Gas cell characterization for laser wakefield acceleration

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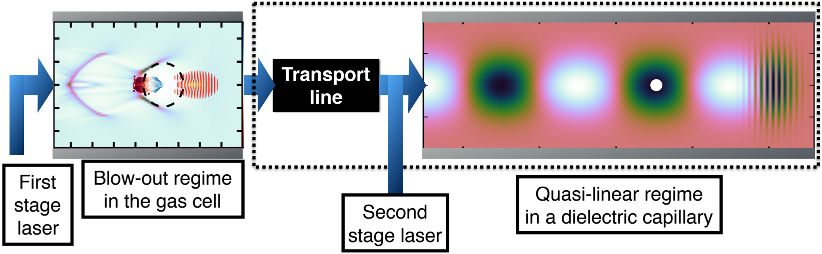
3rd EAAC, Elba, 25-29 September, 2017.

Gas cell for laser wakefield injector



Injector gas target

- The target must provide gas confinement
- Plasma density is a crucial parameter
- Plasma density fluctuations are suspected to have major influence in electron pointing fluctuations

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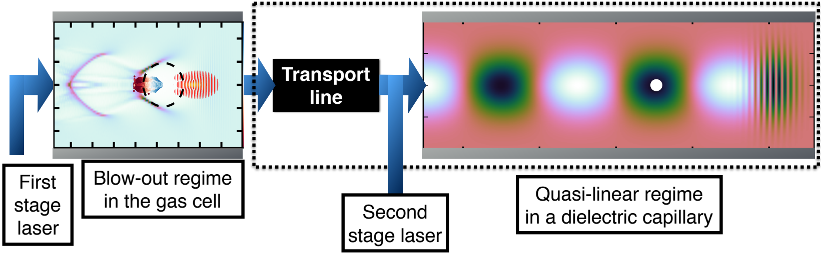

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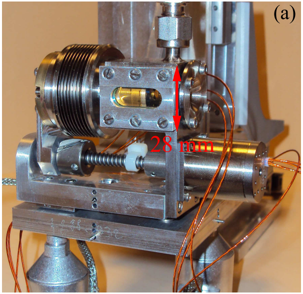
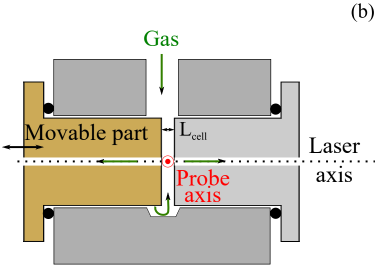
Use of a gas cell to confine the gas.

ELectron Injector for compact Staged high energy Accelerator (ELISA)

Variable parameter gas cell

- $P_{reservoir} = 50 \rightarrow 500$ mbar ($\sim 2\times10^{18} \rightarrow 2\times10^{19}$ cm^{-3})
- $L_{cell} = 0 \rightarrow 10$ mm
- Gas : H_2 or H_2+variable proportions of N_2 (H_2 for characterization)
- Entry and exit holes : $\phi_{aperture} = 200 - 600$ µm, $d_{plate} = 0.5 - 2$ mm





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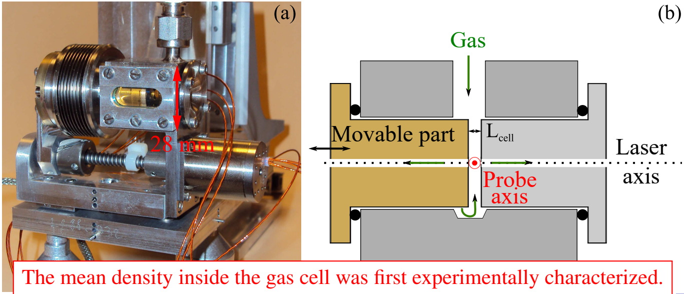
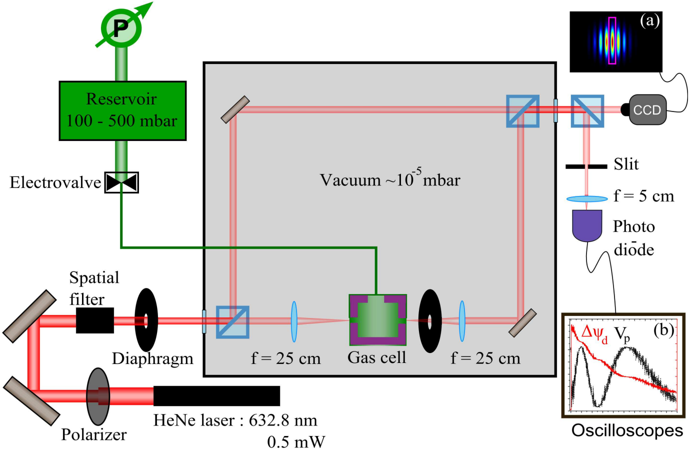


