QUANTUM COHERENCE, COOPER PAIRS AND HIGH PLASMONIC FIELDS

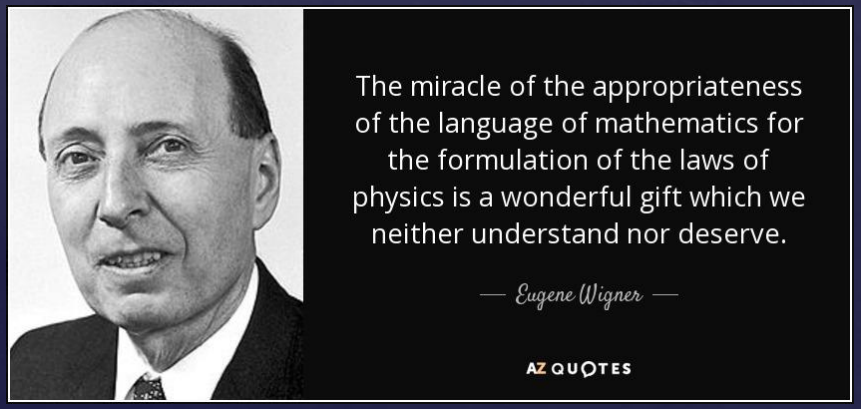
(to commemorate E.P.Wigner)

N.Kroo, P.Racz
Wigner Physics Research Center
Hungarian Academy of Sciences

Wigner Days, 15.11.2017

E.P. WIGNER AS ONE OF THE HEROES OF QUANTUM MECHANICS

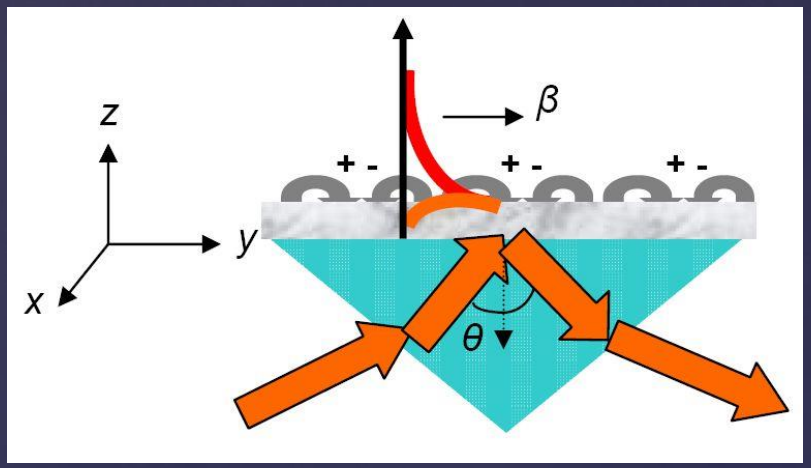
Group theory, applied to atomic spectra (Nobel)
Wigner function
Phase space formulation of QM
Quantum interference (QM Young)
Quantum mechanics and conscience
Interpretation of quantum mechanics
(with J. Neumann)



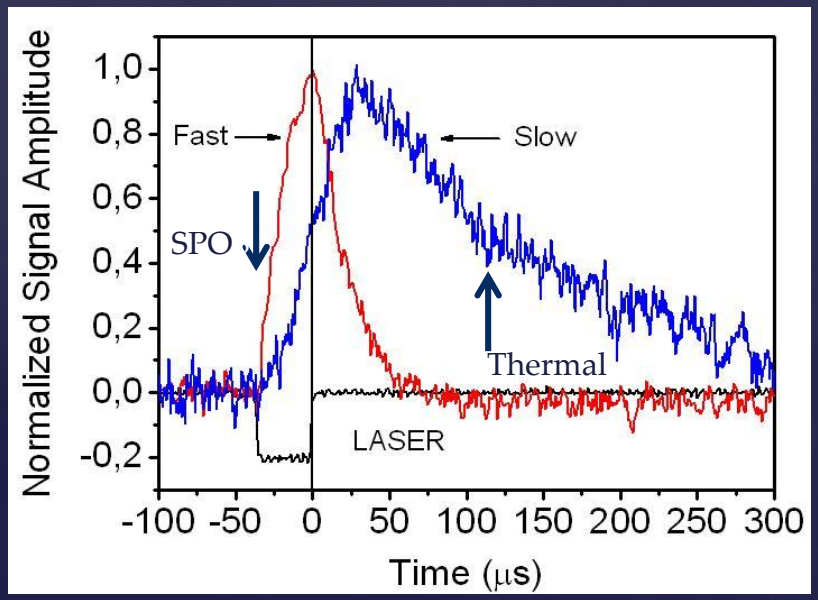
NEAR FIELD STM (against the diffraction limit)

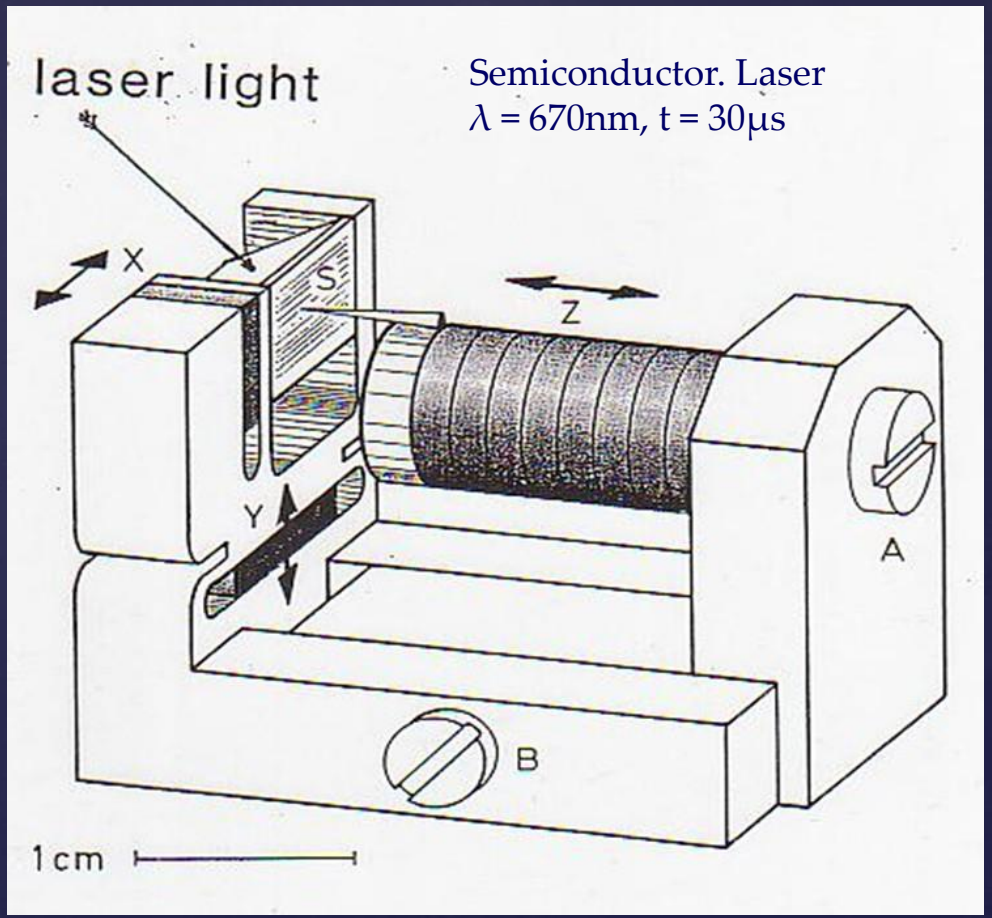
NEAR FIELD:LASER PULSE EXCITED SPO-S

(Kretschmann geometry)

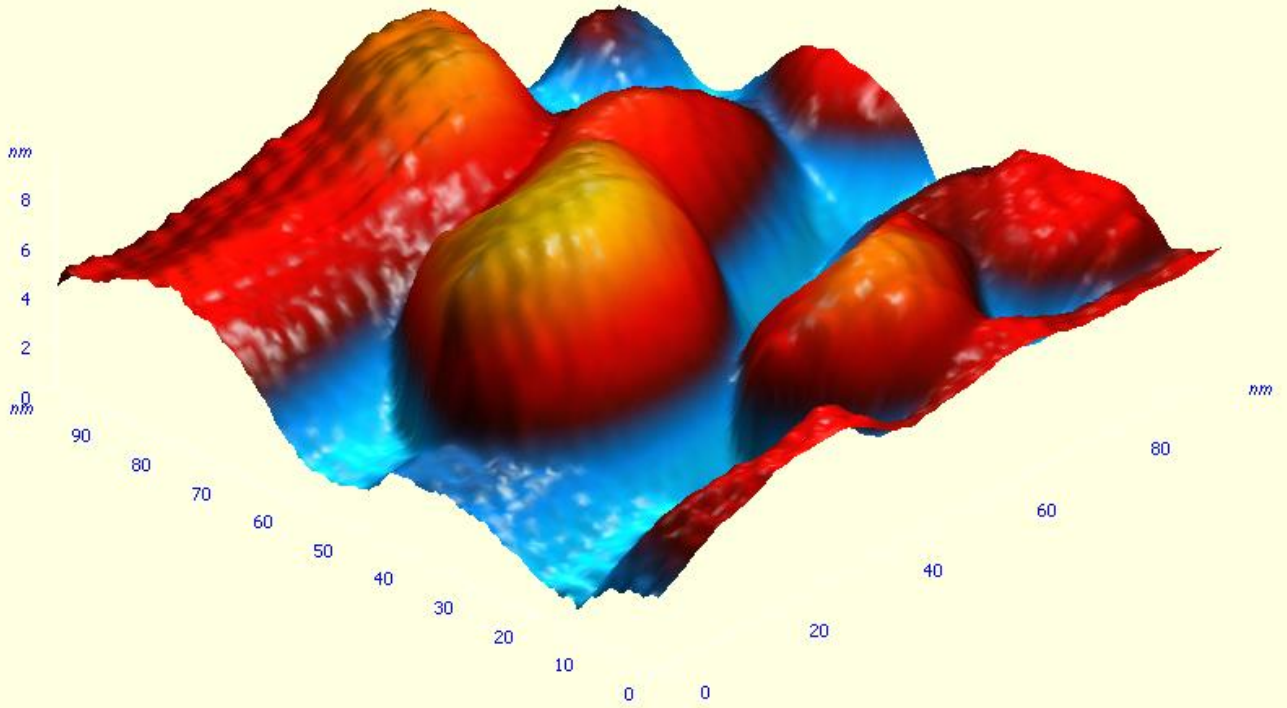


High plasmonic fields!

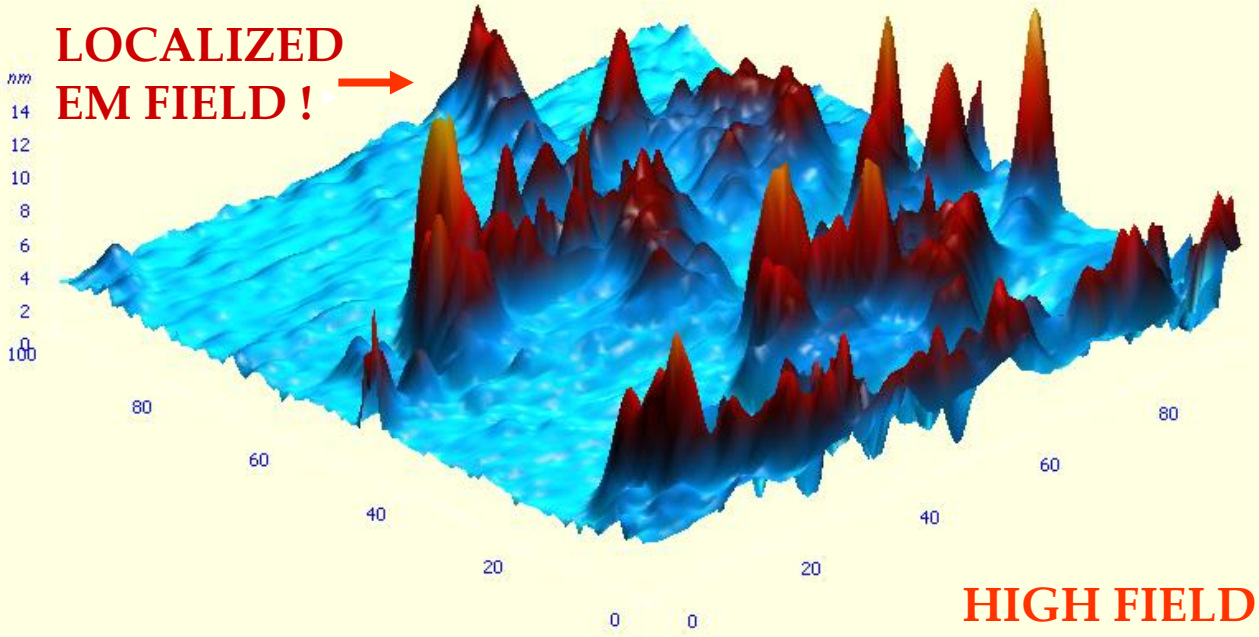


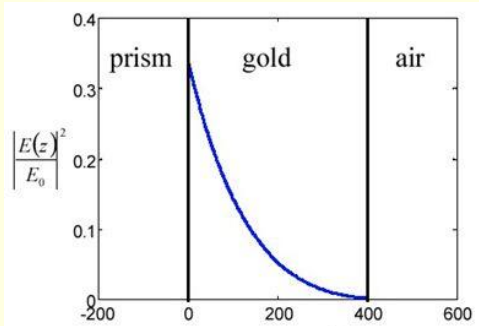


100x100nm Gold Topography and SPO near field STM images

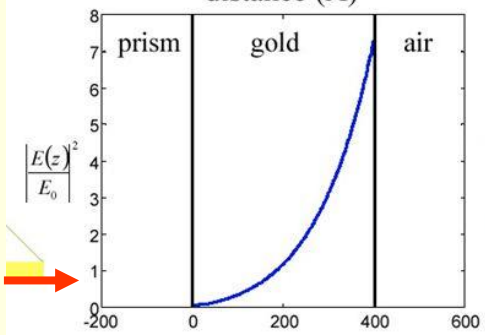


LOCALIZED EM FIELD !





