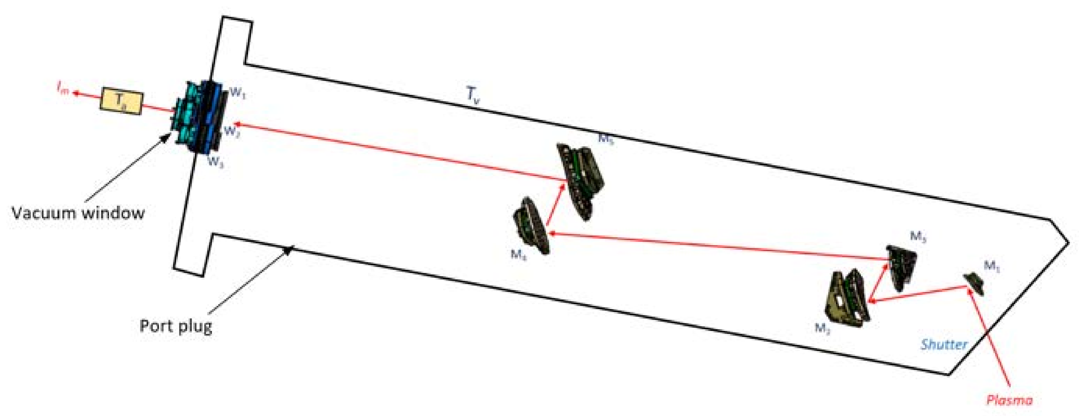
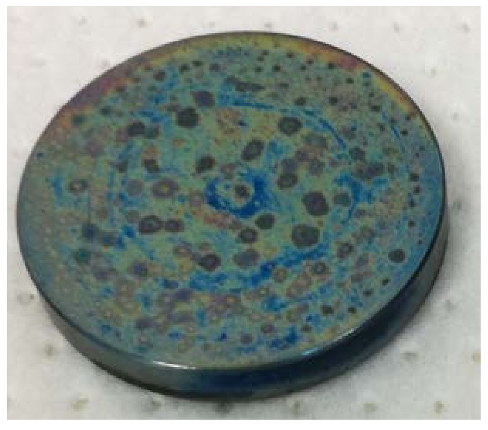
SELF-RADIOMETRIC CALIBRATION SOLUTION FOR TOKAMAK'S OPTICAL DIAGNOSTICS: APPLICATION TO ITER CORE CXRS DIAGNOSTIC

/ INTRODUCTION

The radiometric calibration of optical diagnostics used in tokamaks is critical for monitoring and studying fusion reactors. However, the environment in such installations is particularly severe and the performance of the collection devices (optics) is liable to deteriorate over time. As the constrained environment does not allow the installation of calibrated optical sources in front of the diagnostic, the calibration of the transmission efficiency is done remotely with a retroreflector placed behind the shutter. However, this suffers from its own calibration uncertainties over time as its optical integrity can also be affected by the environment.
In the classical configuration below, the front end components (shutter, M1 mirror) are likely to be affected by plasma sputtering. Likewise, all in port components can be altered during steam events (oxidation, dust deposit).

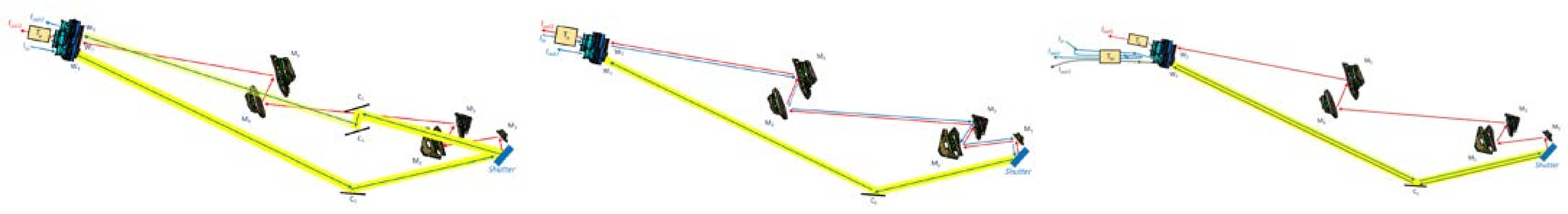


Classical configuration of an optical diagnostic in ITER Port Plug



Mo substrate + Mo coating after steam event

As the integrity of the retroreflector cannot be guaranteed, the radiometric calibration must include its reflectivity measurement. Different proposals have been suggested and all of them have included an additional optical path to measure directly the retroreflector efficiency:



Calibration synoptic alternatives

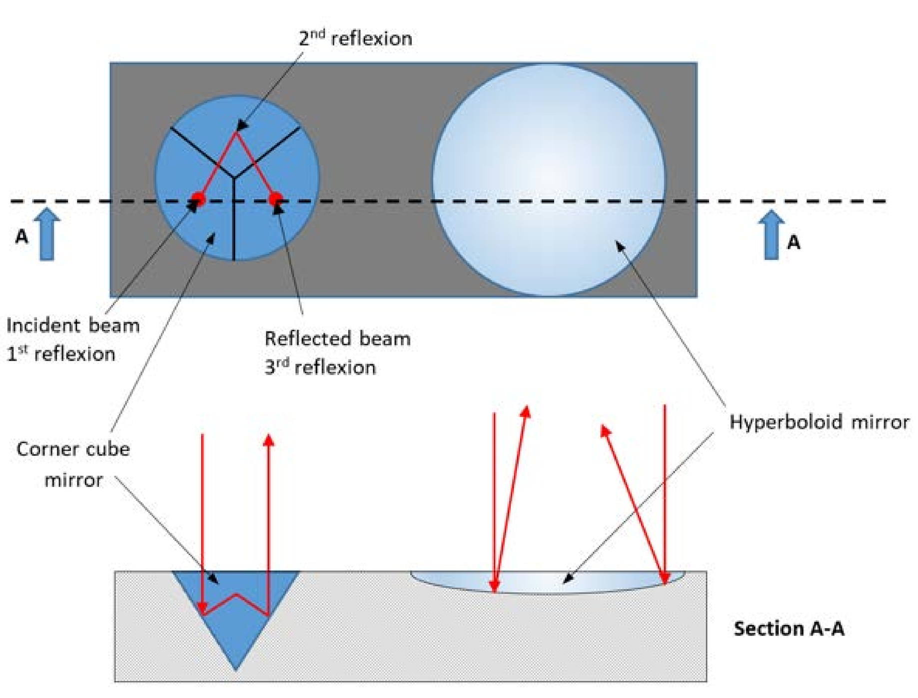
Main issues induced by these proposals

- Additional optical path(s): cost, neutronic shielding,
- Optical paths linked together: in and ex vessel alignment & maintenance complexity
- Additional optical components (Ci): additional degradation risk
- The absolute measure of the reflectivity of the retroreflector assumes that the transmissions of the additional optical paths are unaffected by environment and/or maintenance.

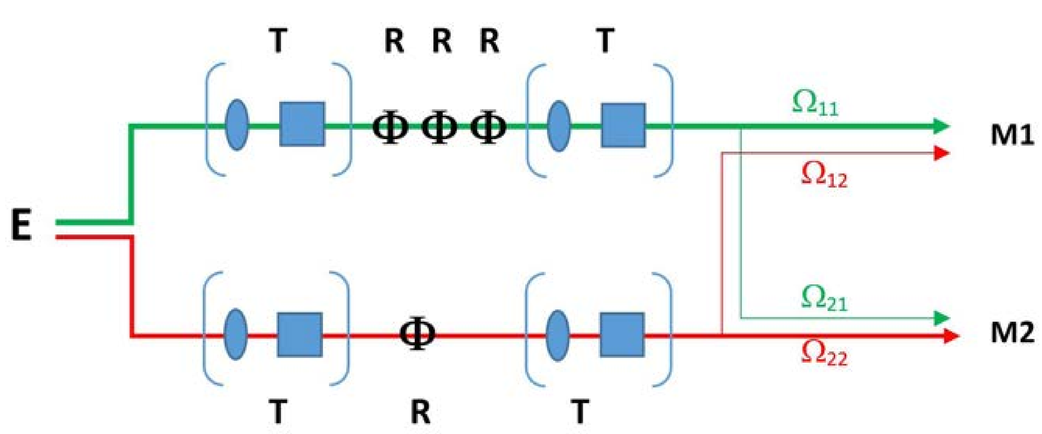
/ INNOVATIVE SOLUTION: A DUAL SHAPE RETROREFLECTOR (PATENT PENDING)

