# NANOPLAZMONIKUS LÉZERES FÚZIÓS PROGRAM (NAPLIFE)

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Wigner Fizikai Kutatóközpont

Budapest, 2020.10.29

# A következő évtizedek talán legnagyobb kihívása:

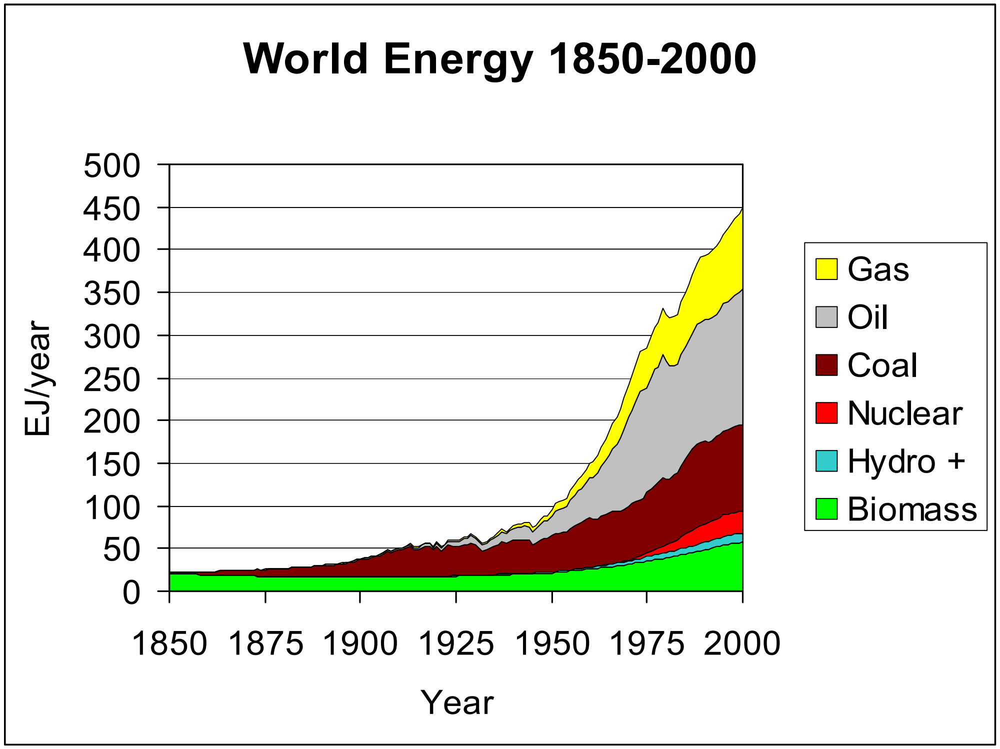
## $10^{10}$ EMBER SZÁMÁRA ENERGIA BIZTOSÍTÁSA

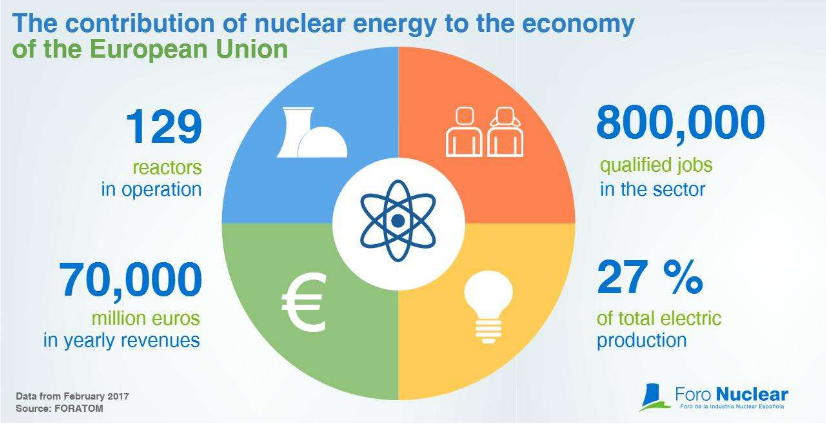
Ehhez 2050-re minimum 10 Terawatt megújuló energiaforrásra lesz szükség

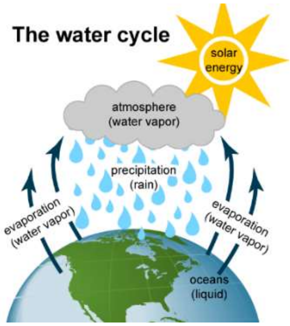
És a globális prosperitás érdekében ennek olcsónak kell lennie

**EZT A JELENLEGI TECHNOLÓGIÁKKAL LEHETETLEN ELÉRNI**

És a környezetkárosítás?



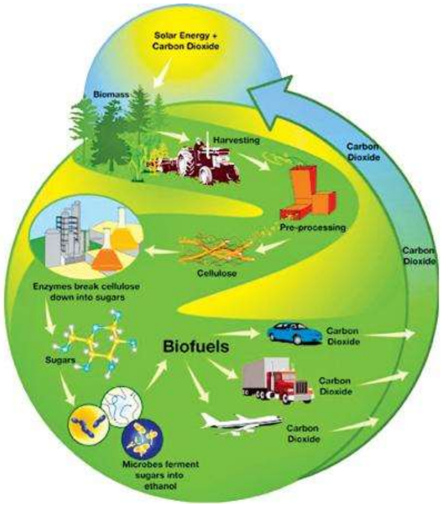





10% hatásfok, ha fúj a szél

**1850 és 2000 között a növekedés 20-szoros. A fosszilis források részesedése 2000-ben 80% volt.**

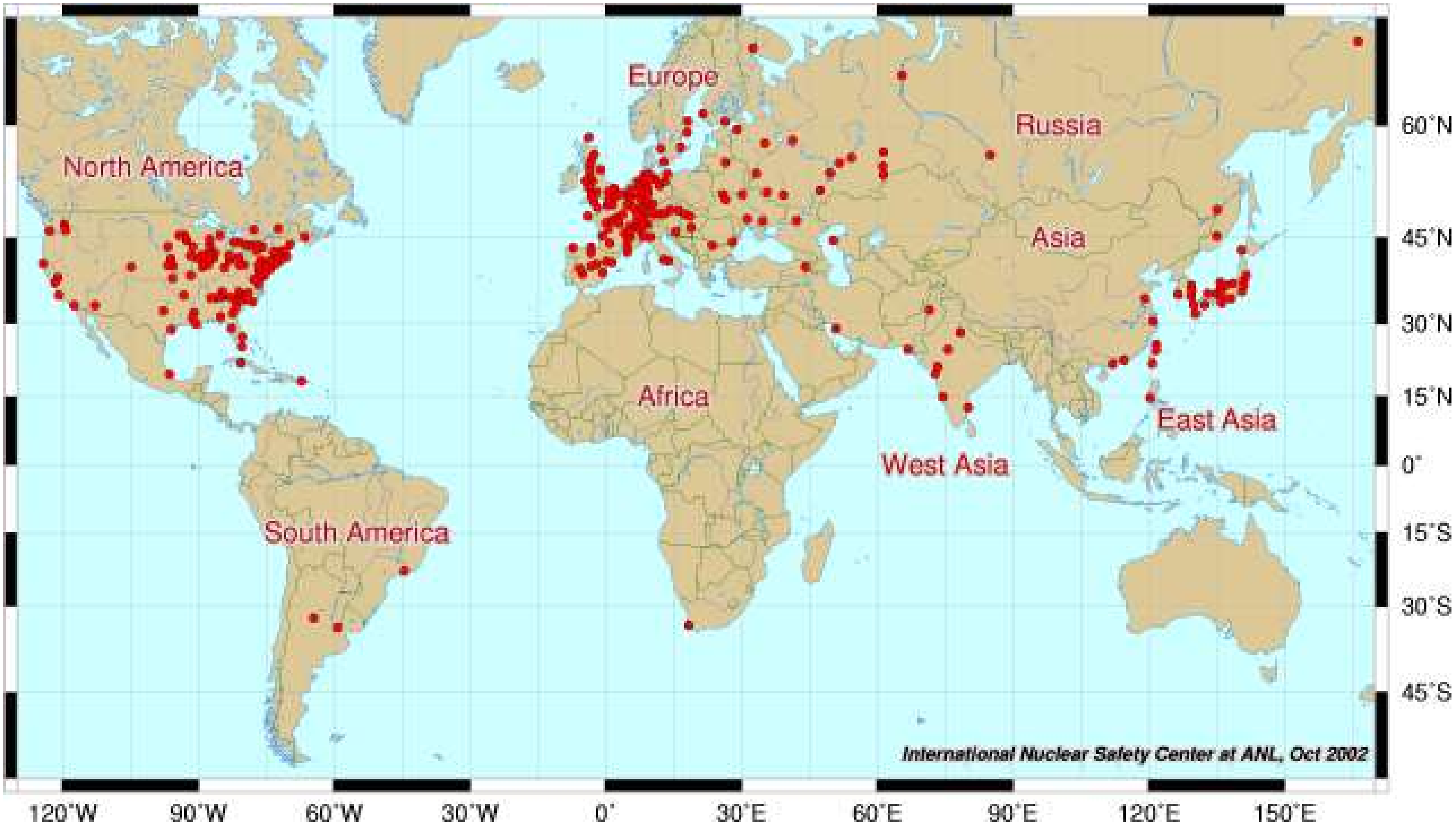
10-20% hatásfok, ha süt a nap. Nagy területigény.



