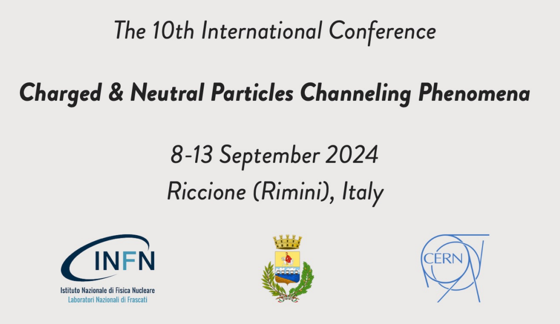
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

INFN Laser indUCed particlE production


The 10th International Conference

Charged & Neutral Particles Channeling Phenomena

8-13 September 2024
Riccione (Rimini), Italy

Team Members:
A Pappalardo
D Oliva
J Suarez
F Abubaker
A Hassan
R Catalano
G Cuttone
F Farokhi
S Fattori
M Guarrera
A Kurmanova
G Petringa
A Sciuto
GAP Cirrone
A Amato
C Manna
F Vinciguerra
D Mascali
G Mauro
A Pidatella

Implementing Capillary Design for Reliable VHEE Beam Delivery

Dr. Sahar Arjmand
Istituto Nazionale di Fisica Nucleare (INFN)
Laboratori Nazionali del Sud (LNS)

Outline

- Very High Energy Electron (VHEE) for Radiotherapy
- Laser-plasma Acceleration (LPA) for VHEE
- Introducing I-LUCE Facility
- Plasma Module & Plasma Diagnostic
- Plasma Modelling in COMSOL Multiphysics

S. Arjmand, PhD – sahar.arjmand@lns.infn.it

VHEE: For RT

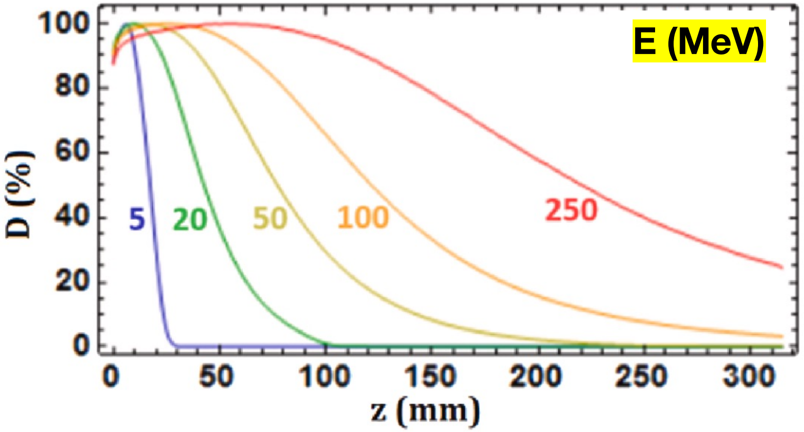
Advanced Radiotherapy

Proton

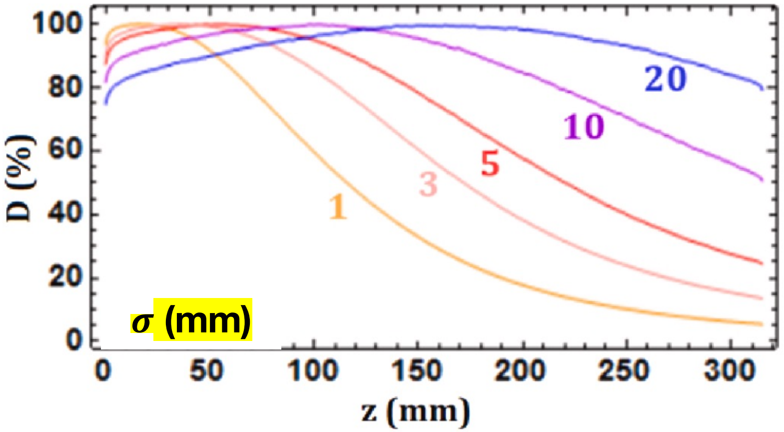
VHEE

Energy Range	~ 250 MeV	~ 250 MeV
Penetration Depth	High (deep-seated tumors)	High (deep-seated tumors)
Dose Distribution	Sharp dose fall-off (Bragg Peak)	Favorable dose distribution
Radiobiological Effectiveness	High due to dense ionization	Comparable to proton/ions in high energy range
Normal Tissue Sparing	Exellent, minimal damage	Good, small penumbra, minimal secondary products
Cost and Infrastructure	High cost, large area	Low cost, ready to implement
Clinical Evidence	Growing (partially established)	Emerging (early studies)
Technology Availability	Limited centers	Increasing with e-accelerators
Treatment Flexibility	High presision, less flexible sparing	Flexible (combination of electron & photon therapy)

Several Electron Beam Energies (all in MeV)



Several Electron Beam Widths (all in mm) at an Electron Energy of 250 MeV



A. Lagzda et al., VHEE Beams, 2020

Bohlen et al., Front. Psychol., Sec. Health Psychology, 2021

S. Arjmand, PhD – sahar.arjmand@lns.infn.it

VHEE: Toward Experimental Implementation via LPAs

VHEE can be generated using LPAs, which leverage plasma technology and intense laser pulses to propel charged particles to very high energies over short distances (via gas jets or discharge capillaries).

Laser Pulse:
Creates a strong electric field in the plasma wake

Plasma (Energy Booster):
Transfers energy from an intense laser pulse to particles

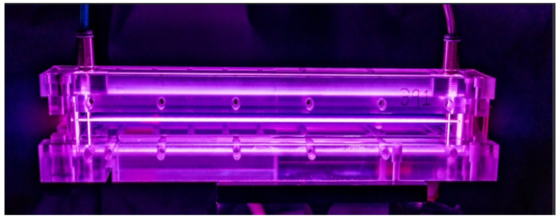
Plasma Advantages

High Accelerating Field
Current electron energy record: up to ~ 10 GeV

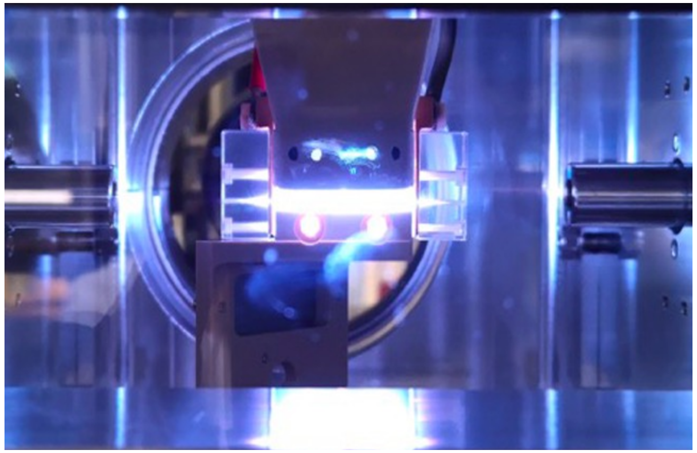
Compactness
(table-top class at hospital)
mm-cm Scale, 1 mm => 100 MeV
(with plasma-discharge capillary)

Cost-effective

Plasma capillary at BELLA (USA)



Plasma capillary at INFN-LNF (Italy)



S. Arjmand, PhD – sahar.arjmand@lns.infn.it

LPAs: Laser Wakefield Acceleration (LWFA)

LWFA Mechanism

➢ Laser Pulse Injection:

A powerful laser pulse is directed into a plasma.

➢ Creation of Plasma Wake:

The high-intensity laser pulse generates a strong electric field in the plasma, known as the plasma wake.

➢ Electron Displacement:

This electric field from the laser pulse pushes electrons away from their original positions in the plasma.

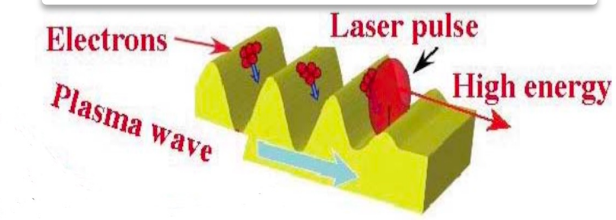
➢ Formation of Positive Charge Region:

This movement of electrons creates a region of positive charge because the heavier ions remain relatively stationary while the lighter electrons move away.

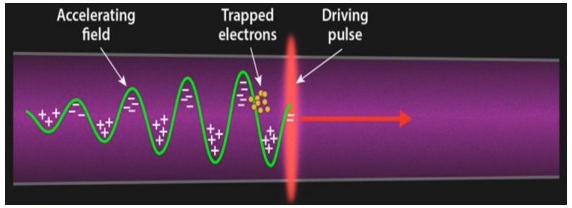
➢ Electron Acceleration:

Electrons are accelerated as they ride the wake created by laser and gain energy as they move through these waves.

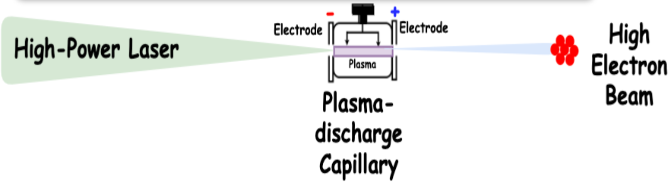
Principal Acceleration Diagram



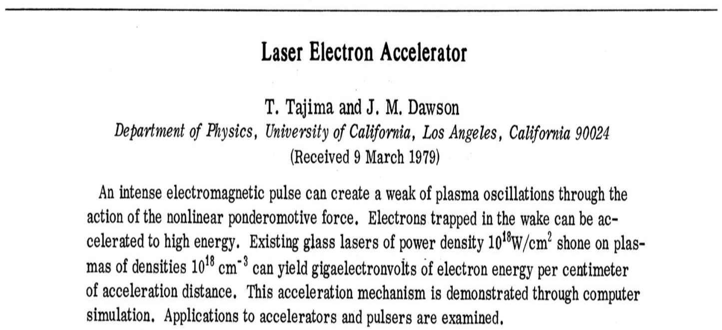
Electron Acceleration



An Experimental Setup Diagram



T. Tajima, J. Dowson, Phys. Rev. Lett, 43 (1979)

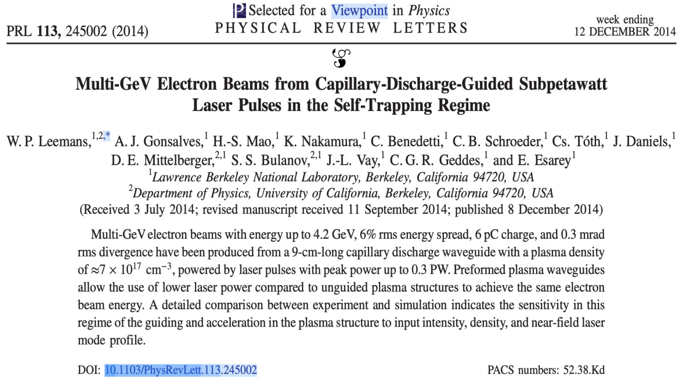


Laser Electron Accelerator

T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024
(Received 9 March 1979)

An intense electromagnetic pulse can create a weak of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{18}W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

W.P. Leemans et al., Phys. Rev. Lett, 113 (2014)



Selected for a Viewpoint in *Physics*
PRL **113,** 245002 (2014) PHYSICAL REVIEW LETTERS week ending 12 DECEMBER 2014

Multi-GeV Electron Beams from Capillary-Discharge-Guided Subpetawatt Laser Pulses in the Self-Trapping Regime

W. P. Leemans,[1,2,*] A. J. Gonsalves,[1] H.-S. Mao,[1] K. Nakamura,[1] C. Benedetti,[1] C. B. Schroeder,[1] Cs. Tóth,[1] J. Daniels,[1]
D. E. Mittelberger,[2,1] S. S. Bulanov,[2,1] J.-L. Vay,[1] C. G. R. Geddes,[1] and E. Esarey[1]
[1]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[2]*Department of Physics, University of California, Berkeley, California 94720, USA*
(Received 3 July 2014; revised manuscript received 11 September 2014; published 8 December 2014)

Multi-GeV electron beams with energy up to 4.2 GeV, 6% rms energy spread, 6 pC charge, and 0.3 mrad rms divergence have been produced from a 9-cm-long capillary discharge waveguide with a plasma density of $\approx 7 \times 10^{17}$ cm^{-3}, powered by laser pulses with peak power up to 0.3 PW. Preformed plasma waveguides allow the use of lower laser power compared to unguided plasma structures to achieve the same electron beam energy. A detailed comparison between experiment and simulation indicates the sensitivity in this regime of the guiding and acceleration in the plasma structure to input intensity, density, and near-field laser mode profile.