To solve all the identified above issue, Bertin has introduced an innovative solution based on a dual shape retroreflector with the following principle:

- 1st mirror shape = 1 optical distribution
- 2nd mirror shape = 1 optical distribution different from the 1st mirror shape
- and the number of reflectivity between the 1st and 2nd mirror shape is different



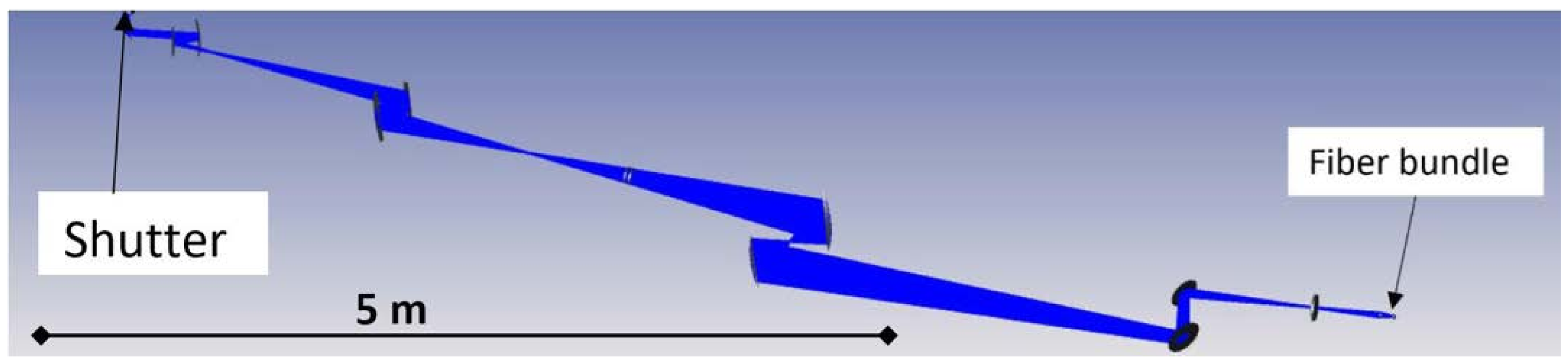
The green measurement
$M1 = \Omega_{11}.T^2.R^3.E + \Omega_{12}.T^2.R.E$
And the red measurement
$M2 = \Omega_{21}.T^2.R^3.E + \Omega_{22}.T^2.R.E$
$T^2.R^3$ because the green path goes through twice the intial system (T^2) and 3 time in the corner cube (R^3).
2 independent equations with 2 unknowns T and R
If $\Omega_{12}.T^2.R << \Omega_{11}.T^2.R^3$
and
$\Omega 21.T^2.R^3 << \Omega 22.T^2.R$

