La source ATTO Lab FABP: interactions laser-plasma ultrarapide

Femto-Atto Beamline: Plasma

Stefan Haessler – Laboratoire d'Optique Appliquée, CNRS

Institut Polytechnique de Paris

FABP - où et qui est-ce?

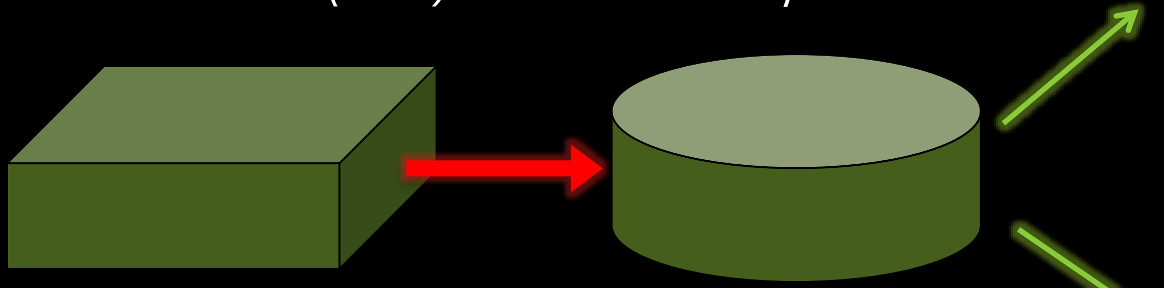
là !

Rodrigo Lopez-Martens,
Marie Ouillé,
S.H., Zhao Cheng, Louis Daniault,
Aline Vernier, Jêrome Faure, ...

FABP - Architecture

Laser pilote relativiste
« Salle Noire 2.0 » (+ 3.0)

Plateformes d'interaction
laser-plasma



Dynamique ultrarapide plasma:

- miroirs plasma:
  dynamique électronique collective attoseconde
- accélération de particules

Technologie des lasers

- fort contraste temporel
- ultra-haute intensité
- contrôle de forme d'onde *(durée few-cycle + CEP)*
- forte puissance moyenne *(kHz)*

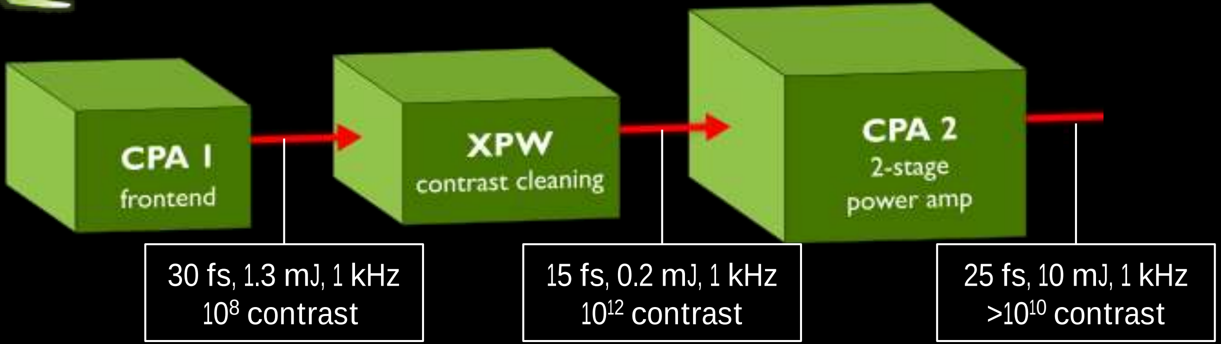
Technologie des cibles laser-plasma *kHz* (solide/gaz)

- récurrence kHz
- forte focalisation *(~ f/1)*
- répétabilité (< µm)
- longévité (~ 1h)

Applications:

- sources secondaires ultrabrèves
  (UVX attoseconde, électrons, ions)

FABP - Performances laser



vital

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- *ultra-haute intensité*
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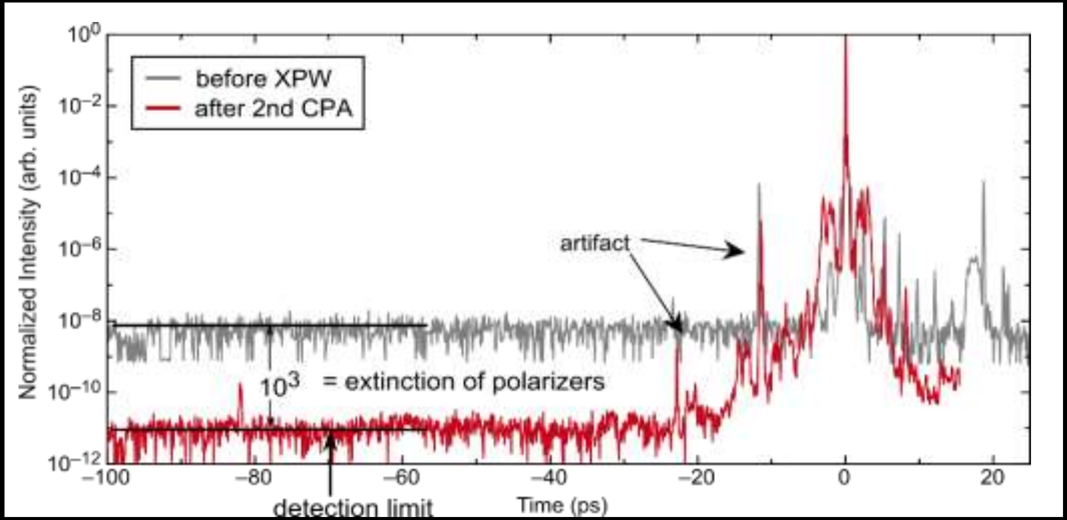
- *forte puissance moyenne (kHz)*

sympa



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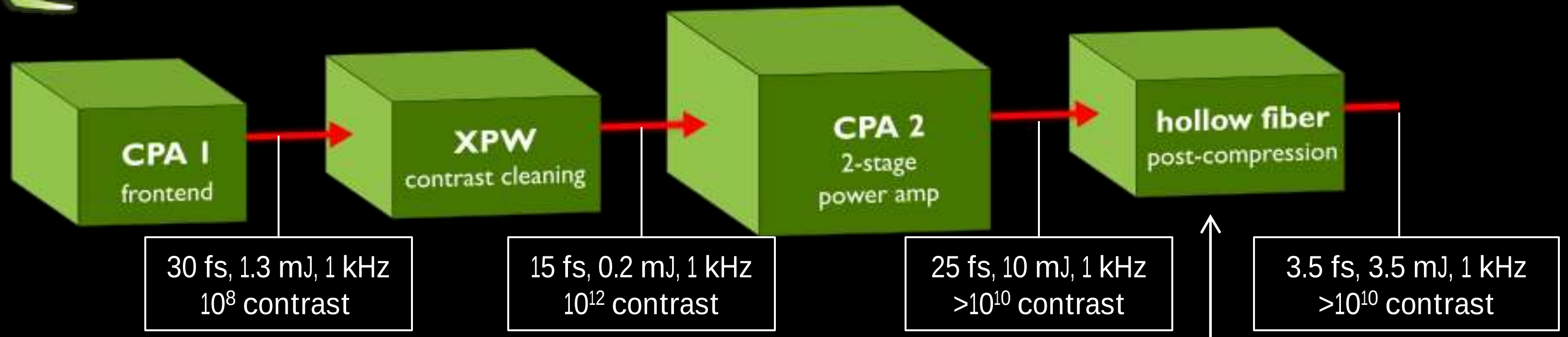

