Performance tests of the ASDEX Upgrade Imaging Motional Stark Effect diagnostic.

Max-Planck-Institut für Plasmaphysik

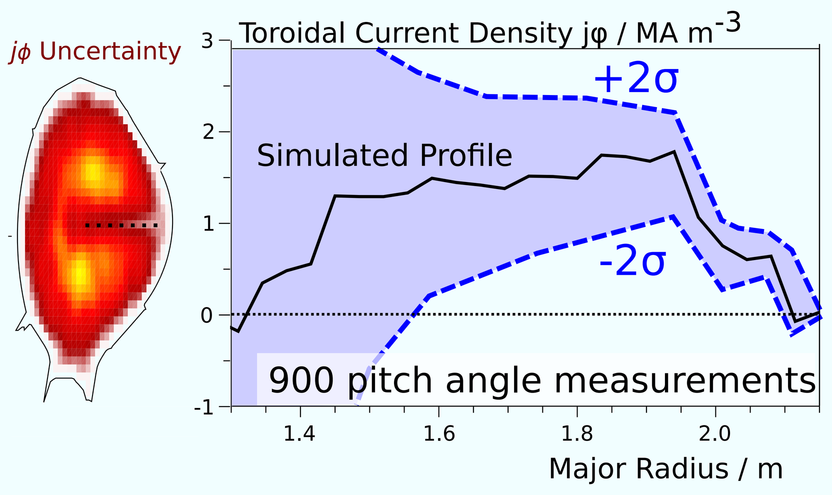
Oliver P. Ford[a], J. Howard[b], R.Wolf[a]

Please e-mail comments/questions to: eps13p@oliford.co.uk
a) Max-Planck-Institut für Plasmaphysik, Greifswald, 17491, Germany
b) Plasma Research Laboratory, Australian National University, Canberra, 0200, Australia

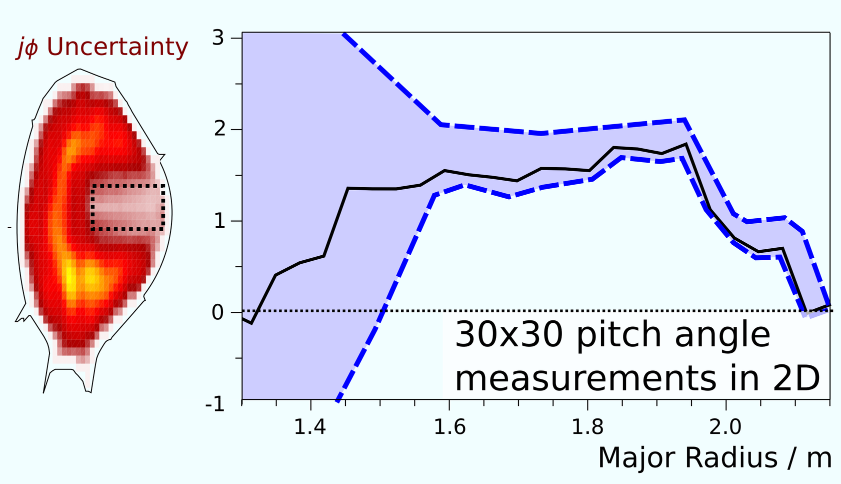
Imaging Motional Stark Effect (IMSE) is a new method of measuring magnetic field pitch angle for fusion plasma devices. Developed by the Australian National University (ANU)[1], it observes an image of the neutral beam from which a 2D image of the pitch angle can be inferred. An IMSE system was built for operation on ASDEX Upgrade and prior to installation was subjected to a series of tests to quantitatively asses its capability and choose optimum operating parameters. During these, several unanticipated effects were discovered, identified and mitigated.

Why 2D Measurements?

Diagnosis of the plasma current is of particular importance in Tokamak plasmas for analysis of stability, transport and many other areas. Tomographic reconstructions of the plasma current[2] from simulated measurements tell us how useful these measurements are. Here, an equal number of pitch angles on a line and in a 2D grid are compared:



Possible tomographic reconstructions of plasma current given external magnetics and a 1D line of 900 magnetic field pitch angle measurements.



