BoCXS: a Compact Multidisciplinary X-ray Source and Medical Imaging project

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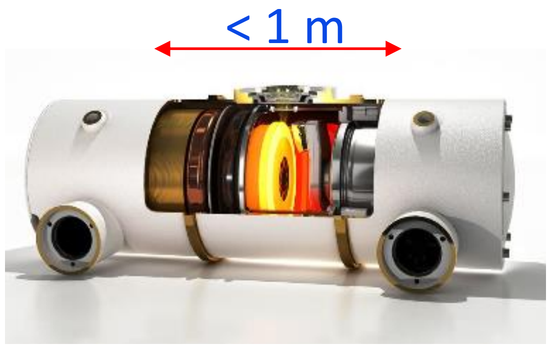
MONOCHROMATIC X-ray SOURCES

CONVENTIONAL X-ray tube

- COMPACT
- AFFORDABLE
- COMMERCIALLY AVAILABLE
- LIMITED BRIGHTNESS



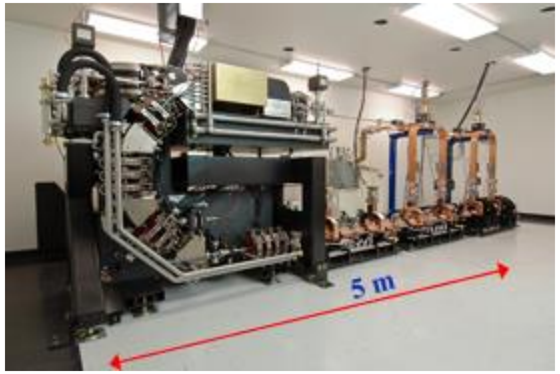
ACCELERATOR DRIVEN

SYNCHROTRON / UNDULATORS

- HIGH BRIGHTNESS
- ENERGY TUNABILITY
- PARTIAL COHERENCE

ICS: ***BRIDGE THE GAP***

- LOWER e- ENERGY
- HIGHER BRIGHTNESS AND X-ray ENERGY
- COMPACT and ACCESSIBLE
- CONTAINED FINANCIAL INVOLVEMENT



ICS and Synchrotron Light Brightness

Courtesy: A. Murokh, L. Serafini

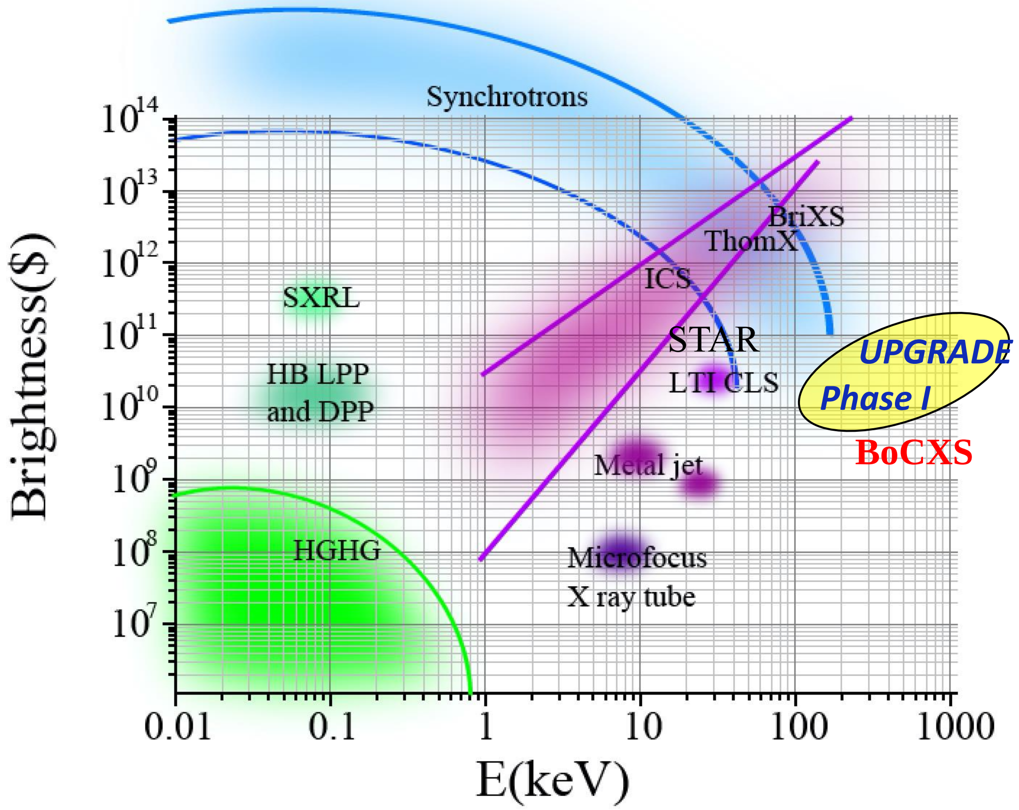
$$\mathcal{B} = \frac{Flux}{4\pi\Sigma_x\Sigma_{x'}\Sigma_y\Sigma_{y'}}$$ [*Photons/s/mm²/mrad²/0.1%BW*]

