Journée thématique sur les irradiations et analyses

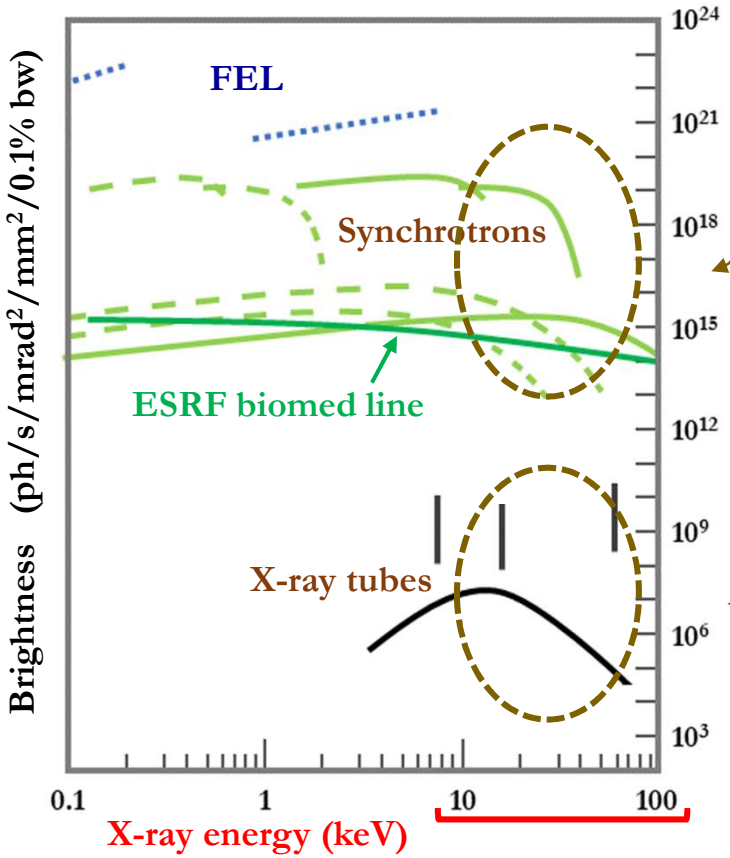
17 novembre 2021 - IJCLab

Intense lab-size Compton sources - The ThomX project

Marie Jacquet on behalf ThomX collaboration

mjacquet@IJCLab.in2p3.fr

Compton sources: **WHY**



Synchrotrons

High power, monochromaticity, coherence

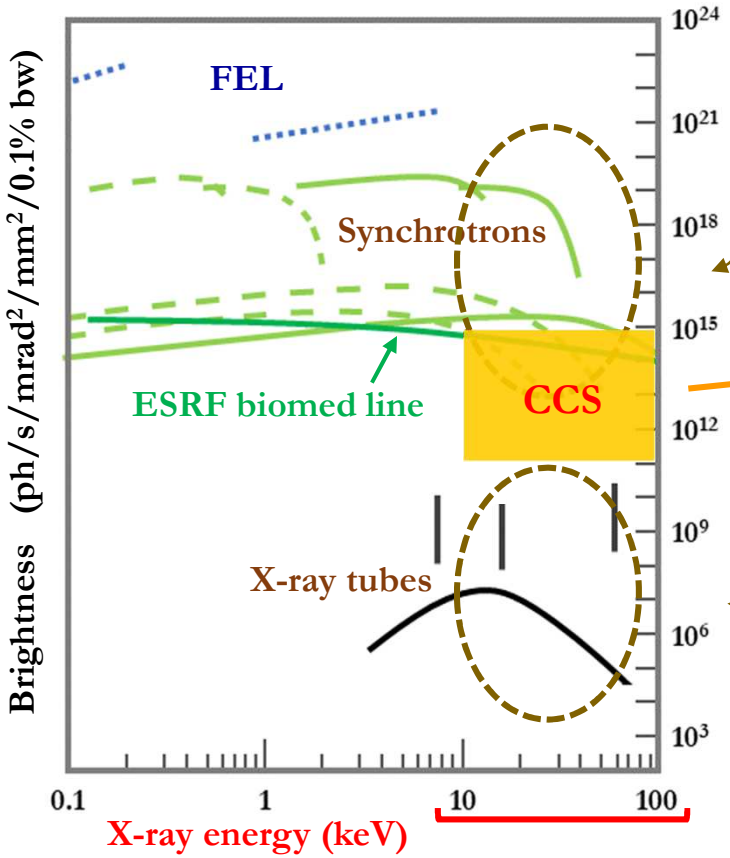
Large facilities, not very practical, limited access time

X-ray tubes

Lab-size sources

Lack of power, monochromaticity, coherence

Compton sources: WHY



Synchrotrons

High power, monochromaticity, coherence

Large facilities, not very practical, limited access time

COMPACT installations (surface < 100 m²)

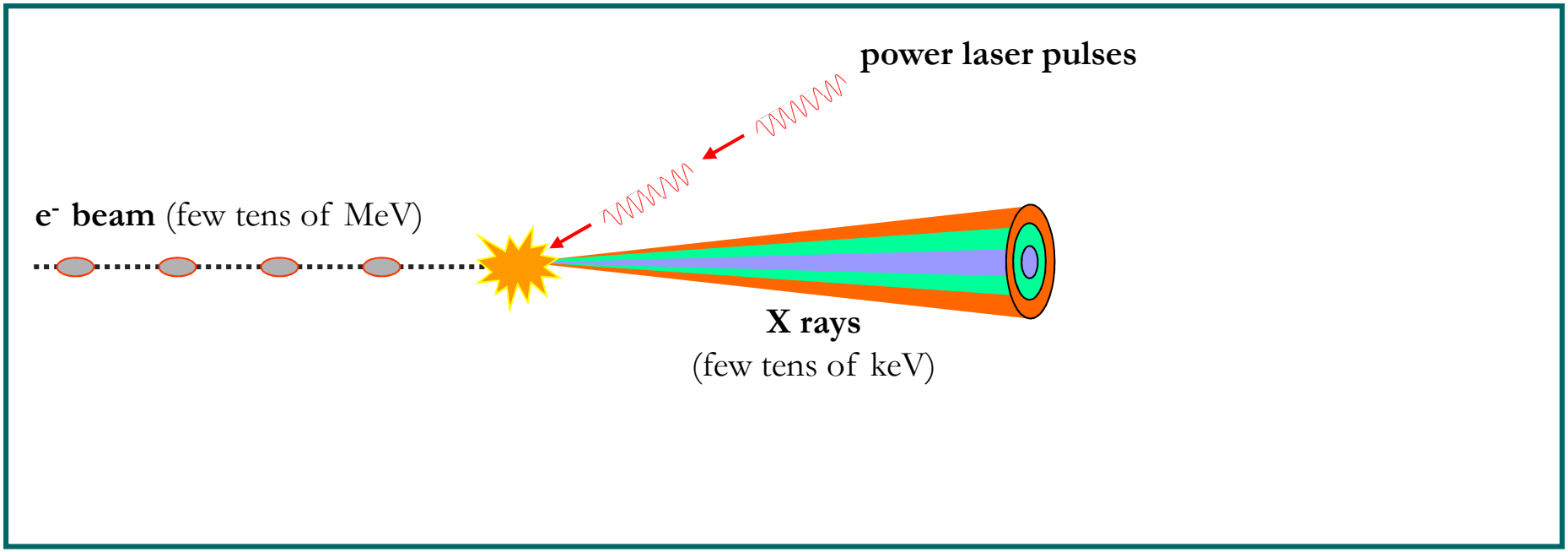
Some powerful analyzes currently realized at synchrotrons and requiring a high brightness beam could be developed in a lab-size environment (hospitals, labs, museums).

X-ray tubes

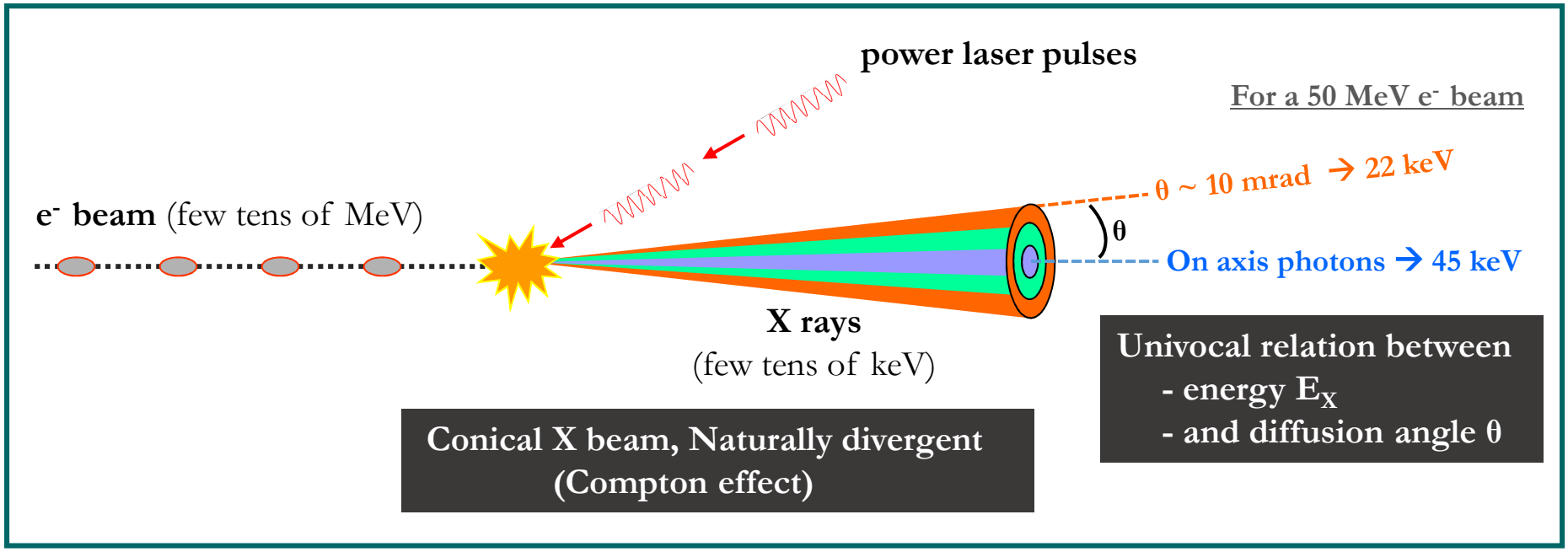
Lab-size sources

Lack of power, monochromaticity, coherence

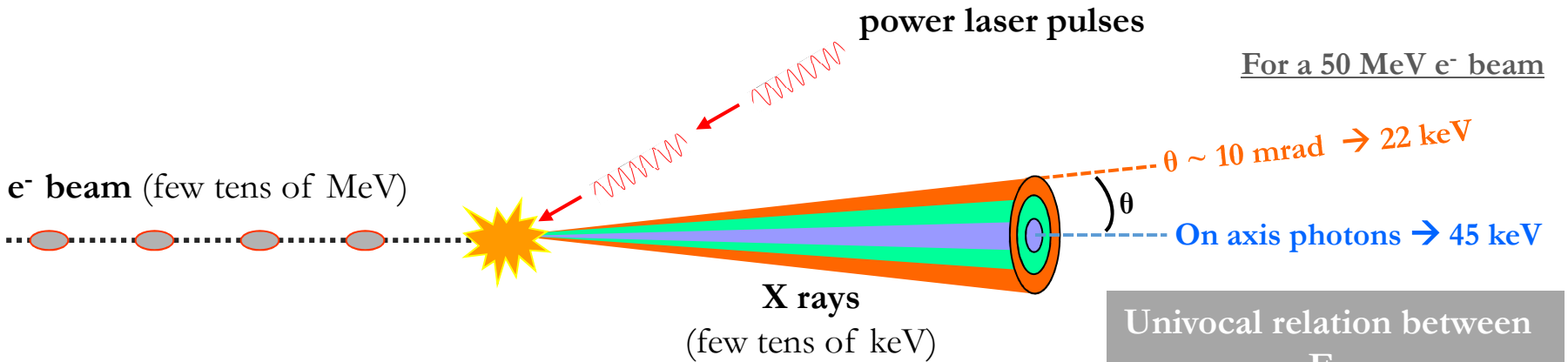
Compton sources: **HOW**



Compton sources: HOW



Compton sources: HOW

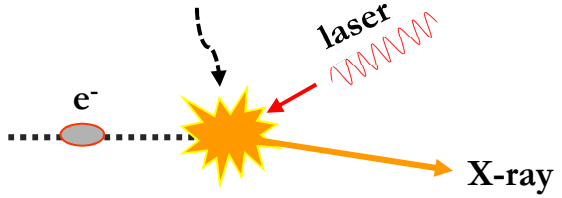


Repetition frequency of e-/laser interactions F_{rep} → Critical parameter

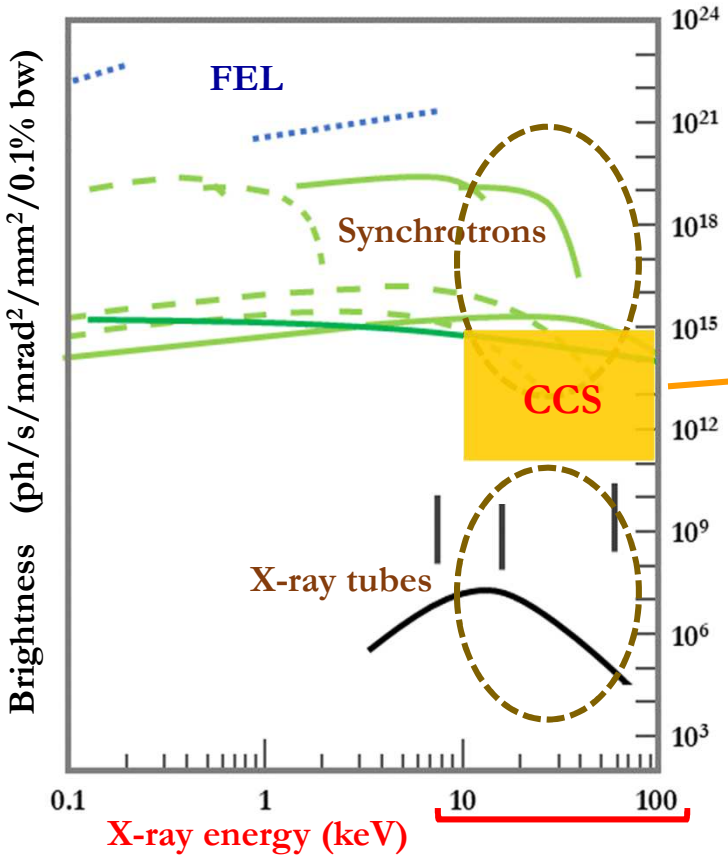
To obtain High Flux (>10^{12} ph/s):

e^-/laser Frep ~ few tens of MHz
Sine qua none condition

Since Compton cross section
is very small (6.6 10^{-25} cm^2)



Compton sources: **HOW**

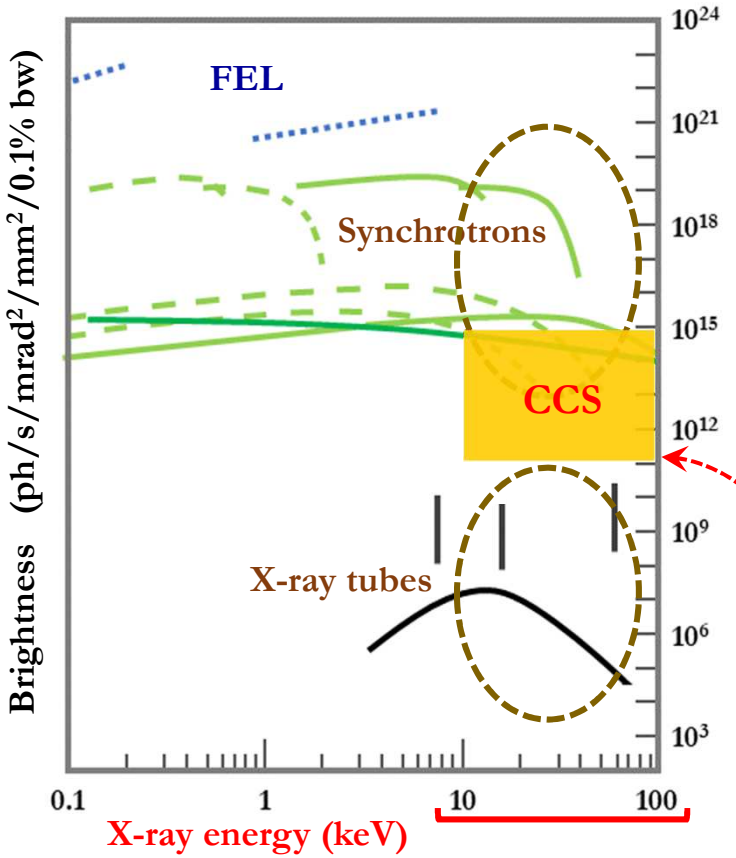


Flux >10^{12} ph/s

→ Frep e^-/laser ~ <u>few tens of MHz</u>

(sine qua none condition)

Compton sources: **HOW**



Flux >10^{12} ph/s

→ Frep e^-/laser ~ <u>few tens of MHz</u>

(sine qua none condition)

<u>Near future CCS</u>

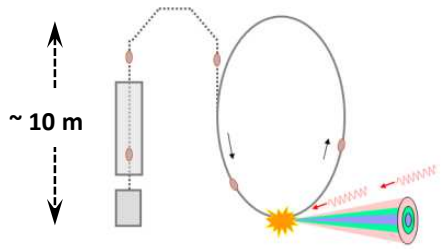
= almost current

("hot" machines)

STORAGE RING scheme

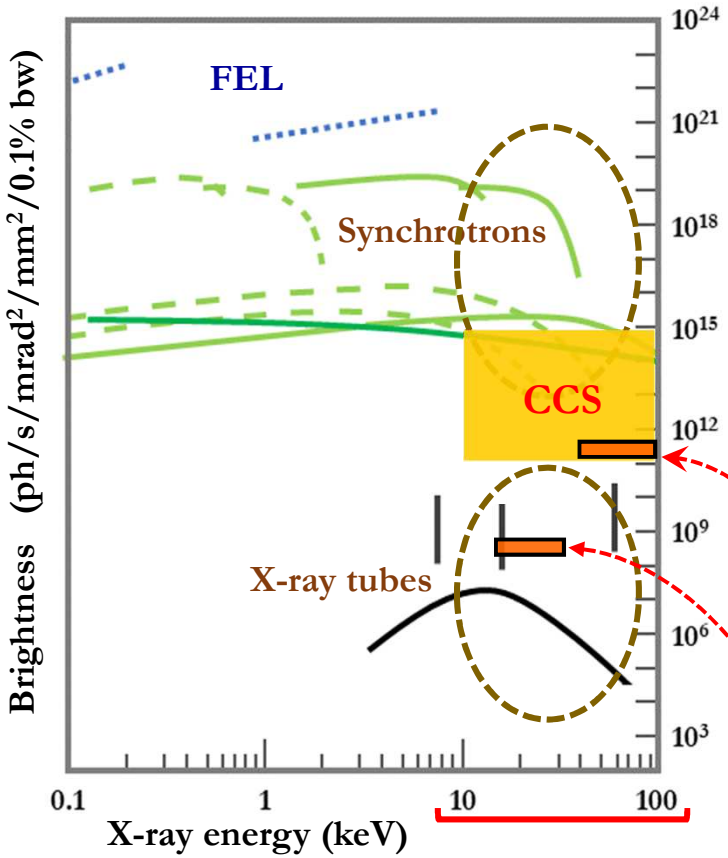
Frep = F_rev ~ tens MHz

Intensity ~ 10 mA



e- emittance: 1 - 10 mm.mrad

Compton sources: **HOW**



Flux >10^{12} ph/s

→ Frep e^-/laser ~ <u>few tens of MHz</u>

(sine qua none condition)

