Contributions of Gas Targets in Laser-Plasma Interaction Research

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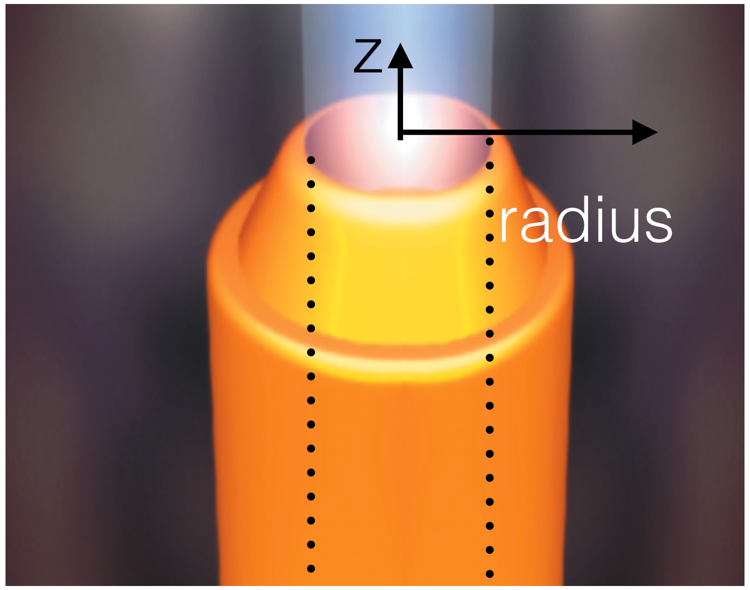
TARG2 Workshop, Paris, France April 20-22 (2015)

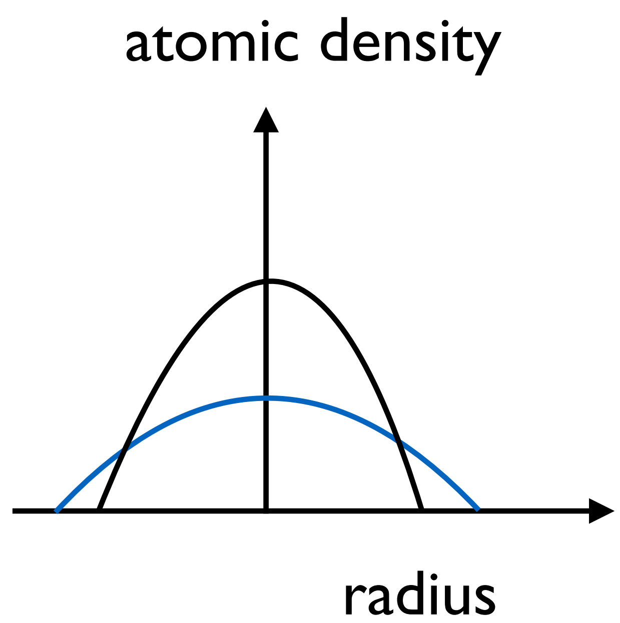
Outline

- **Motivation**
- **Gas jets for fusion related research**
  - Towards the creation of Homogenous plasma
  - Plasma channel
  - Well controlled hot and dense plasma for atomic Phyics
  - Laser smooting, self focusing, RBS, SBS etc..
- **Gas jets for fusion for Laser Plasma Accelerators**
  - Self Modulated Laser Wake Field
  - Forced laser wakefield
  - Bubble
  - colliding
- **High Density Gas Jets for Ion Acceleration**
- **Gas Cell Targets**
- **Plasma lensing**
- **Conclusion**

Gas jet flows

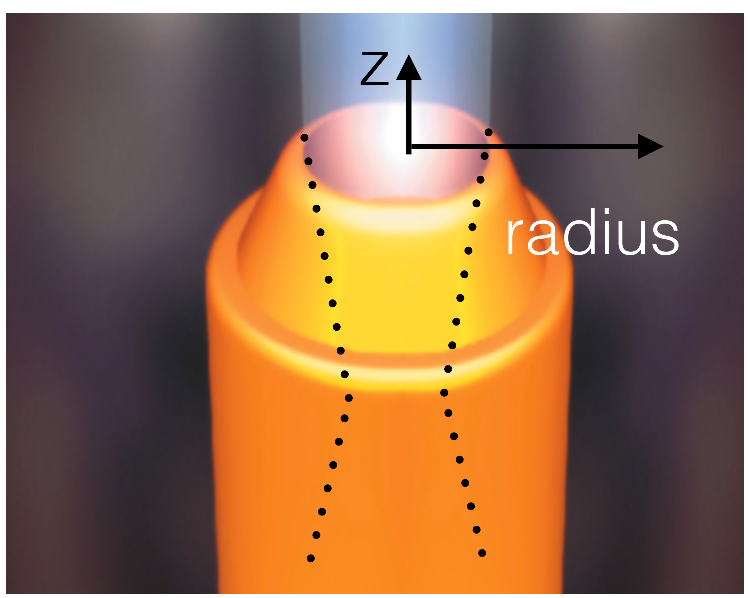
sonic

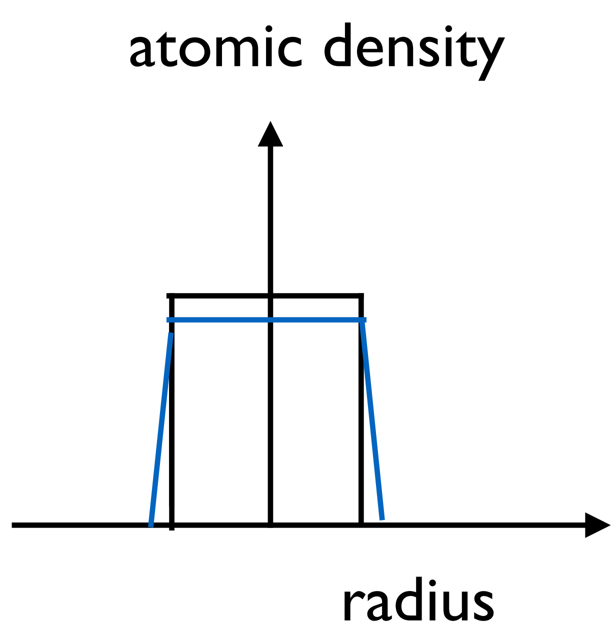




Parabolic density profile
dependant of z
profiles for $z_1>z_2$

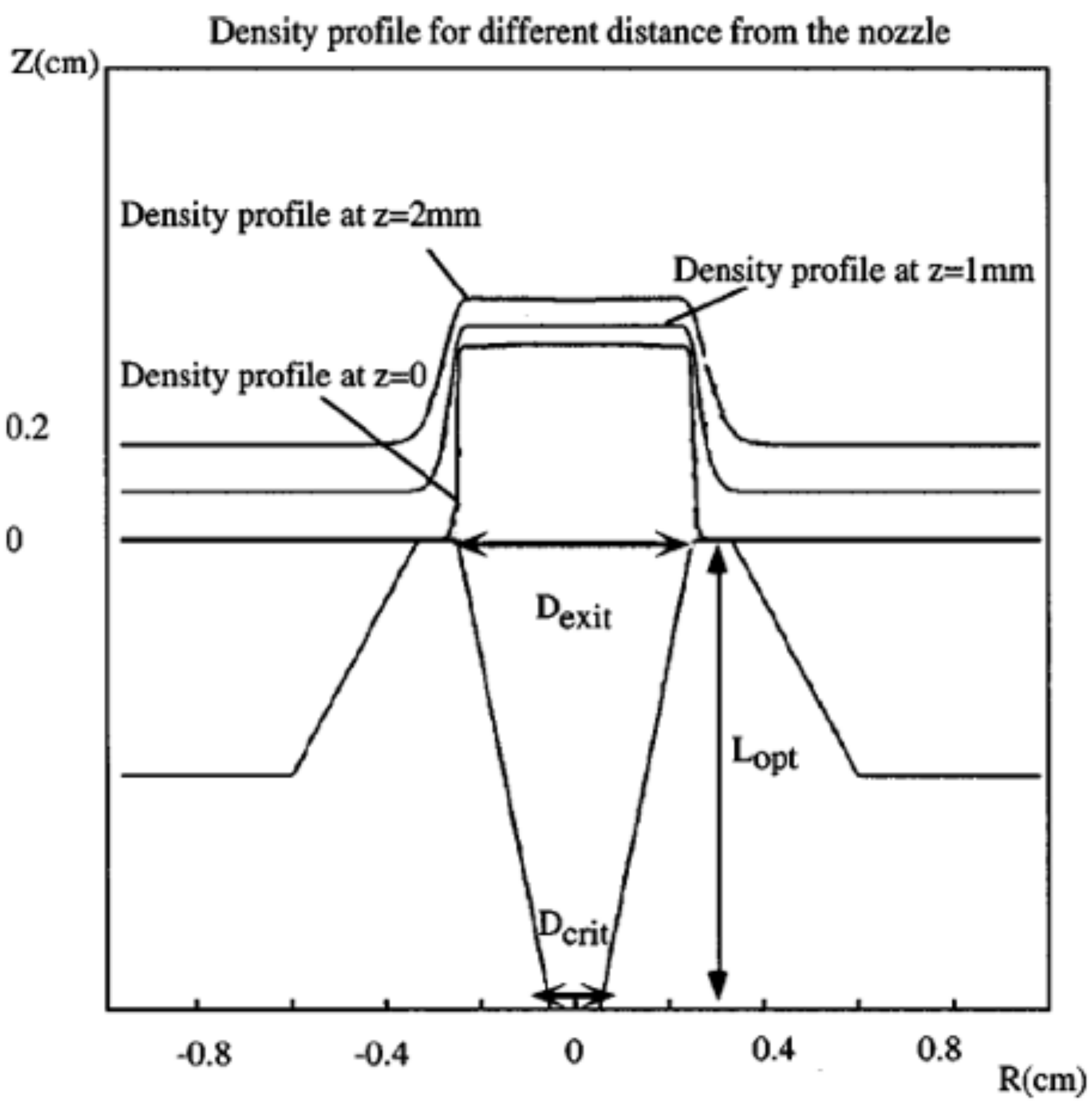
supersonic





Density scales linearly
with the backing pressure
Density profile
can be constant
independant of z
profiles for $z_1>z_2$

Gas jet flows optimisation : conical shapes

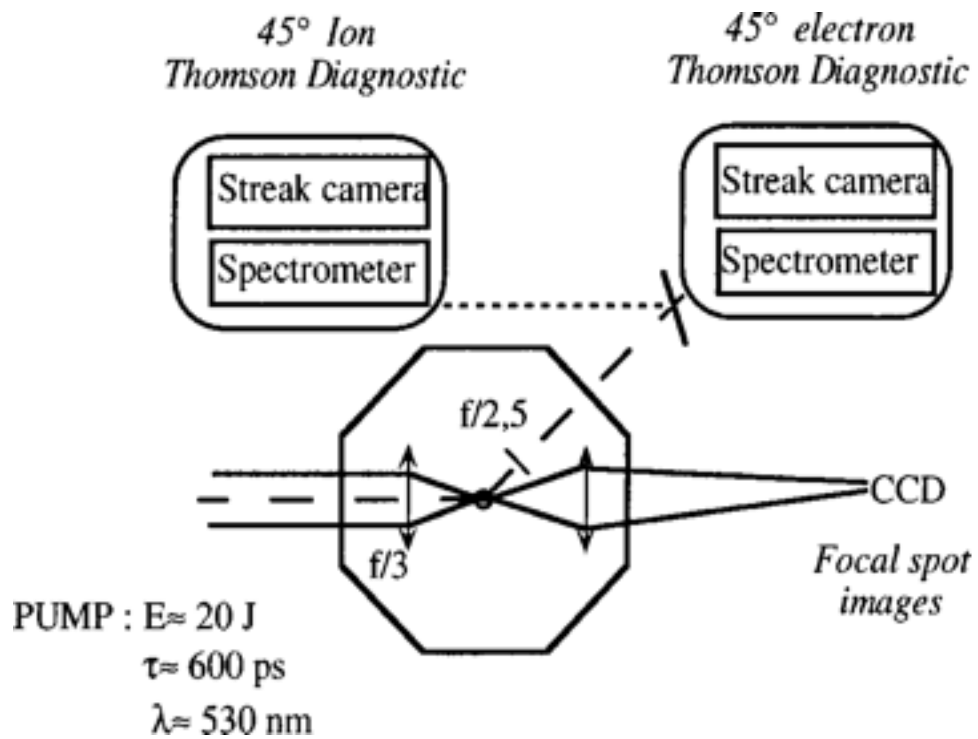


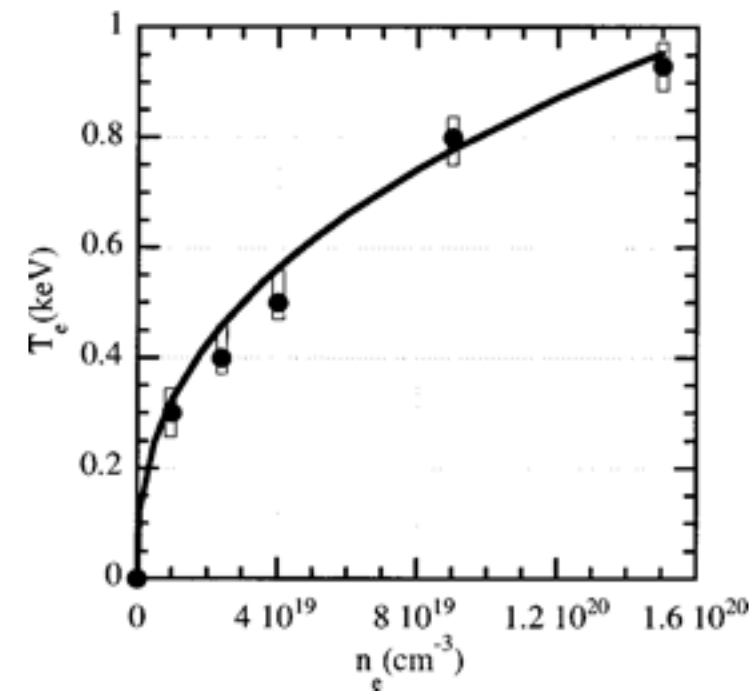
D_{crit}(mm)	D_{exit}(mm)	l_{opt}(mm)	M_{exit}	n_{exit}(cm^{-3})
1	2	6	3.5	18×10^{19}
1	3	7	4.75	7.5×10^{19}
1	5	10	7	2.7×10^{19}
1	10	15	10	0.75×10^{19}
0.5	1	4	3.3	16×10^{19}
0.5	2	5	5.5	4.5×10^{19}
0.5	3	5	6.2	2.1×10^{19}
0.5	5	7	9.5	0.7×810^{19}
0.5	10	15	14.5	0.2×10^{19}

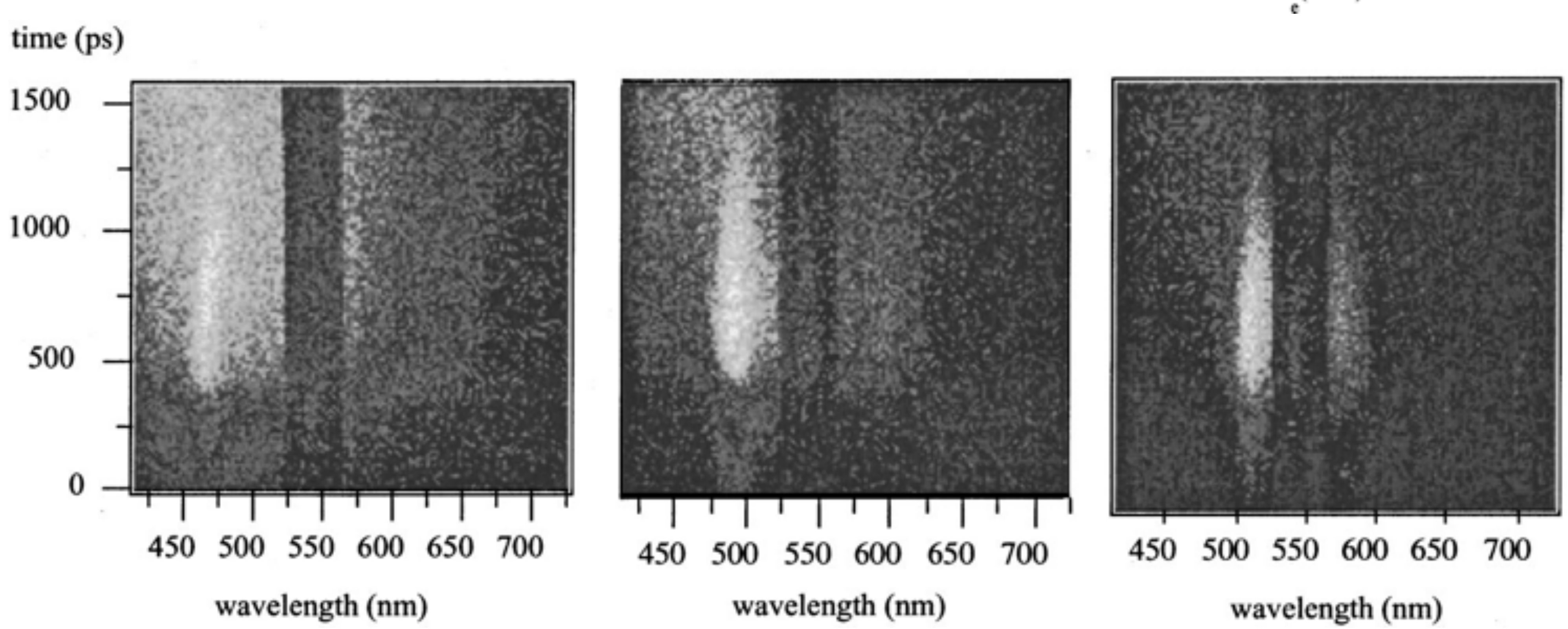
TABLE I. Optimized nozzles parameters. D_{crit}, D_{exit}, and L_{opt} are defined in Fig. 6. The Mach number and the density at 0.5 mm from the nozzle exit are M_{exit} and n_{exit} respectively.

