High Field Plasmonics

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Pisa, 22/10/2014

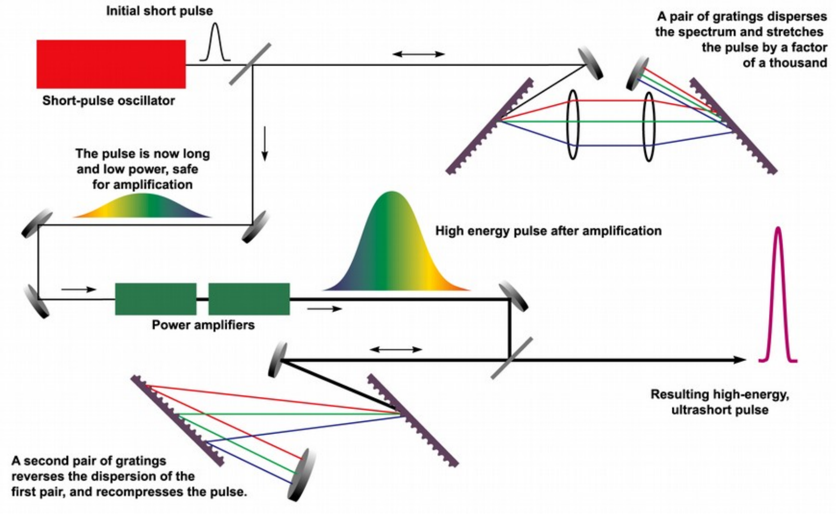
Supervisor: Dr. A.Macchi

Introduction

High Field Plasmonics

Ultra-high intensity laser-matter interaction

Laser systems



Peak power up to 1 PW (10 PW foreseen in the near future)

Intensity up to 10^{22} W/cm^2

Pulse duration of 10s fs

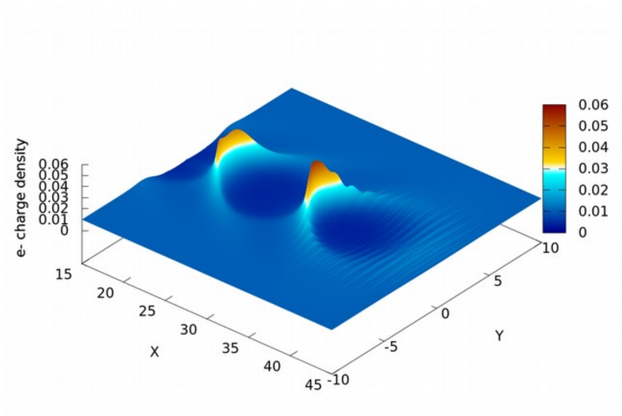
Pulse contrast of $10^{12} – 10^{9}$

Pulse waist of few µm

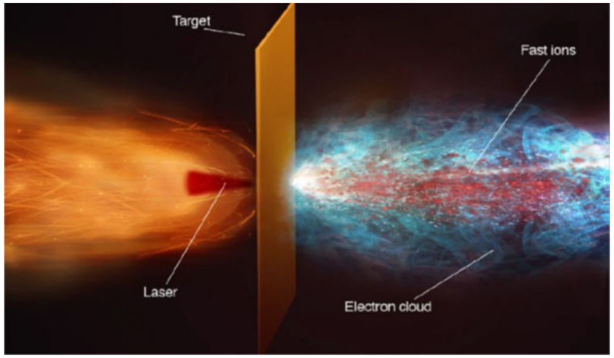
High Field Plasmonics

Ultra-high intensity laser-matter interaction

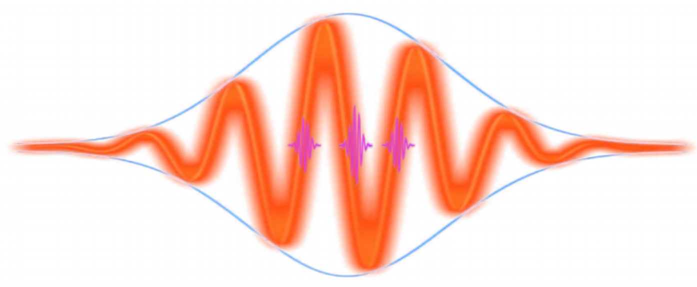
Applications



Electron acceleration, secondary X-ray sources...



Ion acceleration



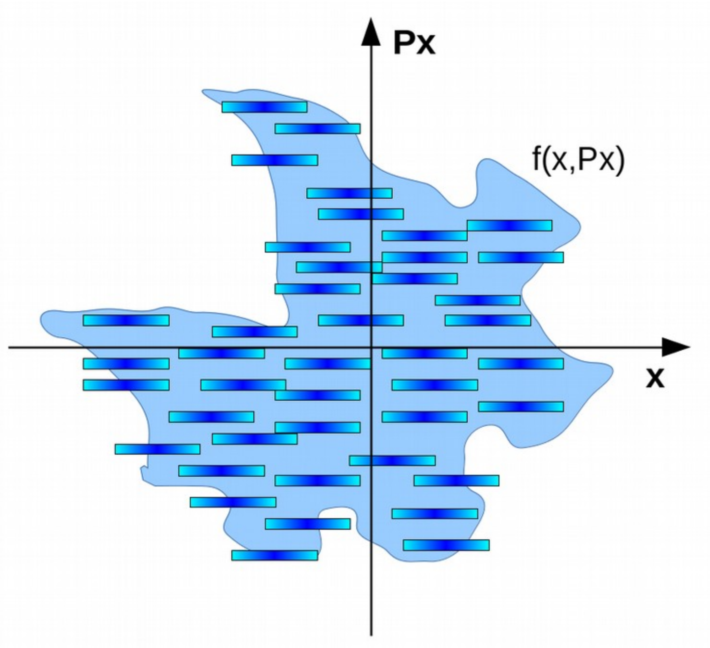
High Harmonic Generation, attoscience...

Numerical tools

Particle in Cell Simulations

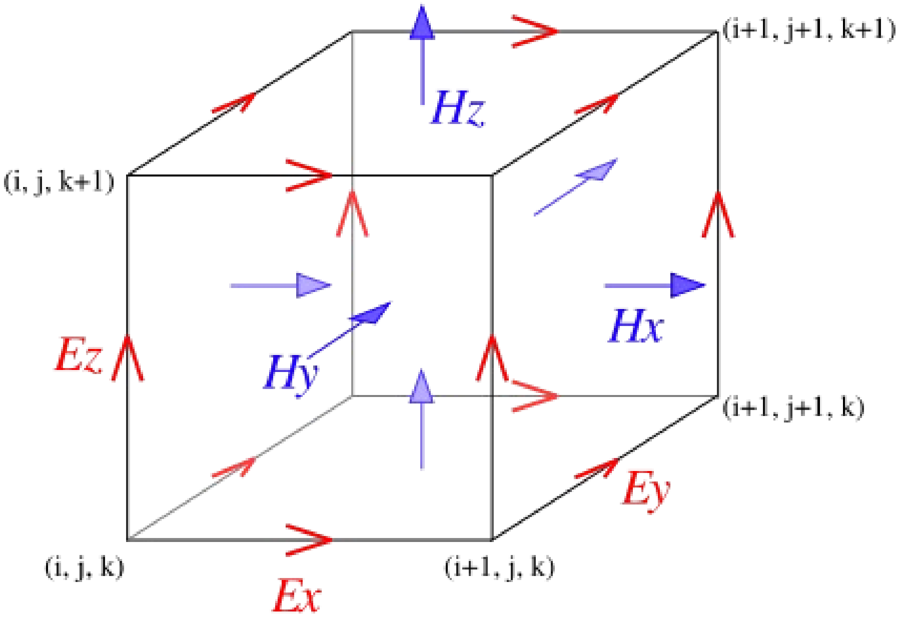
Vlasov equation (+Maxwell eq.) $\partial_t f + v_x \cdot \nabla_x f + q\left(\vec{E} + \frac{\vec{v}}{c} \times \vec{B}\right) \cdot \nabla_{px} f = 0$

