21-04-2015

Particle density dynamics in a flowing gas cell target for LWFA measured by second-harmonic interferometry

INO-CNR
ISTITUTO NAZIONALE DI OTTICA

ILIL
Laboratorio Irraggiamento Laser Intensi

Fernando Brandi
Intense Laser Irradiation Laboratory
CNR-INO, Pisa, Italy

Event: TARG2 Workshop, Paris

INO-CNR
Istituto Nazionale di Ottica

Intense Laser Irradiation Lab (ILIL)

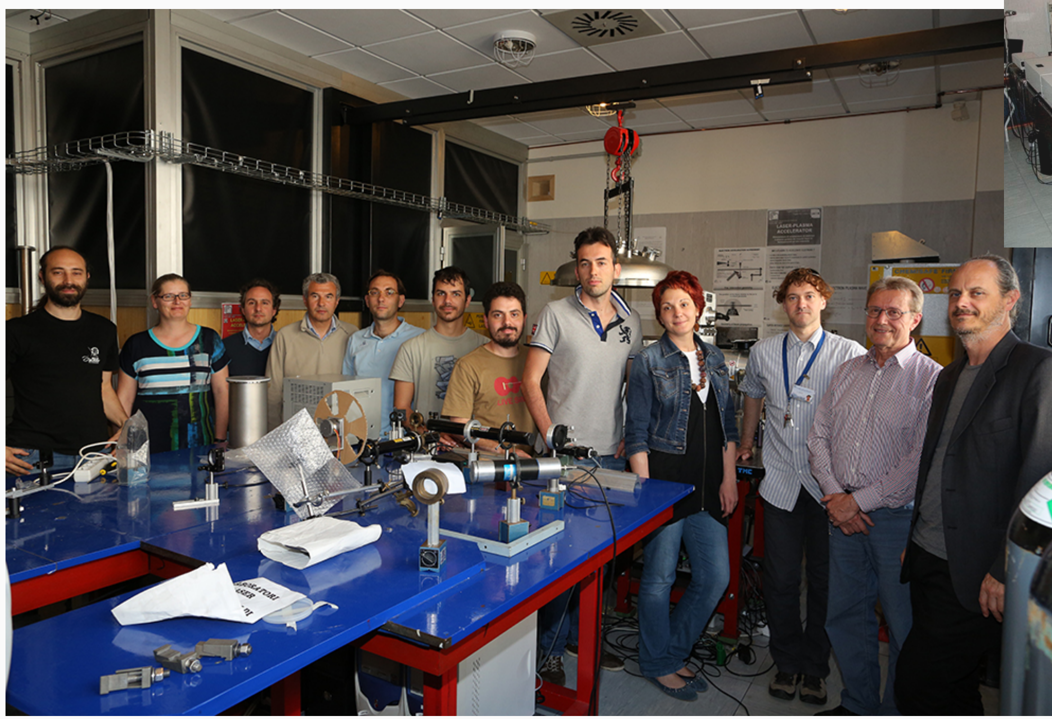
@Istituto Nazionale di Ottica, CNR, Pisa, Italy http://ilil.ino.it

A 10 TW-10 Hz laser coupled with two target chambers (gas/solid)
Upgraded beam line in construction

PEOPLE

- Leonida A. GIZZI* (Head)
- Giancarlo BUSSOLINO
- Gabriele CRISTOFORETTI
- Luca LABATE*
- Fernando BRANDI, Ric. TD.
- Petra KOESTER, Ric. Contr.
- Federica BAFFIGI, A.R.
- Paolo FERRARA, A. R.
- Lorenzo FULGENTINI, A.R.
- Antonio GIULIETTI, Assoc
- Danilo GIULIETTI (Univ. Pisa).*
- Daniele PALLA, PhD student *
- Antonella ROSSI – Tech.

