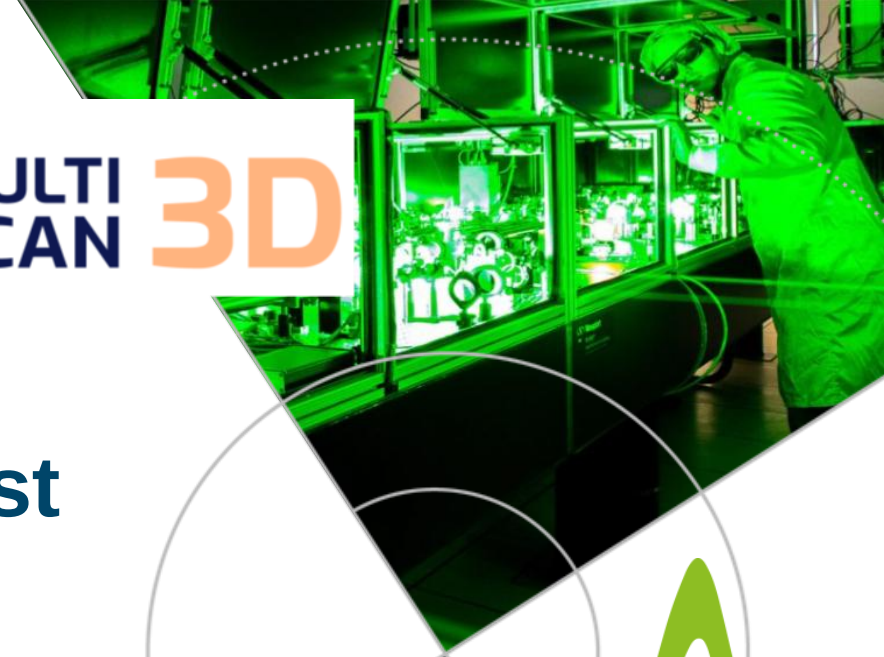

A compact portable X-Ray source for fast 3D tomography using Laser-Plasma Acceleration

Lena Kononenko
on behalf of LOA team and Multiscan3D collaboration

LOA/Ecole Polytechnique/CNRS (Palaiseau, France)

loa.ensta-paris.fr

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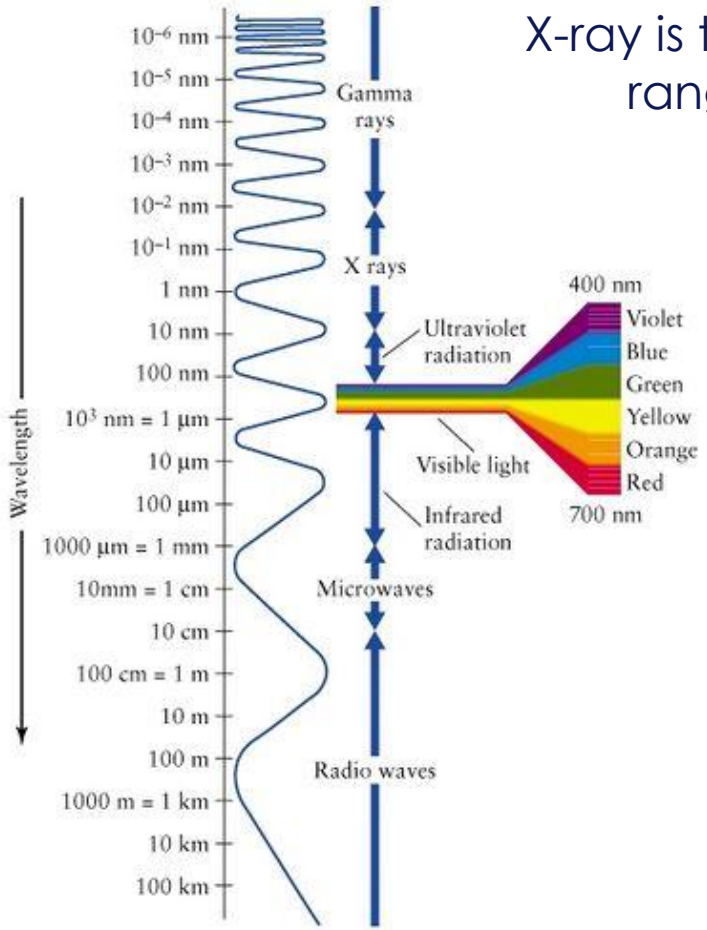
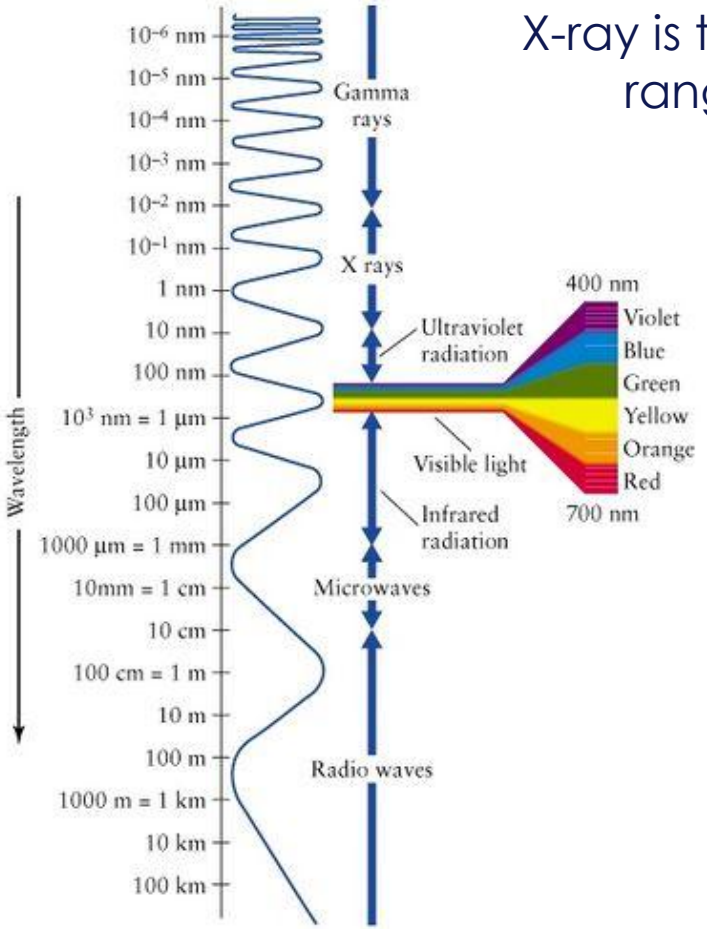
1 – LOA/Ecole Polytechnique/CNRS (Palaiseau, France)
2 - Smith Detections (Vitry, France)
3 – Thales MIS (Velizy, France)
4 – Amplitude-laser (Evry, France)

X-ray imaging and tomography



X-ray is the type of radiation emitted in a form of a photon with wavelength in the range of approximately 10 nm to 10 pm (100s eV – 100s keV respectively)

X-ray imaging and tomography



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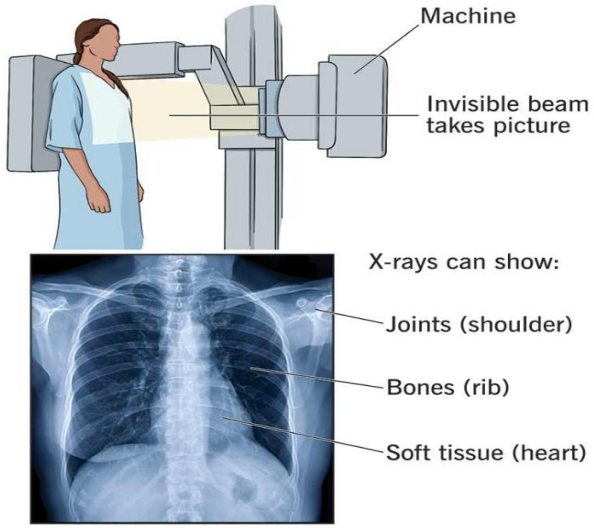
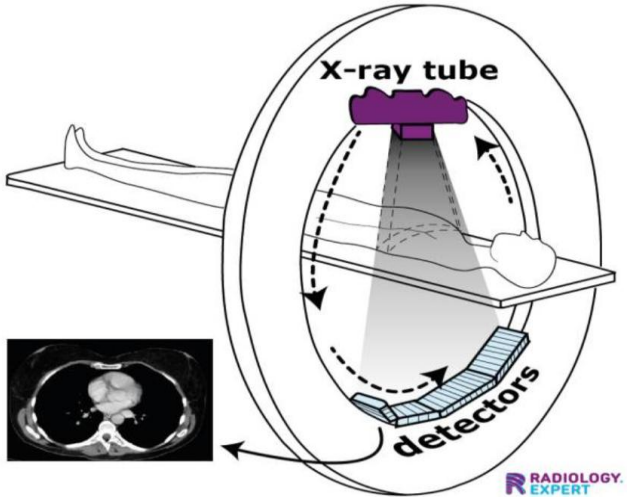


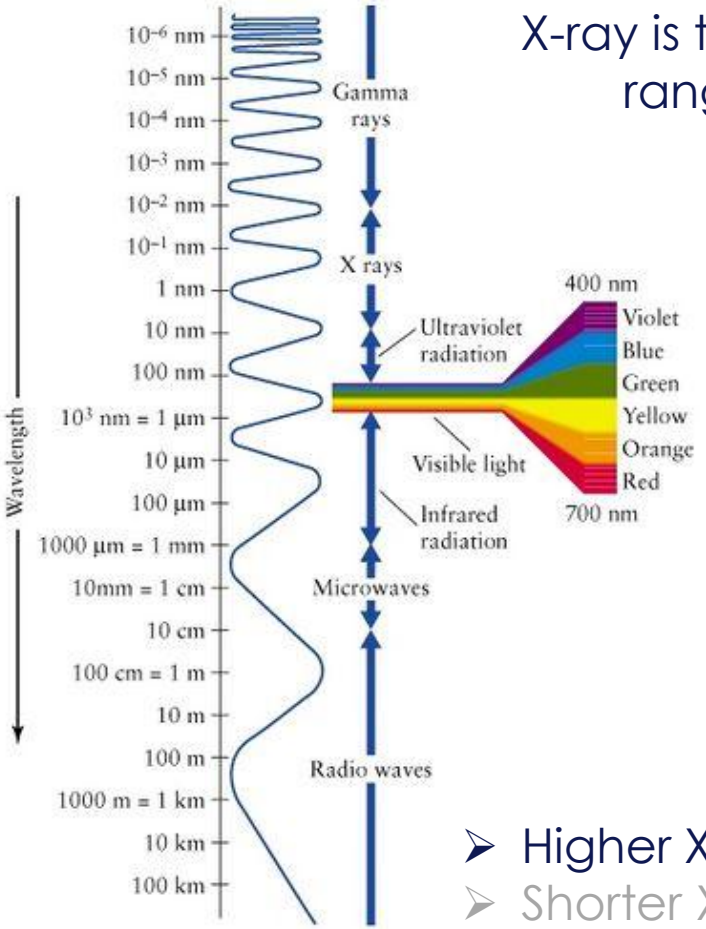
One point of view for 1D/2D image

X-ray computed tomography (CT)



Multiple points of view to reconstruct 3D

X-ray imaging and tomography



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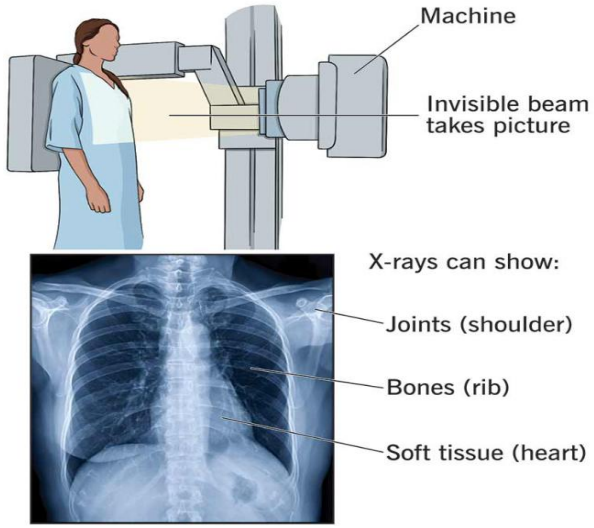
X-ray imaging



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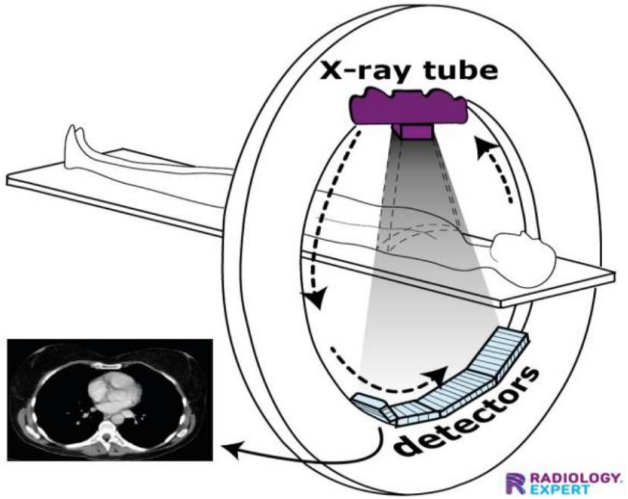
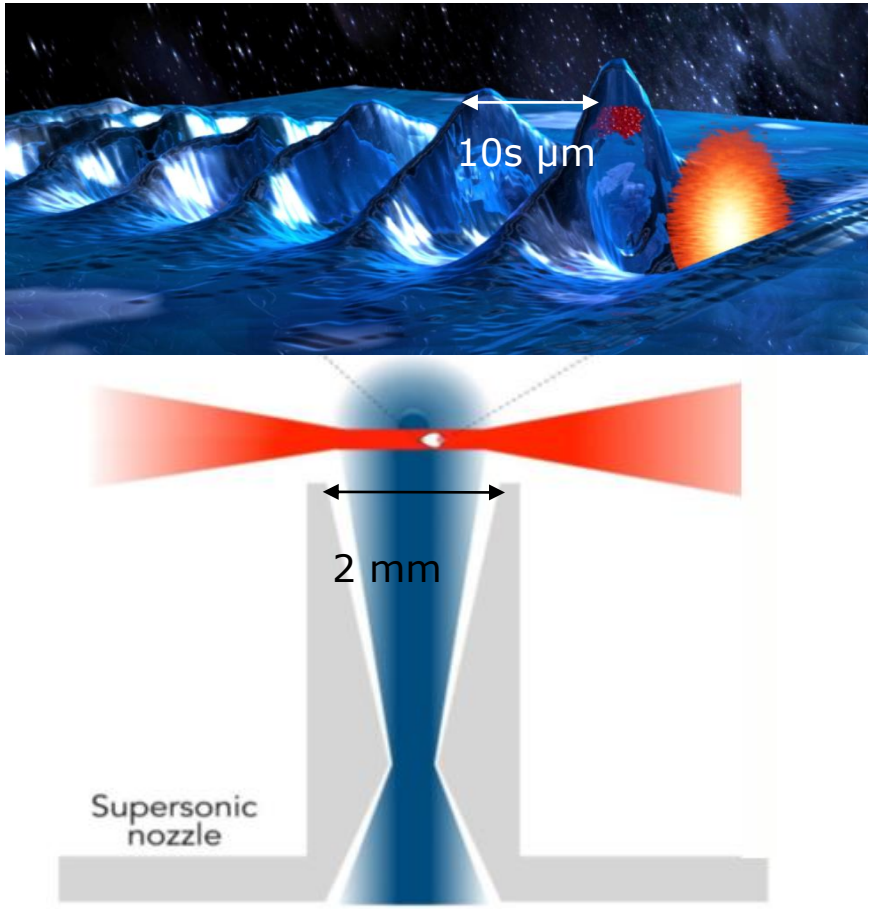


