CILEX-APOLLON : status and projects

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CEA-DSM-SACLAY

Centre Interdisciplinaire Lumière Extrême

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Philippe Martin, Scientific Director (CEA-LIDyL)

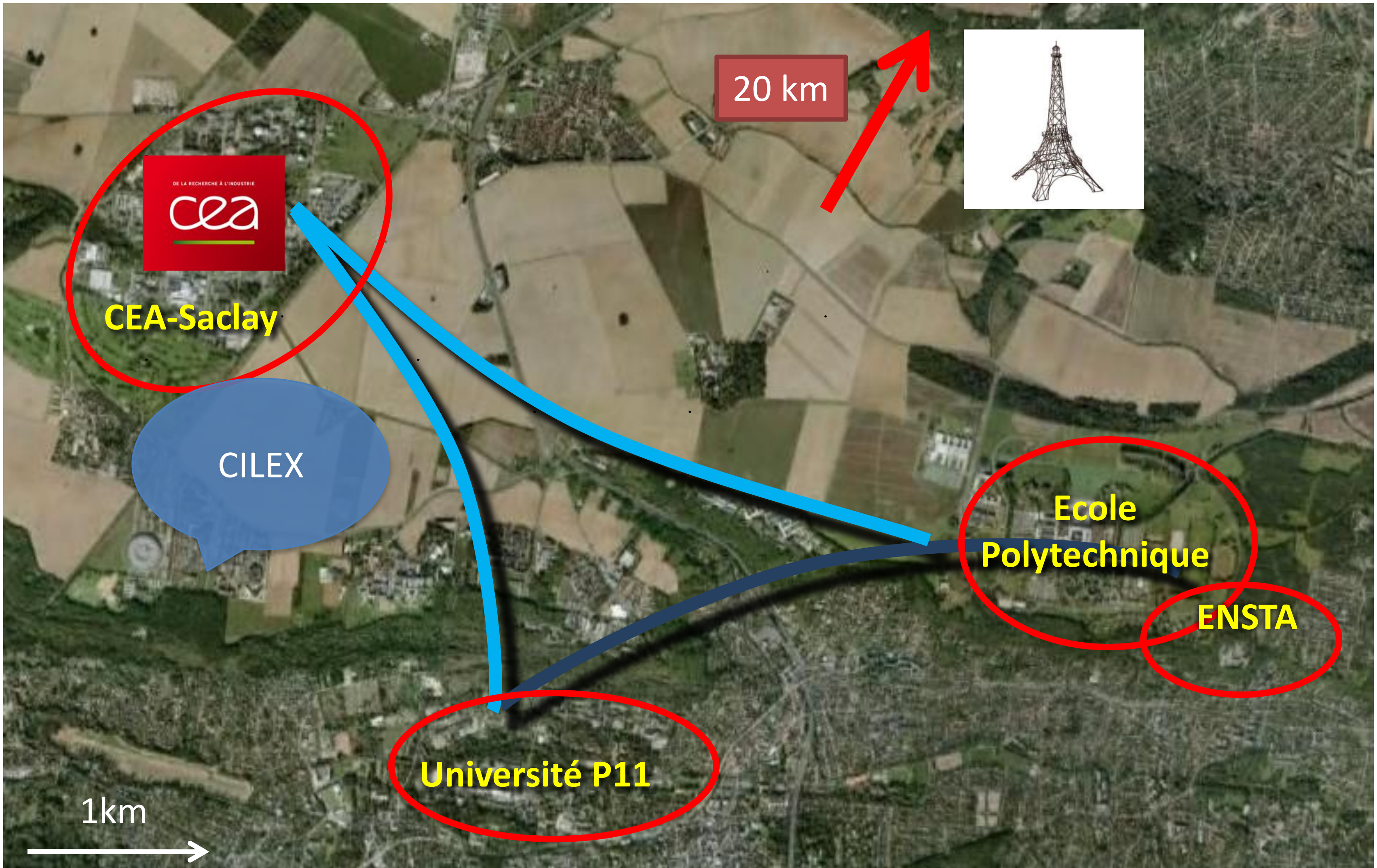
Patrick Audebert, Technical Director (LULI)

P. Monot, Deputy Director(IRAMIS/LIDyL)

F. Mathieu : project manager (LULI)

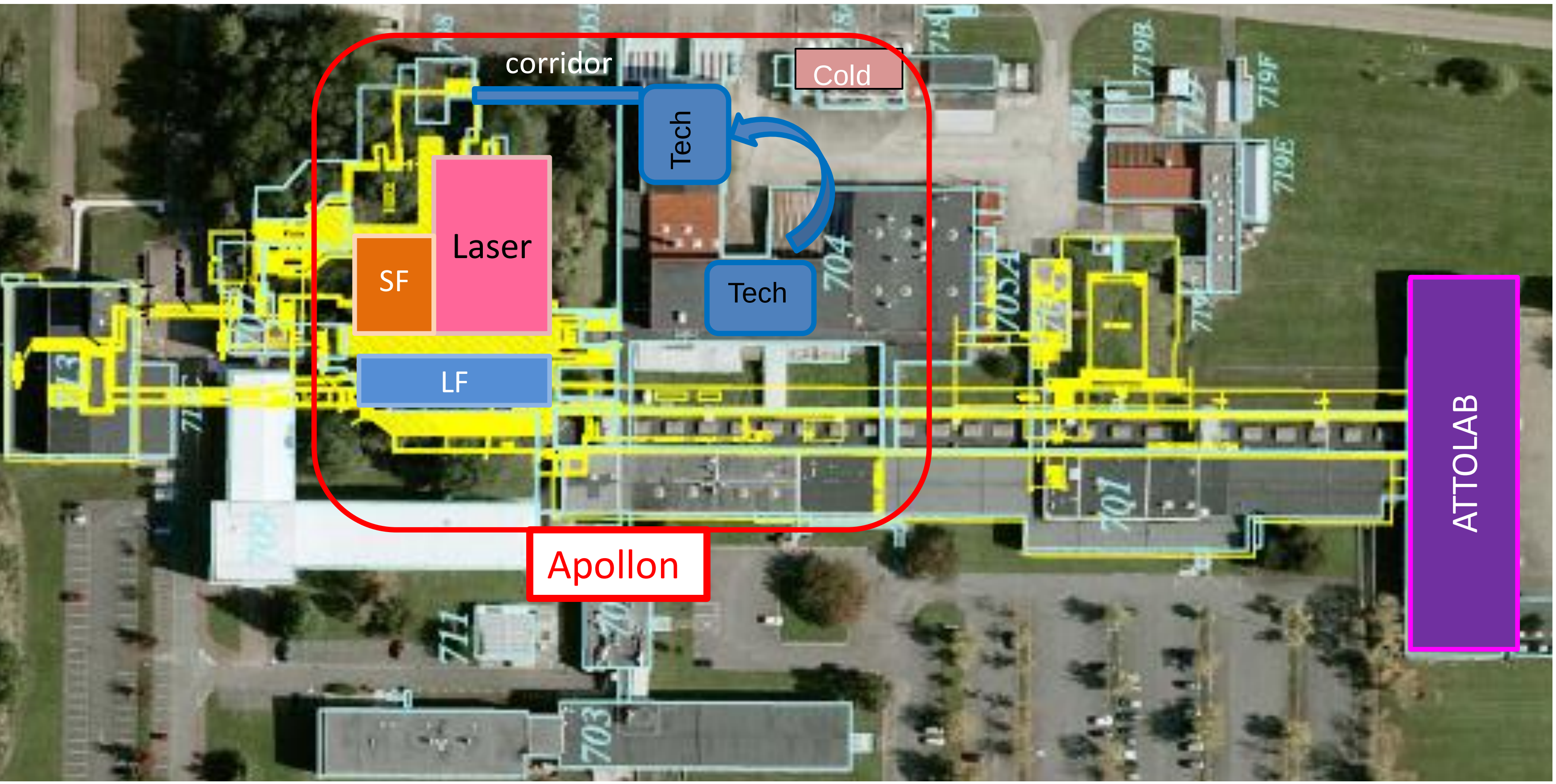
CENTER dedicated to ultra-relativistic optics
Open to national and international Community

Where is it ?


20 km
CEA-Saclay
CILEX
Ecole Polytechnique
ENSTA
Université P11
1km

Location of Cilex equipments

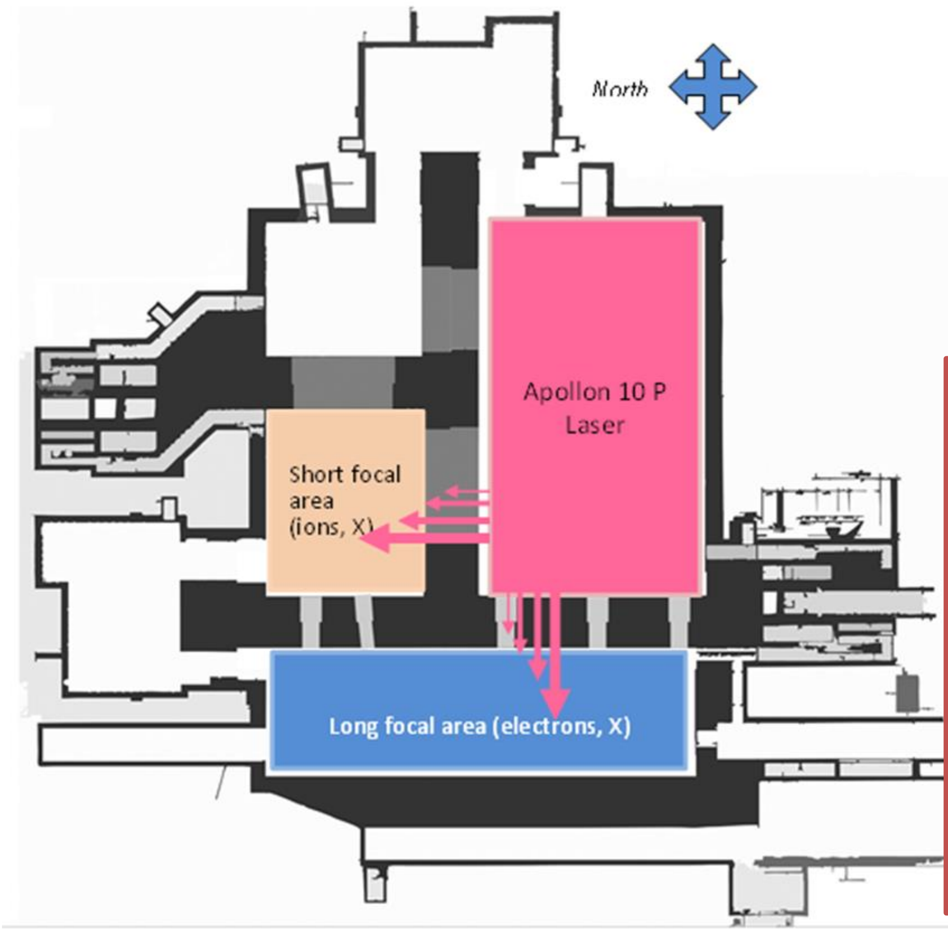
North



250 m

APOLLON

Orme des merisiers site



3 fully radio-protected large scale halls :

- Laser Hall
- Long Focal Hall – moderate intensities
- Short Focal Hall – extreme intensities

F1: **Main short pulse beam : 10 PW**
(150 J, 15 fs – 10 ps, 400 mm diameter)
F2 : Secondary short pulse beam: 1 PW
(15 J, 15 – 200 fs, 140 mm diameter)
F3 : Long pulse beam**:** 300 J max, 1 ns, 140 mm diameter.
F4 : Probe pulse beam**:** 250 mJ < 20 fs, 100 mm diameter.

1700 m^2

LASER area transformations…

At the moment on the « plateau de Saclay »

Operational
100 TW class systems
Three Satellite facilities

UHI100, 100 TW, 25 fs
Salle Jaune, 2 x 60 TW, 30 fs
LASERIX 10J, variable durations

Relativistic Regime

11 participating labs, 100 scientists and engineers

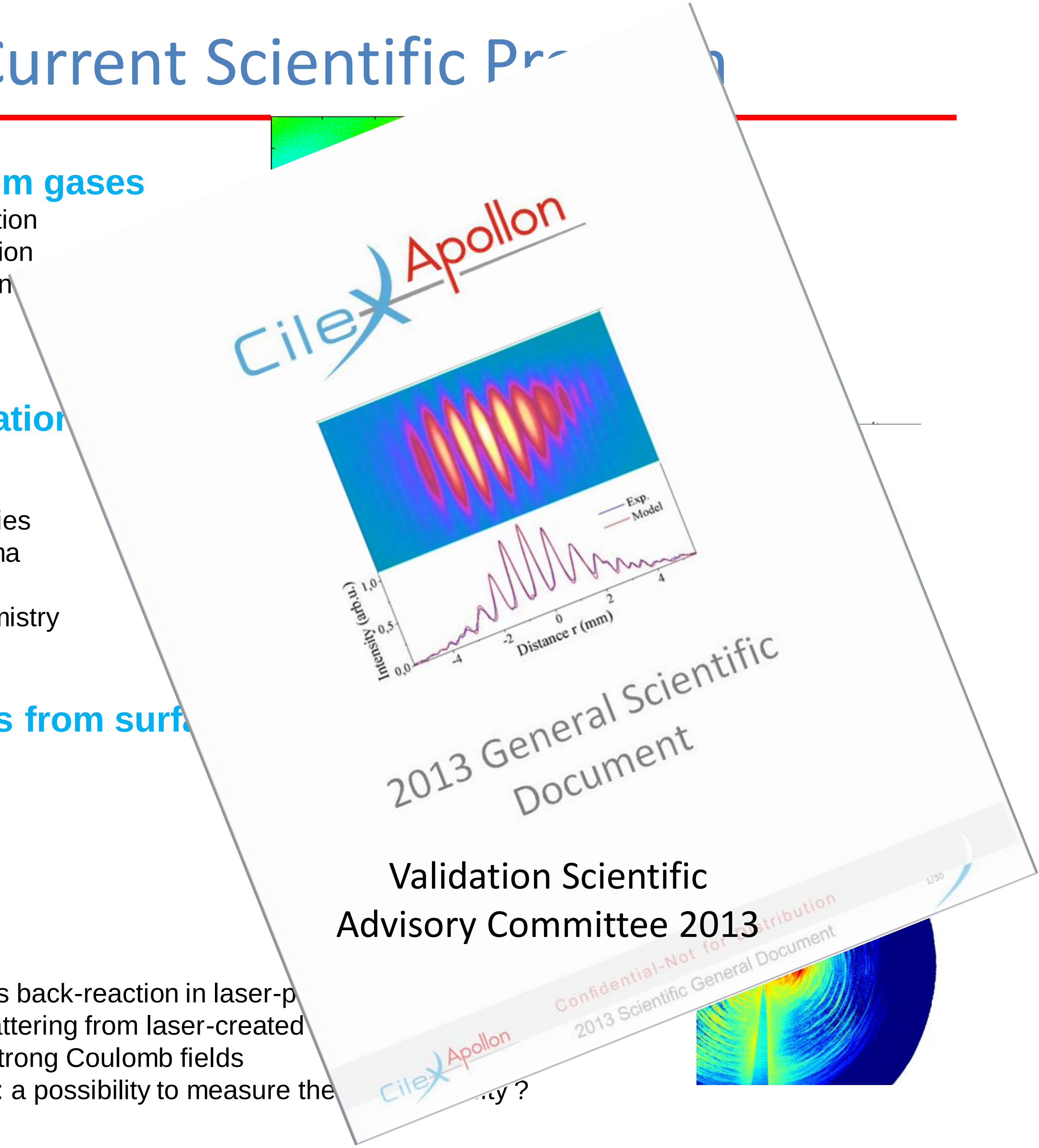
Current Scientific Pr…n

Electron Acceleration from gases
Single-stage laser plasma acceleration
Multi-stages laser plasma acceleration
Positron production and acceleration
Inverse Compton effect
Coupling to an undulator

Electron and Ion acceleratio
Relativistic plasmonics
Relativistic laboratory astrophysics
Warm and Dense Matter basic studies
Stopping power in matter and plasma
Proton Radiography
Time-dependent irradiations in chemistry
Neutron sources

X-ray sources for physics from surf
Harmonics generation
Attophysics
Flying mirrors
Xray lasers
Betatron radiation

High-Field Physics
High energy photon emission and its back-reaction in laser-p
Non-linear Compton / Thomson Scattering from laser-created
Pair production in the presence of strong Coulomb fields
Electron acceleration from vacuum : a possibility to measure the …ity ?



Validation Scientific
Advisory Committee 2013

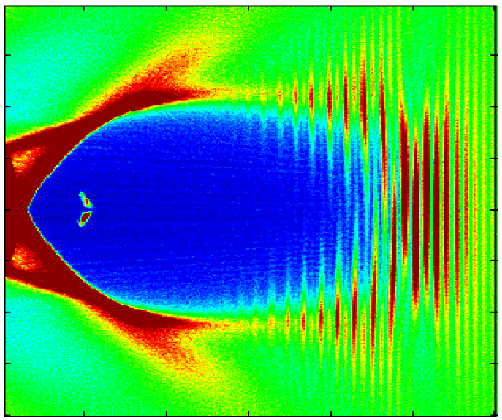
Underdense plasmas

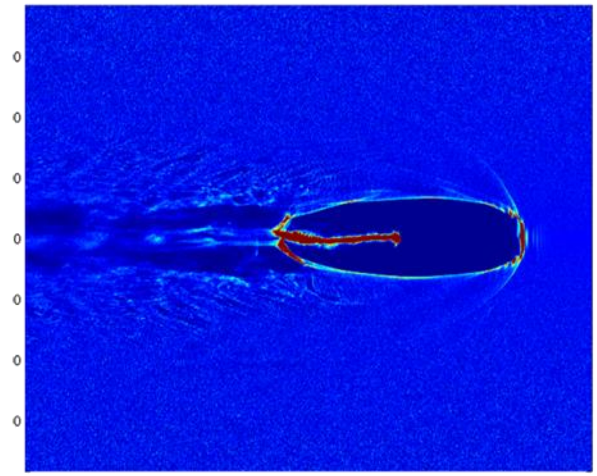
Electron Accélération
Inverse Compton

LOA, LLR, LPGP, LIDyL, DPTA

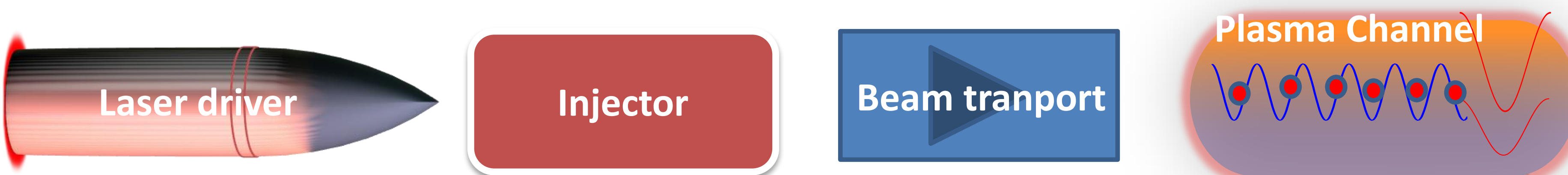
Electron acceleration

Fundamental studies in the extremely non-linear regime :
electron acceleration, NL compton emission, betatron emission