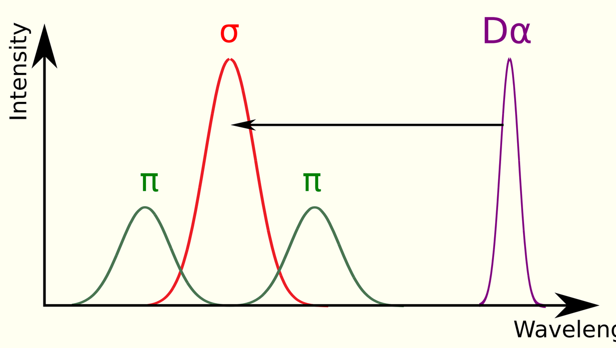
An equal number of points spread out in 2D over a 30x30 grid. The inference improves dramatically.

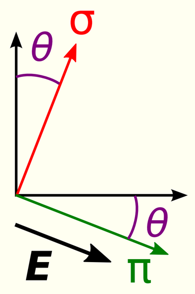
MSE: Motional Stark Effect.

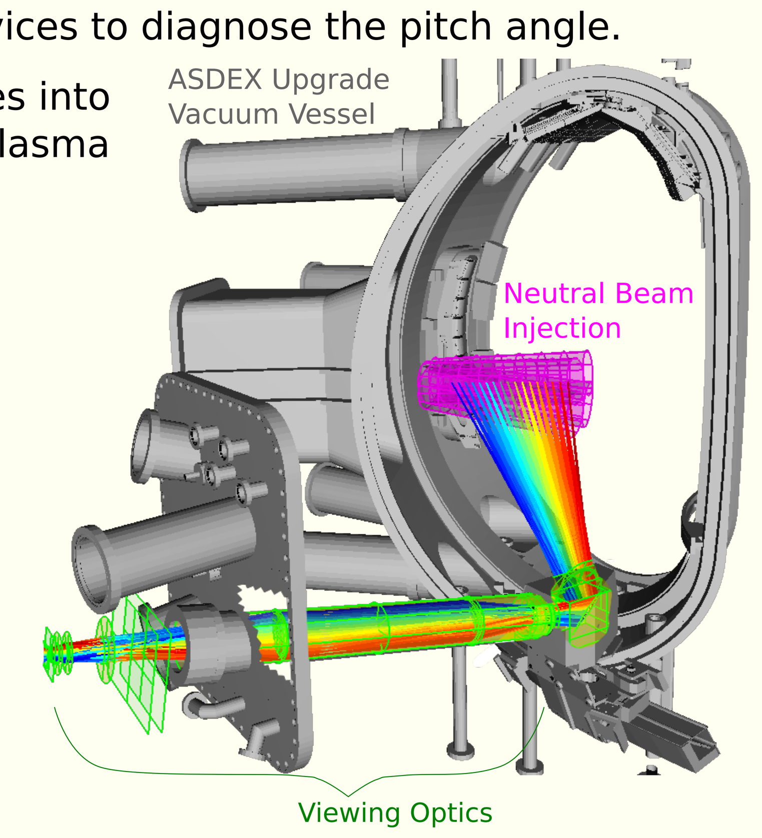
The MSE diagnostic[3] is used on many plasma devices to diagnose the pitch angle.

A Neutral Beam Injector (NBI) fires neutral particles into the plasma. The particles are excited by the plasma ions and emit Dα radiation (Deuterium Balmer-α).

The line emission is Doppler shifted by the particle's motion and Stark split by the electric field in the rest frame of the atom ($\boldsymbol{E} = \boldsymbol{v} \times \boldsymbol{B}$), into two components:





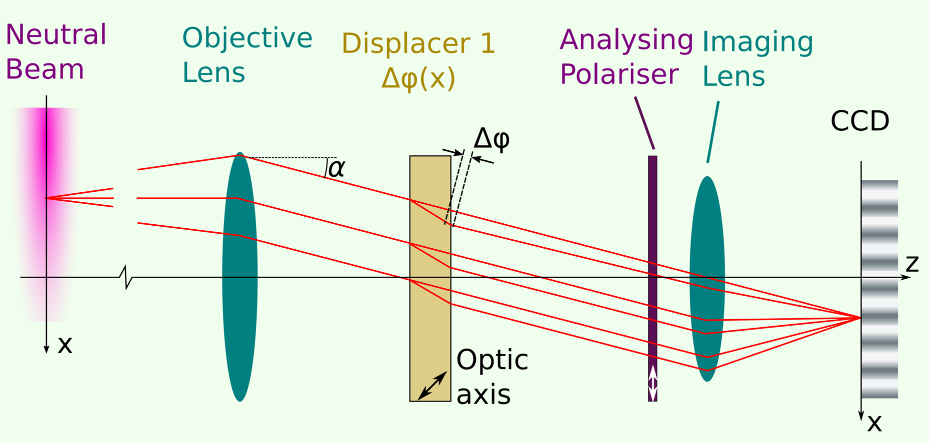


The π and σ components are polarised parallel and perpendicular to $\boldsymbol{E}$.
The direction of **v** is known, so by measuring θ, we can infer the direction of $\boldsymbol{B}$.

Conventional MSE polarimeters measure θ by spectrally selecting one component with a narrow filter and using a photo-elastic modulator (PEM) to analyse the polarisation. Because of the varying Doppler shift, each spatial point requires a very finely tuned filter, optics, sensor and digitiser. Typically only ~10-20 points are observed in a single line.

IMSE Diagnostic Principle

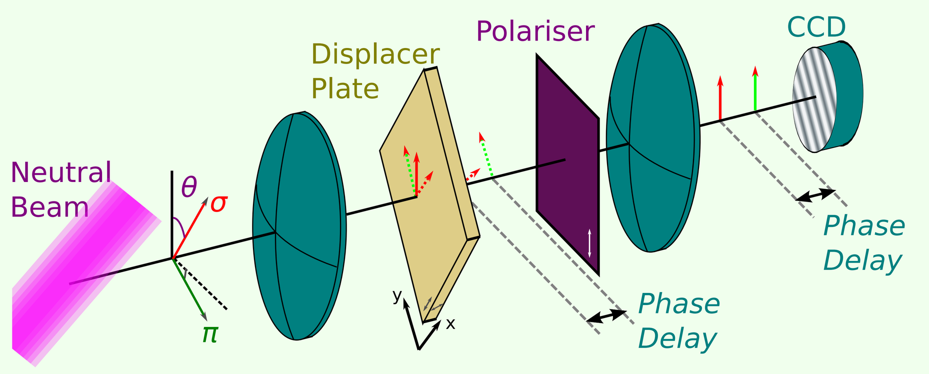
With Imaging MSE (IMSE), the neutral beam is focused onto a CCD after passing through a birefringent 'displacer' plate:



The displacer introduces a phase shift between polarisations that depends on the incidence angle α, and hence varies with image position x.

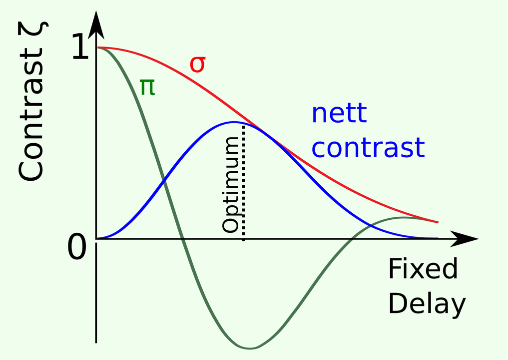
A polariser at 45° interferes the two components, producing fringes on the image. The fringe amplitude depends on the initial polarisation angle θ:

$$I \propto 1 + \cos 2\theta \cos(x)$$



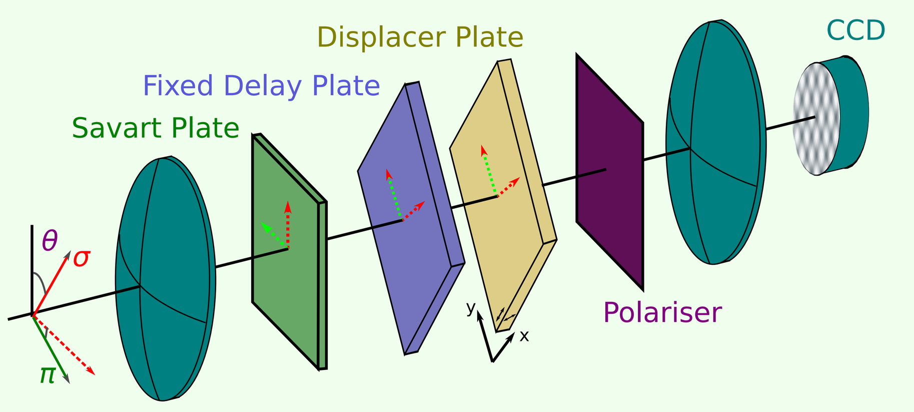
For MSE, fringes from σ and π would cancel due to the 90° difference in θ. With a thick delay plate, the different wavelengths have different phases and the thickness is chosen so that the σ and π have the same phase again.

