Design Issues for the ITER MSE System

N Hawkes[1], A Malaquias[2], P Lotte[3],M VonHellerman[4],
M Brix[1], R Giannella[3], M Kuldkepp[5], E Rachlew[5],
C Negus[1], E Surrey[1]

1 Association Euratom-UKAEA, Culham, Abingdon, UK
2 Instituto Superior Technico, Association Euratom-IST, CFN, Portugal
3 Association Euratom-CEA, CEN, Cadarache, France
4 Association Euratom-FOM, Rijnhuizen, Netherlands
5 Association Euratom-VR (KTH), Stockholm, Sweden

UKAEA Fusion
Working in Europe

Outline

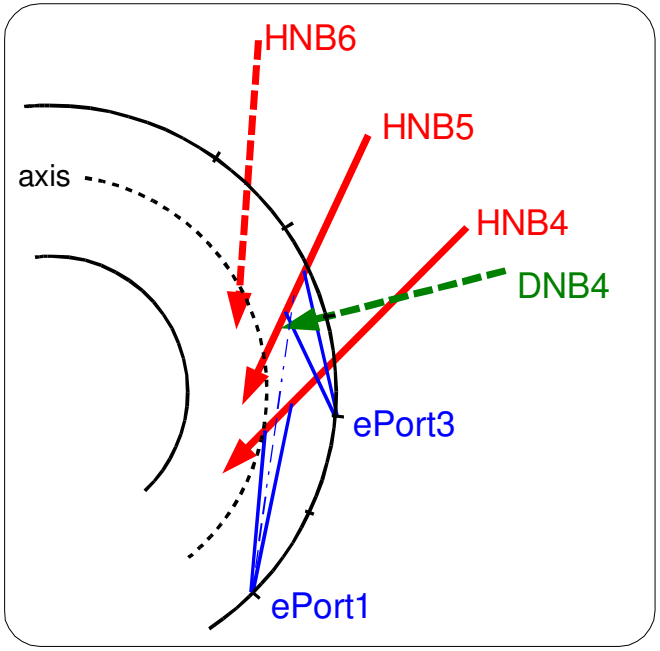
- Interference from different beamlines
- Contributions from multiple segments of injectors
- Power supply stability
- Beam steering and energy range
- (In)-sensitivity to Er
- Importance of circular components
- Need for in-situ mirror monitor with correct geometry

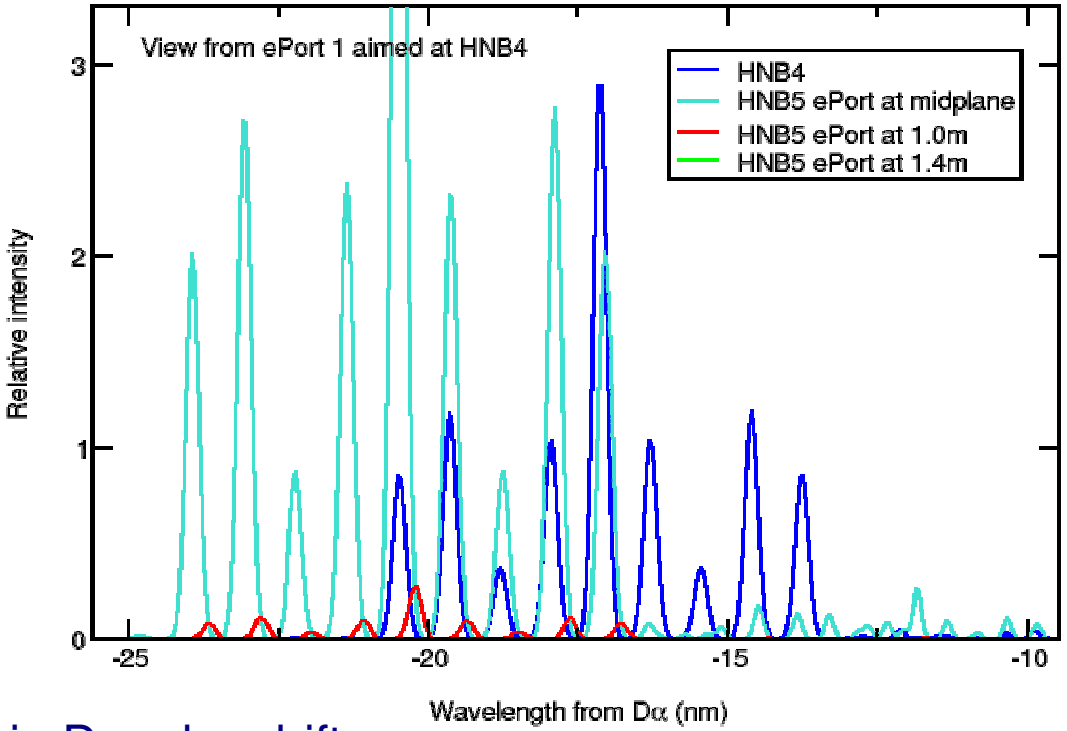
MSE Simulation Program

JET MSE simulation program adapted to ITER geometry:

- Simulates the beam emission spectrum, using Stokes vector formalism to account for the polarisation properties.
- Calculates space resolution for (fairly) realistic conditions and (almost) full 3-D geometry.
- Still some improvements needed:
  - Realistic equilibrium
  - Bremstrahlung calculation

Interference between HNB4 and 5 with ePort1 view





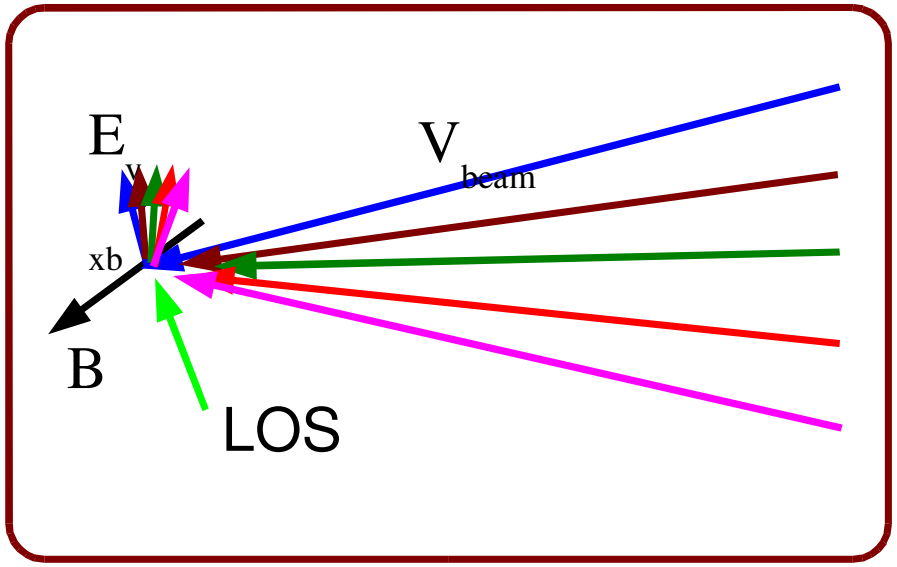
- Despite the large separation in Doppler shift, the large Stark splitting leads to overlap of spectra from different heating beams

