The MAST motional Stark effect diagnostic

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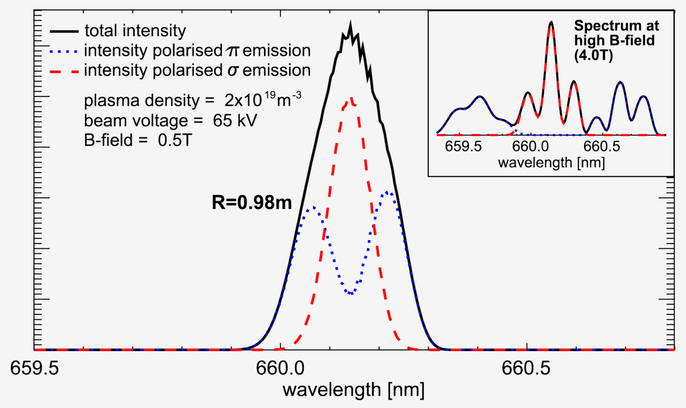
ABSTRACT

A Motional Stark Effect (MSE) diagnostic is now installed and operating routinely on the MAST spherical tokamak, with 35 radial channels, spatial resolution of ~2.5 cm and time resolution of ~1 ms at angular noise levels of ~0.5°. Conventional (albeit very narrow) interference filters isolate π or σ polarised emission. APD detectors with digital phase-sensitive detection measure the harmonics of a pair of photo-elastic modulators operating at 20 and 23 kHz, and thus the polarisation state. The π component is observed to be significantly stronger than σ, in reasonably good agreement with atomic physics calculations, and as a result almost all channels are now operated on π. Trials with a wide filter which admits the entire Stark pattern (relying on the net polarisation of the emission) have demonstrated performance almost as good as the conventional channels. MSE-constrained equilibrium reconstructions can readily be produced between pulses.

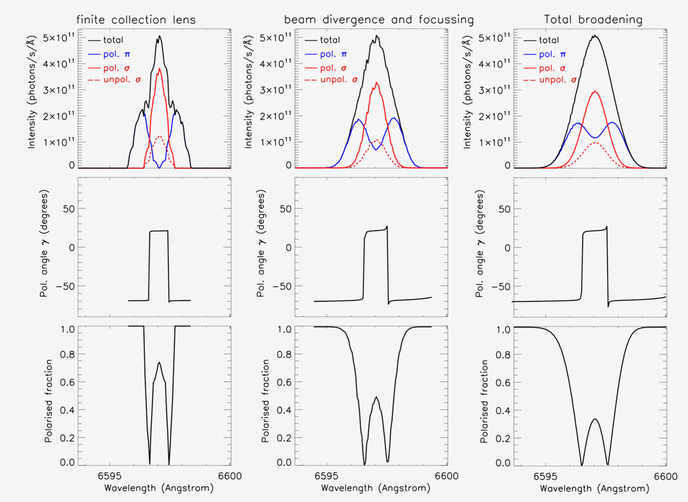
MSE ON SPHERICAL TOKAMAKS

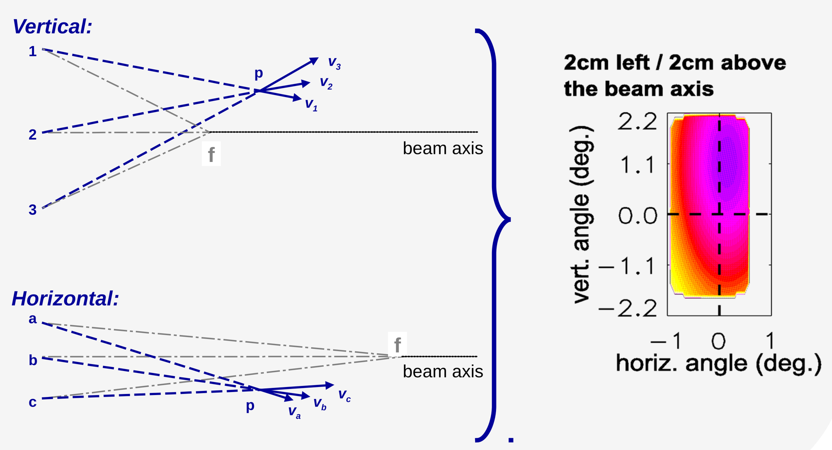
- MSE is harder at low B field…
- Much less Stark splitting but broadening sources similar
- Poor polarisation fraction – must minimise additional broadening in collection optics
- Very narrow filters needed
- Interference filters now meet requirement (but only just narrow enough ~ 0.1 nm)



SOURCES OF SPECTRAL BROADENING

- Principally collection optics (aperture, finite collection volume) and beam 'divergence' (ion optics, geometric focussing of beamlets)
- Beam dominates (and introduces variation of polarisation angle γ vs λ)
- MAST PINI beam sources are rectangular (taller than width)
- Focal length in vertical direction is also very short
- Combination produces much larger angular spread of beam velocities in vertical plane (so ideally no vertical component in view line of sight)

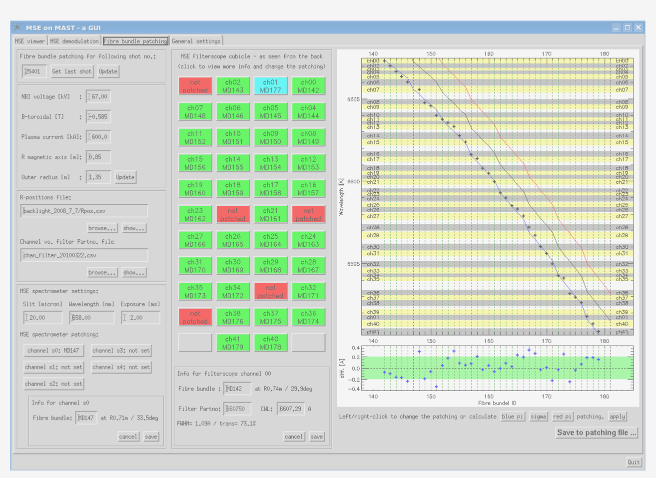




WAVELENGTH MATCHING

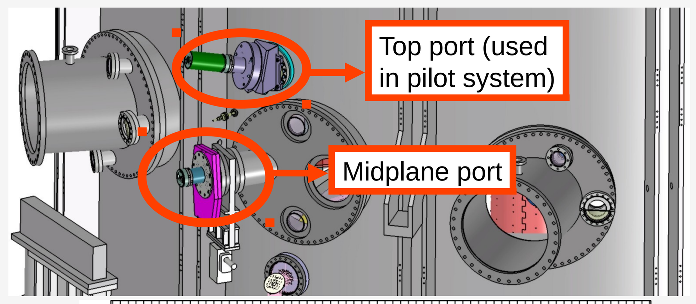
(e.g. to cope with beam voltage changes)

- Tilt tuning impractical for very narrow filters
- Thermal tuning is viable (possible upgrade route for MAST)
- Selected scheme: many channels (35), closely spaced, very small $\Delta\lambda$ steps
- "re-patch" fibre bundles between filterscopes when beam voltage changes

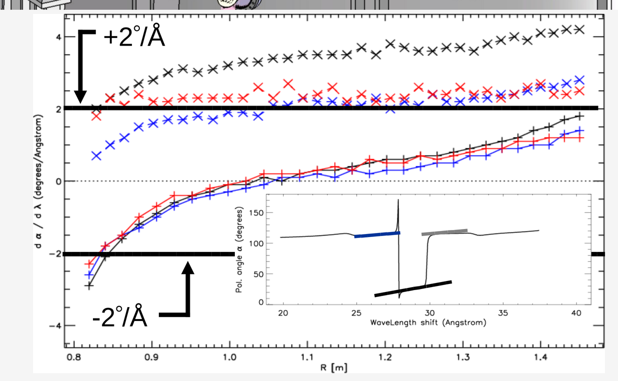


VIEW LOCATION

- Top port worked well for pilot system (2007) (capable of best possible spatial resolution)
- But new modelling code highlighted potential for significant systematic errors – $d\gamma/d\lambda$ large

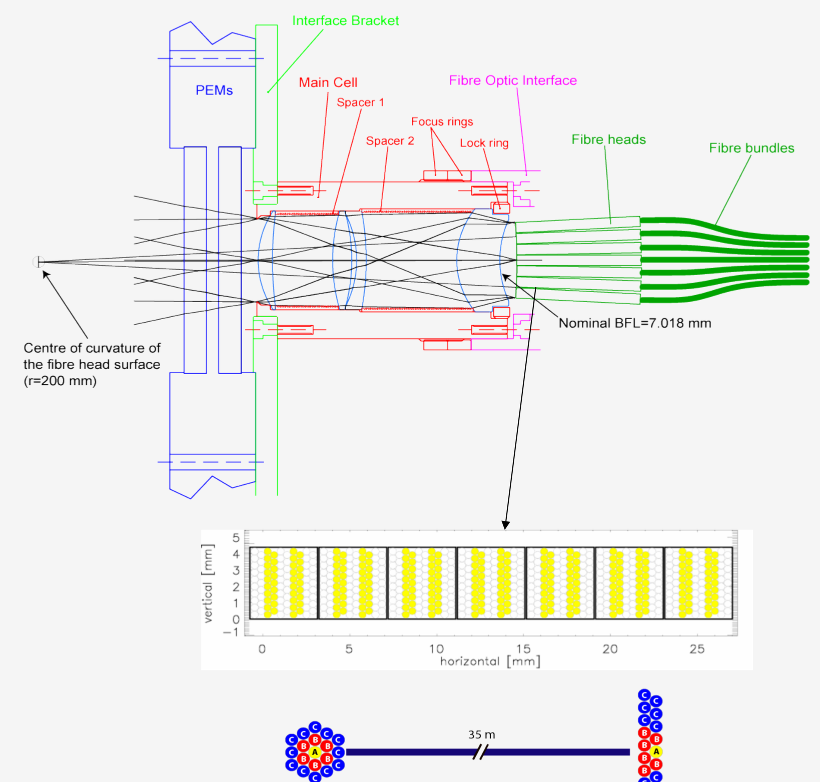


- Alternative view on midplane had much smaller $d\gamma/d\lambda$ and also higher SNR (more $\perp$ to E field)
- Spatial resolution still adequate (~2.5 cm)



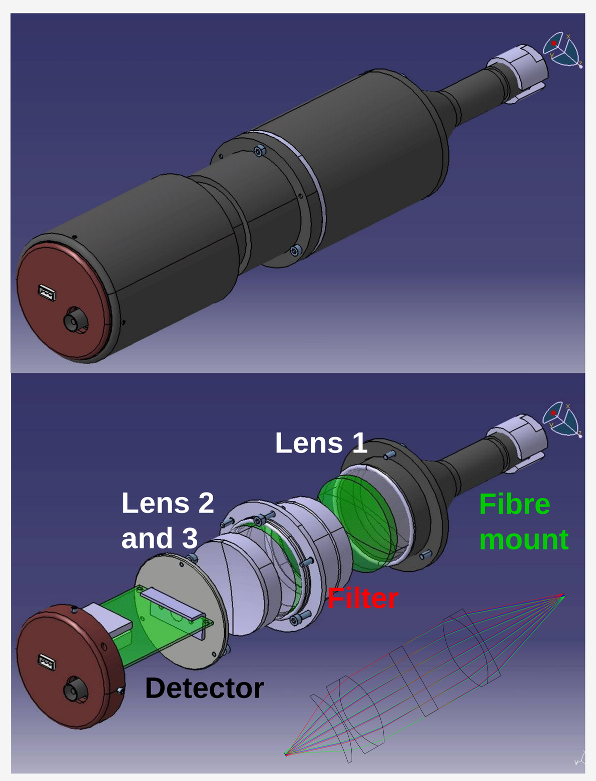
COLLECTION OPTICS AND FIBRE BUNDLES

- Collection lens: 72 mm focal length, f/2
- Circular aperture gives best utilisation of etendue (but must be small to avoid excessive broadening)
- Hinds dual PEMs module (20/23 kHz)
- Fibre bundles: 19 fibres per channel for hexagonal packing at filterscope end (minimises angular spread at filter)
- Fibres mapped: beam axis → centre of filterscope end (brightest emission)
- 7 fibre modules, 5 channels each (8 installed for spare capacity)



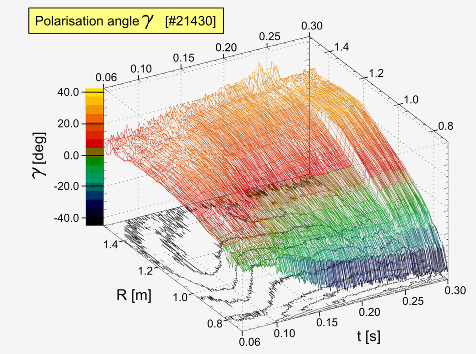
FILTERSCOPES AND DETECTORS

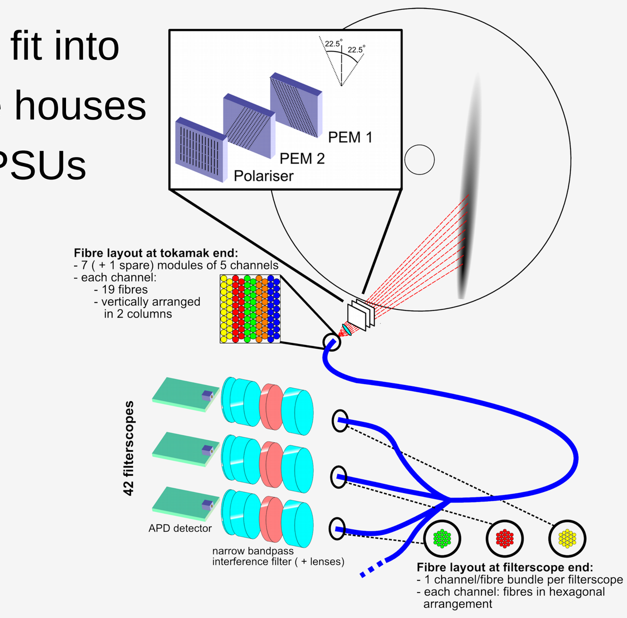
- Filterscope houses filter and detector module
- Collimated light, through filter, focussed onto APD detector (with on-board HV supply)
- Achromatic doublets & meniscus lens for modest aberrations
- Extract at f/1.5, but collection lens is f/2 – catch ~20% extra light that would otherwise be lost through slight spreading over 35 m fibre length
- Detectors have 250 kHz bandwidth – capable of measuring 4th harmonics (permits retardance monitoring and improved γ measurement)



COMPLETED SYSTEM

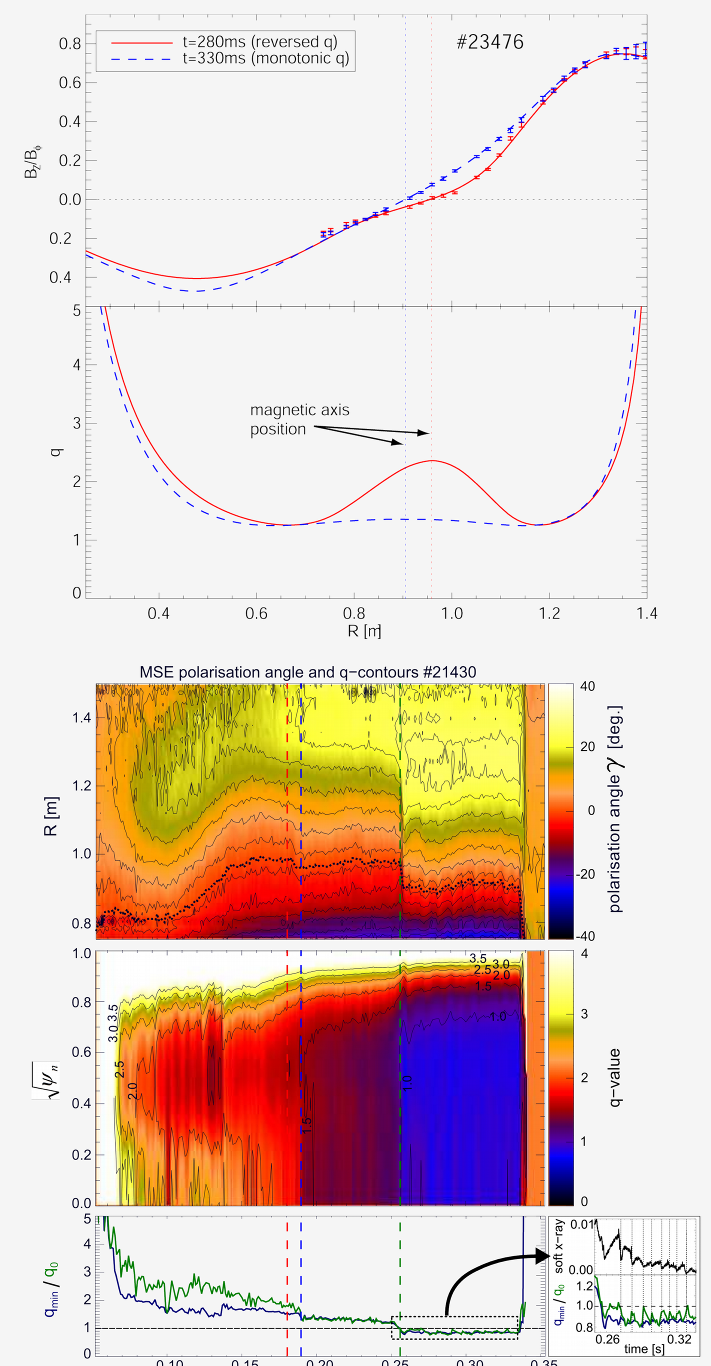
- Compact filterscopes – 42 fit into a single cubicle. 2nd cubicle houses datacq (1MHz, 14bit) and PSUs

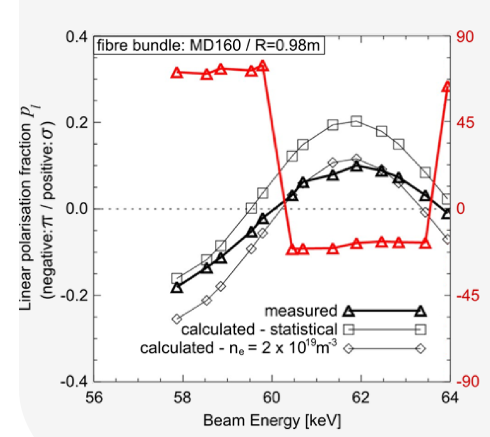


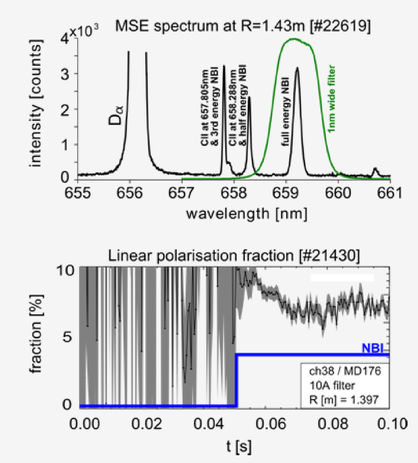


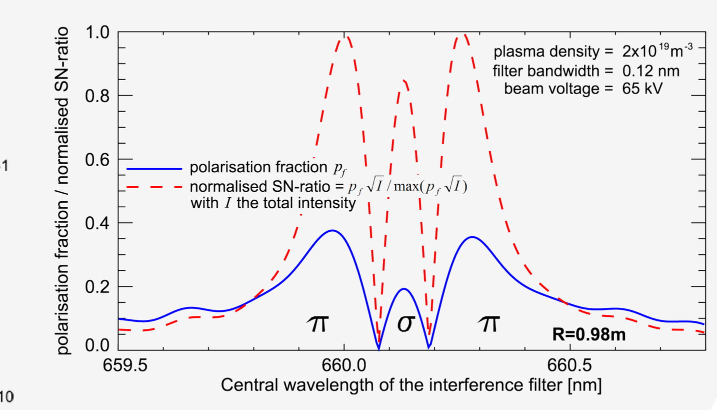
RESULTS

- Excellent performance: typically achieve $\Delta\gamma < 0.5°$ for most chans at $\Delta t \leq 1$ms and for all chans at $\Delta t \leq 2$ms
- MSE-constrained EFIT becoming routine (available inter-shot on request)
- Observe high π/σ ratio caused by non statistical populations – much stronger in gas pulses than plasma (σ is approx. 20% weaked in plasma, 50% in gas)
- Voltage scan to compare with theory, match is reasonable but not perfect
- Net polarisation led to trials with a wide (1nm) filter: good results (error bar only slightly worse than narrow chans, angle matches neighbours)
- Best performance generally available on π component









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