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Towards high sensitivity and low dose medical imaging with laser X-ray sources

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https://www.eli-np.ro/projects/drlaser/

Medical applications of high-power lasers

Dr. LASER

Project included in the Romanian Health Program

- in collaboration with UMFCD Bucharest, IOCN Cluj Napoca, IRO Iasi, POLITEHNICA Bucharest and 2 SMEs
- 35 MEUR for 5 years – contract signed on 20.02.2025 – co-funded by EU and Romanian Government

Laser-driven C-ions for hadron therapy

- 10 PW-class lasers have potential to accelerate heavy-ions to therapeutic energy and dose, at ultrahigh dose rate, in few mm
- laser-driven ultra-high dose rate heavy-ion irradiation can enable the FLASH effect (healthy tissue sparring) (10^{10} Gy/s)
- Proposed medical focus on long term: start from skin-level cancer, progressing to HNC and breast cancer (#1 cause of cancer mortality for women)

Interferometric phase contrast X–ray imaging

- Conventional, absorption-contrast X-ray imaging has poor visibility of soft tissue tumors
- Phase-contrast X-ray imaging investigated as alternative
- Method requires intense, directional, short–pulse and spatially coherent X–ray source: 100 TW class lasers can do this
- Proposed medical focus: breast cancer and later lung cancer

Medical interest radioisotopes production

- High power lasers offer an advantageous alternative for producing medical radioisotopes due to their ability to accelerate different types of particles
- "*on-site*" production of short-lived, medically relevant radioisotopes, such as ^{11}C, ^{13}N or ^{15}O, becomes more affordable with lasers
- 100 TW-class high repetition rate laser sufficient for radioisotope production

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GUVERNUL ROMÂNIEI

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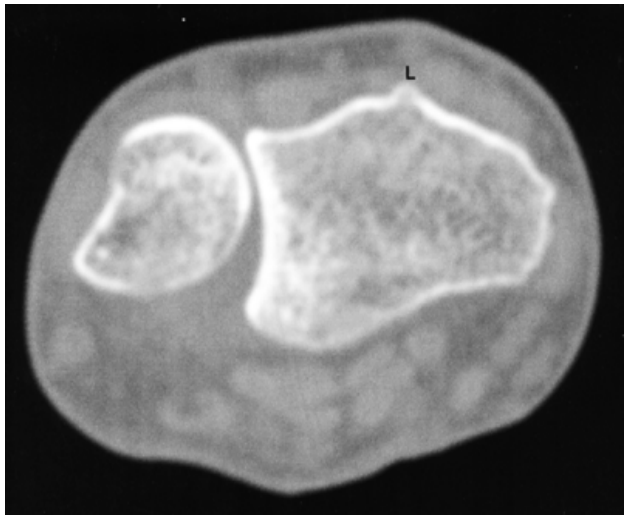
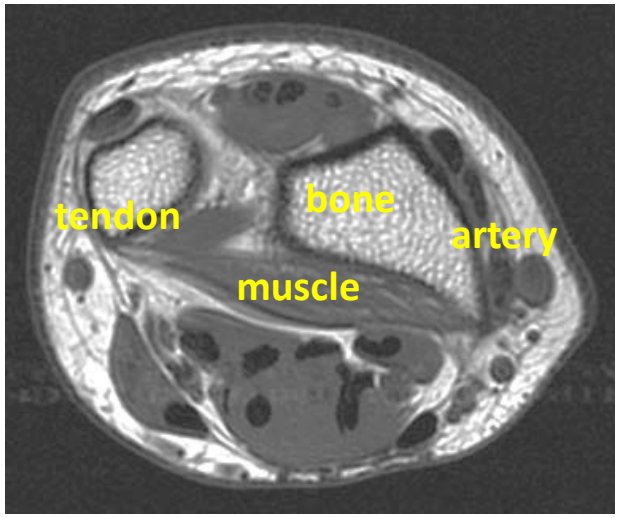
Poor soft tissue visibility and high dose in conventional absorption-contrast X-ray imaging

X-ray



MRI



- Due to weak X-ray photoelectric absorption at clinical energies (20-120 keV)
- Conventional solutions: i) decrease energy (mammography) => dose increase
  ii) many views (computed tomography) => dose increase

