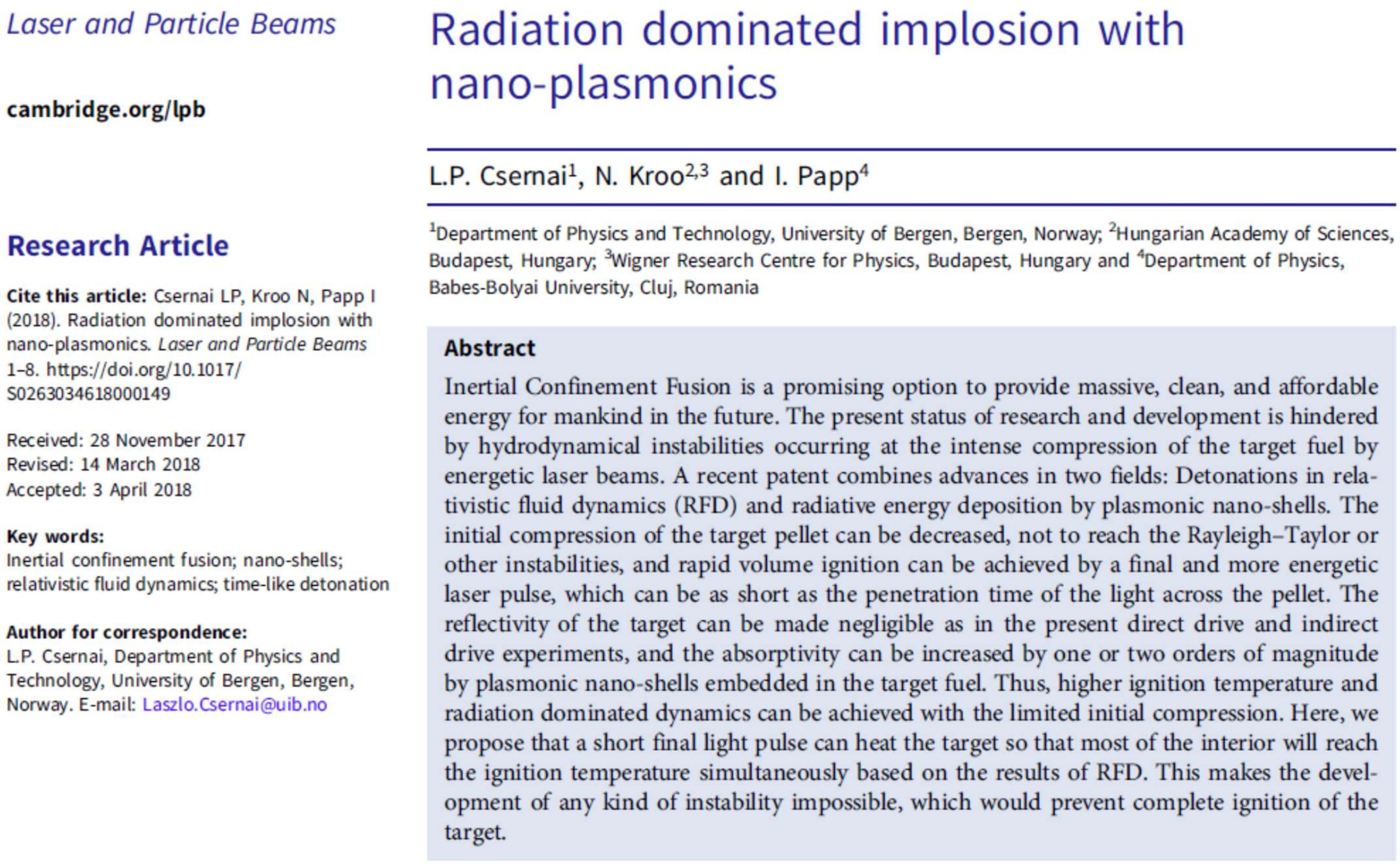
NAPLIFE Progress Report

U Szeged, Physics
Dept. Seminar,
Szeged, 2023.02.15 .

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

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

LPB, 36(2), **(2018)** 171-178.



Laser and Particle Beams

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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

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Accepted: 3 April 2018

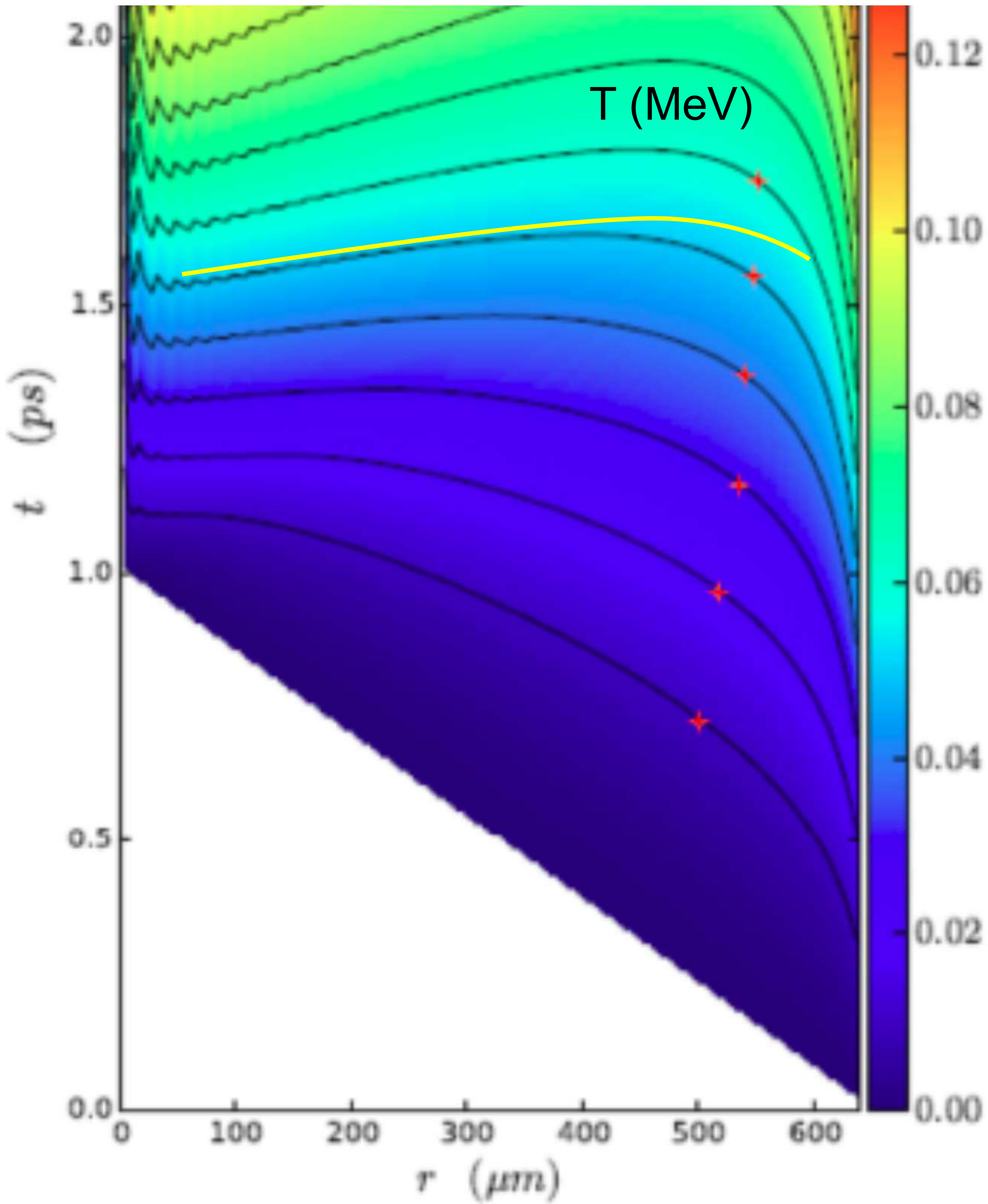
Key words:
Inertial confinement fusion; nano-shells; relativistic fluid dynamics; time-like detonation

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.

L.P. Csernai, N. Kroo, I. Papp, LPB, 36(2), **(2018)** 171-178.



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

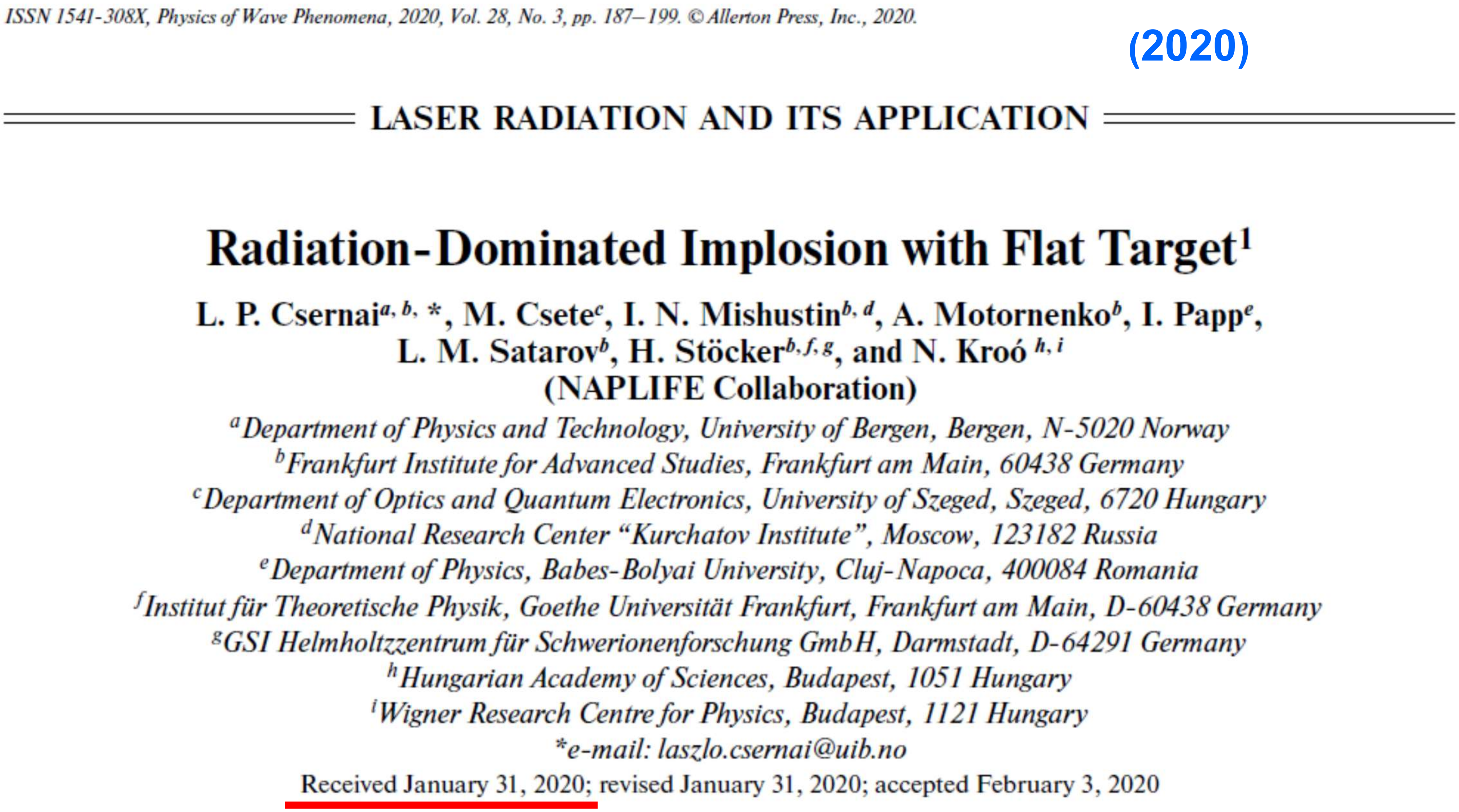
r = 0, $\alpha_K = 30\ \mathrm{cm}^{-1}$ while at the outside

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!**

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



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(2020)

LASER RADIATION AND ITS APPLICATION

Radiation-Dominated Implosion with Flat Target[1]

L. P. Csernai[a, b, *], M. Csete[c], I. N. Mishustin[b, d], A. Motornenko[b], I. Papp[e],
L. M. Satarov[b], H. Stöcker[b, f, g], and N. Kroó[h, i]
(NAPLIFE Collaboration)

[a] *Department of Physics and Technology, University of Bergen, Bergen, N-5020 Norway*
[b] *Frankfurt Institute for Advanced Studies, Frankfurt am Main, 60438 Germany*
[c] *Department of Optics and Quantum Electronics, University of Szeged, Szeged, 6720 Hungary*
[d] *National Research Center "Kurchatov Institute", Moscow, 123182 Russia*
[e] *Department of Physics, Babes-Bolyai University, Cluj-Napoca, 400084 Romania*
[f] *Institut für Theoretische Physik, Goethe Universität Frankfurt, Frankfurt am Main, D-60438 Germany*
[g] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, D-64291 Germany*
[h] *Hungarian Academy of Sciences, Budapest, 1051 Hungary*
[i] *Wigner Research Centre for Physics, Budapest, 1121 Hungary*
**e-mail: laszlo.csernai@uib.no*

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Thick coin like flat target & Two beams only

Thickness of the target is: h

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

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

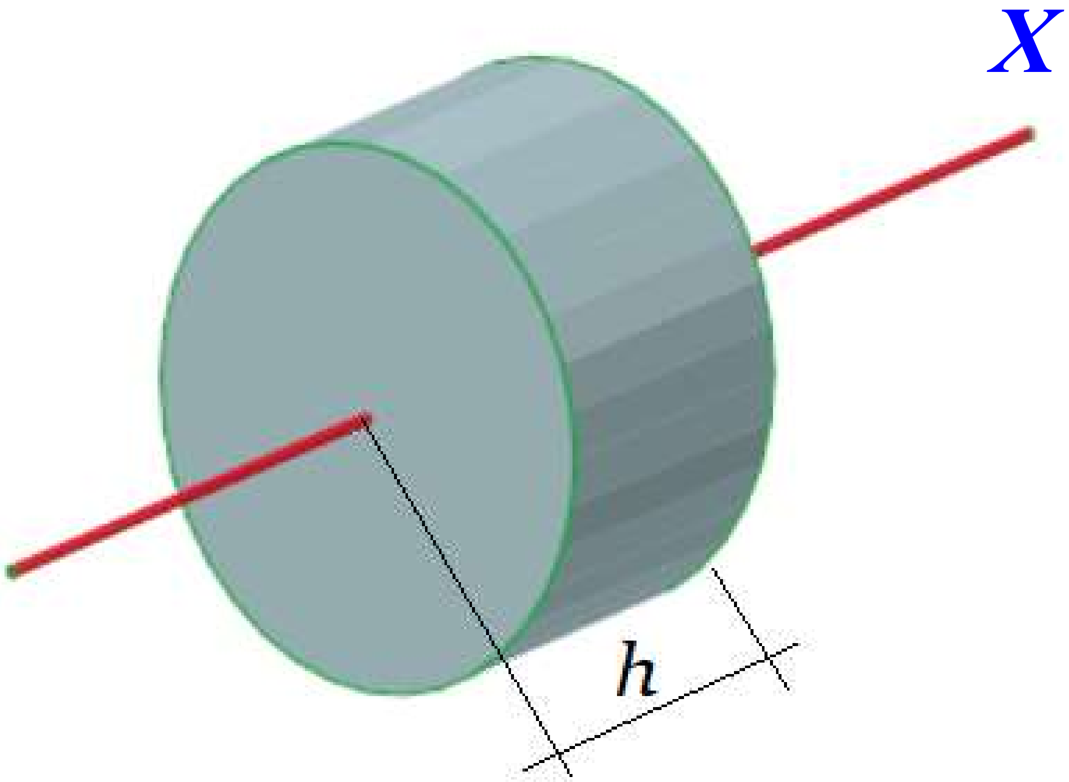
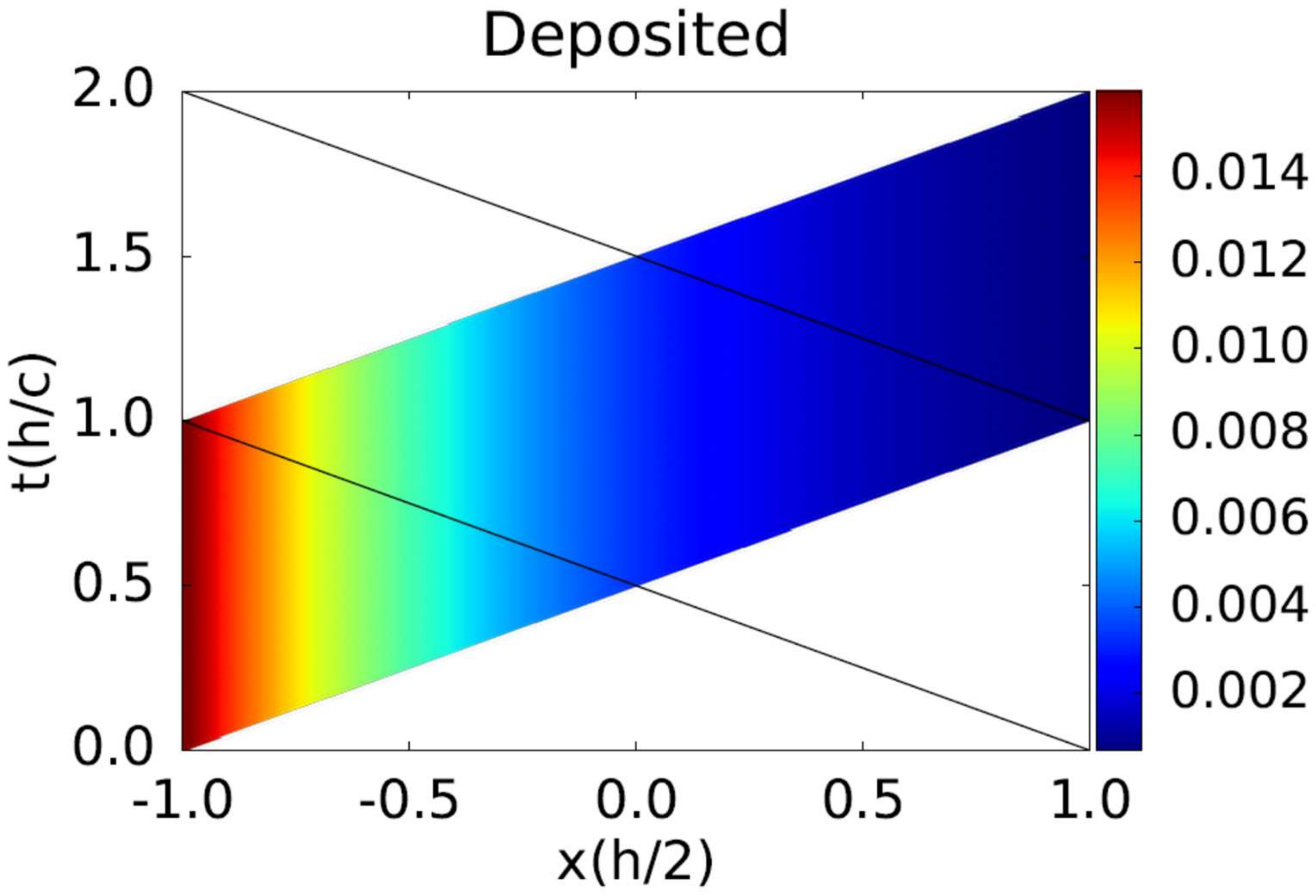
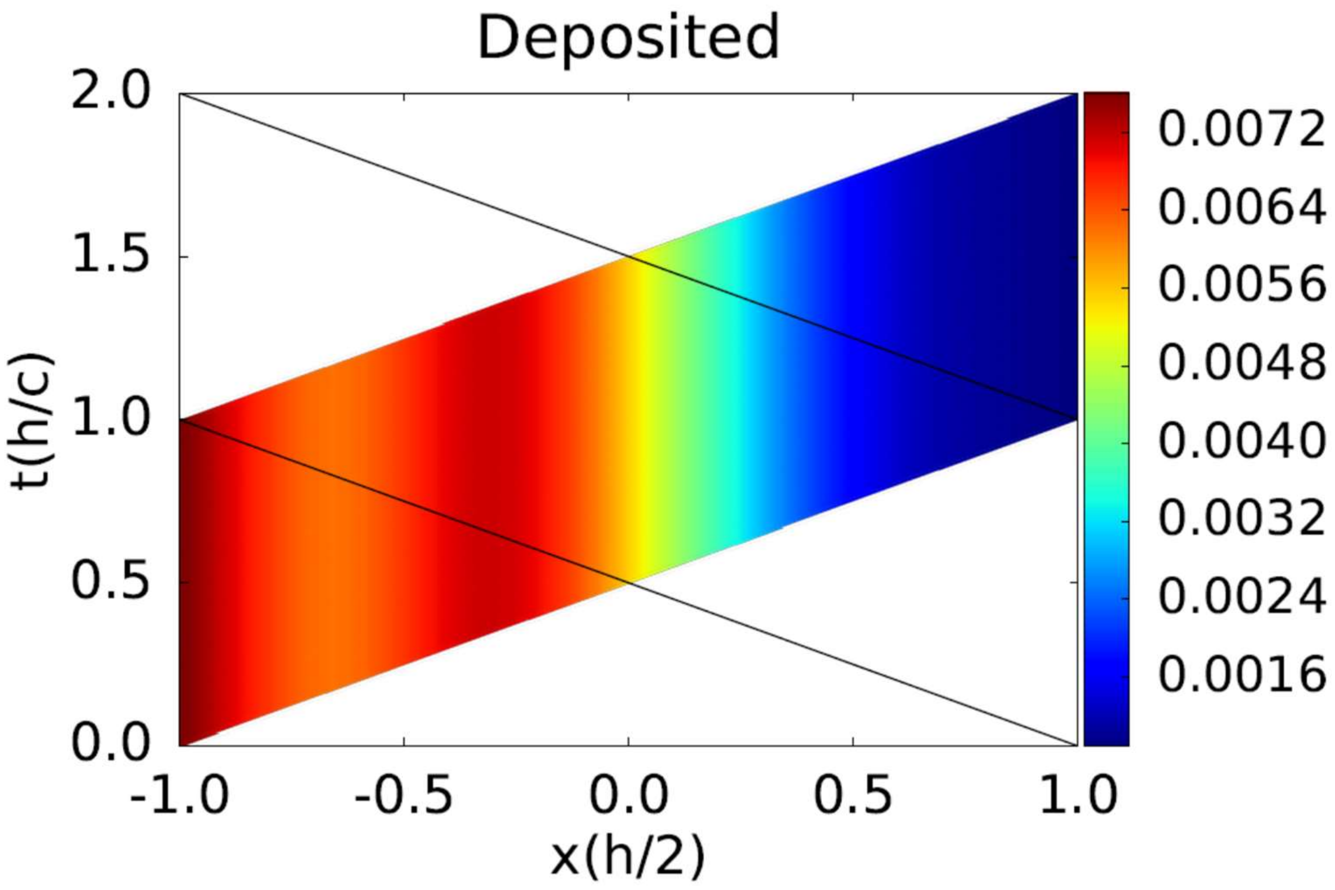


