Minimizing losses in Laser-induced Nano-fusion

Int. Conf. on New Frontiers of Physics, Kolymbari, Crete,03.09.2024

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

UNIVERSITAS BERGENSIS

Batthyány

Professzorok Batthyány Köre

eli attosecond

Academia Europaea ~1988~

HUN REN

Wigner

Energiapolitika 2000 Társulat

FIAS Frankfurt Institute for Advanced Studies

CONSULT BERGEN

NAPLIFE

ΟΡΘΟΔΟΞΟΣ ΑΚΑΔΗΜΙΑ ΚΡΗΤΗΣ

NEMZETI KUTATÁSI, FEJLESZTÉSI ÉS INNOVÁCIÓS HIVATAL

HUN-REN Magyar Kutatási Hálózat

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~ 50 participants

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

https://csernai.no/naplife/

NAPLIFE

-

Select language / Válassz Nyelvet:

NAPLIFE Website at Wigner RCP / NAPLIFE Weboldal a Wigner FK-nál
Csernai Consult Bergen - / - László P. Csernai

NAPLIFE - Publications

https://csernai.no/naplife/publications/Publications-0000.html

[2024]

- Norbert Kroo, Nano-Plasmonic Laser Induced Fusion Energy **(NAPLIFE)**,
  Research Communities (Nature) Physics, Aug. 09, (2024).
  https://communities.springernature.com/c/physics

- N. Kroó, M. Aladi, M. Kedves, B. Ráczkevi, A. Kumari, P. Rácz, M. Veres, G. Galbács,
  L.P. Csernai, T.S. Biró, for the **NAPLIFE Collaboration**,
  Monitoring of nanoplasmonics-assisted deuterium production in a polymer seeded with
  resonant Au nanorods using in situ femtosecond laser induced breakdown spectroscopy,
  Scientific Reports (Nature) **14**, 18288 (2024)., (arXiv:2312.16723)
  https://doi.org/10.1038/s41598-024-69289-4

- 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, on behalf of **NAPLIFE Collaboration**,
  [Submitted 23 June, 2023 (v1), **last revised 21 April, 2024** (this version **v2**)]
  PIC simulations of laser-induced proton acceleration by resonant nanoantennas for fusion,
  *arXiv:*2306.13445v2 [physics.plasm-ph]
  https://doi.org/10.48550/arXiv.2402.2306.13445v2

- Dávid Vass, Emese Tóth, András Szenes, Balázs Bánhelyi, István Papp, Tamás Biró,
  László Pál Csernai, Norbert Kroó, Mária Csete, on behalf of **NAPLIFE Collaboration**,
  Plasmonic nanoprism distributions to promote enhanced and
  uniform energy deposition in passive and active targets,
  *arXiv:*2404.12716 [physics.optics]
  https://doi.org/10.48550/arXiv.2402.18132404.12716

- L.P. Csernai, T. Csörgő, I. Papp , K. Tamosiunas, M. Csete, A. Szenes,
  D. Vass, T.S. Biró, and N. Kroó, on behalf of **NAPLIFE Collaboration**,
  Femtoscopy for the NAno-Plasmonic Laser Inertial Fusion Experiments (NAPLIFE) Project,
  Universe , **10**, 161 (2024)
  https://doi.org/10.3390/universe10040161

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

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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!)

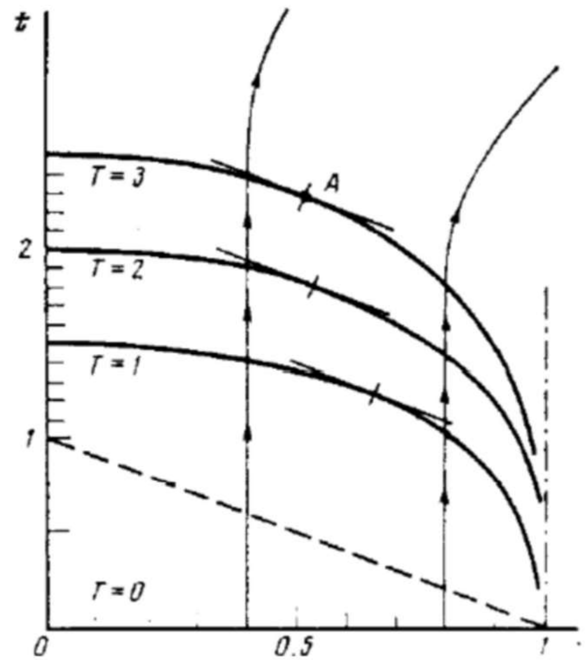
Goal: Laser Induced Fusion Energy

– 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

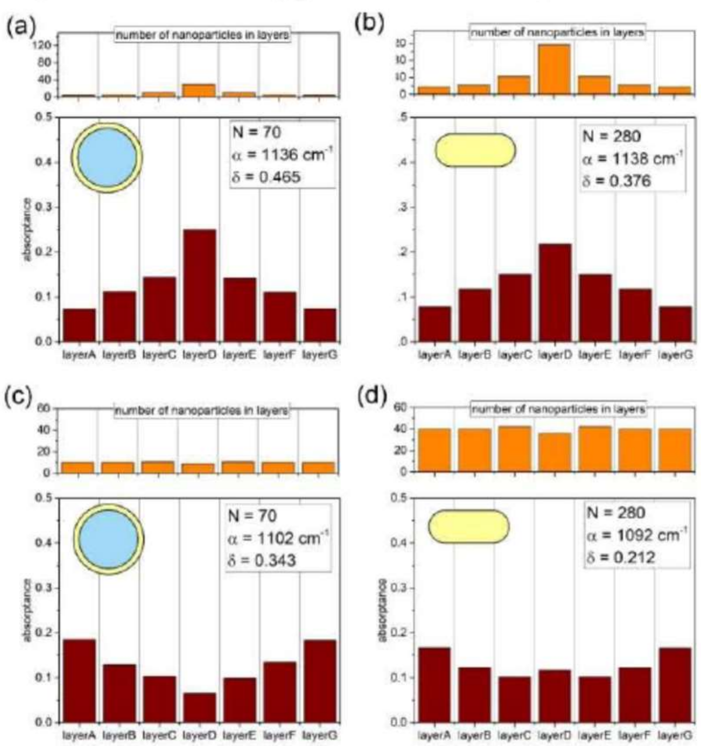
Simultaneous ignition – no



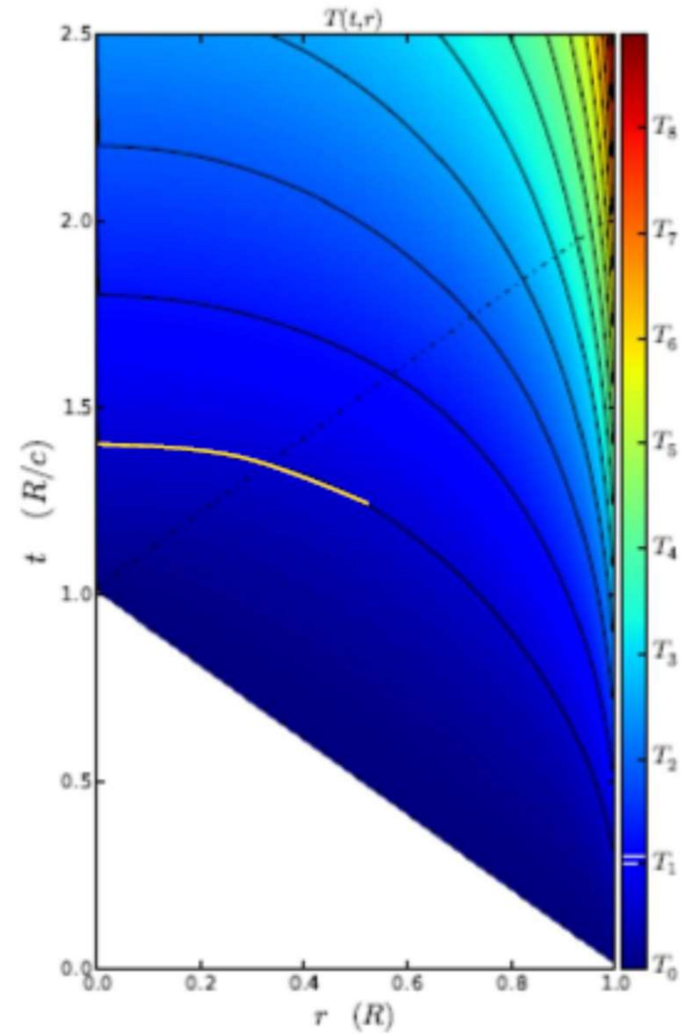
Л. П. Чернаи

[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**)]

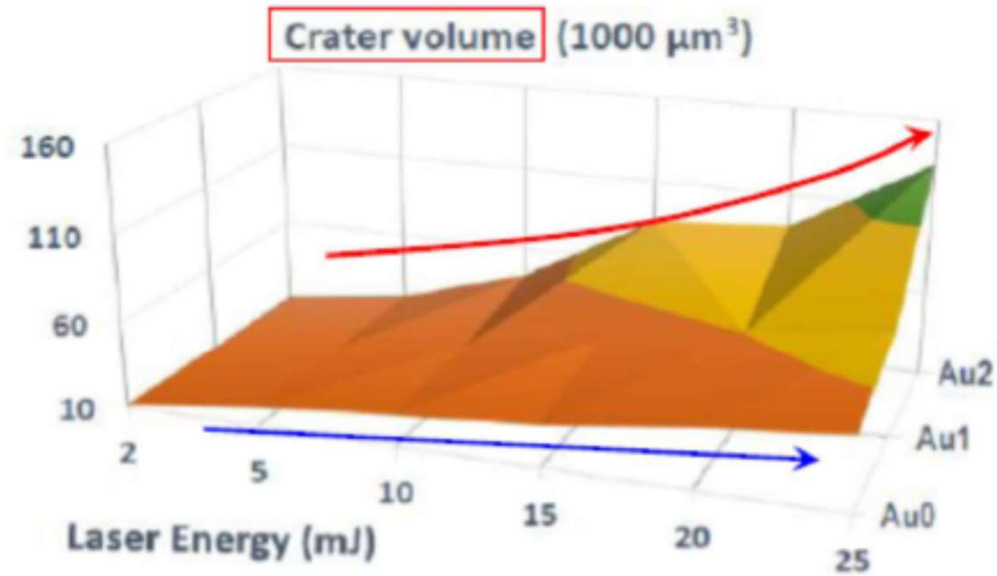


[N. Kroo (2017) & M. Csete et al., (2021)]



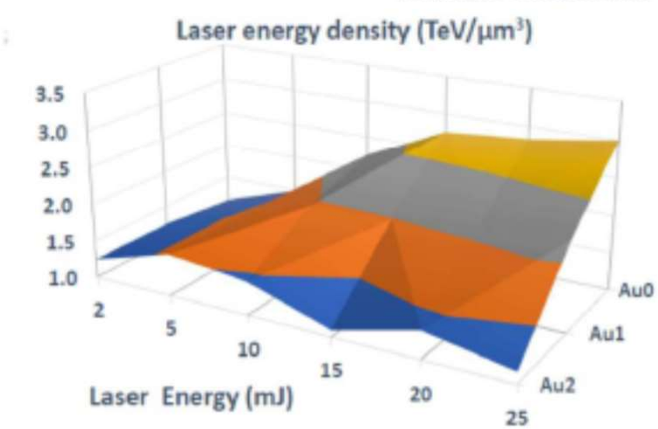
[L.P. Csernai & D.D. Strottman, Laser and Particle Beams 33, 279 (2015).]

