Average Current Enhancement of Laser-Plasma Accelerators

L. Martelli[1,2,*], O. Kononenko[2], I. A. Andriyash[2] , J. Wheeler[2], C. Giaccaglia[2,3], R. Lahaye[2], J. Gautier[2], J.-P. Goddet[2], A. Tafzi[2], V. Tomkus[4], H. Kraft[1], Q.D. Xuan[1] & C. Thaury[2]

[1]THALES - MIS, 2 Rue Marcel Dassault, 78140 Vélizy-Villacoublay, France
[2]LOA, École Polytechnique, ENSTA ParisTech, CNRS, Université Paris-Saclay, 828 Boulevard des Maréchaux, 91762 Palaiseau Cedex, France
[3]Institut Curie, Inserm U 1021-CNRS UMR 3347, University Paris-Saclay, PSL Research University, Centre Universitaire, Orsay, 91471, France
[4]Center for Physical Sciences and Technology, Savanoriu Ave. 231, Vilnius, LT-02300, Lithuania

*lorenzo.martelli@ensta-paris.fr

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Introduction

The motivation for this work arises from the needs of the **Multiscan 3D Project** [1]. We want to exploit the **compactness** of **Laser-Plasma Accelerators** (LPA) in order to develop an **X-ray source** for the **3D tomography** of cargos (Fig.1).

This requires both a **numerical** and **experimental** study to **maximize the beam charge per second** [2,3] in the **energy range of interest** (i.e., <10 MeV).

Here, we first discuss a **preliminary numerical study** and mainly focus on the experimental results obtained at the **Laboratoire d'Optique Appliquée** (LOA), where we obtained charges in the order of **30 nC**.

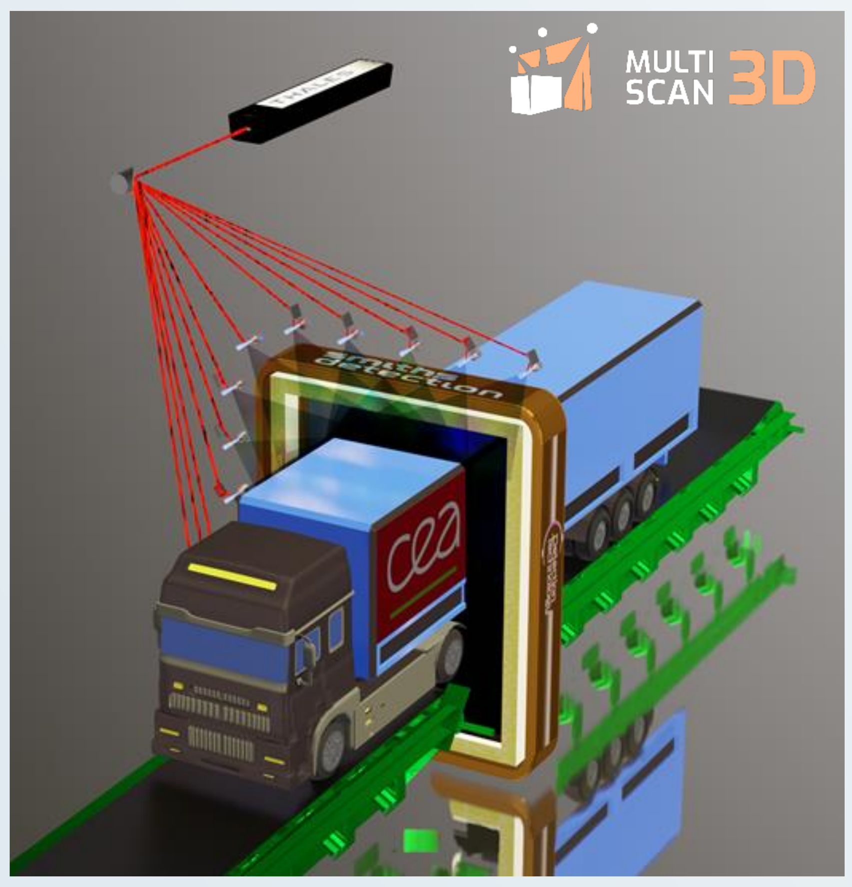

Fig.1: Concept design of an LPA-based cargo tomography scanner.