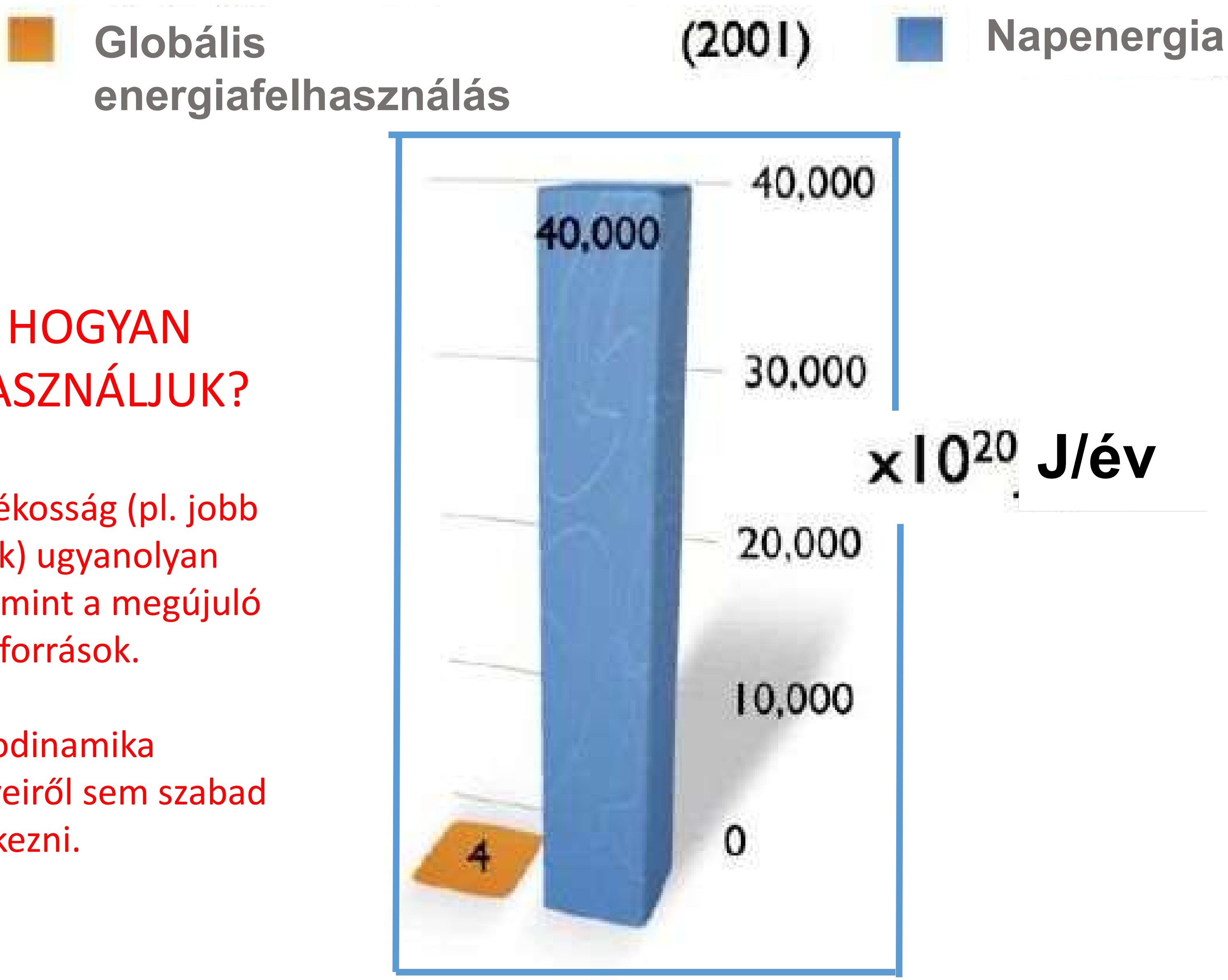
# Atomerőművek Földünkön

## (az E = mc^2 törvény első energetikai alkalmazása)

RÁDIÓAKTÍV HULLADÉK PROBLÉMA!



*International Nuclear Safety Center at ANL, Oct 2002*



## HOGYAN HASZNÁLJUK?

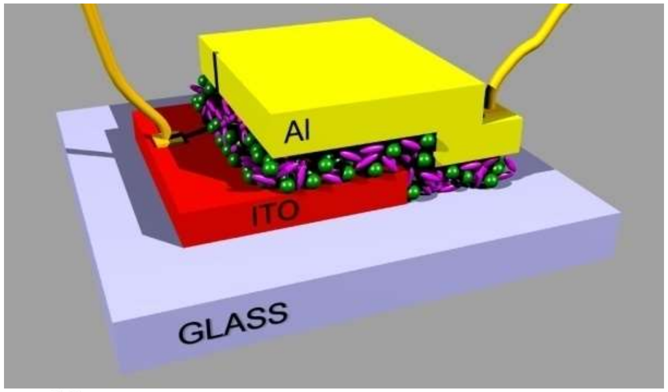
A takarékosság (pl. jobb hatásfok) ugyanolyan fontos, mint a megújuló energiaforrások.

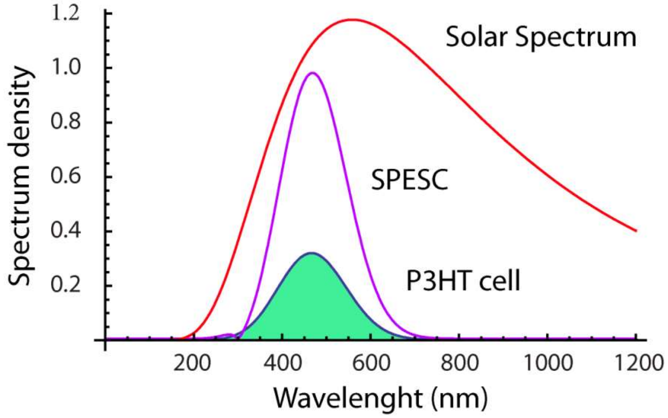
A termodinamika törvényeiről sem szabad elfelejtkezni.

