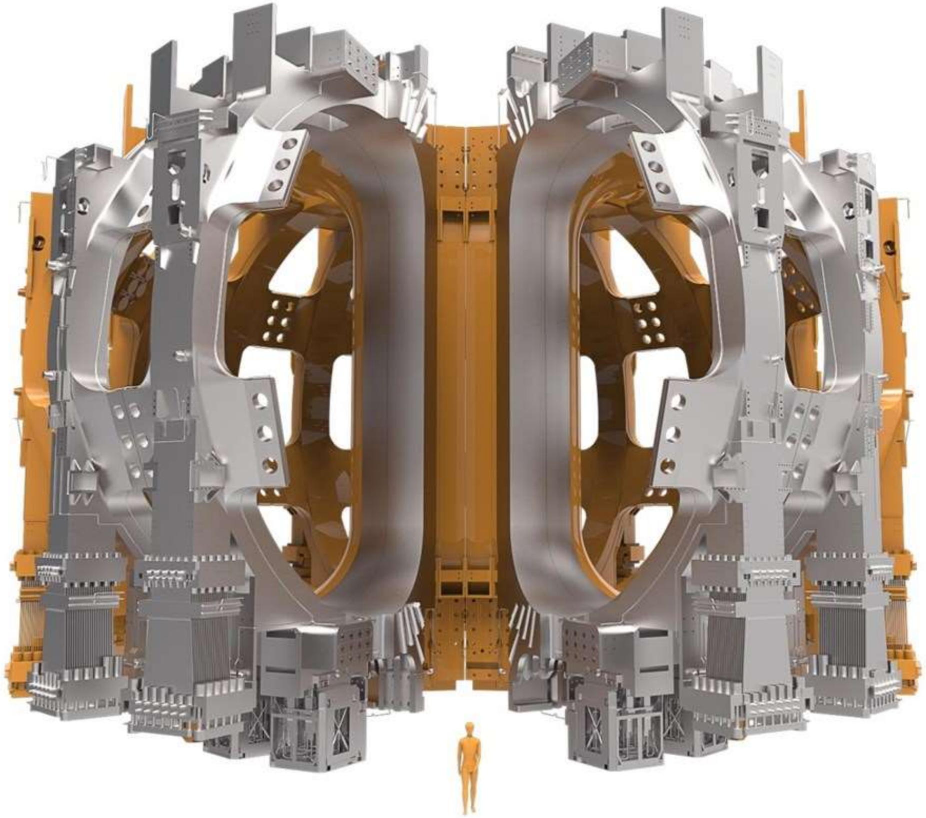
Snapshots of 3D simulation
22.53ns: peak impl. Velocity
23.83ns: bang, max compr.
22.96ns: jet out, up left
Green surface: Ablator/DT-f.
Peaks: Ablator defects
Colours:
Left: fluid speed
Right: matter density





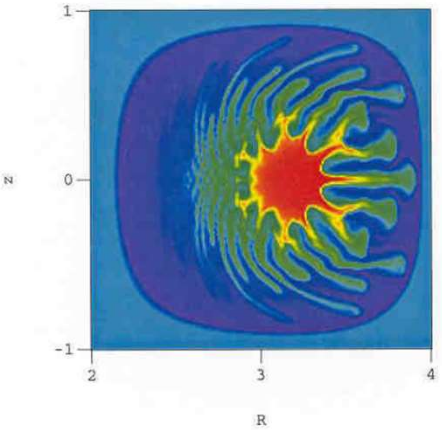
~adiabatic compression ➔ 80 µm & heating

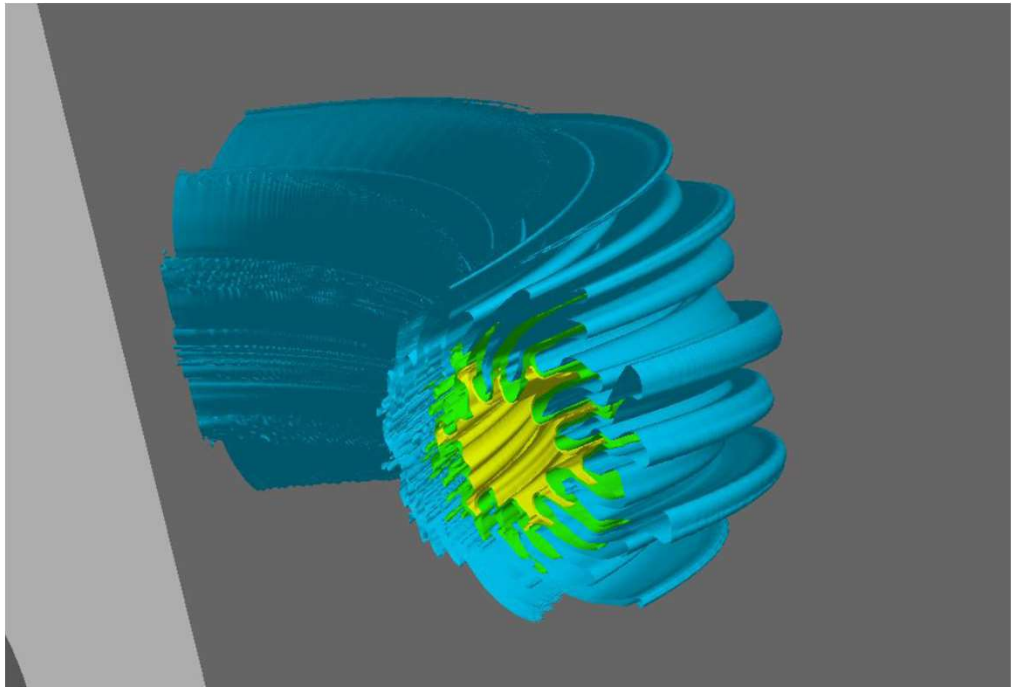
ITER torus



Under construction
Torus: 6x10x18m, V=830 m^3,
Q=10, planned
500MW\8min, plan
2008-2018 ??? >

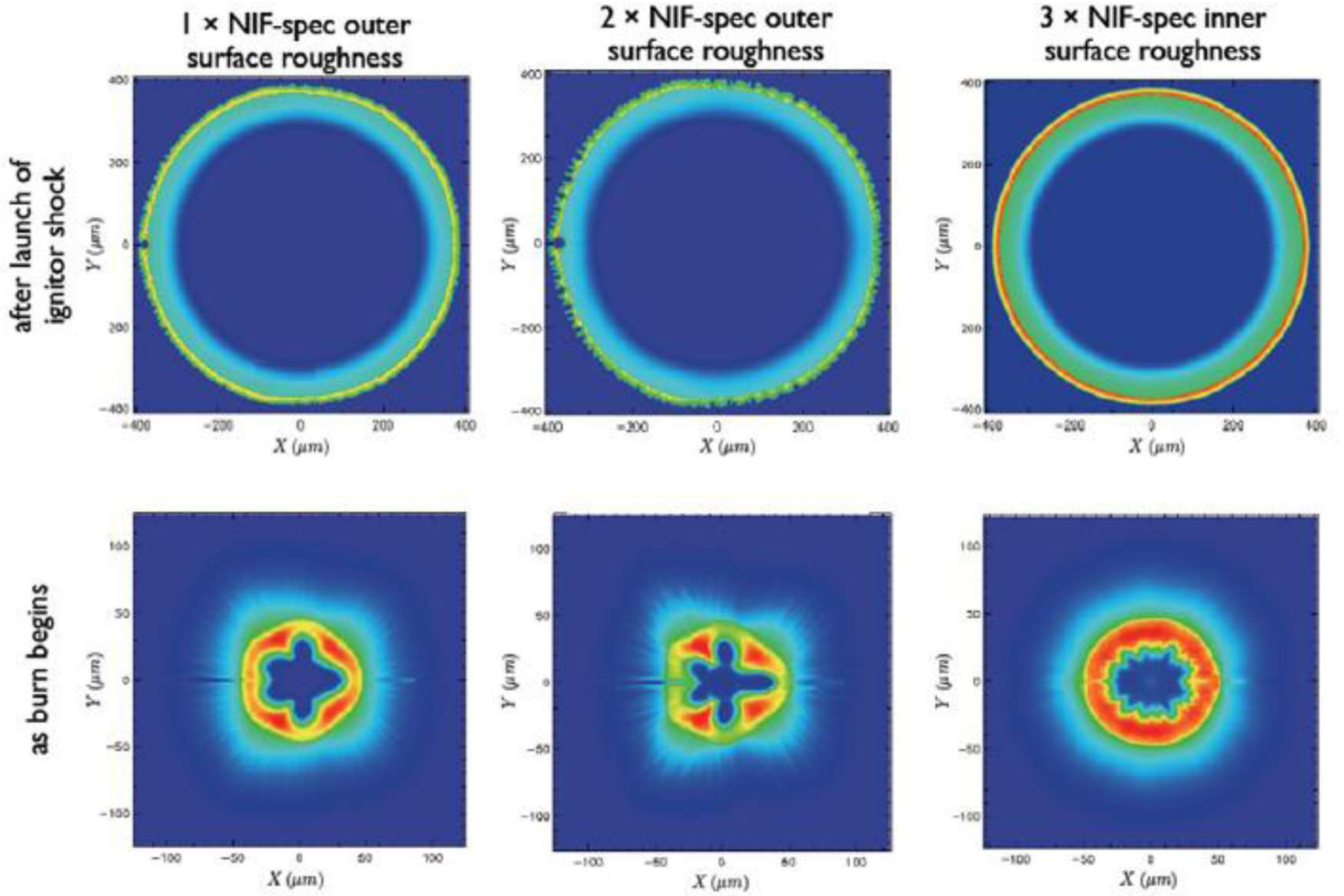
RT instability





Csernai, L.P. [NAPLIFE]

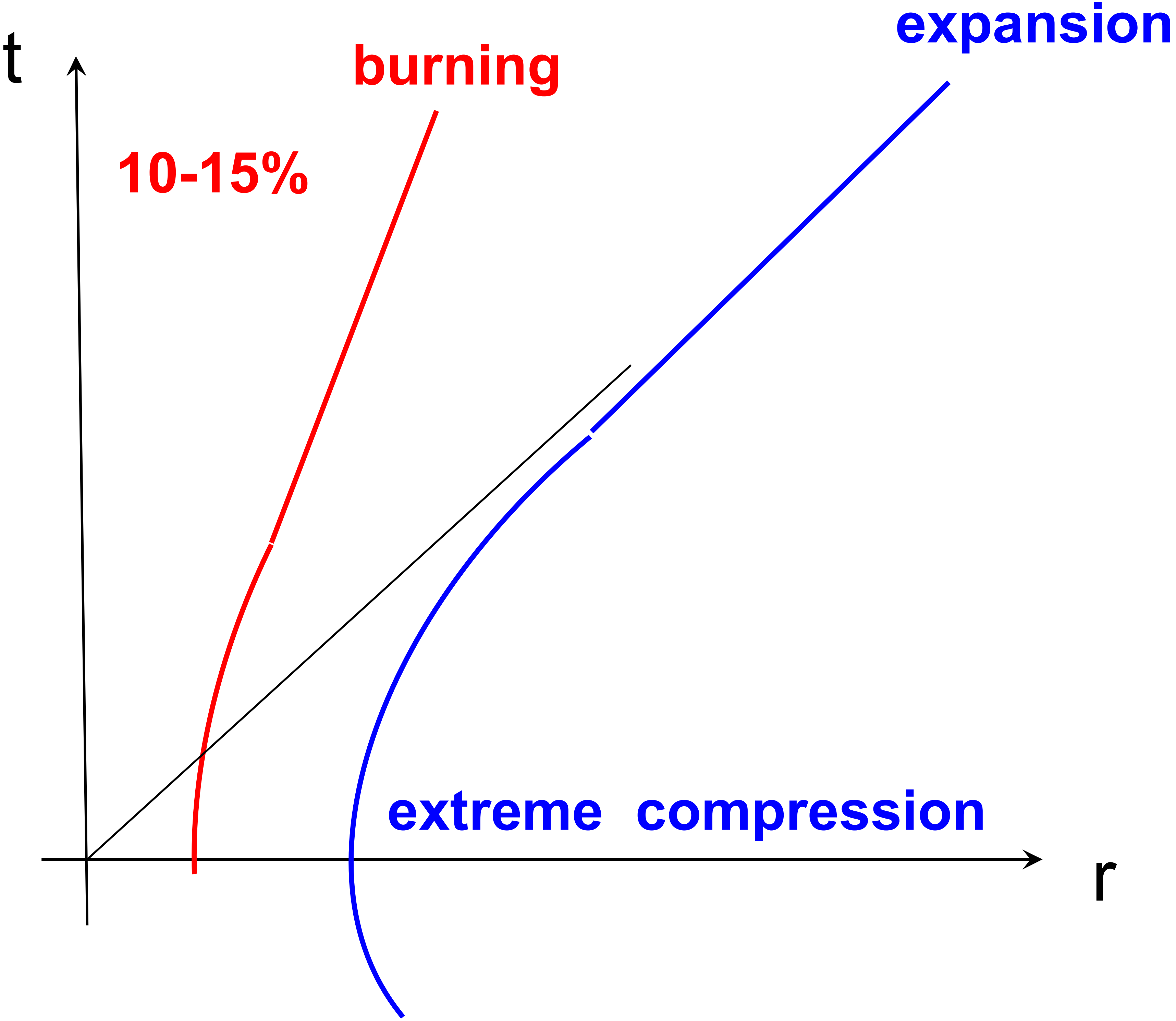
NIF – RT instability



The target is compressed to density ~ 700 g/cm^3.

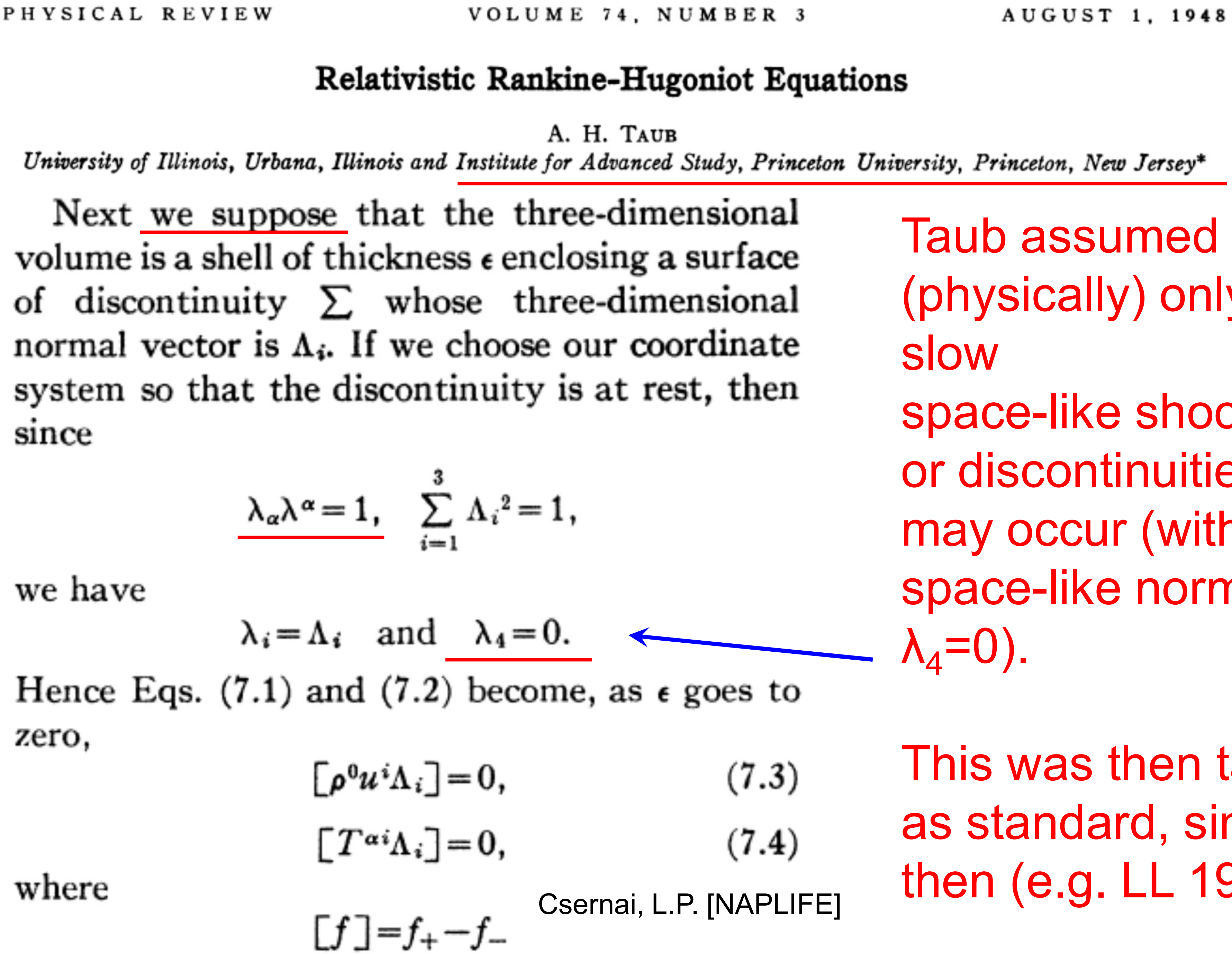
But, although an ablator layer is used, only ~ **10%-of the target** is ignited. Elsewhere the surface protruded as “potato from the potato press”: **RT- instability.**

Slow propagation of burning


t
burning
expansion
10-15%
extreme compression
r

How can we prevent it
Idea - #1

[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,

$$[\rho^0 u^i \Lambda_i] = 0, \tag{7.3}$$

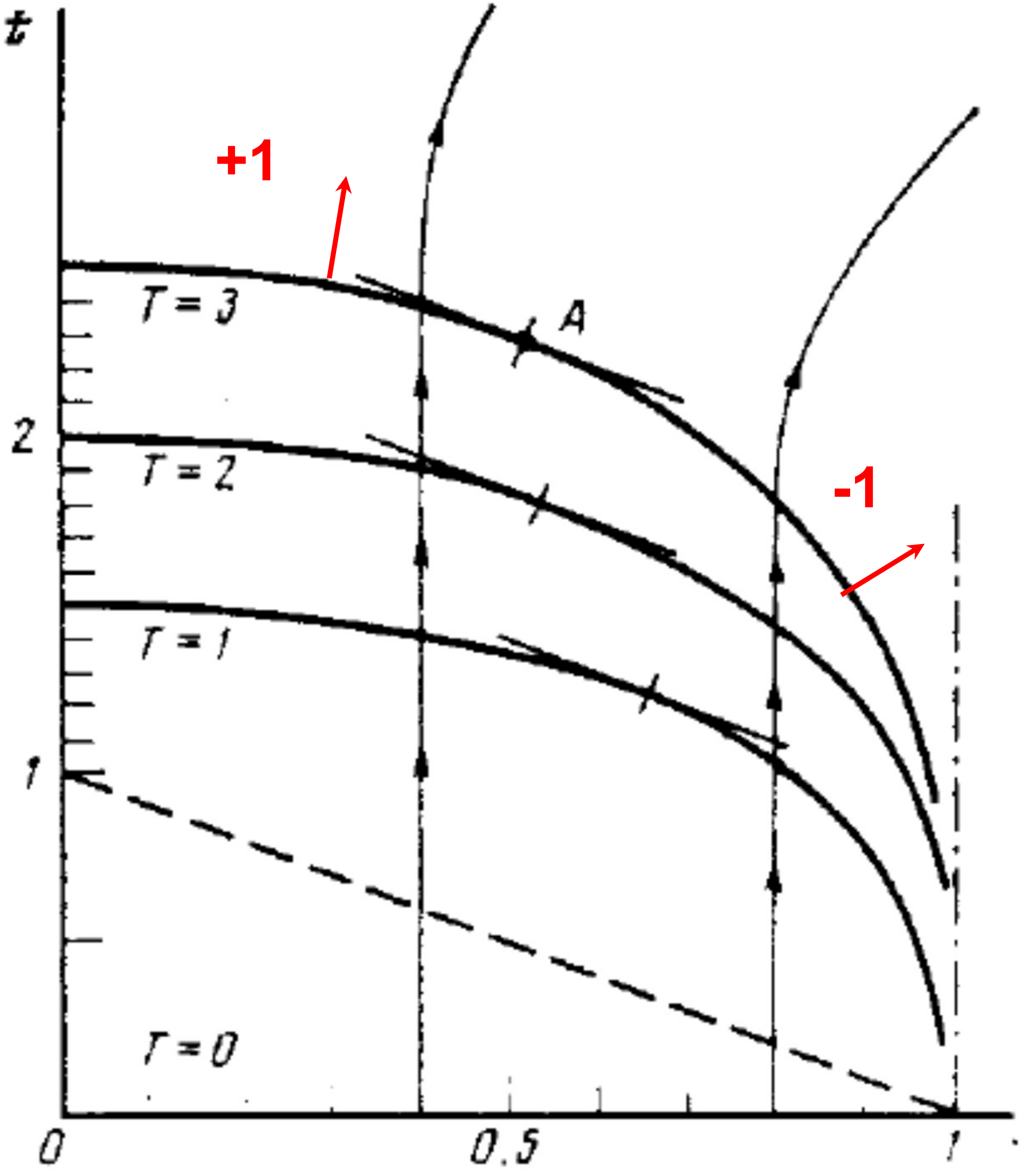
$$[T^{\alpha i} \Lambda_i] = 0, \tag{7.4}$$

