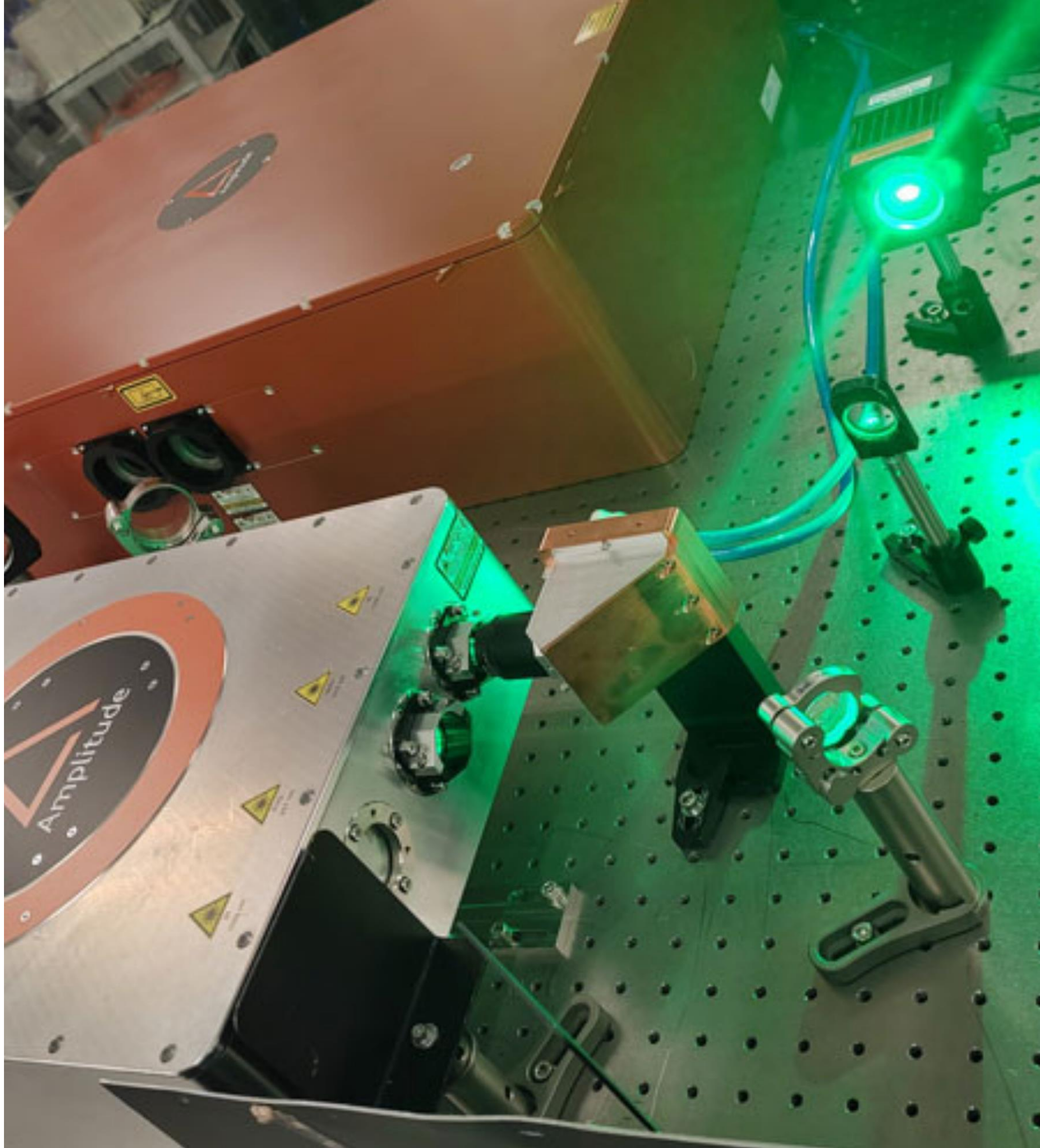
Laser-driven X-ray Sources for Non Destructive Testing in Industry : Opportunities and Challenges

28th of October 2024

Pierre-Mary PAUL

EPIC Online Technology Meeting on Photonics Technologies for Advanced Light Sources

A Laser Bright Future



Ultra Short Pulse Laser Leader Since 2001

From the most renowned scientific installations

To high-tech surgical blocks

To the world's high-end factories

450+
Employees dedicated to ultrafast lasers

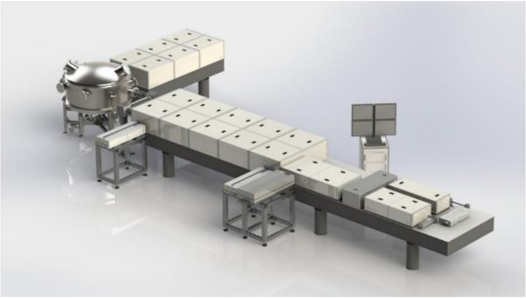
5,000+
m² state-of-the-art production area

5,000+
Femto lasers running in the field

Amplitude Laser Group Headquarter,
Bordeaux, France

Amplitude

3 Main Markets



Industry

- Display
- Semiconductor
- Consumer Electronics
- Micro processing

Science

- Lifescience
- High Intensity and Energy Physics
- Spectroscopy and Imaging
- Instrumentation

