Perspectives of the NAPLIFE project

ELI-ALPS, Szeged

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BTSLXX Workshop, HUN-REN Wigner RCP,
Budapest, Jun 11 – 12, 2026

The NAPLIFE & FUSENOW Collaborations

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~88 participants

Dujuan Wang, Wuhan University of Technology
Dieter D.D. Hoffmann, Xi'an Jiaotong University

HUNGARIAN NATIONAL LABORATORY

Professzorok Batthyány Köre

eli attosecond

Academia Europaea

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~1500 mHUF

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NAPLIFE

DET NORSKE VIDENSKAPS-AKADEMI

Energiapolitika 2000 Társulat

CONSULT BERGEN

Csernai László
University of Bergen, Norway

https://csernai.no/naplife/

NAPLIFE

-

(2019 →)

Select language / Válassz Nyelvet:

90+ Publications
150+ Talks
News

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

Inaugural Meeting of NAPLIFE Collaboration 2019

2019
Kőszeg

2019: Many of the participants of this meeting came from High Energy Heavy Ion field where hadronization (ignition or burning) of the **QGPlasma** happens everywhere at the same time, τ . This was not known in other fields so then and even today only burning spreading from a single hot spot was considered. Simultaneous, **two-sided ignition** was not trivial to achieve **[Cs, Str.'2015],** but in 2017 **[Cs,K,P,2017]** found a **method to regulate and catalyze** fusion by nanotechnology. ➔ **NAPLIFE**

Tamás was in this team from the beginning and became the project leader **(2022-)** of the first Hungarian NAPLIFE project at Wigner RCP as ***National Laboratory***.
We have ~20 joint publications, 5 on Heavy Ions, and the rest on Fusion.

2019

Tihany

Heavy Ions
& Fusion

2022

Budapest

2023
Budapest

2024

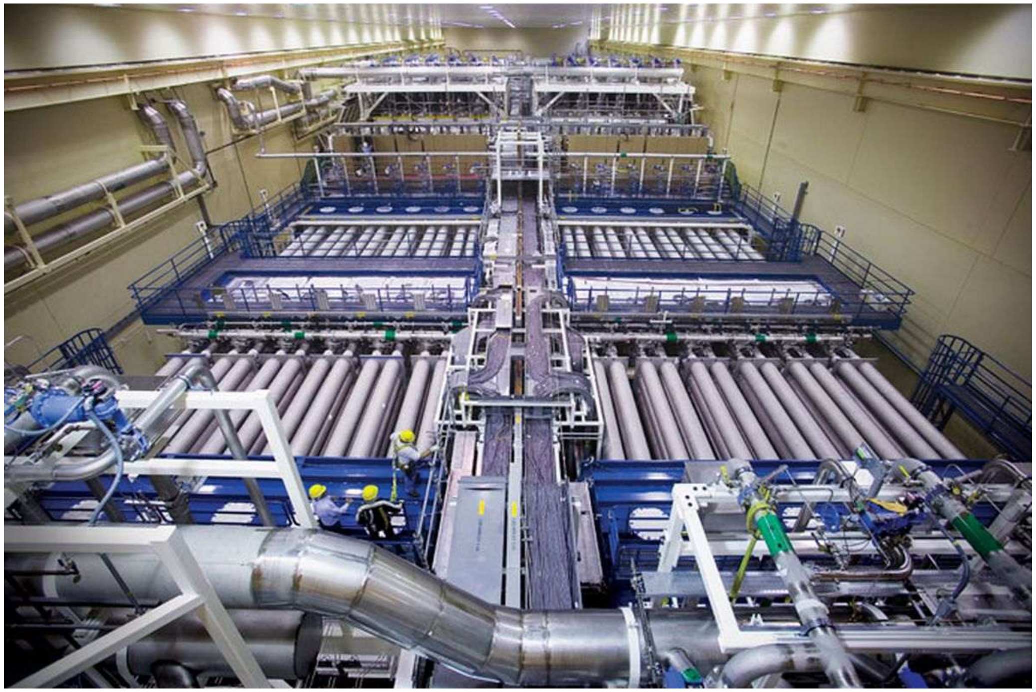
Budapest

2025

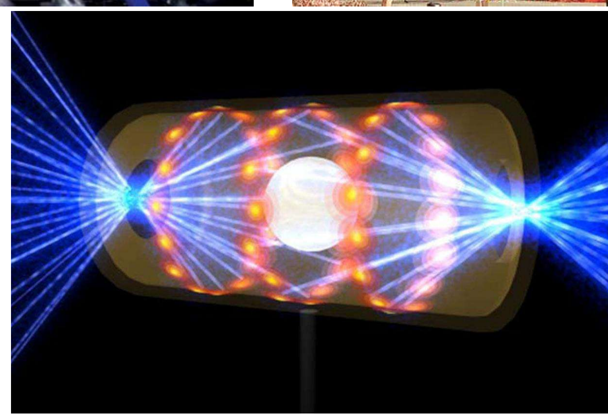
Dresden-Görlitz

Inertial Confinement Laser Fusion

- **Typical Example**
- Laser pulse energy increased ➔
  Ignition by **192** lasers made possible
- Spherical, **LLNL NIF** (hohlraum) thermal, 400 → **8 MJ**, ~ 1/day, extreme compression: expansion is faster than spread of burning, d+t reaction, fuel & products are radioactive.
- $Q_{target} = 4$
- Focused Energy M.Roth -> Bibli NPP



Spherical, LLNL NIF (hohlraum) thermal,
400 → 8 MJ, ~ 1/day, extreme compression: expansion is faster than spread of burning, **d+t** reaction, fuel & products are radioactive.



~ Ø 10 m

10 mm x Ø 5mm

400 → 8 MJ, ~ 1/day

Used also by Focused Energy,
M.Roth converting *Biblis* NPP.

Our Method of Laser Fusion

- ∃ **two-sided** irradiation: (Exists @ Shanghai SG-IIU, planned @ GSI)
- ELI – ALPS Szeged HU NAPLIFE unique:
- Nanoplasmonic *resonant antennas*
  - to amplify and regulate light absorption,
  - radiation dominated &
  - non-thermal (→ Highly efficient, high Q !)