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**)]

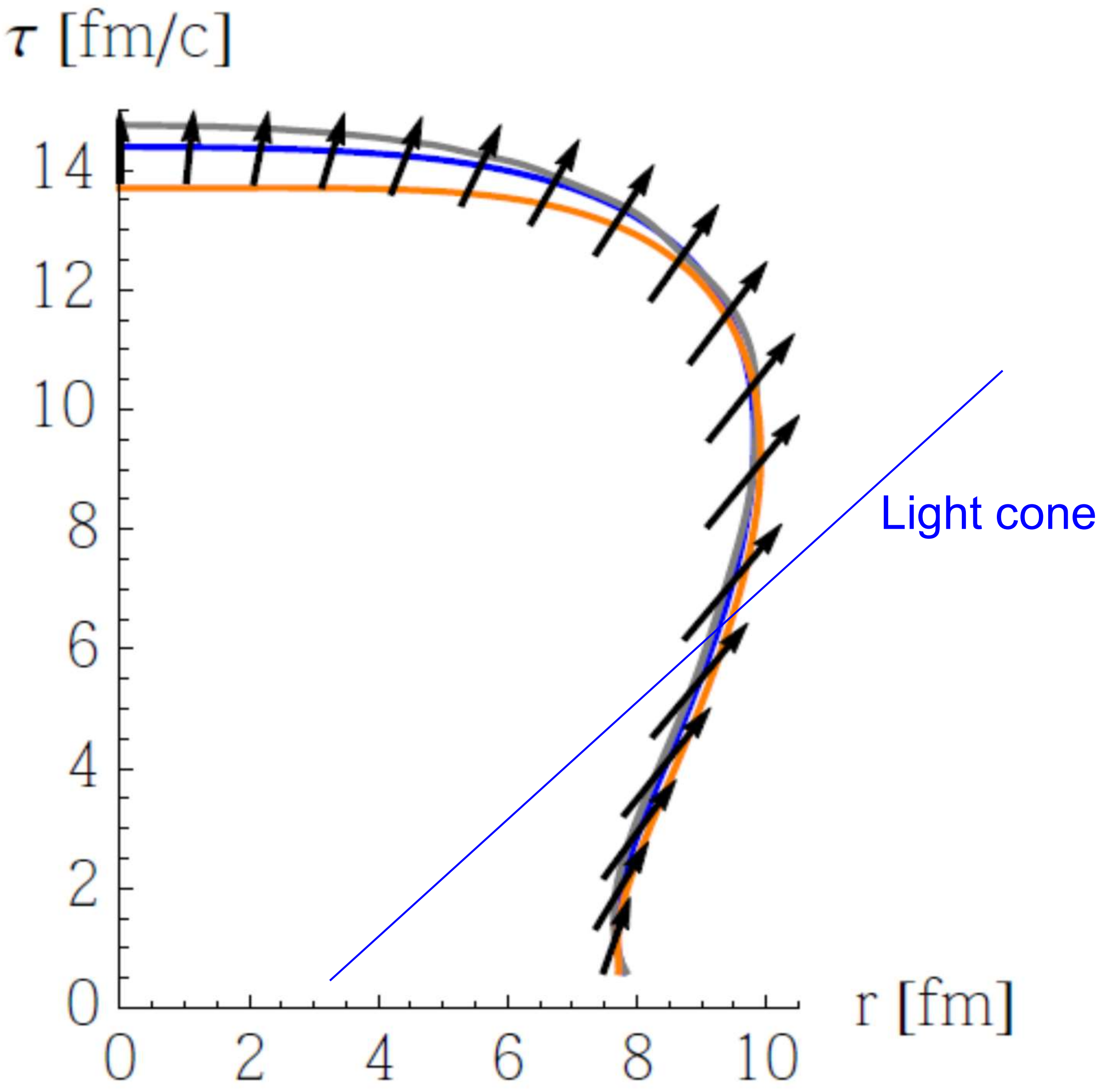
$$\lambda_\alpha \lambda^\alpha = \pm 1$$

Л. П. Чернаи

ДЕТОНАЦИЯ НА ВРЕМЕНИПОДОБНОМ ФРОНТЕ ДЛЯ РЕЛЯТИВИСТСКИХ СИСТЕМ

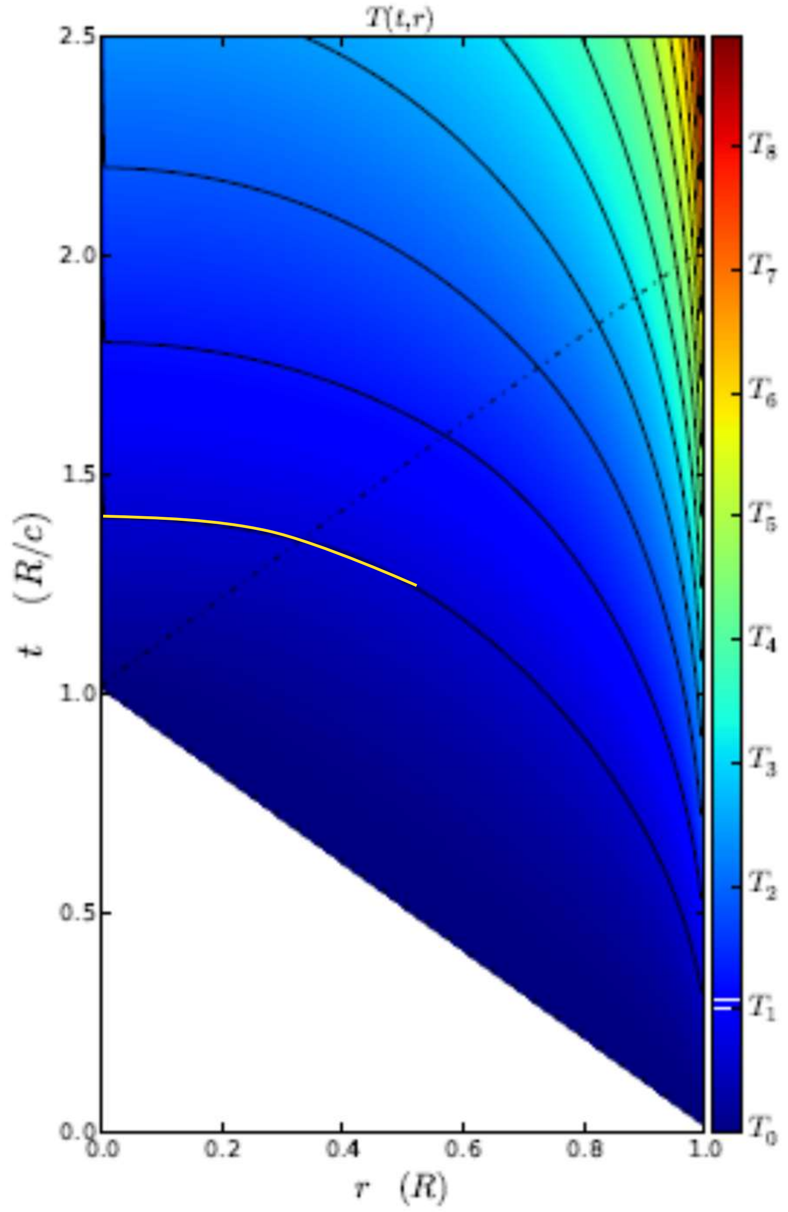
Журнал экспериментальной и теоретической физики

1987



@ CERN in High energy heavy ion collisions

[Stefan Floerchinger, and Urs Achim Wiedemann, Phys. Rev. C 89, 034914 (2014)]



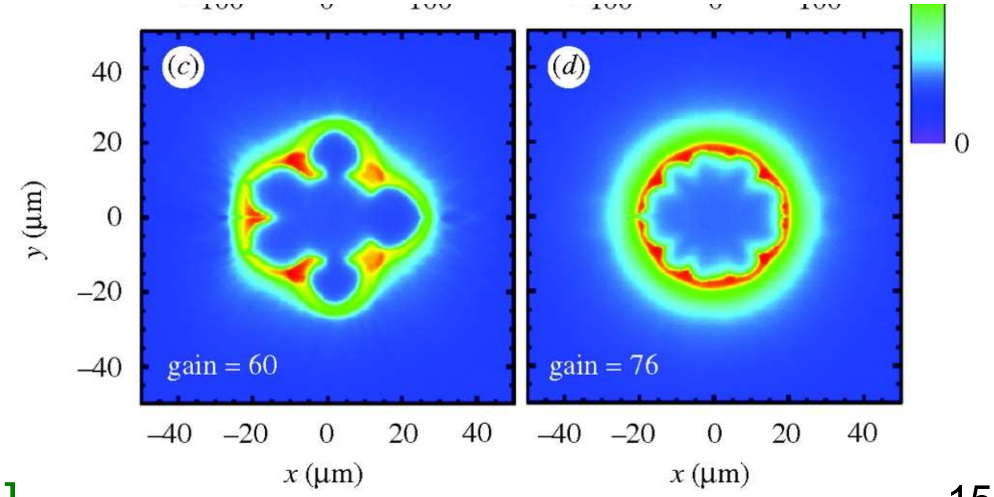
Fusion reaction:

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).

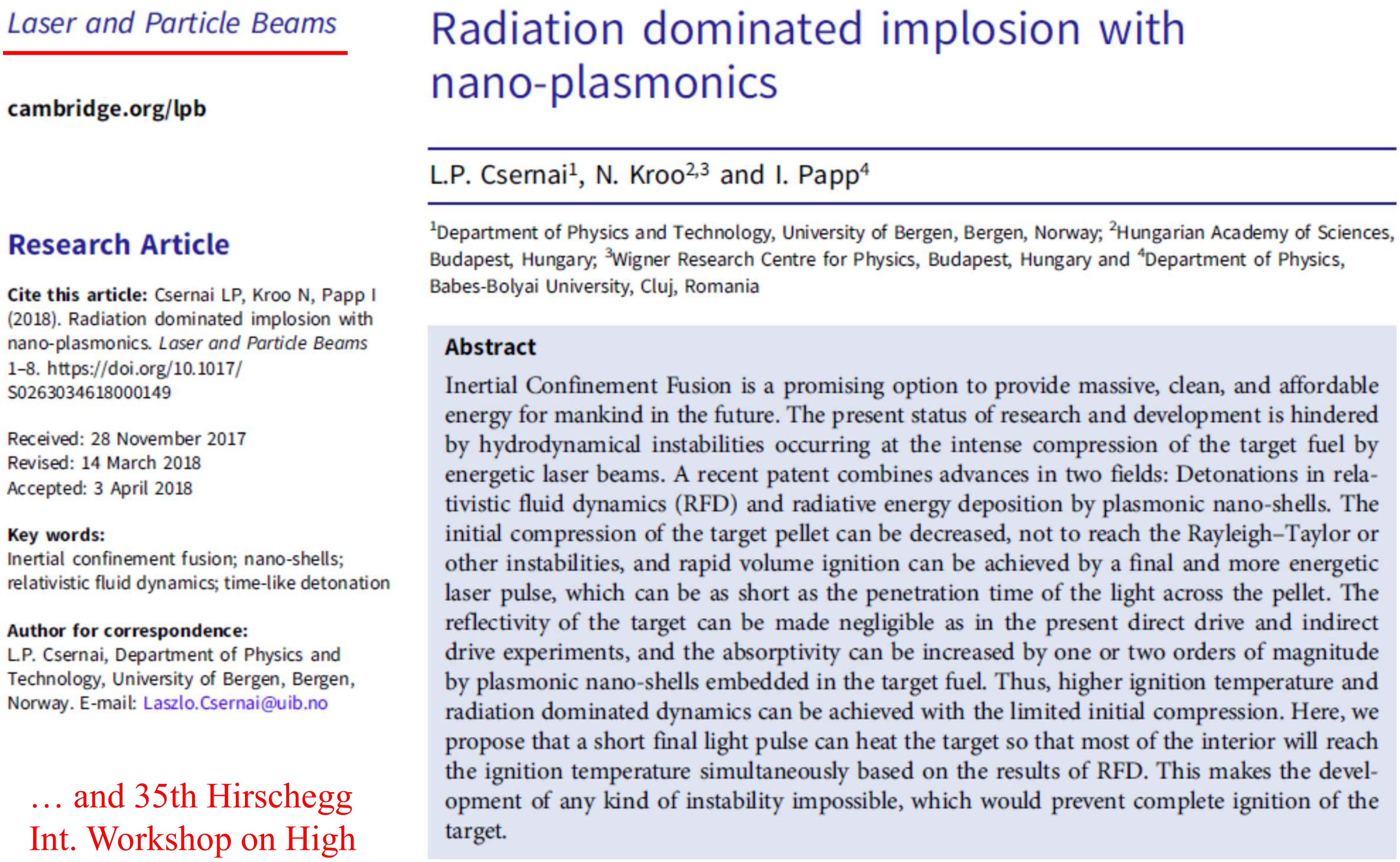
Not too good, but better than:



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

How can we realize it
Idea - #2

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

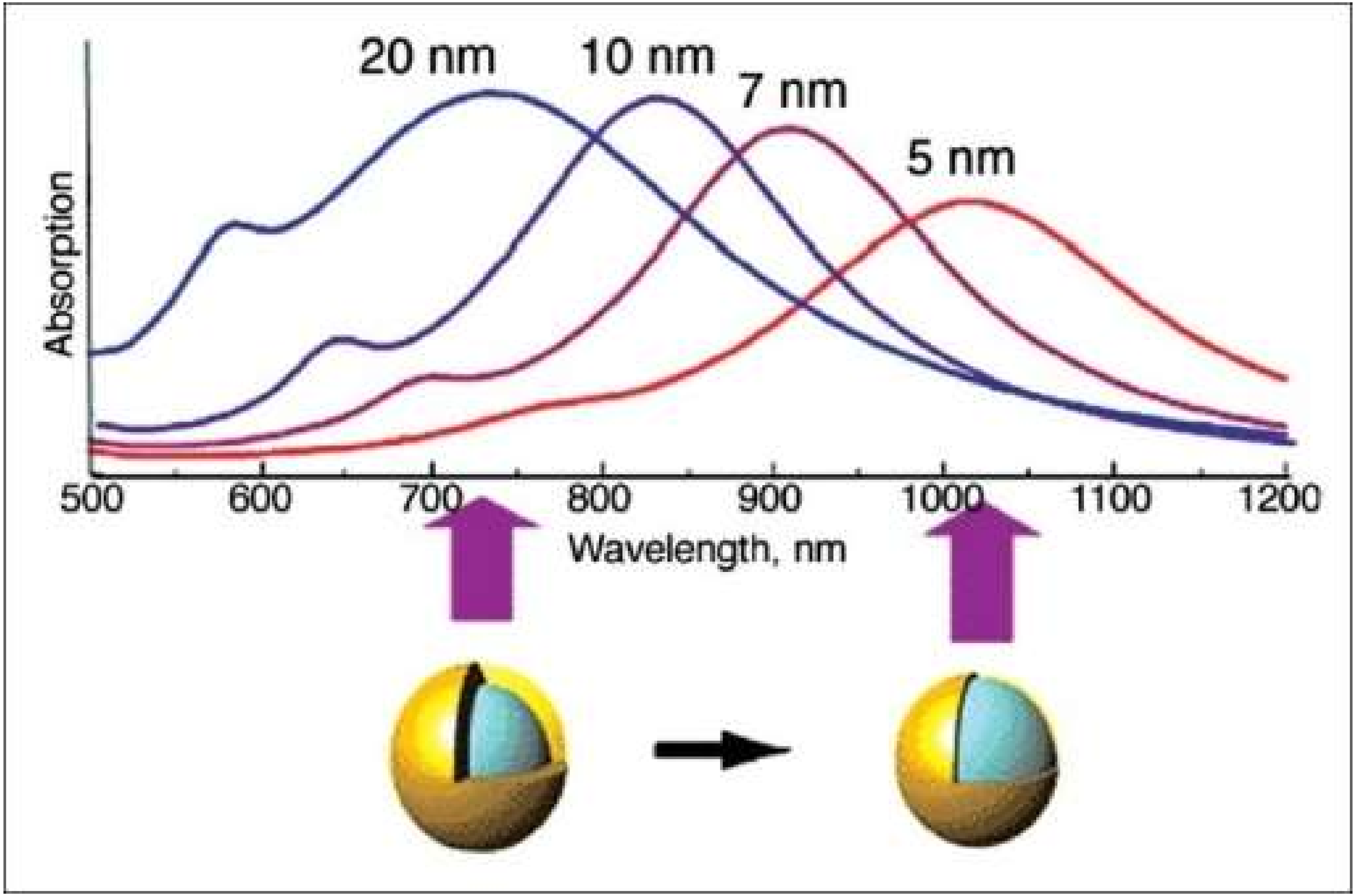
Author for correspondence:
L.P. Csernai, Department of Physics and Technology, University of Bergen, Bergen, Norway. E-mail: Laszlo.Csernai@uib.no