Theoretical analyzis of Crater & Deuterium production



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

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



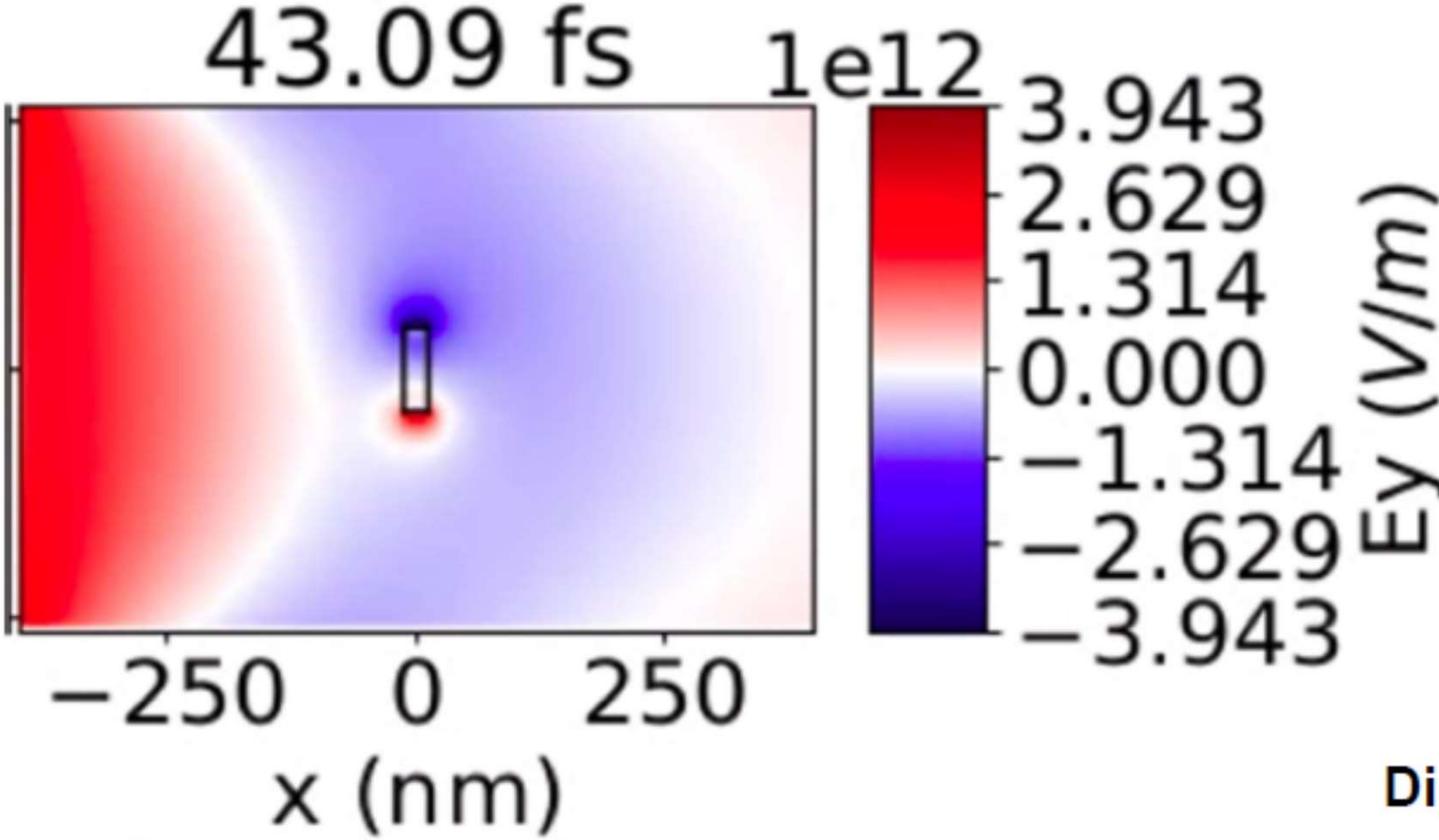
Puzzle ?

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 (?)

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

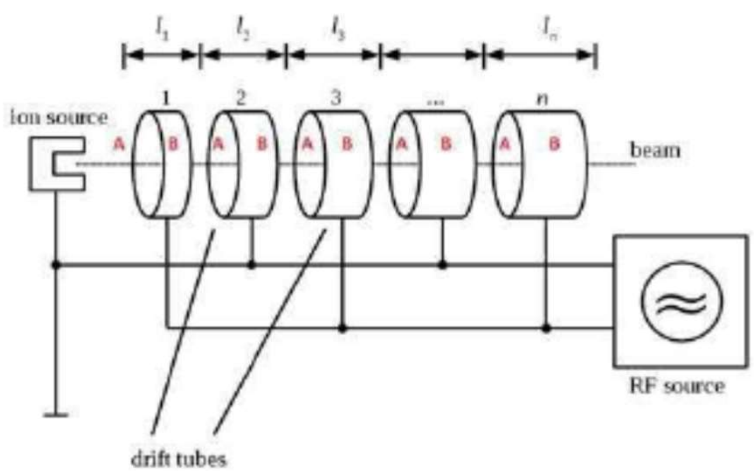


Neighboring protons are accelerated (100-200 nm)

Nuclear transmutation → Deuterium

Dipole L = 85 nm

I = 4 · 10^{17} W/cm² **dV ~ 8 · 10^{12} V/m**



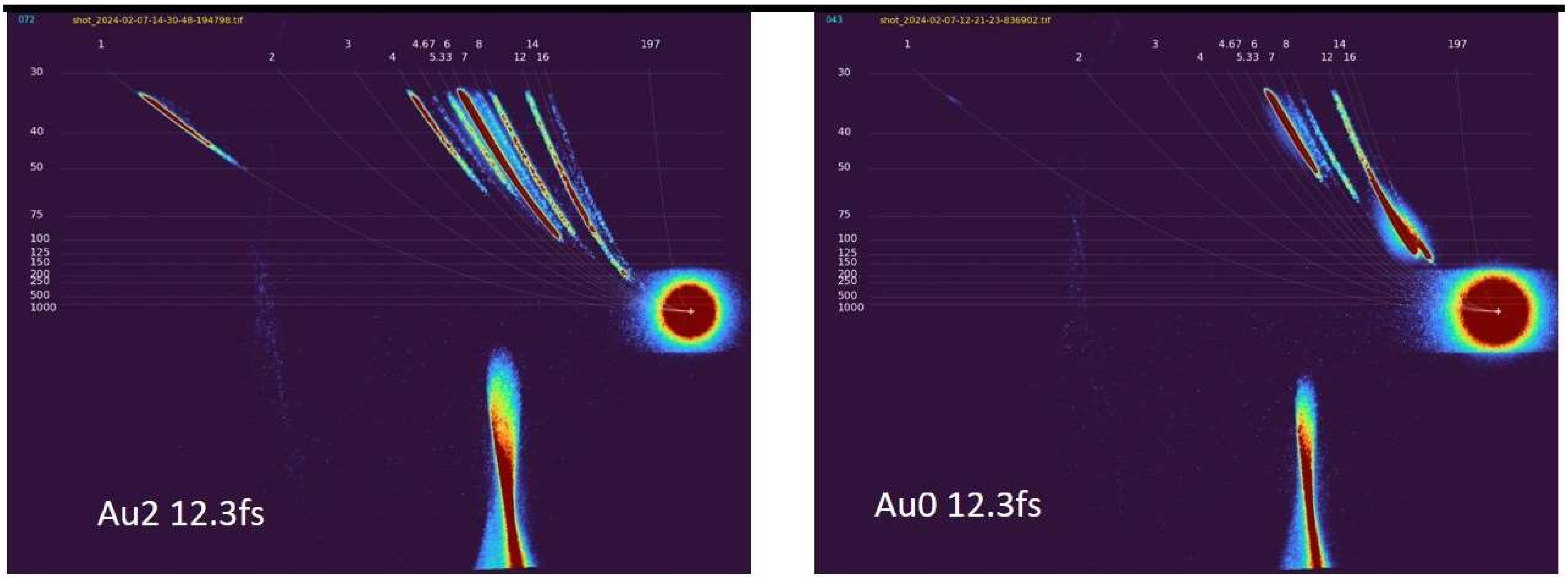
LHC **dV ~ 1 · 10^{6} V/m**

Dipole L ~ 16 cm

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

Csernai, L.P. [NAPLIFE]

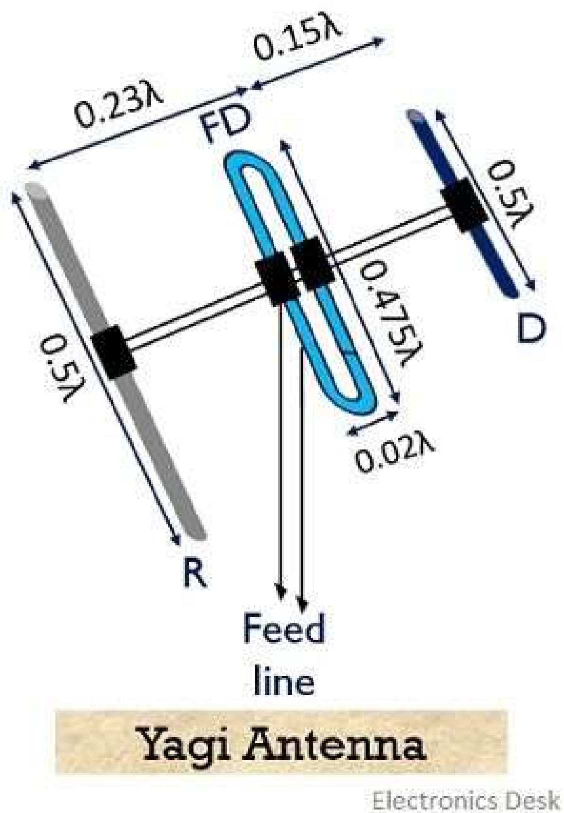
PROOF of Proton acceleration by nano-rod antennas (by Thompson Parabola)



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

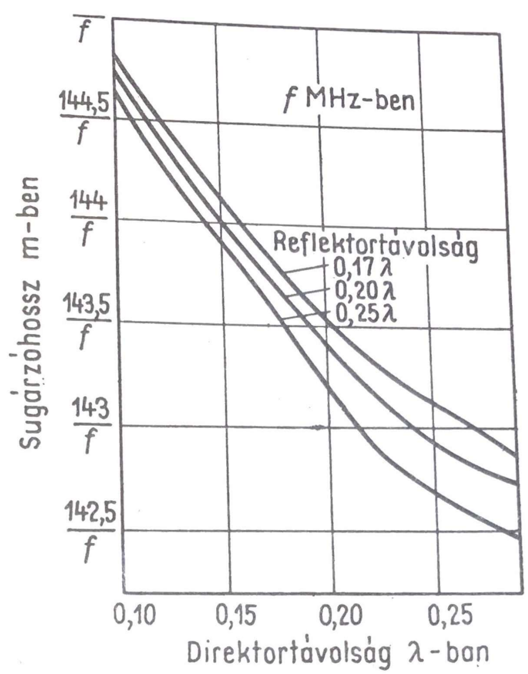
The Yagi-Uda antennas (in short Yagi-antennas) 1926

- 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.