**A földre érkező napenergia jelenlegi fogyasztásunk 10 000 szerese**

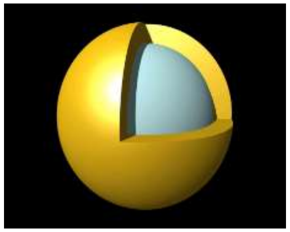
# Potenciális új lehetőségek

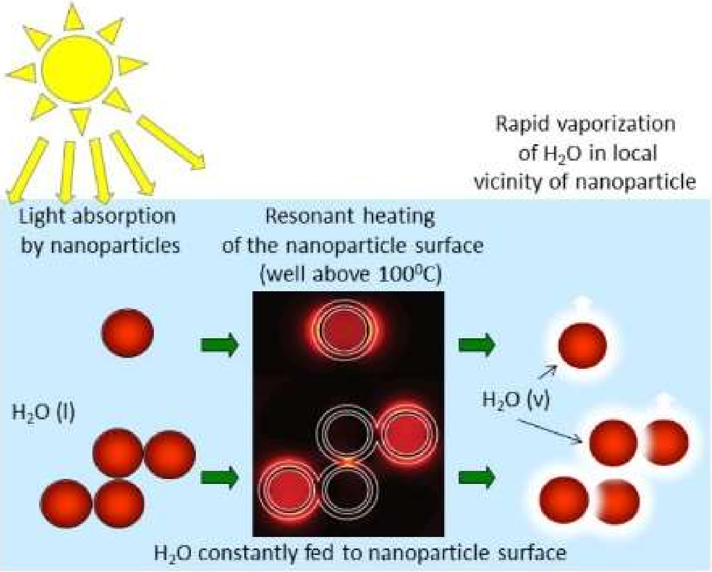
## (Pl. nanotechnológia)



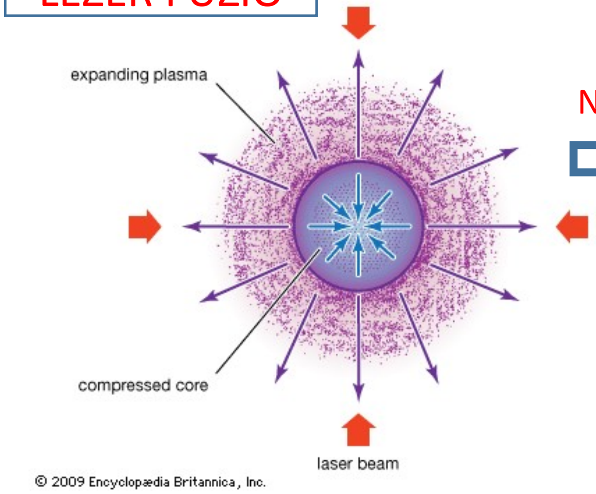


**P3HT Cella**
**hatásfoka = 6%**
**SPESC (P3HT)**
**hatásfoka = 17.5%**





LÉZER FÚZIÓ



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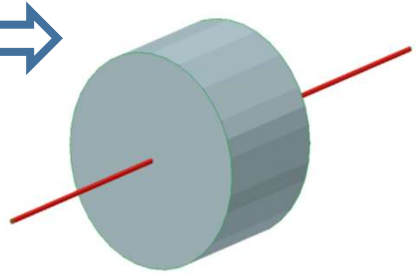
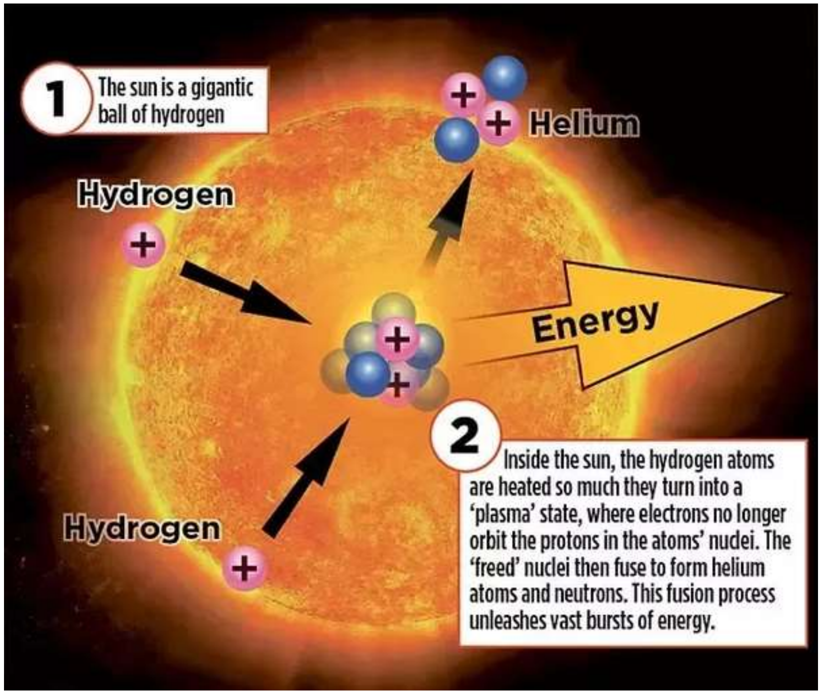
Nanotechnológia



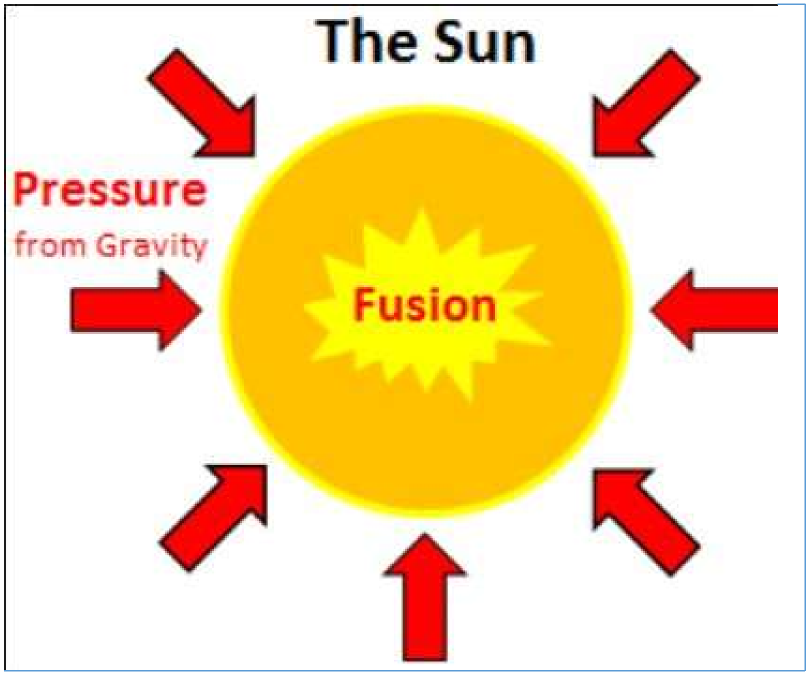
NANOPLAZMONIKUS
LÉZER FÚZIÓ

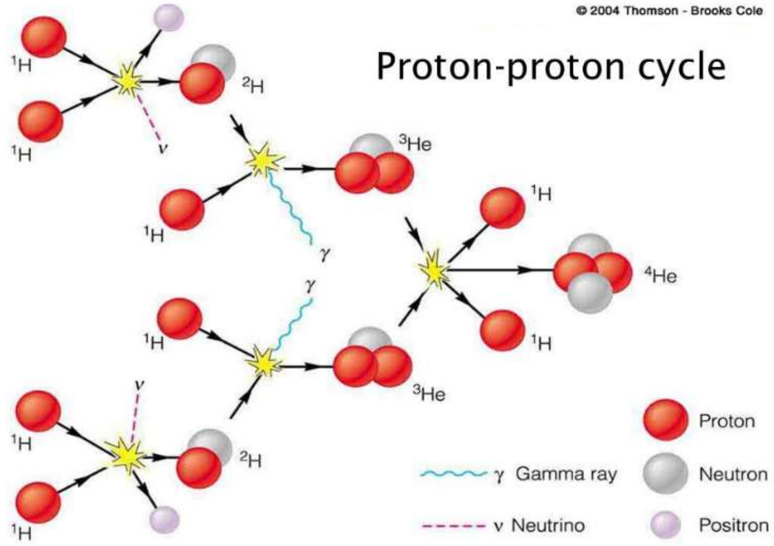
LENR
?