Abstract

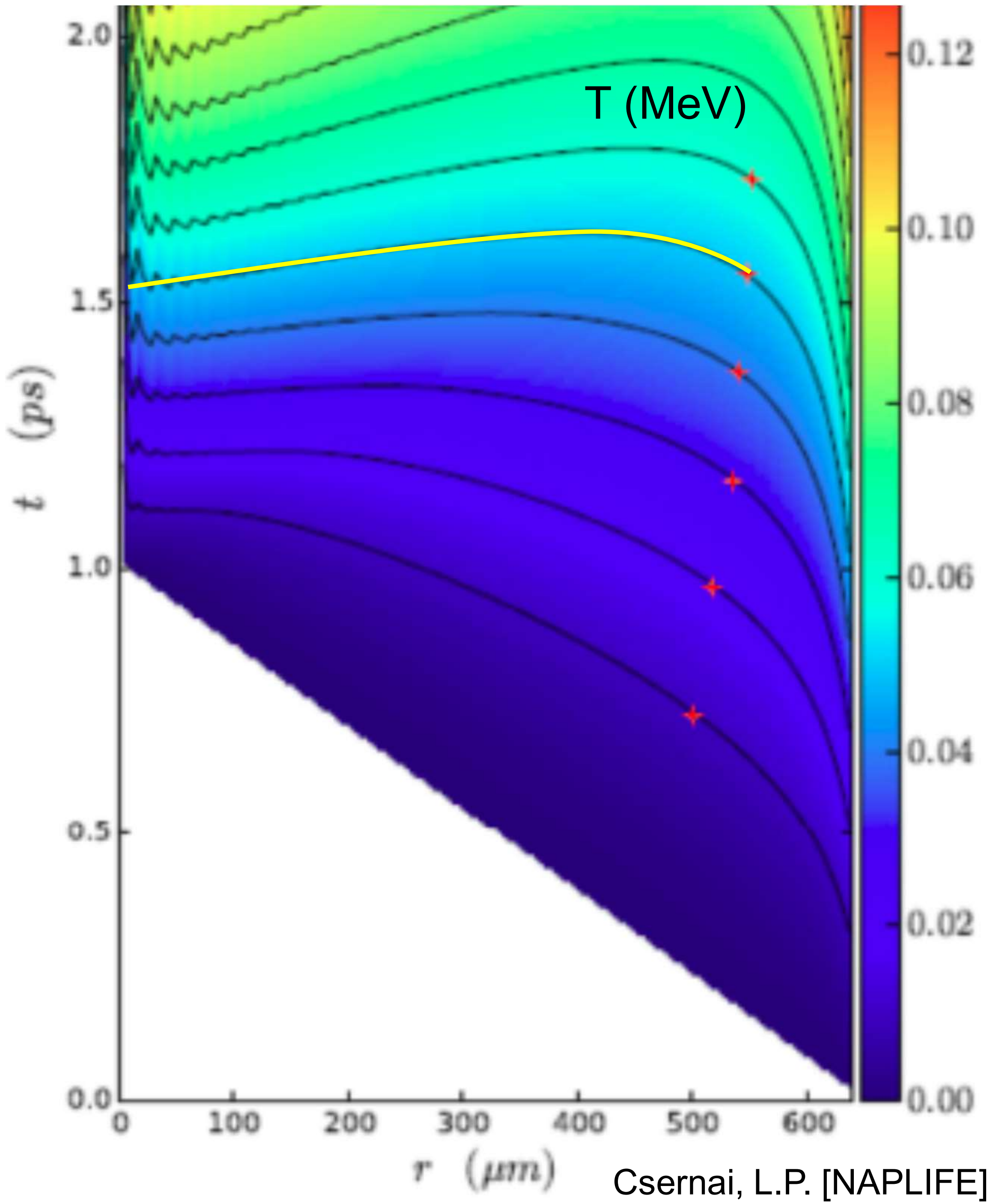
Inertial Confinement Fusion is a promising option to provide massive, clean, and affordable energy for mankind in the future. The present status of research and development is hindered by hydrodynamical instabilities occurring at the intense compression of the target fuel by energetic laser beams. A 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



Csernai, L.P. [NAPLIFE]



Csernai, L.P. [NAPLIFE]

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!**

How can we realize it simpler and with less expense

Thick coin like flat target & Two beams only

Thickness of the target is: h

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

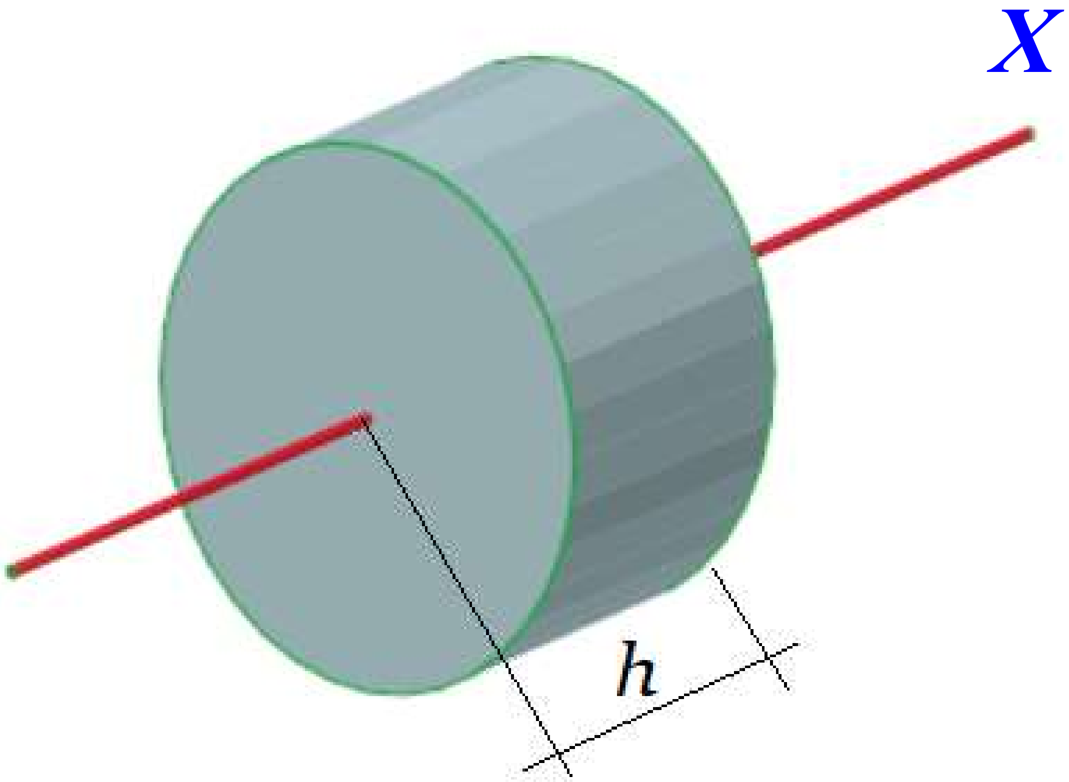
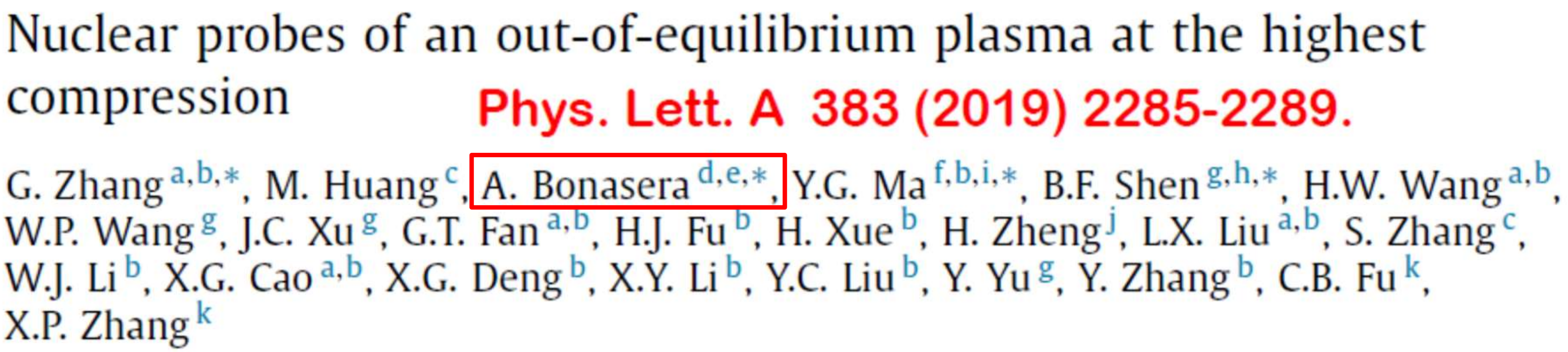


Figure 1: (color online) The target still should be compact to minimize the surface effects. The irradiation is performed along the $x-$axis from both sides towards the target. The laser beam should be uniform hitting the whole face of the coin shaped target.

[Csernai et al., (**NAPLIFE** Collaboration) *Phys. of Wave Phenomena,* **28** (3), 187-199 **(2020).**]

Experimental test of similar configuration @ ShenGuang-II Up, Shanghai :



Nuclear probes of an out-of-equilibrium plasma at the highest compression

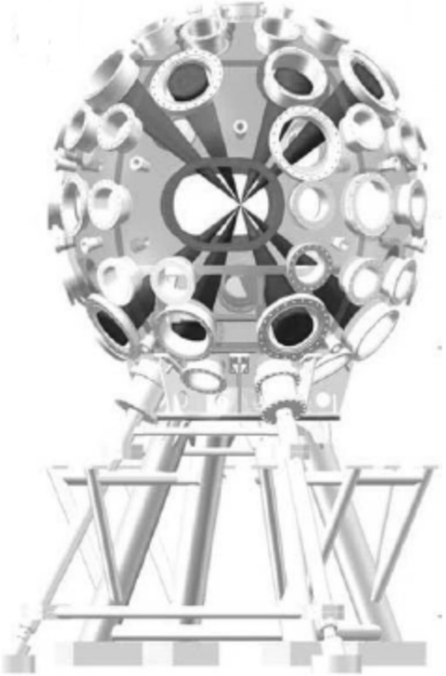
Phys. Lett. A 383 (2019) 2285-2289.

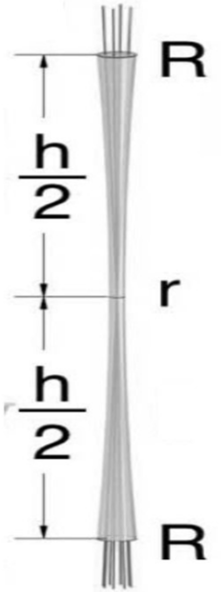
G. Zhang[a,b,*], M. Huang[c], A. Bonasera[d,e,*], Y.G. Ma[f,b,i,*], B.F. Shen[g,h,*], H.W. Wang[a,b], W.P. Wang[g], J.C. Xu[g], G.T. Fan[a,b], H.J. Fu[b], H. Xue[b], H. Zheng[j], L.X. Liu[a,b], S. Zhang[c], W.J. Li[b], X.G. Cao[a,b], X.G. Deng[b], X.Y. Li[b], Y.C. Liu[b], Y. Yu[g], Y. Zhang[b], C.B. Fu[k], X.P. Zhang[k]

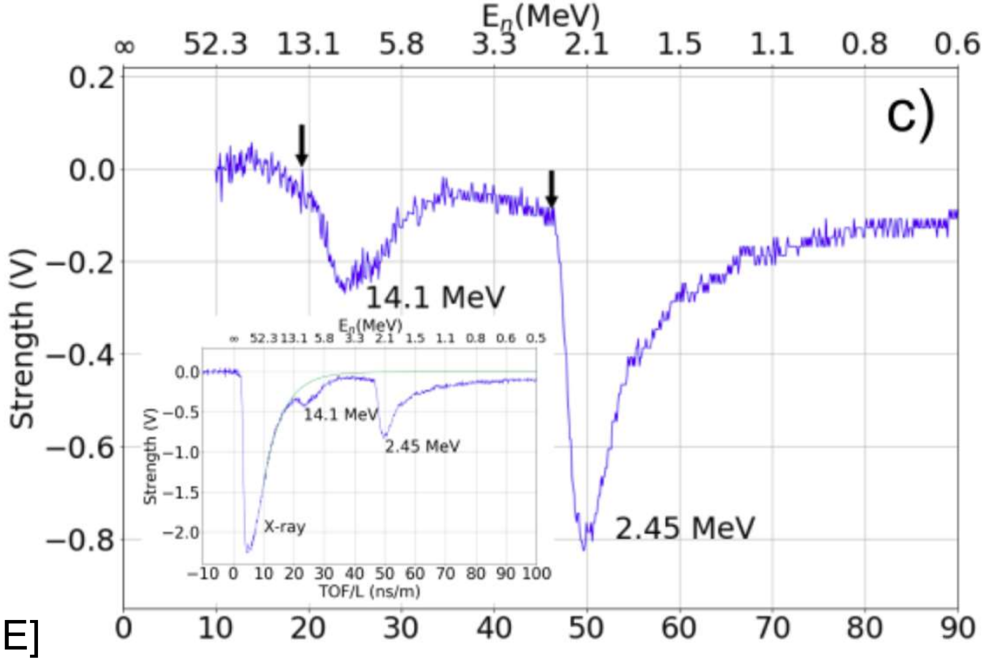
4 (up) + 4(down) lasers
Target thickness, h (3.6μm-1mm)
& radius, R, (150-400μm) were
varied.

Total pulse energy 1.2kJ (2ns) for 8 beams.
Shortest (250ps) pulses -> 100s MeV ions >
non-thermal distr. = directed ion acceleration

Typical fusion neutron energies were measured & used to extract the target density.







Csernai, L.P. [NAPLIFE]

Experimental test of similar configuration @ ShenGuang-II Up, Shanghai :

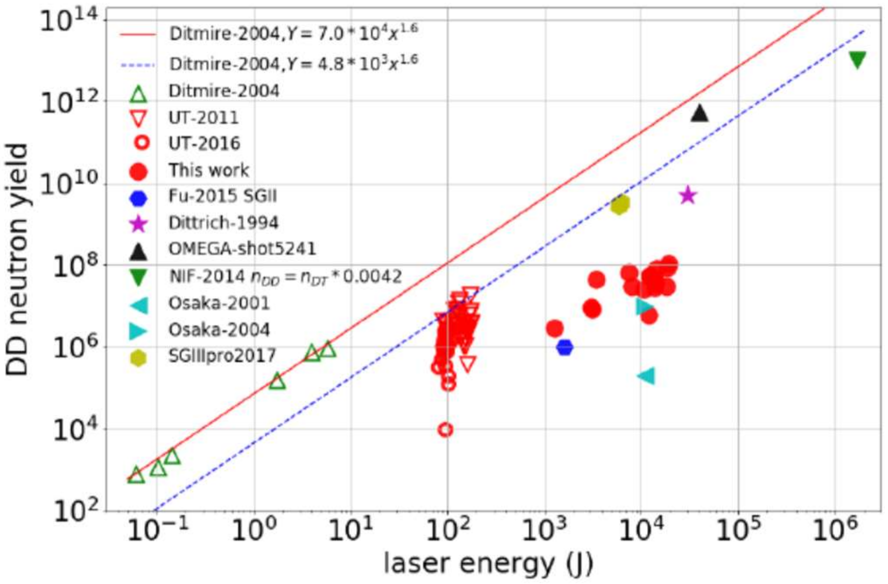


Figure 3: (color online) Fusion yield as function of laser energy. Different experimental results Ditmire-2004[40], UT-2011[20], UT-2016[19], Fu-2015 SGII[45], Dittrich-1994[49] , NIF-2014[48] , Osaka -2001[46], Osaka-2004[47], OMEGA-shot5241[41]and SGIIIpro2017[42] are indicated in the inset.

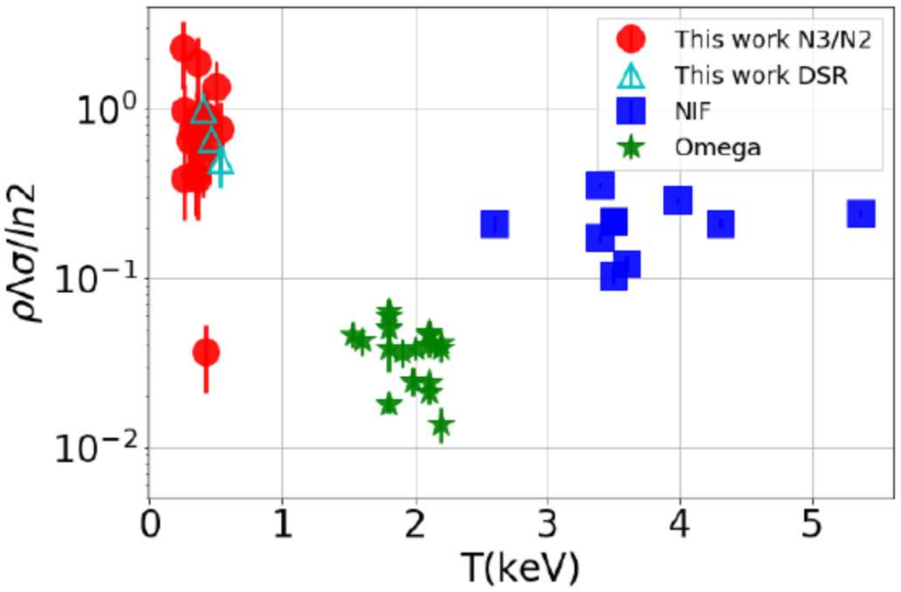
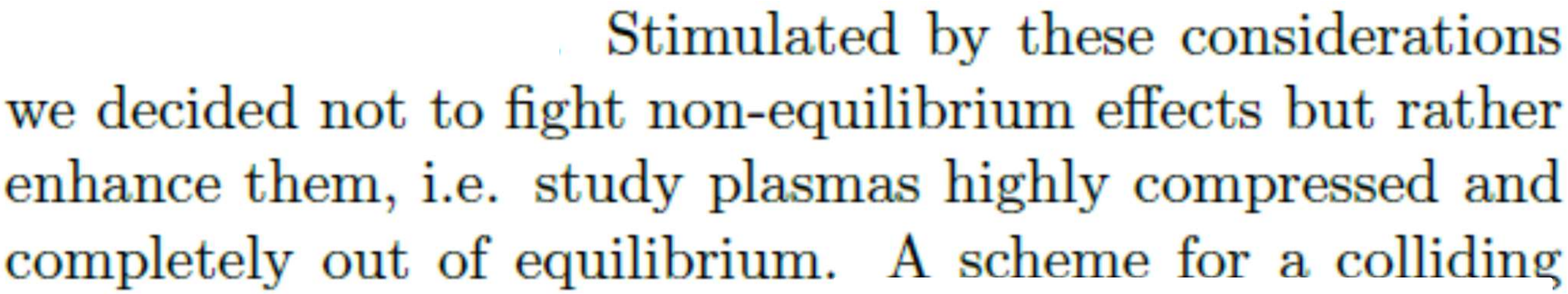
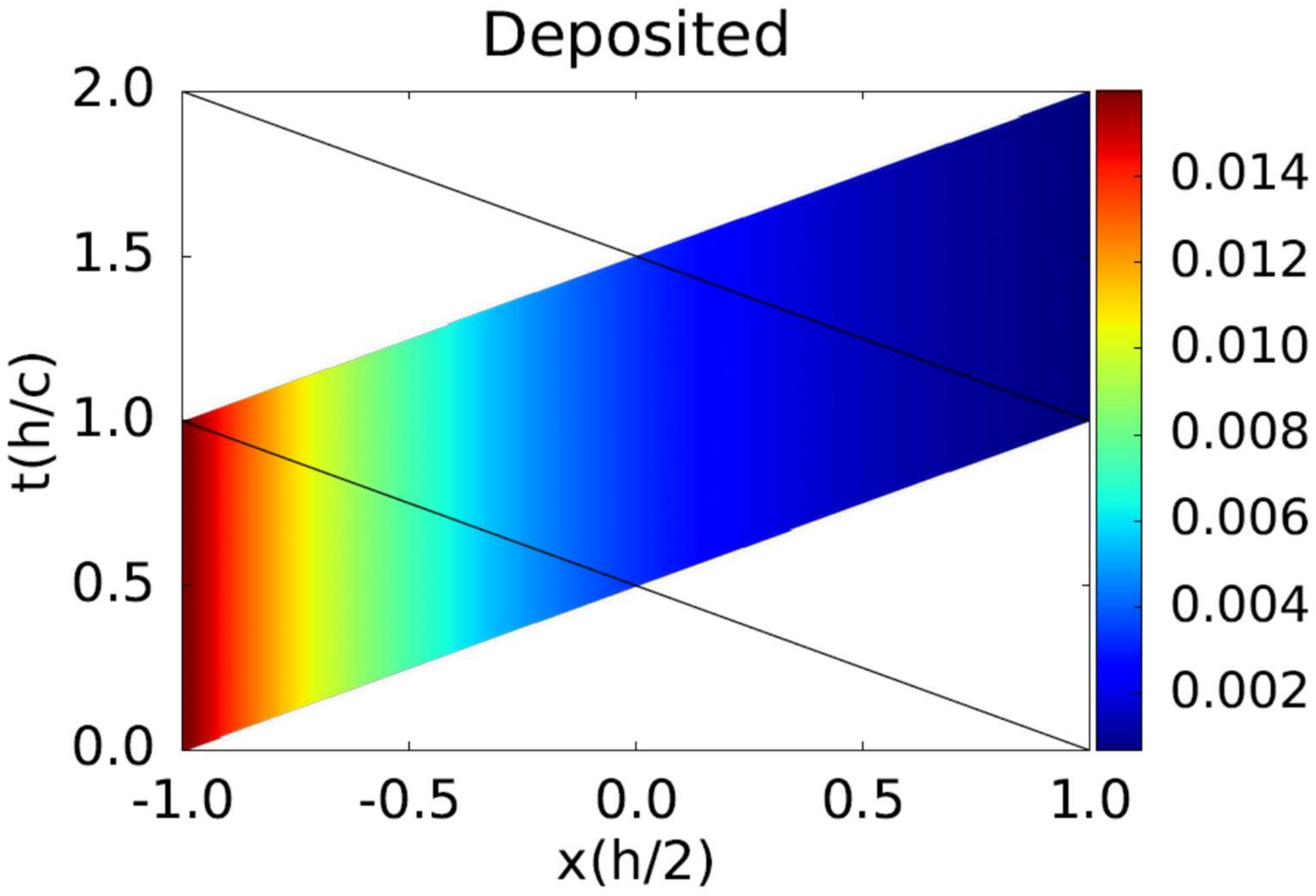