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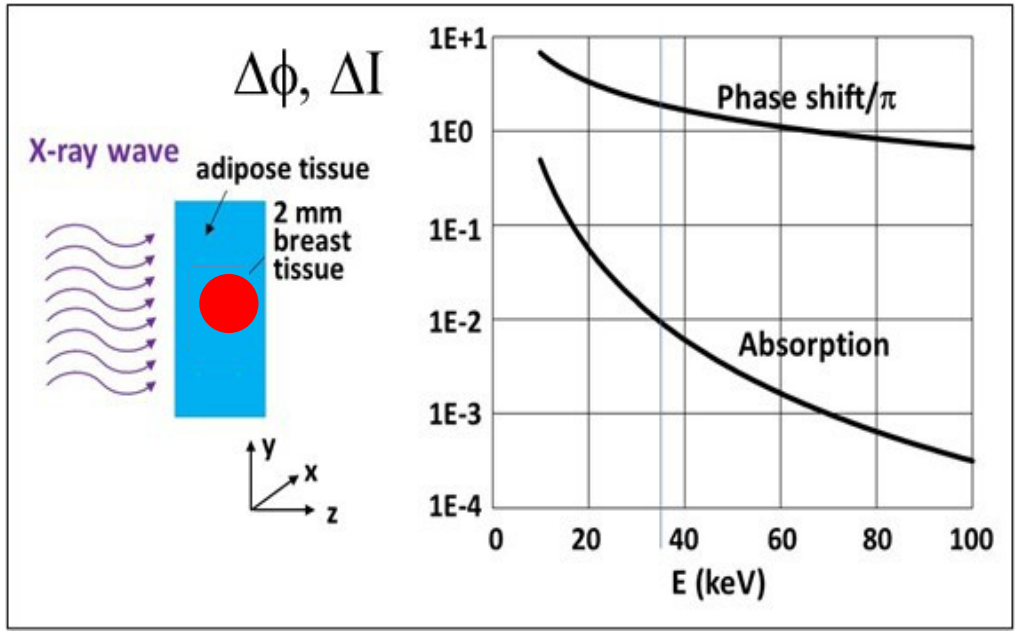
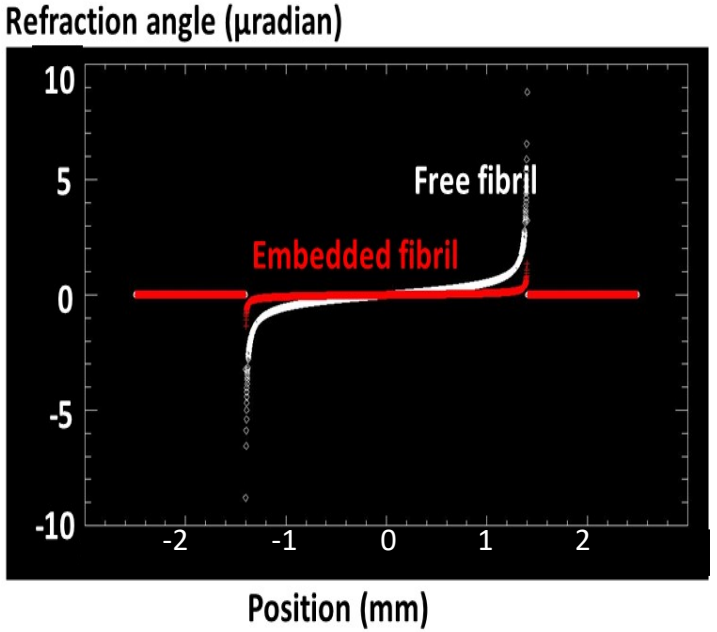
Phase-contrast imaging can strongly increase soft tissue visibility and decrease dose

X-ray phase shift vs. absorption in breast tissue fibril



Refraction angle in fibril (30 keV X-rays)



- Refraction-based imaging -> object can be transparent -> dose can be strongly decreased
- Challenge: in soft tissues X-ray refraction angles < 1 μrad

