Motional Stark Effect Coherence Imaging for ASDEX Upgrade and W7X.

Assesment of capabilities using Bayesian Tomography

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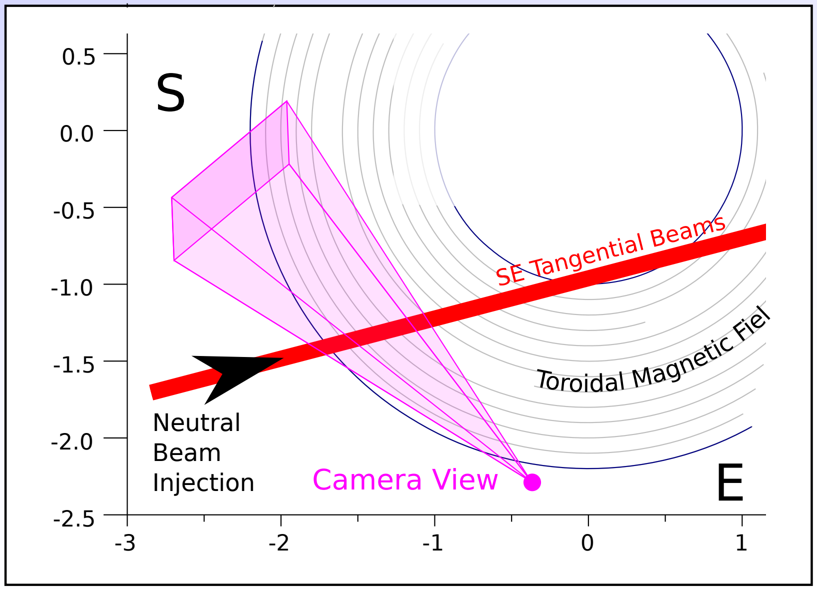
- Introduction to IMSE.
- ASDEX Upgrade Instrument.

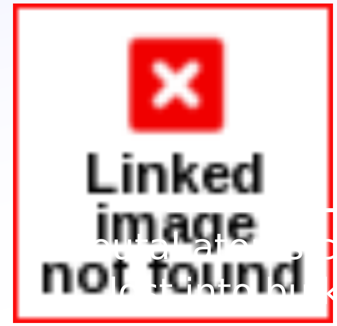
- 2D measurements with Axisymmetry.
  - Mathmatically.
  - Tomographically.

- W7X Instrument.
  - Difficulites for Stellarators.
  - Bayesian Inference using Funtion Parameterisation.

Introduction - Motional Stark Effect



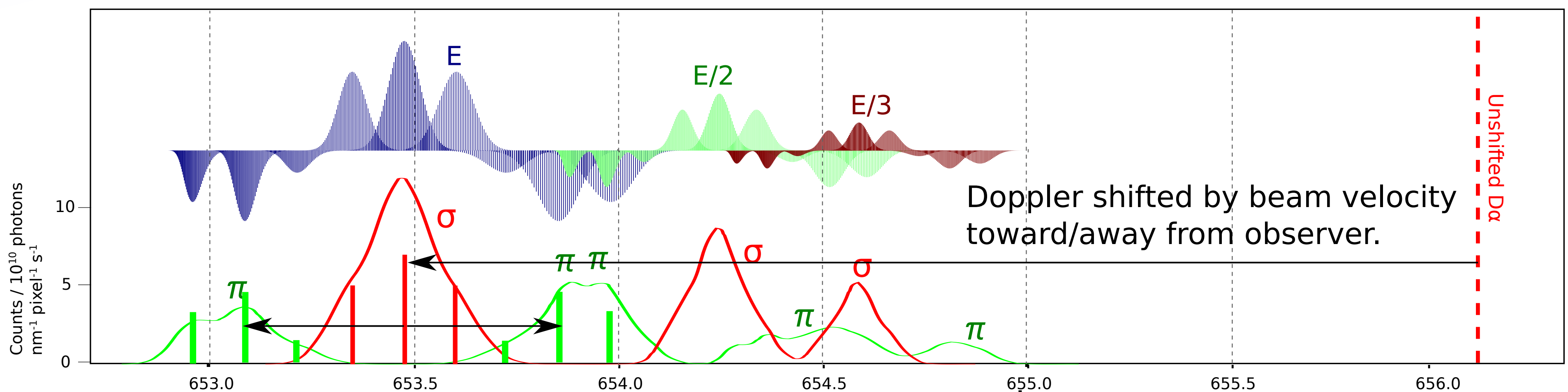
Neutral beam atoms injected into plasma.
Excited by plasma, then emit Hα/Dα radiation.



Complications:

Atoms with different injection energy: different Doppler shift.
Doppler broadening: Beam divergence, line integration etc.
Background Dα (not shown).

Spectrum from a single pixel:



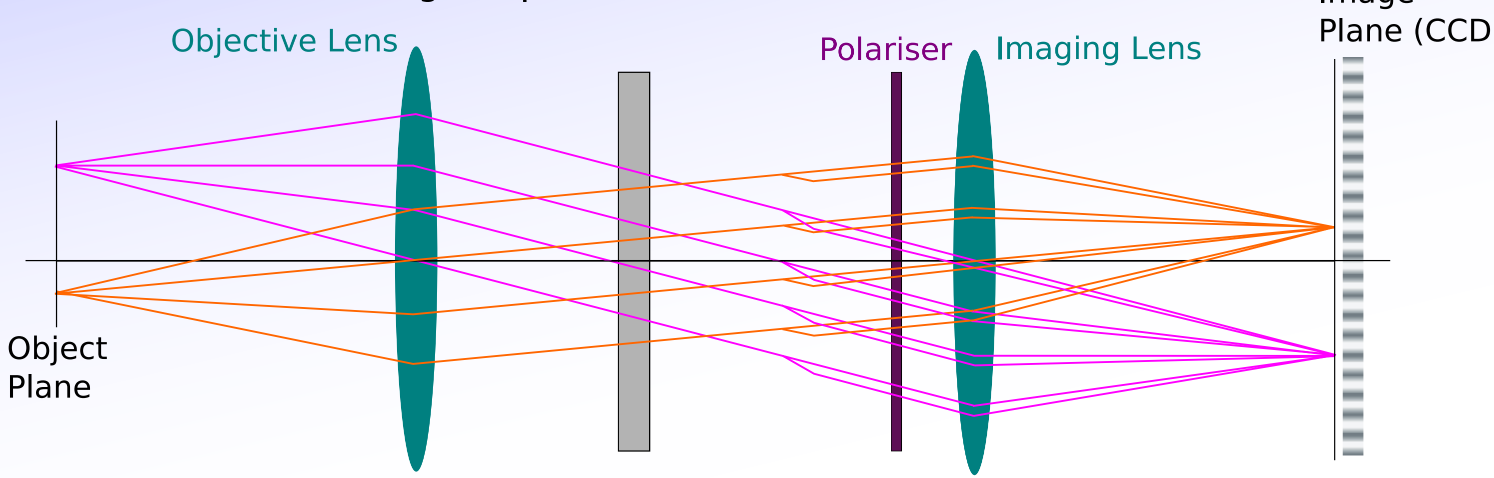
Stark split by electric field in rest frame of atom:

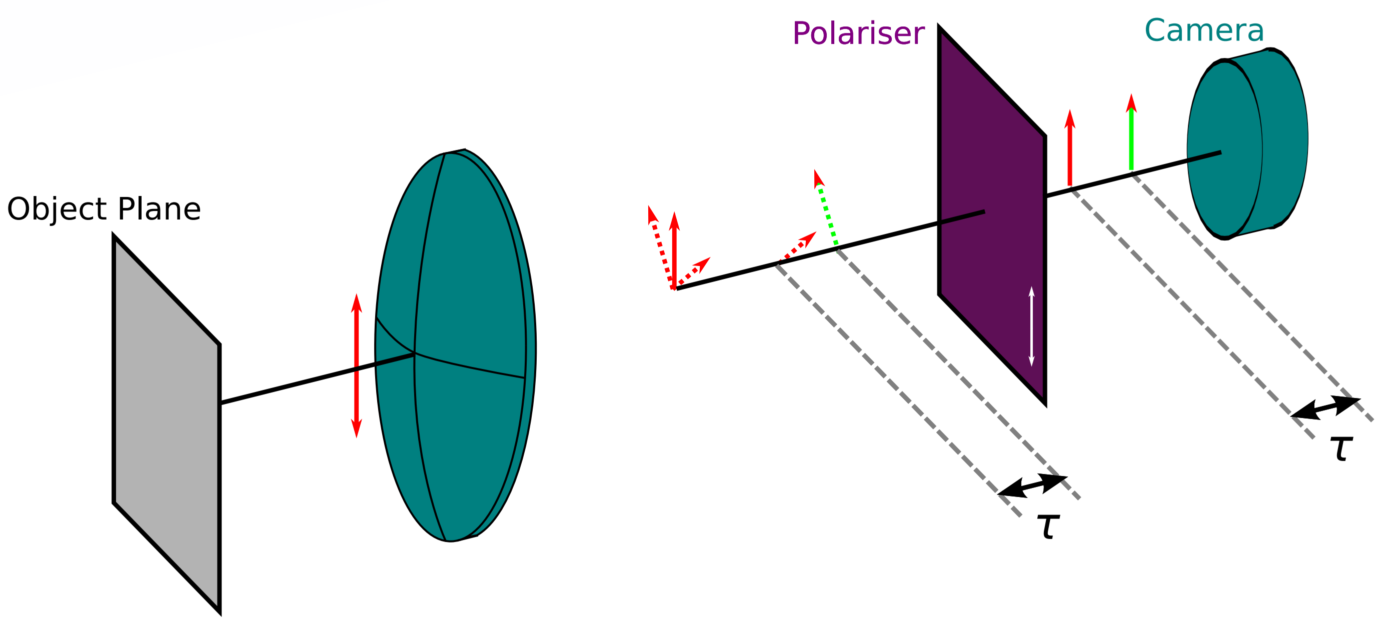
$\boldsymbol{E} = \boldsymbol{v} \times \boldsymbol{B}$

Roughly: π polarised parallel to E.
σ polarised perp' to E.

Savart Plates

We want a full 2D image of polarisation of Dα emission from beam.

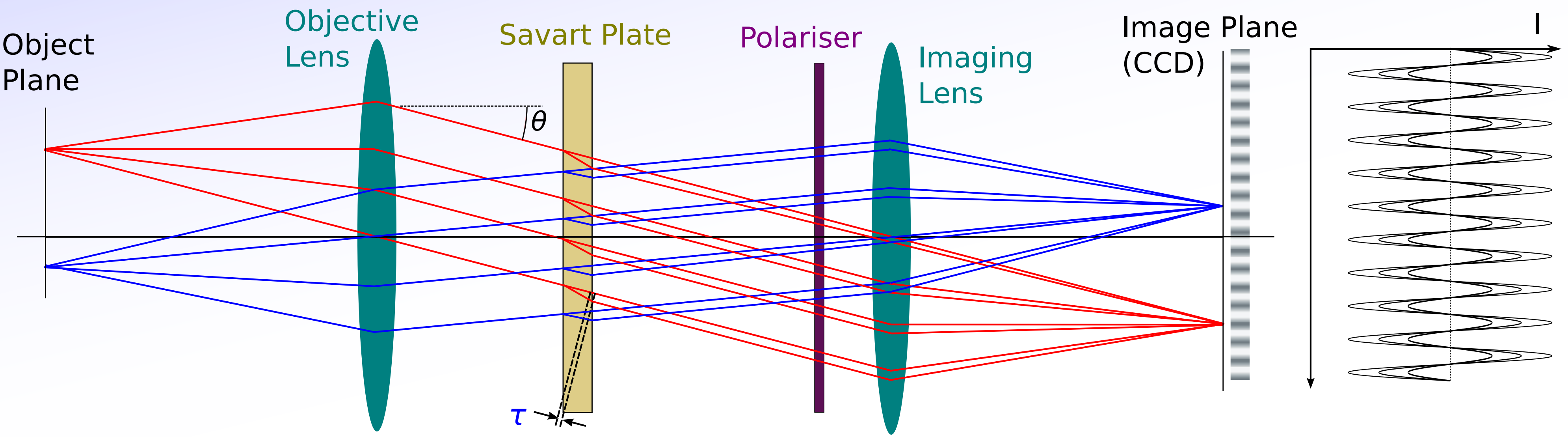




$$\frac{I_0}{2} \left[1 + \zeta \left(\: \cos 2\theta \: \cos(x) + \sin 2\theta \: \sin(x) \: \sin(y) \: \right) \right]$$

