

DE LA RECHERCHE À L'INDUSTRIE



www.cea.fr

POLYCAPILLARY LENSES FOR SOFT-X-RAY TRANSMISSION: MODEL, COMPARISON WITH EXPERIMENTS AND POTENTIAL APPLICATION FOR TOMOGRAPHIC MEASUREMENTS IN TOKAMAKS

D. MAZON
CEA CADARACHE

Many thanks to

**Q. Abadie, F. Dorchies, L. Lecherbourg,
A. Mollard, P. Malard, S. Dabagov**

Conference Channeling 2014 5-10 October 2014 Capri

06 OCTOBER 2014

OUTLINE

Part 1: Introduction

- Soft X-ray measurement in Tokamak
- Brief reminder about polycapillary lenses

Part 2: Experimental measurements at CELIA

- Experimental set up
- Results

Part 3: Modelisation of SXR transmission

- Model description
- Comparison model-experiment

Part 4: Conclusion and perspectives

OUTLINE

Part 1: Introduction

- Soft X-ray measurement in Tokamak
- Brief reminder about polycapillary lenses

Part 2: Experimental measurements at CELIA

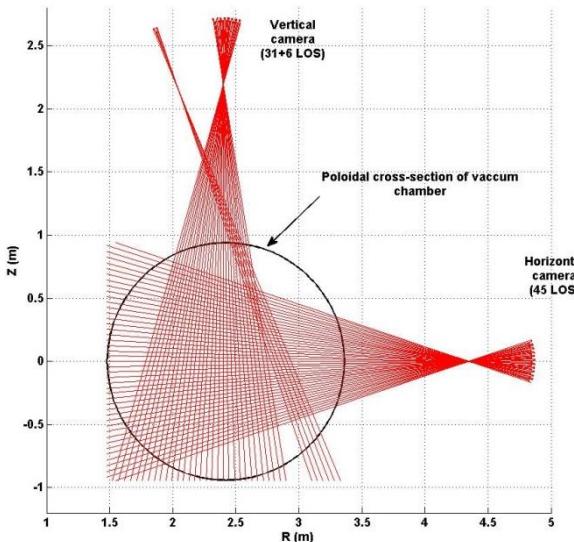
- Experimental set up
- Results

Part 3: Modelisation of SXR transmission

- Model description
- Comparison model-experiment

Part 4: Conclusion and perspectives

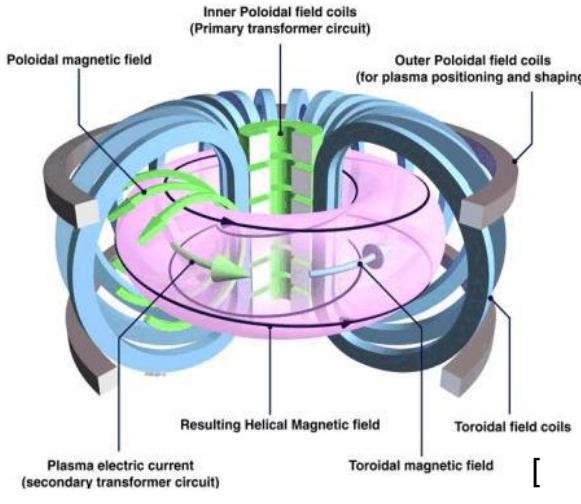
SXR MEASUREMENT ON TOKAMAK



Soft X-ray: **1 to 20 keV**

Most of the time **Semi conductor technology**

Provide lots of many useful informations (impurity distribution, electron density and temperature, plasma shape, magneto hydrodynamic instabilities...)



In ITER : very hot plasma (100 millions °C), high heat fluxes, high fluxes of neutron, gammas and hard X-ray.

Impossible to put detectors near the plasma

Necessity to propose and develop a new system to transport SXR information far away from plasma with the idea to protect the detection system (for us a new domain)

