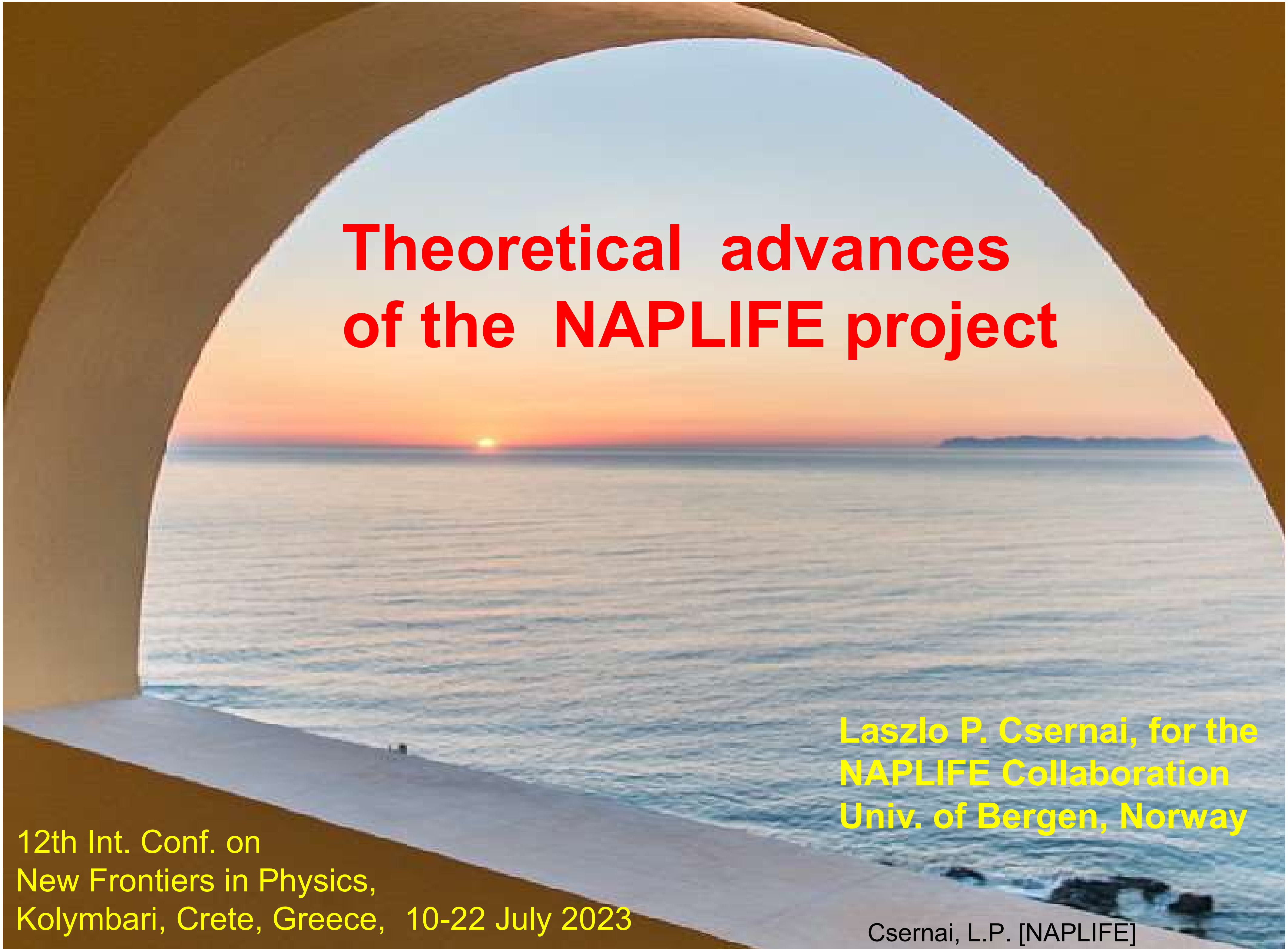


Theoretical advances of the NAPLIFE project

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

12th Int. Conf. on
New Frontiers in Physics,
Kolymbari, Crete, Greece, 10-22 July 2023

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

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

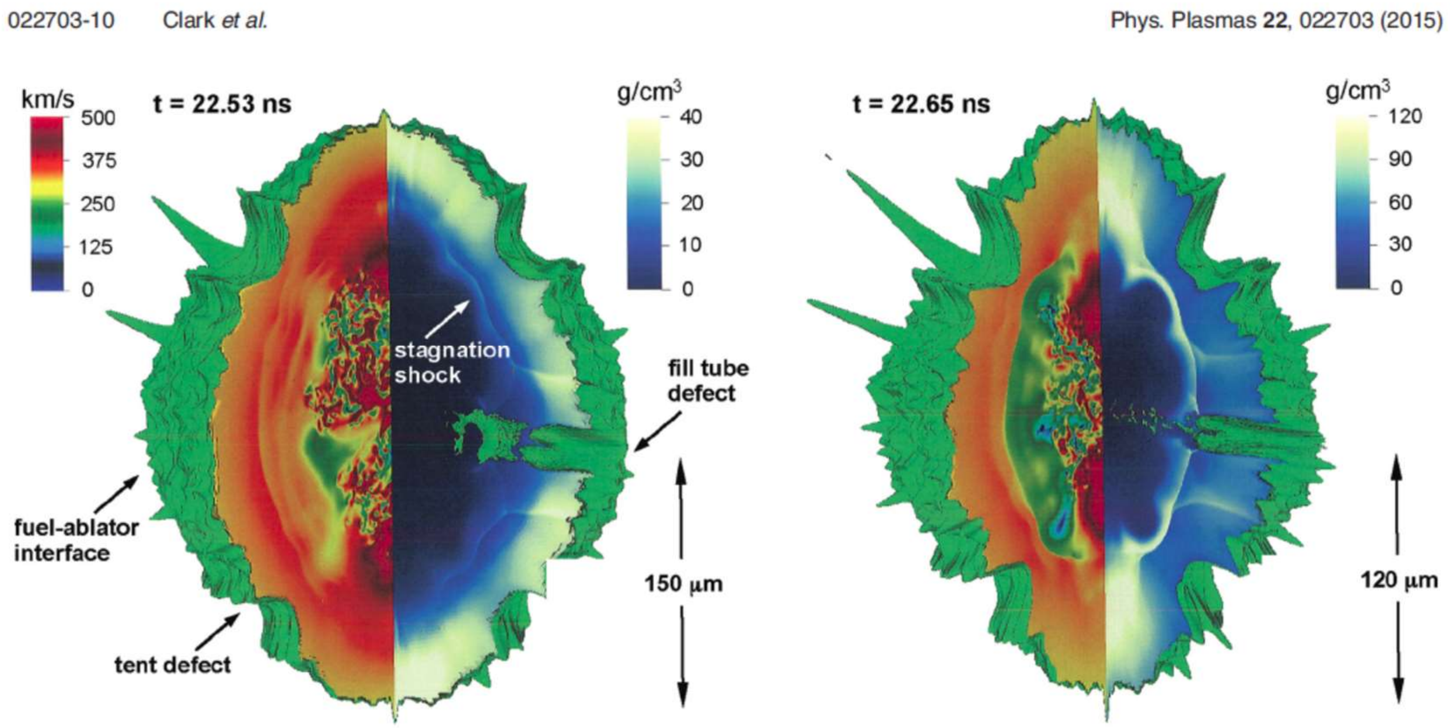
[L.P. Csernai, N. Kroo, I. Papp, ***Laser and Particle Beams,*** **LPB, 36(2), (2018) 171-178.** .
https://doi.org/10.1017/S0263034618000149]

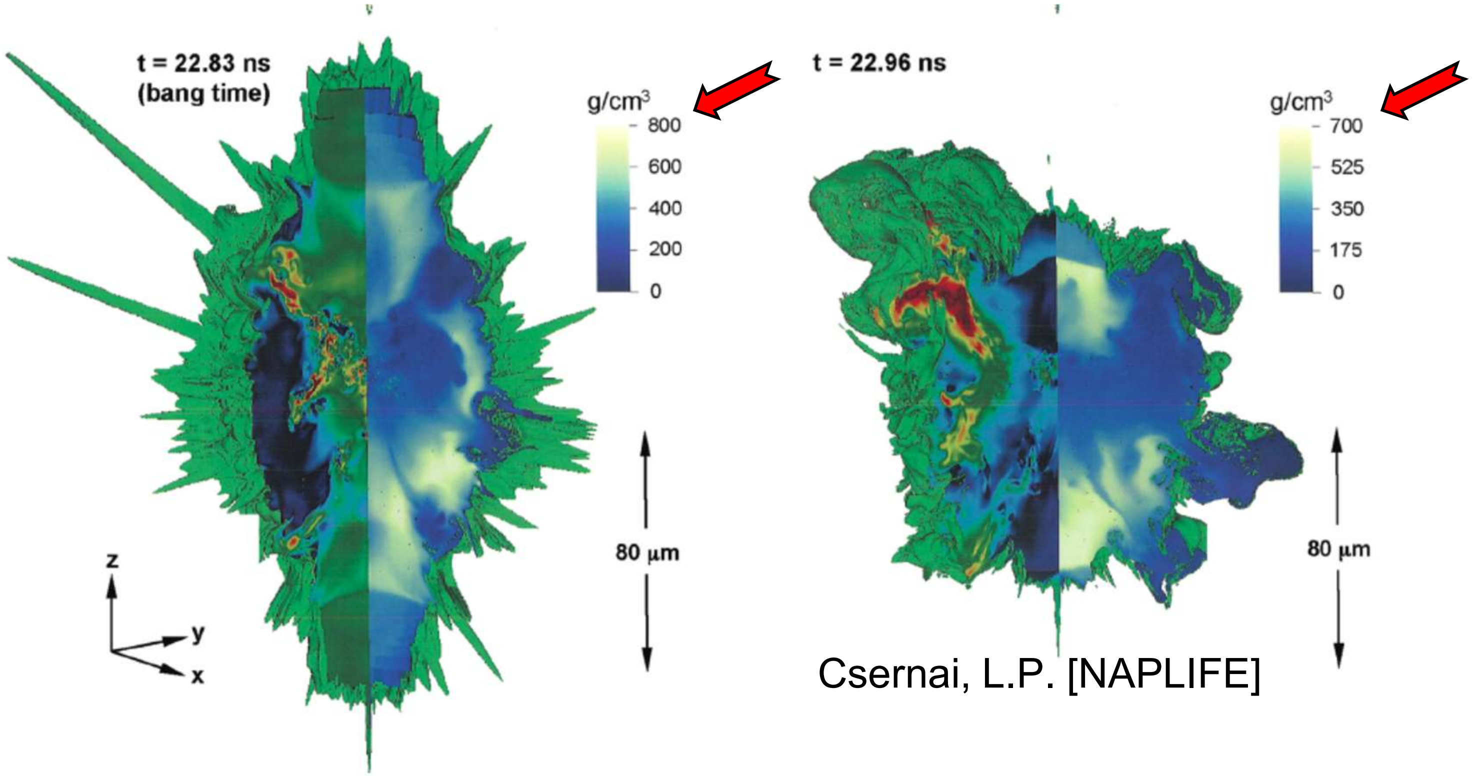
But let us go back in history →

Rayleigh-Taylor Instability

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

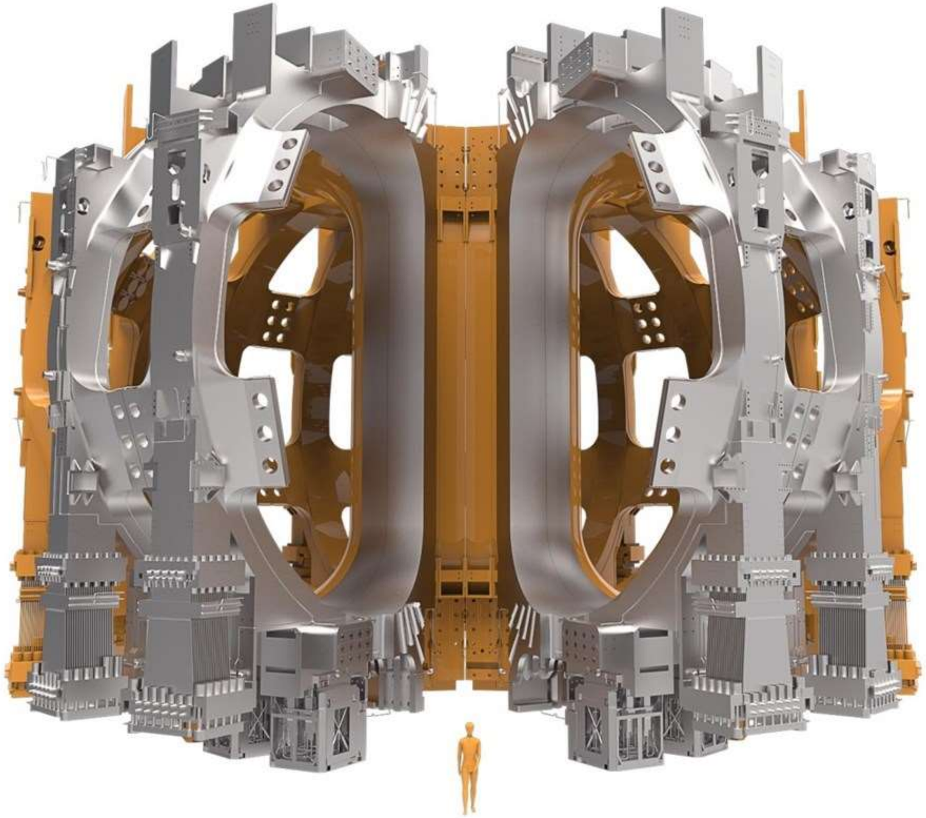
Snapshots of 3D simulation
22.53ns: peak impl. Velocity
23.83ns: bang, max compr.
22.96ns: jet out, up left
Green surface: Ablator/DT-f.
Peaks: Ablator defects
Colours:
Left: fluid speed
Right: matter density





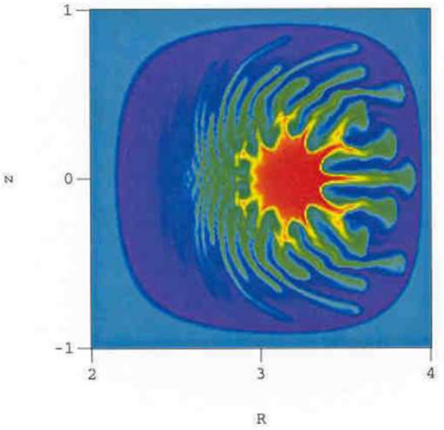
~adiabatic
compression
➔ 80 μm
& heating

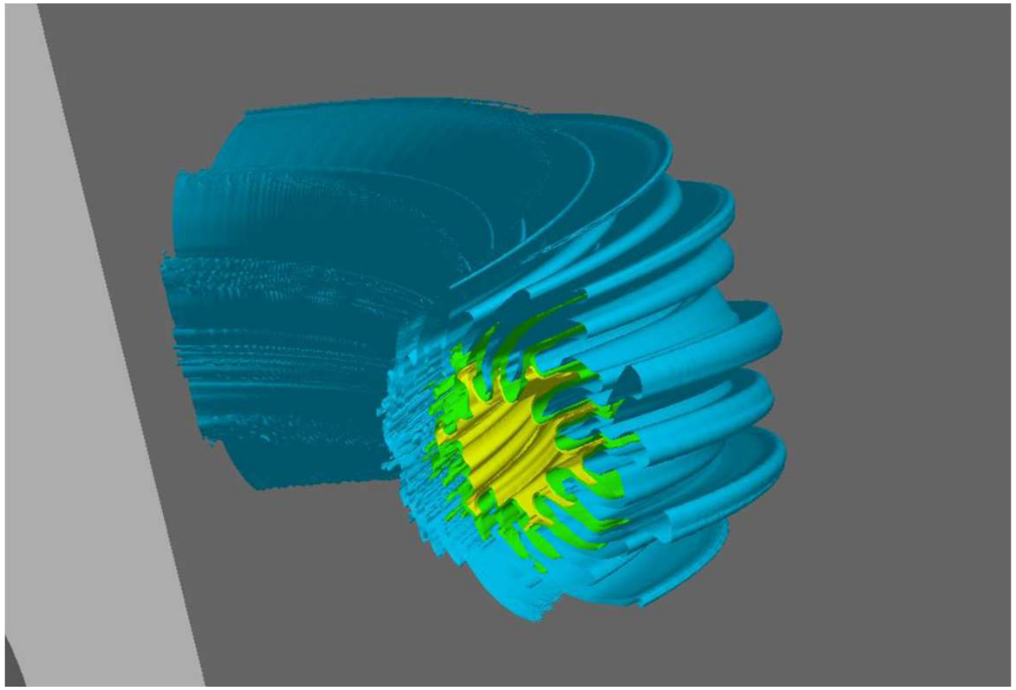
ITER torus



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

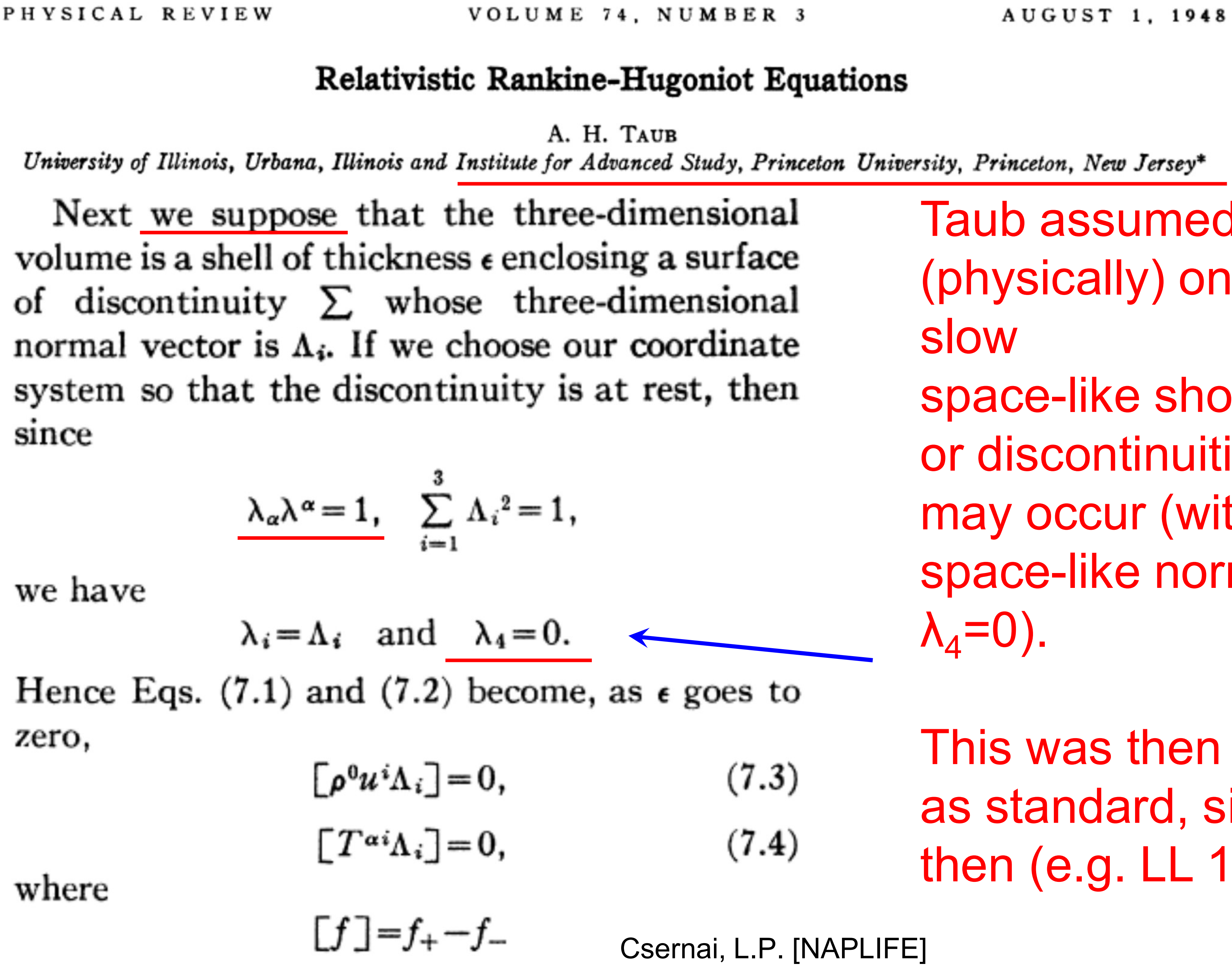
RT instability





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

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

we have

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

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

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

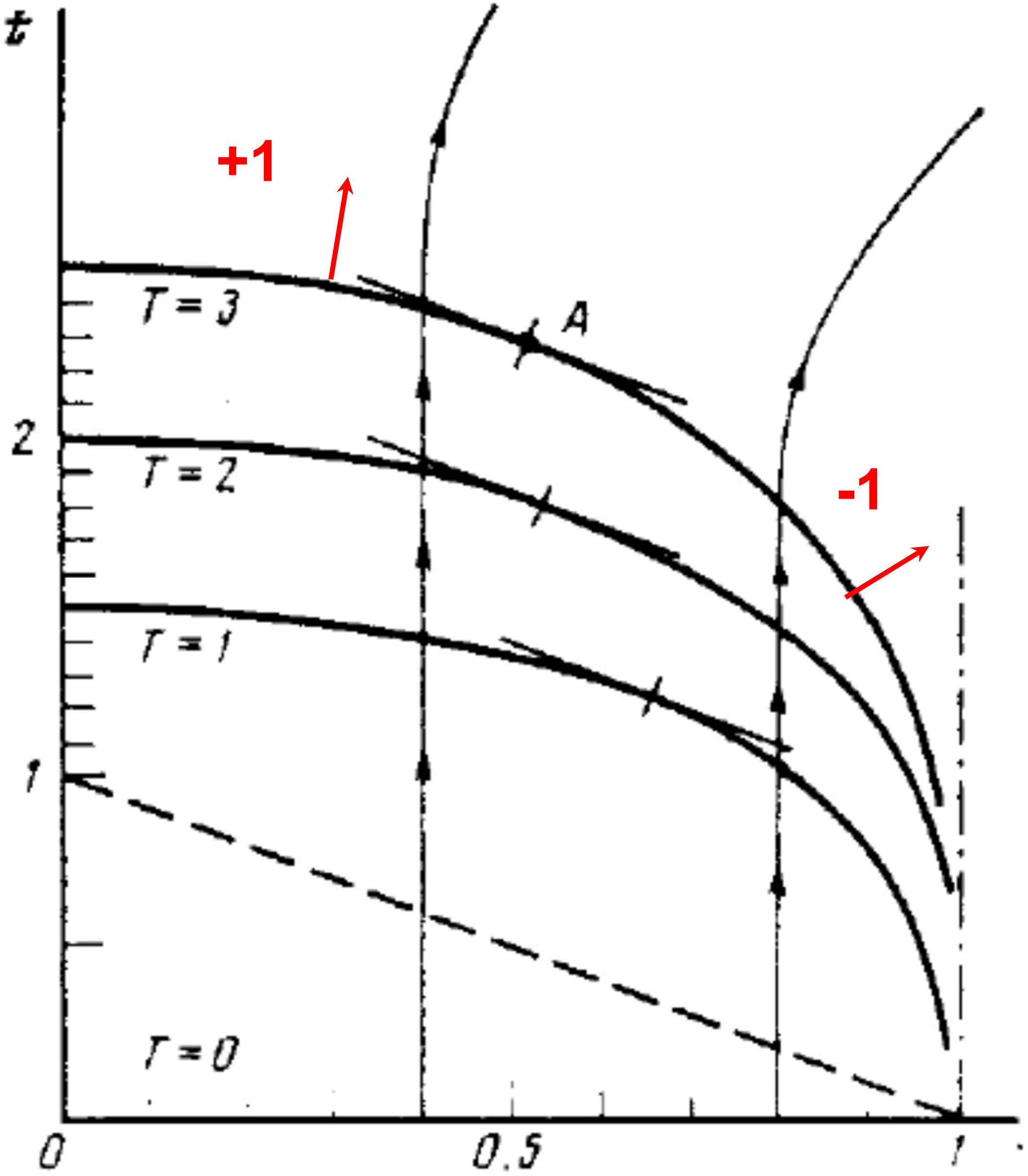
$$[T^{\alpha i}\Lambda_i]=0, \tag{7.4}$$

where

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

Taub assumed that (physically) only slow space-like shocks or discontinuities may occur (with space-like normal, $\lambda_4=0$).