Figure 4: (color online) $\Lambda\rho\sigma/\ln 2$ obtained from eq.(4) vs T from eq.(1). Omega and NIF data are derived from the experiments[25], using the Down Scatter Ratio[23, 21]. Our results using the DSR method (N_4/N_3) are given by the open triangle symbols in good agreement with the N_3/N_2 ratios.



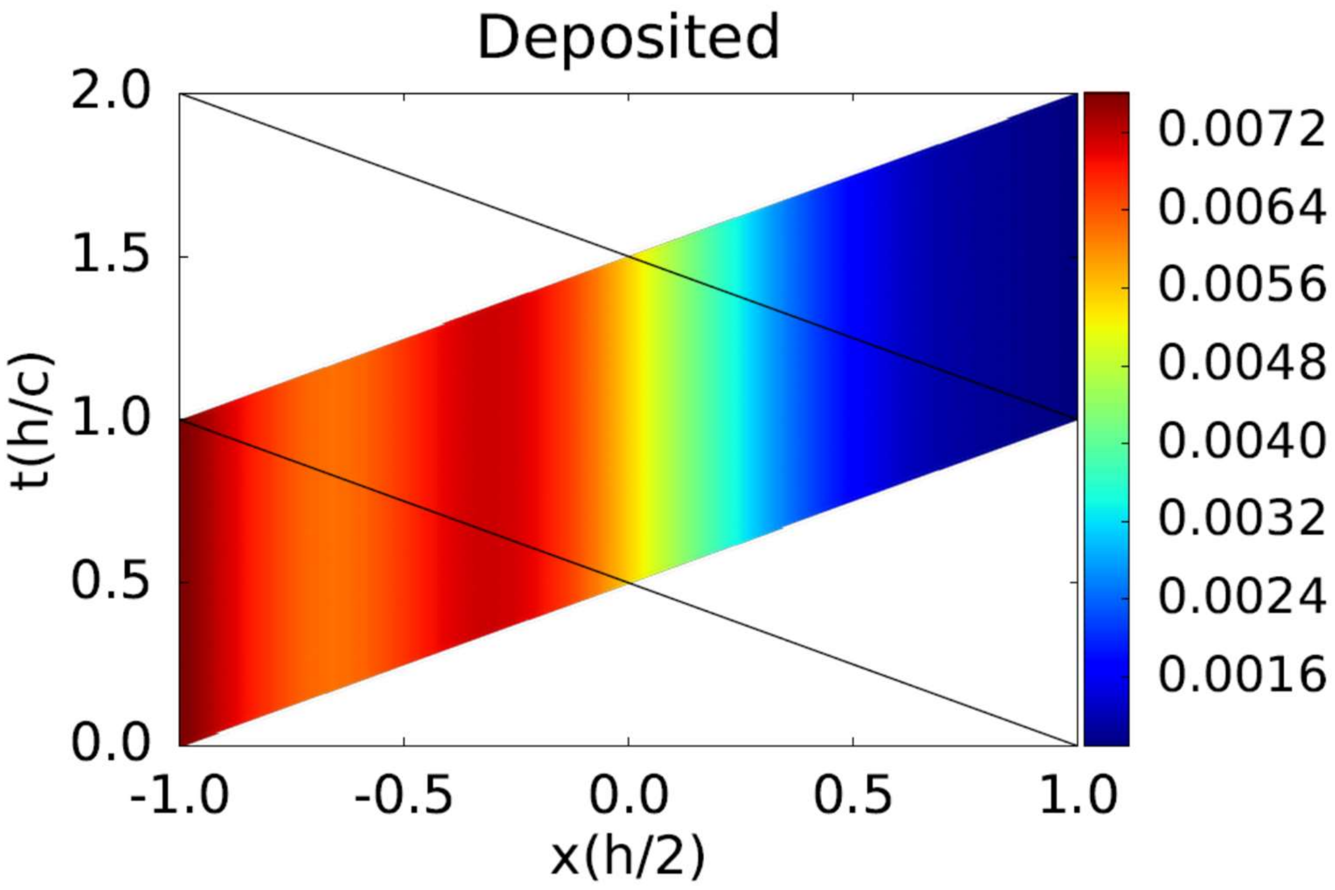
Stimulated by these considerations we decided not to fight non-equilibrium effects but rather enhance them, i.e. study plasmas highly compressed and completely out of equilibrium. A scheme for a colliding

However,
- no simultaneous ignition, and
- no nano-antennas up to now !



Without nano antennas

The deposited energy from laser irradiation from one side only. The absorption is constant, this leads to an exponentially decreasing energy deposition, and only a negligibly small energy reaches the opposite end of the 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.

With nano antennas

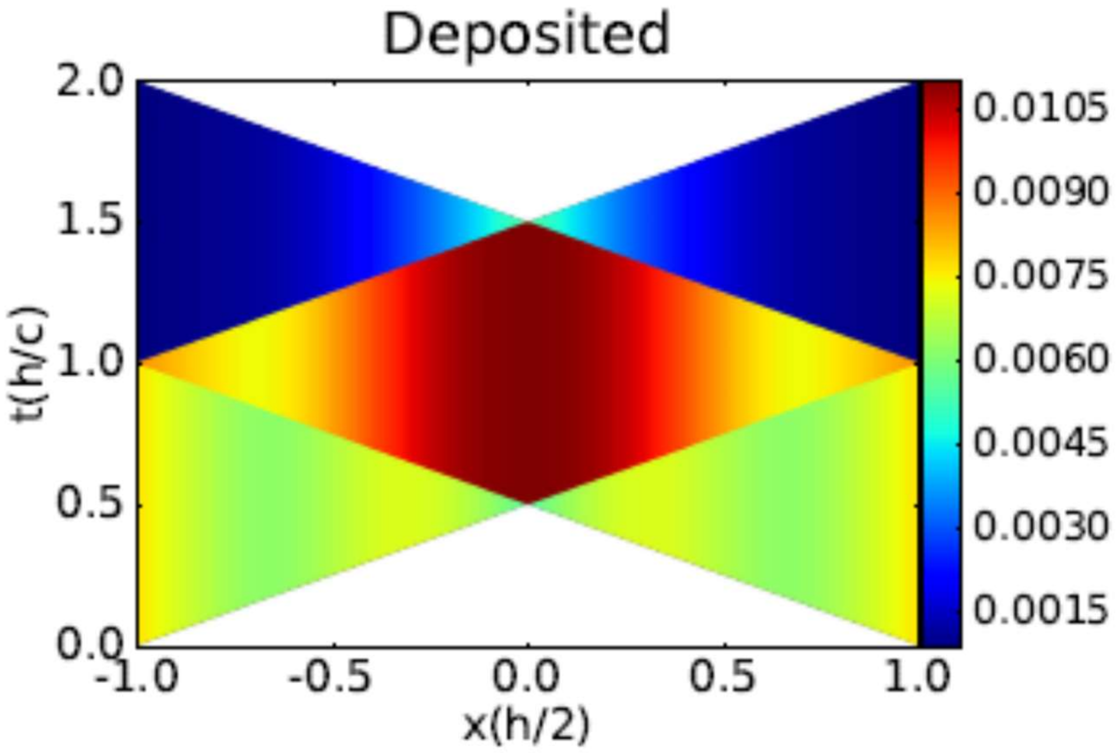


Figure 2: (color online) Deposited energy per unit time in the space-time across the depth, h, of the flat target. The time is measured in units of (h/c), where c is the speed of light in the material of the target. The irradiation lasts for a period of $\Delta t = h/c$ the time needed to cross the target. 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.

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.

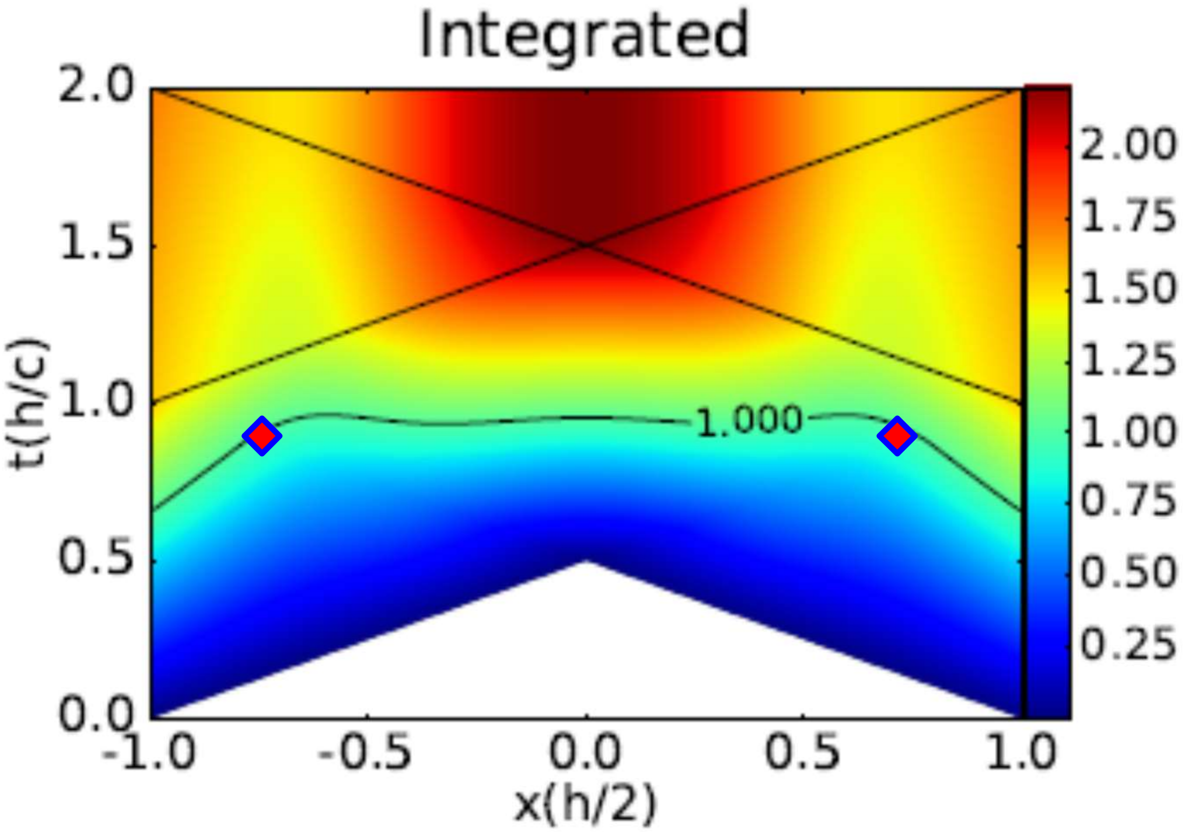


Figure 3: (color online) Integrated energy up to a given time in the space-time across the depth, h, of the flat target. The color code indicates the temperature, T, reached in a given space-time point, in units of the critical temperature, (T_c). The contour line $T = 1$, indicates the critical temperature, 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.

Csernai, L.P. [NAPLIFE]

With nano antennas

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

[Csernai et al., (**NAPLIFE** Collaboration) *Phys. of Wave Phenomena,* **28** (3), 187-199 **(2020).**]

Simultaneous ignition in the whole target volume ➔ Short Pulse: ELI - ALPS

Validation tests at lower energies idea #2 increased absorption via nano-antennas

Wigner RCP, Budapest

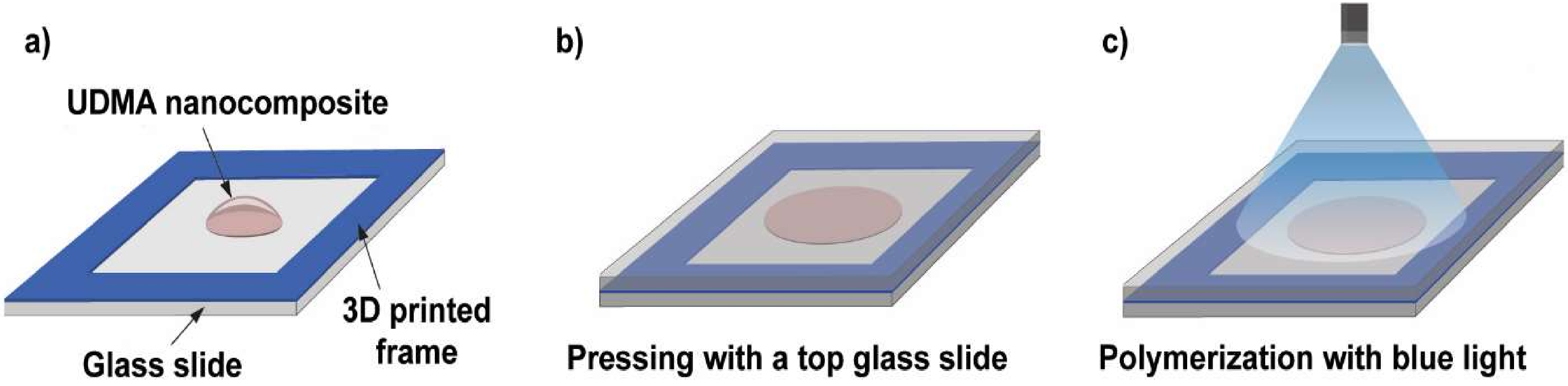
Ti:Sa Hidra Laser: 30mJ, 10Hz, 40fs **[P. Racz et al., Wigner RCP]**

Target Modeling and Manufacturing

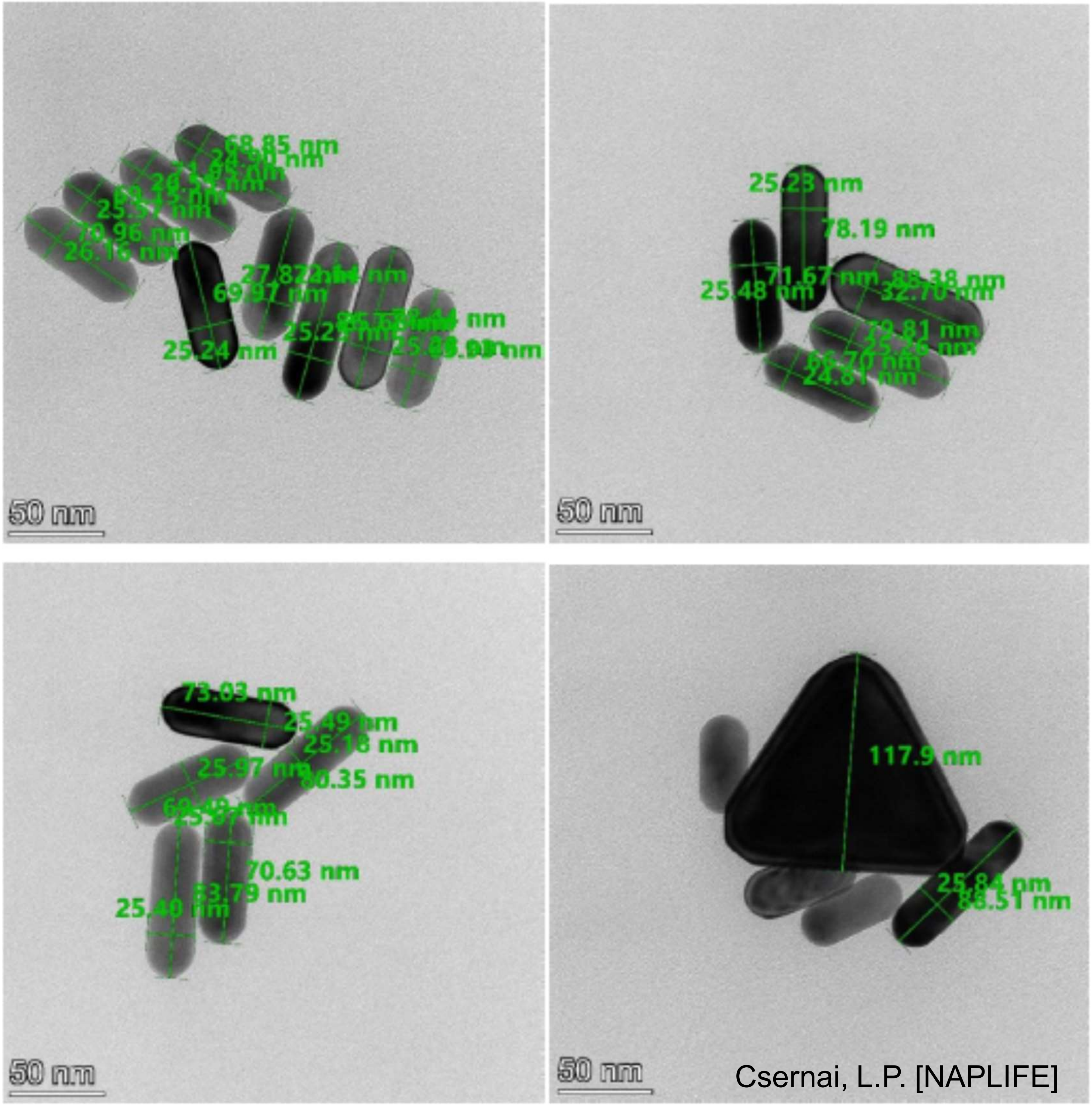
Target materials, absorptivity, implanted nanoantennas