S. Semushin and V. Malka, Rev. Sci. Instrum., Vol. 72, No. 7, July 2001

Gas jet : getting an uniform plasmas







V. Malka *et al.*, Phys. of Plasmas, Vol. 8, No. 7 (2001), J. Faure et al., Phys. Rev. E 64, 026404 (2001)

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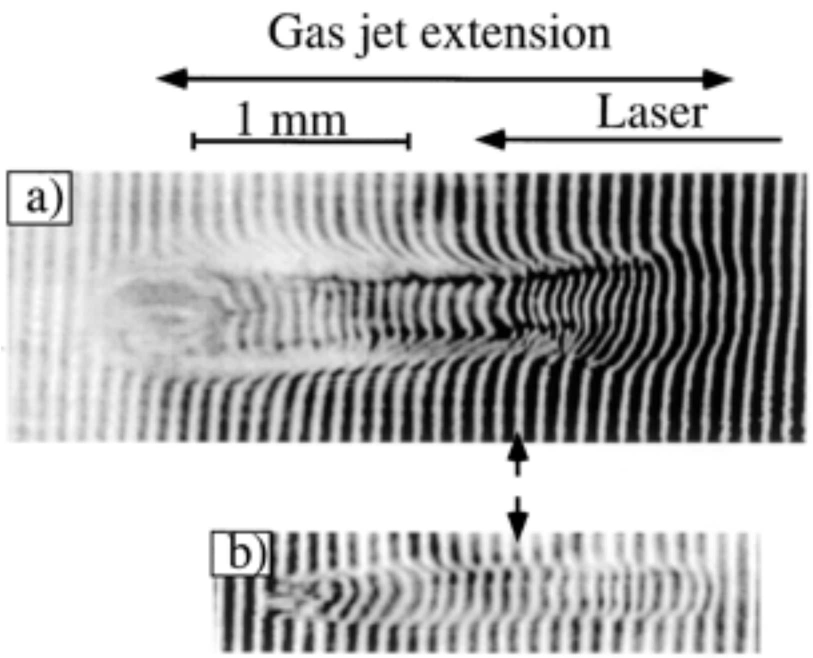
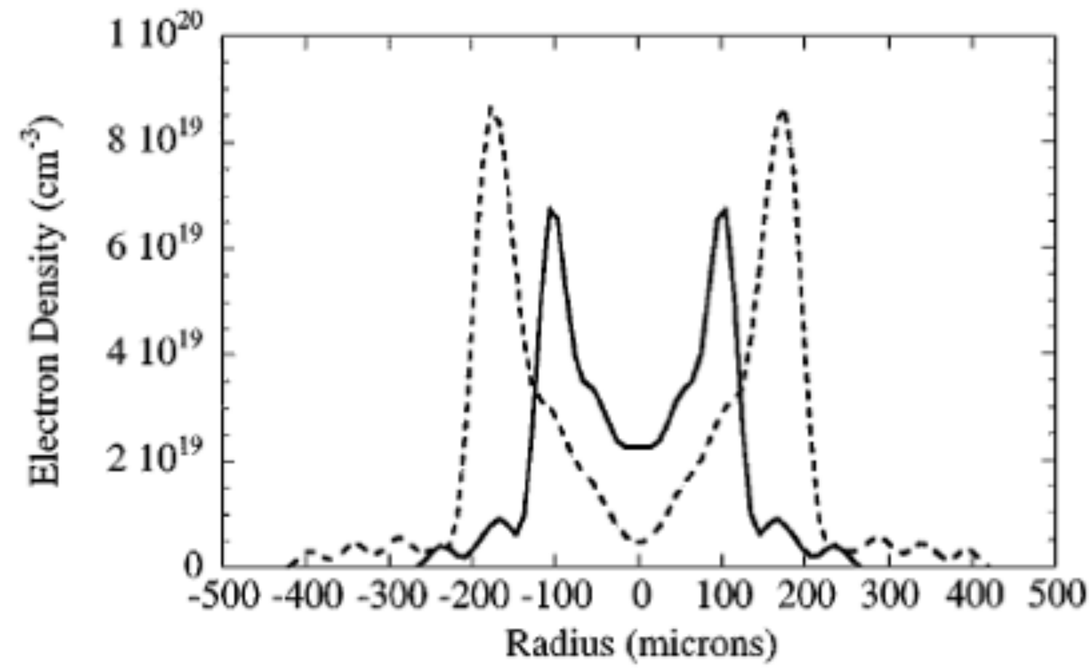
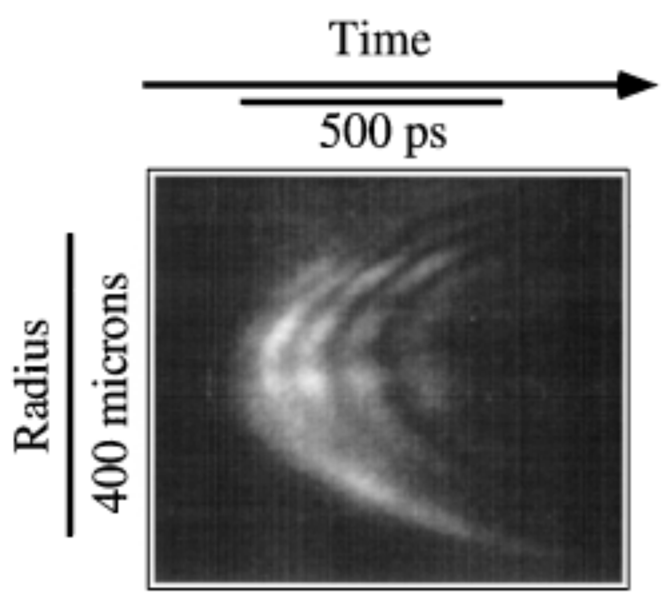
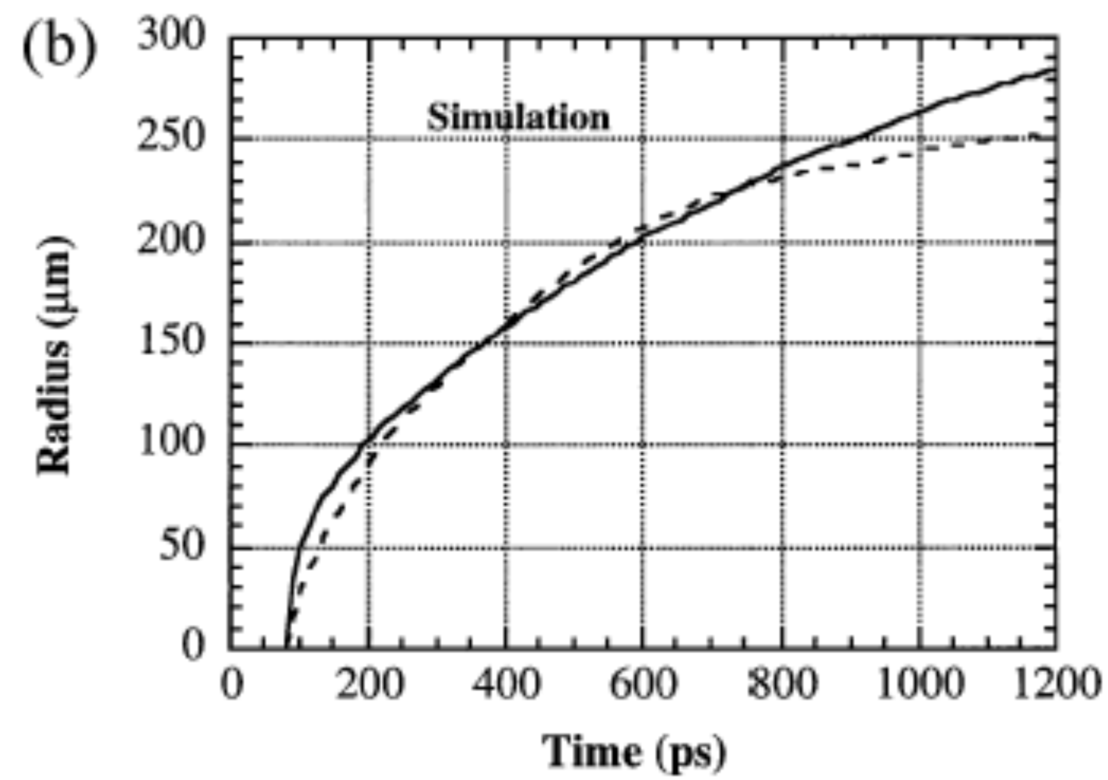
Gas jet : getting a plasmas channel



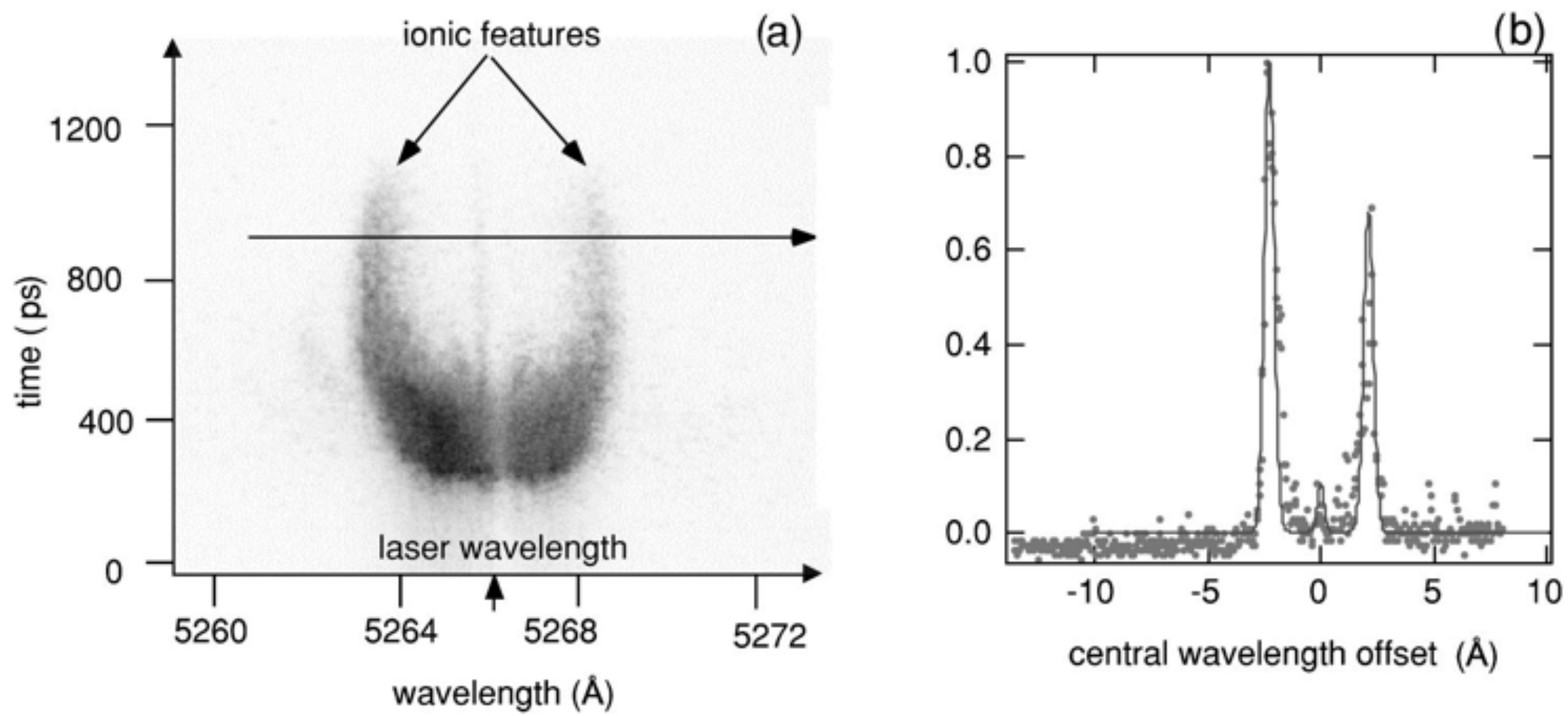






V. Malka *et al.*, Phys. Rev. Lett., Vol. 79, No. 16 (1997)

Gas jet for atomic physics aspects of warm dense matter



The parameters are determined by fitting simultaneously the electron and ion TS spectra.

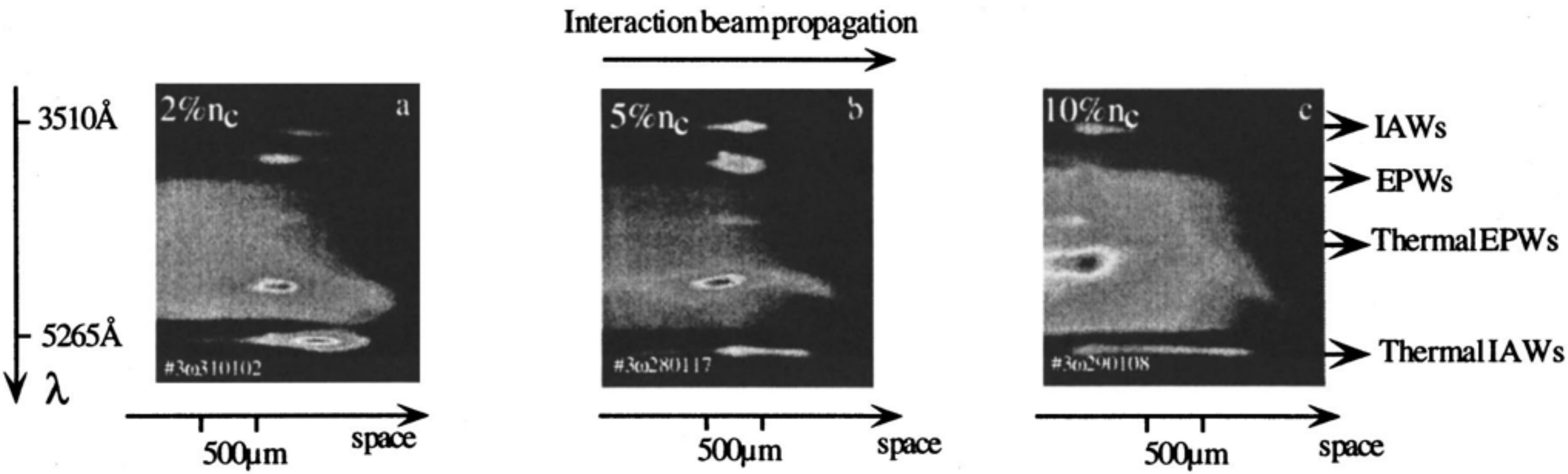
Since the atomic density is known one can determine Z* !

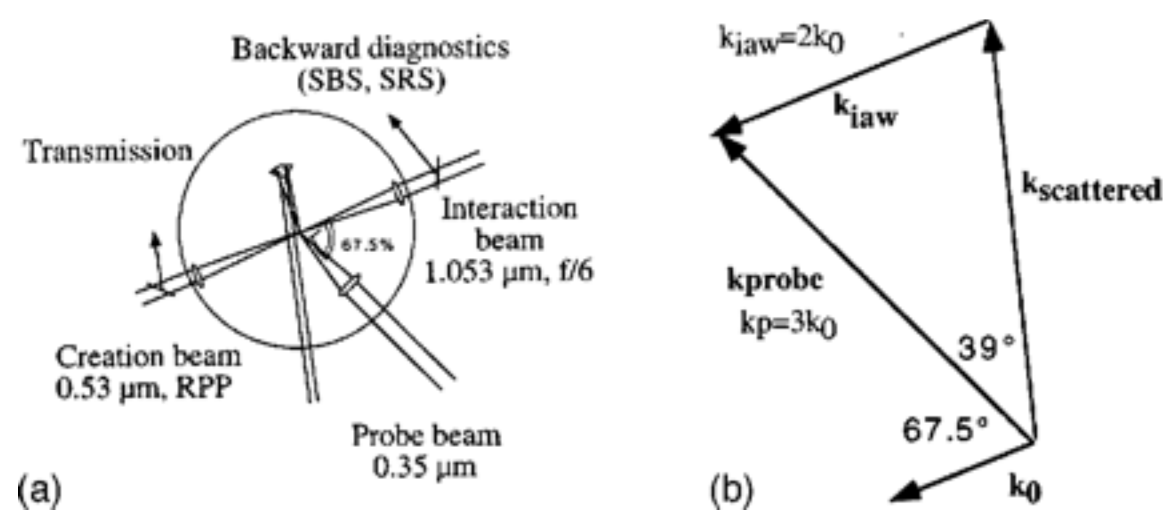
$T_e \simeq 415$ eV, $Z^* \simeq 27.4$, $n_e \simeq 1.30\text{x}10^{20}$ cm^{-3}.