Savart Plates

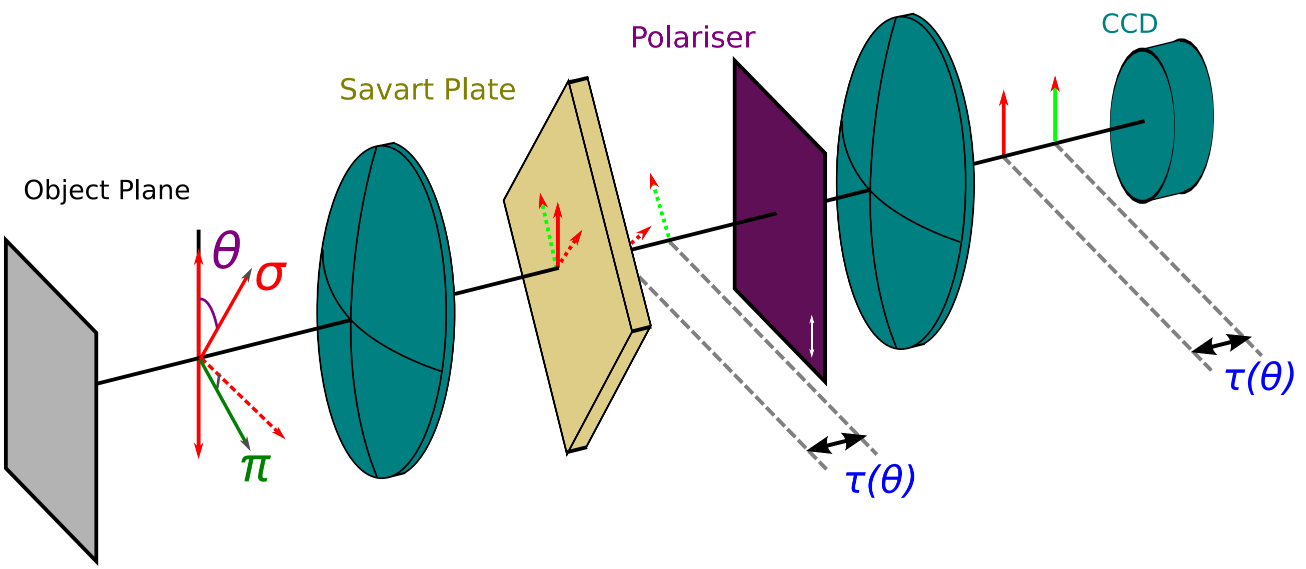
Savart Plate: Angle dependent phase shift --> Interference pattern accross image.



Oscillation amplitude proportional to polarisation angle.

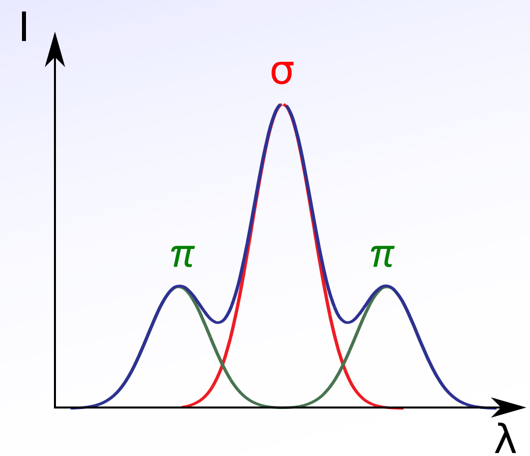
$$I \propto 1 + cos2\theta \, cos(x)$$

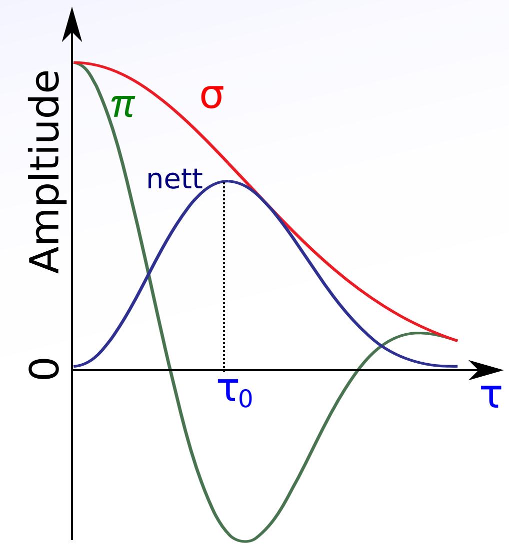
but σ and π are orthogonal.
If they were monochromatic,
they would cancel out...



Double Spatial Hetrodyne

MSE π and polarised σ are orthogonal and always the same intensity, but they have different spectral profiles.



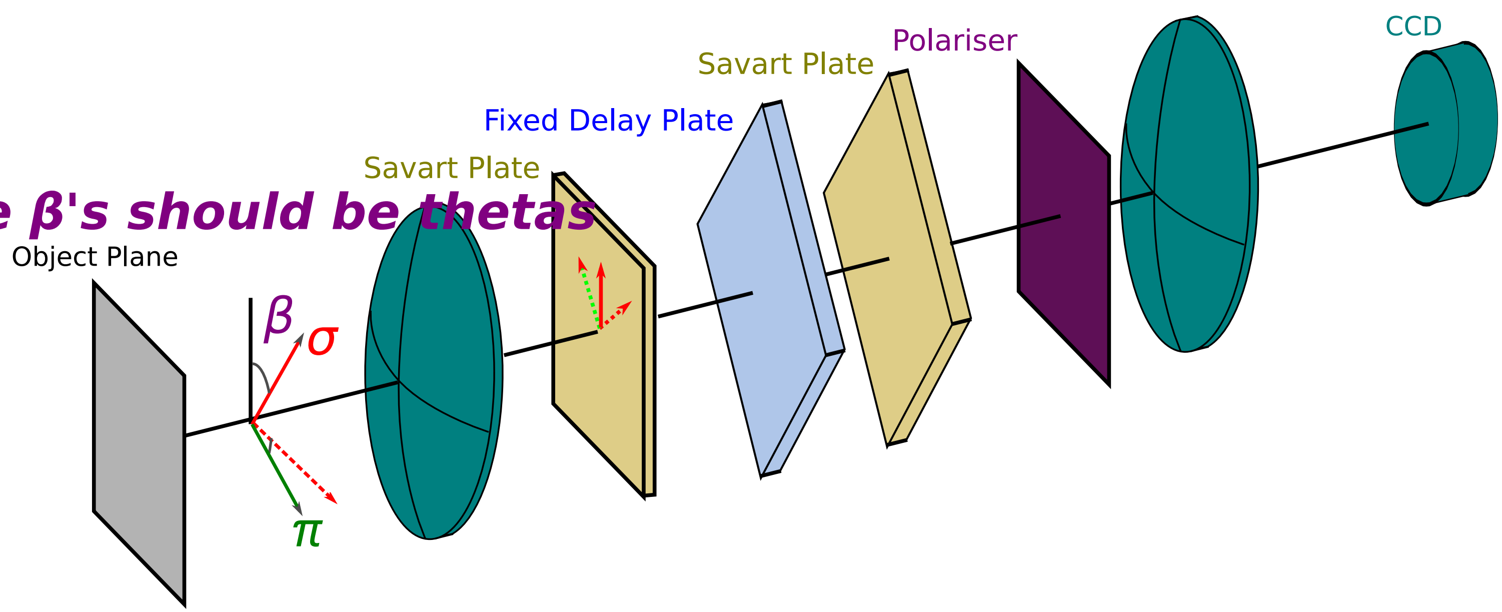


For large τ, different wavelengths have different phases - decoherence.

