Max-Planck-Institut
für Plasmaphysik

Divertor flow monitor simulations

O. P. Ford, D. Gradic, V. Perseo - IPP
M. Carr, A. Meakins, S. Orchard - Luffy AI
M. Kocan - ITER-IO

ITPA Topical Group Diagnostics, October 2021

china eu india japan korea russia usa

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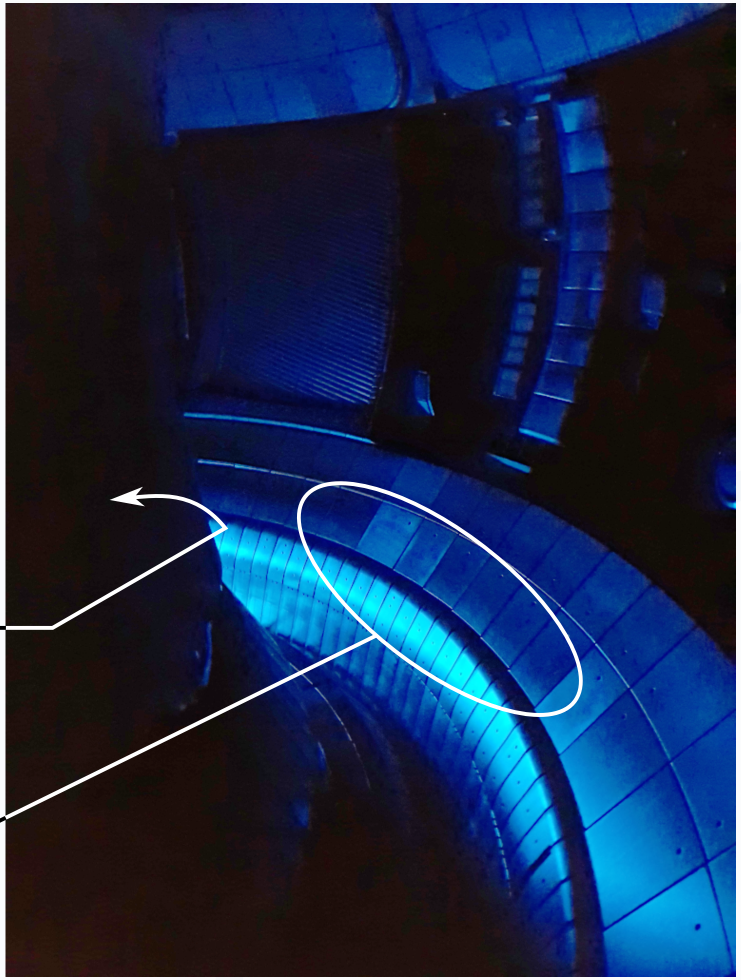
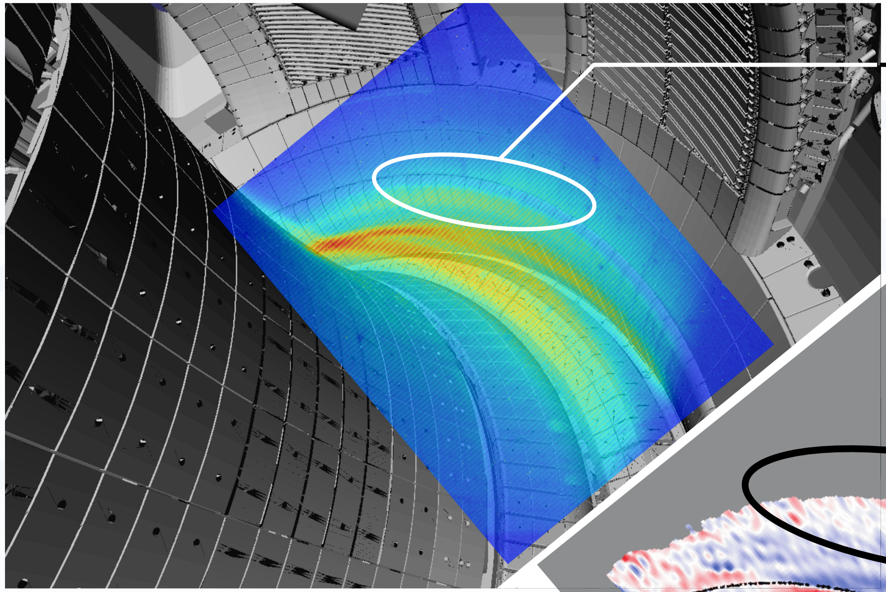
Reflections in CIS at AUG

- Many successful existing coherence imaging spectroscopy (CIS) systems (TEXTOR, MAST, D3D, W7X...)
- Only AUG so far with metal wall --> Effect of reflections noticable in some image areas.

