High-energy Non-thermal Laser-induced Nano-fusion

Professzorok Batthyány Köre

attosecond

Academia Europaea

HUN REN Wigner

Energiapolitika 2000 Társulat

FIAS Frankfurt Institute for Advanced Studies

Consult Bergen

Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal

HUN-REN Magyar Kutatási Hálózat

NAPLIFE

Hungarian Academy of Sciences · 1825 ·

Forskningsrådet
The Research Council of Norway

Det Norske Videnskaps-Akademi

Universitas Osloensis MDCCCXI

Csernai László
University of Bergen, Norway

Nour Jalal Abdulameer, Márk Aladi, L. Balázs, Balázs Bánhelyi, Tamás S. Biró, Attila Bonyár, Alexandra Borók, Larissa Bravina, István Csarnovics, László Pál Csernai, Mária Csete A. Csik, Gábor Galbács, Chris Grayson, Tamás Csörgő, Olivér Fekete, L. Himics, Román Holomb, L. Juhász, Gábor Kasza, Judit Kámán, Miklós Kedves, Rebeka Kovács, S. Kökényesi, Norbert Kroó, Archana Kumari, Tomás Lednický, Péter József Lévai, Igor N. Mishustin, Dénes Molnár, Anton Motornenko, Ágnes Nagyné Szokol, István Papp, Petra Pál, Béla Ráczkevi, Péter Rácz, Johann Rafelski, István Rigó, Leonid M. Satarov, Horst Stöcker, Daniel D. Strottman, G. Szabó, Melinda Szalóki, Géza Szántó, András Szenes, Karolis Tamosiunas, Nóra Tarpataki, Bálint Ferenc Tóth, Emese Tóth, Dávid Vass, Miklós Veres, Shereen Zangana, Konstantin Zhukovsky, (NAPLIFE Collaboration) **~ 50 participants**

About half of participants supported in part by NKFIH, Budapest.

NAPLIFE: Three unique, new ideas

- Simultaneous ignition by monochromatic, linearly polarized laser light to avoid instabilities. Short pulse length is needed ➔ Only ELI-ALPS ! (regular nonthermal) [Patented]

- Using resonant nanorod antennas to increase and regulate light absorption (regular nonthermal) [Patented]

- Accelerating protons via LWFA & LWFC mechanisms in one direction, orthogonal to the two colliding laser beams to start nuclear reactions (regular **nonthermal**)

- Now: **(i)** Theory & ideas **(ii)** Validation status

Radiative electro-magnetic (EM) energy transfer

Thermal or mechanical ? Possible both ways:

- Thermal: Black body radiation → loss & Carnot efficiency → Entropy current. Most fusion energy schemes assume thermal processes ➔ loss!
- "Mechanical": Monochromatic conductors, Coaxial or Rectangular Wave guides, Lasers, Monochromatic (~~~) broadcast, near to 100% efficiency! (Directed radio (TV) broadcast possible to astronomical distances!)

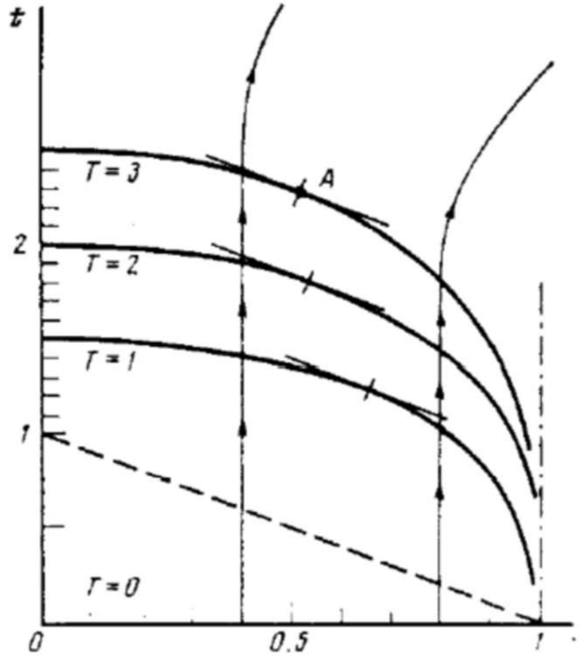
Goal: Laser Induced Fusion Energy

– Transfer laser energy to nuclear reactions with minimal loss →
- Non-thermal processes are preferred
- E.g. convert laser energy to fusion target nuclei (p, d, t, He3, etc.) with least possible loss

Most other fusion initiatives are thermal !

(i) Theory & ideas

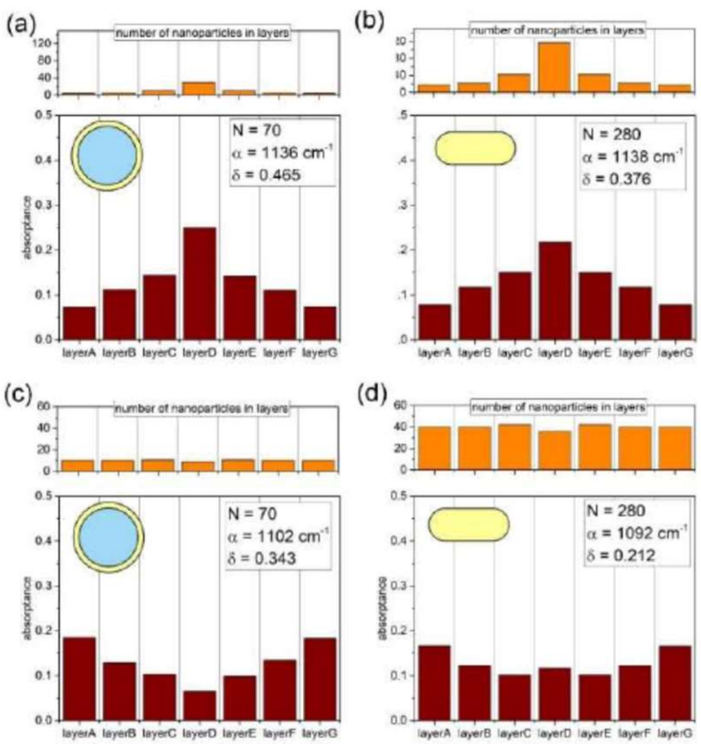
Simultaneous ignition – no instabilities



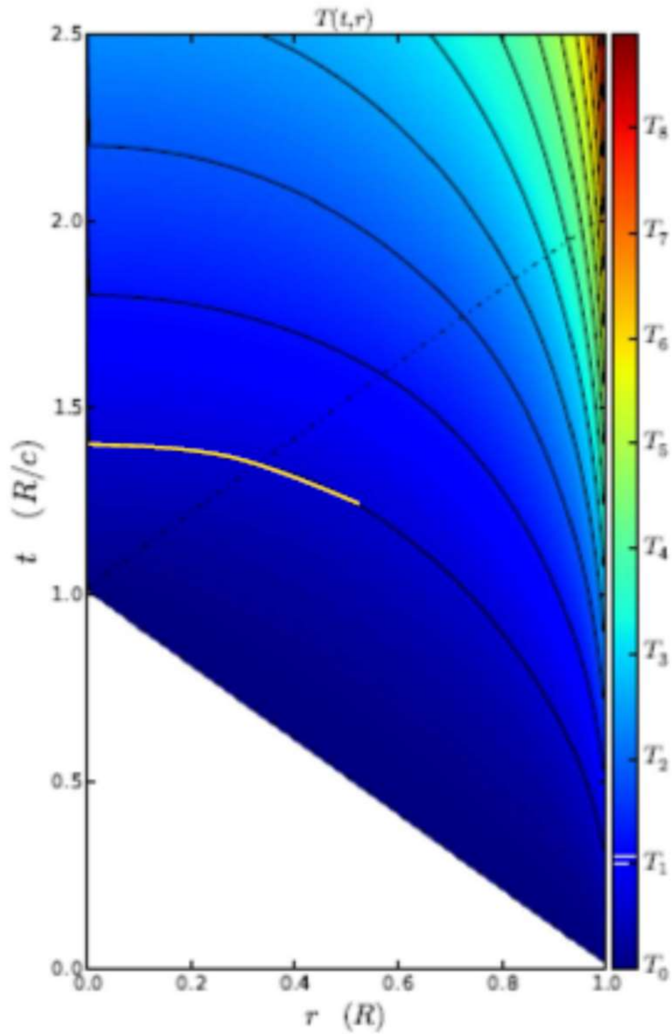
[L. P. Csernai, Zh. Eksp. Teor. Fiz. 92, 379-386 (**1987**) & Sov. Phys. JETP 65, 216-220 (1987)]