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**)]

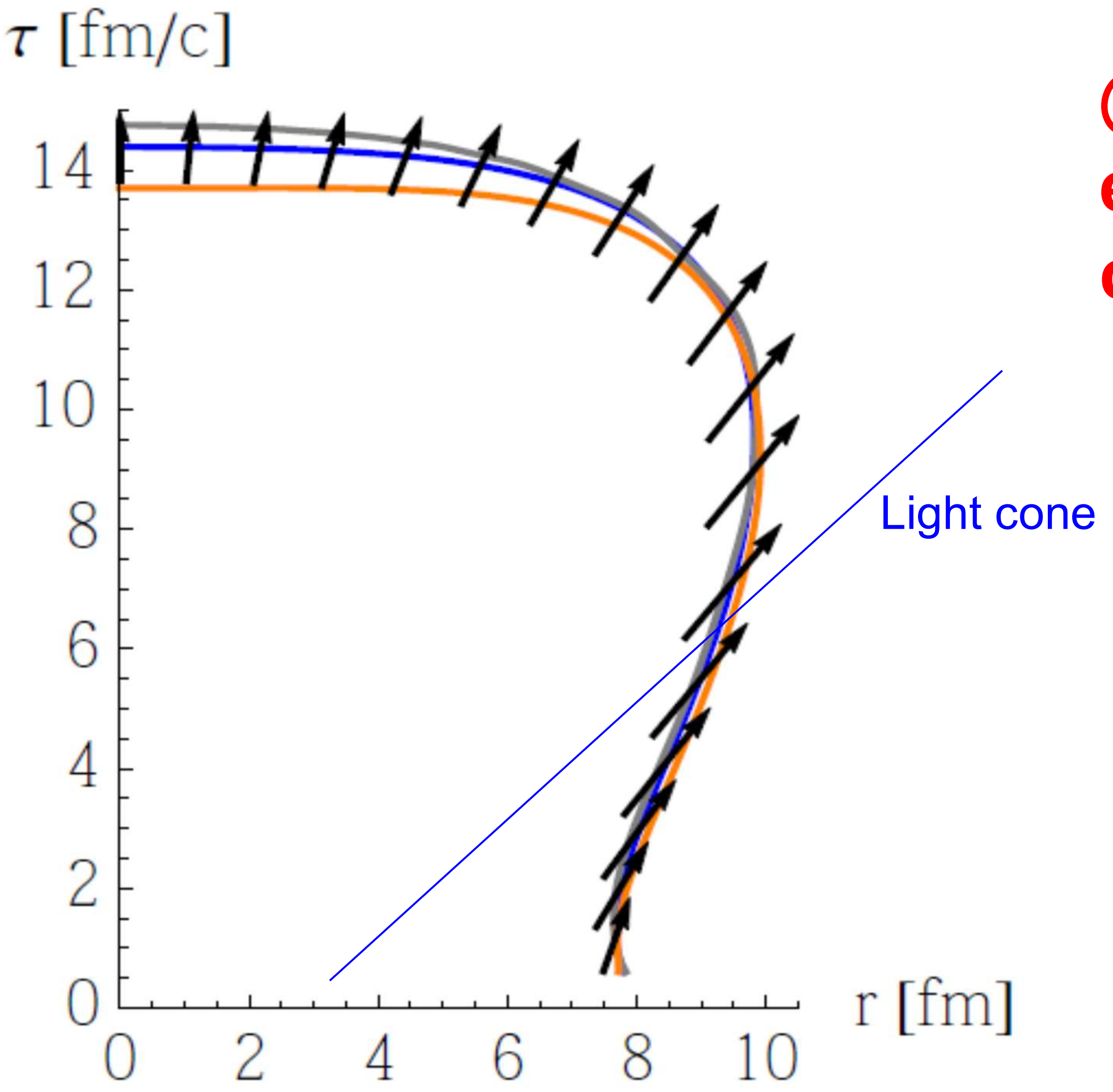
$$\lambda_\alpha \lambda^\alpha = \pm 1$$

Л. П. Чернаи

ДЕТОНАЦИЯ НА ВРЕМЕНИПОДОБНОМ ФРОНТЕ ДЛЯ РЕЛЯТИВИСТСКИХ СИСТЕМ

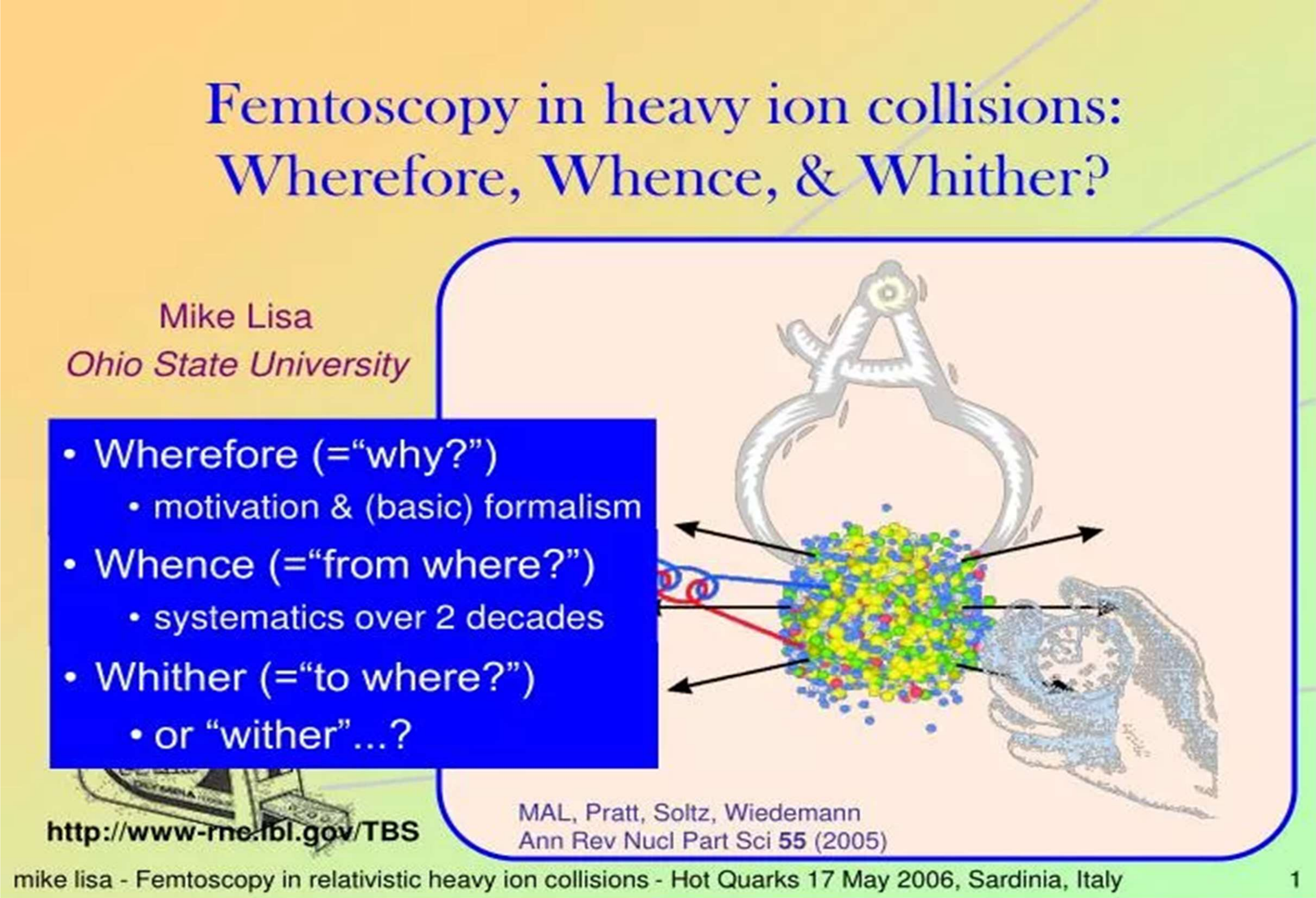
Журнал экспериментальной и теоретической физики

1987



@ CERN in High energy heavy ion collisions

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



Femtoscopy in heavy ion collisions: Wherefore, Whence, & Whither?

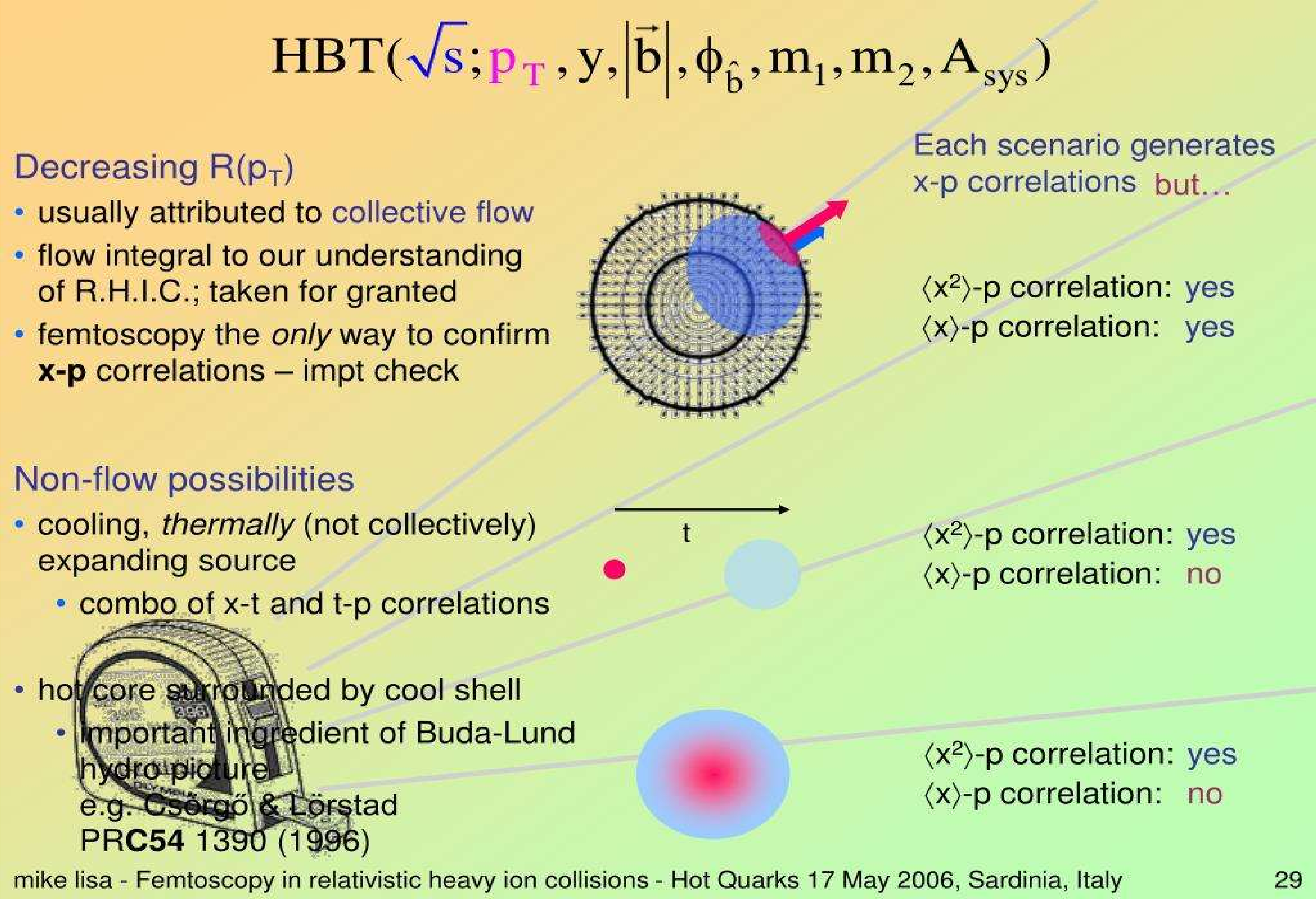
Mike Lisa
Ohio State University

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

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

MAL, Pratt, Soltz, Wiedemann
Ann Rev Nucl Part Sci **55** (2005)

mike lisa - Femtoscopy in relativistic heavy ion collisions - Hot Quarks 17 May 2006, Sardinia, Italy 1



$$\mathrm{HBT}(\sqrt{s}; p_T, y, |\vec{b}|, \phi_{\hat{b}}, m_1, m_2, A_{sys})$$

Decreasing $R(p_T)$

- usually attributed to collective flow
- flow integral to our understanding of R.H.I.C.; taken for granted
- femtoscopy the *only* way to confirm **x-p** correlations – impt check

Each scenario generates x-p correlations but…

$\langle x^2 \rangle$-p correlation: yes
$\langle x \rangle$-p correlation: yes

Non-flow possibilities

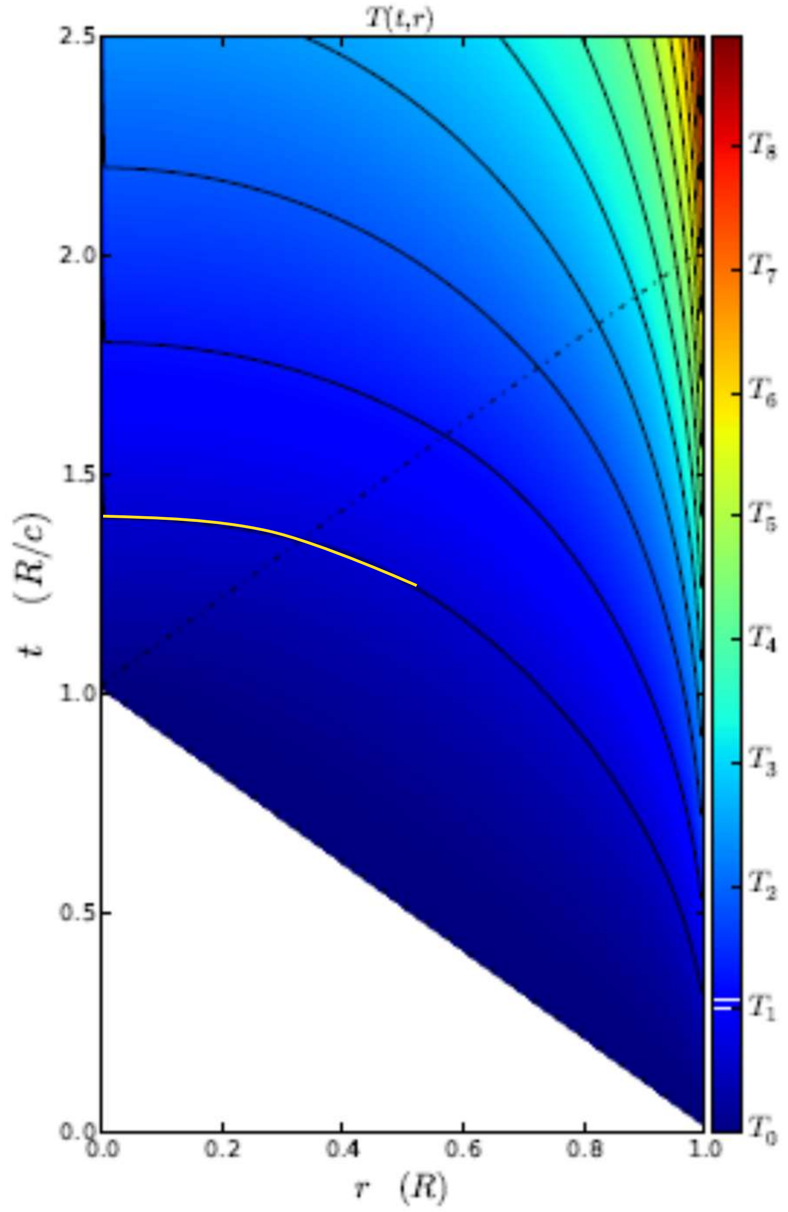
- cooling, *thermally* (not collectively) expanding source
  - combo of x-t and t-p correlations

$\langle x^2 \rangle$-p correlation: yes
$\langle x \rangle$-p correlation: no

- hot core surrounded by cool shell
  - important ingredient of Buda-Lund hydro picture
    e.g. Csörgő & Lörstad
    PR**C54** 1390 (1996)

$\langle x^2 \rangle$-p correlation: yes
$\langle x \rangle$-p correlation: no

mike lisa - Femtoscopy in relativistic heavy ion collisions - Hot Quarks 17 May 2006, Sardinia, Italy 29



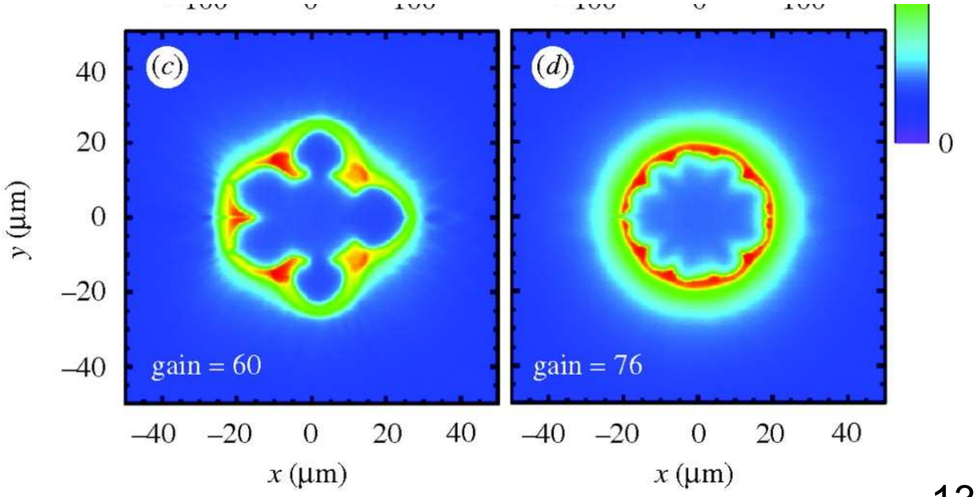
Fusion reaction:

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).