Multiple points of view to reconstruct 3D

- Higher X-ray energy – deeper penetration – thicker/denser objects can be tested
- Shorter X-ray beam – faster processes can be studied
- Smaller source size – higher resolution (better precision)of studied object
- Higher X-ray flux – shorter exposure time
- **More compact source – access to a complicated locations**

Laser-plasma wakefield acceleration as an X-ray source

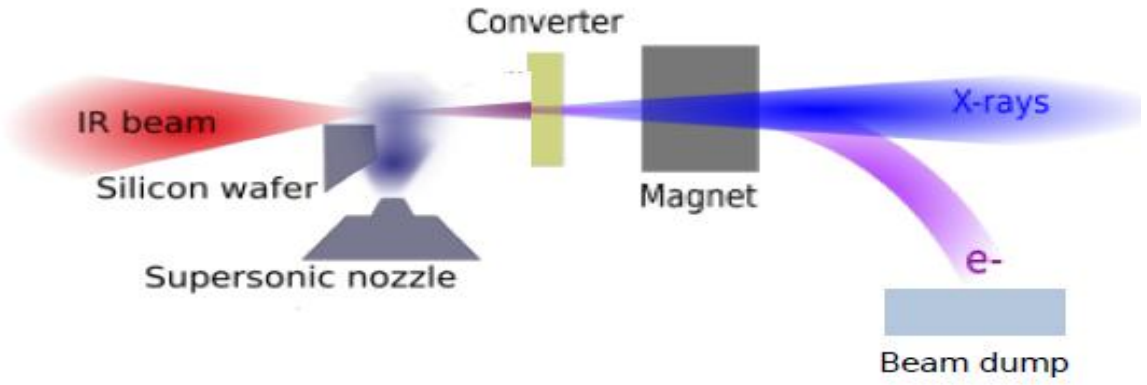
Space-charge distribution in under-critical plasma (blue), formed by intense laser (white-red)



Electron acceleration in plasma wakefield

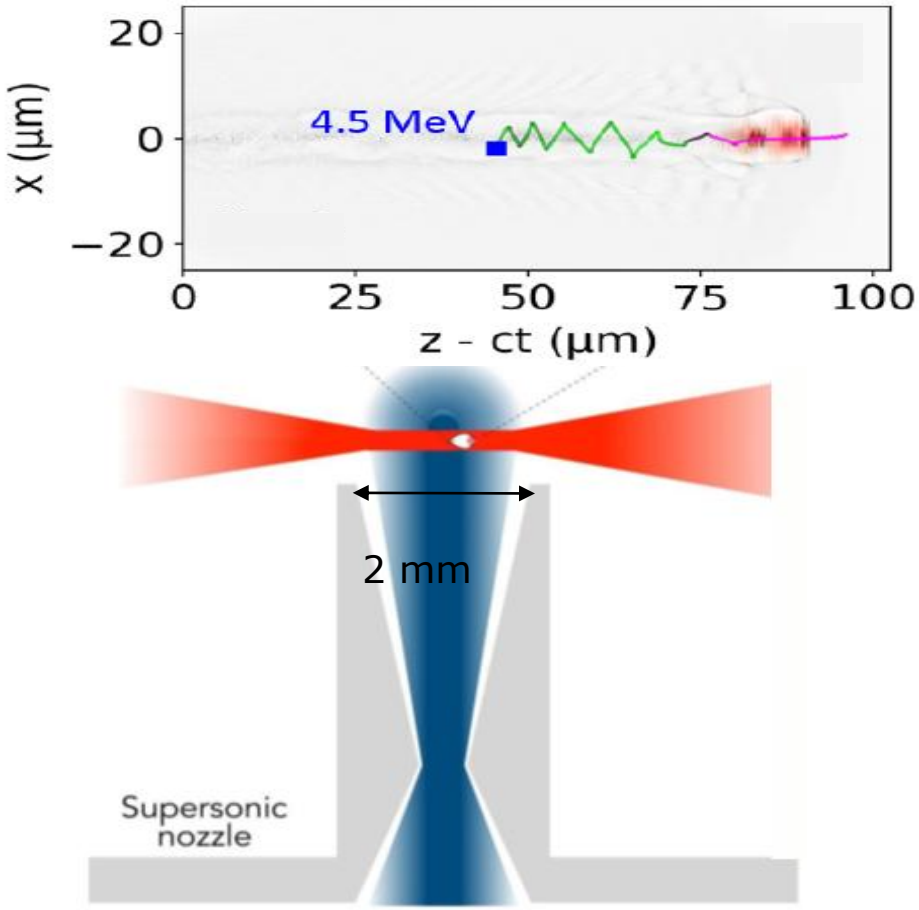
- *Powerful (10s-100s TW peak-power) ultrashort (10s fs) laser focused on a gas target*
- *We use supersonic gas nozzles emitting light gases in pulsed regime inside of a vacuum chamber*
- *laser pulse ionizes the gas along propagation axis and creates space-charge distribution of accelerating cavity*

Bremsstrahlung X-ray generation



Laser-plasma ponderomotive acceleration as an X-ray source

Space-charge distribution in under-critical plasma (gray), formed by intense laser (red)



Electron acceleration by ponderomotive force

- *Due to high density longitudinal structure of wakefield is mostly destroyed and electrons are pushed directly by ponderomotive force*
- *Transverse force maintain channel in plasma, preventing electrons from escaping*
- *Small part of electrons may still get energy from wakefields or by direct laser acceleration and gain higher energies*

L. Martelli et al., Physics of high-charge laser-plasma accelerators for few-MeV applications, Phys. Rev. Applied (2025)

Multiscan 3D: laser – plasma based X-ray source for cargo scanning

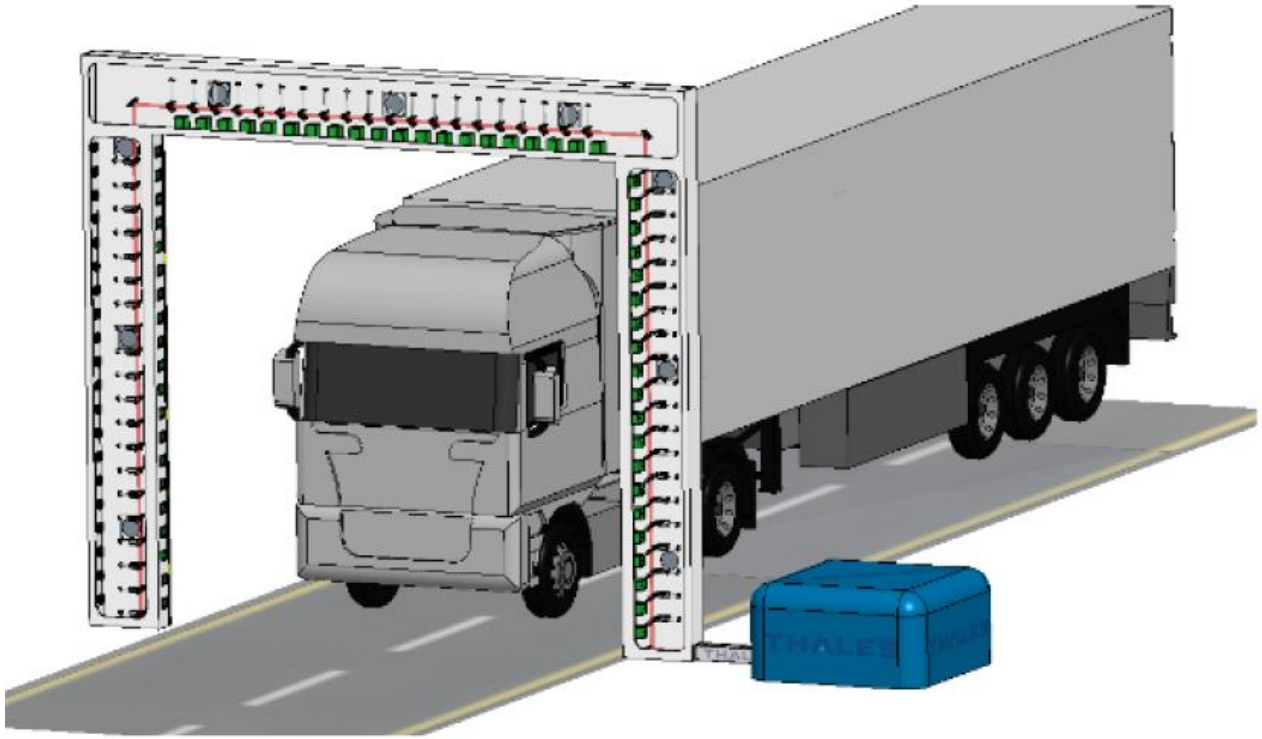
- One laser system delivers beam to multiple gas targets on the frame
- Each gas target generates electron beam
- Each electron beam converts to X-ray beam
- All X-ray beams from frame provides a detailed slice image
- As cargo moves along the frame, a 3D scan is performed

MULTI SCAN 3D

THALES MIS & OME

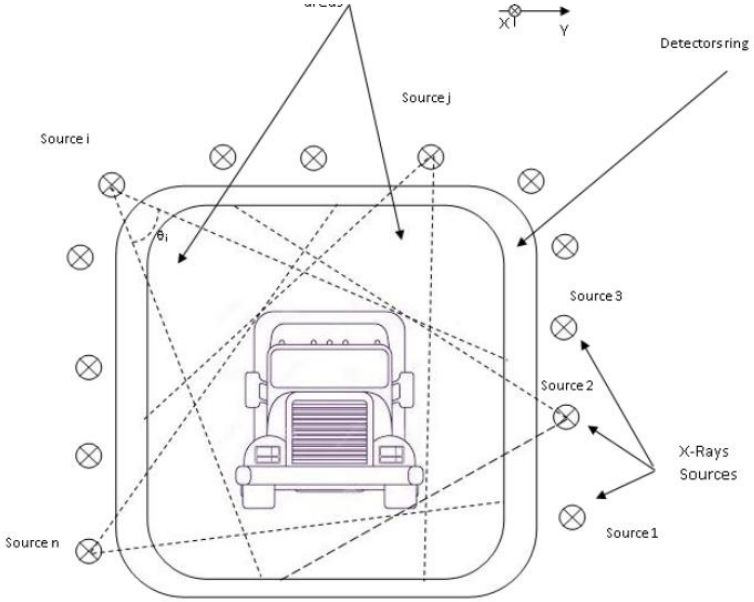
cea

smiths detection



Electron beam:

- Few nC
- < 10 MeV
- > 100 mrad



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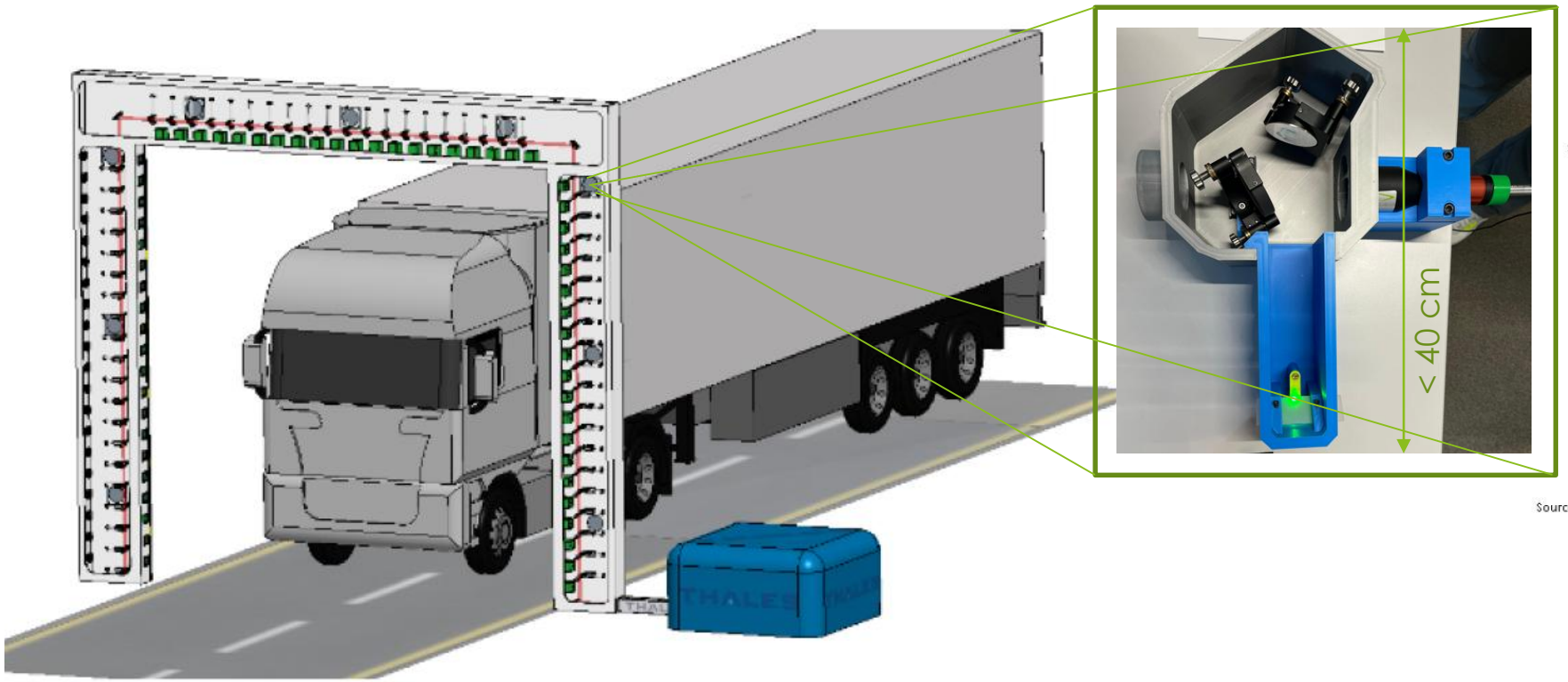
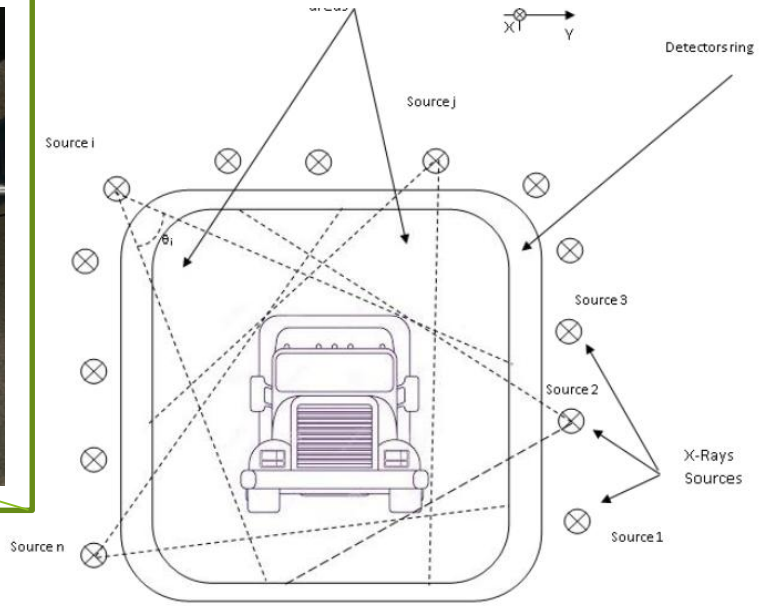
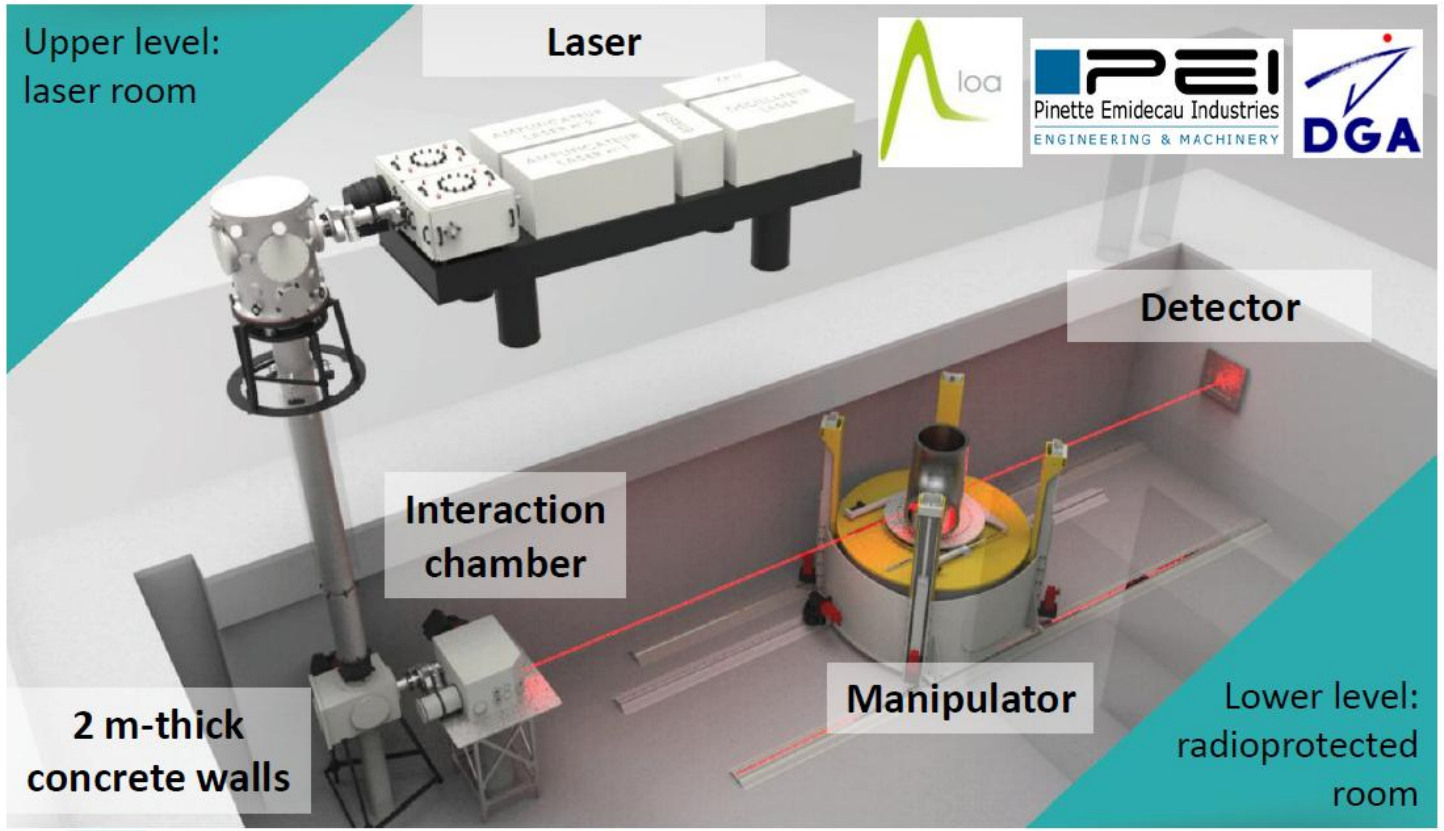




SHERIL platform

The SHERIL Demonstrator at LOA

Demonstrator goal: Proof of concept for commercialization of this platform from 2020



SourceLAB | Laser Plasma Technologies

7 TW, 45 fs, 1 (or 10 Hz) Ti:Sapphire

In-vacuum few meters transport line from compressor to interaction chamber

Large radioprotected area with 2m-thick concrete walls

Compact (610 mm x 750 mm) interaction chamber

Precise manipulator (down to 1° rotation and 1 mm vertical position) available at a distance from 1.5 m to 7 m from the electron source for load up to 1 t.

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The SHERIL Demonstrator at LOA

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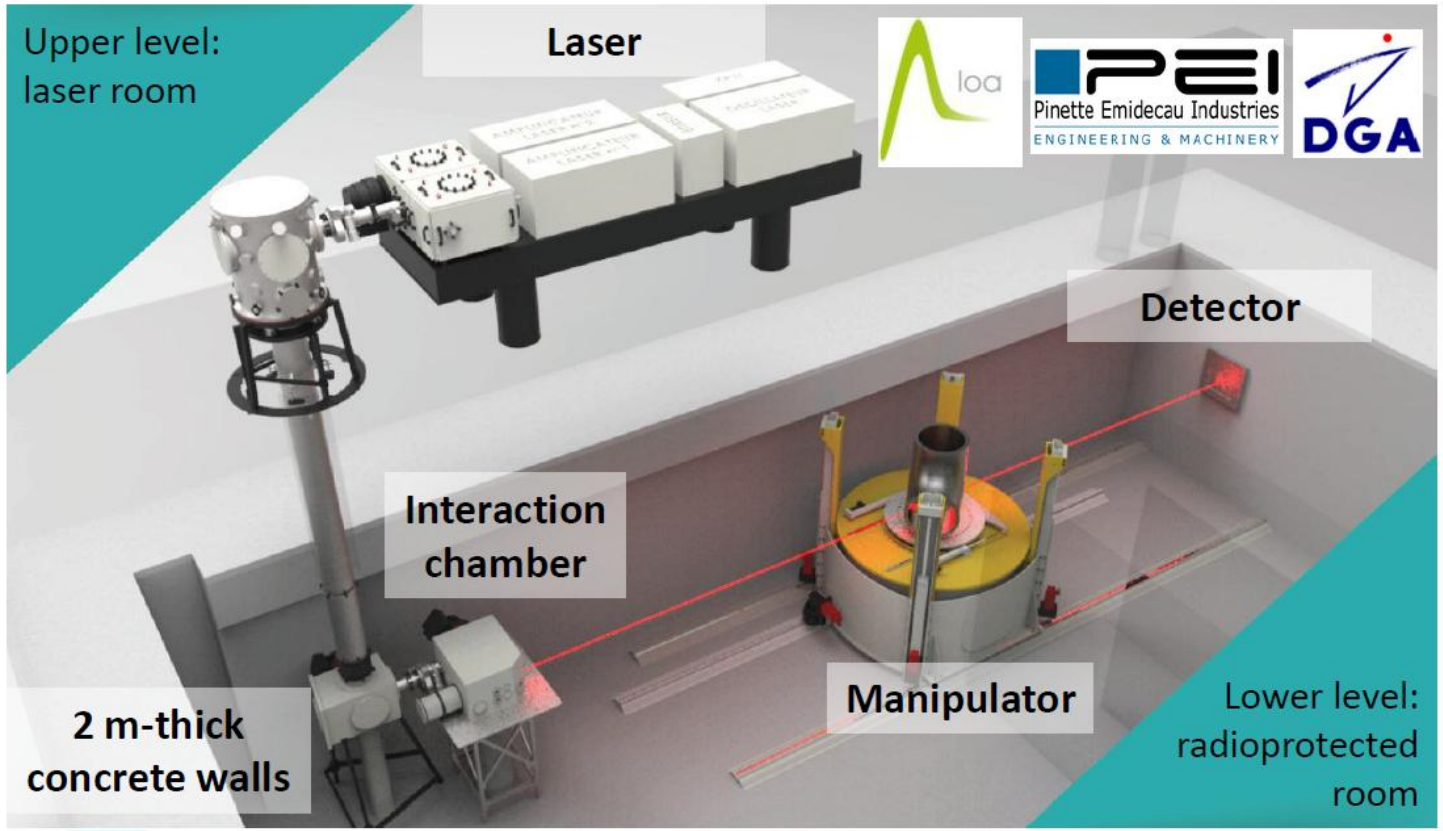
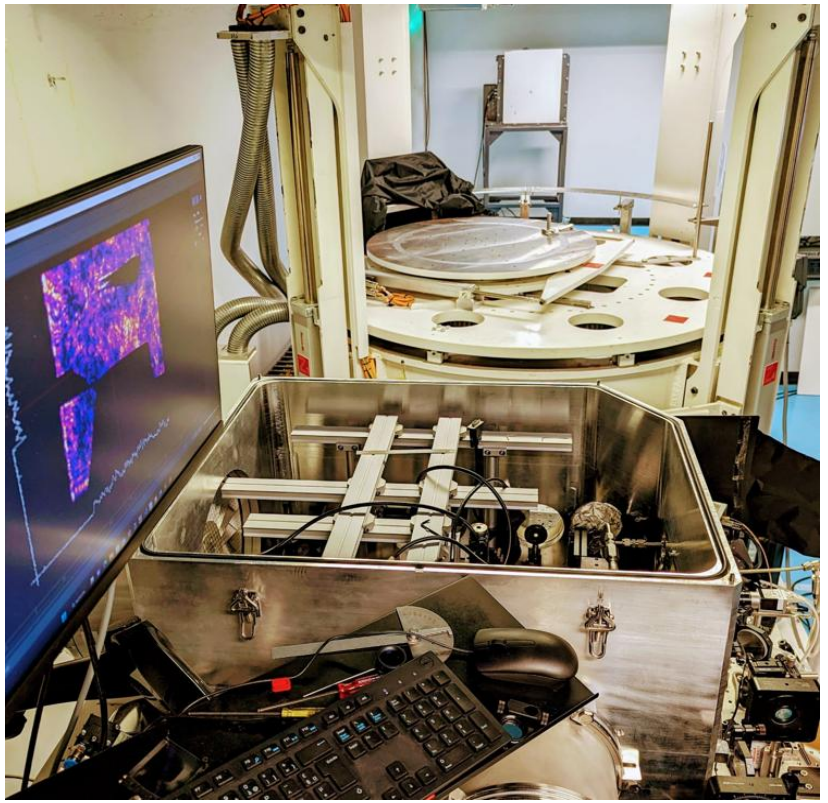


