DE LA RECHERCHE À L'INDUSTRIE

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Toroidal optics for mirror based high resolution imaging systems

Ph. Troussel

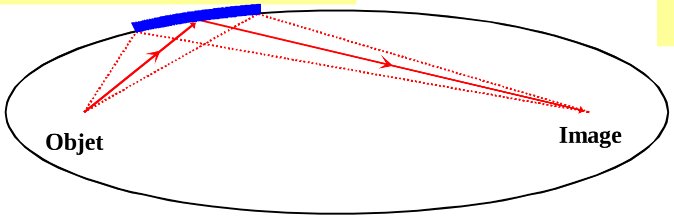
3rd LMJ-NIF diagnostic collaboration workshop

June 29 th

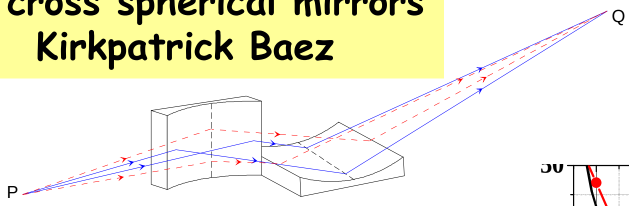
Why toroidal optics design for mirror based imaging systems?

Goal : achieve 1 mm field of view with high spatial resolution (4 à 10 µm)

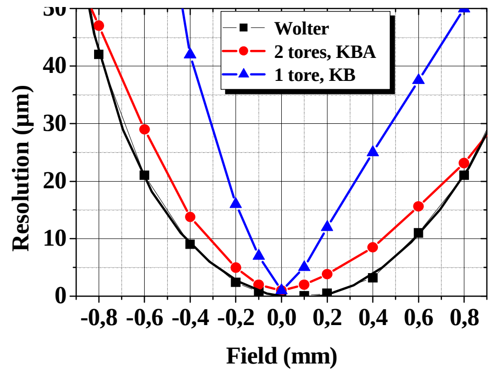
1 ellipsoïdal mirror



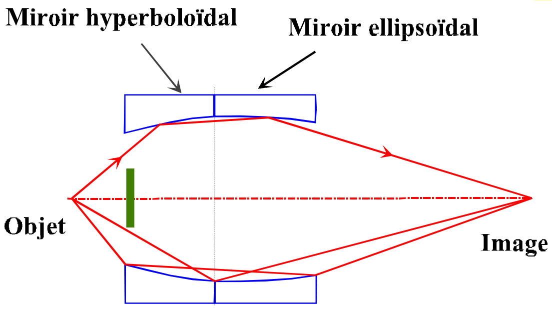
2x cross spherical mirrors Kirkpatrick Baez



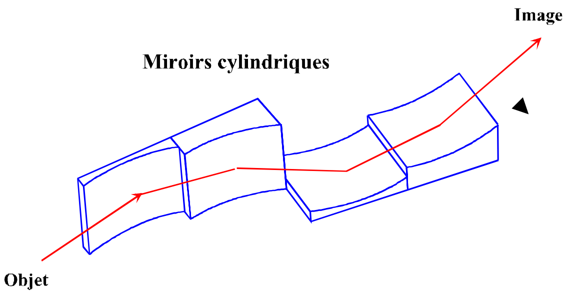
OK for small field of view ~100 µm



Wolter



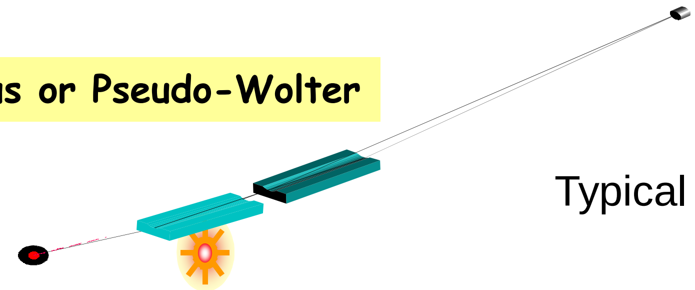
2x improved bi Kirkpatrick Baez



OK for large field of view and resolution but complicated design

Our Choice

2 torus or Pseudo-Wolter



Best performance/complexity ratio

Typical collection solid angle ~ 1 mrad

DE LA RECHERCHE À L'INDUSTRIE

COMPARISON REFLECTIVE OPTIC AND PINHOLE

	Reflective optics		Pinholes
Optic	**Toroidal**	**K-B**	**Pinhole**
Compact requirements	++	+	+++
Brighness	+++	++	+
Typical collection angle	1 µsr	0.15 µsr	0.01 µsr
Depth focus	a few mm	a few mm	infinite
FOV/5 µm	1 mm	0.2 mm	infinite
Energy range E	< 30 keV	< 30 keV	> 1 keV
Energy bandwidth	$\Delta E/E = 10^{-2}$ – a fw units Multilayers	$\Delta E/E = 10^{-2}$ – a fw units Multilayers	By filters
Difficulty of alignment of mirrors	----------	------	+++++
Geometry Beam direction	change	Change	Not change
Working distance (change Magnification)	Adjustable 1D image Not in multi-images	Adjustable 1D image Not in multi-images	Adjustable
Difficulty of manufacture	------------ By french industrial expert	---------	++++++

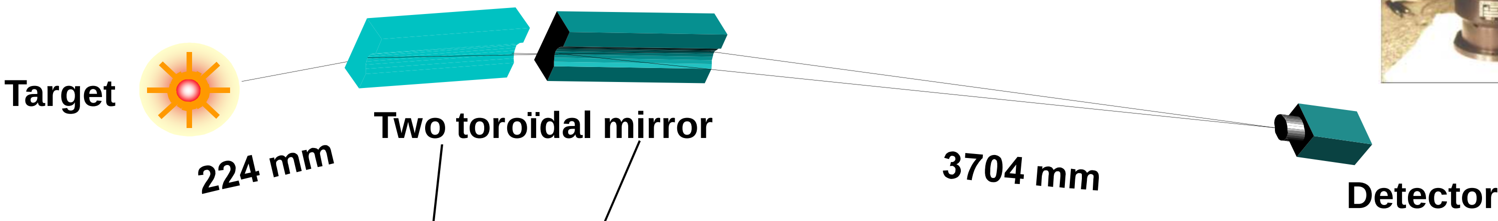
CEA High Resolution X-ray Imaging at LLE
Off axis Wolter-like microscope

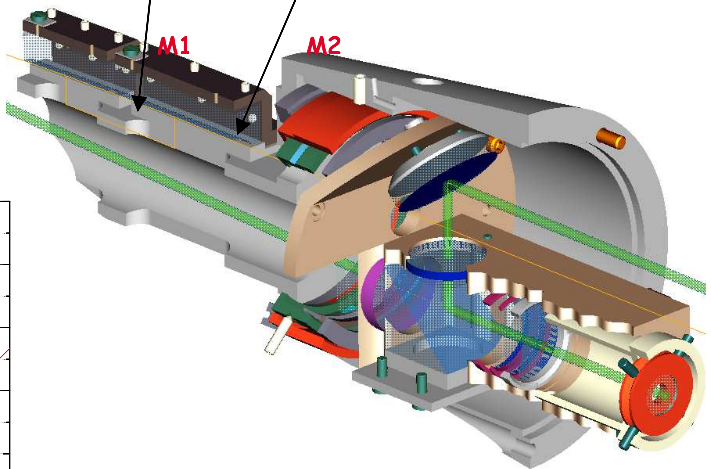
Ω facility

Development of two microscopes :

