Centre for Advanced Laser Applications – CALA

PALS 10 Workshop
22 -24 September 2010, Prague

K. Witte
Ludwigs-Maximilians-University Munich

Research Campus at Garching

Campus Zoom-in View

CALA Roots

Munich Centre
for Advanced
Photonics (MAP)

MAP - Munich Centre for Advanced Photonics

Ludwig-Maximilians-University Munich
Biology, Chemistry, Medicine, Physics

Technical University Munich
Chemistry, Informatics, Medicine, Physics

Max-Planck-Society
Max-Planck-Institute for Quantumoptics
Attosecond Physics, Laser Spectroscopy,
Laser Technology, Quantum Dynamics and Theory

Objectives of CALA

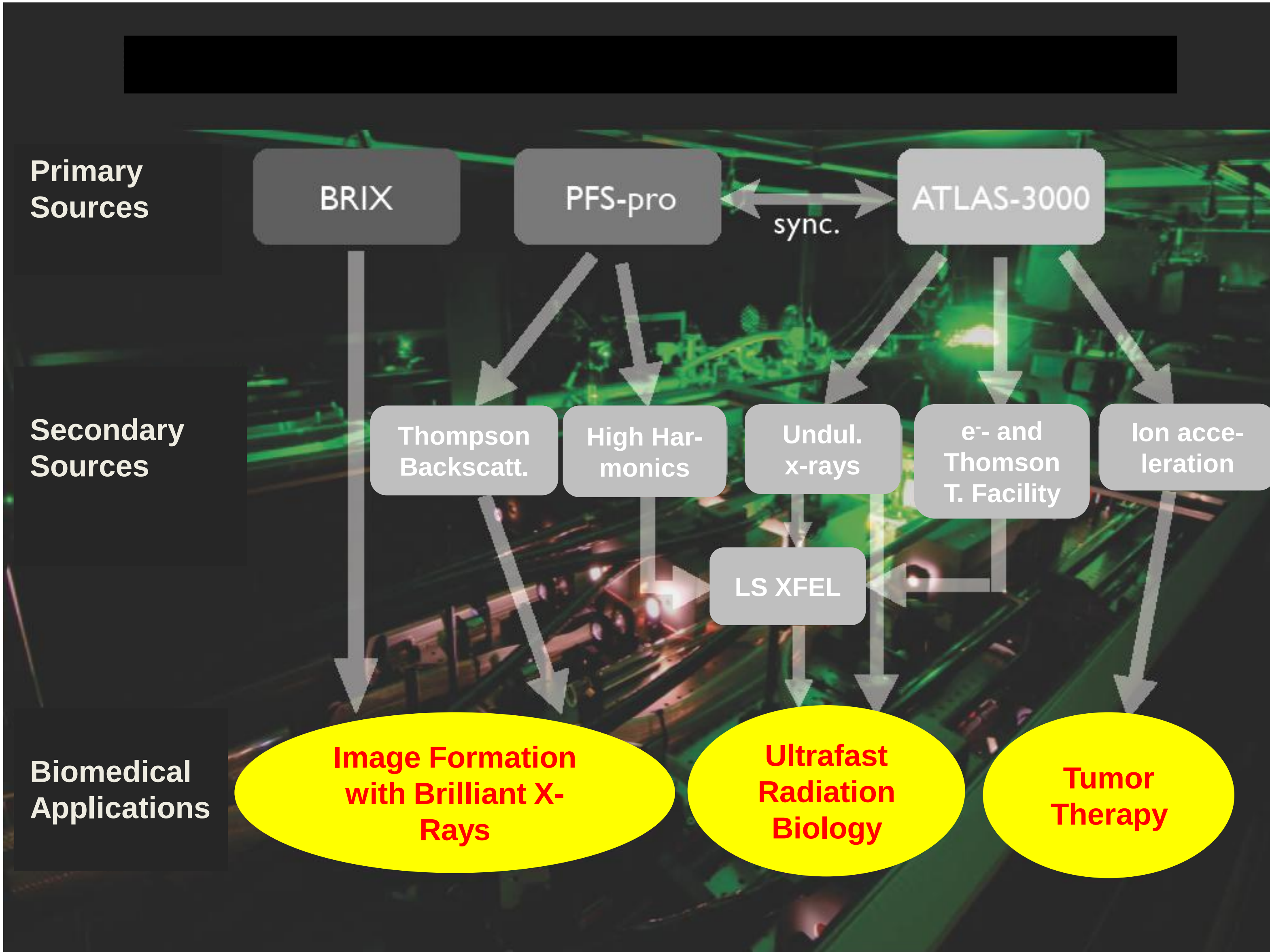
Innovative Laser-Based Methods for Cancer Diagnostic

CALA will use and further develop the phase-contrast technique which is most promising for the early detection of small tumors. This an indispensable prerequisite for a highly efficient particle beam therapy.

Innovative Laser-Based Particle Beams for Cancer Therapy

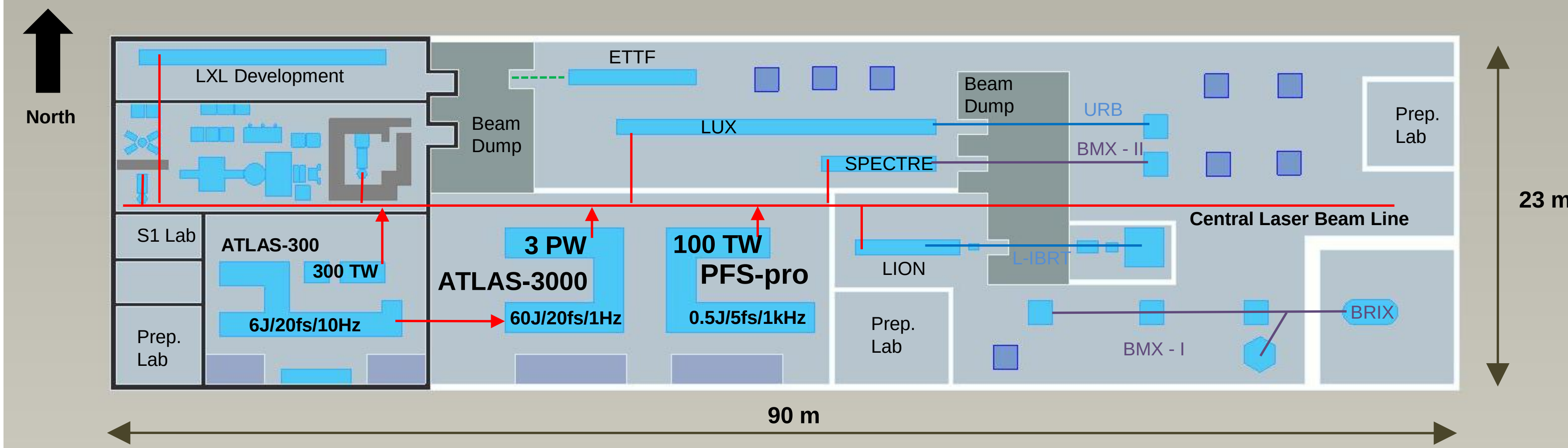
On the one hand, present particle beam facilities based on synchrotrons provide the most efficient and gentlest cancer treatment. On the other hand, they are huge in size, extremely complex and extremely costly.