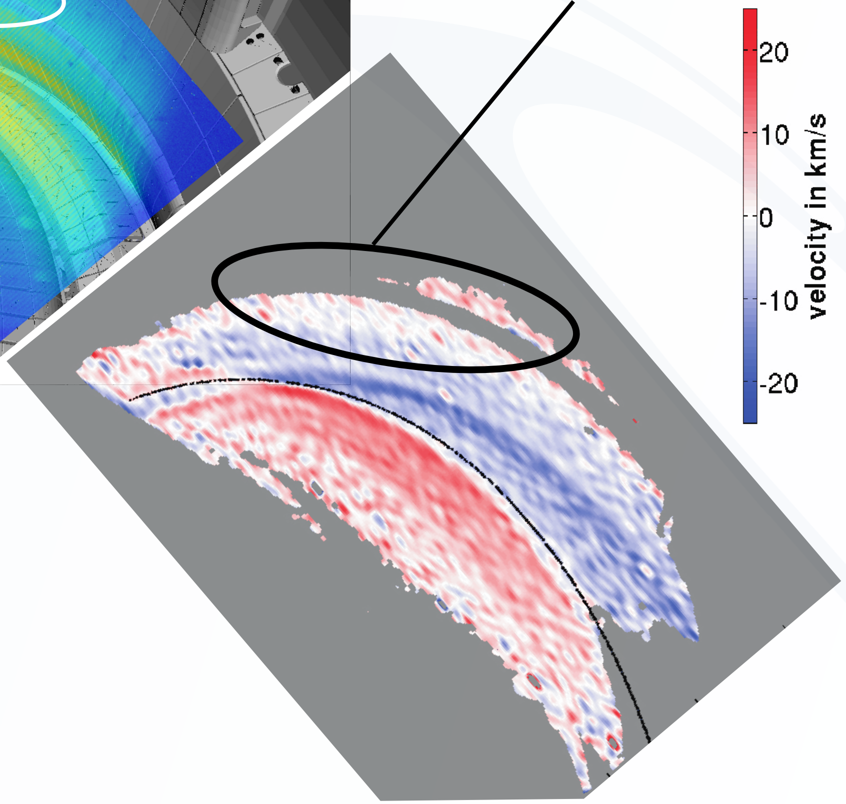


Light source around corner

Strong reflections from top of divertor

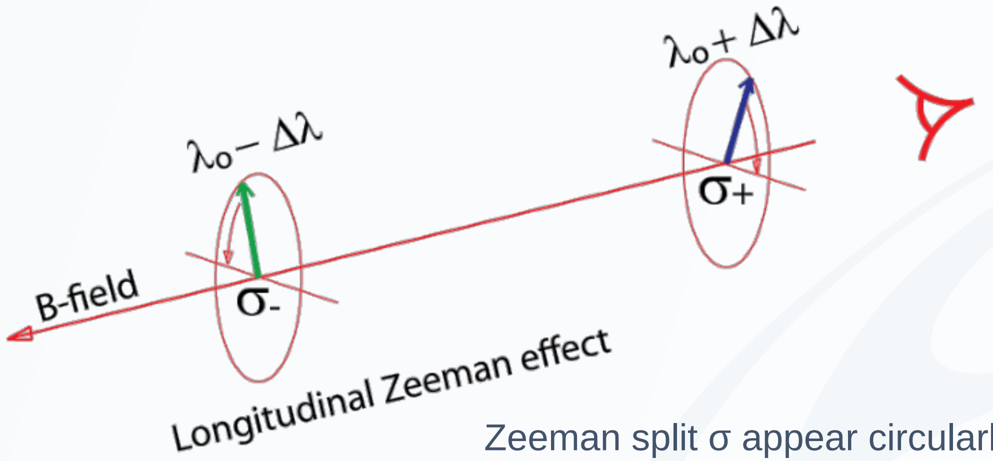


Suspected reflections seen in raw CIS signal (e.g. when tile structure are visible) with possible contamination of velocity.

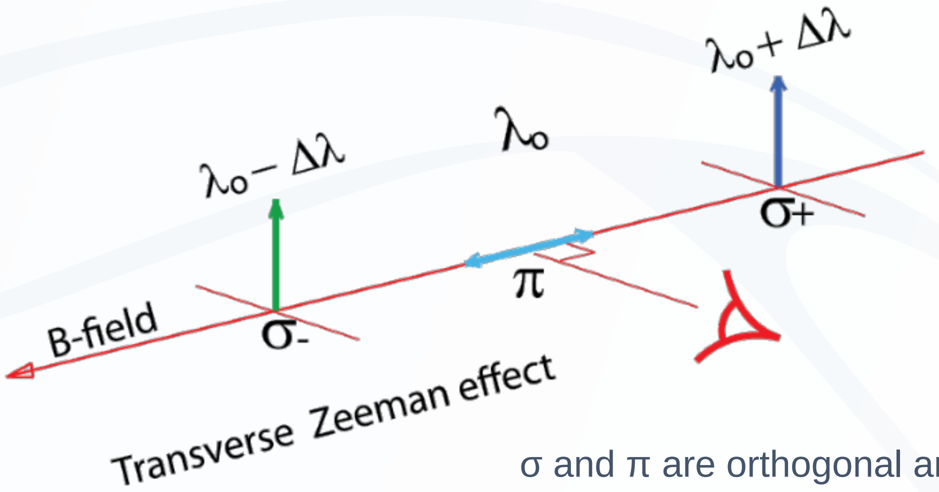


Reflection discrimination with polarisation

- Reflections considered to be a significant issue with visible diagnostics in ITER.
- No experiments with large |B| --> large Zeeman splitting.
- Flow monitor proposes to isolate reflections from signal using different polatisation states of Zeemna-split emission:



Zeeman split σ appear circularly polarized and π has no brightness.



σ and π are orthogonal and linearly polarized when looking across B.

"... because the nett polarized component incident on the wall is dominated by the linearly polarized Stokes components s_1 and s_2 (the emission closest to the wall facet propagates across B), on reflection, it is less likely to interfere with the primarily circularly polarized plasma component s_3 received directly by the camera."

[55.GE Divertor Flow Monitor - The Scientific Basis (YBJ7RW)]

Motivation: Chits

- CDR chit #12: **Is this principle valid and applicable for 55.GE view?**

The suppression of reflection is based on the idea that the majority of light reflected by the wall tiles comes from that emitted nearest to it, which necessarily comes perpendicular to the field and is therefore predominantly linearly polarised. This assumes: a) The diffuse reflection is dominant over specular, and b) reflected linear polarisation does not become circularly polarised. This should be shown for at least clean tungsten, but preferably also beryllium coated tungsten if at all possible.

If (a) is not true, specular reflection from lines of sight hitting tiles almost tangentially will contain a strong S3 component from the reflected continuation of that line of sight. If (b) is not true, the diffuse reflection of nearby plasma may be strongly circularly polarised due to phase shifts between the S and P reflected components.

- CDR chit #14,18: **Does optic relay preserve enough of the polarisation information?**

#14: The polarisation modelling of the optical system should be repeated with realistic mirror/lens coatings to determine if the ideal relay system can be characterised by an invertible Müller matrix.
Faraday rotation in the vacuum window should also be modelled.
Stress-induced birefingence should be considered as far as possible since this may introduce a variable modification to the Müller matrix.

#18: ... more detailed analysis which directly assesses mixing in to S3, and whether the Mueller matrix of the system will be sufficiently invertible, needs to be performed since this is a crucial issue for the measurement scheme.