BRIEF REMINDER

Polycapillary lenses or Kumakhov* optics

Principle : SXR transmission by multiple reflexions

First lenses: years 1980

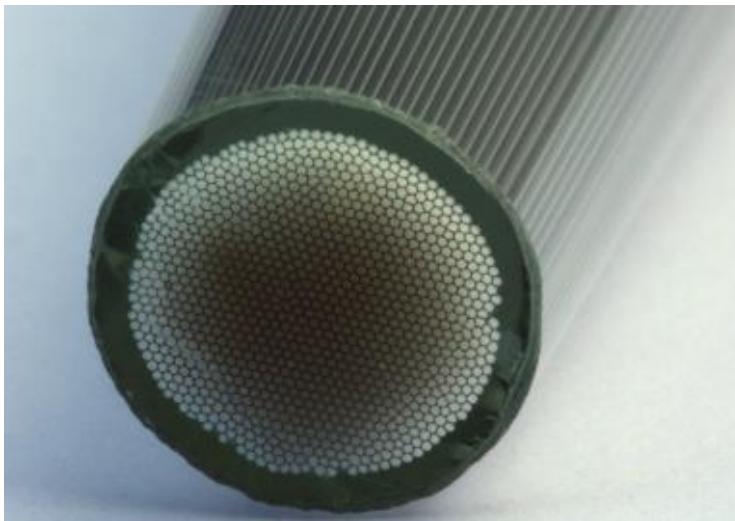


Figure 3 : entry of a polycapillary



Figure 2 : full lens



*Figure 4 : zoom of main entrance
(photo prise au laboratoire CELIA)*

* : http://www.xrayoptic.ru/e_rentoptics.htm

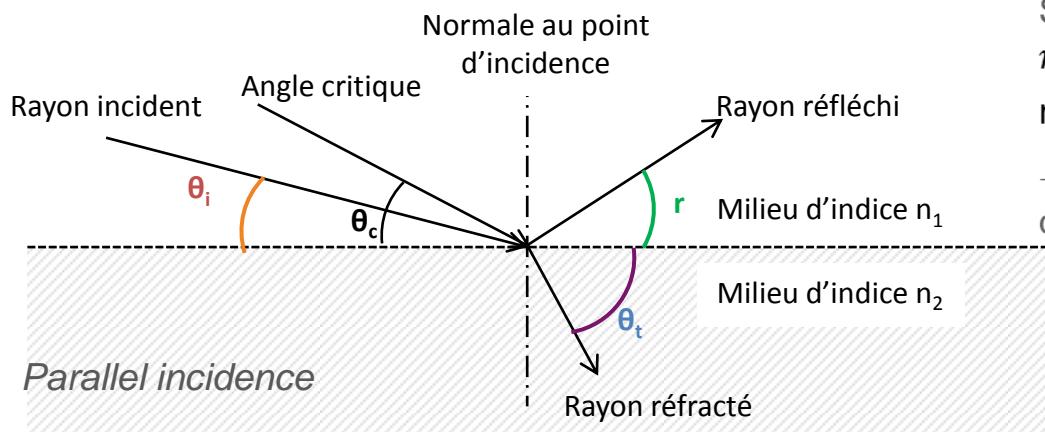
BRIEF REMINDER

Glass refraction index for X-rays :

$$n_2 = 1 - \delta = 1 - \alpha - i\beta \quad (1) \text{ avec } \alpha, \beta \ll 1$$

α and β coefficients are calculated from photon energy and optical material properties

In our conventions :



Snell-Descartes law (parallel incidence) :

$$n_1 \cdot \cos(\theta_i) = n_2 \cdot \cos(\theta_t)$$

$$n_1 = 1 \text{ (vacuum)}, \frac{\cos(\theta_c)}{n_2} = \cos(\theta_t) = 1$$

$\rightarrow \theta_c = \sqrt{2\alpha}$ critical angle critique which depends on material

If $\theta_i > \theta_c$ photon is refracted and absorbed inside material otherwise it is reflected with attenuation:

$$R(\theta_i, E) = \left| \frac{\theta_i - \sqrt{\theta_i^2 - 2\delta(E)}}{\theta_i + \sqrt{\theta_i^2 - 2\delta(E)}} \right|^2 < 1$$

θ_i : incident angle
E : energy of the photon

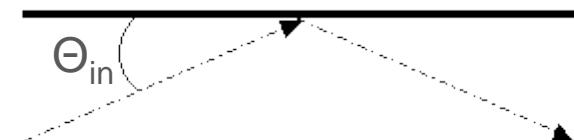
Avec : $\delta(E) = \alpha(E) + i\beta(E)$

