The Compact X-ray source ThomX: context, status and plans

Marie Jacquet on behalf ThomX collaboration

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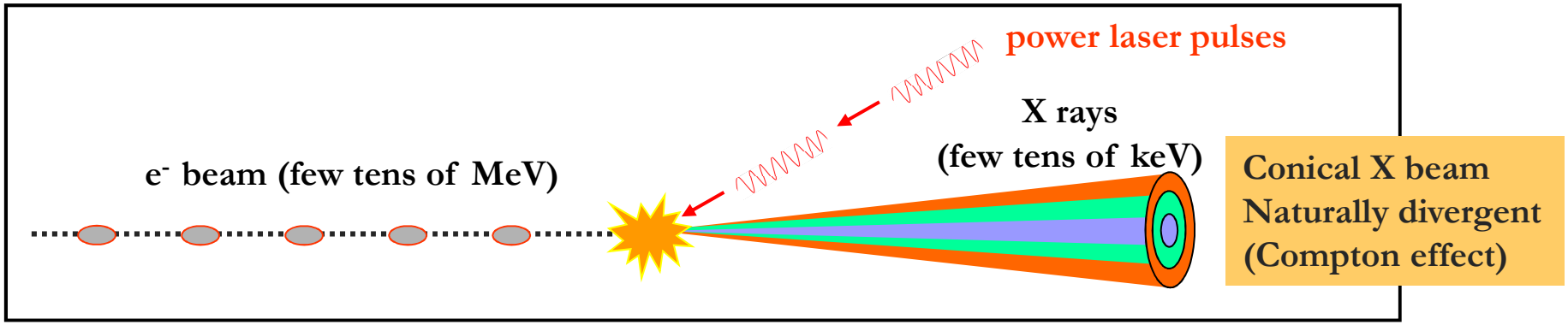
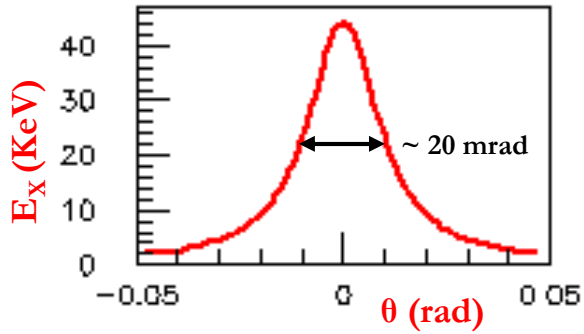
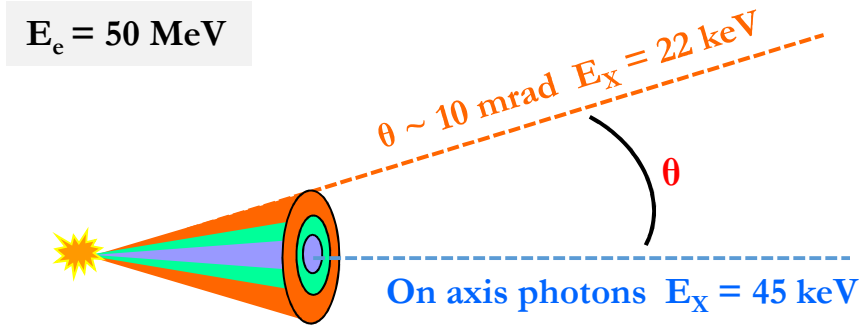
Compton Compton Sources(CCS): principle



Univocal relation between energy E_X and diffusion angle θ : $E_X \sim \dfrac{4\,\gamma^2\,E_{ph}}{1+\gamma^2\,\theta^2}$

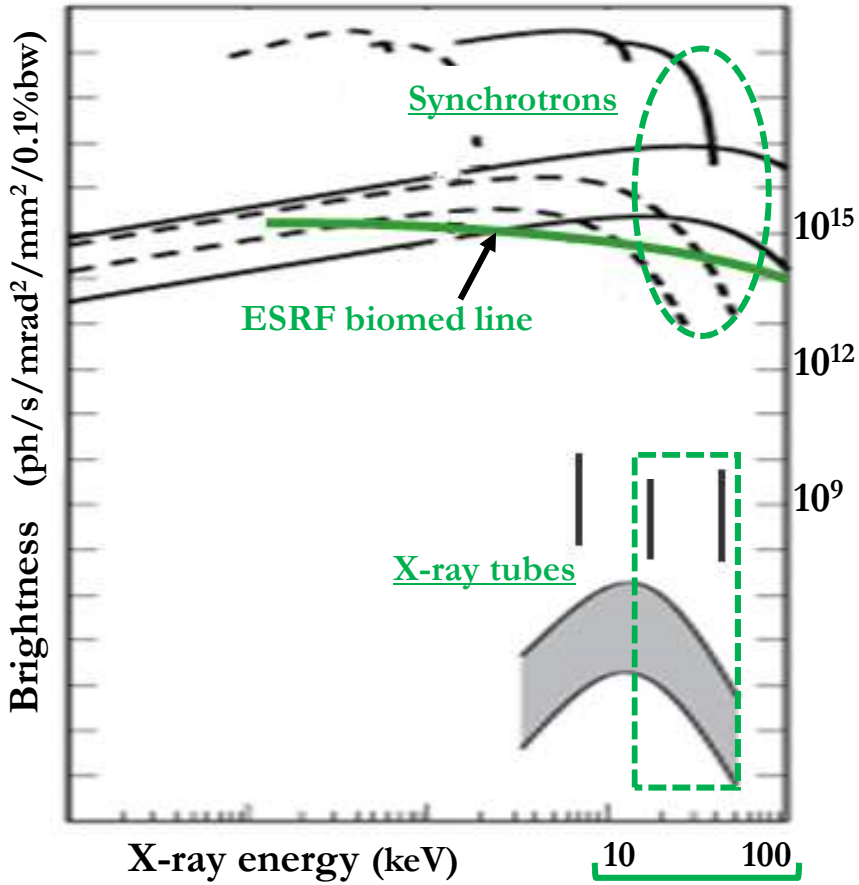




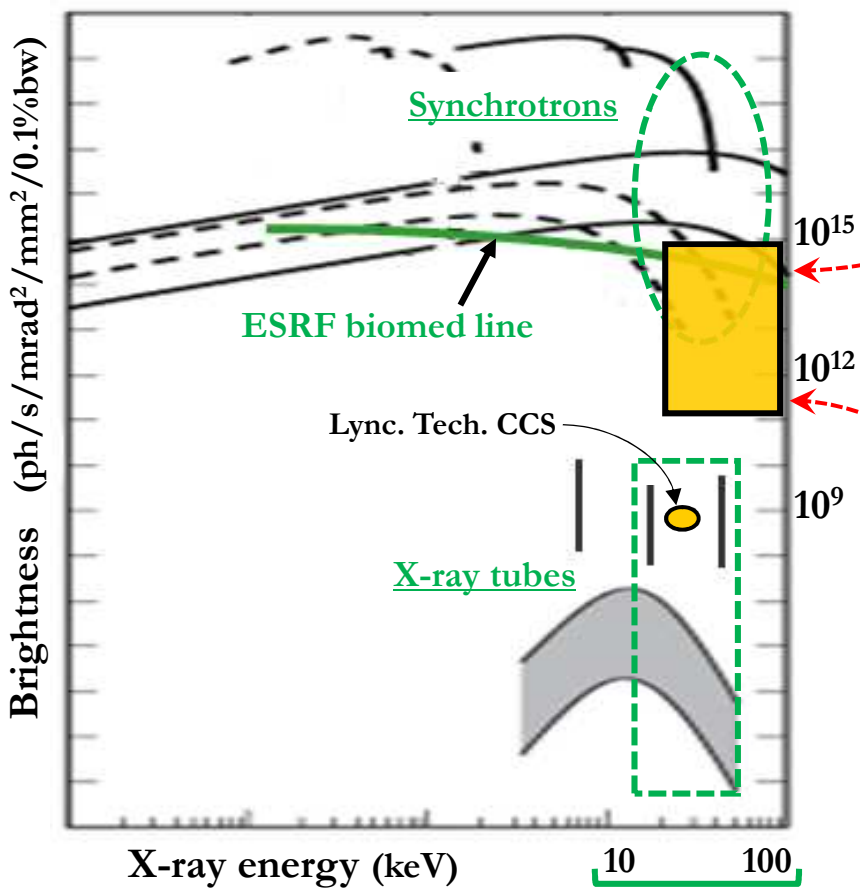
<u>Compton source</u> :

Compact installation (surface < 100 m²)

Brightness of intense X-ray sources



Brightness of intense X-ray sources



Next future CCS

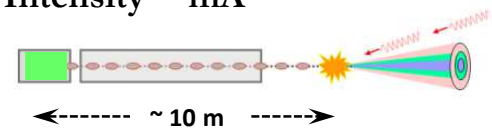
(superconducting machines)