* Also at INFN



MINISTERO DELL'ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA

Ministero della Salute

ELI-ITALY INO-CNR (Pisa)

HiPER

Laserlab Europe

INFN Istituto Nazionale di Fisica Nucleare

www.ino.it

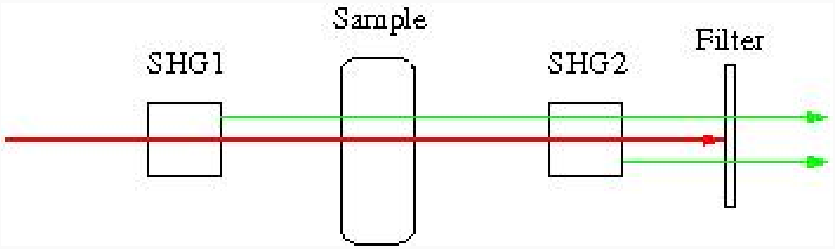
INO-CNR Istituto Nazionale di Ottica

Introduction

- The aim of this study is the investigation and assessment of the use of second harmonic interferometry to evaluate and monitor the particle density inside a flowing gas cell SL-ALC from SourceLab used as target for LWFA experiments.
- The SL-ALC series devices are designed to offer perfectly reproducible laser-underdense plasma interaction conditions.
- The second-harmonic interferometer (SHI) is a fully common-path two-color interferometer sensitive to chromatic dispersion
-

Hopf A. Tomita, and G. Al-Jumaily, Opt. Lett. **5**, 386 (1980);
K. Alum, Y. Koval'chuk, and G. Ostrovskaya, Sov. Tech. Phys. Lett. **7**, 581 (1981).

The Second Harmonic Interferometer



PRINCIPLES

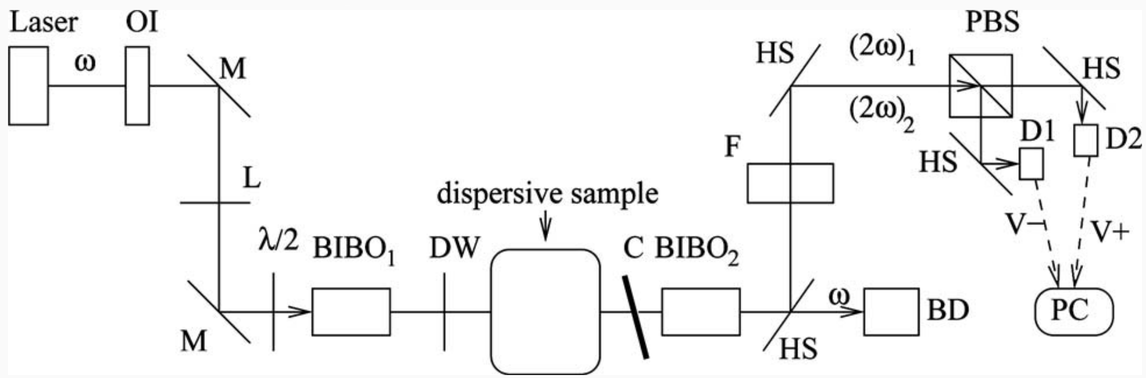
1) The first SH beam is **locked in phase** and **overlapped** with the fundamental beam;
2) The fundamental and SH beams acquire a **phase difference** due to the **chromatic dispersion**;
3) The fundamental beam is **frequency doubled again**, and filtered out;
4) Interference takes place **between the two SH beams** generated before and after the sample;
5)The measured phase difference is **$\Delta\varphi = 4\pi/\lambda \int_L [n(\lambda)-n(\lambda/2)]\, dl$** (compared with $2\pi/\lambda \int_L [n(\lambda)-1]\, dl$ for typical M-Z interferometer).

ADVANTAGES

1) Being a fully common-path interferometer it is **insensitive to vibrations** enabling **high sensitivity**;
2) It uses a **single laser source**, being the second color the SH of the fundamental beam;
3) It is **compact, versatile, reliable** and easy to mount in existing apparatus and industrial/harsh environments;

The CW Nd:YAG based SHI

Quadrature Phase detection,
Self-calibrating,
Time resolution 1-10 μs
phase sensitivity 1.3-0.28 mRad
λ = 1064 nm



$$V_{\pm}=\alpha_{\pm}I^2_0[\beta_1+\beta_2\pm2(\beta_1\beta_2)^{1/2}\sin(\Delta\varphi+\varphi_0)],$$

where $\beta_i I^2$ is the SH intensity, $\alpha_{\pm}$ is the detector responsivity, $\varphi_0=n\pi+\Delta\varphi_0$, $\Delta\varphi_0$ is the uncompensated phase shift.