Cyclic olefin copolymer (COC)
Urethane dimethacrylate (UDMA) - 75%
triethylene glycol dimethacrylate (TEGDMA) - 35%

Flat layered target
One layer thickness: 3 μm
Seven layers: 21 μm



[A. Bonyar et al., In preparation]

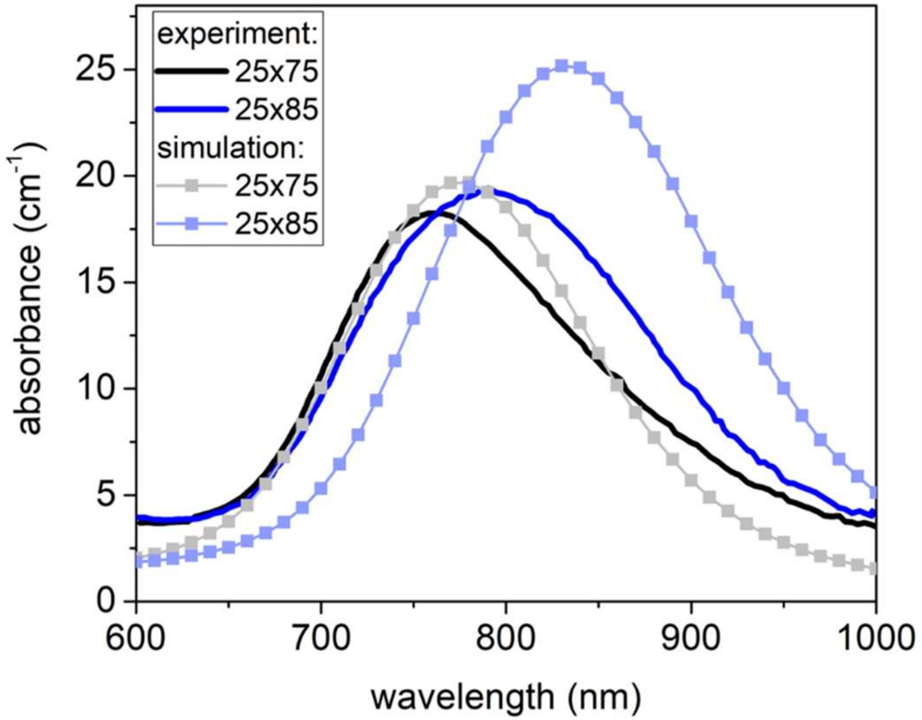


Csernai, L.P. [NAPLIFE]

Transmission Electron-microscopy photos of 75x25 nm gold nano-rod antennas

[Judit Kámán, A. Bonyár et al. (NAPLIFE Collab.)., Gold nanorods …, 10th ICNFP 2021, **Kolymbari]**

Experimental and theoretical absorbance spectra of 75x25 nm and 85x25 nm gold nanorods [M. Csete et al.]

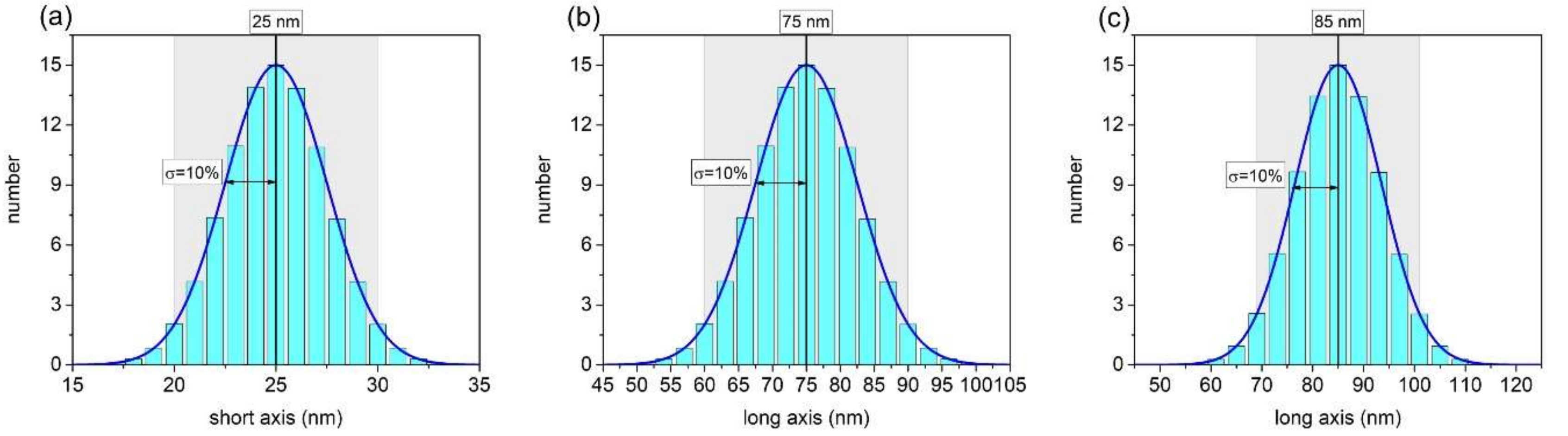


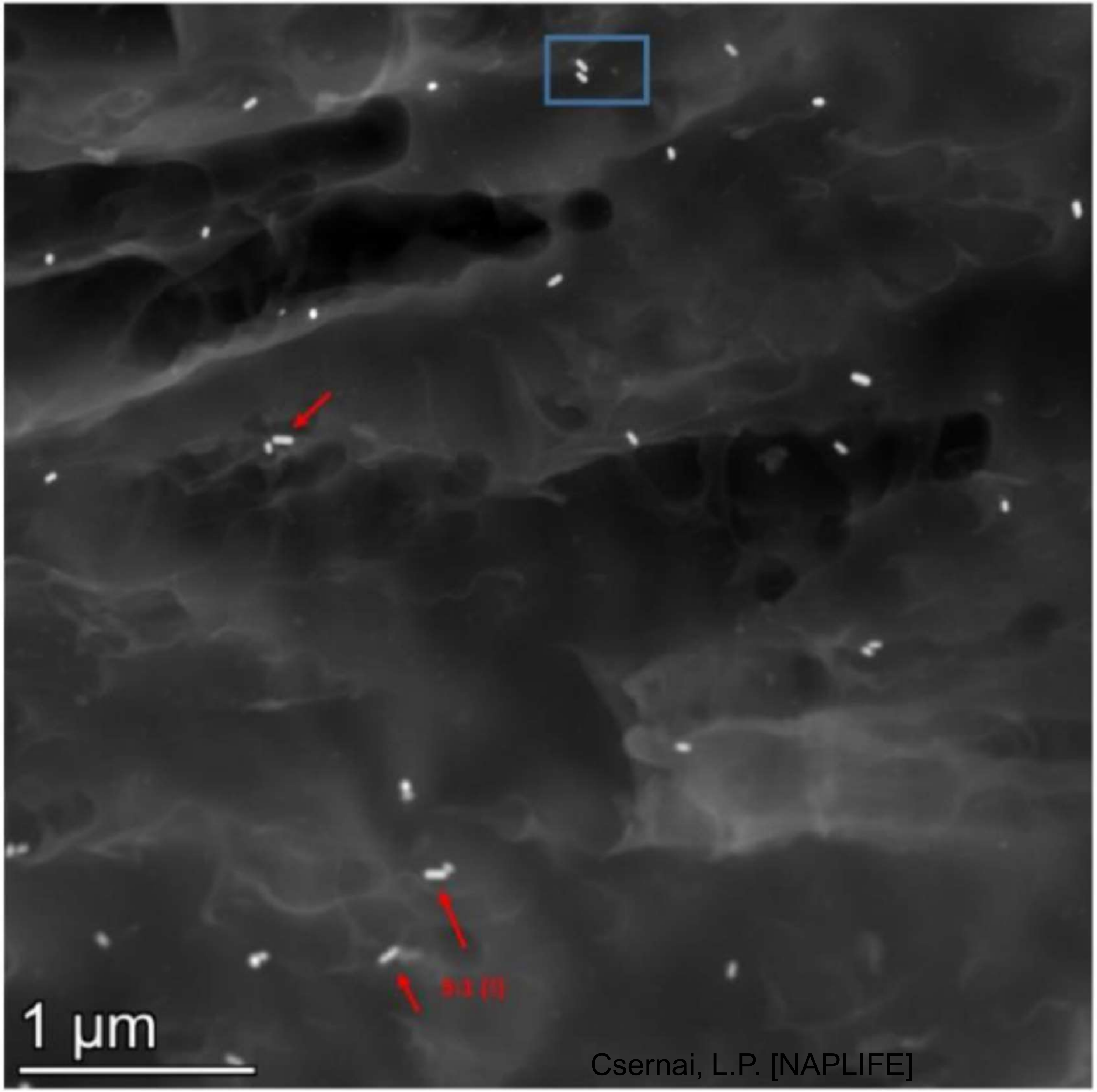
resonance	25x75 nm	25x85 nm
experiment	761 nm	791 nm
simulation	770 nm	830 nm

FWHM	25x75 nm	25x85 nm
experiment	183 nm	204 nm
simulation	164 nm	186 nm

absorbance	25x75 nm	25x85 nm
experiment	16.5 cm^{-1}	19.5 cm^{-1}
simulation	19.7 cm^{-1}	25.2 cm^{-1}

realistic size distribution



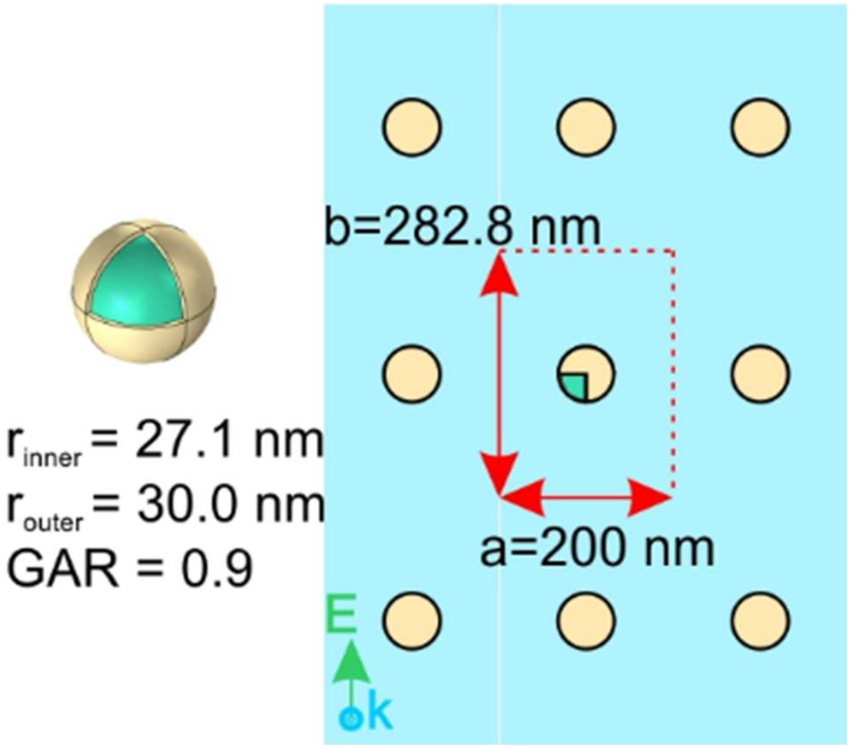


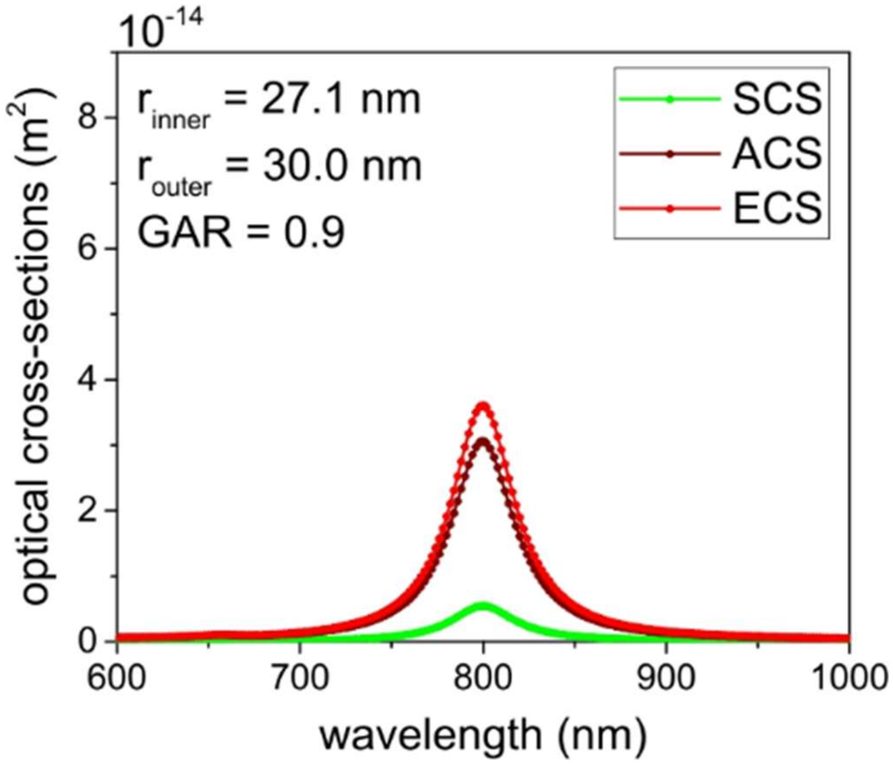
TEM Photo of ~uniformly implanted nanorod antennas in UDMA target polymer. The density is 9-20 / µm^3

[Judit Kámán, A. Bonyár et al. (NAPLIFE Collab.)., Gold nanorods …, 10th ICNFP 2021, **Kolymbari**, Crete, Greece, 30 August 2021.**]**

Nano-particle absorption

The target absorptivity is increased via core-shell type plasmonic nano-shells. Calculations via solving the Maxwell equations, and evaluating the ohmic heating were performed using the COMSOL simulation package.



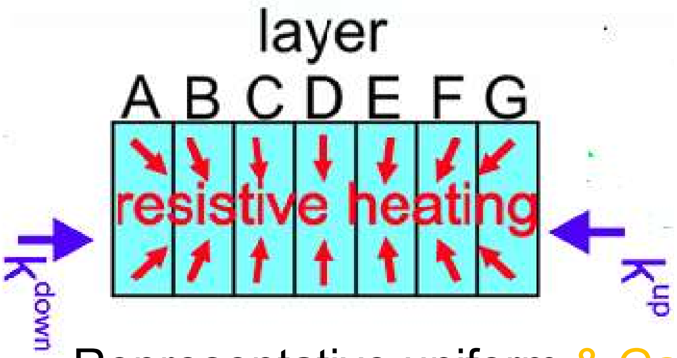


1 ps laser pulse length, λ = 800 nm, one-sided & two-sided irradiation tested, 85-100 % absorption in the target length h.

Nano-antenna shapes, layer configurations, layer distribution varied & analyzed.

[**M. Csete**, et al., U. Szeged, HU https://doi.org/10.1007/s11468-021-01571-x 10.3103/S1541308X20030048]

Layered target with variable light absorption

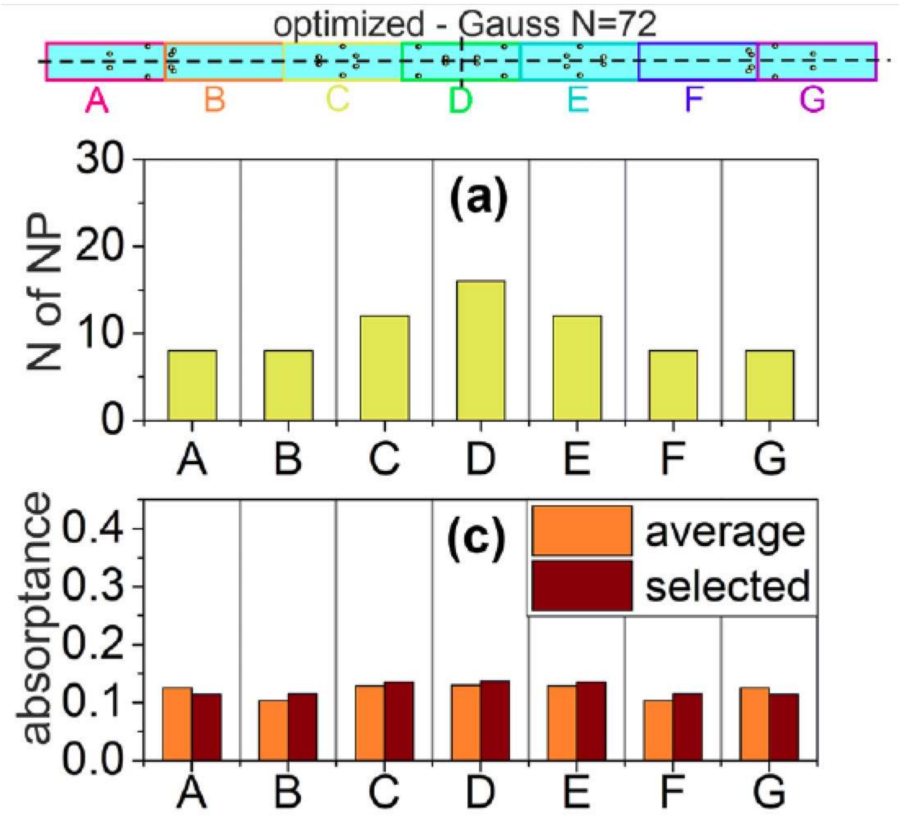


Representative uniform & Gaussian number density distributions of (d) 70 oriented nanorods, in a 1 × 1 × 21 μm3 supercell of UDMA polymer target, with random location distribution.