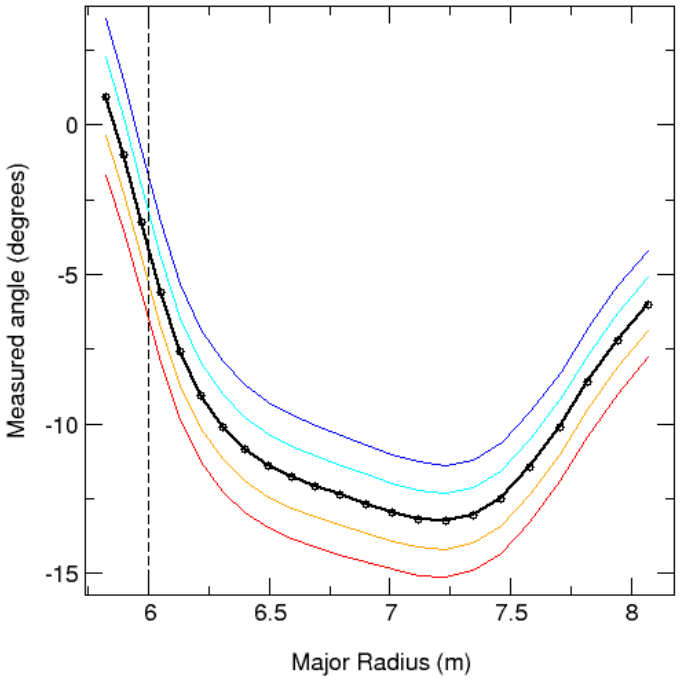
- 3-D calculations indicate that raising the viewing port above the midplane could eliminate the interference

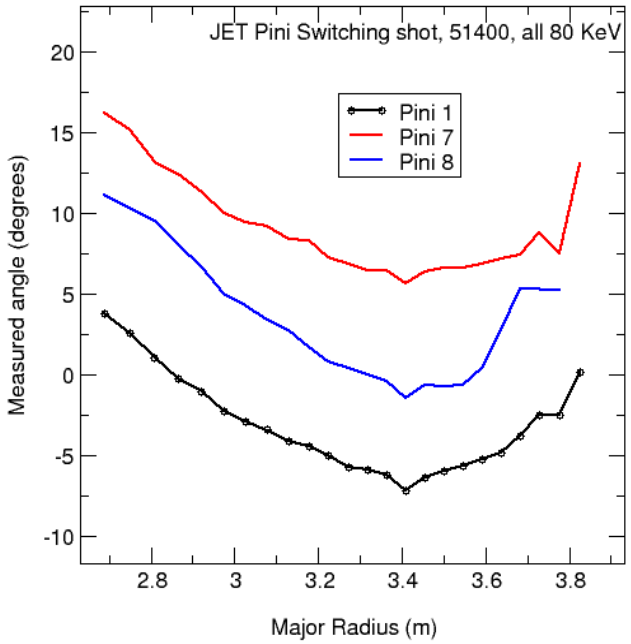
Multiple segments to the negative ion beams

- Negative ion beam sources have relatively low power density so sources have to be extended
- Beams composed of 4 vertical segments, spread of tilt angles 2.9 degrees. Gives about 3.5 degrees spread in the polarisation angles.
  - we are highly dependent on the beam geometries being stable, power balance between segments etc
  - If the segments could be individually switched (they can't) we would have an excellent in-situ calibration technique.

Beam Segment Contributions to Total – weighted sum





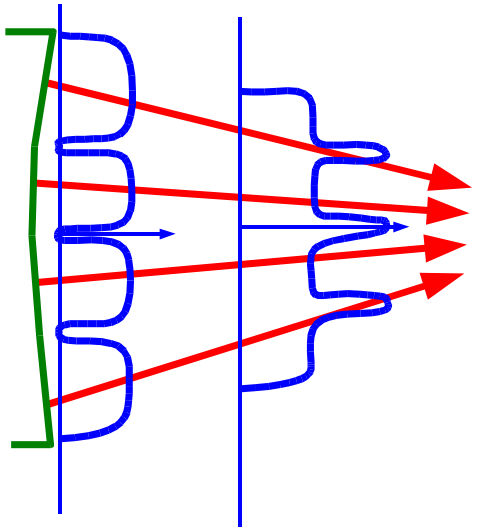


Contributions from the separate ion source segments differ by 3-4°

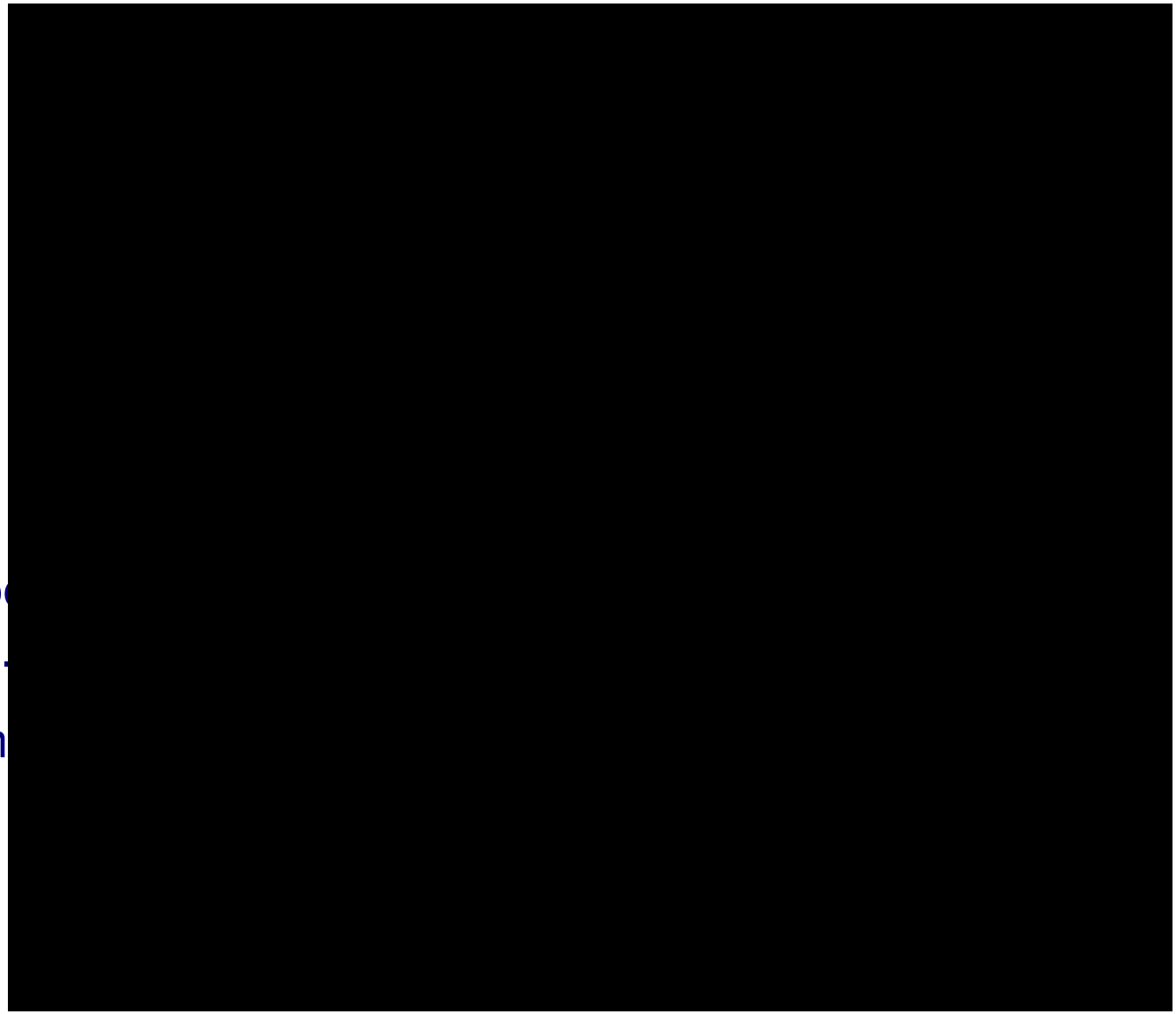
Problem is as on JET before Pini 1 voltage upgrade (although the angular difference is less).

