



NANOTECHNOLÓGIÁVAL A MAGFÚZIÓS ENERGIATERMELÉSÉRT

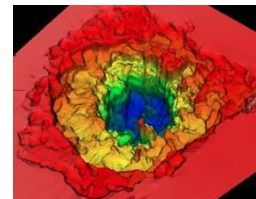
Kroó Norbert
(a NAPLIFE program nevében)
HUN-REN Wigner Fizikai Kutatóközpont és
Magyar Tudományos Akadémia

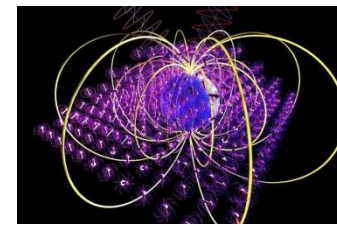
*Motto: Csak azok tudják, hogy milyen messzire
mehetünk, akik készek túl messzire menni.*



NEMZETI
LABOR

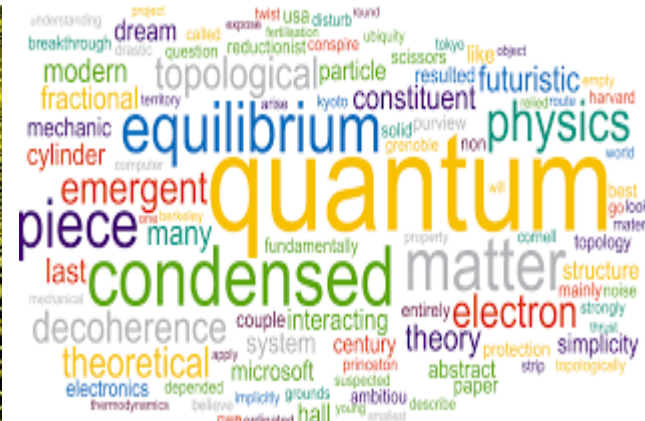
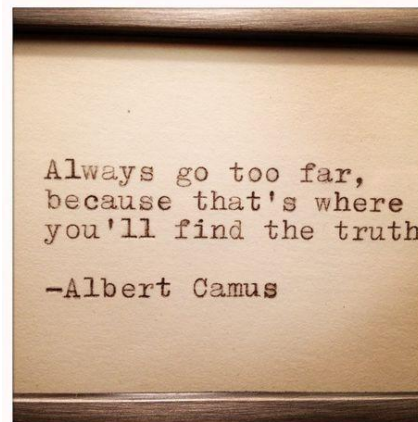
PBK ENERGIA, 2024.09.16





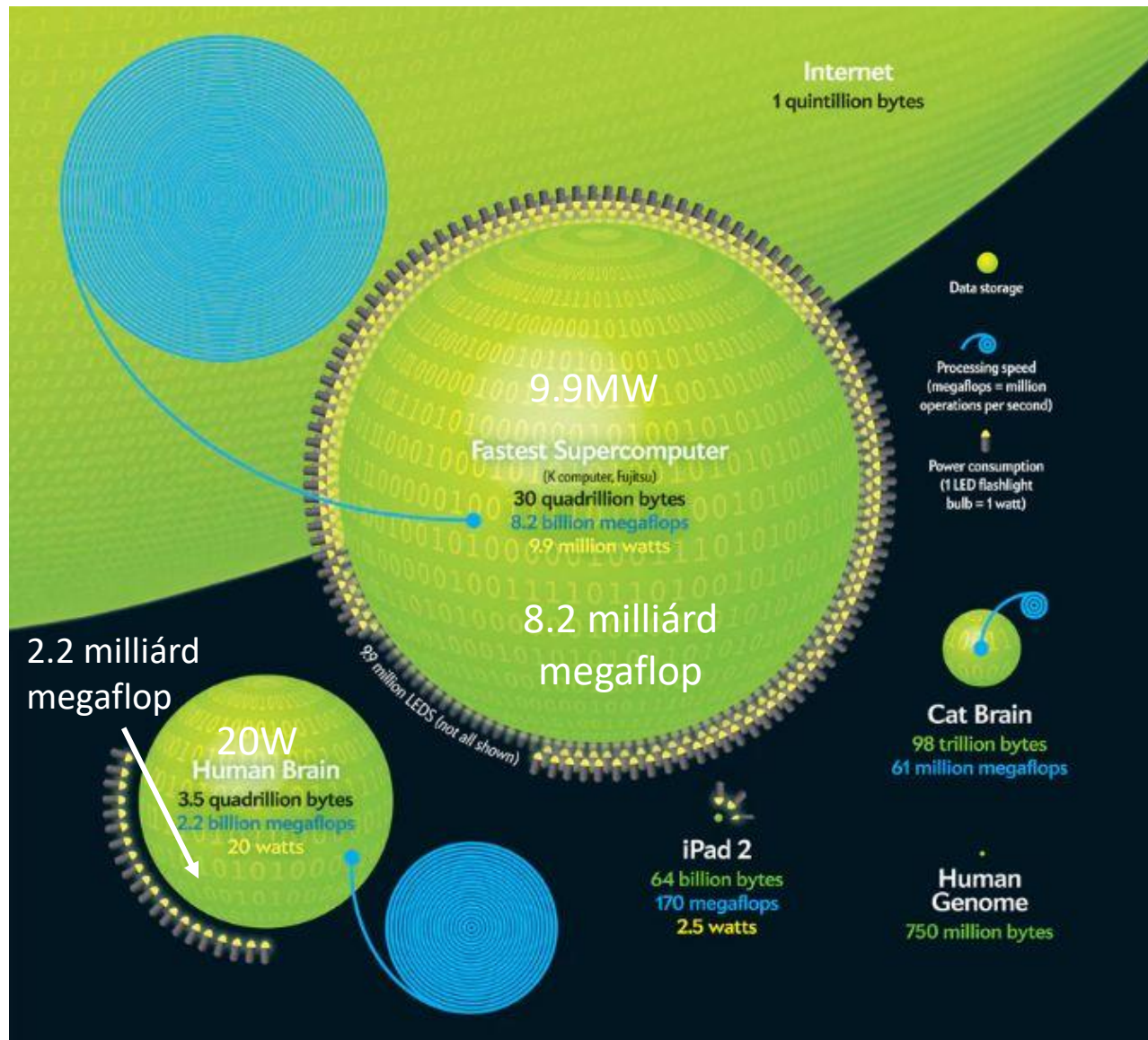
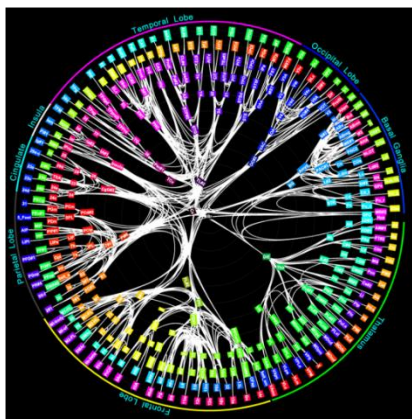
A MIKRO- ÉS NANOVILÁG

KORUNK 5 LEGÍGÉRETESEBB TECHNOLOGIAI FORRADALMA

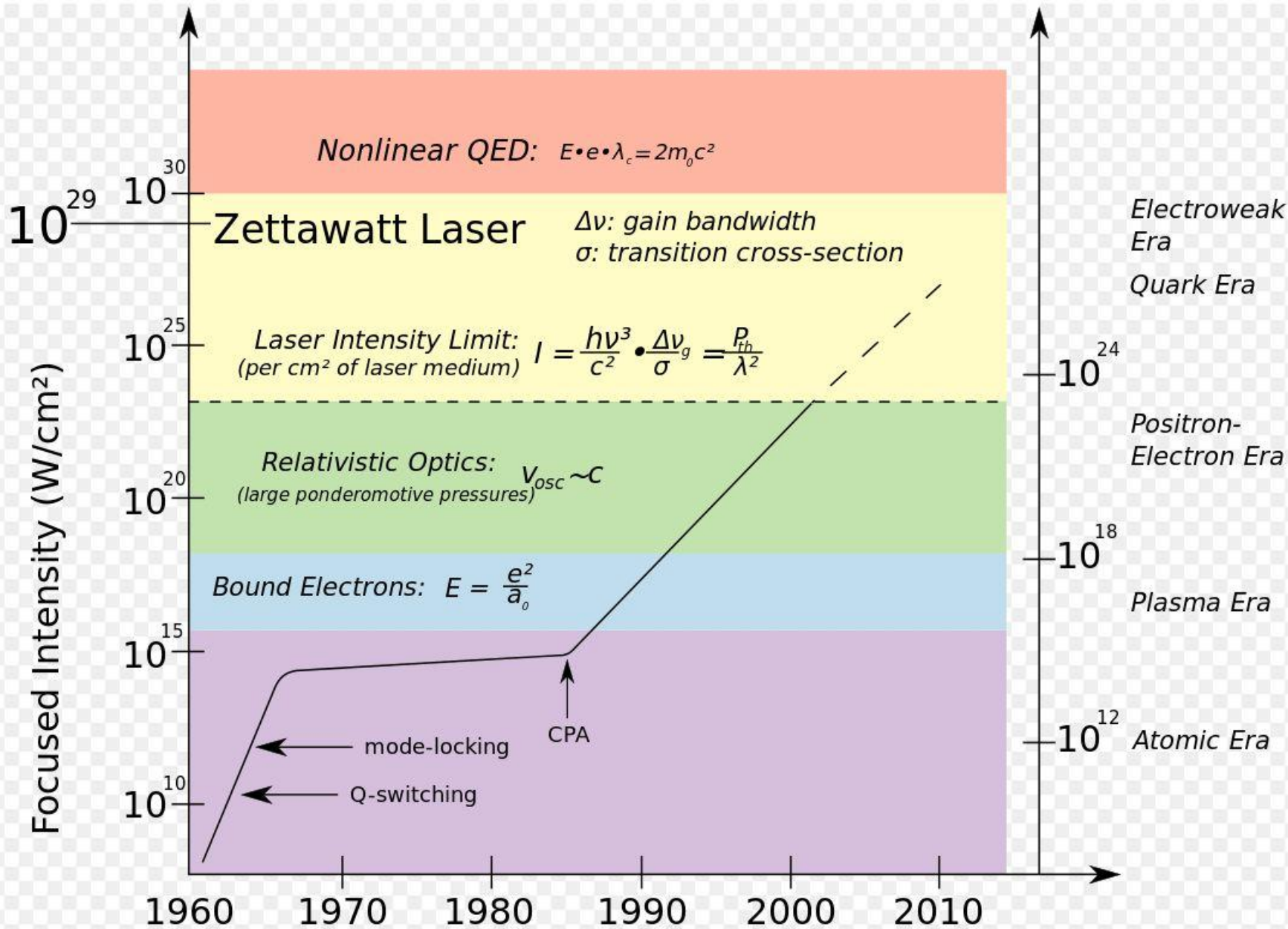


A TERMÉSZET UTÁNZÁSA!

KÜLÖNBÖZŐ AGYI KAPACITÁSOK ÉS SZUPER SZÁMÍTÓGÉP PARAMÉTEREI



Cél az agyi idegműködéshez jobban hasonlító technológia. (IBM TrueNorth chip 1millió neuront és 256 millió szinapszist szimulál és egy összemérhető teljesítményű tradicionális csipnél tízezerszer kevesebb energiát használ) **Memriszorok (nanoszálak)?**



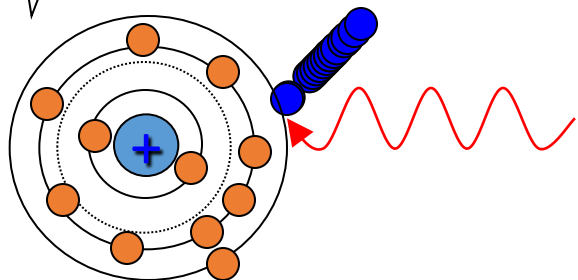
Anyag extrém körülmények között



$$I = 10^{16} \text{ W cm}^{-2}$$

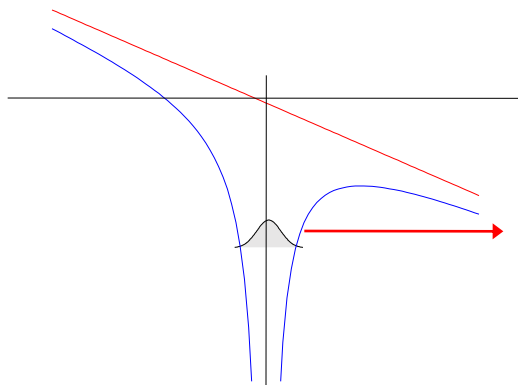


$$E \sim 10^9 \text{ V/cm}$$



Nagy intenzitás:
Fotoelektromos
effektus

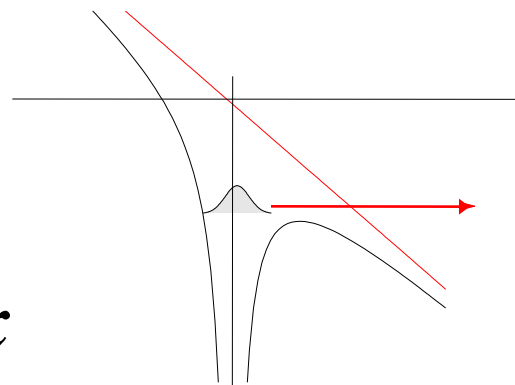
A vezetési elektronok gyors ionizációja



Tunnellezés

$$10^{14} - 10^{15} \text{ W cm}^{-2}$$

$$V = -\frac{q}{x} \pm E \cdot x$$

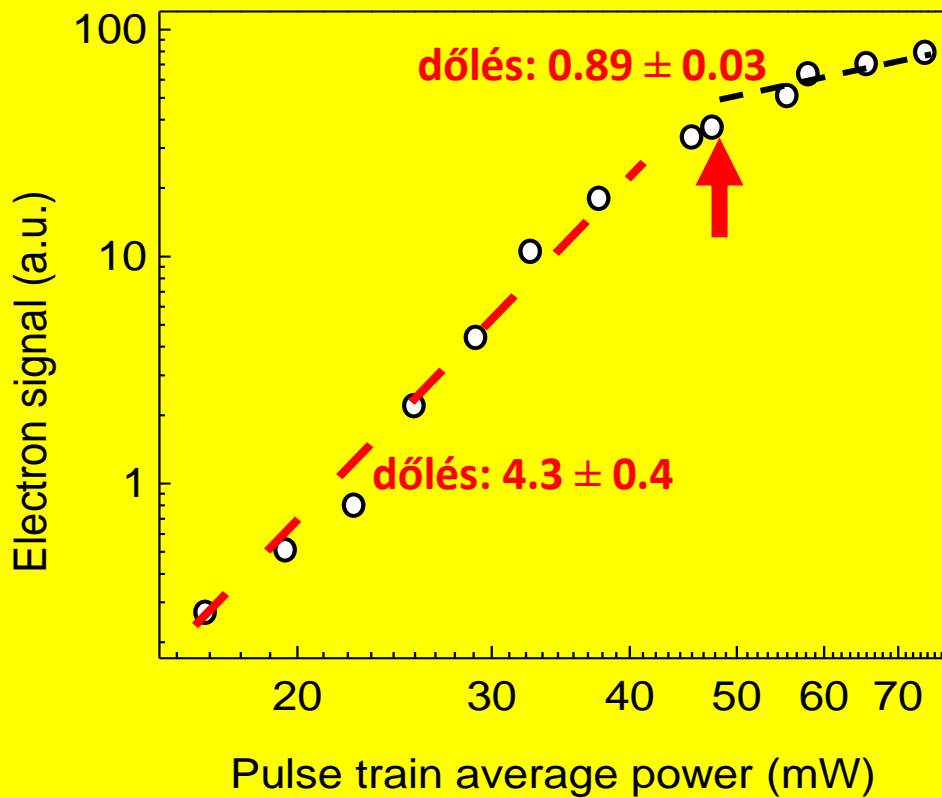


A barrier felett

$$> 10^{15} \text{ W cm}^{-2}$$

Minden atom elveszít legalább egy elektront. Egyesek akár hatot !

Multifoton elektron emisszió aranyból



Multifoton-alagút átmenet

$\sim 4 \times 10^{10} \text{ W/cm}^2$ beeső lézer intenzitásnál,
 $\sim 5.5 \times 10^8 \text{ V/m}$ térnél

Keldysh-gamma $\gamma=31$

→ ez is mutatja a jól ismert, a felületi plazmonok okozta óriási térerősítést.

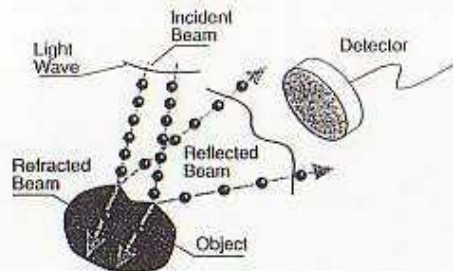
PLAZMONIKUS ERŐSÍTÉS!

W : kilépési munka, E_l : lézerfény térereje

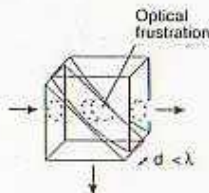
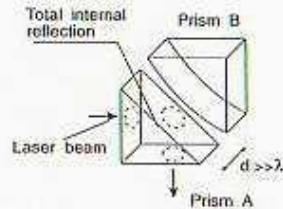
$$\gamma^2 = \frac{W}{2U_p} = \left(\frac{\omega \sqrt{2mW}}{eE_l} \right)^2$$



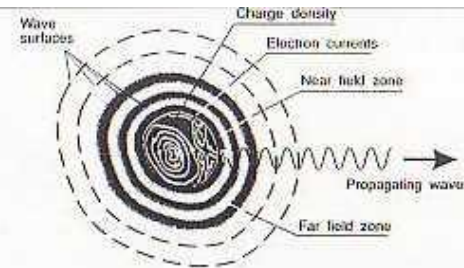
AZ OPTIKAI KÖZELI TÉR



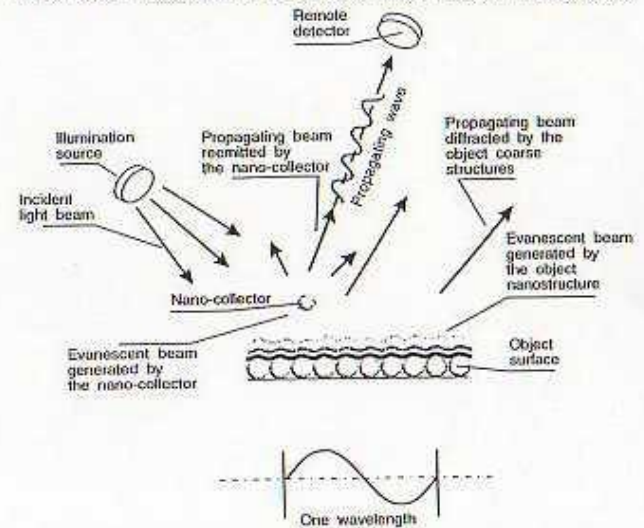
Schematic of the interaction between an object and a light beam. In first approximation, the light beam can be considered as projectiles launched against a target (the object) and then reflected towards the detector. This interpretation is primitive but provides the basis for the understanding of the notion of image.



The famous experiment of Newton. A light beam is projected onto a prism. As expected, the beam is internally and totally reflected on the larger side of the prism. If a second prism is brought to the first one, no effect is detected unless the distance between the two prisms becomes smaller than a fraction of a micron. The light beam then seems to be captured by the second prism, frustrating the total reflection. The beam intensity transmitted through the second prism depends exponentially on the distance d .



Field emitted from an object. The electron currents (in the case of conducting materials) and the charge densities inside the object induce an electromagnetic field radiating from the surface. Far away from the surface the field has the well known structure of propagating waves. Very close to the object (the region of the question mark), the field has a more complex structure since it is composed of propagating and non-radiating components.



Sketch of near field detection. Step 1: generation of the object near field by the illumination process. A light source illuminates an object represented as composed of discrete components. These components are excited by the incident field and re-emit light. The waves associated to the reflected beam are composed of evanescent waves confined on the object surface and of propagating waves. If the periodic structures of the object are smaller than the wavelength (it is the case of the figure), the reflected field, far away from the object, does not contain any information on the fine structure of the object. Step 2: detection of the near field. For detecting the subwavelength object information, a small scattering centre (the nano-collector) is brought close enough to the object surface. The near field lying on the surface will excite the scattering centre which will re-emit light. The re-emitted light is again composed of evanescent waves (non-detectable) and propagating ones which can propagate far away to the remote detector.



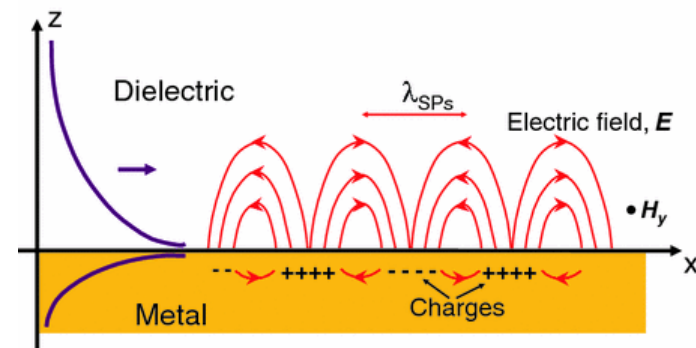
PLAZMONIKA

A fény hosszú hullámhossza ($\approx \mu\text{m}$) probléma az **optoelektronika** nanométeres méretek felé való kiterjesztésében.

Egy lehetséges kiút: a fény konverziója **plasmonokká**. Ezek **hullámhossza sokkal rövidebb** lehet a fényénél és elektronikus jeleket hordozhatnak.