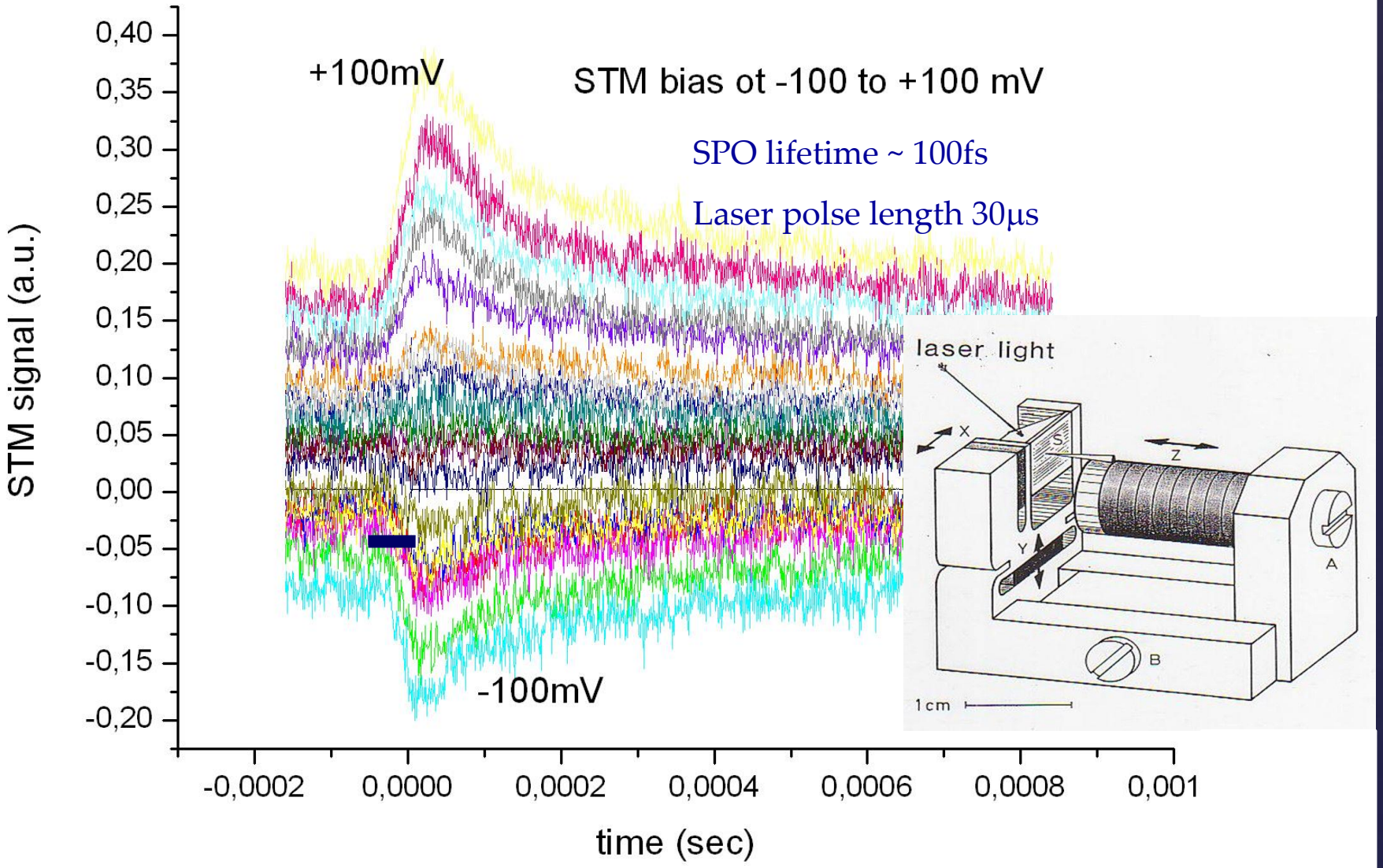
normal incidence



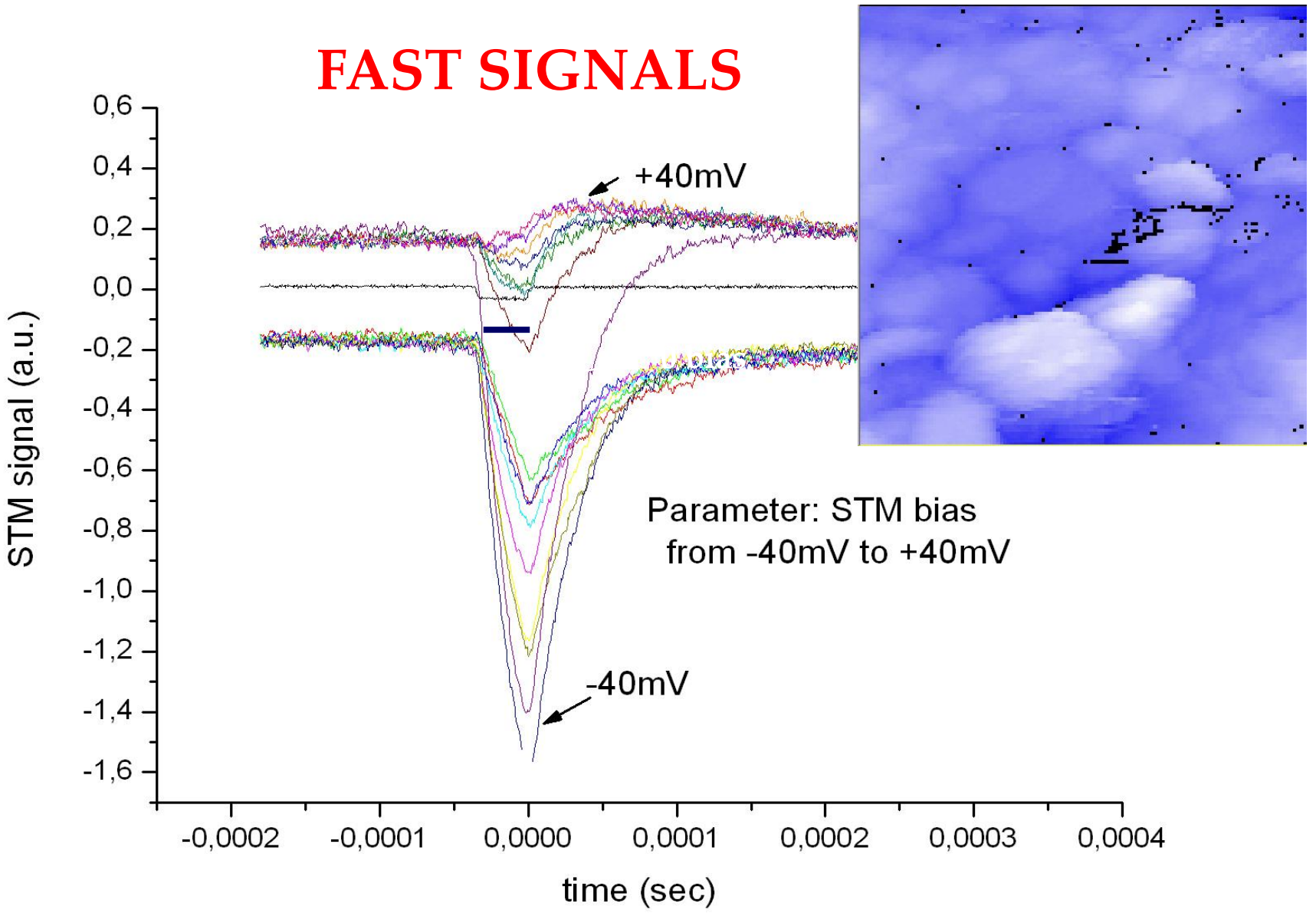
surface plasmon resonance angle

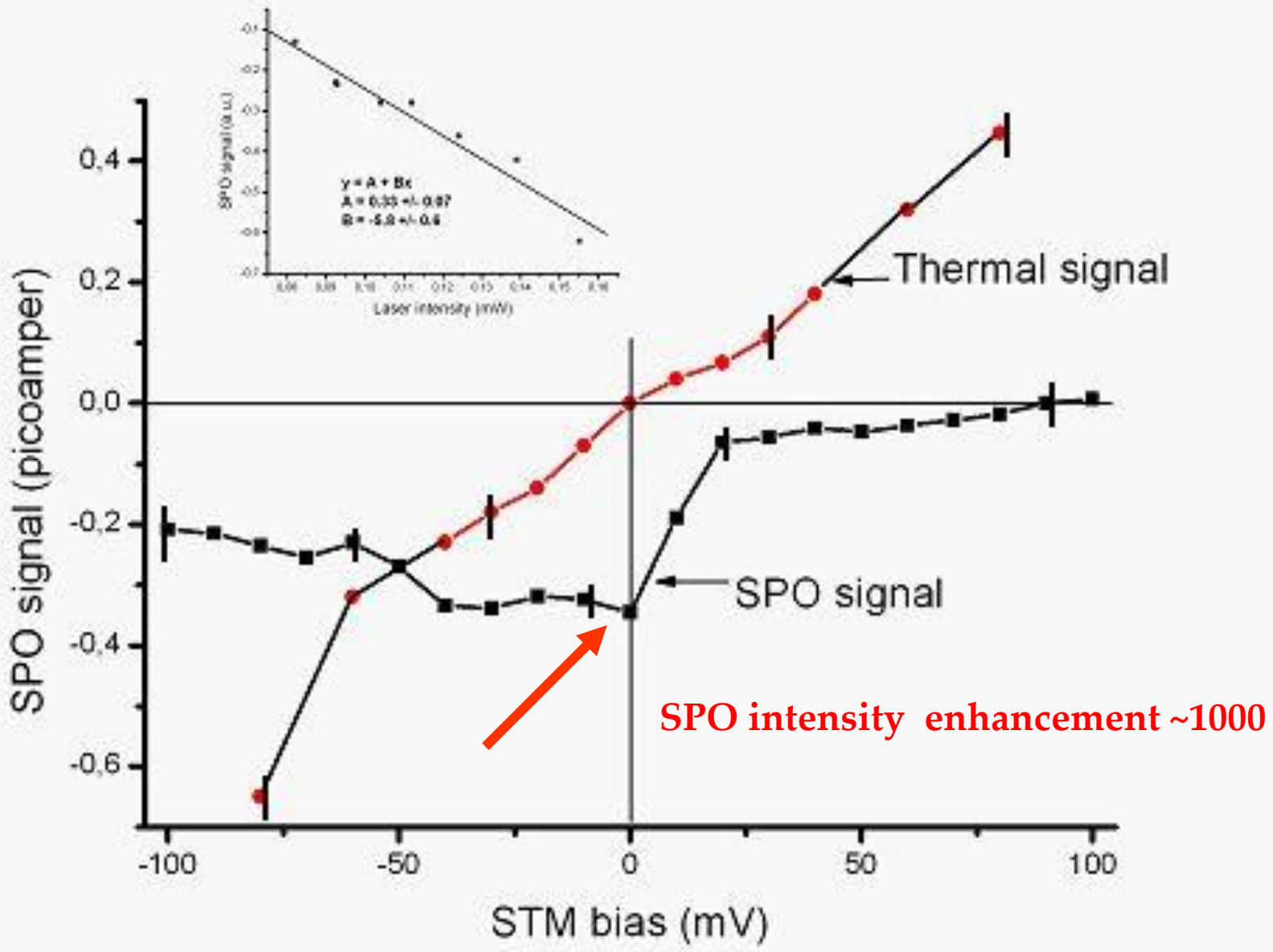
HIGH FIELD

SLOW SIGNALS



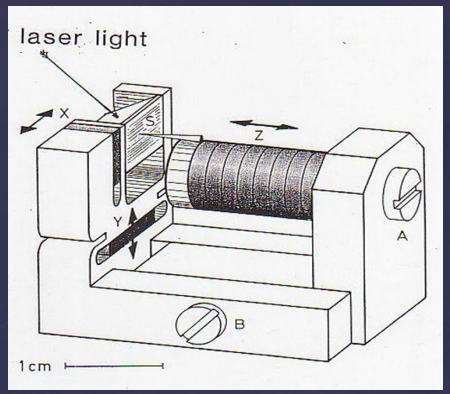
„NEGATIVE" STM SIGNALS IN SOME (HOT) SPOTS




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

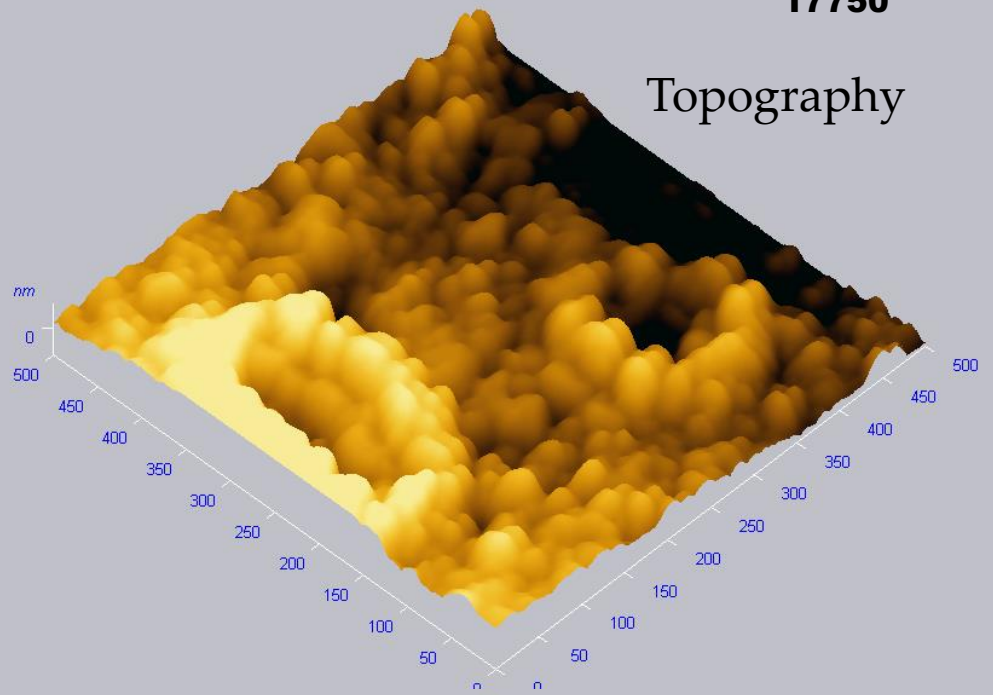
3 IMAGES OF A GOLD SURFACE

(Laser sputtered silver)