Necessitated 'switching' shots to measure relative contributions, even then a major source of error

Calorimeter gives some measurement of beam uniformity

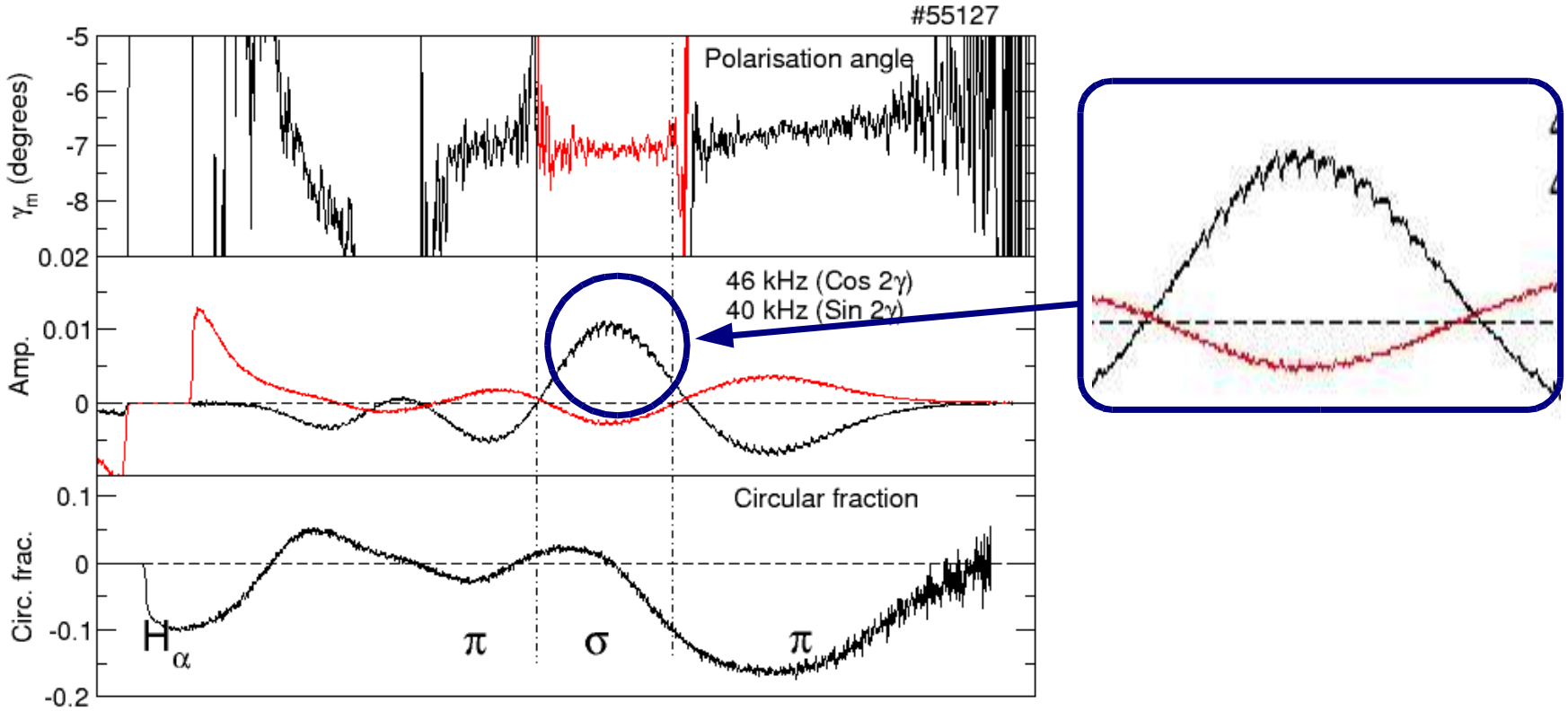


- Power from individual segments overlaps as the fo point (23.4m) is approached.
- Calorimeter measures at 8m from sources.



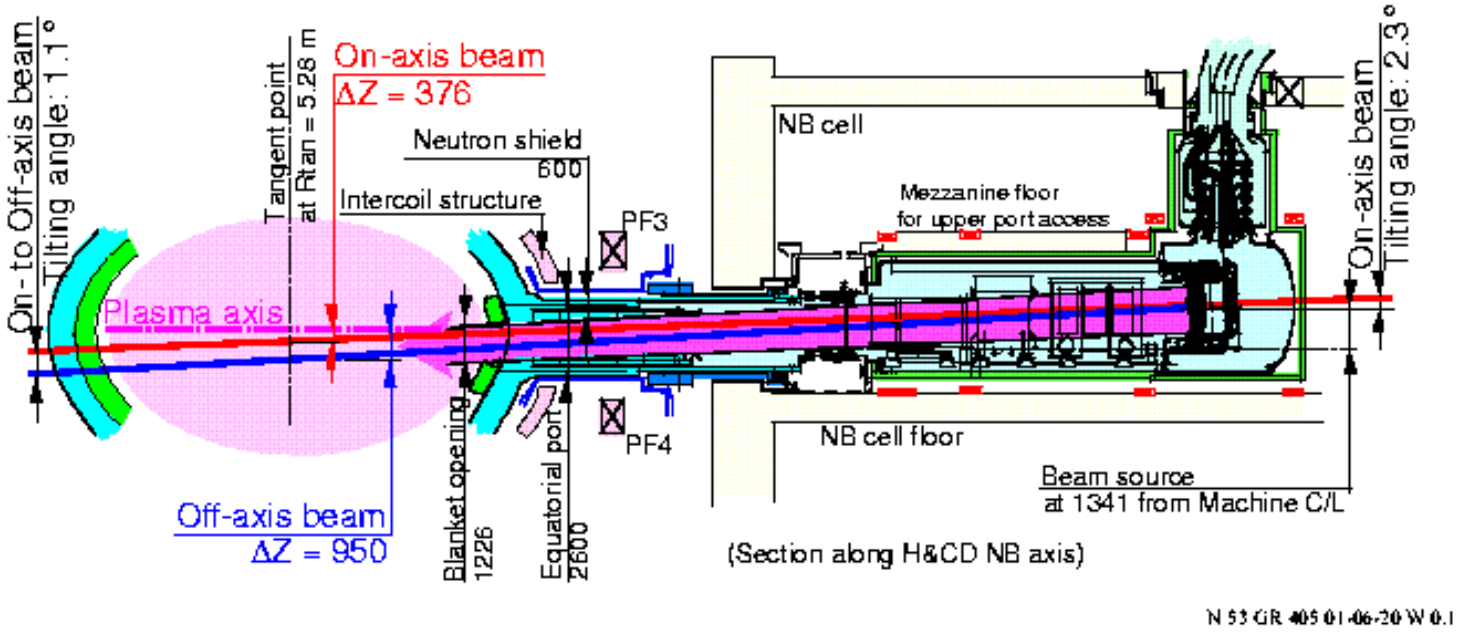
- Ion source uniformity is a high priority for ITER beams, so situation may not be too bad
- However, the total γ_m angle will vary at different points across the beam (different mix of segment fractions)
- Perhaps we can exploit this 'feature' instead of source switching as an in-situ diagnostic calibration (using chords from the top and bottom of the view)
- Different parts of the ion source could be energised separately, but sources are not partitioned to match the extractor grids, and ions would in any case 'spill' from one segment to another.

