# Bayesian Analysis Results on JET - Flux surface and equilibrium uncertainty

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D. C. McDonald[3], A. Meakins[3], E. Solano[3], JET-EFDA Collaborators*

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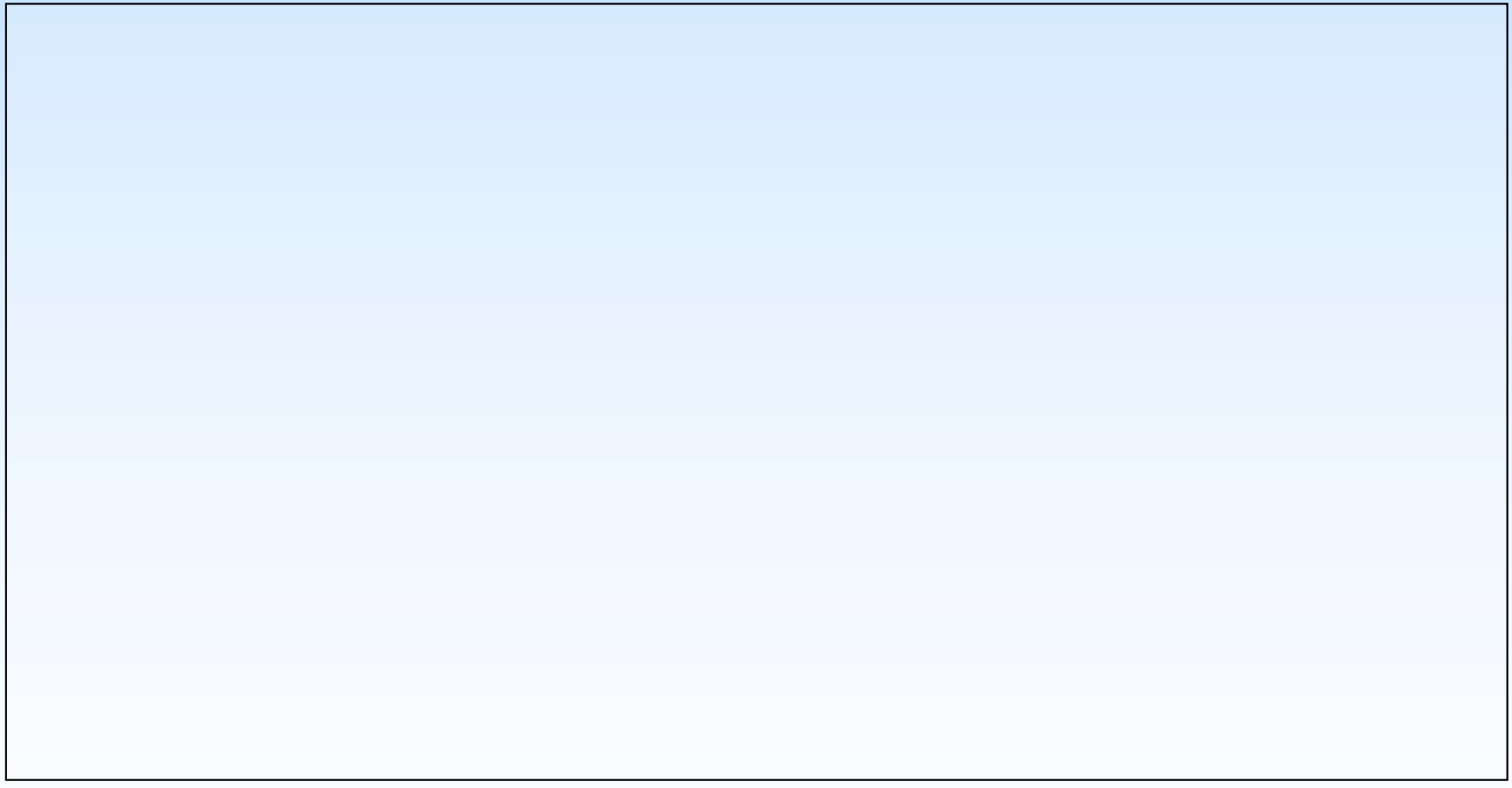
3: UKAEA Fusion Association, Culham Science Centre, OX14 3DB, UK

* See the Appendix of F. Romanelli et al., Fusion Energy Conference 2008 (Proc. 22nd Int. FEC Geneva) IAEA

# Forward Modelling and Bayesian Inference

The basic idea:



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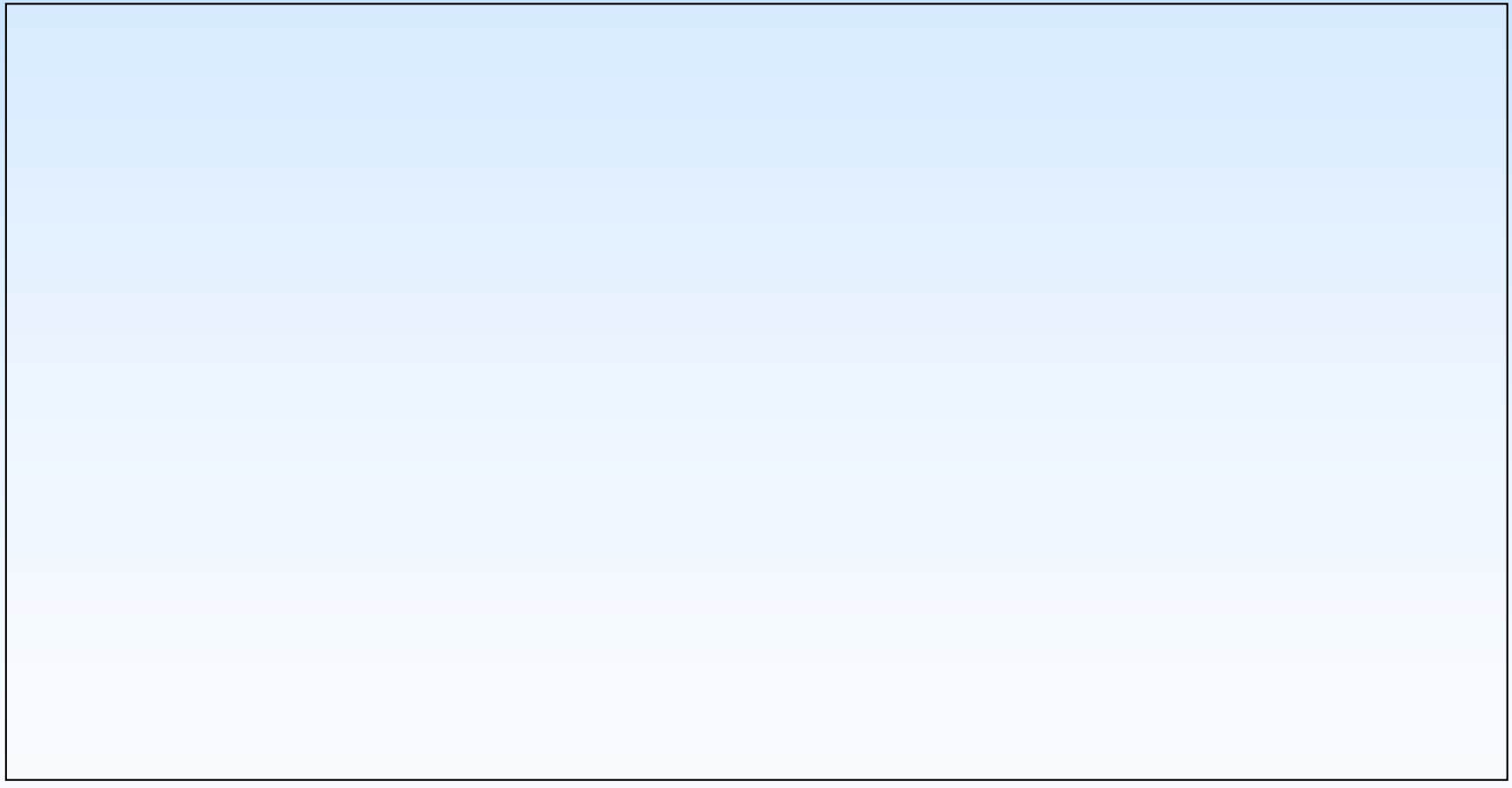

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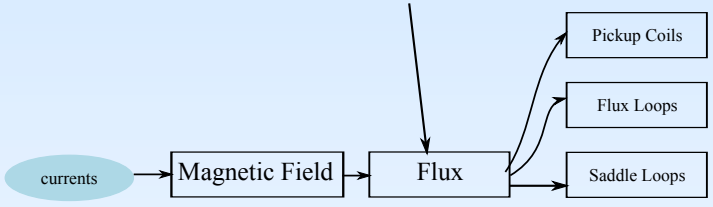


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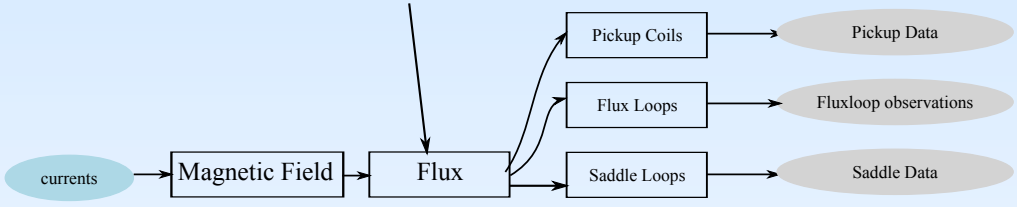

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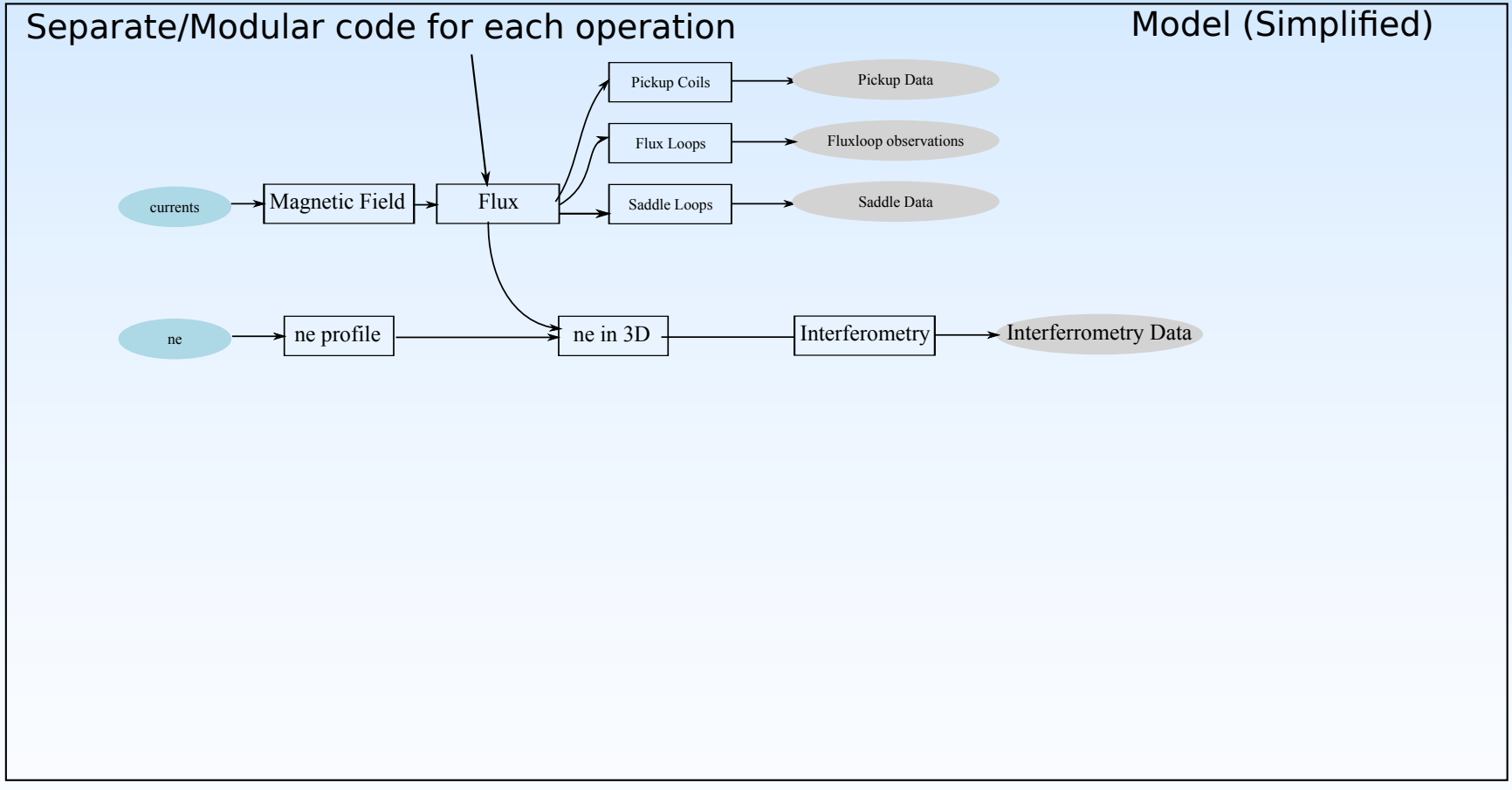