Figure 1: (color online) The target still should be compact to minimize the surface effects. The irradiation is performed along the $x-$axis from both sides towards the target. The laser beam should be uniform hitting the whole face of the coin shaped target.

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

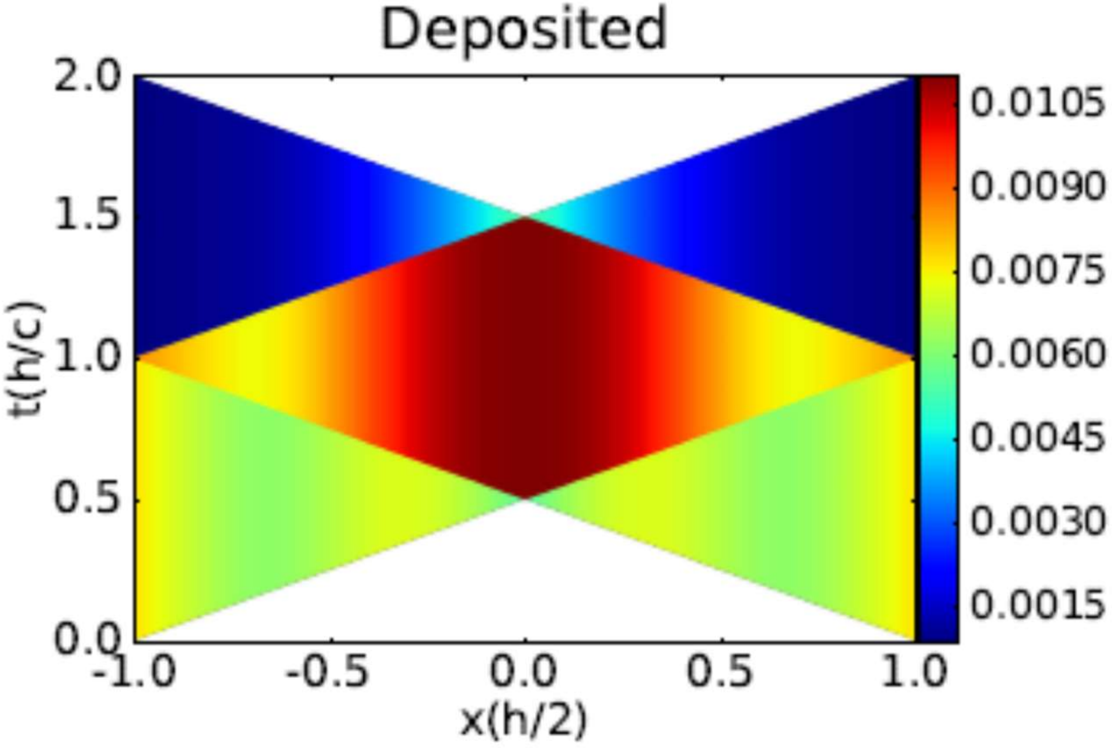


Figure 2: (color online) Deposited energy per unit time in the space-time across the depth, h, of the flat target. The time is measured in units of (h/c), where c is the speed of light in the material of the target. The irradiation lasts for a period of $\Delta t = h/c$ the time needed to cross the target.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

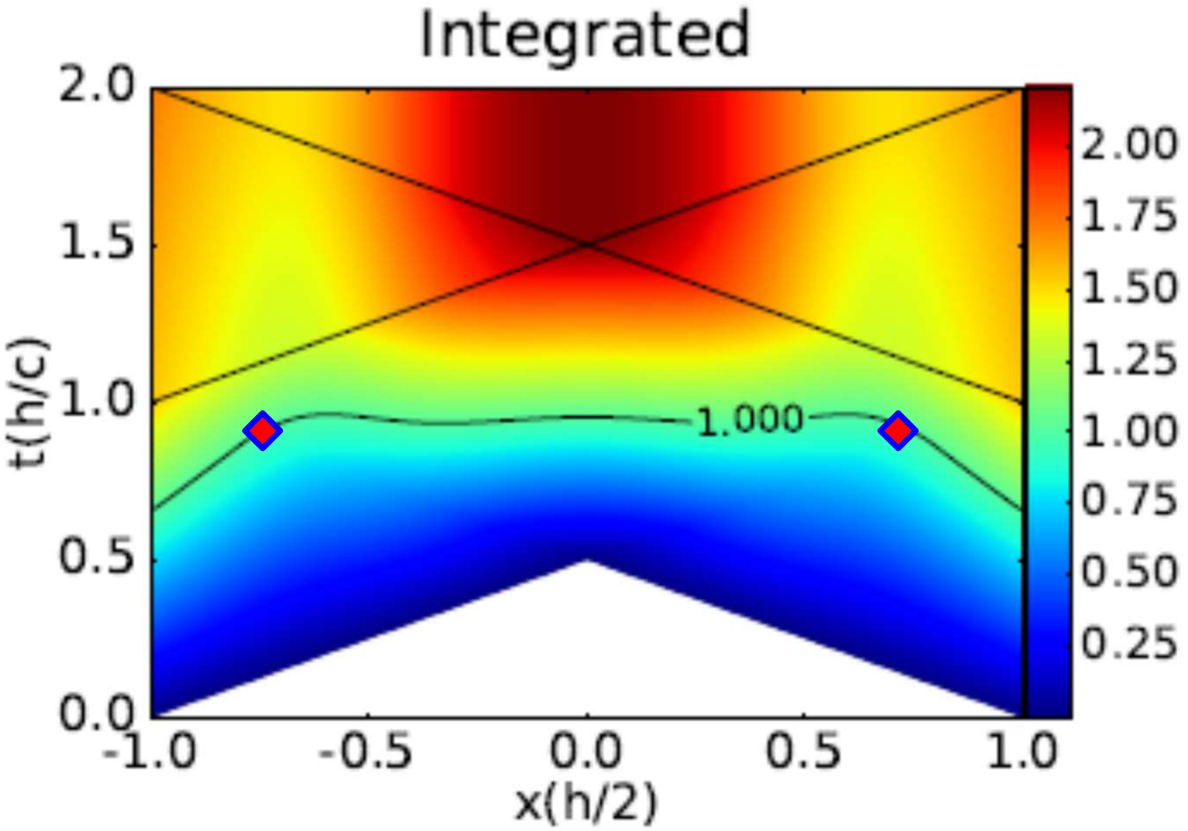


Figure 3: (color online) Integrated energy up to a given time in the space-time across the depth, h, of the flat target. The color code indicates the temperature, T, reached in a given space-time point, in units of the critical temperature, (T_c). The contour line $T = 1$, indicates the critical temperature,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

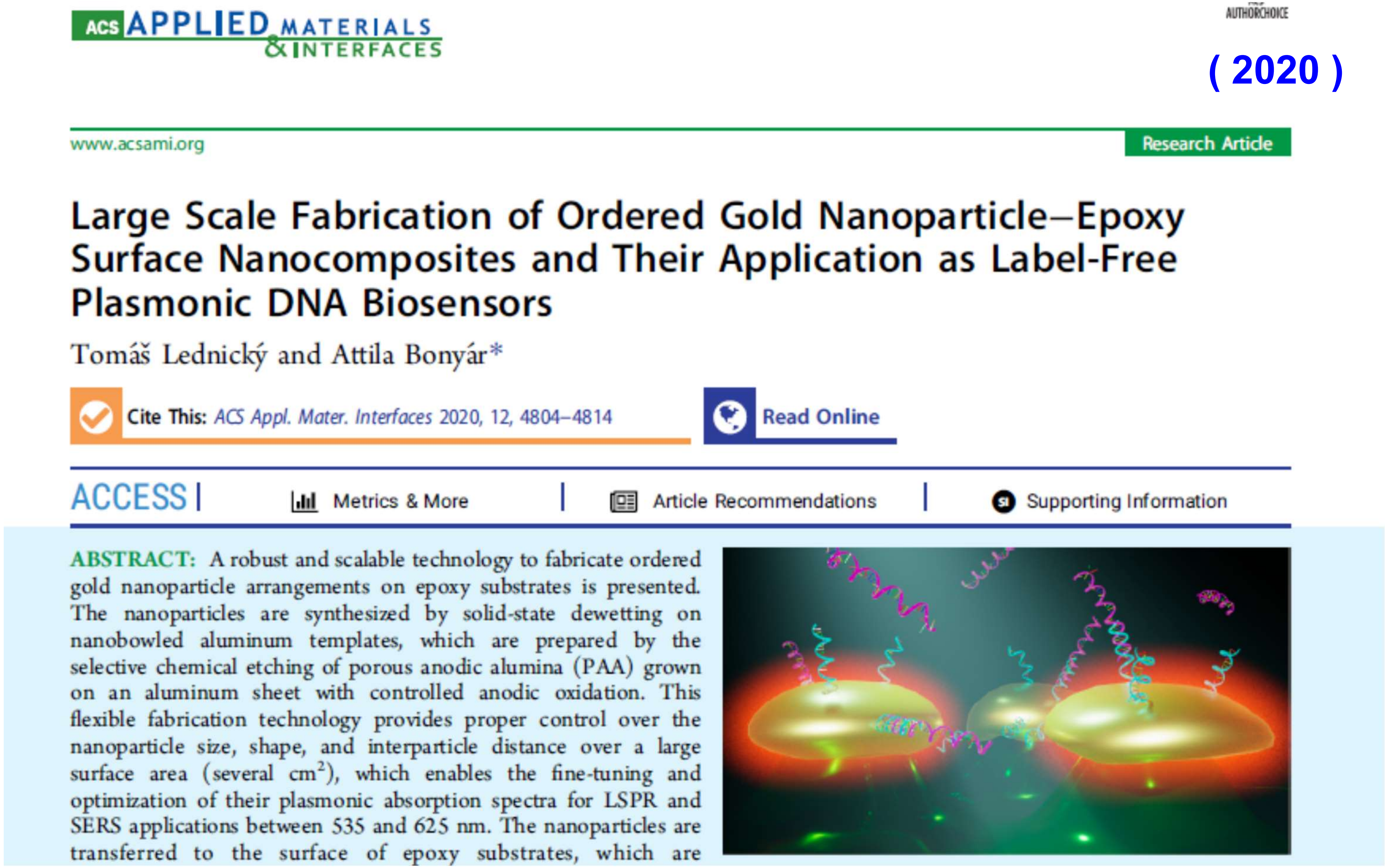
With nano antennas

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

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

Simultaneous ignition in the whole target volume

(2020)



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Research Article

Large Scale Fabrication of Ordered Gold Nanoparticle–Epoxy Surface Nanocomposites and Their Application as Label-Free Plasmonic DNA Biosensors

Tomáš Lednický and Attila Bonyár*

Cite This: *ACS Appl. Mater. Interfaces* 2020, 12, 4804–4814

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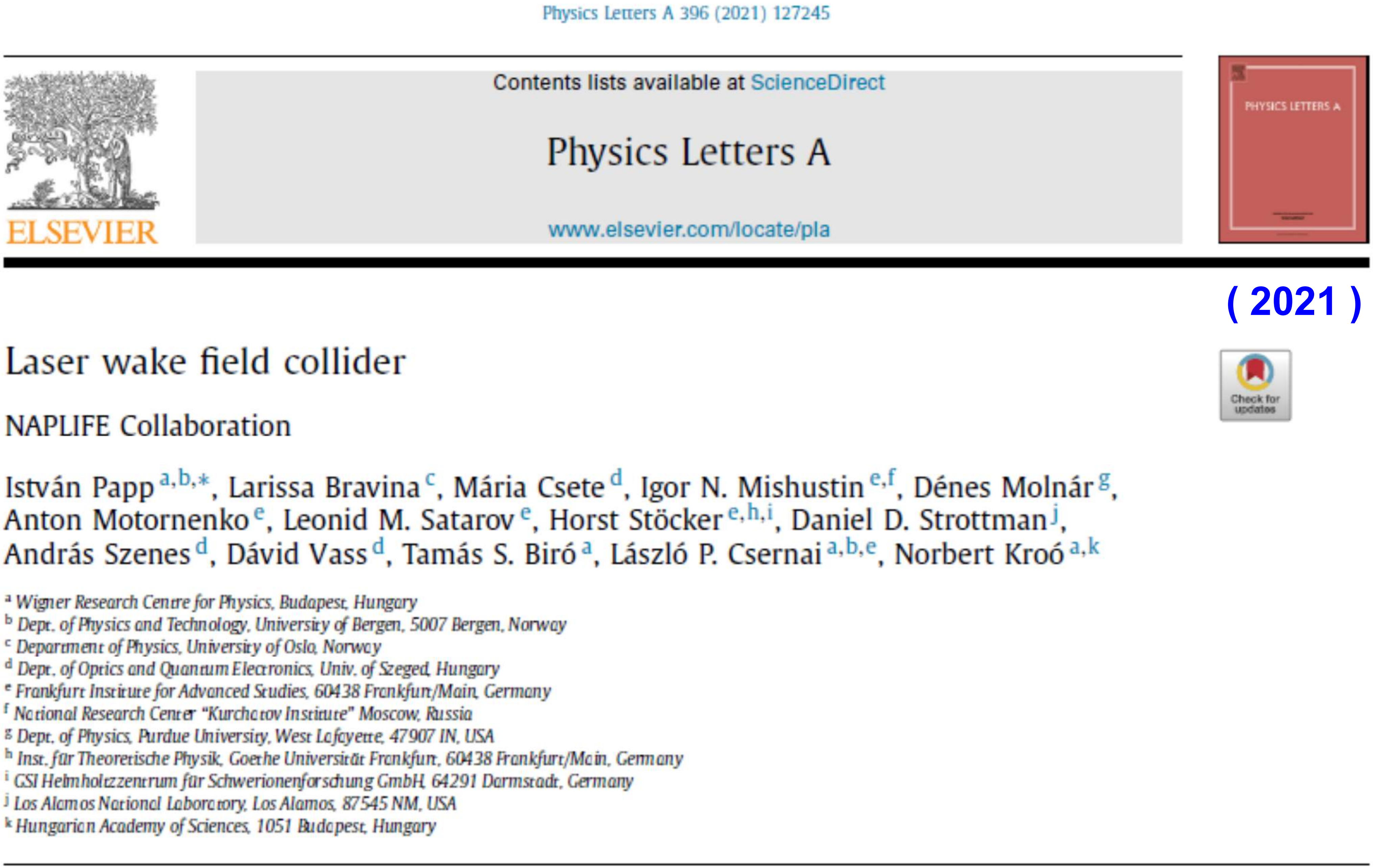
ABSTRACT: A robust and scalable technology to fabricate ordered gold nanoparticle arrangements on epoxy substrates is presented. The nanoparticles are synthesized by solid-state dewetting on nanobowled aluminum templates, which are prepared by the selective chemical etching of porous anodic alumina (PAA) grown on an aluminum sheet with controlled anodic oxidation. This flexible fabrication technology provides proper control over the nanoparticle size, shape, and interparticle distance over a large surface area (several cm^2), which enables the fine-tuning and optimization of their plasmonic absorption spectra for LSPR and SERS applications between 535 and 625 nm. The nanoparticles are transferred to the surface of epoxy substrates, which are