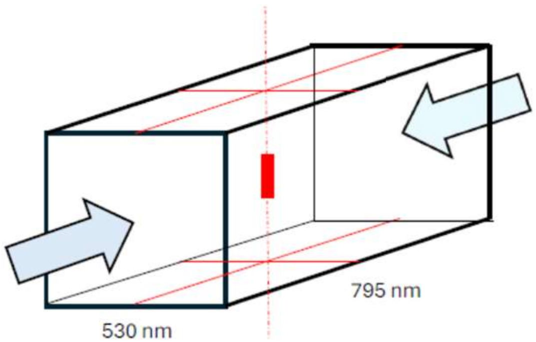
[K. Rotamer: *Antennenbuch*, Deutscher Militärverlag, Berlin (2017)]

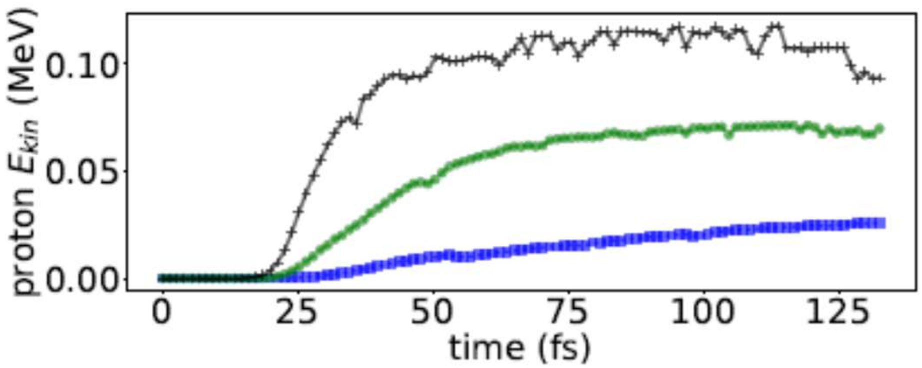
For us no feed line and no looped dipole are needed!

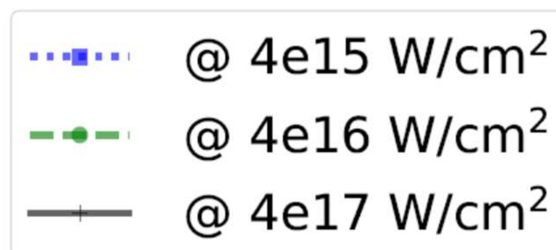


16.7. ábra. A háromelemes Yagi-antenna táplált elemének hossza a direktor és a reflektor távolságának függvényében

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]

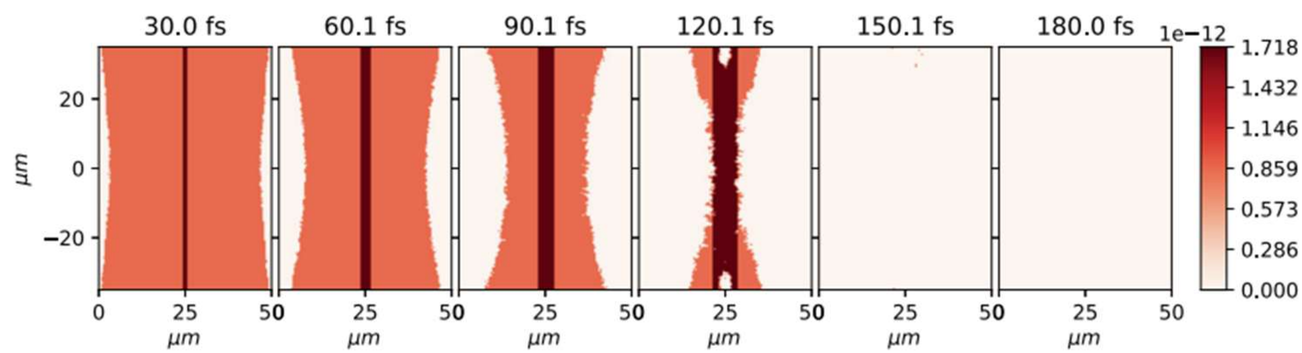


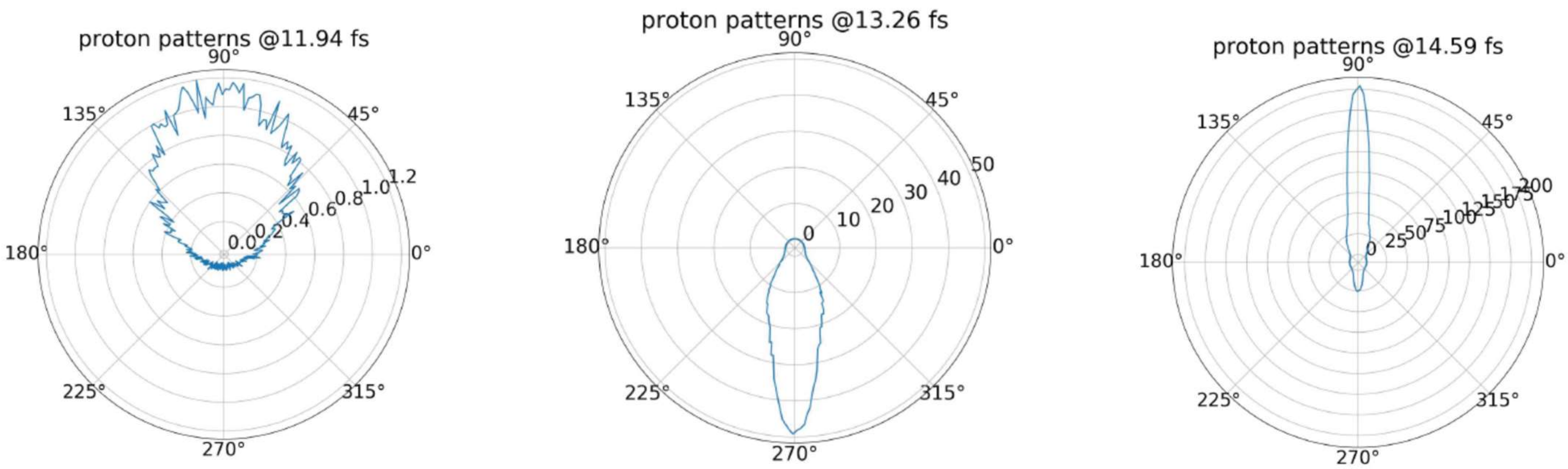
Fig. 2. (Color online) The ionization of the H atoms in a Laser Wake Field (LWF) wave due to the irradiation from both the $\pm x$-directions, on an initial target density of $n_H = 2.13 \cdot 10^{27}$ atoms/m$^3 = 2.13 \cdot 10^{21}$ atoms/cm^3. The energy of the H atoms in Joule [J] per marker particle 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

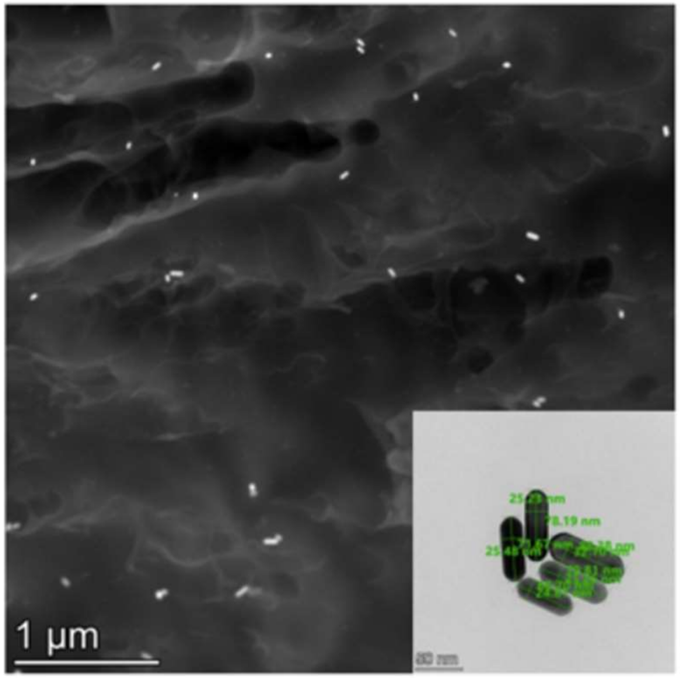
Proton emission from resonant targets



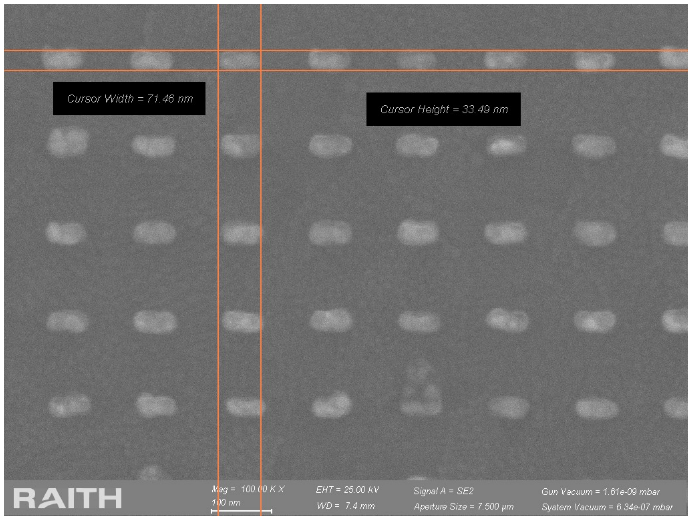
[L.P. Csernai, T. Csörgő, I. Papp , K. Tamosiunas, M. Csete, A. Szenes, D. Vass, T.S. Biró, and N. Kroó, on behalf of **NAPLIFE Collaboration**, Femtoscopy for the NAno-Plasmonic Laser Inertial Fusion Experiments (NAPLIFE) Project, *Universe* , **10**, 161 (2024) https://doi.org/10.3390/universe10040161]

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 ant



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 $\approx 10\,\lambda$ $= \boldsymbol{5\text{-}6\ \mu m}$