POLYCAPILLARY LENSES

Reflexion if $\Theta_{\text{in}} < \Theta_c$

Absorption if $\Theta_{\text{in}} > \Theta_c$

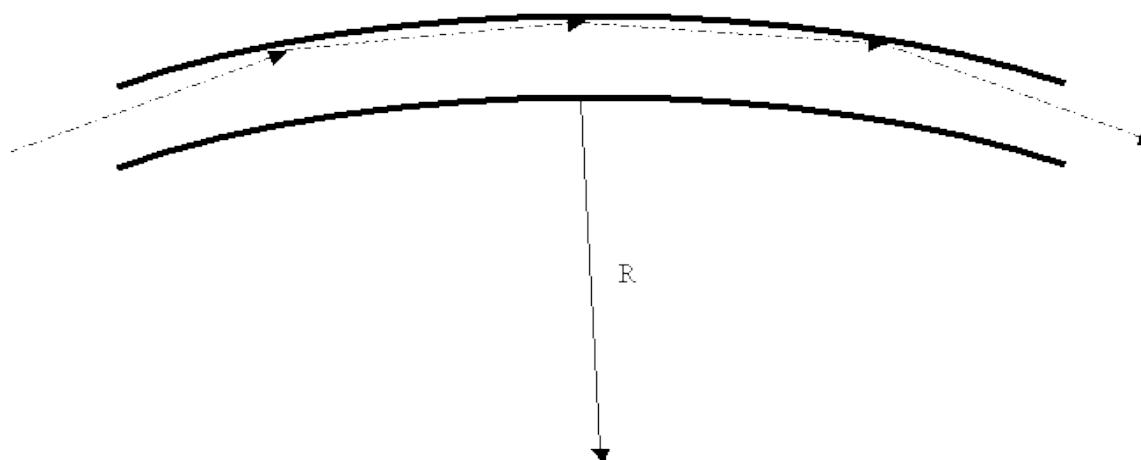
With Θ_c critical reflection angle



Photon reflection on flat surface



Photon canalisation between two surfaces



Photon curvature in between two surfaces

DE LA RECHERCHE À L'INDUSTRIE



www.cea.fr

OUTLINE

Part 1: Introduction

- Soft X-ray measurement in Tokamak
- Brief reminder about polycapillary lenses

Part 2: Experimental measurements at CELIA

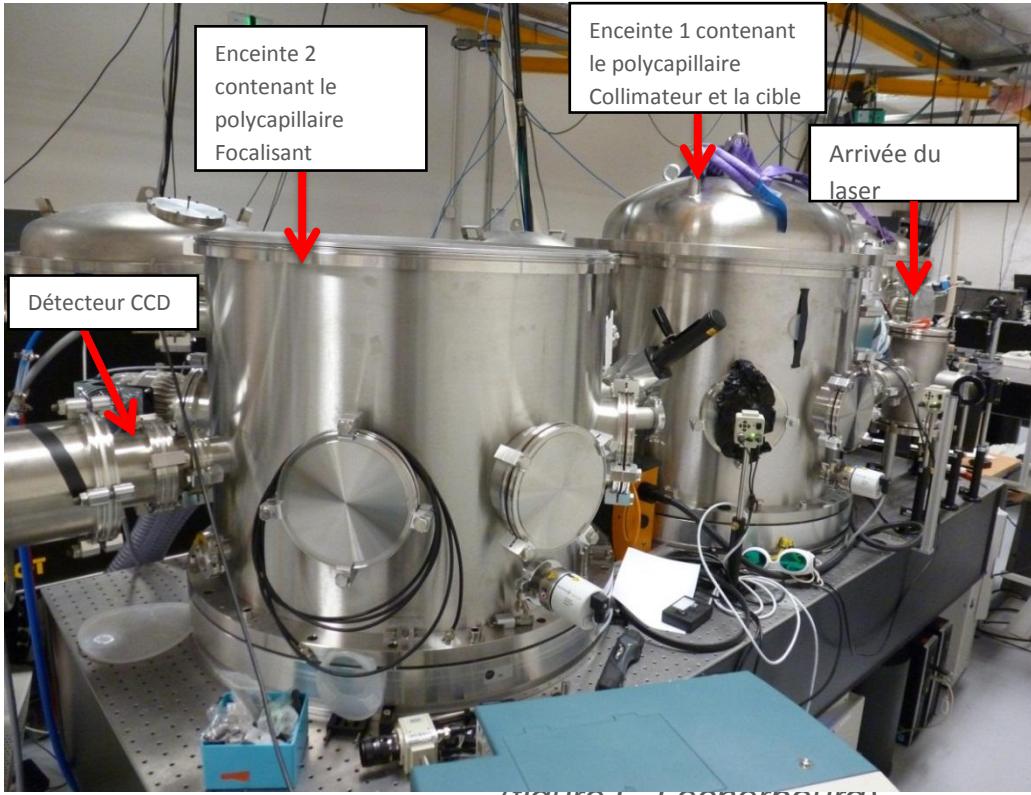
- Experimental set up
- Results

Part 3: Modelisation of SXR transmission

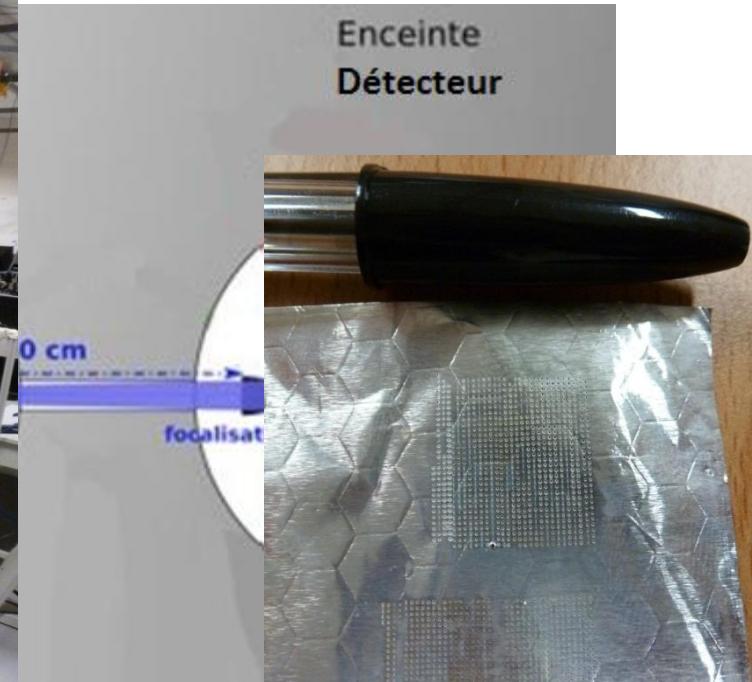
- Model description
- Comparison model-experiment