Physics Letters A 396 (2021) 127245

Contents lists available at ScienceDirect

Physics Letters A

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(2021)

Laser wake field collider

NAPLIFE Collaboration

István Papp [a,b,*], Larissa Bravina [c], Mária Csete [d], Igor N. Mishustin [e,f], Dénes Molnár [g], Anton Motornenko [e], Leonid M. Satarov [e], Horst Stöcker [e,h,i], Daniel D. Strottman [j], András Szenes [d], Dávid Vass [d], Tamás S. Biró [a], László P. Csernai [a,b,e], Norbert Kroó [a,k]

[a] Wigner Research Centre for Physics, Budapest, Hungary
[b] Dept. of Physics and Technology, University of Bergen, 5007 Bergen, Norway
[c] Department of Physics, University of Oslo, Norway
[d] Dept. of Optics and Quantum Electronics, Univ. of Szeged, Hungary
[e] Frankfurt Institute for Advanced Studies, 60438 Frankfurt/Main, Germany
[f] National Research Center "Kurchatov Institute" Moscow, Russia
[g] Dept. of Physics, Purdue University, West Lafayette, 47907 IN, USA
[h] Inst. für Theoretische Physik, Goethe Universität Frankfurt, 60438 Frankfurt/Main, Germany
[i] GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany
[j] Los Alamos National Laboratory, Los Alamos, 87545 NM, USA
[k] Hungarian Academy of Sciences, 1051 Budapest, Hungary

Laser Wake Field Acceleration

For pre-compression before ignition

Electron (e) Energy to $E_e \approx 100$ MeV or more

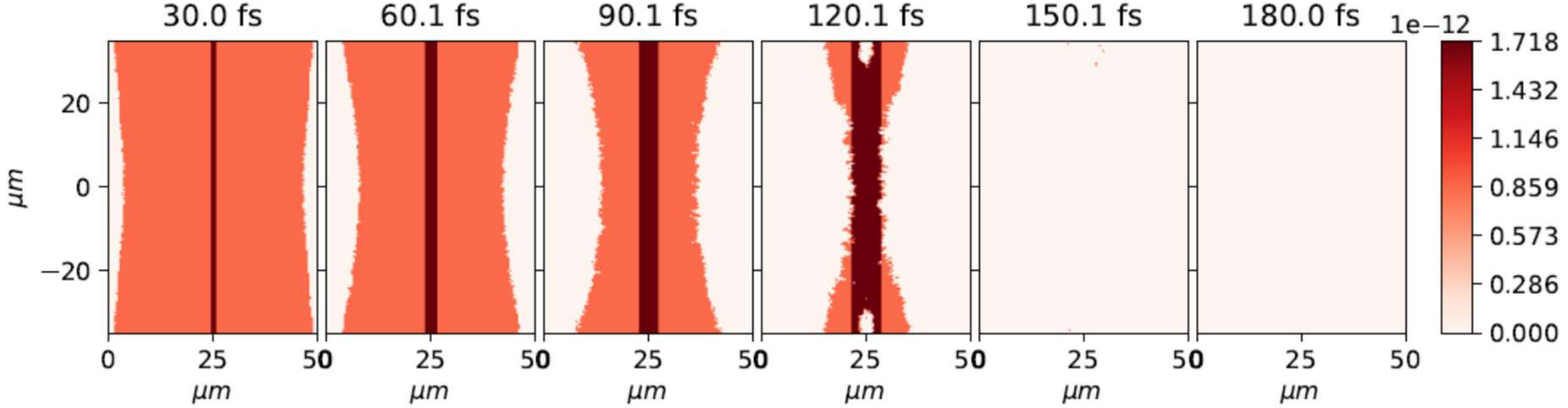
IF: $v_{LW} = v_e \approx v_{ion}$ ➔ $E_{H\text{-}ion} \approx 1836\, E_e \approx 183.6$ GeV

$m_e = 0.511$ MeV, $m_p = 938.3$ MeV, $\gamma = \gamma_e \approx \gamma_p \approx 195$ ➔ $y = 5.97$

Beam density: $n_H = \gamma\, n_0 = 195\ \mathrm{g/cm^3}$

Target density after interpenetration: $n_t = 2\, n_H =$ **$390\ \mathrm{g/cm^3}$**

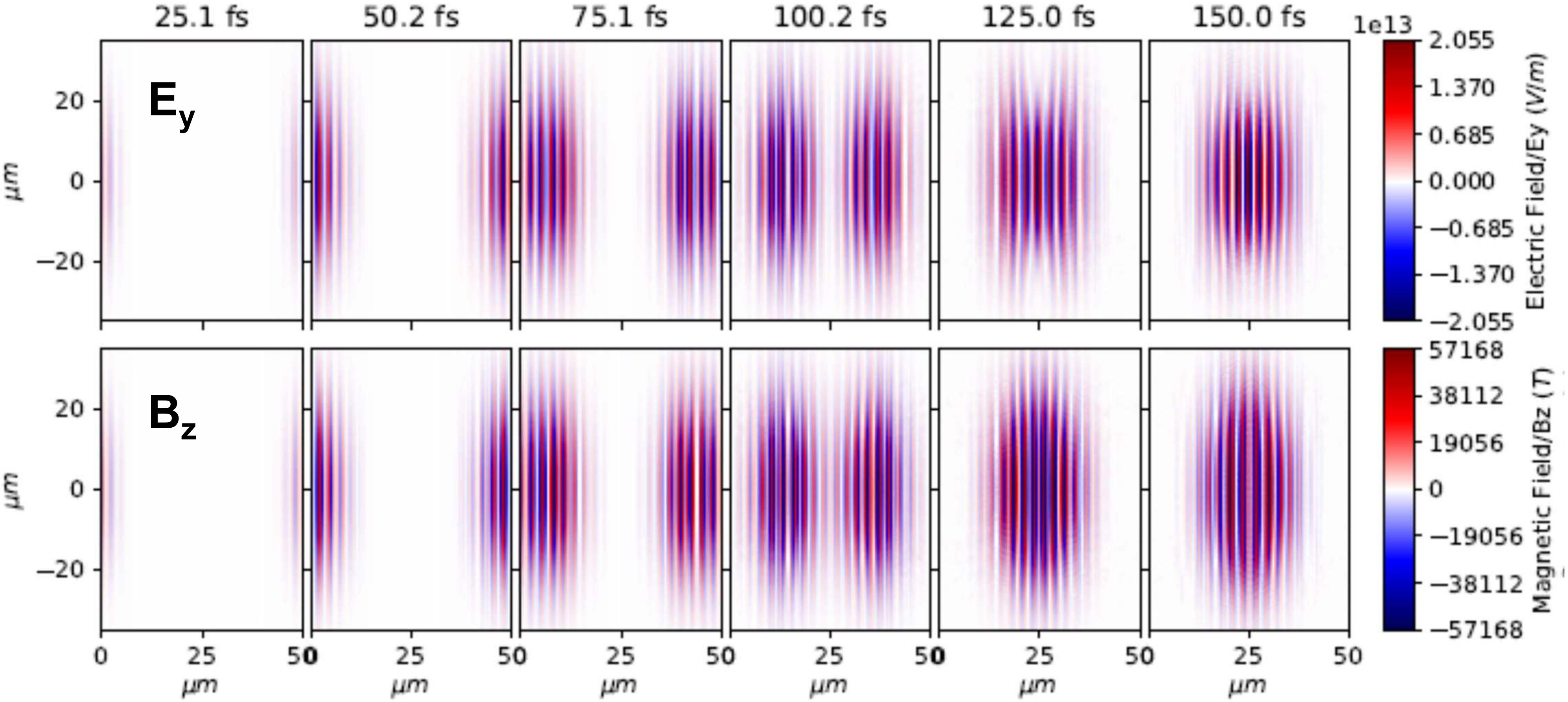
Relative rapidity: **$y = 11.94$**



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 Collaboration, Phys. Lett. A396,127245 (2021)]

Laser Wake Field Collider



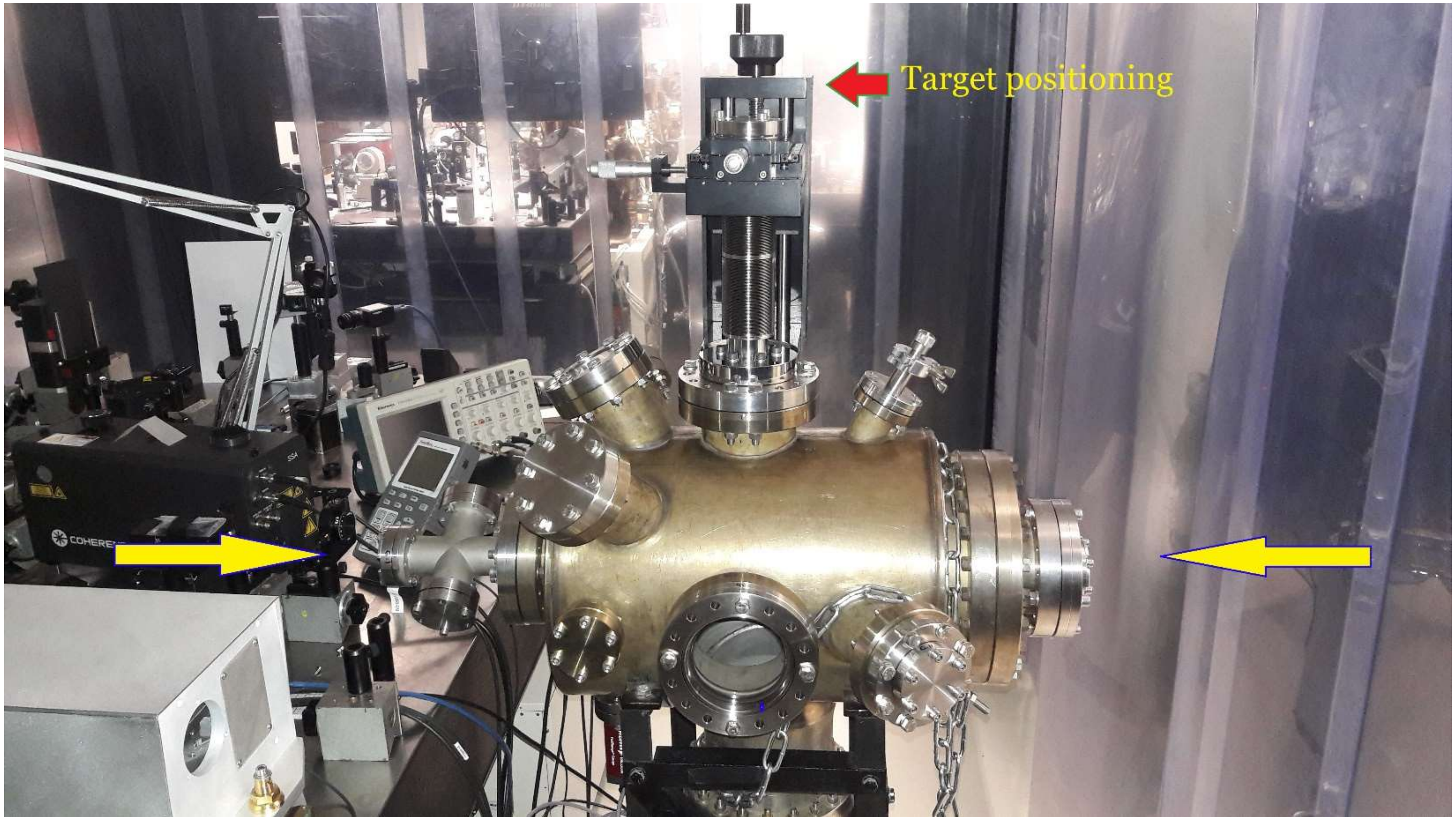
The electric field, E_y (top) and magnetic field, B_z (bottom) in a Laser Wake Field (LWF) wave formed by irradiation from the ±x- direction. The rest number density of the H target is $n_H = 2.13\ \ 10^{25}/m^3 = 2.13\ \ 10^{19}/cm^3$. The laser beam wavelength is $\lambda = 1\mu m$. The LWF wavelength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

[Papp, I., et al., NAPLIFE Collaboration, Phys. Lett. A396,127245 (2021)]

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)**



M. Aladi,
M. Kedves,
A. Kumari,
P. Rácz,
B. Raczkevi

(2021)

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

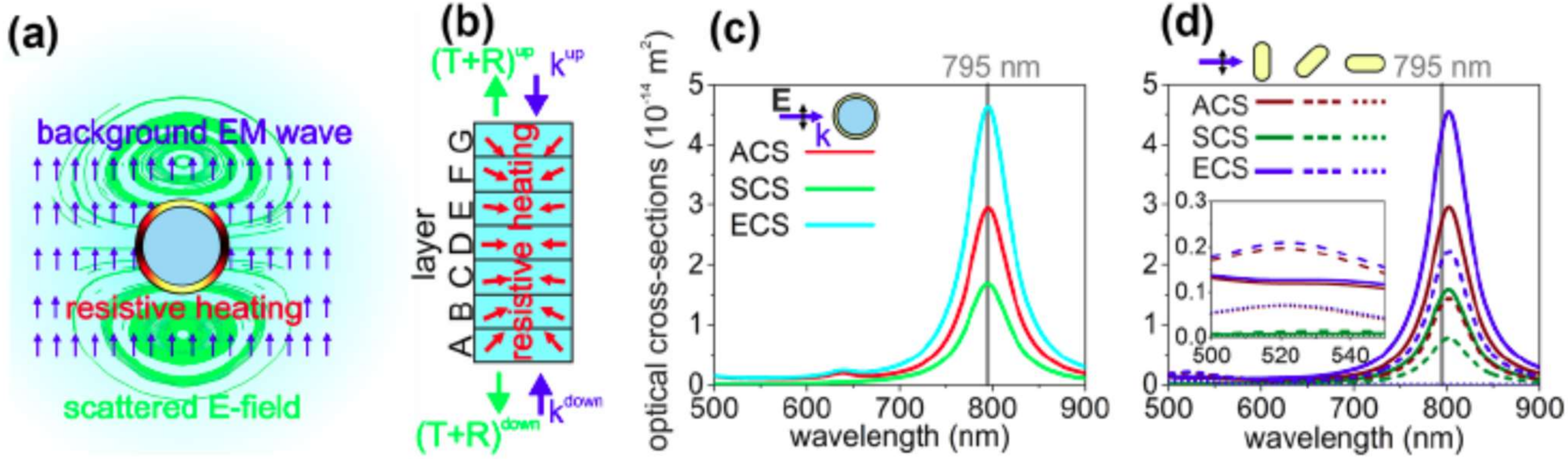
Comparative Study on the Uniform Energy Deposition Achievable via Optimized Plasmonic Nanoresonator Distributions

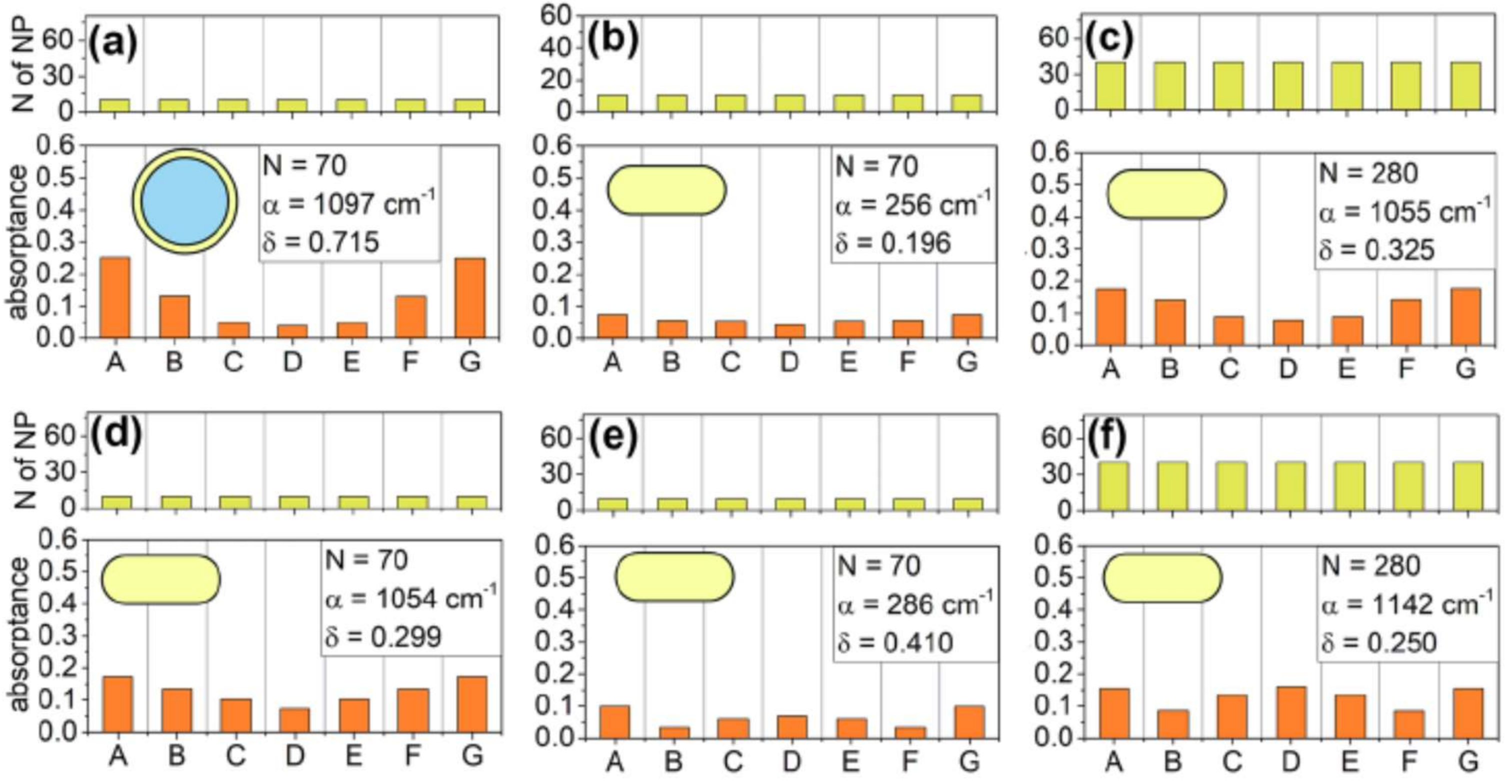
Mária Csete[1] · András Szenes[1] · Emese Tóth[1] · Dávid Vass[1] · Olivér Fekete[1] · Balázs Bánhelyi[2] · István Papp[3,4] · Tamás Bíró[3] · László P. Csernai[3,4,5] · Norbert Kroó[3,6]

