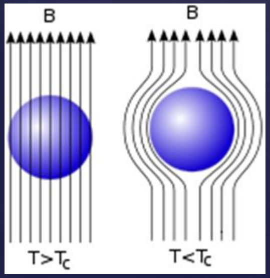
SZOBAHŐMÉRSÉKLETŰ SZUPRAVEZETÉS?

(FELÜLETI PLAZMONOKKAL)

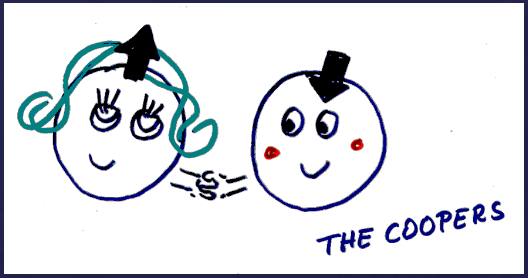
(A kisérleti fizika szépsége)

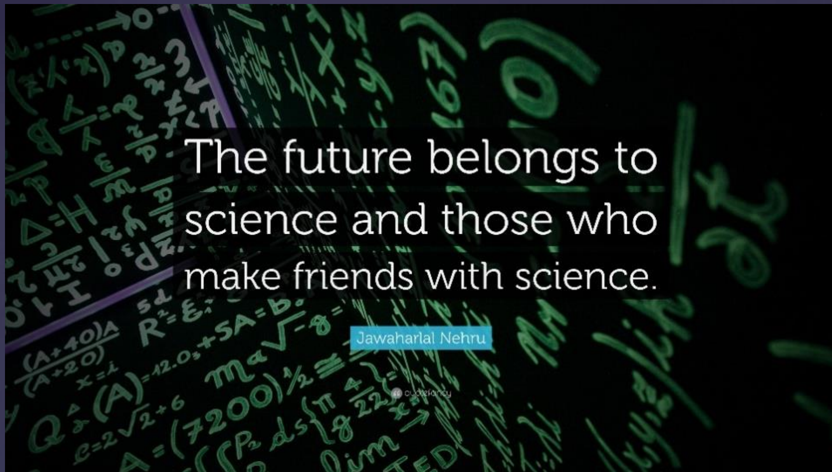
Kroó Norbert

Wigner Fizikai Kutatóközpont



VÁC,Tanankét, 2021.10.22



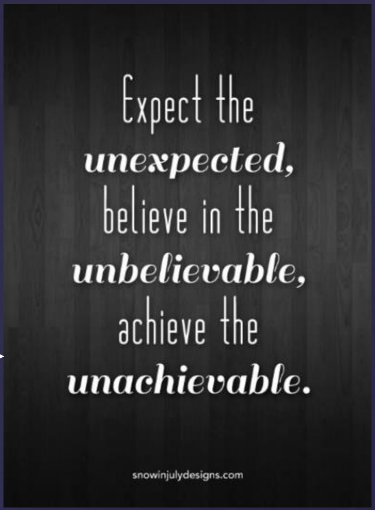


KÍVÜLÁLLÓKNAK

ÜZENETEK

↔

MŰVELŐKNEK

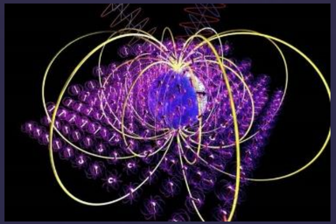


A TUDOMÁNY SZÉPSÉGE, HOGY OTT ÉS AKKOR FEDEZ FEL ÚJ DOLGOKAT, AHOL ÉS AMIKOR AZOK MEGTALÁLÁSÁT A LEGKEVÉSBÉ VÁRJUK .

MINDEN RIOGATÁS ELLENÉRE A TUDOMÁNY KÖSZÖNI SZÉPEN, JÓL VAN. NAGY SZÜKSÉG IS VAN RÁ, PL. ÚJ TECHNOLÓGIÁKHOZ.

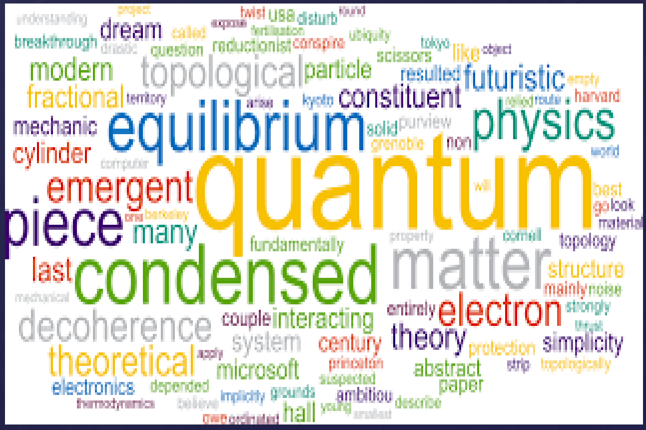
(annak ellenére, hogy sokan nem figyelnek erre, sőt egyesek még riogatnak is bennünket, például J.Hogan, THE END OF SCIENCE című könyvével).

MINDEN TECHNOLÓGIA PEDIG CSAK LEHETŐSÉG ÉS AZ, HOGY HOGYAN HASZNÁLJUK, CSAK TŐLÜNK FÜGG,



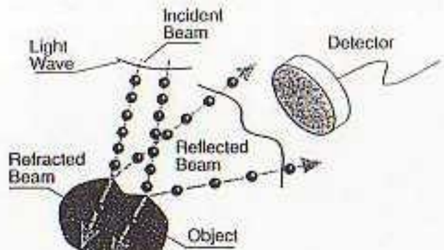
A MIKRO- ÉS NANOVILÁG

KORUNK 5 LEGÍGÉRETESEBB TECHNOLOGIAI FORRADALMA

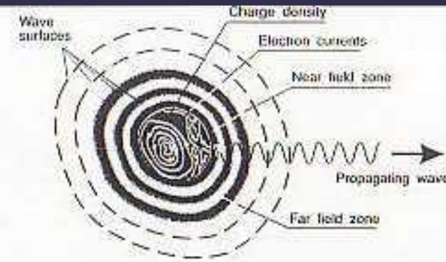


AZ OPTIKAI KÖZELI TÉR

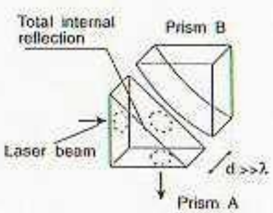
(egy példa)

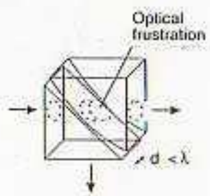


Schematic of the interaction between an object and a light beam. In first approximation, the light beam can be considered as projectiles launched against a target (the object) and then reflected towards the detector. This interpretation is primitive but provides the basis for the understanding of the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

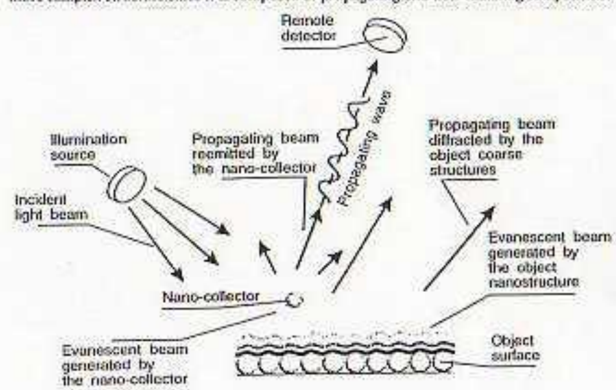


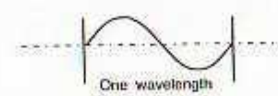
Field emitted from an object. The electron currents (in the case of conducting materials) and the charge densities inside the object induce an electromagnetic field radiating from the surface. Far away from the surface the field has the well known structure of propagating waves. Very close to the object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





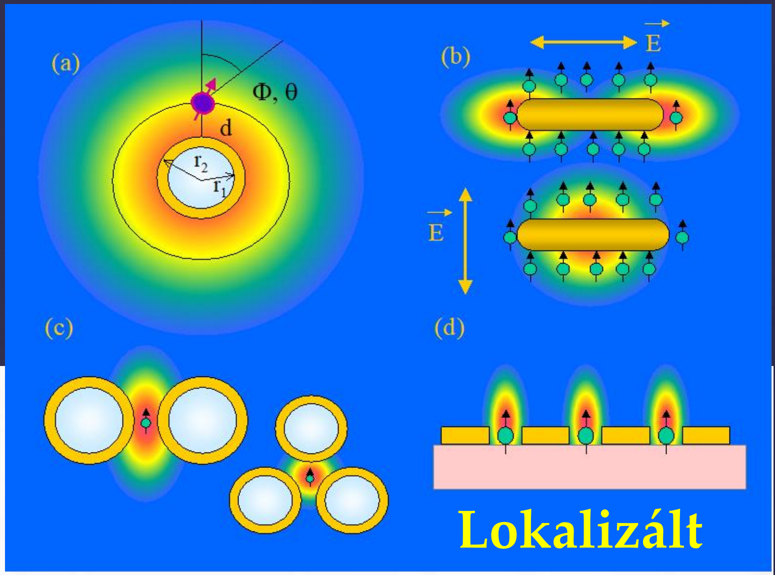
The famous experiment of Newton. A light beam is projected onto a prism. As expected, the beam is internally and totally reflected on the larger side of the prism. If a second prism is brought to the first one, no effect is detected unless the distance between the two prisms becomes smaller than a fraction 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*.

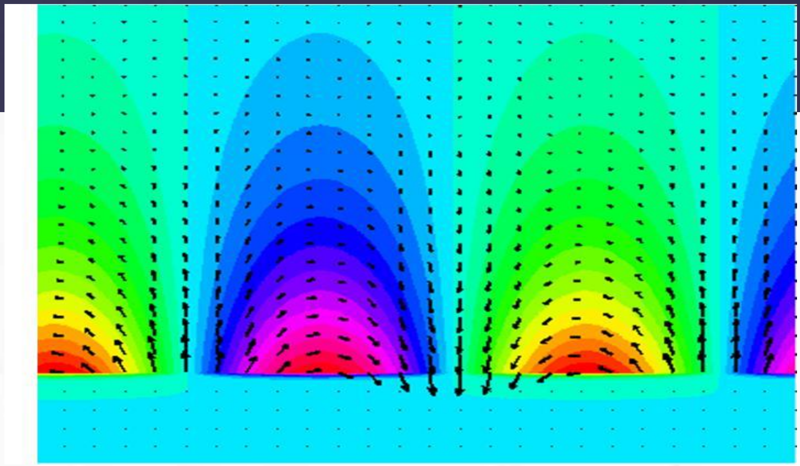


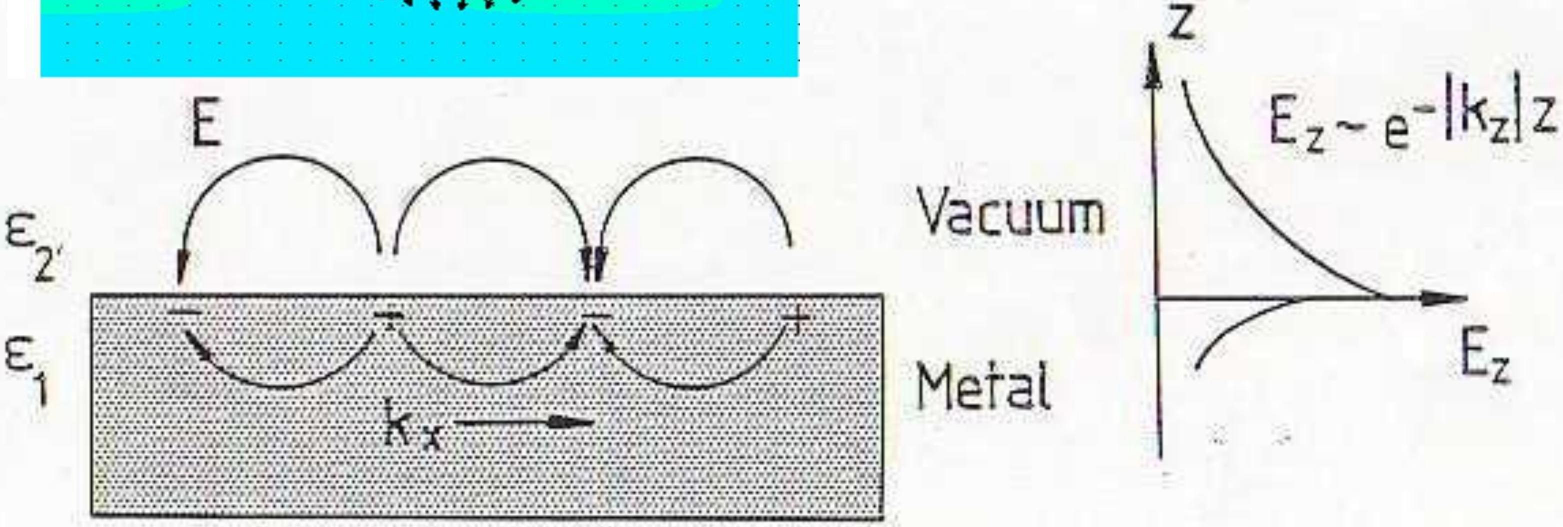


Sketch of near field detection. Step 1: generation of the object near field by the illumination process. A light source illuminates an object represented as composed of discrete components. These components are excited by the incident field and re-emit light. The waves associated to the reflected beam 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.