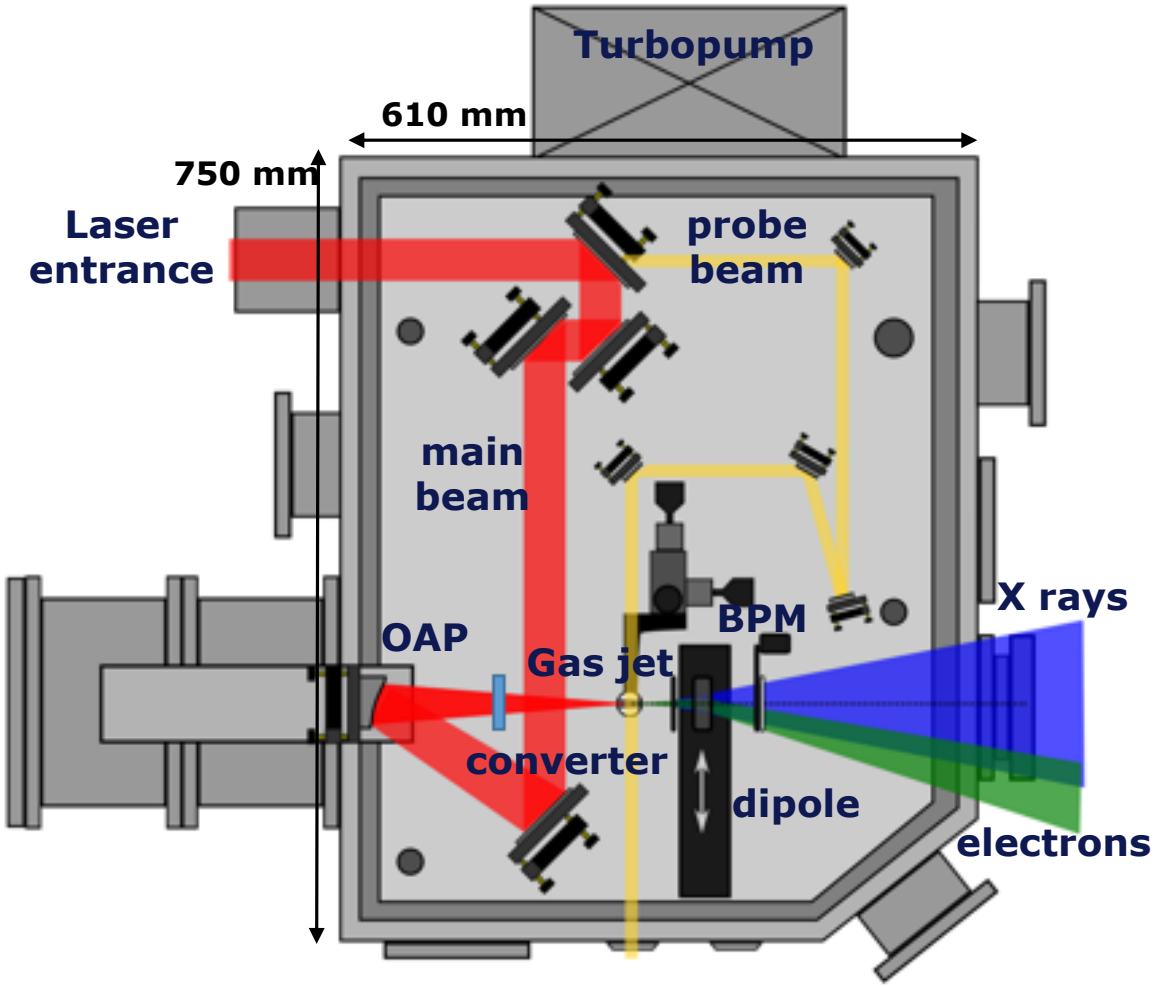
SourceLAB | Laser Plasma Technologies

Photo from above interaction chamber



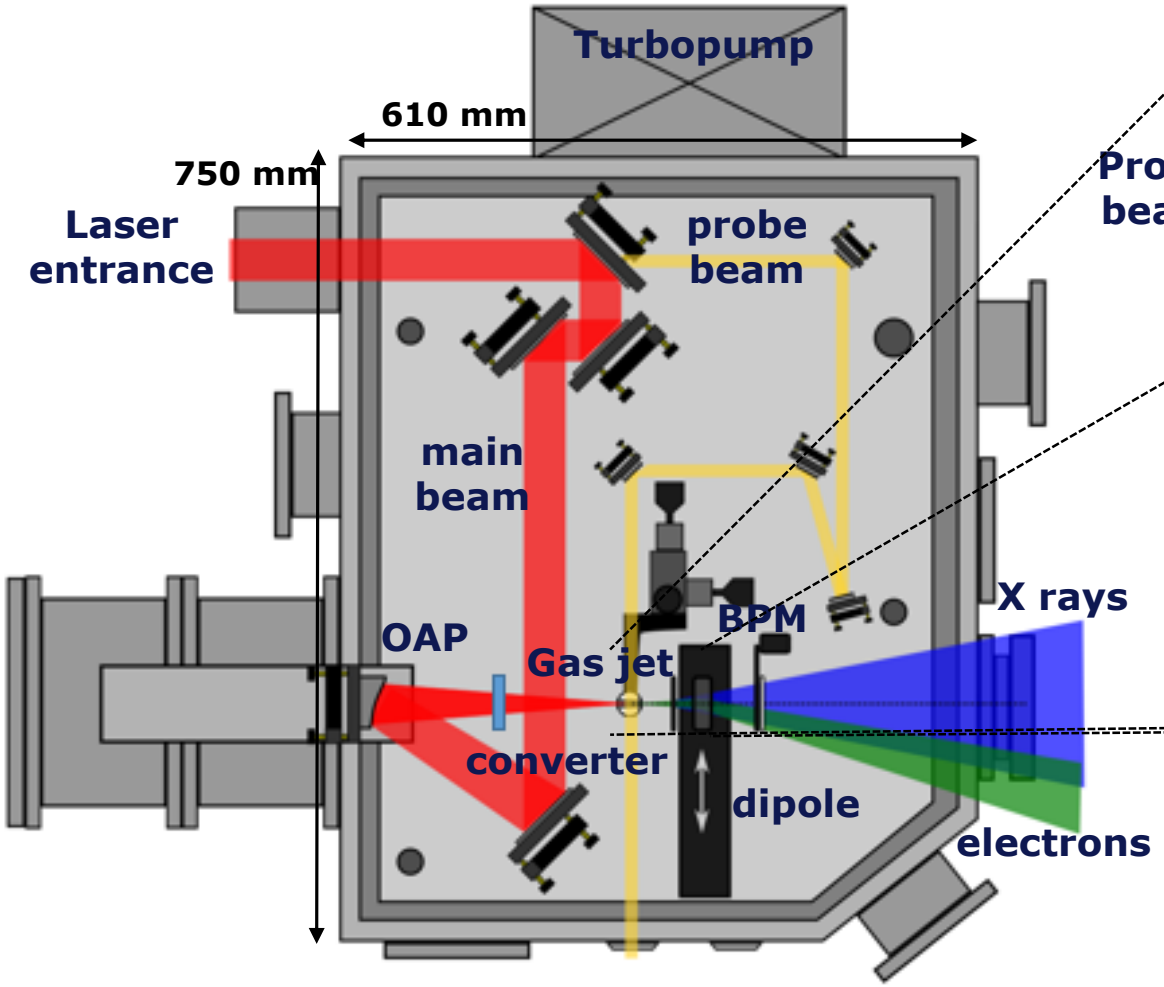
Interaction chamber setup in Salle Radioprotection

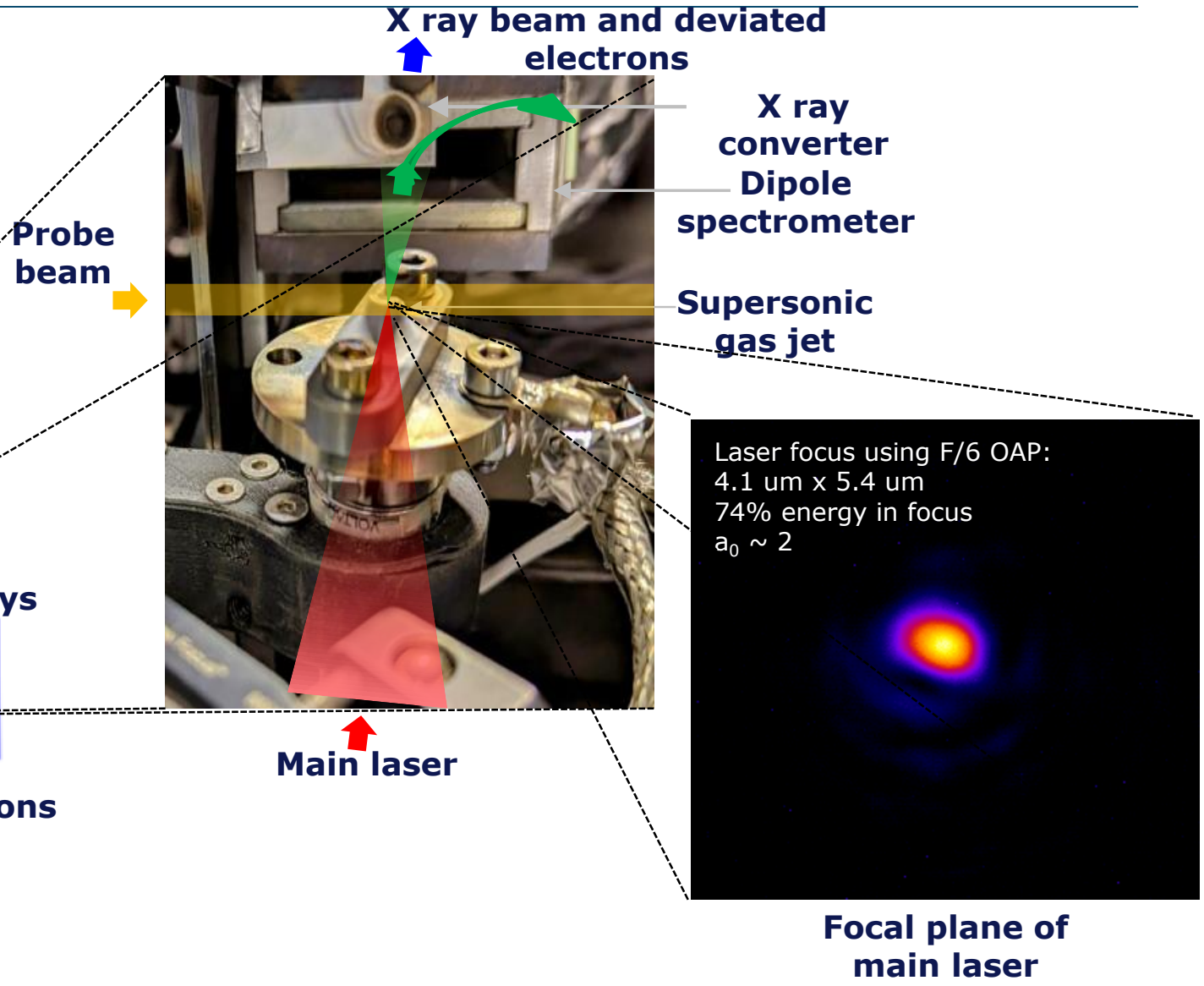
Interaction chamber setup



Interaction chamber setup: target area

Interaction chamber setup

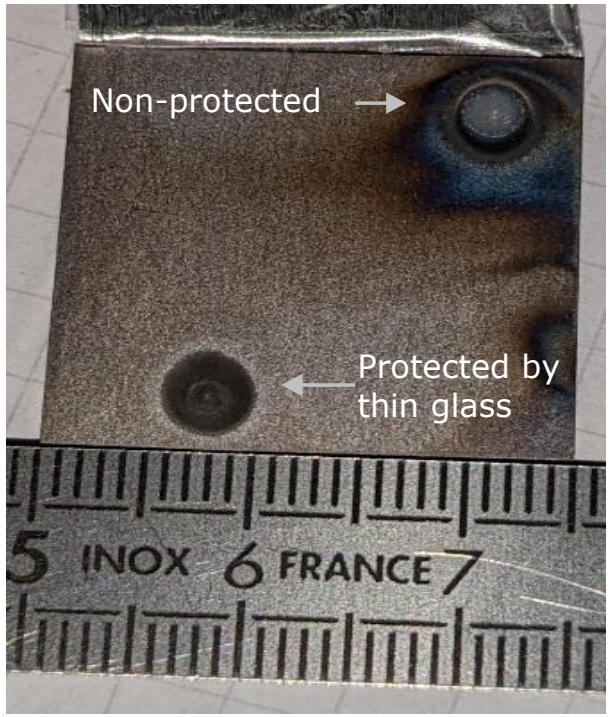


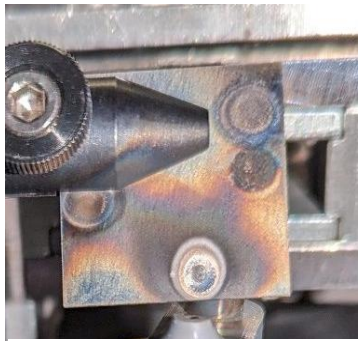


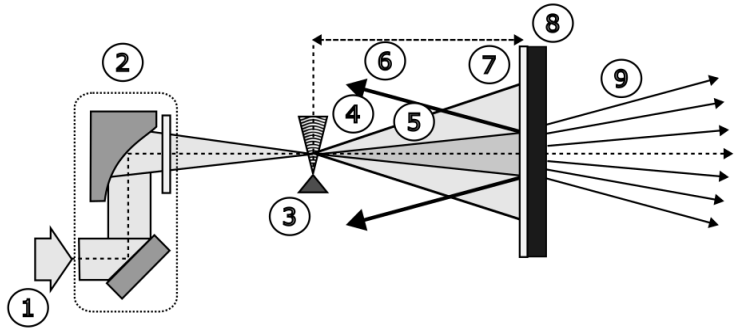
n° dépôt : FR2503843
n° dépôt : FR2503843

X-ray converter and optics protection

- 0.7 mm Tungstan plate
- 7 mm from gas target
- Tilted 40 deg. wrt beam axis







Patent submitted with THALES (No. deposition FR2503843)

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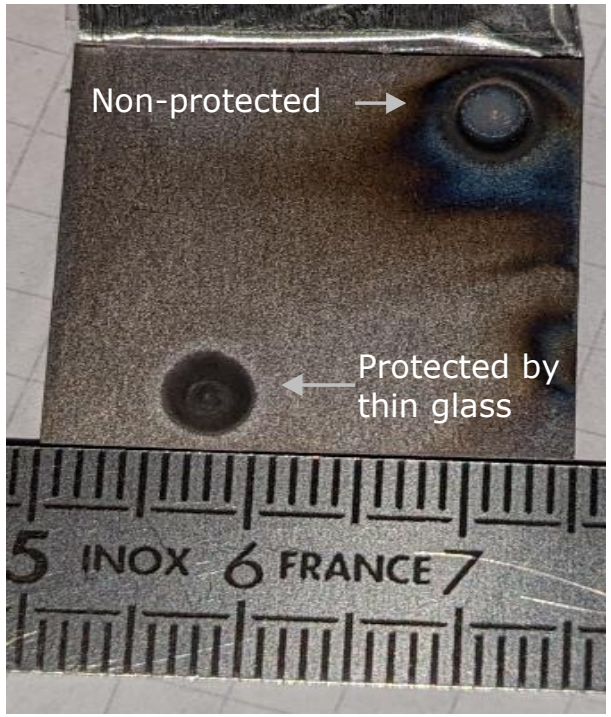