The fixed delay plate also causes wavelengths within the finite width of each component to interfere, reducing the amplitude. The combined effect is the spectral contrast ζ:



A second displacer plate (a Savart plate) produces orthogonal fringes and is placed with optic axis at 45° to the first so that it is sensitive to $\sin 2\theta$. The combined image is:

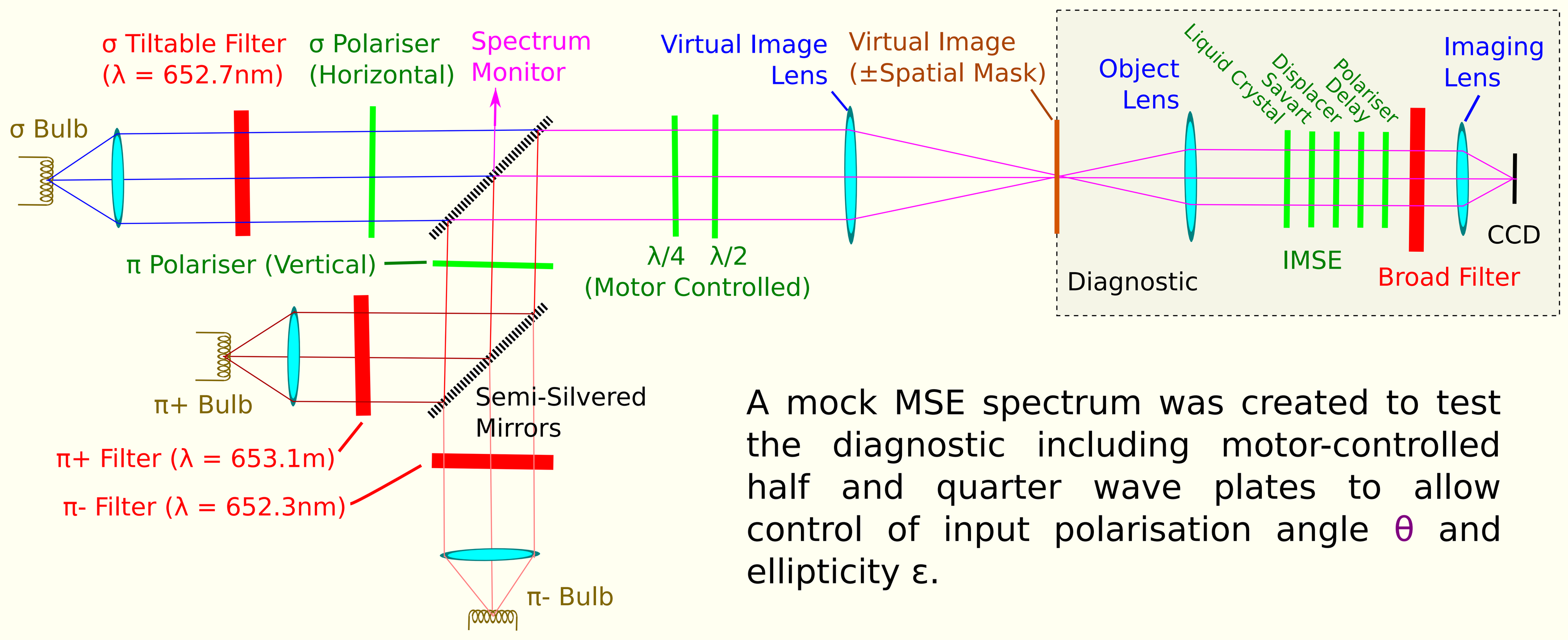
$$I \propto 1 + \zeta \cos 2\theta \cos(x) + \zeta \sin 2\theta \cos(x-y) - \zeta \sin 2\theta \cos(x+y)$$



By dividing the amplitudes, the unknown ζ can be eliminated and an image of $\tan 2\theta$ extracted.