The laser-based particle beams to be developed by **CALA** will be compact, cheap, and hence suited for hospitals.



[redacted]
Primary Sources
BRIX
PFS-pro
sync.
ATLAS-3000
Secondary Sources
Thompson Backscatt.
High Har-monics
Undul. x-rays
e⁻- and Thomson T. Facility
Ion acce-leration
LS XFEL
Biomedical Applications
Image Formation with Brilliant X-Rays
Ultrafast Radiation Biology
Tumor Therapy

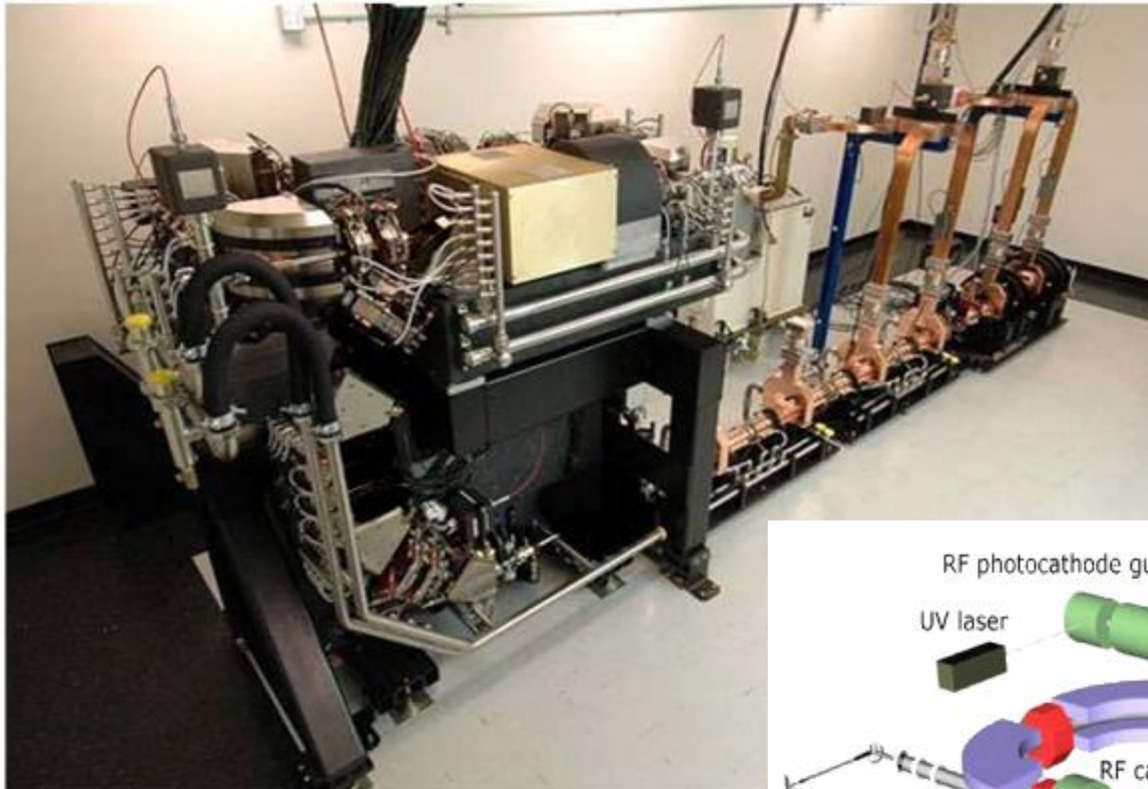
Footprint of the CALA Laboratory

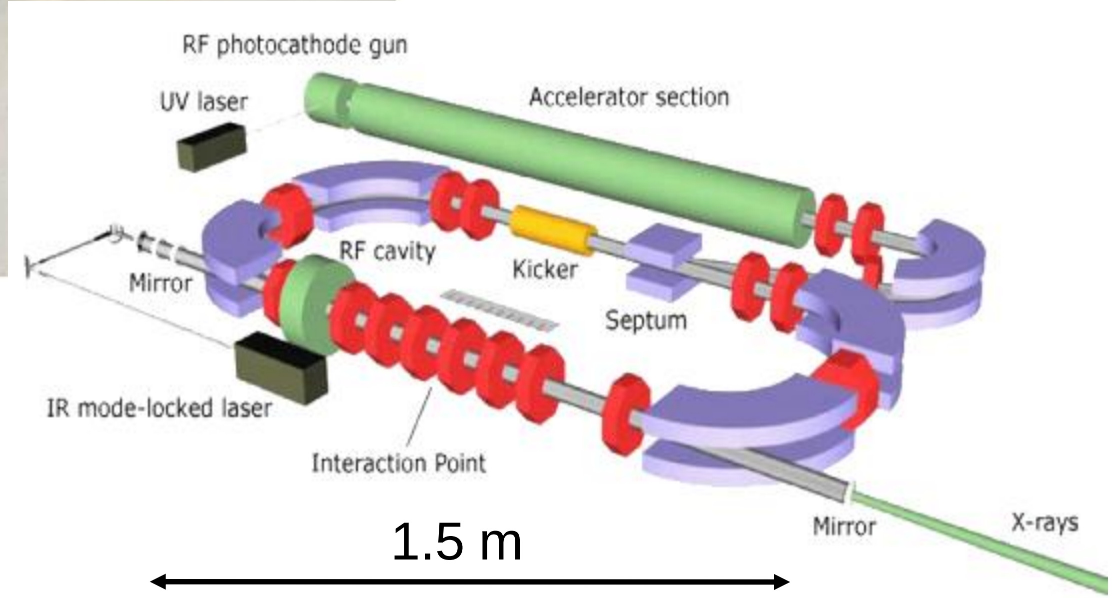


BRIX	**Brilliant X-rays, Synchrotron-based Thomson Source**	**BMX**	**Biomedical X-ray imaging**
ATLAS-3000	**Advanced Ti:sapphire laser, 3000 TW, 1 Hz**	**LION**	**Laser driven IONs**
PFS-pro	**Petawatt Field Synthesizer-pro, 500 TW/10 Hz and 100 TW/1 kHz**	**SPECTRE Compact**	**Source for Powerful, Energetic, Thomson Radiation Experiments**