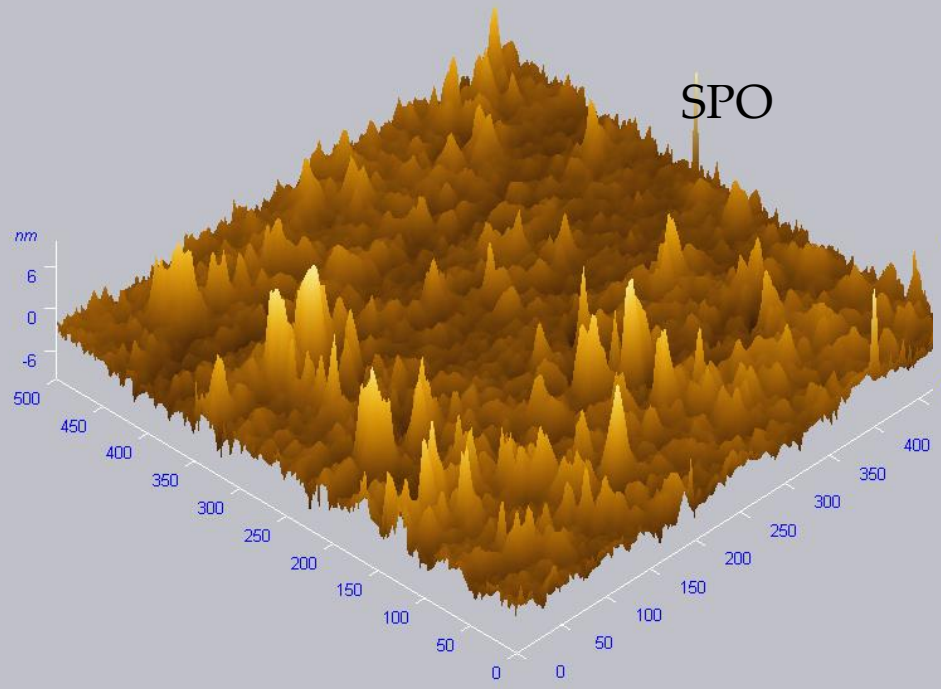


17750

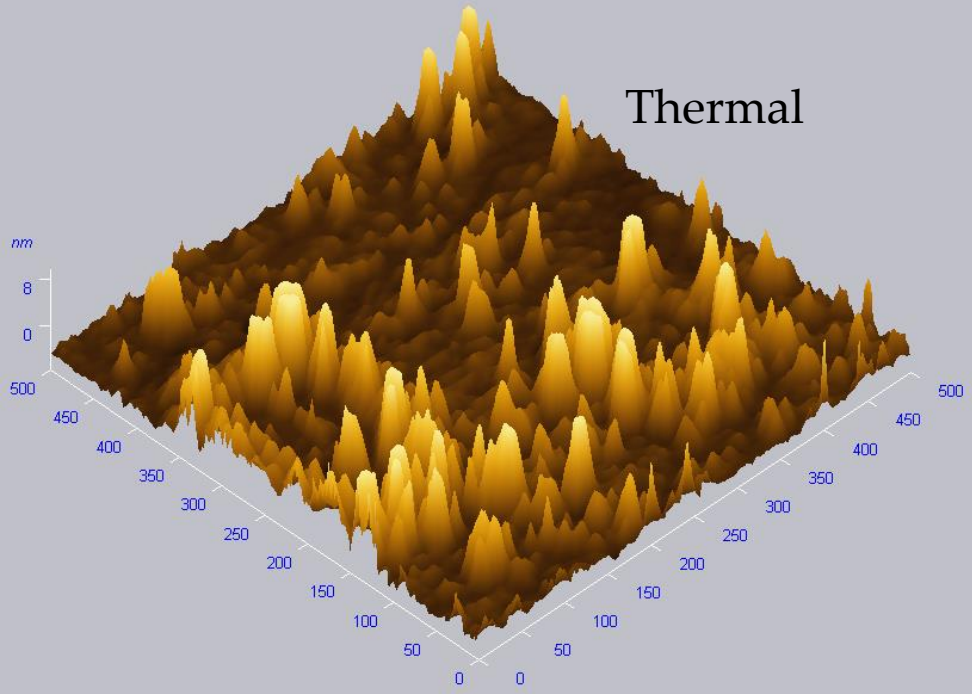
Topography



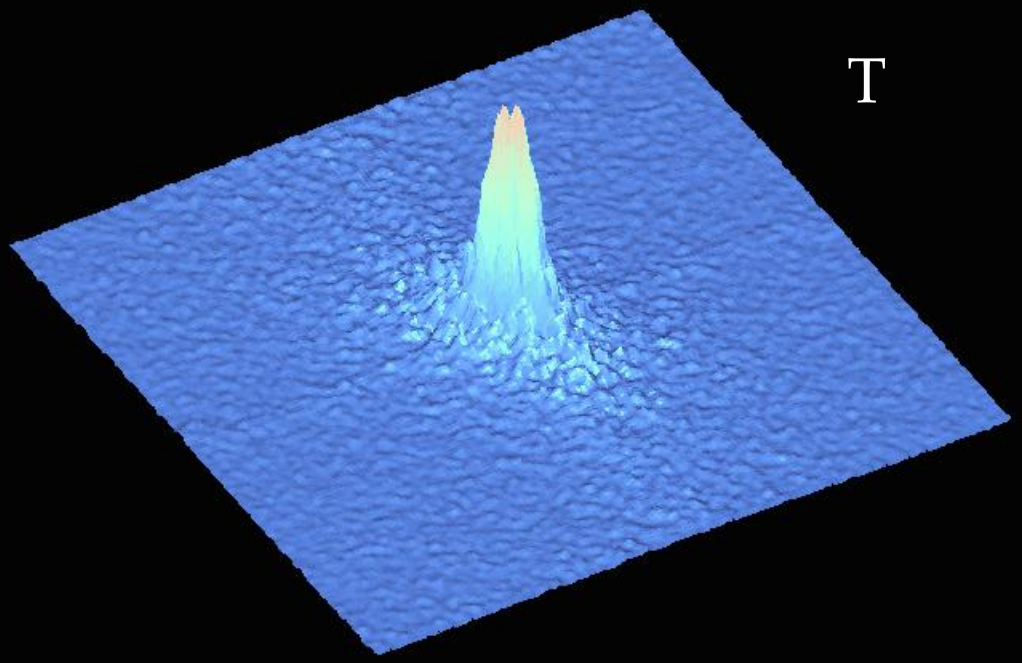
SPO

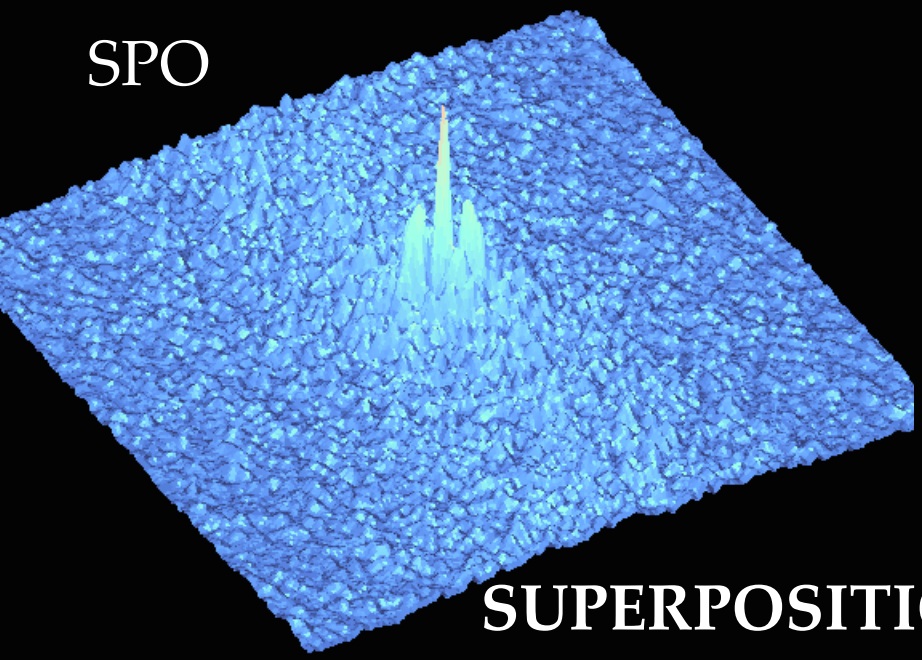


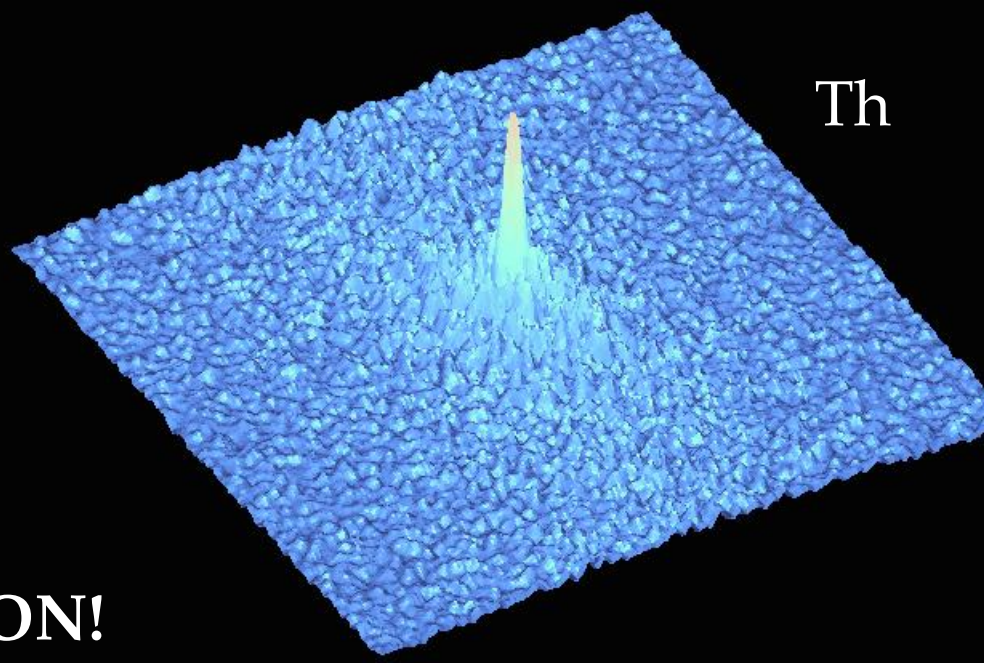
Thermal



FAST FOURIER TRANSFORM OF THE TOPOGRAPHIC, SPO AND THERMAL IMAGES



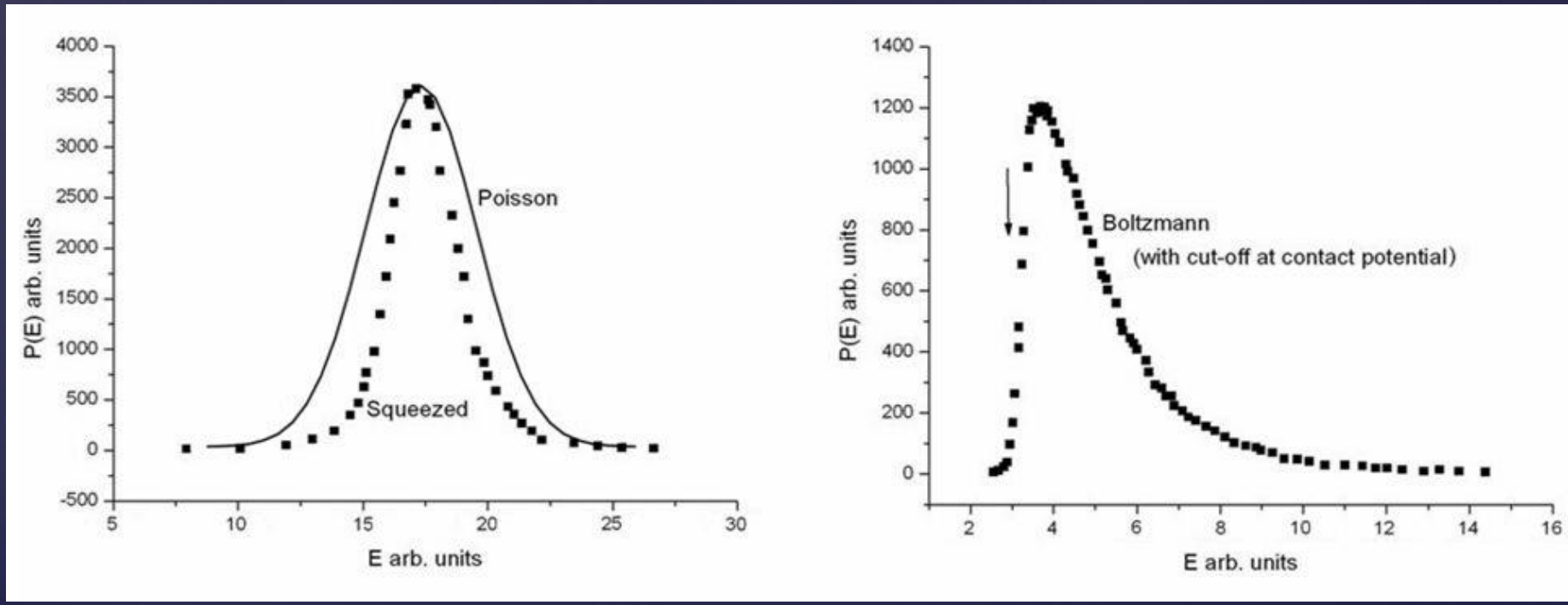


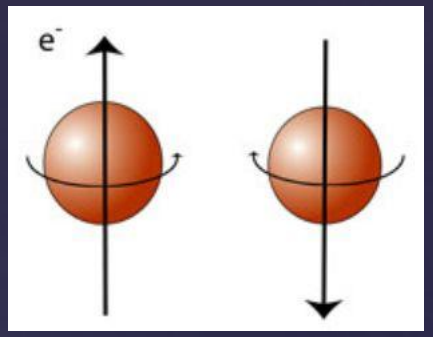


SUPERPOSITION!

23950ss

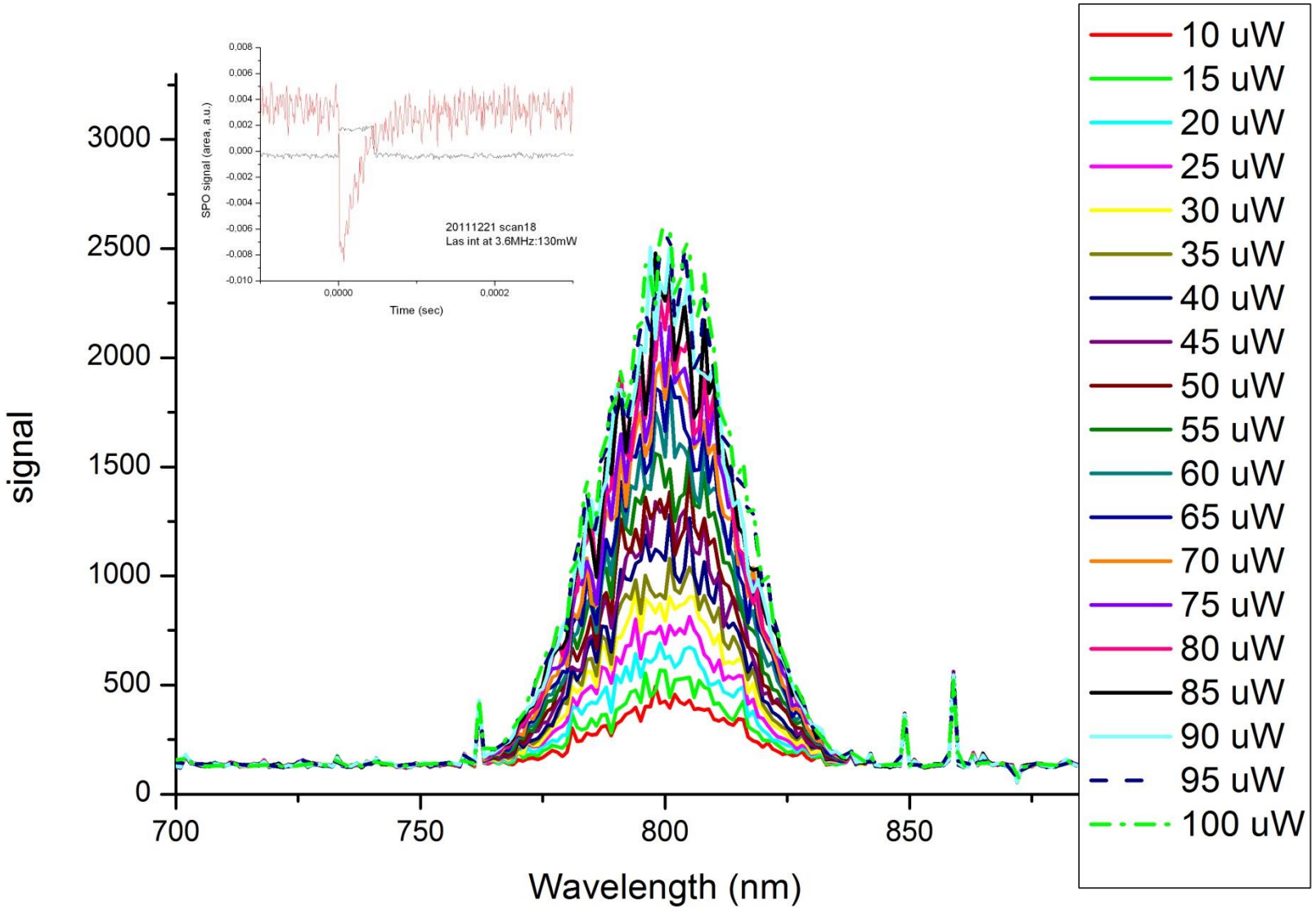
SQUEEZING IN THE SPO IMAGE



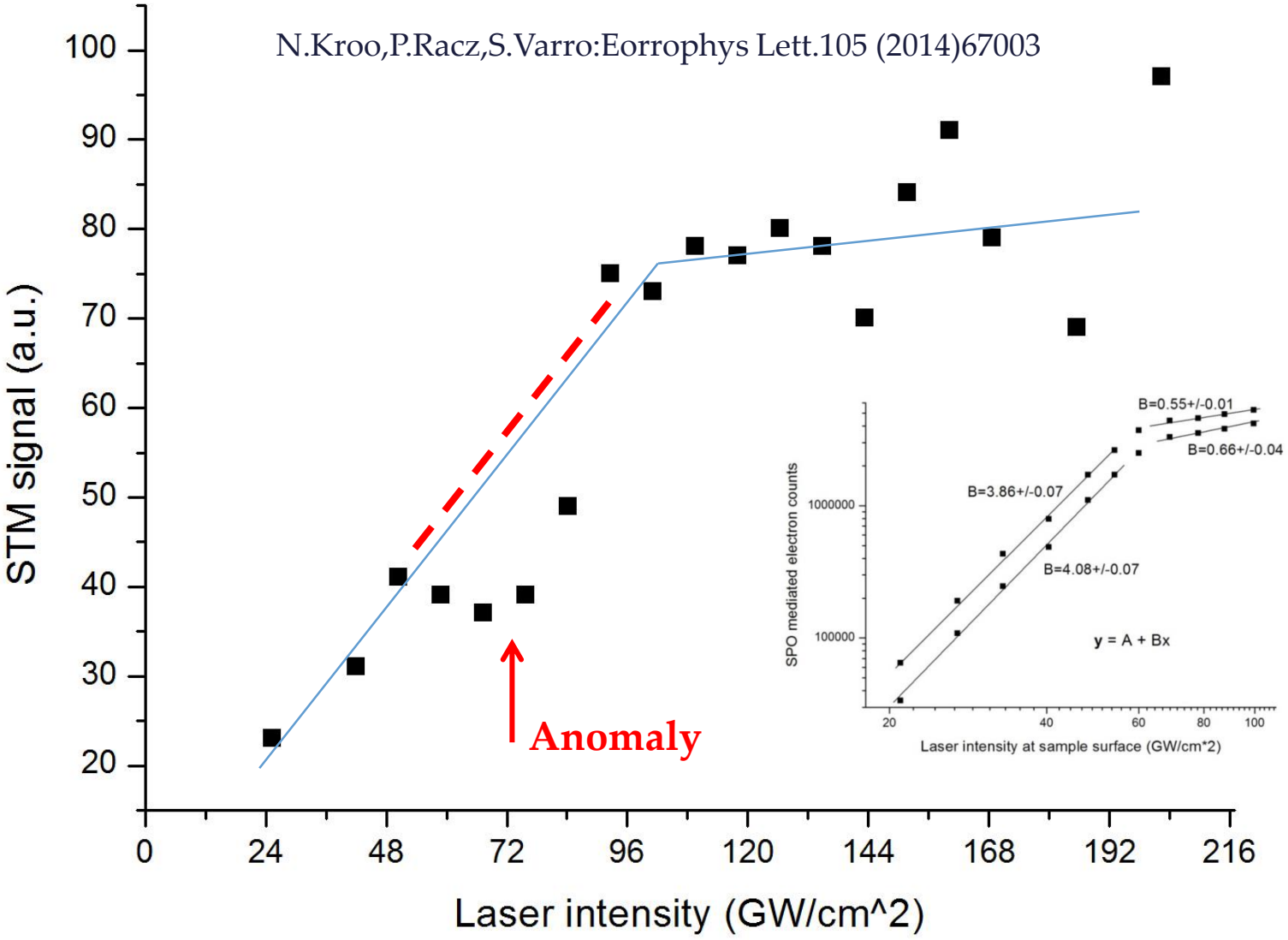


THE GREAT SIDE ABOUT PHYSICS IS THAT IT DISCOVERS THINGS WHERE YOU WOULD LEAST EXPECT THEM TO BE FOUND.

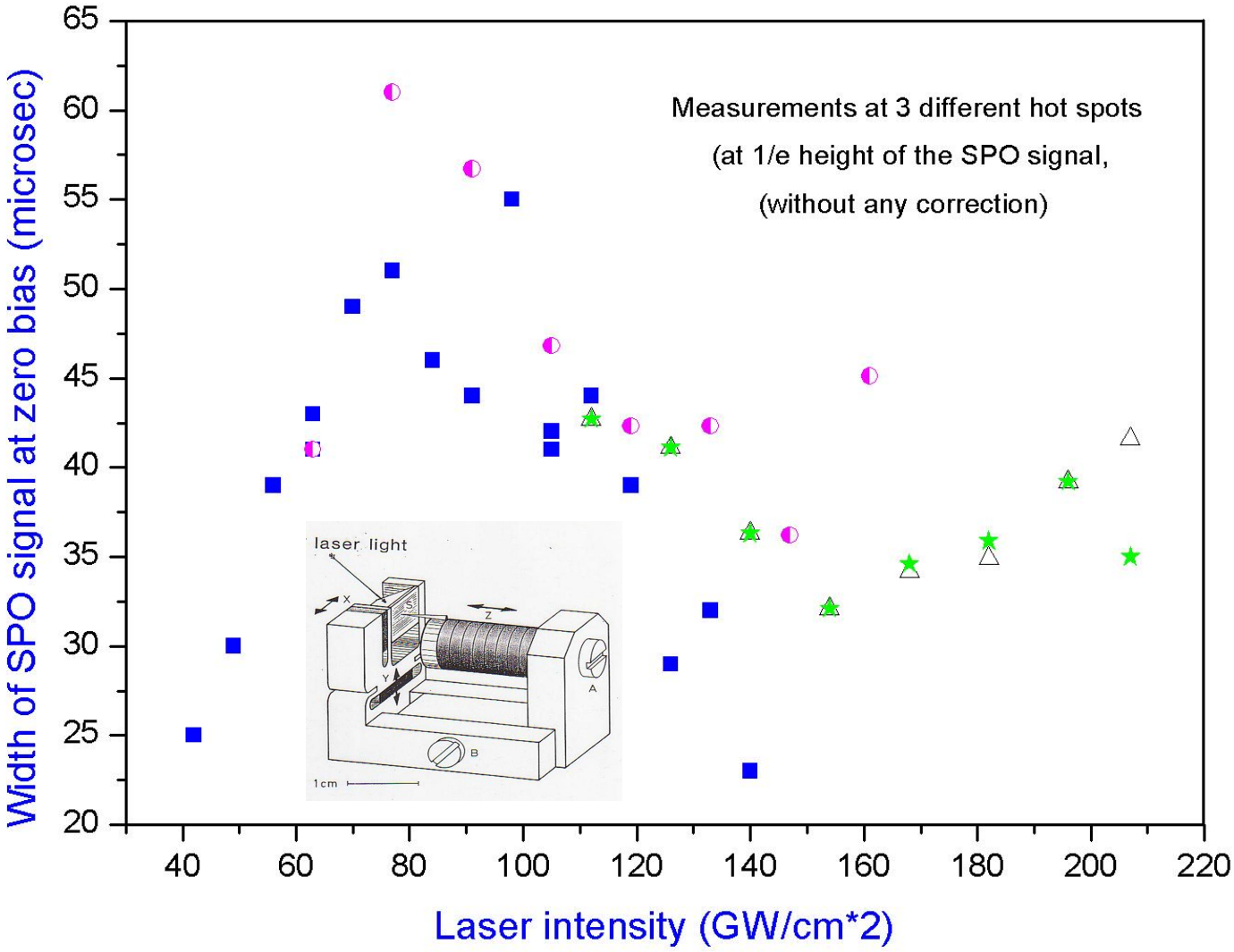
SPECTRUM OF THE Ti:Sa LASER AT DIFFERENT INTENSITIES

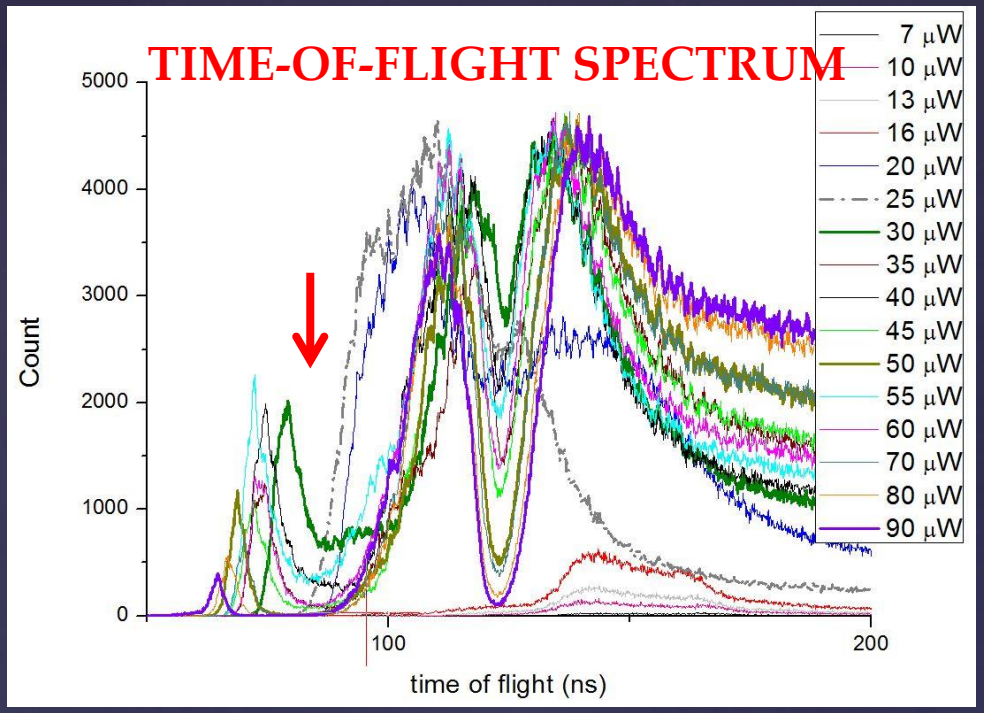


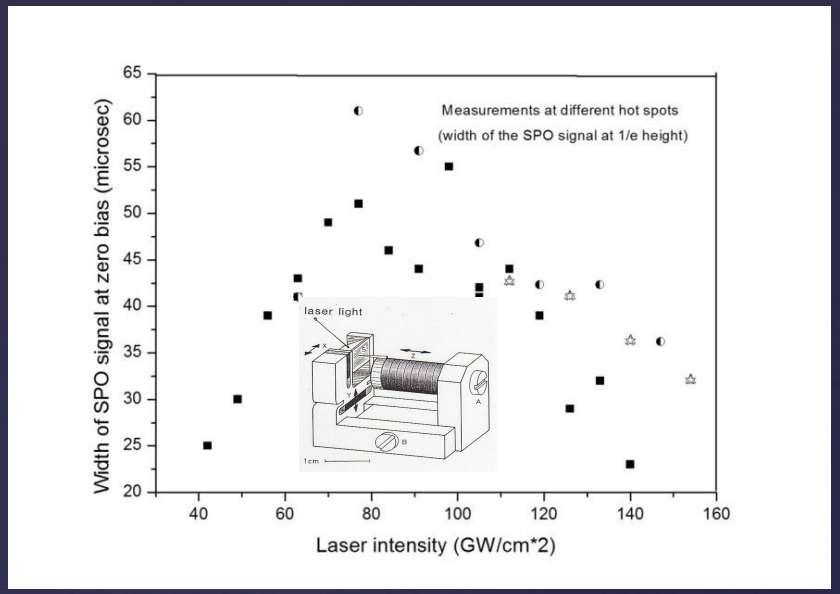
N.Kroo,P.Racz,S.Varro:Eorrophys Lett.105 (2014)67003