Macroparticles



$$f(x, Px, t) = \sum_i S(x_i(t), x)\,\delta(Px - Px_i(t))$$

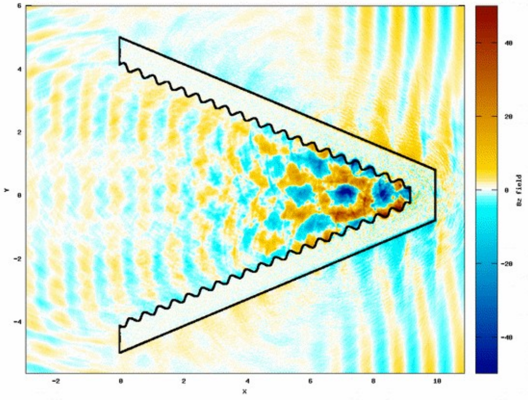
EM fields on a grid

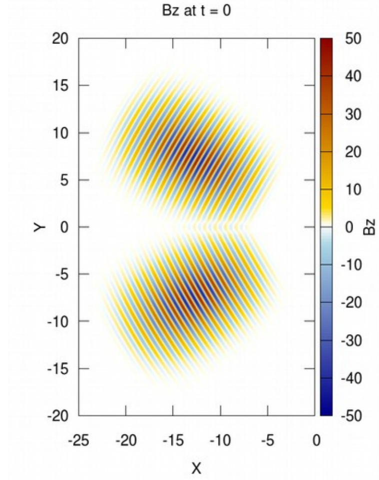


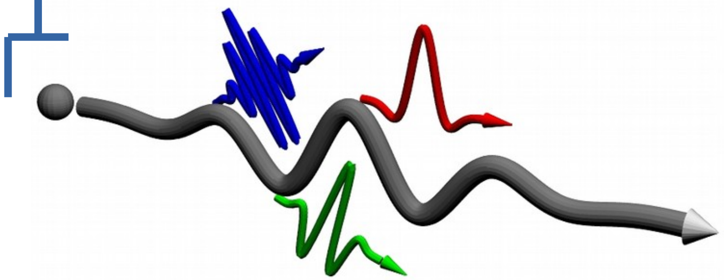
High Field Plasmonics

piccante

- Fully relativistic 3D PIC code
- Open source (GPLv3 license)
  https://github.com/ALaDyn/piccante
- Complex target geometries
- Multiple laser pulses
- Radiation friction effects
- Massively parallel







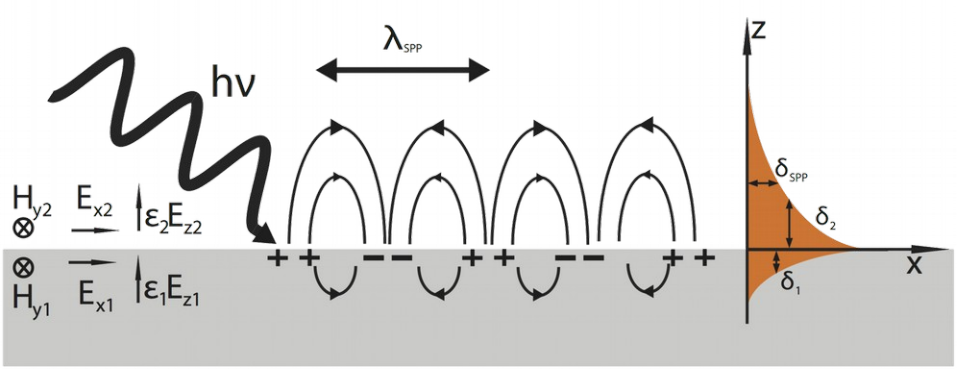
piccante is maintained by
A.Sgattoni, L.Fedeli, S.Sinigardi, A.Marocchino

High Field Plasmonics

High Field Plasmonics

Surface Plasmon Polaritons

Collective e- excitations
at the surface of a metal
or a plasma



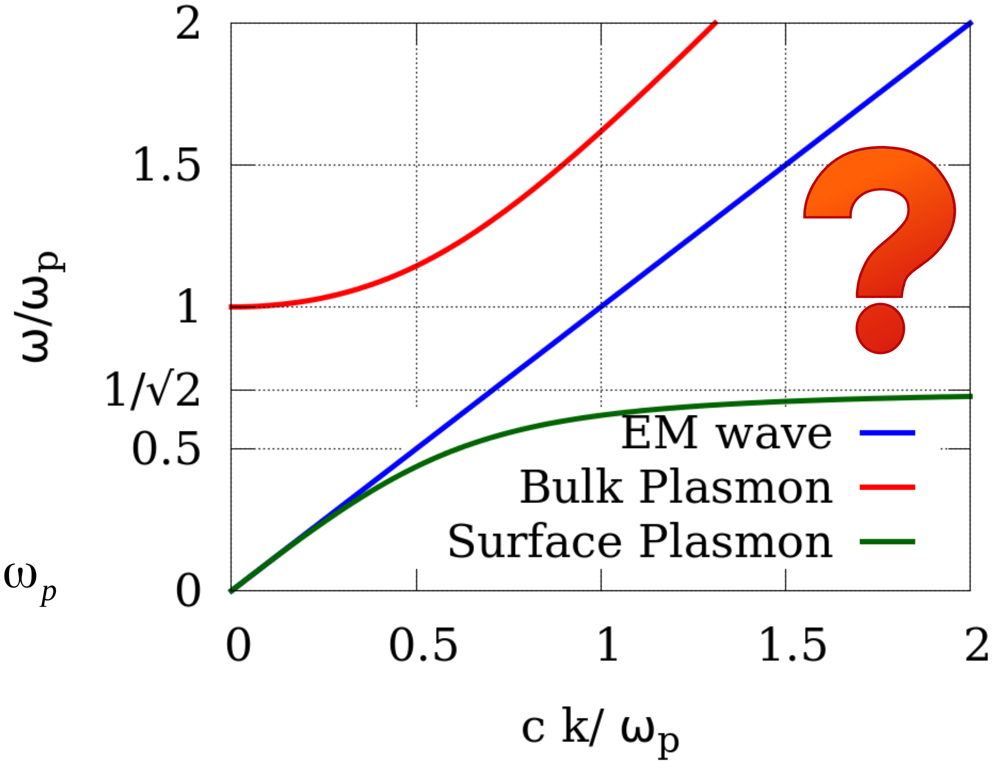
Dispersion relation

$$k_{SPP}(\omega)=\frac{\omega}{c}\sqrt{\frac{1-\omega_p^2/\omega^2}{2-\omega_p^2/\omega^2}}$$

EM-SPP coupling?