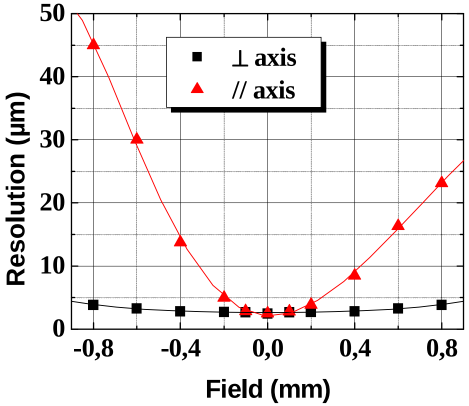
HRXI : Nickel coating in 2002-2007

EHRXI : W/Si non-periodic Multilayer coating in 2012

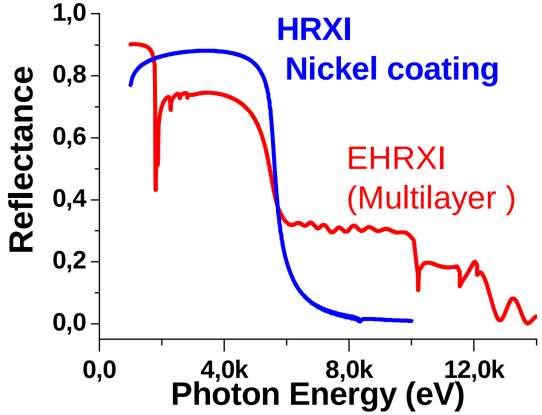




Spatial resolution



Spectral response

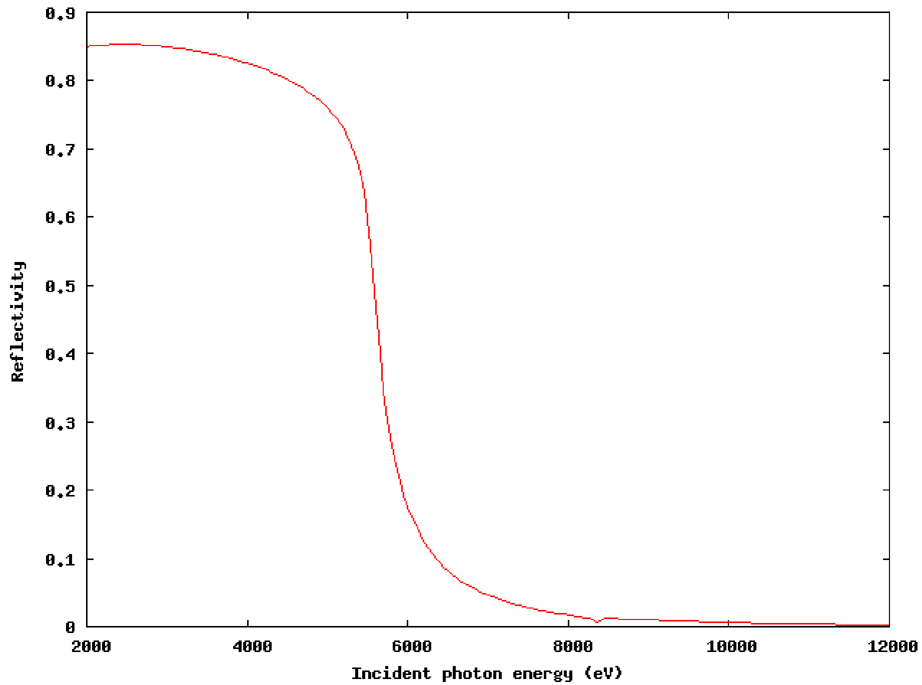


RSI Vol. 76, 1 (2005) Ph. Troussel / Proceedings IFSA 2011 D. Dennetière

WE CHANGED HRXI MIRRORS COATING FOR EHRXI

Old HRXI mirrors

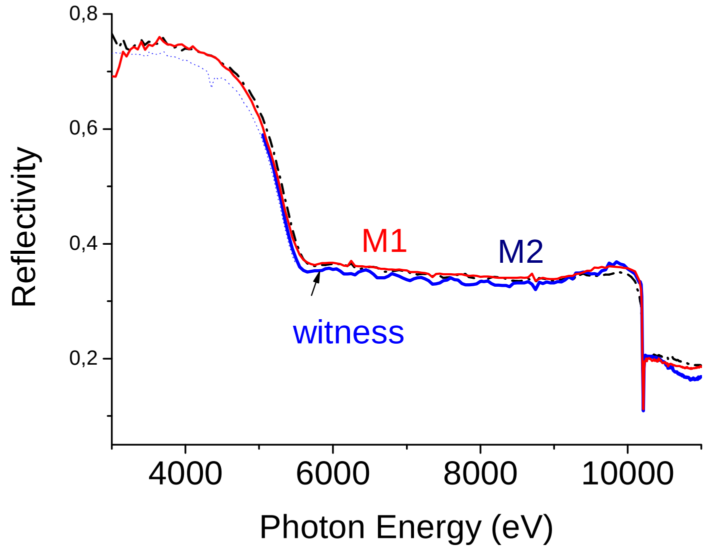
Plain nickel coating



The old bandwith was limited to 6 keV

New EHRXI mirrors

W/SiC multilayer coating



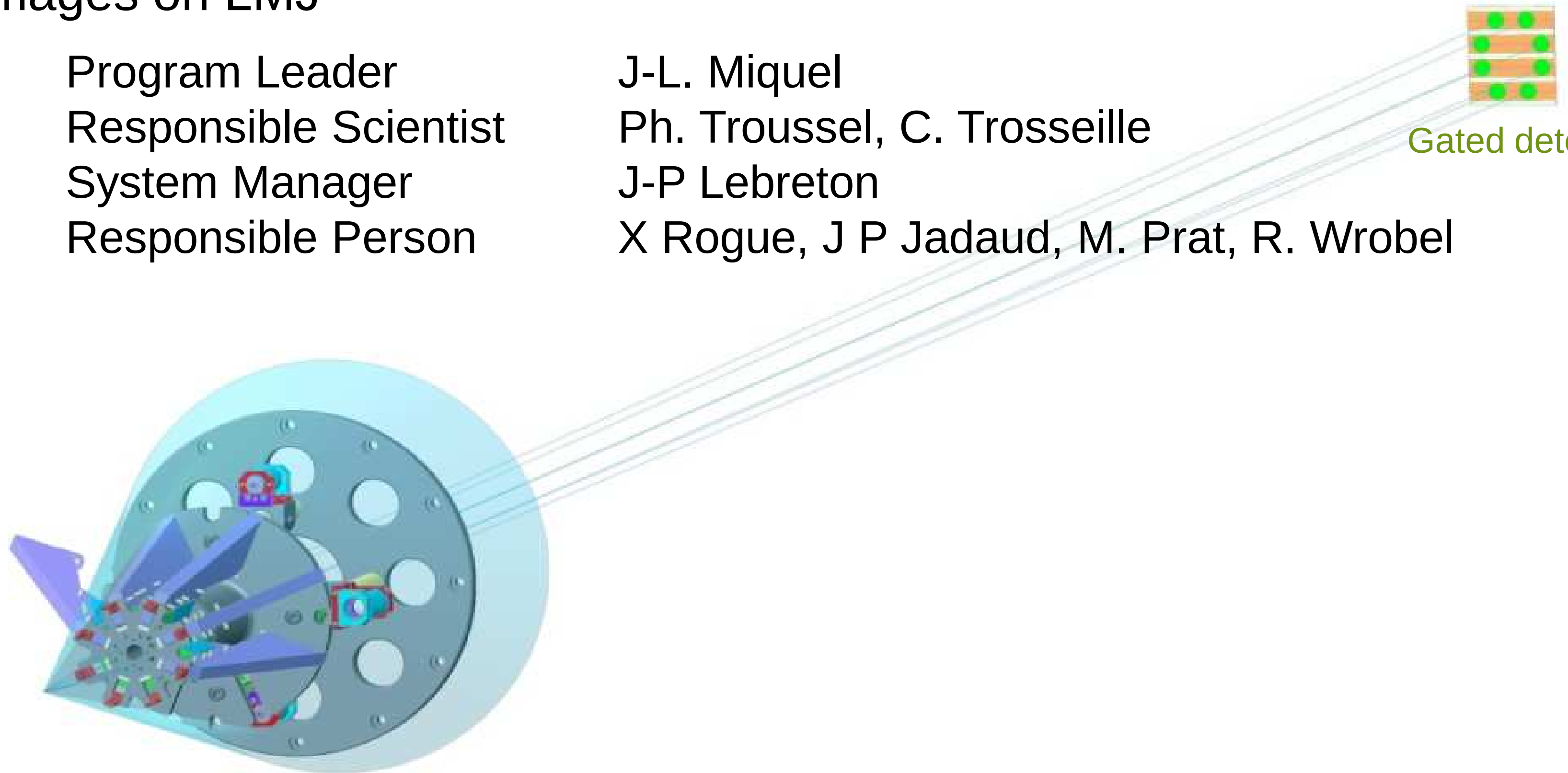
The new bandwidth extends to 12 keV

The spatial aspects (curve radii, position inside the microscope, etc.) of the mirrors haven't change

First point

Development of a framed 8-channel imager for providing time-resolved images on LMJ

Program Leader	J-L. Miquel
Responsible Scientist	Ph. Troussel, C. Trosseille
System Manager	J-P Lebreton
Responsible Person	X Rogue, J P Jadaud, M. Prat, R. Wrobel