vital

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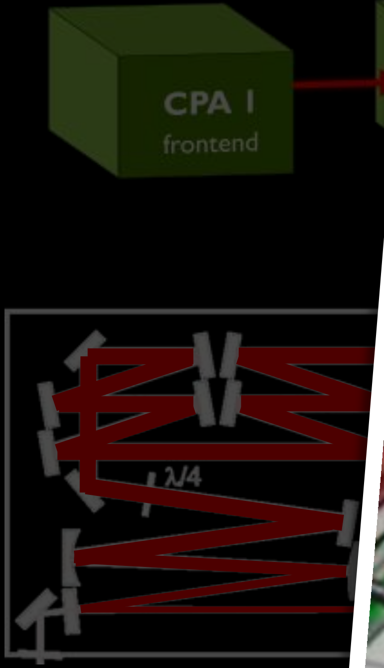
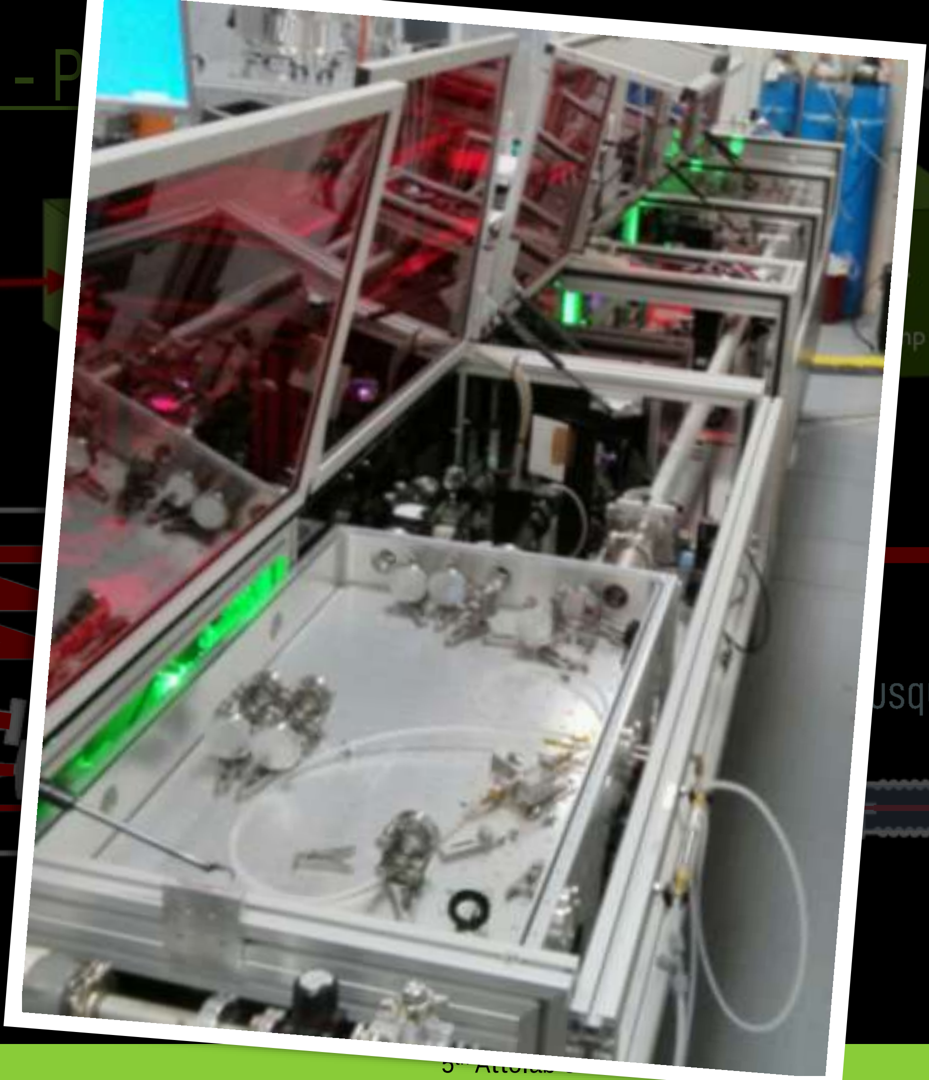
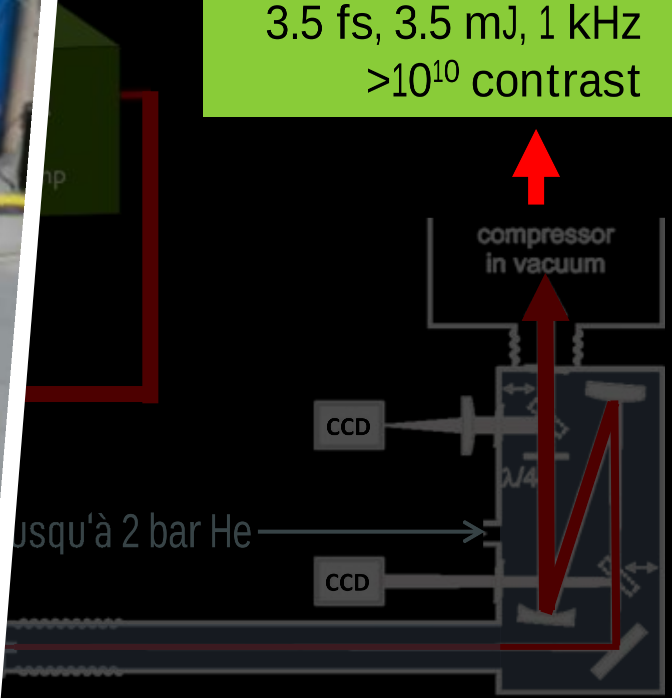
sympa

FABP - P





3.5 fs, 3.5 mJ, 1 kHz
$>10^{10}$ contrast

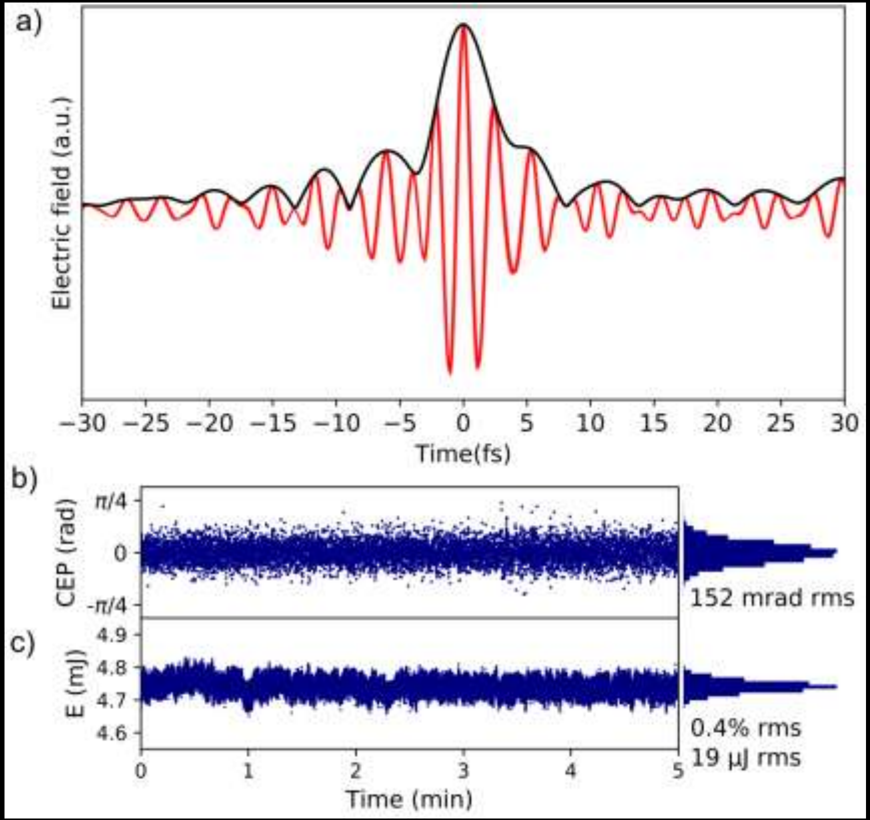


FABP - Performances laser

1 TW 1.5-cycle pulses @ 1 kHz

$>10^{10}$ contrast

excellent stability



M.Ouillé *et al.*, arXiv:1907.01239 (2019)
under consideration at *Light: Science and Applications*