Numerical Study

Using the code **FBPIC** [4], we looked for the best set of **laser** and **plasma** parameters able to produce the **highest charge-per-Joule**.

We observed **three effects** (Fig.2):

- **Non-linear** charge vs laser energy
- **Constant** charge at n_e >5.5x10^{19} cm^{-3}
- **Lower laser energy shift** of the maximum charge-per-Joule

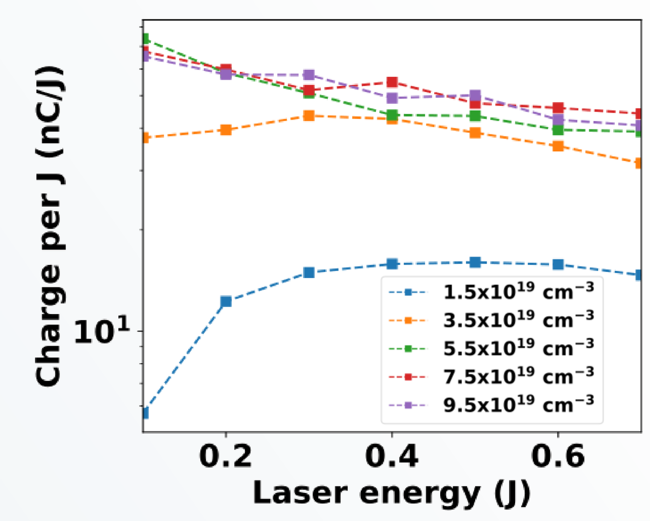

Fig.2: Charge and charge-per-Joule as functions of the laser energy for different n_e in a cone of 1 rad.

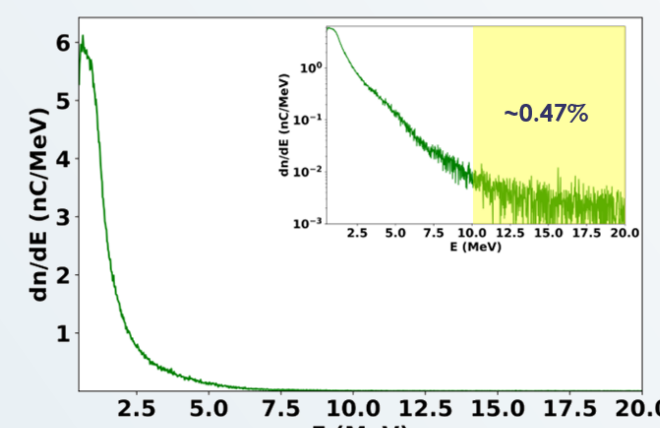

Fig.3: Energy spectrum for the most efficient configuration.

Most efficient condition:

- **n_e = 5.5x10^{19} cm^{-3} at 0.1 J**
- Charge-per-Joule ~ 75 nC/J
- Charge = **7.5 nC** (0.47% >10 MeV, Fig.3)
- Average energy = **1.62 MeV**
- FWHM divergence ~ **380 mrad**

Experimental Setup and Results

We have employed **three main diagnostics** (Fig.4):

- Energy spectrometer
- Beam profile monitor (BPM, charge measurement)
- Phasics (plasma density measurement)