L-IBRT	**Laser-based Ion Beam Radiation Therapy**
LUX	**Laser-driven Undulator X-ray source**
URB	**Ultrafast Radiation Biology**
LXL	**Laboratory-scale X-ray free –electron Laser**
ETTF	**Electron and Thomson Test Facility**

BRIX Brilliant X-Ray Source

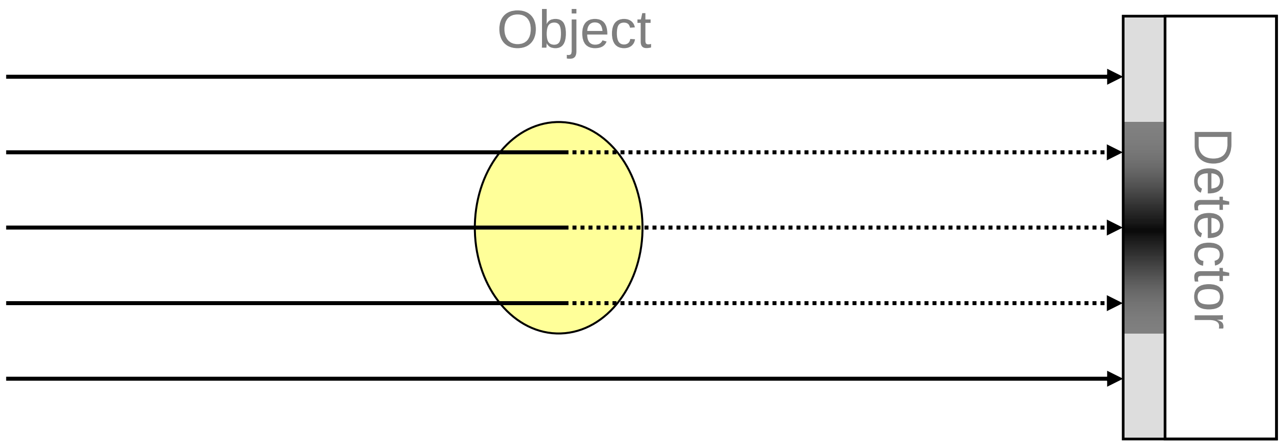




50-MeV/30-ps electron bunch circulating with 65 MHz in a storage ring;
50-ps laser pulse circulating in a ring enhancement cavity with 65/2-MHz.
X-ray output: 30-ps pulse with 20-35 keV and 10^9 ph/(sec mm^2 mrad^2 0.1%BW)

Conventional X-Ray Radiography

Absorption Contrast



$n = 1 - \delta + i\beta$

$\delta \sim \rho Z \lambda^2$; $\delta = 5\text{x}10^{-6}$ at 1 Å

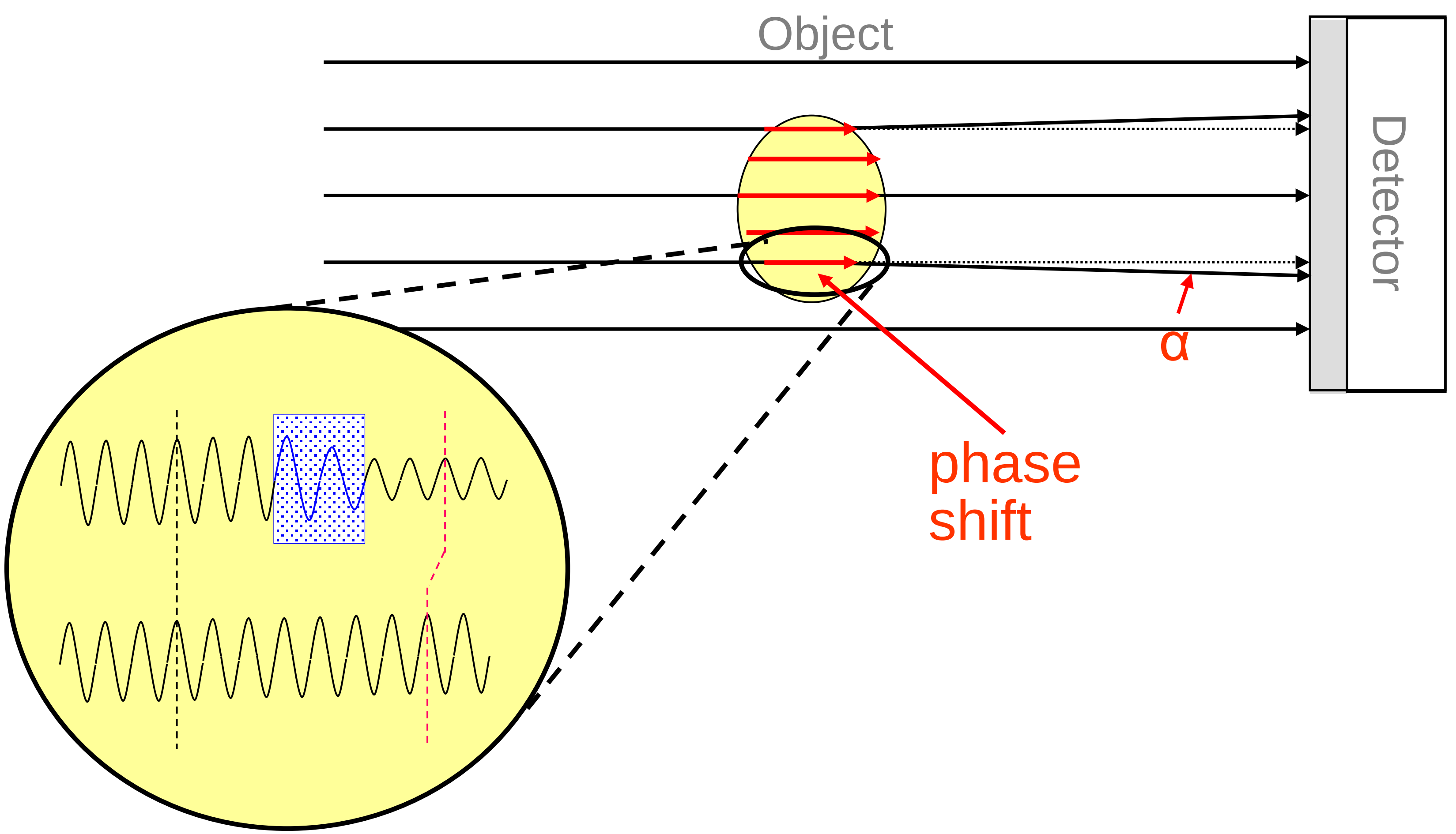
$\beta \sim \rho (Z\lambda)^4 << \delta$