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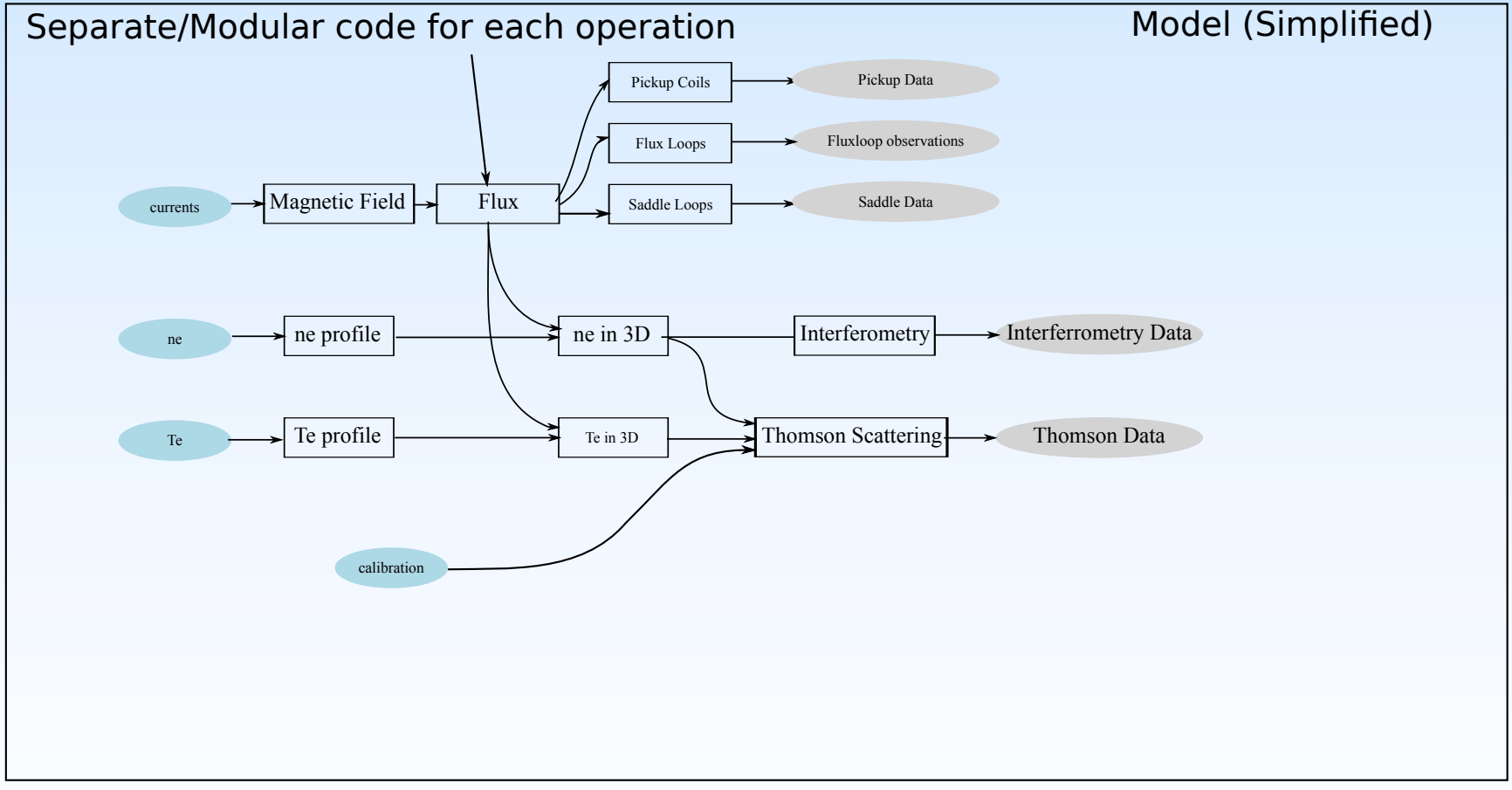

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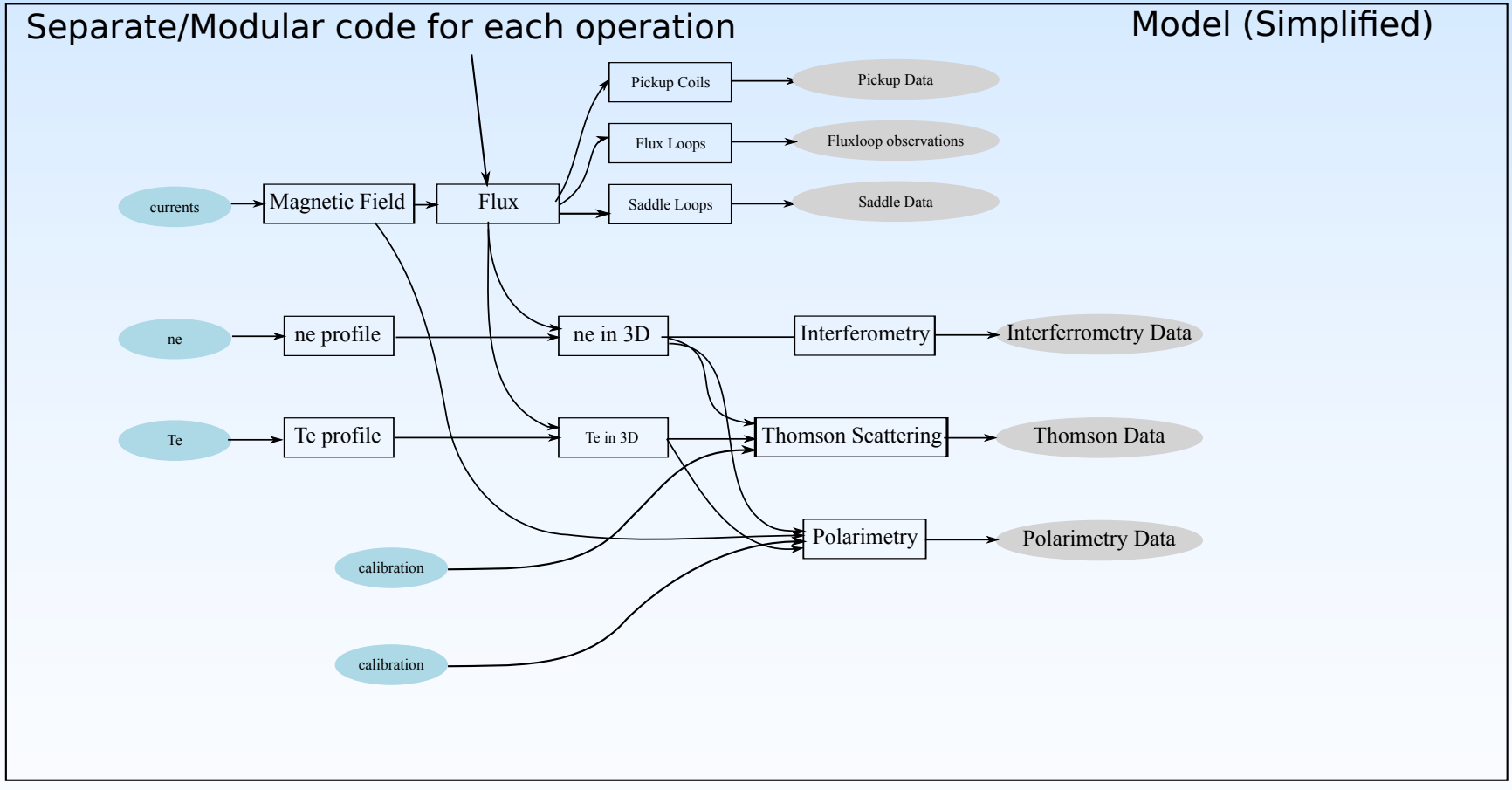

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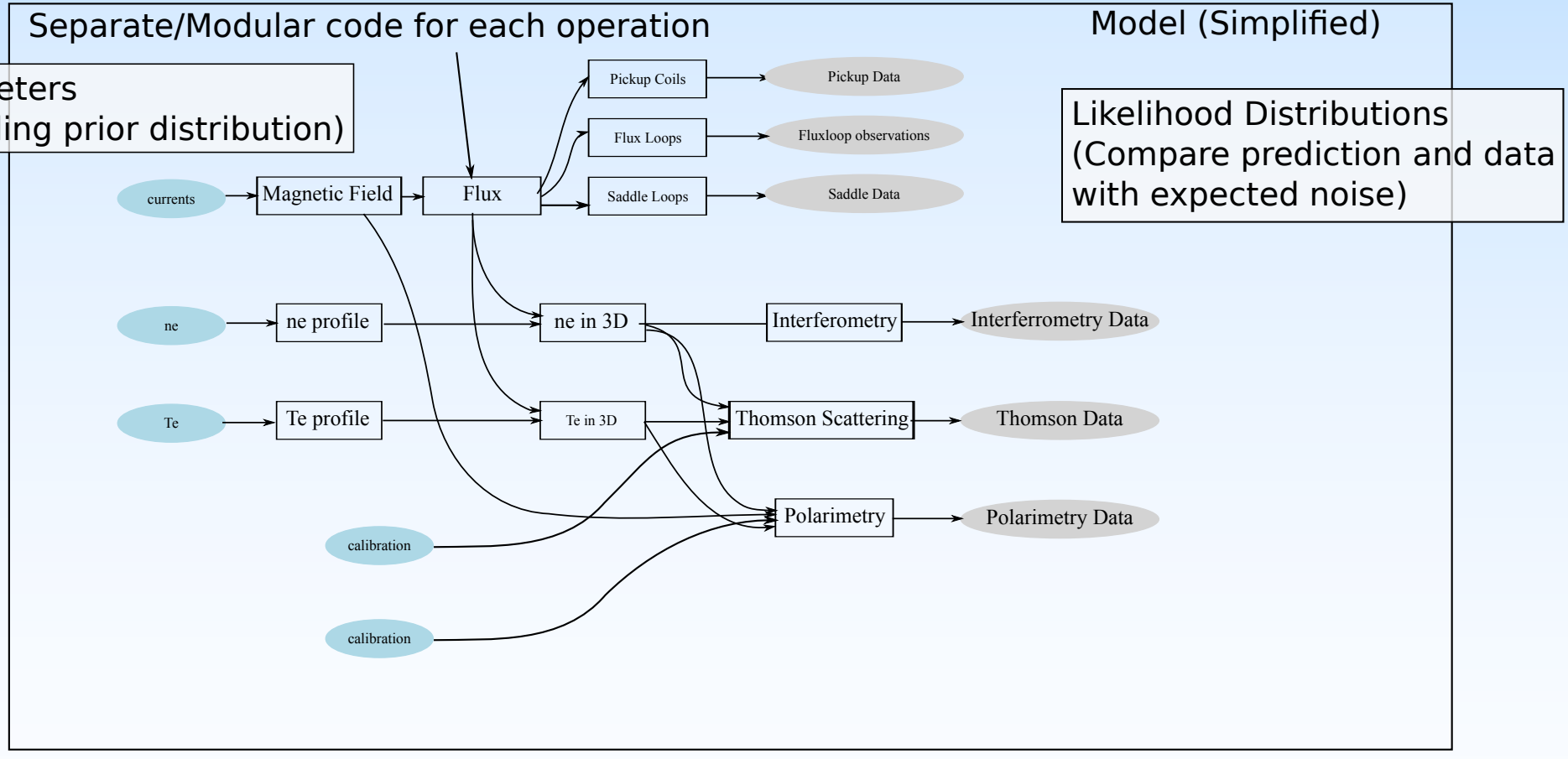

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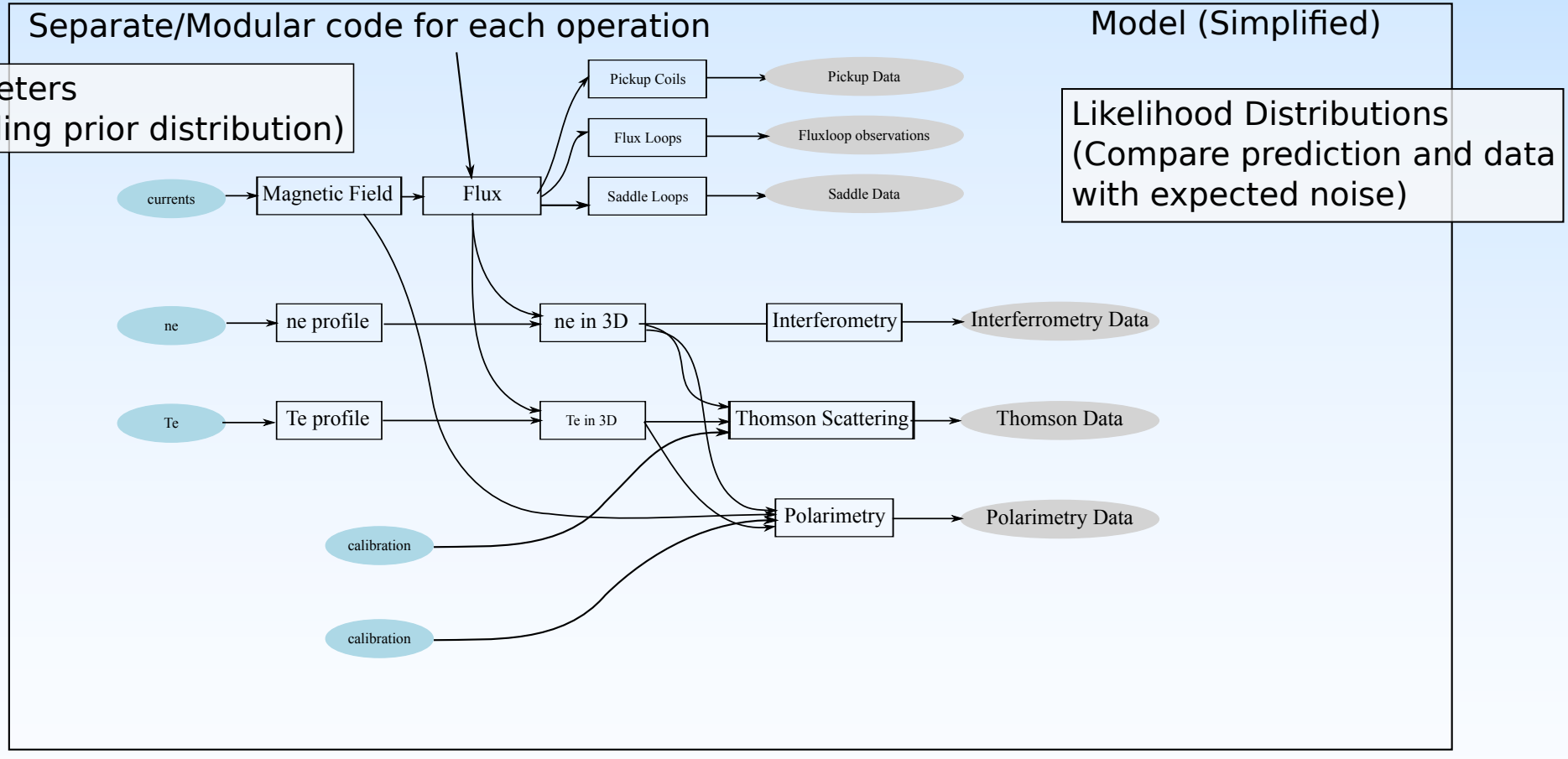