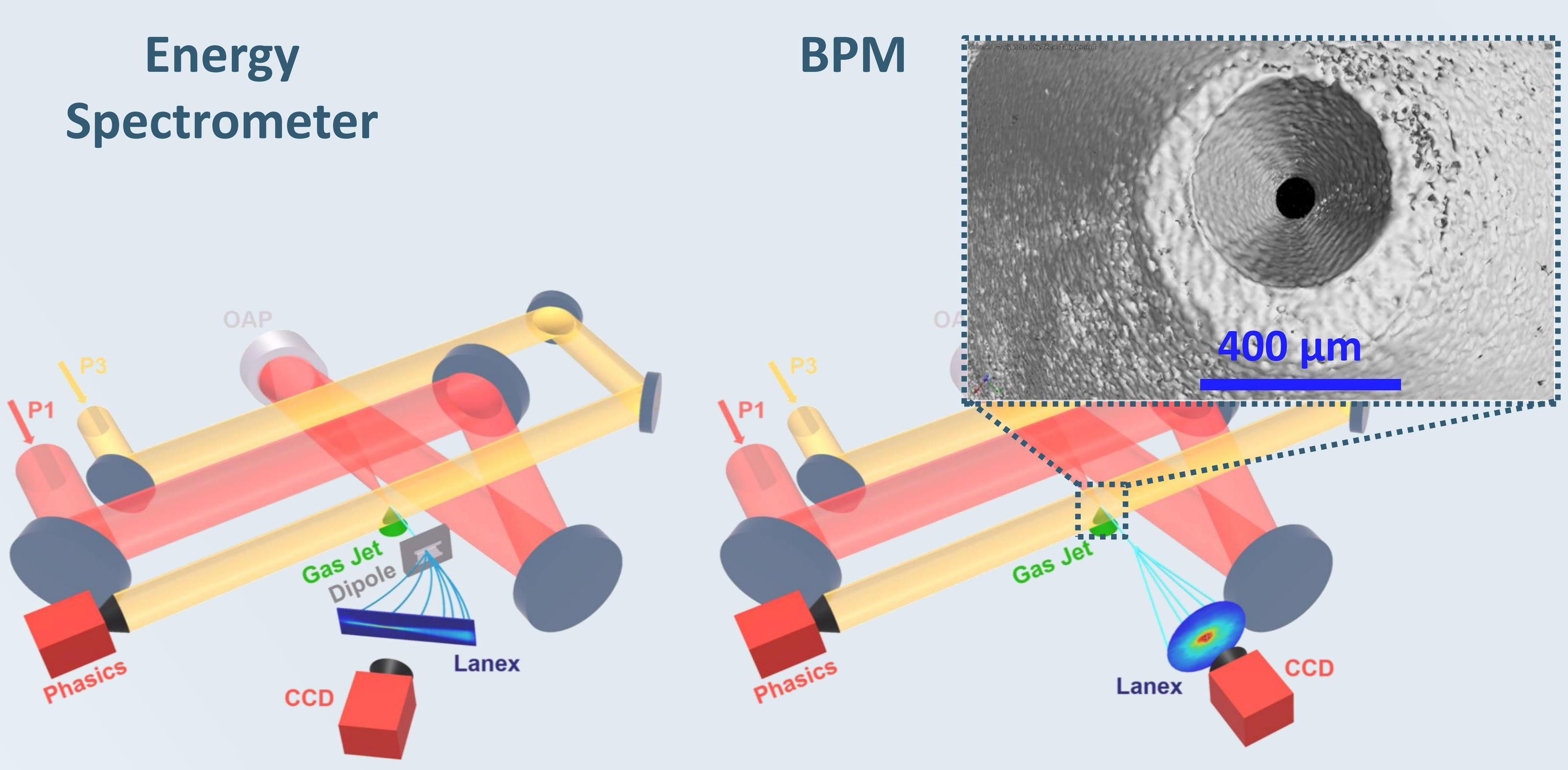

Fig.4: Experimental setup and 0.4 mm nozzle tomography.

Laser Parameters

- $w_{0,FWHM}$ ~ 2.64 µm (**f/4**) & 5.79 µm (**f/8**)
- Max. Laser Energy ~ 1 J
- Laser duration (FWHM) ~ 27 fs
- a0 = 4.38 (**f/4**) and 2.56 (**f/8**)

Targets

- Supersonic Nozzles: **0.4 mm** (**FMTC Center**) and **2.0 mm** exit diameter
- Gas: pure N_2 (10, 30 and 70 bar)
- n_e ~ 10^{20} cm^{-3} (**0.4 mm**) and 10^{21} cm^{-3} (**2 mm**)

We **partially reproduced** the numerical results employing the **f/4** parabola (Fig.5).