Received: 1 July 2021 / Accepted: 2 December 2021

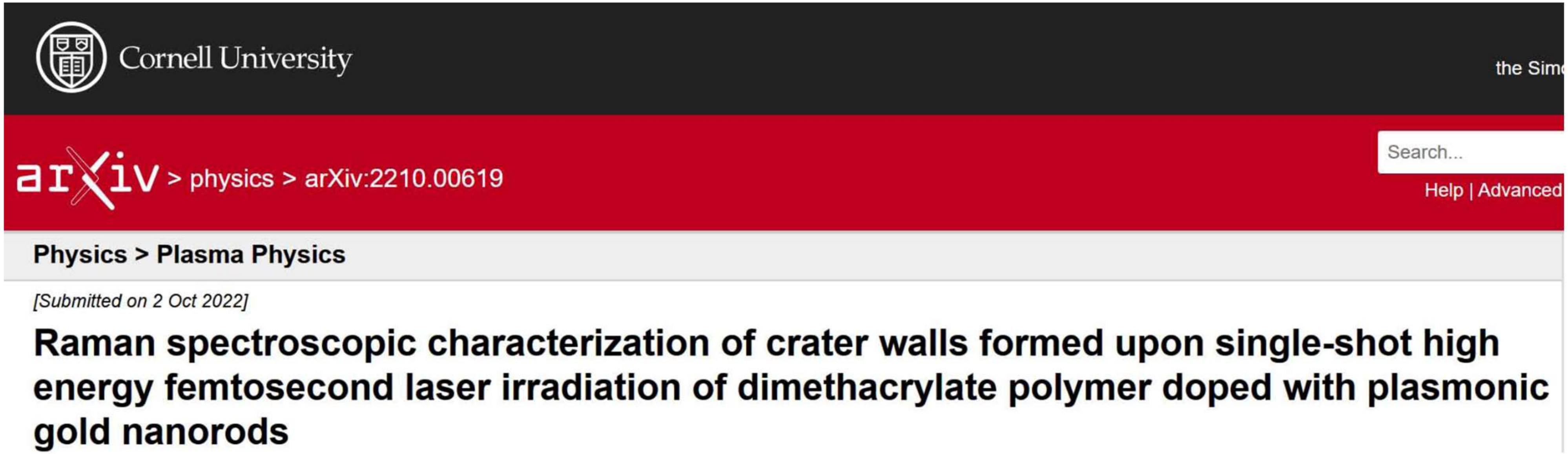
Abstract

Plasmonic nanoresonators of core–shell composition and nanorod shape were optimized to tune their absorption cross-section maximum to the central wavelength of a short laser pulse. The number density distribution of randomly located nanoresonators along a laser pulse-length scaled target was numerically optimized to maximize the absorptance with the criterion of minimal absorption difference between neighboring layers illuminated by two counter-propagating laser pulses. Wide Gaussian number density distribution of core–shell nanoparticles and nanorods enabled to improve the absorptance with low standard deviation; however, the energy deposited until the overlap of the two laser pulses exhibited a considerable standard deviation. Successive adjustment resulted in narrower Gaussian number density distributions that made it possible to ensure almost uniform distribution of the deposited energy integrated until the maximal overlap of the two laser pulses. While for core–shell nanoparticles the standard deviation of absorptance could be preserved, for the nanorods it was compromised. Considering the larger and polarization independent absorption cross-section as well as the simultaneously achievable smaller standard deviation of absorptance and deposited energy distribution, the core–shell nanoparticles outperform the nanorods both in optimized and adjusted nanoresonator distributions. Exception is the standard deviation of deposited energy distribution considered for the complete layers that is smaller in the adjusted nanorod distribution. Optimization of both nanoresonator distributions has potential applications, where efficient and uniform energy deposition is crucial, including biomedical applications, phase transitions, and even fusion.


(a)
background EM wave
resistive heating
scattered E-field
(b)
$(T+R)^{up}$
k^{up}
layer
A B C D E F G
resistive heating
$(T+R)^{down}$
k^{down}
(c)
795 nm
E
k
ACS
SCS
ECS
optical cross-sections (10^{-14} m^2)
0 1 2 3 4 5
500 600 700 800 900
wavelength (nm)
(d)
795 nm
ACS
SCS
ECS
0.0 0.1 0.2 0.3
500 520 540
0 1 2 3 4 5
500 600 700 800 900
wavelength (nm)


(a)
N of NP
0 30 60
absorptance
0.0 0.1 0.2 0.3 0.4 0.5 0.6
N = 70
α = 1097 cm^{-1}
δ = 0.715
A B C D E F G
(b)
0 20 40 60
0.0 0.1 0.2 0.3 0.4 0.5 0.6
N = 70
α = 256 cm^{-1}
δ = 0.196
A B C D E F G
(c)
0 30 60
0.0 0.1 0.2 0.3 0.4 0.5 0.6
N = 280
α = 1055 cm^{-1}
δ = 0.325
A B C D E F G
(d)
N of NP
0 30 60
absorptance
0.0 0.1 0.2 0.3 0.4 0.5 0.6
N = 70
α = 1054 cm^{-1}
δ = 0.299
A B C D E F G
(e)
0 30 60
0.0 0.1 0.2 0.3 0.4 0.5 0.6
N = 70
α = 286 cm^{-1}
δ = 0.410
A B C D E F G
(f)
0 30 60
0.0 0.1 0.2 0.3 0.4 0.5 0.6
N = 280
α = 1142 cm^{-1}
δ = 0.250
A B C D E F G

(2022)



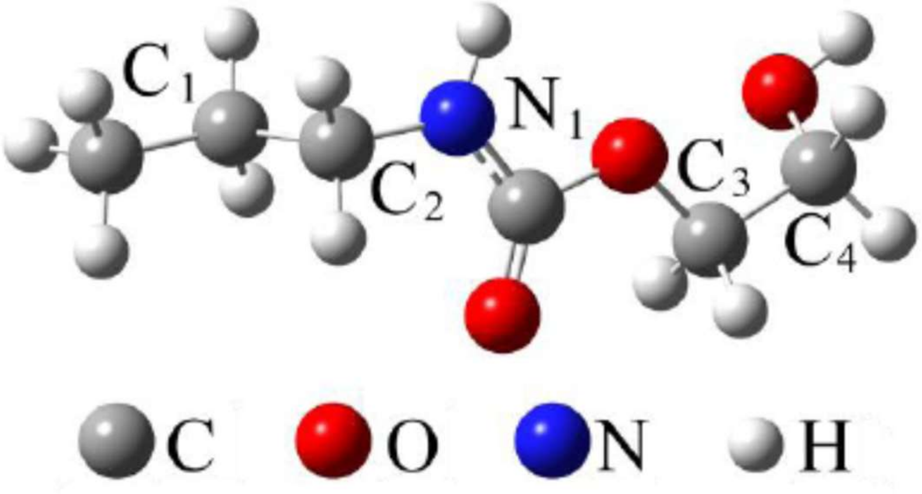
arXiv > physics > arXiv:2210.00619

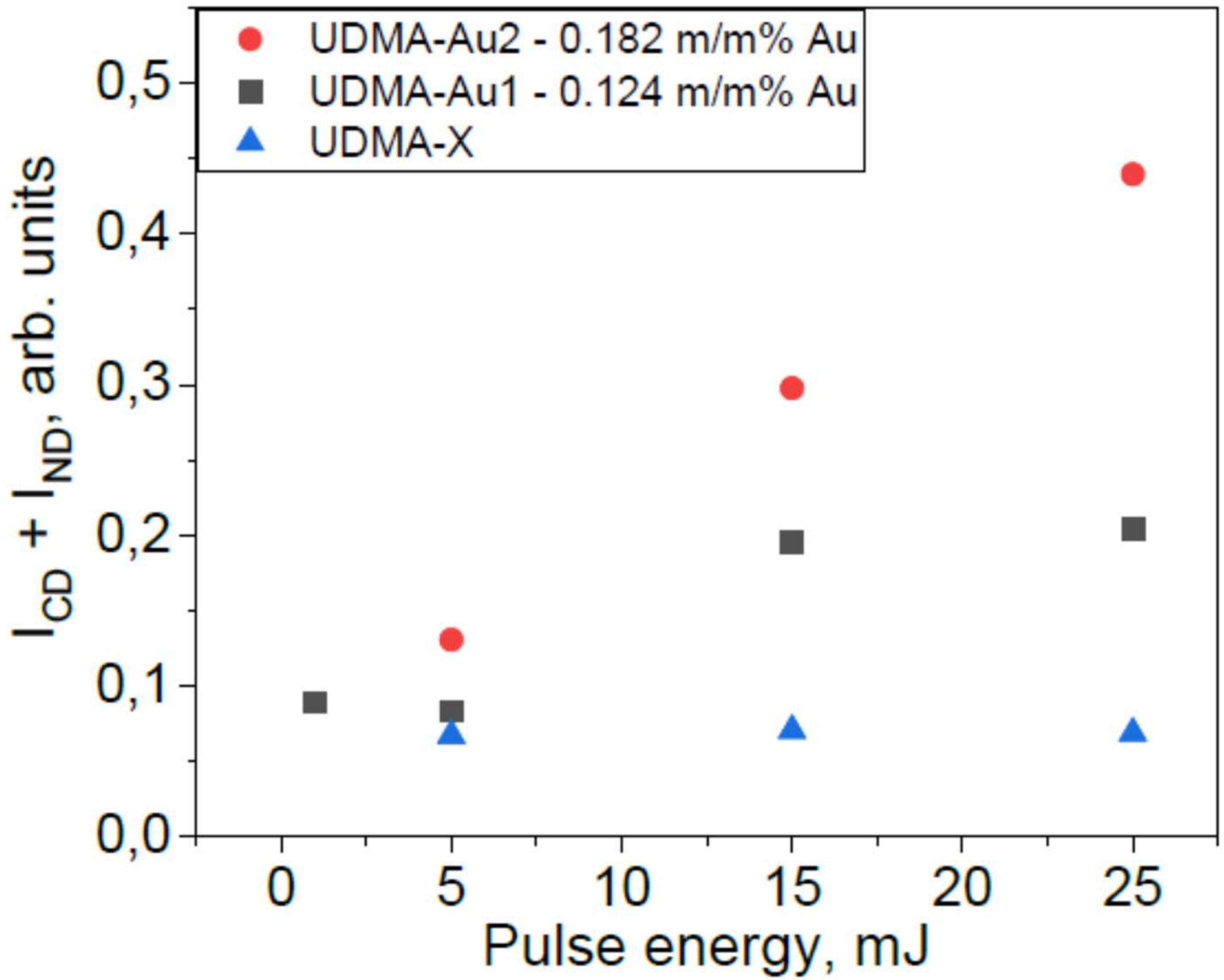
Physics > Plasma Physics

[Submitted on 2 Oct 2022]

Raman spectroscopic characterization of crater walls formed upon single-shot high energy femtosecond laser irradiation of dimethacrylate polymer doped with plasmonic gold nanorods

István Rigó[1], Judit Kámán[1], Ágnes Nagyné Szokol[1], Attila Bonyár[2], Melinda Szalóki[3], Alexandra Borók[1,2], Shereen Zangana[2], Péter Rácz[1], Márk Aladi[1], Miklós Ákos Kedves[1], Gábor Galbács[5], László P. Csernai[1,6,7], Tamás S. Biró[1], Norbert Kroó[1,8], Miklós Veres[1], NAPLIFE Collaboration





With Nanorods (Au2) at 25 mJ laser pulse ~4 times increased D production, compared to 1 mJ pulse

nanomaterials

(2022)

Article

Plasmonically Enhanced Superradiance of Broken-Symmetry Diamond Color Center Arrays Inside Core-Shell Nanoresonators

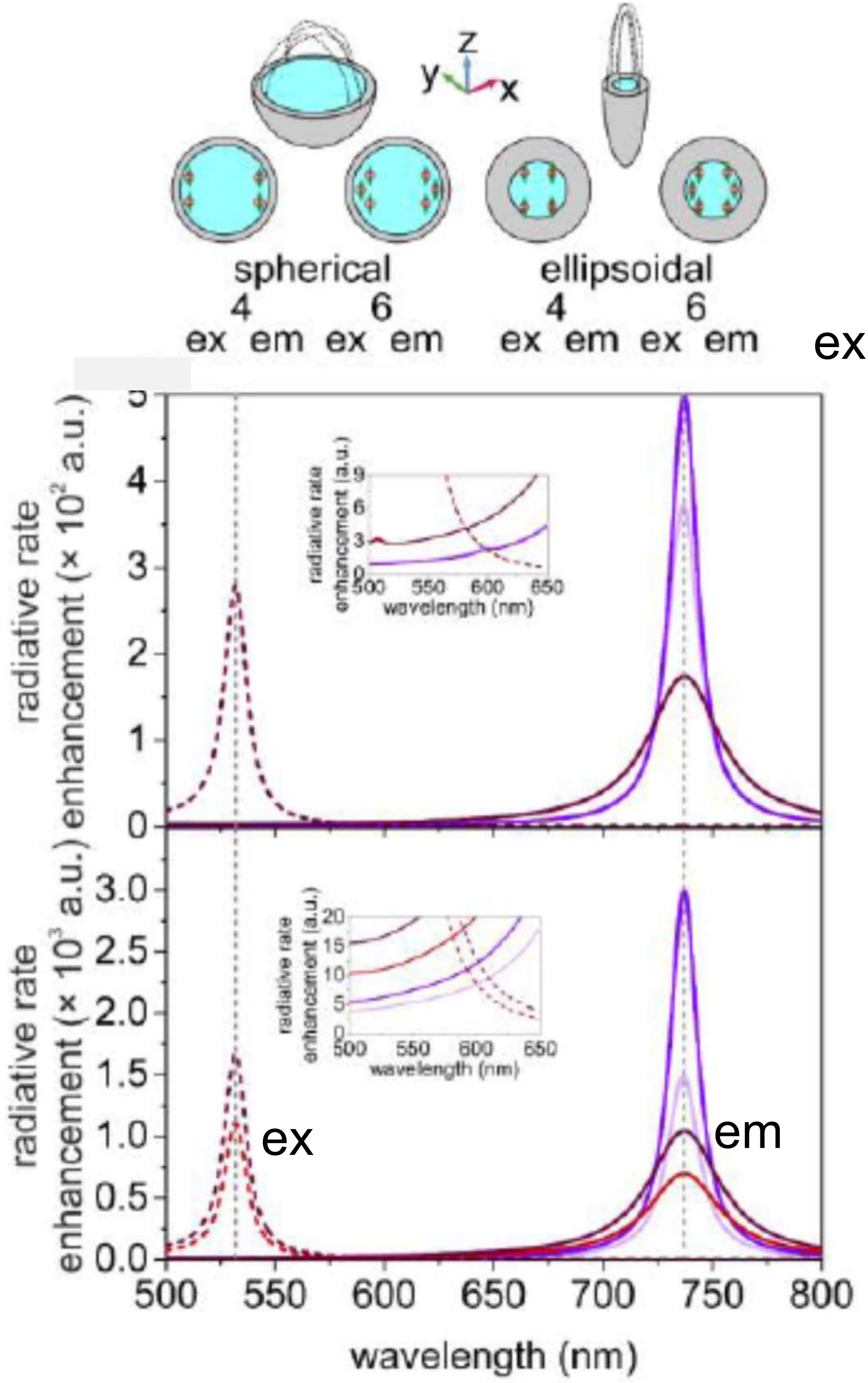
Dávid Vass [1], András Szenes [1], Balázs Bánhelyi [2] and Mária Csete [1,*]

[1] Department of Optics and Quantum Electronics, University of Szeged, Dóm tér 9, 6720 Szeged, Hungary; Vass.David.Imre@stud.u-szeged.hu (D.V.); Szenes.Andras.Laszlo@stud.u-szeged.hu (A.S.)