RaySect + CHERAB

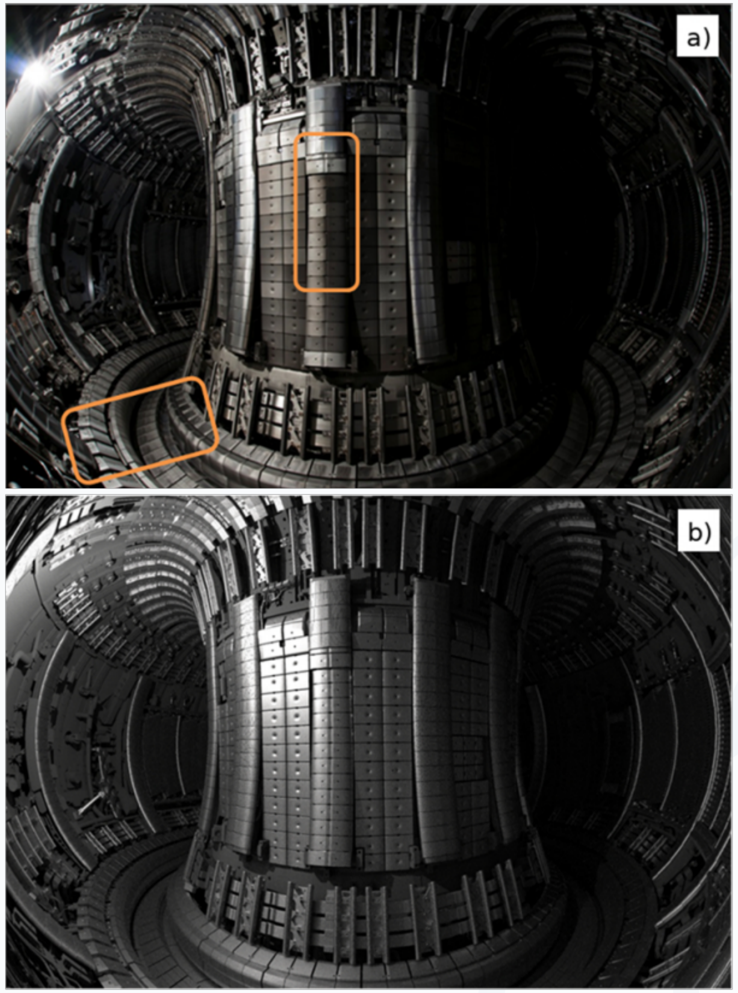


FIG. 6. Measured (a) and simulated (b) JET IVIS light images for calibration and benchmarking of material BRDF properties. The regions of interest marked in orange (a) are identified for later discussion.

RaySect = open-source ray tracing framework.
CHERAB = plasma emission / spectroscopy framework.

Already used for reflection simulation in metal-walled fusion devices.

- Compared in JET to measured images.

- Modelling work for ITER already conducted [Shown at ITPA TGD]

- Lacked polarisation behaviour of emission and reflection.

[M. Carr et al. Rev. Sci. Instrum. 90, 043504 (2019); https://doi.org/10.1063/1.5092781]
[C Giroud et al. http://doi.org/10.5281/zenodo.1206142]

Additional modelling

Additional modelling required for signal/reflection mixing of realistic spectrum/polarisaiton.
Modelling requirements:

1) Emission from ITER plasma with Zeeman-split spectrum. --> CHERAB + Zeeman (IPP)

2) Reflection from ITER wall geometry with realistic materials.

3) Collection with flow monitor optics.

(2 and 3) --> RaySect

4) Full polarisation ray-tracing. --> Upgrade of RaySect by Luffy AI

5) Realistic polarisaiton changes on reflection. --> IPP Measurements

Multiplet / Zeeman model

Full multiplet and Zeeman splitting information from arbitrary emission lines from code maintained by IPP.
[D. Gradic, originally J. D. Hay]

Model validated with high-resolution W7-X measured spectra:
[D. Gradic et al 2021 Nucl. Fusion 61 106041]

To be integrated into CHERAB / RaySect model for ITER.

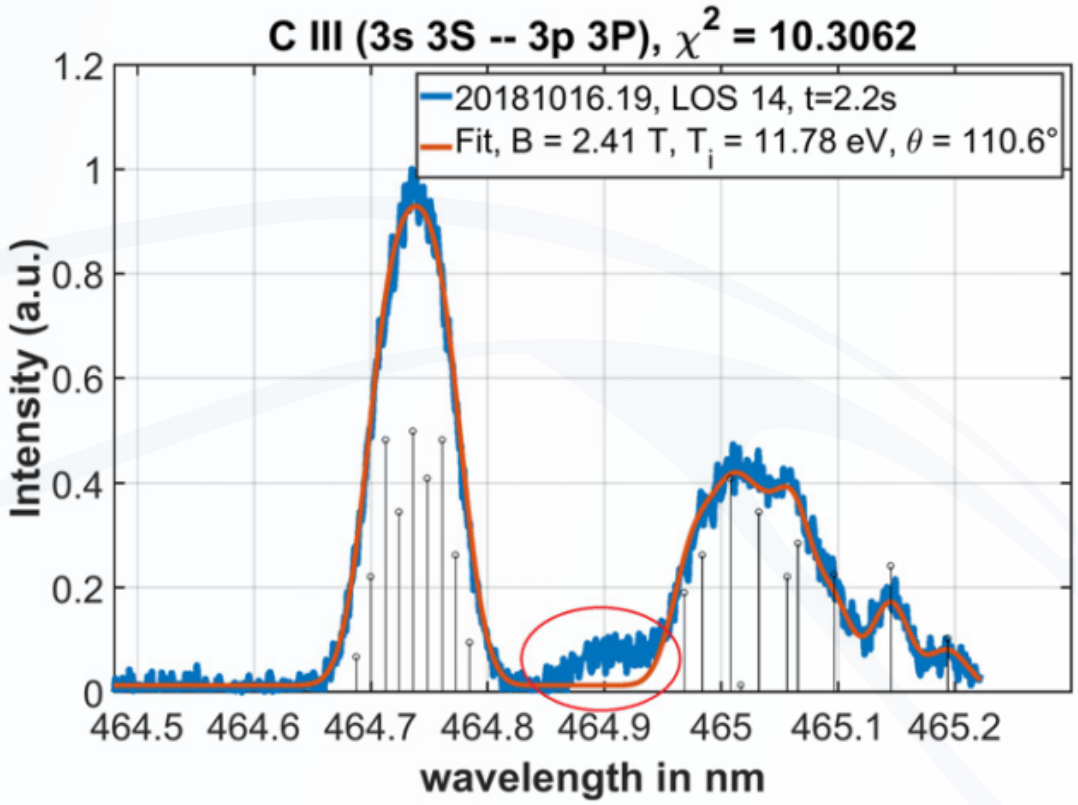


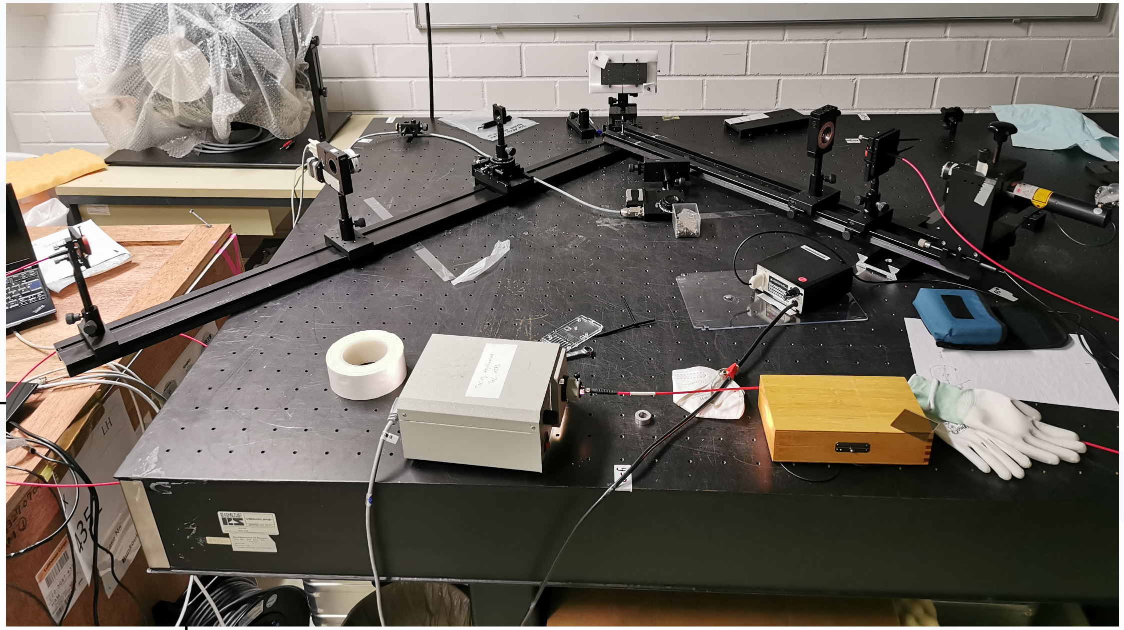
Figure 10. Measured C^{2+} line spectrum (blue) from the SOL of W7-X (along LOS 14 in figure 4) during attached conditions. A spectral fit (orange) was made under the consideration of Doppler broadening, Zeeman splitting and instrument broadening of the spectrometer. A perturbing line in the C^{2+} multiplet is indicated by a red frame.

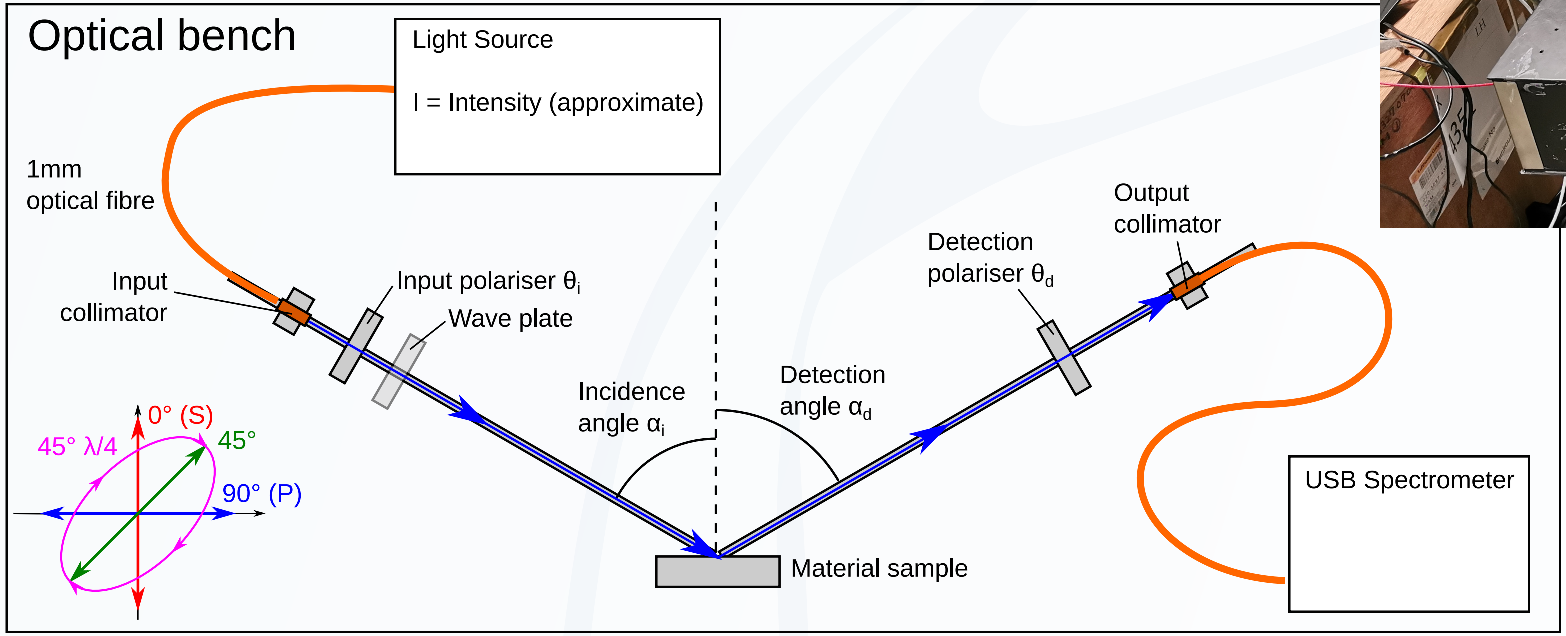
Polarisation reflection

Validation and fine tuning of polarisation/reflection model with measurements at IPP:

1) Absolute measurements of R_p, R_s and $\Delta\varphi$ for range of incidence and reflection angles.

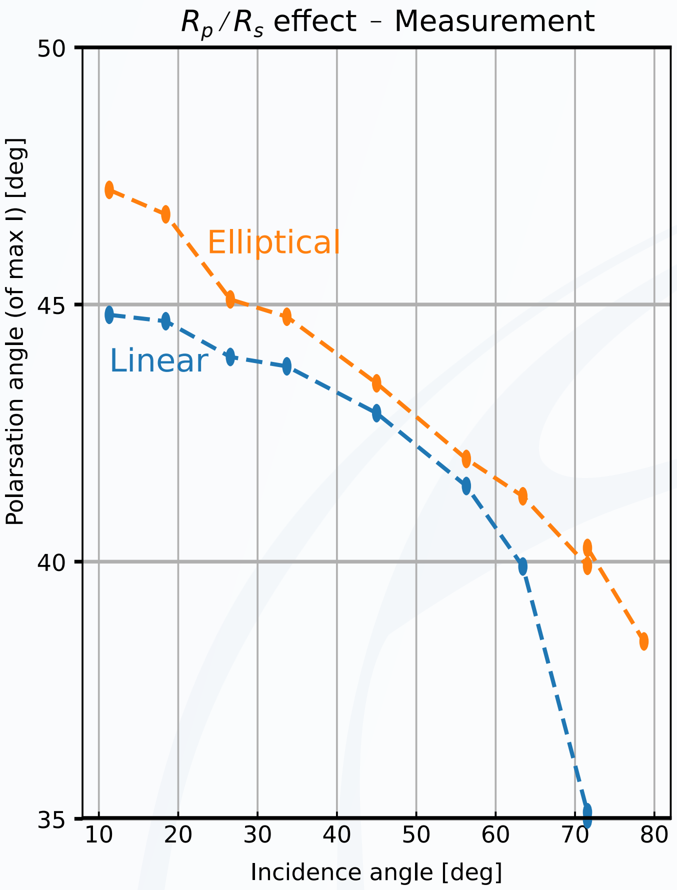
2) Full visible spectrum coverage 400 - 900nm.
3) Multiple sample reflectors.

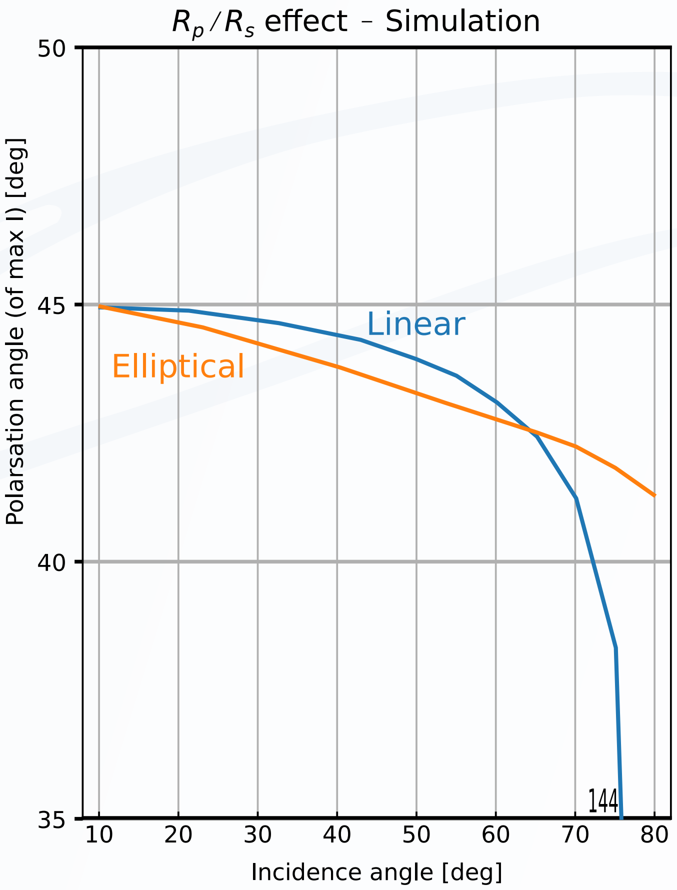


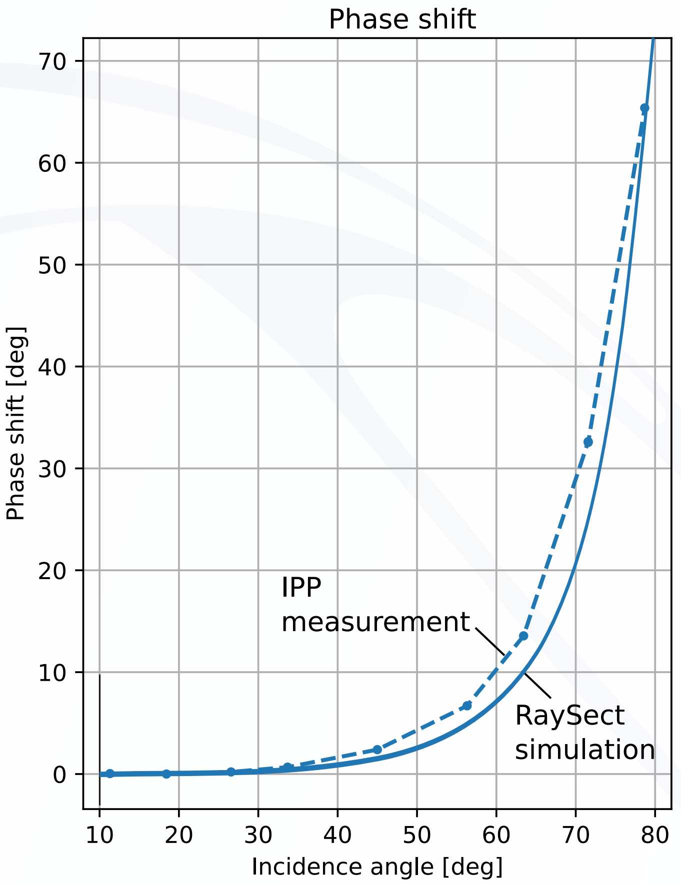


Validate ideal specular reflection

Validation of RaySect's polarisation handling for pure specular reflection by comparison to W7-X aluminium mirror.
- Test of pure theoretical model, not tuned to the real material.



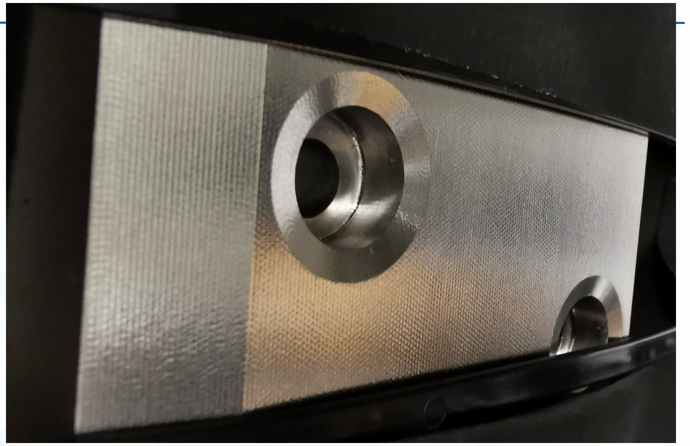


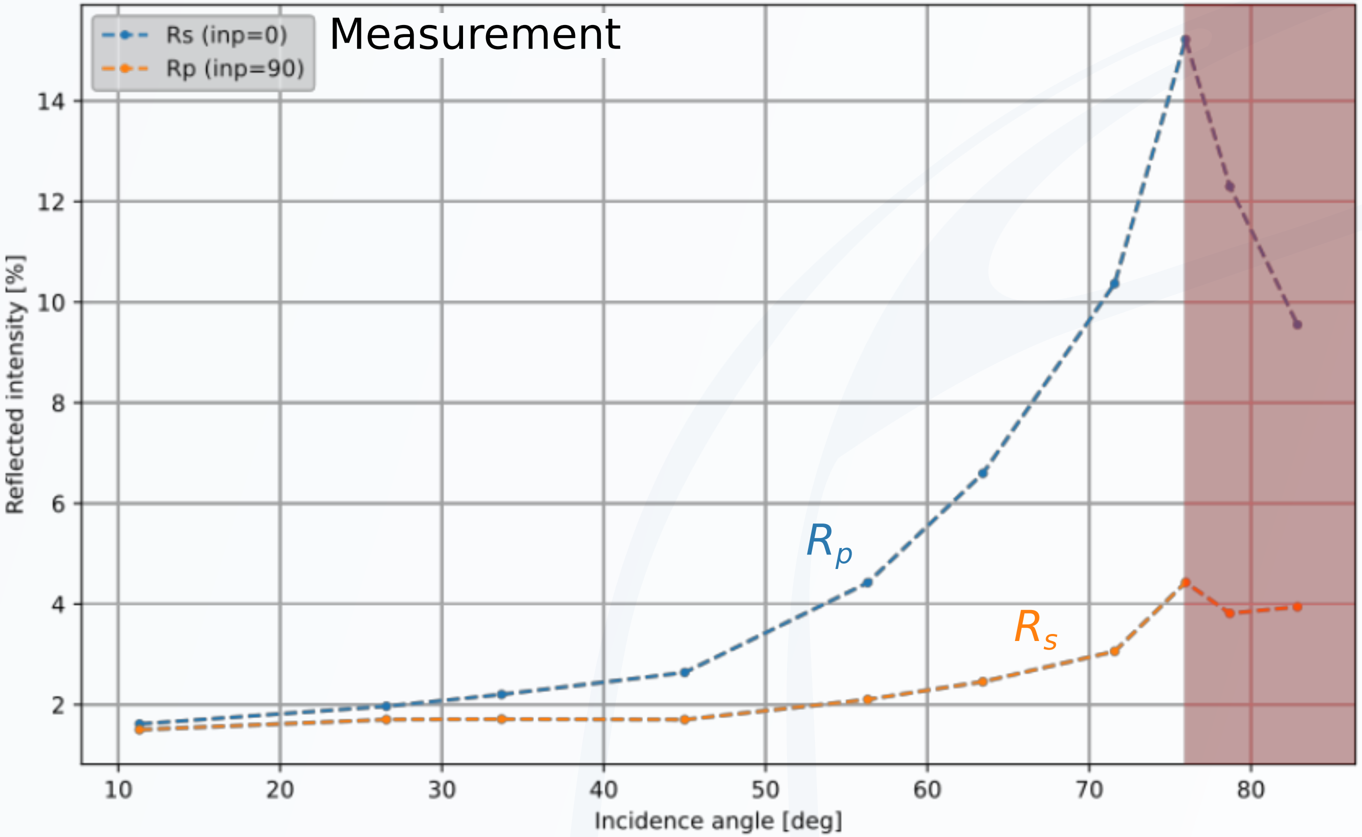


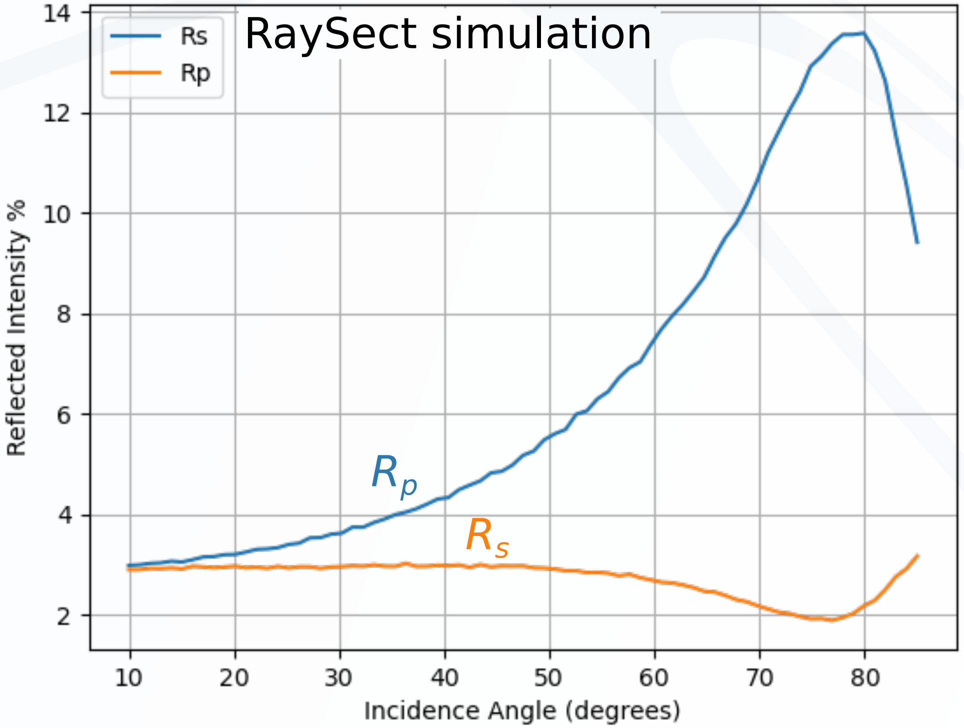
- Good behaviour match --> Trust in RaySect's specular reflection model for polarisation.