<u>Near future CCS</u>

= almost current

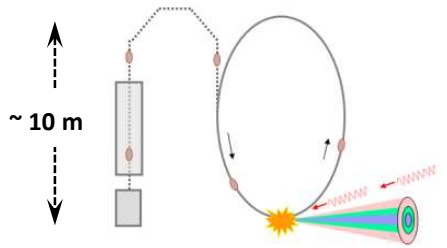
("hot" machines)

The only SR scheme CCS machine in operation
(Munich/Lync. Tech.)
Flux ~ 10^{10}-10^{11} ph/s

STORAGE RING scheme

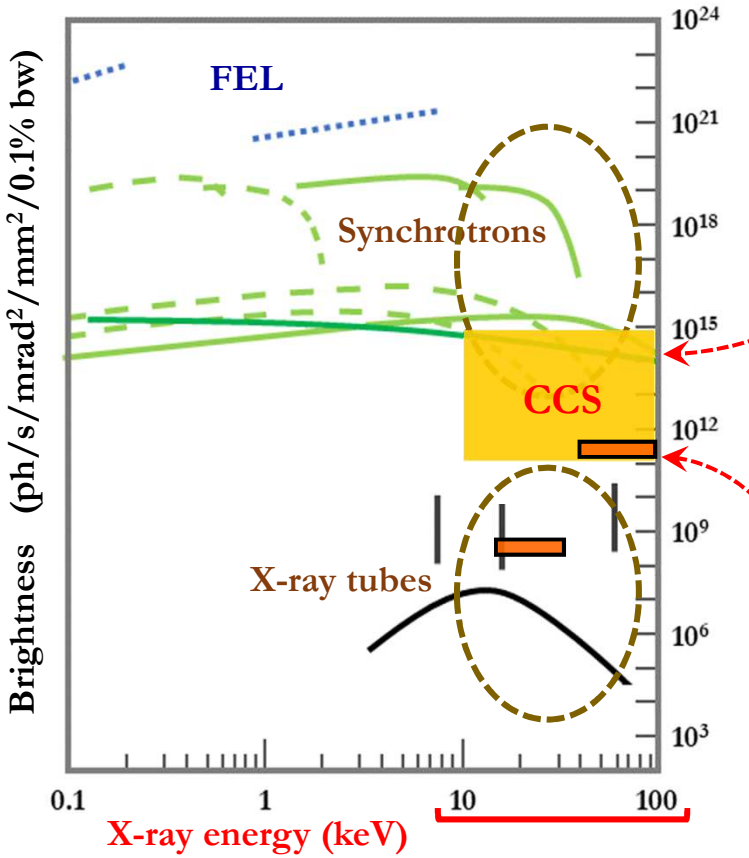
Frep = F_rev ~ tens MHz

Intensity ~ 10 mA



e- emittance: 1 - 10 mm.mrad

Compton sources: HOW



Next future CCS

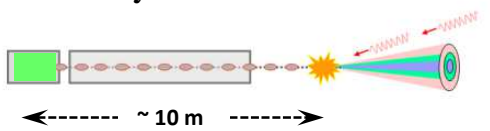
Superconducting electron gun

Not yet mature technology

LINAC scheme

Frep = F_inj ~ tens MHz

Intensity ~ mA



e- emittance: 0.1 - 0.5 mm.mrad

Flux >10^{12} ph/s

→ Frep e^-/laser ~ <u>few tens of MHz</u>

(sine qua none condition)

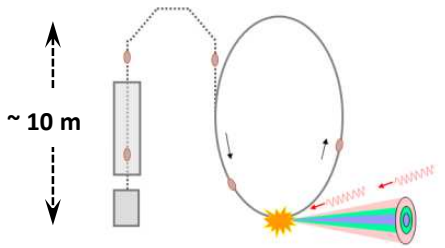
Near future CCS

= almost current ("hot" machines)