Add a delay plate to introduce the best τ_0 - where π and σ combine constructivly.

Amplitude dependant on contrast. To separate spectral this from β, add a second Savart plate at 45º, to create a 2nd carrier:

***** All the β's should be thetas***



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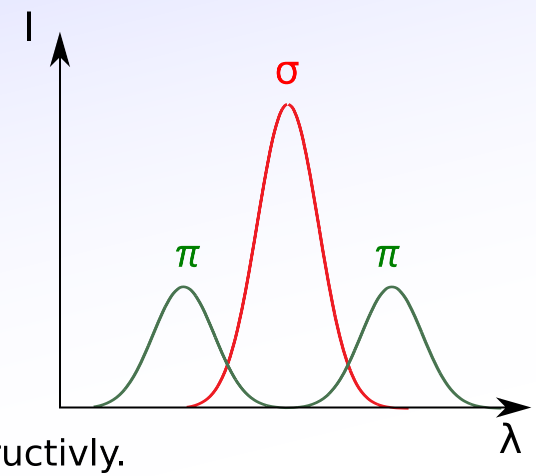

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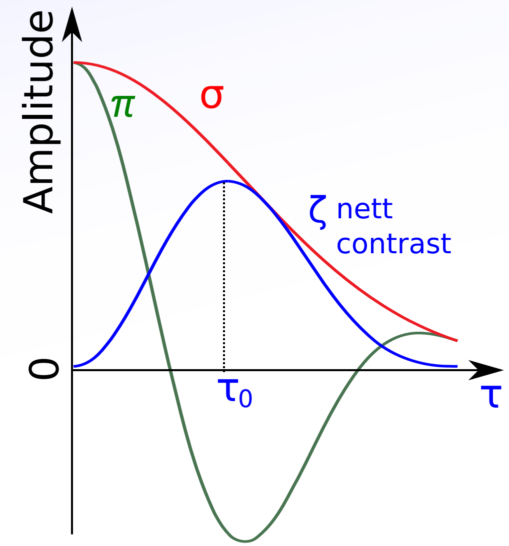
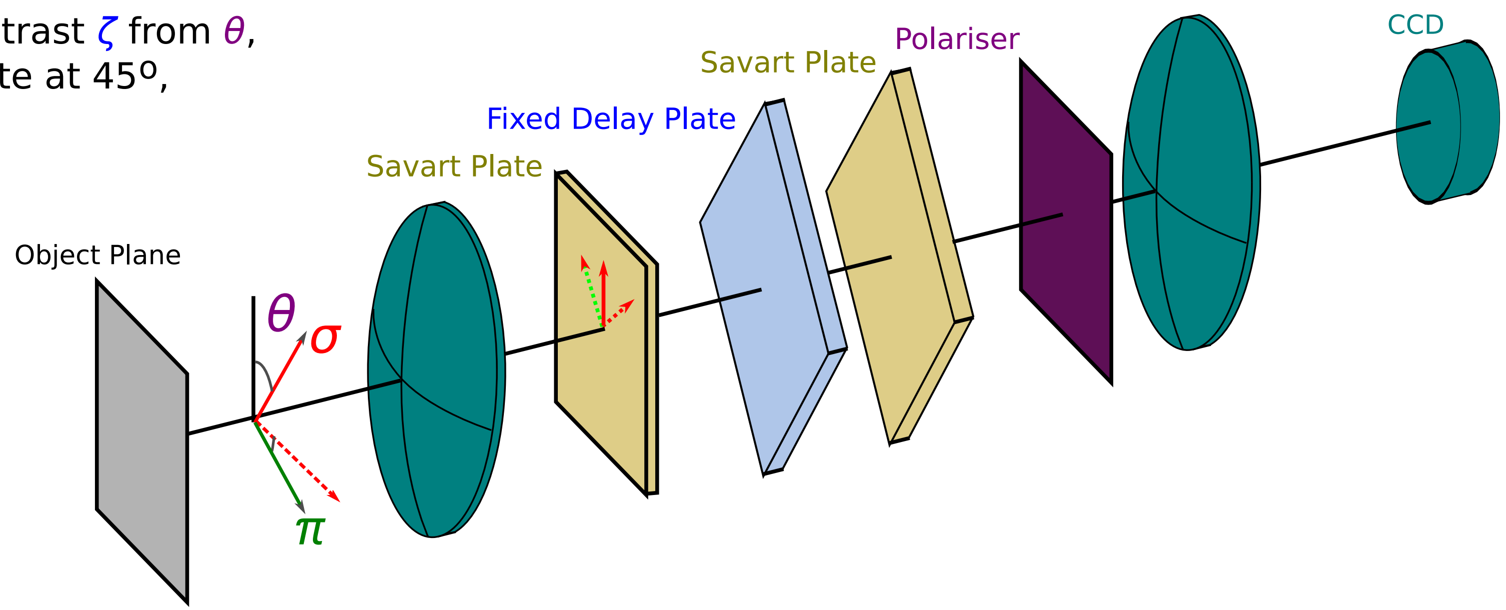


Add a delay plate to introduce the best τ_0 - where π and σ combine constructivly.

Amplitude also dependent on contrast.

$$I \propto 1 + \zeta \, cos2\theta \, cos(x)$$

To separate spectral contrast ζ from θ, add a second Savart plate at 45º, to create a 2nd carrier:



Savart Plates

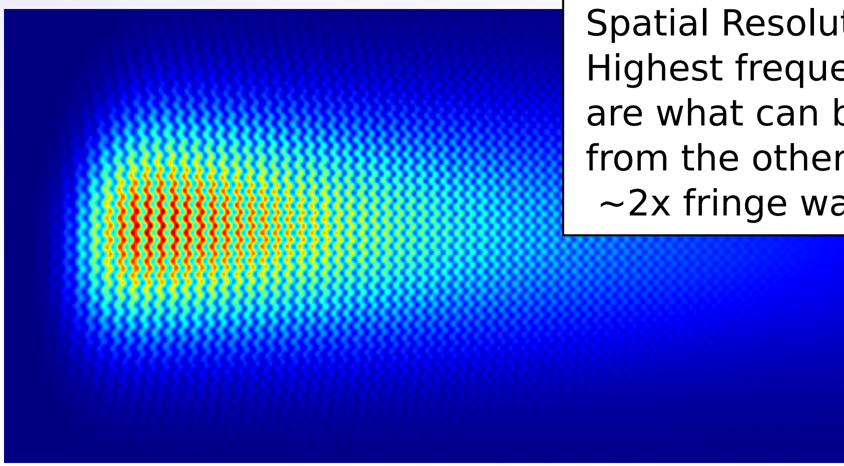
(For the record: This is the '*Ampltiude Modulated Double Spatial Hetrodyne*' system).