ASDEX Upgrade Tungsten tiles

More realistic test with ASDEX Upgrade tungsten tile.
- Rough facet model used in RaySect, using code validated by aluminium.
- Similar behaviour in model as mesaured
  --> Strongly linear polarising at oblqiue angles.
- Some differences in behaviour of $R_s(\theta)$.

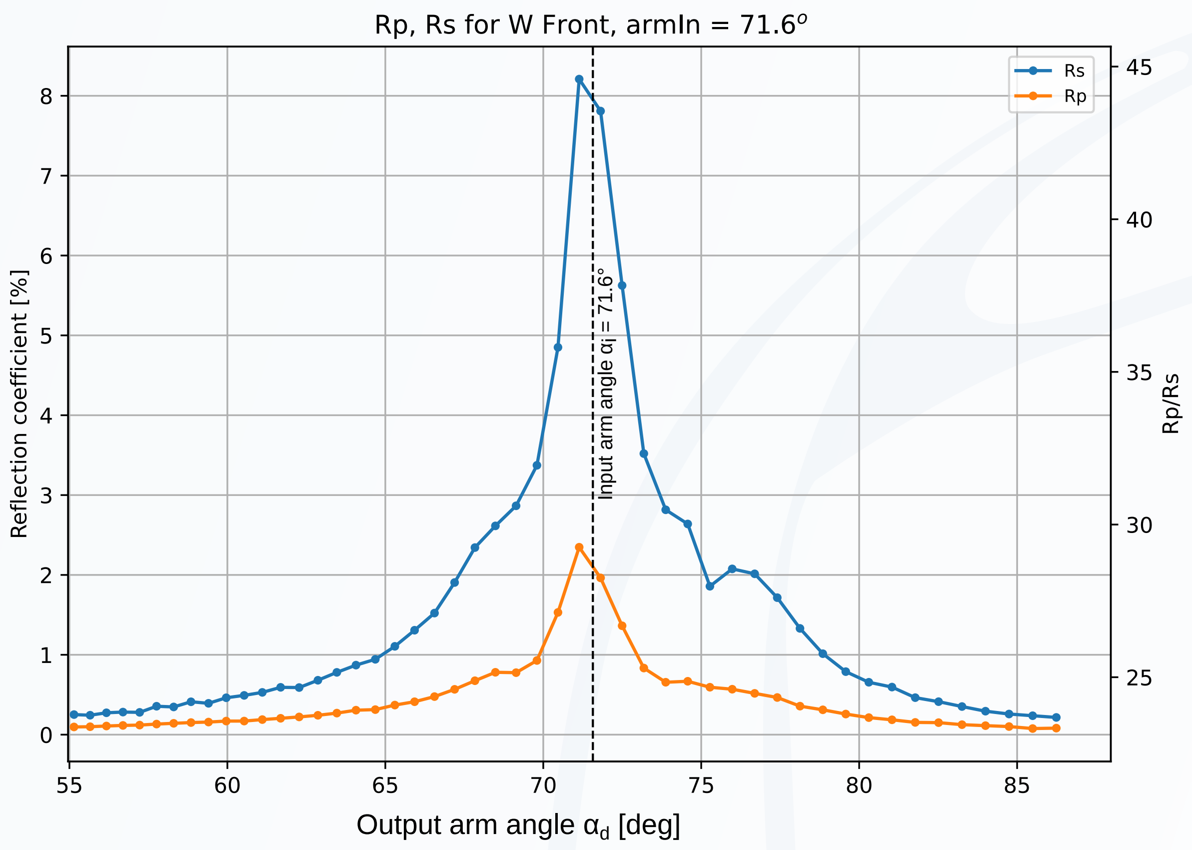


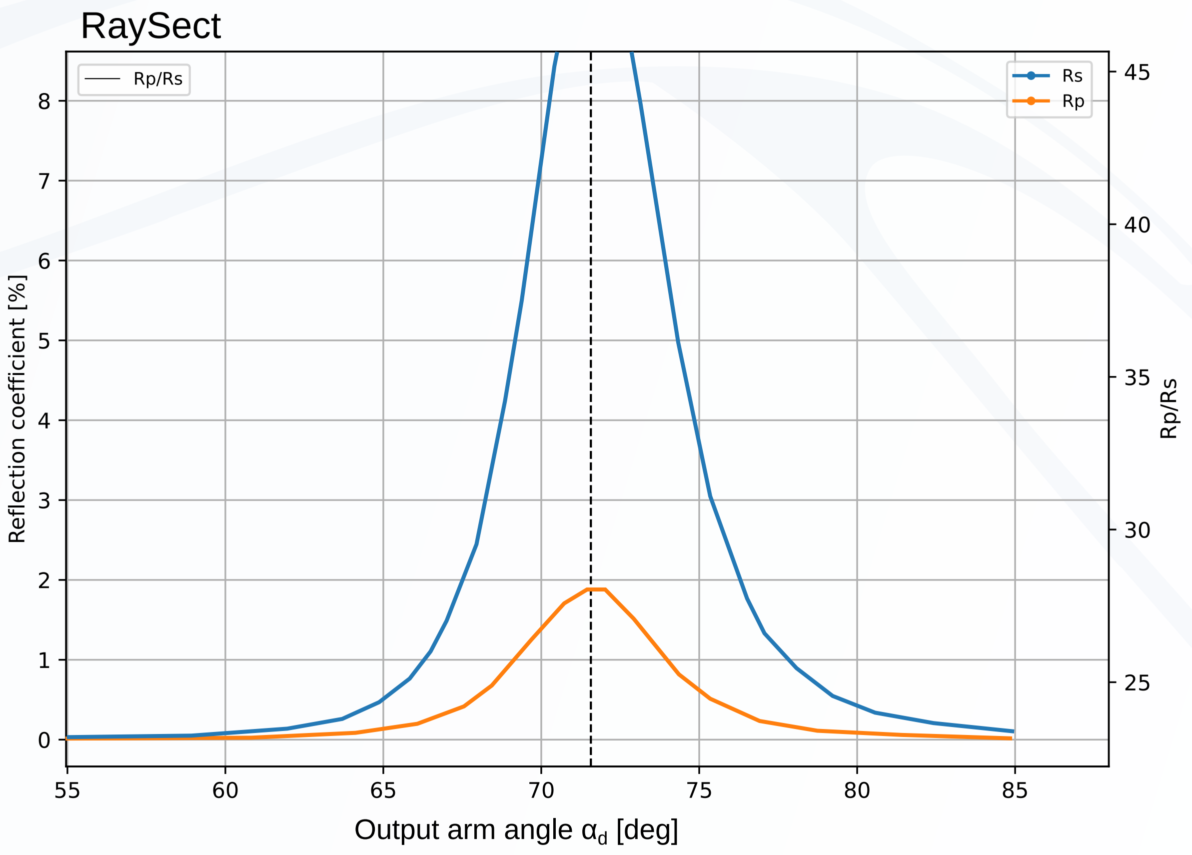




ASDEX Upgrade Tungsten tiles

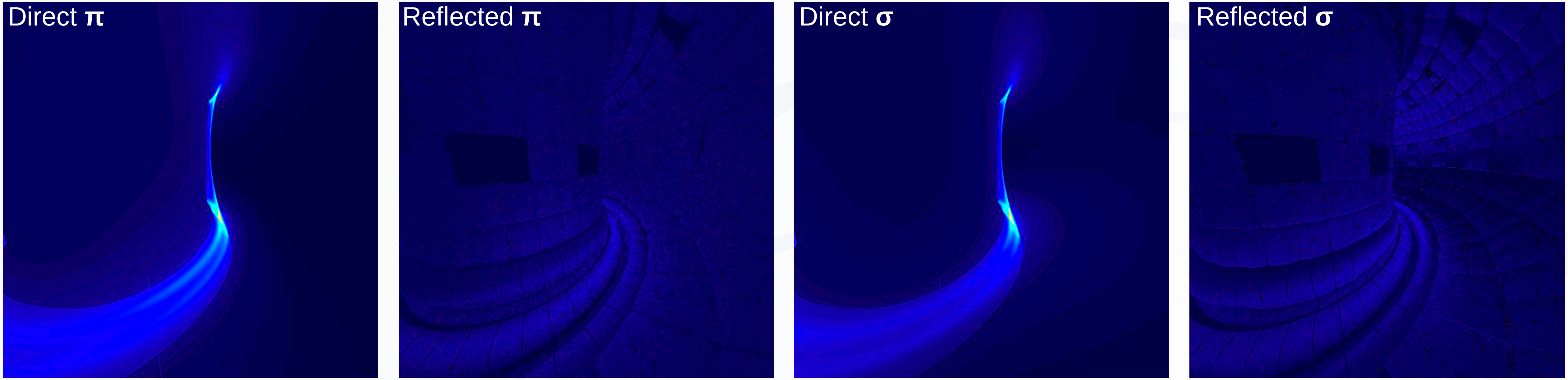
Diffuse reflections due to facets.
RaySect: "Rough tungsten material with Cook-Torrance micro-facet model with GGX distribution"
Good agreement of angular and polarisation behaviour.





Progress in RaySect

- With validated base model, Luffy AI now working on RaySect model using ITER wall geometry, plasma emission.
- Early preview show differences in reflections from different polarisation emission:



Todo:

- Integrate Zeeman multiplet and plasma emission model
- Flow monitor observation geometry and/or optics.
- Use measurement of prototype ITER wall materials --> IPP