Part 4: Conclusion and perspectives

EXPERIMENTAL SET UP



(Figure L. Lecnerbourg)
Installations au laboratoire CELIA

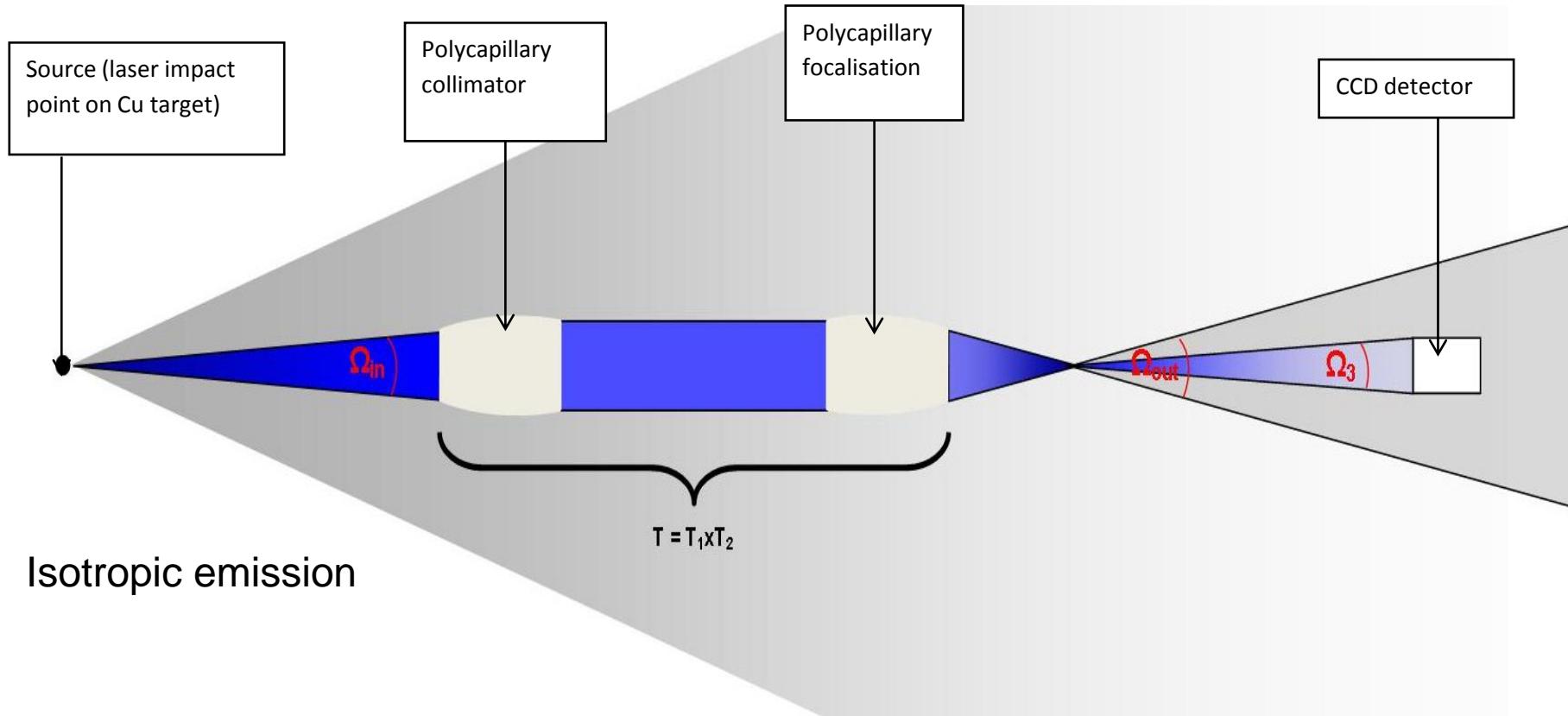


misé au laboratoire Célia
laser sur une cible en aluminium

Laser chain Ti :Saphir
frequency :10 Hz
Energy beam100mJ
Pulse duration: 35-40 femtosecondes
2 vacuum cavity

In one cavity: X source : Cu, Al targets
Collimation and Focalisation using
polycapillaries
In the other cavity detector: spectrum
measurement