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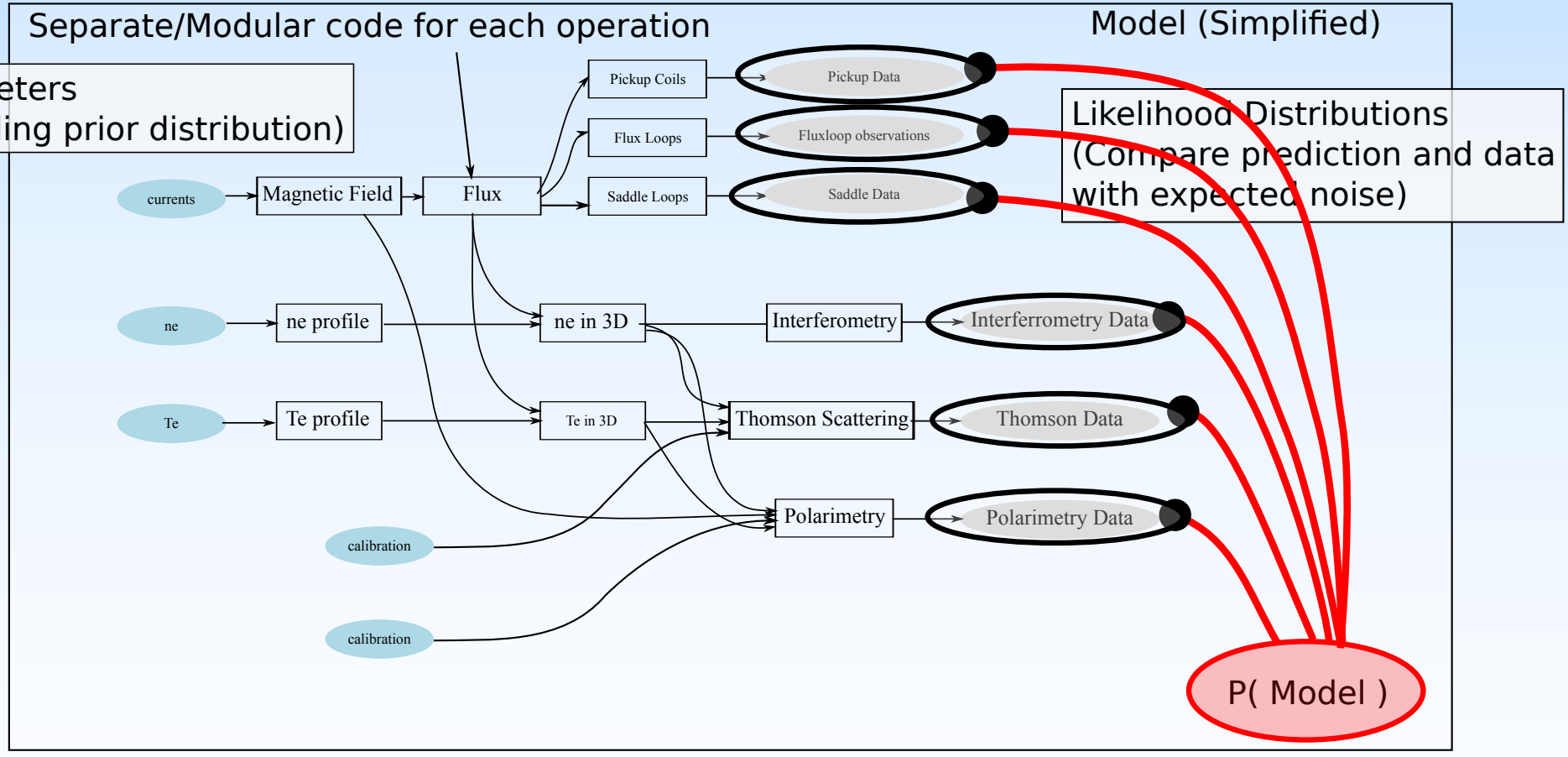


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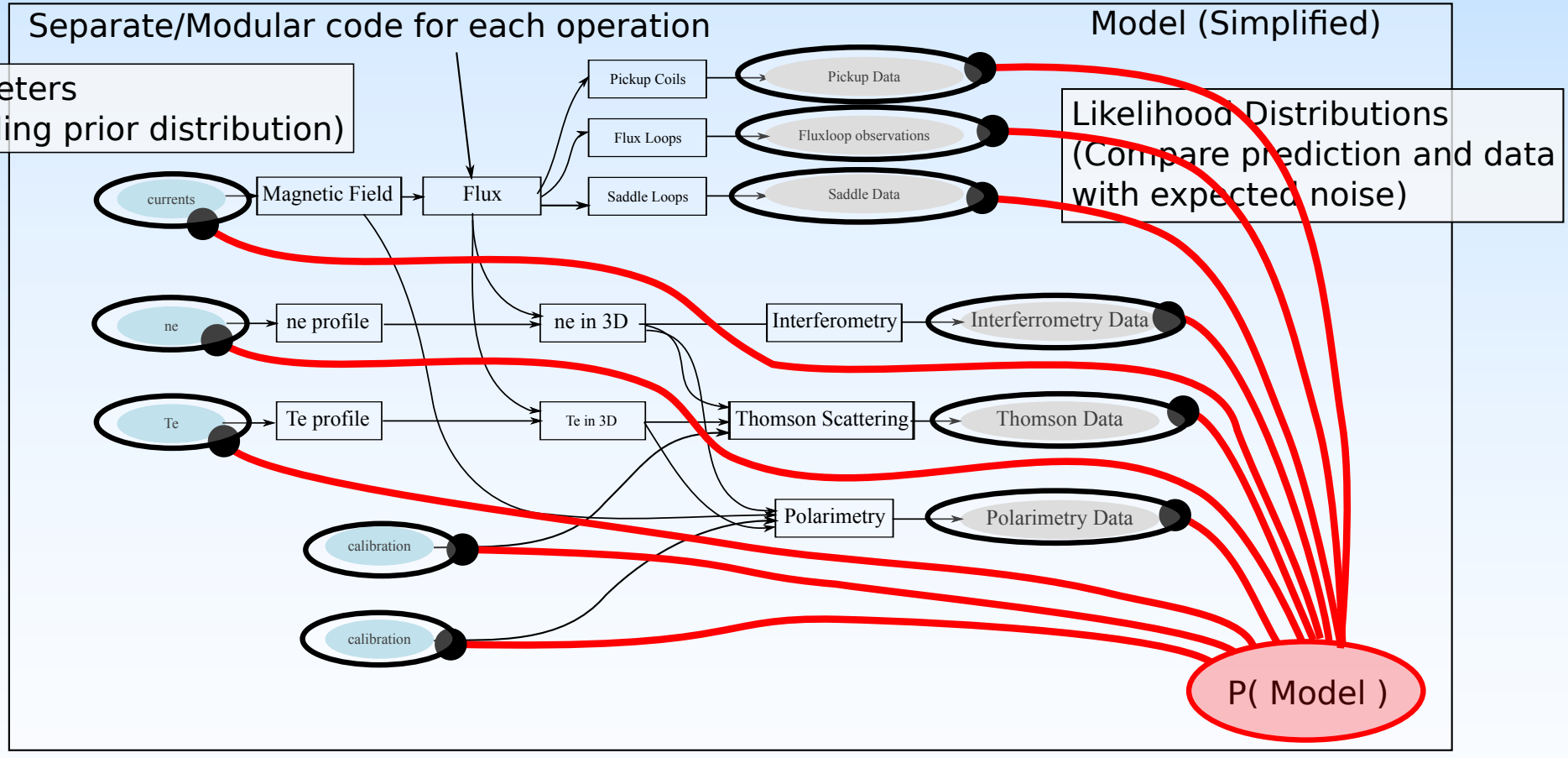


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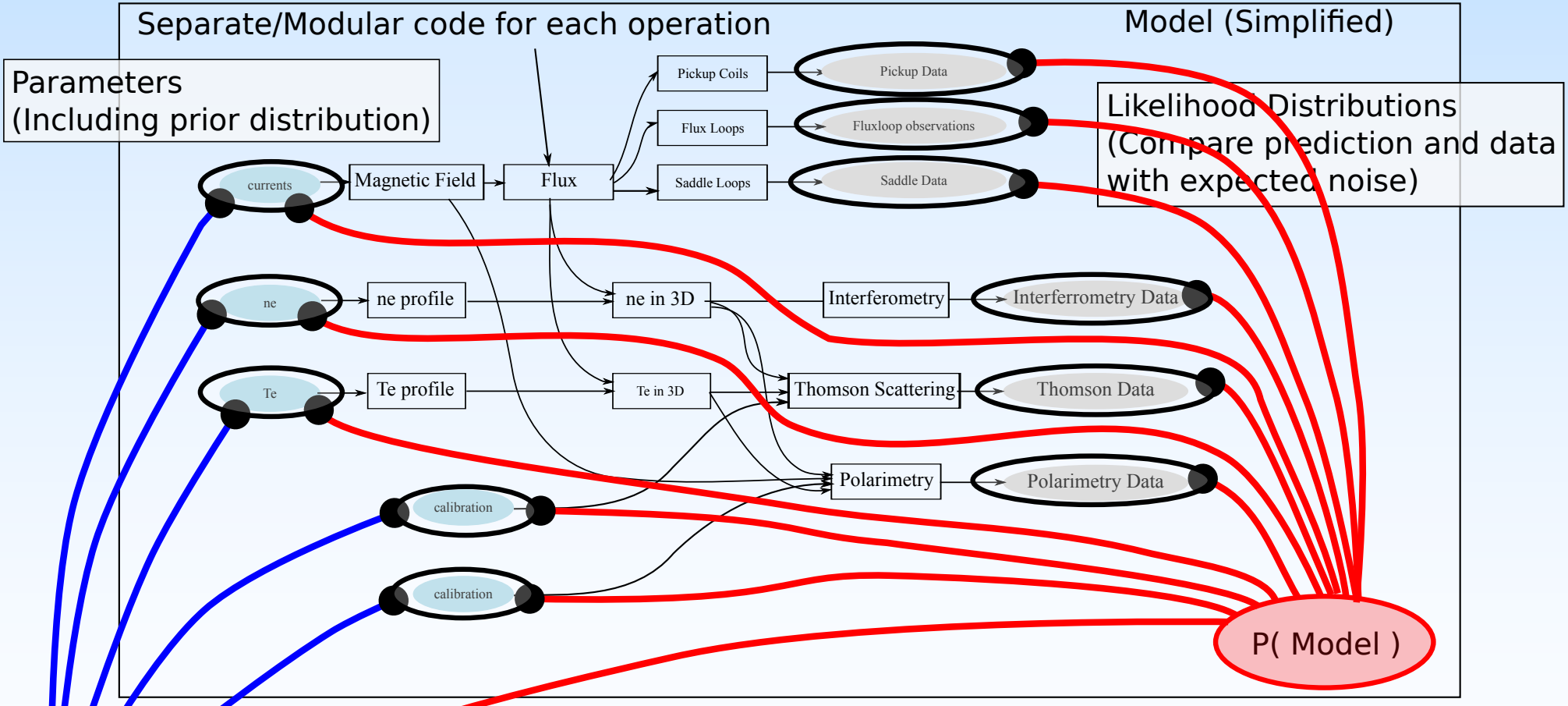


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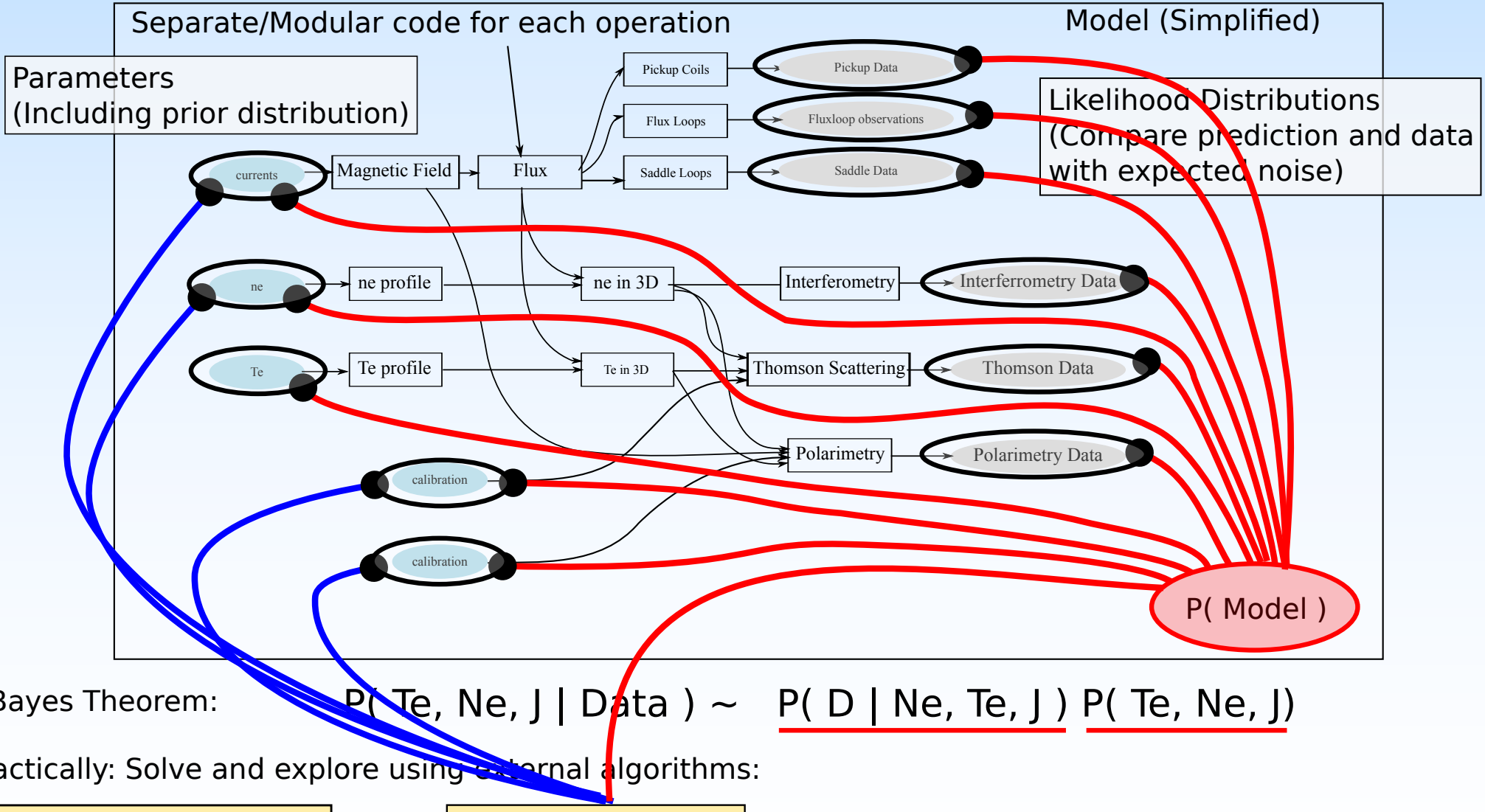