$\frac{\omega}{c}\sin(\theta)=k_{SPP}(\omega)$ no solution if $\omega<\omega_p$

Several coupling schemes exist



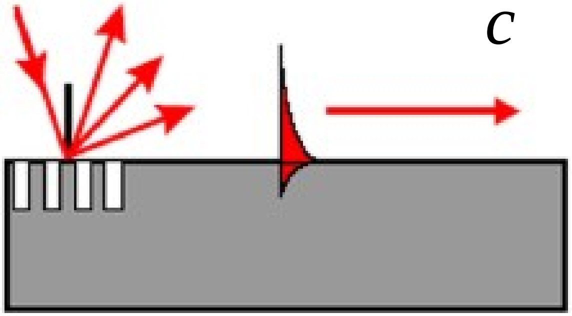
High Field Plasmonics

SPP in high intensity laser-plasma interaction

Target is ionized in one laser cycle (no dielectrics)

EM-SPP coupling
with gratings

$$\frac{\omega}{c}\sin(\theta)=k_{SPP}(\omega)\pm n\frac{2\pi}{d}$$



Relativistic regime (MeV e- in one laser cycle)

No complete theory exists in the literature for relativistic Surface Plasmon Polaritons

High Field Plasmonics

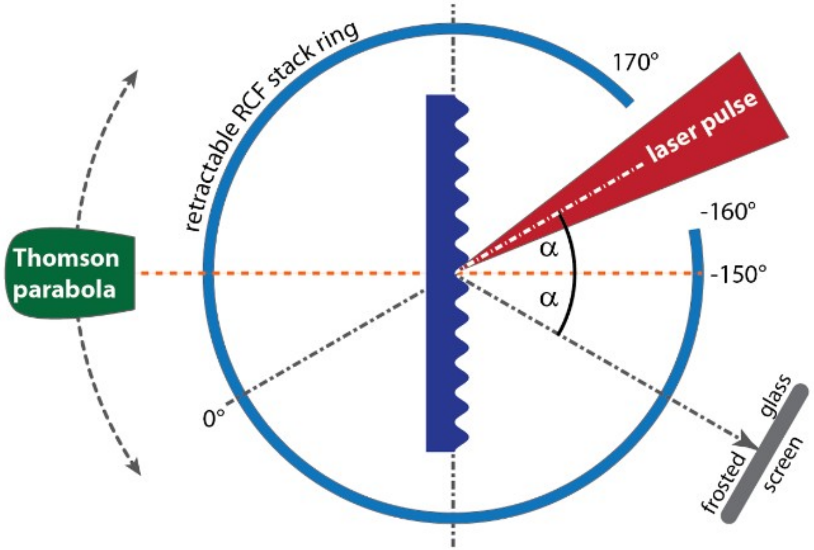
High field plasmonics: enhanced laser-plasma coupling with structured targets

High Field Plasmonics

Introduction

PRL **111,** 185001 (2013) PHYSICAL REVIEW LETTERS week ending 1 NOVEMBER 2013

Evidence of Resonant Surface-Wave Excitation in the Relativistic Regime through Measurements of Proton Acceleration from Grating Targets



- Exp. performed at CEA-Saclay
- Mylar flat foils and grating targets (30° resonance) were tested
- Enhancement in ion cut-off energy and laser absorption for gratings at resonance
- Good agreement between exp. and simulations