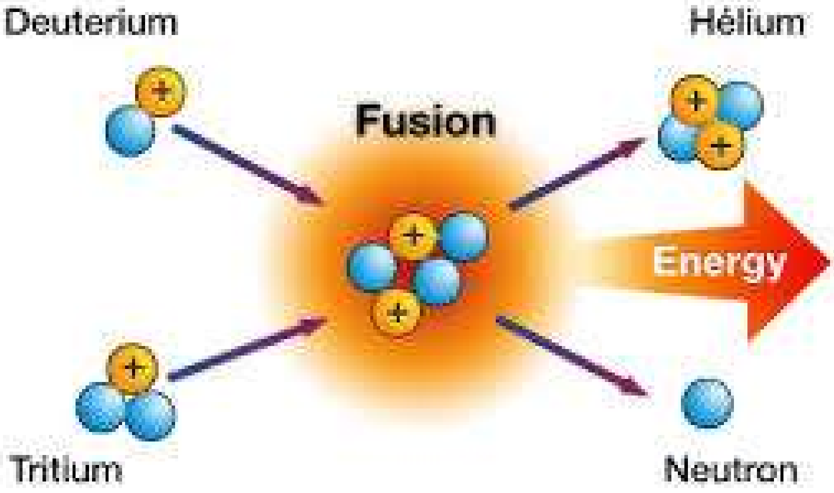


The sun is a gigantic ball of hydrogen

Inside the sun, the hydrogen atoms are heated so much they turn into a 'plasma' state, where electrons no longer orbit the protons in the atoms' nuclei. The 'freed' nuclei then fuse to form helium atoms and neutrons. This fusion process unleashes vast bursts of energy.







# A jövő: fúzió

(két példa)

1.ITER épülőben

2.National Ignition Facility

192 nyaláb, 1.8MJ,
1lövés/nap

# PROBLÉMÁK AZ INERCIÁLIS (NIF) FÚZIÓVAL:

Napenergia.
Hidrogénbomba és megszelidítése (korlátlan energiaforrás).
Többfajta próbálkozás (pl. ITER, NIF).
Utóbbinál óriási lézer energia igény és sok nyaláb (192),
(alacsony lézer hatásfok, ritka lövések).
„Lassú” összenyomás, hosszú lézerimpulzus (néhányszor 10ns).
Rayleigh-Taylor instabilitás.
Rossz hatásfokkal jut be a fény az anyagba.
Begyújtás csak a gömbtarget közepén, nem time-like.

## ALAPÖTLETEINK:

1. Nanorészek a targetben (gyors folyamat, plazmonikus erősítés, térfogati összenyomás, lapos target,csupán két nyaláb)
   Kisebb minta, kisebb energiaigény, gyakori impulzusok.
2. A target „egyidejű” begyújtása

**KUTATÓ LABORATÓRIUM**

## NANOPLAZMONIKUS LÉZER FÚZIÓ (NAPLIFE PROGRAM)

- *A fúzió egyidejű lézeres begyújtása a céltárgy egész térfogatában (saját és új ötlet).*

  *(a következő előadás tárgya:Csernai László)*
- ***Nanoantennák** gyűjtik össze a lézer energiát a céltárgy belsejében (saját és új ötlet)*

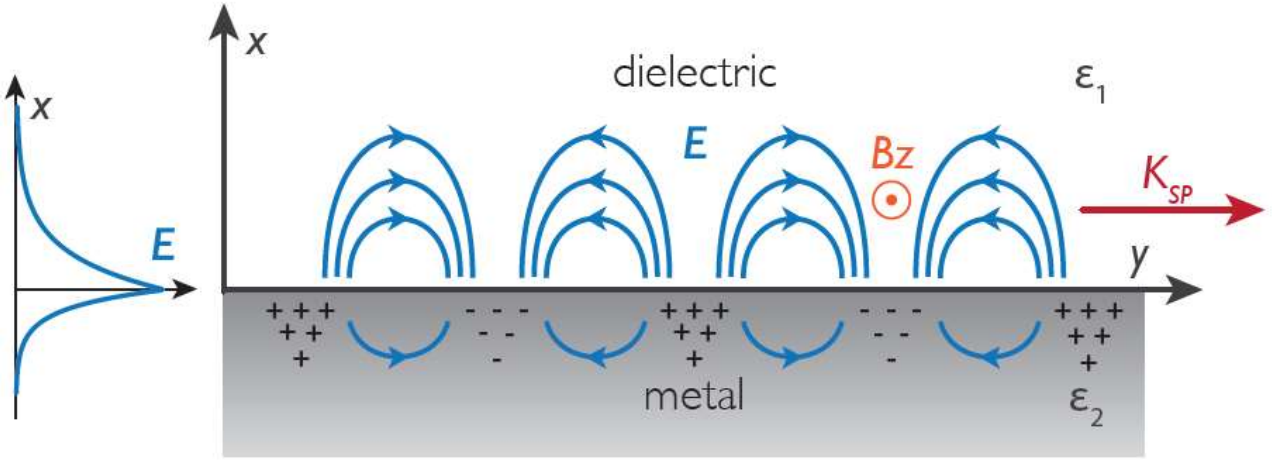
  *(öt nagyságrenddel rövidebb, ~100fs lézerimpulzusokkal)*
- *Lassú termikus égés helyett a lézerbelövés energiáját direkt használjuk.*

  *(nincs termikus egyensúly)*
- *Így a begyújtás és égés nagyságrendekkel gyorsabban történik .*
- *Nagy teljesítményű belövések az ELI-ALPS berendezéseivel (csak 2 nyaláb, 10lövés/sec, 32J)*