Medical

- Ophthalmology
- Protontherapy
- X-Ray Imaging
- Medical Device Manufacturing

From Science to Industry

Our Motivation :

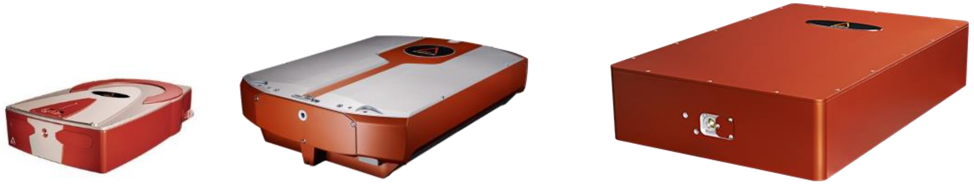
> Provide state-of-the art lasers for scientific exploration

> Develop compact industrial lasers for real-world applications

Exploration

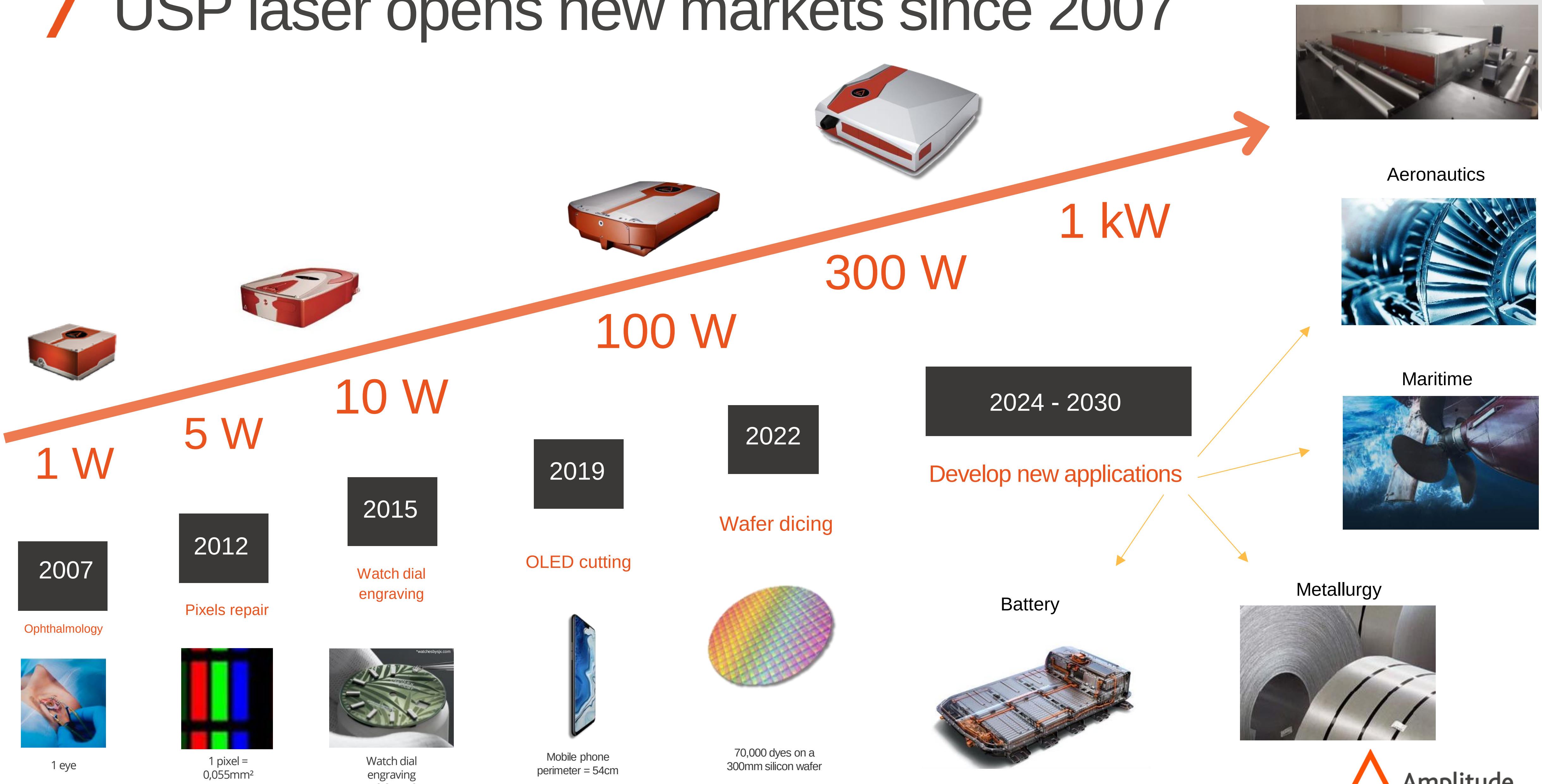
Ti Sa / OPCPA

Exploitation



Diode-pumped Yb

USP laser opens new markets since 2007

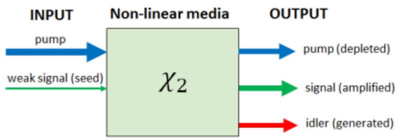


Amplitude