FELÜLETI PLAZMON KÖZELI TÉR



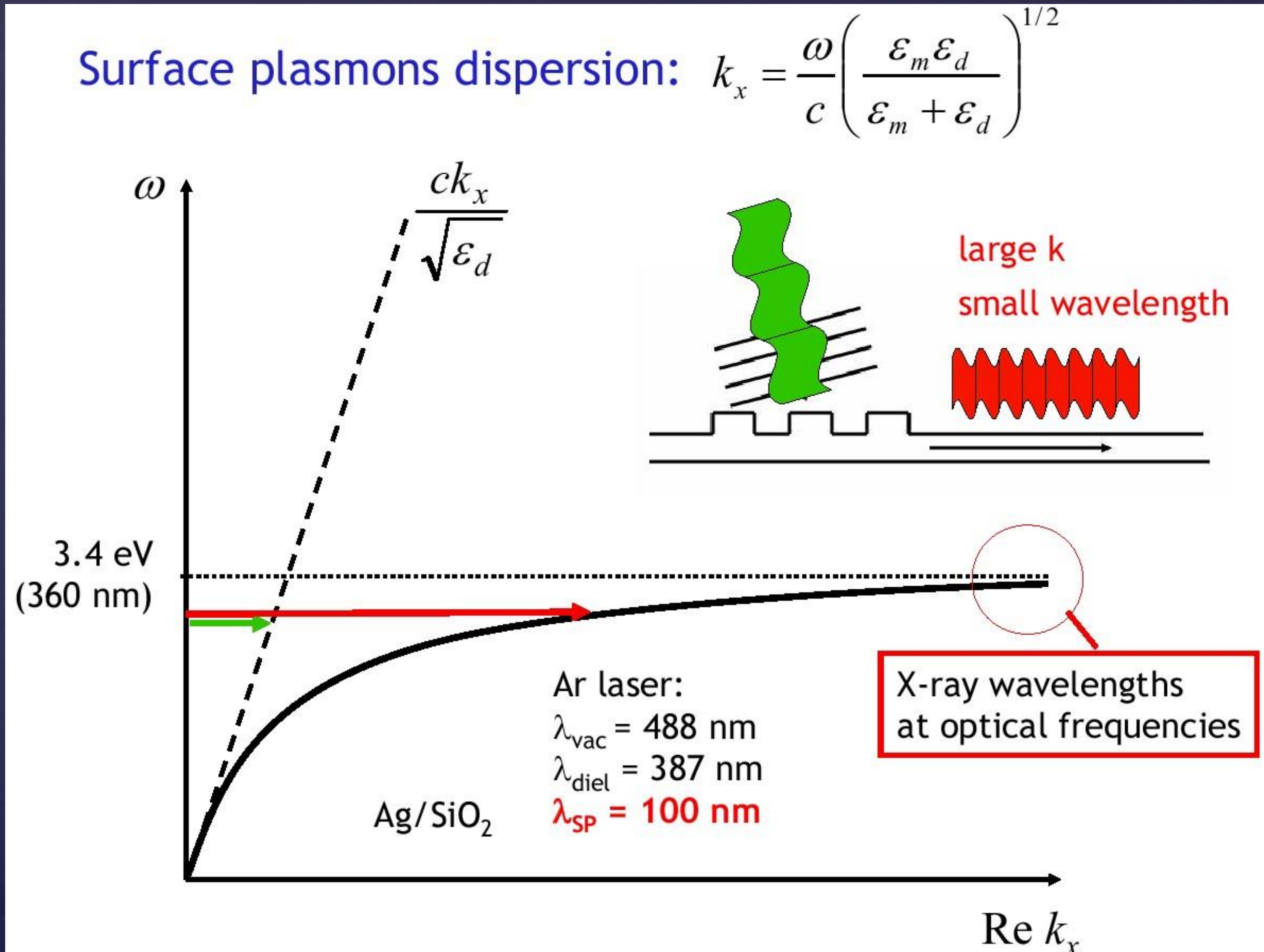




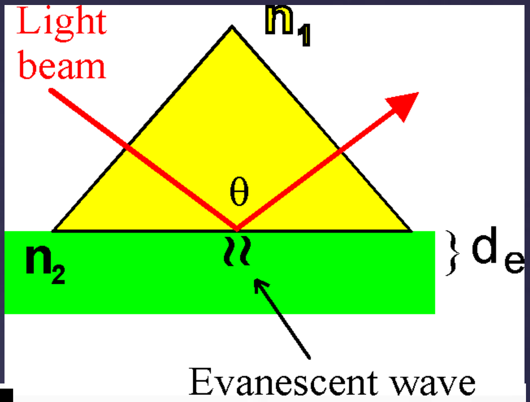
Haladó

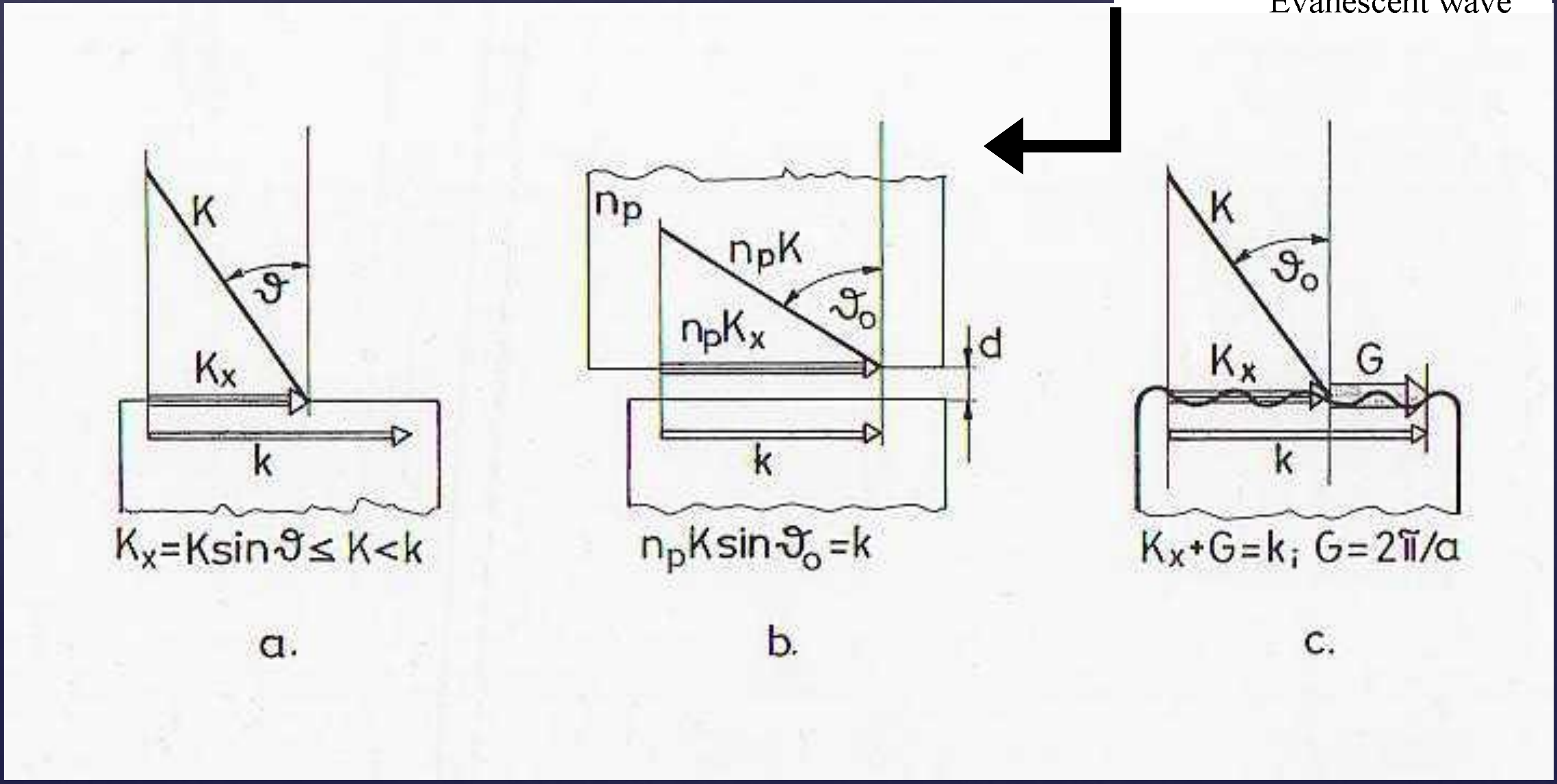
a Maxwell egyenletekből

FELÜLETI PLAZMON DISZPERZIÓS GÖRBE

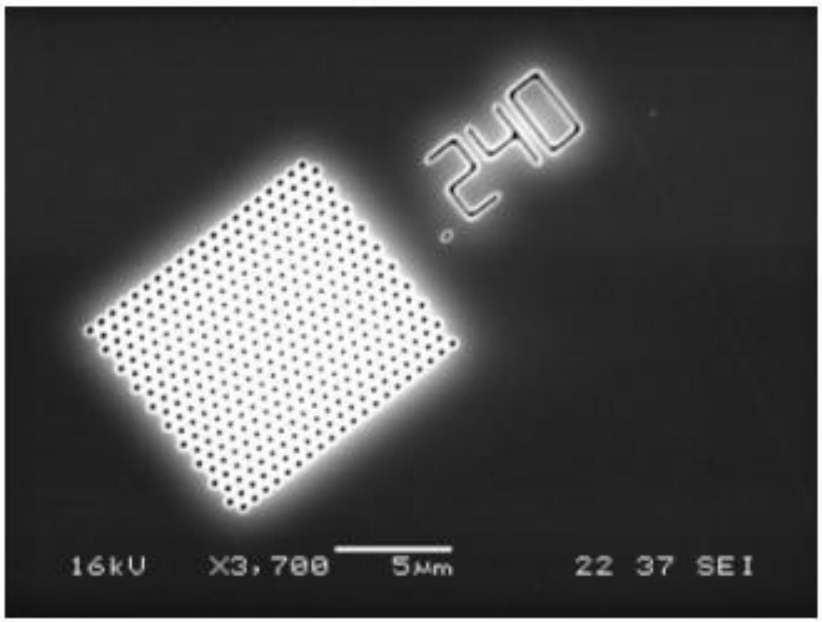


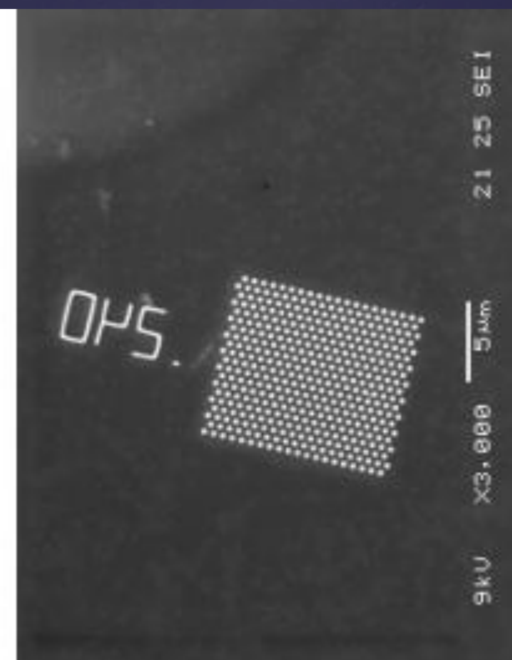
FÉNY-FELÜLETI PLAZMON CSATOLÁS PRIZMÁVAL VAGY OPTIKAI RÁCS SEGÍTSÉGÉVEL



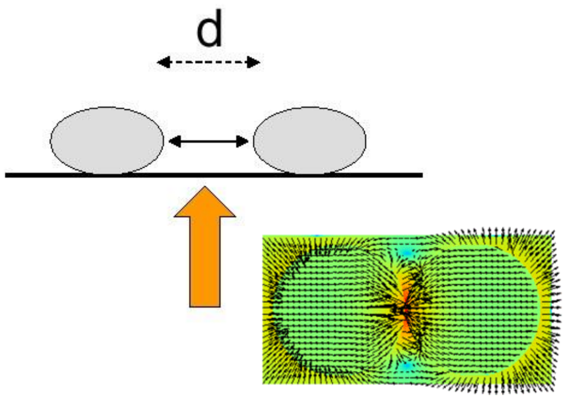


A fény hullámhossznál sokkal kisebb méretű lyukakon (réseken) is áthalad





Lokalizált plazmon rezonancia a hullámhossznál sokkal kisebb és nagyobb részecskék esetén



d << λ

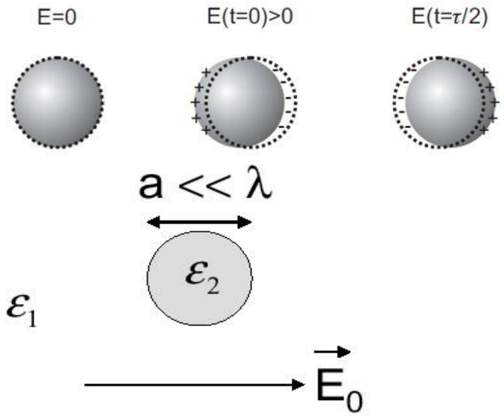
"Near-field coupling"

$\Rightarrow$ Resonator coupling

d >> λ

"Dipole-dipole coupling"

$\Rightarrow$ Interferences



If a << λ $\Rightarrow$ dipole :

$$p = \varepsilon_2 \, \alpha \, E_0$$

with:

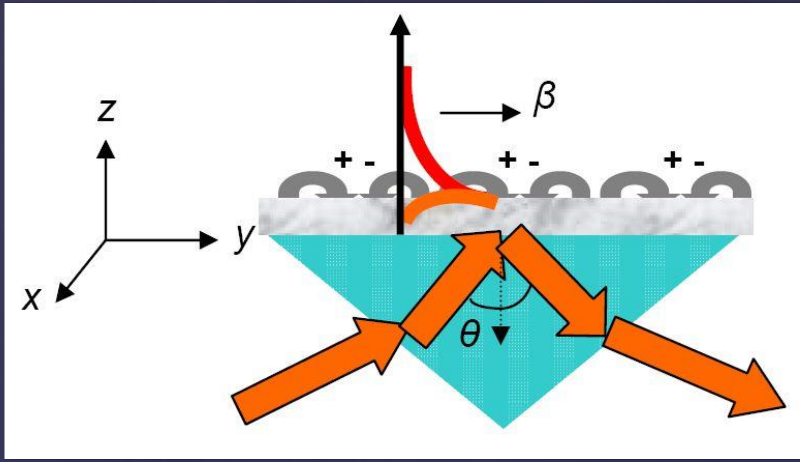
$$\alpha = 4\pi \, a^3 \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + 2\varepsilon_1}$$

Resonance when $\varepsilon_2 (\omega) = - 2 \times \varepsilon_1 (\omega)$

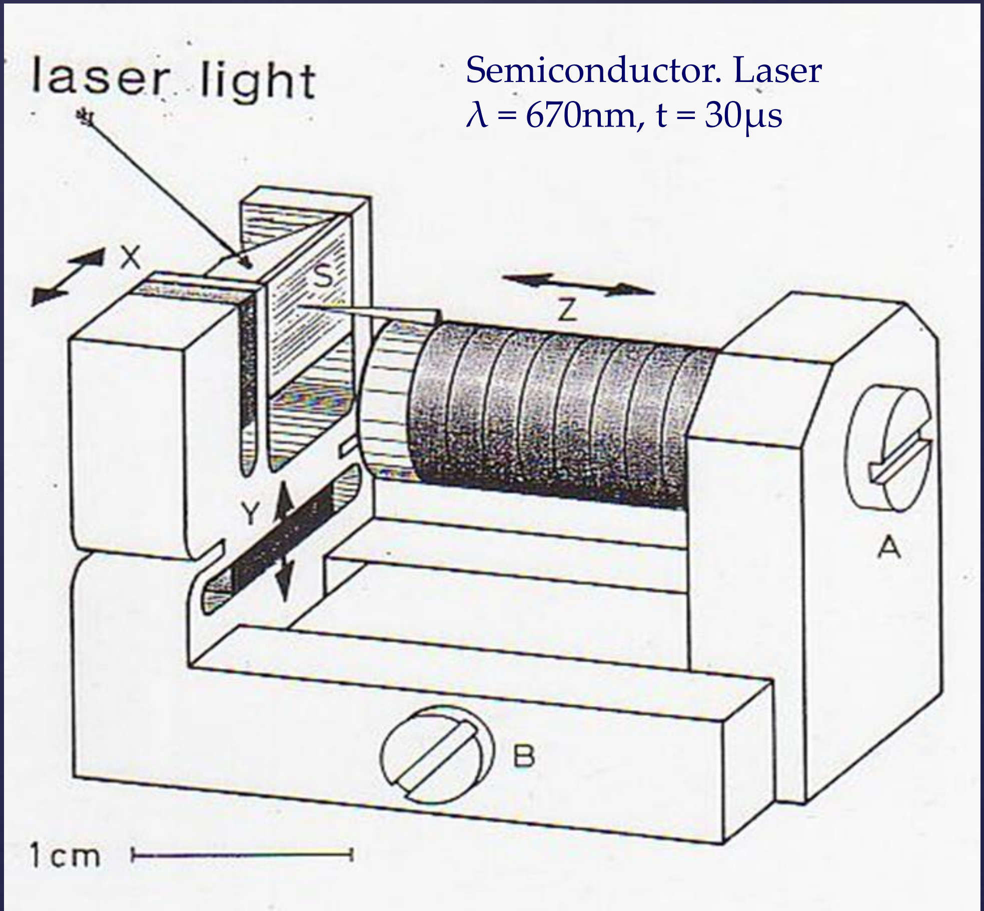
- Enhanced absorption
- Enhancement of the near-field & scattering

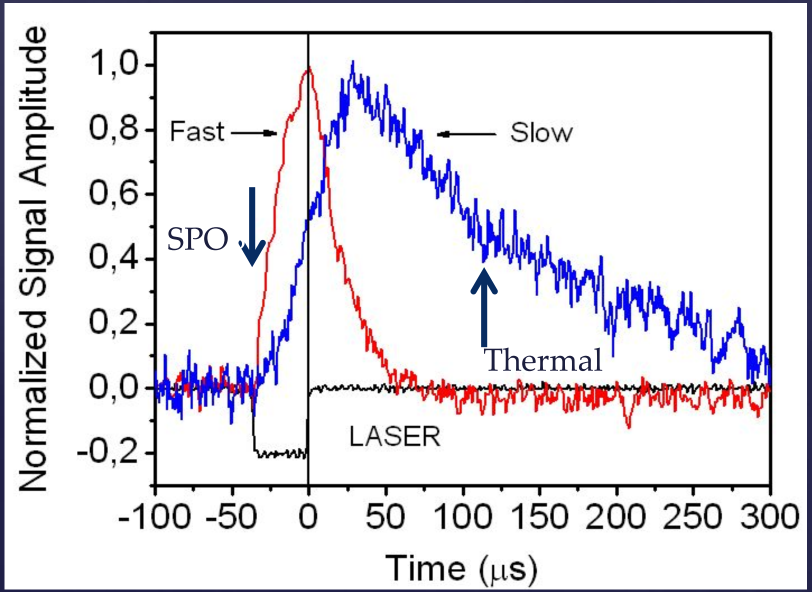
KÖZELI TÉR STM (a diffrakciós limit ellen)

KÖZELI TÉR:LÉZER IMPULZUS GERJESZTETT FELÜLETI PLAZMONOK
(Kretschmann geometria)

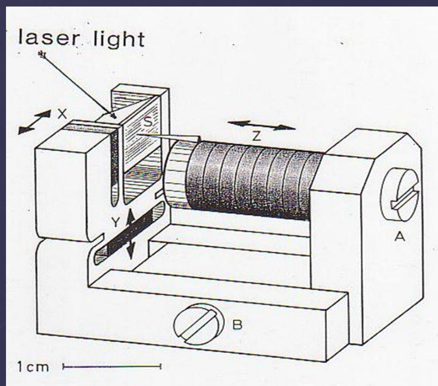


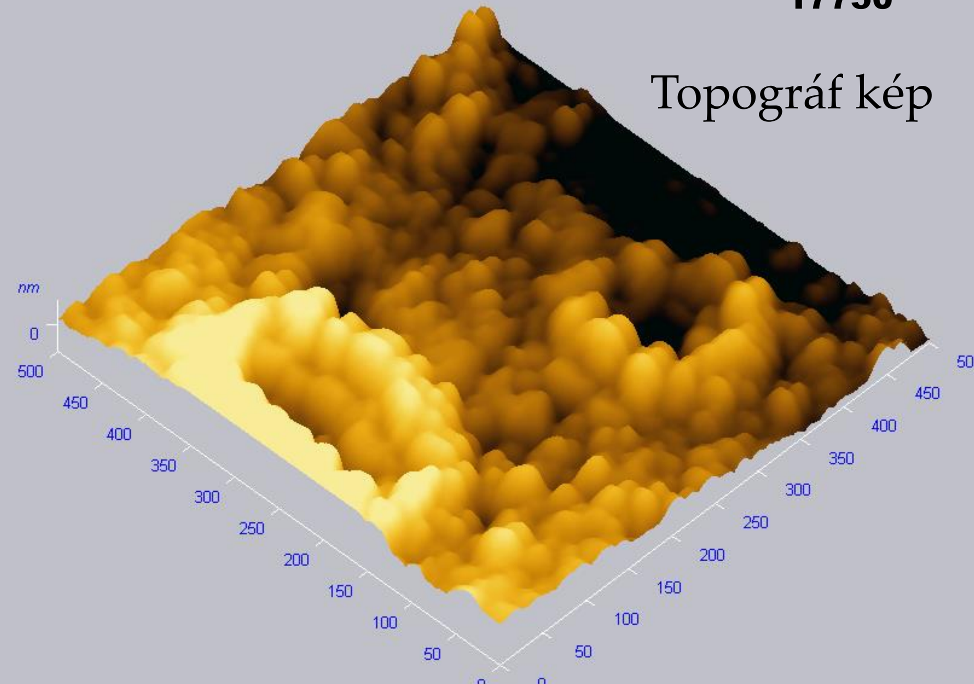
Nagy plazmonikus tér!



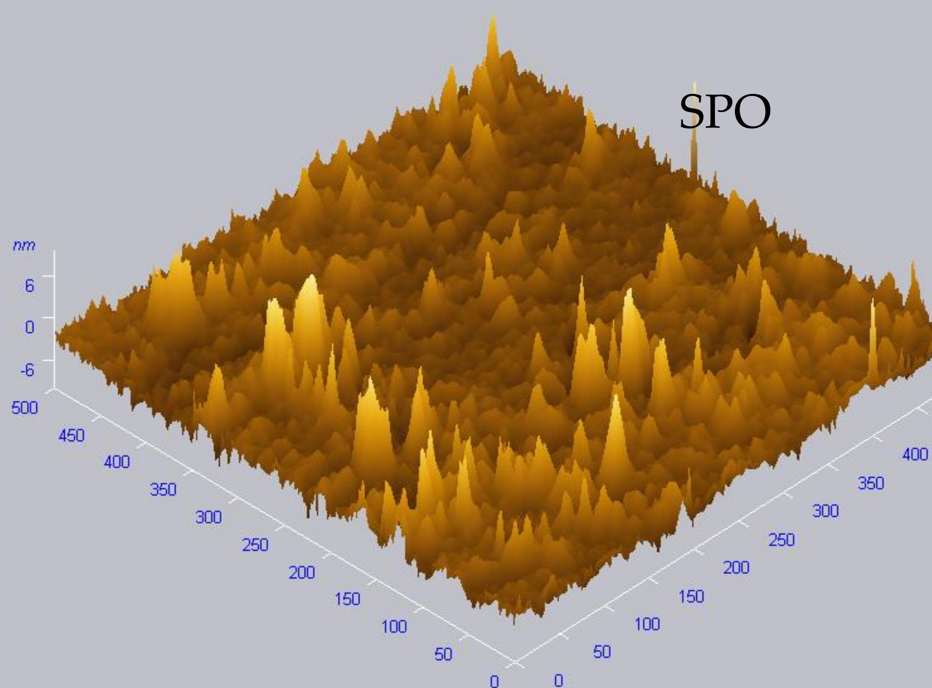


3 STM KÉP AZ ARANY FELÜLETÉRŐL
(Lézer porlasztás)

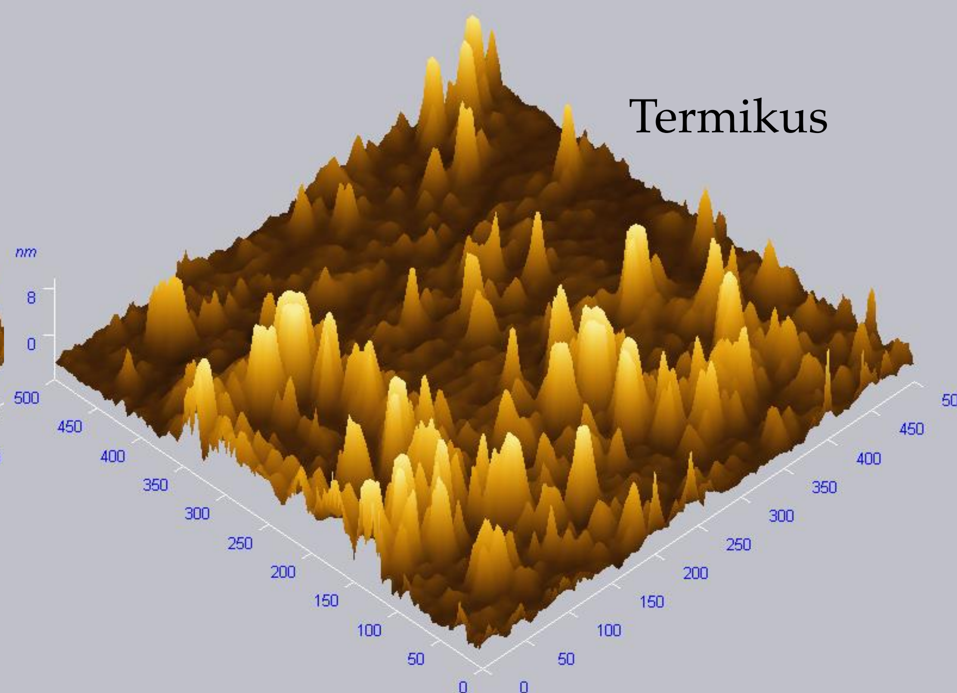




Topográf kép



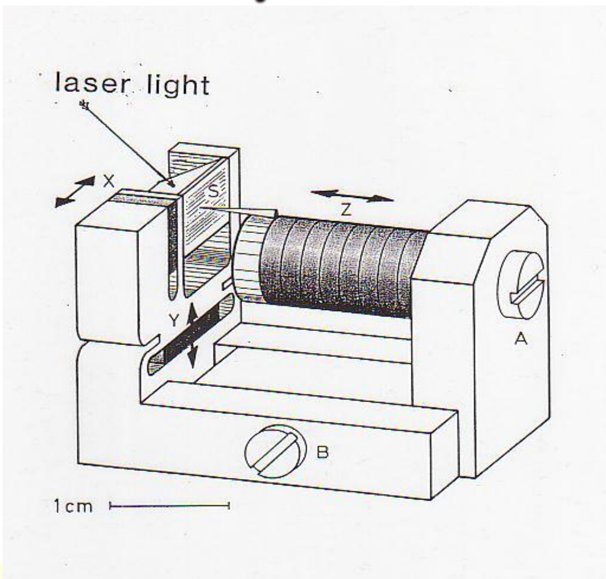
SPO

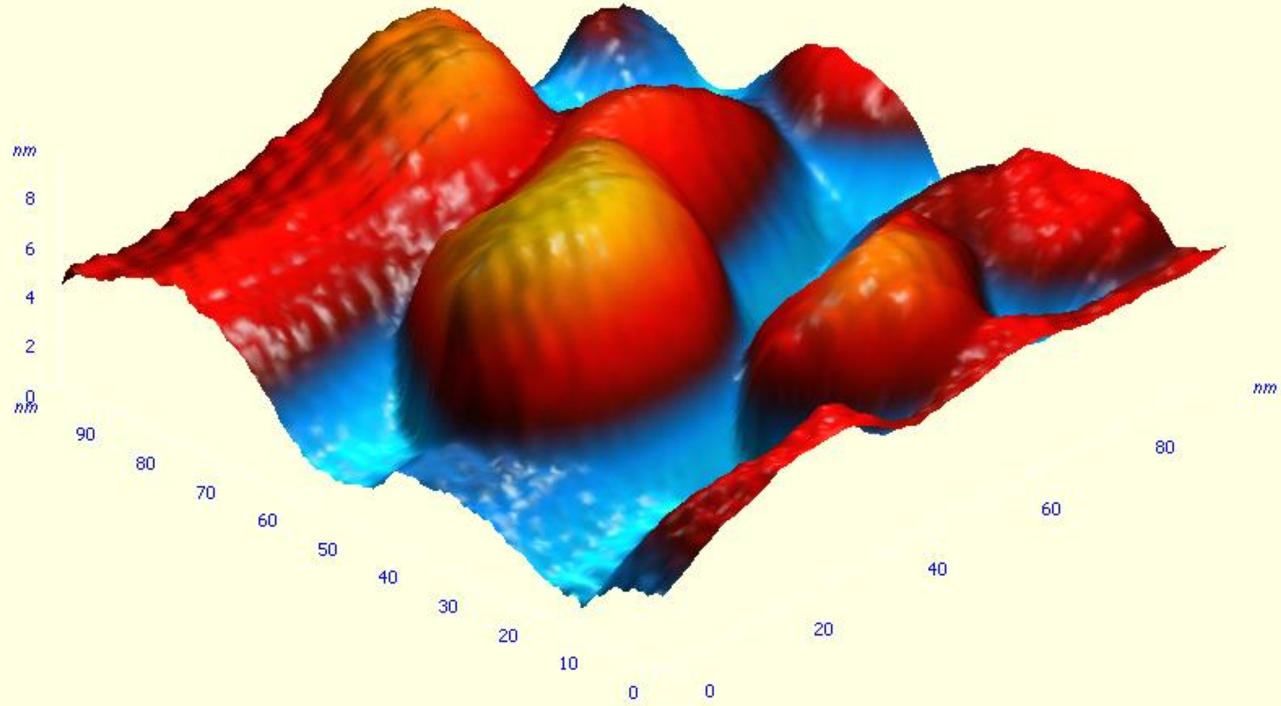


Termikus

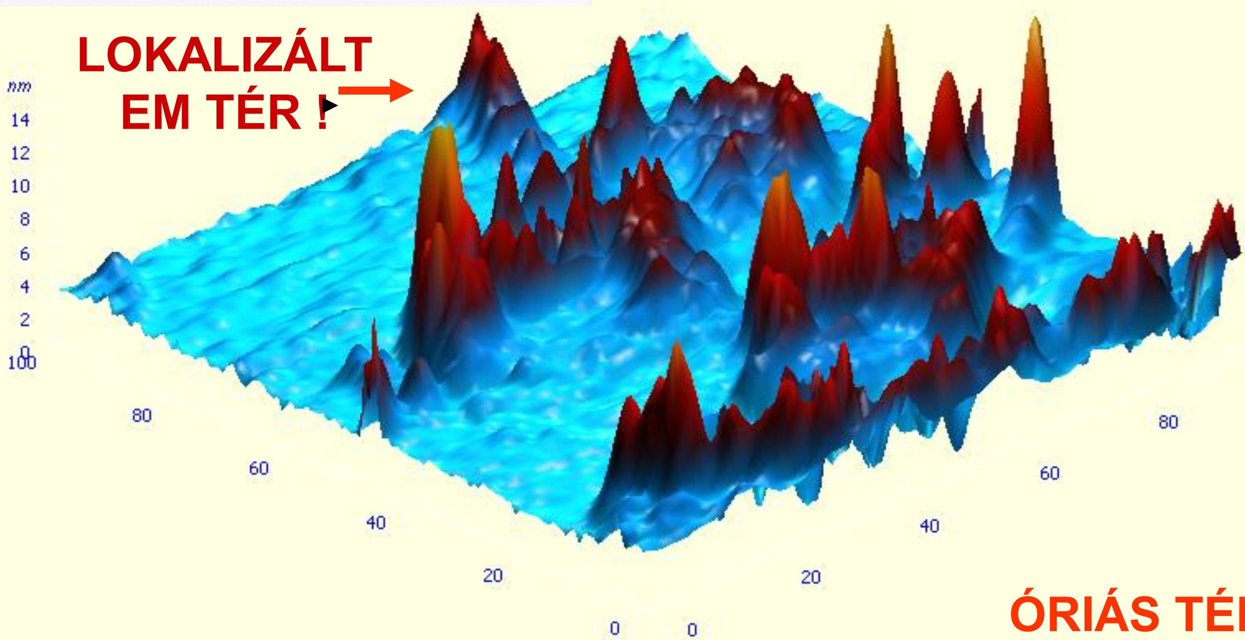
100x100nm

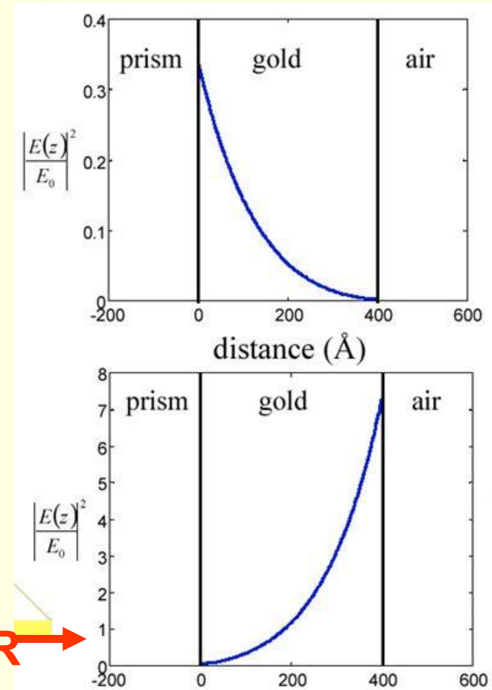
arany





LOKALIZÁLT EM TÉR !



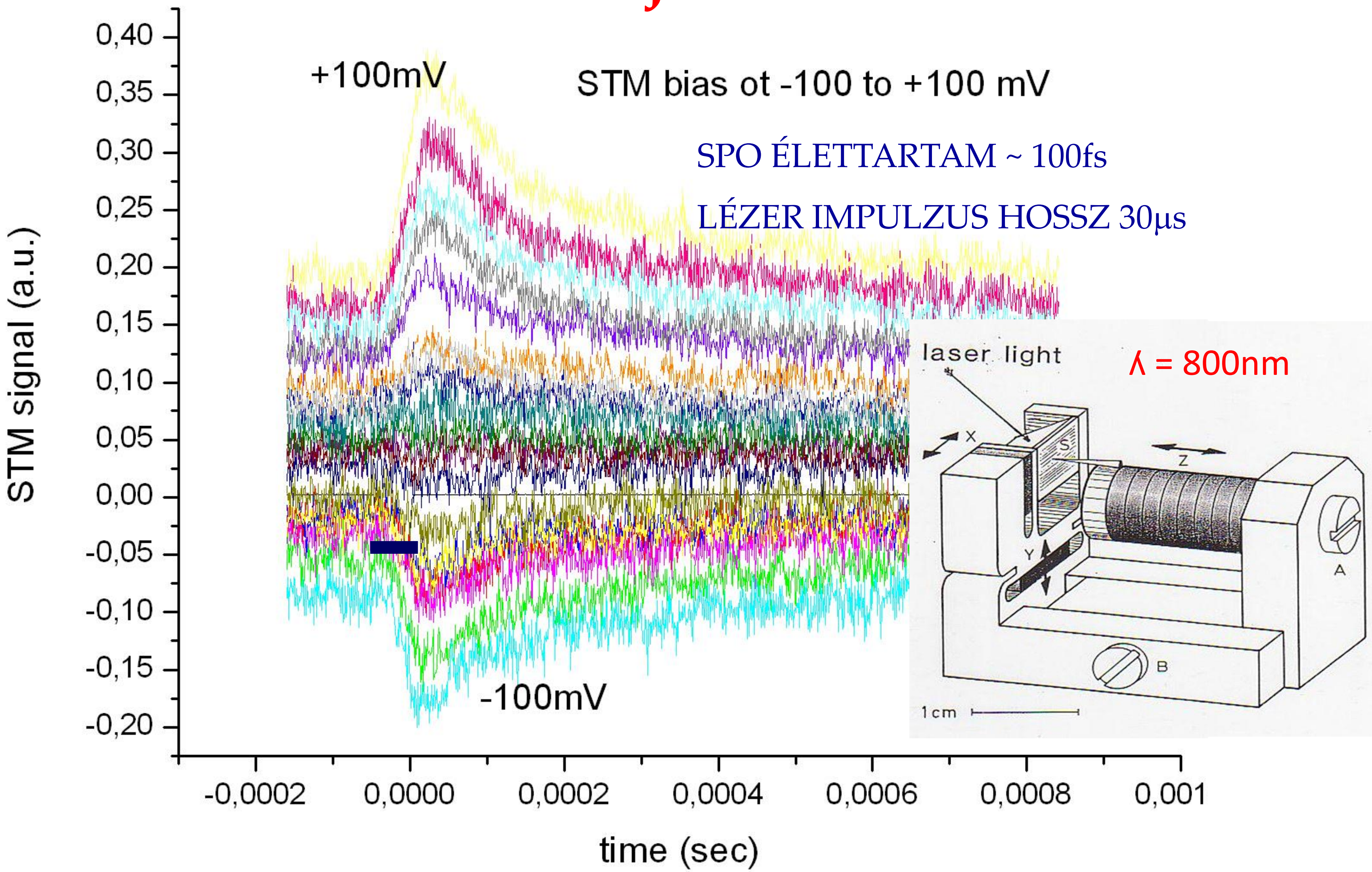


normal incidence

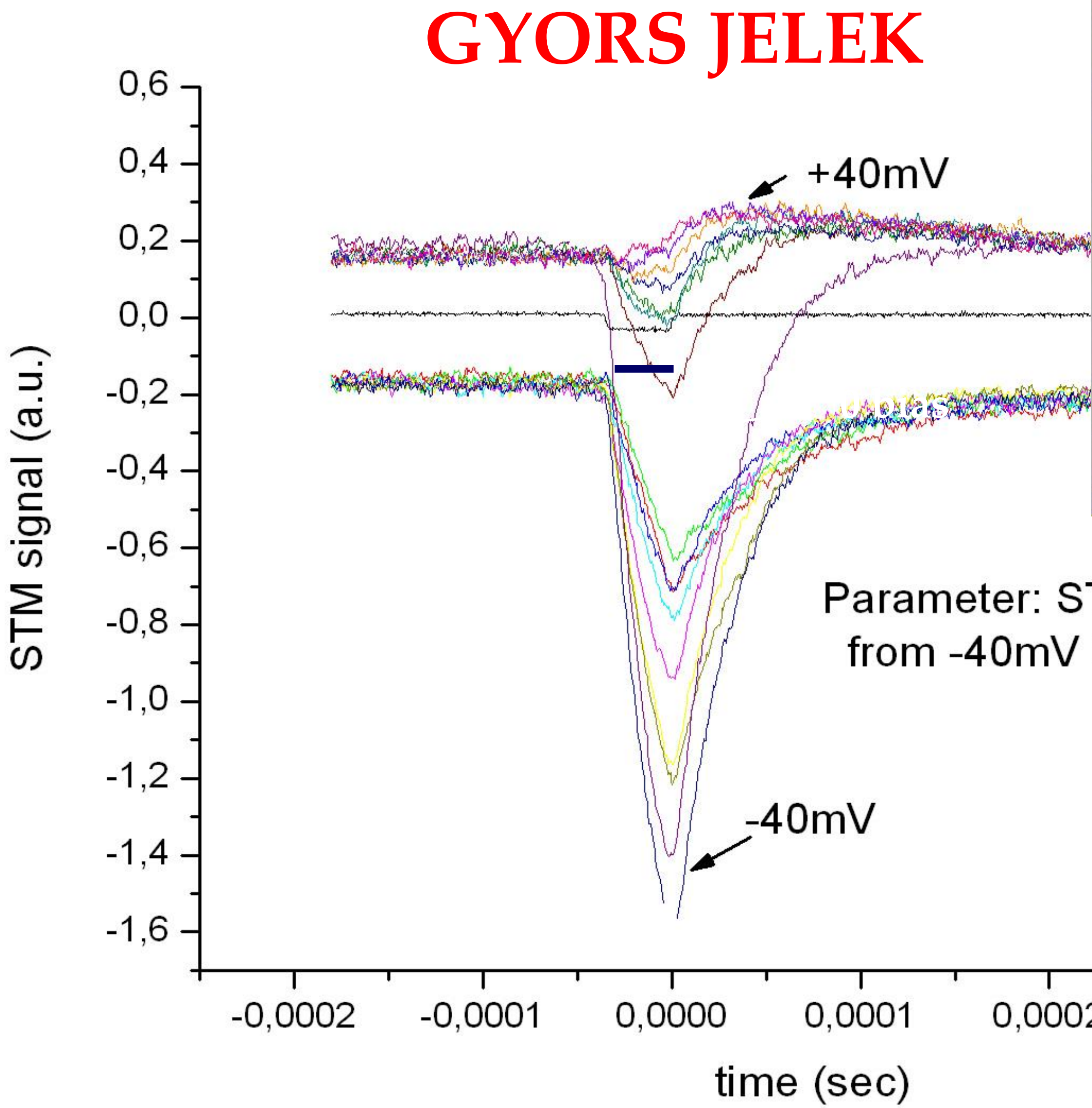
surface plasmon resonance angle

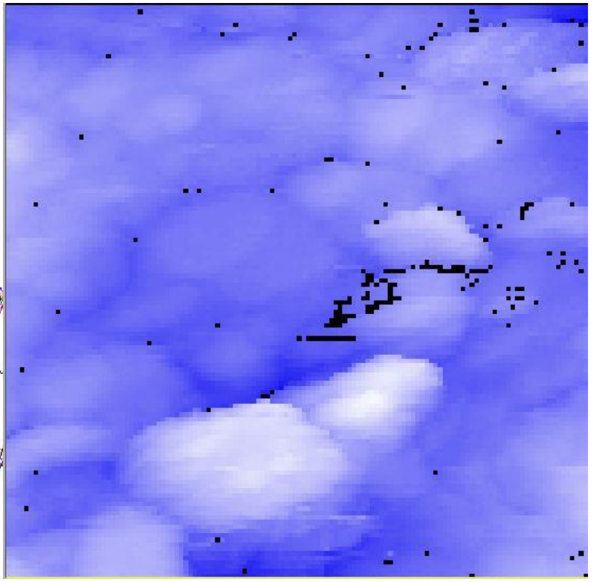
ÓRIÁS TÉR

LASSÚ JELEK


STM signal (a.u.)
time (sec)
+100mV
-100mV
STM bias ot -100 to +100 mV
SPO ÉLETTARTAM ~ 100fs
LÉZER IMPULZUS HOSSZ 30μs
laser light
ʎ = 800nm
X
Y
Z
S
A
B
1cm

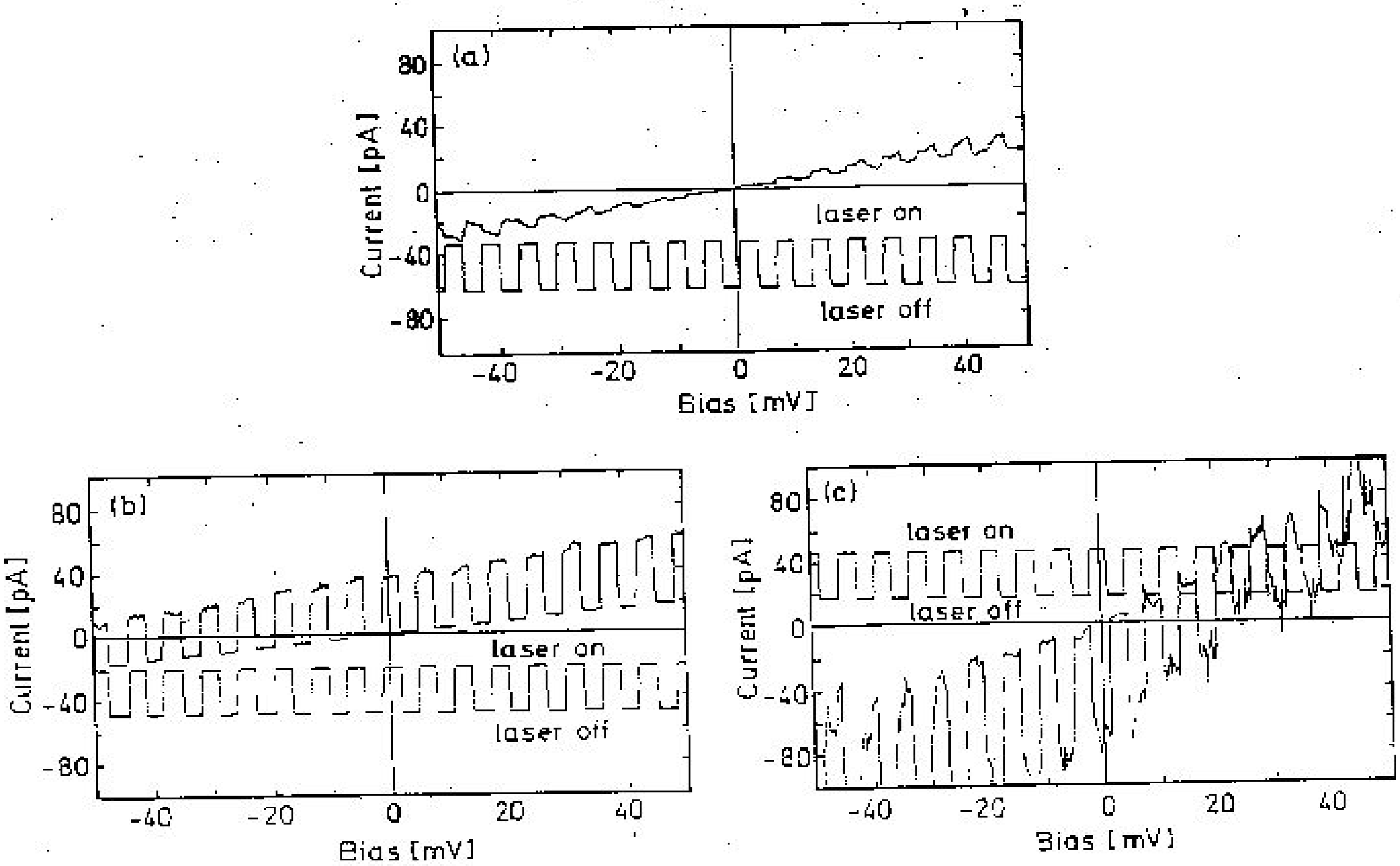
„NEGATÍV" STM JELEK „HOT SPOT" HELYEKEN

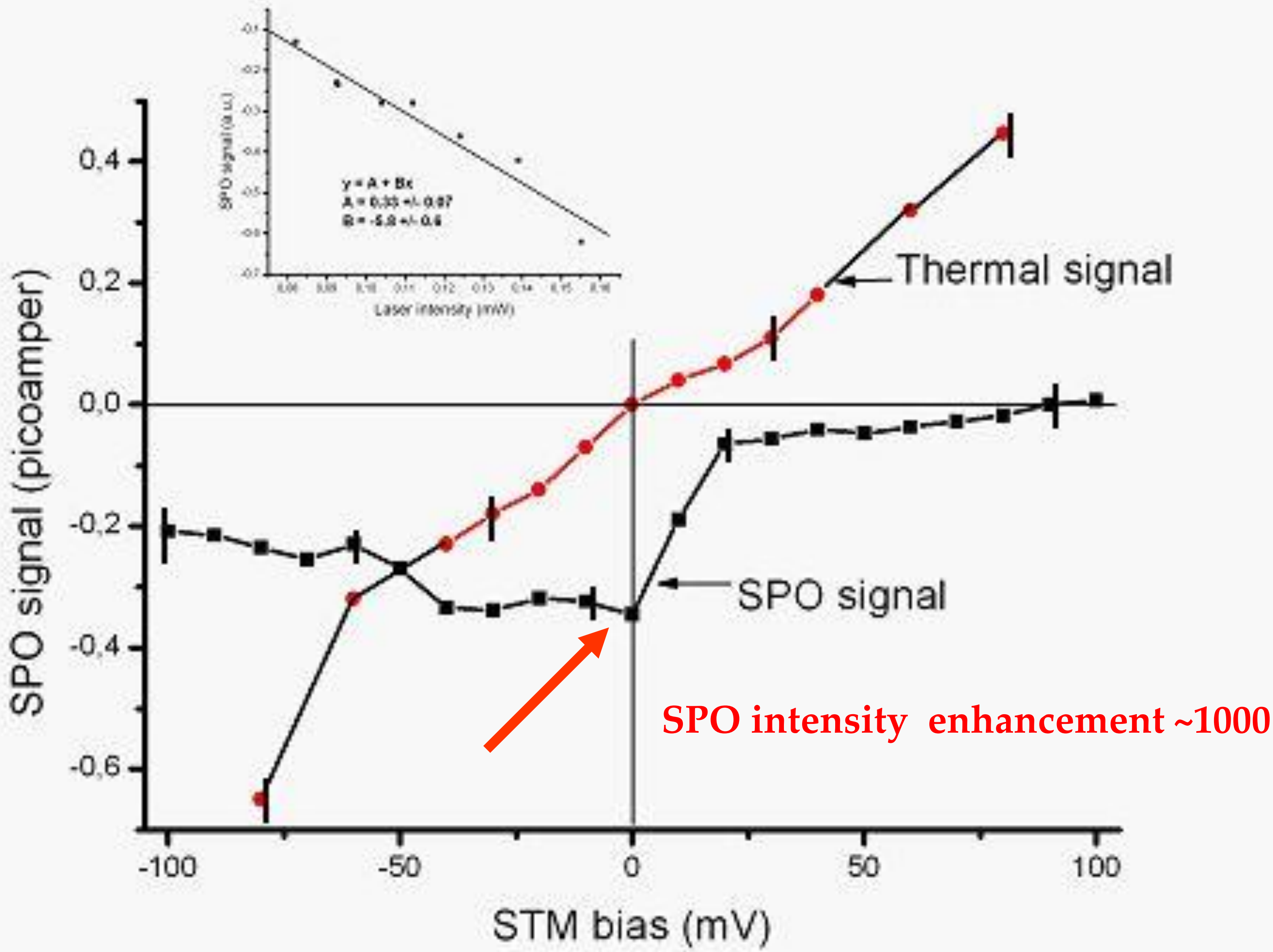




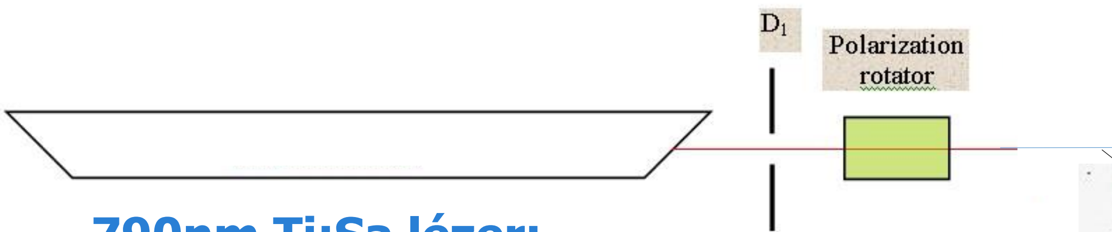
STM mérésekből (bizonyos pontokban az EM tér egyenirányítása)

Europhys.Lett.15, 289 (1991)

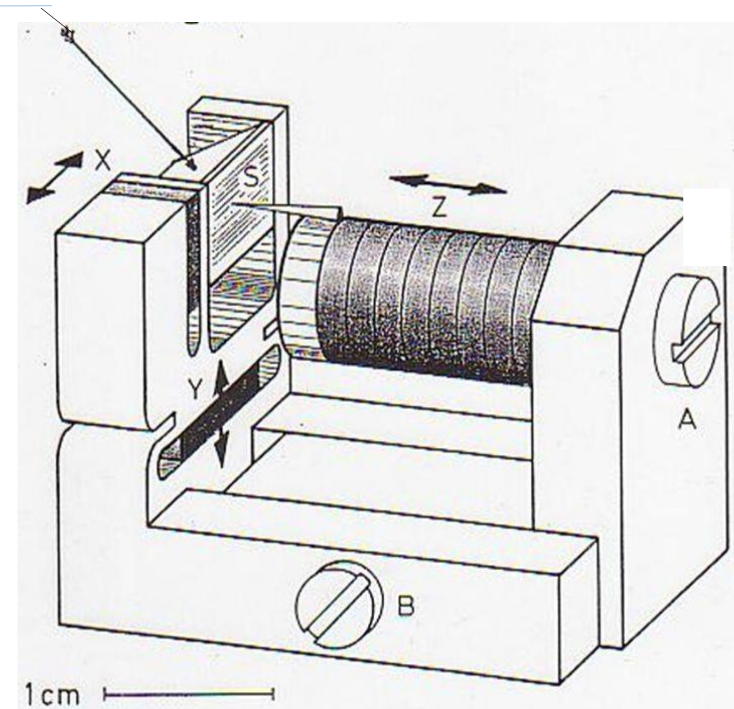



SPO signal (picoamper)
STM bias (mV)
0,4
0,2
0,0
-0,2
-0,4
-0,6
-100
-50
0
50
100
Thermal signal
SPO signal
y = A + Bx
Laser intensity (mW)
SPO intensity enhancement ~1000

FEMTOSZEKUNDUMOS LÉZERREL GERJESZTETT PLAZMONIKUS KÖZELI TÉR STM MIKROSZKÓP



790nm Ti:Sa lézer;
3.6MHz⇒1.2kHz,
110-120fs impulzusok



Hosszú rezonátorban (~80m)

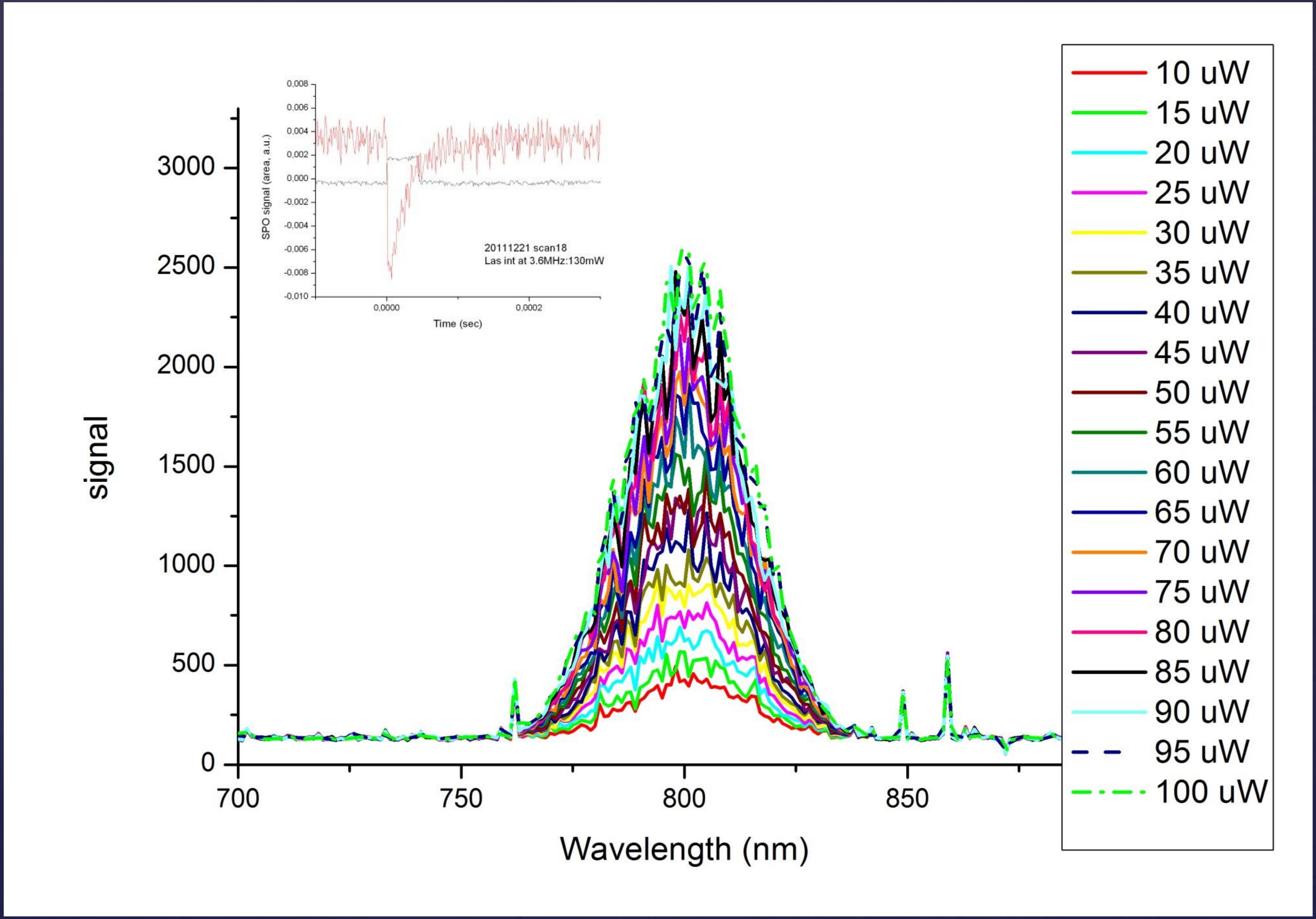
Nd:YAG lézerrel pumpált Ti:Sa lézer

3.6MHz impulzus frekvenciája

1.2kHz-re csökkentve, az STM-be

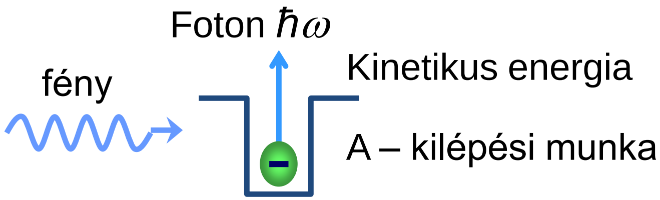
csatolva Kretschmann geometriában

A Ti:Sa LÉZER SPEKTRUMA KÜLÖNBÖZŐ INTENZITÁSOKNÁL



Multifoton elektron emisszió

Einstein: egy foton fotoeffektus



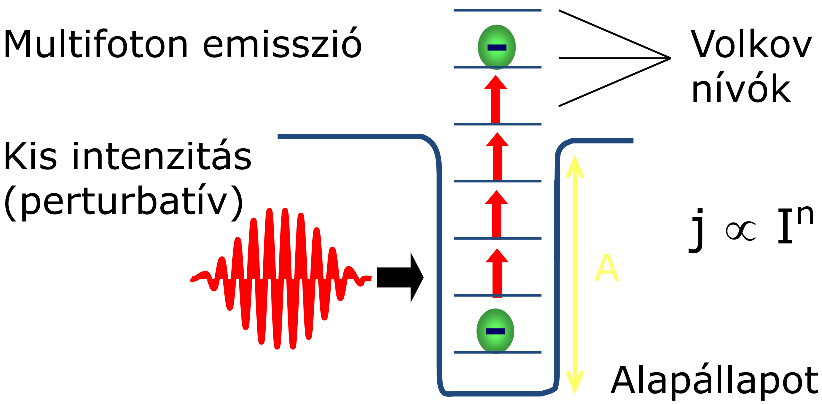
Egy foton Einstein egyenlet

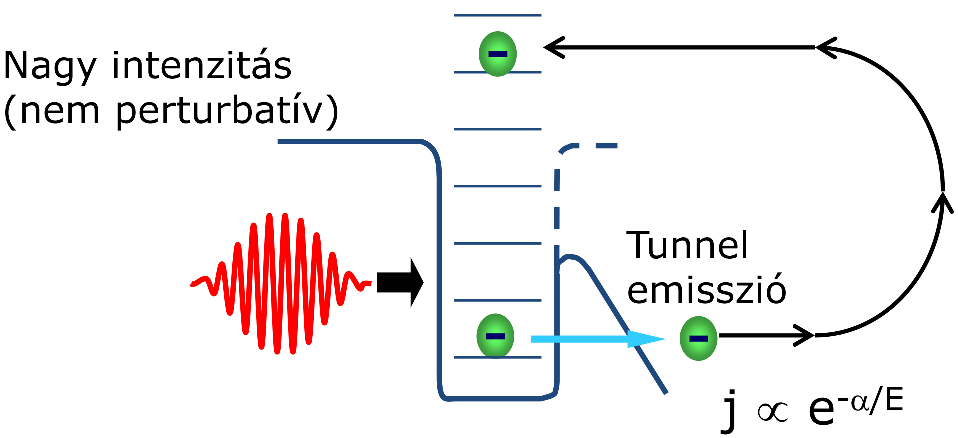
$$\hbar\omega = A + \tfrac{1}{2}mv^2$$

$$j \propto I$$

(fotoáram $\propto$ fényintenzitás)

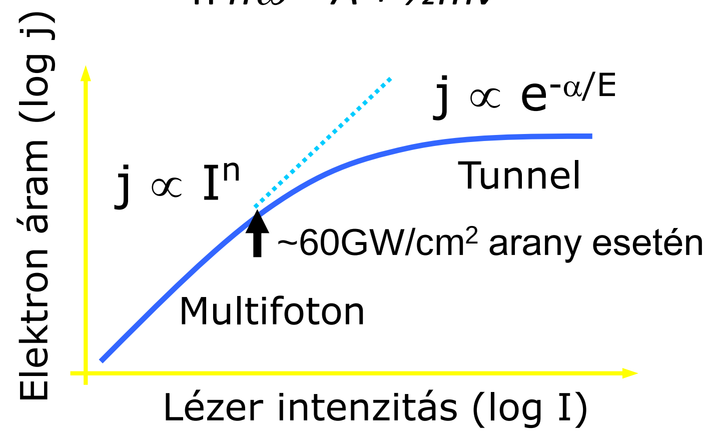
Lézer multifoton fotoeffektus ($\hbar\omega_L << A$):

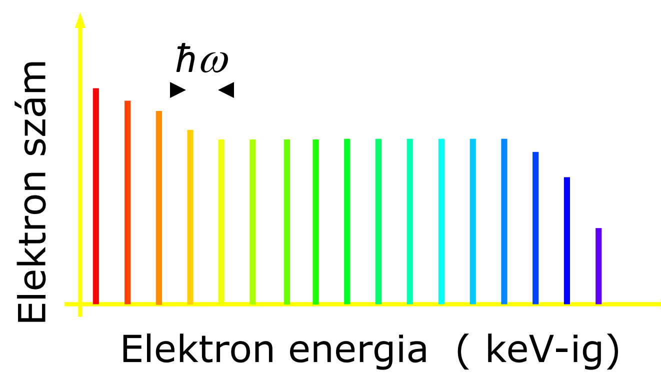




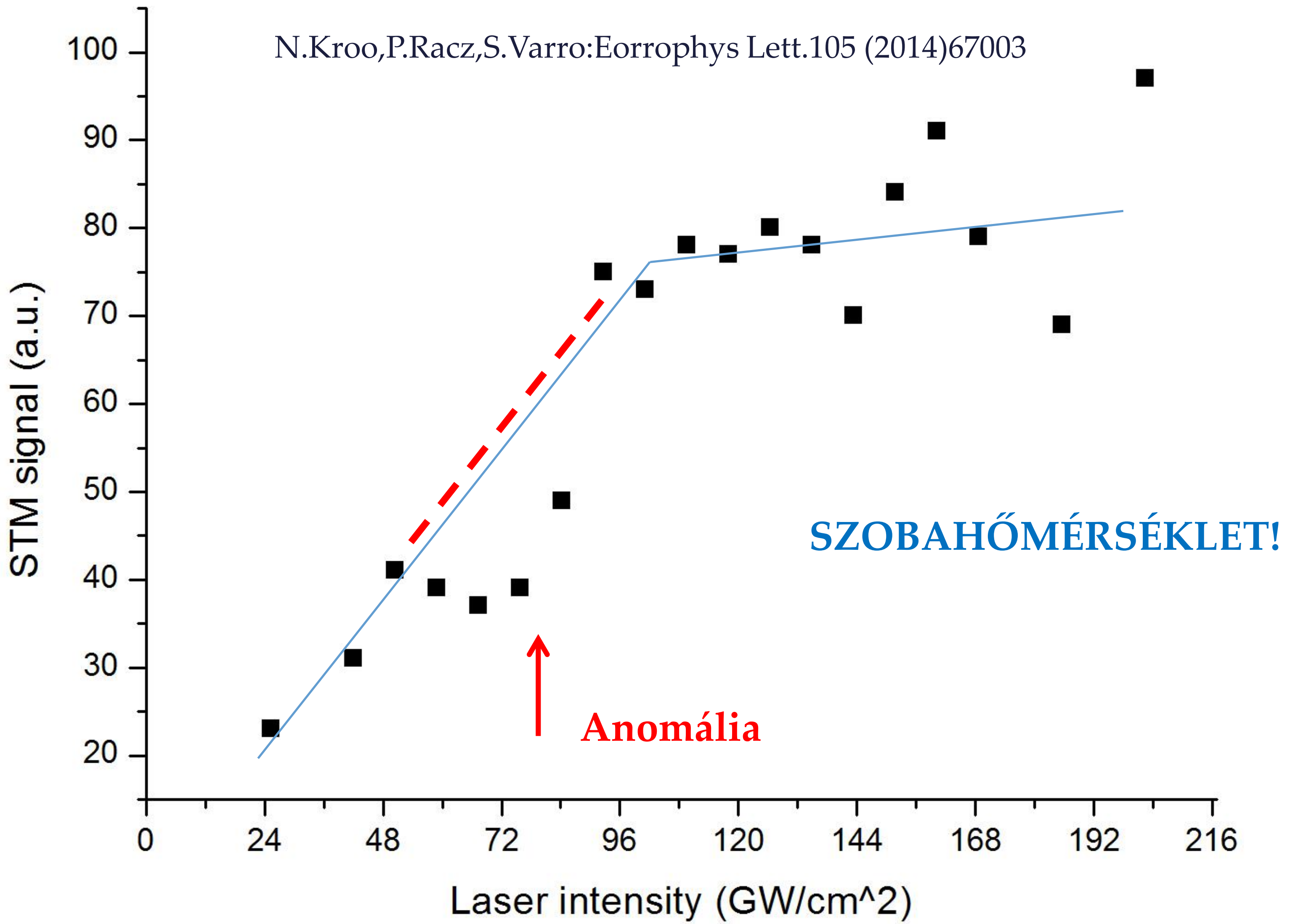
Multifoton Einstein egyenlet:

$$n\,\hbar\omega = A + \tfrac{1}{2}mv^2$$



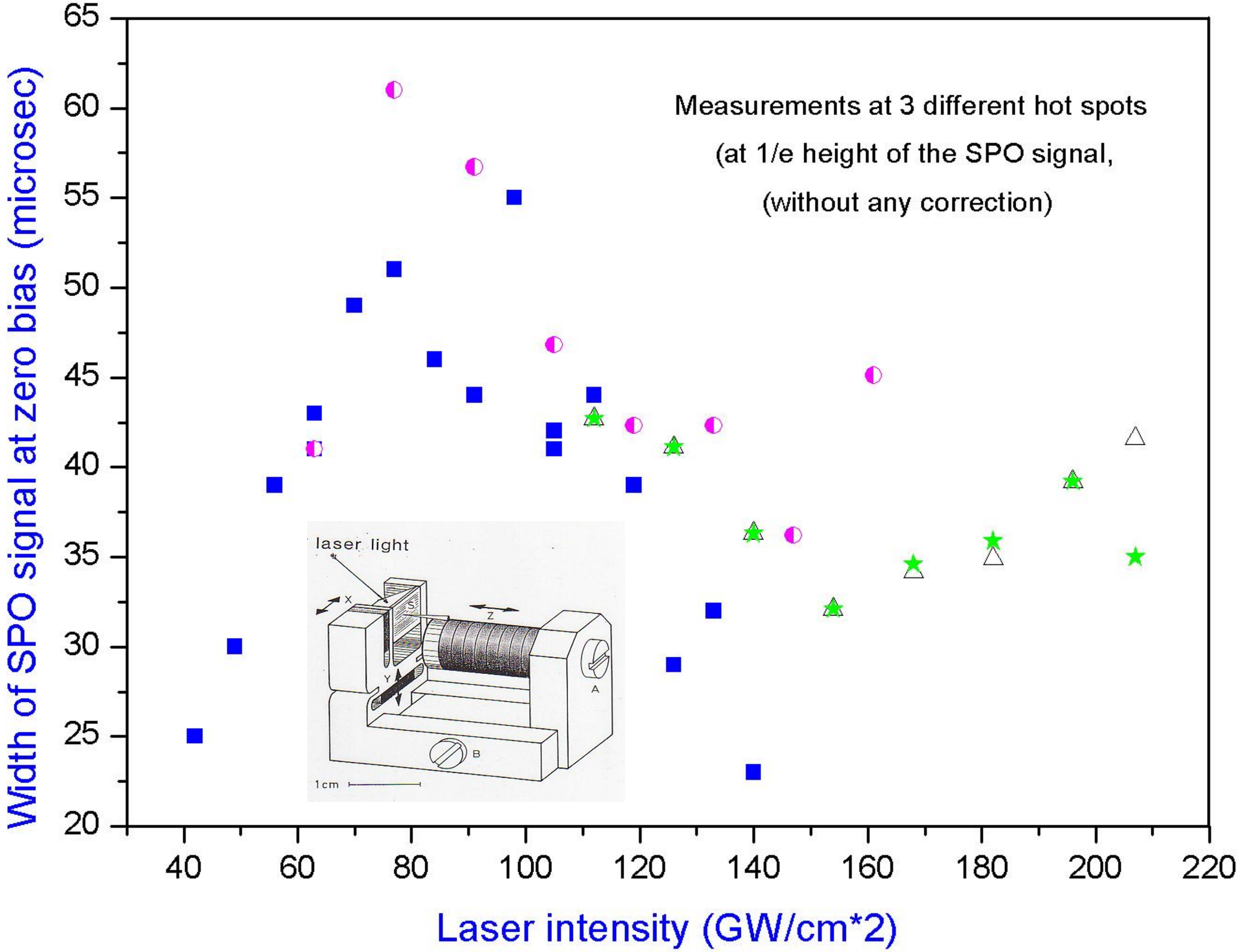


1.



N.Kroo,P.Racz,S.Varro:Eorrophys Lett.105 (2014)67003
STM signal (a.u.)
100
90
80
70
60
50
40
30
20
0
24
48
72
96
120
144
168
192
216
Laser intensity (GW/cm^2)
SZOBAHŐMÉRSÉKLET!
Anomália

AZ ANOMÁLIA SZOBAHŐMÉRSÉKLETEN!



ELEKTRON-ELEKTRON KÖLCSÖNHATÁS EFFEKTÍV POTENCIÁLJA ERŐS ELEKTROMÁGNESES TEREKBEN

$$V_{eff}(\boldsymbol{r}) = V(\boldsymbol{r}) J_n[z_1 \sin(\boldsymbol{k} \cdot \boldsymbol{r} / 2)]$$

,

$$z_1 = 2\mu(c\Delta p'_{\perp} / \hbar\omega)$$

,

$$\mu = eF / mc\omega$$

,

$$V(\boldsymbol{r}) = e^2 / r$$

F: az EM tér amplitúdója

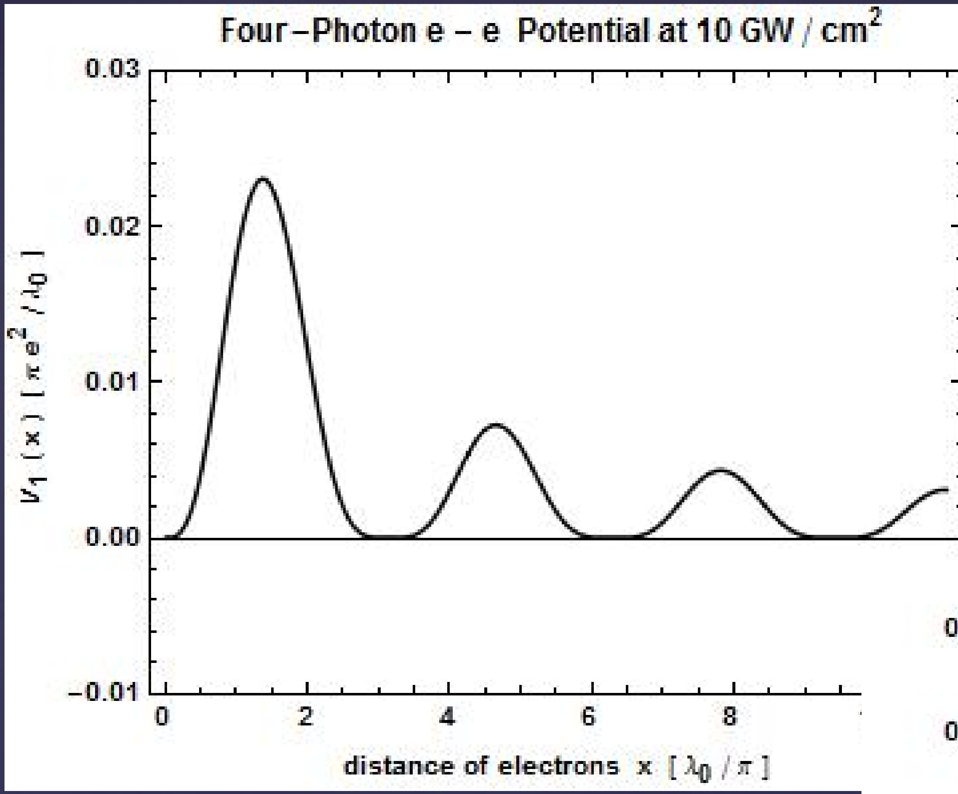
Plazmon tér erősítése: ~40

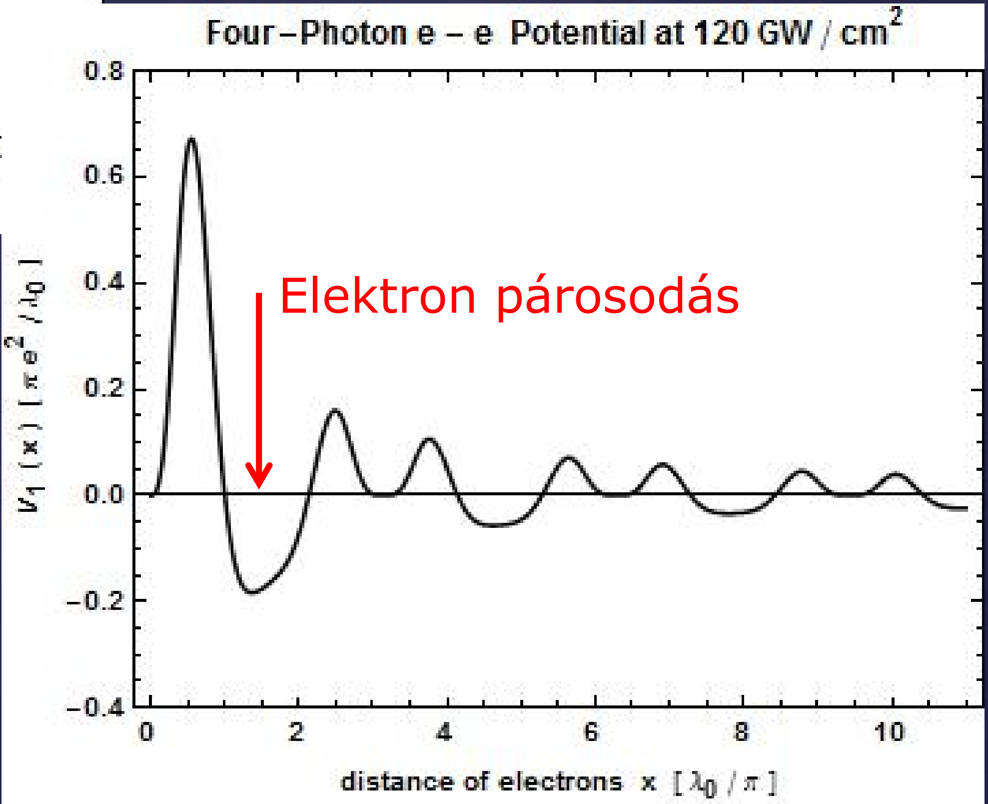
Elecktron párosodás!

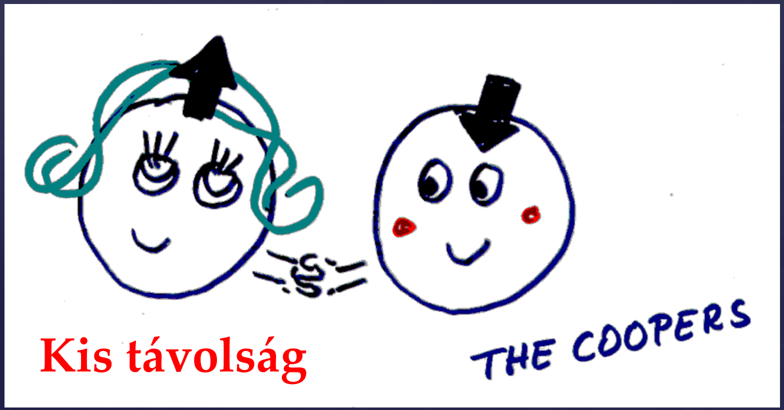
Ha az effektiv potenciál negativ!

J.BERGOU,S.VARRO,
M.V. FEDOROV:1981

AZ EFFEKTIV POTENCIÁL 2 LÉZER INTENZITÁS ESETÉN (az SPP erősítést is figyelembe véve)

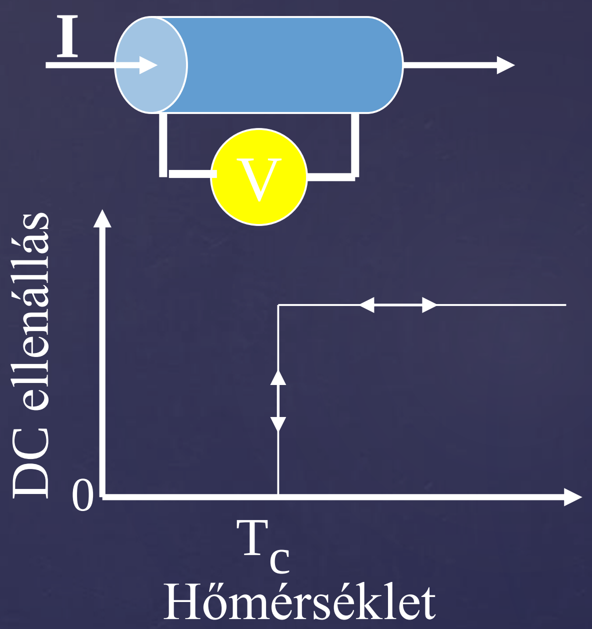




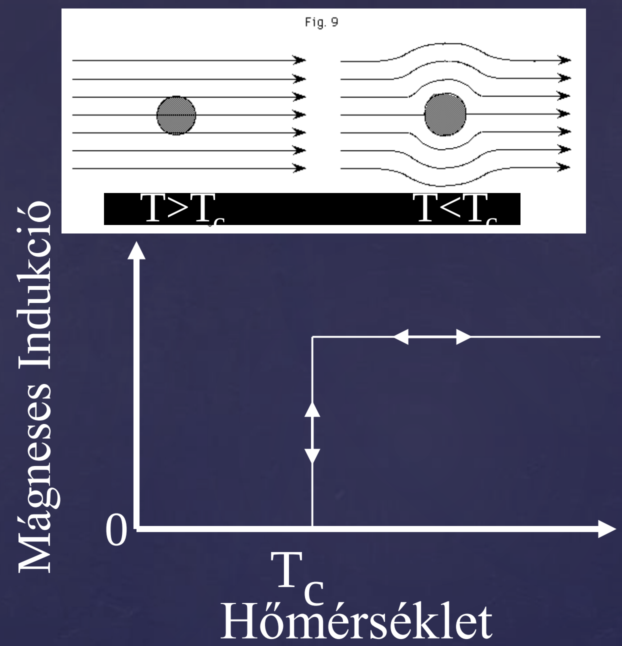


2.A SZUPRAVEZETÉS HÁROM ALAPVETŐ JELLEMZŐJE

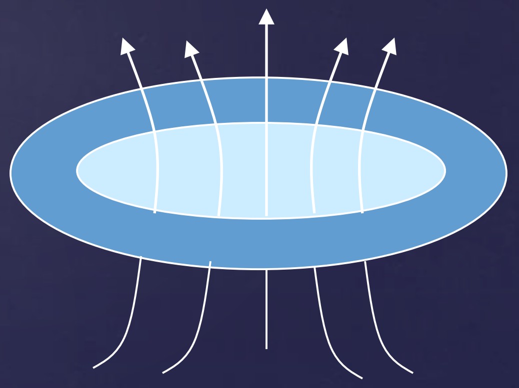
Zérus ellenállás



Ideális Diamágnesség



Makroszkokikus kvantum effektusok

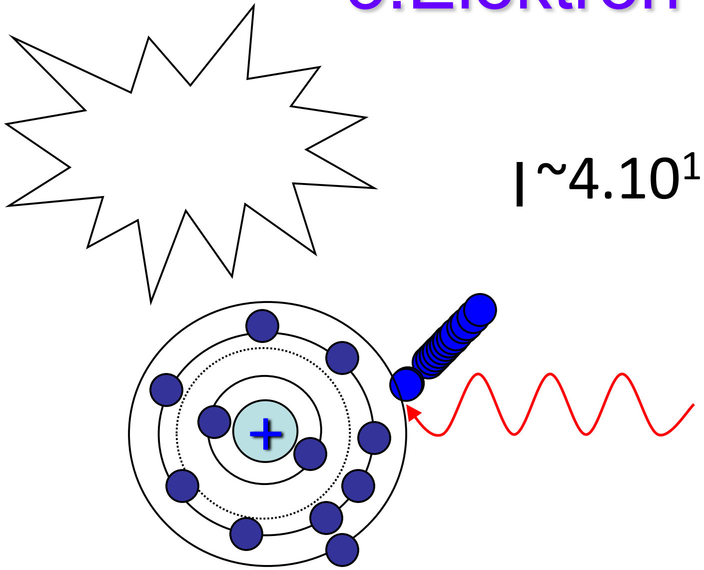


Fluxus kvantálás $\Phi = n\Phi_0$
Josephson Effektus

Meissner effektus

Cooper párok (a vezetési elektronok párosodva haladnak)
Fonon csatolás: alacsony hőmérséklet.

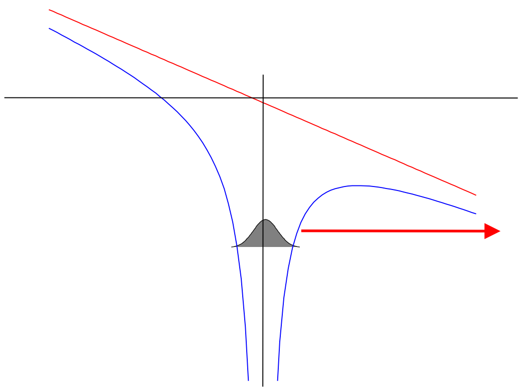
3.Elektron emisszió extrém terekben



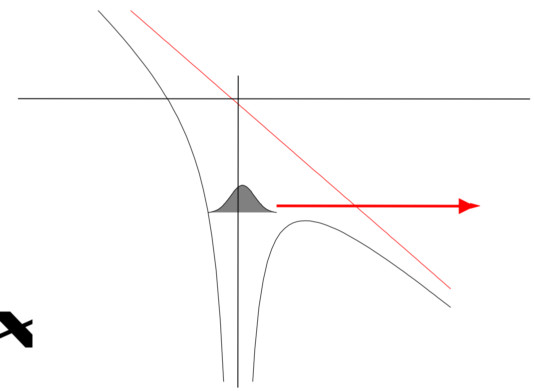
$I \sim 4.10^{16} W/cm^2$ → $E \sim 10^9$ V/cm

Nagy intenzitás
Fotoelektromos hatás

Valencia elektronok gyors ionizációja



$$V = -\frac{q}{x} \pm Ex$$



Alagút effektus

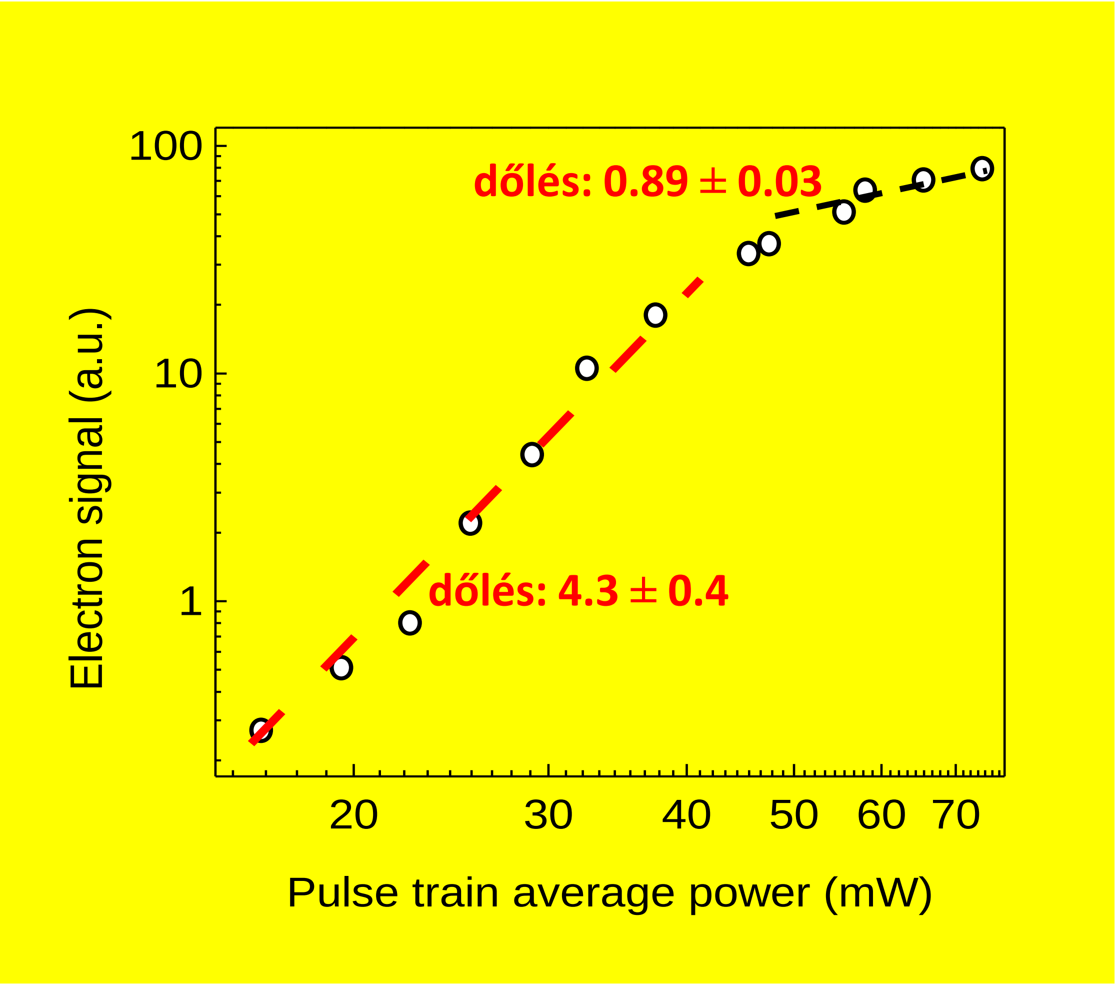
10^{14} - 10^{15} W cm^{-2}

A barrier felett

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

Minden atom legalább egy elektront veszít.

Multifoton elektron emisszió aranyból



Multifoton-alagút átmenet $\sim 4\text{x}10^{10}$ W/cm^2 beeső lézer intenzitásnál, $\sim 5.5\text{x}10^8$ V/m térnél

Keldysh-gamma γ=31

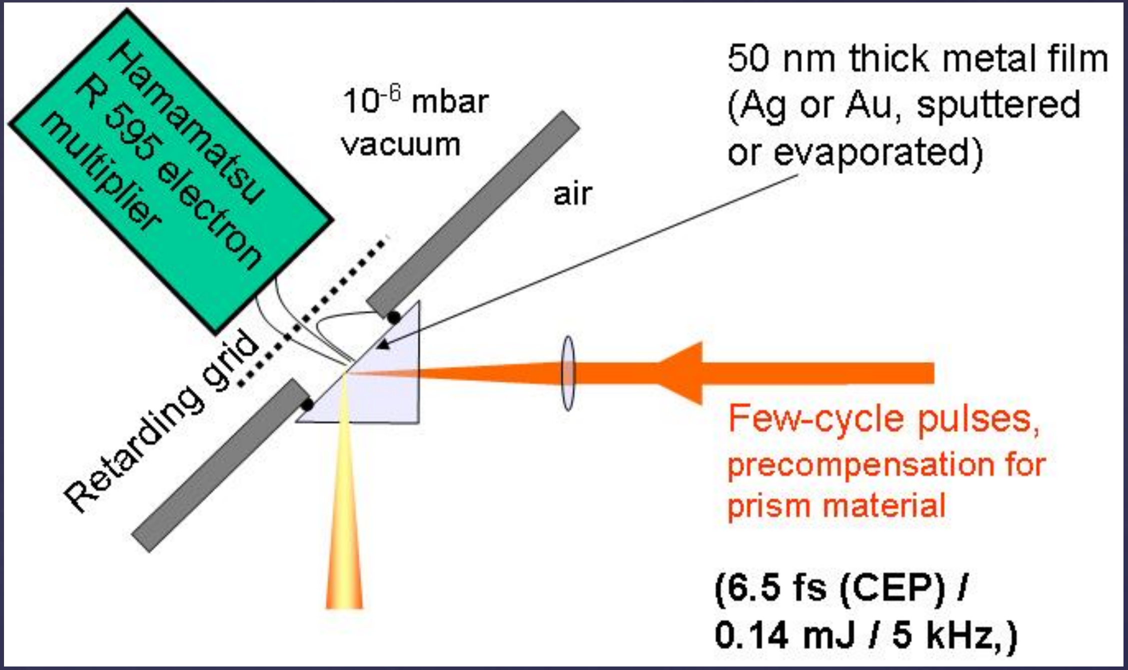
→ indikálja a jól ismert, a felületi plazmonok okozta óriási térerősítést.

PLAZMONIKUS ERŐSÍTÉS!

W: kilépési munka, E_l: lézerfény térereje

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

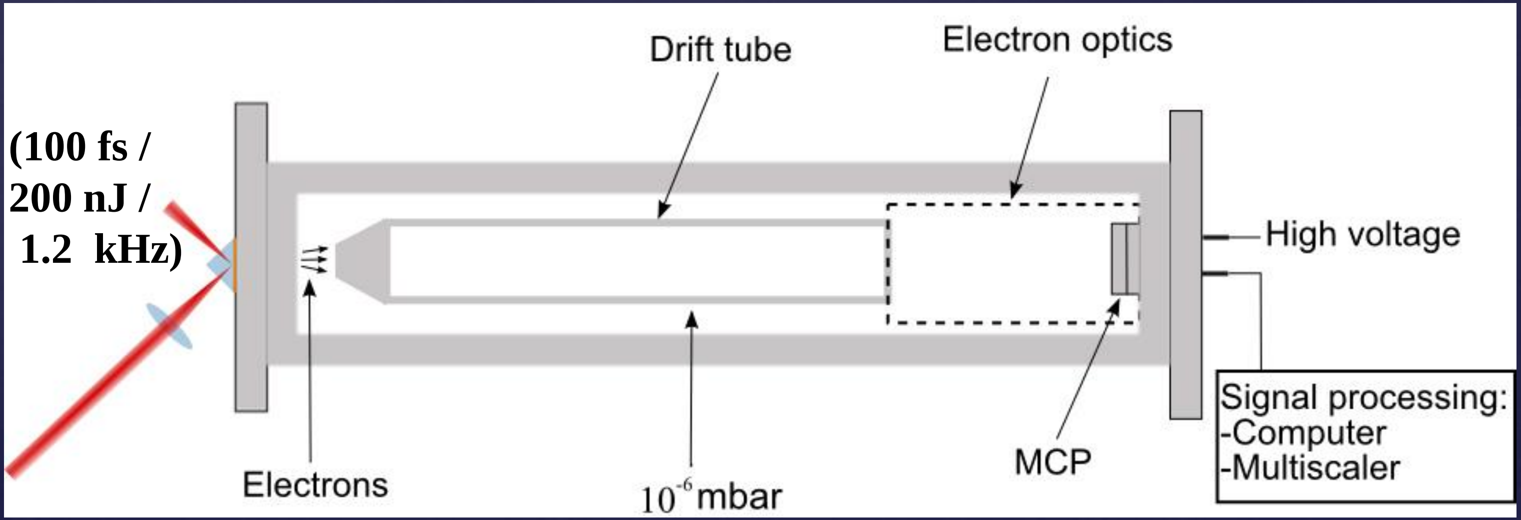
KILÉPŐ ELEKTRONOK SPEKTRUMÁNAK MÉRÉSE

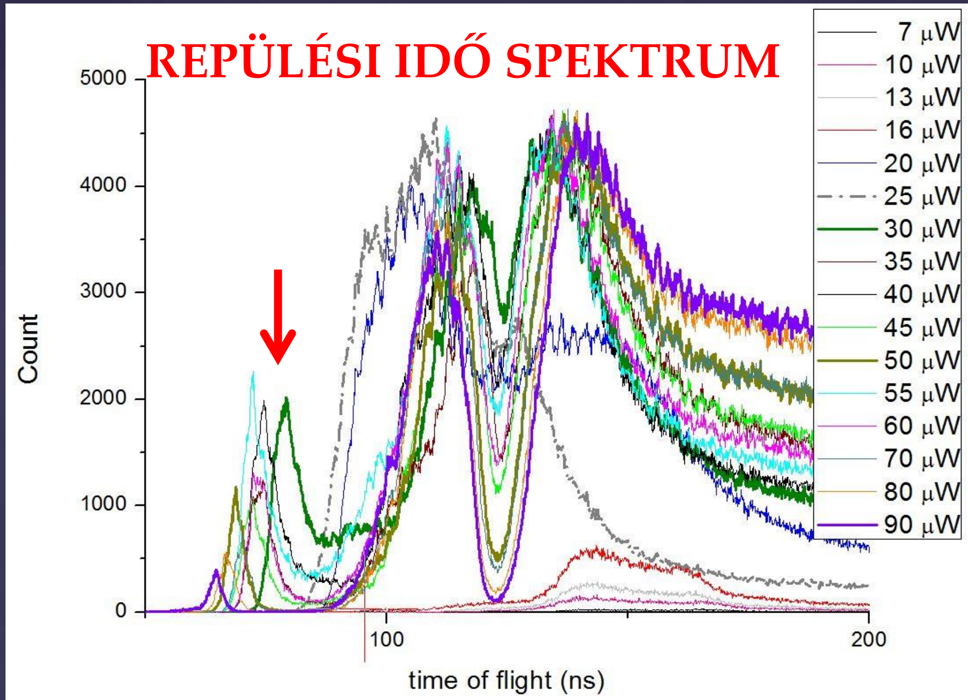


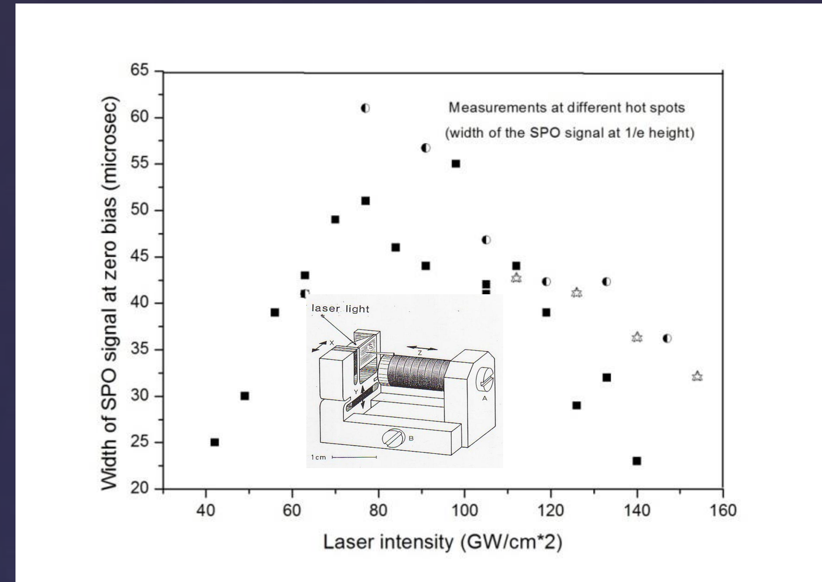
MULTIPLAZMON ELEKTRON EMISSZIÓ

$h\nu_{foton} = 1.5\text{eV}$

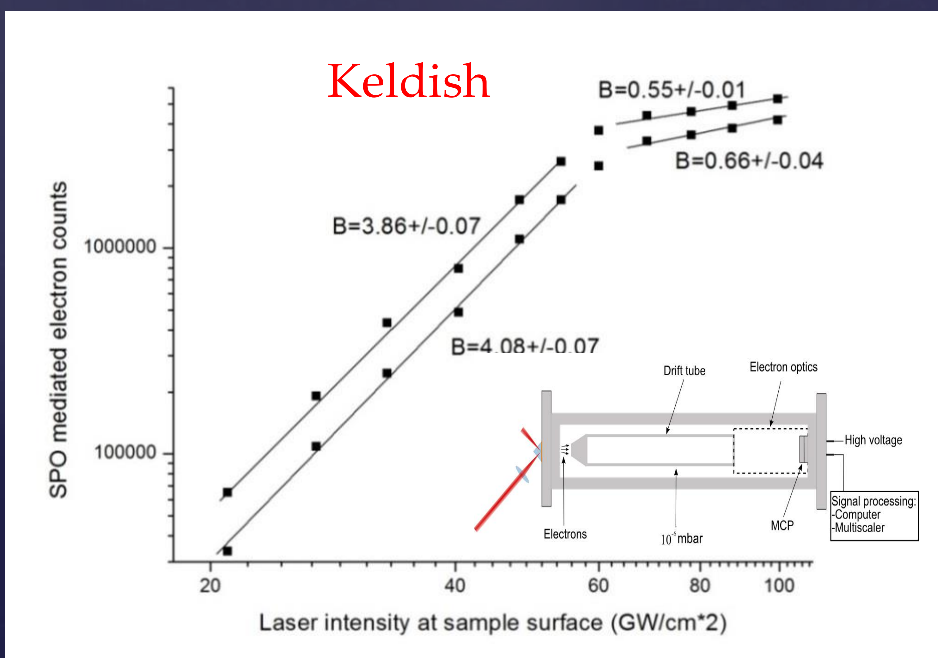
$Au_{kilépési\ munka} = 4.6\text{eV}$

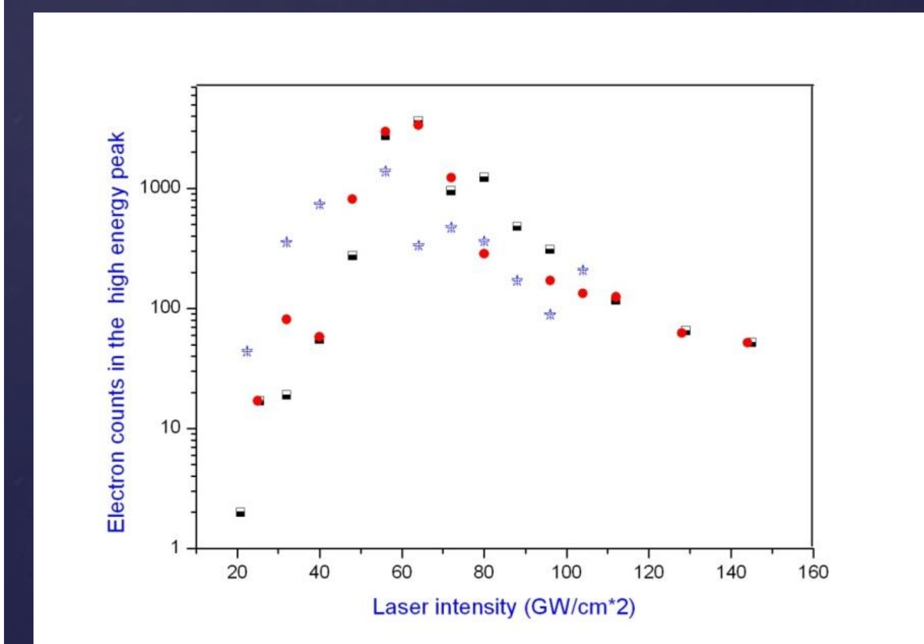


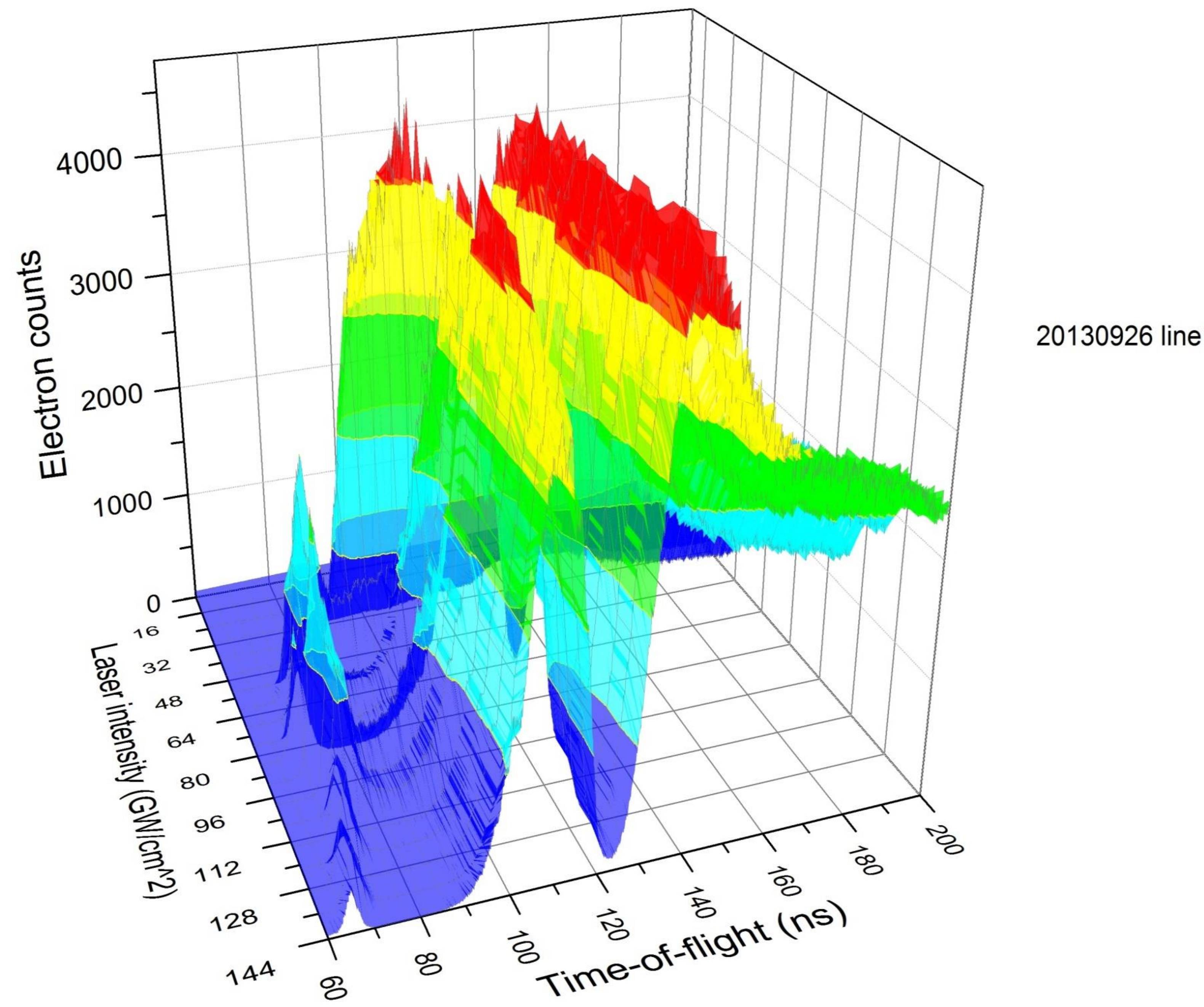




Multiplazmon elektron emisszió

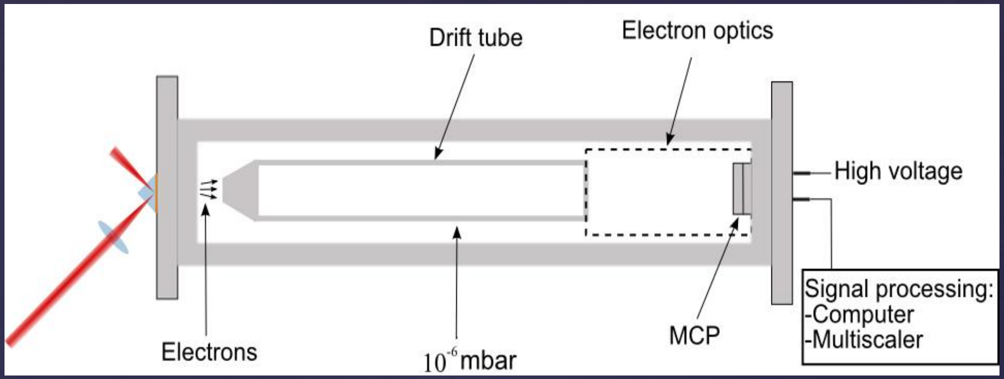


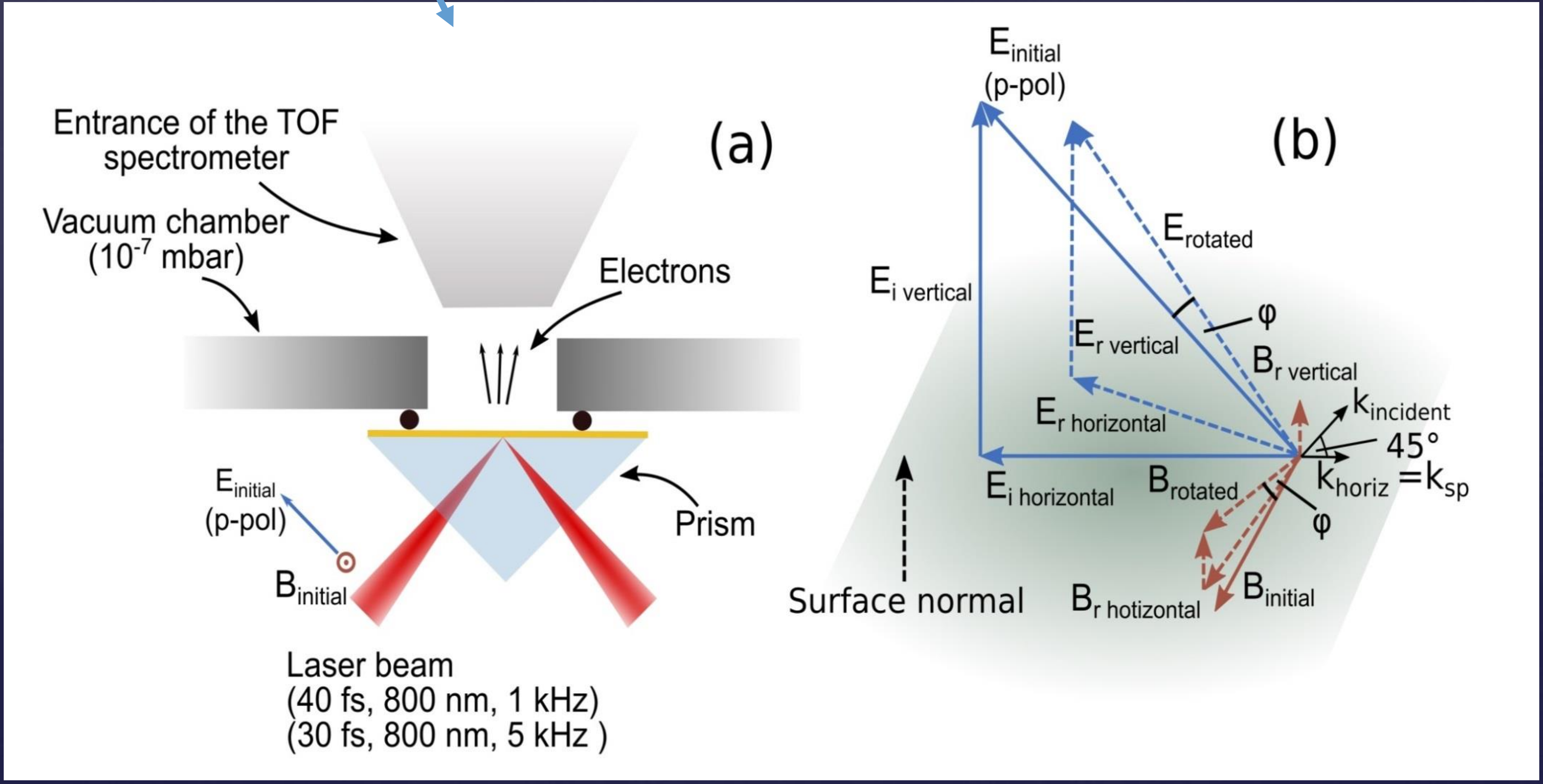




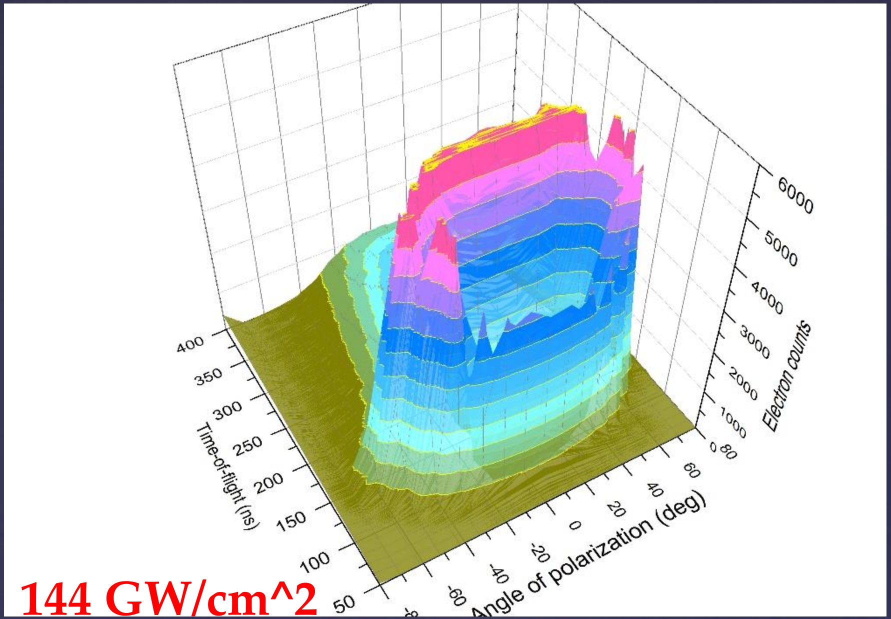
Electron counts
0
1000
2000
3000
4000
Laser intensity (GW/cm^2)
16
32
48
64
80
96
112
128
144
Time-of-flight (ns)
60
80
100
120
140
160
180
200
20130926 line1

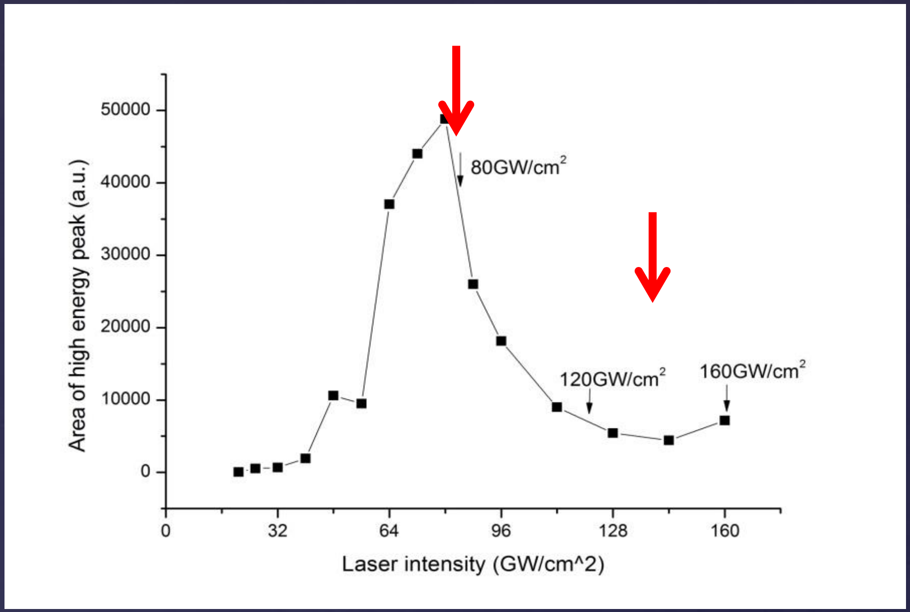
2. MEISSNER EFFEKTUS. SPP GERJESZTÉS GEOMETRIÁJA (a) ÉS AZ EM TÉR VEKTORDIAGRAMJA (b)

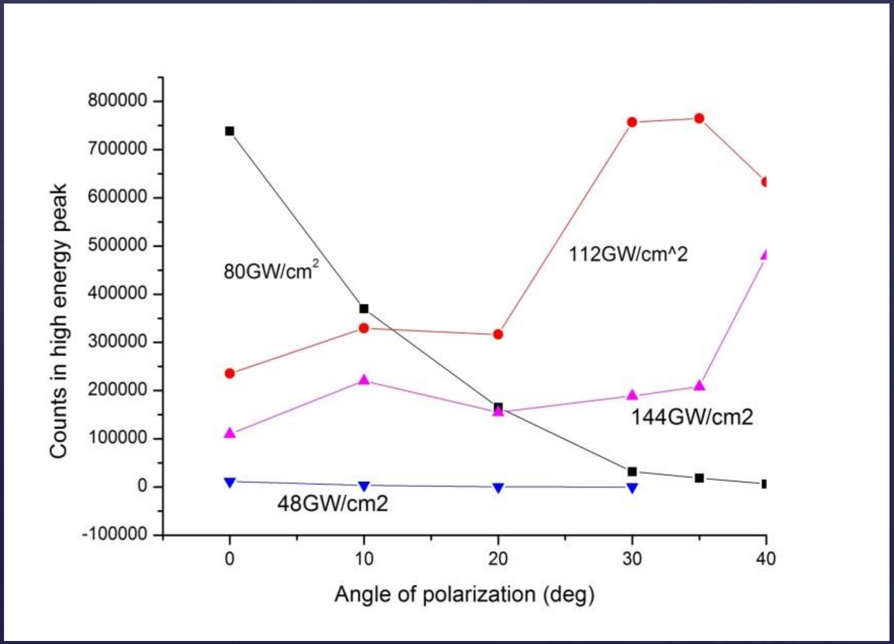


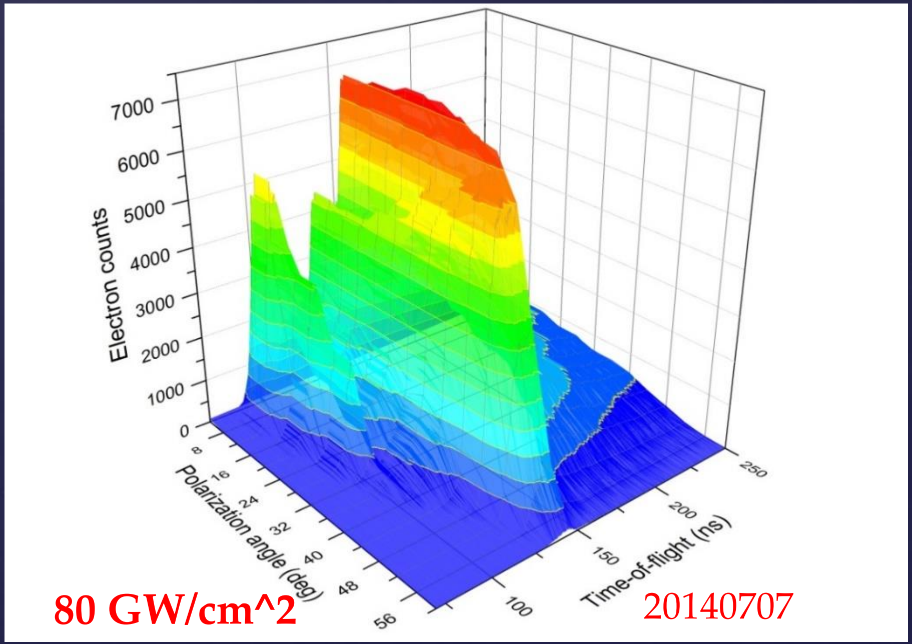


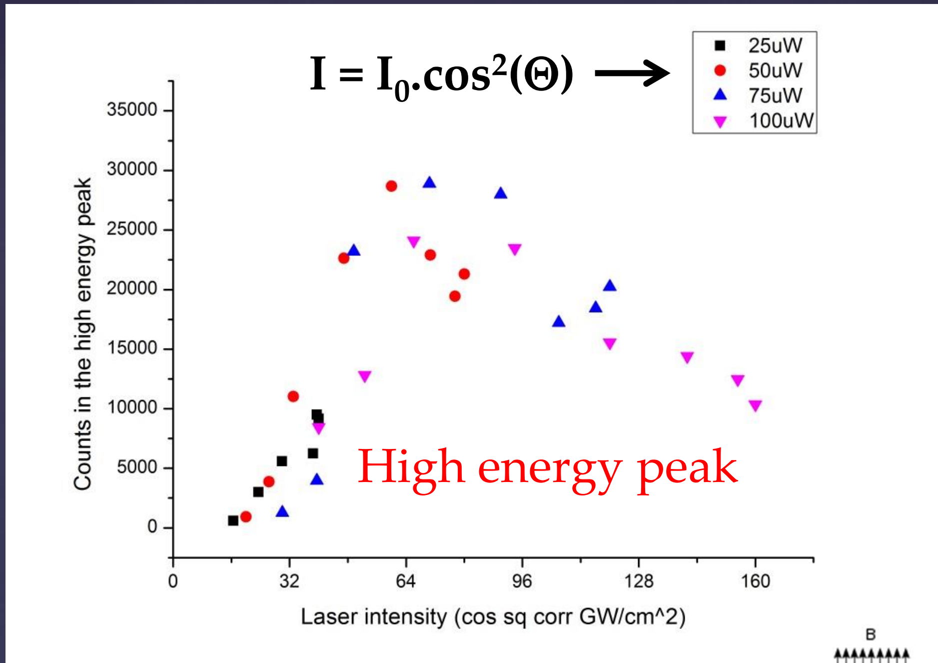
MÁGNESES (egyenirányított EM) TÉR FÜGGÉS



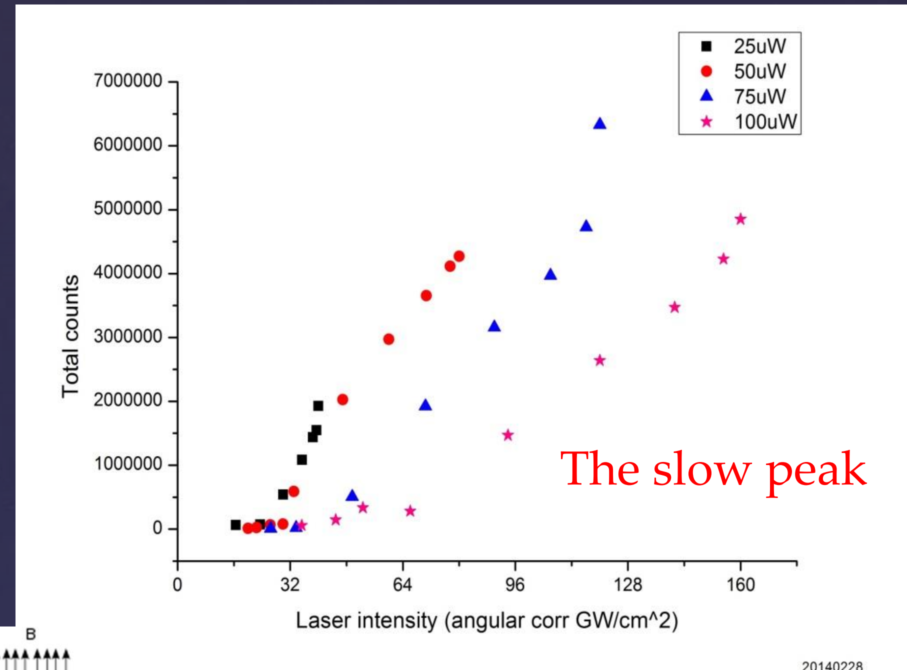




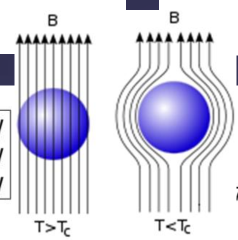




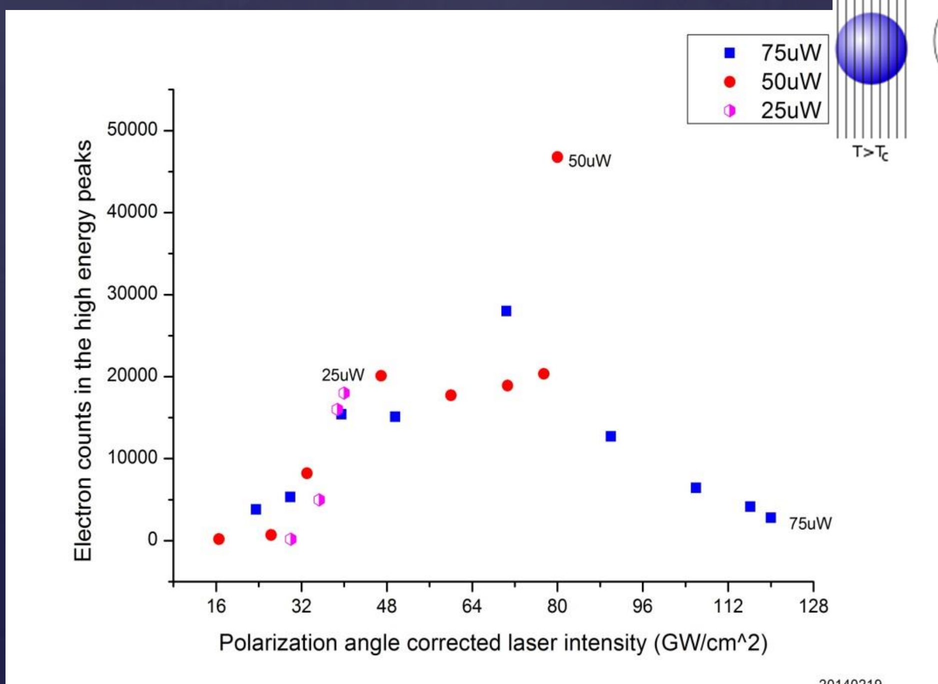
$I = I_0.\cos^2(\Theta)$
25uW
50uW
75uW
100uW
Counts in the high energy peak
High energy peak
Laser intensity (cos sq corr GW/cm^2)



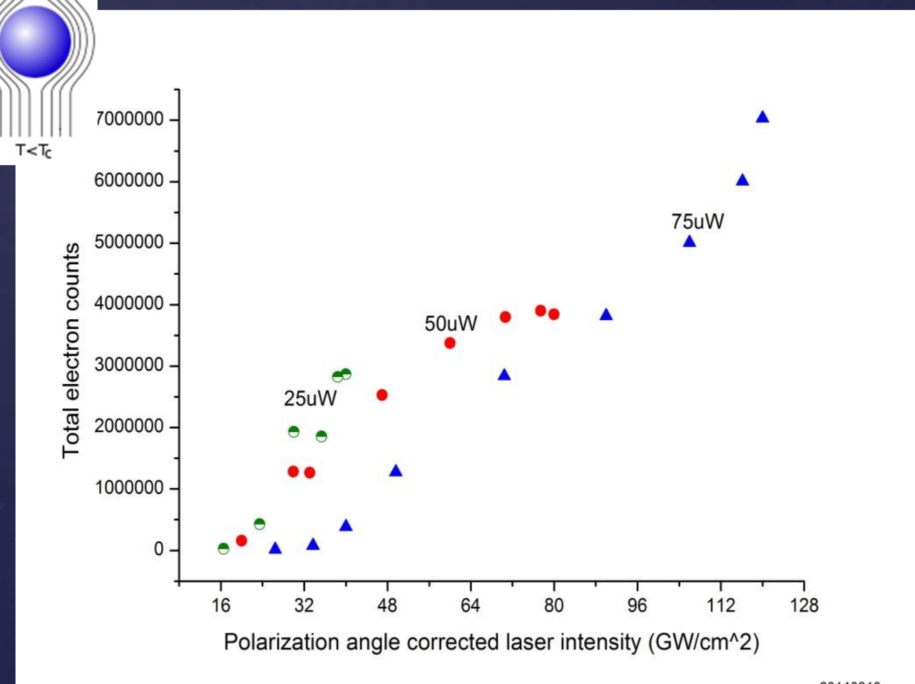
25uW
50uW
75uW
100uW
Total counts
The slow peak
Laser intensity (angular corr GW/cm^2)
20140228



B
T>Tc
B
T<Tc

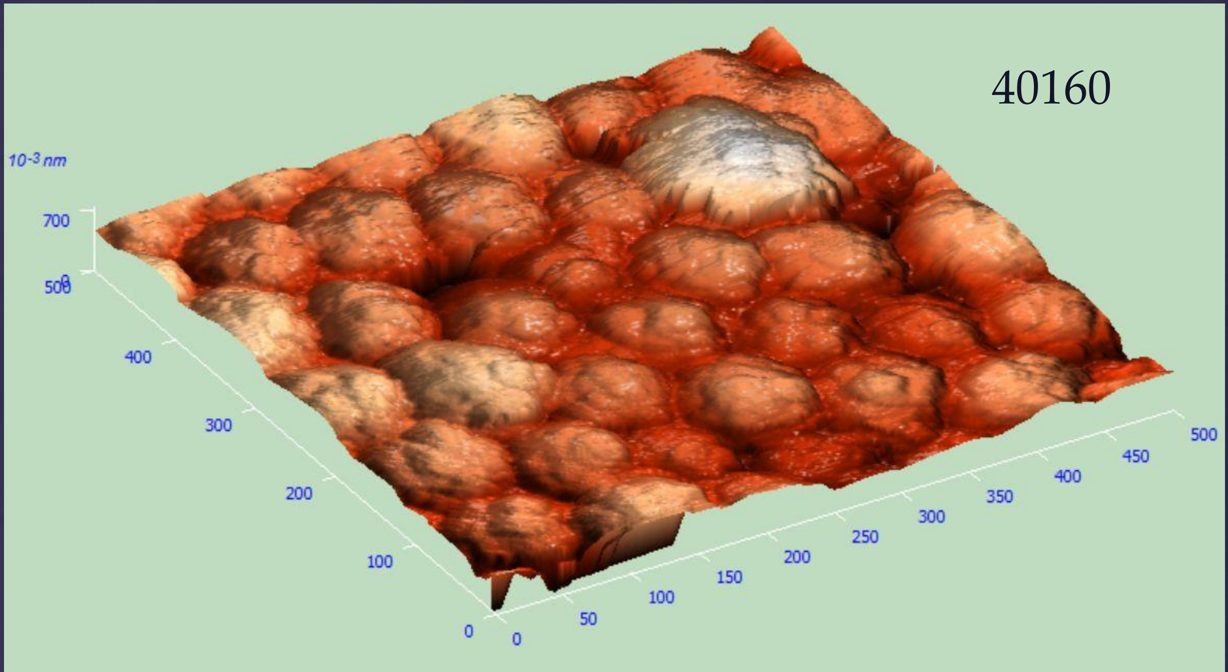


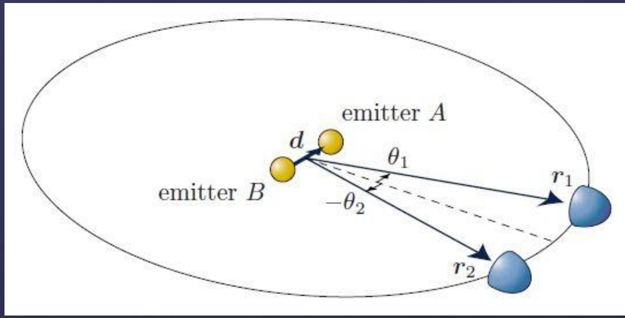
75uW
50uW
25uW
Electron counts in the high energy peaks
50uW
25uW
75uW
Polarization angle corrected laser intensity (GW/cm^2)
20140219



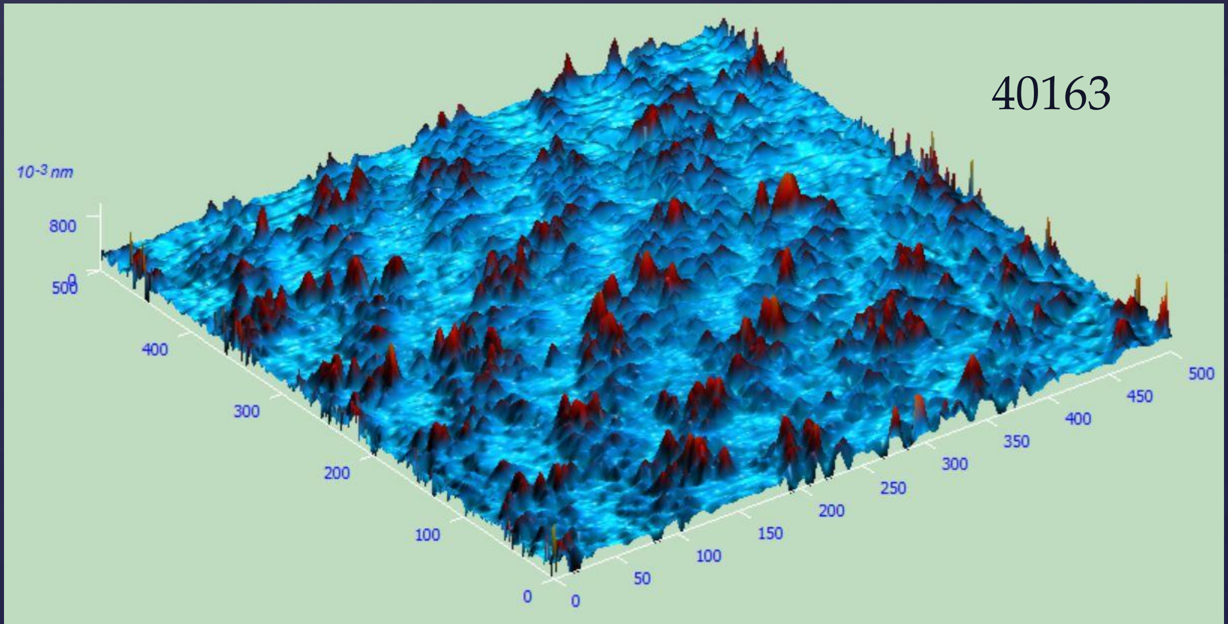
Total electron counts
75uW
50uW
25uW
Polarization angle corrected laser intensity (GW/cm^2)
20140219

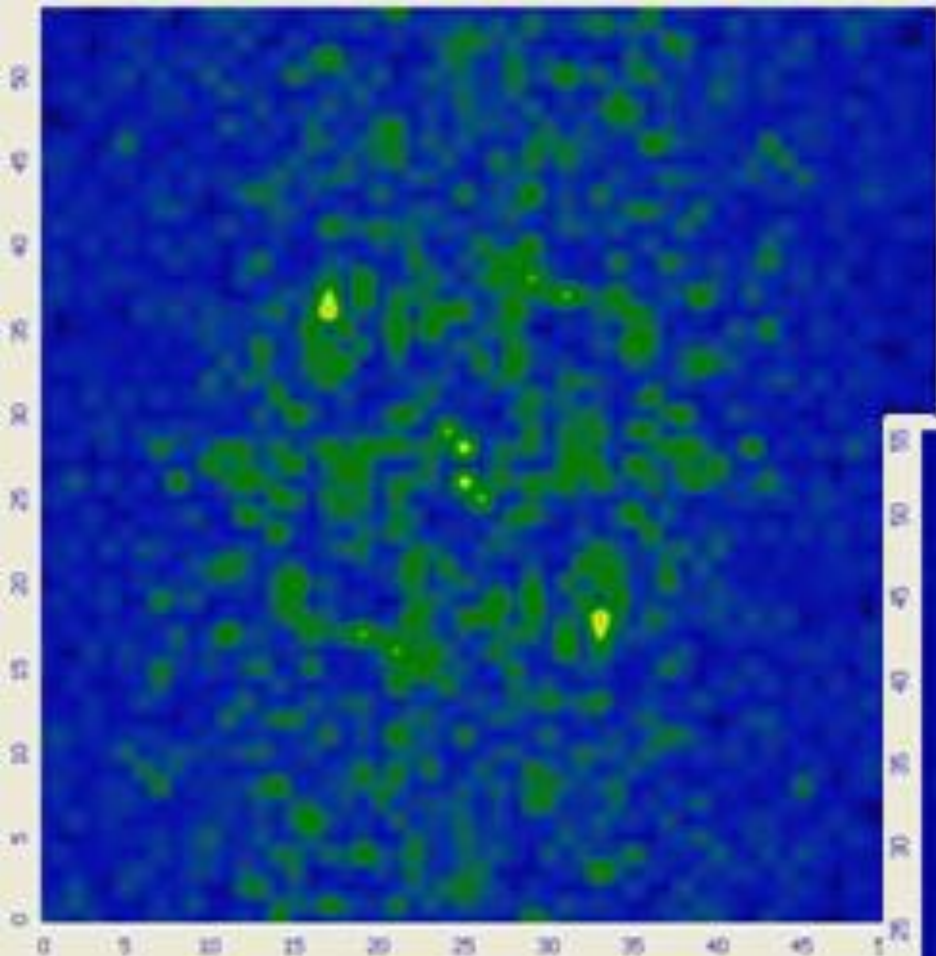
3.Motiváció rendezett minta használatához: az elméletileg jósolt elektron interferencia, két független szupravezető szigetből emittált elektronok esetén **(d = 100nm)**



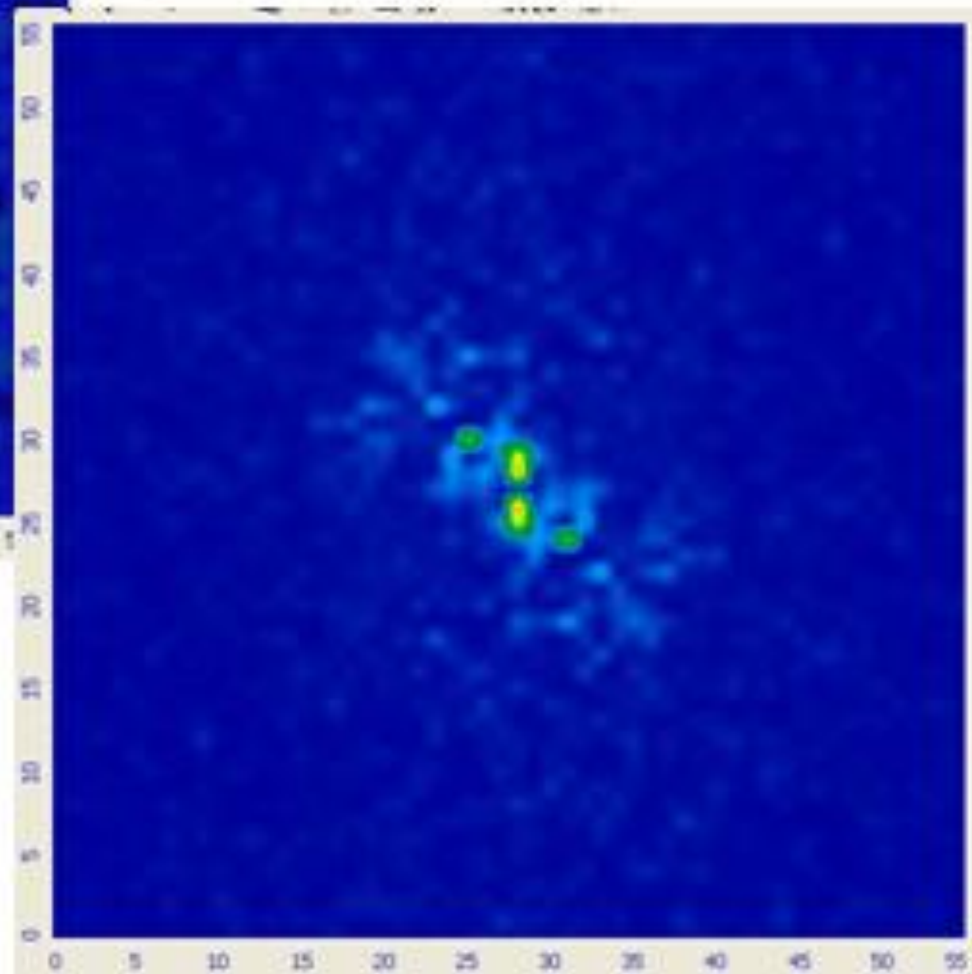


M.Iazzi and K.Yuasa: PhysRevB 81,172501(2010)



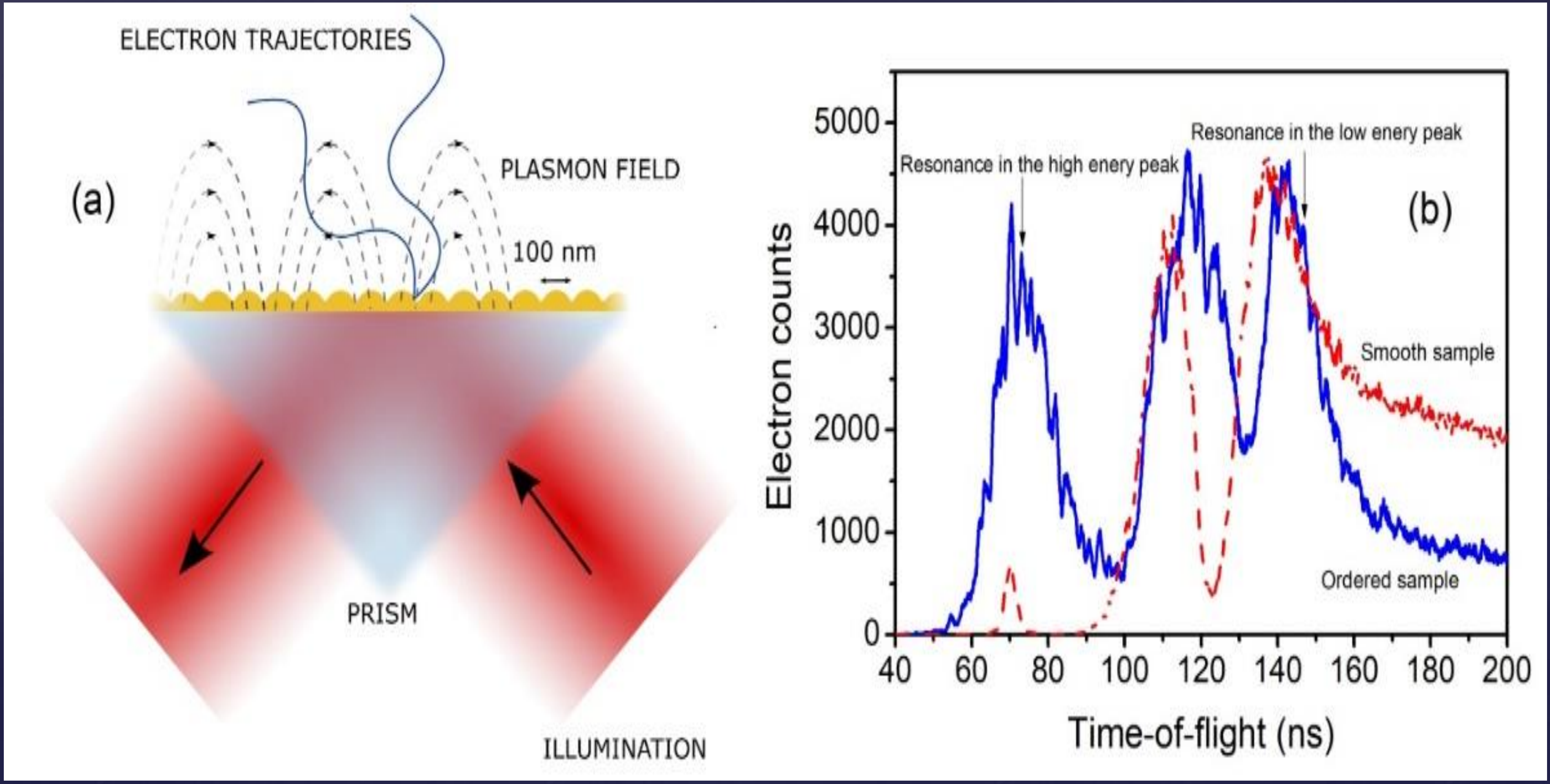


40163 FFT crop
ordered surface
with 80nm spheres

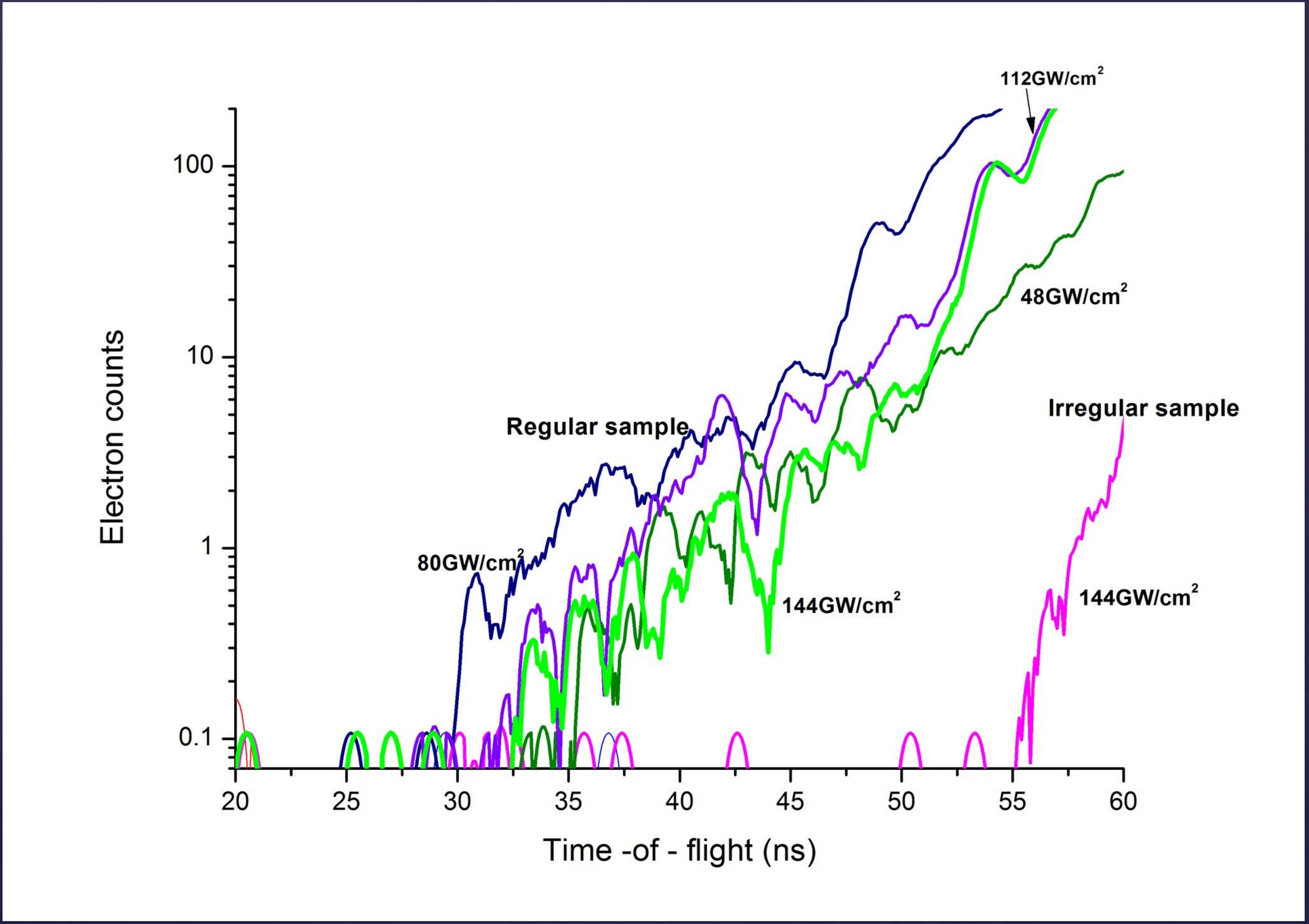


39753 FFT crop
rough surface

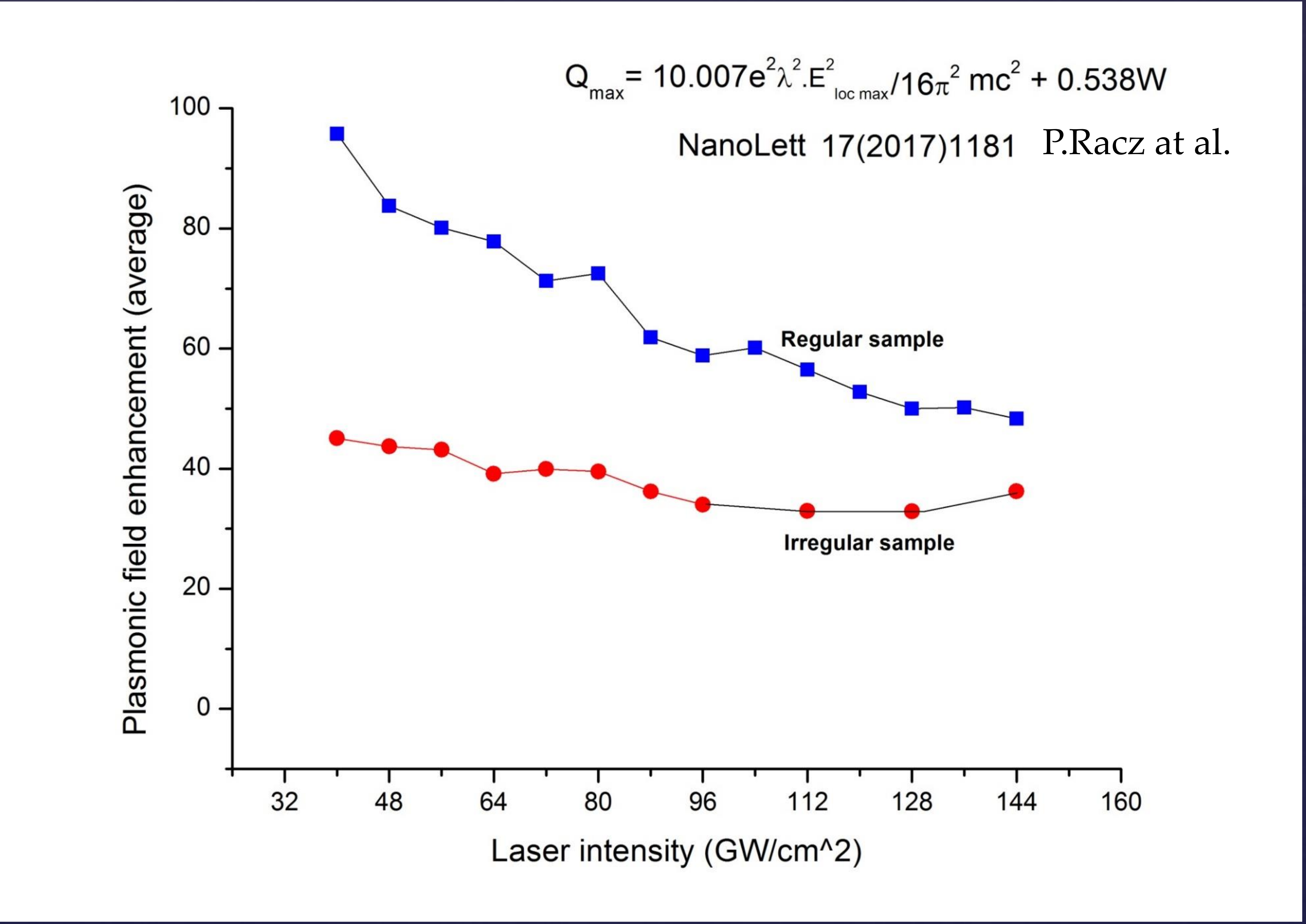
LÉNYEGES ELTÉRÉS A REPÜLÉSI IDŐ SPEKTRUMBAN



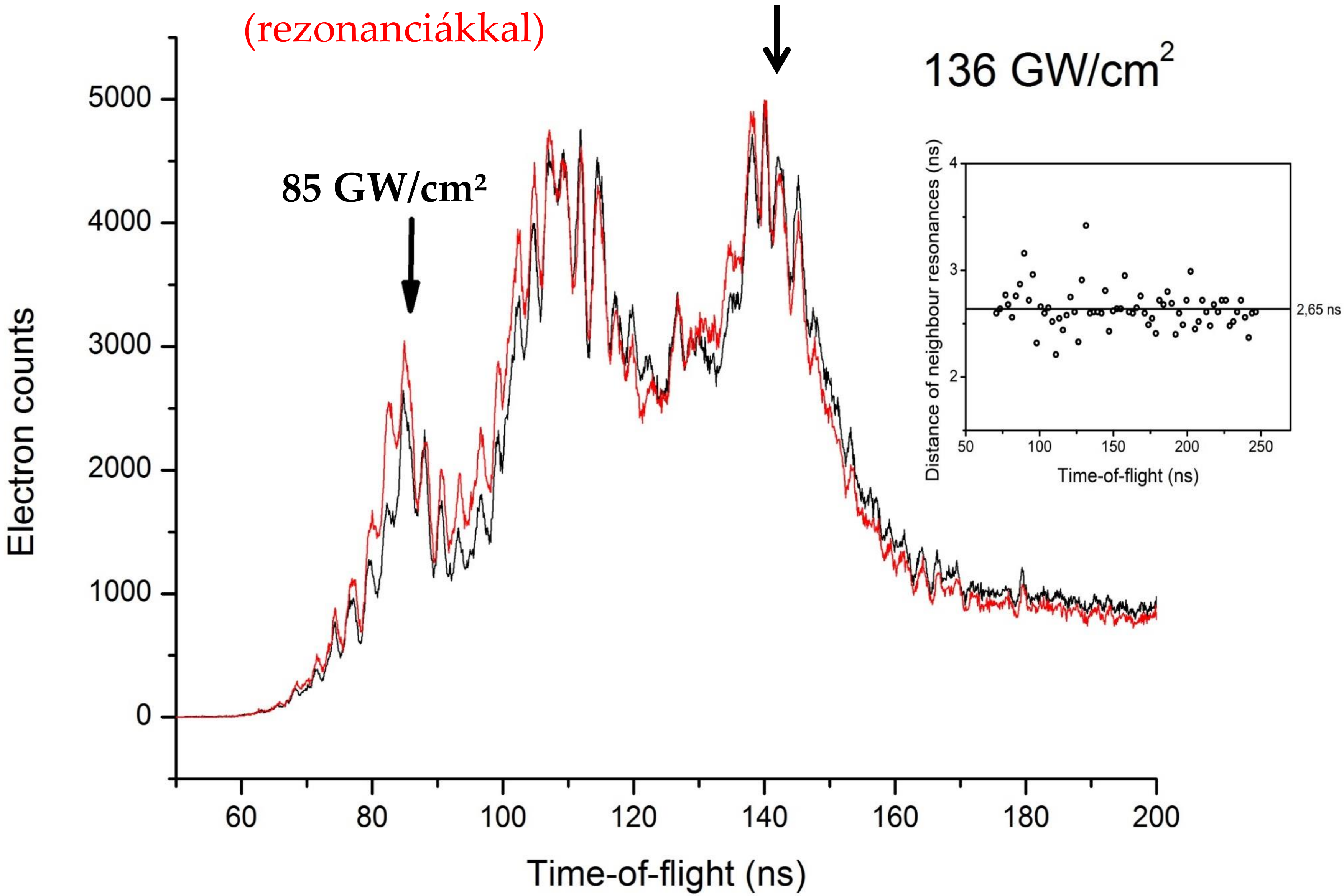
ÉS AZ ELEKTRON ENRGIA MAXIMÁLIS ÉRTÉKÉBEN

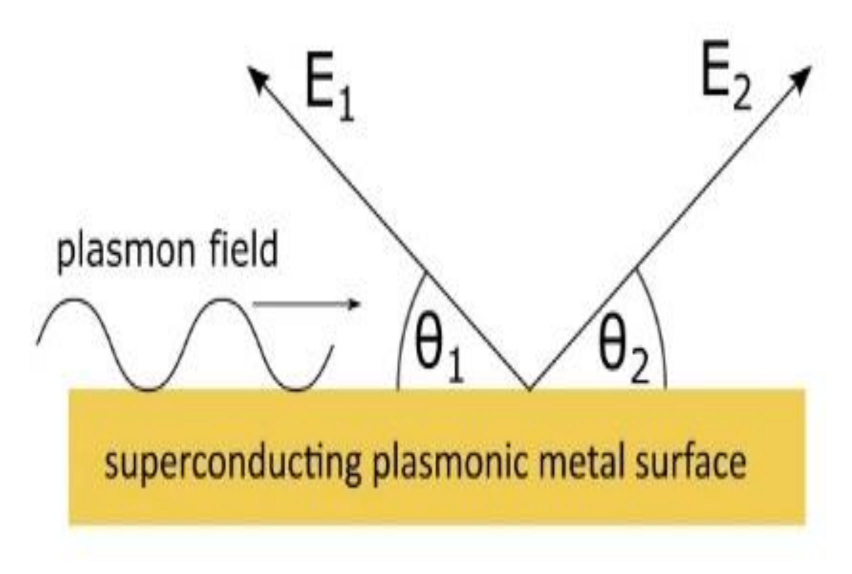


VALAMINT A PLAZMONIKUS EM TÉR ERŐSÍTÉSBEN

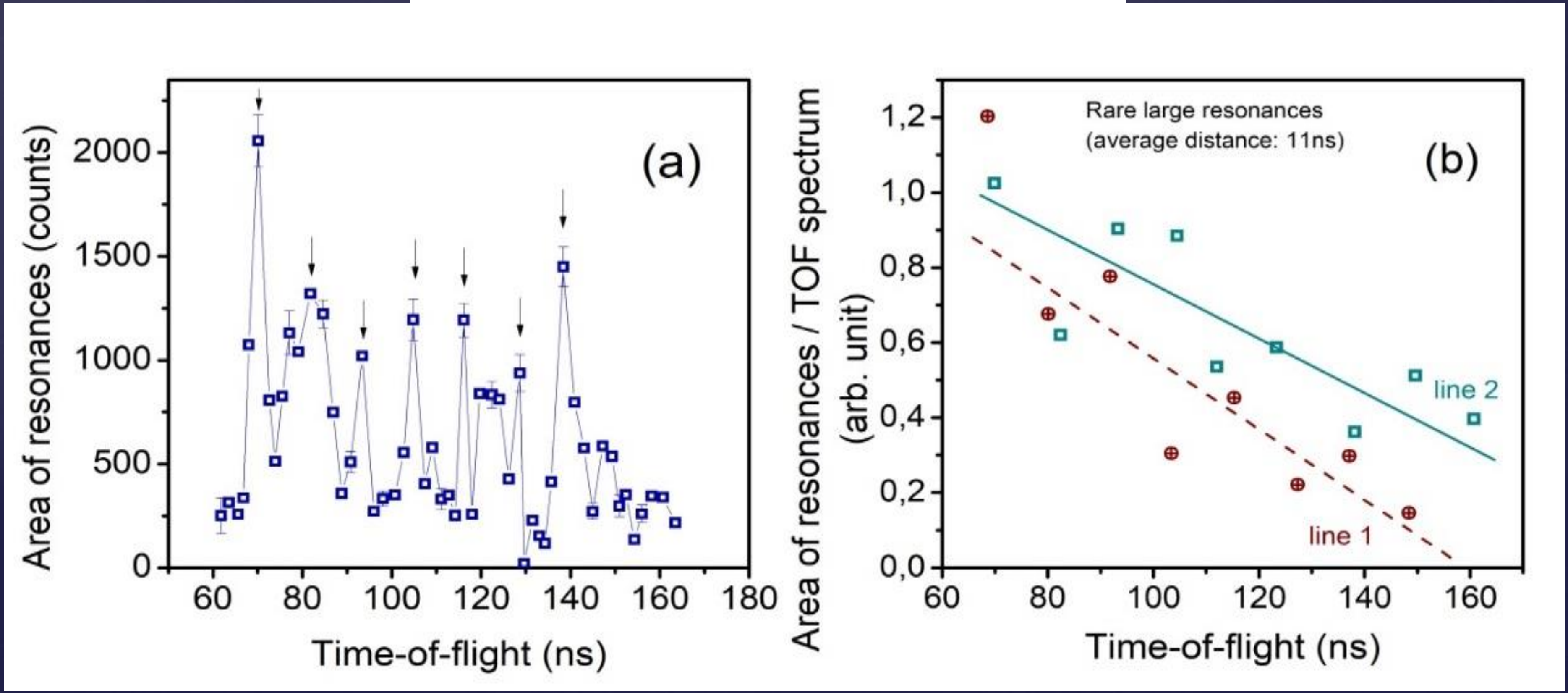


KÉT TIPIKUS TOF SPEKTRUM
(rezonanciákkal)





E_1
E_2
plasmon field
θ_1
θ_2
superconducting plasmonic metal surface



(a)
Area of resonances (counts)
Time-of-flight (ns)
(b)
Rare large resonances
(average distance: 11ns)
line 2
line 1
Area of resonances / TOF spectrum
(arb. unit)
Time-of-flight (ns)

ÖSSZEFOGLALÁS

-TOF és STM mérések anomáliája elektron párok jelenlétére utalnak.
-A polarizációfüggő TOF mérések Meissner effektust indikálnak
-A rendezett minta esetén az elektron párok hányada megnő.
-A rendezett mintán erős keskeny rezonancia maximumok lépnek fel, melyekből megbecsülhető az elektron párok élettartama
-A dupla intenzitású rezonanciák direkt elektron pár detektálást jelentenek.
-A TOF technológiával rövid idejű (esetünkben fs-os) folyamatok ps-os tartományban vizsgálhatók.

KÖSZÖNÖM A FIGYELMÜKET!