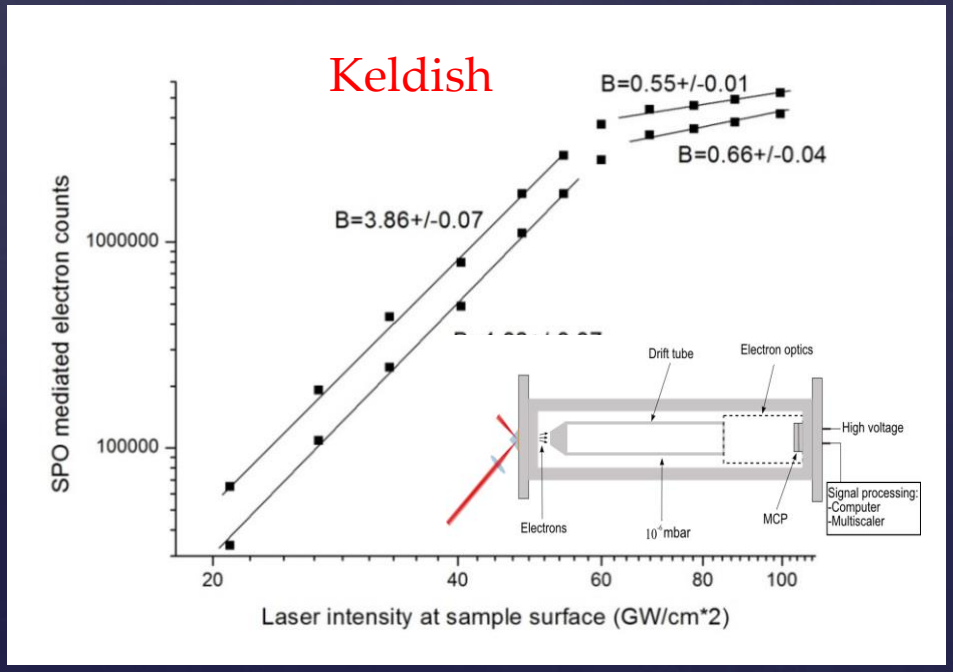
ANOMALY AT ROOM TEMPERATURE!

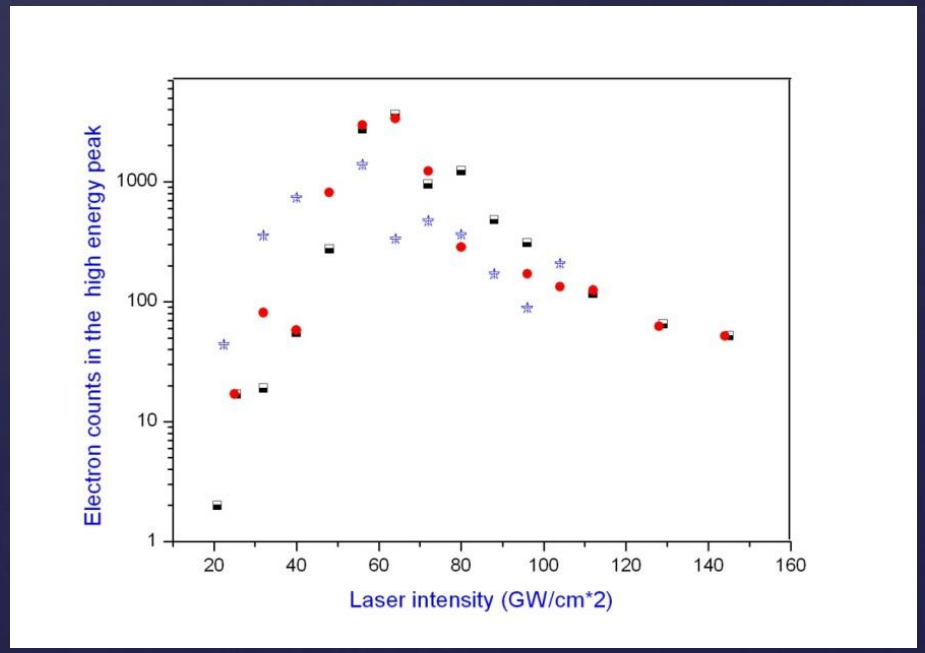


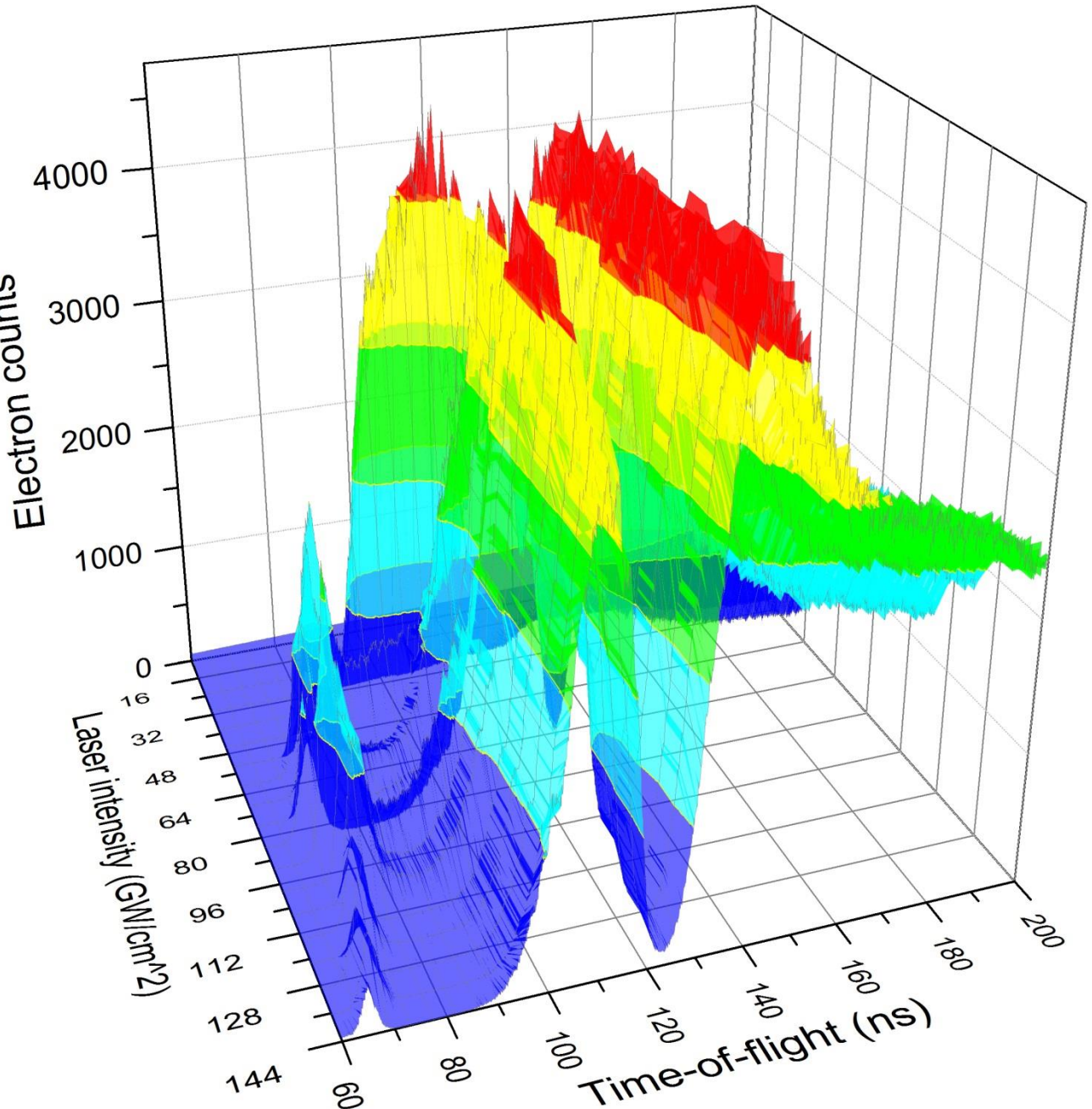




Multiplasmon electron emission






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

EFFECTIVE POTENTIAL OF ELECTRON-ELECTRON INTERACTION IN STRONG ELECTROMAGNETIC FIELDS

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

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

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

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

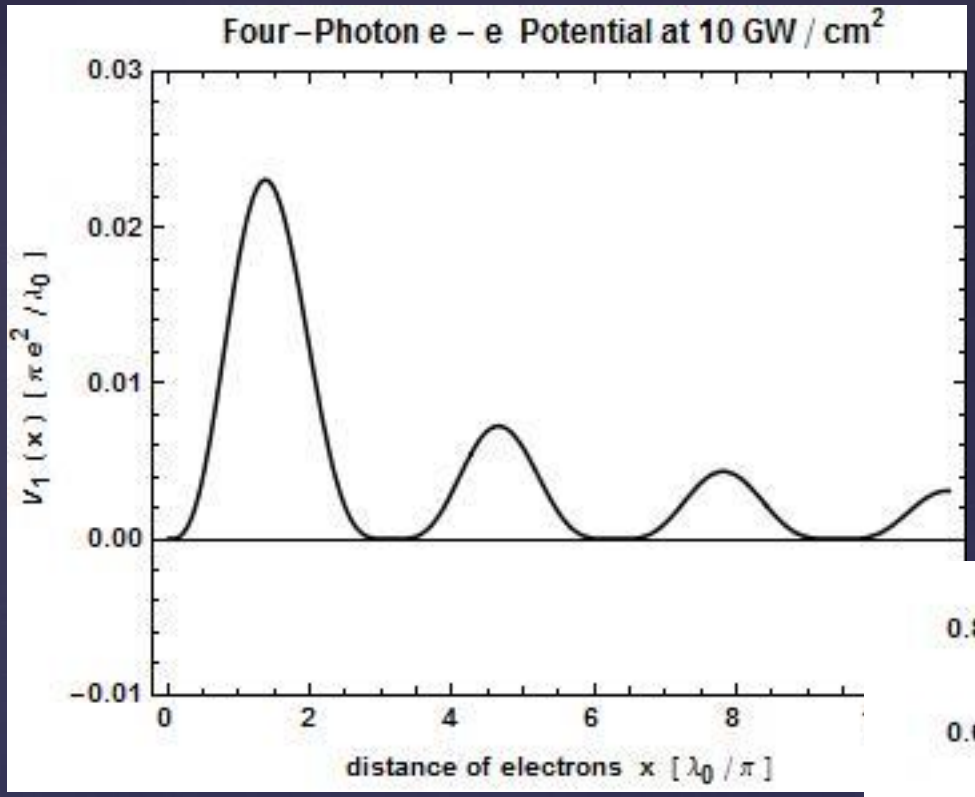
F: amplitude of the EM field

Plasmon field enhancement: ~40

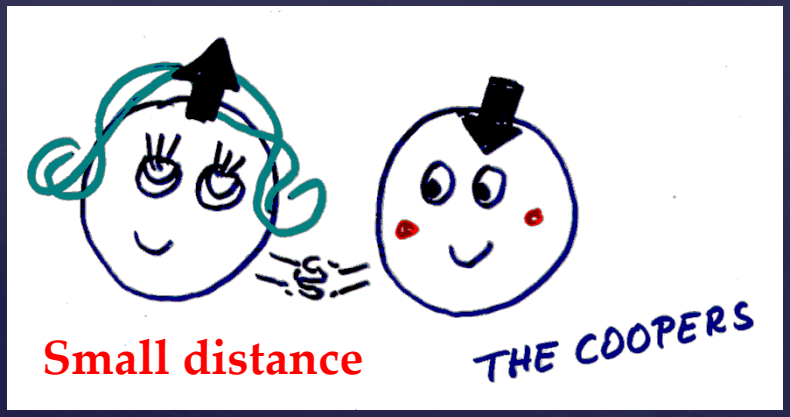
Electron pairing!

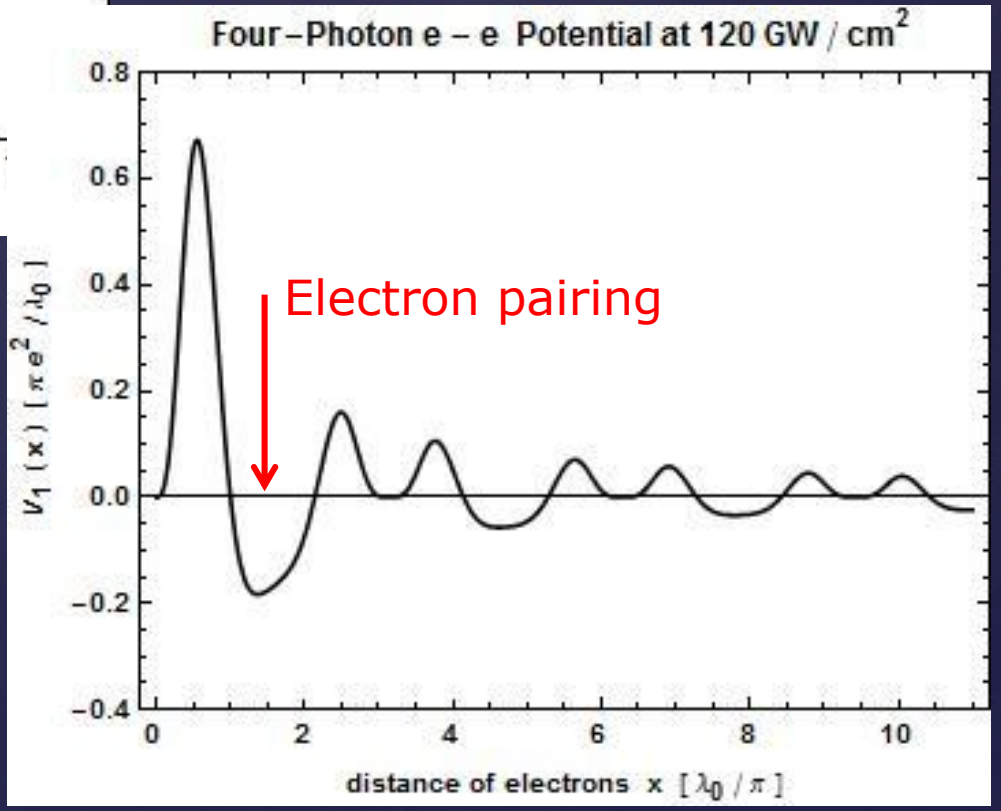
When the effective potential is negative!

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

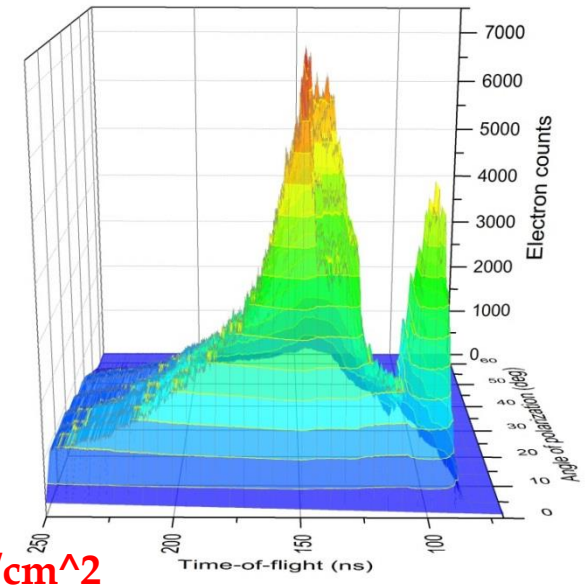


THIS EFFECTIVE POTENTIAL FOR 2 LASER INTENSITIES WITH SPO FIELD ENHANCEMENT INCLUDED

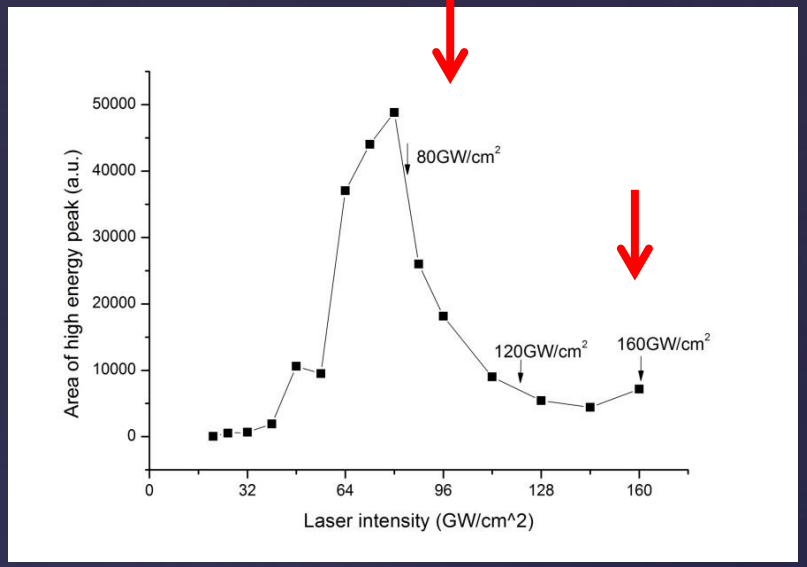


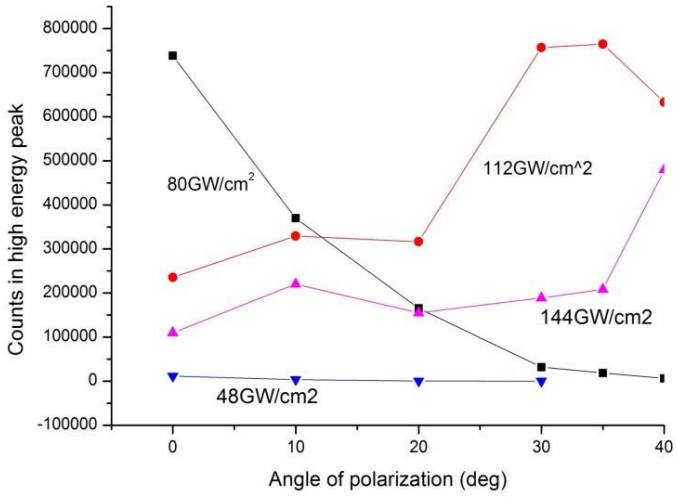


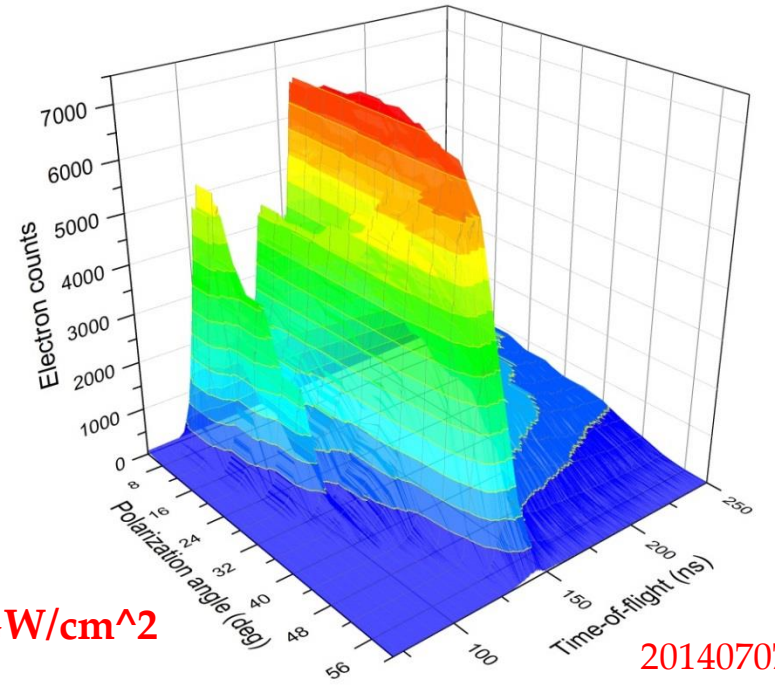
MAGNETIC (rectified EM field) FIELD DEPENDENCE