The equation for the image is now:

$$I = I_0\left[1 + \zeta\left(\cos 2\theta \cos(x) + \frac{1}{2} \sin 2\theta \cos(x-y) - \frac{1}{2} \sin 2\theta \cos(x+y)\right)\right]$$

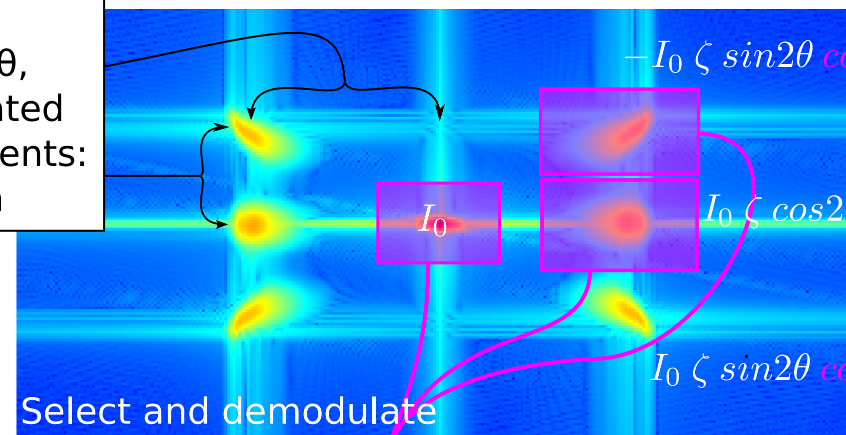
Intensity Contrast Polarisation Angle

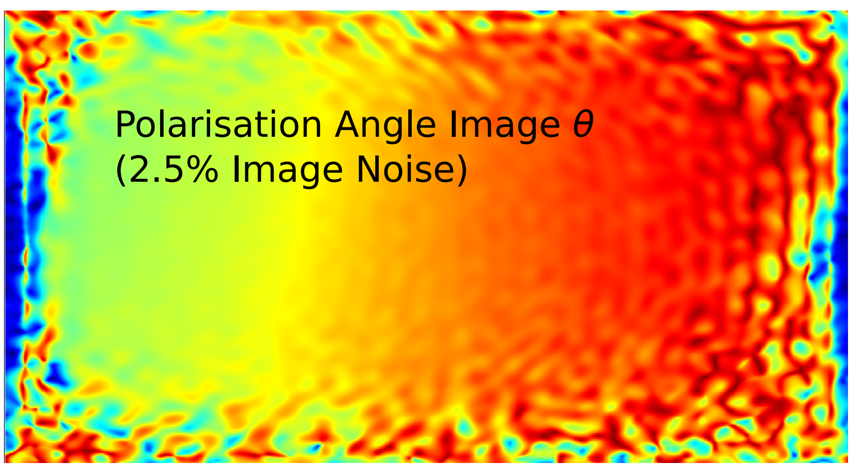
By demodulating the image in x and y, we can find θ, I_0 and ζ.



Spatial Resolution:
Highest frequencies in θ, are what can be separated from the other components:
~2x fringe wavelength