Transverse size

$\approx$ 0.4-0.5 λ $= \boldsymbol{0.01\ \mu m}$

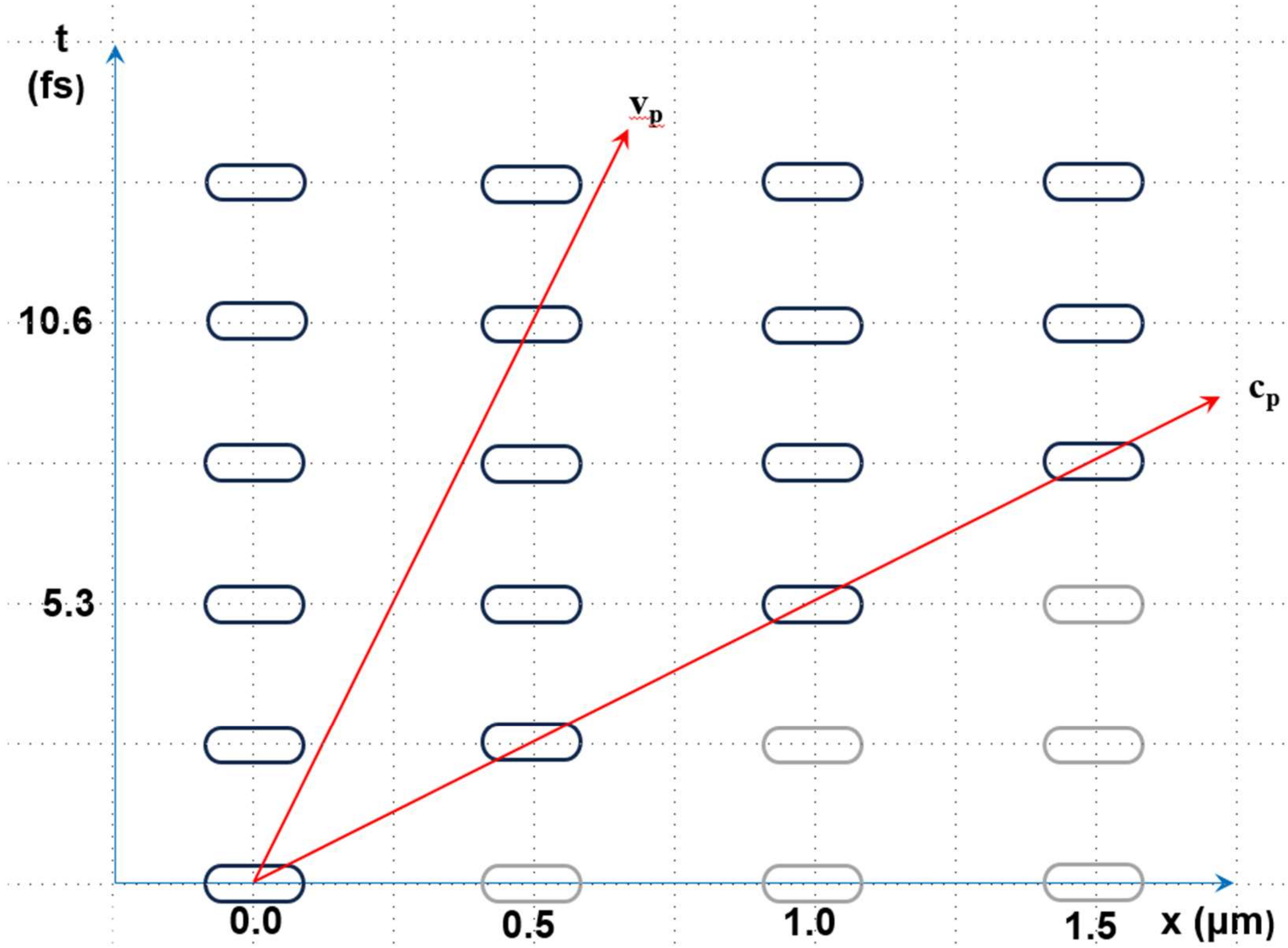
Butterfly ⇔ increased Band width

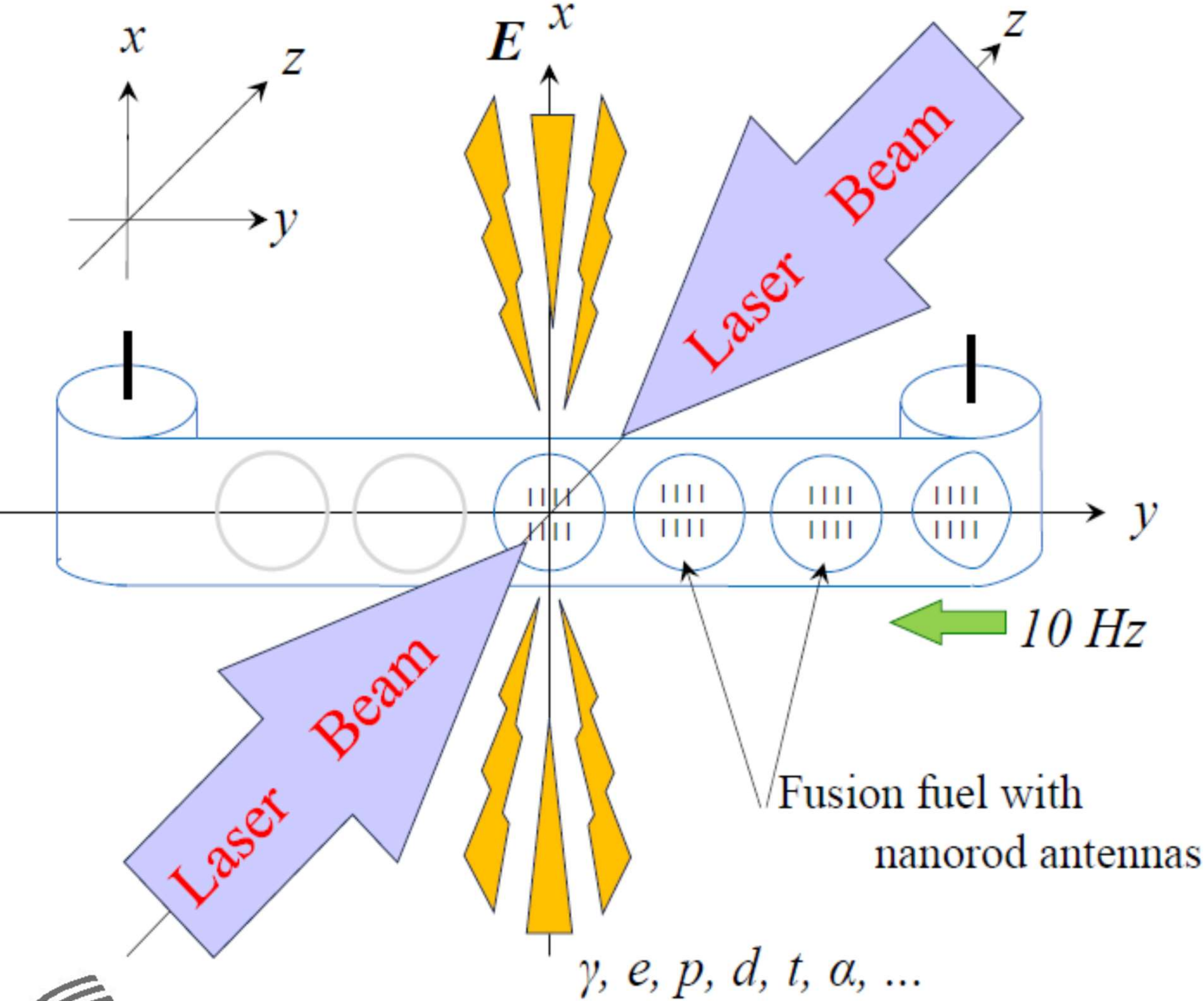
Stacked Yagi antennas ~ Nanowire arrays

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

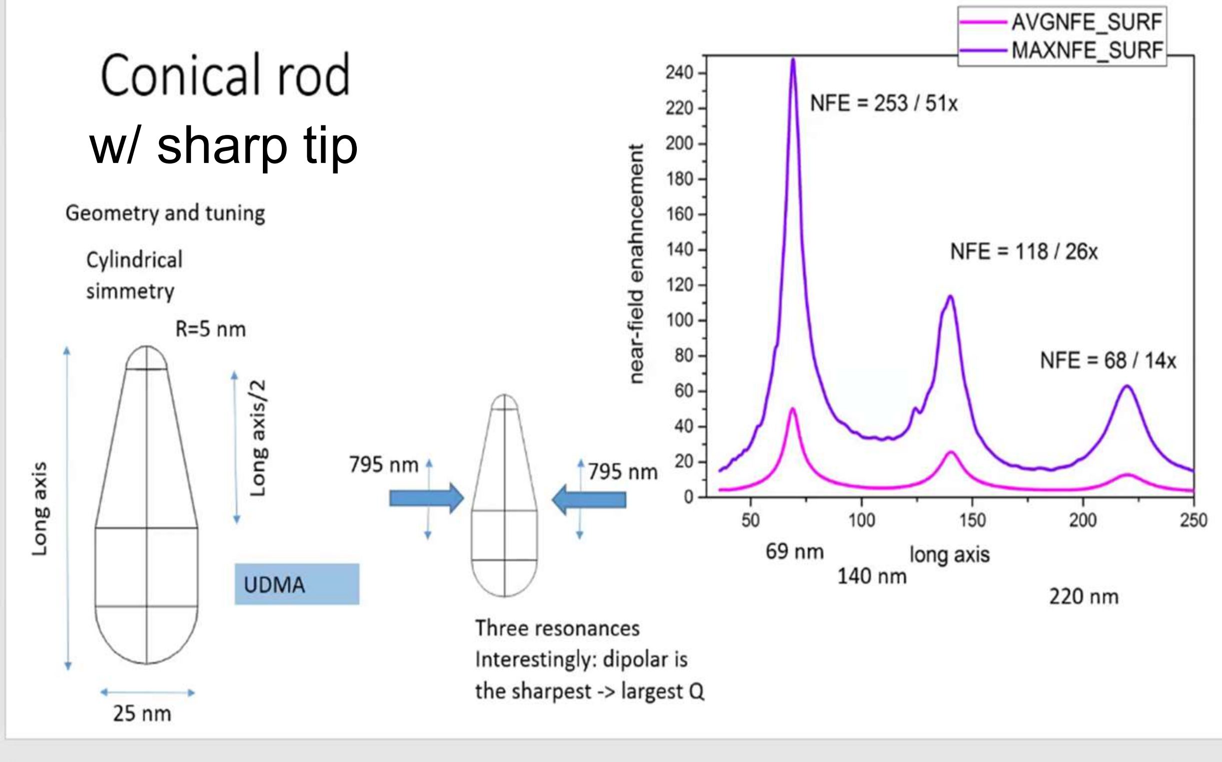
Distance between Yagi-type antenna array columns

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





Industrial setup



p acceleration in one direction

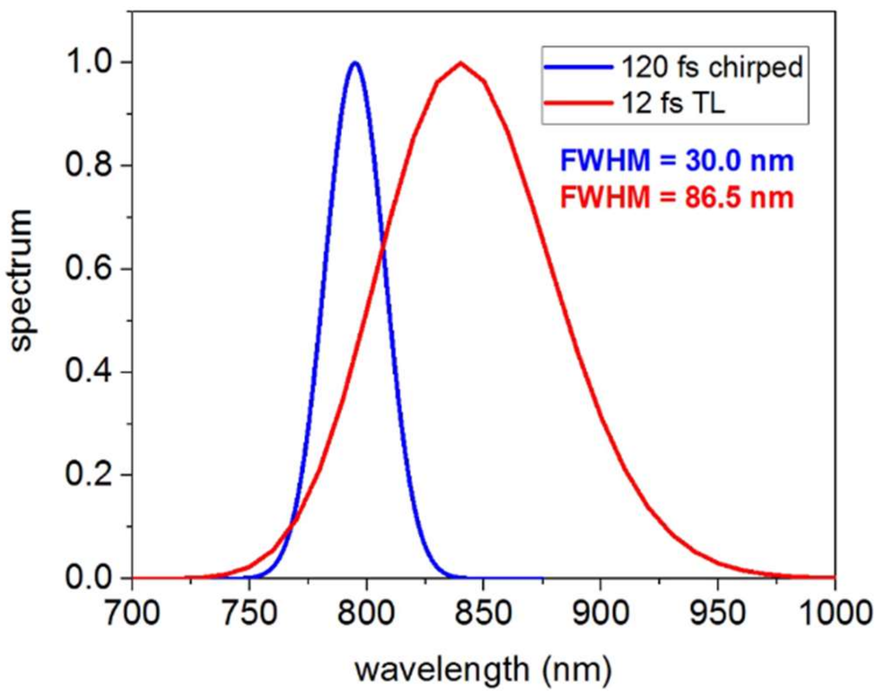
Expectation: protons can leave the asymmetric nano-rod antenna more at the sharp edge (like in case of lightening rods).