FABP - Performances laser

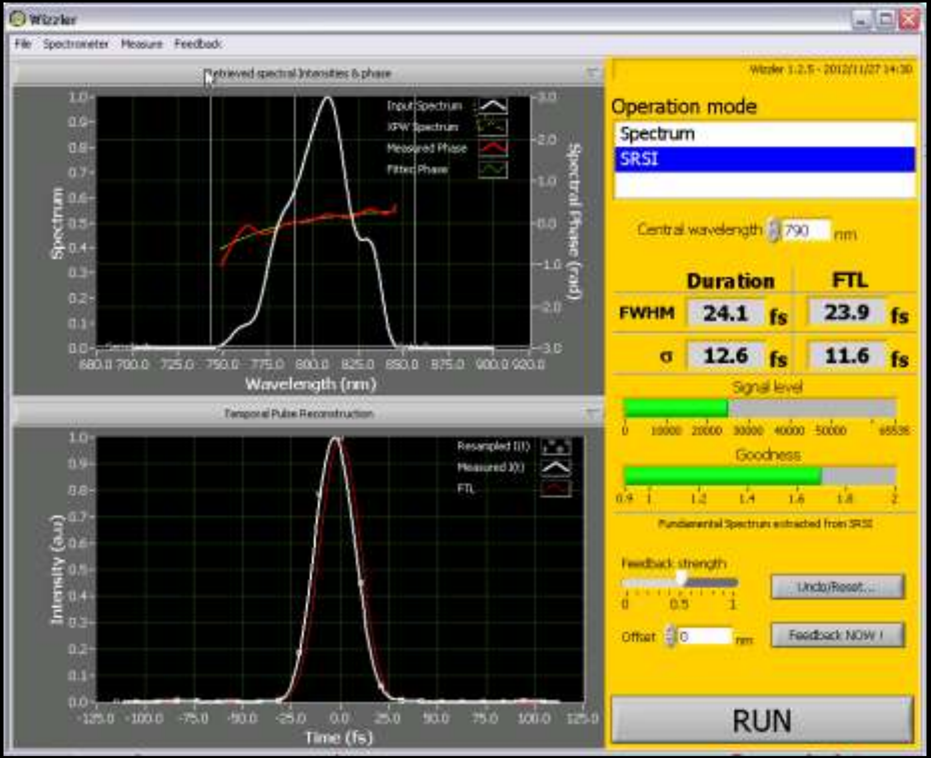
1 TW 1.5-cycle pulses @ 1 kHz

$>10^{10}$ contrast

tunable duration

0 mbar helium → 24 fs

excellent stability



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FABP - Performances laser

1 TW 1.5-cycle pulses @ 1 kHz

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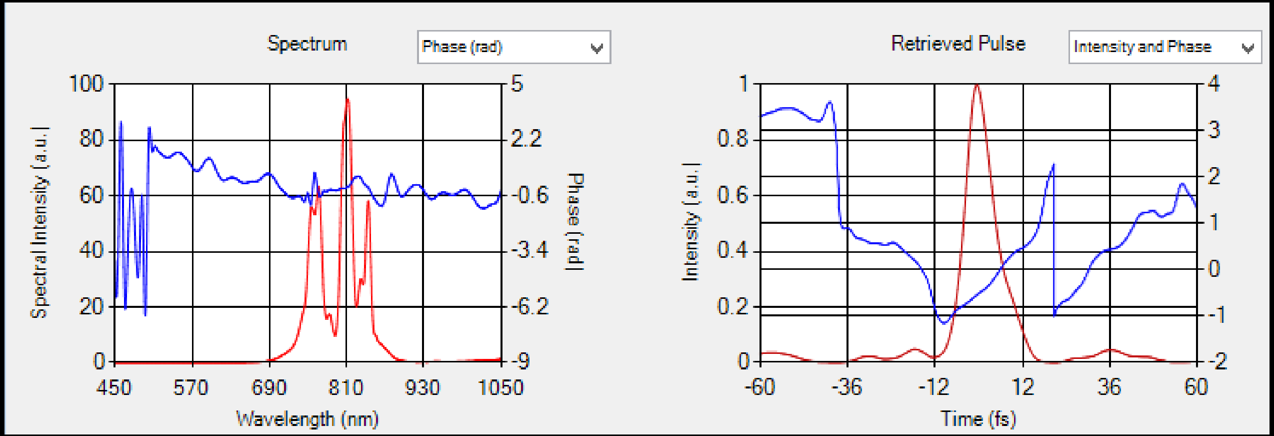
tunable duration

300 mbar helium → 9 fs



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FABP - Performances laser

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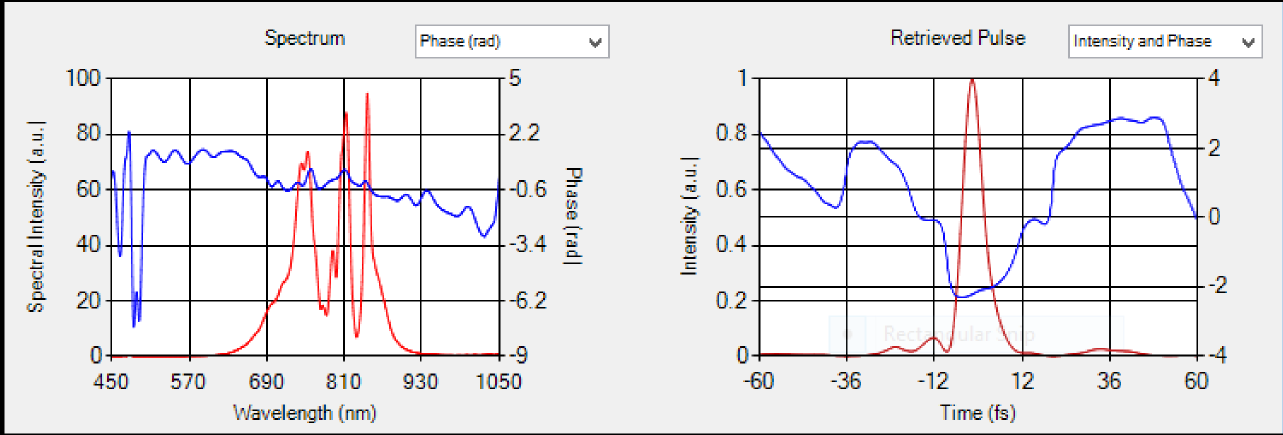
600 mbar helium → 6 fs



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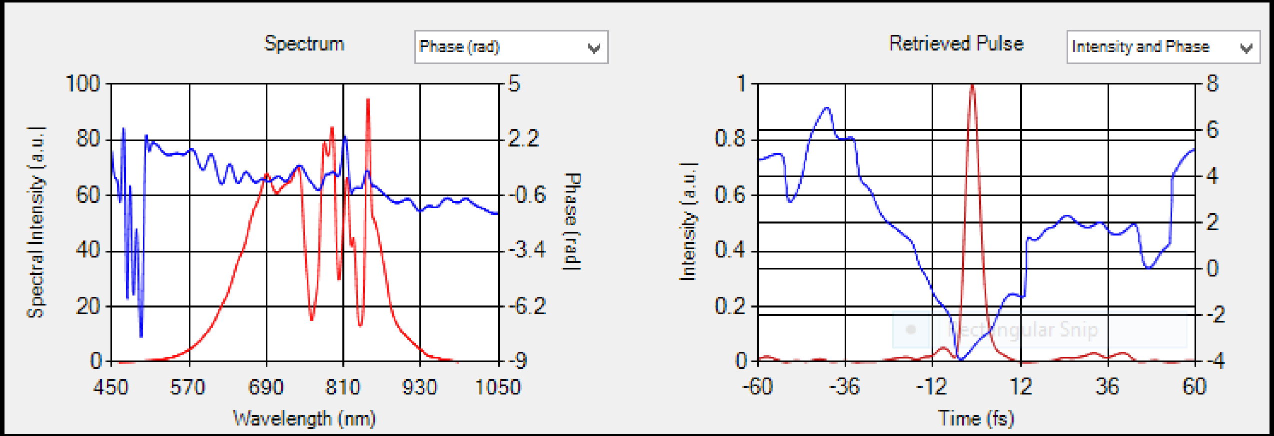
900 mbar helium → 4 fs