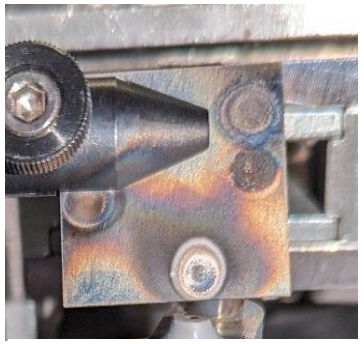

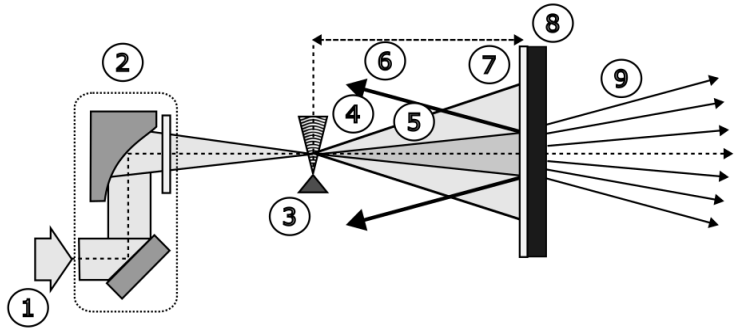

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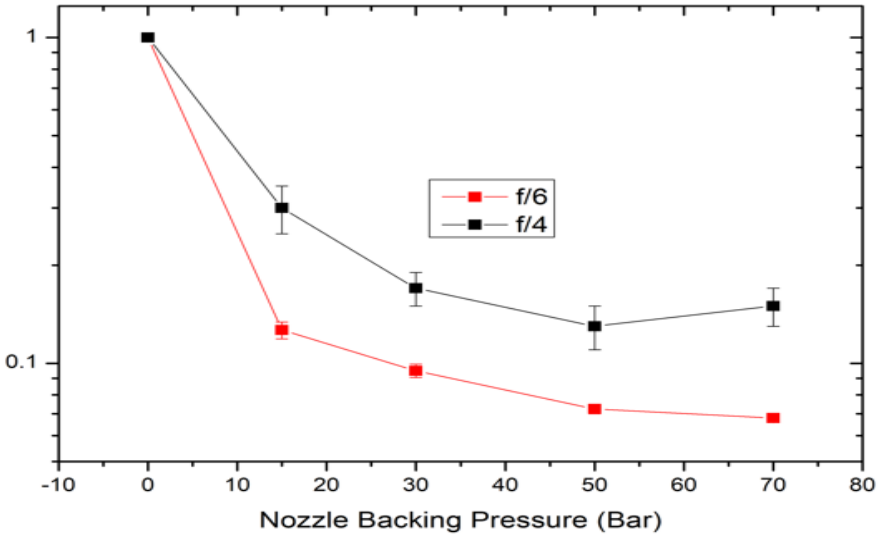
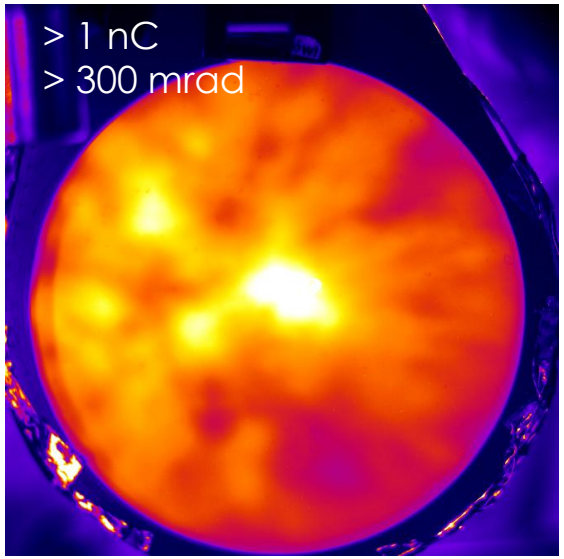
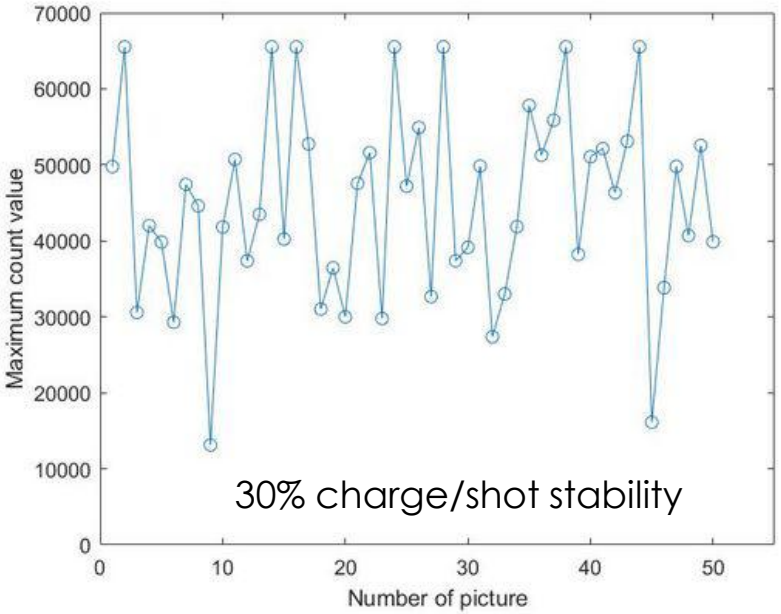


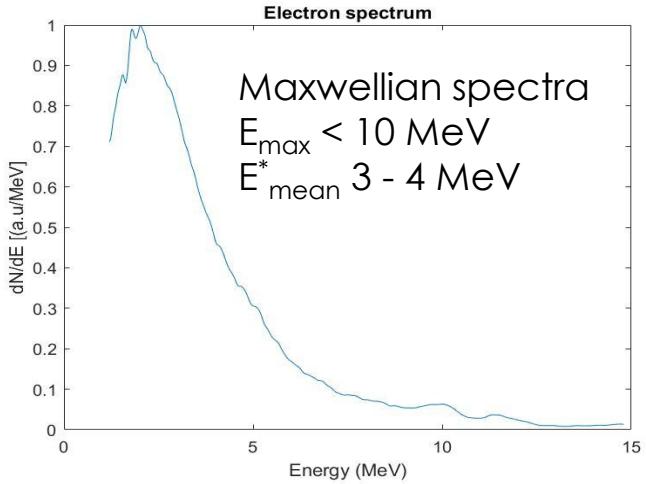
Use of this two approach allowed to reduce the distance between gas target and converter and to increase the number of shots per position of converter without degrading the X-ray beam

X- rays source characterisation

Beam Profile Monitor







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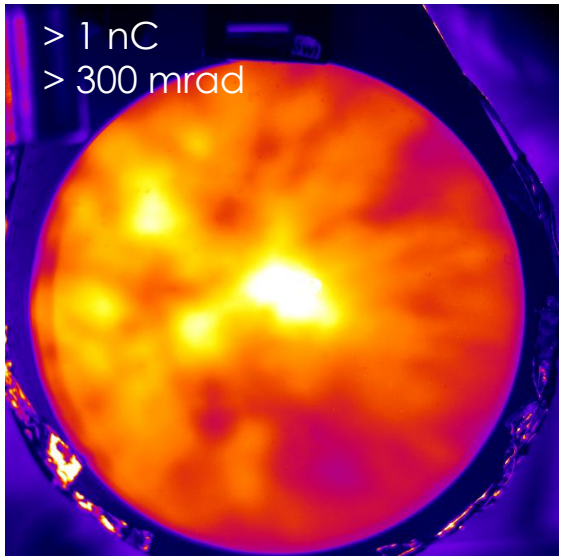
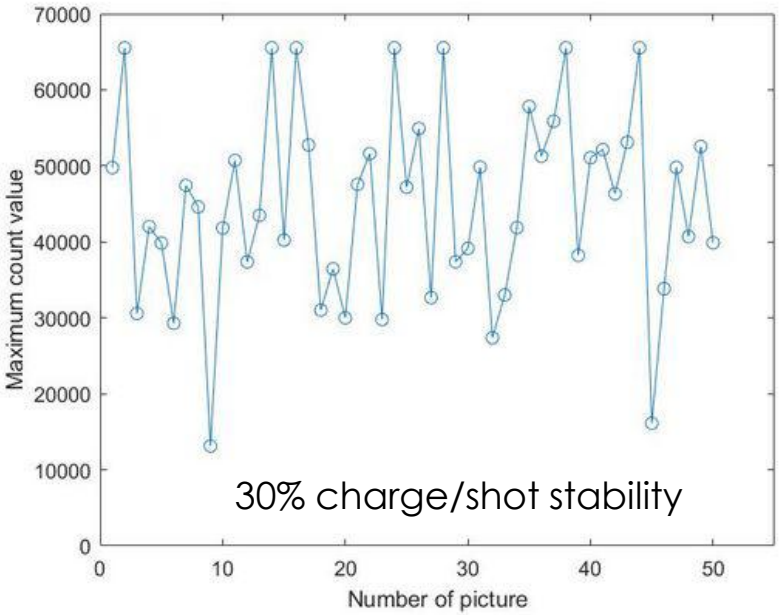
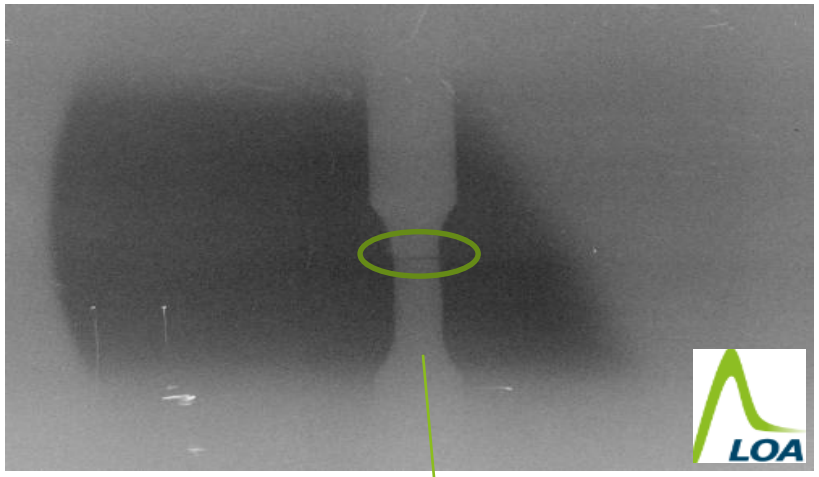
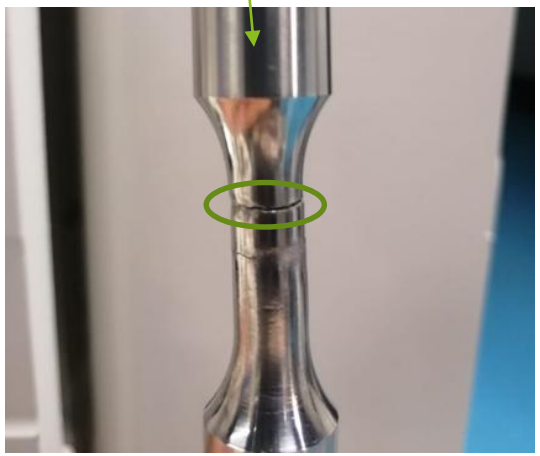
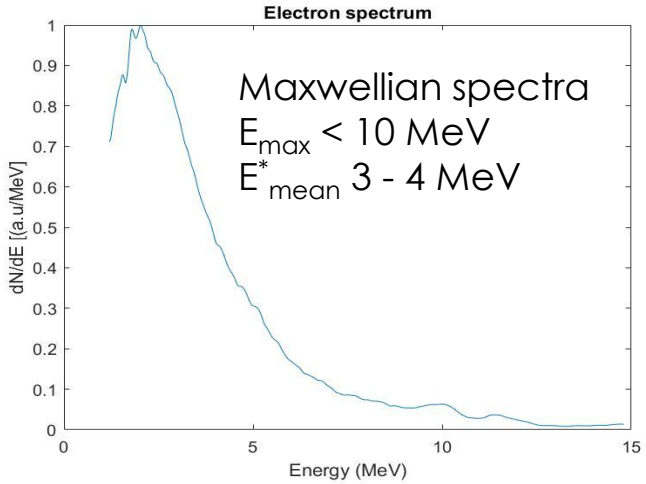




X-rays from 0.7 mm W at 5 mm from target (average of 500 shots)







- 2-3 mm source size
- >300 mrad divergence
- dominated by low energies (< 100 keV)
- Maximum energy > 1 MeV
- > 25 µGy/shot at 60 cm from source

3D Tomography using sensor from smiths detection

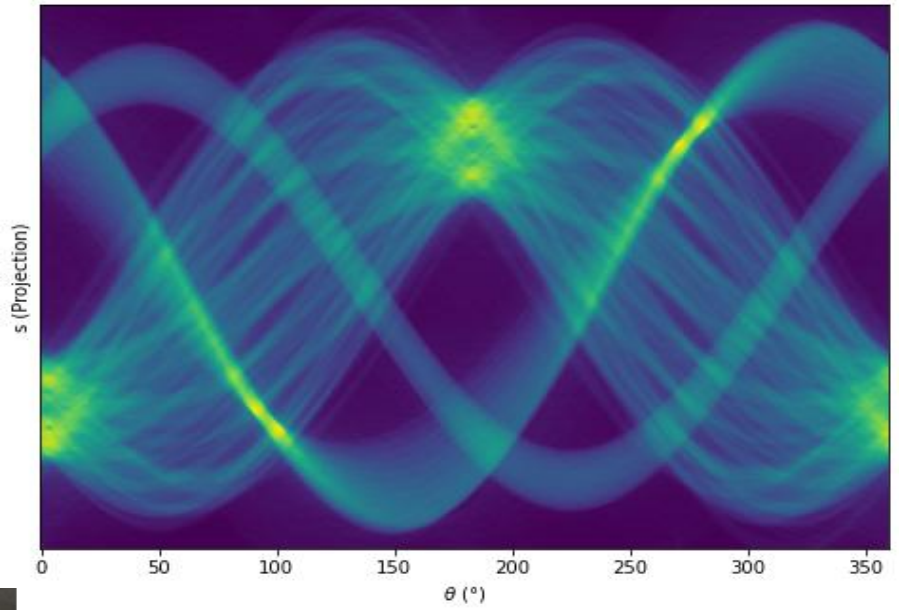
photo

- *Pixelated scintillator*
- *120 lines, 12 row, 48 cm*
- *Distance from source to detector 3.5m*
- *1 Hz, 300 mJ on target*
- *1mm converter 5 mm from electron source*

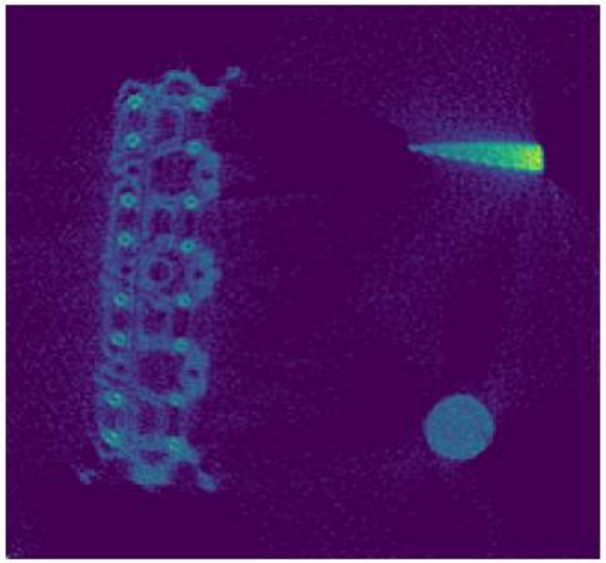
3D Tomography using sensor from smiths detection

photo

sinogram



reconstruction



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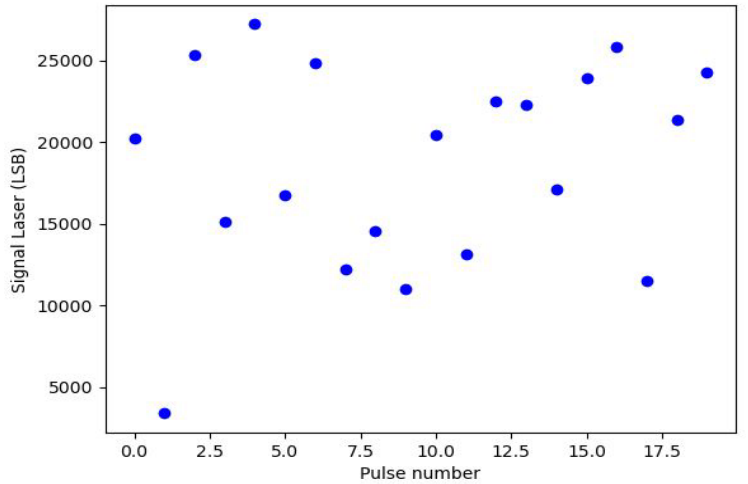