144 GW/cm^2



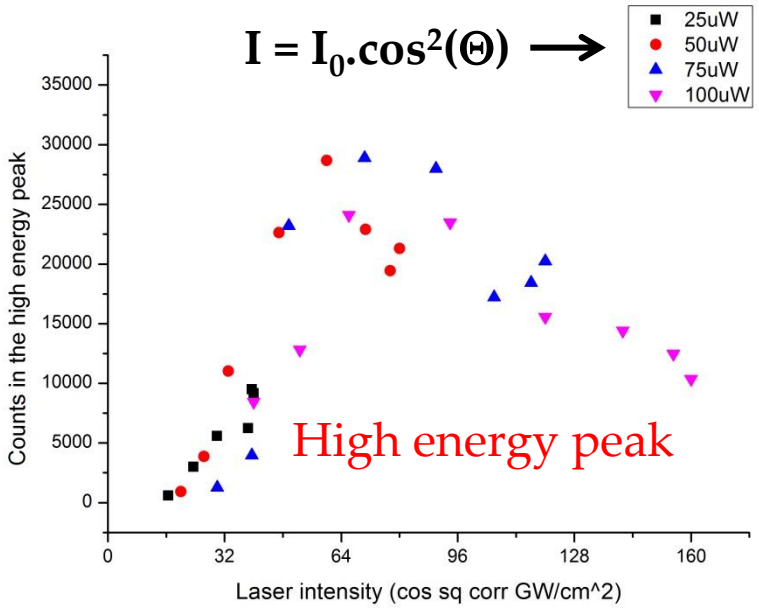


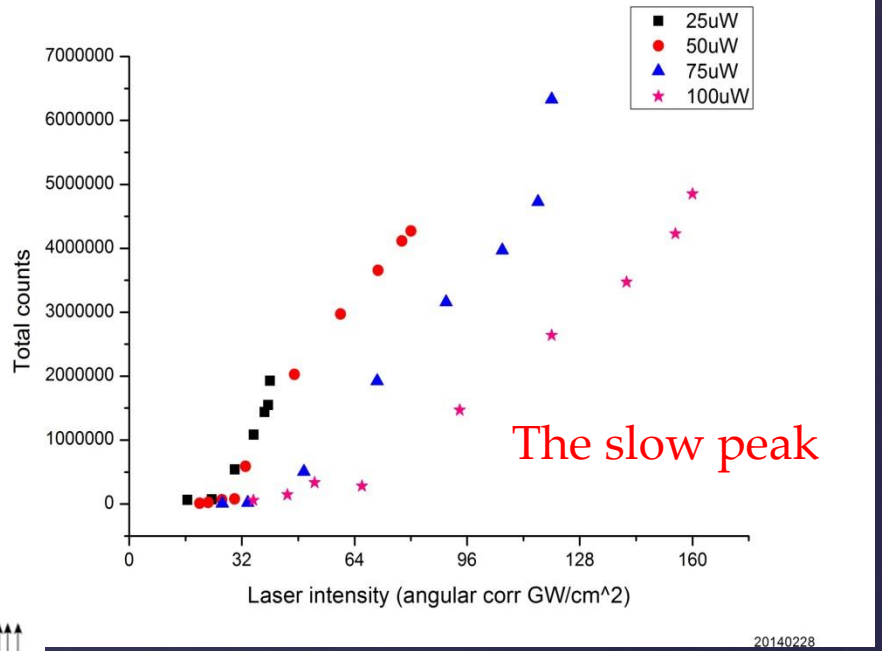


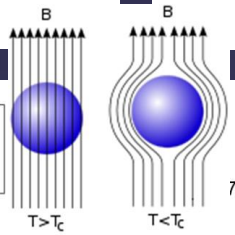
80 GW/cm^2

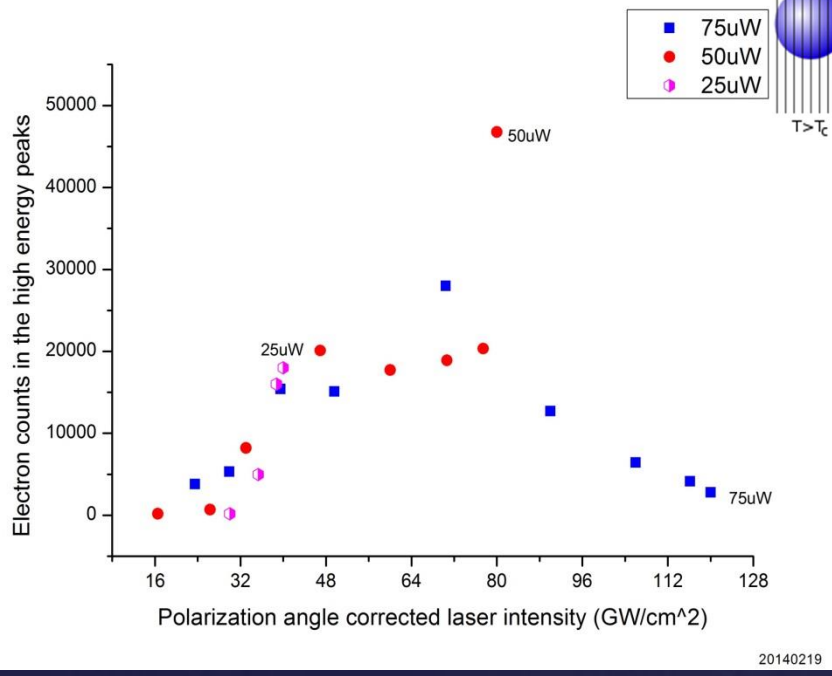
20140707

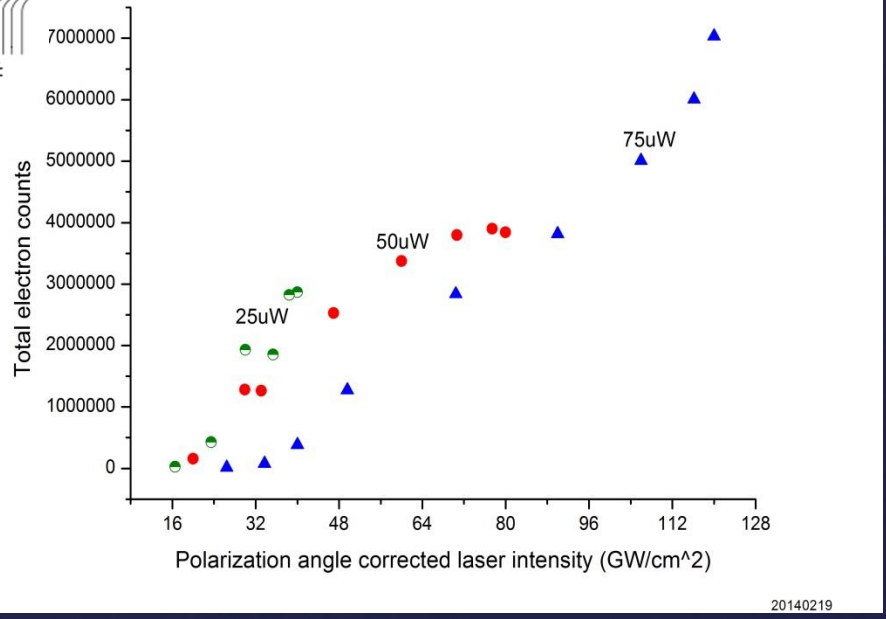
$I = I_0.\cos^2(\Theta)$ →



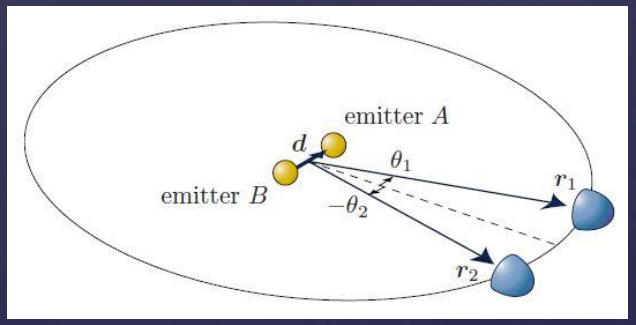




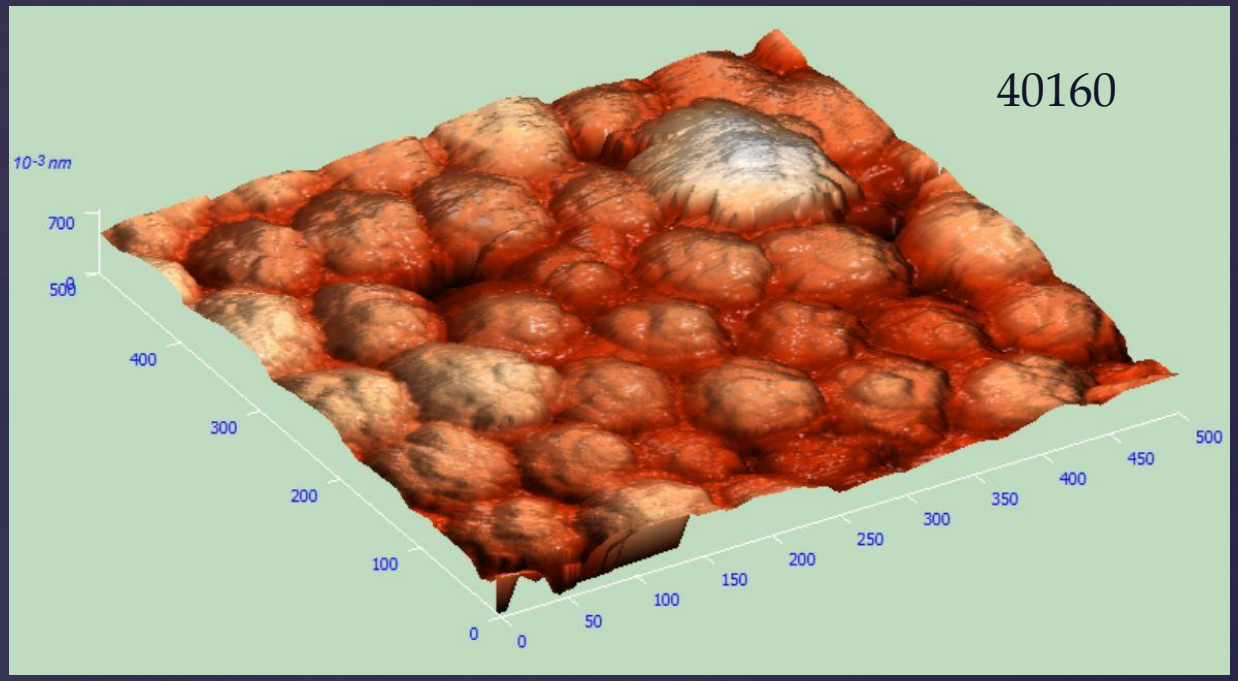


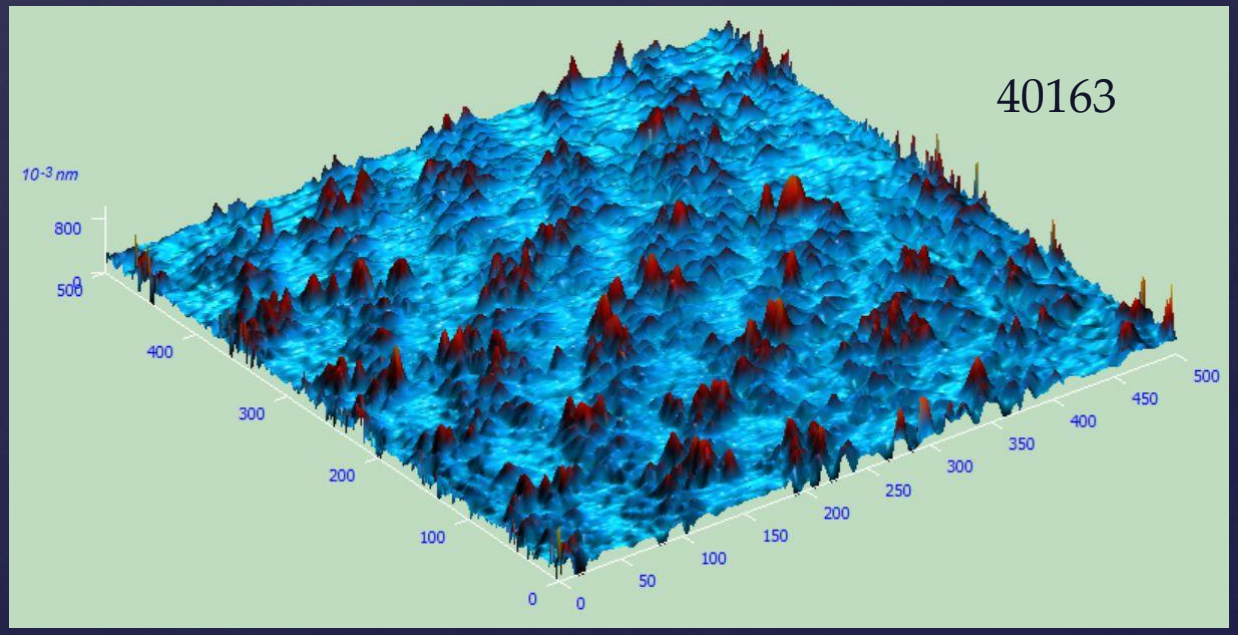


Motivation to use a structured sample:The theoretically predicted interference of electrons, emitted from two independent superconducting islands **(d = 100nm) (boson-like behaviour)**

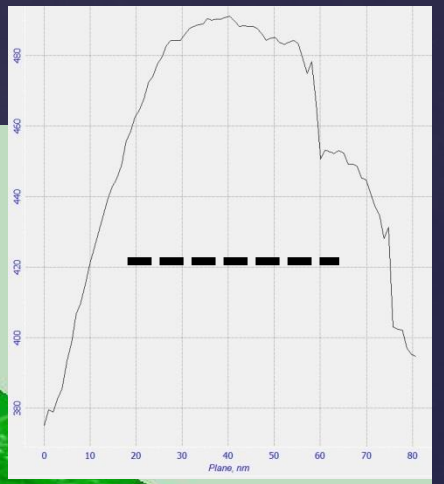


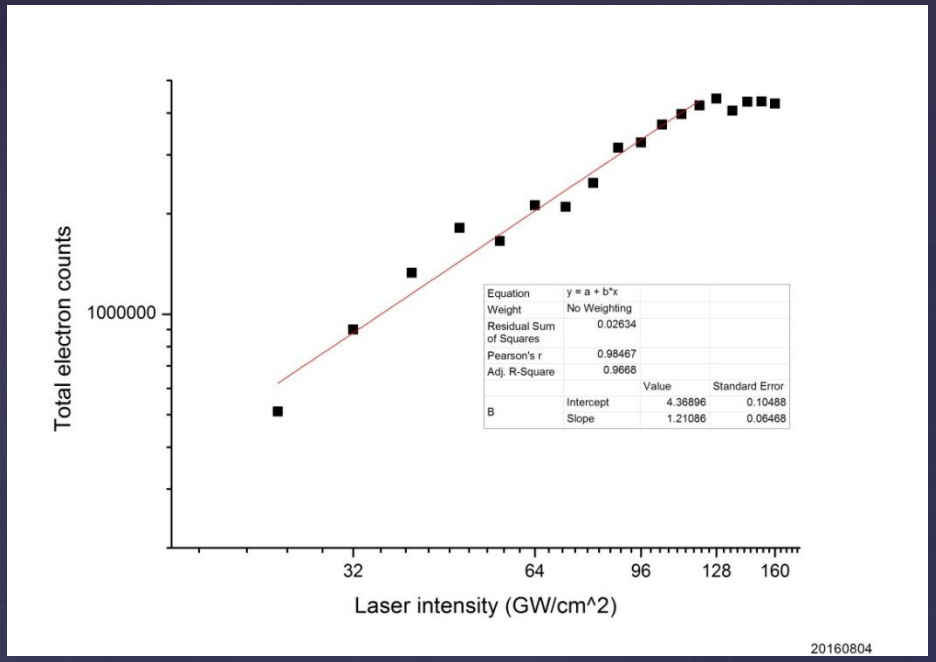
M.Iazzi and K.Yuasa: PhysRevB 81,172501(2010)