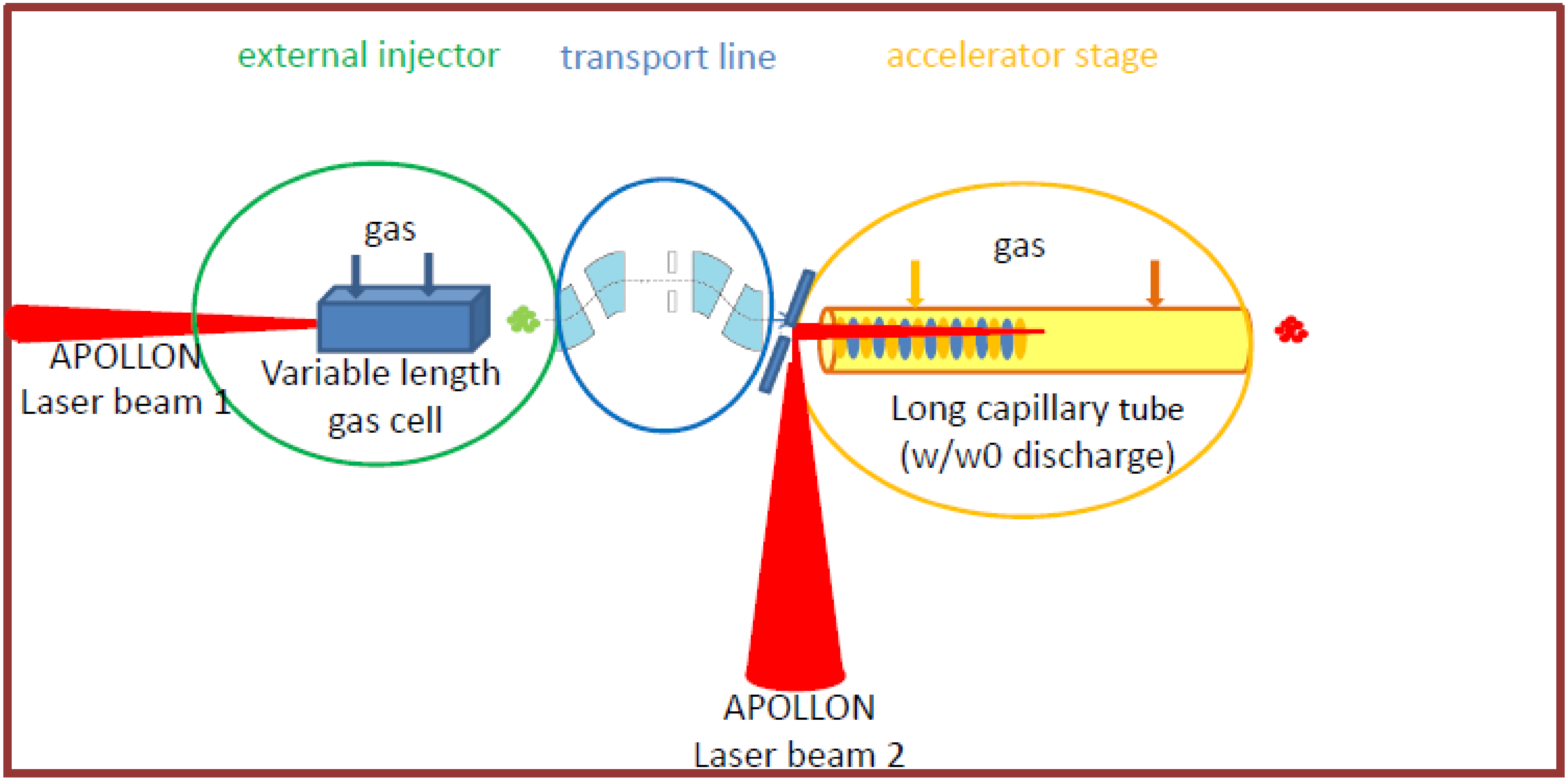




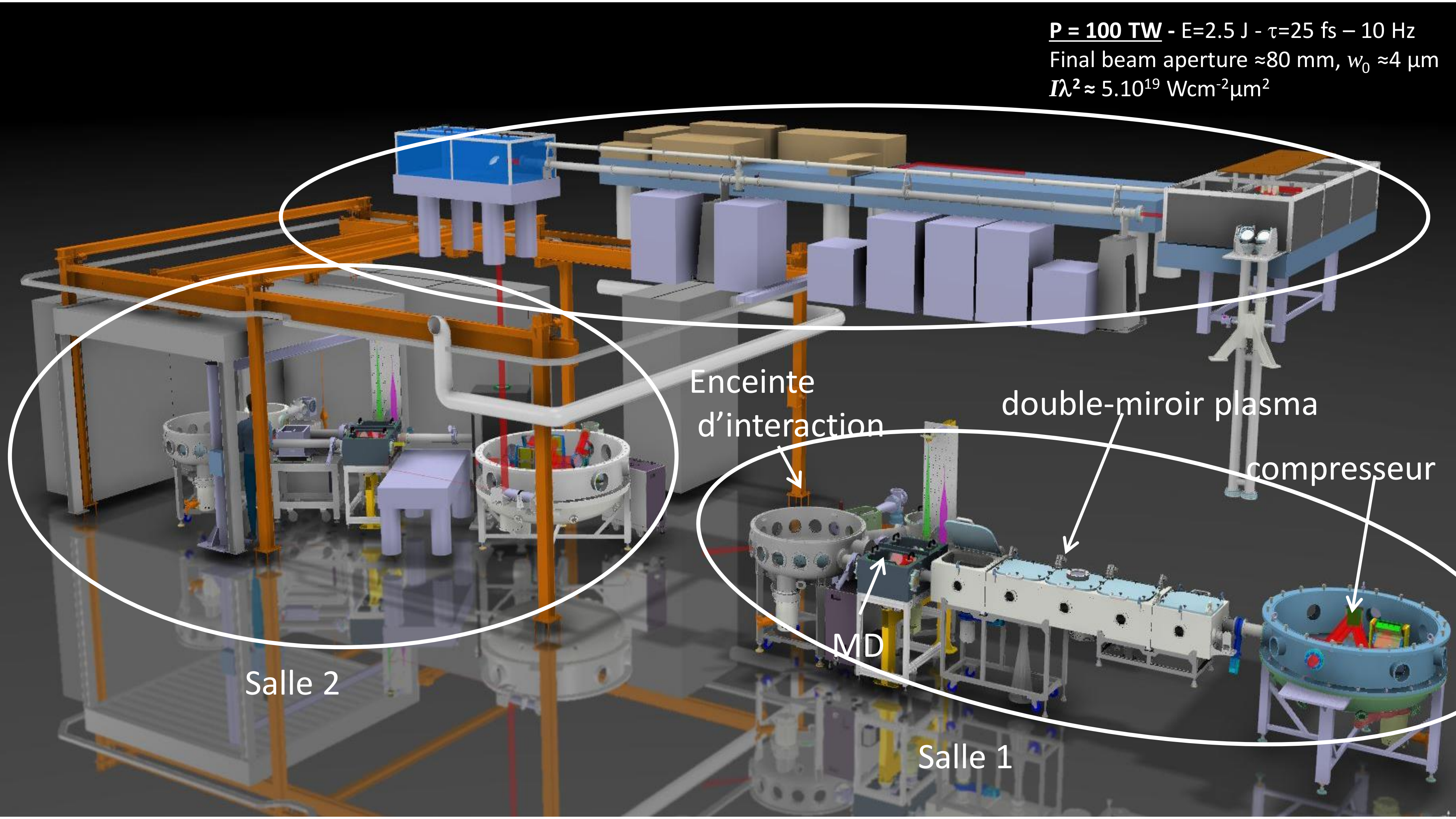
Development a two-stage laser-plasma accelerator as a prototype for future studies on multi-stage laser plasma acceleration



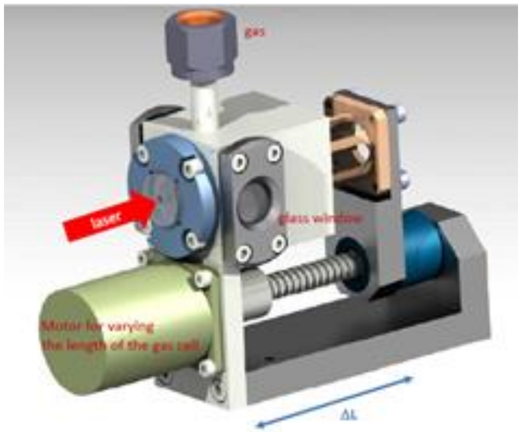
Accélération d'électrons dans le cadre de CILEX

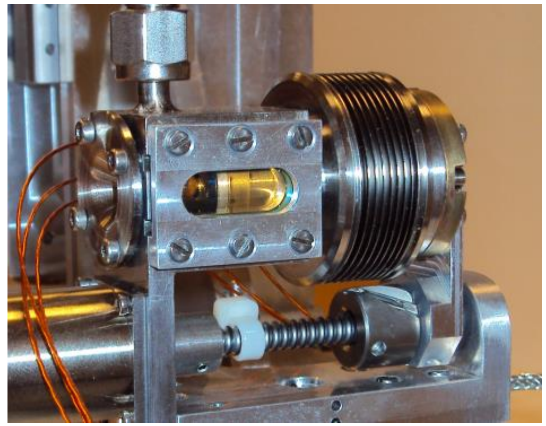


UHI100 - Saclay



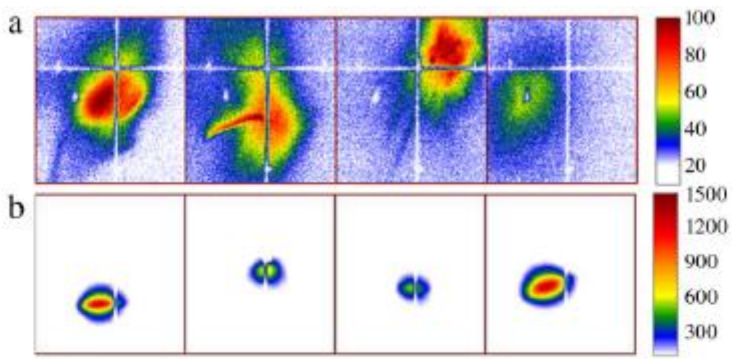
Electron acceleration : Experiments on UHI100





S. Dobosz et al.

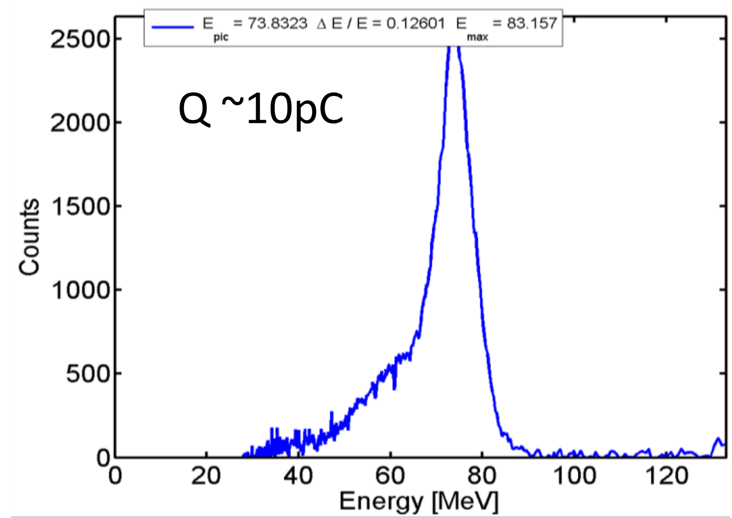
Piégeage par injection par ionisation



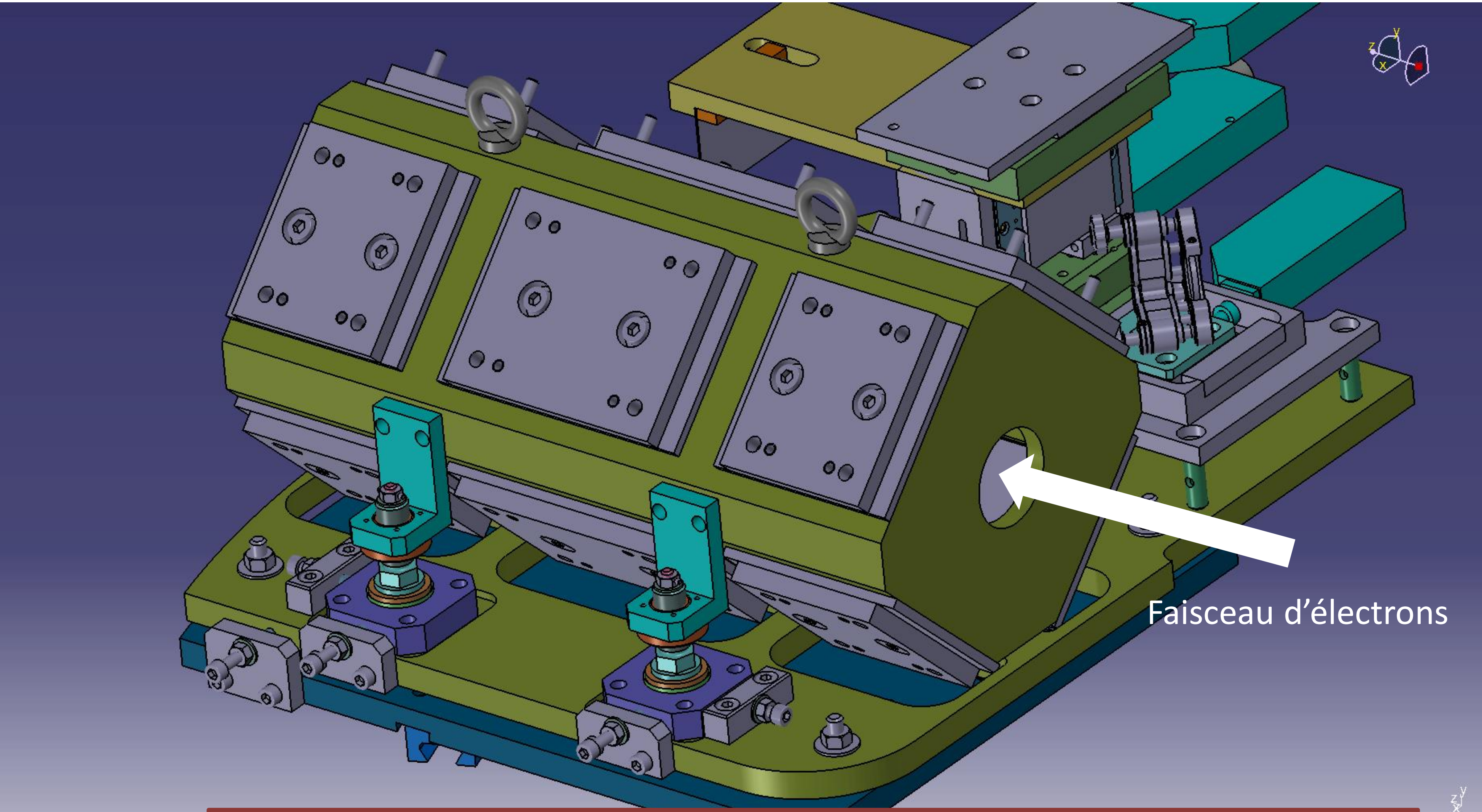
He pur

He +1% Ar

Mc Guffey , PRL 2010



Conceived for 50-80MeV avec ΔE/E~±5%



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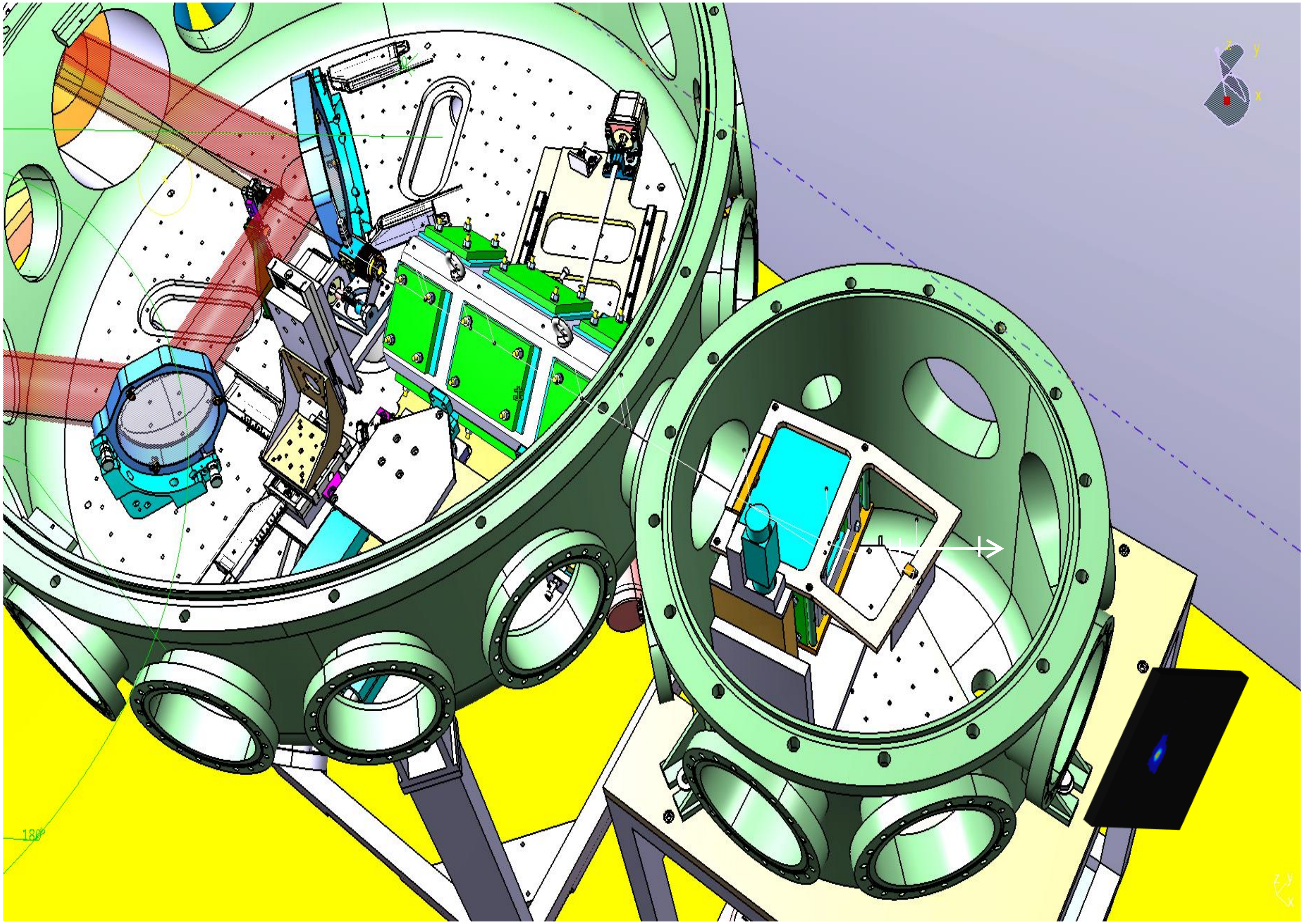
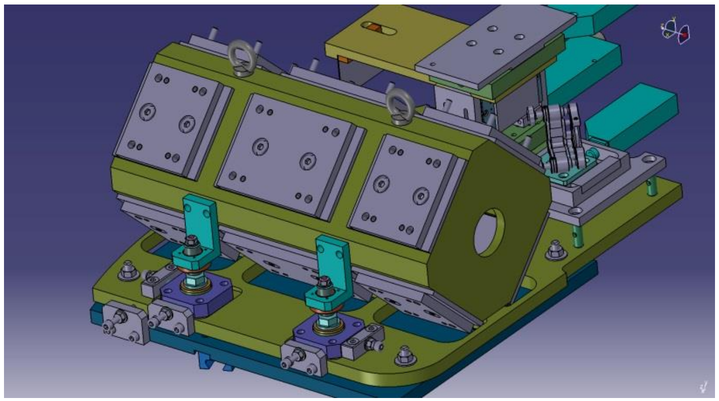
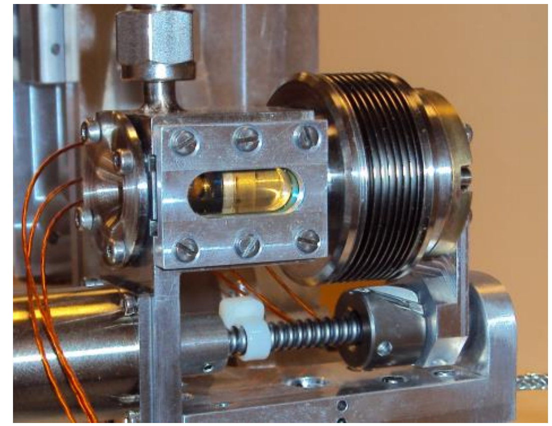
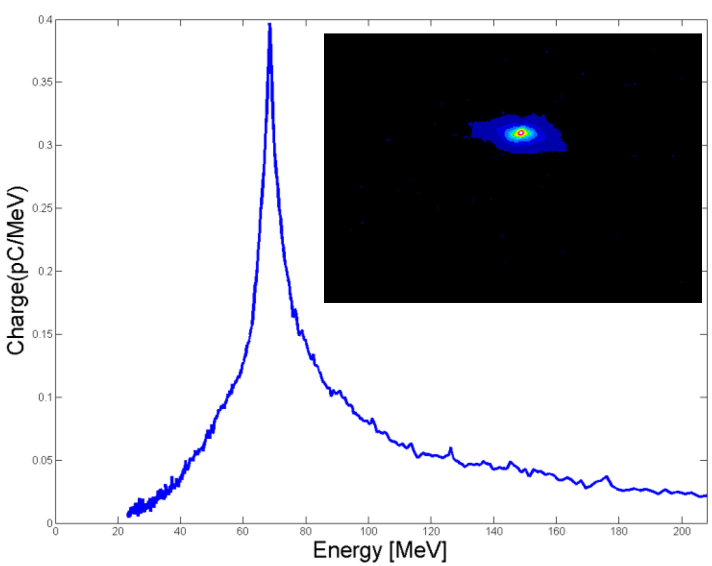
-Calculs: Antoine Chancé (CEA-IRFU)
-CAO/DAO : Olivier Delferrière / M. Bougeard
-Caractérisation du champ magnétique sur banc de mesure LLR (Arnd Specka)