0.1 Å $\leq \lambda \leq$ 1Å

Absorption relies on β, phase contrast on δ. The higher the x-ray energy the more favorable is phase-contrast imaging versus absorption imaging.

New 'Wave-Optical' X-ray Radiography

The concept of phase - contrast imaging is to measure the refractive index of the sample. This requires the measurement of the refraction angle α of a transmitted x-ray wave.



Phase-contrast techniques

Bonse & Hart 1965

X-ray interferometer

$\Delta E/E \sim 10^{-4}$, $\Delta\Theta/\Theta \sim 10^{-4}$

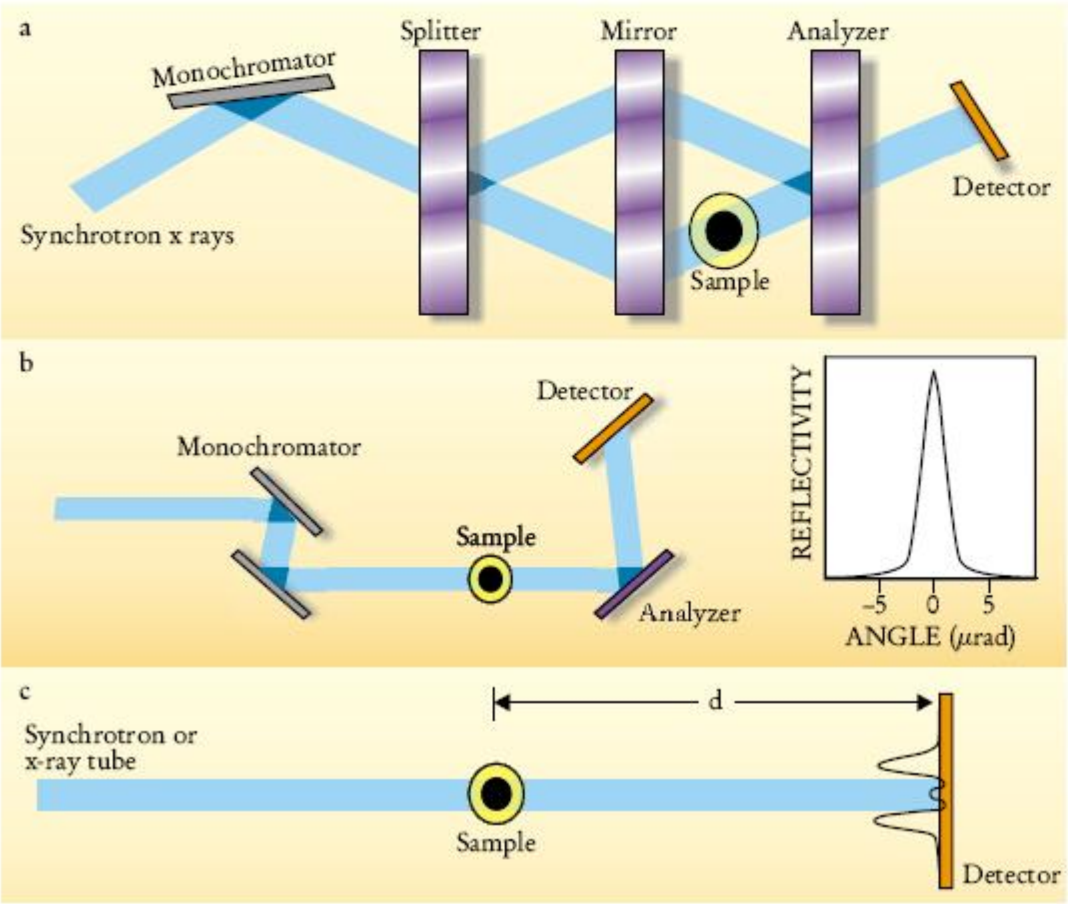
Very sensitive $\Delta\rho \sim 10^{-9}$ g/cm³

Measures **φ** directly

Field of view ~3cm x 3cm

Stability of 0,1 Å required

Used at synchrotrons only



Diffraction-enhanced imaging (DEI)