2. RESULTS USING IFG POLYCAPILLARIES

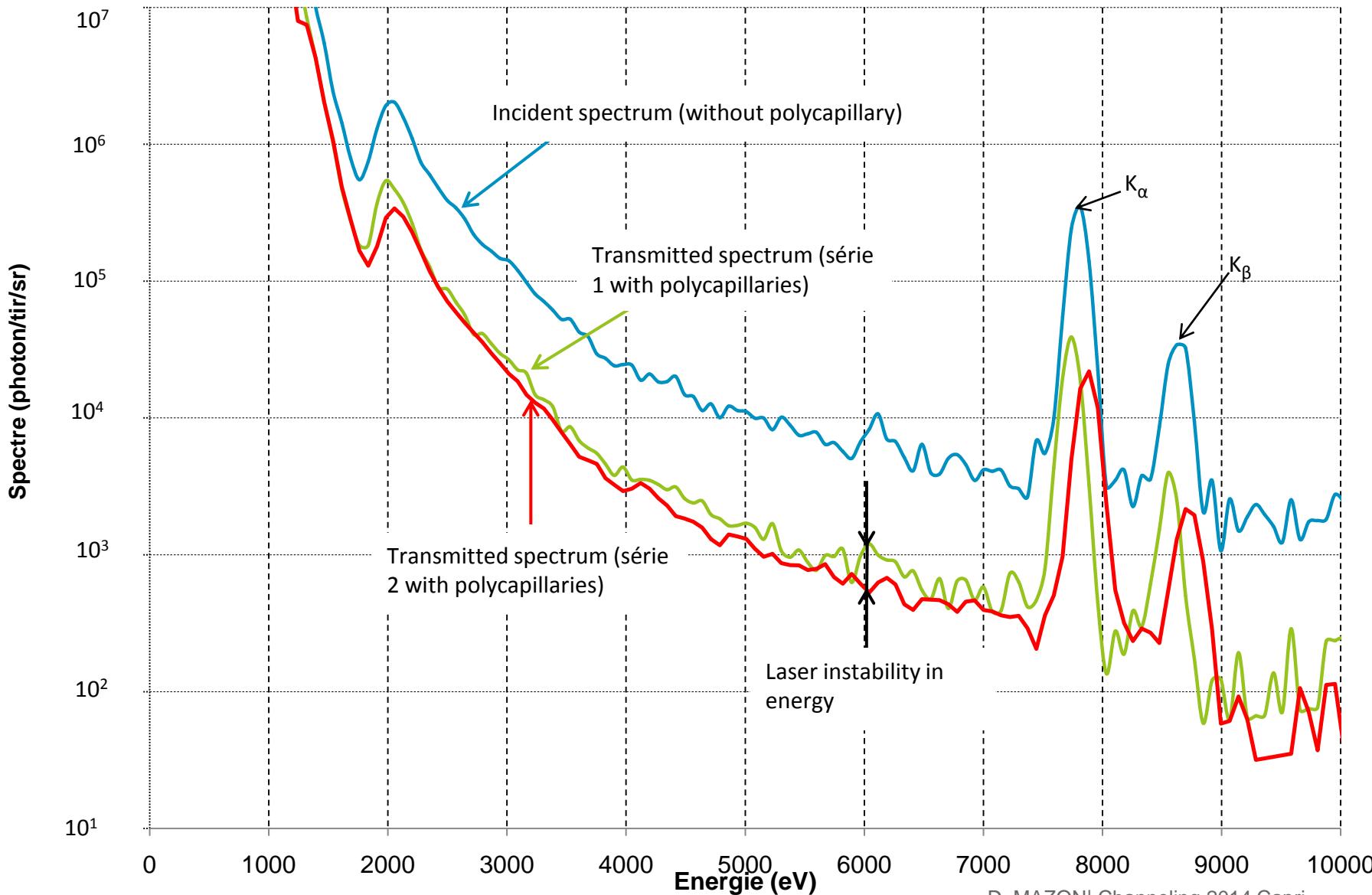


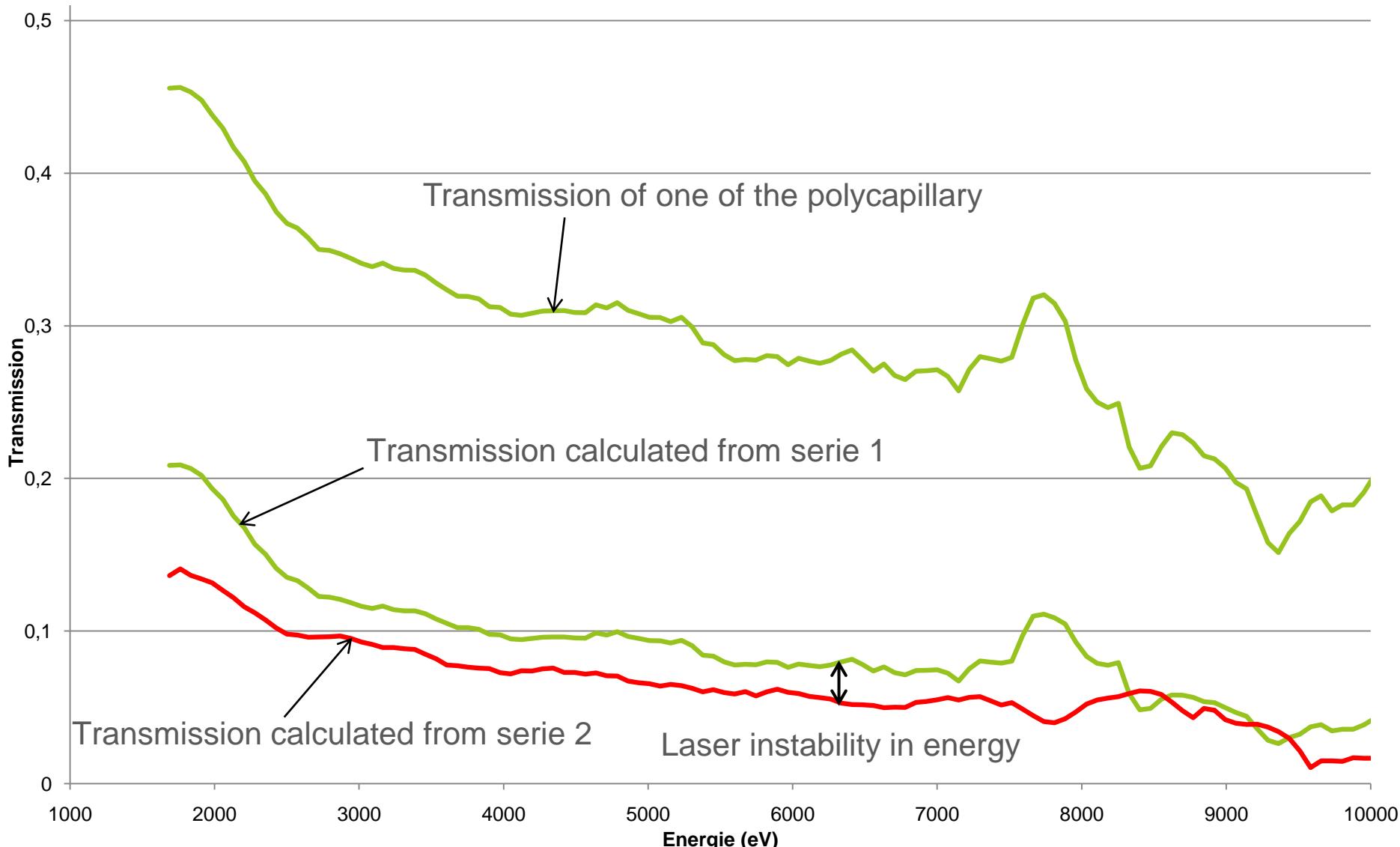
Transmission calculation :

$$N_{in} \times \Omega_{in} \times T = N_{out} \times \Omega_{out}$$

with N_{in} and N_{out} photon/steradian
 Ω_{in} and Ω_{out} solid angles (steradian)

EXPERIMENTAL SPECTRA MEASUREMENTS





OUTLINE

Part 1: Introduction

- Soft X-ray measurement in Tokamak
- Brief reminder about polycapillary lenses

Part 2: Experimental measurements at CELIA

- Experimental set up
- Results

Part 3: Modelisation of SXR transmission

- Model description
- Comparison model-experiment

Part 4: Conclusion and perspectives

MODEL ALGORITHM (RAY TRACING)