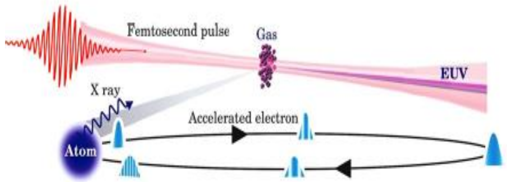
/ Secondary sources

Gigawatt

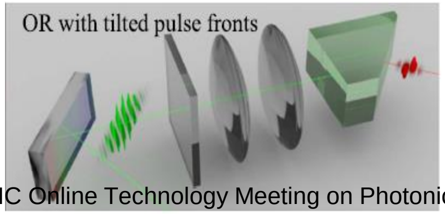
UV-VIS-MIR sources



XUV sources

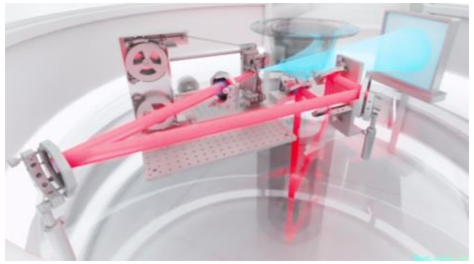


THz sources

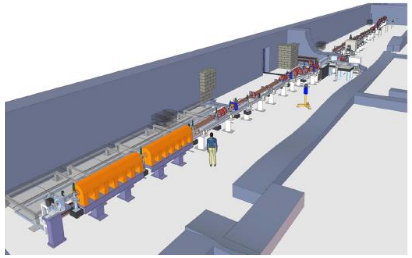


Terawatt

LPP X-ray sources

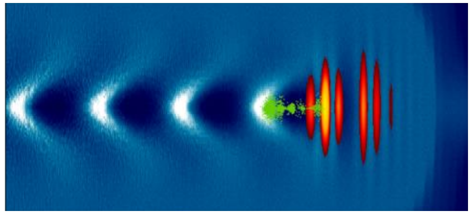


ICS X/γ-ray sources

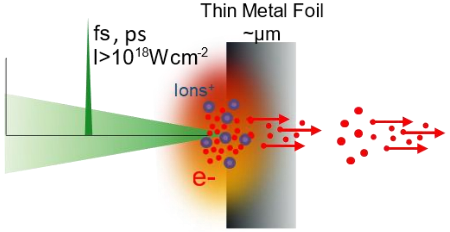


Petawatt

GeV electron sources

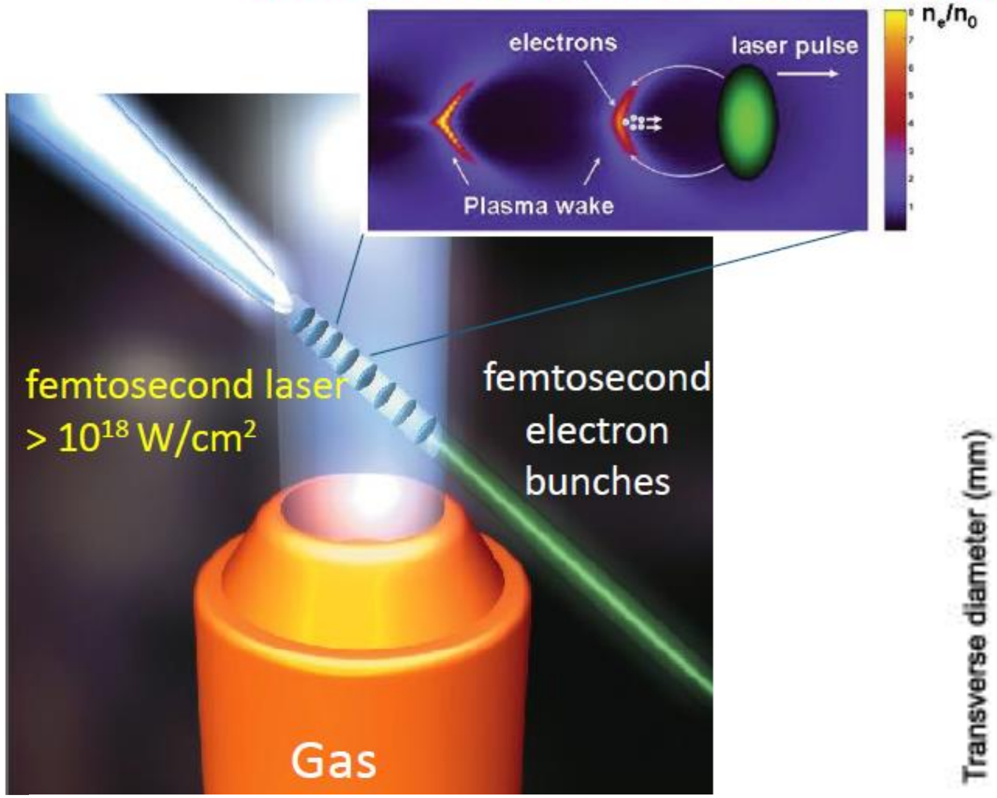


MeV proton sources



Laser Wakefield Acceleration revolution