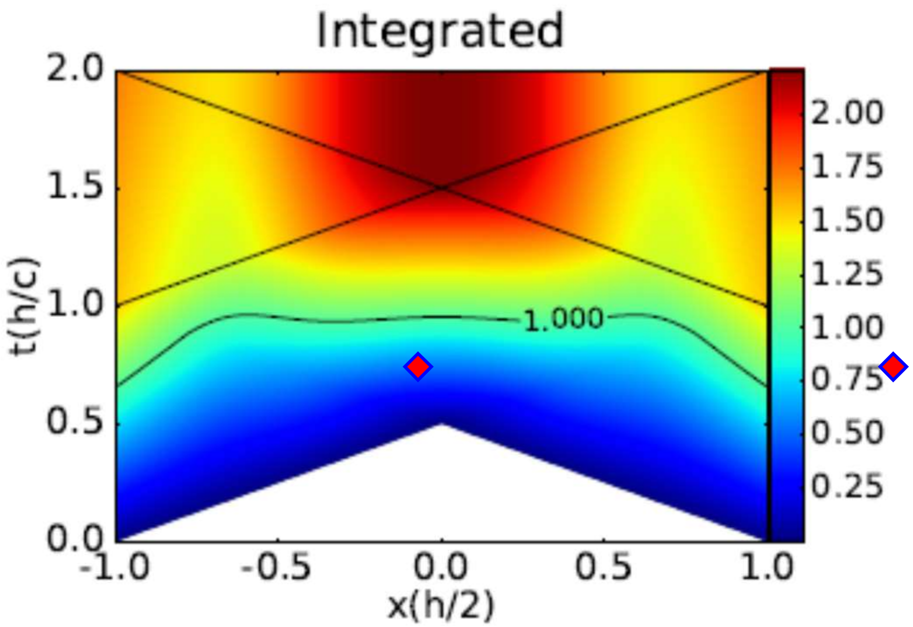


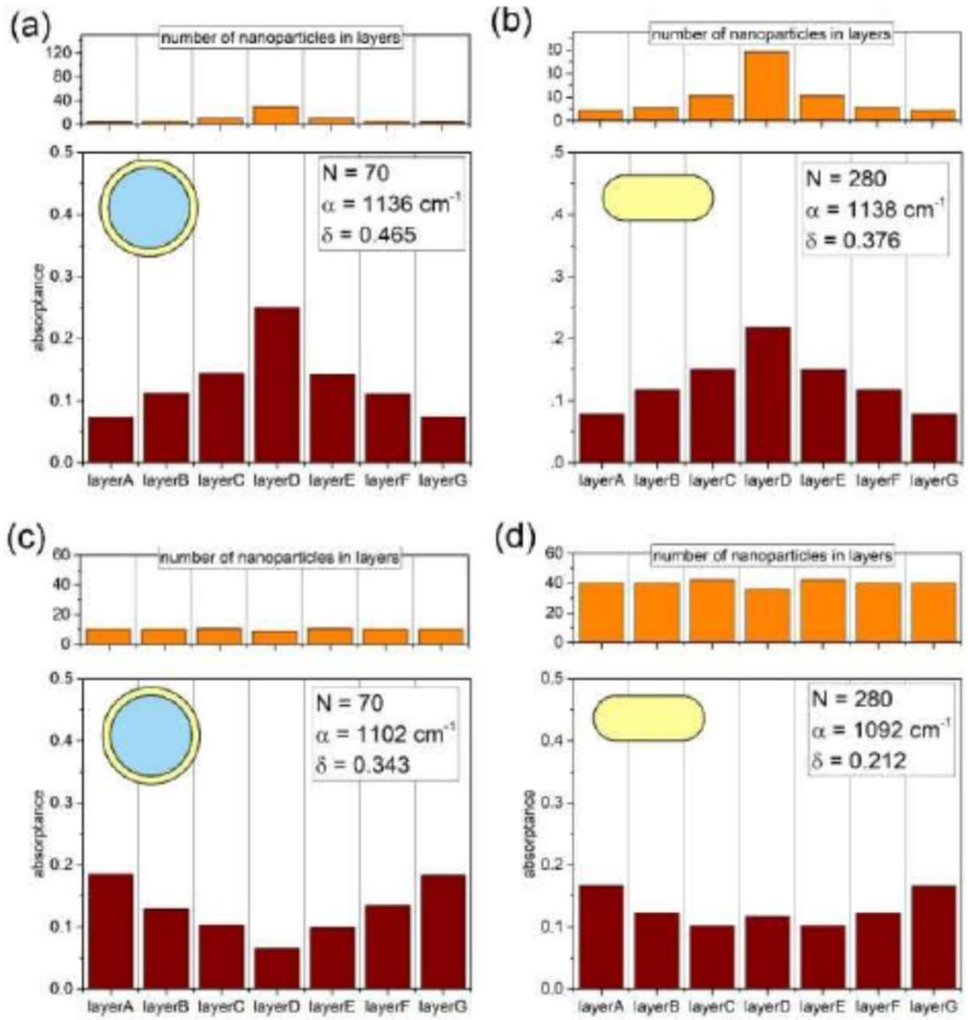
Figure 3: (color online) Integrated energy up to a given time in the space-time across the depth, h, of the flat target. The color code indicates the temperature, T, reached in a given space-time point, in units of the critical temperature, (T_c). The contour line $T = 1$, indicates the critical temperature,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

How can we achieve this ?

With nano-antennas !

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

[L. P. Csernai, M. Csete, I. N. Mishustin, A. Motornenko, I. Papp, L. M. Satarov, H. Stöcker, N. Kroo, ***Physics of Wave Phenomena*, 28 (3), 187-199 (2020).**]



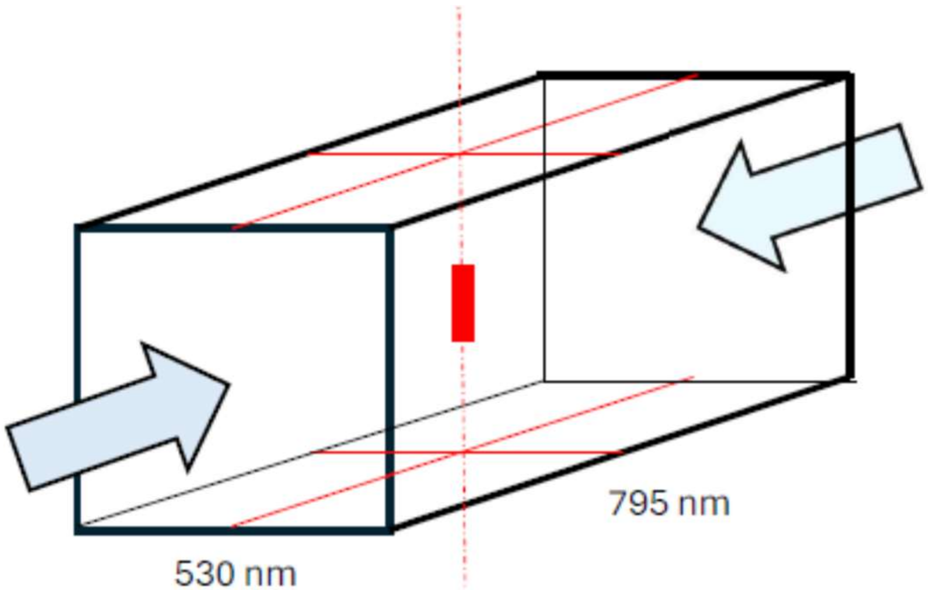
Simultaneous ignition – no instabilities

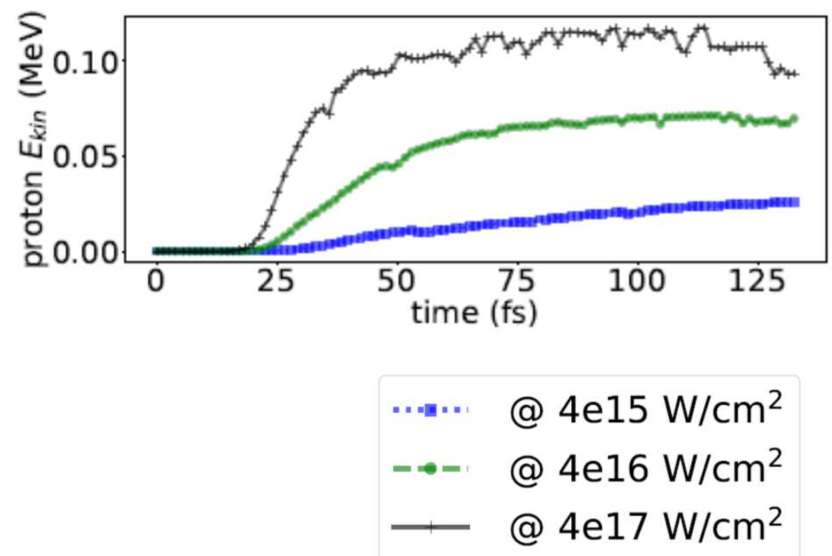
M. Csete et al., (2021)

COMSOL Simulation

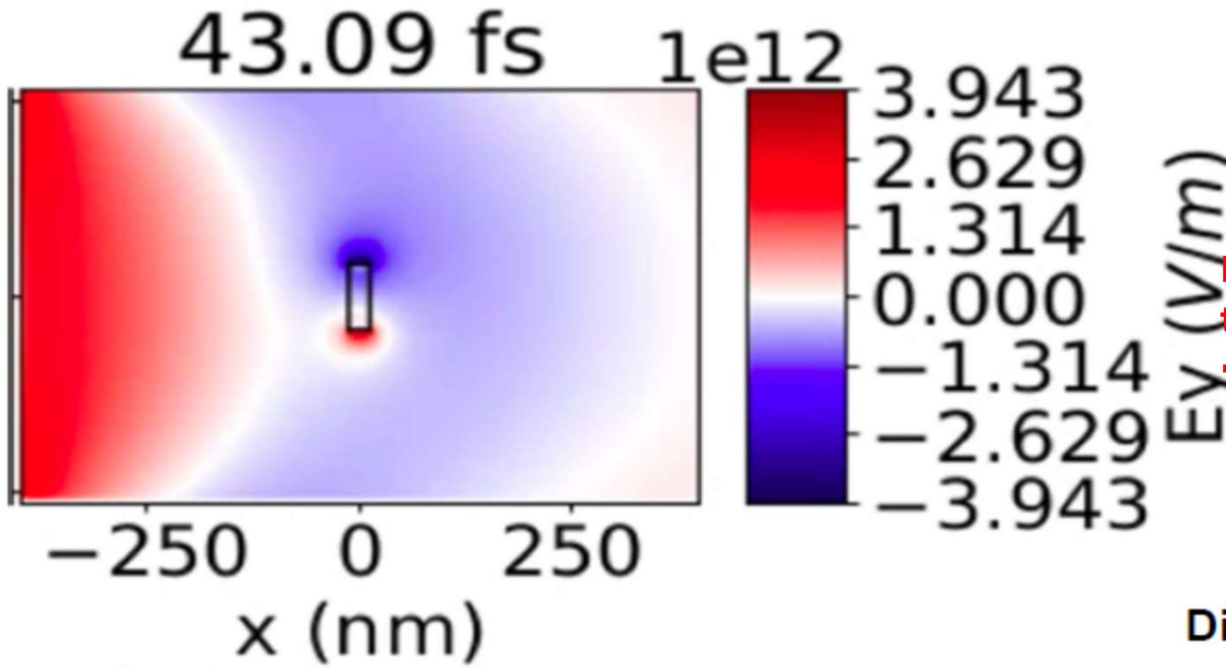
Laser-induced proton acceleration by a resonant nanoantenna

EPOCH PIC Simulation





[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; EPOCH – PIC]

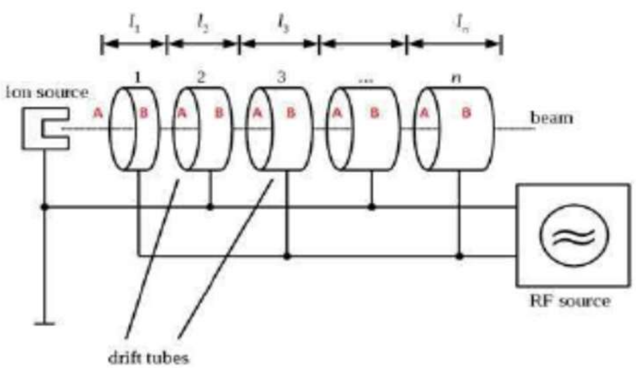


Neighboring protons are accelerated (100-200 nm)