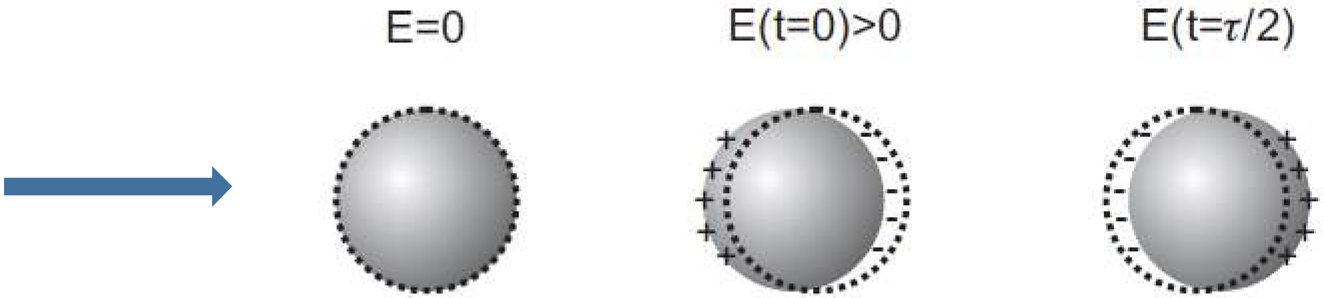
  *(szembe ütköző pl. H és D nyalábok)*

- ***Fúziós energia = legtisztább energia és korlátlan üzemanyag***

# HIGH FIELD PLASMONICS



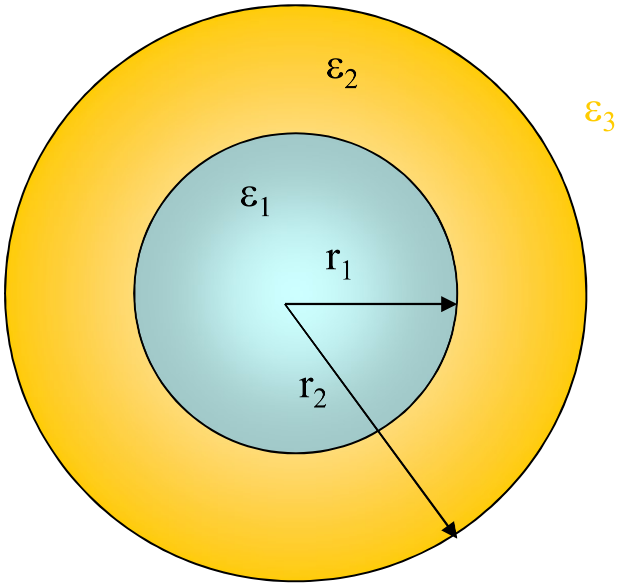
**SPP**

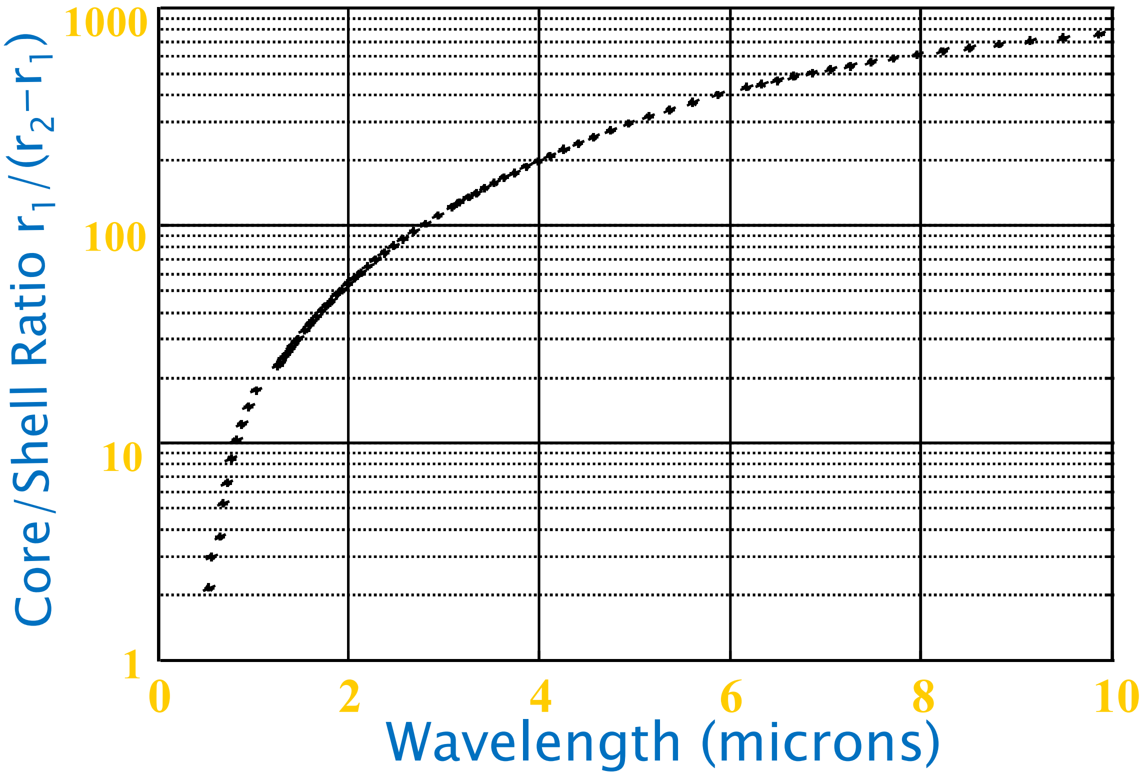


**LSPP**

Ti:Sa lézer: Λ=800nm (~1.5eV)