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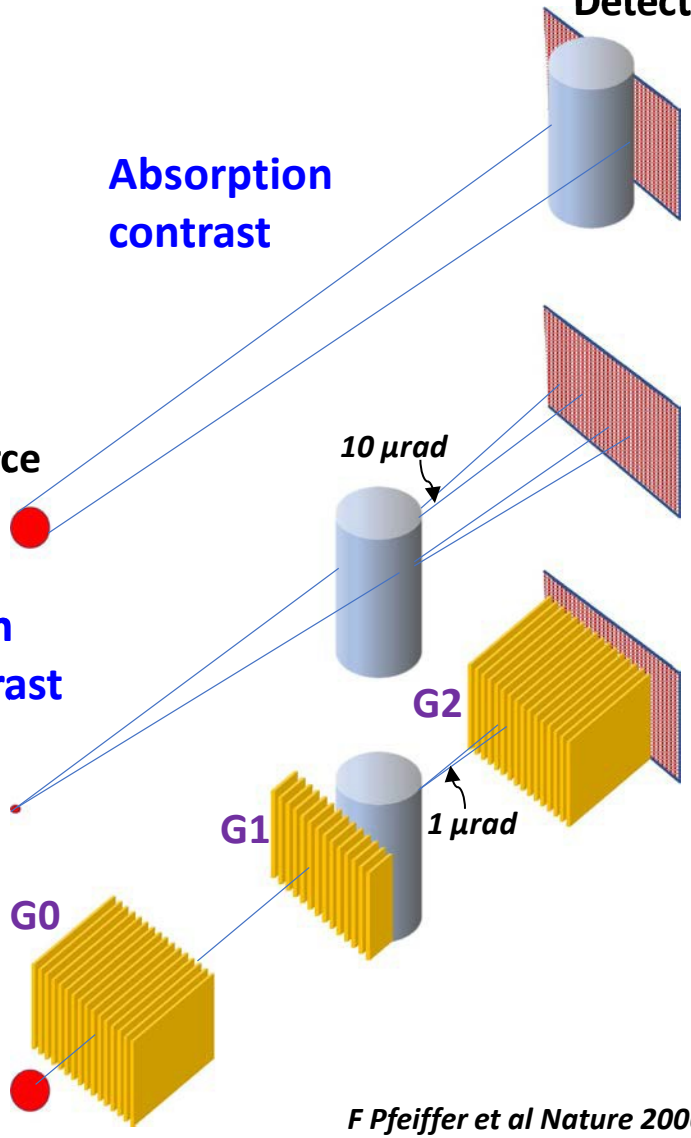
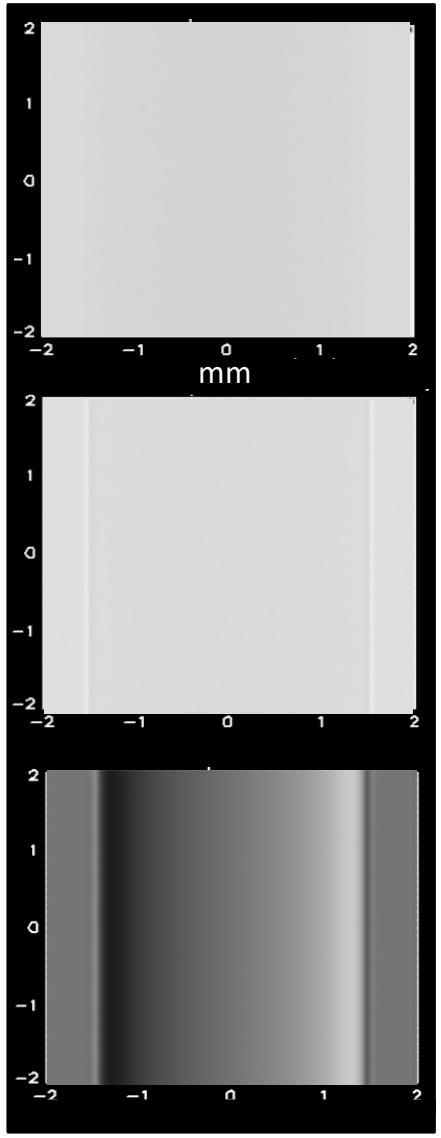
Grating interferometry most sensitive X-ray phase contrast imaging method