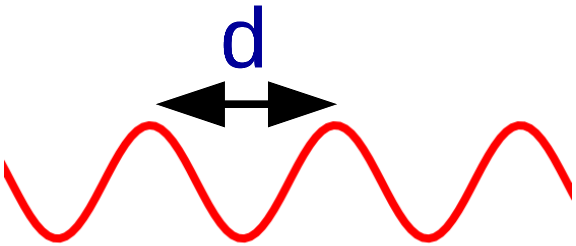
High Field Plasmonics

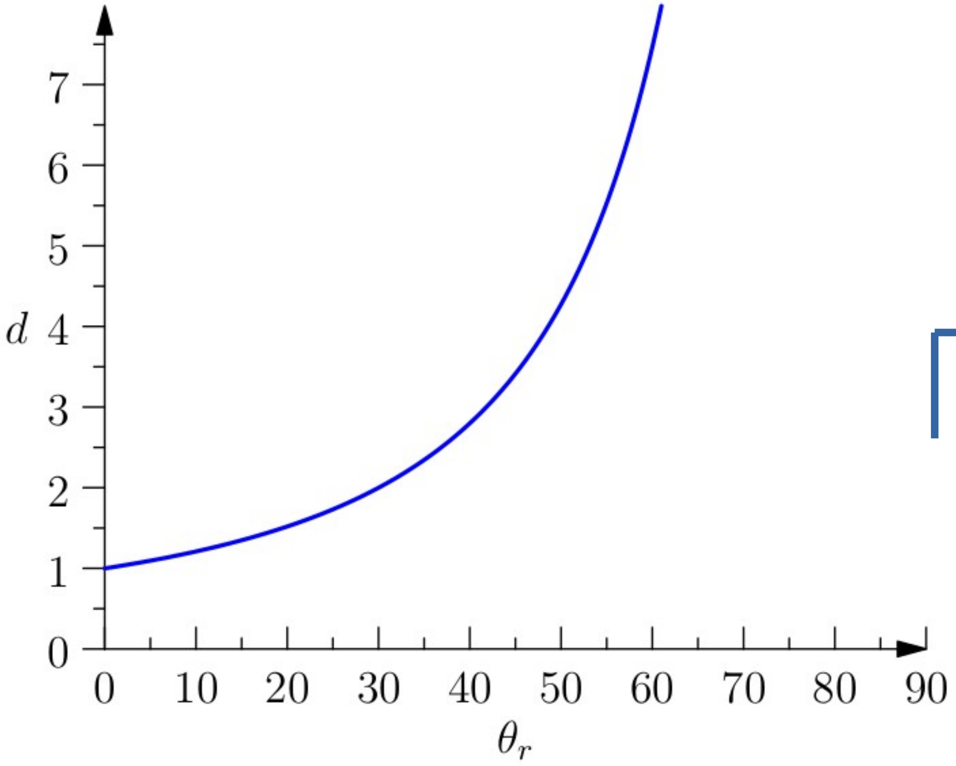
New simulation campaign

All the simulations perfomed at FERMI-CINECA with piccante

Parametric scan to find better targets

$$\frac{d}{\lambda}=\frac{1}{1-\sin(\theta_r)}$$





θ_r	d/λ
0	1
10°	1.210
20°	1.520
30°	2
45°	3.414

Parameters

Laser

$a_0 = 5$, $t = 12.0\ \lambda/c$,

$w_0 = 5\ \lambda$

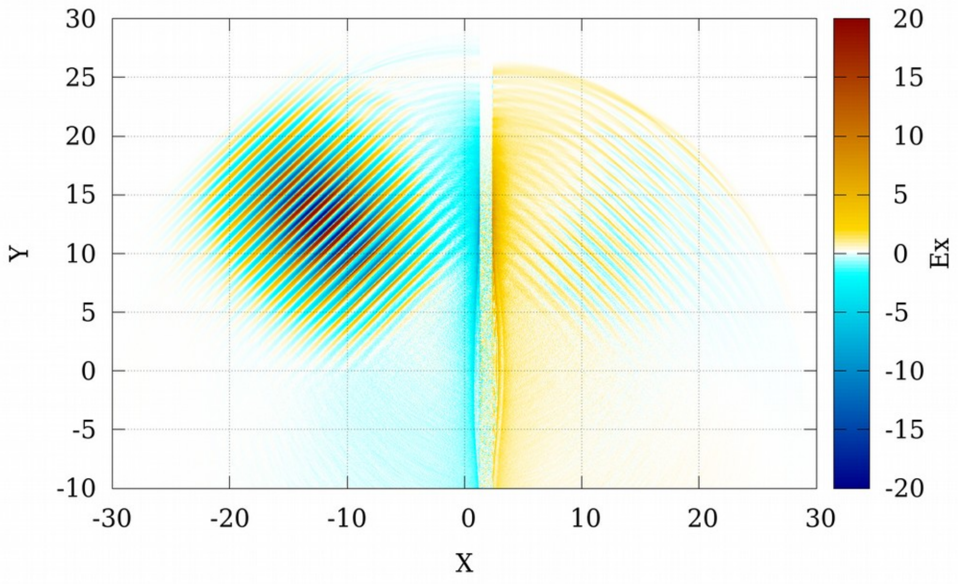
Target

$n = 120\ n_c$, $l = 1\ \lambda$

High Field Plasmonics

Simulation results

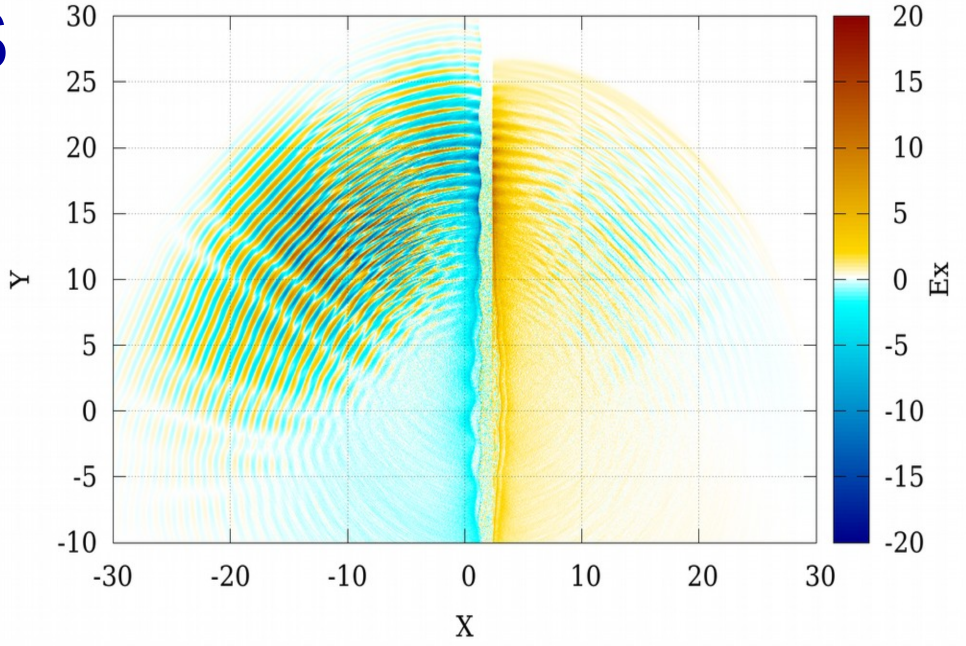
All the simulations
perfomed at FERMI-CINECA with piccante