STORAGE RING scheme

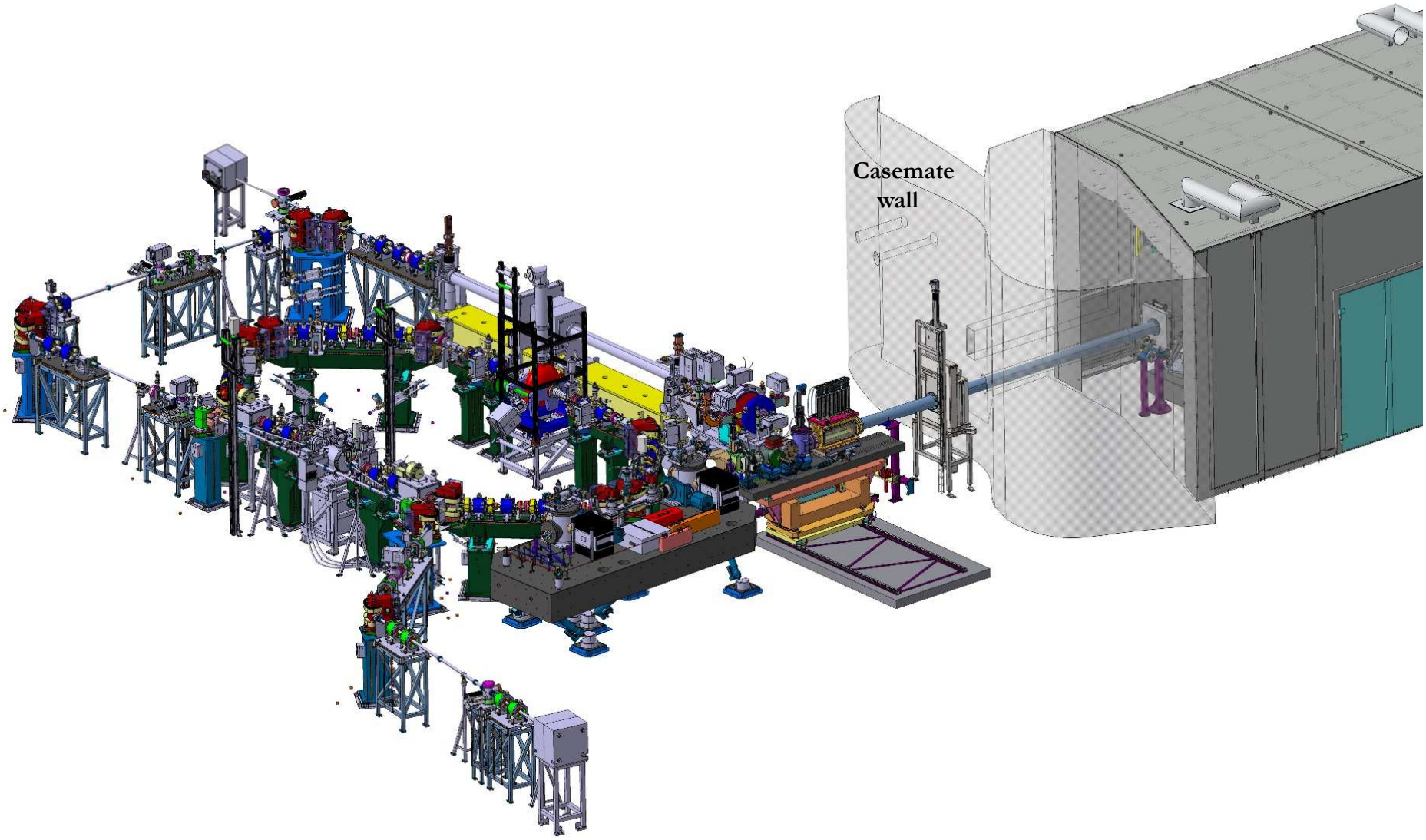
Frep = F_rev ~ tens MHz

Intensity ~ 10 mA

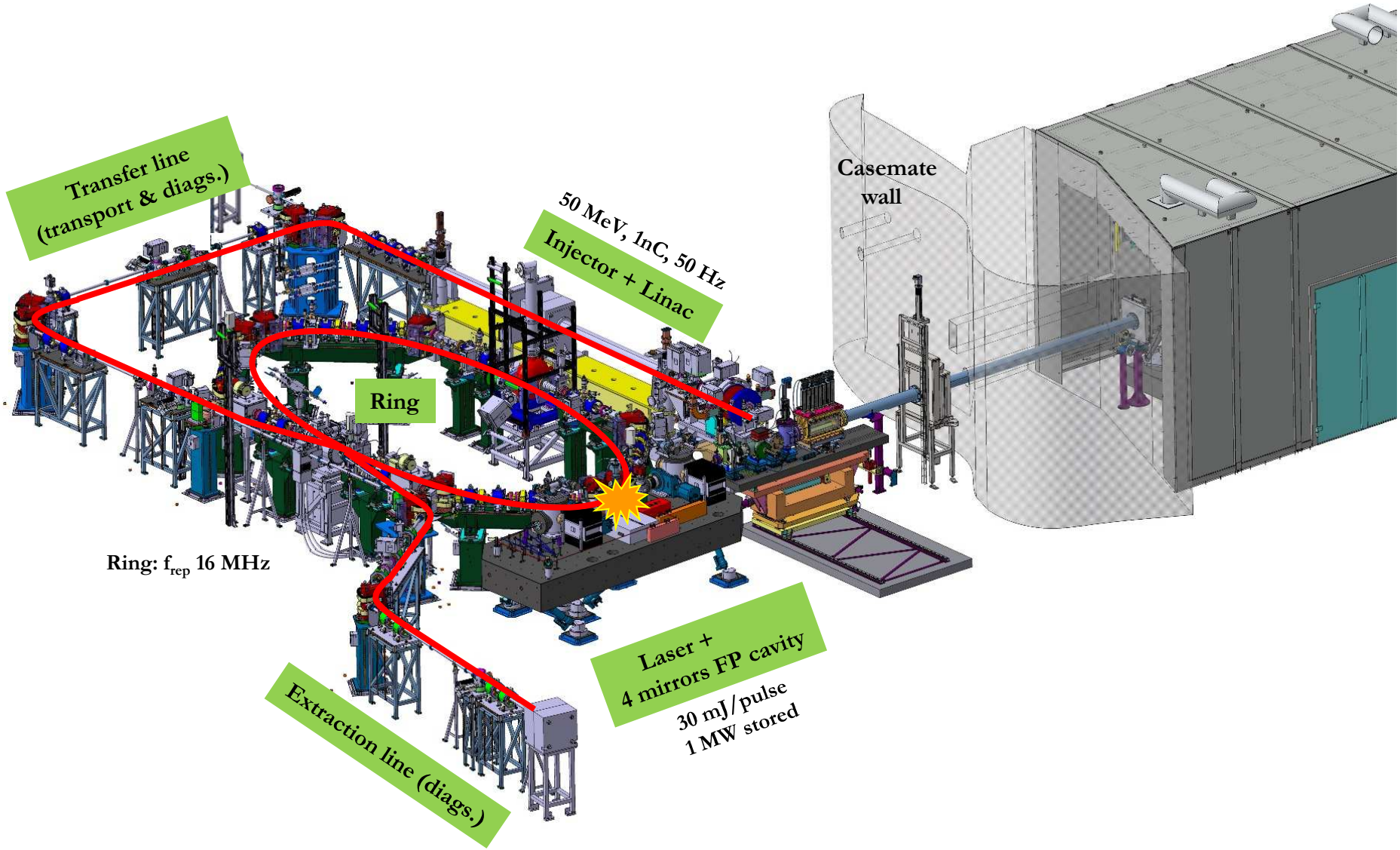


e- emittance: 1 - 10 mm.mrad

ThomX **DESIGN**

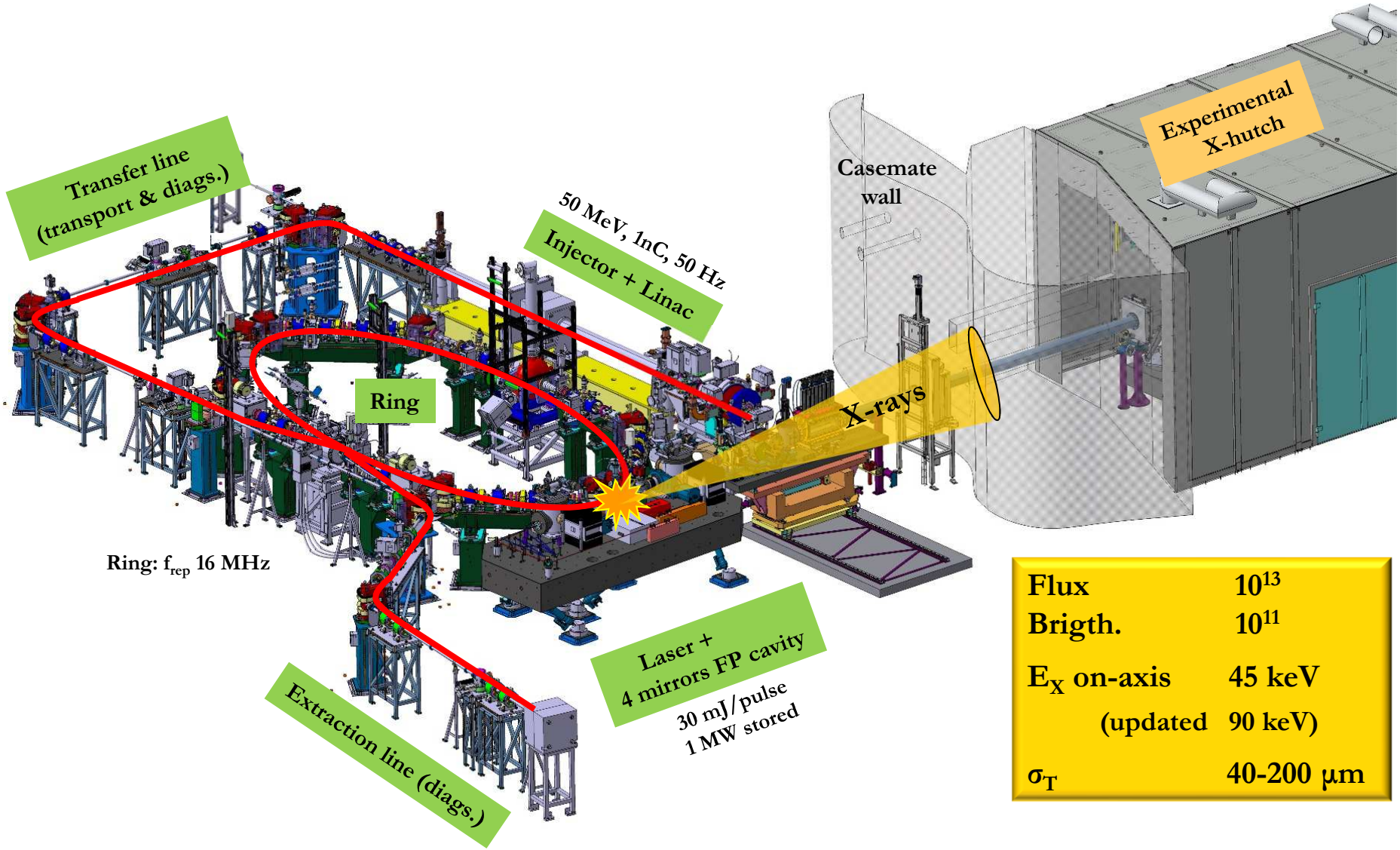


Nominal parameters



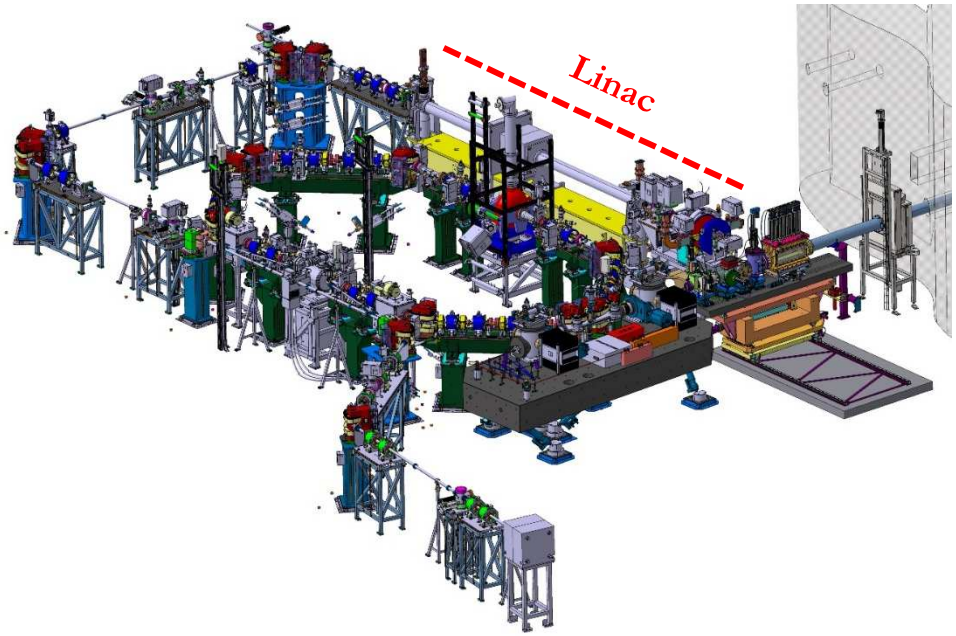
ThomX DESIGN

Nominal parameters

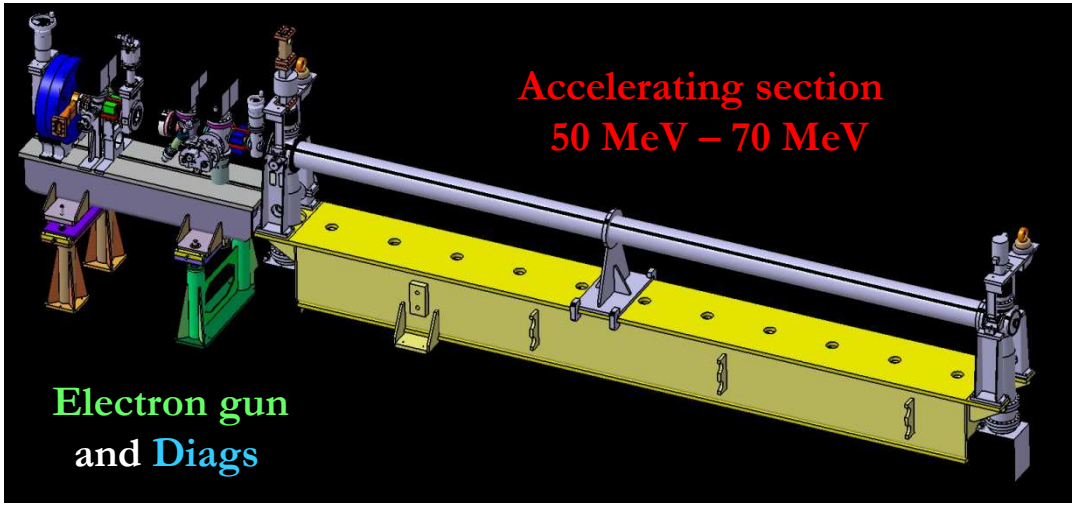


Flux	10^{13}
Brigth.	10^{11}
E_X on-axis	45 keV
(updated	90 keV)
σ_T	40-200 μm

e⁻ gun + Linac



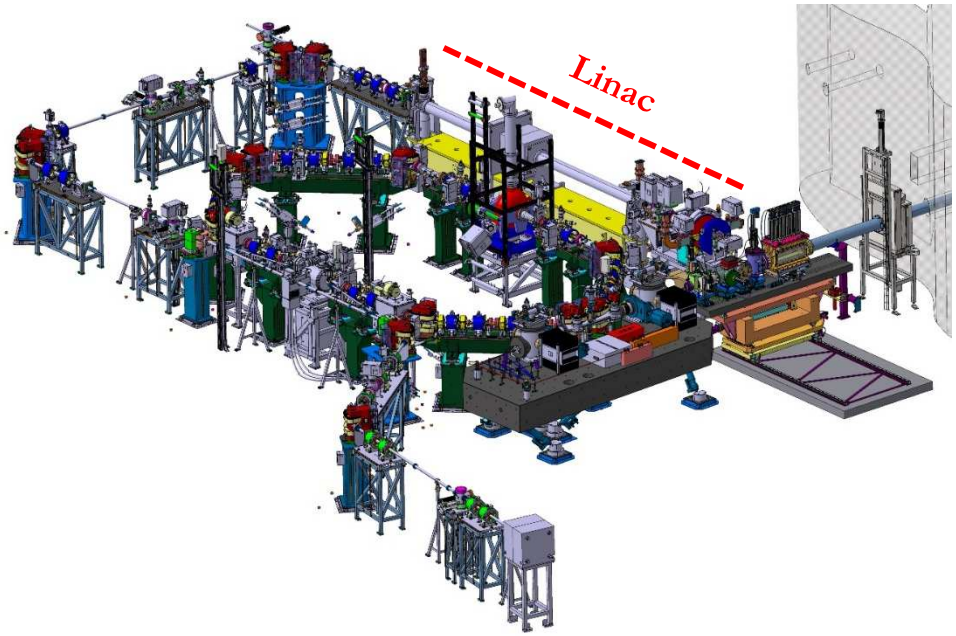
- Electron gun
  - Mg cathode / laser 100 µJ
  - 1 nc / e- bunch
  - 50 Hz inj. freq.
- Accelerating section 50-70 MeV
- Diags (position BPM & charge BCM)



σ_Z ~ 4 ps (rms)

ε_N ~ 5 π.mm.mrad (rms)

e⁻ gun + Linac



- Electron gun
  - Mg cathode / laser 100 µJ
  - 1 nc / e- bunch
  - 50 Hz inj. freq.
- Accelerating section 50-70 MeV
- Diags (position BPM & charge BCM)

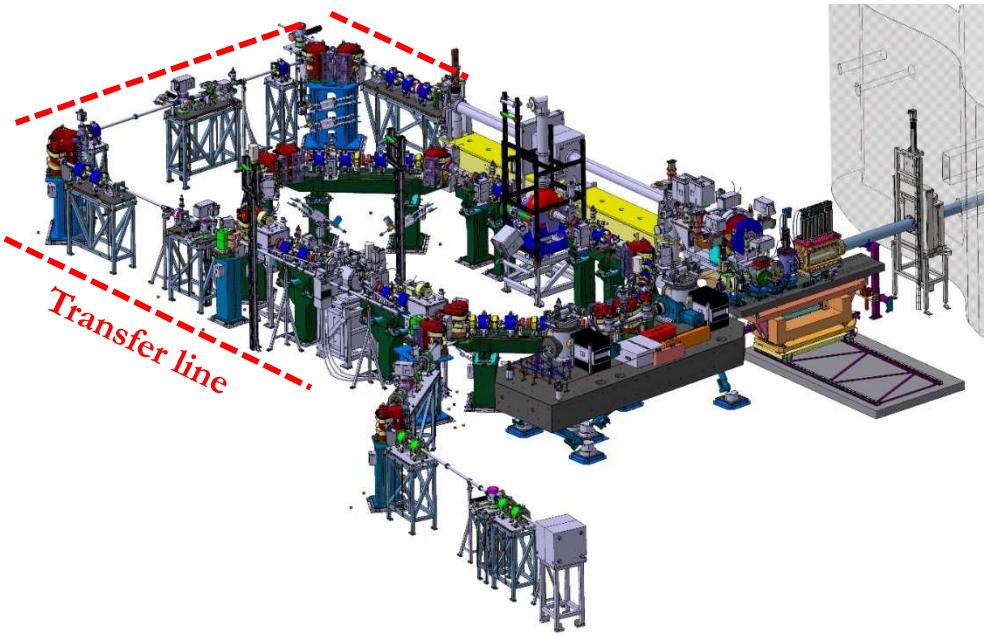
σ_Z ~ 4 ps (rms)

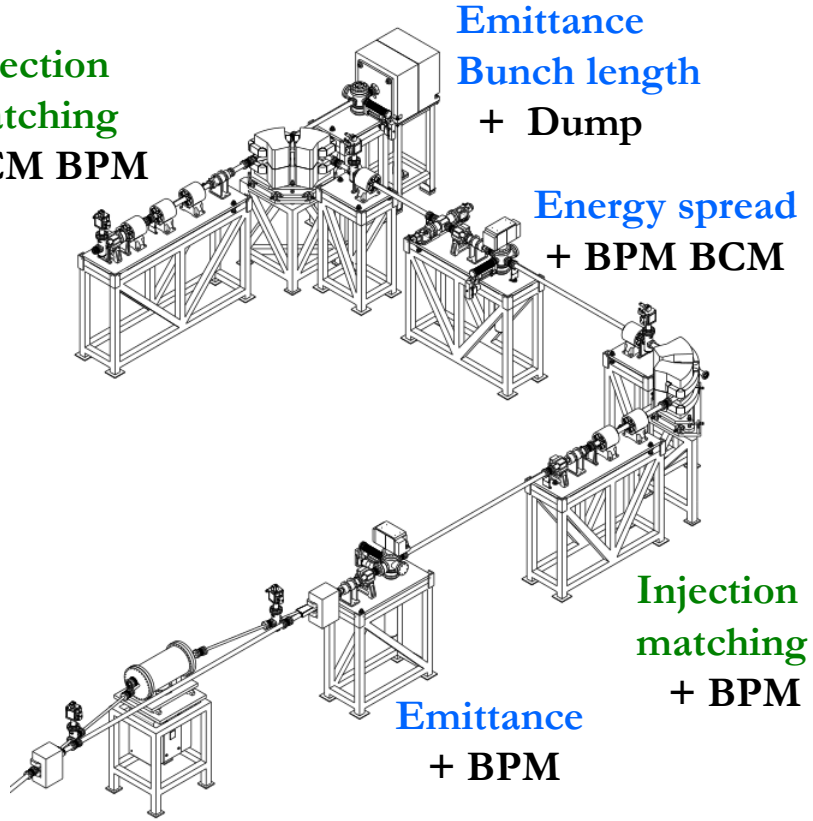
ε_N ~ 5 π.mm.mrad (rms)

Transfer line

- to transfer
- to match
- to diagnose

} the linac beam

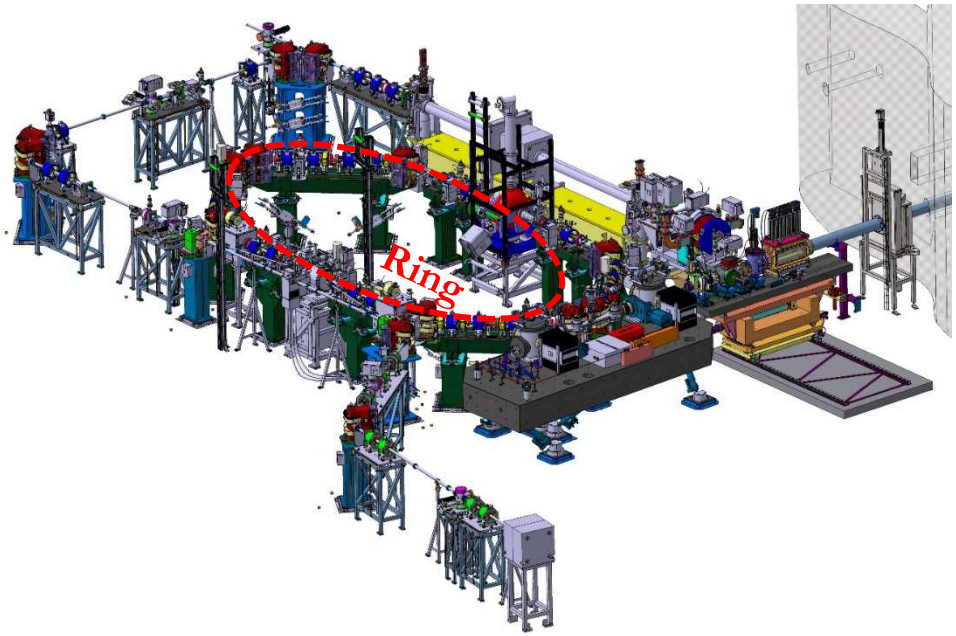


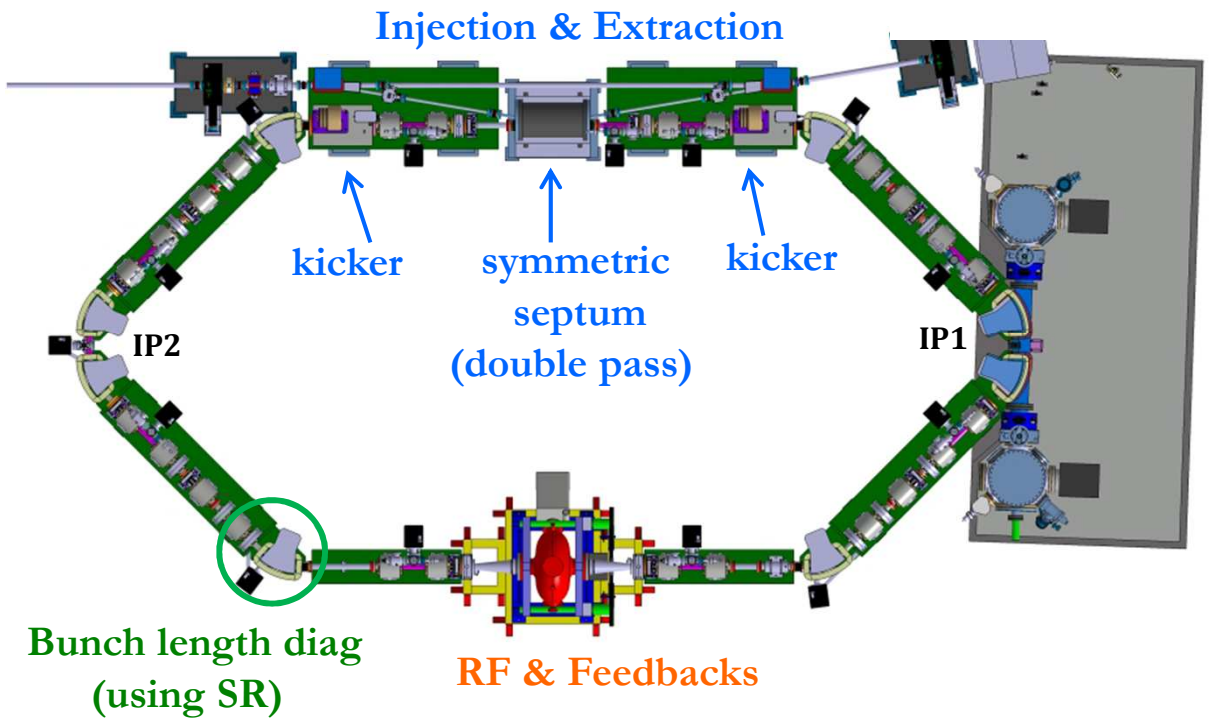


- Energy spread
  Dipole + screen + CCD
- Emittance
  Quadrupole scan /screen
- Bunch length
  e- → radiator → Cherenkov radiation

Ring

- 16.8 m circ. (17 MHz rev. freq.)
- 2 free straight sections
  - → Injection/Extraction
  - → RF & Feedbacks





- 8 dipoles
- 24 quadrupoles
- 12 sextupoles
- 12 correctors
- 12 BPM

<u>At IP, at injection</u> :

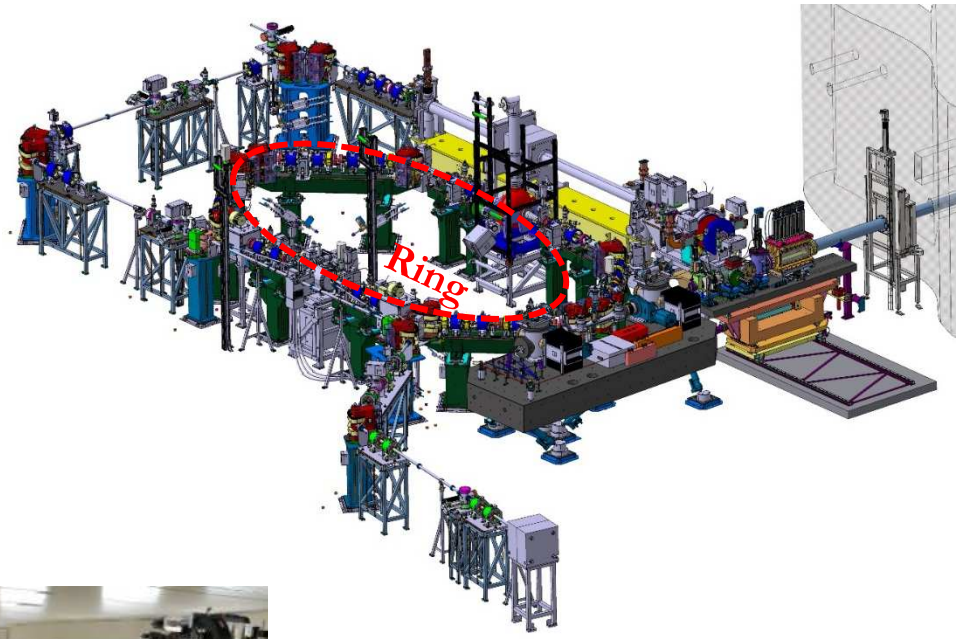
σ_Z ~ 10 - 20 ps (rms)

ε_N ~ 5 π.mm.mrad (rms)

σ_T ~ 40 - 200 μm (rms)

Ring

- 16.8 m circ. (17 MHz rev. freq.)
- 2 free straight sections
  - → Injection/Extraction
  - → RF & Feedbacks



- 8 dipoles
- 24 quadrupoles
- 12 sextupoles
- 12 correctors
- 12 BPM

<u>At IP, at injection</u> :

σ_Z ~ 10 - 20 ps (rms)

ε_N ~ 5 π.mm.mrad (rms)

σ_T ~ 40 - 200 μm (rms)

Laser/Cavity system

- Laser 1W , 34 MHz , 15 ps

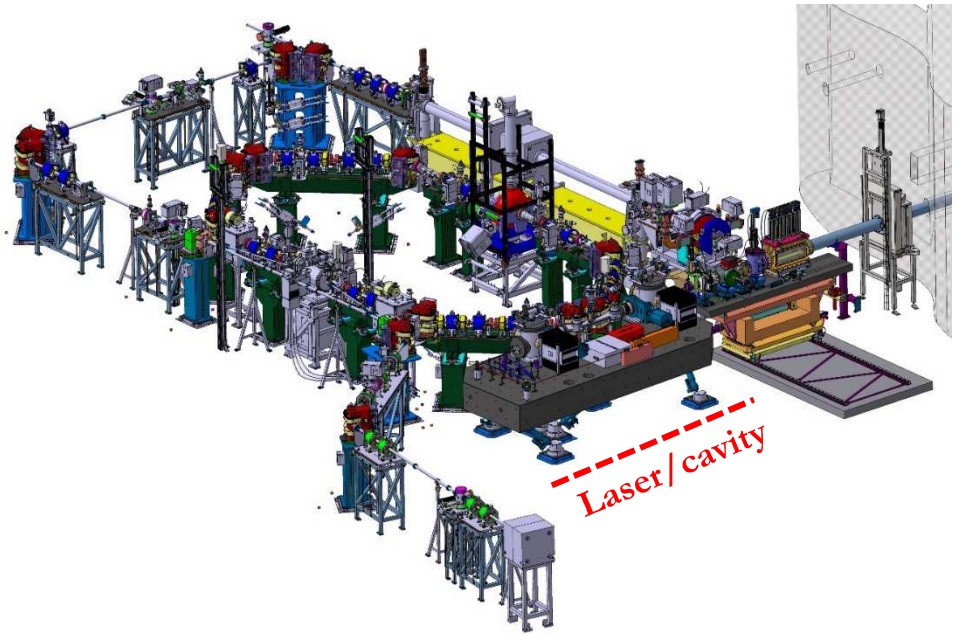
- Optical fiber amplification

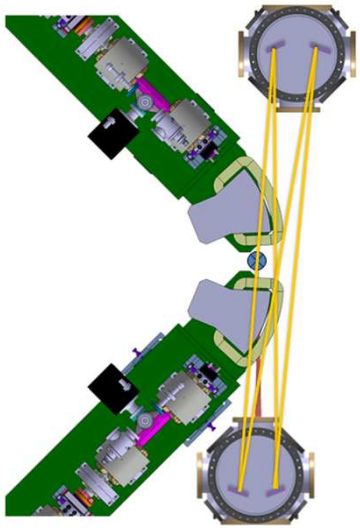
  (fibers doped with Ytterbium)

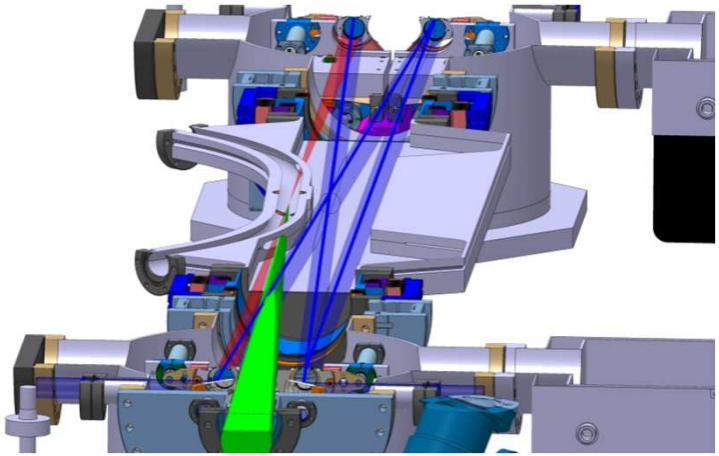
  → 50 - 100 W (1-2 µJ/pulse)