Near future CCS

= almost current ("hot" machines)

LINAC

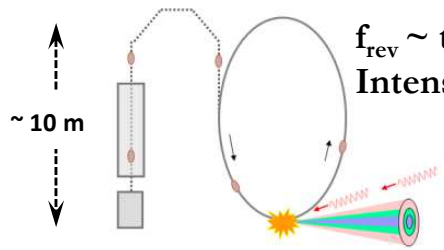
f_{inj} ~ tens MHz
Intensity ~ mA



Emittances e^- 0.1 - 0.5 mm.mrad
Flux $10^{13\text{-}14}$ ph/s
Bright. $10^{14\text{-}15}$

$$Br \sim 1.5\ 10^{-3}\ \frac{\text{Flux}}{(2\pi)^2}\left(\frac{\sigma_e^2+\sigma_L^2}{\sigma_L^2}\right)\left(\frac{\gamma^2}{\varepsilon_N^2}\right)$$

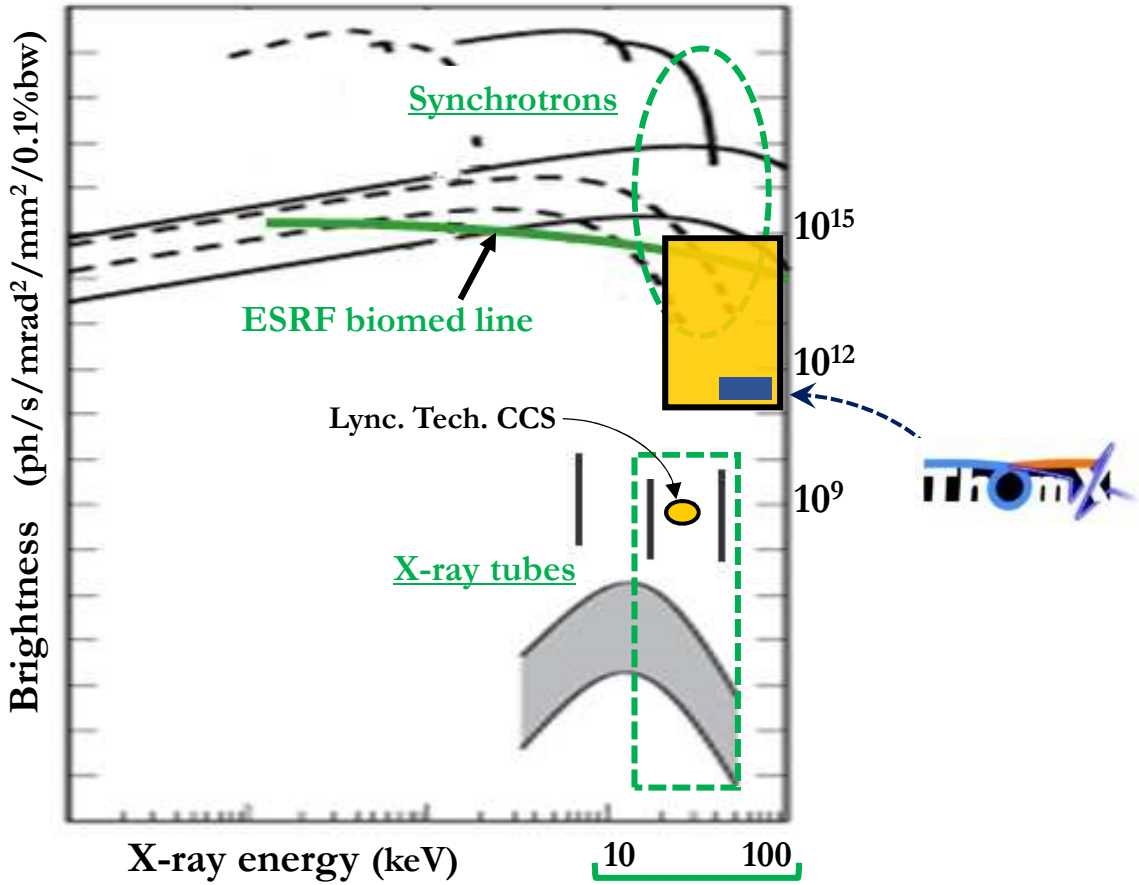
STORAGE RING



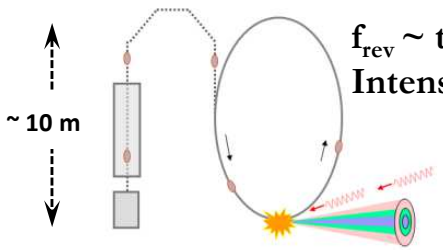
f_{rev} ~ tens MHz
Intensity ~ 10 mA

Emittances e^- 1 - 10 mm.mrad
Flux $10^{12\text{-}13}$ ph/s
Bright. $10^{11\text{-}12}$

