Bayesian Analysis of Fusion Plasma Diagnostics.

A review of research completed for Plasma Physics PhD at the Joint European Torus, Culham UK, funded by Imperial College London and the Culham Centre for Fusion Energy.

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Research Plan:

To investigate what information can be extracted from many existing fusion plasma diagnostics at JET, using the analysis techniques of ***forward modelling*** and the principals of ***Bayesian analysis*****.**

1. To infer the plasma state at any instant, making as few as possible assumptions.

2. Achieve a complete and rigorous description of the uncertainty, from:
   diagnostic noise, calibration uncertainty and degeneracy of possible states.

3. To minimise uncertainty by consistently combining data from multiple diagnostics.

Interferometry + Core LIDAR + Edge LIDAR - Consistent combination of data.

Multiple n_e, T_e diagnostics are available on most Tokamaks and several of these on JET. These quantities are used for interpretation of many other diagnostics, for transport and confinement analysis, pedestal studies, equilibrium constraints, stability analysis, edge modelling and many other Tokamak physics investigations.

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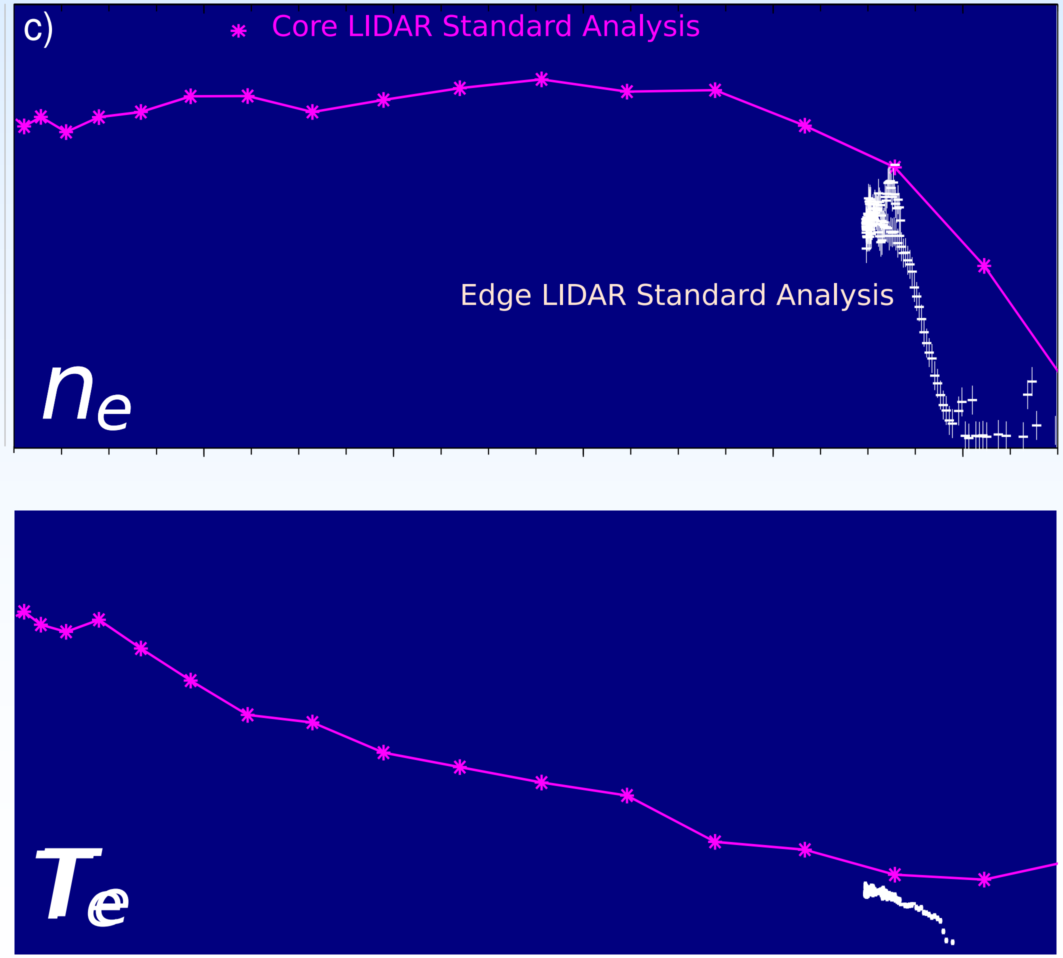

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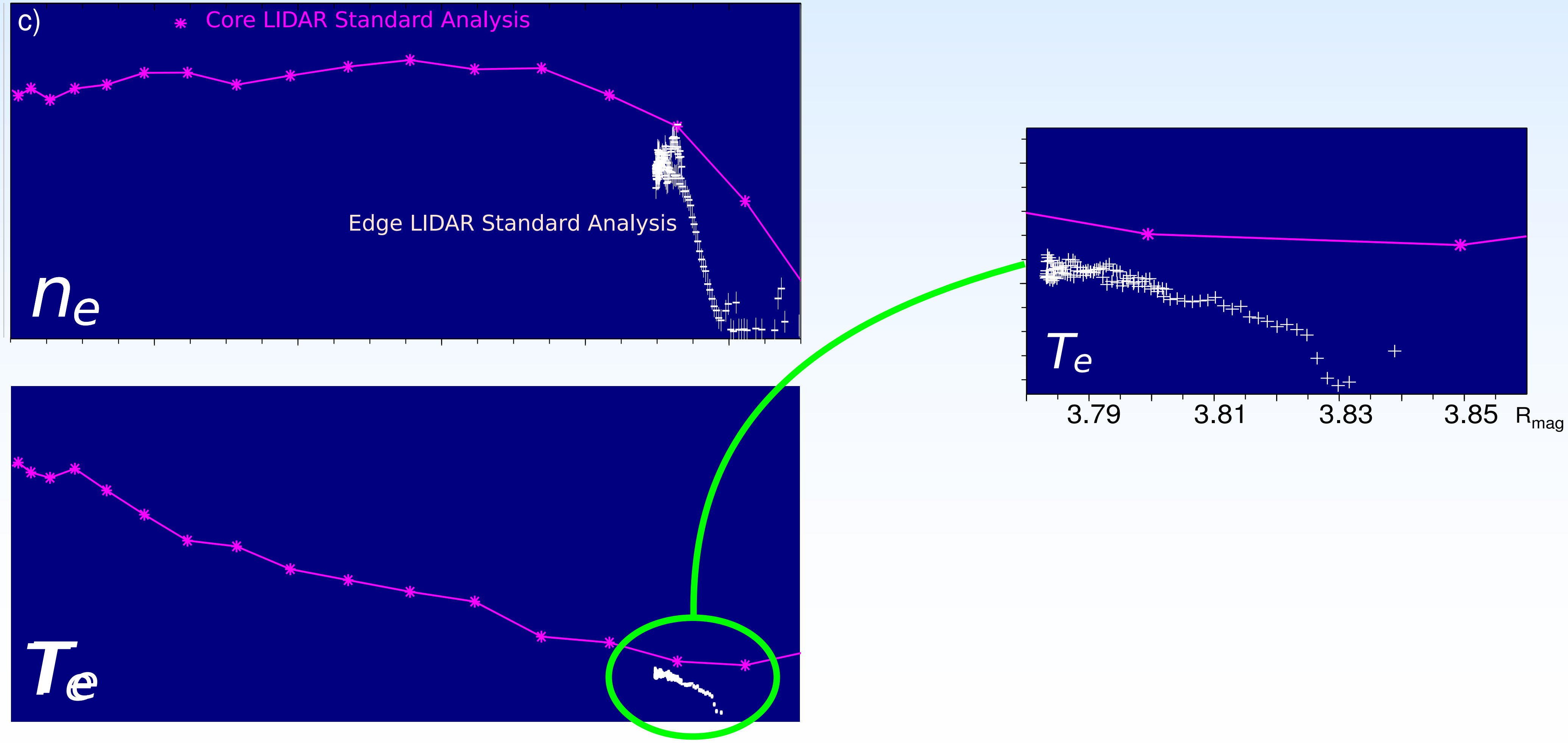

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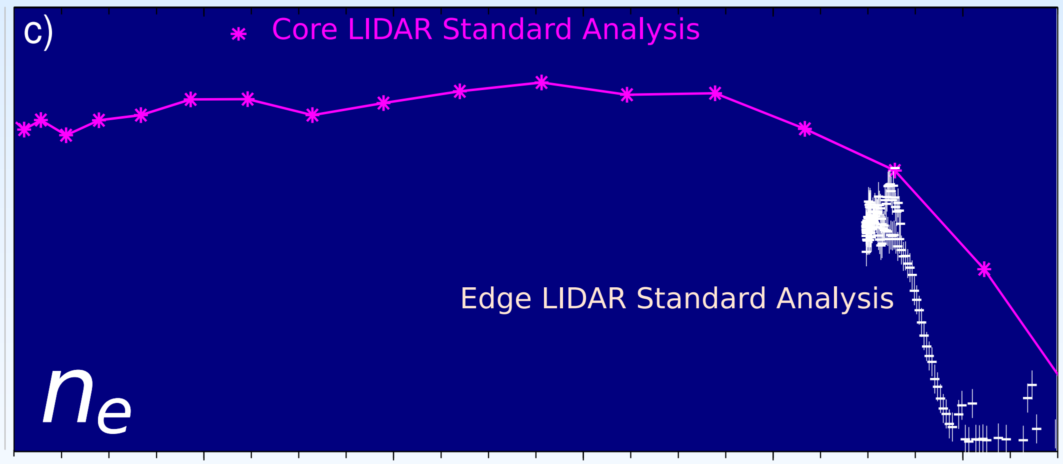
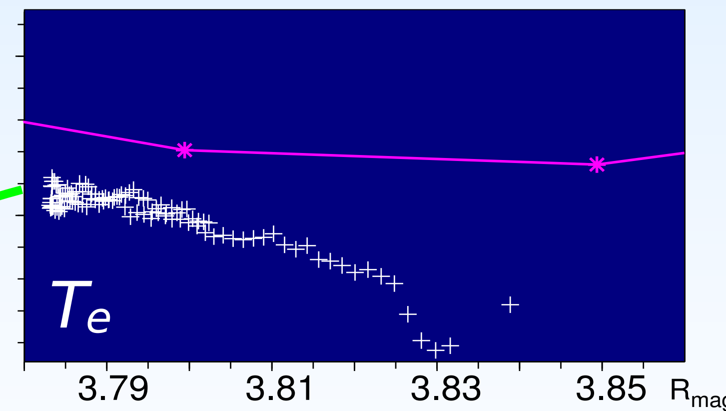
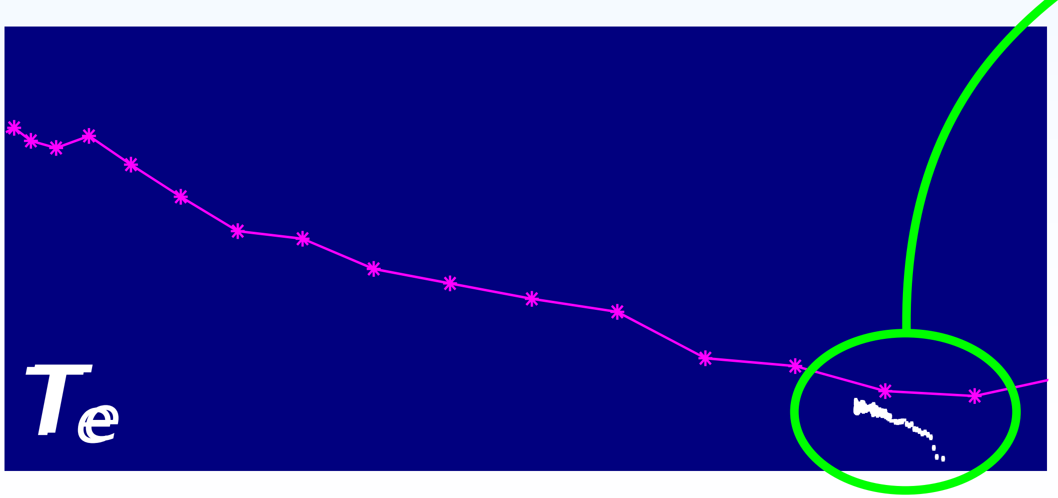


General genetic and Monte-Carlo algorithms find all possible plasmas and calibration states consistent with data. This automatically obtains the full rigorous uncertainty.





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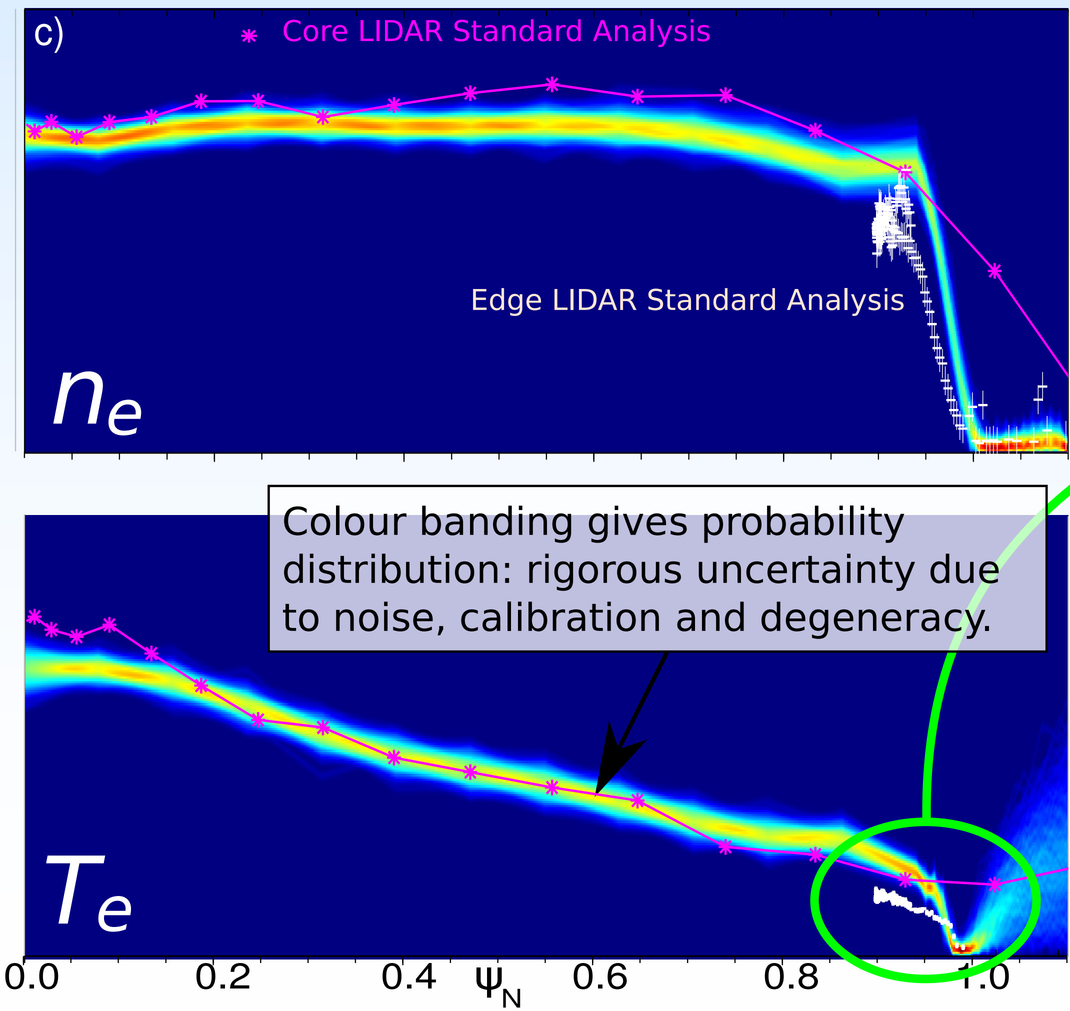

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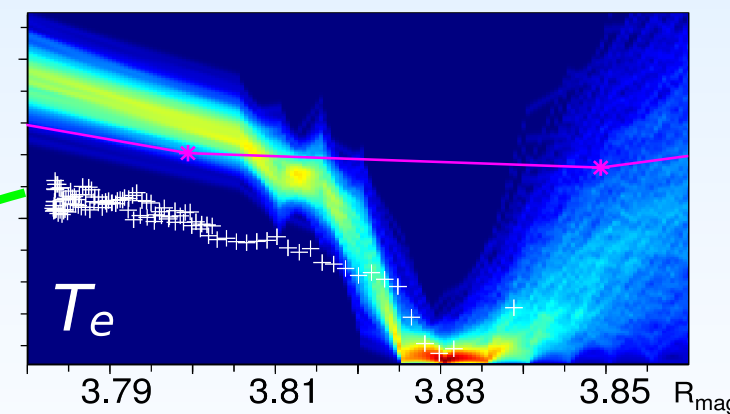

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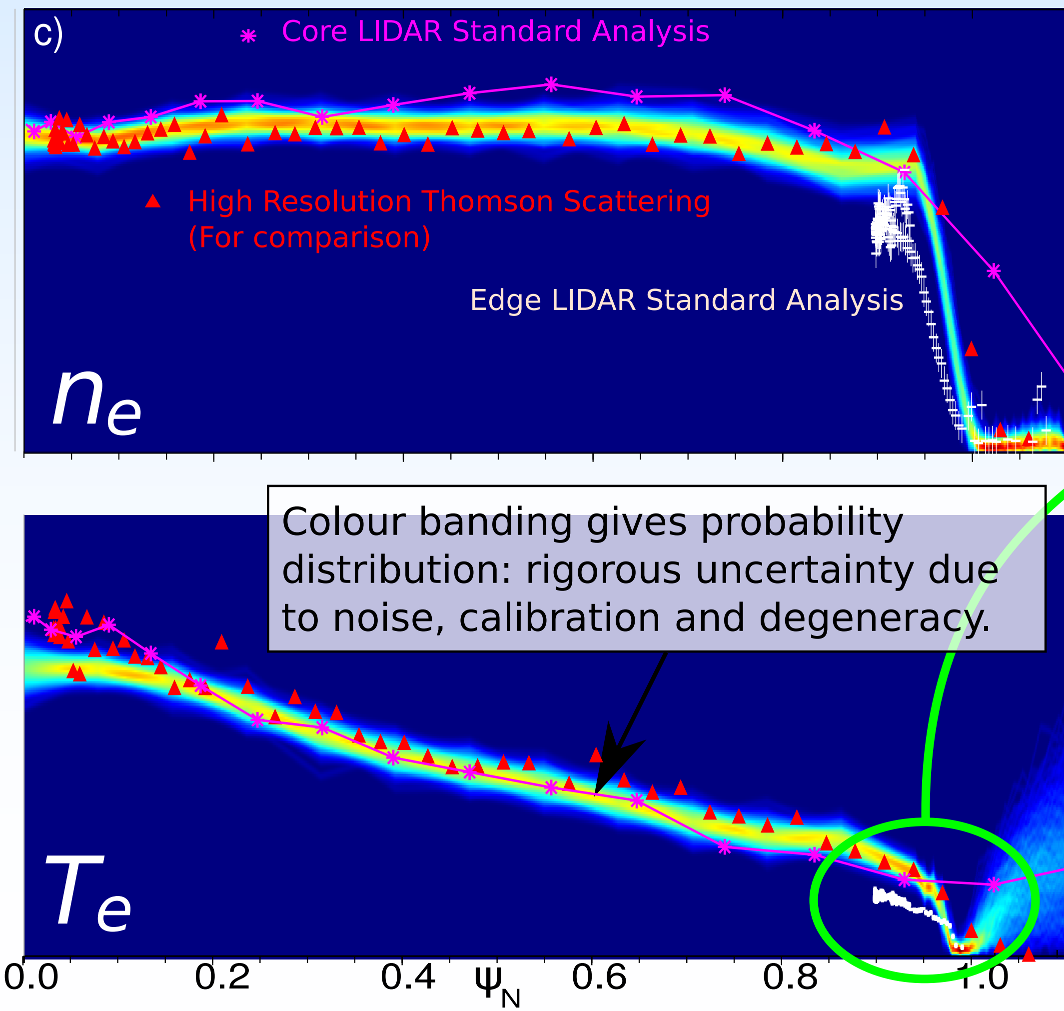

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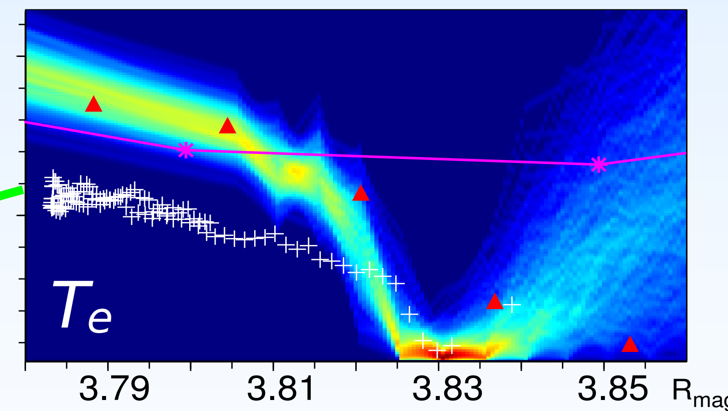