Electrons accelerated in laser-plasma wakefield

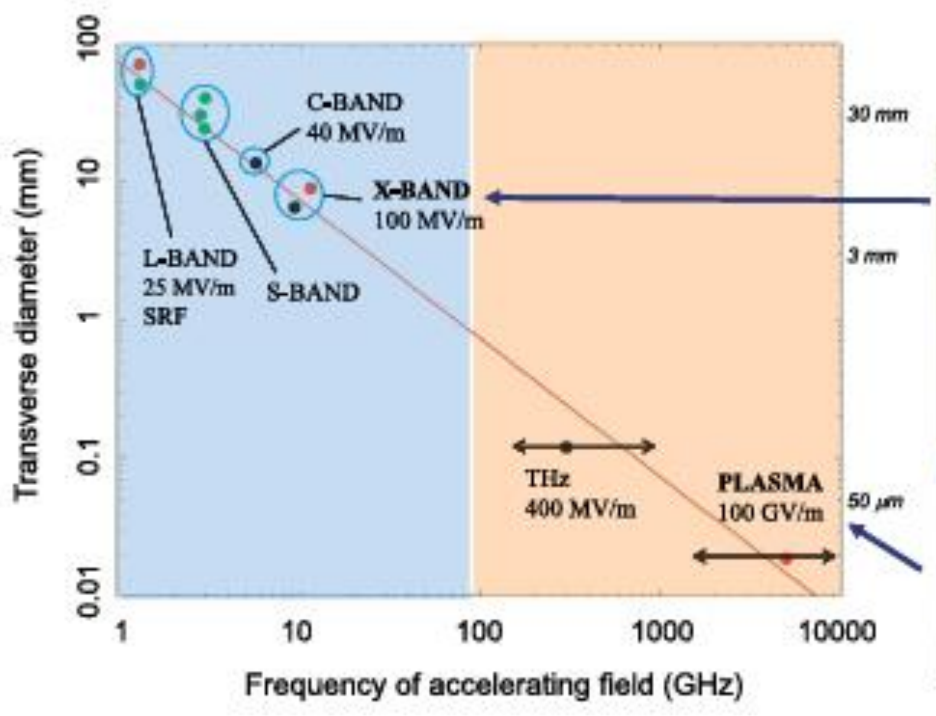


Electron energy gain $\Delta E \propto \tau^2 \propto \lambda_p^2$

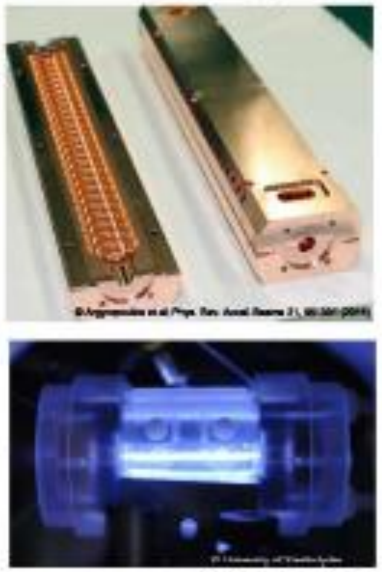
Laser energy scaling $E_L \propto \tau^3 \propto \lambda_p^3$

30 fs → 1 J → 100 MeV-1 GeV
3 fs → mJ → 1-10 MeV

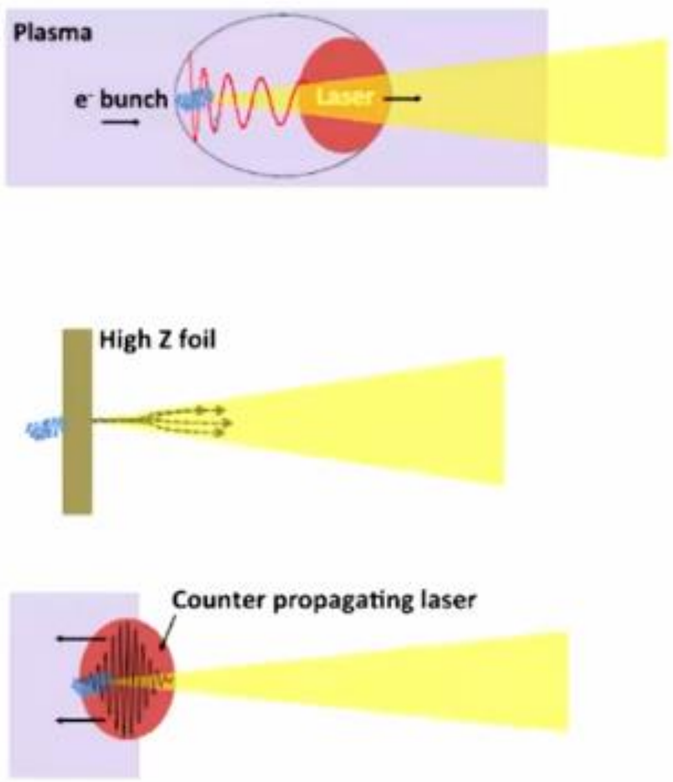
> Gradient ~100GV/m vs 25-100MV/m in conventional LINAC
> Compact accelerator
> Promising for TeV colliders & light sources (FEL)