F Pfeiffer et al Nature 2006

breast tissue fibril in adipose tissue 30 keV



< 1 µrad refraction angles

+

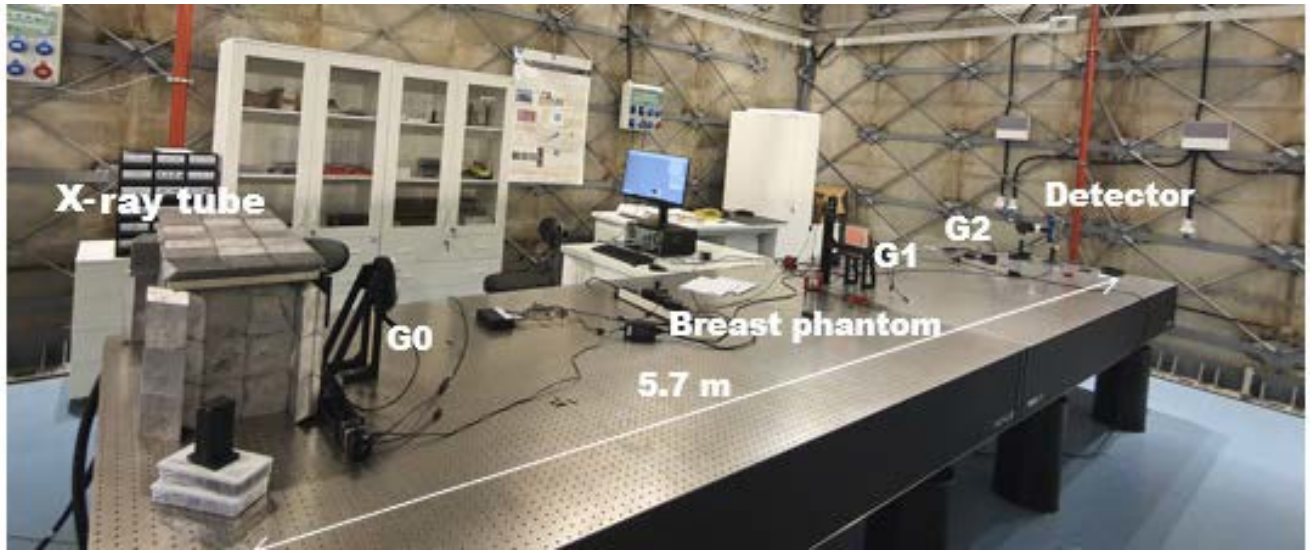
> 2-3 µm feasible grating periods

↓

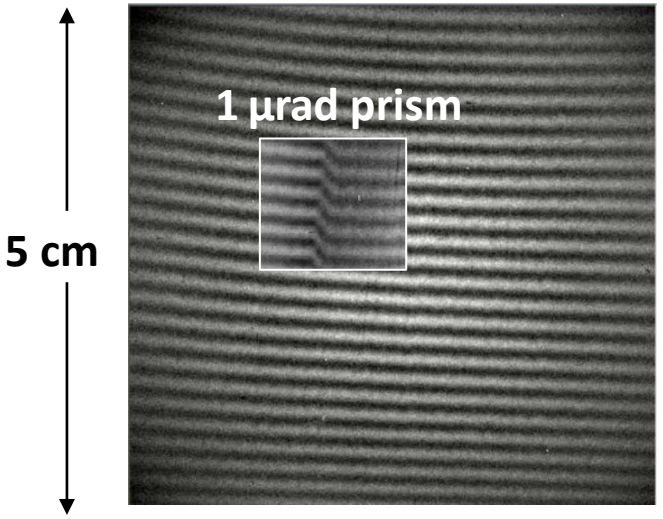
Multi-meter long interferometers for sufficient angular sensitivity

6 m long, 2.4 µm period X-ray interferometer demonstrated at ELI-NP

Operated with 2 kW X-ray tube at 40 kV



Simultaneous ultrahigh angular sensitivity and high fringe visibility



N Safca et al SPIE 2022

- Interferometer works with very broad X-ray spectra $\Delta E/\langle E\rangle \leq 100\ \%$ (Stutman et al SPIE 2023)
- Simulations indicate lengths up to 10 m feasible
- Result made possible by extreme stability of ELI-NP 1500 ton “optical table” – antivibration platform

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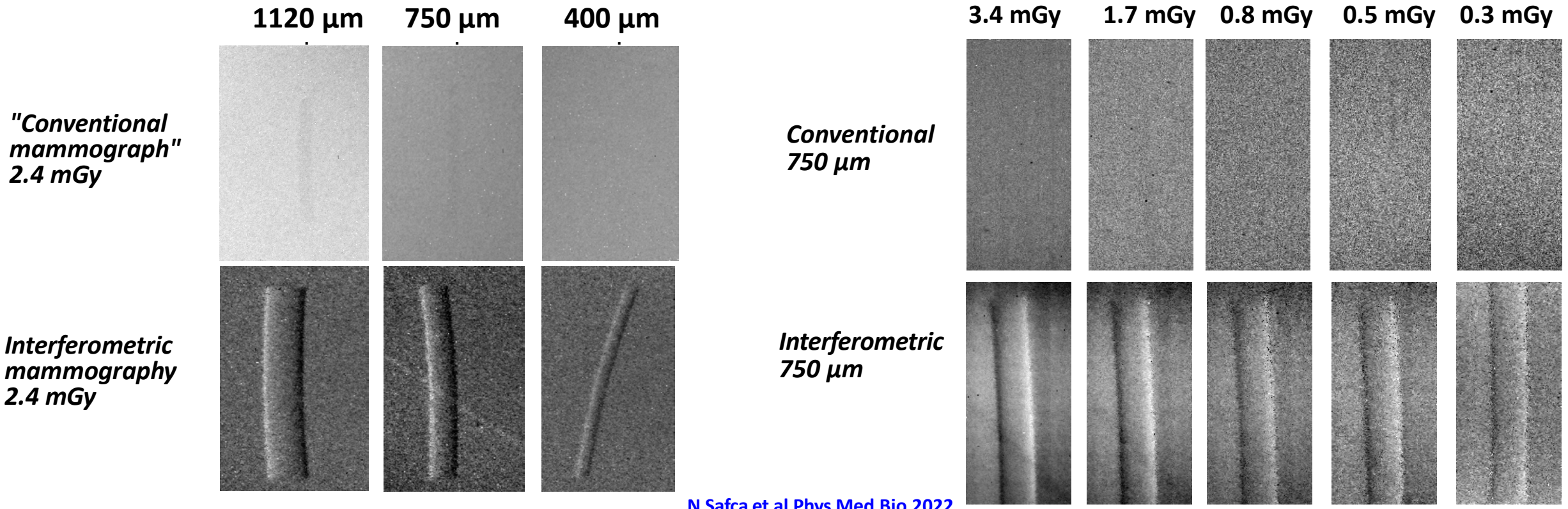
Strongly increased visibility of objects simulating breast cancer and potential for order of magnitude dose reduction