- Optical cavity amplification gain 10000

  → 0.5 - 1 MW stored inside the cavity (10-20 mJ/pulse)



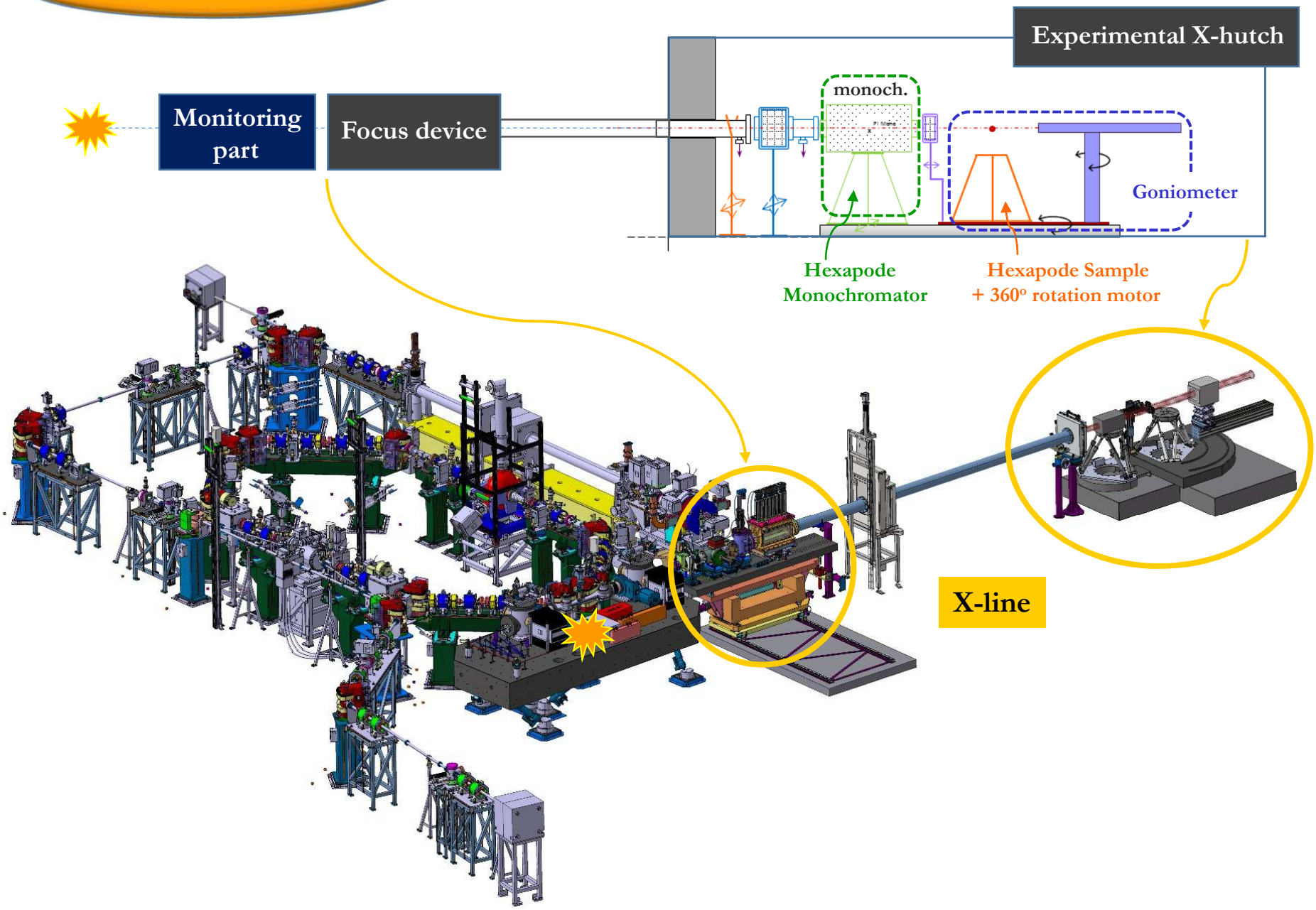




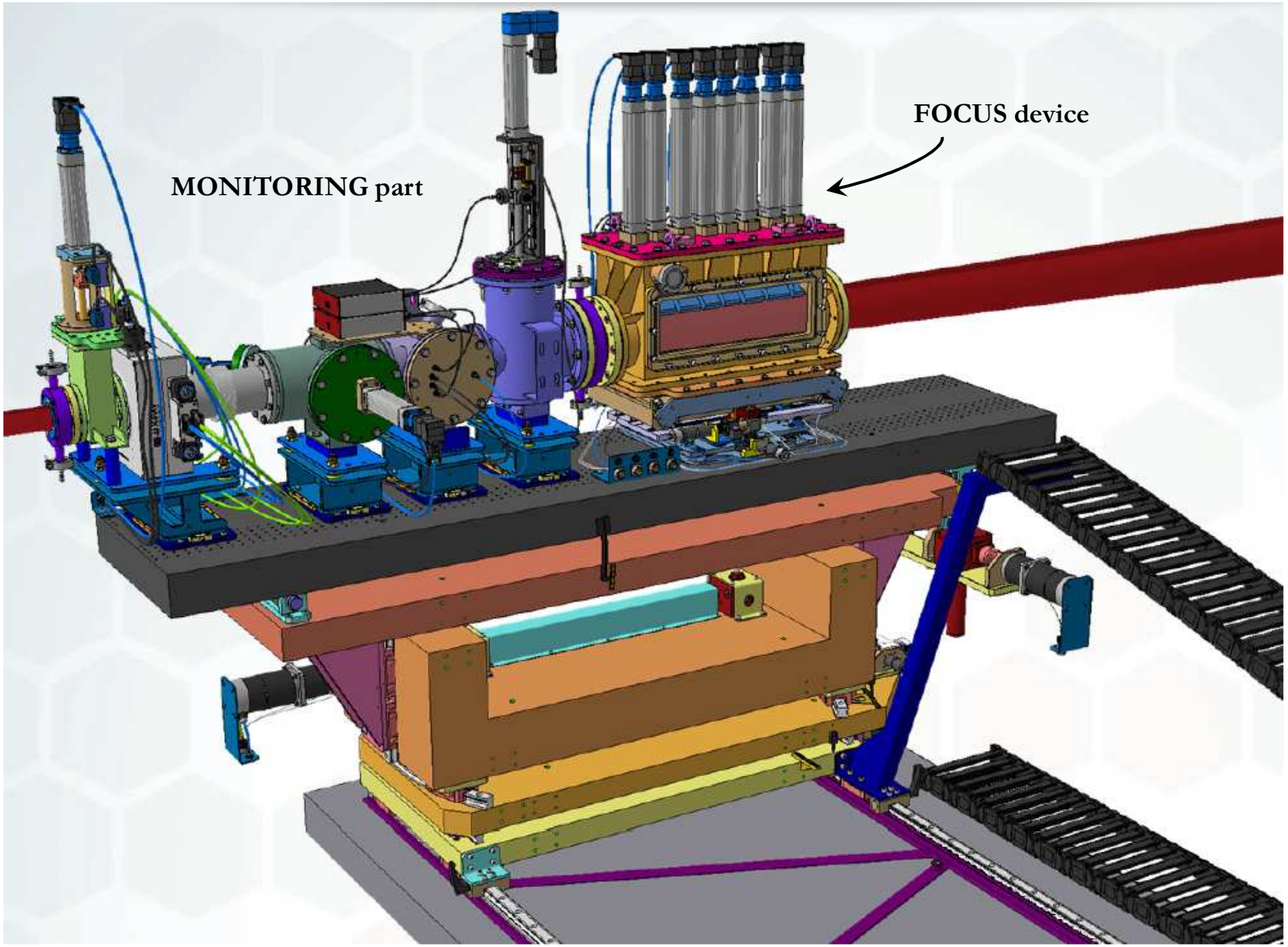
- 4 mirrors planar cavity
- 2 plan & 2 spherical mirrors
- Optical path ~ 8.4 m

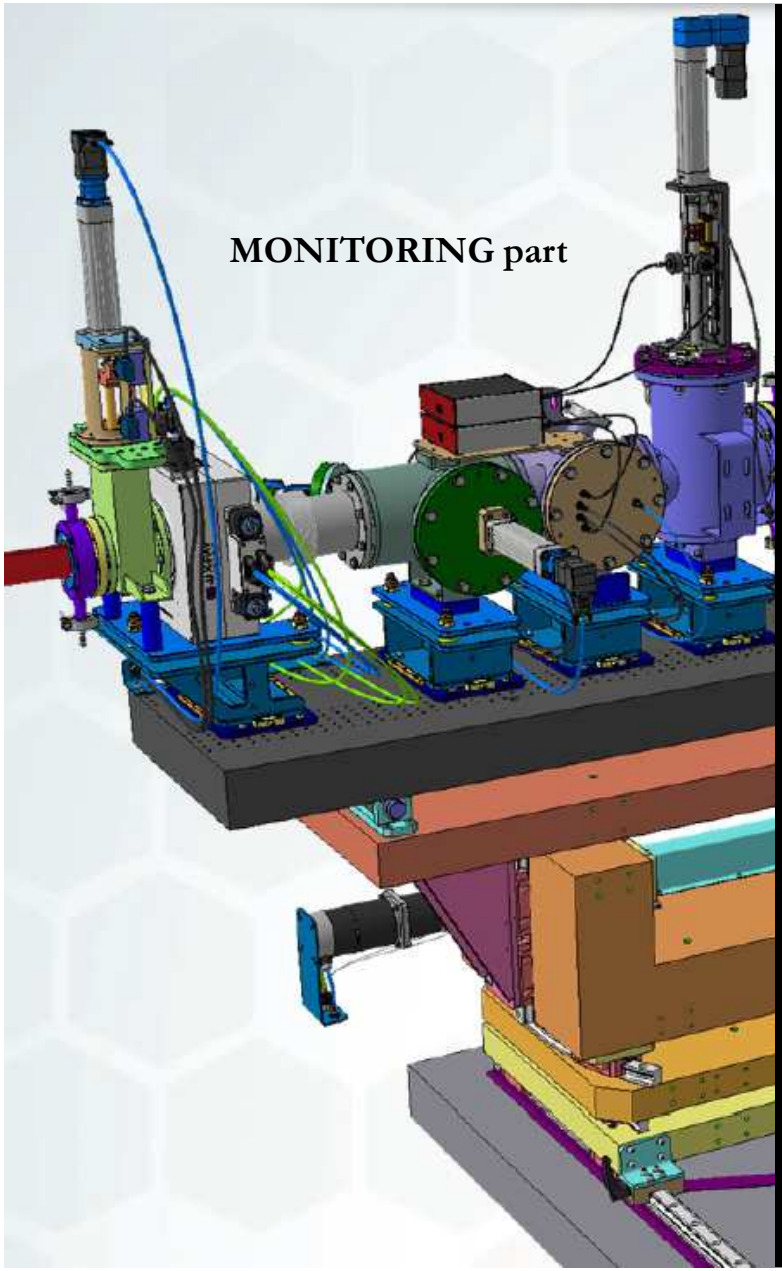
Results on prototype : 200 kW during 30 min