Flat target
45° pulse incidence

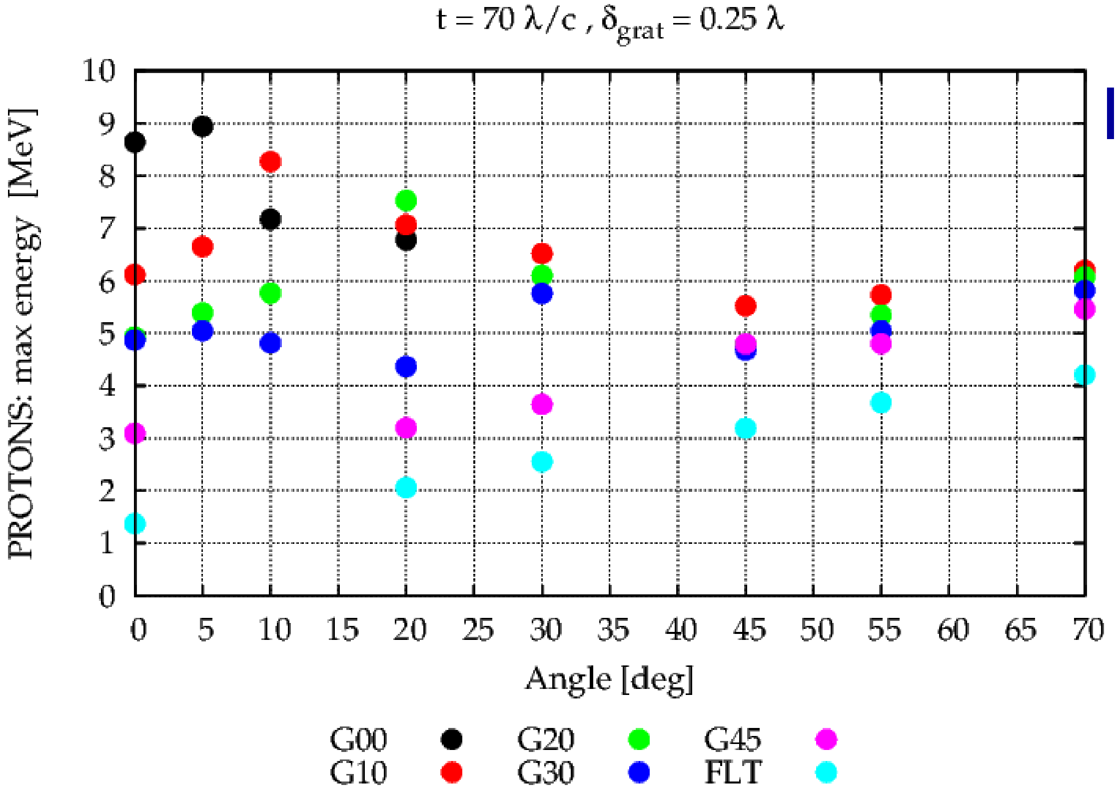
VS

Grating target (45° resonance)
45° pulse incidence

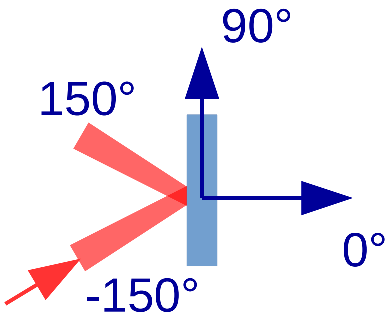


Simulation results

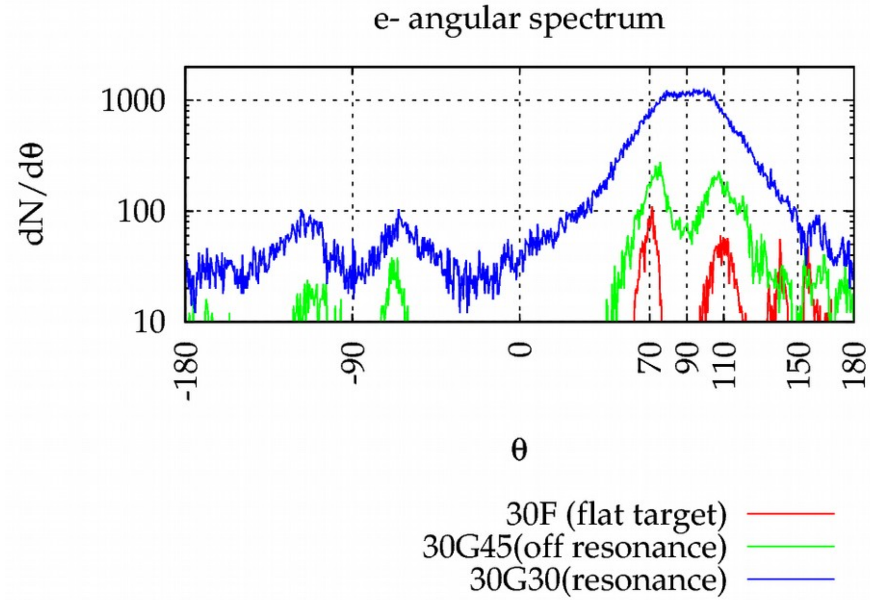
All the simulations perfomed at FERMI-CINECA with piccante



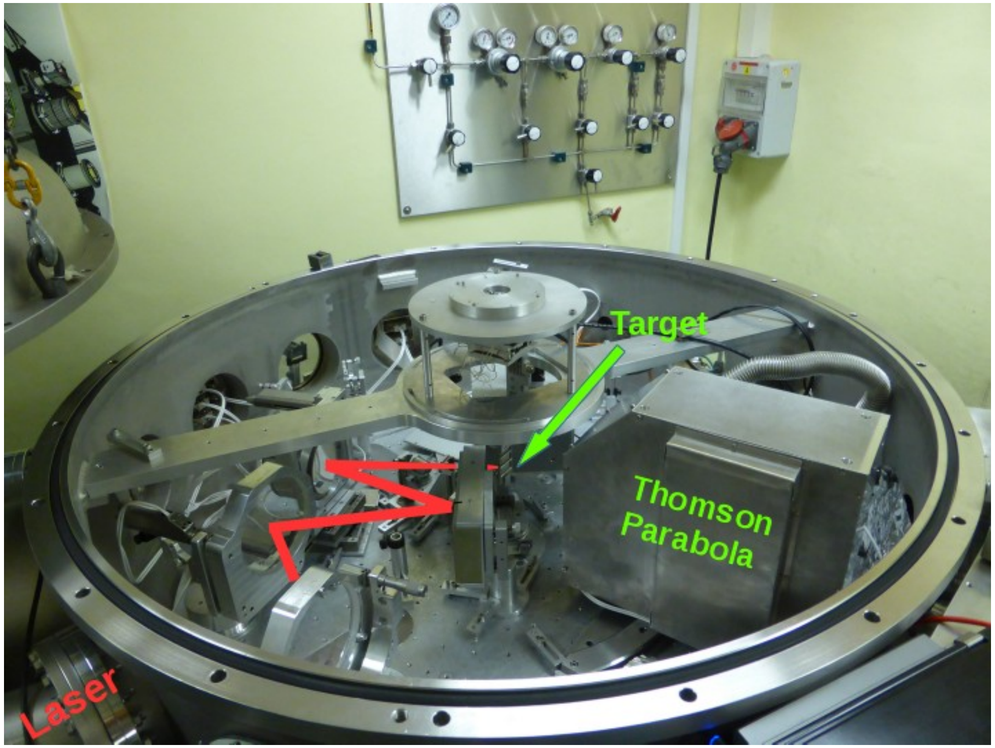
Ion acceleration



e- emission



Experimental campaing: setup



Diagnostics:

- Thomson parabola (for ions)
- Radiochromic film ring
- Electron spectrometer **NEW!**

Targets:

- Mylar, 13 µm, G45°, G30° , G15° and flat
- SiN, 1 µm, G45° and flat

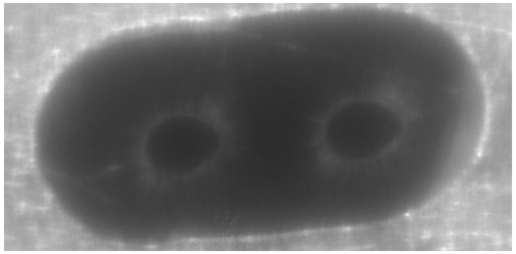
Facility:
CEA-Saclay (France)
SLIC 100 TW laser facility
(pulse duration of 25 fs)

High Field Plasmonics

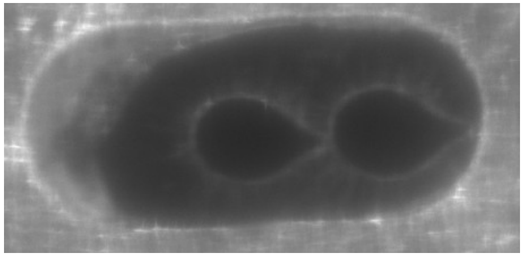
Experimental campaing: preliminary results

⚠ Experimental activity is still ongoing this week.

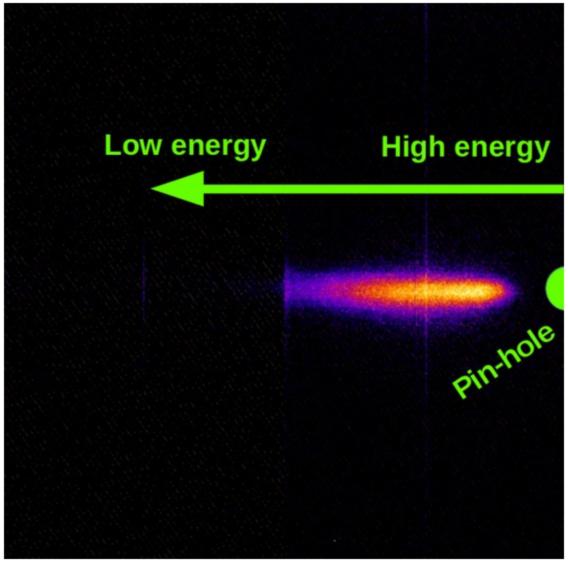
Flat target



Grating at resonance



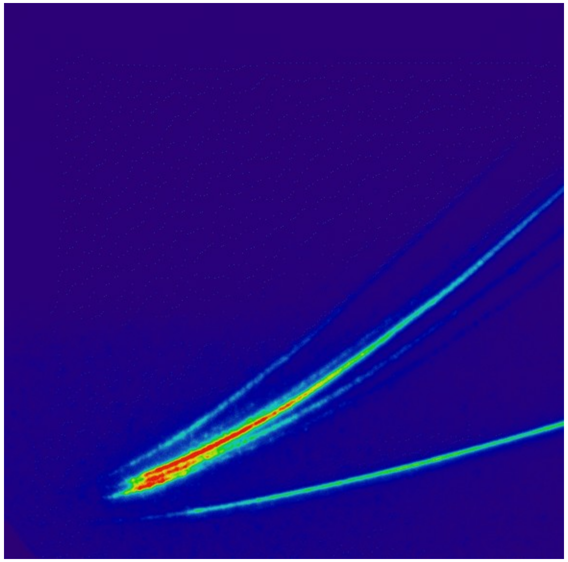
Holes in the target: hole shape for resonant grating target is a strong evidence in favour of plasmonic effects