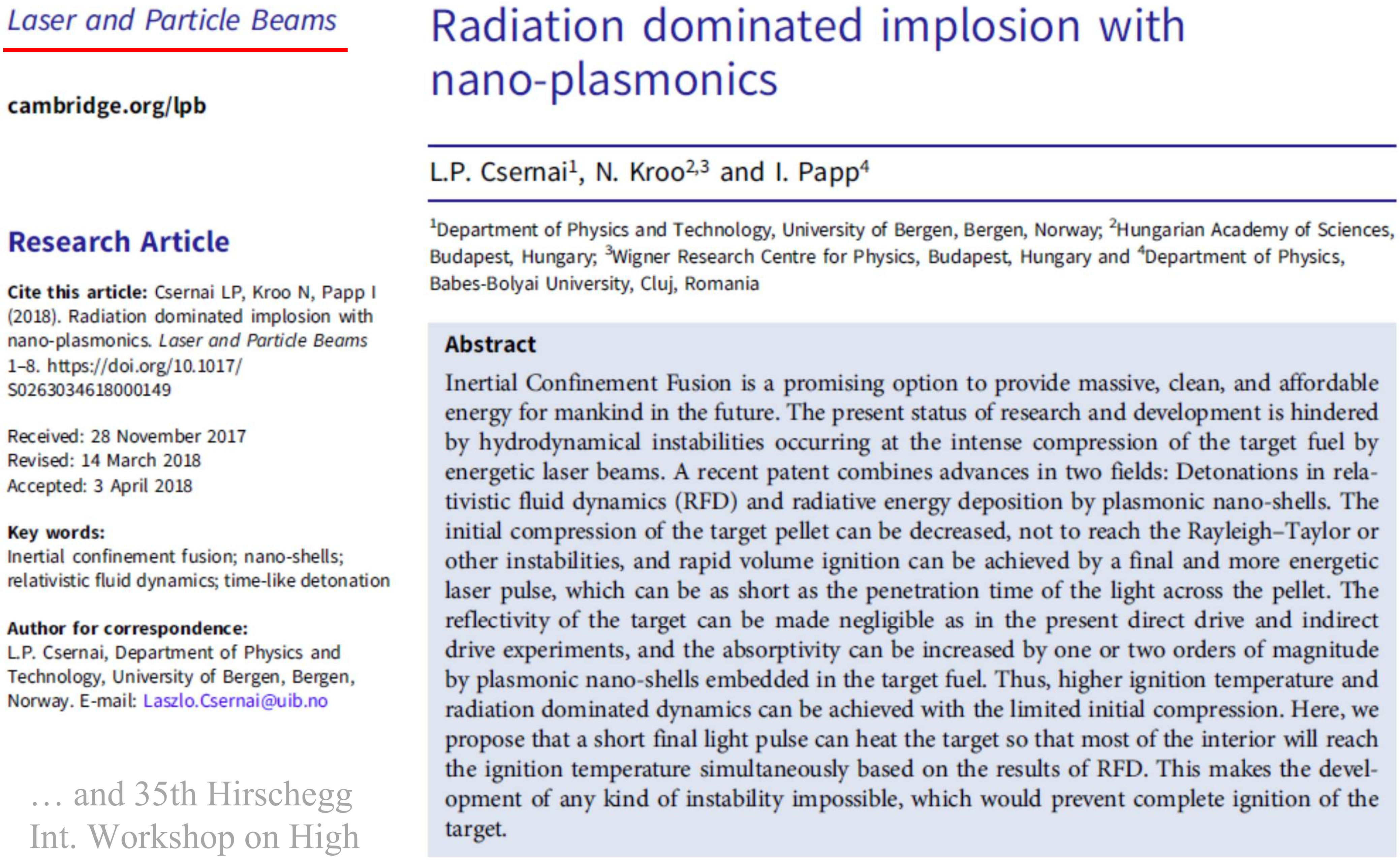
Not too good, but better than:



[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

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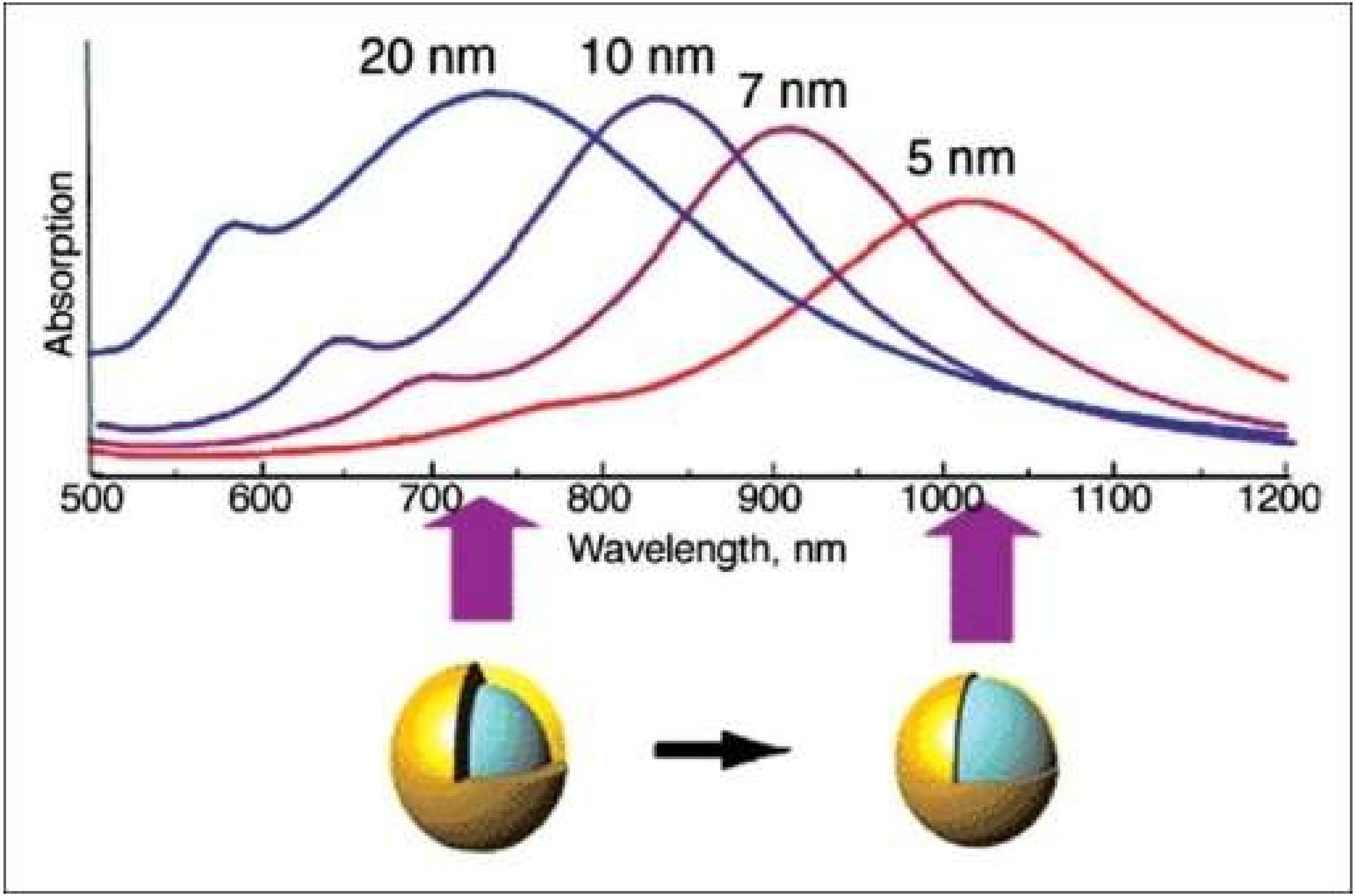
Abstract

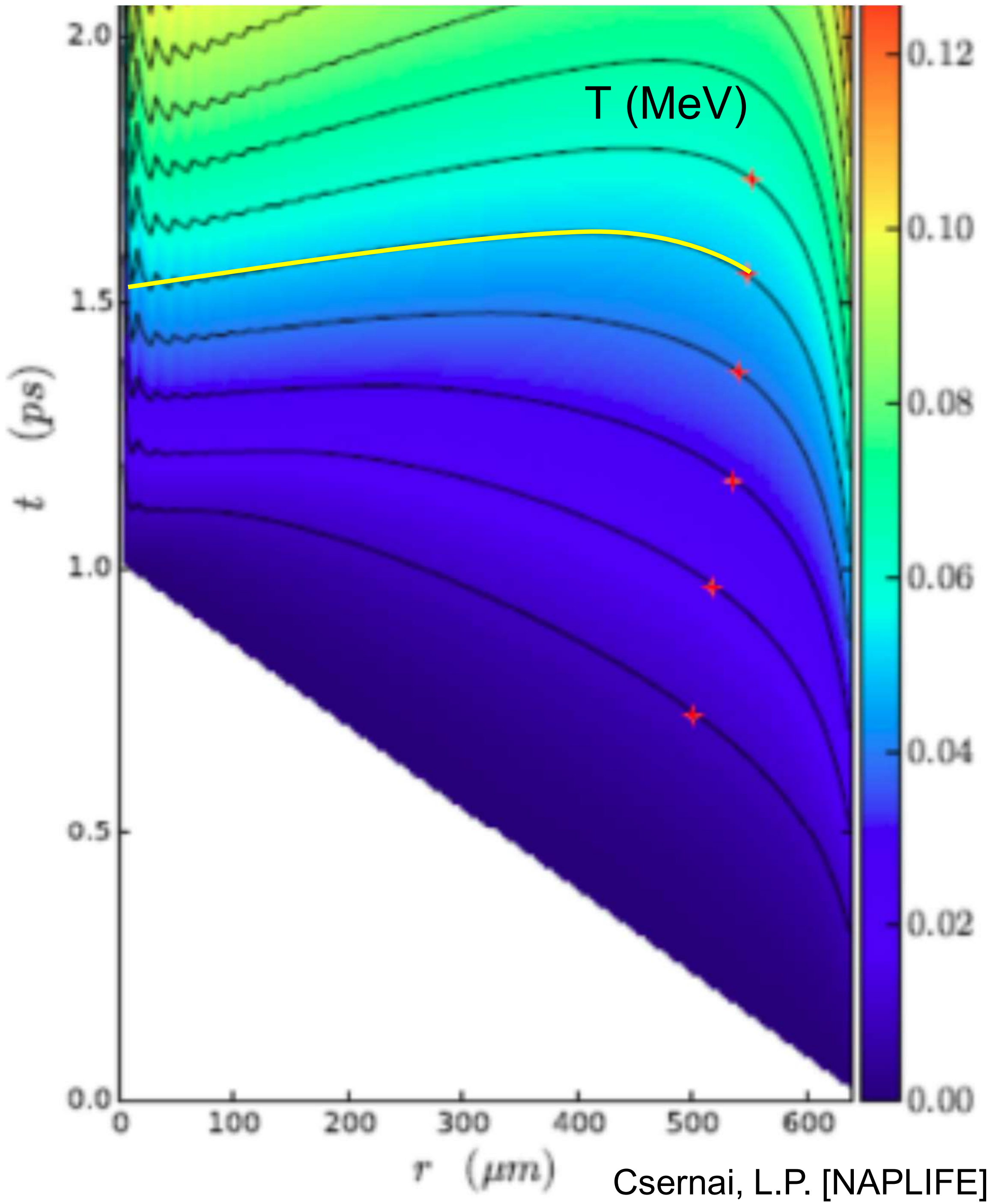
Inertial Confinement Fusion is a promising option to provide massive, clean, and affordable energy for mankind in the future. The present status of research and development is hindered by hydrodynamical instabilities occurring at the intense compression of the target fuel by energetic laser beams. A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

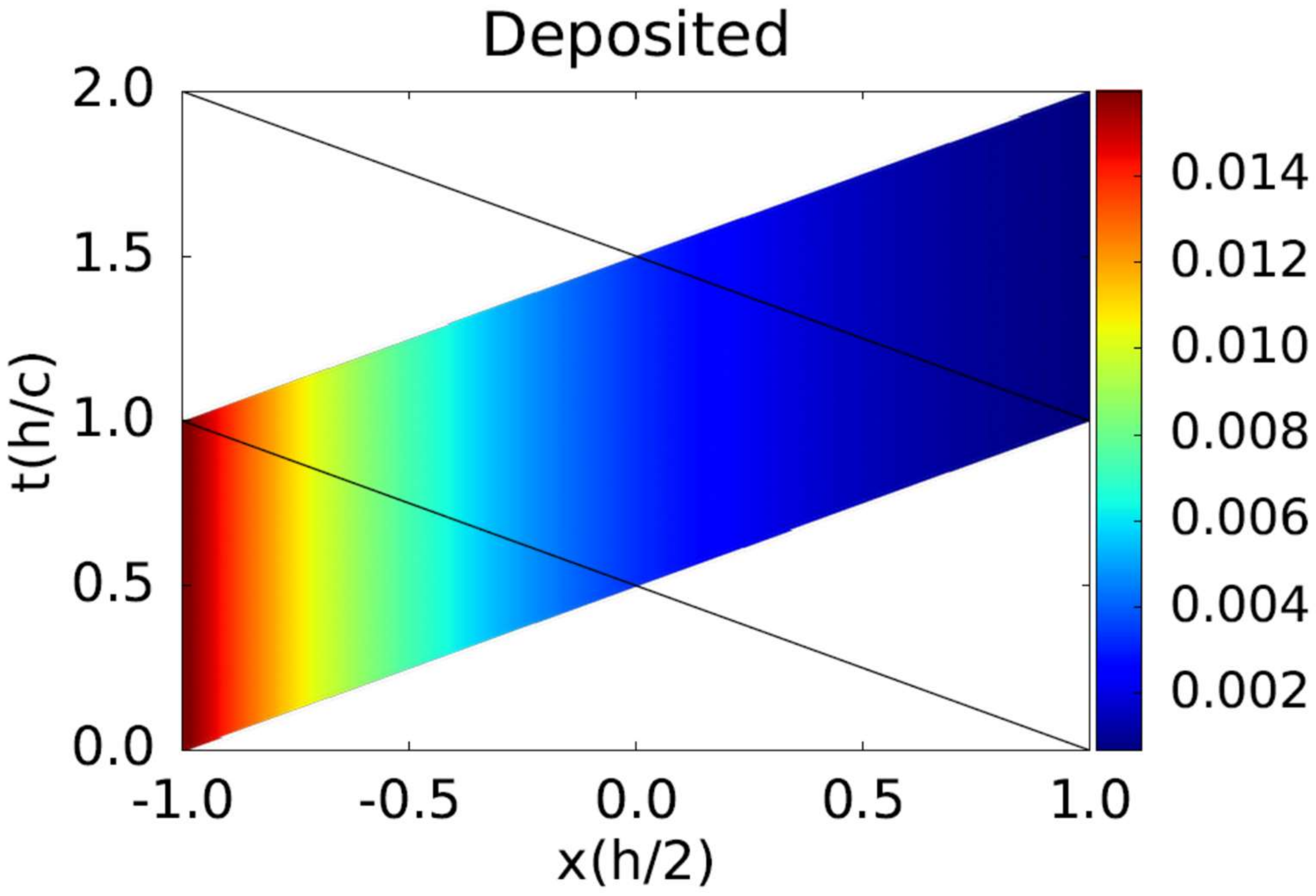
r = 0, $\alpha_K = 30\ \mathrm{cm}^{-1}$ while at the outside

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

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

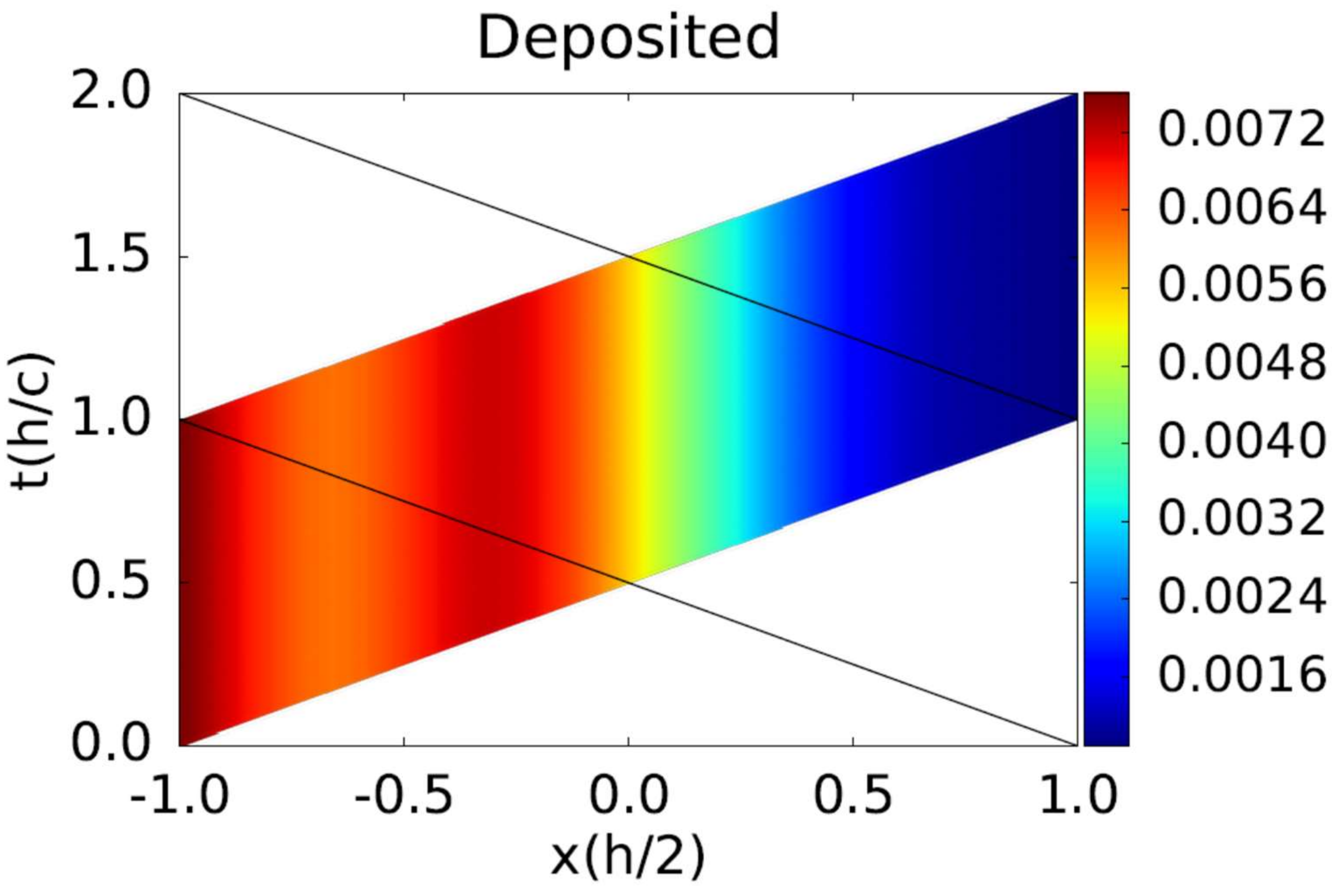
Simultaneous, volume ignition is up to 0.9 R, so **73% of the fuel target!**

How can we realize it simpler and with less expense → Two sided irradiation!



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.

Csernai, L.P. [NAPLIFE]

With nano antennas

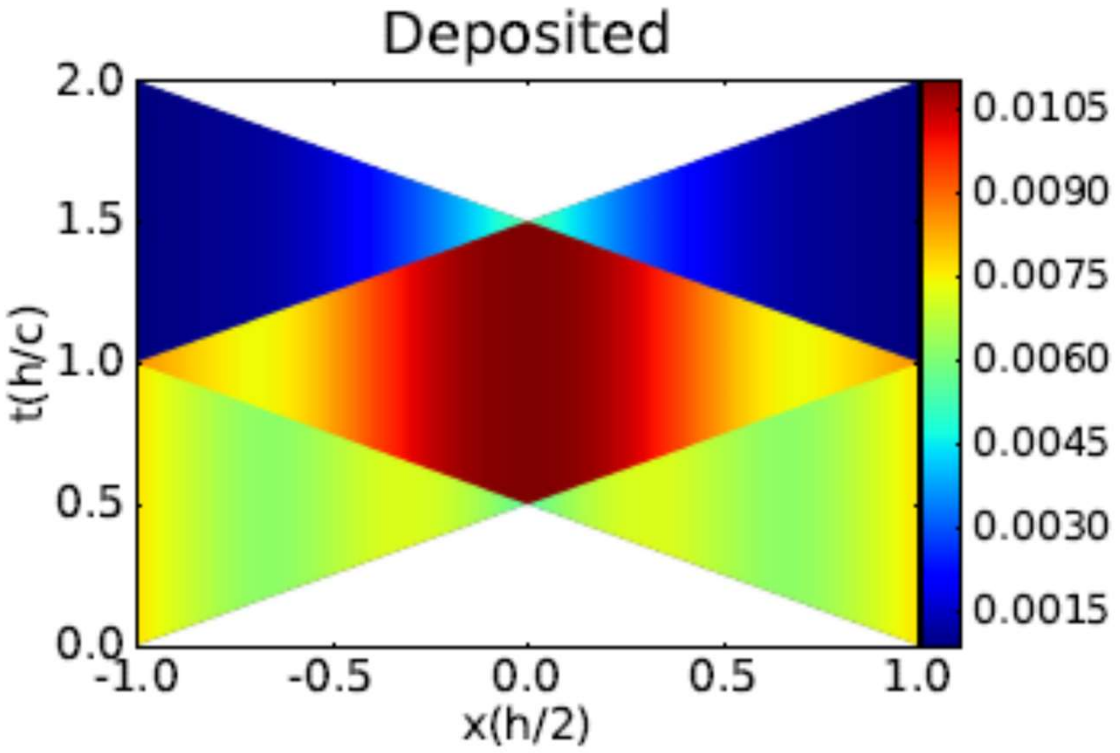


Figure 2: (color online) Deposited energy per unit time in the space-time across the depth, h, of the flat target. The time is measured in units of (h/c), where c is the speed of light in the material of the target. The irradiation lasts for a period of $\Delta t = h/c$ the time needed to cross the target.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

Csernai, L.P. [NAPLIFE]