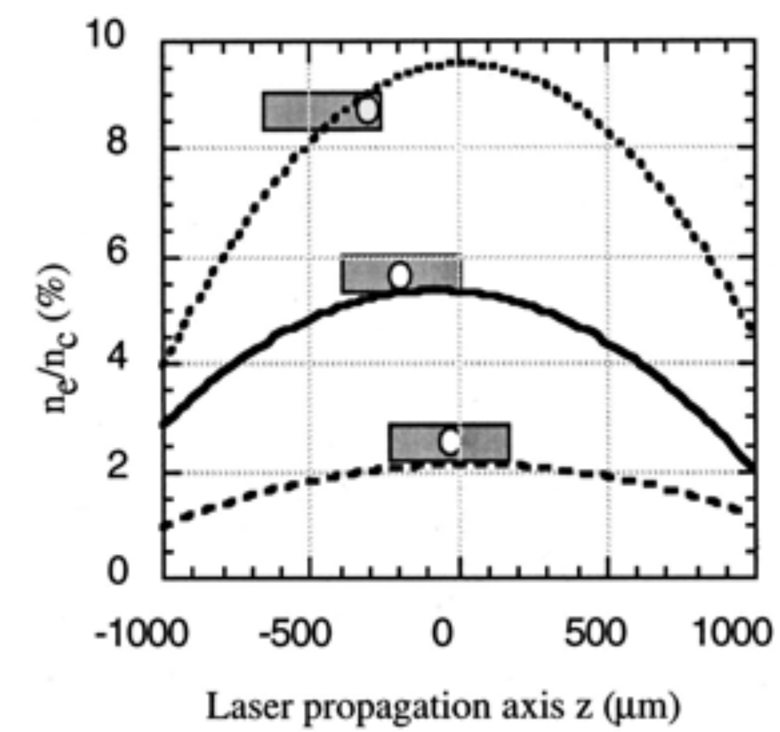
Extremely important for testing NON LTE atomic physics codes

C. C. Popovic *et al.*, Phys. Rev. E, Vol. 65, 046418 (2002)

Gas jet for fusion related studies : propagation studies

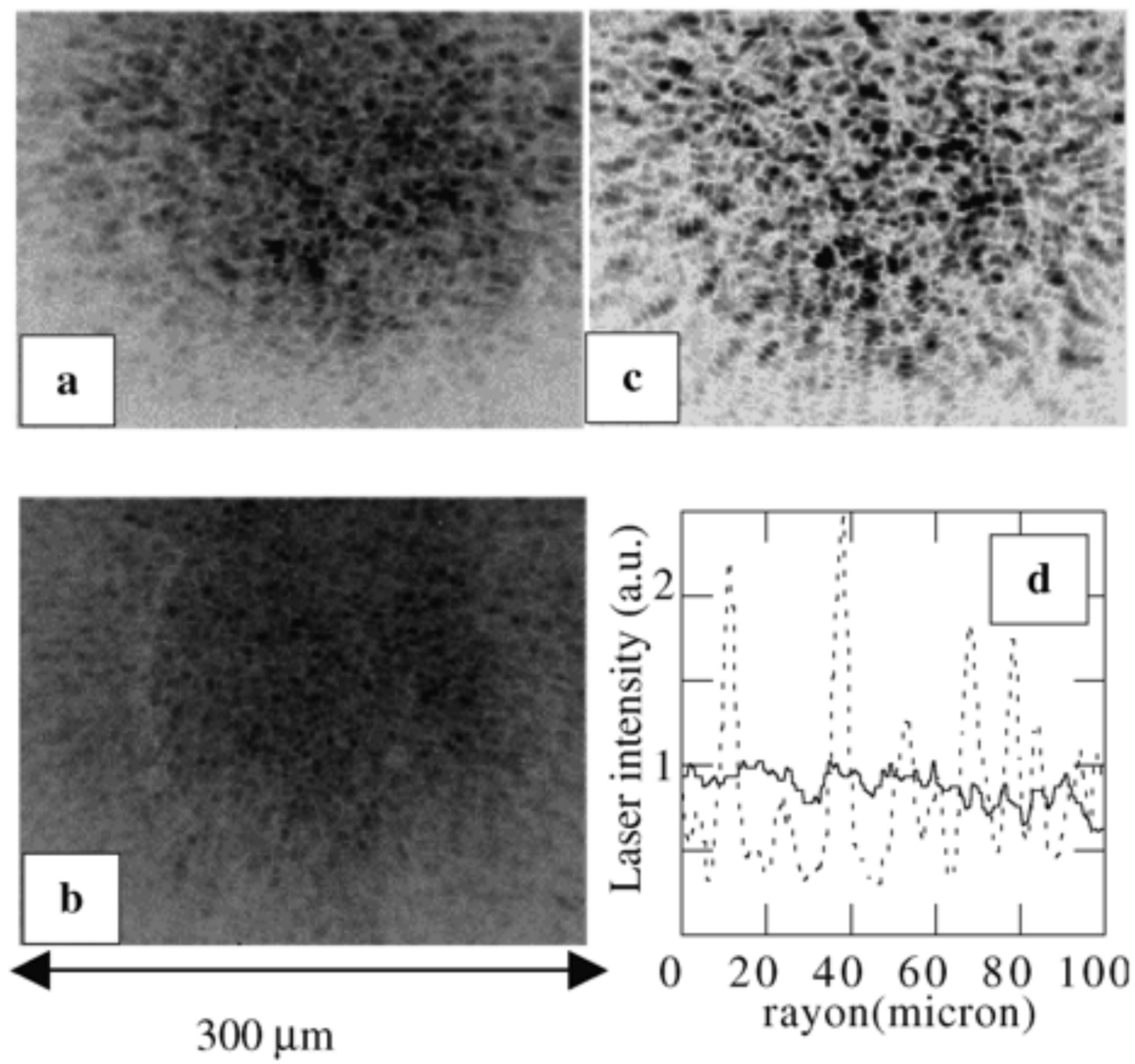






V. Malka *et al.*, Phys. of Plasmas, Vol. 7, No. 10 (2000)

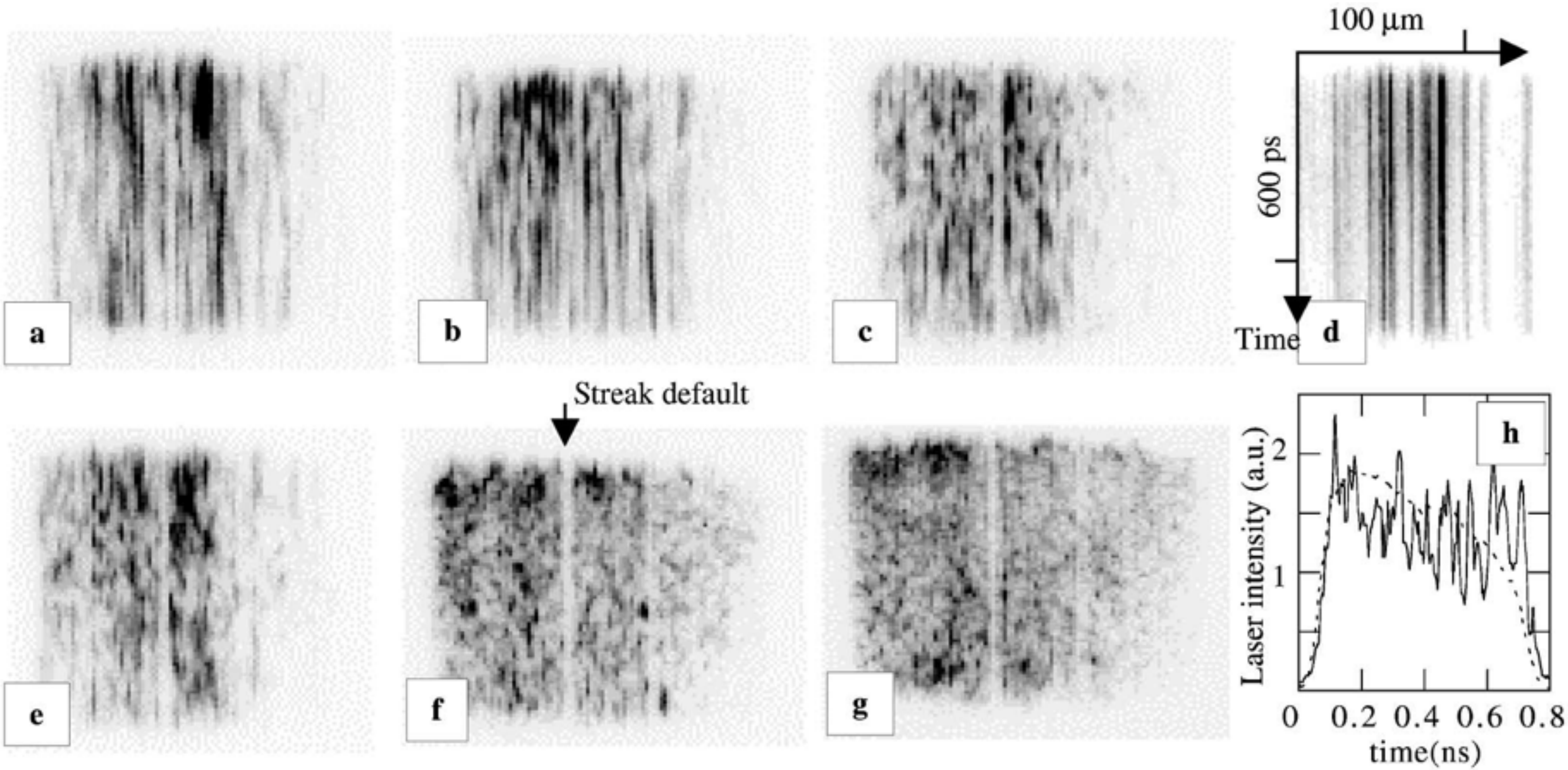
Gas jet for fusion related studies : smoothing studies



Time integrated images of the transmitted laser light in the PP (a) and NPP (b) cases for plasmas with $n_e = 0{:}01 n_c$. (c) Reference image for a vacuum shot without plasma. (d) Radial intensity profile of panels b (solid line) and c (dotted line) at the middle of the laser spot.

V. Malka *et al.*, Phys. Rev. Lett, Vol. 90, No. 7 (2003)

Gas jet for fusion related studies : smoothing studies



Time resolved images of the transmitted laser light in the PP (a) –(c) and NPP (e) –(g) cases for plasmas with n_e/n_c of 0.2 (a),(e), 0.5 (b),(f), and 1% (c),(g) of the critical density. (d) Reference image for a vacuum shot without plasma. (h) Temporal dependence of the intensity for panels f (solid line) and d (dotted line)

V. Malka *et al.*, Phys. Rev. Lett, Vol. 90, No. 7 (2003)

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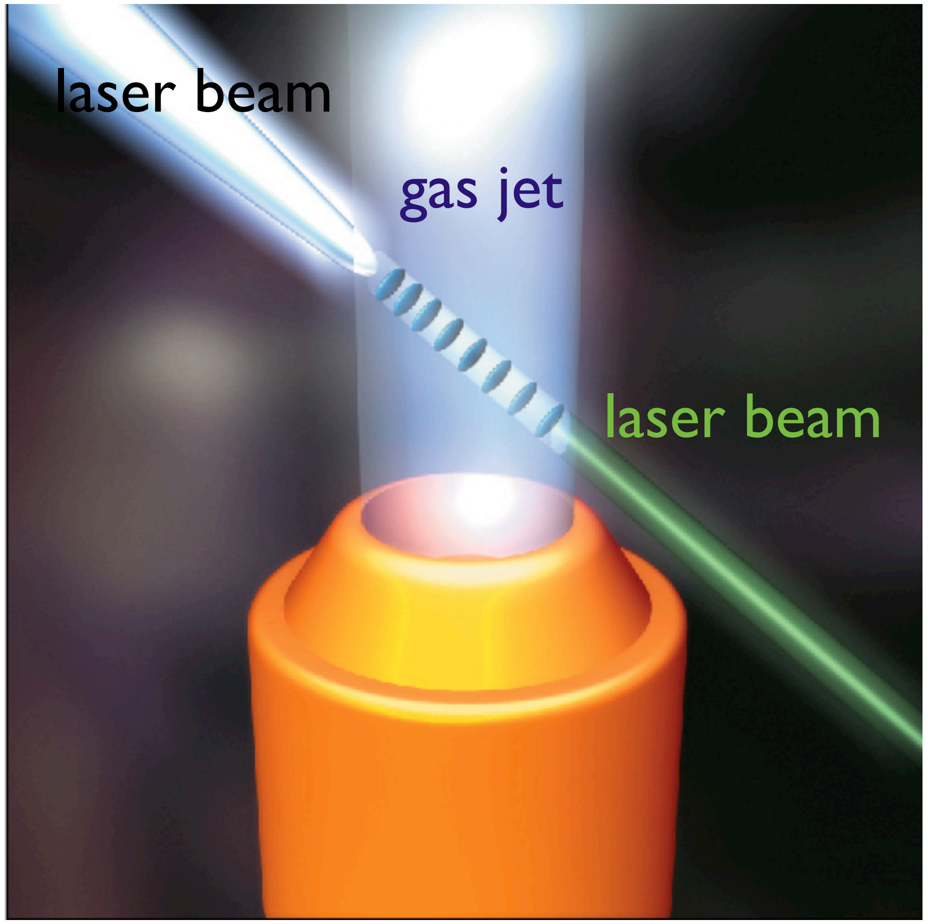
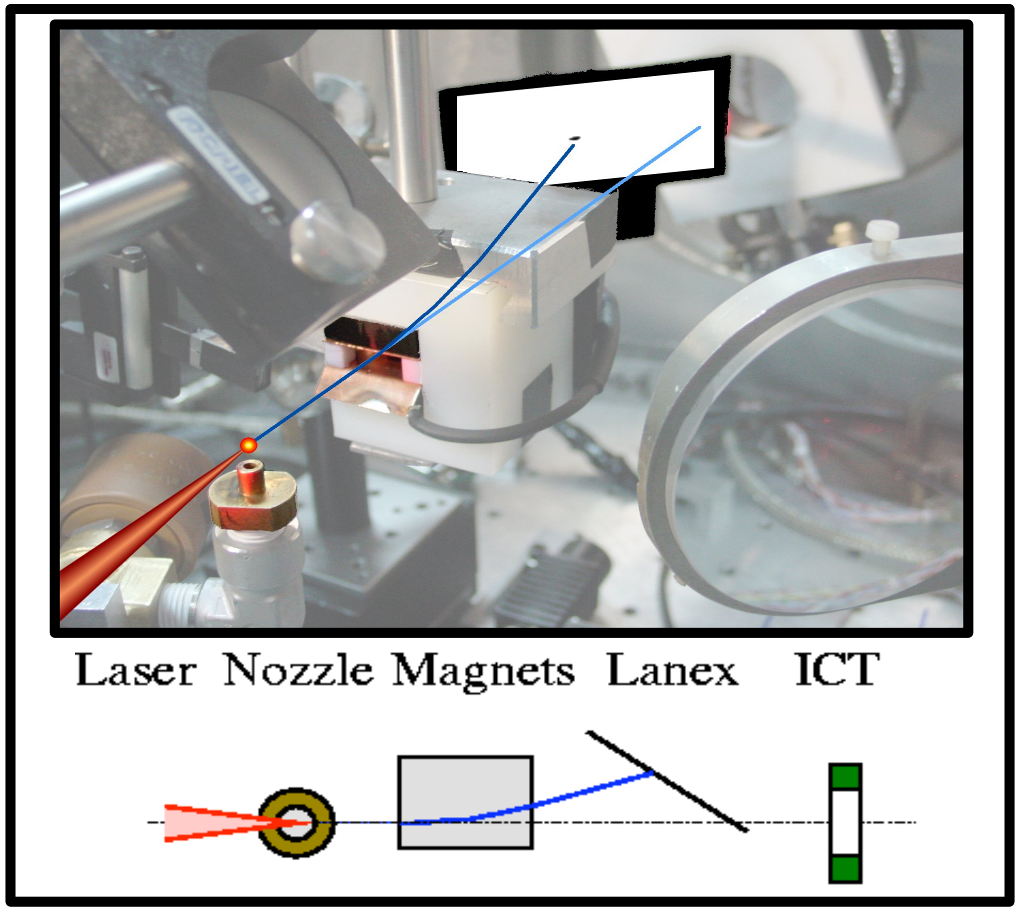
The Bubble regime : experimental set-up

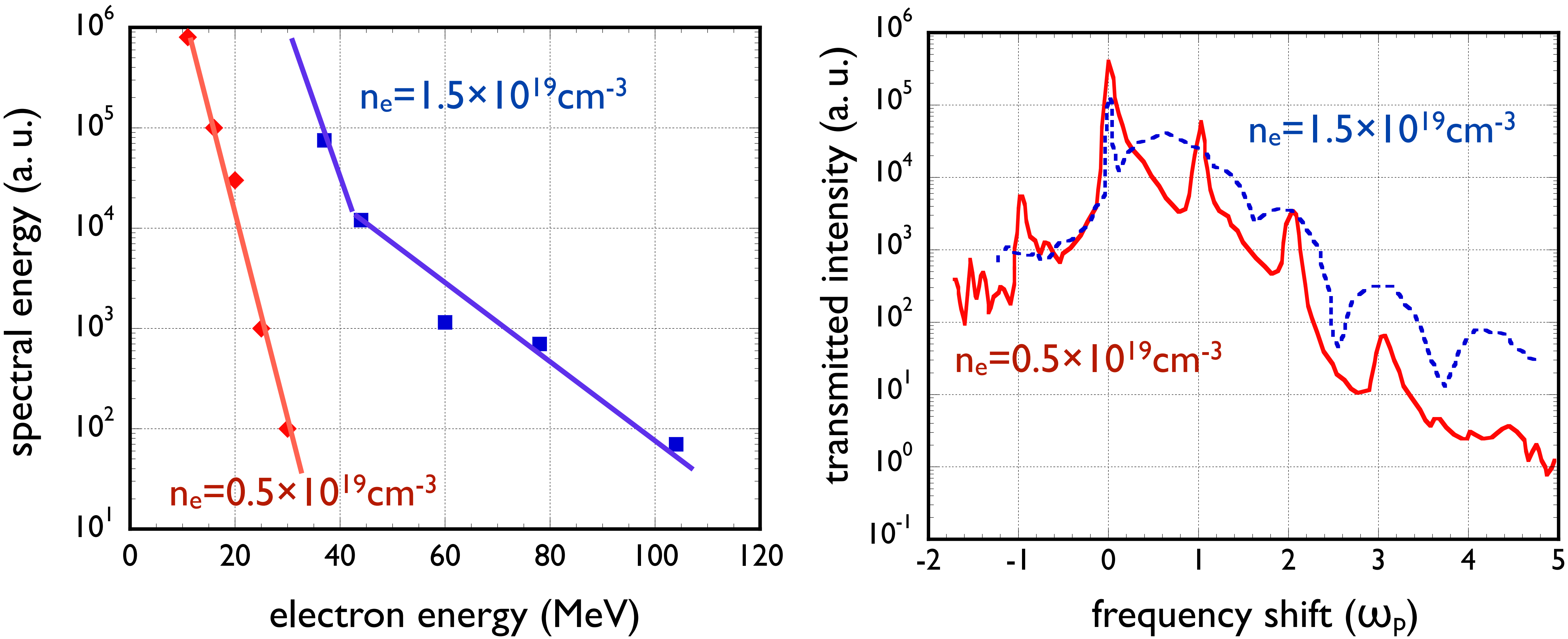


Scheme of principle



Experimental set up

1995 Relativistic wave breaking (RAL/IC/UCLA/LULI)

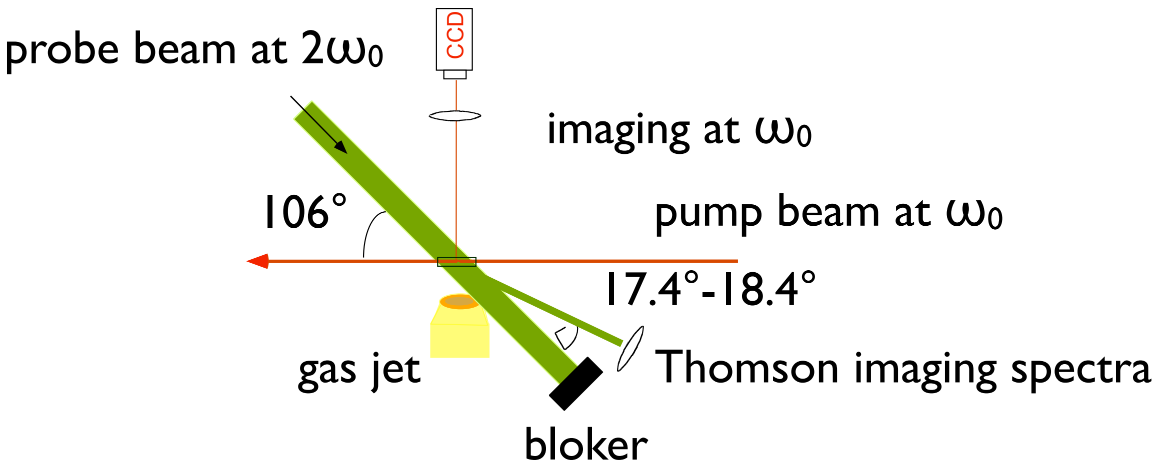


Multiple satellites : high amplitude plasma waves
Broadening at higher densities
Loss of coherence of the relativistic plasma waves