Nuclear transmutation
➔ Deuterium

Dipole L = 85 nm

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

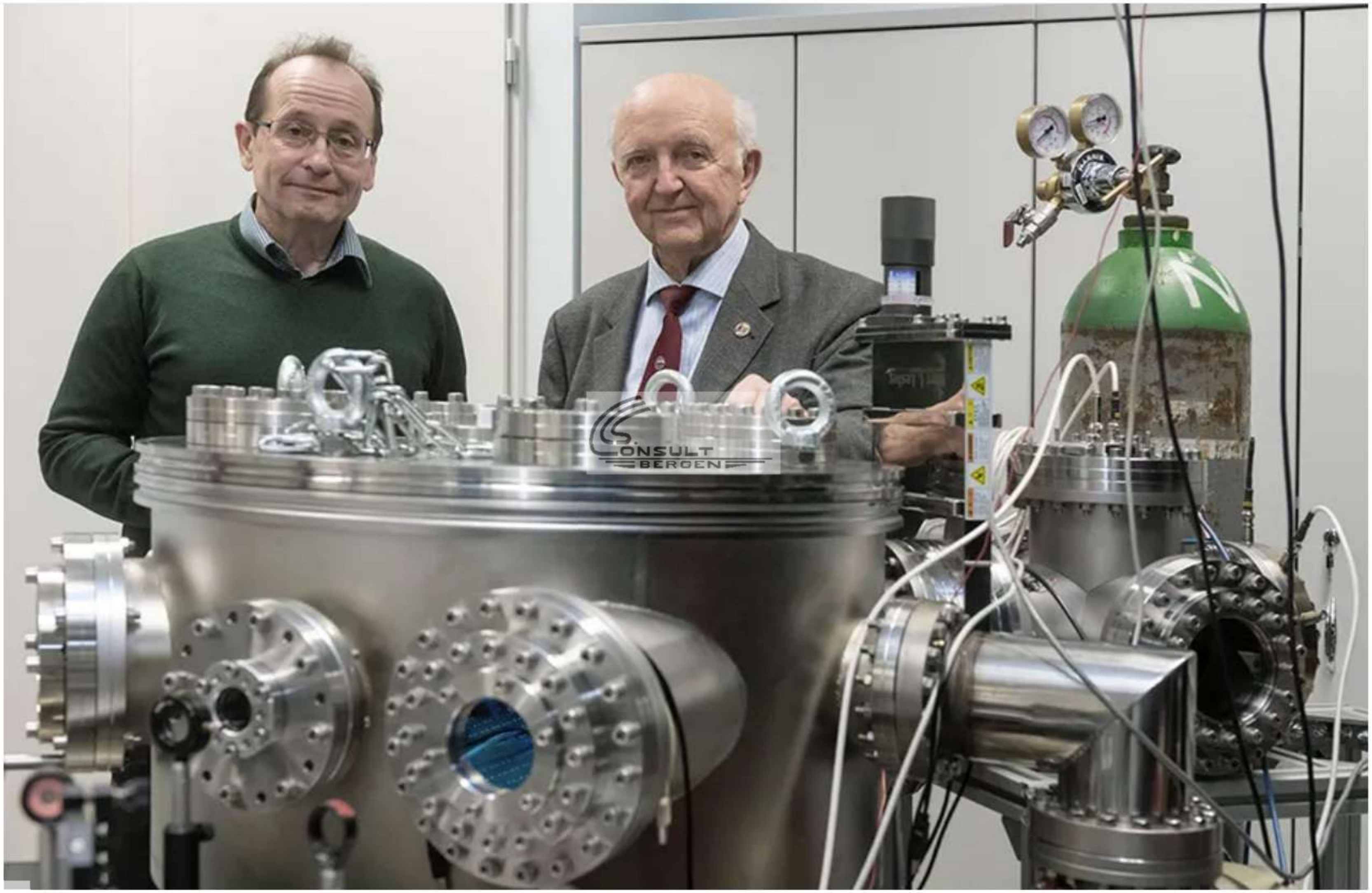


LHC **dV ~ 1 · 10^6 V/m**

Dipole L ~ 16 cm

[I. Papp et al. **PRX Energy 1**, 023001 (2022)]

Experimental Validation Status

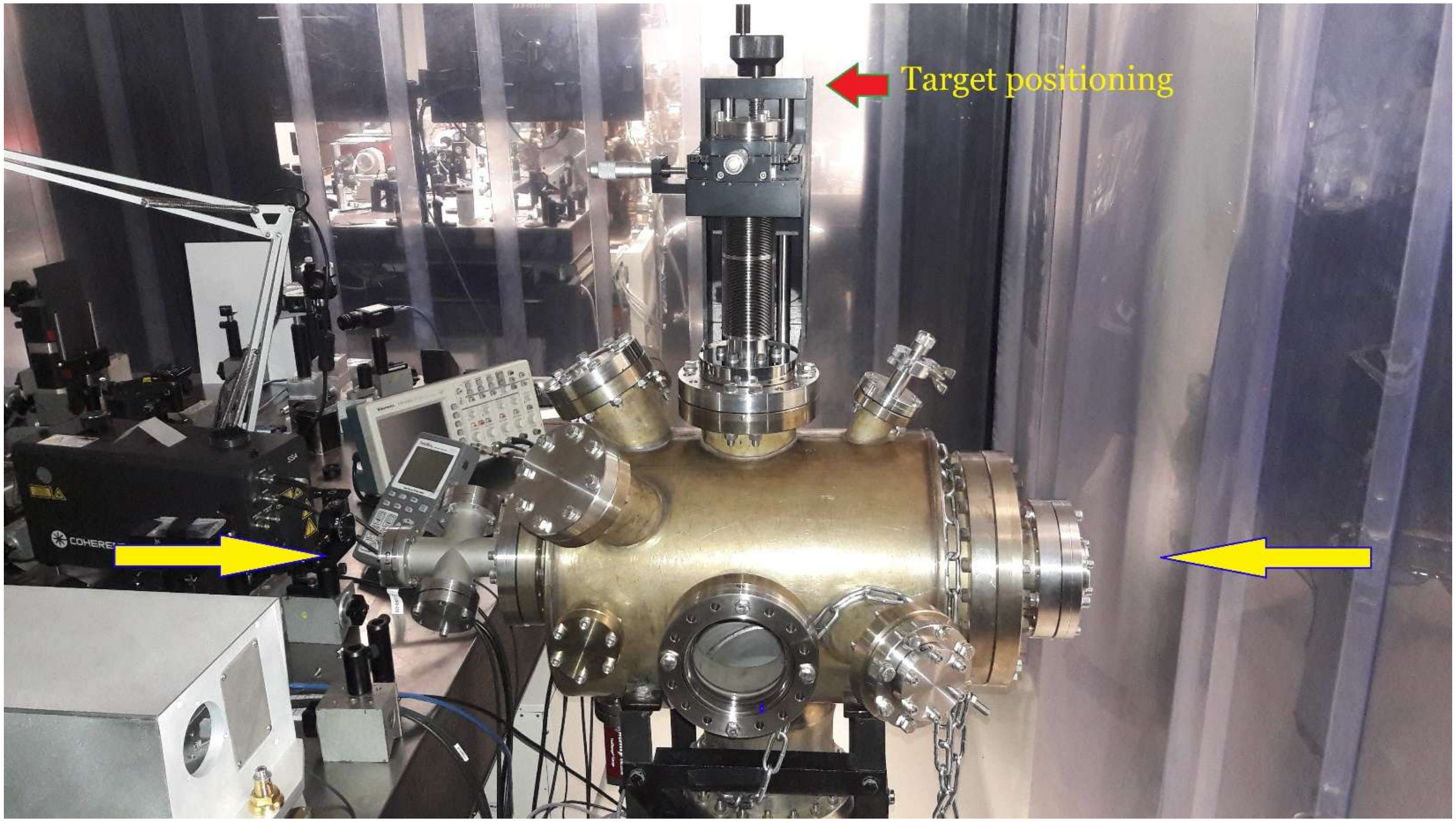


Tamás Biró (left) aims to enhance the energy effectivity of nuclear fusion using nanotechnology.

First experimental setup at Wigner RCP

Péter Rácz et al.