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.

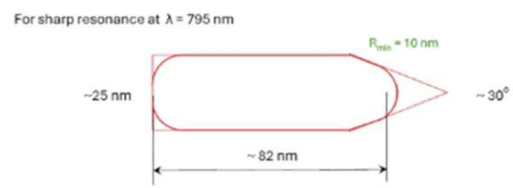
[J. Budai, Zs. Márton, M. Csete et al., 2024]

- 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



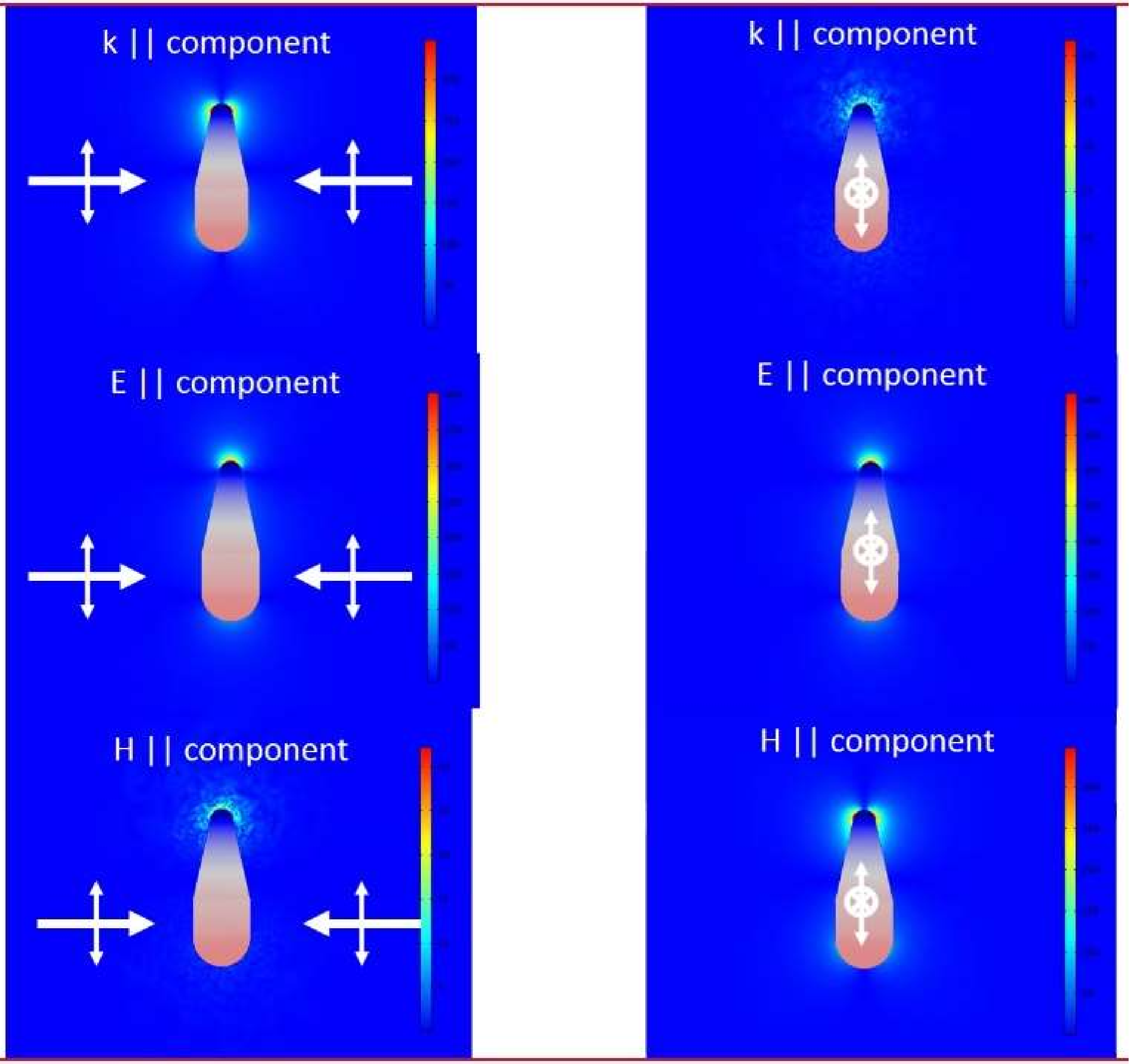
Resonance response bandwidth depends on the length of irradiation pulse
[M. Csete, A. Szenes, et al. 2024]

EM Fields around nano-antenna with sharp tip

Laser

Laser

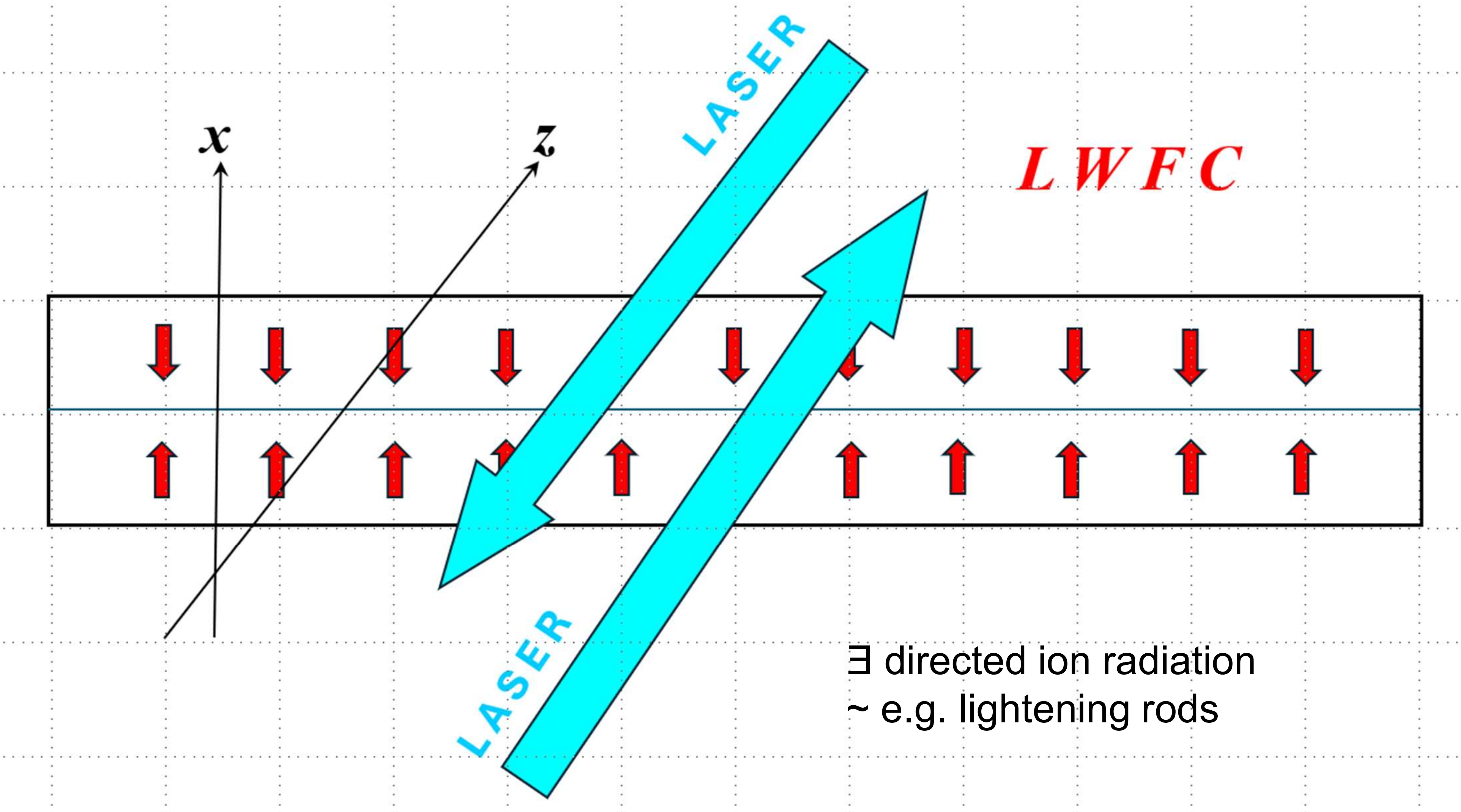
Laser



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 […]