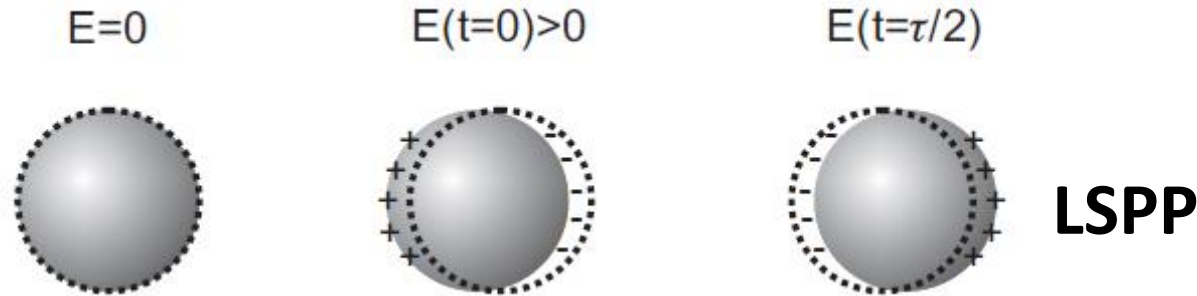
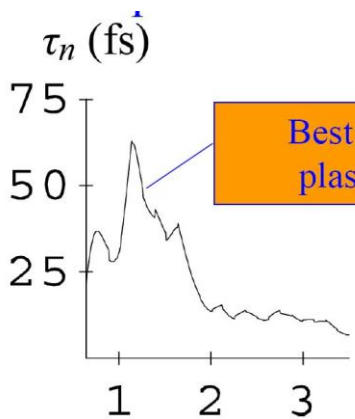
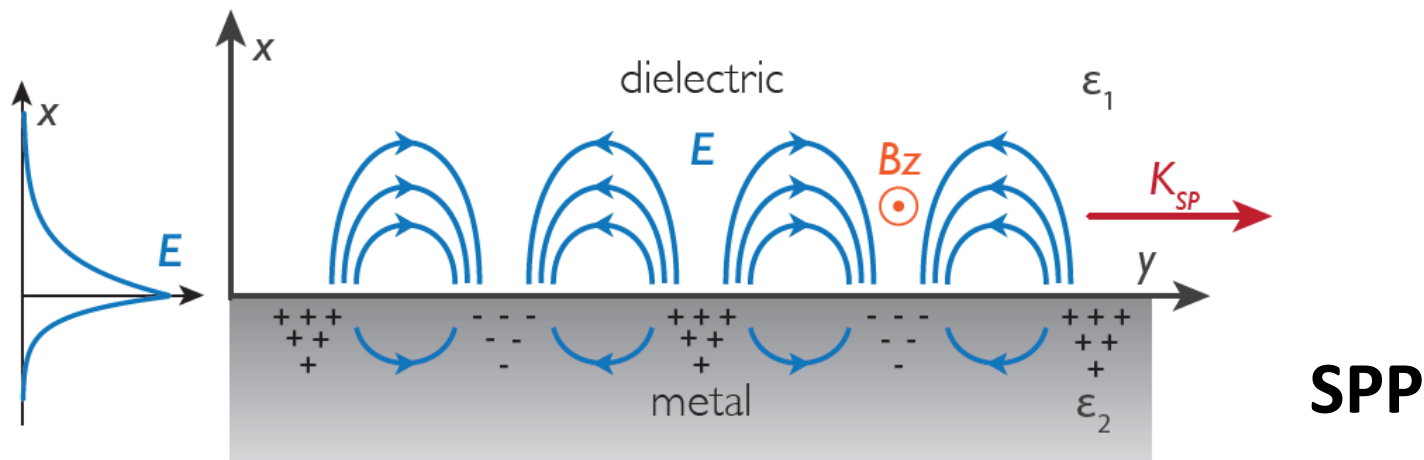
Kompenzálják a **gyenge** foton-foton kölcsönhatást

A NANOVILÁG OPTIKÁJA
(számos további előnnyel)



PLAZMONOK MINT SPECIÁLIS ESET

Ez az előadás: példa a plazmonikus speciális tulajdonságok alkalmazására

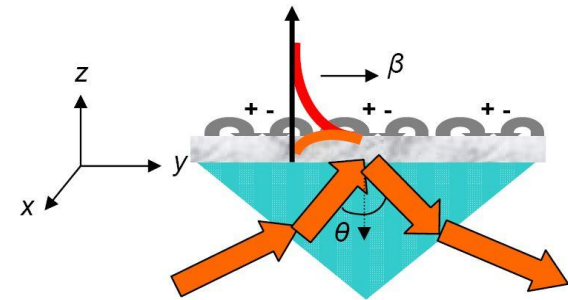
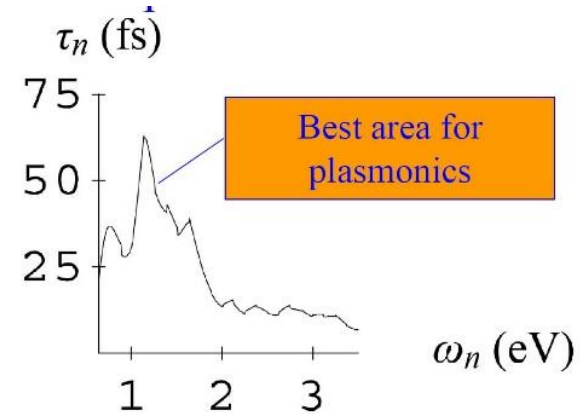
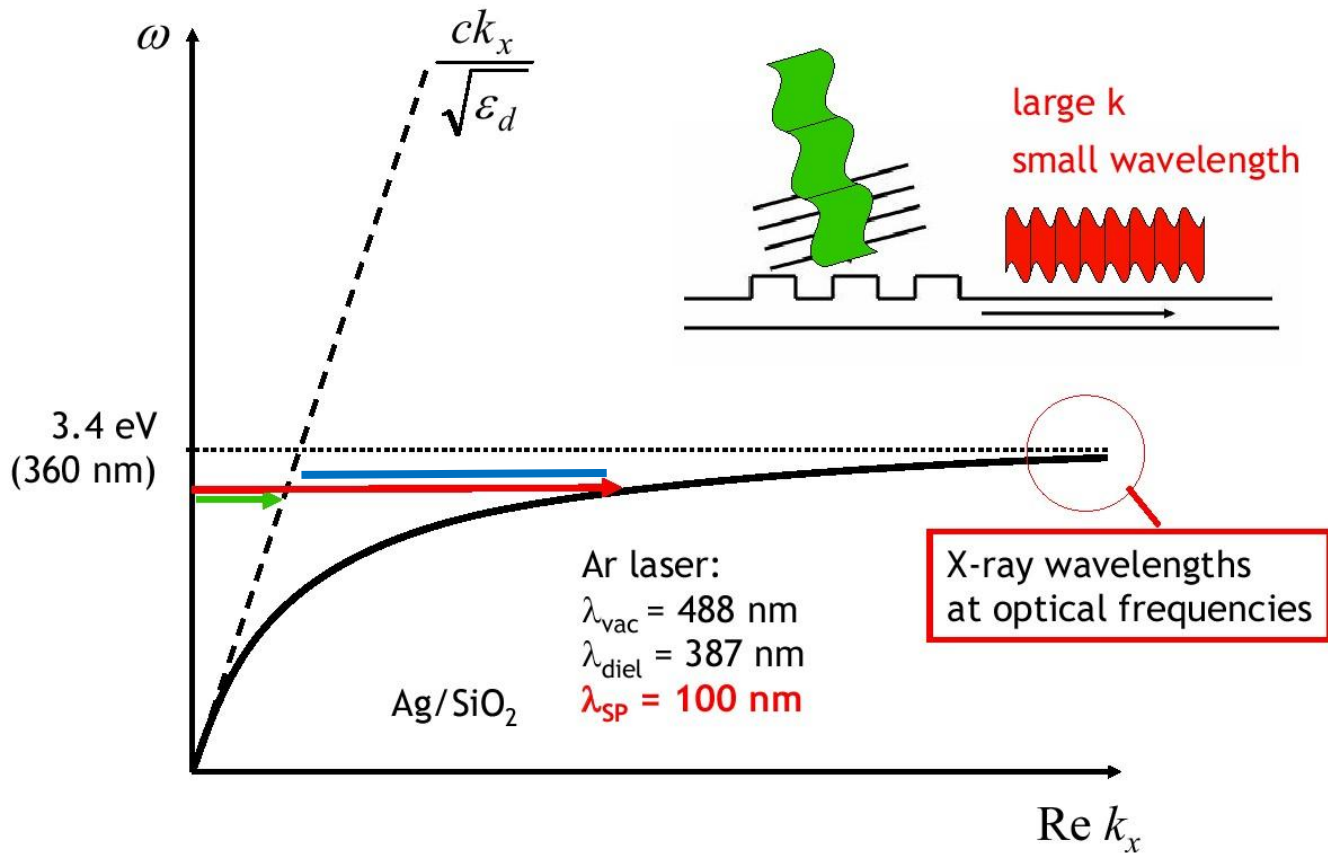


Ti:Sa lézer: $\lambda=800\text{nm}$ ($\sim 1.55\text{eV}$) ; $t_{(SPP)} \sim 30\text{fs}$



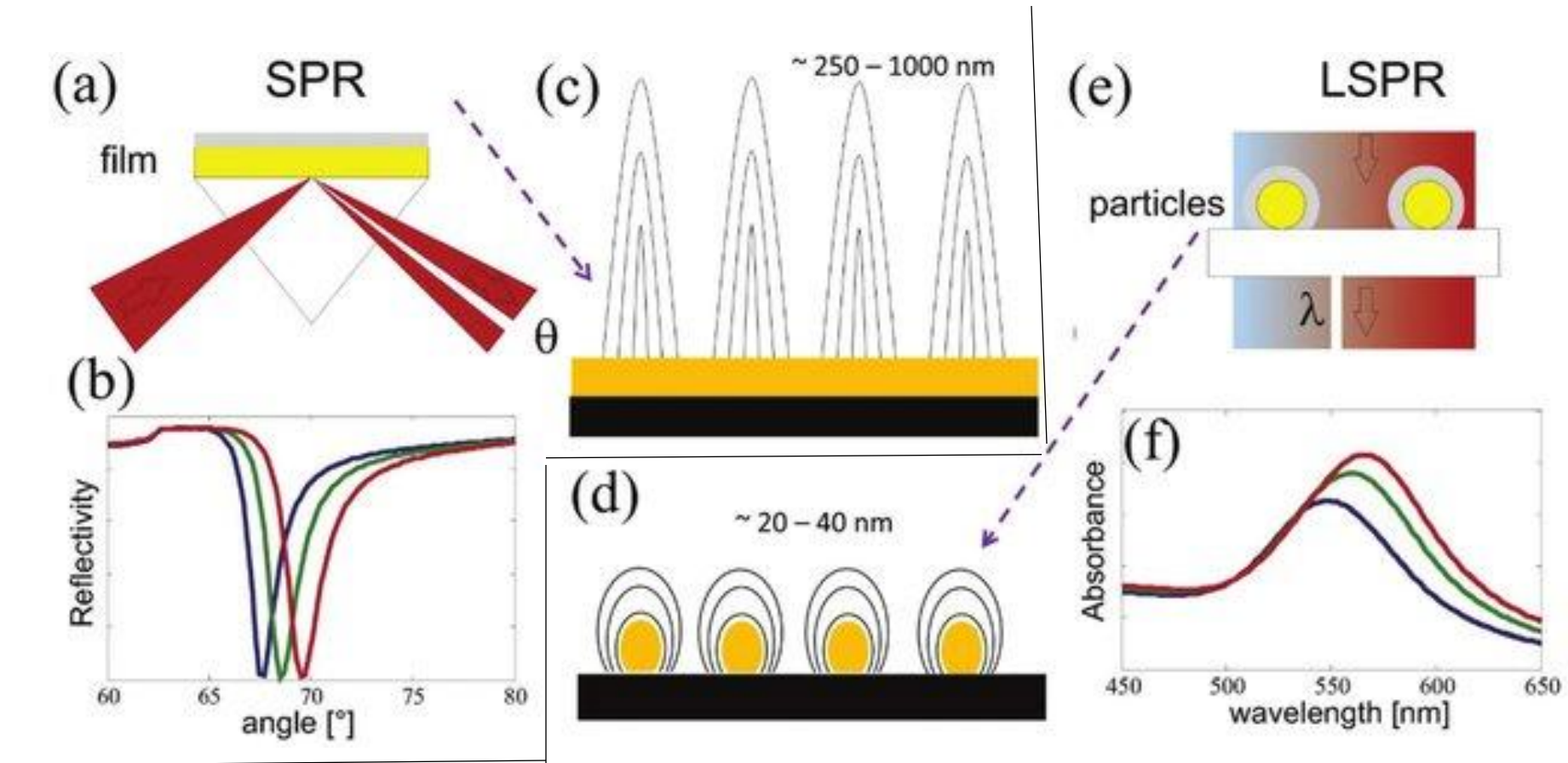
SURFACE PLASMON POLARITONS (SPP)

Surface plasmons dispersion:
$$k_x = \frac{\omega}{c} \left(\frac{\epsilon_m \epsilon_d}{\epsilon_m + \epsilon_d} \right)^{1/2}$$



LOKALIZÁLT PLAZMONOK (LSPR) 10^{20} W/cm²-ig)

(Az alapvető különbség a felületi és lokalizált plazmonok között)



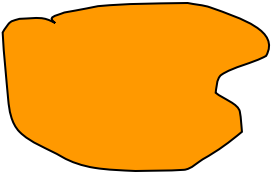
LSPR:- NINCS BEHATOLÁS A PLAZMONIKUS ANYAGBA (e.g. fémbe)


- KISEBB BEHATOLÁS A DIELEKTRIKUMBA /VÁKUMBA

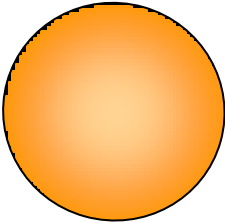
-NINCS DISZPERZIÓ

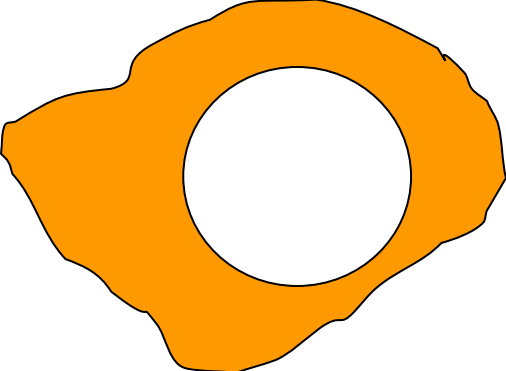
-SZÉLESEBB REZONANCIA

NANORÉSZECSKÉK PLAZMONREZONANCIÁJA ALAK - ÉS MÉRETFÜGGŐ!

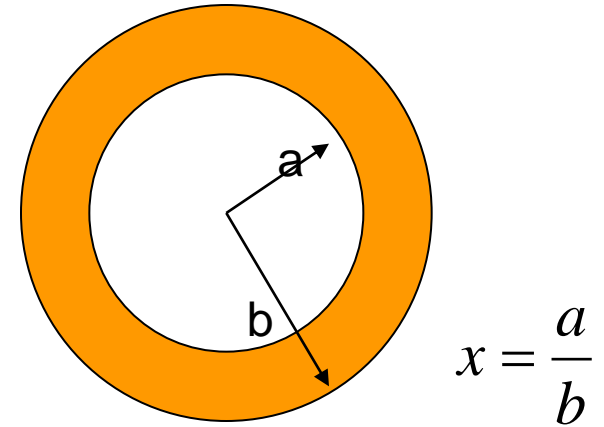
$\omega_B = \sqrt{\frac{4\pi e^2 n}{m_e}}$  Bulk

$\omega_{surf} = \frac{\omega_B}{\sqrt{2}}$  Felület

$\omega_{S,l} = \omega_B \sqrt{\frac{l}{2l+1}}$  Gömb

Üreg  $\omega_{C,l} = \omega_B \sqrt{\frac{l+1}{2l+1}}$

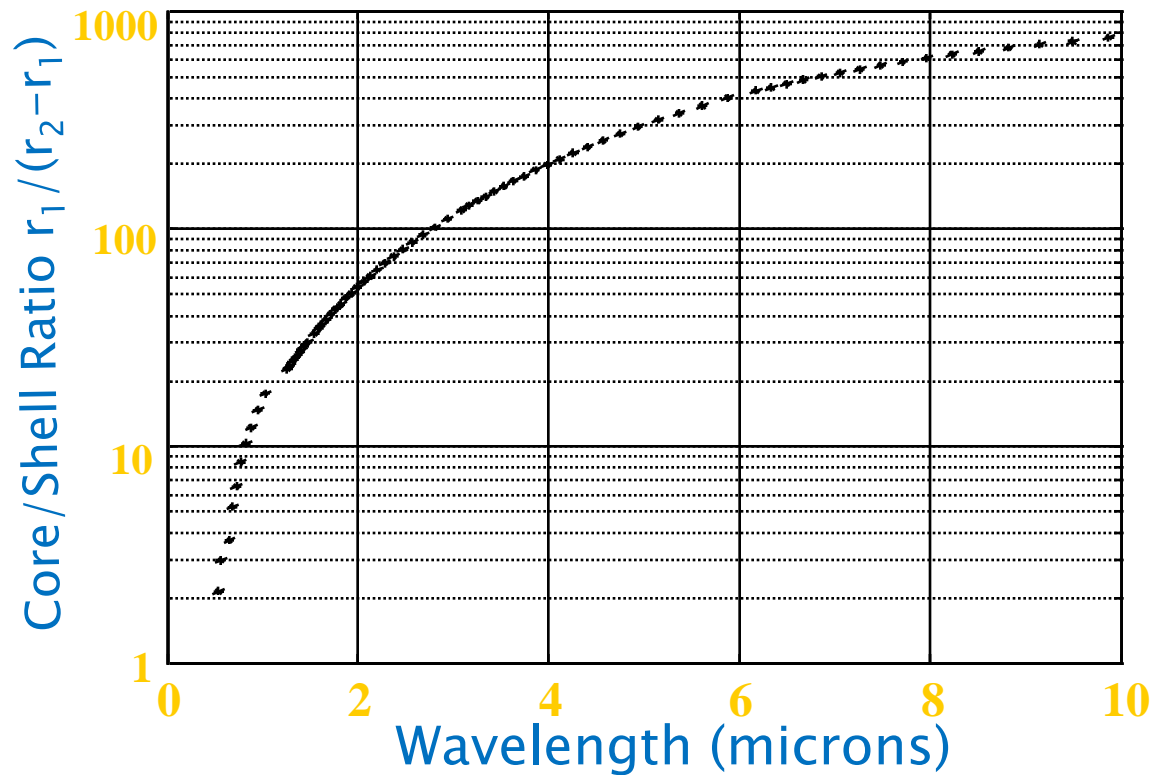
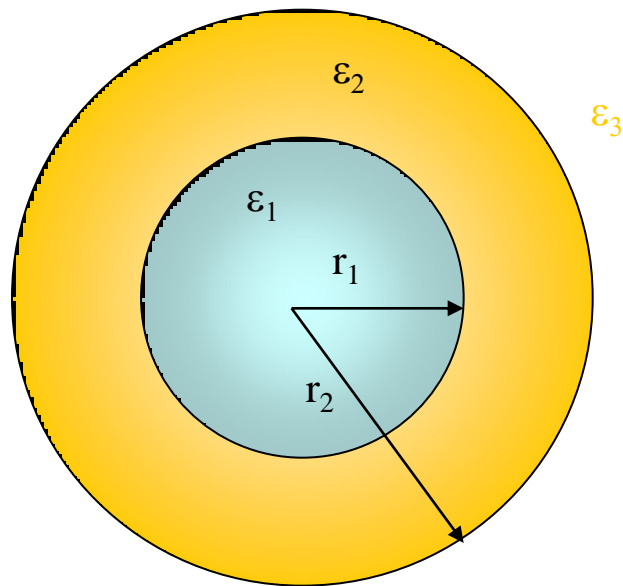
Nanohéj:



$$\omega_{l\pm}^2 = \frac{\omega_B^2}{2} \left[1 \pm \frac{1}{2l+1} \sqrt{1 + 4l(l+1)x^{2l+1}} \right]$$

**Nanohéj plazmon
rezonanciája
az x aránytól függ .**

Spektrális hangolási tartomány (nanohéj plazmon rezonancia)