The mean density inside the gas cell was first experimentally characterized.

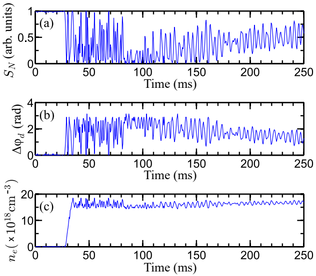
Density at the center of the cell measured by interferometry

- Mach-Zehnder interferometer used to measure the mean density of the plateau

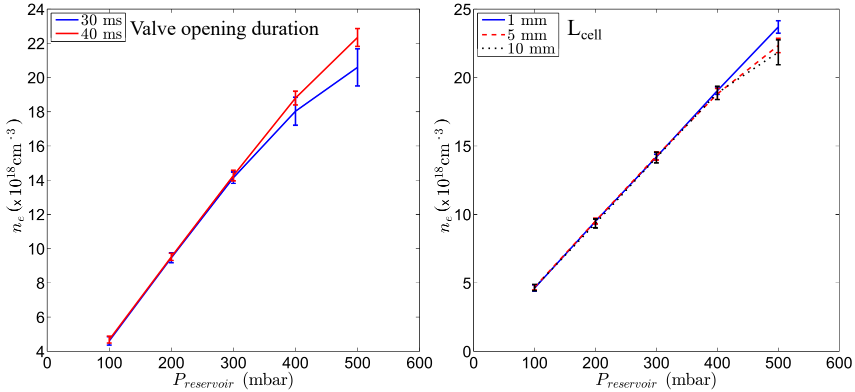


Determination of the density at the center of the cell from photodiode signal

- Photodiode signal :
  - $S(t) = A + Bcos\left[\theta_0 + \Delta\varphi_d(t)\right]$
- Normalization :
  - $S_N(t) = \frac{S(t) - S_{min}}{S_{max} - S_{min}} = \frac{1 + cos[\theta_0 + \Delta\varphi_d(t)]}{2}$
- Inversion :
  - $\Delta\varphi_d(t) = \arccos\left[2S_N(t) - 1\right] - \arccos\left[2S_N(0) - 1\right] + 2k(t)\pi$
- Reconstruction :
  - $n_{H_2}(t) = \frac{n_e(t)}{2} = \Delta\varphi_d(t) \times \frac{\lambda_L}{3\pi A m_H l}$
  - with A the molar refractivity, m_H the mass of the hydrogen atom and l the probed length



Density in the cell depends almost linearly with reservoir pressure in the range of n_e studied



$$\phi_{aperture} = 0.2 \text{ mm}, d_{plate} = 0.5 \text{ mm}$$

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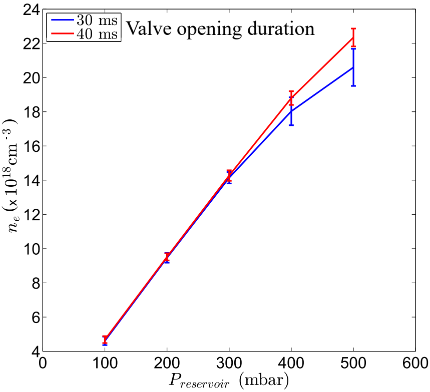
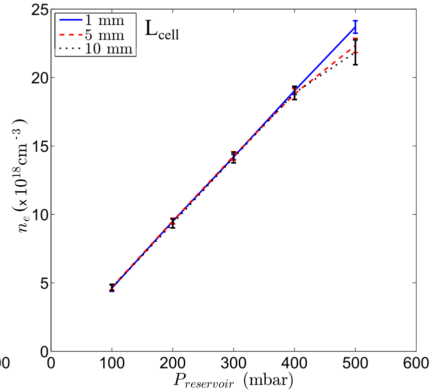
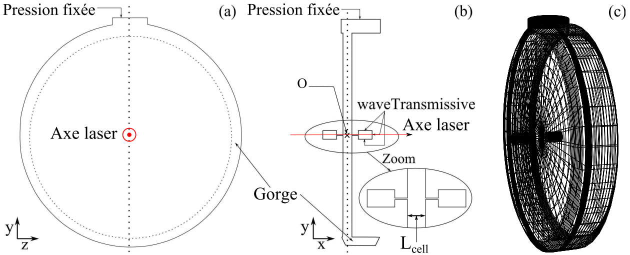