Fibrils in mammography accreditation phantom



N Safca et al Phys Med Bio 2022

Minutes exposure per image with conventional X-ray tube

-> new kind of X-ray source needed for clinical implementation of this concept

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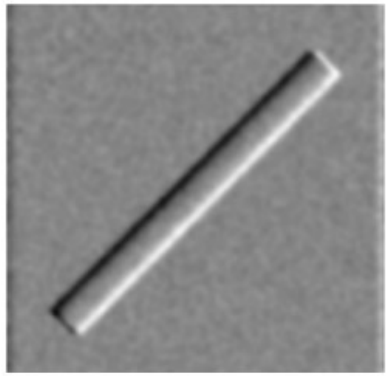
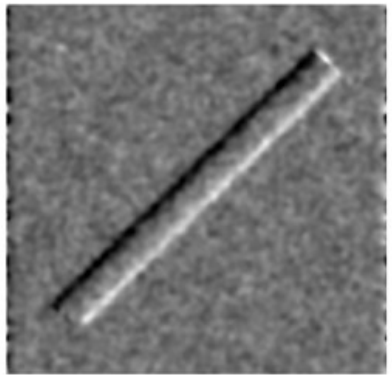
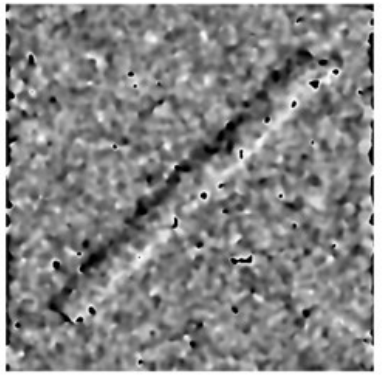
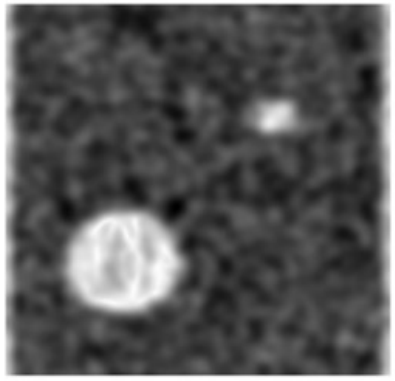
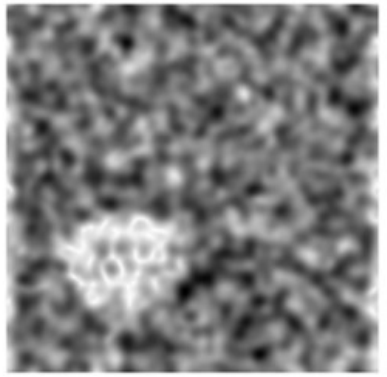
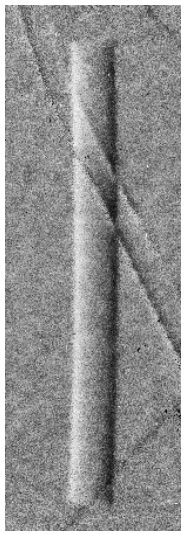
Directional and intense X-ray sources produced by 200 TW-class lasers could be ideal for clinical interferometric mammography

Simulation of interferometric mammography with 200 TW betatron and ICS-like sources (6 m length, 2.4 µm period interferometer, 10-shot phase scans, <E>=33 keV)

	Betatron 2 mGy (3×10^{10} photons/shot)	*ICS* 0.2 mGy (3×10^{9} photons/shot)	0.02 mGy (3×10^{8} photons/shot)
Refraction images of 400 µm breast tissue fibril in adipose tissue			
Dark field images of 540 µm and 160 µm diameter calcifications			

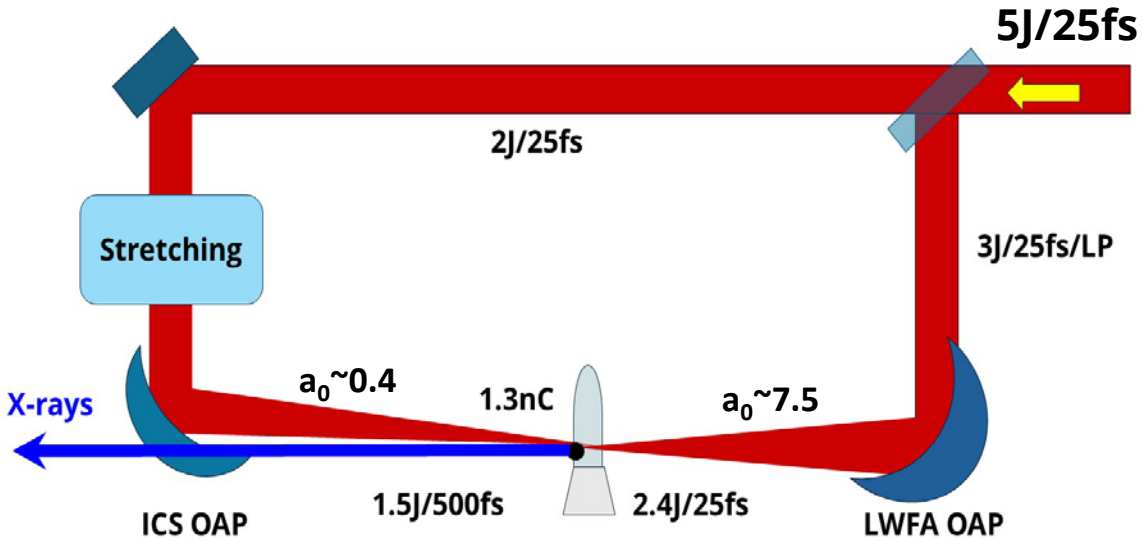
Experiment with 40 kVp microfocus tube 3 m, 2.4 µm interferometer 0.15 mGy