Most efficient condition (2 mm nozzle):

- **n_e = 10^{21} cm^{-3} at 0.12 J**
- Charge-per-Joule = **45 nC/J**
- Charge = **5.34±0.38 nC**
- Average energy = **5.1±0.22 MeV**
- FWHM divergence ~ **320 mrad**

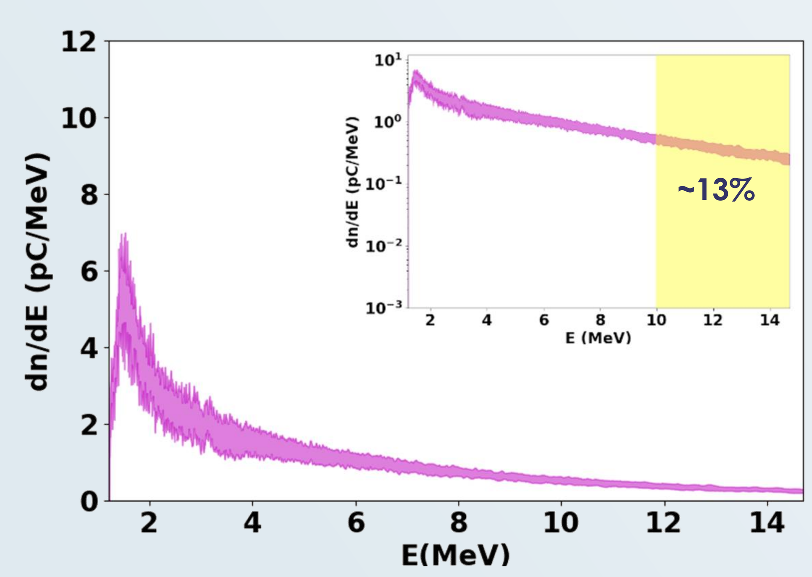

Fig.6: Energy spectrum for the most efficient configuration (2 mm nozzle).