DOI: 10.1103/PhysRevLett.113.245002 PACS numbers: 52.38.Kd

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Acceleration Scheme: Laser Wakefield Acceleration (LWFA)

Wave Amplitude and Laser Pulse Length:

- ➢ The amplitude of the wakefield (the electric field generated behind the laser pulse) depends on the length (vety short) and intensity of the laser pulse.
- ➢ Longer pulses generally excite larger wakefields.

Dependency on Plasma Wavelength:

- ➢ The maximum accelerating field that can be achieved is influenced by the plasma wavelength (λ_p), which is related to the plasma density ($\boldsymbol{n_e}$).

Dependency on Plasma Density:

- ➢ A higher plasma density results in a shorter plasma wavelength.
- ➢ Higher plasma density leads to stronger collective effects, enhancing the wakefield amplitude and the accelerating field.
- ➢ Higher density plasmas support stronger wakefields, leading to more efficient acceleration

Regulation by Background Plasma Density:

- ➢ The background plasma density effectively regulates the accelerating field.
- ➢ The density determines the plasma wavelength, which affects the strength of the wakefield and the efficiency of electron acceleration.

«Plasma density controls the strength of the accelerating field»

Accelerating field:

$$E\,[\mathrm{GV/m}] \approx 96\,(n_e\,[\mathrm{cm}^{-3}])^{1/2}$$

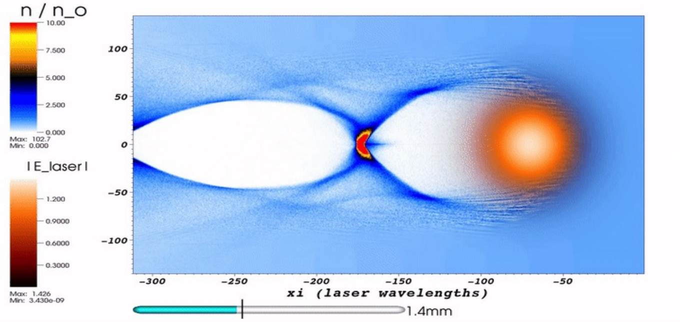
$$E_0 = \frac{c m_e \omega_p}{e},\ n_e = 2\times10^{17}\ \mathrm{cm}^{-3} \Rightarrow \boxed{E_0 \approx 40\ \mathrm{GV/m}}$$

Plasma wavelength:

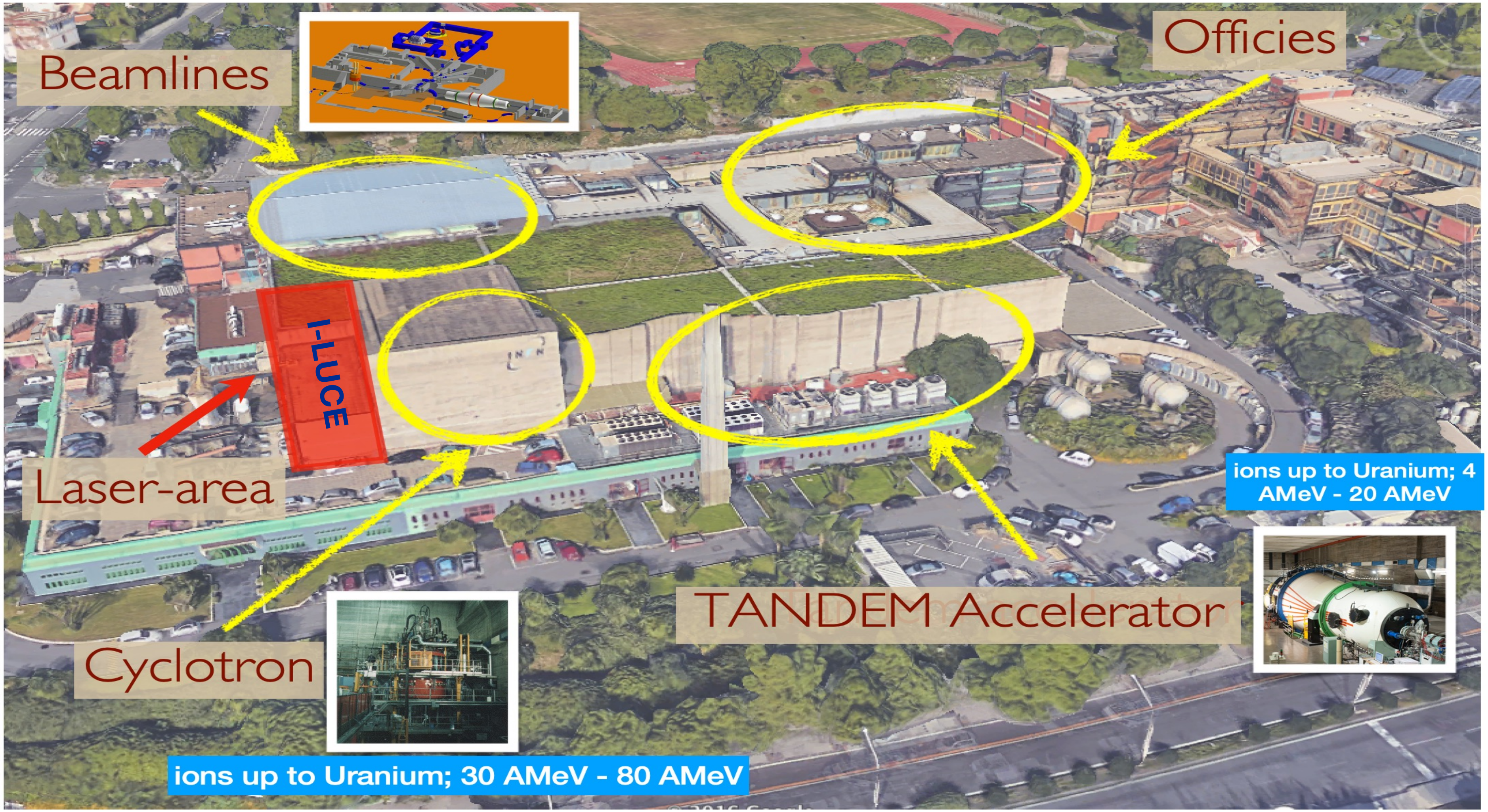
$$\lambda_p \equiv \frac{2\pi c}{\omega_p} \approx 100\ \mu\mathrm{m} \qquad T_{pulse} \approx \frac{\lambda_p}{2\pi c} \approx 50\ \mathrm{fs}$$

Plasma frequency:

$$\omega_p = \sqrt{\frac{n_e\,e^2}{m_e \varepsilon_0}}$$



I-LUCE at INFN-LNS (Laboratori Nazionali del Sud)



Beamlines

Officies

I-LUCE

Laser-area

ions up to Uranium; 4 AMeV - 20 AMeV

TANDEM Accelerator

Cyclotron

ions up to Uranium; 30 AMeV - 80 AMeV

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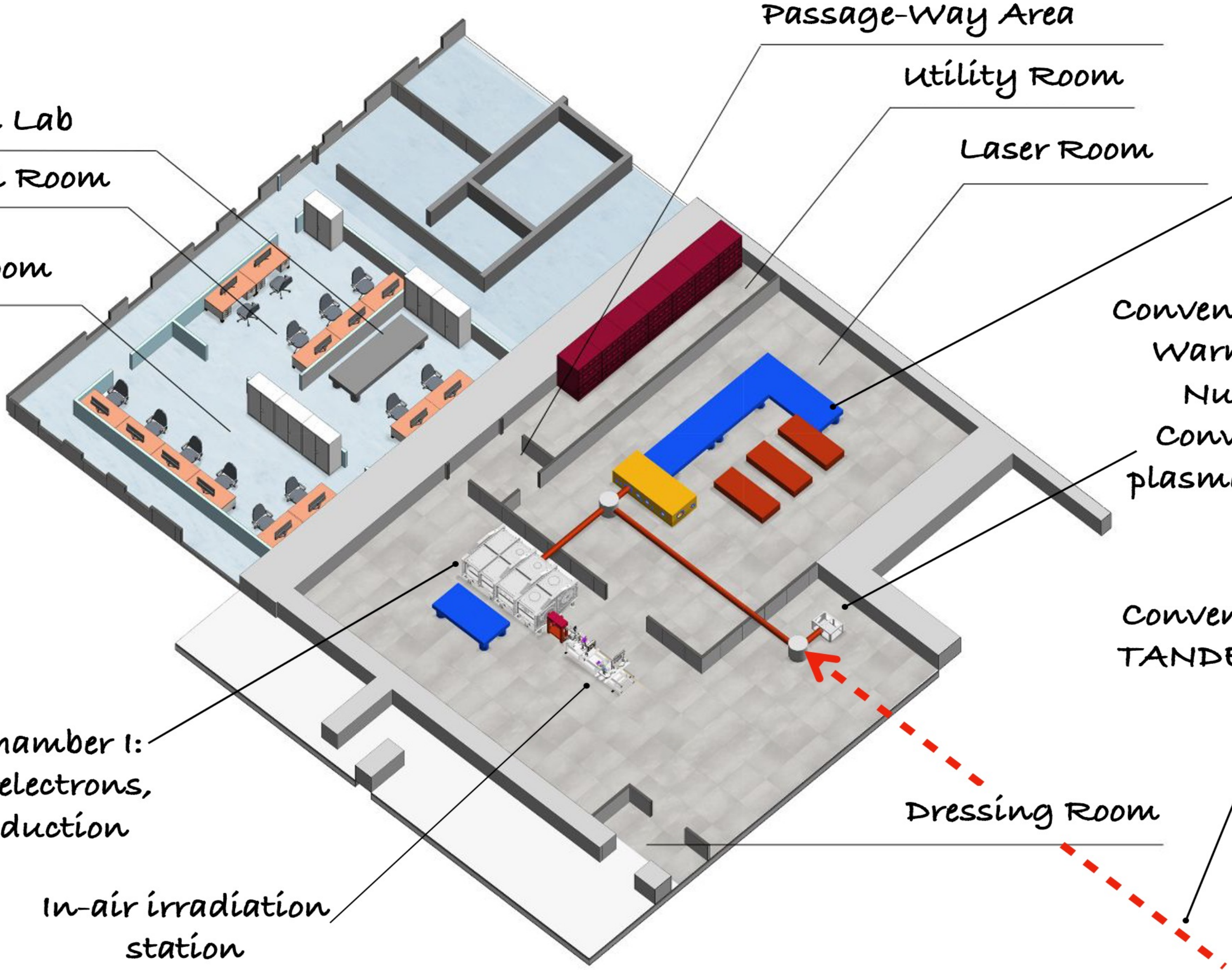
I-LUCE (INFN - Laser indUCEd radiation production) Facility



December 2024
Optical Lab

December 2024
Control Room

User Room

Passage-Way Area

Utility Room

Laser Room

November 2026
Laser System
(THALES)

Conventional Chamber II:
Warm Dense Matter,
Nuclear Physics,
Conventional beam-plasma Interaction, etc.

Conventional Ions: from TANDEM and Cyclotron

Dressing Room

July 2026
Interaction Chamber I:
protons, ions, electrons, neutrons production

In-air irradiation station

Talk by: Dr. GAP Cirrone

I-LUCE Facility: Plasma Source (Plasma-discharge Capillary)

A capillary is a small, narrow tube, often made of dielectric materials such as quartz, non-commercial plastic (VeroClear), sapphire, glass, or etc. that confines the plasma.