$$R=(V_+-V_-)/(V_++V_-)=[\alpha\pm V\sin(\Delta\varphi+\Delta\varphi_0)]/[1\pm\alpha V\sin(\Delta\varphi+\Delta\varphi_0)],$$

where $\alpha=(\alpha_+-\alpha_-)/(\alpha_++\alpha_-)$, and $V=2(\beta_1\beta_2)^{1/2}/(\beta_1+\beta_2)\leq1$ is the visibility

For $\alpha<<1$, and $\Delta\varphi_0$ < 1 mRad

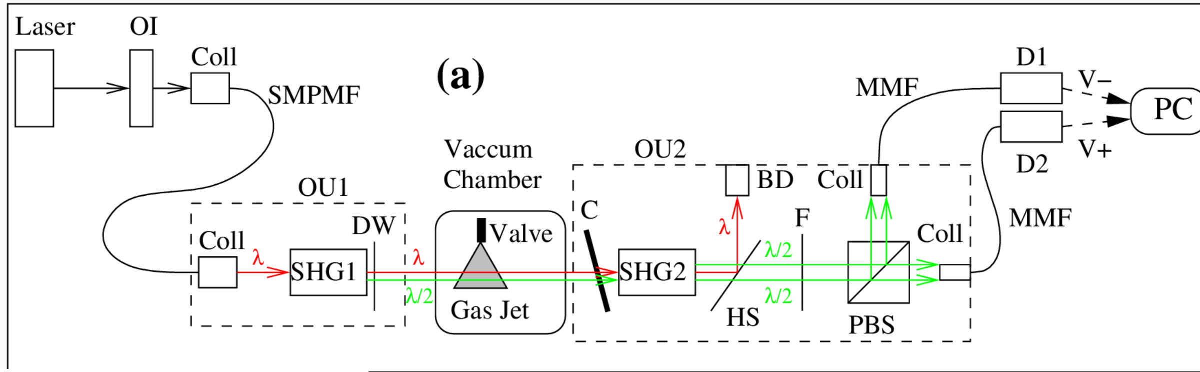
$$R\approx\alpha+V\sin(\Delta\varphi+\Delta\varphi_0)$$

F. Brandi and F. Giammanco Opt. Lett. **32,** 2327 (2007)

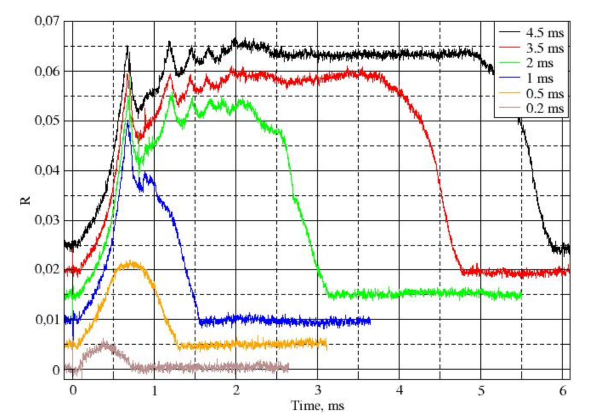
Application example: pulsed gas jet

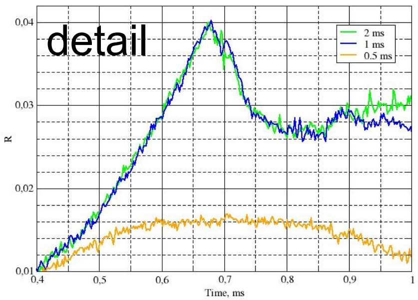
Fully fiber coupled, 1 mm downstream the xenon jet (Series 99 valve).

[F Brandi and F. Giammanco, Opt. Express **19,** 25479 (2011)]