With nano antennas

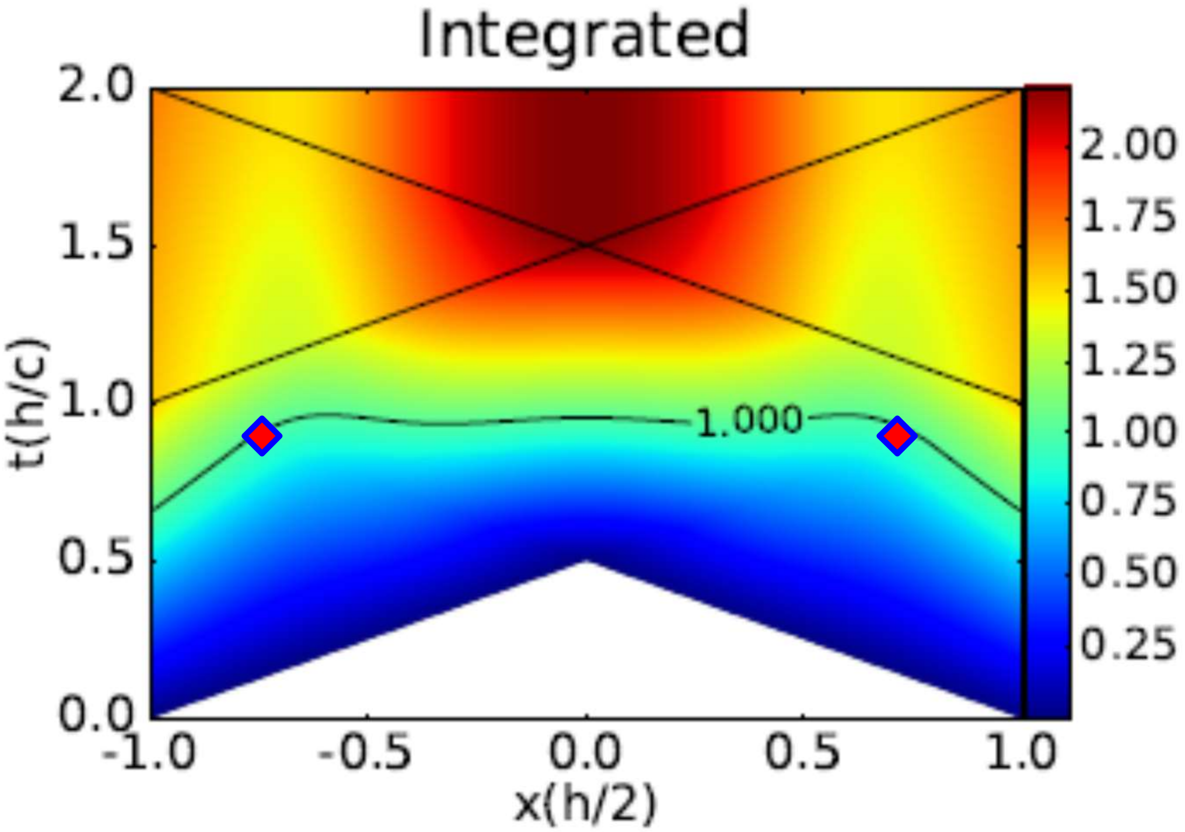


Figure 3: (color online) Integrated energy up to a given time in the space-time across the depth, h, of the flat target. The color code indicates the temperature, T, reached in a given space-time point, in units of the critical temperature, (T_c). The contour line $T = 1$, indicates the critical temperature,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

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

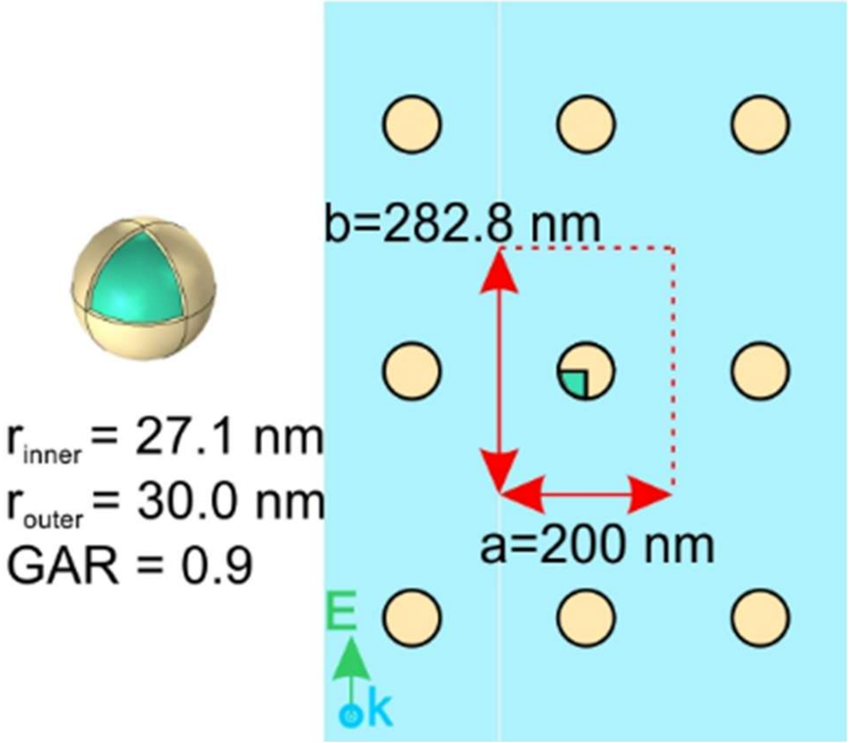
Validation tests at lower energies idea #2 increased absorption via nano-antennas

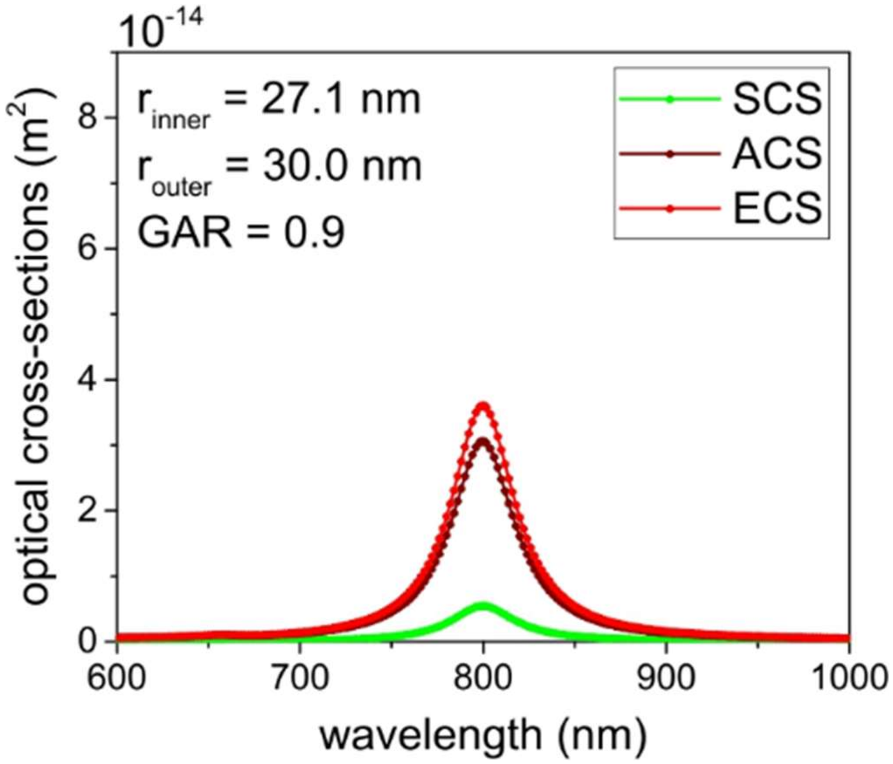
Wigner RCP, Budapest

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

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.



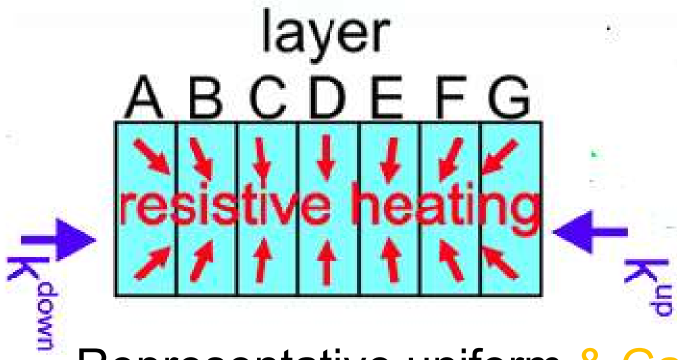


1 ps laser pulse length, λ = 800 nm, one-sided & two-sided irradiation tested, 85-100 % absorption in the target length h.

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

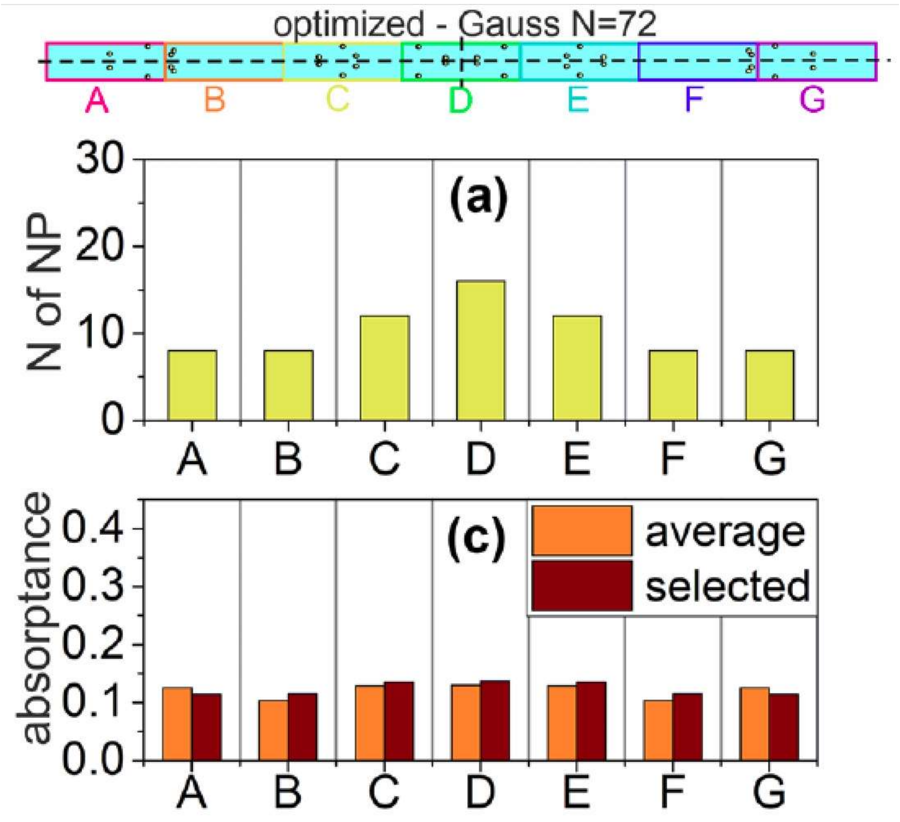


Representative uniform & Gaussian number density distributions of (d) 70 oriented nanorods, in a 1 × 1 × 21 μm3 supercell of UDMA polymer target, with random location distribution.

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.]

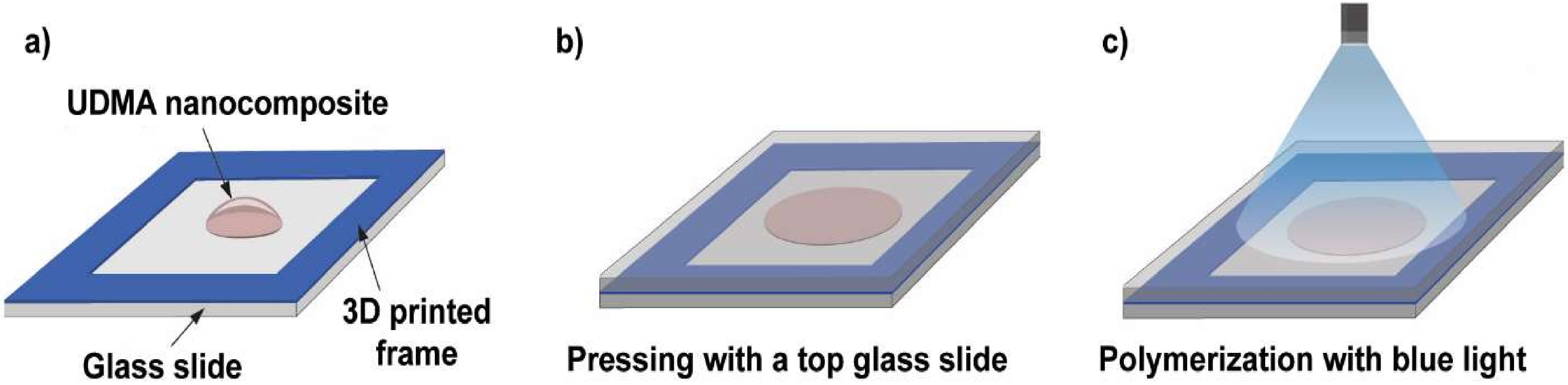
Target Modeling and Manufacturing

➔ Attila Bonyár et al.

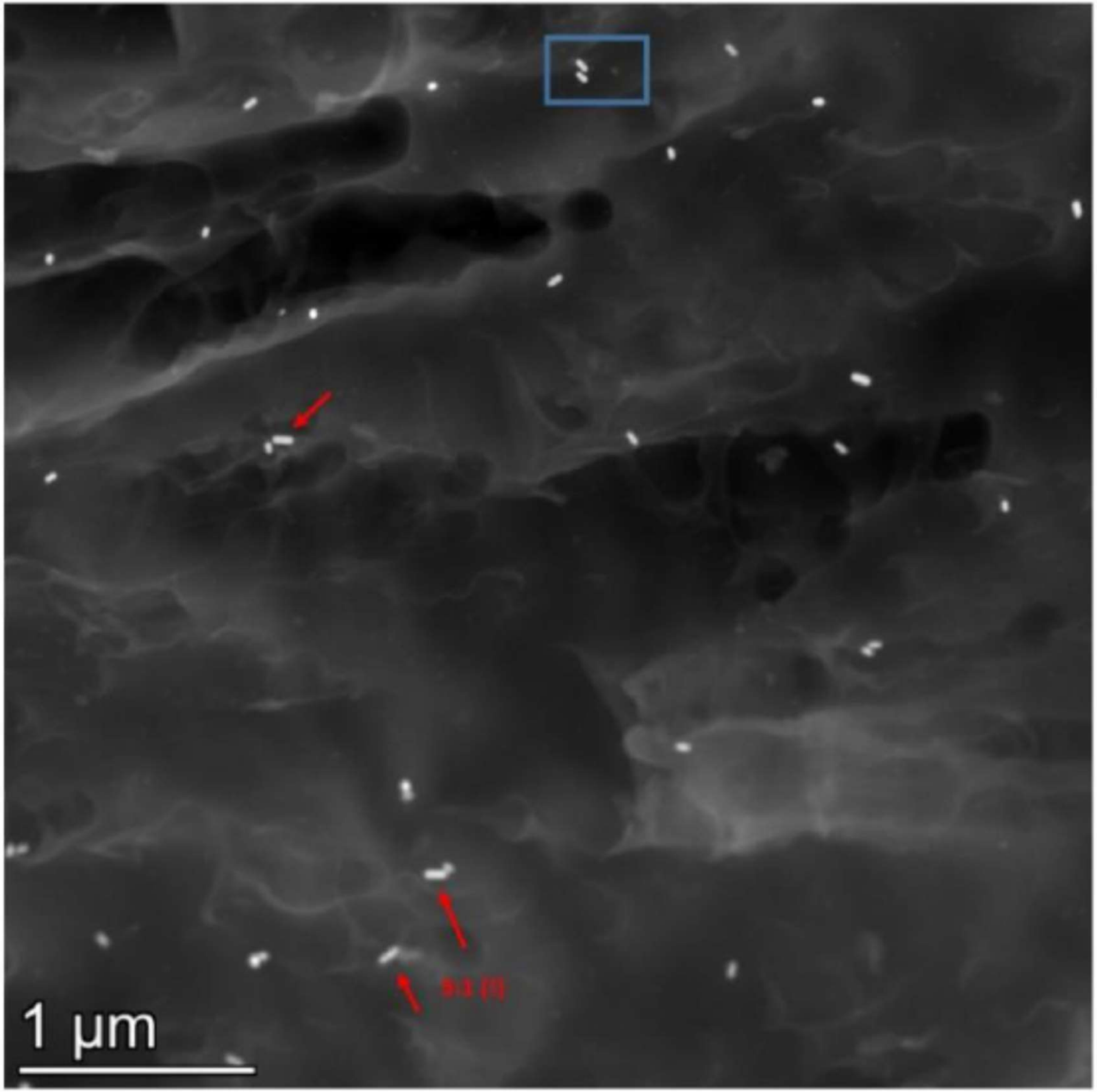
Target materials, absorptivity, implanted nanoantennas

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.,]



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

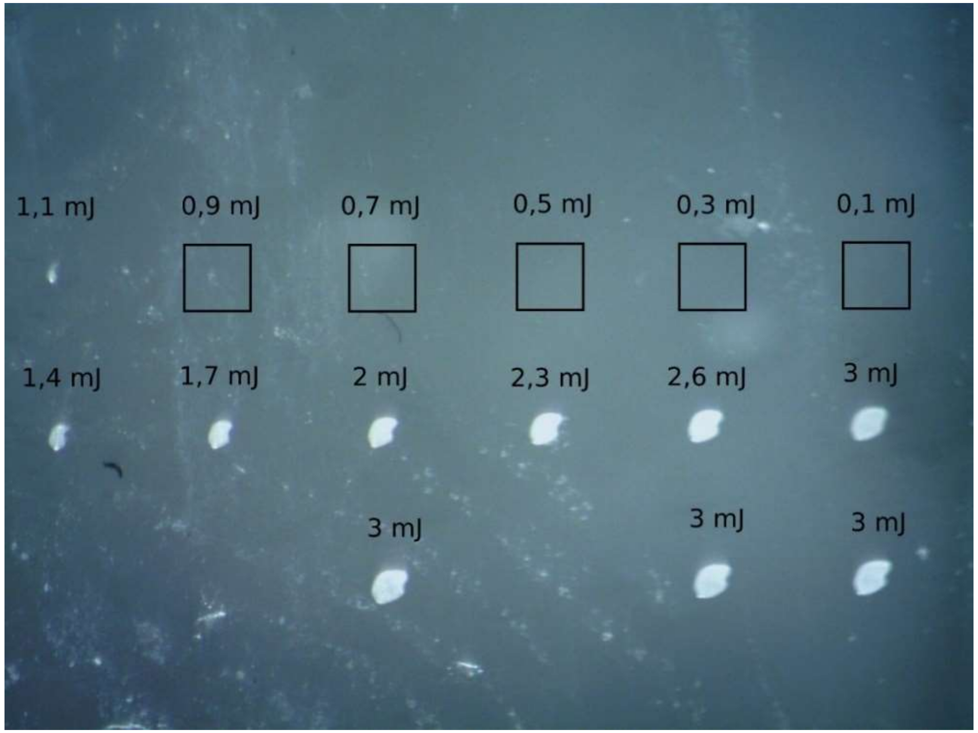
[Judit Kámán, A. Bonyár et al. (NAPLIFE Collab.)., Gold nanorods …, 10th ICNFP 2021, K**olymbari**, Crete, Greece, 30 August 2021.**]**

Effect of Short Pulse Laser Beams on target

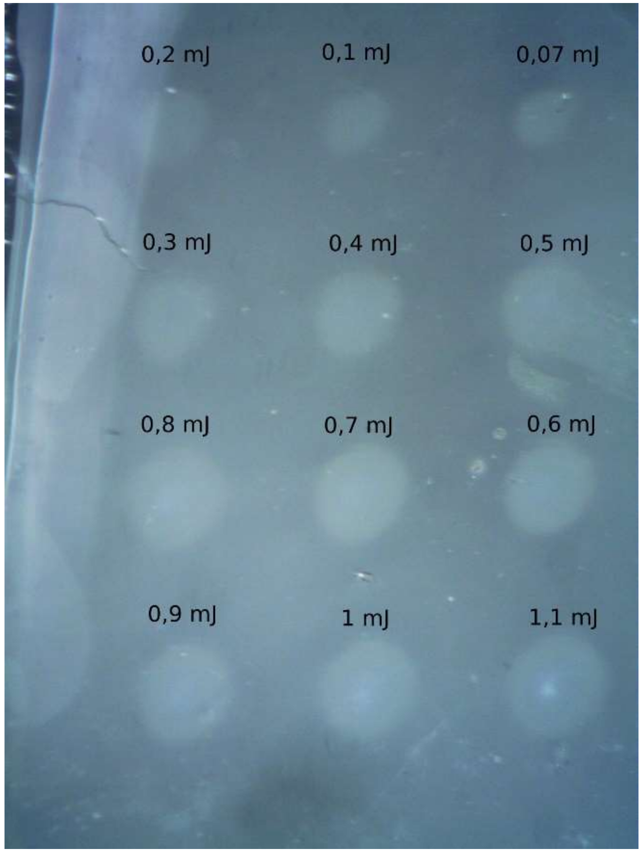
(N.K.*)

[Bonyár, Kroó, et al.]