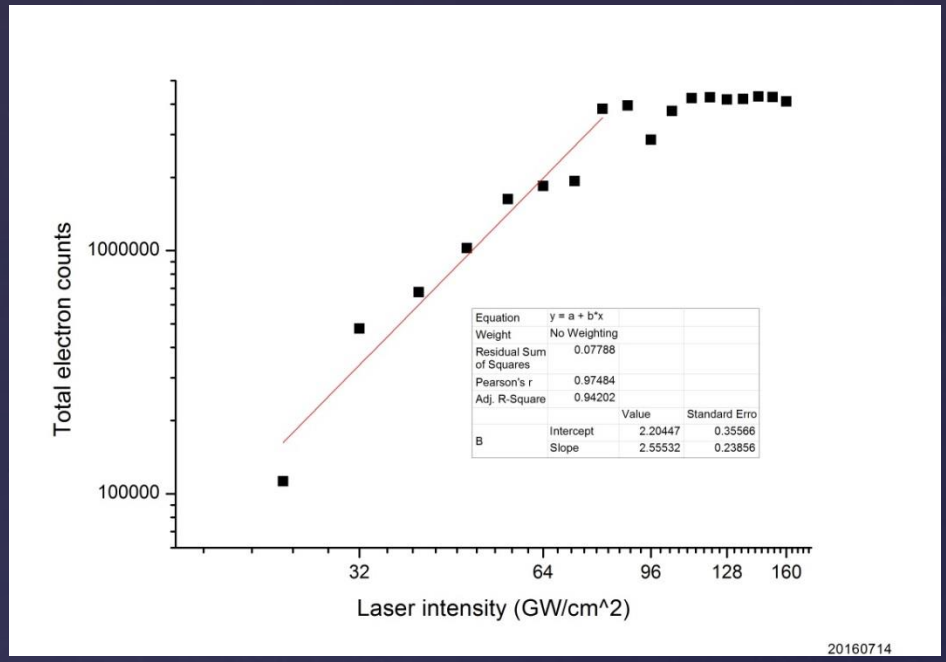


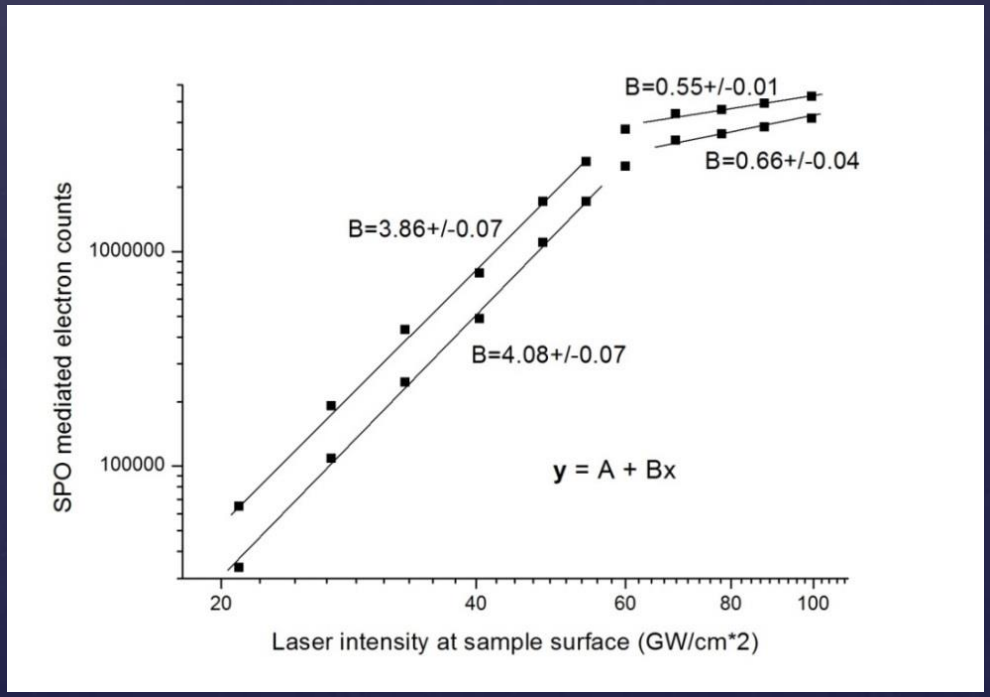


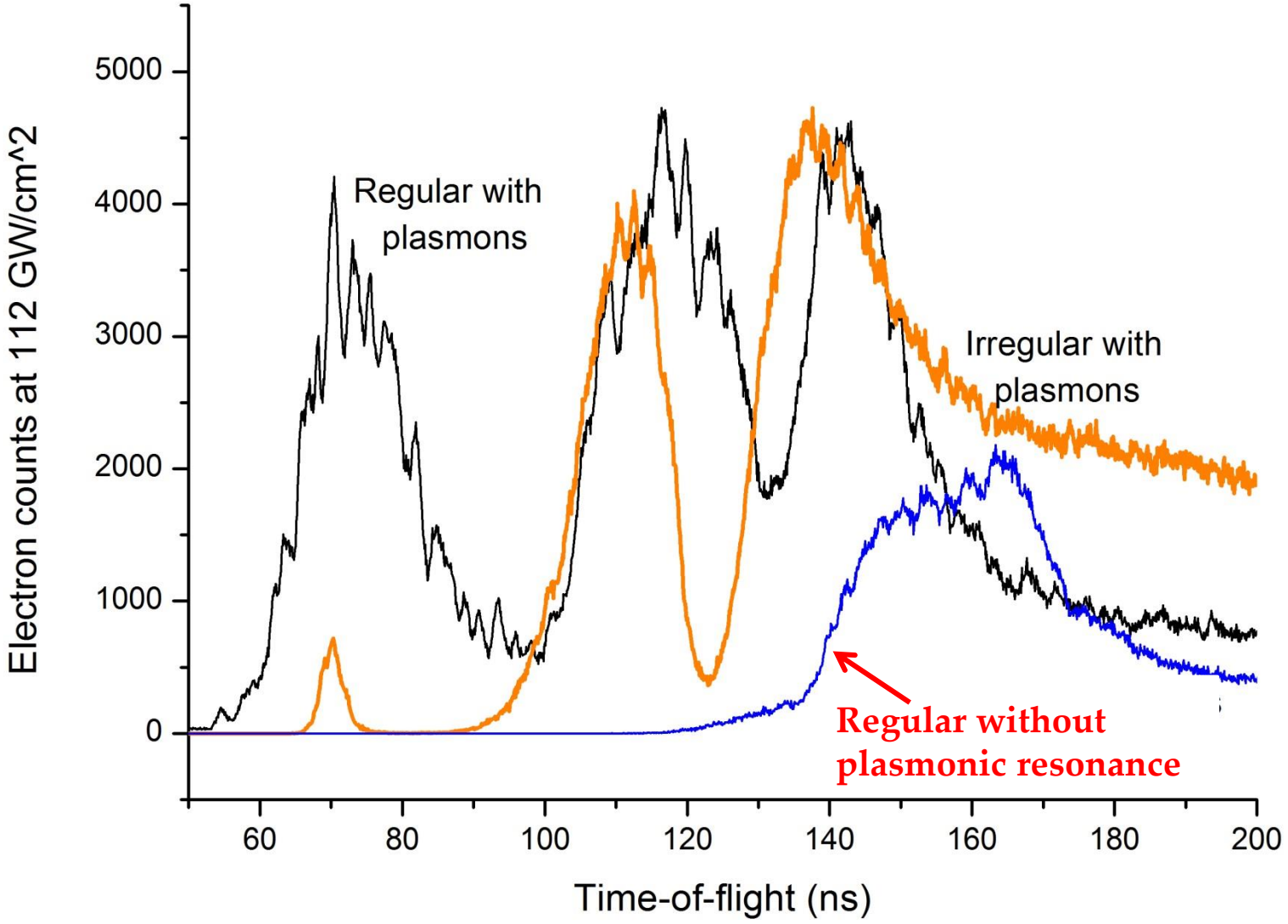
„WHICH WAY" ELECTRON EMISSION



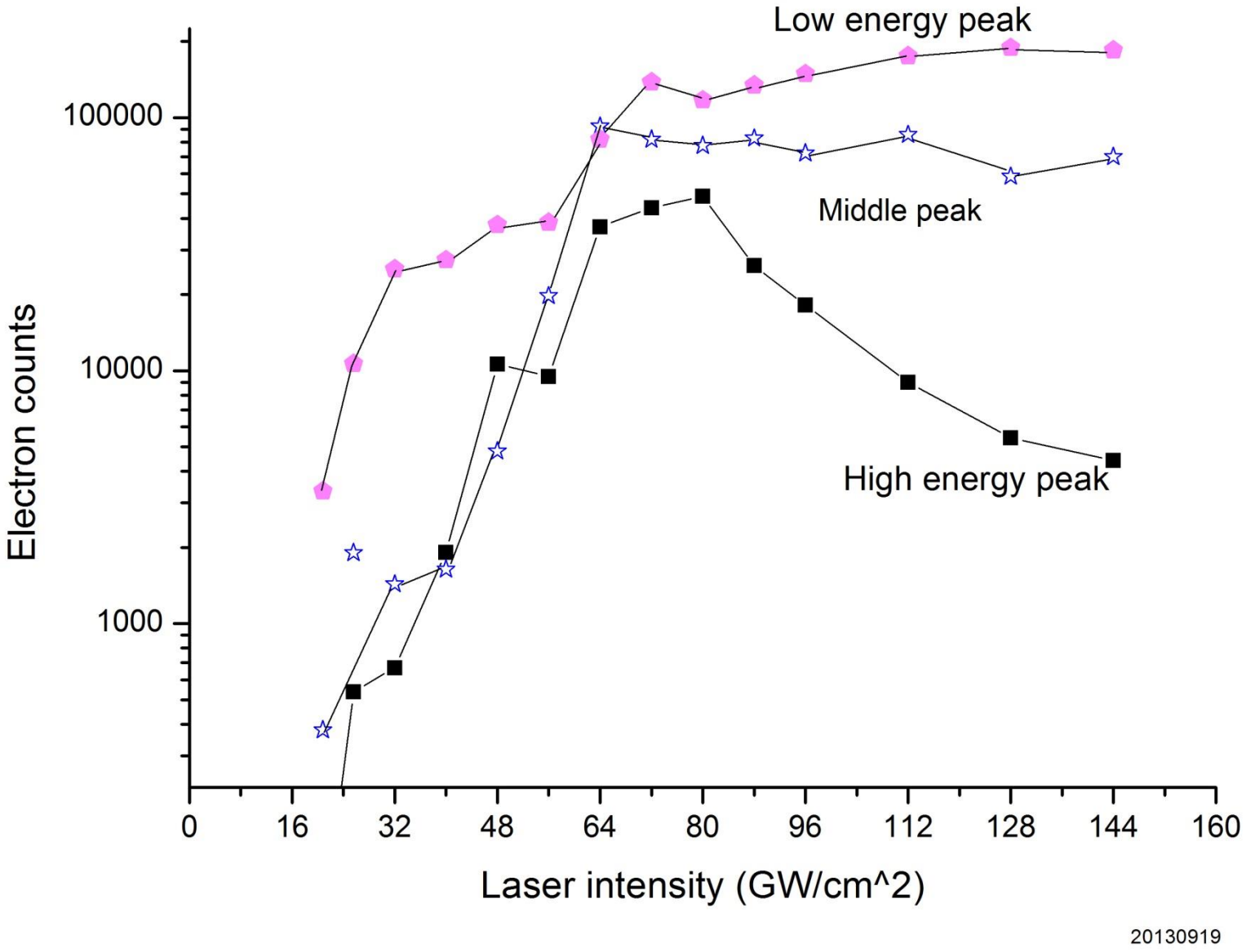

Total electron counts
1000000
32
64
96
128
160
Laser intensity (GW/cm^2)
Equation y = a + b*x
Weight No Weighting
Residual Sum of Squares 0.02634
Pearson's r 0.98467
Adj. R-Square 0.9668
Value Standard Error
B Intercept 4.36896 0.10488
Slope 1.21086 0.06468
20160804

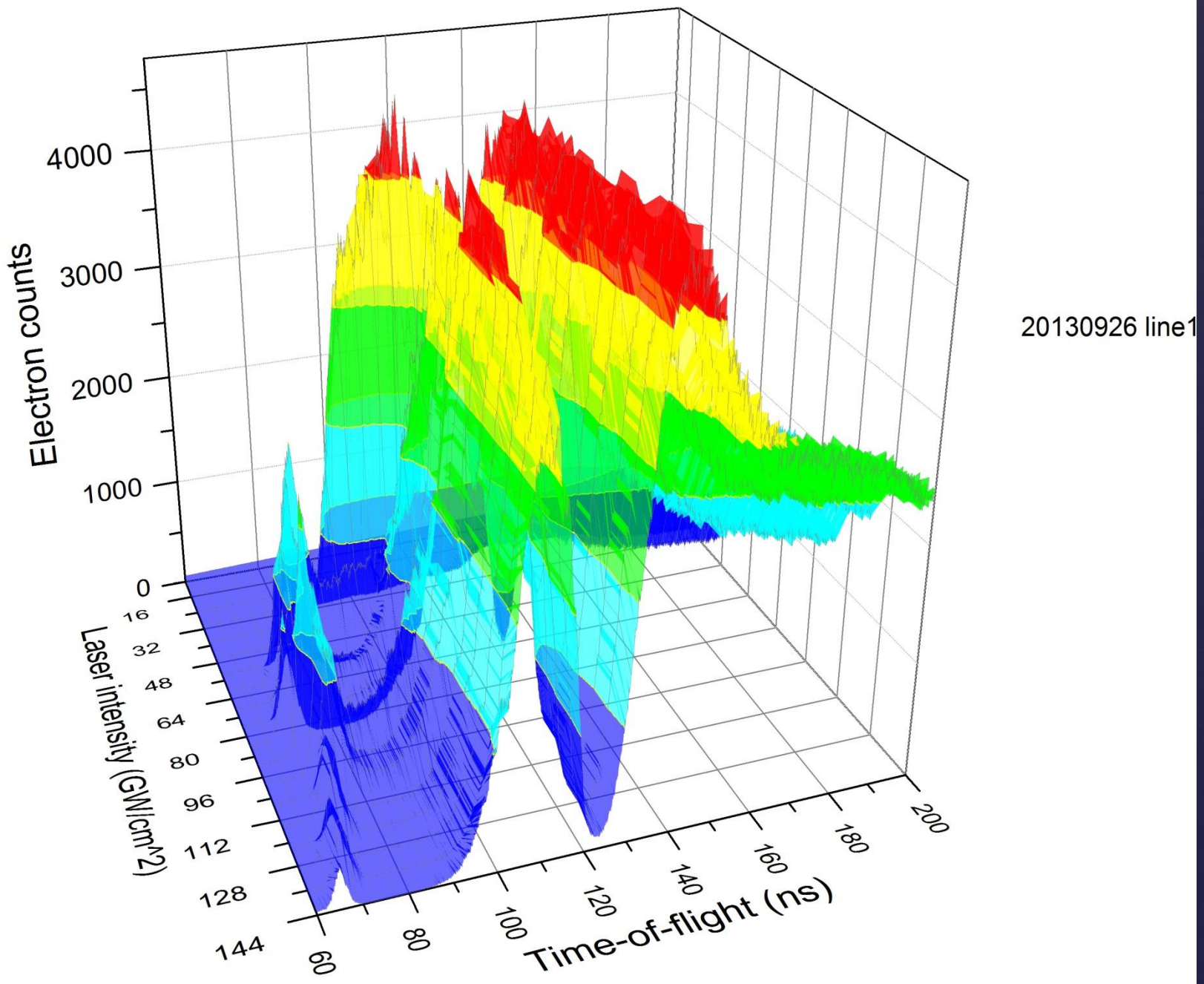

Total electron counts
1000000
100000
32
64
96
128
160
Laser intensity (GW/cm^2)
Equation y = a + b*x
Weight No Weighting
Residual Sum of Squares 0.07788
Pearson's r 0.97484
Adj. R-Square 0.94202
Value Standard Erro
B Intercept 2.20447 0.35566
Slope 2.55532 0.23856
20160714

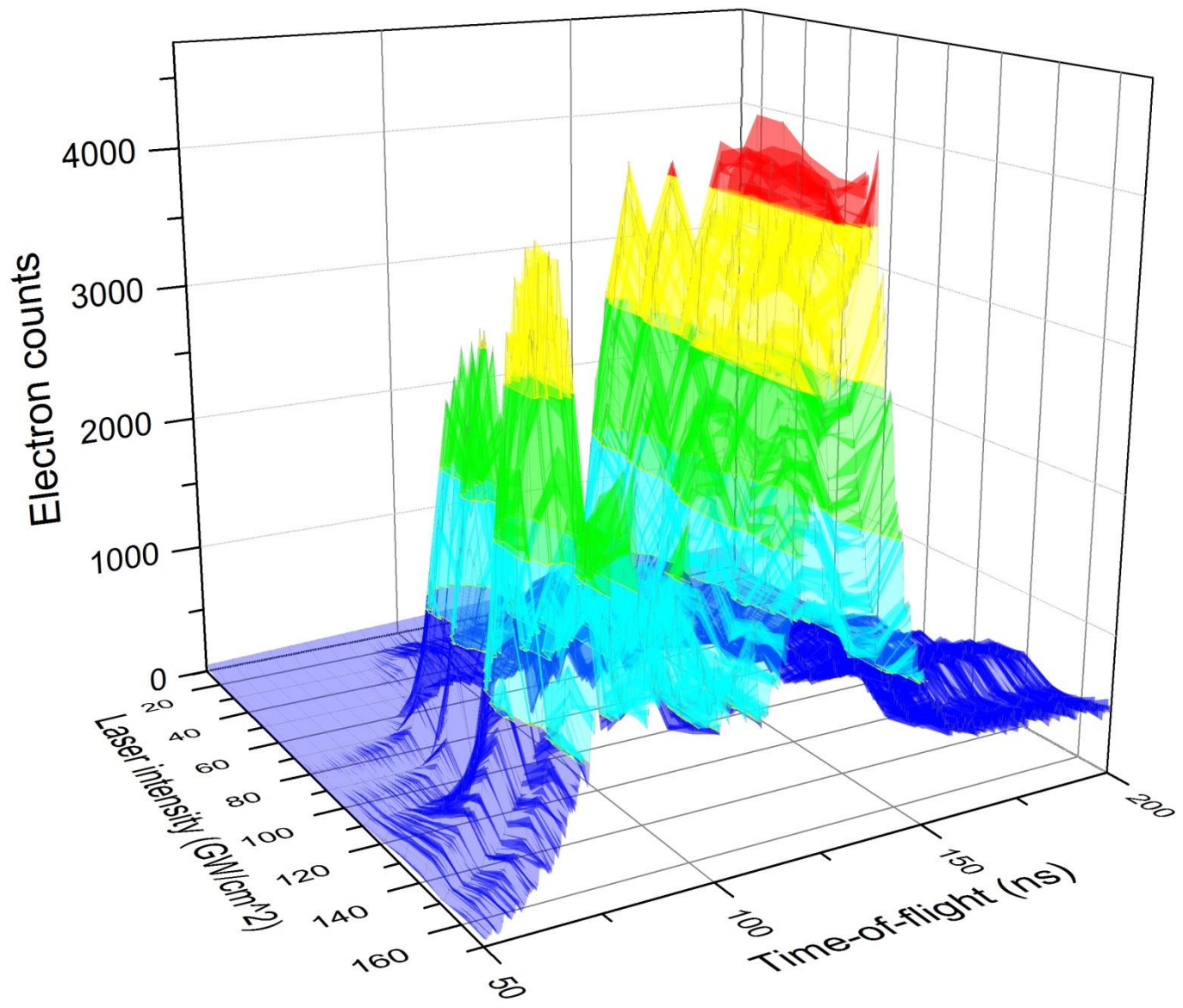

B=0.55+/-0.01
B=0.66+/-0.04
B=3.86+/-0.07
B=4.08+/-0.07
y = A + Bx
SPO mediated electron counts
1000000
100000
20
40
60
80
100
Laser intensity at sample surface (GW/cm*2)