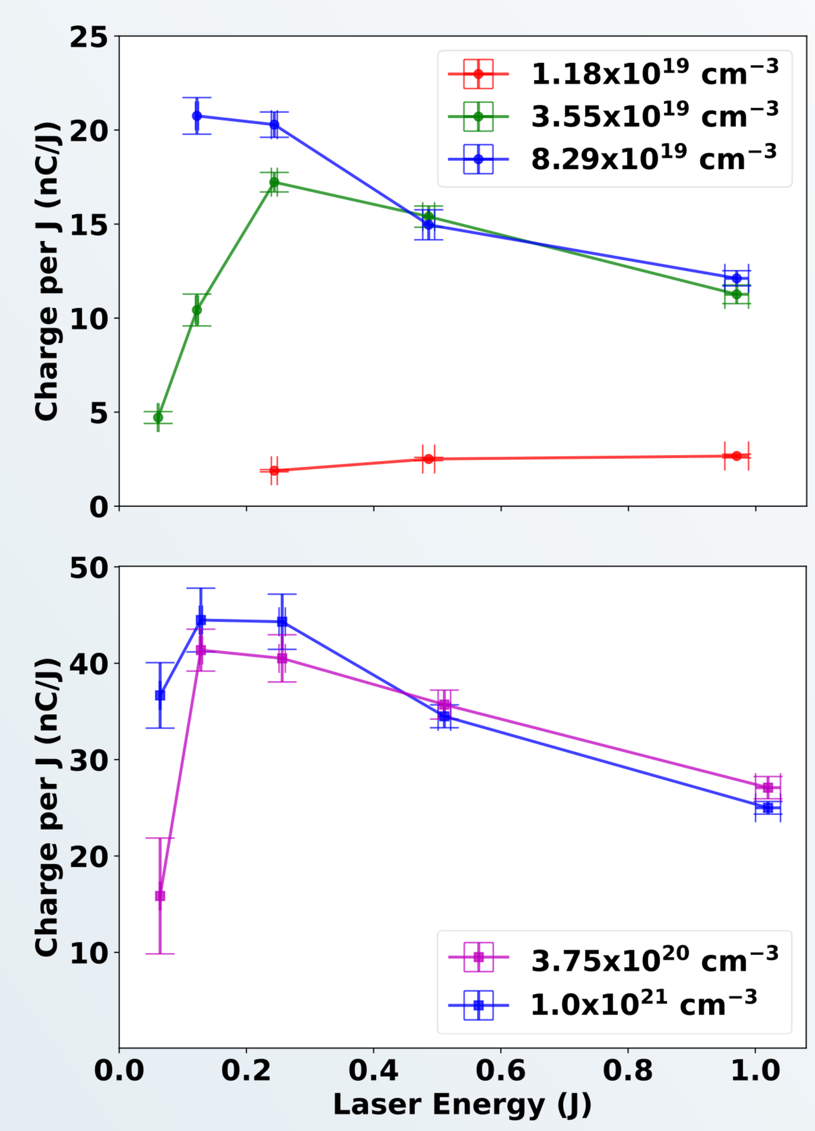

Fig.5: Charge-per-Joule as functions of the laser energy for different n_e for the 0.4 mm (top) and 2 mm (bottom) nozzle.

Results with 2 mm nozzle:

- FWHM divergence ~ **200-300 mrad**
- **f/8** parabola: less divergent electrons (i.e., <200 mrad), **no effect on the charge and the energy**
- **No relevant effect** for n_e > 3.75x10^{20} cm^{-3}

Conclusions

The numerical and experimental results demonstrate the possibility to use **small** and **reliable** laser systems (~**100W**) to produce **extremely high currents** (**~4.5 µC/s**), which are important for the **Multiscan 3D Project**.

<u>**What's next?**</u>

- We are performing **new numerical studies**: the electrons gain energy from **wakefield acceleration, wave-breaking** [5] and **stochastic heating** [6] (Fig.7)
- During the experiment have employed a **dosimetry phantom**, its analysis will give us more insights regarding the **electron beam properties** (i.e., **beam charge** and **divergence**).

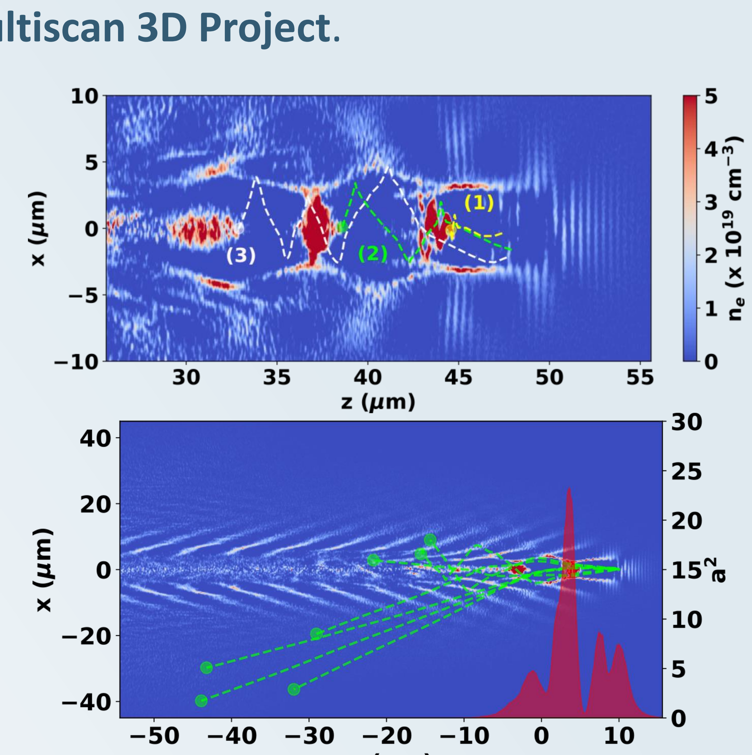

Fig.7: Example of injected (top) and non-injected (bottom) electrons

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