e- spectrometer: very high signal for gratings at resonance along target tangent

good agreement with simulations

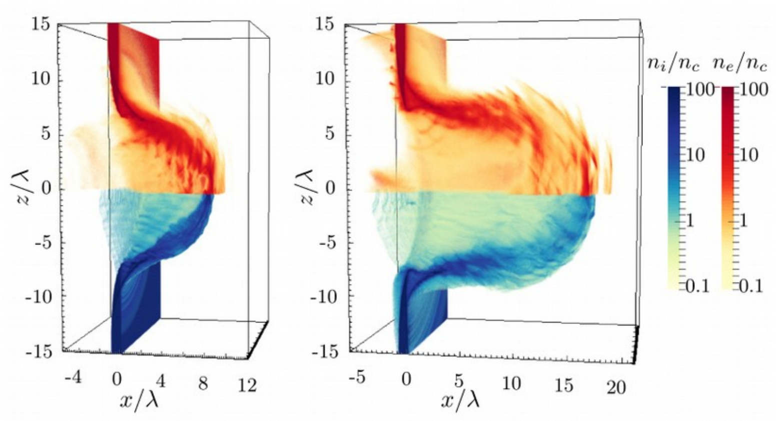
Thompson parabola: data analysis is still ongoing



Rayleigh Taylor-like instability in Radiation Pressure acceleration scenarios

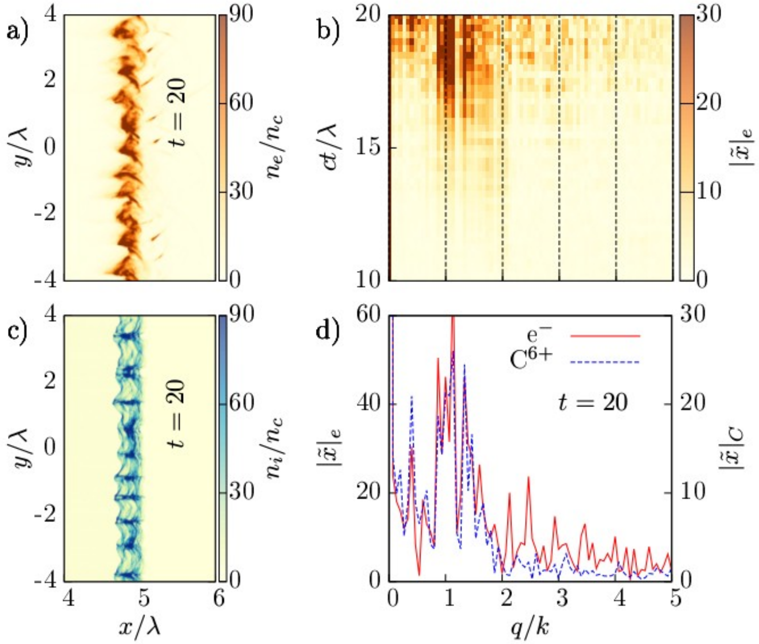
RT instability in Radiation Pressure Acceleration

Radiation Pressure Acceleration (RPA)



Very high intensity laser on thin targets. Laser pressure directly displaces electrons. Ions are dragged by longitudinal E field.

RTI in RPA scenarios



Theoretical model of rippling growth in RPA

Expected resonance at $q = k$ and cut-off at $q = 2k$ ($k = 2\pi/\lambda_{Laser}$)

Simulations confirm theoretical prediction

A.Sgattoni, S.Sinigardi, <u>L.Fedeli</u> , F.Pegoraro, A.Macchi

High Field Plasmonics

Plasmonic Waveguides

Work-plan for the third year

High Field Plasmonics

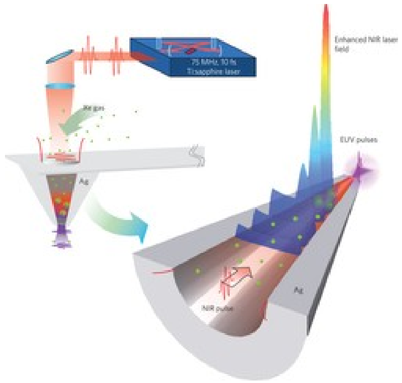
Plasmonic Waveguides

Very promising application of SPP in conventional plasmonics

For EM waves, focalization beyond diffraction limit is impossible: for a waveguide, d>λ/2 to allow wave propagation.

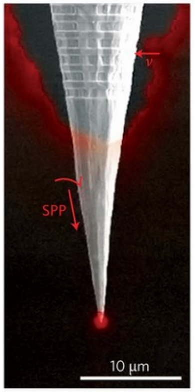
SPP can overcome the diffraction limit.
Coupling of EM waves to SPPs allows **nanofocusing** and **giant field enhancement** (~100x).

Several schemes in the literature



Tapered guides
(see Park et al., NatPhoton 2011)

Tapered tips
(see Gramotnev et al., Nature 2013)



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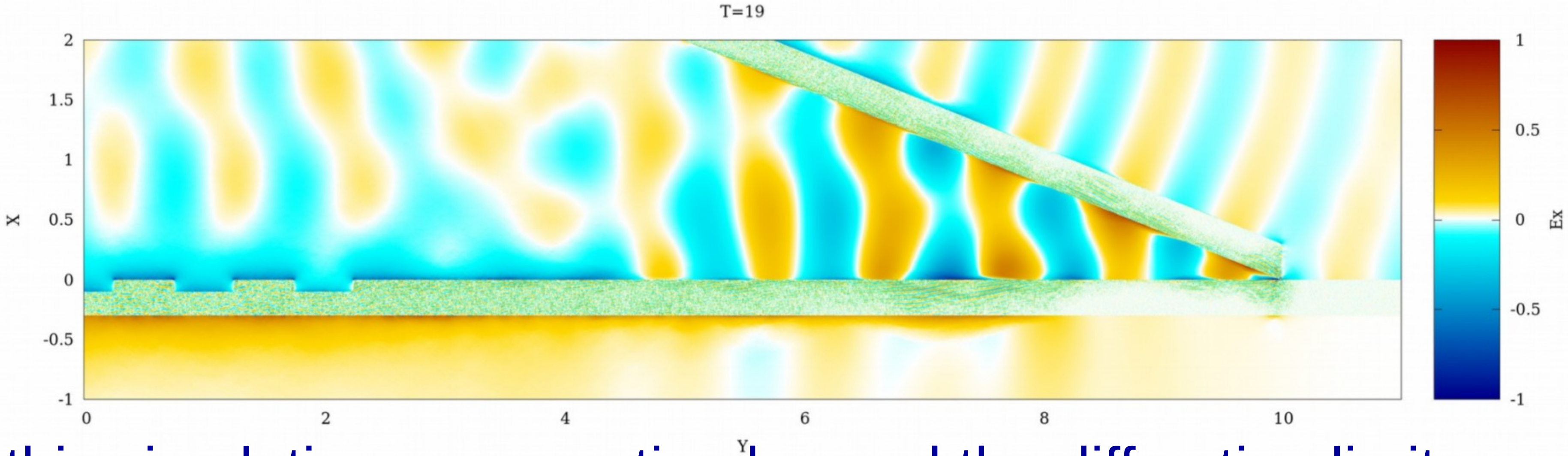
High Field Plasmonics