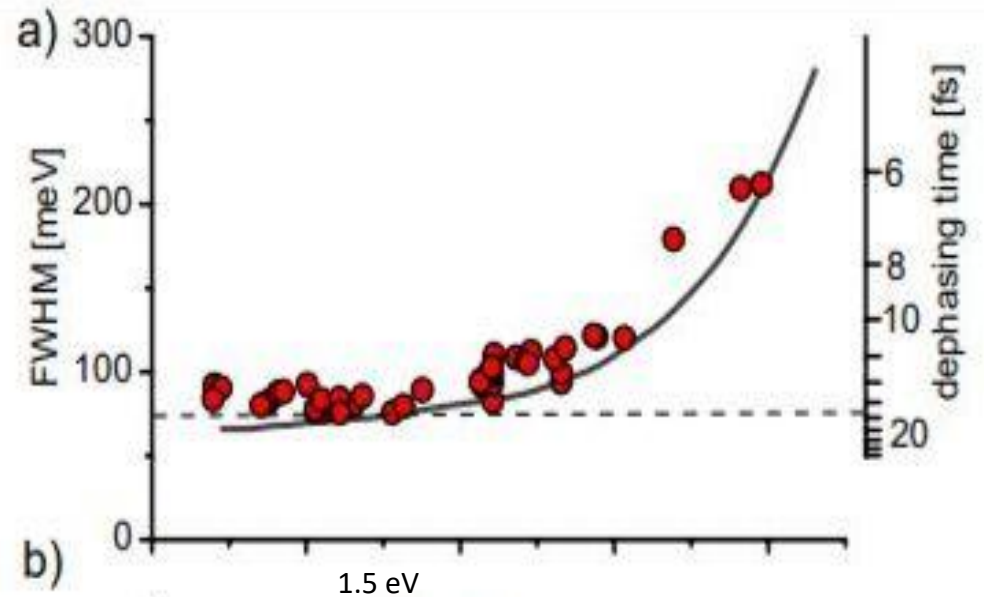
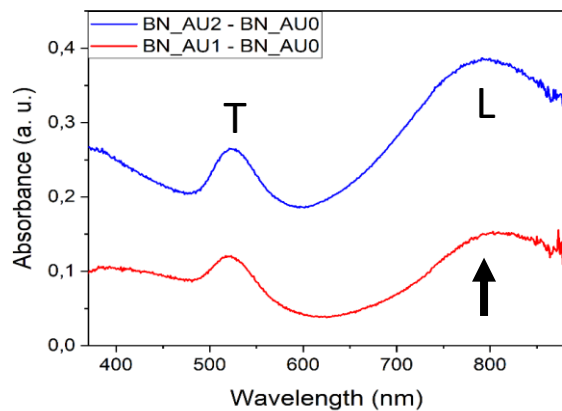
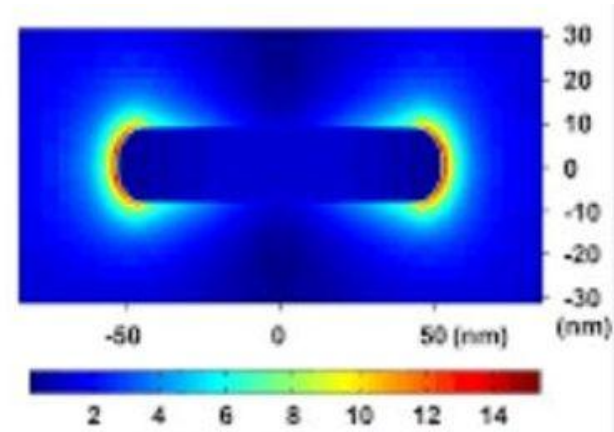
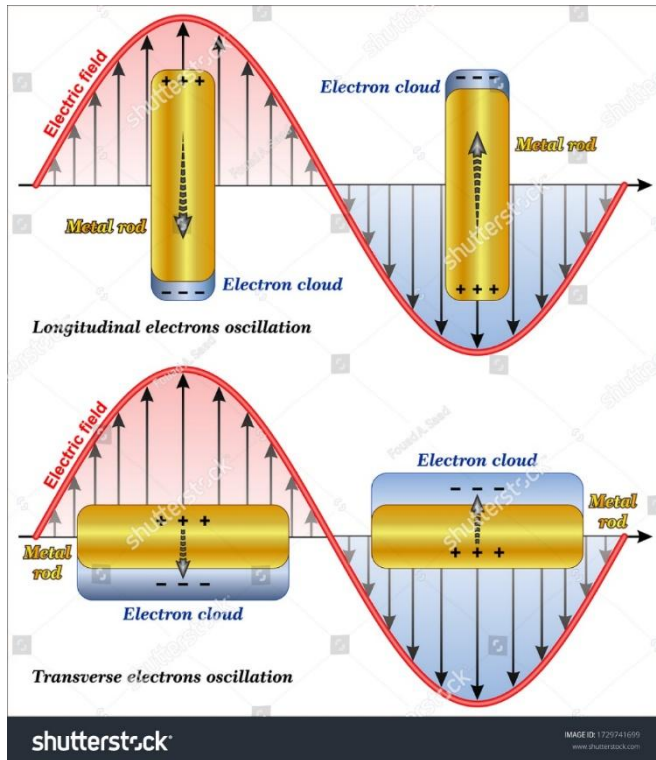


1.24 ← electron volts → 0.124

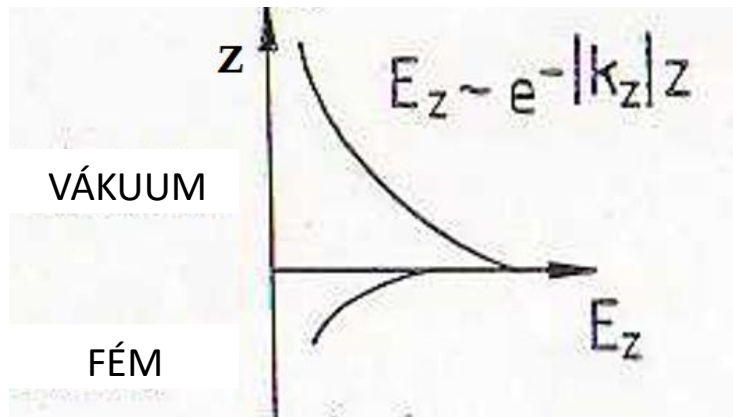
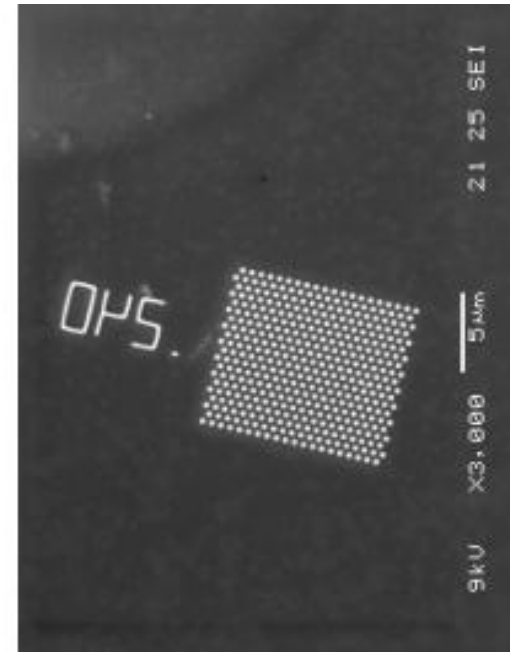
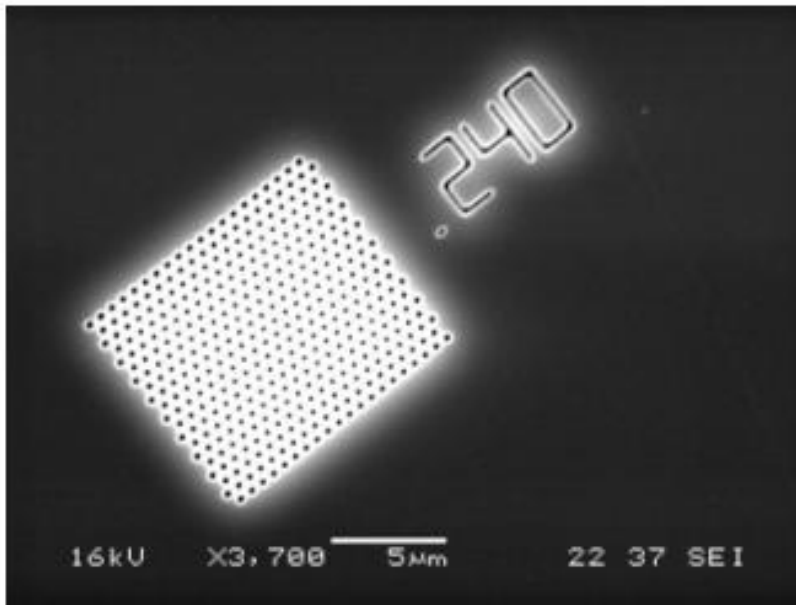
300 ← THz → 30

10,000 ← cm^{-1} → 1,000

Nanorúd: Transzverzális és longitudinális módusok!

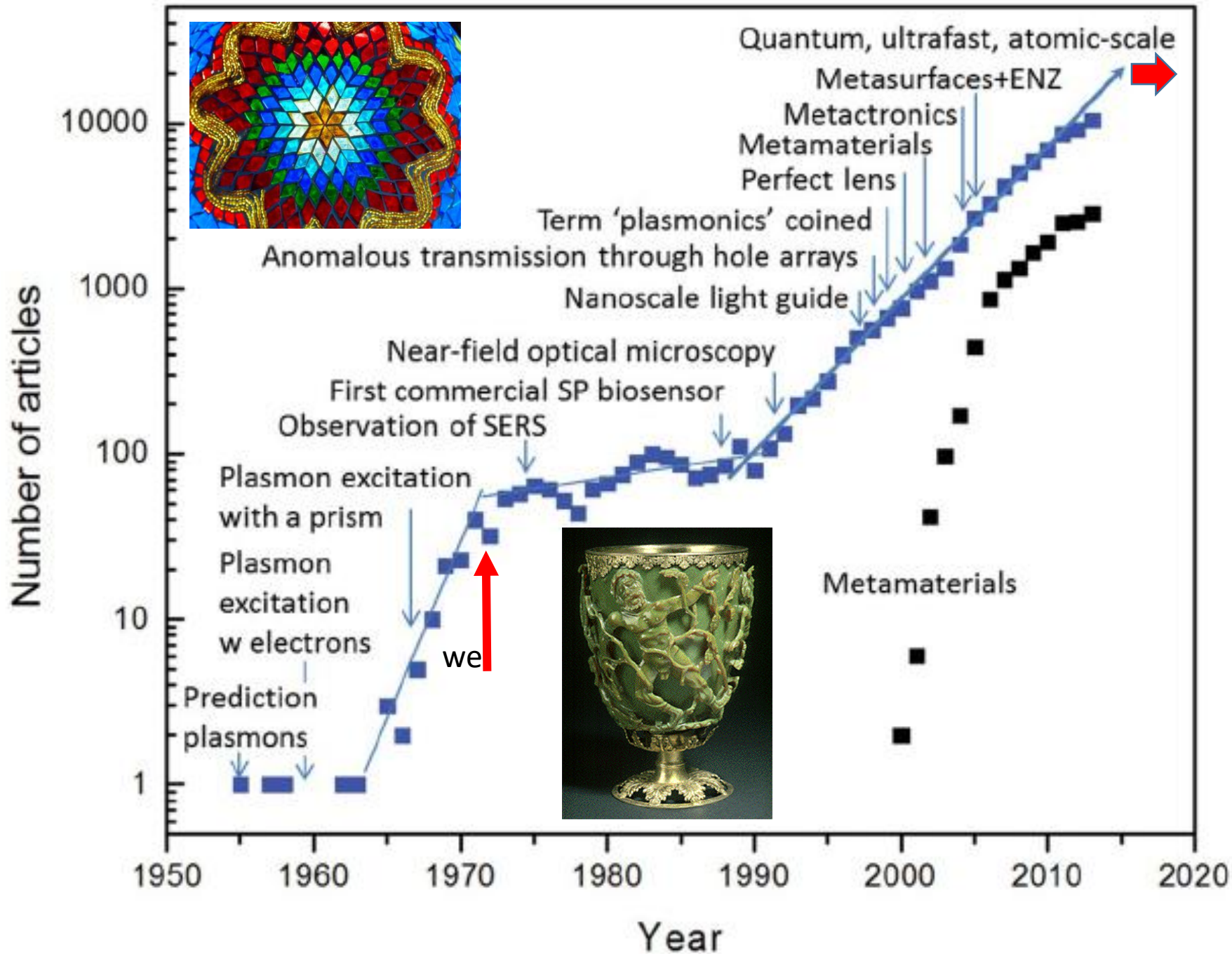


A fény a hullámhosszánál sokkal kisebb méretű lyukakon (réseken) is áthalad



AZ ENERGIA ZÖME A FELÜLETRE
KONCENTRÁLÓDIK: ÓRIÁSI TÉR ERŐSÍTÉS

NAGYSZÁMÚ POTENCIÁLIS ALKALMAZÁS.



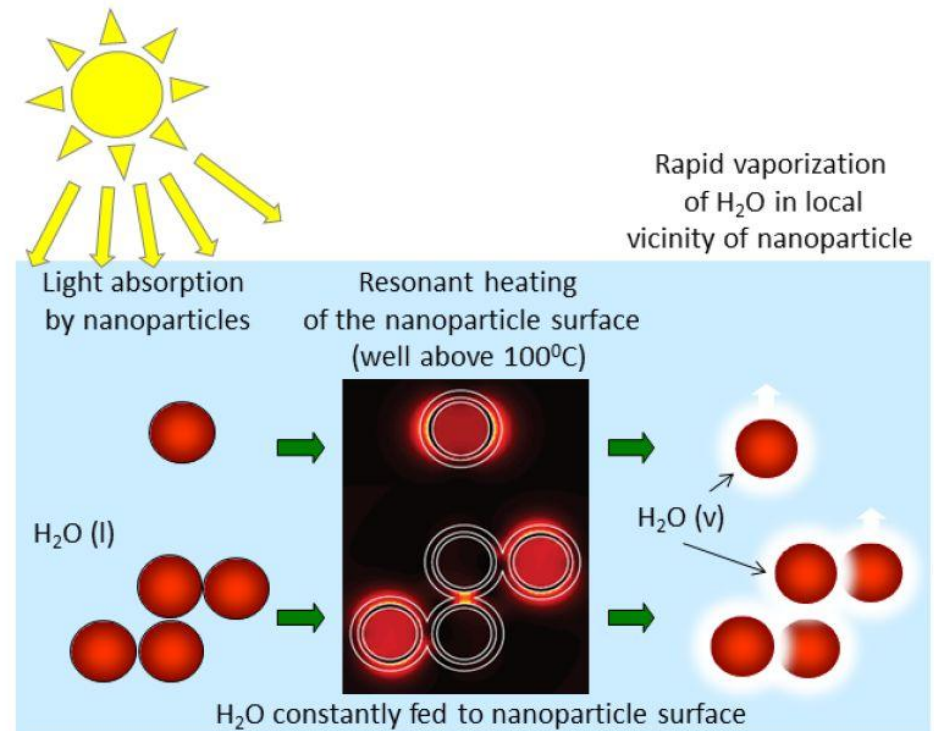
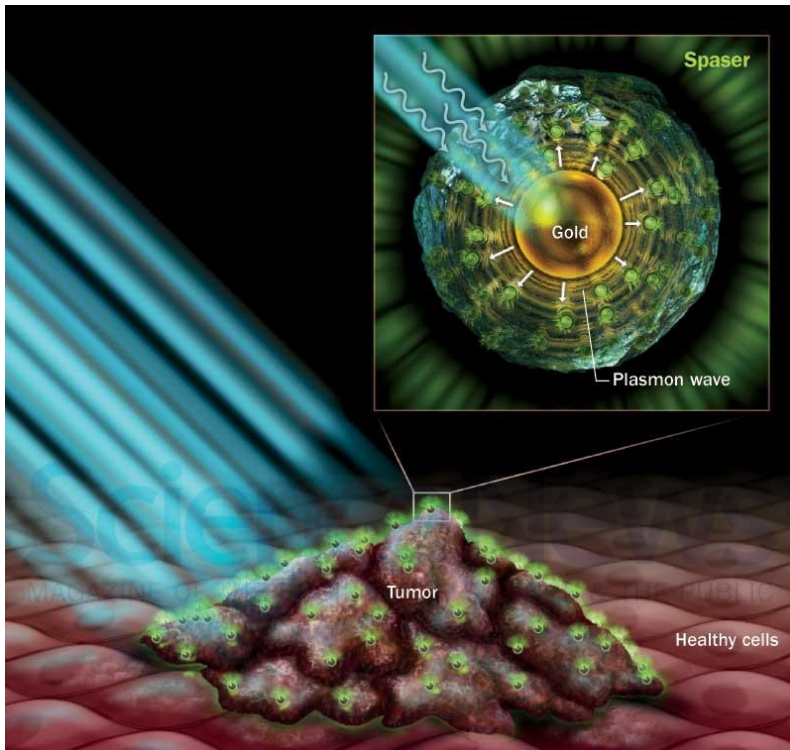
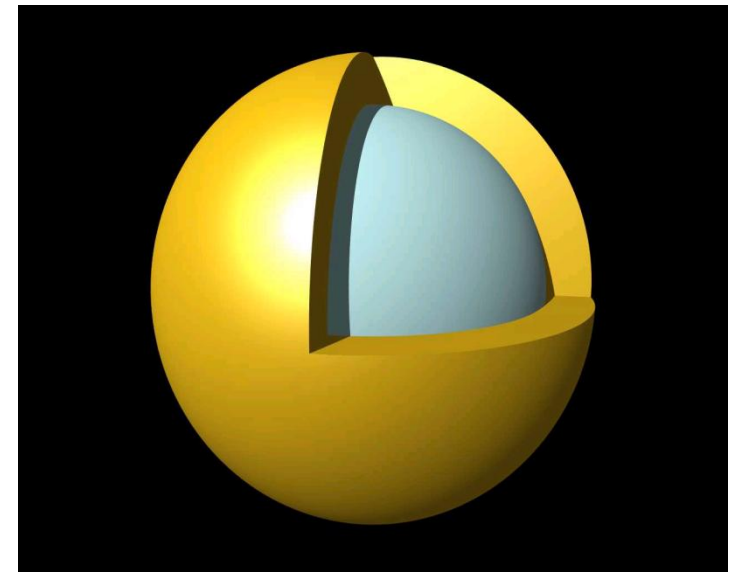
A FÉMOPTIKA HAJNALA :

EGY „ÚJFAJTA FÉNY”: FELÜLETI PLAZMON

POLARITONOK (SPO) AMELYEK:

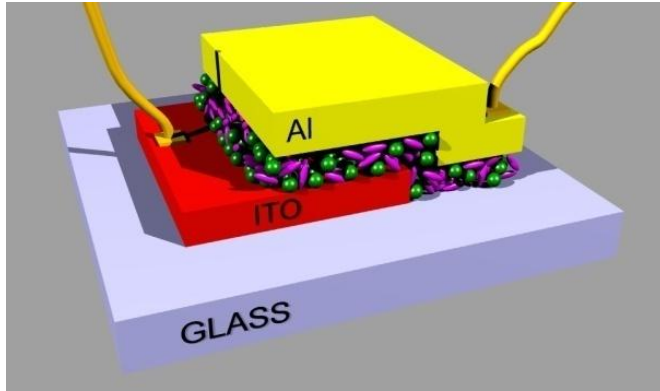
- 1.A (FÉM)FELÜLETHEZ VANNAK KÖTVE,**
- 2 SPECIÁLIS DISZPERZIÓVAL BÍRNAK,**
- 3.TULAJDONSÁGAIKAT NEM KORLÁTOZZA A DIFFRAKCIÓS LIMIT,**
- 4.A FELÜLETEN VEZETHETŐK,**
- 5.IGEN NAGY ELEKTROMOS TERÜK VAN,**
- 6.SPO TILTOTT SÁV HOZHATÓ LÉTRE,**
- 7.LOKALIZÁLÓDhatnak (pl.fém nanogömbökön)**
- 8.INTERFERENCIAÁRA KÉPESEK**
- 9.NEMLINEÁRIS JELENSÉGEK FORRÁSAI**
- 10.NEM KLASSZIKUS TULAJDOSÁGOKAT IS MUTATNAK**

Nanohéjak a rákterápiában és az energiatermelésben

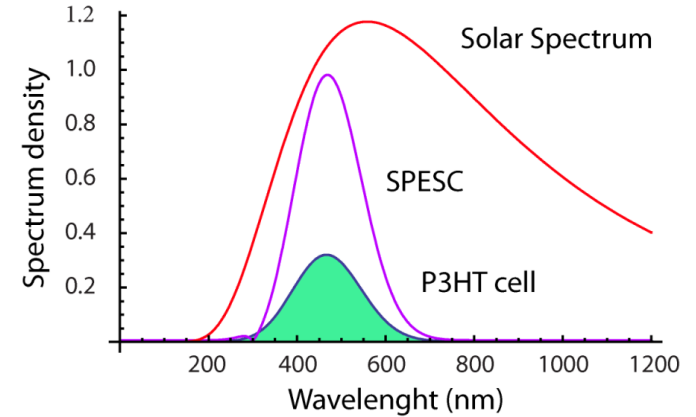


Potenciálisan új energia technológiák

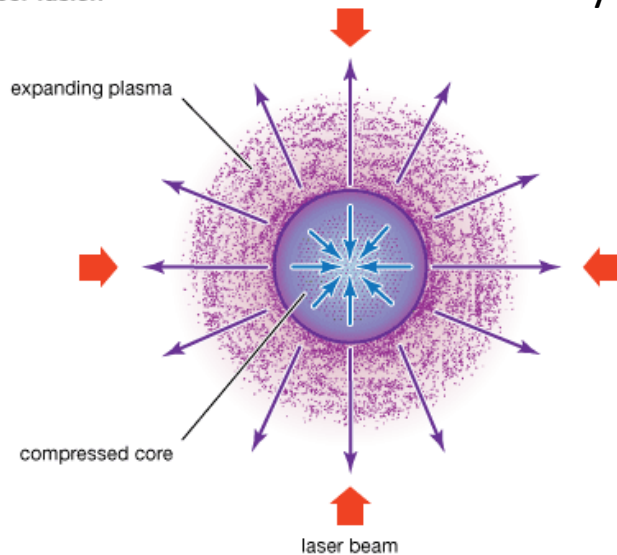
(nanotechnologiai elemekkel)