X-line INTEGRATION

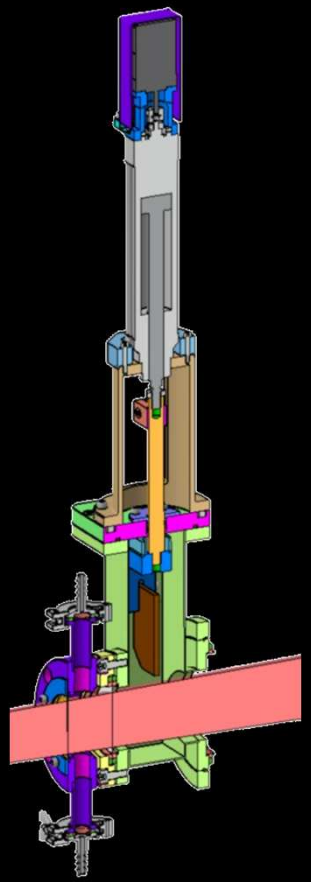


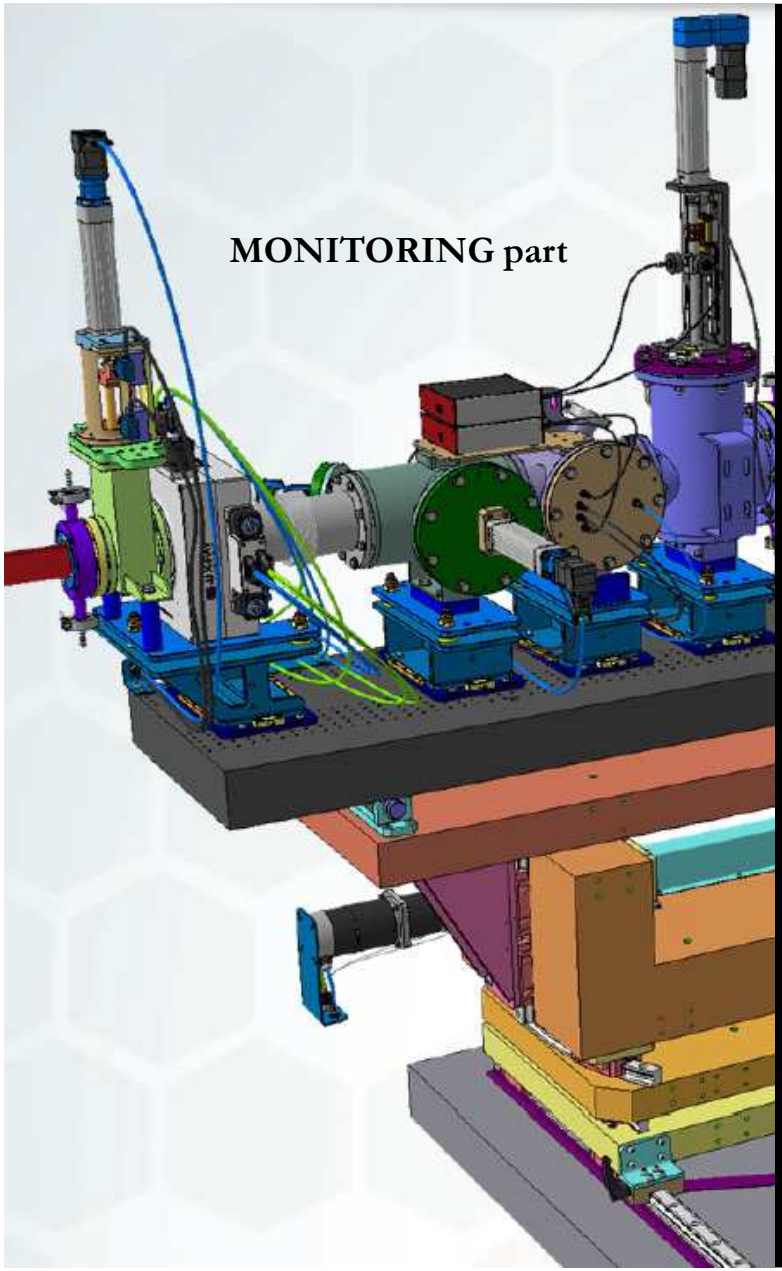
Monitoring and Focusing



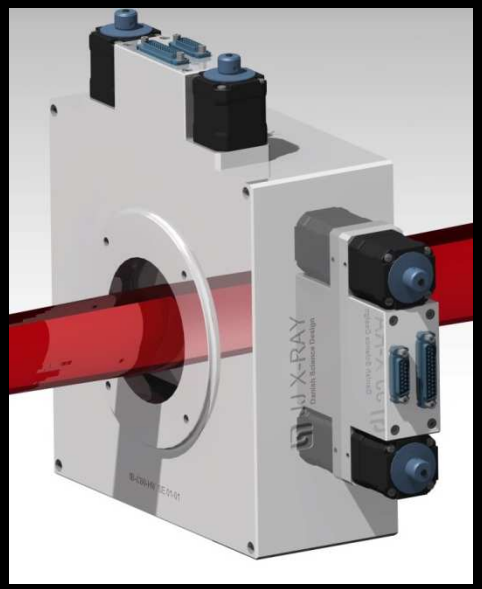


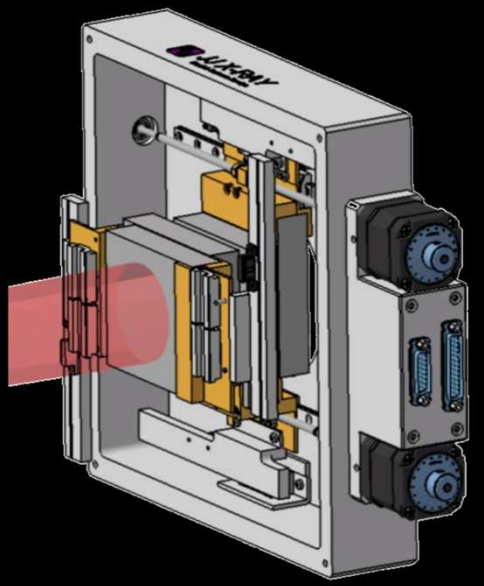
SHUTTER

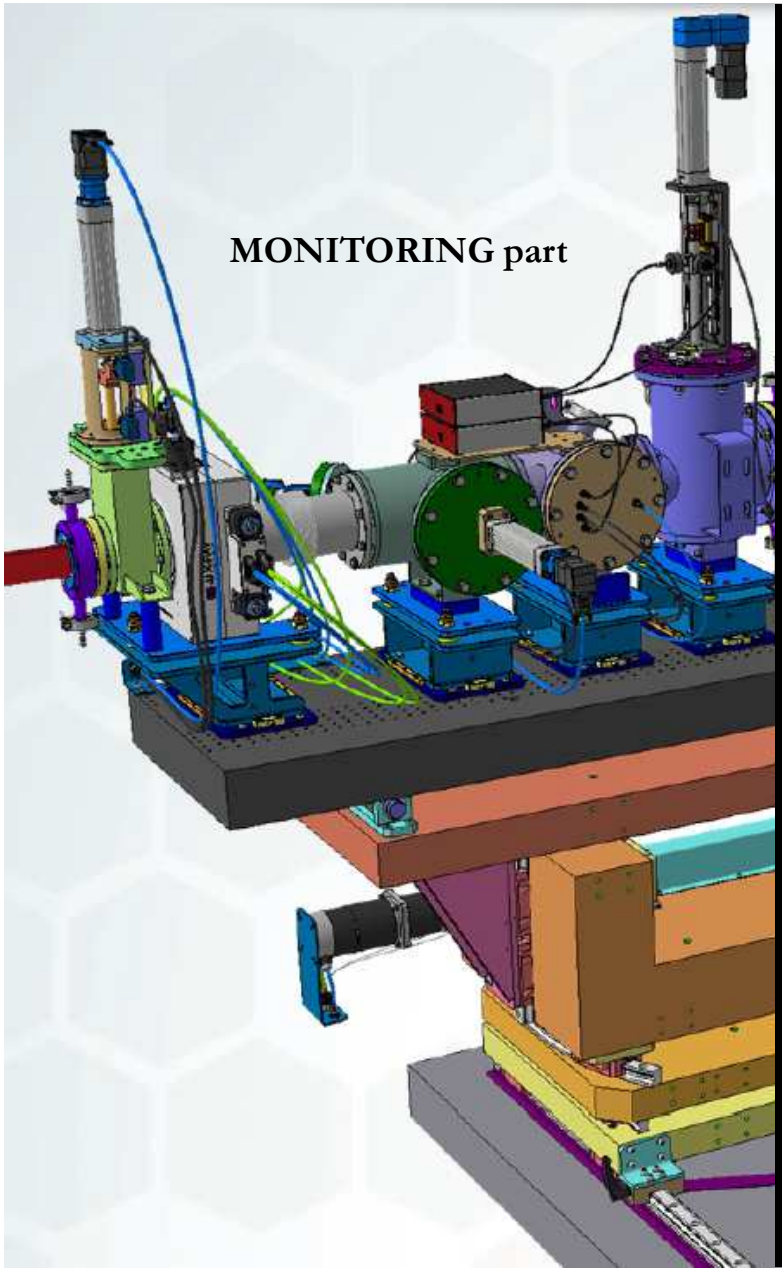




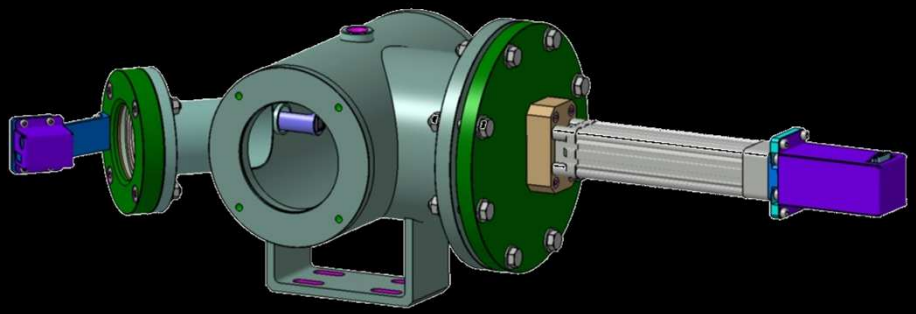
SLITS

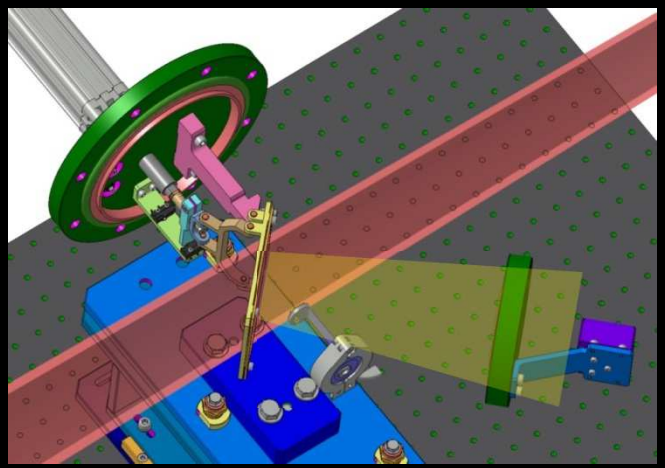


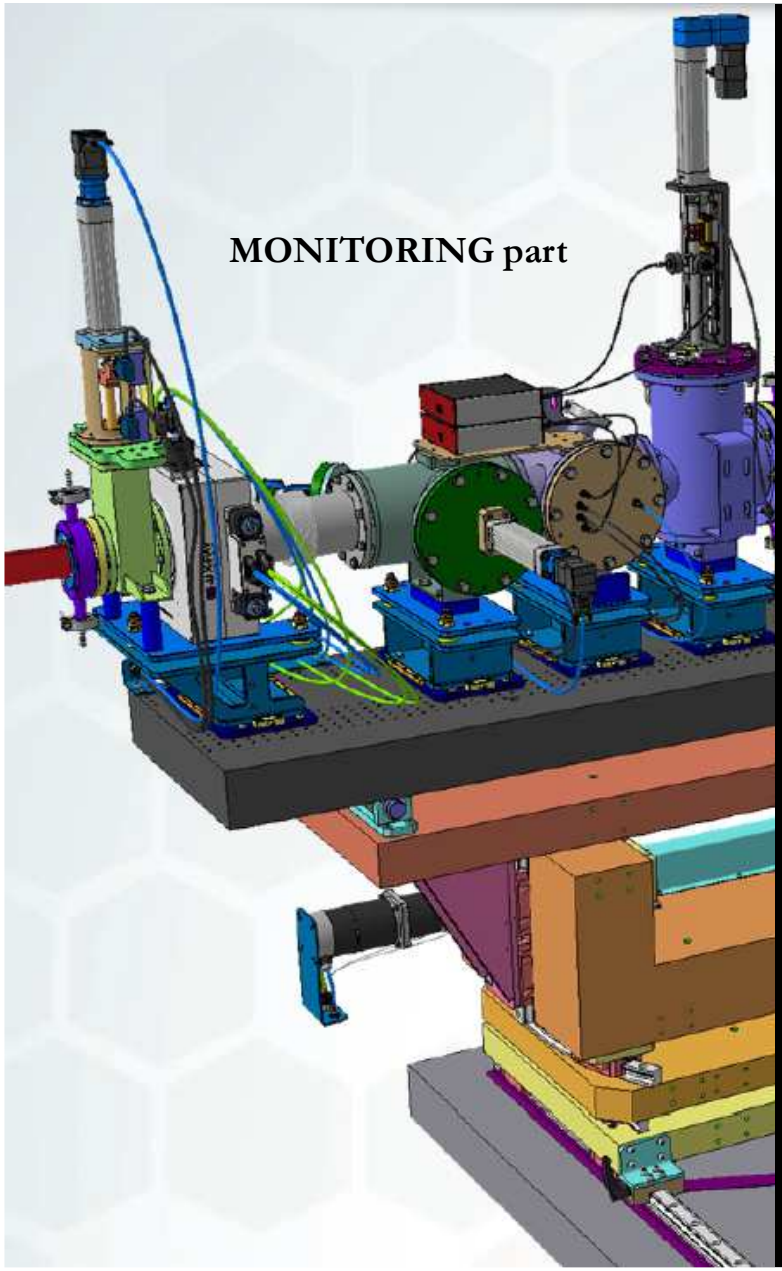




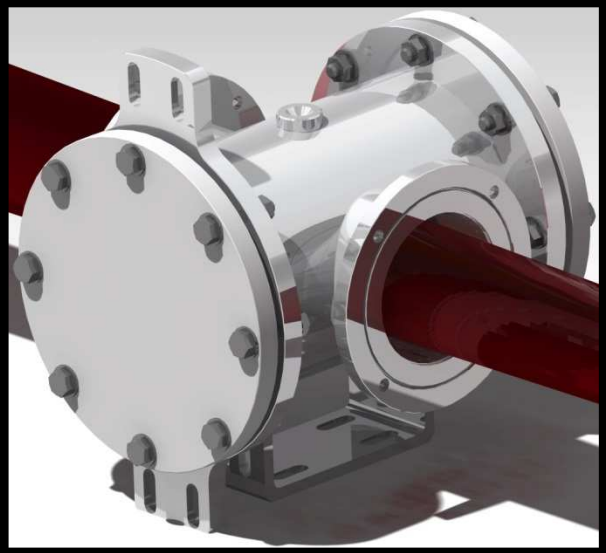
FLUORESCENT detector

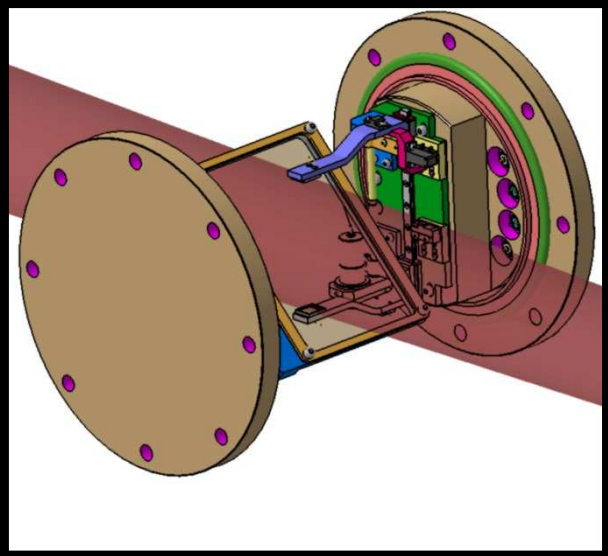


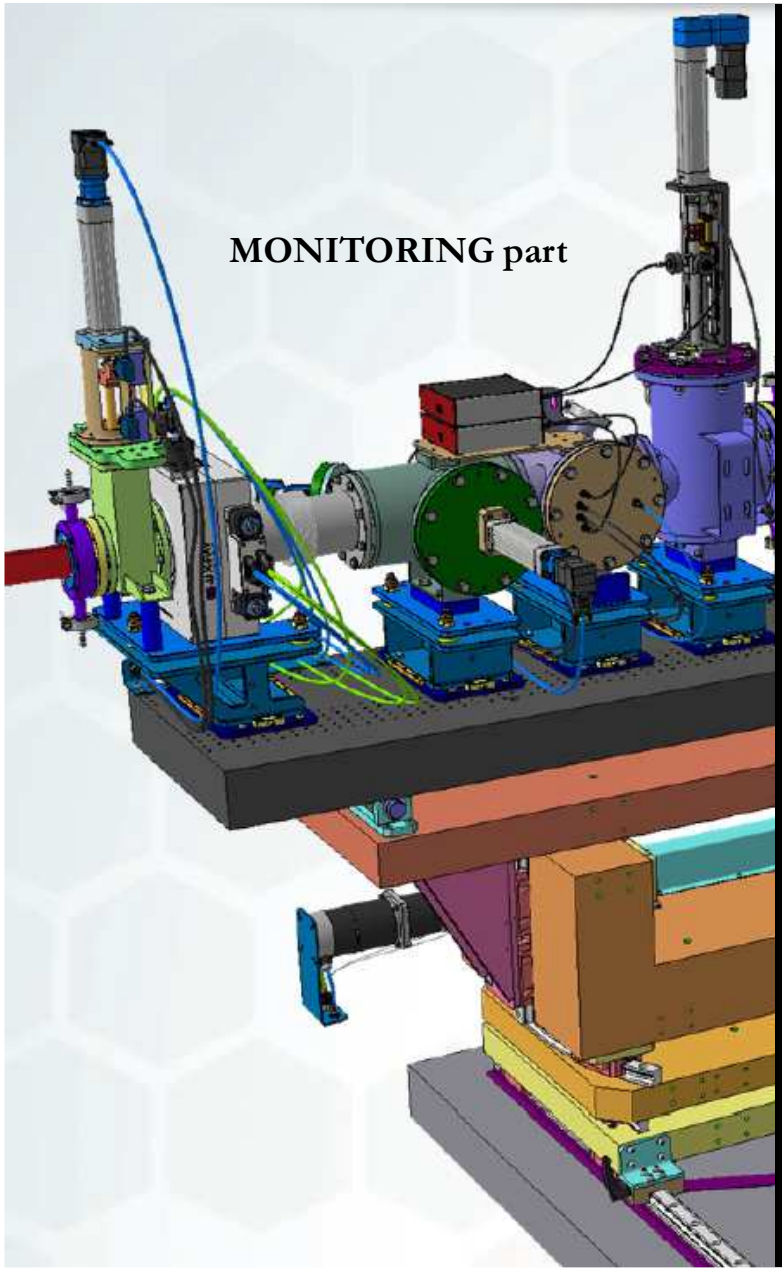




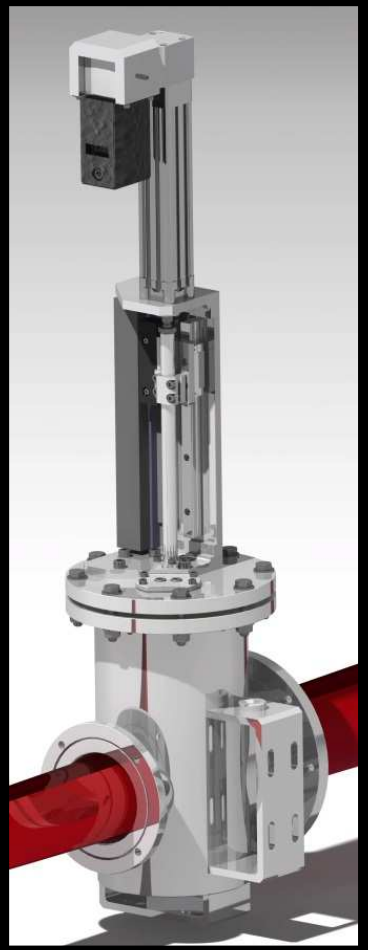
2-DIODES detector

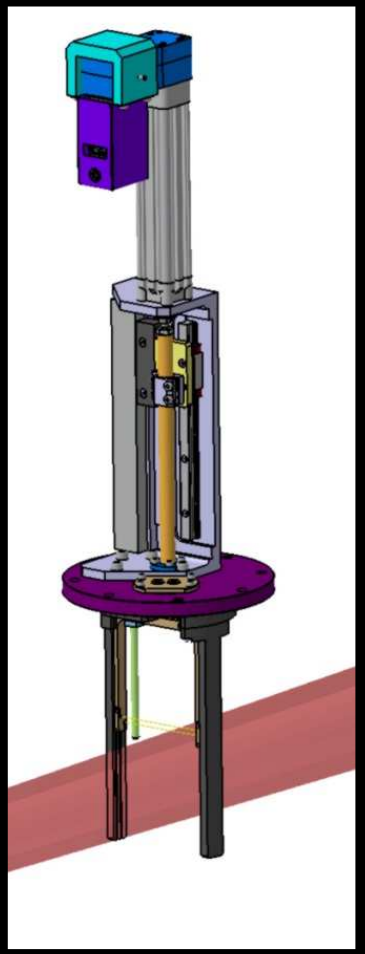




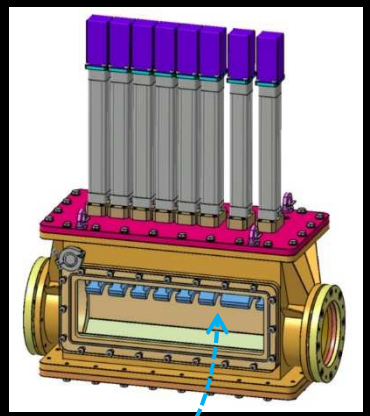


TUNGSTEN WIRE monitor

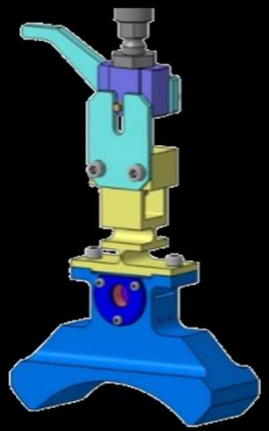


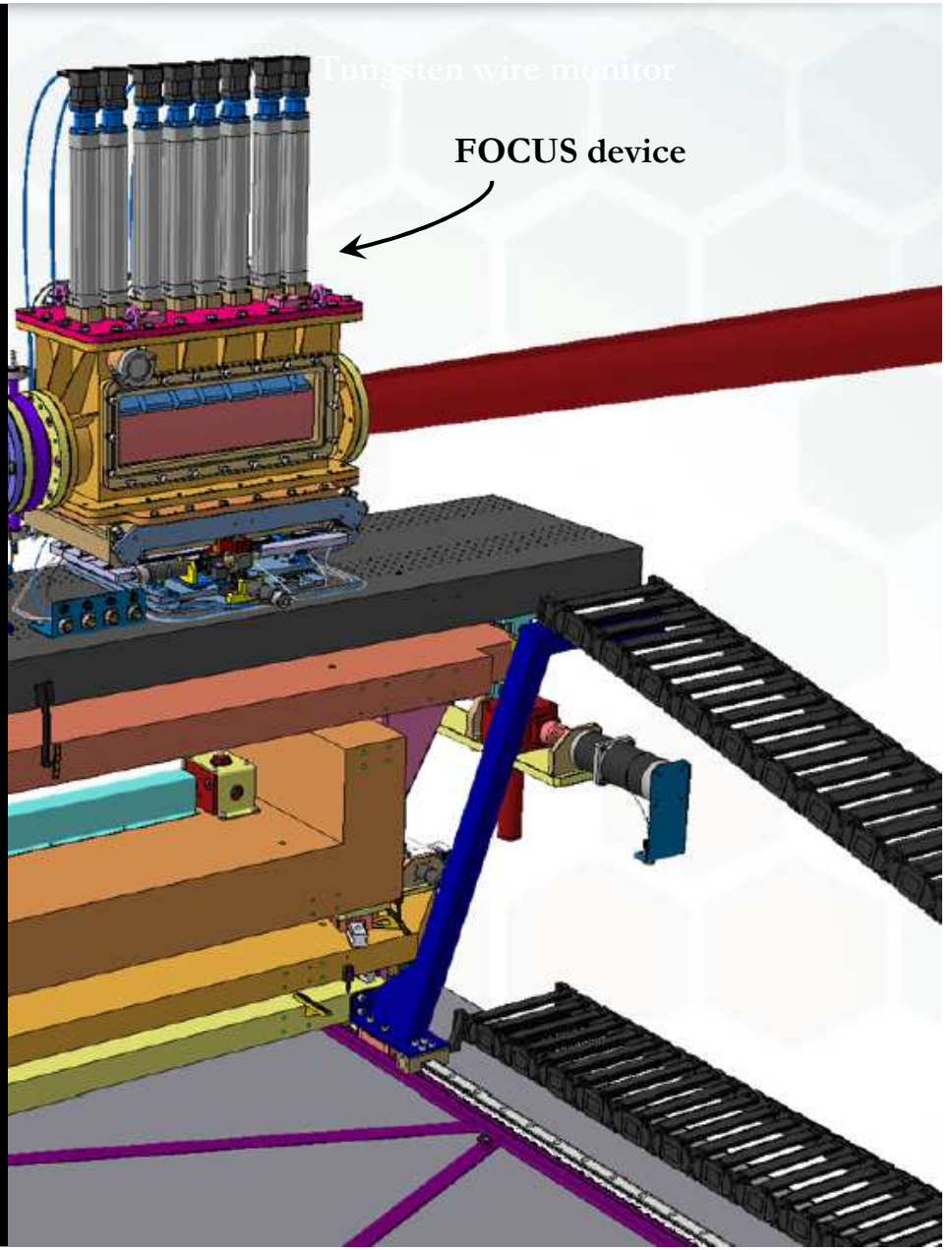


TRANSFOCATOR

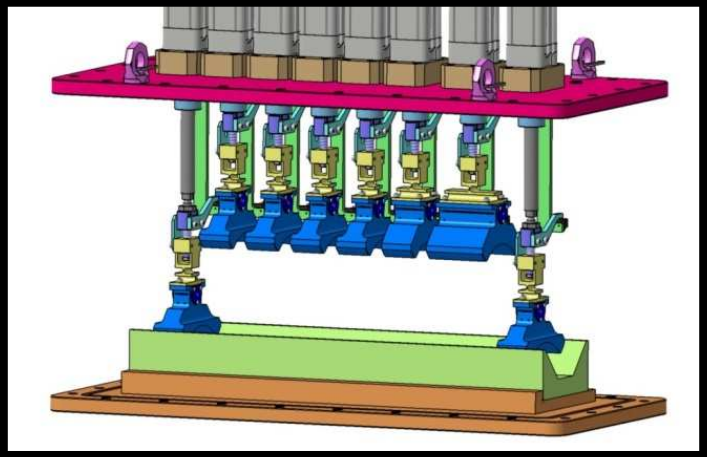


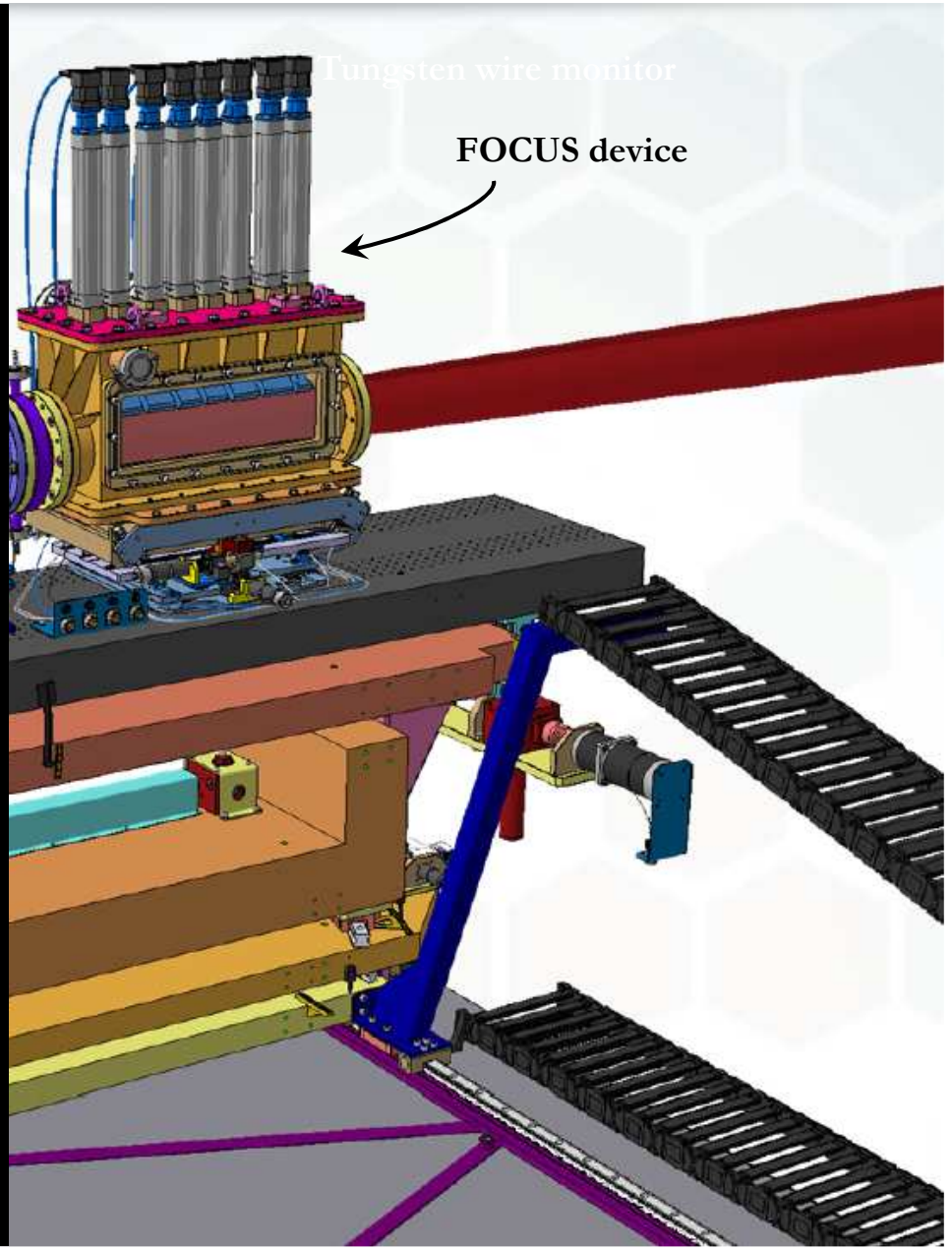
x 8



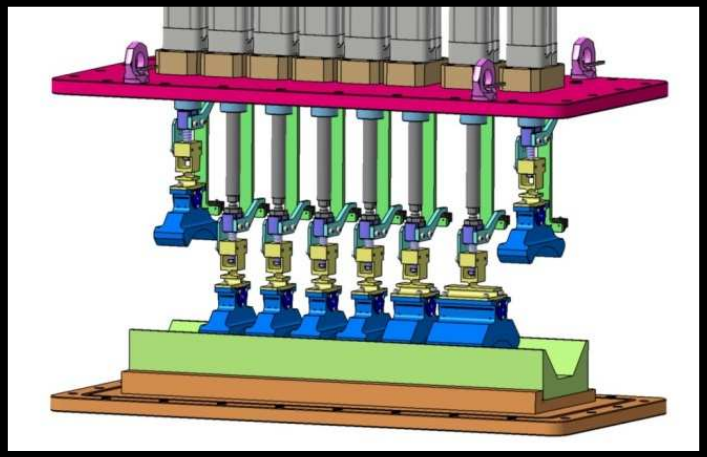


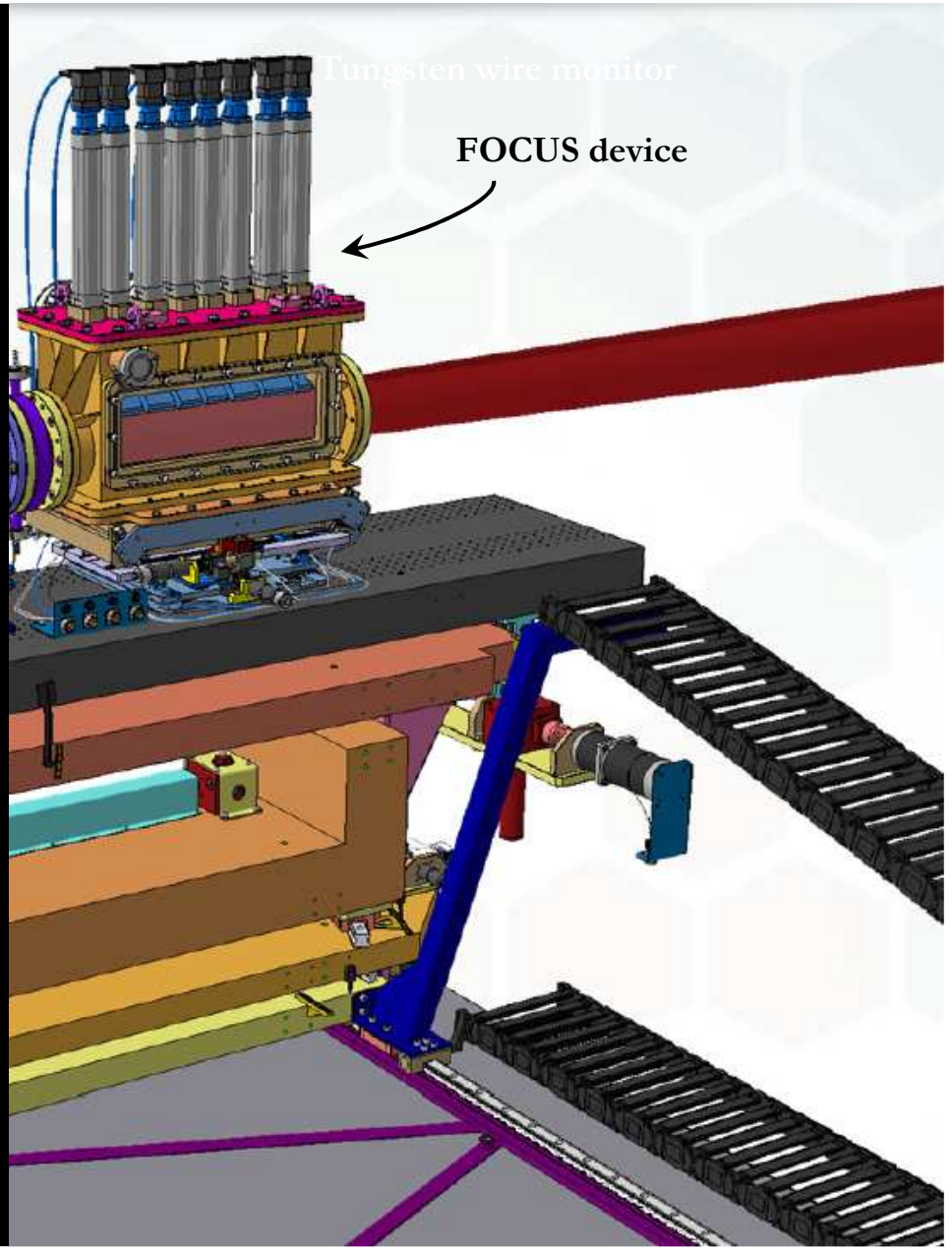