Plasmonics (2022) 17:775–787
https://doi.org/10.1007/s11468-021-01571-x

Comparative Study on the Uniform Energy Deposition Achievable via Optimized Plasmonic Nanoresonator Distributions

Mária Csete[1] · András Szenes[1] · Emese Tóth[1] · Dávid Vass[1] · Olivér Fekete[1] · Balázs Bánhelyi[2] · István Papp[3,4] · Tamás Bíró[3] · László P. Csernai[3,4,5] · Norbert Kroó[3,6]



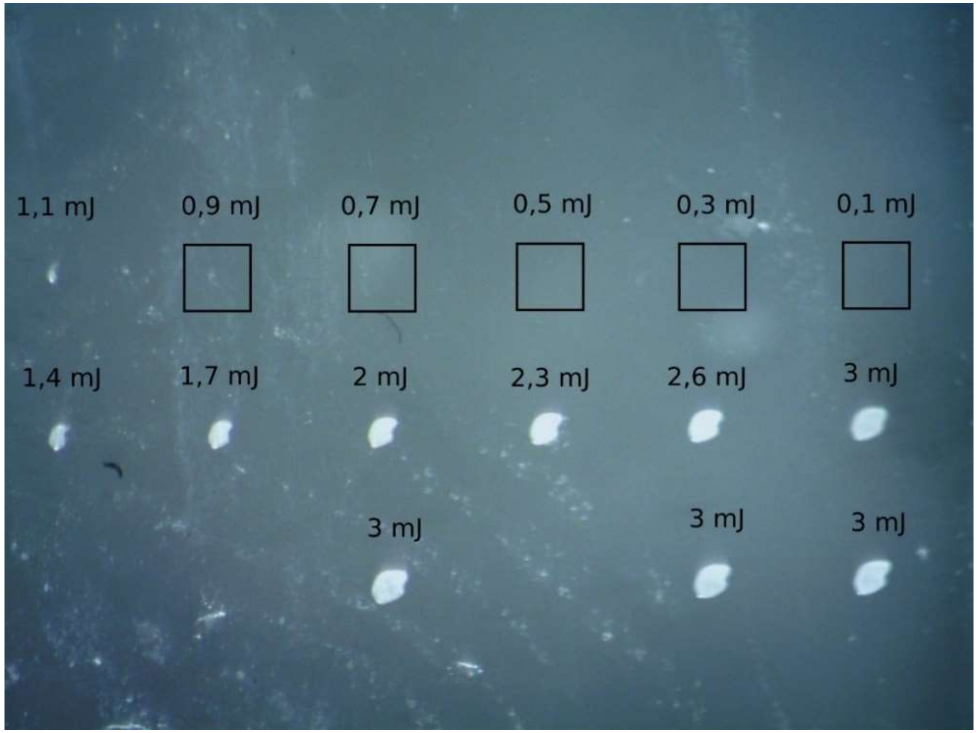
[M. Csete, A. Szenes, E. Tóth, D. Vass, O. Fekete, B. Bánhelyi, T. S. Bíró, L. P. Csernai, N. Kroó: „*Comparative study on the uniform energy deposition achievable via optimized plasmonic nanoresonator distributions*“, Plasmonics (2022), 17: 775-787; https://doi.org/10.1007/s11468-021-01571-x.]

Effect of Short Pulse Laser Beams on target

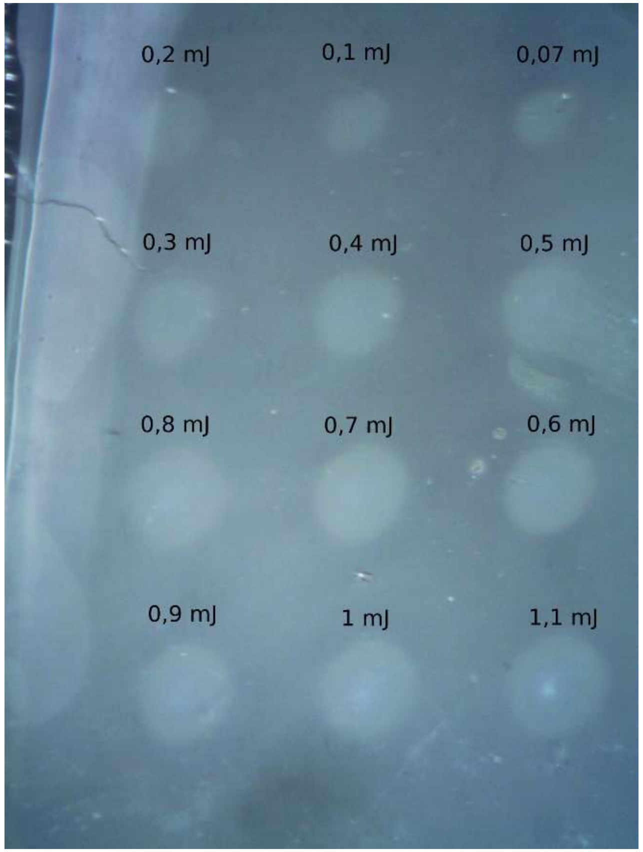
(N.K.*)

[Bonyár, Kroó, et al.]

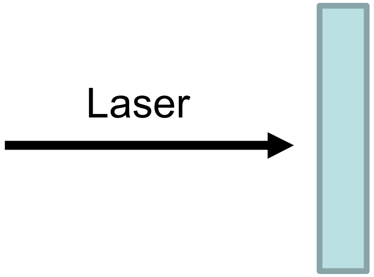
Without nanorods(30x)



With nanorods (40x)



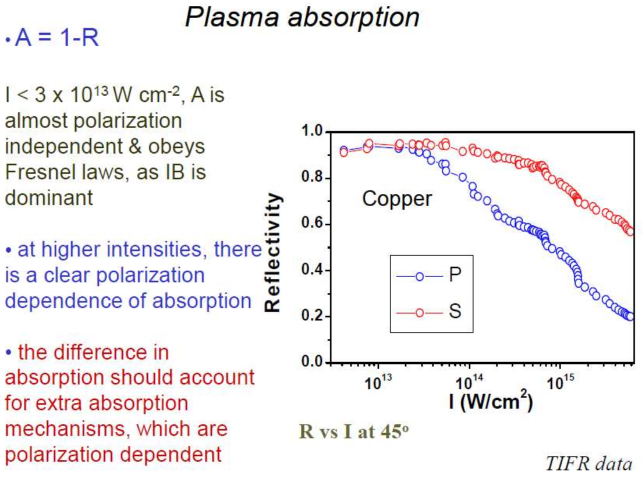
Thickness:
~30μ to 40μ



300 fs long laser pulses

Focus: 85μ diameter
Pulse length: 300fs
Max Intensity ~4.10¹⁴W/cm²

Csernai, L.P. [NAPLIFE]



Plasma absorption

- A = 1-R

I < 3 x 10^{13} W cm^{-2}, A is almost polarization independent & obeys Fresnel laws, as IB is dominant

- at higher intensities, there is a clear polarization dependence of absorption

- the difference in absorption should account for extra absorption mechanisms, which are polarization dependent

R vs I at 45°

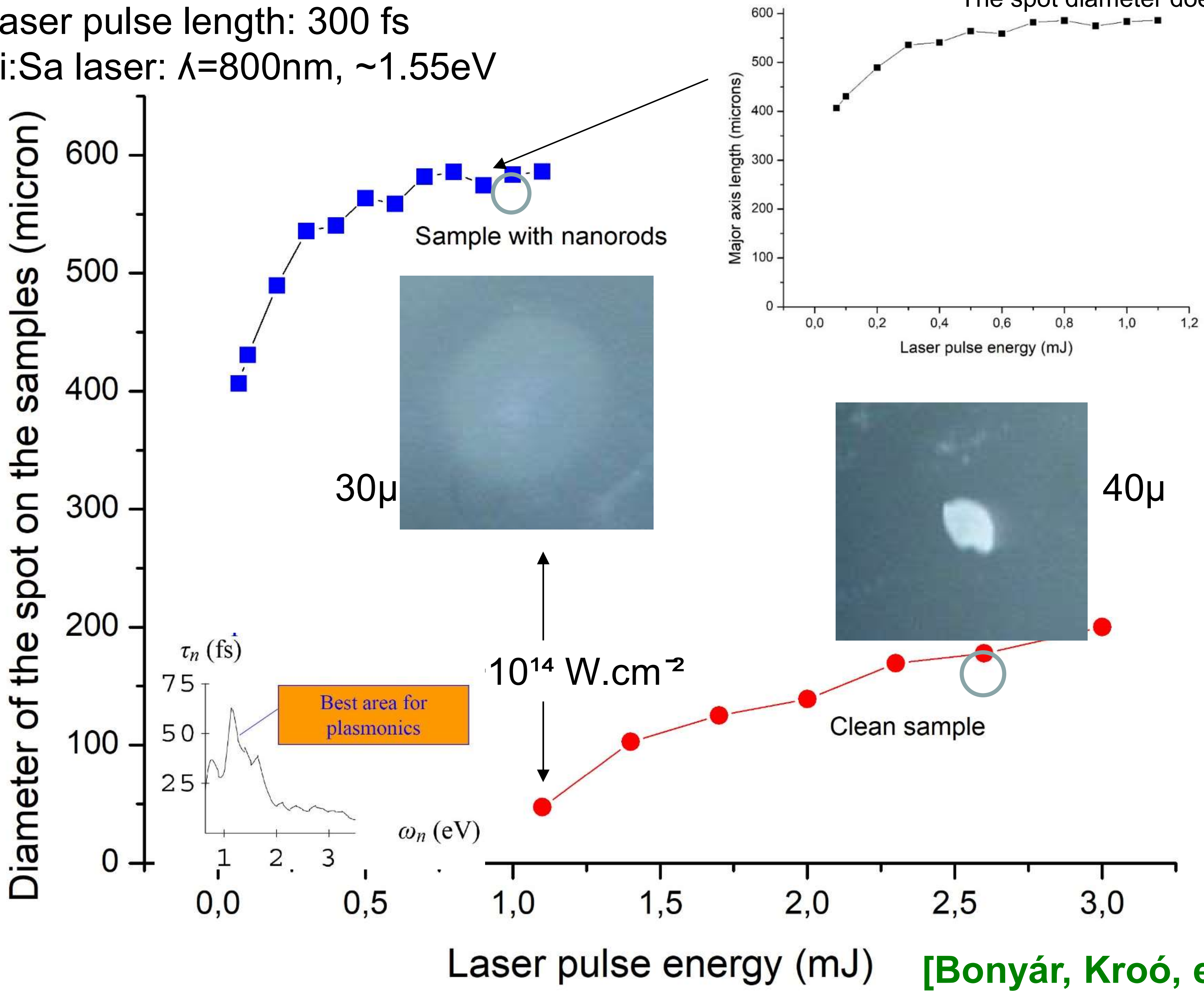
TIFR data

Kumar

Laser pulse length: 300 fs
Ti:Sa laser: ʎ=800nm, ~1.55eV

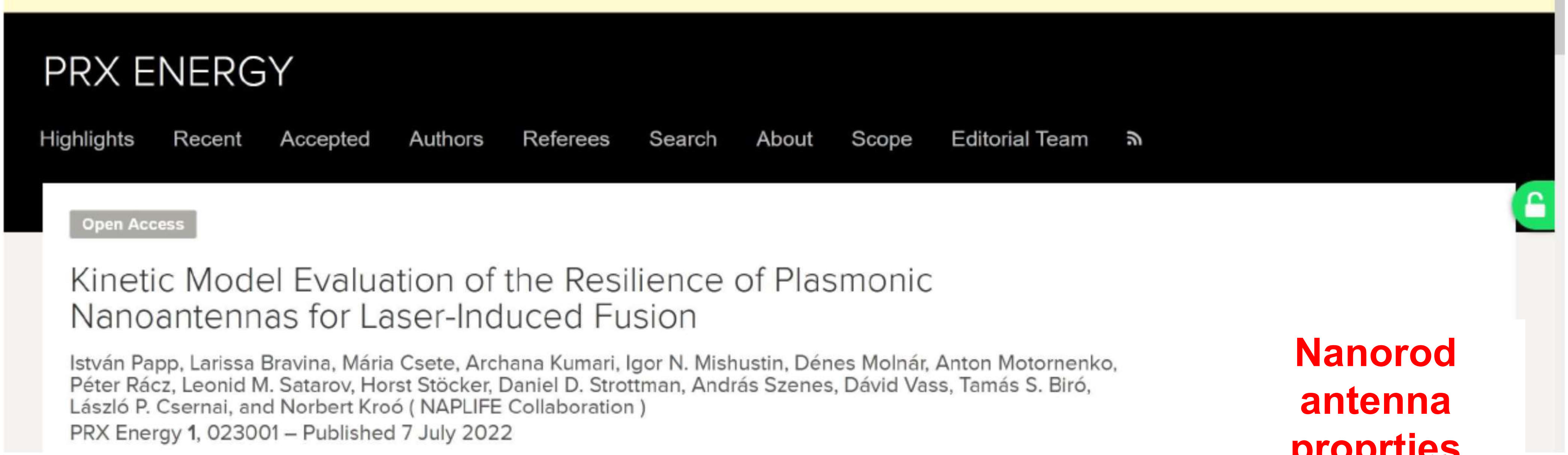
The spot diameter does not increase

(N.K.*)



[Bonyár, Kroó, et al.]

Large plasmonic gain

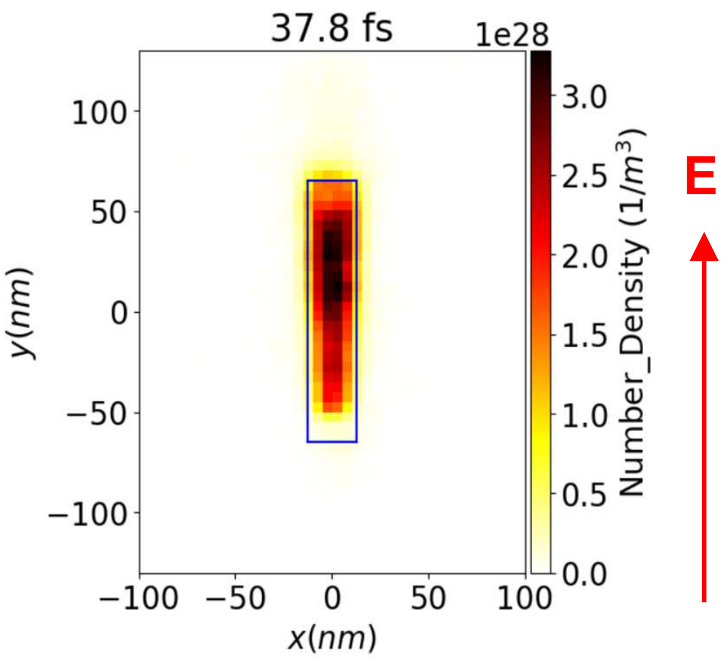


Kinetic Model Evaluation of the Resilience of Plasmonic Nanoantennas for Laser-Induced Fusion

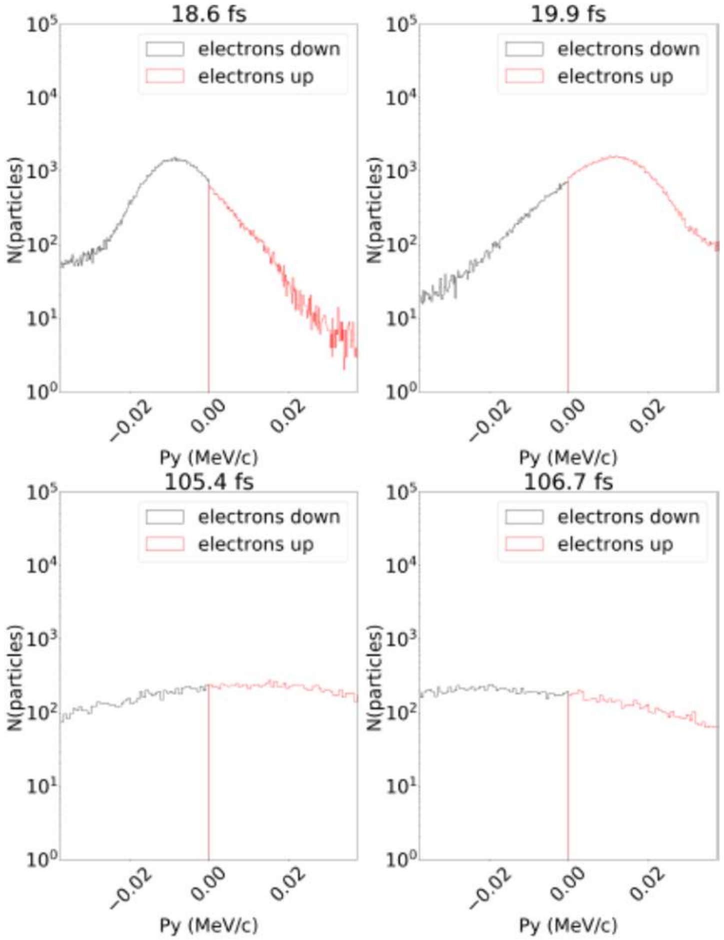
István Papp, Larissa Bravina, Mária Csete, Archana Kumari, Igor N. Mishustin, Dénes Molnár, Anton Motornenko, Péter Rácz, Leonid M. Satarov, Horst Stöcker, Daniel D. Strottman, András Szenes, Dávid Vass, Tamás S. Biró, László P. Csernai, and Norbert Kroó (NAPLIFE Collaboration)

PRX Energy **1**, 023001 – Published 7 July 2022

Nanorod antenna proprties



ρ_e for 25x130 nm antennas, in vacuum. EPOCH



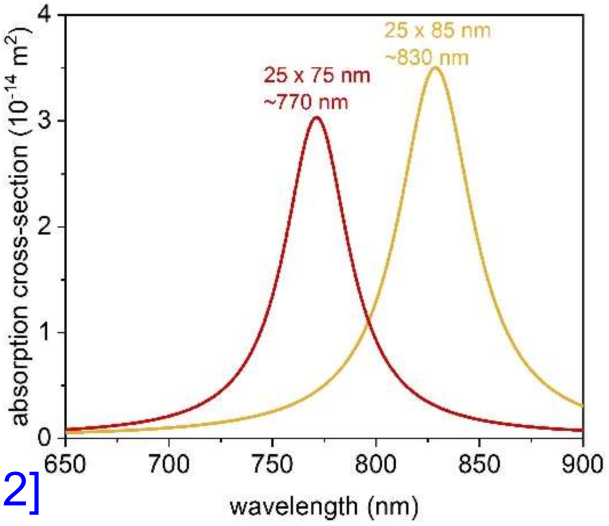
25x130 nm antennas, resonant for λ=795 nm