[2] Department of Computational Optimization, University of Szeged, Árpád tér 2, 6720 Szeged, Hungary; banhelyi@inf.u-szeged.hu

[*] Correspondence: mcsete@physx.u-szeged.hu

Citation: Vass, D.; Szenes, A.; Bánhelyi, B.; Csete, M. Plasmonically Enhanced Superradiance of Broken-Symmetry Diamond Color Center Arrays Inside Core-Shell Nanoresonators. *Nanomaterials* **2022**, *12*, 352. https://doi.org/10.3390/nano12030352



excitation / emission

ex

em

Ellipsoidal antennas (~nano-rods) have some advantage

(2022)

International Journal of
Molecular Sciences

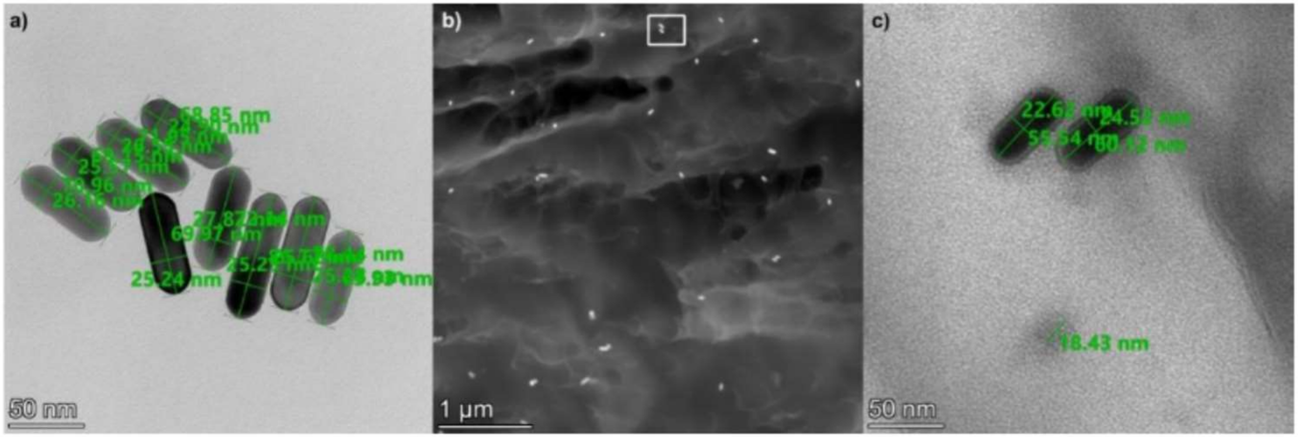
MDPI

Article

The Effect of Femtosecond Laser Irradiation and Plasmon Field on the Degree of Conversion of a UDMA-TEGDMA Copolymer Nanocomposite Doped with Gold Nanorods

Attila Bonyár [1,*], Melinda Szalóki [2], Alexandra Borók [1,3], István Rigó [3], Judit Kámán [3], Shereen Zangana [1], Miklós Veres [3], Péter Rácz [3], Márk Aladi [3], Miklós Ákos Kedves [3], Ágnes Szokol [3], Péter Petrik [4], Zsolt Fogarassy [4], Kolos Molnár [5], Mária Csete [6], András Szenes [6], Emese Tóth [6], Dávid Vas [6], István Papp [3], Gábor Galbács [7], László P. Csernai [3,8,9], Tamás S. Biró [3], Norbert Kroó [3,10] and NAPLIFE Collaboration [3]

Citation: Bonyár, A.; Szalóki, M.; Borók, A.; Rigó, I.; Kámán, J.; Zangana, S.; Veres, M.; Rácz, P.; Aladi, M.; Kedves, M.Á.; et al. The Effect of Femtosecond Laser Irradiation and Plasmon Field on the Degree of Conversion of a UDMA-TEGDMA Copolymer Nanocomposite Doped with Gold Nanorods. *Int. J. Mol. Sci.* **2022**, *23*, 13575. https://doi.org/10.3390/ijms232113575



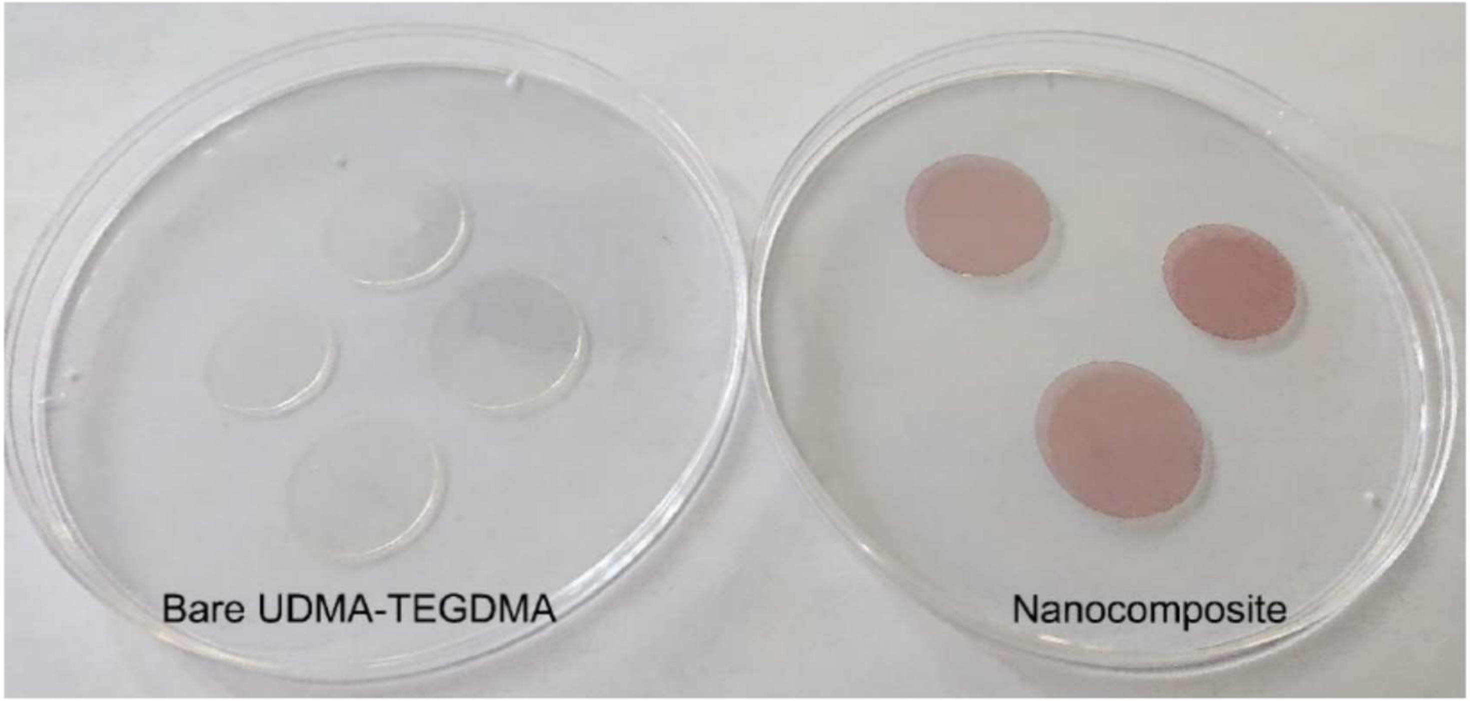
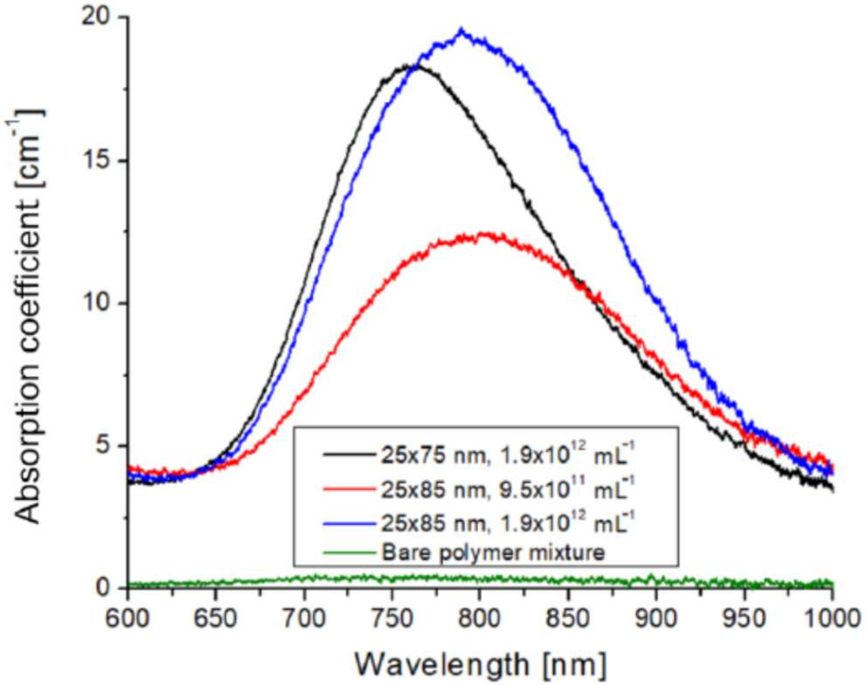
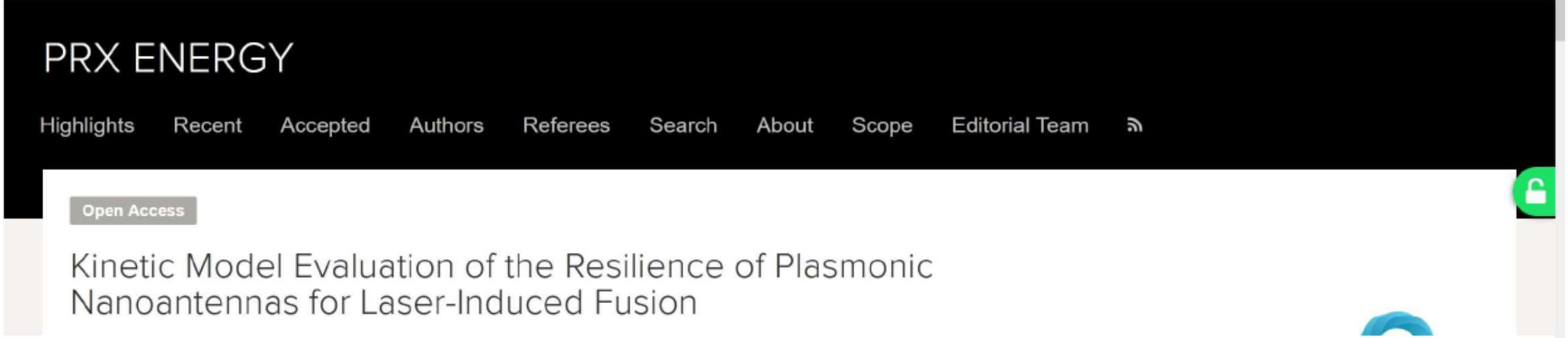


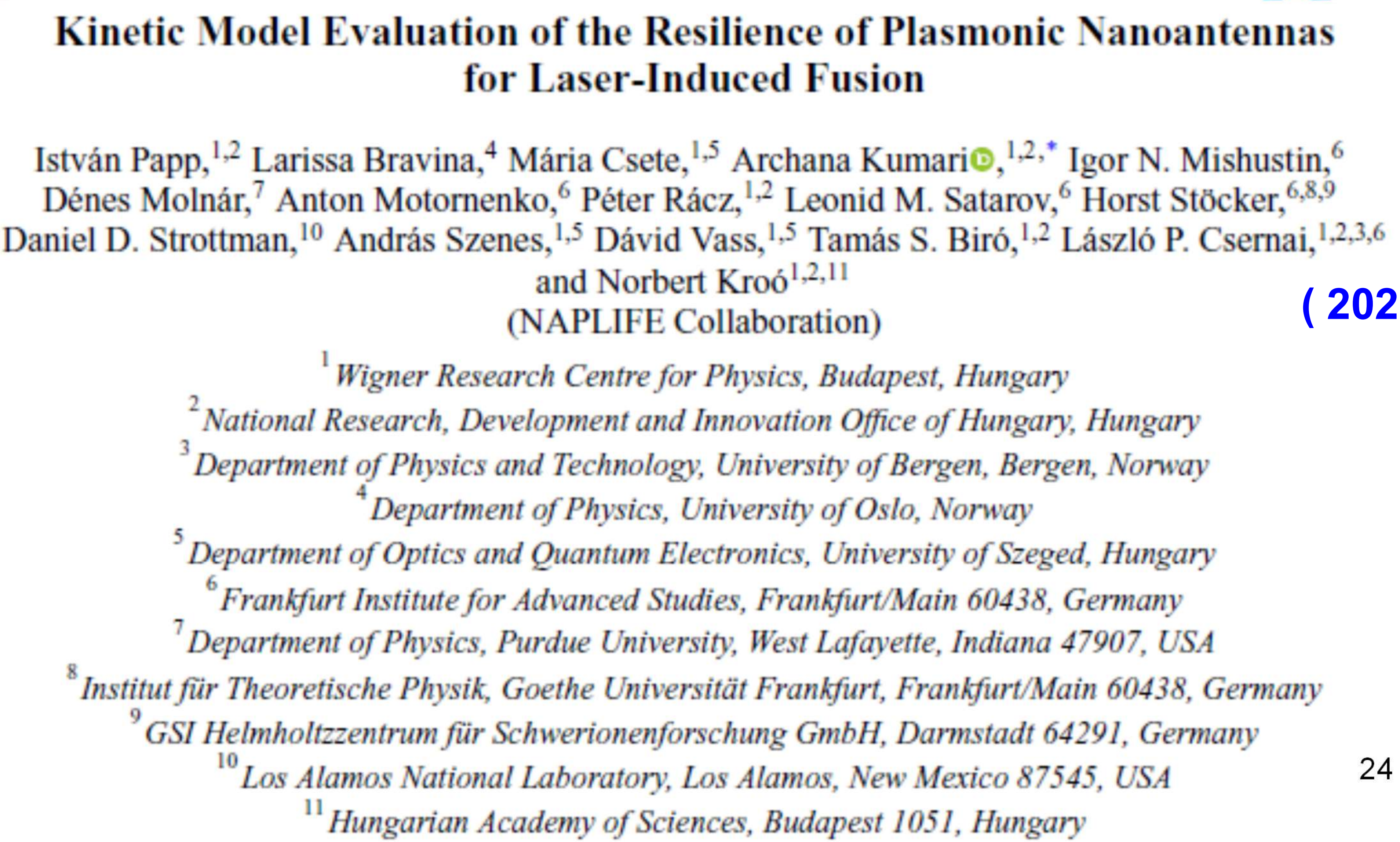
Figure 3. Photographs of bare (left) and Au nanorod-doped (right) photopolymerized resin samples,



Resonant light absorption by nano-rod antennas



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

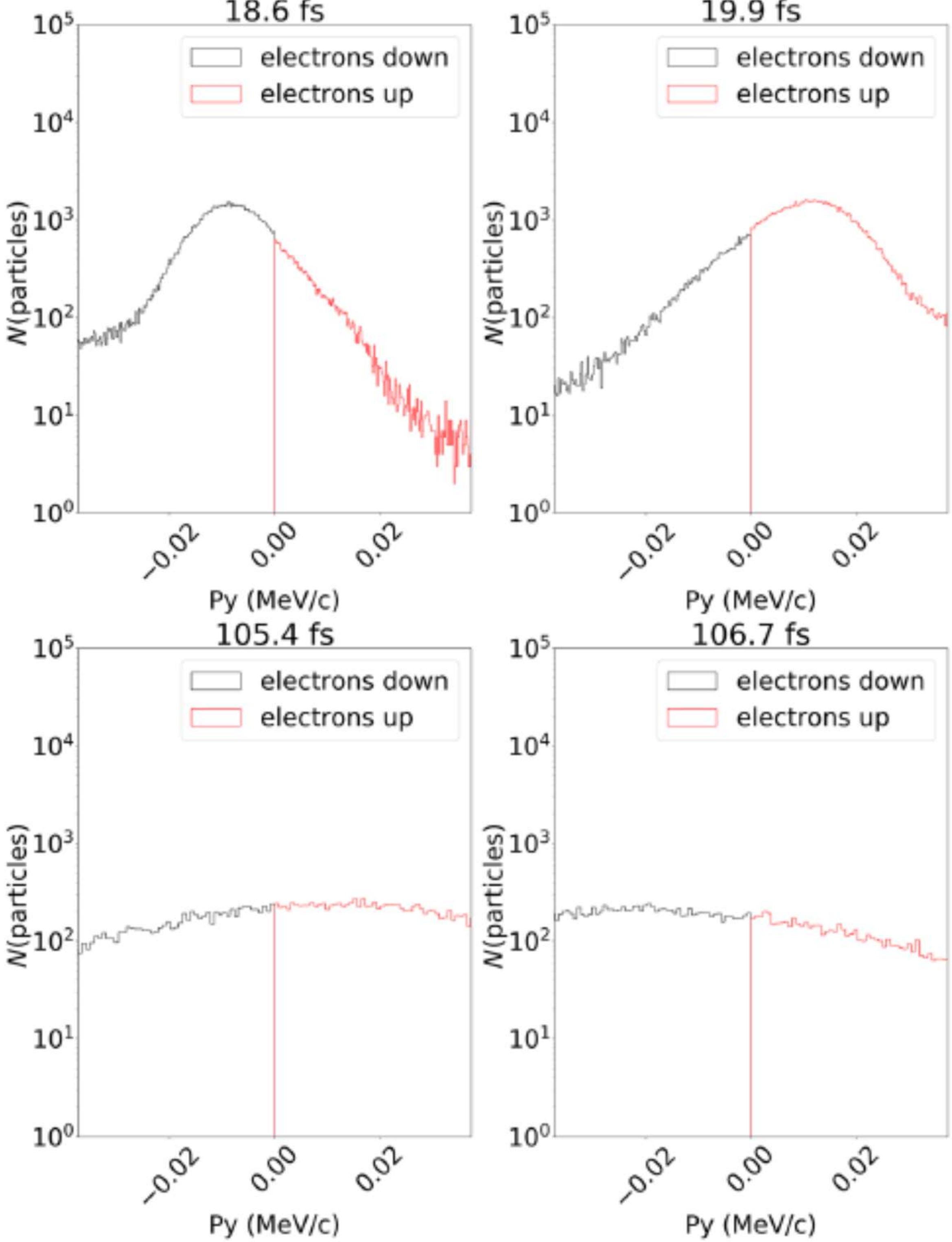


Kinetic Model Evaluation of the Resilience of Plasmonic Nanoantennas for Laser-Induced Fusion

István Papp,[1,2] Larissa Bravina,[4] Mária Csete,[1,5] Archana Kumari,[1,2,*] Igor N. Mishustin,[6]
Dénes Molnár,[7] Anton Motornenko,[6] Péter Rácz,[1,2] Leonid M. Satarov,[6] Horst Stöcker,[6,8,9]
Daniel D. Strottman,[10] András Szenes,[1,5] Dávid Vass,[1,5] Tamás S. Biró,[1,2] László P. Csernai,[1,2,3,6]
and Norbert Kroó[1,2,11]
(NAPLIFE Collaboration)

[1] *Wigner Research Centre for Physics, Budapest, Hungary*
[2] *National Research, Development and Innovation Office of Hungary, Hungary*
[3] *Department of Physics and Technology, University of Bergen, Bergen, Norway*
[4] *Department of Physics, University of Oslo, Norway*
[5] *Department of Optics and Quantum Electronics, University of Szeged, Hungary*
[6] *Frankfurt Institute for Advanced Studies, Frankfurt/Main 60438, Germany*
[7] *Department of Physics, Purdue University, West Lafayette, Indiana 47907, USA*
[8] *Institut für Theoretische Physik, Goethe Universität Frankfurt, Frankfurt/Main 60438, Germany*
[9] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt 64291, Germany*
[10] *Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
[11] *Hungarian Academy of Sciences, Budapest 1051, Hungary*

(2022)



25x130 nm antennas,
resonant for λ=795 nm

Initial   2 ord. magn.

[L. Novotny (2007)]

$$\frac{\lambda_{\text{eff}}}{2R\pi} = 13.74 - 0.12[\varepsilon_\infty + 141.04] - \frac{2}{\pi} + \frac{\lambda}{\lambda_p} 0.12\sqrt{\varepsilon_\infty + 141.04}.$$

“Final.

