Collaboration projects under the French-Russian inter-academic agreements and the European Seventh Framework Program

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Centre Lasers Intenses et Applications
Université Bordeaux 1 – CNRS – CEA, France

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International workshop on high power laser applications

Outline

- **CELIA and its place in the inertial fusion research**
- **Programs of international cooperation:**

  University, CNRS, EGIDE, EU
- **Research visits of Russian scientists**
- **Bi-lateral collaborations with Russian laboratories**
- **Marie Curie European exchange program**
- **Examples of collaborative projects conducted recently**
- **Perspectives & subjects for future collaborations**

Presentation of the CELIA

The Center for Intense Lasers and Applications (CELIA) is a joint research unit (UMR5107) in partnership with

- ♦ **the Bordeaux University**
- ♦ **the National Scientific Research Center (CNRS)**
- ♦ **the Atomic Energy Commission (CEA)**

CELIA offers an outstanding opportunity for gathering expertise in

- ♦ **the Strong Field and Ultra-High Intensity Physics**
- ♦ **the Inertial Fusion for Energy (IFE).**

Research topics are presented by four groups:

- **Femtosecond lasers and optics**
- **Harmonics and short pulse applications**
- **X-ray sources, plasmas and ions**
- **Physics of hot dense plasmas**

Missions of the CELIA

CELIA reassembles more than 60 university professors, research scientists, engineers, postdocs and graduate students, equipped with high performance computing systems and high power laser systems

The mission of CELIA is to conduct the research on the frontiers of the physics related to the high power and high intensity lasers:

- Laser plasma interactions
- Inertial confinement fusion for energy
- Laboratory astrophysics
- Laser plasma ultra-short X-ray sources
- Hot dense plasma and warm dense matter
- Applications of high intensity laser pulses in industry and medicine

In collaboration with the Institute of Lasers and Plasmas CELIA provides access to the laser installations of the CEA in the Bordeaux region: ALIZE et LIL

CELIA participates in the construction of the PETAL installation and preparation of coming experimental campaigns

International cooperation programs

CELIA maintains a broad network of international collaboration with many countries. Four major instruments of the collaboration support are:

University program for graduate students, postdocs and visiting scientists

CNRS programs of the international exchange:

- Bilateral agreements with research organizations
- International Programs for Scientific Cooperation (PICS)
- International Joint Units (UMI)

EGIDE scientists exchange program:

- partenariats Hubert Curien, program ECO-NET, program Eiffel

EU Marie Curie exchange programs:

- International Research Staff Exchange Scheme (IRSES)

IAEA coordinated research project on the IFE:

- Pathways to energy from inertial fusion - an integrated approach

University programs

University program provides:

Financial support for visits of foreign scientists to the laboratory for the periods of 1 and 6 months:

2002 V.Yu. Bychenkov, Lebedev Physics Institute, Moscow, 1 mois

2005 A.A. Andreev, Institute of the Laser Physics, St-Petersburg, 6 mois

2006 A.V. Brantov, Lebedev Physics Institute, Moscow, 6 mois

Financial support for undergraduate and graduate students (Eiffel, co-responsibility in the PhD programs), two grants in 2006 and 2009

Possibility for participation of Russian students in the National Master Program “Sciences of Fusion”:

> 10 French Universities and High Schools propose a 1 year integrated training in the magnetic and inertial confinement fusion physics and technology. Actual promotion 40 students, 20% of foreigners

CNRS programs

Bilateral agreements on the exchange visits of scientists between two partner laboratories (2 years, 3500 €/y)

2004 − 2006 CELIA – Institute of Laser Physics (St-Petersburg, A.A. Andreev) Ultra-intense laser-plasma sources for energetic particles and X-ray radiation

5 publications in the leading journals, many presentations on the international conferences

2008 − 2009 CELIA – Lebedev Physics Institute (Moscow, V.Yu. Bychenkov) Theoretical studies of particle acceleration by high intensity laser pulses

7 publications in the leading journals, many presentations on the international conferences

2006 − 2009 Contract in the IAEA research program: Pathways to energy from inertial fusion - an integrated approach (15 countries)

Direct drive ignition studies for the MegaJoule laser facility

a forum for efficient exchanges in the inertial fusion energy programs: Beam plasma/matter interaction, Building blocks: driver, target, chamber and interface issues, Integrated approach, Education and training

European union: Marie Curie program

Collaboration program “Interaction of ultra-intense laser pulses with plasmas” between four research organizations of three countries: France (CELIA), Germany (GSI) and Russia (Institute of Applied Physics, Nizhny Novgorod and Lebedev Physics Institute, Moscow)

2009 − 2011, 24 months of exchange visits, 40 000 €/3 years

Theoretical developments, numerical simulations and experiments in four topics:

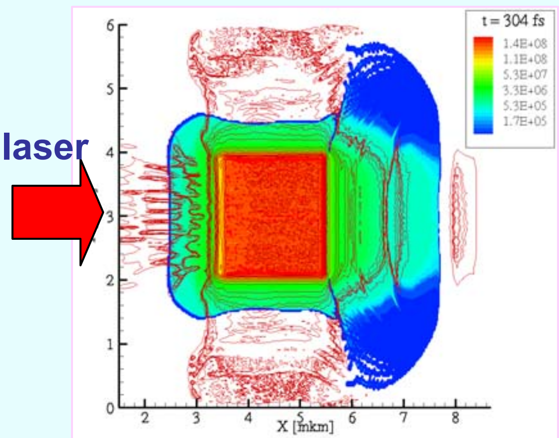
1. Electron and ion acceleration by the ponderomotive force of ultra-relativistic laser pulses in dense plasma and applications to the inertial confinement fusion
2. Effects of electron-ion collisions in a strong laser field − production of directed fluxes of high energy electrons and efficient plasma heating
3. Interaction of intense laser pulses with low density structured targets (foams and aerogels) with application to the laser beam smoothing and efficient laser energy absorption.
4. Generation of intense electromagnetic pulses in the THz domain using the tightly focused sub-picosecond laser pulses.

Ion separation in multispecies plasmas

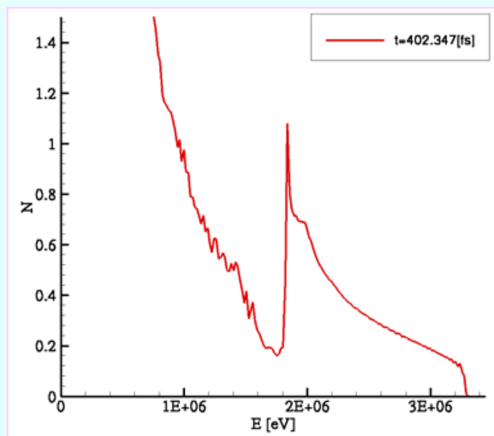
Collaboration project between CELIA, Lebedev Physics Institute (V. Yu. Bychenkov) and the Institute of the Laser Physics, St-Petersburg (A. A. Andreev)

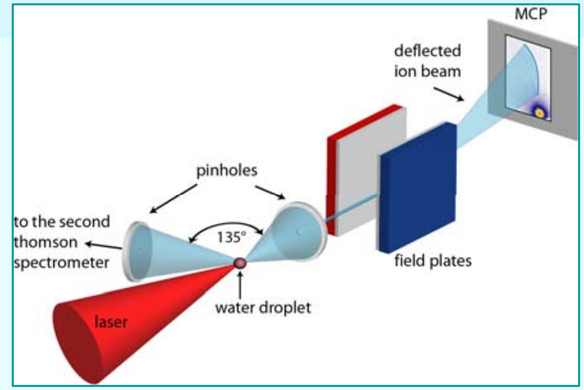
2005: The light ions can be accelerated by the electrostatic field created by hot electrons at the front of heavy ions

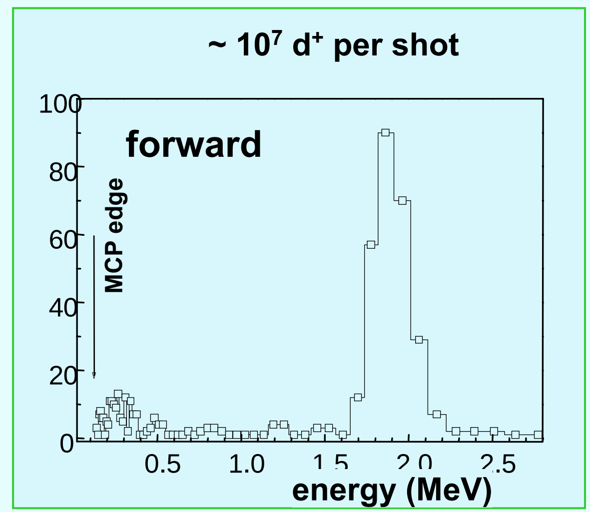
2D PIC simulations 2x2 µm
D_2O 10^{19} W/cm² + 20 nm 0^{6+}



Deuterons @ 300 fs





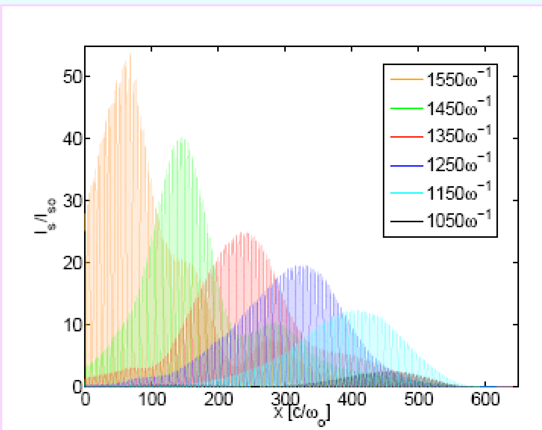


2006: observation of the deuteron peak in the experiment at MBI (Berlin) on the laser interaction with heavy water droplets

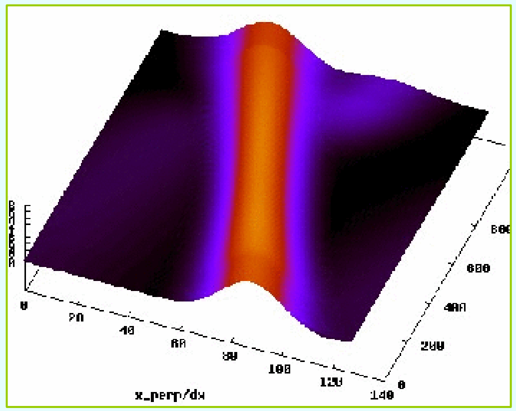
Pulse amplification and compression by SBS

Collaboration project between CELIA and the Institute of the Laser Physics, St-Petersburg (A. A. Andreev)

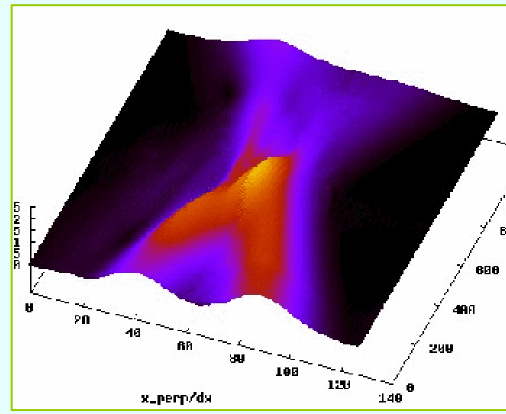
2006: The *Stimulated Brillouin Scattering* could operate in the regime of amplification for the compression of ultra-short laser pulses: *in the* regime strong coupling predicted amplification $\times 1000$ over the length of 100 µm and the pulse duration less than 100 fs



seed pulse amplification



laser pump beam

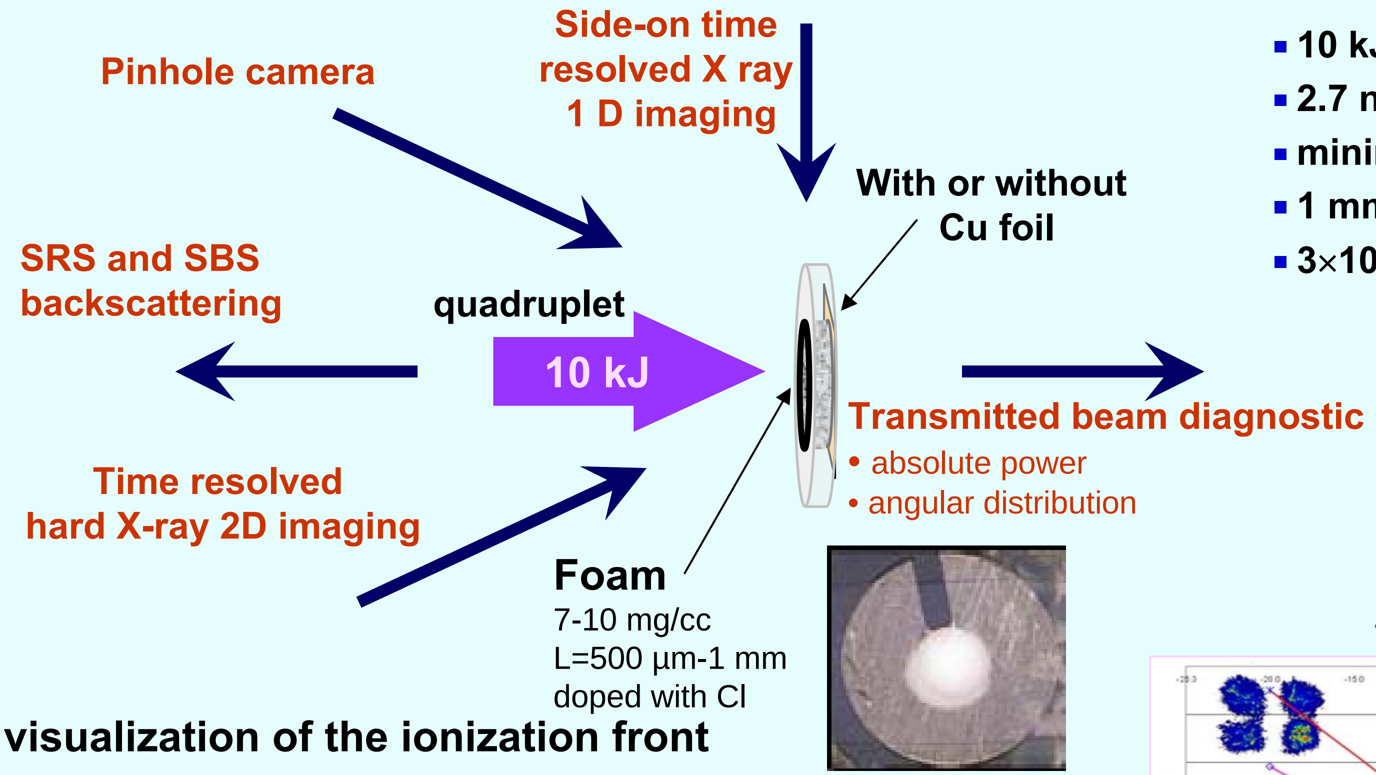


amplified beam

2008: recent experimental campaign on LULI 100 TW laser: demonstration of an efficient seed pulse amplification in agreement with theoretical previsions

LIL experiment on the laser beam smoothing

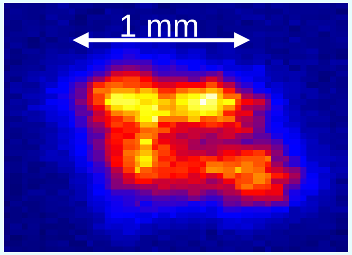
2007 – 2009 experiment on the laser beam imprint smoothing in the foam targets (fabricated by the N. Borisenko group at the Lebedev Physics Institute)



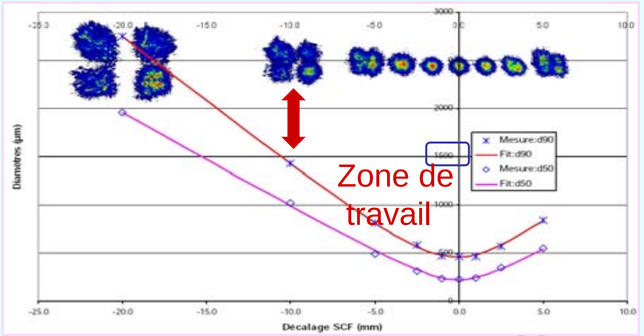
LASER

- **10 kJ of 351 nm light**
- **2.7 ns square pulse**
- **minimum SSD level (< 1 Å)**
- **1 mm spot size**
- **3×10^{14} W/cm² on target**

Laser focal spot



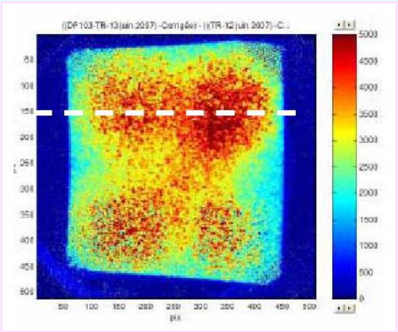
5 mm from the focal plane

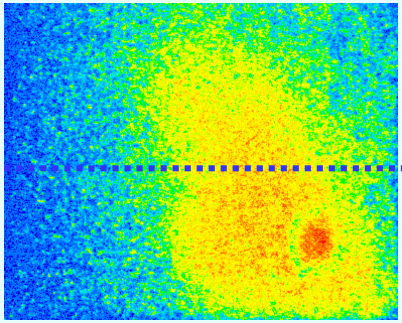


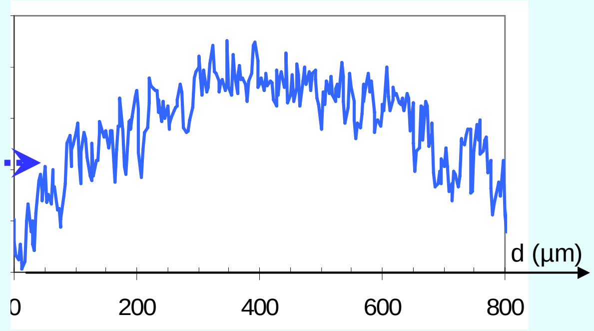
- **visualization of the ionization front**
- **measurement of the foam ionization energy budget**
- **foam effect on laser backscattering**
- **validation of the foam smoothing effect**

Demonstration of the foam smoothing effect

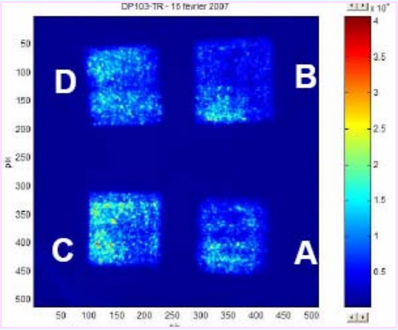
Experiment demonstrated an efficient smoothing in the supersonic regime
Interpretation is conducted in collaboration with the Lebedev Physics Institute (group of V. B. Rozanov) and the Czech Technical University (J. Limpouch)

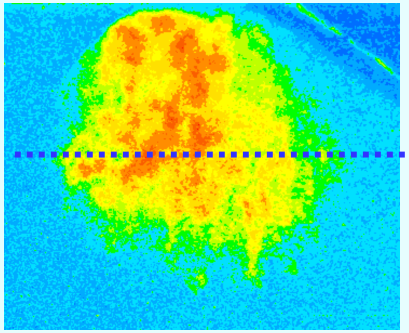


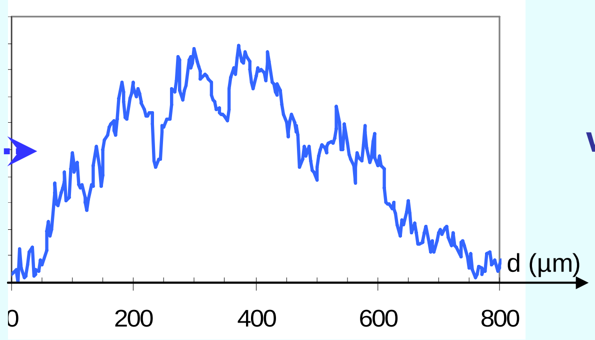




with foam
7 g/cc 1 mm







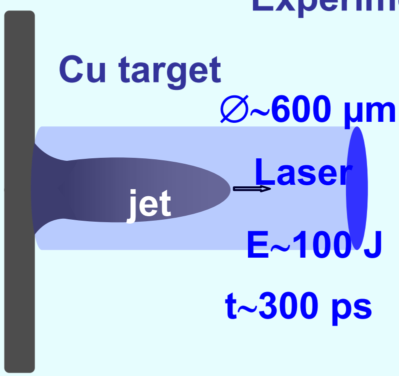
without foam

Near field image of the incident quadruplet and transmitted through 1 mm underdense foam

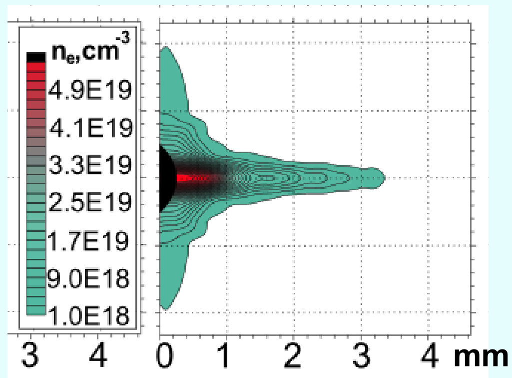
Far field image of the laser spot at the copper target w/out foam and behind a 7 g/cc 1 mm foam

Plasma jet formation and propagation

2007 – 2008 PALS campaigns on the radiative jet formation and supersonic jet collisions with low density plasmas: LASERLAB collaboration project – CELIA + PALS group + IPPLM, Warsaw



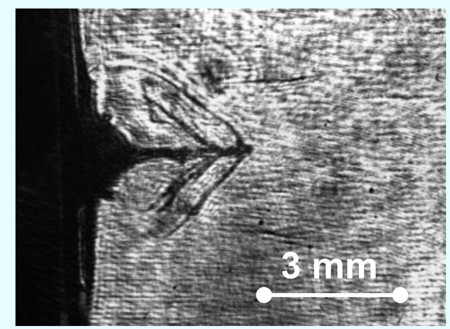
Experimental electron density distribution



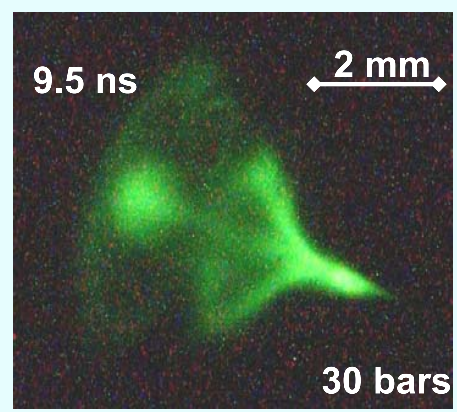
- Mach number : M ~ 10
- Velocity : U = 500 km/s
- Length : L = 3 - 4 mm
- Duration $\tau \geq 10$ ns

Radiative jets offer a better understanding of a nonlinear stage of hydrodynamic instabilities in the fusion plasma and can be rescaled to the astrophysical conditions

Copper jet collision with Ar plasma @ 5 bar: shadowgraphic image

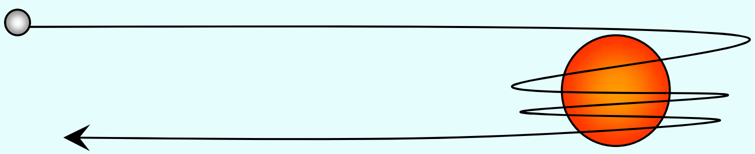


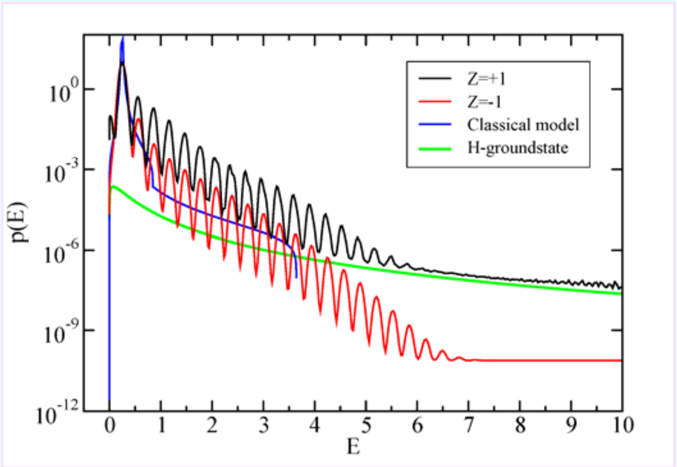
Copper jet collision with He plasma @ 30 bar: soft X-ray image

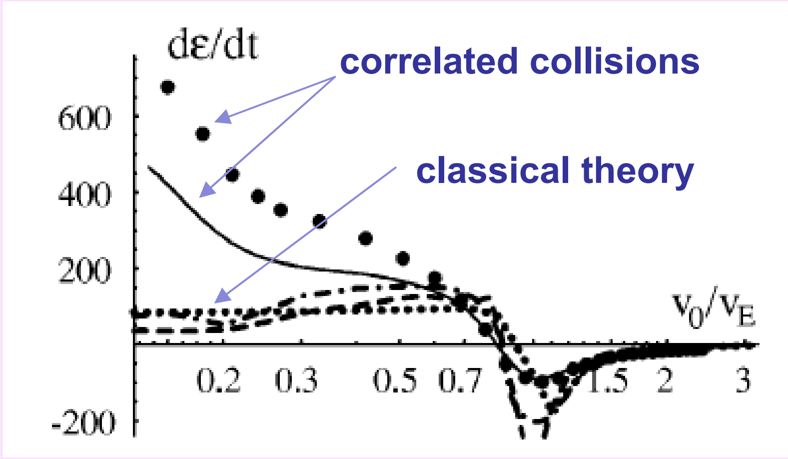


Laser-assisted correlated electron-ion collisions

Electron-ion collisions with small impact parameters in strong laser fields create a significant population of fast electrons via multi-photon scattering. This effect is missed in the classical theory of inverse Bremsstrahlung heating.







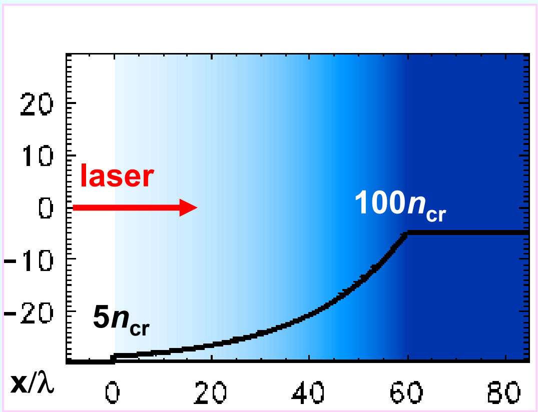
Classical and quantum models slow strongly enhanced transition rates and partial population of bound states due to correlated collisions

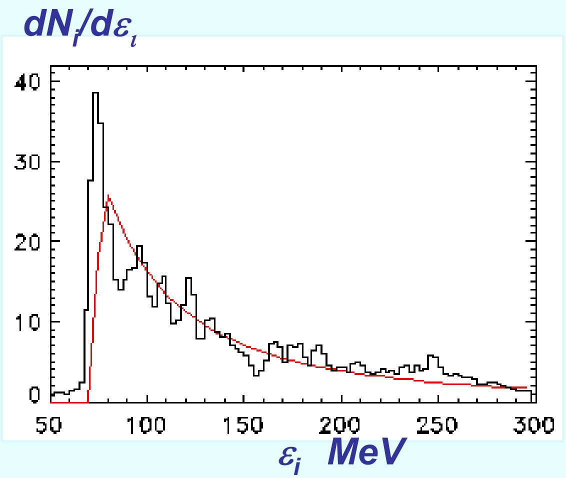
The energy gain of electrons is dominated by the correlated collisions for large amplitude electric fields $v_{osc} > v_{Te} \ln \Lambda$

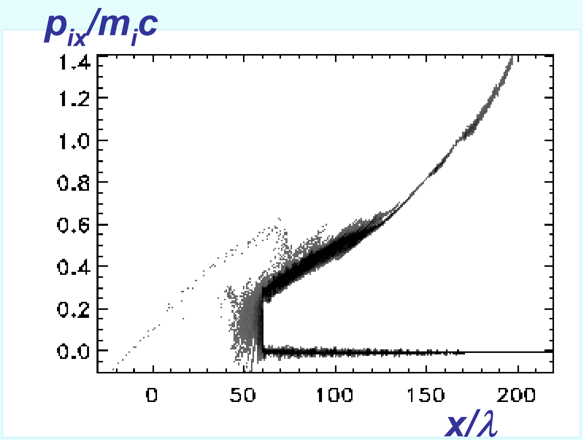
Extension to the relativistic conditions is planned

Ponderomotive ion acceleration & hole boring

Laser pulses of circular polarization open a possibility for direct ponderomotive acceleration of ions. Cold electrons enable an efficient charge neutralization.







Laser fluence: 20 GJ/cm^2
Intensity 4×10^{22} W/cm^2
Ions: 5.4 GJ/cm^2 (27%)
Electrons: ~1%
High energy photons: ~ 10%

The ions are gaining the main part of laser energy, the electrons remain cold due to the radiation losses

2D PIC simulation – channel formation

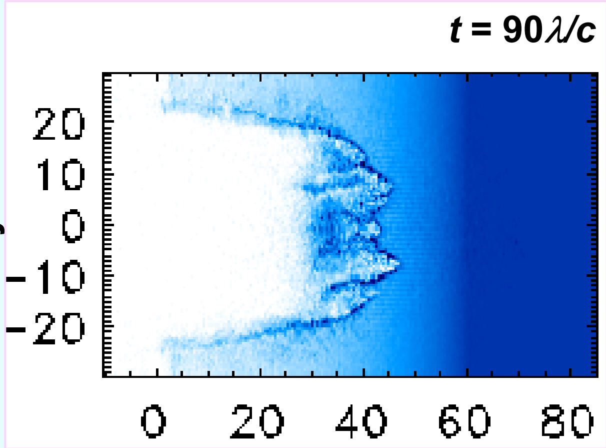
Two-dimensional simulations with a flat-top laser intensity profile demonstrate an efficient ion acceleration ande hole boring in the plasma

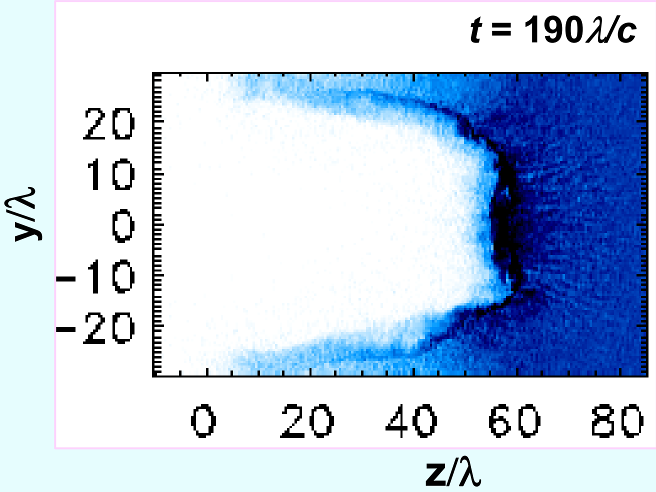
A clean and a stable channel

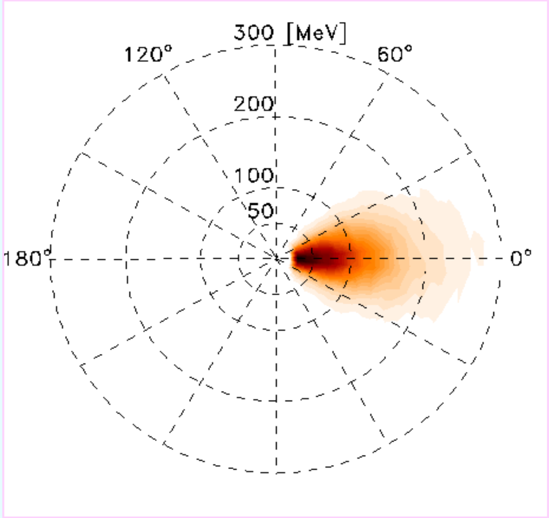
Filamentation is strongly suppressed due to radiation losses

Velocity of hole boring is in agreement with the 1D model

A narrow ion angular distribution

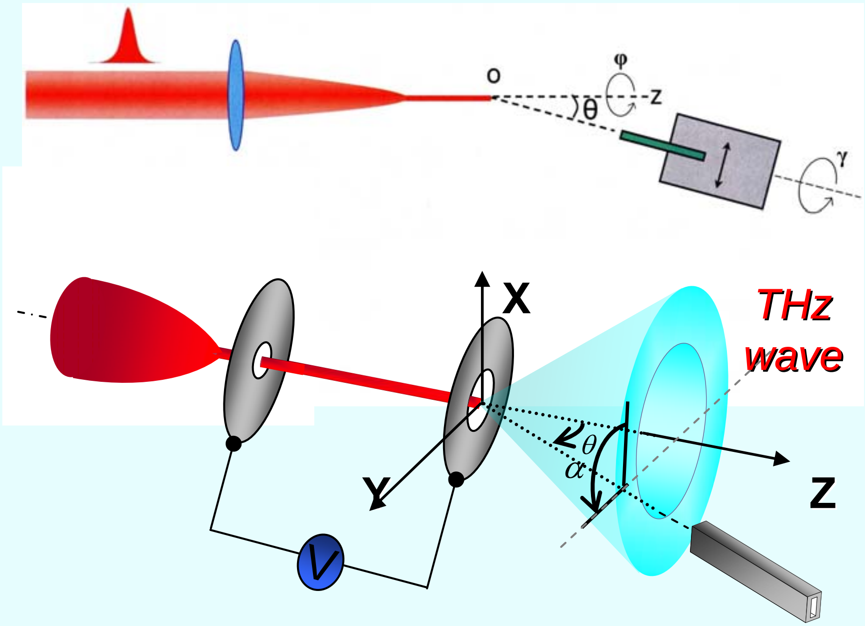






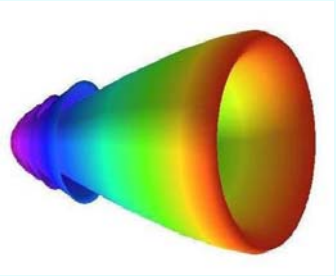
Directed THz emission from the laser filaments

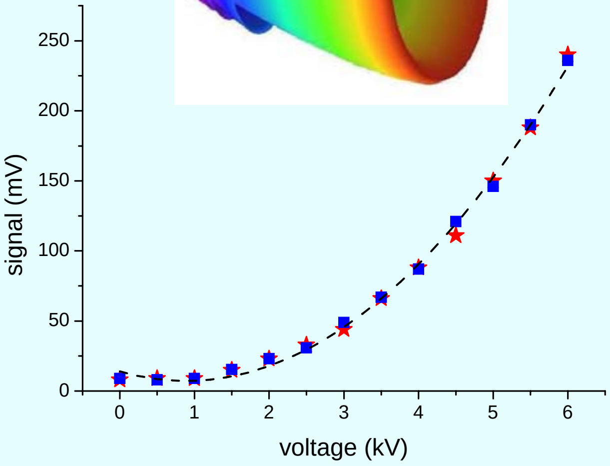
Laser beam filamentation in air offers a possibility to create efficient sources in the THz domain with flexibility in positioning, spectrum control and a good directionality



The Cerenkov-like radiation is emitted within a hollow cone

$$\Delta\theta = \sqrt{\lambda / L}$$

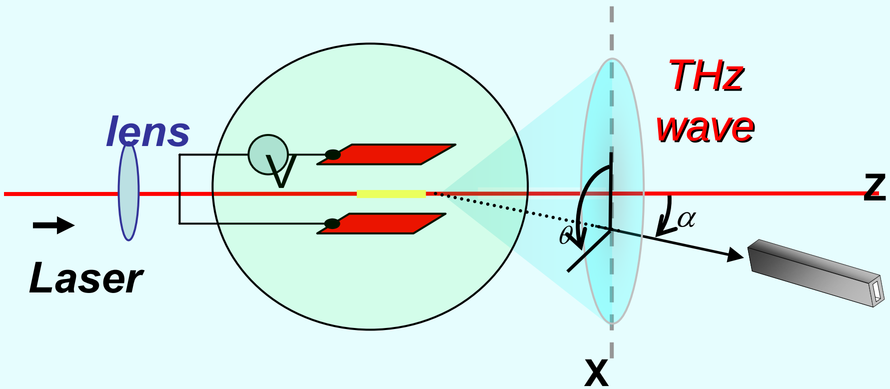




Experiments at the LOA (Palaiseau) Laser pulse:
W_{las} ~ 15 mJ , λ = 0.8 μm, t_{las} = 50 fs, rep rate = 100 Hz DC E-field: E = 1 – 10 kV/cm

Control of THz emission with DC fields

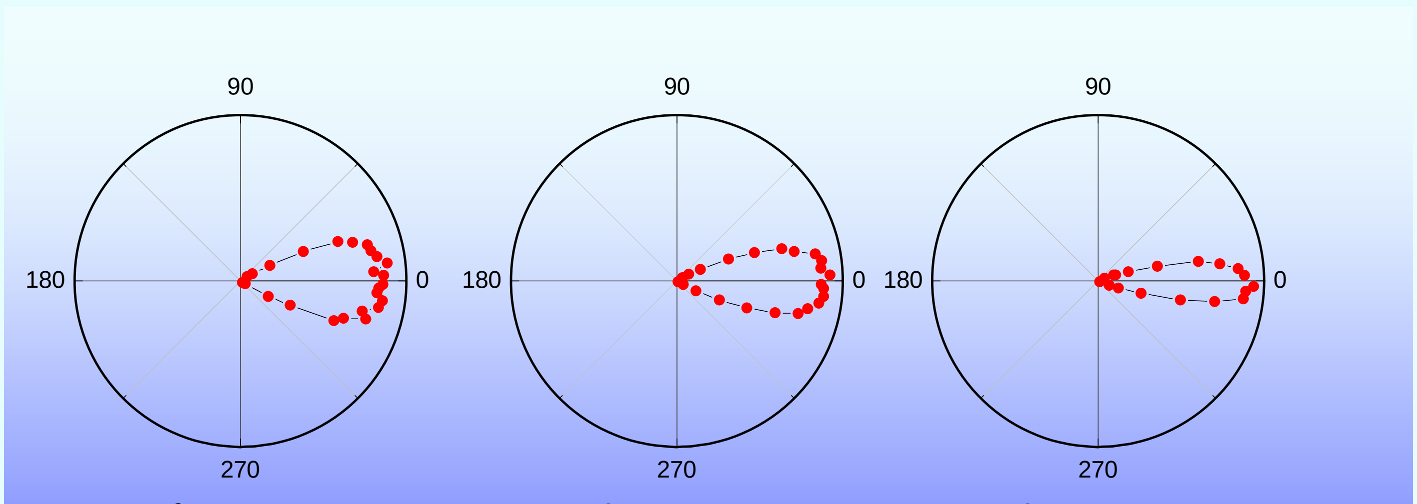
DC field allows to control a directionality and intensity of the THz signal



Experiments at the LOA (Palaiseau) Laser pulse: W_{las} ~ 15 mJ , λ = 0.8 μm, t_{las} = 50 fs, rep rate = 100 Hz

DC E-field: E = 1 – 10 kV/cm

Signal is enhanced 10^3 times in the DC field



f = 750mm f = 1000mm f = 2000mm

Objectives for future collaborations

- Laser acceleration of charged particles to high energies: exploration of acceleration mechanisms, transport of particles and the beam quality, efficient energy deposition
- Applications of the high intensity charged particle beams for medicine, astrophysics and material processing
- Interaction of intense laser pulses with structured materials: energy absorption and transport, development of laser smoothing and absorption strategies for the IFE projects
- Generation of intense electromagnetic pulses in the THz domain using the tightly focused sub-picosecond laser pulses
- Common theoretical projects, participation in the preparation of experimental proposals and experimental campaigns, student and young scientists training

Formats for future collaborations

- Bi-lateral projects on specific subjects
- Coordinated efforts of several laboratories with complementary specialization
- Participation in a large-scale European projects: HiPER, ELI
- Coordinated experimental programs, experiments on European facilities within the LASRLAB program
- Participation in the development of the experimental program for the facilities under construction: PETAL
- Student exchange program, formation and training of young scientists