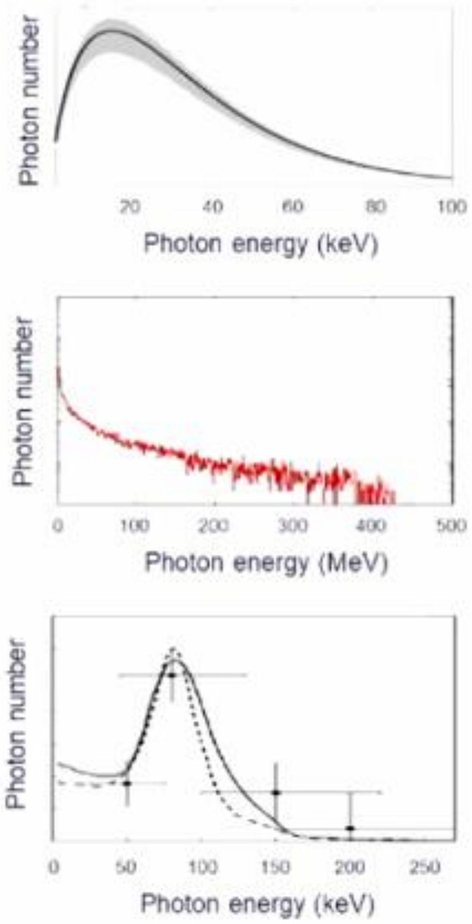


EuPRAXIA



Converting electrons into X-rays





Albert & Thomas PPCF **58**, 103001 (2016);
Tsai et al, Phys. Plasmas **22**, 023106 (2015)

Betatron

- Broad energy distribution
- 10 – 100 keV
- Source size ~ 1 μm

Bremsstrahlung

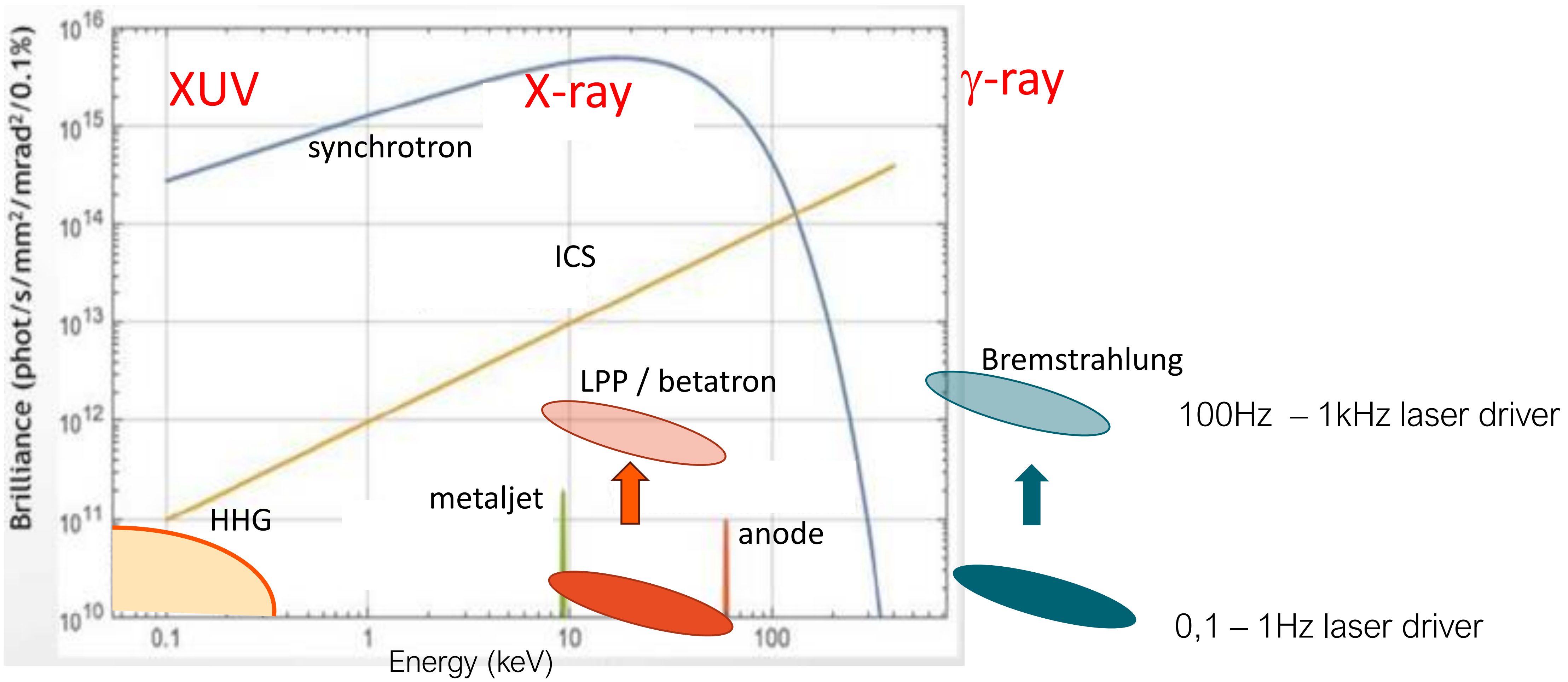
- Broad energy distribution
- Multi-MeV
- Source size < 100 μm