P3HT Cell
hatásfok = 6%
SPESC (P3HT)
hatásfok = 17.5%

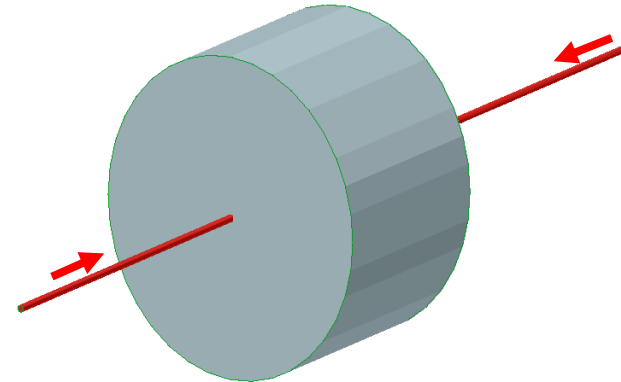


Laser fusion



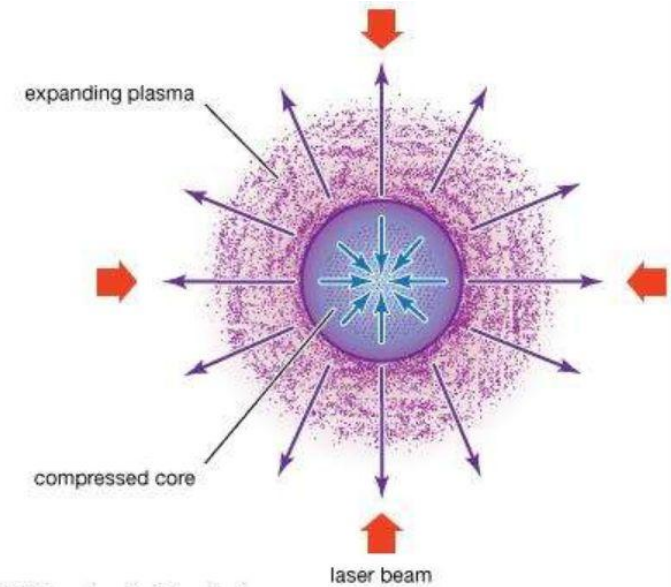
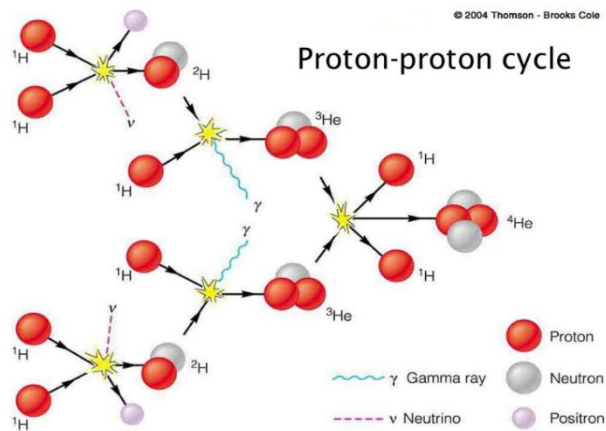
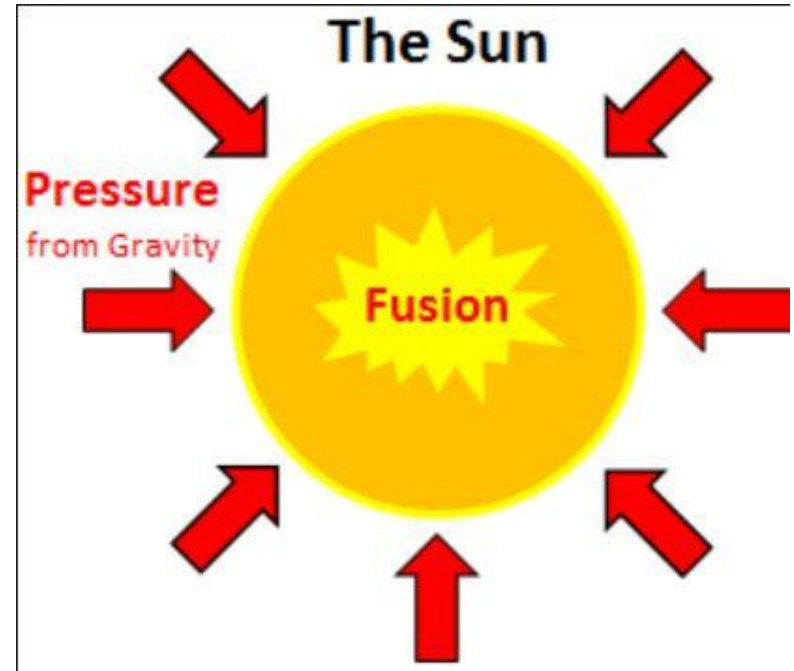
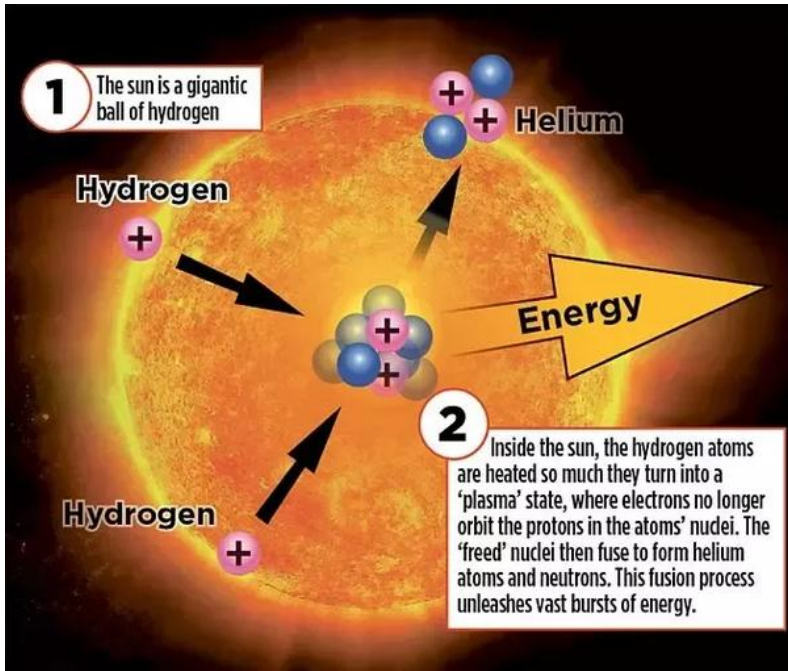
Összenyomás

Gyors behatolás

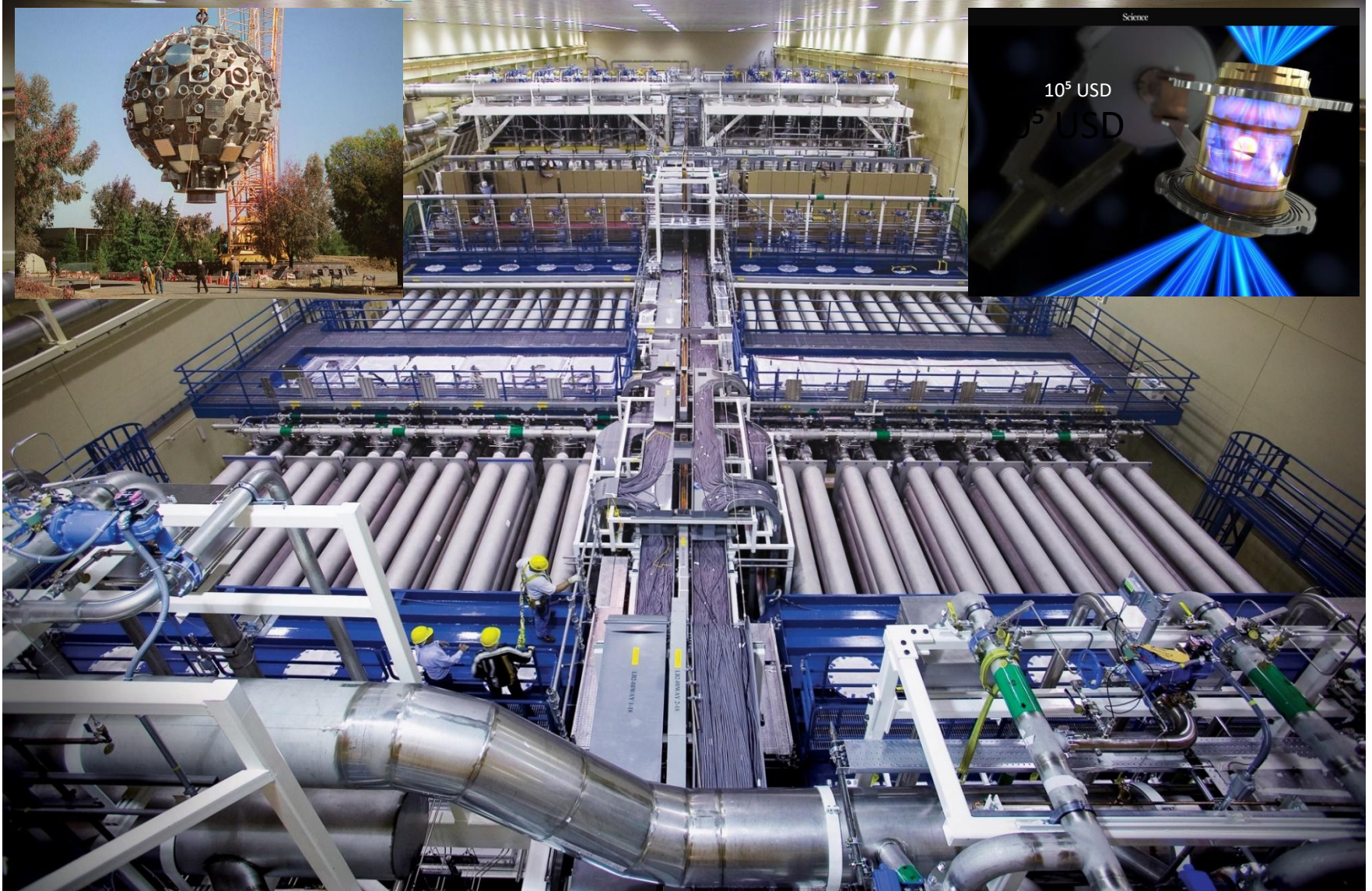


Út saját javaslatunk felé

KÖNNYŰ ATOMMAGOK FÚZIÓJA

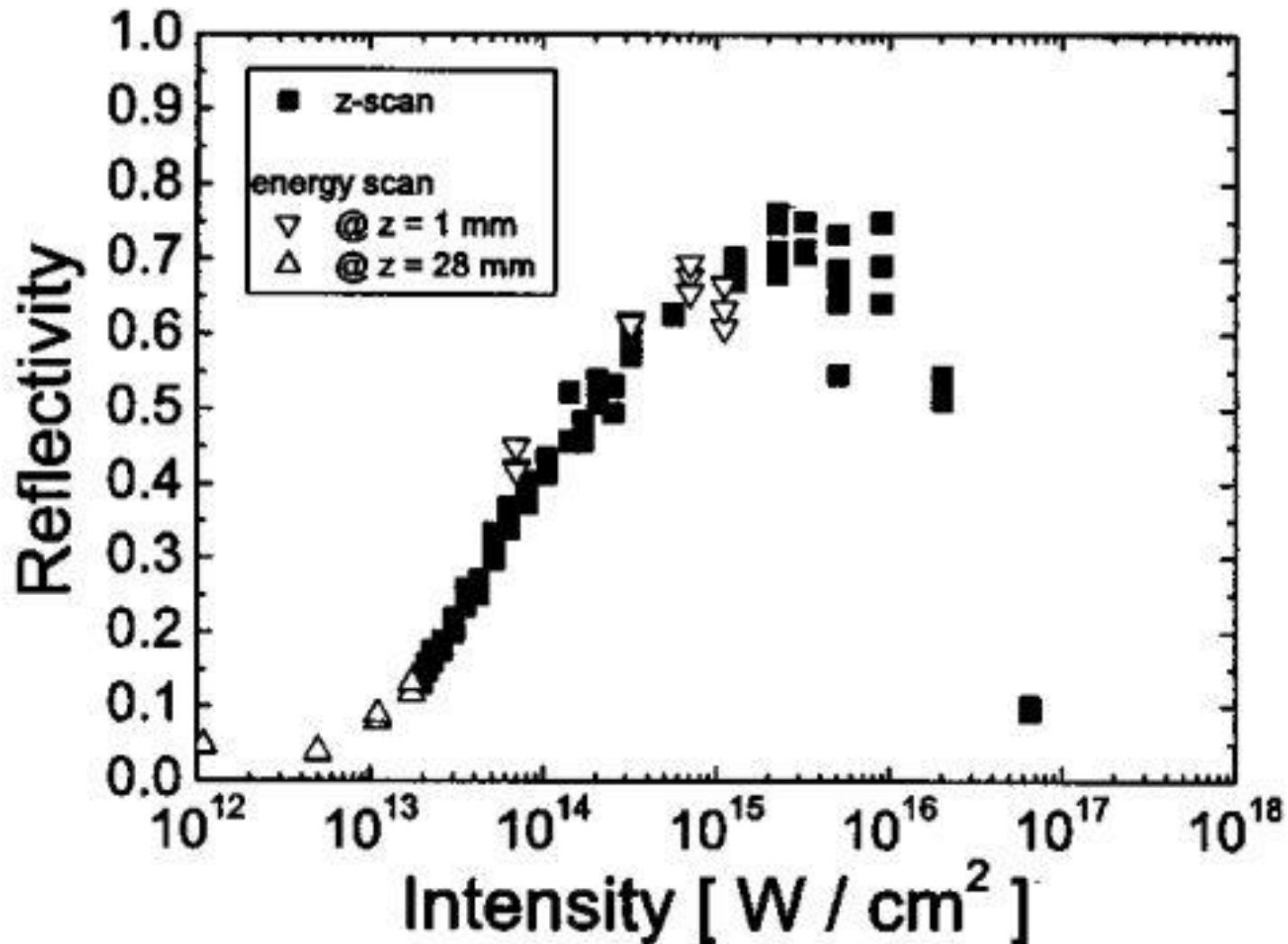


A NIF (a gravitációs összenyomás kiváltása)



192 lézer, 400MJ, ebből a mintán 2MJ. Ebből a fúziós energia 3MJ. A target ára $\sim 10^5$ USD. Impulzushossz: **10-50ns**, 1 imp/nap. A berendezés ára többmilliárd USD.

PLAZMA TÜKÖR REFLEKTIVITÁS



$\sim 10^{20}$ W/cm² intenzitásig működik

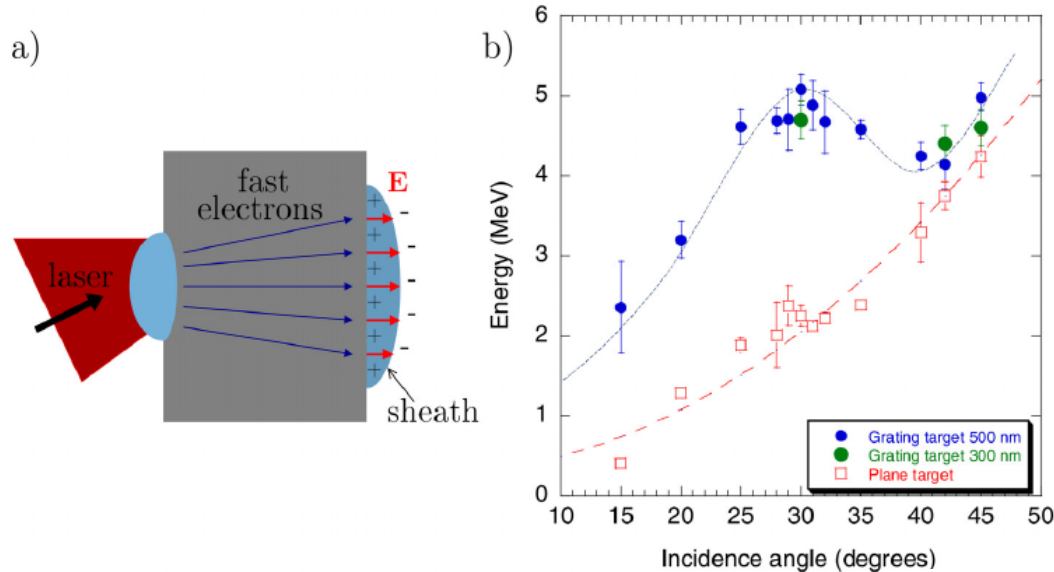


FIG. 5. Plasmon-enhanced TNSA of protons.⁹⁵ (a) Schematic of TNSA. The fast electrons produced by the interaction at the front side cross the target and produce a sheath at the rear side, where ions are accelerated. (b) Experimental data from the interactions of a high-contrast 25 fs, 2.5×10^{19} W cm⁻² laser pulse with solid plastic targets. The cut-off energy of protons emitted from the rear measured as a function of the incidence angle from both flat and grating targets (for two different values of the grating depth). An up to 2.5-fold energy increase is observed for gratings, with a broad maximum around the resonant angle for SP excitation (30°). Data from Ref. 95.

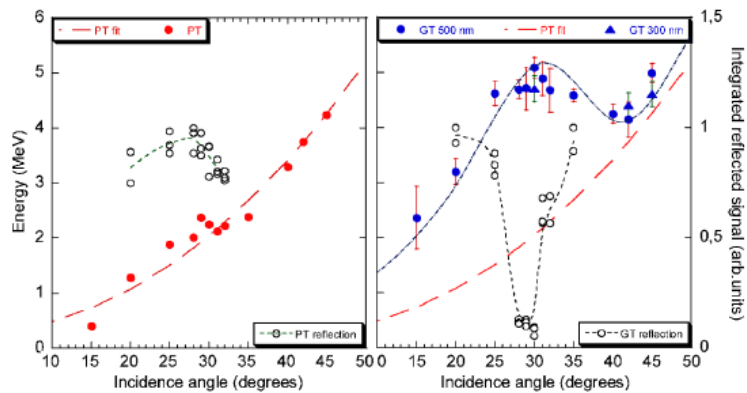


FIG. 3 (color online). Maximum proton energy (filled data points) and reflected light signal (empty data points) as a function of incidence angle α . Left and right frames correspond to 20 μ m thick plane targets and to 23 μ m thick grating targets, respectively. Filled circles and triangles correspond to 0.5 and 0.3 μ m deep gratings, respectively. The (red) dashed line is proportional to $\sin^2 \alpha / \cos \alpha$. The other lines are guides for the eye.

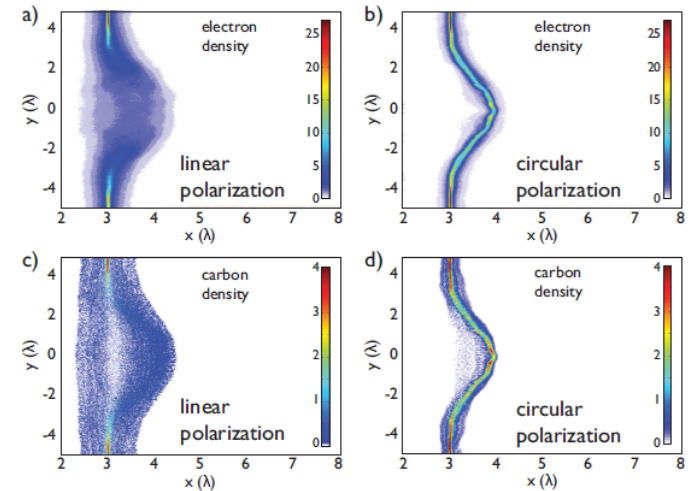


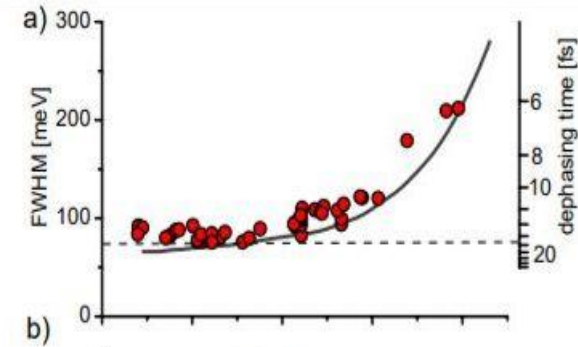
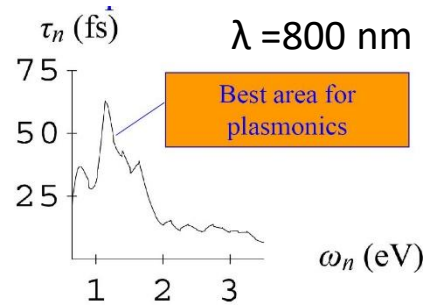
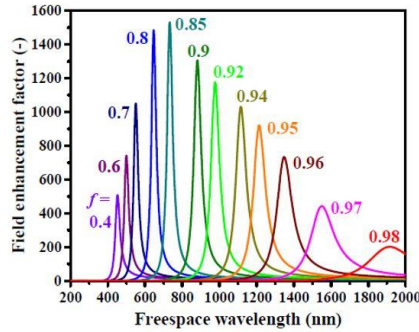
FIG. 4: (color). Cycle-averaged electron (a,b) and carbon ion (c,d) density at $t = 61$ fs after the peak of the laser pulse reached the 5.3 nm target initially located at $x = 3\lambda$. While linear polarization results in strong expansion of the target caused by hot electrons, for circularly polarized irradiation the foil is accelerated as a dense, quasi-neutral plasma bunch.