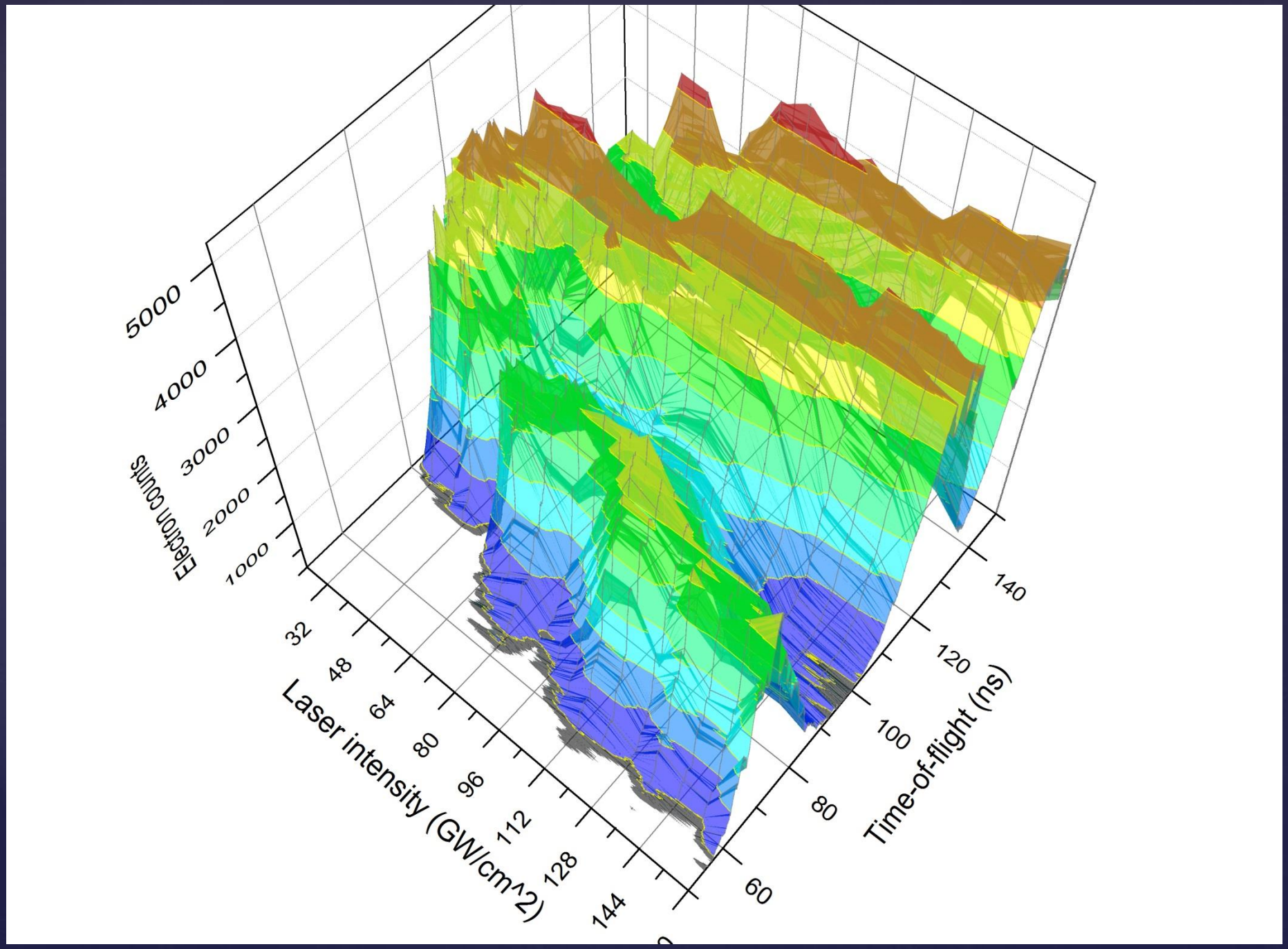


20160831,20130926,20170412

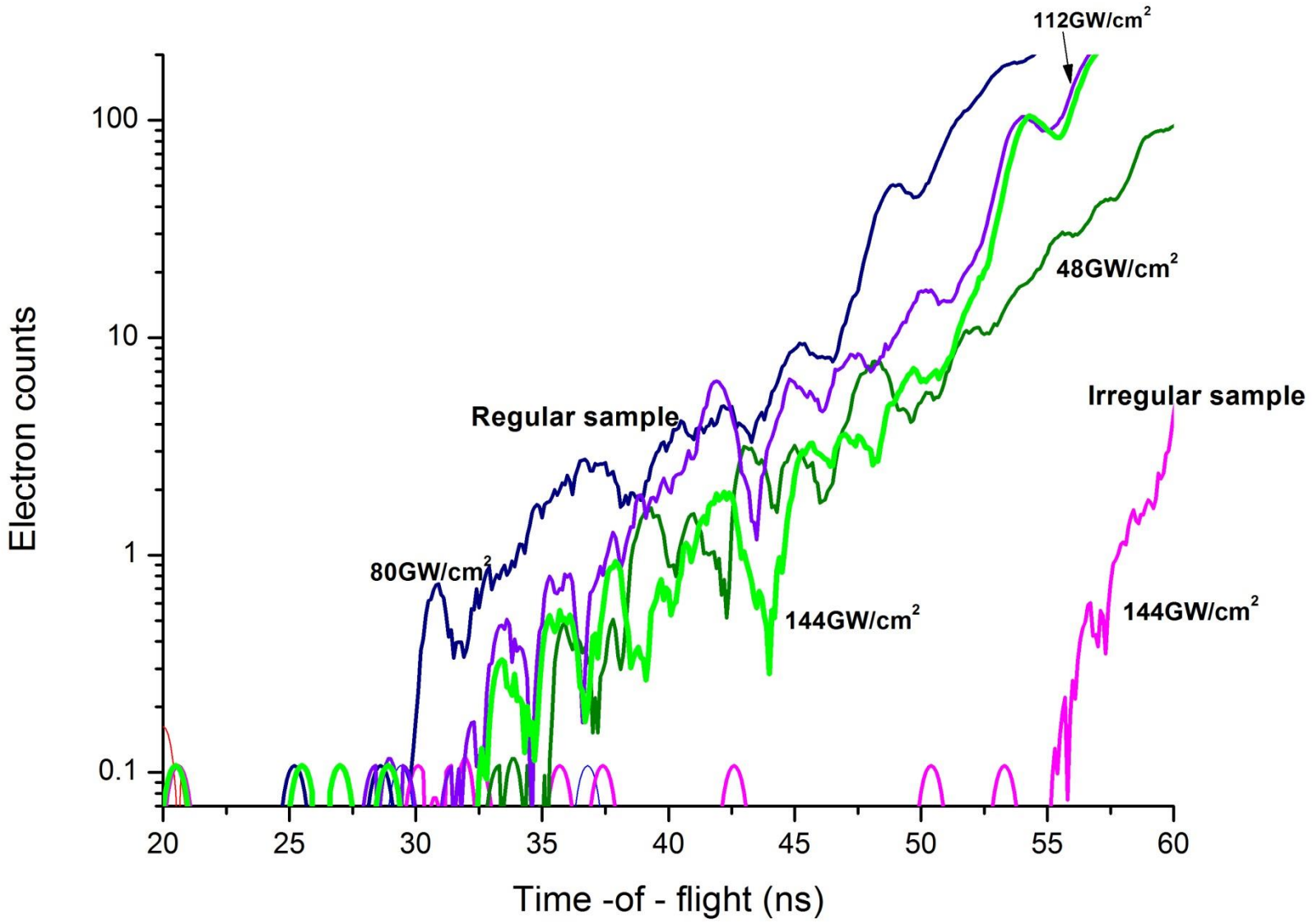

Low energy peak
Middle peak
High energy peak
Electron counts
100000
10000
1000
0
16
32
48
64
80
96
112
128
144
160
Laser intensity (GW/cm^2)
20130919


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

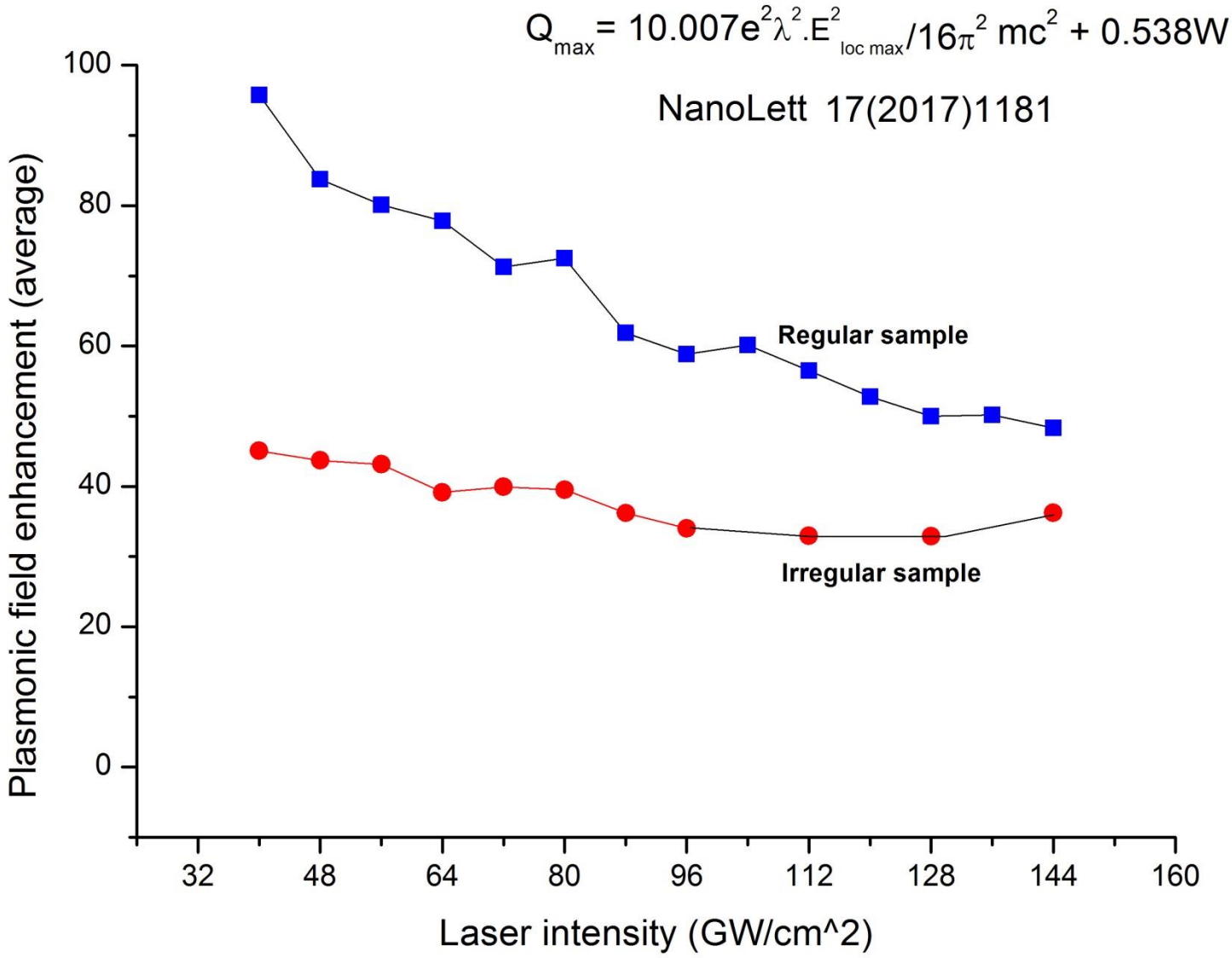

Electron counts
4000
3000
2000
1000
0
Laser intensity (GW/cm^12)
20
40
60
80
100
120
140
160
Time-of-flight (ns)
50
100
150
200

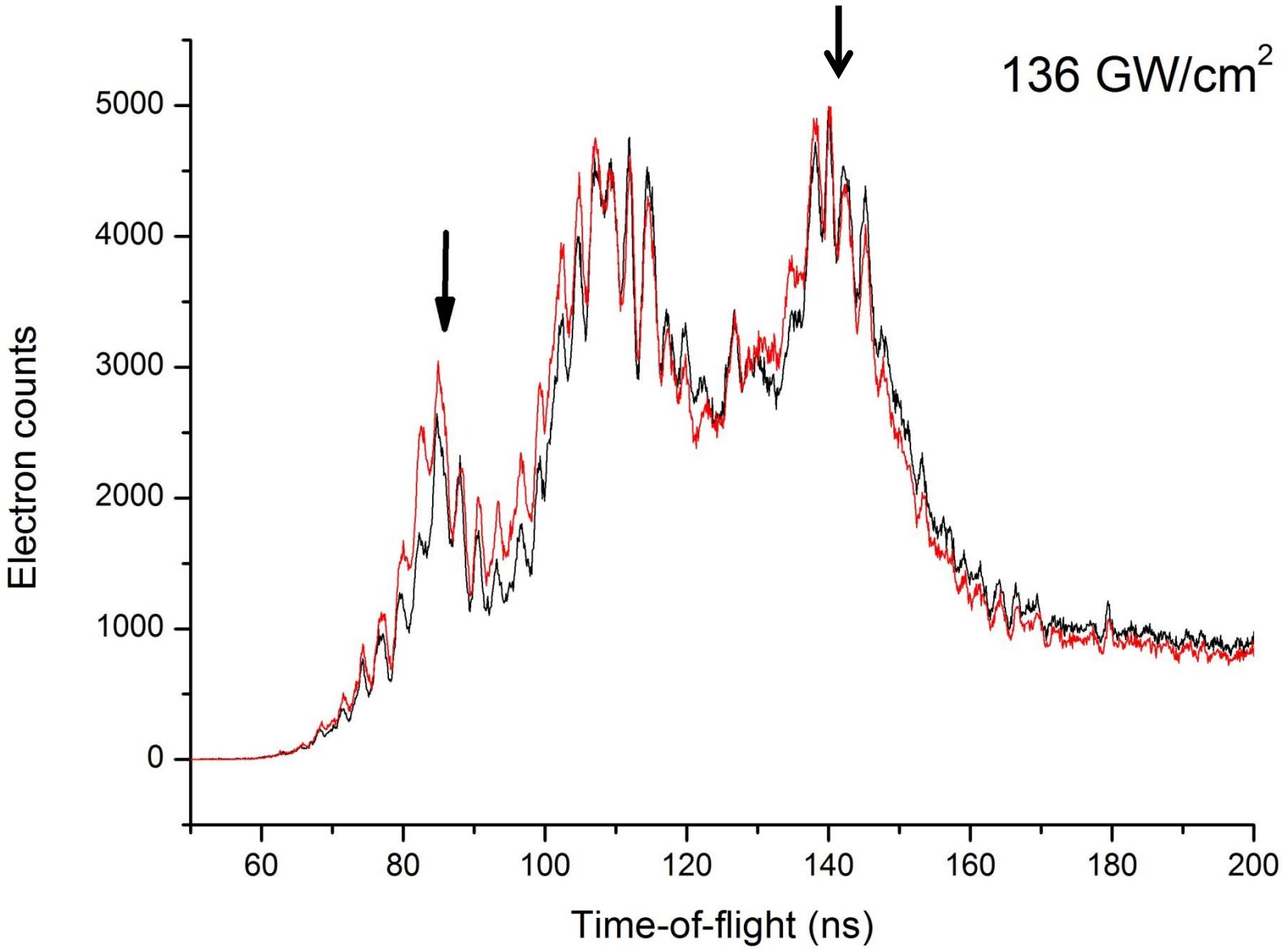

5000
4000
3000
2000
1000
Electron counts
32
48
64
80
96
112
128
144
Laser intensity (GW/cm^2)
60
80
100
120
140
Time-of-flight (ns)