- Use complete model to evaluate signal/reflection separation by polarisation state --> IPP

Initial assessment

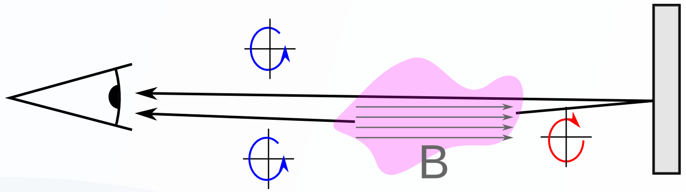
Some conclusions of reflection measurements:

1) Reflection behaviour more strongly determined by machining than metal.
2) Poloished metals have little effect on polarisation at near-normal angles:
3) Strong phase shift at oblique angles.
4) Rough metal surfaces give diffuse scattering which can be still strongly polarised.
5) No significant de-polarisation observed in any samples.

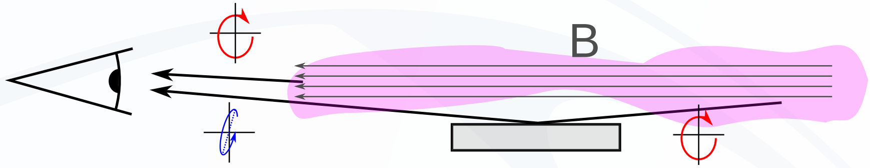
Implications for ITER flow monitor:

- Some reflections will be distinguishable, others not - no simple answer.
- Real behaviour will be very dependant on first wall machining properties.
- Much of the image area will be at most weakly affected by reflections.
- RaySect model will be important for determining from which areas the flow velocity can be trusted.

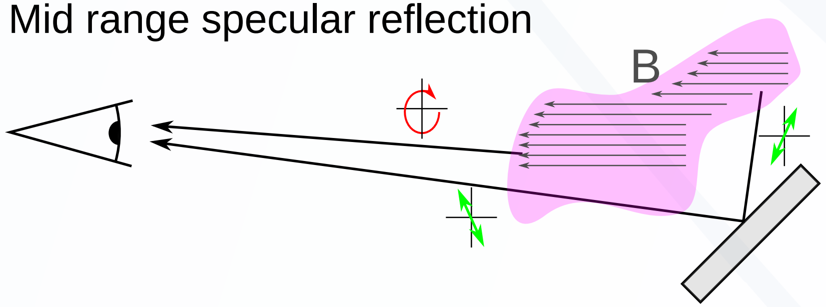
Specular reflector behind emitter



Oblique specular reflection



Mid range specular reflection



Diffuse reflection behind emitter