Brightness of intense X-ray sources



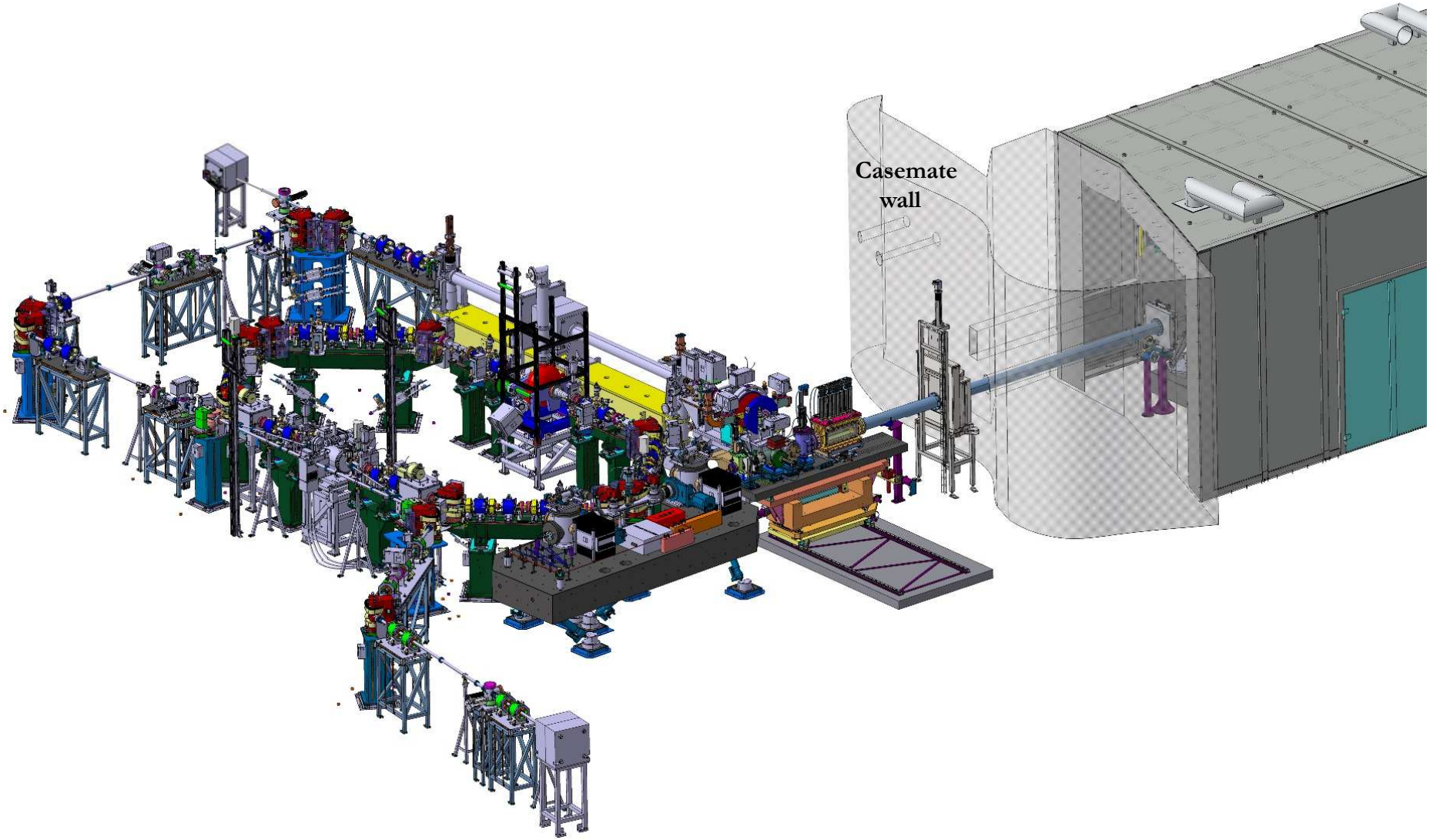
STORAGE RING



f_{rev} ~ tens MHz
Intensity ~ 10 mA

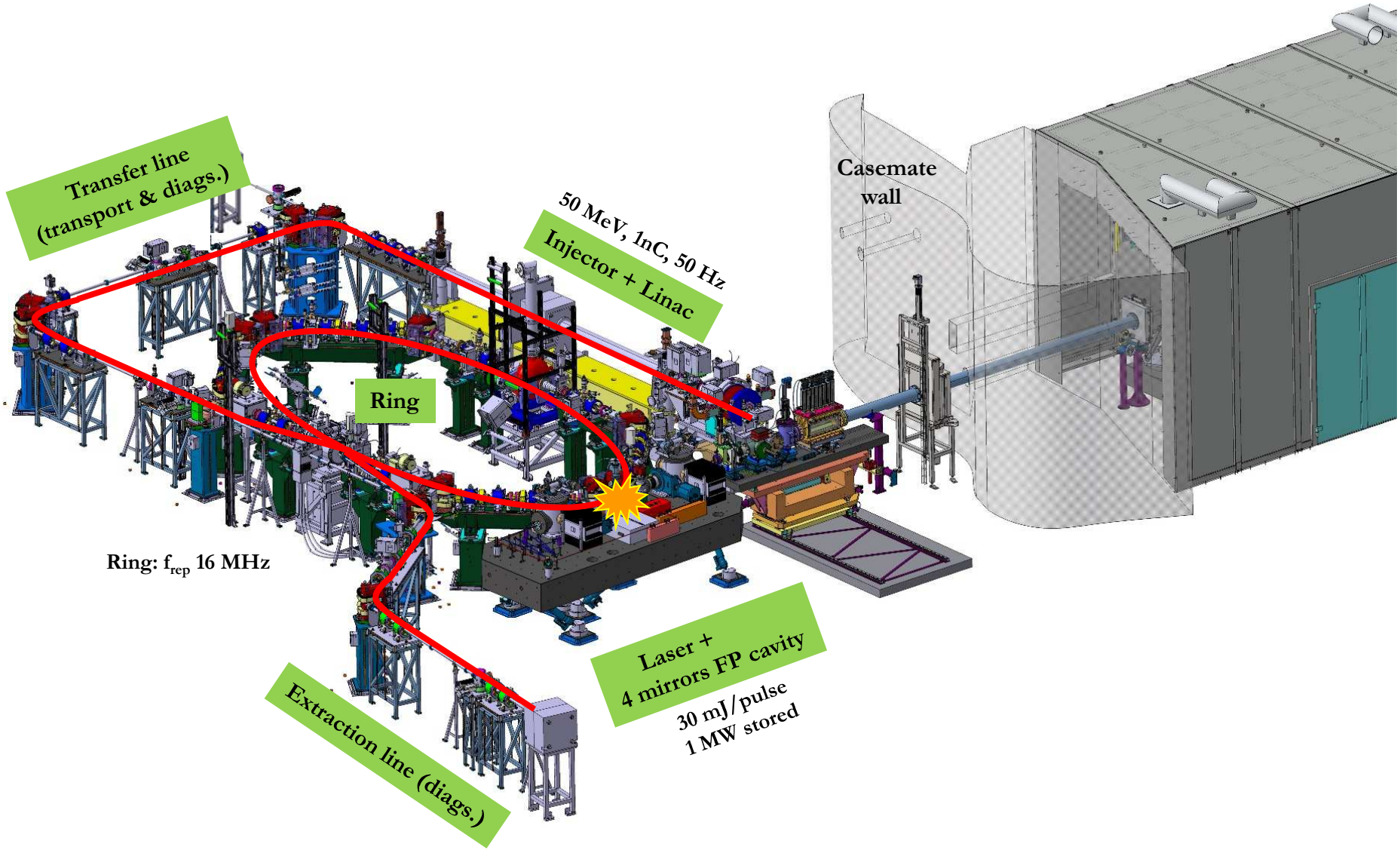
Emittances e^- 1 - 10 mm.mrad
Flux $10^{12\text{-}13}$ ph/s
Bright. $10^{11\text{-}12}$

ThomX design



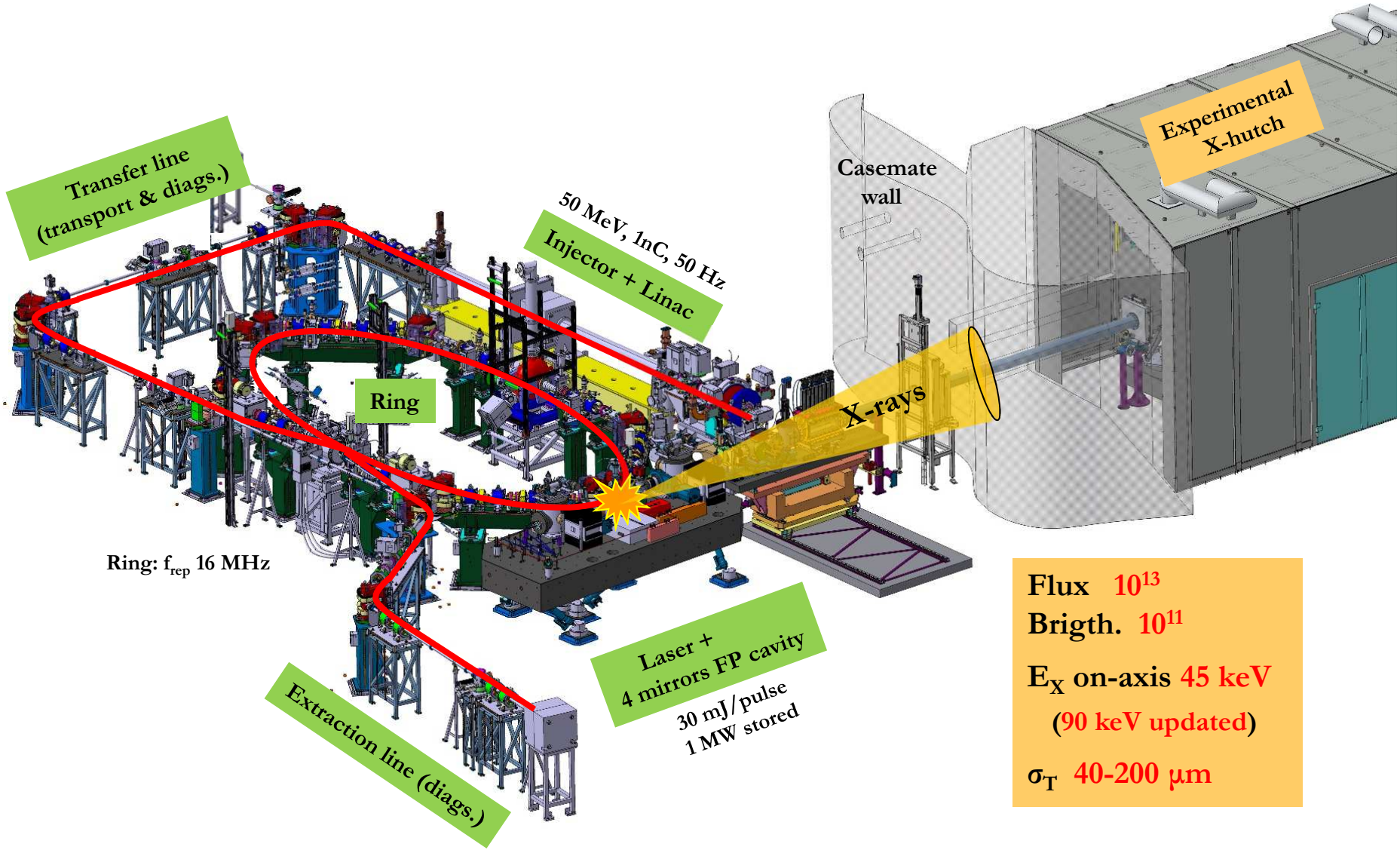
ThomX design

Nominal parameters



ThomX design

Nominal parameters



Flux 10^{13}
Brigth. 10^{11}

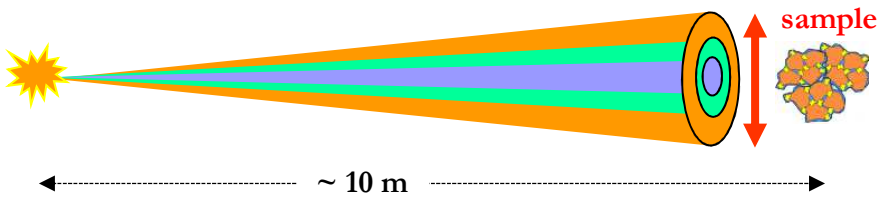
E_X on-axis 45 keV
(90 keV updated)

σ_T 40-200 μm

2 ways to use a Compton beam

With nominal ThomX parameters

NATURAL DIVERGENCE of the Compton process



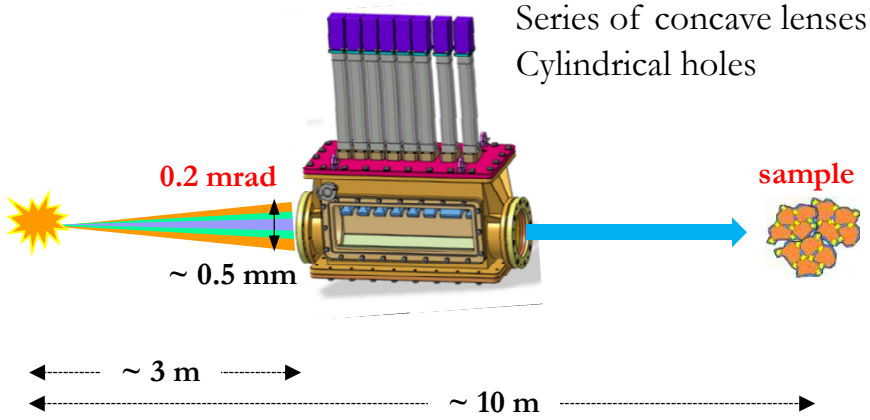
- 0 - 15 cm diameter beam
- Pink beam (few % - 30% bw)
- 45 keV (90 keV after update)
- Flux ~ 10^{11} - 10^{13} ph/s

→ Measure large sample with no more need to move it (patient, materiel …)

FOCUS device

Transfocator

Series of concave lenses
Cylindrical holes

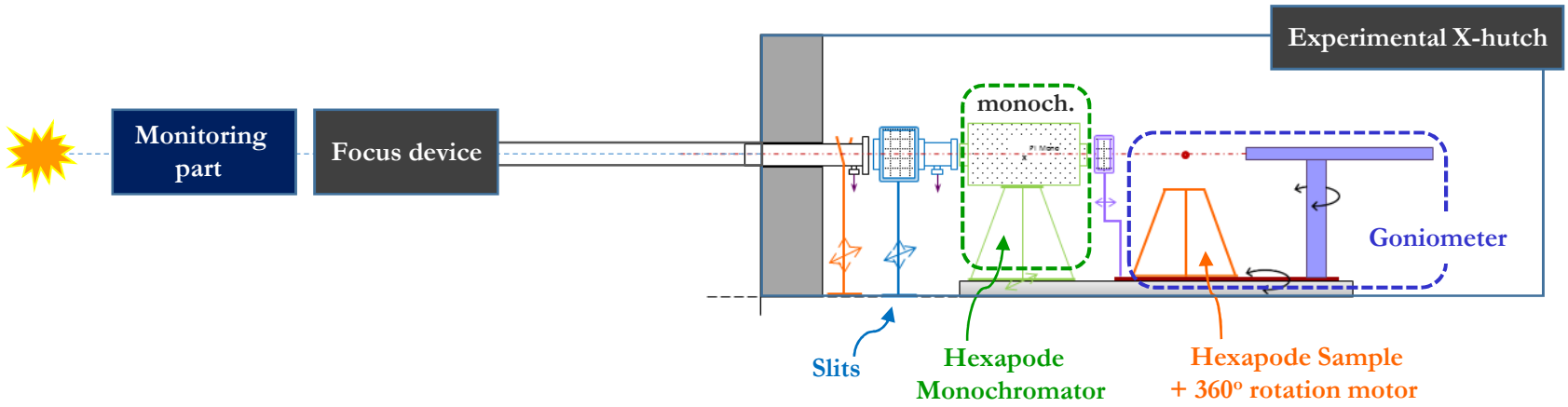


- 150 - 200 µm beam
- 3-4 % to 0.01% (with mono)
- 45 keV (90 keV after update)
- Flux ~ 10^{8} - 10^{6} ph/s

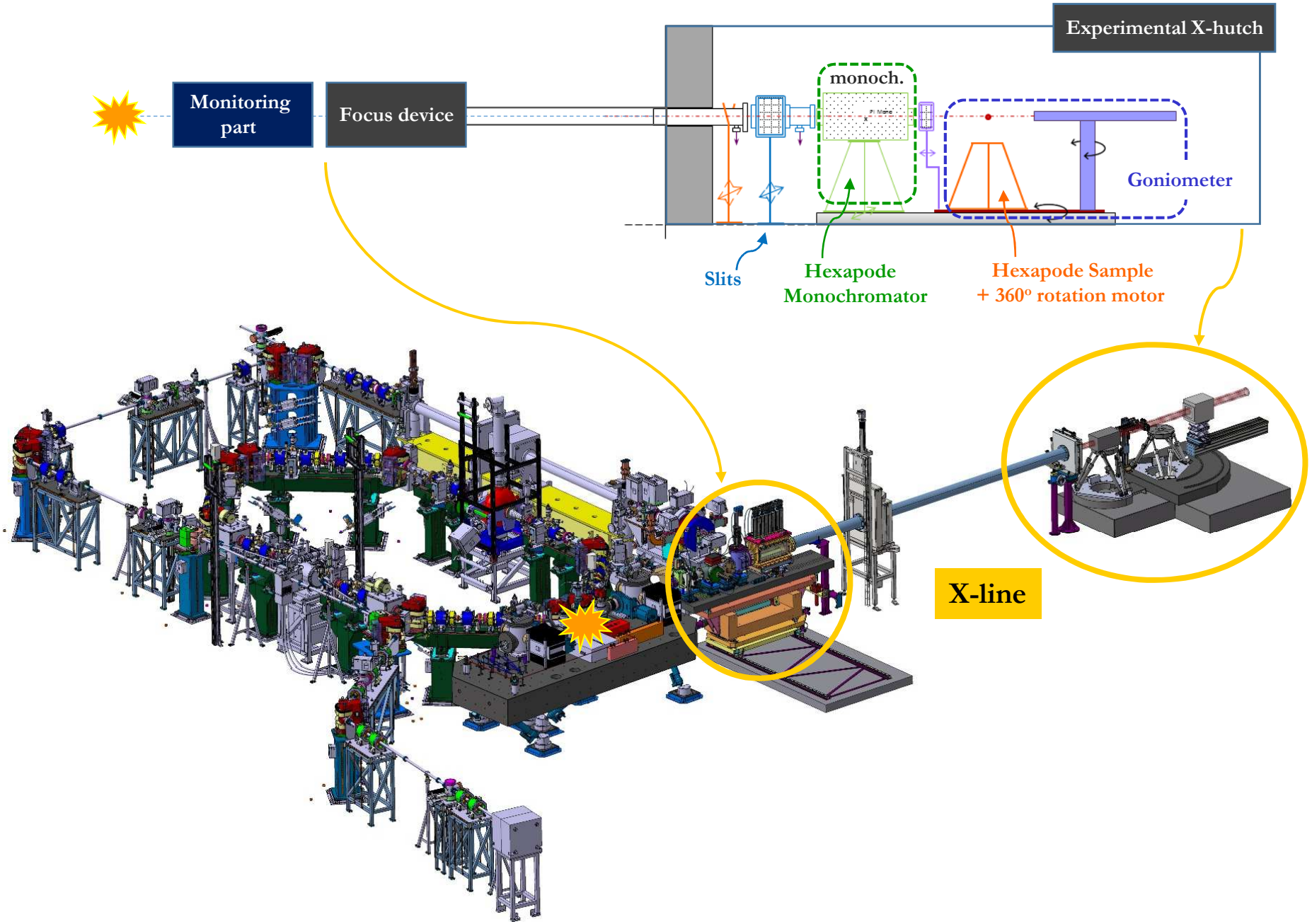
→ Material structural & chemical determination

M. Jacquet & C. Bruni, J. Synch. Rad. (2017) 24

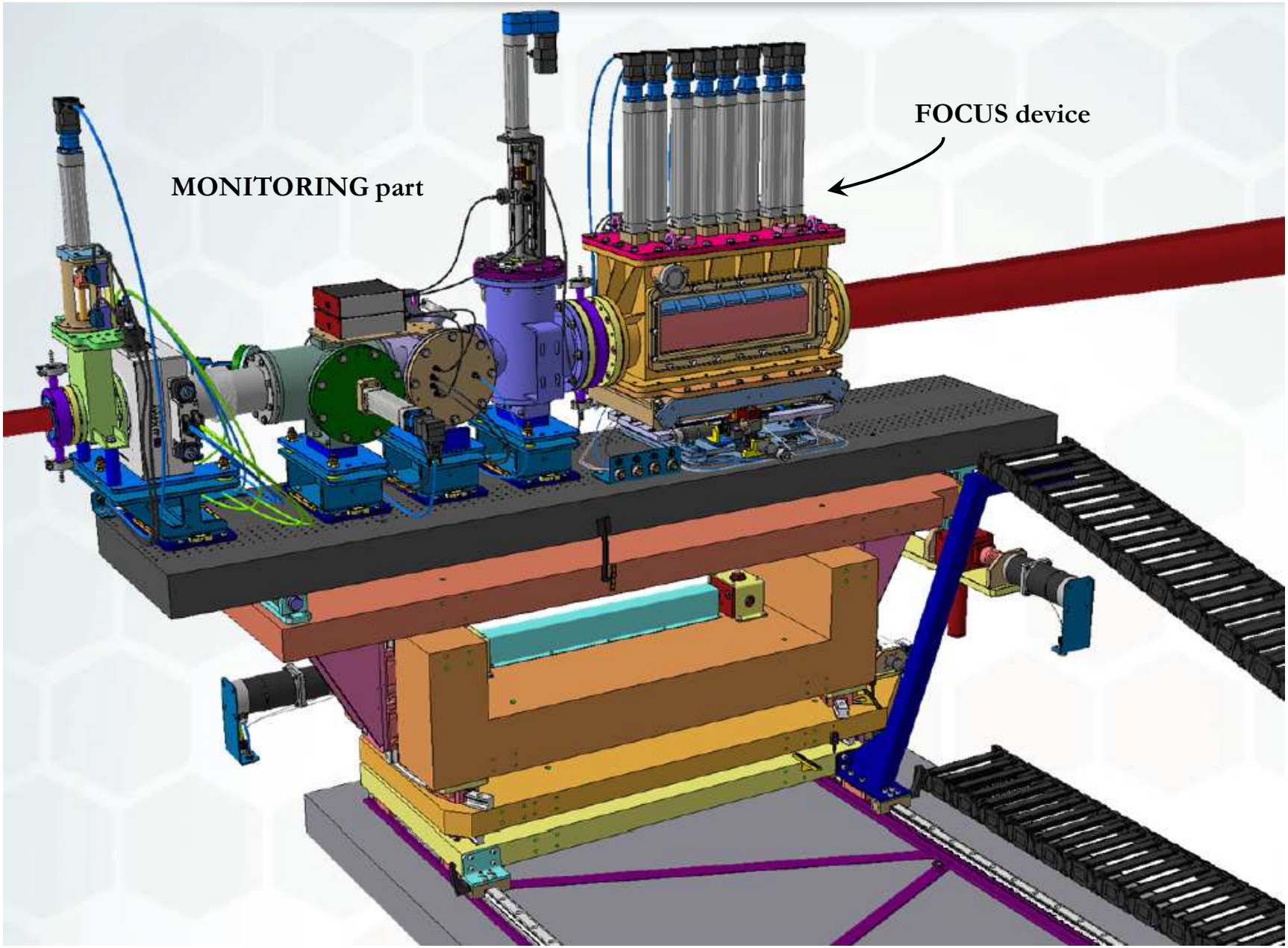
X-line integration



X-line integration



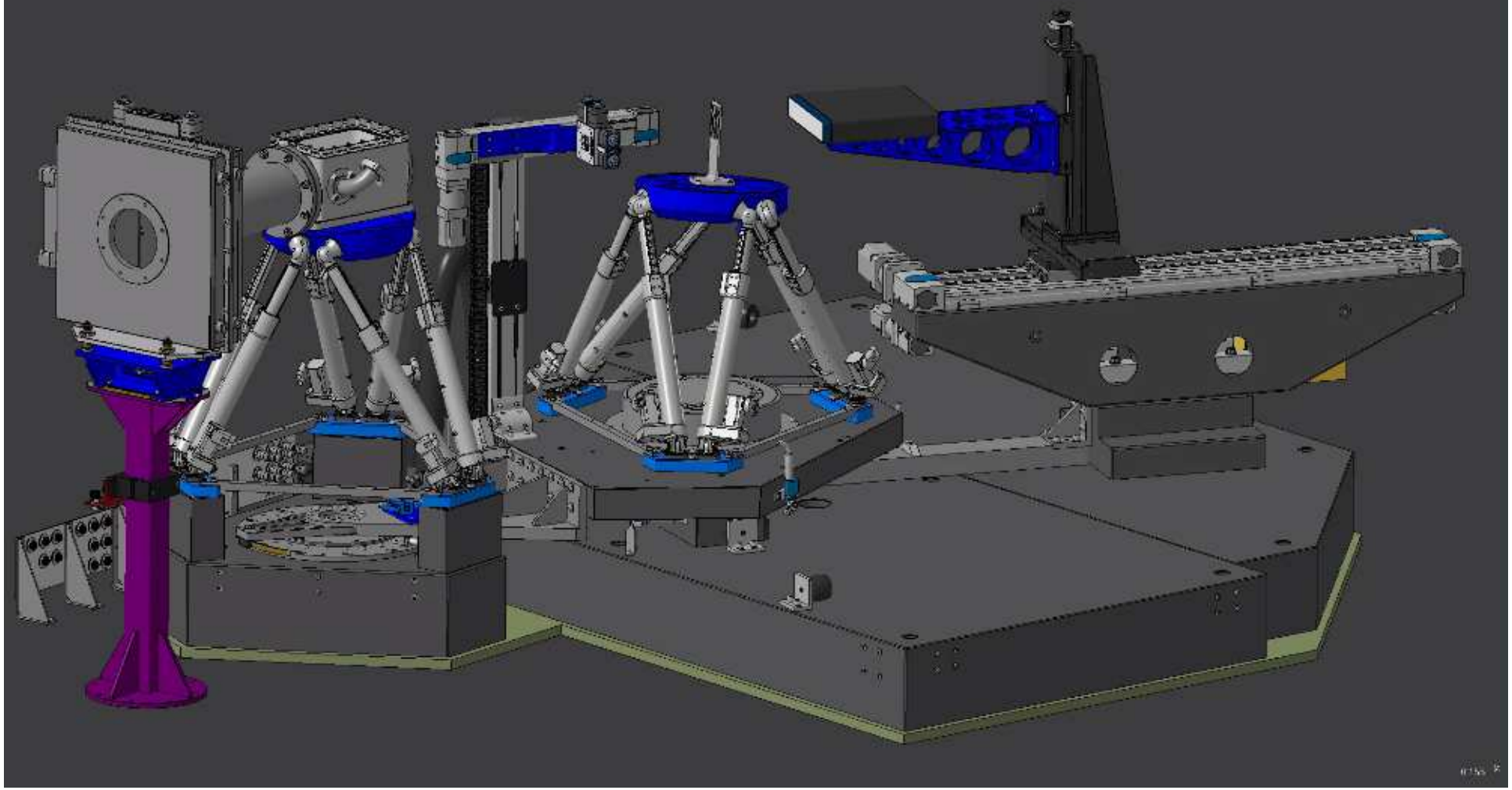
Monitoring and Focusing



X-ray experimental hutch

→ Design a modulable equipment in order to be able to explore the main analysis techniques

- Standard imaging
- Phase contrast imaging
- Tomography
- Fluo spectro
- Diffraction



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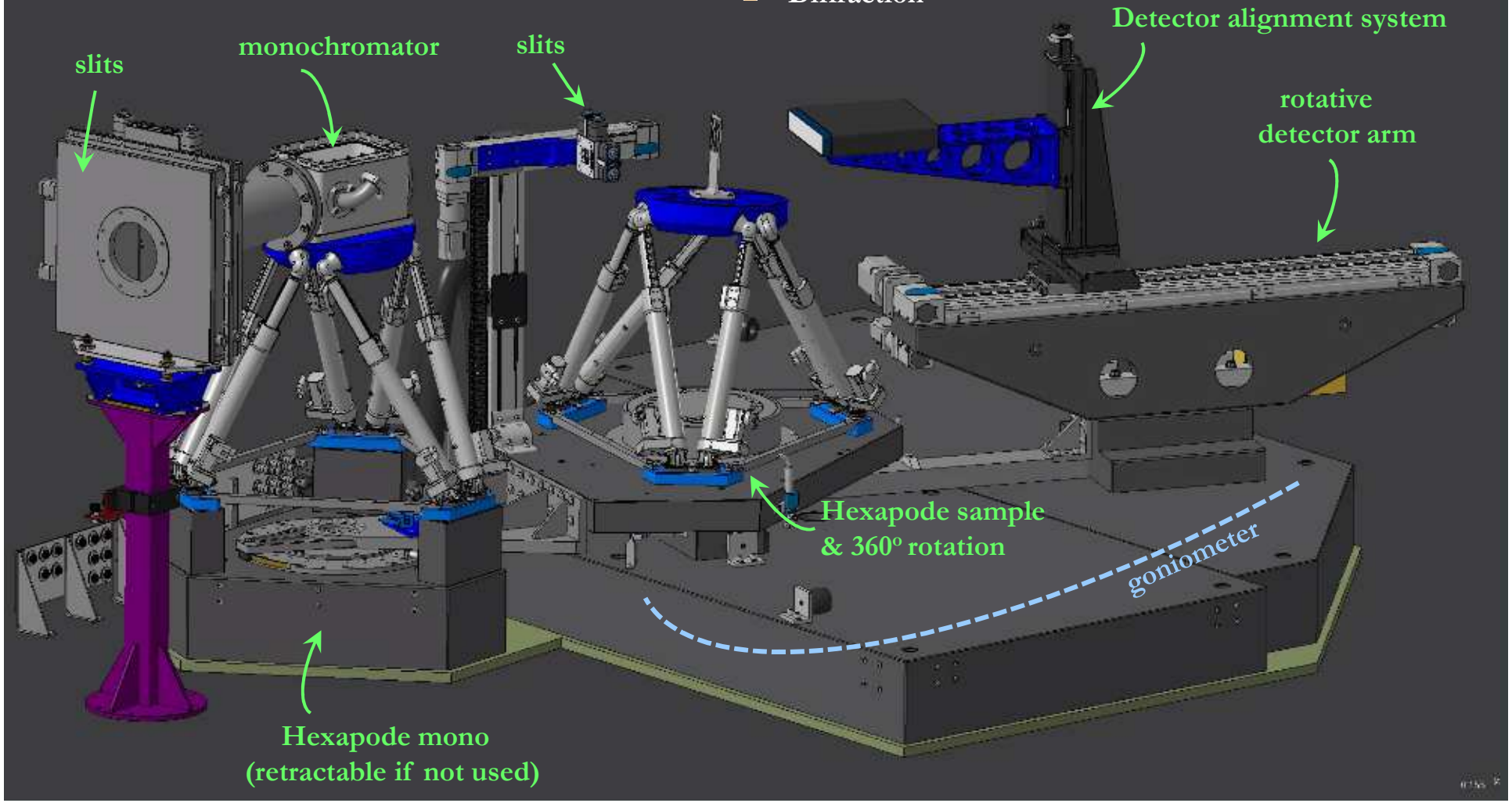
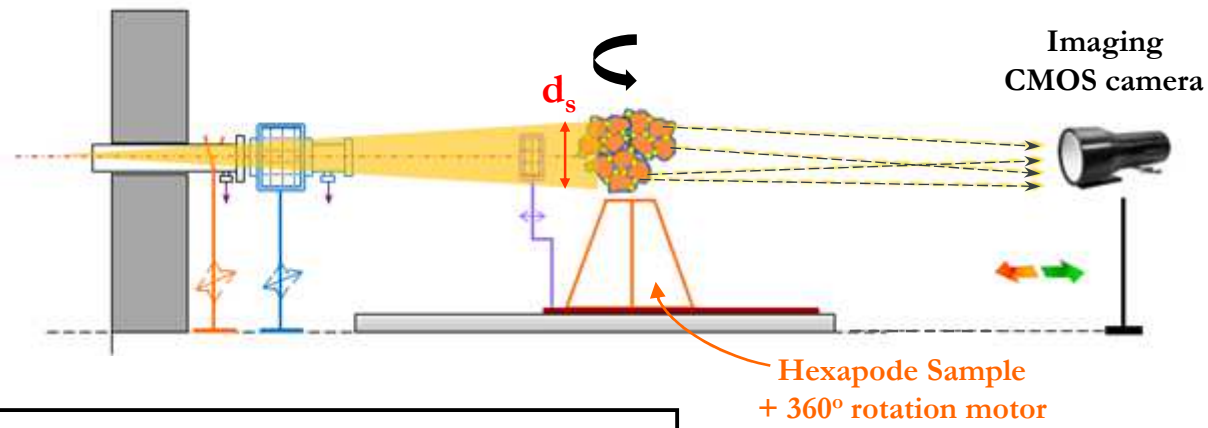


Analysis techniques : orders of magnitude

- Standard imaging
- Phase contrast imaging
- Tomography
- Fluo spectro
- Diffraction

IMAGING



d_S = 5 cm (D = 10 m)

45 keV , bw ~ 10%

~ 10^{12} ph/s

With a detector
~ 50 µm pixel size

~ 1.3 10^6 ph/s/pixel

→ Tomo (conventional, PCI) in few seconds

M. Jacquet / Phys Med 32 (2016) 1790–1794

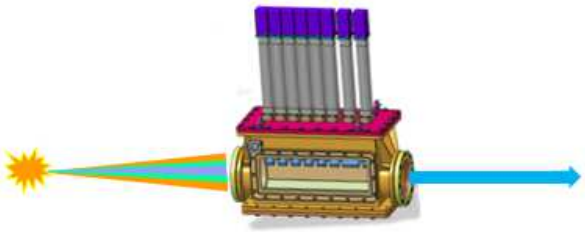
- Large beam size, quasi monochromatic

- PCI: Source-sample distance: only 10 m
- PCI : Source size: ~ 50 - 100 µm

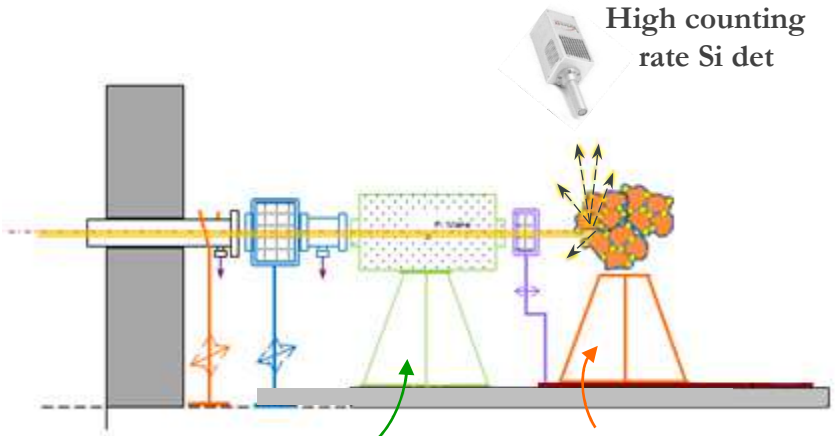
Analysis techniques : orders of magnitude

- Standard imaging
- Phase contrast imaging
- Tomography
- Fluo spectro
- Diffraction

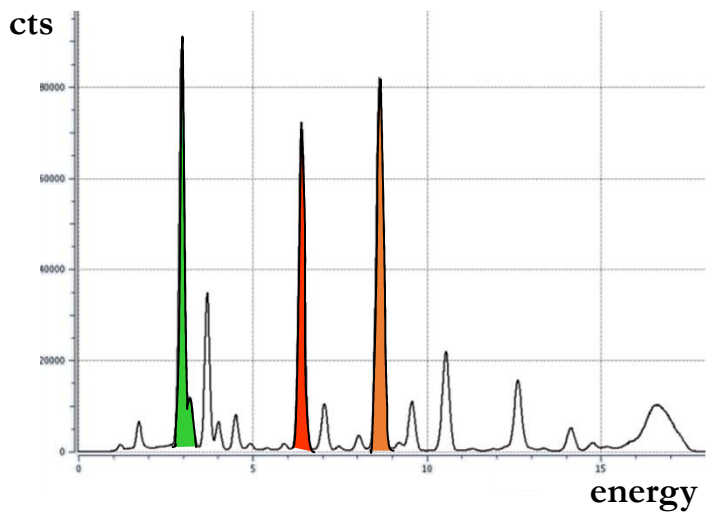
FLUO



Transfocator
(present or retracted)



- Monochromatic or pink beam
- Focused beam or not
- Tunable energy



Synchrotrons increase the sensisibility of detection by 1 to 2 orders of magnitude compared to X-ray tubes.

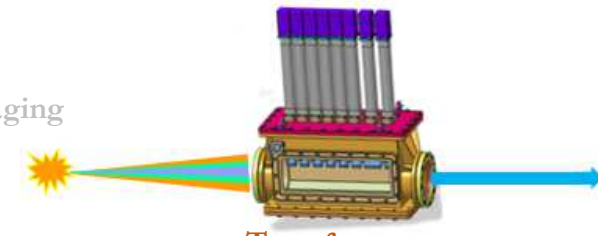
Ex : Detection limit of Cu

X-ray tube	~ 2000 ppm	→ ThomX: between both
Synchrotron	~ 60 ppm	

Analysis techniques : orders of magnitude

DIFFRACTION

- Standard imaging
- Phase contrast imaging
- Tomography
- Fluo spectro
- Diffraction



Transfocator
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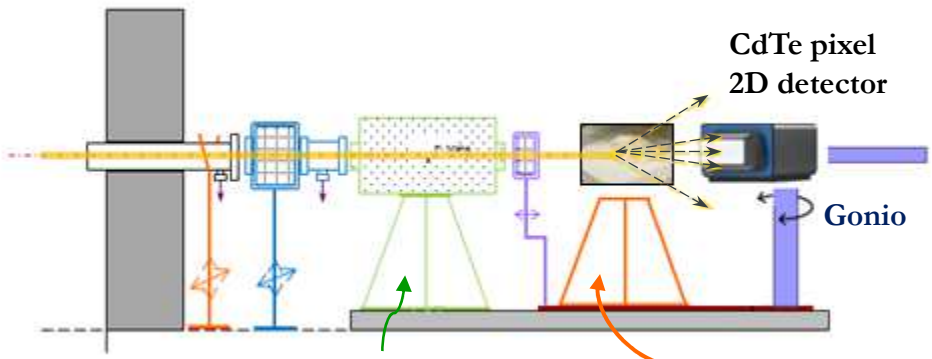
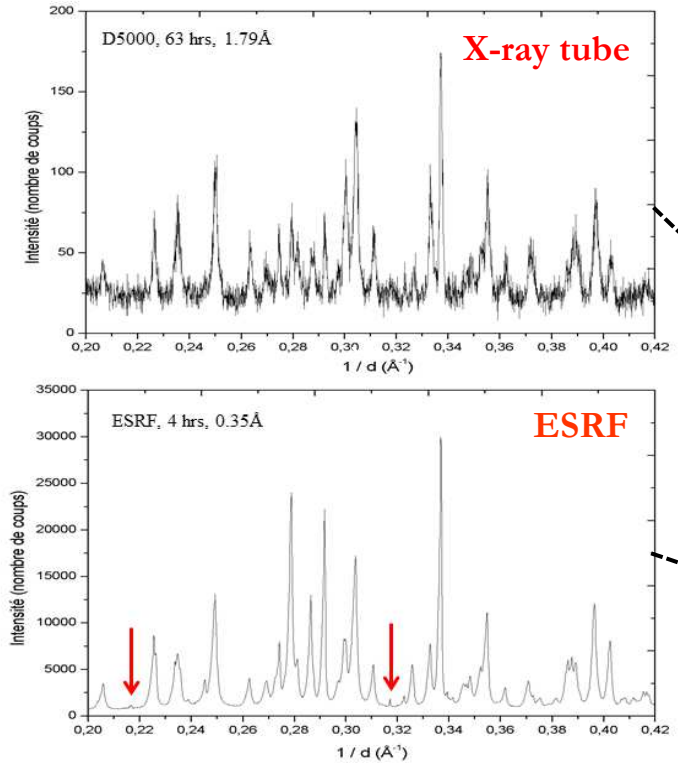


Diffraction patterns of a powder



- Monochromatic or pink beam
- Focused beam or not

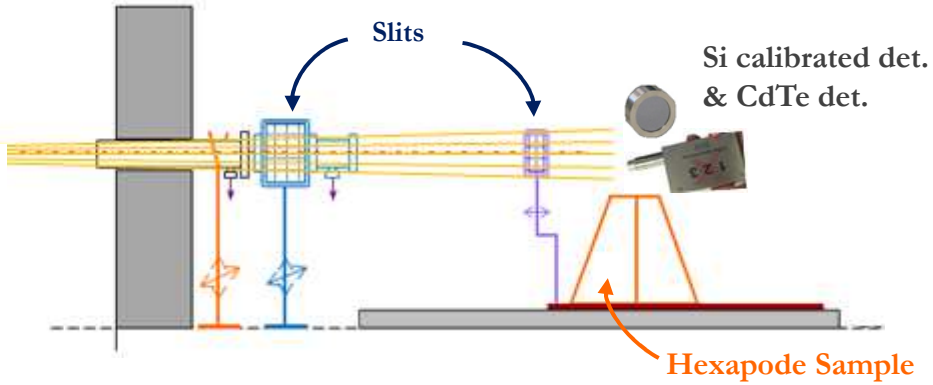
Poor resolution

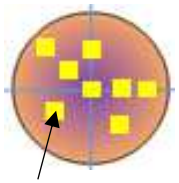
→ ThomX: between both

Minor phases present in the powder are visible

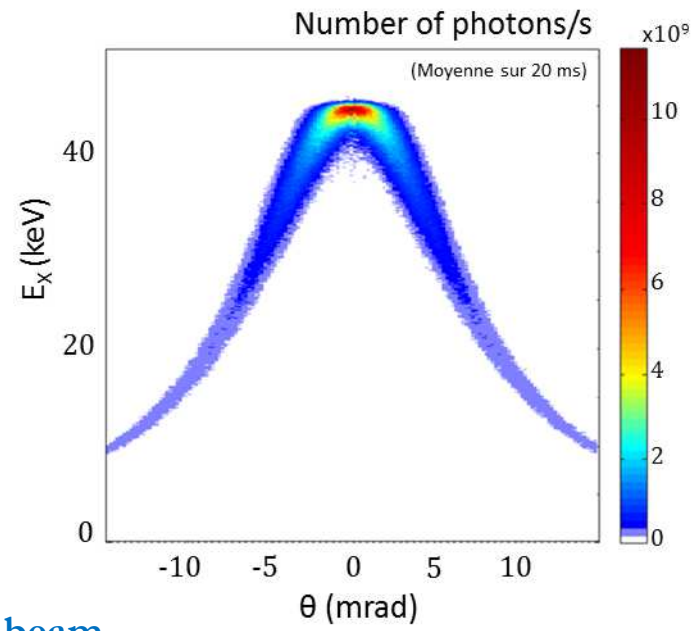
Also, as soon as a relatively stable beam is available,

Beam
CHARACTERISATION





Energy and flux
measured at each point



→ **Reconstruct the energy/angle distribution**

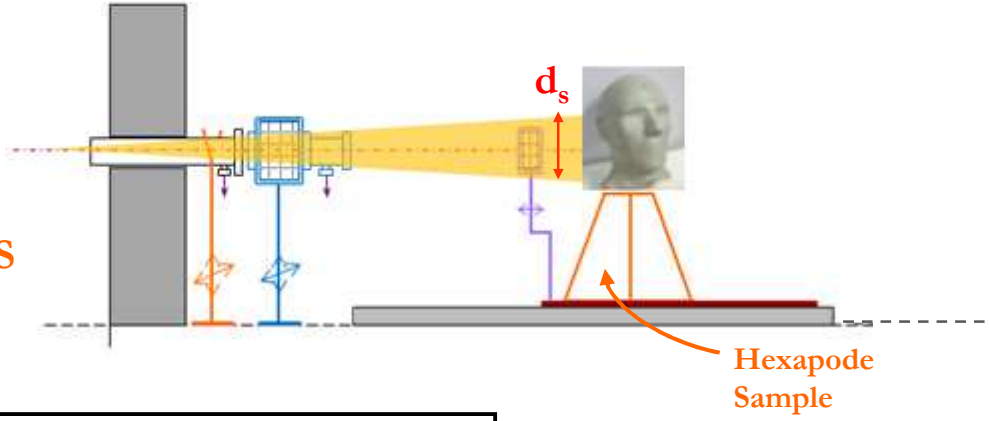
→ **Then, study the agreement with the electron beam emittance and energy spread measurements**

With the ThomX update (70 MeV e- beam → 90 keV X-ray)

RADIOTHERAPY

RADIOBIOLOGY

High Z drugs & nanoparticles STUDIES



d_S = 3 cm (D = 10 m) ; 80 keV ± 10 keV

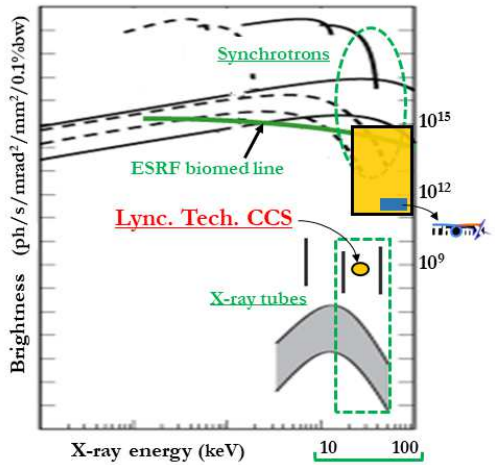
- ThomX: ~ 10^9 ph/s/mm^2
- SSRT ESRF: ~ 10^9 ph/s/mm^2

- Large beam size
- Dose rate comparable to SSRT ESRF

- Spatially inhomogeneity over the irradiation field to be corrected

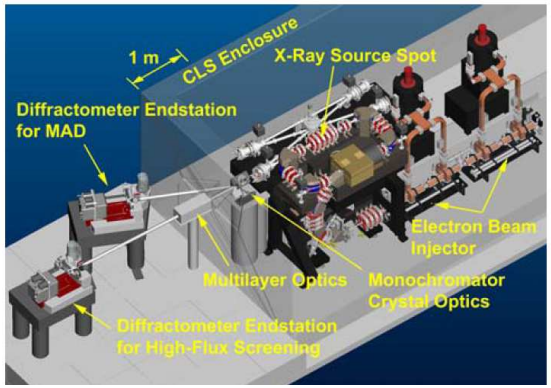
M. Jacquet, P. Suortti, Phys Med 31 (2015) 596-600

PROOFS of PRINCIPLE @ Lyncean Tech. / Munich

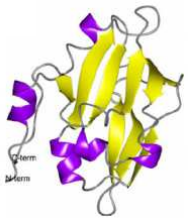


DIFFRACTION

Lyncean Tech. (2010)



3D structure determination
Protein MytuGCSPH



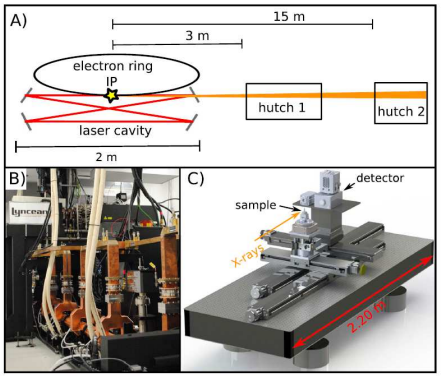
- **E = 15 keV**
- **5. 10^6 ph/s, few % bw**
- **X beam: 120 µm on crystal**

Flux and results comparable with the same analysis realized at a rotating anode

[J. Struct. Funct. Gen. 11, 2010, 91-100]

PHASE CONTRAST IMAGING

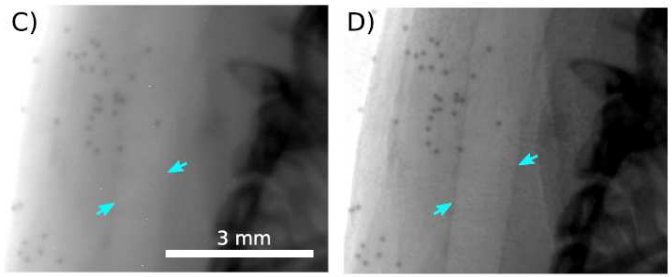
Munich/Lync. Tech. (2017)



Mouse trachea region imaging

- **E = 25 keV**
- **10^8 - 10^9 ph/s, 3-4% bw**
- **16 mm diameter beam**

Exposure time = 1 sec



Standard imaging — Prop. based PCI

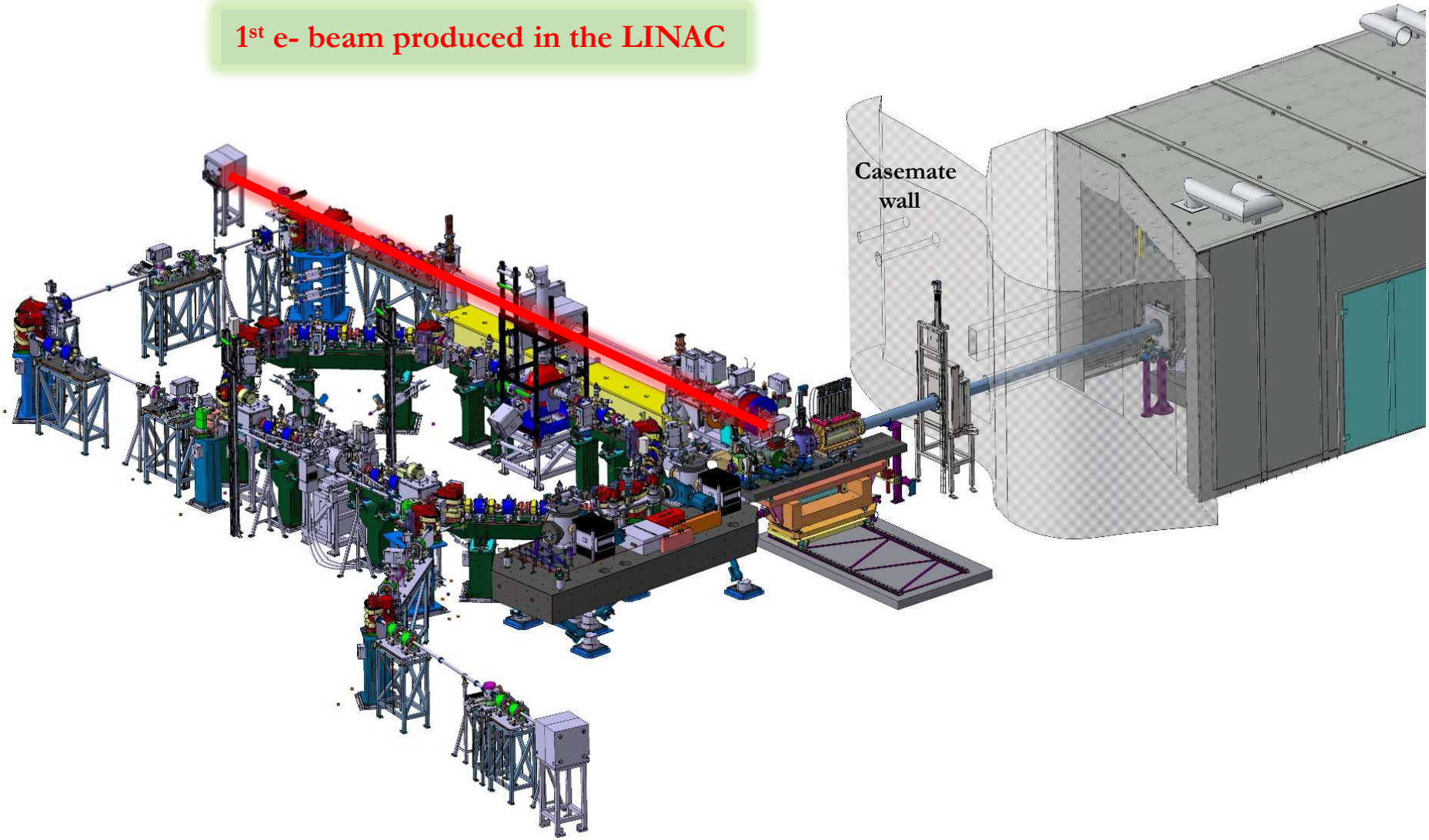
Air/tissue interfaces more visible

[Scientific Reports volume 7, 4908, 2017]

Current planning

Today: COMMISSIONING

1st e- beam produced in the LINAC



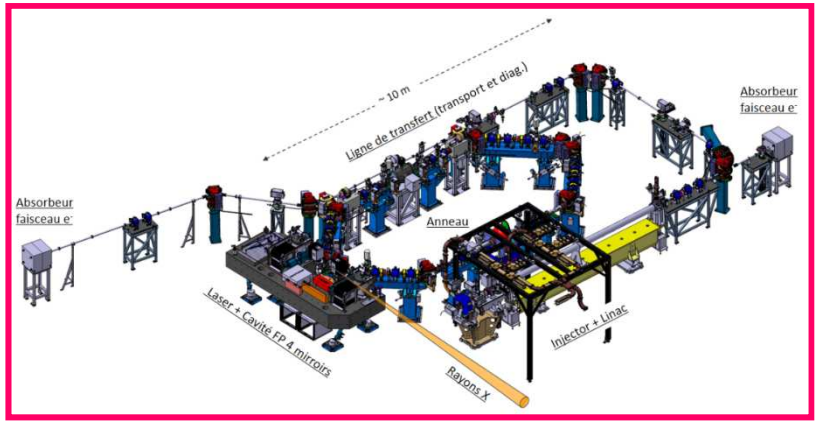
Current planning

2021	2022	2023

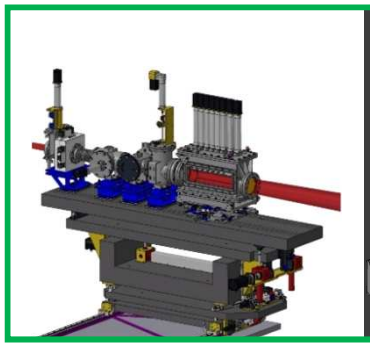
Source Commissioning

first X beam

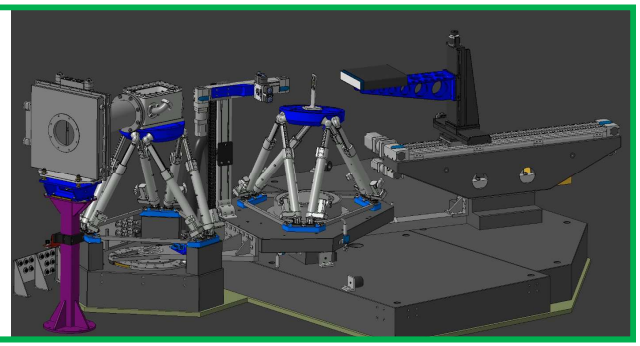
X-line Commissioning



Casemate part



Experimental X-hutch



- e^- gun + Linac
- Transfer line
- Ring
- Laser / FP cavity

1) FIND e-/laser interactions

→ Commissioning - Beam MONITORING system
- X-hutch detectors

2) CHARACTERISATION of

Source qualification

- The X beam (quality, energy/angle distribution)
- Each ANALYSIS TECHNIQUE (imaging, diffraction, fluo)
- The FOCUS DEVICE (transfocator)