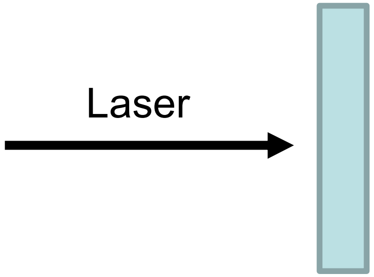
Without nanorods(30x)



With nanorods (40x)



Thickness:
~30μ to 40μ



300 fs long laser pulses

Focus: 85μ diameter
Pulse length: 300fs
Max Intensity ~4.10^{14}W/cm²

Csernai, L.P. [NAPLIFE]

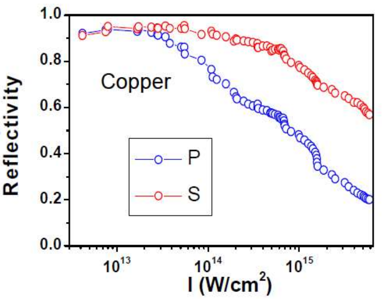
Plasma absorption

- 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°

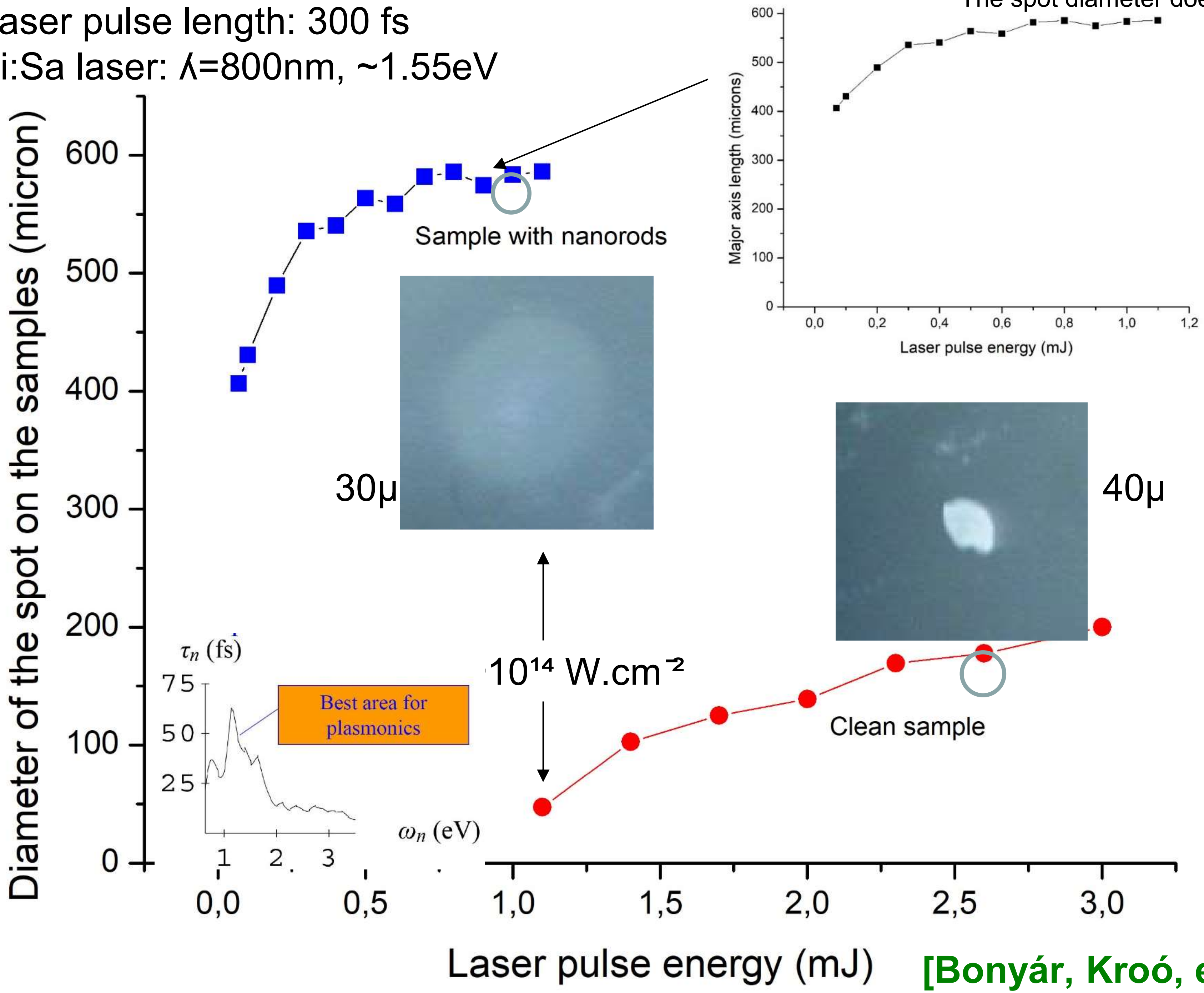
TIFR data

Kumar

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

The spot diameter does not increase

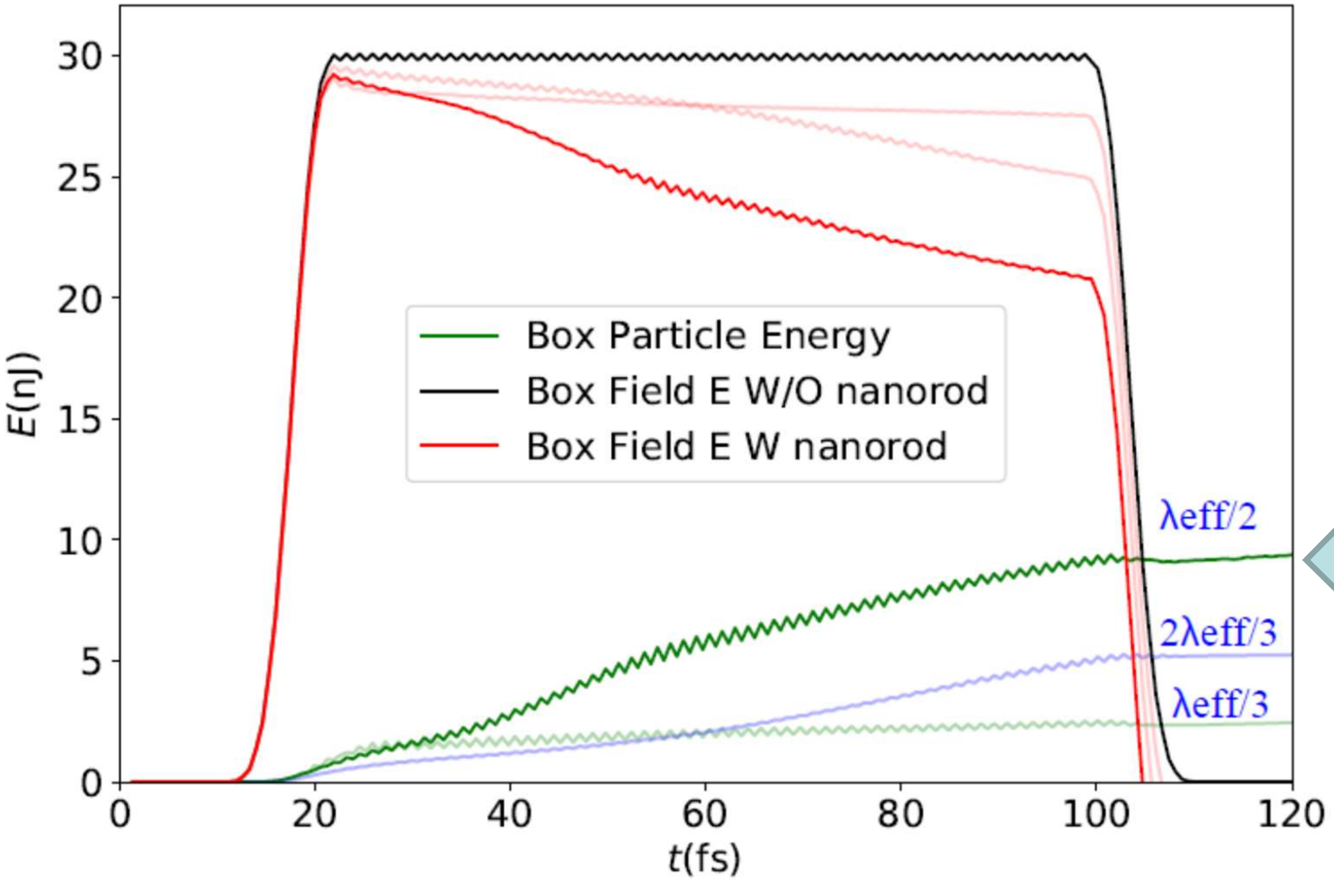
(N.K.*)



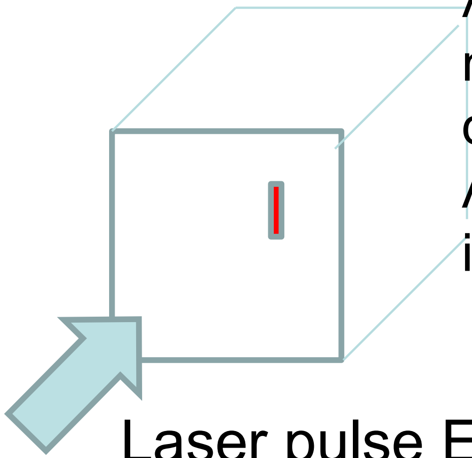
[Bonyár, Kroó, et al.]

Large plasmonic gain

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**]

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

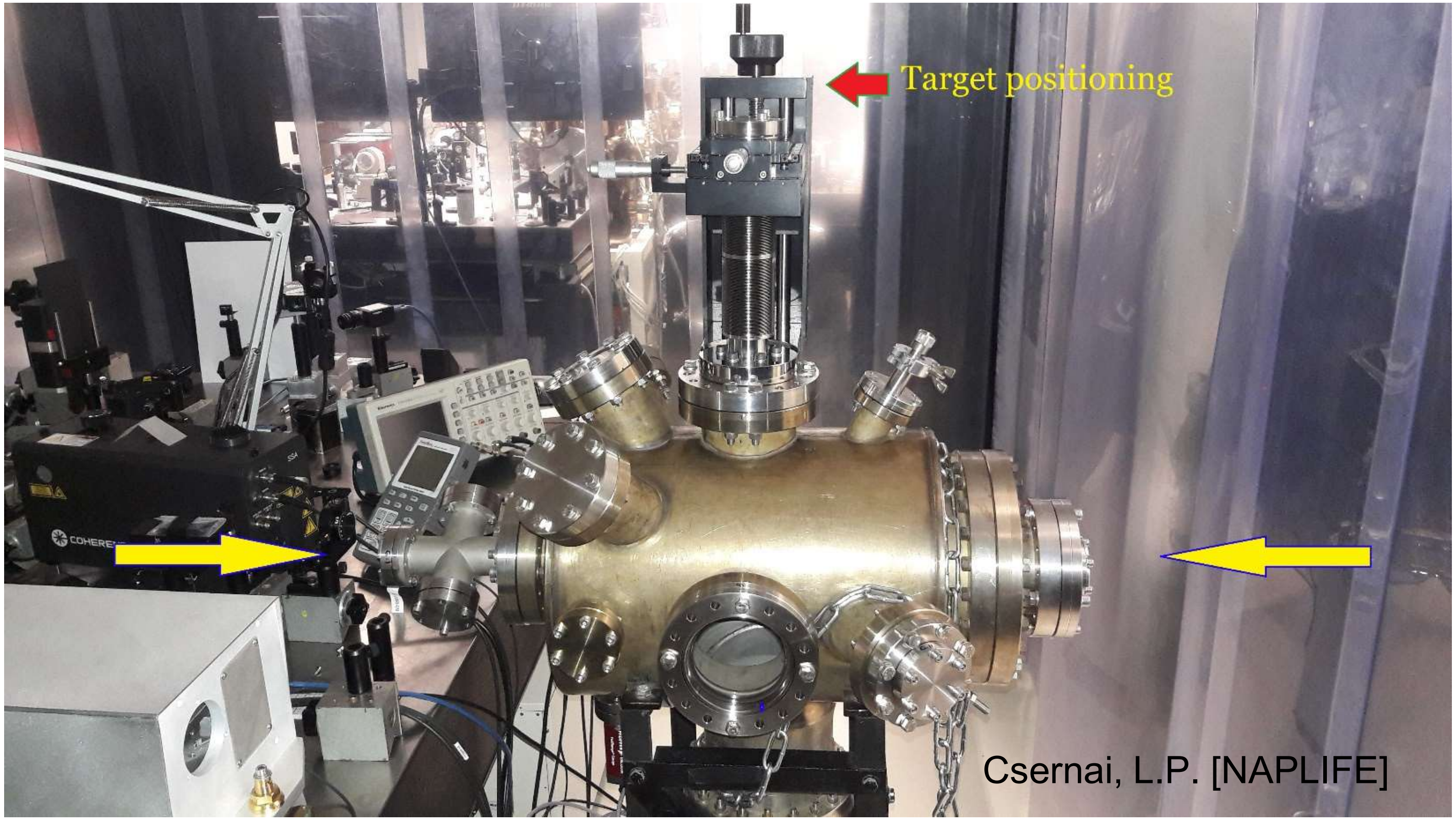
➔

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)**



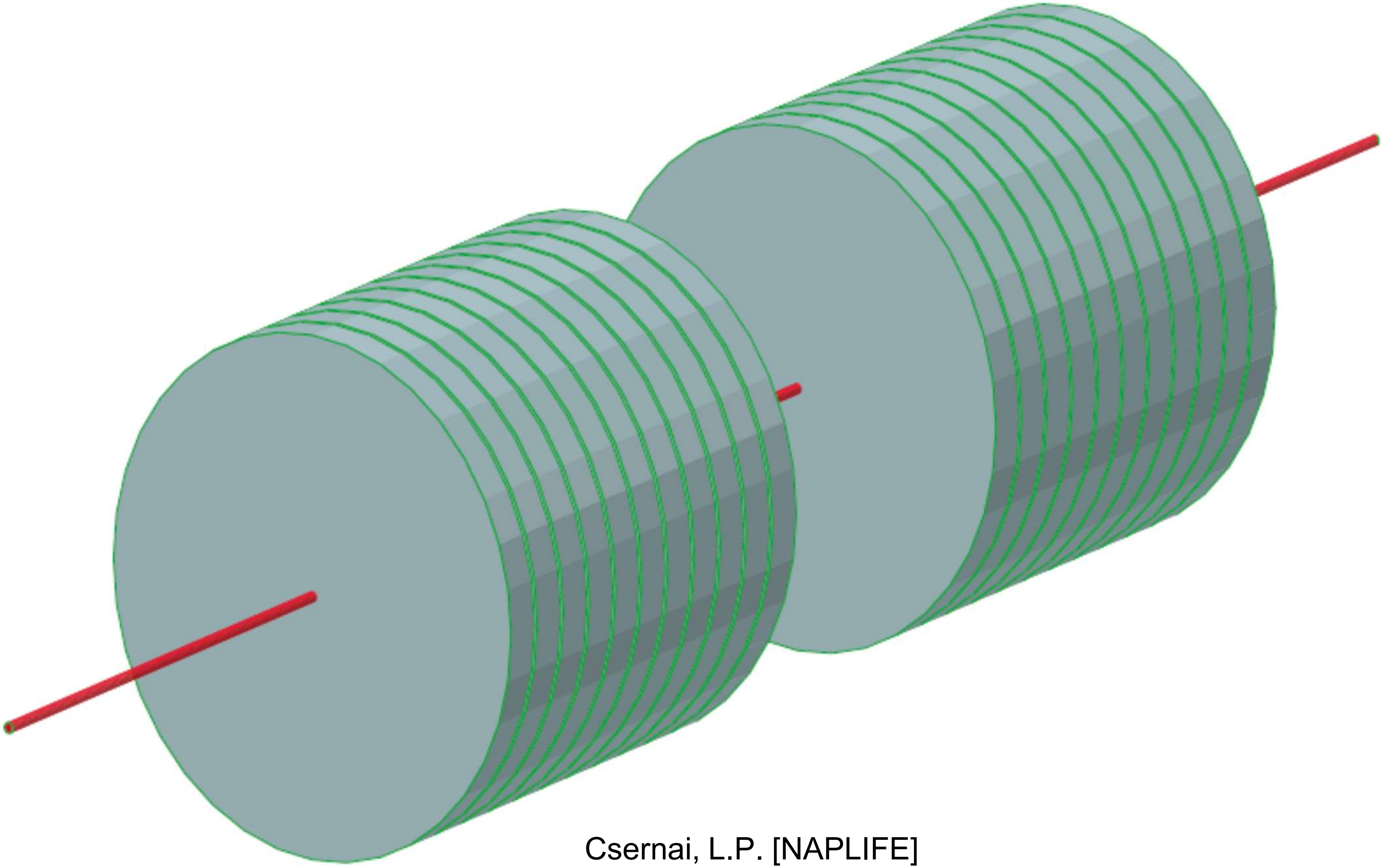
Csernai, L.P. [NAPLIFE]

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

In preparation

★

Multilayered fuel target



Laser Wake Field Collider

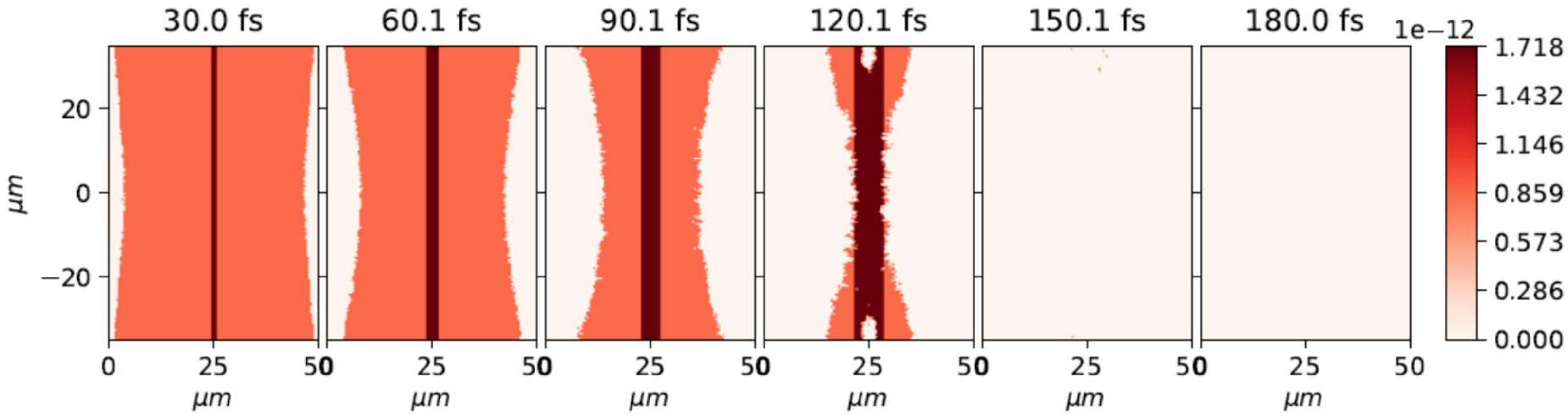
∃ Pre-compression/acceleration, before ignition

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

Initial beam densities assumed: $n_H \approx \gamma\, n_0 = 2\cdot10^{-19}/\mathrm{cm}^3$ and $2\cdot10^{-21}/\mathrm{cm}^3$

$\approx n_{\text{liquid-H}}$, $\approx n_{\text{NIF}}$ /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).]