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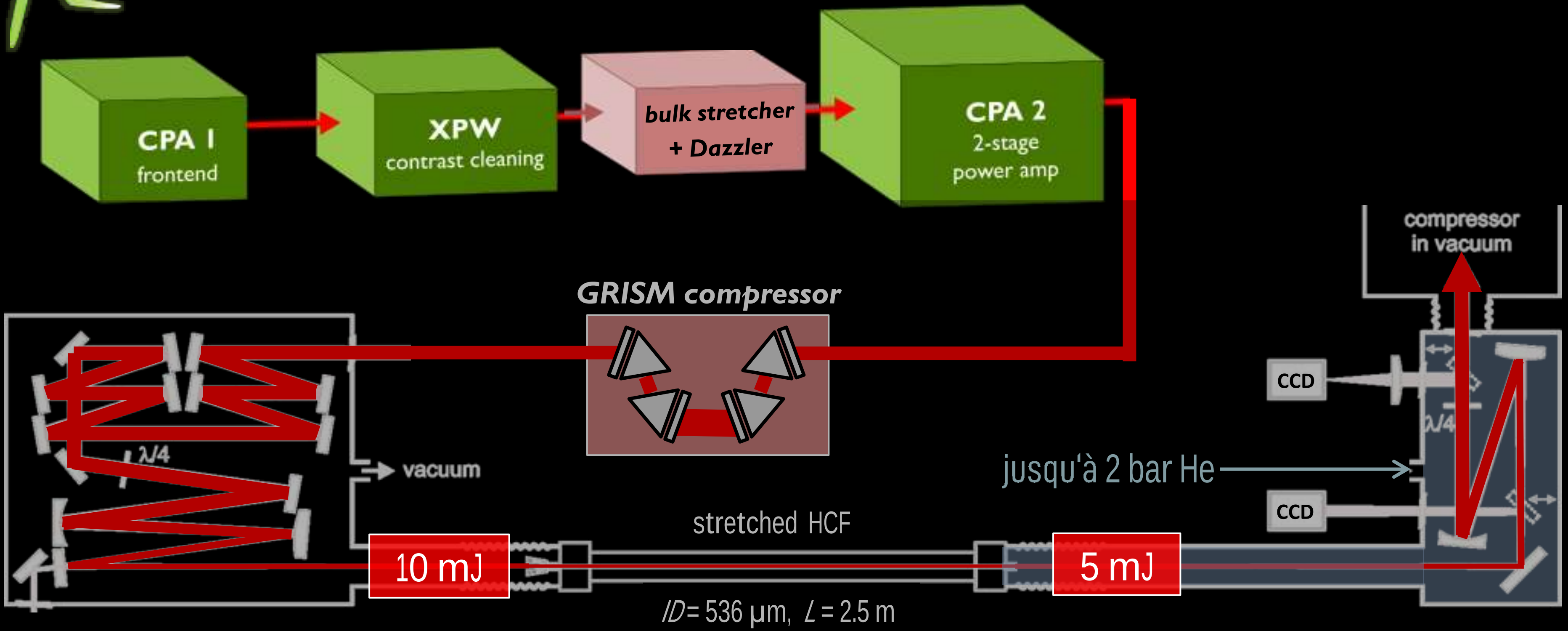
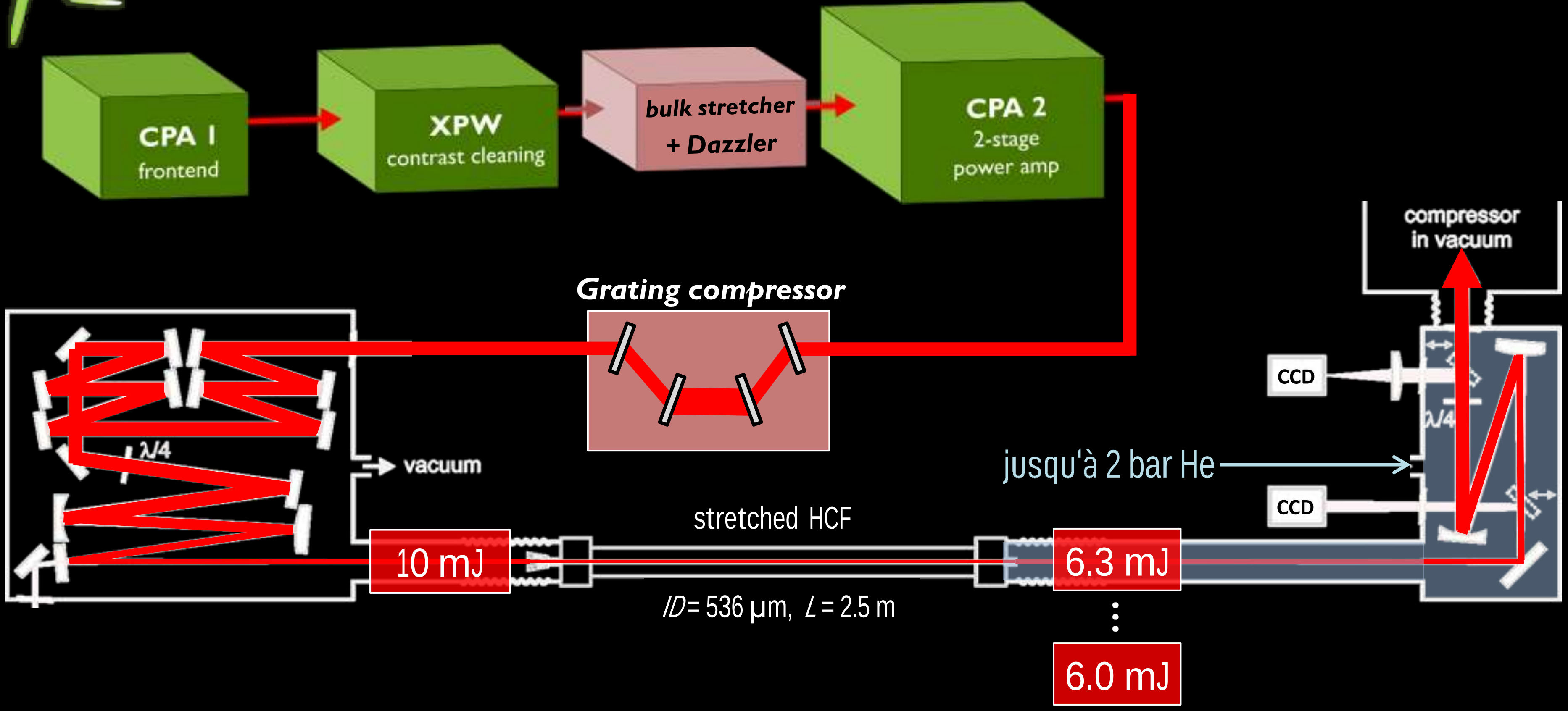


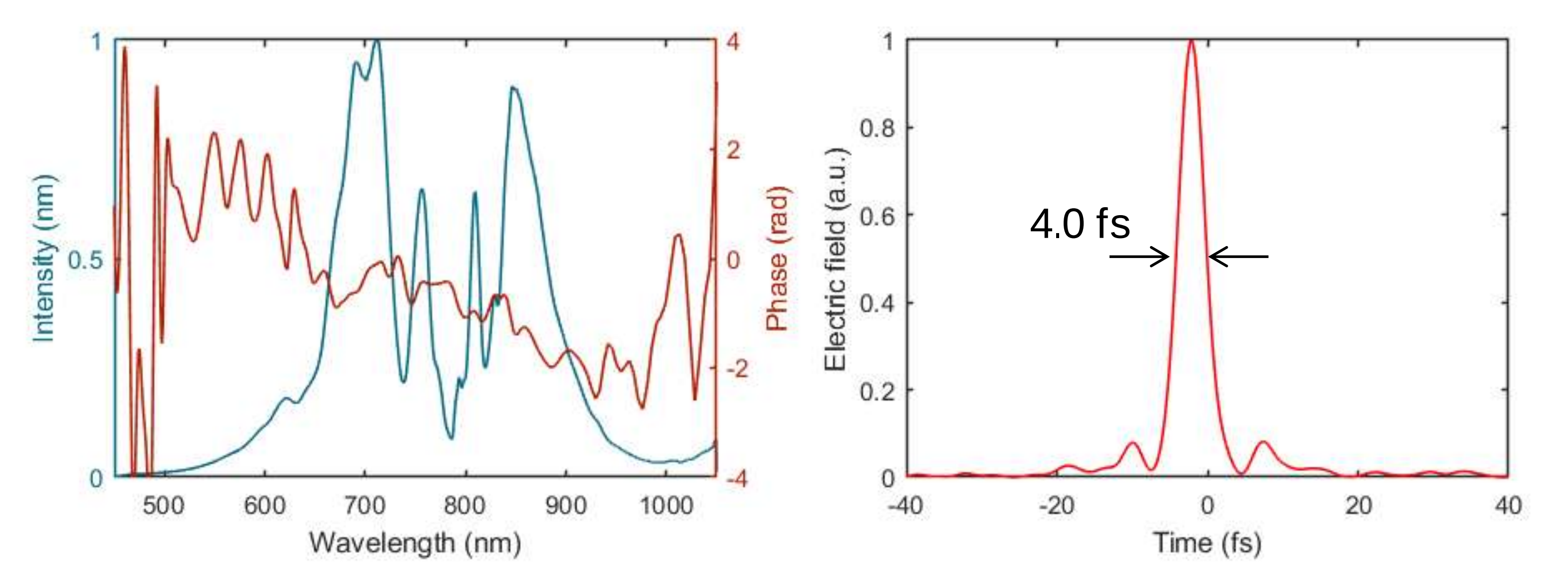
FABP - Performances laser



FABP - Performances laser

bulk stretcher

CPA 2



Since November 2019: 30% energy increase: 4.4 mJ , 4.0 fs → **1.1 terawatt**

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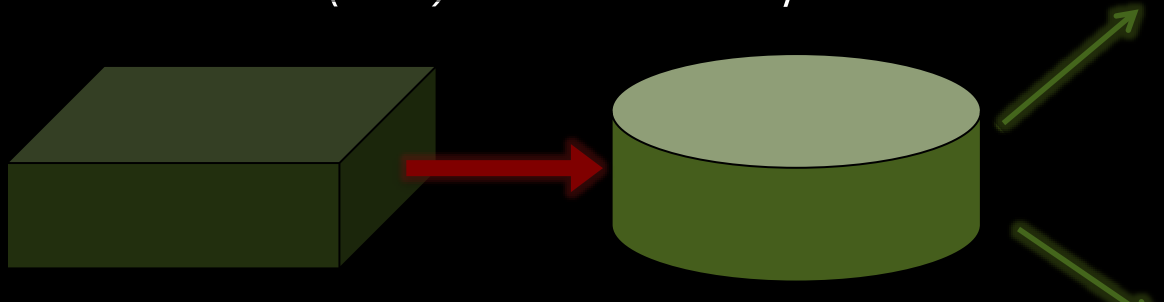