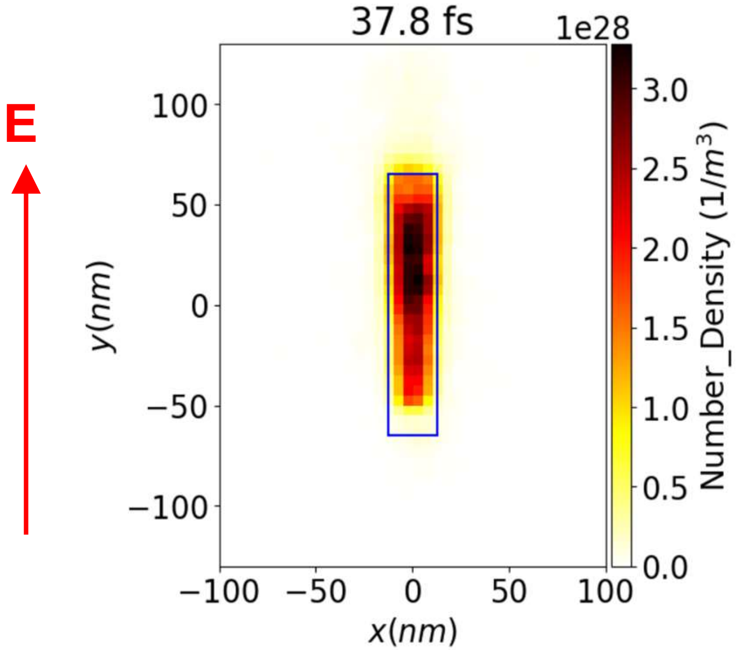
Laser Intensity:
$I = 4 \cdot 10^{15}$ W/cm^2

see I.Papp's talk in this session of ICNFP2022

Nanorod antenna properties

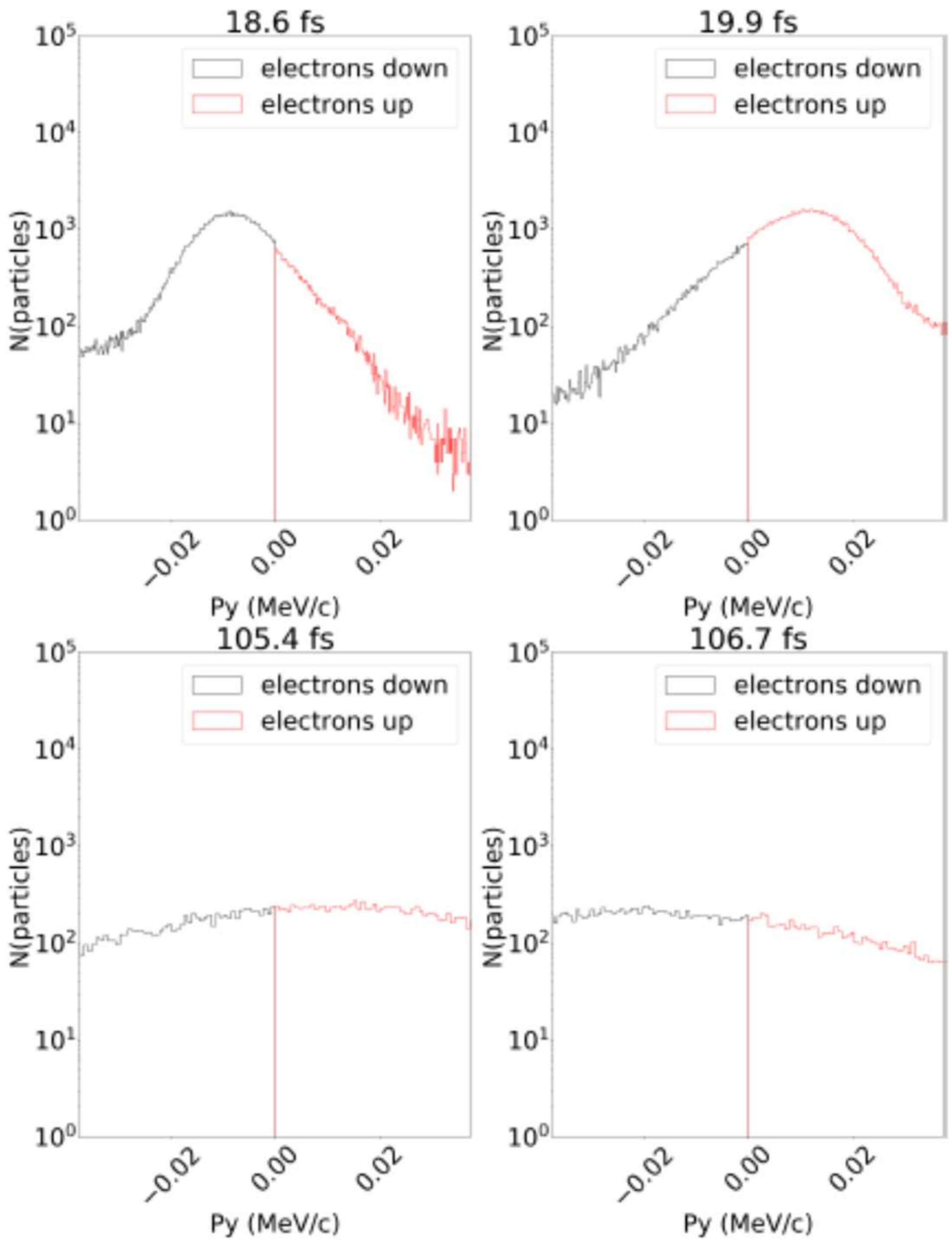
25x75 nm & 25x130 nm antennas, resonant for λ=795 nm, in UDMA.
[M. Csete et al. [NAPLIFE], Plasmonics 2022]





ρ_e for 25x130 nm antennas, in vacuum. EPOCH
[I. Papp et al. (NAPLIFE) ***PRX Energy***]

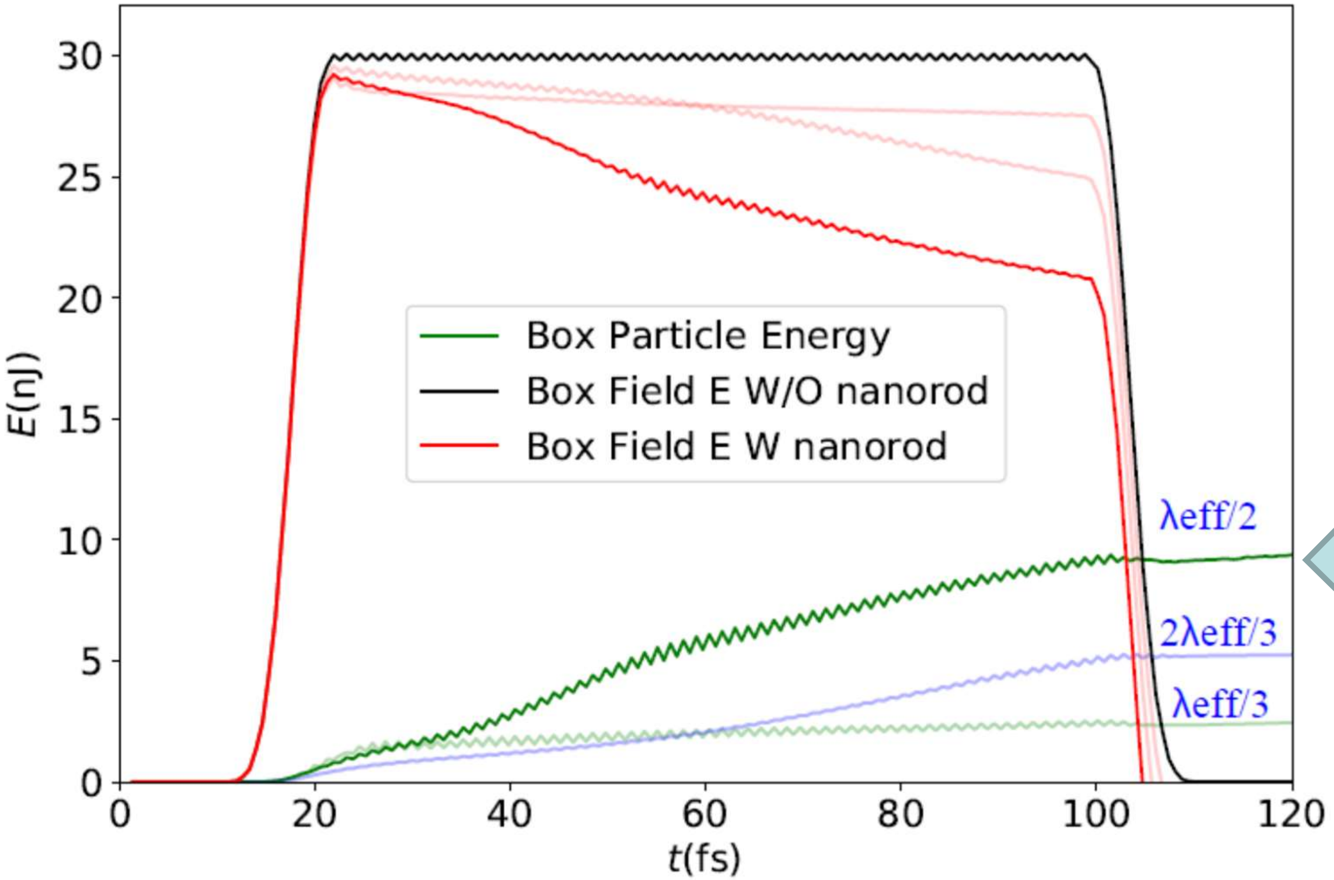
Resilience



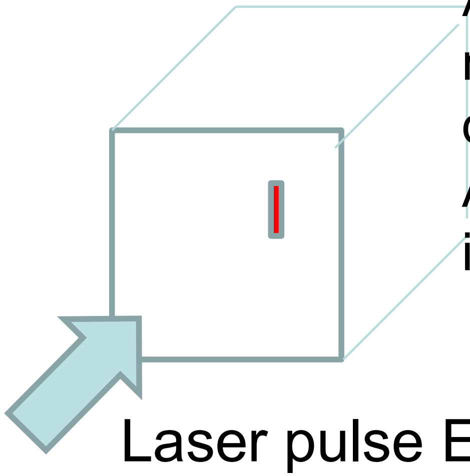
Intensity: I = $4 \cdot 10^{15}$ W/cm^2

Csernai, L.P. [NAPLIFE]

Resilience of Nanorod Antenna with EPOCH/PIC



Calculation Box (CB):
530x530x795 nm
λ = 795 nm



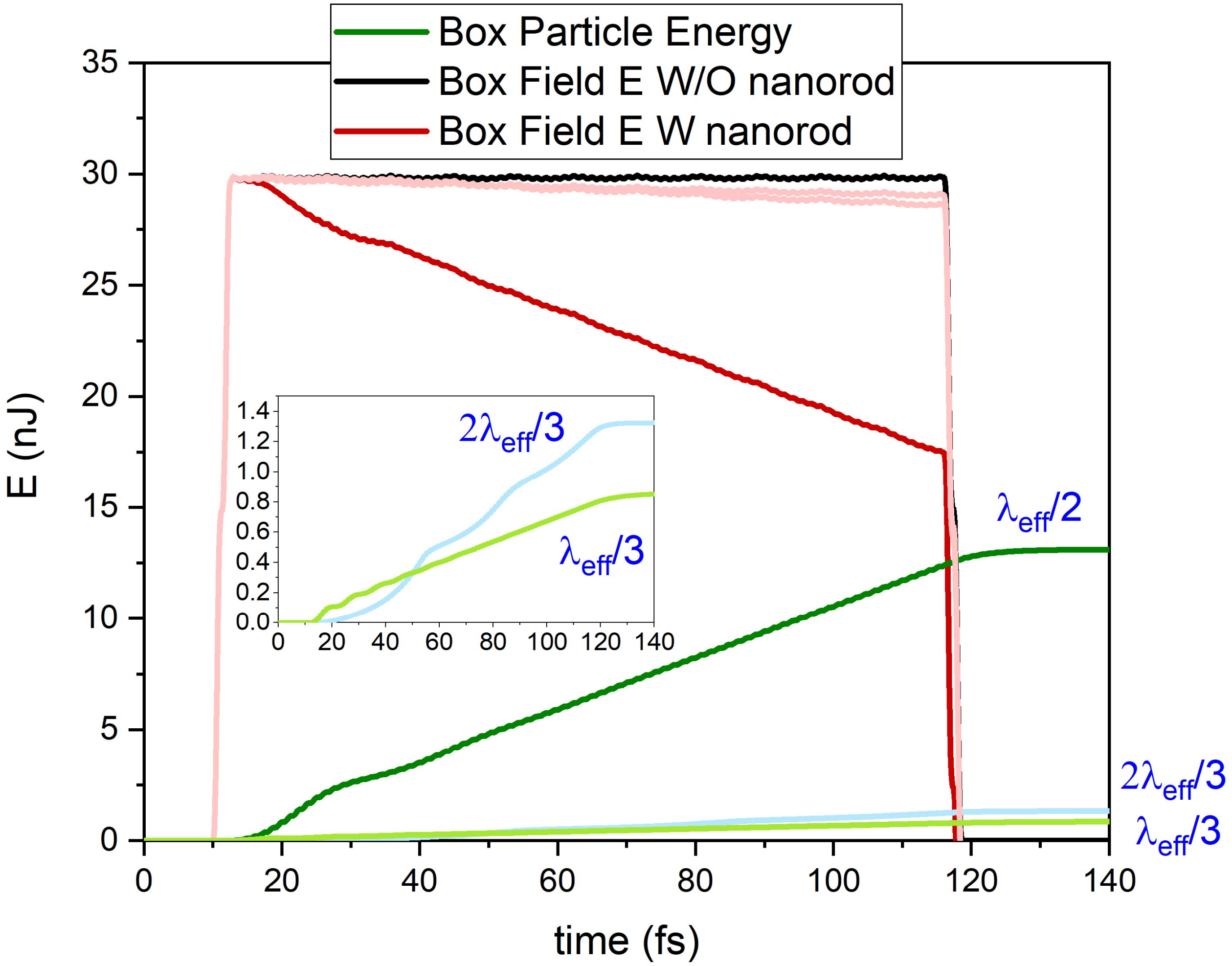
λ_{eff}=260nm
nano-ant.
dipole length
$\Lambda_{eff}/2$=130nm
i.e.,130x25nm

Laser pulse E_P=30mJ
in CB, T_P=106 s ≈ 40λ/c

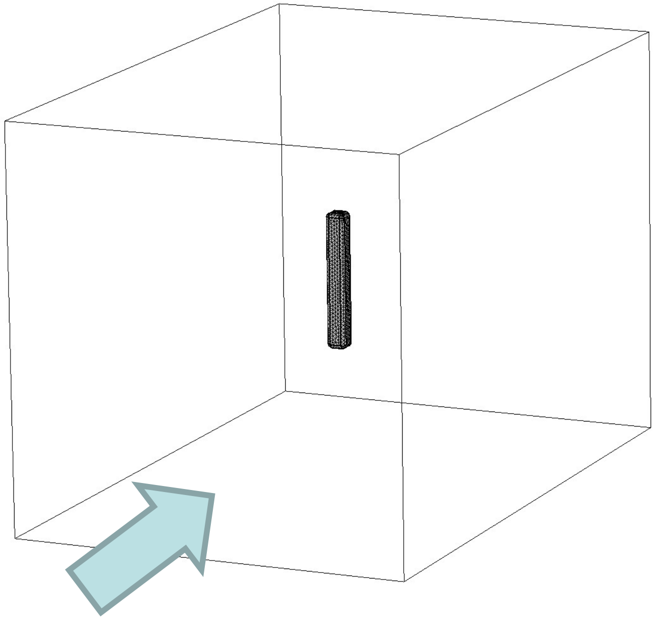
The nanorod antenna has a light absorption cross section, which is nearly 28.5 times bigger than its geometrical cross section

[I. Papp et al. (NAPLIFE Coll.) ***PRX Energy***, **1**, 023001 (2022)], and *see I.Papp's talk in this session of ICNFP2022*.

Resilience of Nanorod Antenna with COMSOL



FEM computations with the same model parameters



[M. Csete et al. NAPLIFE]

Good qualitative agreement between FEM and EPOCH/PIC methods
Quantitative difference:
the hydrodynamic model of the electron plasma (FEM) predicts a sharper resonance than the kinetic model (EPOCH/PIC)

Validation tests at lower energies idea #1 Simultaneous (time-like) transition (ignition)

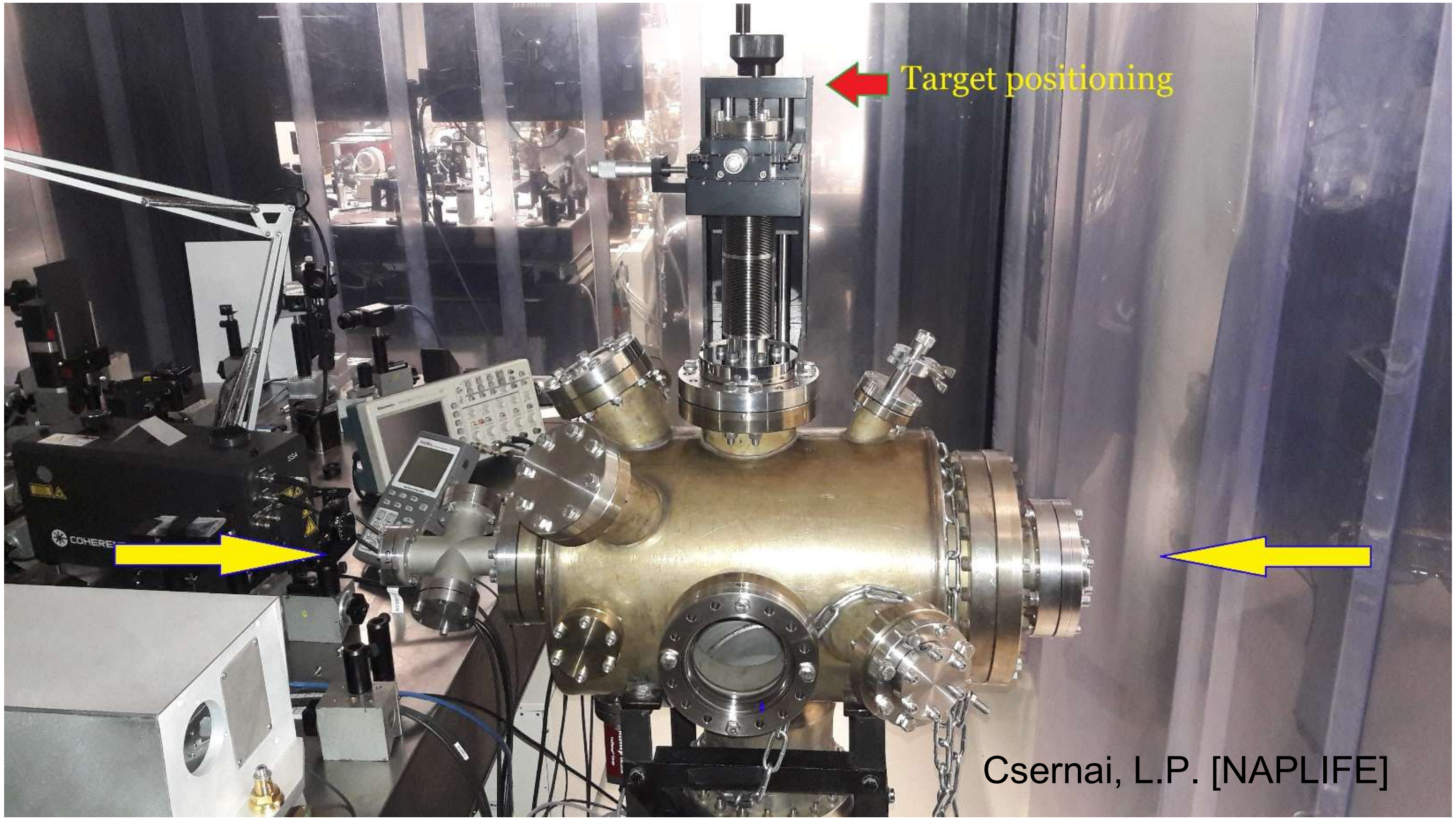
➔

Two opposing beams

Validation tests – Target manufacturing

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

- **Implanted with nano-antennas ➔ Amplified absorption** √
- **Multilayer targets ➔ Simultaneous Ignition (in progress)**

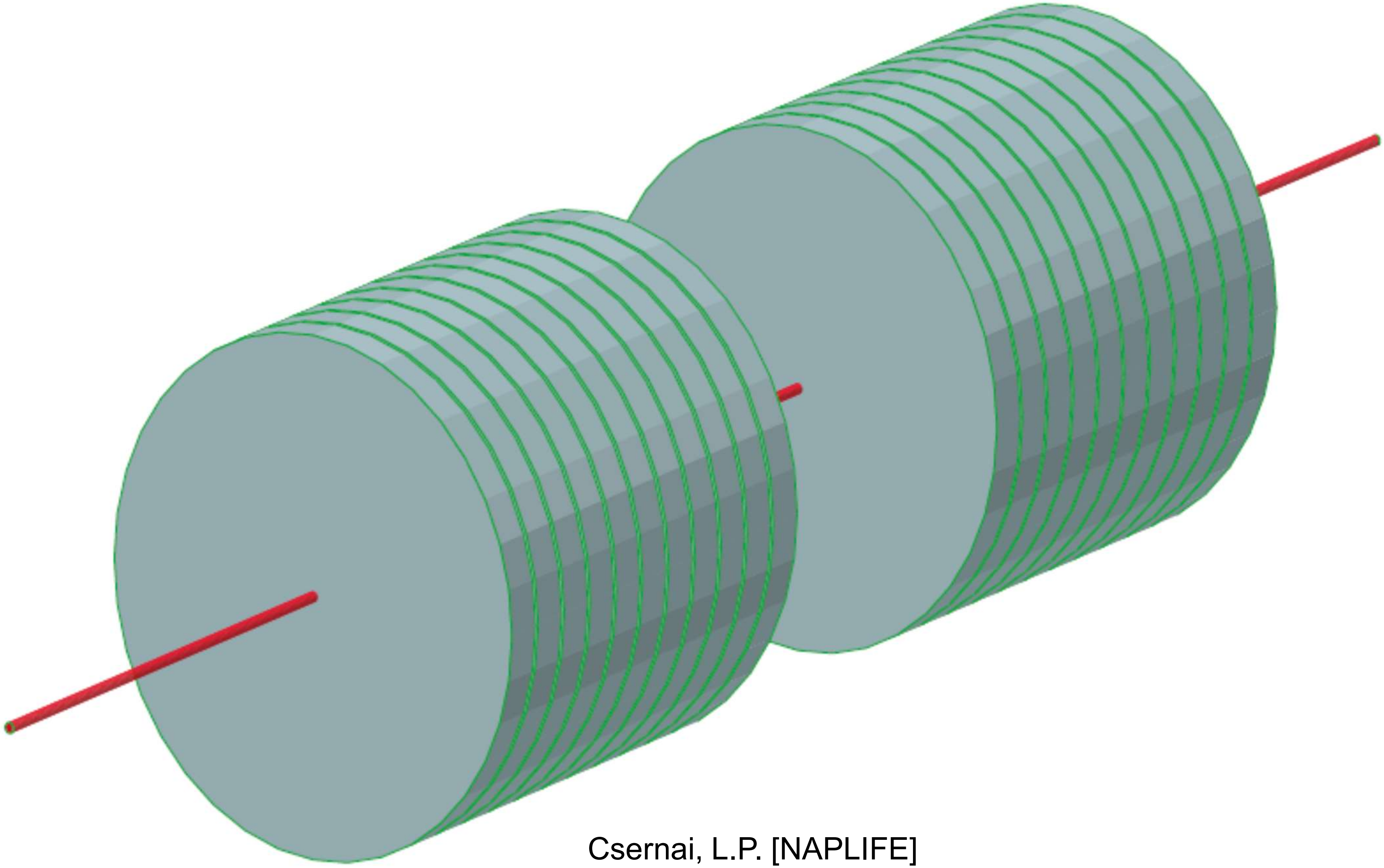


Csernai, L.P. [NAPLIFE]

[M. Csete, A. Bonyár, I. Papp, P. Rácz, et al.]