Csernai, L.P. [NAPLIFE]

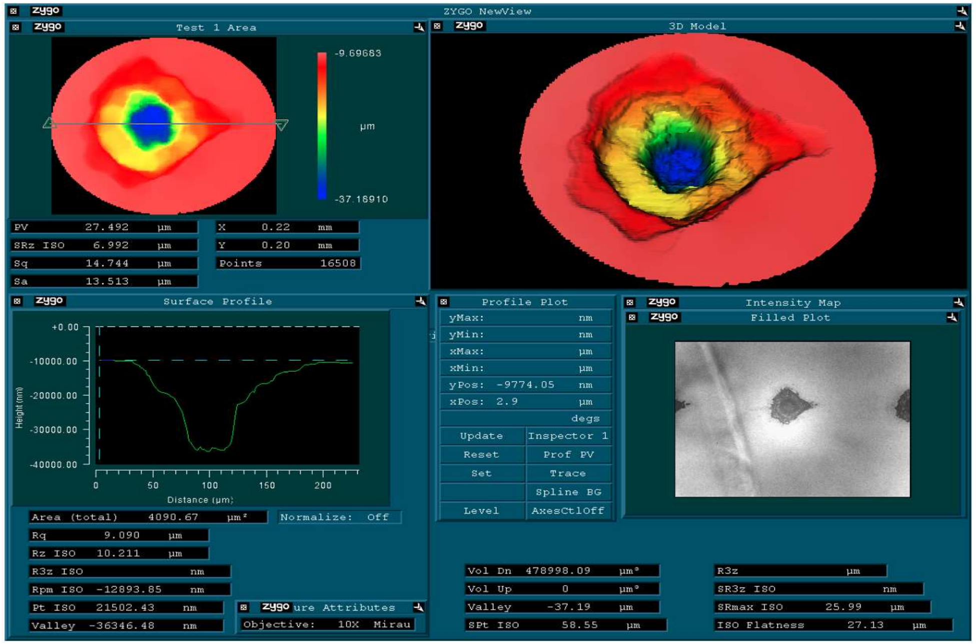
Validation tests ➔

Laser Induced Fusion with Nanoantennas

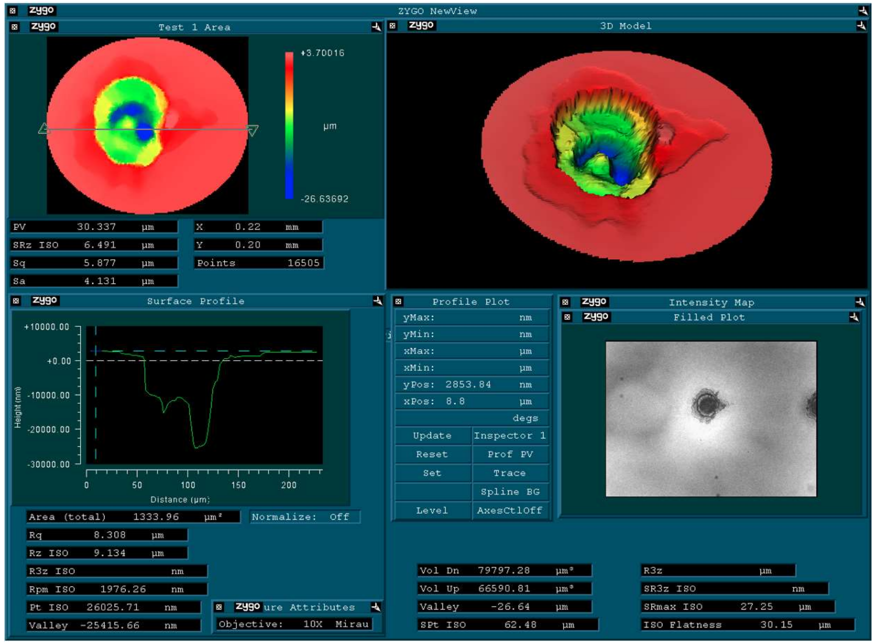
(N.K.*)

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

UDMA-TEGDMA target 20-100 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

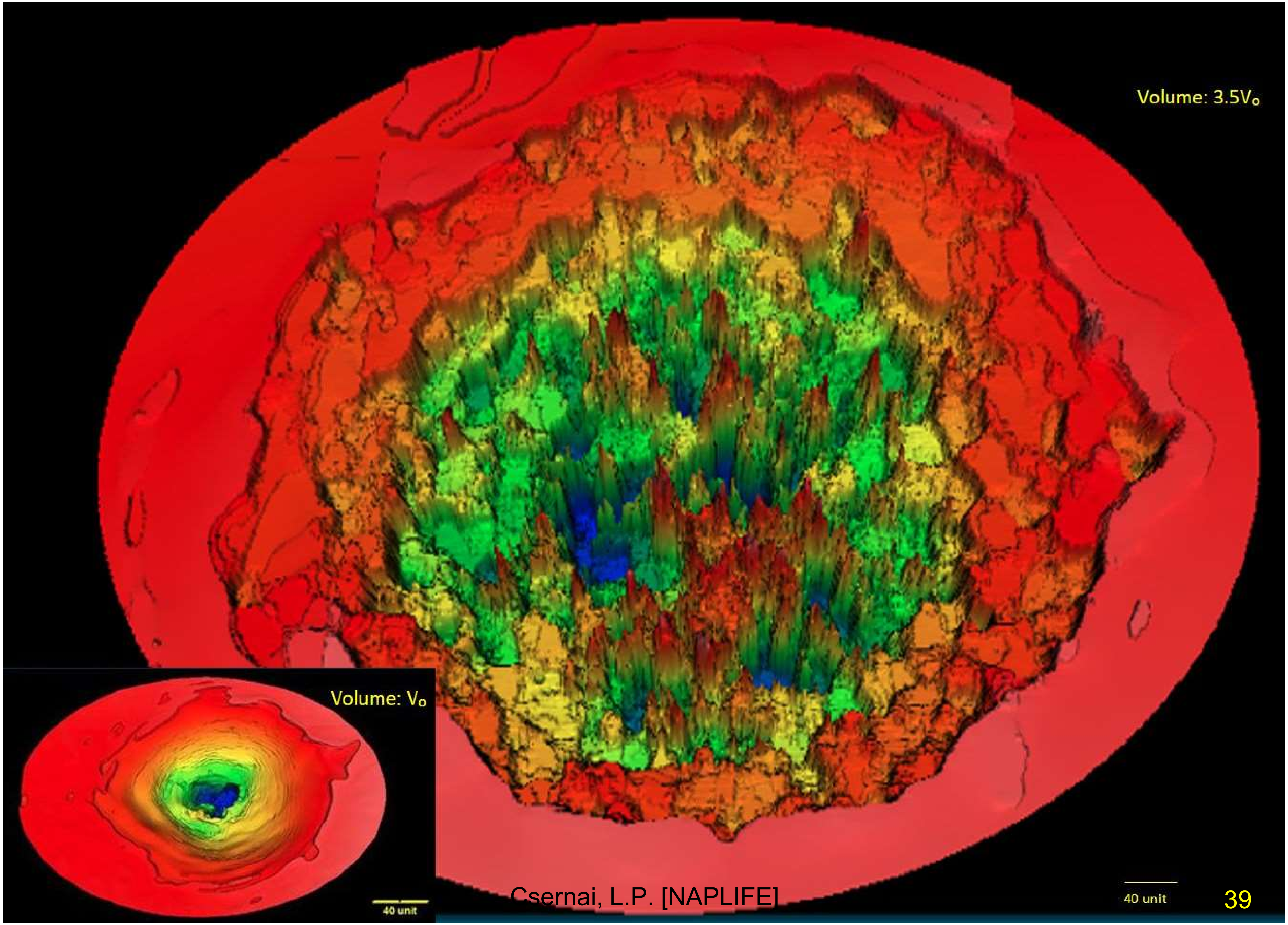


PV 27.492 µm
SRz ISO 6.992 µm
Sq 14.744 µm
Sa 13.513 µm
X 0.22 mm
Y 0.20 mm
Points 16508
yMax: nm
yMin: nm
xMax: µm
xMin: µm
yPos: -9774.05 nm
xPos: 2.9 µm
degs
Area (total) 4090.67 µm²
Normalize: Off
Rq 9.090 µm
Rz ISO 10.211 µm
R3z ISO nm
Rpm ISO -12893.85 nm
Pt ISO 21502.43 nm
Valley -36346.48 nm
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



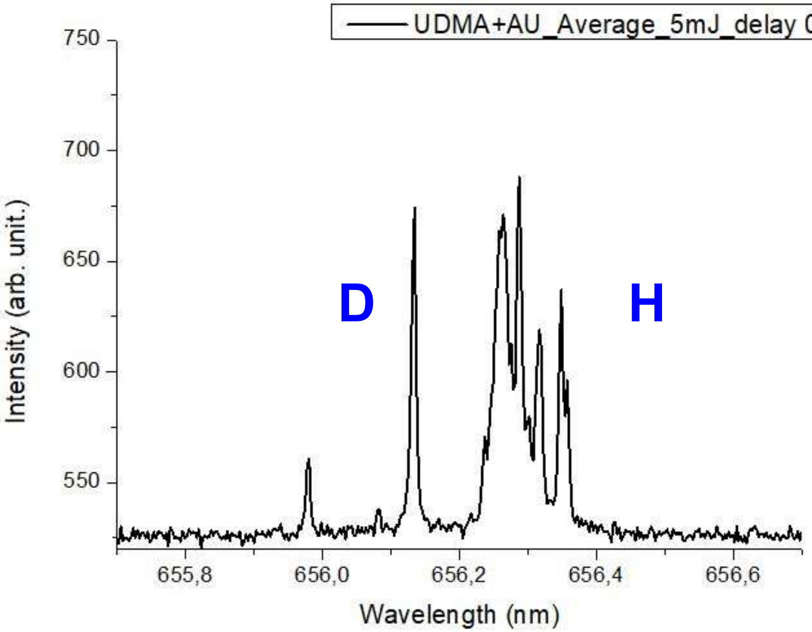
PV 30.337 µm
SRz ISO 6.491 µm
Sq 5.877 µm
Sa 4.131 µm
X 0.22 mm
Y 0.20 mm
Points 16505
yMax: nm
yMin: nm
xMax: µm
xMin: µm
yPos: 2853.84 nm
xPos: 8.8 µm
degs
Area (total) 1333.96 µm²
Normalize: Off
Rq 8.308 µm
Rz ISO 9.134 µm
R3z ISO nm
Rpm ISO 1976.26 nm
Pt ISO 26025.71 nm
Valley -25415.66 nm
Objective: 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).



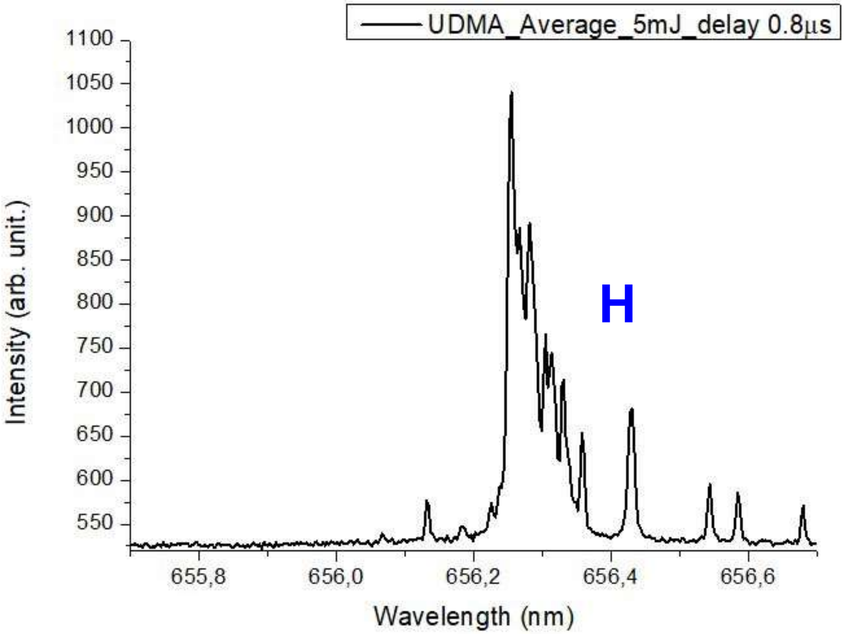
Csernai, L.P. [NAPLIFE]

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



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

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



100% **H**

Balmer-α line

Two step process (average of 20 shots):

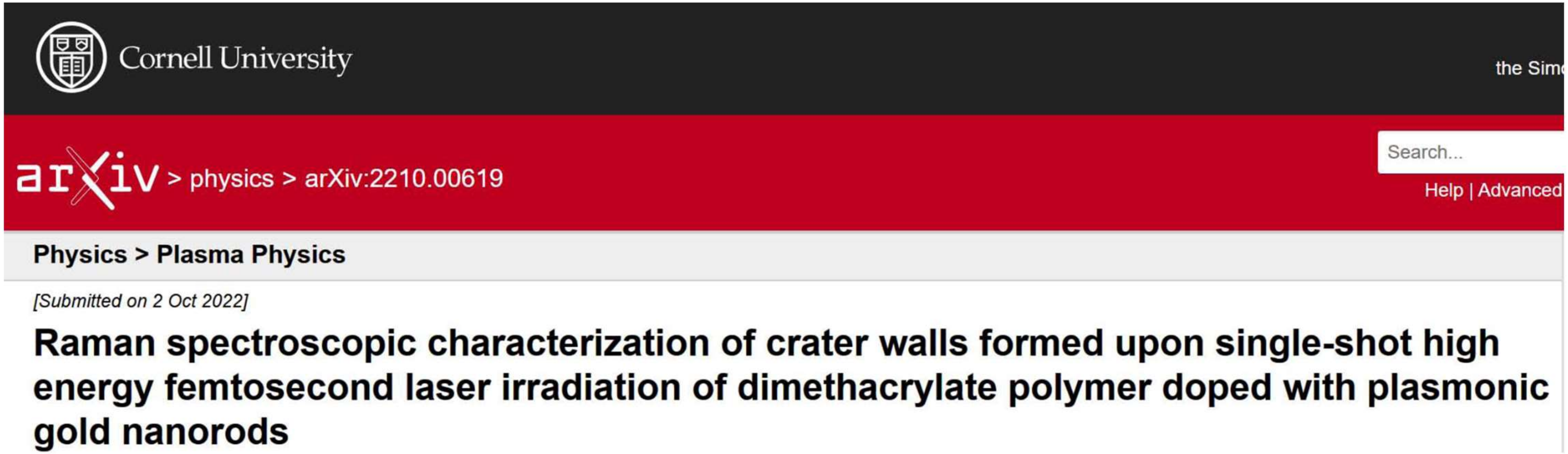
$p + e^* \rightarrow n + \nu$ \ electron capture (-1.24 MeV)

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

Electron capture may happen spontaneously in heavy nuclei,
here laser light and resonant nanorods act similarly, high e density

UDMA (470: H38, C23, O8, N2)

(2022)

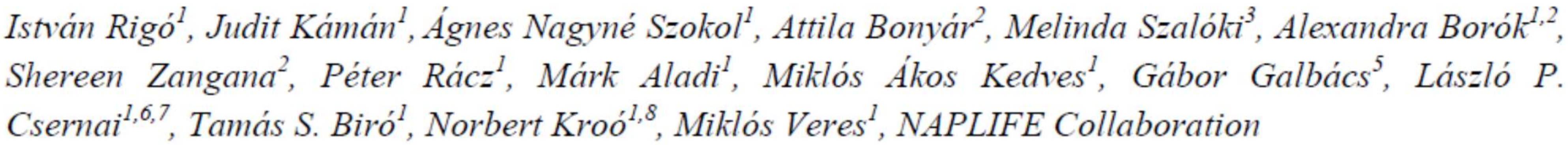


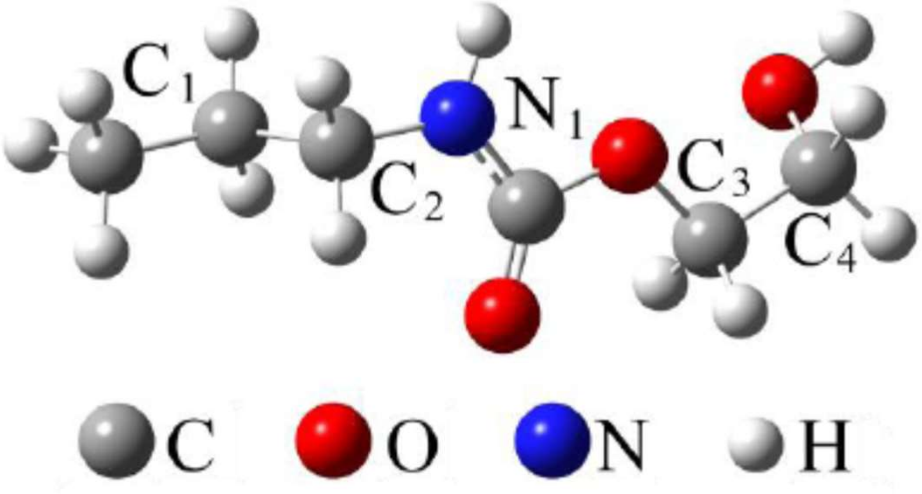
arXiv > physics > arXiv:2210.00619

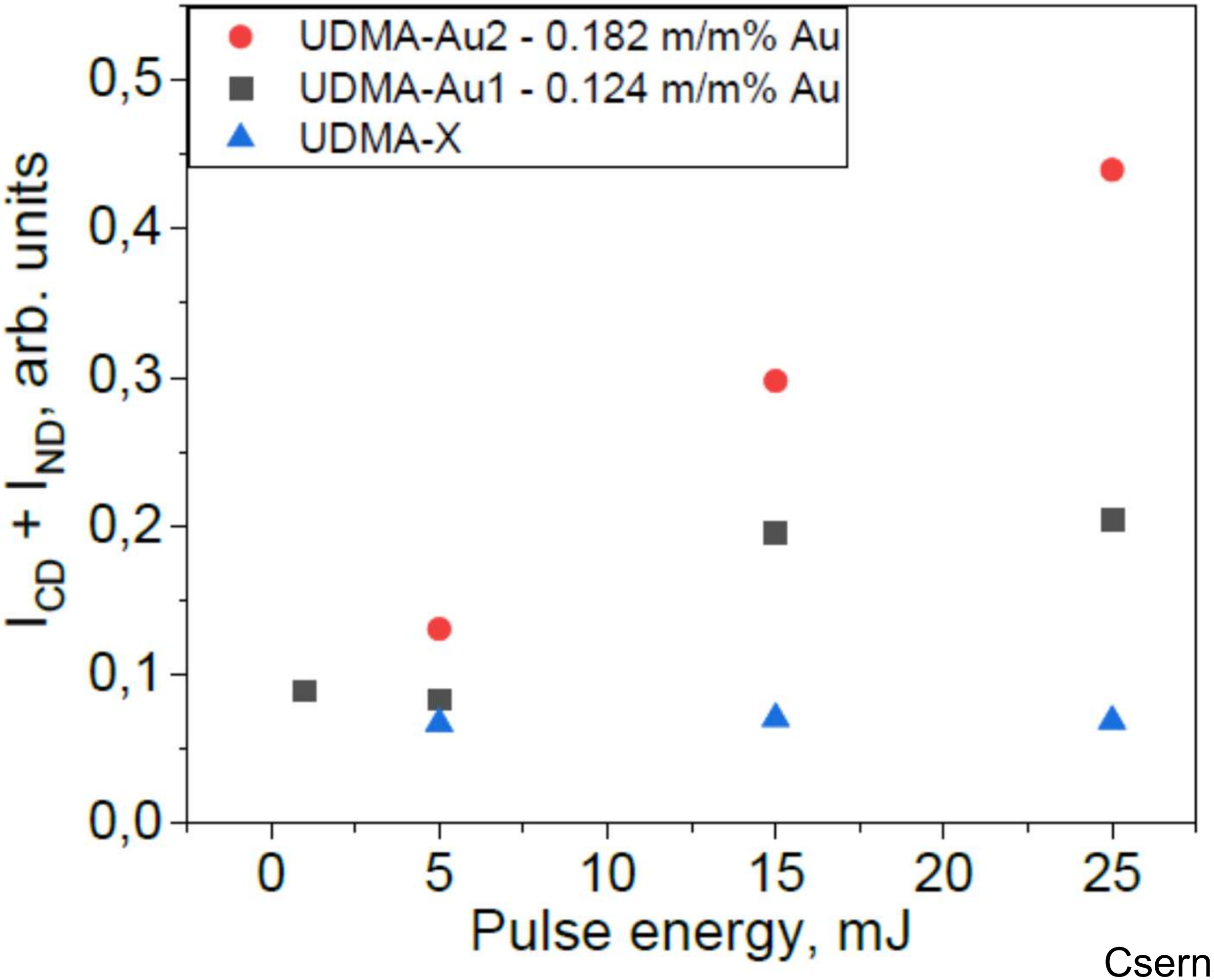
Physics > Plasma Physics

[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

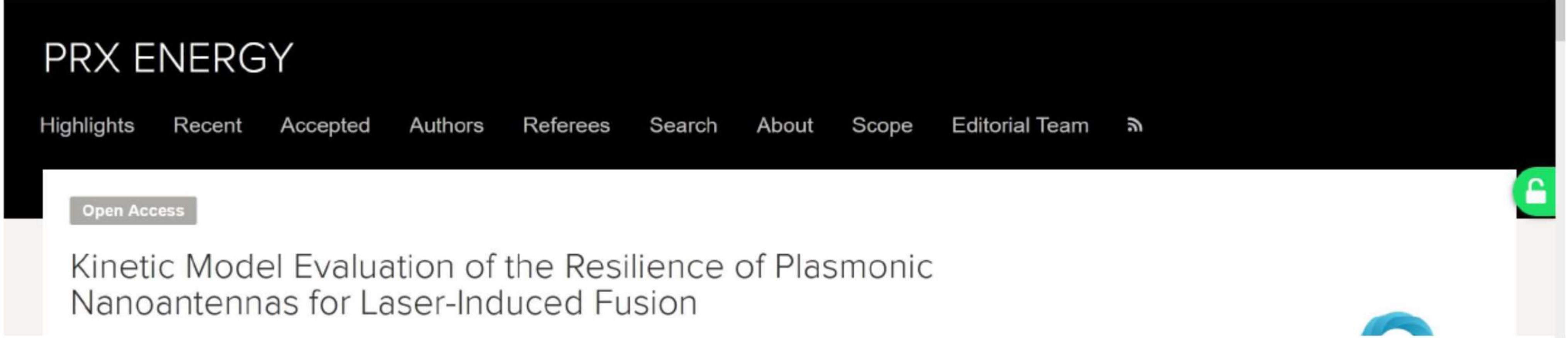

István Rigó[1], Judit Kámán[1], Ágnes Nagyné Szokol[1], Attila Bonyár[2], Melinda Szalóki[3], Alexandra Borók[1,2], Shereen Zangana[2], Péter Rácz[1], Márk Aladi[1], Miklós Ákos Kedves[1], Gábor Galbács[5], László P. Csernai[1,6,7], Tamás S. Biró[1], Norbert Kroó[1,8], Miklós Veres[1], NAPLIFE Collaboration





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

Csernai, L.P. [NAPLIFE]


PRX ENERGY

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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)

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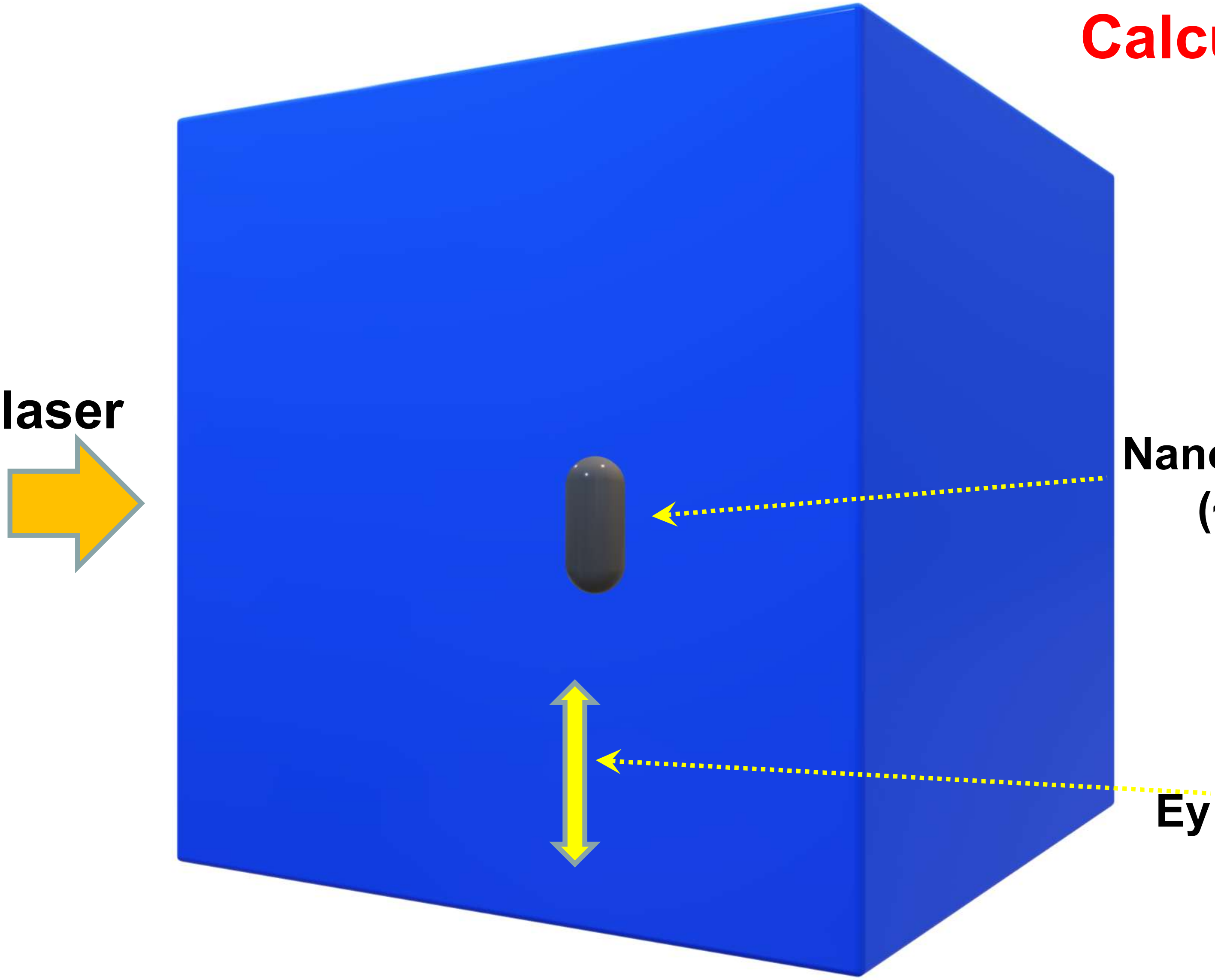
[11] *Hungarian Academy of Sciences, Budapest 1051, Hungary*

(2022)

Calculational Box (CB)

$(530 \text{ nm})^3$



laser

Nano-rod antenna
(~ 85x25 nm)

Ey Ffield

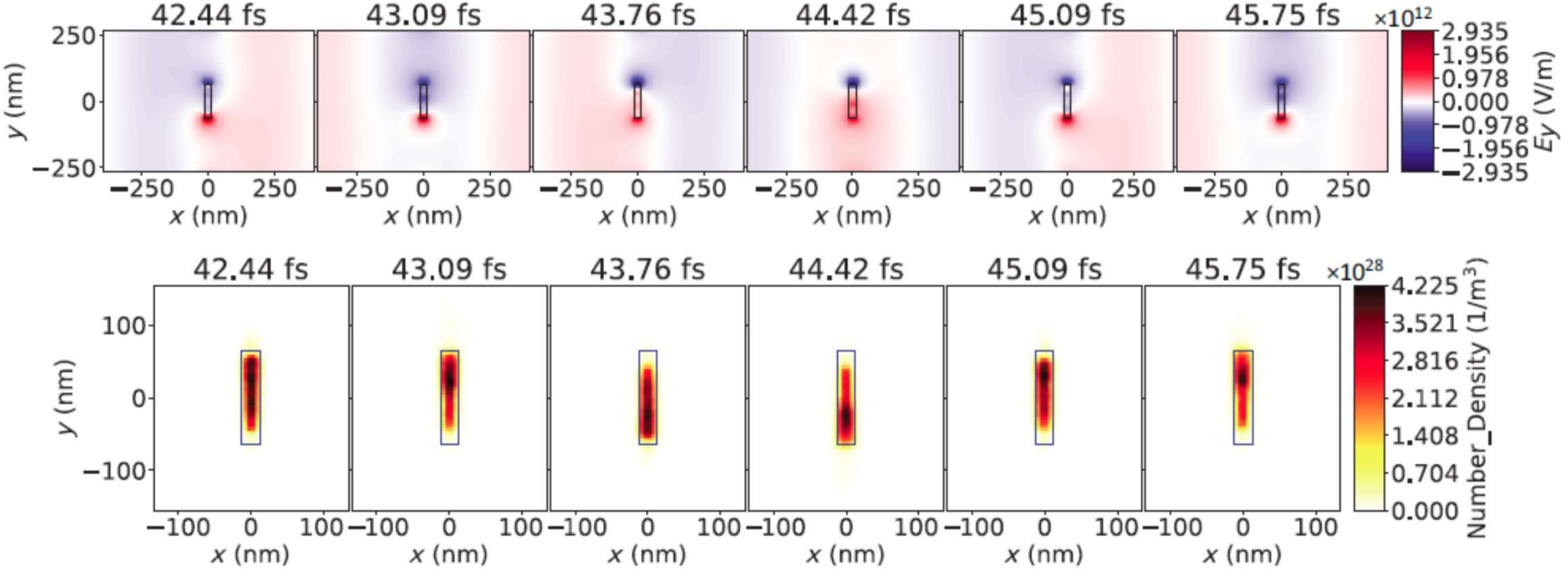
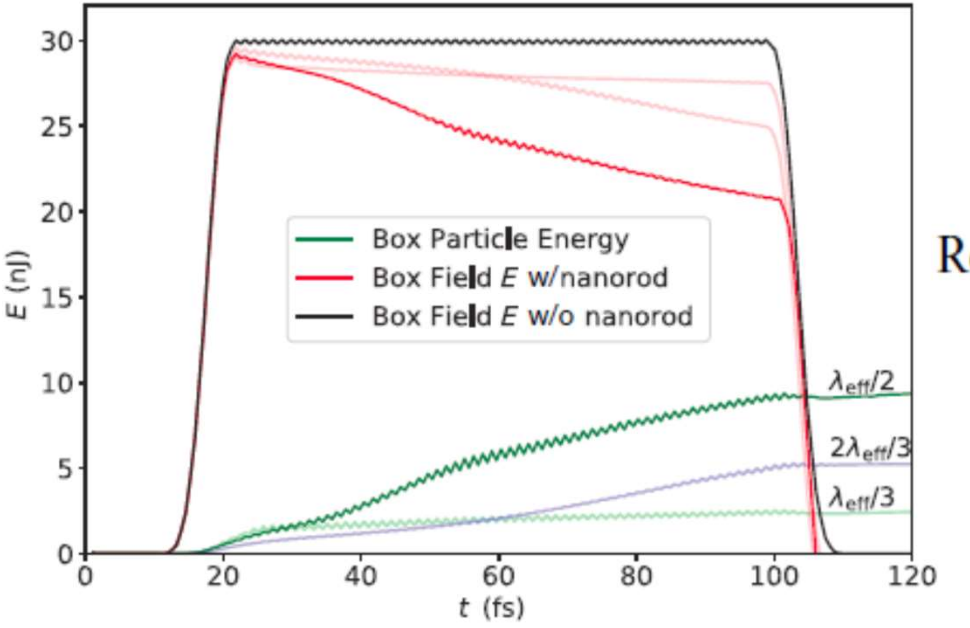


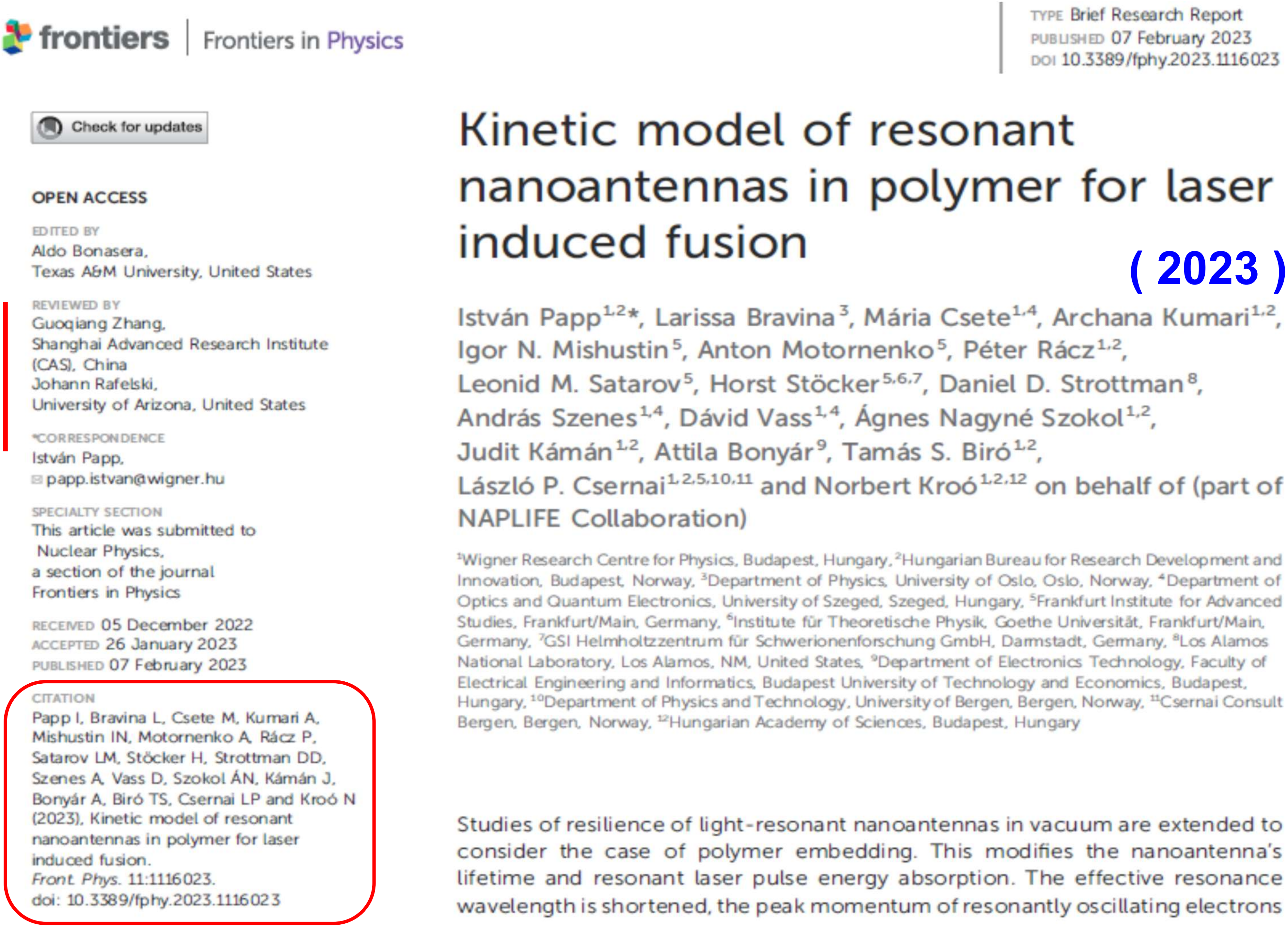
FIG. 2. Top: evolution of the E field's y component from 42.44 till 45.75 fs in a quarter of a period ($T/4 = 0.6625$ fs) steps, arour



Regarding the intensity, we estimate an enhancement of

$$I_x = 0.3\, I_p\, \frac{S_{\rm CB}}{S_{\rm NR}} = 25.9\, I_p . \qquad (3)$$

Csernai, L.P. [NAPLIFE]



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Front. Phys. 11:1116023.
doi: 10.3389/fphy.2023.1116023

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)

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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

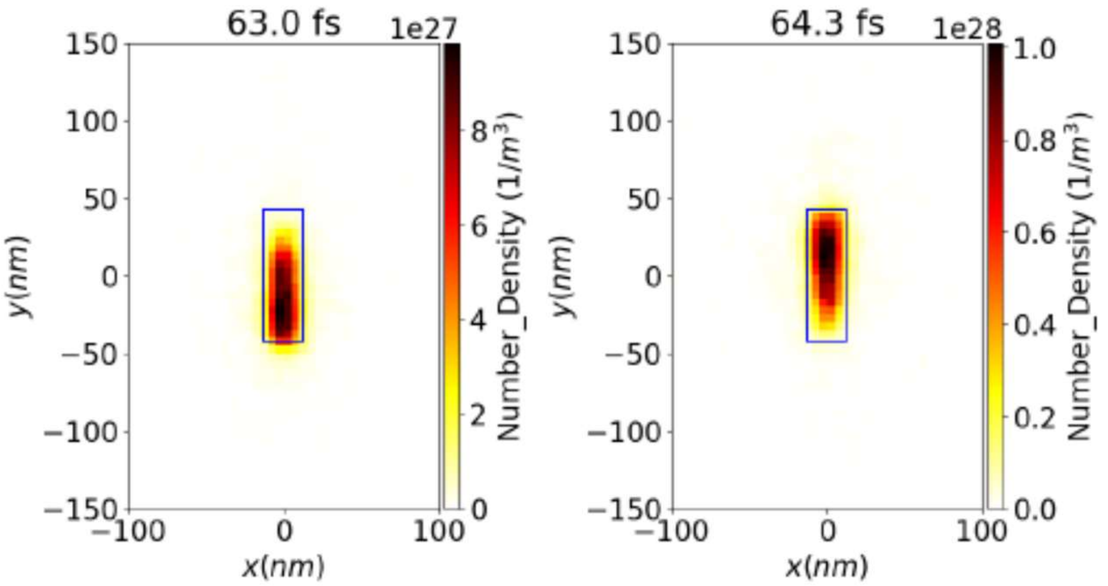
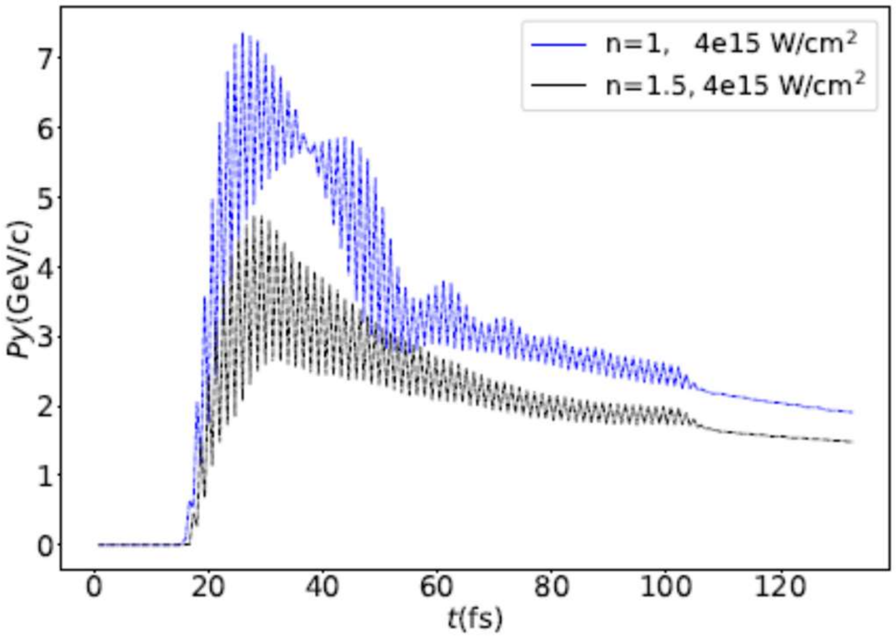


Figure 1: (color online) Cross section of the 25 nm (diameter) x 85 nm nanorod

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)

Csernai, L.P. [NAPLIFE]

arXiv > physics > arXiv:2211.14031

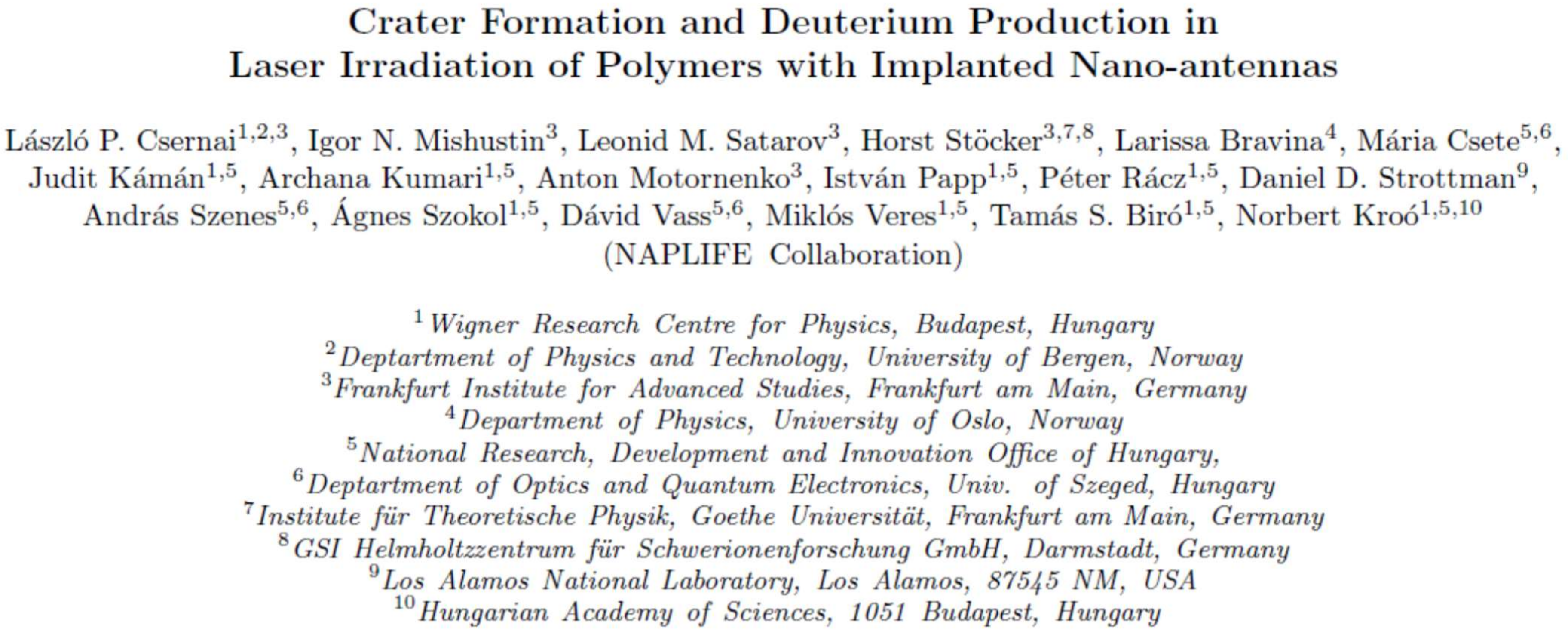
Physics > Plasma Physics

[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)

(Phys. Rev. E 2023)



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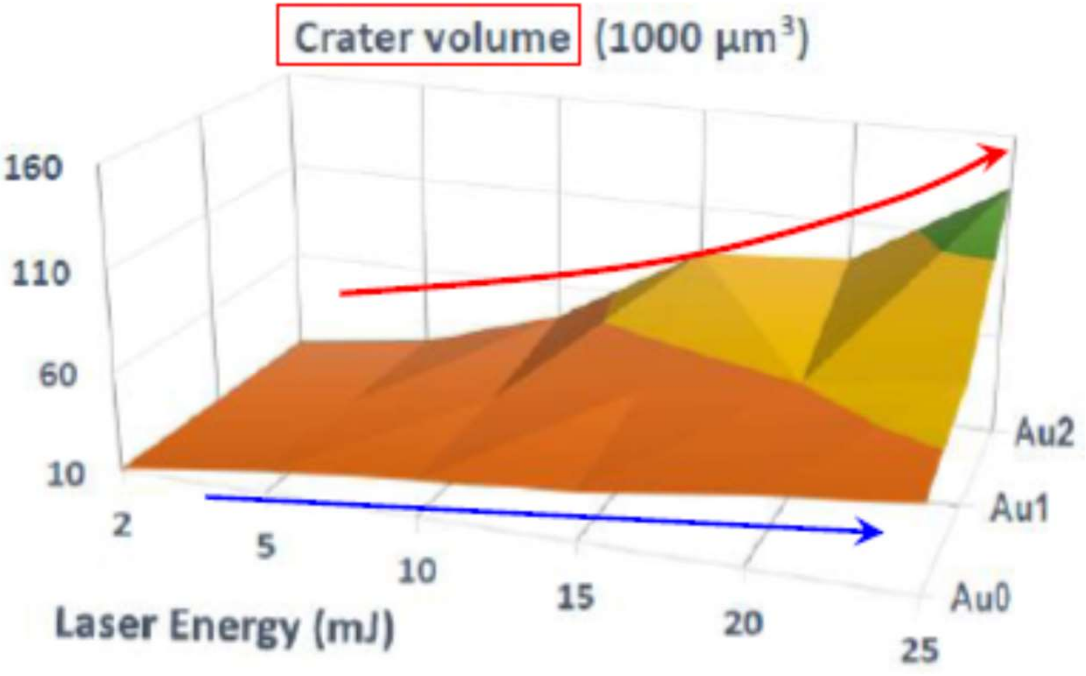
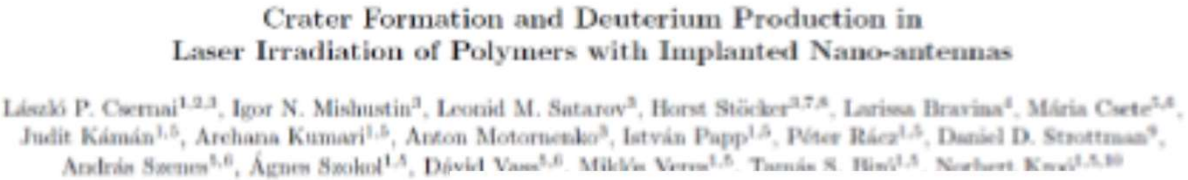
[10] *Hungarian Academy of Sciences, 1051 Budapest, Hungary*

Theoretical analyzis of Crater & Deuterium production

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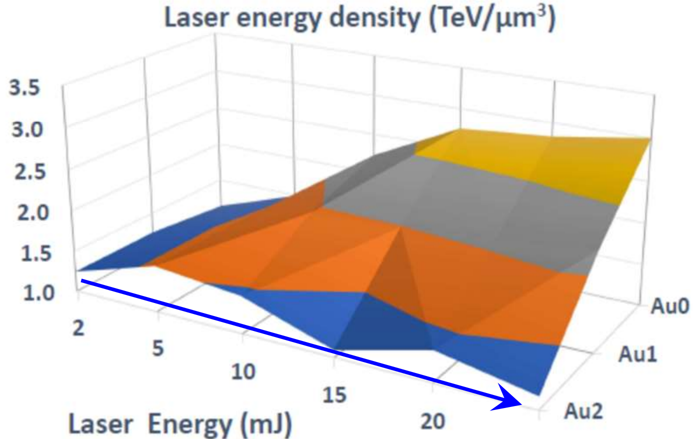


Puzzle ?