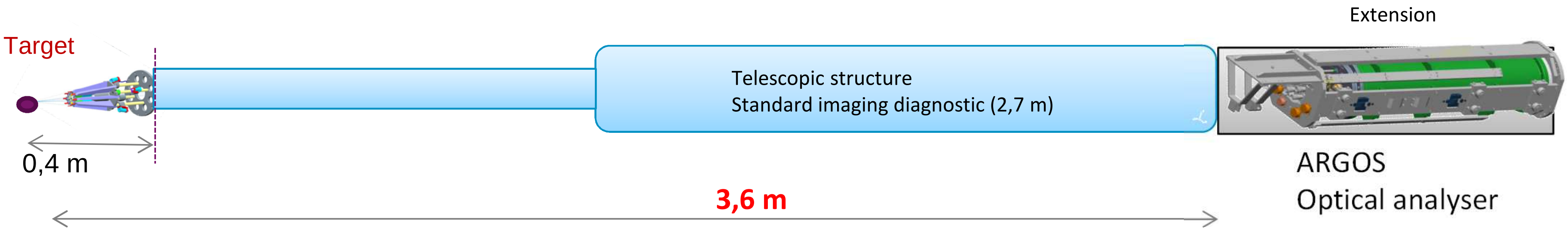
GXI-3 DIAGNOSTIC MAIN FEATURES

Our term objective for shots at LMJ in fall 2019 is 8 time-resolved images with these parameters:

SID PETAL	Equatorial
Images	8
Spatial resolution	7 µm
Field of view	1 mm
Working distance	40 cm
Min. time resolution Δt	50 ps
Multilayer coating ΔE	1-13 keV
PETAL environment Yield tolerance	10^{12}-10^{13} 2,45 MeV 10^{12}-10^{15} neutrons

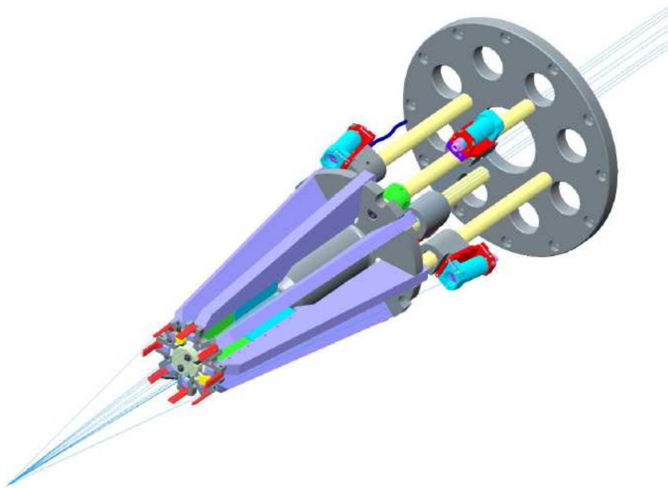
It is an impossible task to try achieve these performances with an only diagnose, because of the contraints of the gated detector.
We propose two scalable configurations with an old and an upgrade detector.

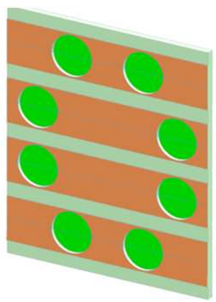
GXI-3: FIRST STEP USING ARGOS X-RAY GATED DETECTOR « MEDIUM RESOLUTION- HIGH FIELD »



SID PETAL	Equatorial
Images	8
Spatial resolution	15 µm
Field of view	1.5 mm
Working distance	40 cm
Time resolution Δt	130 ps
Multilayer coating ΔE	1-13 keV
PETAL environment Yield tolerance	10^{12}-10^{13} 2,45 MeV 10^{12}-10^{15} neutrons

Optical design microscope arrangement of 8 bi-mirrors





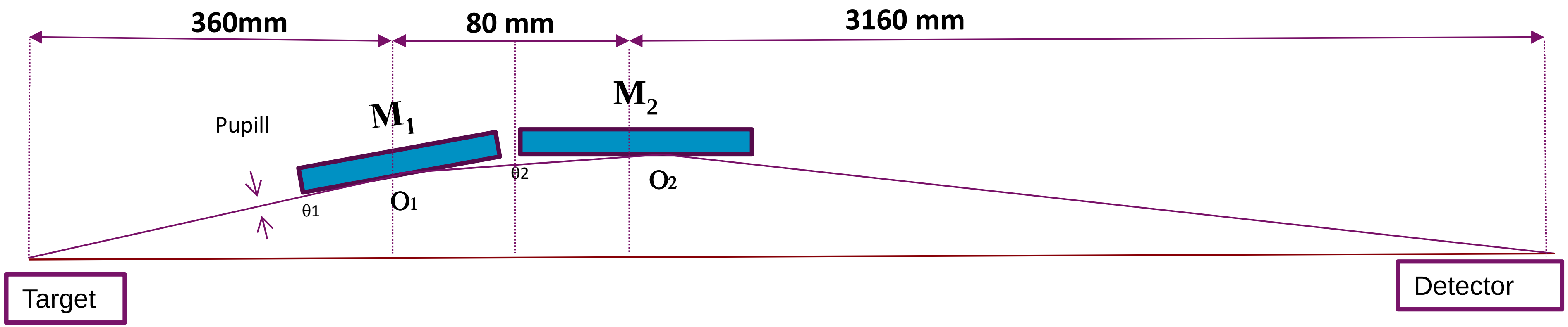
Framing camera

> 8 channels (bi-toroidal mirrrors)

Geometry	SID PETAL
Throwput to the detector	3,6 m
Source to optics-center distance	400 mm
Closest approach distance	220 mm

Design of the single channel : Wolter-like microscope (Magnification x 8):

This project is a variation of the deployed HRXI microscope at LLE:
Two off-axis toroidal mirrors in a Wolter configuration.



Main optical parameters

Mirror	M_1	M_2
Grazing angle	0.6°	0.6°
R (m)	104	110
r (mm)	12 ± 0.1	11,7 ± 0.1
Length (mm)	50	70
Thickness (mm)	15	15
wide (mm)	To define	

Microscope specifications

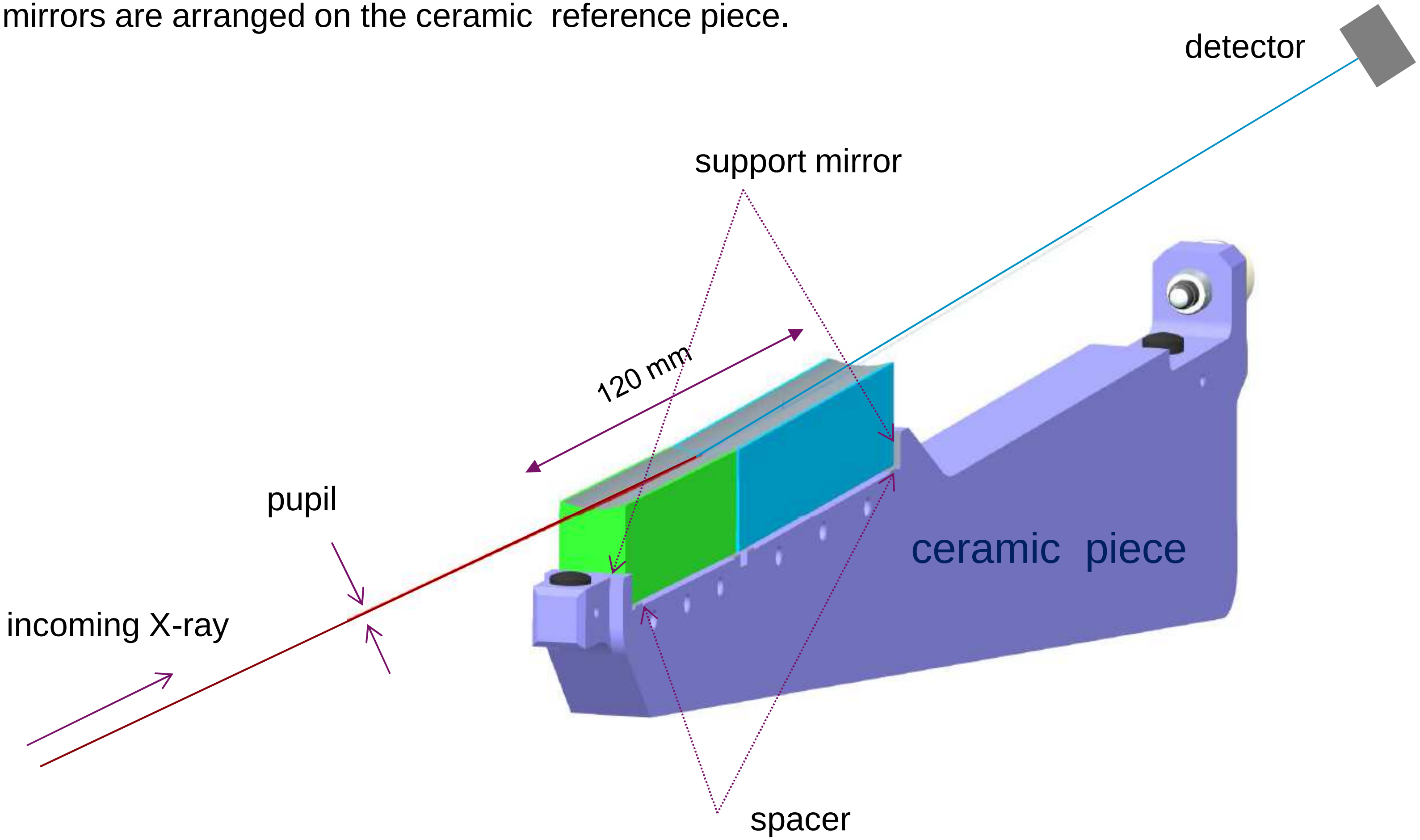
Ω = 0.8 mrad²
Spatial Resolution 7µm over a FOV = 1500 µm
Current magnification x 8
Working distance from the plasma : 400 mm

Close design of HRXI microscope with a small dilation.