2021



European Laser Infrastructure – Szeged, HU

Only @ **ELI-ALPS** Szeged: EU Extr. Light Infrastructure ,
Attosec. Light Pulse Source
2PW High Field laser, 10 Hz, <10fs, **20 J**

2022 100 **mJ**
2026 8.5 **J !**

ELI-ALPS Target chamber

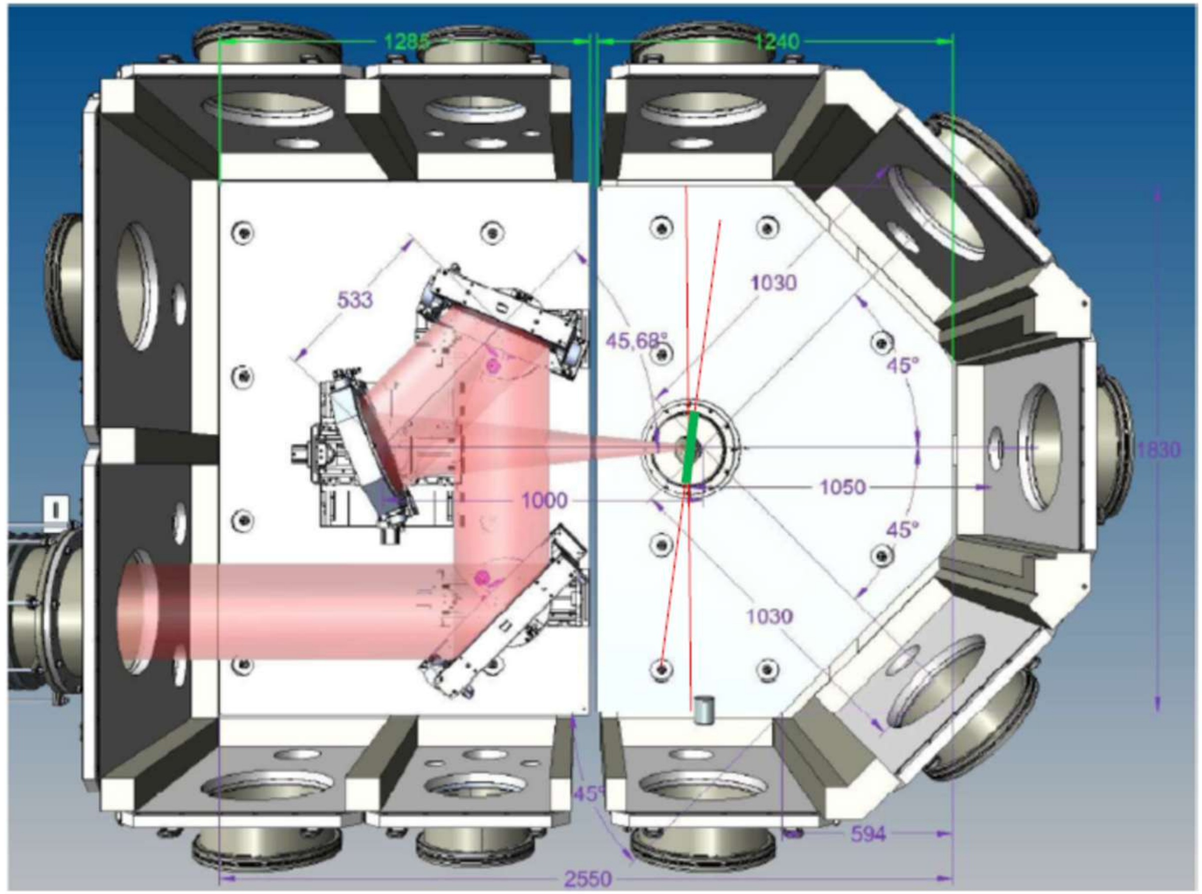
[K. Osvay et al.]

FUSENOW (Bergen) Proposal

8.5 Joule pulse energy

Jan Petter Hansen,
L.P. Csernai, et al.
ELI 7th Call (2025),
Etc.

Directed targets by
Attila Bonyár



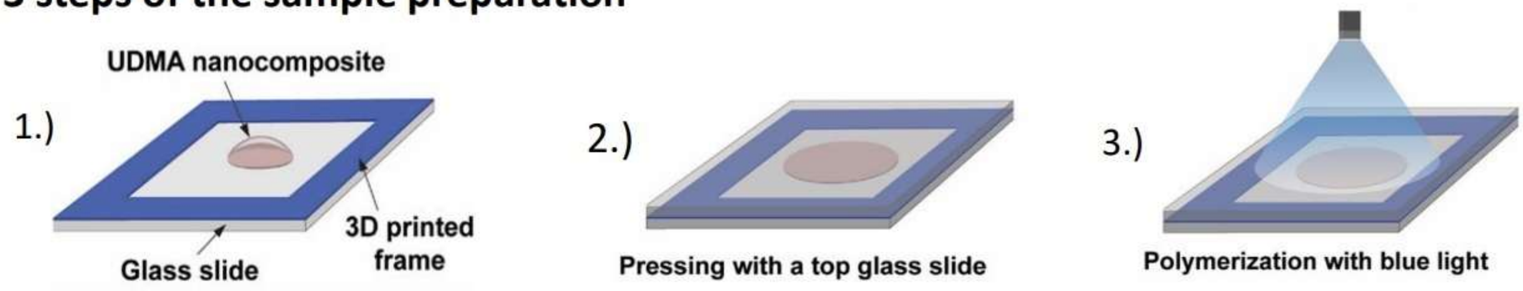
In: 8.5 J x 12 Hz = 100 W → if Q=10 ➔ **1kW**

Fusion Targets

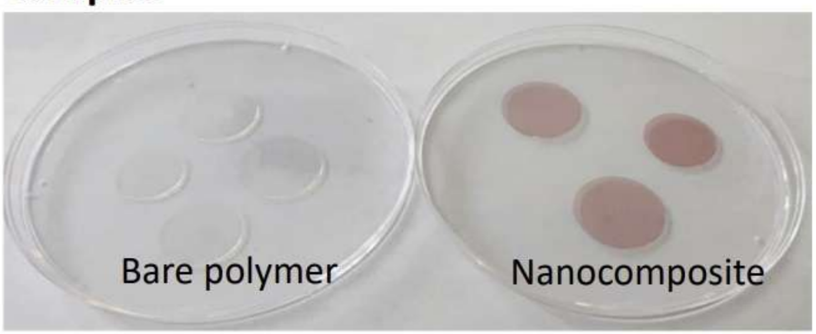
Fabrication methods – Sandwich Pressing

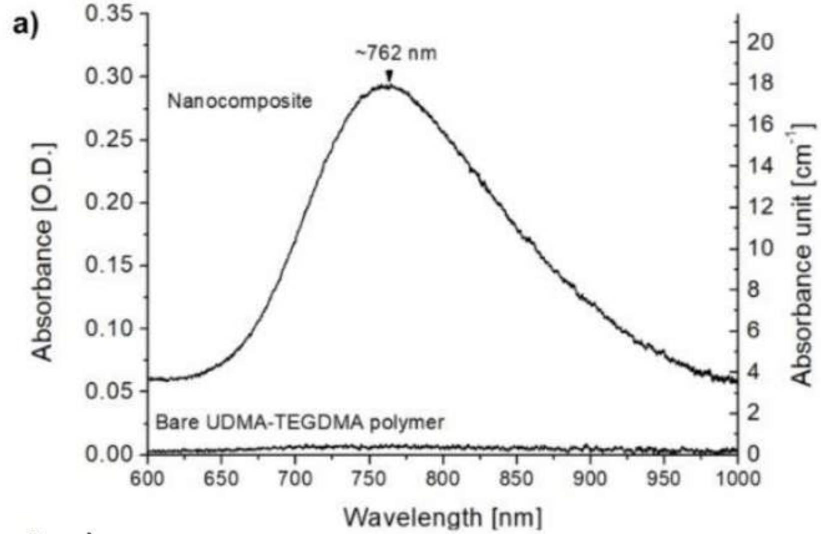
A. Bonyár et al. (2023)

3 steps of the sample preparation



Images of the bare and the doped samples





<u>Challenges:</u>

- the viscosity needs to be controlled,
- layer uniformity needs to be controlled (pressing).

Nanorod characterization- STEM

[A. Bonyár et al. (2023)]

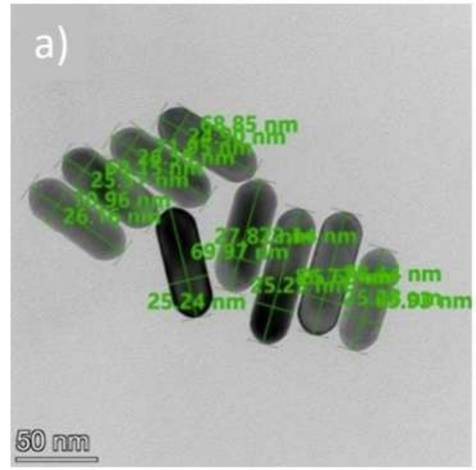
a) STEM image of the gold nanorods on a carbon filter

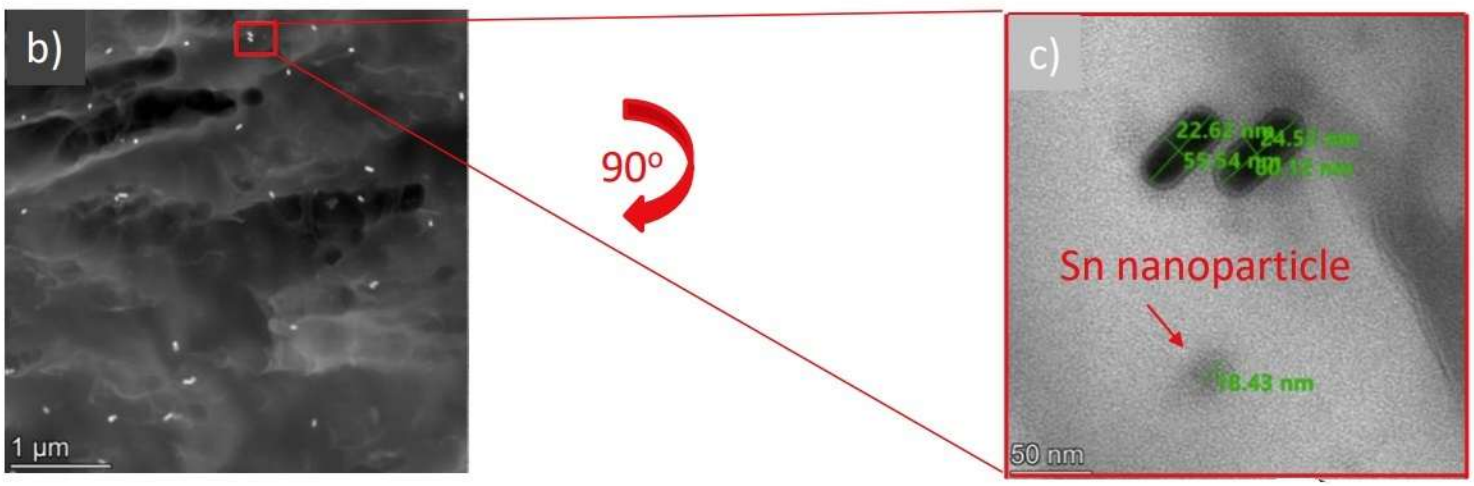
- ➡ Size of the nanorods: 76 ± 8 nm and 26 ± 2 nm