$\Delta E/E \sim 10^{-4}$, $\Delta\varphi/\varphi \sim 10^{-4}$

Measures grad**φ**

Analyzer sensitivity a few μrad

Used at synchrotrons only

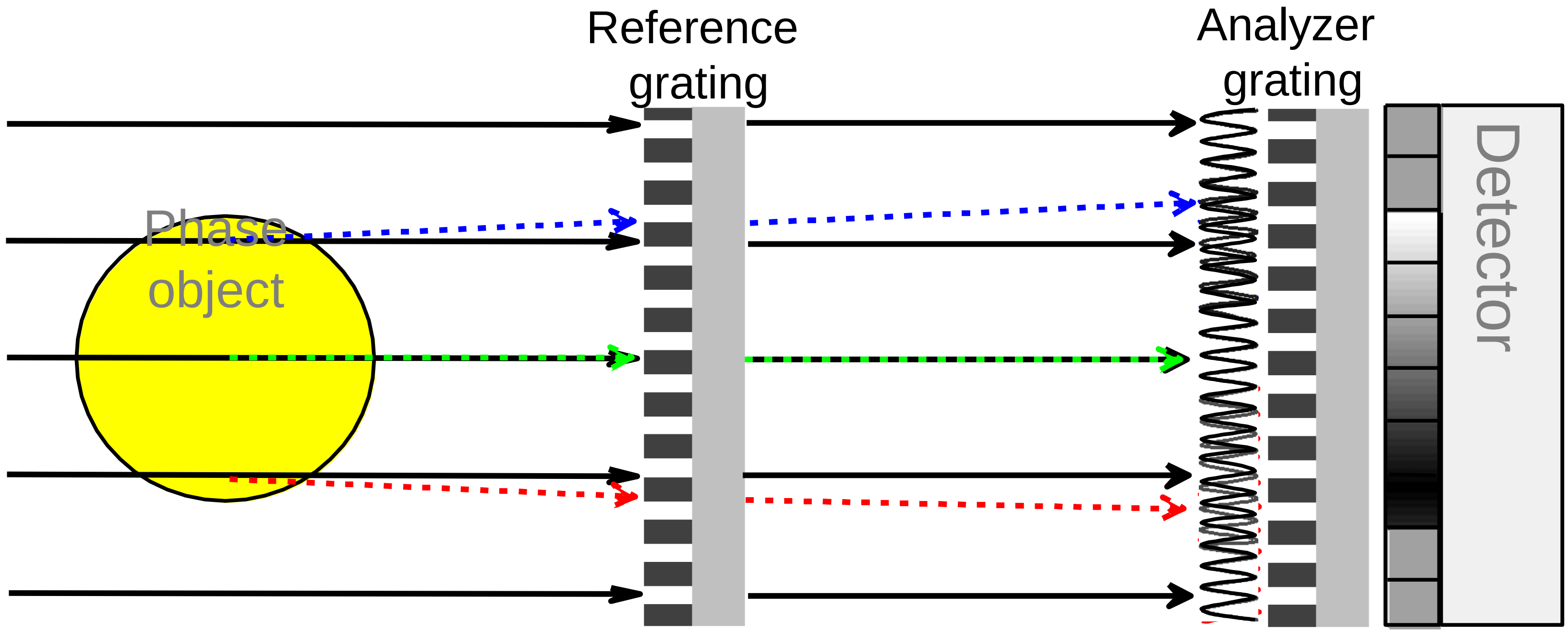
In-line phase-contrast imaging

(Gabor hologram)

Edge enhancement by Fresnel diffraction; contrast $\propto \Delta\varphi$

Phase-Contrast Imaging

The idea of using a grating interferometer for measuring the refraction angles is that a slight angular change experienced by a wave upon transmission of an object causes a transverse displacement of the interference pattern produced by the grating.

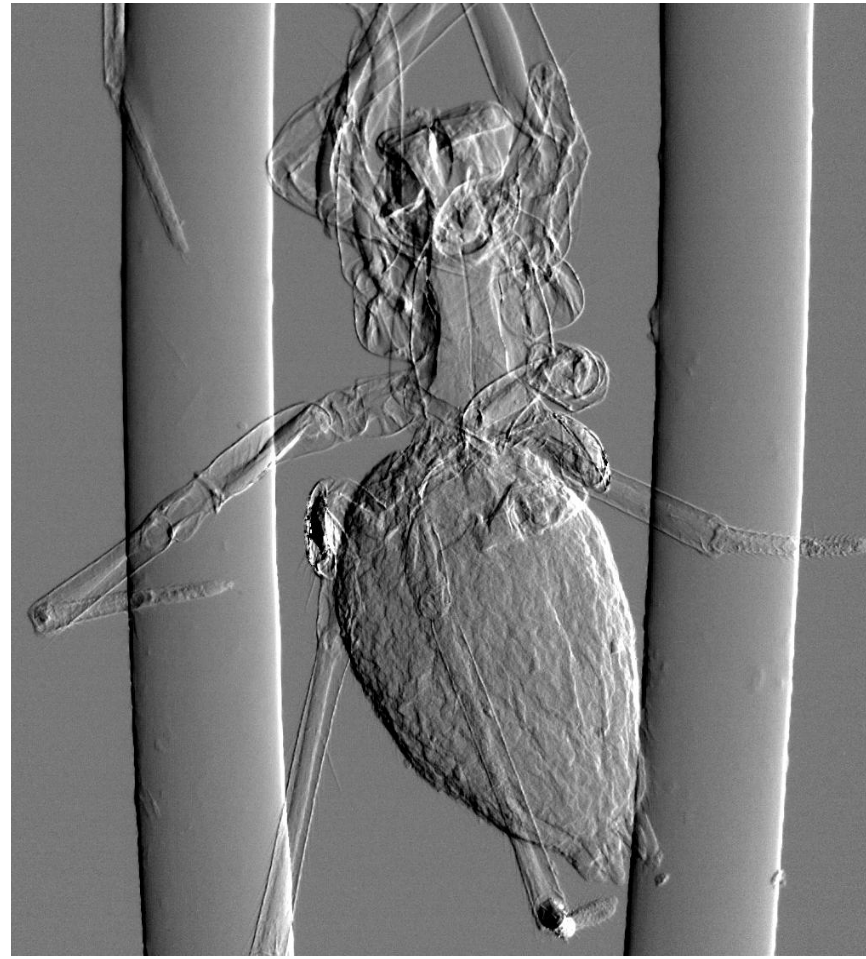


F. Pfeiffer et al, patent applications EP05012121 (2005) & EP06014449 (2006)
F. Pfeiffer et al, Phys Rev Lett 94, 164801 (2005)
F. Pfeiffer et al, Nature Physics 2, 258 (2006)