NANOPLAZMONIKA ÉS ENERGIAKONCENTRÁCIÓ



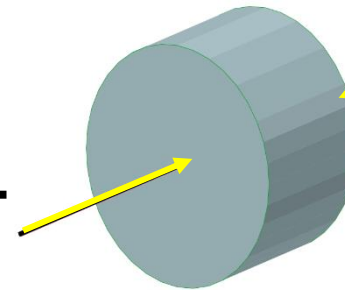
NANOHÉJ
($n \times 10 \text{ nm}$)

NANORÚD ($\sim 85 \times 25 \text{ nm}$)

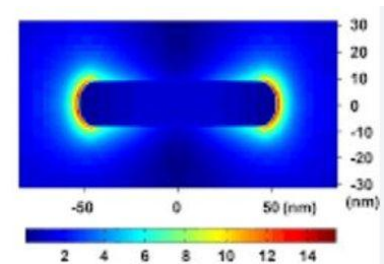


$n \cdot 10 \mu$

NANORÉSZECSKÉK A FÚZIÓS ANYAGBAN



$d \sim n \cdot 10 \mu$



FEMTOSZEKUNDUMOS LÉZER IMPULZUSOK (10^{-6} ns)
 NAGY ISMÉTLÉSI FREKVENCIA
 FÉNYSEBESSÉG: NINCS INSTABILITÁS
 CSAK KÉT NYALÁB
 TÉRFOGATI BEGYÚJTÁS

-HOT SPOT
 -ÁRNYÉKOLÁS
 -PONDEROMOTOROS
 GYORSÍTÁS
 -KORRELÁLT MOZGÁS

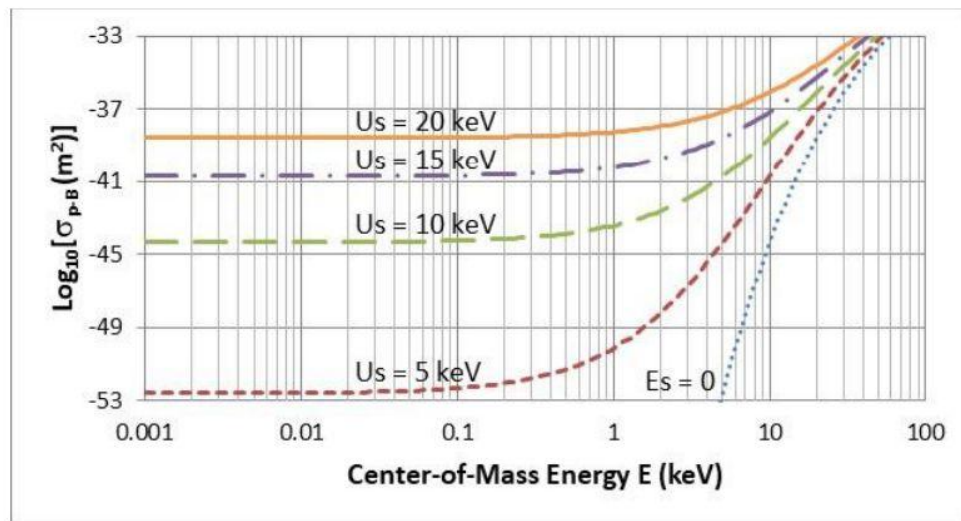
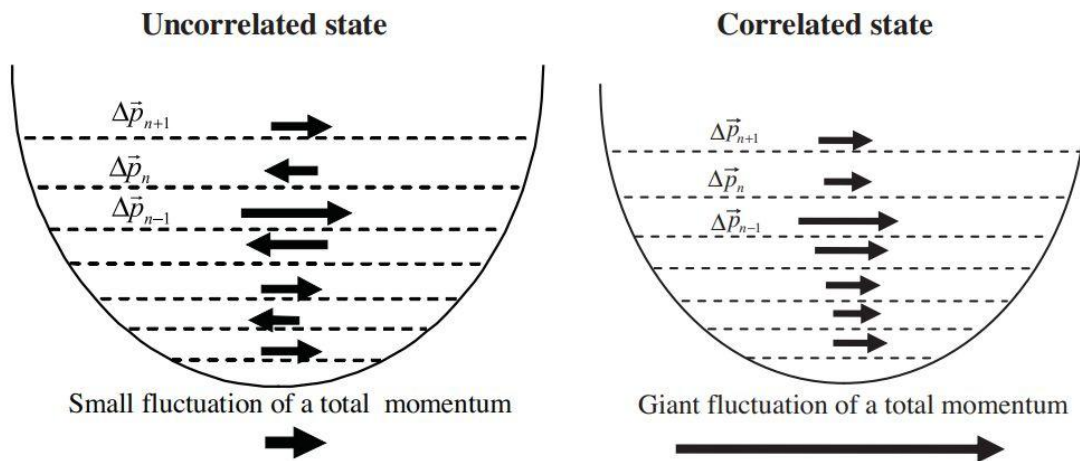
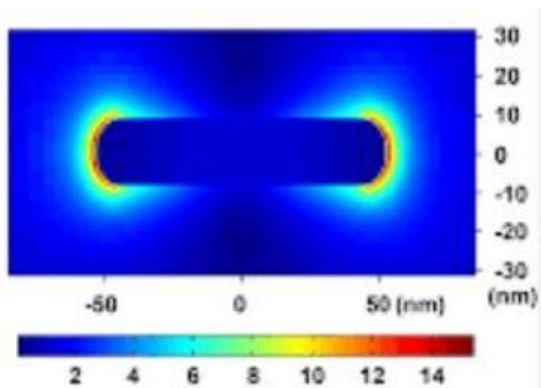
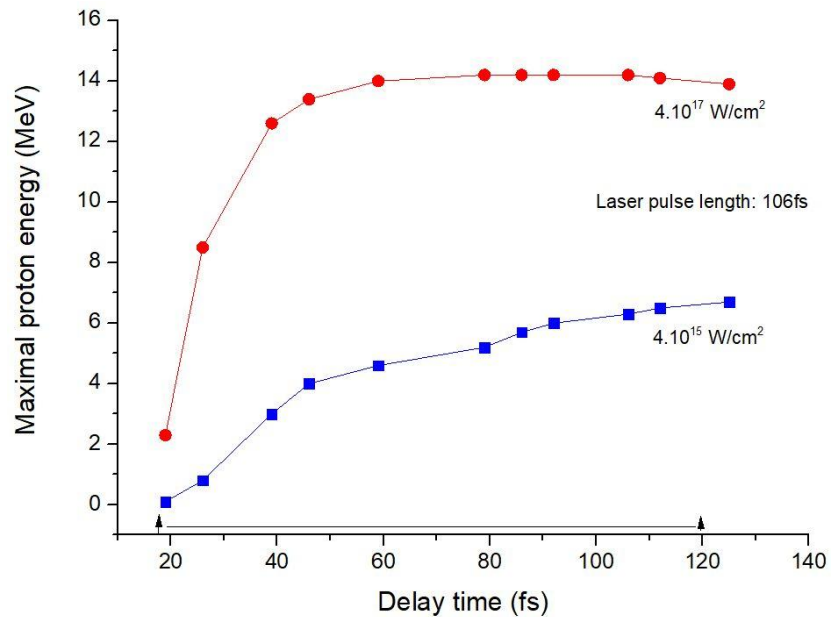
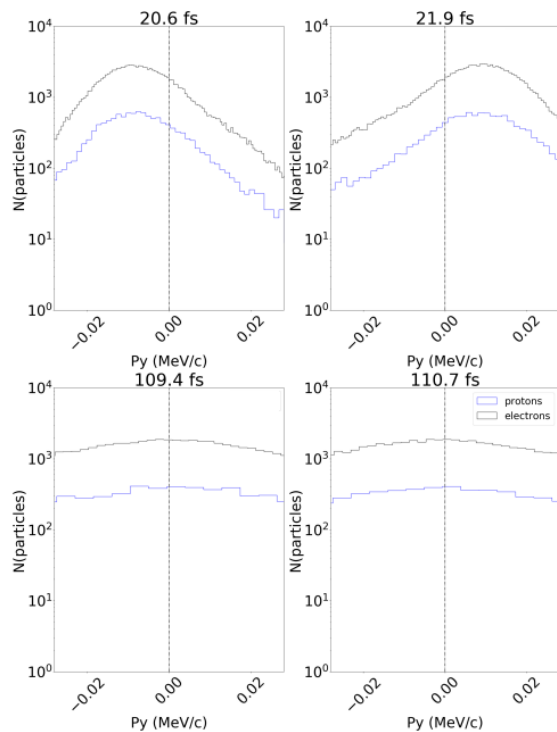
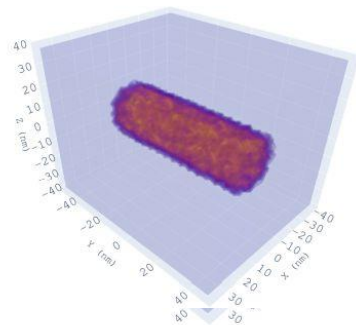


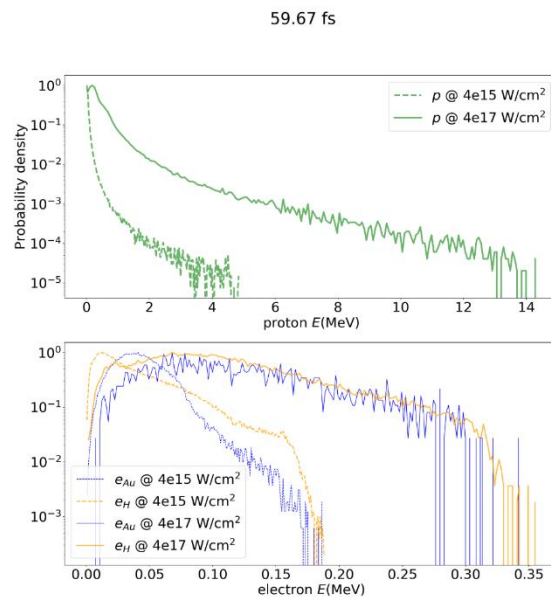
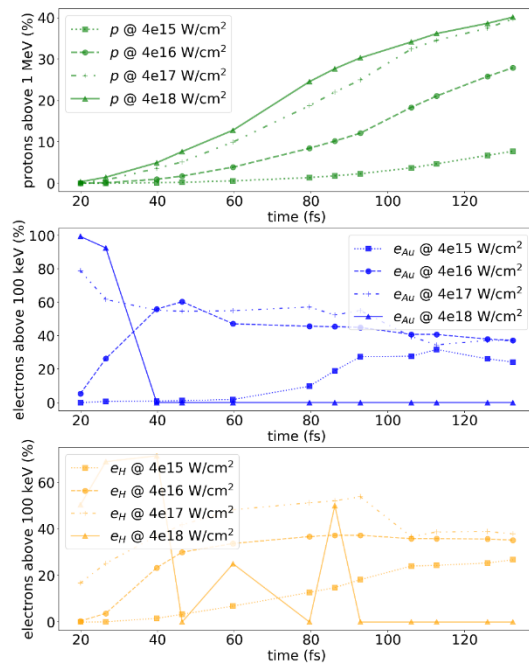
Figure 1: $p\text{-}^{11}\text{B}$ cross section as function of particle energy for the screening electron densities up to $E_s = 20\text{keV}$. The cross section near $E = 10\text{eV}$ grows over 14 orders of magnitude (from 10^{-53} to 10^{-39}m^2) over the range of 5 to 20keV.



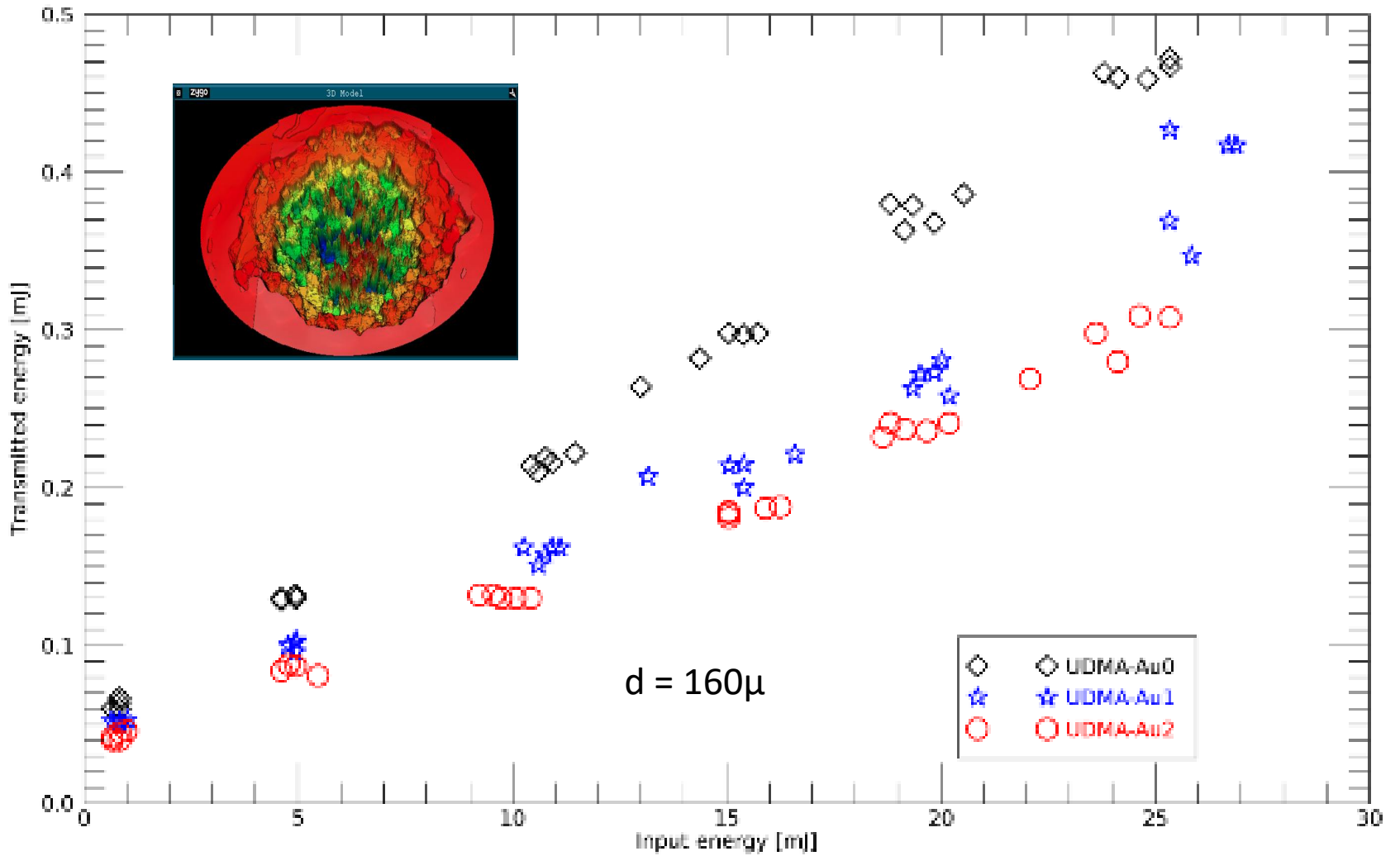
Nanorod inside a PIC simulation box



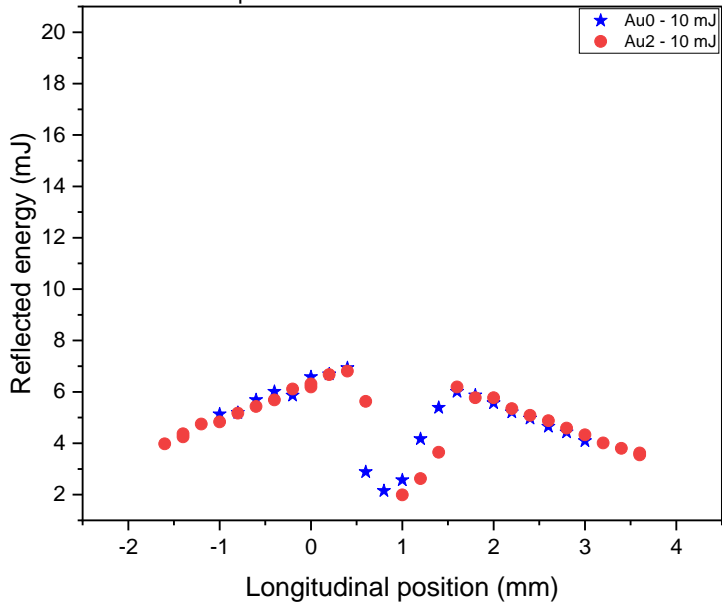
Fraction of particles at energies



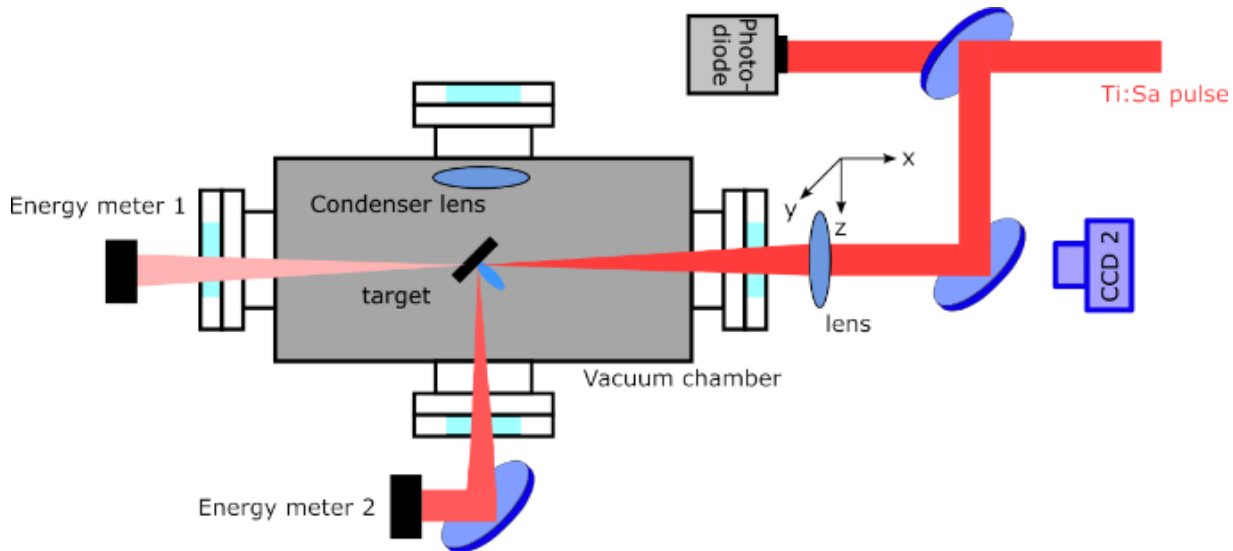
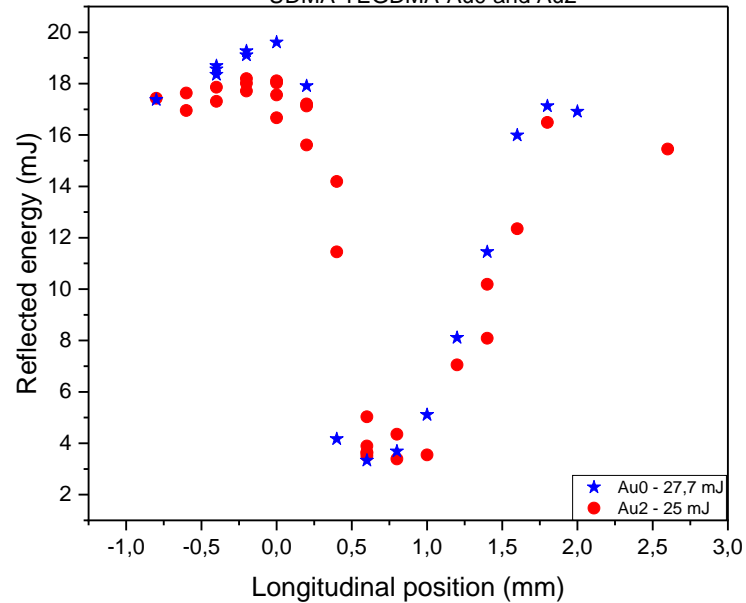
Laser pulse energy transmitted through the UDMA samples



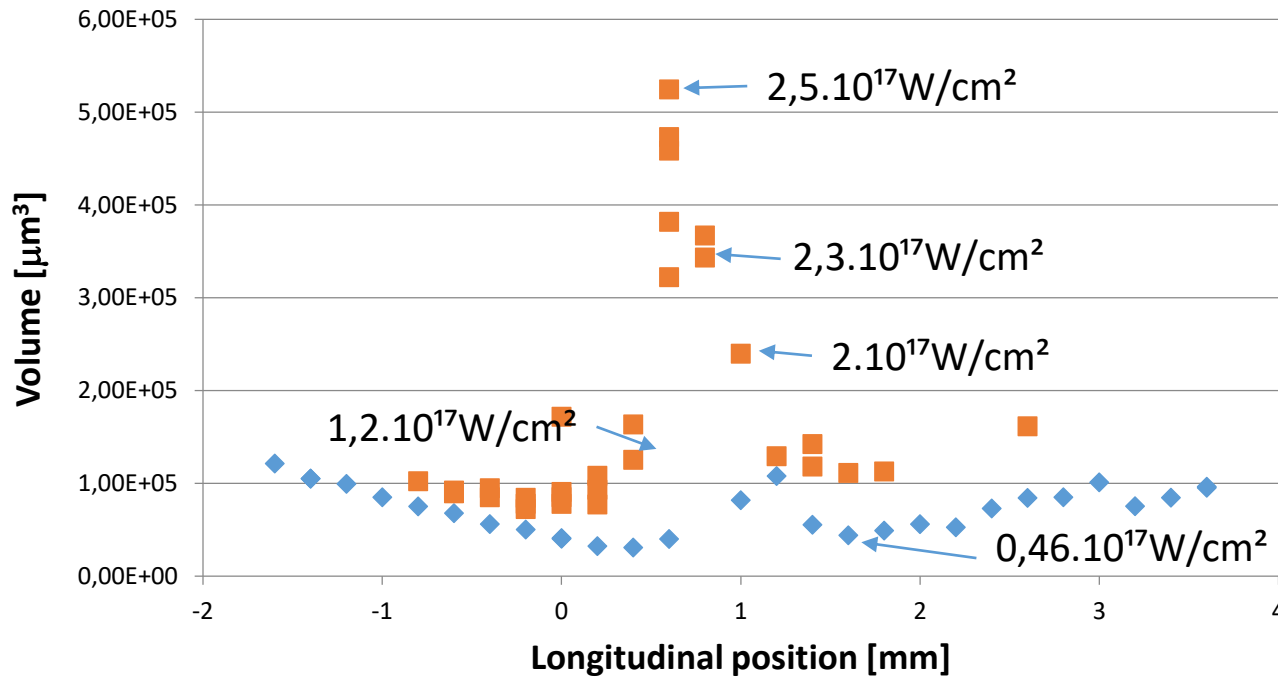
Reflected energy as the function of the longitudinal position
 Energy of the impulse: 10 mJ
 Samples: UDMA-TEGDMA-Au0 and Au2



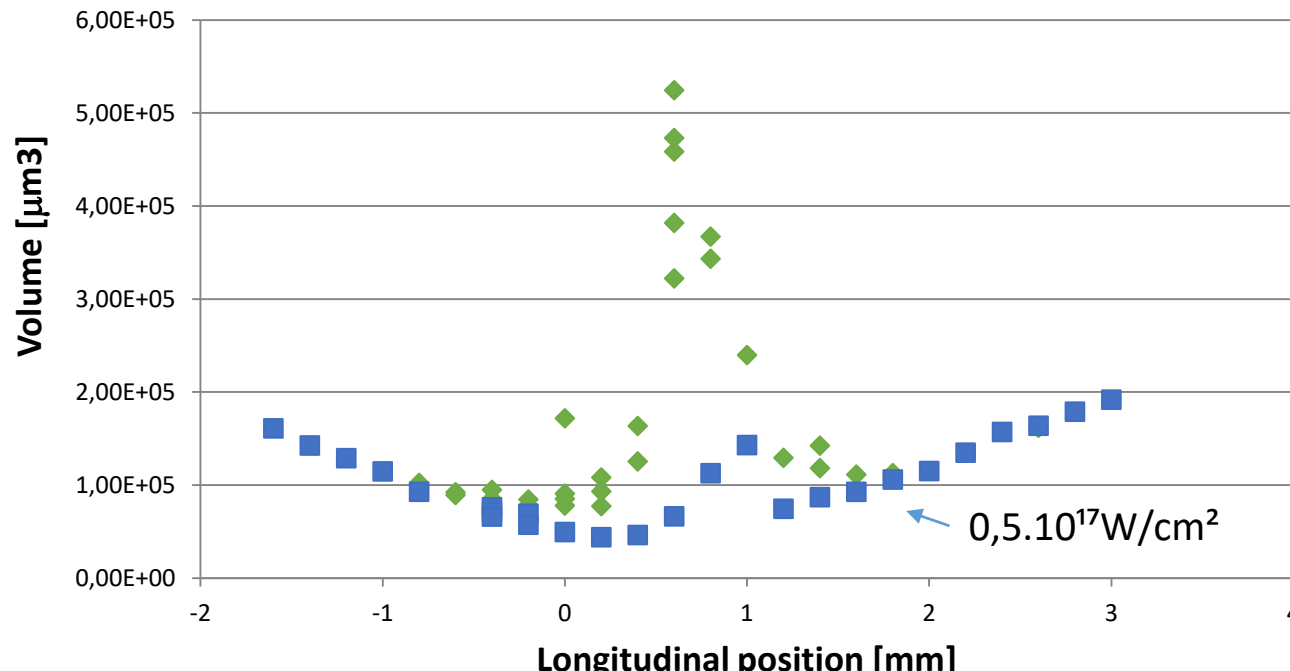
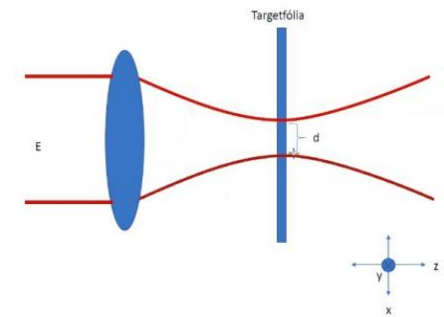
Reflected energy as the function of the longitudinal position
 Energy of the impulse: 25 mJ
 UDMA-TEGDMA-Au0 and Au2