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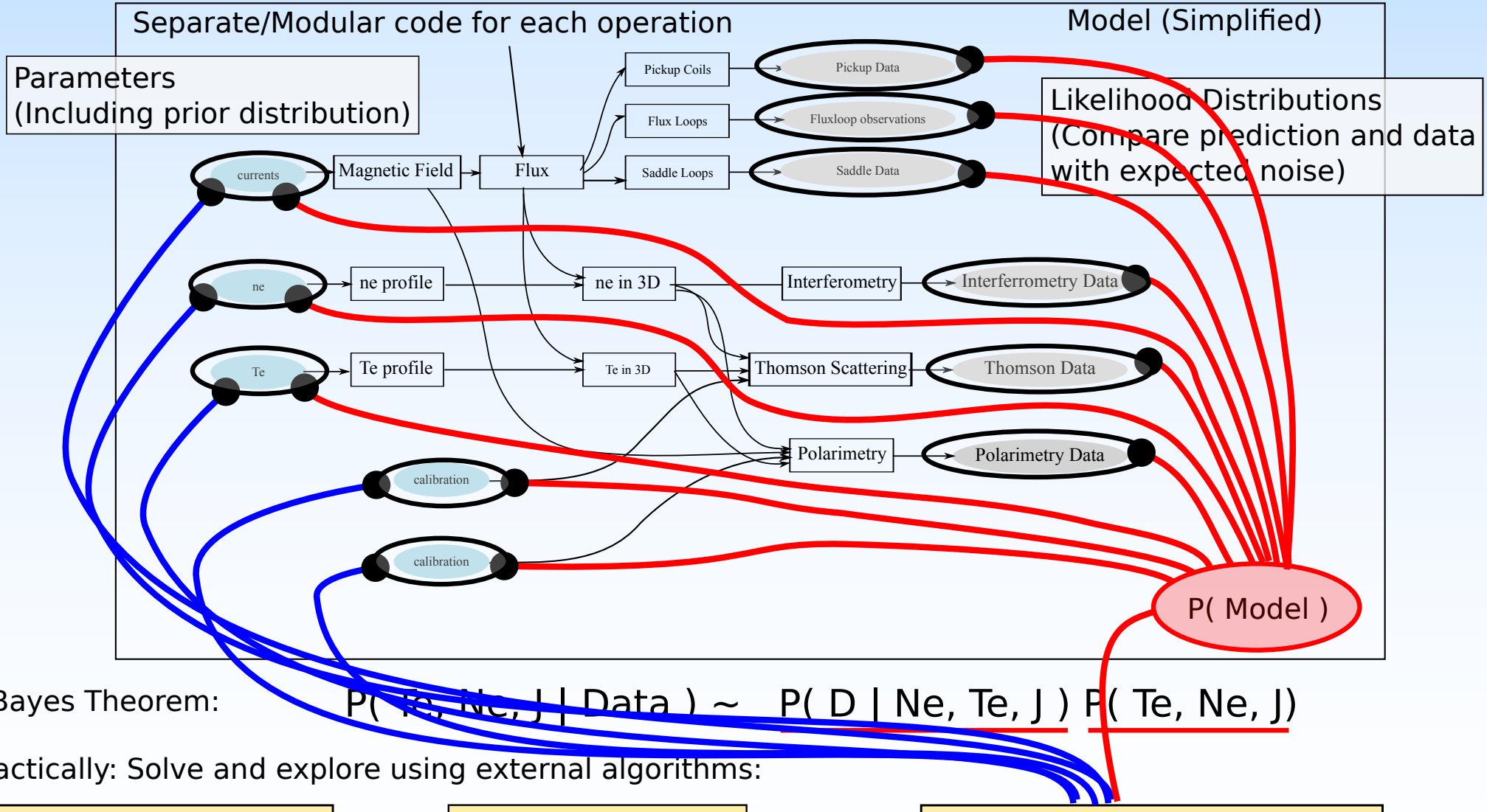


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Metropolis Hastings
MCMC Non-linear Exploration:
--> Uncertainty

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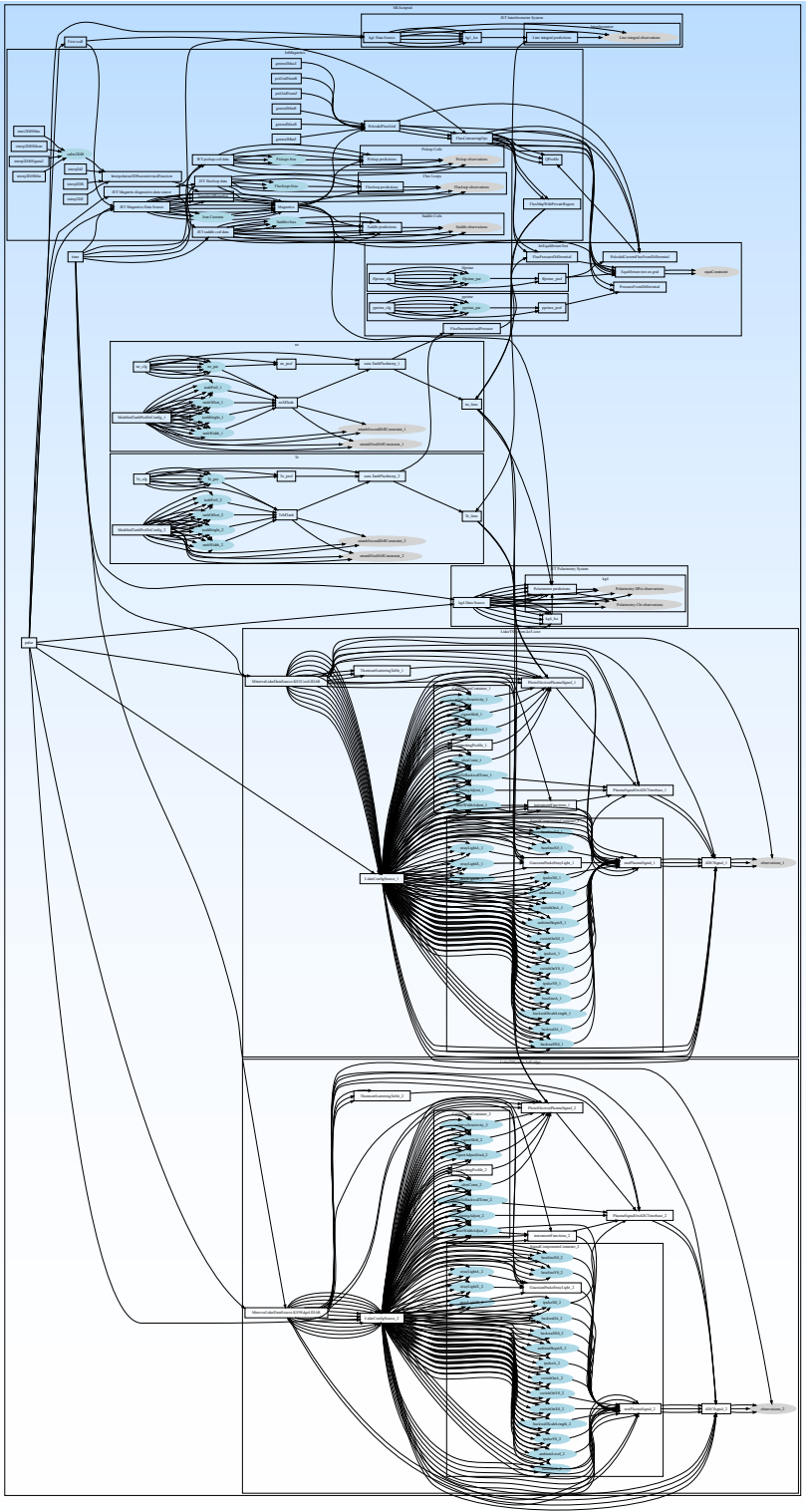
Software framework handles the rest.



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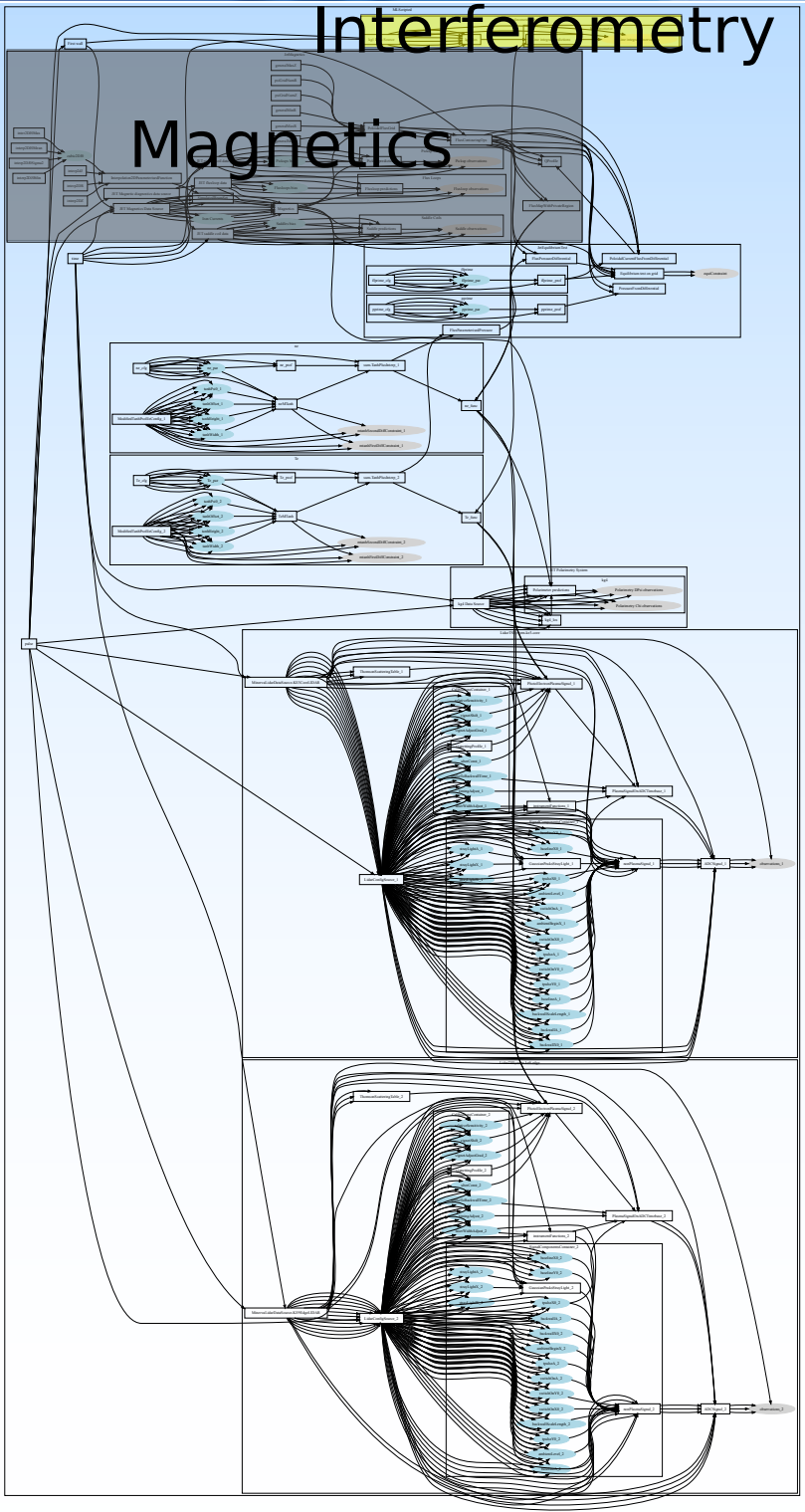


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- Magnetics (field/flux calculations and JET magnetics)
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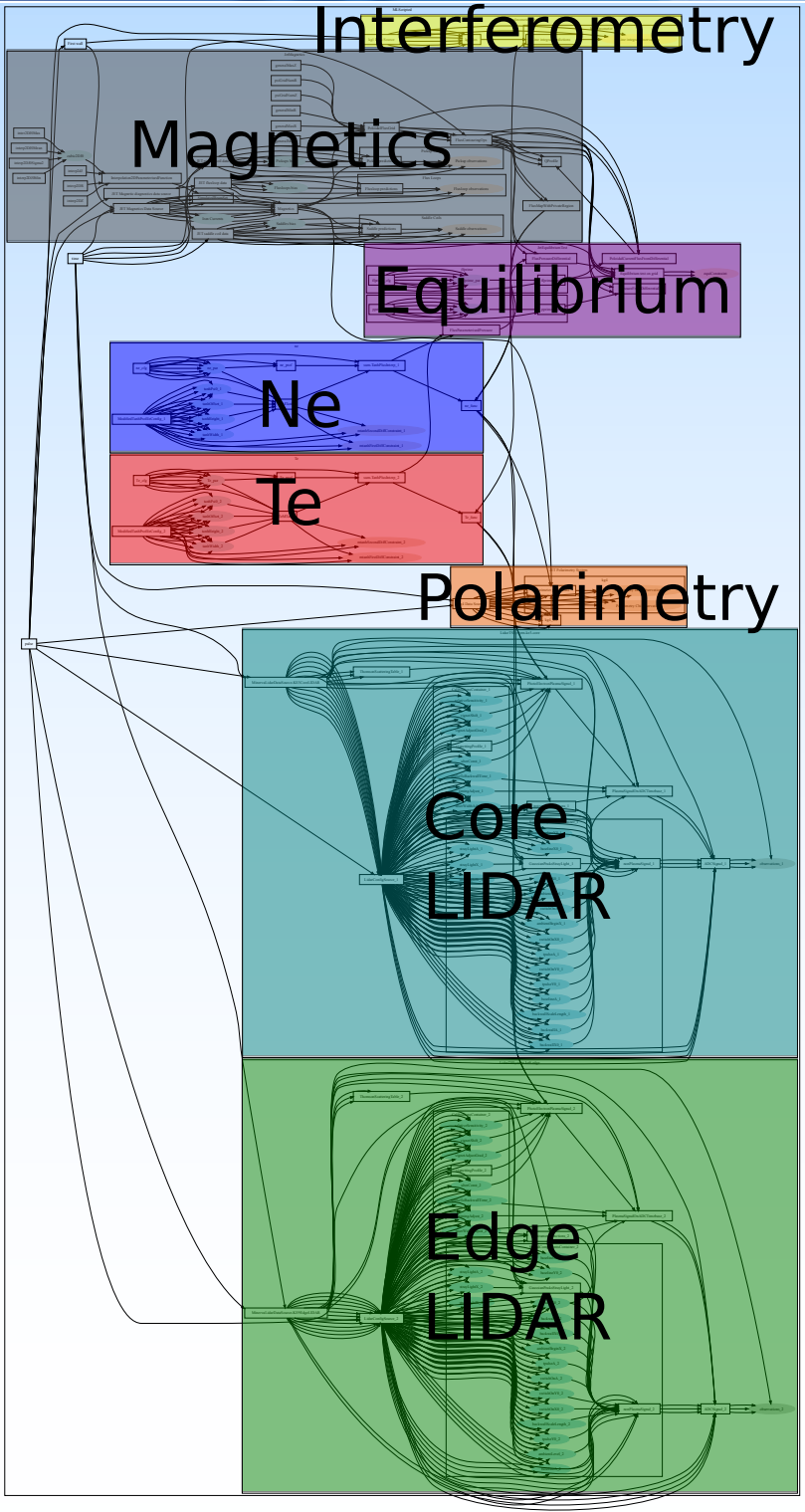