First Synchrotron Results

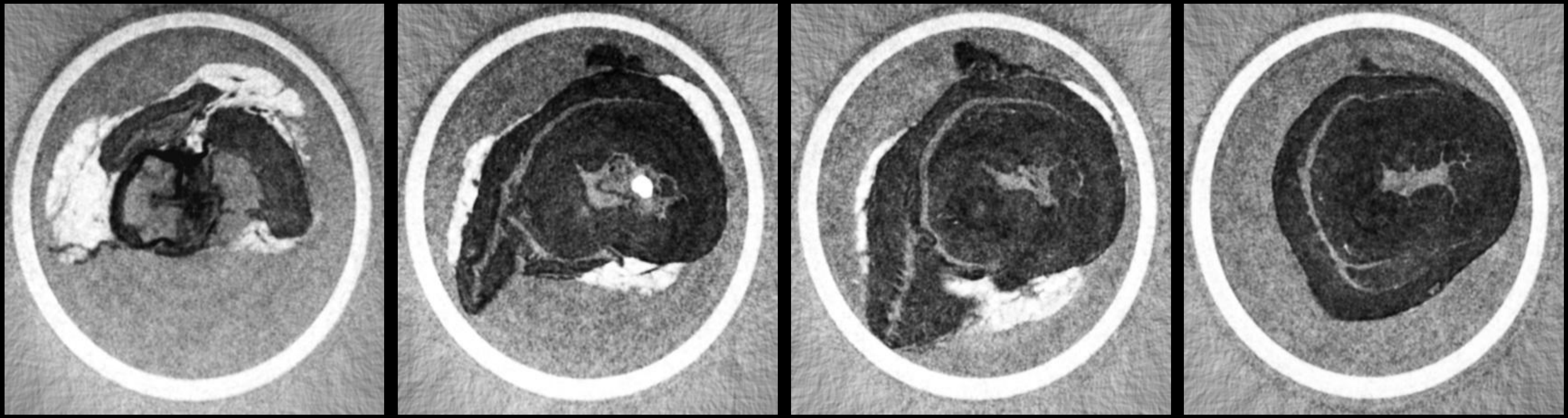
Transmission

Phase contrast

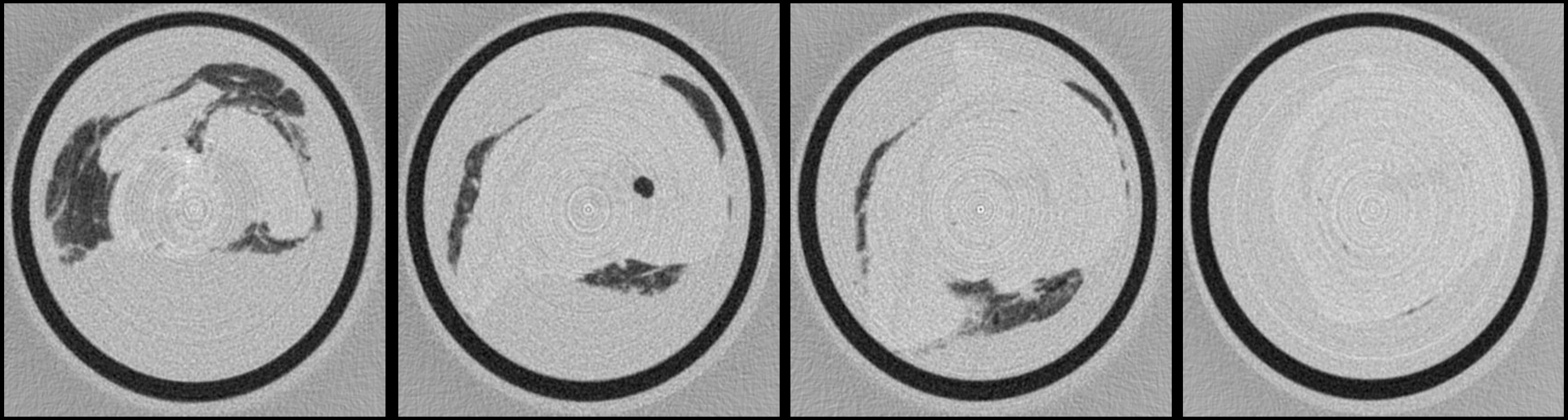


ESRF ID 19, June 2005, 17.5 keV

T. Weitkamp et al., Optics Express 13, 6296 (2005) phase-contrast CT



Chicken heart, in-vitro, 360 projections, ~28 keV, x-ray tube, same exposure time !