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

Л. П. Чернаи

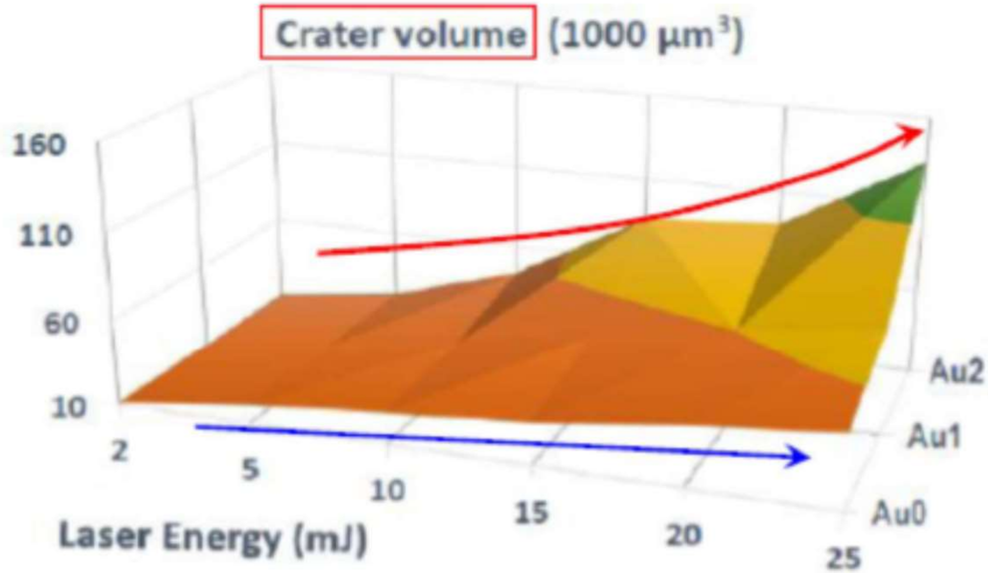


[N. Kroo (2017)
&
M. Csete et al., (2021)]



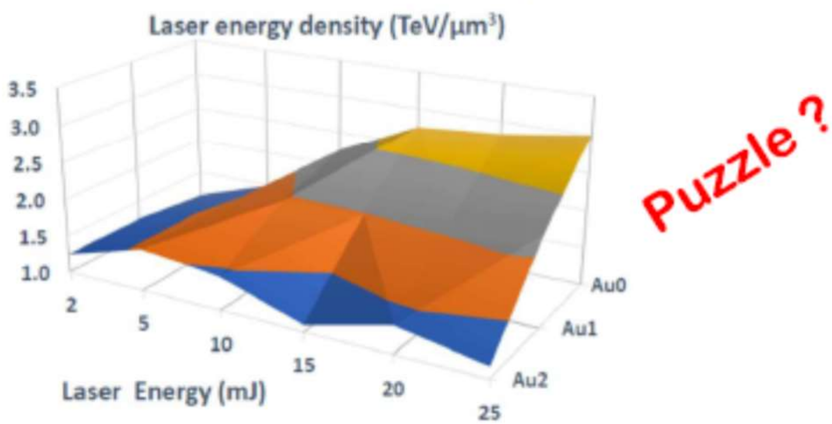
[L.P. Csernai & D.D. Strottman, Laser and Particle Beams 33, 279 (2015).]

Theoretical analyzis of Crater & Deuterium production



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

László P. Csernai, Igor N. Mishustin, Leonid M. Satarov, Horst Stöcker, Larissa Bravina, Mária Csete, Judit Kámán, Archana Kumari, Anton Motornenko, István Papp, Péter Rácz, Daniel D. Strottman, András Szenes, Ágnes Szokol, Dávid Vass, Miklós Veres, Tamás S. Biró, Norbert Kroó

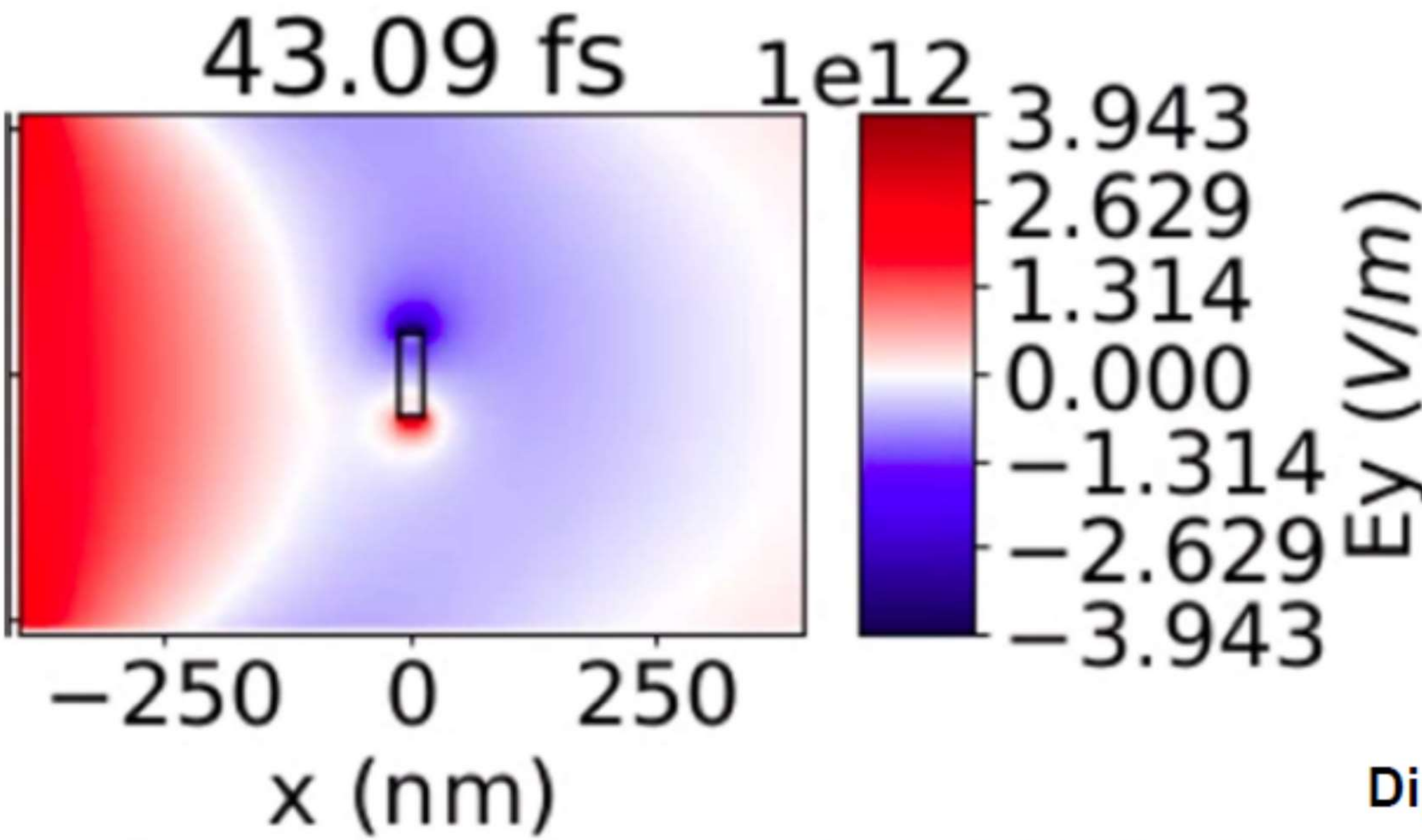


With nanorods V grows non-linearly. Increasing energy deposition. Several types of targets are considered: Au1 and Au2 with implanted nano-rod antennas, and Au0 without implantation. The mass concentrations of implanted particles in UDMA are 0.126% and 0.182% for targets Au1 and Au2, respectively.

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

Origin of this extra energy (?)

[LP. Csernai et al., Phys. Rev. E, 108(2) 025205 (2023)]

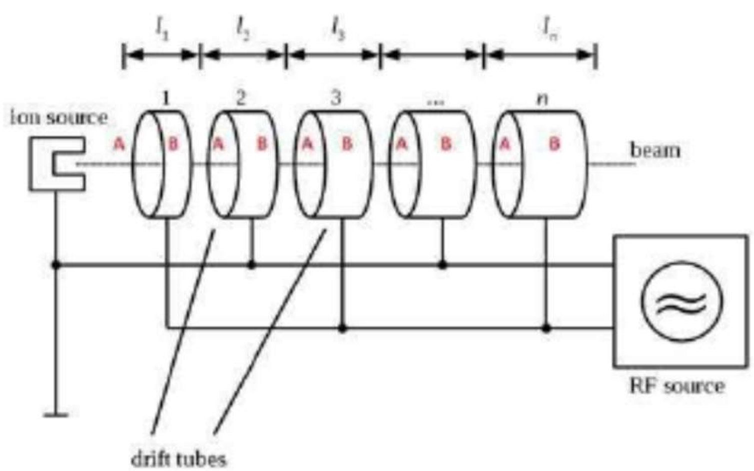


Neighboring protons are accelerated (100-200 nm)