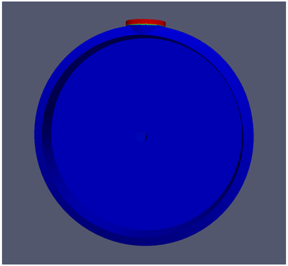
The density at the center of the cell was well characterized but the density profile along the laser axis has to be characterized.

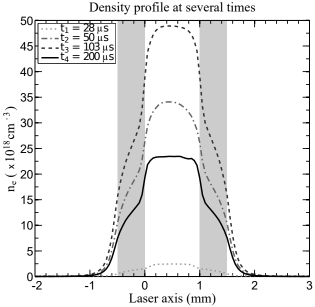
Geometry in OpenFOAM

- Construction of the full 3D geometry
- Spatial scales :
  - Cell diameter ~ 20 mm
  - $\phi_{aperture} = 0.2$ mm



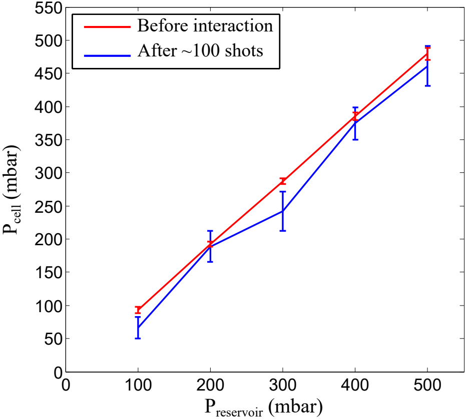
Density profile obtained by numerical simulation of the gas flow



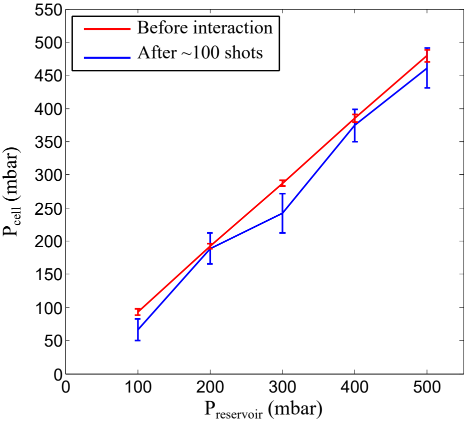


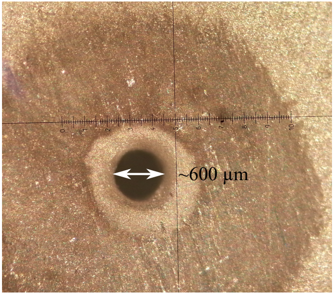
- Fluid simulations using OpenFOAM and SonicFoam (transient, turbulent solver with sonic flow capabilities)
- Plateau inside the cell, sharp gradients at transitions and smooth gradients in the plates

Modifications of entry and exit plates



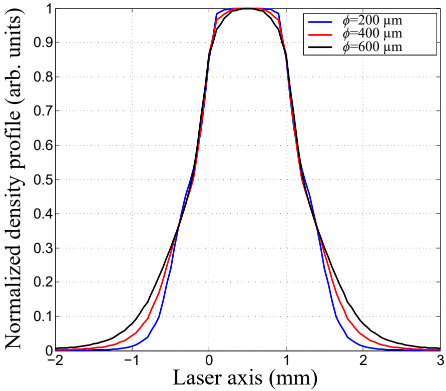
Modifications of entry and exit plates





- Apertures are enlarged by the laser during laser wakefield experiments

Modeling of bigger aperture diameter



Aperture diameter modifications

- Smoother gradient with larger diameter
- Plateau length is reduced

Modifications of exit plate thickness

- Electron bunch properties at the exit of the injector is critical for injection in a second stage
- Exit plasma profile can have a large impact on electron properties