In preparation

Multilayered fuel target



Csernai, L.P. [NAPLIFE]

Laser Wake Field Collider

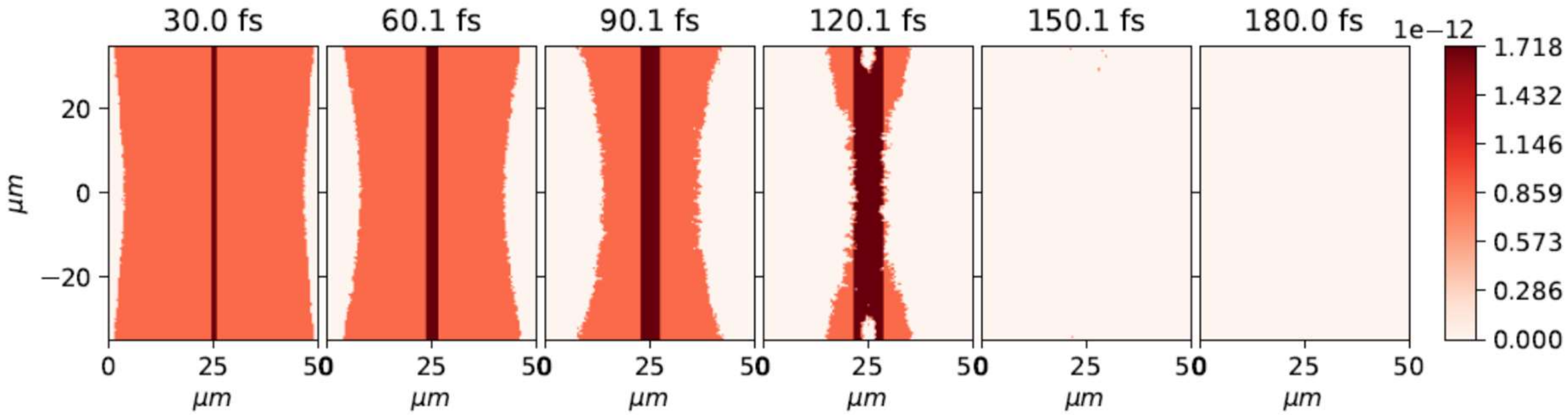
∃ Pre-compression/acceleration, before ignition

Ion (e.g. p) Energy $E_p \approx 50$ MeV (or more)

Initial beam densities assumed: $n_H \approx \gamma\, n_0 = 2 \cdot 10^{-19}/\mathrm{cm}^3$ and $2 \cdot 10^{-21}/\mathrm{cm}^3$

$\approx n_{\text{liquid-H}}$, $\approx n_{\text{NIF}}$ /1000 (/wo precompression!)

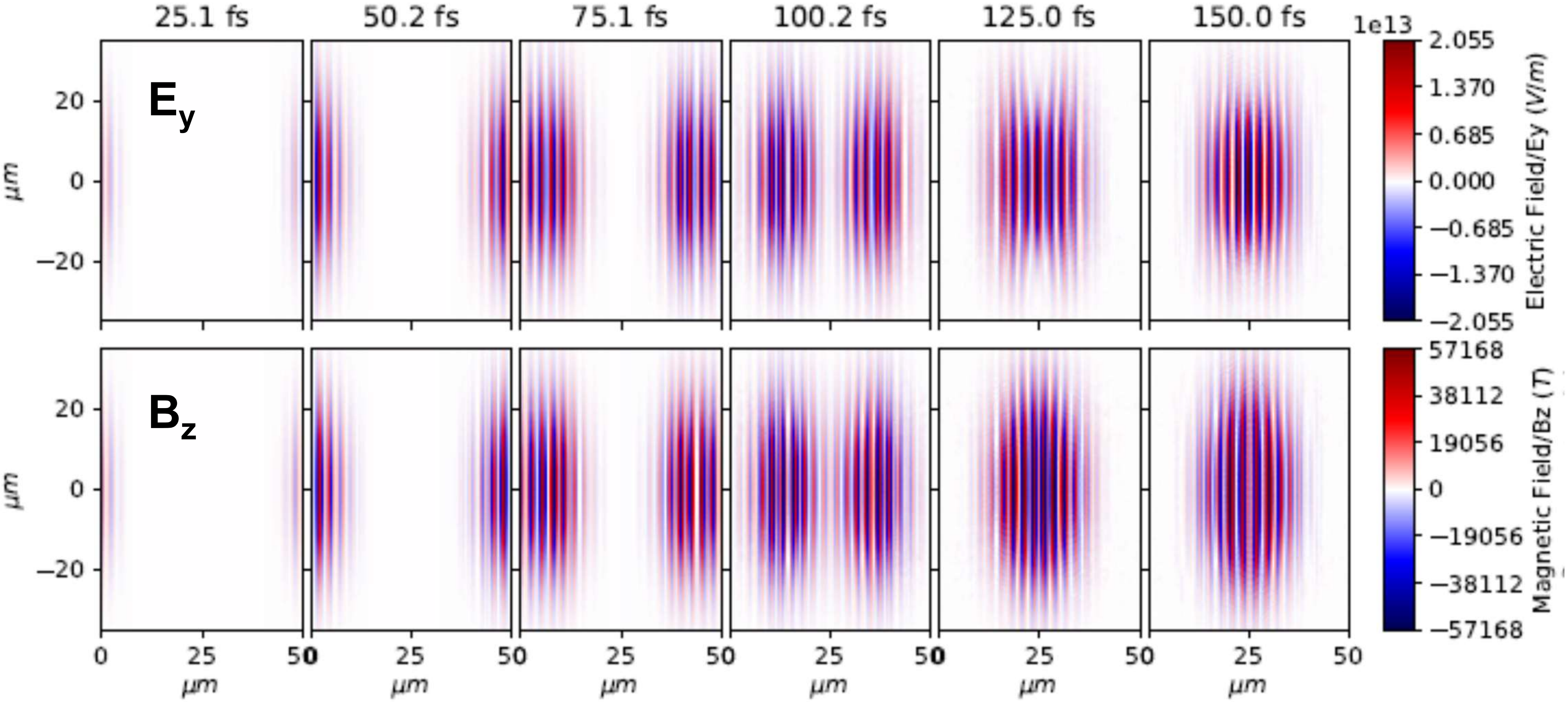
Target density after interpenetration: $n_t \geq 2\, n_H$



The ionization of the H atoms at ignition in a Laser Wake Field (LWF) wave due to the irradiation from both the +/- *x* directions

[Papp, I., et al., NAPLIFE, Phys. Lett. A 396, 12724 (2021).]

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 ±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**.

..

Validation tests ➔

Laser Induced Fusion with Nanoantennas

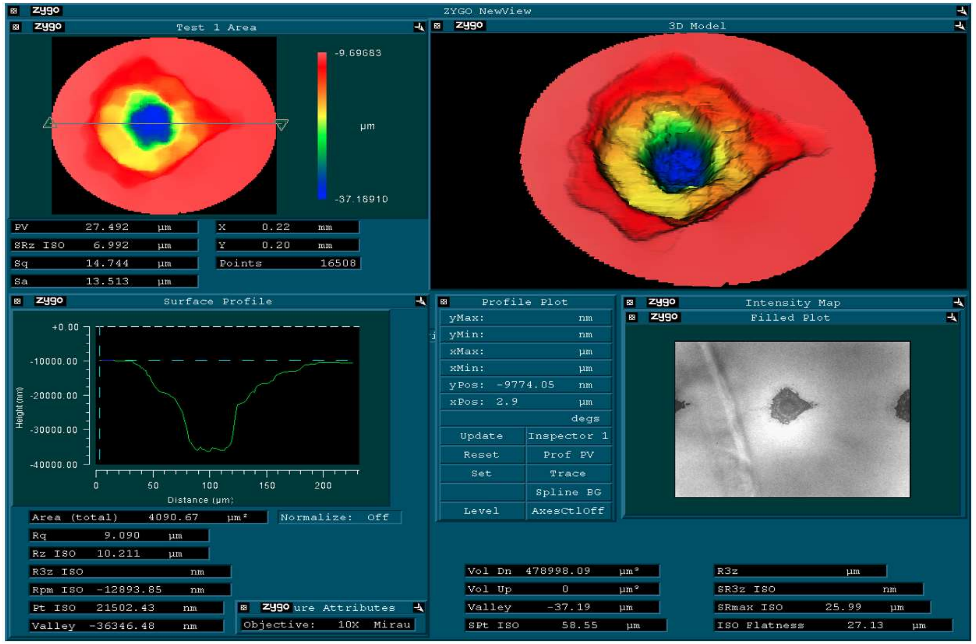
Crater in thick target

(N.K.*)

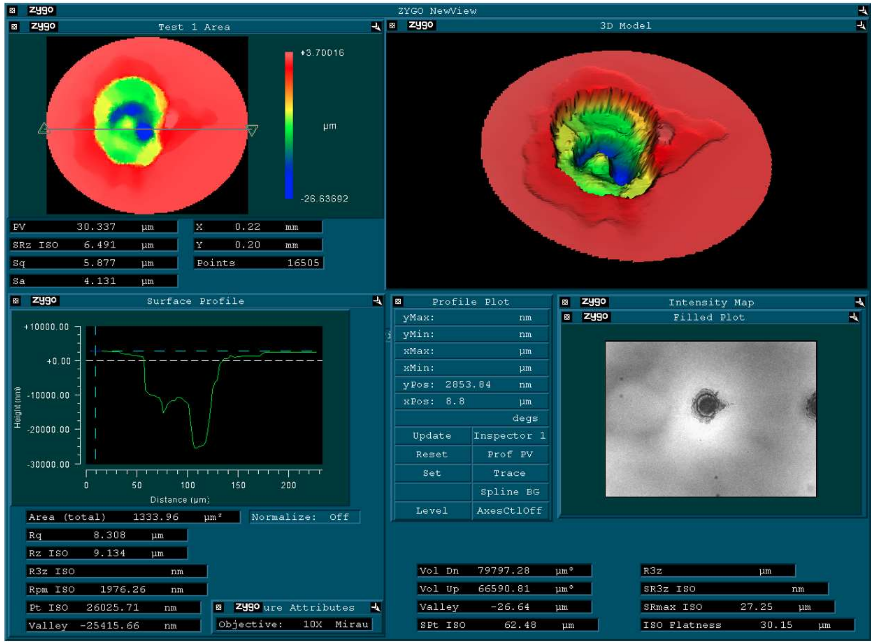
ith 795nm 40fs Ti:Sa laser 10^{16}-10^{17} W/cm^2 intensity

UDMA-TEGDMA target 20-**160** μm thick, \w & \wo Au nanorods 25x85nm.

➔ 5 mJ pulse -> crater of 4.55-1.07·10^{14} μm^3 \w &\wo Au ~ 15/ μm^3



PV 27.492 μm
SRz ISO 6.992 μm
Sq 14.744 μm
Sa 13.513 μm
X 0.22 mm
Y 0.20 mm
Points 16508
yMax: nm
yMin: nm
xMax: μm
xMin: μm
yPos: -9774.05 nm
xPos: 2.9 μm
Area (total) 4090.67 μm²
Normalize: Off
Rq 9.090 μm
Rz ISO 10.211 μm
R3z ISO nm
Rpm ISO -12893.85 nm
Pt ISO 21502.43 nm
Valley -36346.48 nm
Objective: 10X Mirau
Vol Dn 478998.09 μm³
Vol Up 0 μm³
Valley -37.19 μm
SPt ISO 58.55 μm
R3z μm
SR3z ISO nm
SRmax ISO 25.99 μm
ISO Flatness 27.13 μm

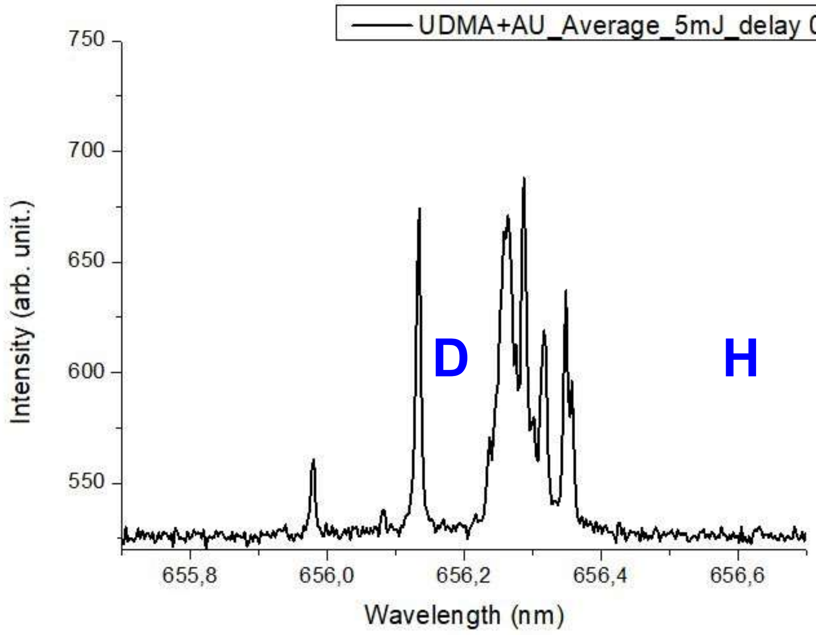


PV 30.337 μm
SRz ISO 6.491 μm
Sq 5.877 μm
Sa 4.131 μm
X 0.22 mm
Y 0.20 mm
Points 16505
yMax: nm
yMin: nm
xMax: μm
xMin: μm
yPos: 2853.84 nm
xPos: 8.8 μm
Area (total) 1333.96 μm²
Normalize: Off
Rq 8.308 μm
Rz ISO 9.134 μm
R3z ISO nm
Rpm ISO 1976.26 nm
Pt ISO 26025.71 nm
Valley -25415.66 nm
Objective: 10X Mirau
Vol Dn 79797.28 μm³
Vol Up 66590.81 μm³
Valley -26.64 μm
SPt ISO 62.48 μm
R3z μm
SR3z ISO nm
SRmax ISO 27.25 μm
ISO Flatness 30.15 μm

➔ From the crater the emitted matter was analysed by Raman spectroscopy & Laser Induced Breakdown Spectroscopy (LIBS).

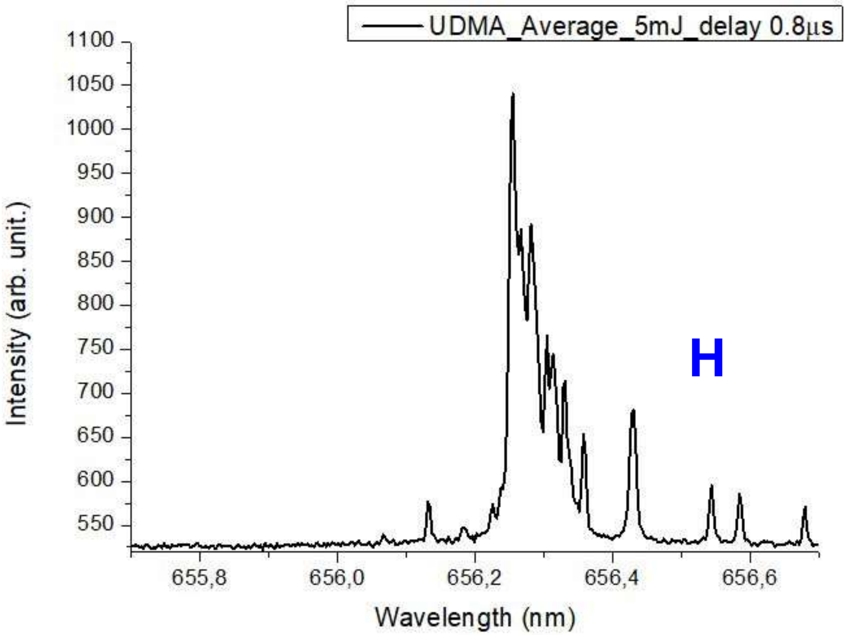
See Judit Kámán’s & Ágnes Nagyné Szokol’s talk in this session.

Deuterium production (PRELIMINARY ! ?) (N.K.*)



5-12% **D + 88-95% H**

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



100% **H**

Balmer-α line

Two step weak process (average of 20 shots), UDMA (470: H38, C23, O8, N2)

$p + e^* \rightarrow n + \nu$ \ electron capture (-1.24 MeV)

$n + p \rightarrow d + \gamma$ \ neutron capture (+2.22 MeV)

Electron capture may happen spontaneously in heavy nuclei,

here laser light and resonant nanorods may act similarly at high e density.

Alternatively n transmutation from C-13 or other nuclei to H → D.

See Archana Kumari's & Miklos Veres's talk in this session

High Energy, Short Pulse Laser,
unique
at
ELI – ALPS
Szeged

European Laser Infrastructure
ELI-ALPS
Szeged, HU

Csernai, L.P. [NAPLIFE]

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**

Csernai, L.P. [NAPLIFE]

Thanks for your attention