b) HAADF STEM image of the implanted nanorods inside the polymer matrix

- ➡ Distribution of the nanorods: 9 - 20 μm^{-3}

c) HRTEM image of nanoparticles inside the polymer matrix

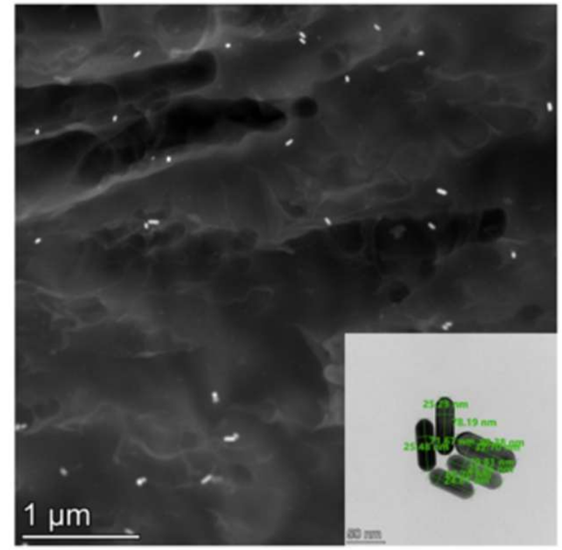




Resonant targets (Unique !)

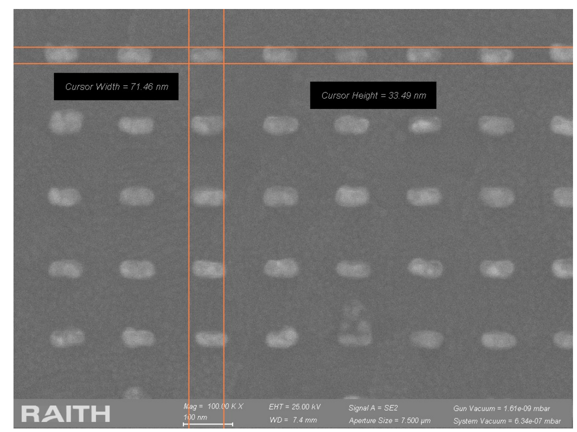
Solid targets at room temperature → hard polymer: UDMA (470: H38, C23, O8, N2), TEGDMA, MMA - large hydrogen content (evt. deuterated) & 85x25 nm nanorod antennas (sort !)

1st random orientation, 85x25nm, Au0,
Au1 (0.1m%),
Au2 (0.2m%)
[A. Bonyár et al., (BME)] These targets are used up to now >>

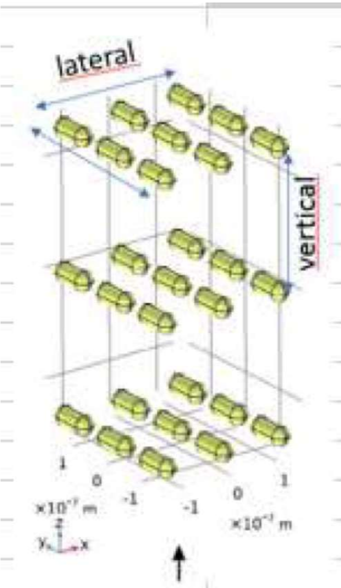


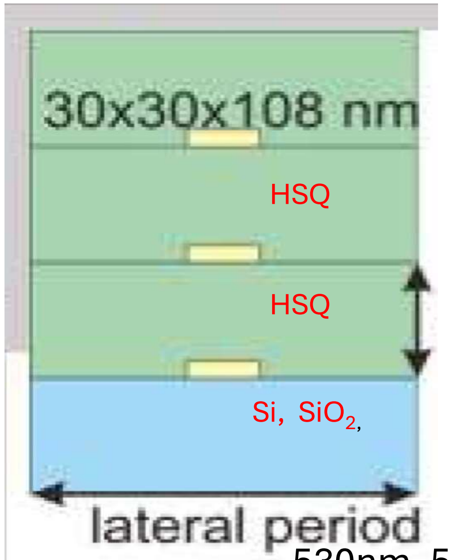
Directed & ordered nanoantennas

[Zs. Márton, J. Budai,
M. Csete et al., ELI-ALPS



New: Directed multi-layer antenna array targets @ ELI-APLS



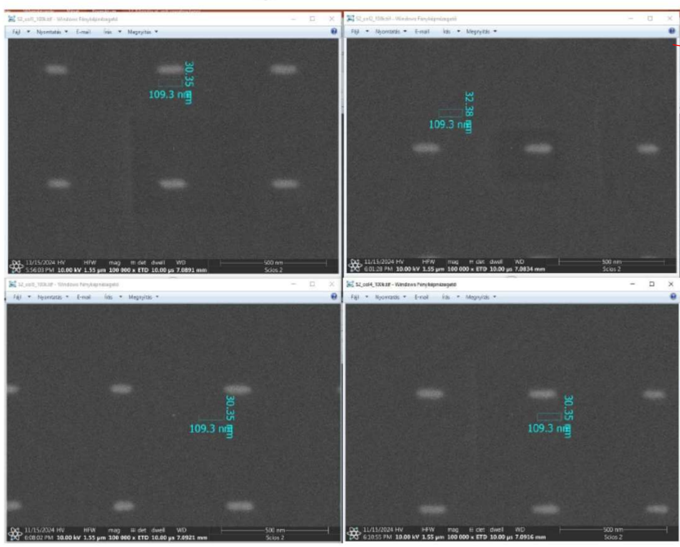


530nm, 570nm

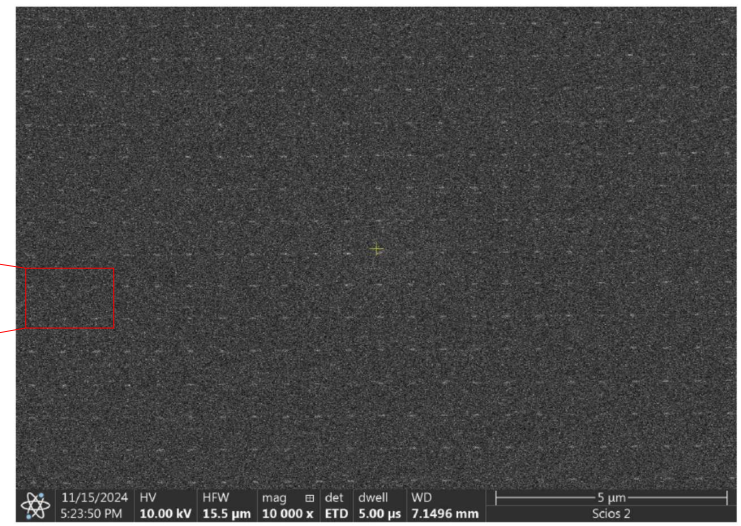
Vertical period: 410nm, 480 nm

Longitudinal p.: n x λ_{eff}, n > 2. $\lambda_{eff}/2 = 108$ nm in HSQ

Directed proton emission ? Will be tested at ELI !!!



500 nm



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

1.0 x 0.6 mm

scientific reports

Scientific Reports | (2024) 14:30087 | https://doi.org/10.1038/s41598-024-80070-5

2024

Check for updates

OPEN

Indication of $p + {}^{11}B$ reaction in Laser Induced Nanofusion experiment

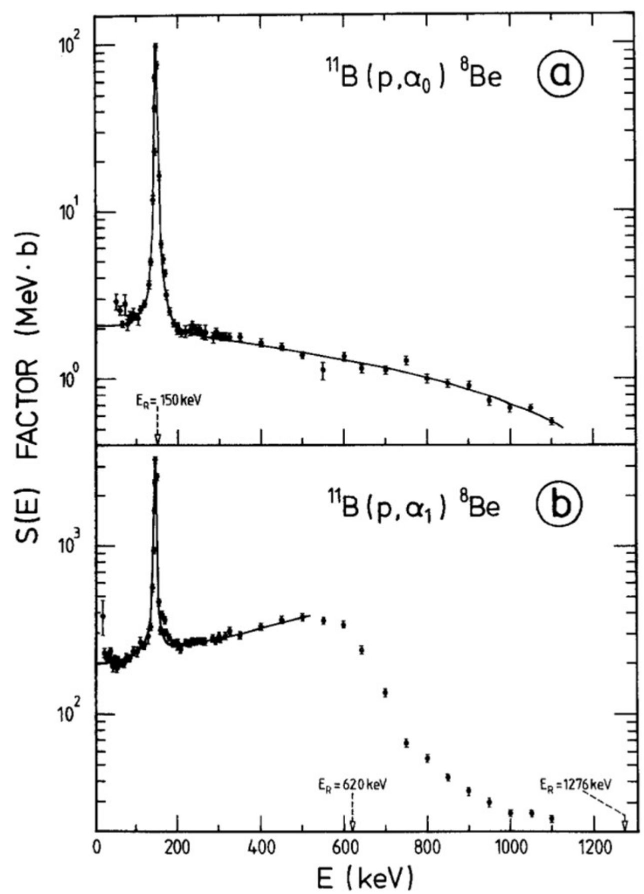
N. Kroó[1], L. P. Csernai[2,3,4], I. Papp[1,5], M. A. Kedves[1], M. Aladi[1], A. Bonyár[6], M. Szalóki[7], K. Osvay[8,9], P. Varmazyar[8], T. S. Biró[1] & (for the NAPLIFE Collaboration)