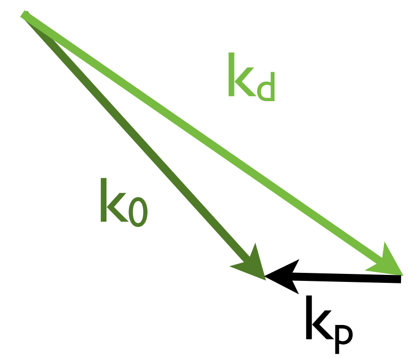
A. Modena *et al.*, Nature (1995)

1998 Thomson scattering diagnostic

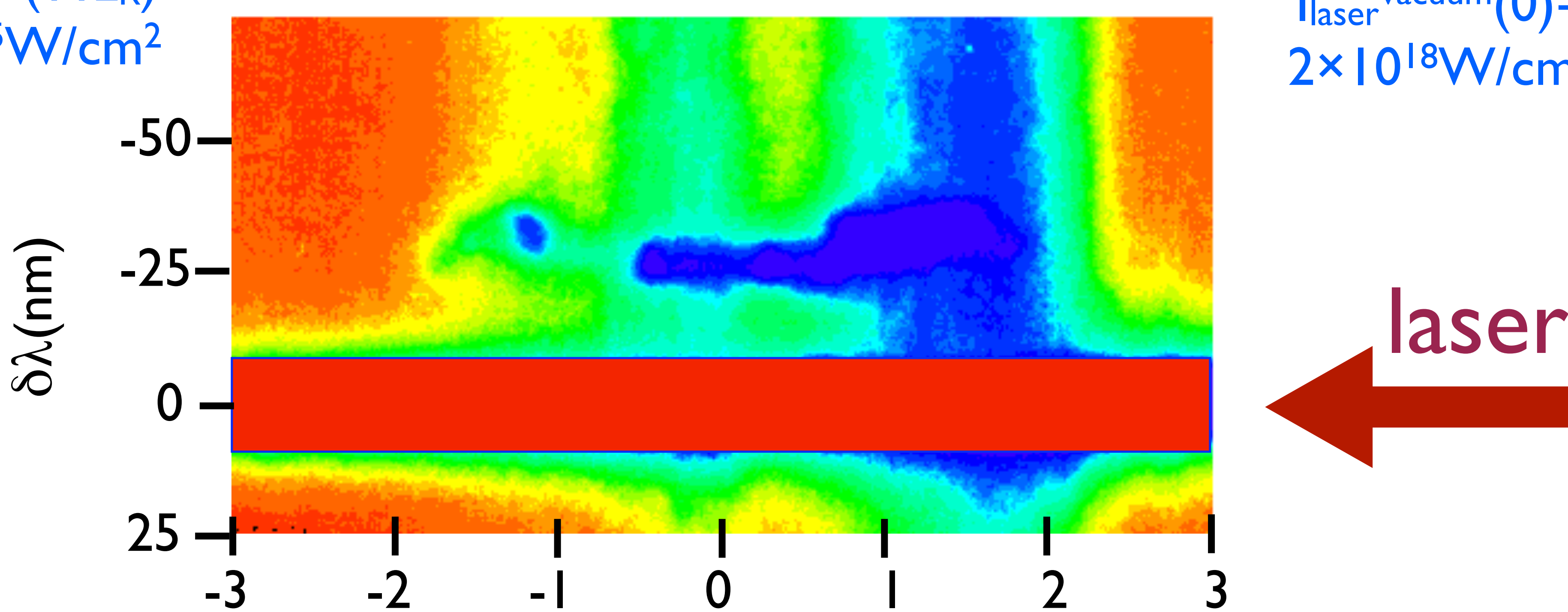
experimental set-up



waves geometry



$I_{laser}^{vacuum}(11z_R)=$
$2\times10^{15}W/cm^2$

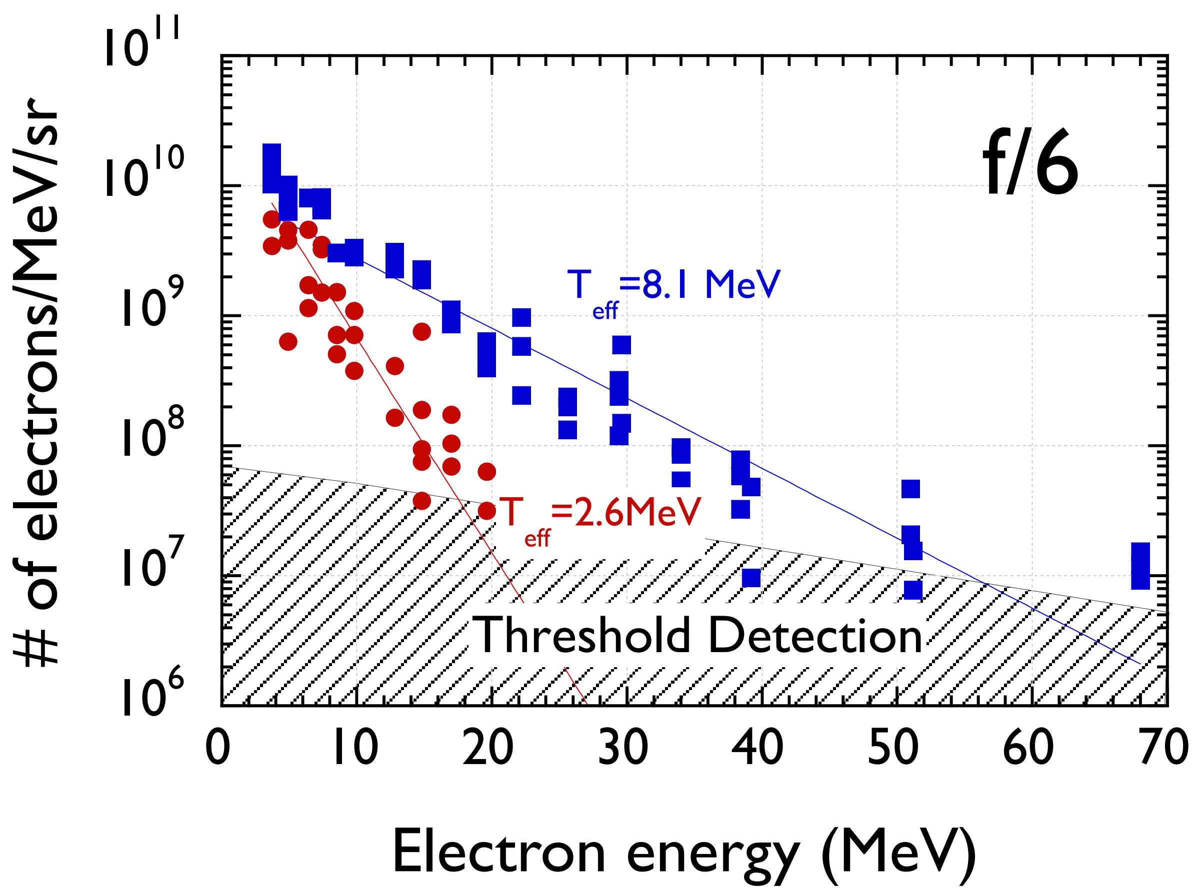


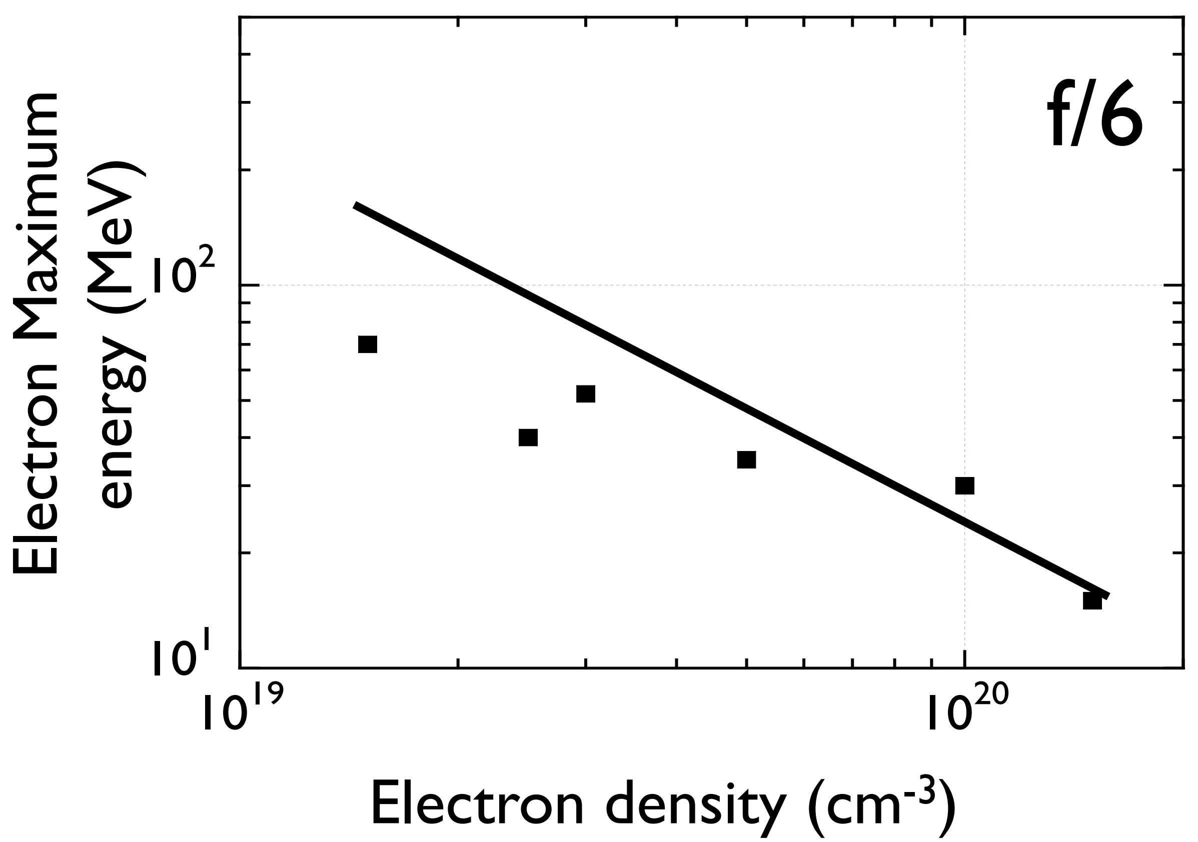
$I_{laser}^{vacuum}(0)=$
$2\times10^{18}W/cm^2$

Clayton *et al.*, PRL **81**, 1 (1998)

Spectra : E_{max} increases when n_e decreases

Parameters: $n_e=5\times10^{19}cm^{-3}$ & $1.5\times10^{20}cm^{-3}$, $\tau_L=35fs$, $E=0.6J$, $I_L= 2\times10^{19}W/cm^2$

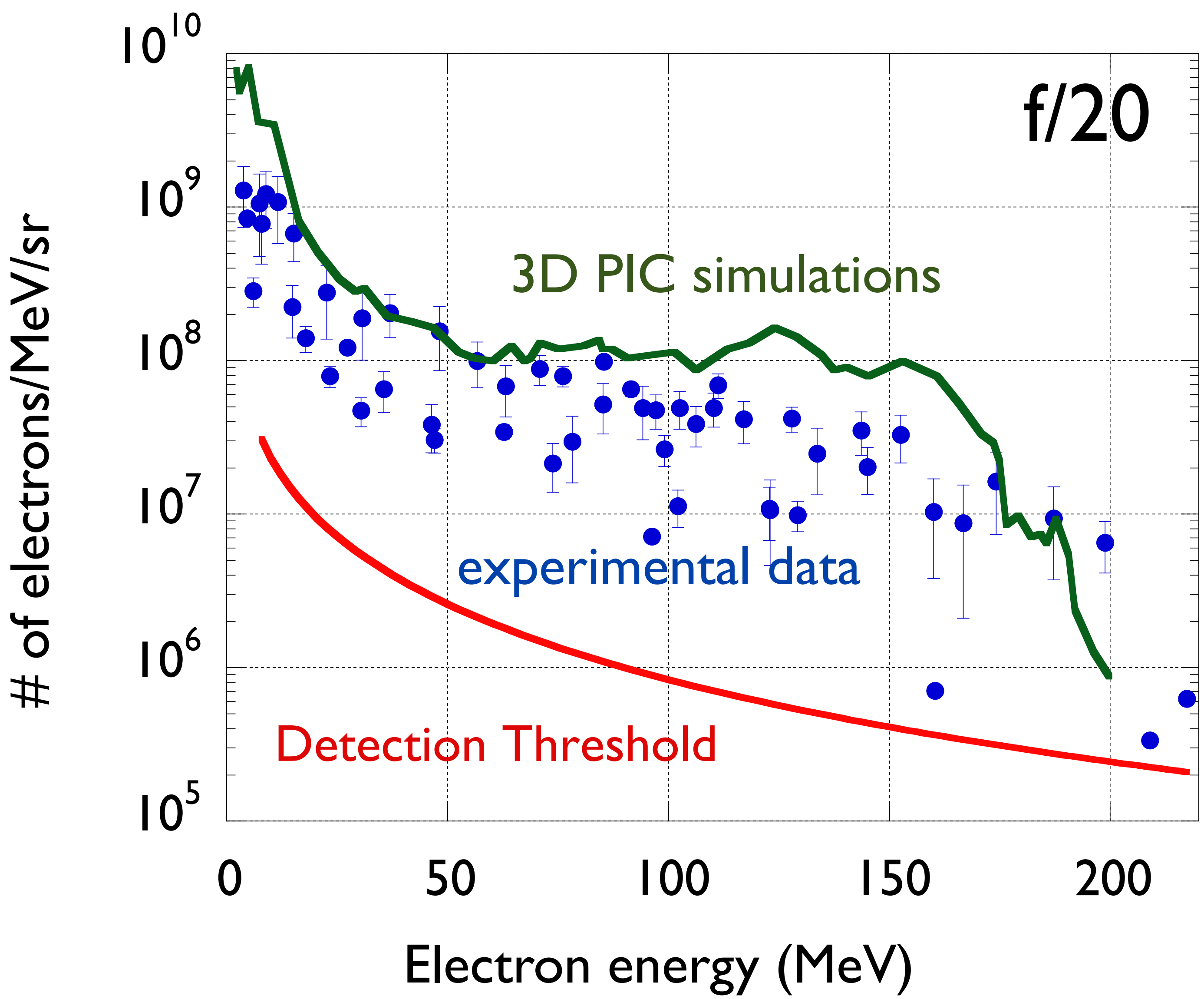




V. Malka et al., Phys. of Plasmas **8**, 6 (2001)

2002 The Forced Laser Wakefield: the NL regime

Parameters: n_e=1.5×10^{19}cm^{-3}, τ_L=35fs, E=0.6J, I_L= 1×10^{18}W/cm^2 with $k_p w_0$>1

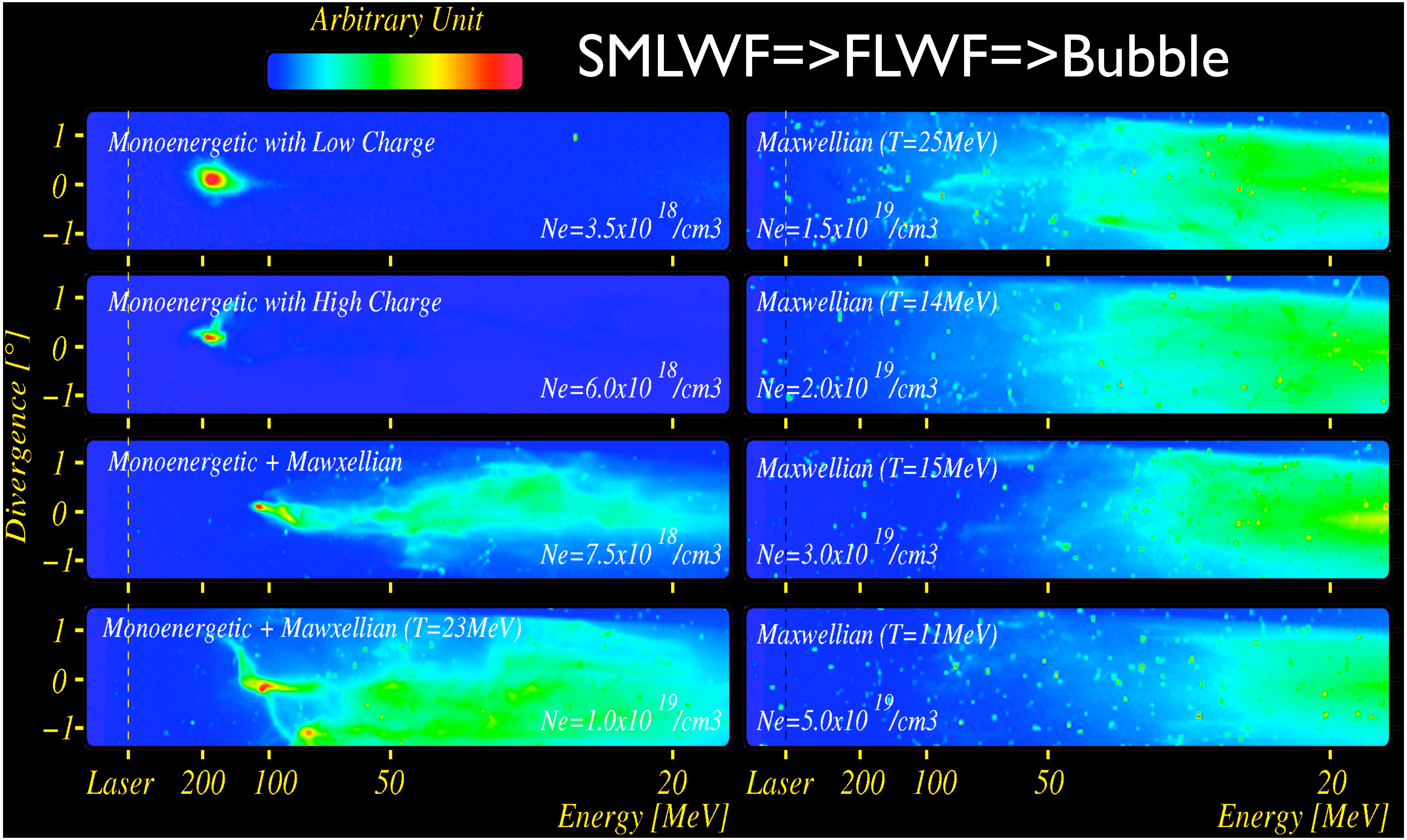


V. Malka *et al.*, Science **298**, 1596 (2002)

*CARE project

TARG2 Workshop, Paris, France April 20-22 (2015)