Rev. Scient. Instrum. Vol. 76 063707-1 (2005) Ph. Troussel

Mechanical alignment of the mirror path

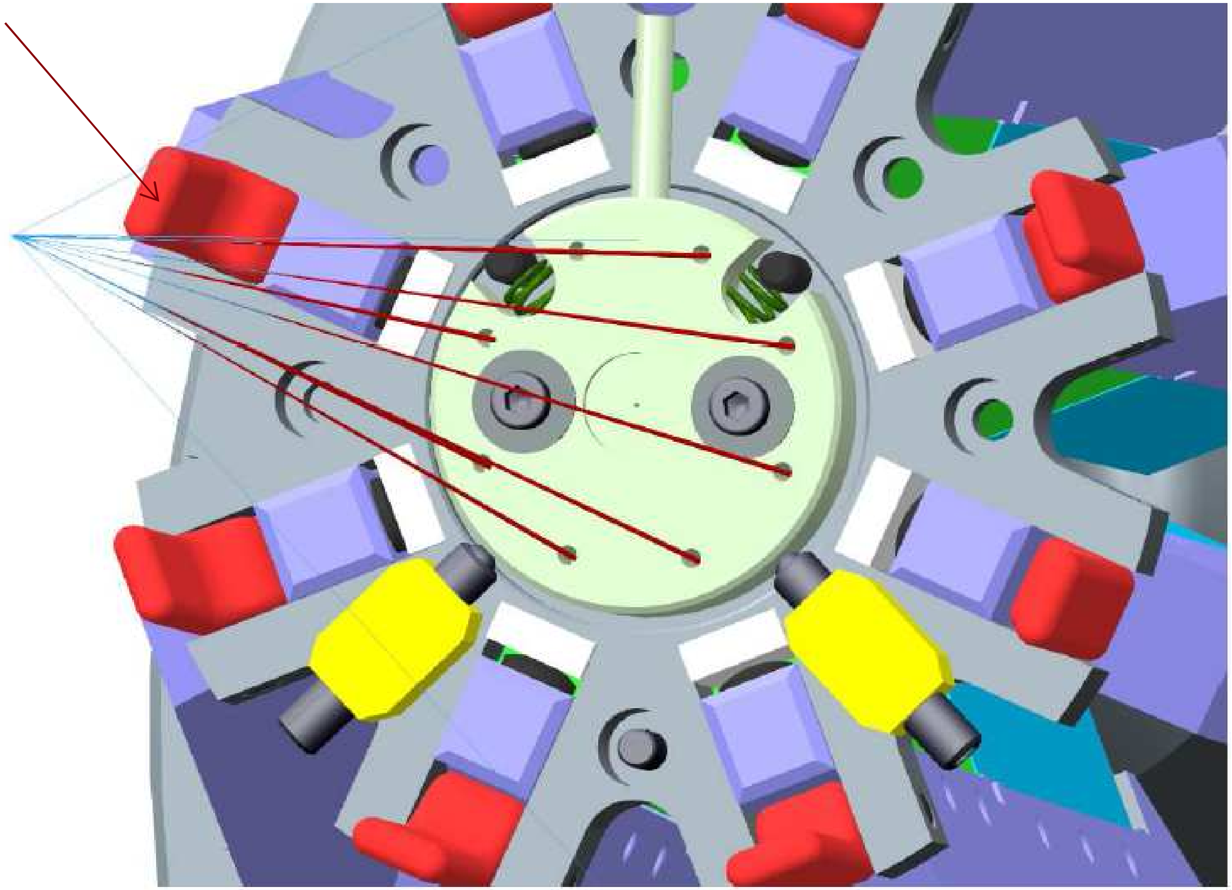
- The positioning of images on the detector is set in advance by the industrial with a laser and then in our laboratories with x-ray continuous Source.
- Viewing angle of each channel is given by spacer placed under each mirror.
- The thickness of the spacer allows the user to accurately position the image on the detector nearly to ± 250 µm (for 10 µm spacer typically).
- Support mirrors are arranged on the ceramic reference piece.



This microscope have **a** manual adjustable system x 8 pupil.

Snap for support mirrors

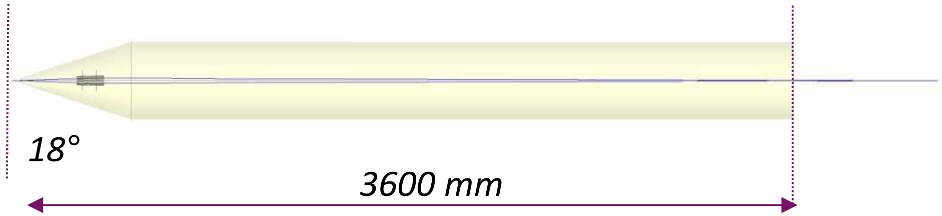
8 pupils

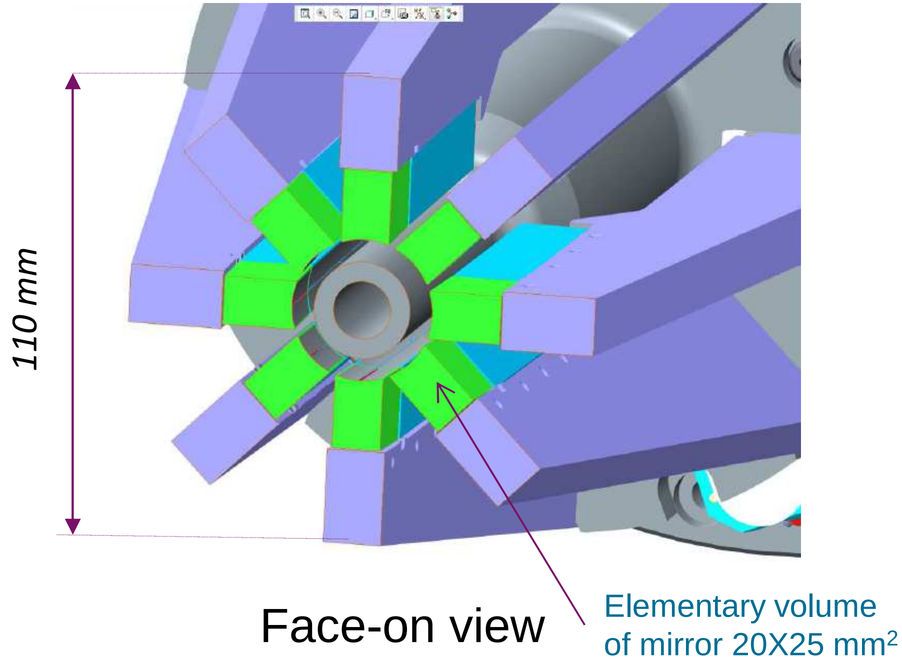


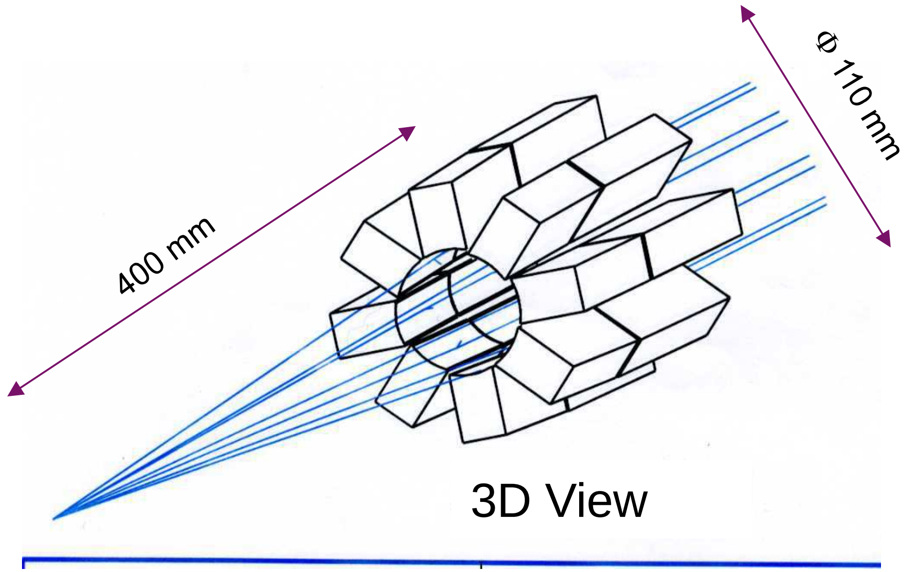
Aperture diameter of each pupil is ~ 280 µm.
=> Large collection efficiency: 0,8 mrad numerical aperture.
(efficiency ~ x 100 compared to 0,1 mrad for a pinhole.