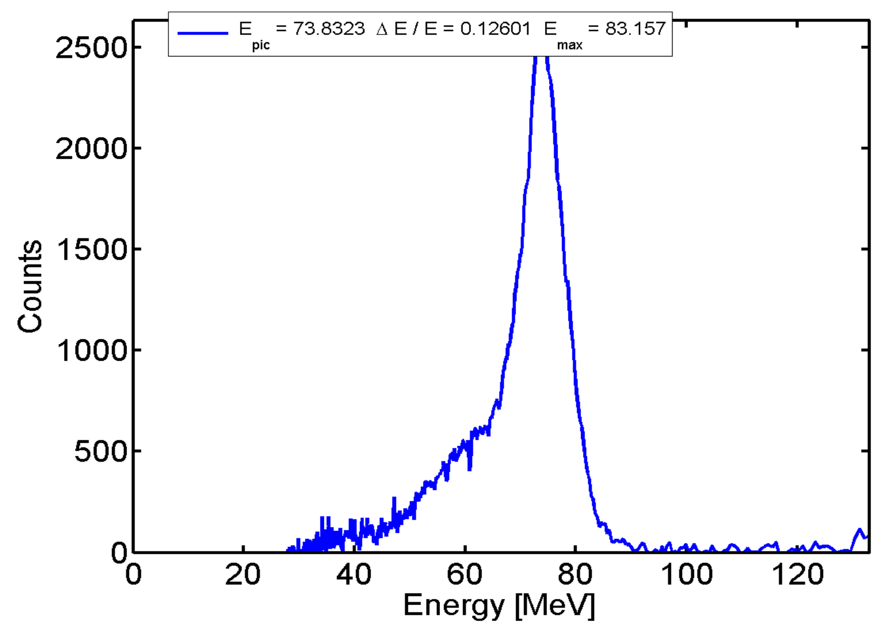


First encouraging results on UHI100

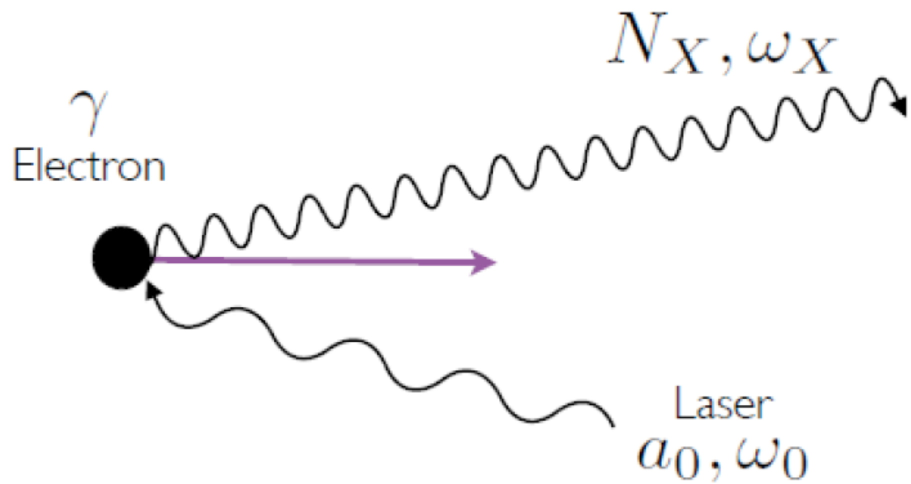








Inverse Compton Scattering

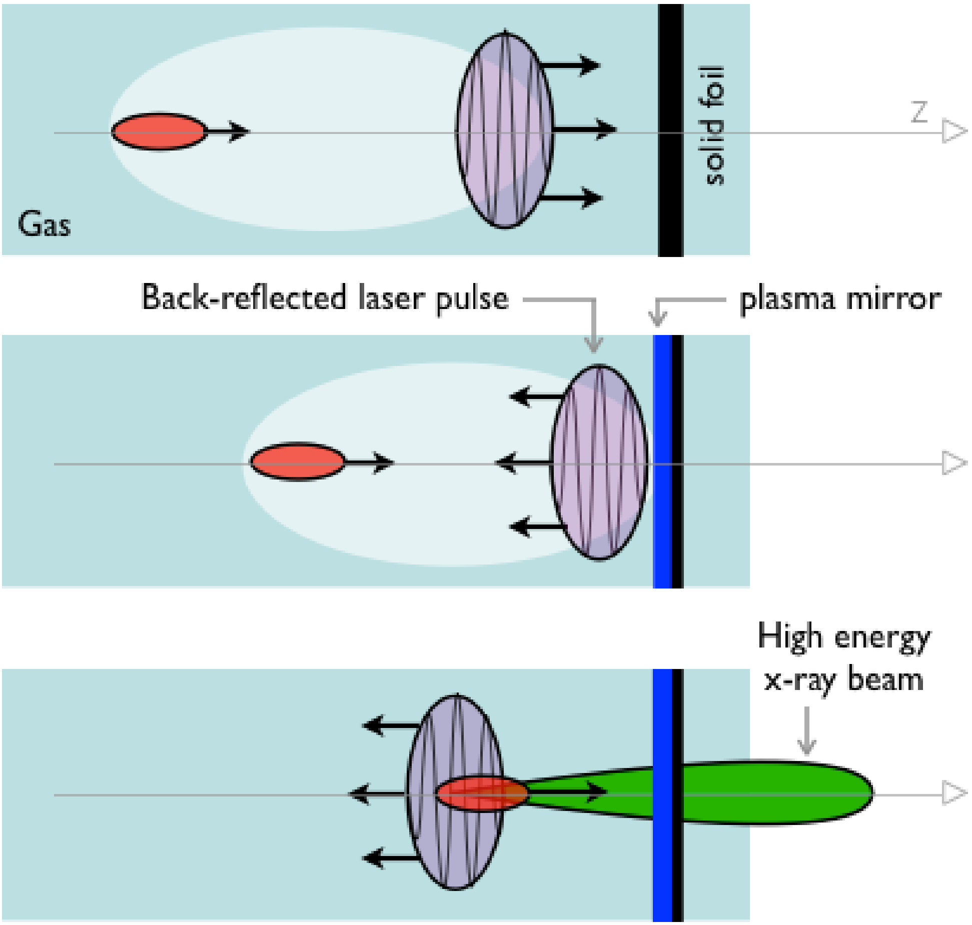


Doppler upshift : high energy photons with modest electrons energy : $\omega_X = 4\gamma^2\omega_0$

20 MeV electrons can produce 10 keV photons
200 MeV electrons can produce 1 MeV photons

Bottlenecks :
- superposition of e-laser beams (fs/µm precision)

Inverse Compton Scattering : New scheme



A single laser pulse

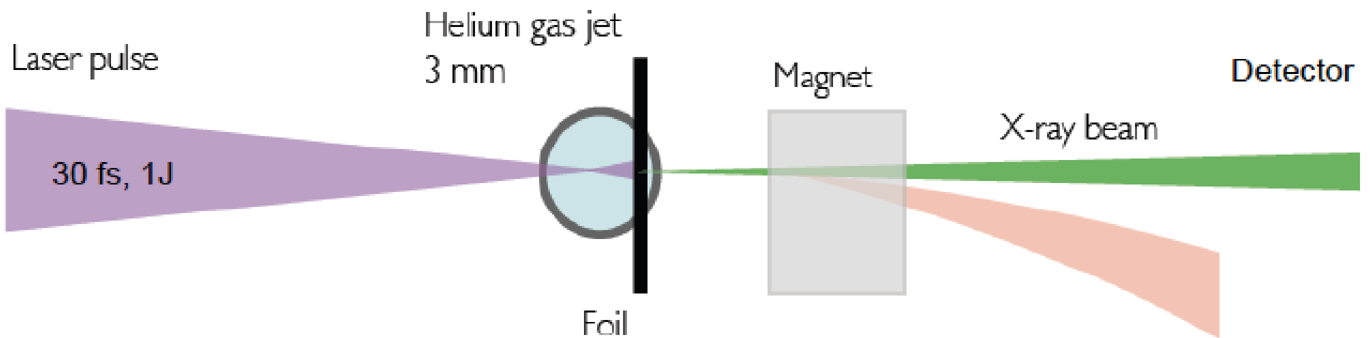
A plasma mirror reflects the laser beam

The back reflected laser collides with the accelerated electrons

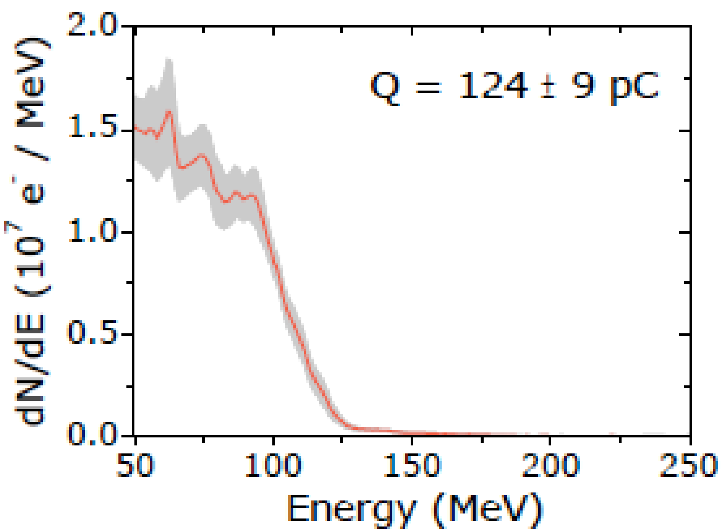
No alignment : the laser and the electron beams naturally overlap

Save the laser energy !

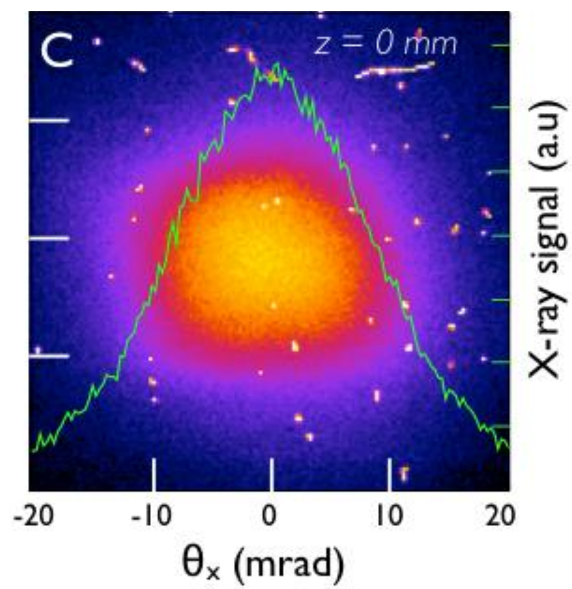
Inverse Compton Scattering : New scheme



Electron spectra



X ray beam profile



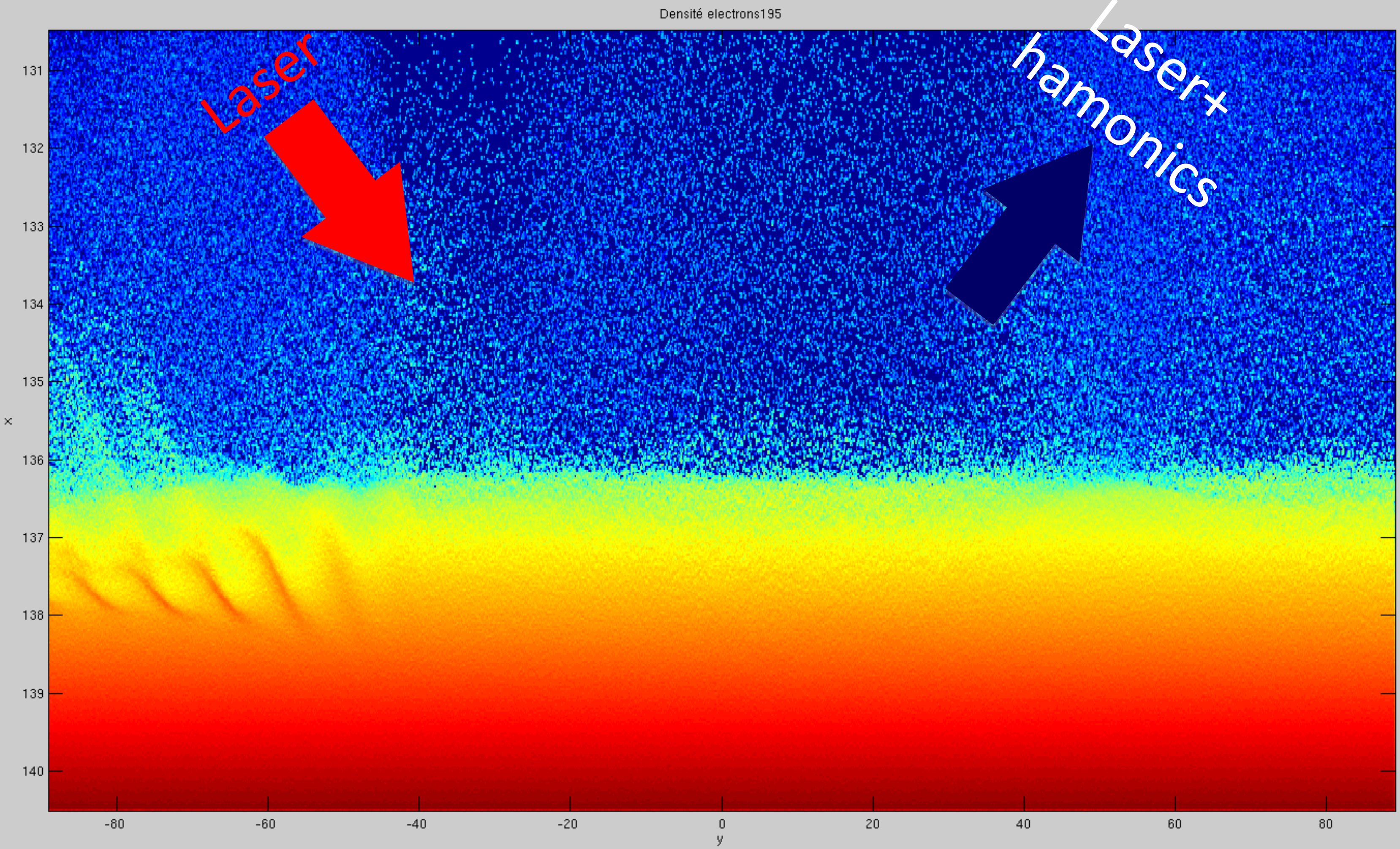
K. Ta Phuoc et al, Nature Photonics 6, 308–311 (2012)

Overdense plasmas

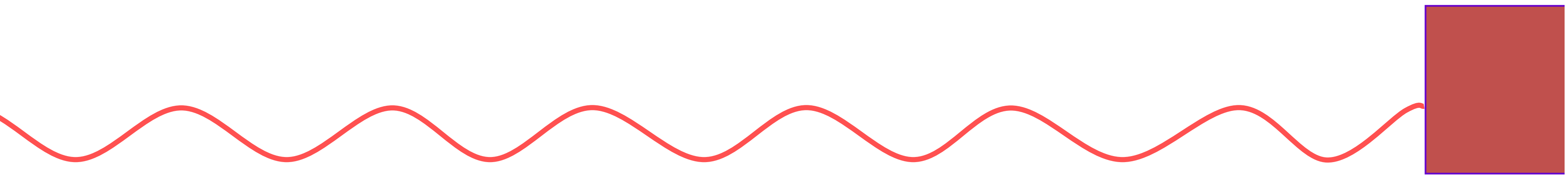
High Order Harmonics generation
Attophysics
Ion acceleration
Electron acceleration

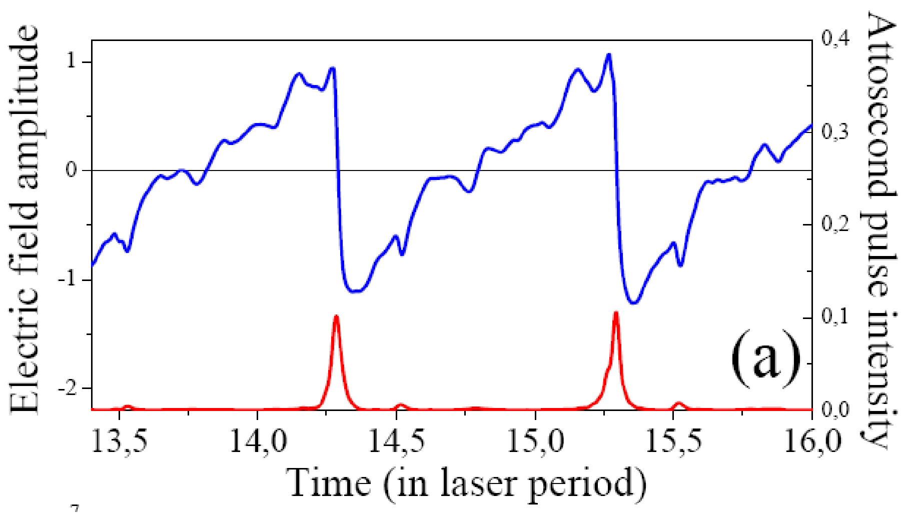
LIDyL, LOA, DPTA

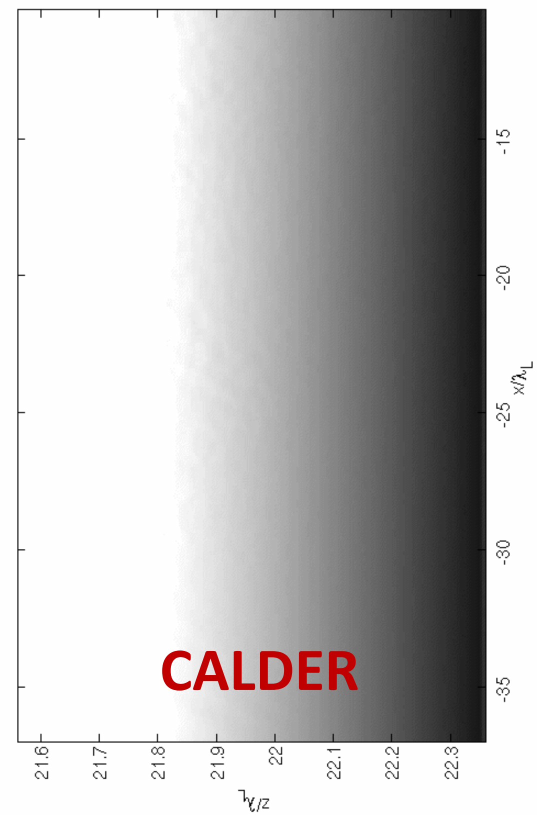
HHG on plasma mirrors in the Relativistic Regime



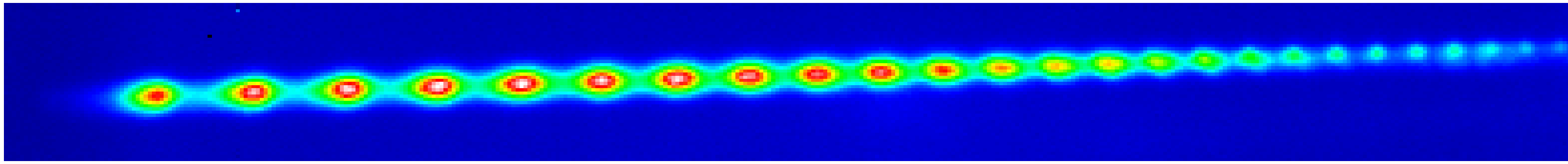
Particle-In-Cell simulations $I=3.\ 10^{19}$ W/cm²