TRANSFOCATOR



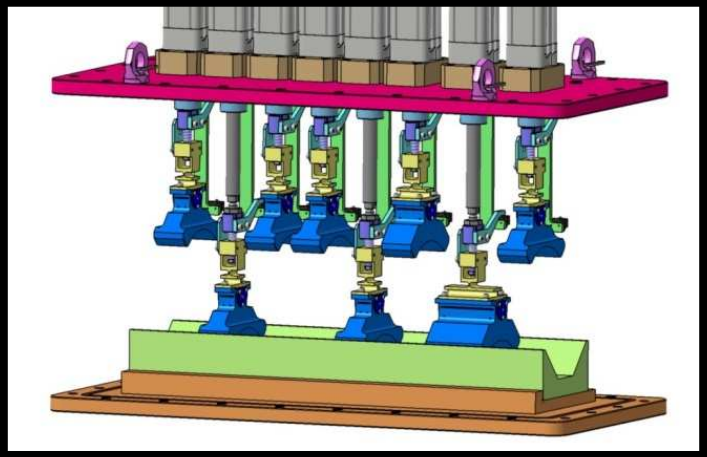


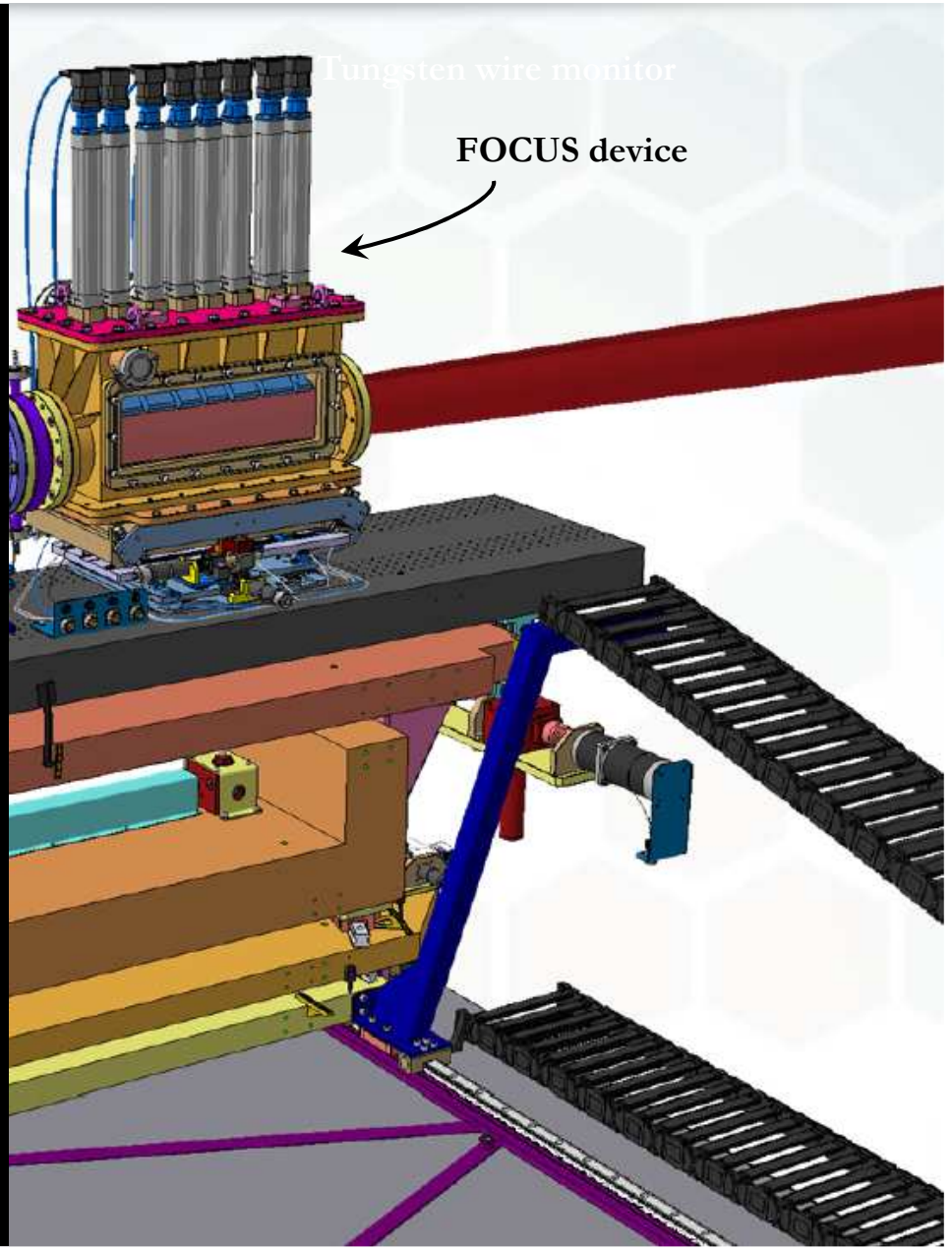
TRANSFOCATOR



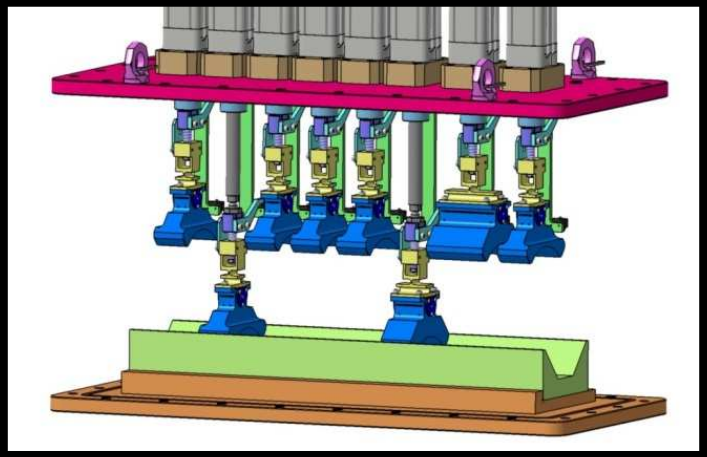


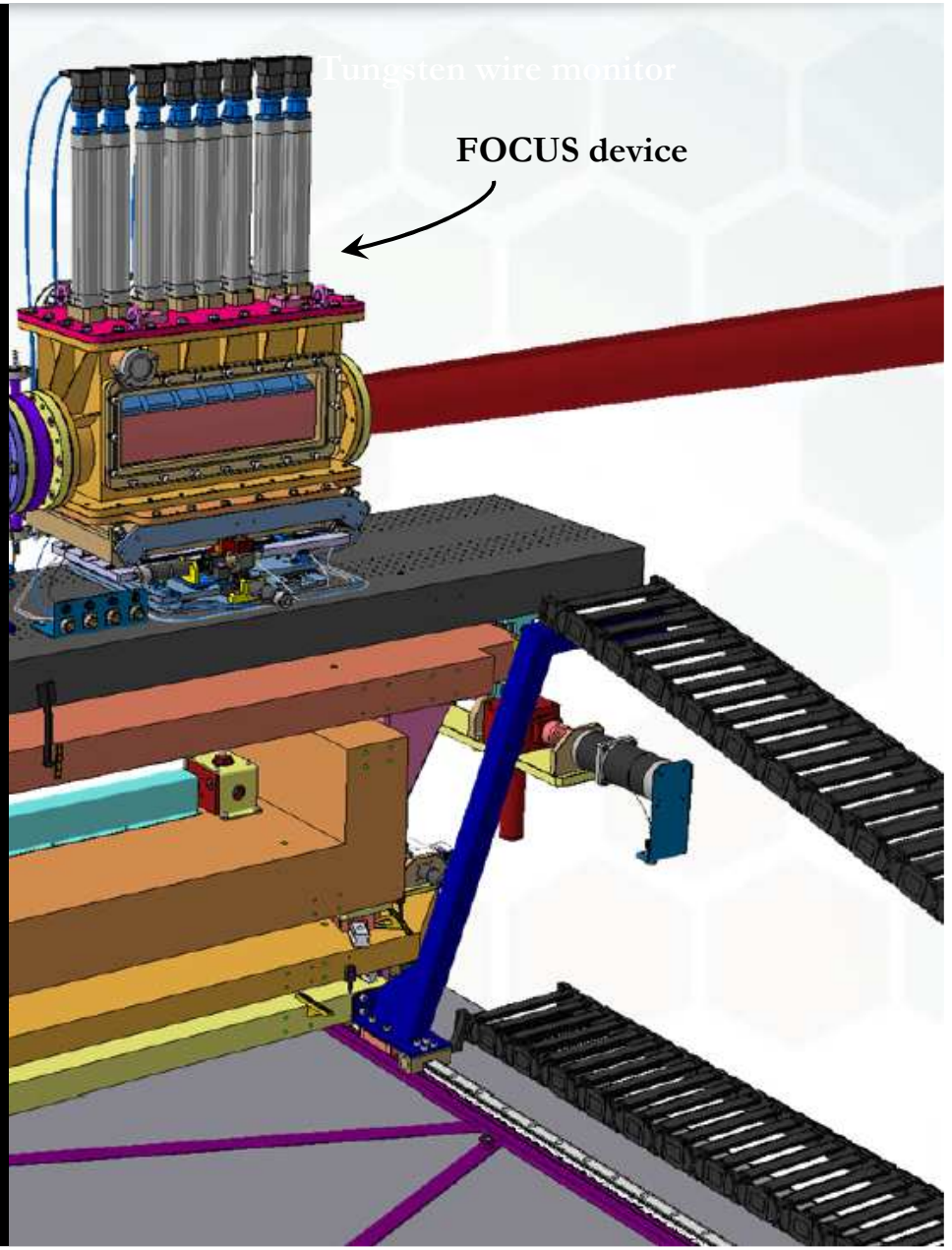
TRANSFOCATOR



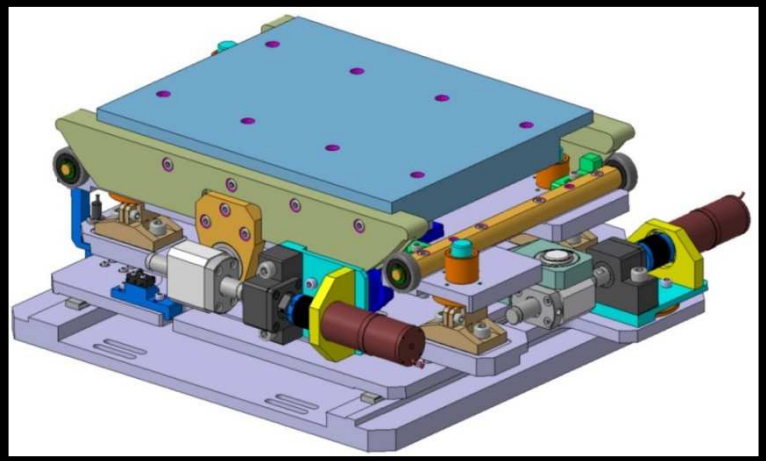


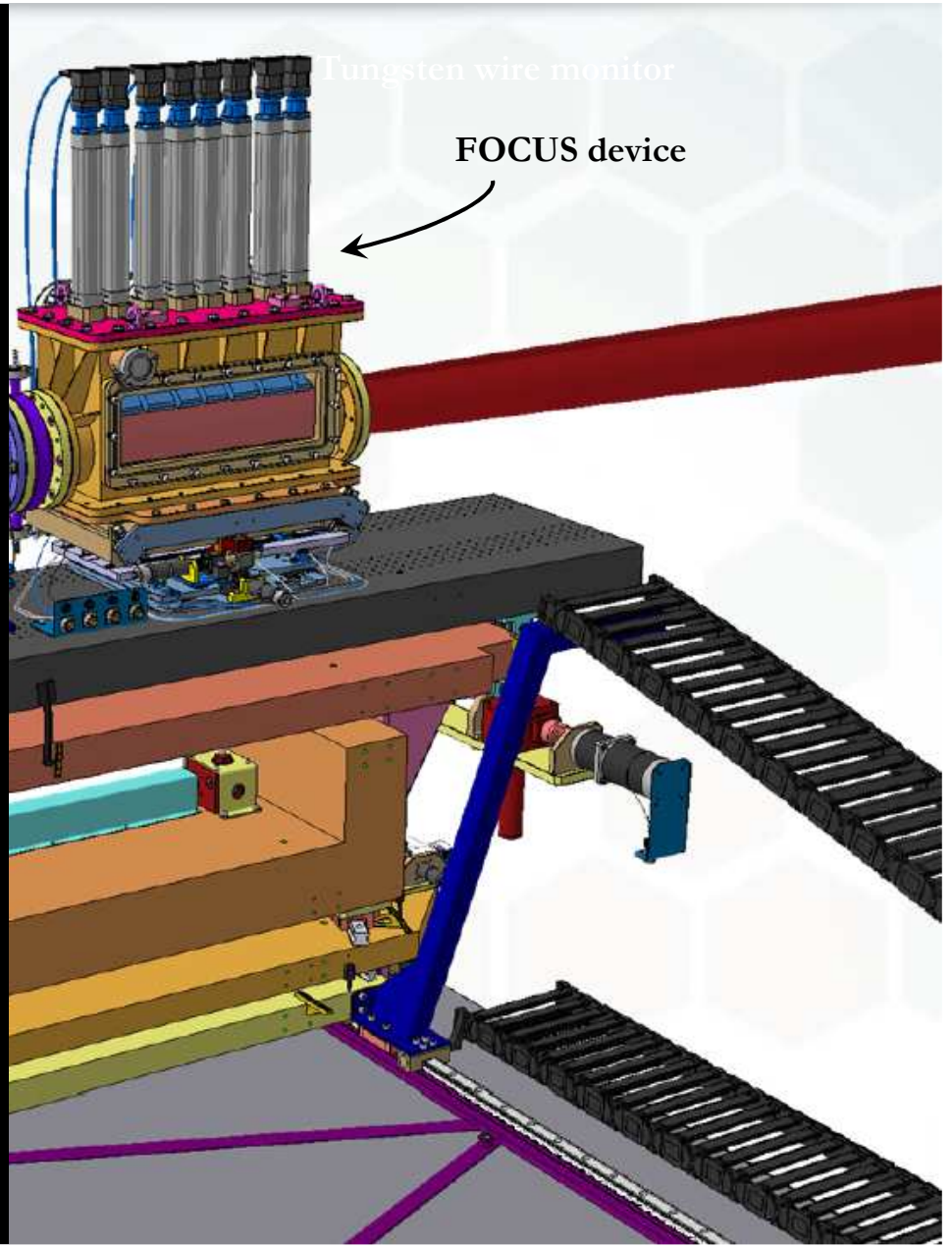
TRANSFOCATOR





Transfocator SUPPORT

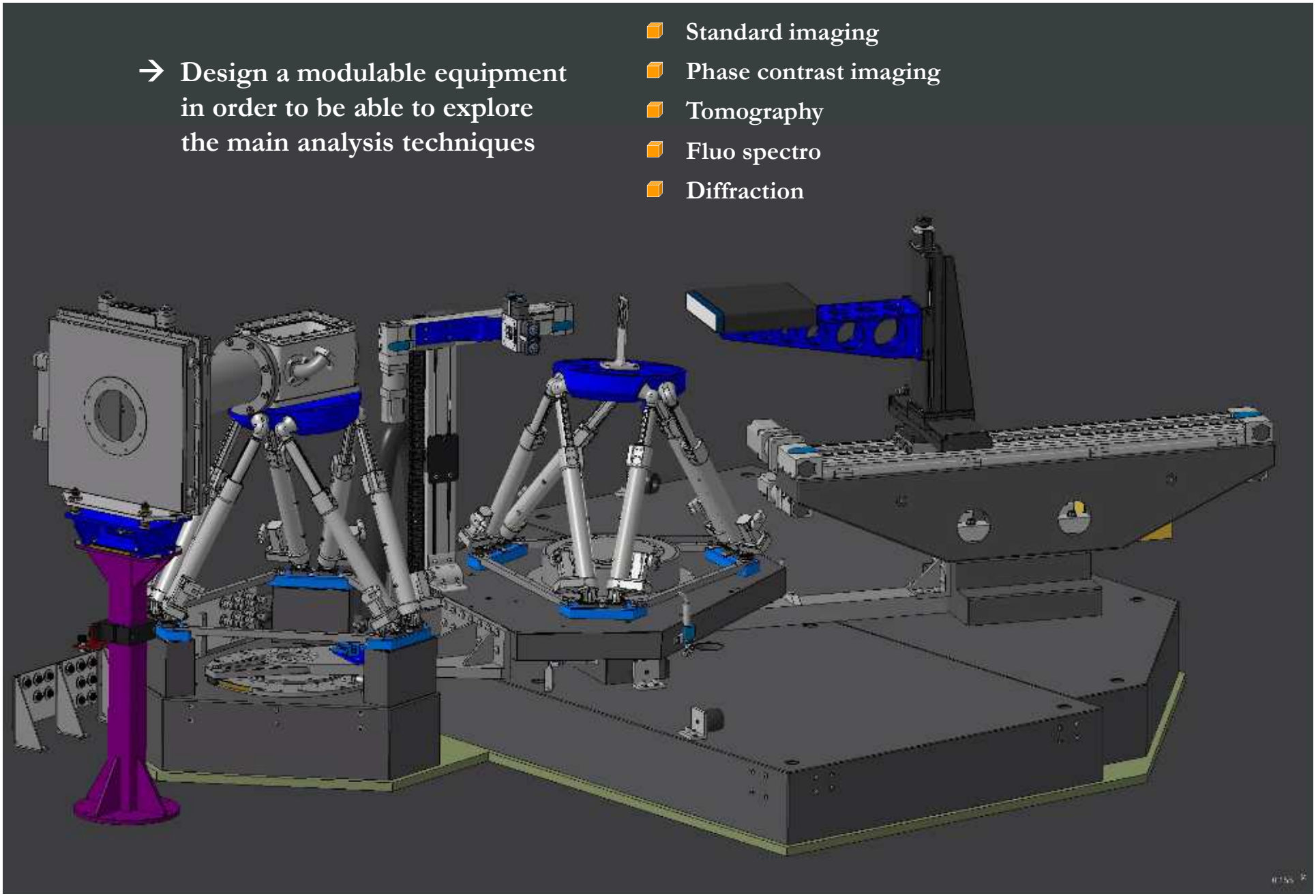




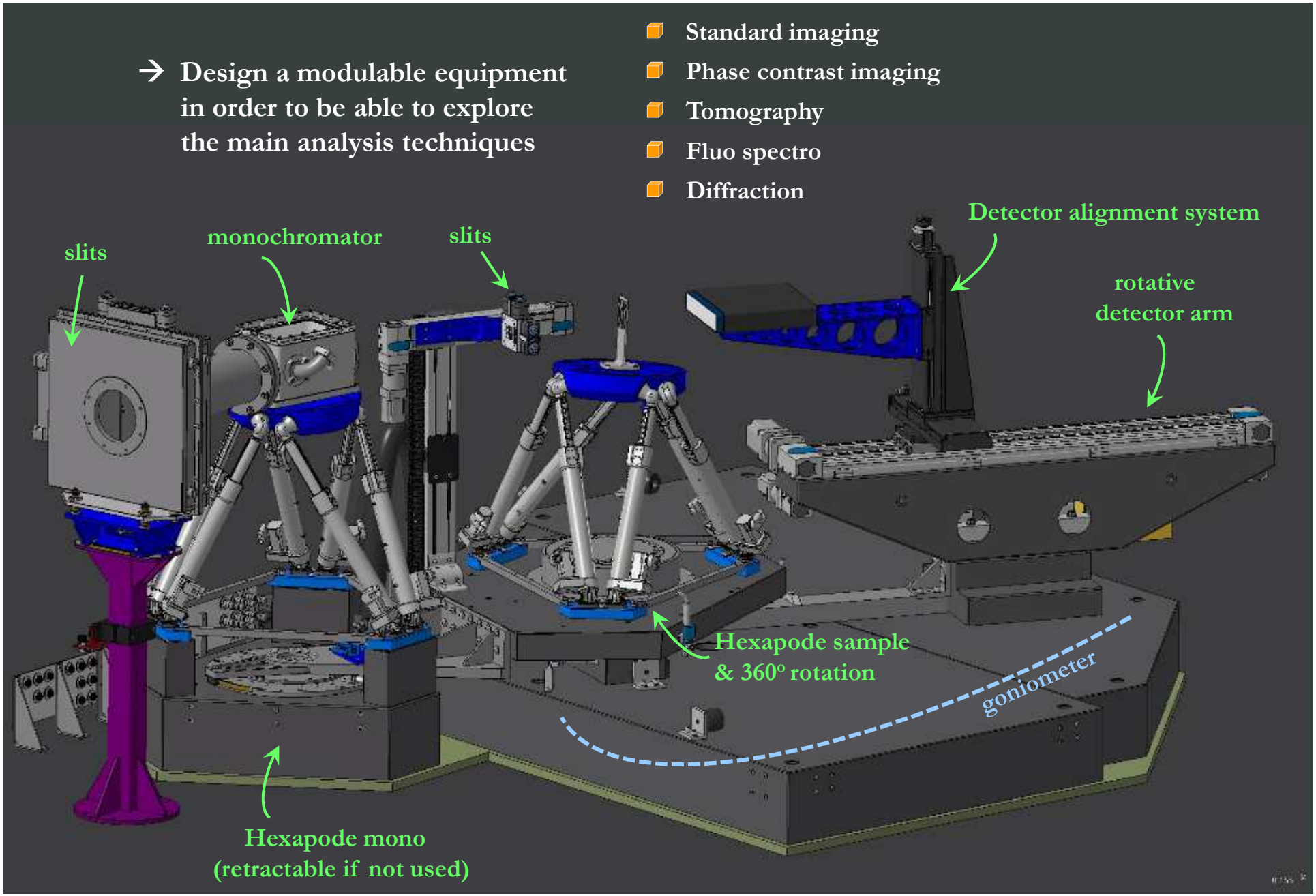
X-ray experimental hutch

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

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



X-ray experimental hutch

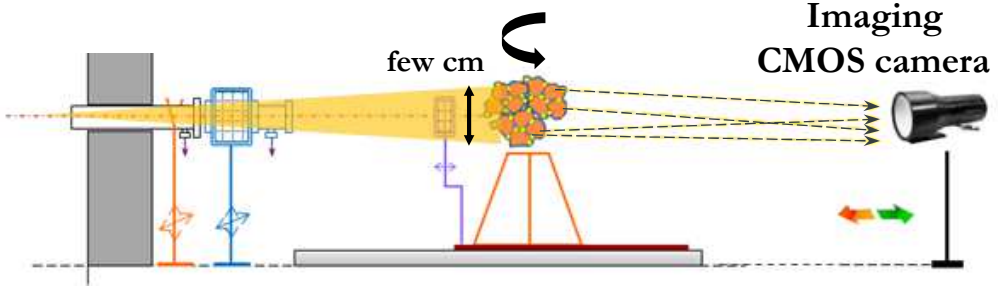


Orders of magnitude

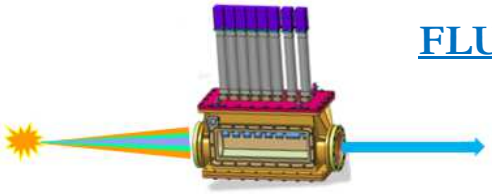
- Standard imaging
- Phase contrast imaging
- Tomography
- Fluo spectro
- Diffraction

IMAGING

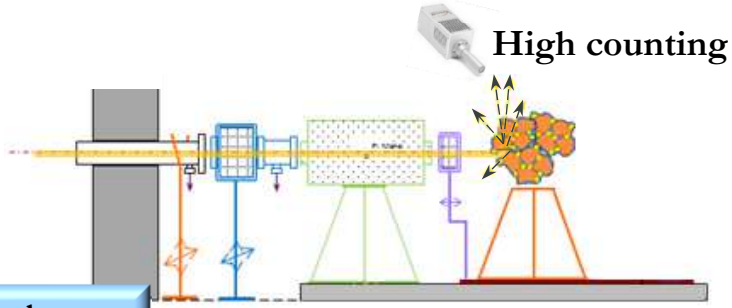
few cm beam
bw : few %
~ 10^{12} ph/s



FLUO

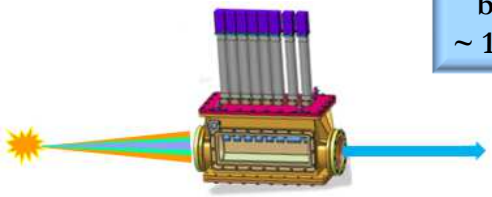


Transfocator
(present or retracted)

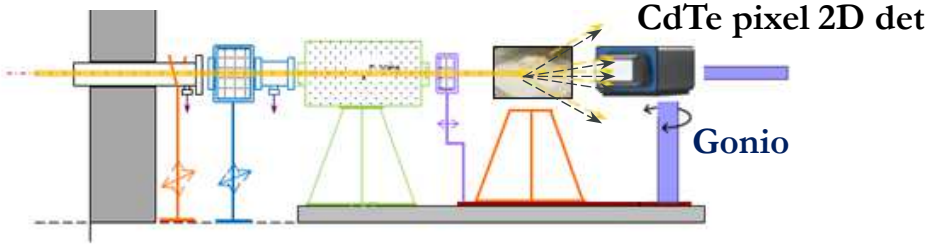