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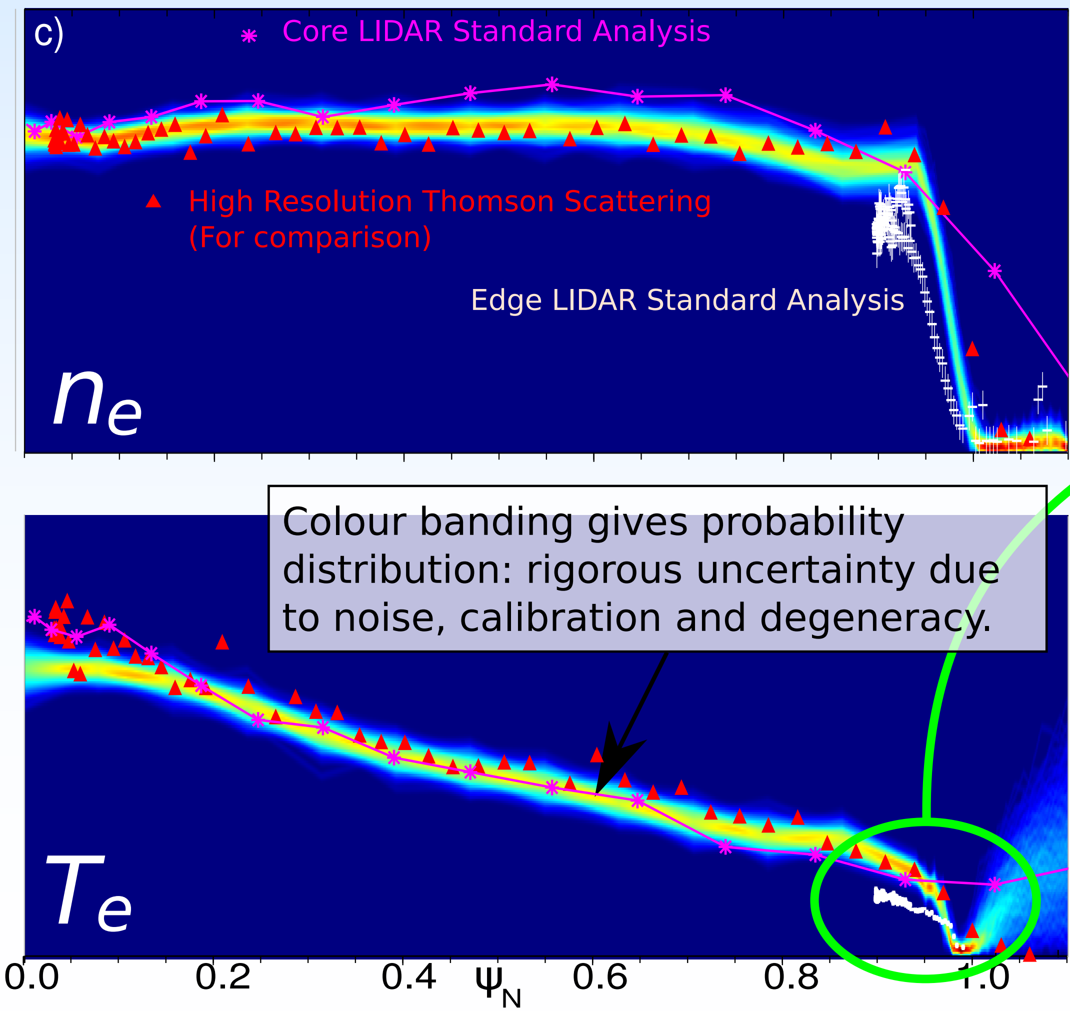

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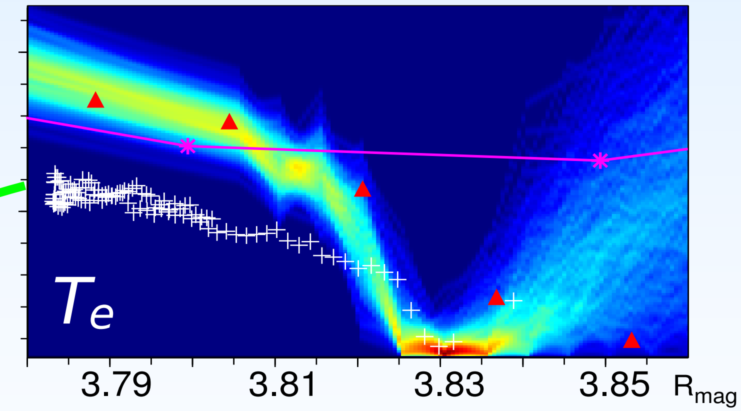

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P2.150, 36th EPS Conference on Plasma Phys. (2009)

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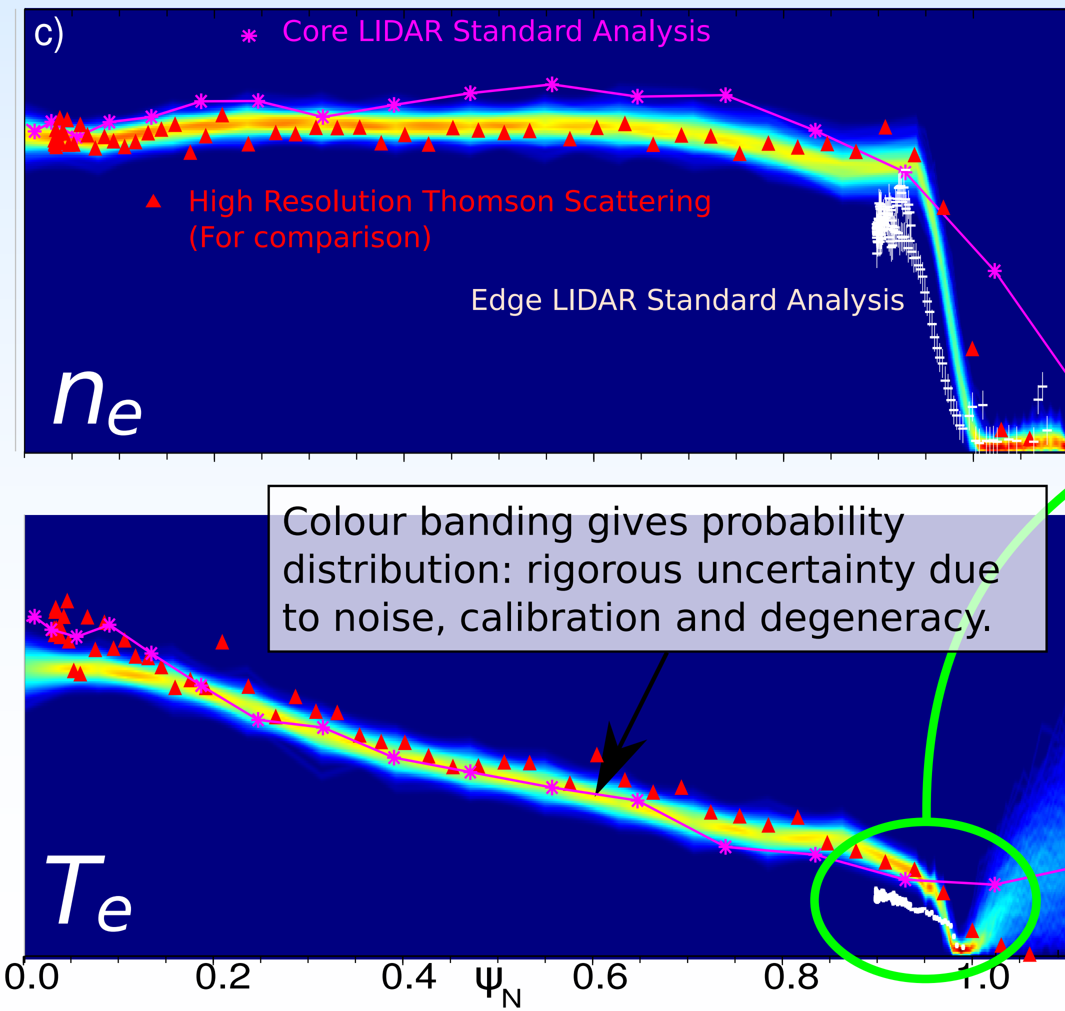

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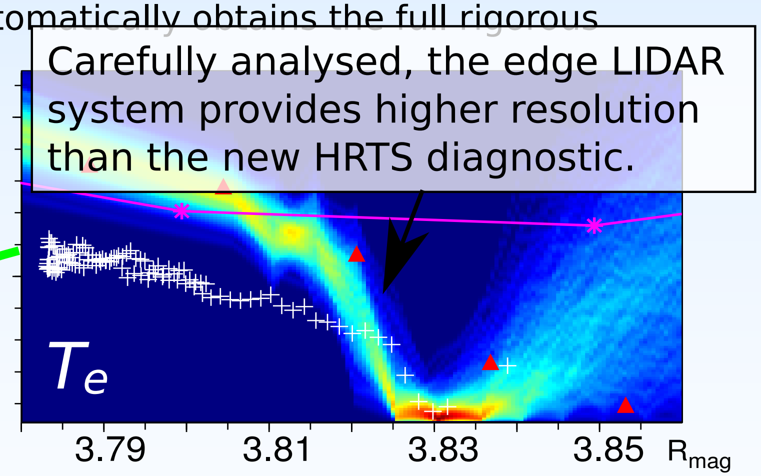

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The inferred plasma current and magnetic field topology effects also all Tokamak experimental physics, from mapping of other quantities (assumption of constancy on flux surfaces) through to ELM models and stability analysis.

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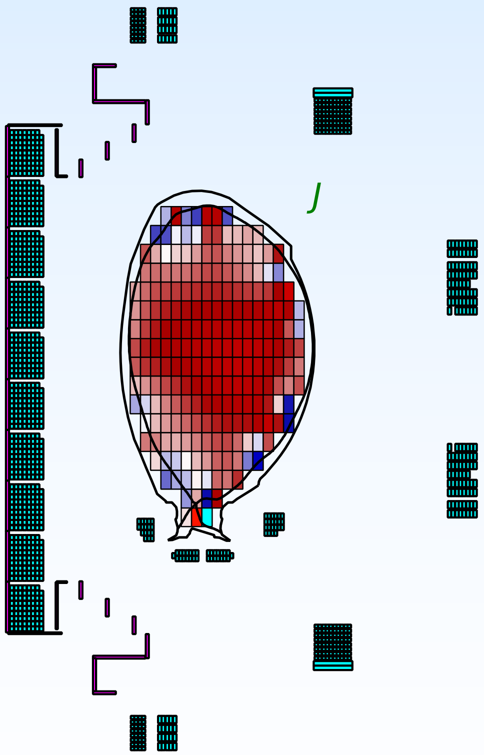

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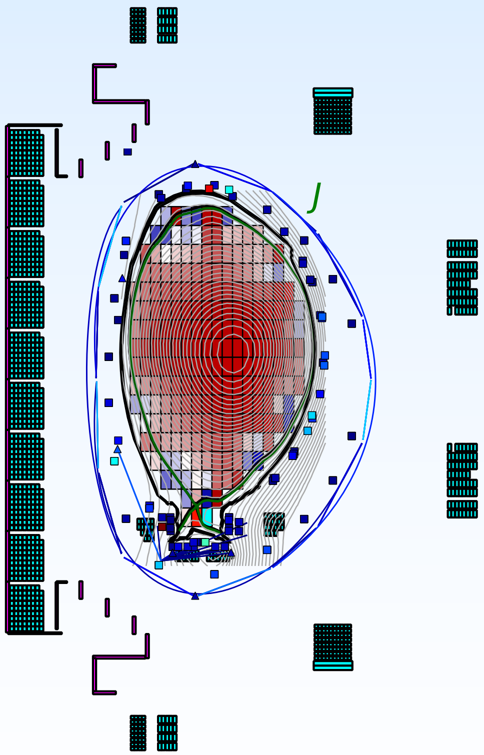

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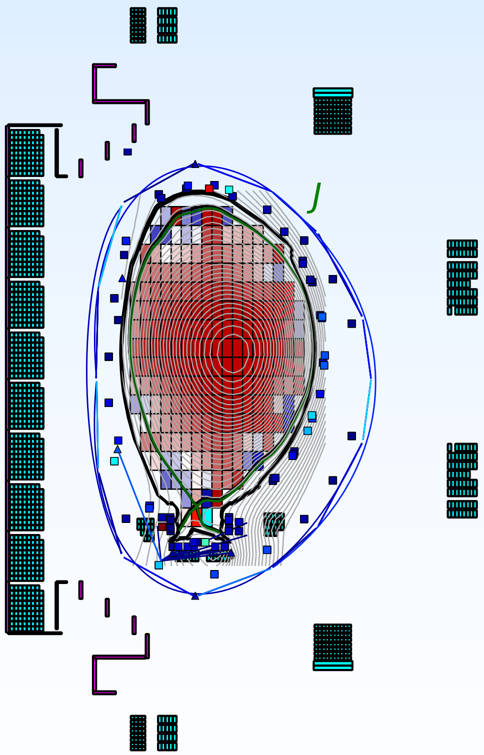

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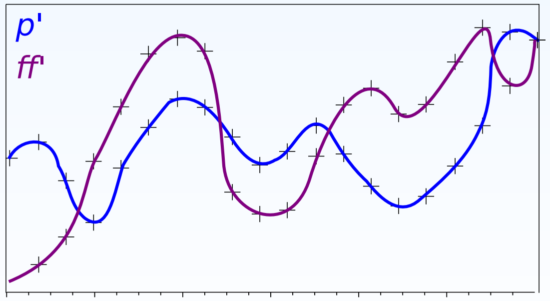

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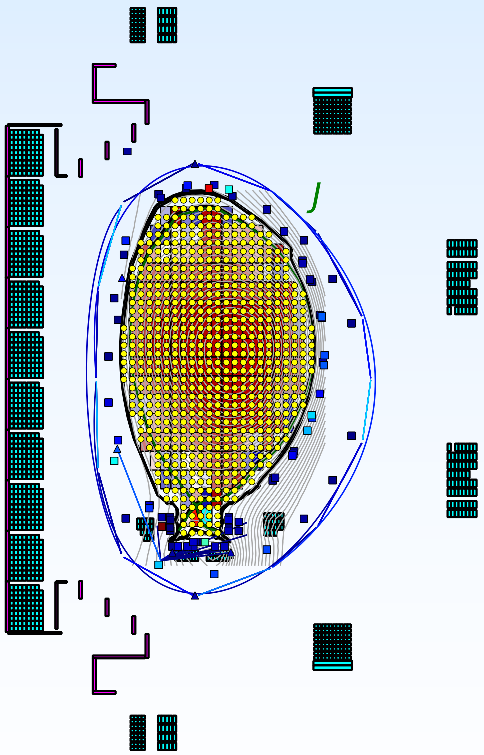

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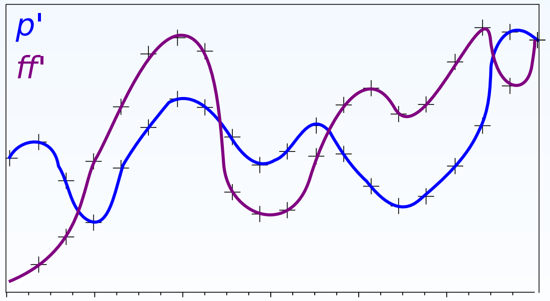
VERY PRELIMINARY RESULTS

$$J_\phi \approx Rp' + \frac{\mu_0}{R} f f'$$

(For now: Assume isotropic pressure and low flow)



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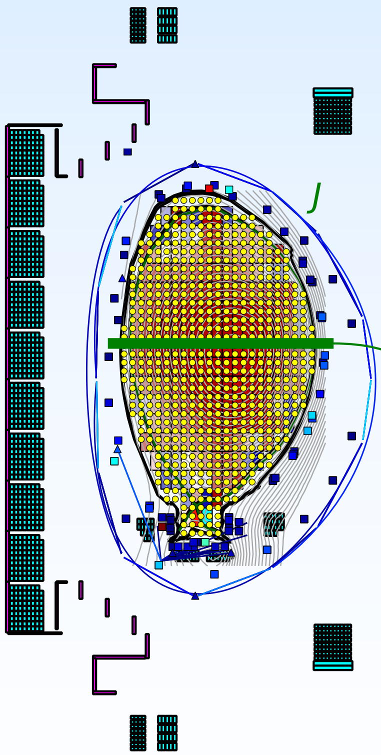

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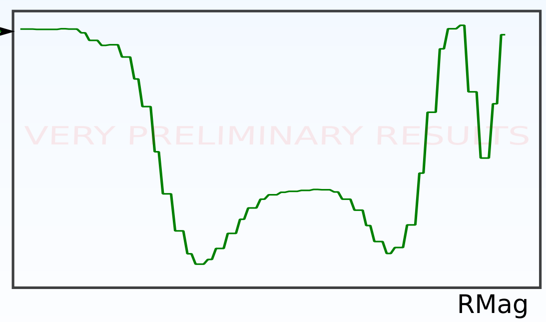

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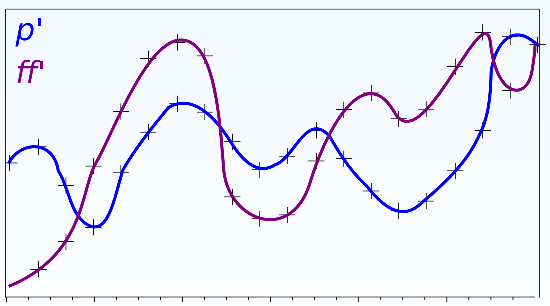

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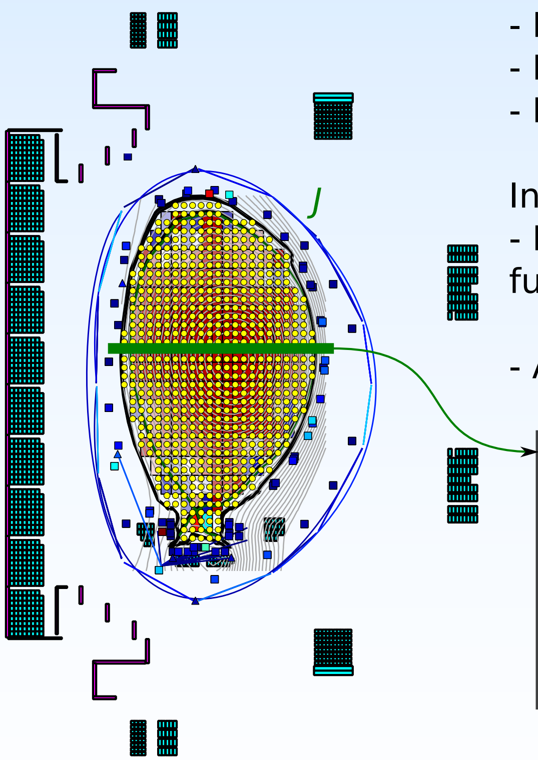

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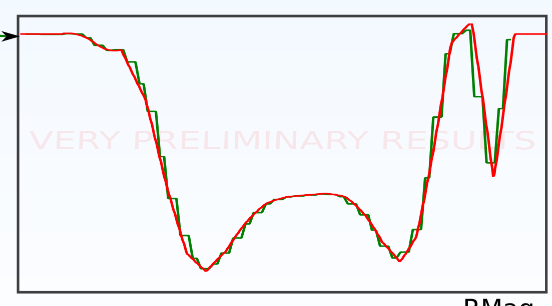

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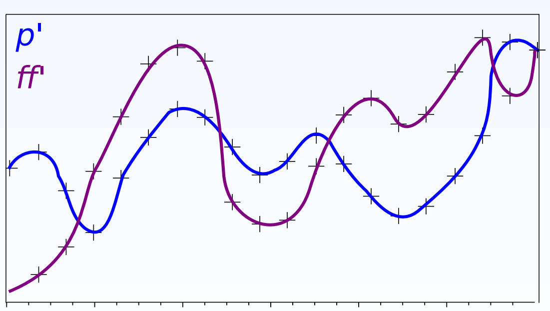

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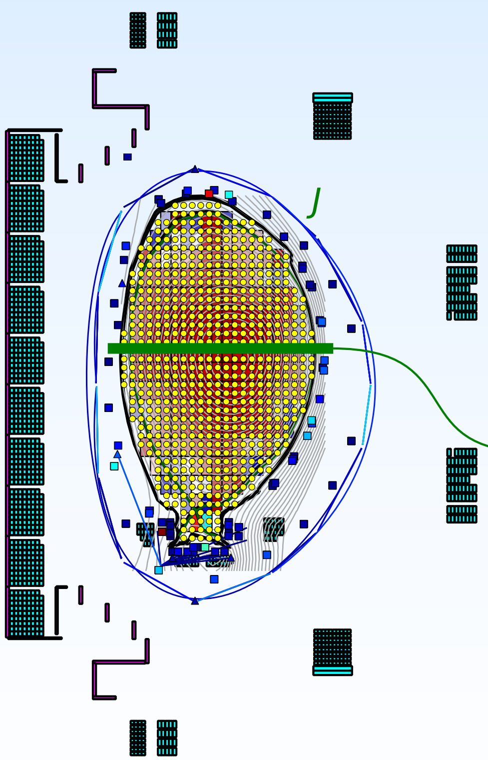

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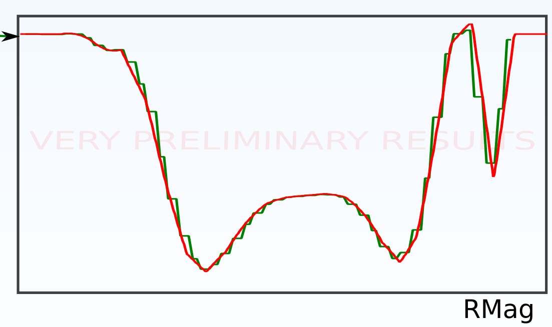

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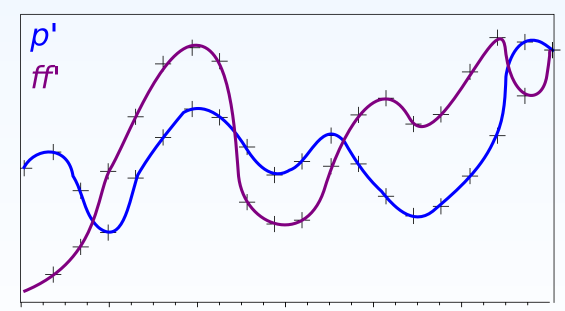

The problem (now a non-linear 1000D+ distribution) is difficult for the algorithms to handle.

- Parallelise the linear solver and iterate to find most probable answer.
- Parallelise MCMC algorithms and explore the posterior.

Magnetics and Equilibrium: Extraction of information.