The Bubble regime : distribution quality improvements



V. Malka *et al.*, Phys. of Plasmas **12**, 5 (2005)

The Dream Beam

Monoenergetic beams of relativistic electrons from intense laser–plasma interactions

S. P. D. Mangles[1], C. D. Murphy[1,2], Z. Najmudin[1], A. G. R. Thomas[1], J. L. Collier[2], A. E. Dangor[1], E. J. Divall[2], P. S. Foster[2], J. G. Gallacher[3], C. J. Hooker[2], D. A. Jaroszynski[3], A. J. Langley[2], W. B. Mori[4], P. A. Norreys[2], F. S. Tsung[4], R. Viskup[3], B. R. Walton[1] & K. Krushelnick[1]

[1]*The Blackett Laboratory, Imperial College London, London SW7 2AZ, UK*
[2]*Central Laser Facility, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, UK*
[3]*Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK*
[4]*Department of Physics and Astronomy, UCLA, Los Angeles, California 90095, USA*

High-quality electron beams from a laser wakefield accelerator using plasma-channel guiding

C. G. R. Geddes[1,2], Cs. Toth[1], J. van Tilborg[1,3], E. Esarey[1], C. B. Schroeder[1], D. Bruhwiler[4], C. Nieter[4], J. Cary[4,5] & W. P. Leemans[1]

[1]*Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, California 94720, USA*
[2]*University of California, Berkeley, California 94720, USA*
[3]*Technische Universiteit Eindhoven, Postbus 513, 5600 MB Eindhoven, the Netherlands*
[4]*Tech-X Corporation, 5621 Arapahoe Ave. Suite A, Boulder, Colorado 80303, USA*
[5]*University of Colorado, Boulder, Colorado 80309, USA*

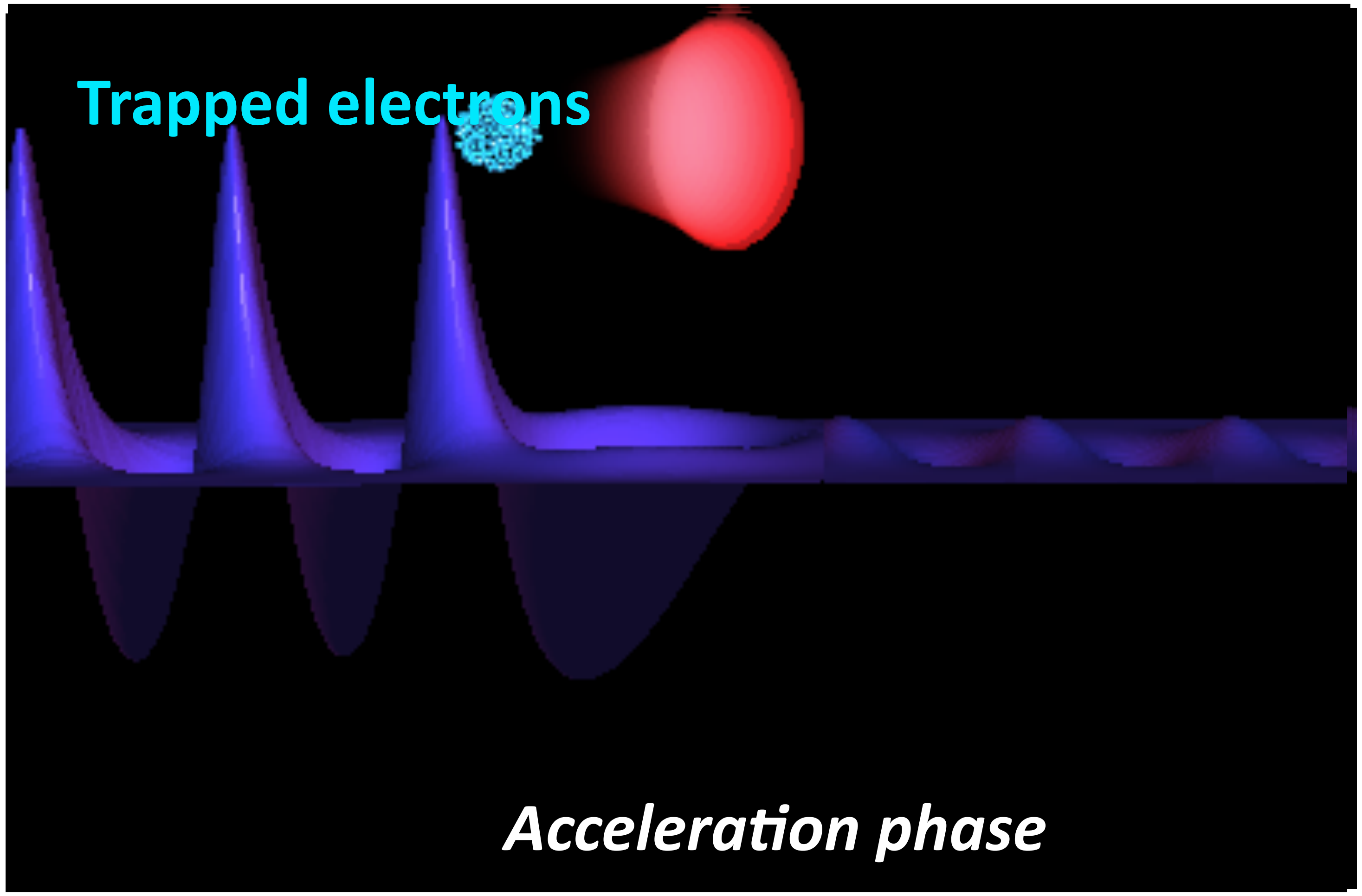
A laser–plasma accelerator producing monoenergetic electron beams

J. Faure[1], Y. Glinec[1], A. Pukhov[2], S. Kiselev[2], S. Gordienko[2], E. Lefebvre[3], J.-P. Rousseau[1], F. Burgy[1] & V. Malka[1]

[1]*Laboratoire d'Optique Appliquée, Ecole Polytechnique, ENSTA, CNRS, UMR 7639, 91761 Palaiseau, France*
[2]*Institut fur Theoretische Physik, 1, Heinrich-Heine-Universitat Duesseldorf, 40225 Duesseldorf, Germany*
[3]*Département de Physique Théorique et Appliquée, CEA/DAM Ile-de-France, 91680 Bruyères-le-Châtel, France*

Colliding Laser Pulses Scheme

The first laser creates the accelerating structure
A second laser beam is used to heat electrons

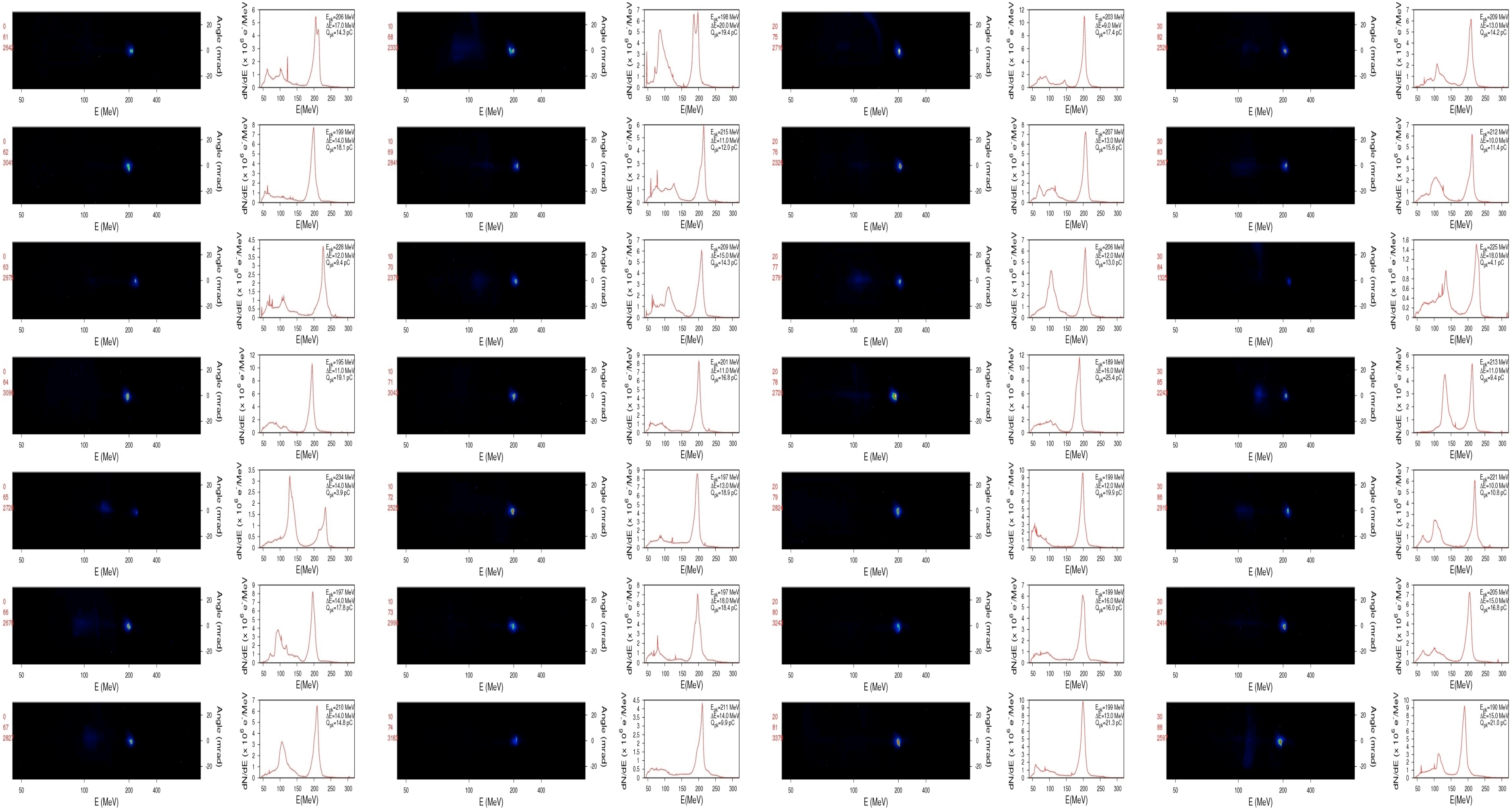


Ponderomotive force of beatwave: $F_p \sim 2a_0a_1/\lambda_0$ (a_0 et a_1 can be "weak")
Boost electrons locally and injects them INJECTION IS LOCAL and IN FIRST BUCKET

Theory : E. Esarey *et al.*, PRL **79**, 2682 (1997), H. Kotaki *et al.*, PoP **11** (2004)
Experiments : J. Faure *et al.*, Nature **444**, 737 (2006)

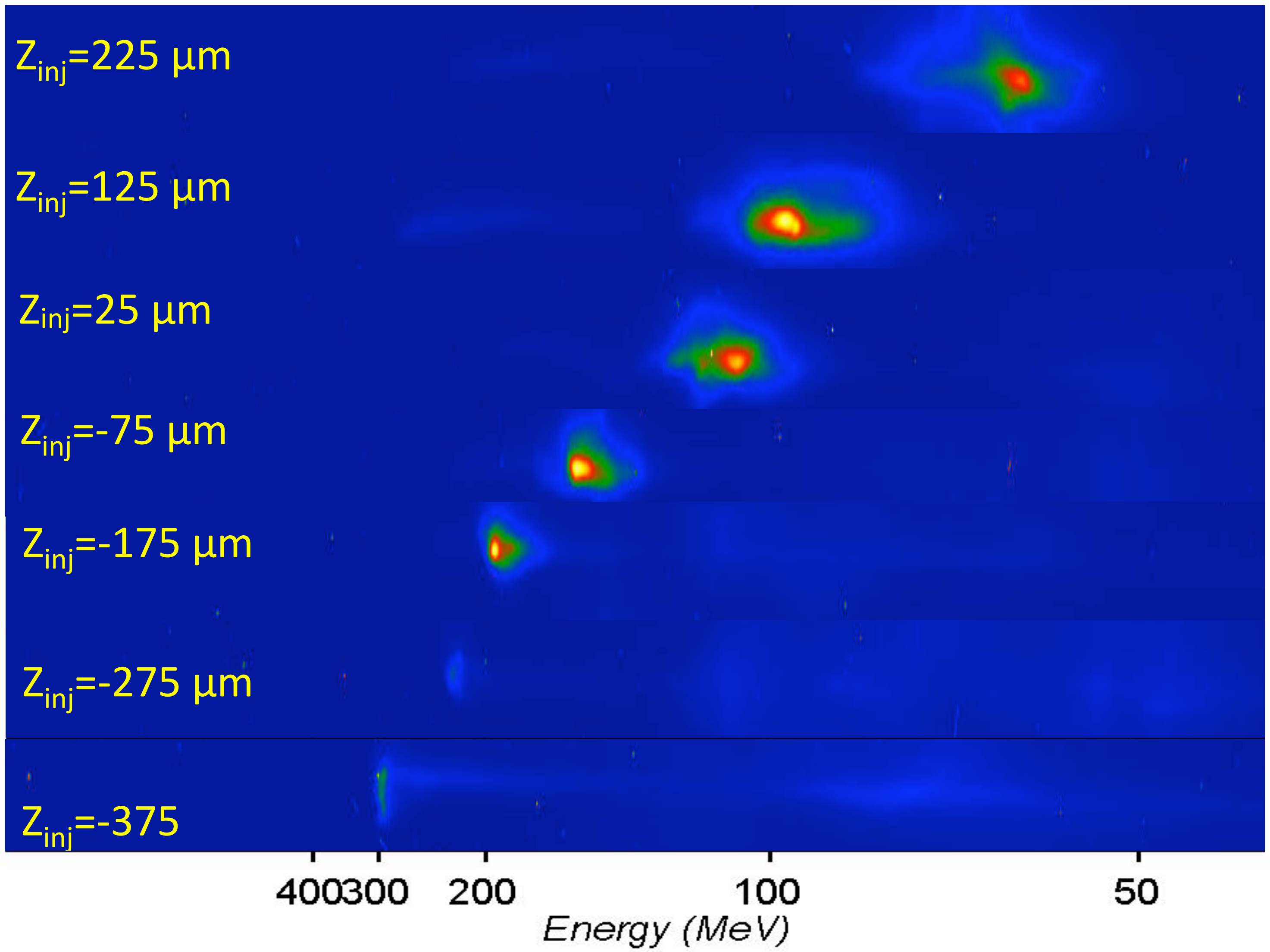
Towards a Stable Laser Plasma Accelerators

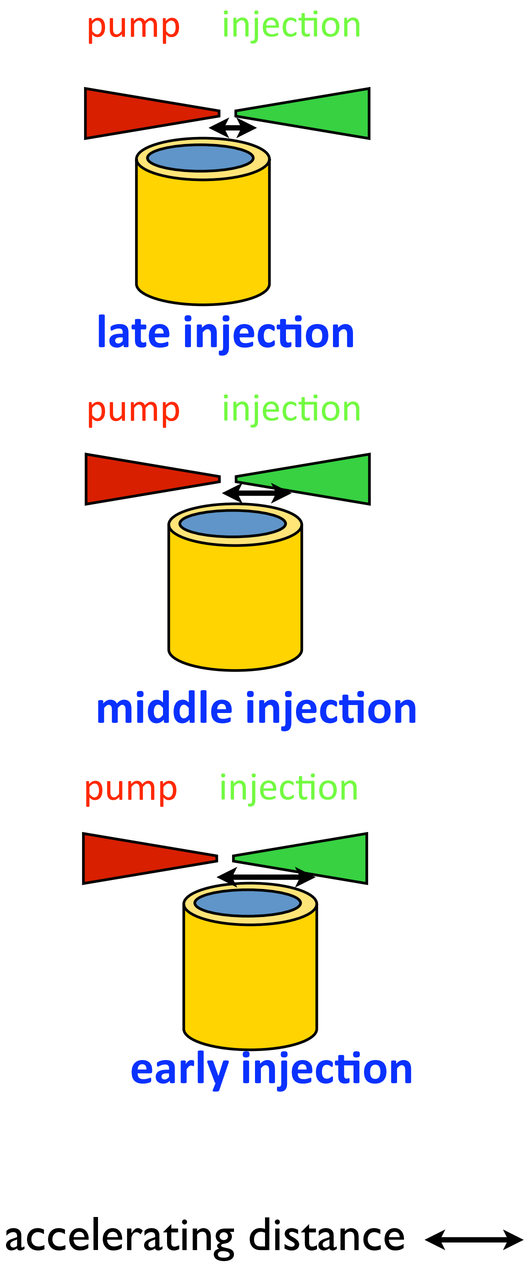
Series of 28 consecutive shots with : $a_0=1.5$, $a_1=0.4$, $n_e=5.7\times10^{18}cm^{-3}$



Nb: very few electrons at low energy, $\delta E/E=5\%$ limited by the spectrometer