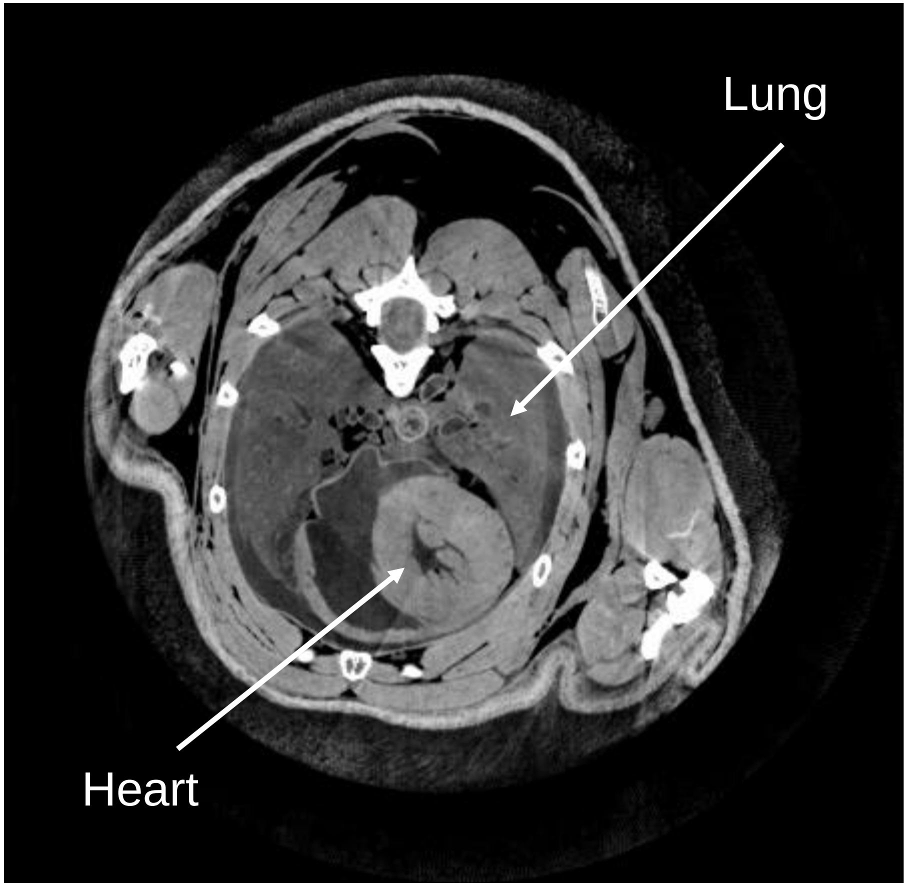


conventional absorption CT

M. Bech et al, Phys. Med. Biol. 54, 2747 (2009)

Conventional CT

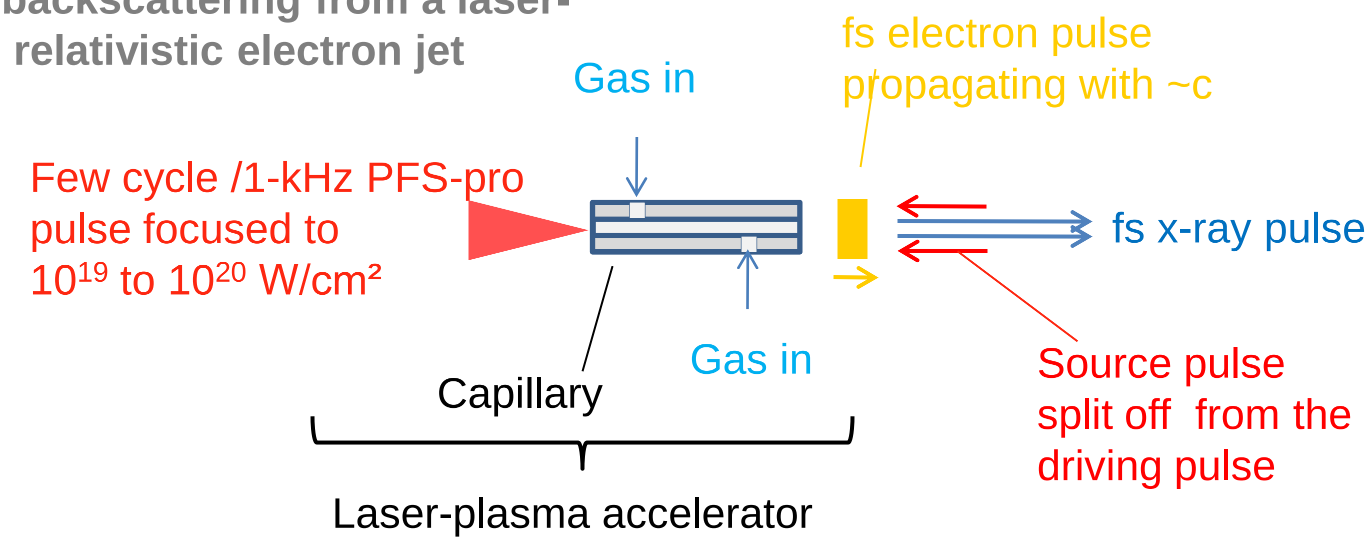
Grating phase-contrast CT



Tomographic image of the breast area of a mouse

Laser-based x-ray source → SPECTRE

Thomson backscattering from a laser-generated relativistic electron jet



The laser-generated electron pulse is rather monochromatic and tunable in energy. Hence the backscattered x-ray pulse is also tunable in energy.

$$\lambda_x = (\lambda_L / 4\gamma^2) \cdot (1 + a_L^2/2 + \gamma^2 \Theta^2)$$

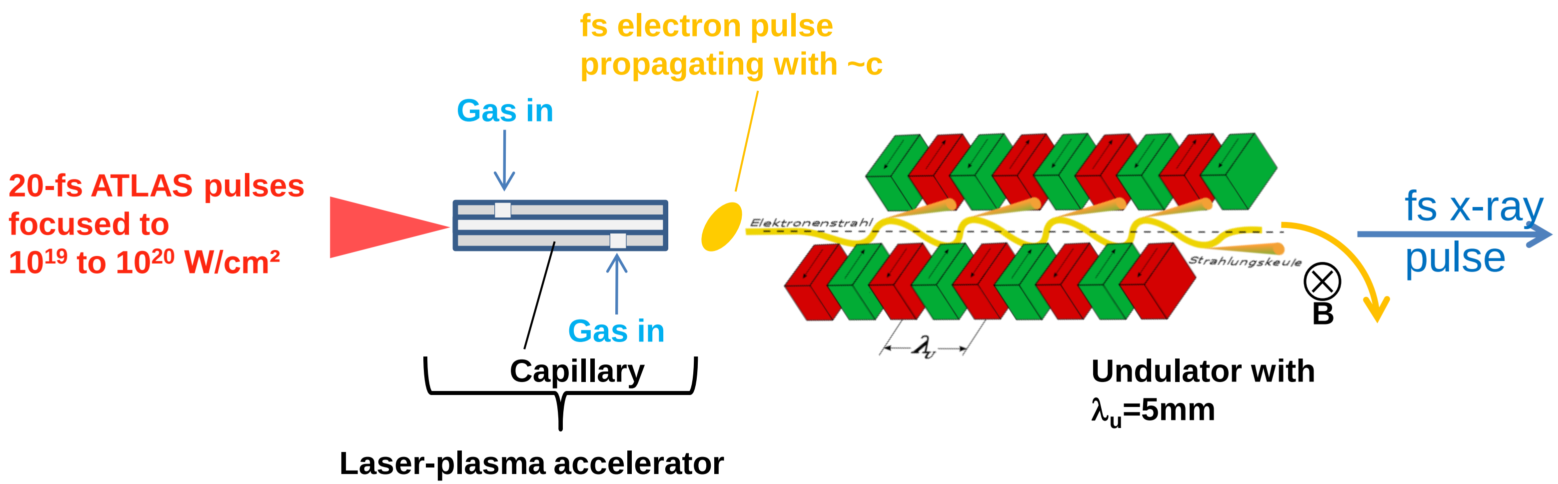
For $a_L < 0.5$ and $\Theta \cong 0$ (on-axis) $E_x = 4\gamma^2 E_L$

Range of x-ray energies at $E_L = 1.5$ eV and $E_e = 25 - 200$ MeV } $E_x = 15$ keV – 1 MeV

With 10^{10} x-ray photons/s and a few percent bandwidth well suited for phase-contrast imaging with gratings.

Laser-based x-ray sources→ LUX, LXL

LUX Spontaneous undulator emission; XFEL Stimulated undulator emission



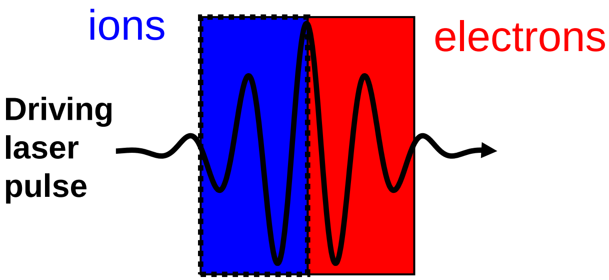
$$\lambda_x=(\lambda_u/2\gamma^2)\cdot(1 + K^2/2 +\gamma^2\Theta^2)$$

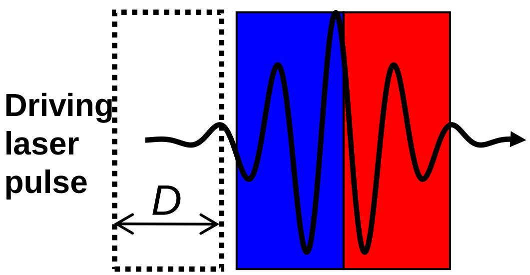
First success with spontaneous undulator emission :
A 210-MeV (γ=412) electron beam generated with ATLAS yielded 10-fs, on-axis x-ray pulses at 18nm.
M. Fuchs et al., Nature Physics 2010

XFEL needs ATLAS-3000 and a high-quality e-beam.
Both will be developed within CALA.