The NanoPlasmonic Laser Induced Fusion Energy (NAPLIFE)[1] project proposed fusion by regulating the laser light absorption via resonant nanorod antennas implanted into hydrogen rich urethane acrylate methacrylate (UDMA) and triethylene glycol dimethylacrylate (TEGDMA) copolymer targets. In part of the tests, boron-nitride (BN) was added to the polymer. Our experiments with resonant nanoantennas accelerated protons up to 225 keV energy. Some of these protons then led to $p + {}^{11}B$ fusion, indicated by the sharp drop of observed backward proton emission numbers at the 150 keV resonance energy of the reaction. The generation of alpha particles was verified by CR-39 (Columbia Resin #39) nuclear plastic track detectors.

Only two other such measurements are reported up to now:

- "First measurements of p11B fusion in a magnetically confined plasma“ R.M. Magee et al., Nature Commun. (2023) 14:955, (**M.C.**) and
- "A multi-MeV alpha particle source via proton boron fusion driven by a 10-GW tabletop laser" V. Istokskaia et al., (nature) Commun. Physics (2023) 6:27. **ELI-B**eamlines.

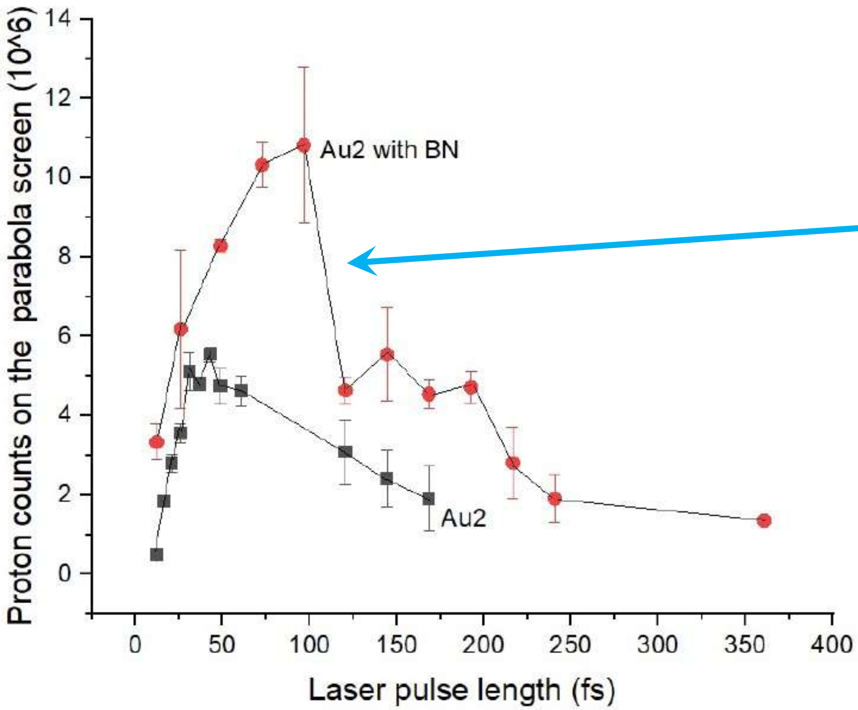
H.W. Becker et al.: Low-Energy Cross Sections for $^{11}B(p, 3\alpha)$



Indication of p + 11B Reaction

Cross section resonance
at **148 keV**

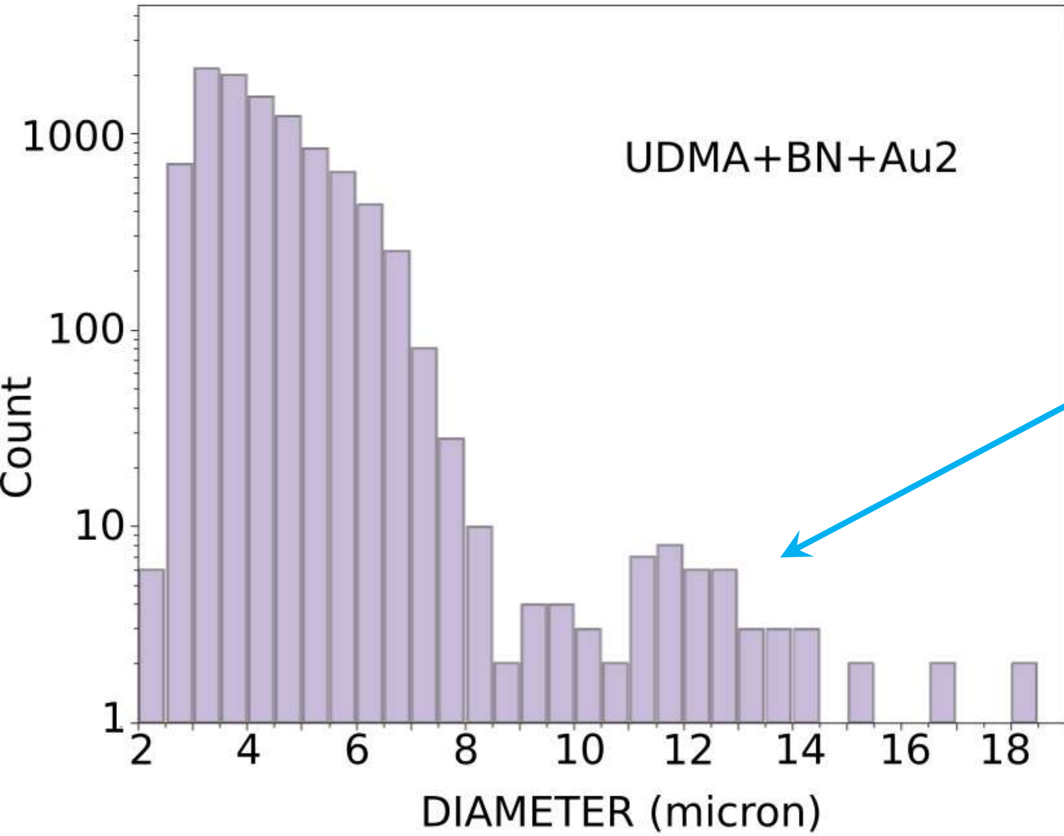
[N. Kroo, L.P. Csernai, I. Papp, M.´A. Kedves, M. Aladi, A. Bonyar, M. Szaloki, K. Osvay, P. Varmazyar, and T.S. Biro, (for the NAPLIFE Collaboration) Sci.Rep. **14**, 30087 (2024)]



Indication of p + 11B Reaction

T=2.65 fs

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= 8.3×10^{18} 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

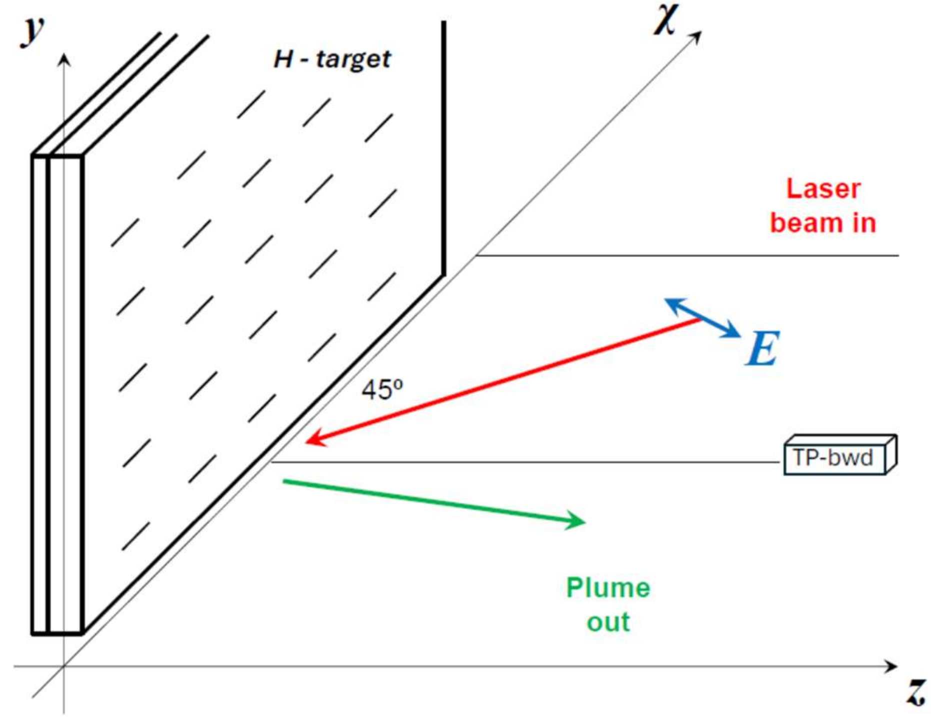
Number of impact traces versus the diameter of the trace spot in µm in CR-39 detections with boron-nitride in the target shows a second peak at diameter ∼12 µm, corresponding to the emitted α **particles**.