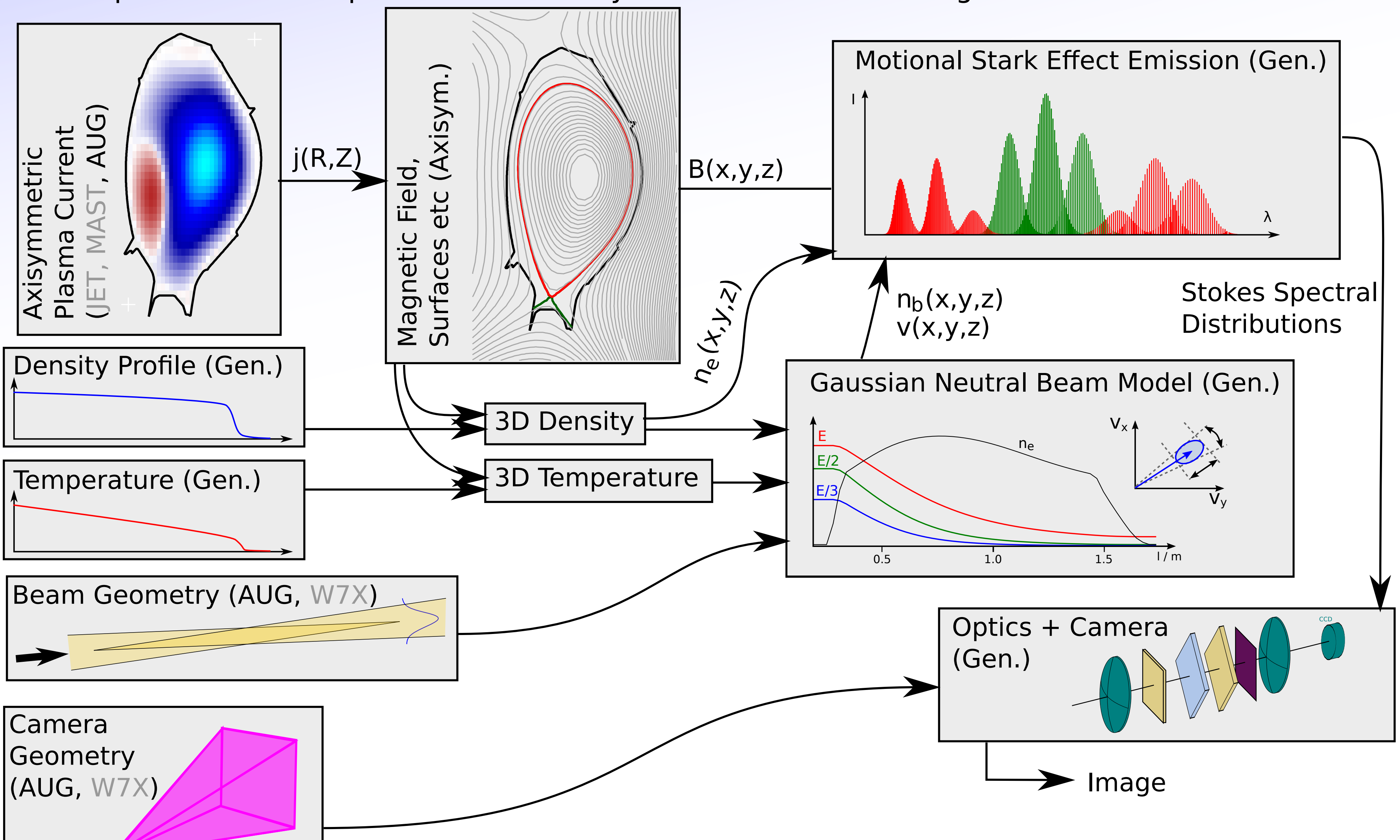
FT





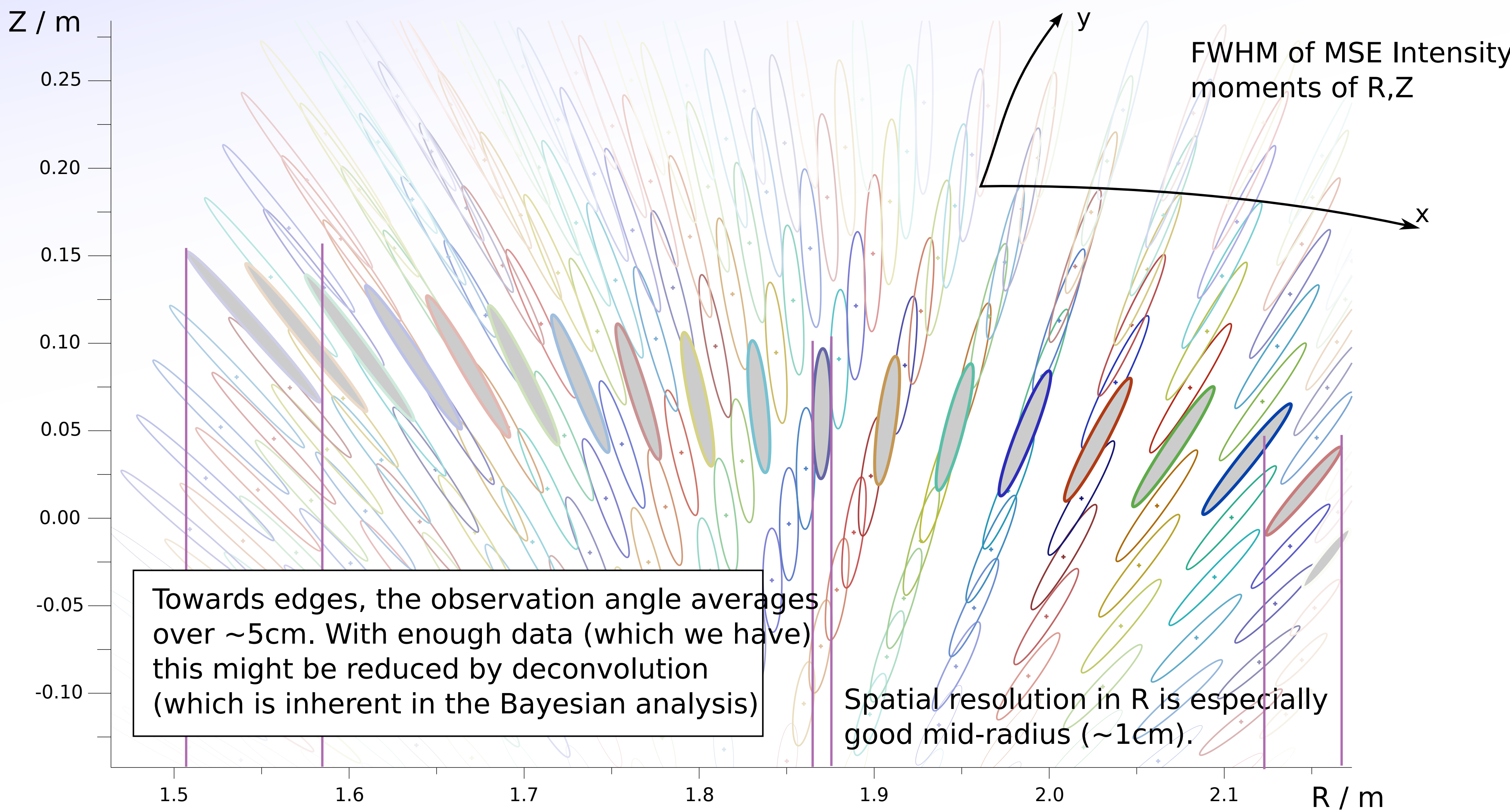
Forward Model

Developed several components for the Bayesian/Forward modelling framework



AUG: θ Spatial Resolution

The recovered θ are really <θ> over the LOS. Spatial resolution is a combination of pixel-pixel averaging due to modulation (1cm) and the LOS averaging.
The LOS averaging varies over image (x,y):



Recovery of plasma current - Axisymmetric

To final objective is to measure plasma current j.
For normal 1D measurements: not possible so θ used as a constraint for equilibrium.
Does having 2D measurements make it possible to calculate j without equilibrium?

Assuming toroidal symmetry, the current is:

$$-\mu_0 j_\phi = \frac{\partial B_z}{\partial R} + \frac{1}{R}\frac{\partial^2}{\partial Z^2}\int_0^R R' B_z(R', Z)\, dR'$$

Assume we know B_ϕ as the vacuum field, then we can calulate B_Z from θ.