Tunability of Laser Plasma Accelerators : electrons energy





J. Faure *et al.*, Nature **444**, 737 (2006)

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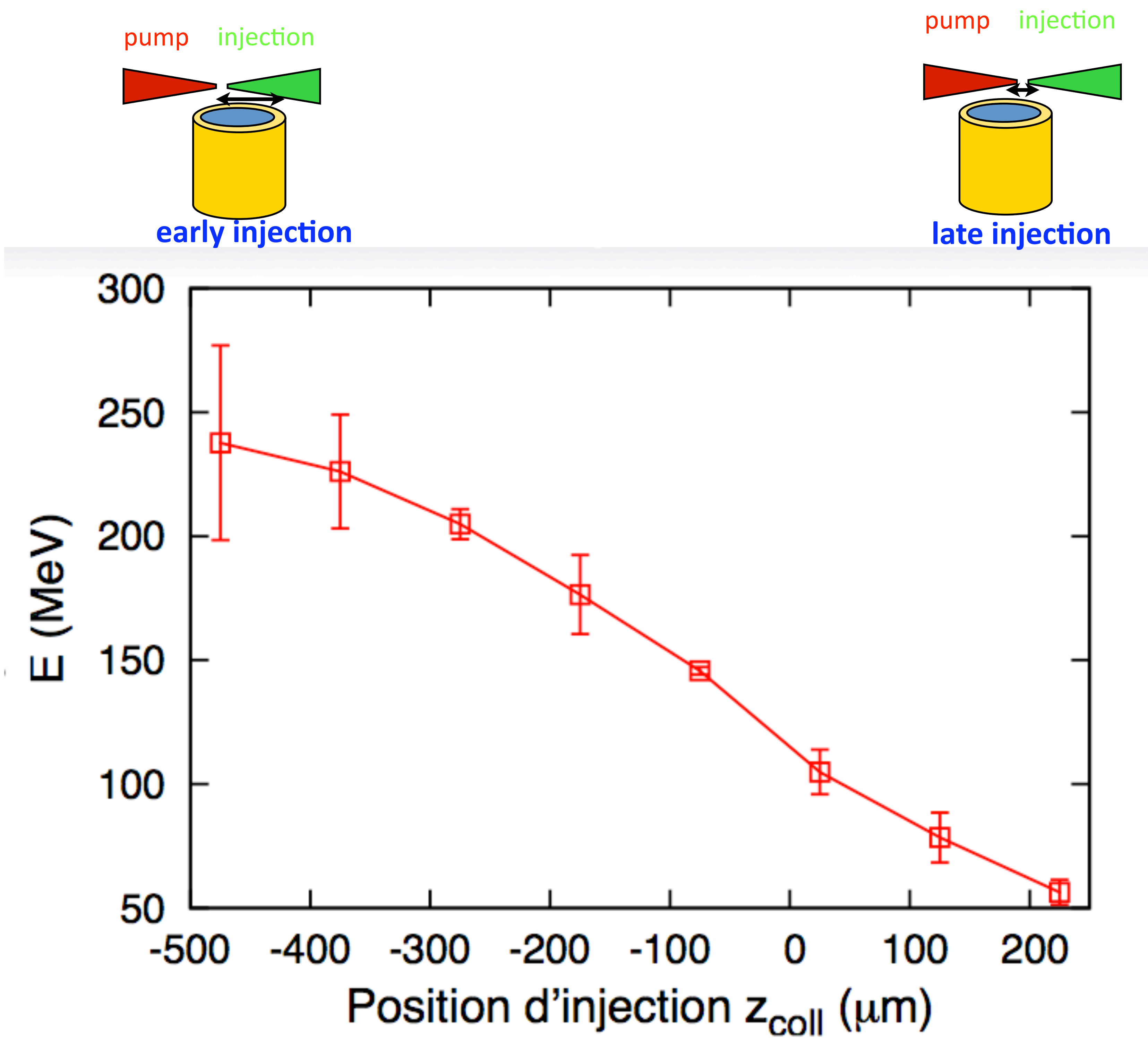
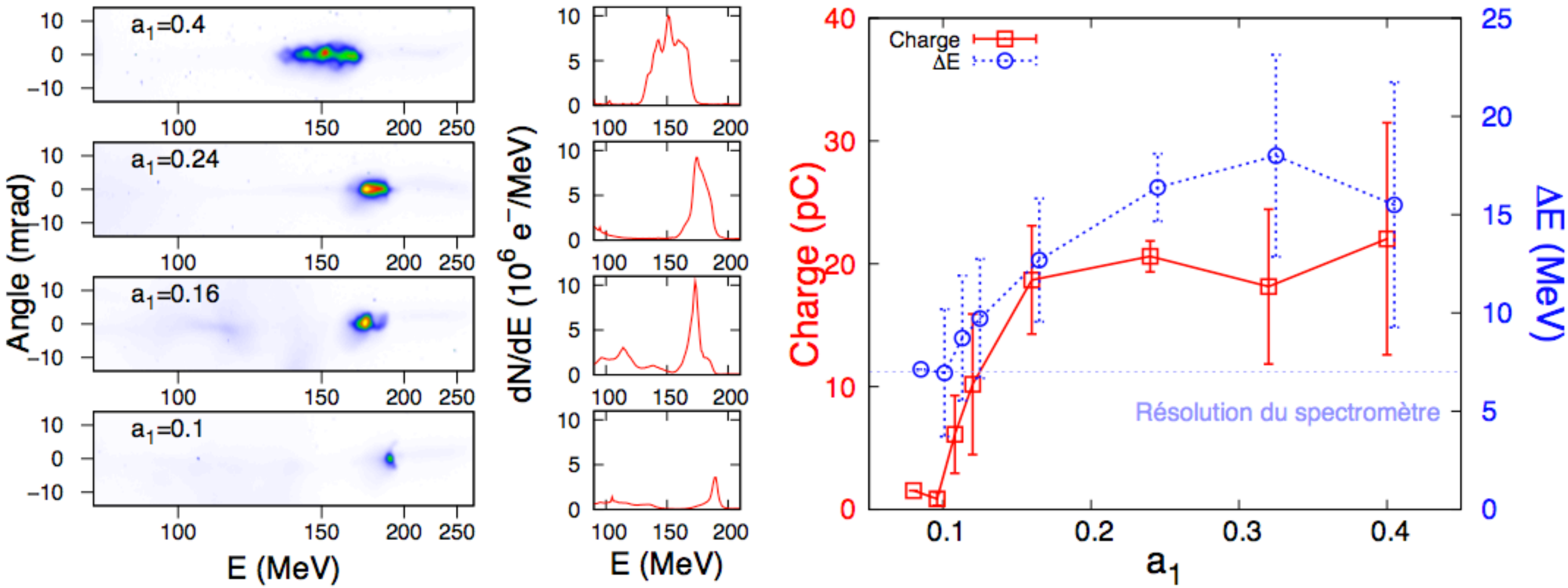


Tuning charge & energy spread with the inj. laser intensity



Charge from 60 pC to 5 pC, ΔE from 20 to 5 MeV

C. Rechatin *et al.*, Phys. Rev. Lett. **102**, 164801 (2009)

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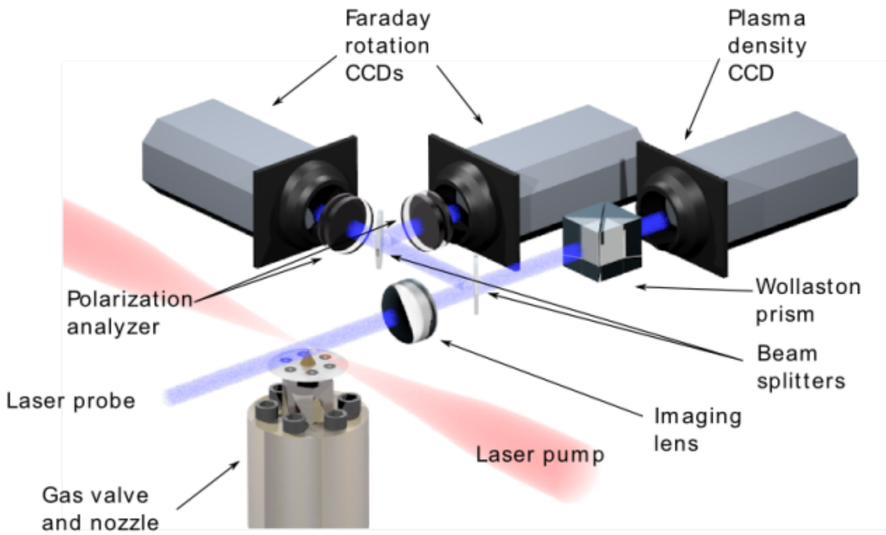
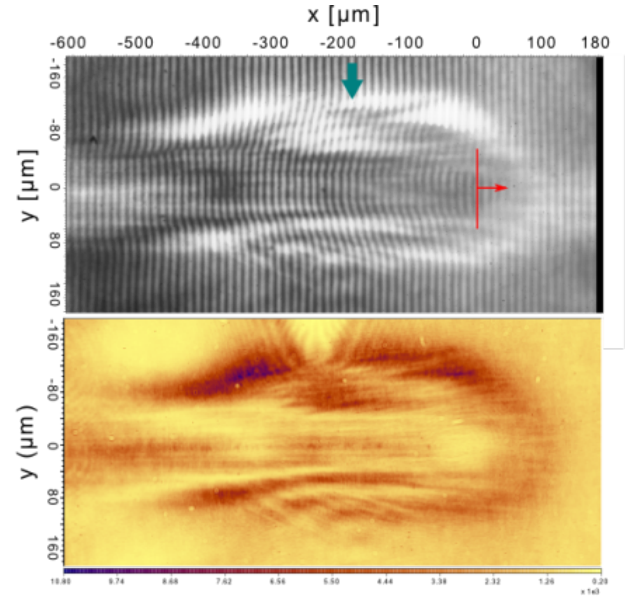
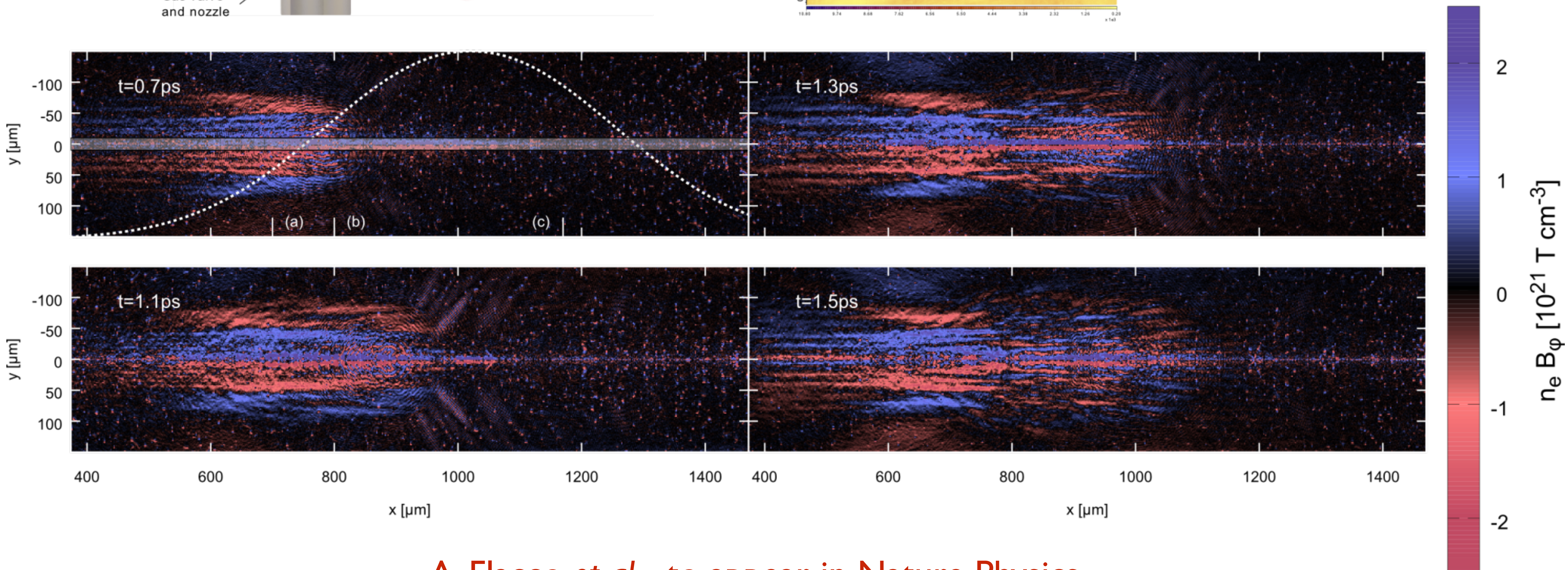
Gas jet for fusion related studies : smoothing studies