Inverse Compton Scatter

- Narrow energy spread
- 50 keV – 10s MeV
- Source size ~ 10 μm

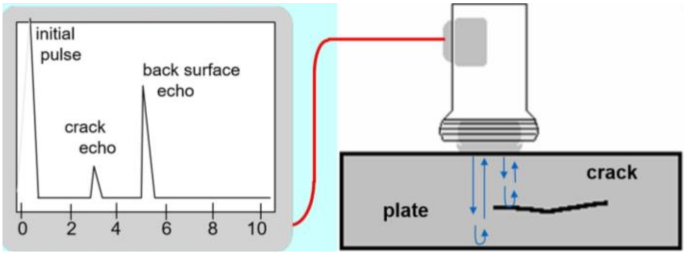
Amplitude

Technology comparison

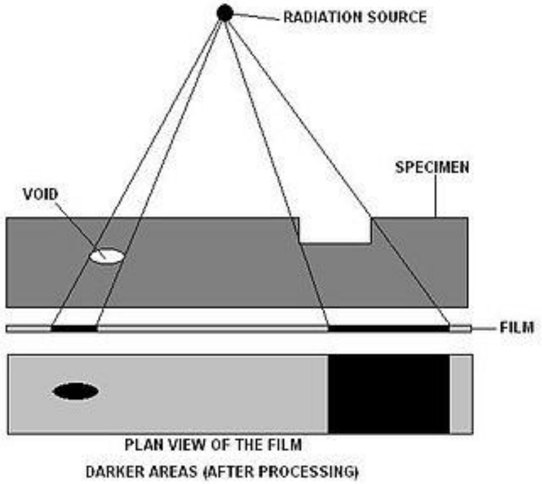


Non Destructive Testing

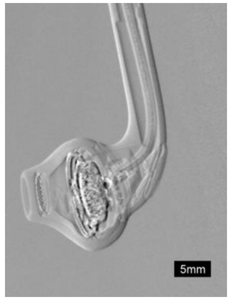
Ultrasonic



Radiography

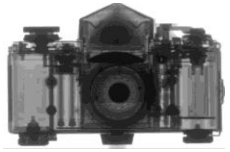


Absorption imaging

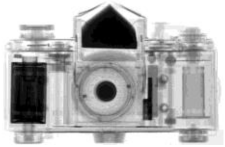


Phase contrast imaging

X-rays

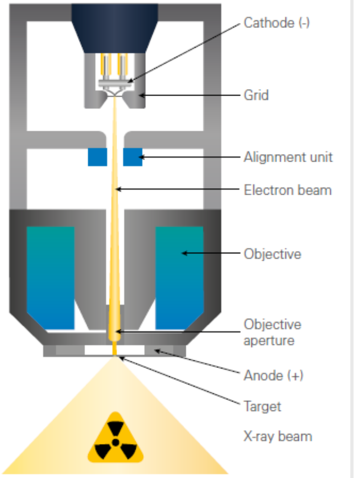


neutrons



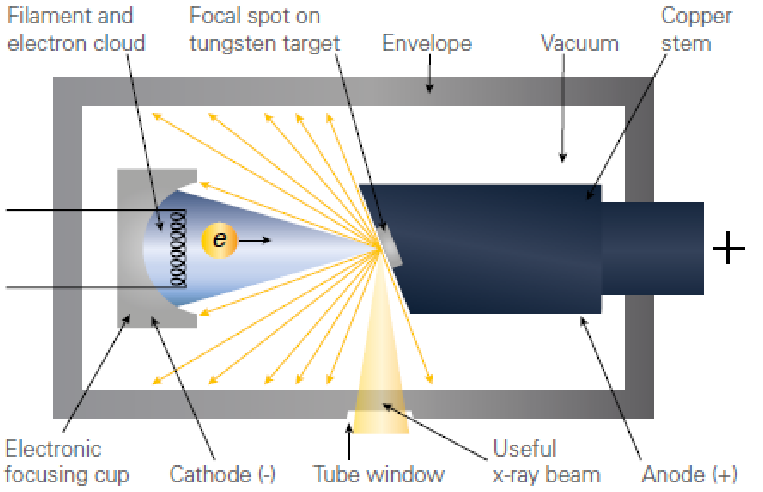
X-ray sources for NDT

Precision radiography



Microfocus
Electron beam power : 10-100W
Spot size : typ 1µm
Penetration ~20mm (160kV)

Standard CT/radiography



Rotating anode
Electron beam power : Multi kW
Spot size : typ 0,1-1mm
Penetration 50-70mm (300-450kV)

Deep radiography

LINAC
Electron beam power : kW
Spot size : typ 1-2mm
Deep penetration/dense objects(3-9MeV)

Precision tomography (µCT)