CRATER VOLUMES



- Volume Au2 - 10 mJ
- Volume Au2 - 25 mJ

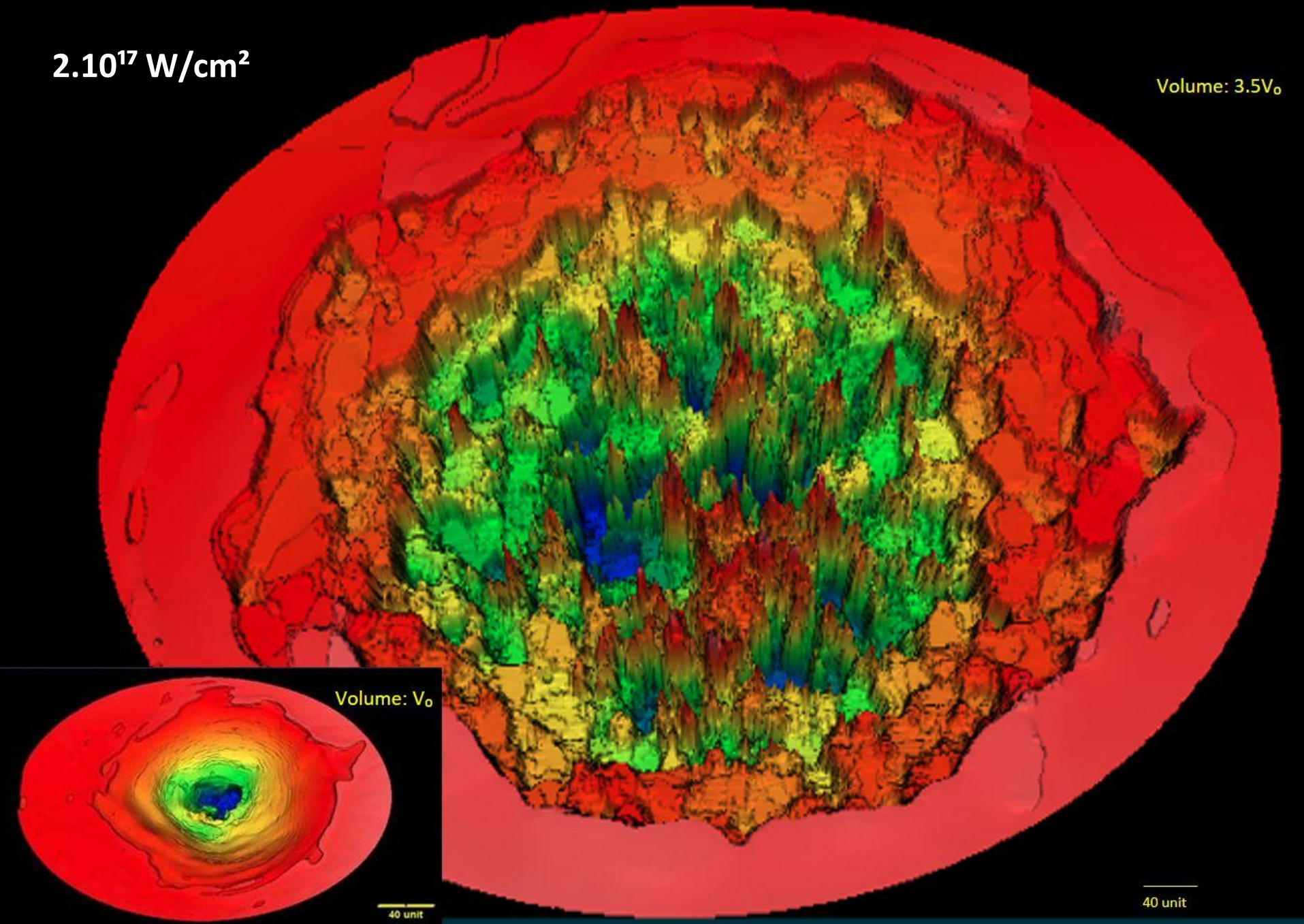


- Volume - Au2 - 25 mJ
- Volume - Au0 - 27,7 mJ

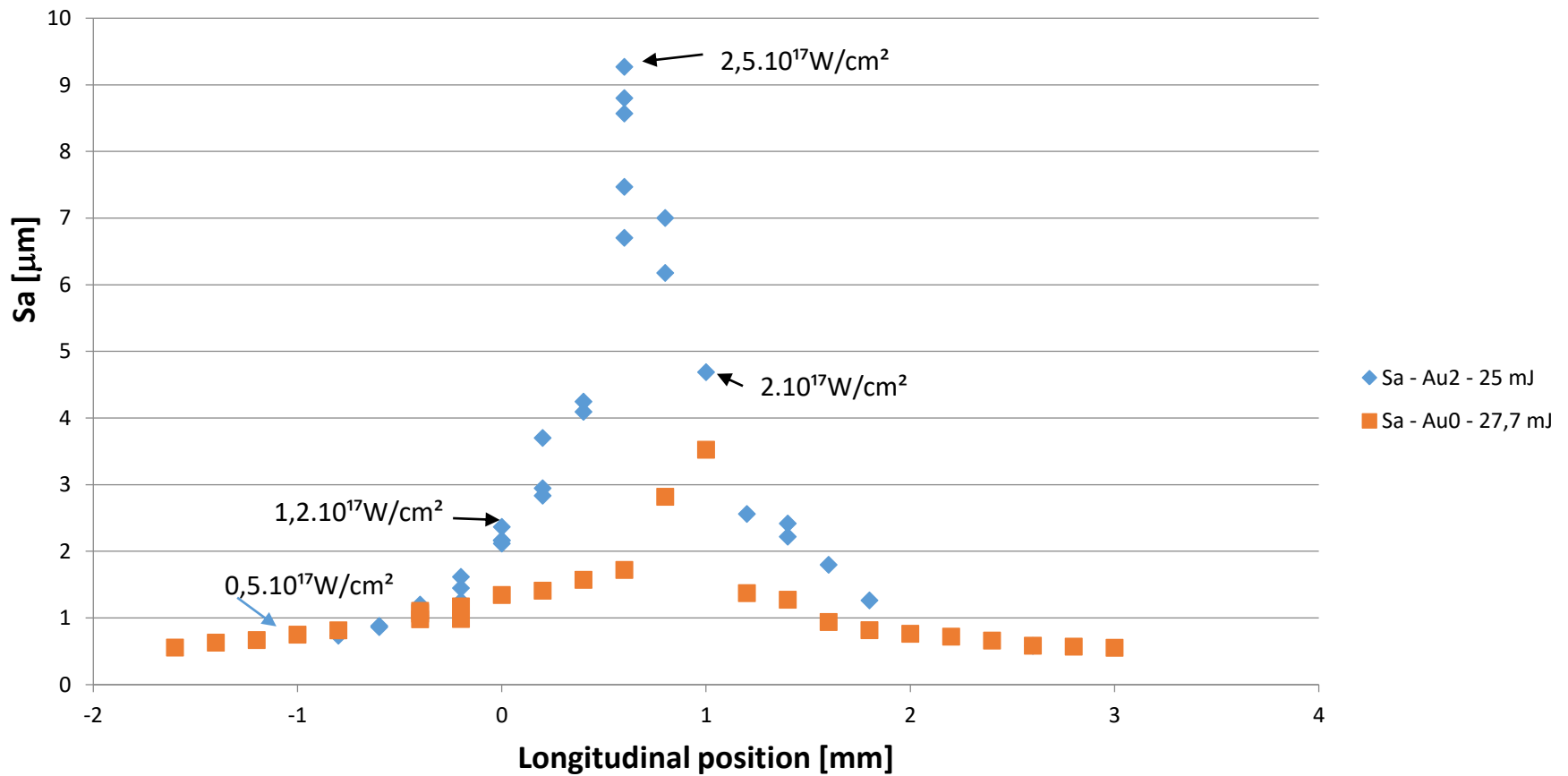
**A NAGYTERŰ
PLAZMONIKA
MŰKÖDIK!**

$2 \cdot 10^{17} \text{ W/cm}^2$

Volume: $3.5V_0$

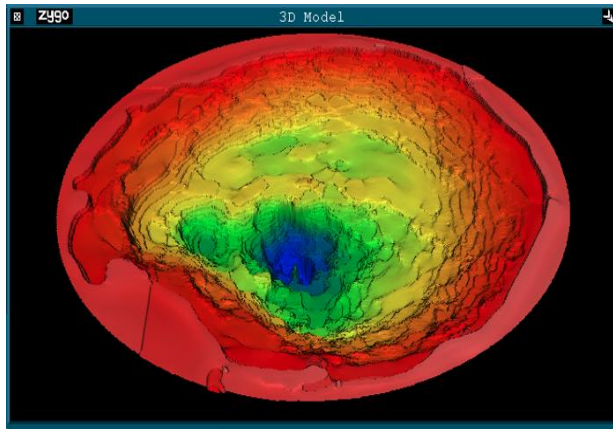


Felületi érdesség vs longitudinális pozíció
Au2 és Au0 minták
Impulzus energia: 27,7 mJ (Au0) és 25 mJ (Au2)

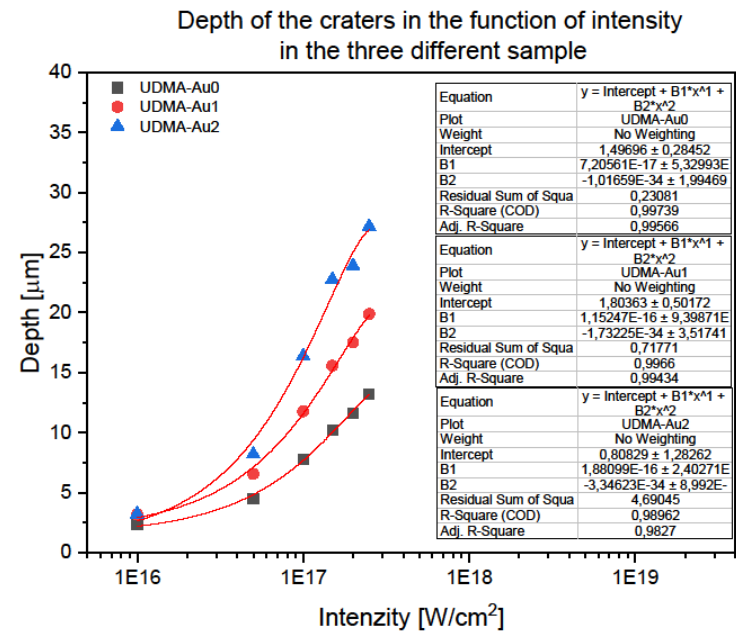
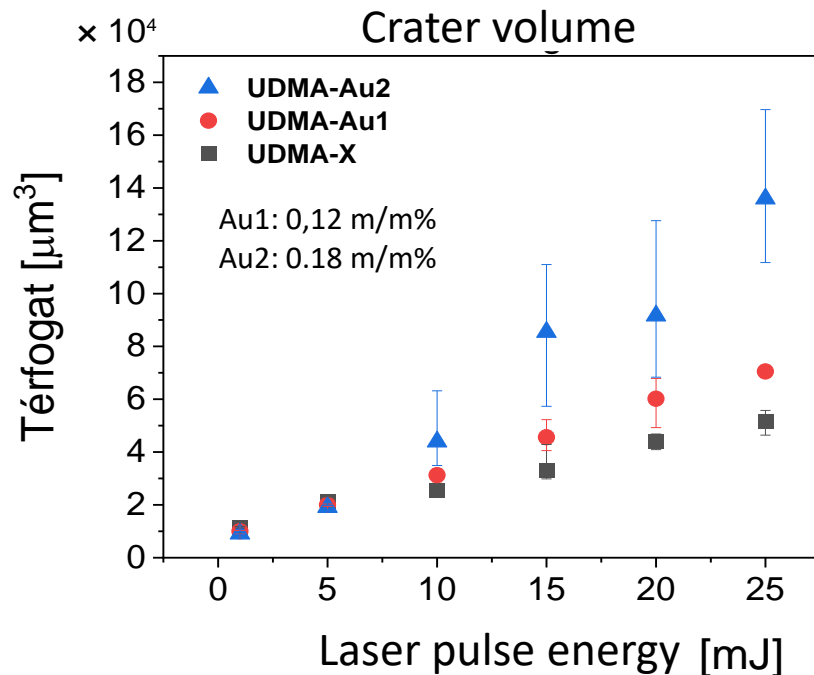
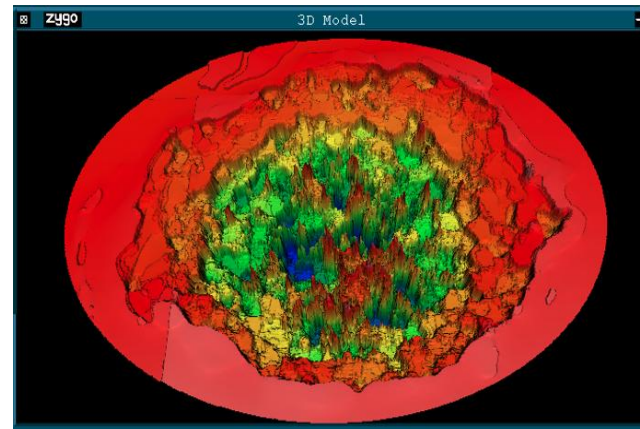


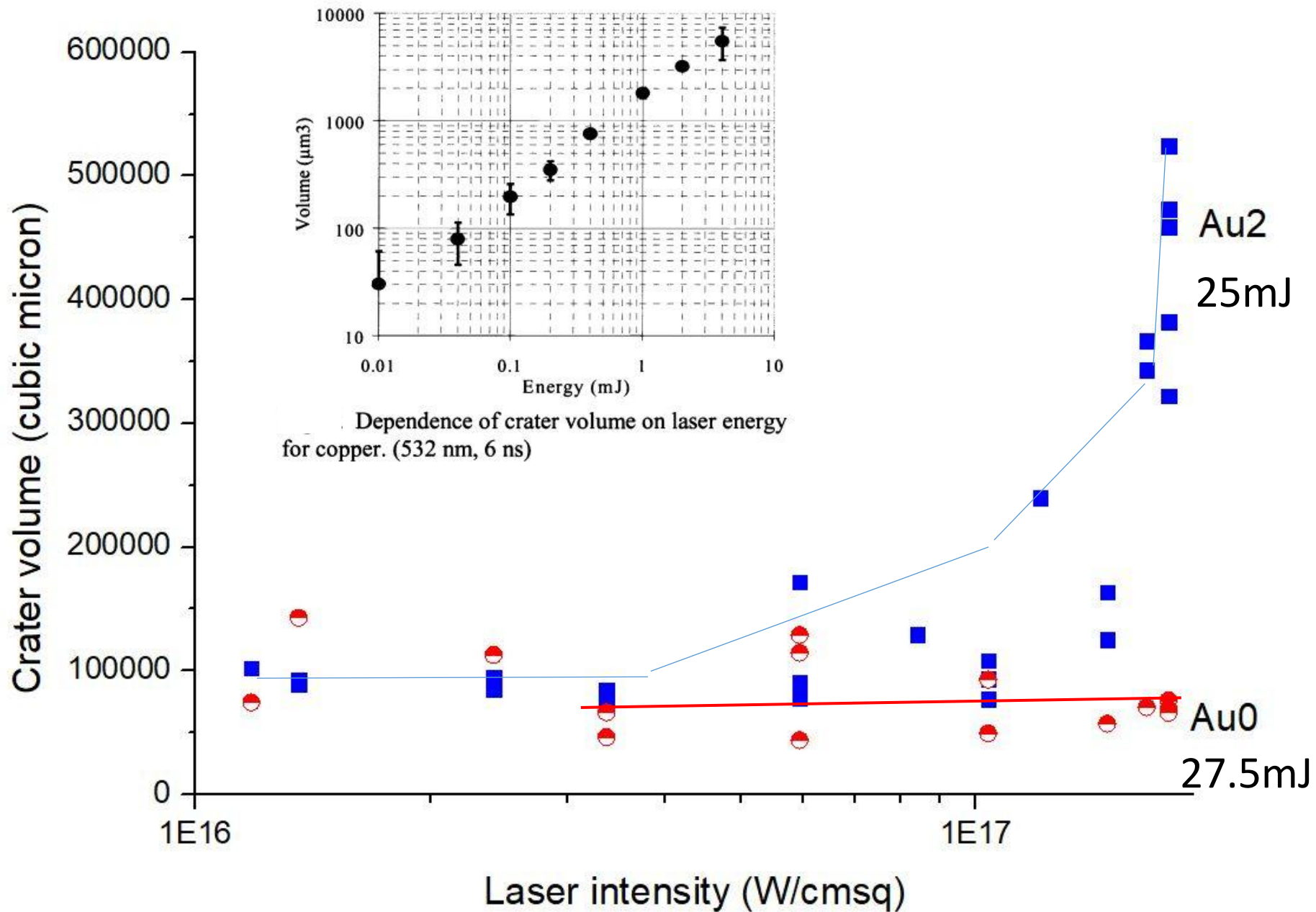
1. DIAGNÓZIS (kráter térfogat)

Volume: V_0



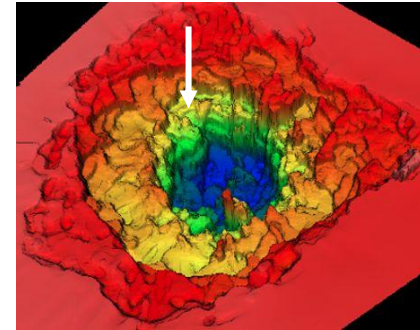
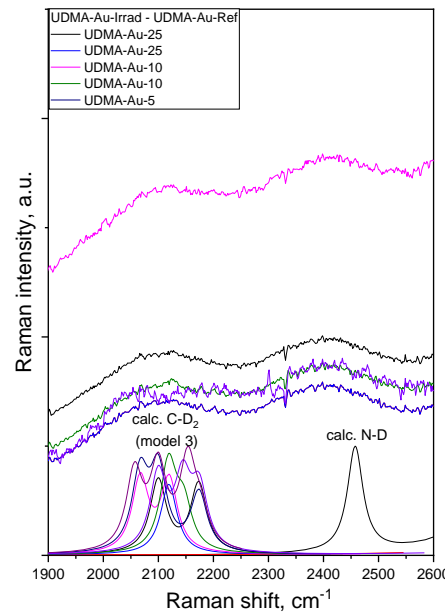
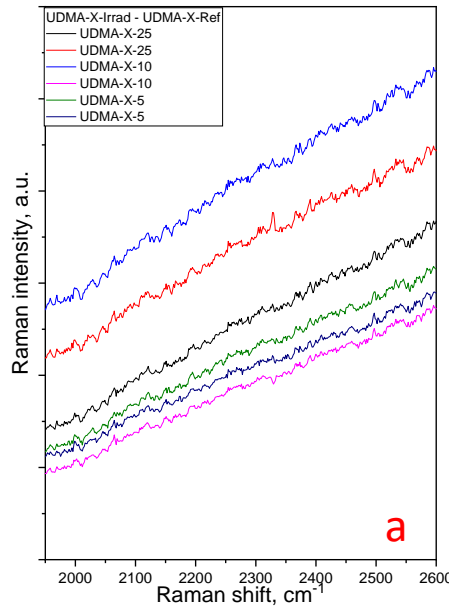
Volume
max. $3.5V_0$