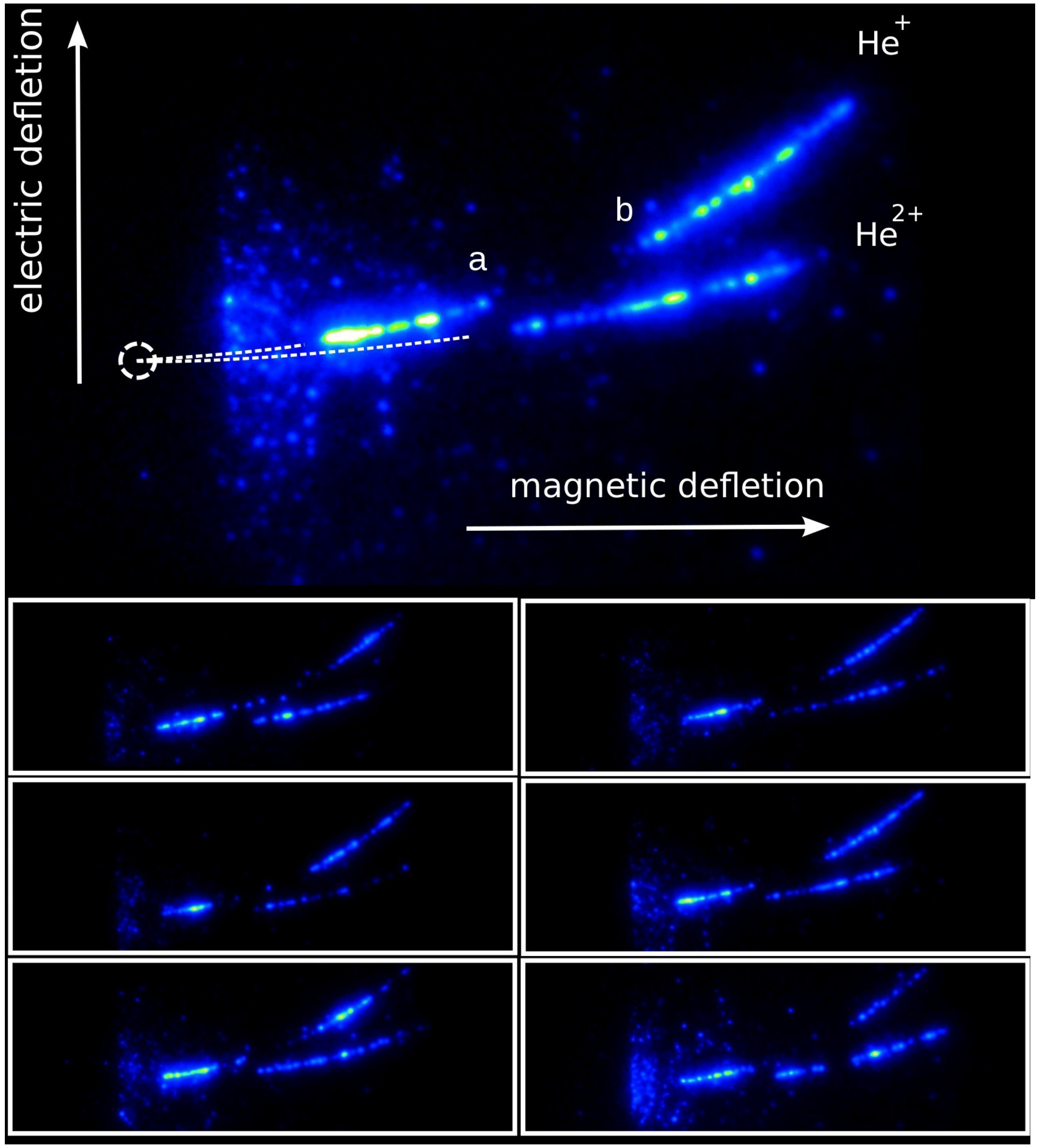


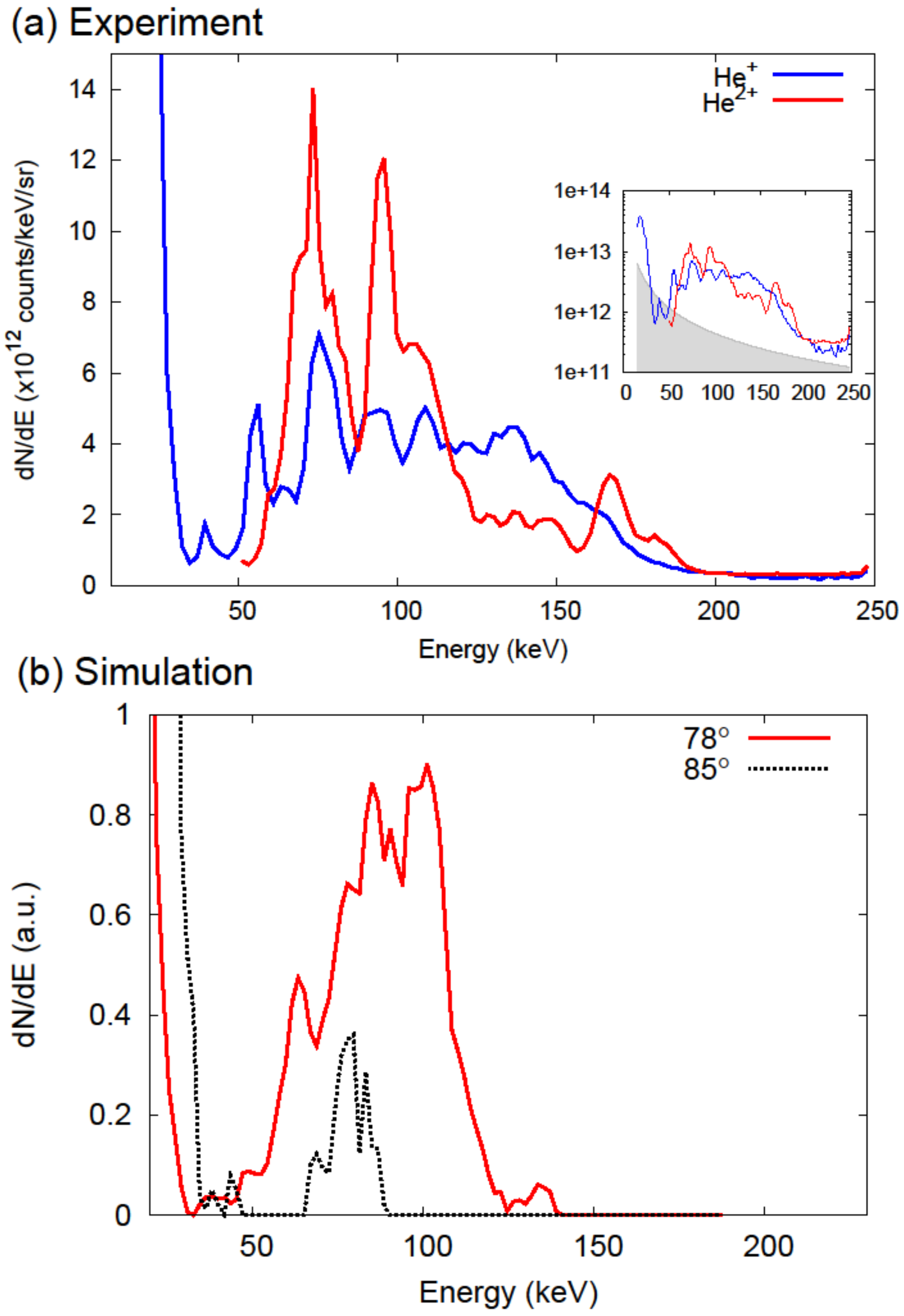




A. Flacco *et al.*, to appear in Nature Physics

Gas jet for fusion related studies : smoothing studies





A. Lifschitz *et al.*, New Journal of Physics 16, 033031 (2014)

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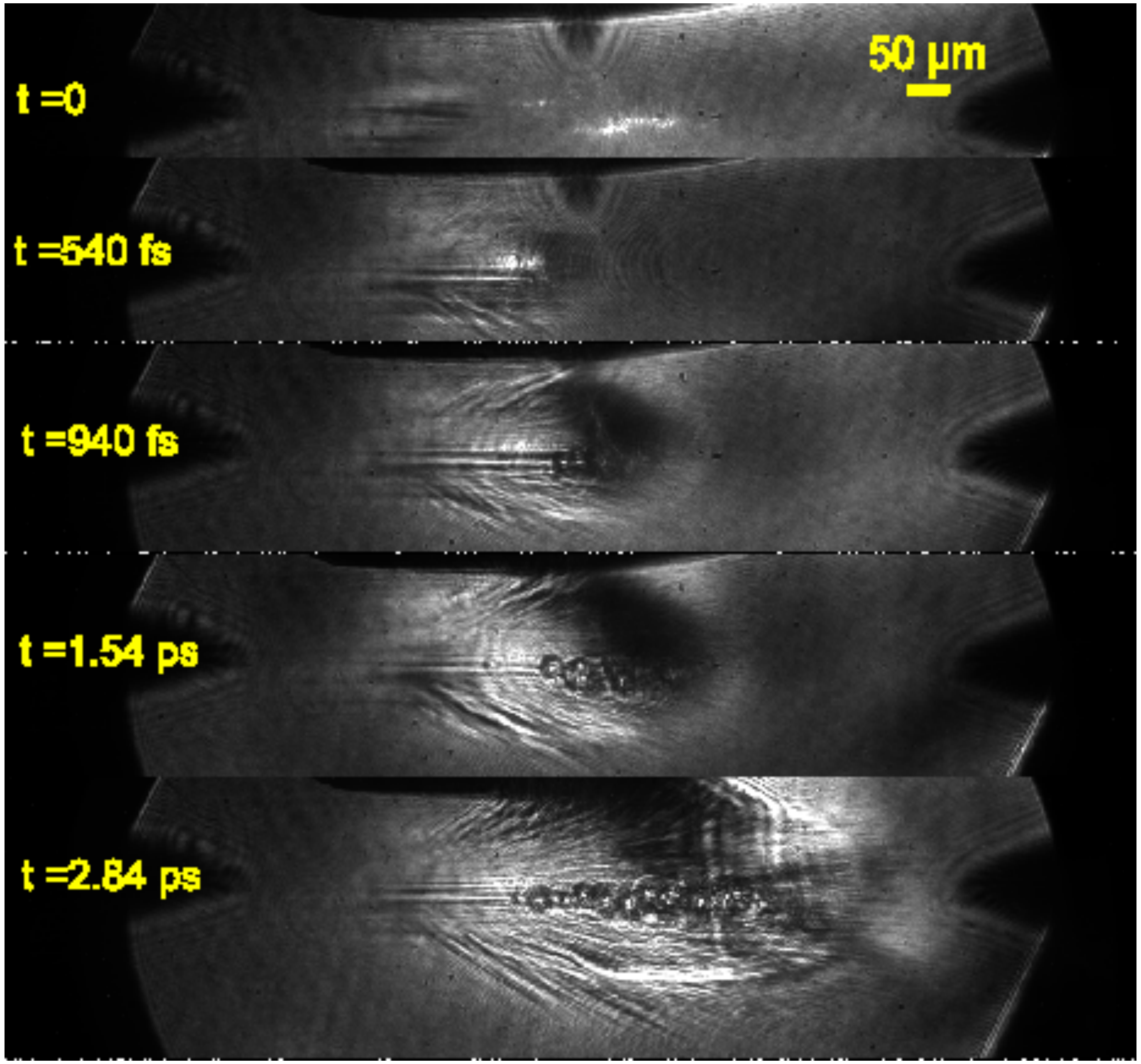

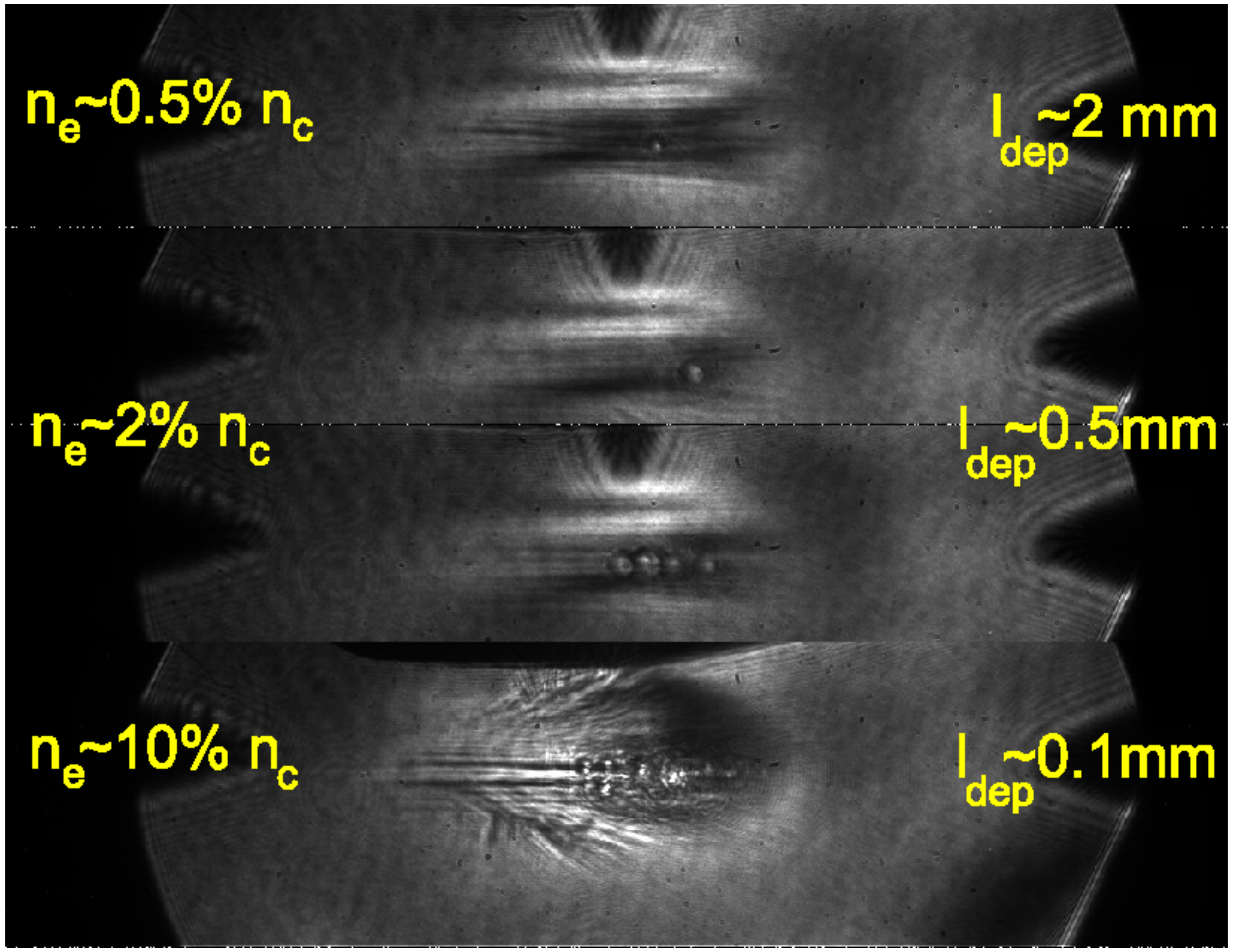

l_{plasma} = 0.7mm
l_{pulse} = 10 µm
Abundant excitation when $l_{dep} \leq l_{plasma}$

F. Sylla *et al.*, Phys. Rev. Lett, Vol. 108, 115003 (2012)

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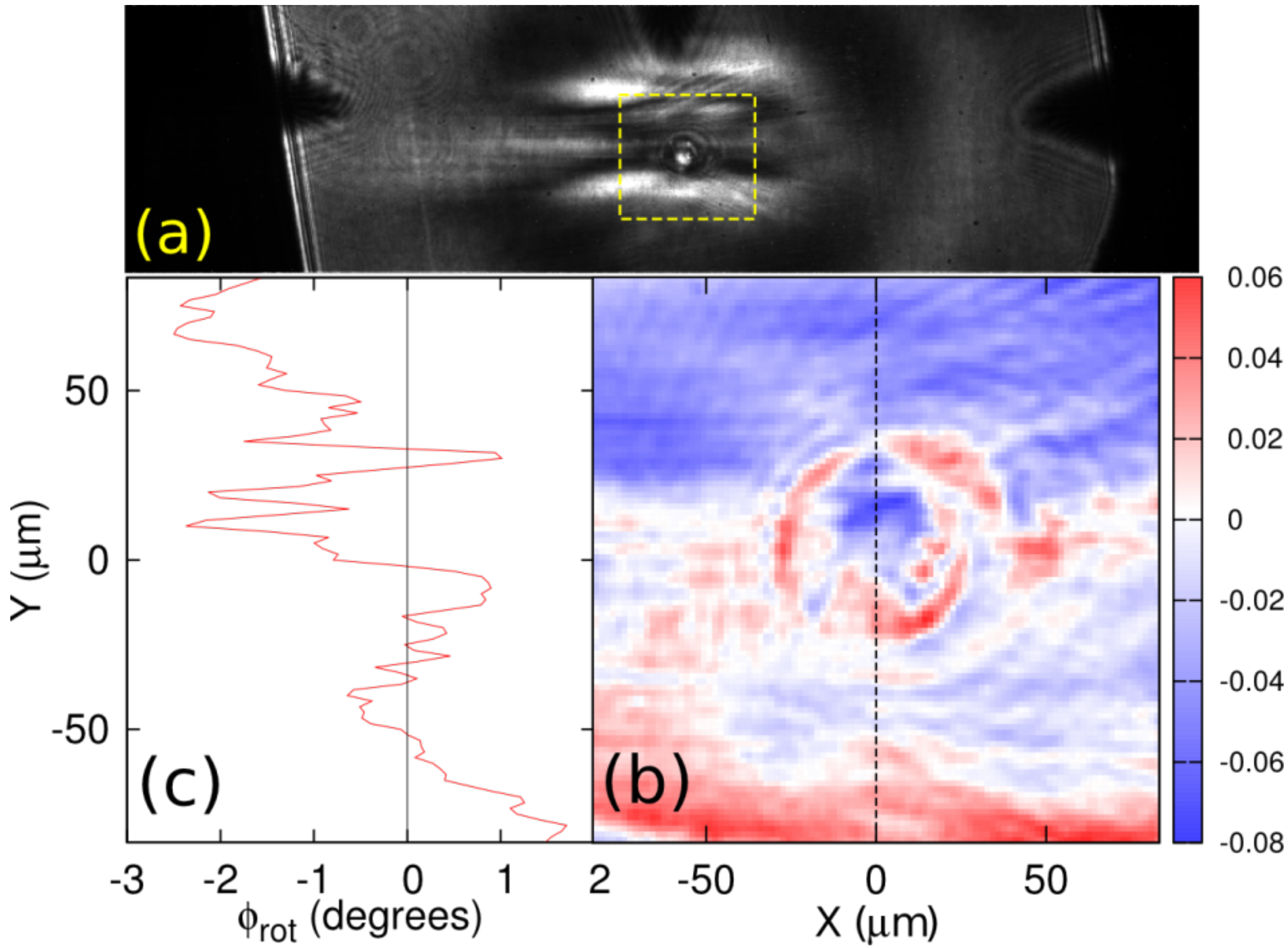

F. Sylla *et al.*, Phys. Rev. Lett, Vol. 108, 115003 (2012)

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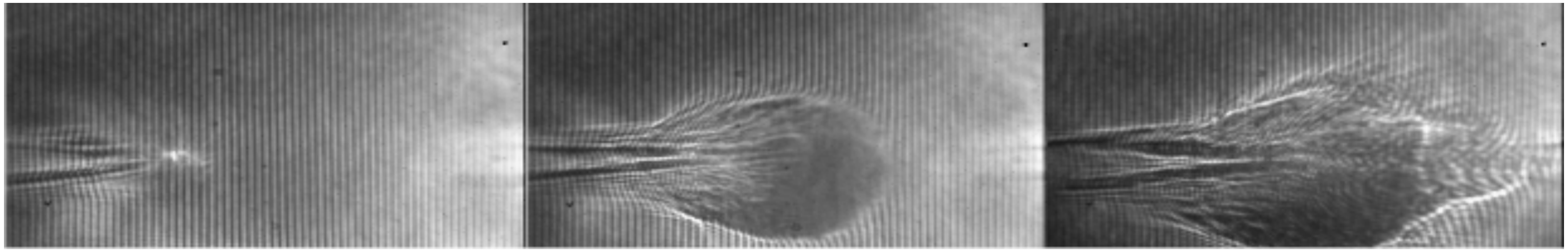