Ions by Light Pressure Acceleration → LION

Human therapy requires proton energies of 150-200 MeV and carbon ion energies of 4 to 6 GeV or 350 to 500 MeV/u. Present models predict that intensities of ~10^{23} W/cm² are needed. This is within reach of ATLAS-3000.





Optimal foil thickness: $D/\lambda = (n_c/n_e)\, a_L/\pi$

Tripathi et al., Plasma Phys. Contr. Fusion **51**, 024014 (2009)

n_e electron density

n_c critical electron density

D target thickness

λ laser wavelength

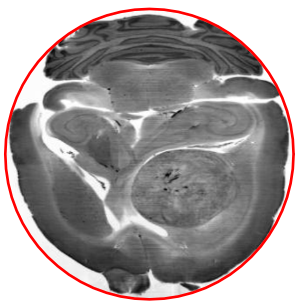
a_L dimensionless vector potential

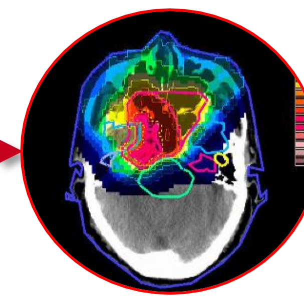
Bunch characteristics
Laser: Femtoseconds, 10^{12} particles/pulse
Classical: Seconds, 10^7 to 10^{10} particles/pulse

CALA Vision

Brillant X-Rays

Ion-/ Proton Beams





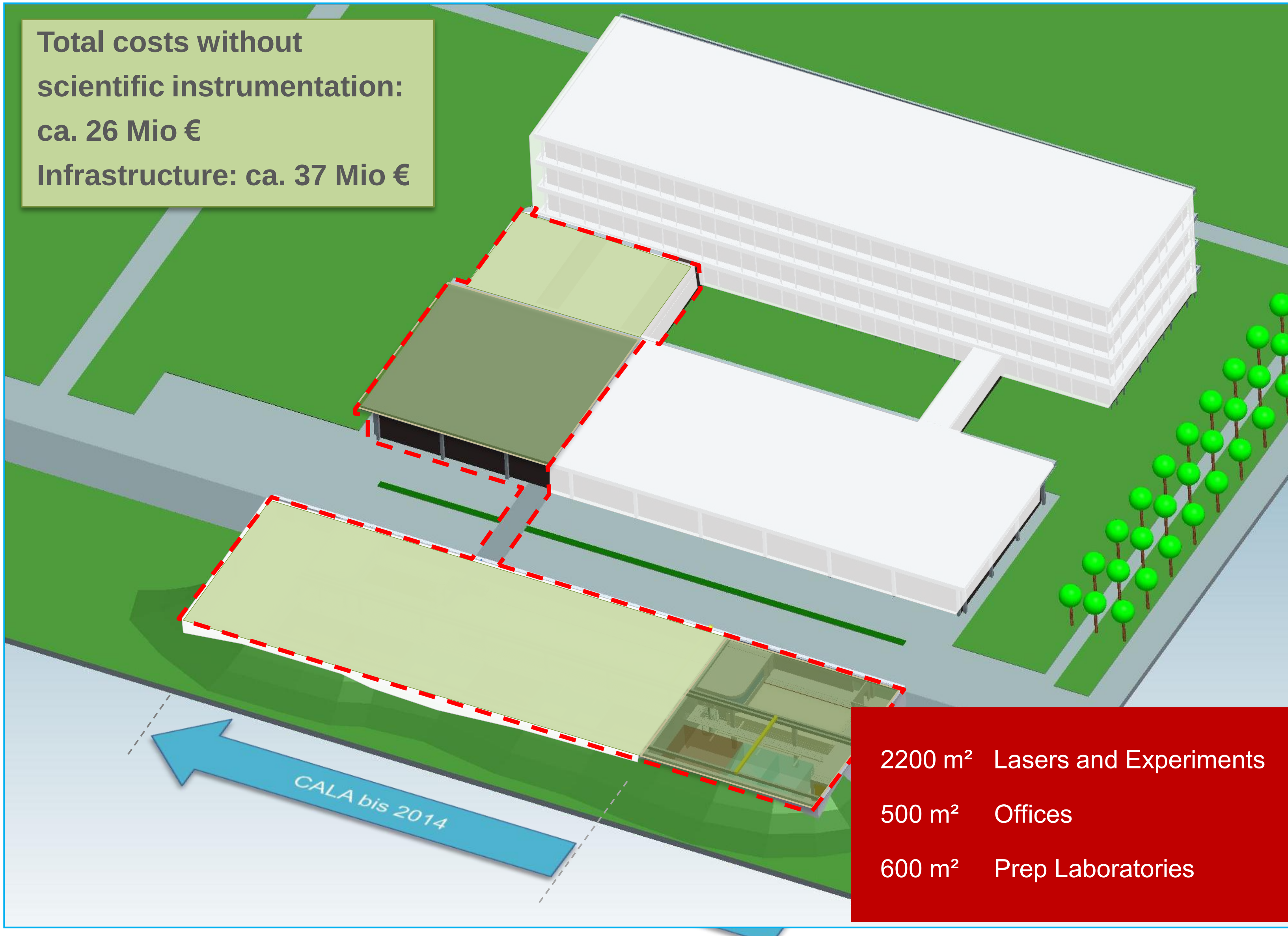
High-Resolution
Phase-Contrast Imaging

Patient

Precisely Targeted
Tumor Therapy

Compact, low-cost purely laser-driven facility simultaneously used for cancer diagnostics and treatment. This will offer patients a broad access to the most efficient healing method.

Projected completion till 2014



Total costs without scientific instrumentation: ca. 26 Mio €

Infrastructure: ca. 37 Mio €

2200 m²	Lasers and Experiments
500 m²	Offices
600 m²	Prep Laboratories