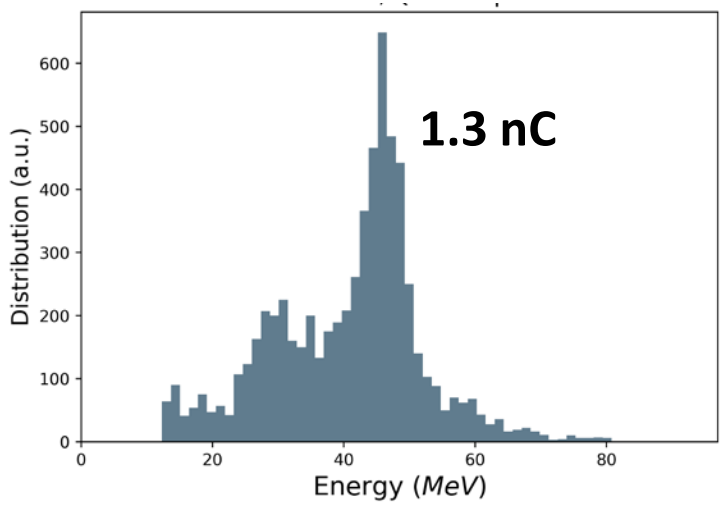
- **Usable soft tissue contrast at up to 1/100 of the patient dose in conventional mammography**
- **Experiment with microfocus X-ray tube supports prediction**

New ICS scheme proposed for interferometric mammography

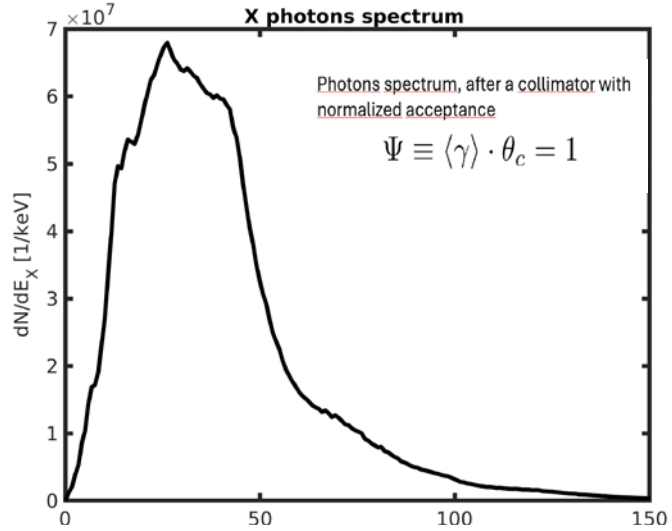
Self-synchronized "all-optical" ICS scheme



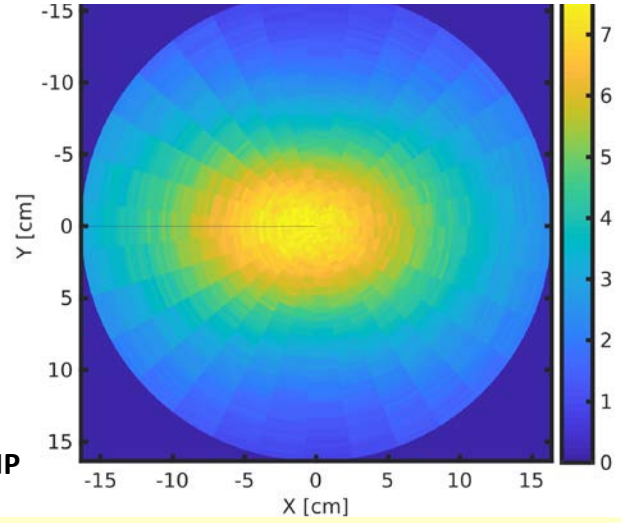
Electron spectrum with down-ramp N_e



$3x10^9$ photons/shot in 20-60 keV band, 20 mrad cone, 2.5 µm diameter/5 µm length source