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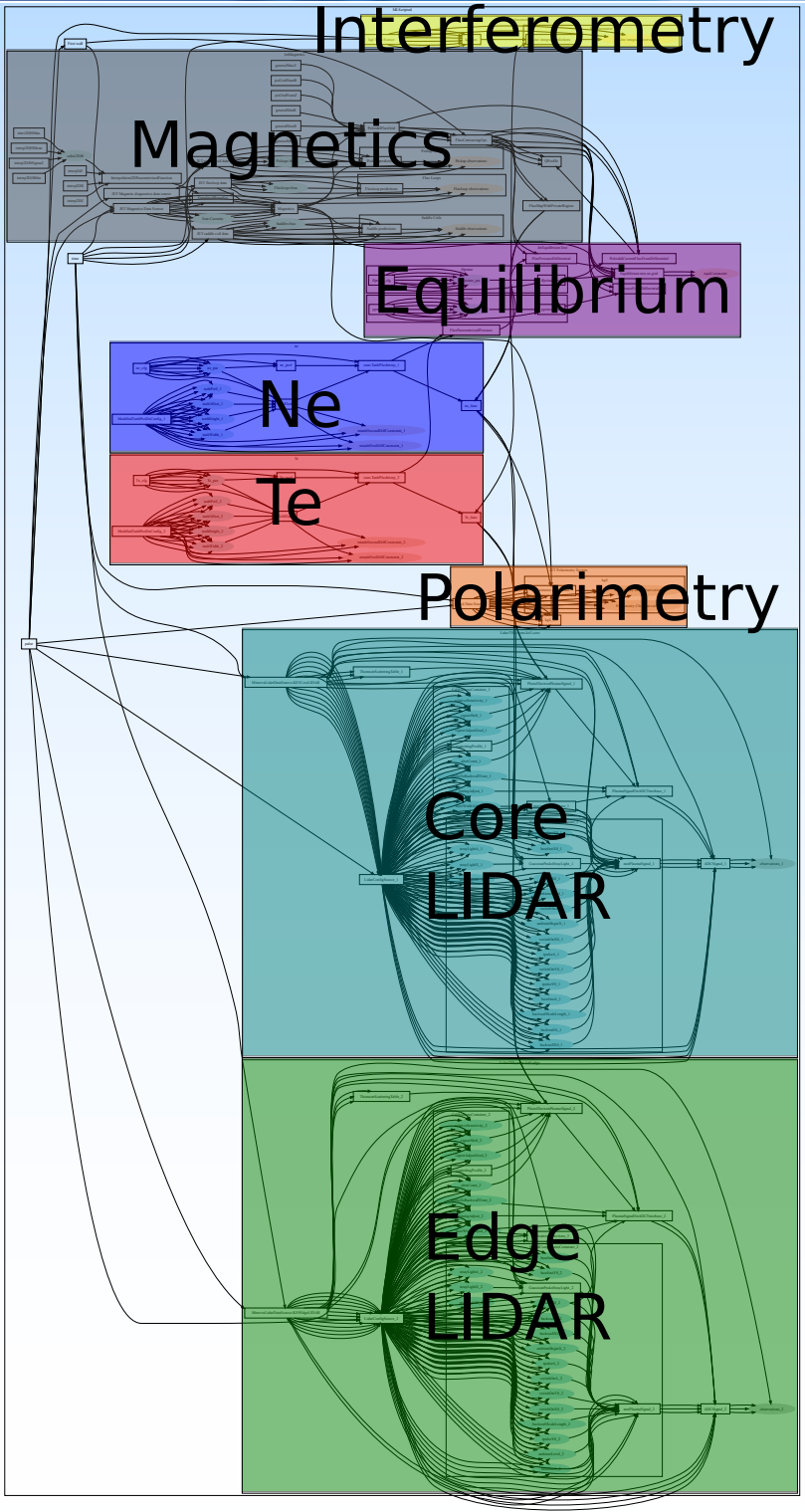


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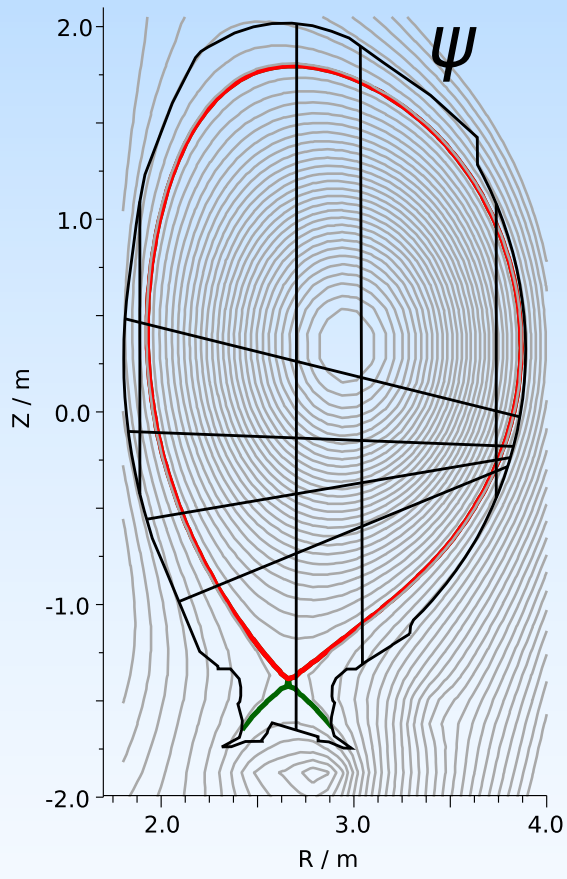
Other parts written during the past 3 years:
- JET MSE
- JET Reflectometry
- JET Infrared strikepoint camera
- MAST Magnetics
- MAST MSE
- MAST Thomson Scattering
- ... and a few others ...

# Interferometry

A simple Bayesian + forward modelling practical demo:

We have 8 line integrated density measurements.



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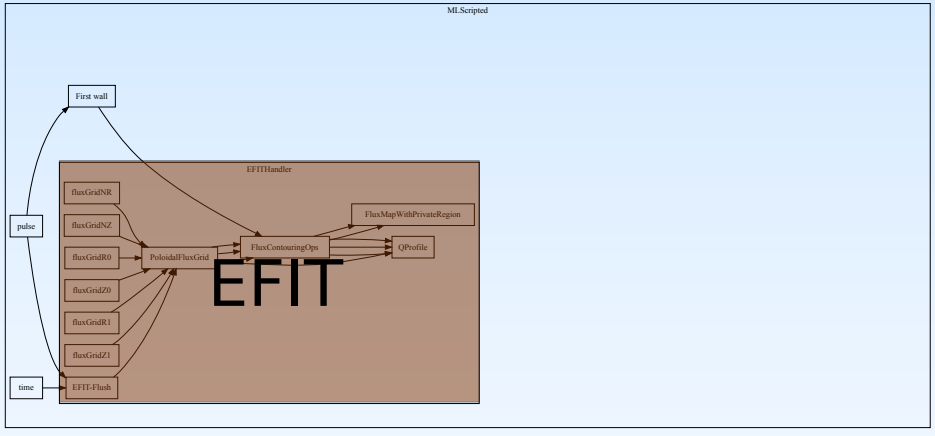


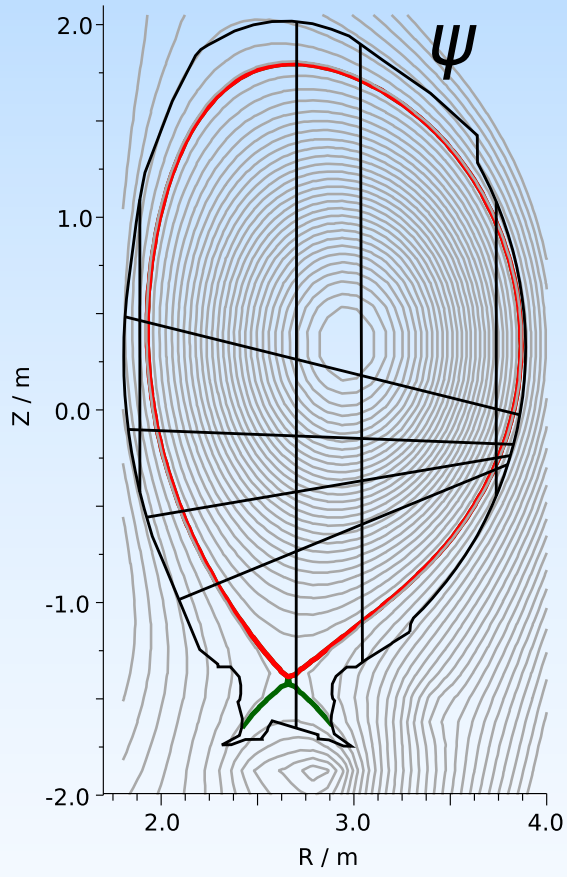

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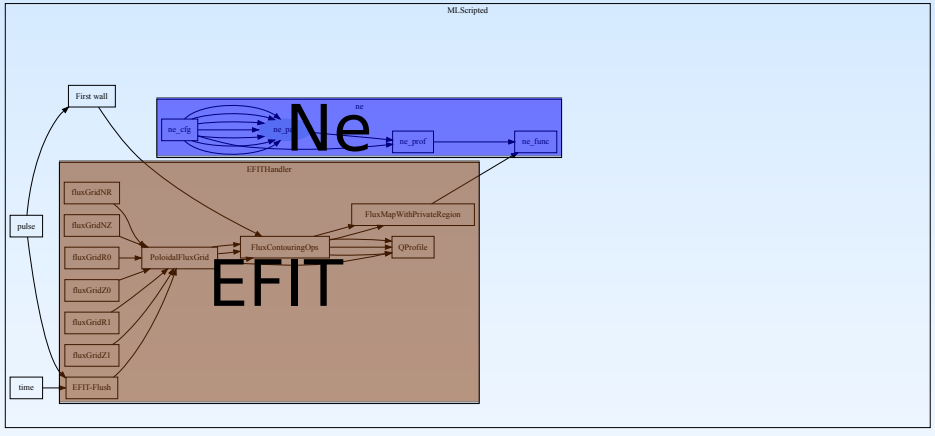


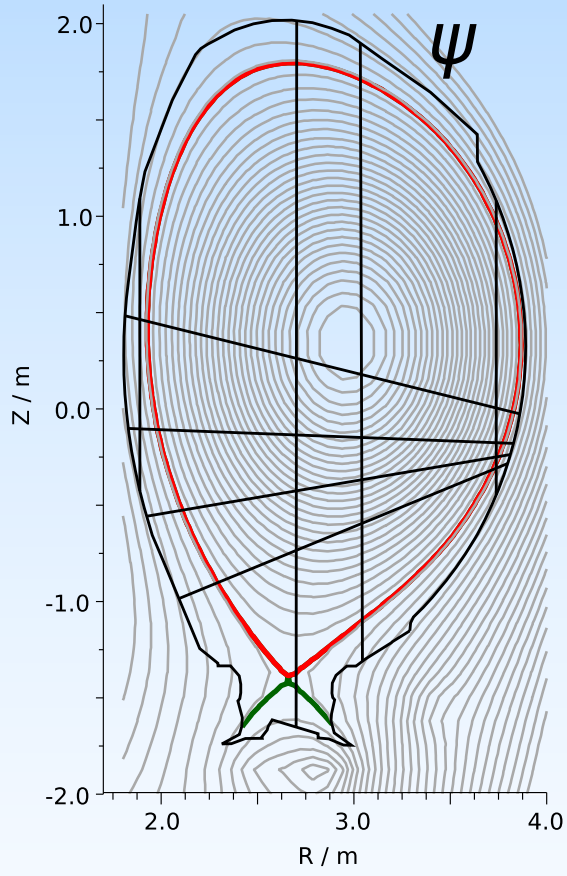

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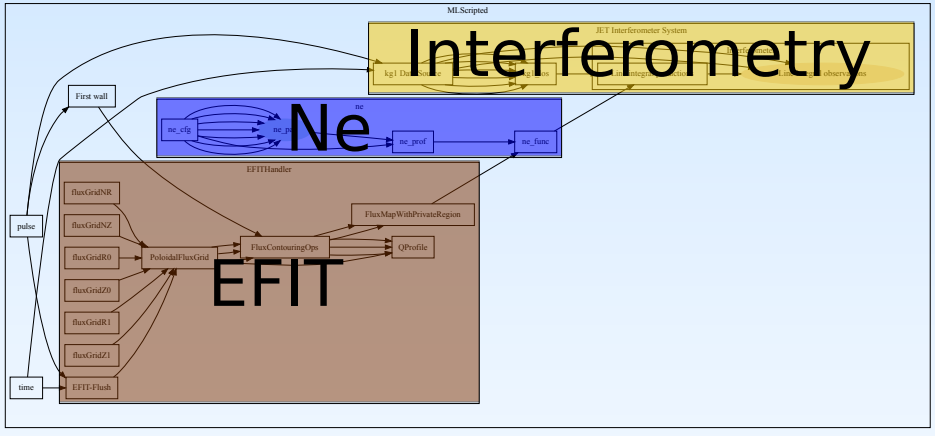


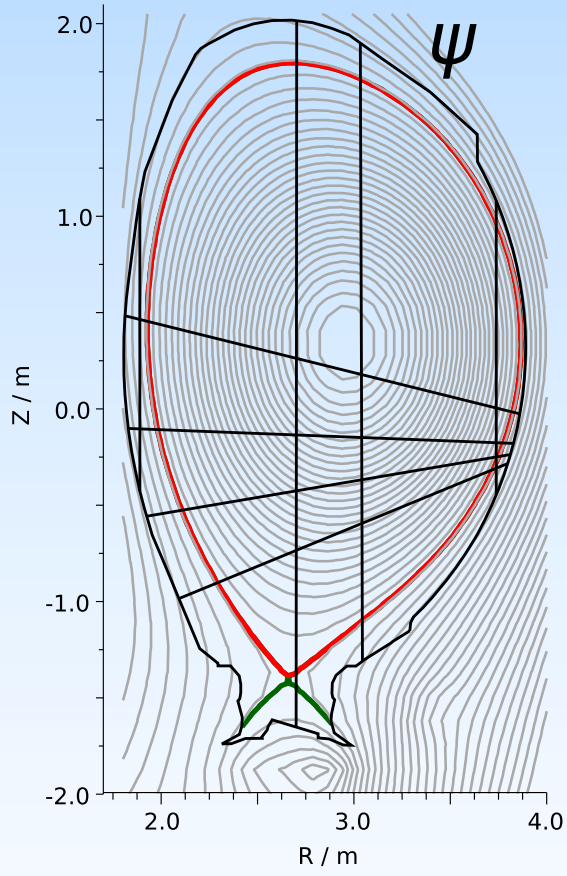

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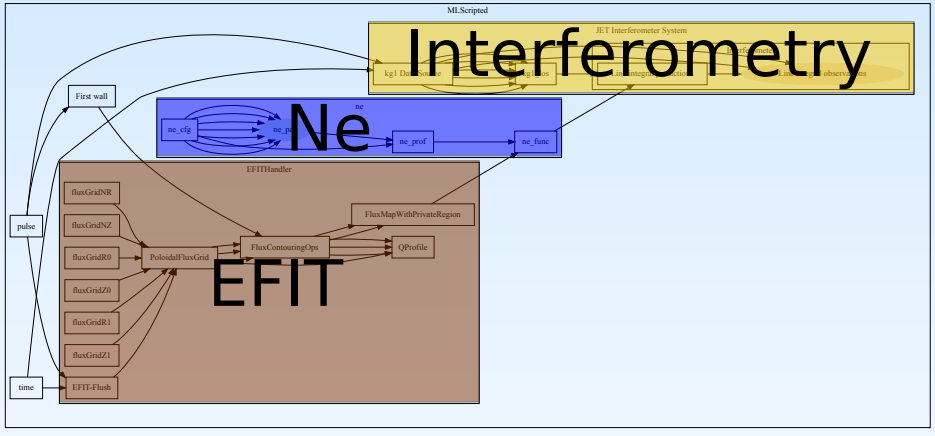