150 - 200 µm beam
bw : few % to 0.01%
~ 10^{8} - 10^{6} ph/s

Monochromator
(present or retracted)



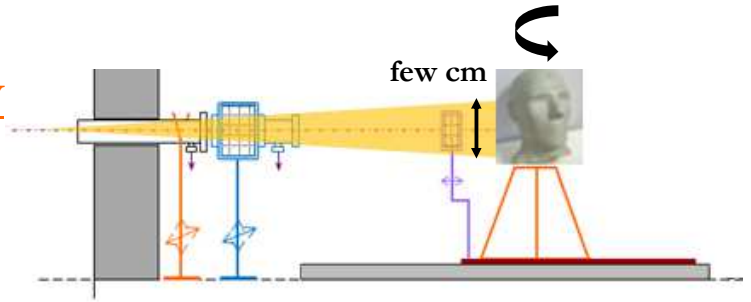
DIFFRACTION



With the ThomX update (90 keV max X-ray)

RADIOTHERAPY / RADIOBIOLOGY
High Z drugs PAT STUDIES

3 cm beam / 80 keV ± 10 keV
~ 10^{9} ph/s/mm^2



Orders of magnitude

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

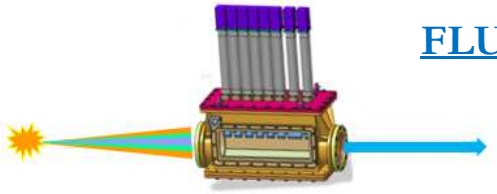
IMAGING

few cm beam
bw : few %
~ 10^{12} ph/s

ThomX: 1.3 10^6 ph/s/pixel (50 µm)
→ Tomo (conventional, PCI) in few seconds

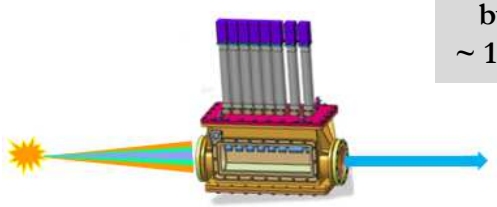
M. Jacquet / Phys Med 32 (2016) 1790–1794

FLUO



Transfocator
(present or retracted)

150 - 200 µm beam
bw : few % to 0.01%
~ 10^8 - 10^6 ph/s



DIFFRACTION

ThomX: between classical X-ray lab sources and synchrotron sources

With the ThomX update (90 keV max X-ray)

RADIOTHERAPY / RADIOBIOLOGY
High Z drugs PAT STUDIES

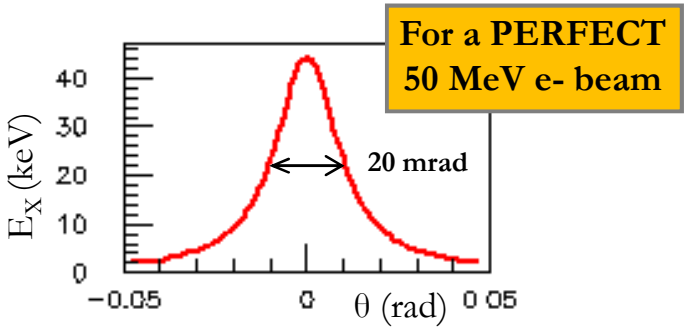
3 cm beam / 80 keV ± 10 keV
~ 10^9 ph/s/mm^2