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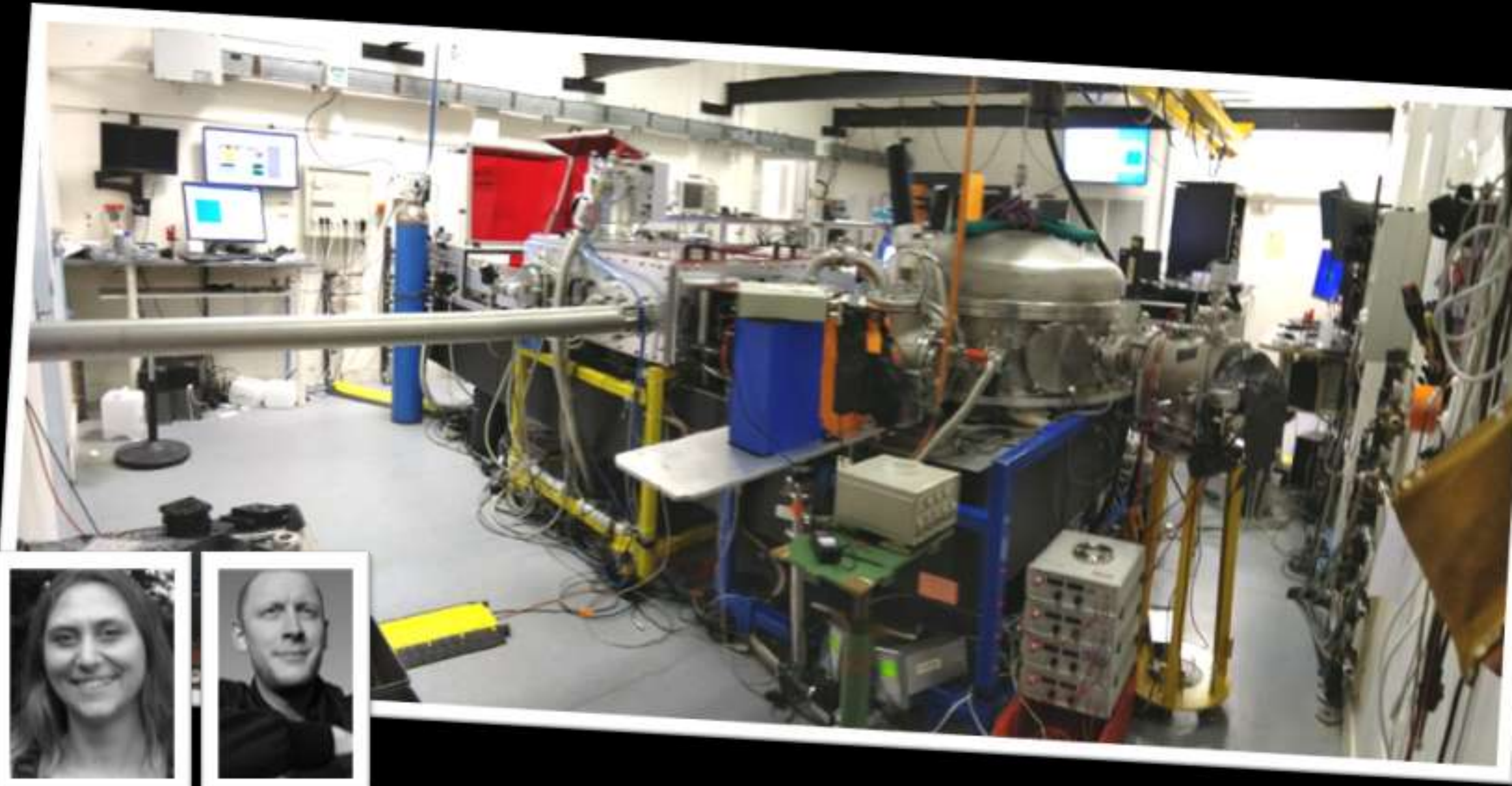
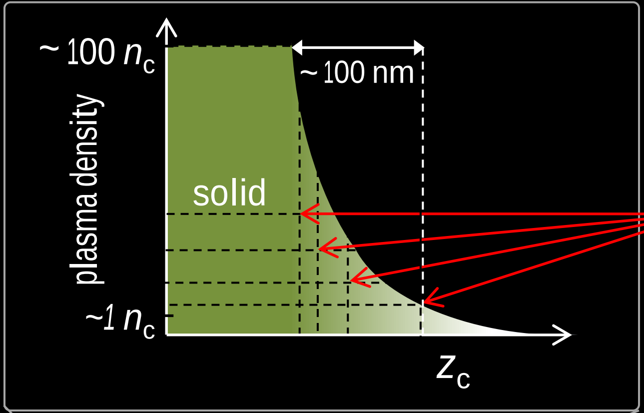
FABP - Salle Noire 2.0: solid target



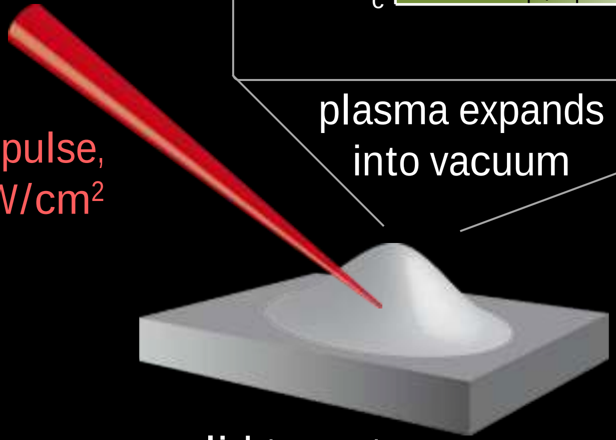
Plasma mirrors



effective « interaction surface » with decreasing plasma density after ~ps delay

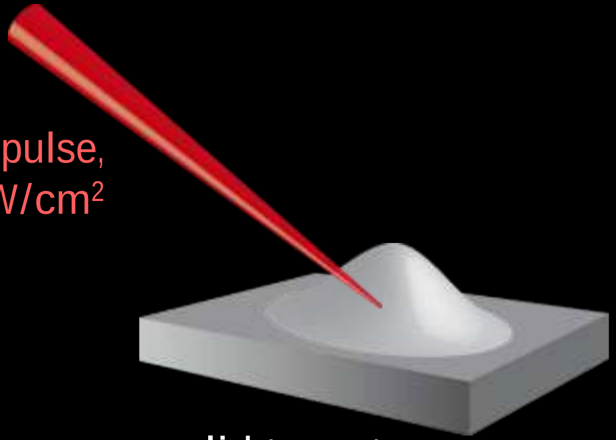
plasma expands into vacuum

weak fs pre-pulse, $10^{14} - 10^{15}$ W/cm^2



solid target
(optically polished glass)

Plasma mirrors



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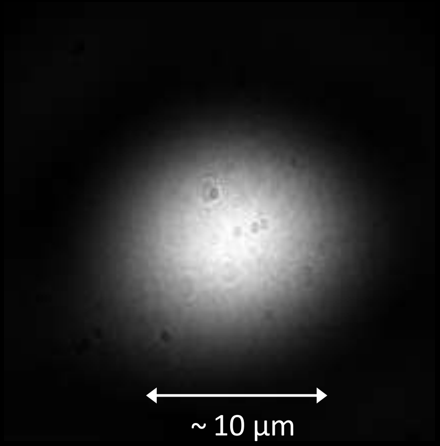
(optically polished glass)