1. Discretisation ; generation of the incident photon trajectories
2. Calcul of intersection points

3. Radius Transmission inside polycapillary

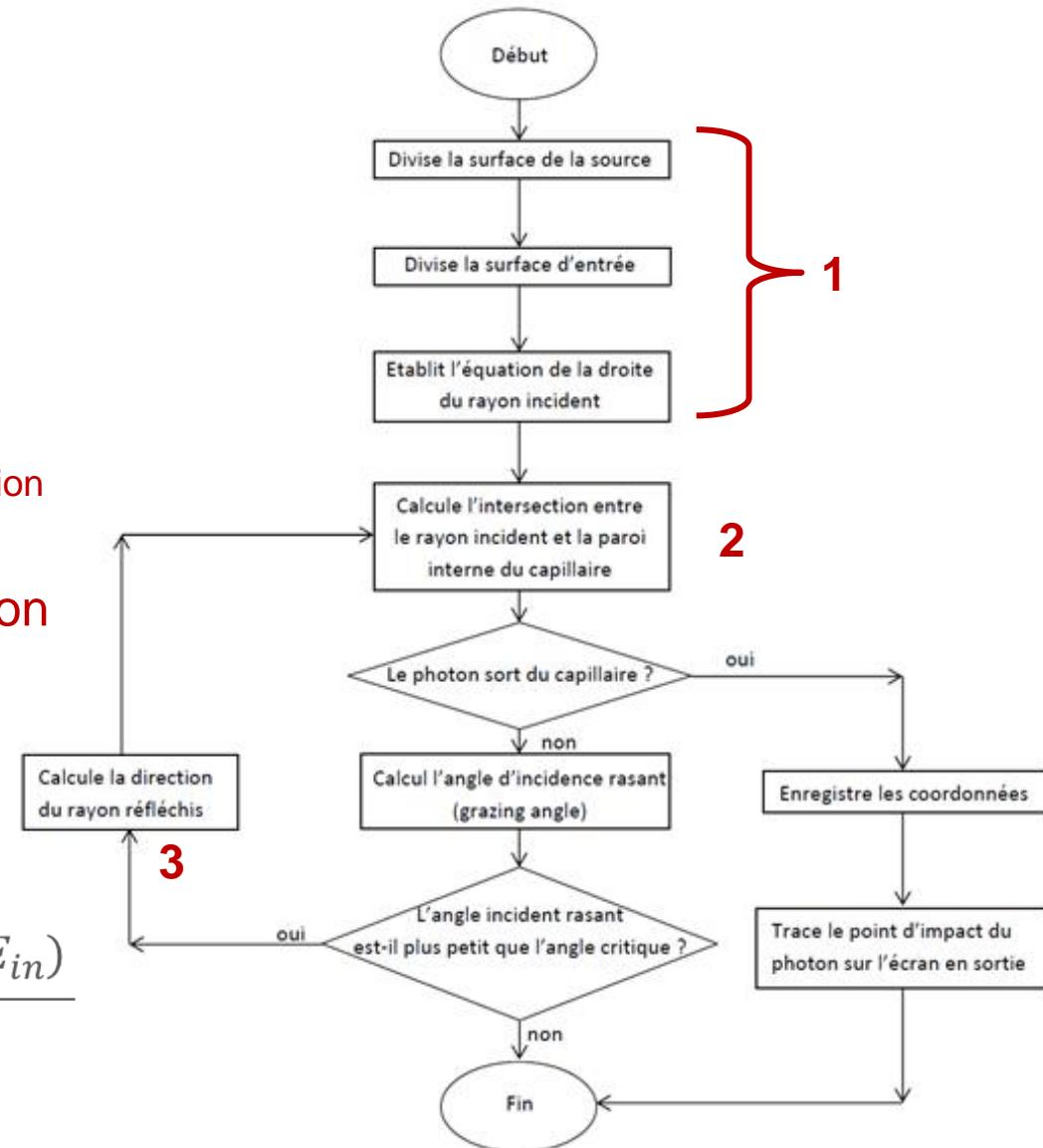
Trajectories calculation

Multiplication of the light intensity by reflection coeff R

4. At the polycapillary exit: calculation of the impact point coordinates

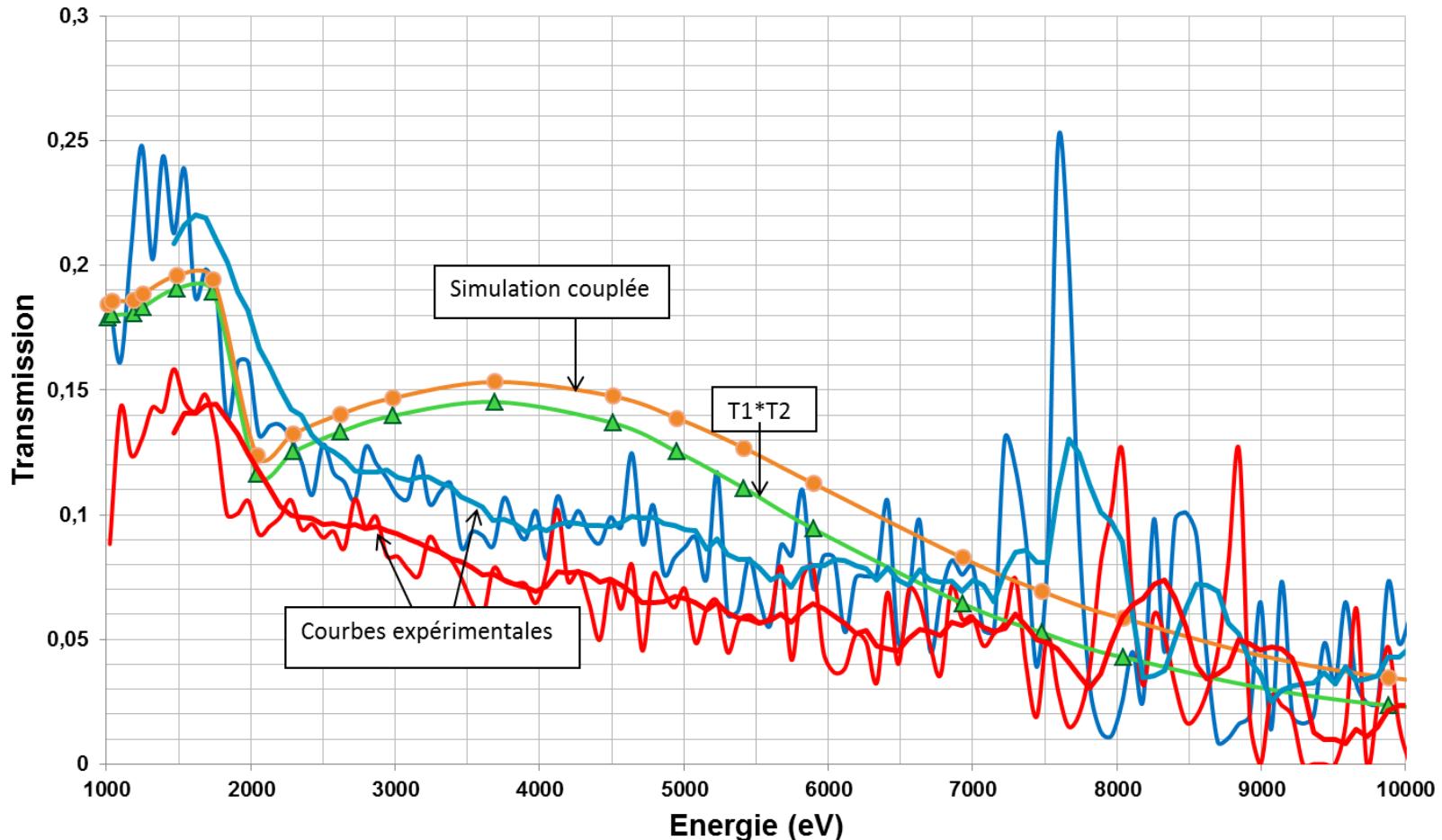
Transmission calculation

$$T = \frac{\sum_{i=1}^{N_{ph_in}} - N_{ph_abs}}{N_{ph_in}} \prod_{j=1}^{reflections_i} R(\theta_{i,j}, E_{in})$$