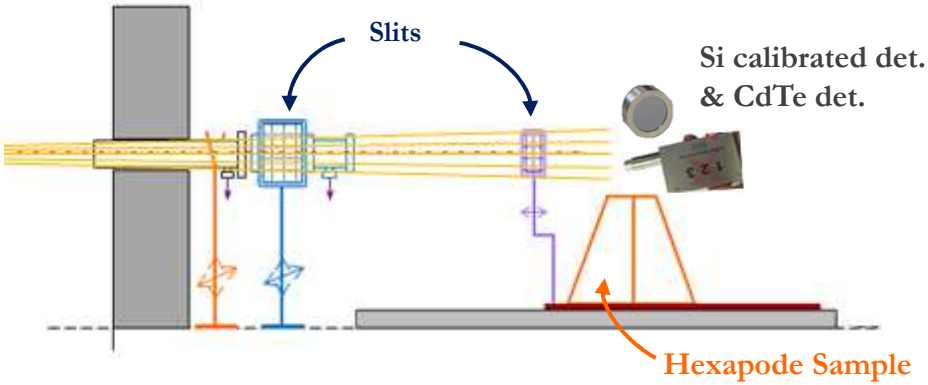
- ThomX: ~ 10^9 ph/s/mm^2
- SSRT ESRF: ~ 10^9 ph/s/mm^2

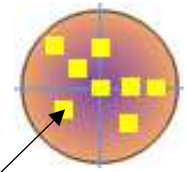
M. Jacquet, P. Suortti, Phys Med 31 (2015) 596-600

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

Beam CHARACTERISATION



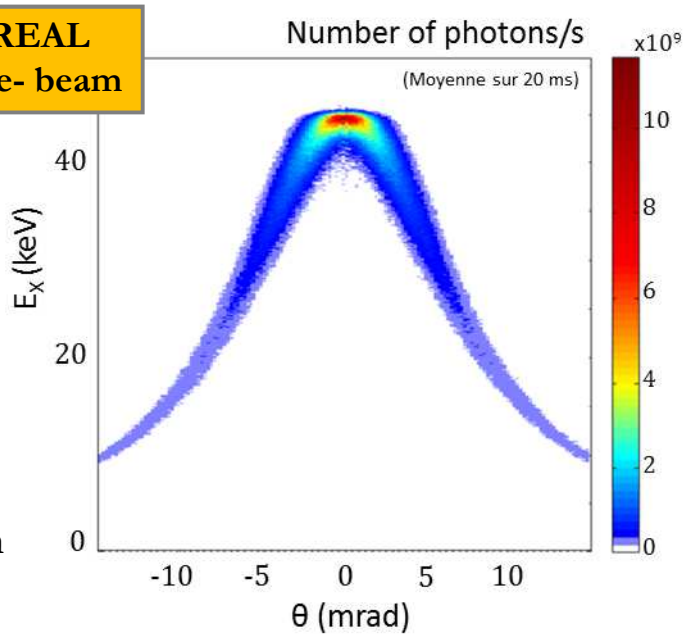




For each point: Measure the energy and flux

→ Reconstruct the energy/angle distribution

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



Detectors

1 CdTe detector
25 mm²
Integrated electr.
(Amptek)

1 calibrated Si diode
(Canberra)

→ Beam characterization (spectral flux)

288 K pixels
250 x 33 mm²

1 CdTe 2D pixel detector
(Dectris)

→ Diffraction θ-2θ

2 SDD detectors
25 mm² + FalconX electr.
(Hitachi)

→ Fluorescence (high count rate)

16 M pixels
55 x 55 mm²

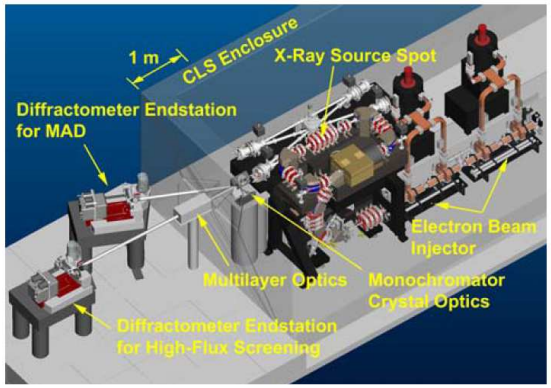
1 « médical » 2D detector
Scintill + CMOS camera
(Photonic Science)

→ Imaging (small spatial resolution)

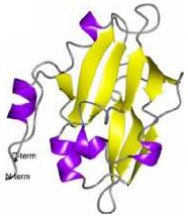
PROOFS of PRINCIPLE @ Lyncean Tech. / Munich

DIFFRACTION

Lyncean Tech. (2010)



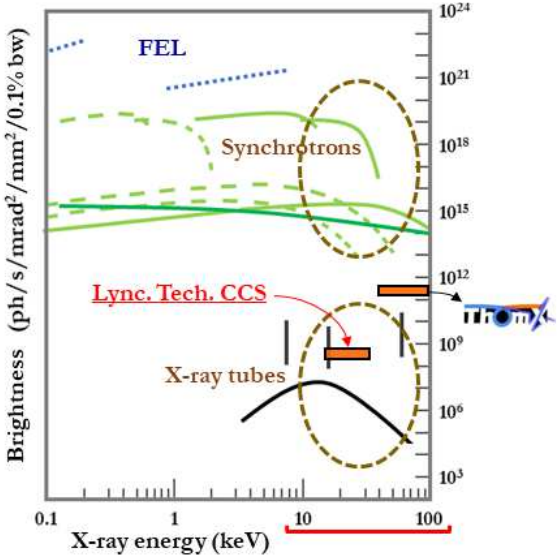
3D structure determination
Protein MytuGCSPH



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

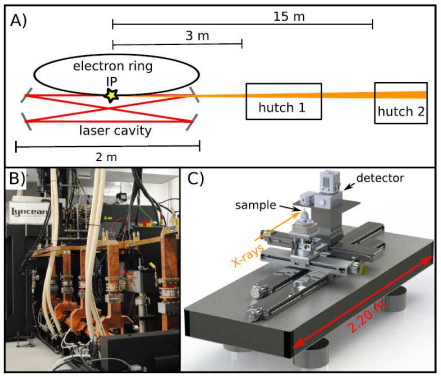
Flux and results comparable with the same analysis realized at a rotating anode

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



PHASE CONTRAST IMAGING

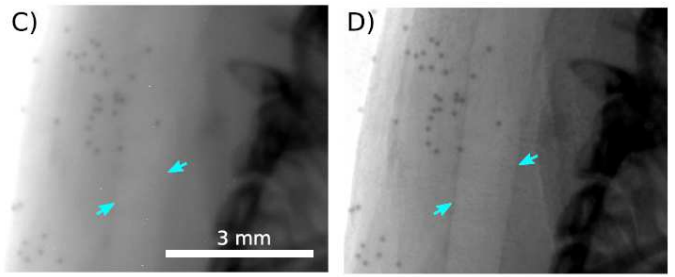
Munich/Lync. Tech. (2017)



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

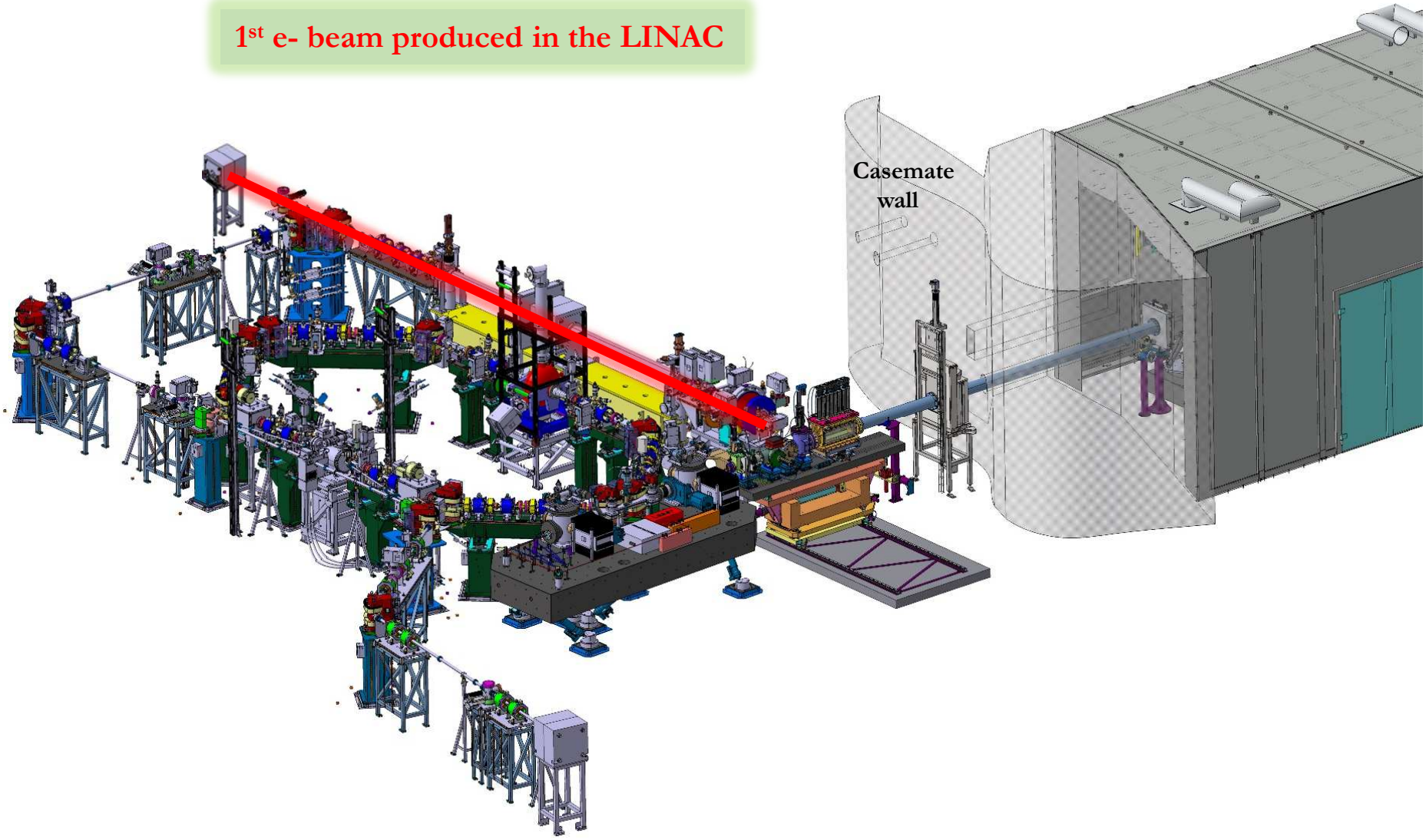
Air/tissue interfaces more visible

[Scientific Reports volume 7, 4908, 2017]

Current planning

Today: COMMISSIONING

1st e- beam produced in the LINAC

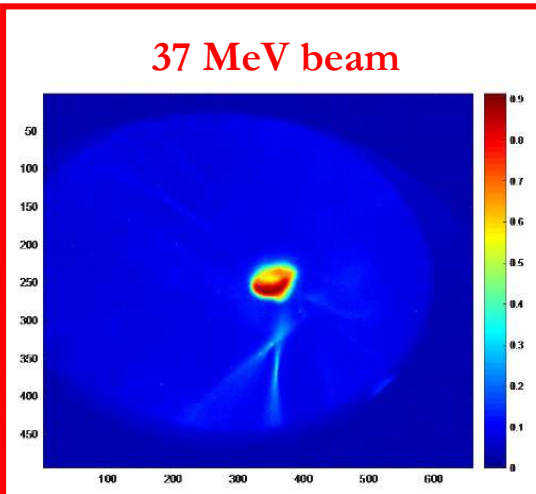


Current planning

Today: COMMISSIONING

1st e- beam produced in the LINAC

37 MeV beam



Foreseen to go to 50 MeV with full RF power (klystron > 30 MW)

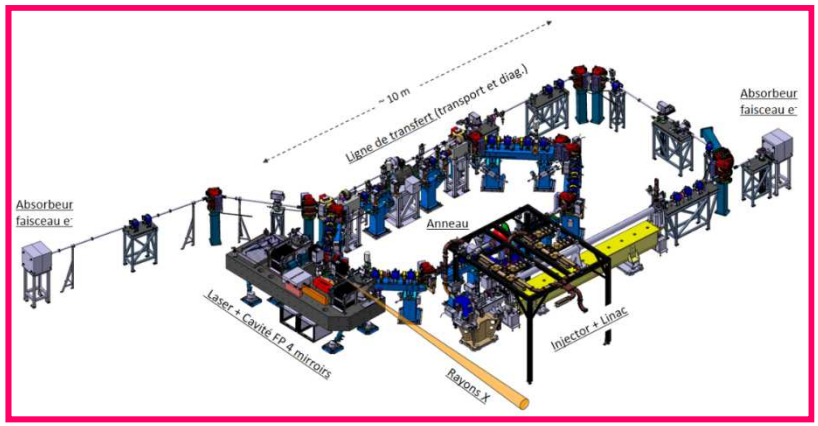
Current planning

2021	2022	2023

Source Commissioning

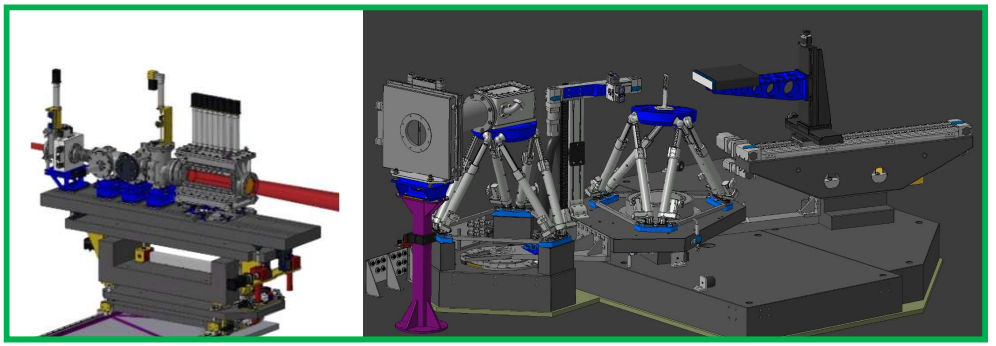
first X beam

X-line Commissioning



Casemate part

Experimental X-hutch



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

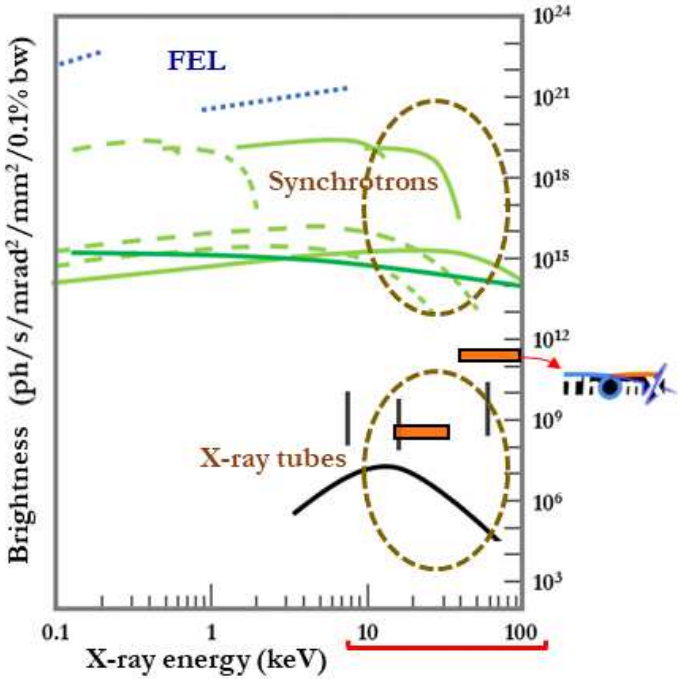
1) FIND e-/laser interactions

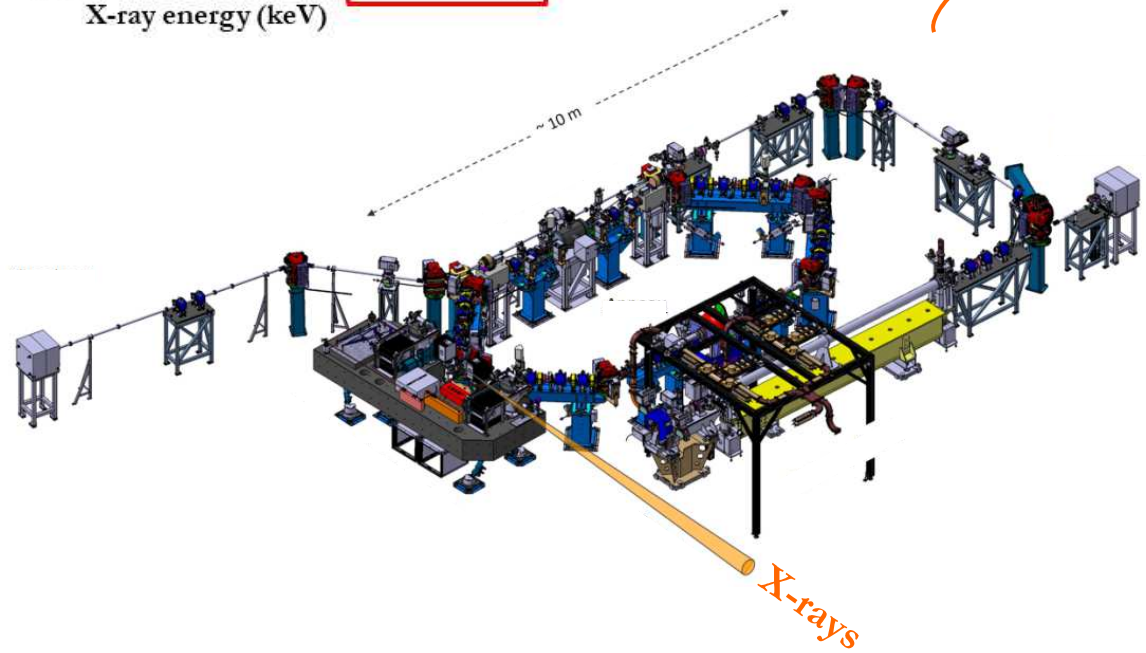
→ Commissioning - Beam MONITORING system
- X-hutch detectors

2) CHARACTERISATION of

Source qualification

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


FEL
Synchrotrons
X-ray tubes
Brightness (ph/s/mrad²/mm²/0.1% bw)
10²⁴
10²¹
10¹⁸
10¹⁵
10¹²
10⁹
10⁶
10³
0.1
1
10
100
X-ray energy (keV)


~ 10 m
X-rays

Thank you