Capillary Advantages

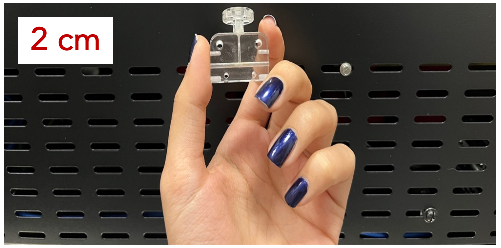
Stable Plasma Channel:
Provides a more stable and uniform plasma column over longer distances

Guidance and Focusing:
Reducing beam divergence and improving acceleration efficiency

Beam Quality:
High beam quality with narrow energy spreads and low emittance

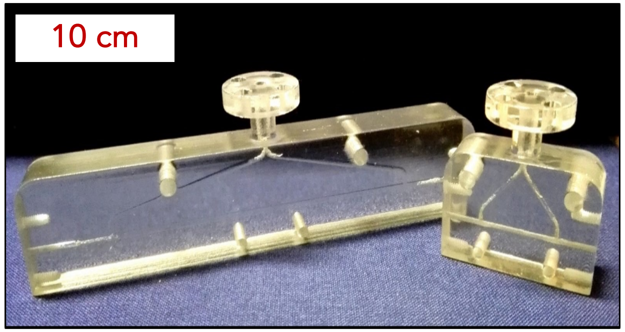
Enhanced Acceleration Length:
Extend the effective acceleration length, allowing electrons to gain more energy

Flexible Geometry:
mm-m/length, µm-mm/diameter

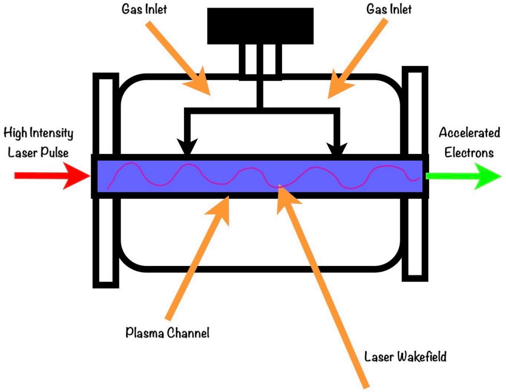


2 cm

3 cm

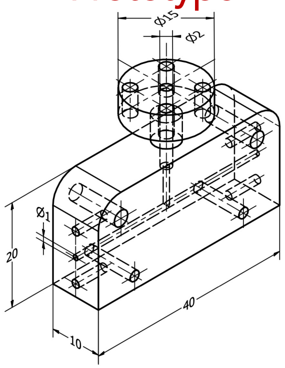


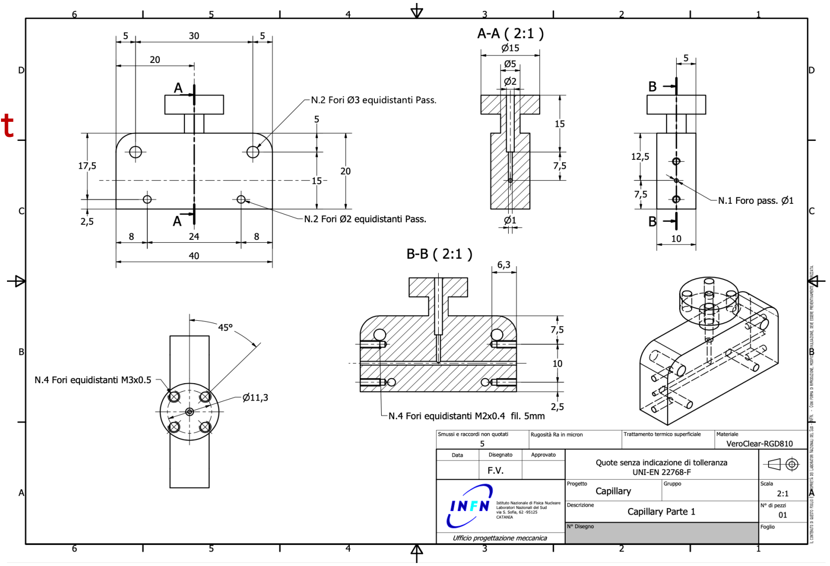
10 cm

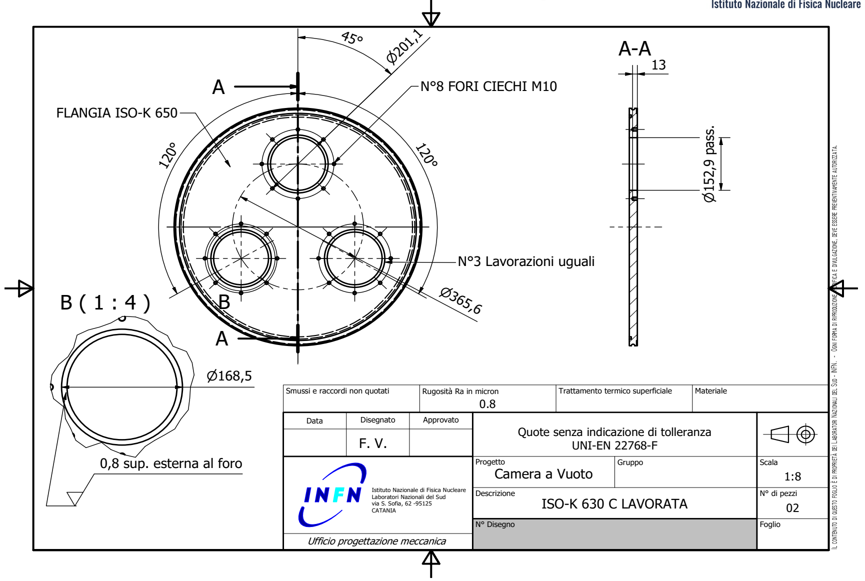


I-LUCE Facility: Plasma LAB

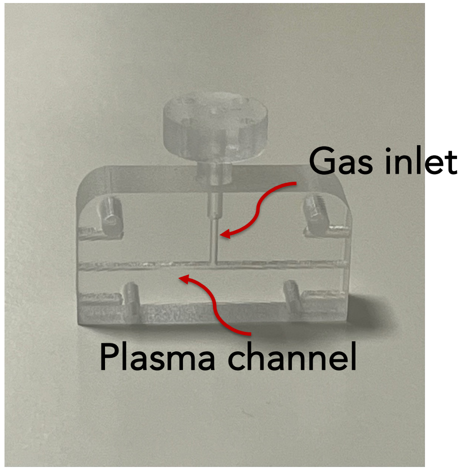
CAD Design of first Prototype







3D Printed
VeroClear ($C_2O_2H_8$)
Plasma Discharge Capillary
(4 cm/long-1 mm/diameter)



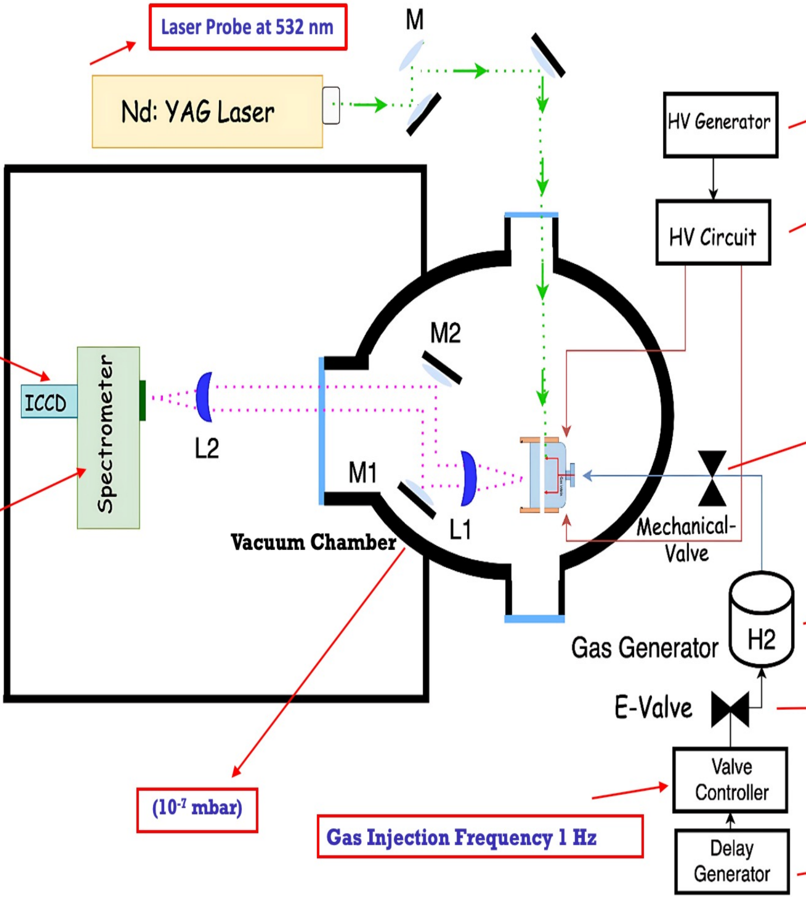
April 2025

Testing Vacuum Chamber (82x60 cm) for Capillaries up to
10 cm/long capillaries

I-LUCE Facility: Plasma LAB (Direct Current Plasma Discharge)

Ideal gas law:

$$P = n_m\, k_B\, T$$



Laser Probe at 532 nm

Plasma Density $10^{17}\ cm^{-3}$

Plasma lasts 10 - 20 μs

Resolution
1024 x 255 pixels

- **Spectral resolution 0.1 nm**
- **Grating 1200 g/mm, 2400 g/mm**
- **Focal length: 275 mm**
- **Aperture ratio: f/3.8**

(10^{-7} mbar)

Gas Injection Frequency 1 Hz

Voltage lasts 1 μs

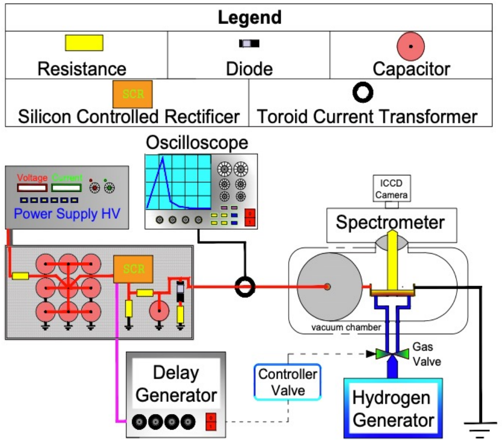
Resistor Capacitor Circuit

10-50 mbar
(imposes the density $10^{17}\ cm^{-3}$)

Hydrogen is highly ionized at reletively low temperatures

Gas injection time: 3 ms

Synchronizes Timing:
- **Valve Opening Time**
- **Voltage Delay Time**
- **Trigger of ICCD Camera**

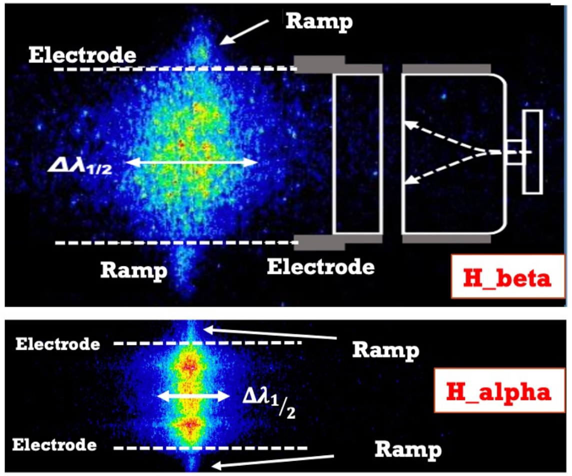


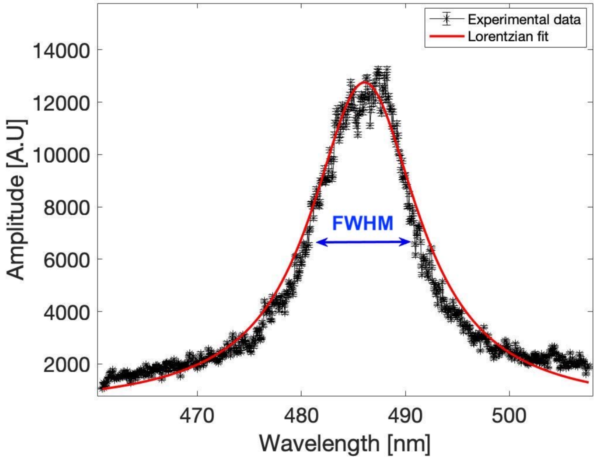
S. Arjmand, PhD – sahar.arjmand@lns.infn.it

Plasma Diagnostic: Density Measurements

- Emission Spectroscopy: Studies the light emitted by atoms, etc. during transitions from higher to lower energy states.
- Broadening Mechanism: Natural, Doppler, and Collisional (Stark) broadenings, that can allow us to measure the electron density.

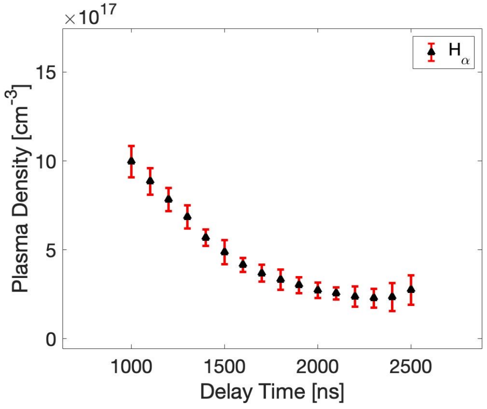
Balmer Spectral Lines

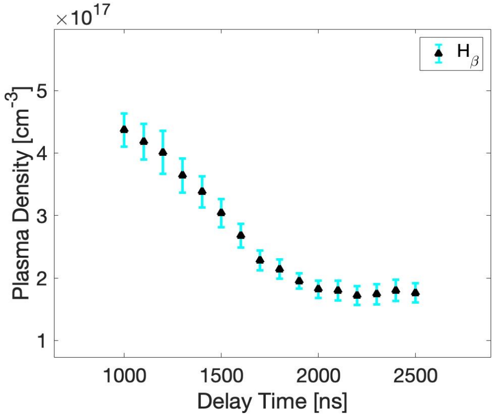




HR Griem, Academic Press Inc, App. III (1974)

$$n_e = 8.02 \times 10^{12} \left(\frac{\Delta\lambda\_Stark_{1/2}}{\alpha_{1/2}}\right)^{3/2} \ cm^{-3}$$





Balmer α (H_alpha):
- ➢ Lower excitation energy
- ➢ Higher probability of being emitted
- ➢ Higher sensitivity to light
- ➢ Self-absorption effect

S. Arjmand et al., JINST, 18, C05007 (2023)

Balmer β (H_beta):
- ➢ Higher excitation energy
- ➢ Lower probability of being emitted
- ➢ Less sensitive to light
- ➢ Less self-absorption

S. Arjmand et al., JINST, 18, P08003 (2023)

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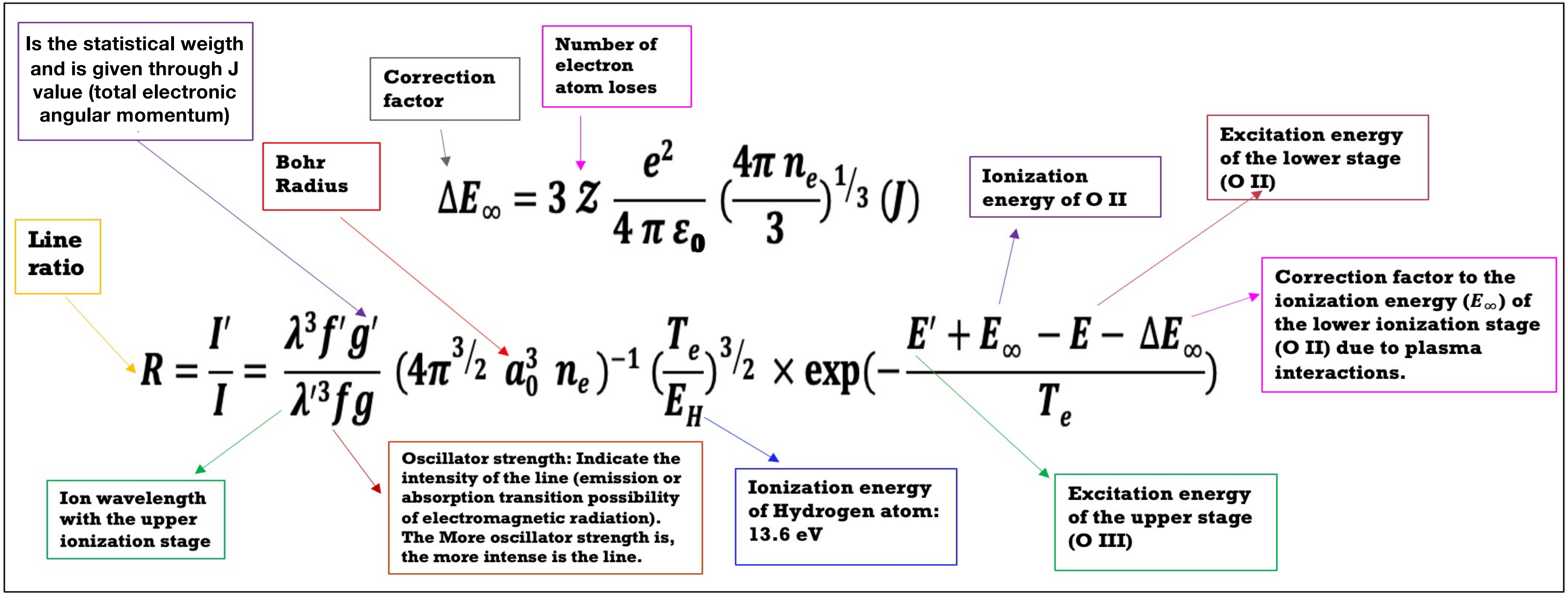
Plasma Diagnostic: Temperature Measurements

- Lower ionization stage: I, g, f, λ
- Higher ionization stage: I', g', f', λ'

Intensity Ratios: Using the intensity ratios of different spectral lines to infer the electron temperature.



Is the statistical weigth and is given through J value (total electronic angular momentum)

Correction factor

Number of electron atom loses

Bohr Radius

$$\Delta E_\infty = 3\,Z\,\frac{e^2}{4\pi\varepsilon_0}\left(\frac{4\pi n_e}{3}\right)^{1/3}(J)$$

Ionization energy of O II

Excitation energy of the lower stage (O II)

Line ratio

$$R = \frac{I'}{I} = \frac{\lambda^3 f' g'}{\lambda'^3 f g}\left(4\pi^{3/2} a_0^3\, n_e\right)^{-1}\left(\frac{T_e}{E_H}\right)^{3/2} \times \exp\left(-\frac{E' + E_\infty - E - \Delta E_\infty}{T_e}\right)$$

Correction factor to the ionization energy (E_∞) of the lower ionization stage (O II) due to plasma interactions.

Ion wavelength with the upper ionization stage

Oscillator strength: Indicate the intensity of the line (emission or absorption transition possibility of electromagnetic radiation). The More oscillator strength is, the more intense is the line.

Ionization energy of Hydrogen atom: 13.6 eV

Excitation energy of the upper stage (O III)

S. S. Harilal et al., 52, 3 (1998)

S. Arjmand et al., JINST, 18, P08003 (2023)

S. Arjmand, PhD – sahar.arjmand@lns.infn.it

Plasma Diagnostic: Temperature Measurements

HR Griem, Academic Press Inc, App. III (1974)

Plasma Density: $10^{17}\ cm^{-3}$ Temperature: 1 - 4 eV

Two mechanisms:

- **Ablation:** Typically generated by intense laser pulse focused on solid target (in our case small amount of surface ablation), causing material to be ejected/melted from the surface.
- **Desorption:** Refers to when atoms or molecules leave the surface of material without fully vaporizing the surface (the most dominant mechanism.

VeroClear ($C_5O_2H_8$):
82.92% Carbon
16.50% Oxygen
0.57% Nitrogen due to impurity (78% in the air)

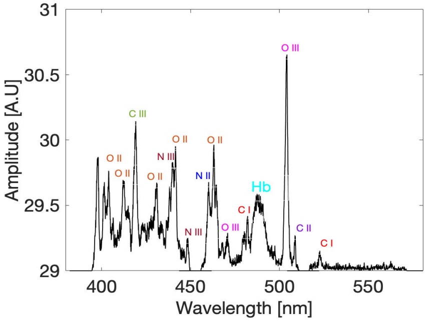
Emitted

O I, O II, O III, N I, N II, N III, C I, C II, C III

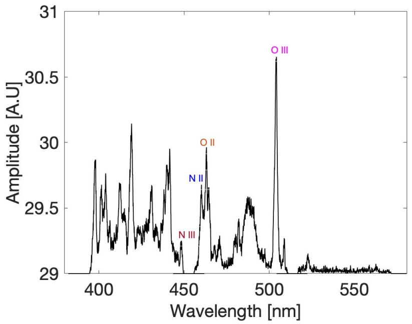
Considerd

- O II (471.9803 nm) or N II (471.8377 nm)
- O III (508.8922 nm) or N III (454.970 nm)

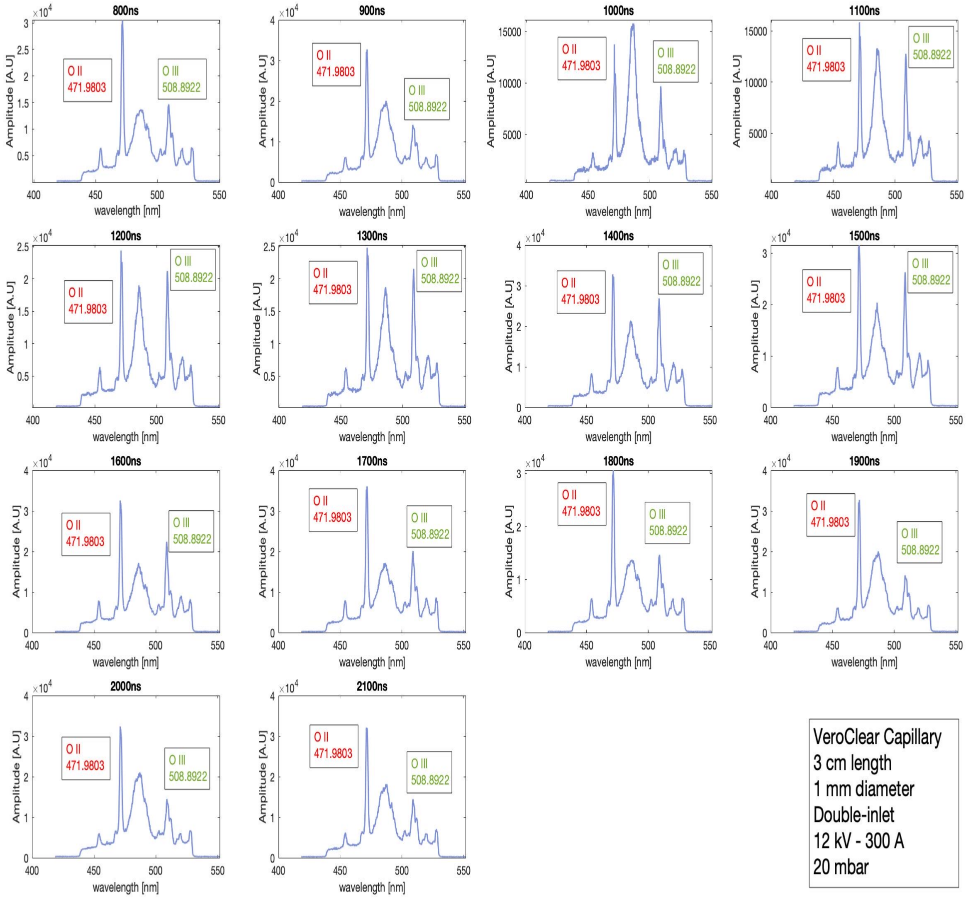
Emitted Spectral Lines



Considered Spectral Lines



Evolution of the Oxygen Ions (800-2100 ns)

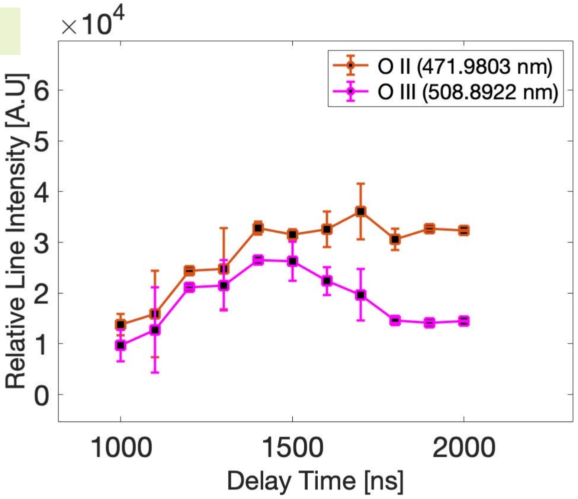


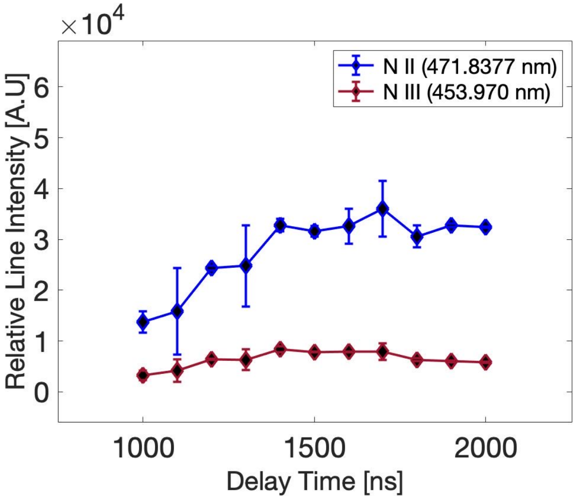
VeroClear Capillary
3 cm length
1 mm diameter
Double-inlet
12 kV - 300 A
20 mbar

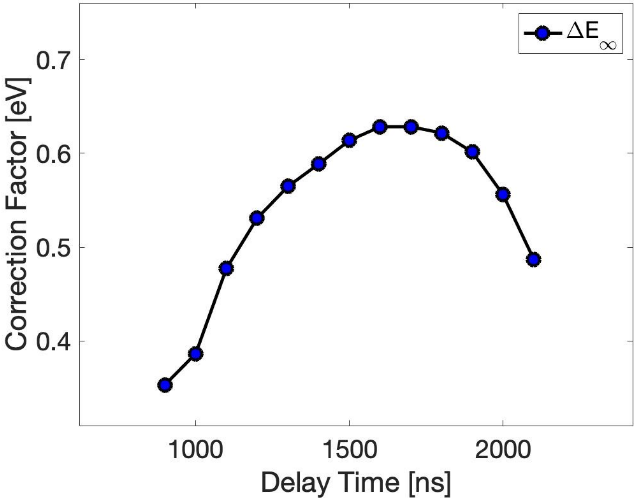
Plasma Diagnostic: Temperature Measurements

NIST Database (https://physics.nist.gov/PhysRefData/ASD/levels_form.html)

Oxygen Element Spectroscopic Data	
Parameter	**Value**
λ_1: Wavelength of O II	471.9803 (nm)
λ_2: Wavelength of O III	508.492 (nm)
g_1: Statistical Weight of O II	1
g_2: Statistical Weight of O III	1
f_1: Oscillator Strength of O II	8.57×10^4 (DI)
f_2: Oscillator Strength of O III	6.15×10^6 (DI)
J_1: Lower-level and Upper-level Angular Momentum Quantum Number of O II	$\frac{3}{2}, \frac{3}{2}$
J_2: Lower-level and Upper-level Angular Momentum Quantum Number of O III	2, 2
E_1: Excitation Energy of O II	2.62 (eV)
E_2: Excitation Energy of O III	2.43 (eV)
E_∞: Ionization Energy of Lower State of O II	35.11730 (eV)
Z: Number of Electrons Lost by O II	1
Nitrogen Element Spectroscopic Data	
Parameter	**Value**
λ_1: Wavelength of N II	471.8377 (nm)
λ_2: Wavelength of N III	453.970 (nm)
g_1: Statistical Weight of N II	1
g_2: Statistical Weight of N III	1
f_1: Oscillator Strength of N II	3.02×10^7 (DI)
f_2: Oscillator Strength of N III	5.71×10^7 (DI)
J_1: Lower-level and Upper-level Angular Momentum Quantum Number of N II	4, 4
J_2: Lower-level and Upper-level Angular Momentum Quantum Number of N III	$\frac{1}{2}, \frac{1}{2}$
E_1: Excitation Energy of N II	2.62 (eV)
E_2: Excitation Energy of N III	2.77 (eV)
E_∞: Ionization Energy of Lower State of N II	29.6013 (eV)
Z: Number of Electrons Lost by N II	1
Physical Constants	
Parameter	**Value**
E_H: Hydrogen Ionization Energy	13.6 (eV)
ε_0: Vacuum Permittivity	8.85×10^{-12} (F m^{-1})
a_0: Bohr Radius	$5.2917724 \times 10^{-11}$ (m)
m_e: Electron Mass	9.10938×10^{-31} (kg)
e: Electron Charge	1.602×10^{-19} (C)
$\hbar$: Reduced Planck Constant	1.05457×10^{-34} (J s)





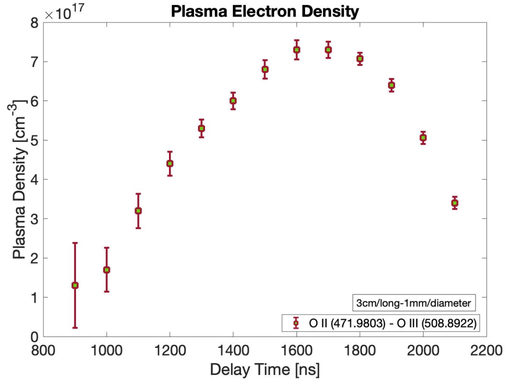


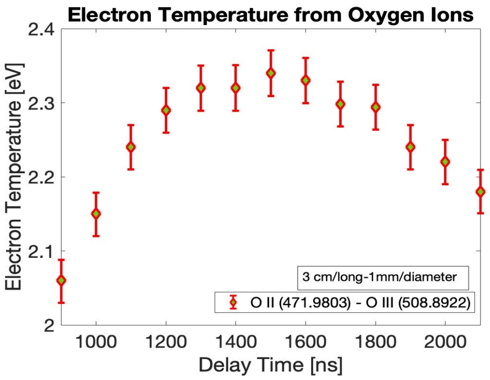
Plasma Diagnostic: Temperature Measurements (Oxygen Ions)

A. J. Gonsalves et al., Journal of Applied Physics, 119, 033302 (2016)

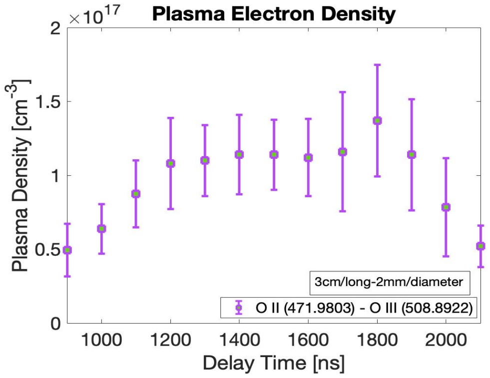
S. Arjmand et al., JINST, 18, P08003 (2023)

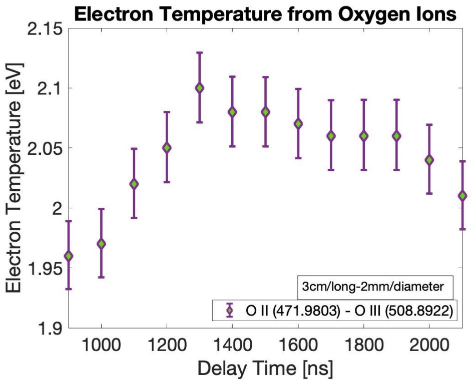
3 cm length
1 mm diameter
Double-inlets
20 mbar
12 kV – 400 A



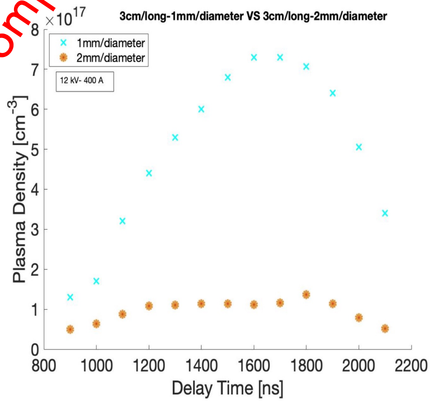


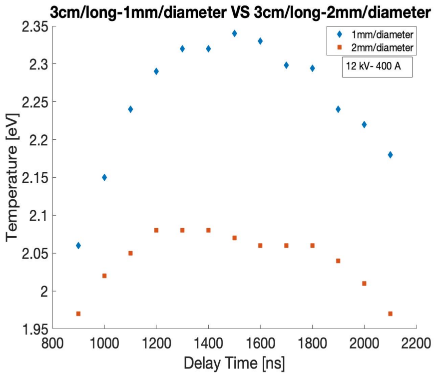
3 cm length
2 mm diameter
Double-inlets
20 mbar
12 kV – 400 A

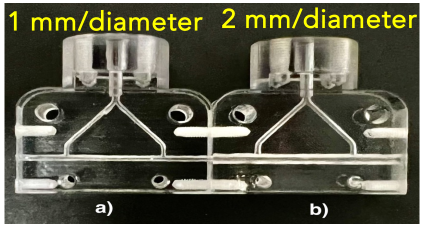




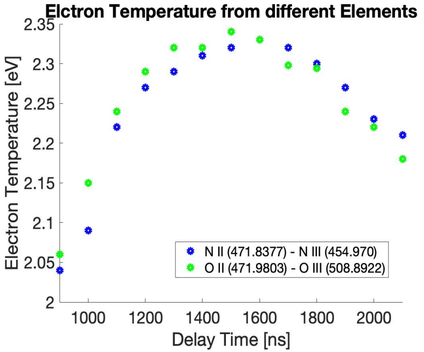
Comparison







- 3 cm long
- 1/2 mm diameter
- 20 mbar
- 12 kV – 400 A

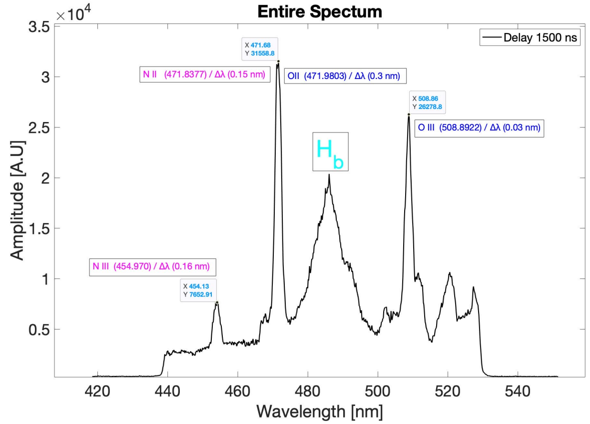


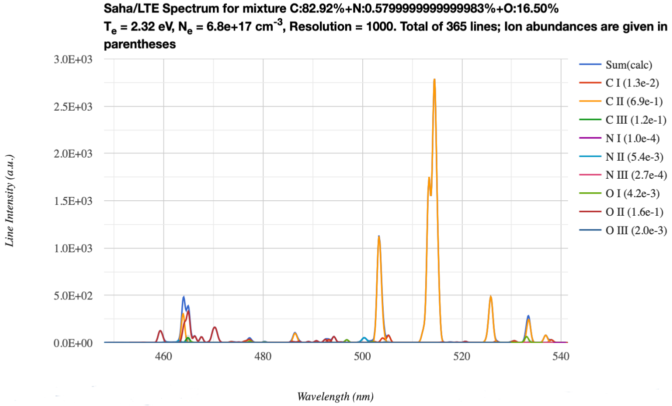
S. Arjmand, PhD – sahar.arjmand@lns.infn.it

Plasma Diagnostic: Temperature Simulation (O & N Ions)

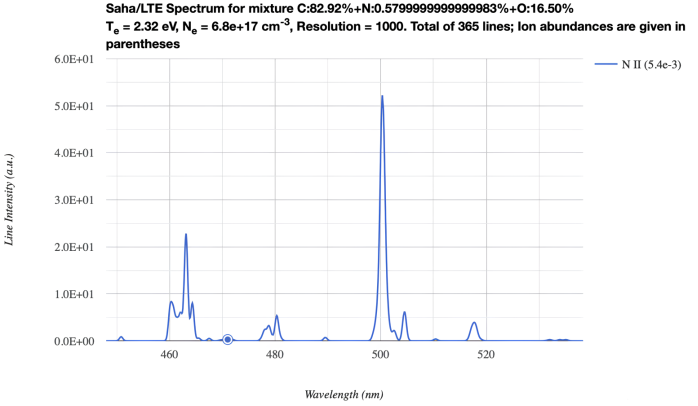
VeroClear ($C_5O_2H_8$):
82.92% Carbon
16.50% Oxygen
0.57% Nitrogen due to impurity

NIST Database (https://physics.nist.gov/PhysRefData/ASD/levels_form.html)

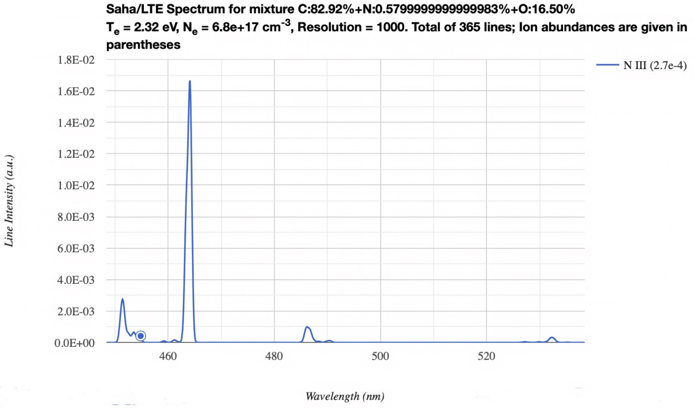

Entire Spectum


Saha/LTE Spectrum for mixture C:82.92%+N:0.5799999999999983%+O:16.50%
T_e = 2.32 eV, N_e = 6.8e+17 cm^{-3}, Resolution = 1000. Total of 365 lines; Ion abundances are given in parentheses

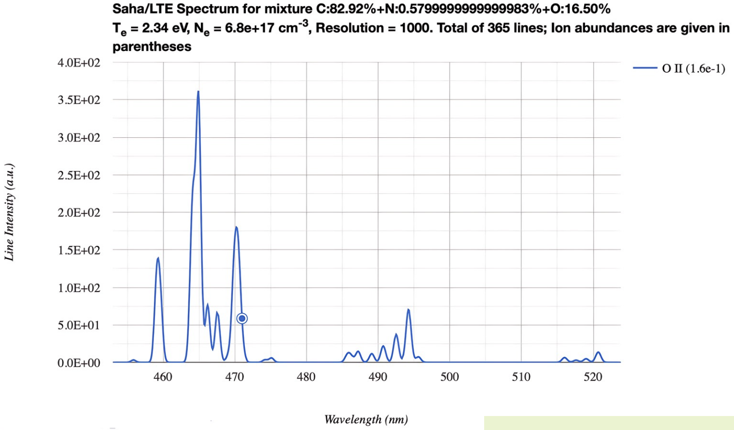
Nitrogen II


Saha/LTE Spectrum for mixture C:82.92%+N:0.5799999999999983%+O:16.50%
T_e = 2.32 eV, N_e = 6.8e+17 cm^{-3}, Resolution = 1000. Total of 365 lines; Ion abundances are given in parentheses

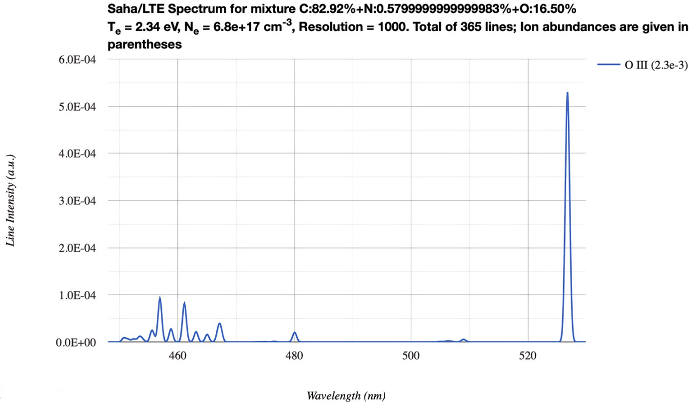
Nitrogen III


Saha/LTE Spectrum for mixture C:82.92%+N:0.5799999999999983%+O:16.50%
T_e = 2.32 eV, N_e = 6.8e+17 cm^{-3}, Resolution = 1000. Total of 365 lines; Ion abundances are given in parentheses

Oxygen II


Saha/LTE Spectrum for mixture C:82.92%+N:0.5799999999999983%+O:16.50%
T_e = 2.34 eV, N_e = 6.8e+17 cm^{-3}, Resolution = 1000. Total of 365 lines; Ion abundances are given in parentheses

Oxygen III


Saha/LTE Spectrum for mixture C:82.92%+N:0.5799999999999983%+O:16.50%
T_e = 2.34 eV, N_e = 6.8e+17 cm^{-3}, Resolution = 1000. Total of 365 lines; Ion abundances are given in parentheses

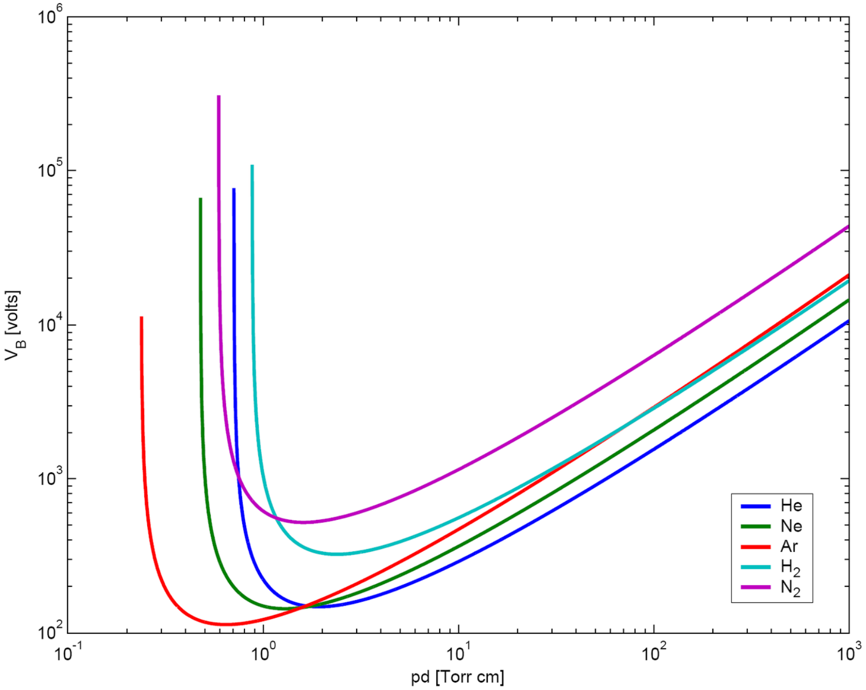
S. Arjmand et al., JINST, 18, P08003 (2023)

Plasma Diagnostic: 2D Discharge Modelling in COMSOL Multiphysics

B. Radjenovic et al., Acta Physica Slovaca 63(3):105-205

Paschen curve for different gases in electrical discharge

$$V_{volt} = f\,(p_{Torr} \times d_{cm})$$



Particle-particle reaction (excitations, ionisations, chrage exchange)
Reactions (ionisations, recombinations) on cathode and capillary surface.

Ar collision processes
Ar: Atom, Ar*: Excited Argon, Ar+: Ionized Argon

1) e + Ar => e + Ar* (Elastic Scattering)
2) e + Ar => e + Ar* => e + Ar + photon (Excitation)
3) e + Ar* => e + Ar (Superelastic)
4) e + Ar => 2e + Ar+ (Ionization)
5) e + Ar* => 2e + Ar+ (Ionization)
6) Ar* + Ar* => e + Ar + Ar+ (Penning Ionization)
7) Ar* + Ar => Ar + Ar (Metastable Quenching)

Surface Reactions:
Ar atoms or metastable atoms intercat with the wall and transition back to ground state

1) Ar+ => Ar
2) Ar* => Ar

https://www.comsol.com/

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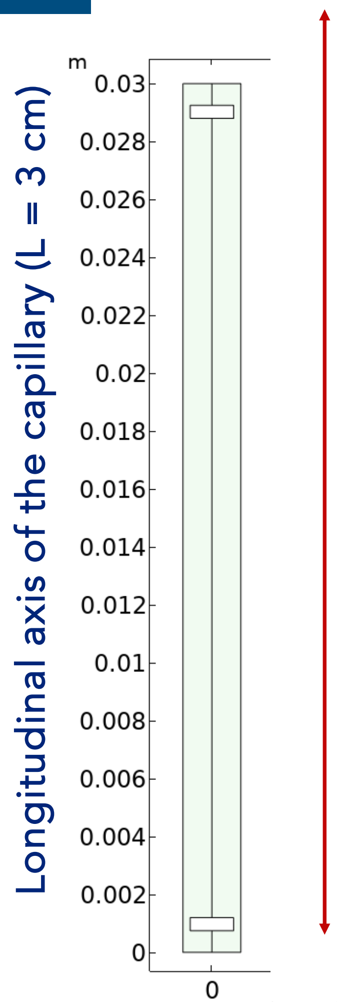
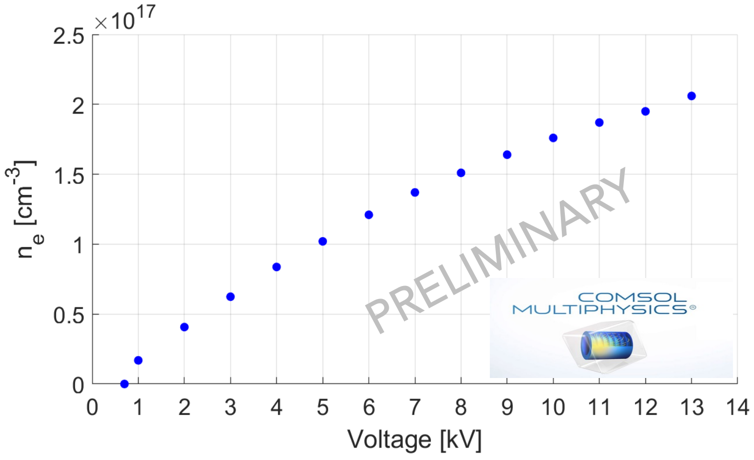
Plasma Diagnostic: 2D Modelling in COMSOL Multiphysics



- A capillary of length L = 3 cm and diameter of d = 1 and 2 mm, filled with Argon at the pressure p = 7.5 Torr (10 mbar) is considered, to generate a plasma in the range of $10^{17}\ cm^{-3}$.
- From the Argon Paschen curve, the minimum voltage required to initiate gas breakdown results V0 ~ 800 V for a capillary of length L = 3 cm, at the pressure p = 7.5 Torr (10 mbar) .
- At voltage lower than the one needed to initiate the breakdown, no discharge occurs (the electron density is lower than the initial one, fixed at n_{ei} = 10^7 cm^{-3}).
- When the applied voltage is higher than the breakdown one, the electron density starts to increase.
- All values taken in the simulation time t = 2 µs, at which the density results almost stationary.

Electron Density Vs Applied Voltage

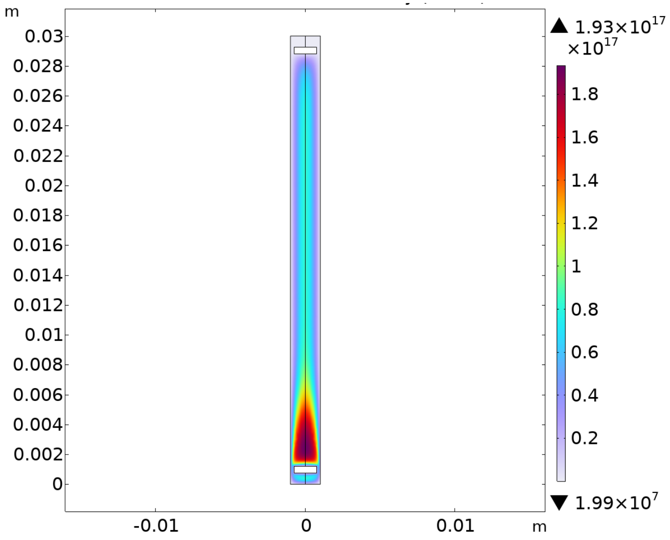


https://www.comsol.com/

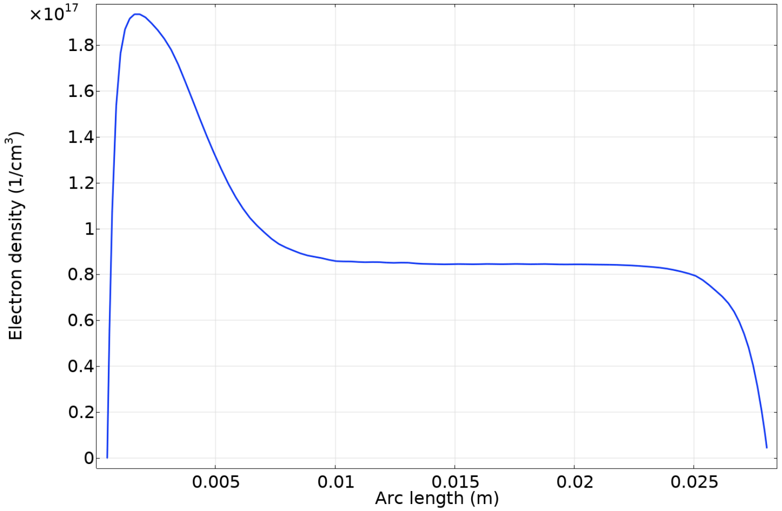
Plasma Diagnostic: 2D Modelling in COMSOL Multiphysics

3cm/long-2mm/diameter
10 mbar, 10 kV, 2 µs
With Argon gas

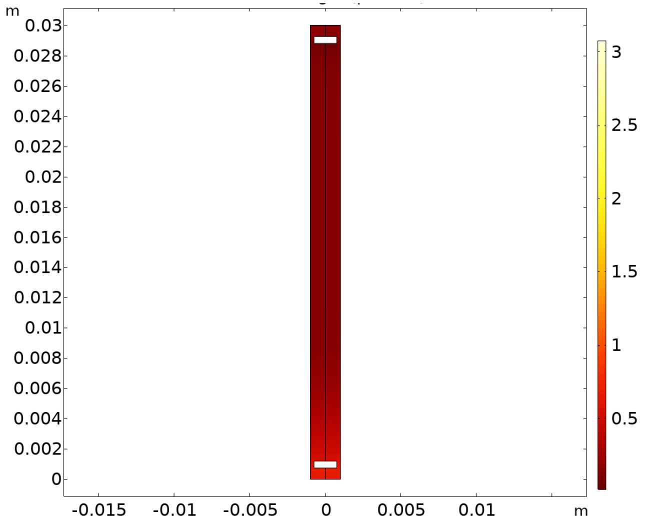
Electron Density inside Capillary



Electron Density along Capillary



Electron Temperature inside Capillary



PRILIMINARY

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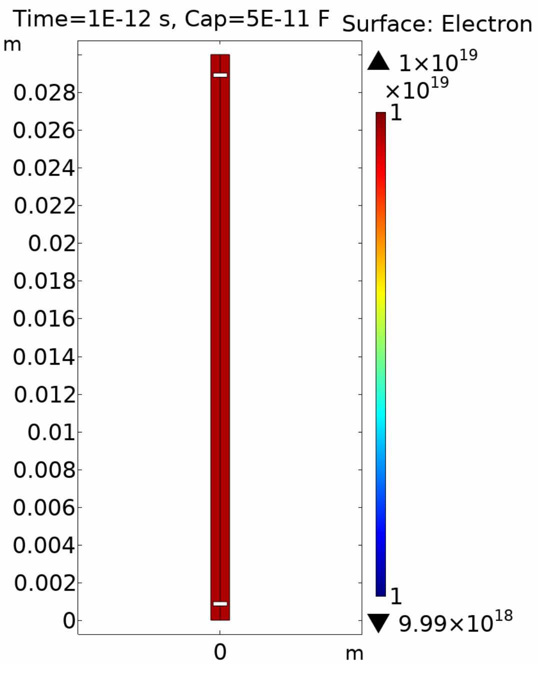
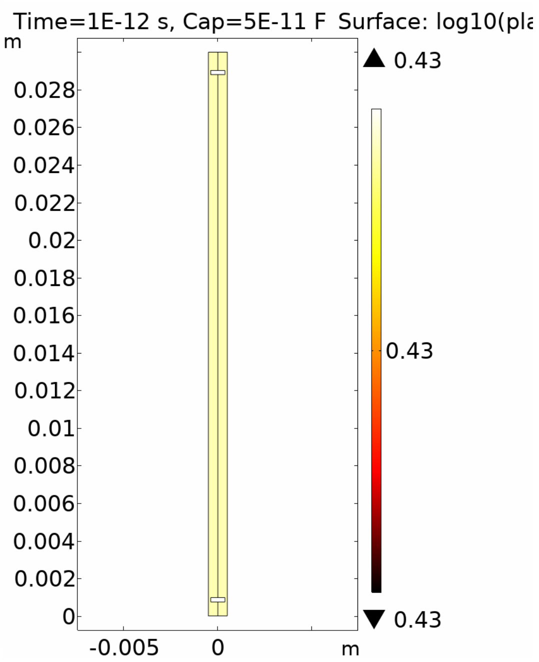
Plasma Diagnostic: 2D Modelling in COMSOL Multiphysics

3cm/long-2mm/diameter
10 mbar, 15 kV

Density
m^{-3}

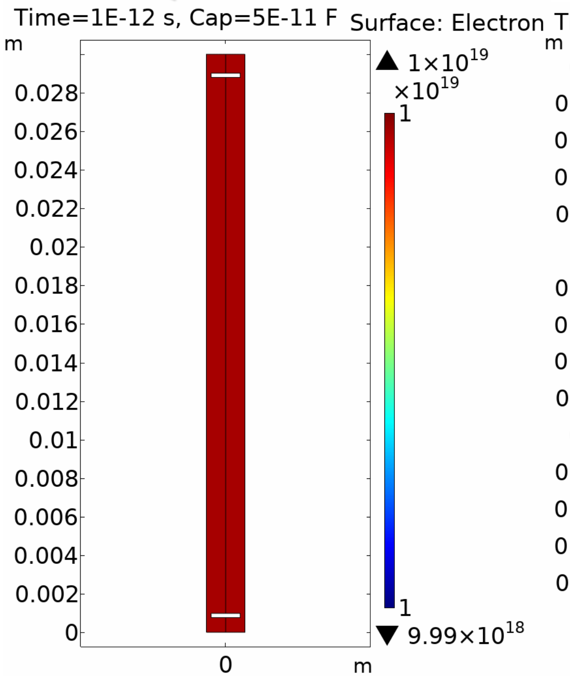


Temperature

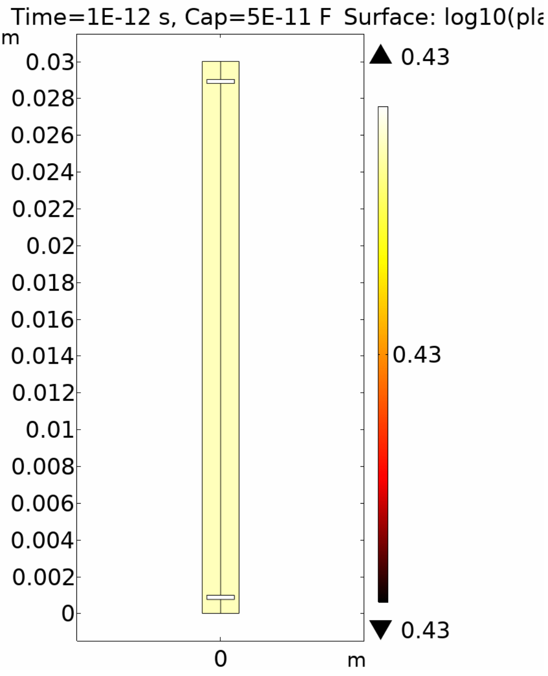


3cm/long-1mm/diameter
10 mbar, 15 kV

Density
m^{-3}



Temperature

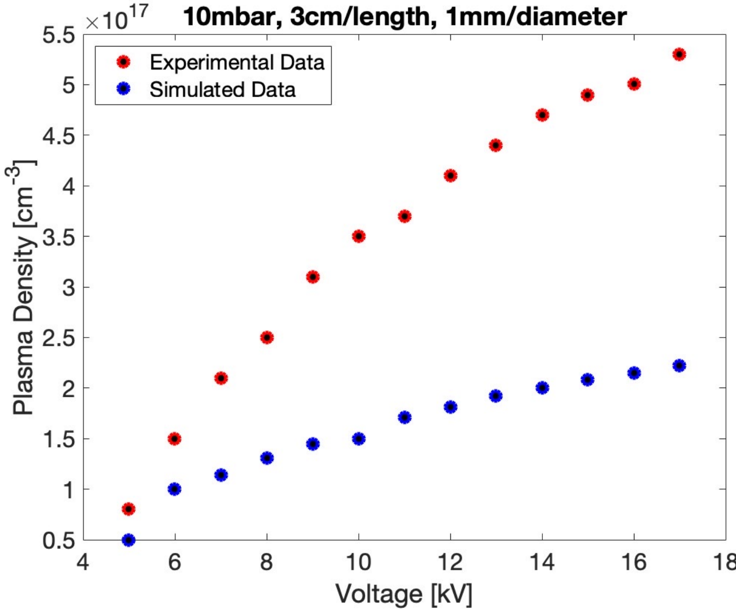


PRELIMINARY

Plasma Diagnostic: 2D Modelling in COMSOL Multiphysics

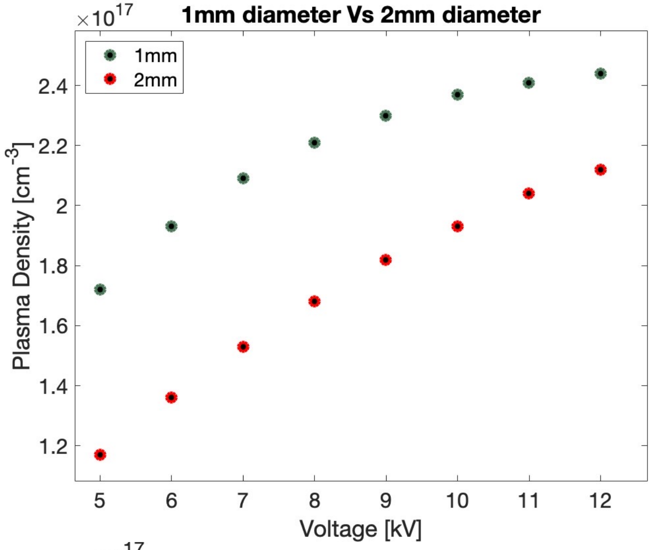
Comparison of experimental & simulated Data

3cm/long
1mm/diameter
7.5 Torr (10 mbar)
With Argon gas (Simulation)
With Hydrogen gas (Experimental)



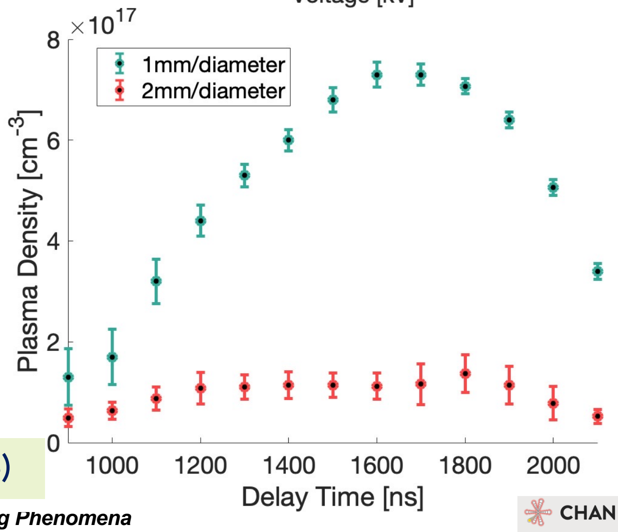
Simulated Data

3cm/long
1mm and 2mm/diameter
7.5 Torr (10 mbar)
With Argon gas



Experimental Data

3cm/long
1mm and 2mm/diameter
7.5 Torr (10 mbar)
With Hydrogen gas
12 kV

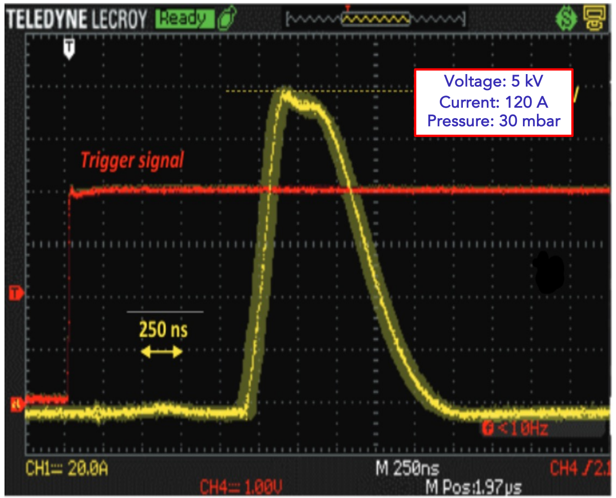


S. Arjmand et al., JINST 18, C04016 (2023)

S. Arjmand, PhD – sahar.arjmand@lns.infn.it

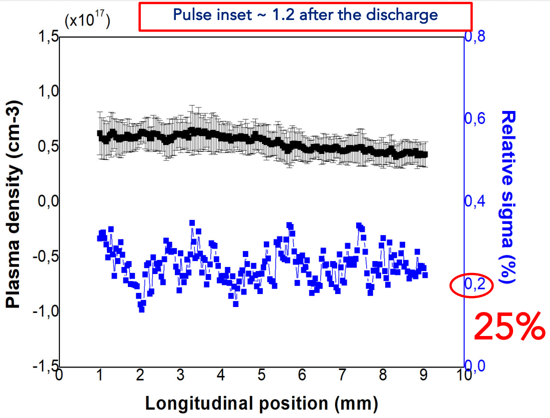
Plasma Stability: Shot-to-shot Stability

~ 150 ns timing jitter



Voltage: 5 kV
Current: 120 A
Pressure: 30 mbar

Pulse inset ~ 1.2 after the discharge

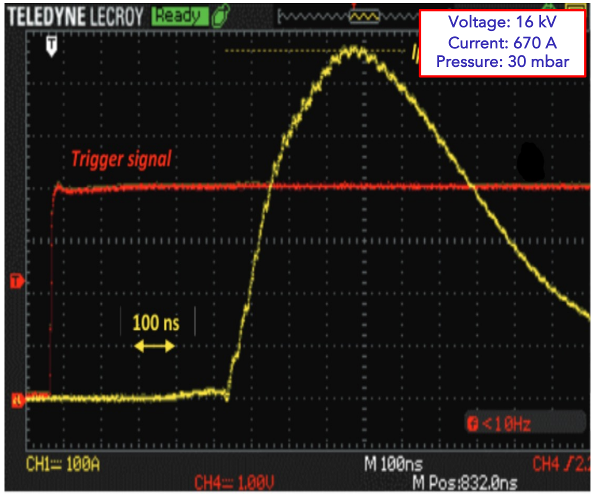


25%

100 consecutive current pulse waveforms acquired by an oscilloscope at a 1~Hz repetition rate.

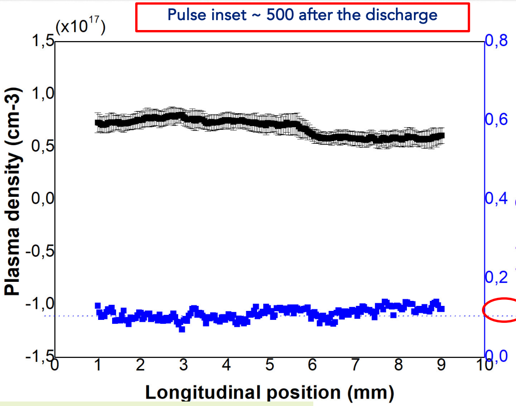
Timing jitter: measuring the enlargement of the current pulse waveforms by setting the infinitive persistence on the oscilloscope

~ 20 ns timing jitter

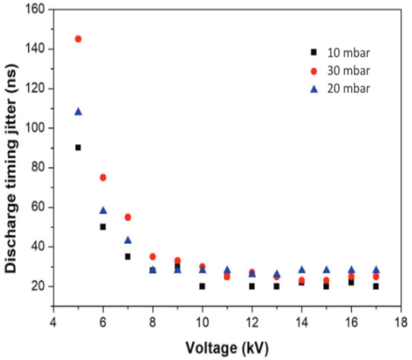


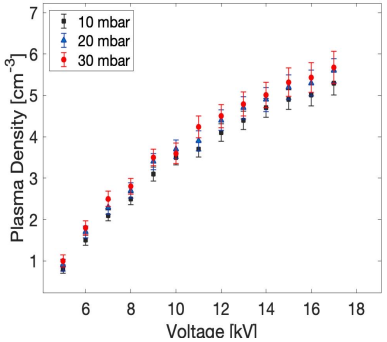
Voltage: 16 kV
Current: 670 A
Pressure: 30 mbar

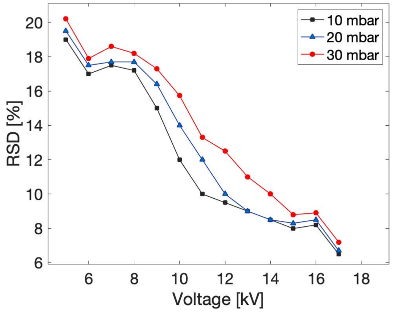
Pulse inset ~ 500 after the discharge



11%



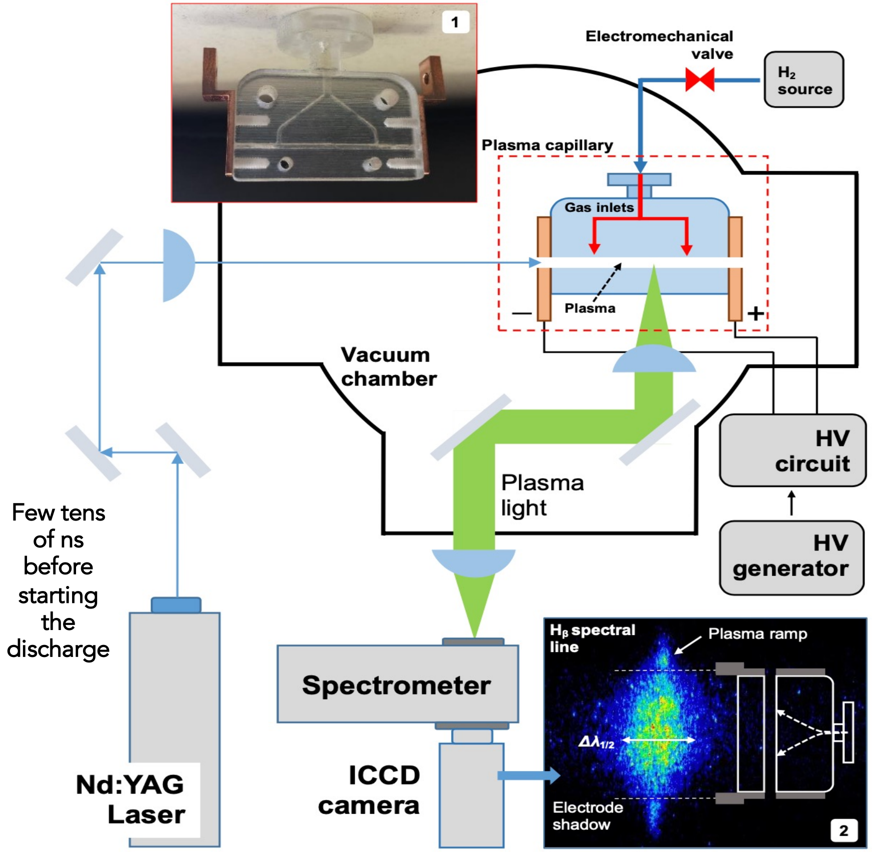




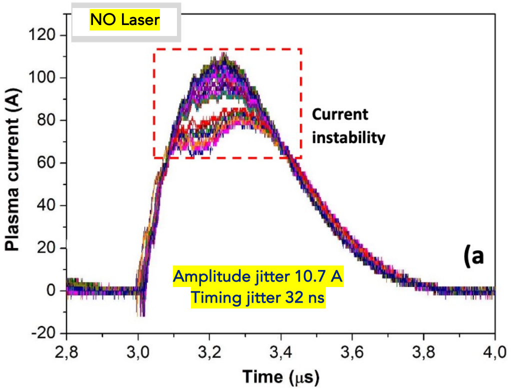
S. Arjmand et al., JINST 18, C04016 (2023)

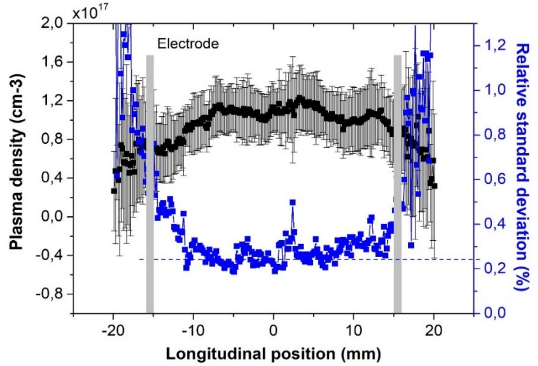
Plasma Stability: Stabilization by a Laser Technique

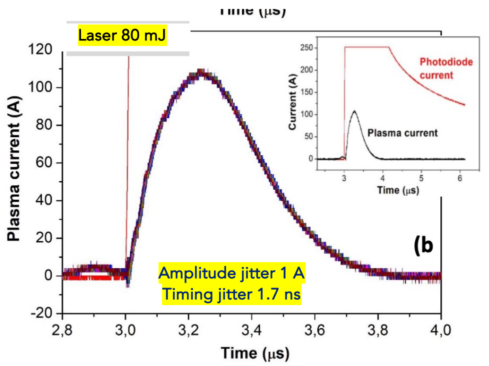
3 cmx1mm
2 inlets
20 mbar
Voltage: 5 kV
Laser: 80 mJ
Current: 110 A

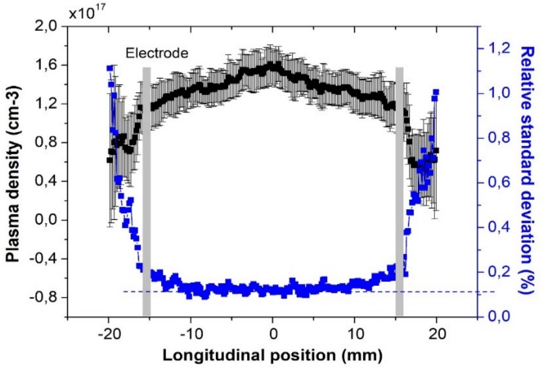


1064 nm, 11 ns, $10^{10}\ \frac{\mathrm{W}}{\mathrm{cm}^2}$









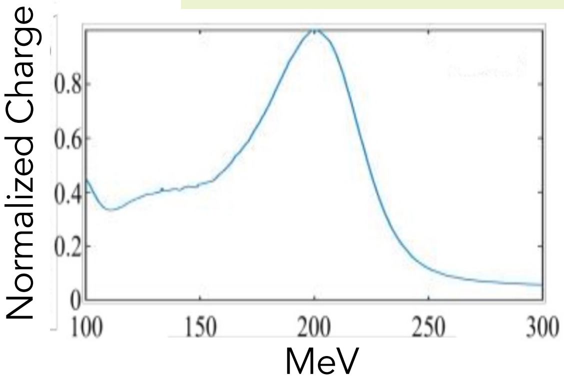
A. Biagioni, S. Arjmand et al., Plasma Phys. Control Fusion, 63 115013 (2021)

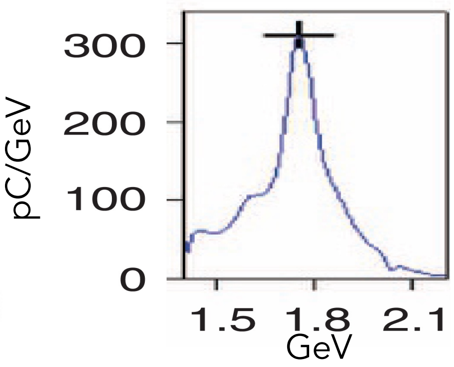
I-LUCE Facility: Electron Beam Expectation

W.P. Leemans et al., Nature physics, 2 (2006)

X. Wang et al., Nature Communications, (2017)

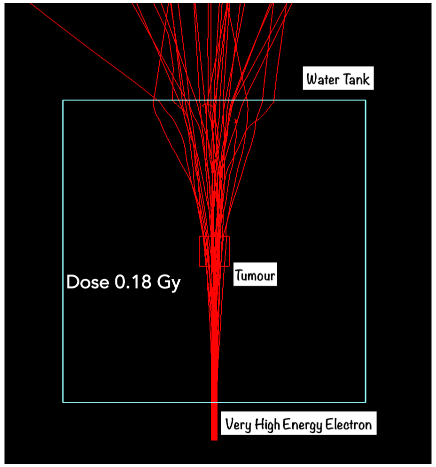
S. Lee et al., Appl. Sci. 133, 2564, (2022)

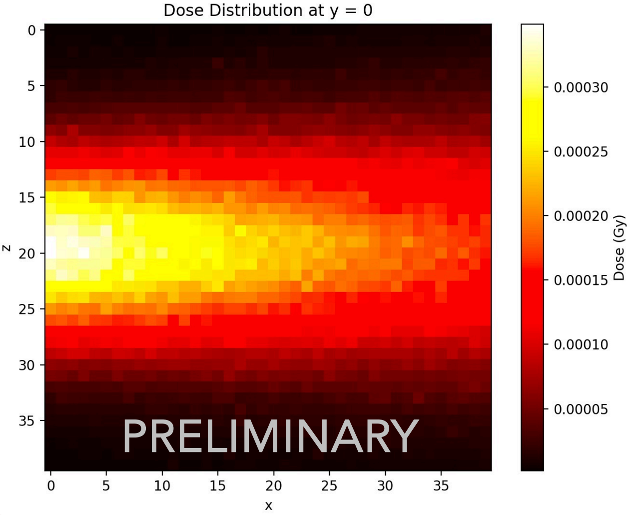




Laser Power	50 – 350 TW
Laser Energy per pulse	1 – 7 J
Laser Pulse Duration	23 – 150 fs
Laser Intensity	$10^{17} - 10^{19}\ \frac{W}{cm^2}$
Repetition Rate	1 – 10 Hz
Plasma Density	$10^{17} - 10^{19}\ cm^{-3}$
Capillary Length	3 – 9 cm
Capillary Radius	500 µm – 0.5 mm
Beam Energy	100 MeV – 3 GeV
Beam Charge	30 – 400 pC
Particle per Pulse	$10^8 - 10^9$

200 MeV
100 pC





At 10 Hz: 1.8 gray at one second

At 100 Hz: 18 gray at one second

FLASH-RT:Ultra high dose rate region (8-9 Gy in less than one second)

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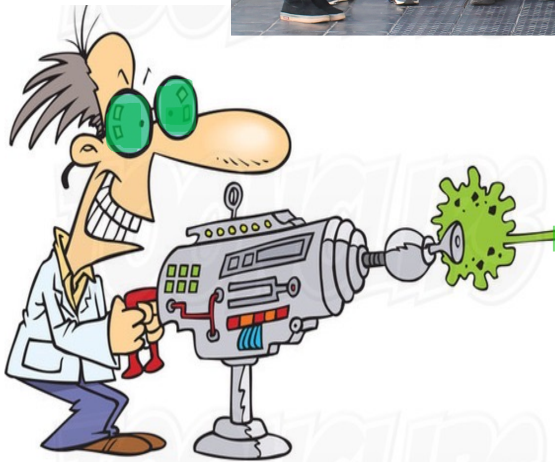
Medical Physics and Laser Group at LNS

Scan me ☺



Thanks for Listening ☺