Motional Stark Effect Imaging on ASDEX Upgrade:

2012 / 2013 Results

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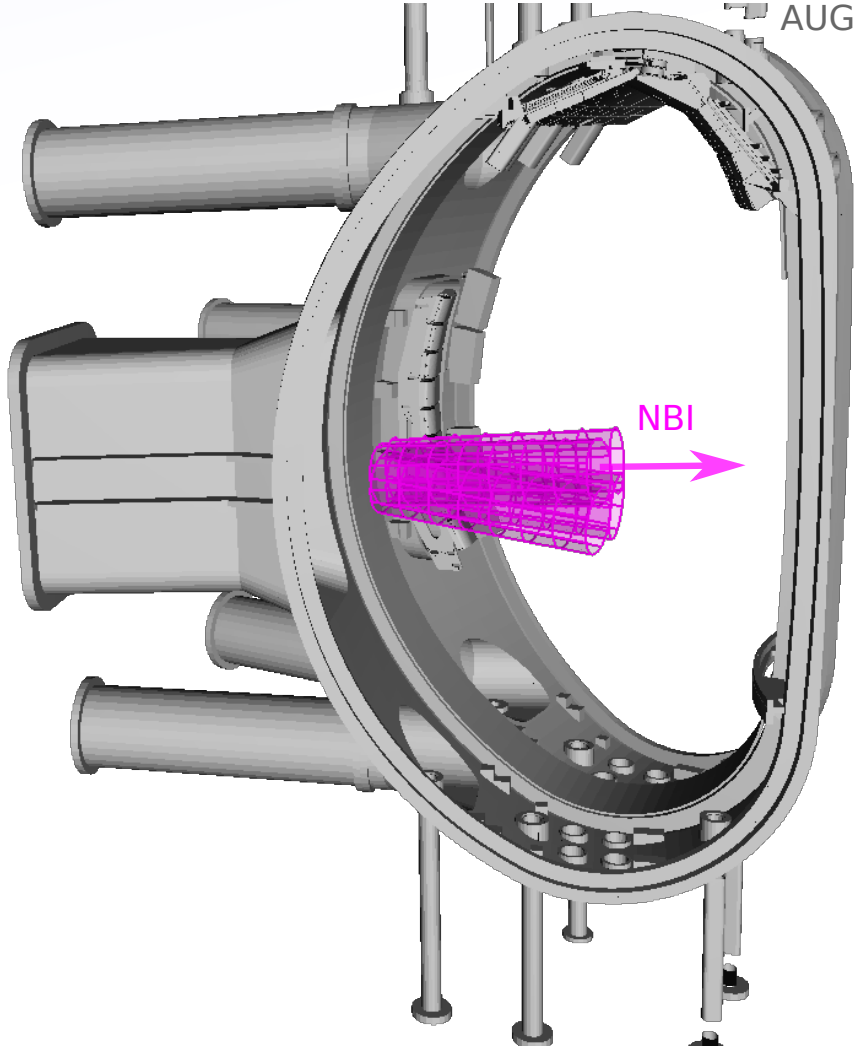
April 2013: Reinstalled at AUG with various improvements. Hydrogen NBI.

Imaging Motional Stark Effect at AUG

The IMSE system fits to the back of the the existing MSE optics.

Rendering of beams + background



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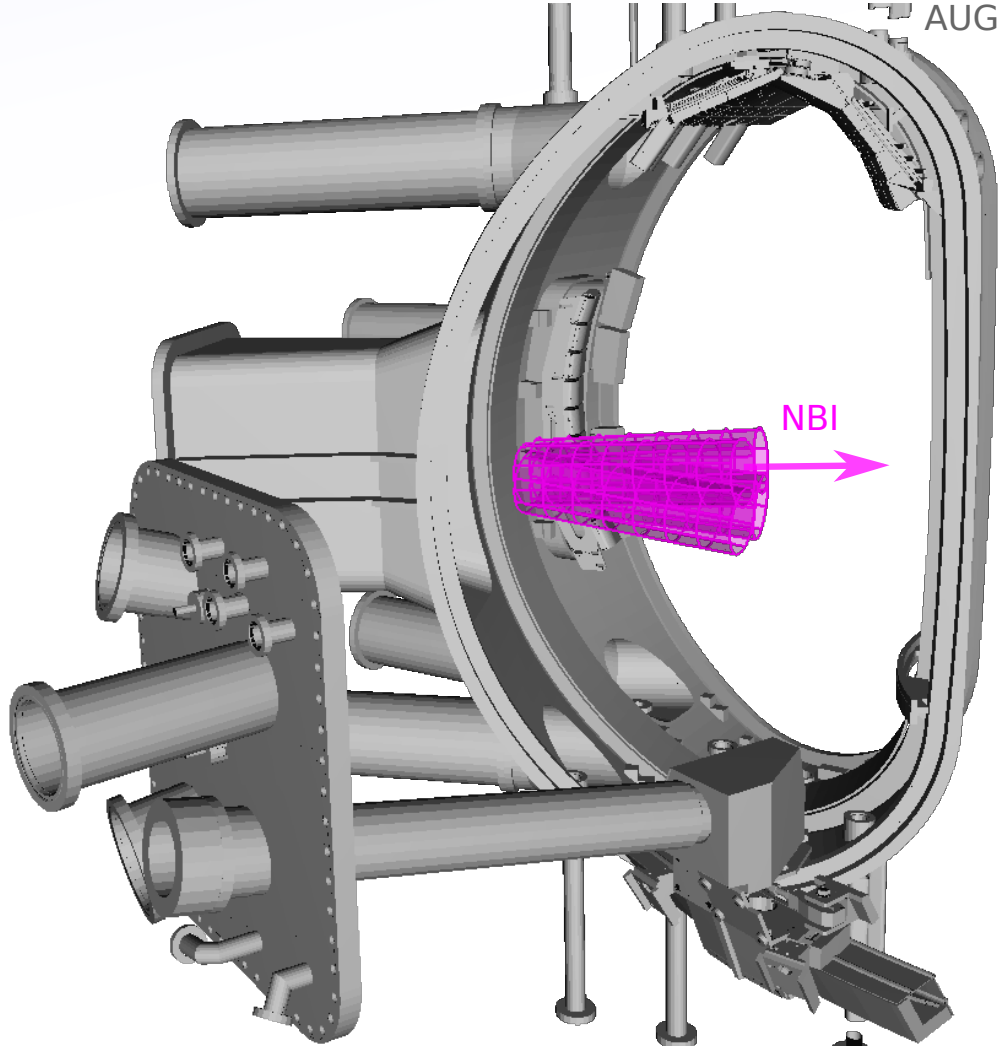

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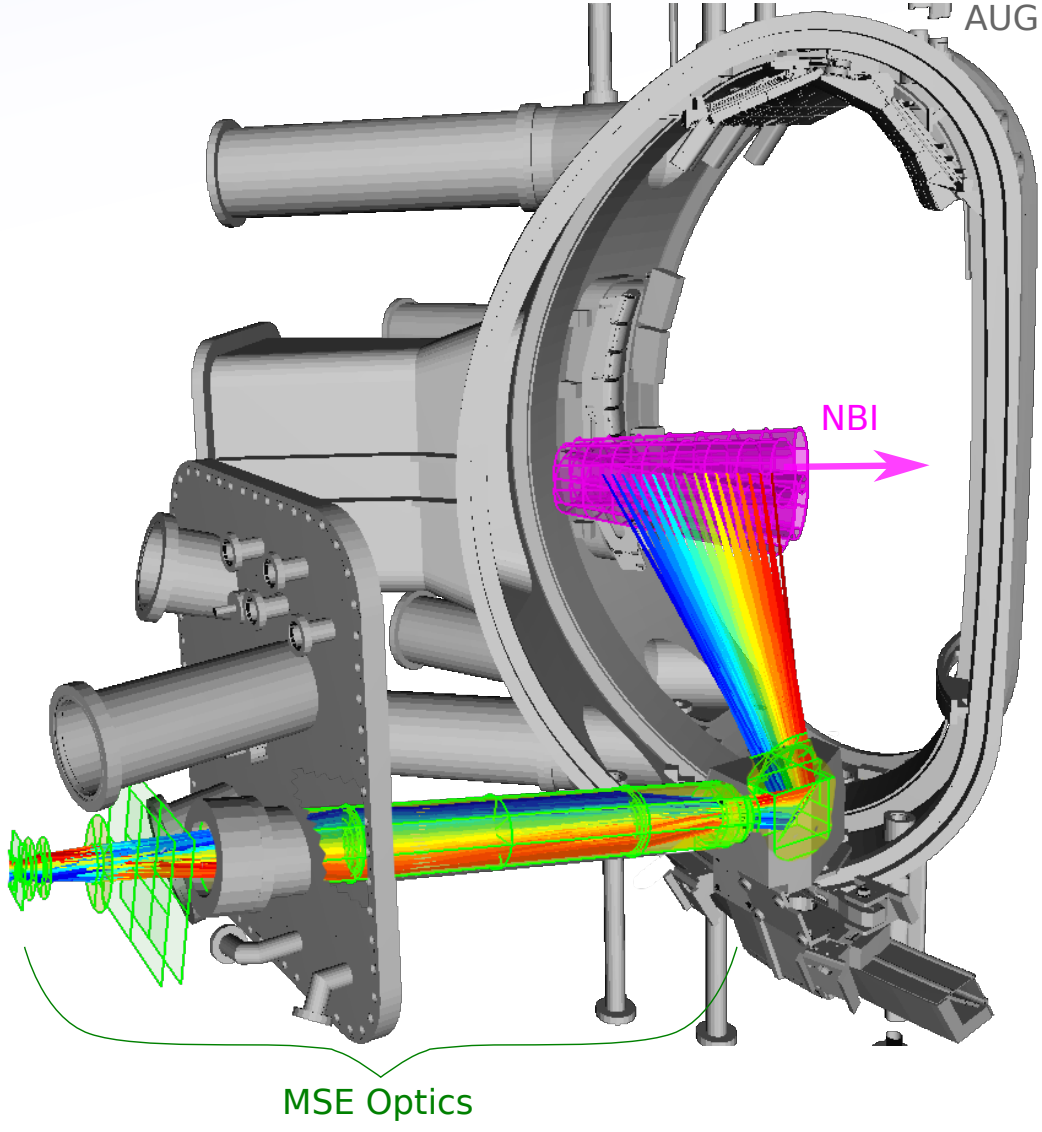

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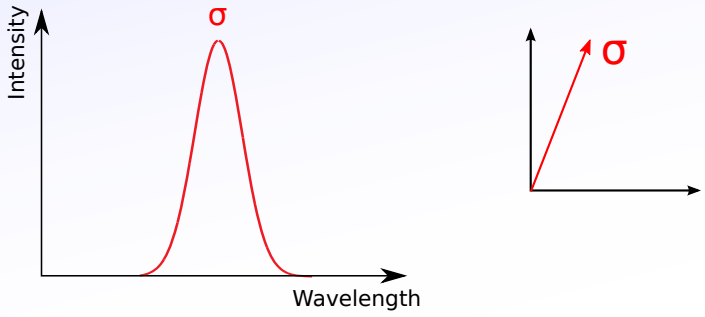

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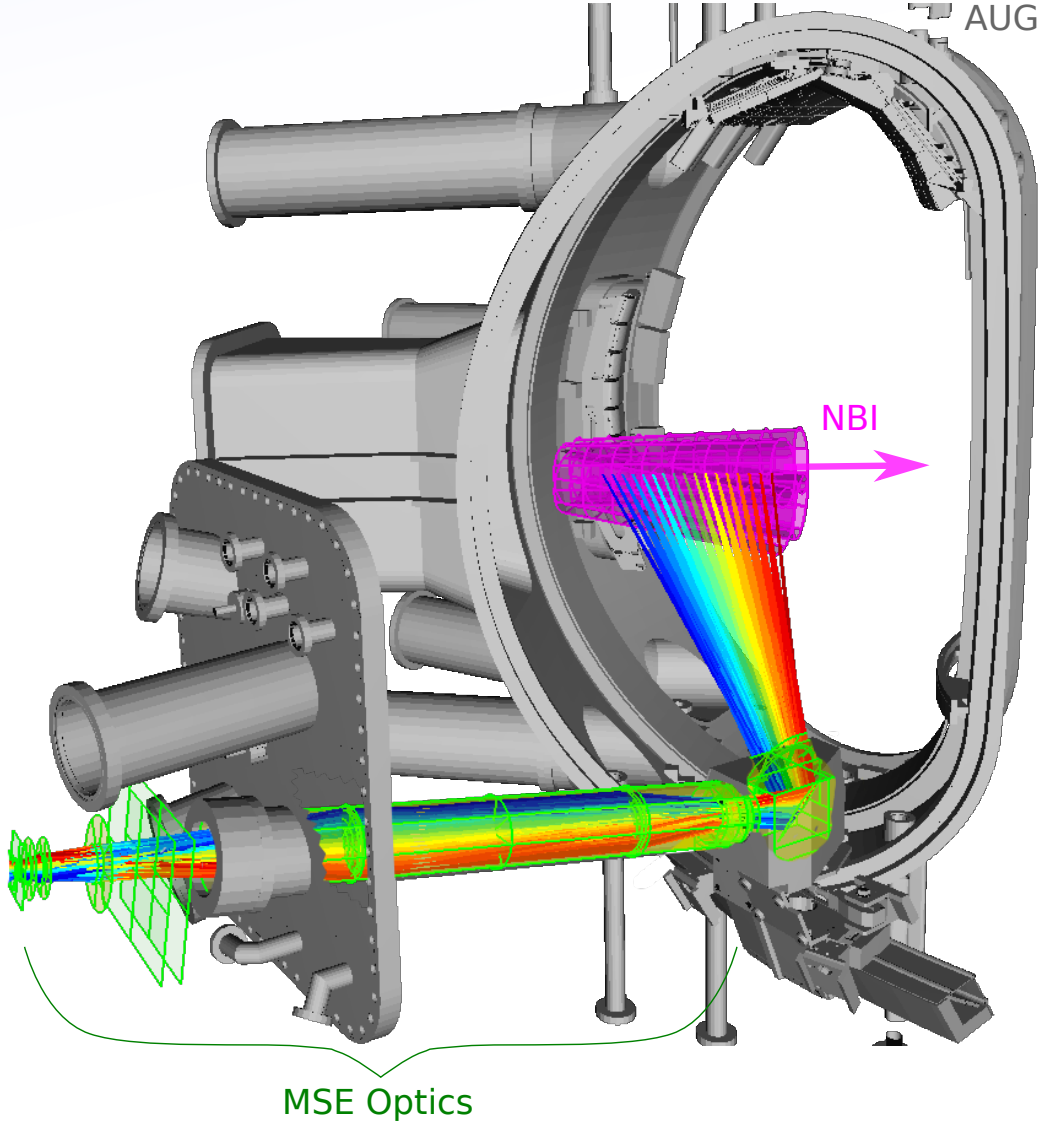

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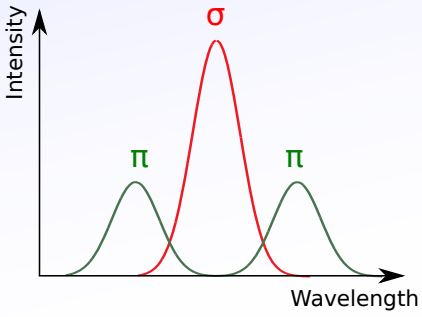

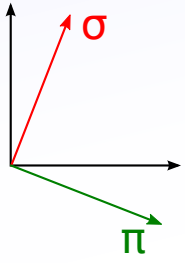

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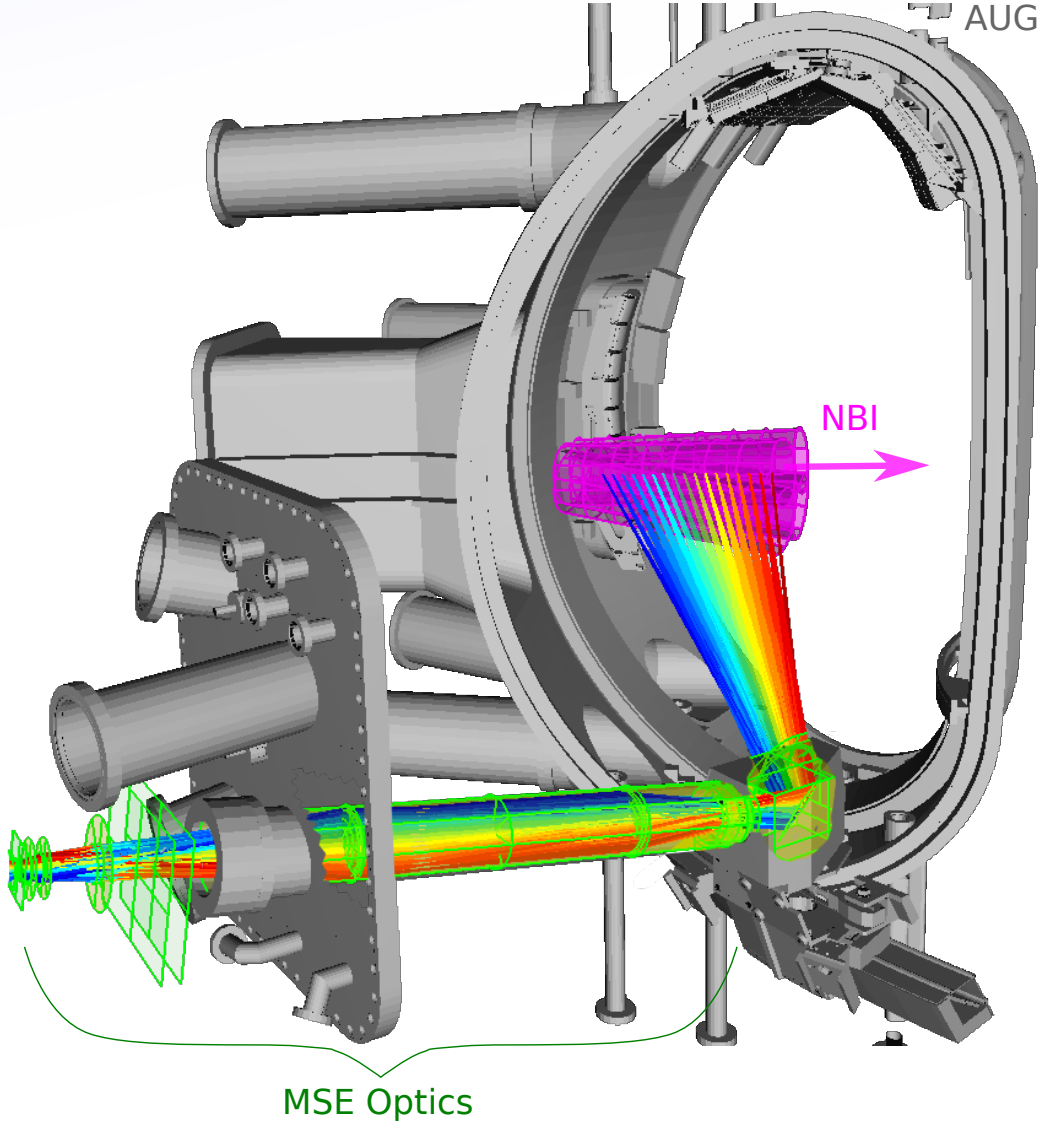

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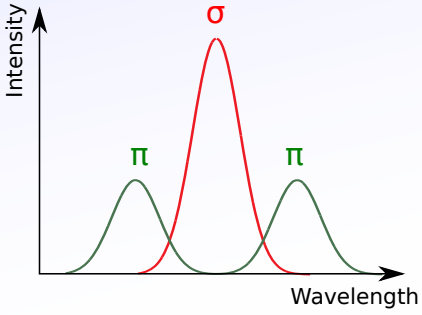

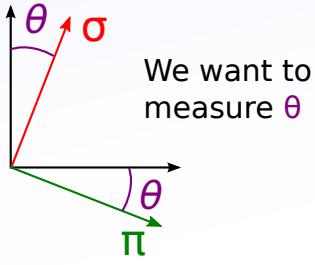

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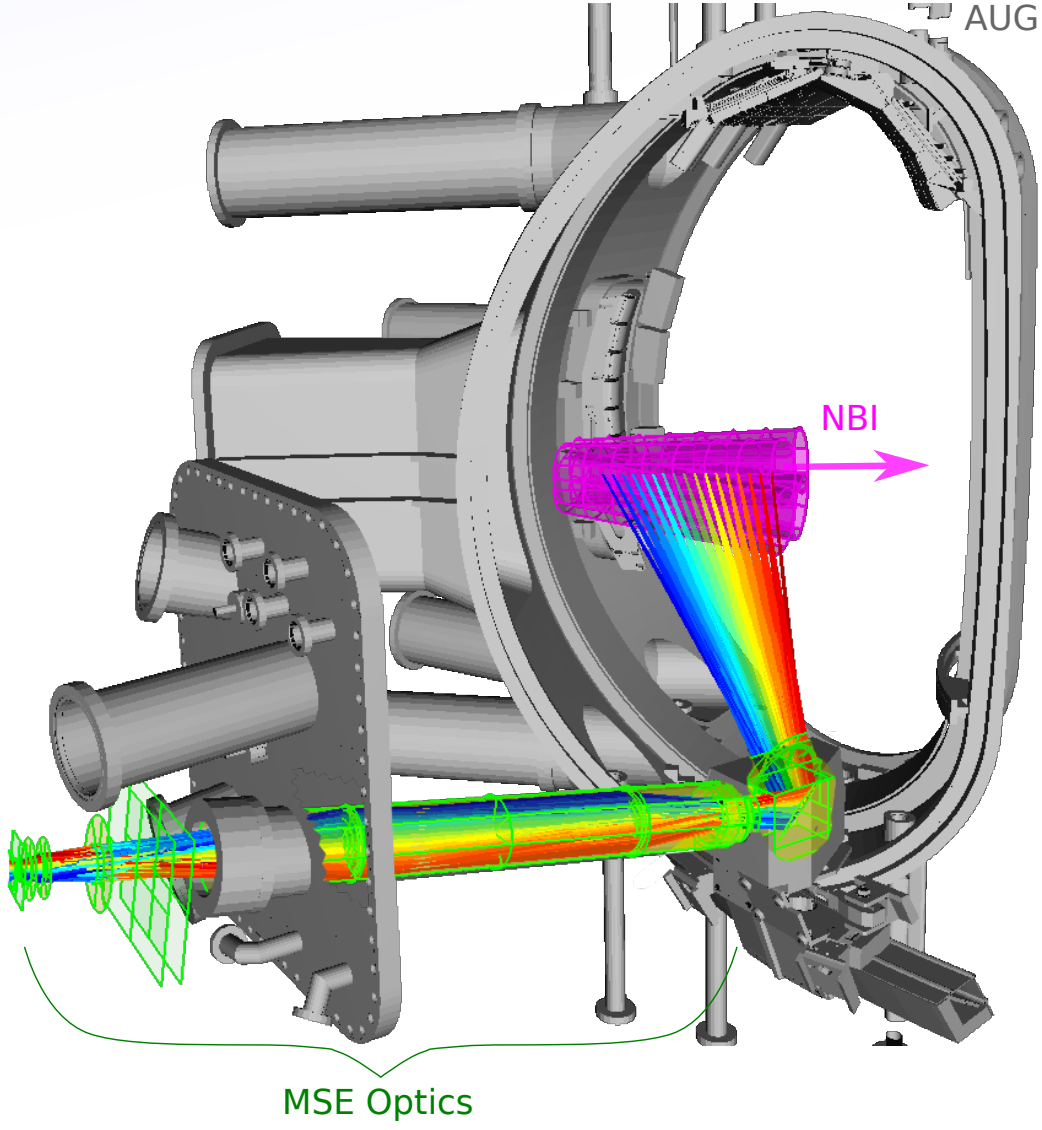

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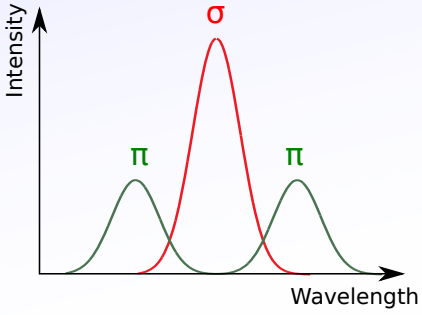

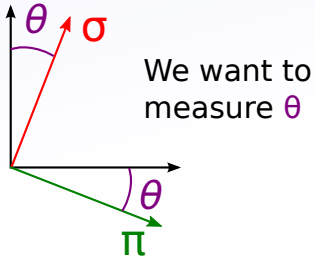

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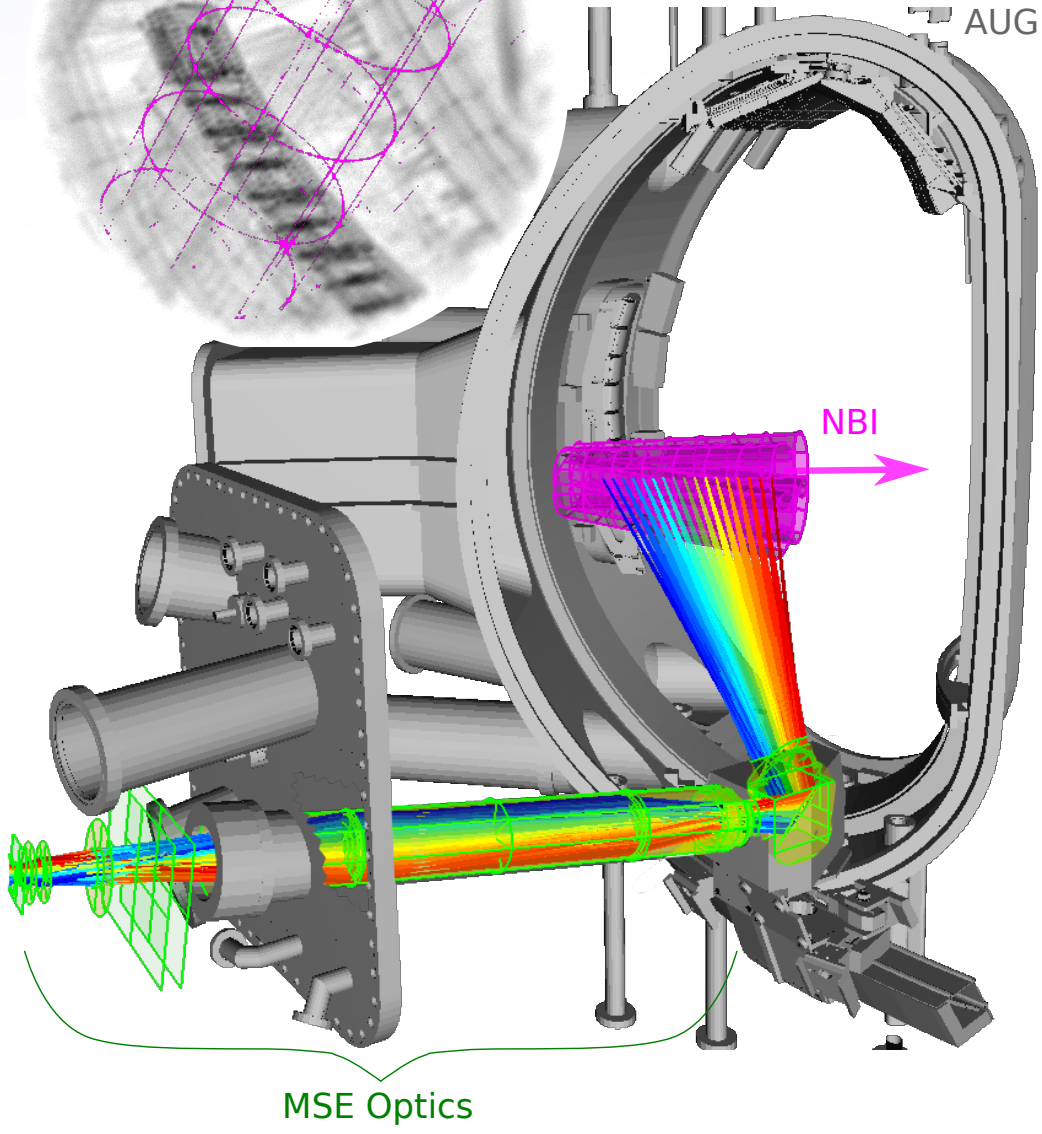

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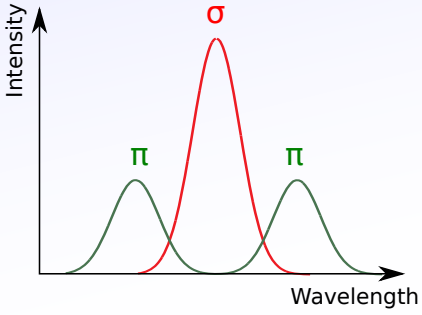

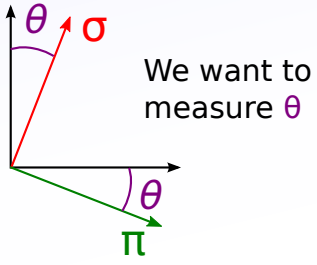

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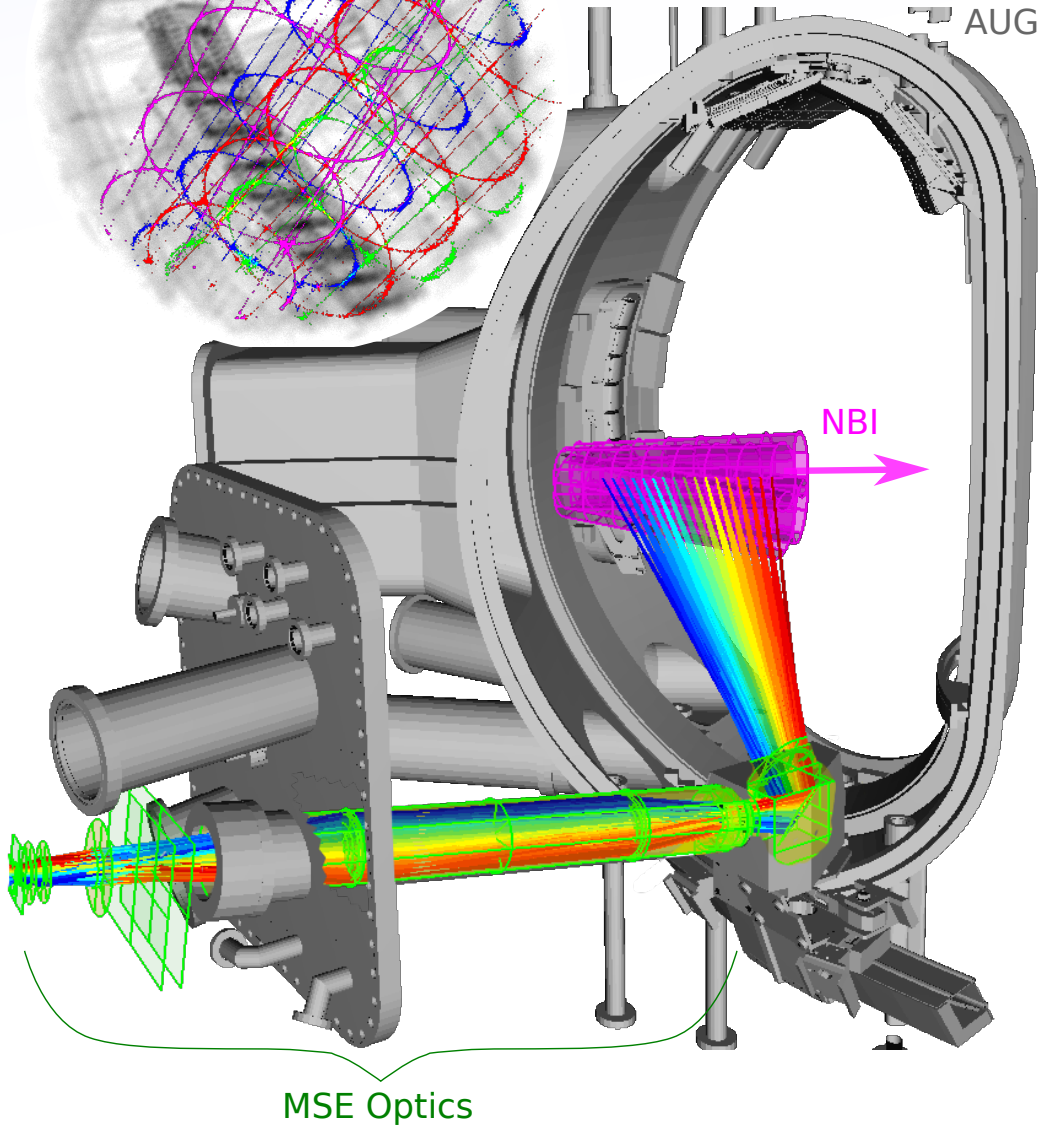

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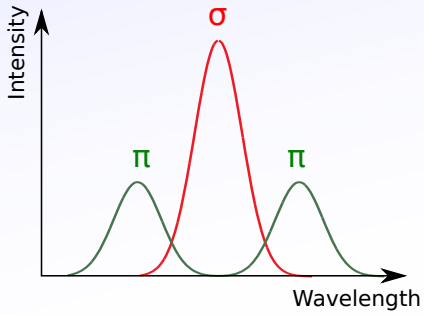

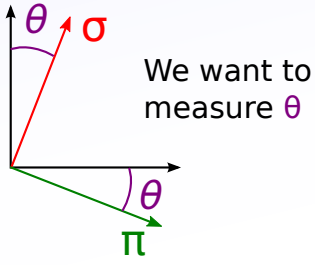

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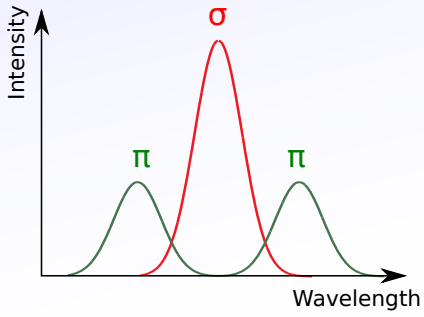

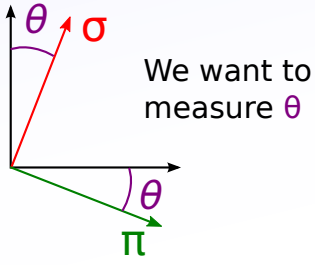

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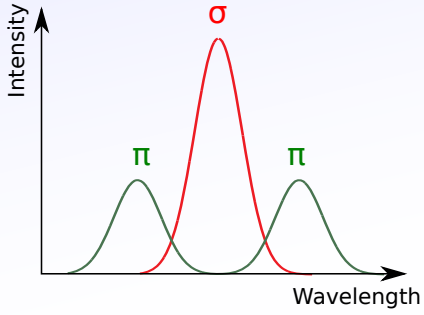

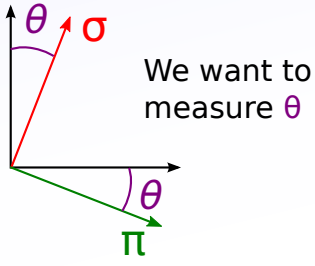

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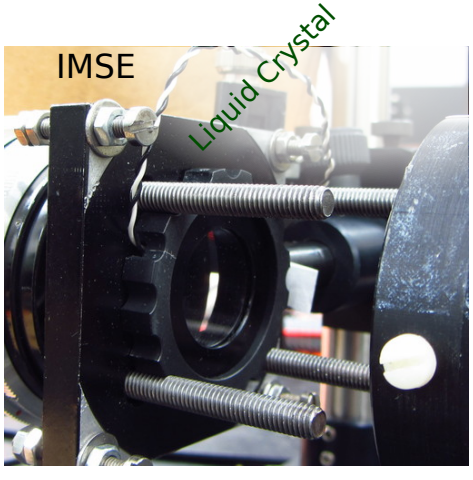

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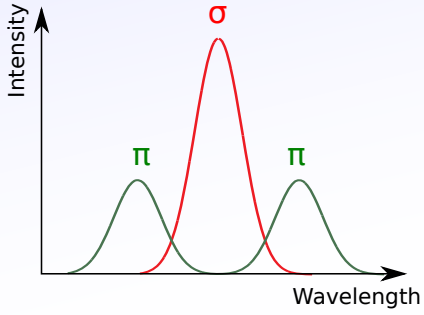

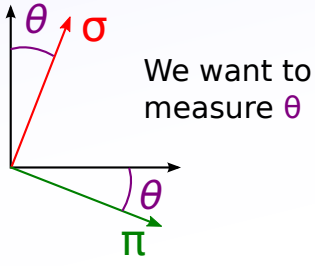

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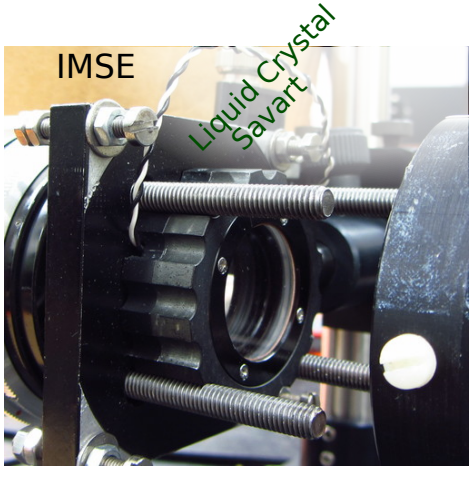

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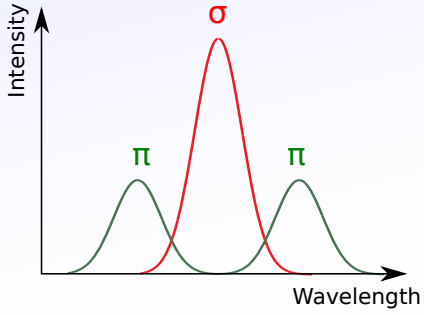

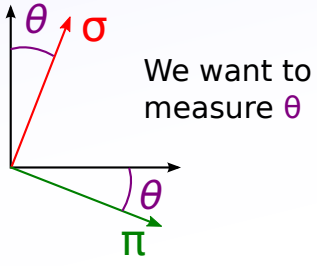

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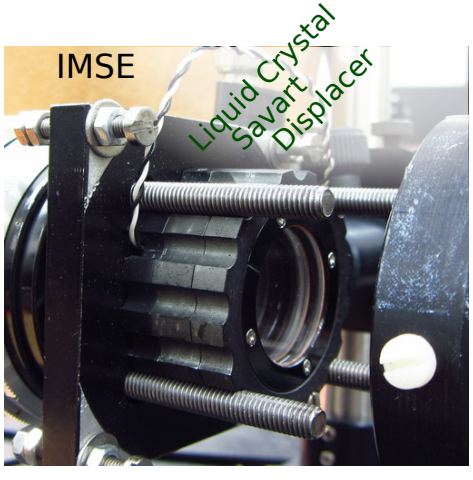

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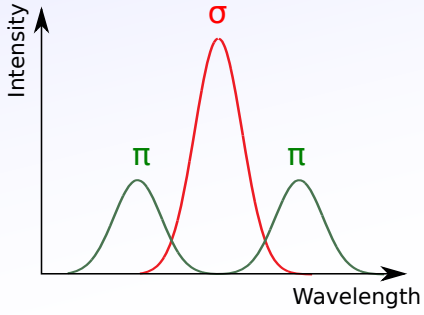

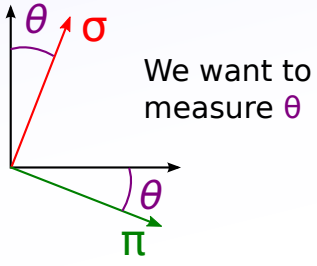

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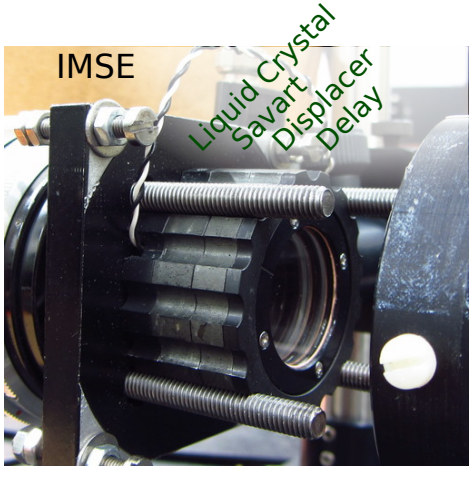

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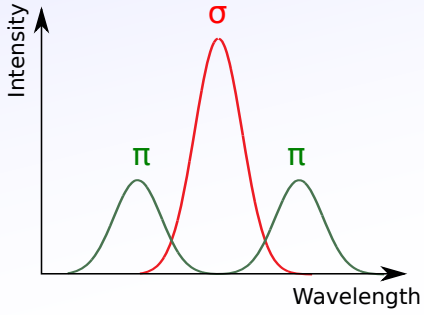

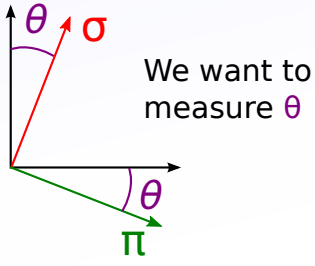

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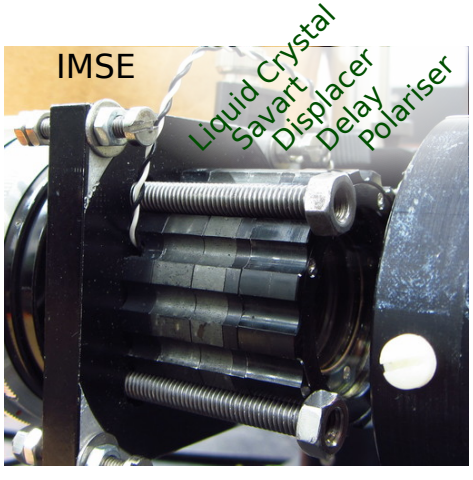

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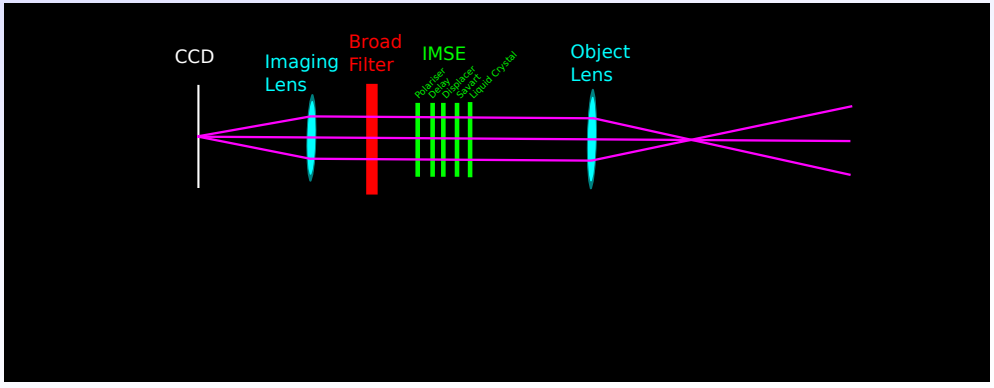
IPP Greifswald

November 2012: Performance Tests.

Concept and performance test in HGW lab with full mock MSE spectrum:



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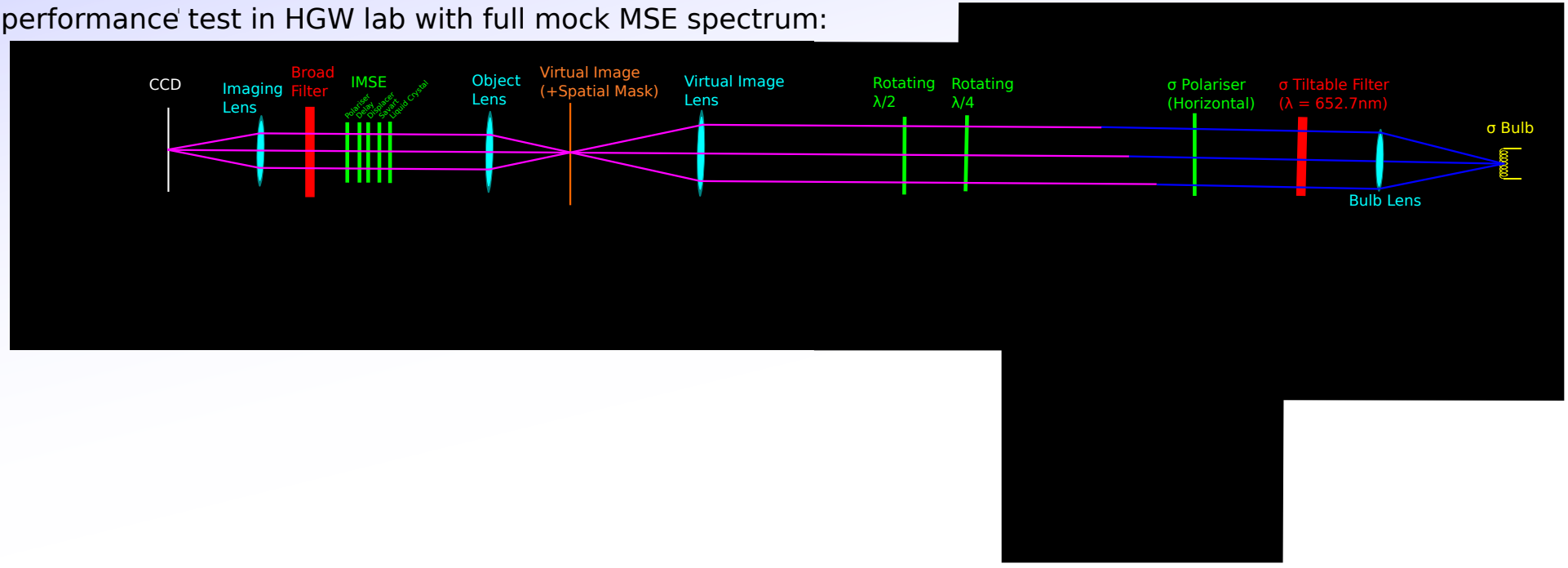

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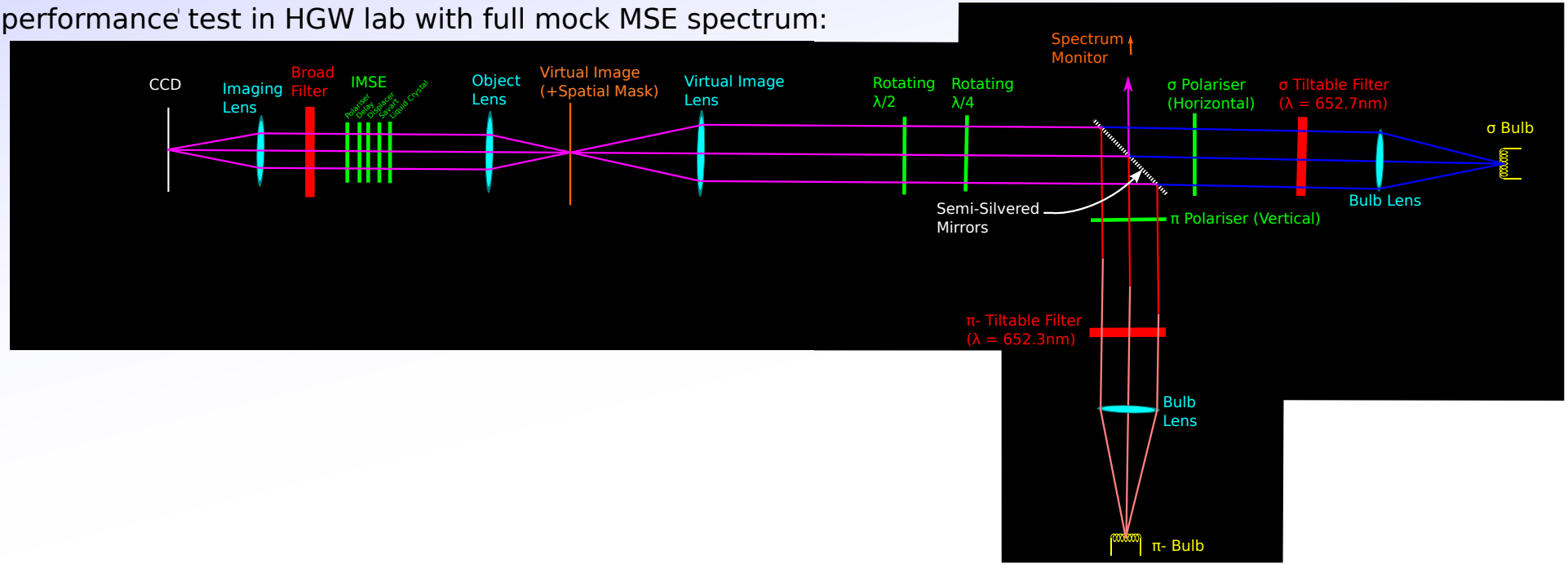

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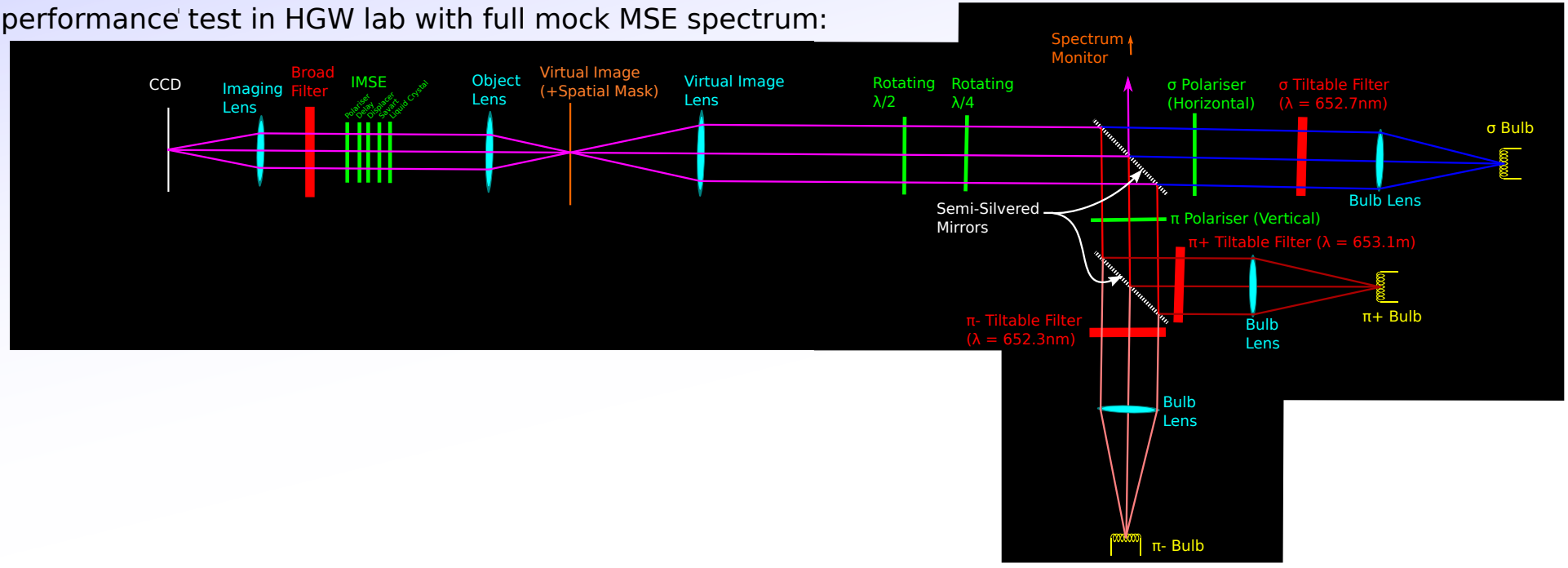

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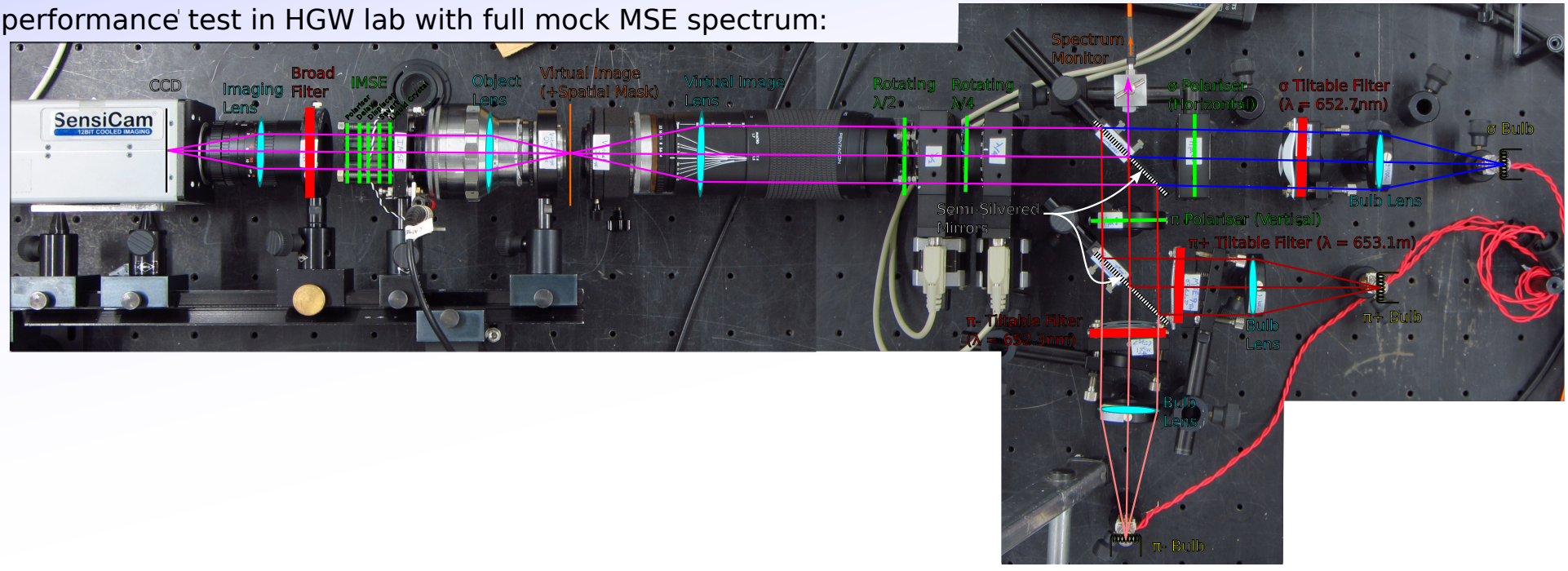

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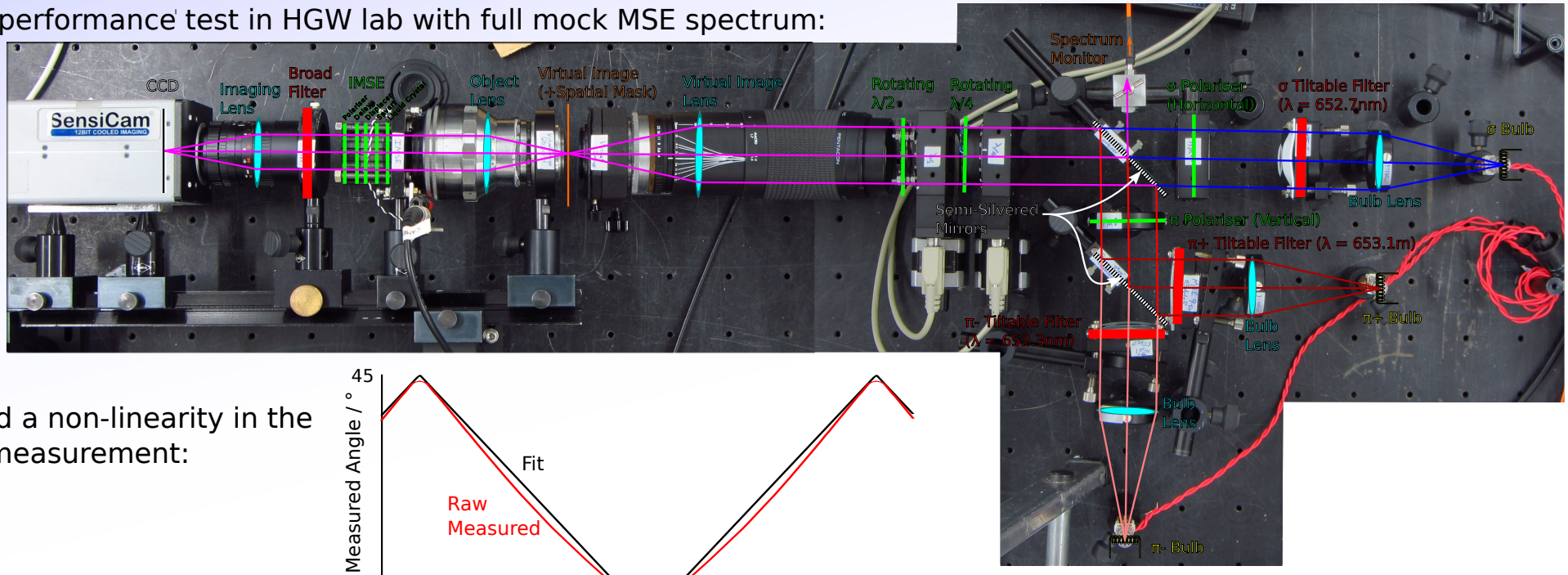
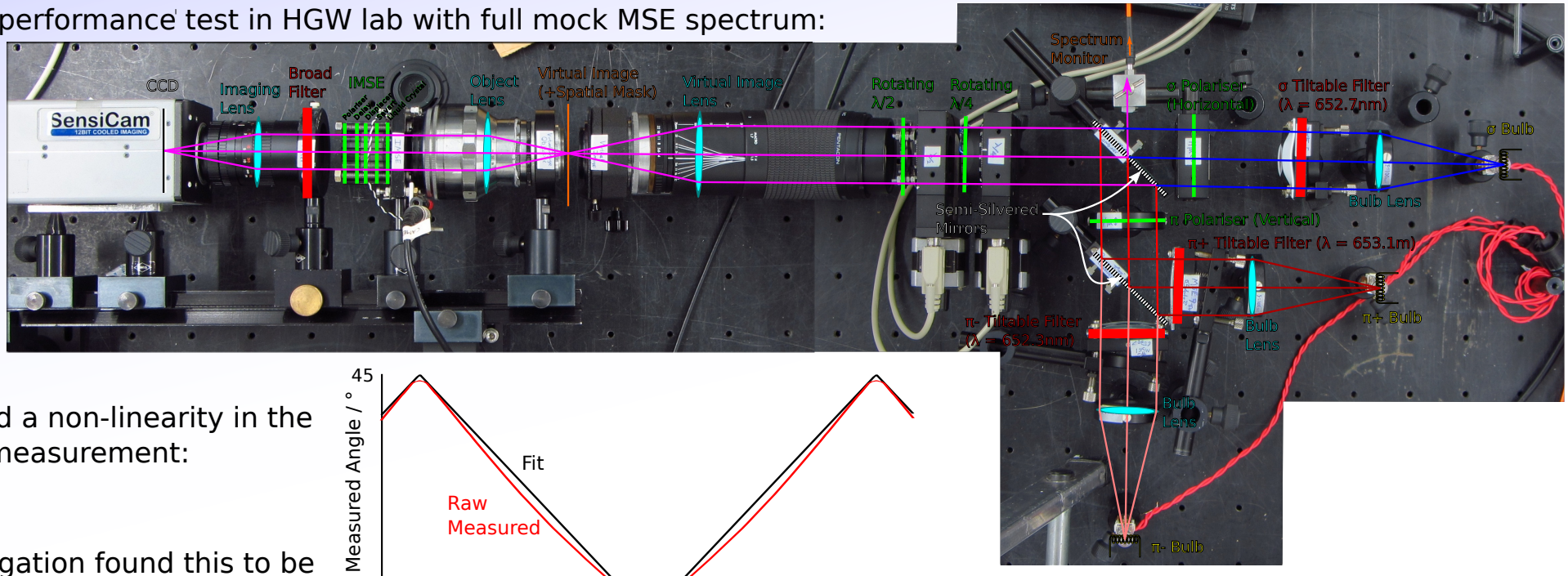


Tests revealed a non-linearity in the polarisation measurement:

Oliver Ford
IPP Greifswald

November 2012: Performance Tests.

Concept and performance test in HGW lab with full mock MSE spectrum:



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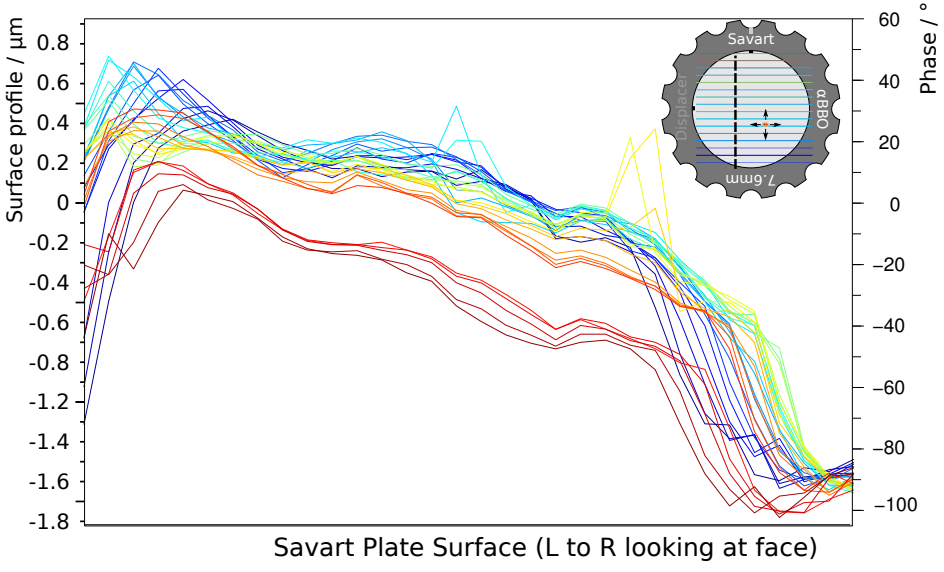

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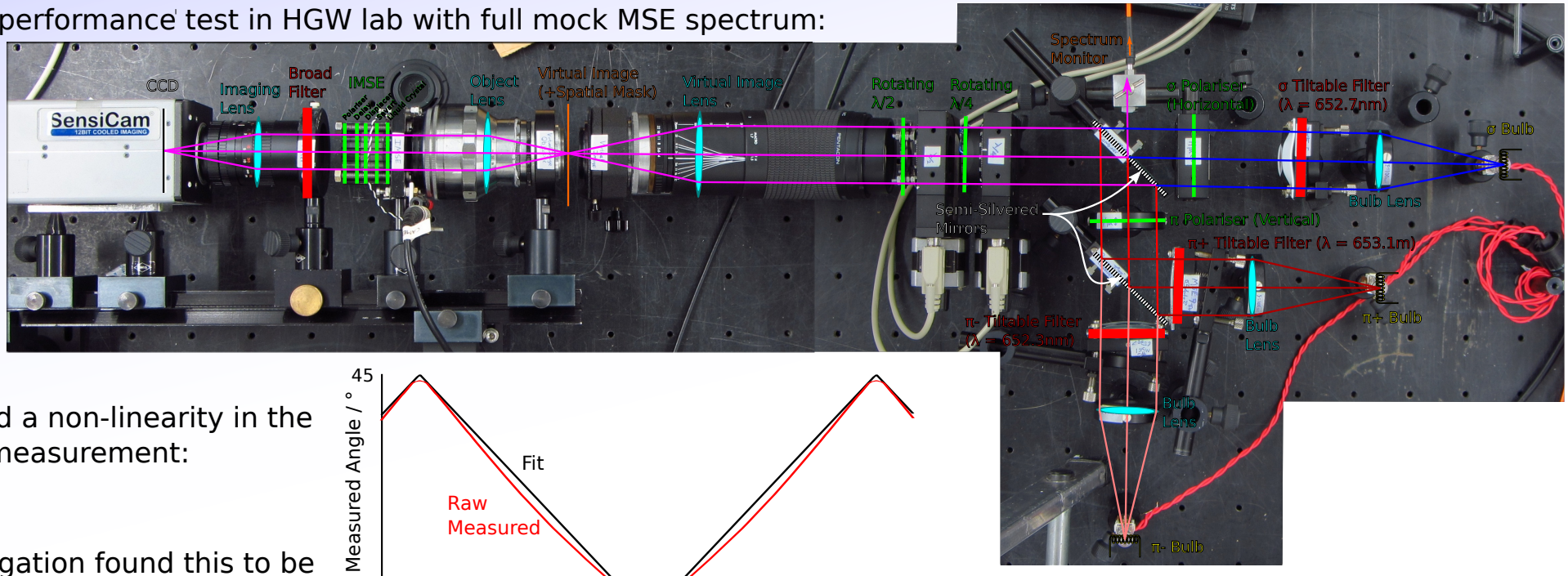

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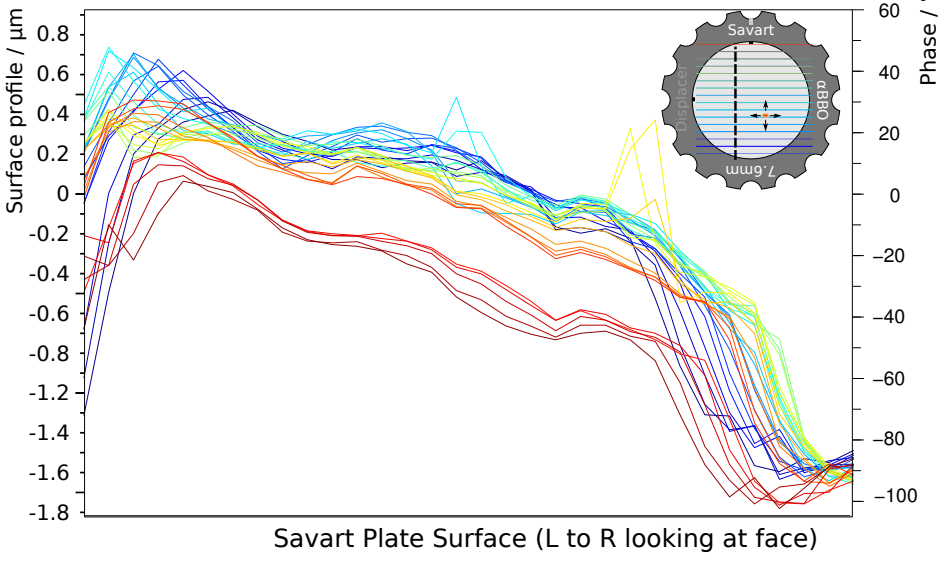

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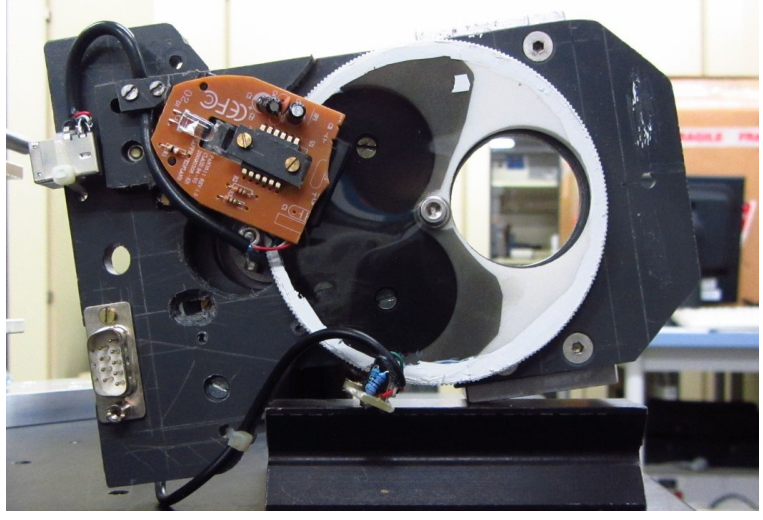

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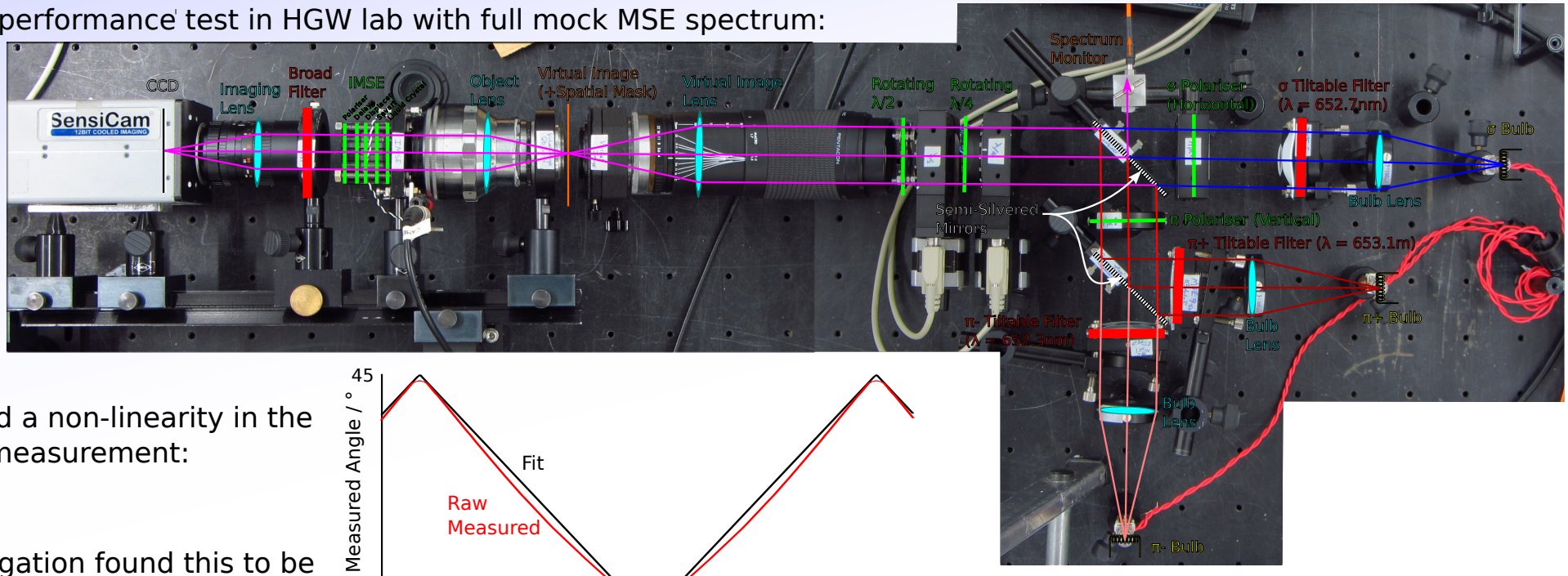

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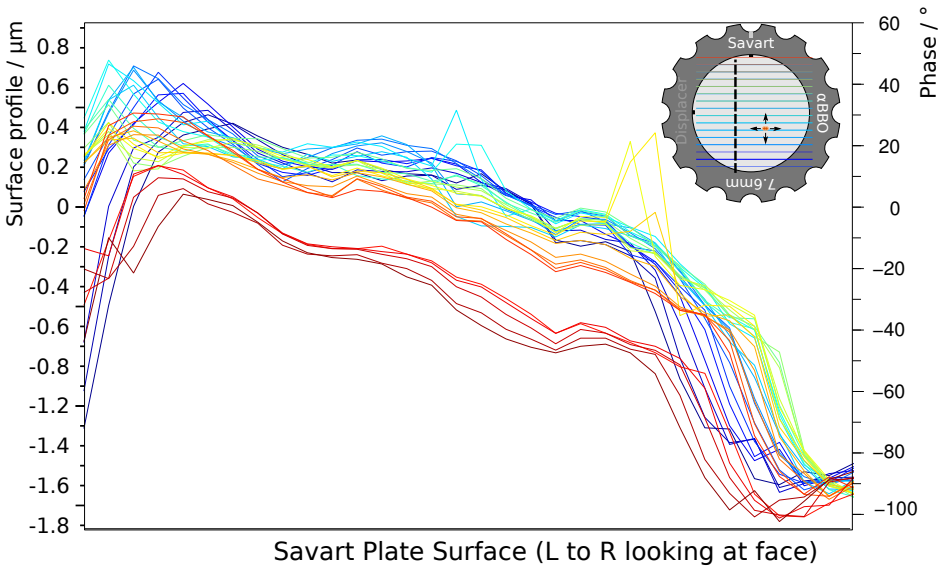

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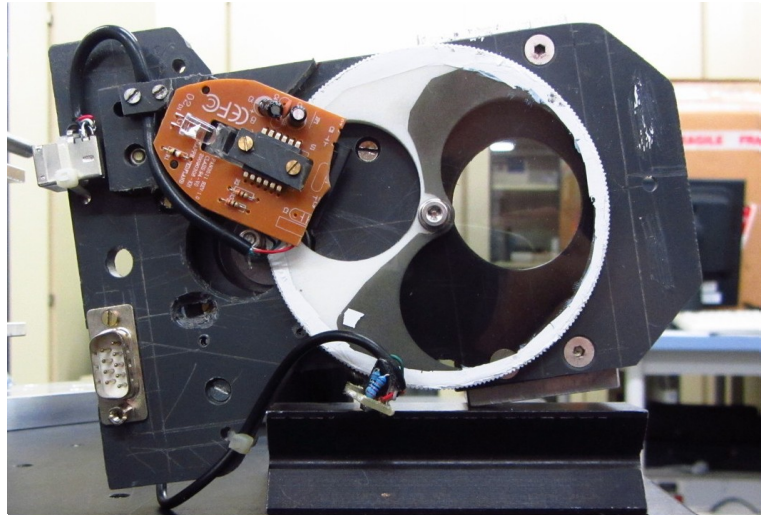

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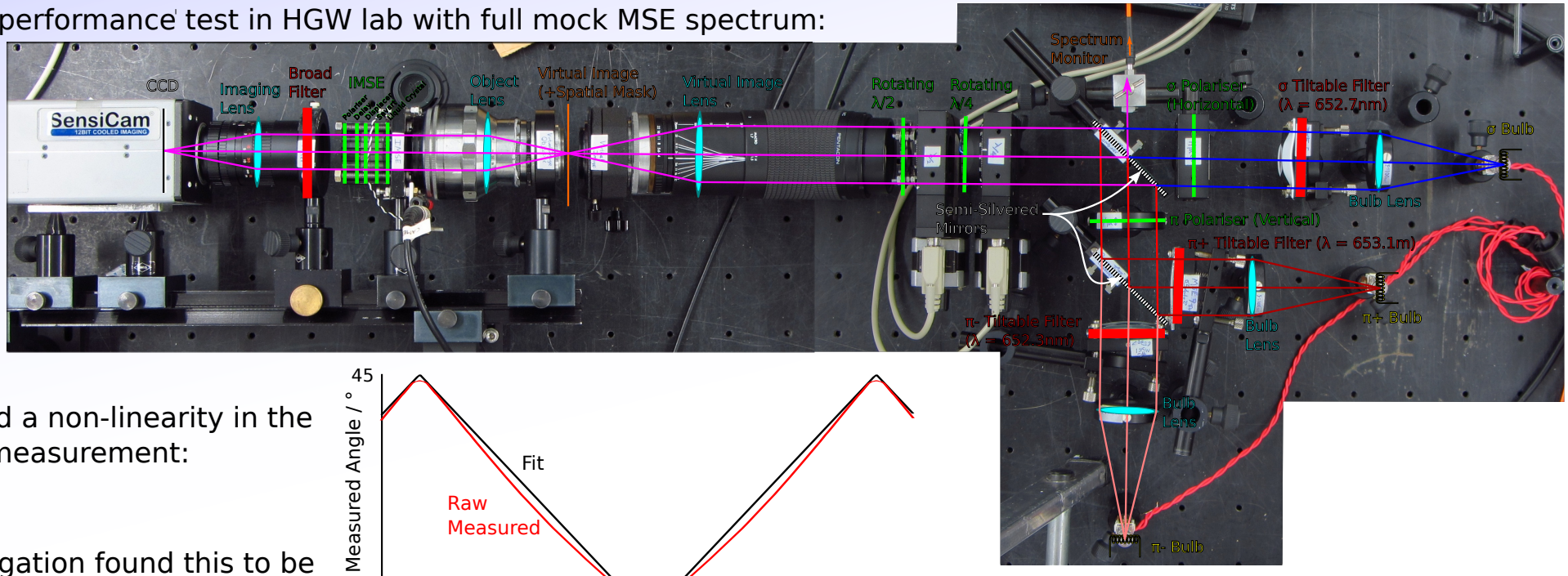

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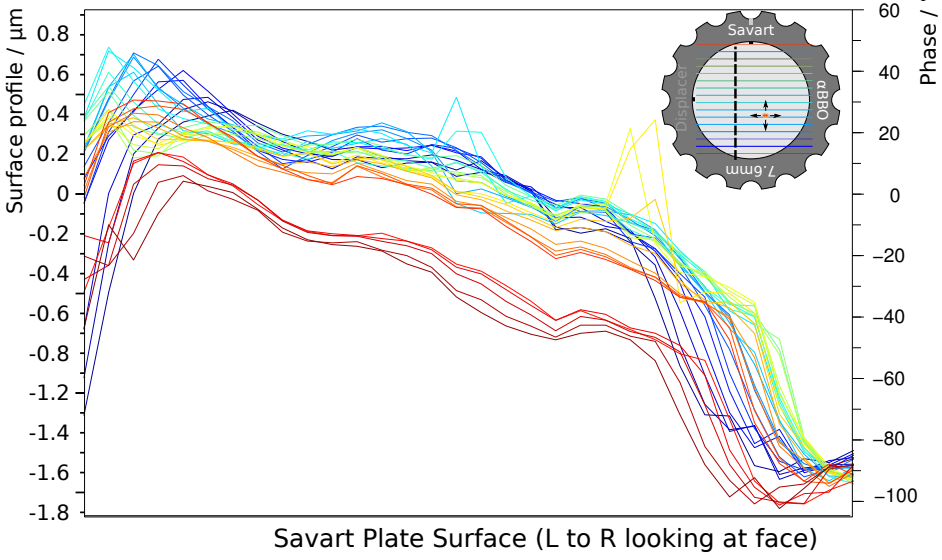

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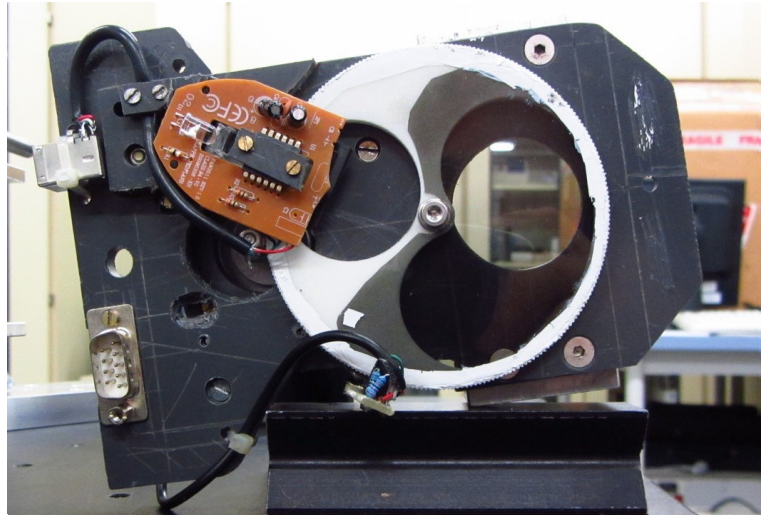
Tests were otherwise successful and proved accuracy down to the required 0.3°.



Oliver Ford
IPP Greifswald

January: First installation

Diagnostic assembled and fitted to ASDEX Upgrade for 5 shot days over two weeks.
Temporarily replaced the existing MSE.

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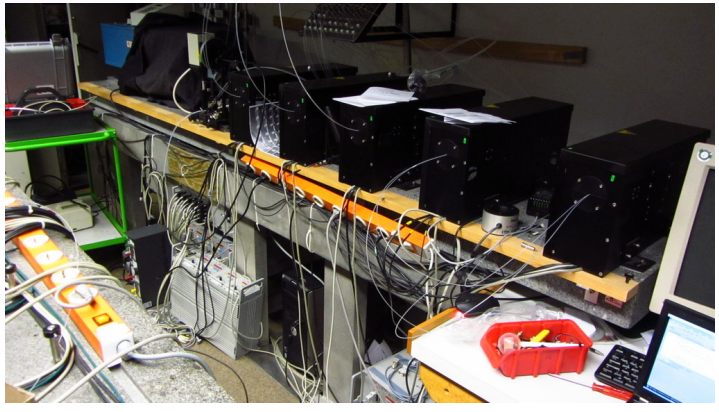
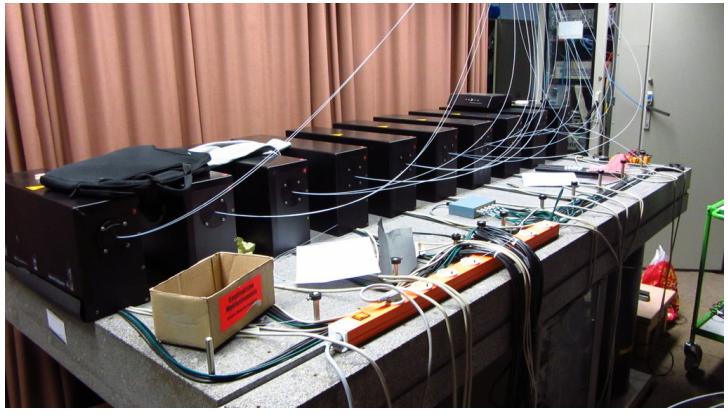
MSE

Per Channel:
- Optic fibre from torus hall.
- Narrow spectral filter.
- Filter optics
- Oven
- Photo-diode/PMT





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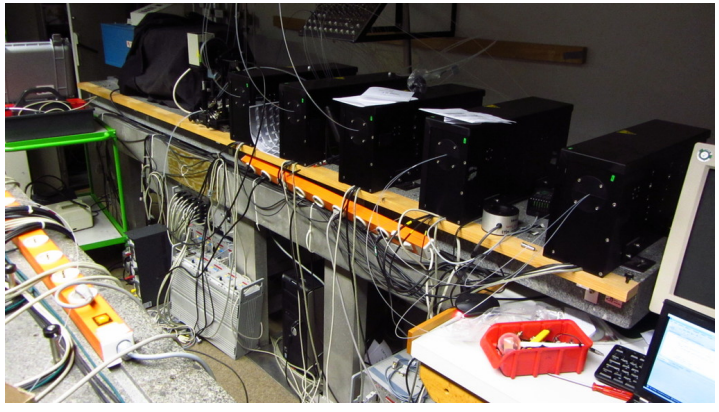

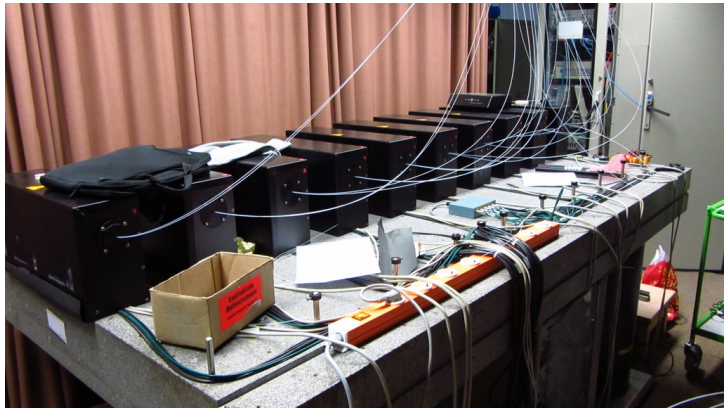

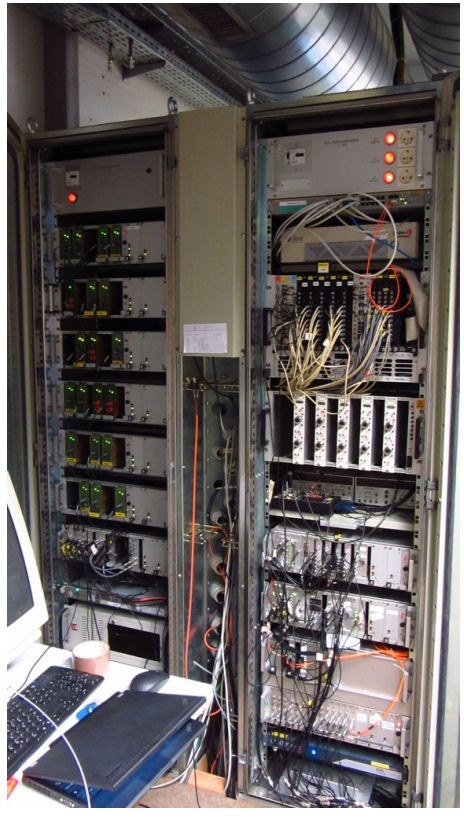

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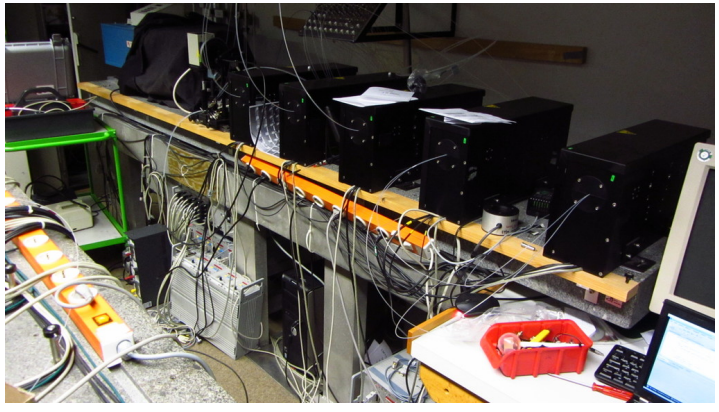
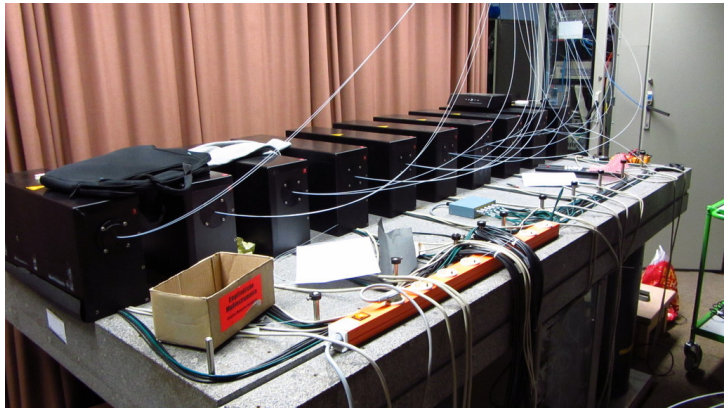
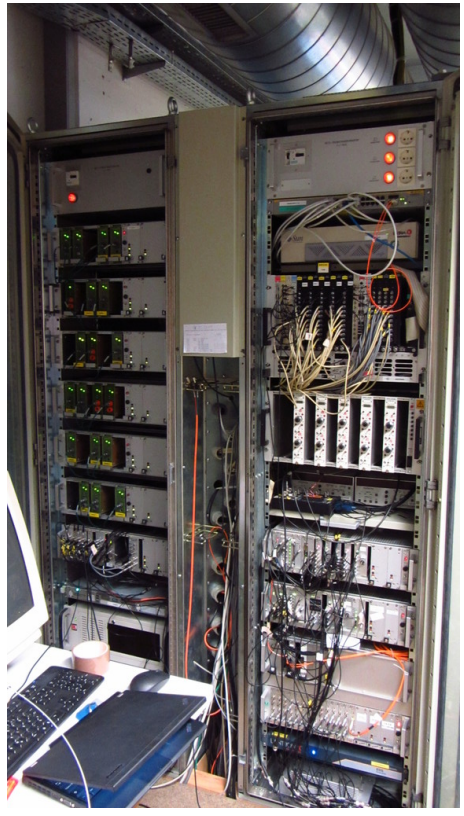
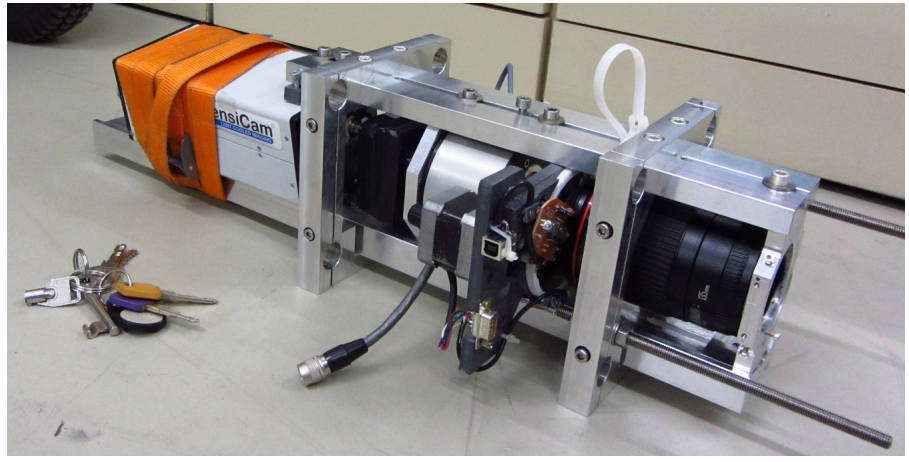






IMSE



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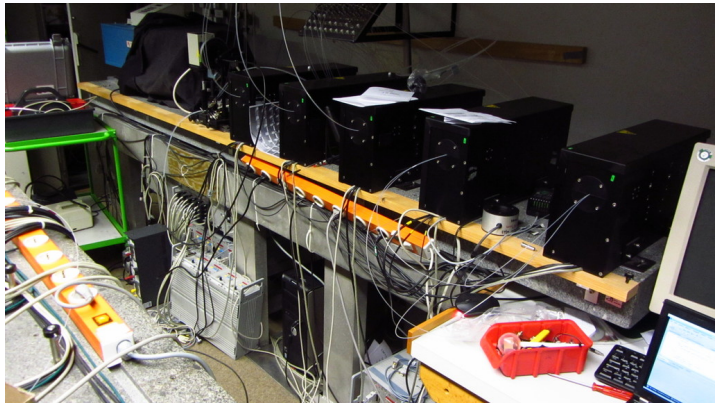

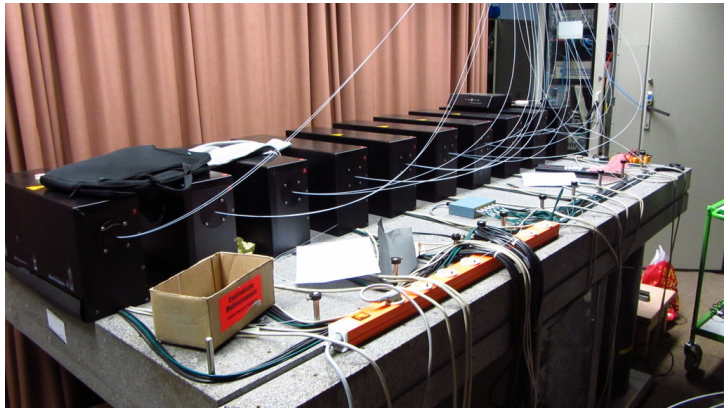

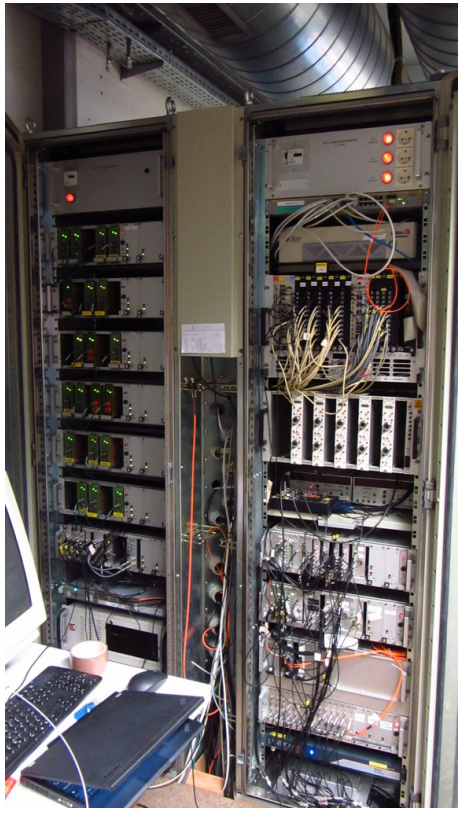

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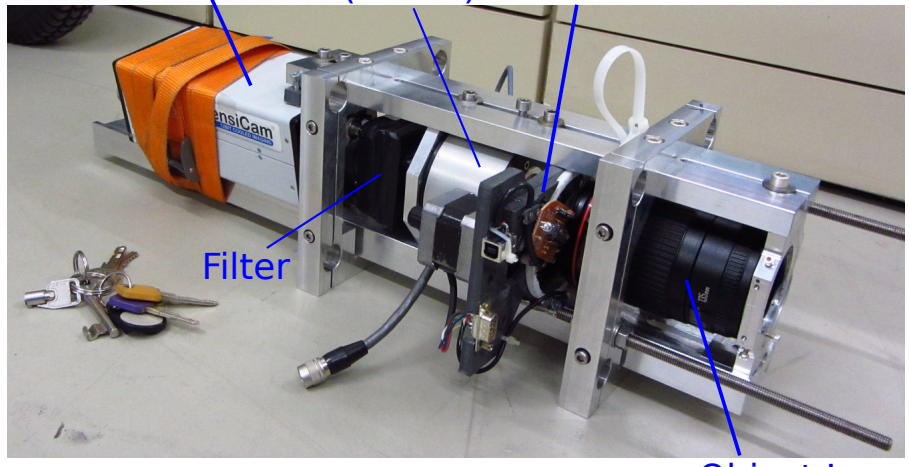

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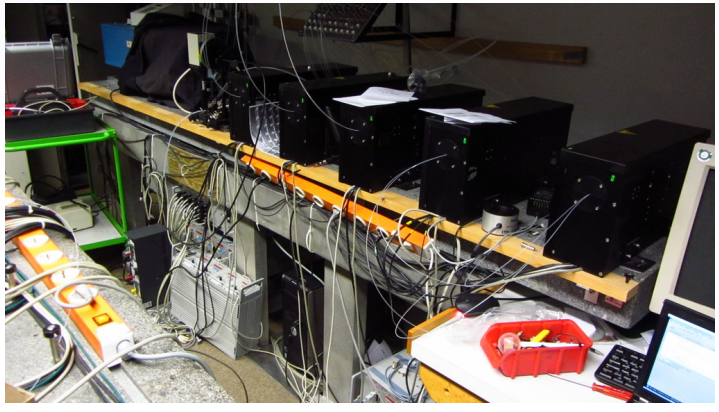

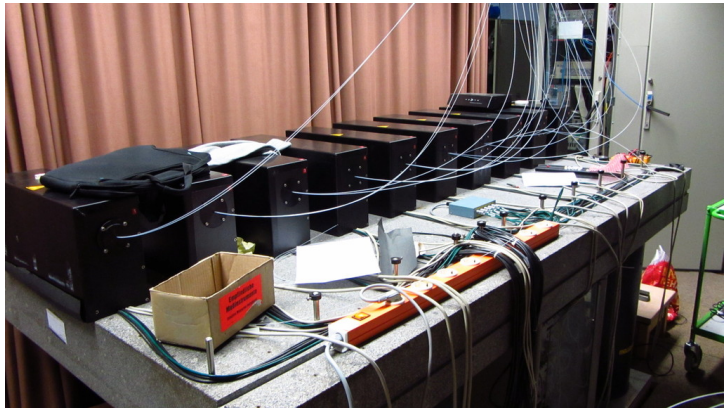

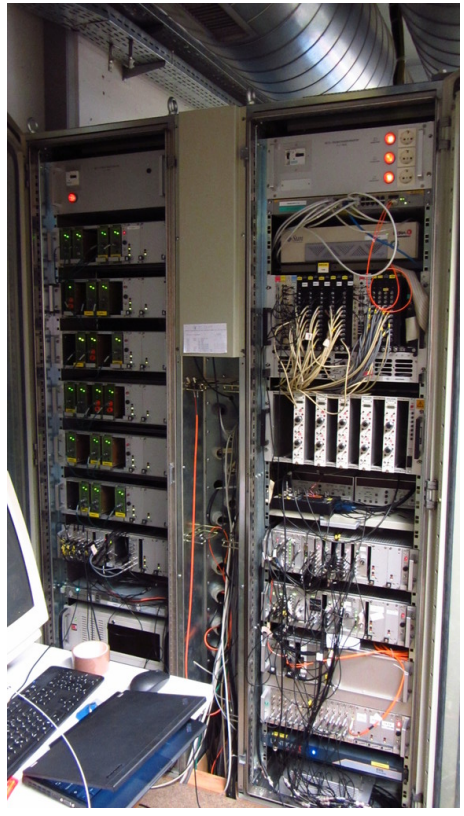

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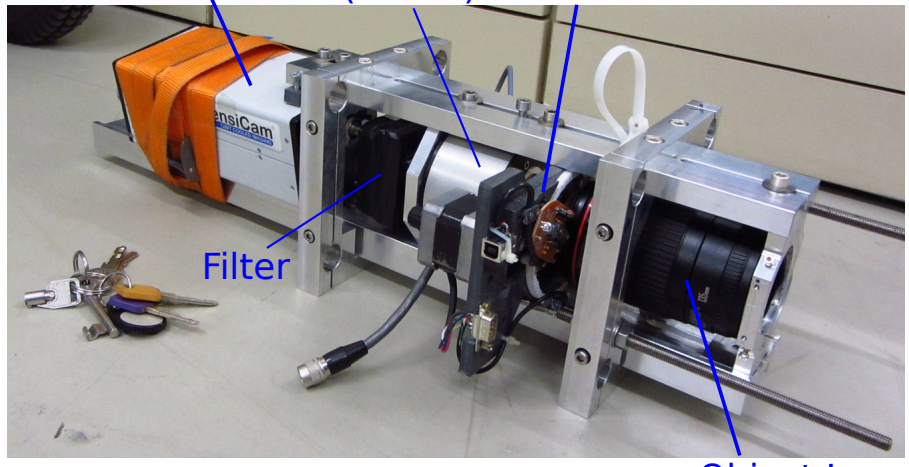

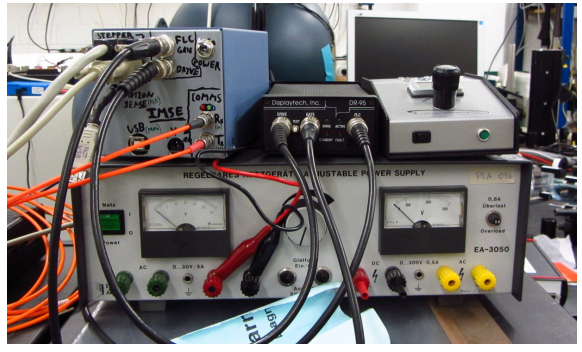

Torus hall controller (40€ Arduino) + power supplies.

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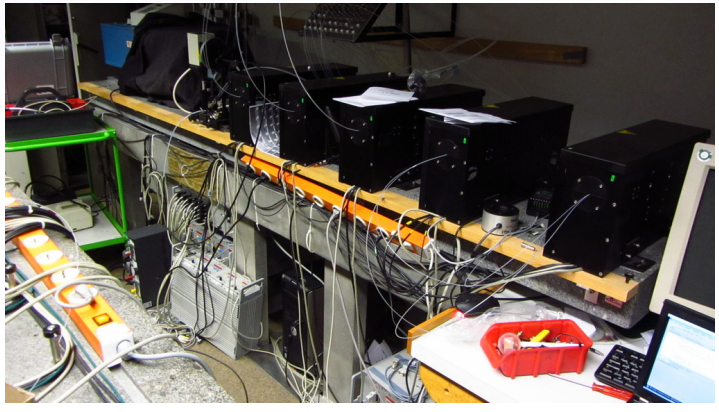

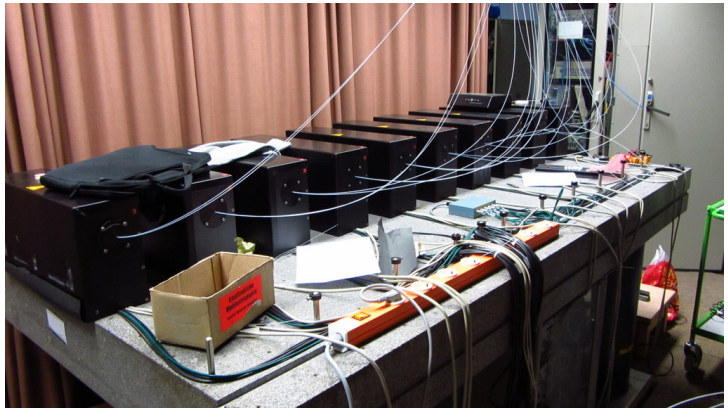

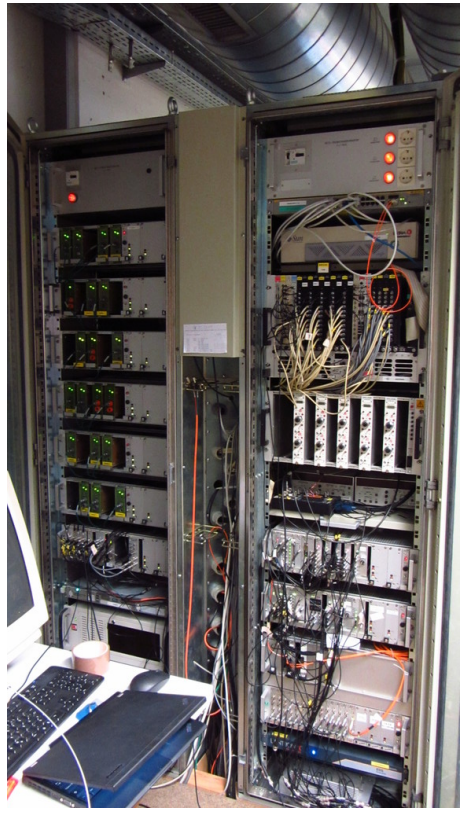

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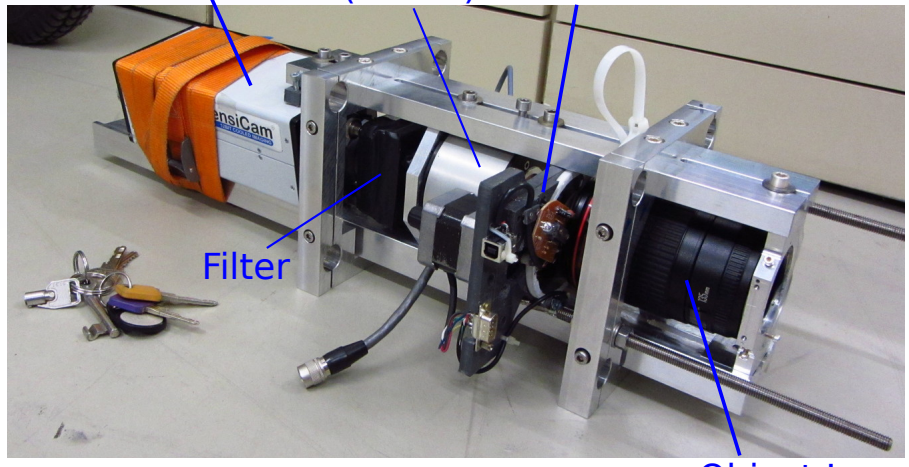

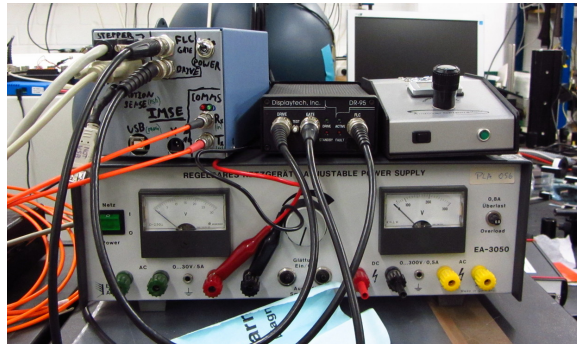

Torus hall controller
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+ power supplies.

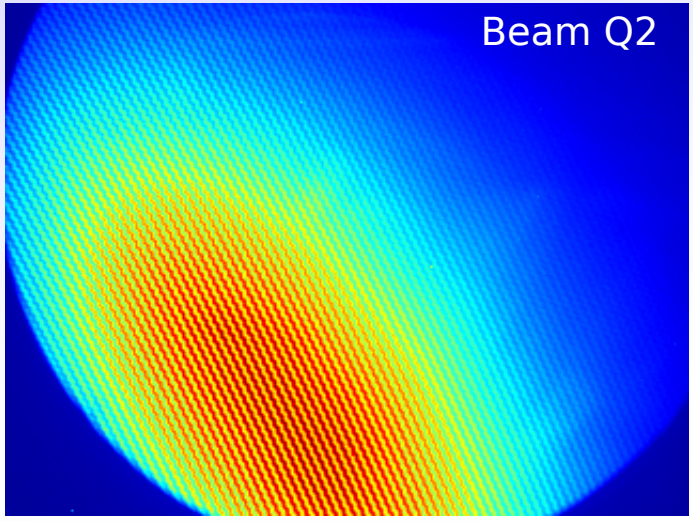
Control PC:
- Camera card
- ADC card.



Oliver Ford
IPP Greifswald

January: First images

Raw images from first day of operation: Beam emission with interference pattern:



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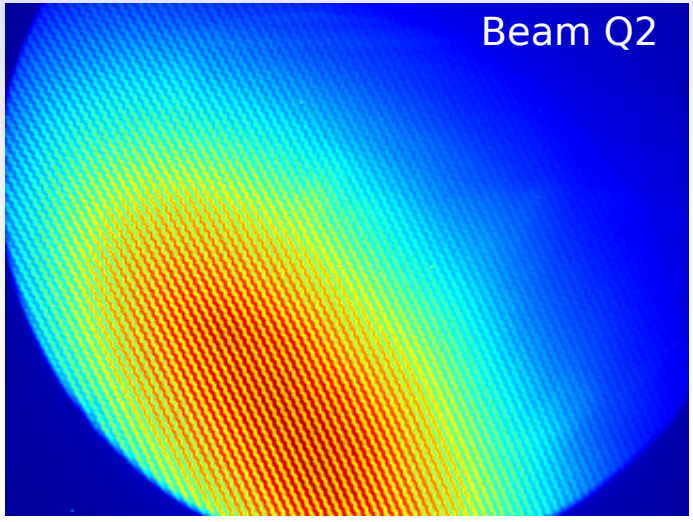
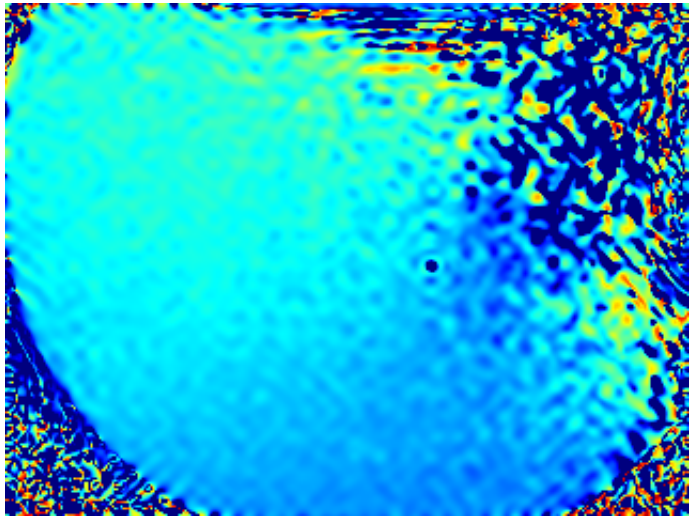


Raw demodulated polarisation angle:



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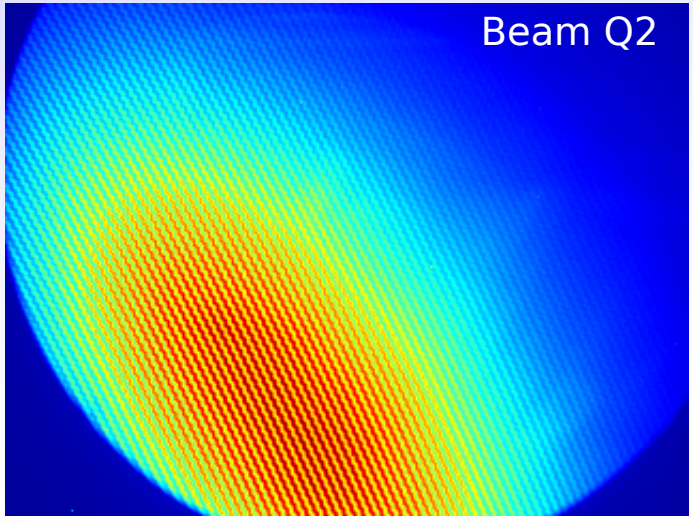

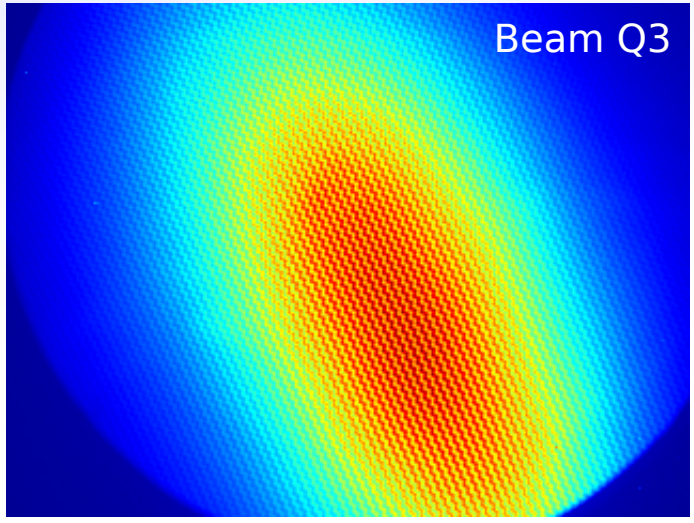

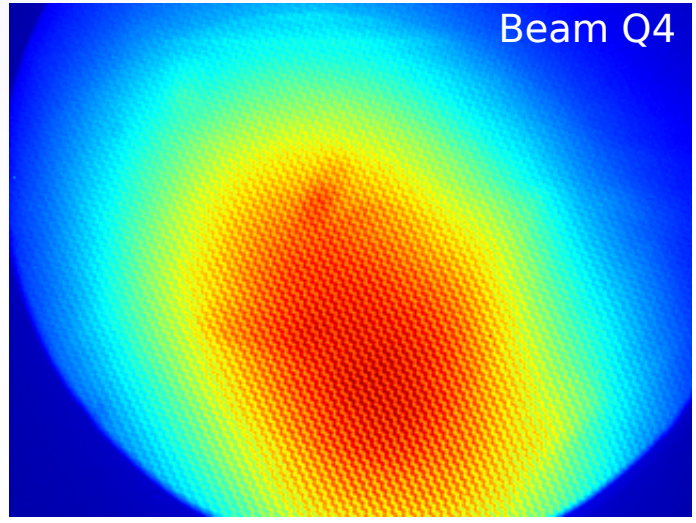

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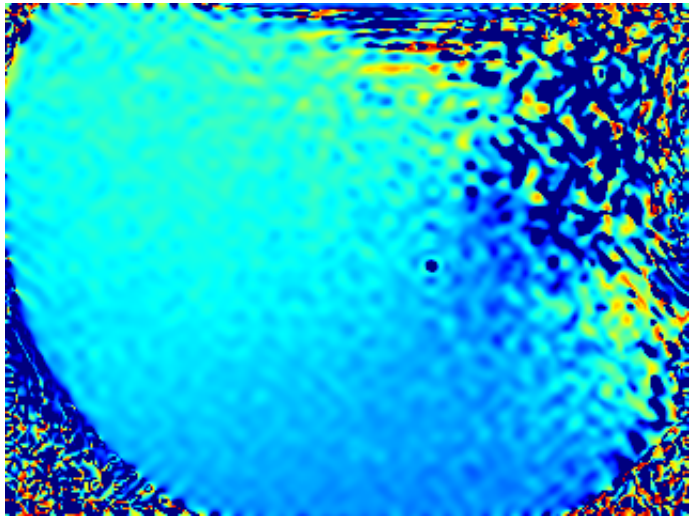

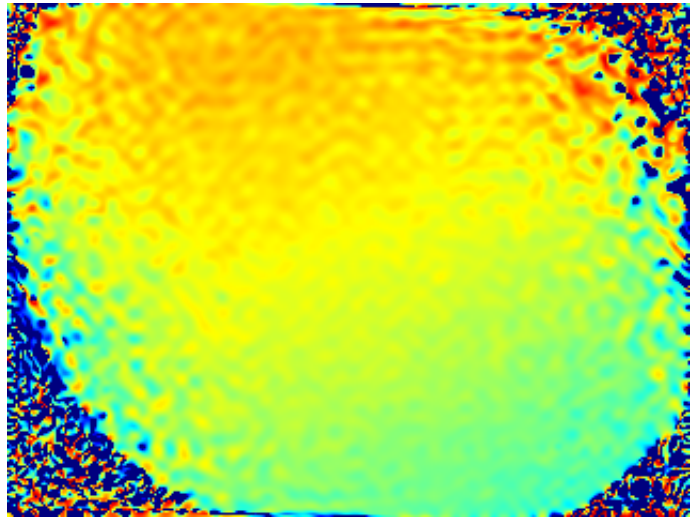

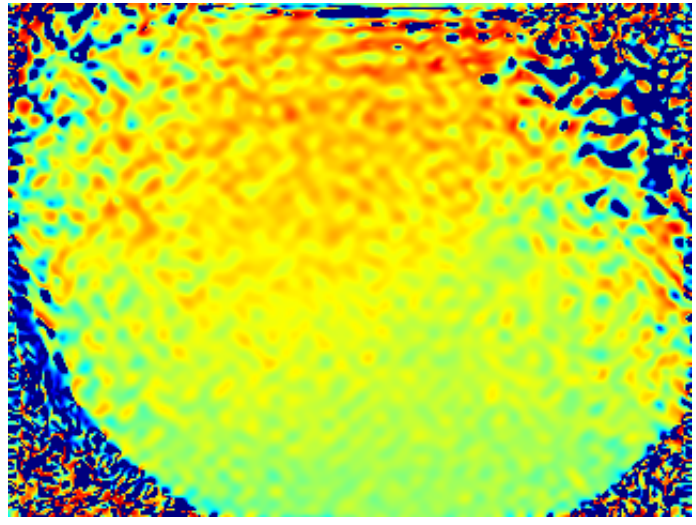

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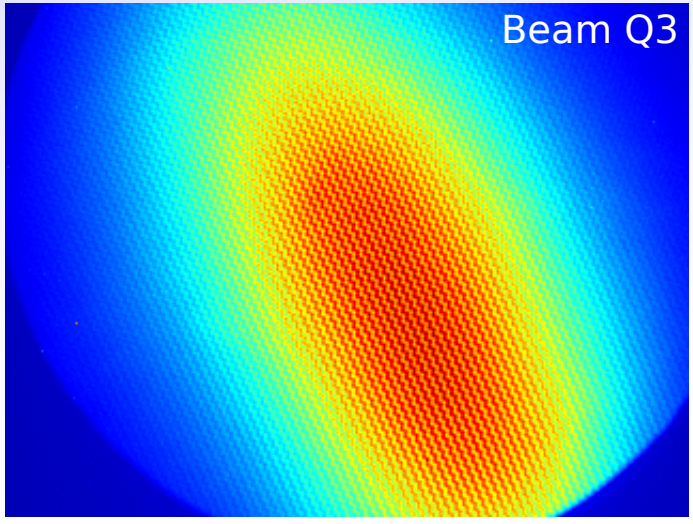
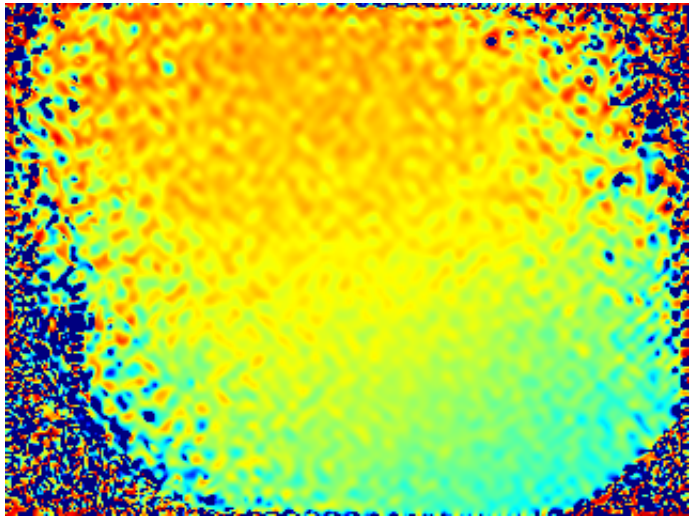
January: First indication of success:

Early results showed expected pitch angle movement during plasma current ramp-up:





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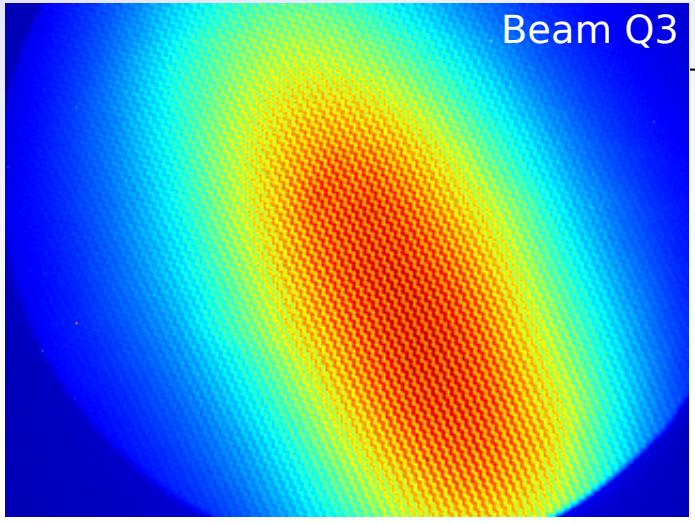

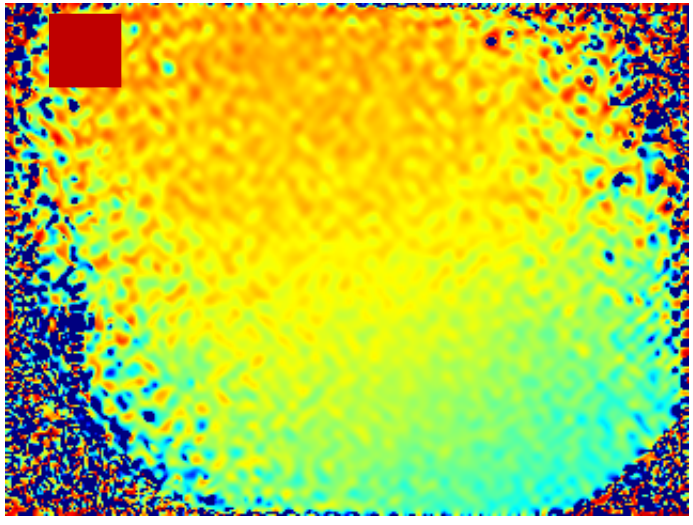

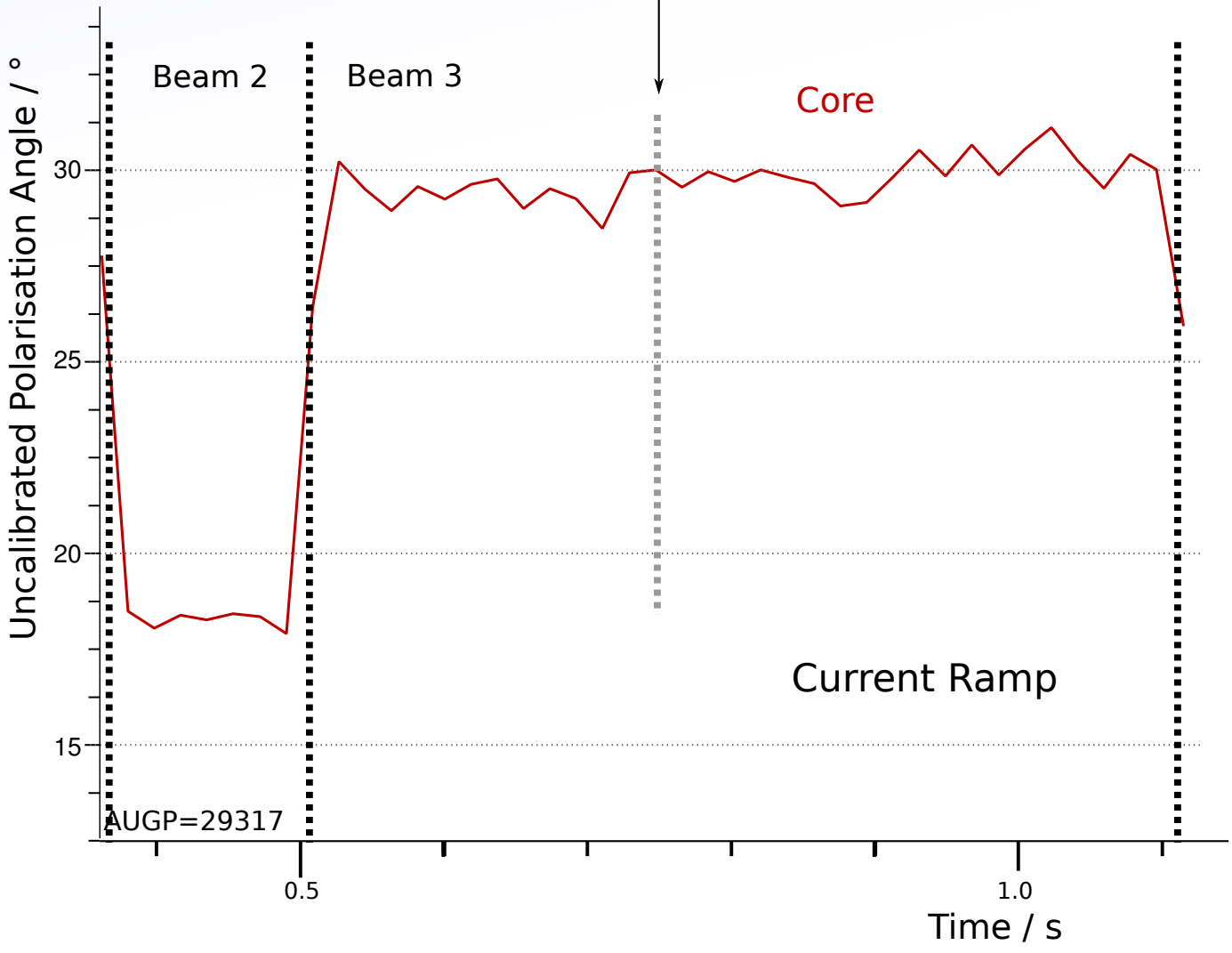

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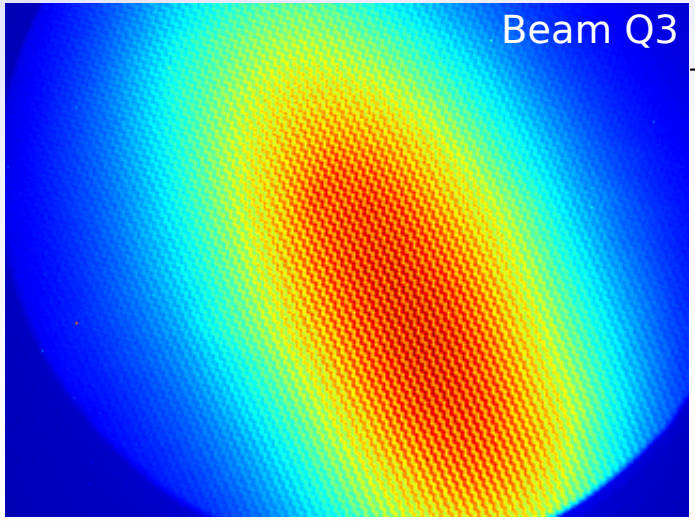

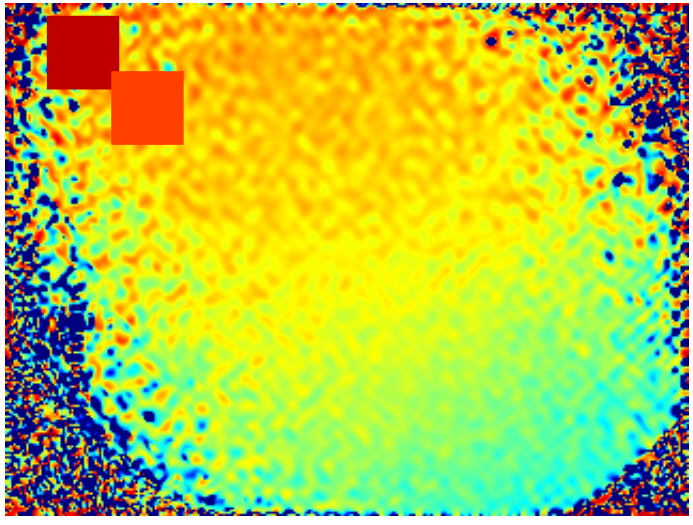

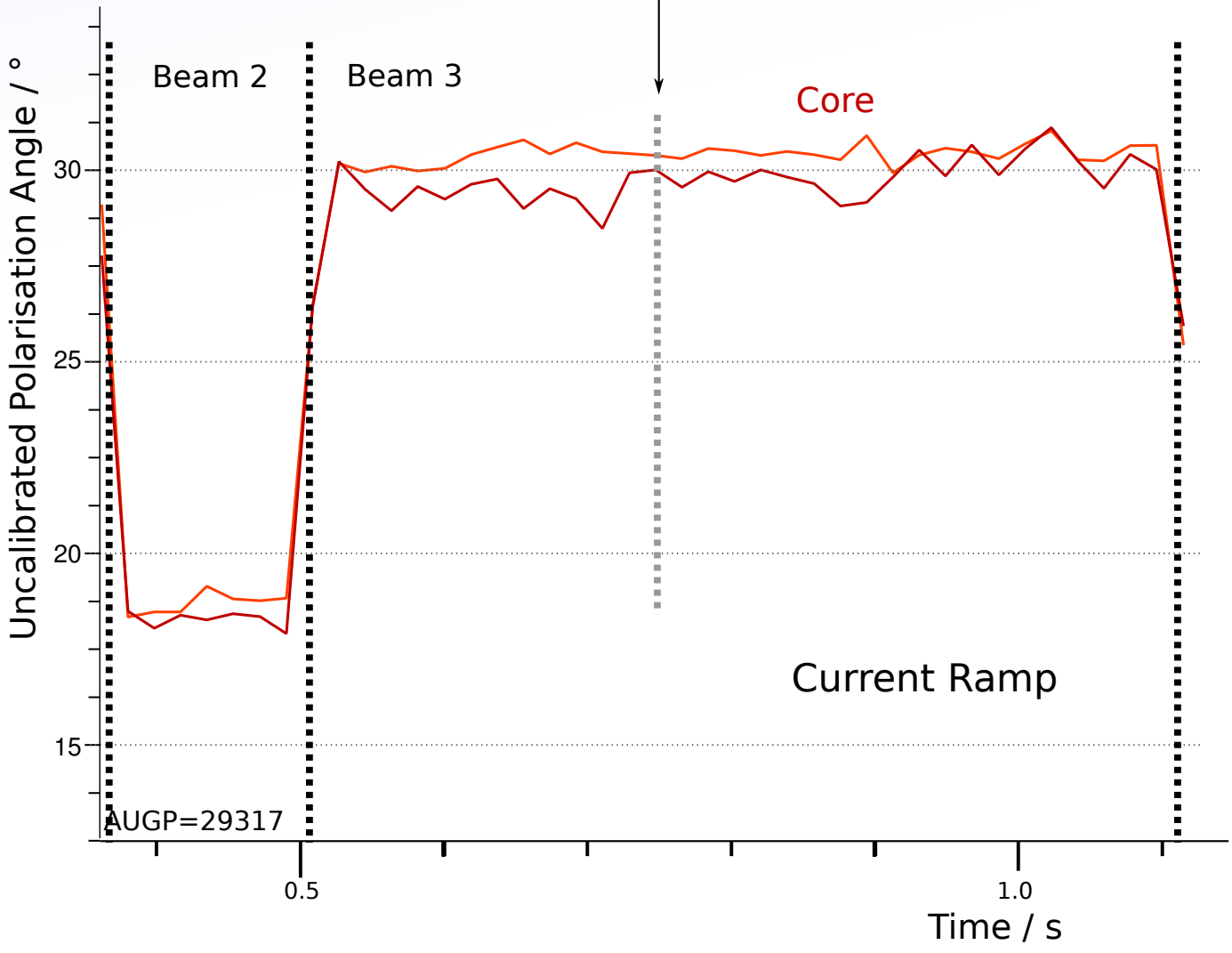

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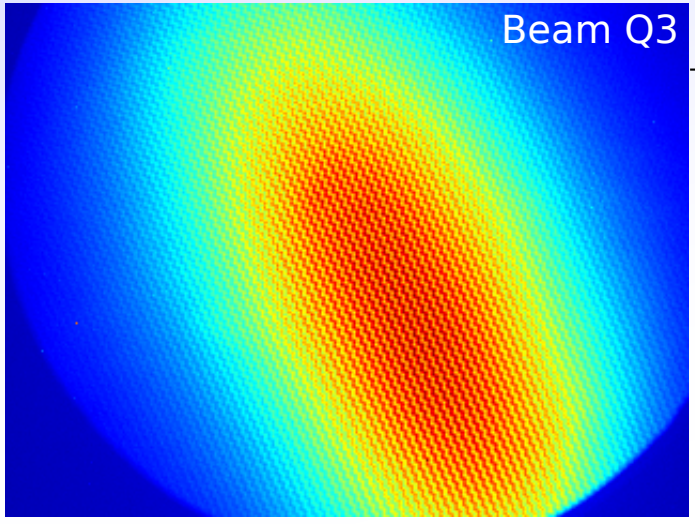

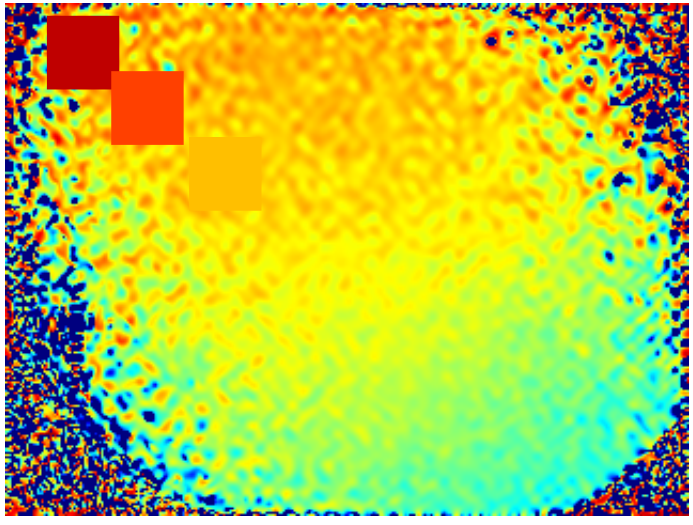

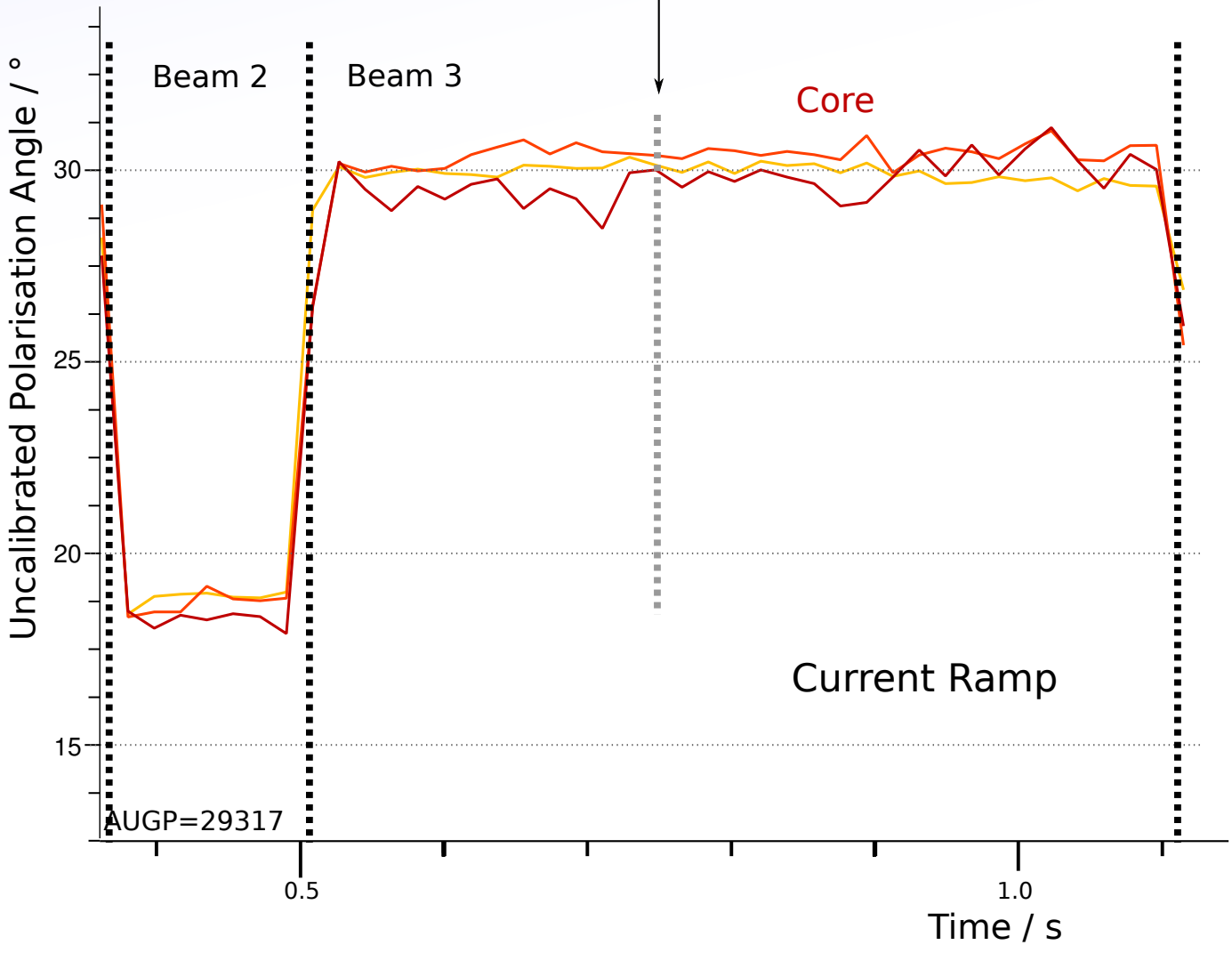

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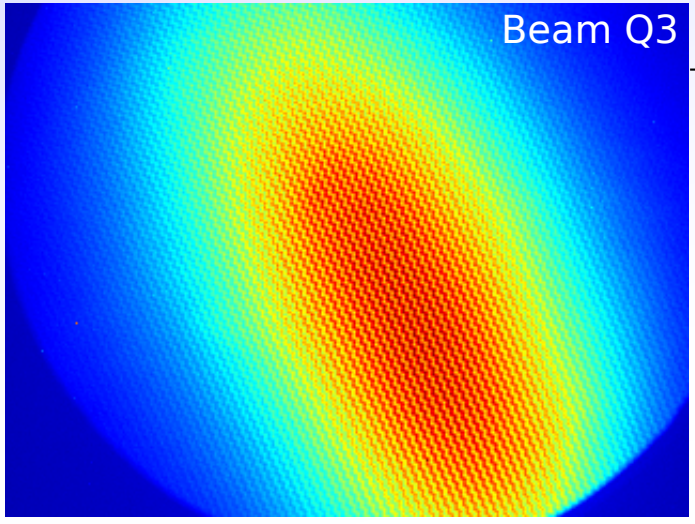

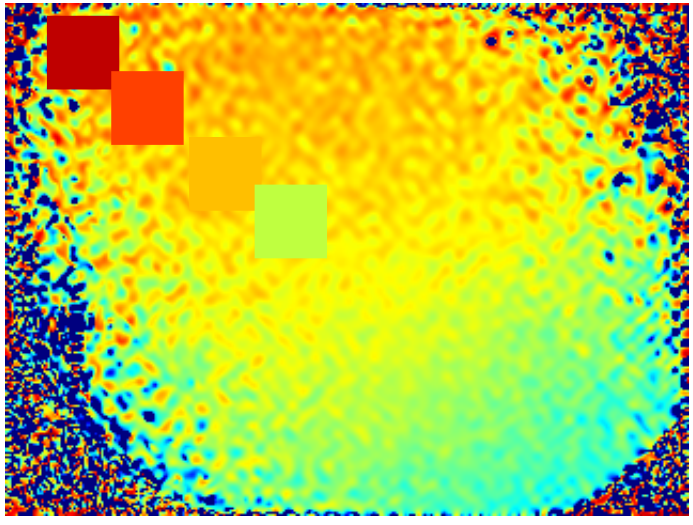

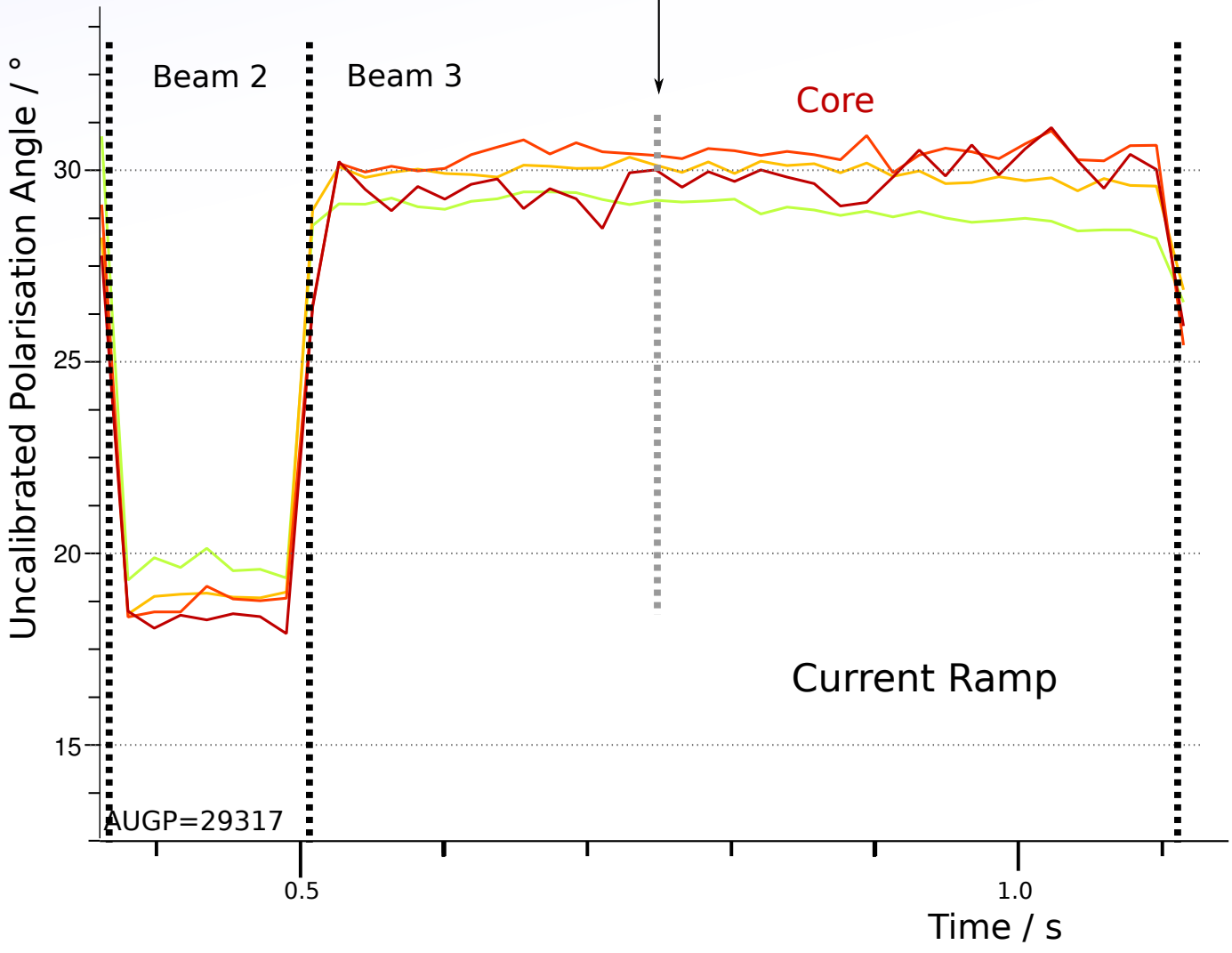

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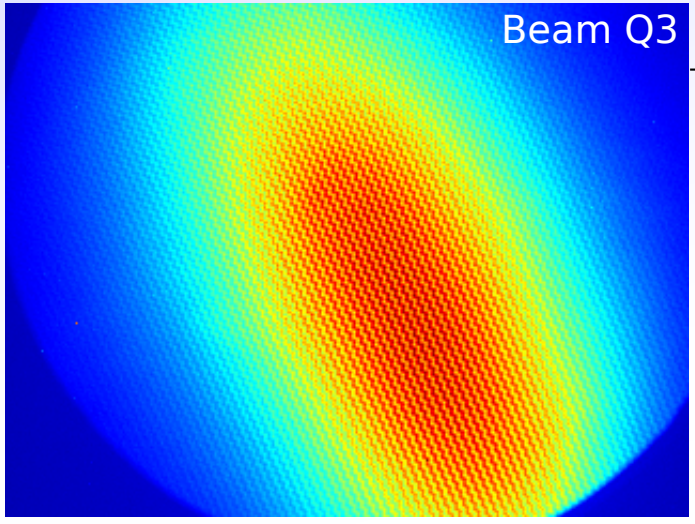

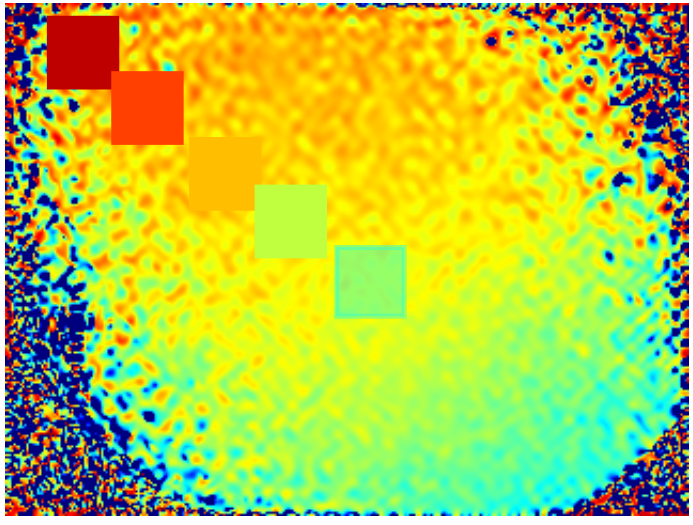

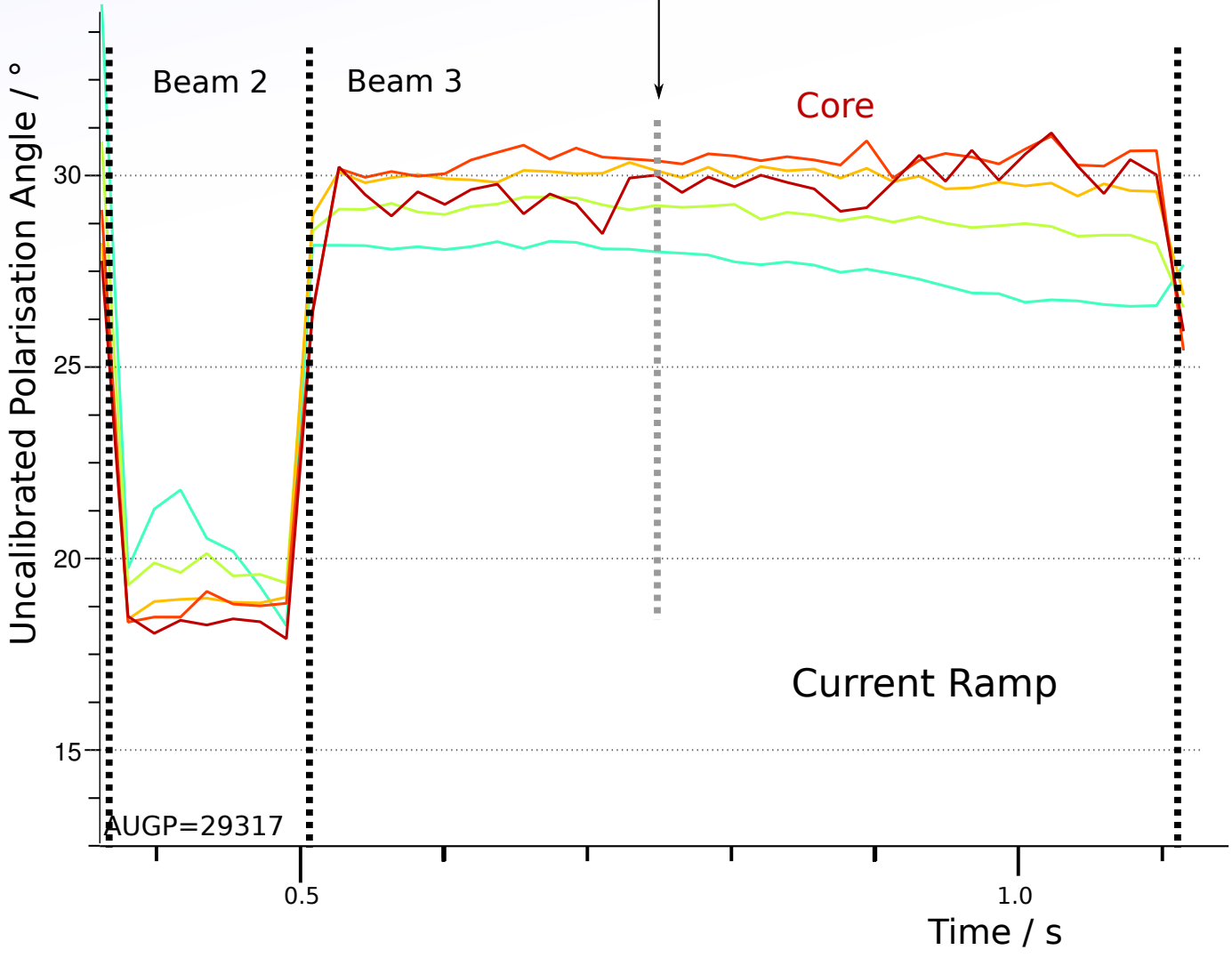

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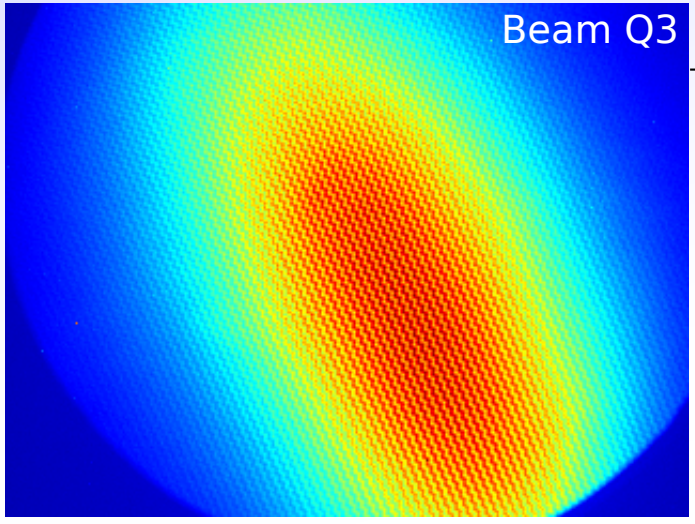

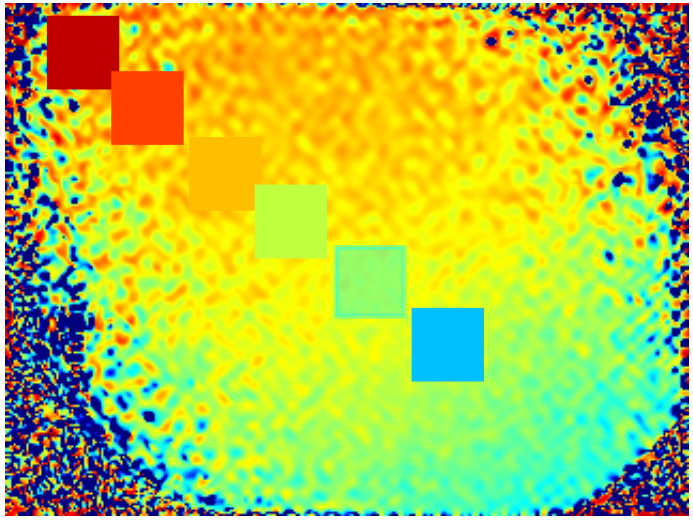

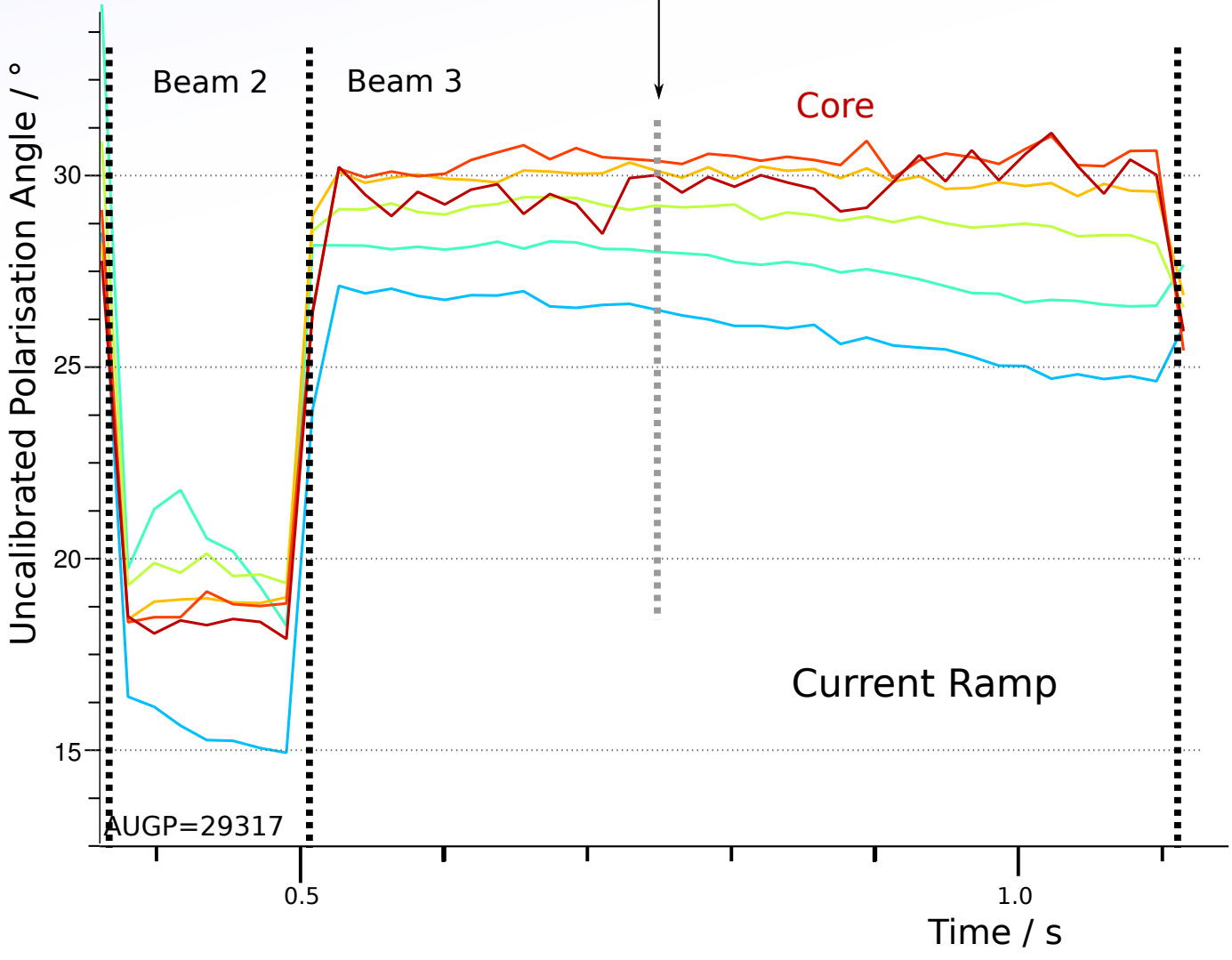

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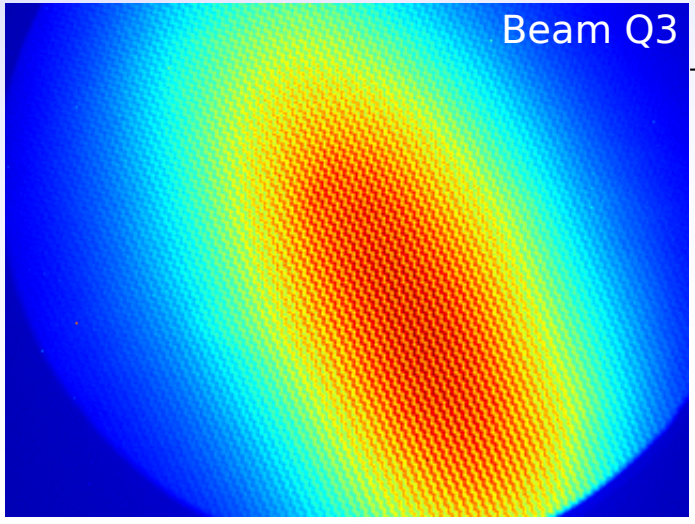

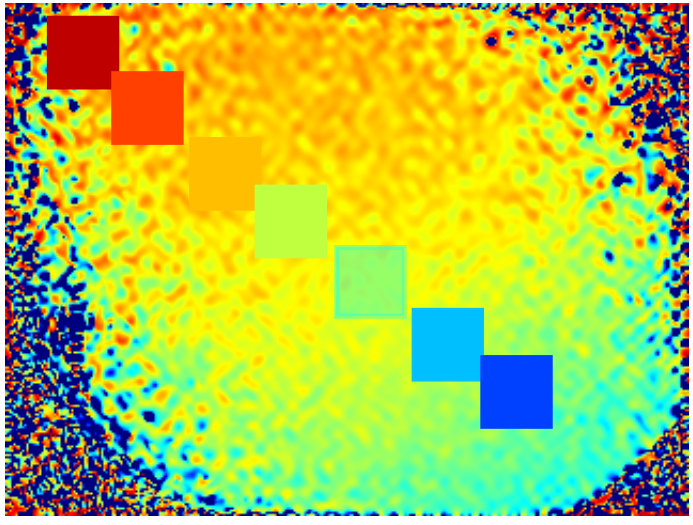

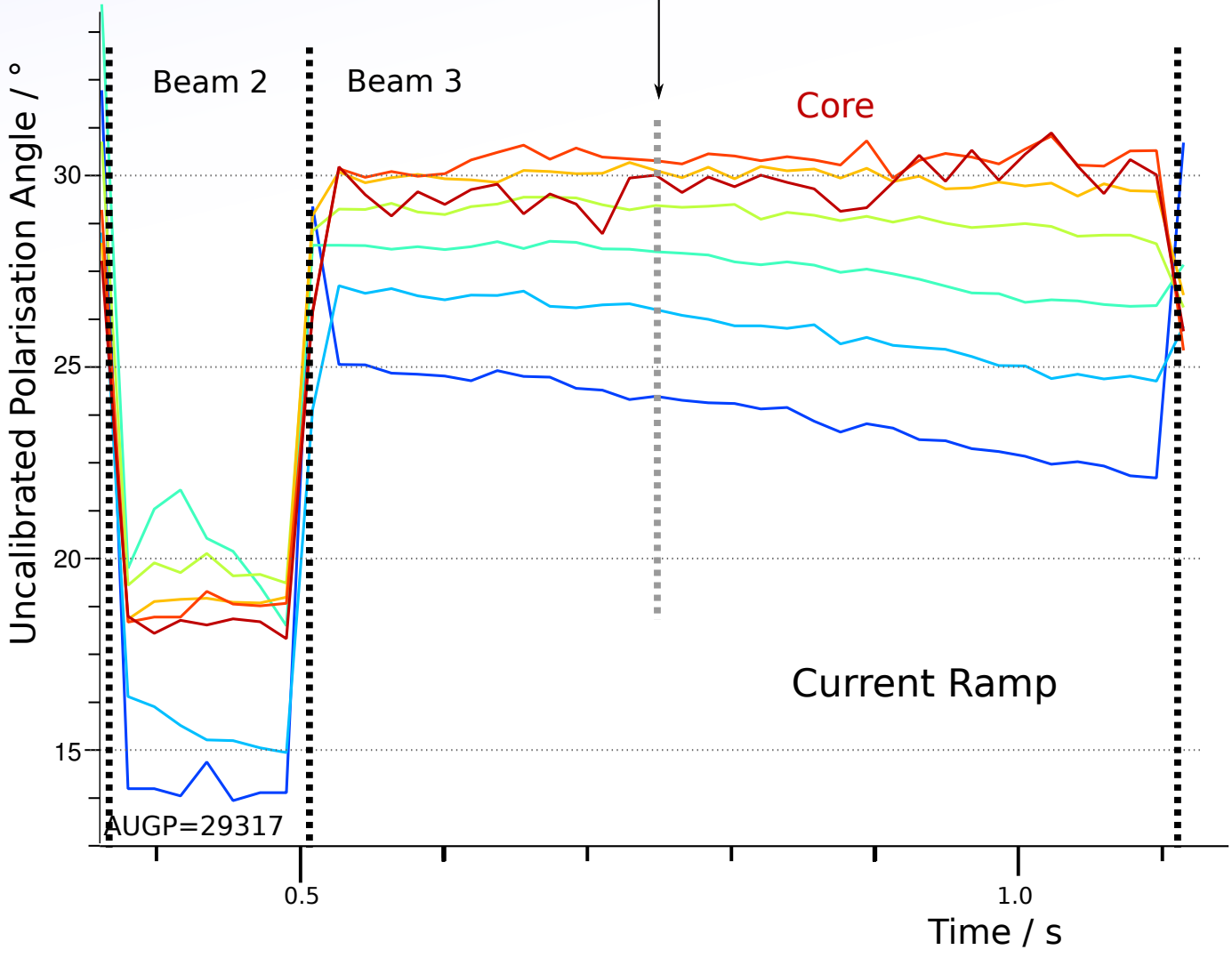

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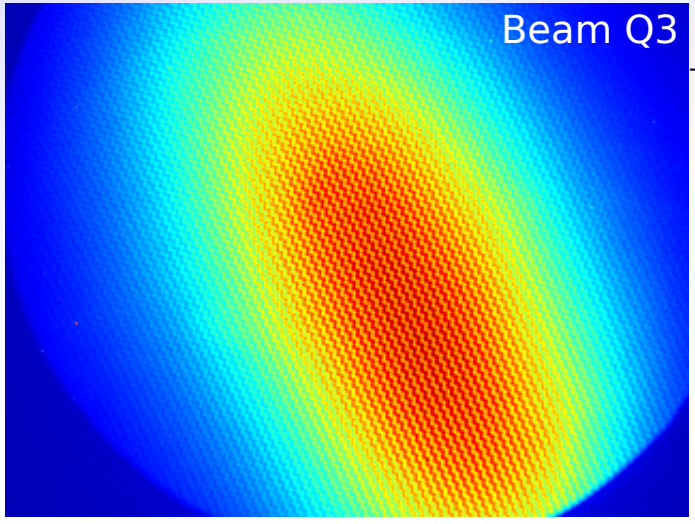

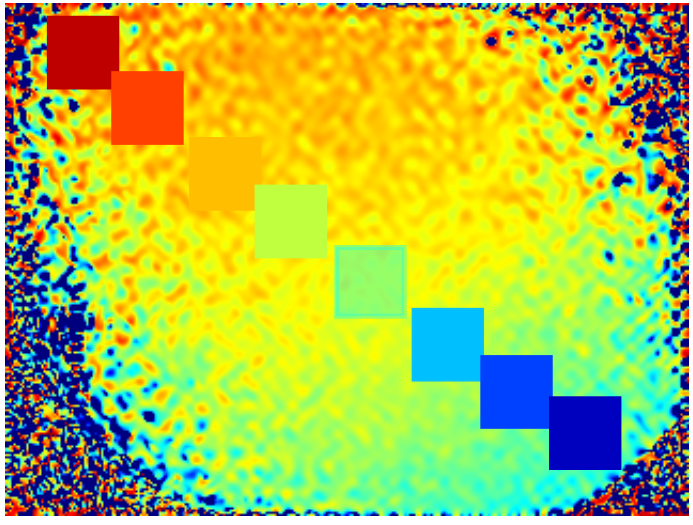

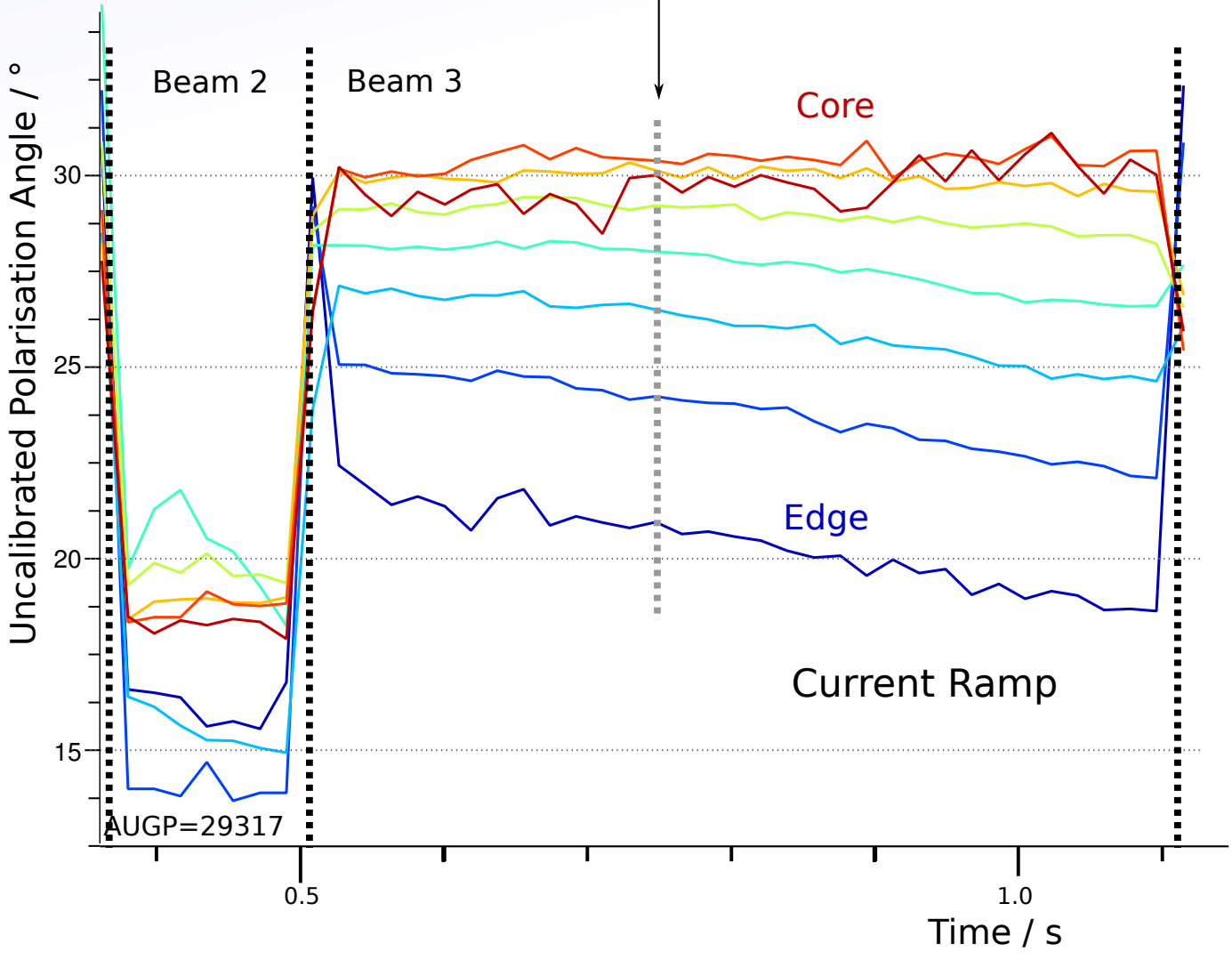

Image Transform

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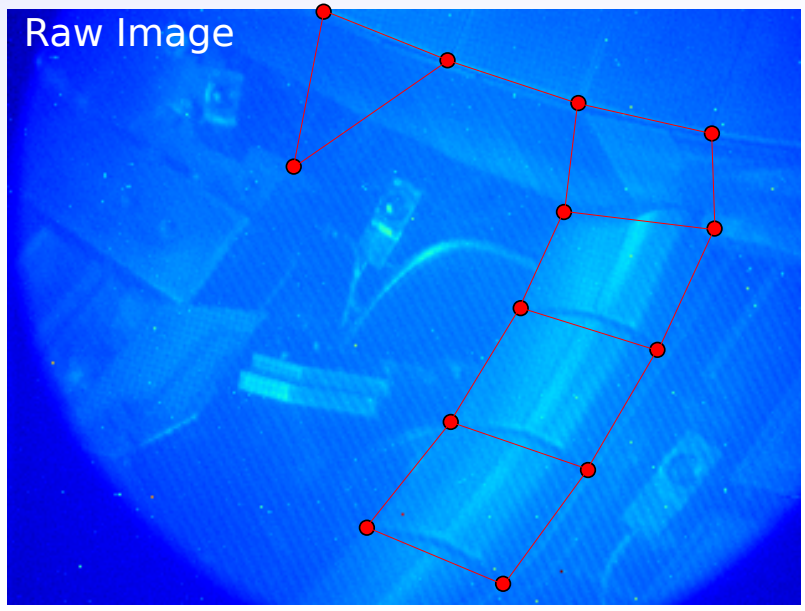
Use background during bright Dα events (e.g. disruptions) for mapping the image to R,Z coordinates at the beam:



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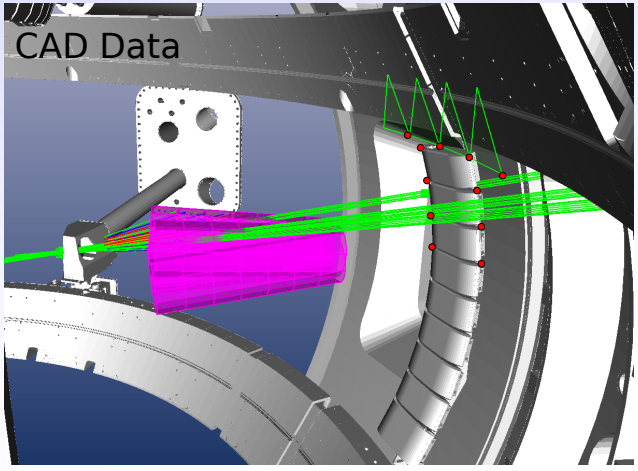

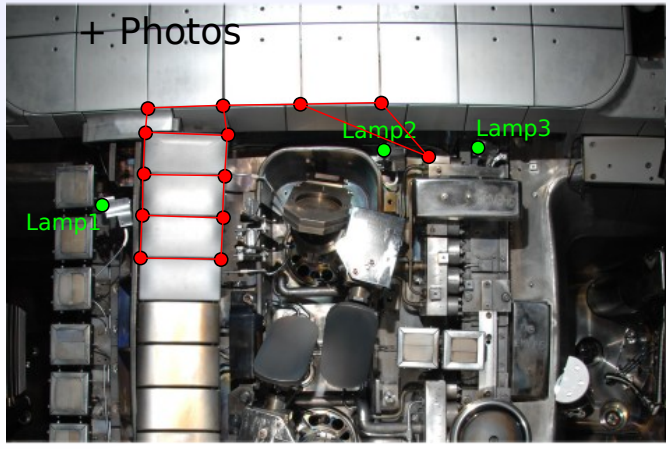

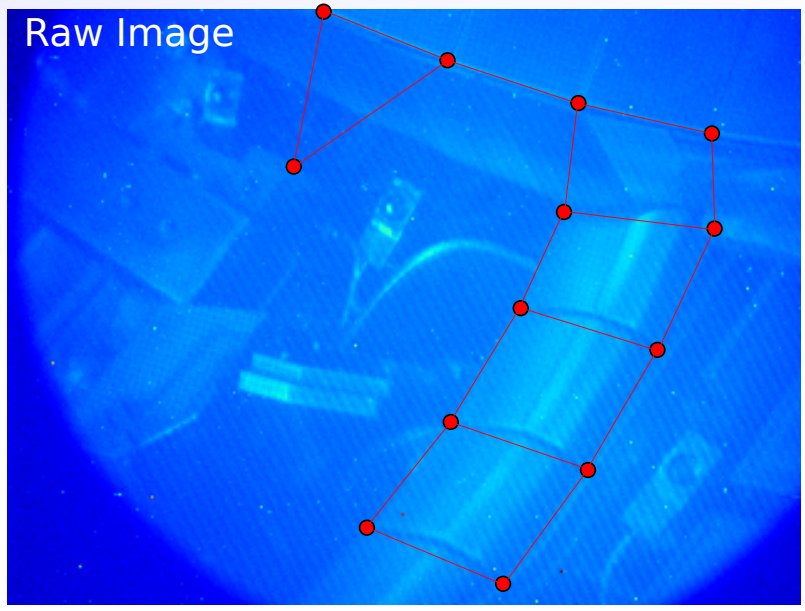

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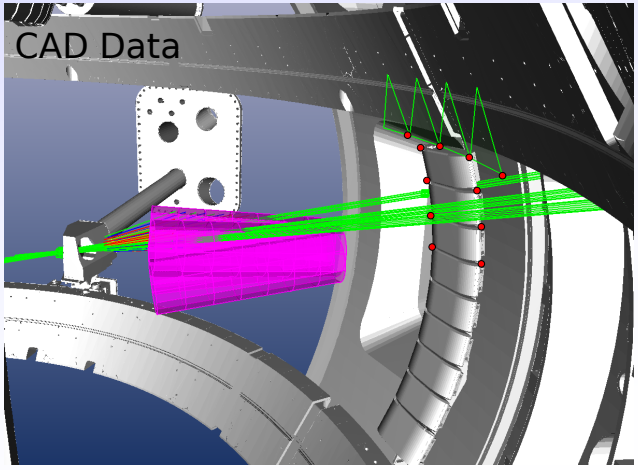

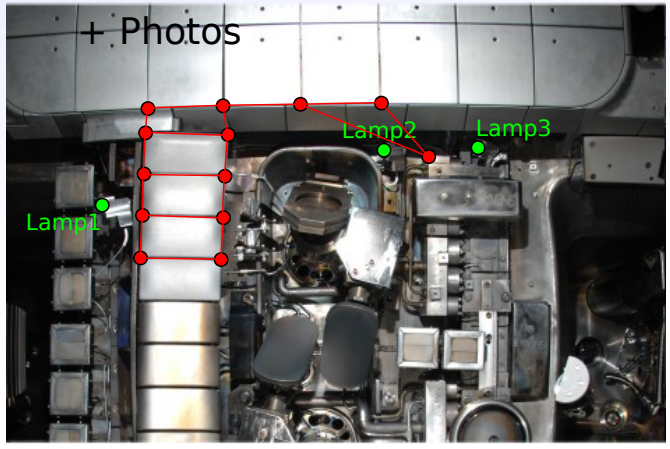

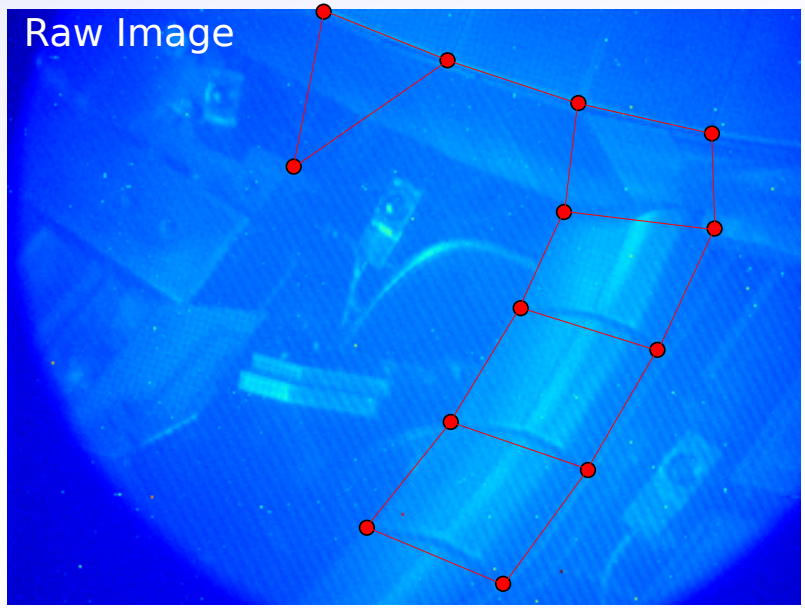

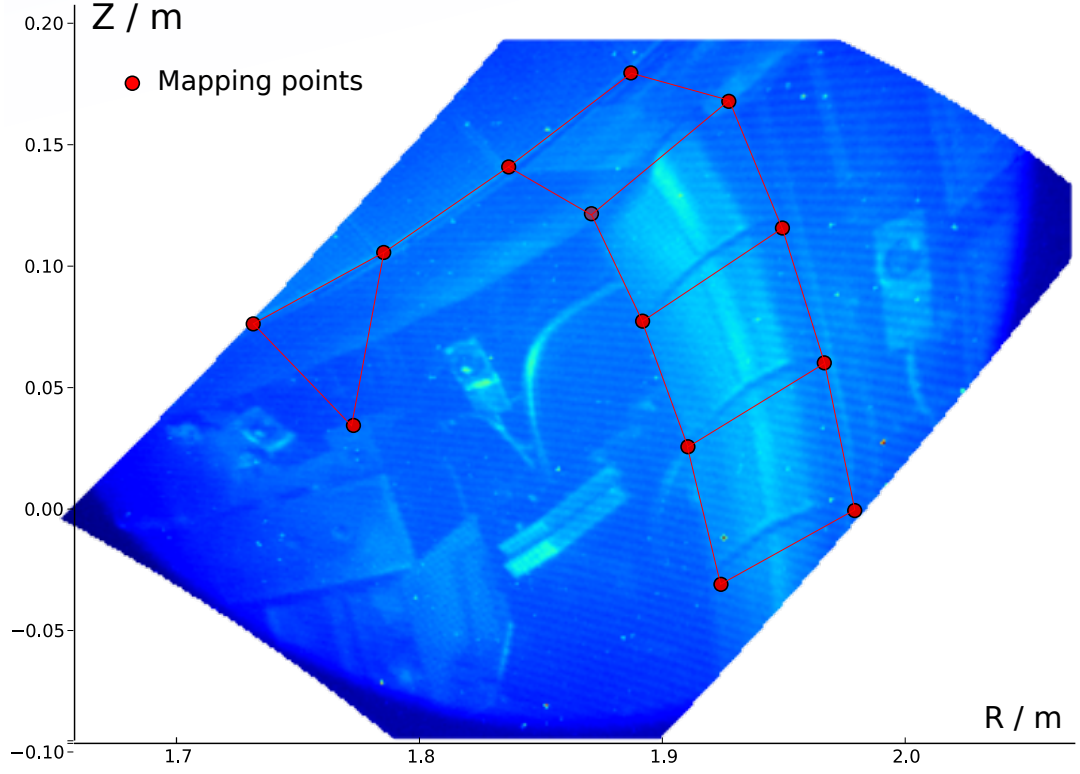

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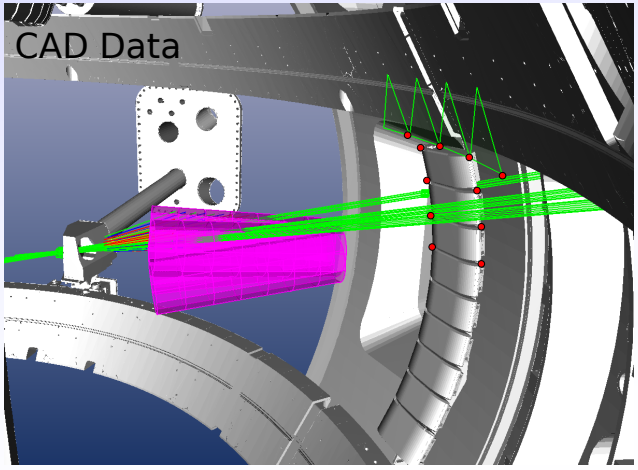

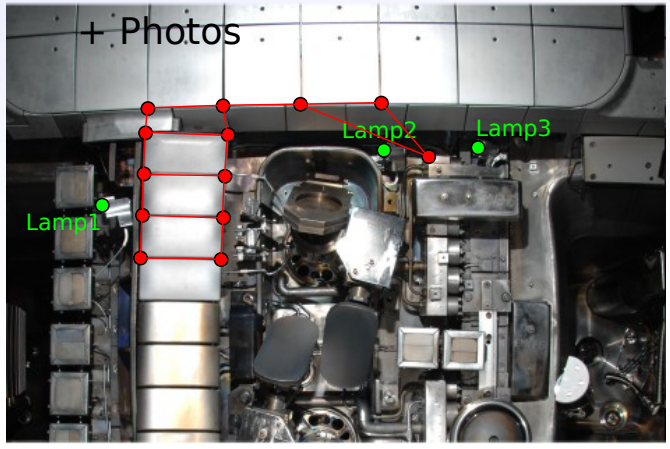

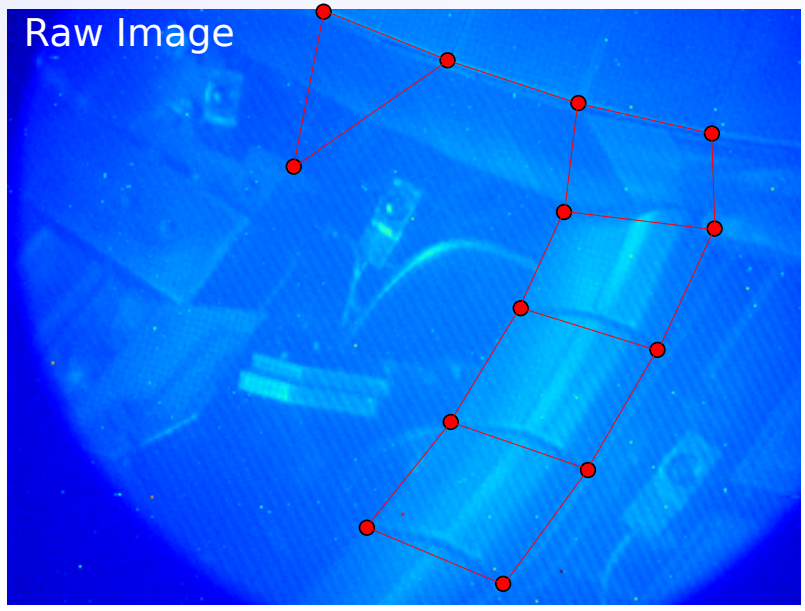

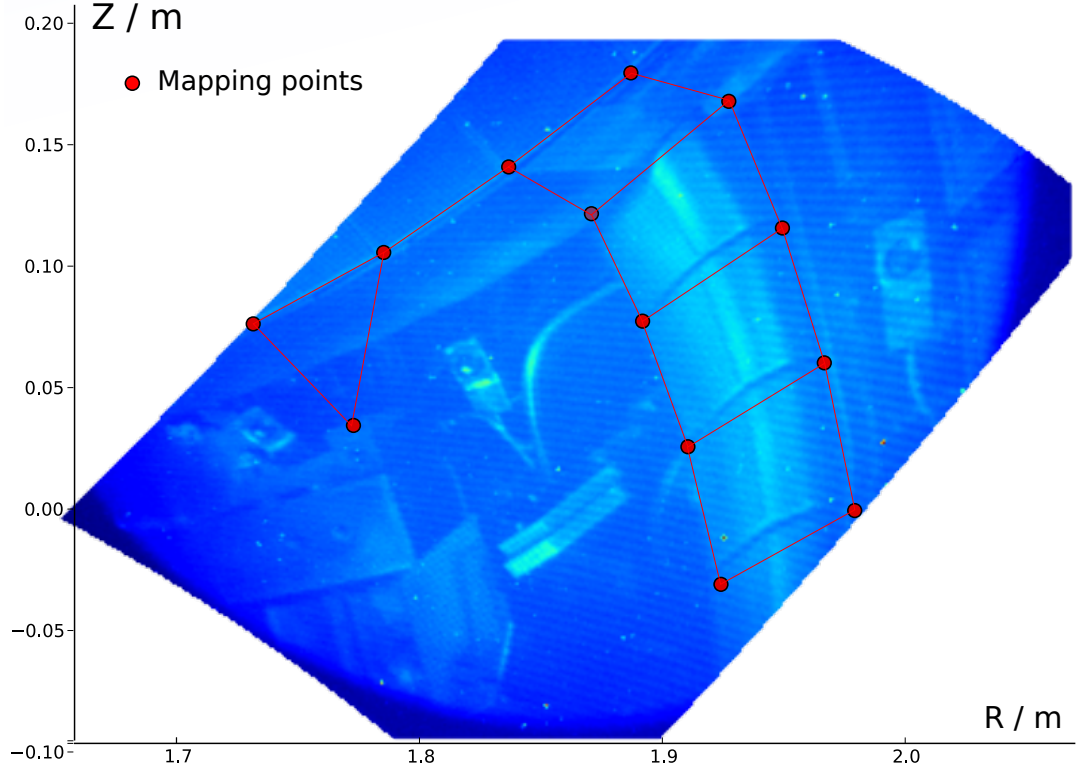

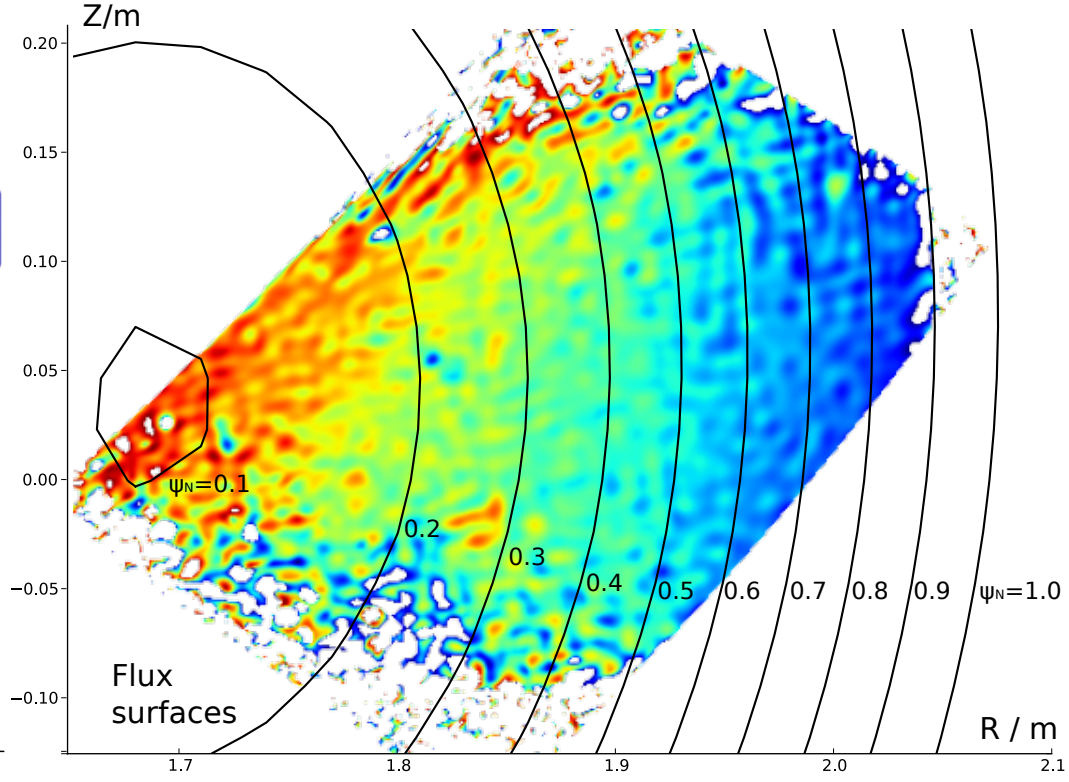

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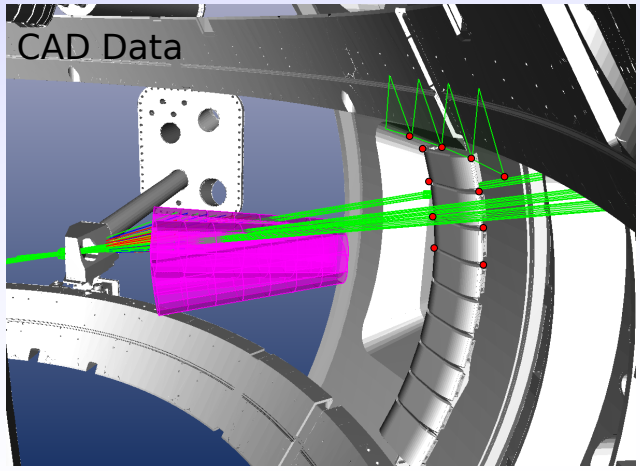

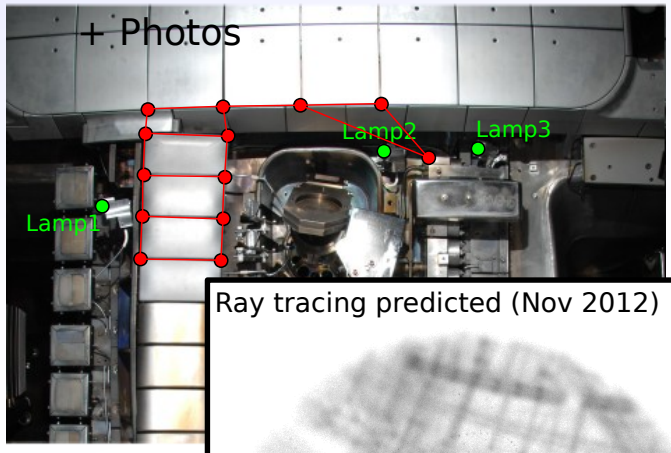

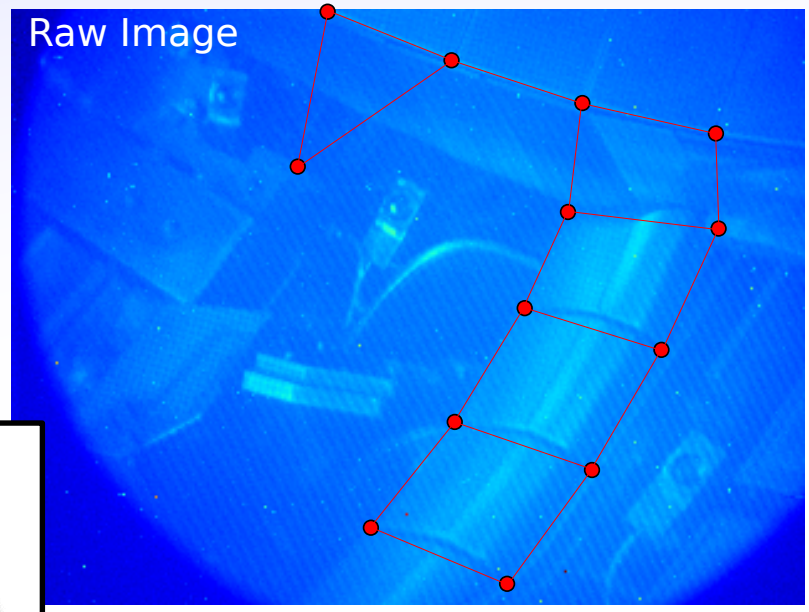

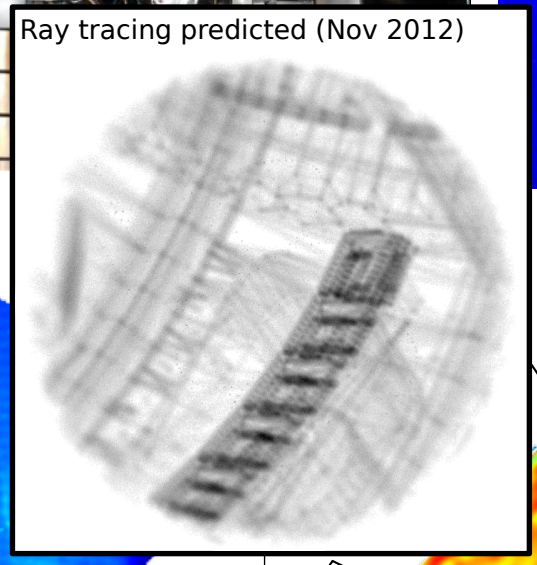

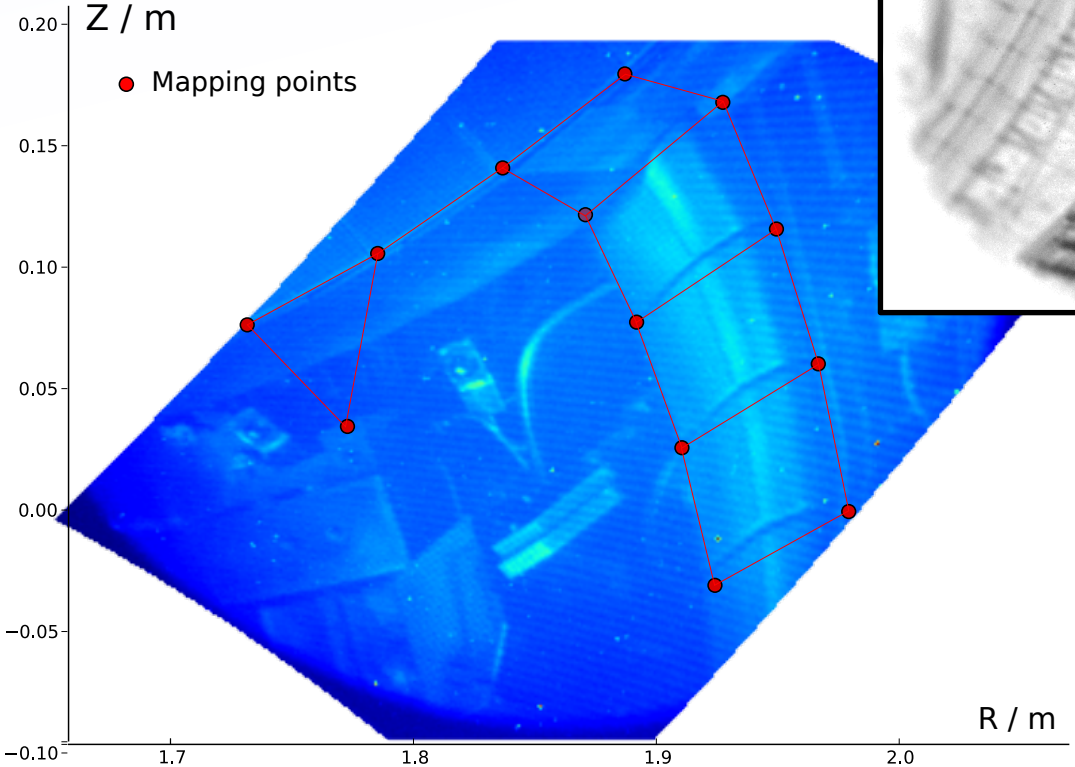

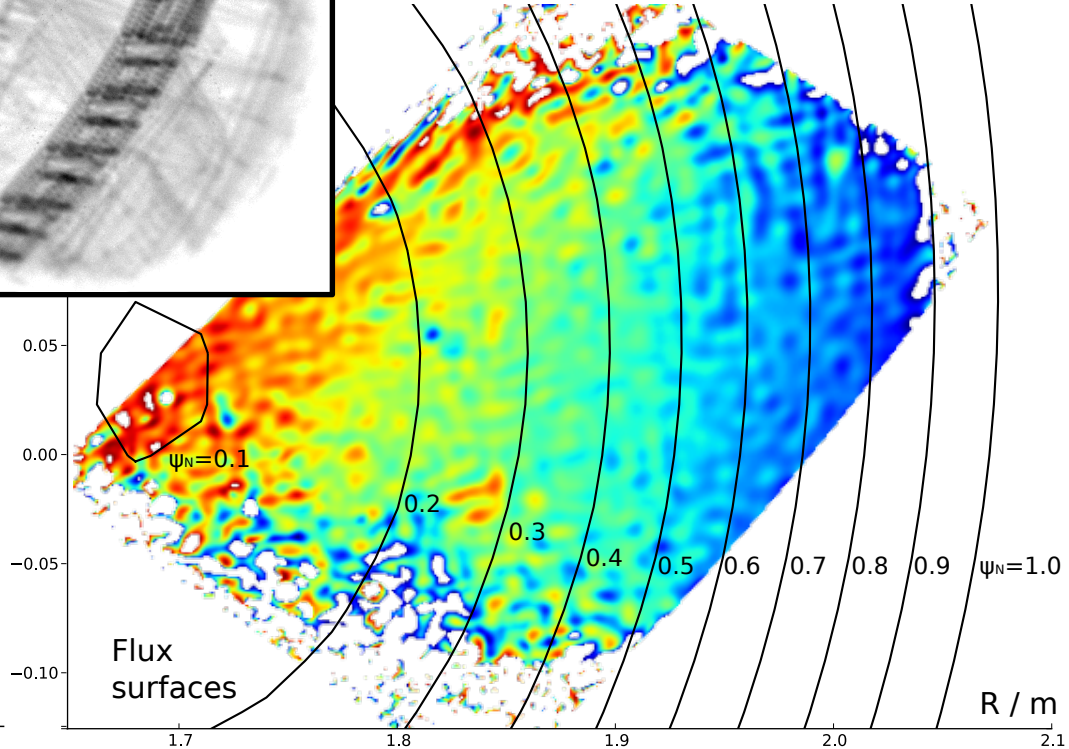

Intrinsic Contrast Calibration

Oliver Ford
IPP Greifswald

Calibration of non-linearity requires the polariser to be in place during a plasma, with the beam on:

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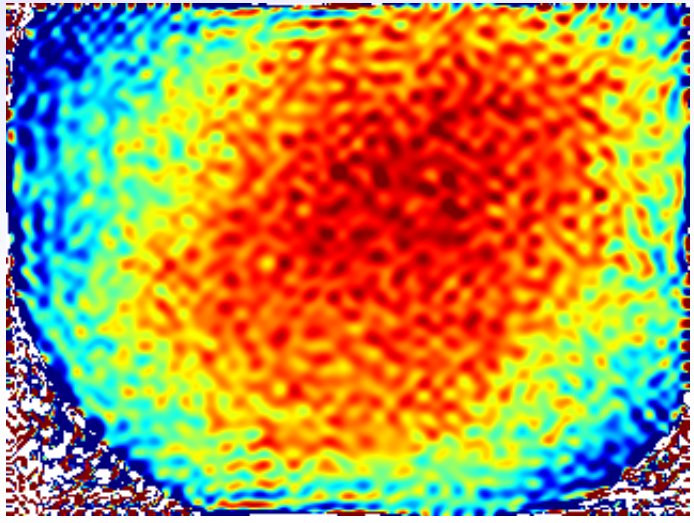
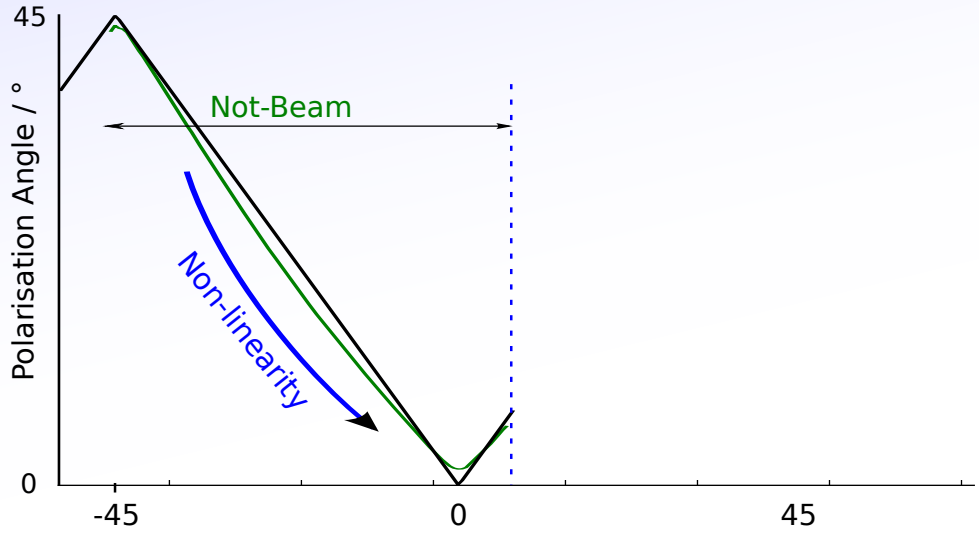
Calibration of non-linearity requires the polariser to be in place during a plasma, with the beam on:

Not-Beam (Dα background)





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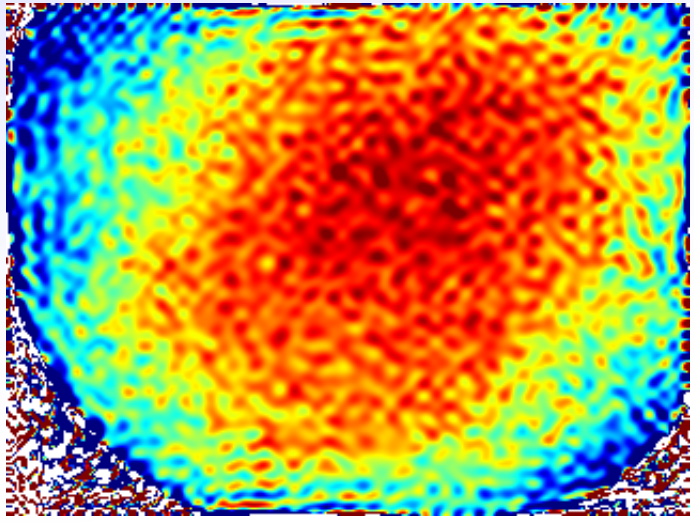
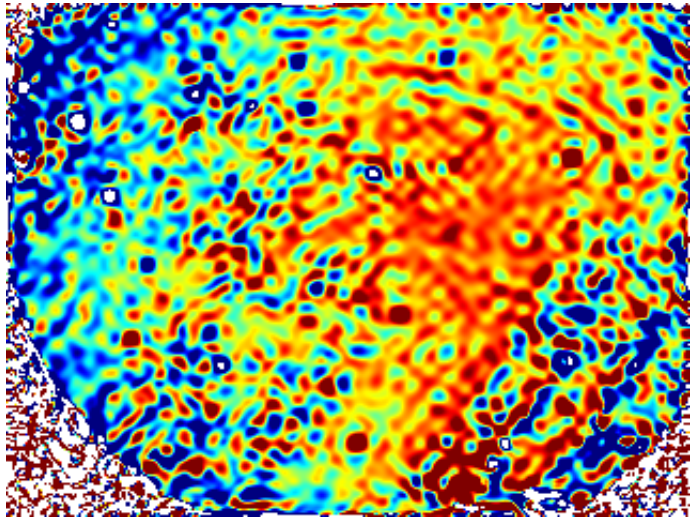
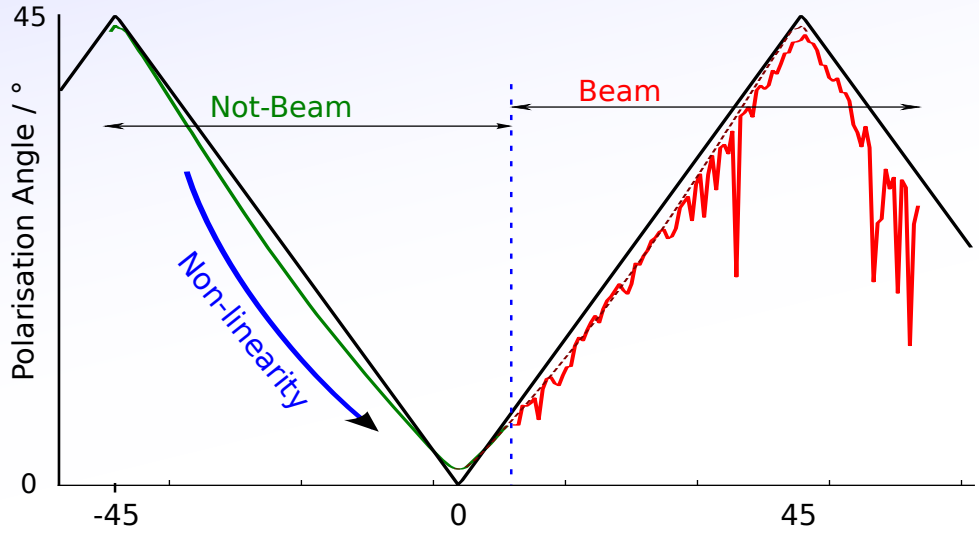


Beam





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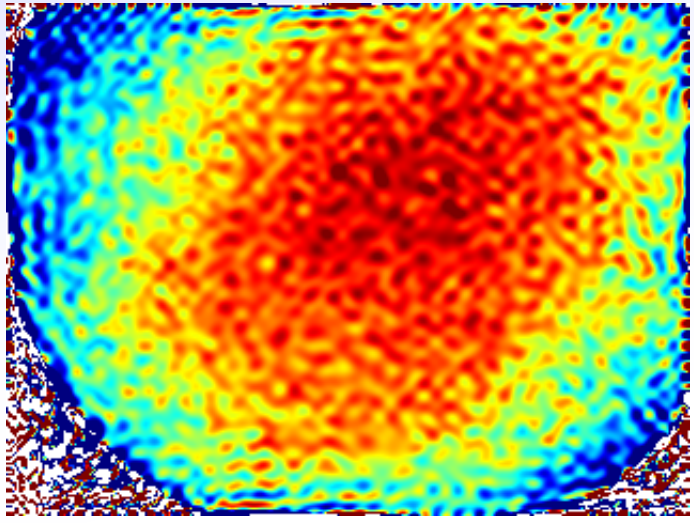

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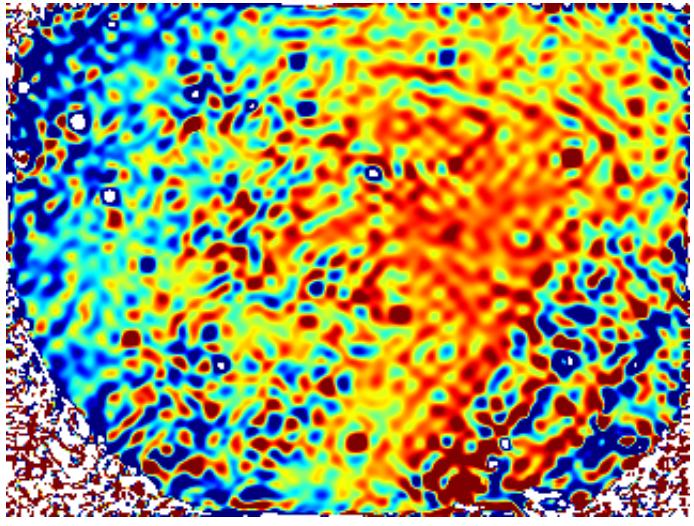
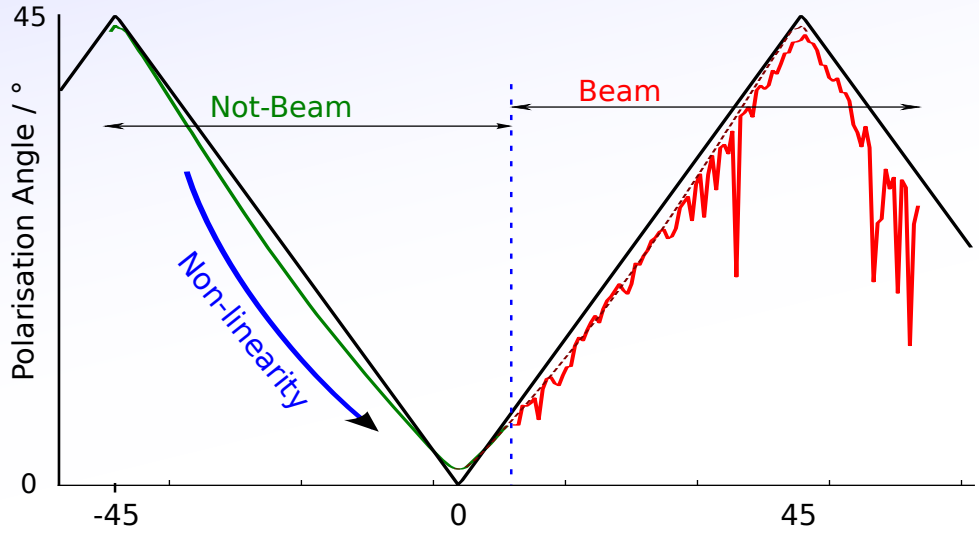
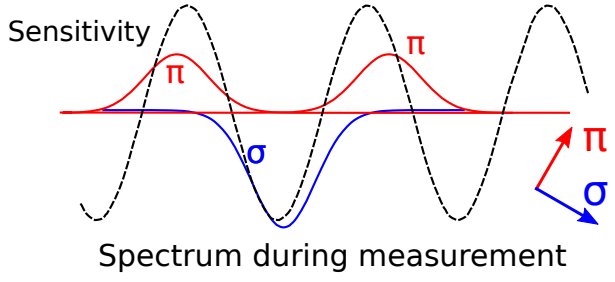




Beam has very low contrast, because the system is optimised for σ and π interferrograms to add when polarised at 90°.



Spectrum during measurement

Intrinsic Contrast Calibration

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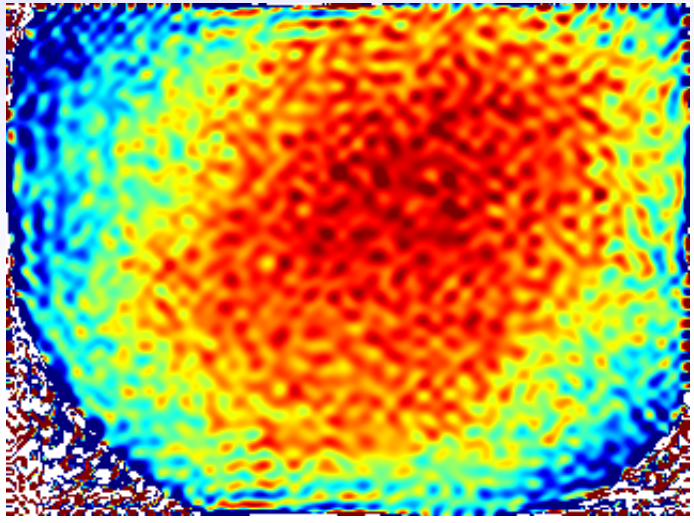
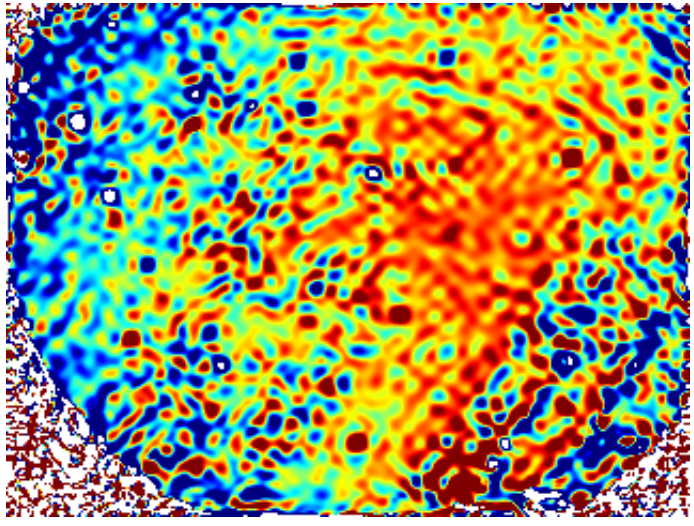
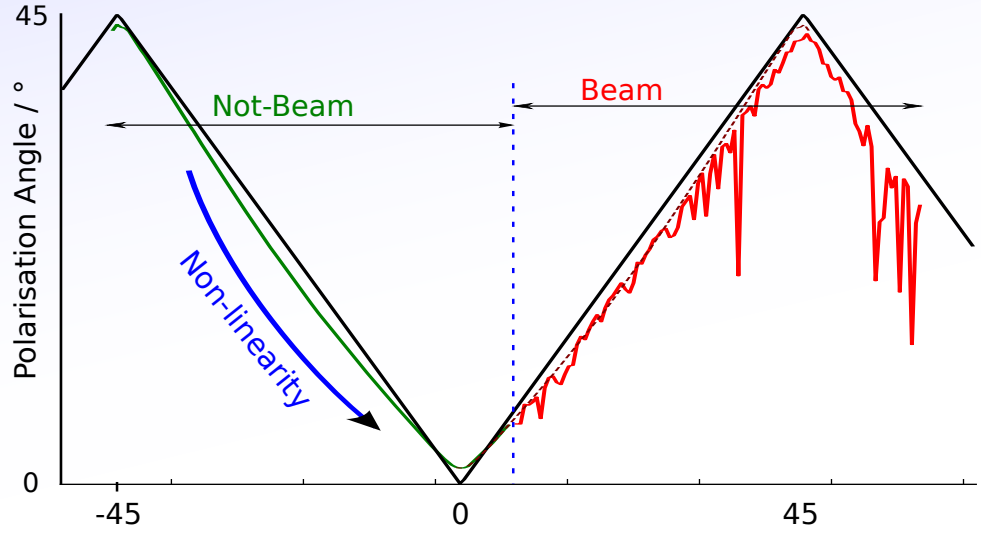
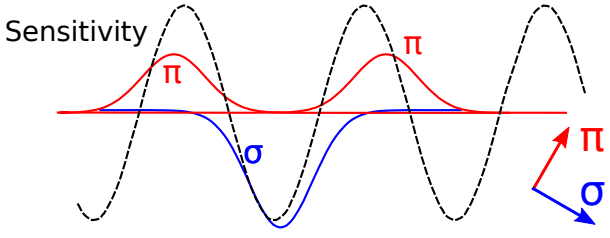


Beam

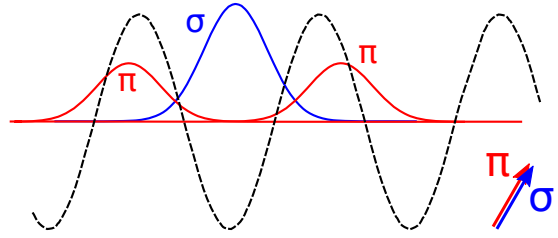




Beam has very low contrast, because the system is optimised for σ and π interferrograms to add when polarised at 90°. With calibration polariser, they are parallel so the system is now 'optimised' for them to destructively interfere.



Spectrum during measurement



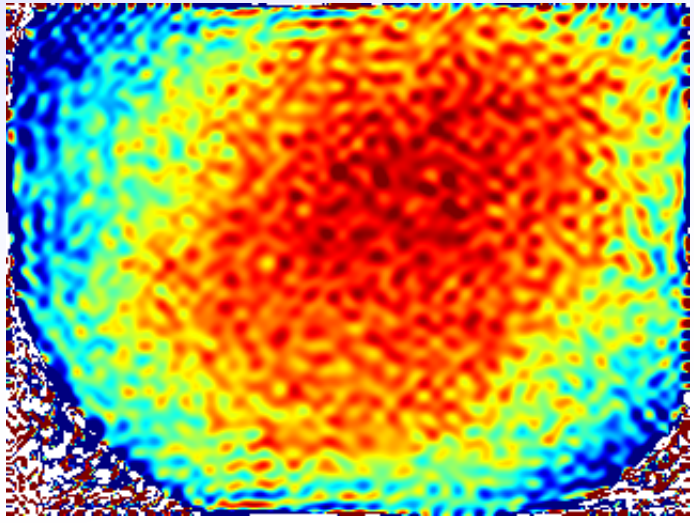
Spectrum during calibration

Intrinsic Contrast Calibration

Oliver Ford
IPP Greifswald

Calibration of non-linearity requires the polariser to be in place during a plasma, with the beam on:

Not-Beam (Dα background)



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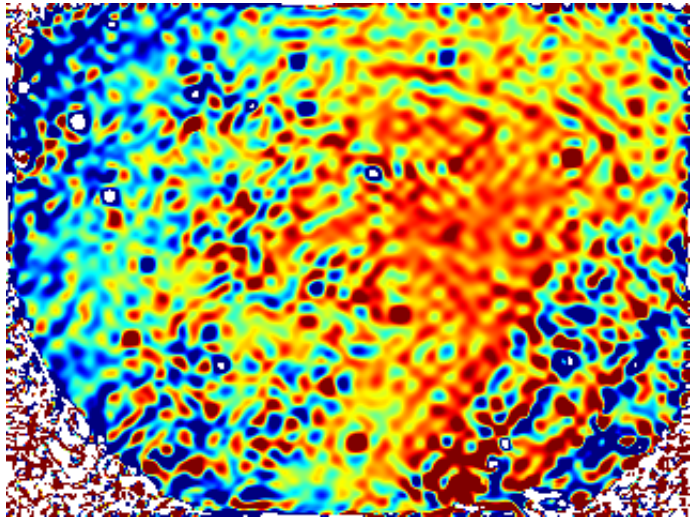

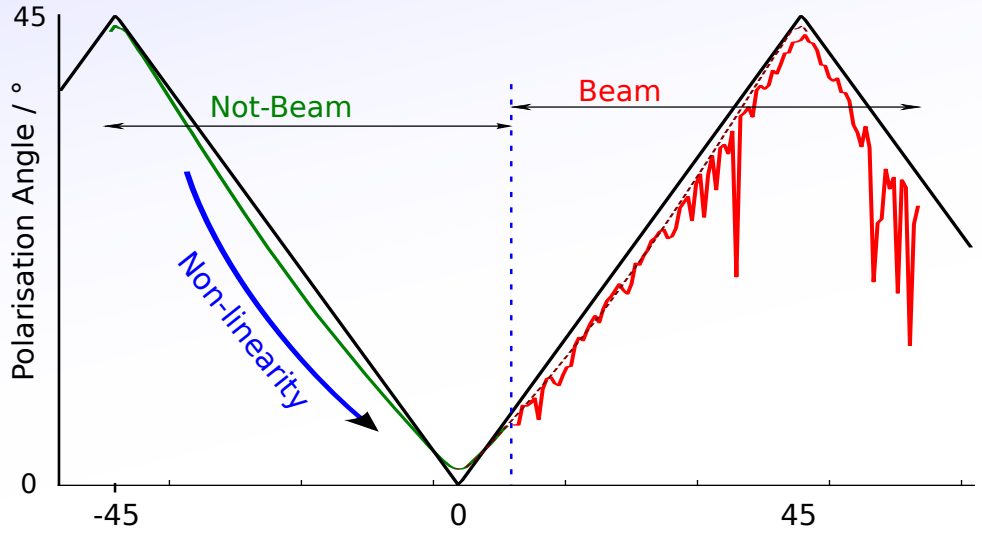

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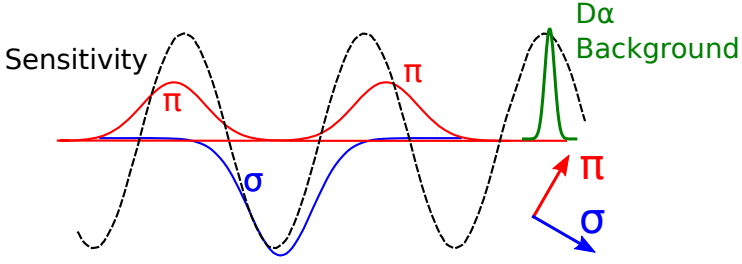
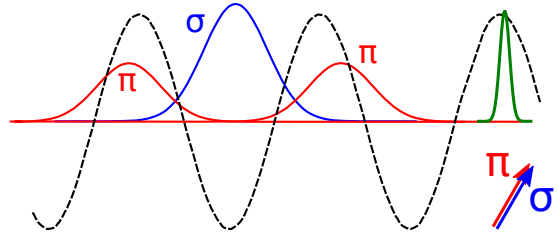


Spectrum during measurement



Spectrum during calibration

Background Dα is a single spectral peak, so remains strong. The January calibration data is mostly from the background, so not reliable.

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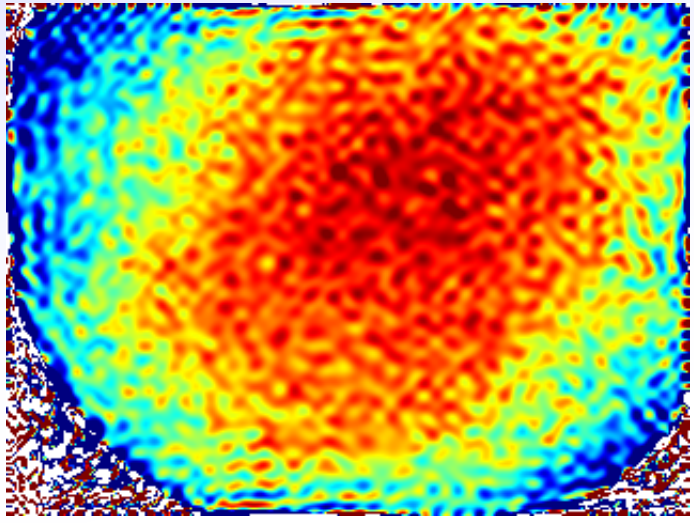
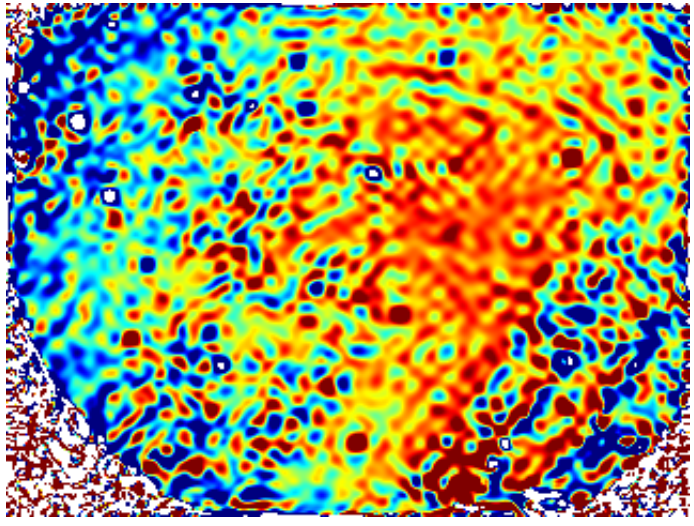
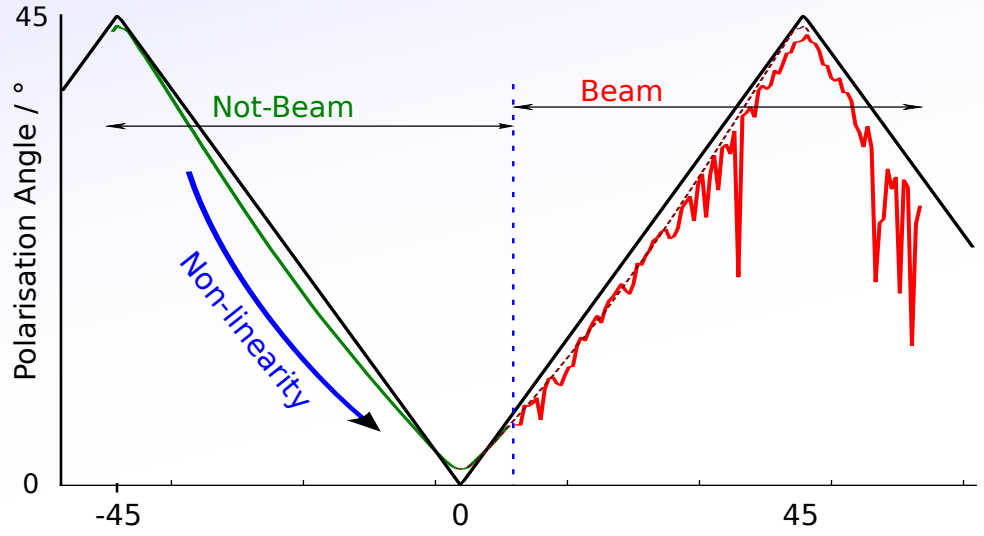


Beam





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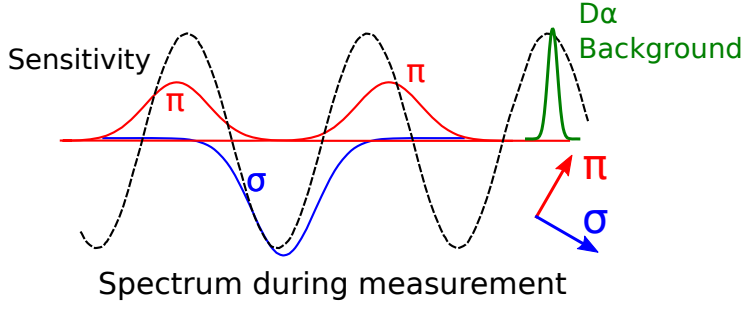

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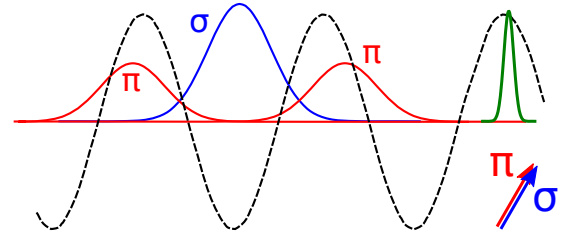

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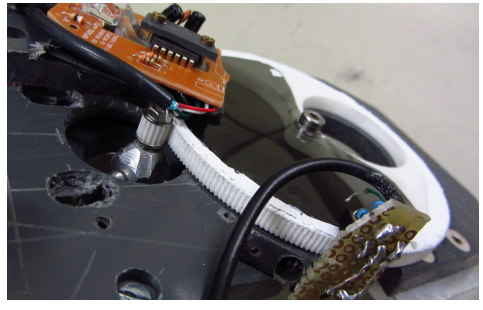
Improvements for April:
- 3D printed polarisation wheel for better accuracy.



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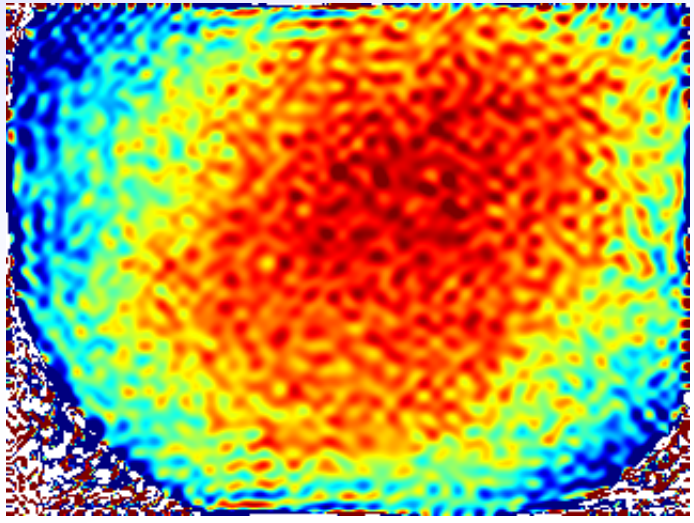

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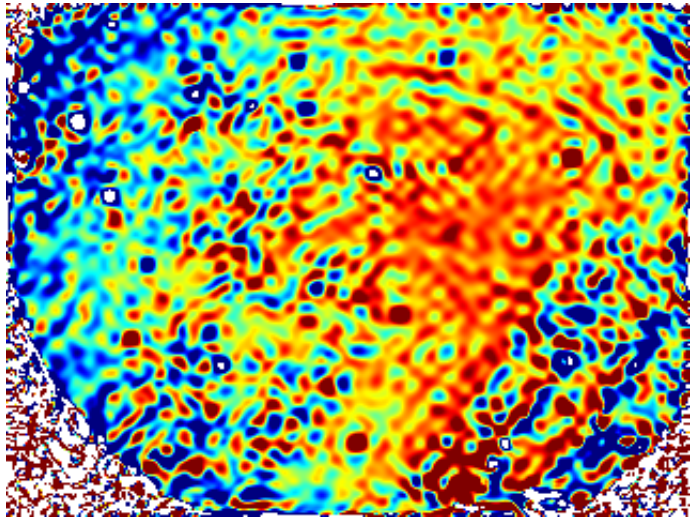

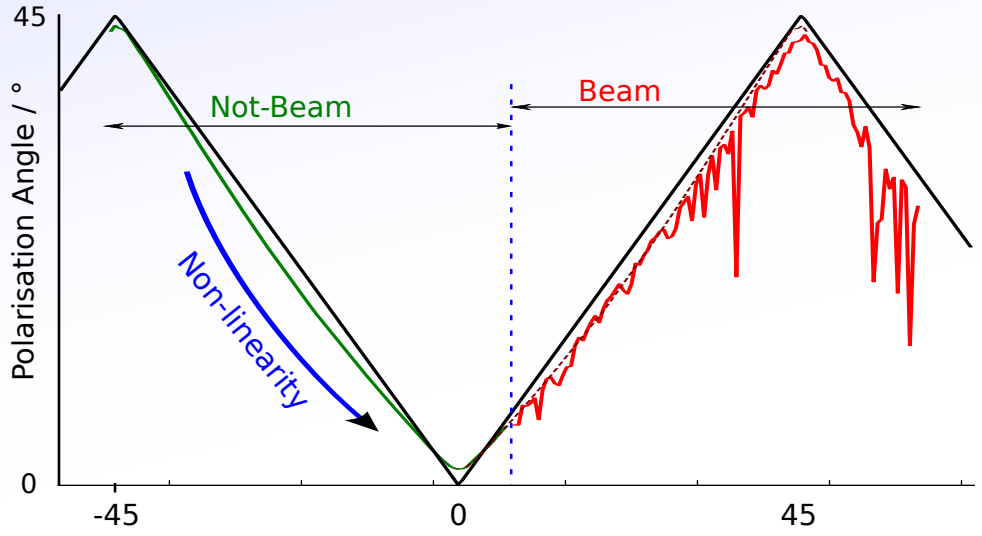

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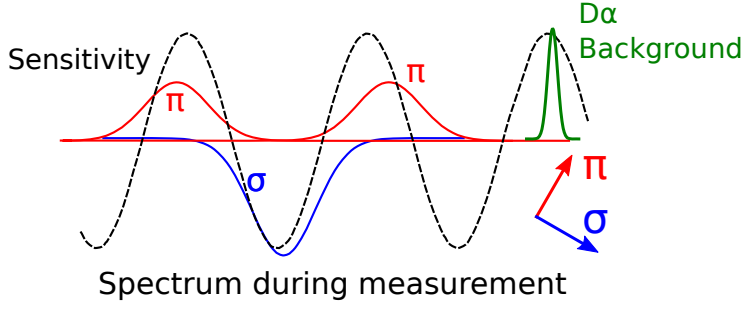

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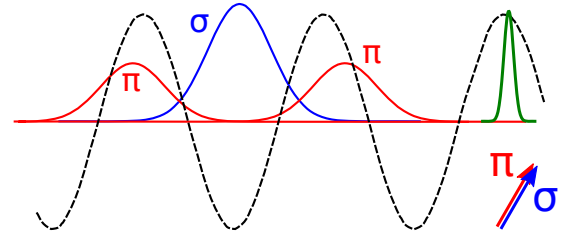
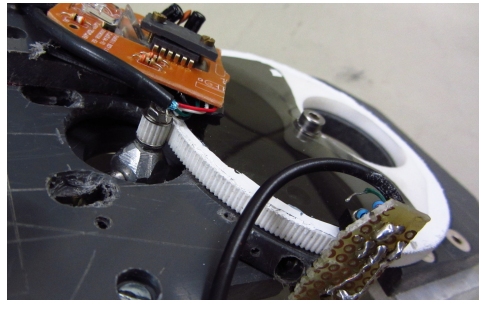


Spectrum during calibration

Background Dα is a single spectral peak, so remains strong. The January calibration data is mostly from the background, so not reliable.

Improvements for April:

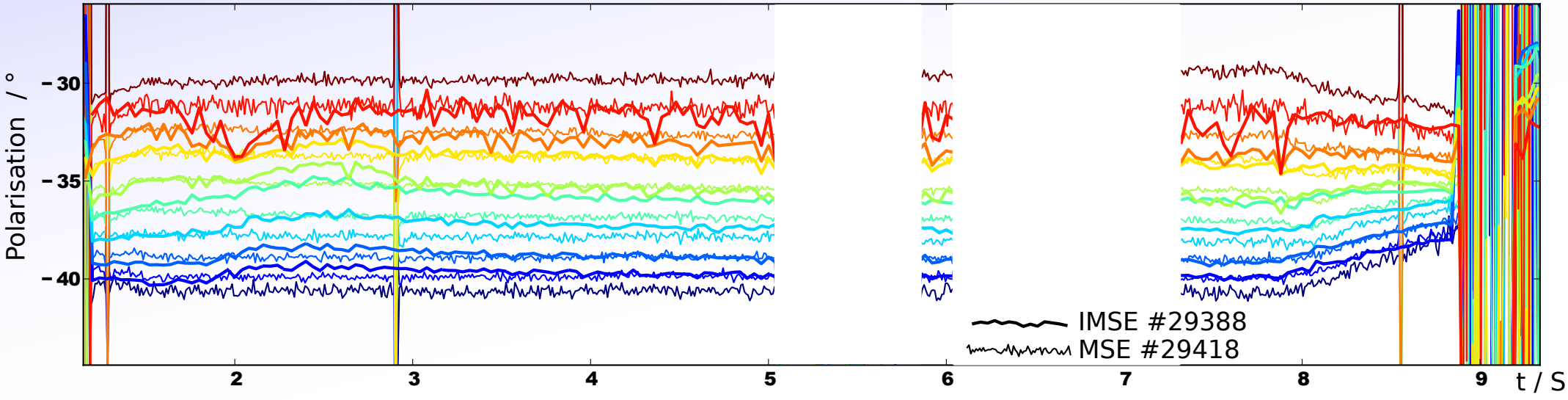
- 3D printed polarisation wheel for better accuracy.
- Increase stepper motor voltage so it works during plasma. (It stopped in Jan due to PF coils fields)
- Calculate best position of polariser for calibration.



Direct MSE - IMSE comparison

Oliver Ford
IPP Greifswald

To compare the IMSE/MSE systems directly the same pulse was run the following week with the MSE system. Used the MSE's a polarising wheel as a common zero reference, so the offset should be correct but 1.1° offset is still required:



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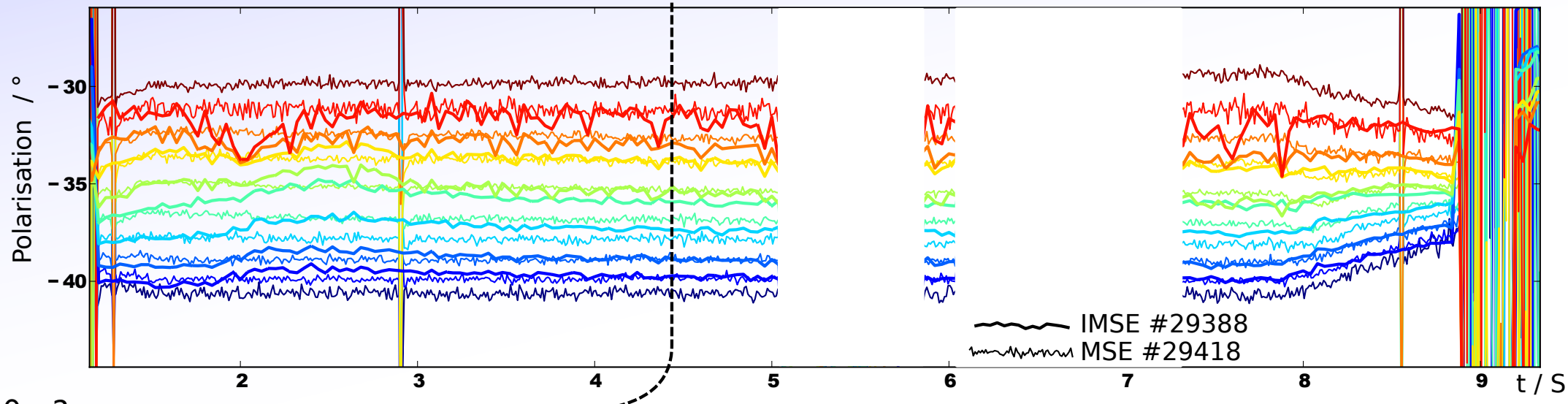
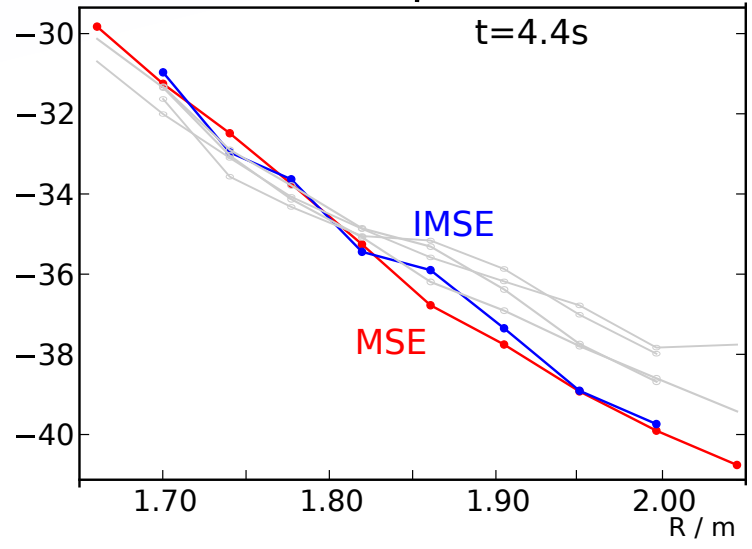


θ - ?



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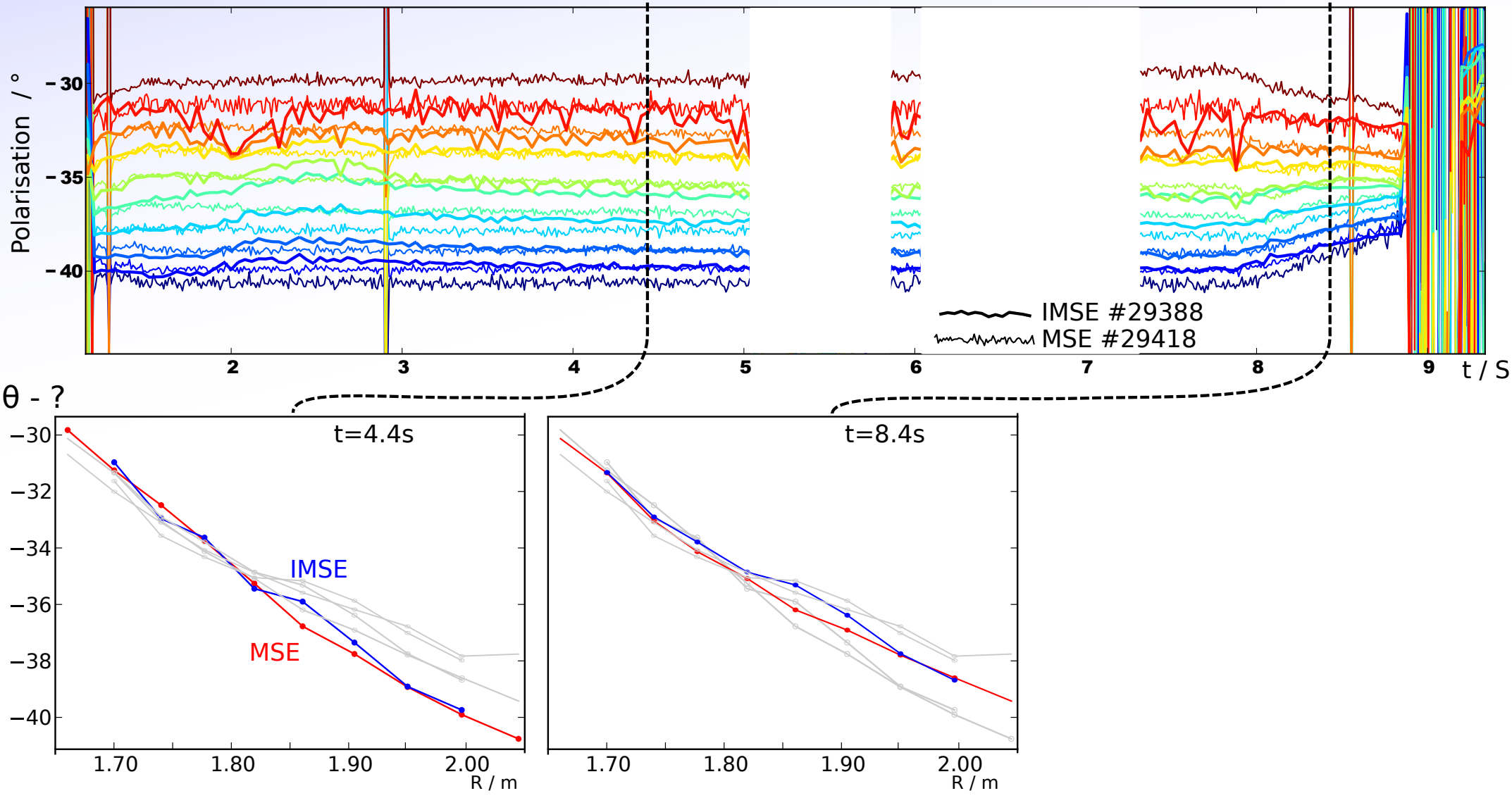

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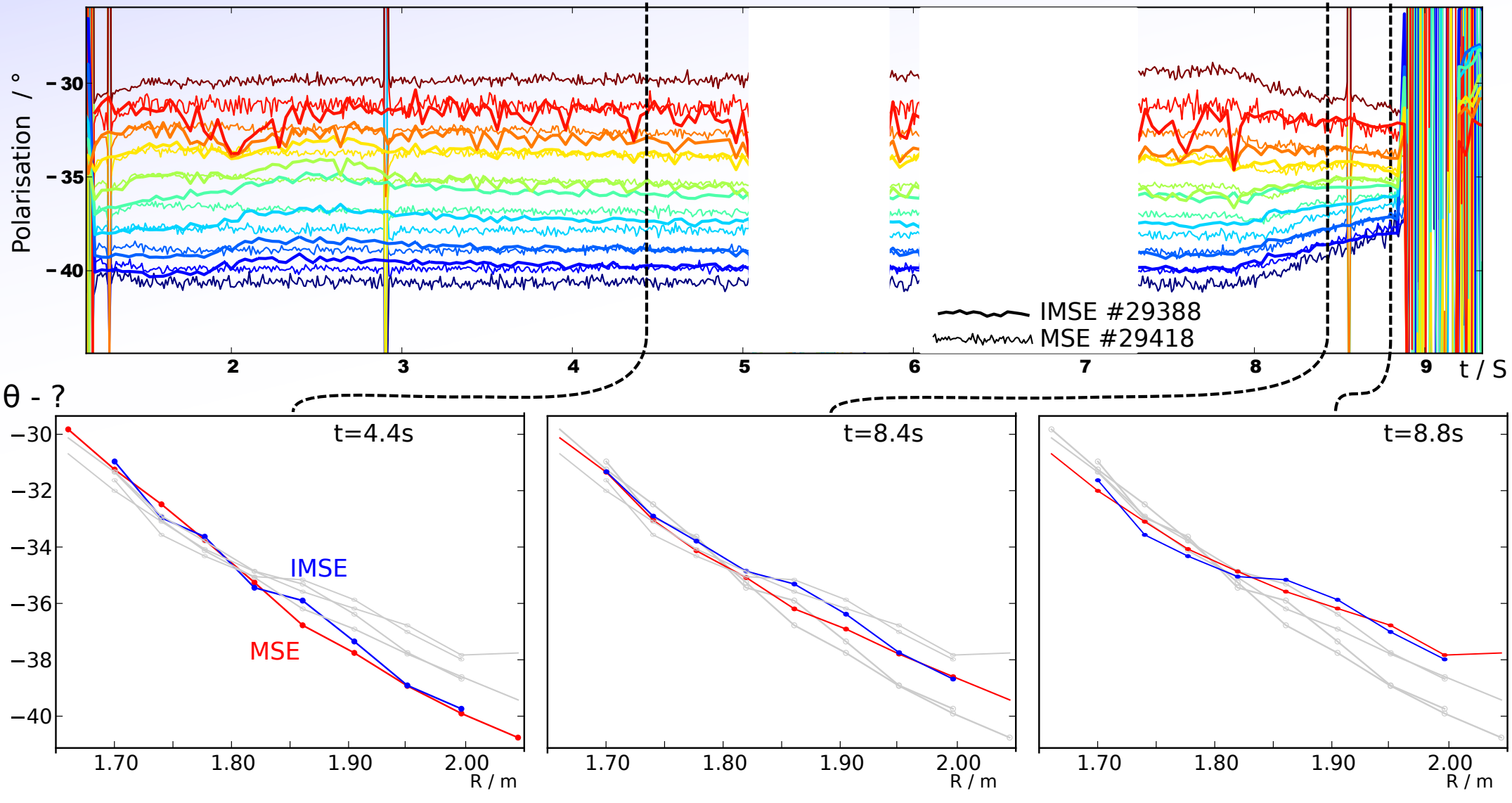

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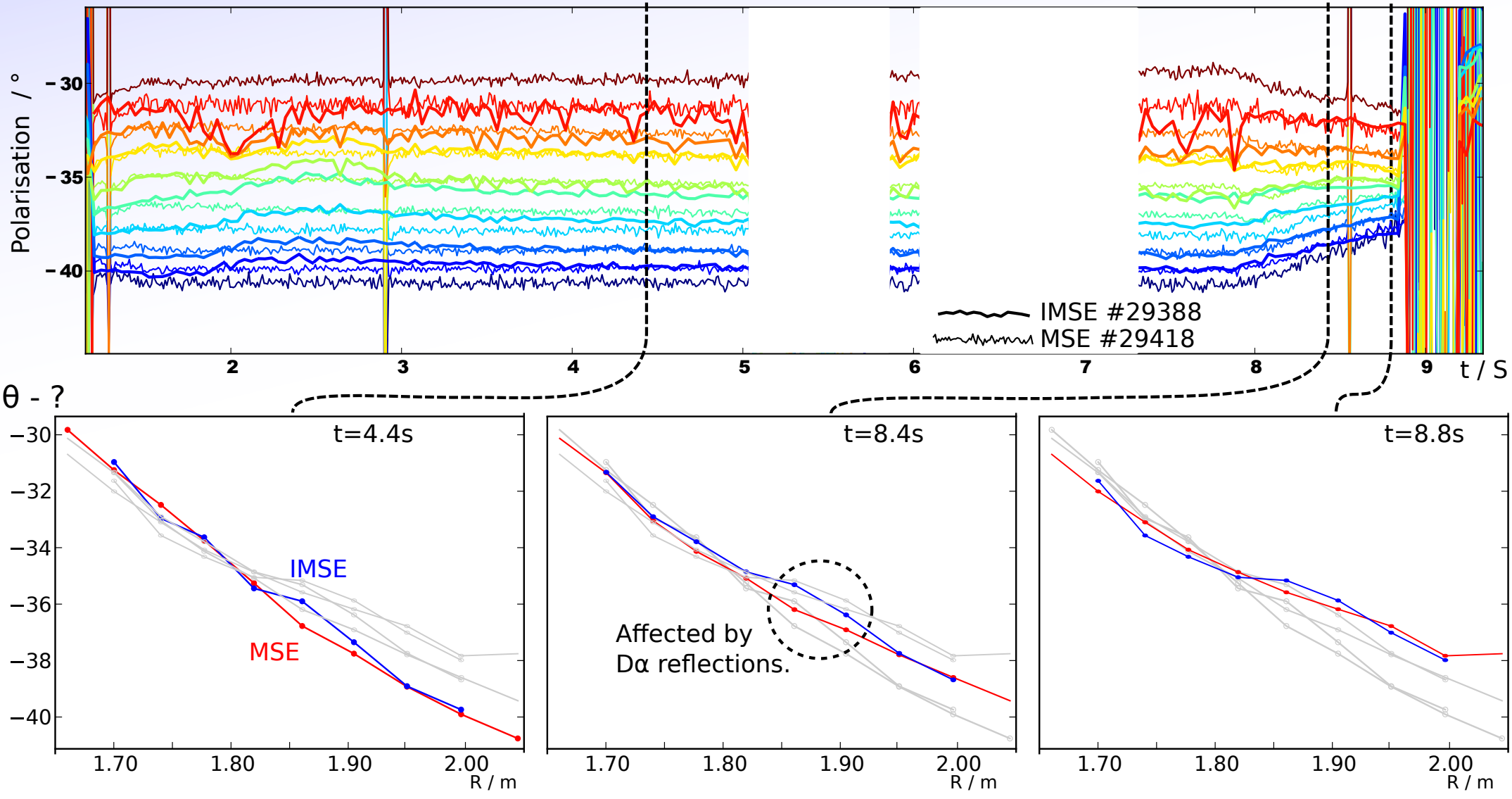


- ✓ Temporal evolution agreement is very good.
- ✓ Spatial agreement is reasonable (despite calibration problems)
- ✗ An unidentified offset of 1.1° remains.

Oliver Ford
IPP Greifswald

Reflections - Background Dα

During H-mode / high density operation, Dα light reflecting from background structure contaminates the signal.

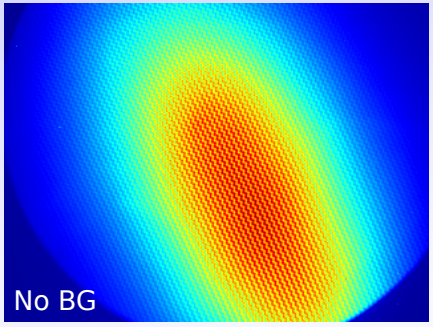
Particularly bad during detachment and pellets but also makes data unusable during most high power H-modes.

No BG

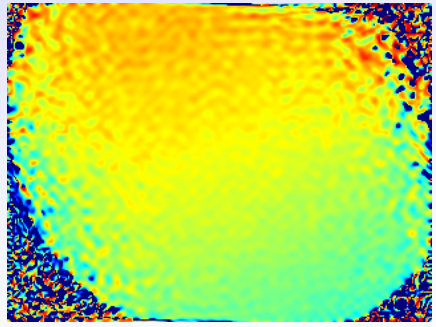
Reflections - Background Dα

Oliver Ford
IPP Greifswald

Image



Polarisation:



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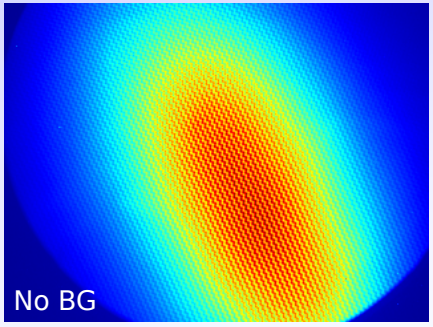

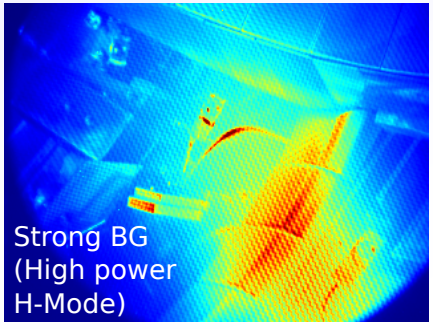

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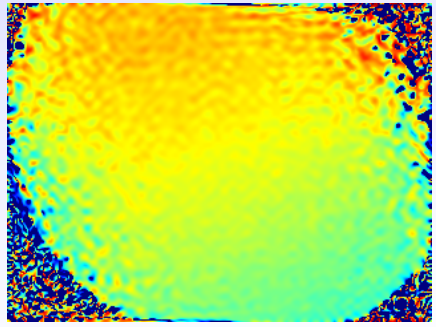

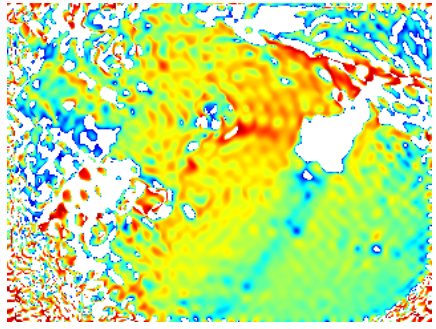

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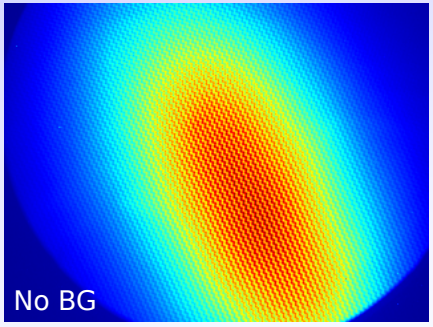

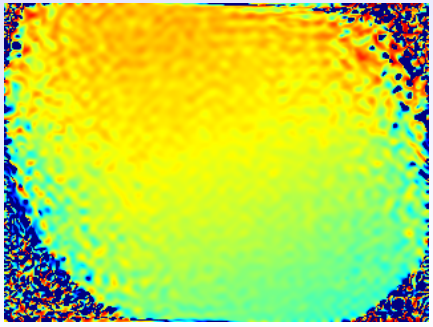

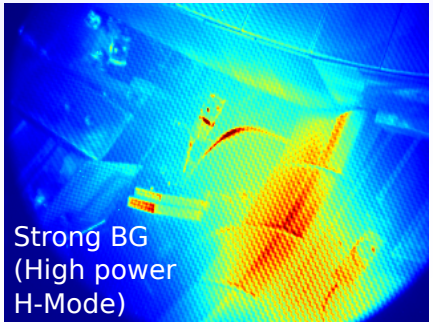

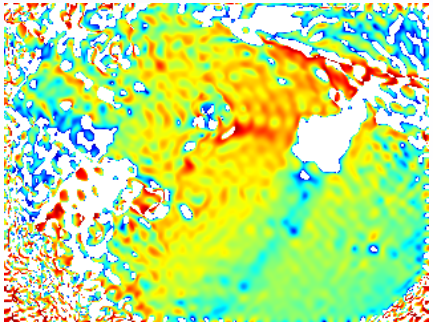

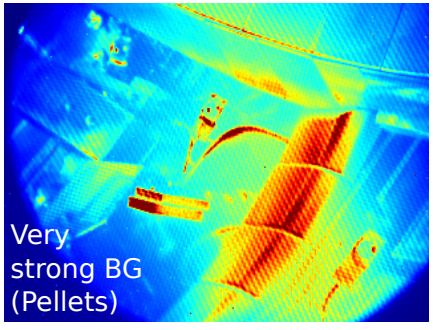

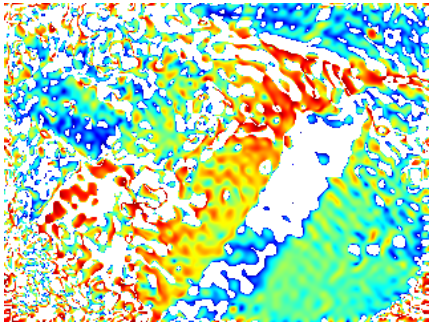

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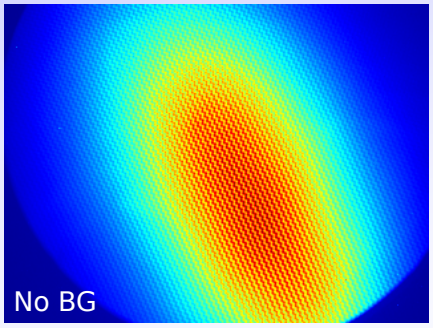

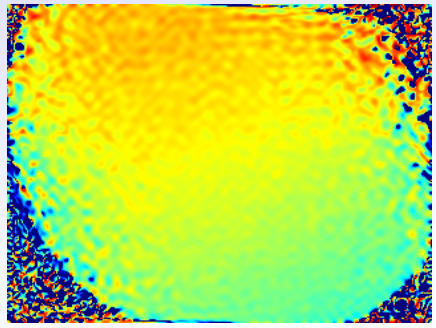

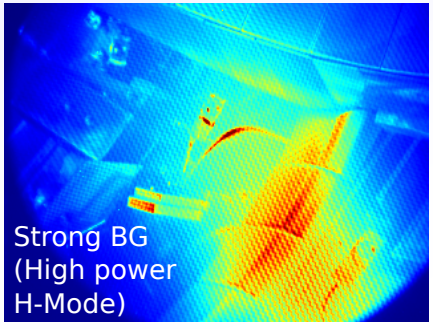

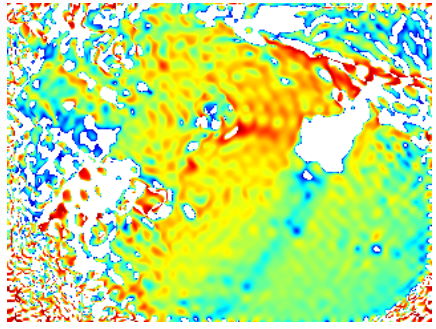

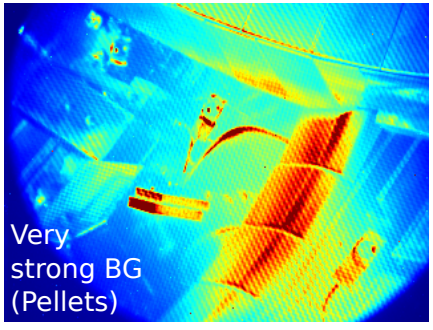

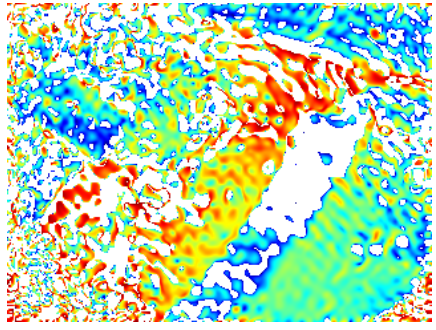

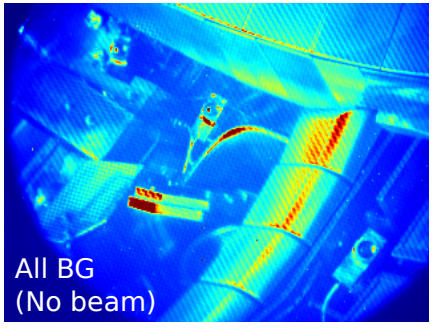

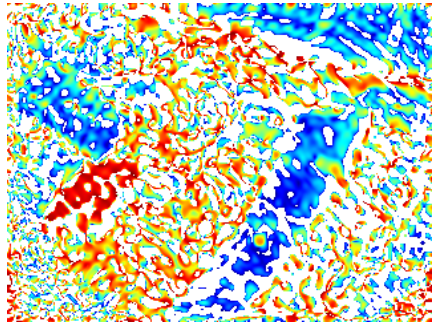

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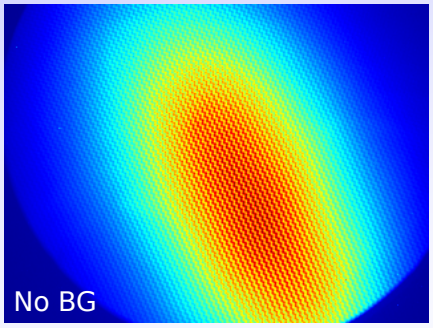
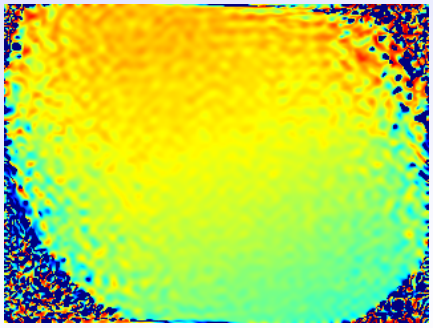
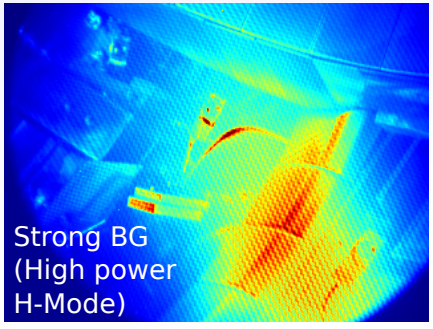
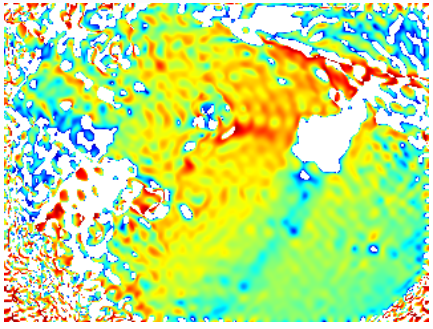
Image

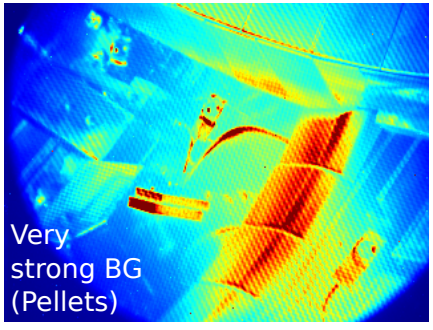
Polarisation:

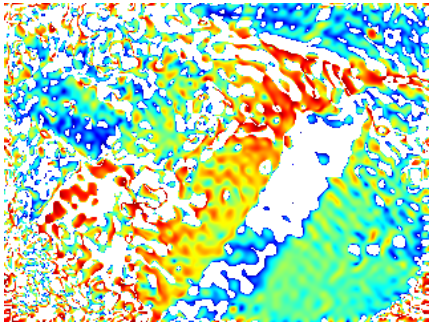


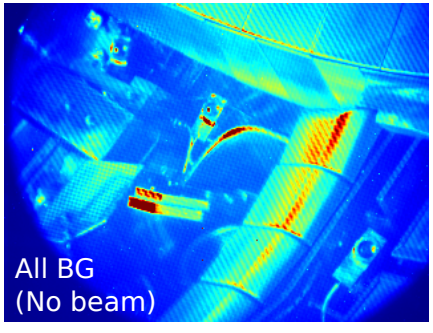


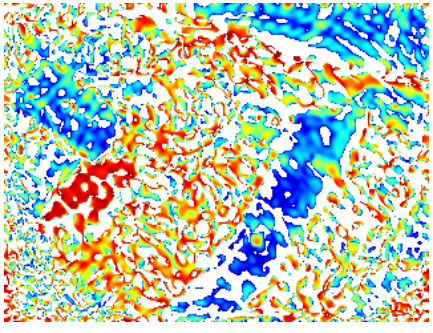












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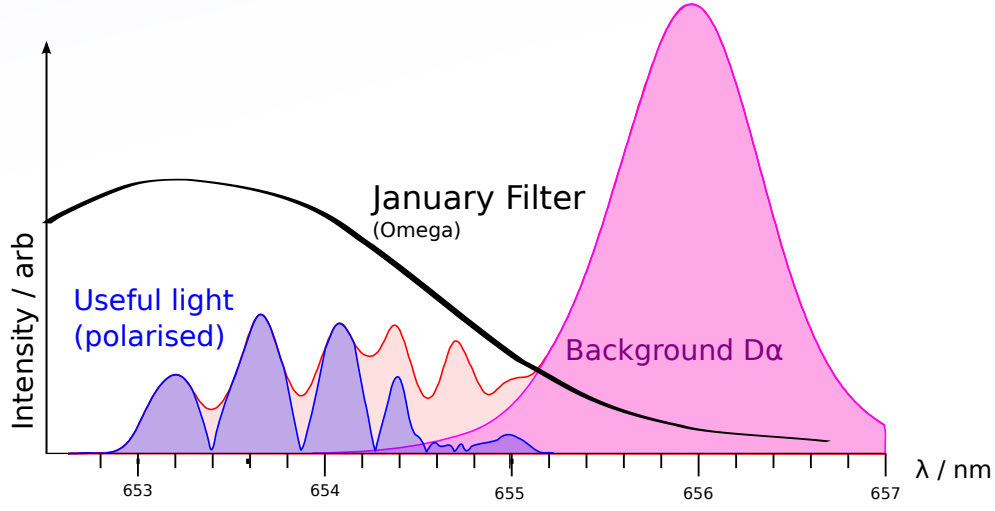
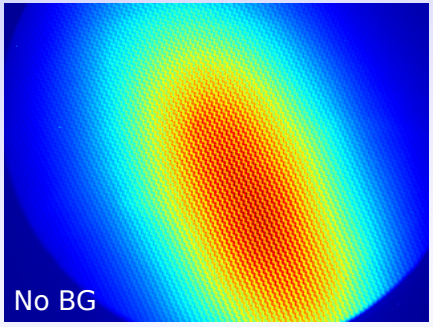
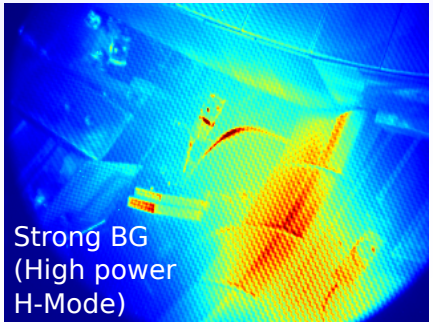


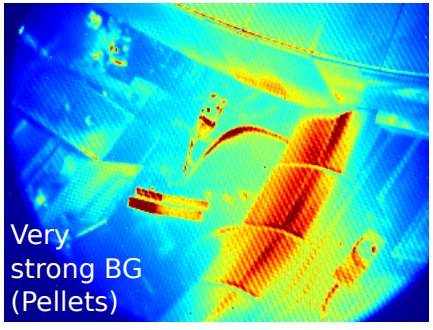
Reflections - Background Dα

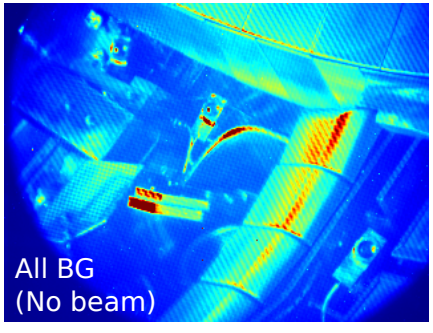
Oliver Ford
IPP Greifswald

Image









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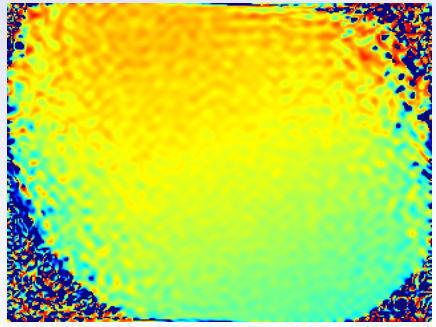

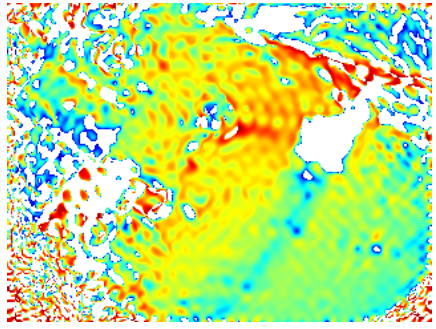

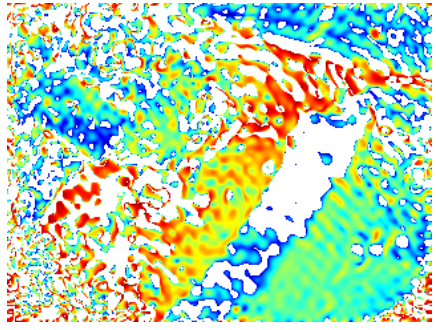

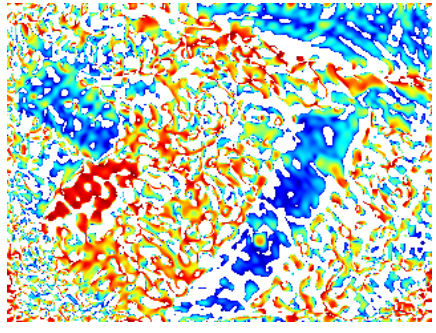

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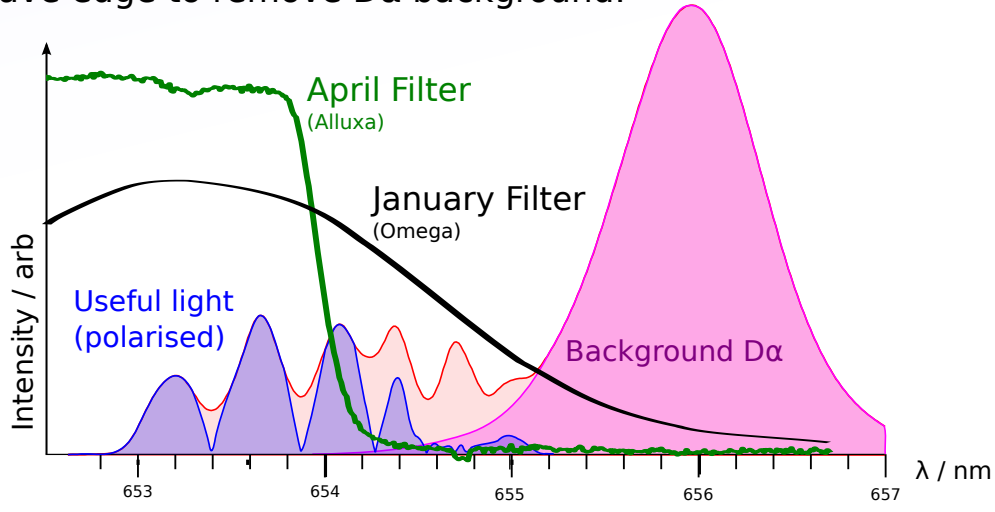

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Oliver Ford
IPP Greifswald

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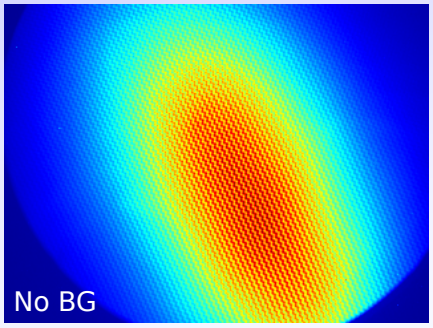

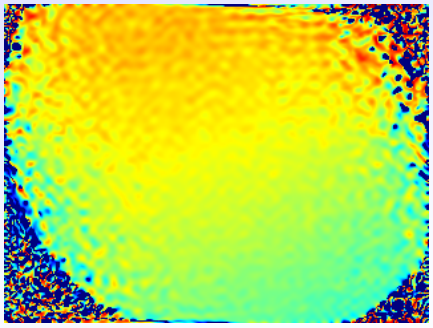

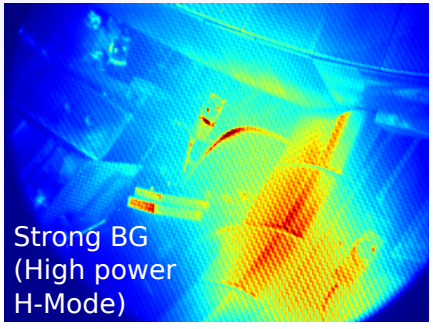

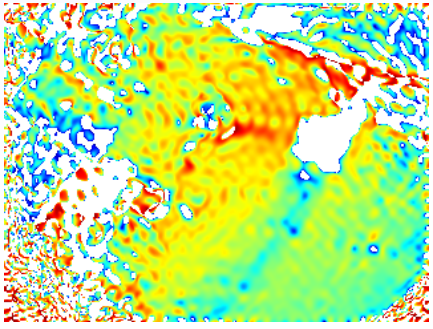

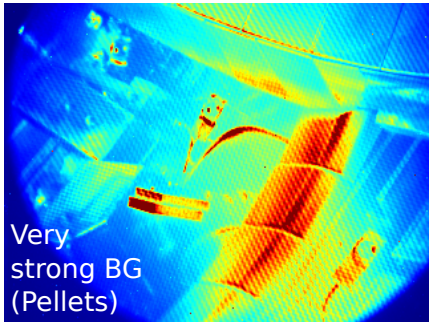

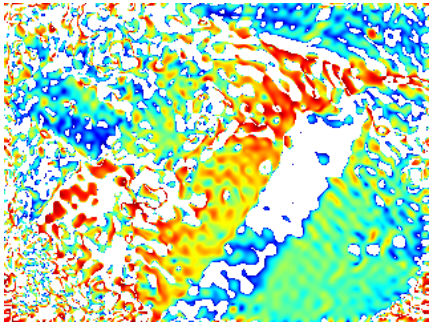

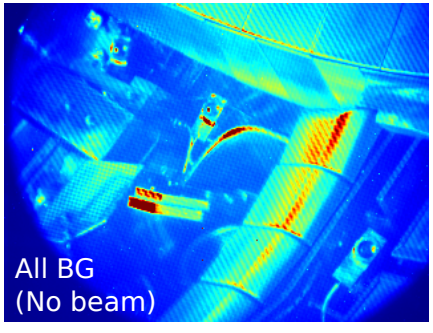

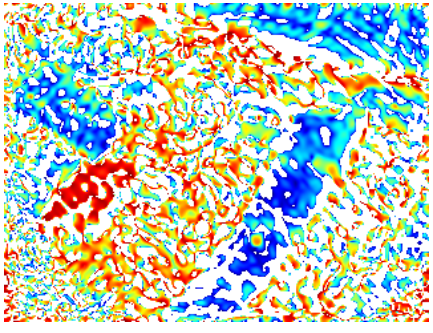

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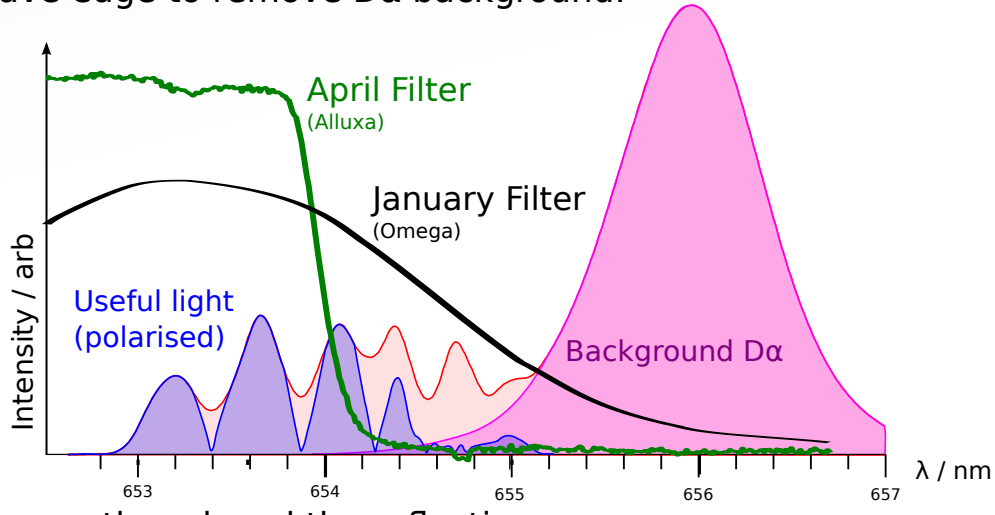
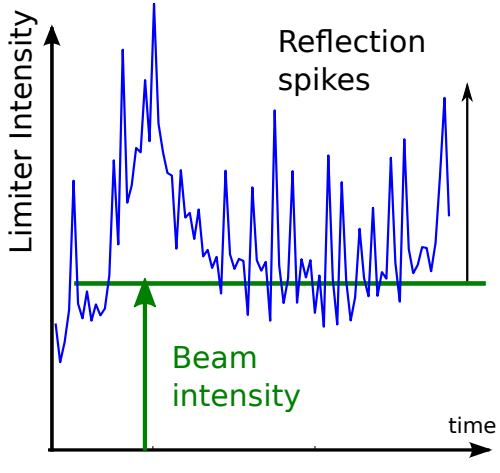
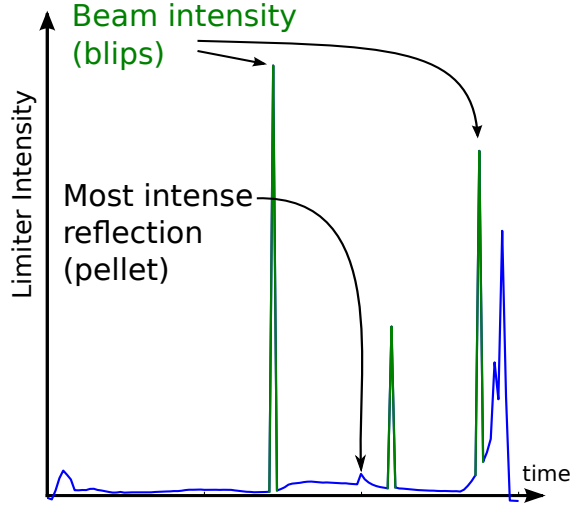


New filter greatly reduced the reflections:





Oliver Ford
IPP Greifswald

April 2013 Results overview

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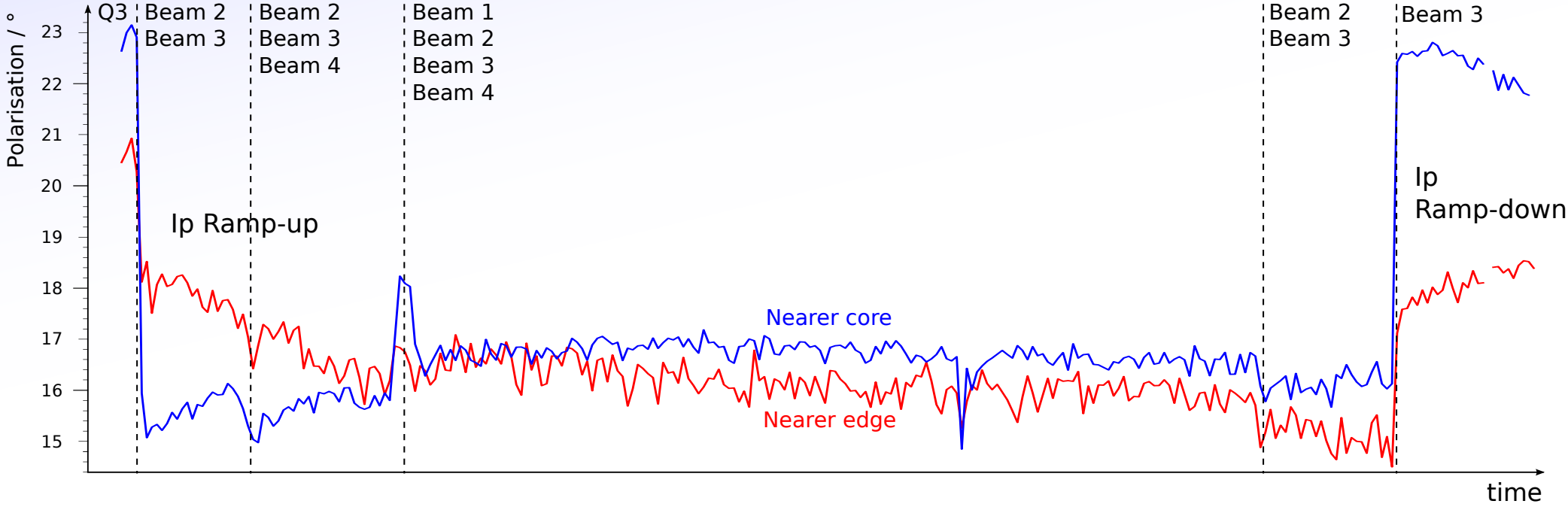

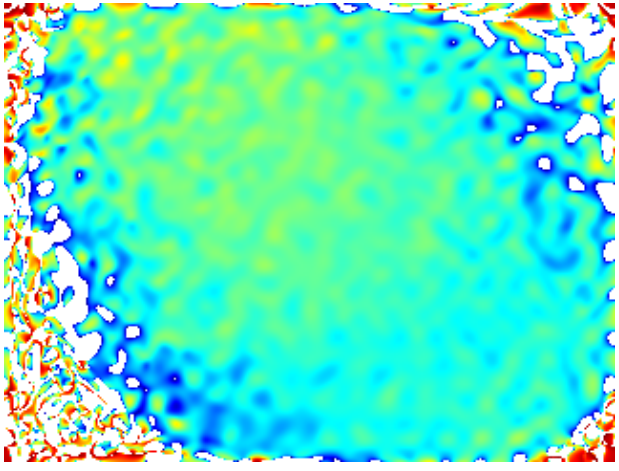

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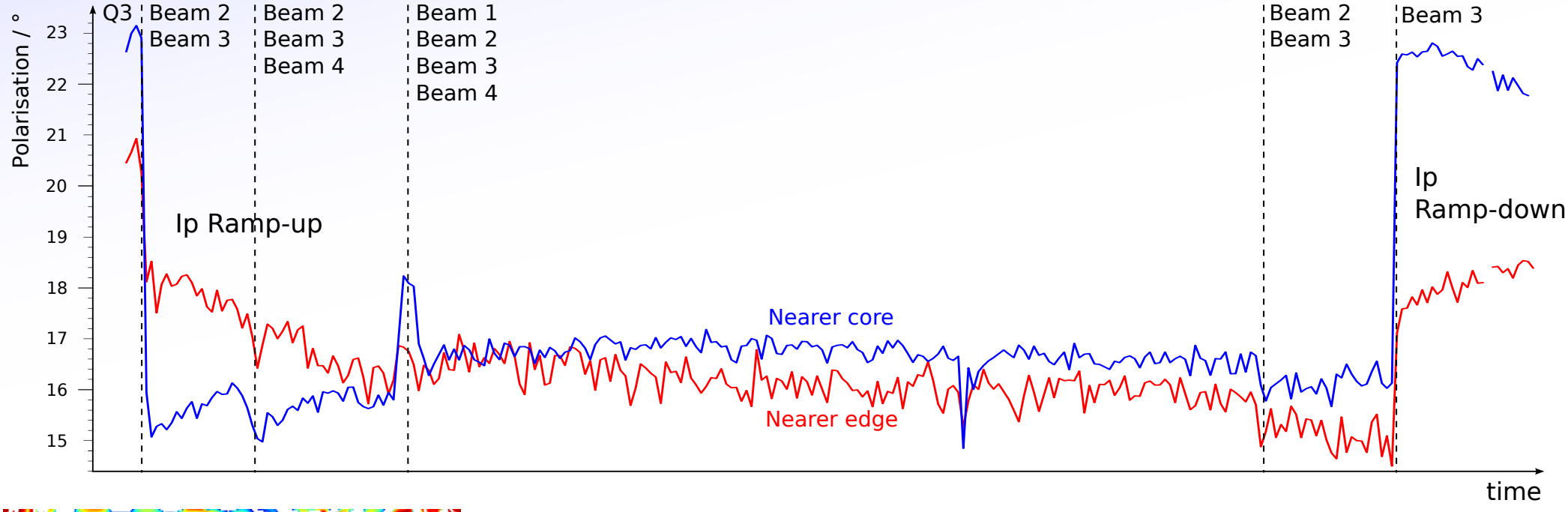

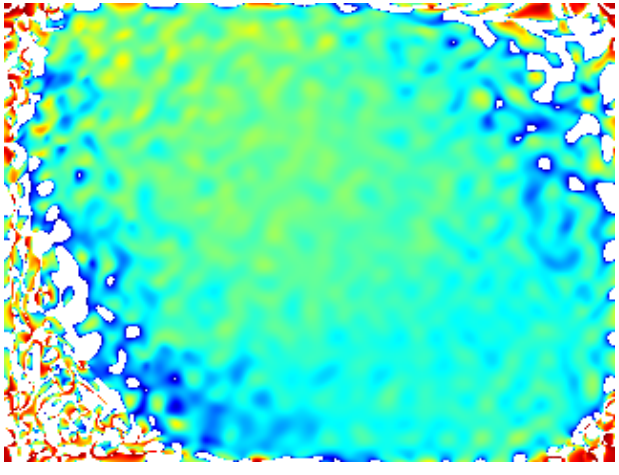

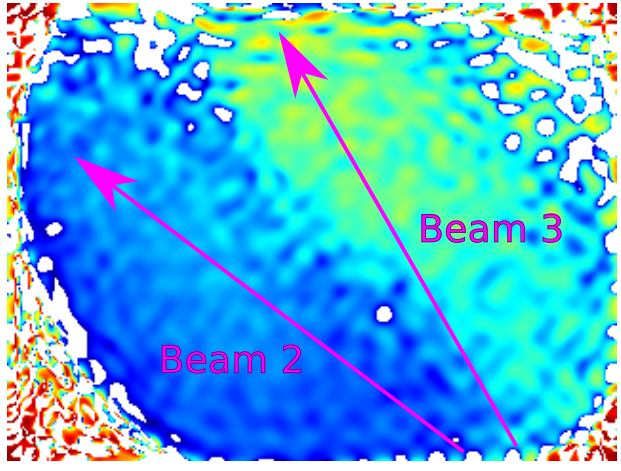

All H-Mode data is unfortunately mixed-beam.

In principle, still possible to use but it will much longer to analyse as it requires knowing the beam geometry and attenuation very accurately.

The beam information is much better separated than my model predicted - so need to improve the beam model and fit the beam waist and divergence.

Absolute Angles

Oliver Ford
IPP Greifswald

Attempt to predict absolute polarisation angles at IMSE instrument entirely from first principles, to be compared to the measurement later. No calibrations, arbitrary shifts, offsets or flipping of signs to match the observations allowed (proper blind trial)

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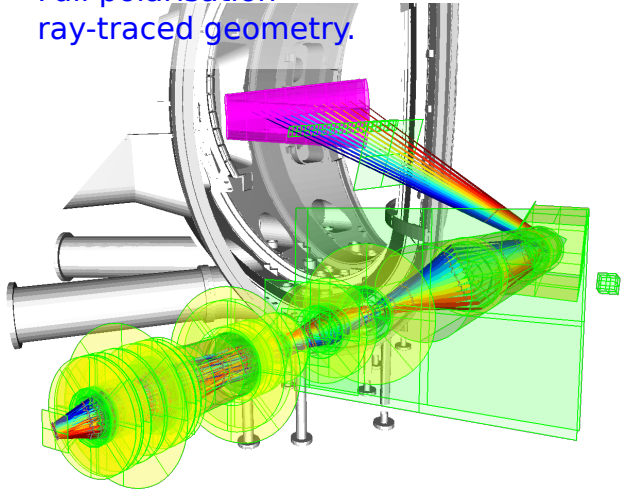
Full polarisation
ray-traced geometry.



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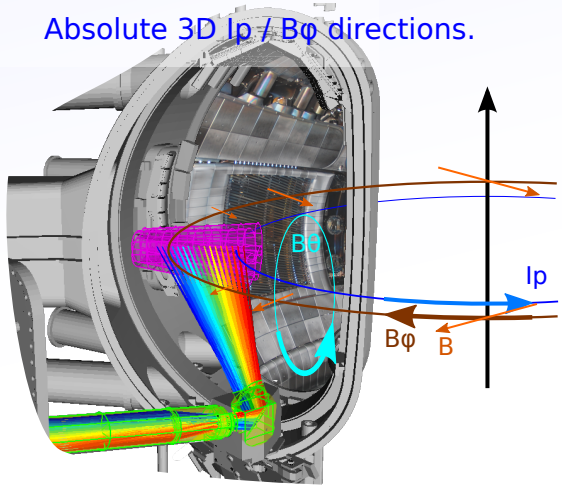

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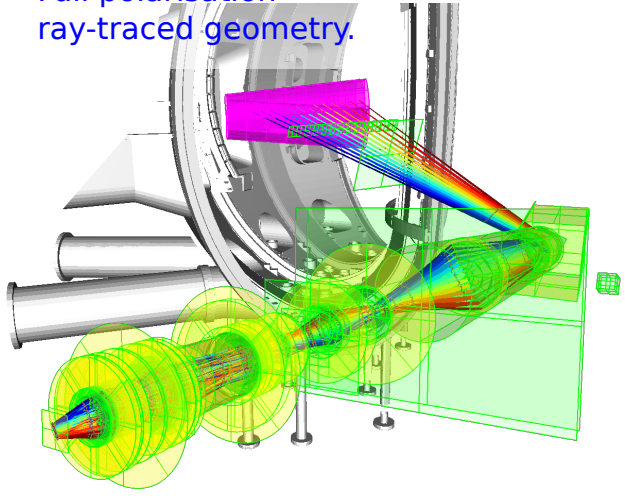

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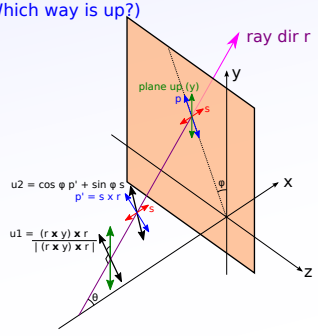
Some subtleties about defining polarisation in 3D
(Which way is up?)



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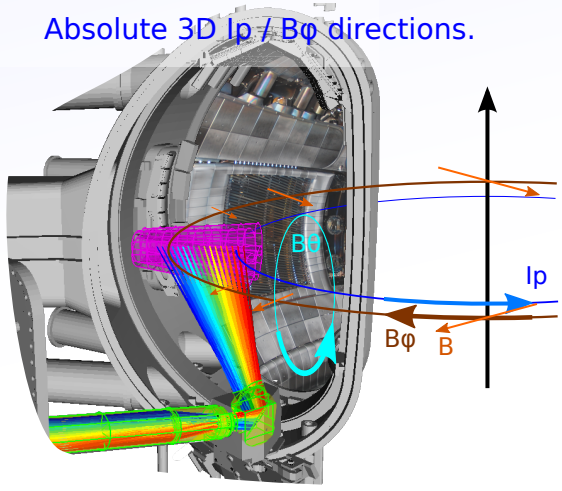

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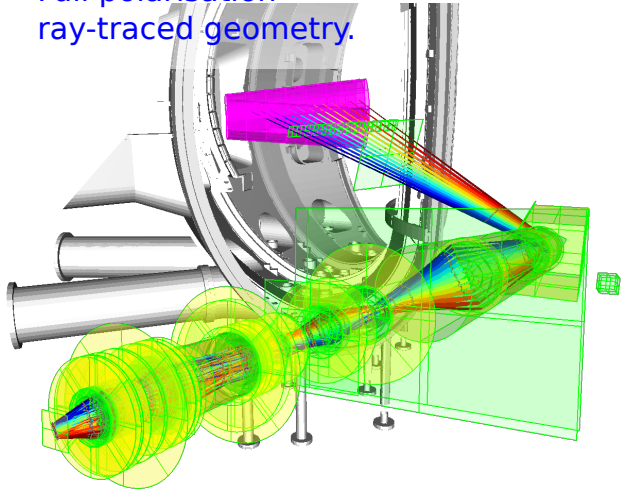

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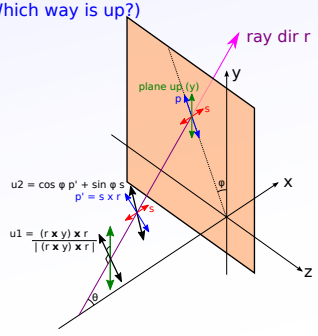

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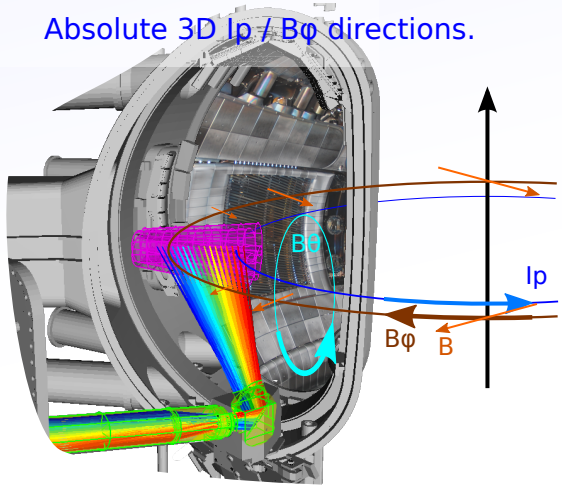

Mirror behaviour

(The spherical cyclops in space problem).



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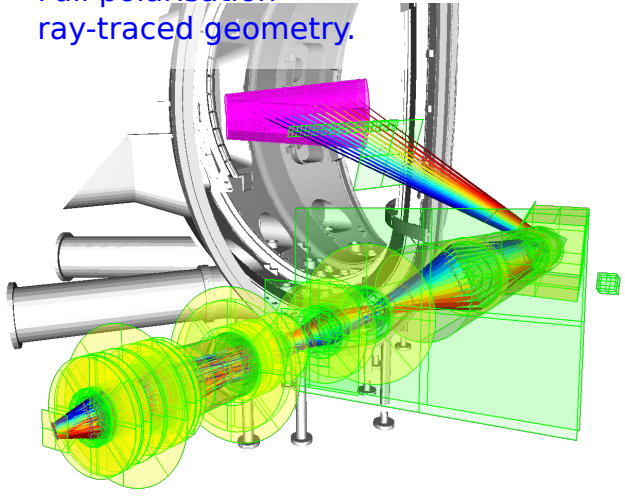

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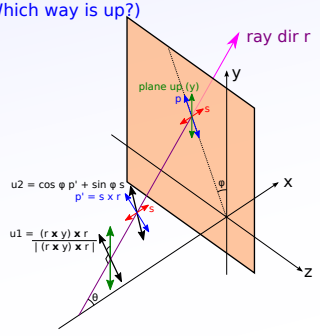

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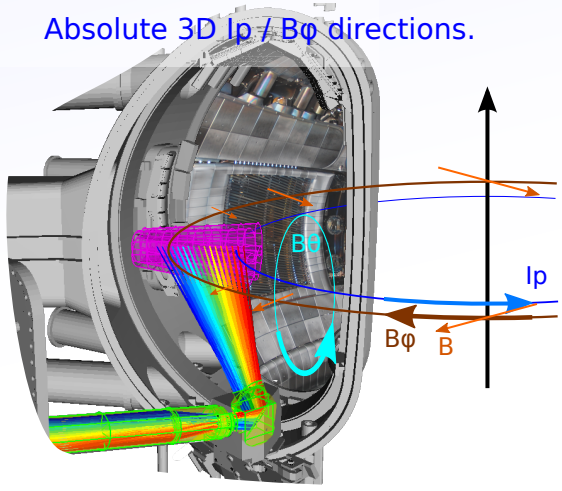

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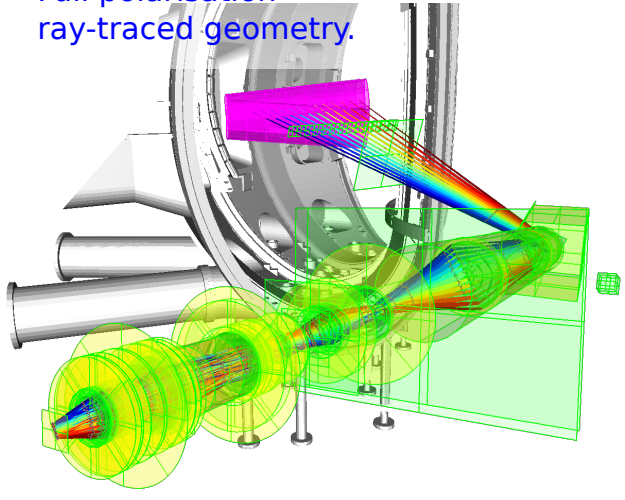
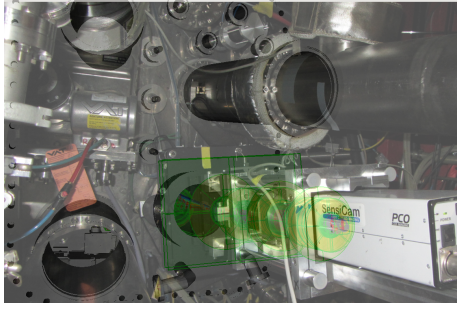


Mounting of IMSE carriage in port flange.



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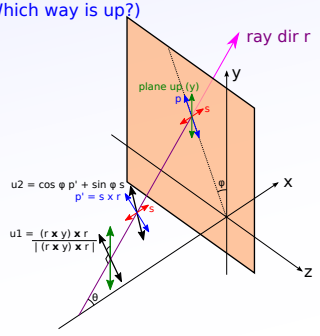

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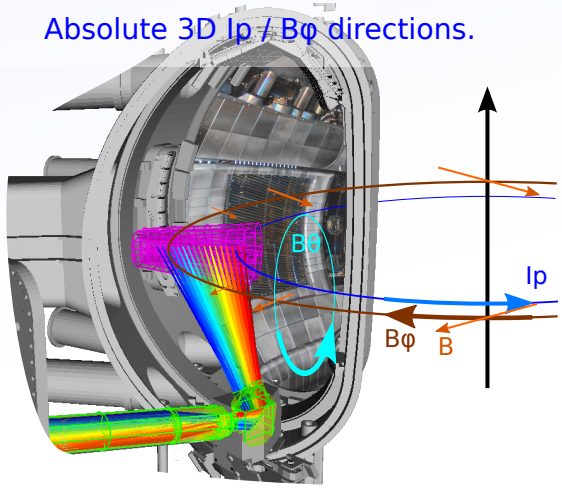
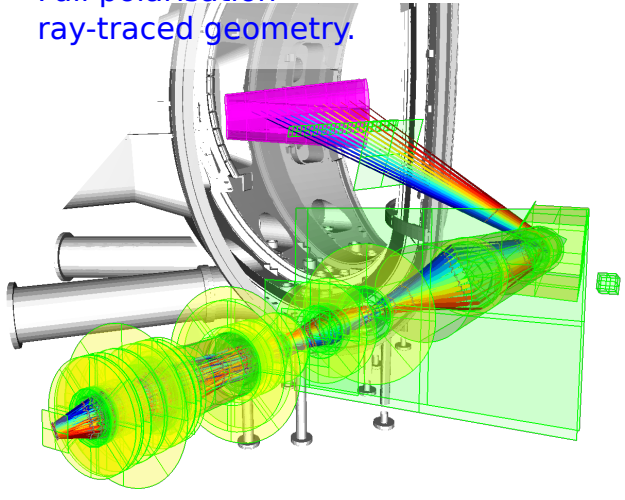


Mirror behaviour

(The spherical cyclops in space problem).



Full polarisation ray-traced geometry.



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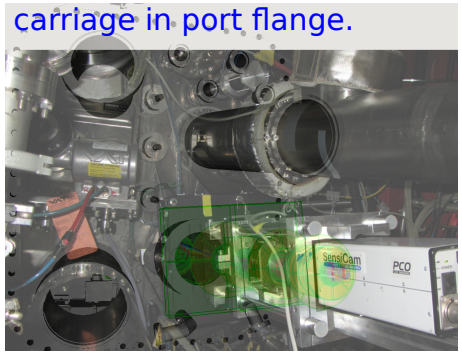

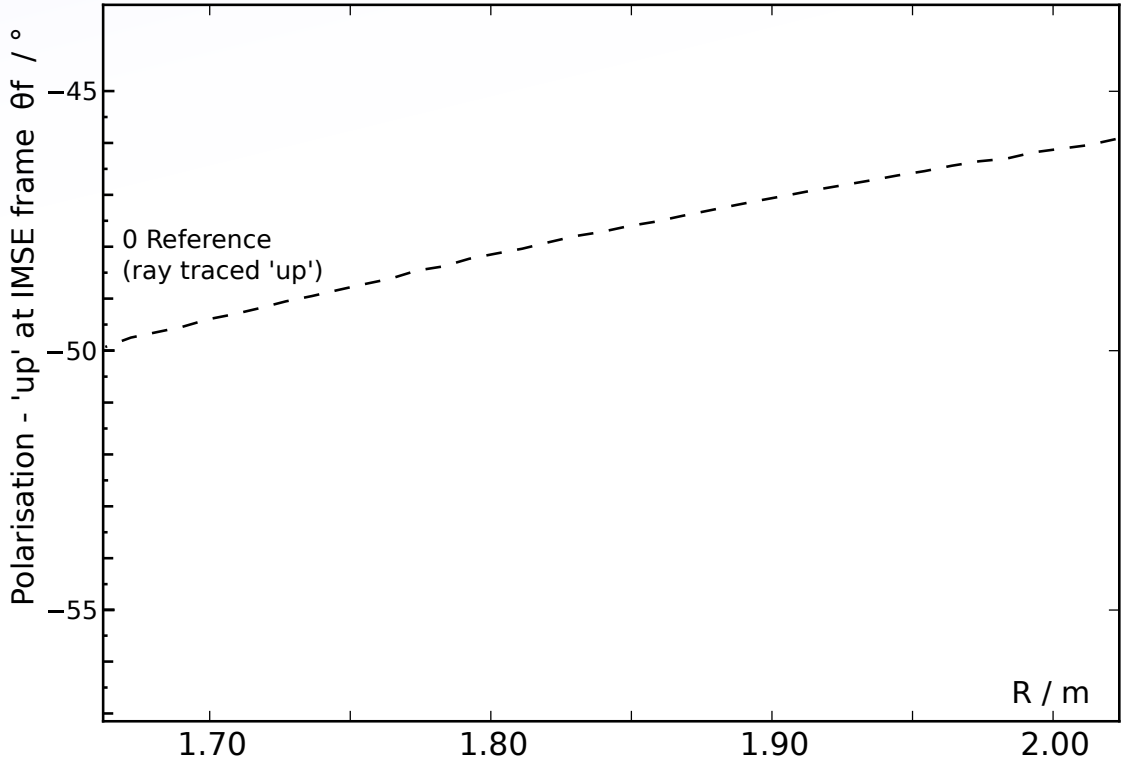

Oliver Ford
IPP Greifswald

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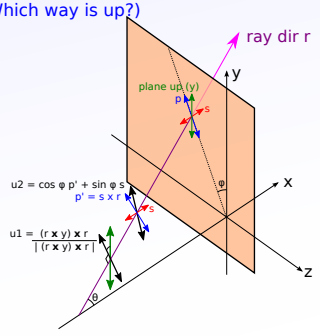

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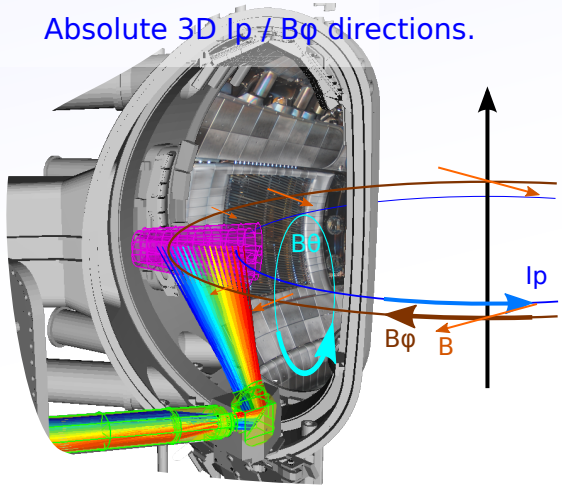

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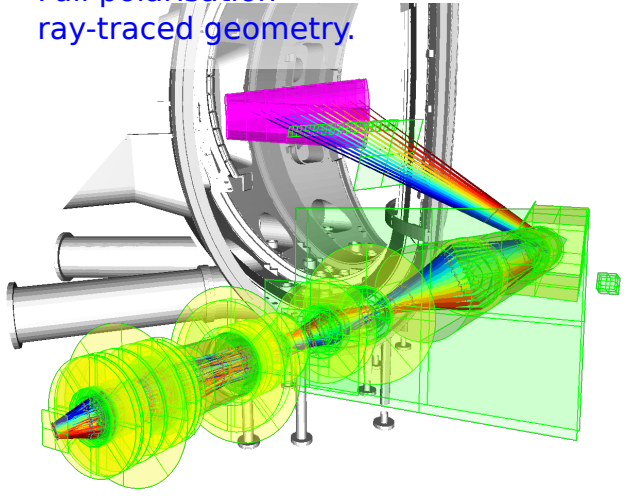

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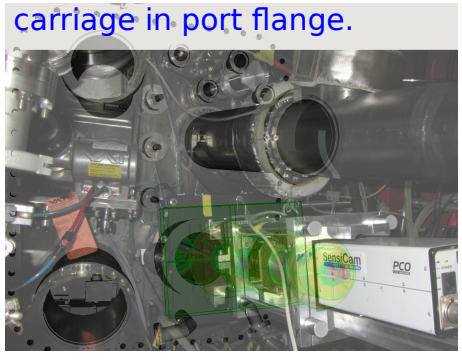

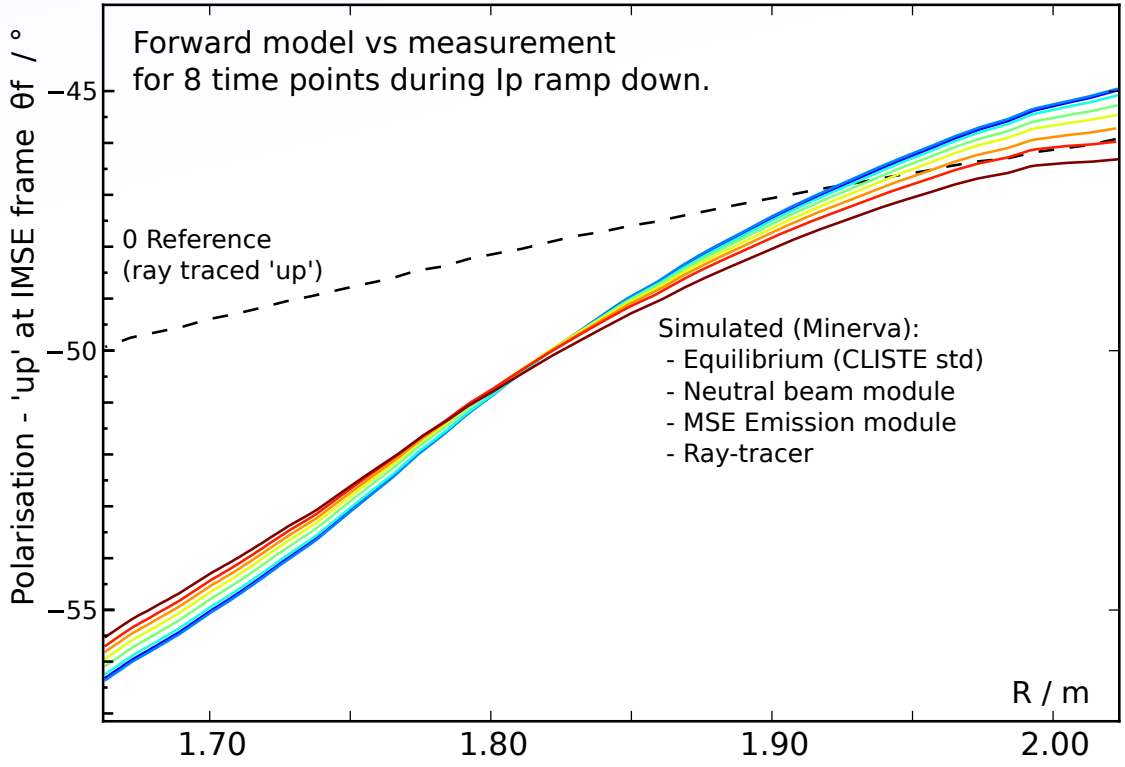

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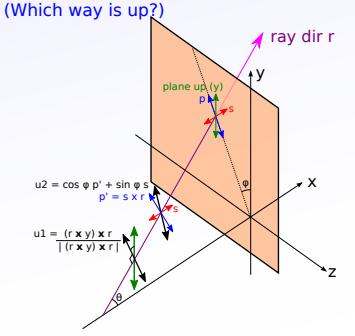

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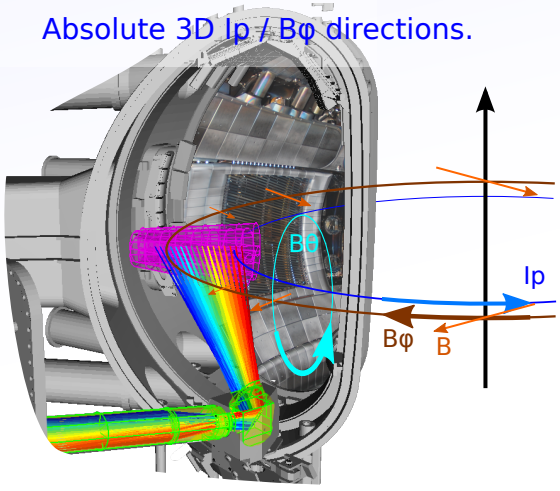

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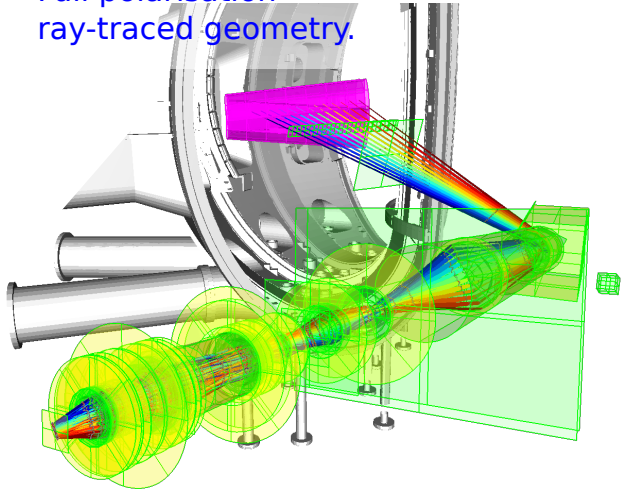

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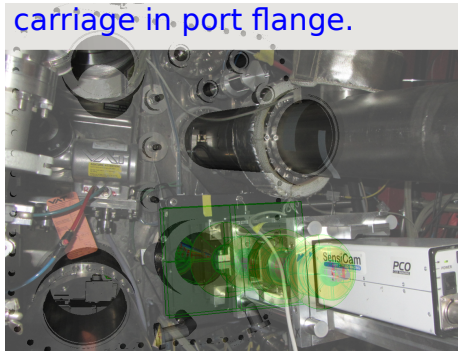

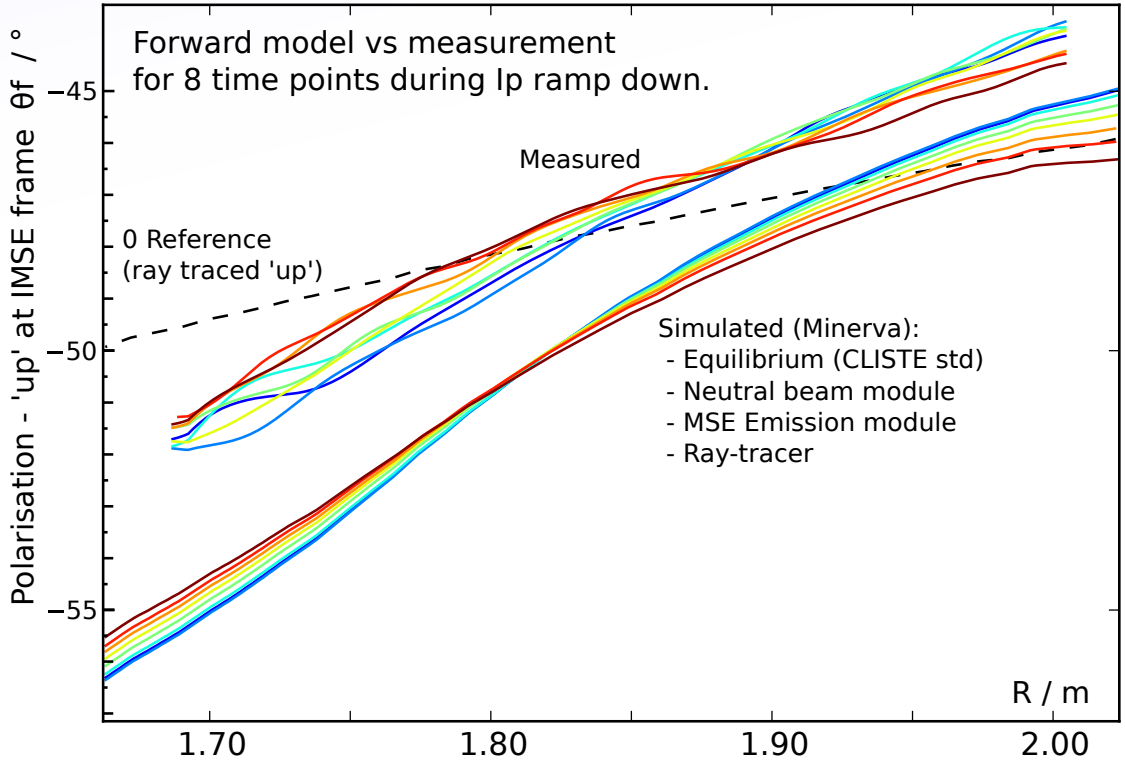

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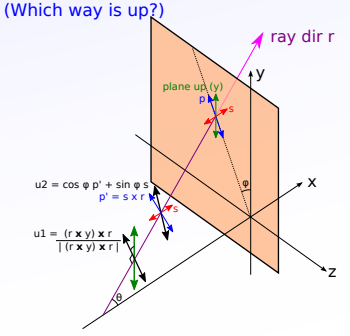

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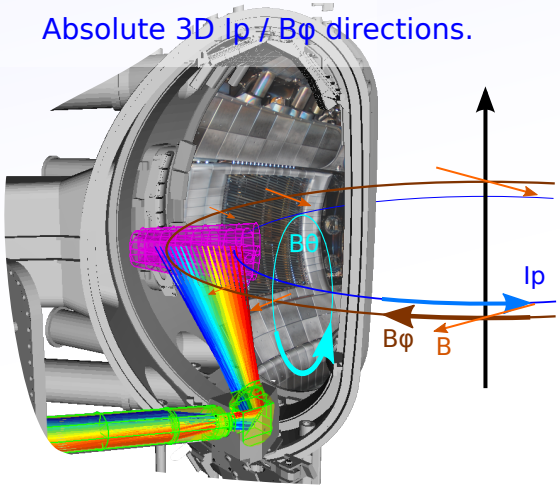

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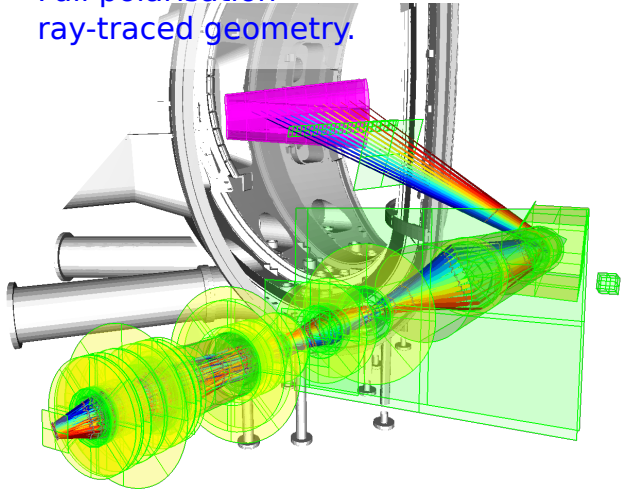

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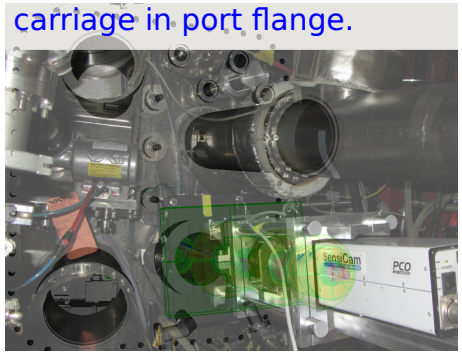

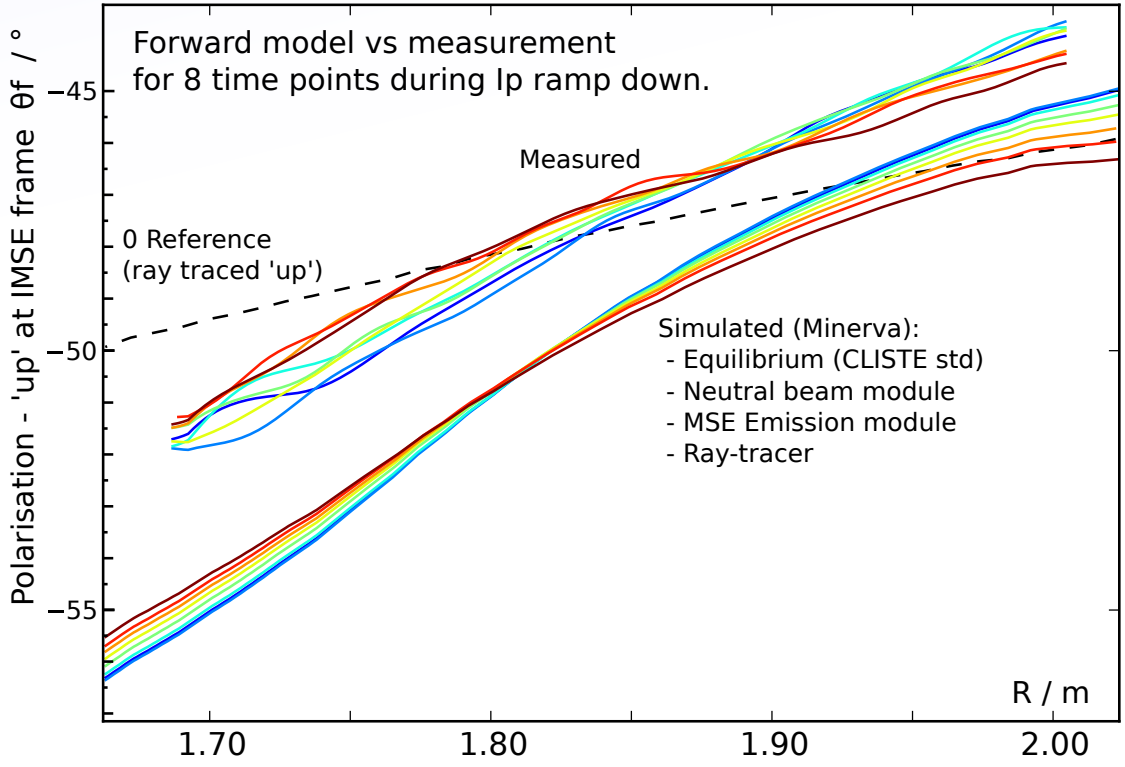

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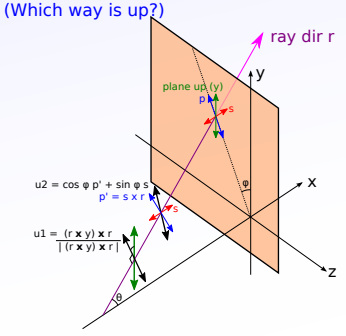

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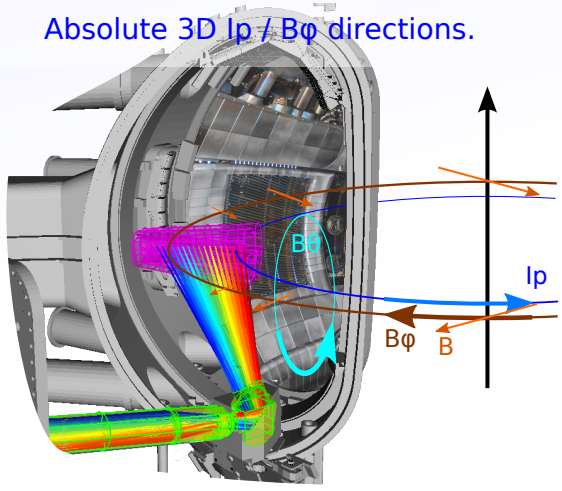

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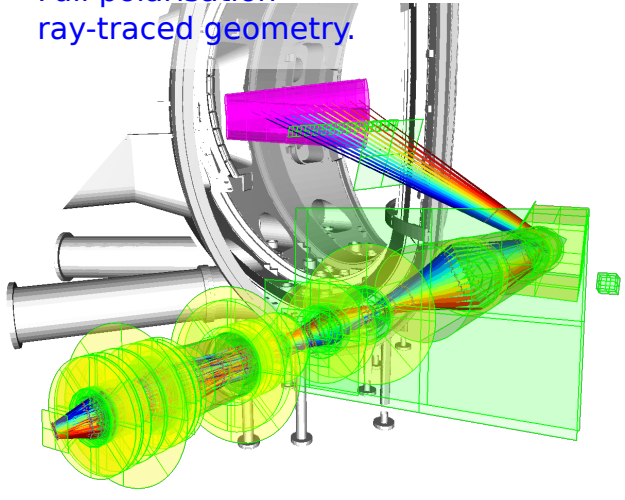

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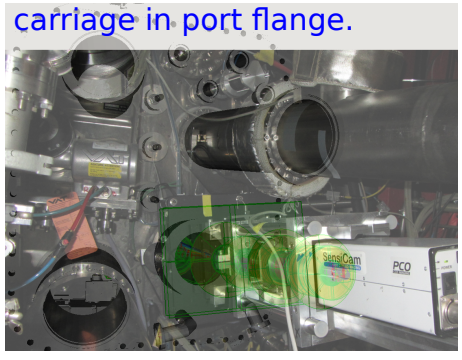

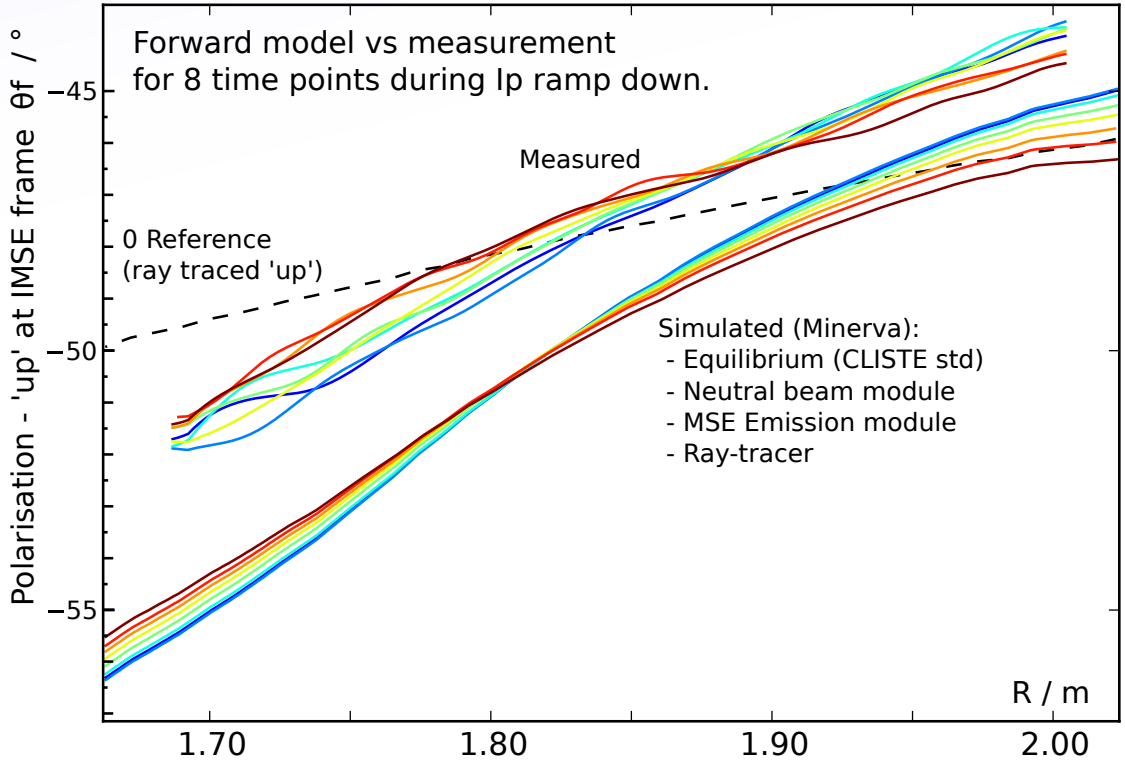

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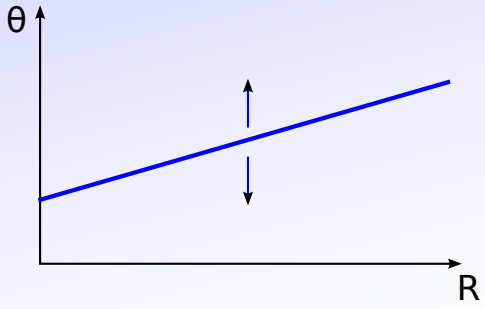
The optics Faraday effect not yet included (±1.4° offset)

Oliver Ford
IPP Greifswald

Calibration Strategies

Global offset



Expected and to some extent acceptable. To my knowledge, no MSE system has ever been successfully absolutely calibrated (without plasma and an equilibrium code).
Strategies:

- Measured background Zeeman-split Dα polarisation.
- Consistency for plasma with different beams (Different **V x B** projections).
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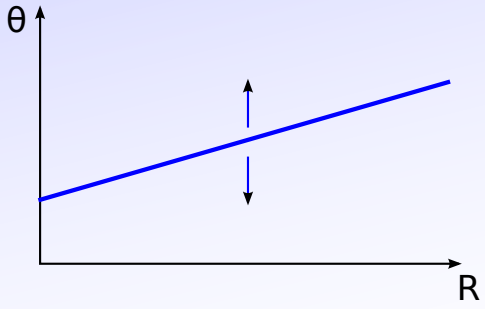

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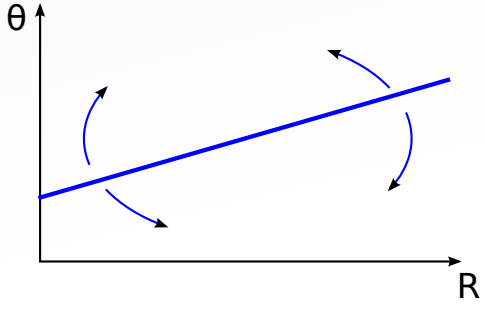

MSE system has an offset for each channel. IMSE should in principle remove this requirement. Remains to be clearly demonstrated.
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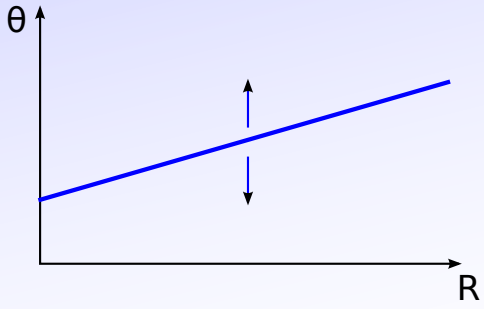

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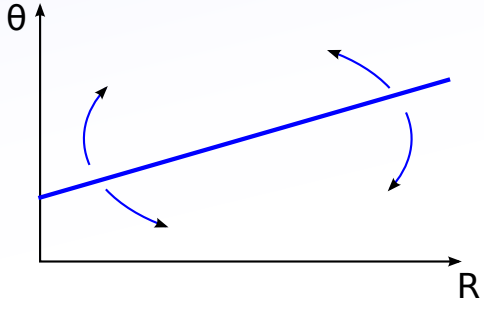

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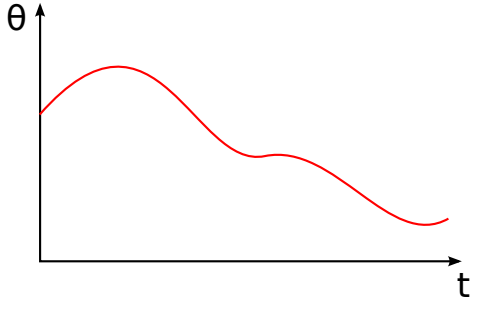
Long term drifts



Stability over long periods of offset - drifts of rotation in the forward optics (coatings etc) and isolation of the Faraday effect in the forward optics.
Strategies:
- Zeeman split background Dα.
- Limiter reflection polarisation (linearly polarised for some reason).

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Status

- ✔ Modelling for AUG spectrum and view.
- ✔ Plate and optics design for AUG.
- ✔ In-depth performance tests for polarisation measurement.
- ✔ Control, calibration, capture, demodulation and processing software.
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- ••• Infer absolute offset for Jan and April data.
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EPS + Satellite diagnostics conference.

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} EPS + Satellite diagnostics conference.

- ••• Consider installing permanent system to run alongside MSE.
- ••• Devise method of absolute angle calibration.
- ••• Complete ellipticity recovery investigation (needs better test sources).
- ••• Model Stark-Zeeman coupling (can ellipticity tell us something?)
- ••• Deeper investigation of θ --> Jφ inference methods (including equilibrium codes)

- ✓ Modelling and image generation for W7X.
- ✓ Ability to infer polarisation angle for W7X images.
- ✓ Ability to infer parallel current for W7X.
- ✓ Modelling of AUG MSE emission spectrum/polarisation.
- ✓ Modelling of generated images and ability to infer polarisation angle images.
- ✓ Asses ability to infer axisymmetric current from polarisation images.
- ✓ Ray tracing of existing MSE optics to see the image delivered.
- ✓ Asses lens options for optics coupling.
- ✓ Calculate and order required crystals (for middle range of lenses)
- ✓ Calculate and order filter
- ✓ Investigate non-orthogonal fringes idea (works great)
- ~✓ Build polarisation test setup (simulated spectrum, OK, getting better filters).
- ✓ Measurement principal test (Zeeman splitting).
- ✓ Software/Methods for exact alignment of plates.
- ✓ Design support structure.

- ••• Model polarisation effects of MSE forward optics.
- ••• Spectrum+Image model for MAST.
- ••• Calculate expected absolute light level (hence max absolute frame rate).
- ••• Find optimum optical setup (fielding etc).
- ••• Interface to objective auto-focus.
- ••• Plasma-based absolute calibration method/check.
- ••• Add Stark/Zeeman coupling to forward model (Ellipticity).
- ••• Reproduce non-linearity in ray tracer (requires full E/O ray splitting to work)
- ••• Improve edge effect / non-periodic FFT demodulation problems.
- ••• W7X assessment based on AUG results.