Principle for assemblying the individual channels

This microscope provides 8 images that can be coupled to a framing camera.





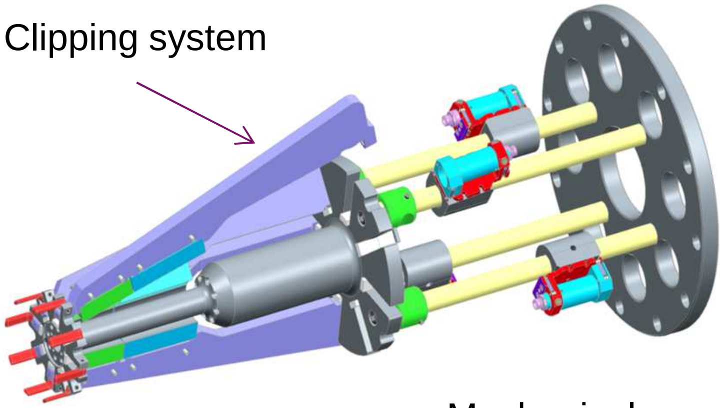


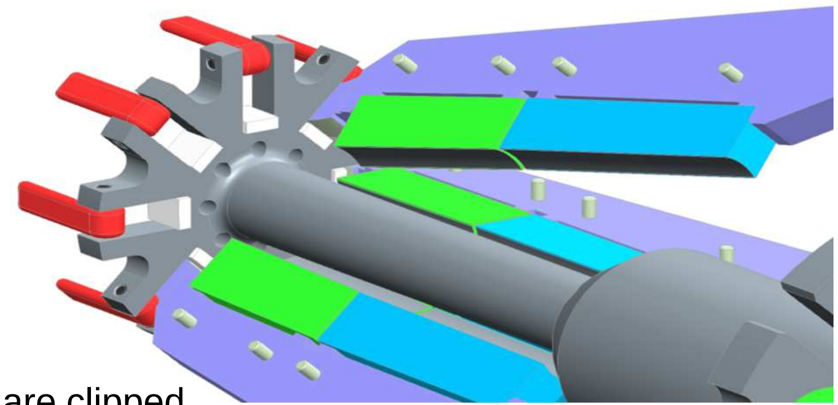
The mirrors are assembled in a simple circle.
Outside of the mirrors forms a 8-sided regular octogon.

Reflect article:
REVIEW OF SCIENTIFIC INSTRUMENTS 83, 10E518 (2012) F.J. Marschall

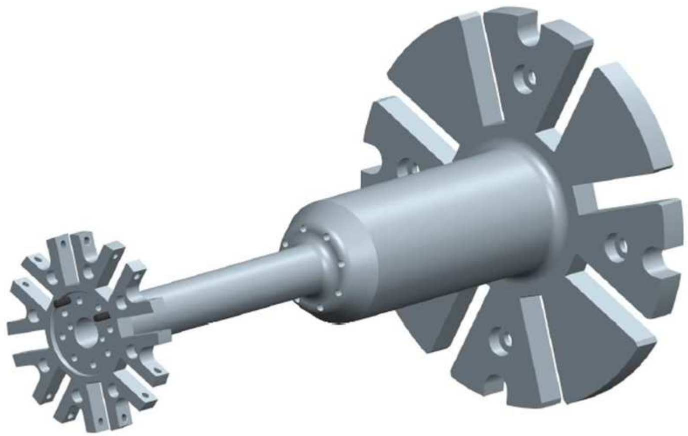
Optical media => CAD drawing

Clipping system

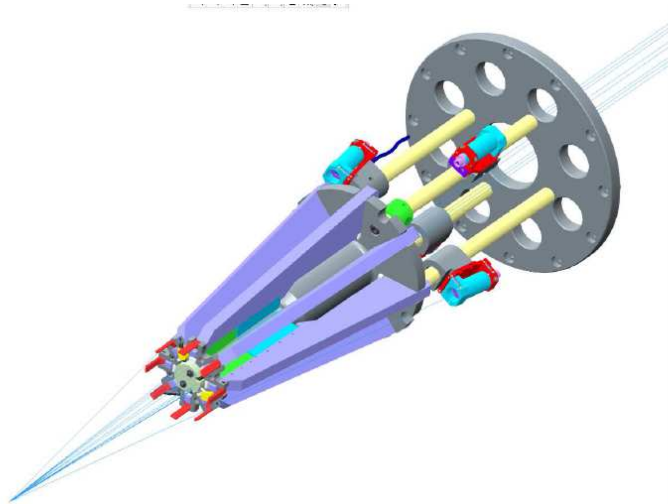




Mechanical supports are clipped
to change mirrors.



The mechanical precision is based on the quality of the main
mechanical component reference .



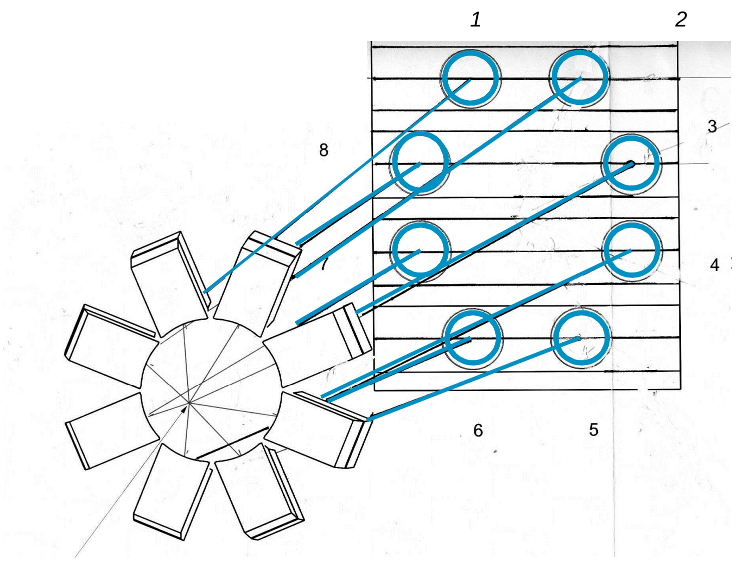
Weight optic block 10 kg max
30 cm long, 15 cm diameter

Design at the back (framing camera)

- Four 13 mm-wide, transmission lines deposited onto the MCP.
- The tube can be equipped with a large, 72 x 72 mm^2 MCP
- Each image falls on a circle whose the diameter of the circle depends of the spacer.

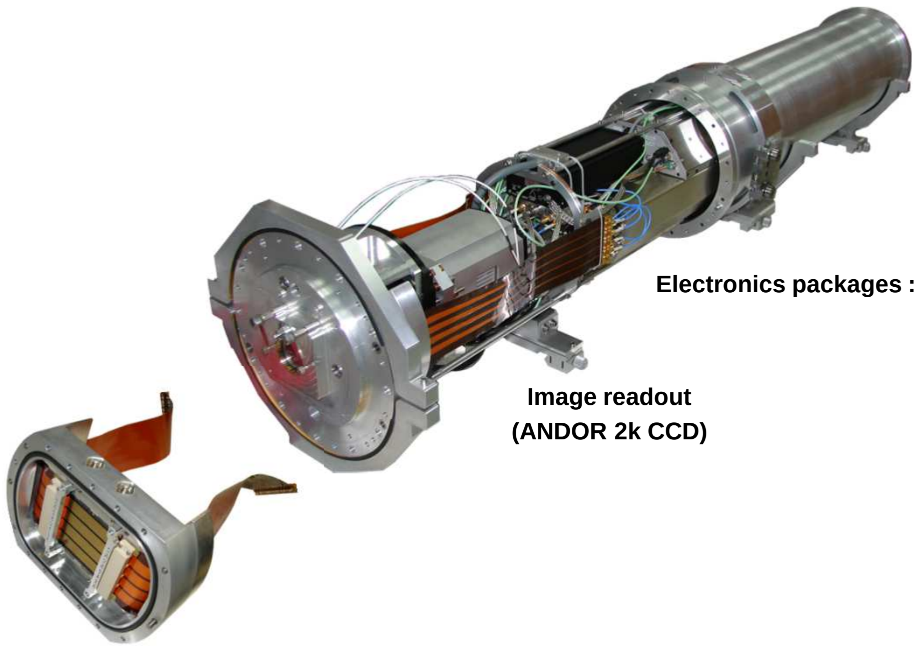
Each image is separated in time by 100 ps and observed with an 130 ps frame time.