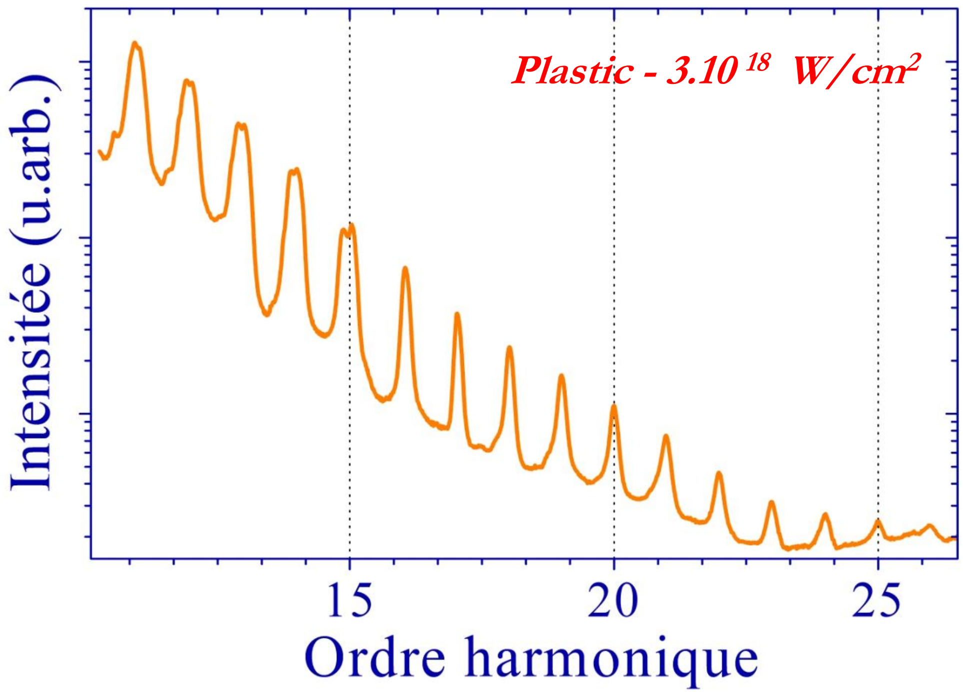






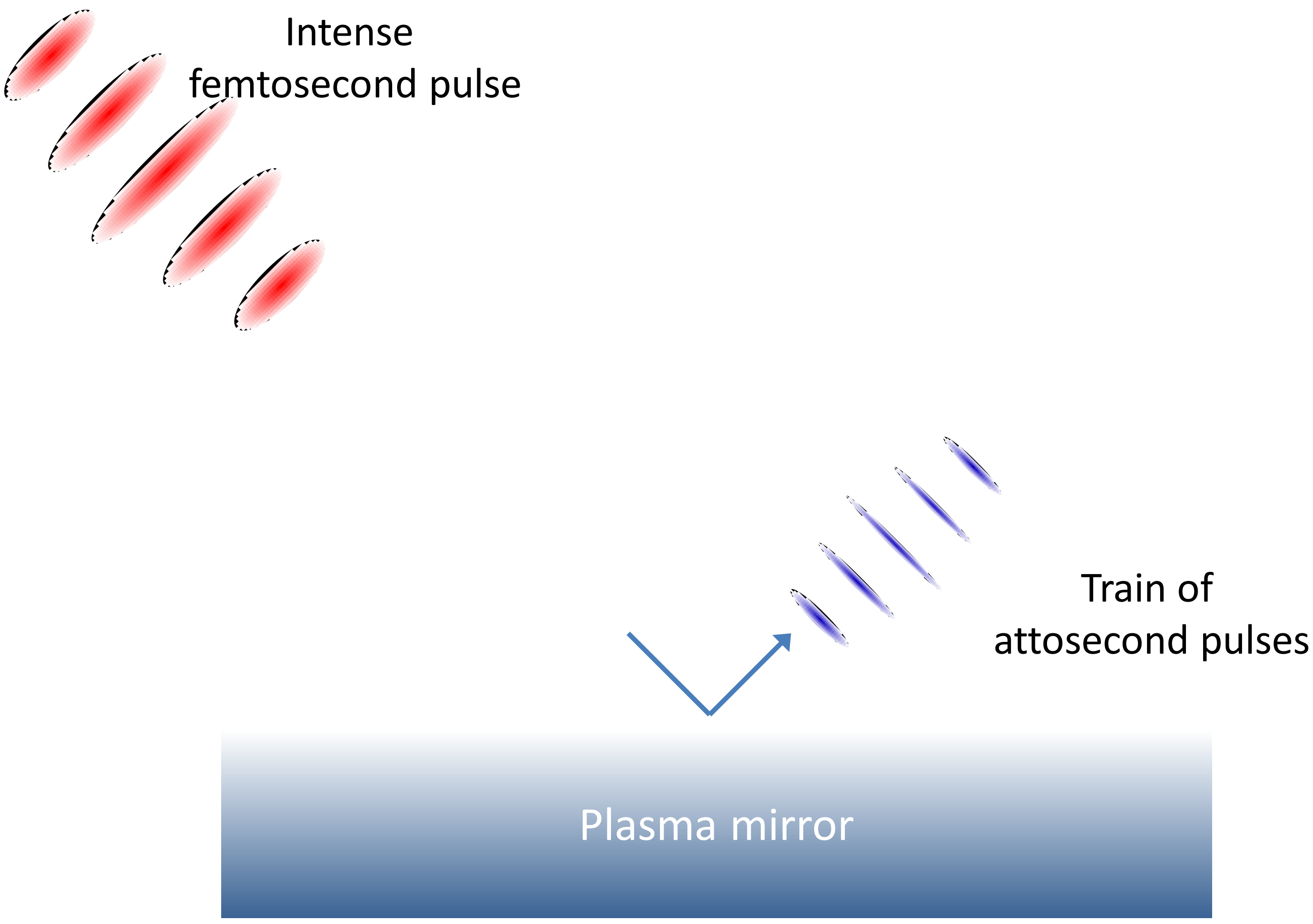
Experimental evidence : relativistic harmonics





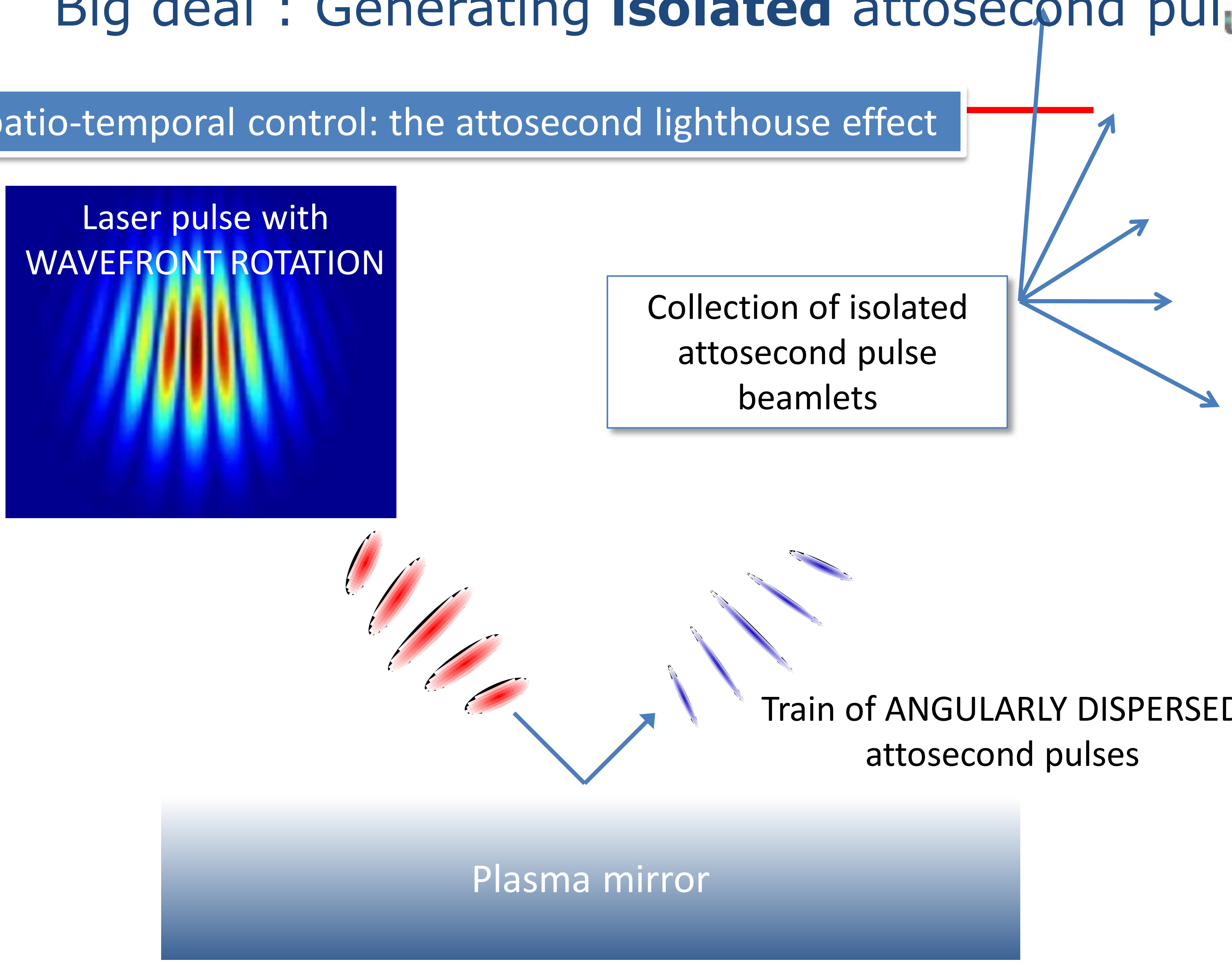
Thaury et al, Nature Physics 3, 424 (2007)

How to generate isolated attosecond pulses?



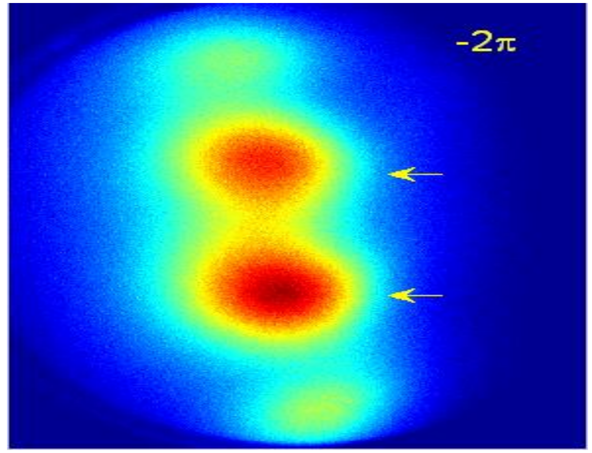
Big deal : Generating **isolated** attosecond pul

Spatio-temporal control: the attosecond lighthouse effect



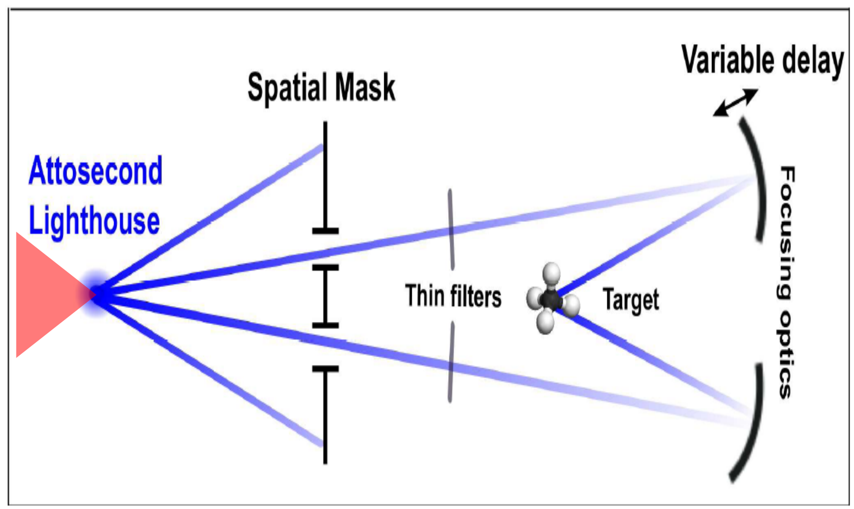
H. Vincenti and F. Quéré, PRL 108 (2012)

Applications of ultrafast wavefront rotation



J. Wheeler et al, Nature Photonics 6, 828-832 (2012)

Control:
Attosecond lighthouses



Applications:
Atto-Attophysics

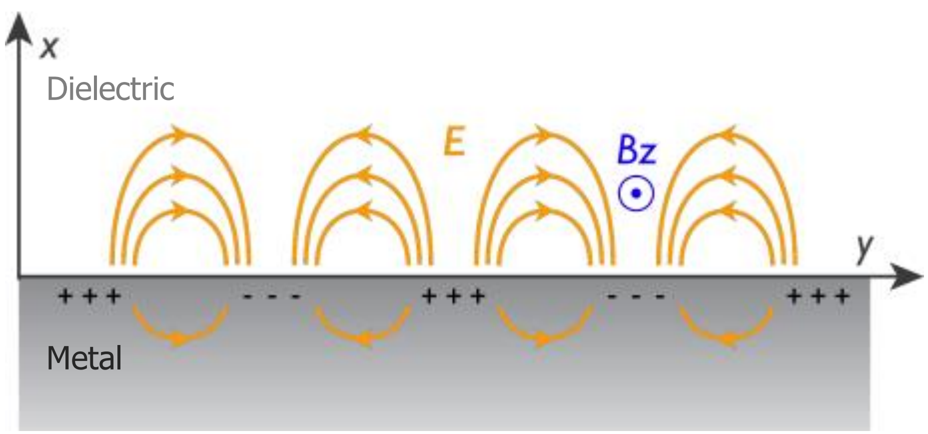
F.Quéré et al, J. Phys. B 47 (2014) 124004

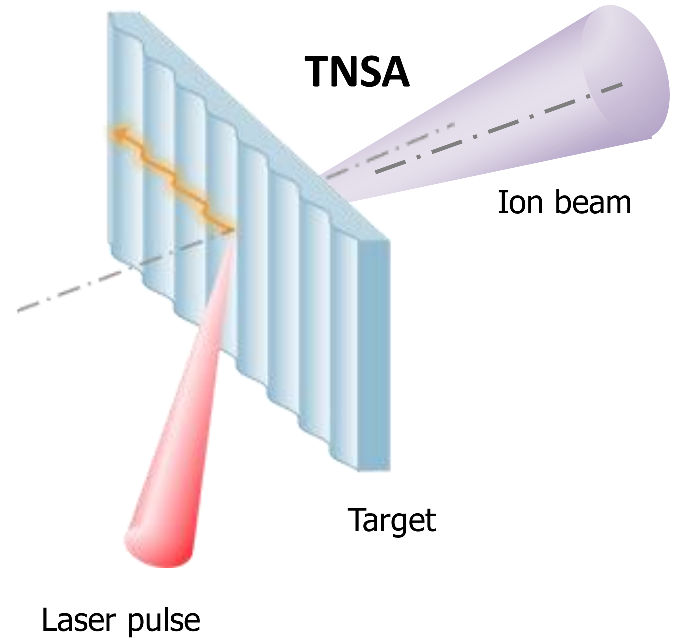
Research framework on electron and ion acceleration

Goal: Enhance particle acceleration

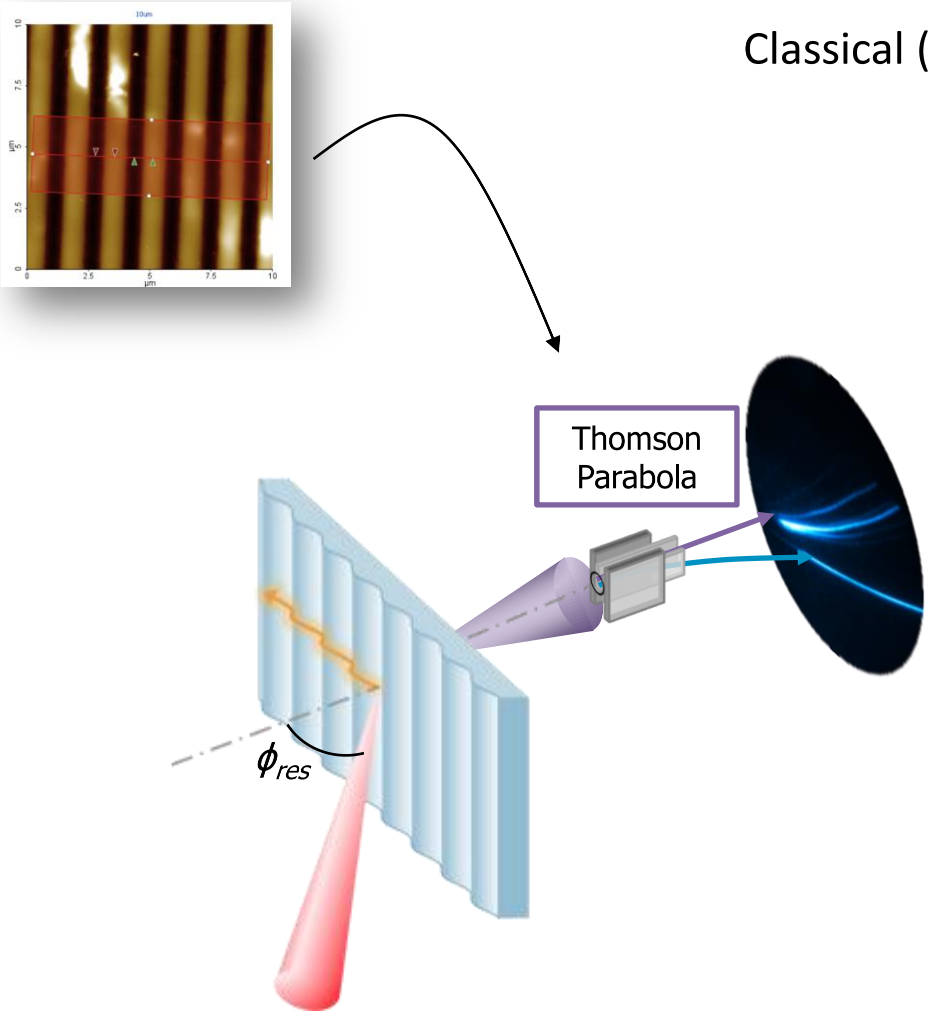
Approach: Improving laser-target energy coupling

Idea: Excite resonant modes in the solid target (*Surface Plasma Waves*, *SPW*)



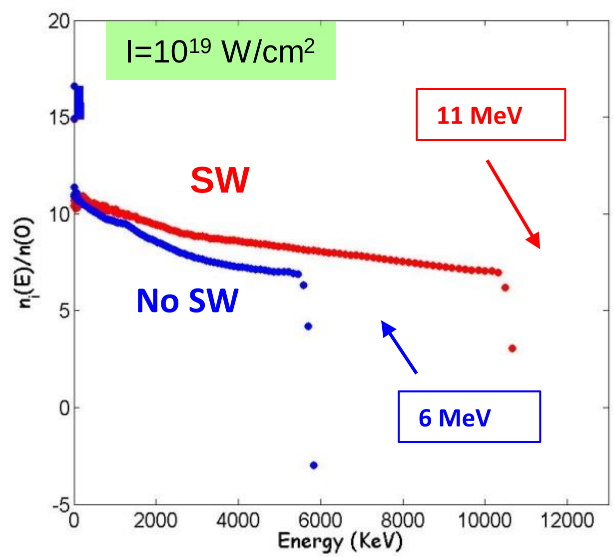


ION ACCELERATION FROM GRATINGS



Classical (non-relativistic) matching equation for a SPW

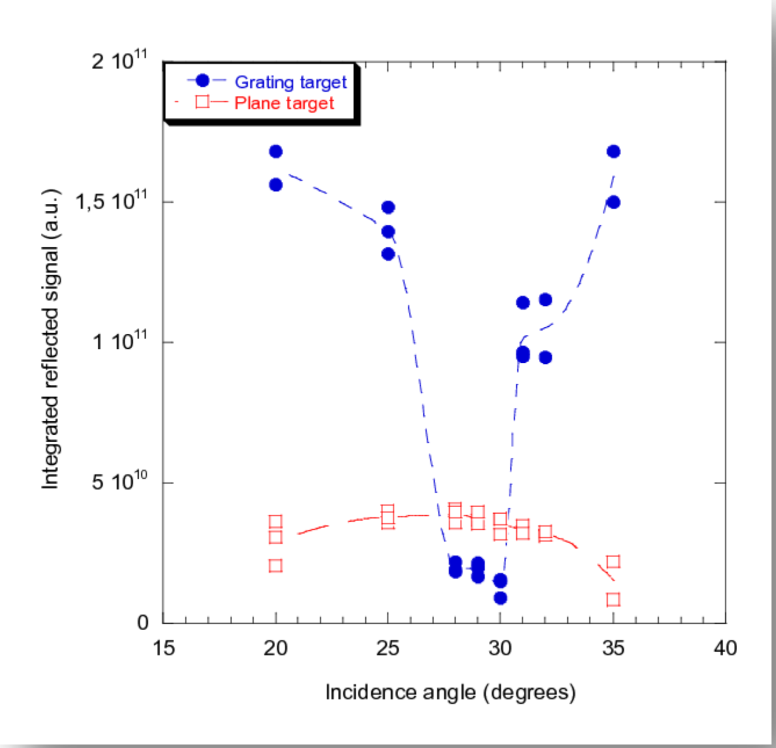
$$\sin\alpha + \frac{l}{a} = 1 + \frac{n_e}{2n_c}$$