HIGH ENERGY CUT – OFF OF TOF ELECTRON SPECTRA

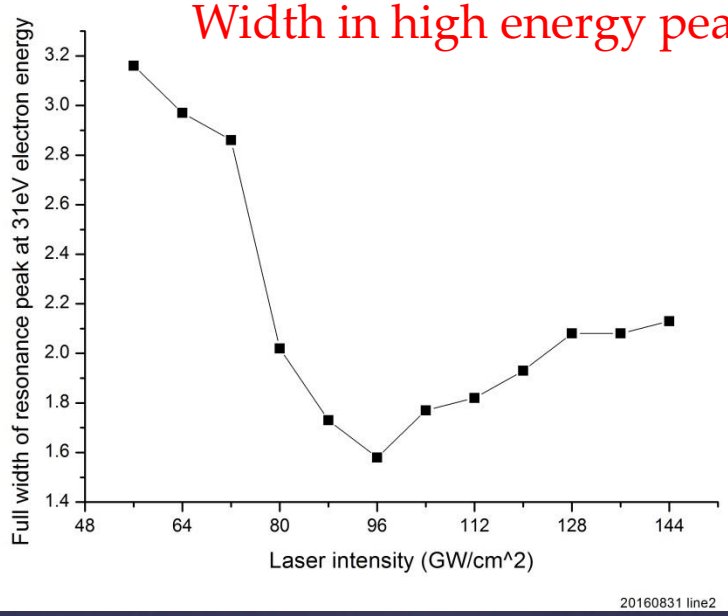


PLASMONIC EM FIELD AMPLIFICATION

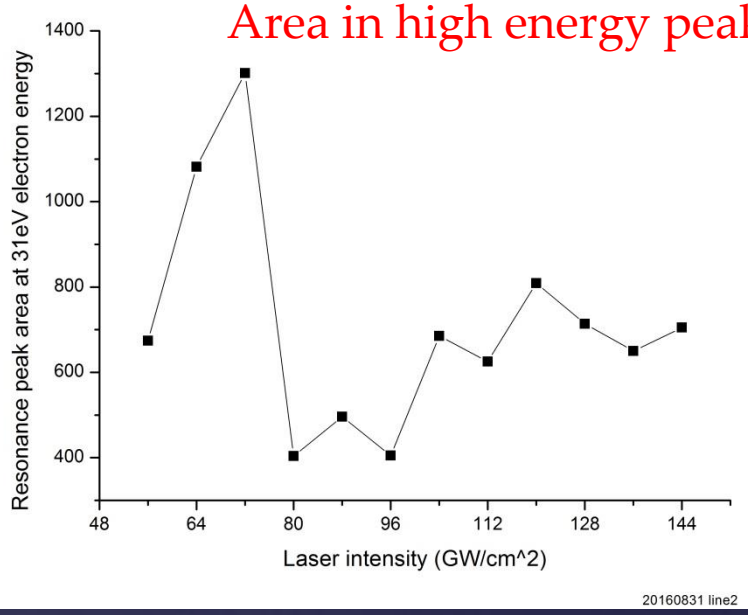



136 GW/cm2
Electron counts
5000
4000
3000
2000
1000
0
60
80
100
120
140
160
180
200
Time-of-flight (ns)

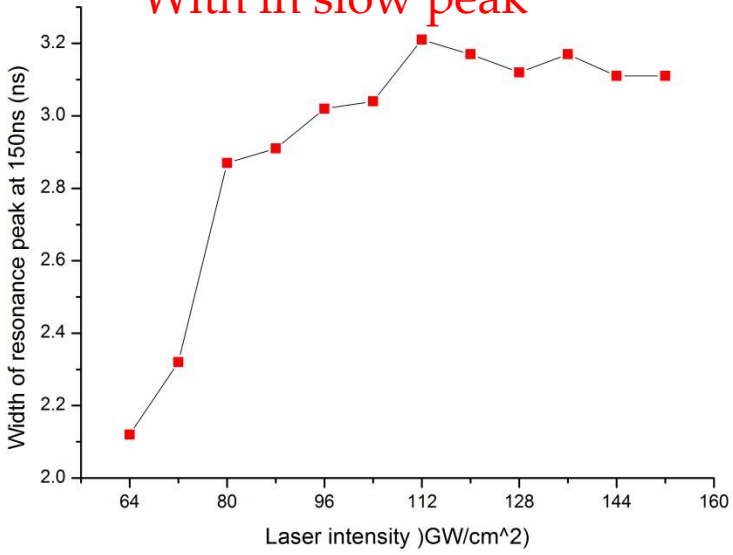
Width in high energy peak



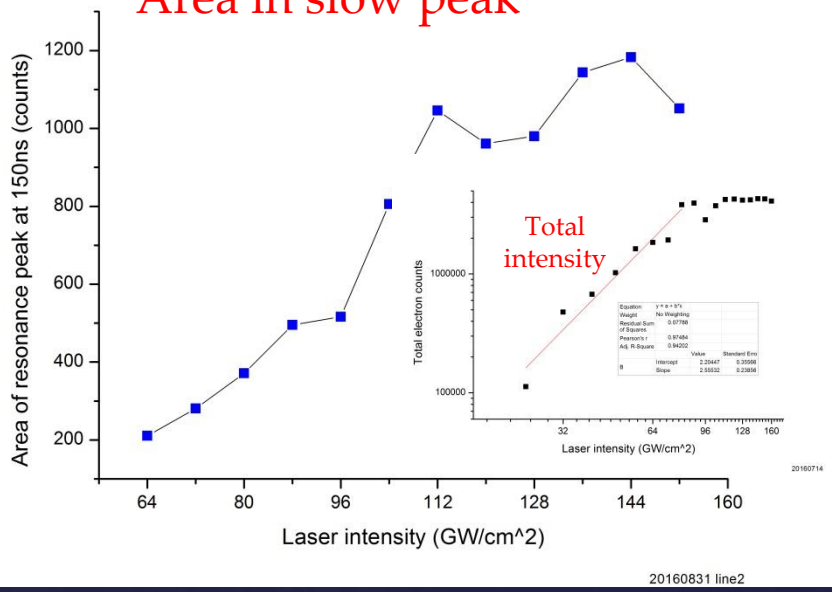
Area in high energy peak



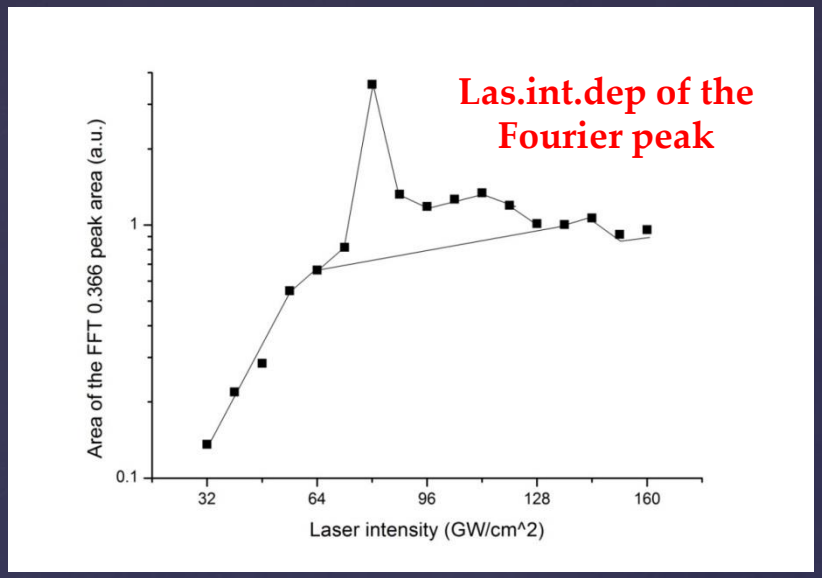
With in slow peak



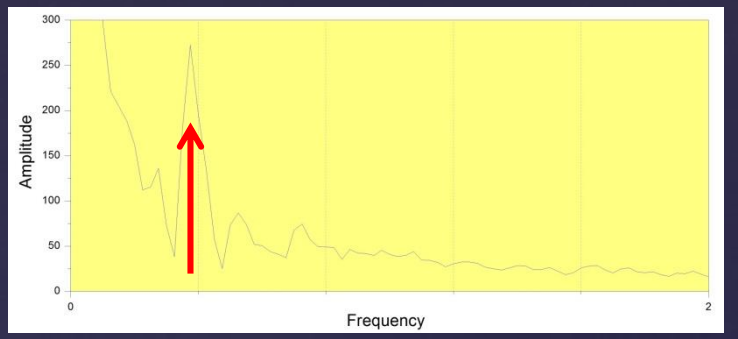
Area in slow peak



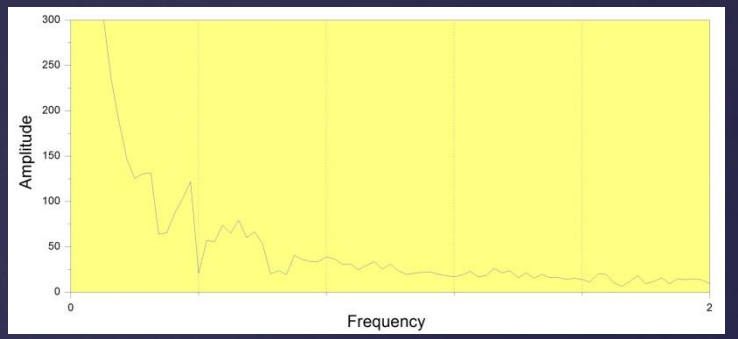
Regular sample FFT

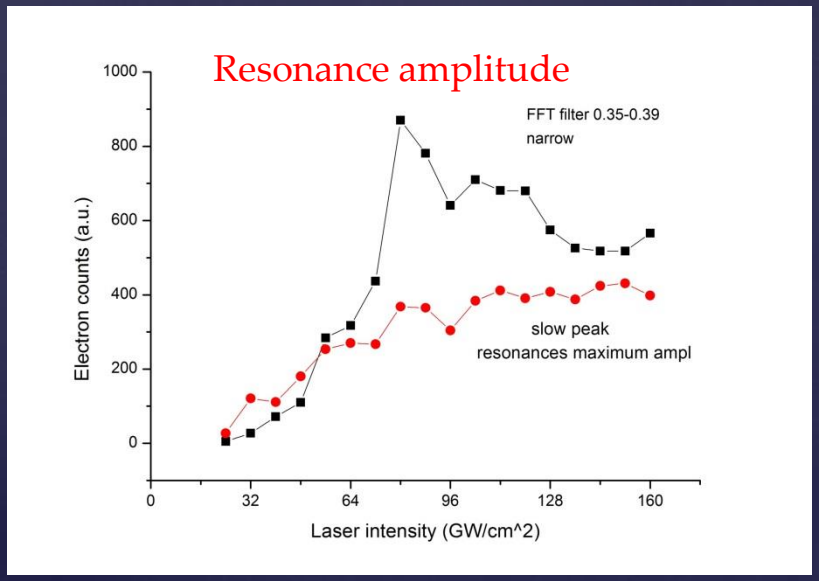


Fast

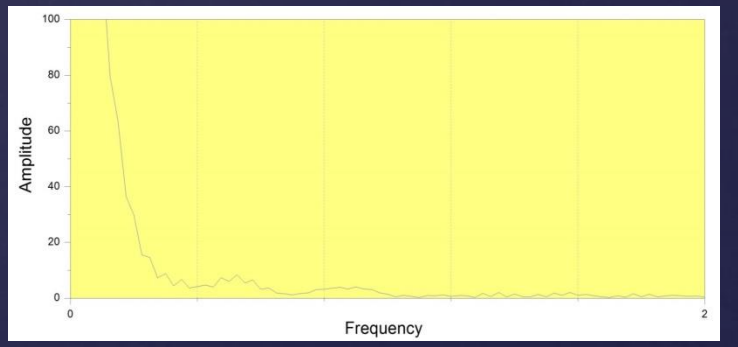


Slow

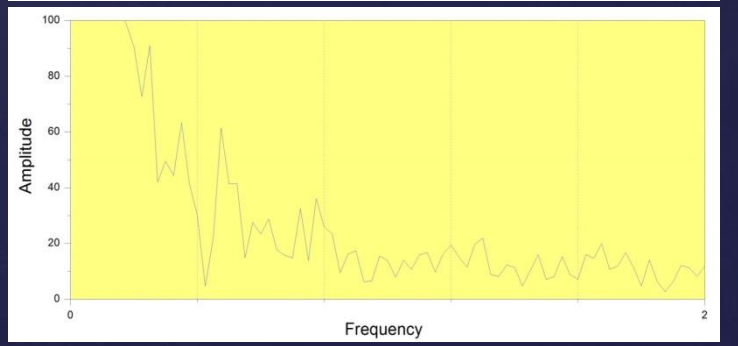




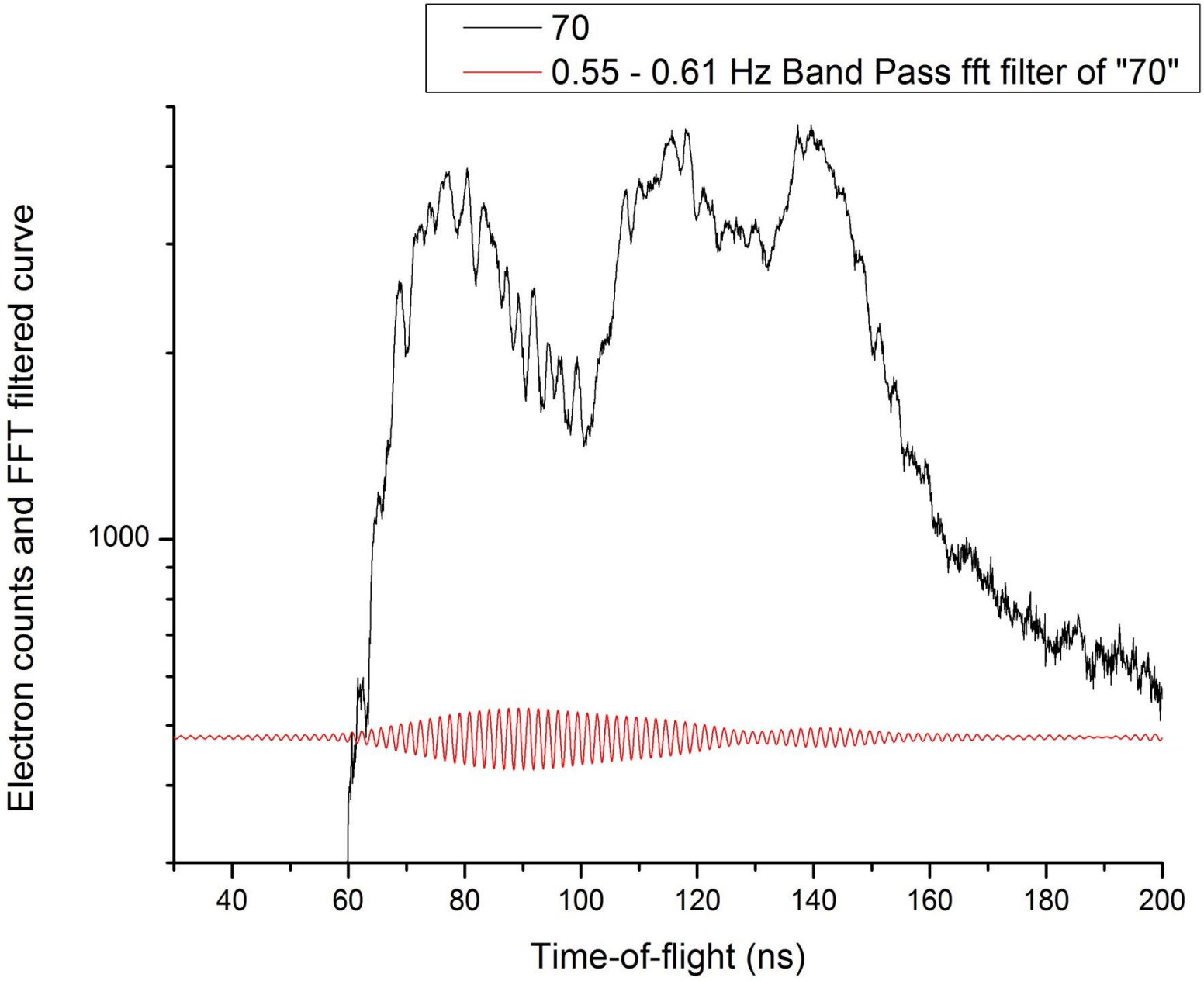
Fast

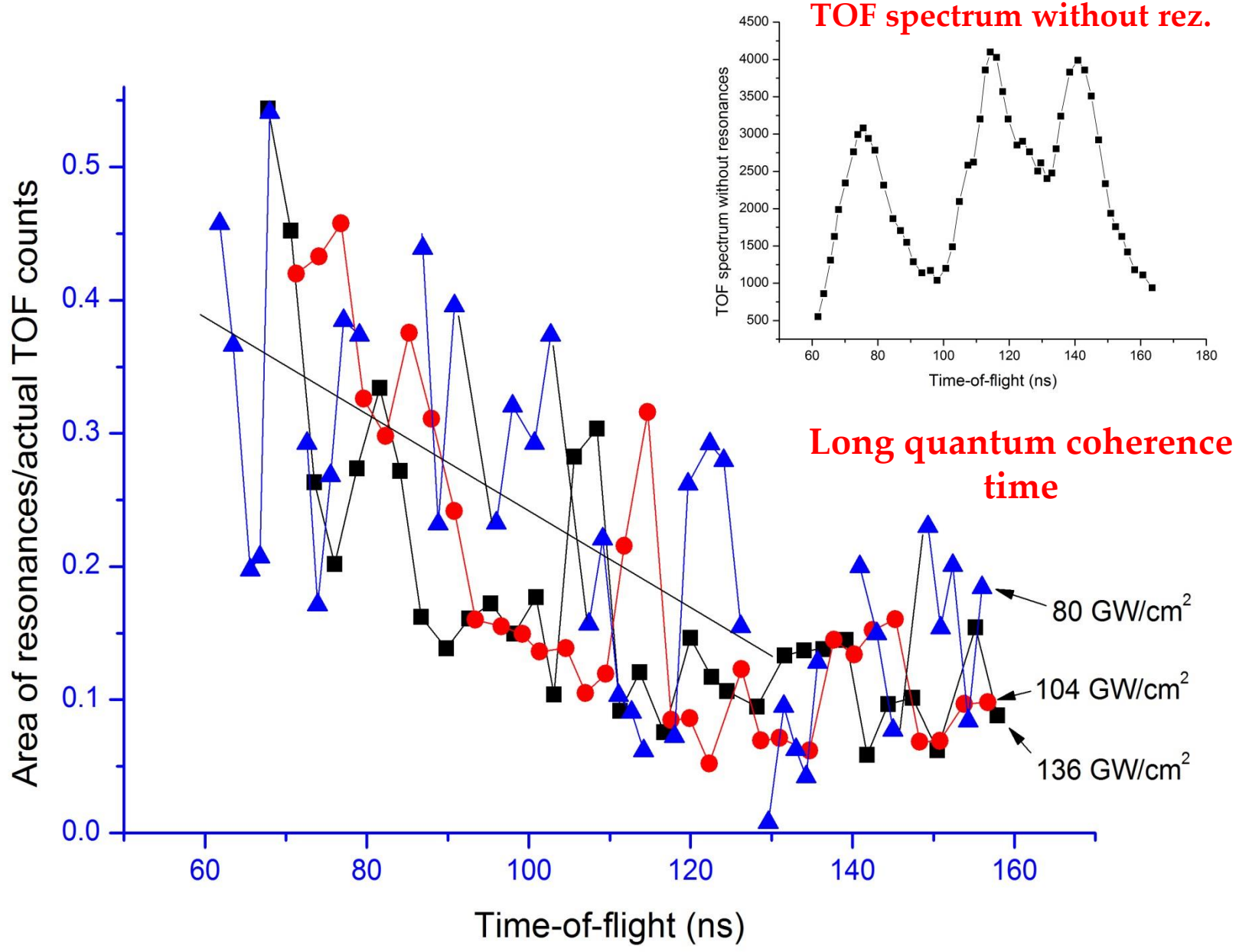


Slow

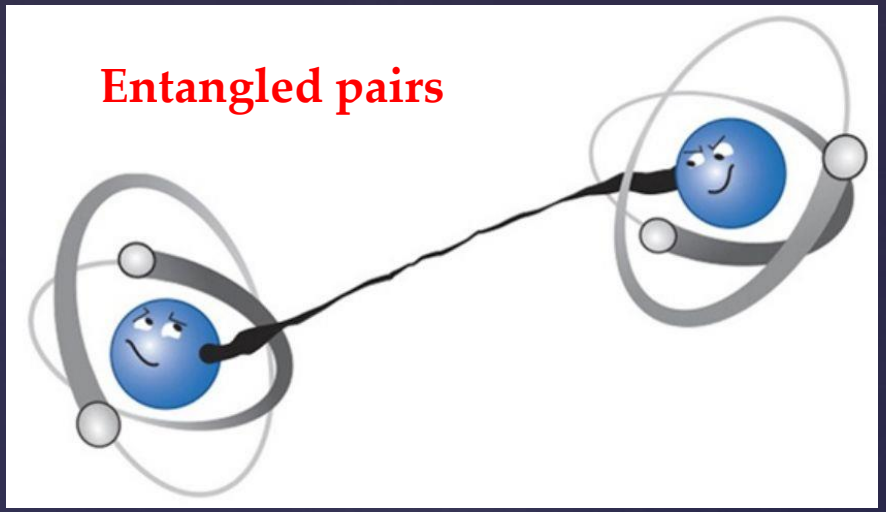


Irregular sample FFT


70
0.55 - 0.61 Hz Band Pass fft filter of "70"
Electron counts and FFT filtered curve
1000
40
60
80
100
120
140
160
180
200
Time-of-flight (ns)


TOF spectrum without rez.
TOF spectrum without resonances
Time-of-flight (ns)
Long quantum coherence time
Area of resonances/actual TOF counts
Time-of-flight (ns)
80 GW/cm2
104 GW/cm2
136 GW/cm2

CONCLUSIONS



„Smooth" sample
Electron pairing and
ideal diamagnetism
Structured sample
Electron pairing (more electrons and broader)
Increased SPP field amplification. Lower work function.
A sequence of narrow resonances in the total TOF spectrum but different parameters (field dependent position, width and area) in the high energy peak than in the remaining part of the spectrum. Long lasting quantum coherence!
These differences in the resonance parameters thought to be explained by the interference (which way) of electrons, entangled with their pairs („boson like" behaviour) but **fermionic** properties of electrons in the slow peak
(as for „non-Cooper"electrons of Iazzi and Yuasa)

THANKS FOR YOUR ATTENTION!