Transportable LPA source with ENSTAMobile laser

- *3 TW Ti:Sapphire, 50 fs , 10 Hz*
- *3.3 m (L) x 1.4* m (W) x 1.8 m (H)*
- *1.3 tones, transportable by forklift*
- *SHERIL interaction chamber: 61 cm x 75 cm*
- *< 3 days installation time (including laser stabilization 24h)*

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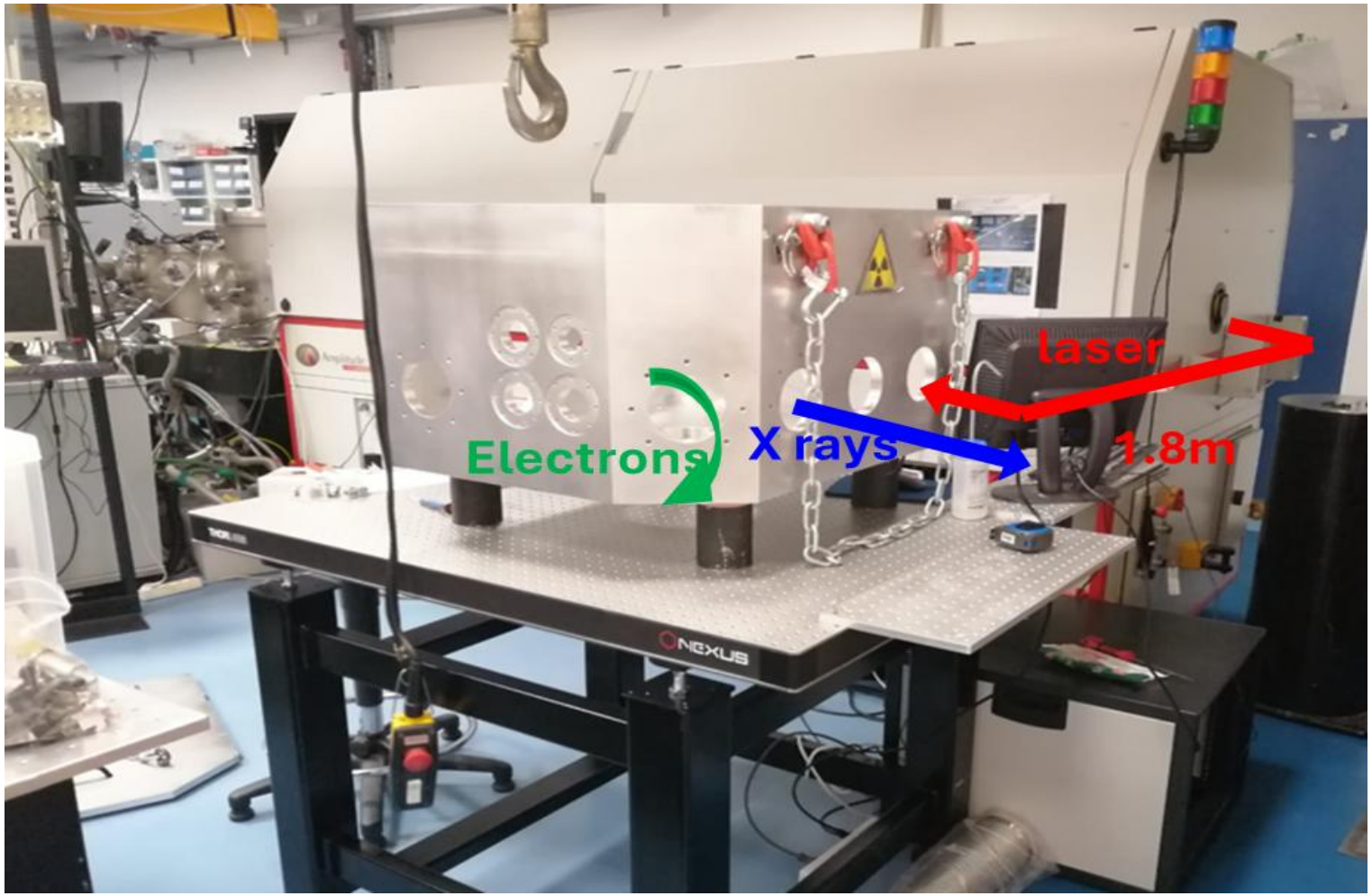
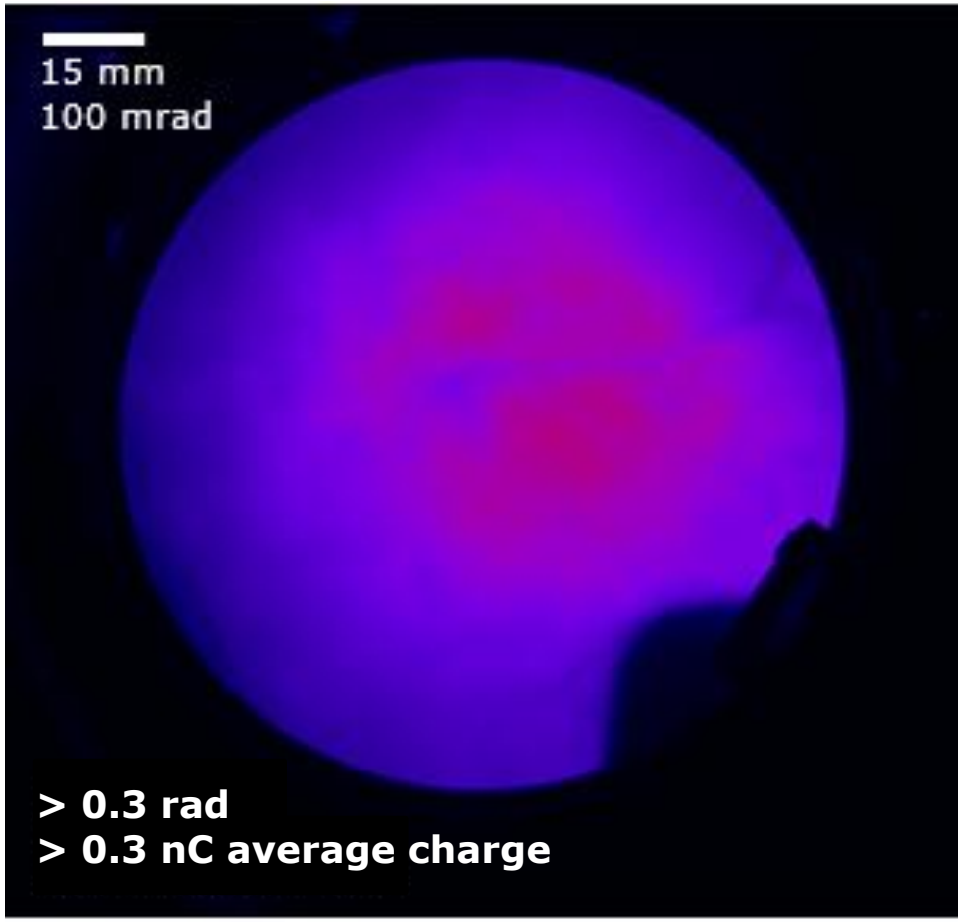
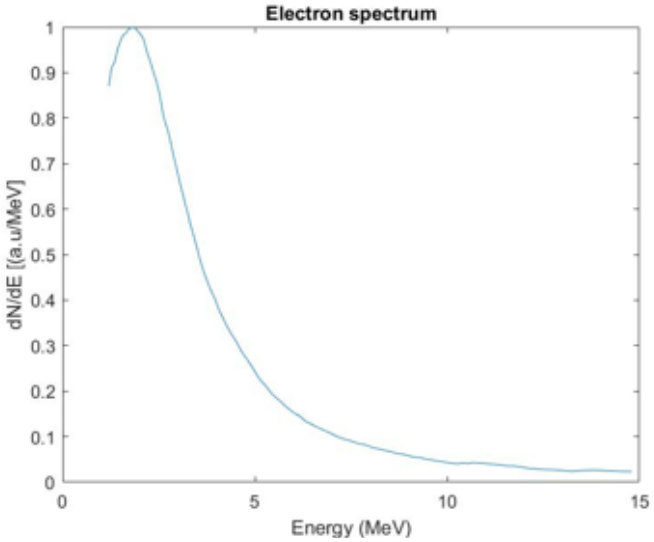
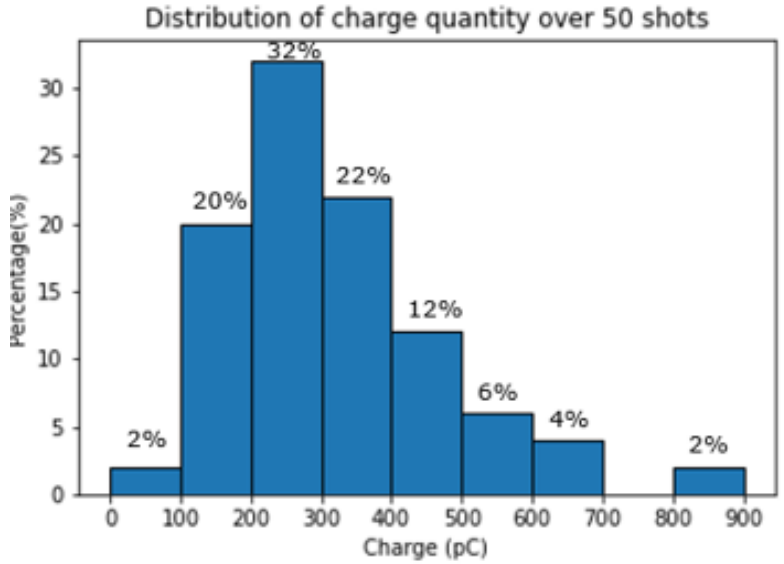


Electron source using ENSTAMOBILE laser



Laser beam on target





Electron energy :

$E_{mean} = 3.8\ MeV$

Same as with SHERIL laser

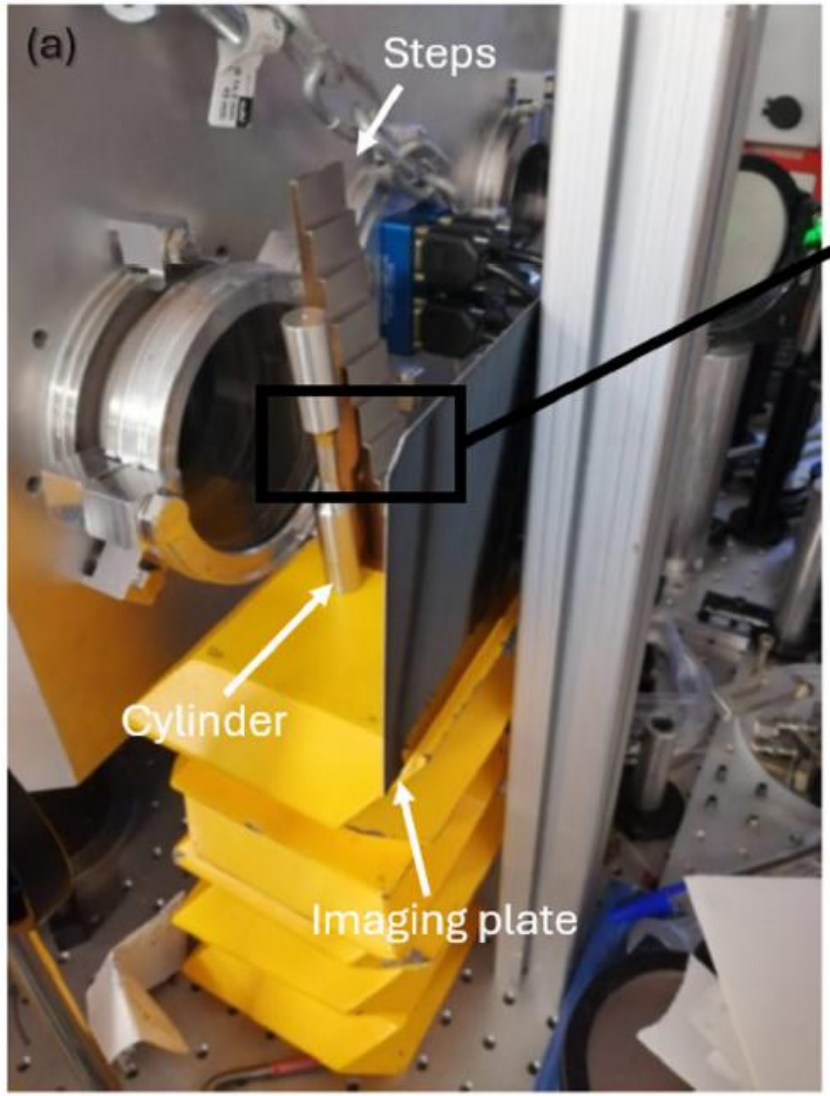
Charge:

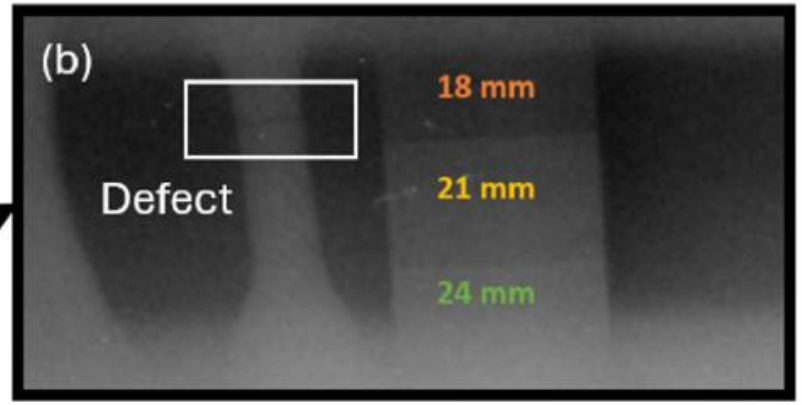
$C_{mean} = 320\ pC$

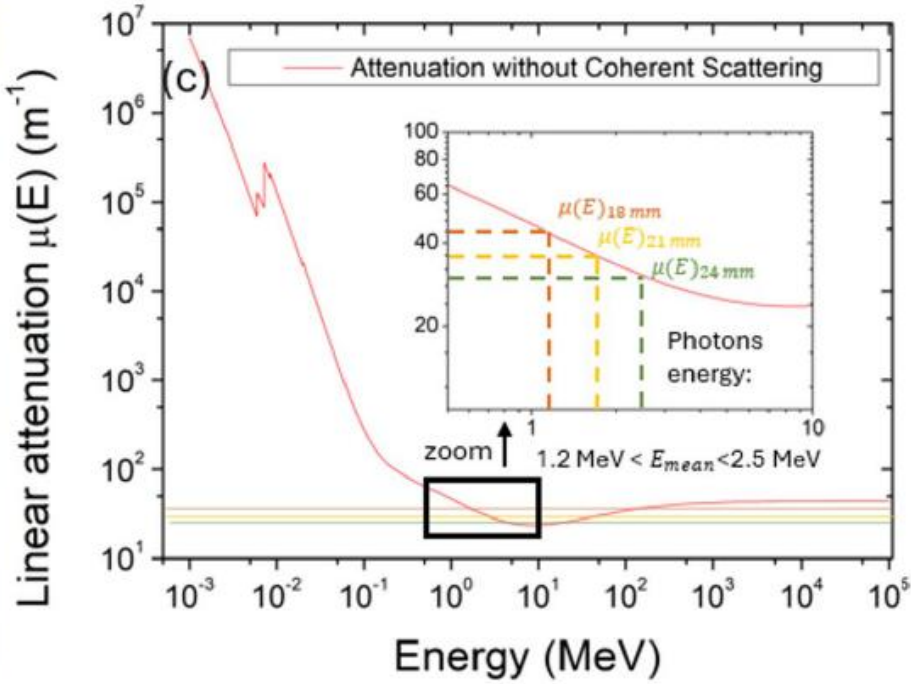
5 times lower charge per shot
-> 2 times higher per second!