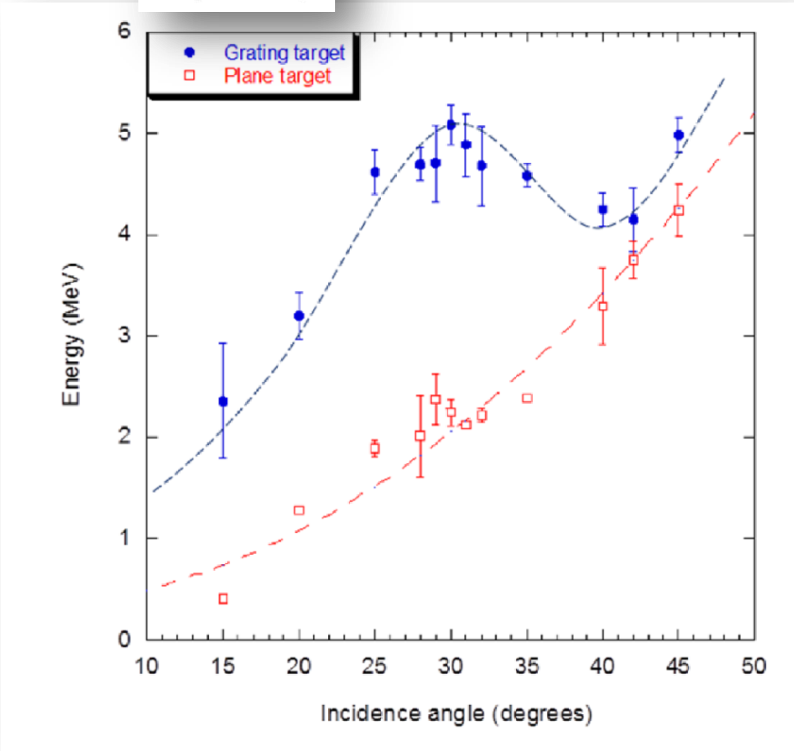


SPW Excitation ⇨ proton energy ~ x 2

Relativistic plasmonics

Laserlab : LIDyL, Czech Technical University, INO



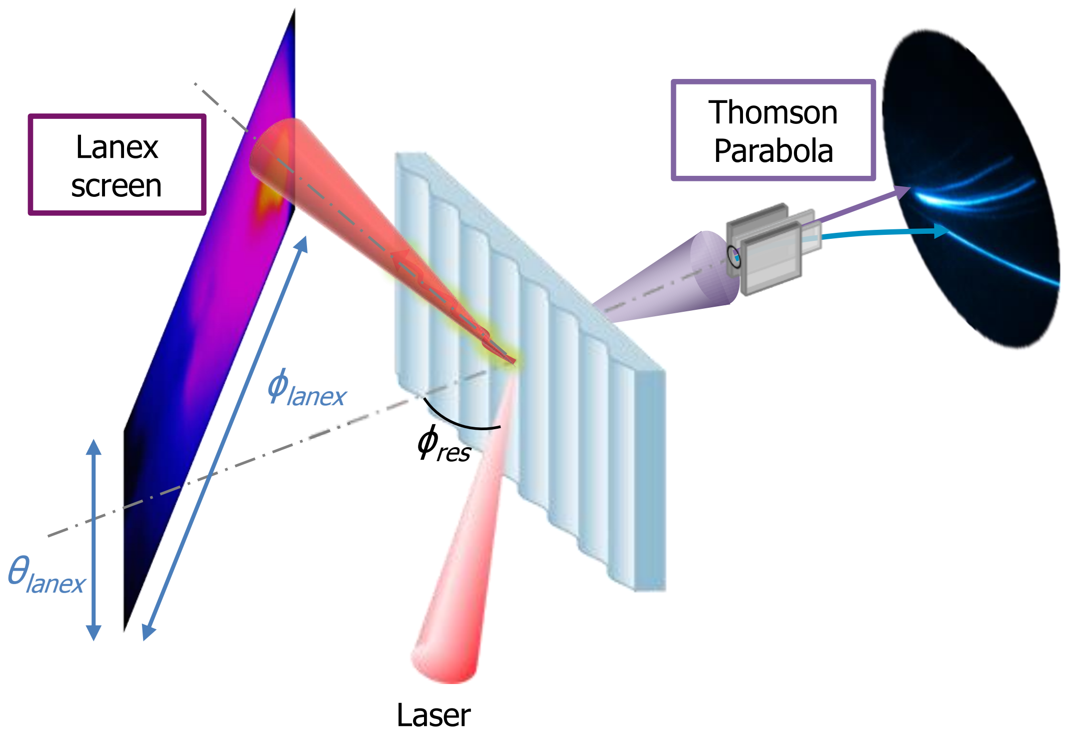


First experimental evidence of SPW excitation in the relativistic regime

T. Ceccotti et al., Phys. Rev. Lett. 111, 185001, (2013)

Campaign to investigate electron emission

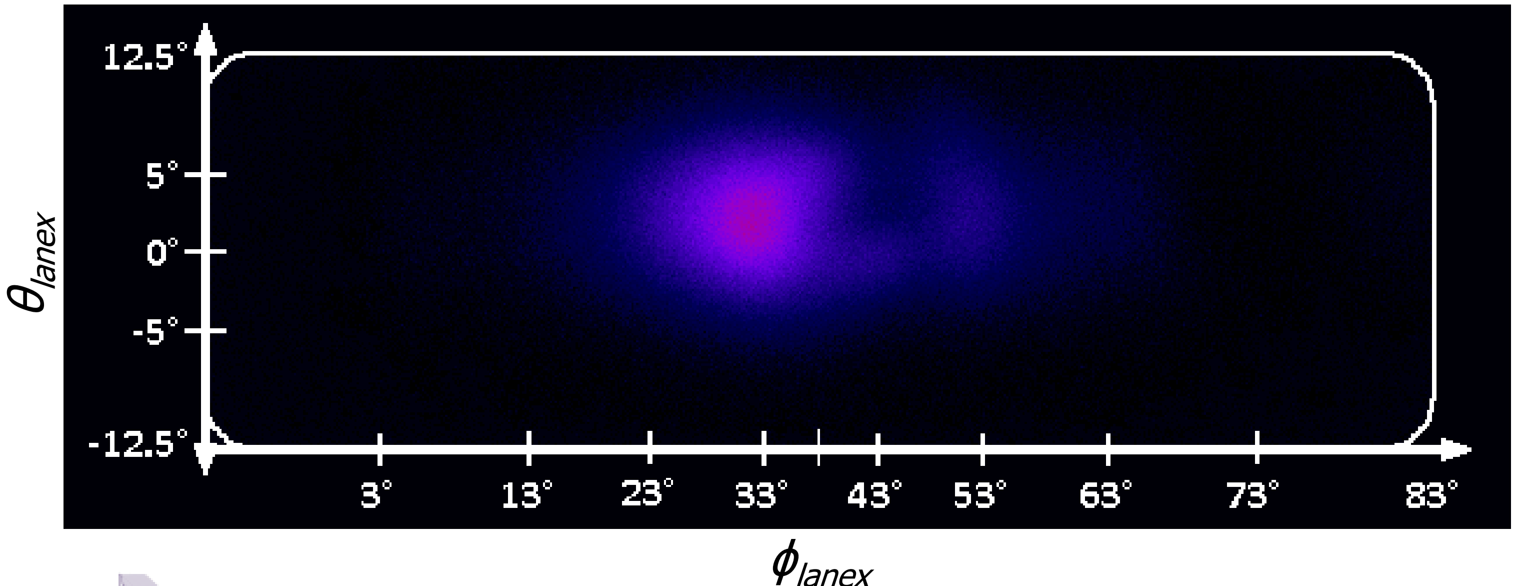
P.I. : A. Macchi - INO

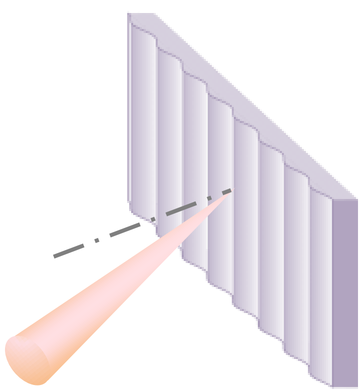


Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within $\pm 5^\circ$ error)
- reduction of electron signal at tangent; larger spread of the electron bunch





φ_i= 15°

m=0 at 75°

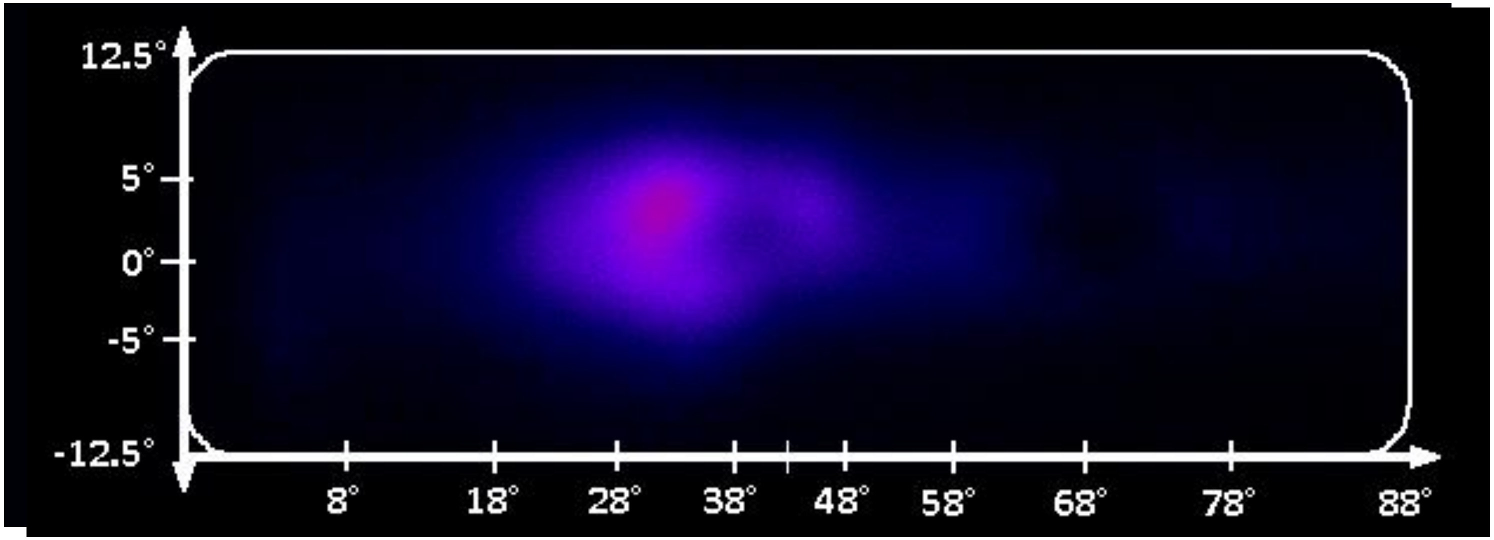
m=-1 at 42°

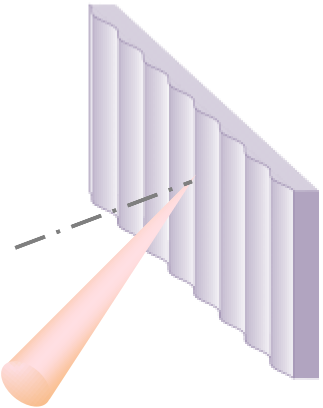
(φ angular scale is shifted in figure because of lanex misalignment)

Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within ± 5° error)
- reduction of electron signal at tangent; larger spread of the electron bunch





φ_i= 20°

m=0 at 70°

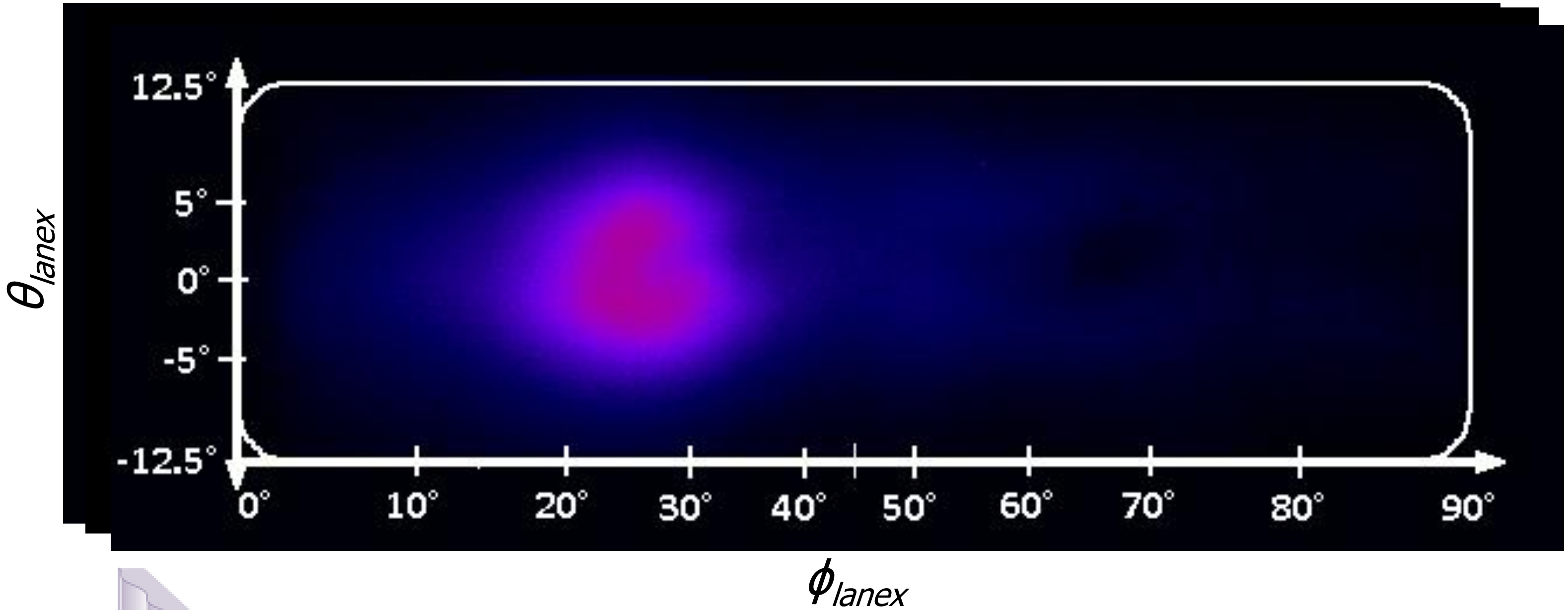
m=-1 at 35°

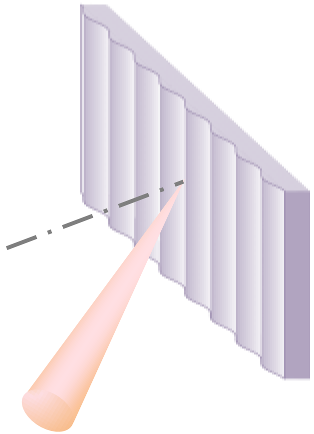
(angular scale is shifted in figure because of lanex misalignment)

Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within ± 5 ° error)
- reduction of electron signal at tangent; larger spread of the electron bunch





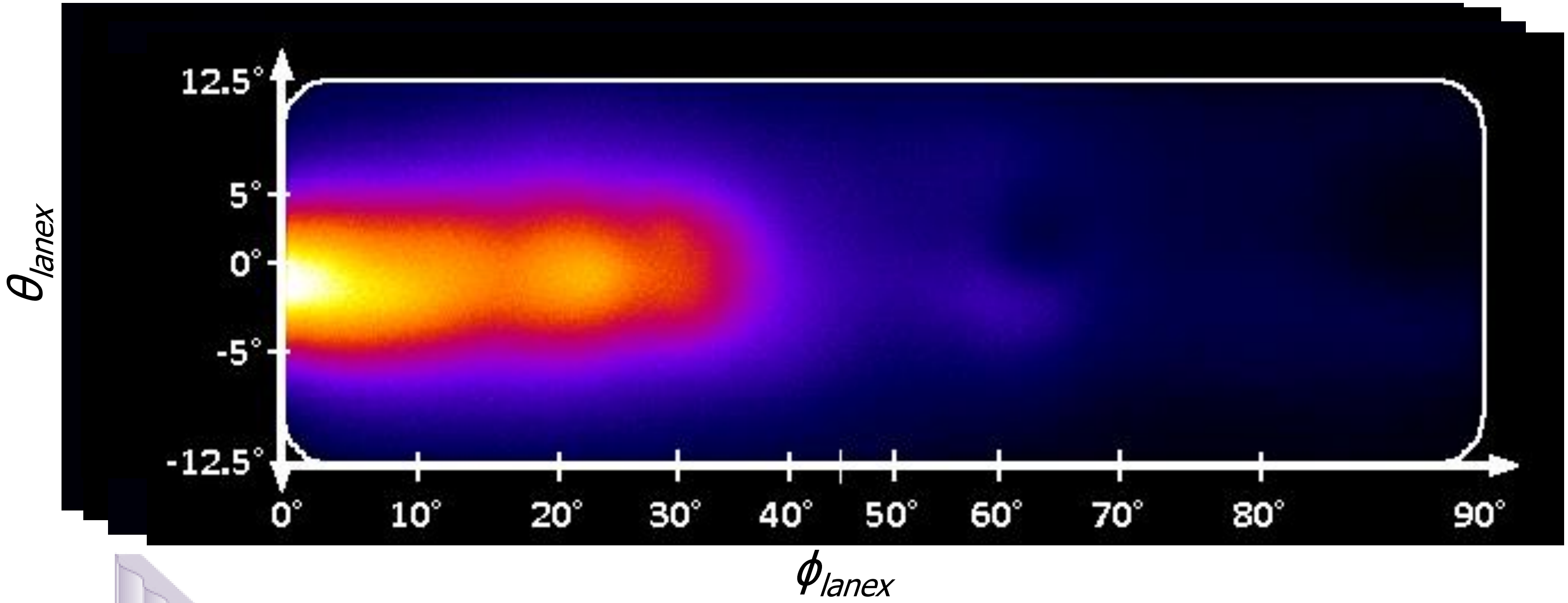
φ_i= 25°

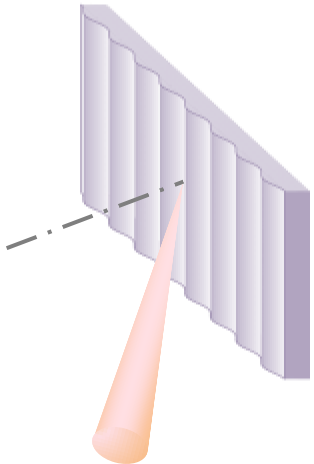
m=0 at 65°
m=-1 at 25°

Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within ± 5 ° error)
- reduction of electron signal at tangent; larger spread of the electron bunch