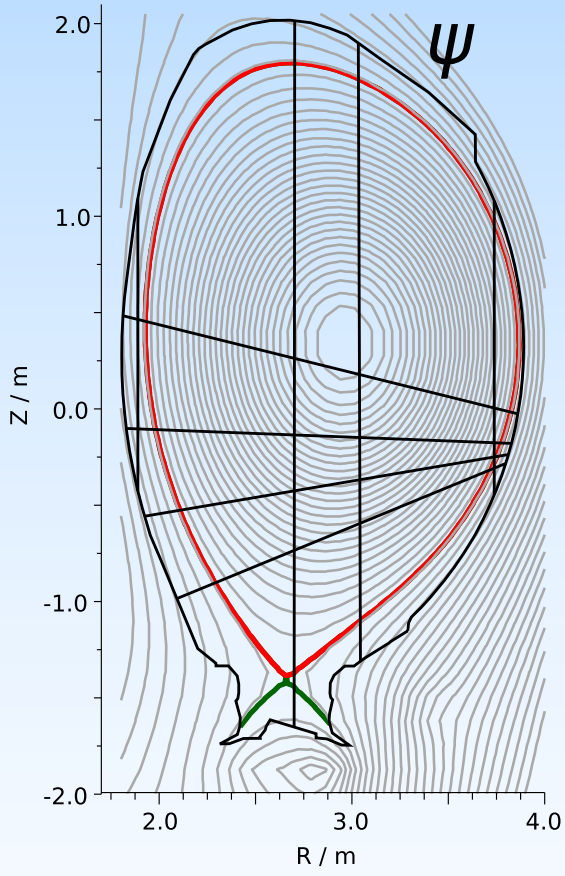


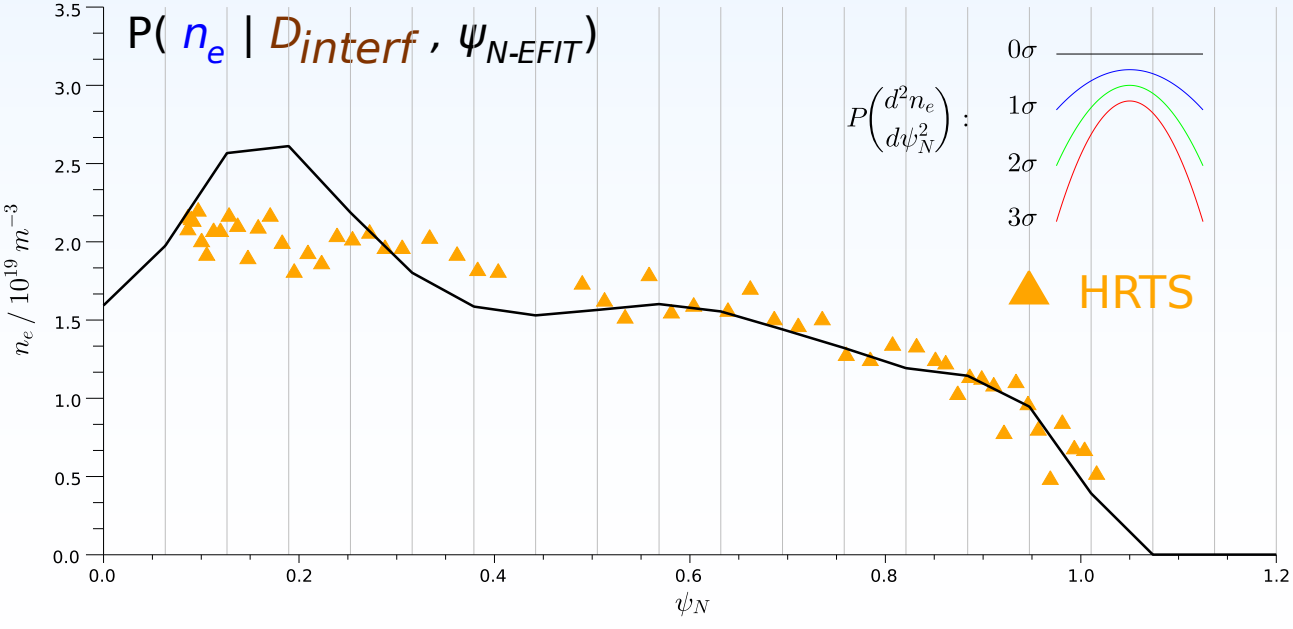


78625
Ohmic
(recovery pulse)

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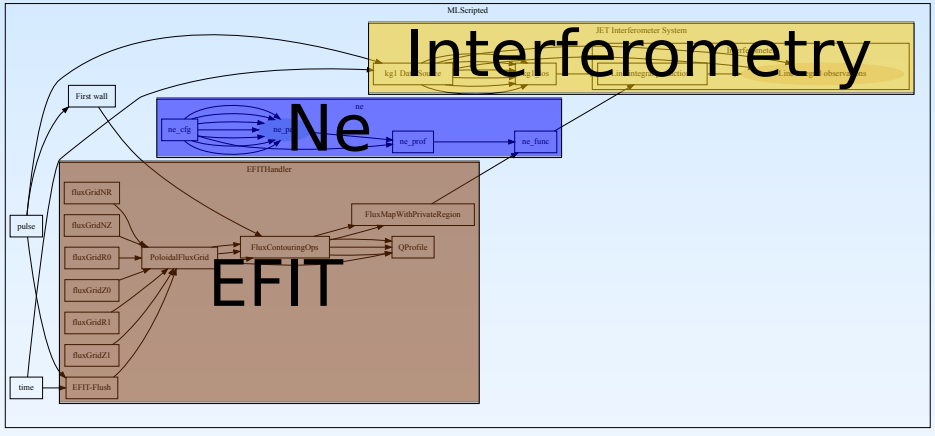


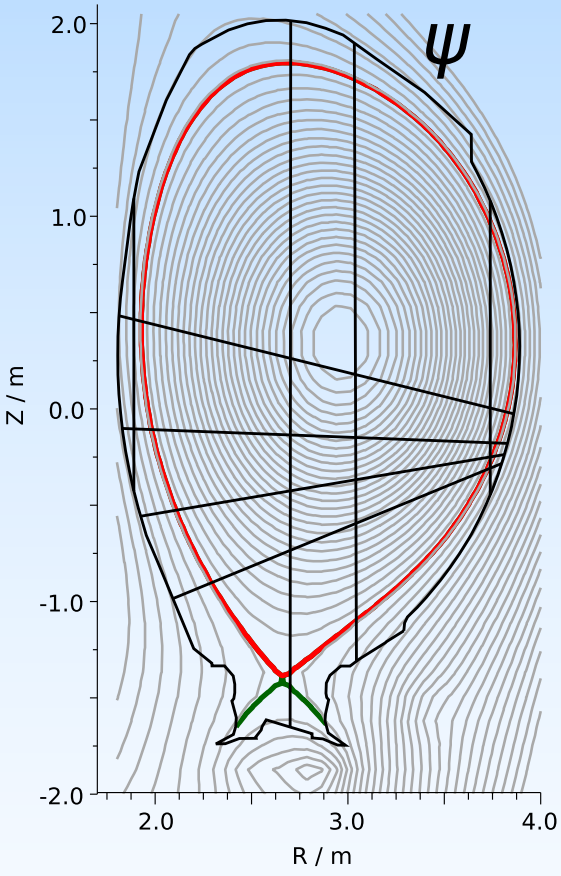


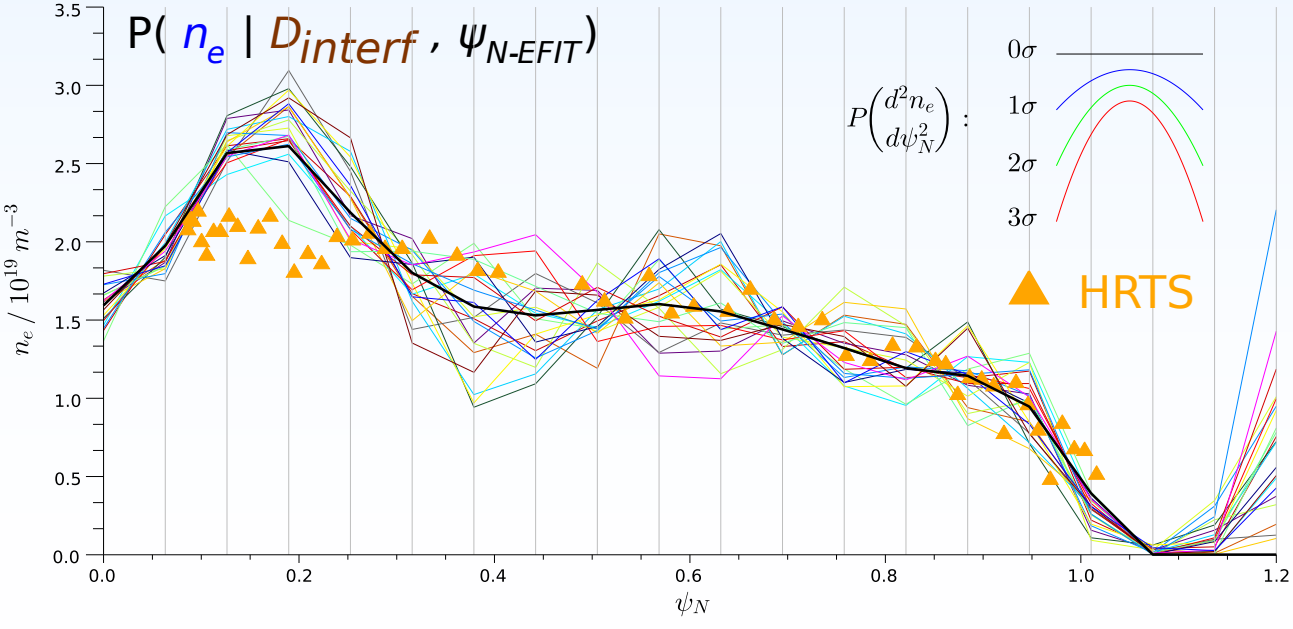


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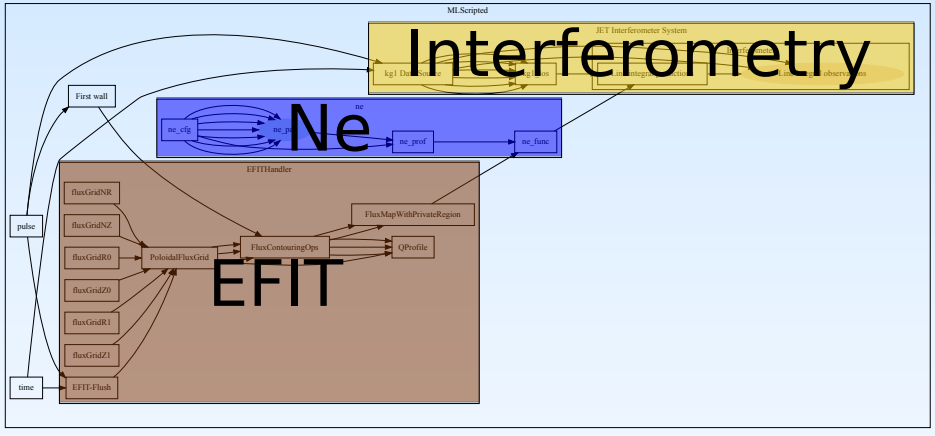