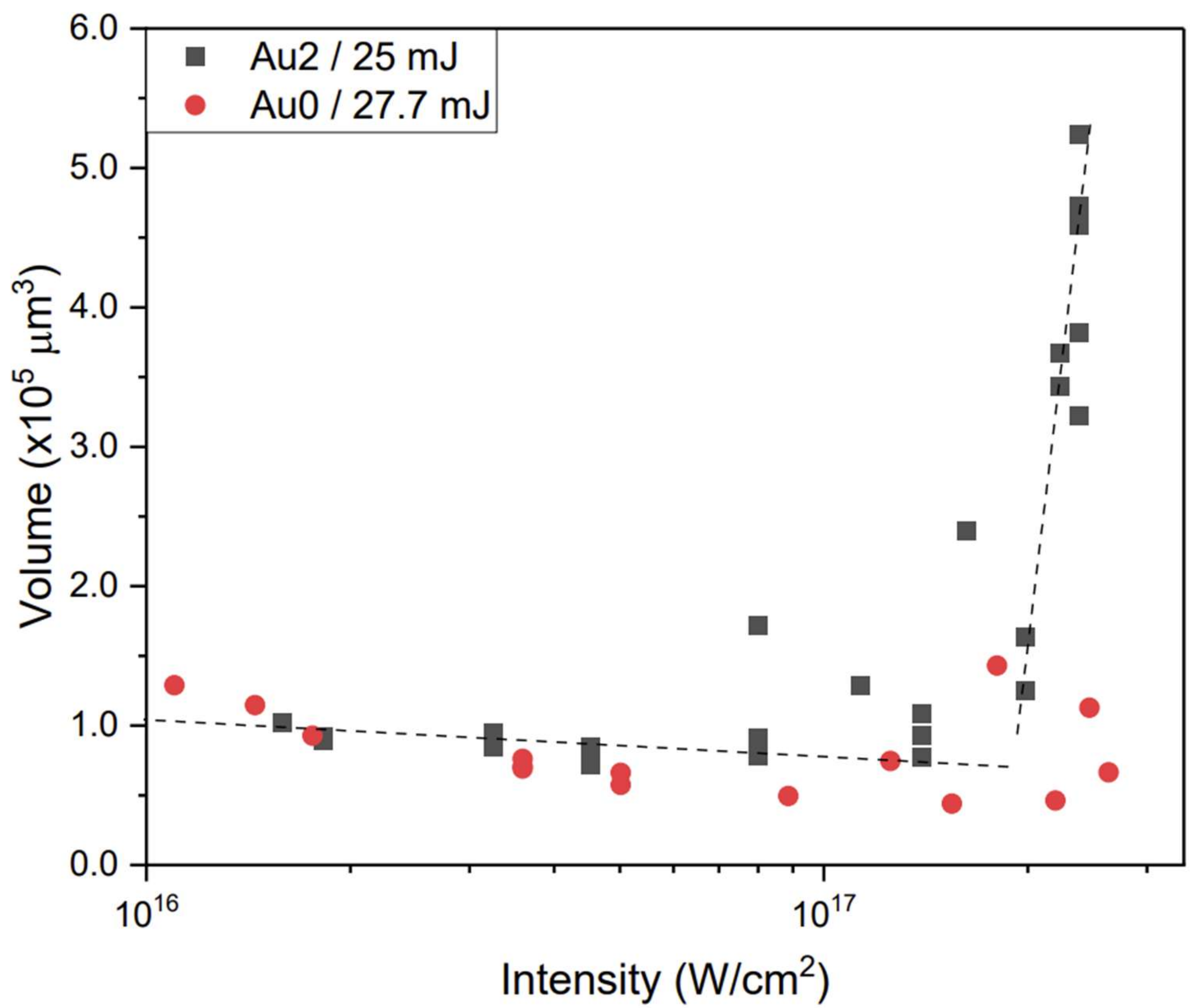
- Laser irradiation
  one sided irradiation up to now,
  Wigner RCP Budapest, 30 mJ Ti:Sa Hydra I= ~ 2 10^{17} W/cm^2
  ELI-ALPS Szeged, 30 mJ SYLOS I= ~ 2 10^{19} W/cm^2

- p + 11B fusion
  Proton absorption by Boron containing target is observed with
  α –particle production at ELI-ALPS

Crater Volume

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

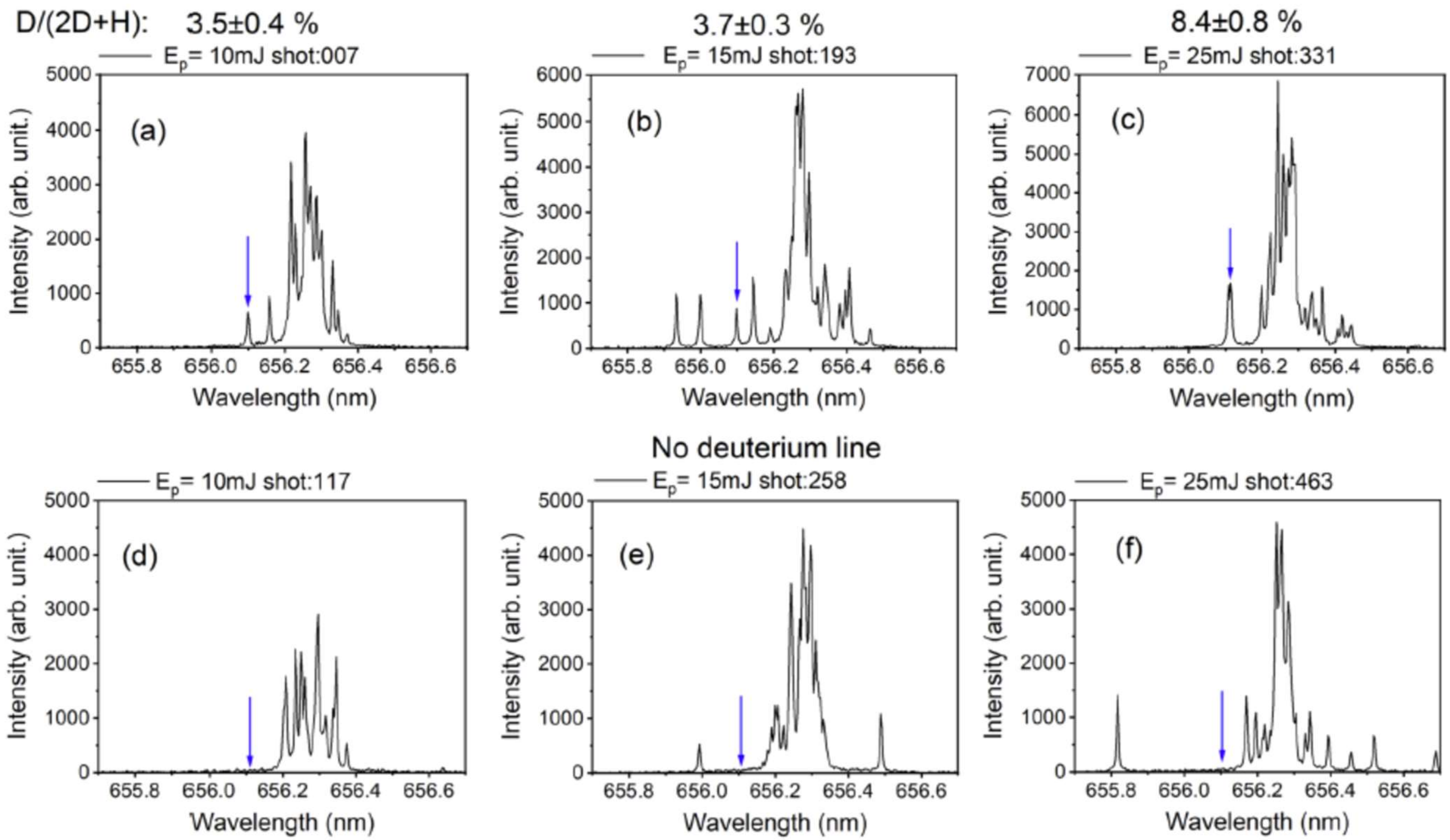
Q = ~ 6



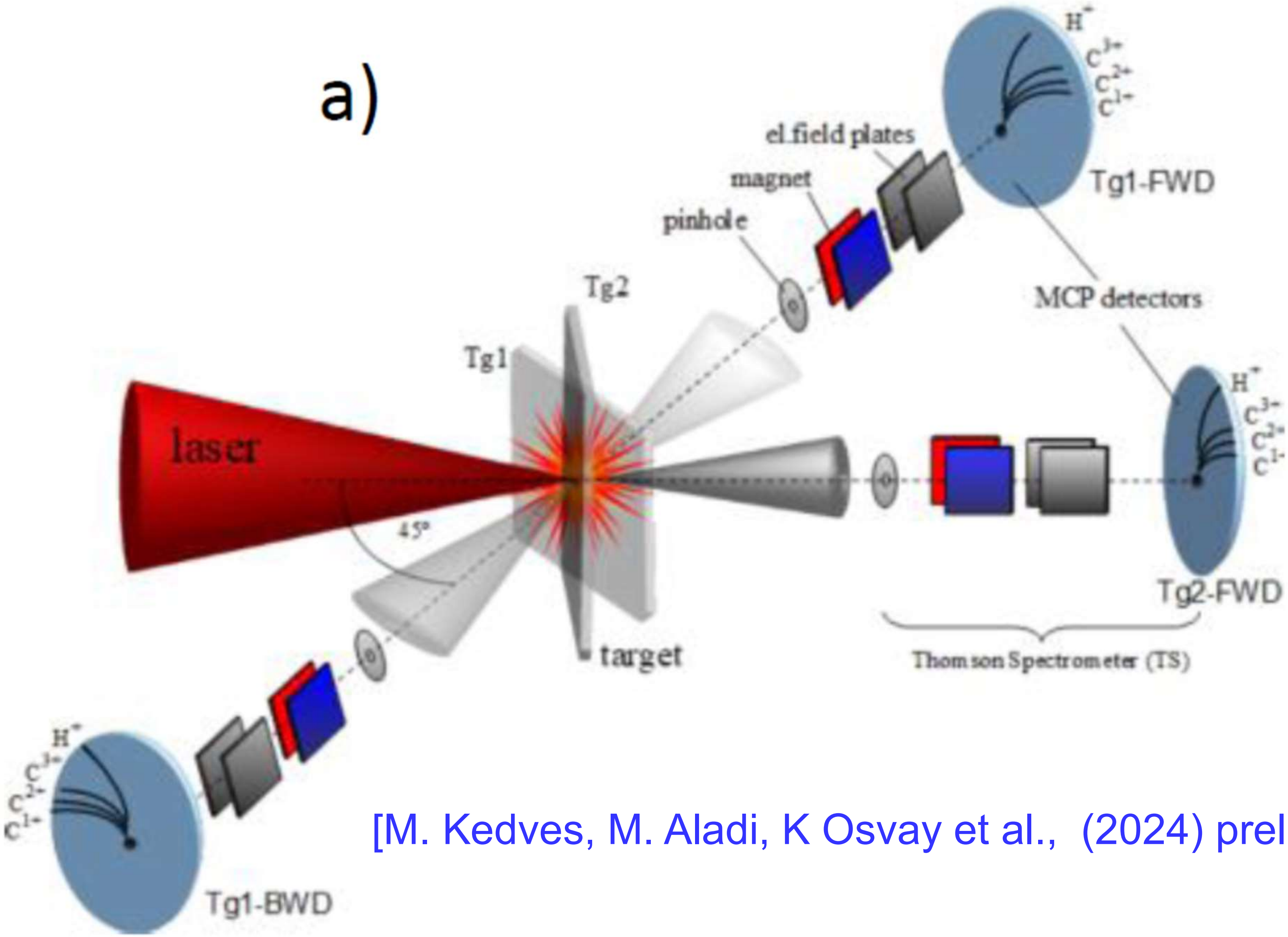
Change of the crater volume with the amount of laser light reflected by the target (plasma mirror) for the laser irradiations of the undoped (Au0) and gold nanorod containing (**Au2**) targets

[N. Kroó, M. Aladi, M. Kedves, B. Ráczkevi, A. Kumari, P. Rácz, M. Veres, G. Galbács, L.P. Csernai, T.S. Biró, for the **NAPLIFE Collaboration**, Monitoring of nanoplasmonics-assisted deuterium production in a polymer seeded with resonant Au nanorods using in situ femtosecond laser induced breakdown spectroscopy,
Scientific Reports (Nature) **14**, 18288 (2024)., (arXiv:2312.16723)
https://doi.org/10.1038/s41598-024-69289-4]