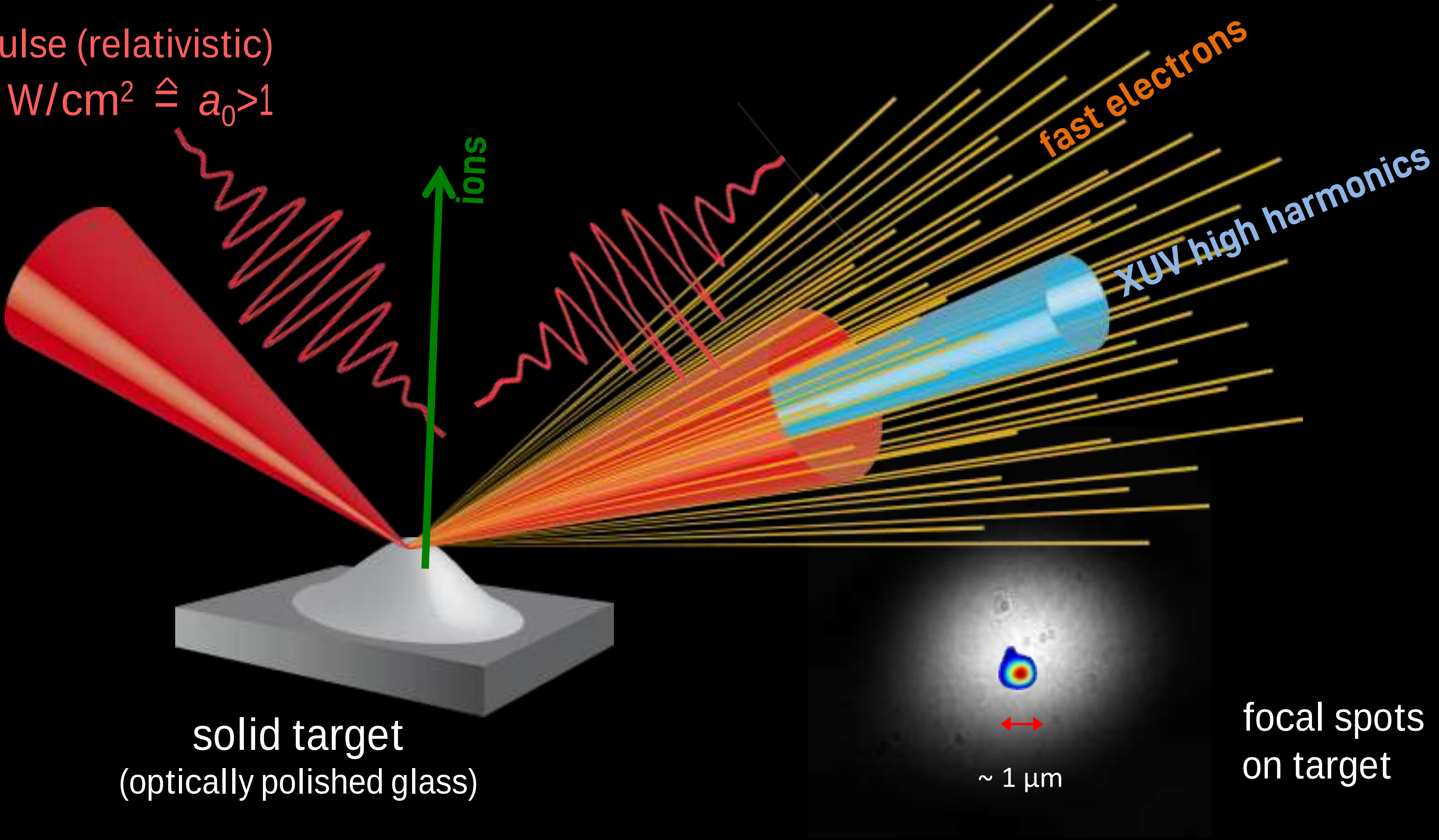


focal spots
on target

Plasma mirrors

driving fs laser pulse (relativistic)

~10^{19} W/cm^2 ≙ a_0>1



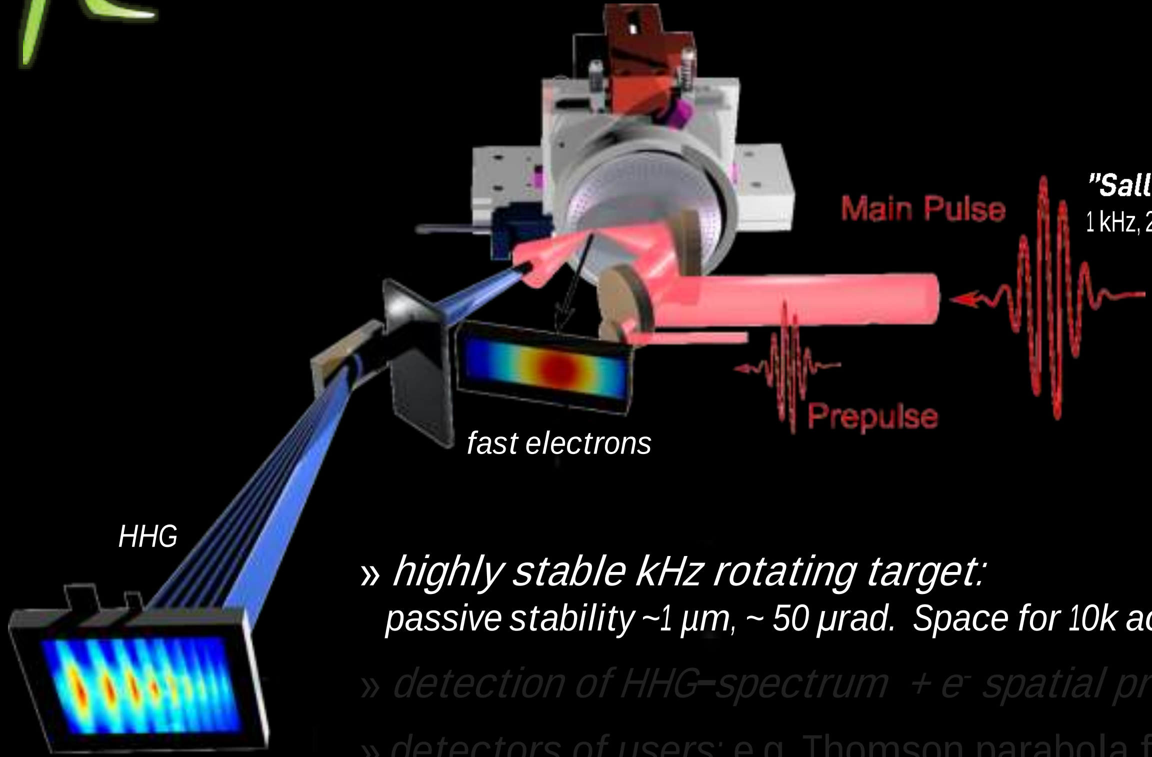
solid target
(optically polished glass)

~ 1 µm

focal spots
on target

FABP - Salle Noire 2.0: solid target

A. Borot *et al. Rev. Sci. Instrum.* 85, 13104 (2014)
M. Bocoum *et al. Phys. Rev. Lett.* 116, 185001 (2016)
F. Böhle, *PhD thesis* (2017)



***"Salle noire" :** 1.5-cycle terawatt laser @ LOA*

1 kHz, 25–3.5 fs, 3.5 mJ, CEP locked, >10^{10} temporal contrast ratio

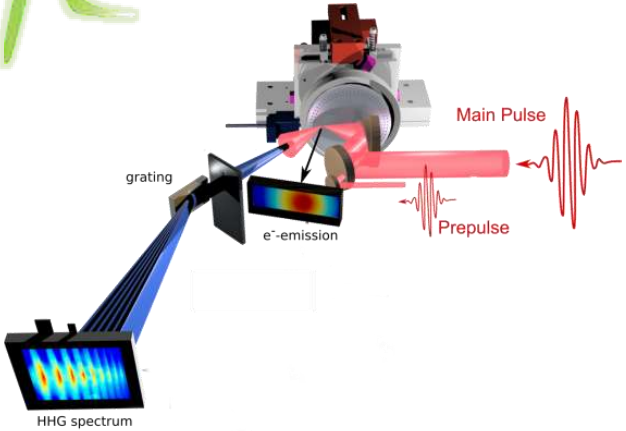
» *highly stable kHz rotating target:*
passive stability ~1 µm, ~ 50 µrad. Space for 10k acquisitions of 100-shot bursts.

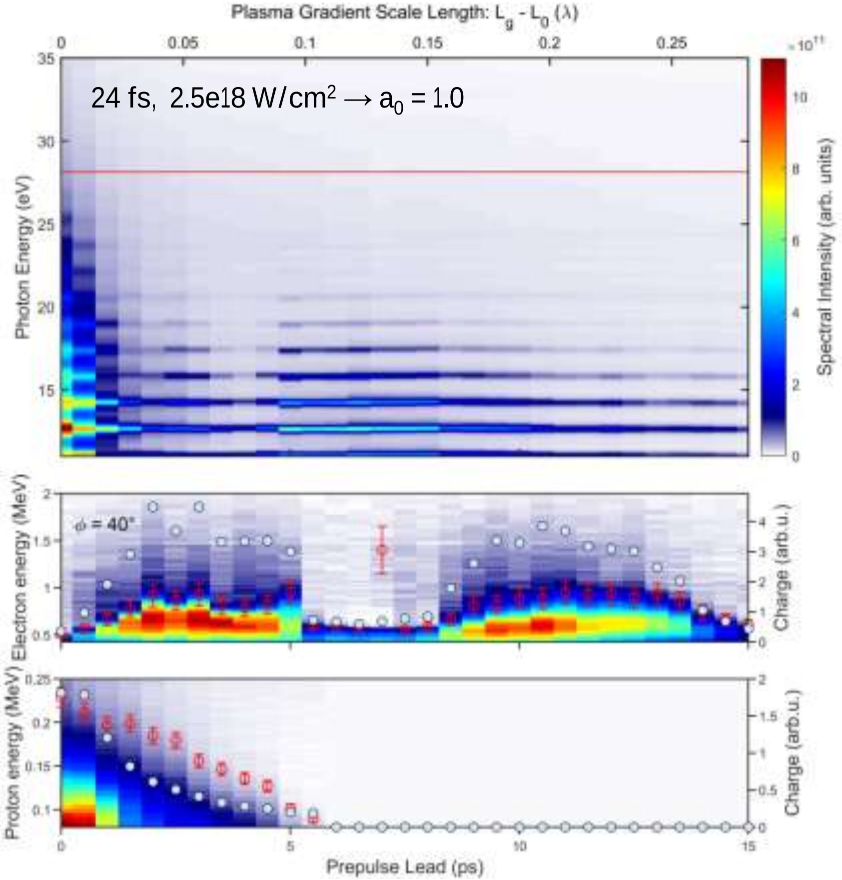
» *detection of HHG–spectrum + e^- spatial profile / spectrum*