78601 High ne
H-Mode (pellets)

Because of modularity, we can switch parametrisation and priors of *J*, *p*' and *ff*' at will and on-the-fly.
For H-Mode, fast changes at edge so:

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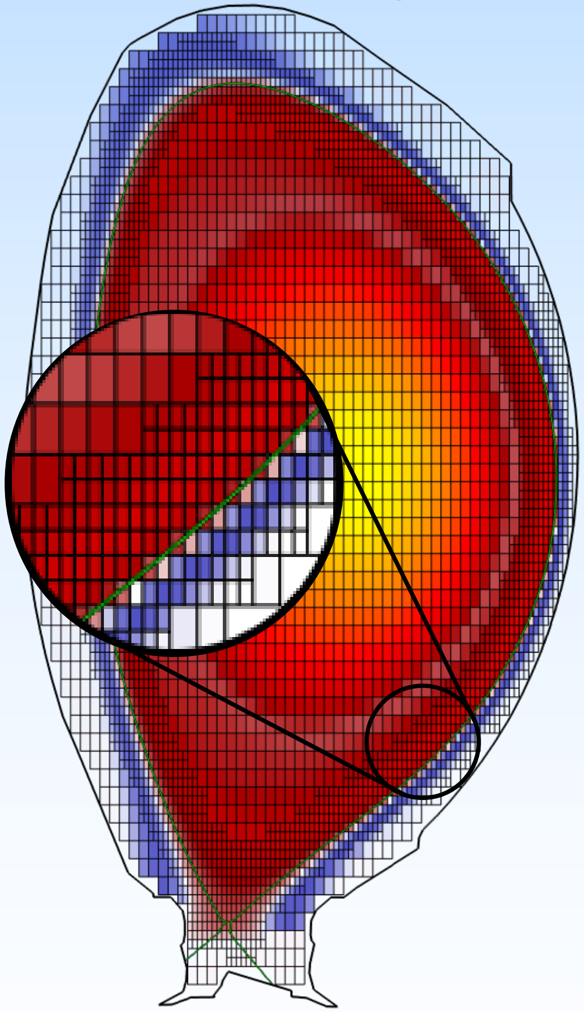
$p'(\psi_N)$, $ff'(\psi_N)$: 20 knots, weak smoothing priors.
Assume small in SOL (but not fixed to 0)



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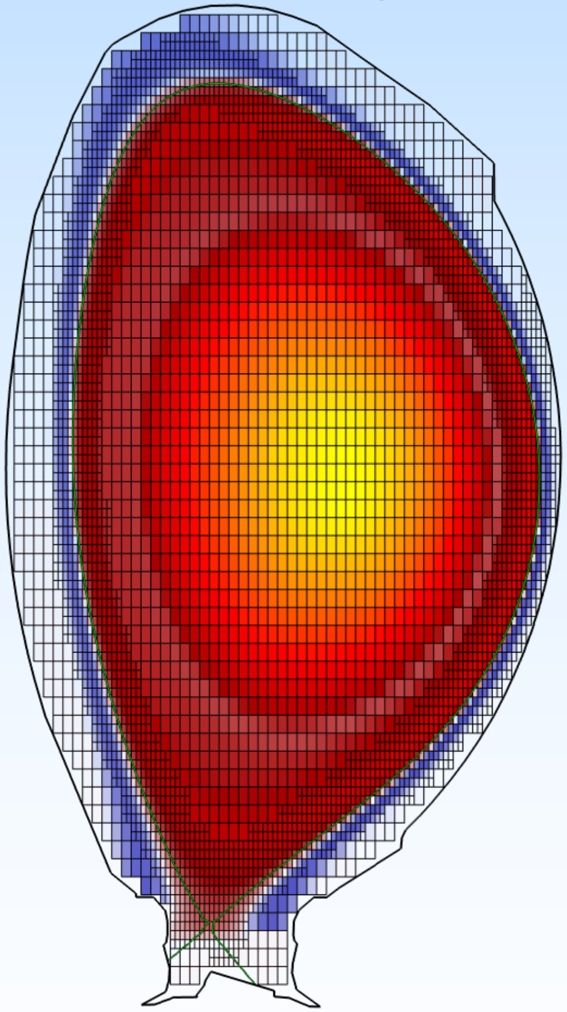

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Adjust p' and ff' priors to get something sensible **for 1 time slice**:

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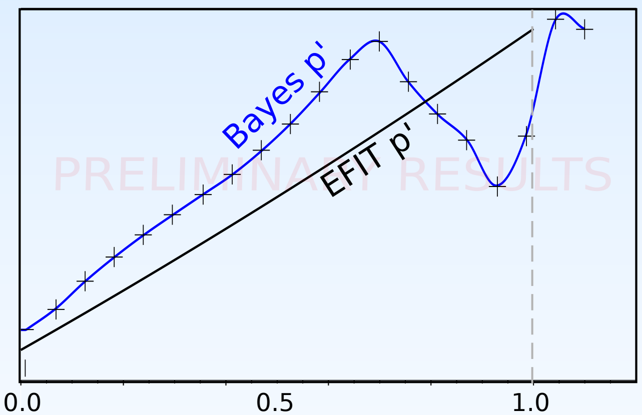

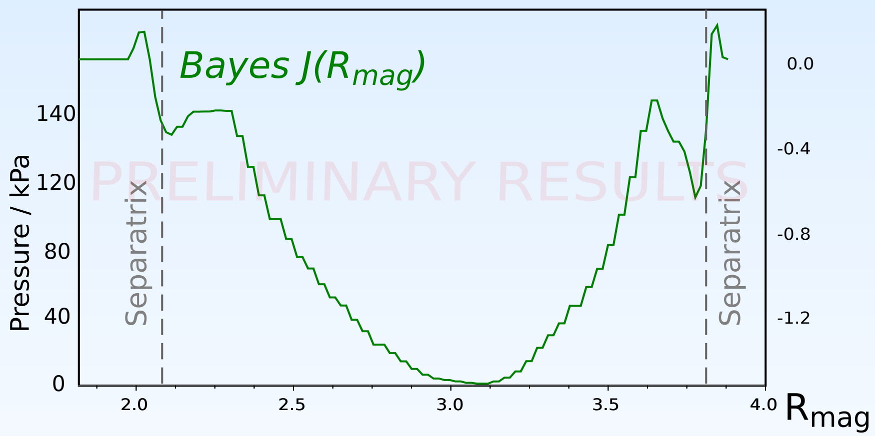

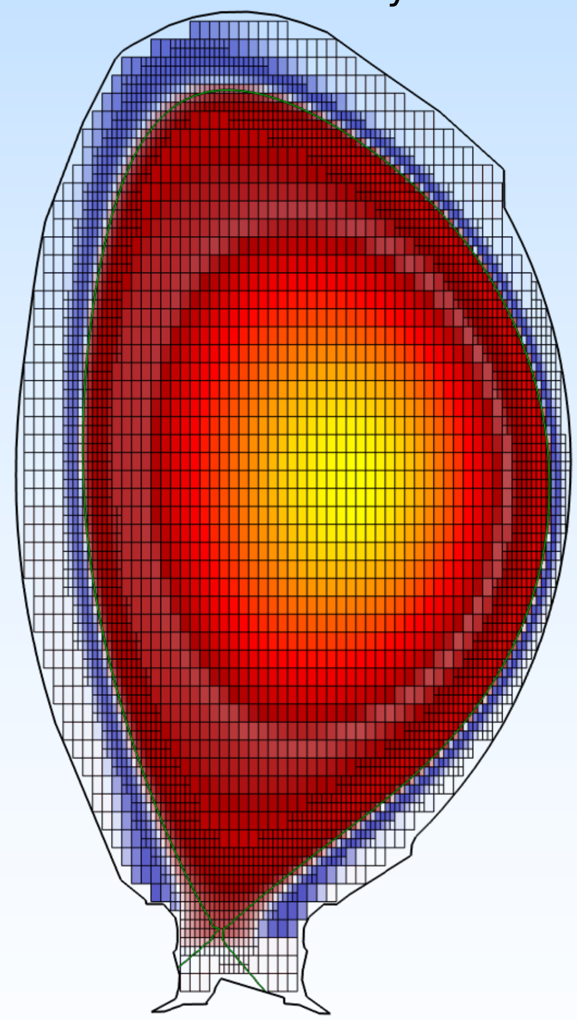

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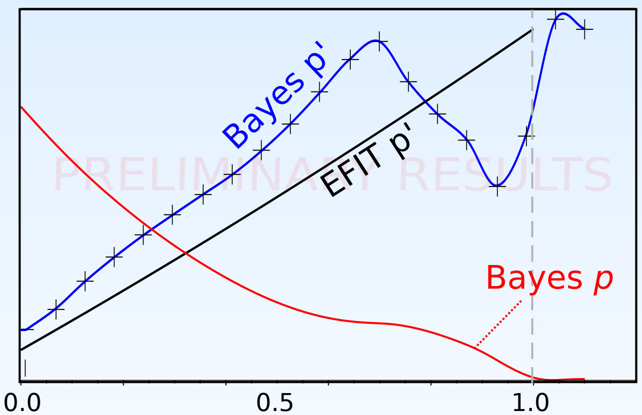

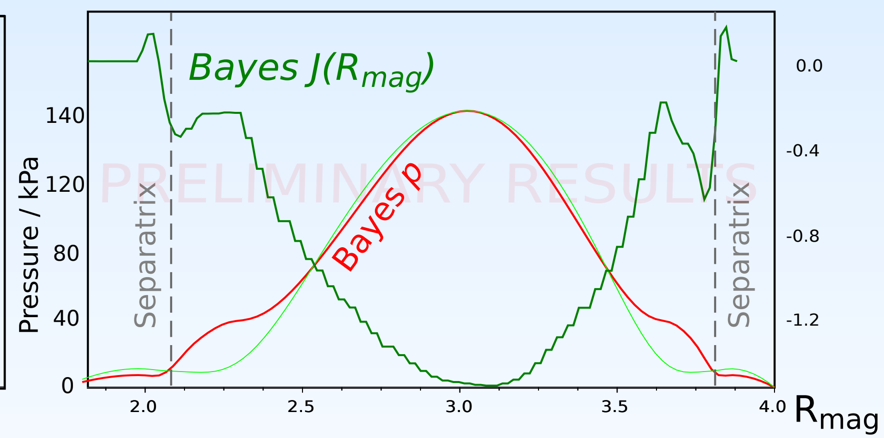

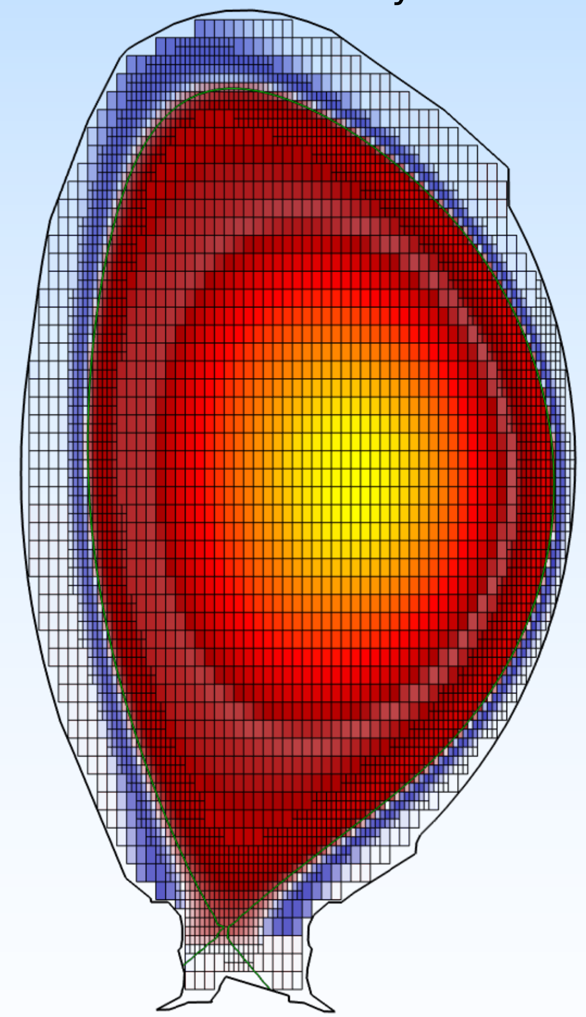

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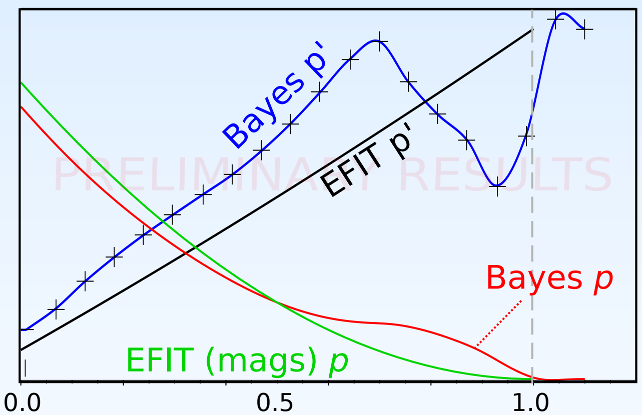

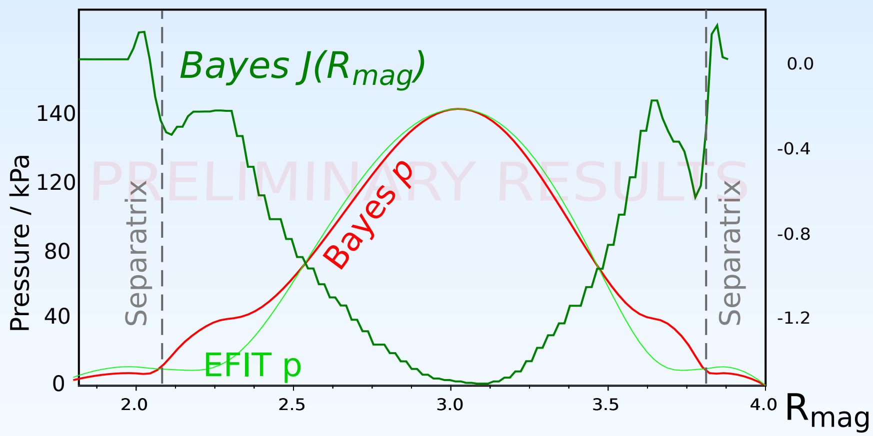

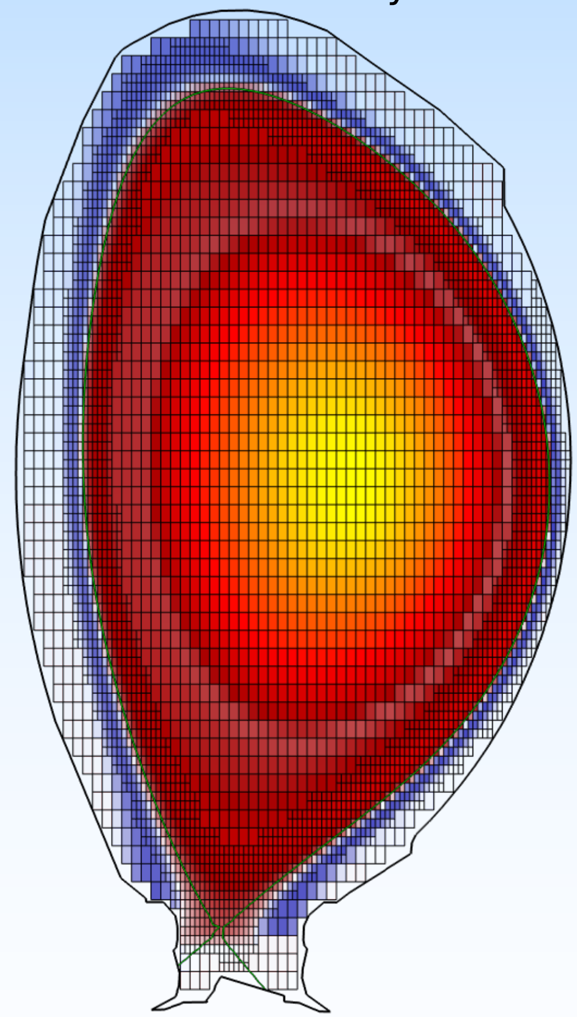

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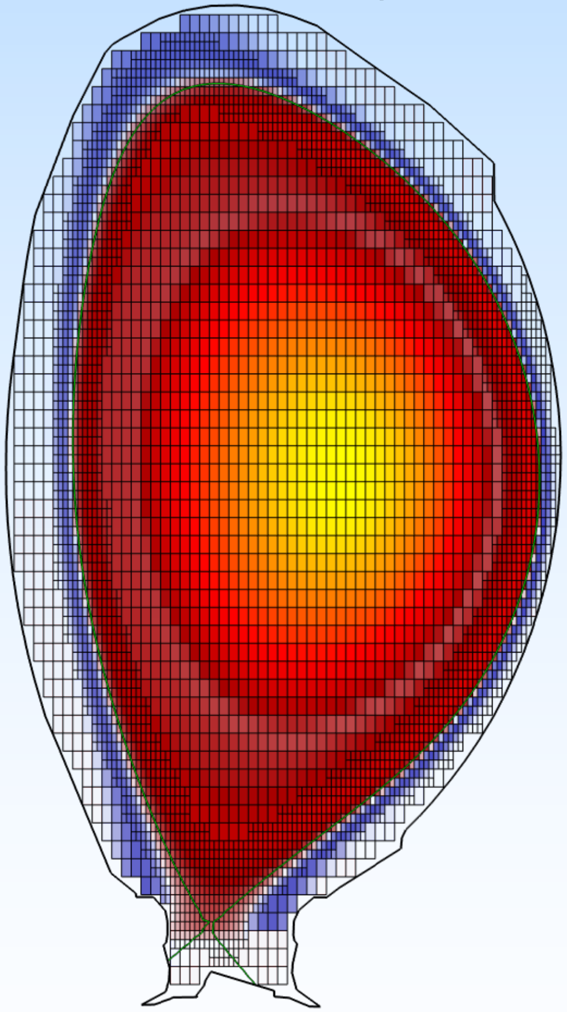

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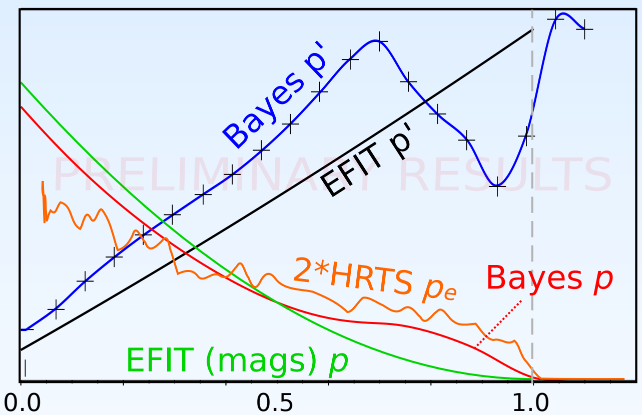

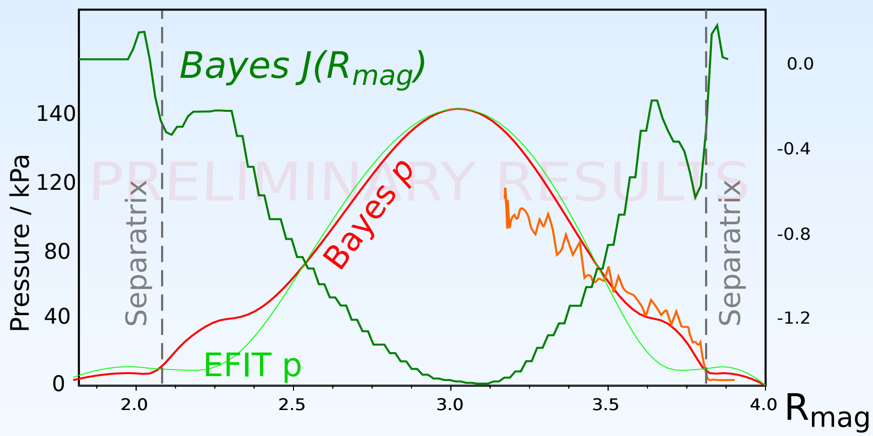

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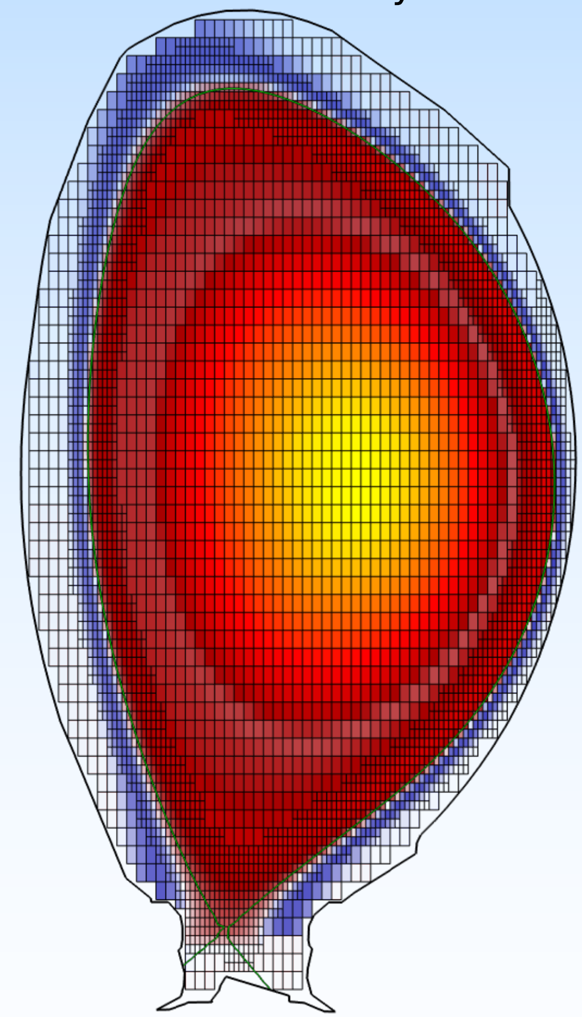

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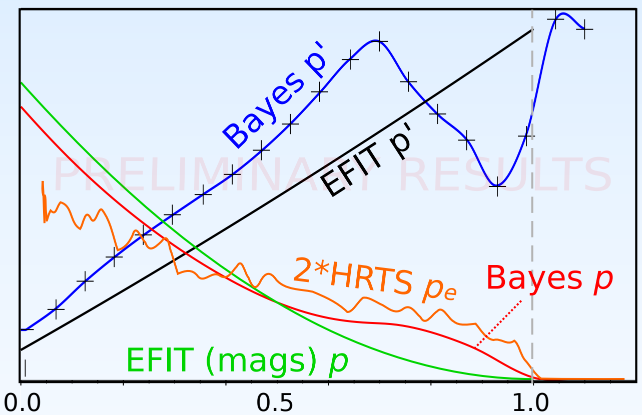