Deuterium production



ELI-ALPS – High Intensity Tests 2024 –Thompson Parabola

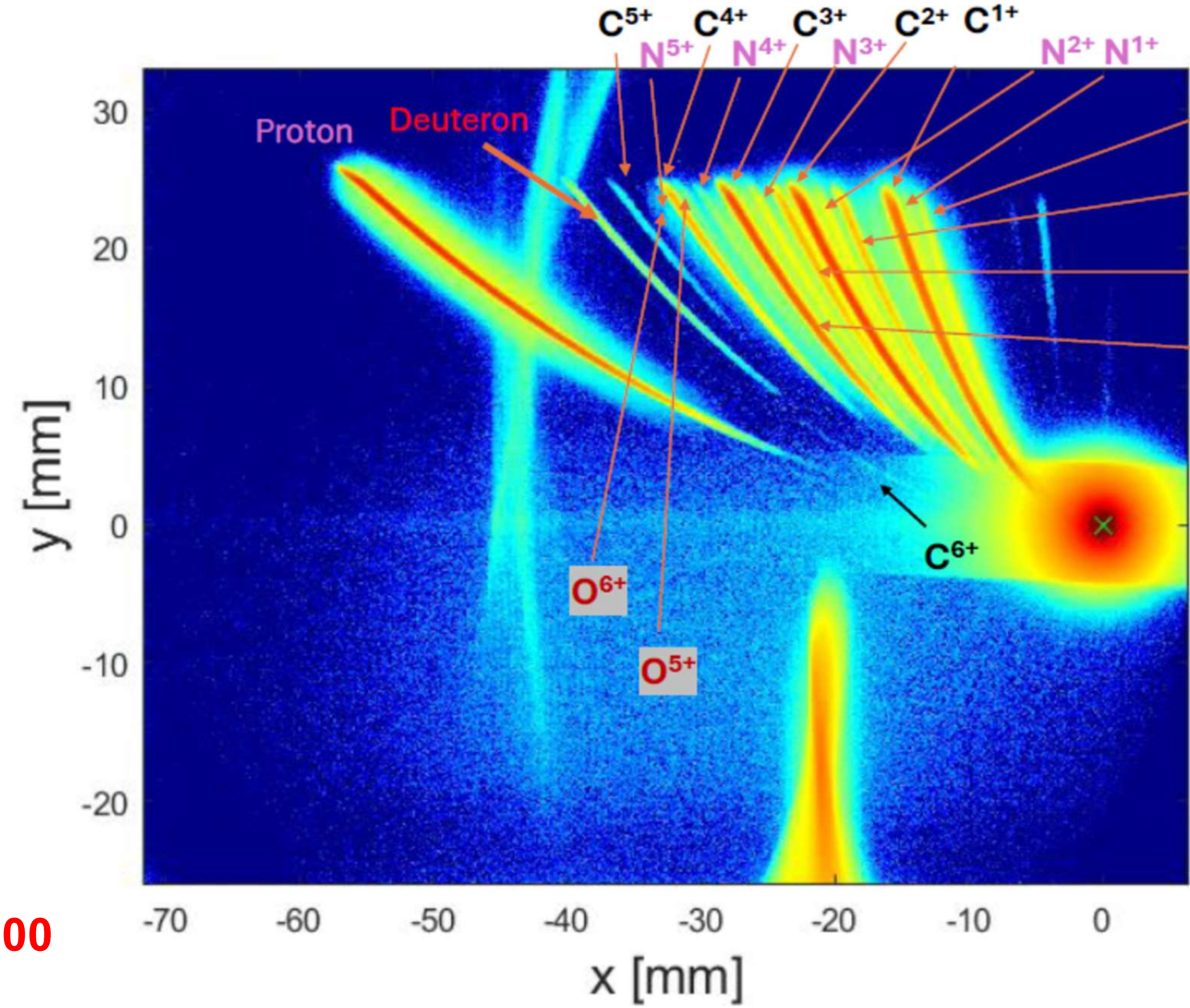


[M. Kedves, M. Aladi, K Osvay et al., (2024) preliminary.]

[NAPLIFE –ELI-ALPS 2024] preliminary

D100 sample

>100 spectra are averaged



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

MMA (Methyl methacrylate), $C_5H_8O_2$

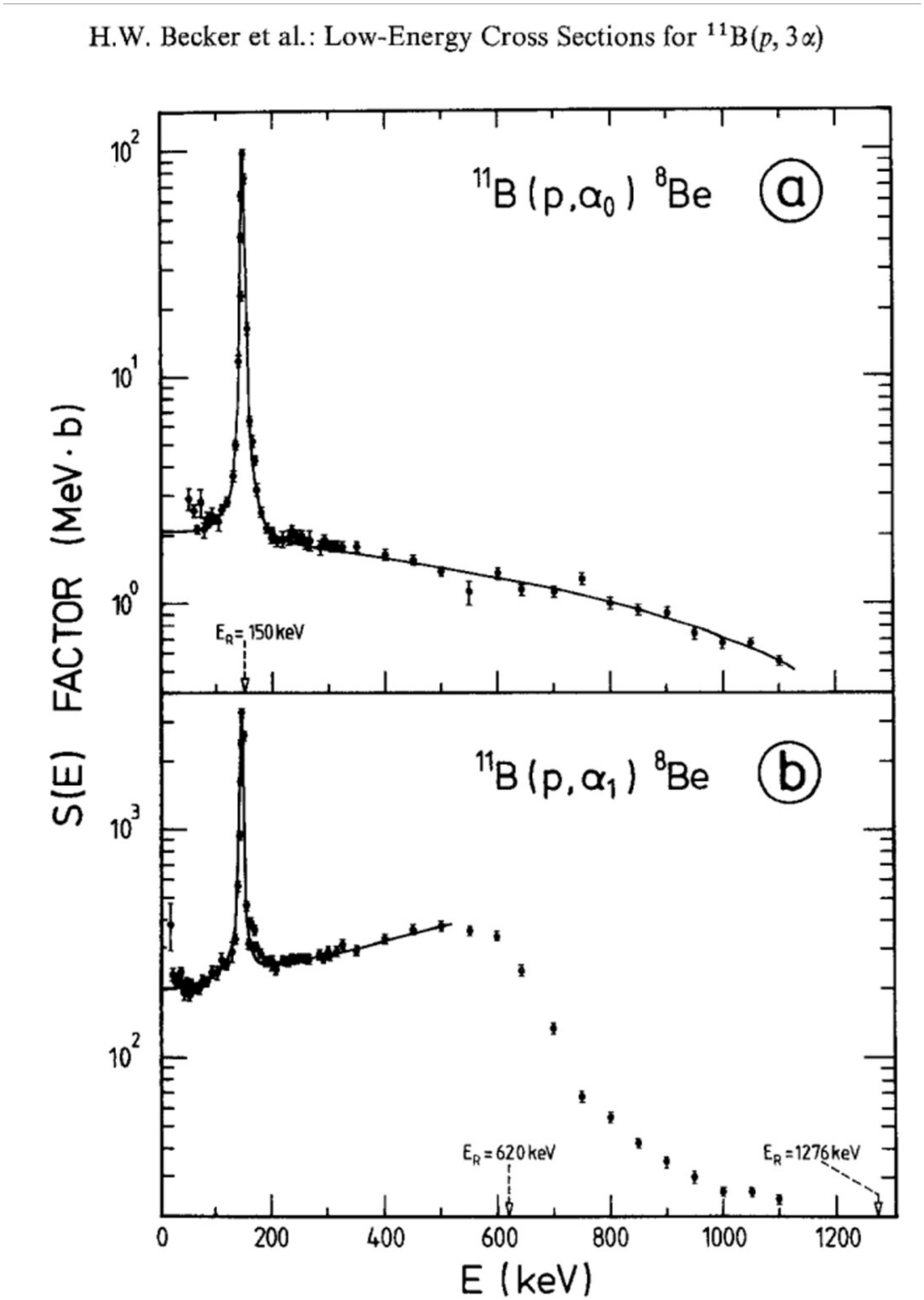
MMA-D (Methyl-d_3 methacrylate-d_5), $C_5D_8O_2$ **= D100**

C^{6+}: 490 eV

O^{7+}: 740 eV

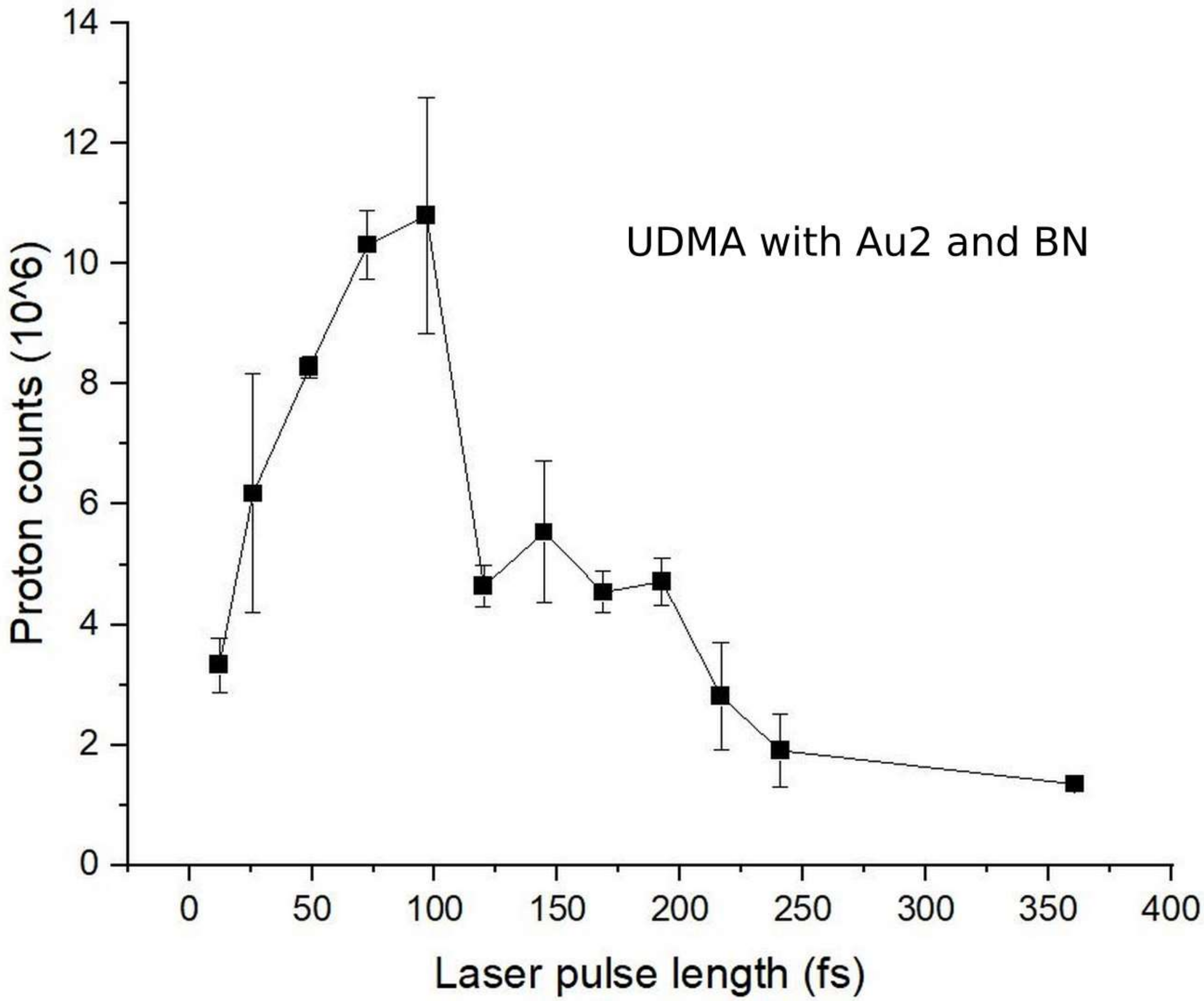
Speakers (Realtek(R) Audio):