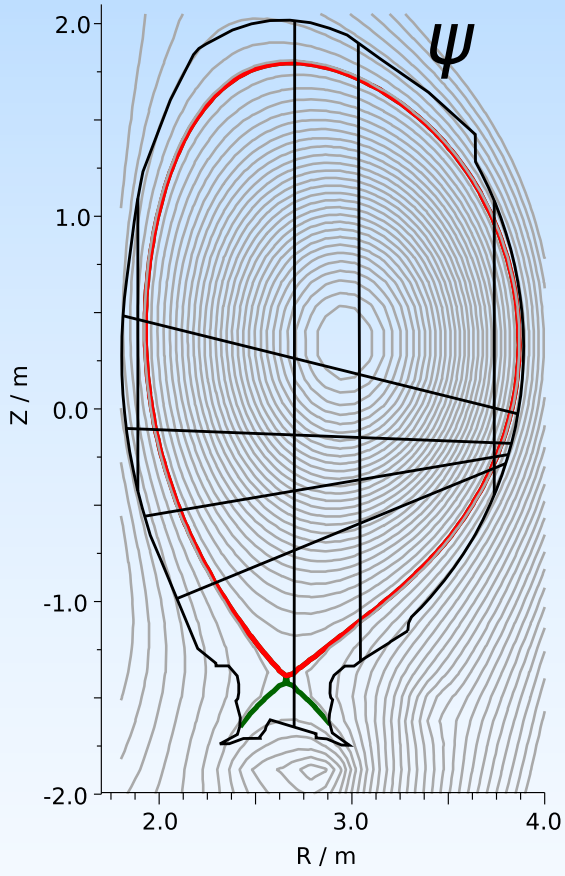


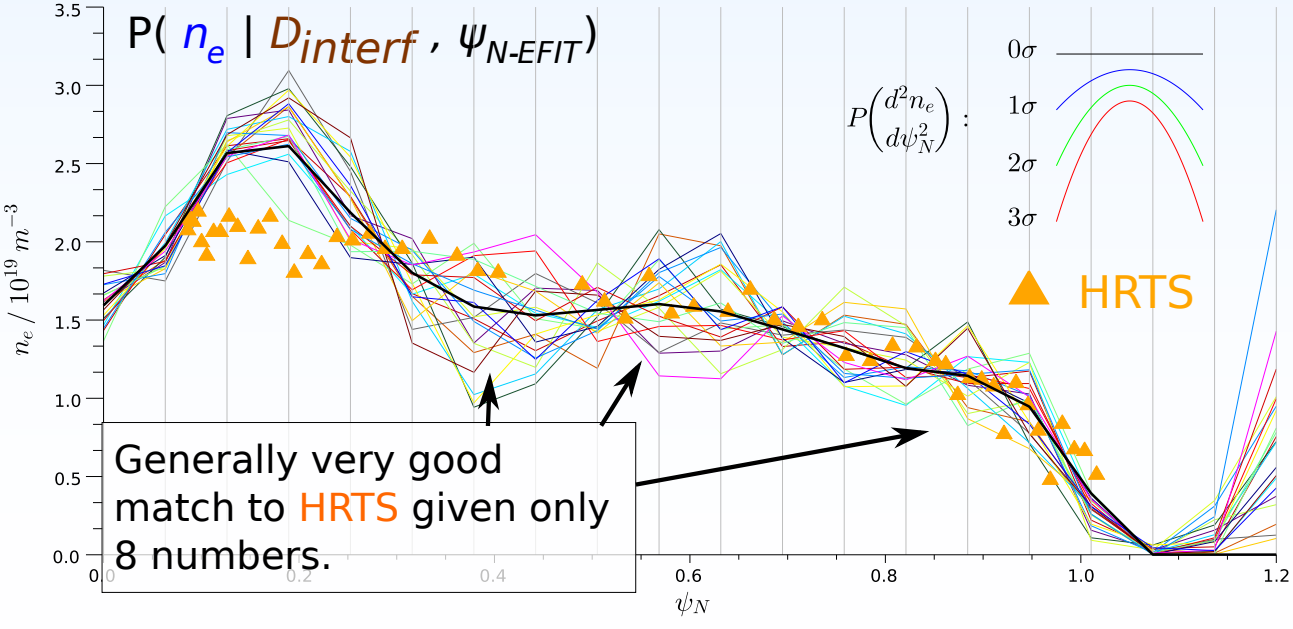


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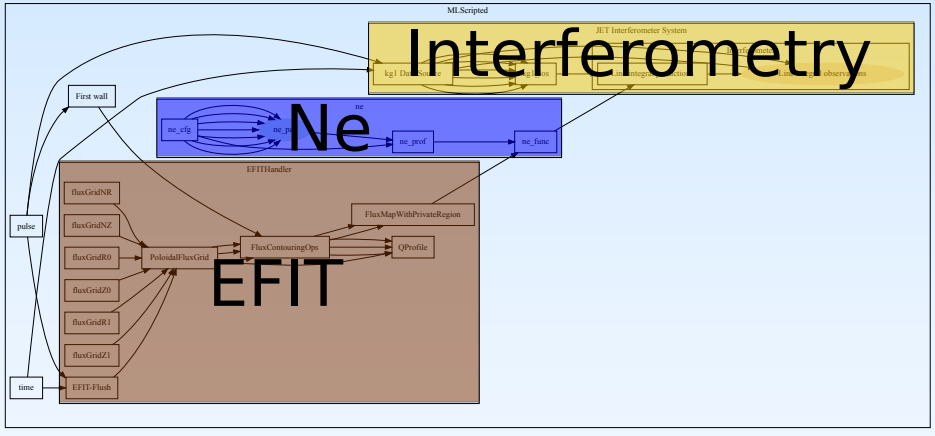


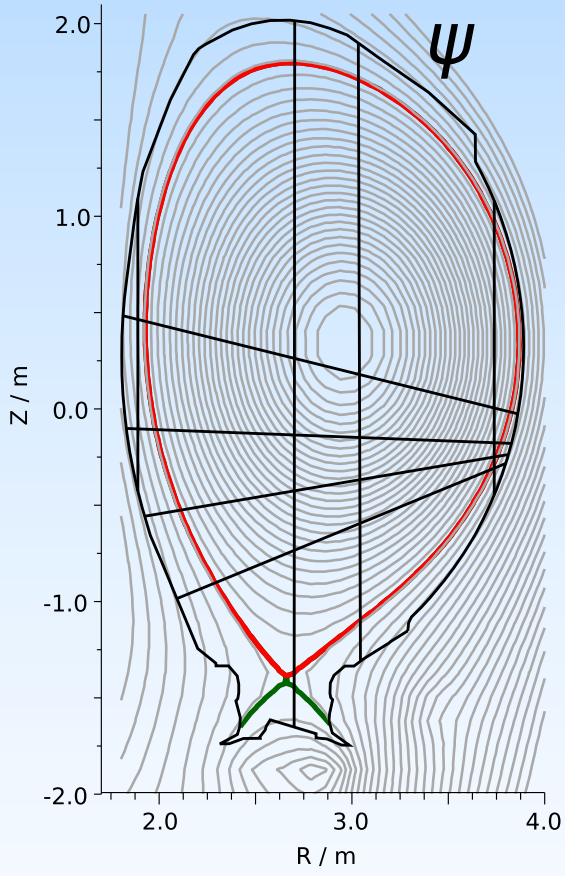


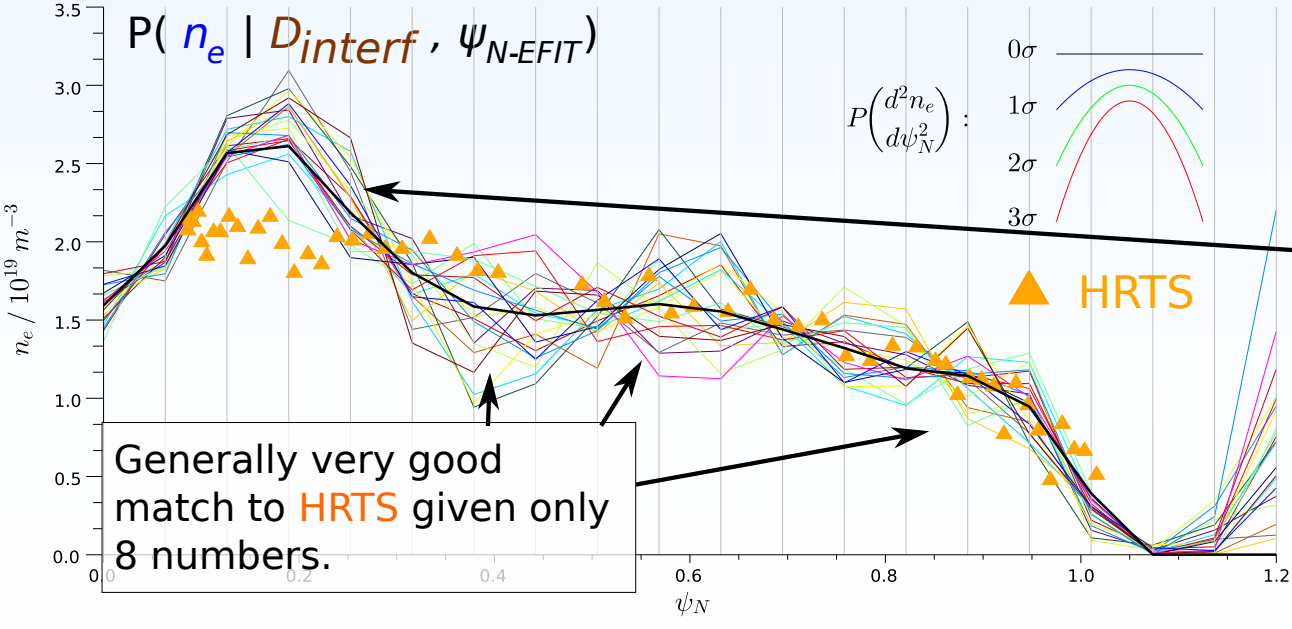


Generally very good match to HRTS given only 8 numbers.

But, all possible profiles show structure we do not believe, so an assumption must be incorrect:
$\psi_N$ not perfect?

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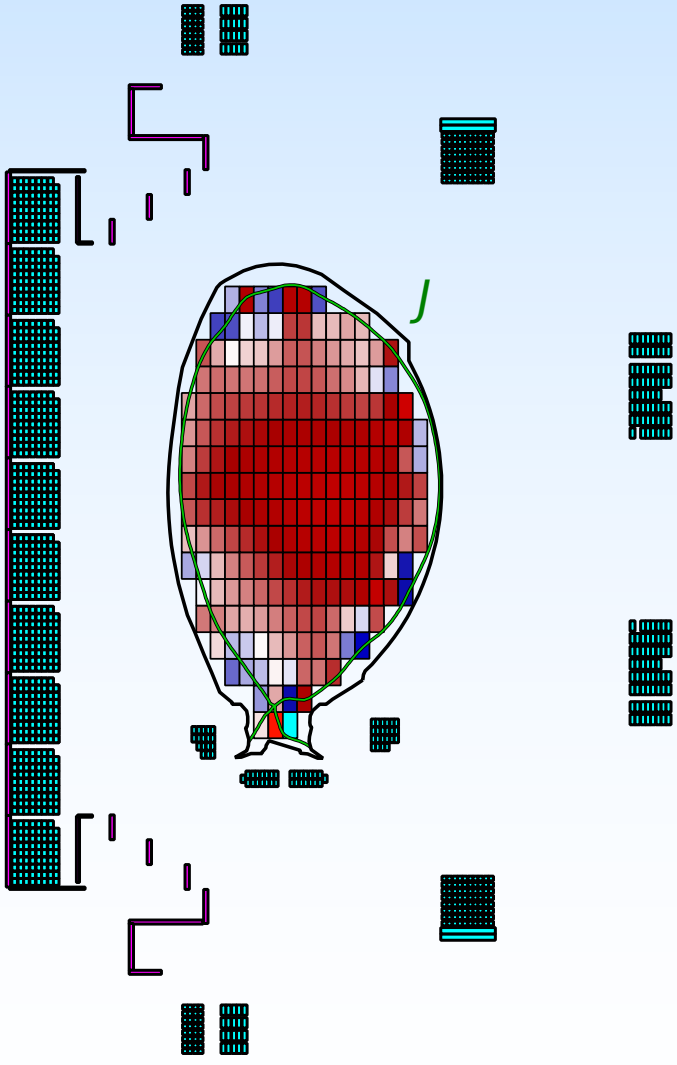
# Interferometry + Current Tomography I

Instead, calculate $\psi_N$ from toroidal currents $J$



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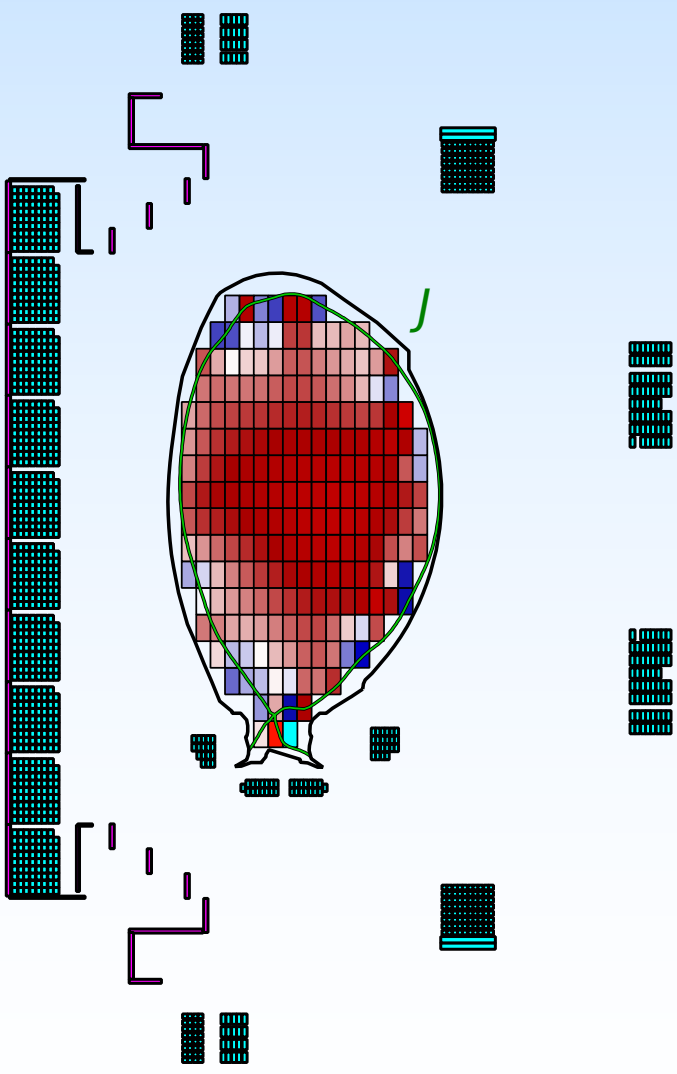
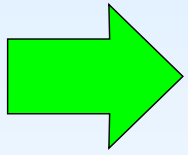
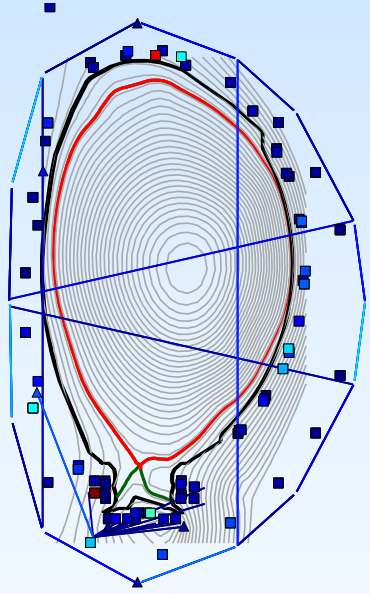
Instead, calculate $\psi_N$ from toroidal currents $J$, include magnetics diagnostics and invert to full posterior:

i.e: Find combinations of $J$ and $n_e$ that are consistent with both interferometry and magnetics (and with $n_e$ and $J$ priors).