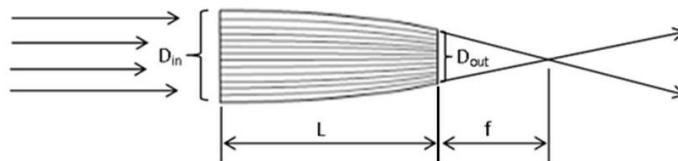


MODE-EXPERIMENT COMPARISON

Good agreement but slight difference between 3-5 keV
 (matérial?, rugosity?, ordering of polycapillary?)

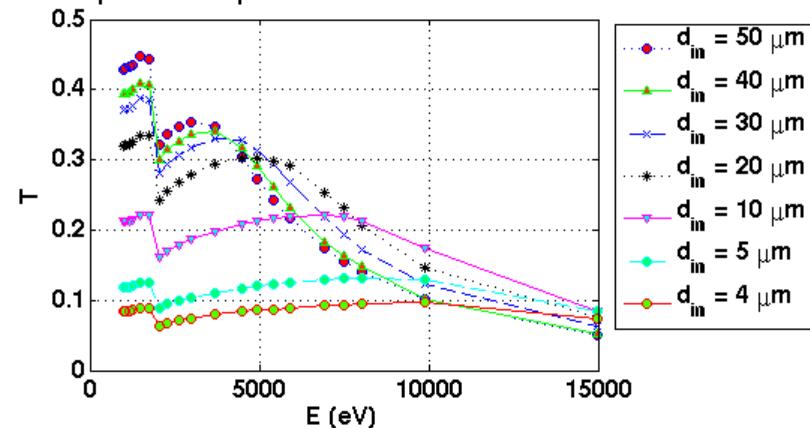


PARAMETRISATION: CAPILLARY DIAMETER INFLUENCE

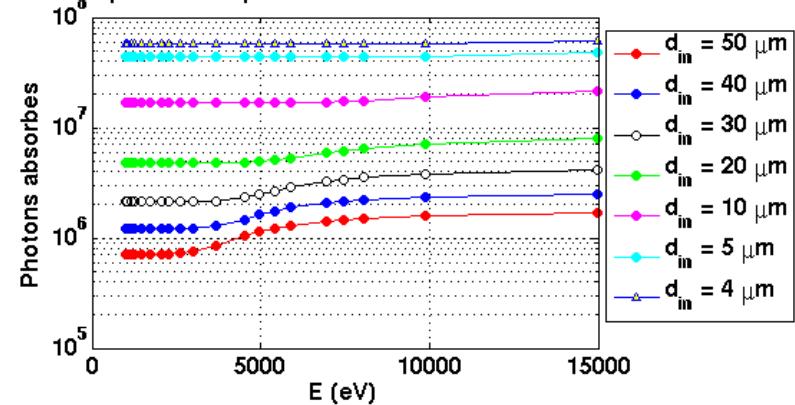


- High energy photon transmission is independent from polycapillary diameter
- Partial absorption of photons (through R) is the main attenuation cause of transmission at high energy.

Transmission de la lentille
en fonction de l'énergie des photons
pour des capillaires de diamètre variables



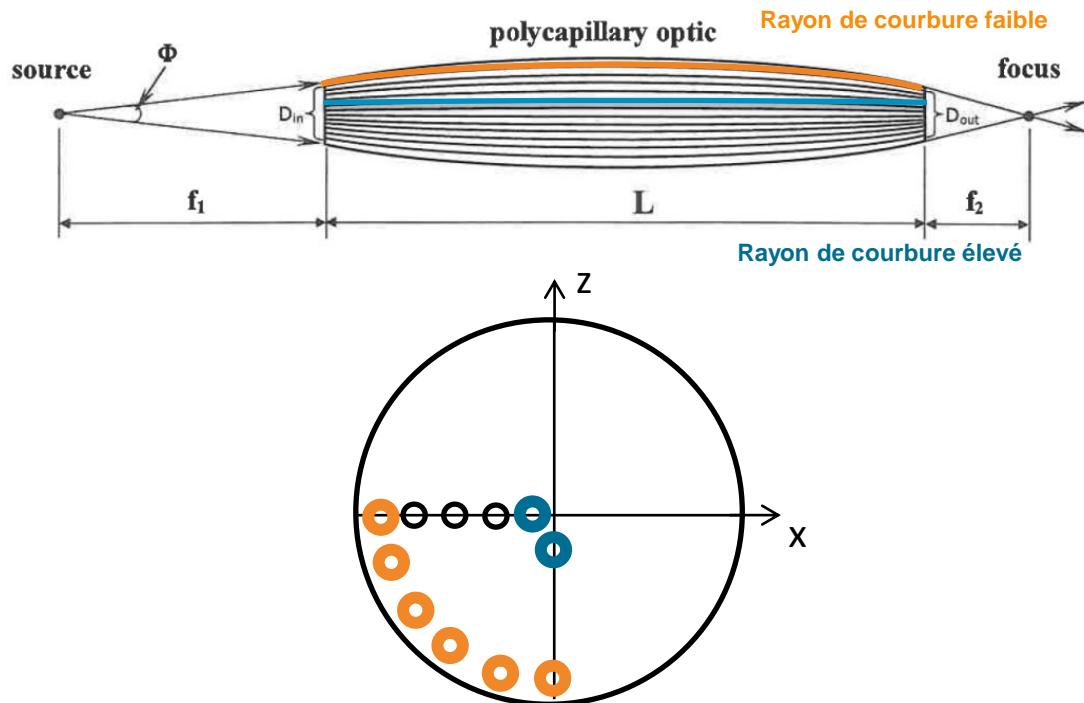
Nombre de photons absorbés par la lentille
en fonction de leur énergie
pour des capillaires de diamètre variables