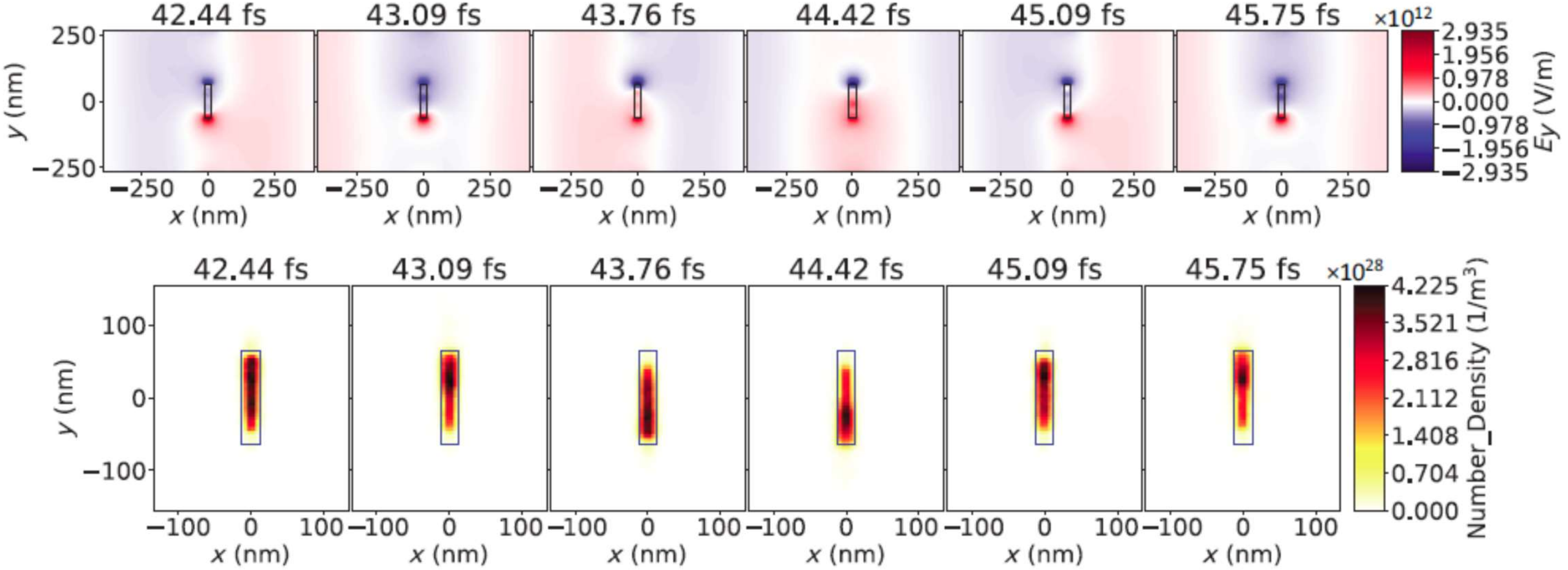
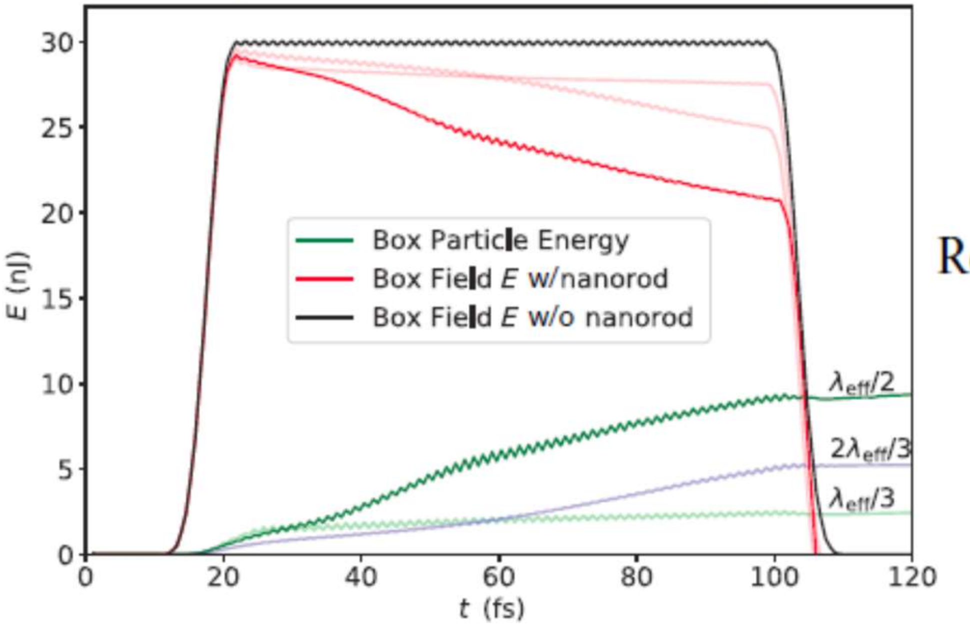
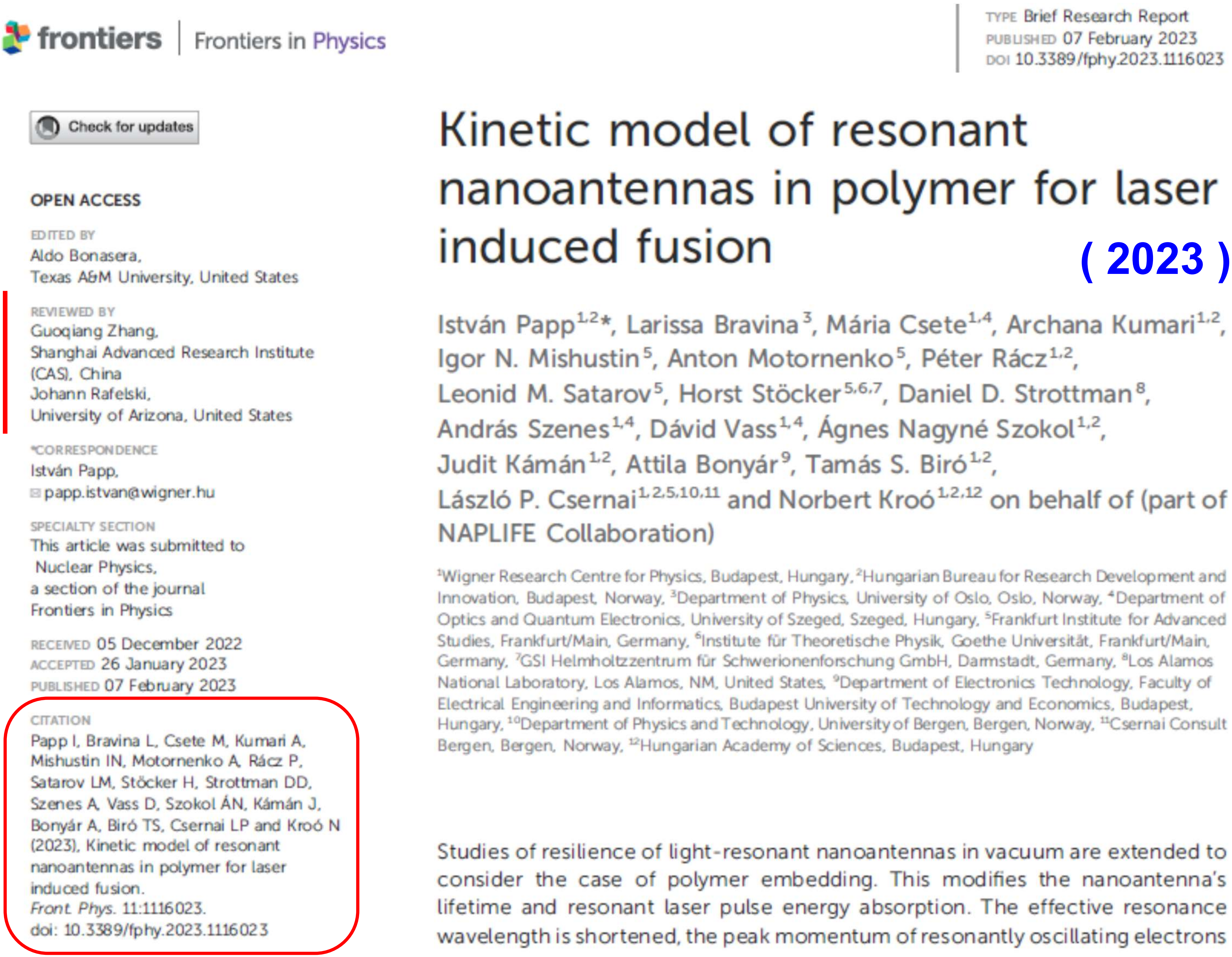


FIG. 2. Top: evolution of the E field's y component from 42.44 till 45.75 fs in a quarter of a period ($T/4 = 0.6625$ fs) steps, arour



Regarding the intensity, we estimate an enhancement of

$$I_x = 0.3\, I_p\, \frac{S_{\mathrm{CB}}}{S_{\mathrm{NR}}} = 25.9\, I_p. \tag{3}$$



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Kinetic model of resonant nanoantennas in polymer for laser induced fusion

(2023)

István Papp[1,2]*, Larissa Bravina[3], Mária Csete[1,4], Archana Kumari[1,2], Igor N. Mishustin[5], Anton Motornenko[5], Péter Rácz[1,2], Leonid M. Satarov[5], Horst Stöcker[5,6,7], Daniel D. Strottman[8], András Szenes[1,4], Dávid Vass[1,4], Ágnes Nagyné Szokol[1,2], Judit Kámán[1,2], Attila Bonyár[9], Tamás S. Biró[1,2], László P. Csernai[1,2,5,10,11] and Norbert Kroó[1,2,12] on behalf of (part of NAPLIFE Collaboration)

[1]Wigner Research Centre for Physics, Budapest, Hungary, [2]Hungarian Bureau for Research Development and Innovation, Budapest, Norway, [3]Department of Physics, University of Oslo, Oslo, Norway, [4]Department of Optics and Quantum Electronics, University of Szeged, Szeged, Hungary, [5]Frankfurt Institute for Advanced Studies, Frankfurt/Main, Germany, [6]Institute für Theoretische Physik, Goethe Universität, Frankfurt/Main, Germany, [7]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany, [8]Los Alamos National Laboratory, Los Alamos, NM, United States, [9]Department of Electronics Technology, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics, Budapest, Hungary, [10]Department of Physics and Technology, University of Bergen, Bergen, Norway, [11]Csernai Consult Bergen, Bergen, Norway, [12]Hungarian Academy of Sciences, Budapest, Hungary

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EDITED BY
Aldo Bonasera,
Texas A&M University, United States

REVIEWED BY
Guoqiang Zhang,
Shanghai Advanced Research Institute (CAS), China
Johann Rafelski,
University of Arizona, United States

*CORRESPONDENCE
István Papp,
✉ papp.istvan@wigner.hu

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Studies of resilience of light-resonant nanoantennas in vacuum are extended to consider the case of polymer embedding. This modifies the nanoantenna's lifetime and resonant laser pulse energy absorption. The effective resonance wavelength is shortened, the peak momentum of resonantly oscillating electrons

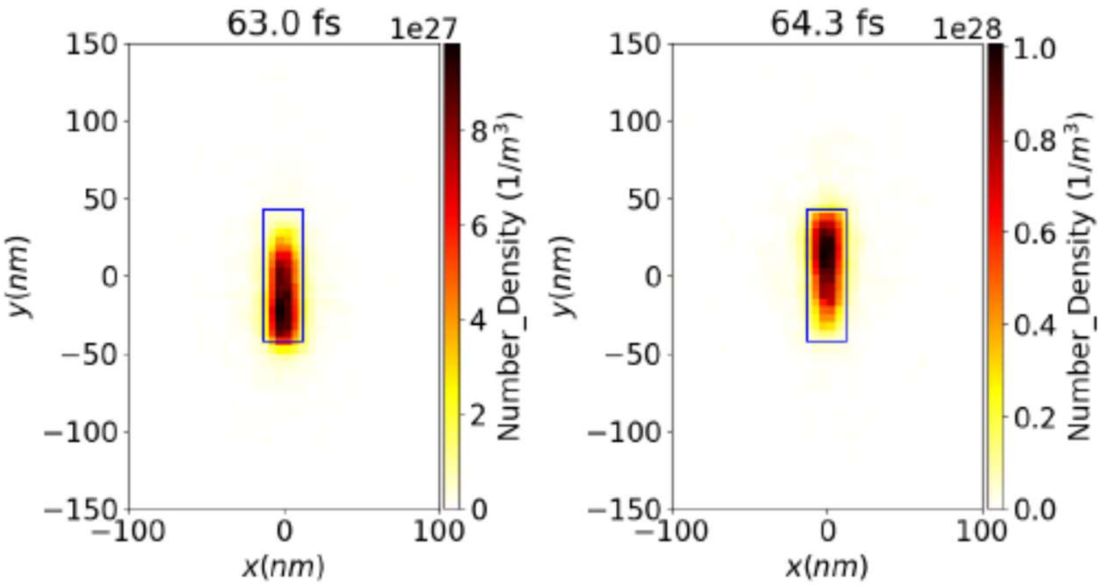
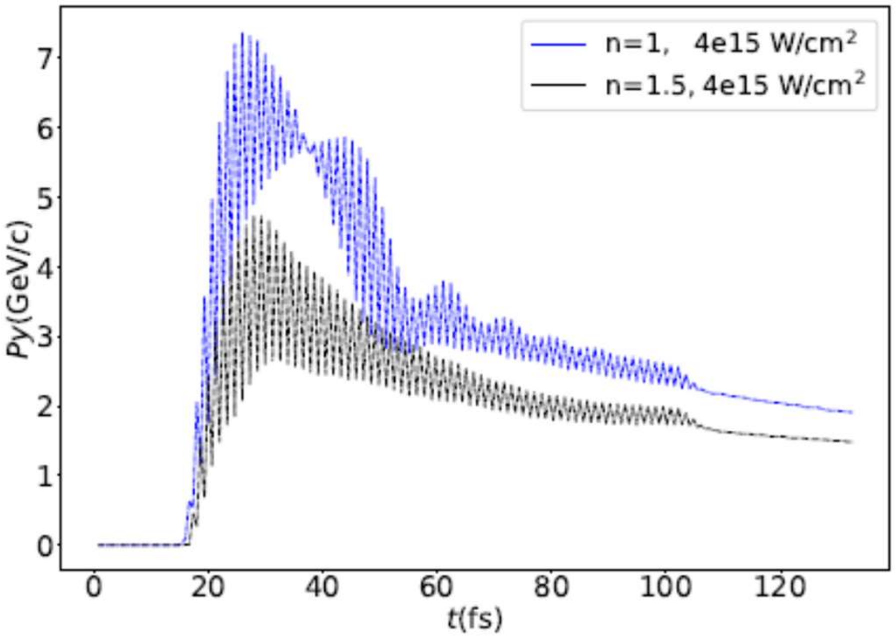


Figure 1: (color online) Cross section of the 25 nm (diameter) x 85 nm nanorod

25x85 nm antennas, resonant for λ=795 nm in UDMA polymer

[L. Novotny (2007)]

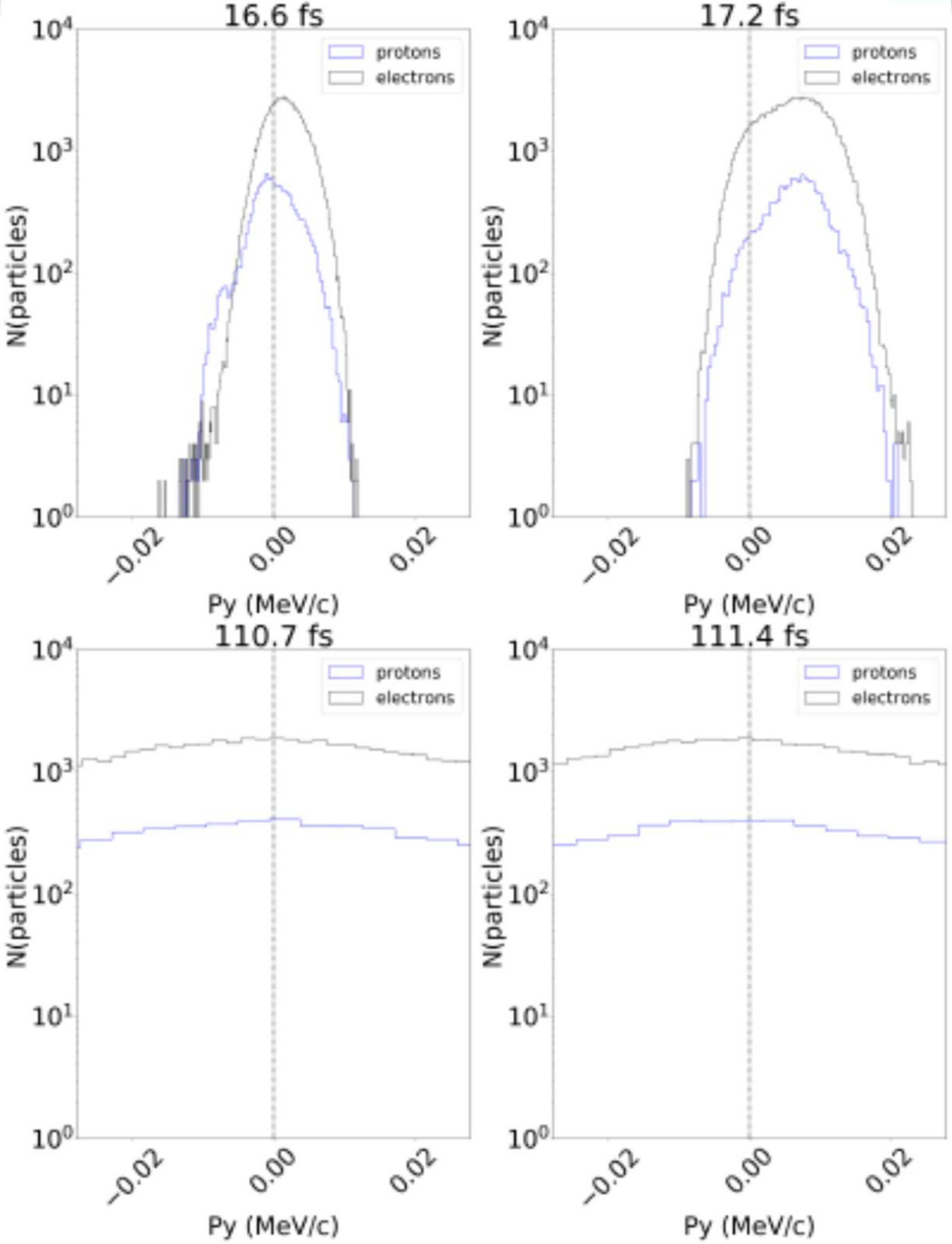
$$\frac{\lambda_{eff}}{2R\pi} = 13.74 - 0.12[\varepsilon_\infty + \varepsilon_s 141.04]/\varepsilon_s - \frac{2}{\pi} + \frac{\lambda}{\lambda_p} 0.12\sqrt{\varepsilon_\infty + \varepsilon_s 141.04}/\varepsilon_s$$



Accumulated momentum of conduction electrons in vacuum (blue) and in UDMA (black)

in polymer UDMA

[I.Papp's talk ICNFP2022]



Protons surrounding the nanorod

Initial 3 ord. magn.