Plasmonic Waveguides

Can we exploit some of these schemes in High Field Plasmonics?



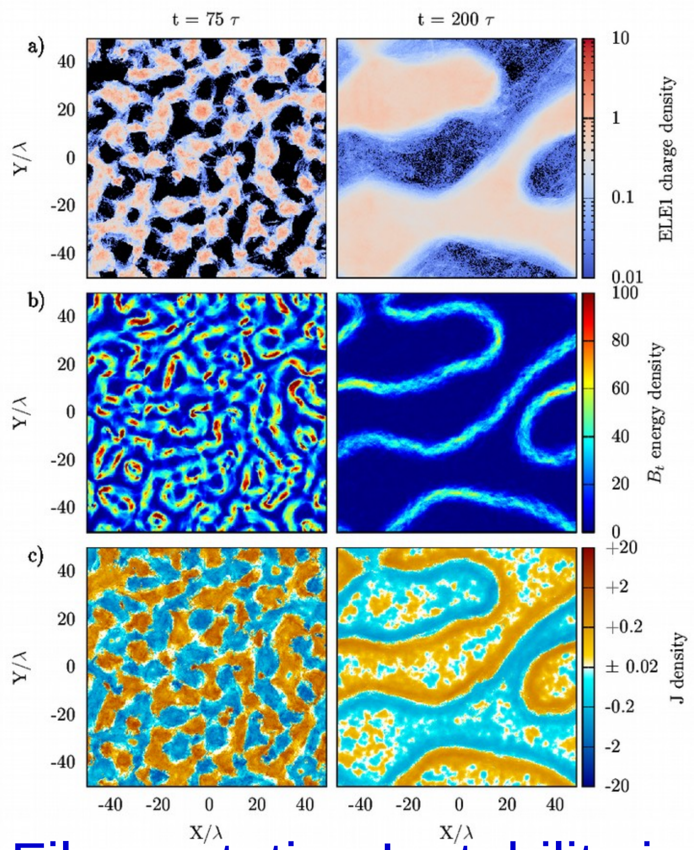
In this simulation, propagation beyond the diffraction limit was achieved, but energy concentration was not satisfactory.

Achieving significant field enhancement in High Field Plasmonics could be very interesting

Additional research activity

High Field Plasmonics

Additional research activity

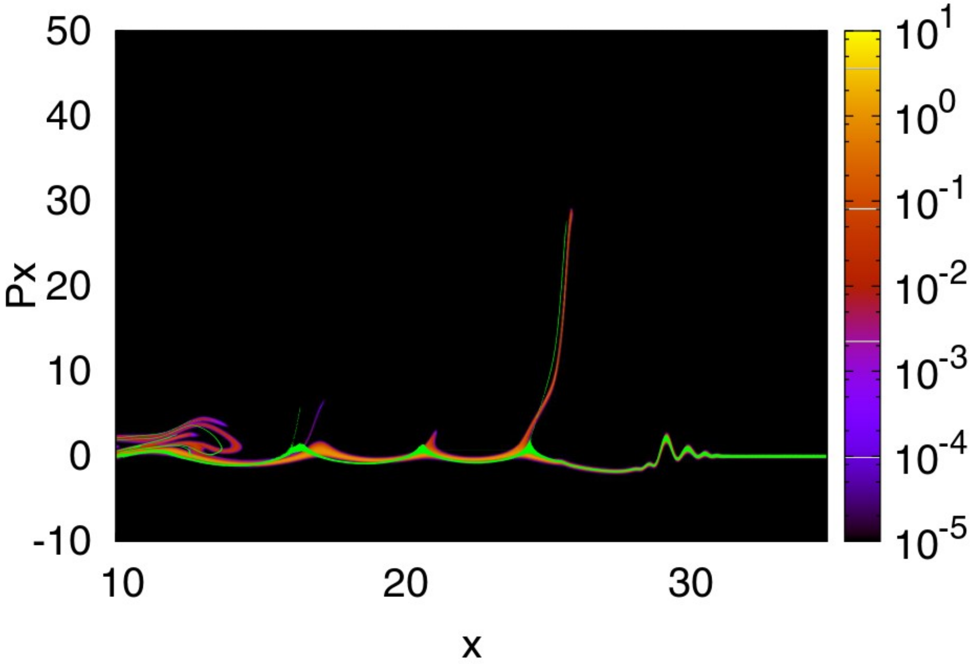


Filamentation Instability in relativistic counter-streaming pair plasmas.

Master thesis of M.D'Angelo. Paper to be submitted soon

Phase space dynamics after the breaking of a relativistic Langmuir wave in a thermal plasma

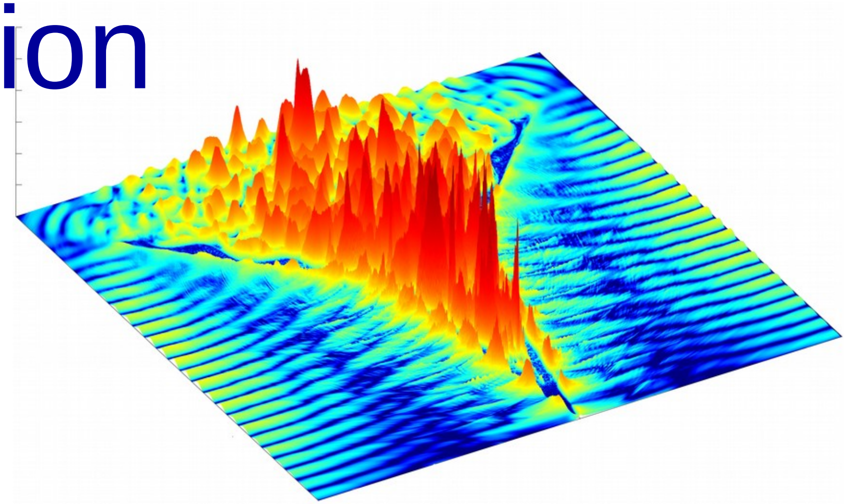
A. Grassi, L. Fedeli, A. Macchi, S.V. Bulanov and F. Pegoraro, EPJD 2014



High Field Plasmonics

END

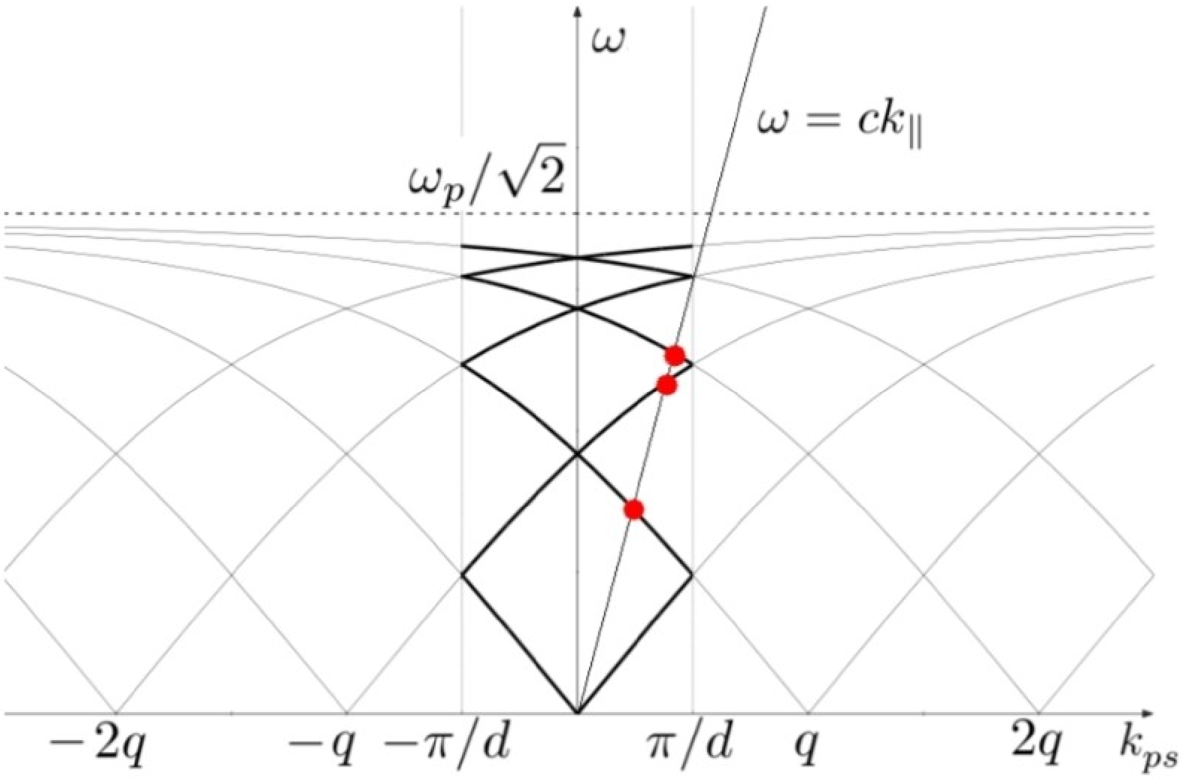
Thank you for
your attention



EM-SPP coupling with gratings

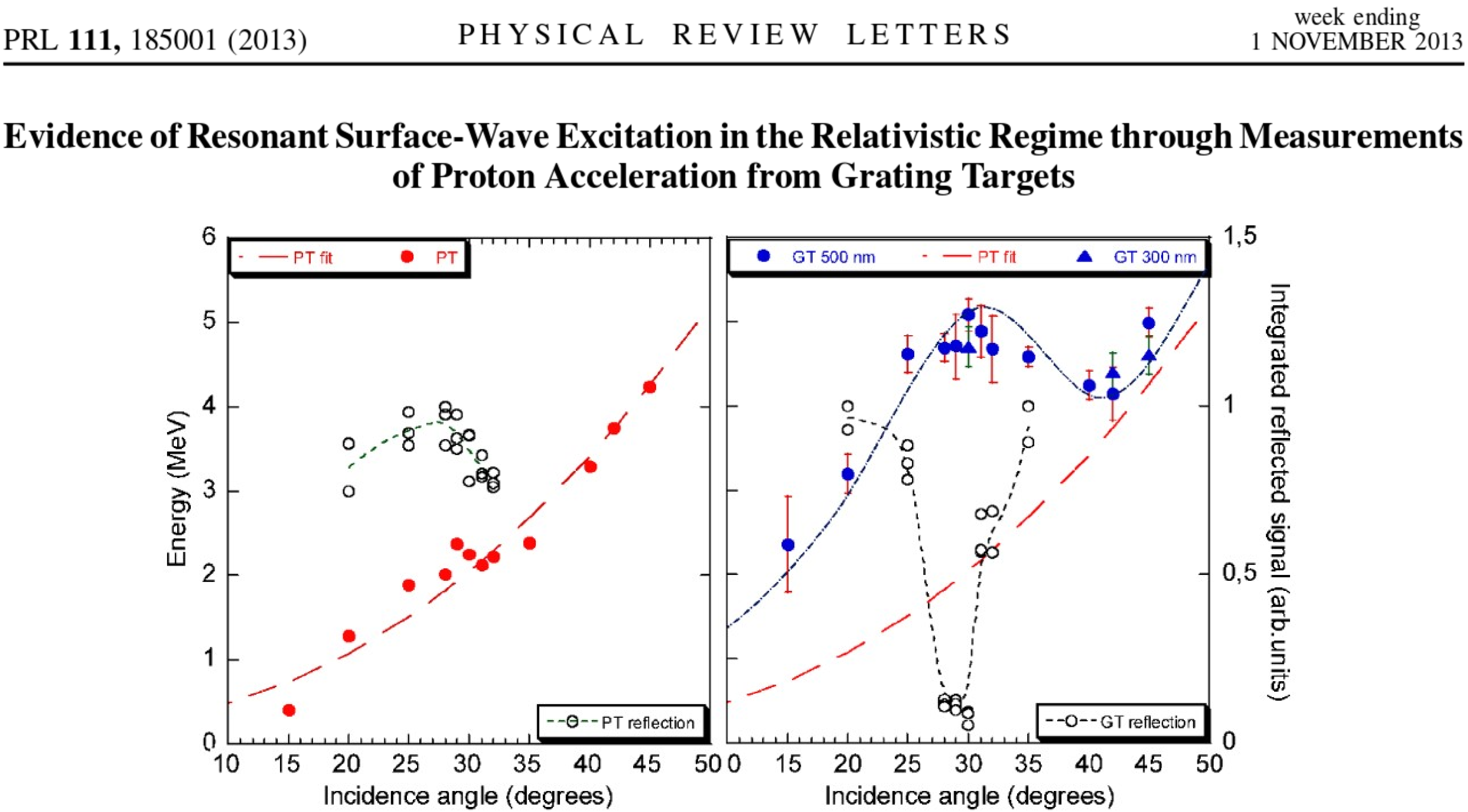
$$\frac{\omega}{c}\sin(\theta)=k_{SPP}(\omega)\pm n\frac{2\pi}{d}$$

Bloch theorem



The system is symmetric for discrete translations along the grating.

Enhanced laser-plasma coupling with gratings



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