Beam power supply stability



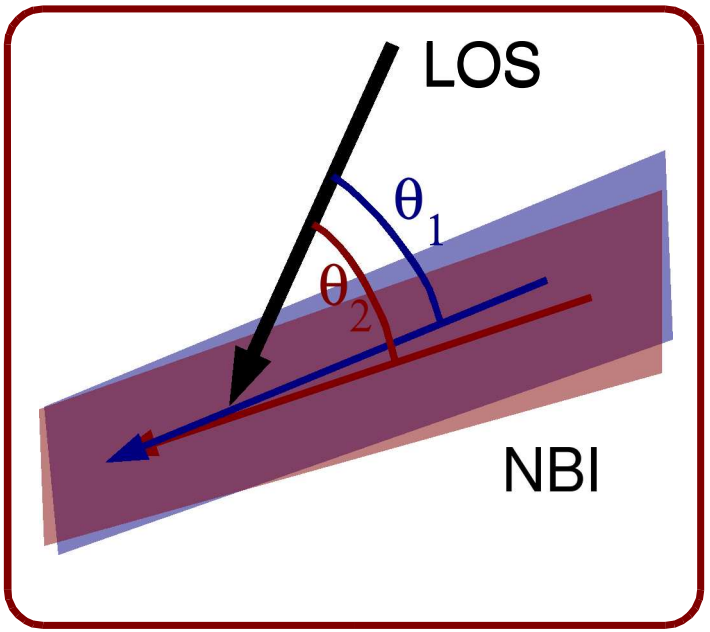
- See a similar effect in JET during spectral sweep, but no phase change across emission peaks ⇒ modulation only of power, not voltage.
- The specified 5% modulation of voltage would contribute 0.35nm to line widths – acceptable

Beam steering

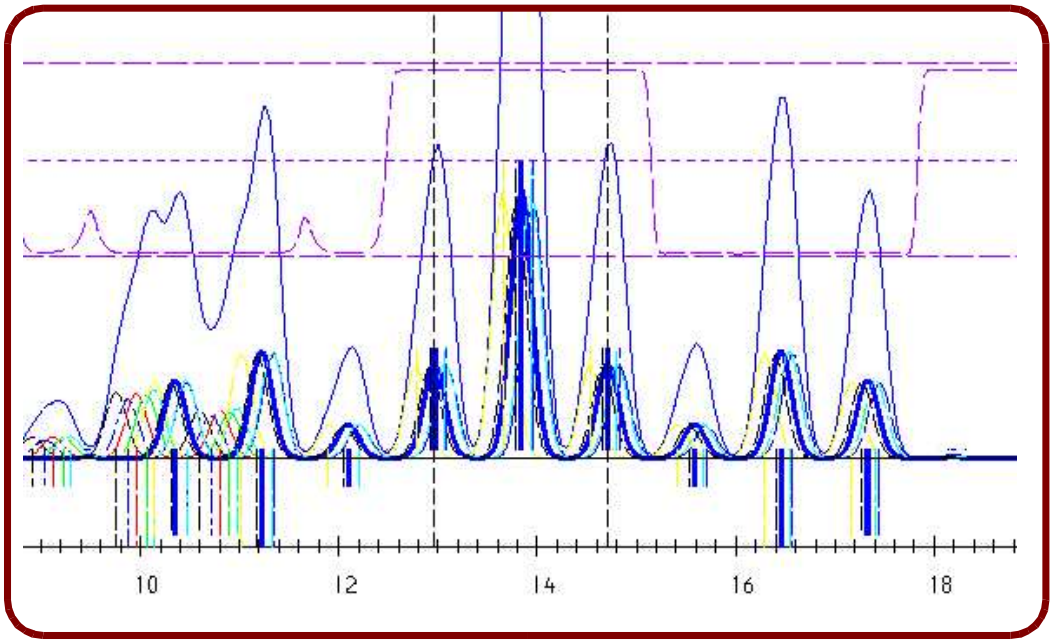


- Beams can steer downwards for off-axis current-drive, up to 3° seen from the viewing port
  - probably best accommodated with multiple fixed sightlines, rather than tracking optics.
- Beam energy range 400-1000 KeV and choice of H/D operation gives very wide spectral range required
  - use spectrometers not filters, or both.