Nuclear transmutation → Deuterium

Dipole L = 85 nm

I = 4 · 10^{17} W/cm^2 **dV ~ 8 · 10^{12} V/m**

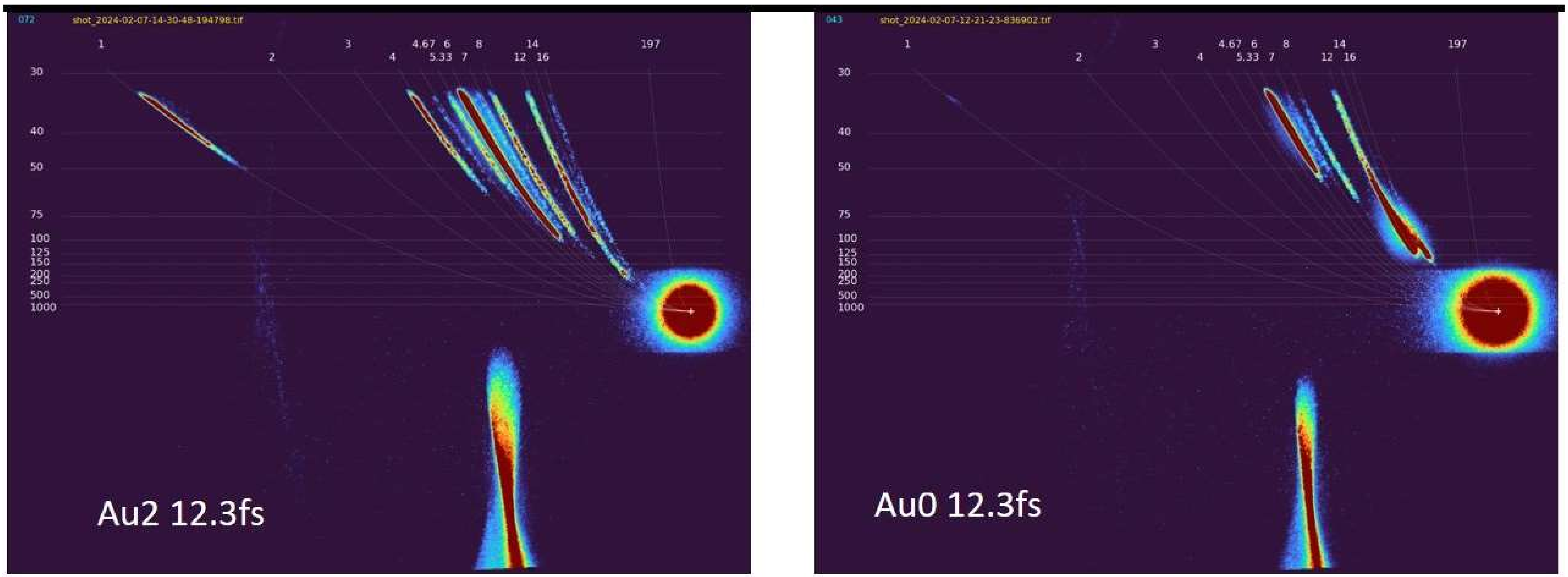


LHC **dV ~ 1 · 10^6 V/m**

Dipole L ~ 16 cm

[I. Papp et al. EPOCH PIC kinetic model]

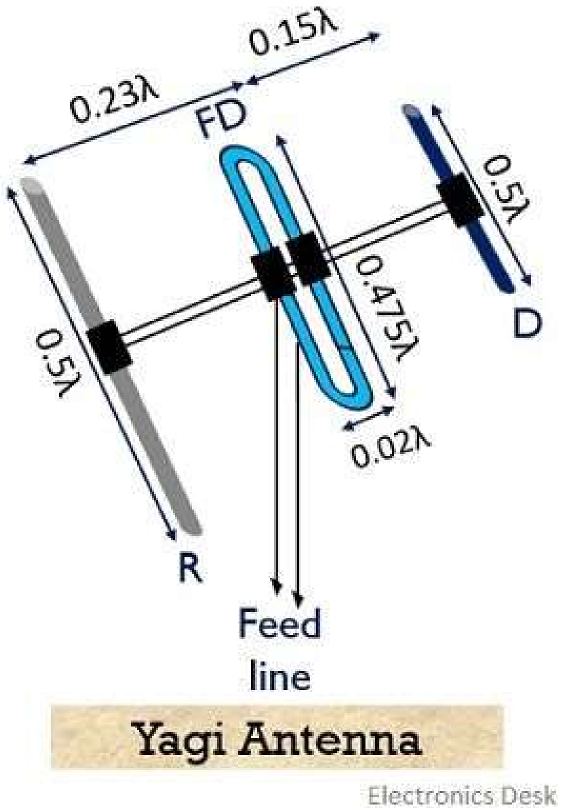
PROOF of Proton acceleration by nano-rod antennas (by Thompson Parabola)



With Au2 nano-antennas we observe accelerated, ~100 keV protons, while without none! [M. Kedves, M. Aladi et al., ELI-ALPS preliminary]

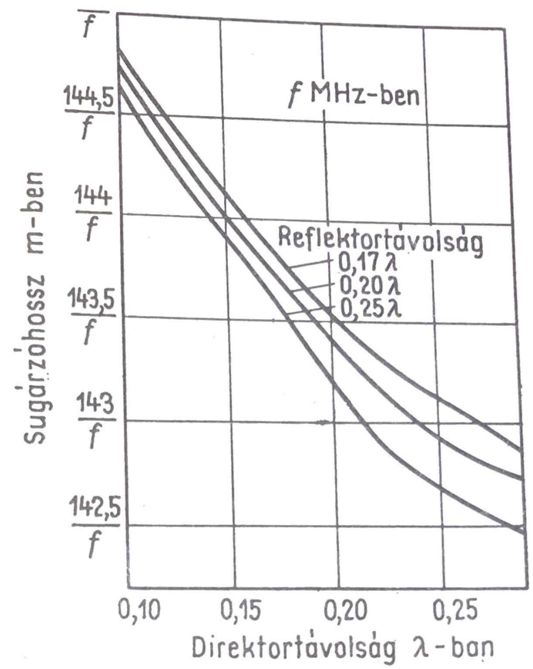
The Yagi-Uda antennas (in short Yagi-antennas) 1926

- The single thin wire resonant dipole antenna can receive EM broadcast even from weak signal and considerable noise. Then the received signal can be led to the receiver with a cable (e.g. coaxial or other type)
- **Yagi H.** and **Uda S.** increased the efficiency of these antennas in **1926** by adding director and reflector elements to the dipole.



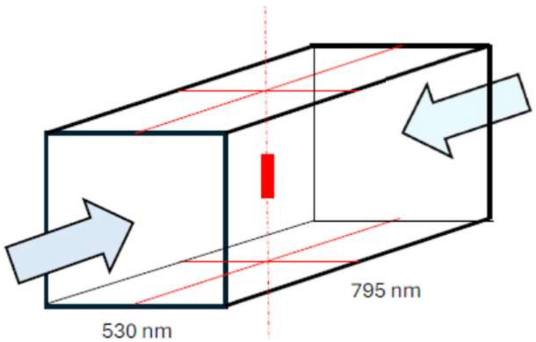
[K. Rotamer: *Antennenbuch*, Deutscher Militärverlag, Berlin (2017)]

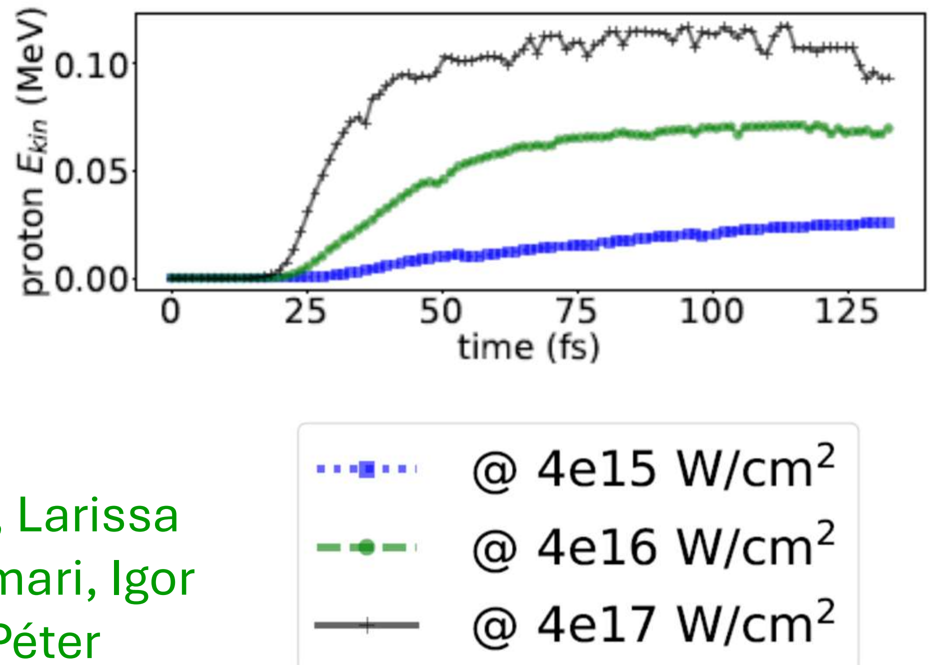
For us no feed line and no looped dipole are needed!



16.7. ábra. A háromelemes Yagi-antenna táplált elemének hossza a direktor és a reflektor távolságának függvényében

Laser-induced proton acceleration by a resonant nanoantenna





[arXiv:2306.13445v2, István Papp, Larissa Bravina, Mária Csete, Archana Kumari, Igor N. Mishustin, Anton Motornenko, Péter Rácz, Leonid M. Satarov, Horst Stöcker, András Szenes, Dávid Vass, Tamás S. Biró, László P. Csernai, Norbert Kroó]

See tomorrow !

Physics Letters A 396 (2021) 127245

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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]

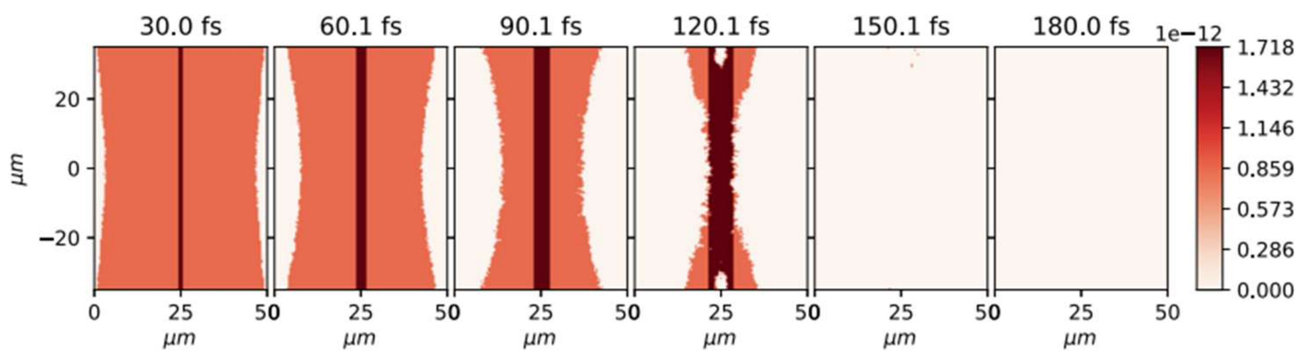


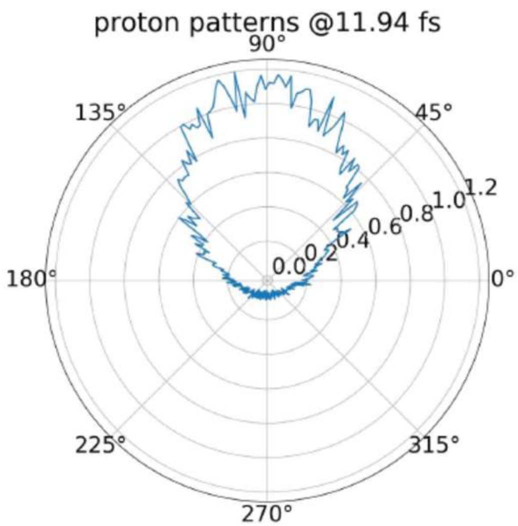
Fig. 2. (Color online) The ionization of the H atoms in a Laser Wake Field (LWF) wave due to the irradiation from both the $\pm x$-directions, on an initial target density of $n_H = 2.13 \cdot 10^{27}$ atoms/m^3 $= 2.13 \cdot 10^{21}$ atoms/cm^3. The energy of the H atoms in Joule [J] per marker particle is shown. The H atoms disappear as protons and electrons are created. Due to the initial momentum of the colliding H slabs, the target and projectile slabs interpenetrate each other and this leads to double energy density. Several time-steps are shown at 30 fs time difference.

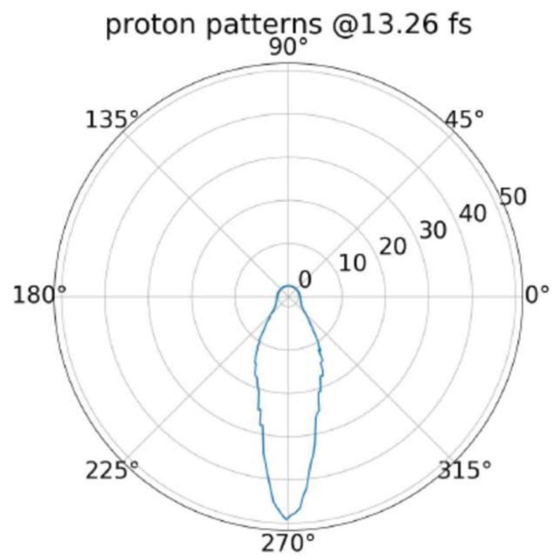
Laser Wake Field Collider

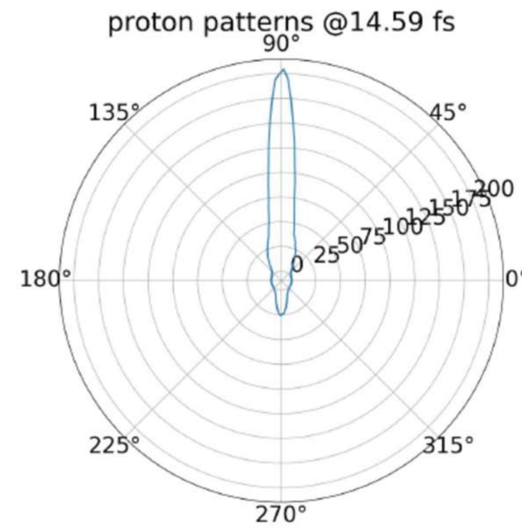
non-spherical, non-thermal, not "NIF-TYPE"

- Deuterons, (protons, 3He ions, ...) can be accelerated in **one direction** (not thermalized !!!).
- Two such colliding beams with full energy may lead to **higher energy nuclear fusion reactions**, with higher reaction rate.
- In the x (E-field) direction two slabs (/w evt gap) on top of each other accelerated towards each other with non-thermal speed. The materials of the two slabs may be different,
  e.g. Deuteron → ← He^3 or d → ← t

Proton emission from resonant targets







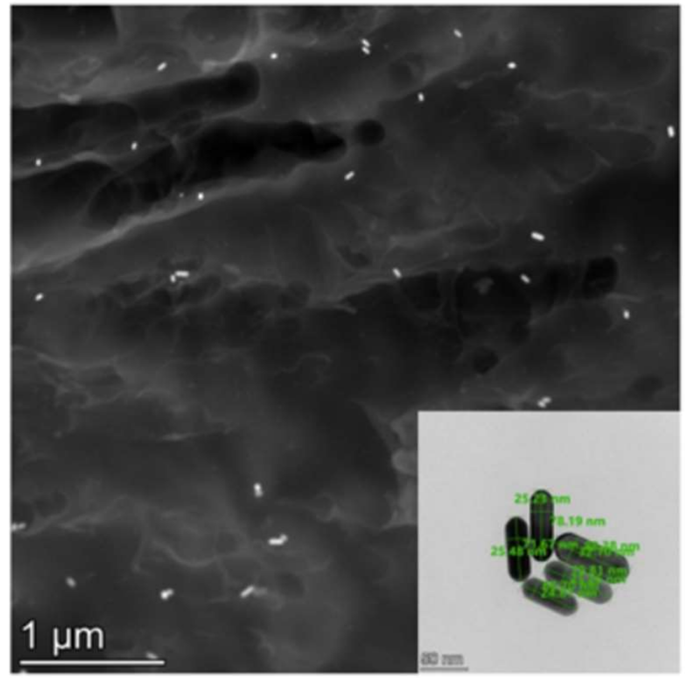
[arXiv:2309.05156v3]

Nuclear physics method to detect size, timespan and flow in nanoplasmonic fusion

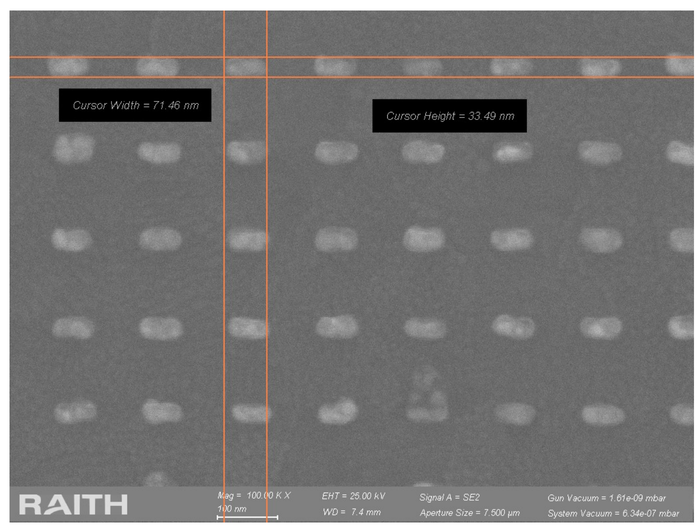
L.P. Csernai, T. Csörgő, I. Papp, M. Csete, András Szenes, Dávid Vass, T.S. Biró, N. Kroó

Resonant targets

Solid targets at room temperature → hard polymer: UDMA (470: H38, C23, O8, N2), TEGDMA, MMA - large hydrogen content (evt. deuterated) &
85x25 nm nanorod antennas (sort !)



1st random orientation, 85x25nm,
Au0,
Au1 (0.1m%),
Au2 (0.2m%)
[A. Bonyár et al., (BME)]



2nd directed & ordered [**in progress**]
[Zs. Márton, J. Budai, M. Csete et al., ELI-ALPS]

Long Yagi antennas with many directors

Nano-wire rods can also be used for good absorption

Length $\approx 10\lambda = \mathbf{\mathit{5\text{-}6\ \mu m}}$

Transverse size

$\approx 0.4\text{-}0.5\lambda = \mathbf{\mathit{0.01\ \mu m}}$

Butterfly ⇔ increased Band width

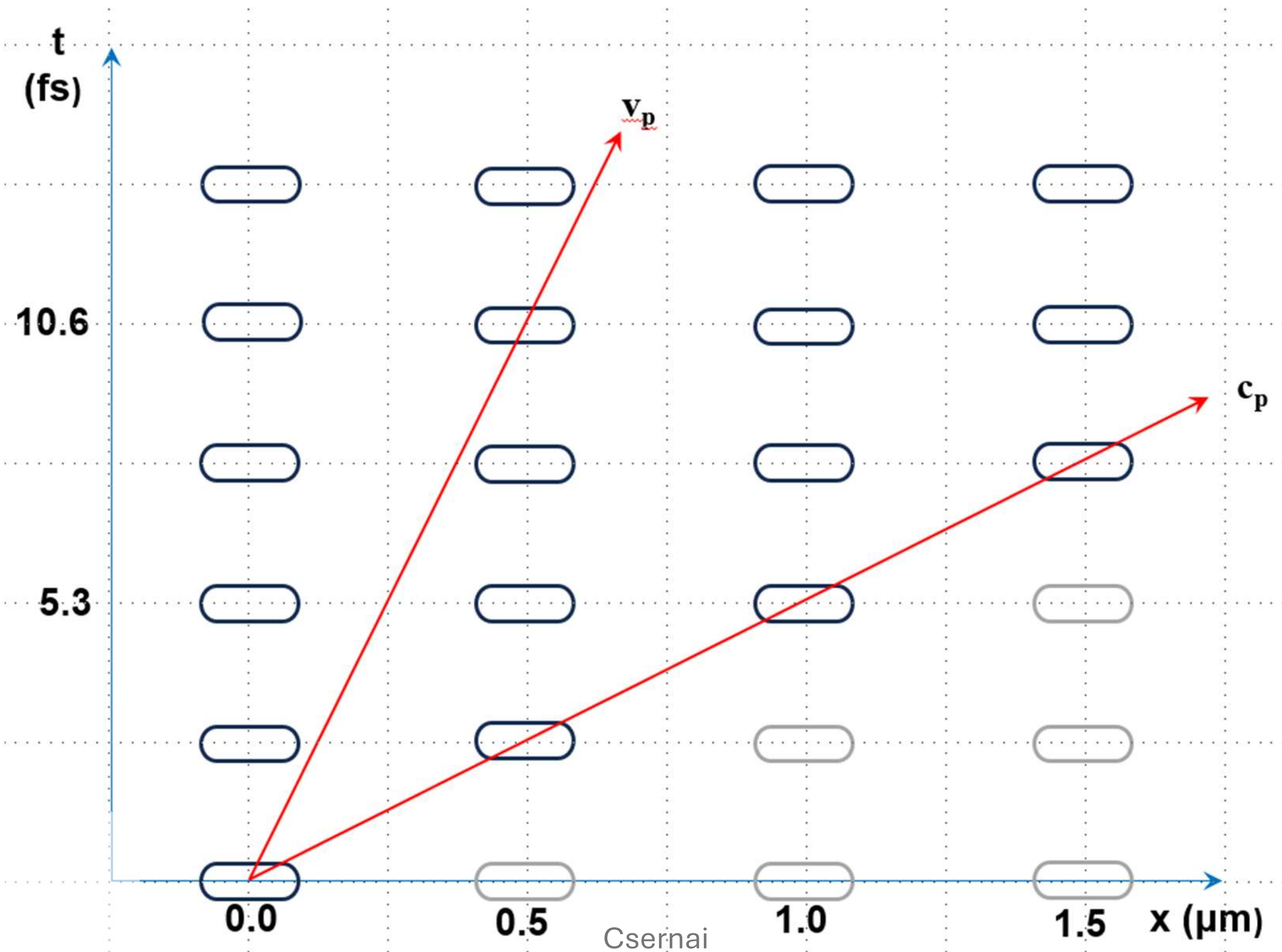
Csernai

Stacked Yagi antennas ~ Nanowire arrays

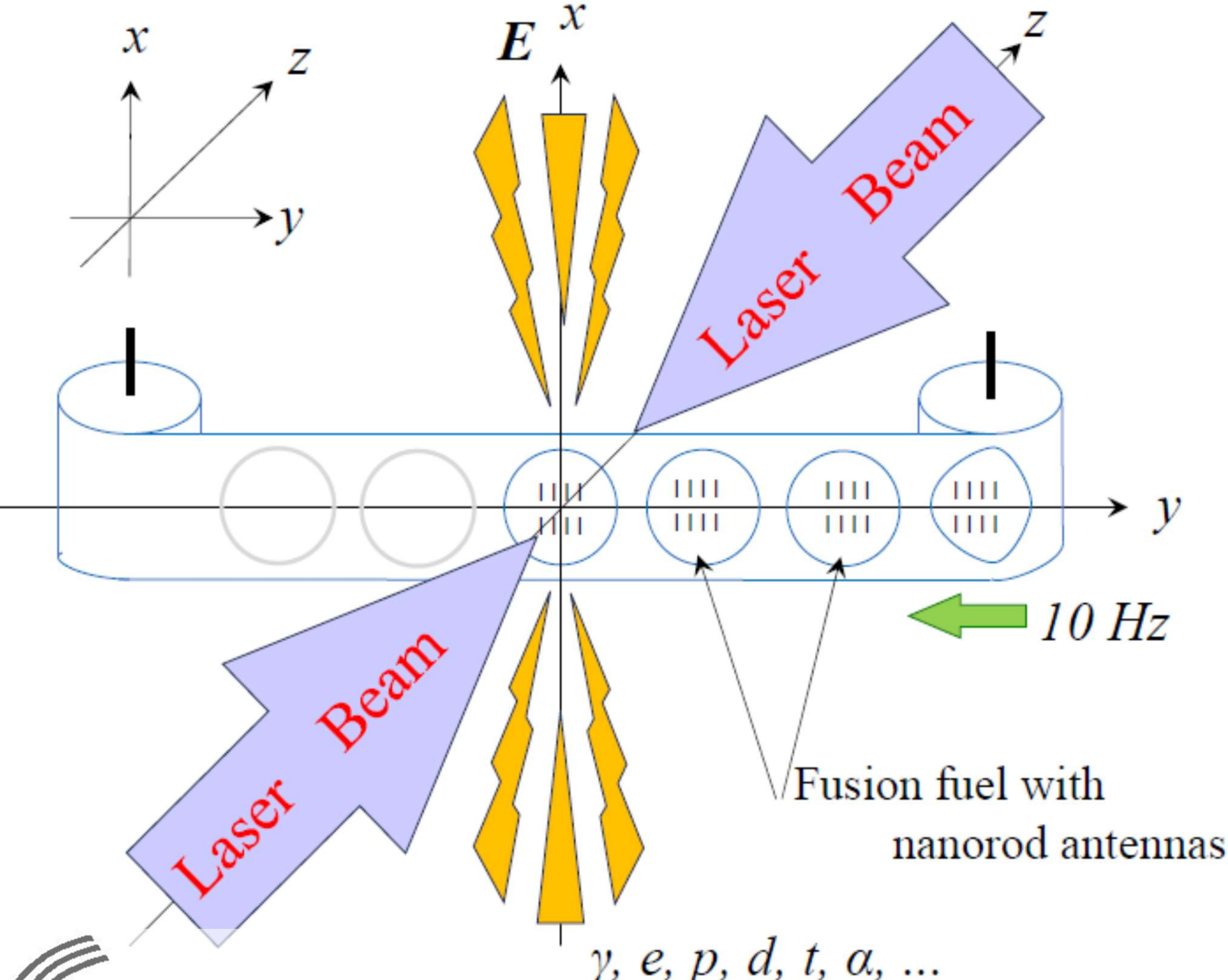
- We do not need “FEED Line”,
- We want to **accelerate protons or deuterons,**
- In the direction of the dipoles
- With two-sided laser irradiation

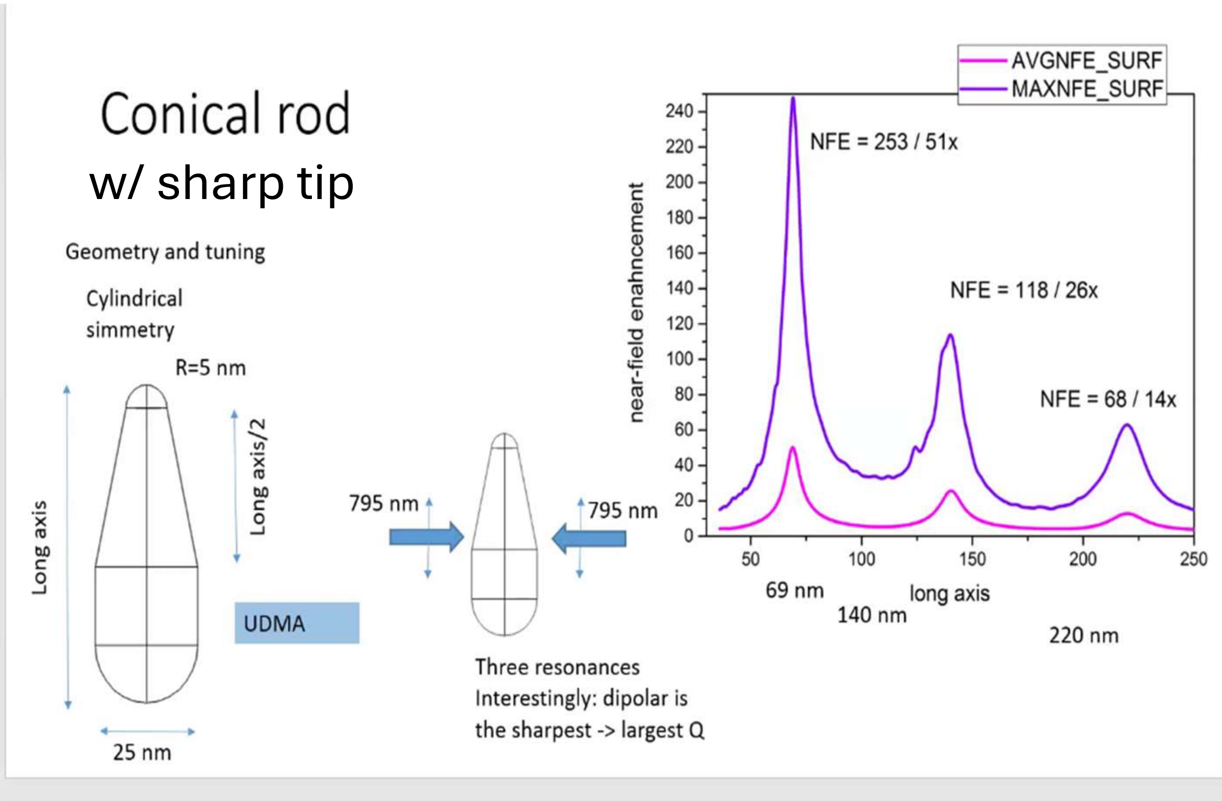
Distance between Yagi-type antenna array columns

Director distance should be such that the protons/deuterons are reaching the next array when that is in the phase, which accelerates it further.



ıdustrial
;etup





p acceleration in one direction

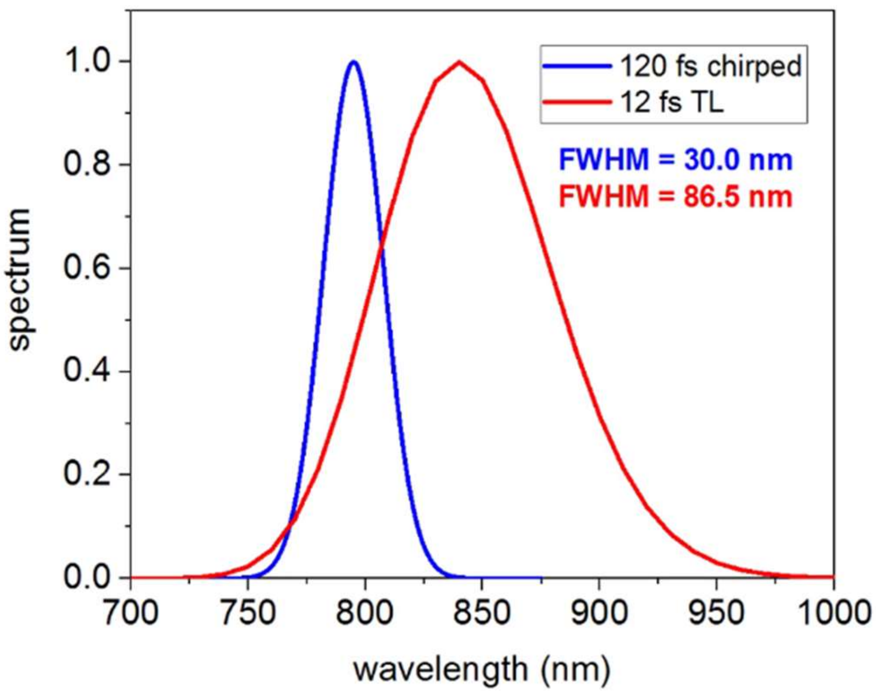
Expectation: protons can leave the asymmetric nano-rod antenna more at the sharp edge (like in case of lightening rods).

This is similar to directed laser beam radiation where at one end of the resonating lasing body there is a half reflecting mirror, while at the other end there isa fully reflecting one.

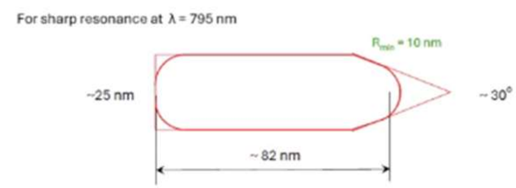
[J. Budai, Zs. Márton, M. Csete et al., 2024]

- The prime resonance of the asymmetric nanorod antenna is sharp, well separated from the much weaker higher harmonics.
- This feature enables us to generate correlated and aligned, ***non-thermal*** proton beams!
- Thus, in all steps of ignition process we can avoid losses arising from thermalization

Bandwidth of short pulses

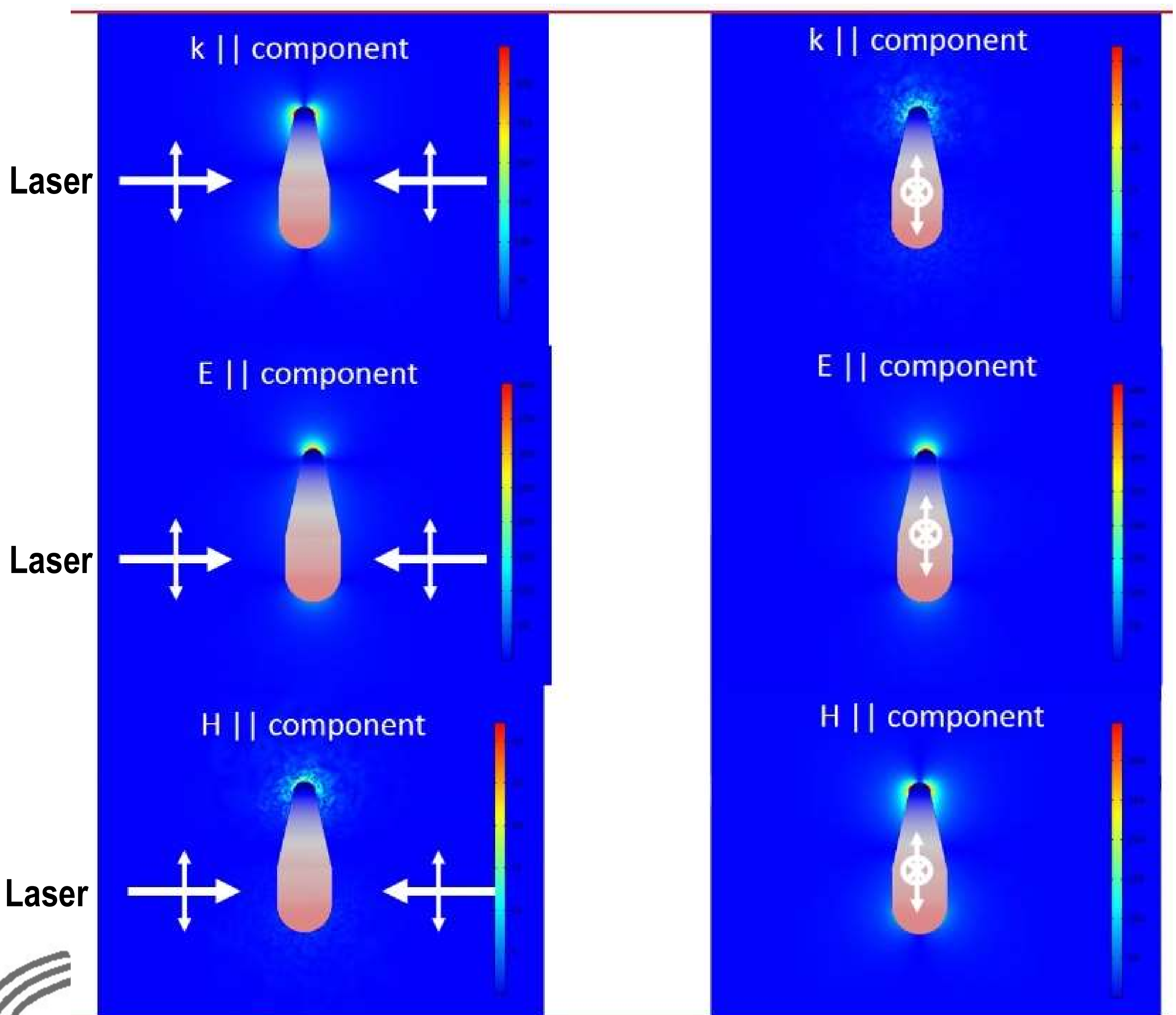


Idea of conical rods



Resonance response bandwidth depends on the length of irradiation pulse
[M. Csete, A. Szenes, et al. 2024]

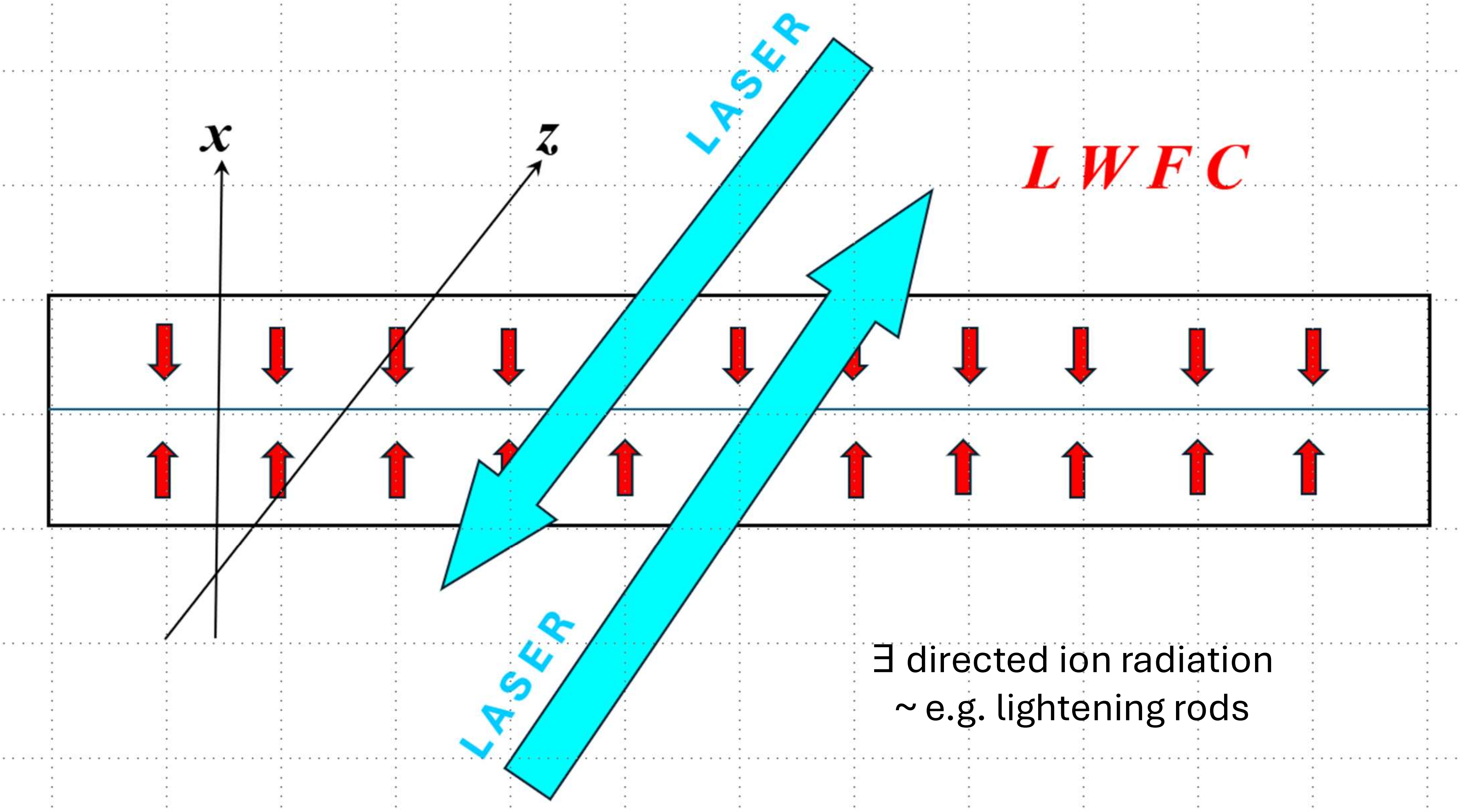
EM Fields around nano-antenna with sharp tip



Laser from top & bottom

Electric field (E) at sharp tip is extreme high (COMSOL) [A.Szenes, M.Csete et al.] ➔

Large proton flux is **expected** in EPOCH PIC kinetic model with sharply directed and near monochromatic emission to one direction!
Non-thermal



- Laser beam from $\pm z$ direction
- Nanorod antennas pointing to $\pm x$ direction
- Flat fusion fuel target is in the $[x - y]$ plane

(ii) Validation status

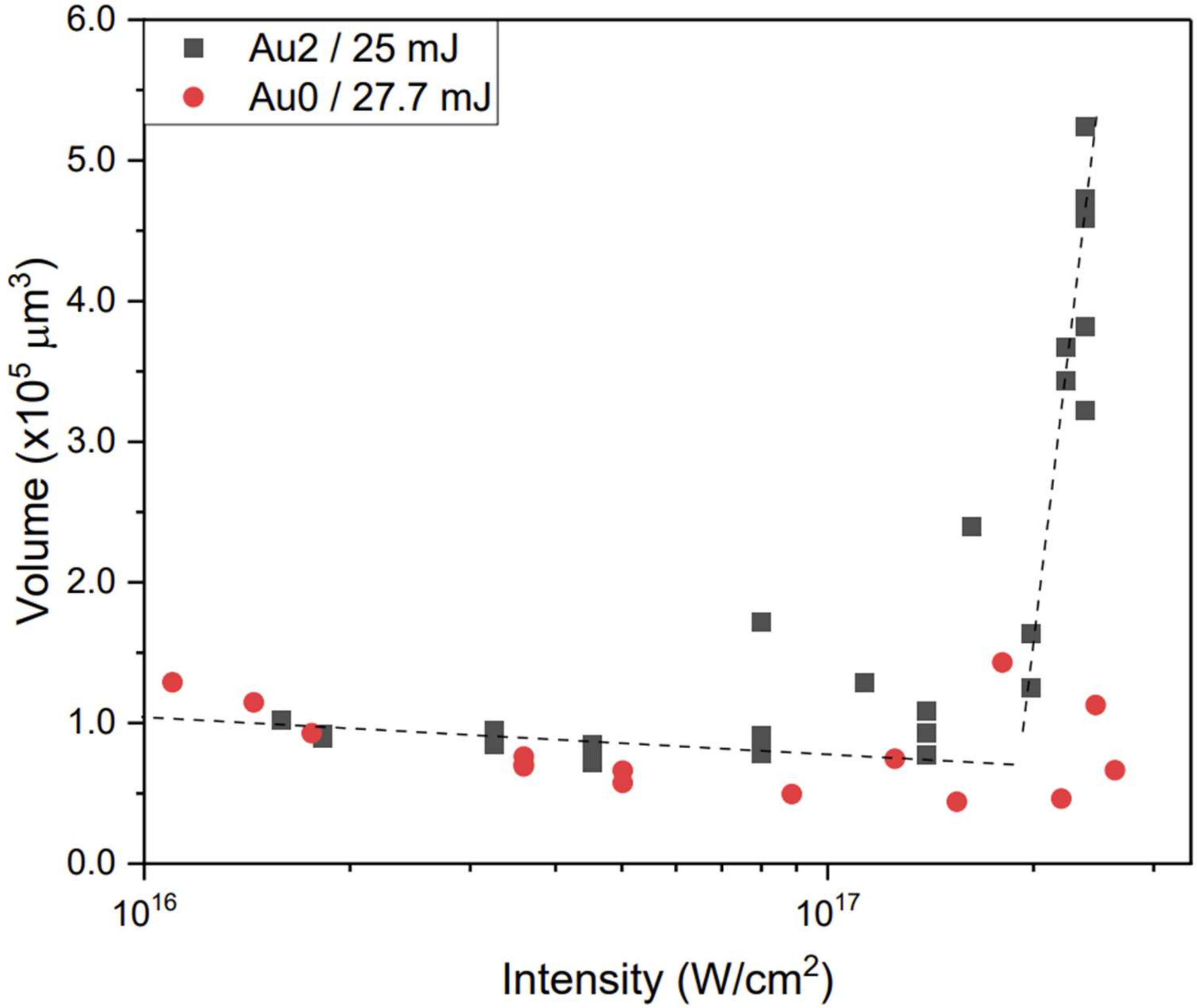
- Targets, Polymers, UDMA, TEGDMA, MMA, Deuterated MMA,
  resonant nano-rods random oriented and placed [BME, U. Debrecen]
  ordered & aligned nanorods [ELI – ALPS], directed nanorods [...]