# Spectral tuning range nanoshell plasmon rezonance





1.24 ← electron volts → 0.124

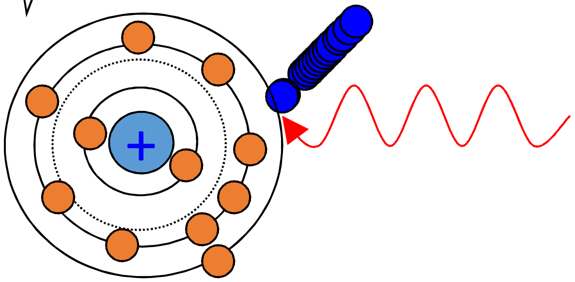
300 ← THz → 30

10,000 ← $cm^{-1}$ → 1,000

# Matter under extreme conditions (extremely high intensities)

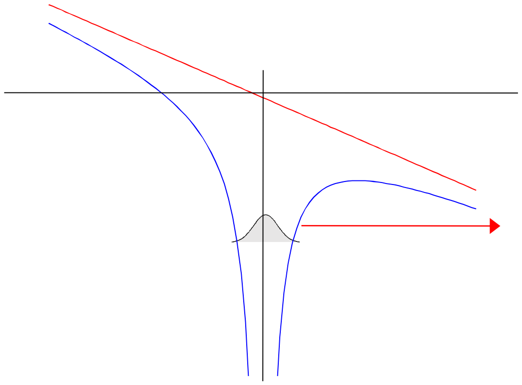
**single atom**

$I = 10^{16}$ W cm$^{-2}$ → $E \sim 10^{9}$ V/cm

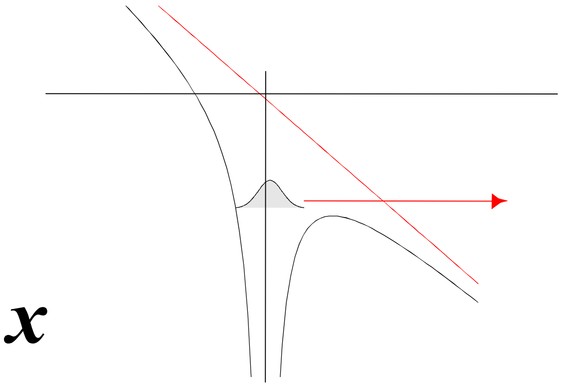


High intensity
Photoeletric Effect

*Rapid ionization of valence electrons*



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



Tunnelling

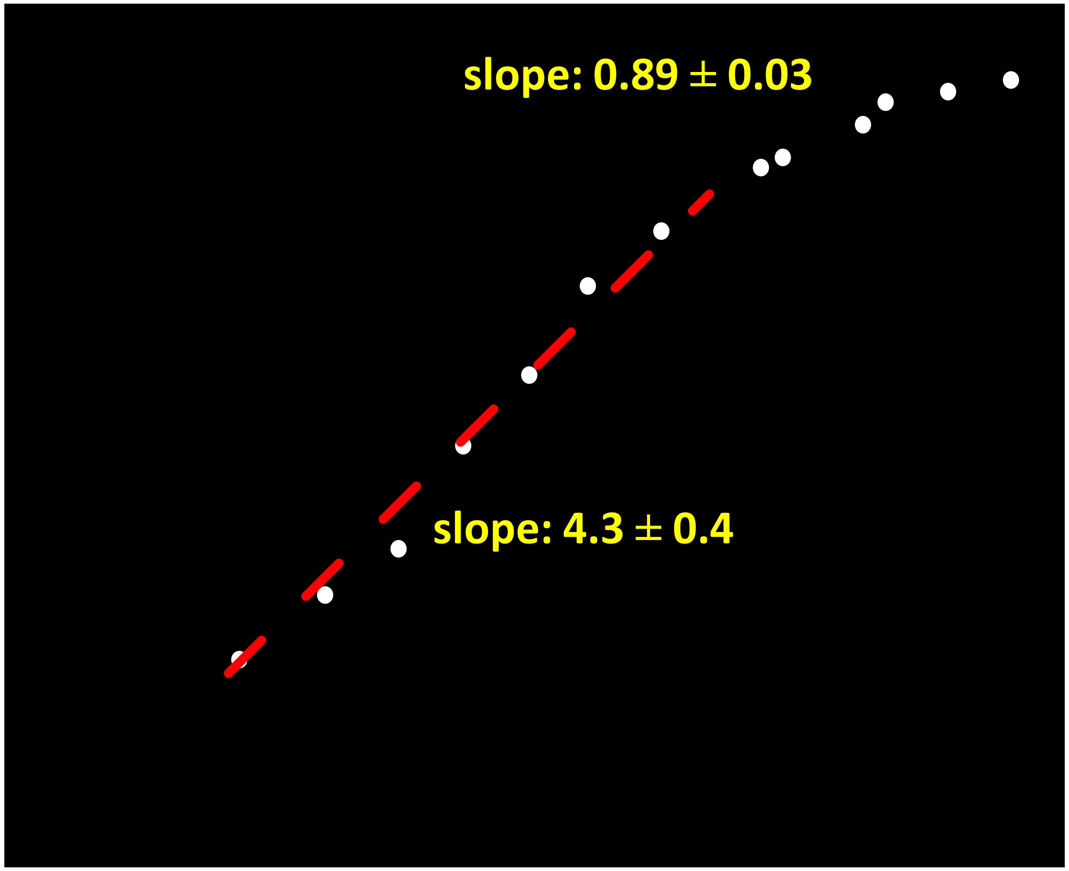
$10^{14}$ - $10^{15}$ W cm$^{-2}$

Over the barrier

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

Each atom loses at least one electron. Some can lose as many as 6 !

# Multiphoton electron emission from gold



Multiphoton-tunneling
transition at
~4x10$^{10}$ W/cm$^2$ incident
intensity,
~5.5x10$^8$ V/m field