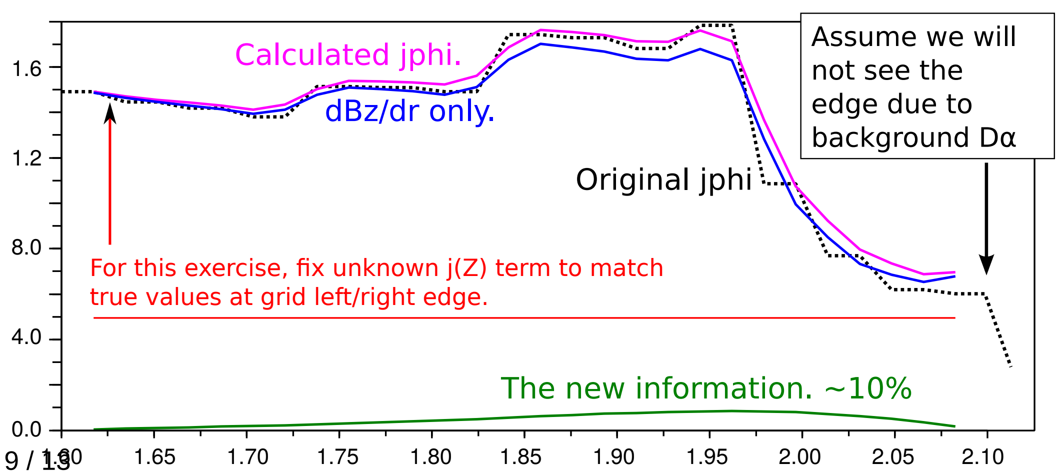
However, we only see where the MSE emission is, so can only integrate from some $R = R_0$:

$$-\mu_0 j_\phi = \frac{\partial B_z}{\partial R} + \frac{1}{R}\frac{\partial^2 \psi(R_0, Z)}{\partial Z^2} + \frac{1}{R}\frac{\partial^2}{\partial Z^2}\int_{R_0}^R R' B_z(R', Z) dR'$$

This we have with 1D MSE.

Function of Z that we cannot know.

The new term gives localisation of current in Z (~via curvature of field).

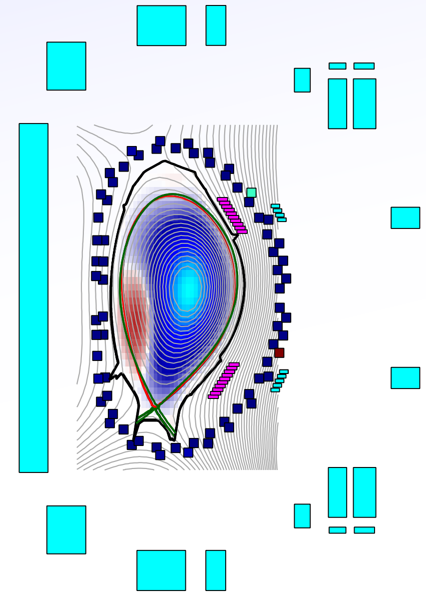


With the new term, we can in theory calculate j_ϕ ra profiles except for a fixed constant (because the f(Z) term is still not known).

In practice, d^2B/d^2 is much too noisy.

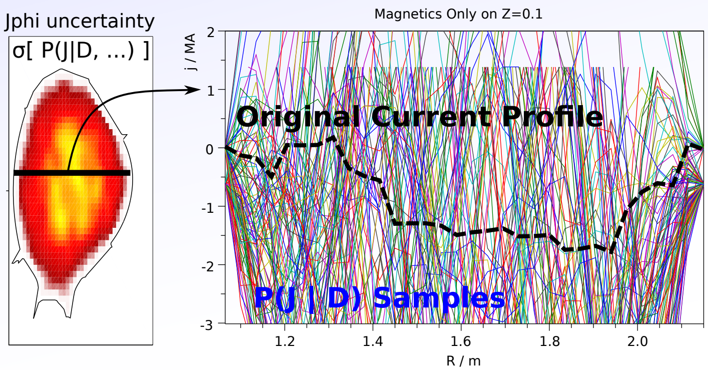
However, we also gain *dBz/dR* at different *Zs*.
Together with normal coil measurements,
it is now part of a complex tomography problem

By current tomography...



Add model for AUG PF coils, pickups etc to Minerva. Can now do Current Tomorgraphy and Bayesian Equilibrium for AUG.

1) Magnetics only: We have the usual tomography situation:

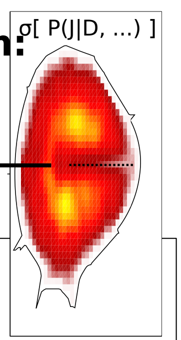


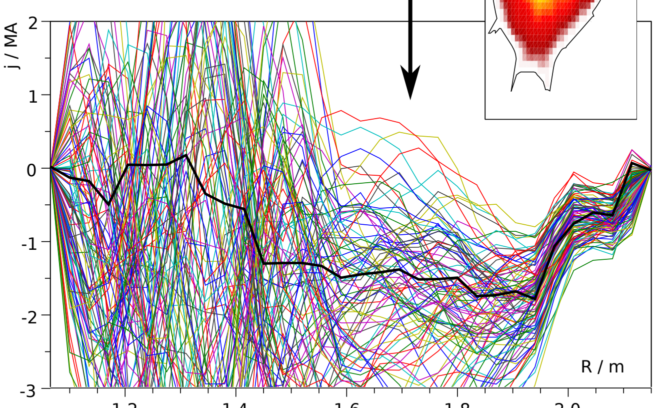
(Almost) no prior/regularisation

(Almost) infinite uncertainty
(but B and flux still good)

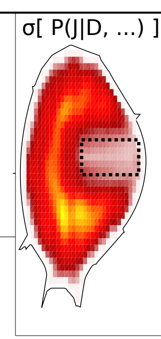
Each case has 900 measurements at σ = *10mT.*
So difference is only in the ***type*** of information.

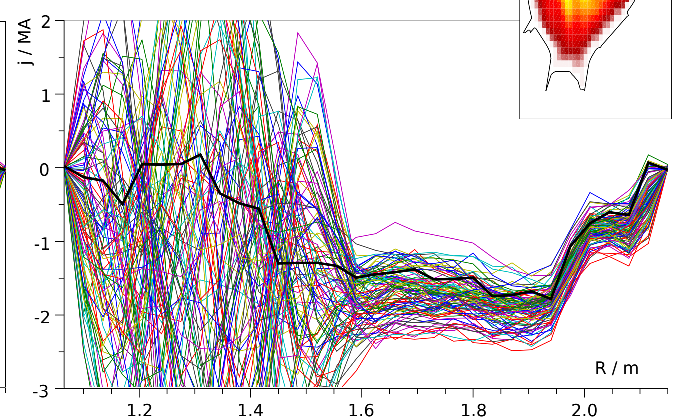
2) Normal MSE system:
30 x *Bz* at 30 positions along NBI centre.



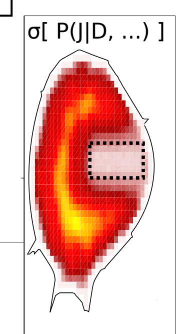


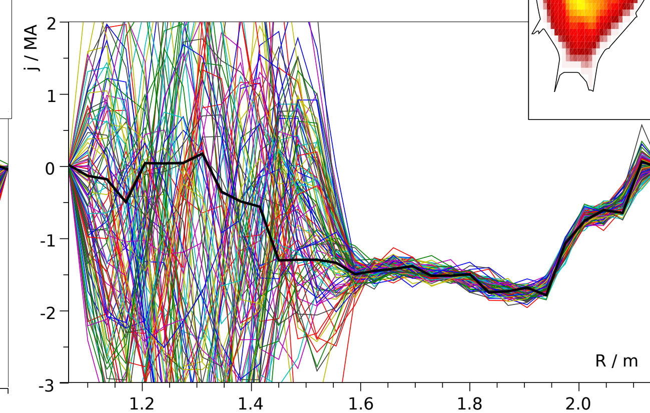
3) IMSE System:
30x30 grid of *Bz* measurements.