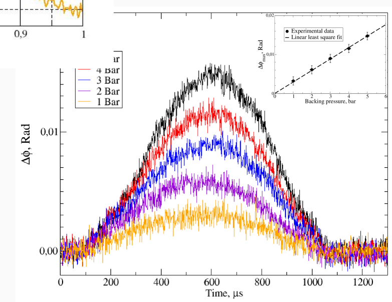


Gas dynamics VS opening time

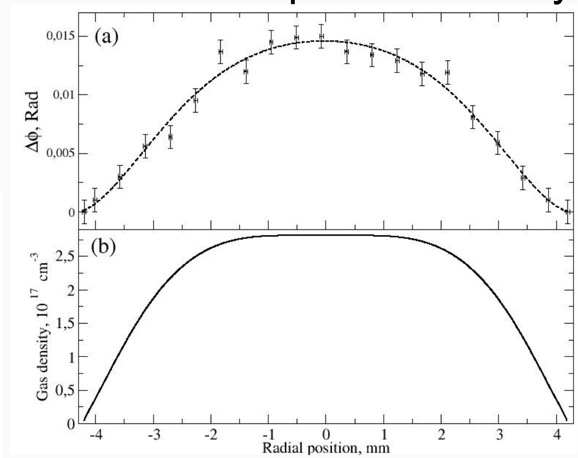




Backing pressure



Abel inversion → particle density



Other application examples:

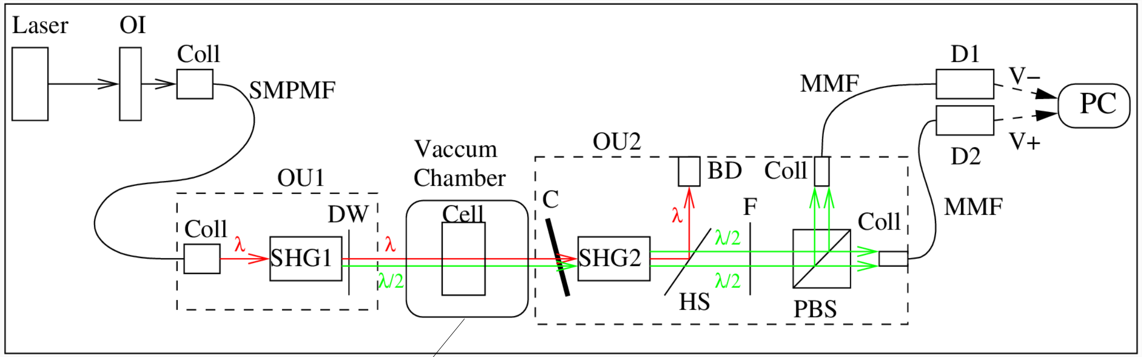
-) Electron density measurements [F Brandi, P Marsili and F Giammanco, AIP Conf. Proc. **CP998**, 132 (2008), and F Brandi, F Giammanco, WS Harris, T Roche, E Trask and FJ Wessel, Rev. Sci. Instrum. **80**, 113501 (2009)]

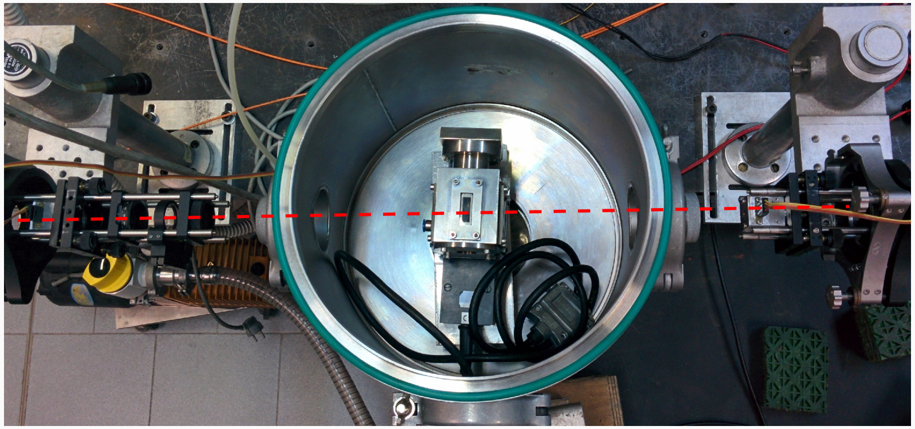
-) Picosecond and third harmonic interferometer [F Brandi and F Giammanco, Opt. Lett. **33**, 2071 (2008)]

-) High spatial resolution (60 micron) [F Conti, M Tiberi, F Giammanco, A Diaspro and F Brandi, Laser Phys. Lett. **10**, 056003 (2013)]