Pionneered with synchrotron light sources

µfocus&nanofocus sources provide portable solutions with high resolution

Limitation : low penetration & low flux

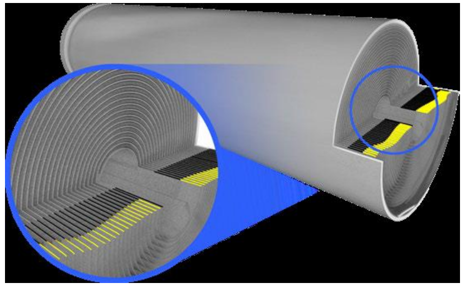
Motivation : detect small voids & defects

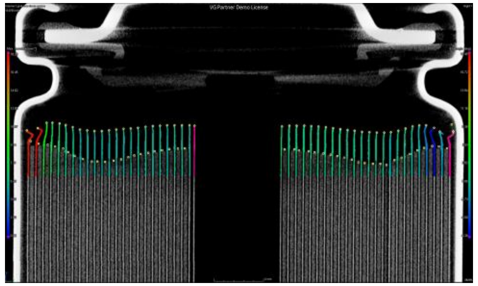
Resolution : few µm

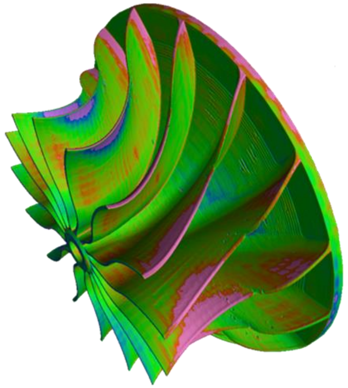
Applications :

- Batteries
- Additive Manufacturing
- Electronics

Growing demand for fast measurement on large scale







Composite analysis

Imaging composites during curing process

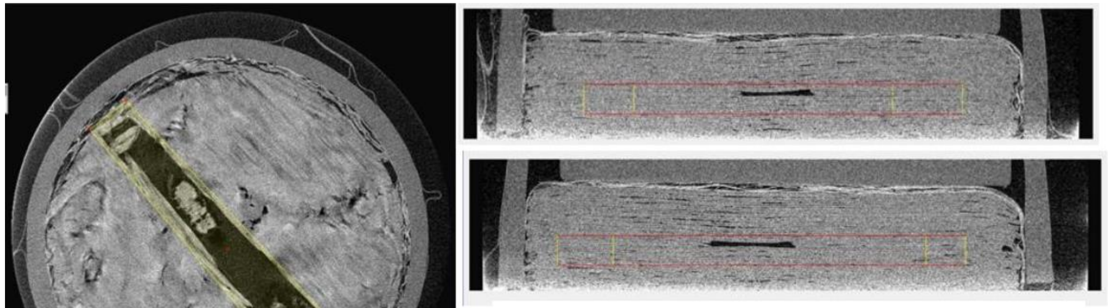
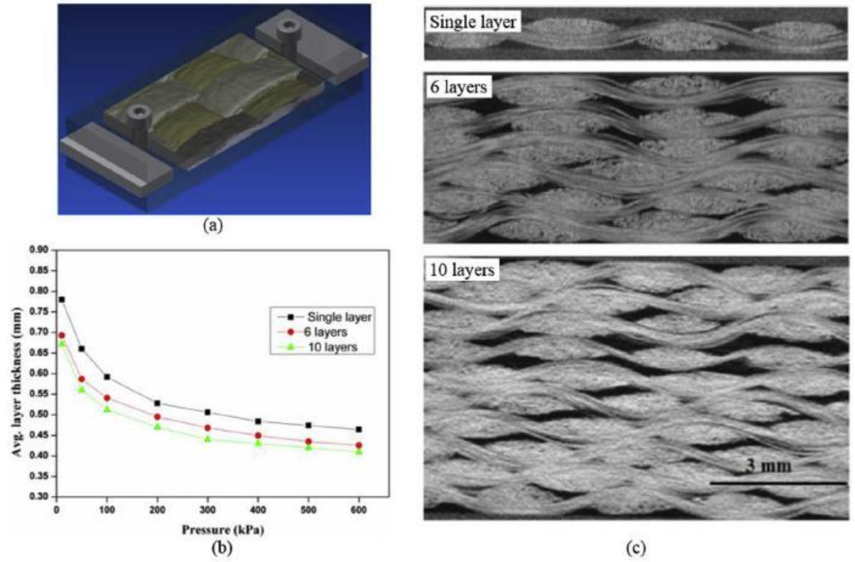


Figure 7: Drawing the region of interest on the 3D reconstruction of the first scan. The same region of interest is used on each reconstruction. Space is allowed below the gap as the sample will shrink vertically as it consolidates.