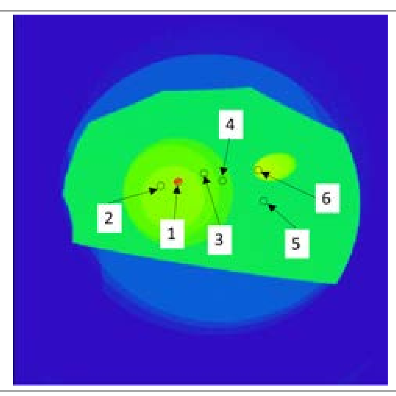
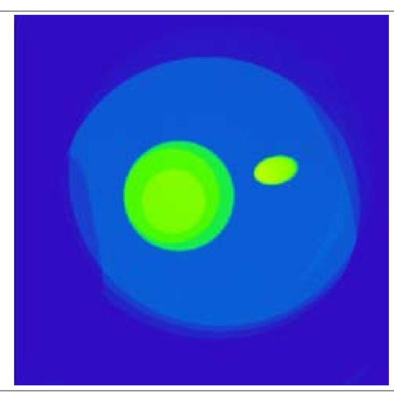
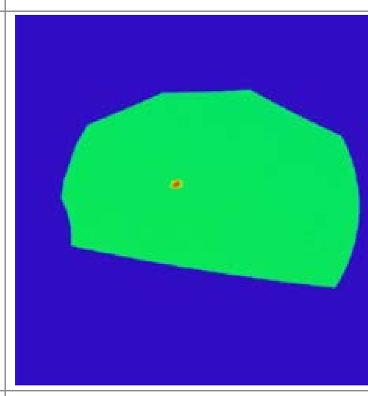
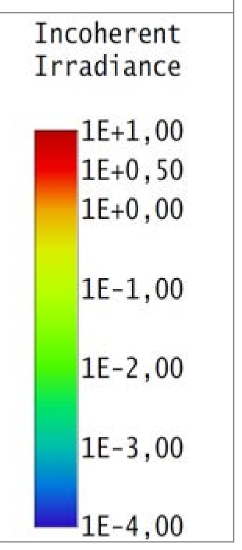


$$T = \sqrt{\frac{1}{E_0}\frac{M2}{\Omega_{22}}\sqrt{\frac{\Omega_{11}\,M2}{\Omega_{22}\,M1 - \Omega_{22}.M2}}}$$

$$R = \sqrt{\frac{\Omega_{22}.M1 - \Omega_{22}.M2}{\Omega_{11}.M2}}$$

/ THEORETICAL CALIBRATION PERFORMANCES ON CXRS DIAGNOSTIC



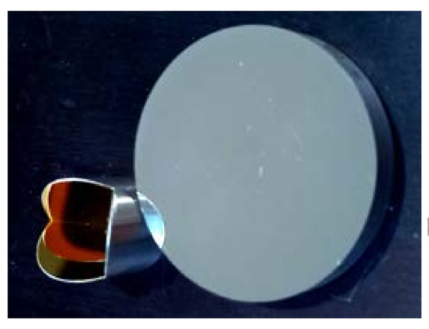
Signal	1 - Global irradiance	2 - Only Stray light	3 - Only retro reflected	Log scale
Detector image (false colour)				
Signal	100%	42%	58% (40% hyperboloid, 18% Corner Cube)	

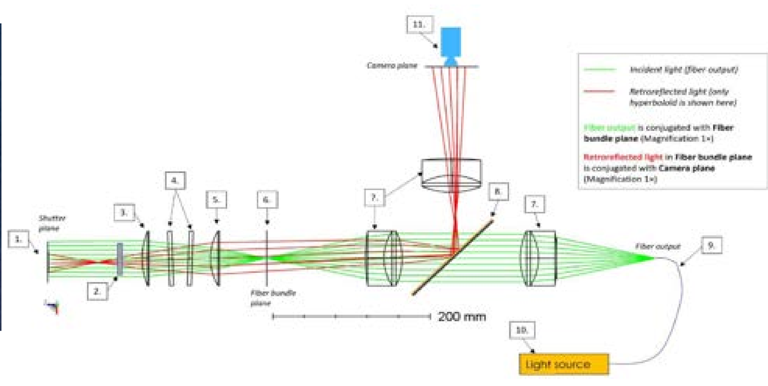
SNR using 5 mw output LED (505 nm)				
Fibre position#	Acquisition time (s) single picture	SNR	Acquisition time (s) Dedicated pictures	SNR
1	2.80e-05	7 045	2.80e-05	7 045
2		60	1.76e-03	475
3		82	3.54e-03	928
4		117	6.34e-03	1758
5		231	1.44e-02	5230
6		30	5.31e-04	132

Thanks to dual shape retroreflector principle, absolute radiometric calibration can be performed within seconds with the simplified synoptic below which reduces complexity, cost and risks.