» *detectors of users:* e.g. Thomson parabola for proton spectra (with Dan Levy, Weizmann Institute)

» *planned for 2020: liquid sheet target, in reflection and transmission*
(with Enam A. Chowdhury, Ohio State University)

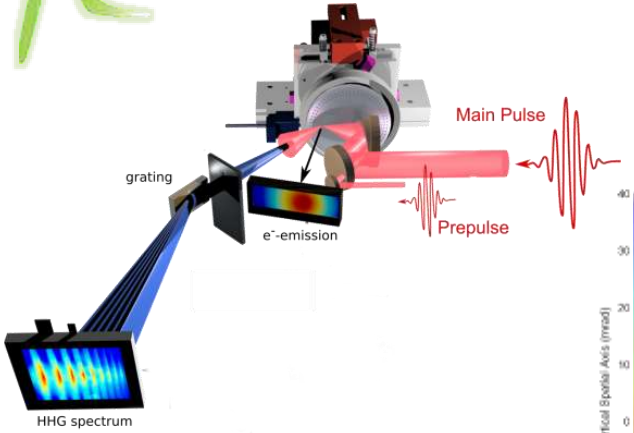
FABP - Salle Noire 2.0: solid target



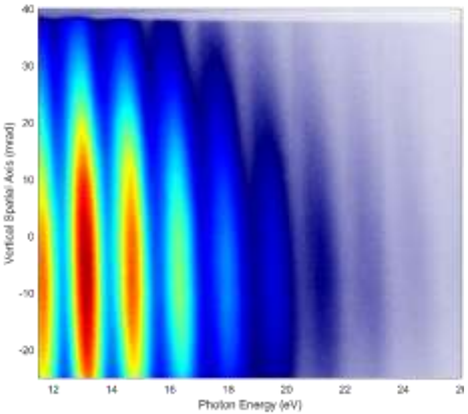


- » simultaneous detection of HHG, electrons and ion emission from plasma mirror,
- » driven by relativistically intense (few-cycle) pulses,
- » with controlled plasma density gradient on solid target

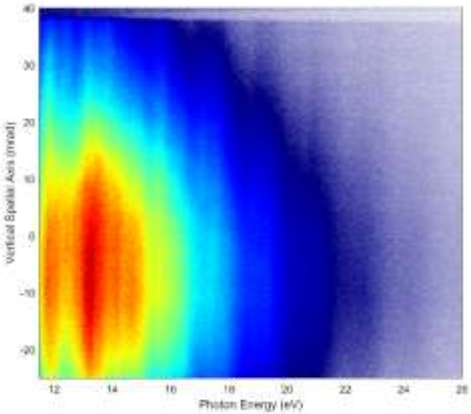
FABP - Salle Noire 2.0: solid target



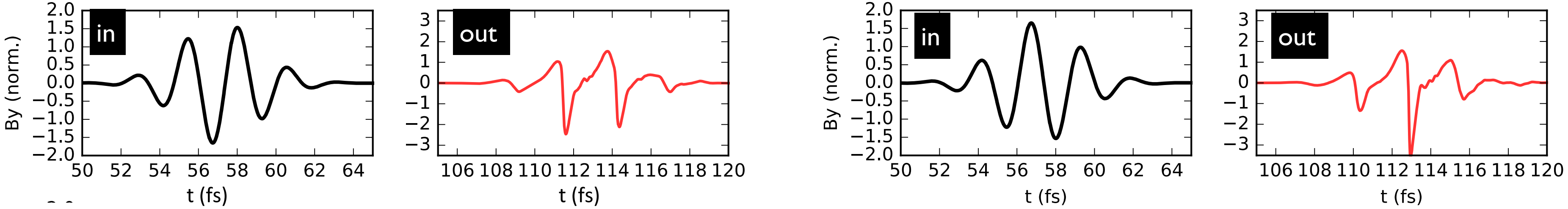
» 3.5 fs, $a_0 \approx 2$, $L_g = 0.1\lambda$, CEP locking (mediocre) ➔ HHG relativiste
spectre HHG continu ➔ *impulsion attoseconde isolée*



ΔCEP = π



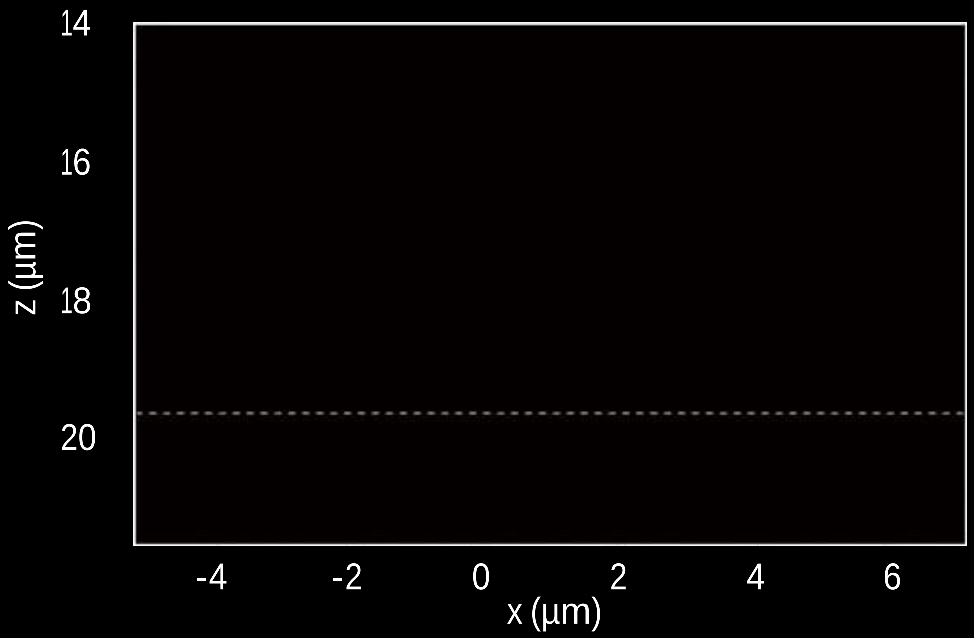
2D PIC simulations by Maxence Thévenet (Berkeley Lab) :



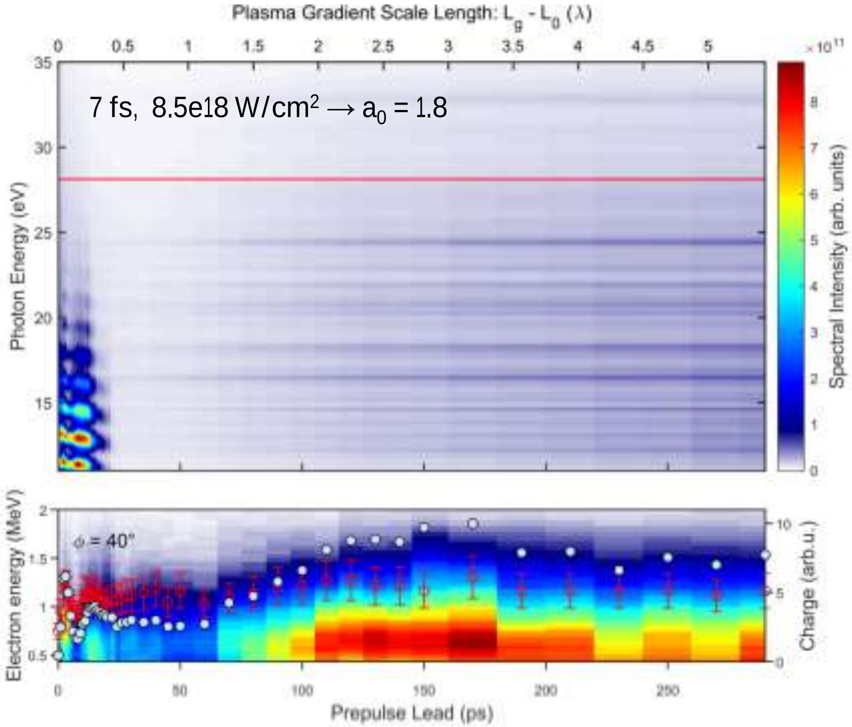
Waveform control : <4-fs, CEP

a_0 =2, 1.5-cycle, experimental condtions at LOA
2D PIC simulations by M. Thévenet (LBNL Berkeley)

CEP for ***"optimal push-pull once"***



- Compression to *isolated 350 as pulse without spectral filtering.*
- Contains 35% of incident energy
  (most of it in the lowest harmonics)