ICS and Synchrotron Light Sources compete above 80-100 keV

Critical Frequency in Dipolar Emission

Transverse e- beam sizes in SR (Quantum Emission)

$: Photons/s/mm²/mrad²/0.1%BW



THE MEDICAL IMAGING CHALLENGE

Conventional X ray absorption SOFT-TISSUE DIAGNOSTICS

Cartilages, Angiography, Breast, Brain, Lungs

➡ **Low contrast, limited detectability in anatomical background**

Detectability usually enhanced using **contrast agents**

not always patient-friendly (catheterization, allergic reaction, toxicity)

Advanced X ray imaging

⬇

INCREASED DIAGNOSTIC POWER

LOW DOSE / SHORTER EXPOSURE

LOWER OR NO USE of CONTRAST AGENTS

NEW IMAGING TECHNIQUES
phase contrast, dual energy

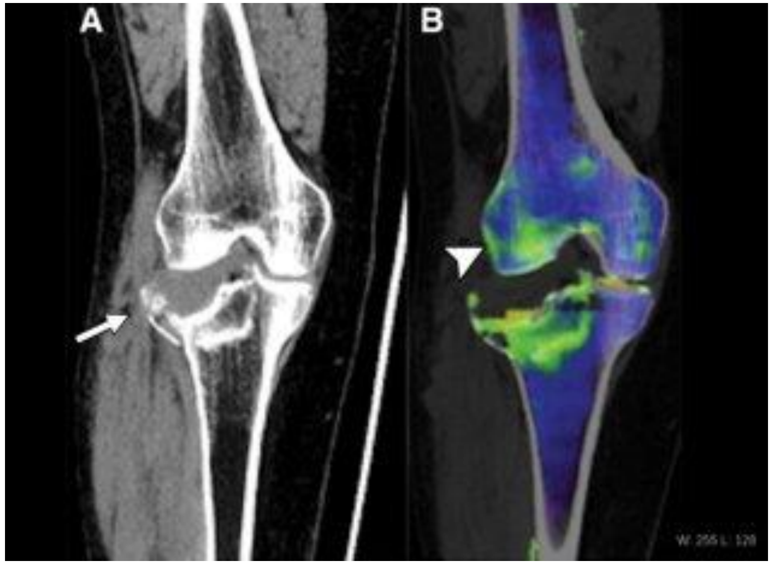
⬅ **COMPACT ICS X-ray sources**

DUAL-ENERGY IMAGING

A brilliant **tunable** monochromatic (or quasi-monochromatic) source allows to implement:

Dual (or multi) energy imaging

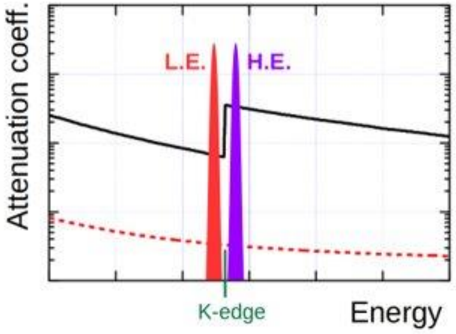
Patino, Manuel, et al. "Material separation using dual-energy CT: current and emerging applications."*Radiographics* 36.4 (2016): 1087-1105

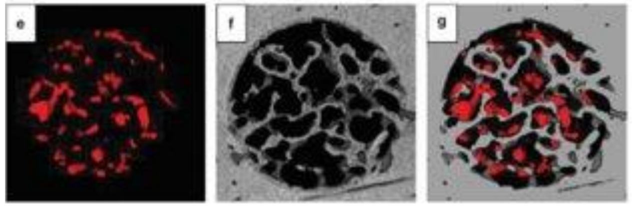


Assessment of bone marrow edema using dual-energy CT.

K-edge subtraction (KES) imaging

Matsumoto, T et al "Subtraction micro-computed tomography of angiogenesis and osteogenesis during bone repair using synchrotron radiation with a novel contrast agent." (2013) *Laboratory Investigation* 93.9

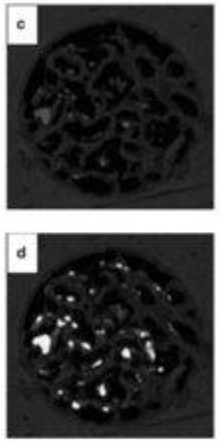




Contrast medium

Surrounding tissue

Tissue + Contrast medium



HE absorption image

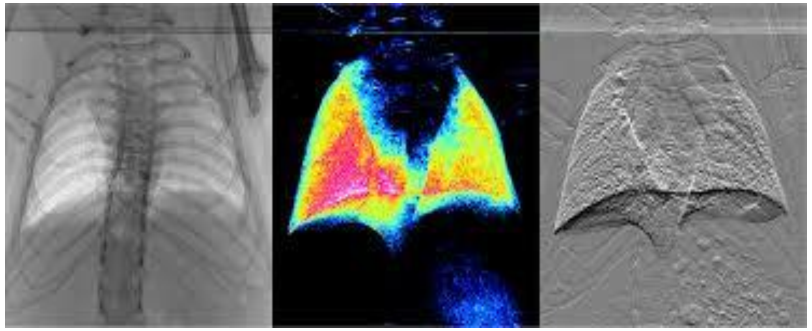
LE absorption image

PHASE-CONTRAST IMAGING

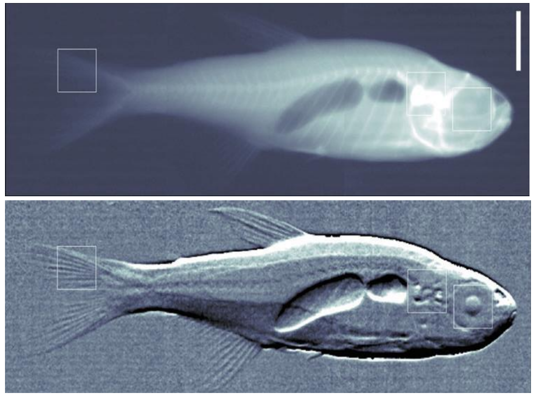
A brilliant **coherent** (or partially coherent) source allows to take advantage of X-ray refraction

X-ray Phase-Contrast Imaging

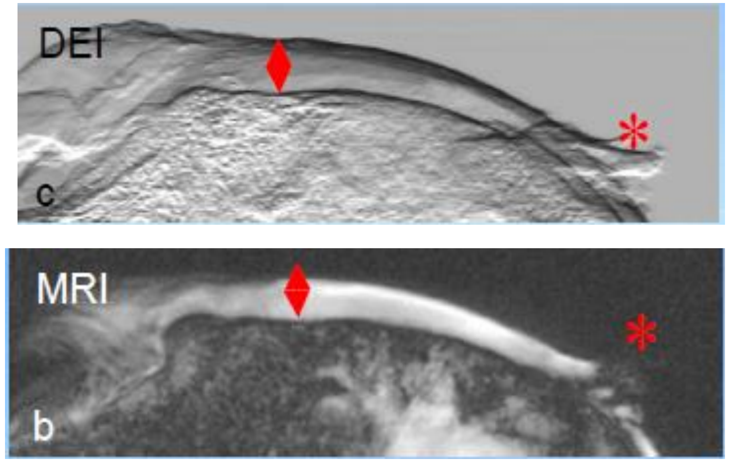
high-resolution images of low contrast details not visible in conventional absorption X-ray imaging



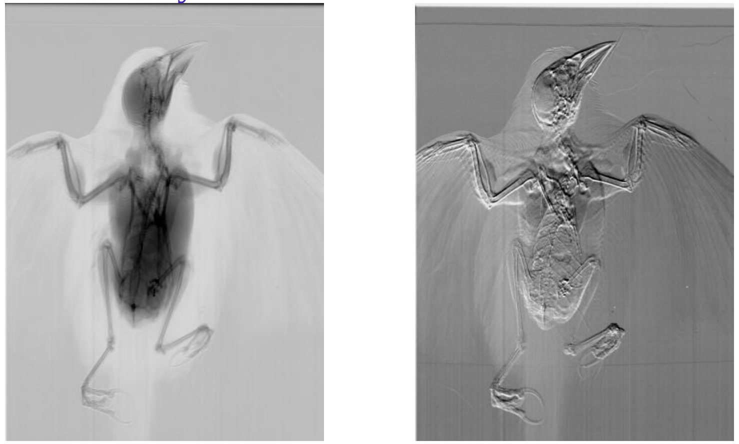
Courtesy: M. Kitchen et al. / Monash University



Courtesy: F. Pfeiffer et al. / TUM



Courtesy: G. Tromba et al. / Elettra TS

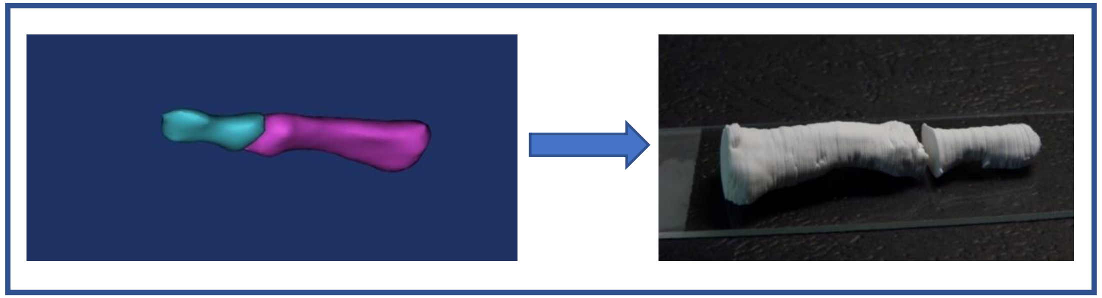


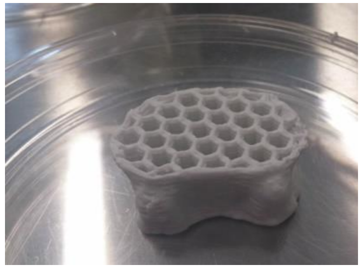
Courtesy: G. Tromba et al. / Elettra TS

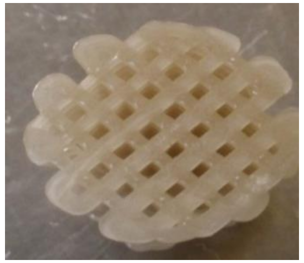
Laboratorio RAMSES
Laboratorio di Studi Preclinici per la Medicina Rigenerativa dell'Apparato Muscolo-scheletrico
Dirigente Responsabile Dott.ssa Brunella Grigolo

BIOFABRICATION

DESIGN E REALIZATION OF CUSTOM-MADE CONSTRUCTS BASED ON CLINICAL DATA

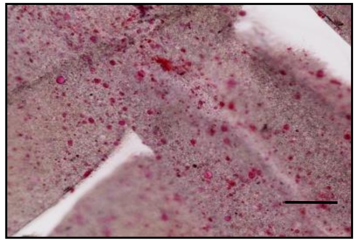




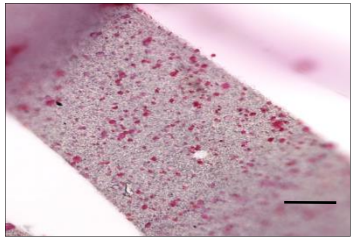


PCL+ MN

DAY 14



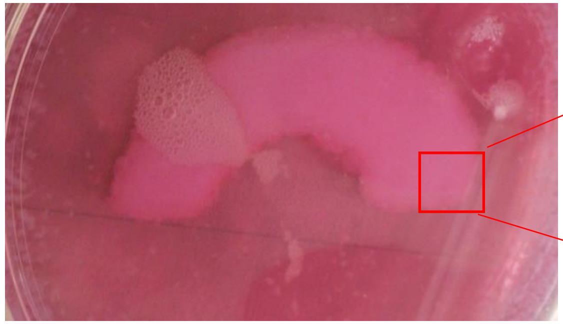
DAY 21



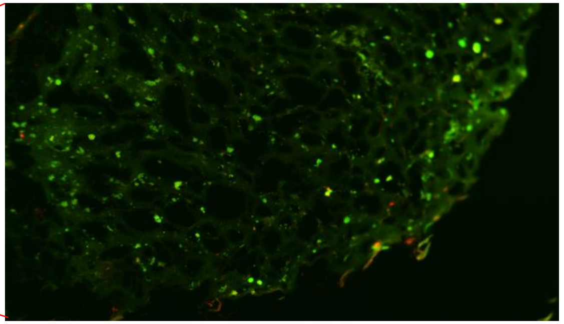
BIOCATIVE COMPOSITES:
PCL + Bioglass
PCL + Magnetic Nanoparticles (MN)

EVALUATION OF THE OSTEOGENIC POTENTIAL BY ALIZARIN RED STAINING

DESIGN AND DEVELOPMENT OF DIFFERENT MUSCOLO-SKELETAL SUBSTITUTES



Meniscus prototype made in collagen seeded with mesenchymal stem cells

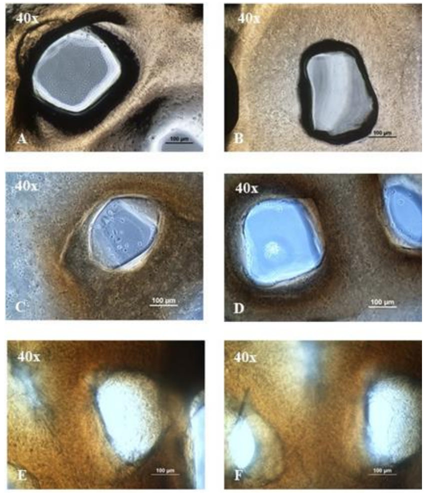


Viability test with Live & Dead assay at 28 days

Post-printing

Day 14

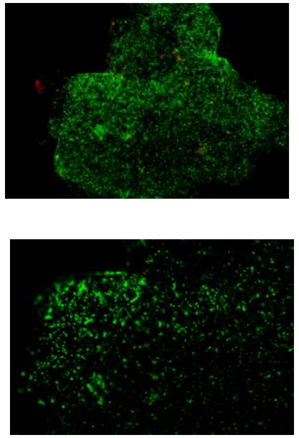
Day 28



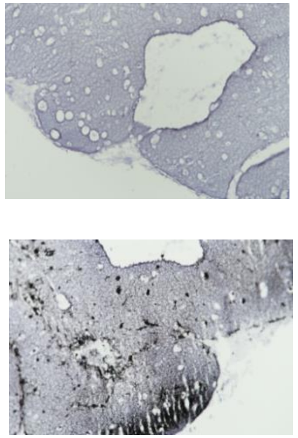
Silk fibroin scaffold functionalized with $CaCl_2$ seeded with mesenchymal stem cells for bone regeneration

Post-printing

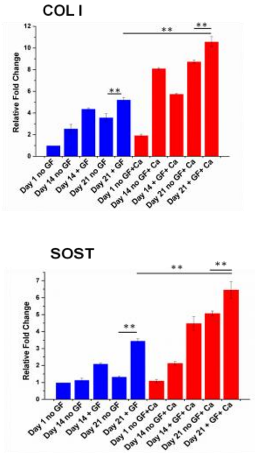
Day 28



Cell viability



von kossa staining



Gene expression

FROM SYNCHROTRON TO ICS X SOURCES

SYNCHROTRONS
UNDULATOR

X-ray energy has
similar expressions but…

COMPACT SOURCE
ICS

$$E_X^u \sim \frac{hc}{(m_e c^2)^2} \frac{E_e^2}{\lambda_u}$$

$$\lambda_{ph} \sim 10^{-4}\, \lambda_u$$

$$E_X^u \sim \frac{4\, hc}{(m_e c^2)^2} \frac{E_e^2}{\lambda_{ph}}$$

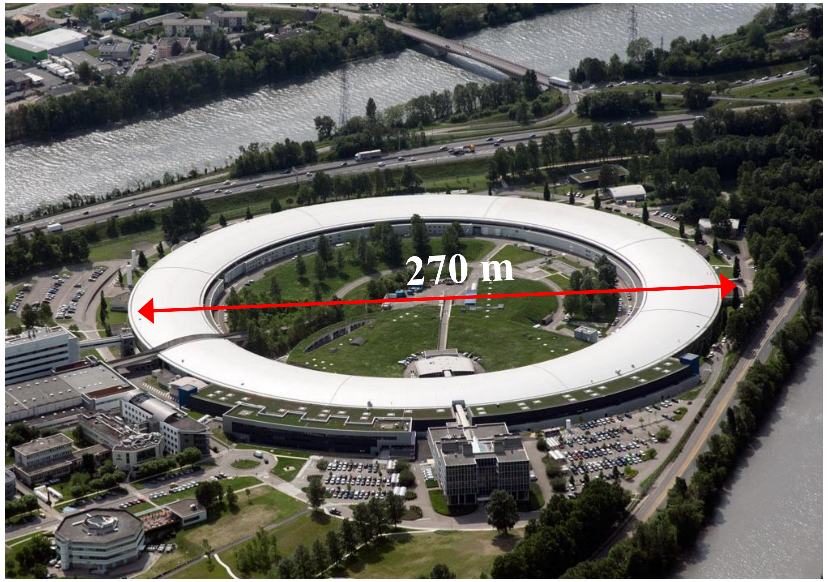
TWO BIG ADVANTAGES

$$E_{ICS} \sim 10^{-2}\, E_u$$

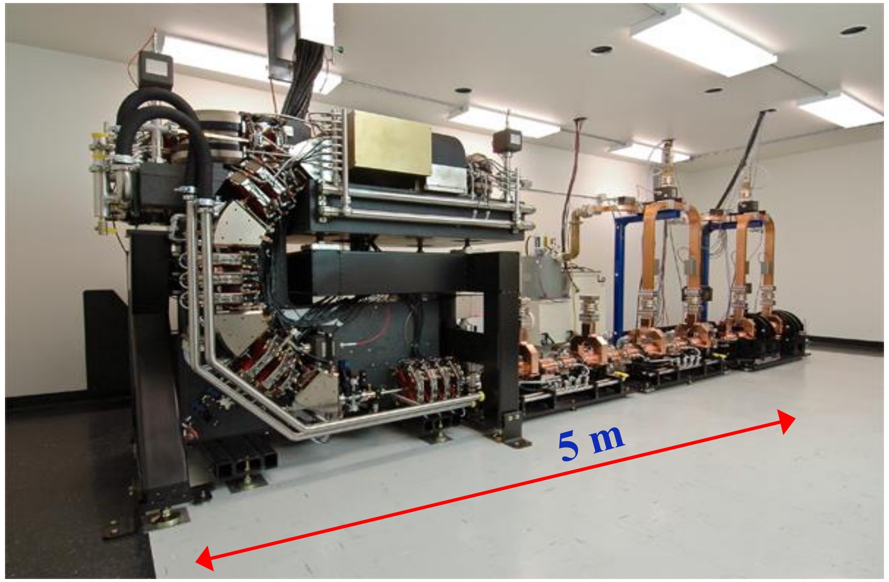
COMPACTNESS, COSTS
HIGHER E_x *@ LOWER* E_u

$$\alpha_X^{ICS} \gg \alpha_X^u$$

SHORTER
IMAGING DISTANCE



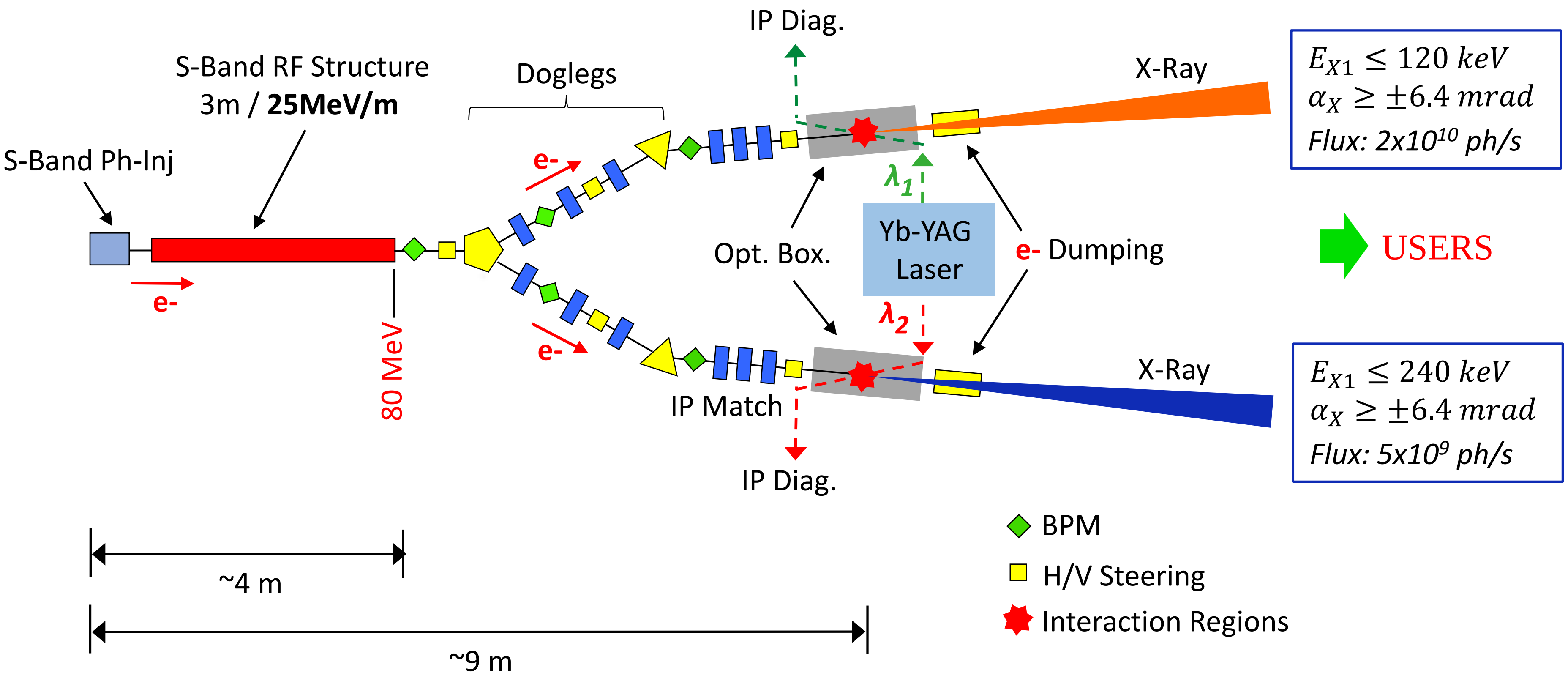
ESRF: 6 GeV e- / **844 m** Circumference
10-40 keV X-rays



CLS: 40 MeV e- / **5x4 m²** footprint
30-40 keV X-rays

PROPOSED FACILITY BoCXS

Double Arm S-Band STAR–like Source



FOOTPRINT ~ 3 x 9 m^2

SHORT PARAMETER LIST

Scattered Photon **Energy** scales with the **square** of the **electron Energy** and the **Laser Harmonic**

$$E_X = 1.9 \times 10^{-2} \frac{E_e^2(MeV)}{\lambda_{ph}^0(\mu m)} h_L$$

Key parameters range

E_e 40 - 80 MeV

h_L =1 **flux 2 10^{10} ph/s**
E_X 30-120 KeV

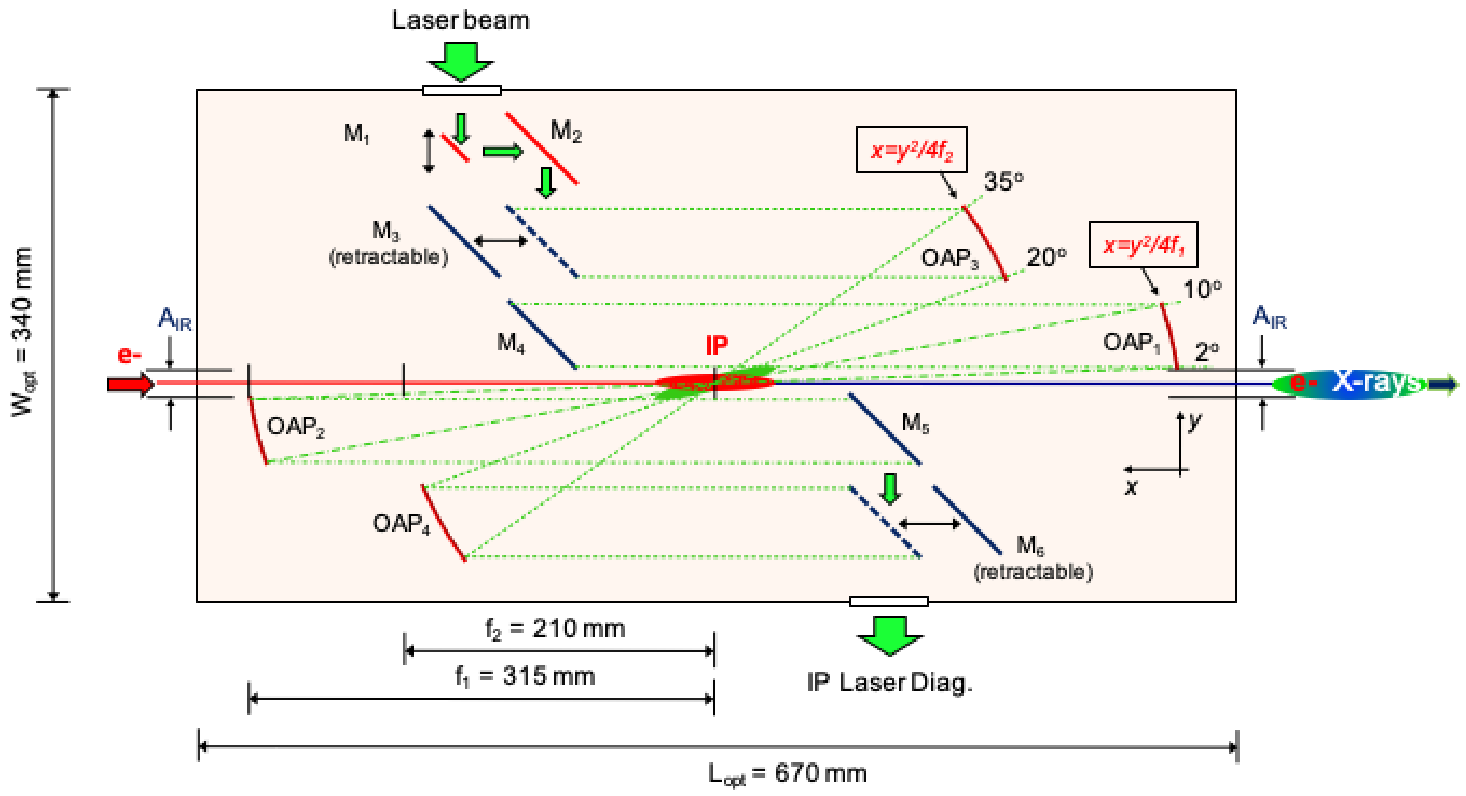
h_L =2 flux 0.5$10^{10}$ ph/s
E_X 60-240 KeV

SOURCE	PARAMETER		VALUE
LINAC	Energy	*MeV*	80
	Bunch charge	*pC*	500
	Bunch length	*ps*	3.5
	Peak current	*A*	140
	Avg. current	*μA*	0.05
	Rep. Rate	*Hz*	100
Yb-YAG LASER	Pulse Energy	*J*	0.85
	Wavelength	*nm*	1024-512
	Harmonic h_L		1-2
	Pulse duration	*ps*	5
	Rep. Rate	*Hz*	100
X-ray	Energy	*keV*	120- (240)
	Pulse duration	*ps*	<5
	Flux	*ph/s*	2- (0.5))x10^{10}
	Divergence	*mrad*	+/- 6.4

Scattered Photon **Flux** scales with the **Linac current** and the **Inverse square** of the the **Laser Harmonic**

$$\dot{N}_X = \sigma_T L = \frac{\sigma_T}{A(\varphi)} \frac{E_{LP}^0 I_{linac}}{e\,hc} \frac{\lambda_{ph}^0}{h_L^2}$$

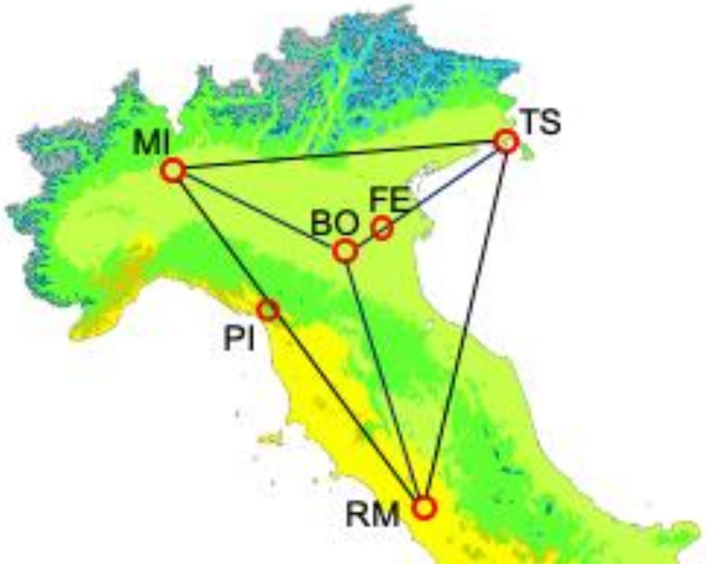
Optical System for Interaction Angle Tuning



Small angle (2º-10º) setup for **fine tuning**. Large angle (20°-35°) for **dual energy** (2-4 KeV X-ray shift)

THE DREAM

A MULTIDISCIPLINARY INITIATIVE POINTING AT
ADVANCED MEDICAL IMAGING (AND MORE)
LOCATED IN THE BOLOGNA METROPOLITAN AREA
IN THE CENTER OF A SCIENTIFIC AND TECHNOLOGICAL TRIANGLE



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THANK YOU FOR YOUR ATTENTION

A PROJECT IS A DREAM WITH A DEADLINE