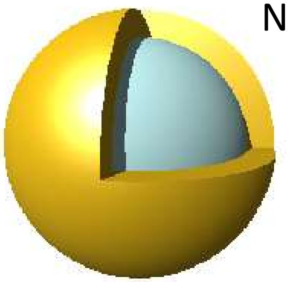
Keldysh-gamma $\gamma$=31

→ indication of well-known field enhancement of surface plasmonic fields

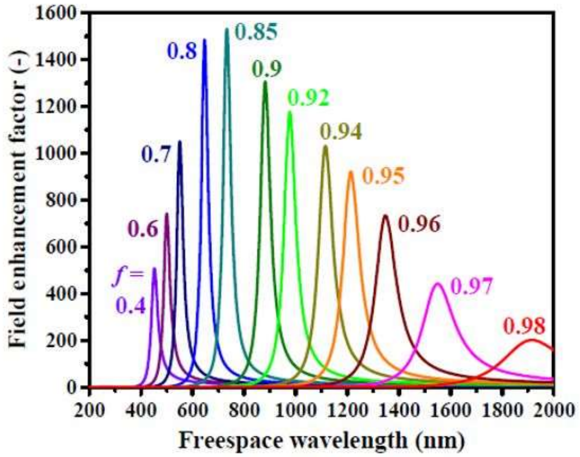
**PLASMONSIC ENHANCEMENT!**

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

*W*: work function, $E_l$: laser field strength

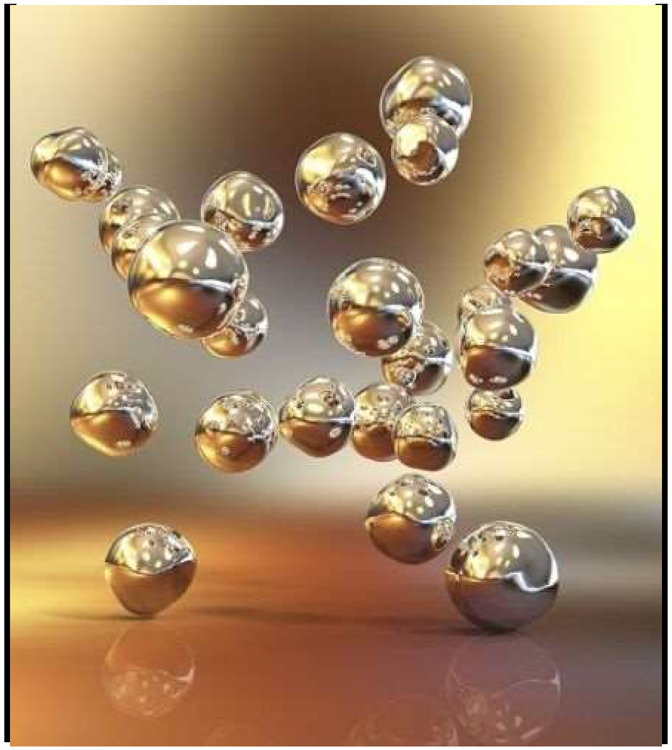


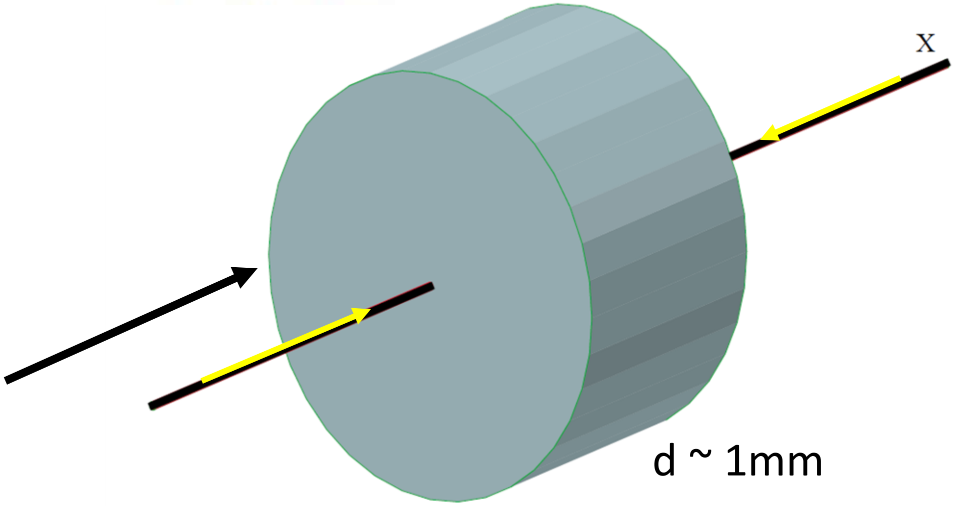
NANOSHELL



ʎ = 800nm

NANOROD





d ~ 1mm

PICO/FEMTOSECOND LASER PULSES

HIGH REPETITION RATE

LIGHT SPEED: NO INSTABILITIES

TWO BEAMS

VOLUME IGNITION

NANOPARTICLES
DOPED FUEL

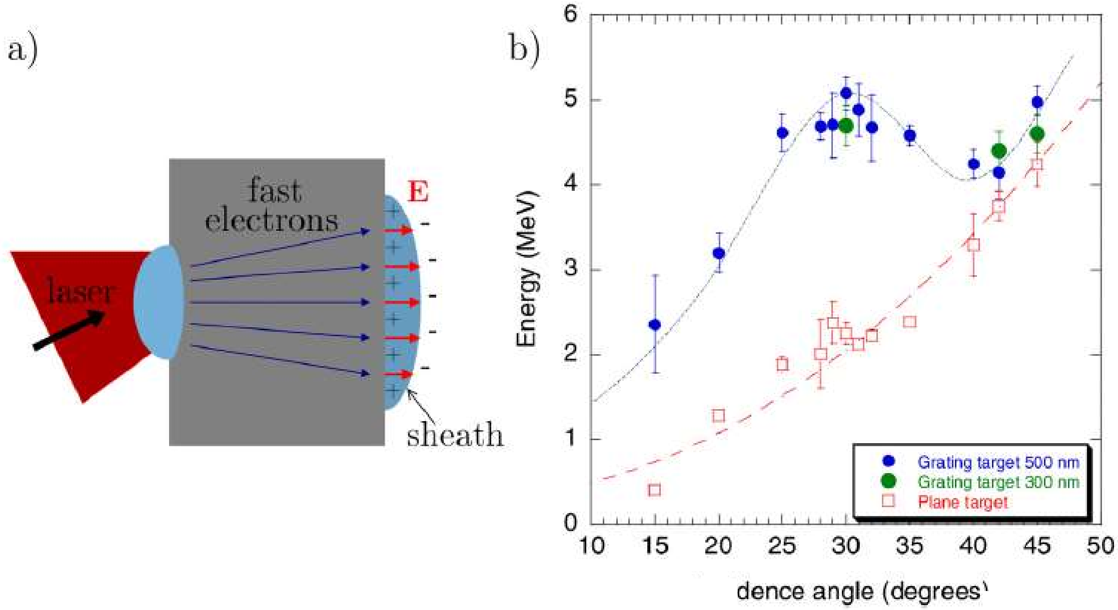


FIG. 5. Plasmon-enhanced TNSA of protons.[95] (a) Schematic of TNSA. The fast electrons produced by the interaction at the front side cross the target and produce a sheath at the rear side, where ions are accelerated. (b) Experimental data from the interactions of a high-contrast 25 fs, $2.5 \times 10^{19}$ 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.

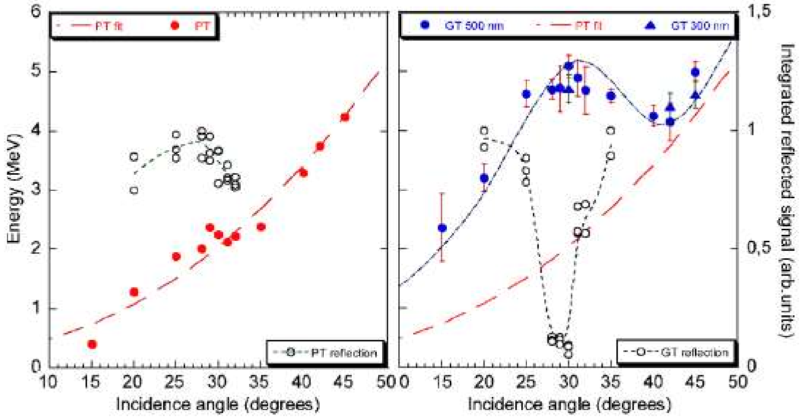


FIG. 3 (color online). Maximum proton energy (filled data points) and reflected light signal (empty data points) as a function of incidence angle $\alpha$. Left and right frames correspond to 20 $\mu$m thick plane targets and to 23 $\mu$m thick grating targets, respectively. Filled circles and triangles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

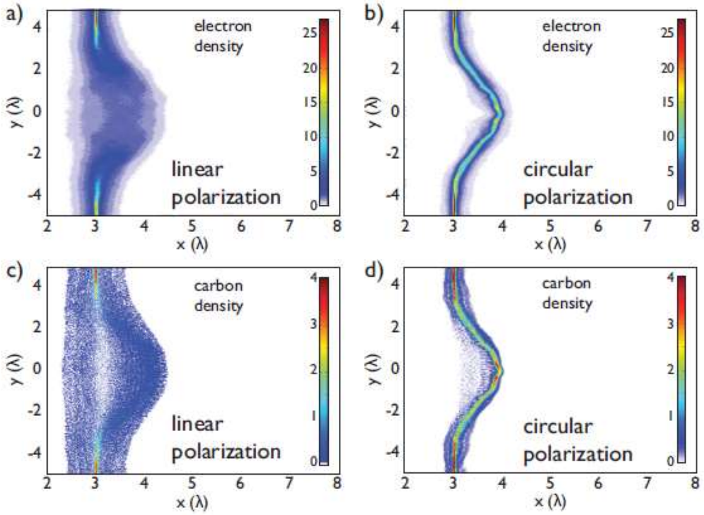


FIG. 4: (color). Cycle-averaged electron (a,b) and carbon ion (c,d) density at $t = 61$ fs after the peak of the laser pulse reached the 5.3 nm target initially located at $x = 3\lambda$. While linear polarization results in strong expansion of the target caused by hot electrons, for circularly polarized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

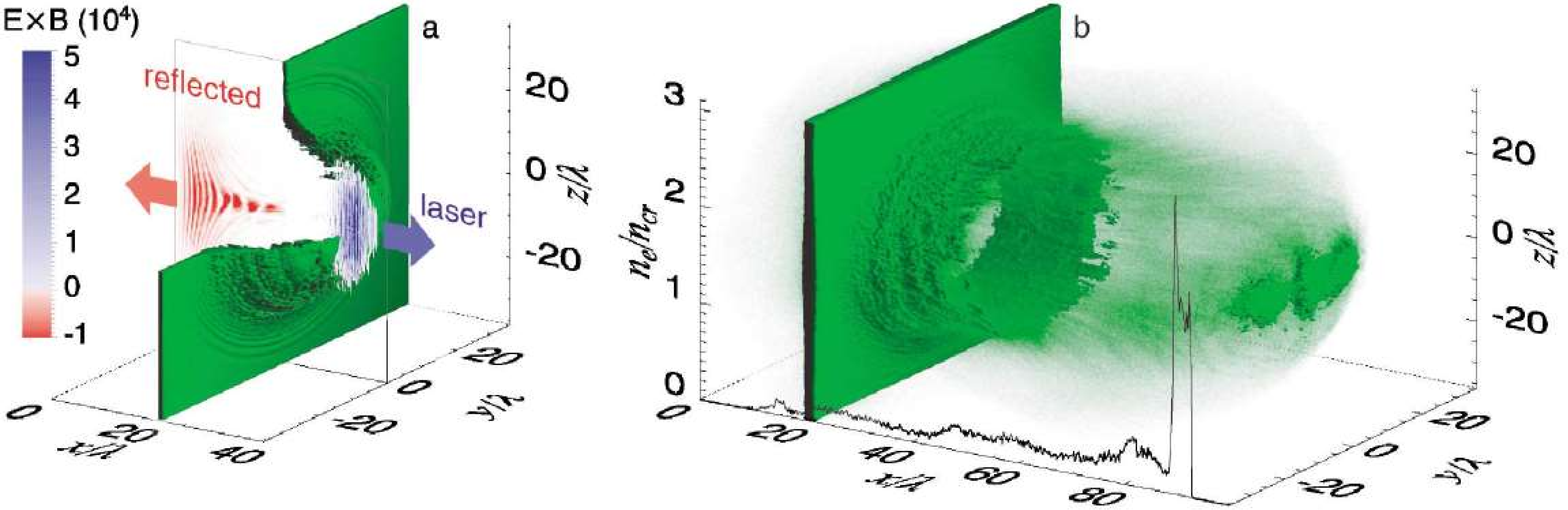


FIG. 1 (color). (a) The ion density isosurface for $n = 8n_{cr}$ (a quarter removed to reveal the interior) and the $x$ component of the normalized Poynting vector $(e/m_e \omega c)^2 \mathbf{E} \times \mathbf{B}$ in the $(x, y = 0, z)$ plane at $t = 40 \times 2\pi/\omega$. (b) The isosurface for $n = 2n_{cr}$, green gas for lower density at $t = 100 \times 2\pi/\omega$; the black curve shows the ion density along the laser pulse axis.