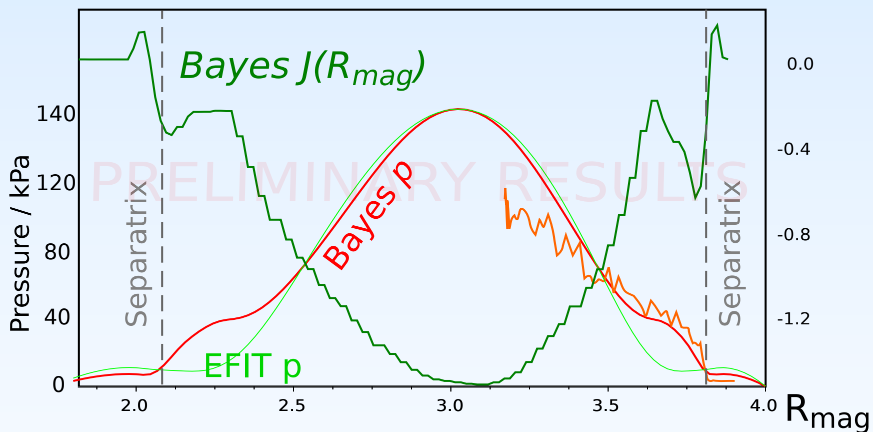

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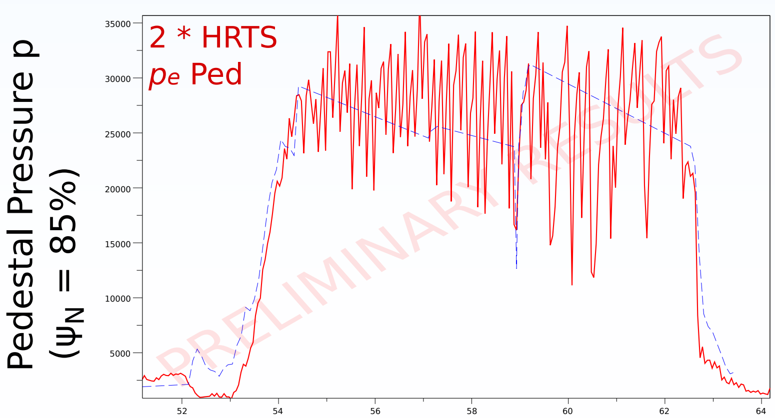

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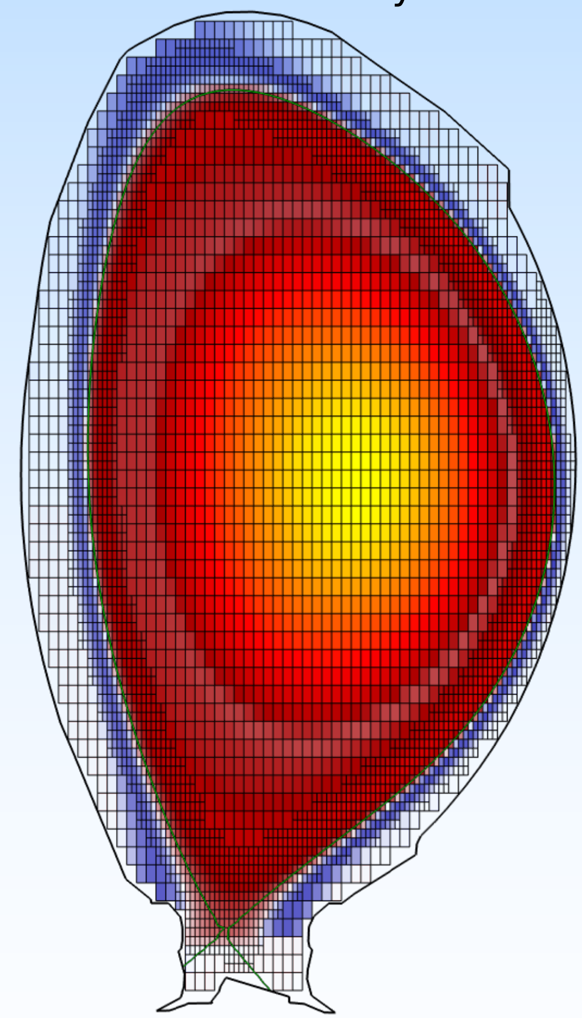

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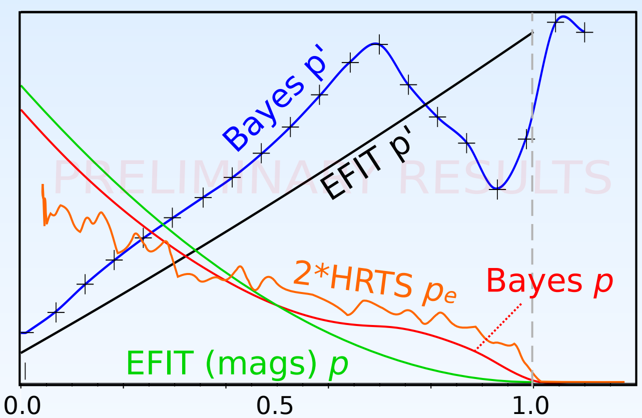

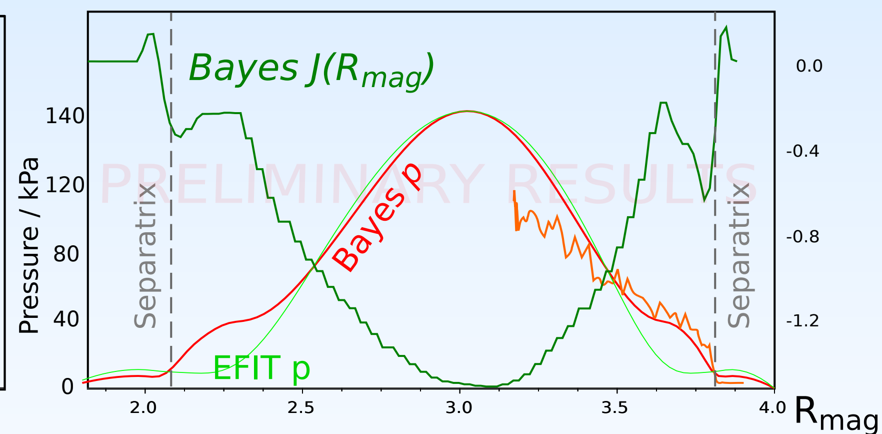

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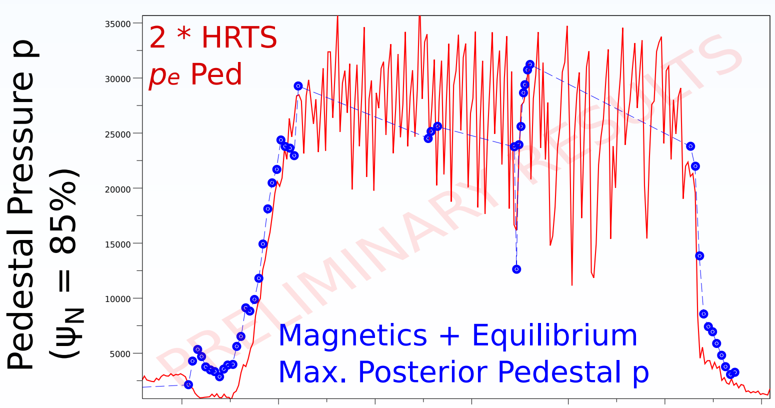

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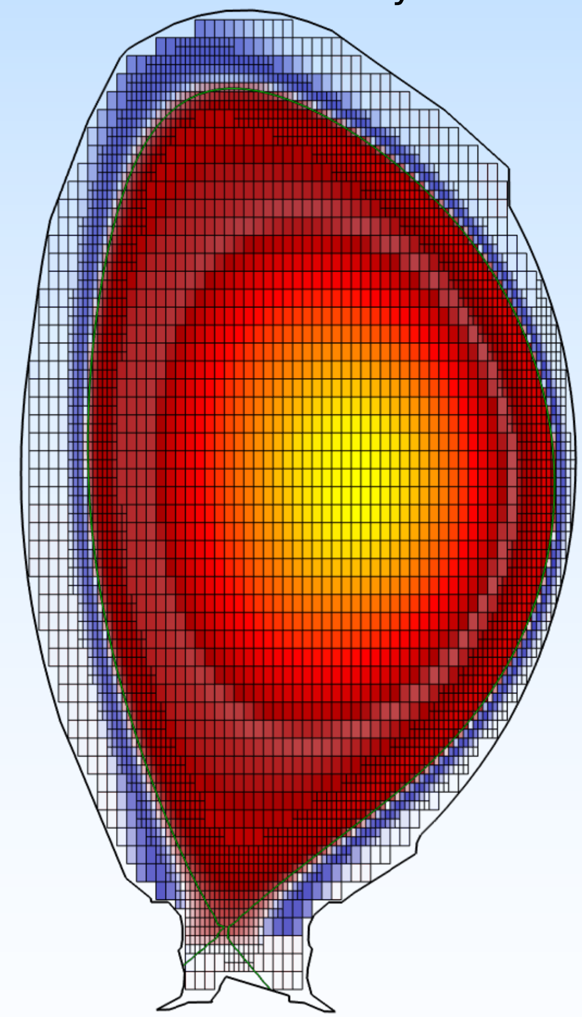

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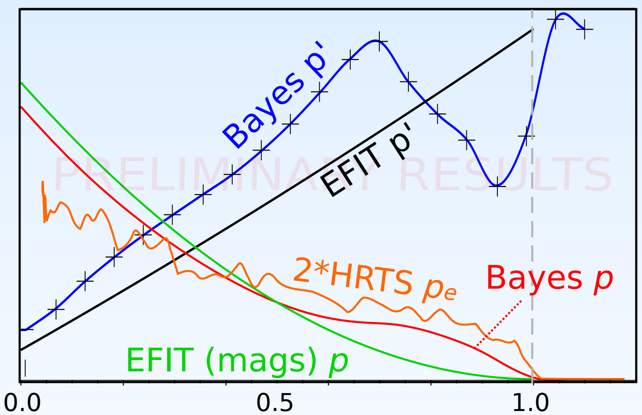

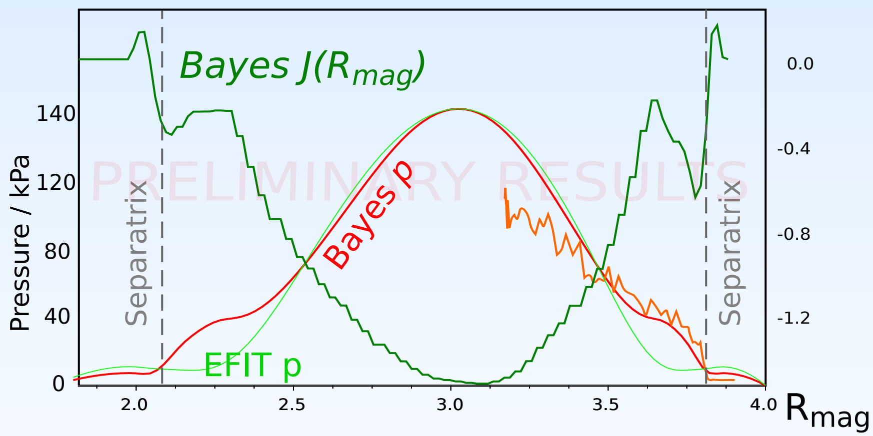

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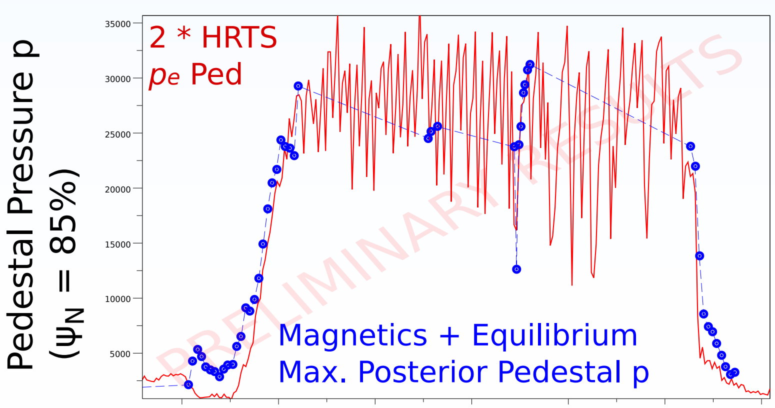

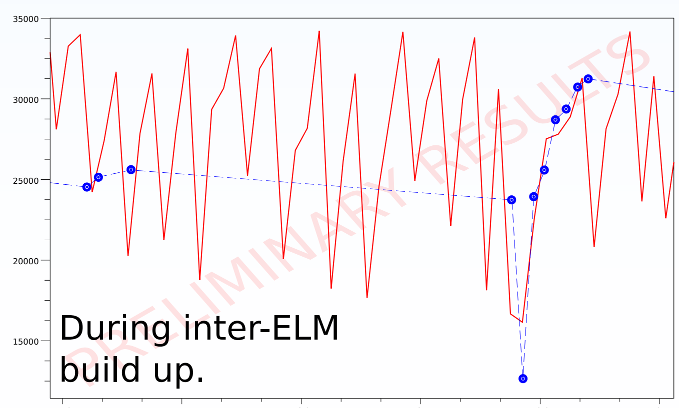

Imperial College London

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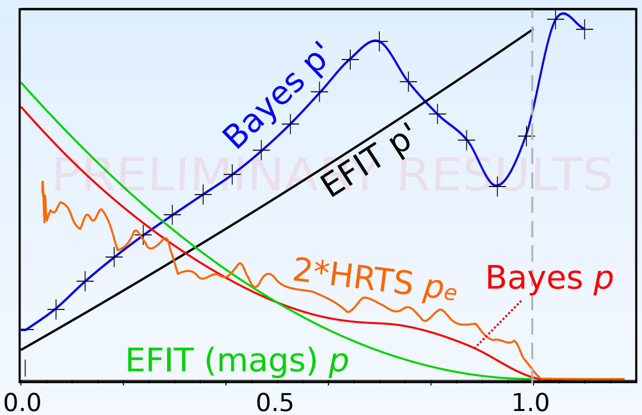

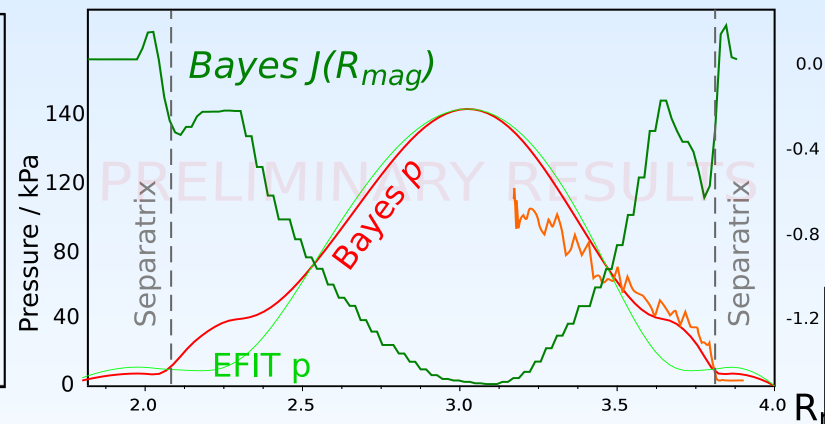

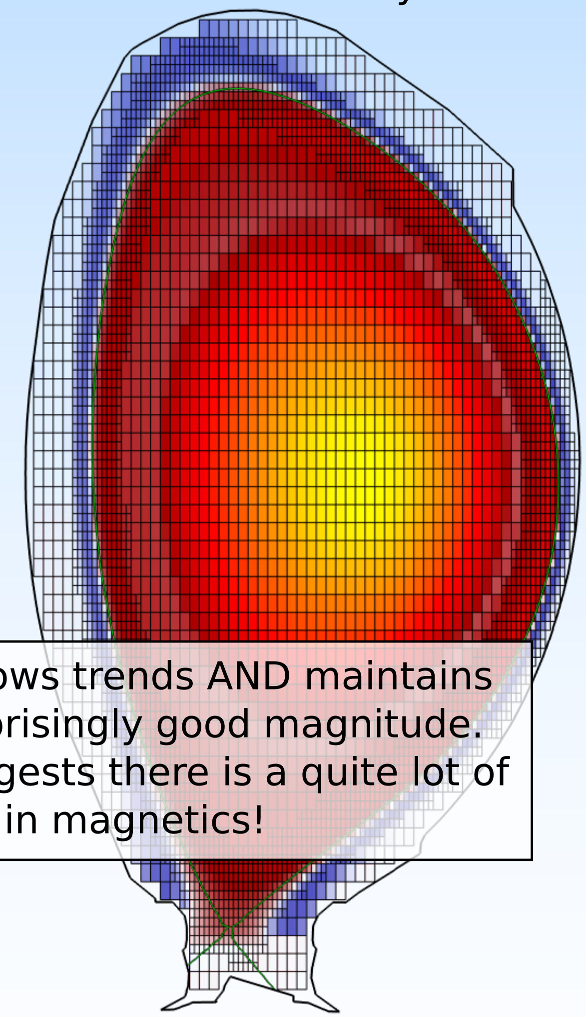

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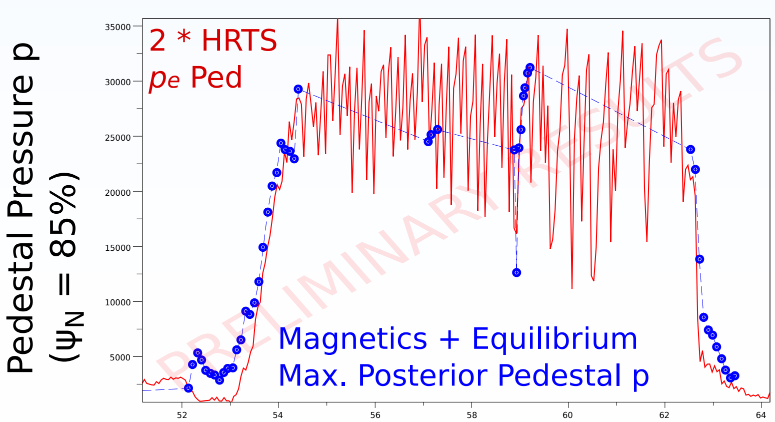

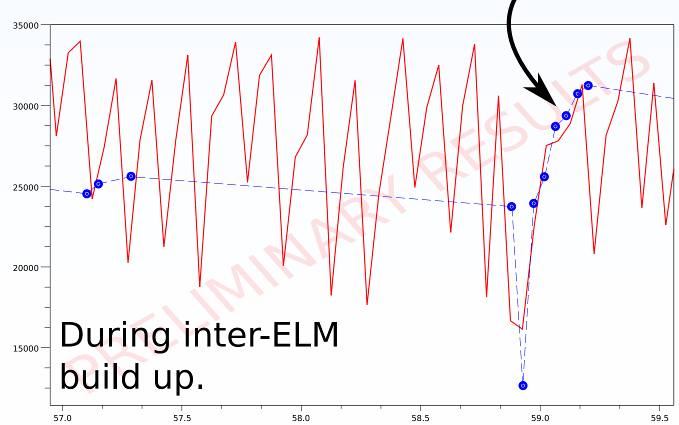

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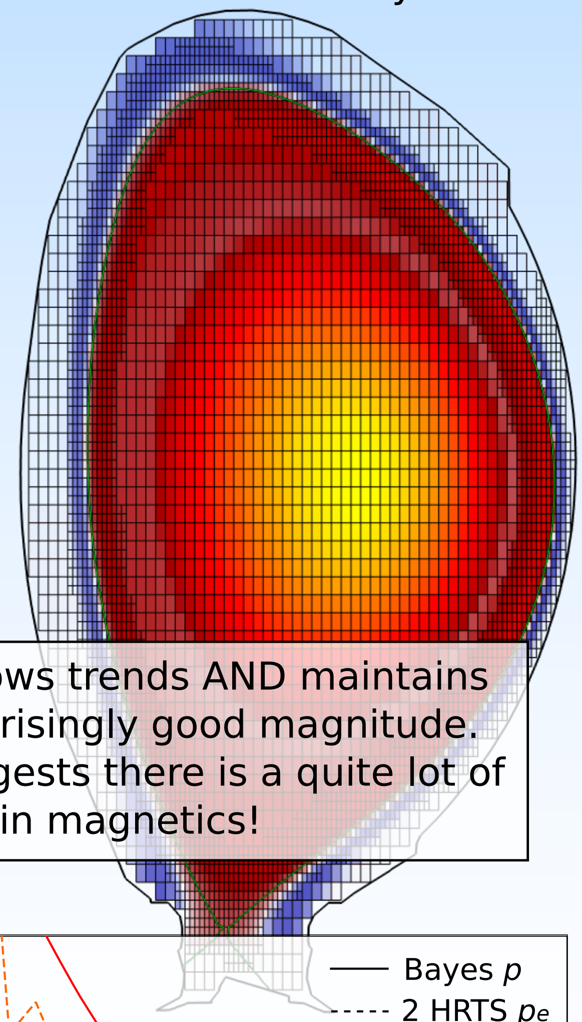

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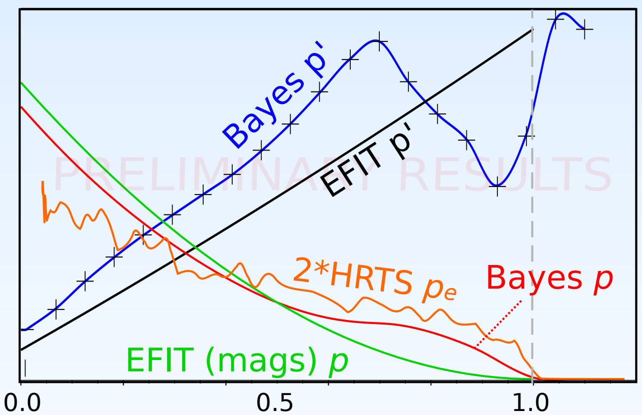

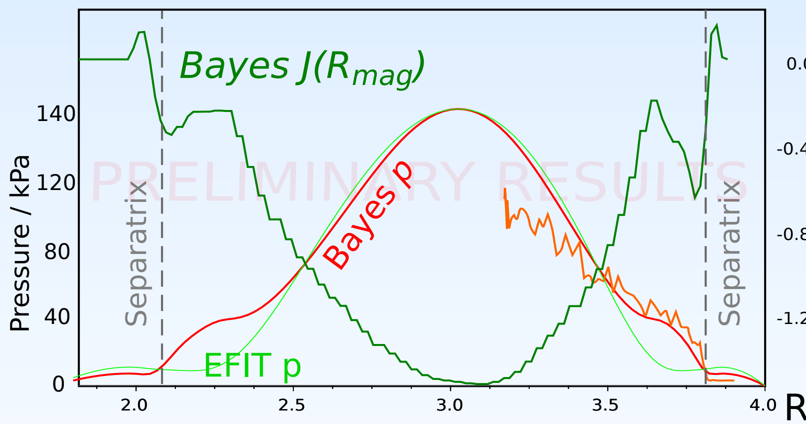

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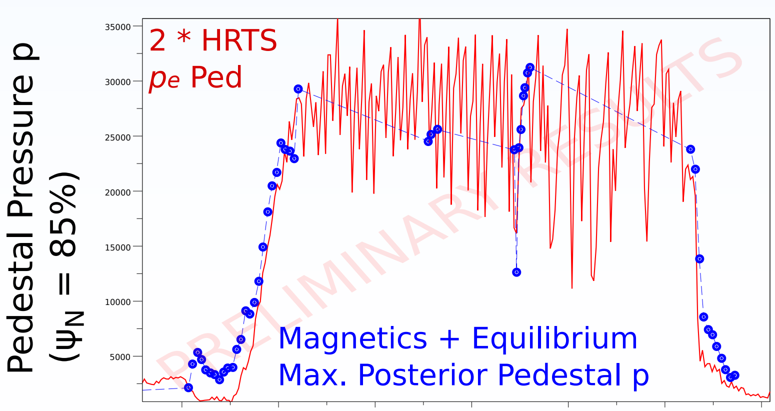

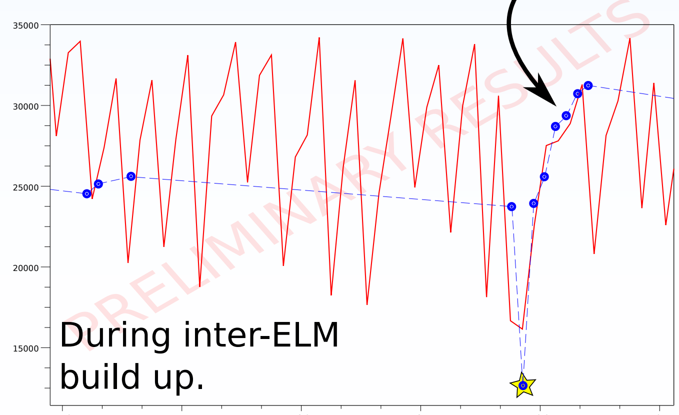

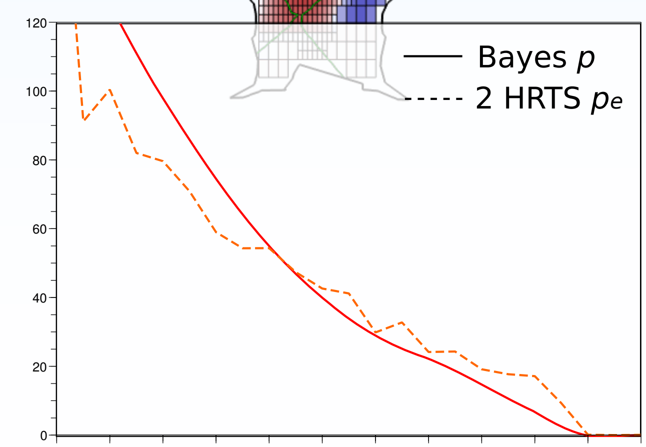

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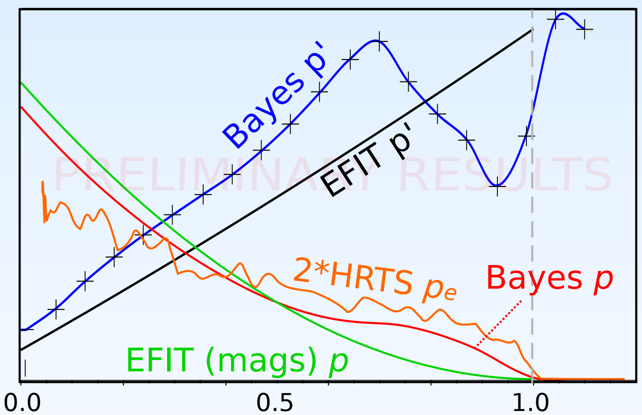

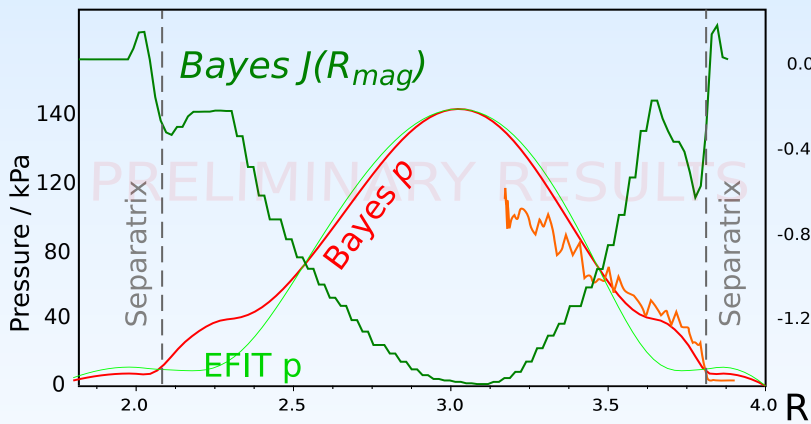

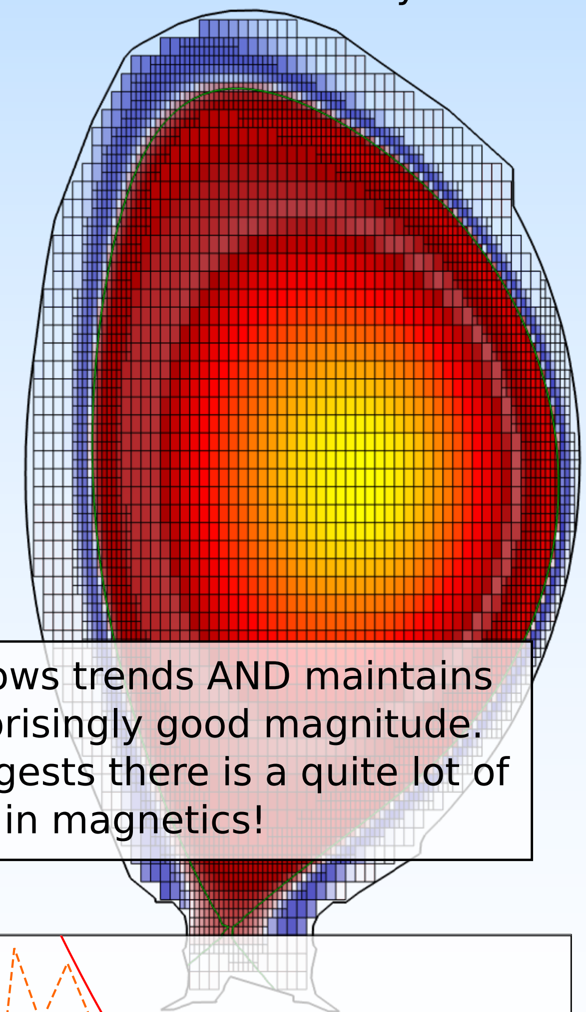

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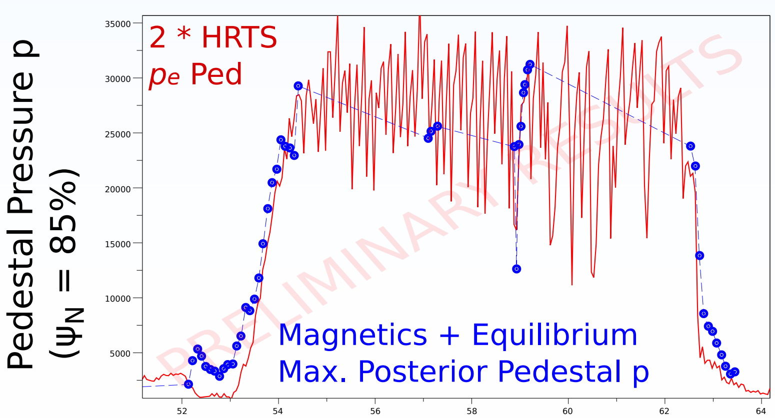

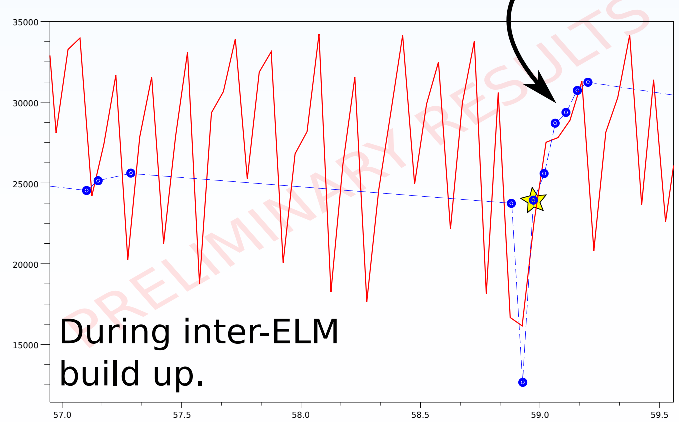

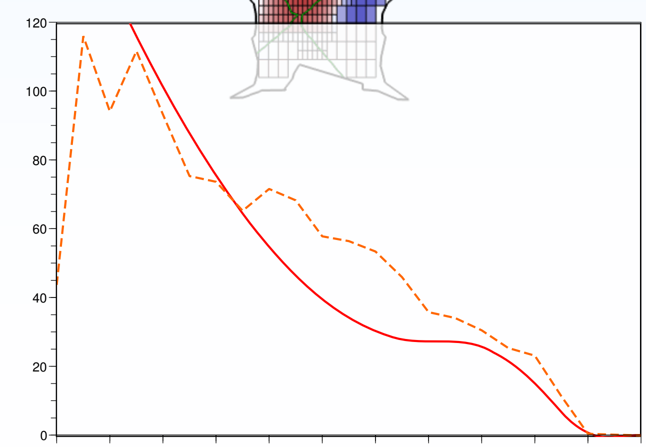

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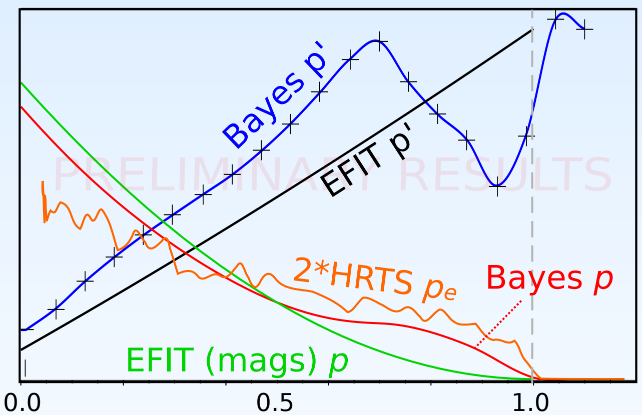

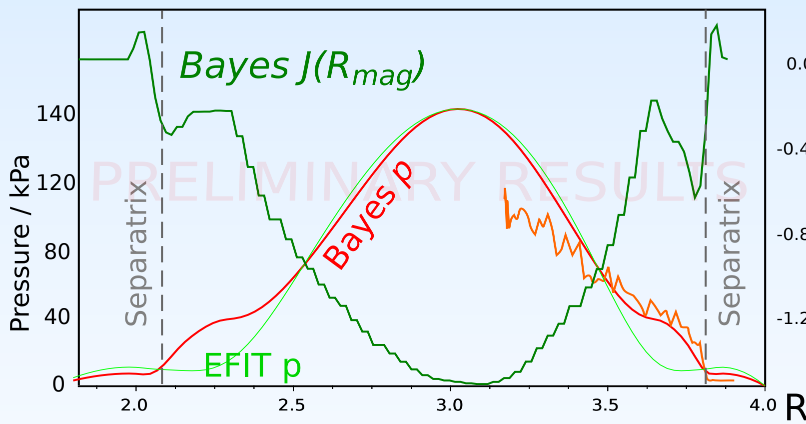

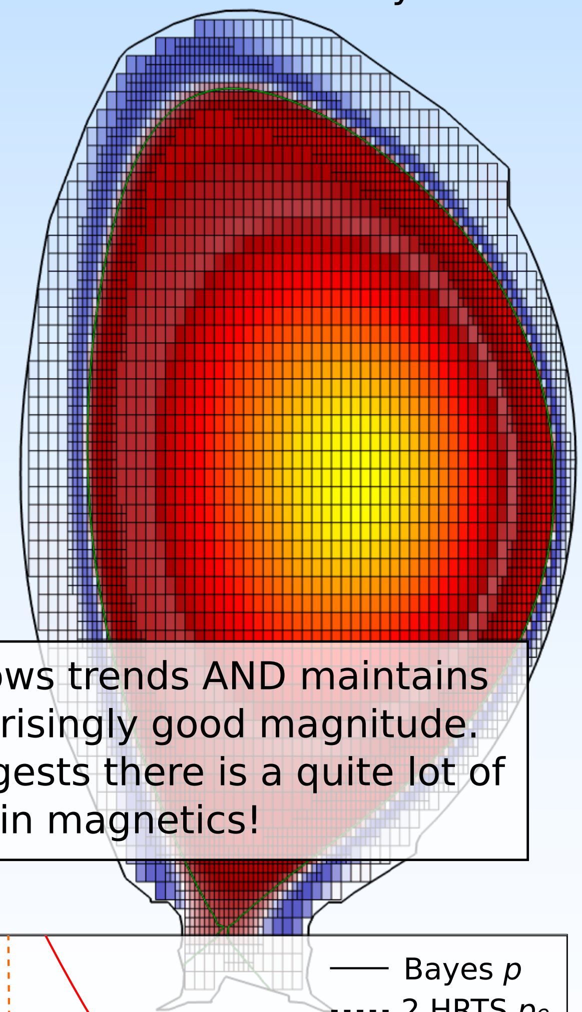

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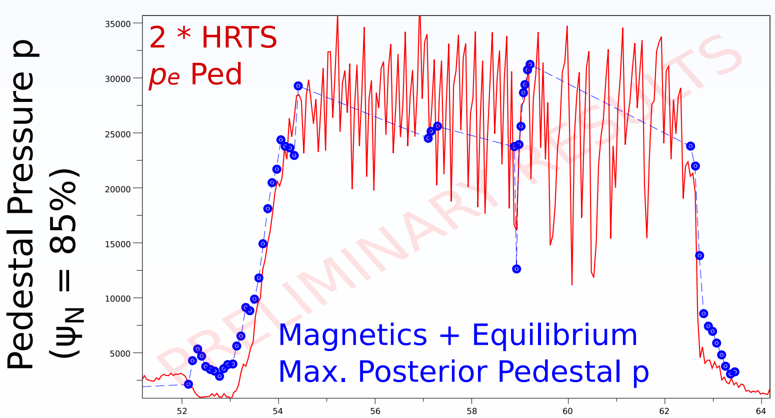

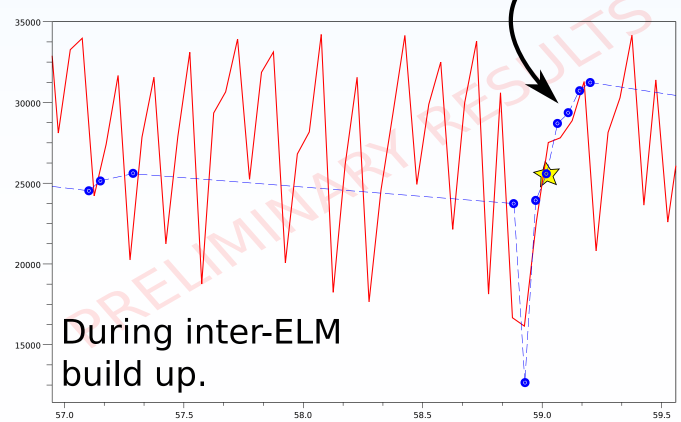

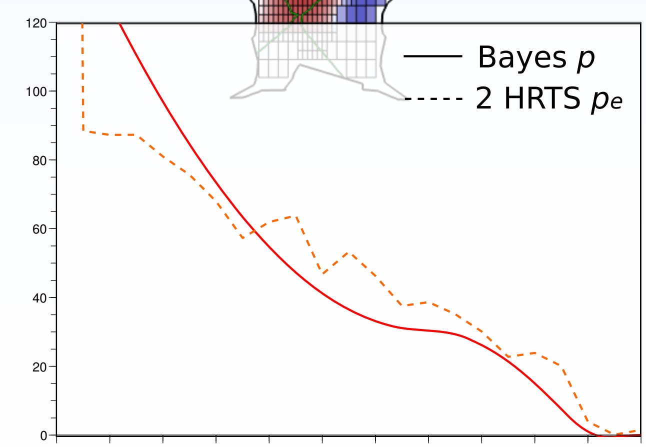

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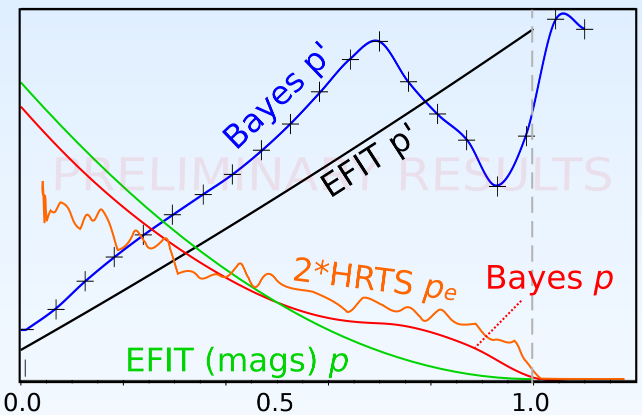

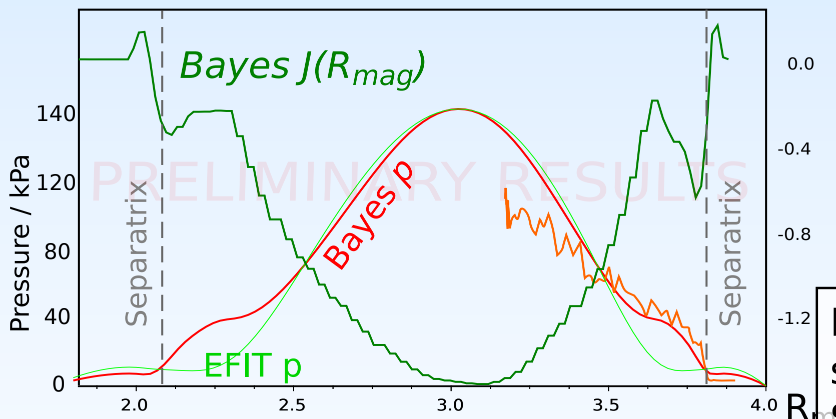

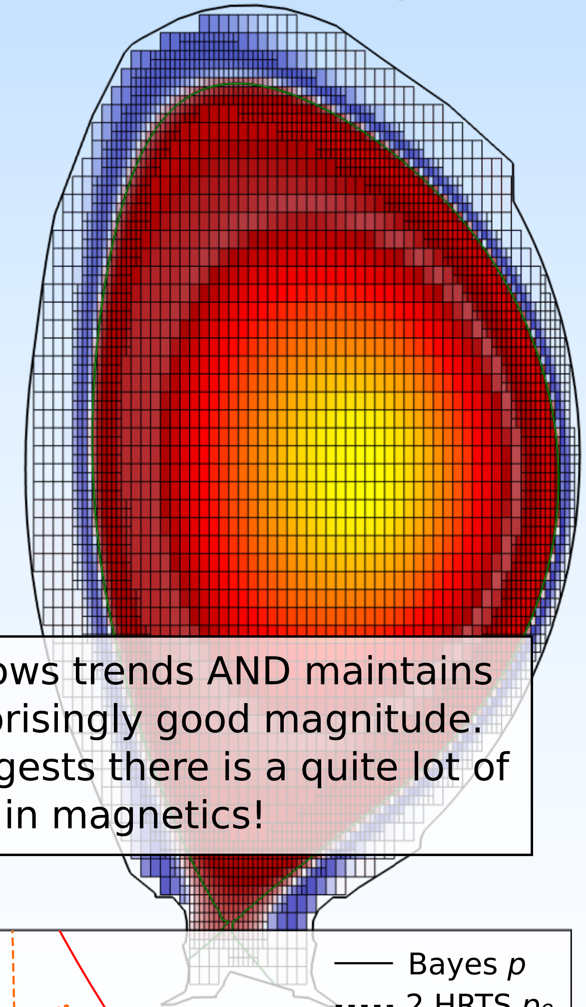

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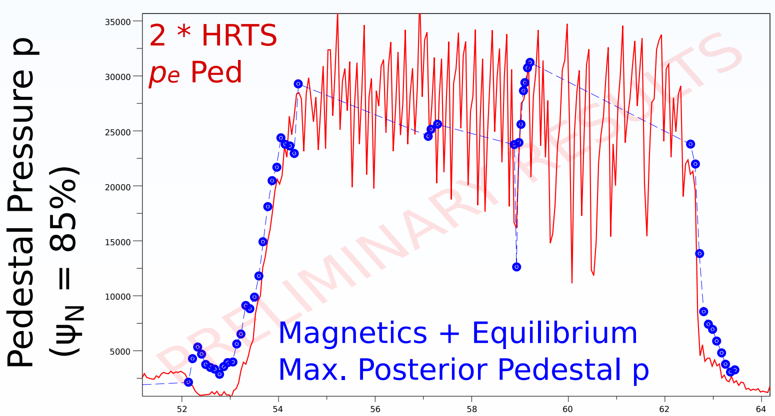

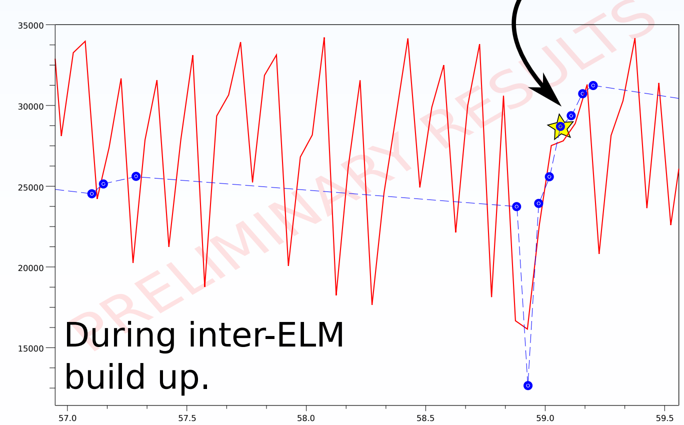

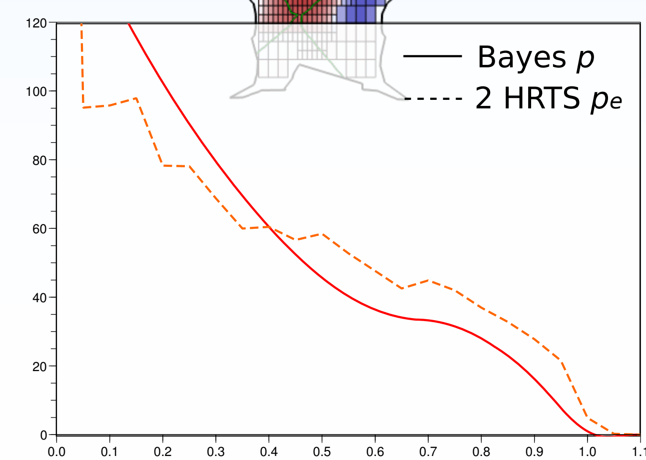

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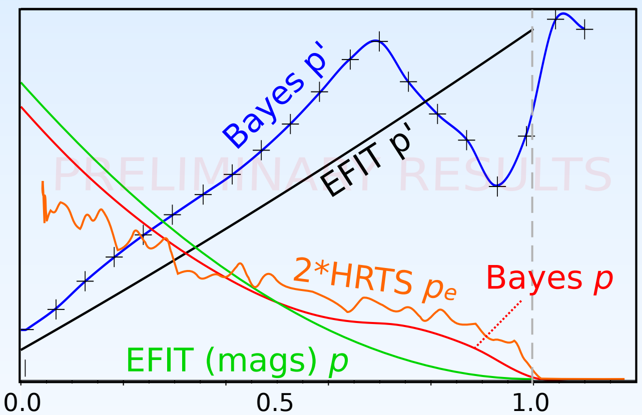

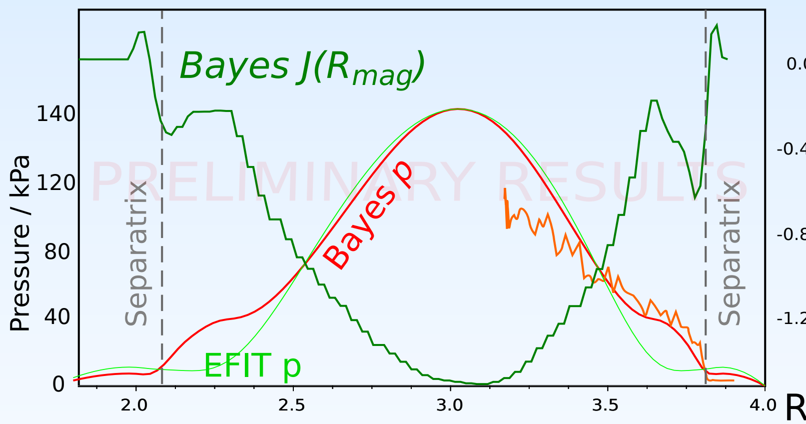

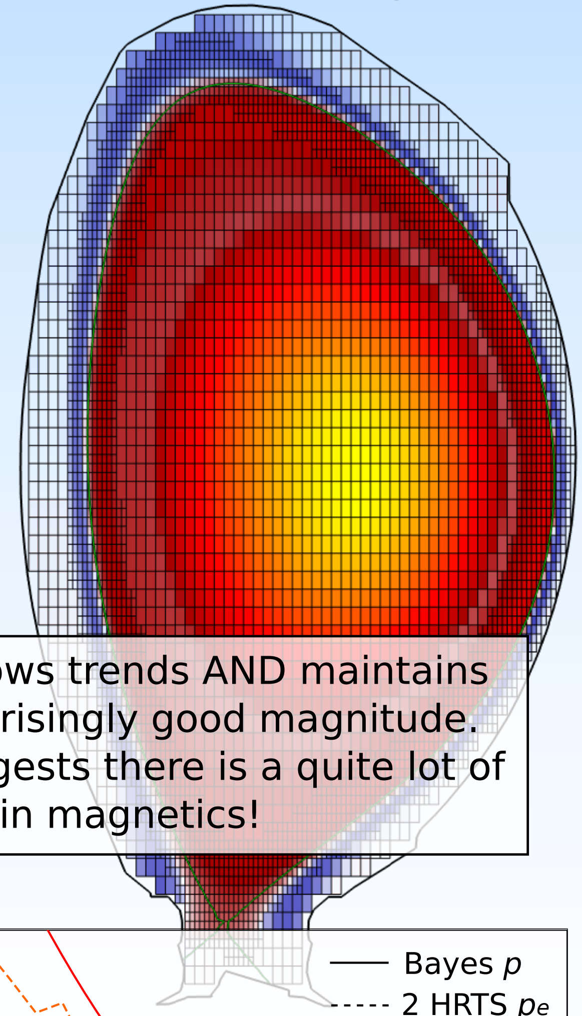

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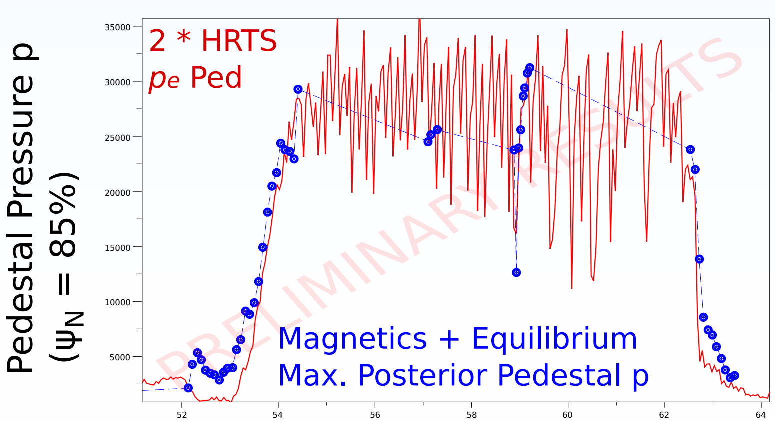

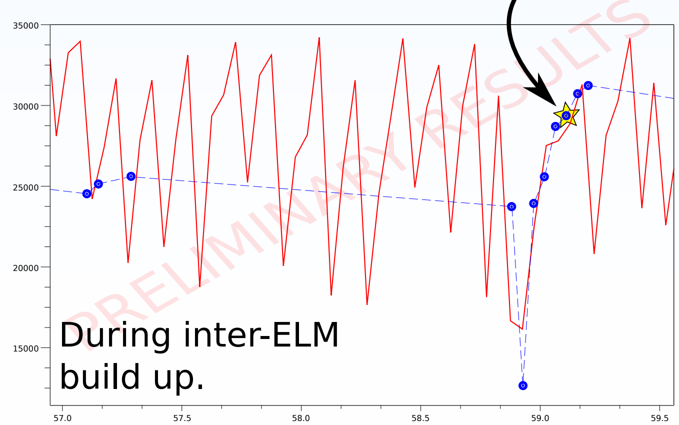

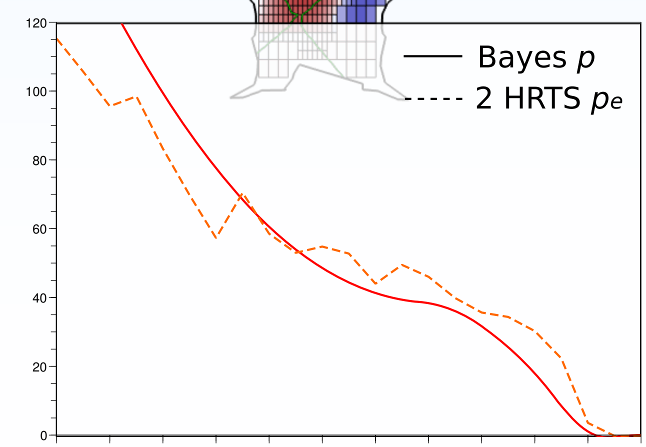

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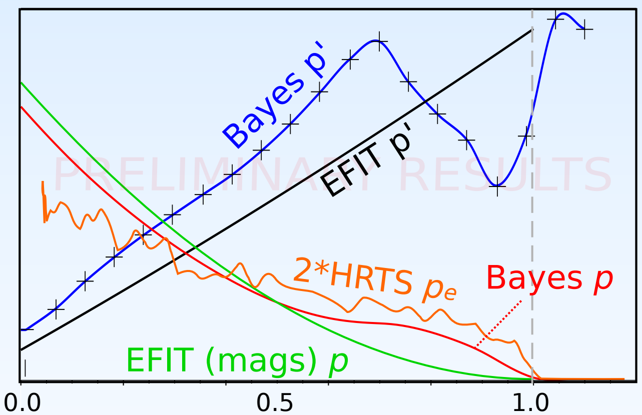

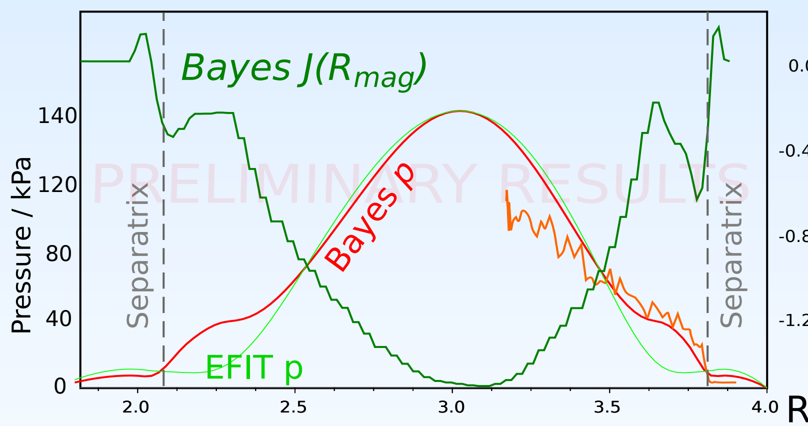

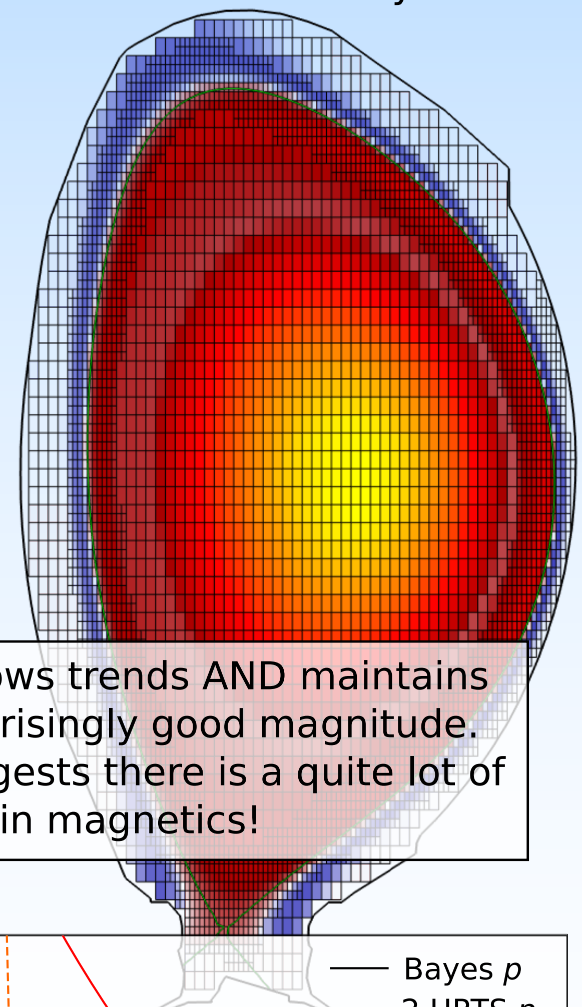

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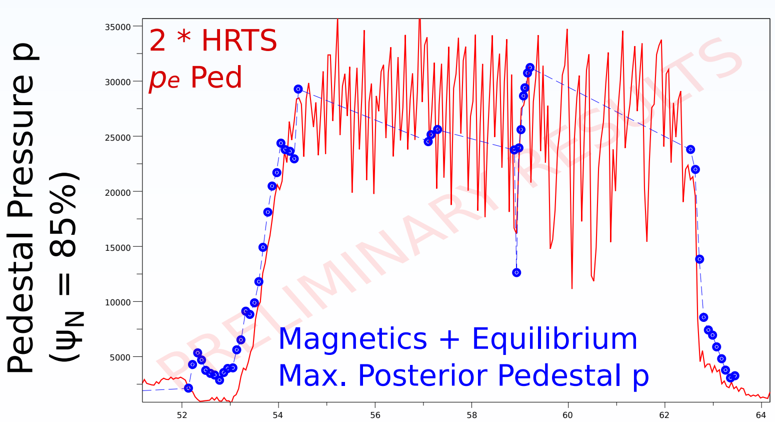

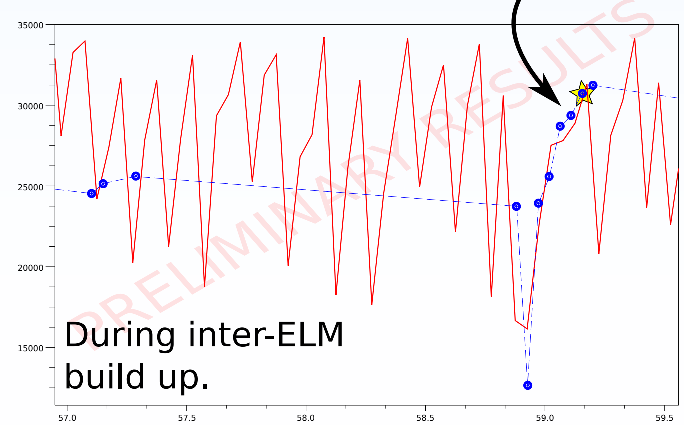

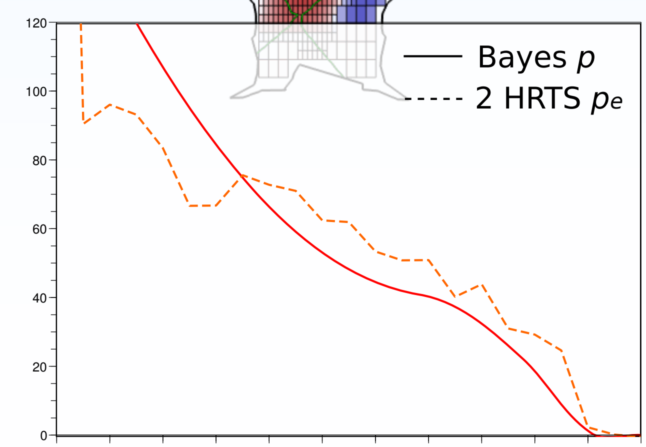

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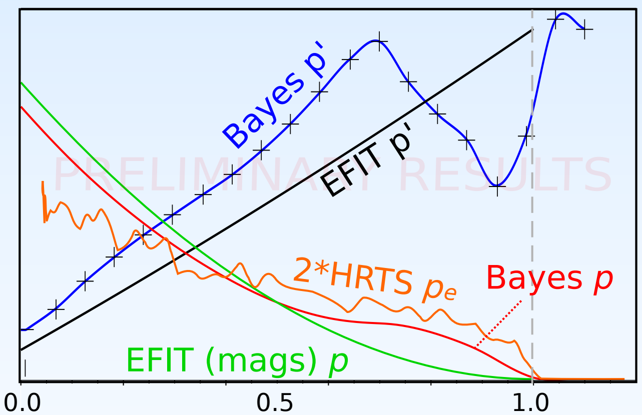

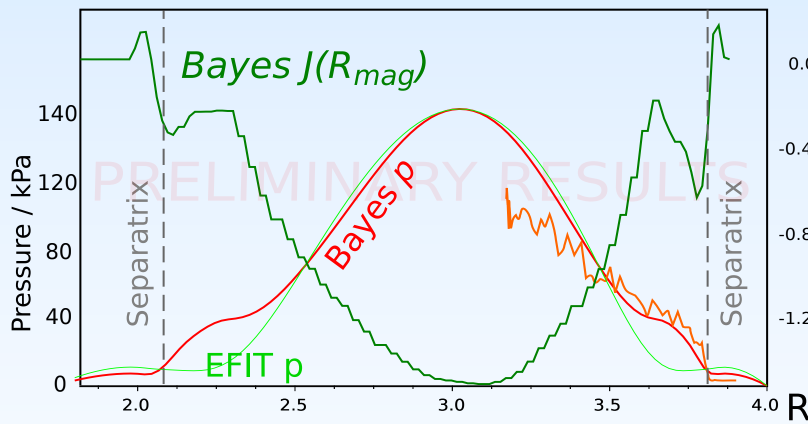

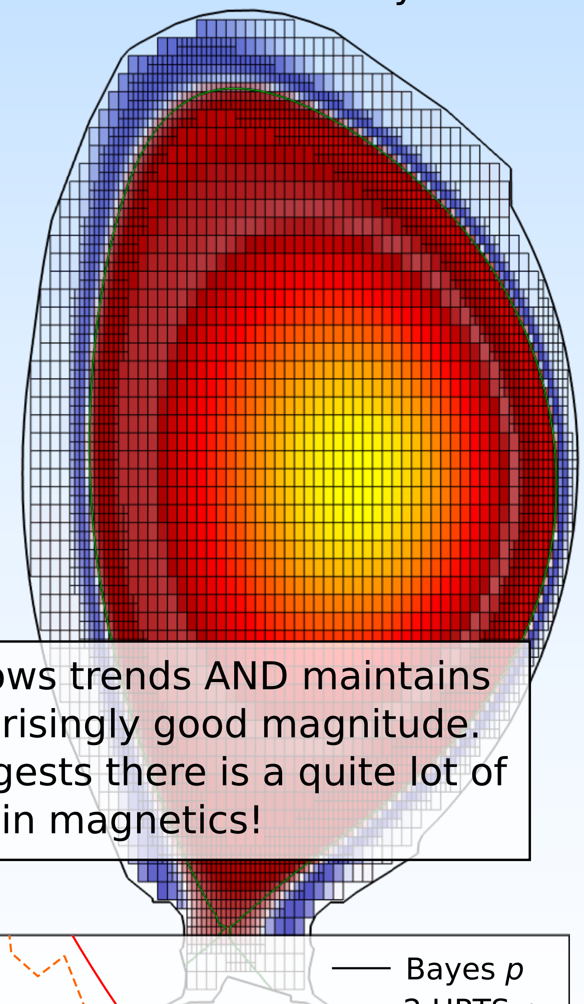

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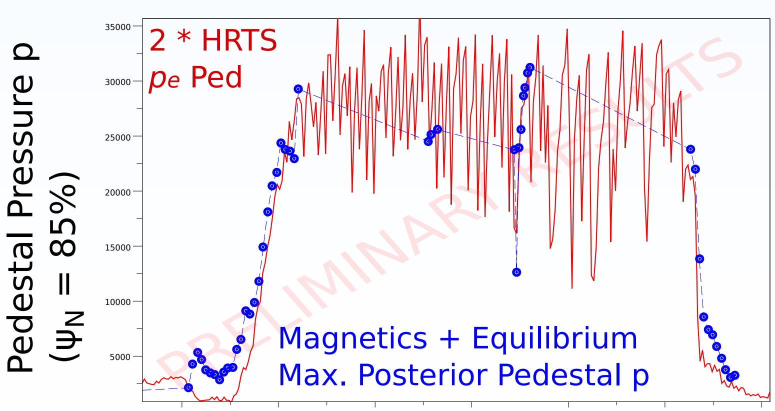

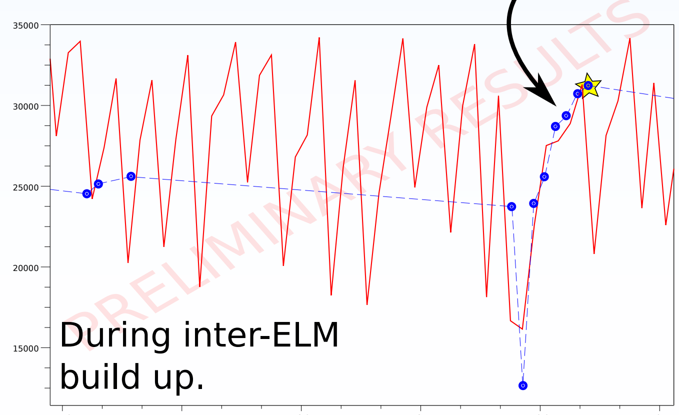

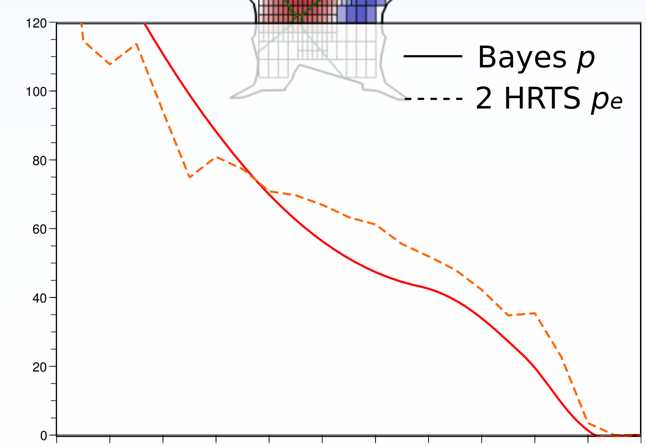

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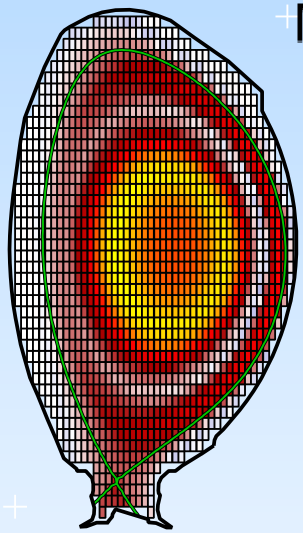

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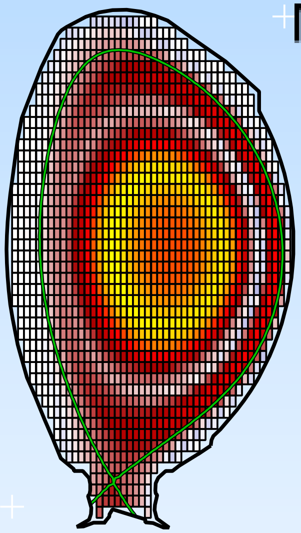

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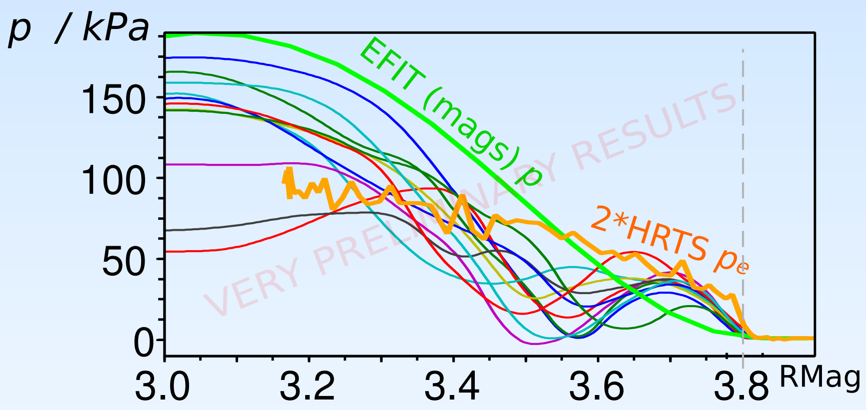

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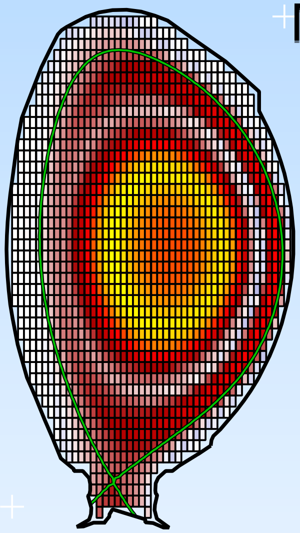

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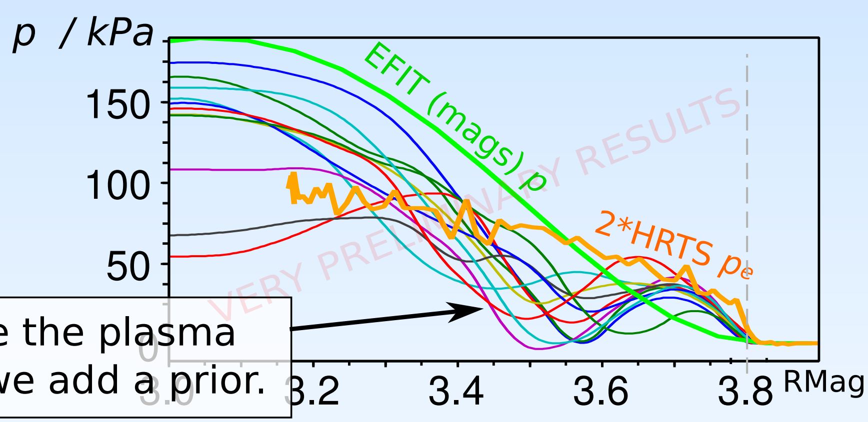

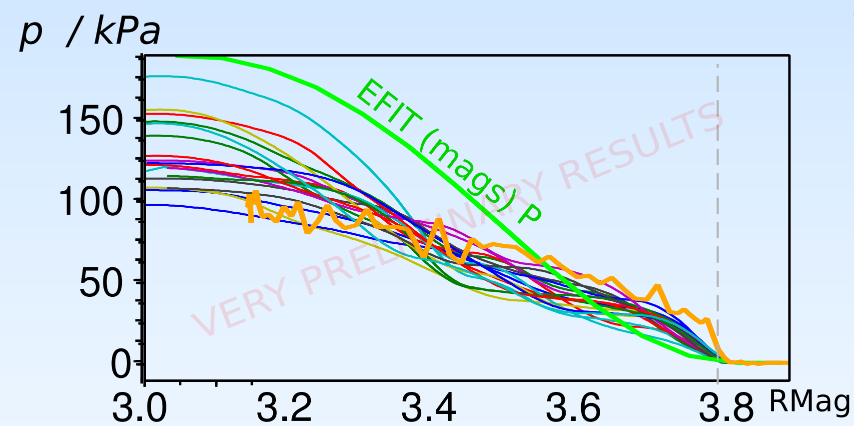

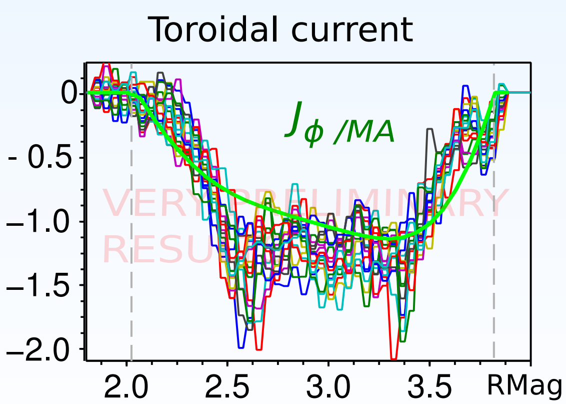

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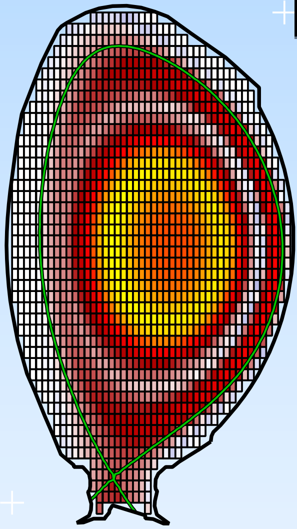

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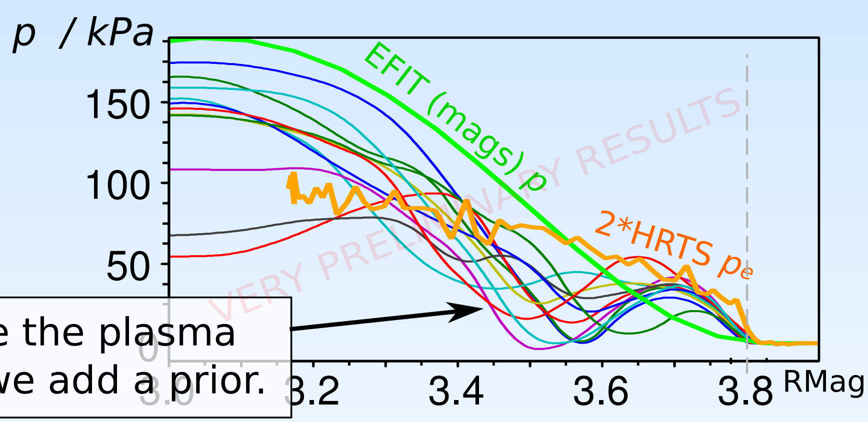

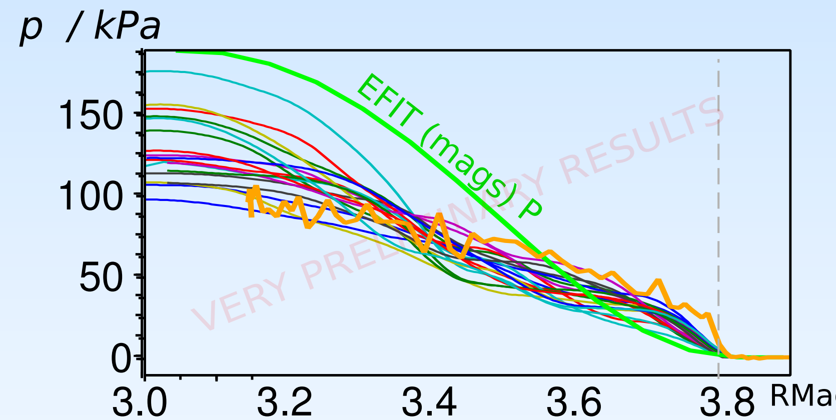

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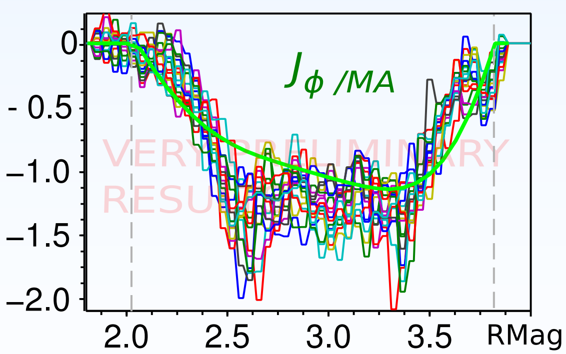

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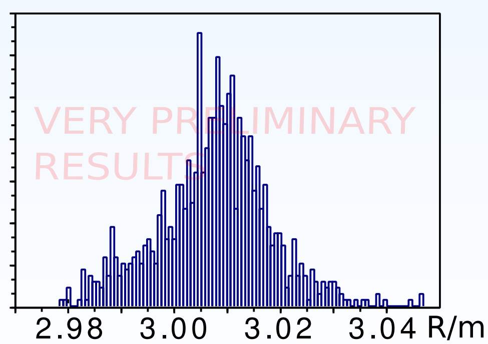

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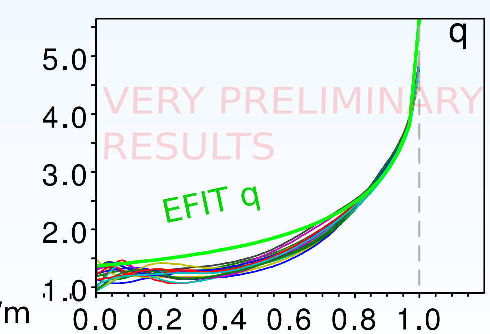

Flux surfaces
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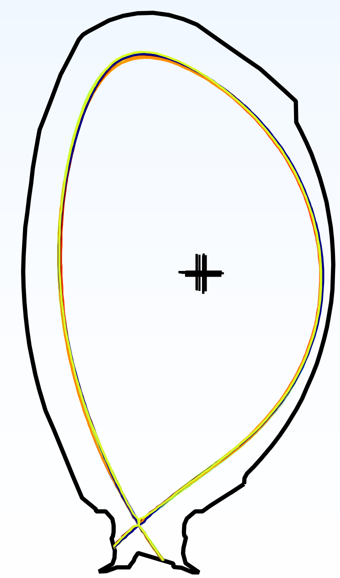

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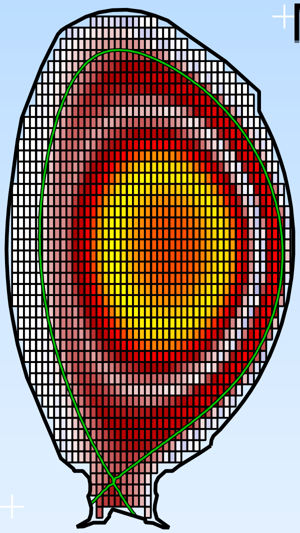

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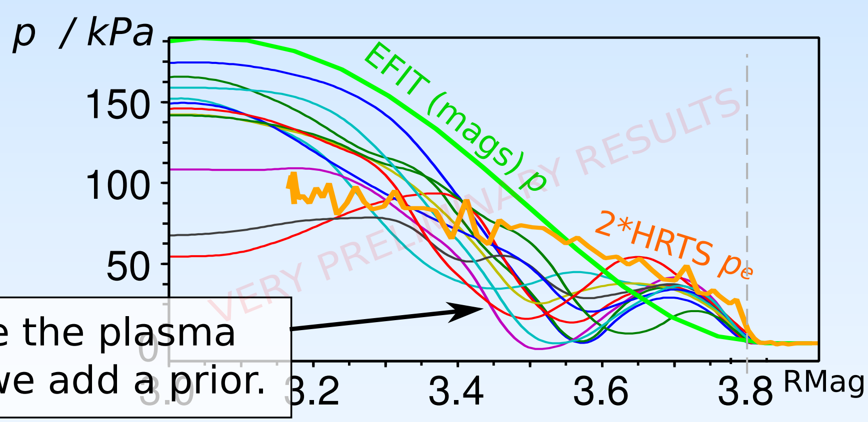
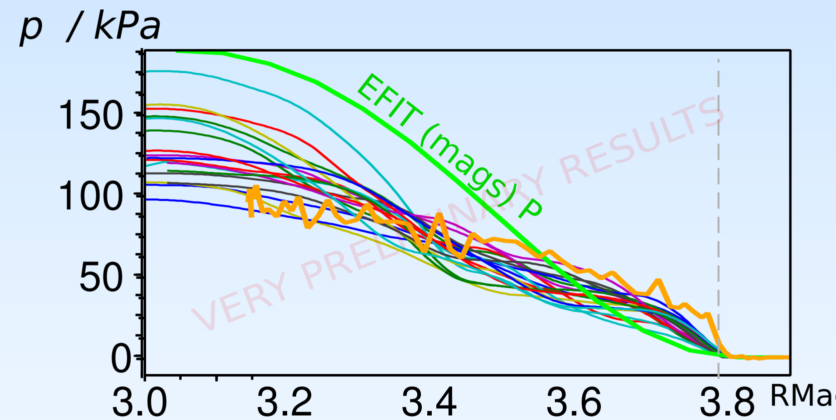


We don't believe the plasma can do this, so we add a prior.



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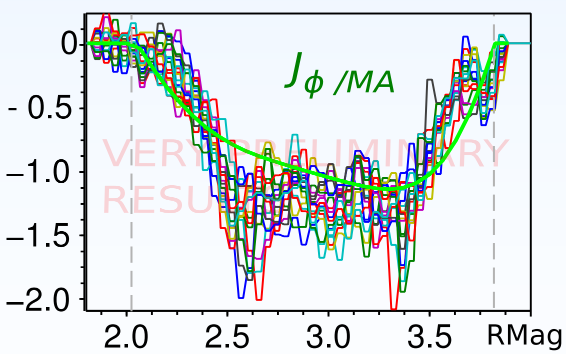

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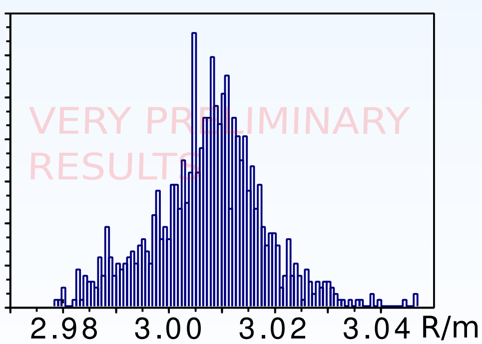

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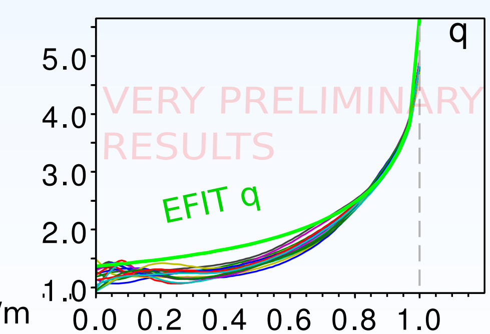

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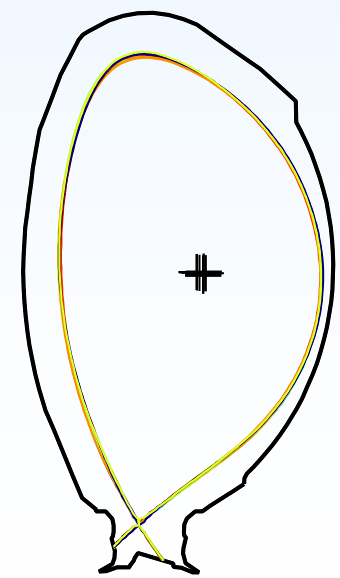

Simple to add diagnostics (Polarimetry, Diamagnetic loop, MSE, LIDAR-TS etc) and to modify parametrisation, priors and equilibrium model.

All directly transferable to MAST as it is part of the common code base for Bayesian analysis on JET, MAST, ANU, W7-AS, and will work directly from the MAST magnetic model.

[To be submitted as part of PhD thesis and for publication later this year]

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- Add the necessary parametrisation and equilibrium model to include flow and/or anisotropic pressure.

Polarimetry - Verification of finite T_e effects and relativistic polarisation theory.

- Detailed modelling of diagnostics allows extraction of a plasma physics results, from existing data, and from far below the noise level.

Plasma polarimetry usually treated using 'cold plasma' model based on fluid approximation.
Two papers gave corrections for finite-T_e effects derived from kinetic theory:

a) S.E. Segre (2002): Argues non-relativistic kinetic approximation is sufficient:
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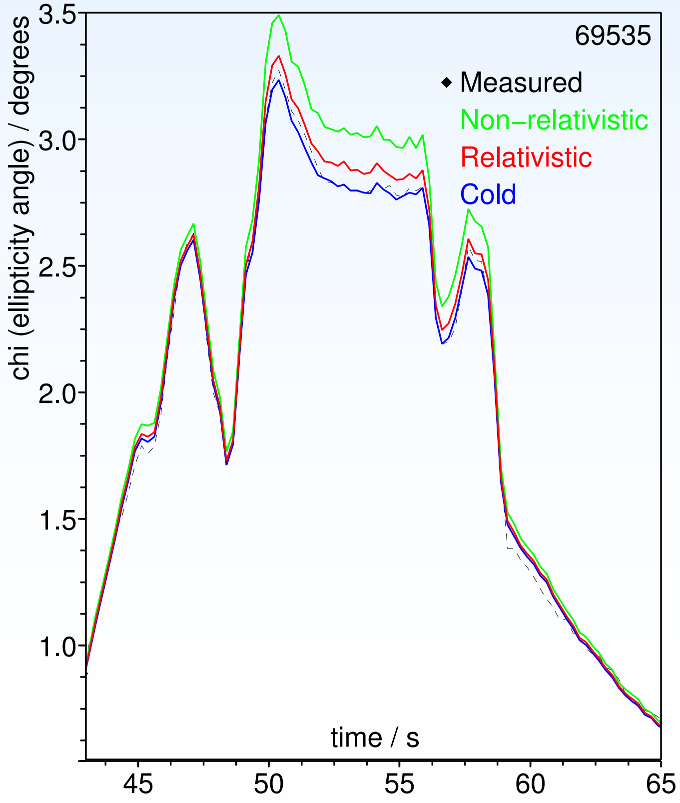

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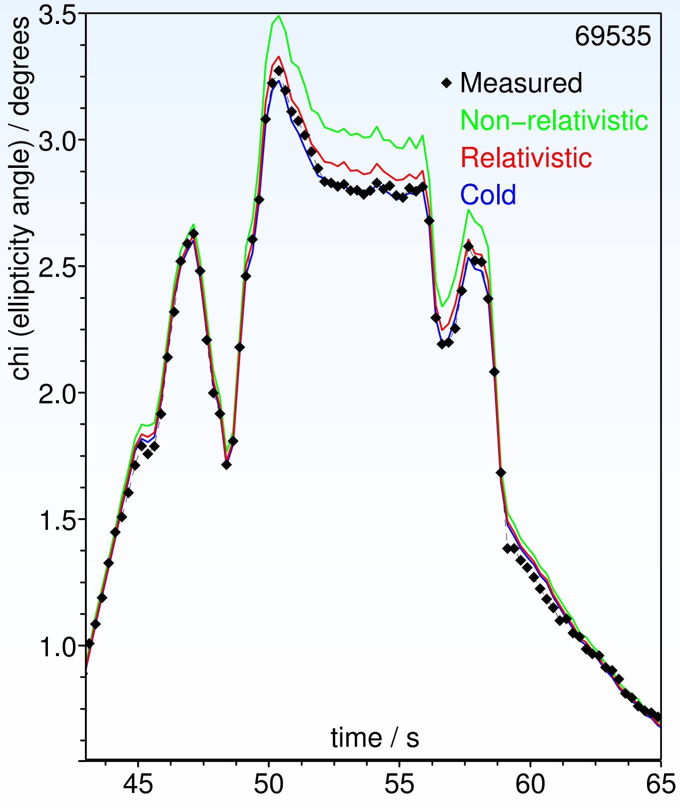

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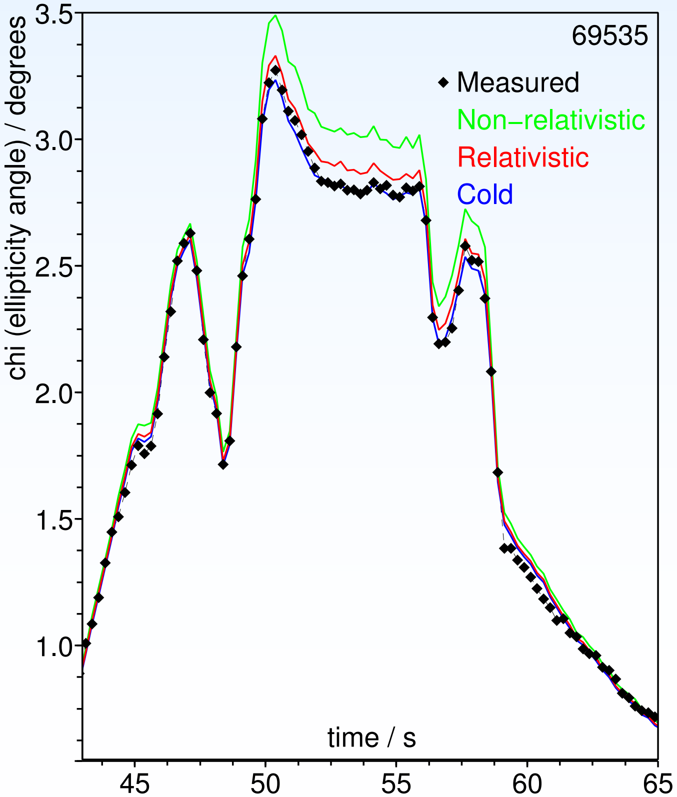

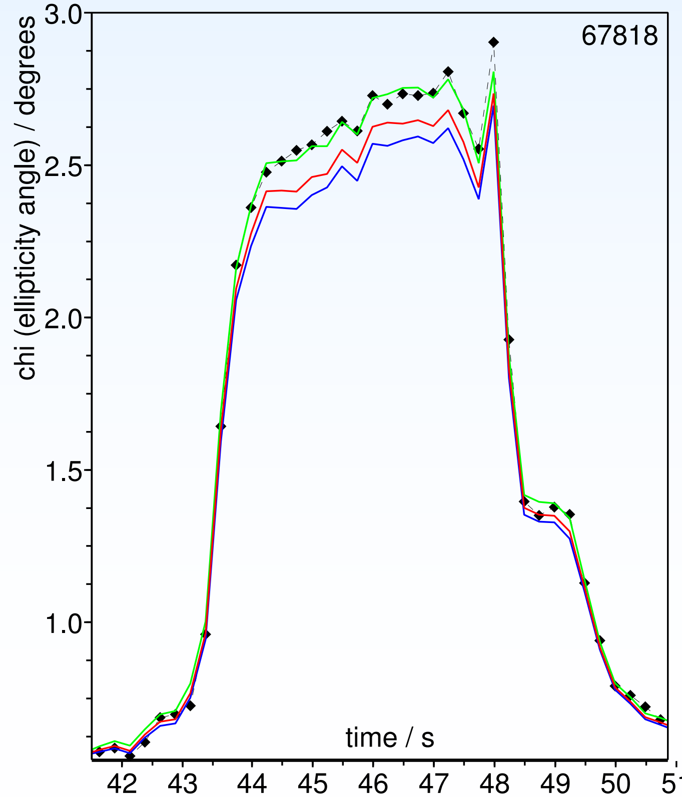

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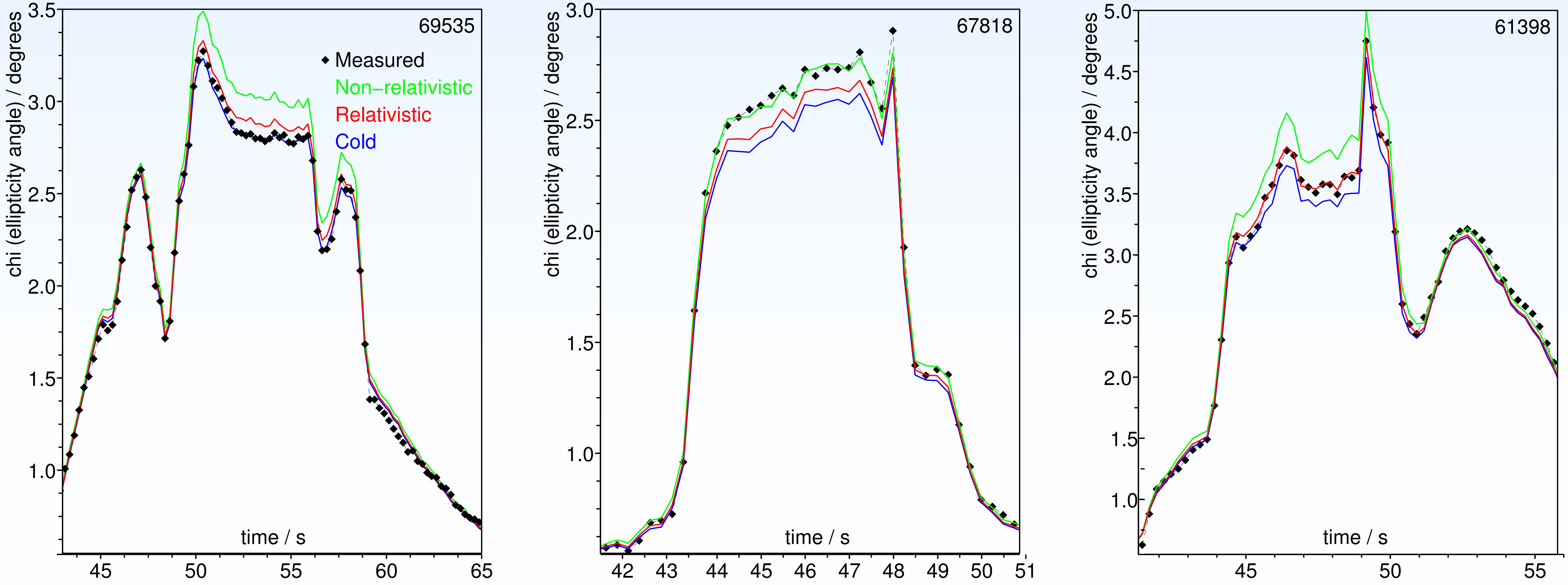

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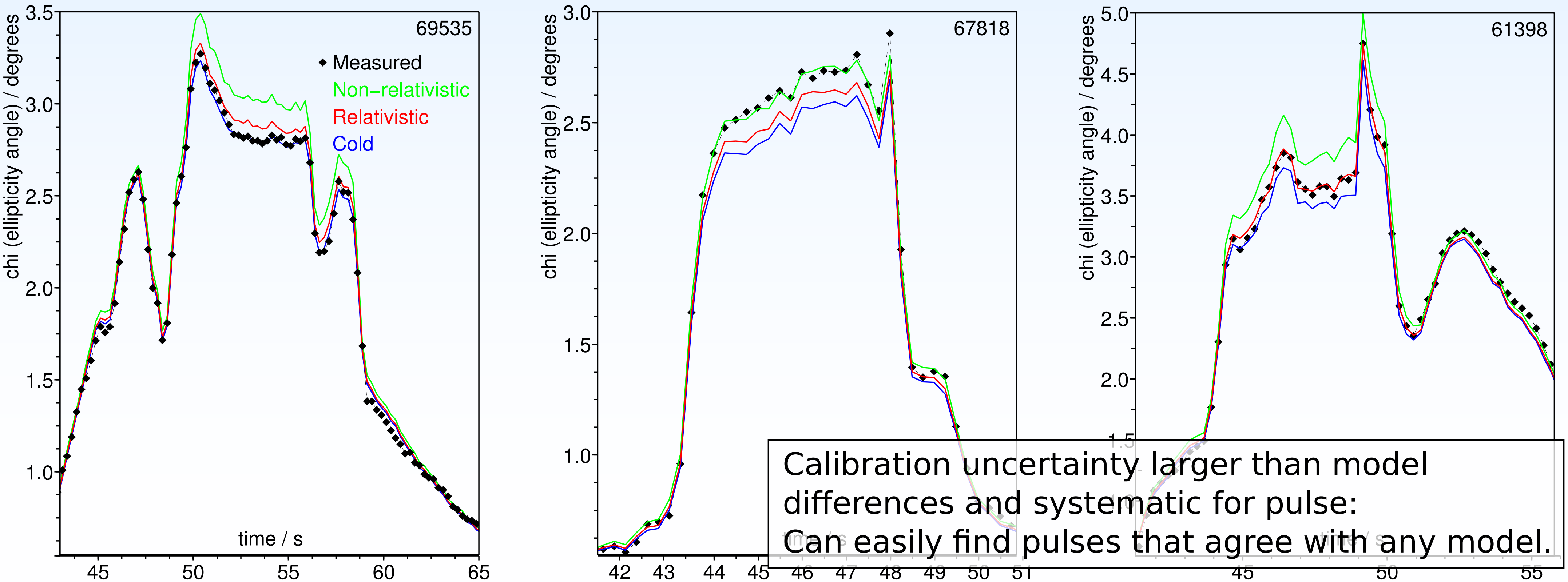

Calibration uncertainty larger than model differences and systematic for pulse:
Can easily find pulses that agree with any model.

Polarimetry - Verification of finite T_e effects and relativistic polarisation theory.

Diagnostic uncertainty is due to calibration and cannot depend on plasma core T_e.
Polarimeter has been on JET for a long time so we have a lot of data...

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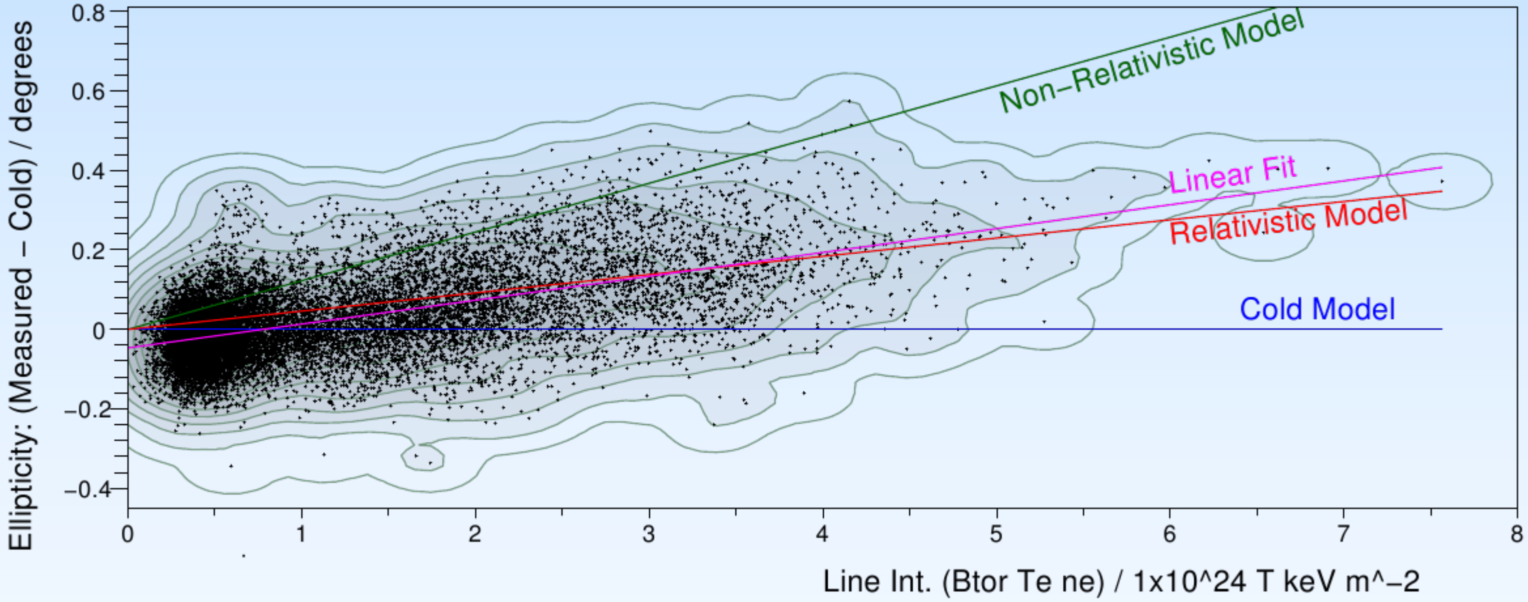

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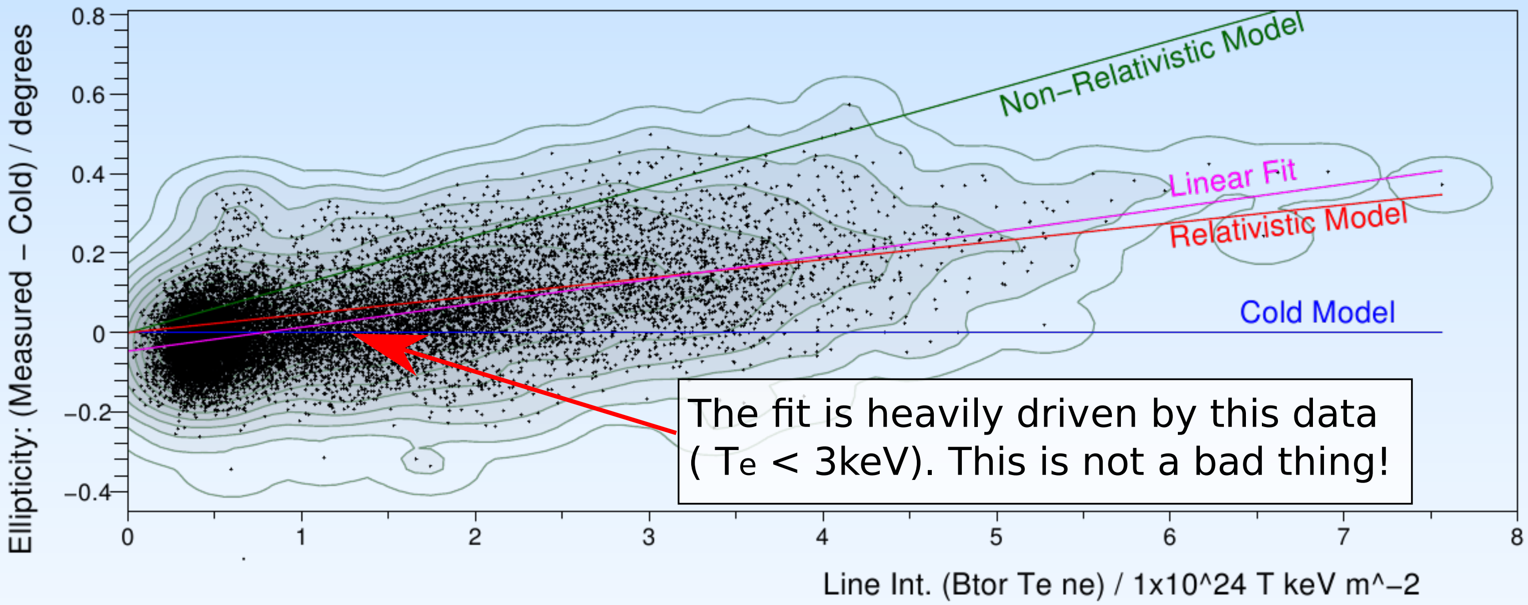

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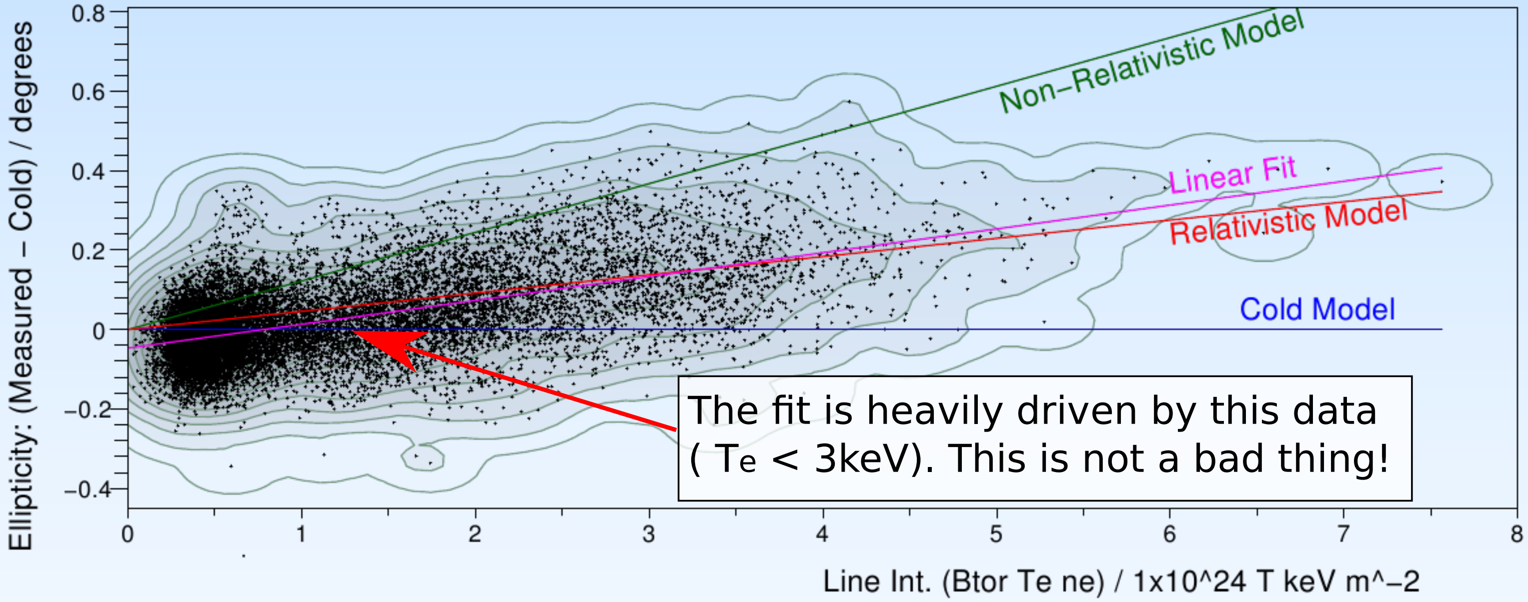

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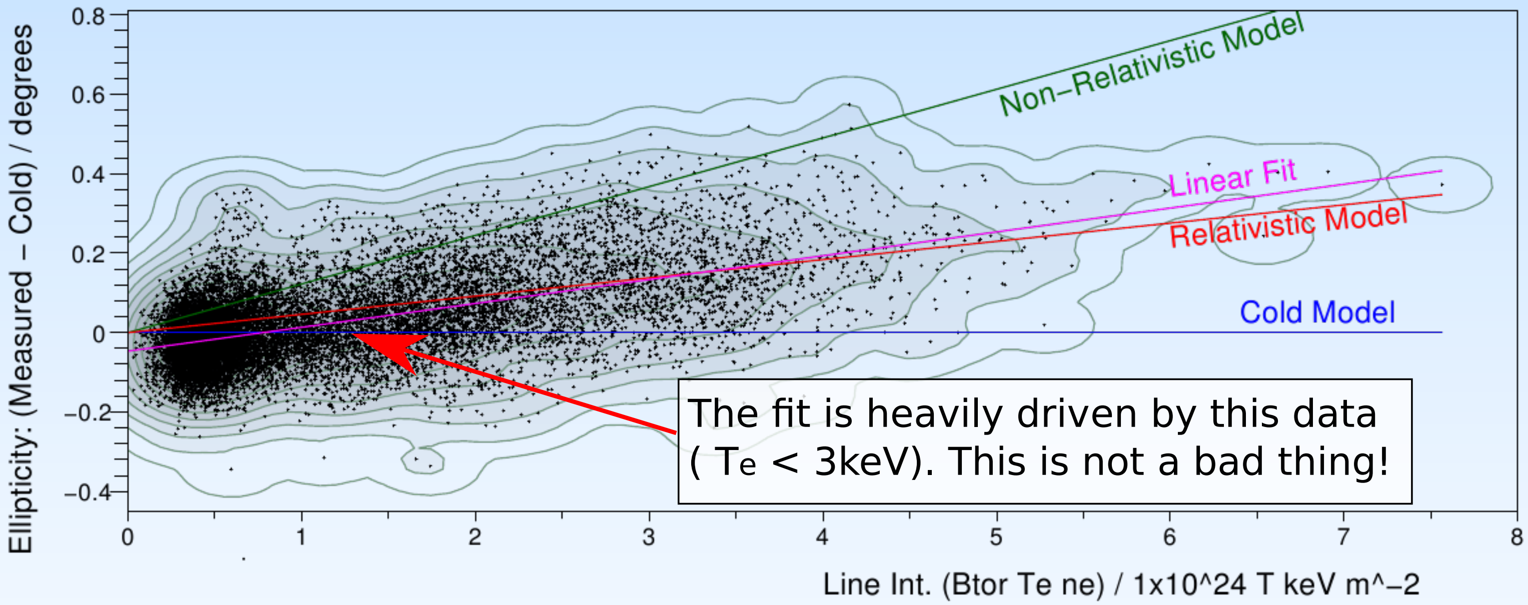

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Independently:
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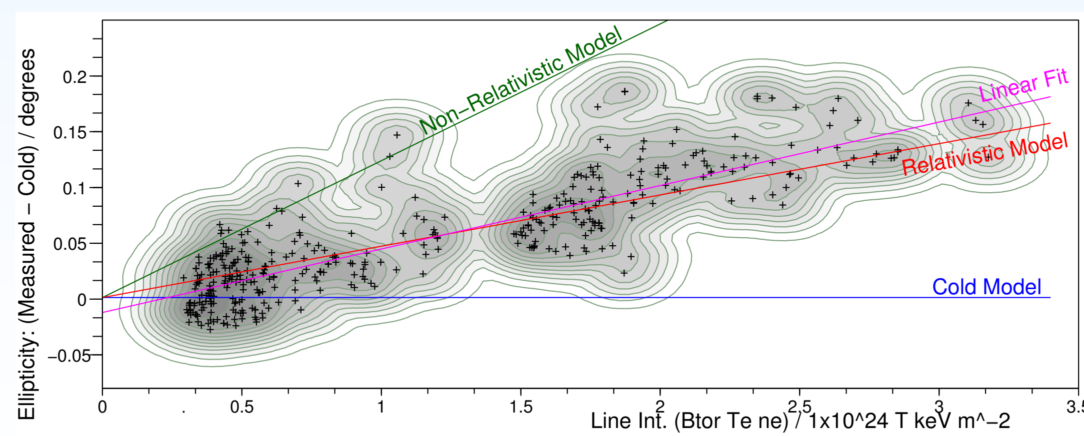
2) Compare data in high T_e period:



"*Forward modeling of JET polarimetry diagnostic*" - Rev. Sci. Instrum **79** 10F324 (2008)

"*Experimental verification of relativistic finite temperature polarimetry effects at JET*"
Plasma Phys. Control. Fusion **51** 065004 (2009)   (Included in IOP select and PPCF highlights 2009.)