Directed Resonant Nanoantenna Arrays

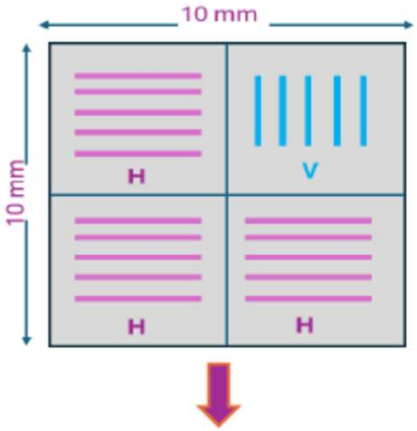
parallel to the polarization of the laser bean (horizontal)

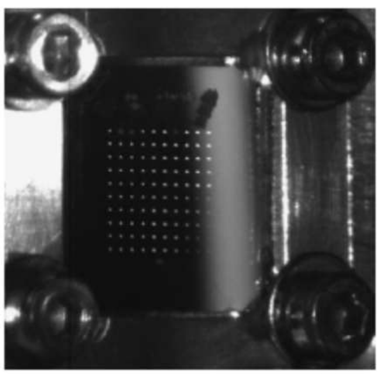
Uunder publicatoion
(arXiv 2601.05331**v3**)

Comparison of horizontal and vertical directed antennas in the target [Zs. Márton et a.]

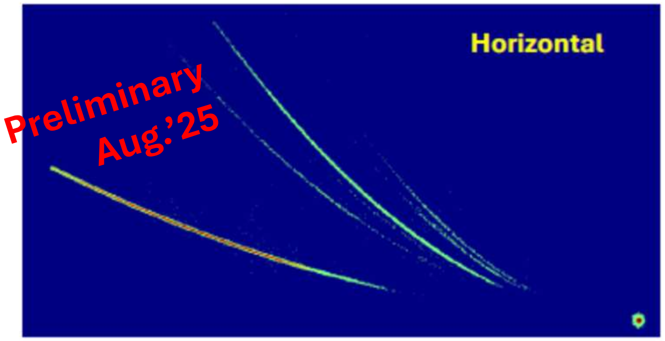


BWD TP Spectrum: Oriented Au nano.rod structures on Quartz Substrate

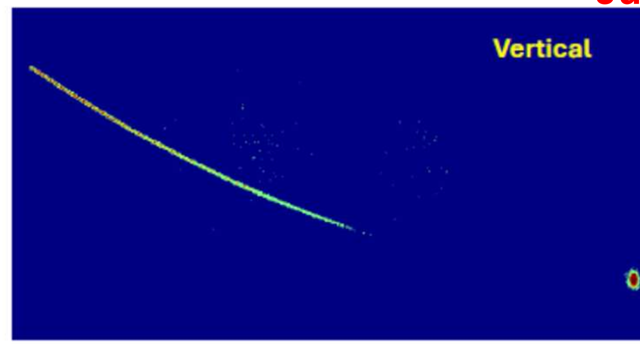




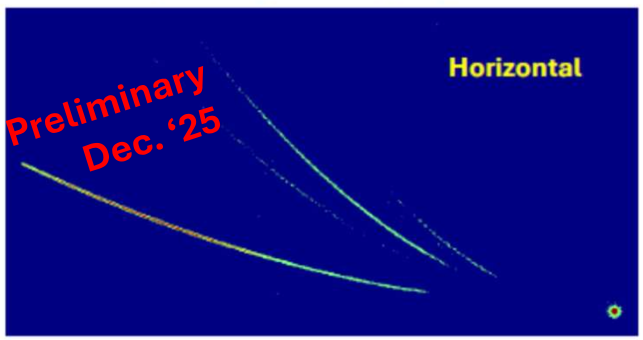
S1V_B_ Orient.n.rods +50 nm B_
-500 GDD_120.5 fs_180shot_bwd_(06.06.2025)



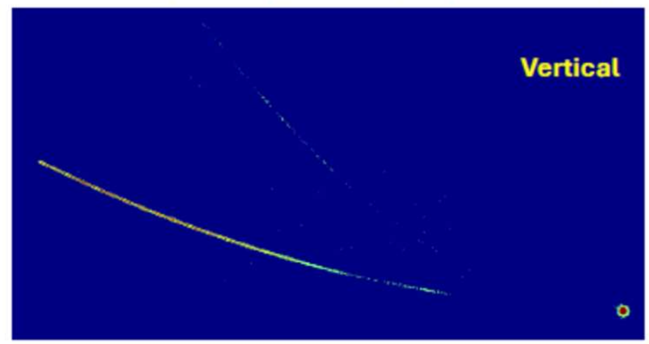
S1V_B_ Orient.n.rods +50 nm B_
-500 GDD_120.5 fs_189shot_bwd_(06.06.2025)



S1P_Orient.n.rods+170 nm PMMA_
-500 GDD_120.5 fs_350 shot_bwd_(06.06.2025)



S1P_Orient.n.rods+170 nm PMMA_
-500 GDD_120.5 fs_363 shot_bwd_(06.06.2025)



June. 2025

Laser beam is **horizontally** polarized !!!

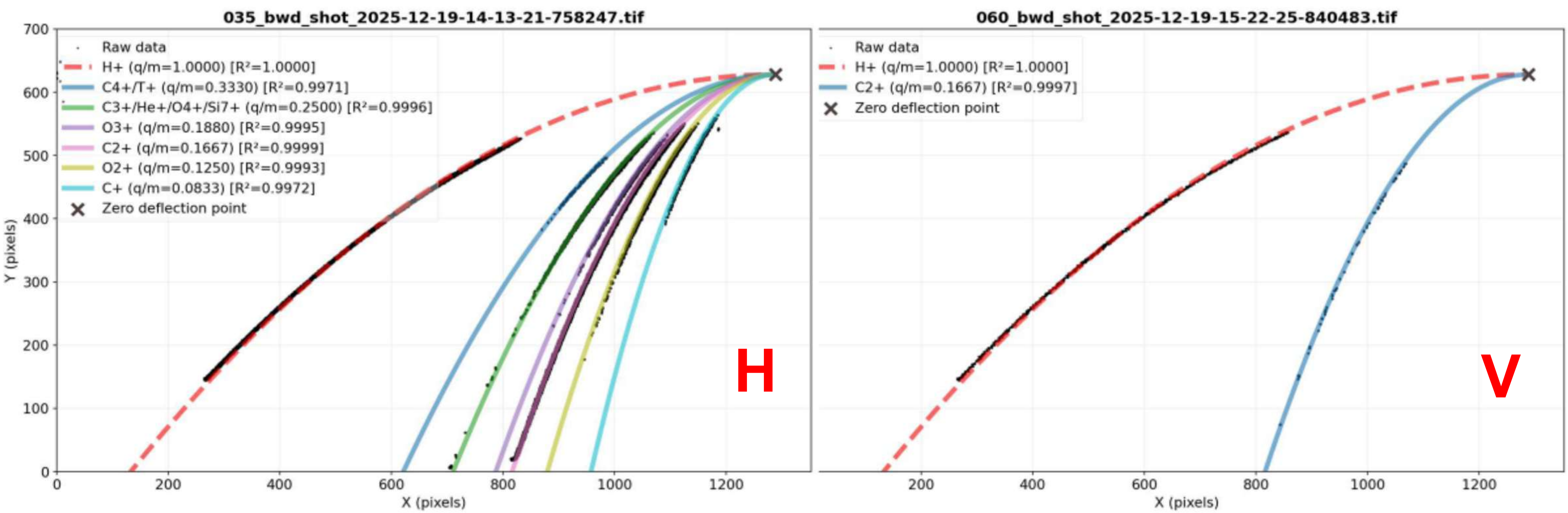
→

Nanorod antennas accelerate protons **horizontally** !!!