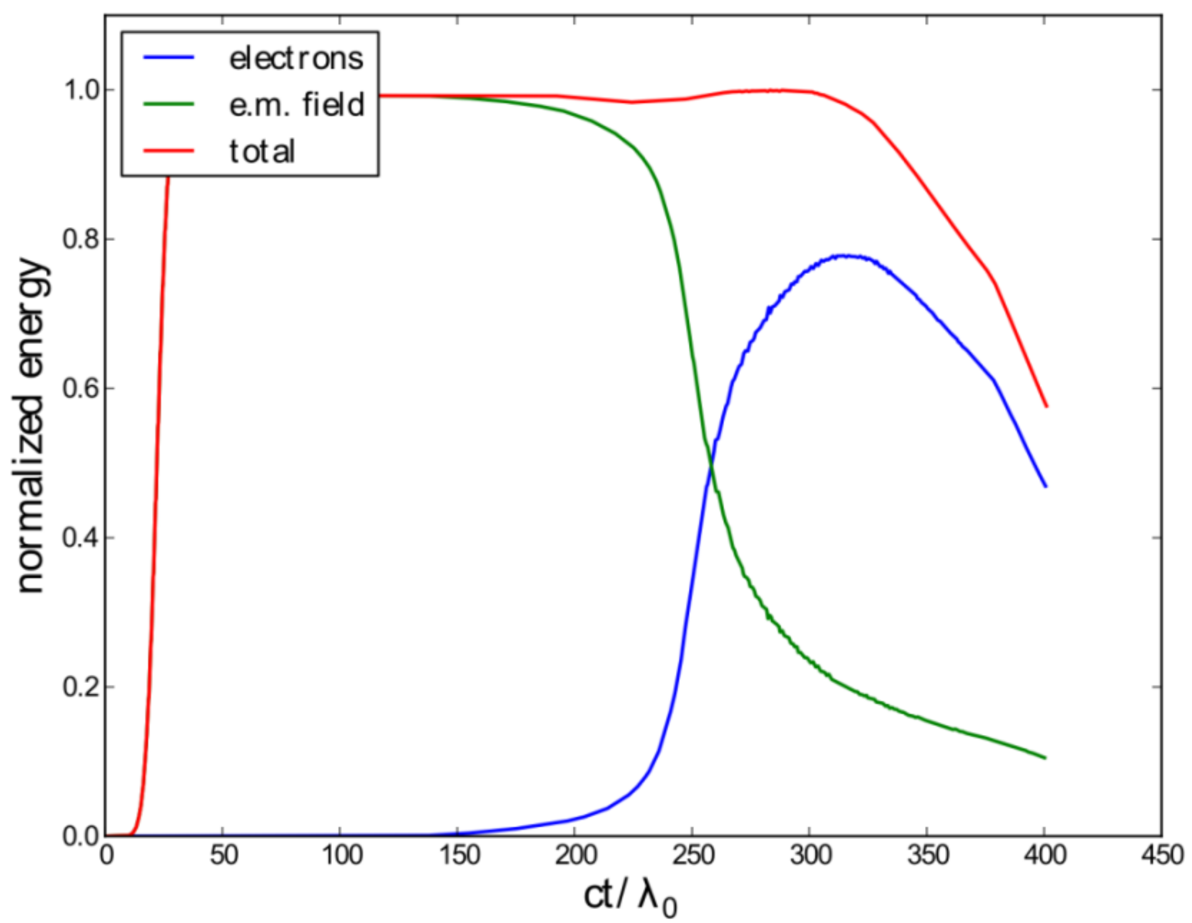

F. Sylla *et al.*, Phys. Rev. Lett, Vol. 108, 115003 (2012)

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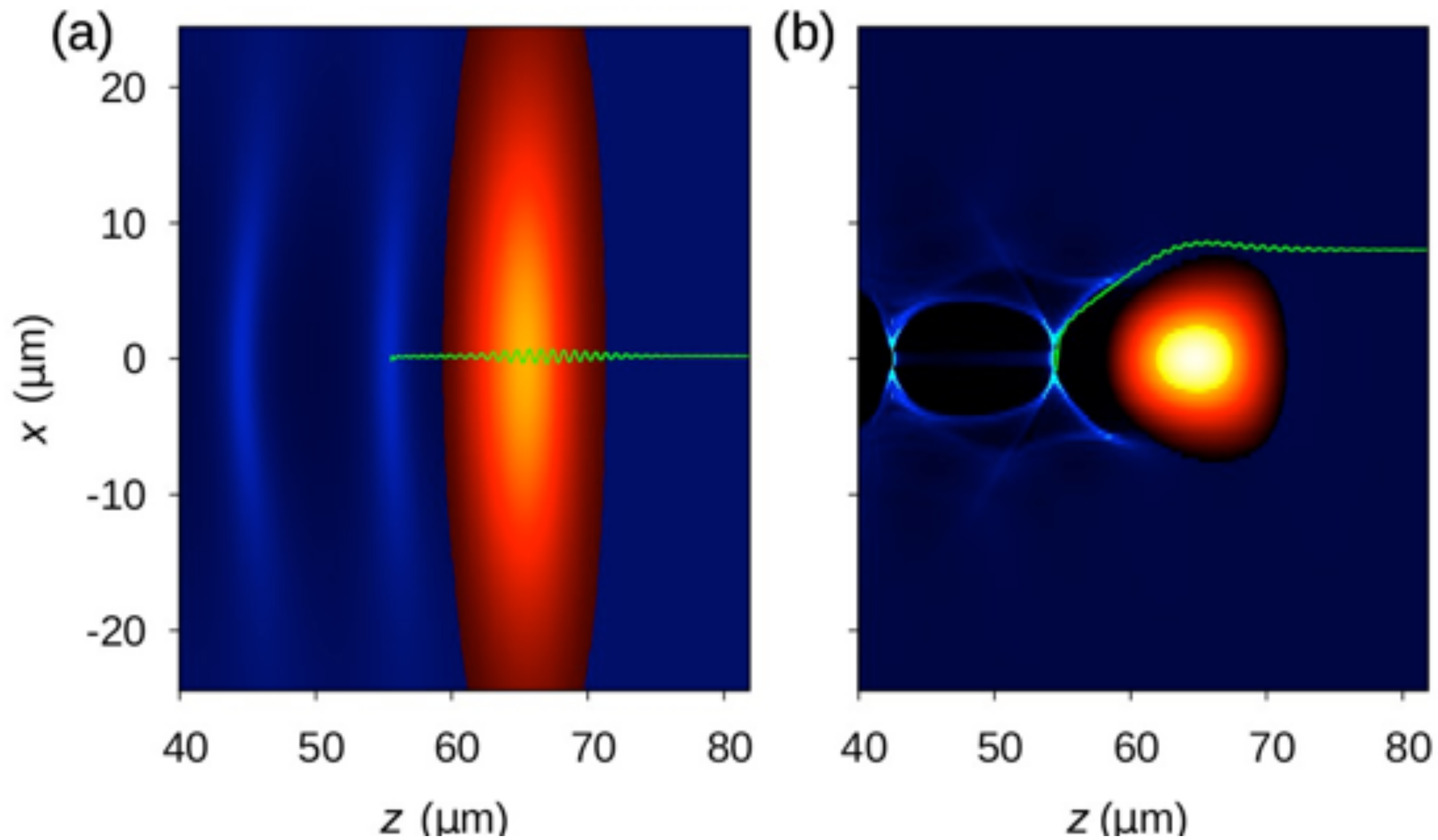
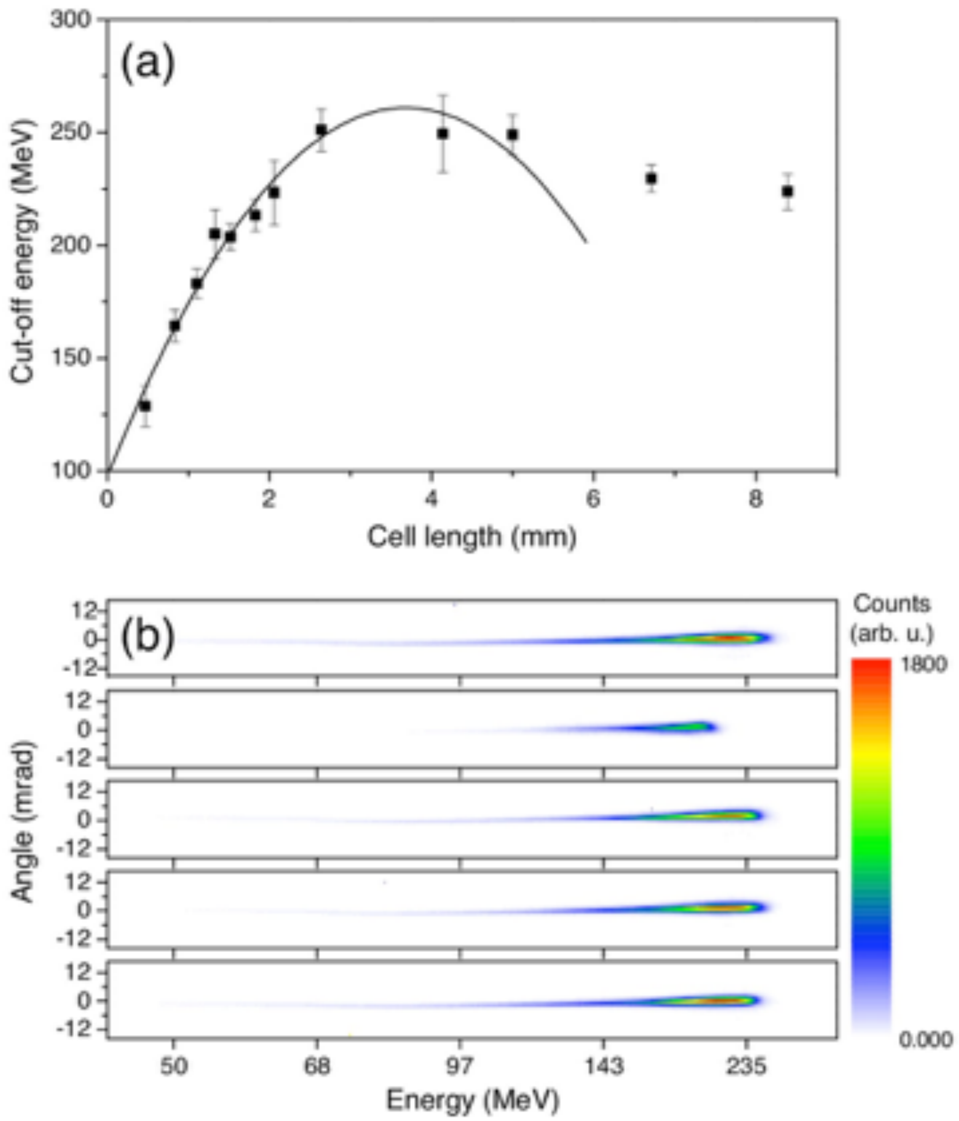
2013 Longitudinal injection

Two different self-injection mechanisms take place :



•At lower plasma density transverse injection is prevented

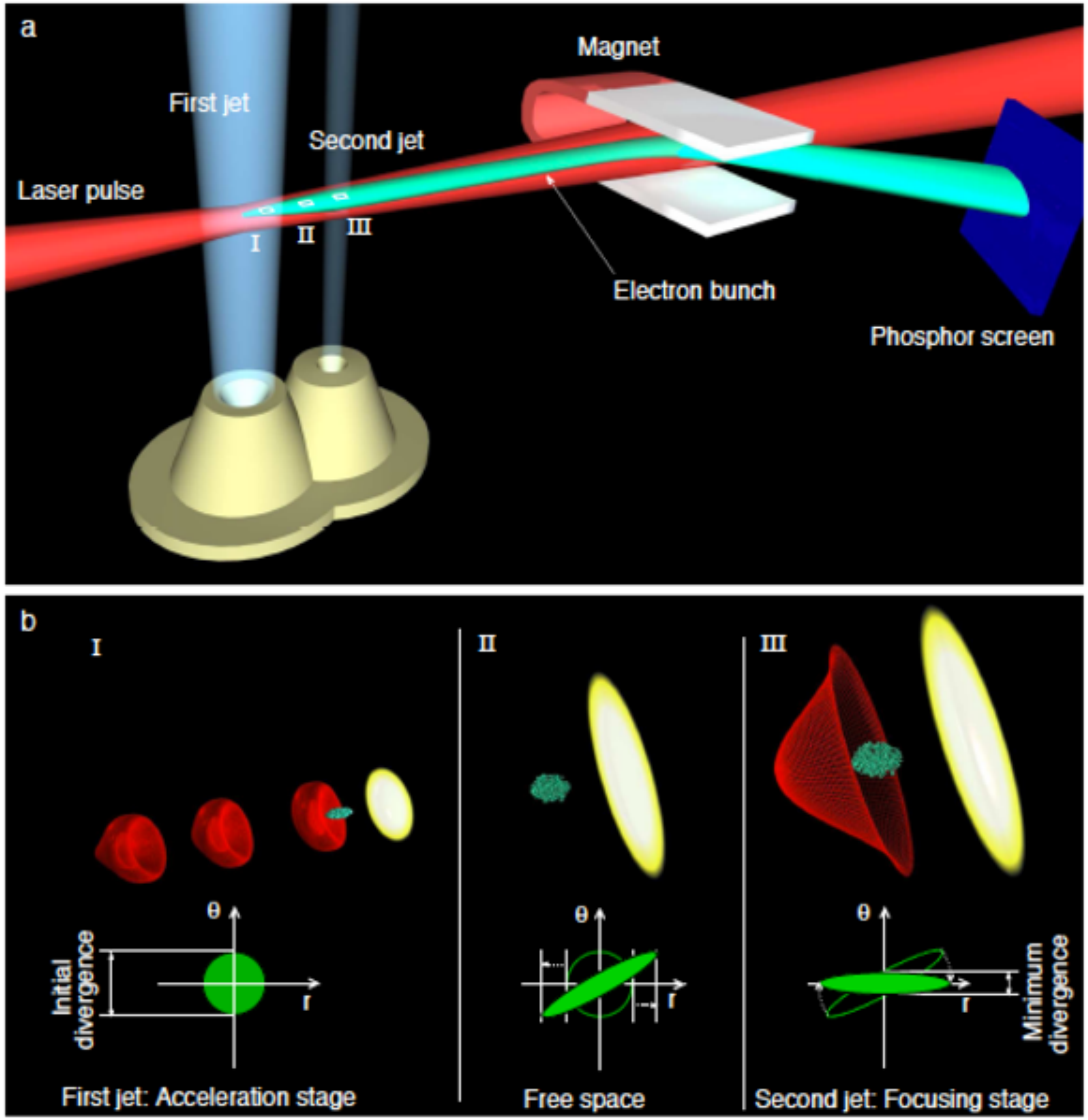
•Only one bunch is injected (longitudinal injection)



longitudinal injection improves
- the stability of the electron beam
and
- reduces the divergence of the electron beam

S. Corde *et al.*, Nature Communications (2013)

Laser Plasma Lens : principle



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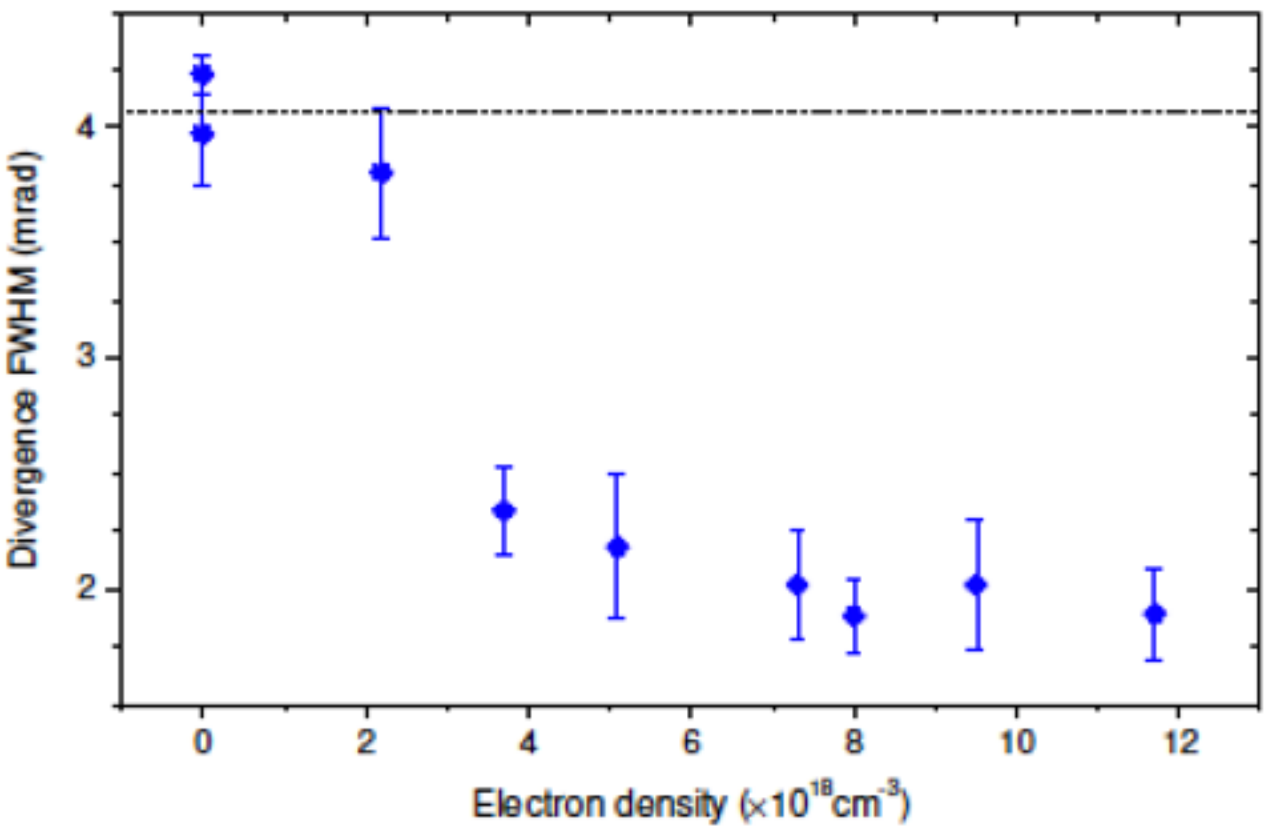
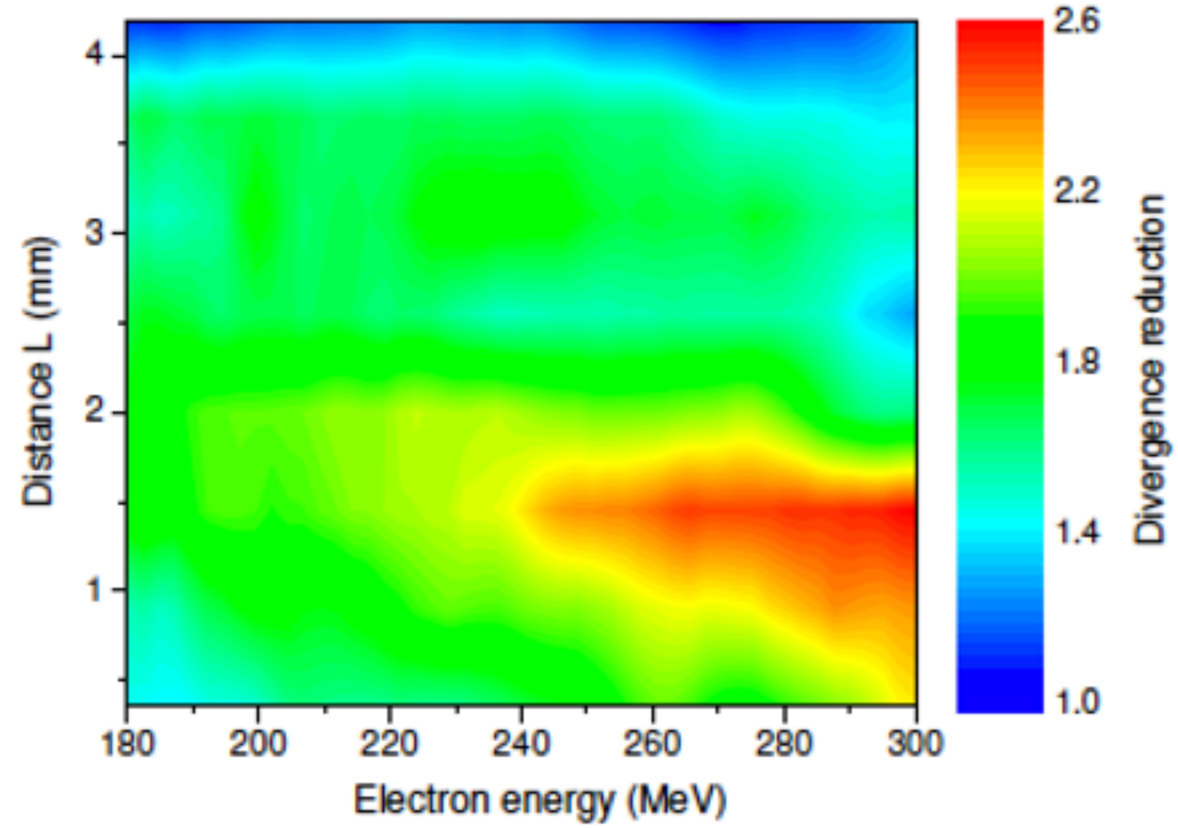
Laser Plasma Lens : experimental demonstration

Optimization with the electron density



Chromaticity studies



Theoretical studies : R. Lehe *et al.*, PRST AB **17**, 121301 (2014)
Experimental studies : C. Thaury *et al.*, Nature Communications, 10.1038/ncomms7860 (2015)

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Conclusions

- In laser plasma physics, as in many other domains, targetry is playing an important role, and is a source of discoveries.

- Stable and reproducible gas targets are crucial for future applications

- Particle (electrons, protons, ions, neutrons) and radiation (X-rays, Gamma rays) beams performances with depend on them.

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