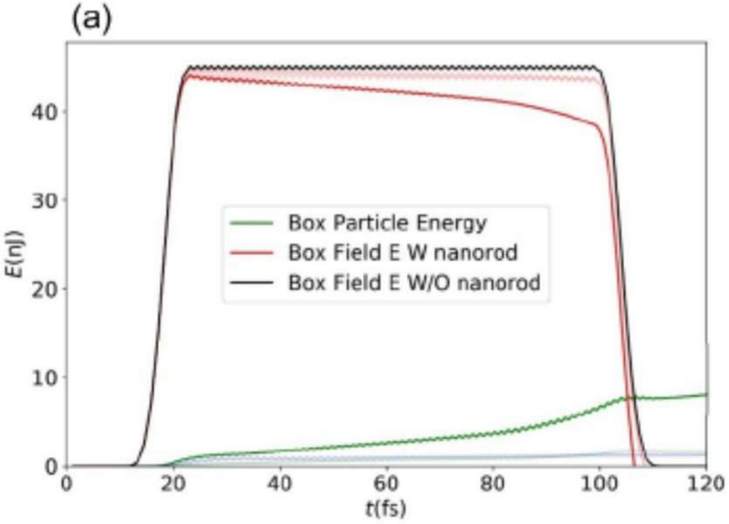
Considerations for the simulation box:
$S_{CB} = 530 \times 530\text{nm}^2 = 2.81 \times 10^{-9}\text{cm}^2$ and length of $L_{CB} = 795\text{nm}$

beam crosses the box in $T = 795\text{nm}/c = 2.65\text{fs}$

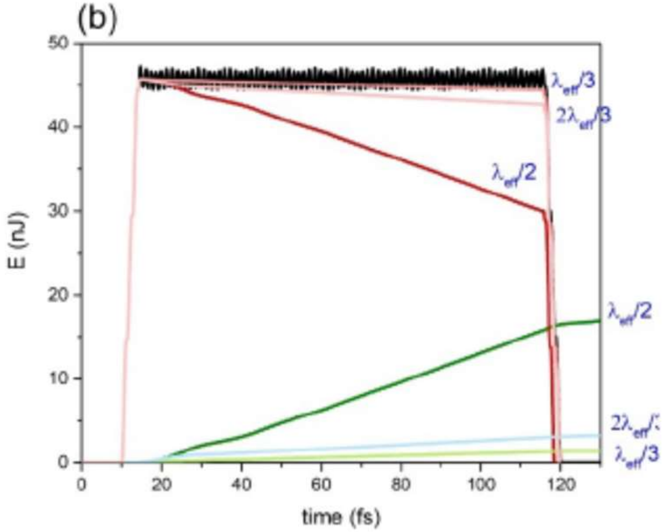
Nanorod size: **25** nm diameter with **85** nm length

Pulse length: $40 \times \lambda/c = 106$ fs
Intensity: 4×10^{15} W/cm^2

EPOCH – PIC
I. Papp et al.



COMSOL - FEM
M. Csete et al.

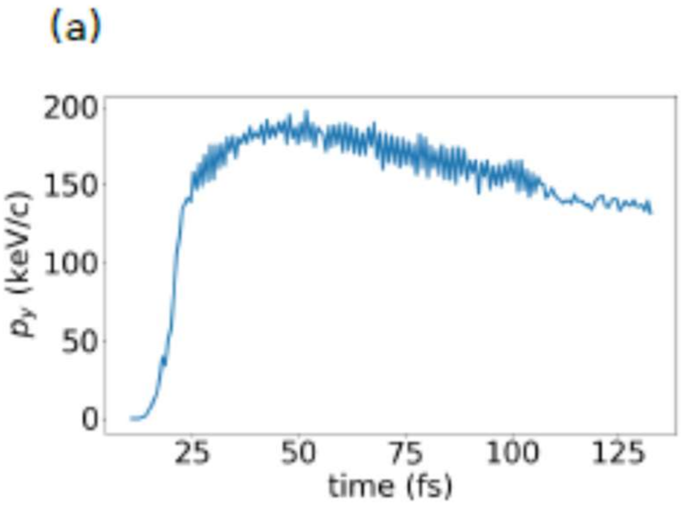


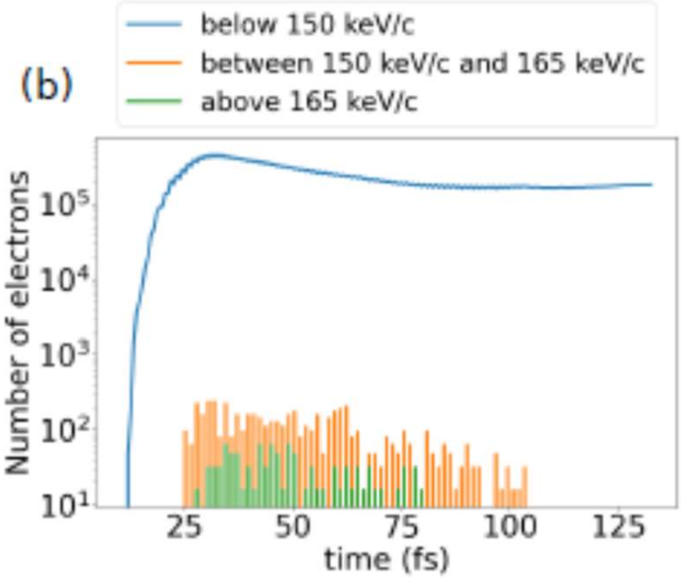
Calculation Box (CB):
530x530x795 nm
λ = 795 nm

Deposited energy in the nano-rod (green)

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

Maximum momentum of spilled out electrons





Distribution of momentum of spilled out electrons

Margaret Island Symposium 2022 on Vacuum Structure, Particles, and Plasmas, Budapest, May 15-18, 2022.

(2022)

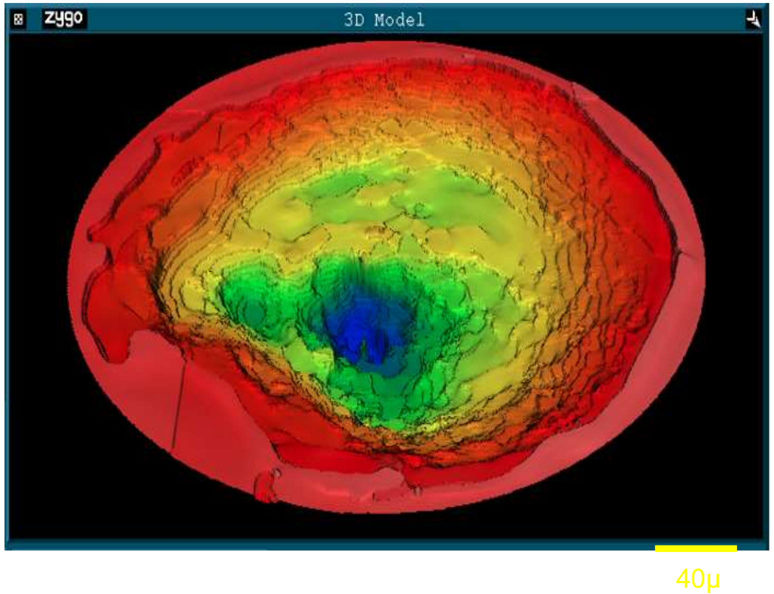
Effect of the embedded plasmonic gold nanorods on the interaction of high intensity laser irradiation with UDMA polymer – volume loss during crater formation

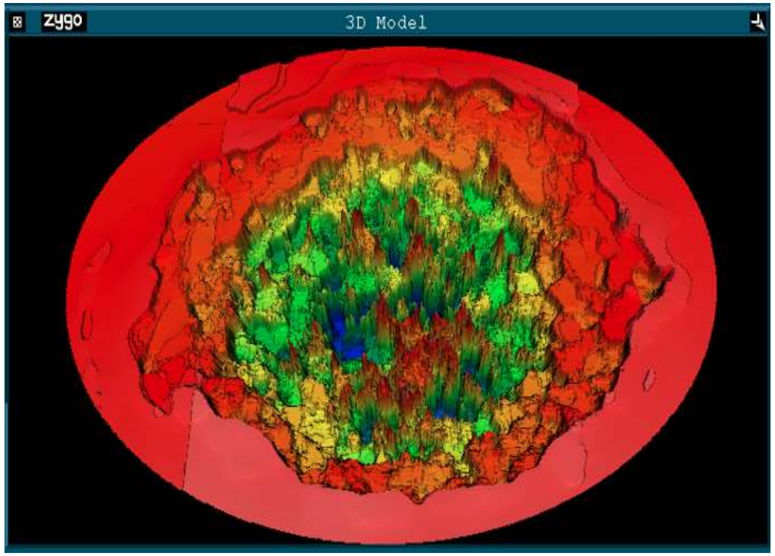
ICNFP 2022
7. September 2022
Kolymbari, Crete

Ágnes Nagyné Szokol
Wigner Research Centre for Physics
Budapest, Hungary

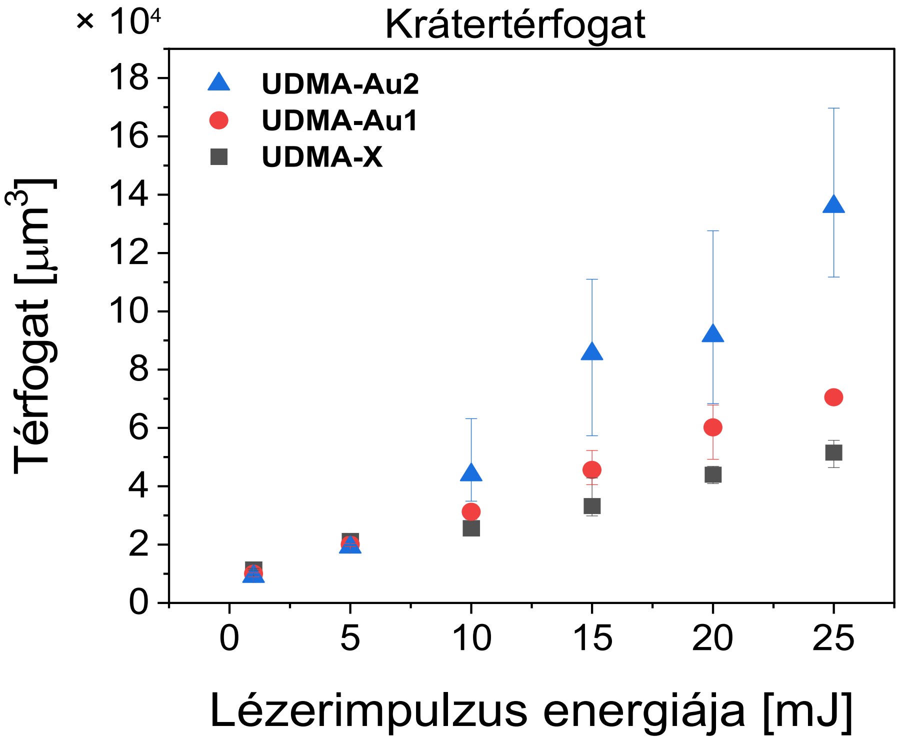
1. DIAGNÓZIS (kráter térfogat)

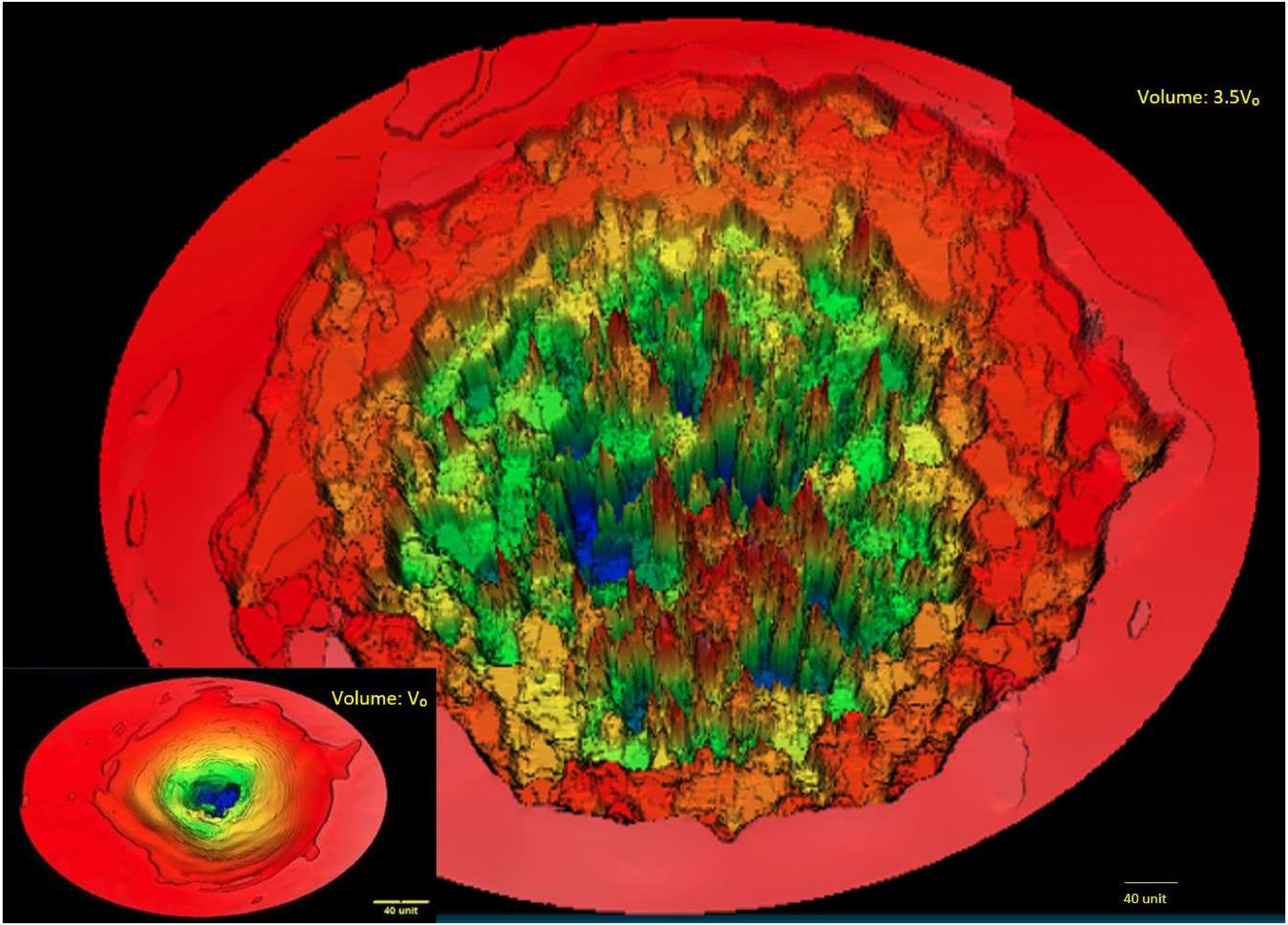
Térfogat:V_0





Térfogat
max.
$3.5V_0$




Volume: 3.5V_o
40 unit
Volume: V_o
40 unit

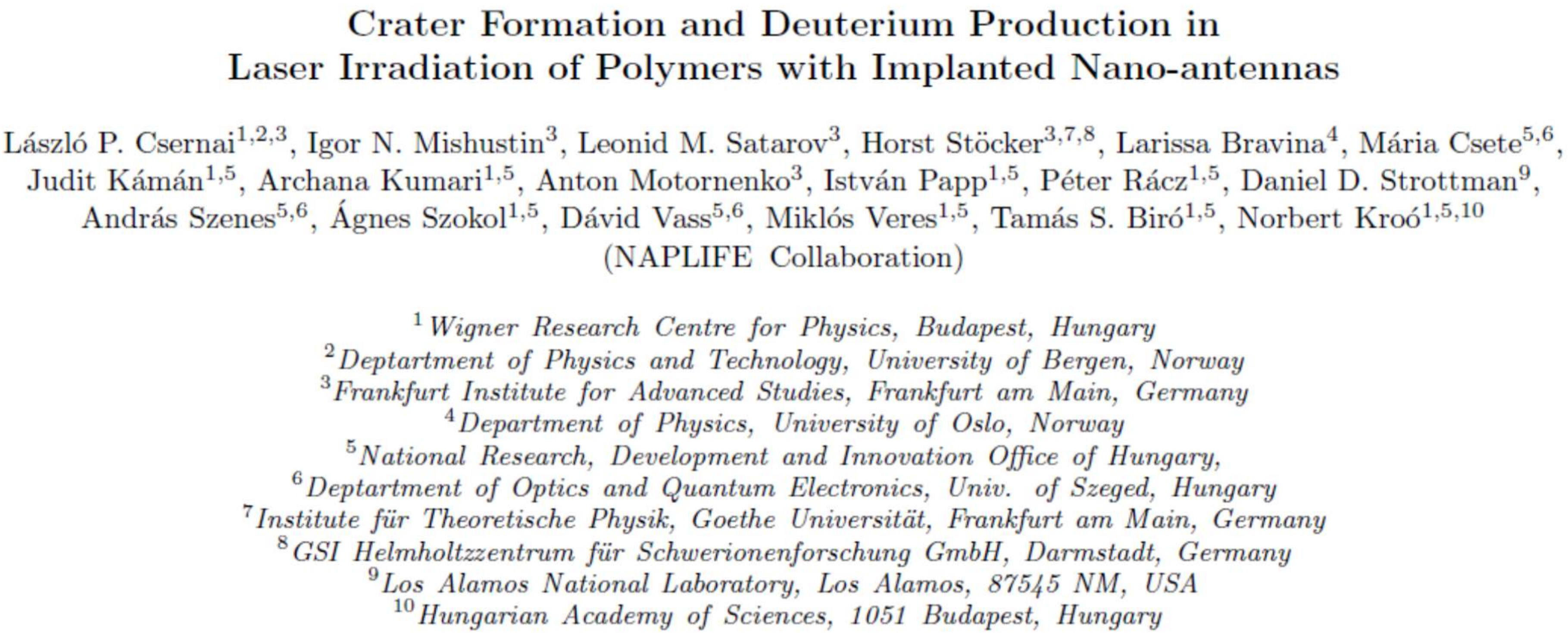
Physics > Plasma Physics

[Submitted on 25 Nov 2022]

Crater Formation and Deuterium Production in Laser Irradiation of Polymers with Implanted Nano-antennas

L. P. Csernai, I. N. Mishustin, L. M. Satarov, H. Stoecker, L. Bravina, M. Csete, J. Kaman, A. Kumari, A. Motornenko, I. Papp, P. Racz, D. D. Strottman, A. Scenes, A. Szokol, D. Vass, M. Veres, T. S. Biro, N. Kroo (NAPLIFE Collaboration)

(2022)