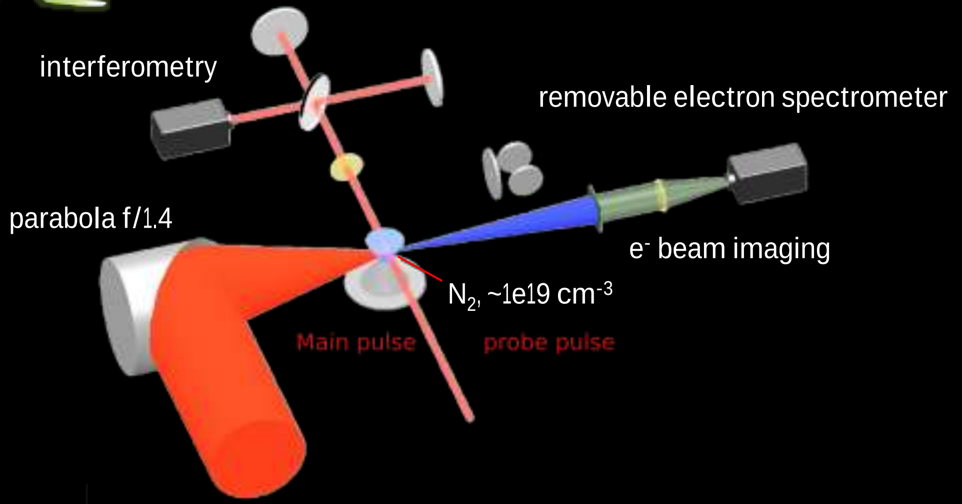

Plasma Gradient Scale Length: $L_g - L_0$ (λ)
7 fs, 8.5e18 W/cm^2 → a_0 = 1.8
Photon Energy (eV)
Spectral Intensity (arb. units)
×10^{11}
Electron energy (MeV)
ϕ = 40°
Charge (arb.u.)
Prepulse Lead (ps)

Plasma Gradient Scale Length: L_g (λ)
(a) 24 fs; a_0 = 1.0
(b) ≈ 10 fs; a_0 = 1.6
(c) ≈ 7.5 fs; a_0 = 1.8
(d) ≈ 5 fs; a_0 = 2.3
(e) ≈ 3.5 fs; a_0 = 2.7
(f)
Charge Density (pC/rad)
24 fs
≈ 10 fs
≈ 7.5 fs
≈ 5 fs
≈ 3.5 fs
Azimuth Angle θ (deg)
Electron Charge (pC)
Prepulse Lead (ps)

FABP - Salle Noire 2.0: gas target

Jêrome Faure Aline Vernier

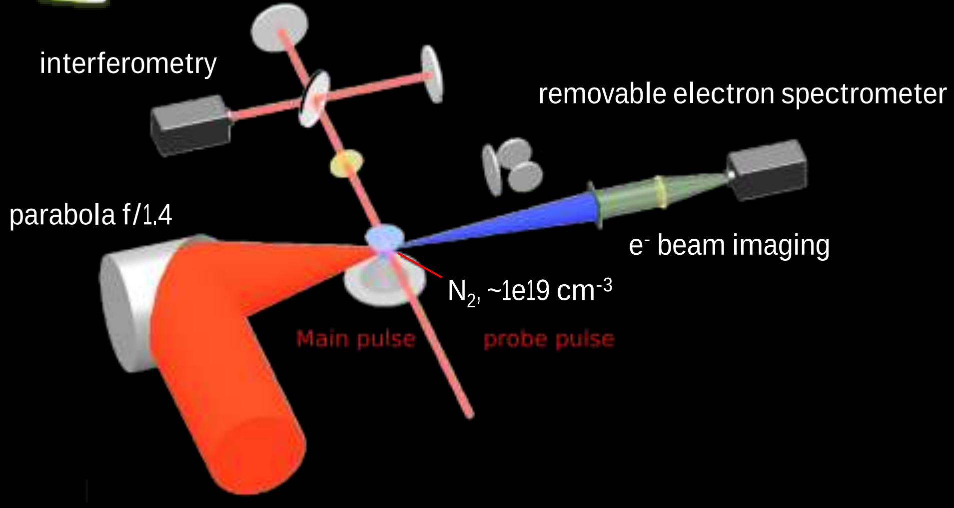
FABP - Salle Noire 2.0: gas target

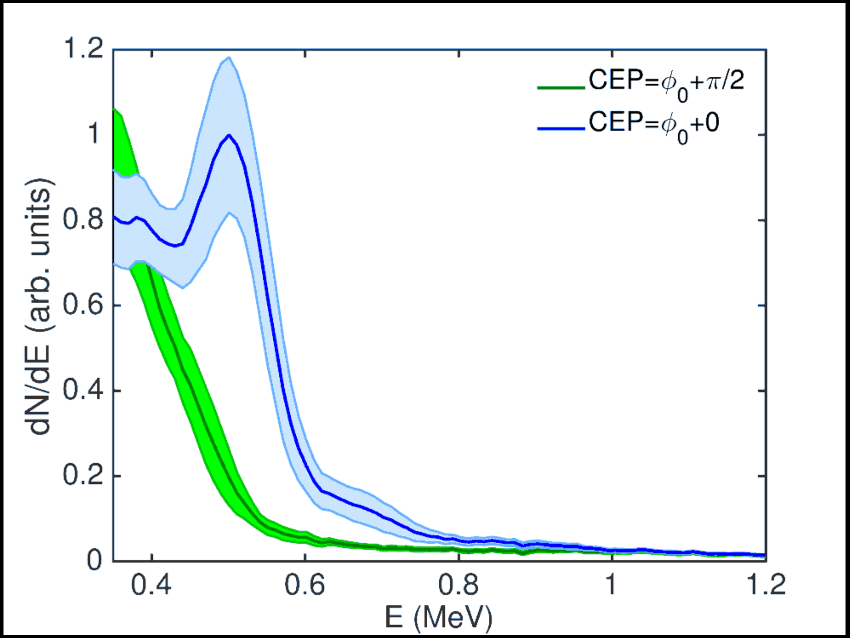


» electron beam (~1 fs) with up to 5 MeV energy, kHz, ~25 pC /shot, divergence ~20 mrad

D. Guenot *et al.*, Nature Photonics 11, 293 (2017)
D. Gustas *et al.*, Phys. Rev. Accel. Beams 21, 013401 (2018)
J. Faure *et al.*, Plasma Phys. Control. Fusion 61, 014012 (2019)

FABP - Salle Noire 2.0: gas target





» ***première observation d'un effet CEP sur l'acceleration laser-wakefield***

[M.Ouillé *et al.*, arXiv:1907.01239, under consideration at *Light: Science and Applications*]

➔ controle attosecode d'injection par ionisation

FABP - Salle Noire 3.0

laser	energy / intensity on target	rep. rate	duration	contrast	CEP	pointing	availability
SN 2.0	>2.5 mJ ≈ 10^{19} W/cm^2	1 kHz	24 – 3.5 fs	>10^{10} @10 ps	< 200 mrad	1/10 focal spot	today
SN 3.0	1 (→ 5) mJ	1 kHz	< 20 fs (→<4 fs)	> 10^{11} @10 ps	< 250 mrad	1/10 foc. spot	(today)

» platform for technological developments :

- contrast filter + post-compression by nonlinear ellipse rotation (with MBI Berlin + ELI-ALPS)
- sub-relativistic plasma mirror in few-cycle regime: validation of temporal contrast cleaning for (future) large infrastructures

FABP - Salle Noire 4.0

laser	energy / intensity on target	rep. rate	duration	contrast	CEP	pointing	availability
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SN 3.0	1 (→ 5) mJ	1 kHz	< 20 fs (→<4 fs)	> 10^{11} @10 ps	< 250 mrad	1/10 focal spot	(today)
SN 4.0 ?	→ ~100 mJ	0.1—1 kHz	few-cycle				?

» 2020: high-energy postcompression of TRUMPF thin disk amplifier (~100 mJ, kHz, 1030 nm , 800 fs)

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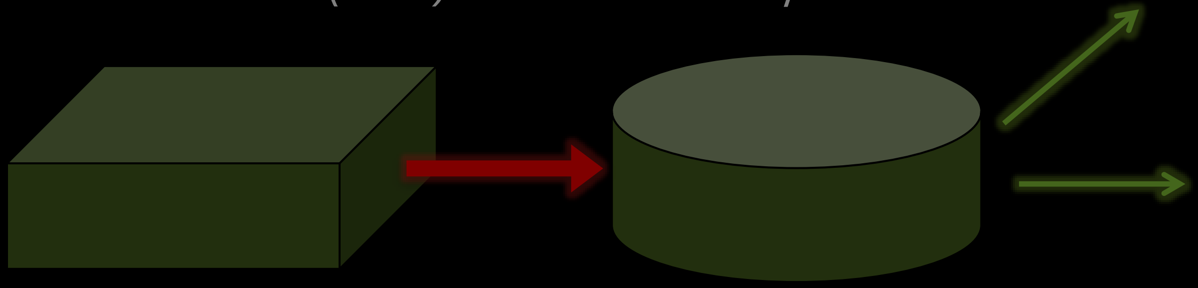

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– fin –

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