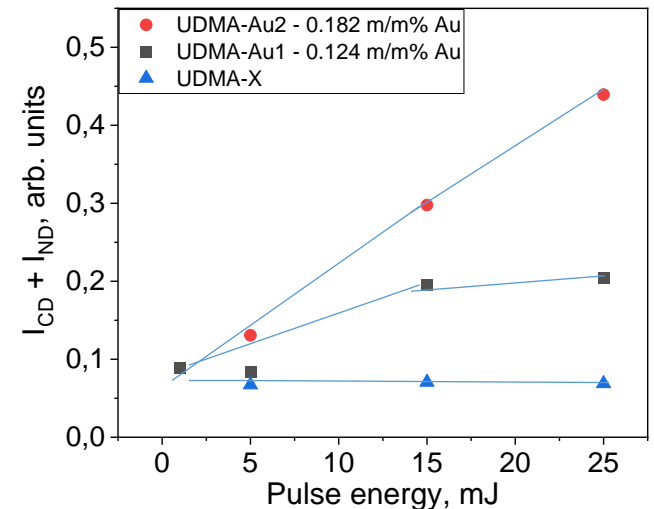
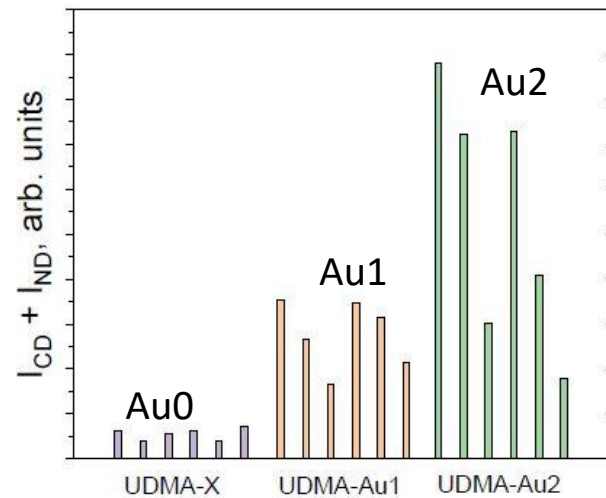
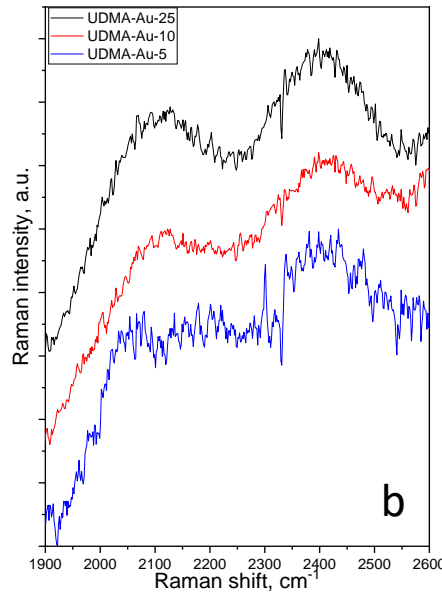
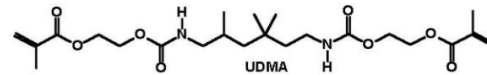


Energia forrása H → D: 2.Raman szórás a kráter felületéről

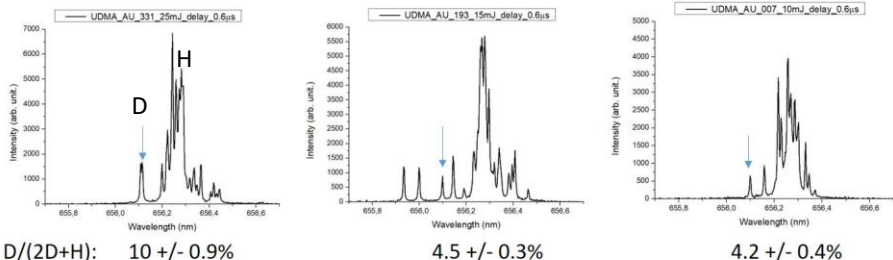
arXiv2210.00619(2022), submitted to Advanced Optical Materials



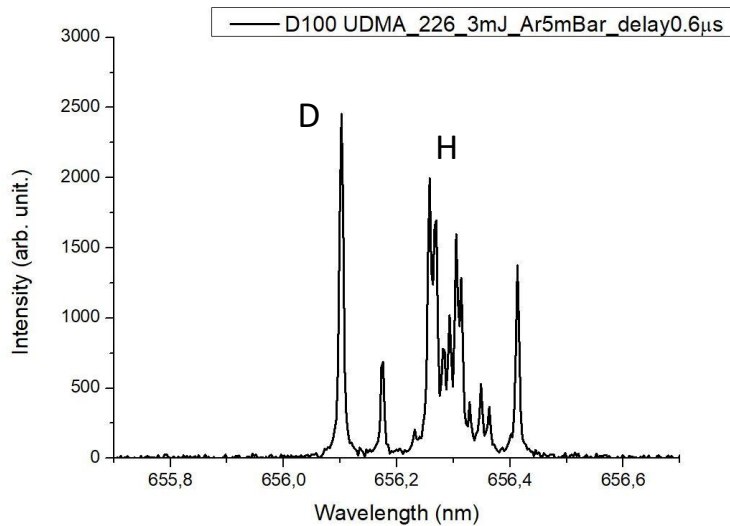
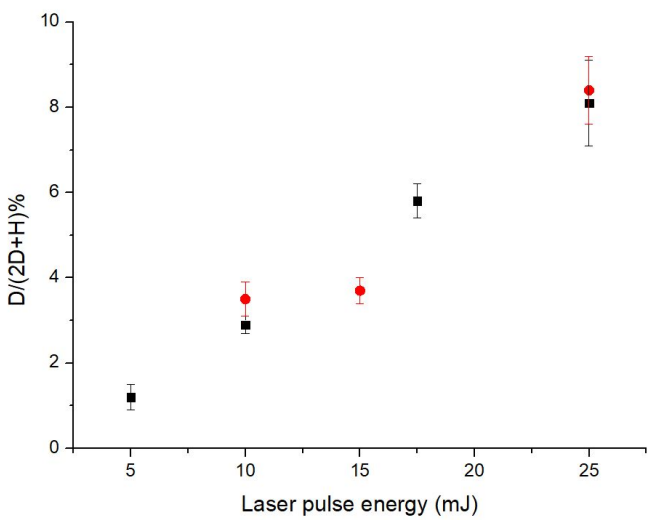
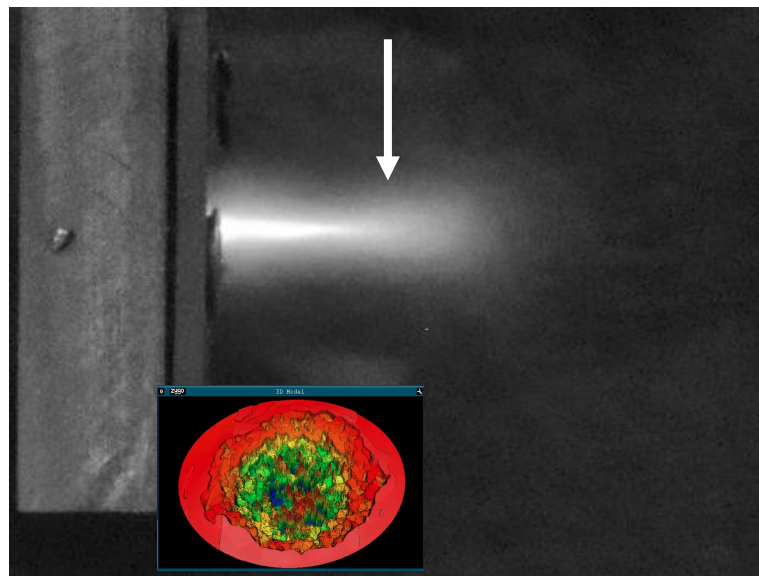
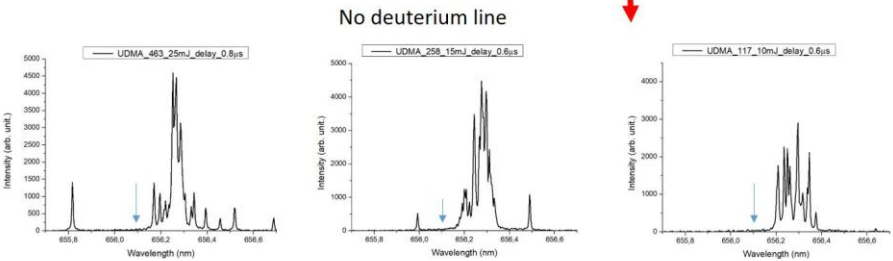
$I_{\text{laser}} > 10^{16} \text{ W/cm}^2$



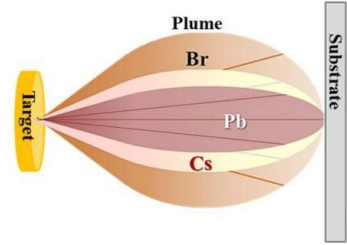
3.NÉHÁNY TIPIKUS H^α ÉS D^α VONAL A LIBS SPEKTRUMOKBAN



TYPICAL LIBS SPECTRA (at 3 laser pulse energies with and without Au nanoparticles)



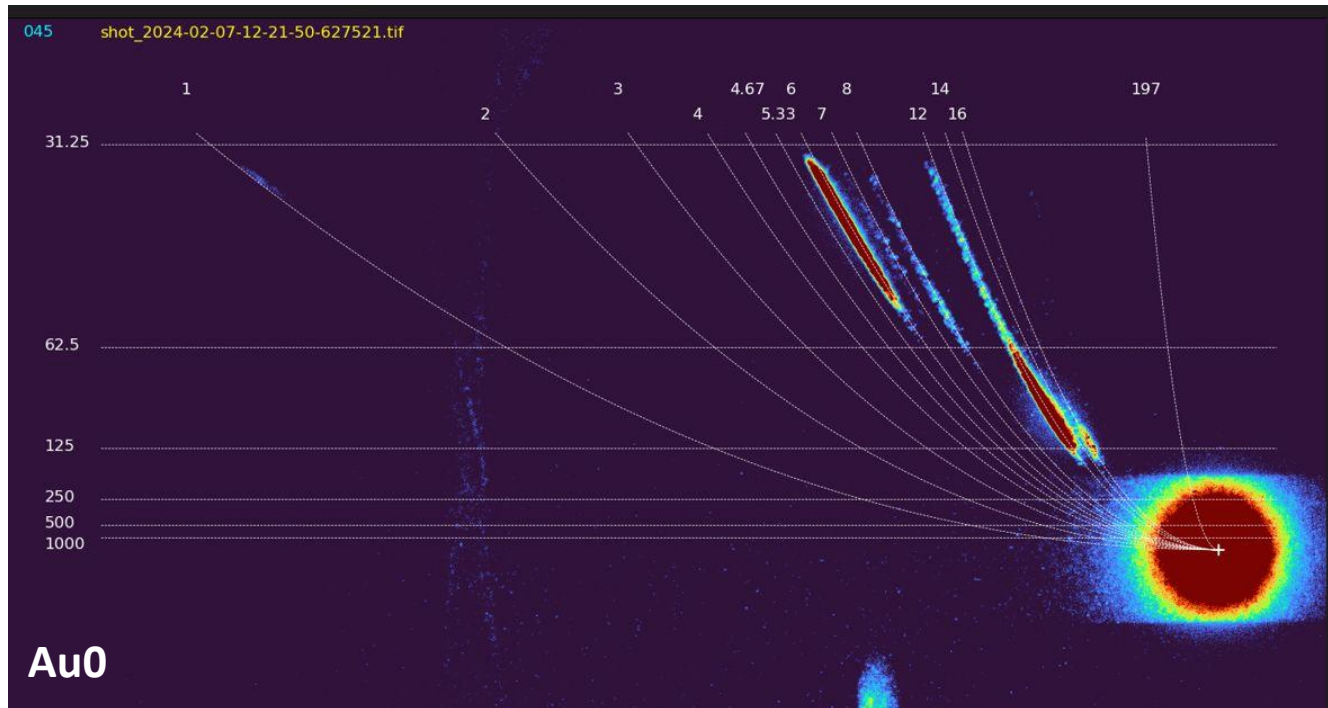
Deuterizált (23%) minta



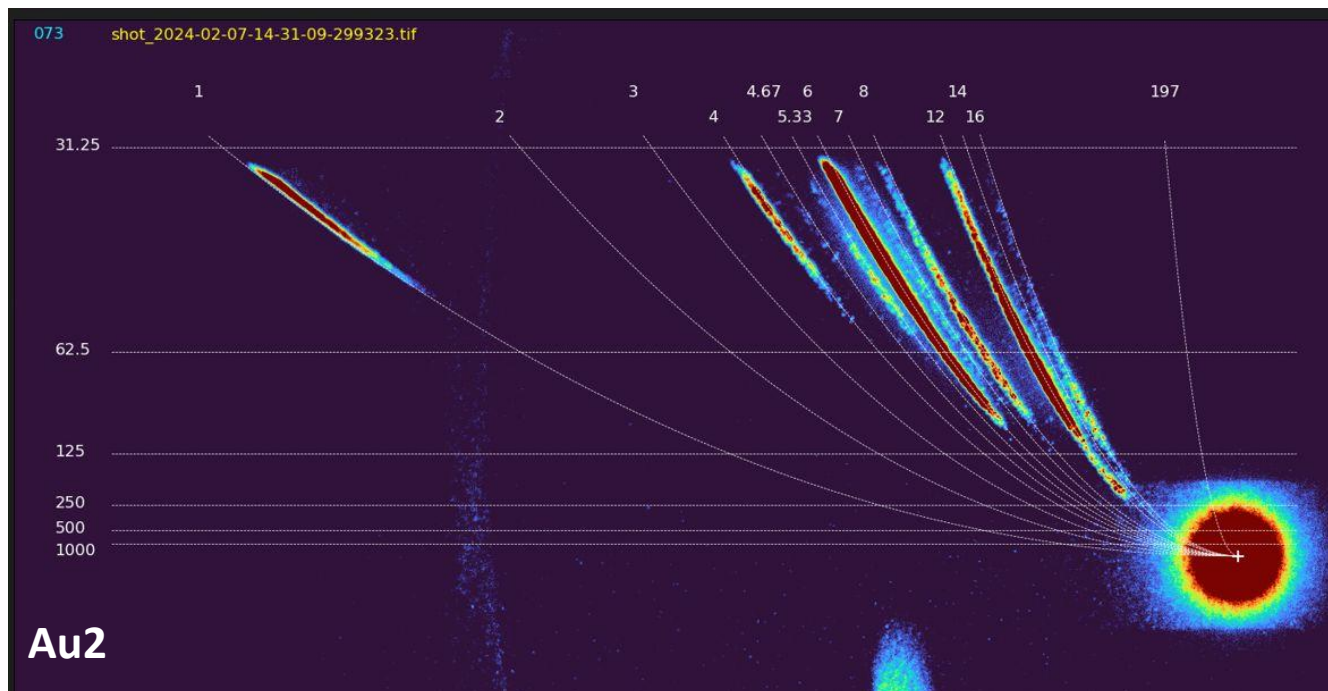
2D+H : a H atomok teljes száma a transmutation előtt

A deutérium atomok száma 25mJ lézer impulzus esetén : $\sim 4 \times 10^{14}$

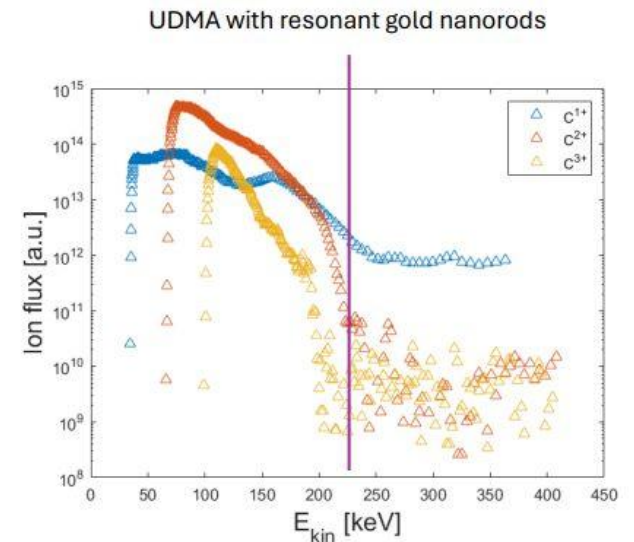
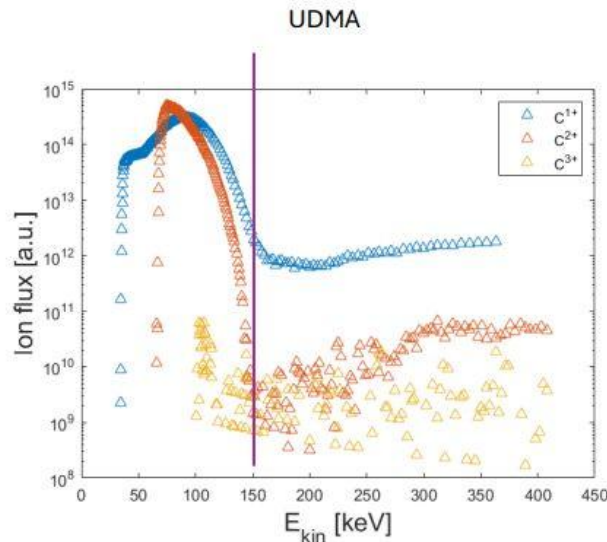
ELI-ALPS
Szeged



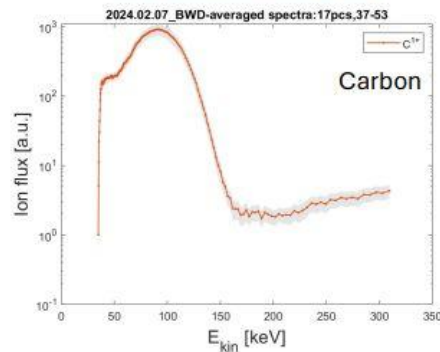
Thompson
parabola
measurements



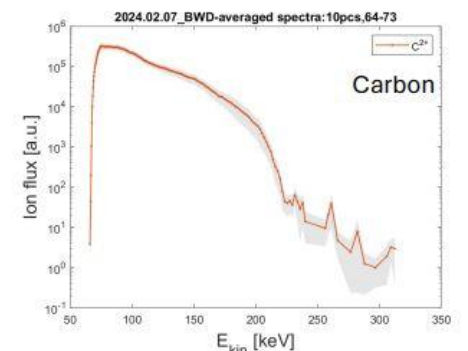
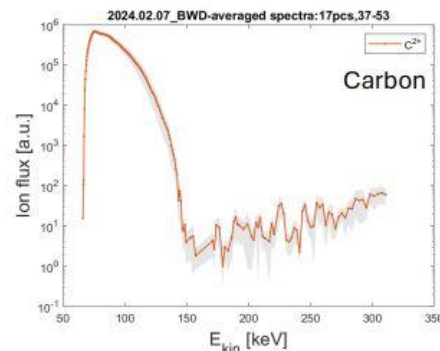
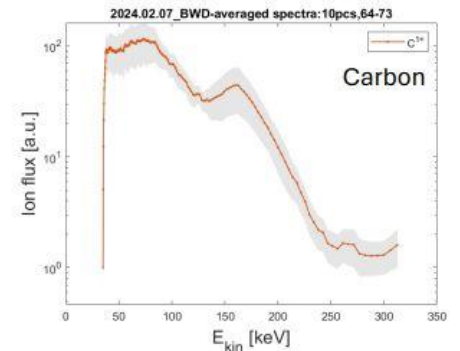
A NAGY
INTENZITÁSÚ
PLASMONIKA
MŰKÖDIK

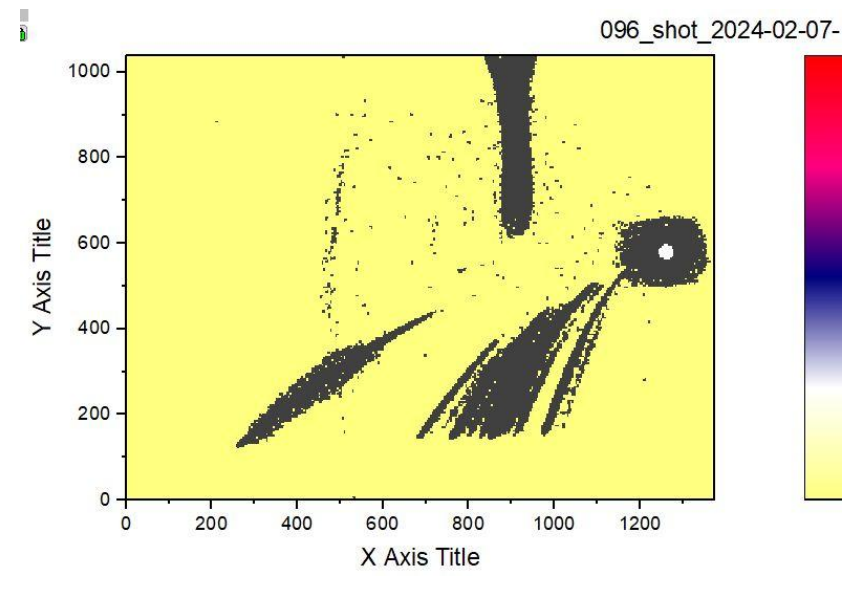
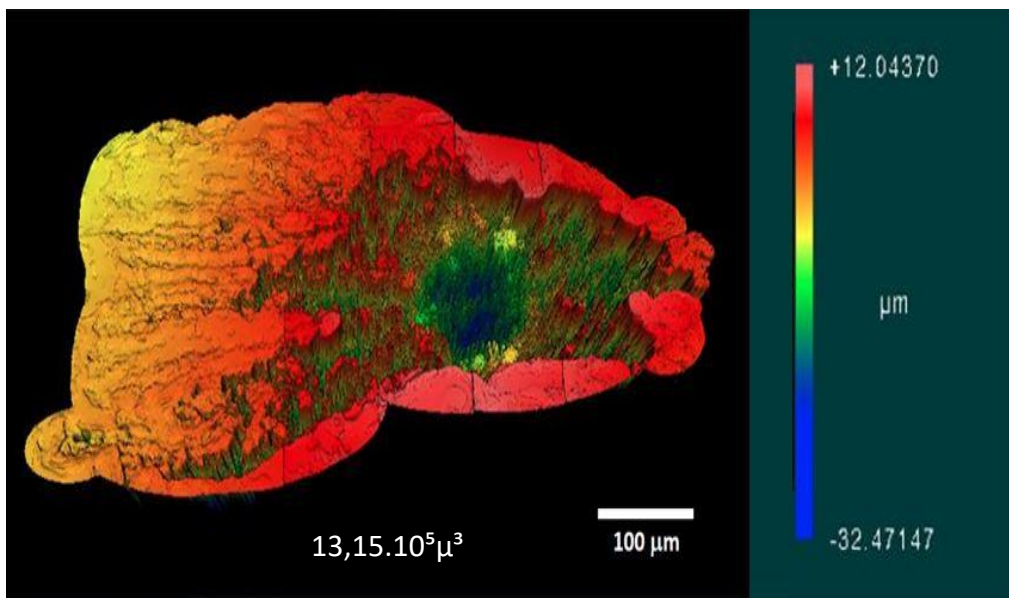