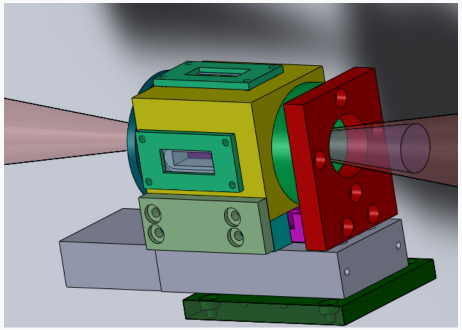
Experimental set-up

Fiber-coupled CW laser SHI





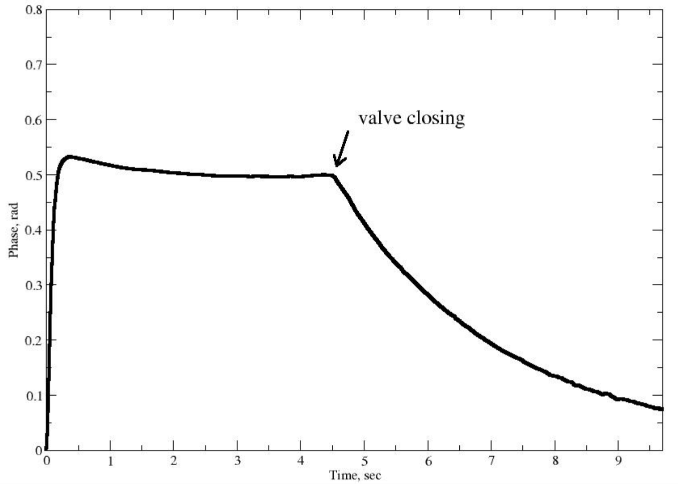
Distance between nozzles 12 mm
Optical path inside the cell 55 mm

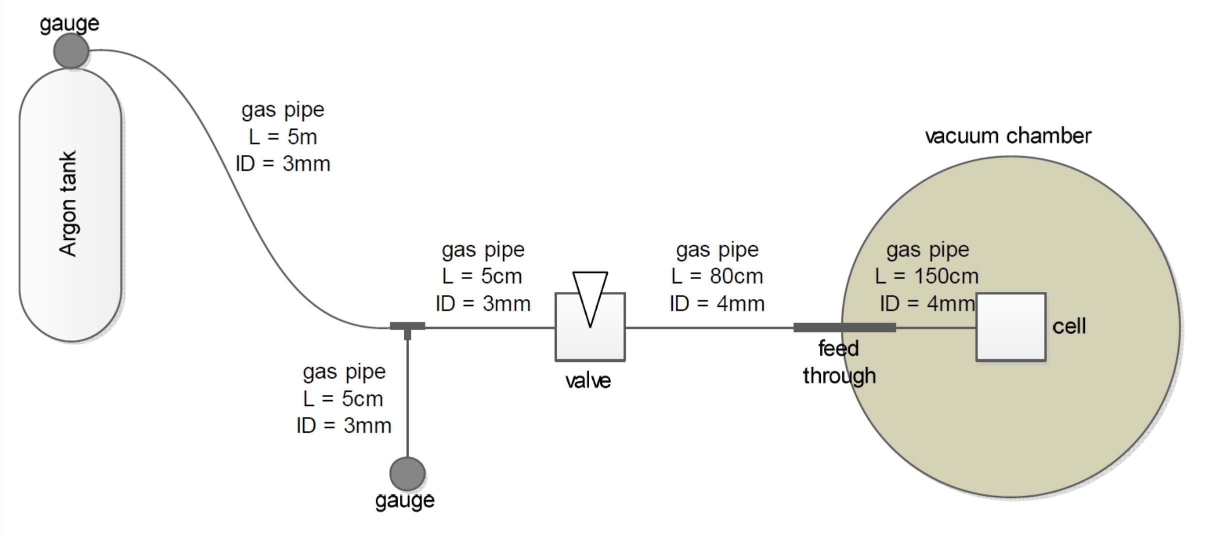


SourceLAB

Experimental procedure

- 3 nozzles tested: 0.2 mm, 0.5 mm and 2 mm
- 4 backing pressures used: 0.8, 0.6, 0.4 and 0.2 Bar
- Laser beam diameter about 1 mm
- Measure at middle point between nozzles
- $\Delta n(Ar) = 40 \times 10^{-7}$ at STP