Photon density on screen at 12.5 m

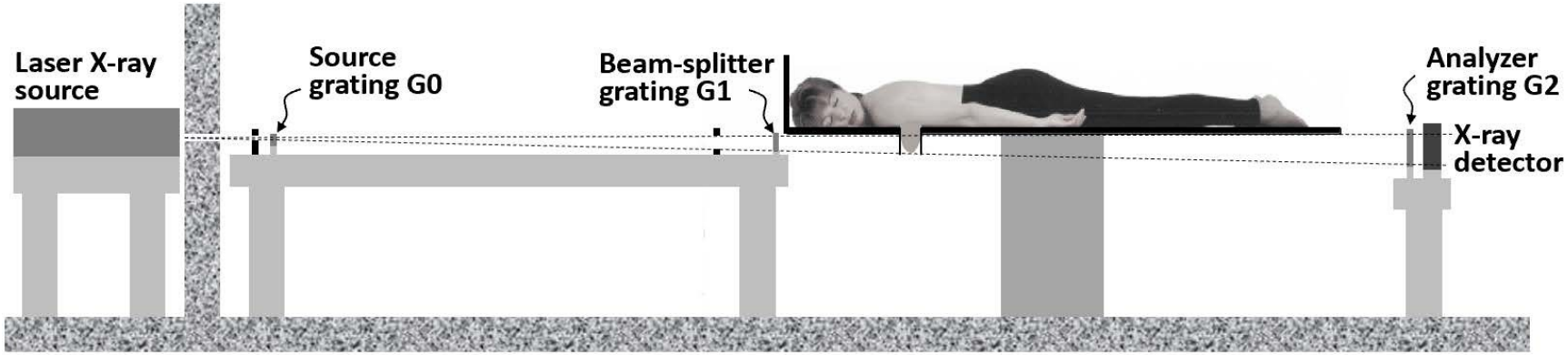


P Tomassini ELI-NP

200 TW betatron sources demonstrated close to interferometric mammography needs (Fourmaux et al 2024)

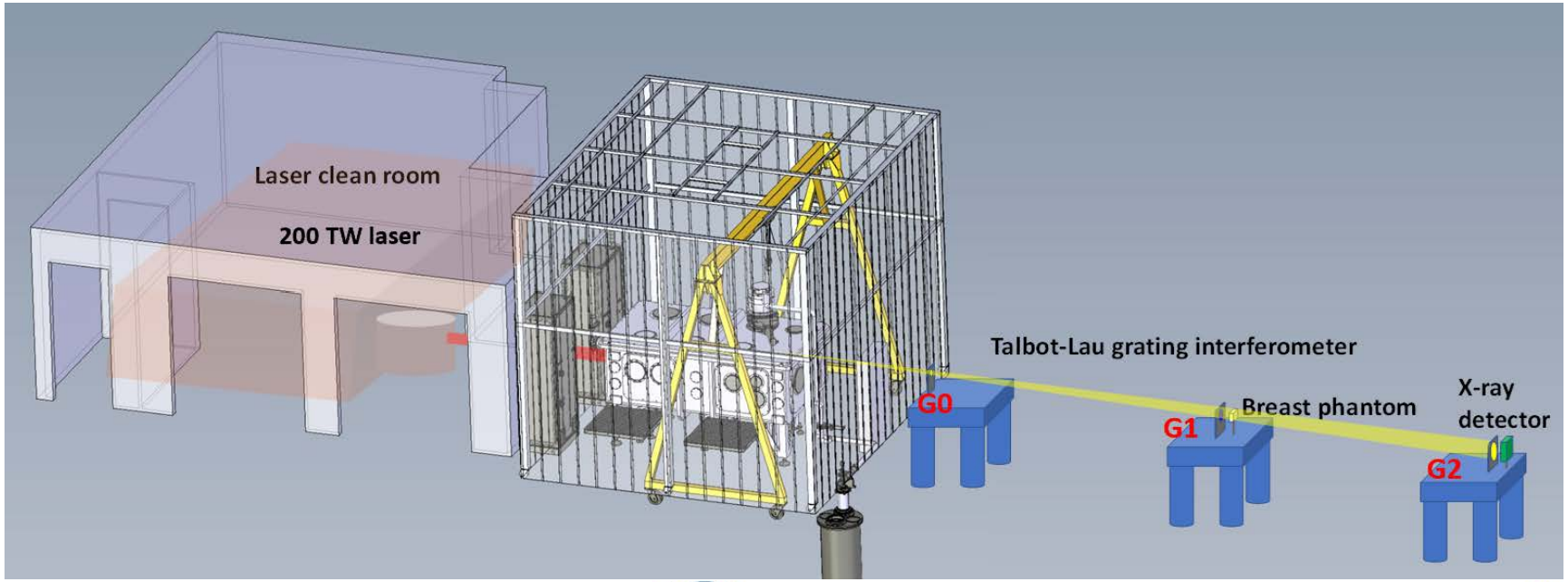
Dr. LASER project at ELI-NP (2025-2030) aims to advance interferometric mammography towards clinical implementation

Long-term goal



New 200 TW Experimental Area for medical applications of high-power lasers

Project's goal



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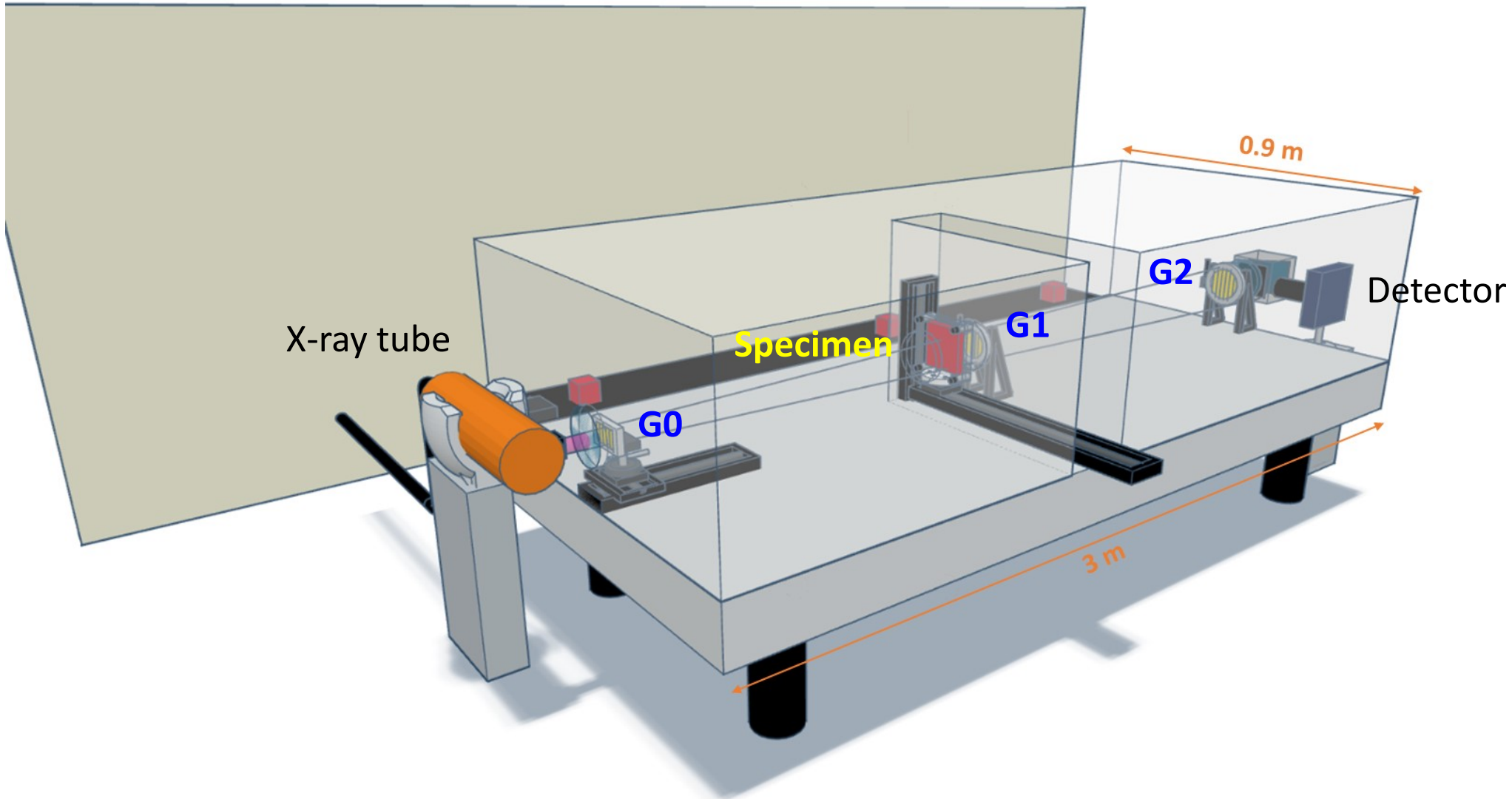
Tube-based, 3 m length 2.4 µm period interferometer to be installed in a hospital for studies of phase contrast imaging on fresh surgical specimens



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Summary

- Sensitive interferometry with laser X-ray sources could improve diagnostic and lower dose for patients
- Other laser mechanisms might also make bright µfocus X-ray sources (e.g. “peeler scheme” Shen et al 2025, DLA in NCD plasma)
- For medical application in hospitals the lasers must become less costly and more efficient
- Positions for research on medical laser applications at ELI-NP

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Thank you !

Dr. LASER

“Medical applications of high-power lasers - Dr. Laser”

www.eli-np.ro/projects/drlaser/

SMIS Code: 326475

Project co-financed by the European Union and the Romanian Government within the Romanian Health Program

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