- Laser irradiation
  one sided irradiation up to now,
  Wigner RCP Budapest, 30 mJ Ti:Sa Hydra I= ~ 2 10^{17} W/cm^2
  ELI-ALPS Szeged, 30 mJ SYLOS I= ~ 2 10^{19} W/cm^2

Crater Volume

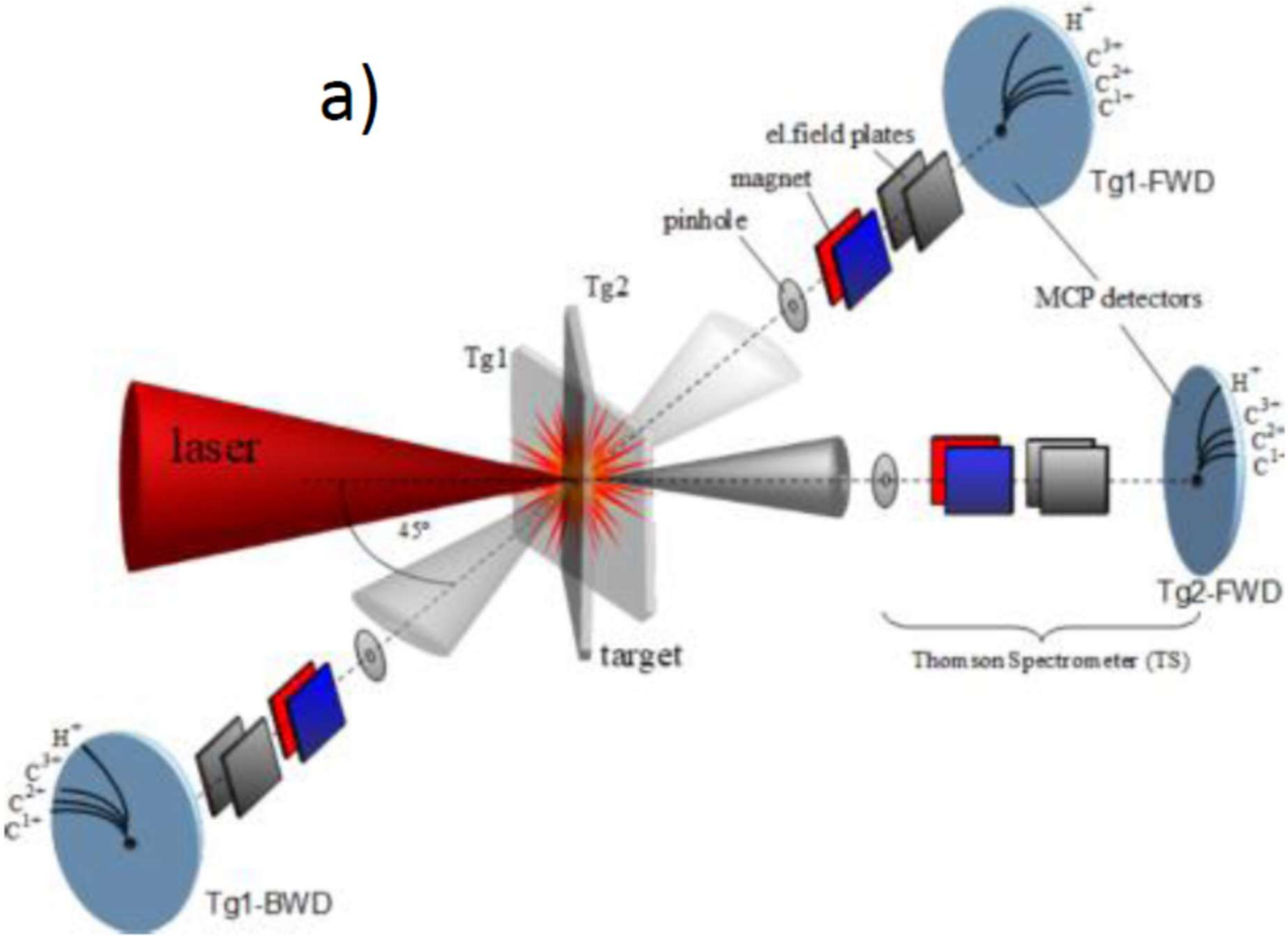
[Ágnes Nagyné Szokol et al., arxiv.org/pdf/2402.18138]

See next talk in detail !!
Q = ~ 6



Change of the crater volume with the amount of laser light reflected by the target (plasma mirror) for the laser irradiations of the undoped (Au0) and gold nanorod containing (**Au2**) targets

ELI-ALPS – High Intensity Tests 2024 –Thompson Parabola



[M. Kedves, M. Aladi et al., (2024) preliminary.]

[NAPLIFE –ELI-ALPS 2024] preliminary

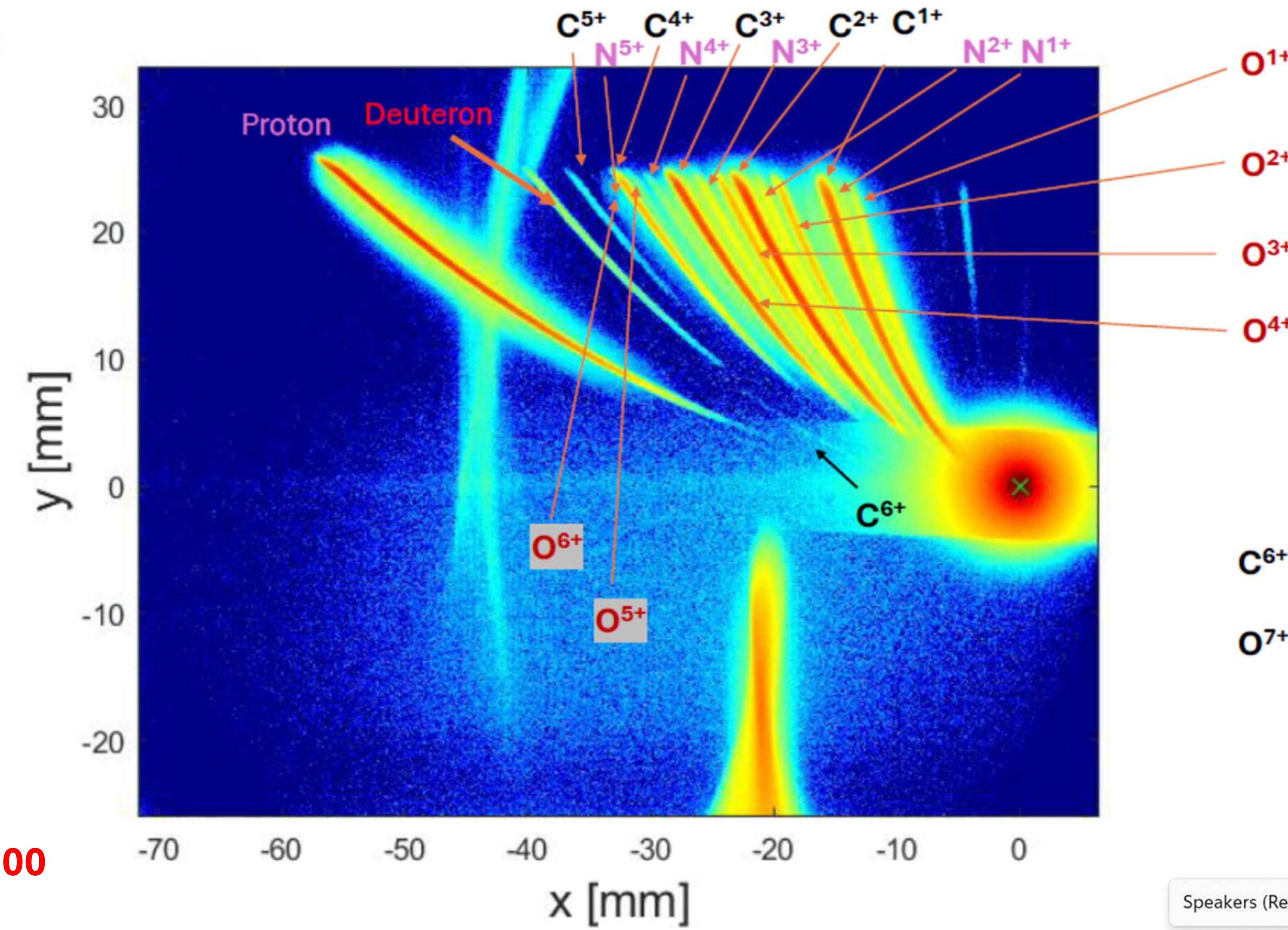
D100 sample

>100 spectra are averaged

UDMA (urethane dimethacrylate), $C_{23}H_{38}N_2O_8$

MMA (Methyl methacrylate), $C_5H_8O_2$

MMA-D (Methyl-d_3 methacrylate-d_5), $C_5D_8O_2$ **= D100**



C^{6+}: 490 eV

O^{7+}: 740 eV

[M. Kedves, M. Aladi et al., (2024) **preliminary**.]

See tomorrow !

CONCLUSIONS

- Plasmonic amplification is verified
- Proton acceleration is verified
- Nuclear transmutation reactions are achieved
- Formation of Deuteron nuclei is verified

contrary to the fact that

- Only 30 mJ laser pulse energy was used
- Only one-sided laser irradiation was available

Thanks for your attention