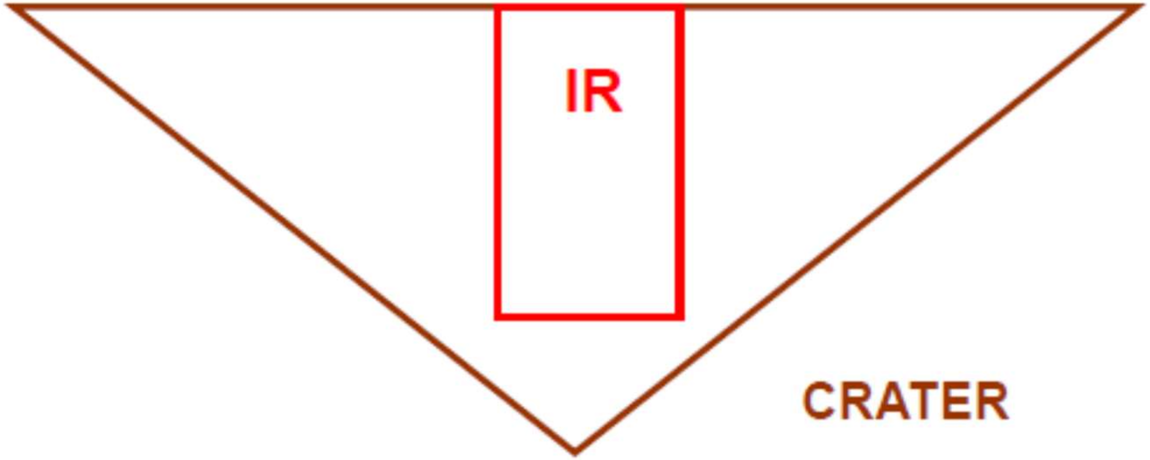
With nanorods V grows non-linearly. Increasing energy deposition. Several types of targets are considered: Au1 and Au2 with implanted nano-rod antennas, and Au0 without implantation. The mass concentrations of implanted particles in UDMA are 0.126% and 0.182% for targets Au1 and Au2, respectively.

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

Origin of this extra energy (?)

[Phys. Rev. E in press.]

Csernai, L.P. [NAPLIFE]



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

Theoretical studies in progress

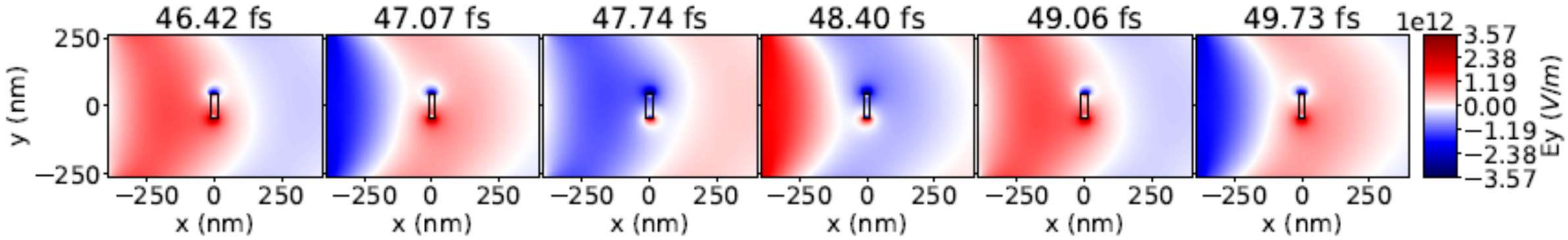
We pursue kinetic model (EPOCH) studies in the same Calculational Box, where the nano-rod antenna is surrounded be hydrogen target.

W assume that the hydrogen is relatively dense and ionized, in order to study what effect will have the nano-rod antennas on the surrounding protons.

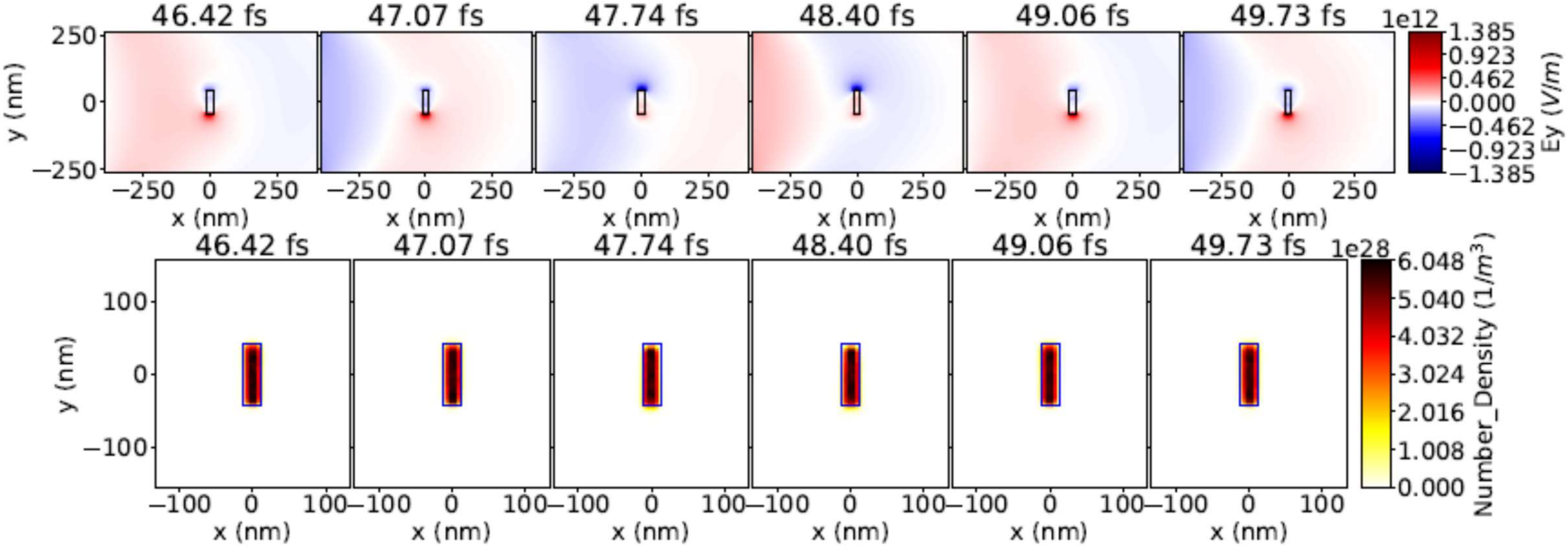
[István Papp et al., arXiv:2306.13445,
Laser induced proton acceleration ...,]

Laser

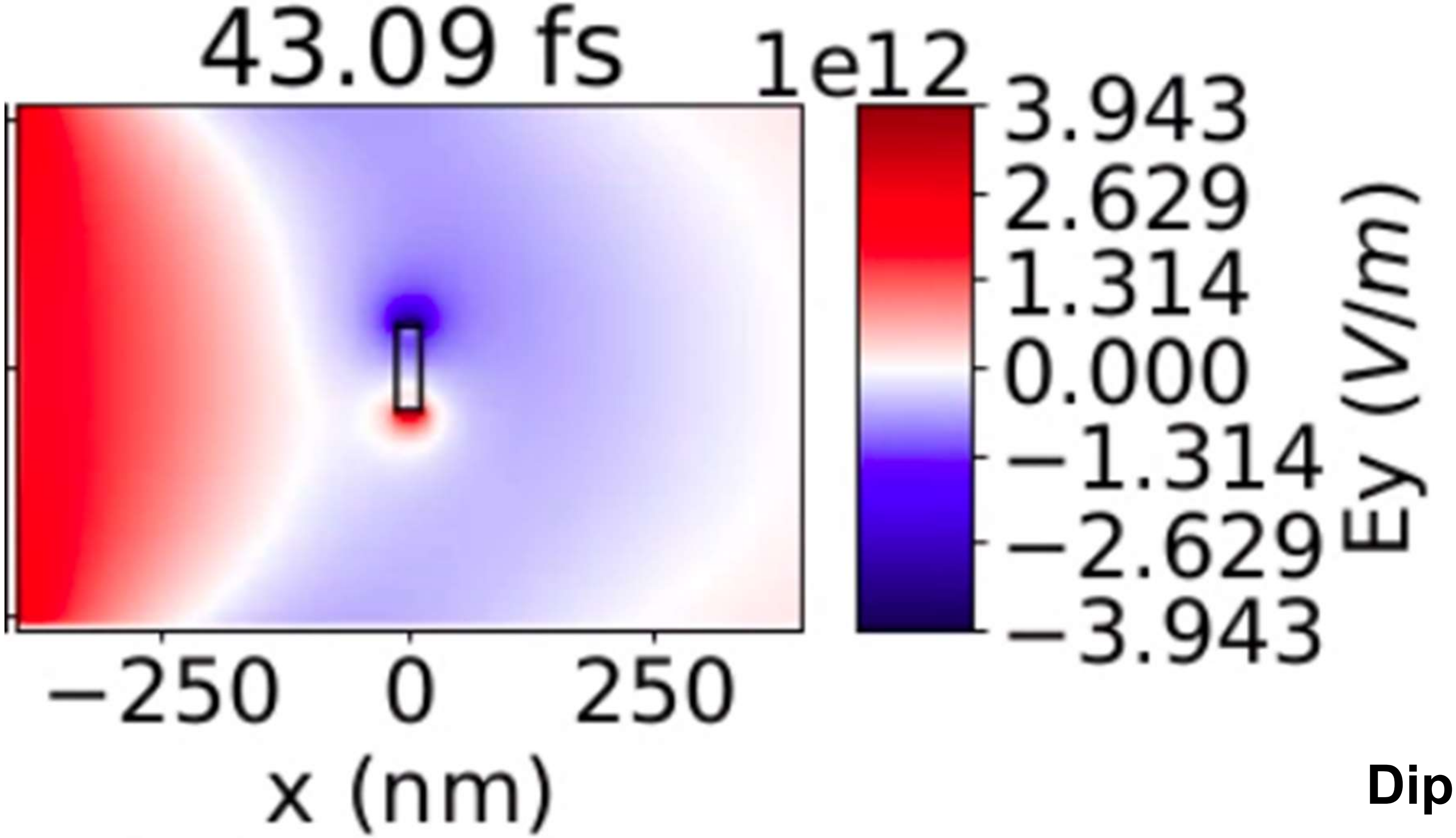
$I = 4 \cdot 10^{17}$ W/cm^2 $V \sim 7.1 \cdot 10^{12}$ V/m



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



Csernai, L.P. [NAPLIFE]

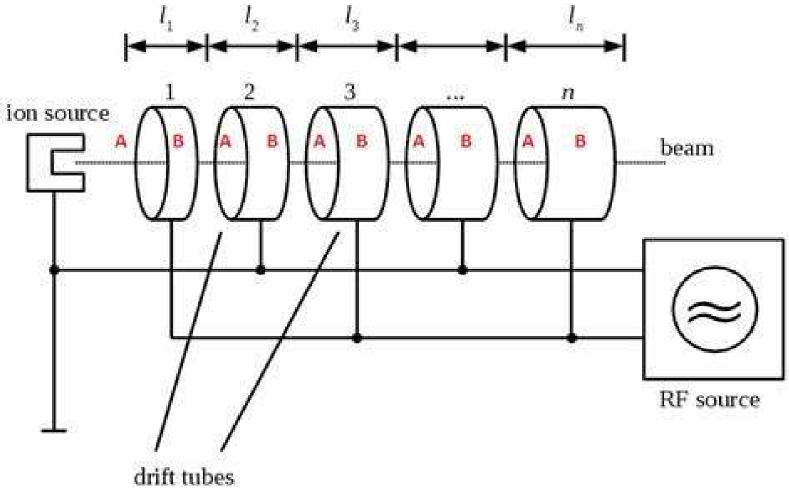


Neighboring protons are accelerated (100-200 nm)

Dipole L = 85 nm

I = 4 · 10^{17} W/cm^2

dV ~ 8 · 10^{12} V/m



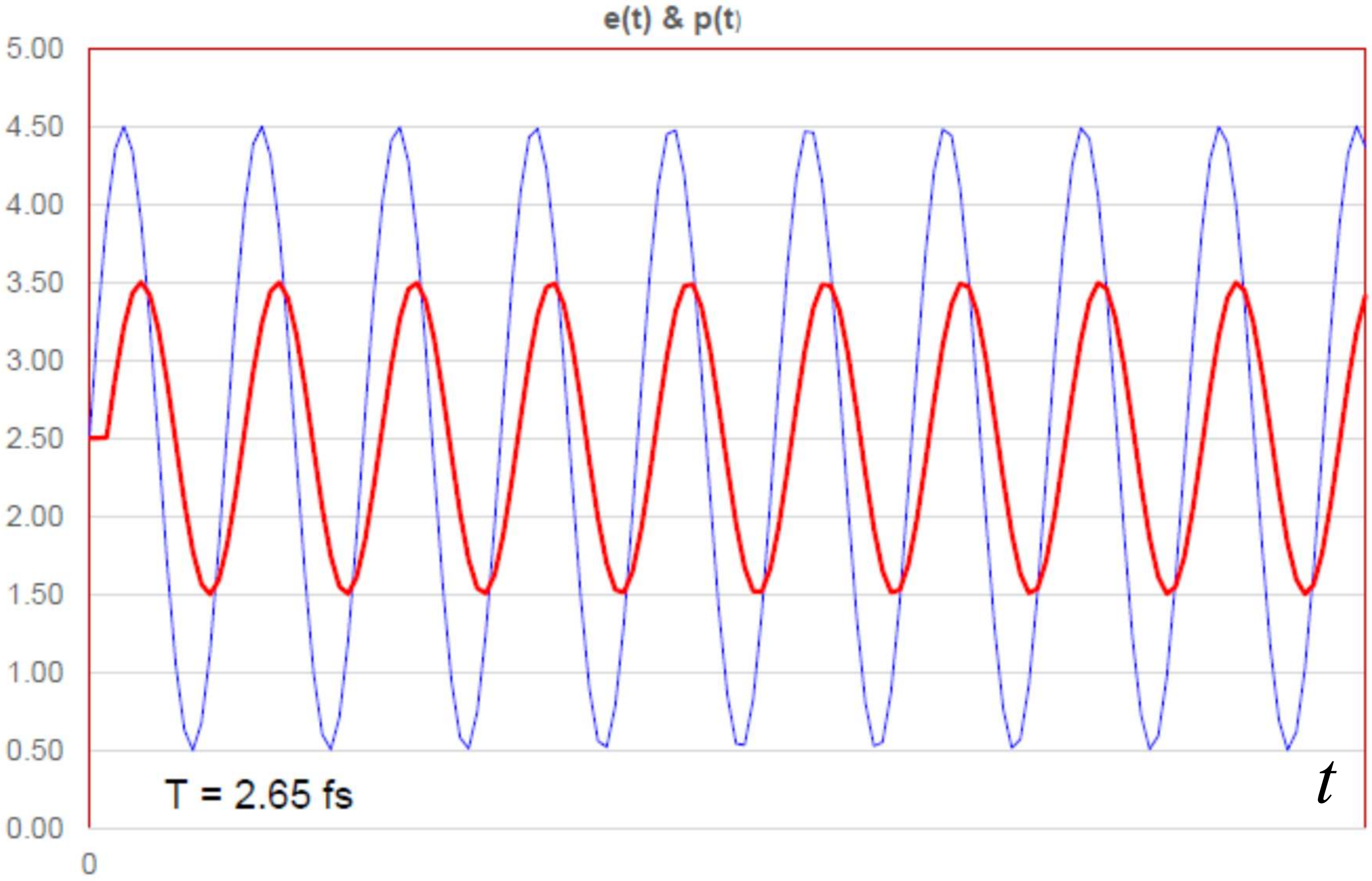
LHC

dV ~ 1 · 10^6 V/m

Dipole L ~ 16 cm

Csernai, L.P. [NAPLIFE]

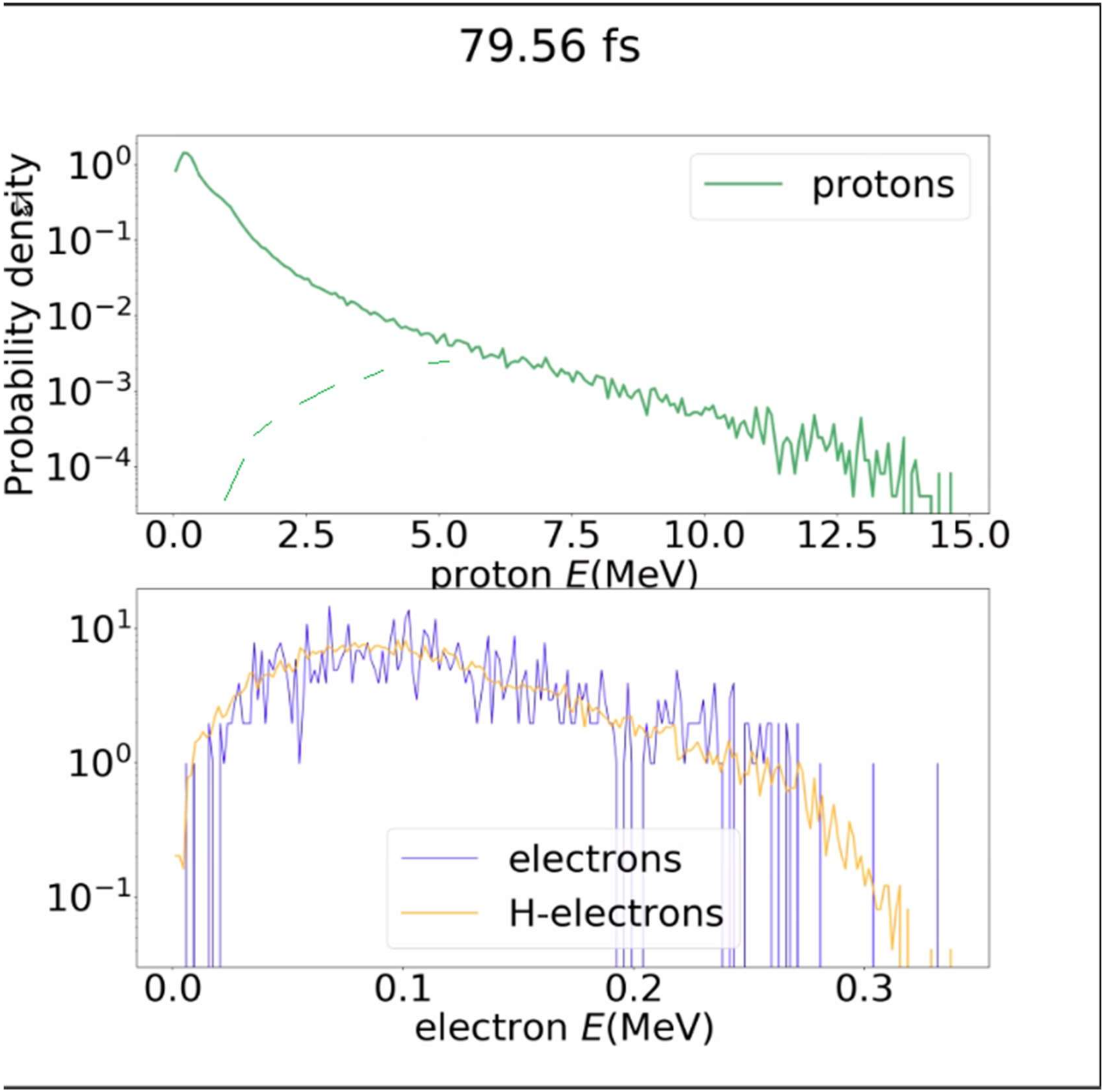
Laser wake field acceleration mechanism =>



BUT:
Proton
amplitudes
& speeds
are smaller.

Protons
follow
electrons by
phase delay!

Csernai, L.P. [NAPLIFE]



Number of
1-2 MeV
protons is
about 1-100
=>
small number
of Deuterium

Csernai, L.P. [NAPLIFE]

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 and evaluate if the rate that can be achieved this way is sufficient for massive energy production

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

Csernai, L.P. [NAPLIFE]

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

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

Thanks for your attention