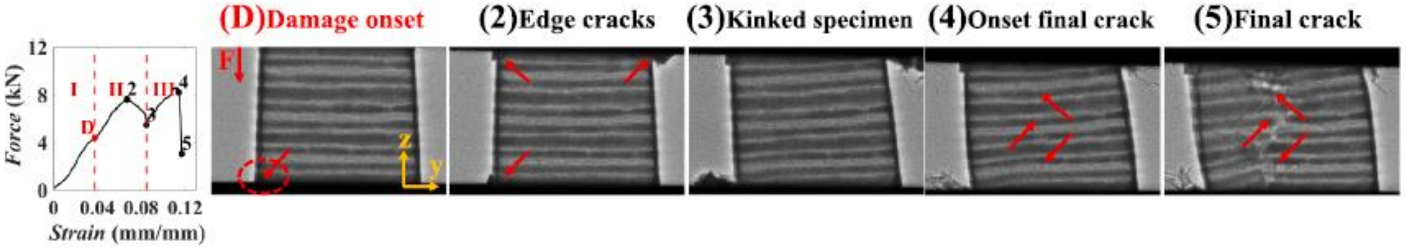
Pickard et al, Int Conf on Composite Mat, 2017

Nesting effect in composites production process



Garcea et al, Composite Sc & Tech, 2018

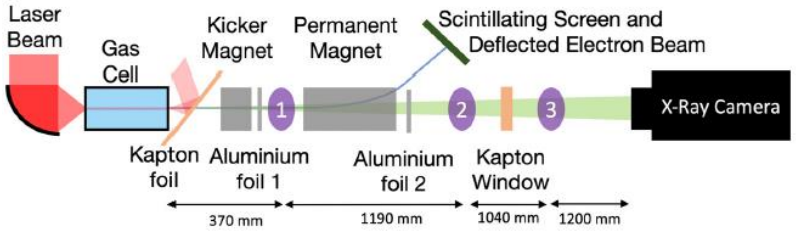
Cracking process of composites under compression



Pournoori et al, Composites PartA, 2021

Radiography of batteries & composites with betatron

7J 50fs @3shot/min (Gemini – STFC)

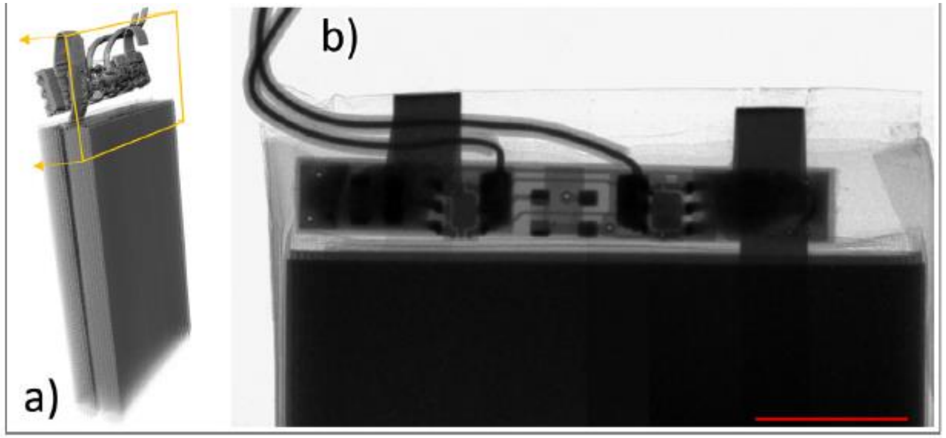


Synchrotron-like spectrum with E_{cr}=14keV

Average flux : 10^9 ph/s

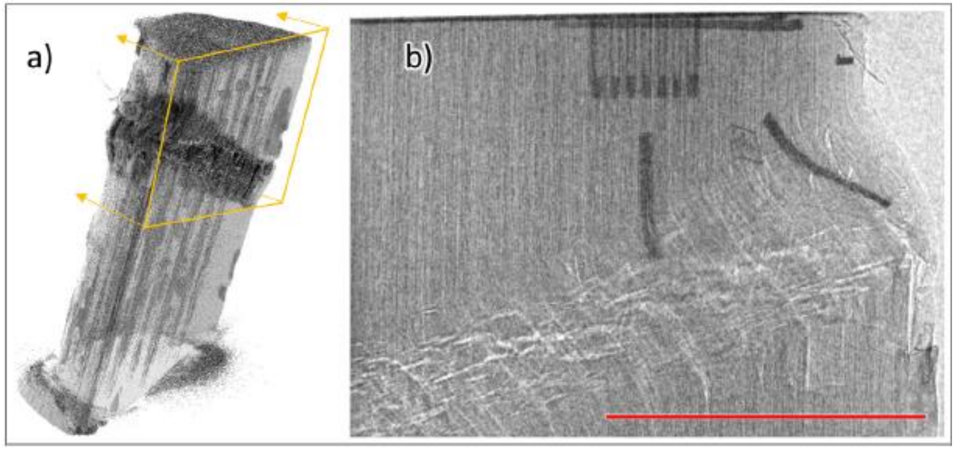
µm spot size, fs pulse duration

Brightness $5.2 \pm 1.7 \times 10^7$ph/mrad²/shot



Pouch cell battery

Recording time : 10 shots = 3min



Composite material, phase enhanced

Grüse et al, Nucl Inst 2020
doi.org/10.1016/j.nima.2020.164369

/ Conclusion and perspectives

> Synchrotrons and XFELs open new modalities for industry

> Growing need for quality control with X-rays (AM, CFRP, batteries) require precision & fast scanning

> Fast improving laser technology opens new secondary sources

> Industrial & medical applications will benefit from increasing average power TiSa AND Yb technologies

> … while other technologies make big progress also

> XFEL will open new applications in ultrafast X-ray dynamics, such as fusion ignition