2mm nozzle, shock, 50 bar of N_2, no shock, f/4, 10 Hz

Conversion to X rays using electrons from ENSTAMOBILE laser







1 mm W converter with 0.5 mm protection glass, 5 mm distance from electron source

Cylinder with default and stainless steel step-wedge 43 cm from converter. Imaging plate 8 cm behind the objects. 1000 shots

Unfortunately, charge fluctuations were too high for "field tests", but this experiment was a first demonstration of a transportable X-ray source

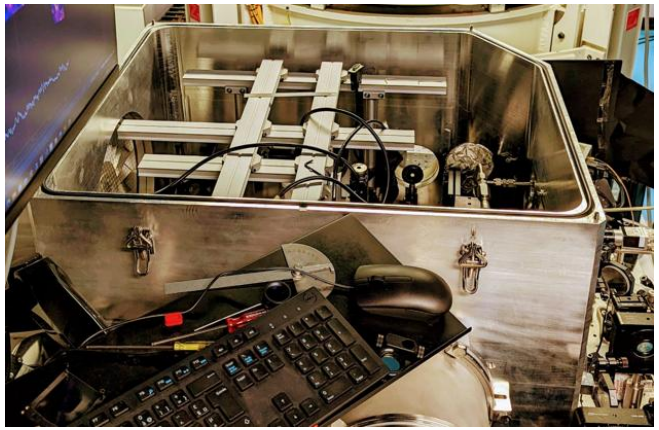
E. Morel, O. Kononenko et al., Sci. rep. 15 29008 (august 2025)

A transportable laser-plasma accelerator in the MeV range

Erwan Morel[1,4], Olena Kononenko[1,4], Jonathan Wheeler[1], Achraf Ayeb[1], Pascal Rousseau[1], Magali Lozano[1], Amar Tafzi[1], Lorenzo Martelli[1,2], Yves-Bernard André[1], Sara Rushe Palacios[1], Xuan Quyen Dinh[2], Jean-Philippe Denis[2], Henri Kraft[2], Philippe Demengeot[3], Aurélien Houard[1] & Cedric Thaury[1]

Summary

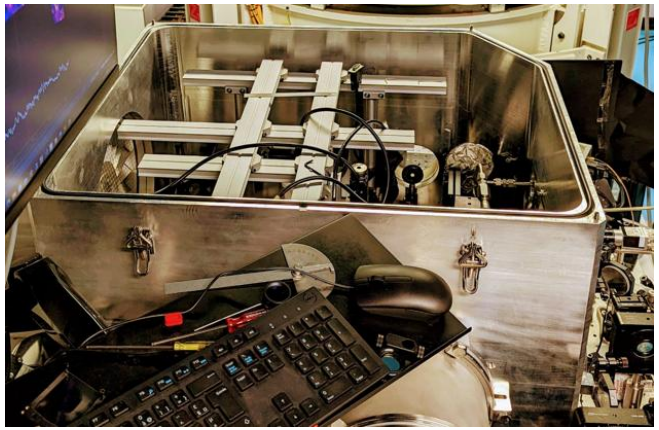
Tabletop laser system & ~m^3 X-ray source



Summary

"Camping-trailer" laser & "handbag" X-ray source

~~Tabletop laser system & ~m^3 X-ray source~~



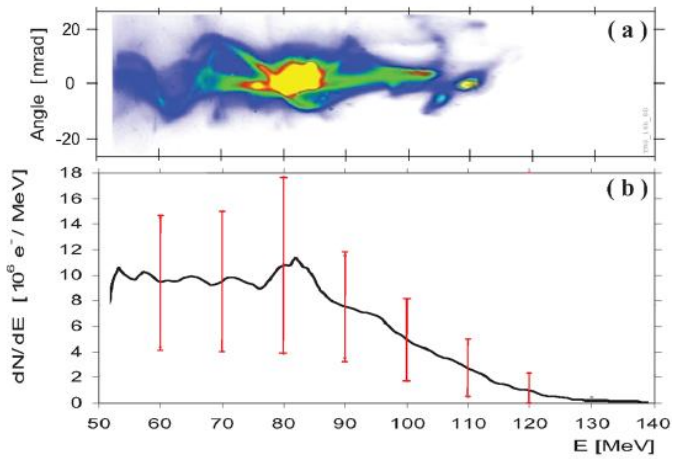
Summary

- Large variety of possible applications for table-top LPA (including low energy, high divergence beams)
- Strong potential for a LPA-based X-ray sources for 3D cargo-scan (Multiscan3D)
- First demonstration of transportable LPA-based MeV X-ray source.

Thank you for the attention!

X-ray source at Salle Jaune, LOA (60 TW 27 fs laser)

2005: Spectra and angular profile of electron beam

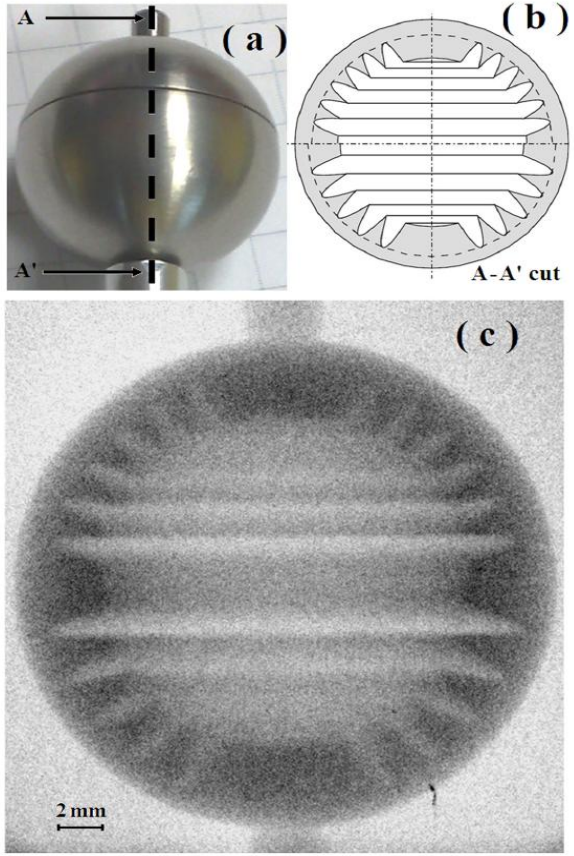


Generated inside High-Z solid converter
X-ray beam with 30 µm source size

Y. Glinec *et al.* Phys. Rev. Lett. 94, 025003 2005

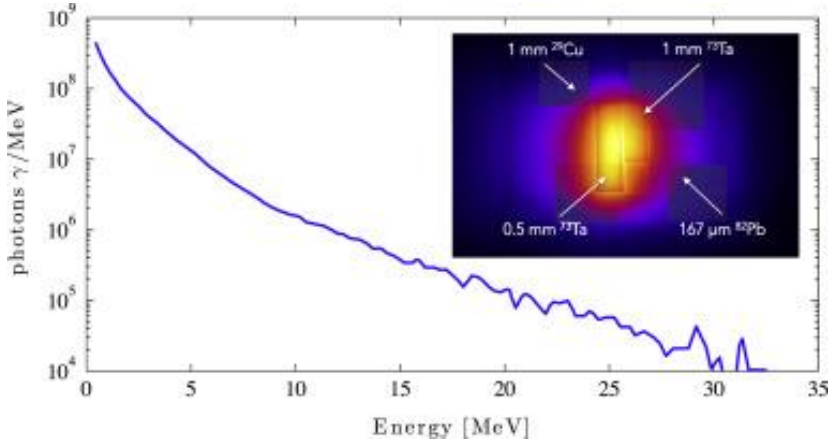
Table-top system*

2011: X-ray radiogramme of 20 mm tungsten ball

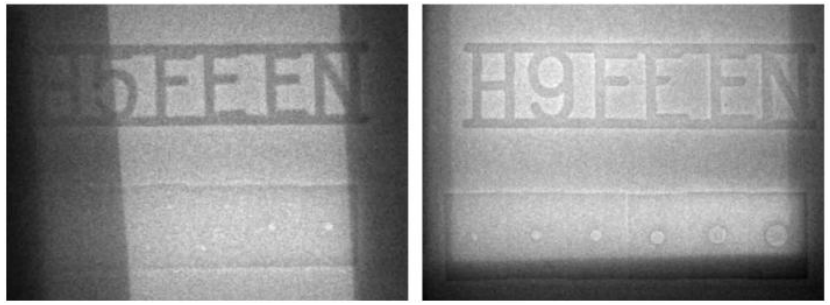


A. Ben-Ismaïl et al., Appl. Phy. Letters 2011

2016: X-ray spectra from 0.5 mm tantalum converter 2 mm from electron source exit



X-ray image with 200 um resolution

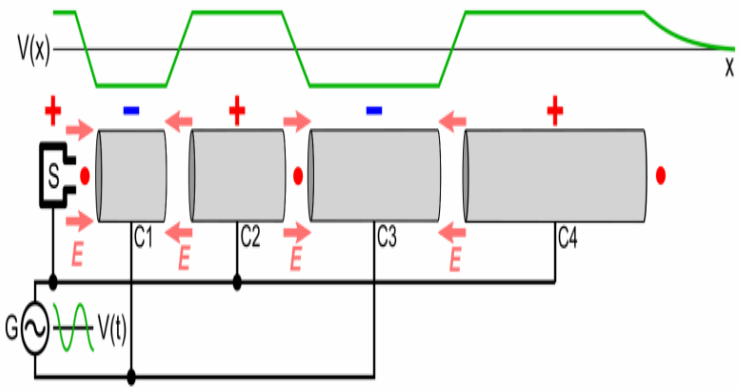


A. Döpp *et al.* NIMA 830, 515–519 2016

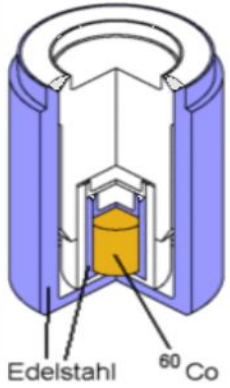
LPA vs."classic" X-ray sources

- Usually X-rays are emitted during brake movement of electron in a nucleus field – Bremsstrahlung
- Sometimes gamma-rays emitted by the radioactive nucleus can be considered as X-rays (Co60)

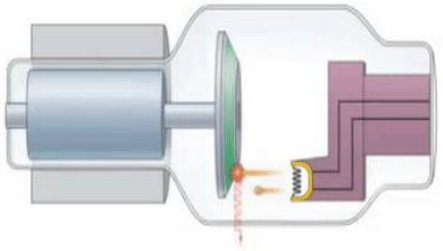
RF accelerator, followed by Bremsstrahlung target



Cobalt 60 radioactive source



X-ray tube

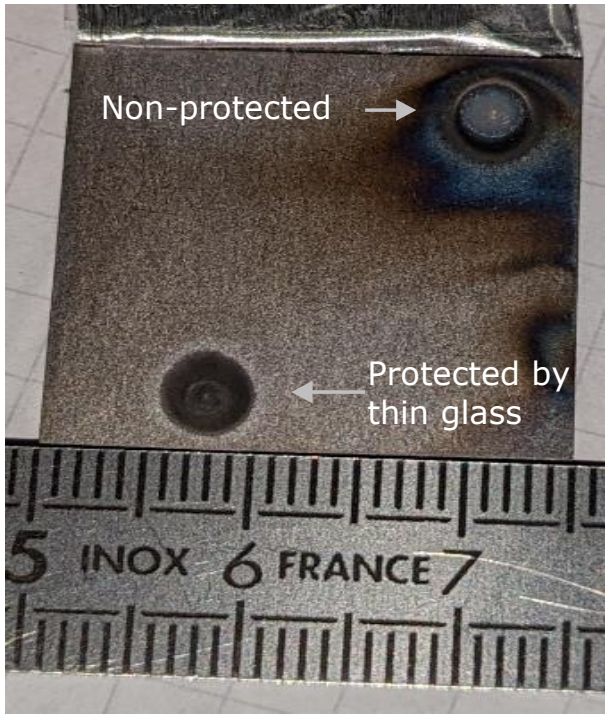


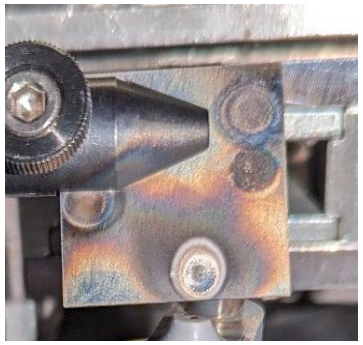
Sources X	Laser-plasma SHERIL	Accélérateurs linéaires	Gammagraphes cobalt 60	Tubes radiogènes
Energie	1 - 20 MeV Ajustable continument	3 - 15 MeV Non ajustable	1.15 et 1.33 MeV Non ajustable	450 ou 600 keV Ajustable
Temps de pose (pour 200 mm d'acier)	< Minute	Minutes	Plusieurs heures	Impossible
Débit de dose à 1m	20 Gy/min	10 Gy/min	< 0.1 Gy/min	< 1 Gy/min
Taille de la source	≈ 50 µm	> 2 mm	3 à 5 mm	< 50 µm
Source radioactive	Non	Non	Oui	Non
Coût d'une source	≈ 1 M€	0.5 – 1.5 M€	0.2 M€	0.1 - 0.2 M€