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



Indication of p + 11B Reaction

[N. Kroo, L.P. Csernai, I. Papp, M.´A. Kedves, M. Aladi, A. Bonyar, M. Szaloki, K. Osvay, P. Varmazyar, and T.S. Biro, (for the NAPLIFE Collaboration) in preparation]



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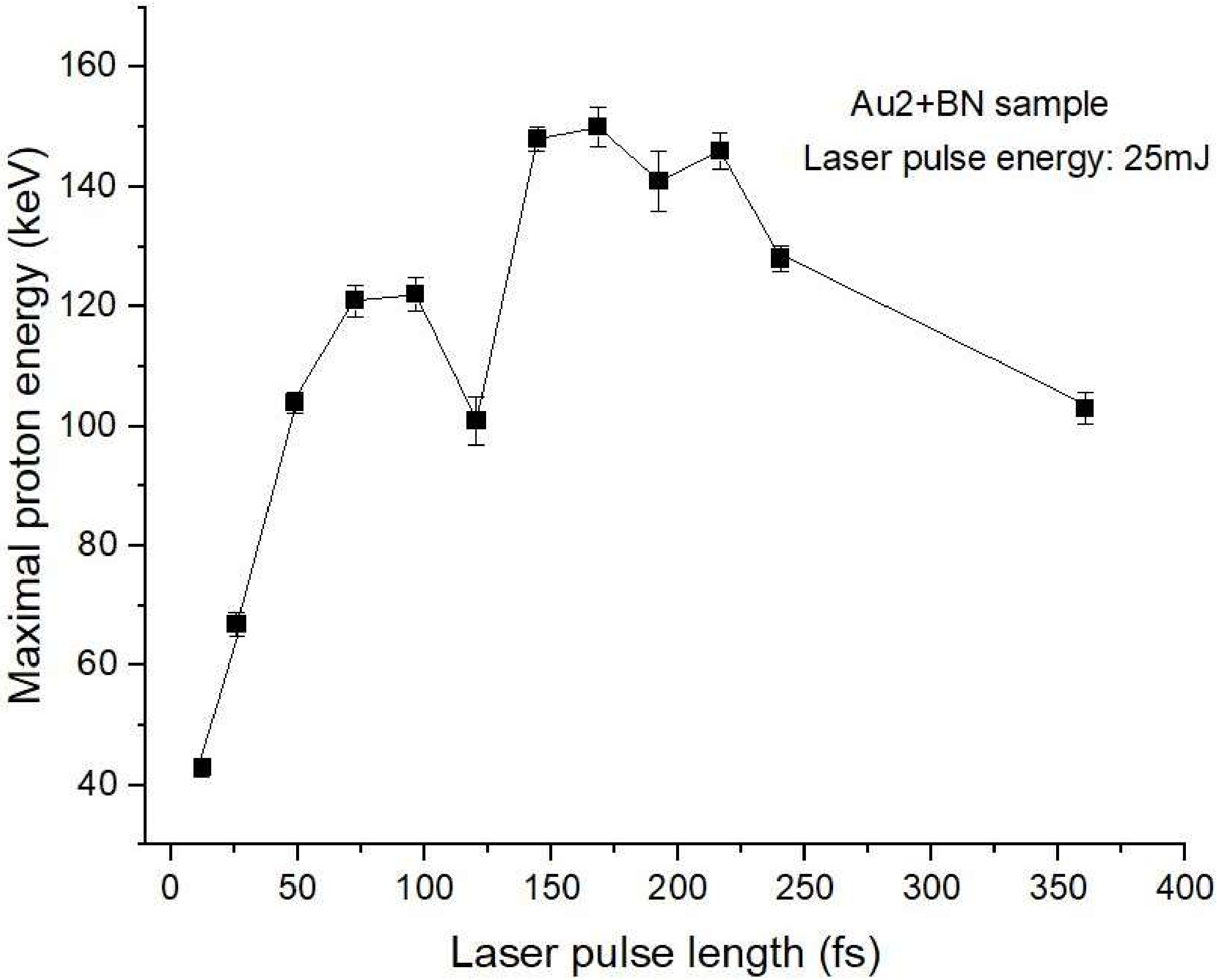
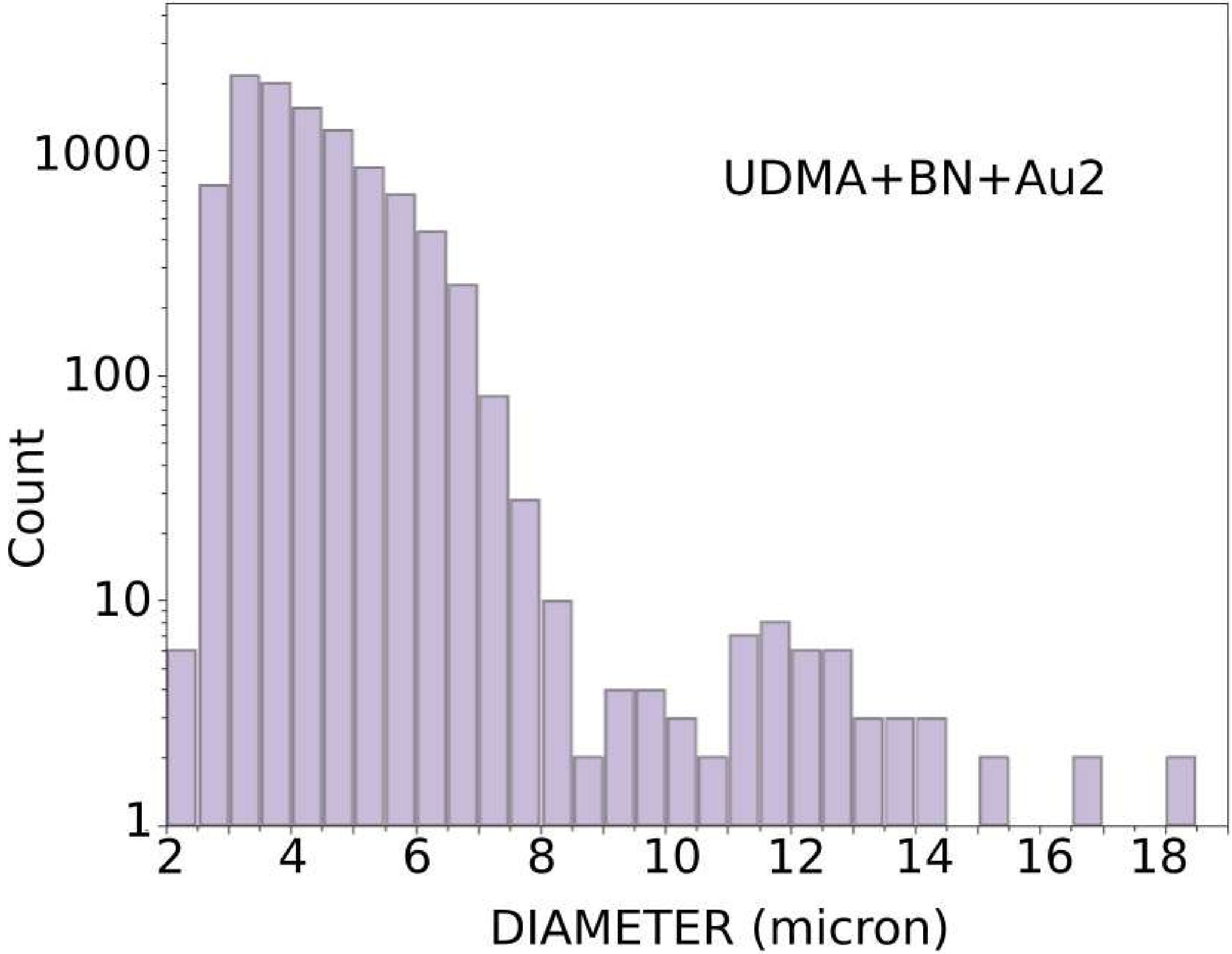
The integral number of proton signal in a backward direction, measured at ELI-ALPS SEA laser with pulse energy 25 mJ, applying various pulse lengths from 12.3 to 360 fs.

The maximum beam intensity at 12.3 fs was I= 8.3×1018 W/cm2. The target was an UDMA-TEGDMA copolymer with embedded resonant gold nanorod antennas at the density Au2=0.182 m/m%, and boron-nitride (BN) with 2.5m/m% density. This BN number density corresponds to 43% of the number of UDMA-TEGDMA monomers. Averaged numbers are shown for 2-12 shots at each laser pulse length, with the corresponding root mean squares indicated by error bars.



Indication of p + 11B Reaction

Maximum proton energy detected in the backward 45-degree direction with respect to the laser beam for different laser pulse lengths by Thomson parabola. As can be seen in Fig. 1 at 100-125 fs, the resonant protons are absorbed by the Borons in the fusion reactions, and only lower than 150 keV energy protons remain. In the range 150-250 fs pulse length protons above the 150 keV resonance energy are observed. These originate from those protons, which were already exceedingly well the resonance energy of the p+11B cross section.



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Number of impact traces versus the diameter of the trace spot in μm in CR-39 detections with boron-nitride in the target shows a second peak at diameter ~12 μm, corresponding to the emitted α particles.

CONCLUSIONS

- Plasmonic amplification is verified
- Proton acceleration is verified
- Nuclear transmutation reactions are achieved
- Formation of Deuteron nuclei is verified
- $p+^{11}B$ fusion reaction is detected

contrary to the fact that

- Only 30 mJ laser pulse energy was used
- Only one-sided laser irradiation was available
- Nanorod antennas were randomly directed

Perspectives 1

$p + {}^{11}B$ differential cross section evaluation in UrQMD, PACIAE, in analytic methods … with all emission steps

Larissa B., Daimei Z., Anke Lei, … Konrad T., … Jan S. V., …

Perspectives 2

Target manufacturing with nanorod antennas and ^{11}B in Bergen, and atom-phys. evaluation of laser light absorption, electron pair formation at high energies and evt. proton acceleration (?)

Martin G., Jan-Peter H., Morten F., …

Perspectives 3

Rescale the PICR hydro to μm sizes, and include EoS for Dense Plasma

Yilong X., Duhuan W., Angel R., Volodya M., …

Thanks for your attention