Lateral focussing ⇒ divergence ⇒ spectral broadening



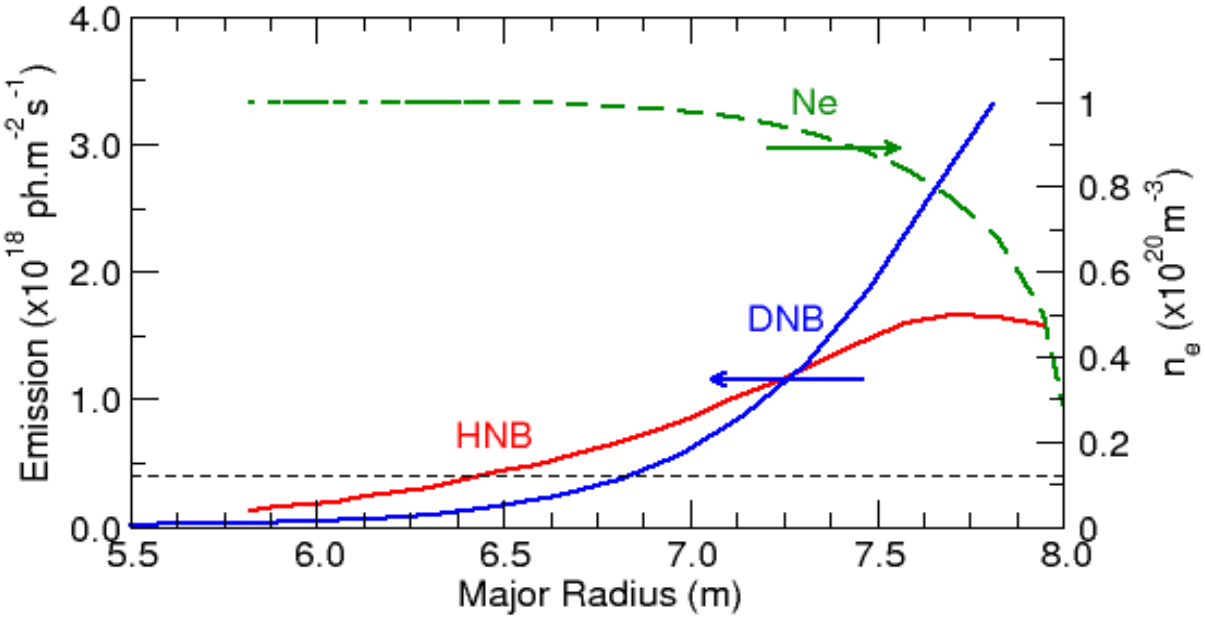
Beams are segmented (again 4 segments) in the horizontal direction



- Range of angles in toroidal direction causes some spectral broadening: 0.2 nm for port 6 case – Acceptable

DNB has different issues

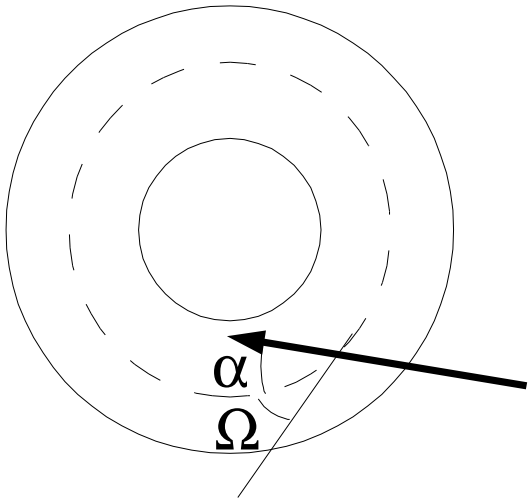
- DNB is exempt from steering and energy changes but still has a segmented source (unless a positive ion injector)
- Geometry is in any case wrong for conventional (polarimetric) MSE measurements, being radial
- Attenuation is worse than heating beams, would not reach the axis



(In)-Sensitivity to Er

2-D approximation:

$$\tan \gamma_m = \frac{B_p \cos(\alpha + \Omega) + \frac{E_r}{v_b} \cos \Omega}{B_T \sin \alpha}$$



hence perturbation due to Er is $\frac{E_r}{v_b B_T} \frac{\cos \Omega}{\sin \alpha}$

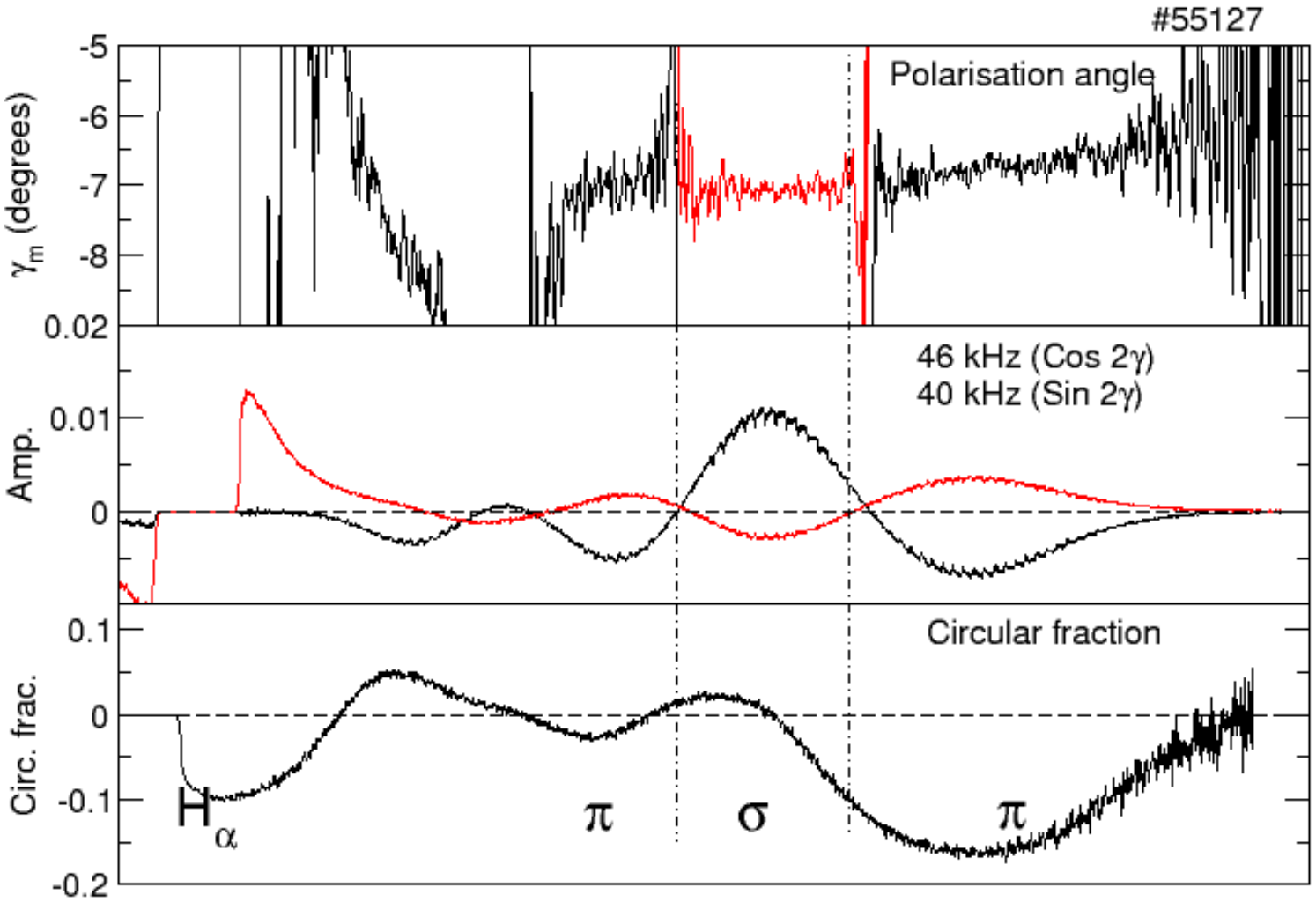
Beam velocity of heating beams is about double the diagnostic beam (5x higher energy per amu), geometric terms reduce the difference further to only 30% difference:

HNB 5 / Port 6	44°	7°	9.8×10^6	0.23°
DNB 4 / Port 3	90°	30°	4.4×10^6	0.32°

Assuming Er=140 kV/m

Effect is small and difference even more so, ie not a worry for MSE interpretation, but not feasible for monitoring E_r

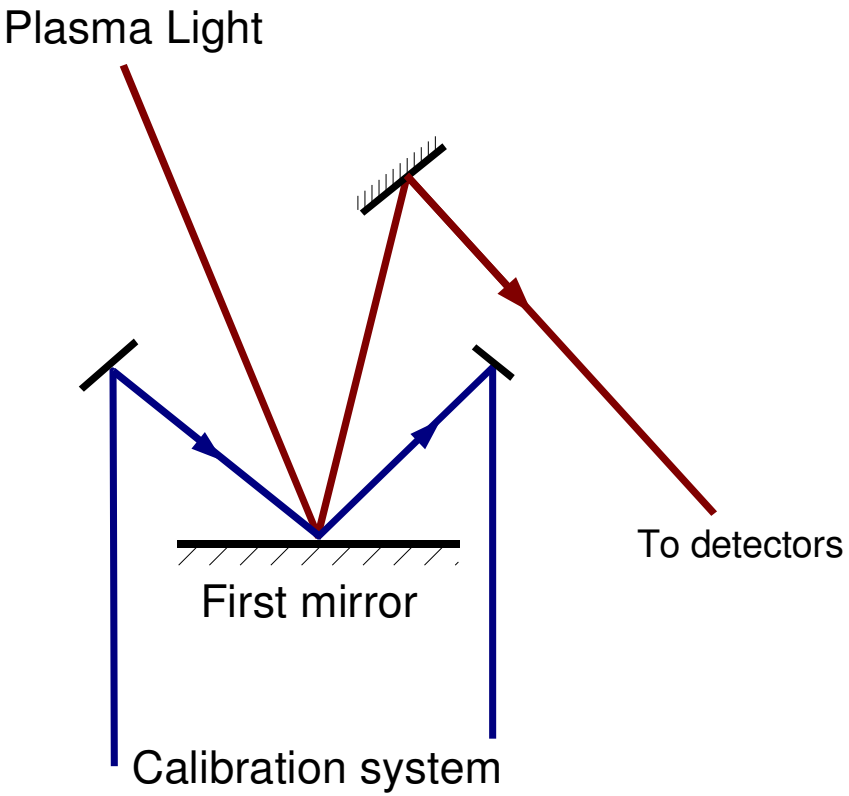
Circular components in Stark Spectrum from Atomic Physics