Cutoff energy
No resonant nanorods



With resonant nanorods

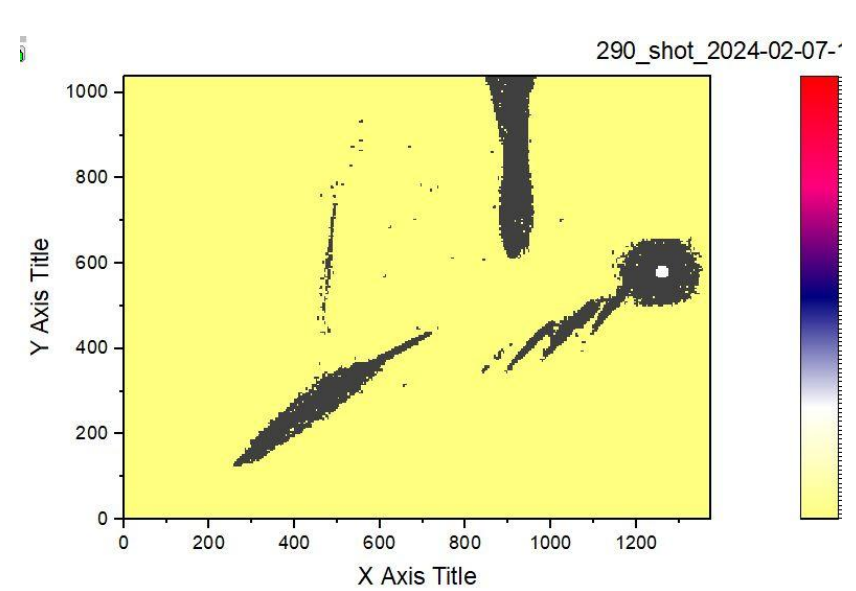
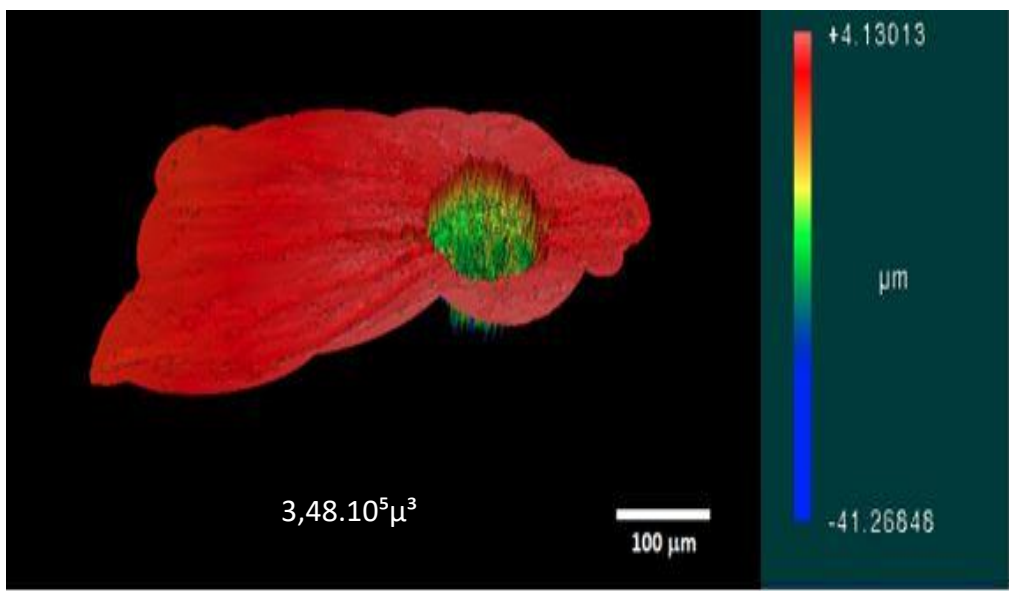




$V_2/V_0 = 3.78$

Laser pulse length: 43fs

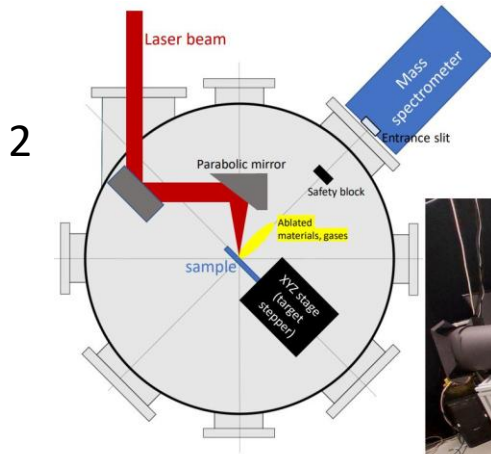
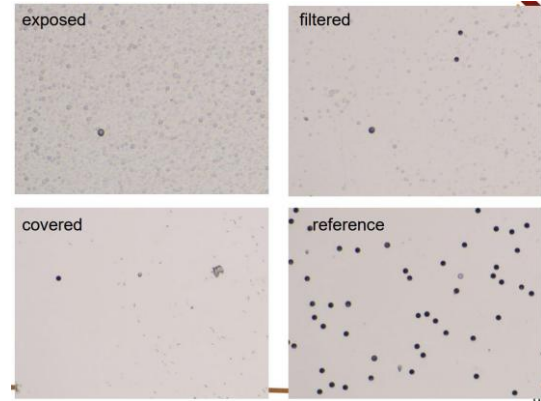
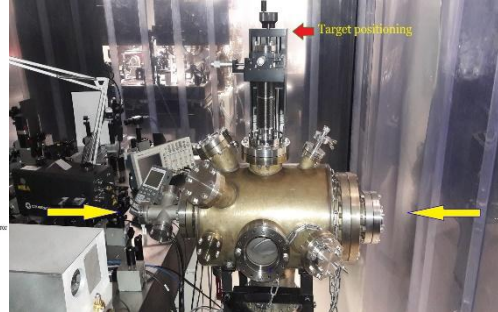
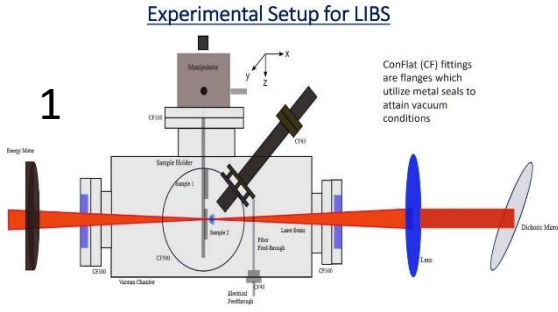
$C_2/C_0 = 6.54$
Total: ≈ 2



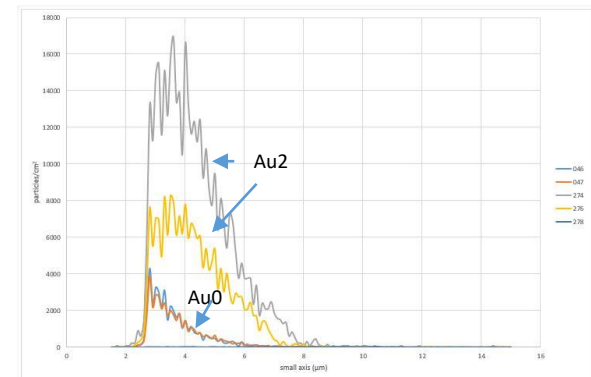
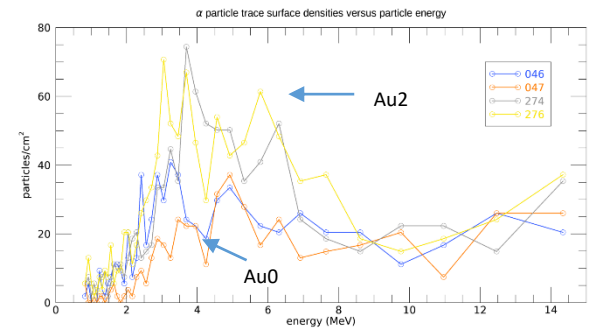
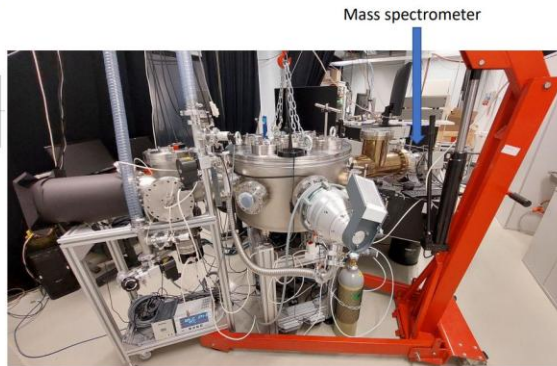
FOLYAMATBAN KONKLÚZIÓ ELŐTT:

1. Atomi optikai spektroszkópia,
2. Tömeg spektrometria.
3. Nukleáris detektáló technikák.

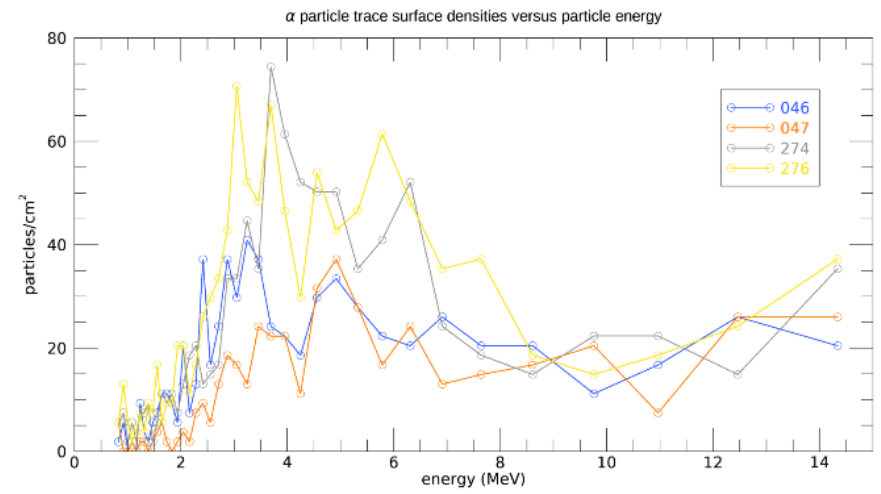
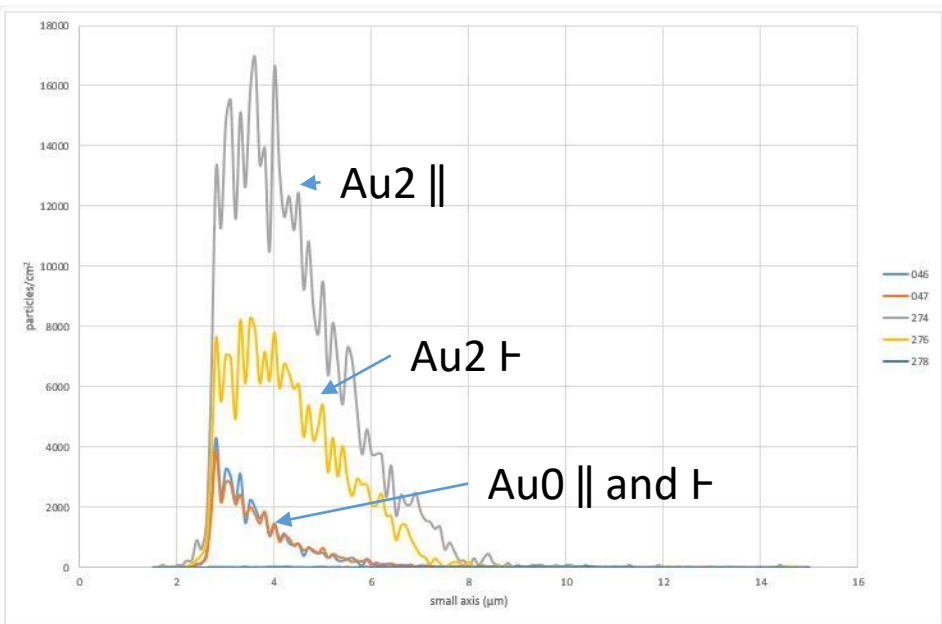
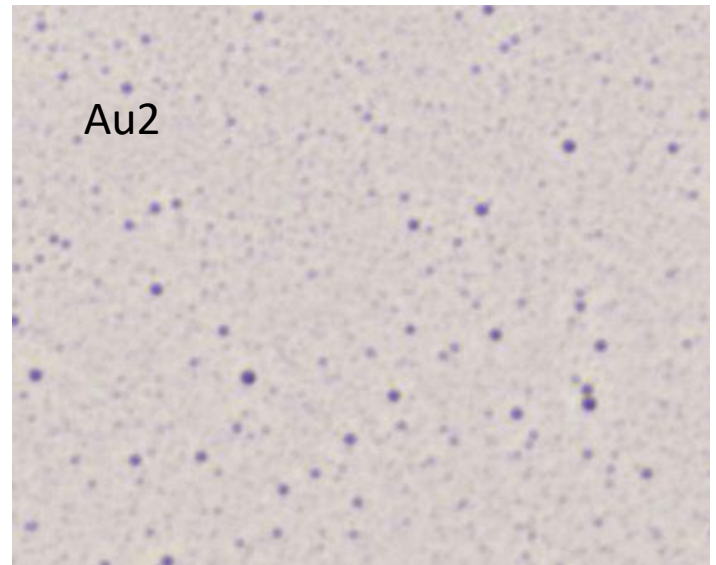
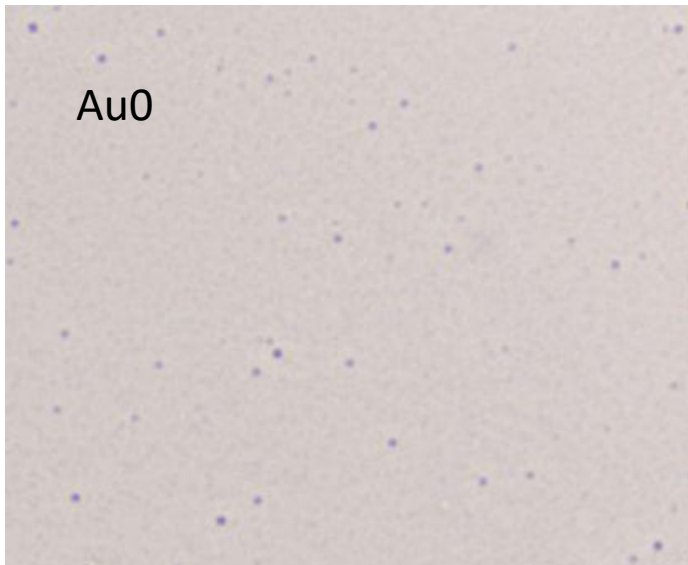
3: CR39 film, 1 lézer lövés



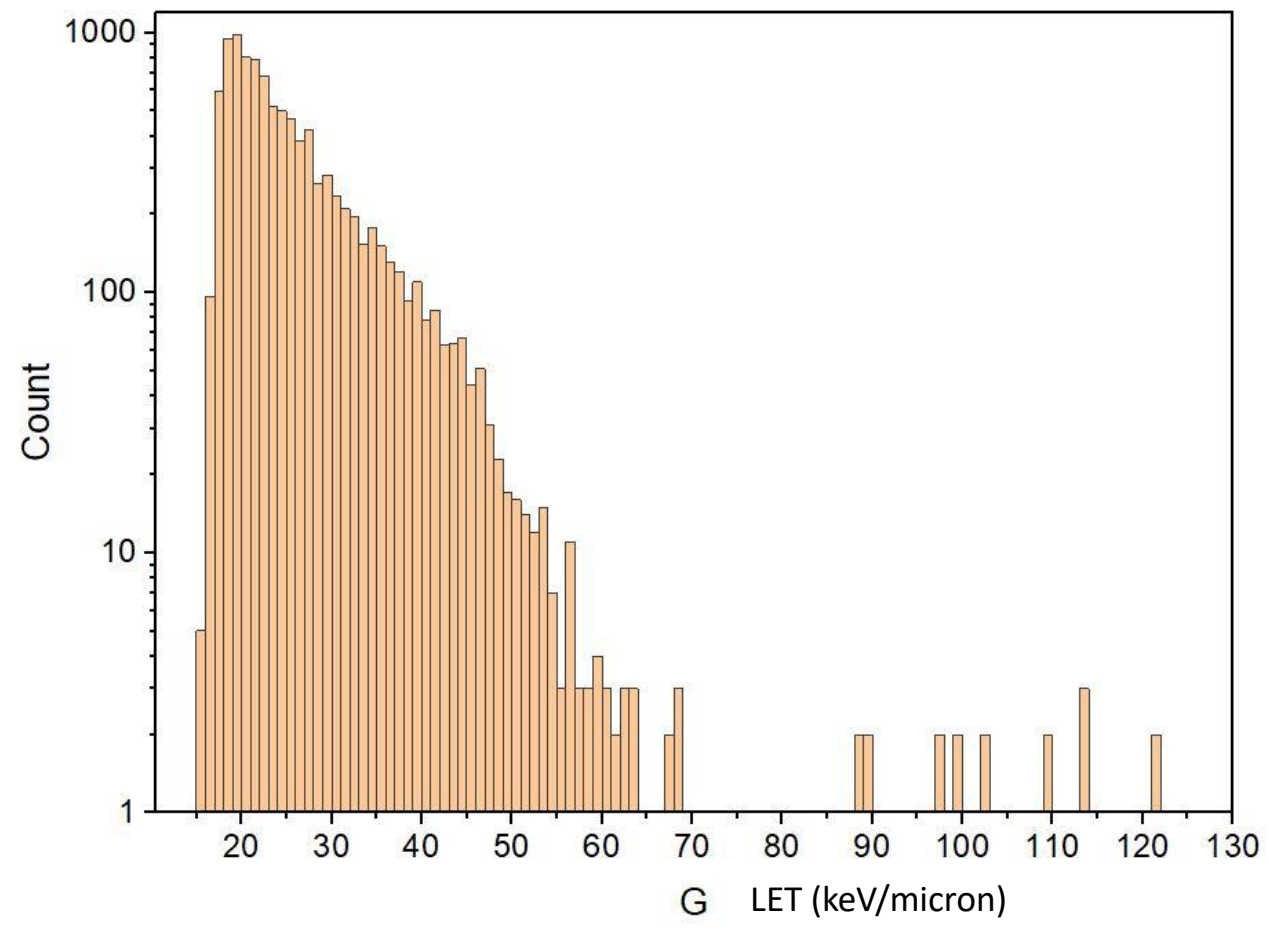
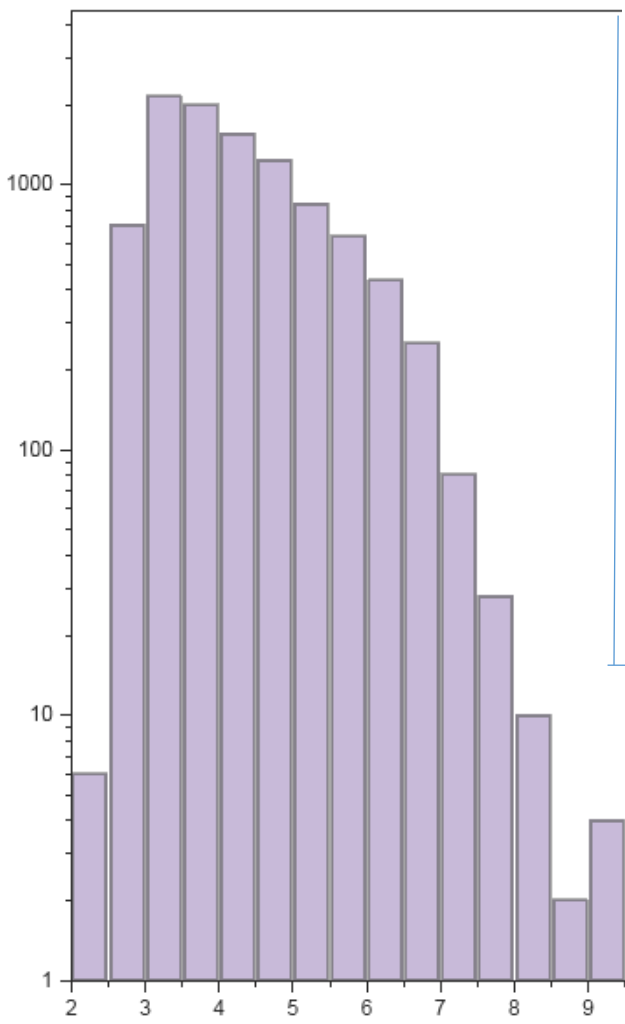
Experimental arrangement



Bórnitriddel implantált minták



G



DIAMETER (micron)

G LET (keV/micron)

Európai Lézer Infrastruktúra – Szeged, HU



itt is elindulhattak a kísérletek!

ELI-ALPS Szeged:
EU Extrém Fény Infrastruktúra
Attosec. Impulzusú Fényforrás
2PW extrém nagy térerősség
10 Hz(?), **<10fs**, **30 J**

ÖSSZEFOGLALÁS:

- A lokalizált plasmonok (LSPP) több tulajdonságban eltérnek a haladó hullámúaktól, számunkra néhány előnyös következménnyel.
- A paramétereik anyag és alakfüggőek (az Au és Ag rezonanciái a látható spektrumban)
- Nagy lézerintenzitásoknál nincs plazma tükör.
- A nanorészecskék effektívek nagy lézer intenzitásoknál is.
 - Térerősítés (hot spots).
 - Optimális élettartam femtoszekundumos lézerekhez (e.g. Ti:Sa, 800nm)
 - Egyszerű geometria.
 - Árnyékolás (közeli tér és ponderomotív gyorsítás)
 - Korrelált impulzus átadás
- Energia termelés (kráter térfogat hétszer nagyobb Au nanorudakkal) és $H \rightarrow D$ transzmutáció (fúzió) mint energiaforrás. Ez utóbbit mutatják a Raman szórásos spektrumok (C-D és C-N rezgések), valamint a LIBS mérések is.
- A Thompson parabola mérések pedig azt mutatják, hogy az energia termelés még nagyobb is lehet.
- Támogató modellezési eredmények.
- Bőven vannak még nyitott kérdések.

KÖSZÖNOM A FIGYELMÜKET!



Ha a változás szelei fújnak egyesek bűvóhelyeket építenek,
mások azonban szélturbinákat.

*In any field find the
strangest thing and
and then explore it.*

John Archibald Wheeler



More science quotes at Today in Science History todayinsci.com