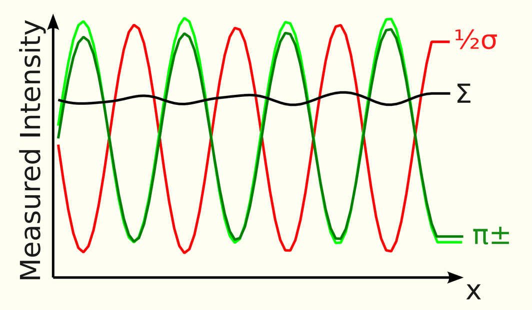
IMSE Advantages:
- \+ Better current inference: 2D Data.
- \+ Lots of data: > 60x60 θ measurements.
- \+ Simpler/cheaper hardware: One set of optics
- \+ More light: No narrow filters.
- \+ Only θ offset calibration required.
- \+ Insensitive to spectrum changes.

Test Spectrum Generation

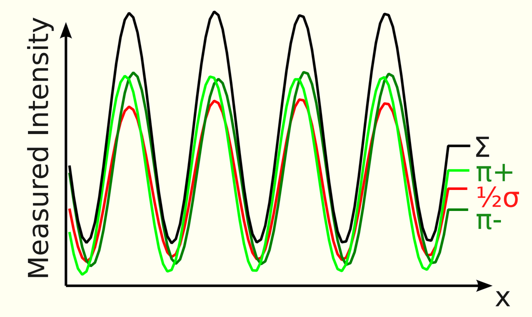


A mock MSE spectrum was created to test the diagnostic including motor-controlled half and quarter wave plates to allow control of input polarisation angle θ and ellipticity ε.

With only the first displacer and polariser, the σ and π arms cancel:

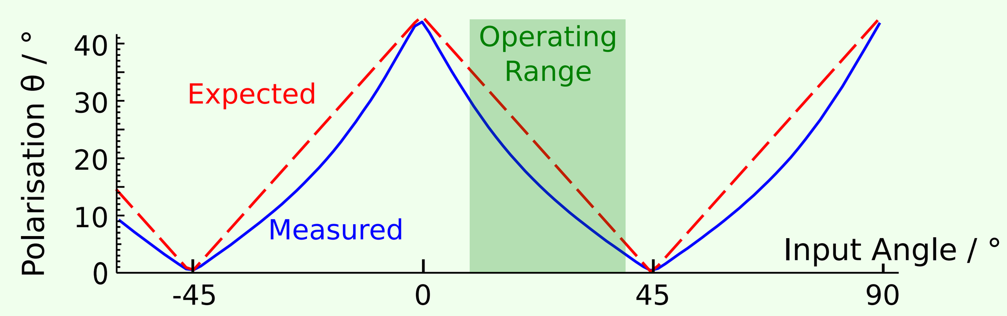


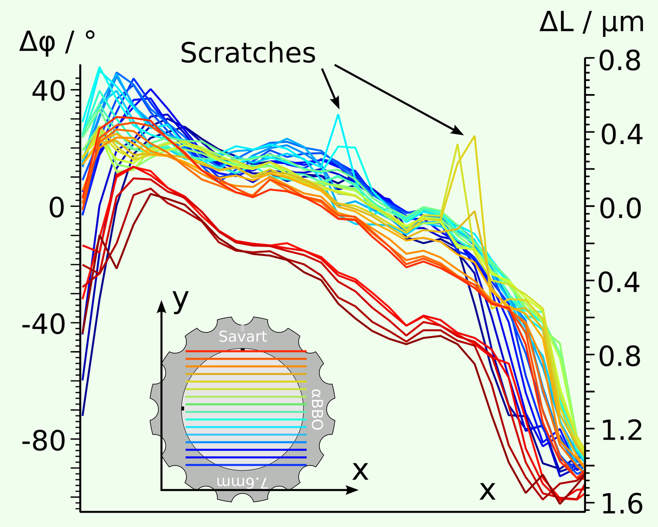
With the delay plate as well, it is confirmed that they roughly add:



Investigation and Performance

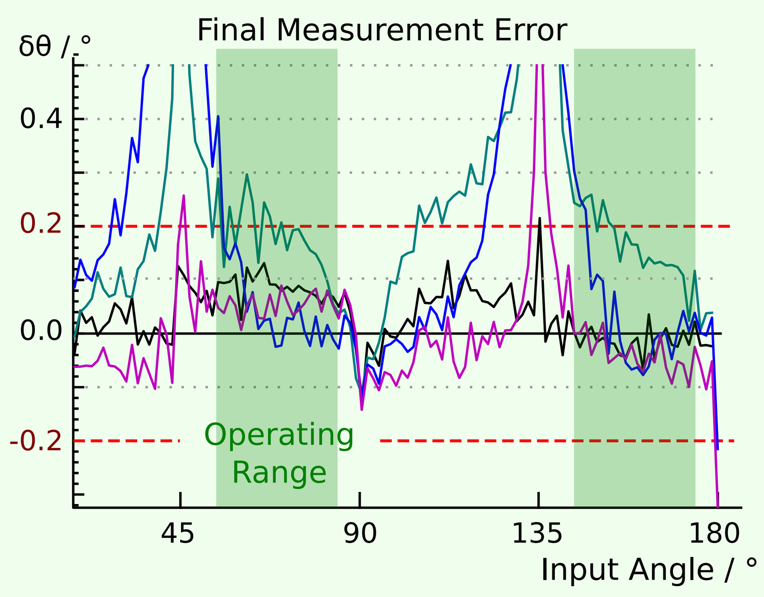
At first, the inferred θ did not match that expected:





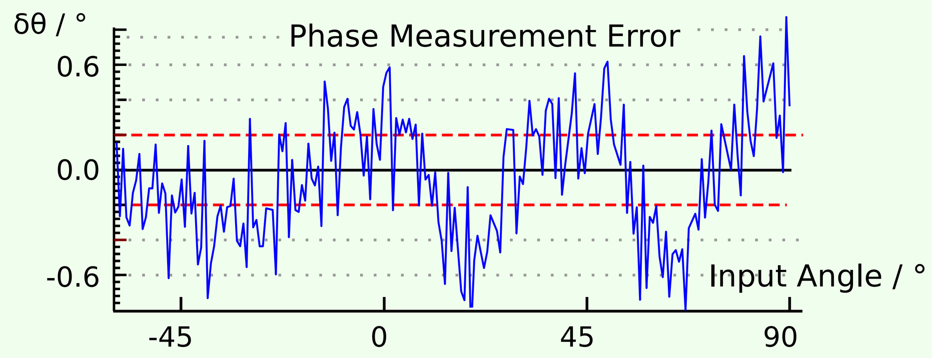
Measured Savart Plate Surface Profile

After much investigation, this was found to be due to an uneven Savart plate surface (right) and had to be mitigated by installation of a calibration polariser.



With this corrected, the response error was below the desired **±0.2°** for most of the image within the expected operating range (left).

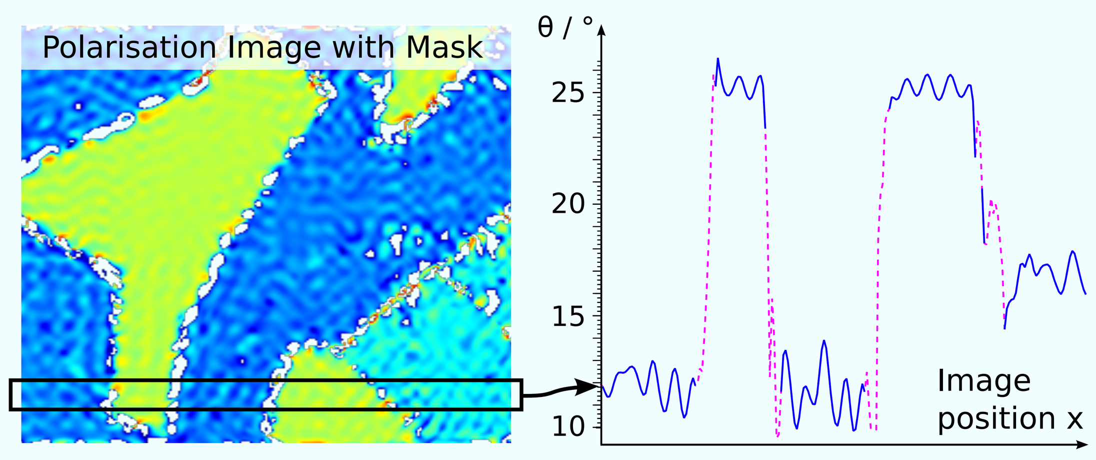
The alternative operating mode[4], where θ is encoded in the phase of the interferogram was also investigated, but showed poorer resolution:



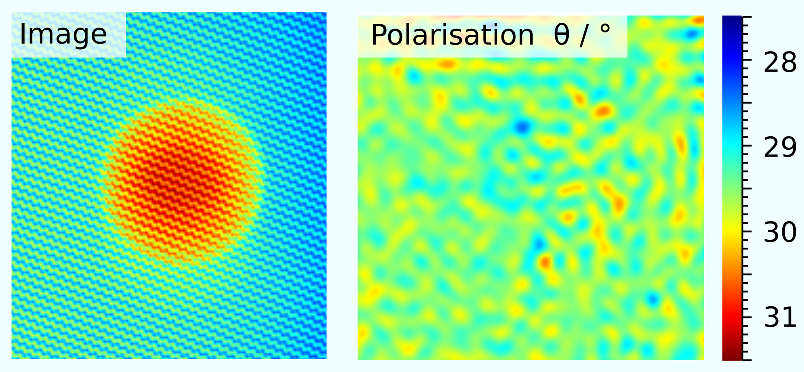
Resolution and Contamination

Spatial resolution can be examined by placing a spatial polariser mask in the virtual image plane:

Polarising Mask:



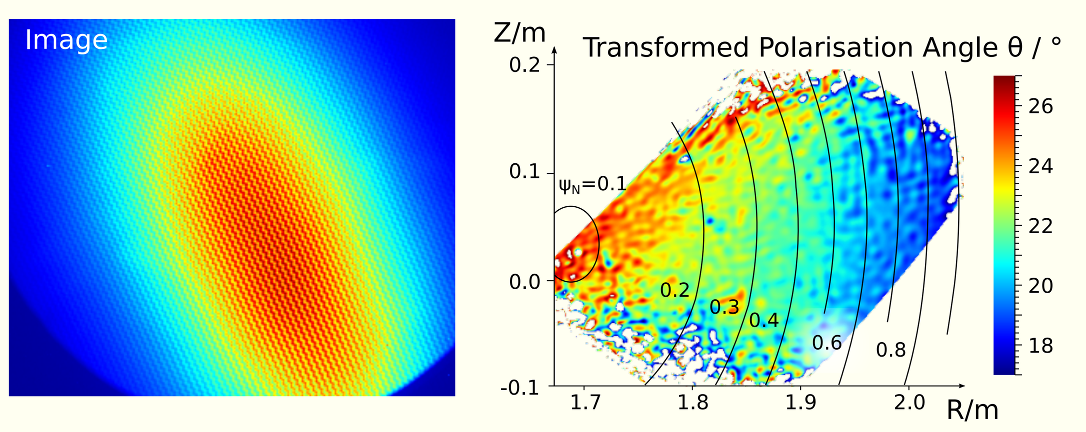
For unpolarised or broadband light, the fringe pattern is not created, so the measurement is not affected. To demonstrate, a broadband polarised source was added to the test set-up. The polarisation signal was not measurably disturbed:



Conclusions

- ✔ An IMSE diagnostic was build and tested with a mock MSE spectrum.
- ✔ Some unexpected problems were identified and eliminated.
- ✔ The final performance is within the desired **±0.2°** accuracy.
- ✔ Good spatial resolution with sharp changes has been demonstrated.
- ✔ Insensitivity to unpolarised or broadband contamination has been demonstrated.
- ✔ 2D data was shown to improve tomographic plasma current inference.
- ✔ With the performance verified, the IMSE diagnostic was later installed at ASDEX Upgrade and successfully measured the polarisation:

Presented in the main EPS 2013 conference (O2.110)



[1] J. Howard *"Snapshot-imaging motional Stark effect polarimetry"* PPCF **50** 125003 (2008)
[2] J. Svensson, A. Werner. *"Current tomography for axisymmetric plasmas"*. PPCF **50** 8:085002 (2008)
[3] F. M. Levinton *"Magnetic field pitch-angle measurements in the PBX-M Tokamak using MSE"* Phys. Rev. Lett. 63, 2060–2063 (1989)
[4] J.Howard, J.Chung, *"Spatial heterodyne Stokes vector imaging of the motional Stark-Zeeman multiplet"* Rev. Sci. Instrum. **83**, 10D510 (2012)