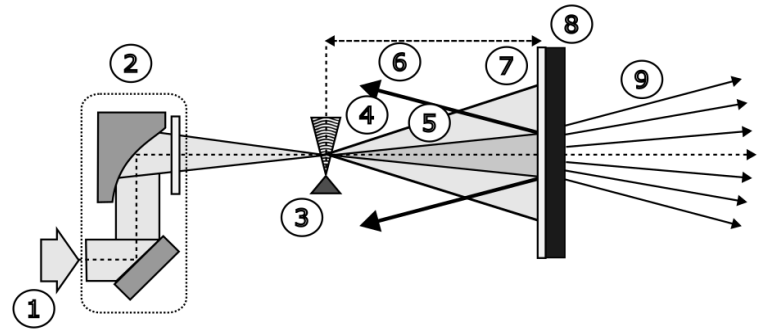
From SHERIL report of 2019 made by François Sylla

X-ray converter protection: patent with THALES

- 0.7 mm Tungstan plate
- 7 mm from gas target
- Tilted 40 deg. wrt beam axis







Use of a thin protection layer allows to reduce the distance between gas target and converter and to increase the number of shots per position of converter without degrading the X-ray beam

This approach allowed put converter at < 5 mm from gas jet and last for > 1000 shots

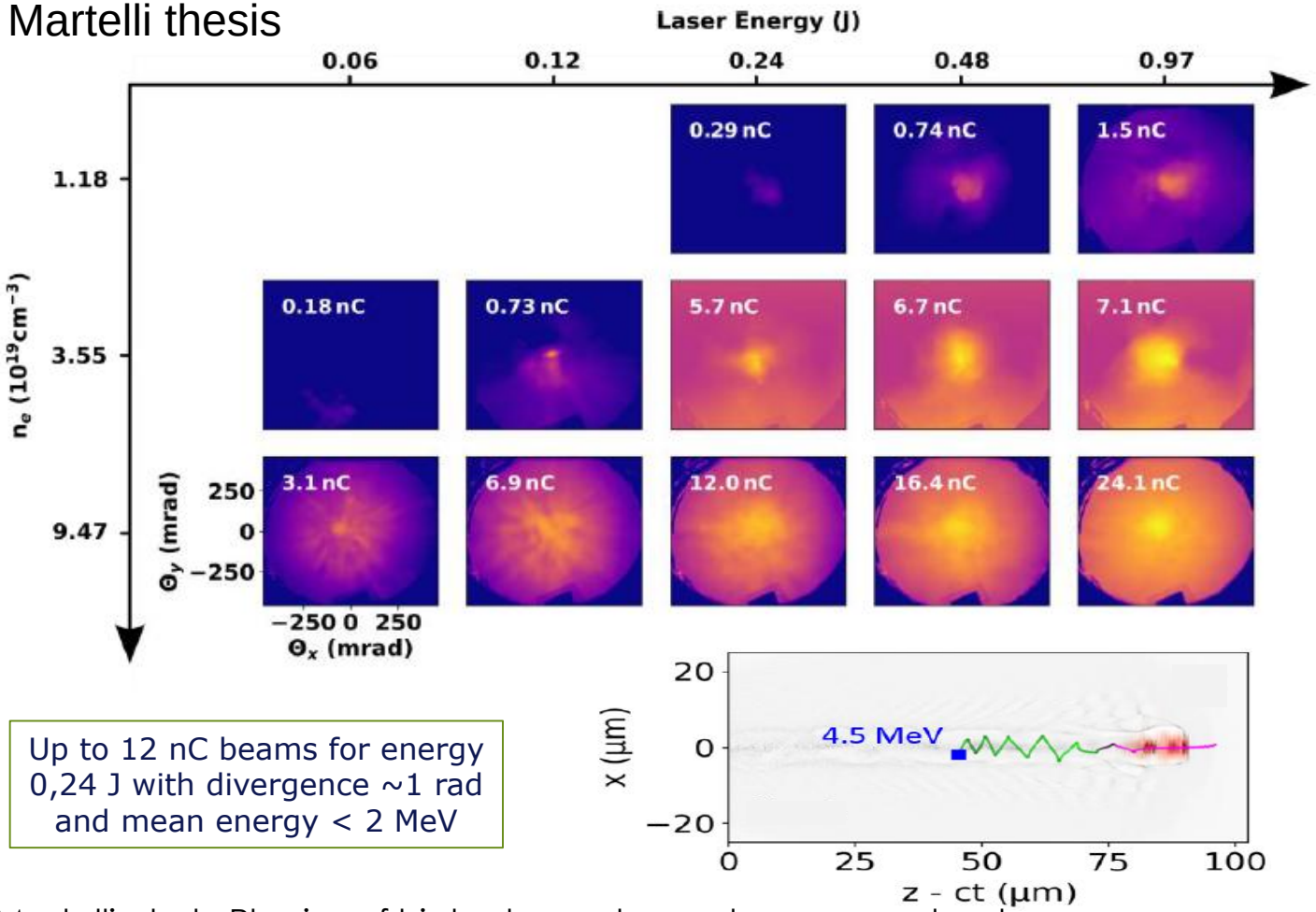
Patent submitted - Ecole Polytechnique/CNRS/ENSTA, THALES-MIS (No. deposition FR2503843)

MULTI SCAN 3D

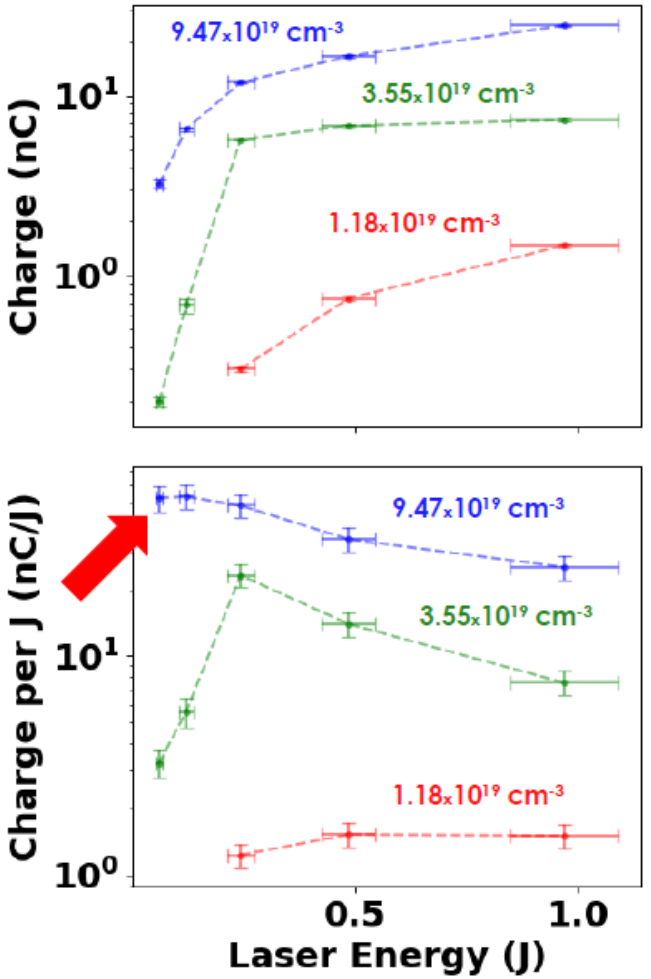
Salle Jaune research towards low energy and high charge

f/4 OAP and 0.4 mm nozzle

L. Martelli thesis



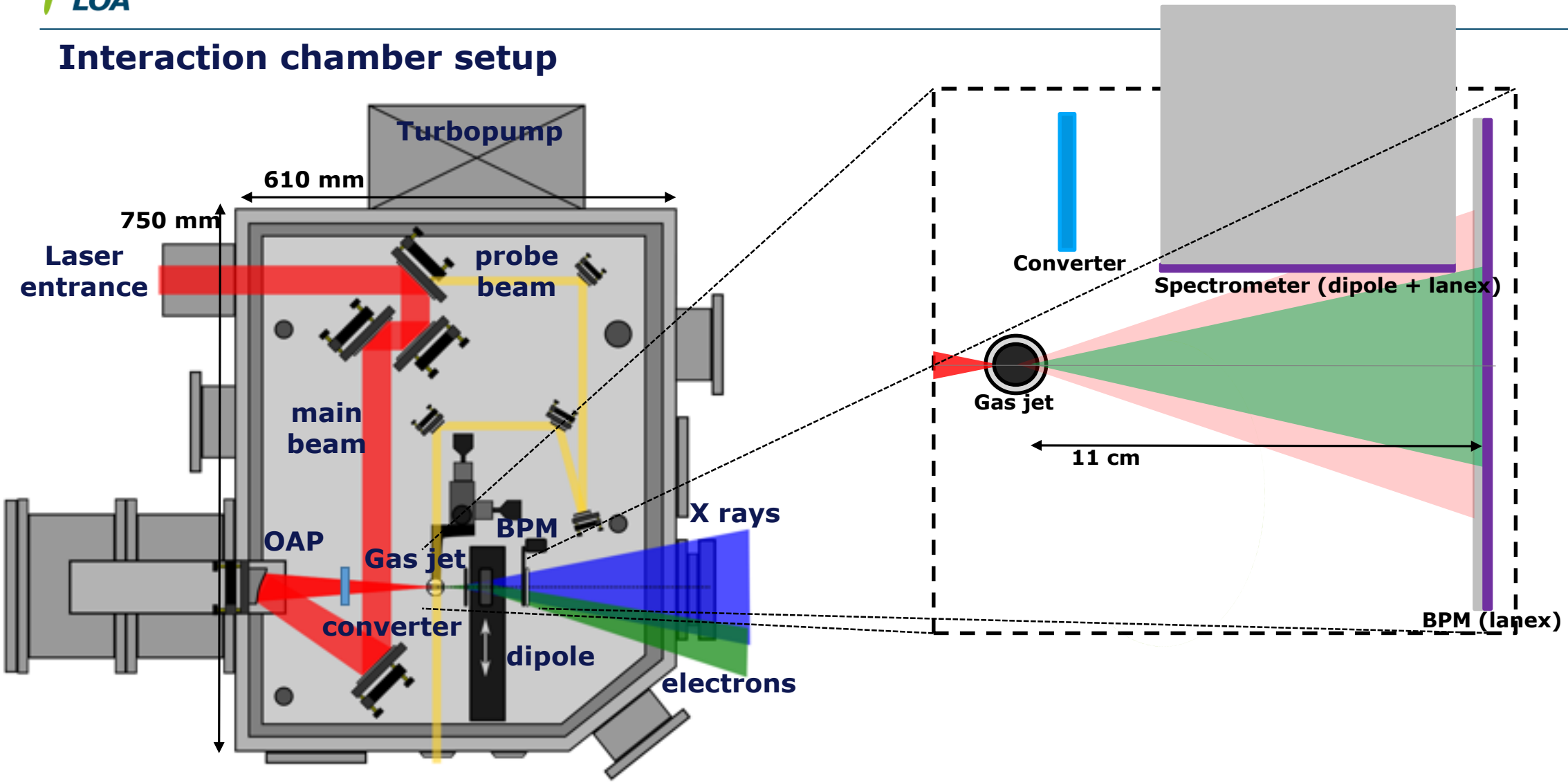
Up to 12 nC beams for energy 0,24 J with divergence ~1 rad and mean energy < 2 MeV



L. Martelli et al., Physics of high-charge laser-plasma accelerators for few-MeV applications, Phys. Rev. Applied (2025)

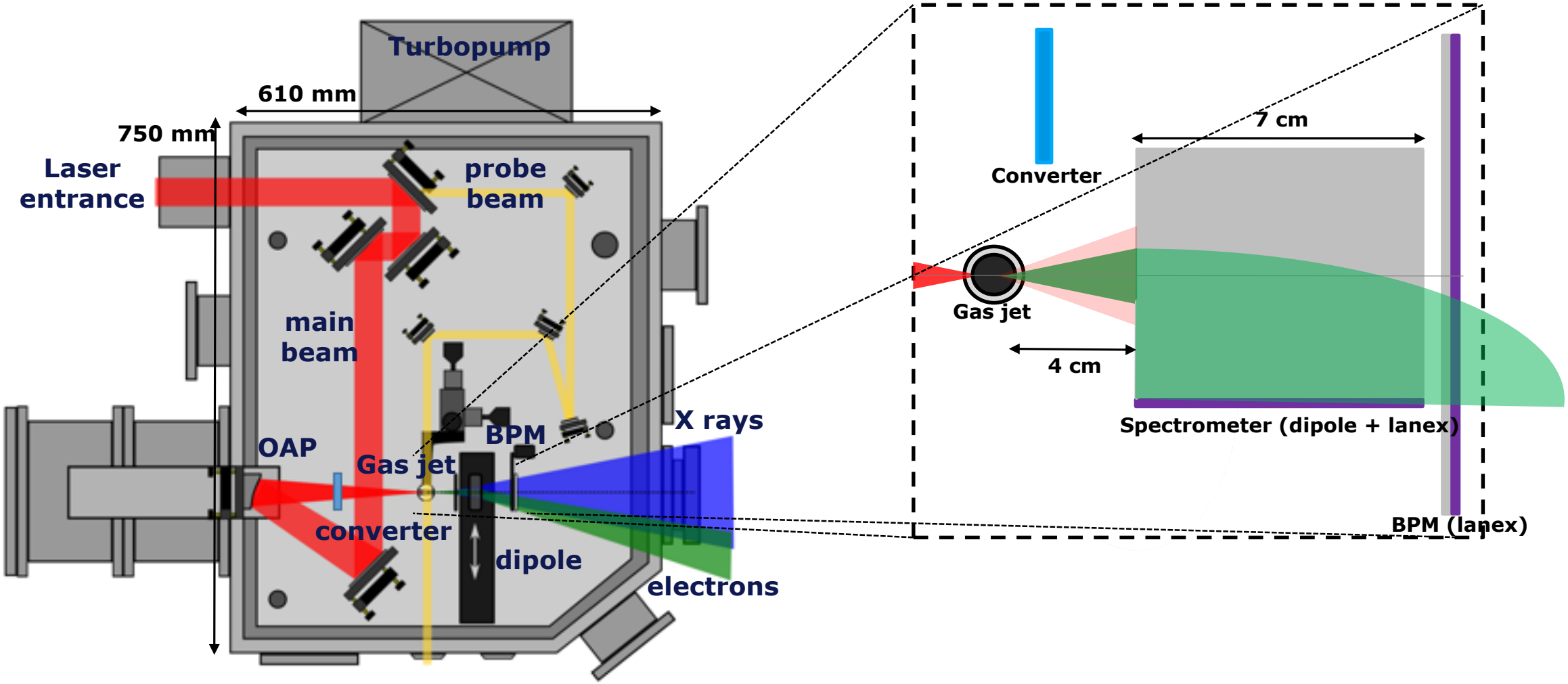
Interaction chamber setup: Beam Profile Monitor (BPM)

Interaction chamber setup



Interaction chamber setup: Electron spectrometer

Interaction chamber setup



Interaction chamber setup: X-ray converter

Interaction chamber setup