ARGOS framing camera developped by C. Trosseille [1]



target

Schematic of the four-strip framing camera design with superposed images



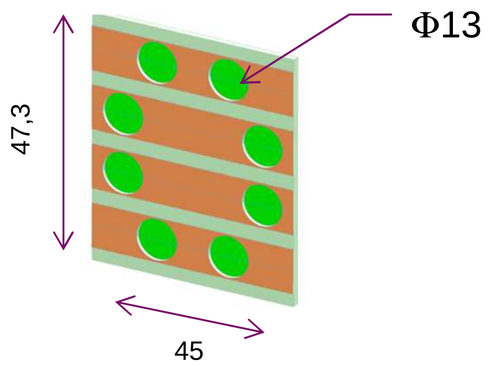
Electronics packages :

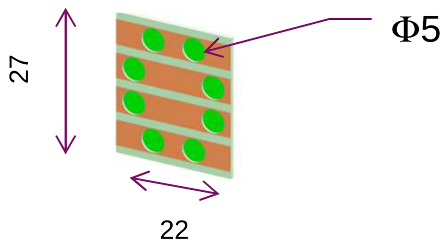
Image readout (ANDOR 2k CCD)

[1] C. Trosseille, Overview of the ARGOS X-ray framing camera for laser MegaJoule, Rev. Sci. Instrum. 85, 11D620 (2014).

GXI-3: Second step using a update of ARGOS x-ray gated detector « High resolution- medium field »

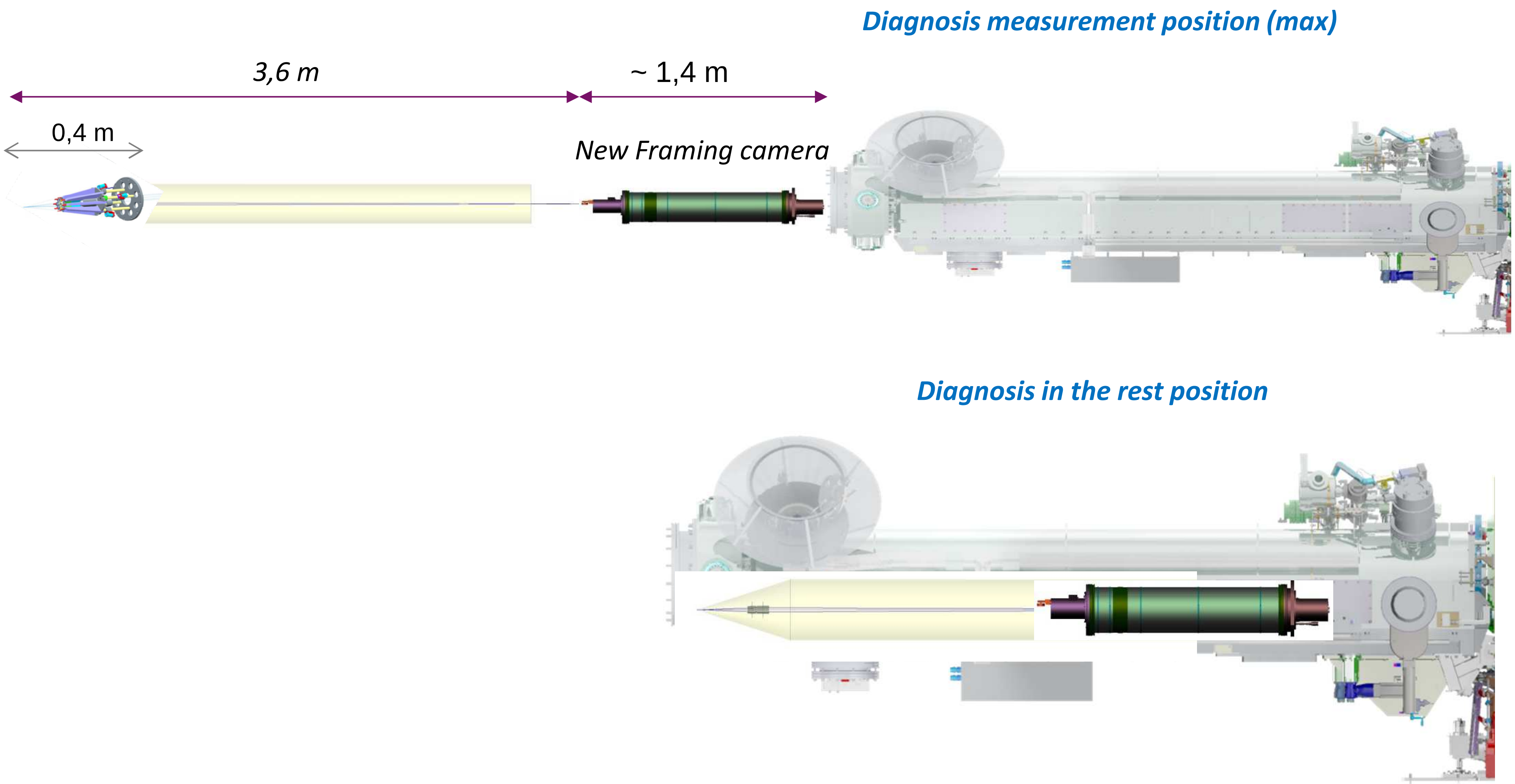
Development of a update X-ray detector ARGOS with a smaller MCP
⇒Consists of four 5 mm wide transmission lines (instead of 13 mm)
⇒lower field
⇒Higher temporal resolution





	2018	2019
Images	8	8
Resolution	15 µm	7 µm
Field of view	1.5 mm diameter	0.5 mm diameter
Working distance	40 cm	40 cm
Δt	130 ps	50 ps
Multilayer coating ΔE	1-13 keV	1-13 keV

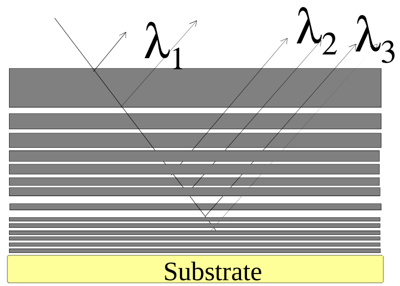
GXI-3: Second step using a update of ARGOS x-ray gated detector « High resolution- medium field »

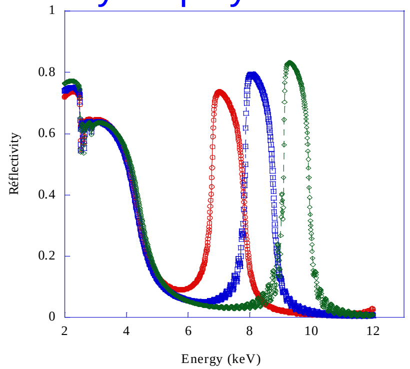


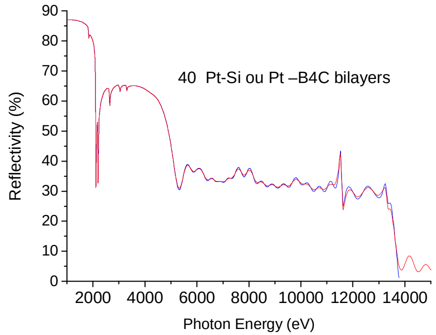
Spectral study: Pt non-periodic MLs for extending X-ray spectral range

The ML is design to create a flat reflectivity response up to 13 keV

• Non-periodic multilayer : polychromatic Bragg reflector







In comparison with a periodic structure We will obtain an important enlargement of the bandwidth (4 - 13 keV) but with a small reduction in the reflectivity

Development of a x-ray microscope combining new technological characteristics

- original optical design (octogonal geometry)
- coating with non-periodic Pt/SiC multilayers