φ_i= 30°

m=0 at 60°

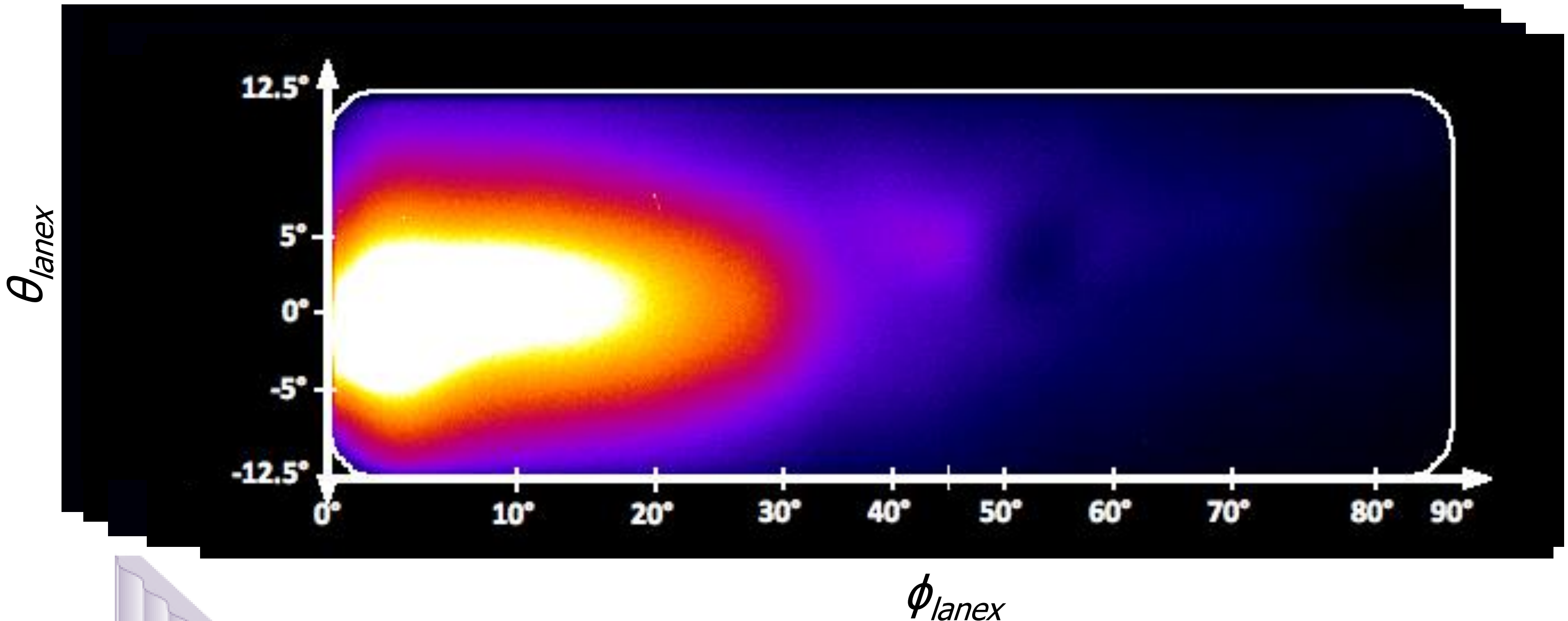
m=+1 at 89°

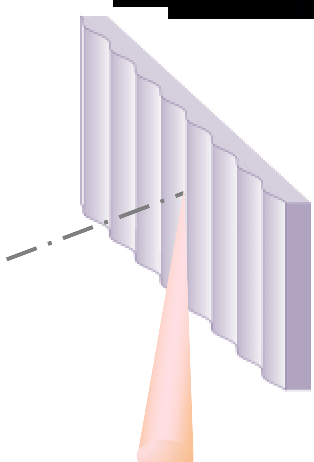
m=-1 at 11°

Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within ± 5° error)
- reduction of electron signal at tangent; larger spread of the electron bunch





φ_i= 35°

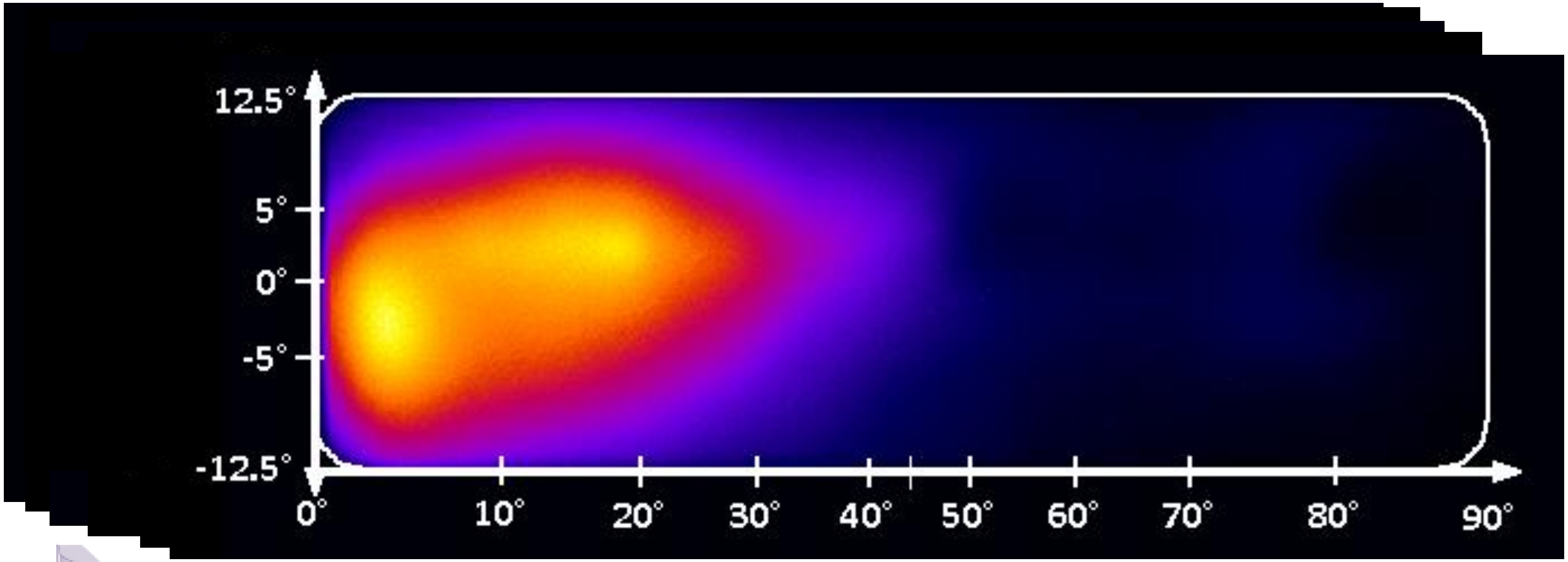
m=0 at 55°

m=+1 at 85°

Spatial distribution

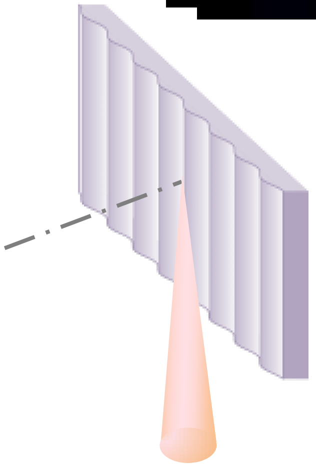
Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within ± 5 ° error)
- reduction of electron signal at tangent; larger spread of the electron bunch



θ_{lanex}

ϕ_{lanex}



φ_i= 40°

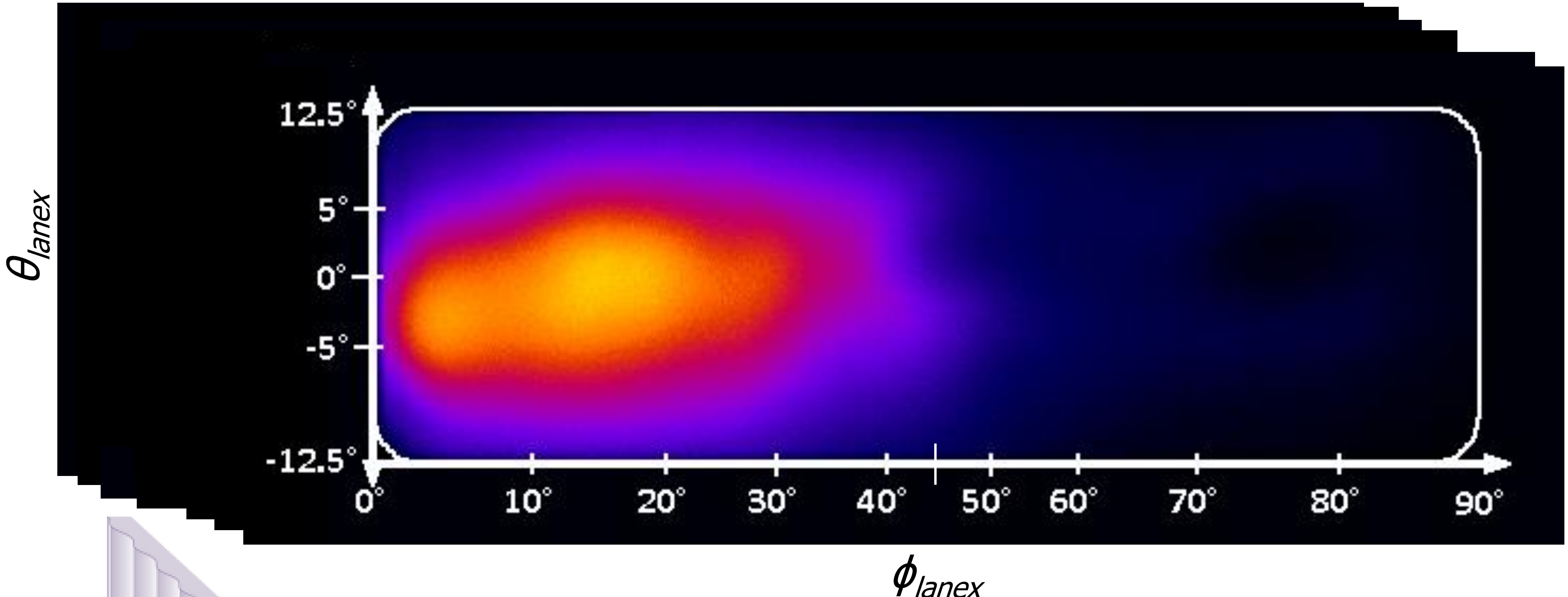
m=0 at 50°

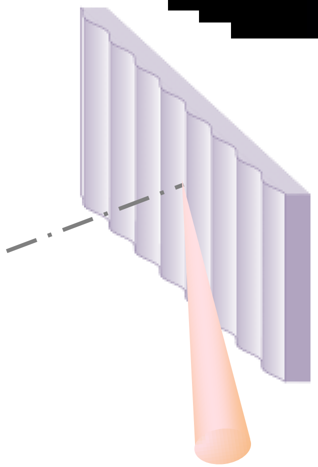
m=+1 at 81°

Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within ± 5° error)
- reduction of electron signal at tangent; larger spread of the electron bunch





φ_i= 45°

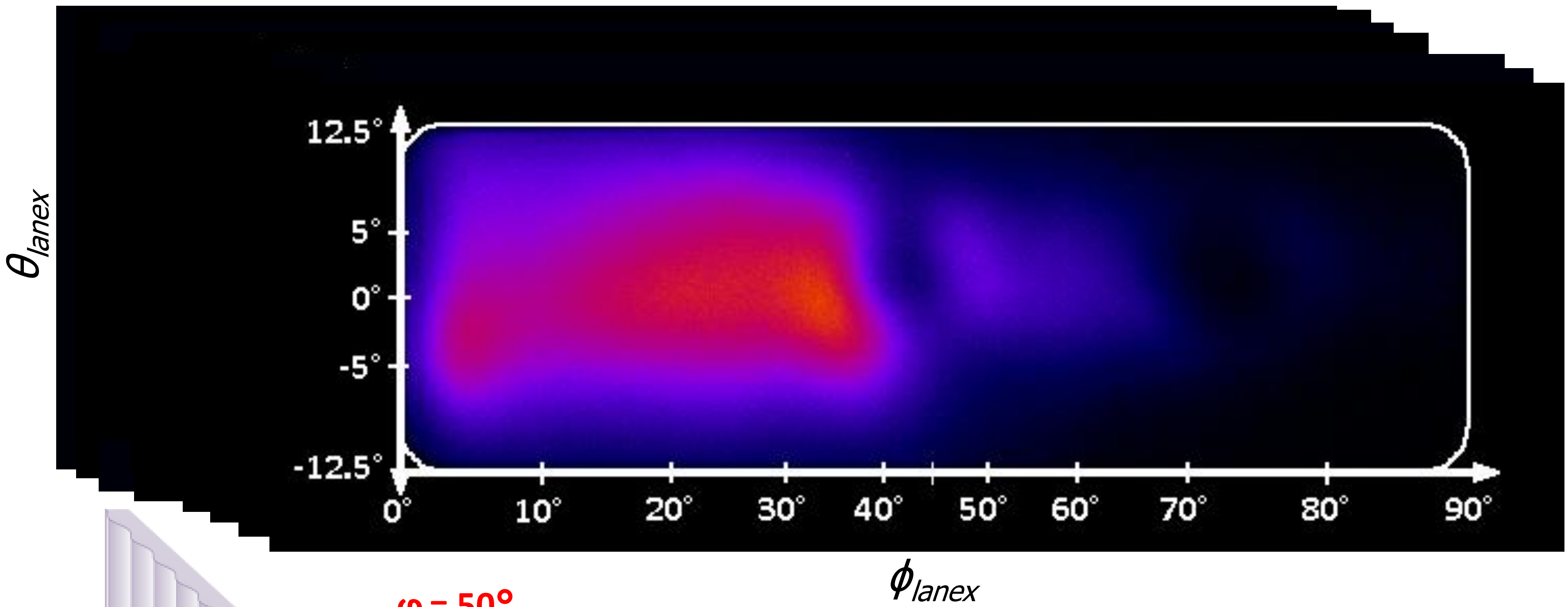
m=0 at 45°

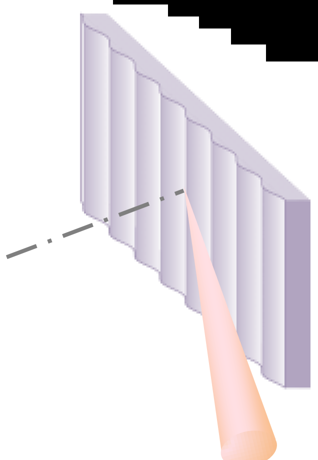
m=+1 at 77°

Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within $\pm 5°$ error)
- reduction of electron signal at tangent; larger spread of the electron bunch





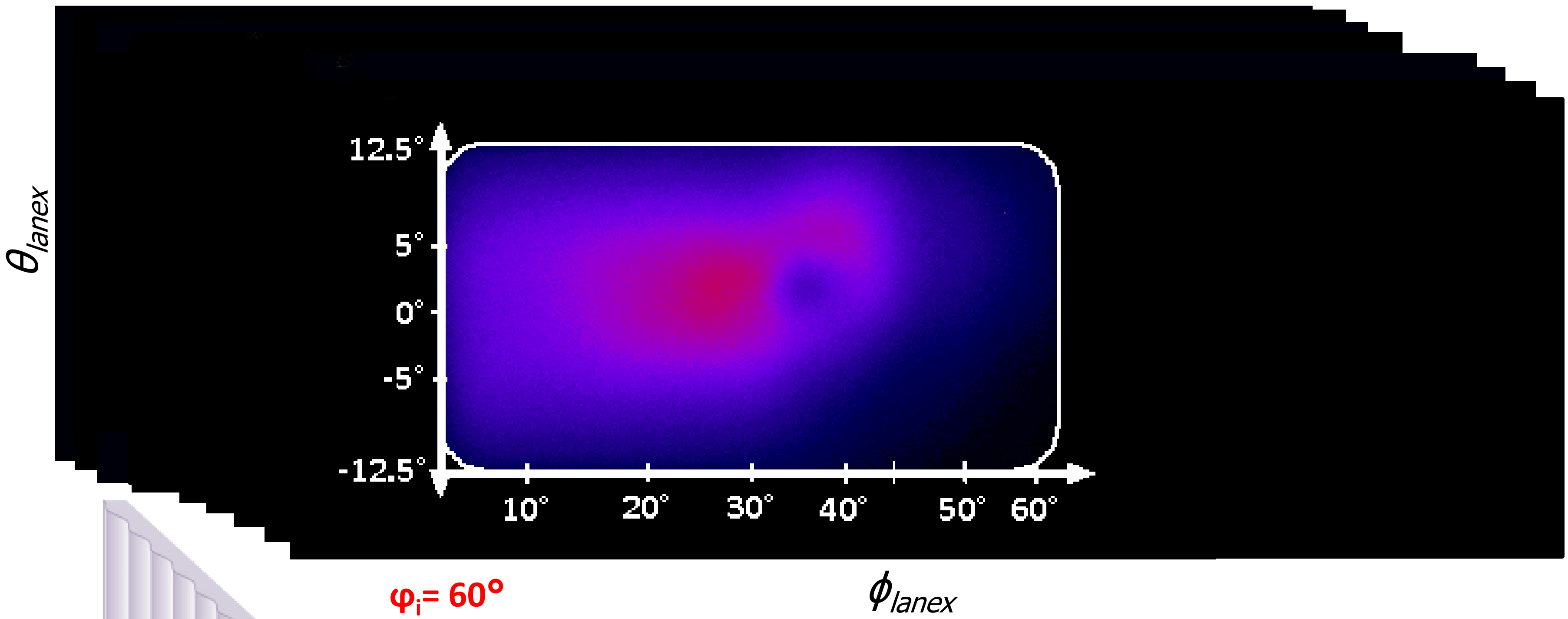
φ_i= 50°

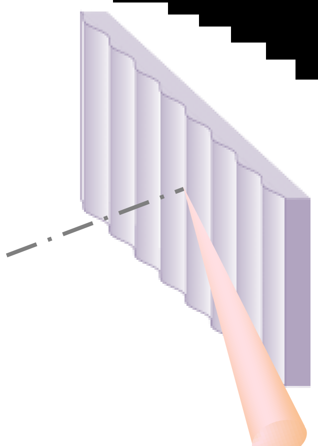
m=0 at 40°
m=+1 at 73°

Spatial distribution

Varying the laser incidence angle φ_i:

- shift of the diffraction orders (position within $\pm 5^\circ$ error)
- reduction of electron signal at tangent; larger spread of the electron bunch





φ_i= 60°

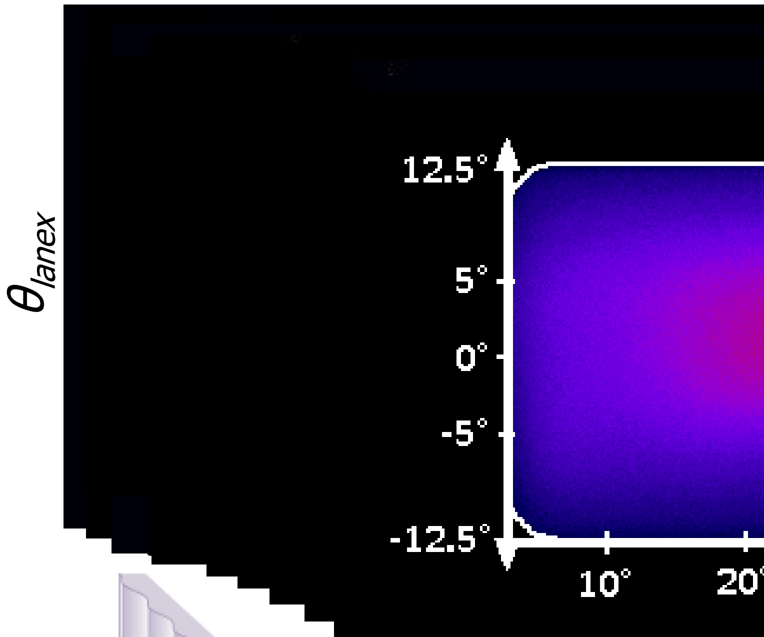
m=0 at 30°

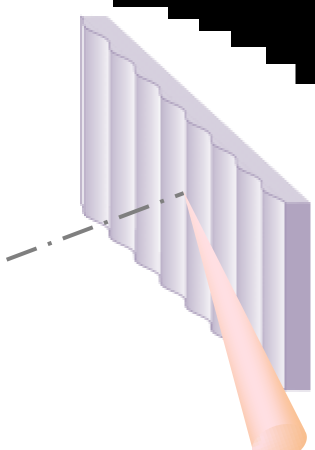
m=+1 at 67°

Spatial distribution

Varying the laser incidence angle φ_i:

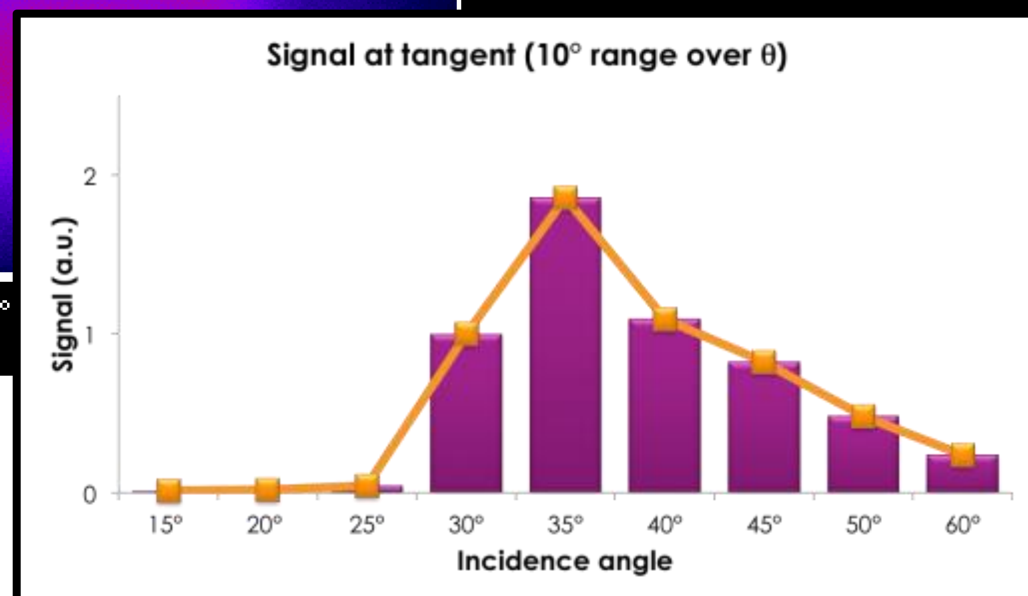
- shift of the diffraction orders (position within $\pm 5°$ error)
- reduction of electron signal at tangent; larger spread of the electron bunch





φ_i= 60°

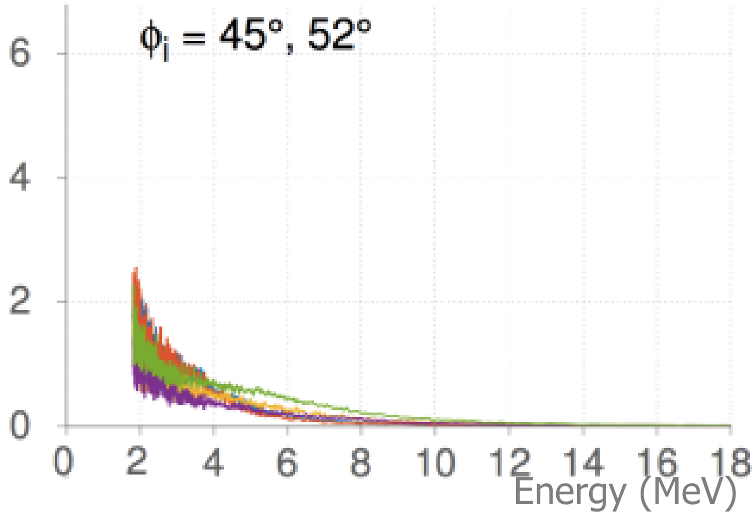
m=0 at 30°
m=+1 at 67°



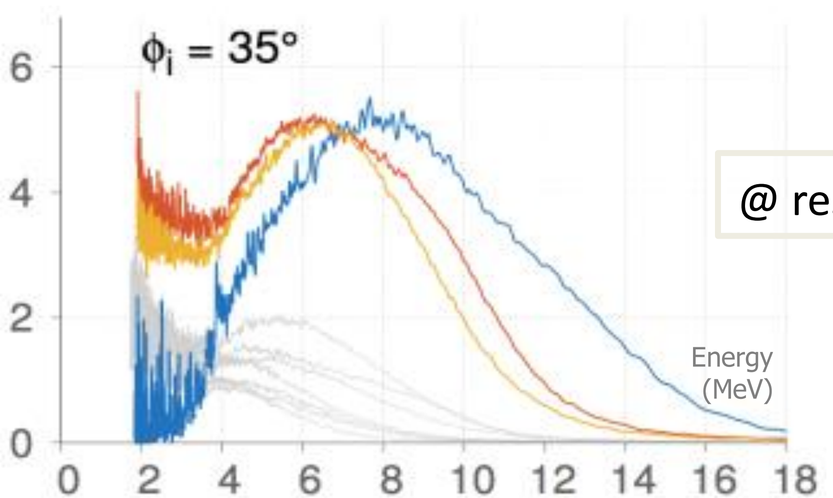
Are there any other processes competing with surface plasmons acceleration along the tangent?

>> see Hu et al., Phys. of Plasmas, **17**, 3102 (2010)

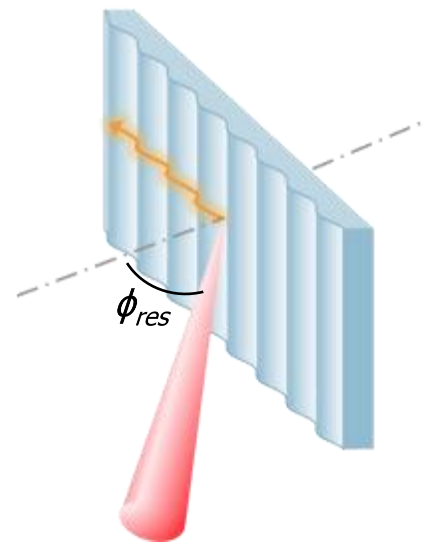
Electron spectra



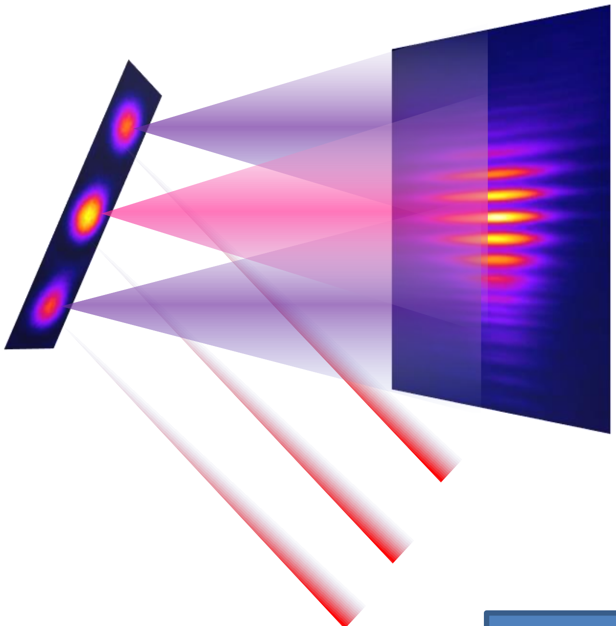
Off resonnance



@ resonance ($\varphi_{i=}$ 35°)

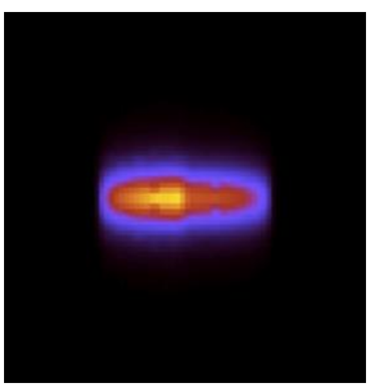


Ultimate goals on APOLLON
Ultra-Relativistic Optics with plasma Mirrors



Light manipulation with Plasma
Ultra-High HHG XUV intensities
Route to atto-physics,
electron acceleration
ion acceleration…

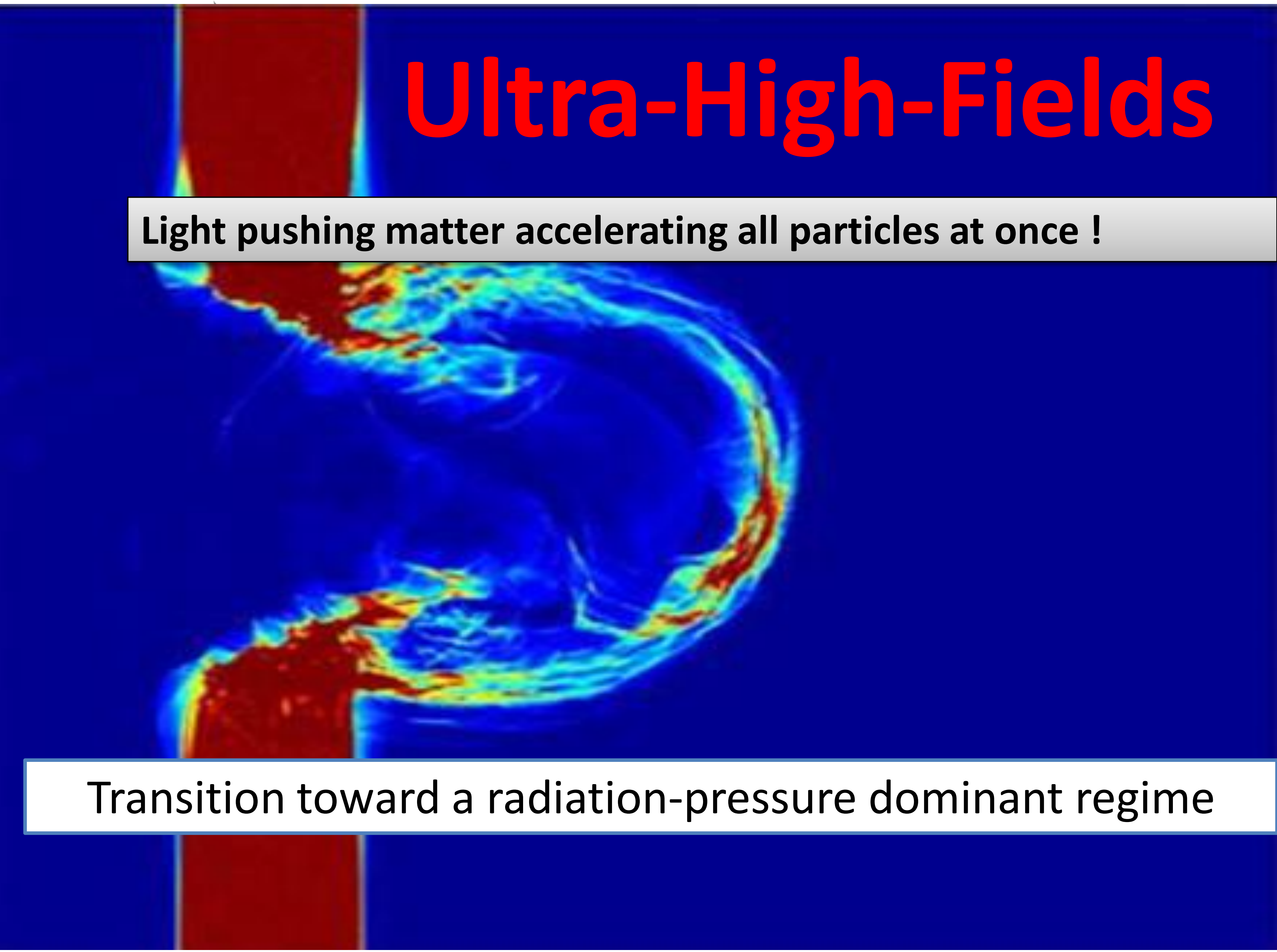
X-ray lasers and applications



X-ray laser future trends :
shorter wavelengths, brighter beams, shorter durations!

Ultra-High-Fields

Light pushing matter accelerating all particles at once !

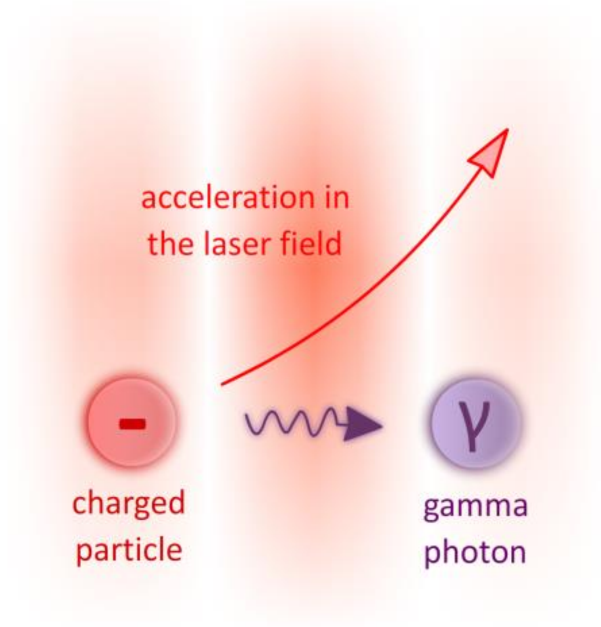


Transition toward a radiation-pressure dominant regime

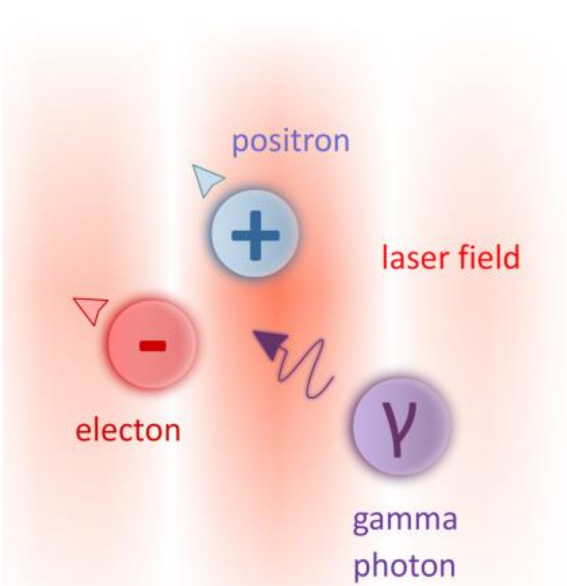
Above 10^{22} W/cm^2

High Energy Photon emission and QED processes must be taken into account

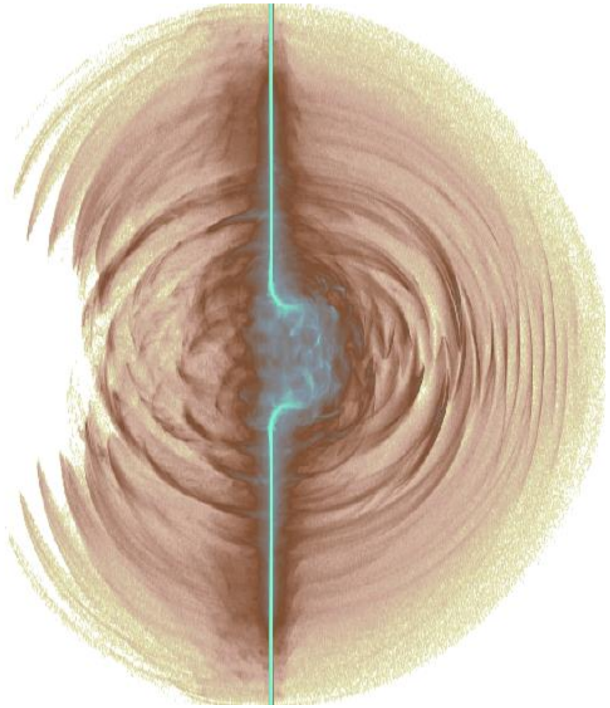
Thomson / Compton non linéaire, Bremmstrahlung, pair production, photon recoil,…



Non-linear Compton scattering: high-frequency photon emission in the laser field



Multiphoton Breit-Wheeler: e^- generation in the laser field 10^{23} Wcm^{-2})



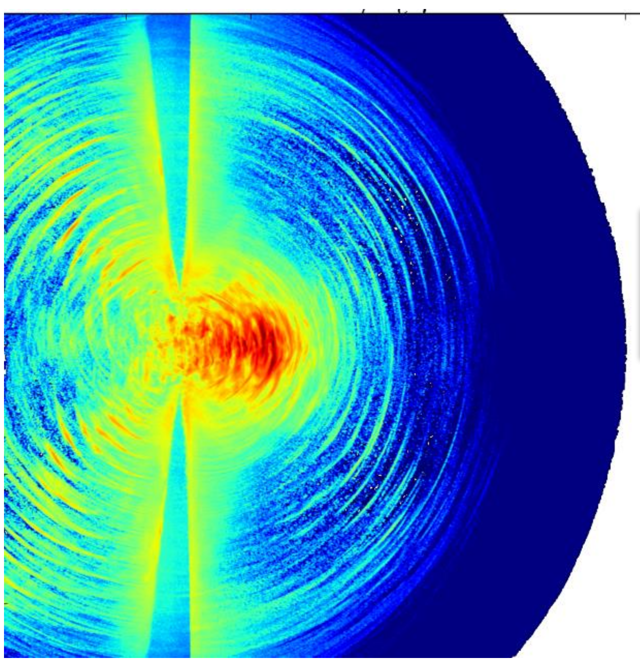
Implementation of these mechanisms in the PIC codes

High-Field- Physics

Design and Interpretations of future experiments with APOLLON and above

Fundamental importance to account for physical effects occurring above 10^{22} W/cm^2 as Radiation Reaction forces

Needs for theory and intensive PIC-Monte Carlo simulations



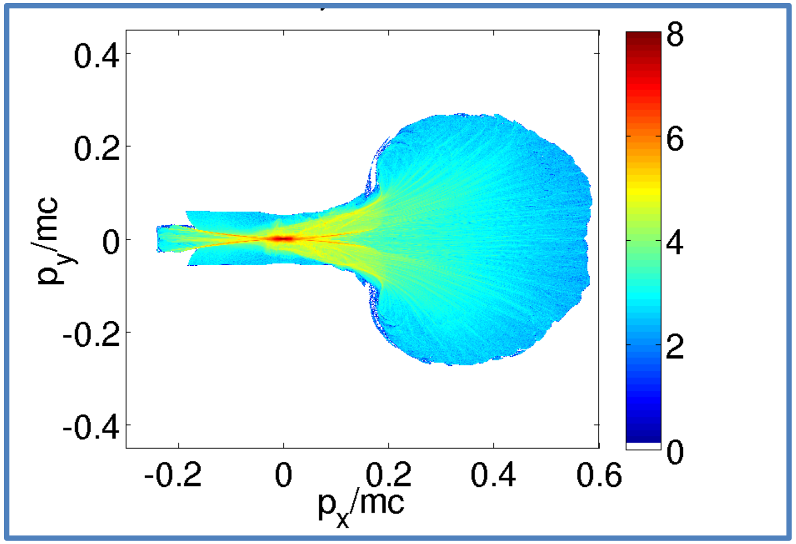
M. Lobet, C. Ruyer, A. Debayle, M. Grech, E. d'Humières, M. Lemoine, L. Gremillet

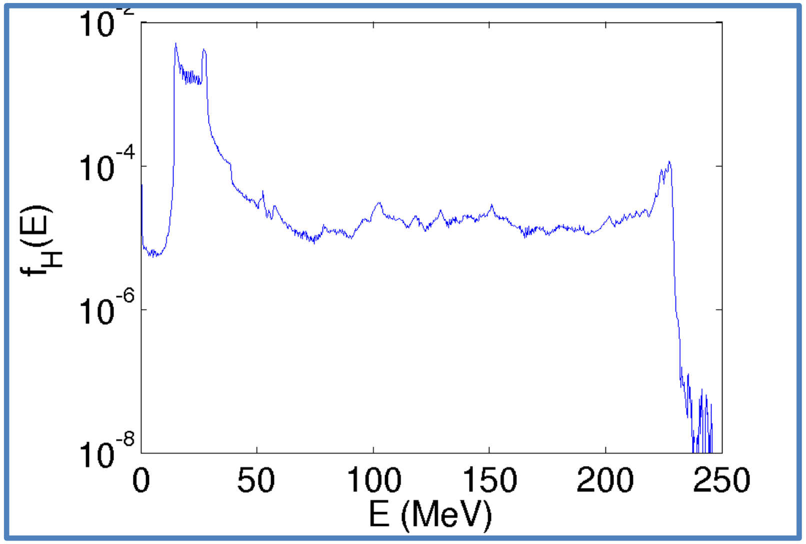
SMILEY PIC code, coll A. Di-Piazza, H. Vincenti,…

Benchmarking for the laser characterization

PIC simulations in the APOLLON parameters range (L. Gremillet-CALDER)

1.8×10^{22} Wcm^{-2}, 100 nm



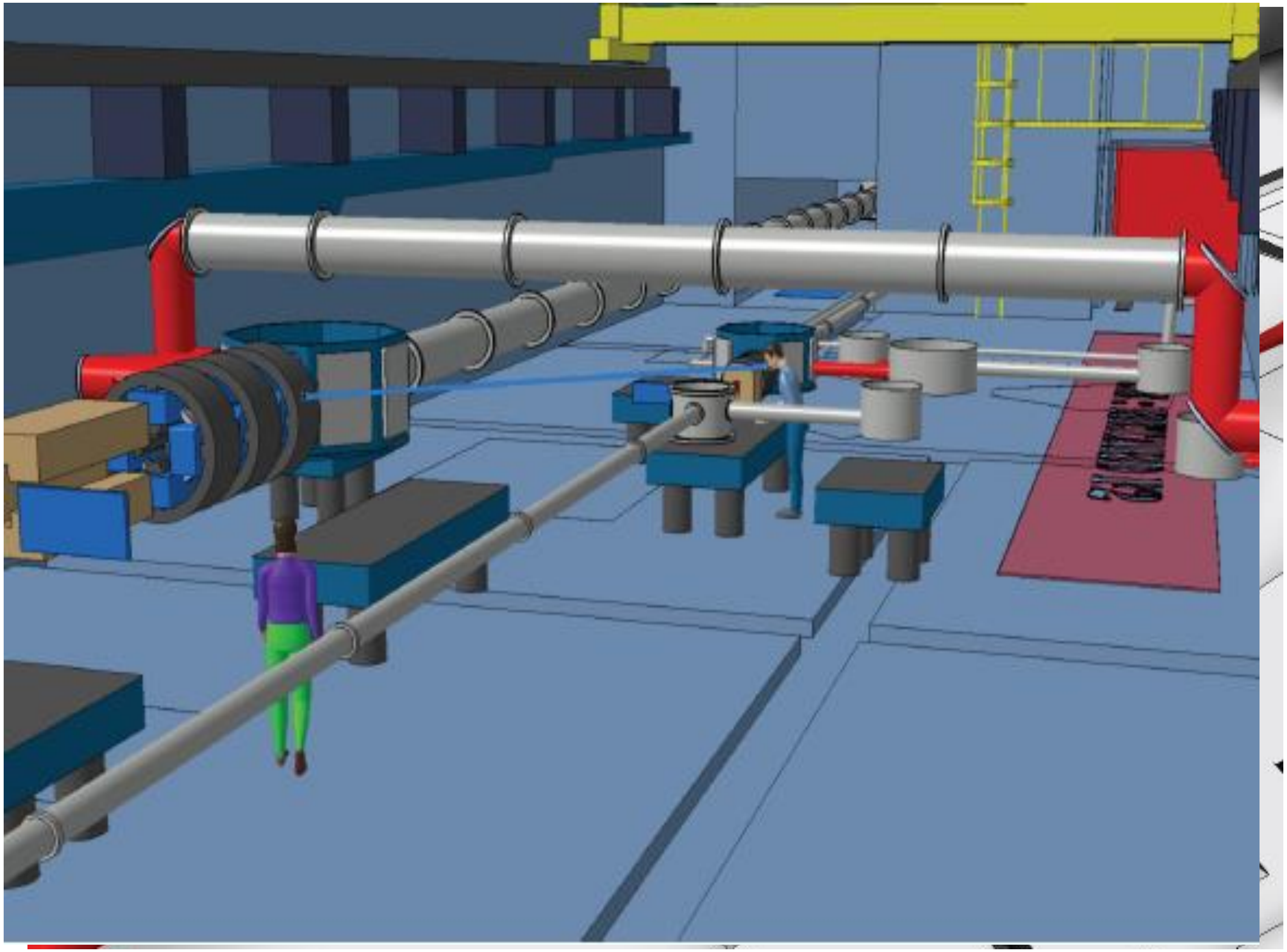


Back to CILEX experimental areas

Where are we at the minute ?

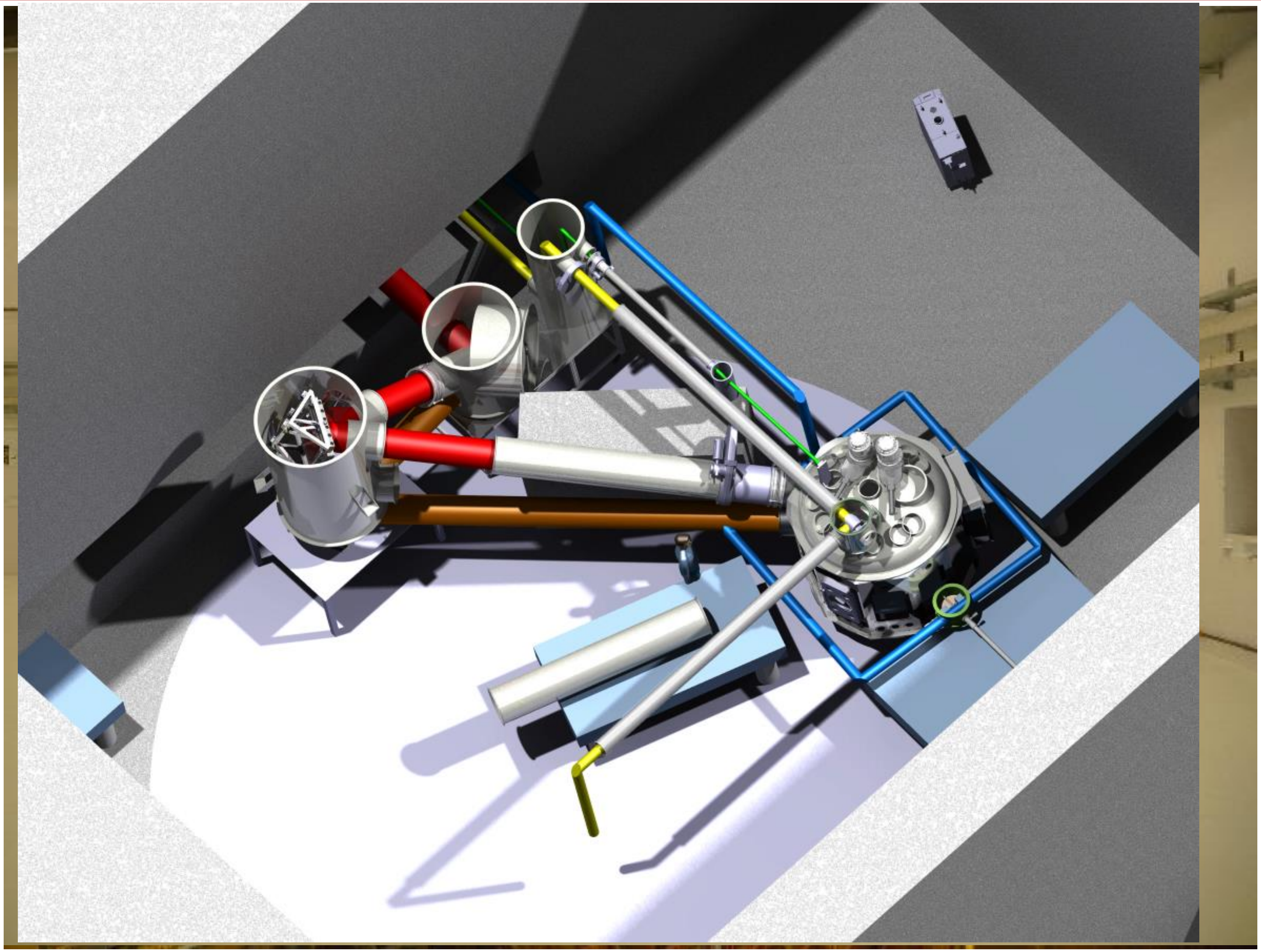
Long Focal area for electron acceleration and X ray sources

Efficient acceleration requires long focus (33 m)



Short Focal area for UHI physics

Ultra-High-Intensities requires tight focusing then short focus (1.5 m)



Apollon in l'Orme = 2015

First shots = 2016

First experiments = juanuary 2018

CileX

UPMC PARIS UNIVERSITAS

ENSTA ParisTech

cnrs INP

ÉCOLE POLYTECHNIQUE ParisTech

INSTITUT d'OPTIQUE GRADUATE SCHOOL

UNIVERSITÉ PARIS SUD

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AGENCE NATIONALE DE LA RECHERCHE ANR

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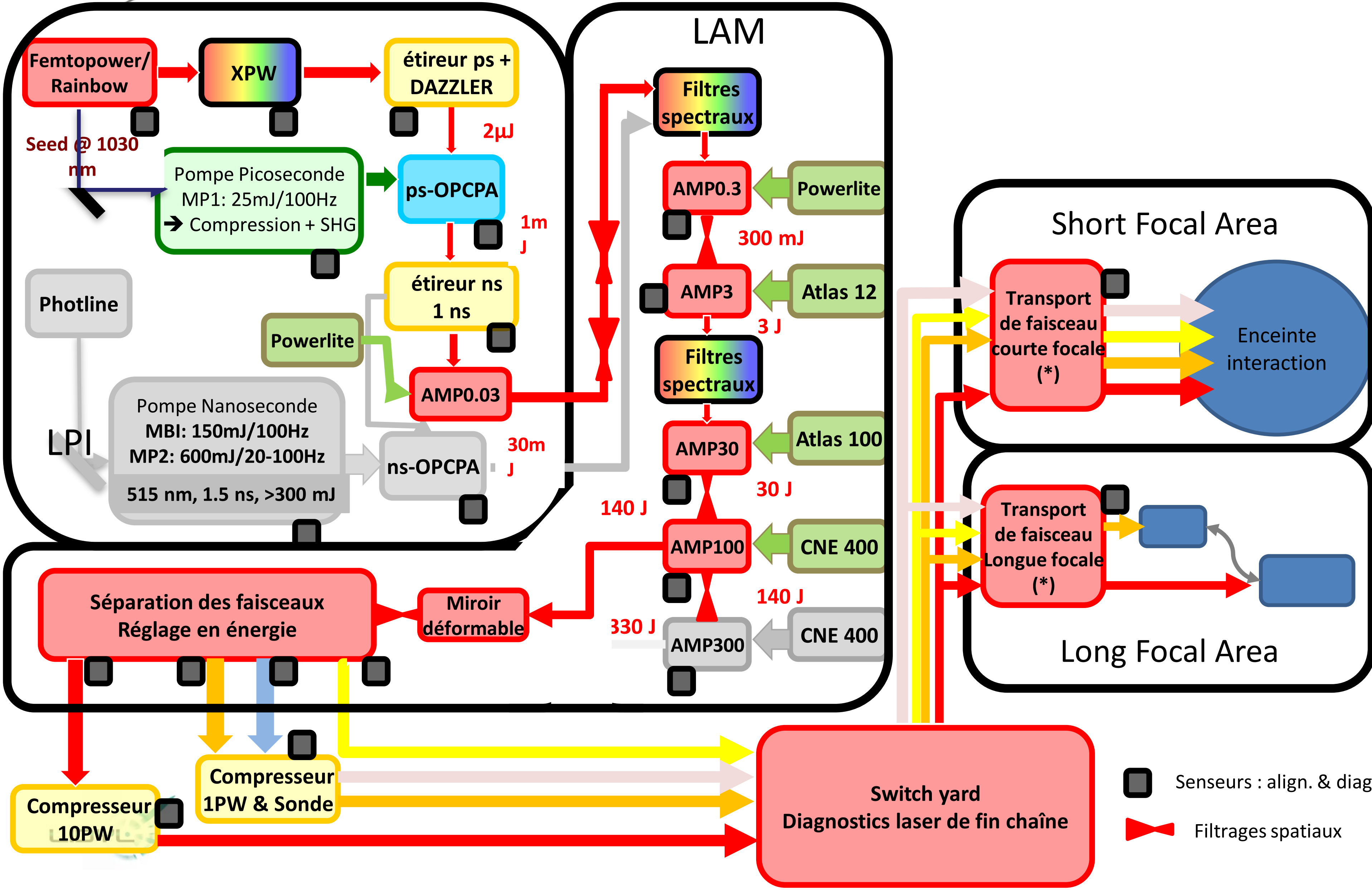
Essonne LE CONSEIL GÉNÉRAL

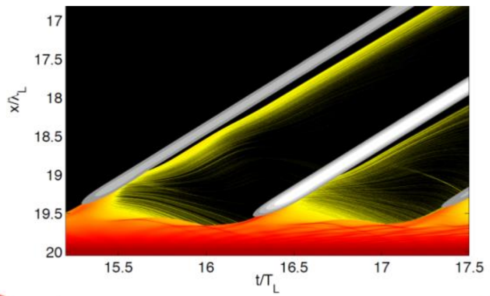
LIDYL

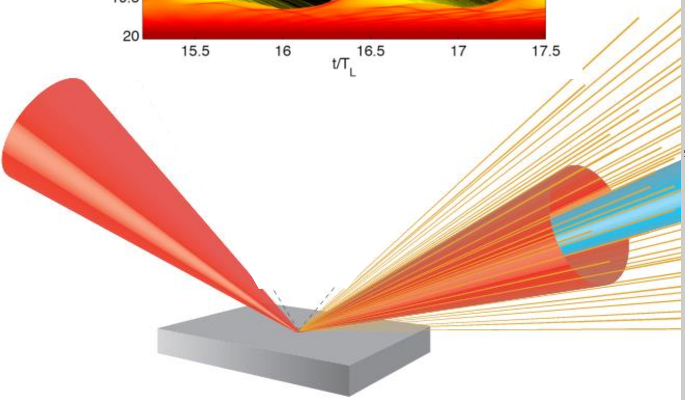
Synoptique



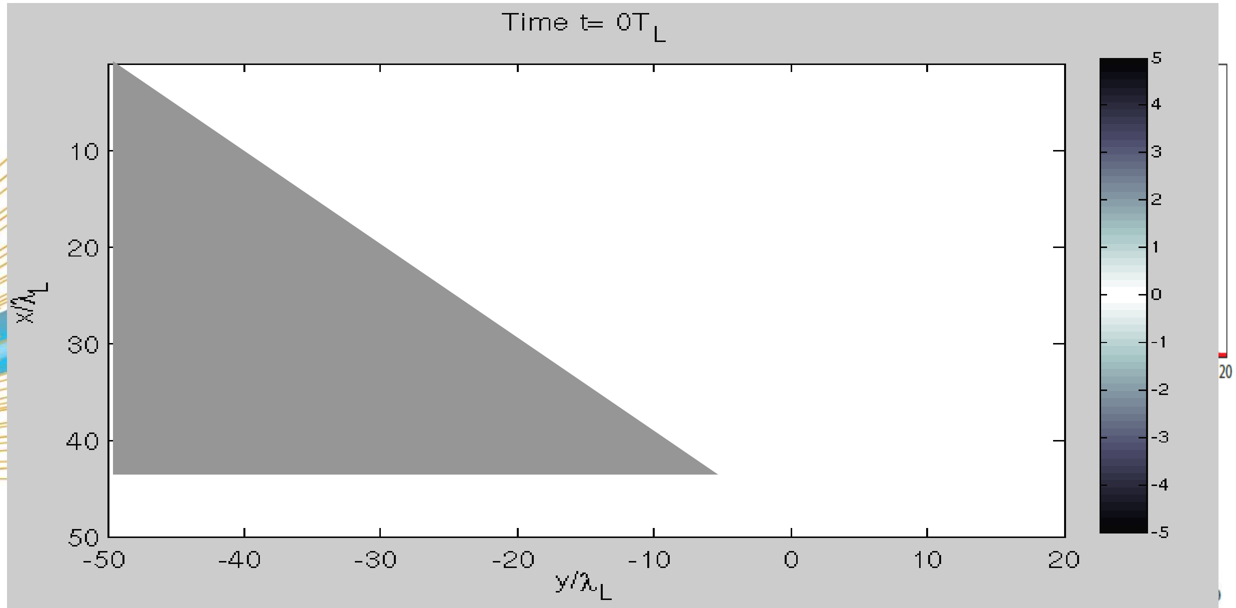
Femtopower/ Rainbow
XPW
étireur ps + DAZZLER
2µJ
Seed @ 1030 nm
Pompe Picoseconde MP1: 25mJ/100Hz ➔ Compression + SHG
ps-OPCPA
1m J
Photline
étireur ns 1 ns
Powerlite
AMP0.03
LPI
Pompe Nanoseconde MBI: 150mJ/100Hz MP2: 600mJ/20-100Hz
515 nm, 1.5 ns, >300 mJ
ns-OPCPA
30m J
LAM
Filtres spectraux
AMP0.3
Powerlite
300 mJ
AMP3
Atlas 12
3 J
Filtres spectraux
AMP30
Atlas 100
30 J
140 J
AMP100
CNE 400
140 J
330 J
AMP300
CNE 400
Séparation des faisceaux Réglage en énergie
Miroir déformable
Compresseur 10PW
Compresseur 1PW & Sonde
Switch yard Diagnostics laser de fin chaîne
Short Focal Area
Transport de faisceau courte focale (*)
Enceinte interaction
Transport de faisceau Longue focale (*)
Long Focal Area
Senseurs : align. & diag
Filtrages spatiaux

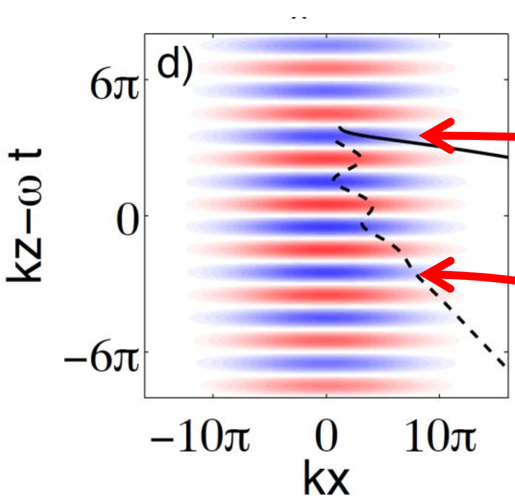
Les miroirs plasma comme injecteur d'électrons relativistes

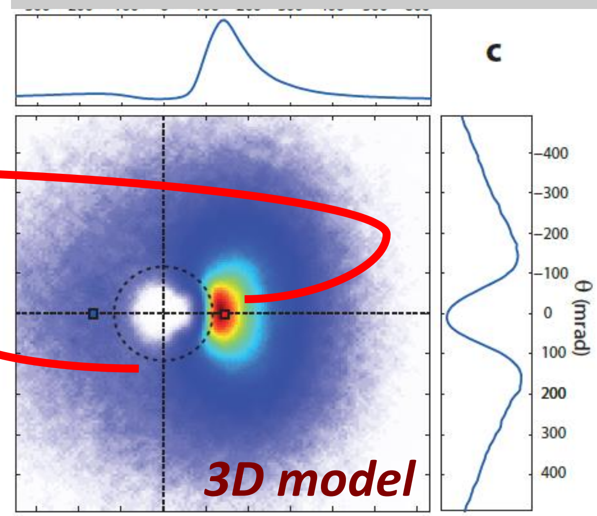


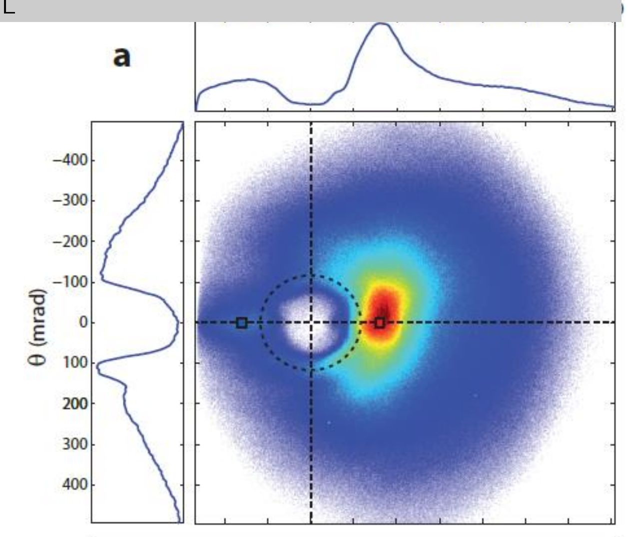


<u>Collaboration LOA (</u>J. *Faure et coll.)*









Dodin & Fish, Phys. Rev. E 68, 056402 (2003)

Thenevet el al, submitted