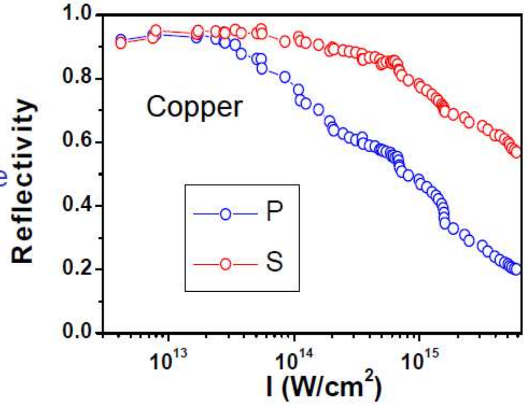
## *Plasma absorption*

- A = 1-R

$I < 3 \times 10^{13}$ W cm$^{-2}$, A is almost polarization independent & obeys Fresnel laws, as IB is dominant

- at higher intensities, there is a clear polarization dependence of absorption

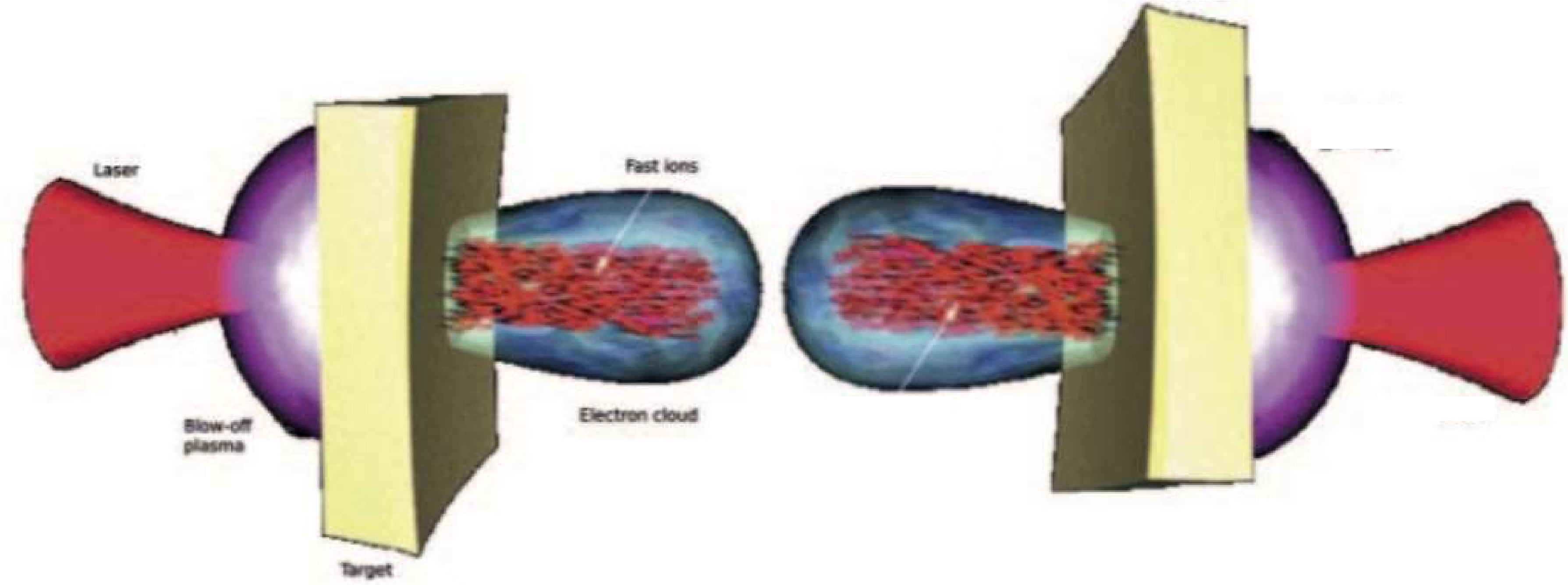
- the difference in absorption should account for extra absorption mechanisms, which are polarization dependent

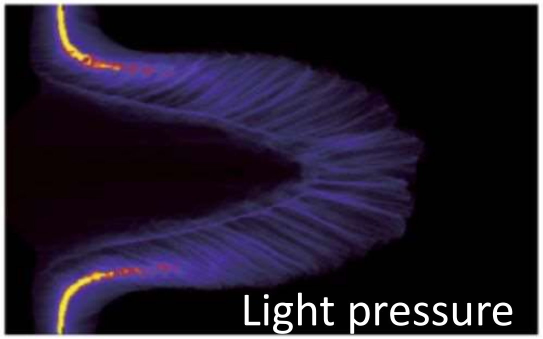


**R vs I at 45°**

*TIFR data*

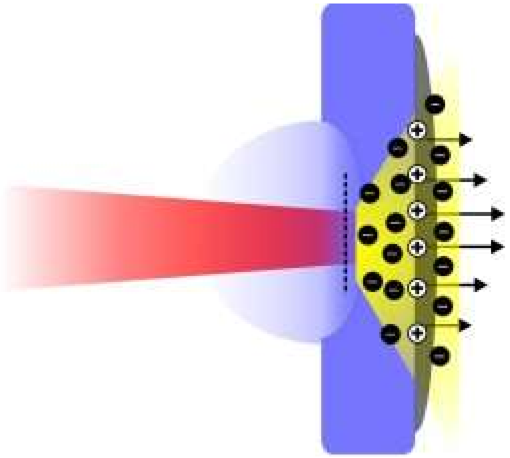
# COLLIDING PARTICLE BEAMS



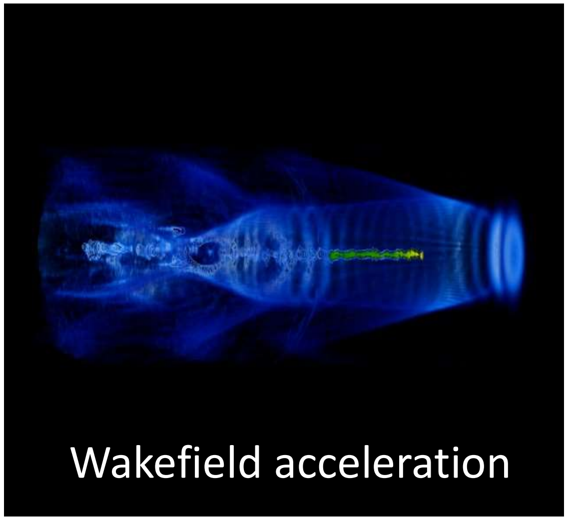


Proton acceleration by radiation pressure (100 MeV)

Nanoparticles: also volume contraction



Target normal sheath acceleration



# Európai Lézer Infrastruktura – Szeged, HU

ELI-ALPS Szeged:
EU Extr. Fény Infrastruktura
Attosec. Impulzusú Fényforrás

2PW extrém nagy térerősség
10 Hz, <10fs, **20 J**