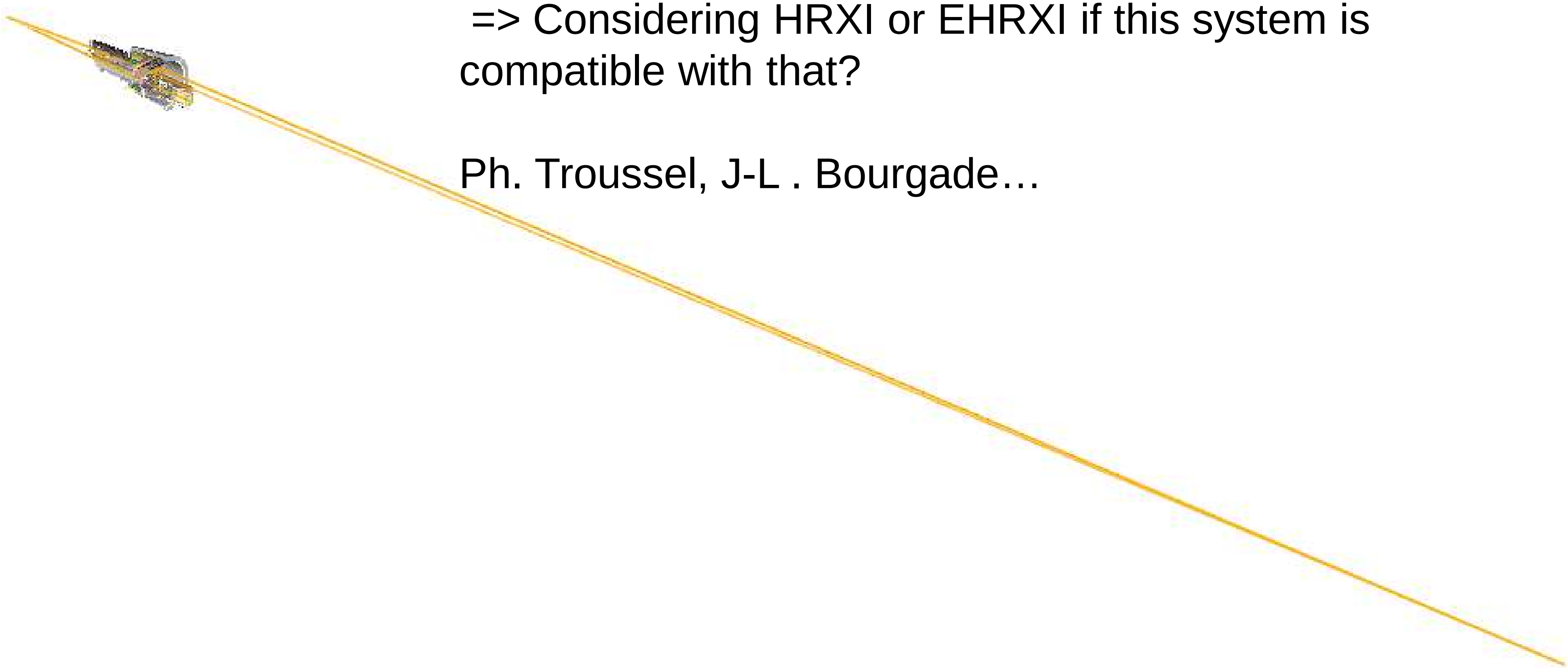
GOAL : to achieve 7 µm of spatial resolution in a field better than 500 µm, with a spectral range from 2 to 13 keV.

** H. Maury et al. Design and fabrication of supermirrors for (2-10 keV) high resolution X-ray diagnostic imaging, NIM A (2010)*

Second point

Project to bring a SLOS to the OMEGA laser before NIF
=> Considering HRXI or EHRXI if this system is compatible with that?

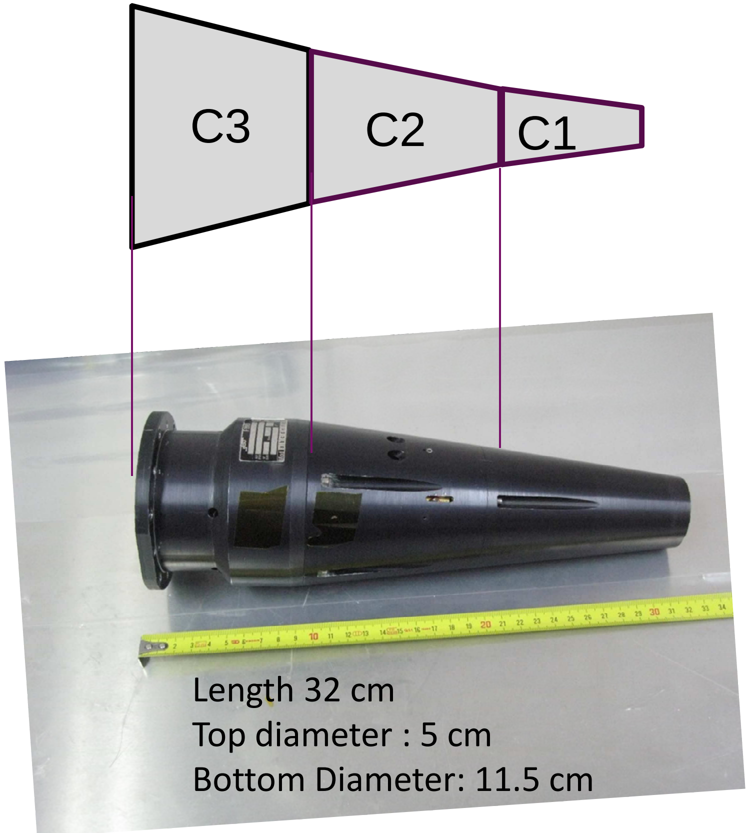
Ph. Troussel, J-L . Bourgade…



Tritium activity measurements in 2013

EHRXI has been contaminated by tritium in May 2012 on OMEGA.

$S1 = 251\ cm^2$
$S2 = 304\ cm^2$
$S3 = 282\ cm^2$



THE EXISTENCE OF THE ANODIZED COATING IS OVERALL (INSIDE AND OUTSIDE)

OUTSIDE SURFACE (C1+ C2 + C3) : 0.2 BQ.CM^{-2}
INTERNAL SURFACE C1 : < 0.1 BQ.CM^{-2}
MIRROR ENVELOP: < 0.1 BQ.CM^{-2}
INTERNAL C3: 0.5 BQ.CM^{-2}
INTERNAL C2: 0.6 BQ.CM^{-2}

CONCLUSION ON EHRXI

Different possibilities:

- LLE accepted EHRXI with anodized coating and we can package it.

- LLE don’t accept => we dissamble the mirrors in France et the optics for tool alignment, remove the anodized part at LLE, setting mirrors in France (Winlight System)