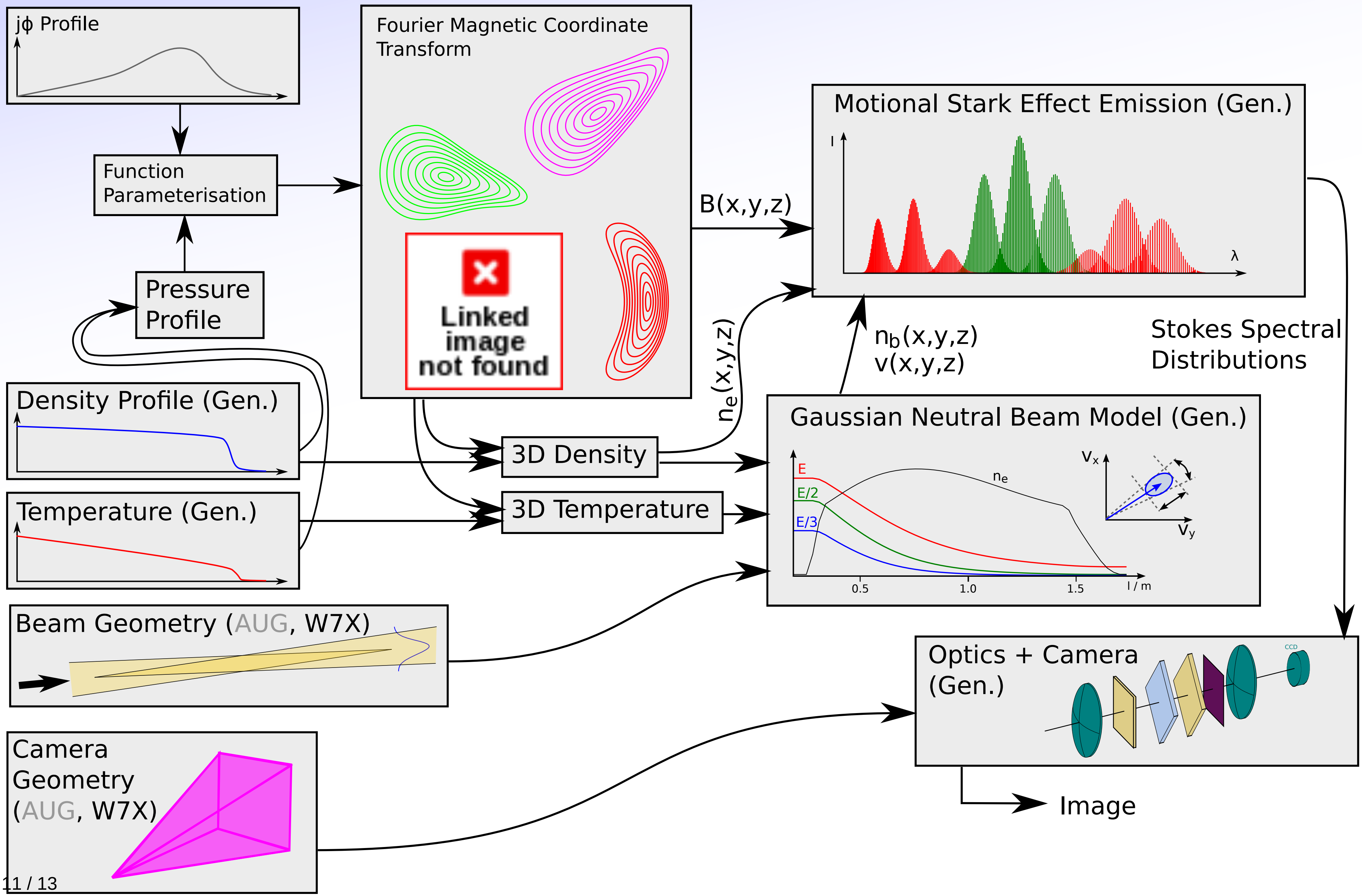


4) +Br (for interest)
30x15 grid of *Bz*
30x16 grid of *Br.*



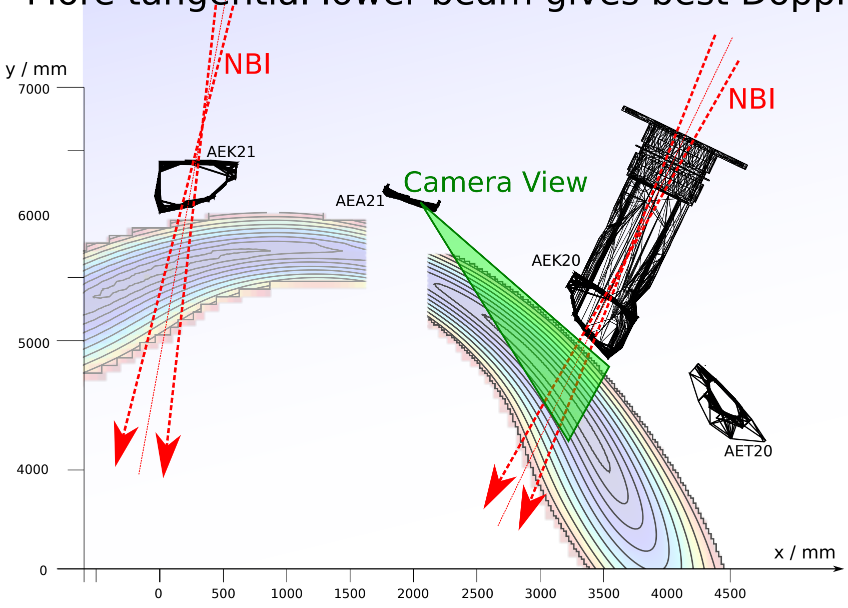


Forward Model (W7X)



Geometry (W7X)

Best view of NBI to reduce cross-surface integration: from port AEA21, looking along const Z plane.
More tangential lower beam gives best Doppler shift --> Better image fringe contrast.



View is almost to surfaces here --> Reasonable flux surface resolution:
Beam attenuation is rapid due to high electron density so only outboard side is seen: