Motional Stark Effect Coherence Imaging for ASDEX Upgrade.

Design and evaluation progress.

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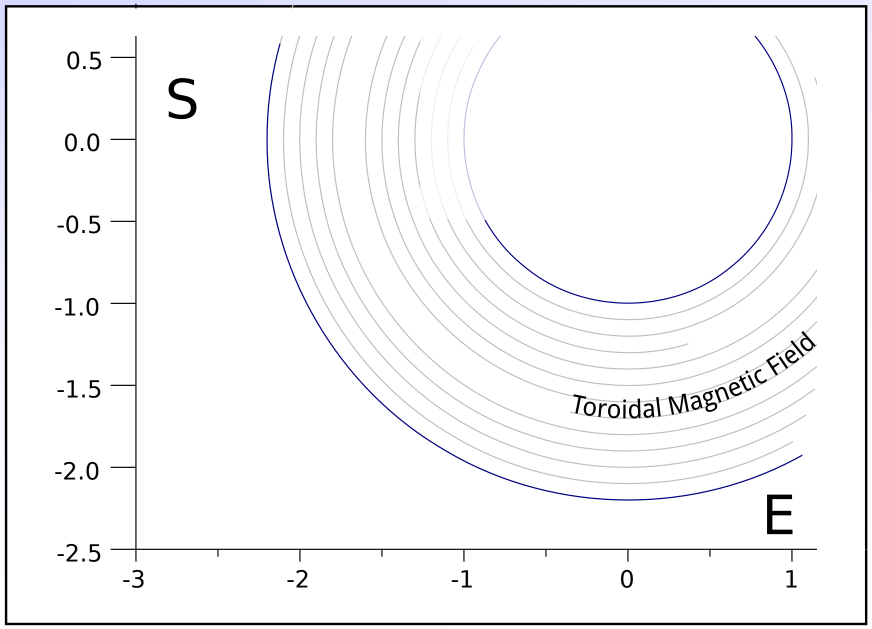
- Brief (re)introduction.
- Line integration and resolution.
- What do we gain with 2D measurements?
    - in Theory,
    - in Practice
- Model improvements.
- Outlook

Very Brief Introduction



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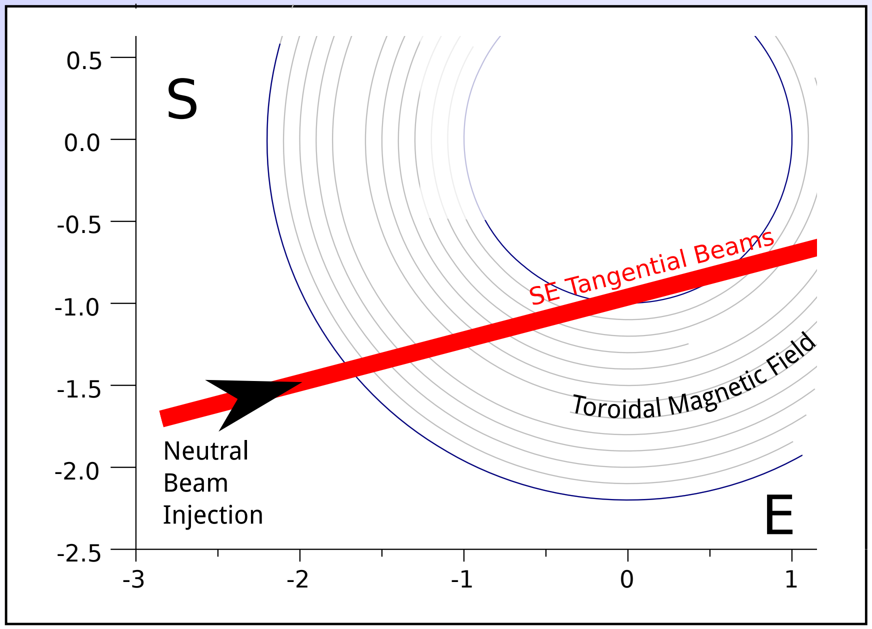

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Excited by plasma, then emit Hα/Dα radiation.

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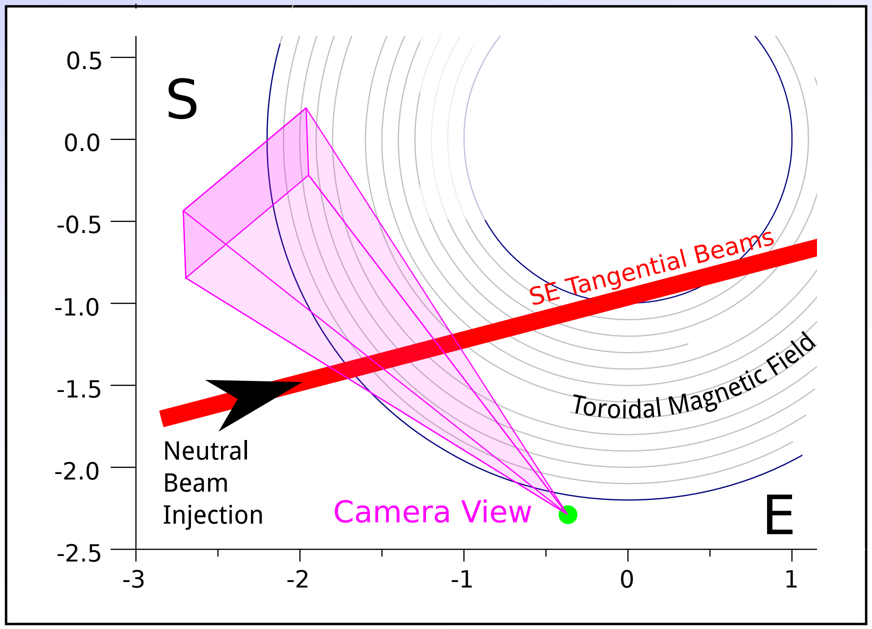

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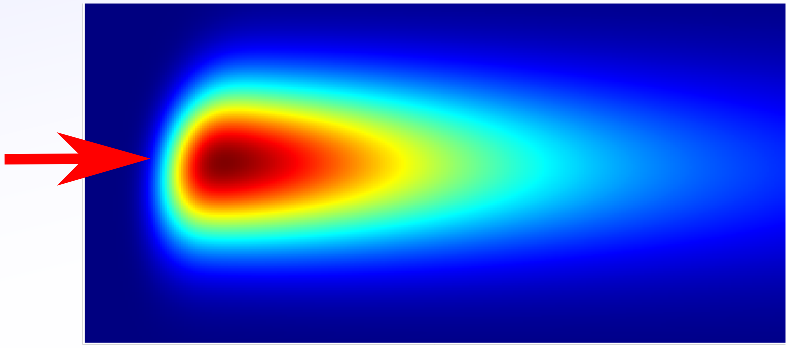

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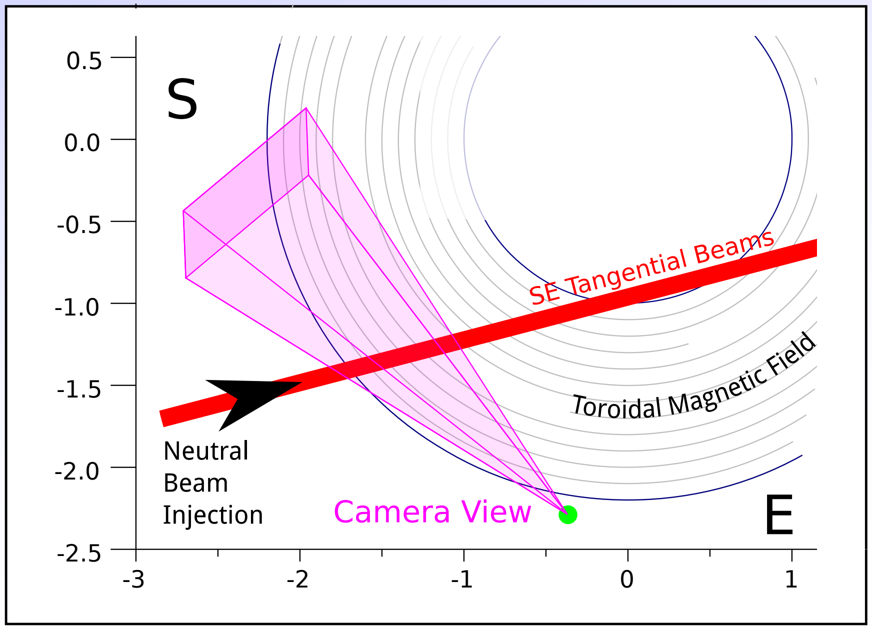

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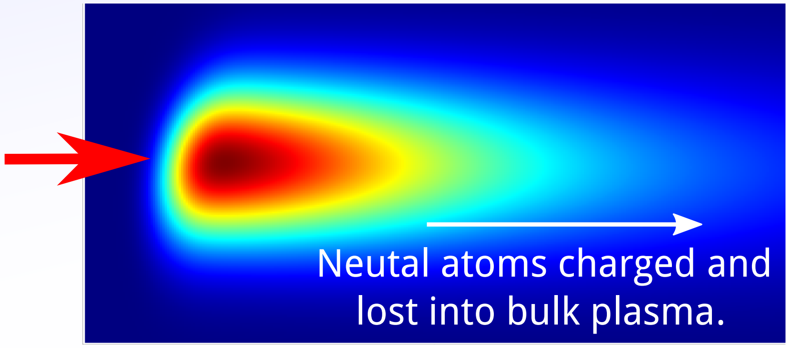

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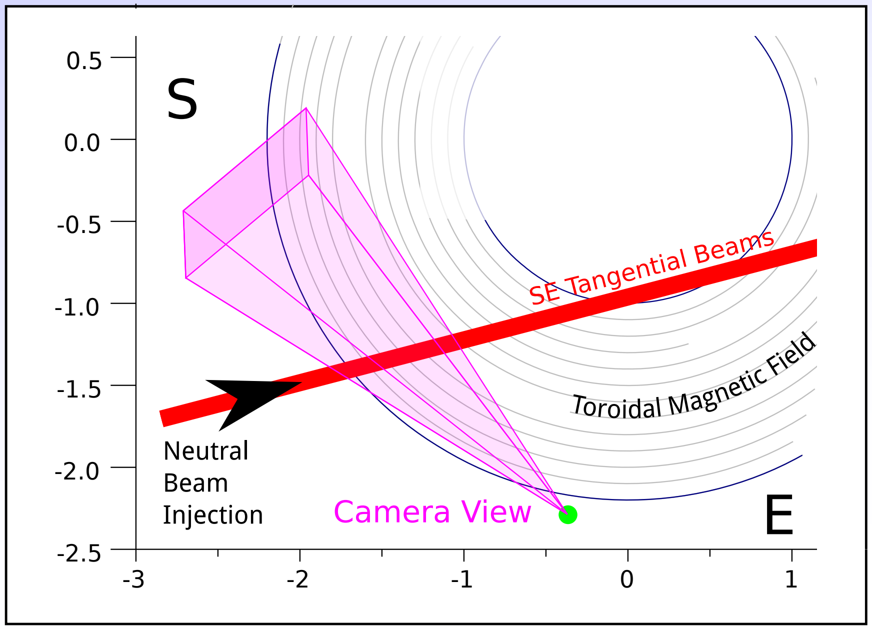

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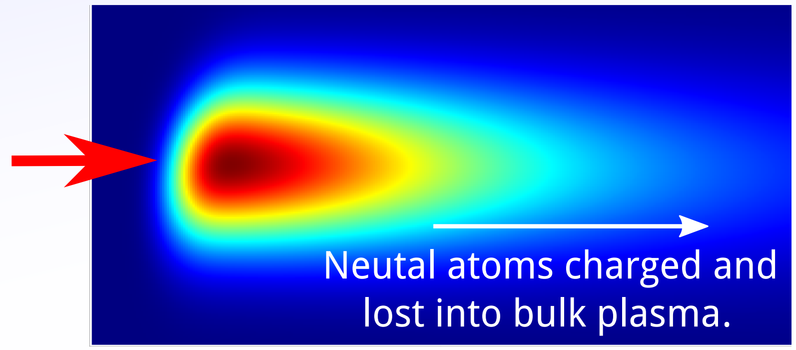

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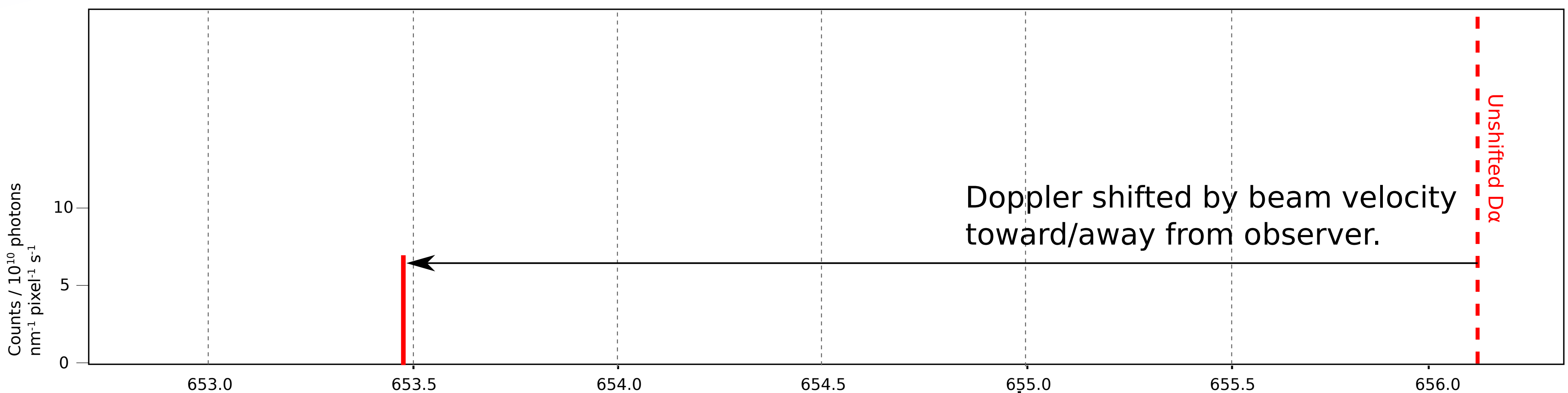

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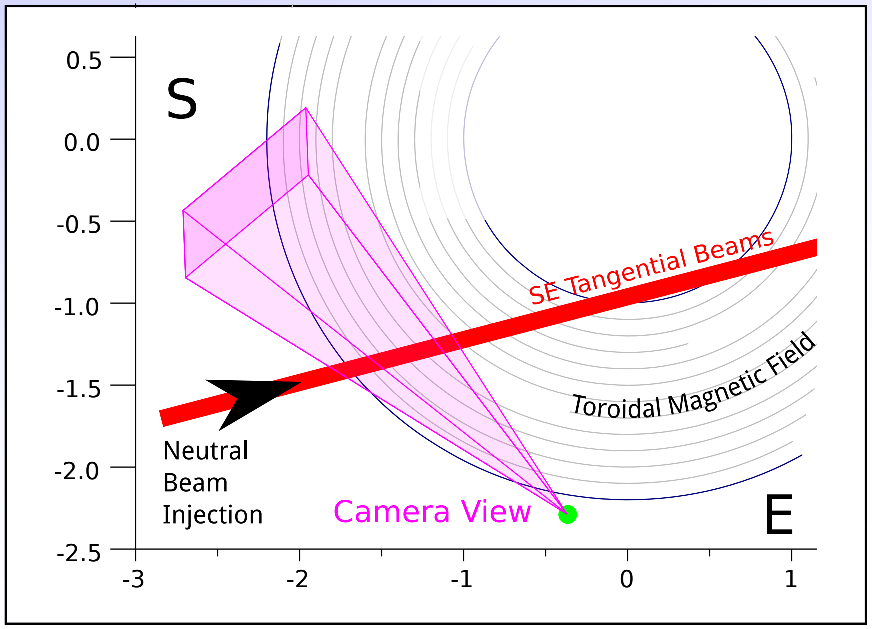

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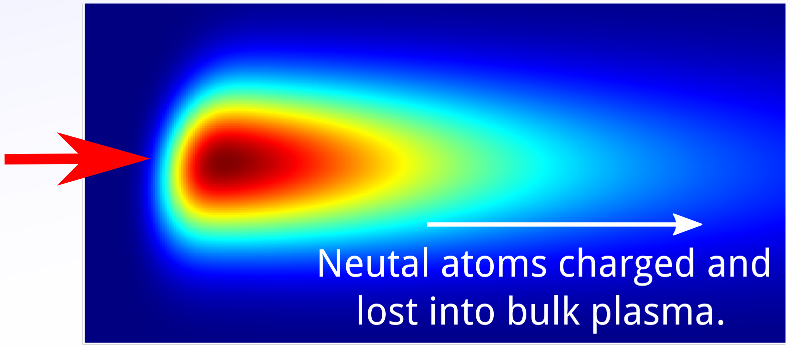

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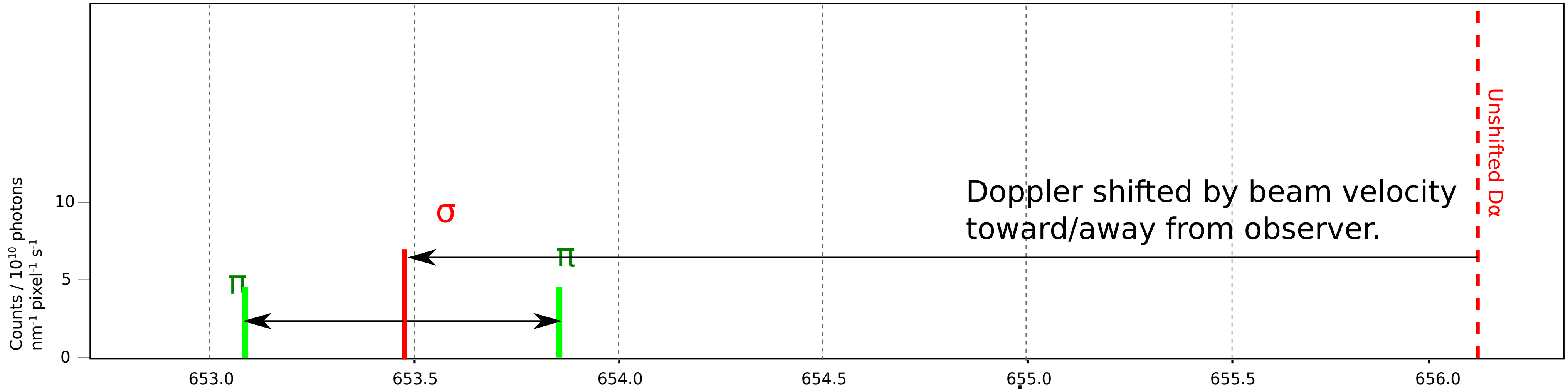

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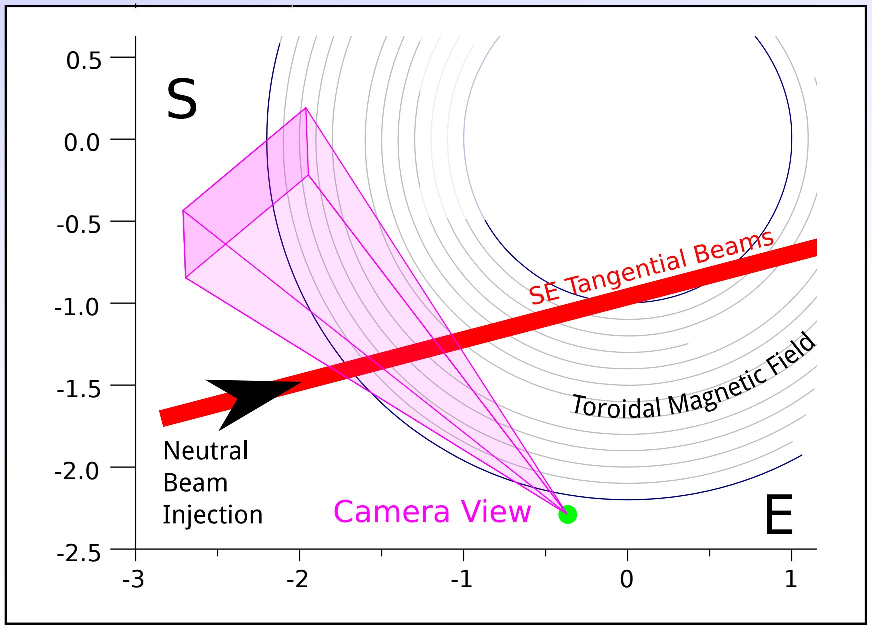

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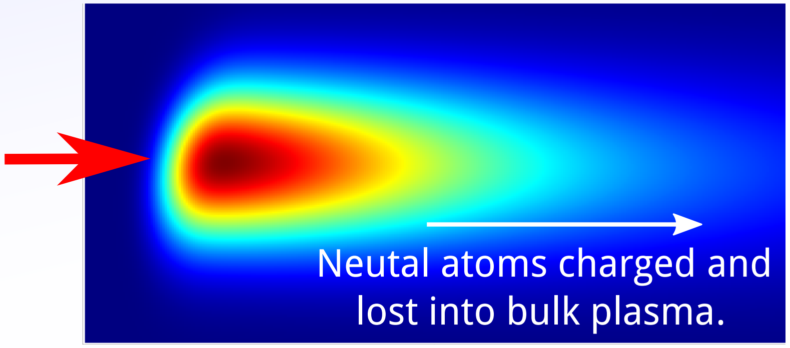

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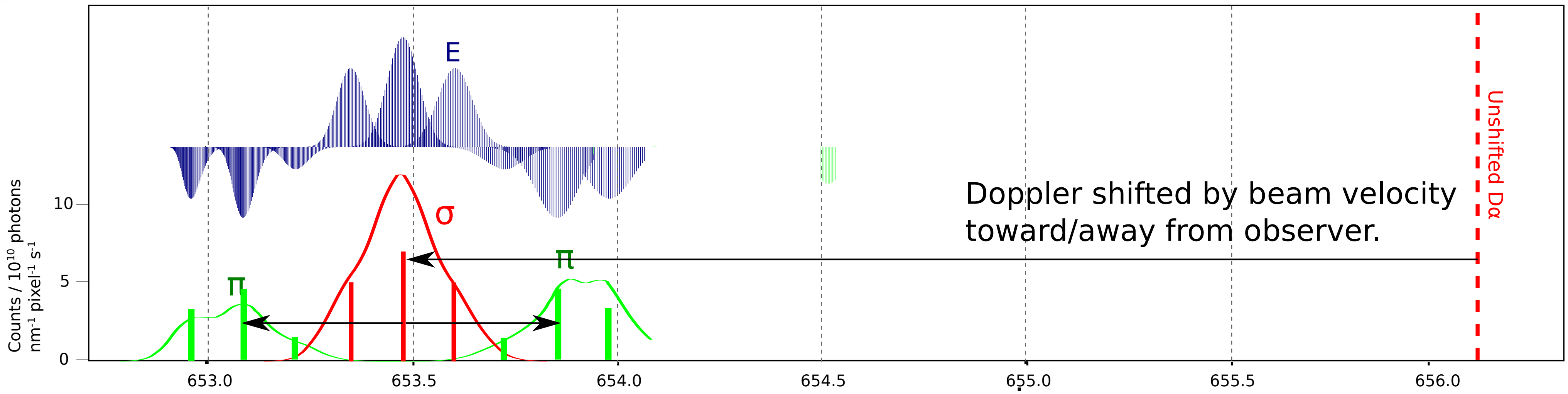

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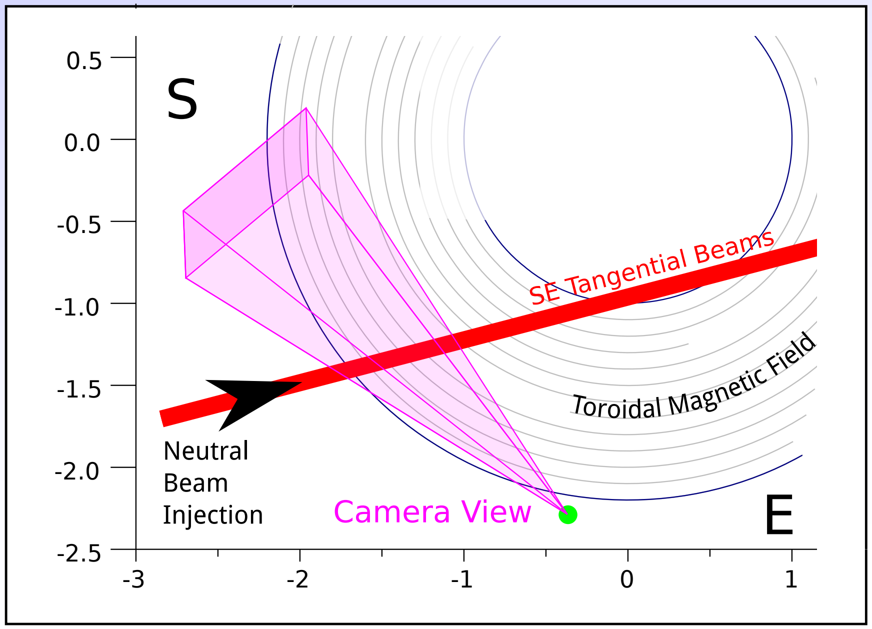

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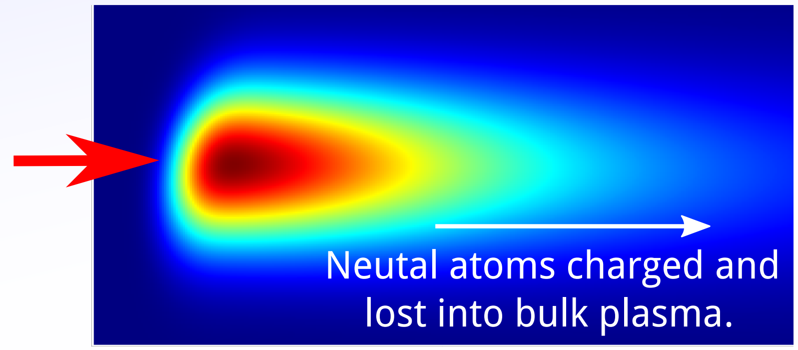

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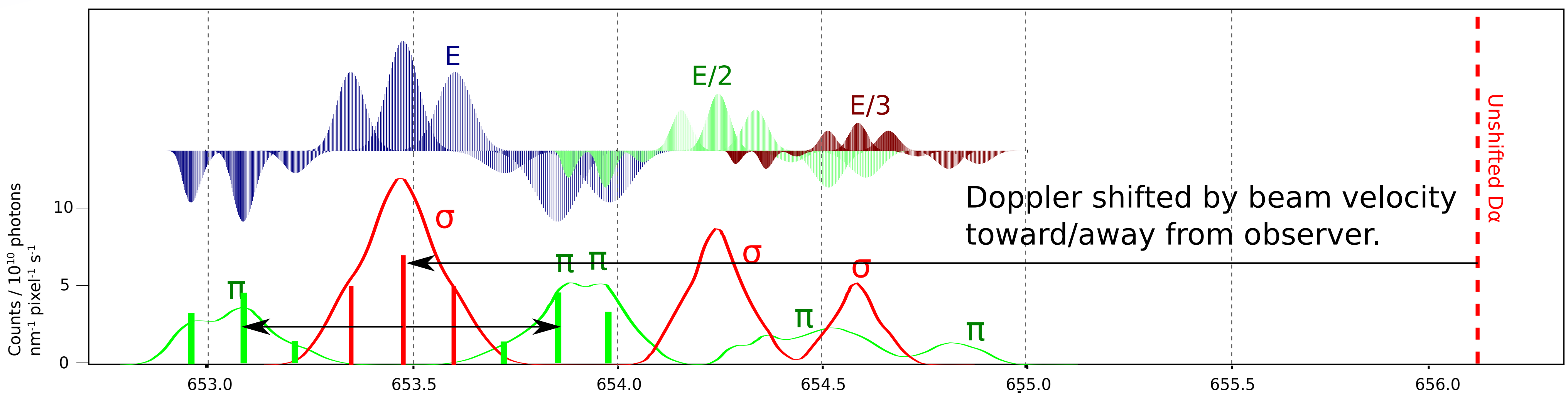

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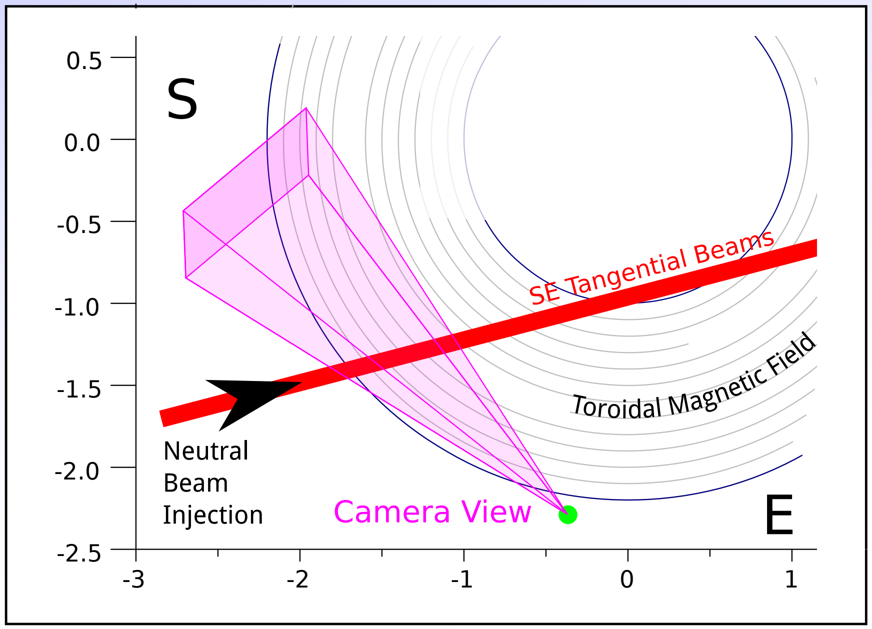

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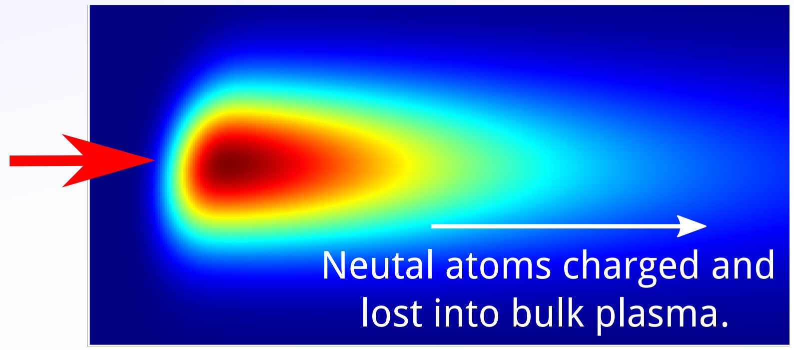

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- Doppler broadening: Beam divergence, line integration etc.
- Background Dα (not shown).

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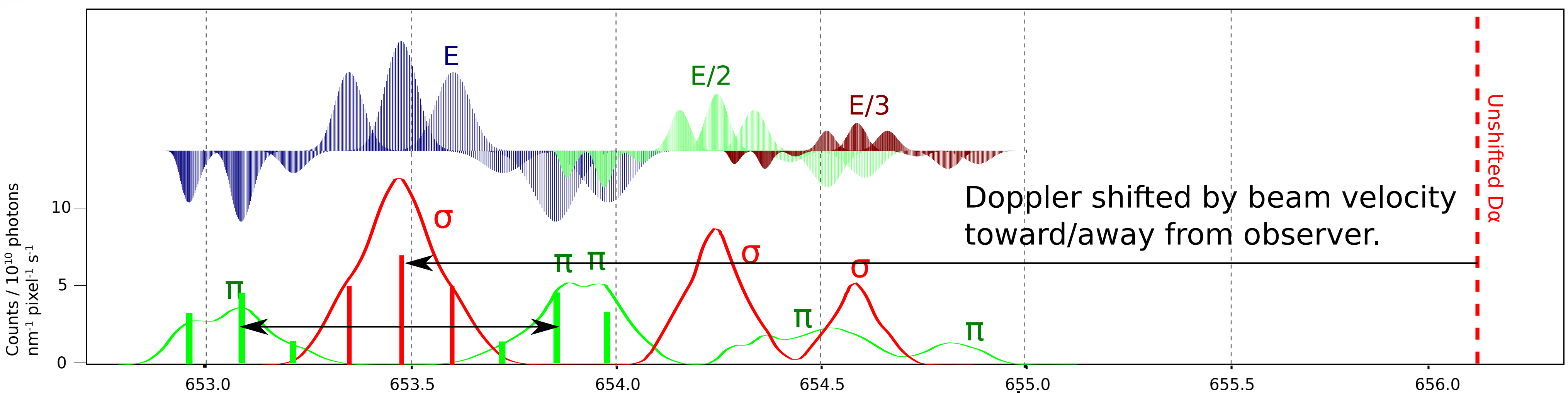

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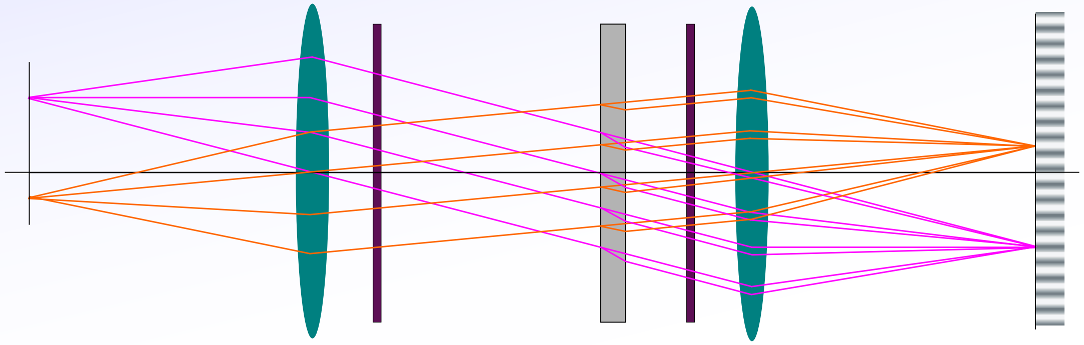

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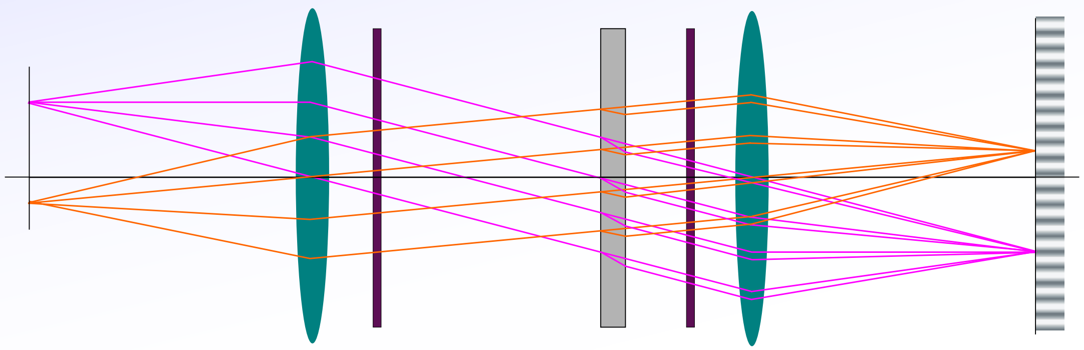

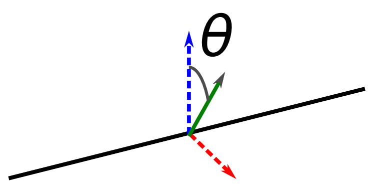

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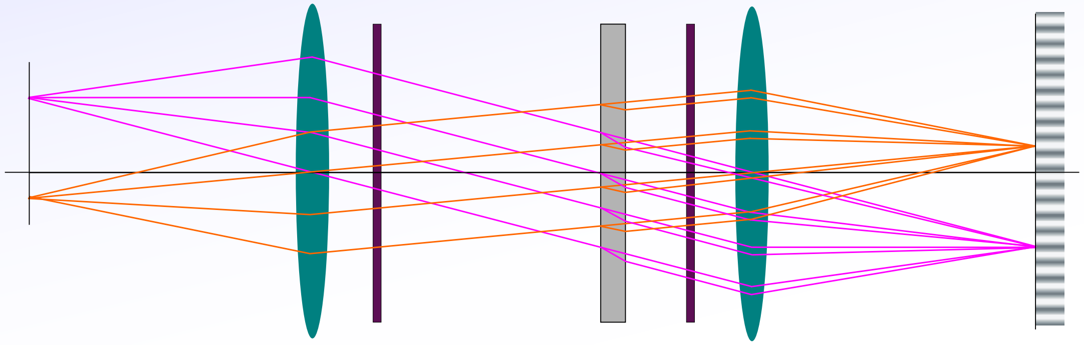

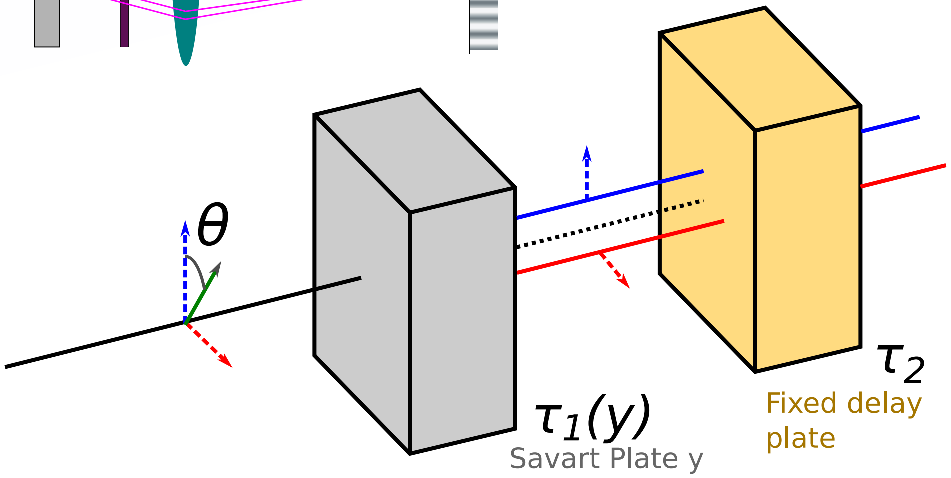

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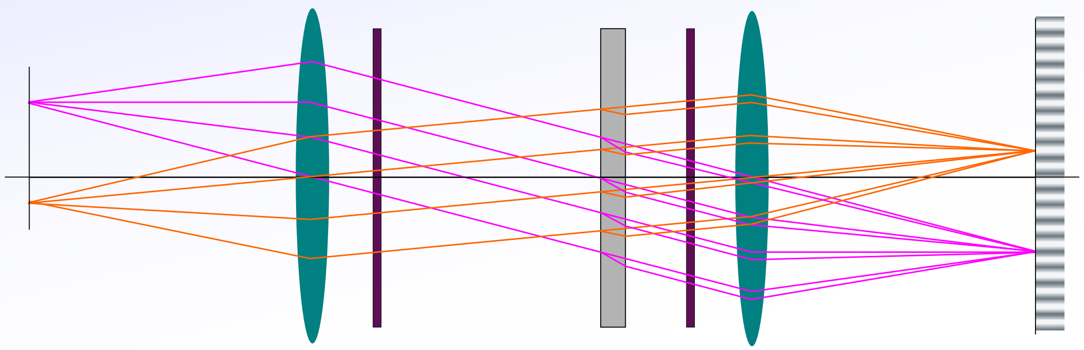

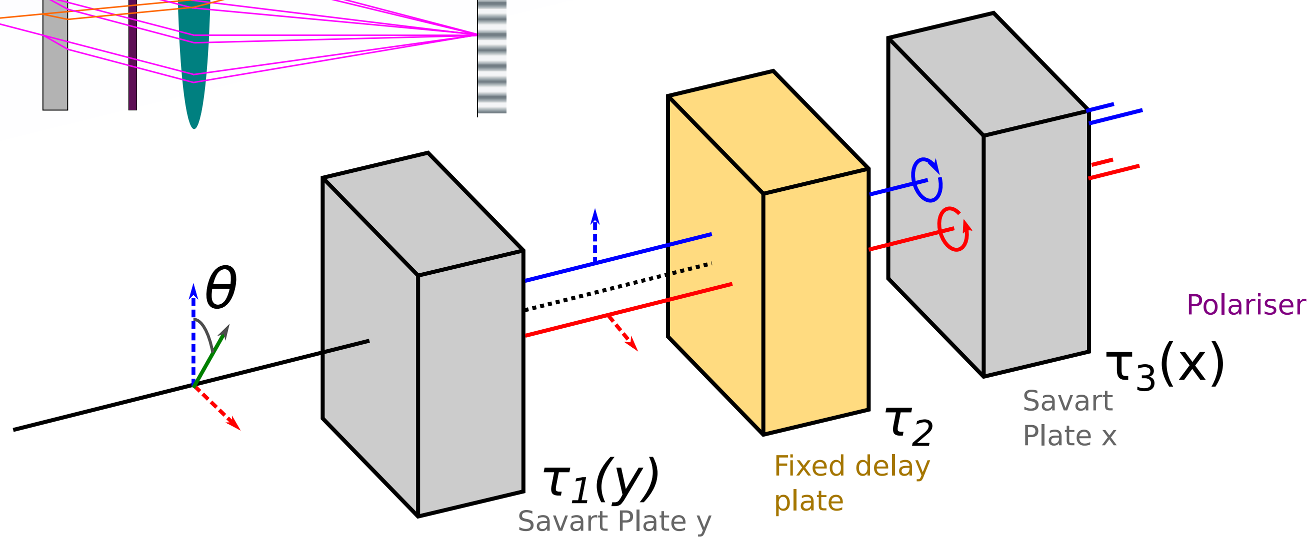

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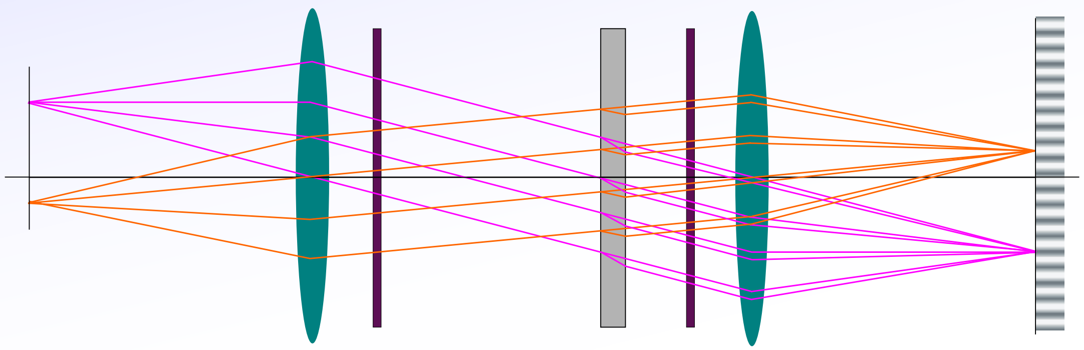

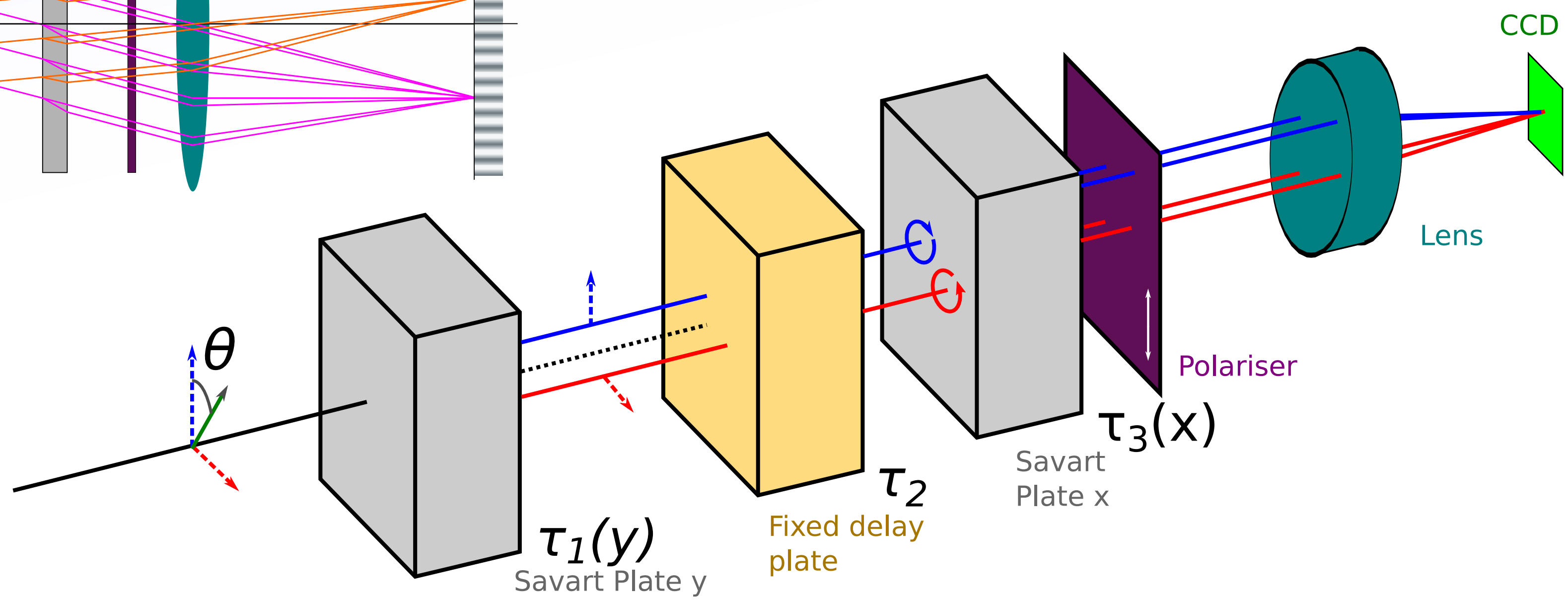

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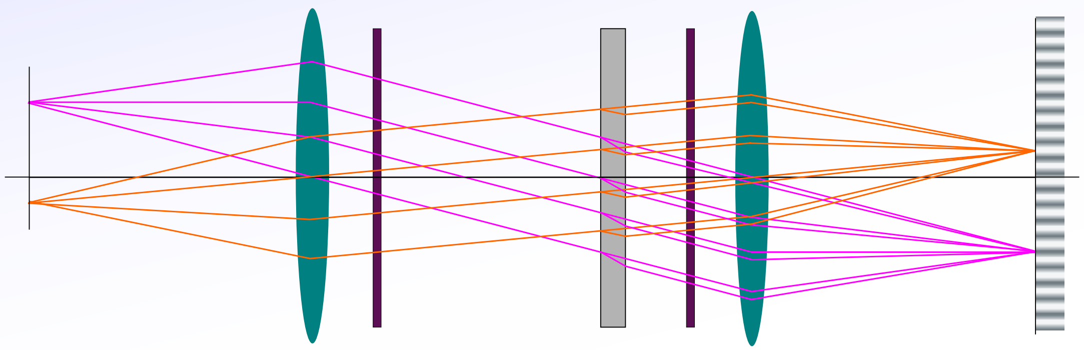

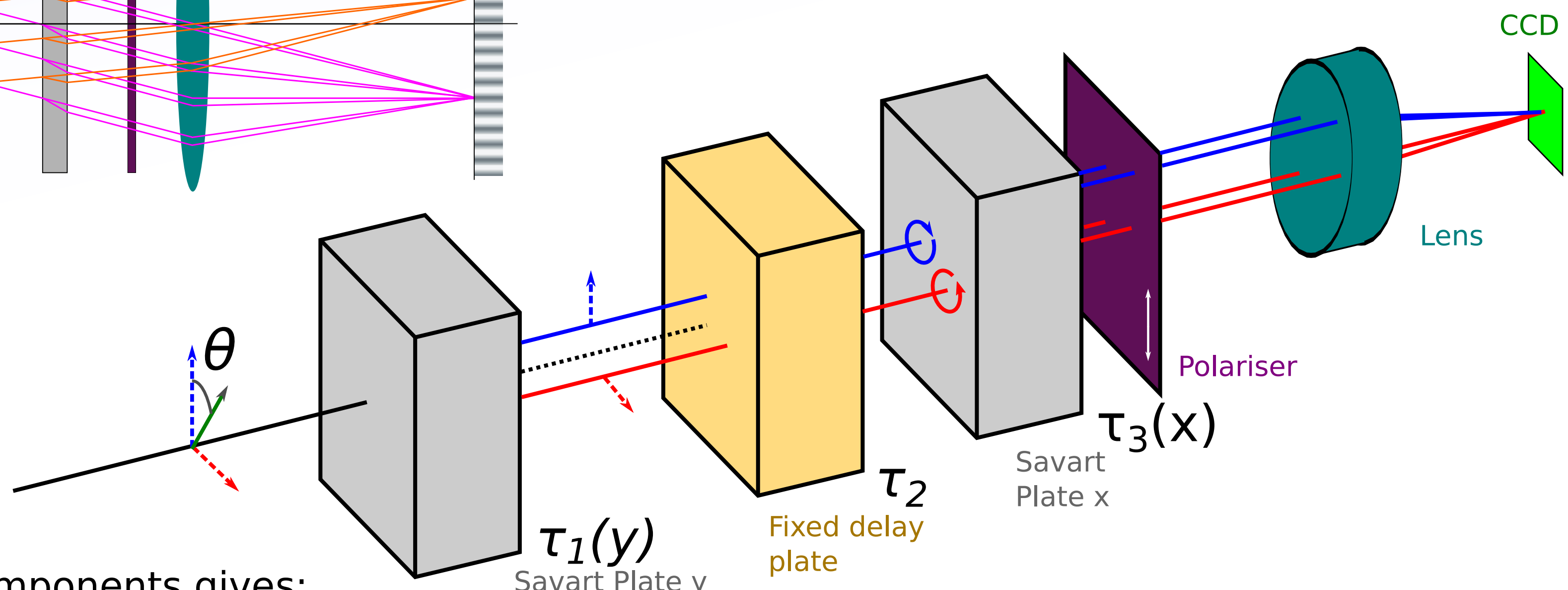

The interference of all 4 components gives:

$$I = \frac{I_0}{2}\left[1 + \zeta\left(\, cos2\theta\, cos(x) + sin2\theta\, sin(x)\, sin(y)\,\right)\right]$$

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

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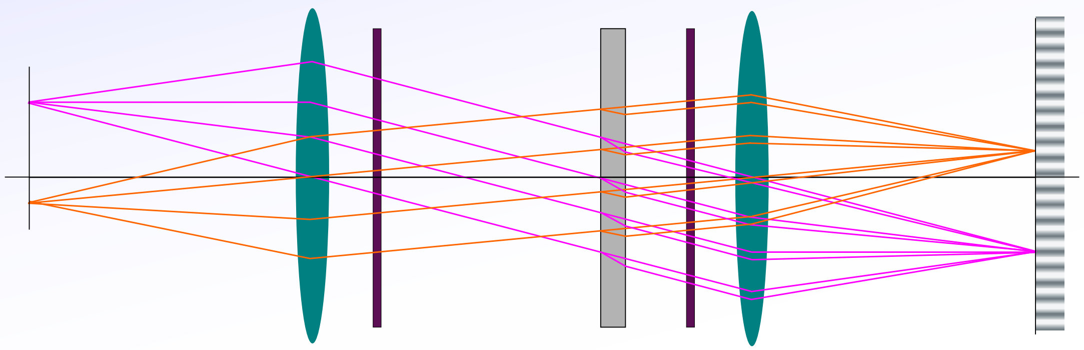

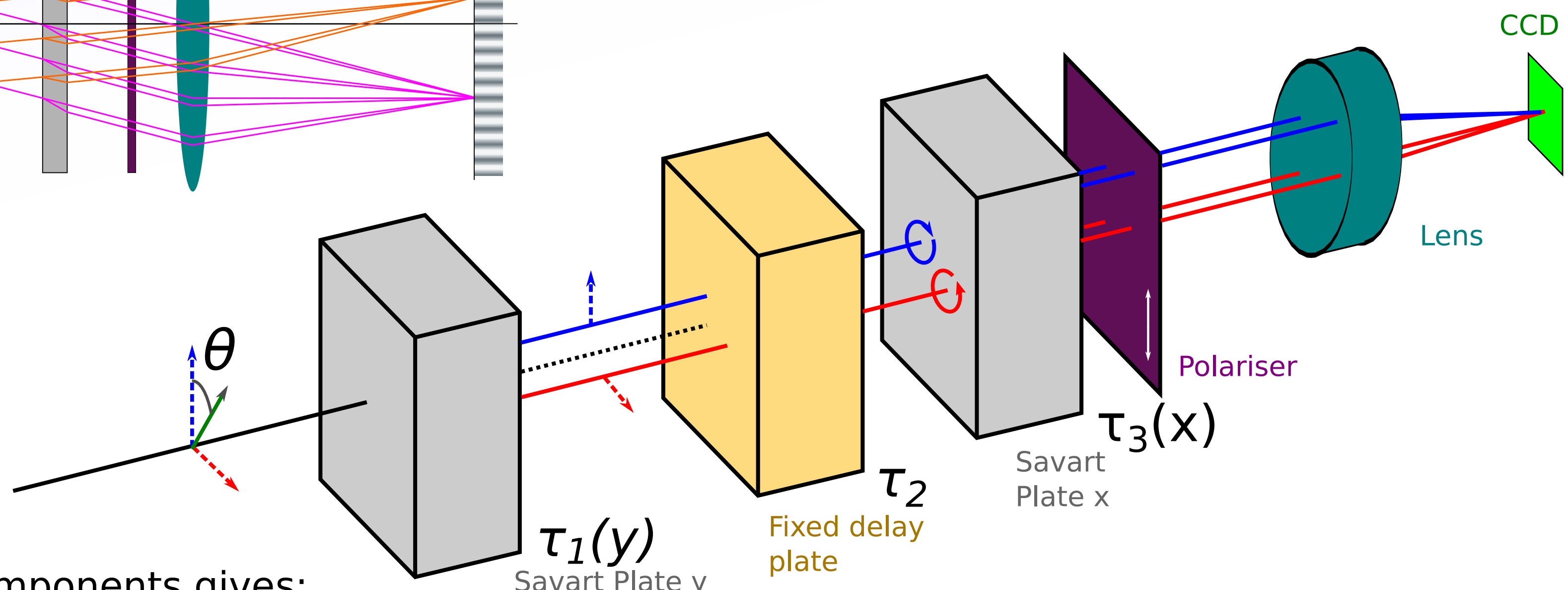

The interference of all 4 components gives:

Intensity — Fringe Contrast — Polarisation Angle

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

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

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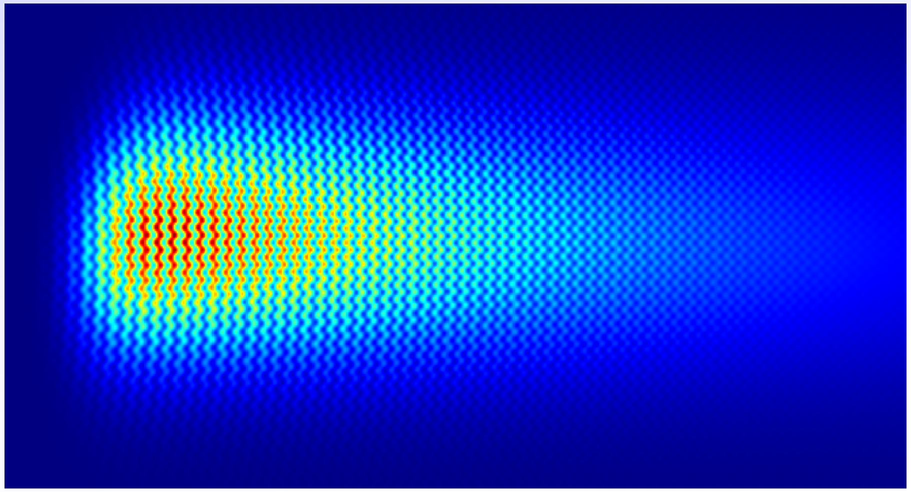
Simple Demodulation

The image will look something like this:



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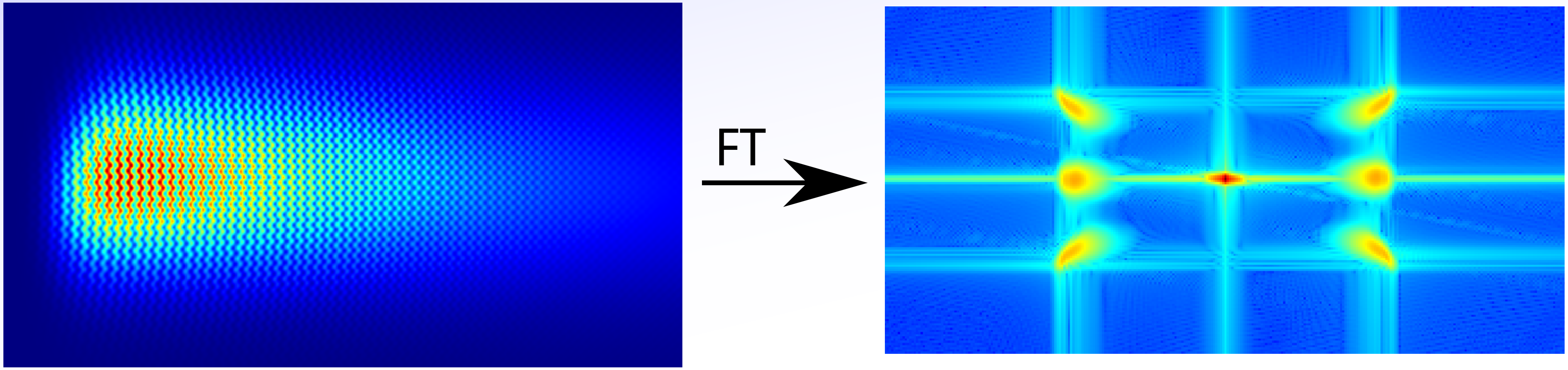

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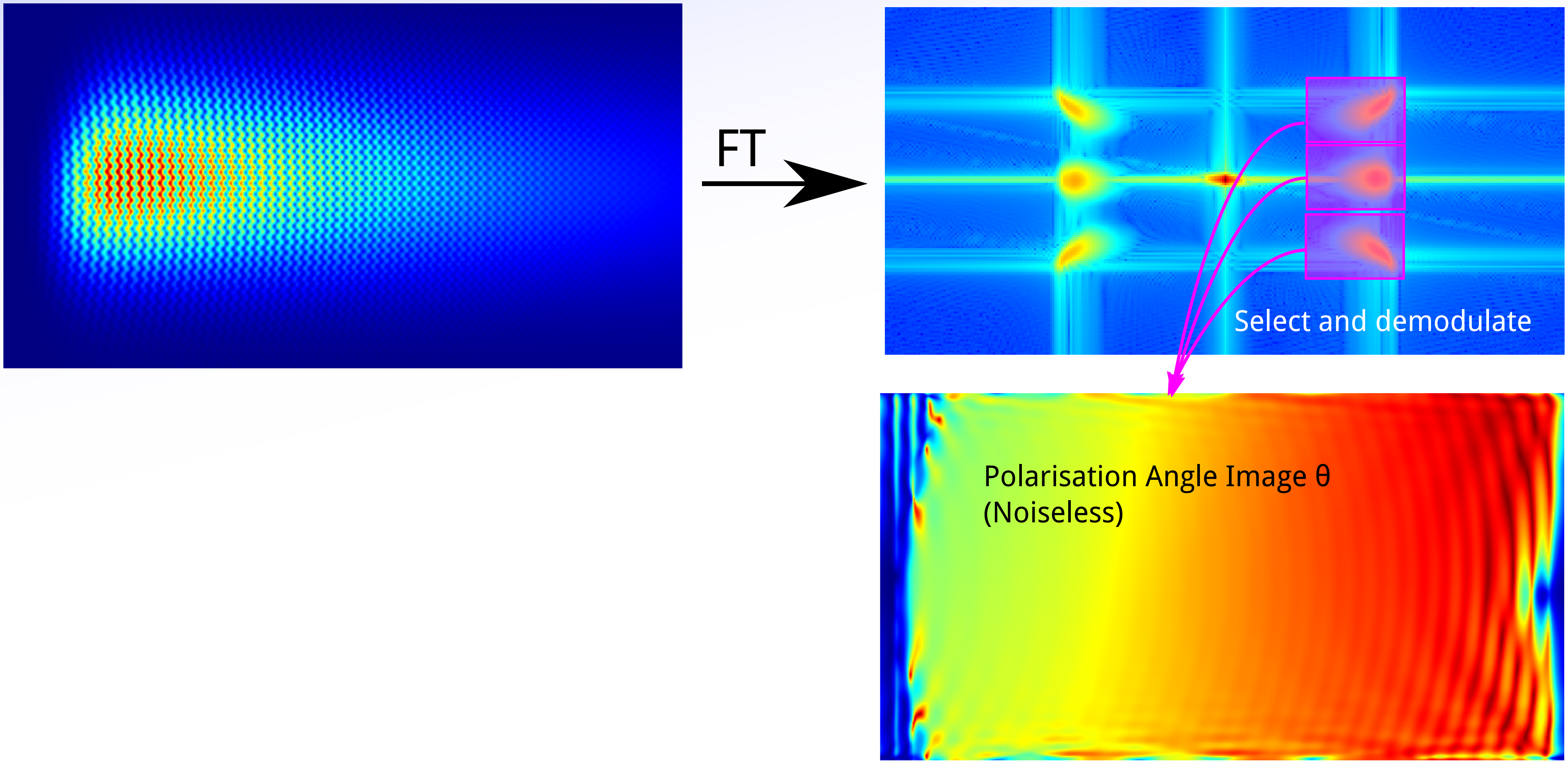

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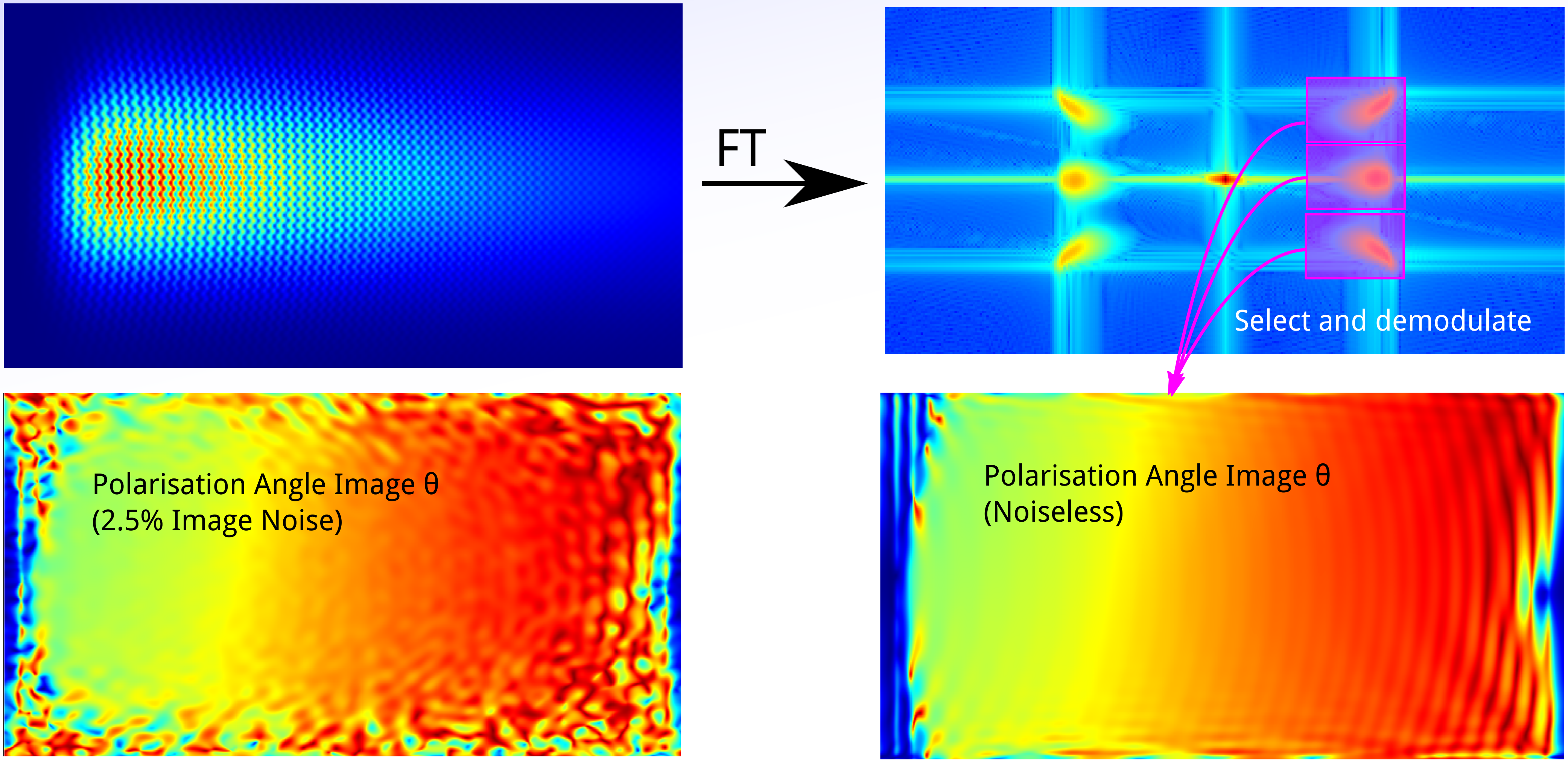

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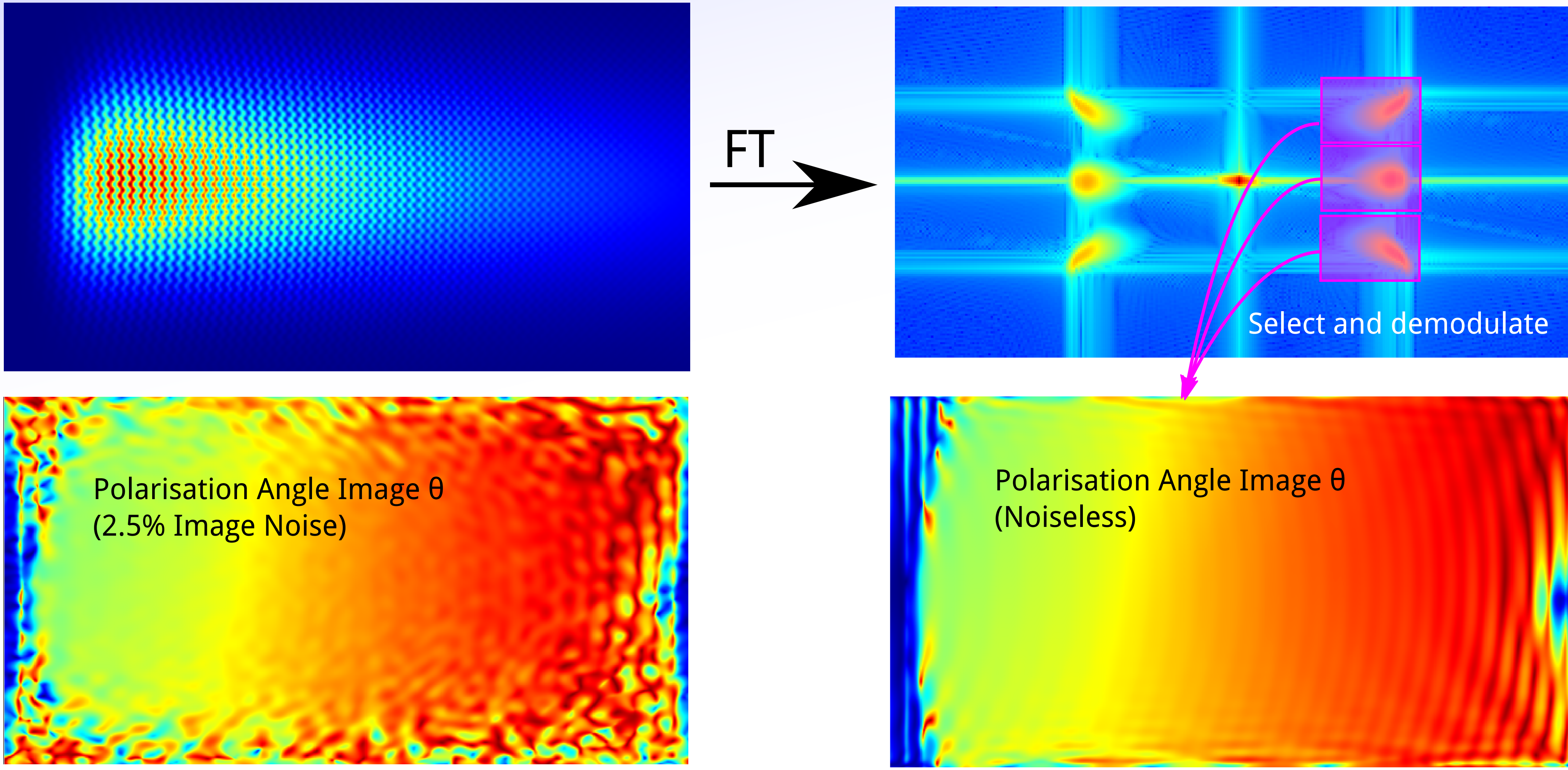


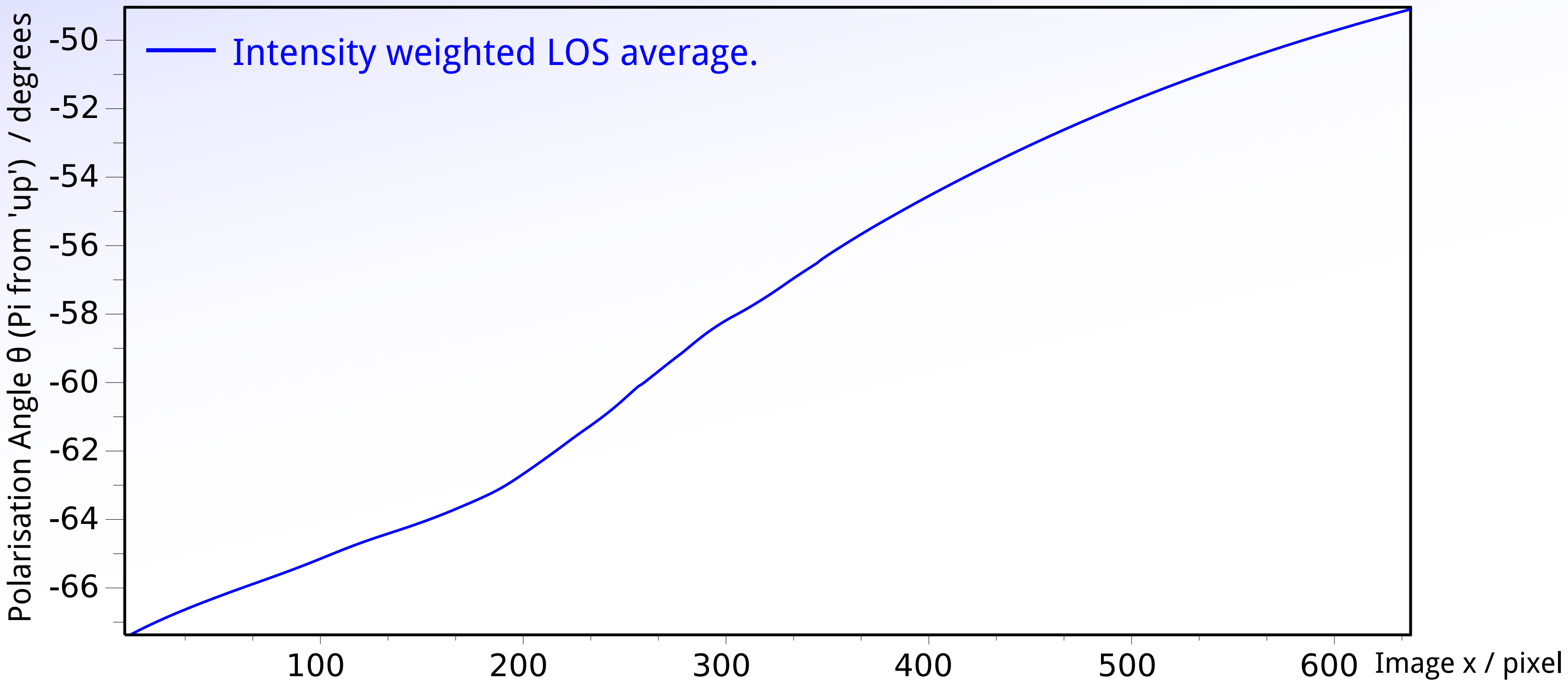
$$I = \int \frac{I_0}{2} \left[1 + \zeta \left(cos2\theta \; cos(x) + sin2\theta \; sin(x) \; sin(y) \right)\right] \; dl$$

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

Actually, this is wrong. The image is really the integral of this over the LOS.
However - it seems that if we assume it is, the recovered θ is the same as the LOS average for each pixel.
The other terms are not equal to their LOS averages and introduce extra phases.

Demodulation: Accuracy of θ recovery.

Recovery of θ from a noiseless and noisy images gives us our probably accuracy:



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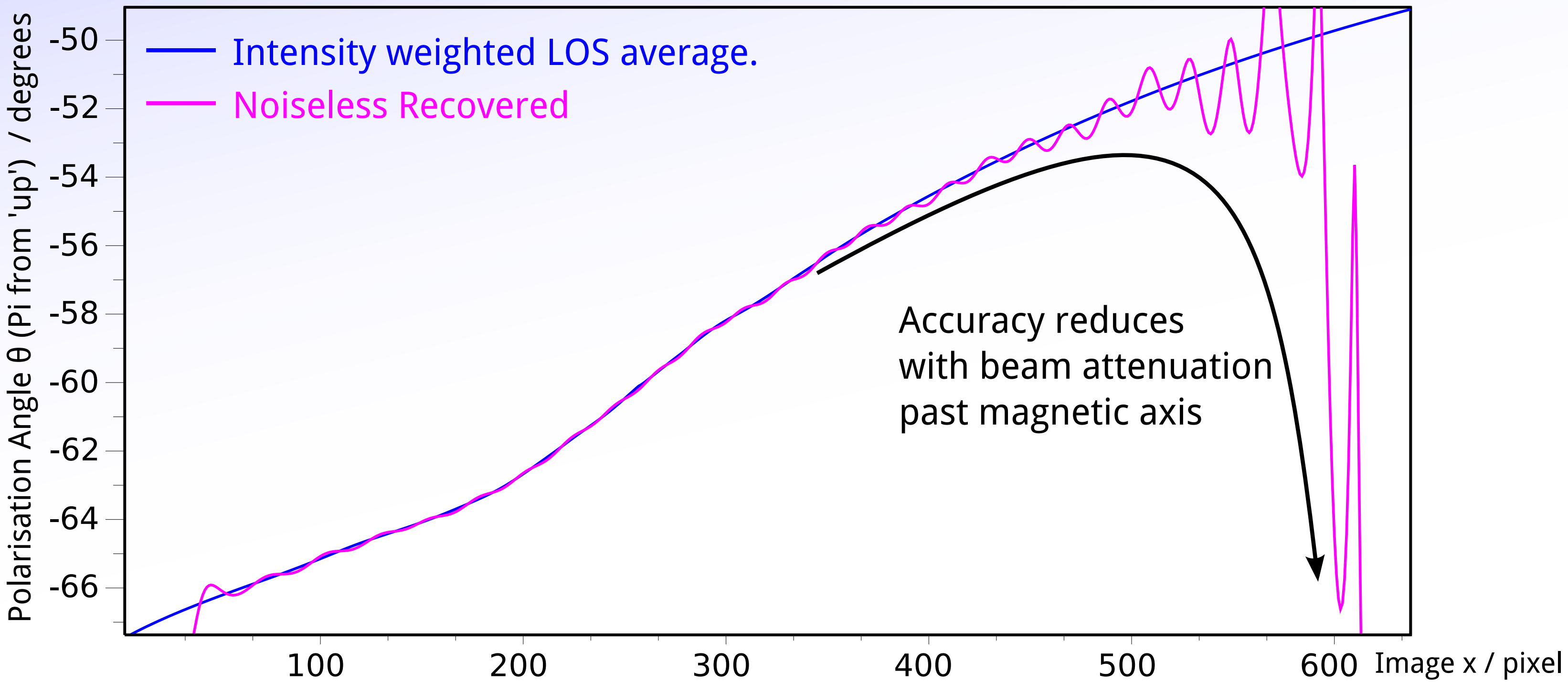

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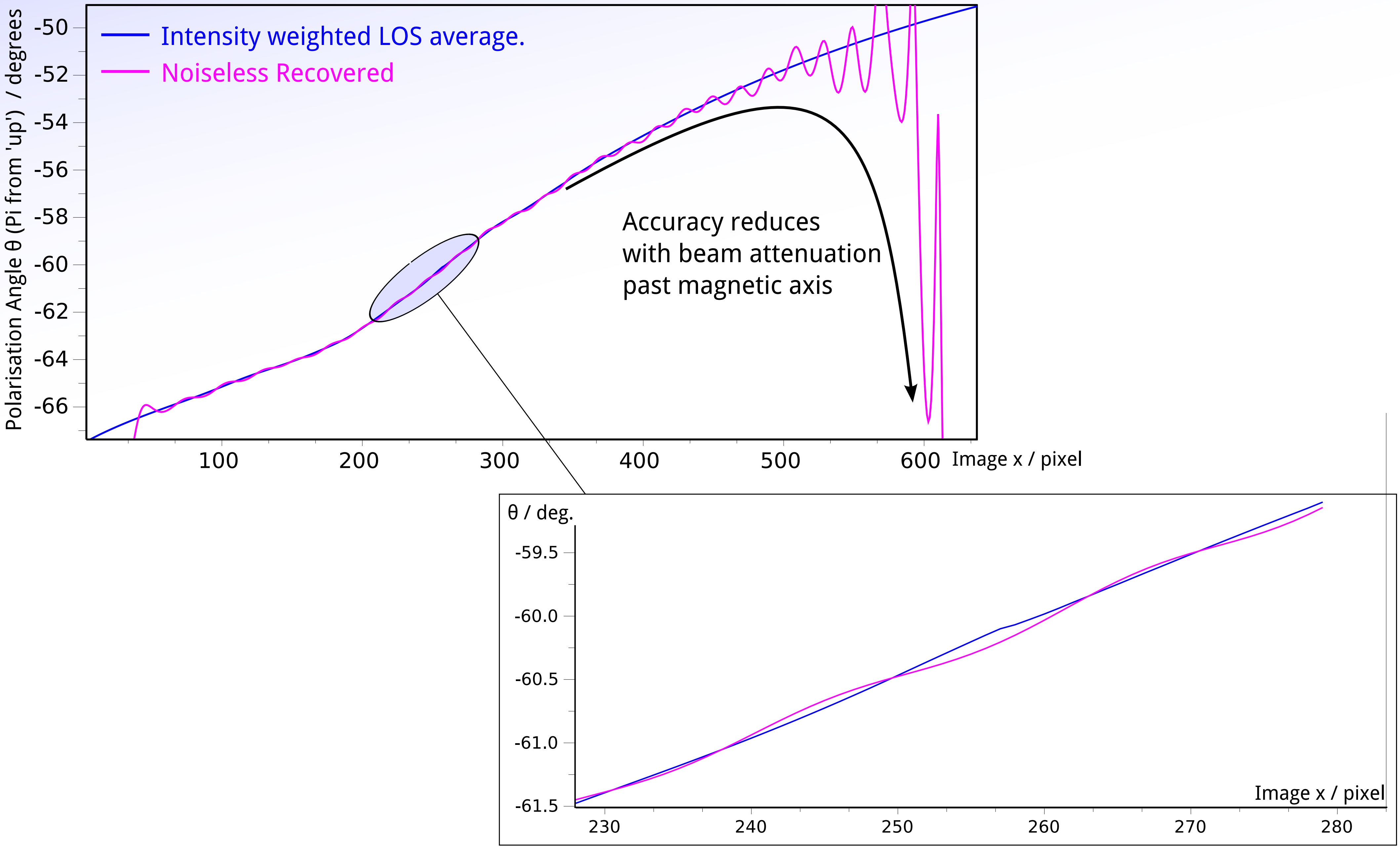

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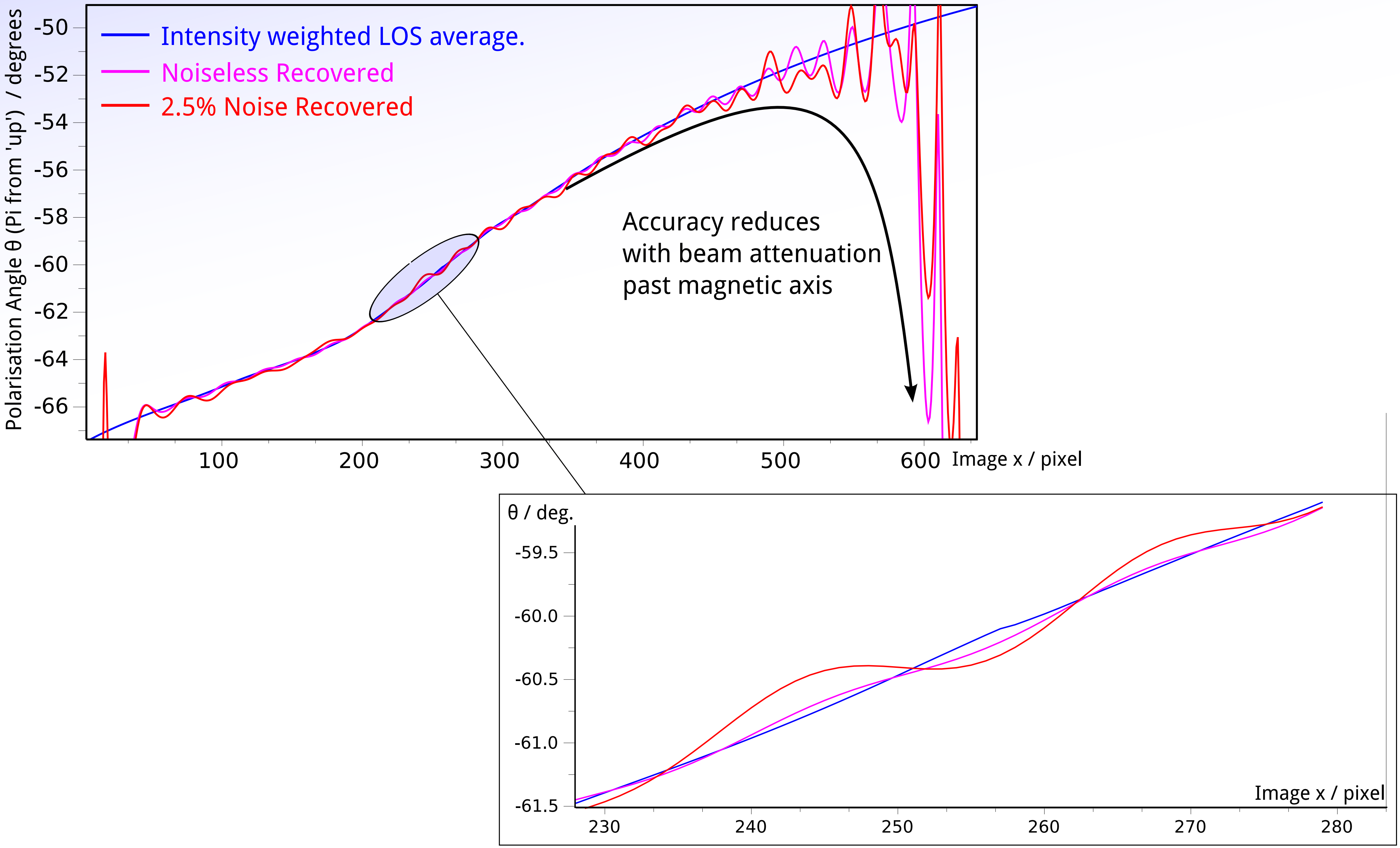

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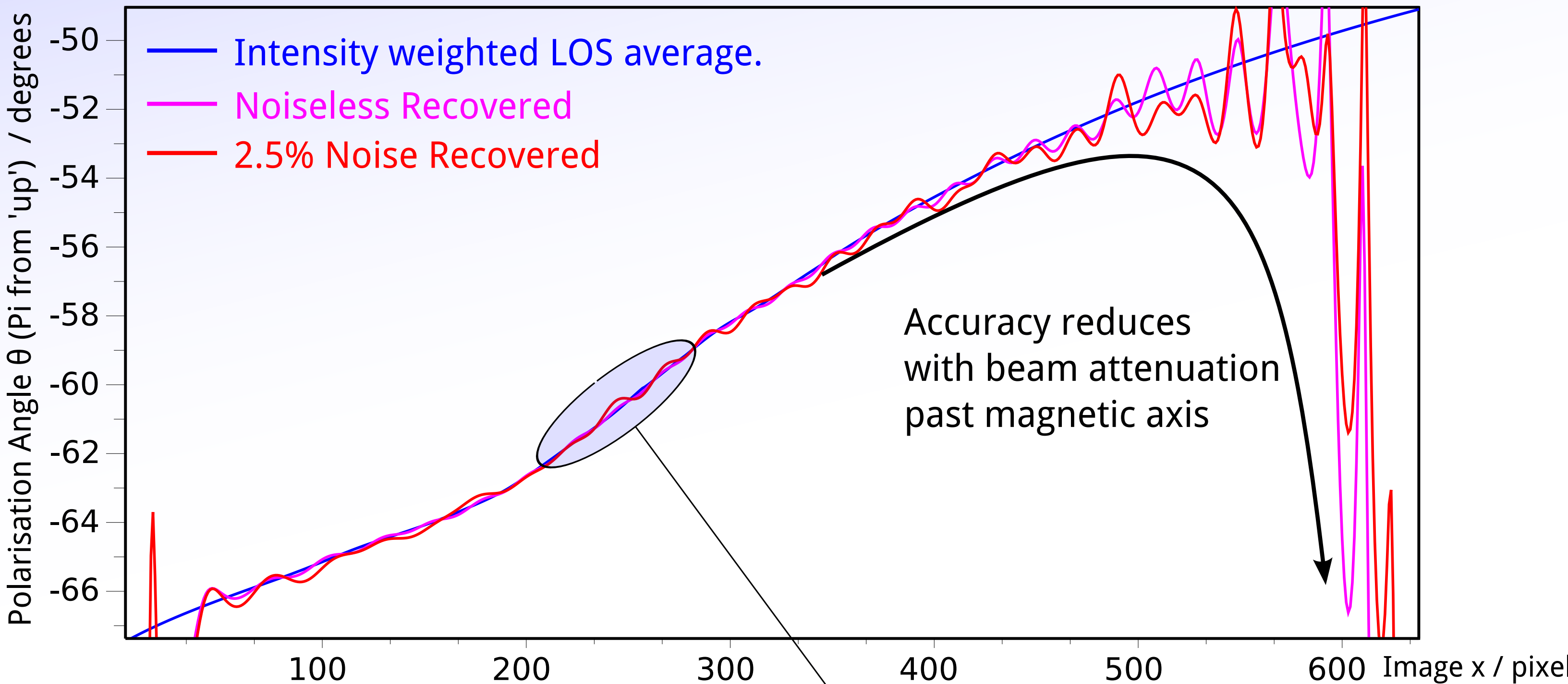
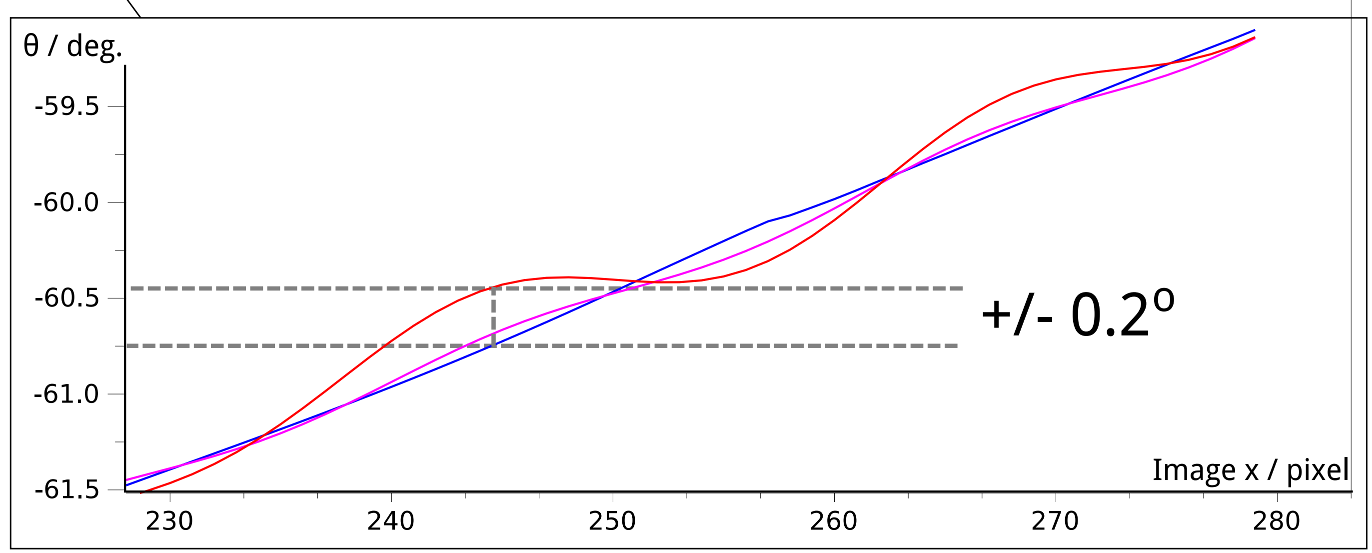


It might be better than this, since these are partly artifacts of the demoulation. However, for now we can take θ +/- 0.2° as the accuracy.



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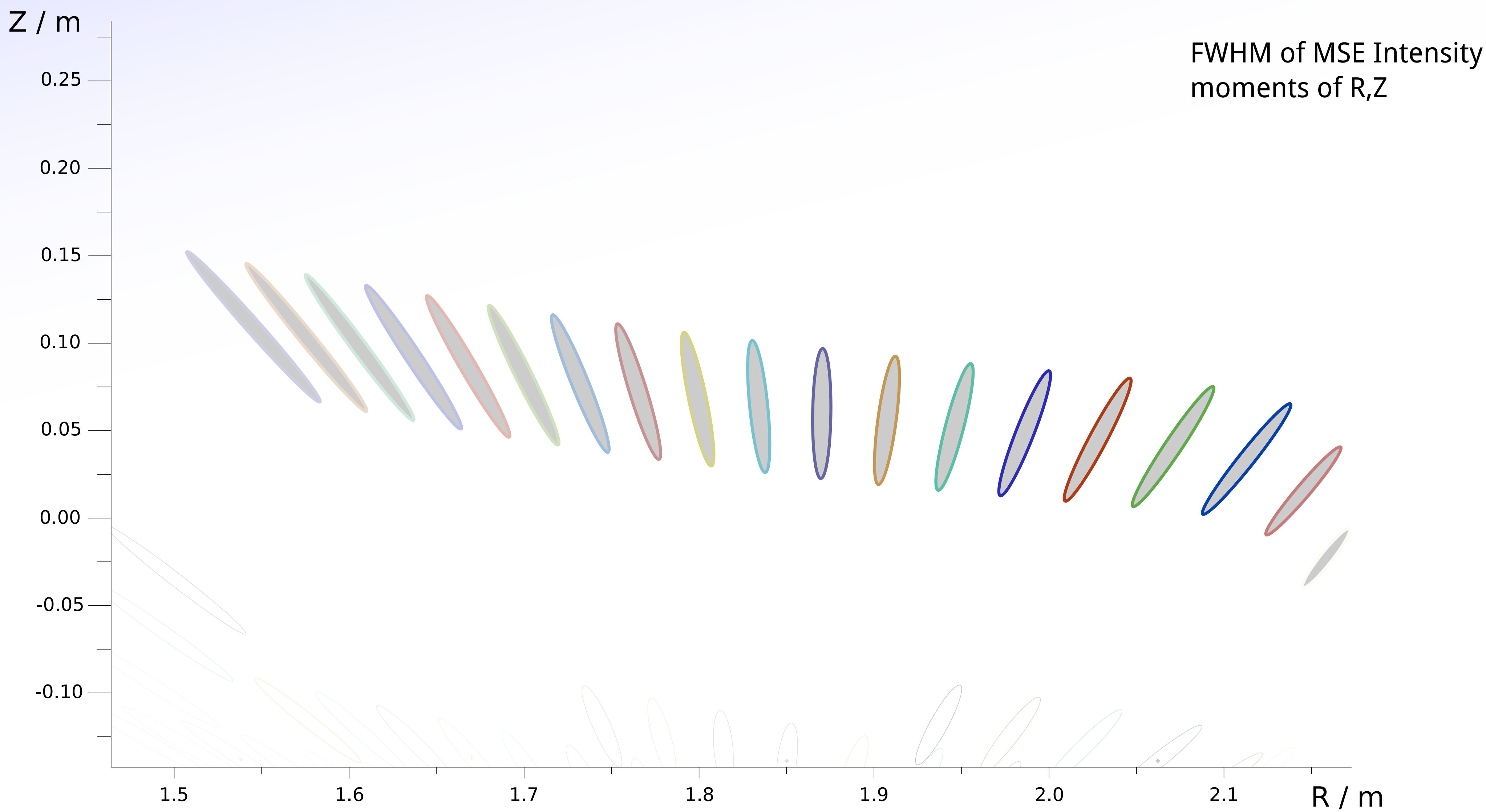

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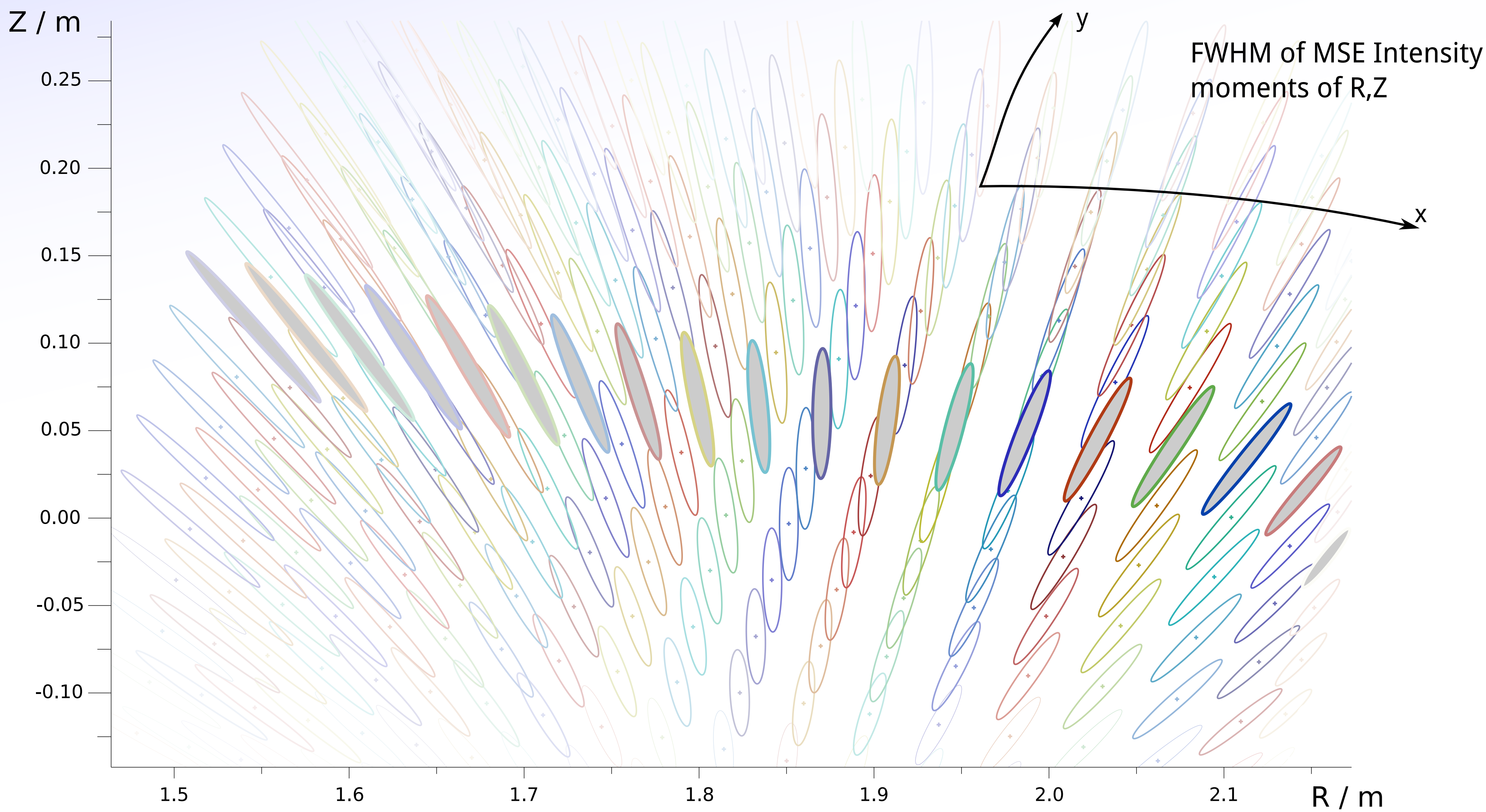

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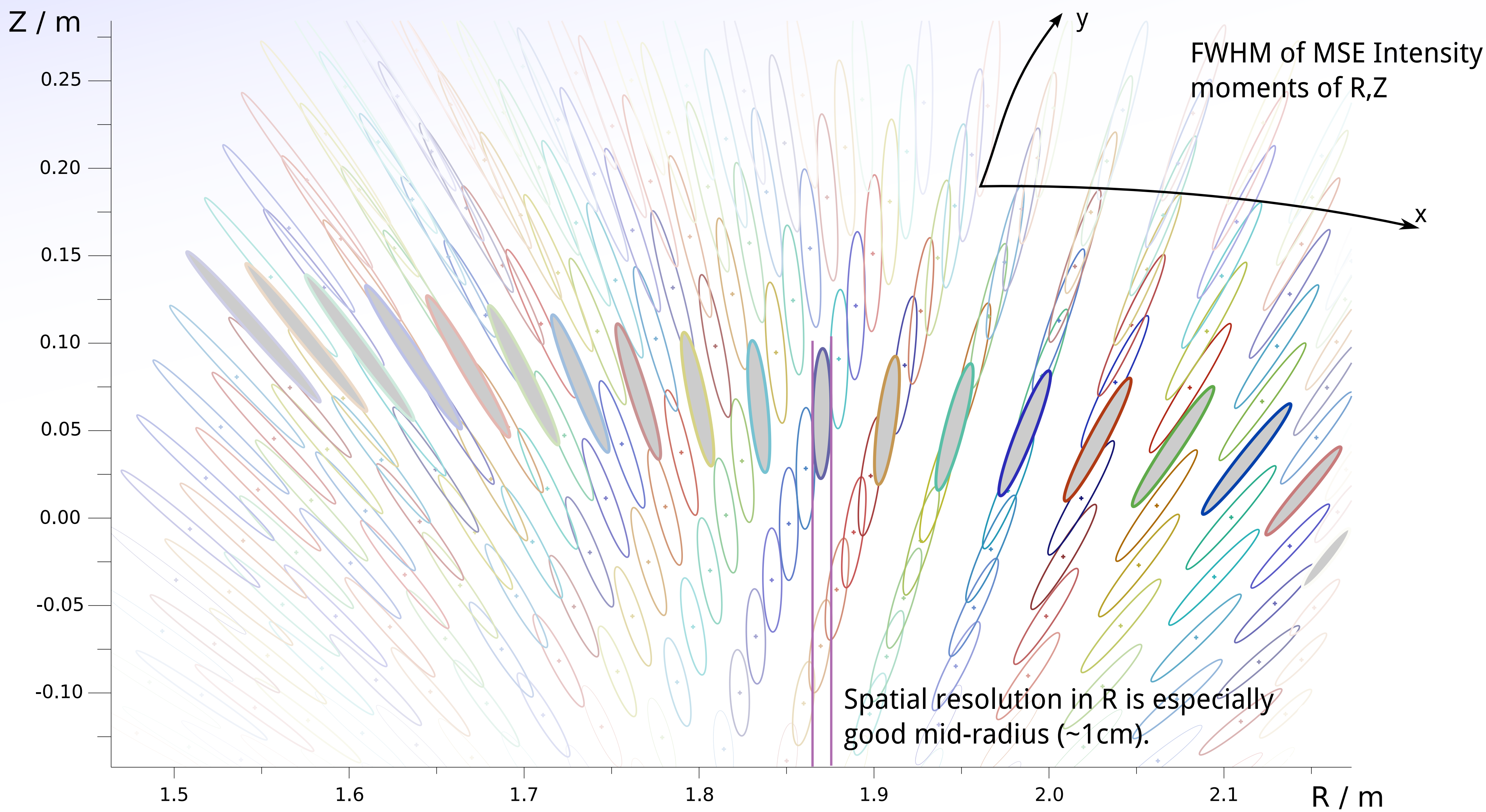

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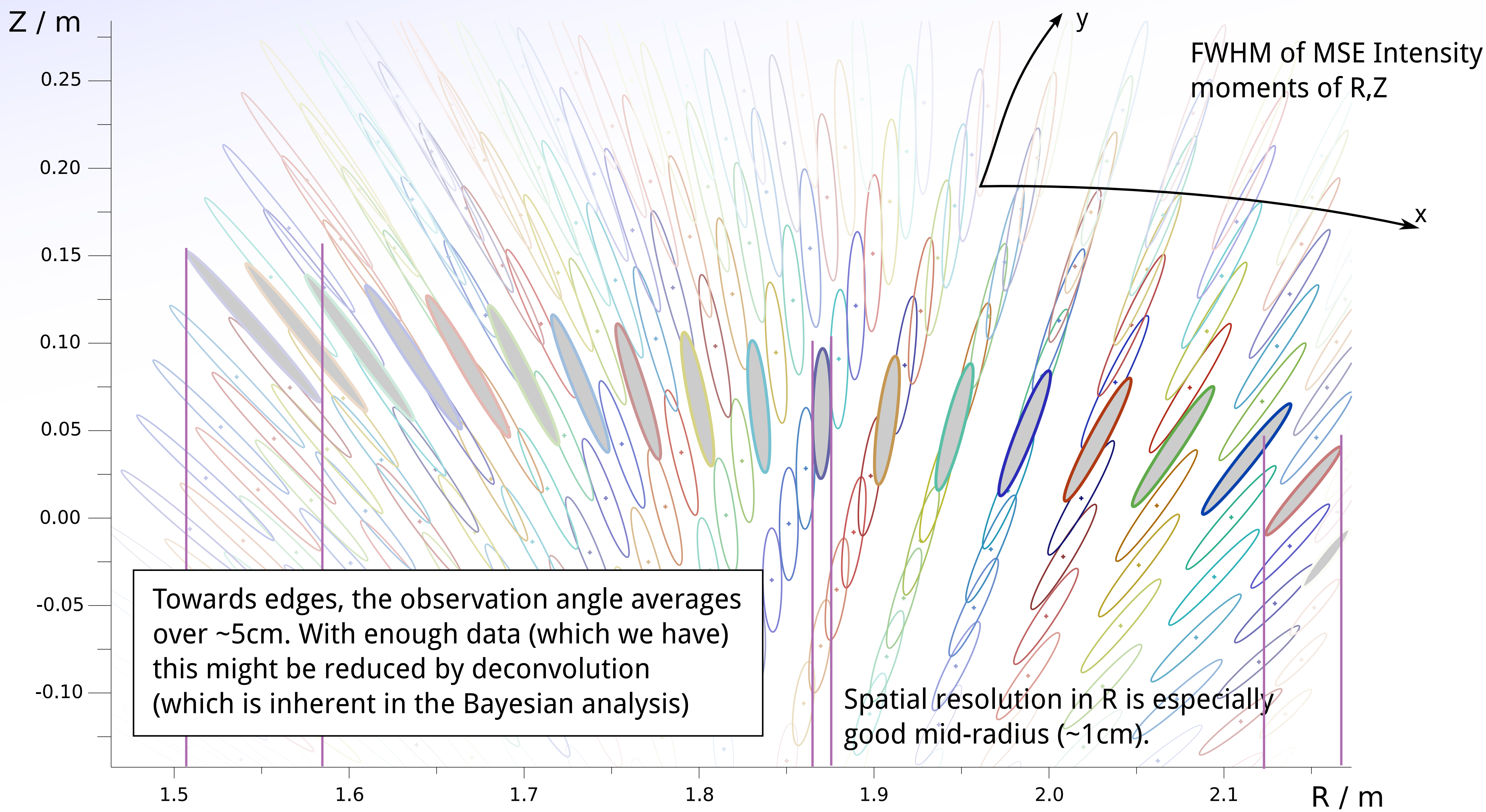

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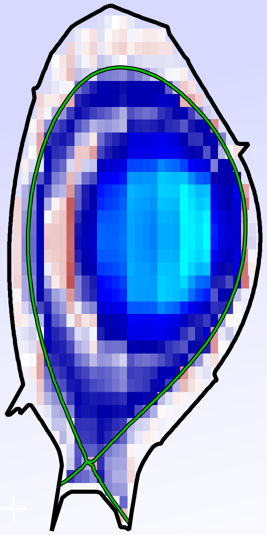
A normal MSE system has only $B_z(R)$ so cannot calculate the 3rd term.
In theory, with 2D measurements, we can.



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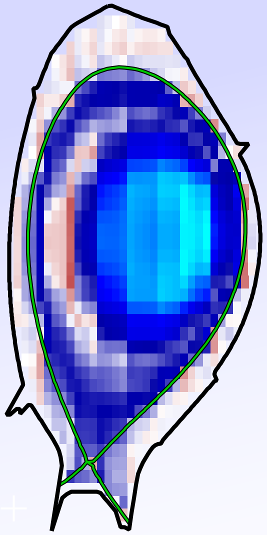

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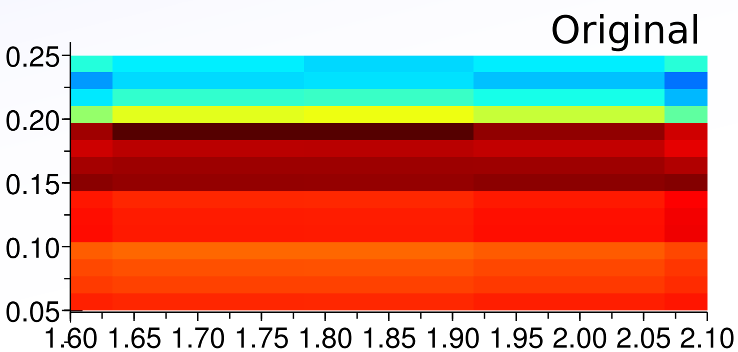

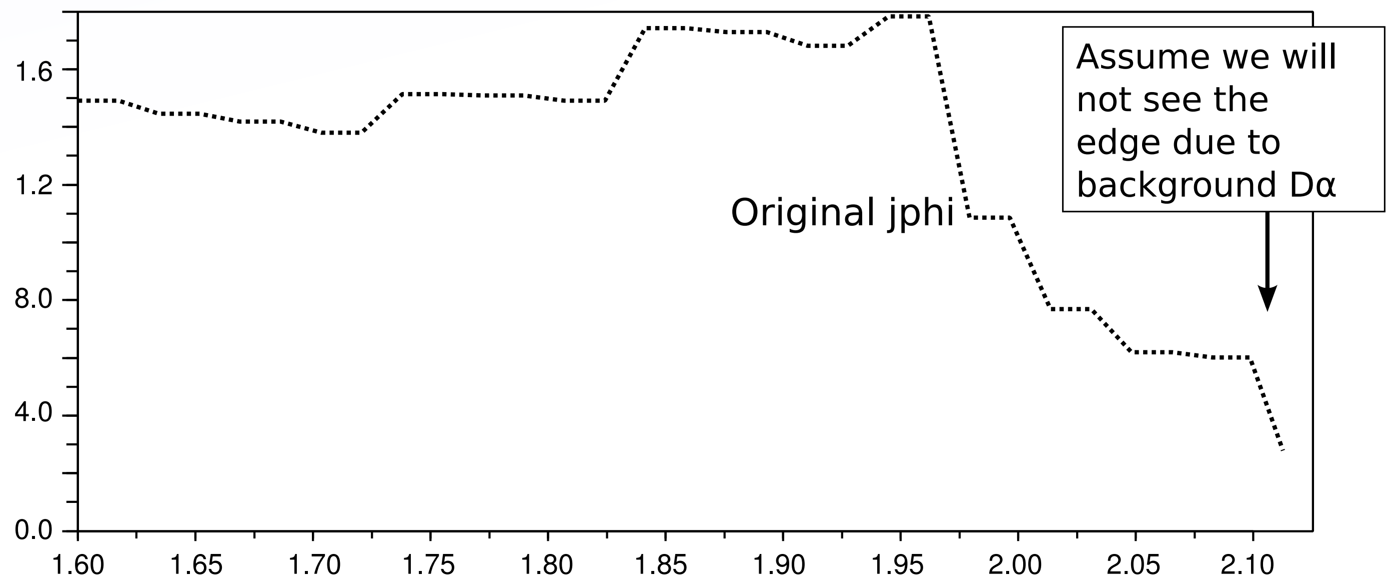

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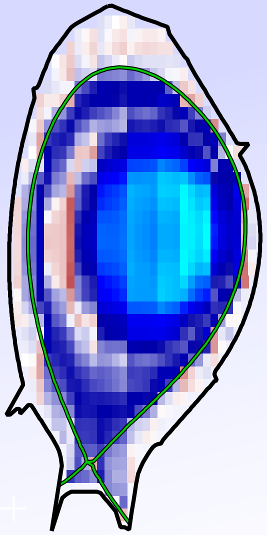

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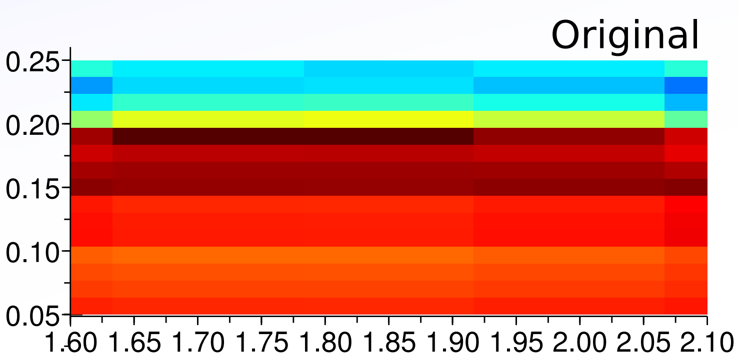

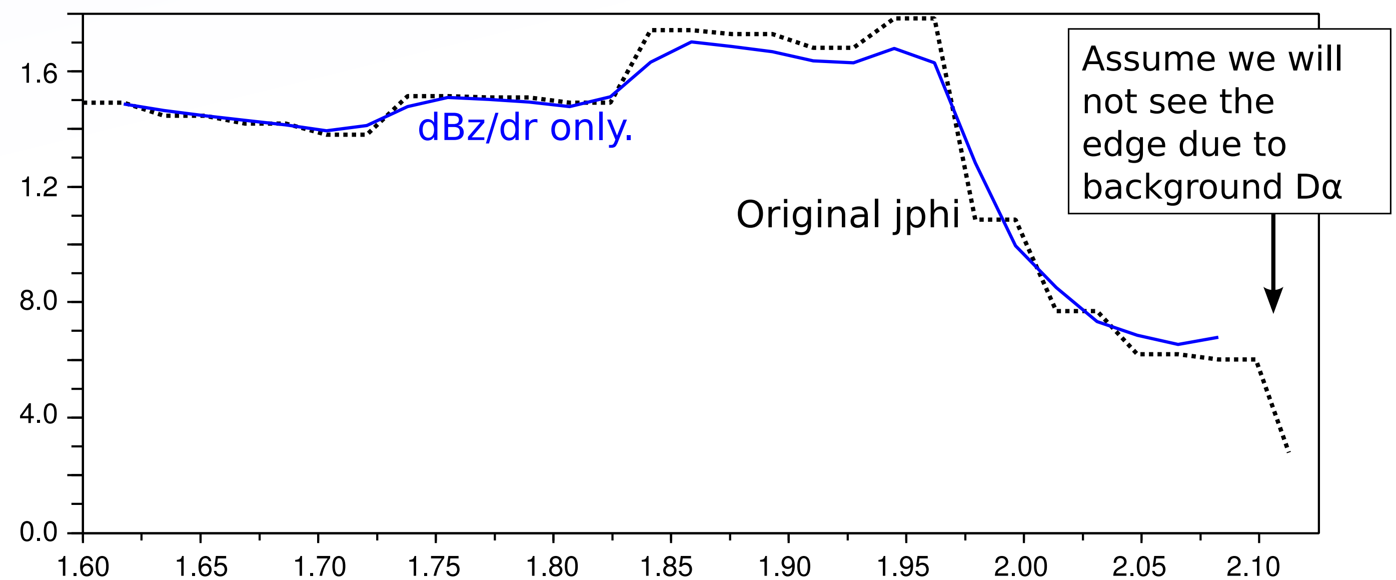

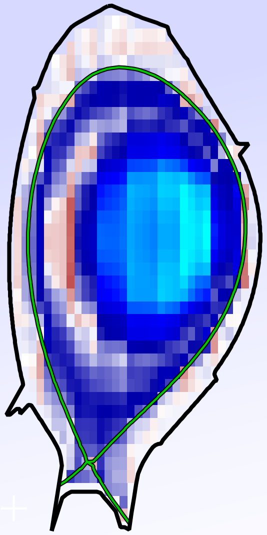

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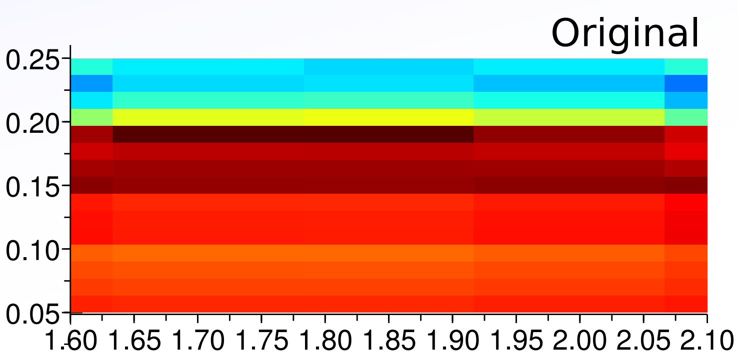

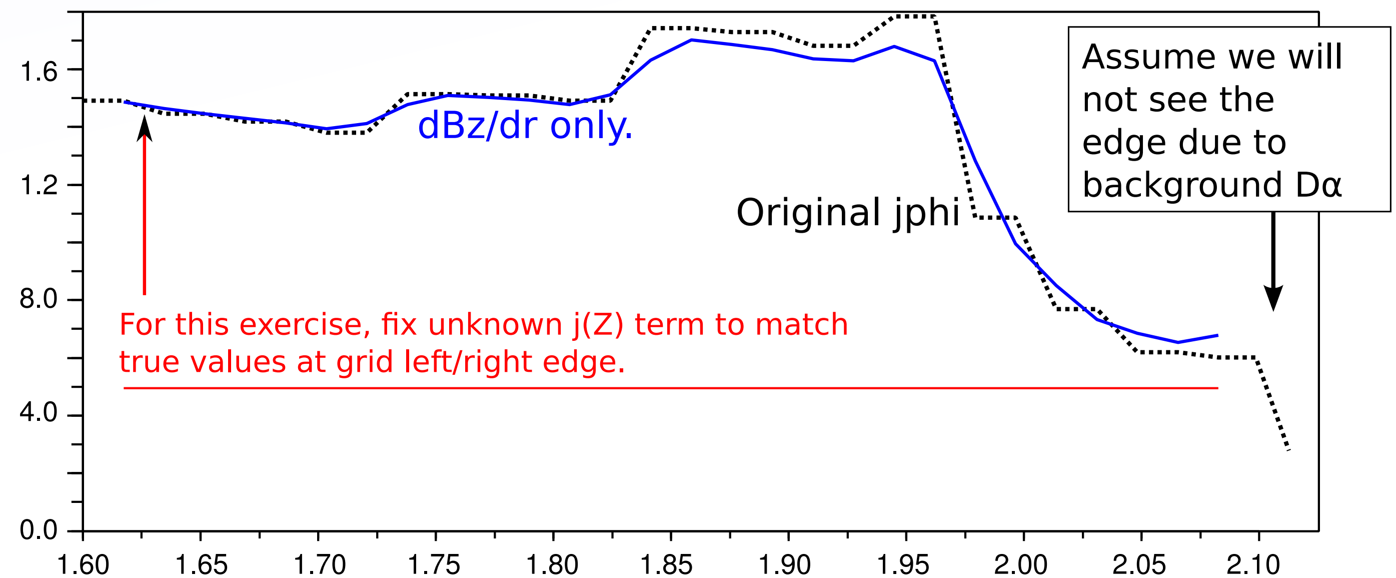

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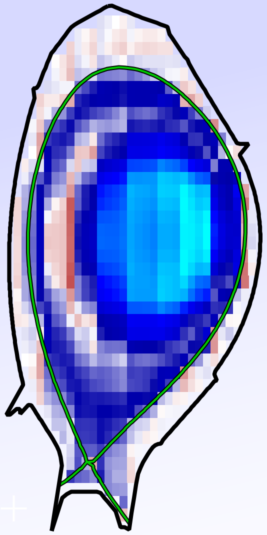

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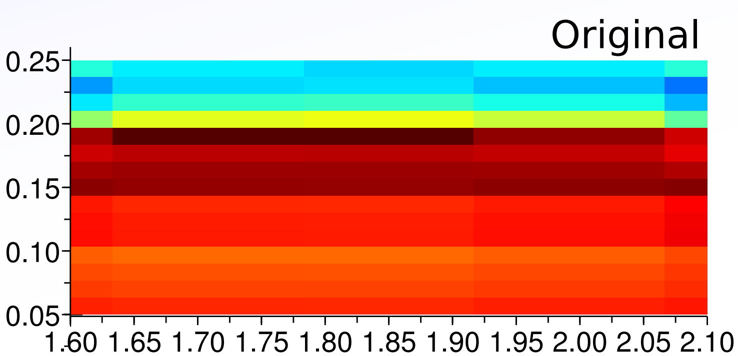

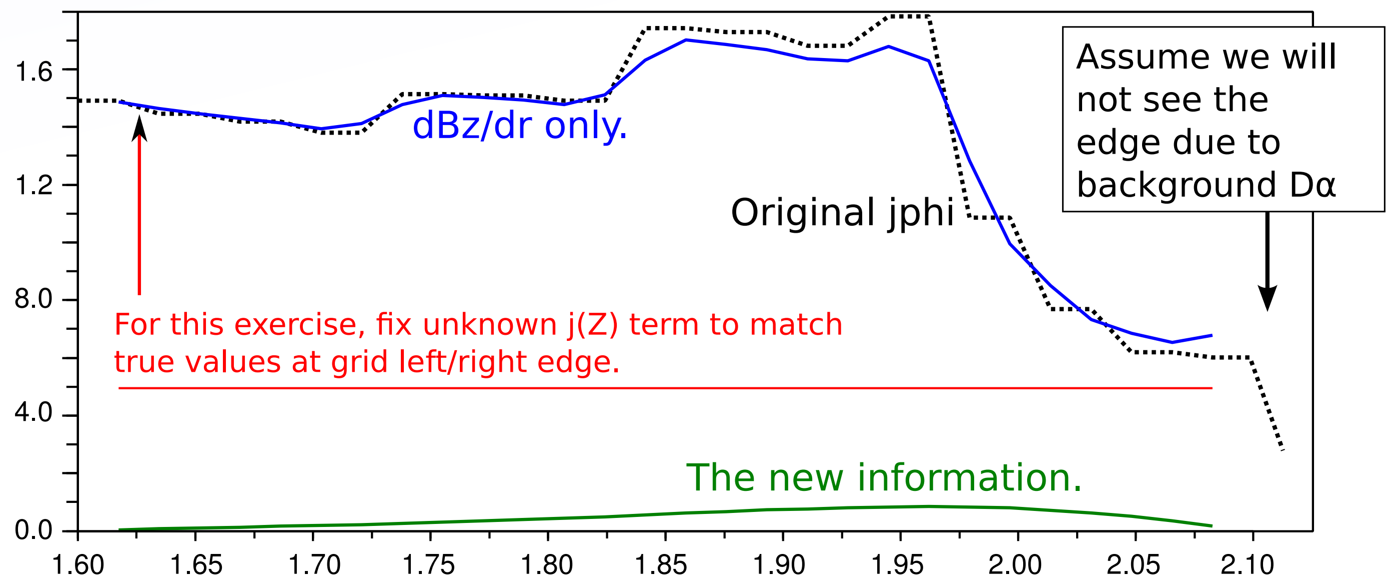

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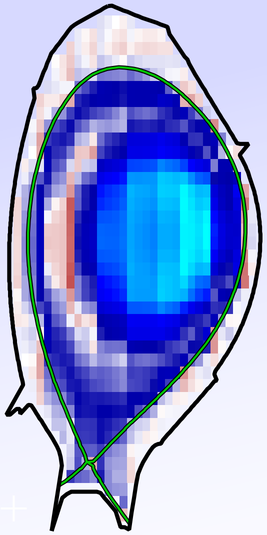

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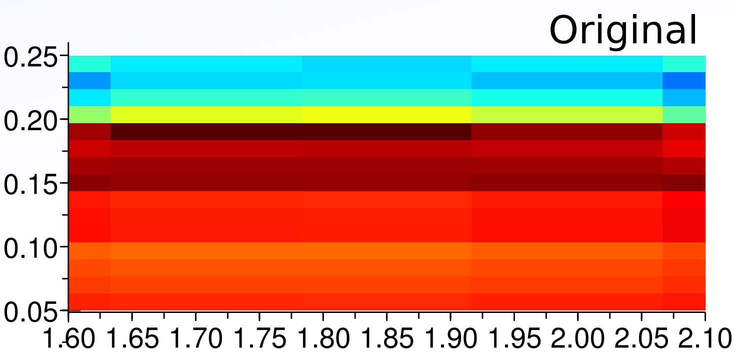

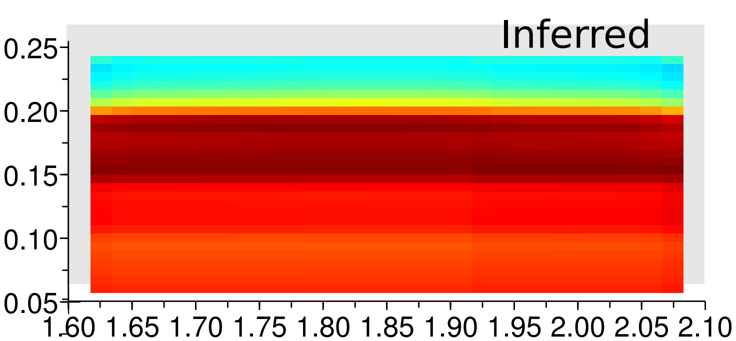

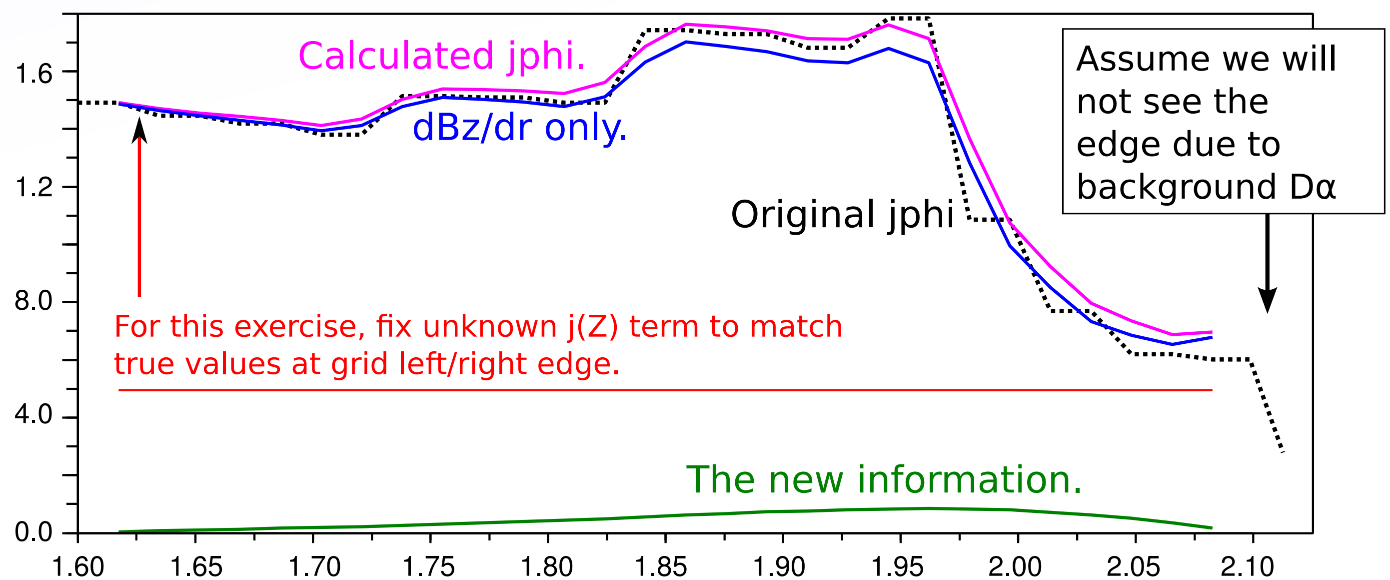

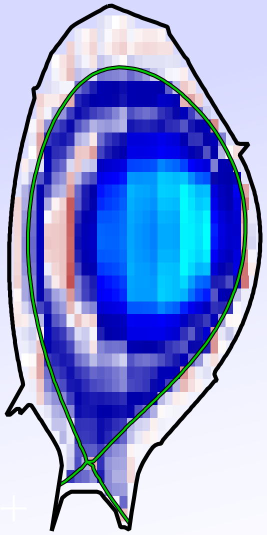

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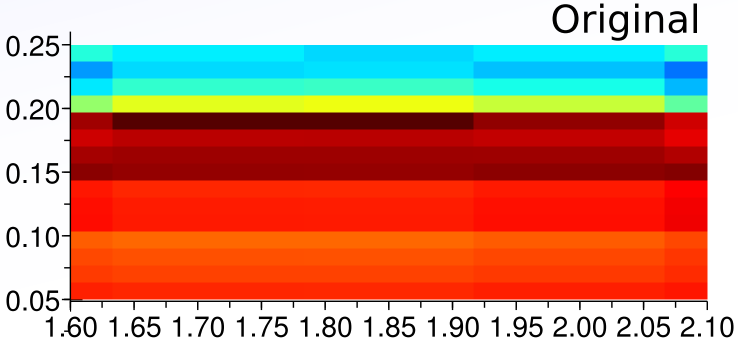

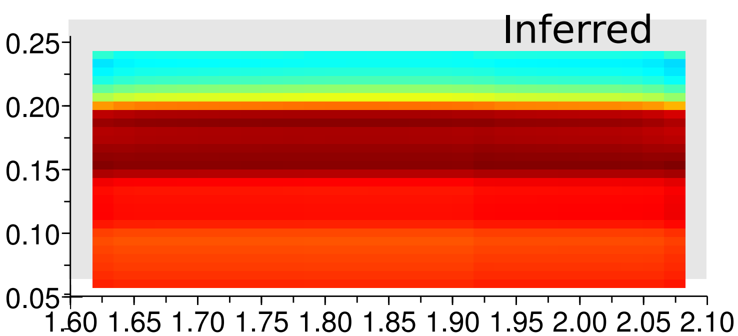

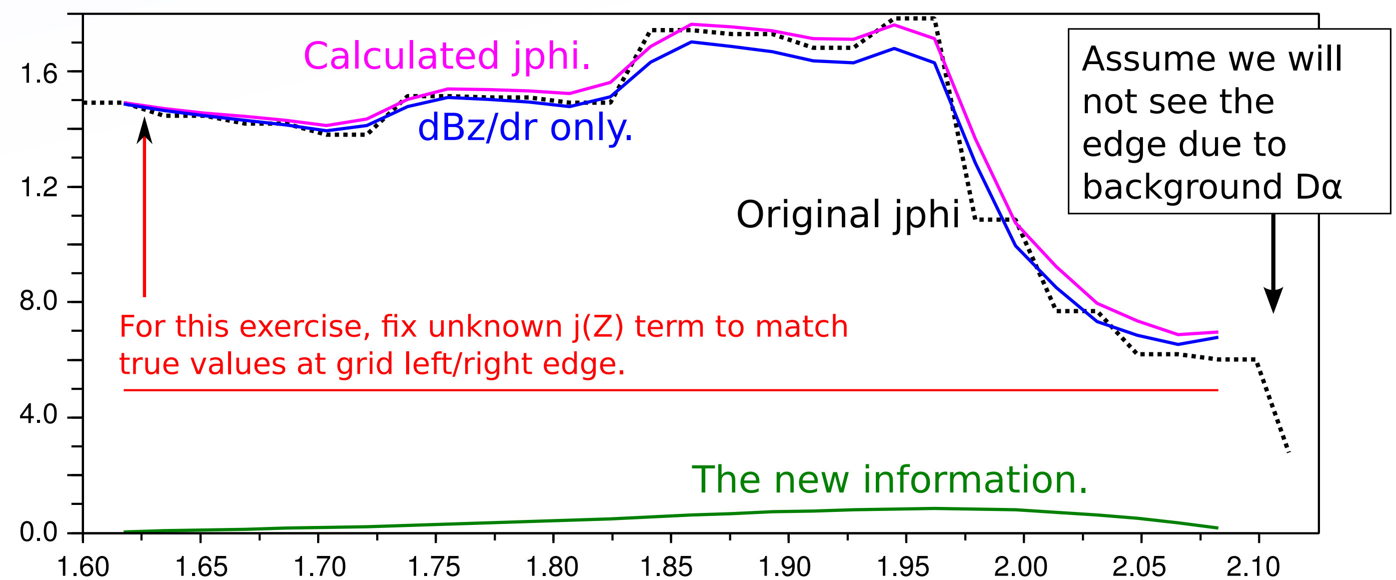

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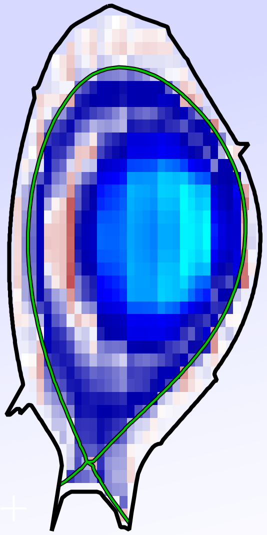
Conclusion: **No**. You still cannot exactly calculate j_ϕ directly.



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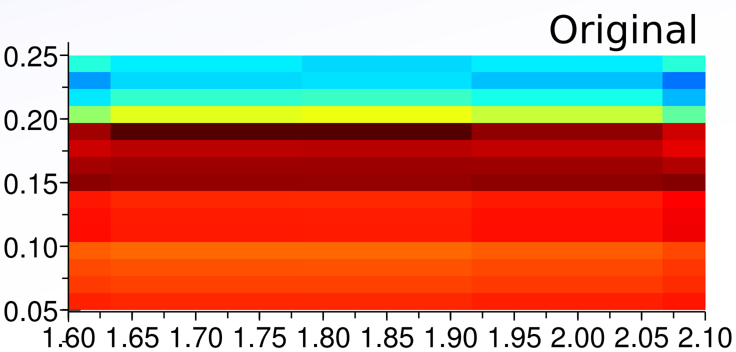

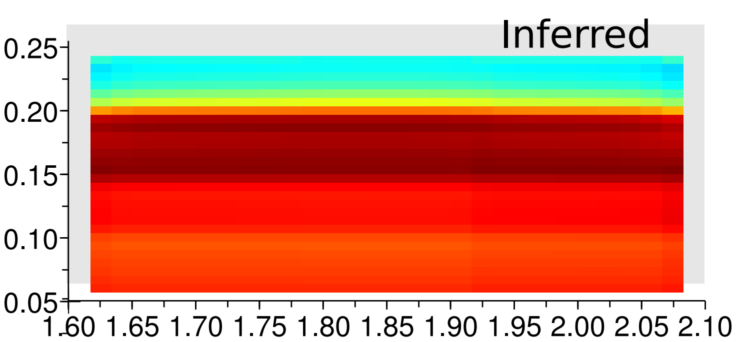

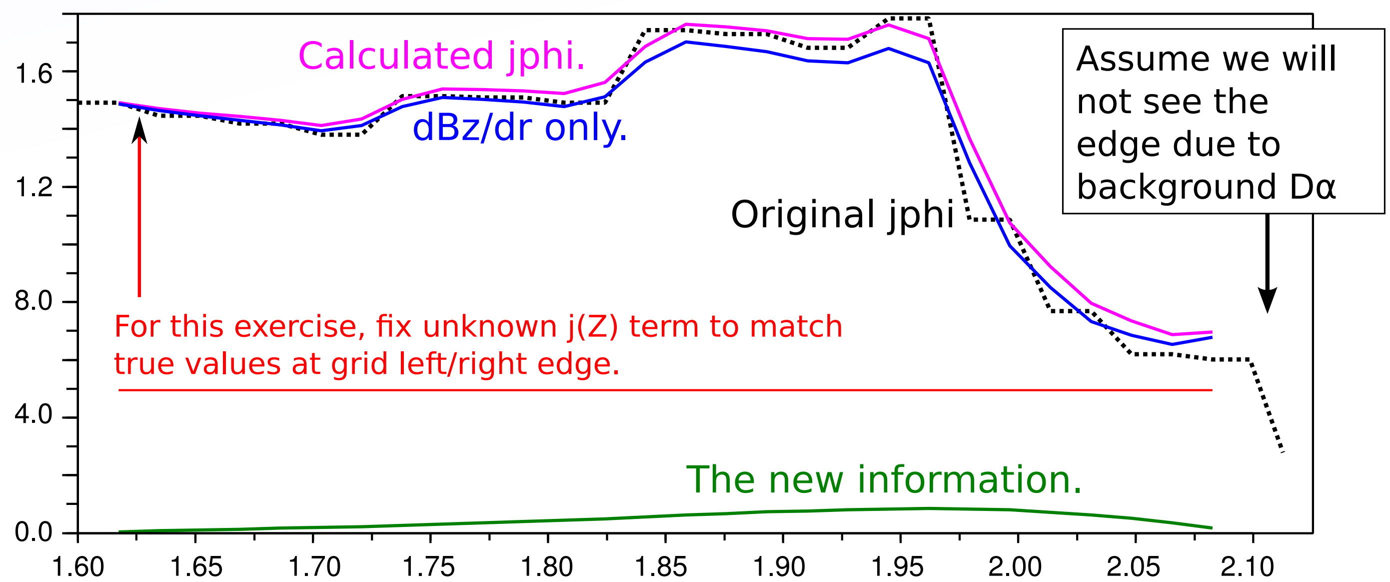

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However, we still might not need to go as far as equilibrium as we also gain measurements of dBz/dR at different Zs. Together with normal coil measurements, it is now part of a complex tomography problem that we have done before.

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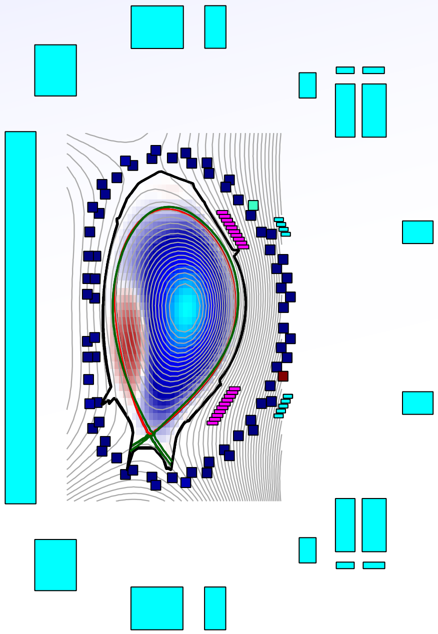
AUG PF coils and pickups model now in Minerva, so we can do Current Tomorgraphy and Bayesian Equilibrium for AUG. Try simple tomography from:



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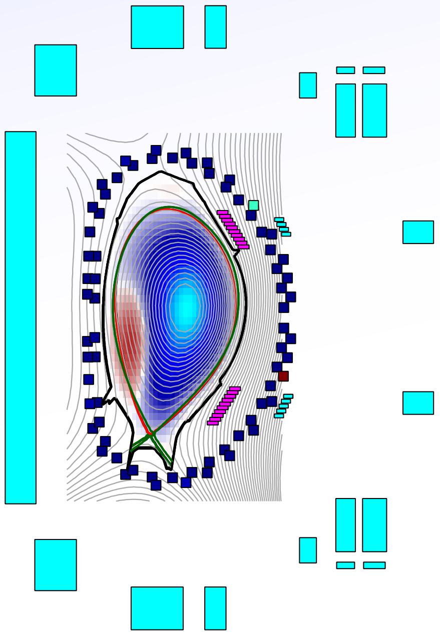

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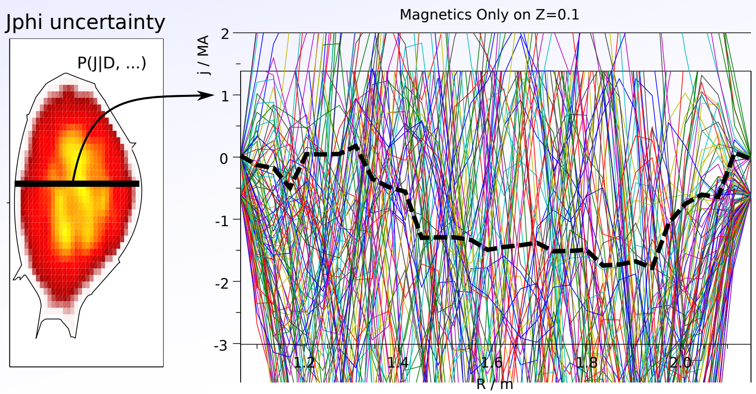

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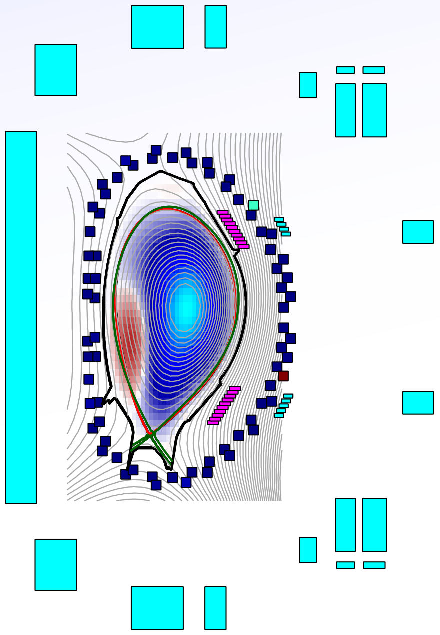

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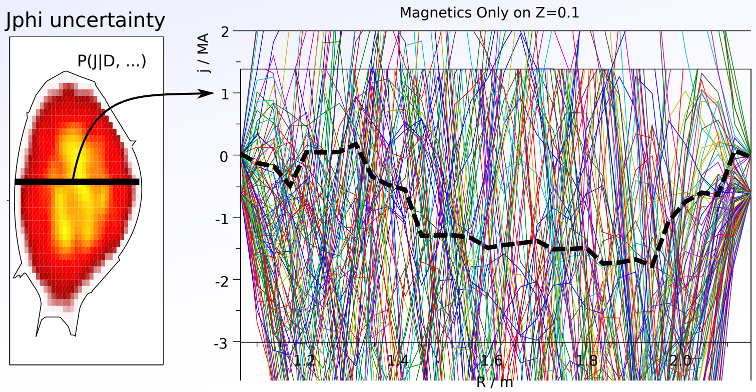

(Almost) no prior/regularisation

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

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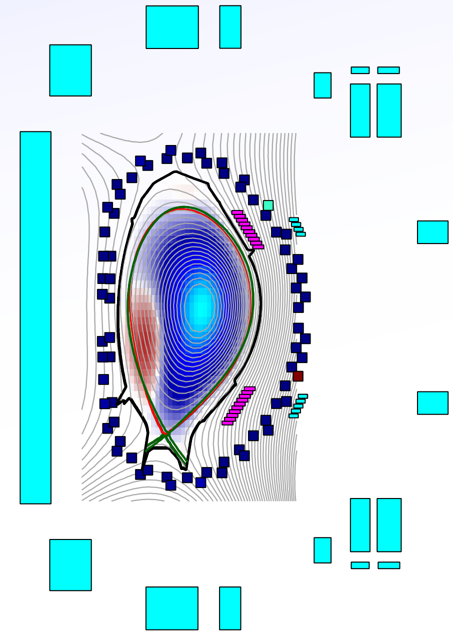

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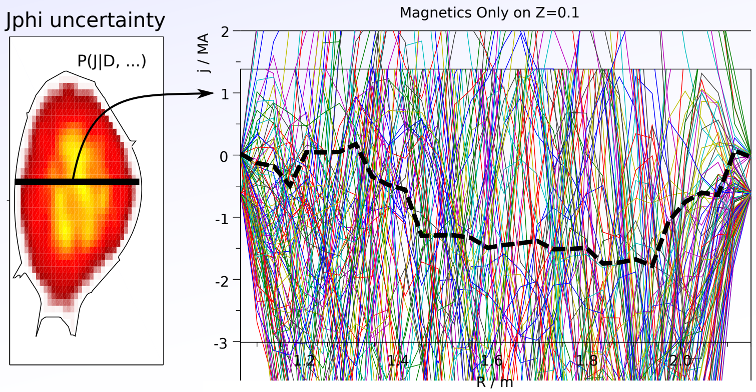

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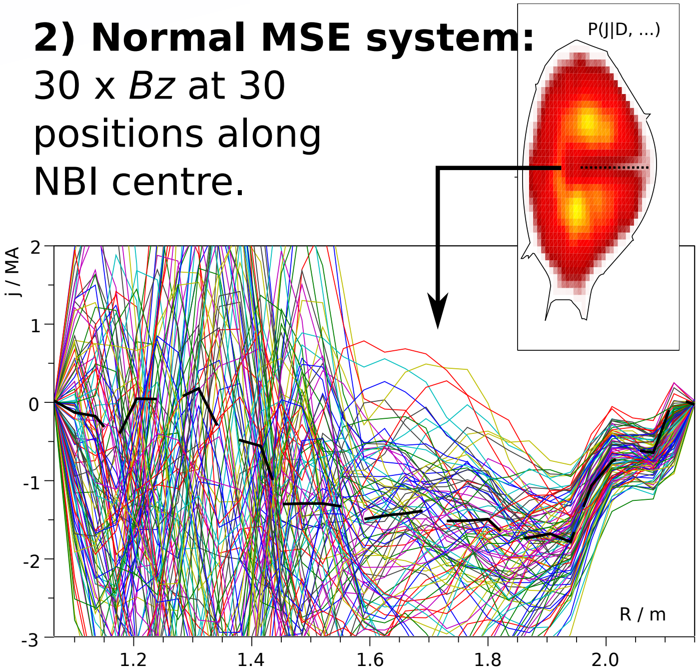

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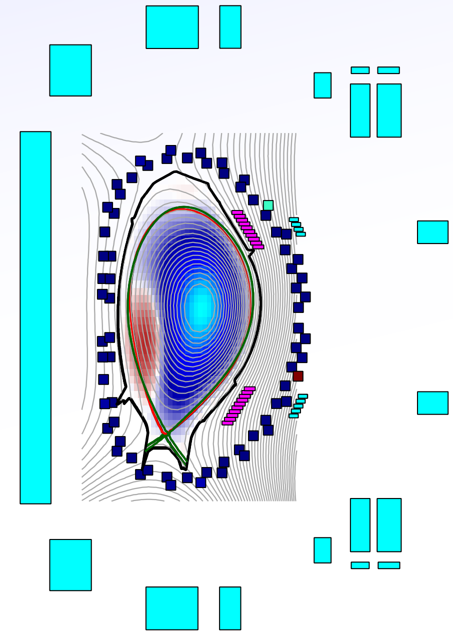

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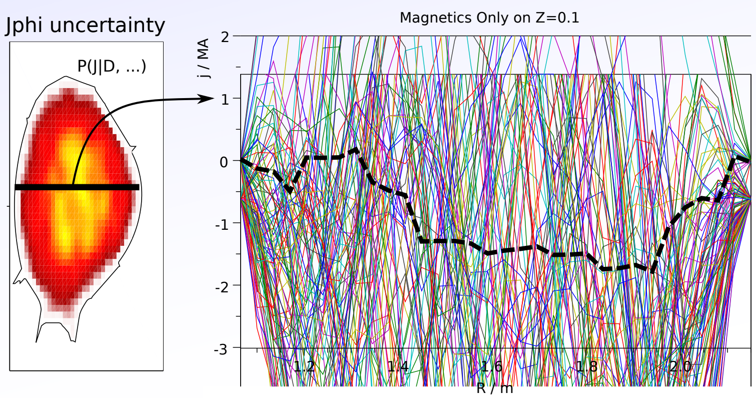

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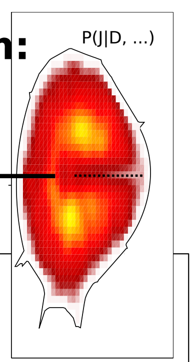

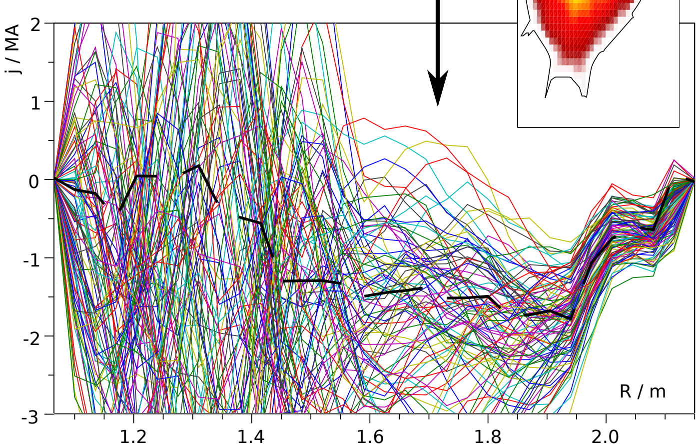

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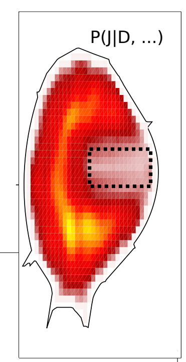

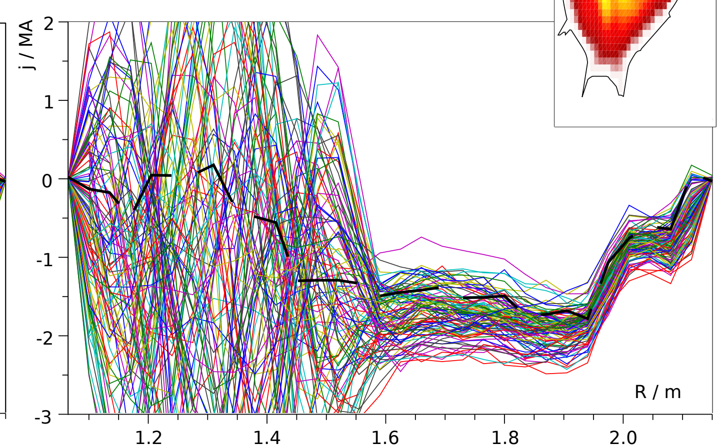

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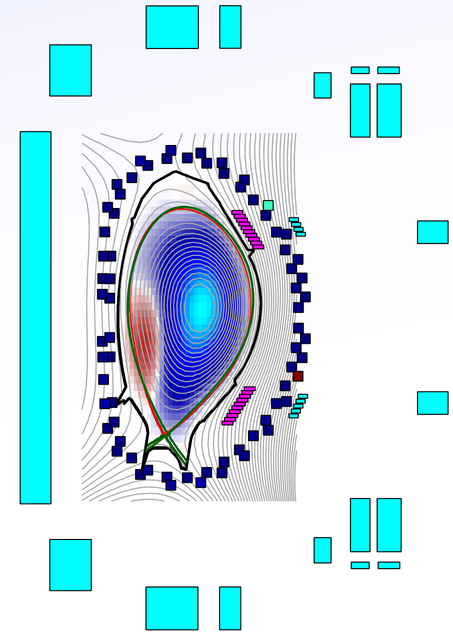

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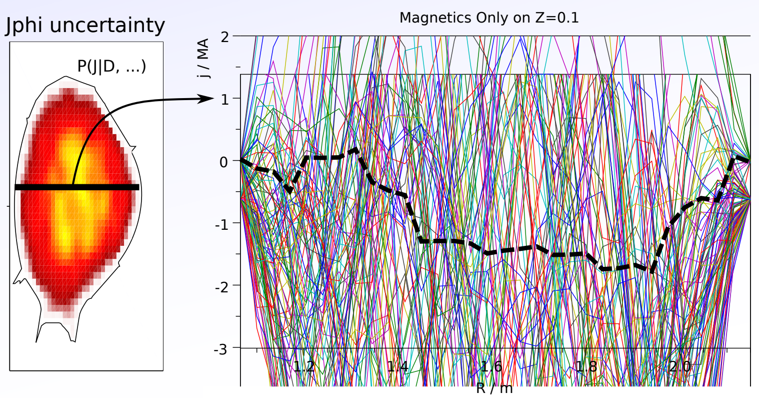

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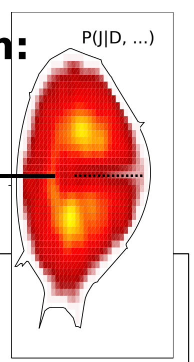

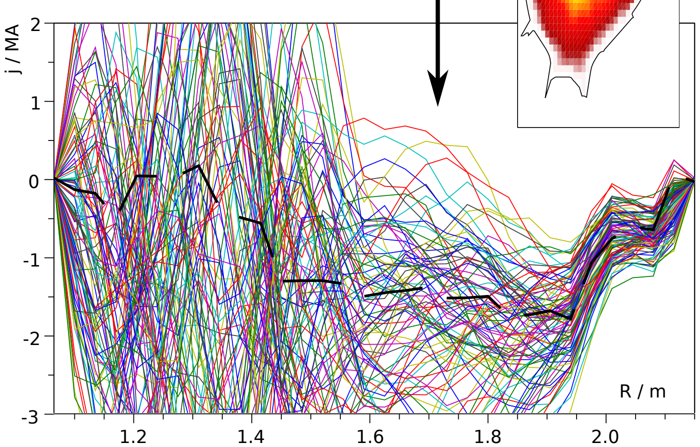

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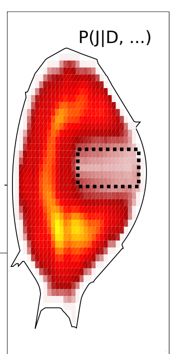
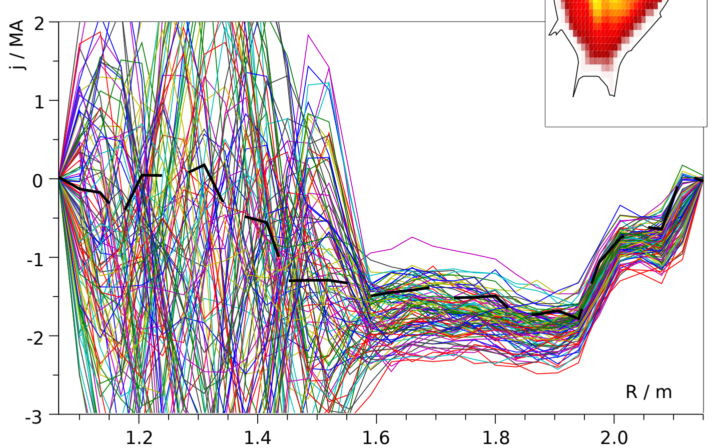
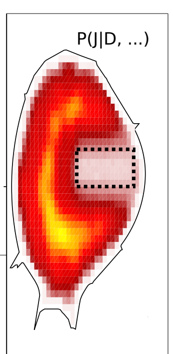
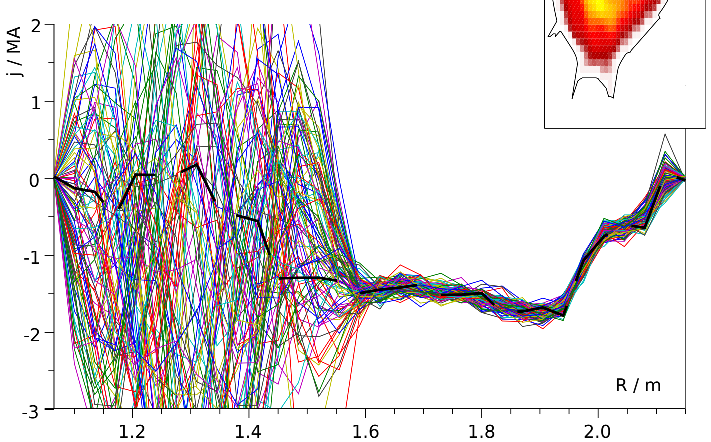




4) +Br (for interest)
30x15 grid of *Bz*
30x16 grid of *Br*.





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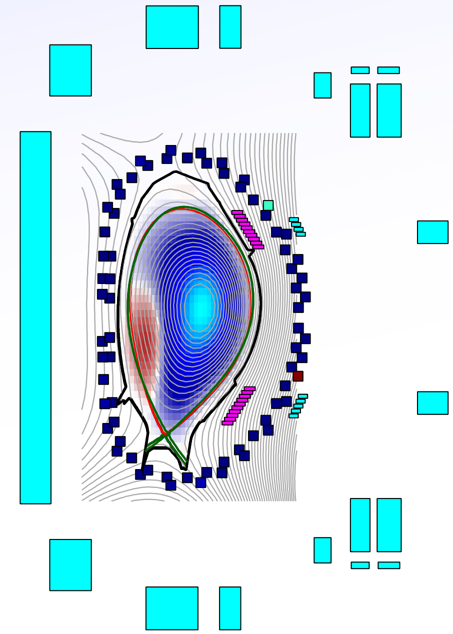

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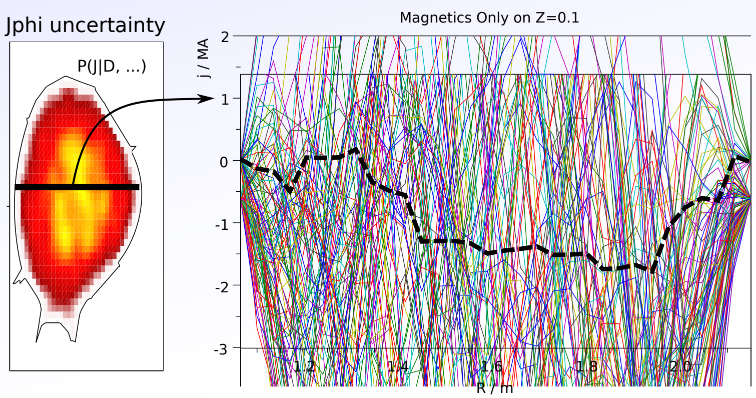

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Each case has 900 measurements at sigma = 10mT.
So difference is only in the ***type*** of information.

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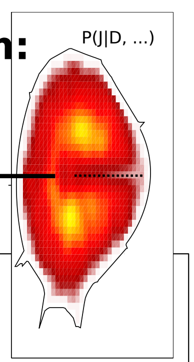

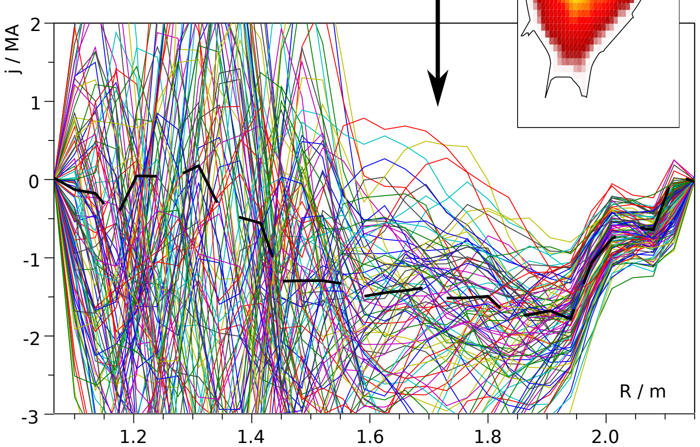

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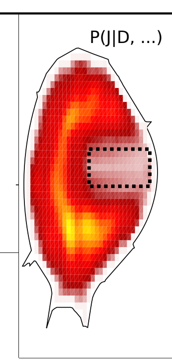
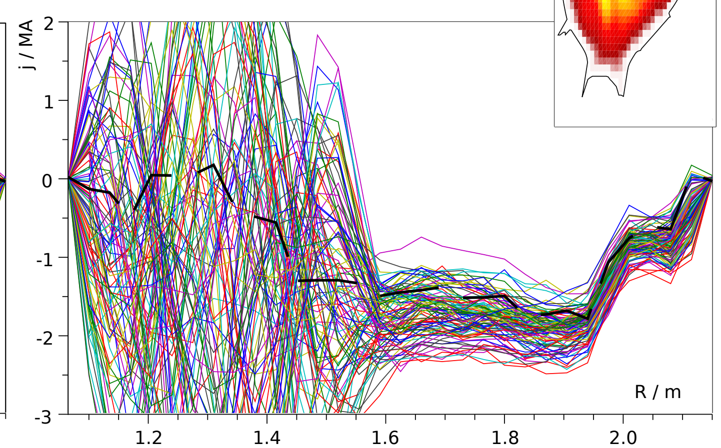
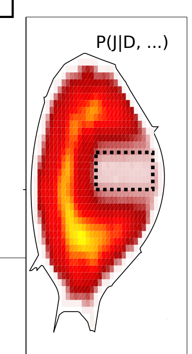
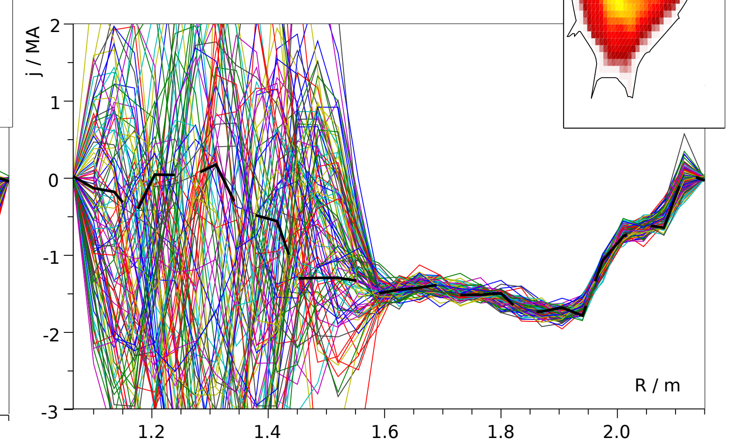




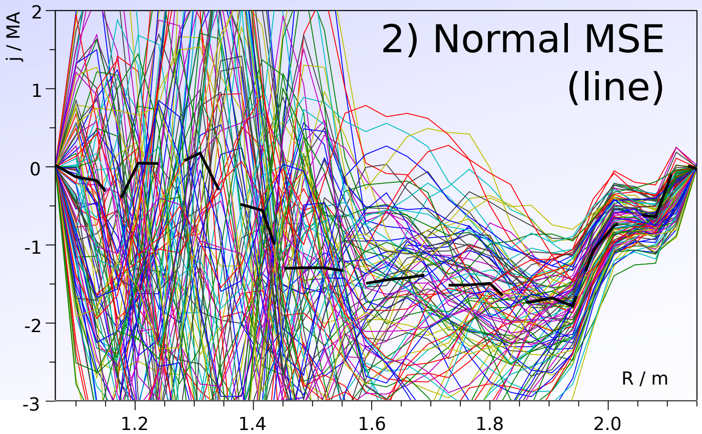
4) +Br (for interest)
30x15 grid of *Bz*
30x16 grid of *Br.*

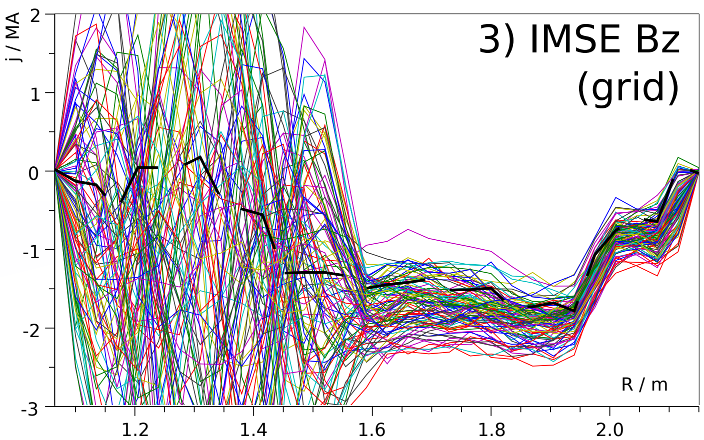


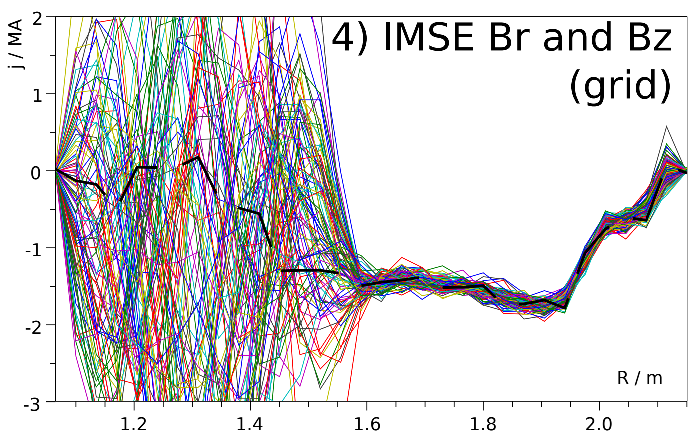


All sigmaBr = sigmaBz =10mT

By current tomography II







The IMSE still has a large uncertainty in j_ϕ offset. The unknown term it is not entirely pinned down by the magnetics.

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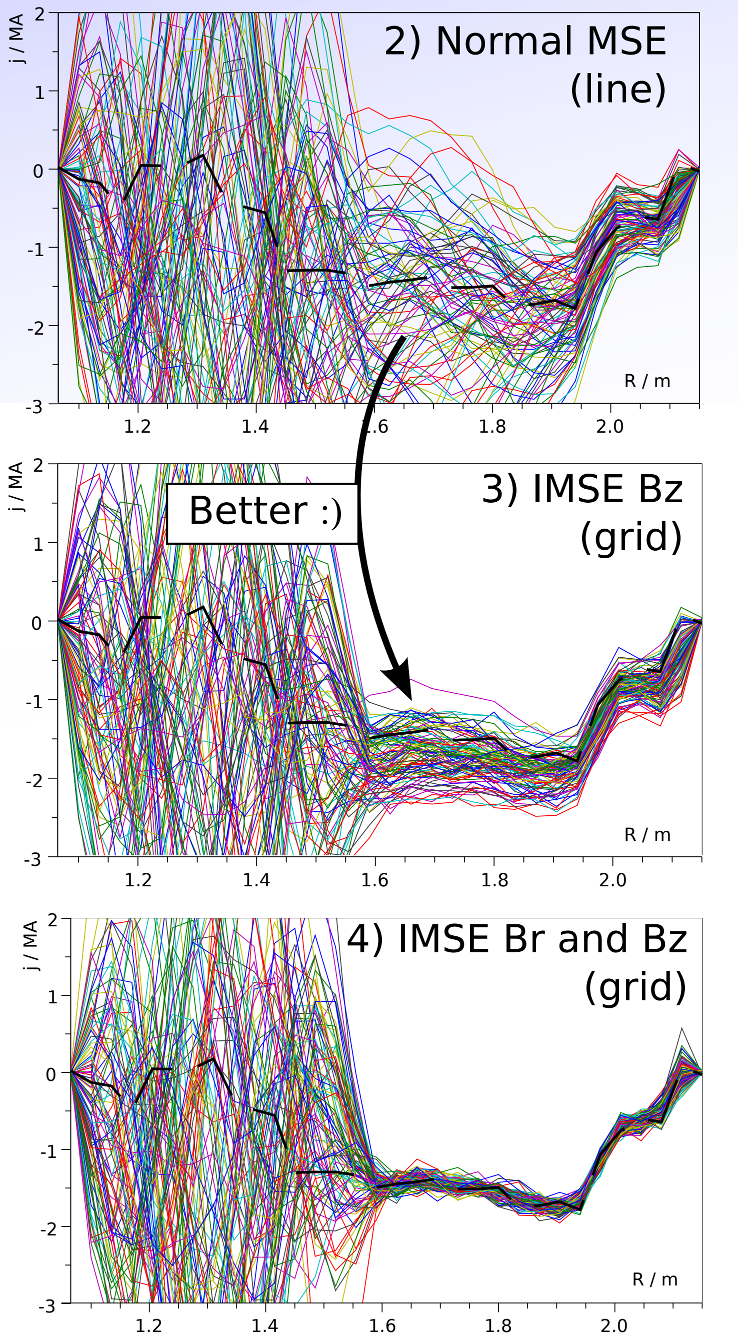

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The 2D IMSE inference is much better than the equivalent MSE system.

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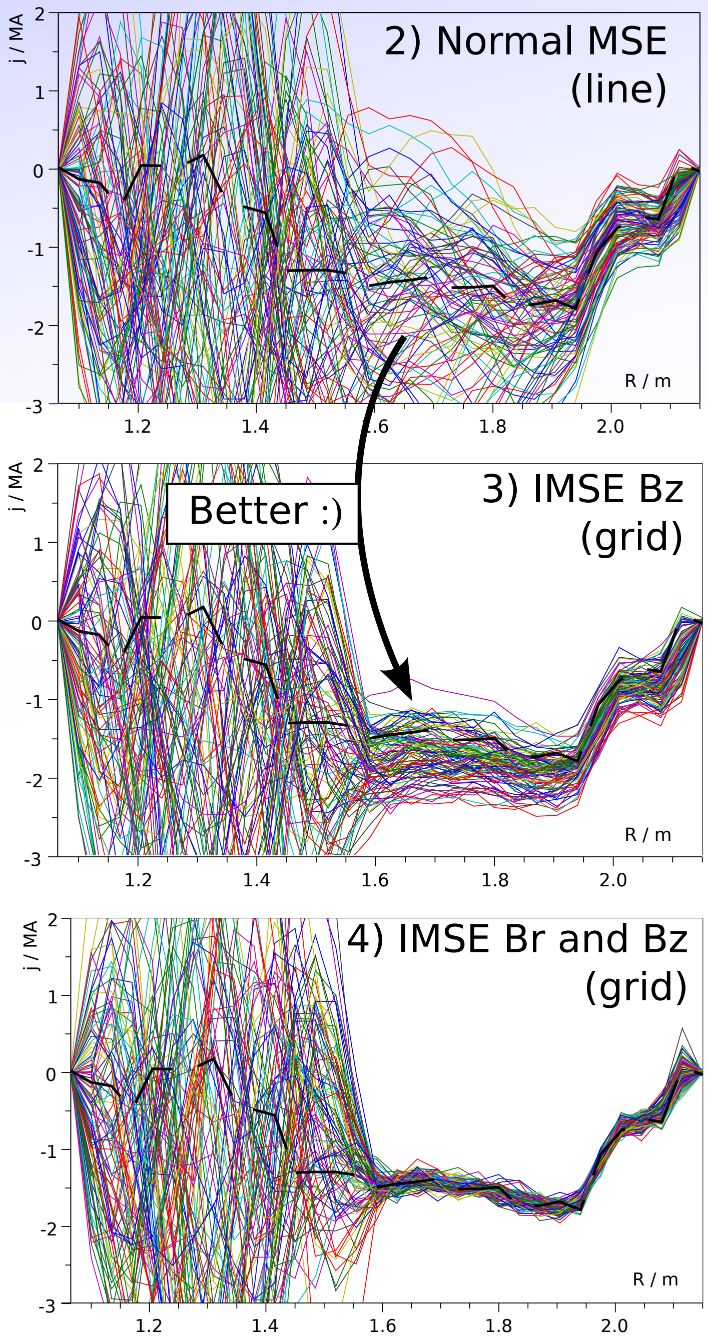

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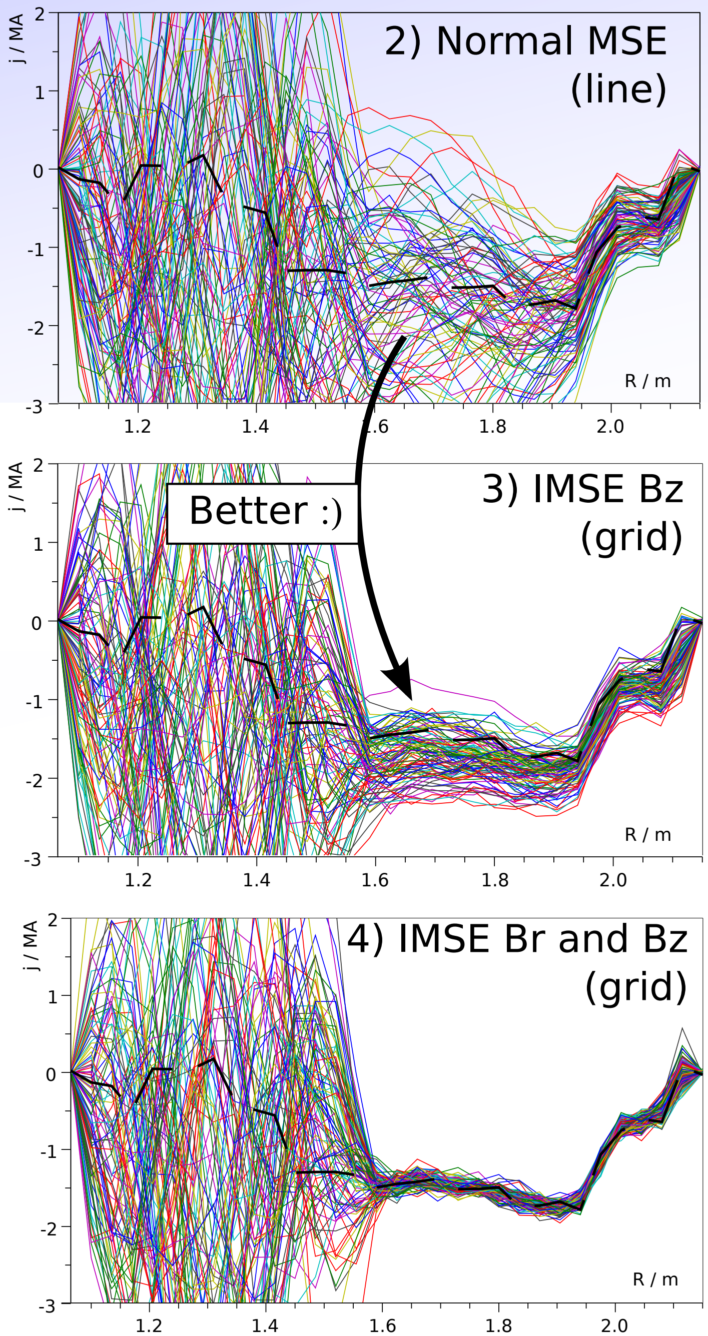

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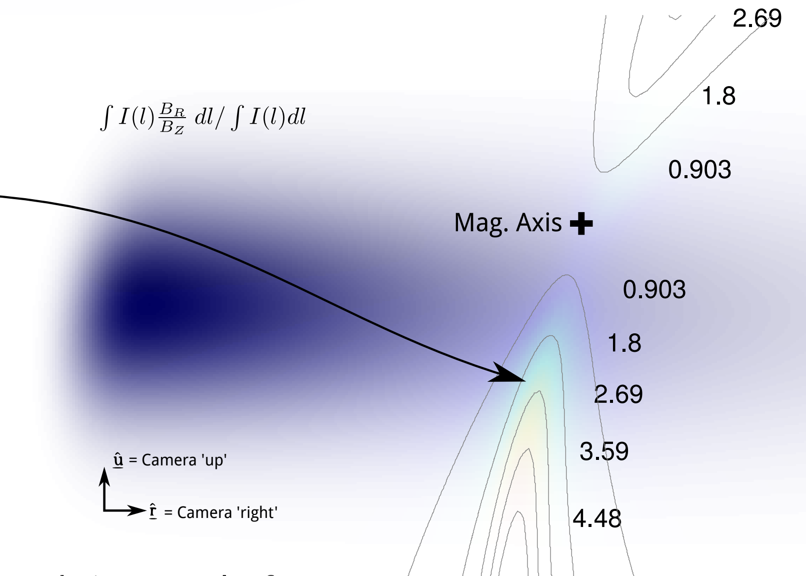

Relative stength of Br: MSE Intensity weighted LOS integral Br/Bz

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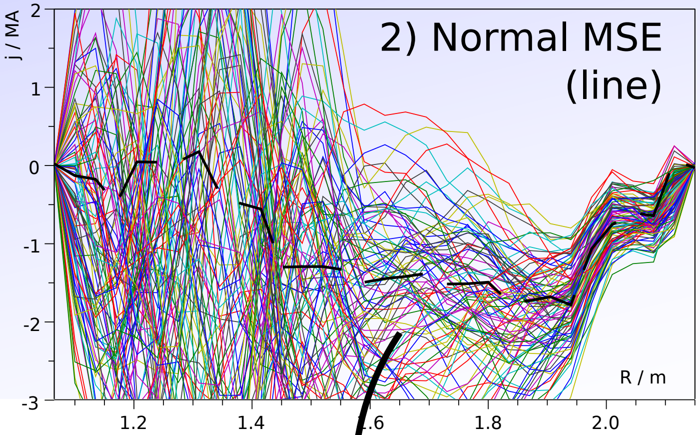

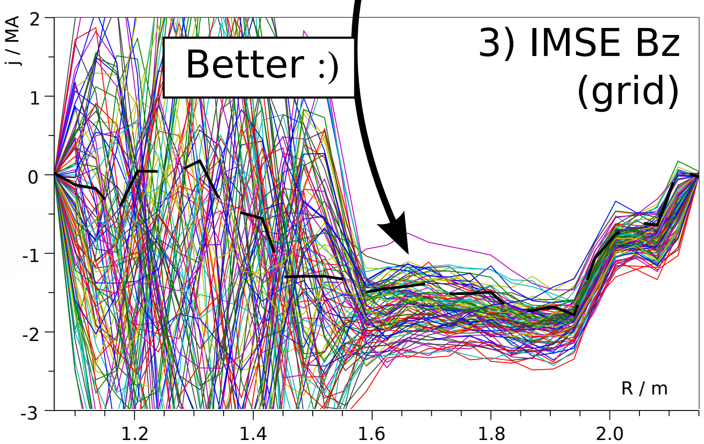

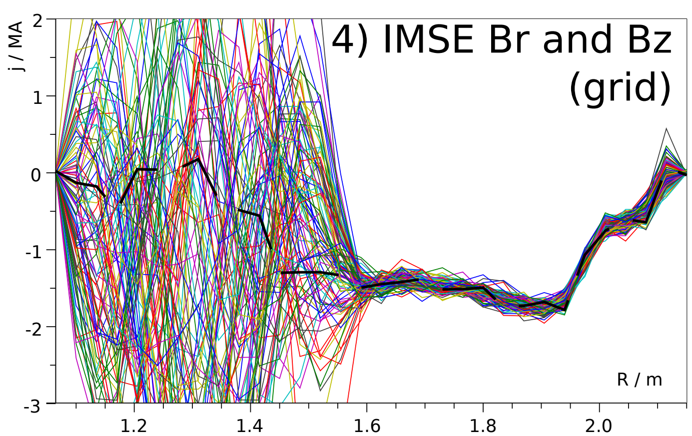

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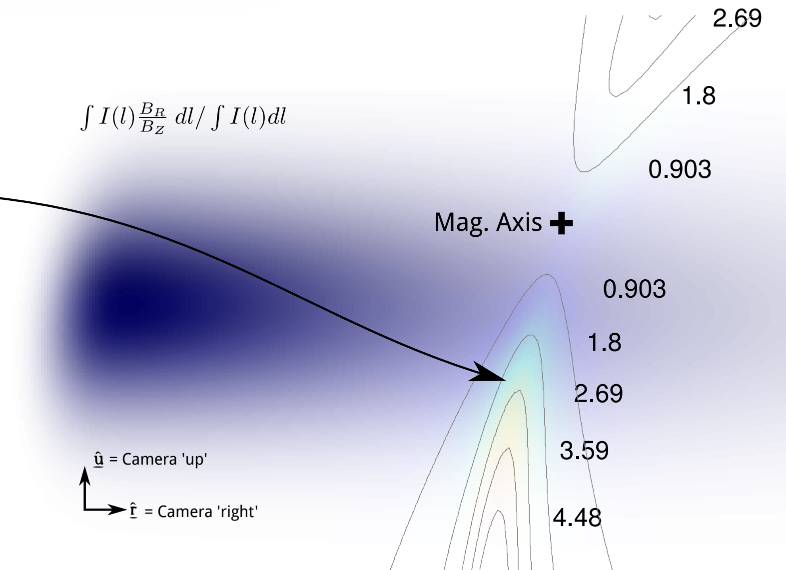

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$$\tan\beta \approx 0.17 + 0.54\frac{B_Z}{B_\phi} + 0.05\frac{B_R}{B_\phi}$$

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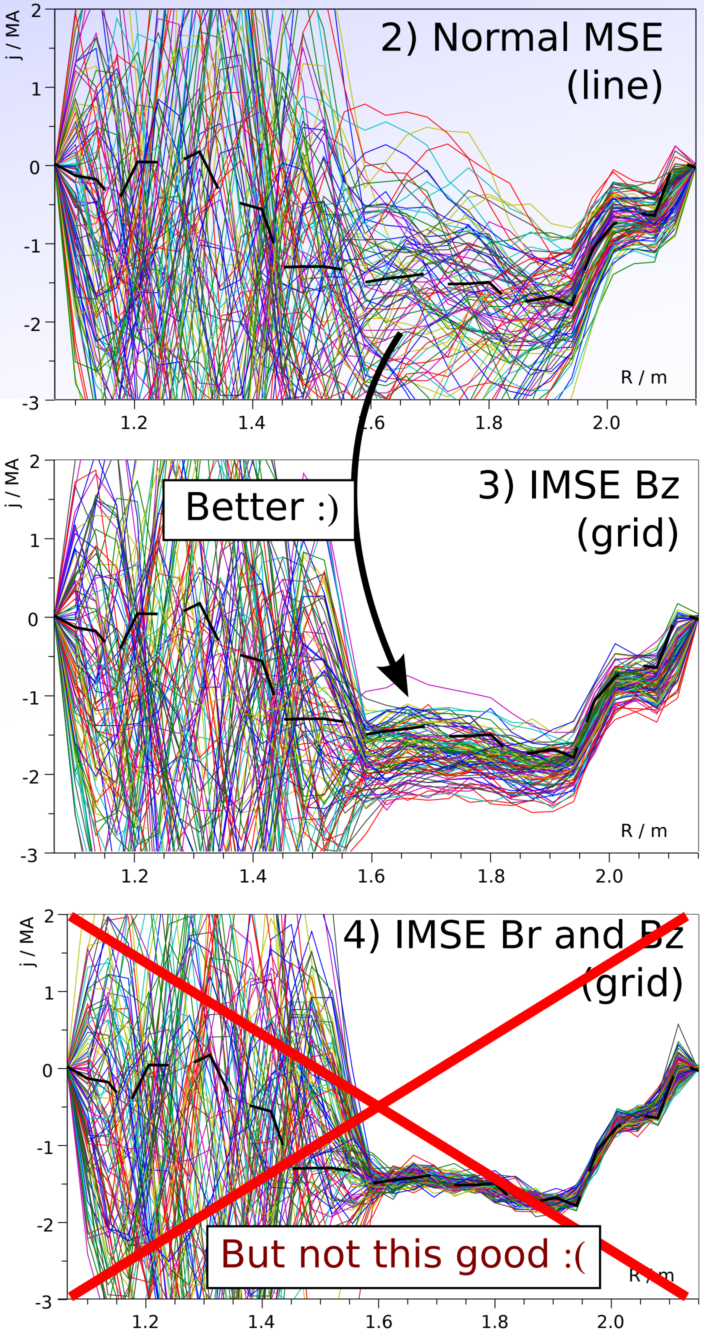

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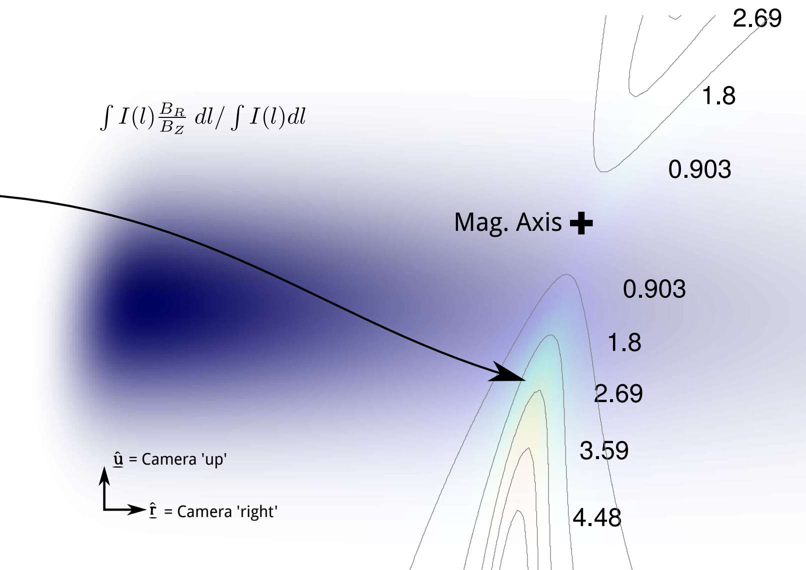

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At 5 - 10%, it will have an effect, but we do not expect to see the full current recovery from 2D tomography.

Full Inference

From this week, I can now do the full inversion from polarisation angle to plasma current $\theta(x,y)$ --> $j_\phi(R, Z)$, (without equilibrium) thanks to some new non-parametric (Gaussian process) priors (J. Svensson) and getting access to an unloaded linux cluster (on wednesday).

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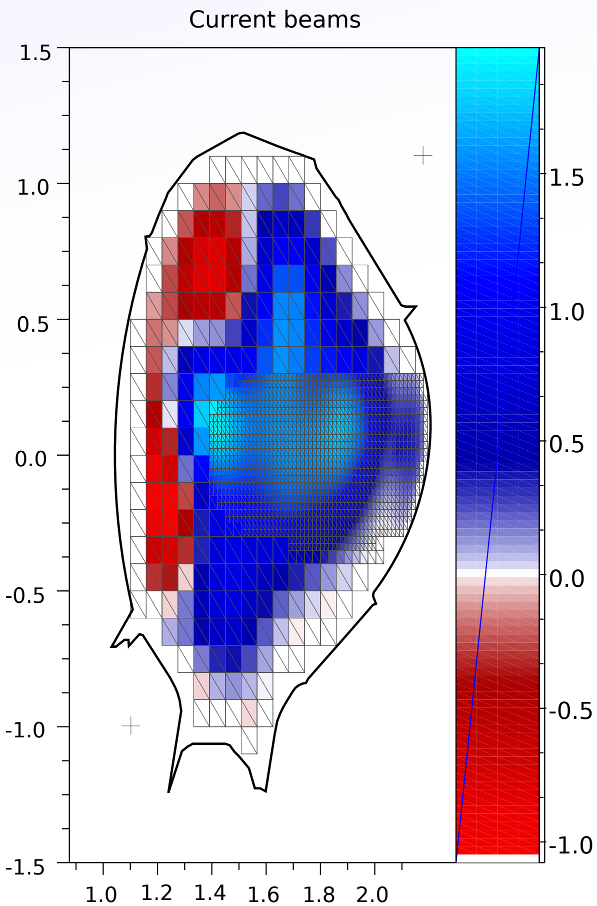

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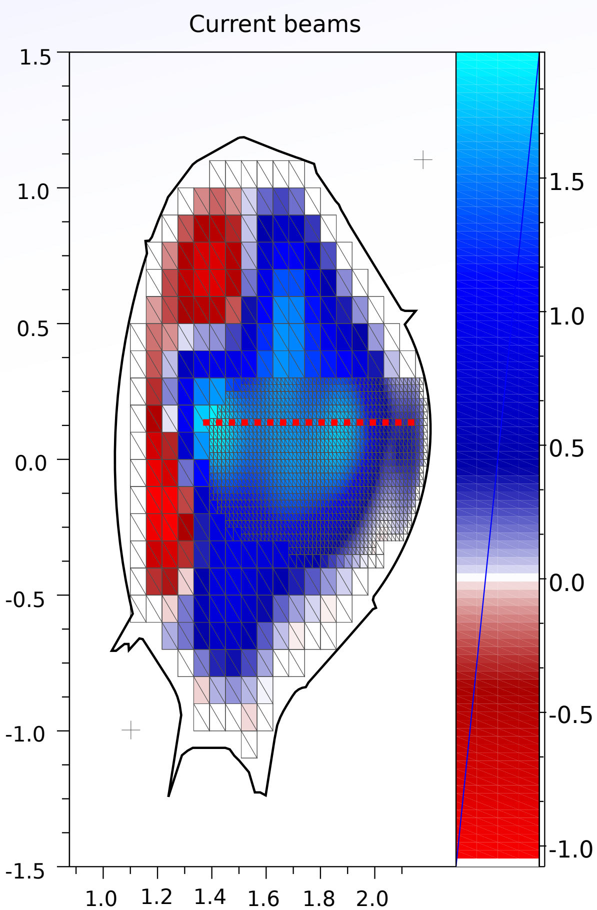

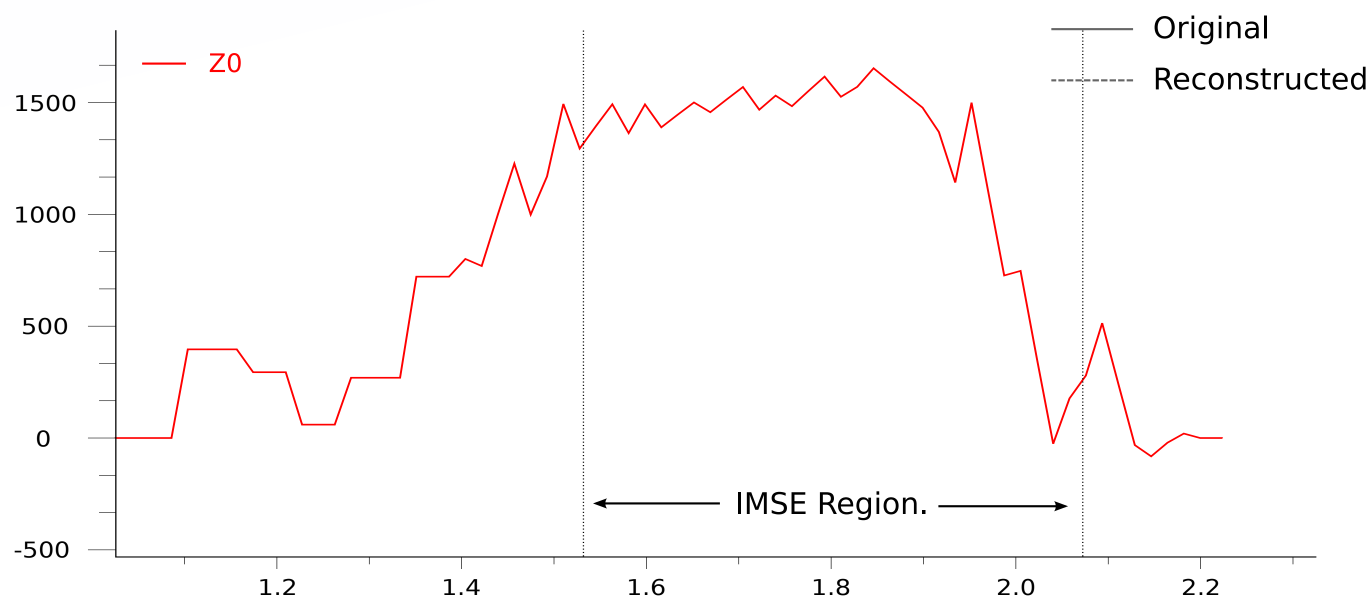

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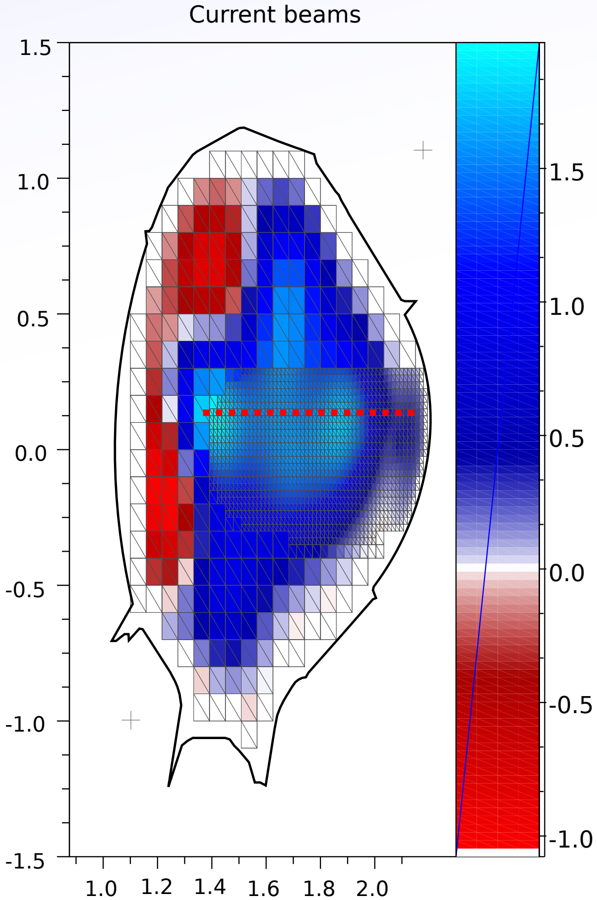

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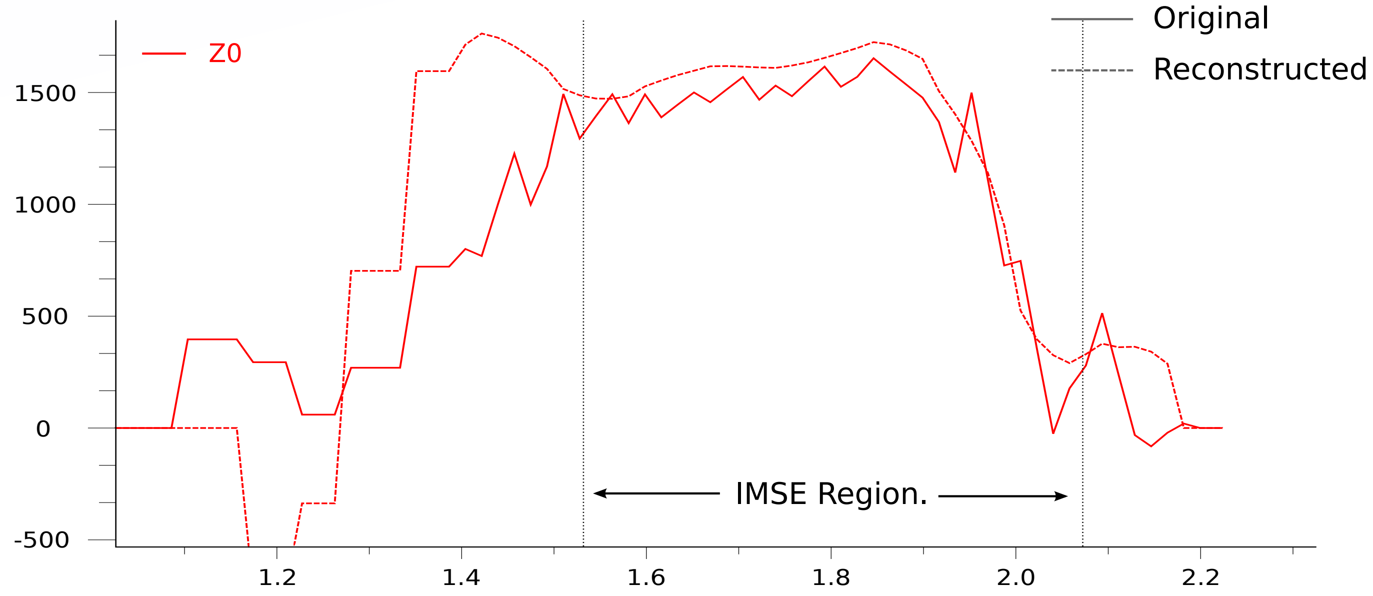

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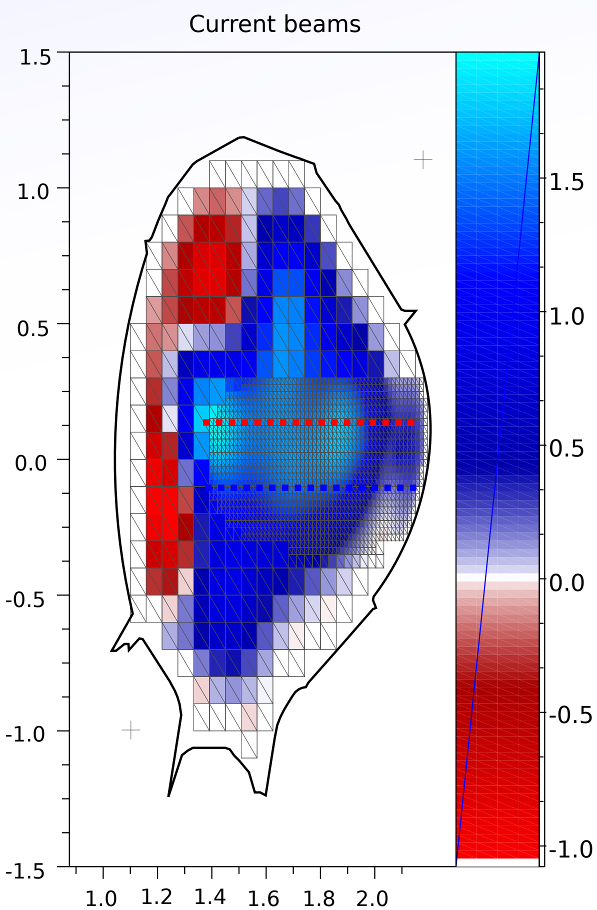

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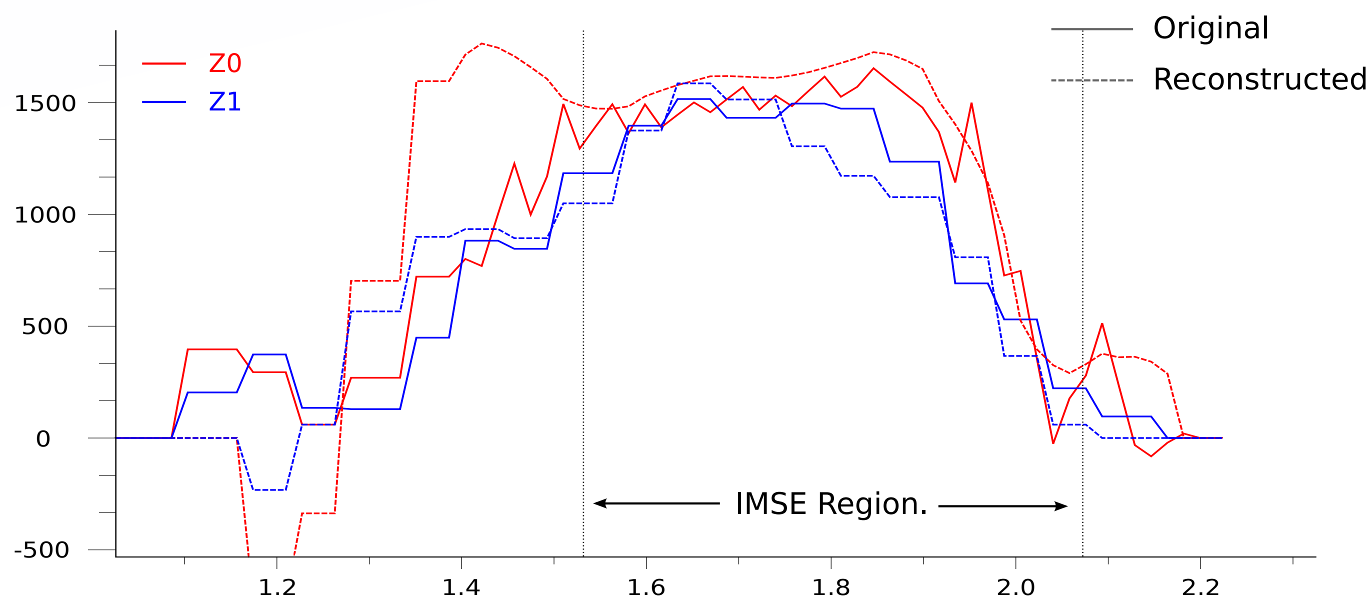

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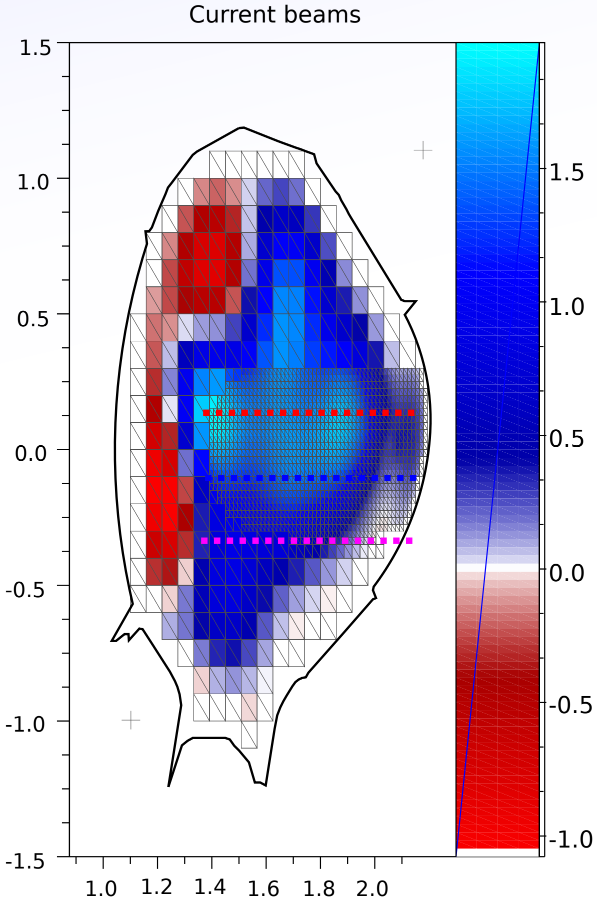

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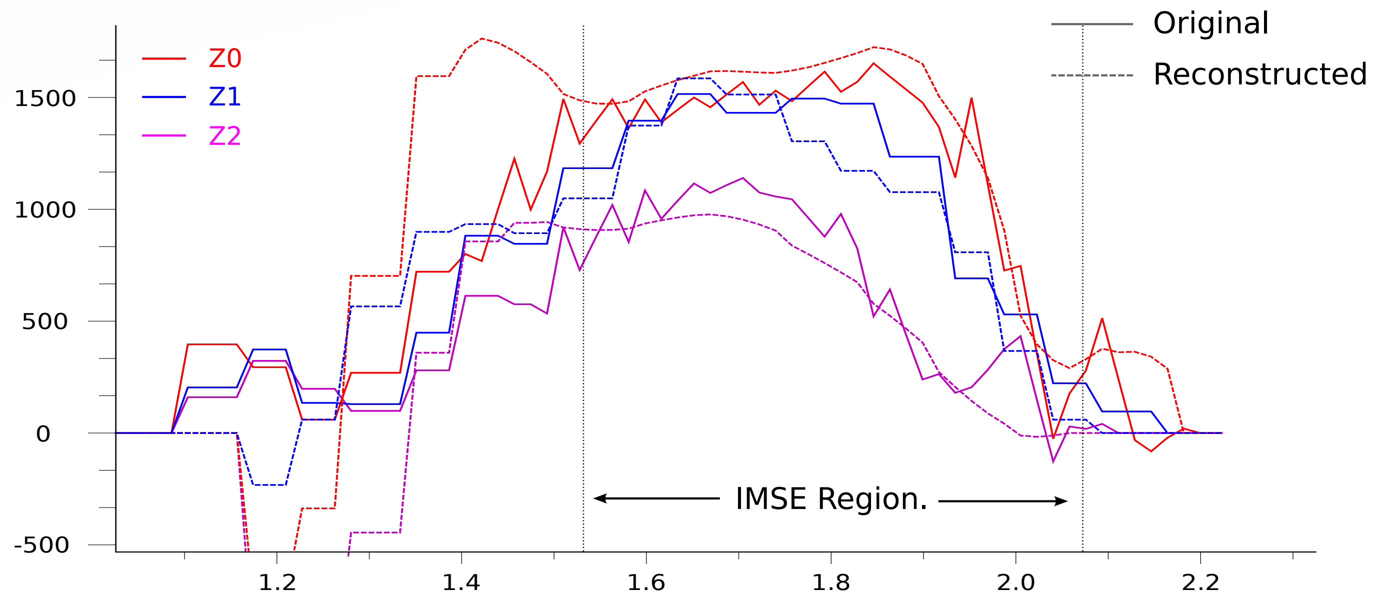

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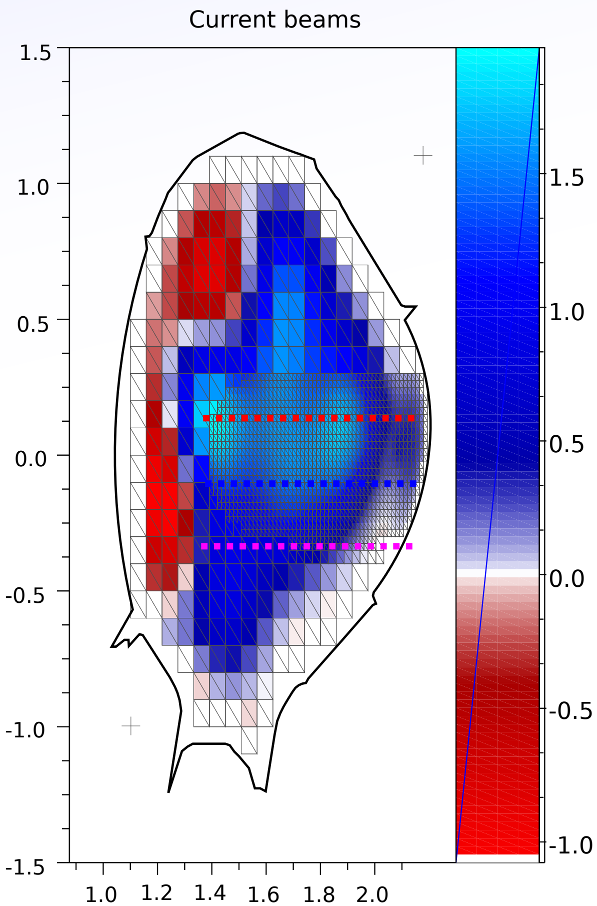

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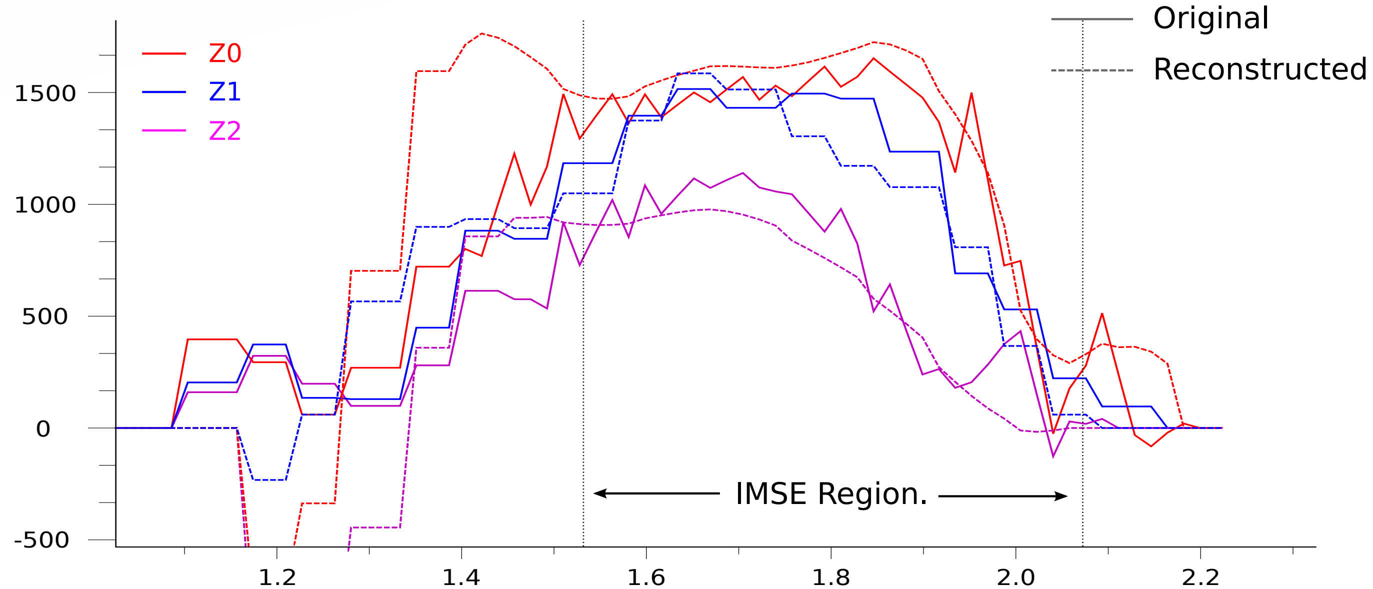
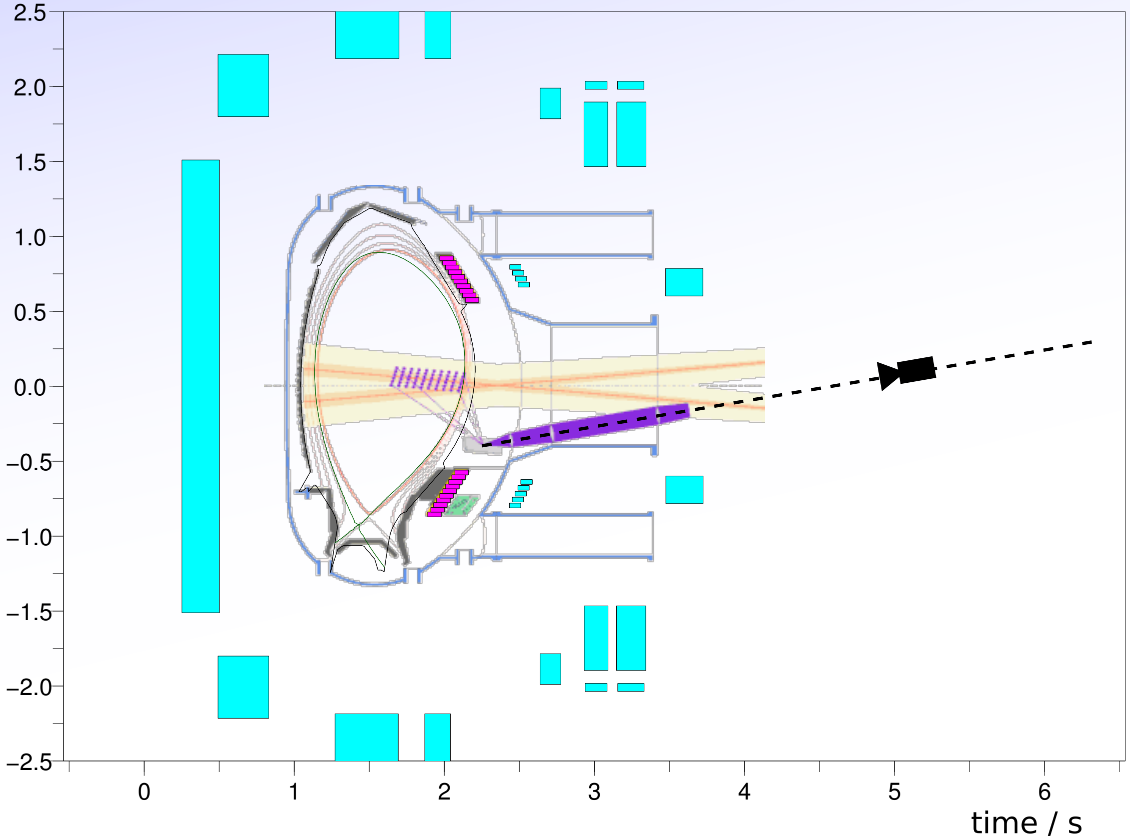


Initial results indicate that it is possible to recover the $j_\phi(R, Z)$ to at least a good resolution for studying the bulk plasma (e.g. testing different equilibrium models etc). This is MUCH better than is currently possible. Resolution is processing limited - Higher resolution may be possible, but computation cost rises with resolution as $\sim n^4$.

Other progress (Hardware)



Ideally, we want to fix the camera and optic plates directly to the viewing optics (no fibre etc).

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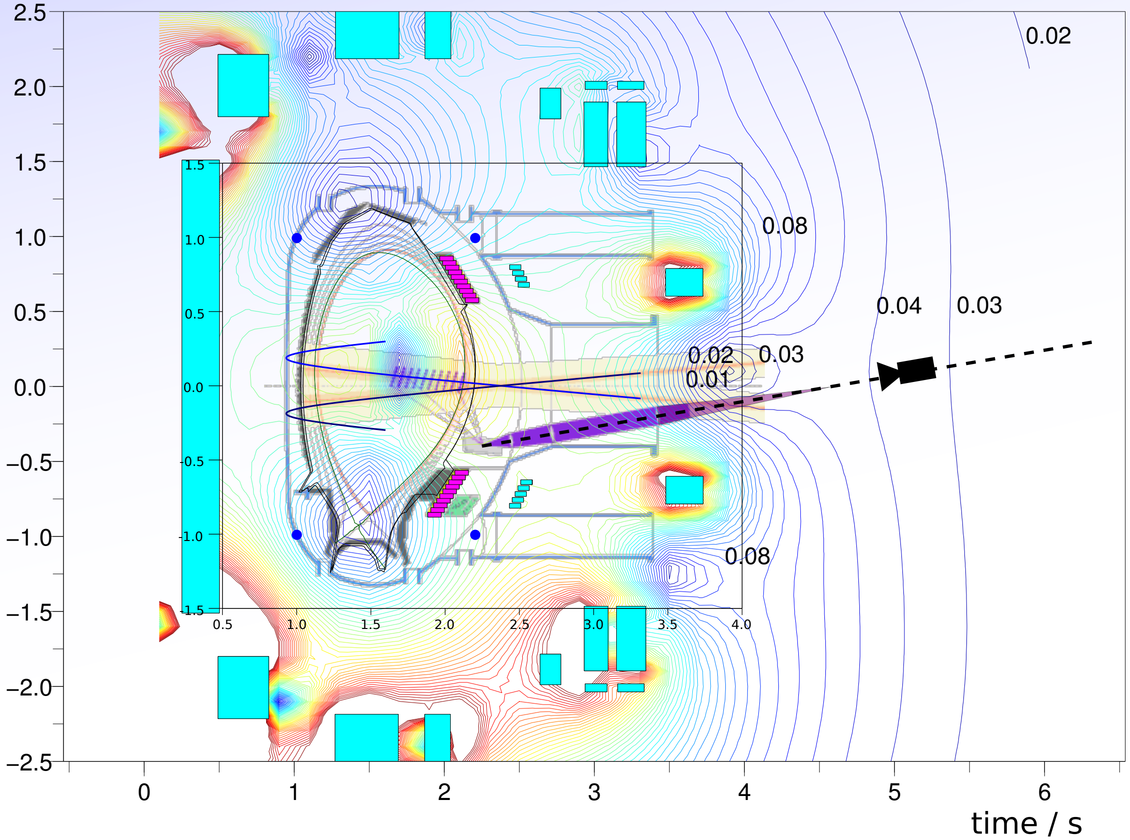

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Camera will be subject to magnetic field, which Minerva can predict from the PF coils.
For the highest plasma current (I_p = 1.2MA),
$|B| < 50mT$:

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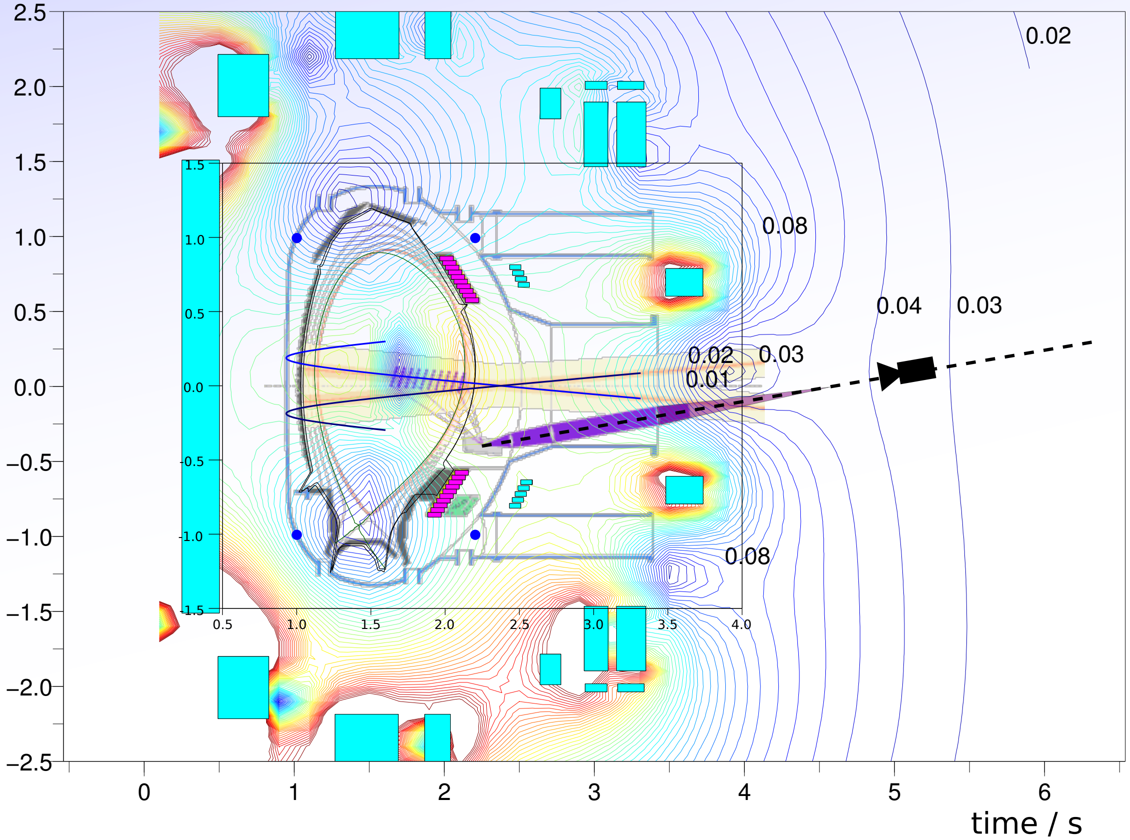

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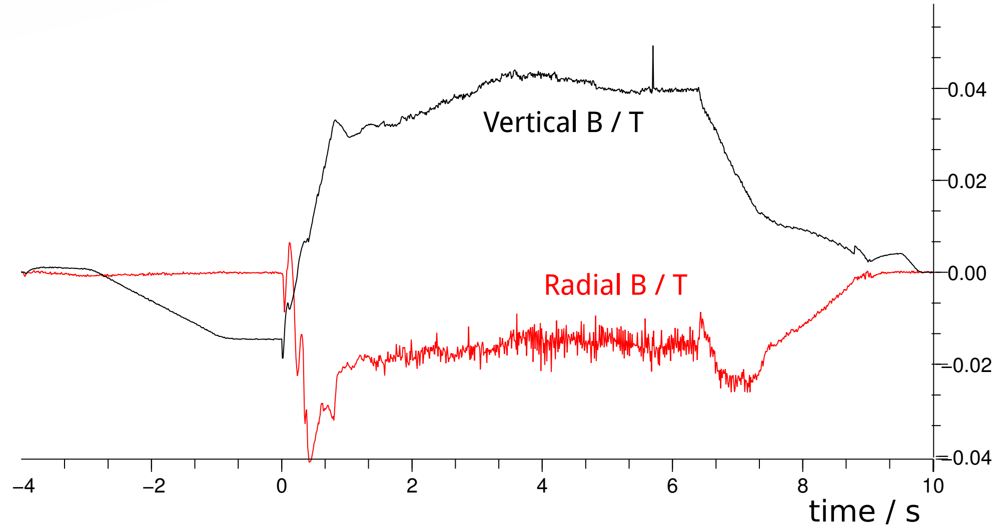

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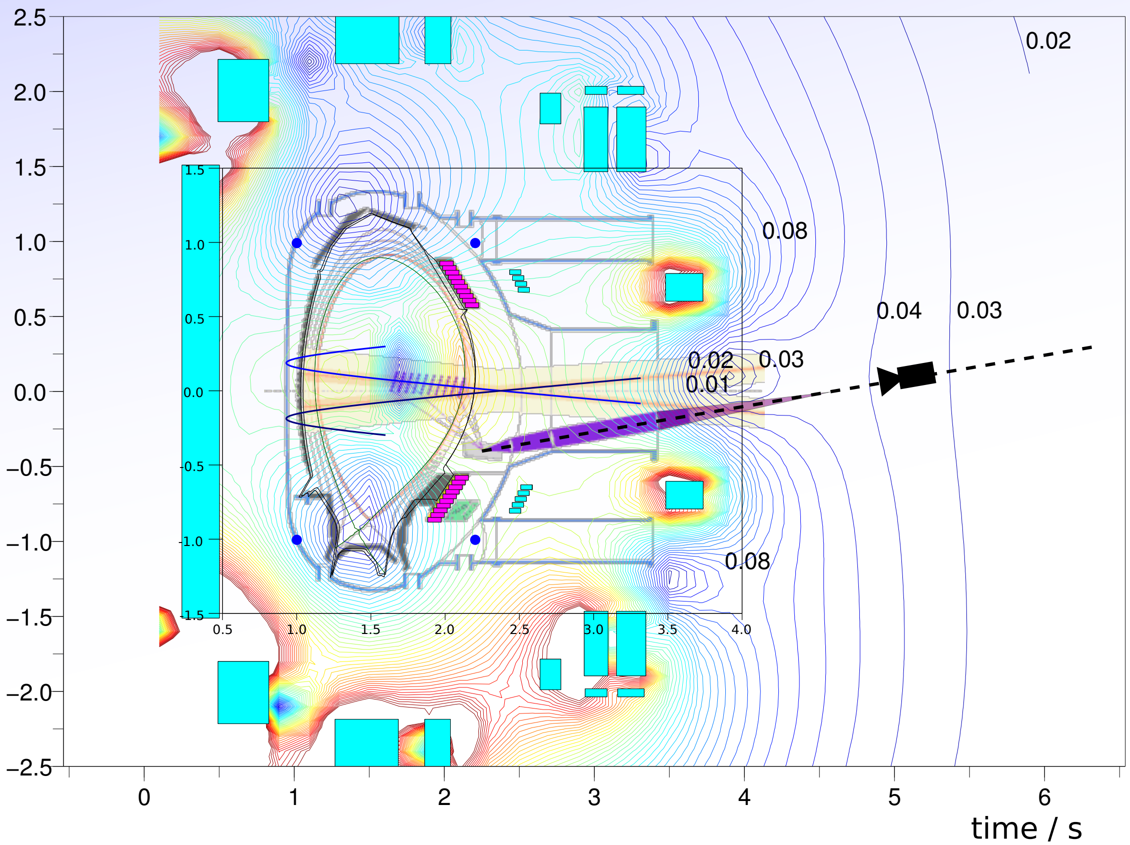

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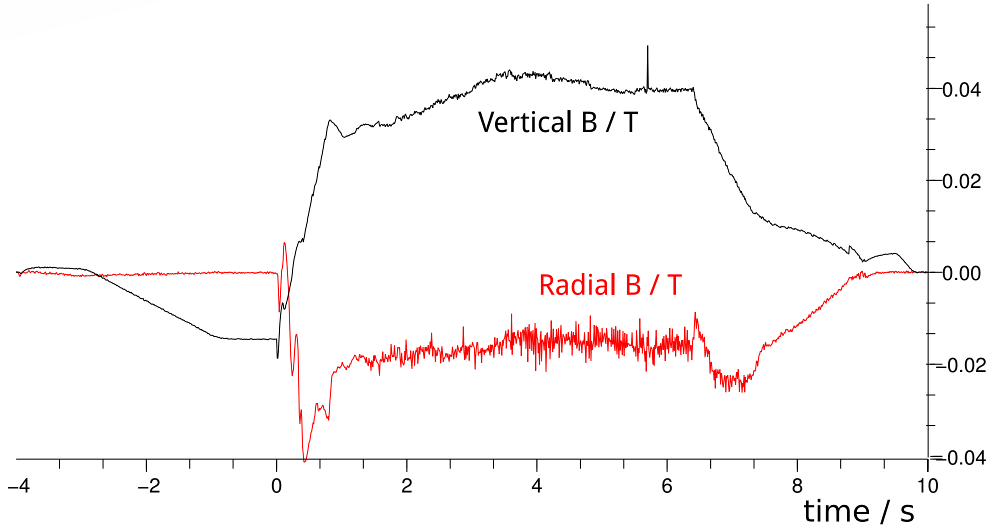

- The camera we have (12bit 1376x1040 Imager QE) was used next to the coils in Pilot (PSI) last year, so may survive this. Apart from a very slow frame rate (10Hz), it is otherwise perfectly suited, so could be used for a first attempt.

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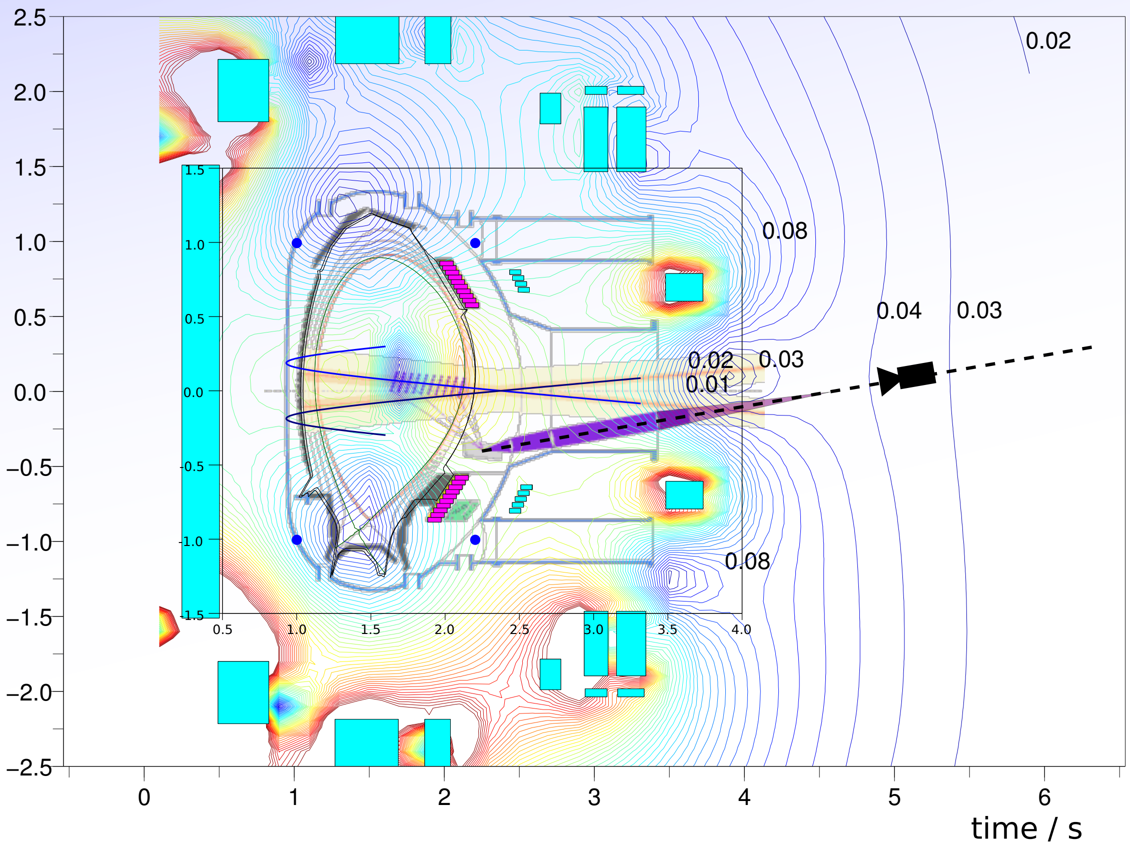

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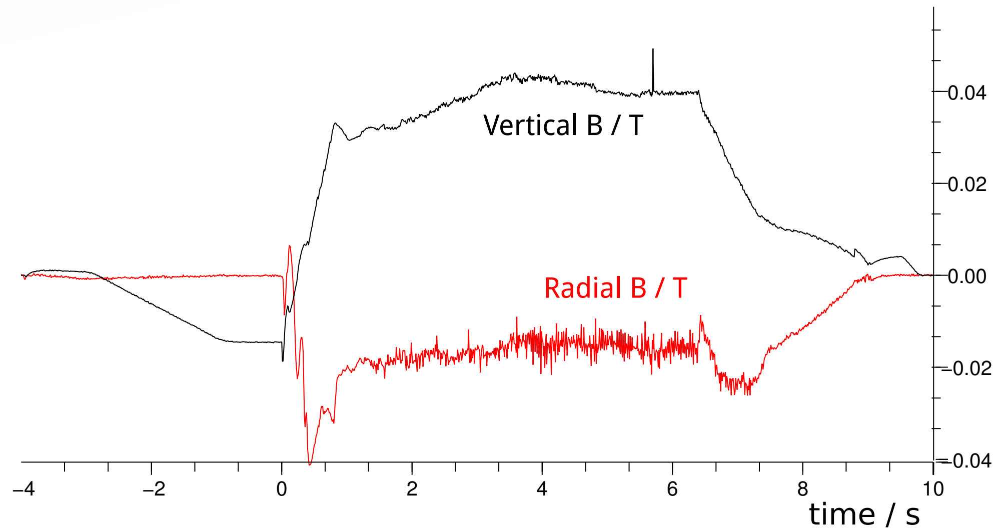

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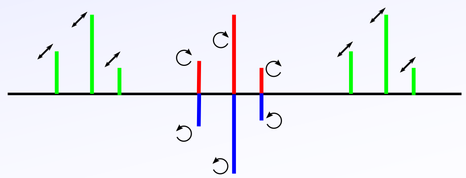
- Faraday rotation due the field in the Savart plates will not be a problem, but the main delay plate might be. (I'm assuming Lithium Niobate, but I can't find a Verdet constant for it in the Literature. Any suggestions?)

Other progress (Model)

Various other effects have been corrected in the forward model:

- Detail of Stark splitting and component polarisations. (Thanks to R. Reimer for pointing this out)



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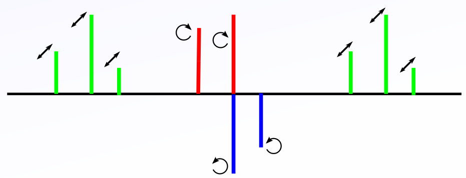

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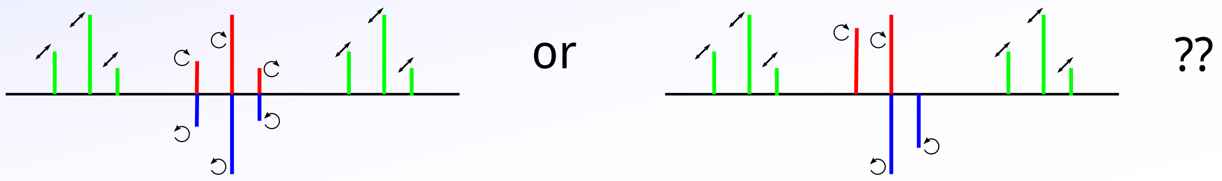

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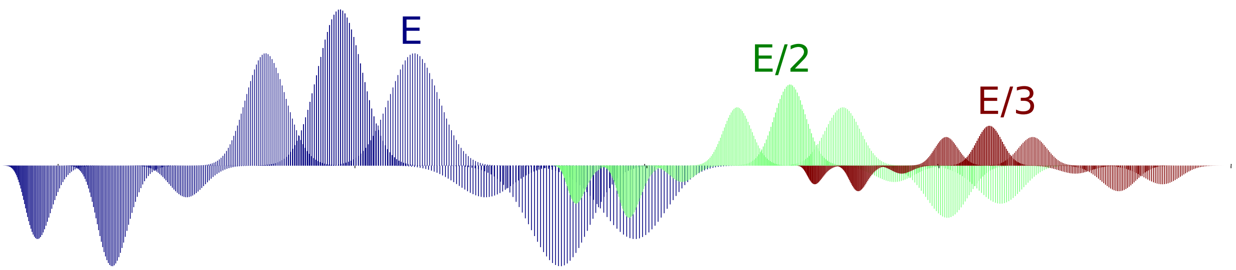

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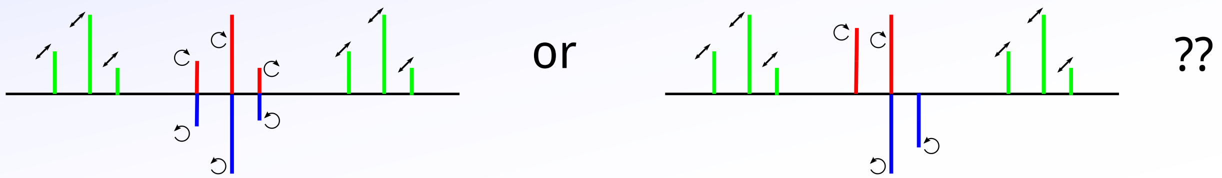

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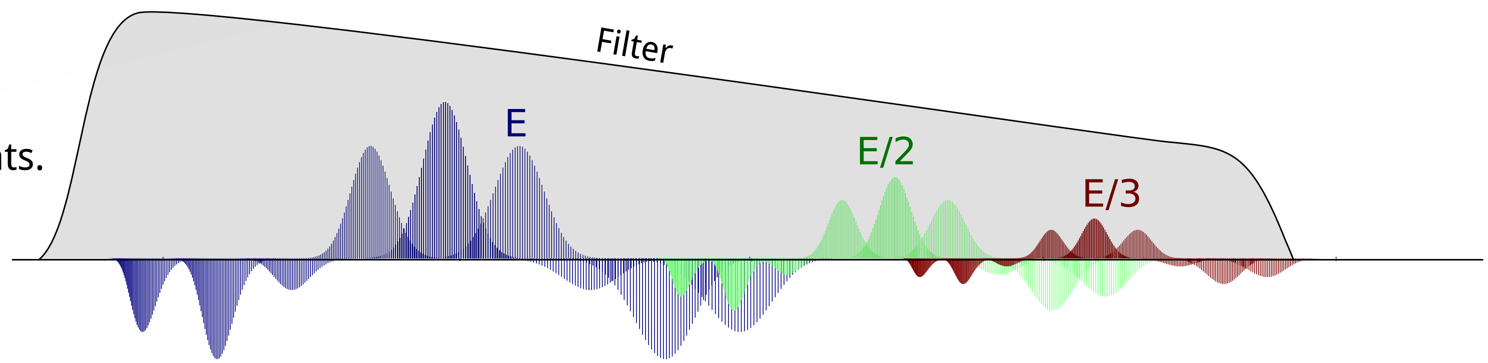

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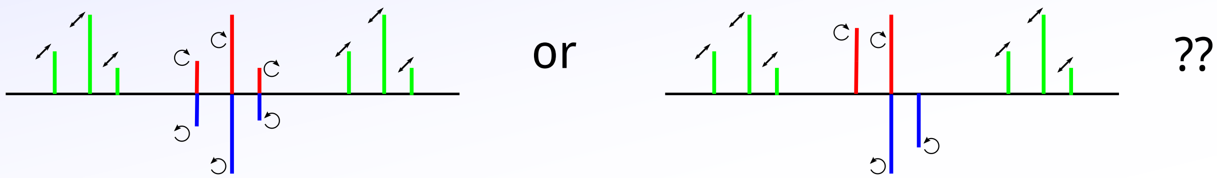

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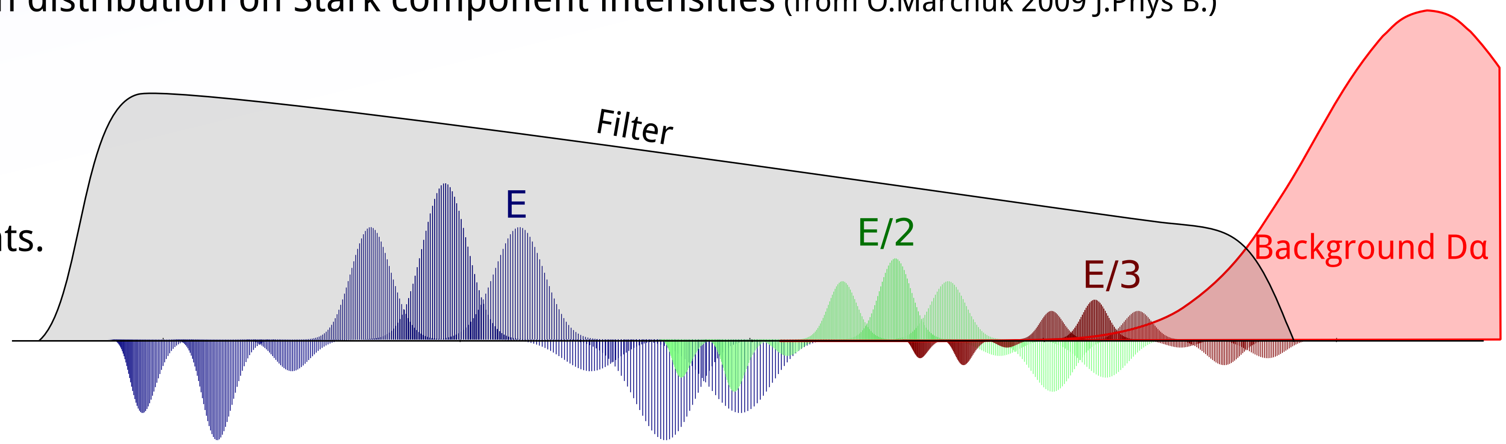

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Things still to add:

- Background D-Alpha and FIDA. (These will only reduce S/N).
- CCD noise (other than photon statistics).
- Viewing optics.