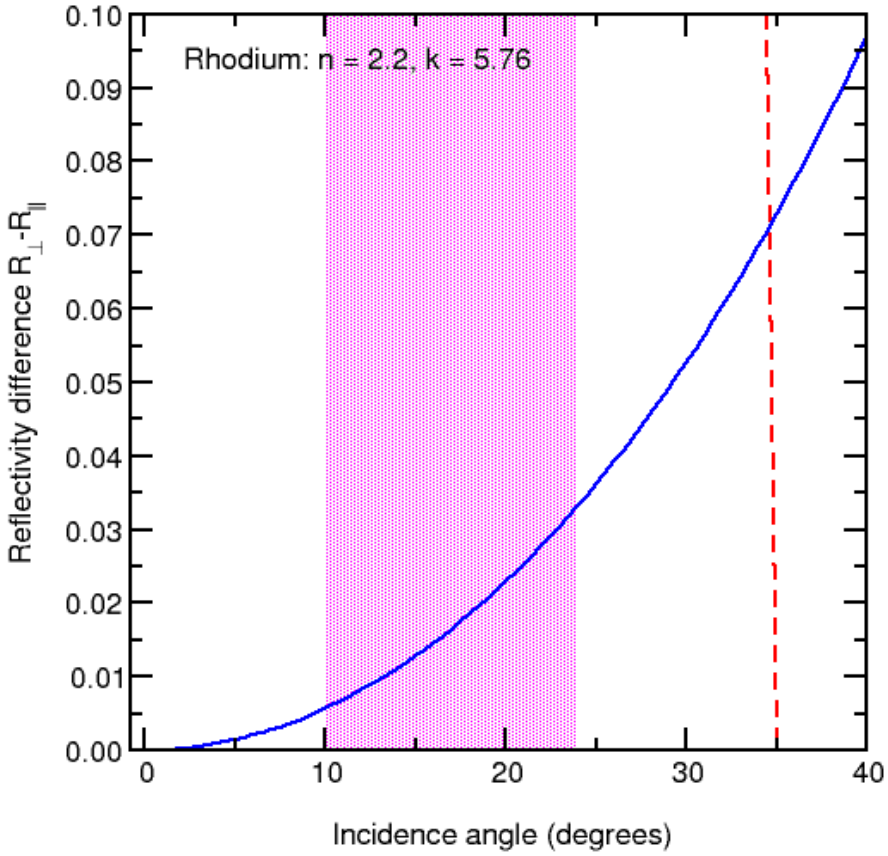


Important to record ω_1 as well as $2\omega_1$ and $2\omega_2$

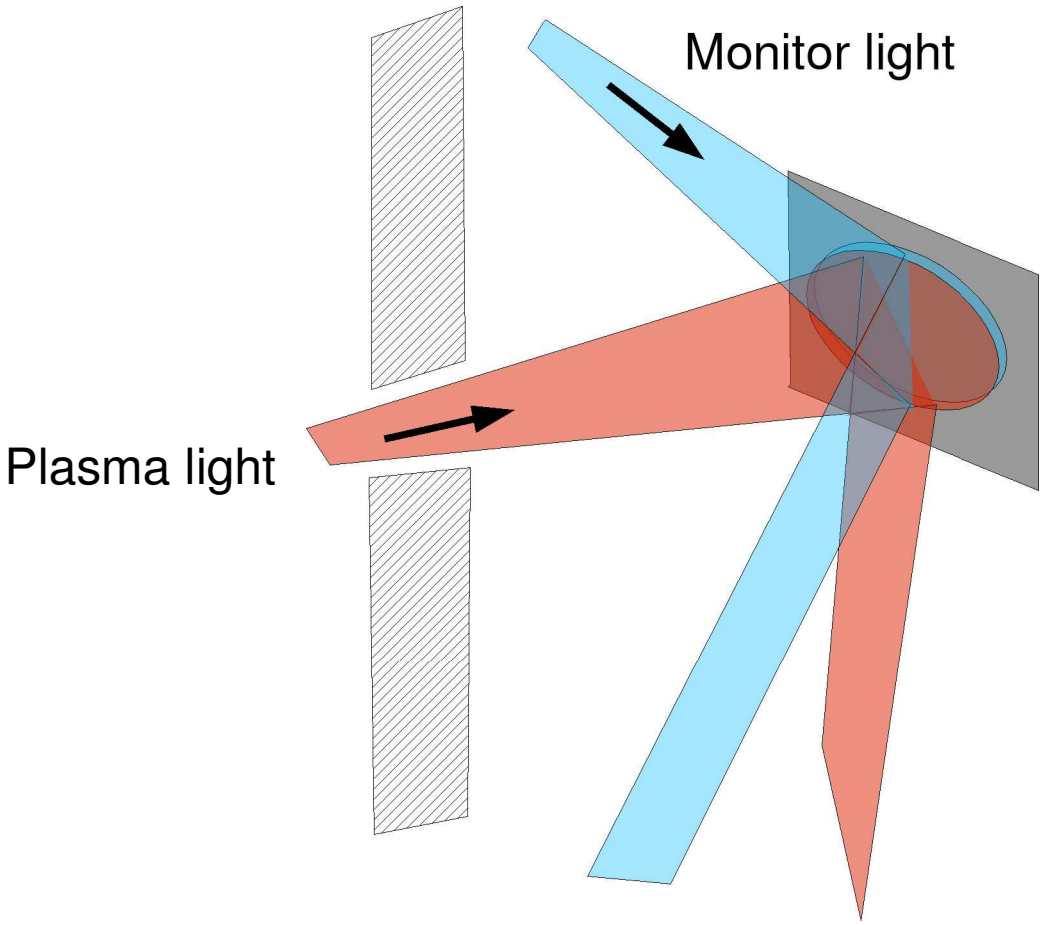
Need Correct mirror monitor geometry

- Optical models of mirror coating are not reliable enough to 'back extrapolate' from a different incidence angle



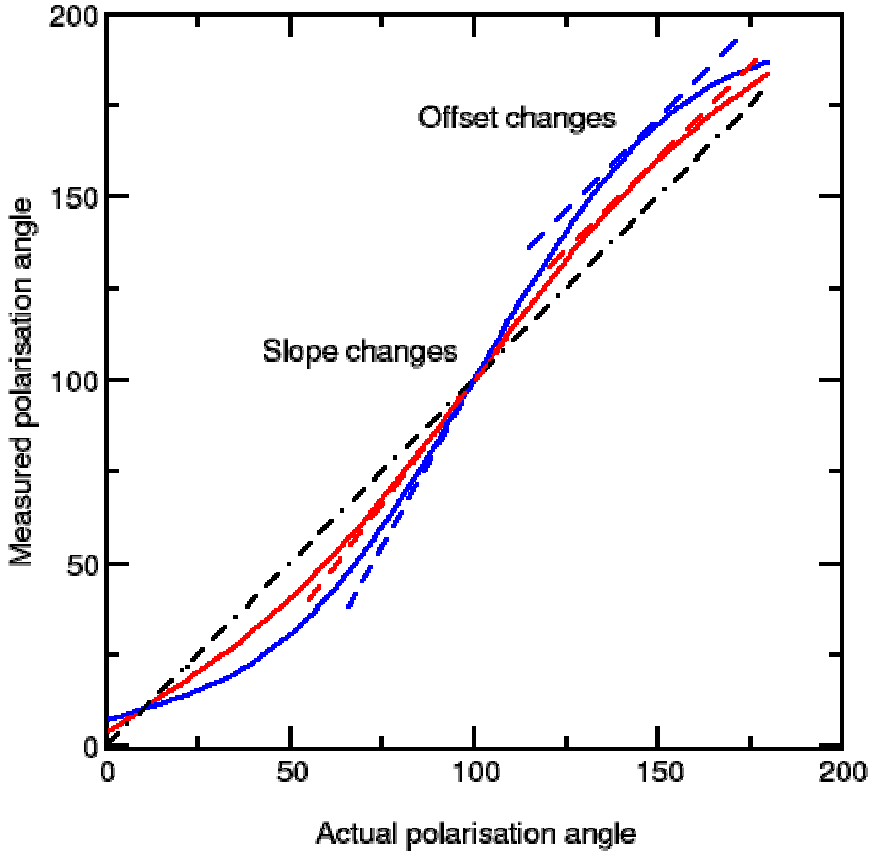


- Use test beam with the same incidence angle and illumination area as a monitor of mirror changes



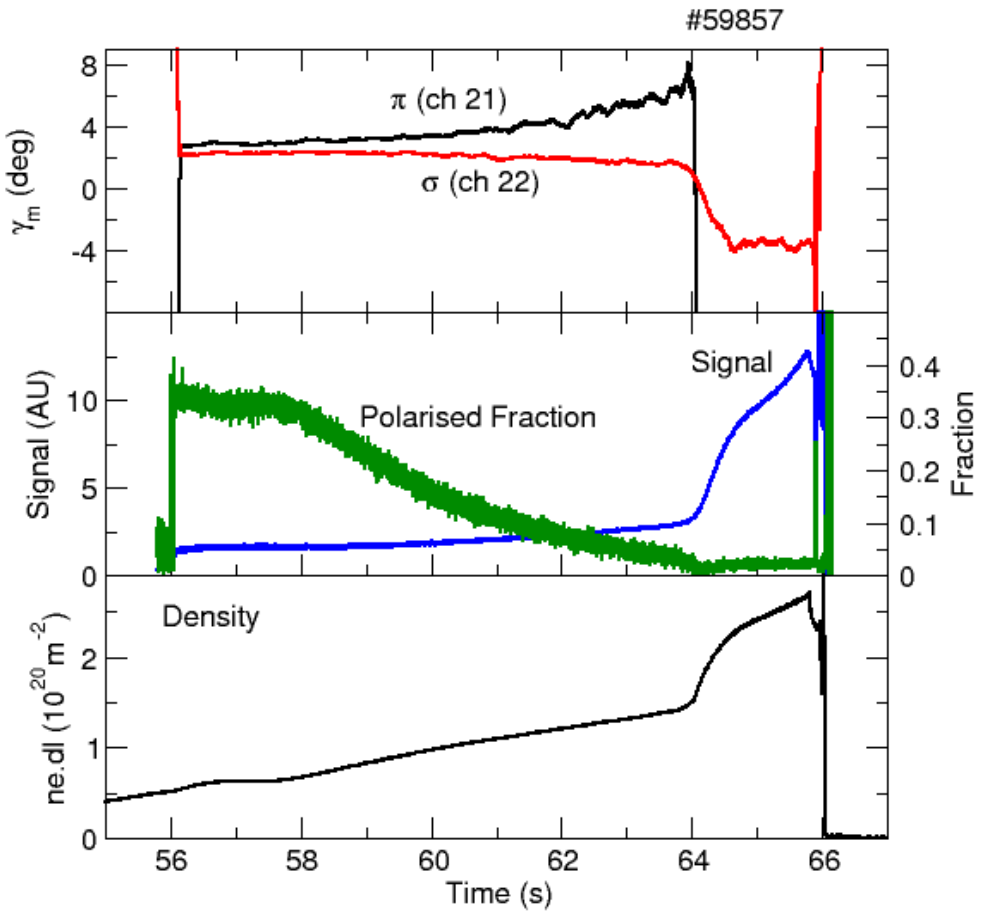
Optimum mirror operating point

- Depends on calibration (offset or slope easiest to calibrate)