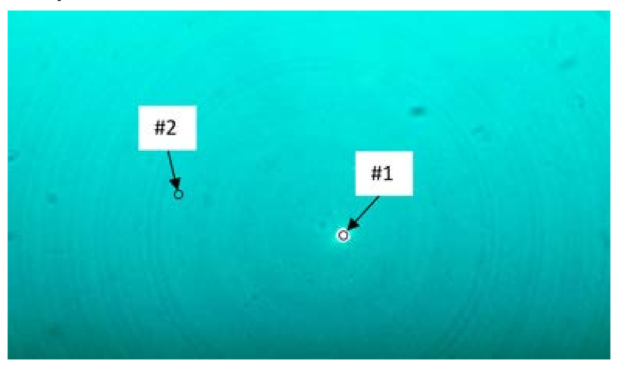
/ CXRS DEMONSTRATOR

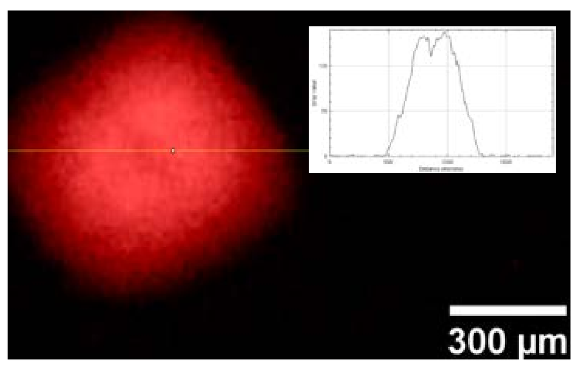
Bertin decided to build a simplified but representative demonstrator of the CXRS configuration (retroreflector size, etendue) to verify the theoretical SNR performances obtained.





Results
Acquisition config: Blank (stray light) substracted
Light source: LED 5 mW, 300µm
Camera: canon EOS 6D
Acquisition:1/4000s





Fibre position #	Theoretical Zemax analysis			Measured		
	Signal-background	Noise	SNR	Signal-background	Noise	SNR
1	9.89 E07	10 267	9637	9.02 E07	9801	9200
2	1.28 E04	990	327	8.29E03	318	260

/ IMPORTANT NOTICE:

The work leading to this invention received funding from the European Joint Undertaking for ITER and the Development of Fusion Energy under the auspices of the European Commission ITER and the Development of Fusion Energy in under contract No. F4E-OFC-0847-02. According to the IO agreements with F4E, the use of the patent is available for IO & DAs members for diagnostic developments for ITER.

Fiji image processing software has been used in this poster

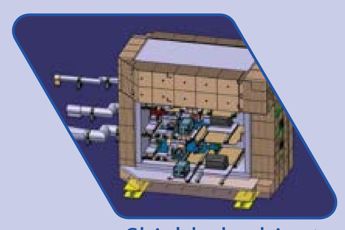
MORE ABOUT BERTIN

Bertin Technologies develops and installs plasma diagnostics for inertial and magnetic fusion:

- DP7-DP8: Visible optical diagnostics
- DP5: Visar diagnostic
- X-ray streak cameras

Rhodium coated mirror for In-vessel First Mirror

Dual reflector for in-vessel photometry calibration



Shielded cabinet for radiation protection

Laser Megajoule Common Reference

AD. Anthoine[a], S. Hamdani[a], V. Carrat[a], M. De Bock[b]
Corresponding Author: david.anthoine@bertin.group
[a] Bertin Technologies, Aix-en-Provence, France, [b] ITER Organization, St Paul-lez-Durance, France
www.bertin-technologies.com