Development of an ultrafast X-ray laser-plasma source

XXXVI Biennial Meeting of the RSEF

Symposium of Nuclear Physics

PhD Student Lucía Martín Blanco

Grupo Experimental de Núcleos y Partículas (GENP)
Instituto Gallego de Física de Altas Energías (IGFAE)

Universidad de Santiago de Compostela
OUTLINE

• Motivation
• Introduction
• X-Ray Source
  o Experimental Results
  o Target Engineering
  o Plasma emissions
  o X-Ray Imaging
• Conclusions
MOTIVATION

Conventional acceleration technology:

8 TeV pp LHC, 27 km, 8e9 euros
Superconducting RF 55 MV/m
RF: 10-100 MV/m

LHCB
ATLAS
CMS
ALICE
LHC

Laser-plasma technology

GeV, Small facilities, 5e6 euros
Electric fields: 100GV/m
Power = \[ \frac{1.2 \text{ J}}{25 \text{ fs}} = 48 \text{TW} \]

| Power | 270 TWh |

Red eléctrica de España (2011)
Power = \frac{\text{Energy}}{\text{Time}}

Ultrashort laser pulses of femtosecond length

1 \text{ fs} = 0.000\ 000\ 000\ 000\ 001 \text{ second}

High energy concentration.

Bullets of light
LAMBDA CUBE REGIME

Intensity = \frac{\text{Energy}}{\text{area} \cdot \text{time}} = \frac{N \cdot h\omega}{\text{area} \cdot \Delta t}

Many photons for a certain (very short) time focused onto a small spot

\[ I(350\lambda^3) = \frac{1\text{mJ}}{(4\mu\text{m})^235.10^{-15}\text{s}} = 1,8 \cdot 10^{17} \frac{W}{cm^2} \]
PACKING LIGHT
PACKING LIGHT
Overdense laser plasma

Tunnel-Ionization

Laser EM Pressure

Energy exchange

Electrons

X-Rays

Target Thickness

$\Delta t < 10-100 \text{ ps}$

Electron-Energy $E_e$

X-Ray Energy

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• Energy per pulse: up to 650μJ
• Pulse duration: 35fs
• P Polarization

• Focusing point: 4 μm
• Incidence: 45°
• Repetition Rate: 1kHz
X-RAY SOURCE Target System

Target is destroyed in each laser pulse
Continuous refresh of the target surface

Target system:
- 2 linear motors
  - Change radius
  - Focusing
- 1 Rotation motor

Continuous operation up to 20 minutes!
X-RAY SOURCE  Fit Analysis

**Target: Cu**

- Reconstructed Spectrum
- Original Spectrum
- Fit Bremsstrahlung Background
- Fit $T_{\text{cold}}$
- Fit $T_{\text{hot}}$

**Bi-Maxwellian like distribution**

**Pile-up effects at high energies**

**Laser Intensity** $= 7.8 \times 10^{16}$ W/cm$^2$

- $N_K / N_{\text{Total}} = 13.2\%$
- $N_K = 2.7 \times 10^5$ phs
- $N_{\text{Bremsstrahlung}} = 1.8 \times 10^6$ phs

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X-RAY Angular Characterization

Counting falls at wider angles

Kα ratio increases at wider angles

Bremsstrahlung counting falls
X-RAY Angular Characterization

**Graph:**
- Laser Intensity = $7.8 \times 10^{16}$ W/cm$^2$
- Counts vs. Angle (degrees)
  - Counts (a.u.)
  - Ratio $K_\alpha$ vs. Total (%)

- **Observation:**
  - Counting falls at wider angles
  - $K_\alpha$ ratio increases at wider angles
  - Bremsstrahlung counting falls
X-RAY Angular Characterization

Temperatures-Angle Analysis

Laser Intensity = $7.8 \times 10^{16}$ W/cm$^2$

**Normalized Counts (a.u.)**

- $6^\circ$, $T_H = 40$ keV
- $35^\circ$, $T_H = 25$ keV
- $40^\circ$, $T_H = 18$ keV
- $45^\circ$, $T_H = 11$ keV

**Temperature (keV)**

Most energetic X-Rays concentrate on angles near $0^\circ$ (Surface normal)
Wide variety of Kα peaks using different target materials

- **Molybdenum**
  - Target: Cu, θ=20.9°
  - $E_K = 7.92$ KeV
  - $E_K = 17.9$ KeV
  - $E_K = 20.5$ KeV

- **Copper**
  - Target: Cu, θ=20.9°
  - $E_K = 7.92$ KeV

- **Nickel**
  - Target: Ni, θ=20.9°
  - $E_K = 7.18$ KeV
  - $E_K = 8.53$ KeV

- **Zinc**
  - Target: Zn, θ=20.9°
  - $E_K = 7.18$ KeV
  - $E_K = 9.76$ KeV

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X-RAY SOURCE Stability

SEM Images

35.54µm

Target Stability

Target: Cu $\theta=16^\circ$

Counts (a.u.)

Energy (keV)

3.53 $10^{16}$ W/cm², D = 15.1 cm
3.59 $10^{16}$ W/cm², D = 15.1 cm

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New Target designs

- Several layers with microns - sub microns thickness
- Mixing materials with different $K_\alpha$ emissions
- Spectrums give information about penetration of $e^-$ in target

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Plasma self-emission

Ablation Plume

Ejected material shadowgraph

Refraction index

Number of e- in plasma
X-RAY SOURCE Imaging

- Laser-Plasma
- X-Ray Tube

Microtomography Station
- High Quality Imaging
- Target Characterization
- Phase Contrast Tomography
CONCLUSIONS

X-Ray Source

- Operating in air
- Target Material Study
- Energy-Angle Characterization
- First X-Ray Images
- First Plasma Images

Next Improvements

- Focusing System
- Complete X-Ray Source Characterization
- In vacuum development
- Shadowgraphy/ Interferometry Beam
- Development and characterization of new targets
# PEOPLE INVOLVED

### Authors:

- Lucía Martín, USC
- José Benlliure, USC
- Camilo Ruiz, USAL
- Dolores Cortina, USC
- Juan José Llerena, USC

### Collaborations:

- David González, USC
- Jesús Mosqueira, USC
- Manuel V. Ramallo, USC
- Daniel Sóñora, USC
- Guillermo Hernández, USAL
- Francisco Fernández, USAL
- José Manuel Udías, UCM
- Luis Mario Fraile, UCM
THANKS!
Laser-Plasma State of the art

Plasma frequency

$$\omega_p = \left( \frac{e^2 n_e}{\varepsilon_0 m_e} \right)^{1/2}$$