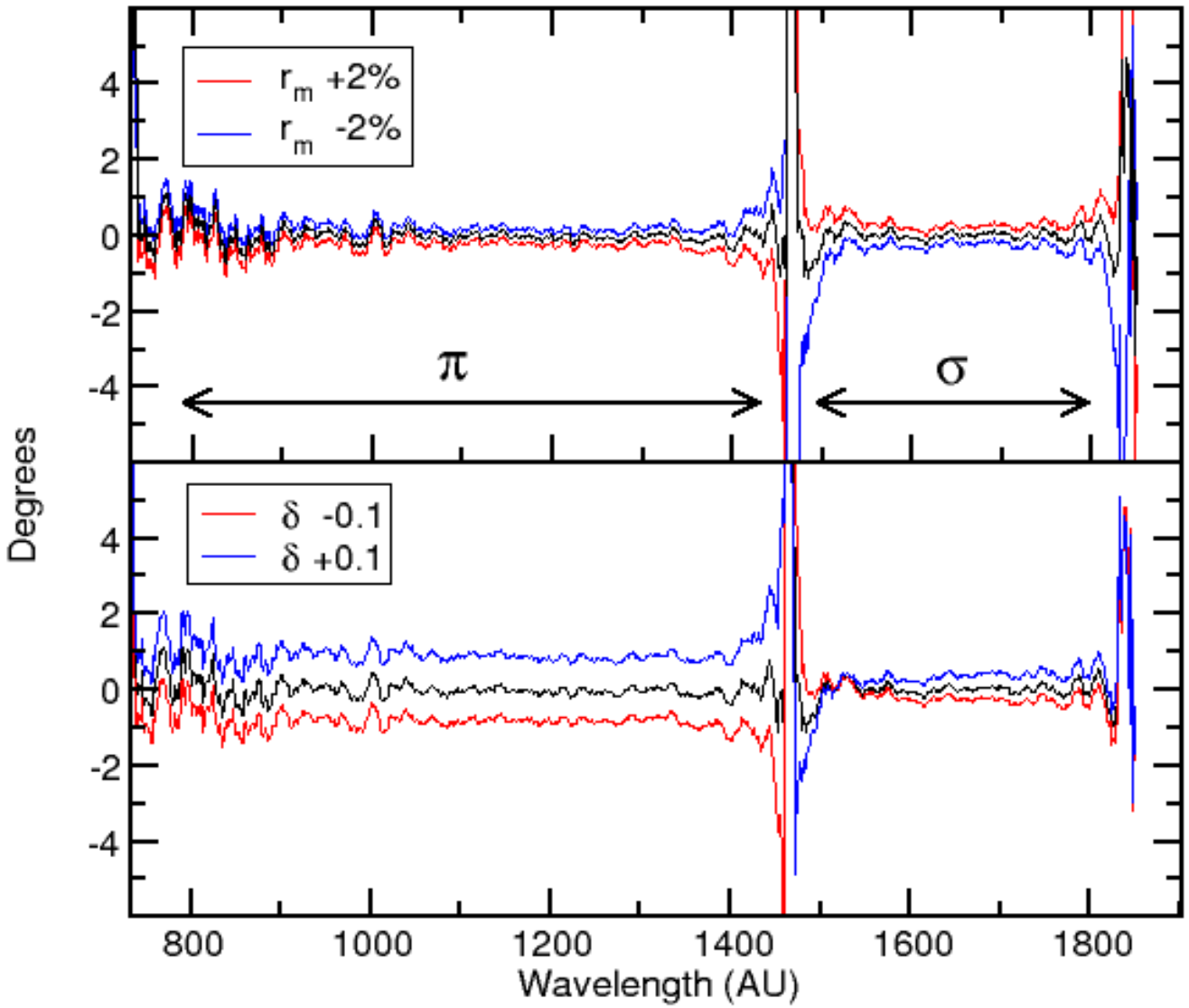


Parallel polarimetry of σ/π

- Measure simultaneously the σ and π polarisations and thus detect onset of interfering light signals
- Adjacent channels of JET system tuned to σ and π during density ramp – encouraging results

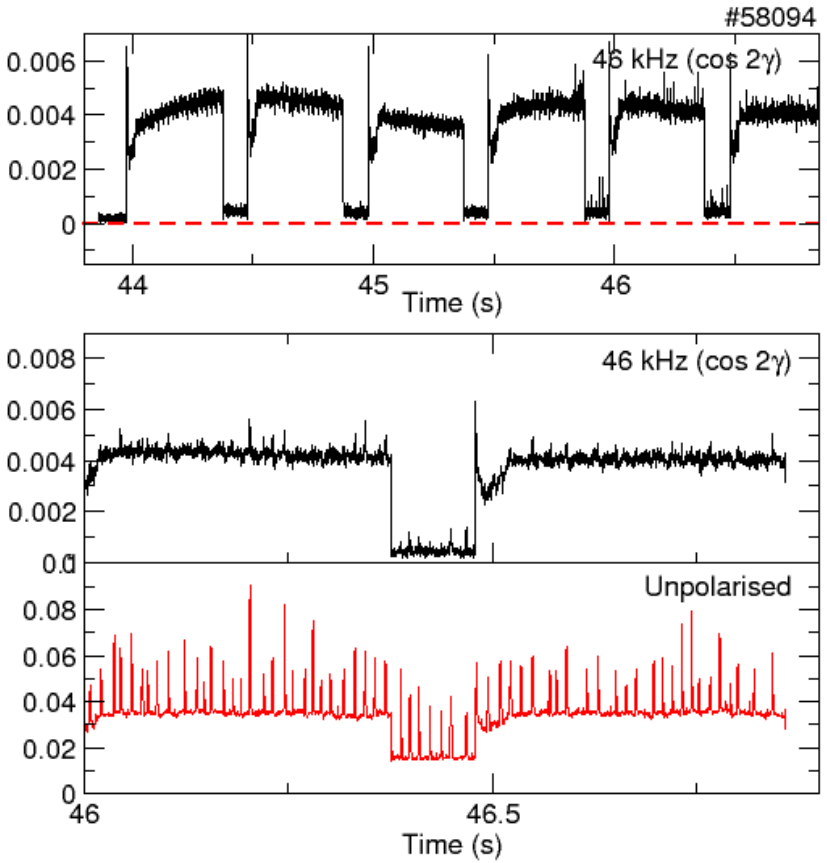


Under good conditions σ and π angles give a way to calibrate the mirror properties



Parallel polarimetry of σ/π and background

- Interfering light is the most significant limitation on operating range of JET diagnostic.
  - Beam modulation is used to subtract out background light
  - Sucessful but limited by ELM behaviour
  - Monitoring empty spectral region beyond MSE spectrum with a multichannel spectrometer/detector might be ideal – test on JET.
- Viewing dumps ?



Conclusions

- First mirror degradation
  - seems soluble with careful/elaborate calibration
- Convergent beam trajectories
  - could be a serious problem
  - but might be able to exploit it to advantage instead
- Interference between beamlines will require tilted views and or selection of π^+ / π^- lines