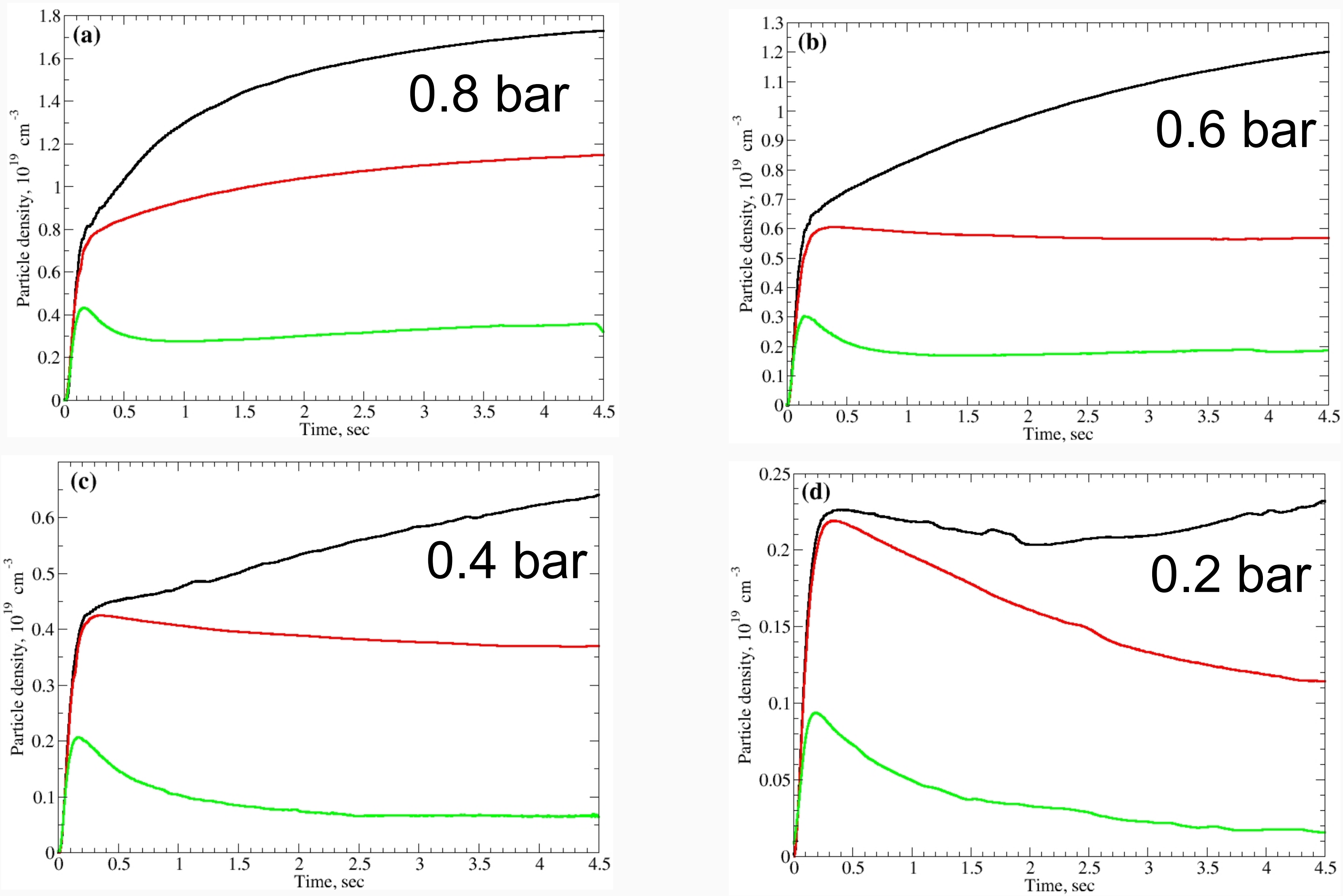




INO-CNR
Istituto Nazionale di Ottica

Experimental results I

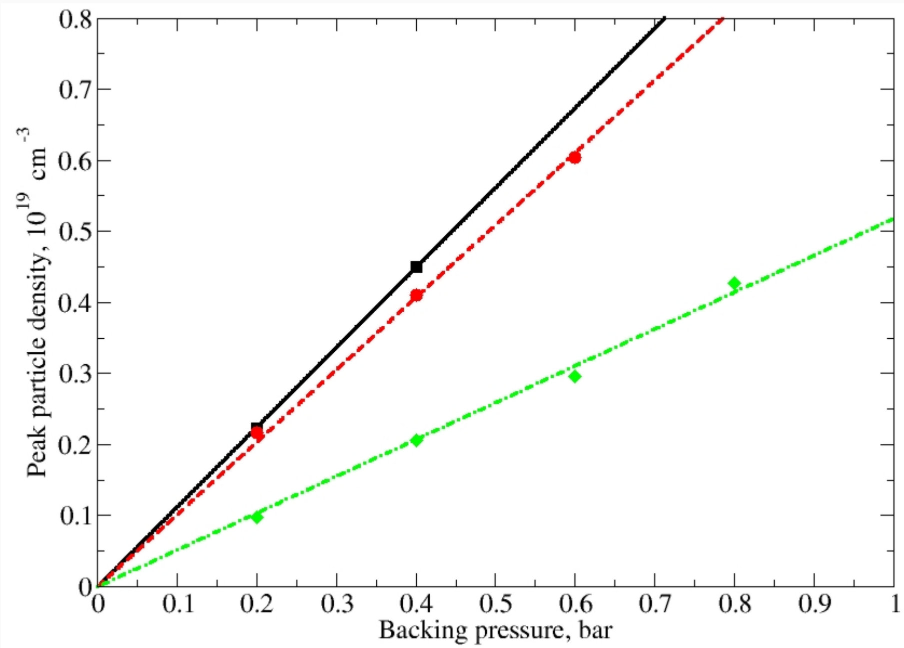
Nozzles: Black-0.2 mm Red-0,5 mm Green-2 mm



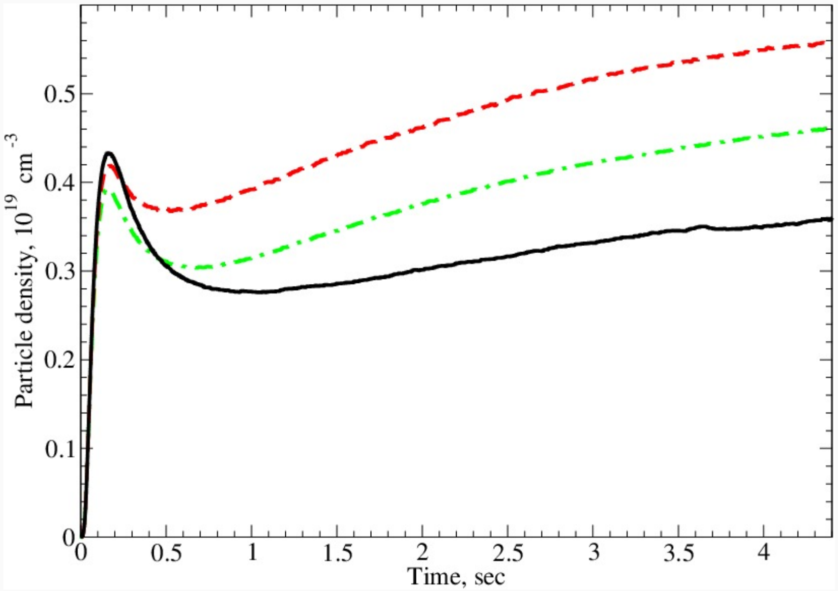
www.ino.it

Experimental results II

Peak density VS backing pressure



Homogeneity for 2 mm nozzles
Measurements at 3 mm from nozzles
(red and green curves)



Conclusions and out-look

Conclusions

- It is demonstrated that the SHI is well adapted to monitor the particle density inside a flowing gas cell placed in vacuum;
- The measurement is accurate and fast;
- The SHI can be used as sensor to implement a feed-back loop to control in real time the density → long term stable LWFA;

Out-look

- A compact and vacuum compatible SHI is feasible;
- A wide-field imaging SHI can be implemented to map the particle/electron density in real time

INO-CNR
Istituto Nazionale di Ottica

Acknowledgements

- François Sylla, SourceLAB

- Prof. F. Giammanco and F. Conti, Physics Department University of Pisa & Plasma Diagnostics and Technologies

- The Istituto Italiano di Tecnologia Genova (Italy)