- We recover the mirrors pasted on the mechanical and we remake a mechanical

- *We can propose another microscope PIXEL…*

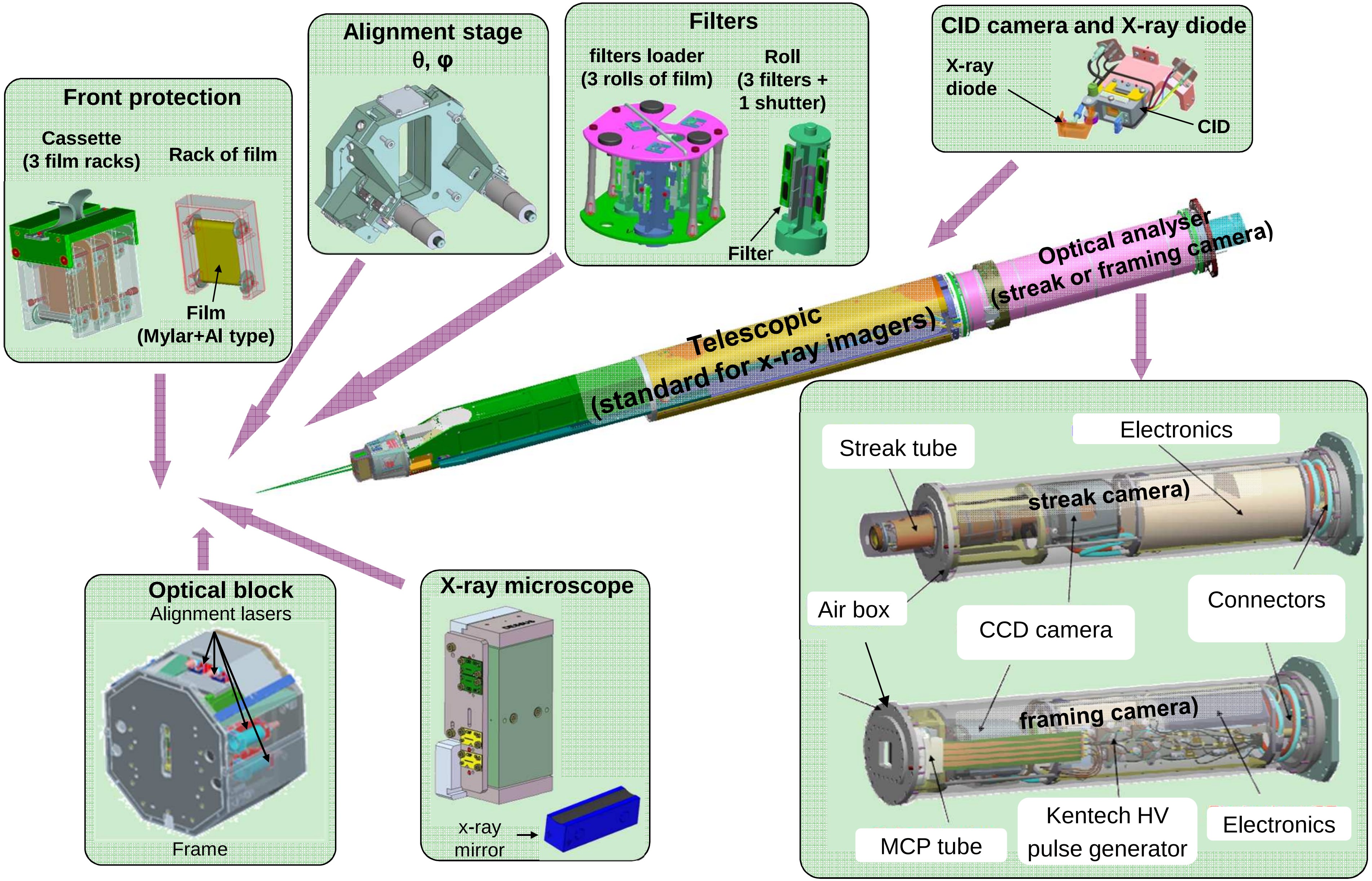
Other slides

COMPARISON REFLECTIVE AND DIFFRACTIVE OPTICS

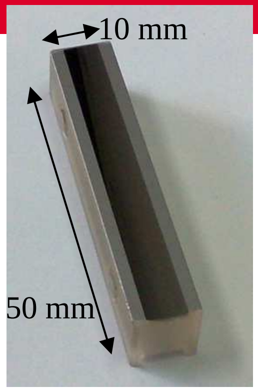
	Reflective optics: Mirrors	Reflective optics: ML	Diffractive optics Transmission ZP
Energy range E	< 50 KeV	< 80 KeV	< 25 KeV
Flexibility of E	Yes	Move angle	Move working distance
Energy band width ΔE/E	White beam	10^{-2}	10^{-2} - 10^{-3}
Best measured resolution Δ	> 4 µm		<< 4 µm
Field	limited		< 1 mm
Numerical aperture	0.2 - 1 mrad		1 - 5 mrad
Alignment	Not easy		Compact, simple
Beam direction	change		not change
Fragile	No		yes

LMJ X-ray Imager are based on the same structure: GXI-1,

3 à 4 m
150 kg



Exemple d'étude de SUPERMIROIR :
Miroir large bande pour les imageurs du LMJ



Etude (2 ans)

Spécifications spectrales

Bande passante 2 - 10 keV
Angle d'attaque 0,7°
Réflectivité élevée et constante

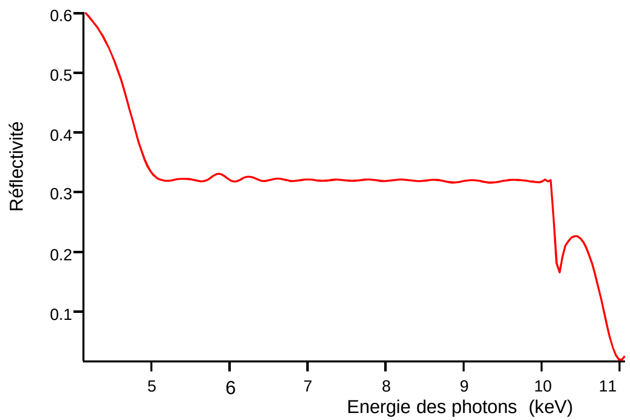
Dépôt sur miroir torique (R = 90 m, r = 20 mm)
Maquette premiers diagnostics LMJ

1. Etude préalable

Choix du couple W/SiC avec 32 couches

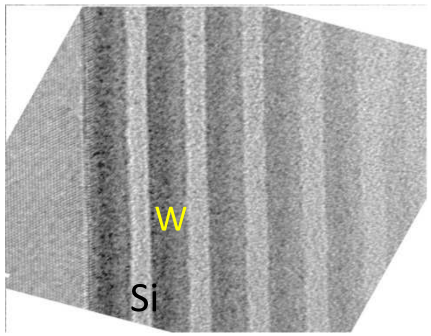
2. Utilisation d'un code d'optimisation d'épaisseur
TF Cal

3. Prise en compte des effets d'interface

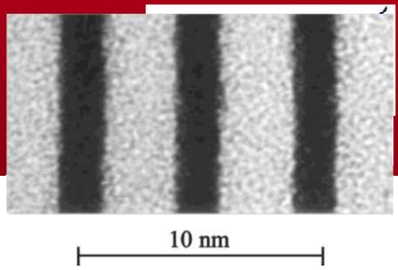


Dans le cas du système W/SiC : formation de composés d'interface

Corriger les effets d'interface
atteindre un contrôle optimal des épaisseurs de dépôt



Les étapes de l'étude expérimentale
La caractérisation avec un réflectomètre X rasants…

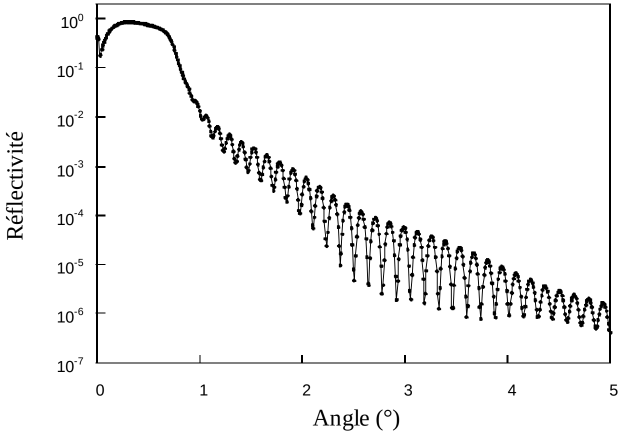


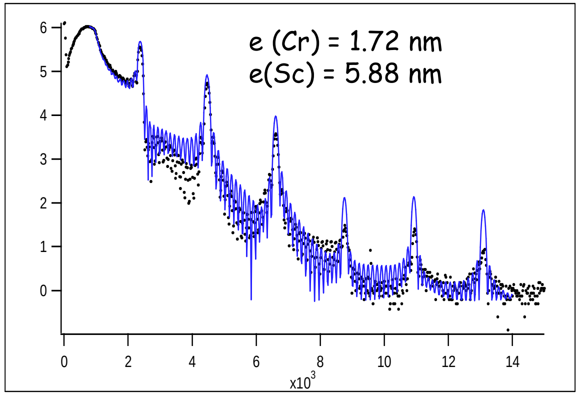
⇒ Etalonnage des épaisseurs effectives Des deux matériaux Cr et Sc

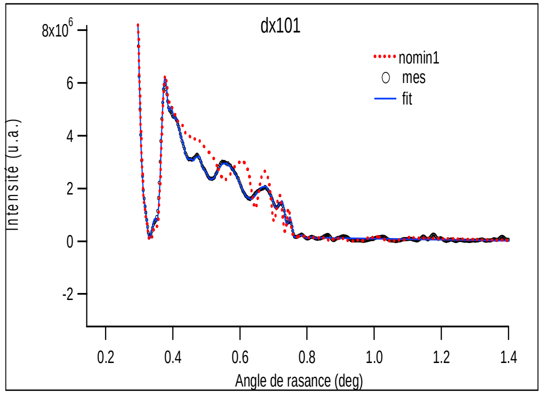
1) en couches minces (300Å)

2) en couches périodiques Cr / Sc

3) en couches apériodiques







Angle d'attaque (seconde d'arc)

=> Obtention des droites d'étalonnage
Vitesse des dépôts / épaisseur

Quantification des phénomènes interfaciaux Cr/Sc =>
=> vitesse Cr sur Sc et Sc sur Cr
=> rugosité limitée entre 0.254 et 0.4 nm

Dernières corrections
On affine…

⇒ Maîtrise sur les épaisseurs de dépôts (~ ± 0.1 nm)

Lancement d'un premier échantillon MIM apériodique « abouti »
Avant de le caractérisation auprès du rayonnement synchrotron