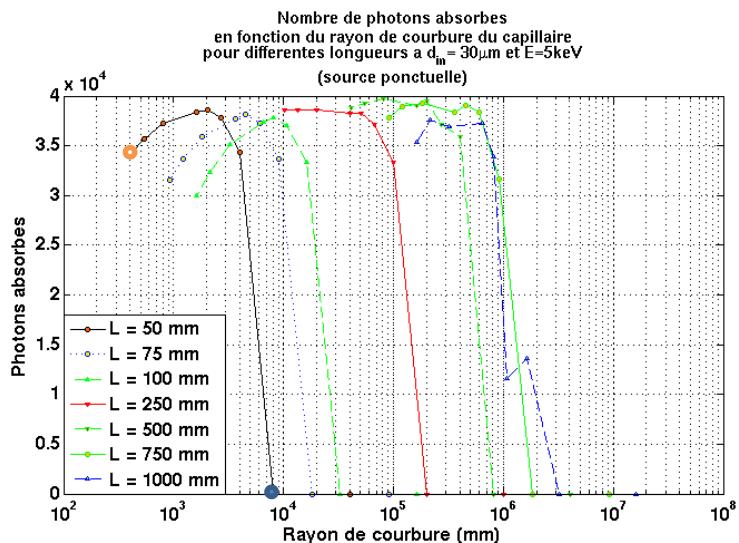
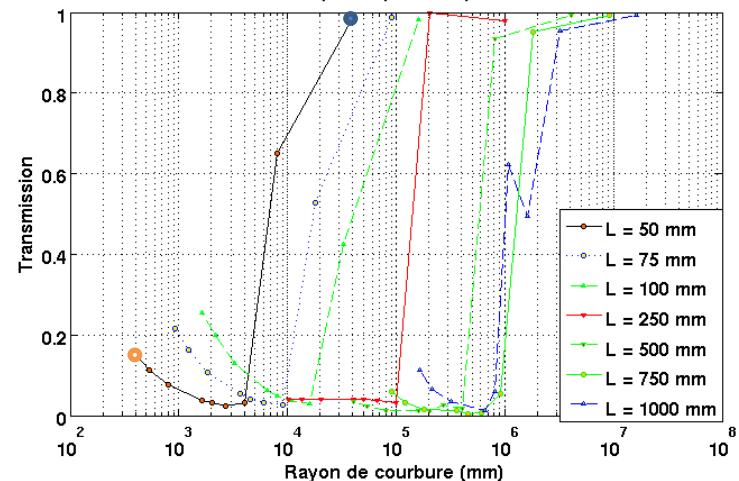
INFLUENCE OF LENGTH

On which distance should we transport X-Rays?

- Capillary curvature radius is variable in a polycapillary lens



Capillary transmission at Fixed Energy (5keV) and diameter (30 μm) (point source)



OUTLINE

Part 1: Introduction

- Soft X-ray measurement in Tokamak
- Brief reminder about polycapillary lenses

Part 2: Experimental measurements at CELIA

- Experimental set up
- Results

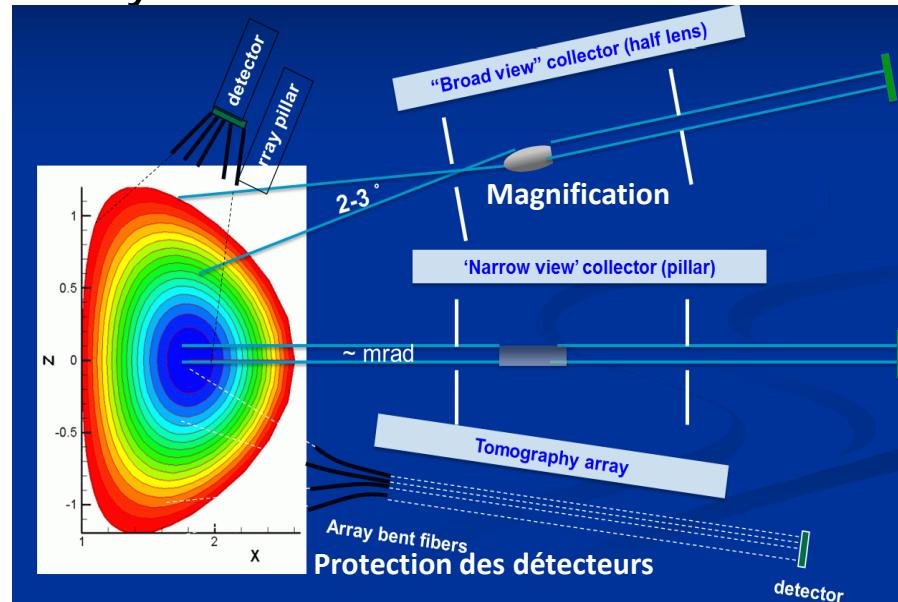
Part 3: Modelisation of SXR transmission

- Model description
- Comparison model-experiment

Part 4: Conclusion and perspectives

CONCLUSIONS

- A transmission model has been developed and validated on SXR source induced by laser at CELIA
- Good agreement between model and experiment
- Authorise simulations and optimisation of polycapillaries for application to tokamaks.
- Model will be tested soon on a continuous source at CEA laboratory.



**THANK YOU FOR YOUR
ATTENTION**

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Cadarache | 13108 Saint Paul Lez Durance Cedex
T. +33 (0)4 42 25 46 59 | F. +33 (0)4 42 25 64 21

Etablissement public à caractère industriel et commercial | RCS Paris B 775 685 019

DSM
WEST