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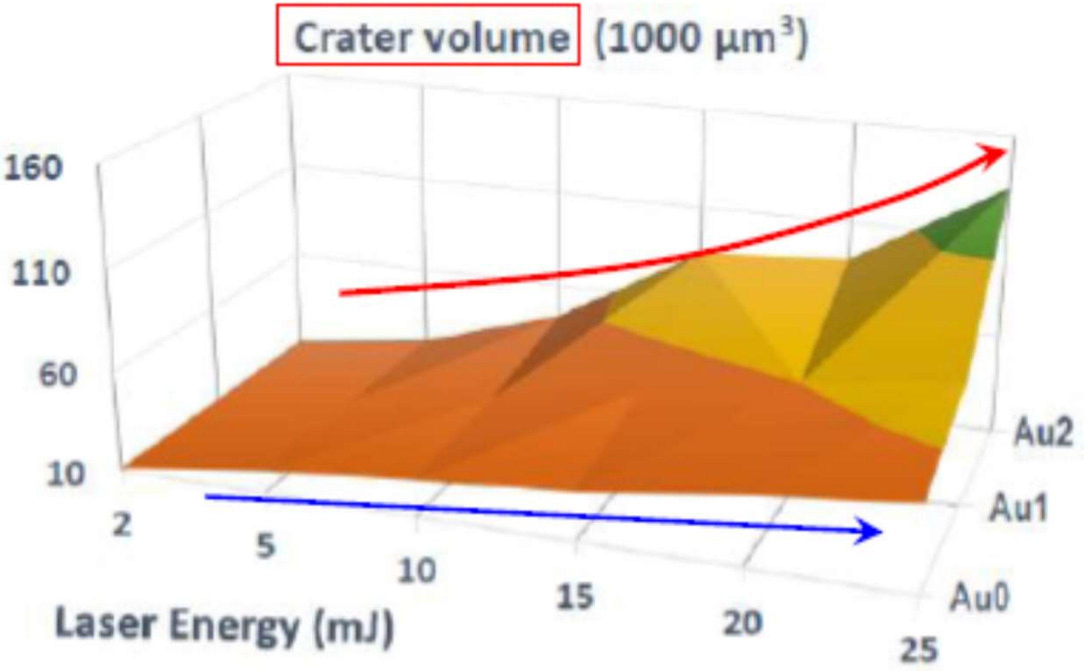
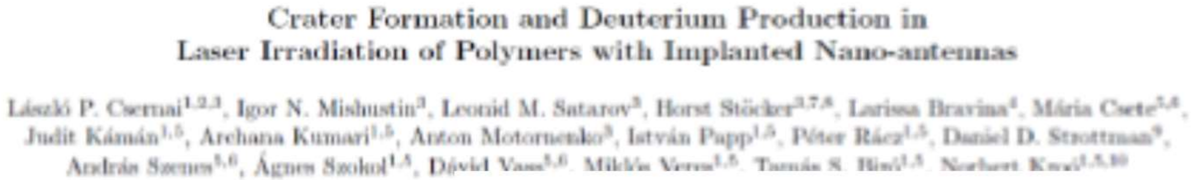
Theoretical analyzis of Crater & Deuterium production





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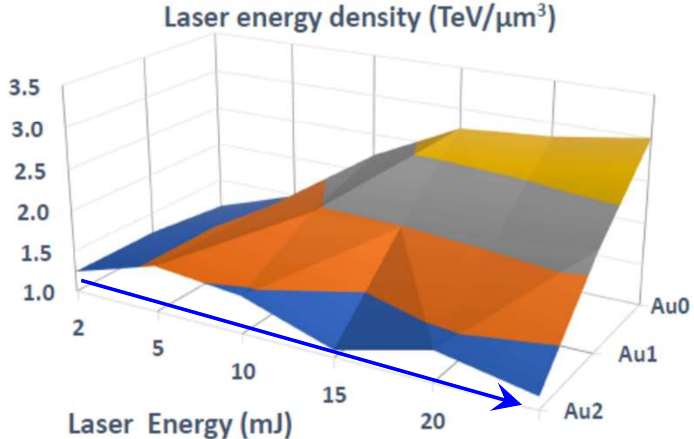
arXiv: 2211.14031 [physics-

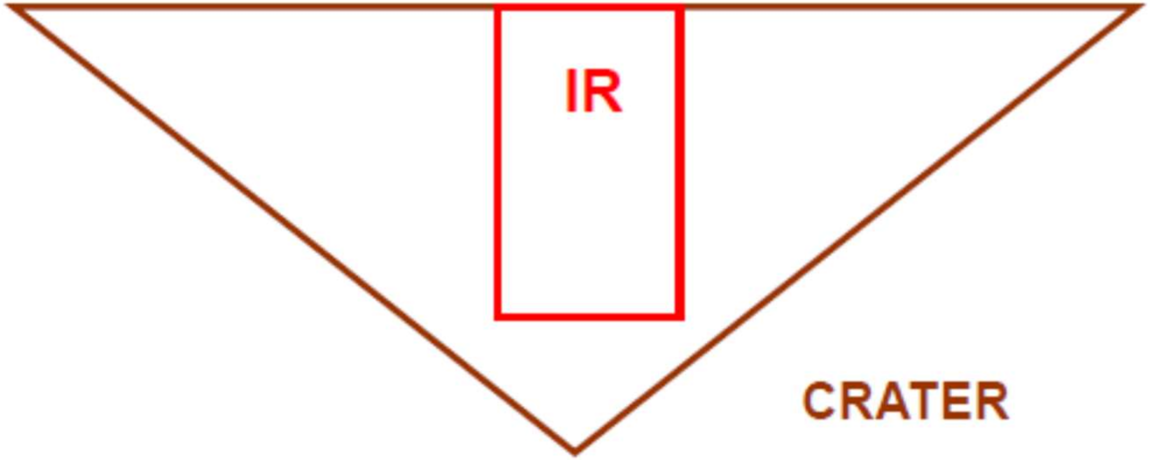


Puzzle ?

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 (!?)

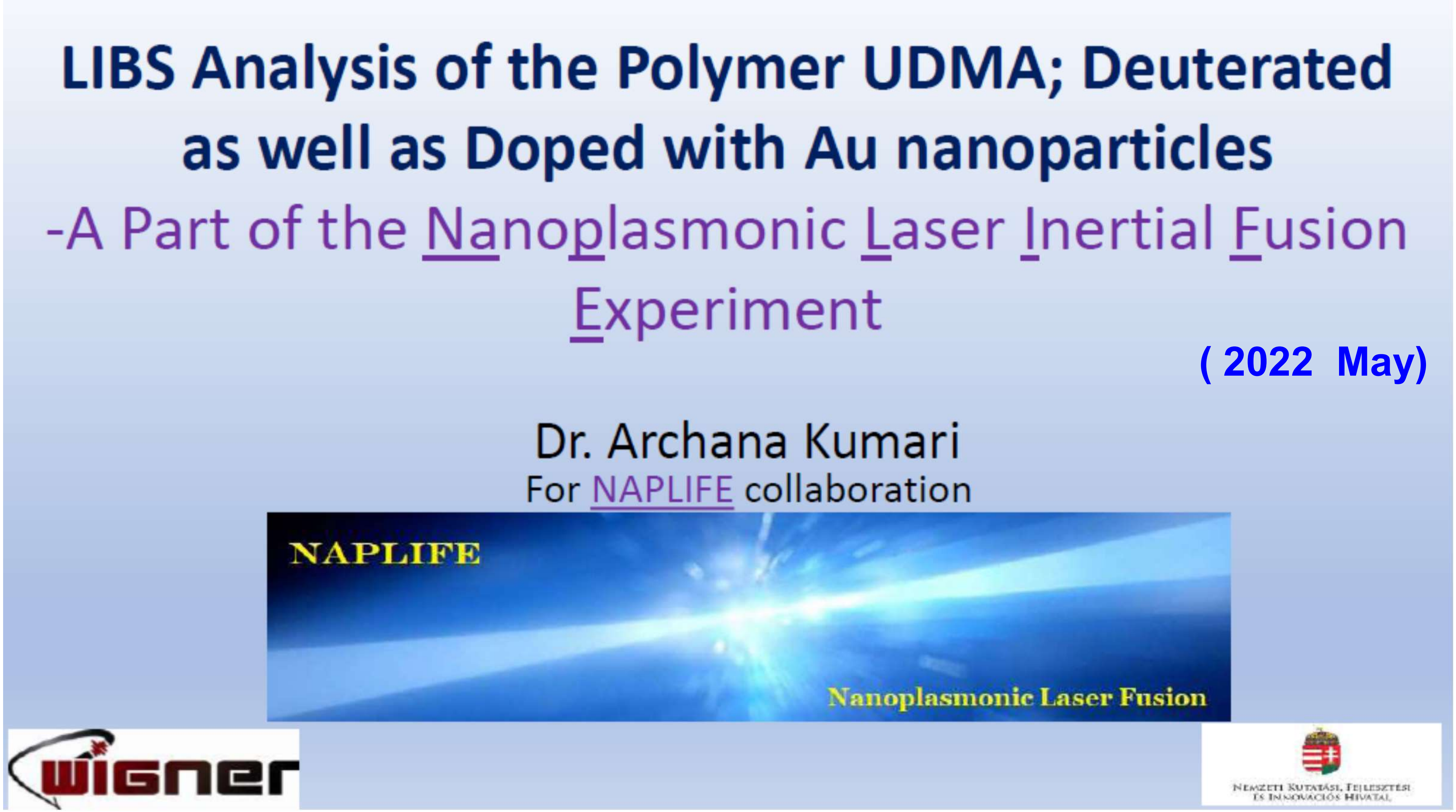
Origin of this extra energy (?)



In the case of the reaction (5), substituting $E_p = 20$ MeV, $E_d = 5.92$ MeV (this value follows from Eq. (9)), and using Eqs. (34), (35), one gets the estimate

$$\frac{\mathrm{D}}{\mathrm{H}} \sim 118 \times \frac{d}{p} \simeq 1.2 \cdot 10^{-3}. \qquad (37)$$

This value is still below experimental ratios for the Au2



LIBS Analysis of the Polymer UDMA; Deuterated as well as Doped with Au nanoparticles

-A Part of the Nanoplasmonic Laser Inertial Fusion Experiment

(2022 May)

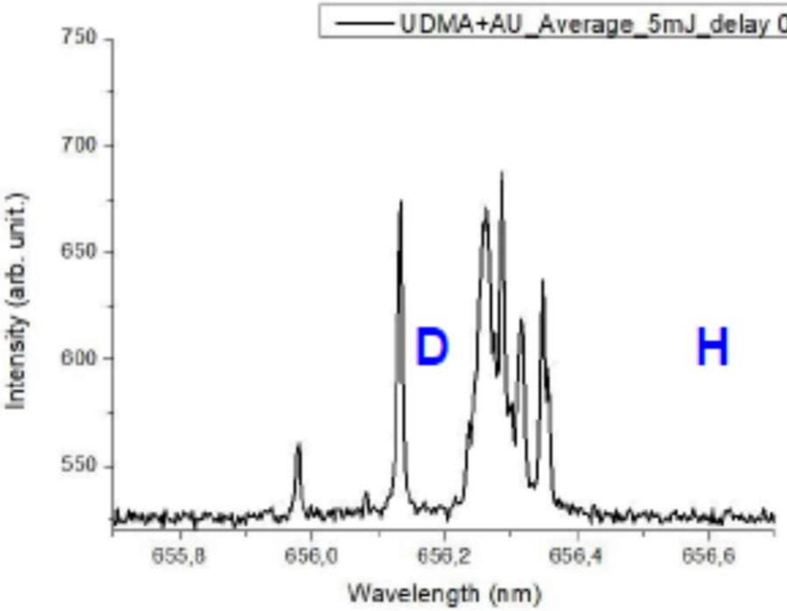
Dr. Archana Kumari

For NAPLIFE collaboration

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

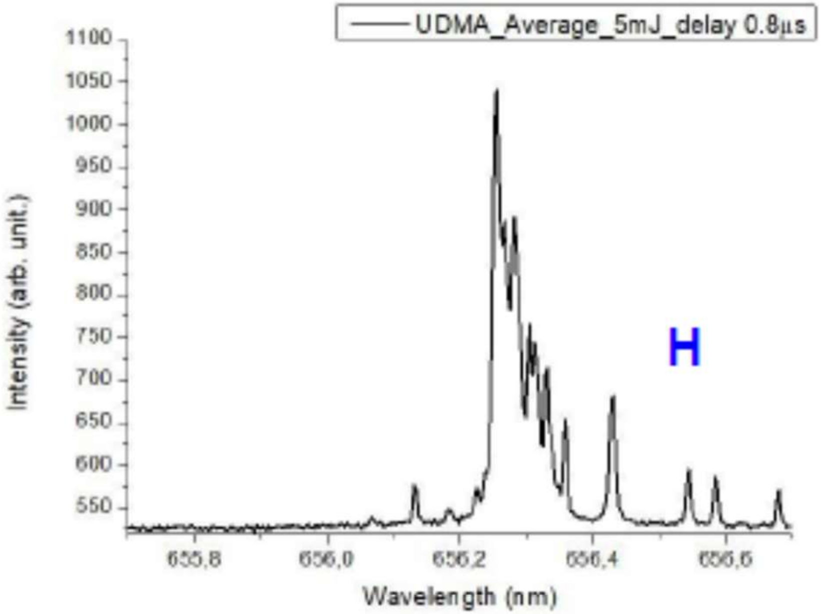
Péter Rácz, Margaret Island Symposium 2022 on Vacuum Structure, Particles, and Plasmas, Budapest, May 15-18, 2022

Deuterium production (PRELIMINARY ! ?)



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)

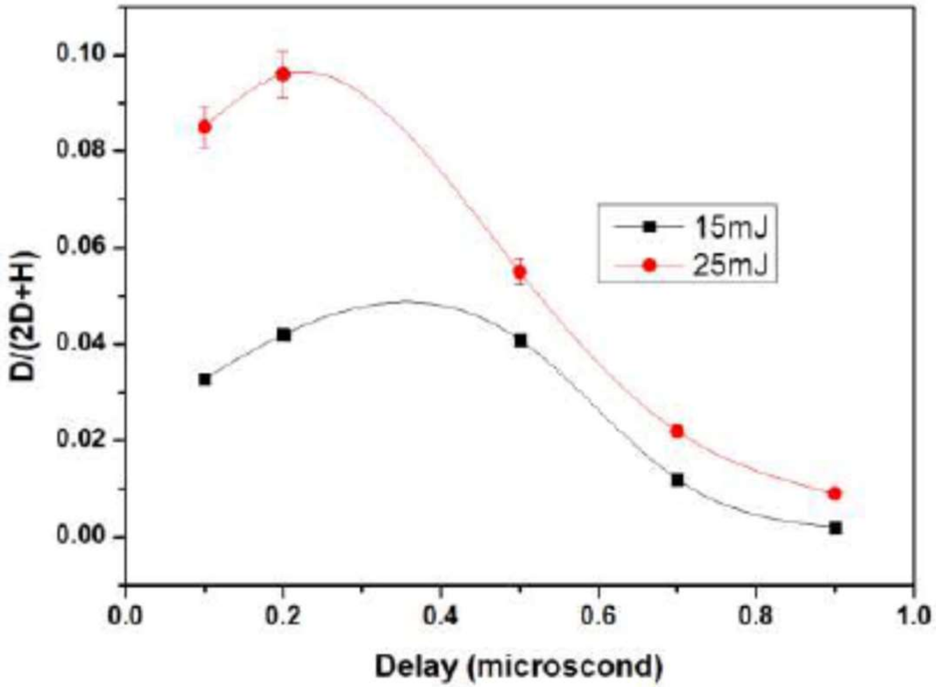
Electron capture may happen spontaneously in heavy nuclei,

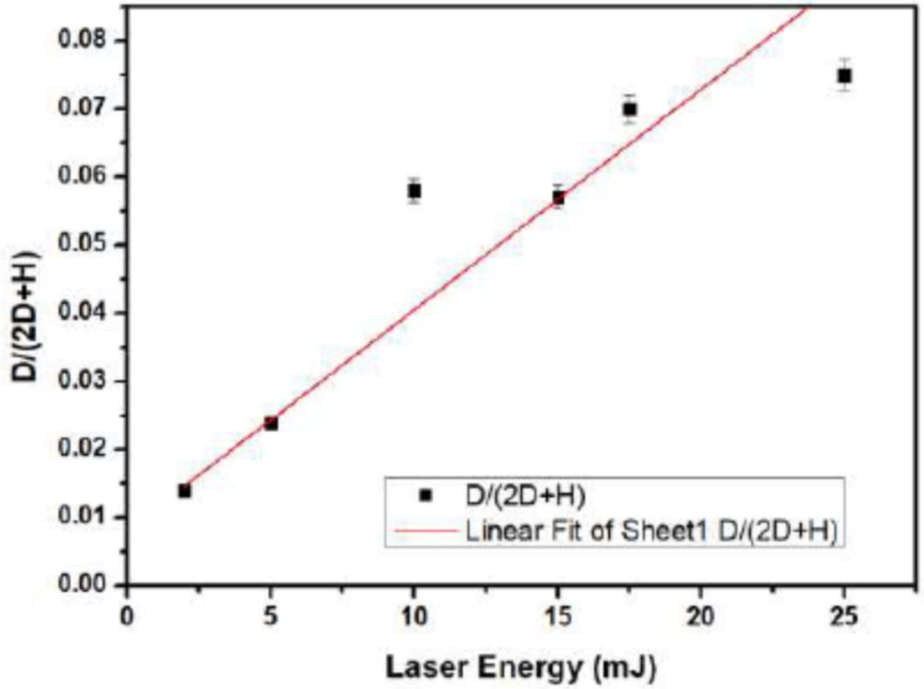
here laser light and resonant nanorods may act similarly at high e density.

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

[Archana Kumari & Miklos Veres's talk in ICNFP 2022]

Calculation of ratio; D/(2D+H)





At 17.5 mJ, D(A)=1.828, H(A)=8.32
D(A)/H(A)=0.21
D(A)/[2*D(A)+H(A)]=0.15
No. of H atoms=2.51*10^16
No. of atoms that were converted from H to D=3.765*10^15

Please refer to Agnes Nagyne Sokol's talk on Crater Data Analysis!

SUMMARY

- Crater size increase, in excess of laser beam energy increase, in case of plasmonic nano-rods!

- Deuterium production (nuclear reactions) are indicated in case of nano antennas by Raman spectroscopy!

- Deuterium production is indicated in case of nano antennas by low statistics LIBS spectroscopy (not confirmed yet ☹); Theoretical estimates without nano-rods give no significant D production.

- Higher (10x) energy laser pulse would be needed to test/verify the mechanisms of Deuterium production, the possibilities of other nuclear fusion reactions and their reaction rates.

European Laser Infrastructure – Szeged, HU

Csernai, L.P. [NAPLIFE]

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

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

The END