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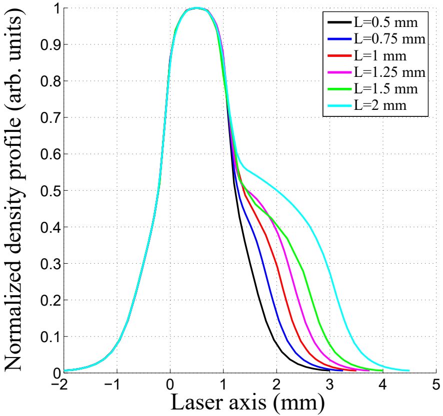
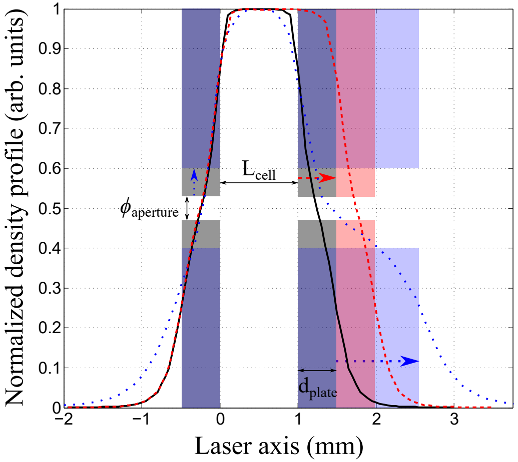


Summary of density control



This target was used experimentally and optimized in simulations → See P. Lee talk in WG6, 18h40 on Tuesday.

Conclusion

- The ELISA variable length gas cell was built and the gas flow was characterized both experimentally by fluid simulation.

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- The density profile has a major influence on laser propagation and electron injection $\longrightarrow$ It can be taylored to optimize electron properties
- Laser ablation has to be taken into account.

Perspectives

- Characterize the density fluctuations.

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- Studies of the target lifetime.

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- Characterize the density fluctuations.
- Studies of the target lifetime.
- This transverse diagnostic could be used to control density at each shot and adjust the backing pressure.

Thank you !

Thank you for your attention

Backup slides

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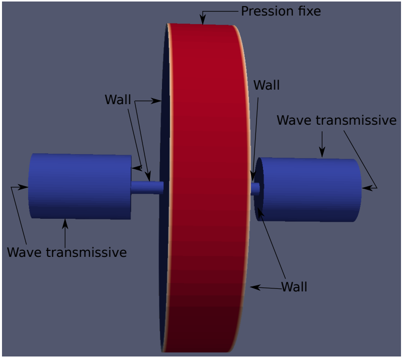
Reduced geometry to reduce computational time



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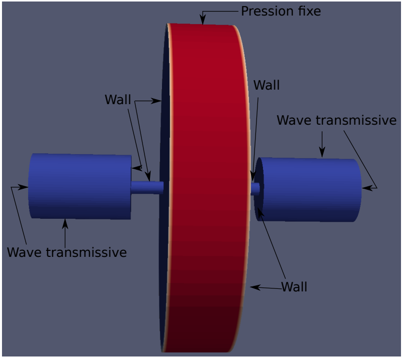

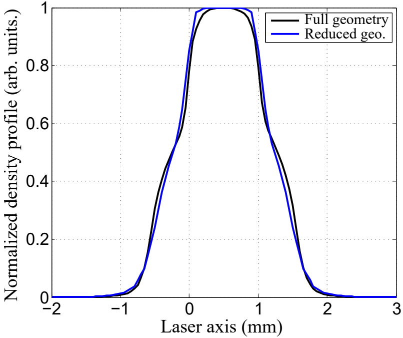

- Computational time reduced by reducing the simulation volume
- Agreement when the gas inlet is the same surface as the full 3D simulation