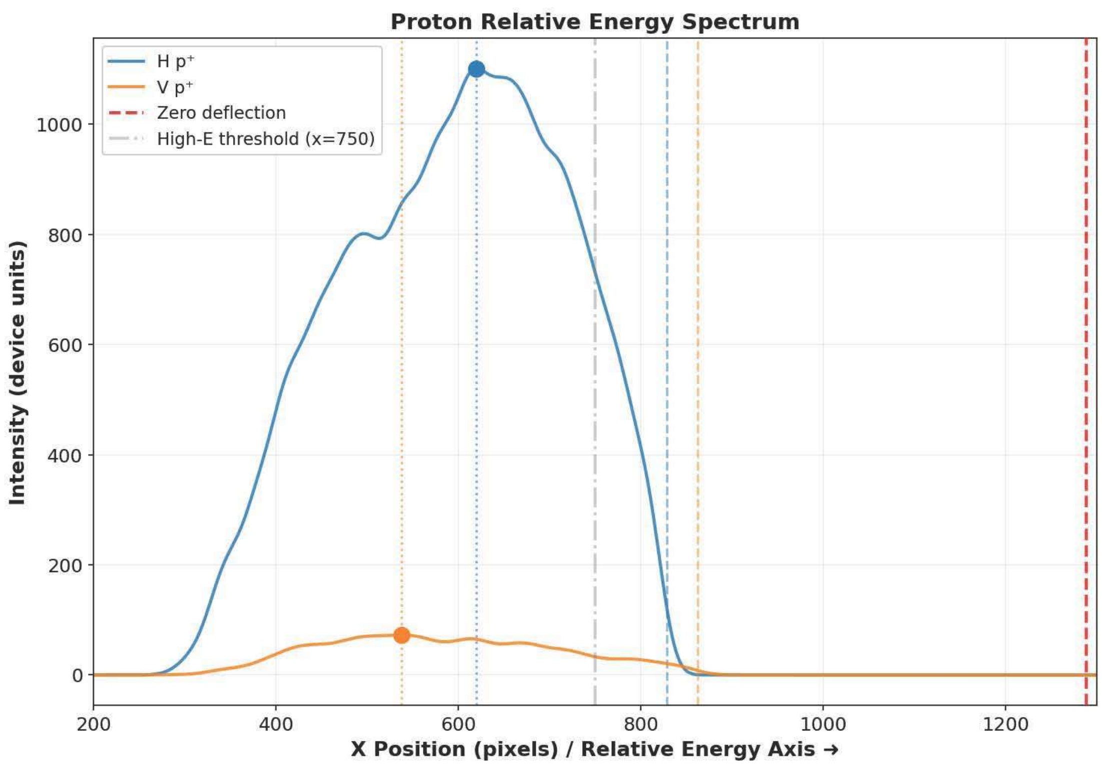
Imene Benabdelghani et al., (NAPLIFE Collaboration) @ ELI-ALPS: XIV ICNFP **July** 2025

Measured BWD TP Spectrum

The laser beam pulse energy was 30 mJ, the pulse duration was 120.5 fs, and the target thickness was 170 μm. The length of the nanorod antennas was 102 nm.

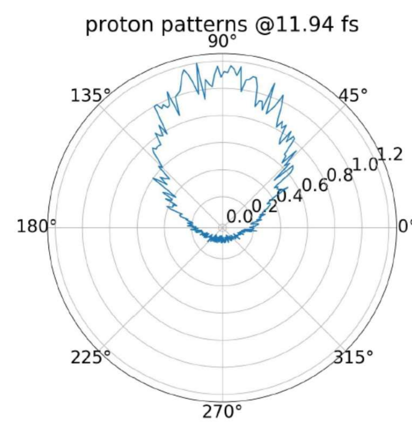


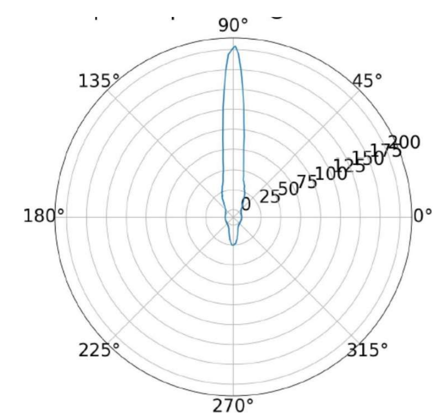
Measured BWD TP Spectrum

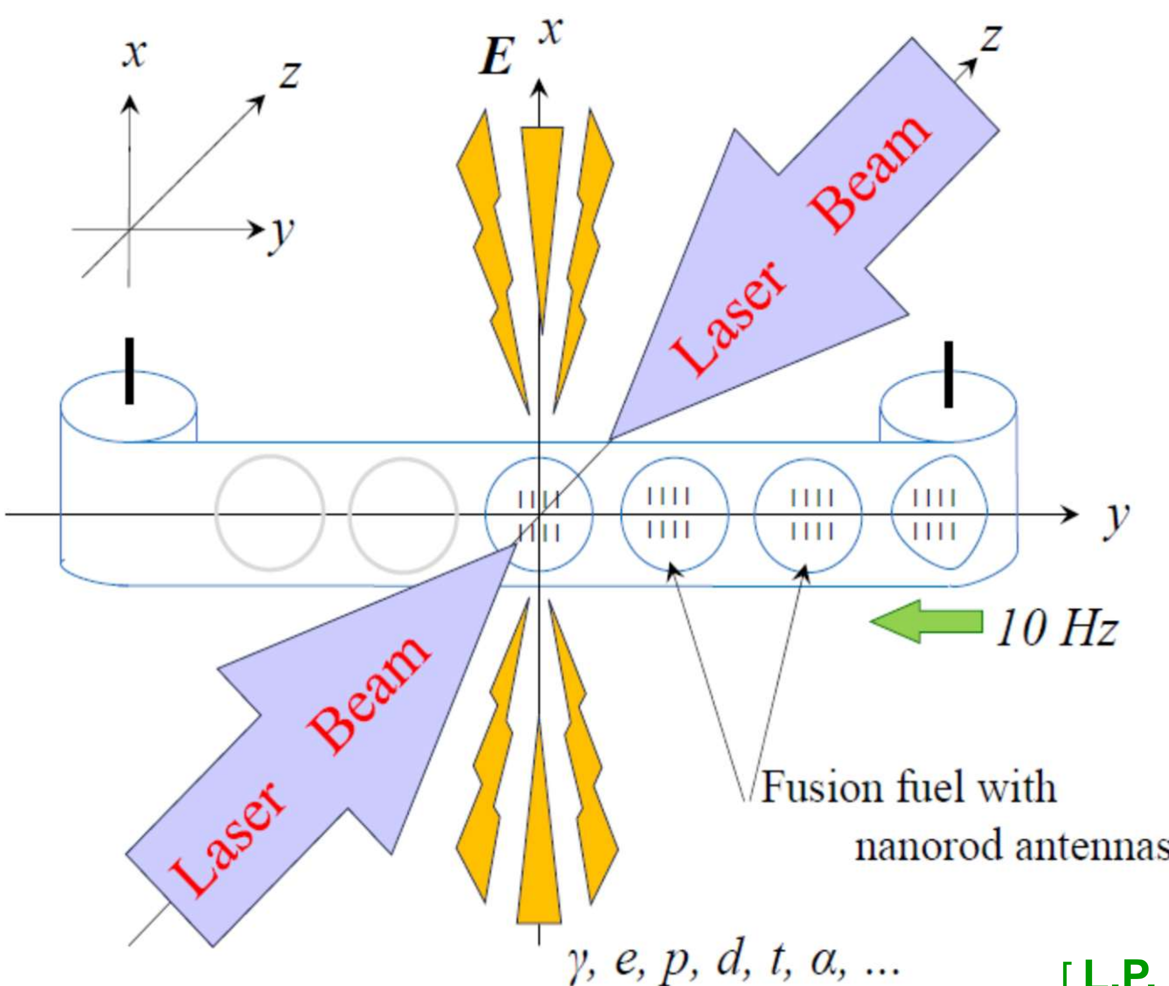


The **relative energy spectrum** of emitted **protons** with respect to the Zero deflection point energy after irradiation of targets with Horizontal (H, blue line) and Vertical (V yellow line) nanorod targets, measured by the BKW TP detector in the ***z*** -direction. The Horizontal target has nanorod antennas that are 45^0 from the polarization vector direction of the infalling laser light, while the Vertical target has nanorod antennas orthogonal to the polarization of the laser light. Partly parallel polarization leads to increased resonance and proton acceleration, both the energy and proton number are significantly larger in this case.

EPOCH PIC simulations by I. Papp (IJMPE 2026) ➔







Present antenna developments:
Phased Antenna Arrays
Elon Musk: STAR Link, 12k sat.
NAVY ship radars (Br/Re)

Industrial setup possible

[**L.P. Cs.**, Eur. Phys. J. Spec. Top. (2025), https://doi.org/10.1140/epjs/s11734-025-01466-6]

Industrial energetics

Ranges achievable at ELI-ALPS Szeged:

PRESENT ELI-ALPS : in: 8.5 J x 12 Hz = 100 W → if Q=10 ➔ out: **1kW**
Higher frequency : in: 8.5 J x 60 Hz = 500 W → if Q=10 ➔ out: **5 kW**
Higher laser pulse : in: 25 J x 50 Hz = 1250 W → if Q=10 ➔ out: **12.5 kW**
Higher Q value : in: 25 J x 50 Hz = 1250 W → if Q=100 ➔ out: **125 kW**

My Skoda Superb 2L diesel engine is: **100 kW**

LLNL NIF (400MJ **!**) : in ***2 MJ*** x (1/86400)Hz= **23.15 W, Q**$_{target}$=5 ➔ out: **115.75 W**
=1/day (= **$ 100 000**/day)

Next step industrial development: at **Paks 1 VVER 440 MW** (now 500) is 50yrs. **Reactor vessel** could be replaced (like **Biblis** near FfM by M. Roth et al.) secondary circuit may still be operational.

CONCLUSIONS

- Plasmonic amplification is verified
- Proton acceleration is verified
- Formation of Deuteron nuclei is verified
- $p + ^{11}B$ fusion reaction is detected
- Proton acceleration Parallel to laser polarization is verified

Contrary to the fact that

- Only 40 mJ laser pulse energy was used
- Only one-sided laser irradiation was available

planned progress for NAPLIFE & FUSENOW (Bergen)

- **~10 Joule** project is planned, directed thick target (A. Bonyár)
- Massive, directed $p + ^{11}B$ fusion is expected

Thanks for your attention