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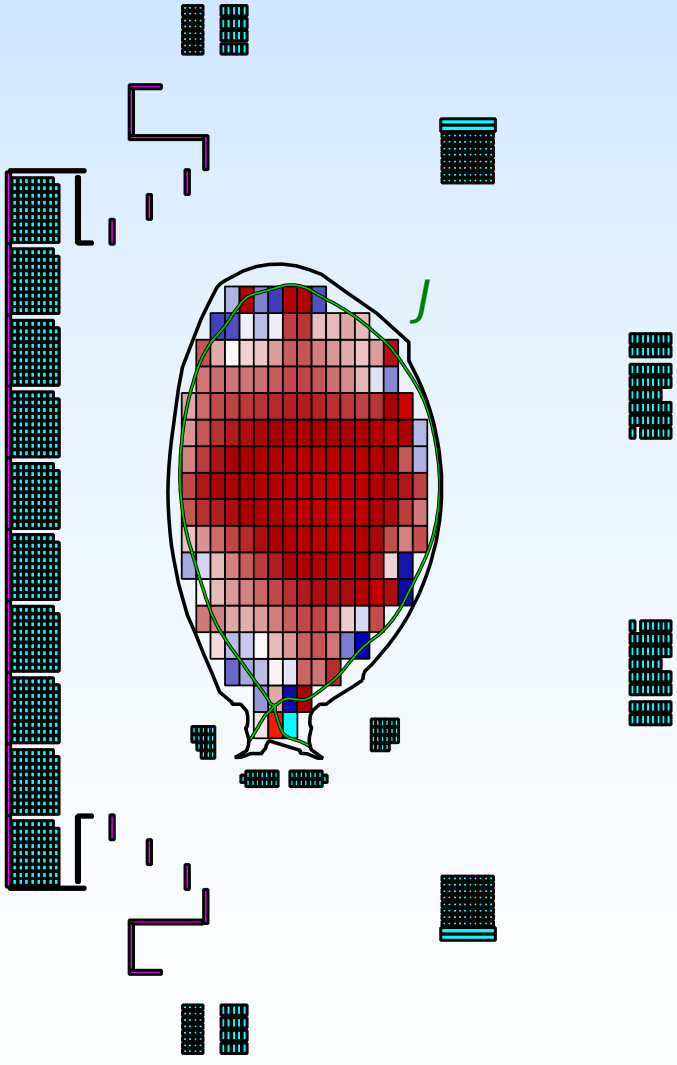


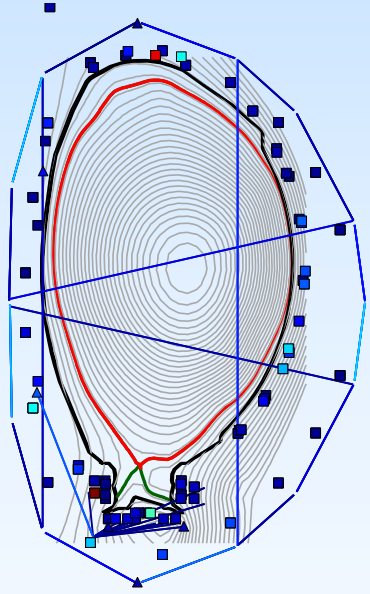

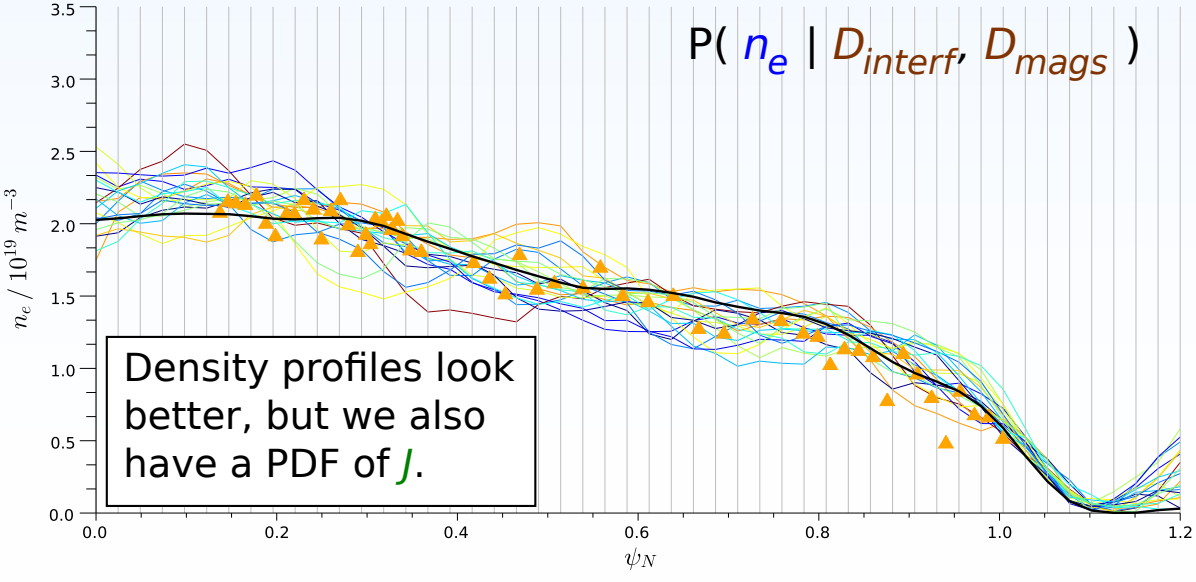

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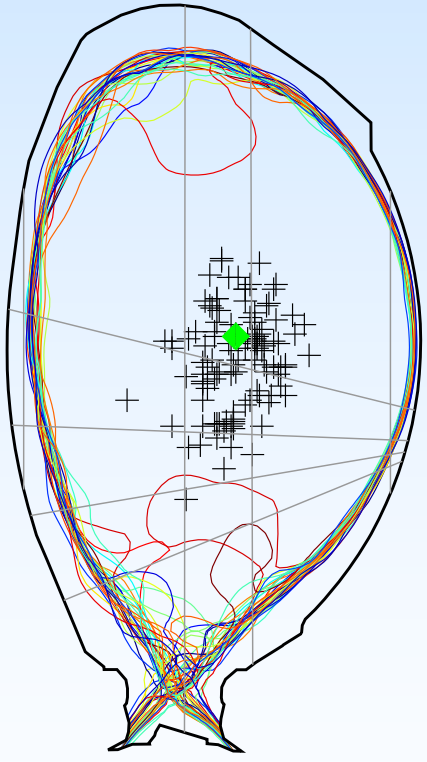
Deliberatly using over-weak currents priors, that with only magnetics gives:

$P(J \mid D_{mags})$



Magnetics
+Weak CAR prior

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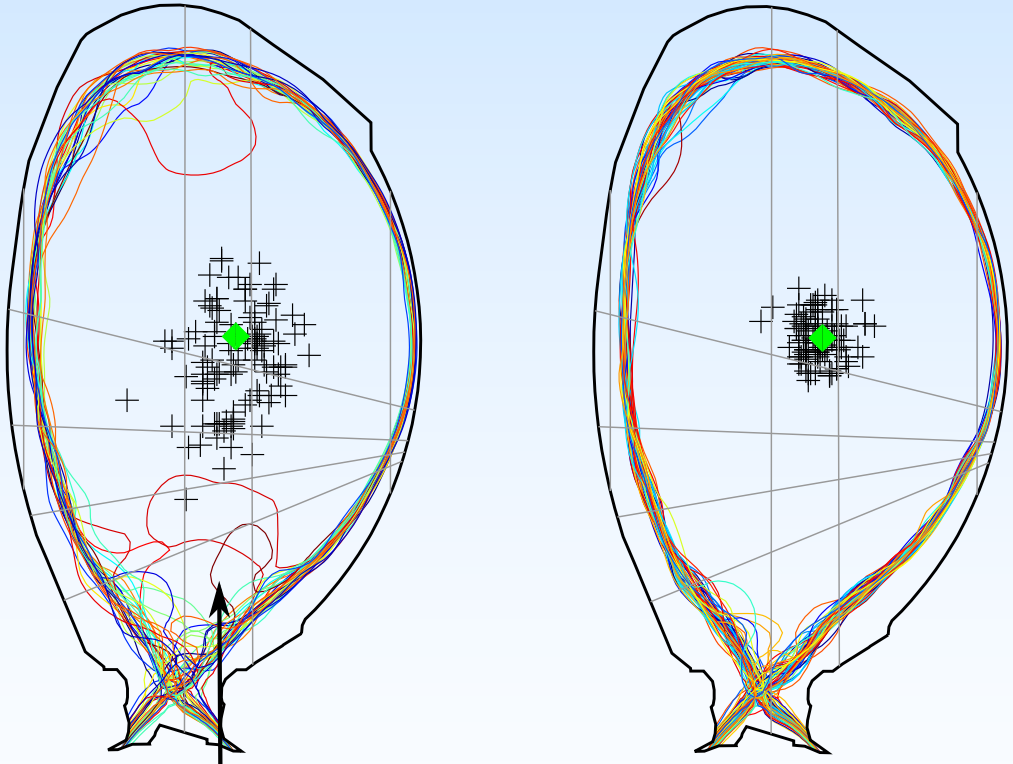

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Interferometry combined with $n_e$ assumptions
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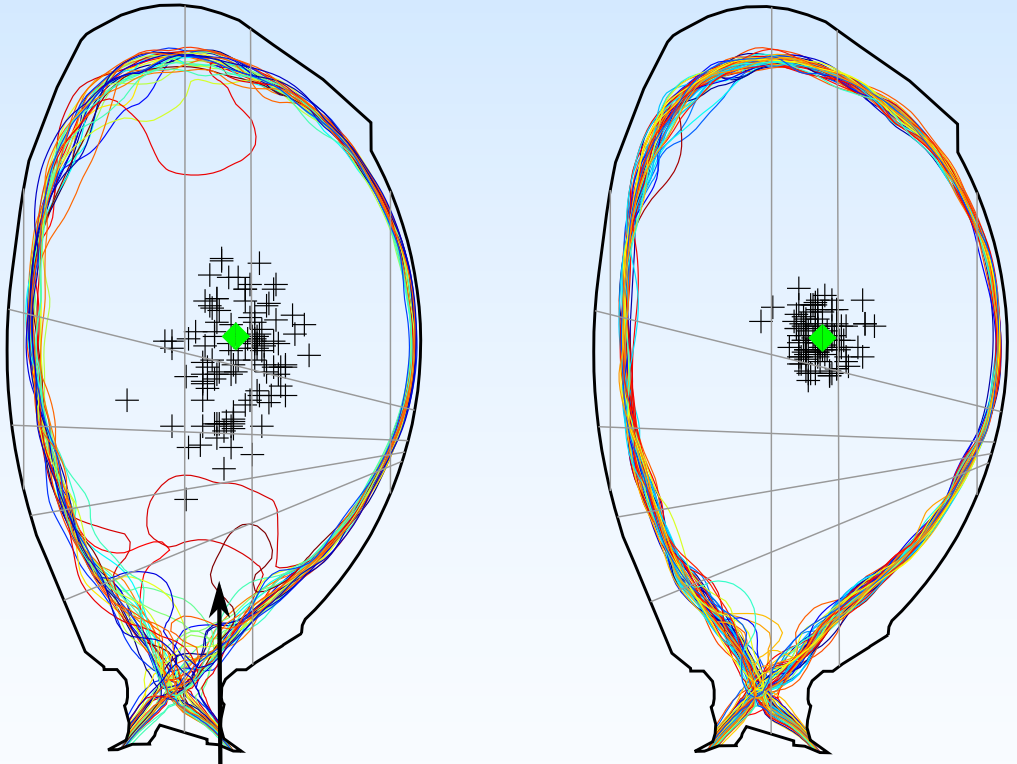

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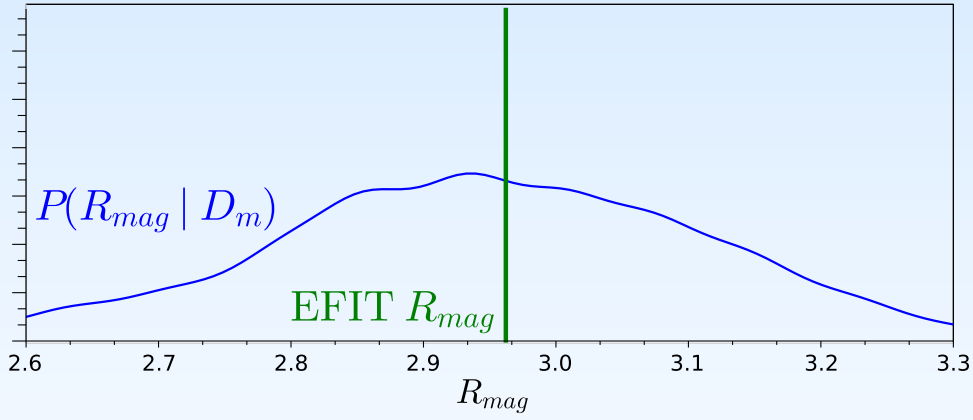


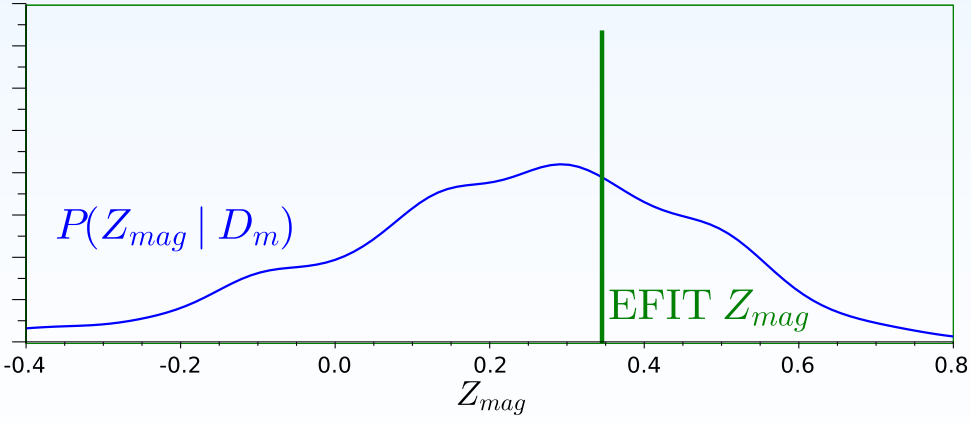


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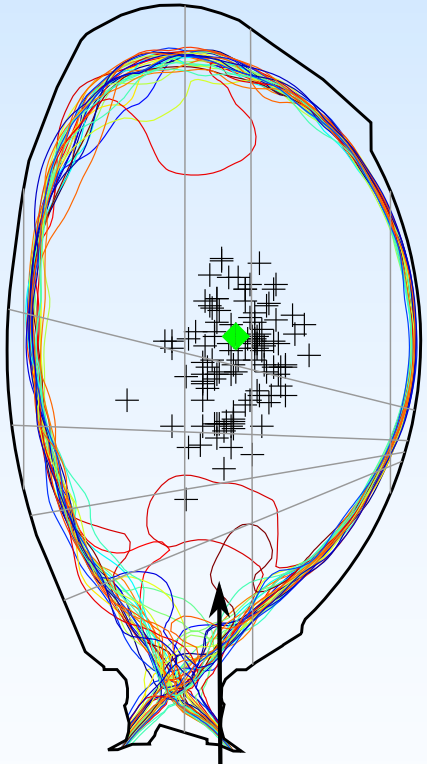

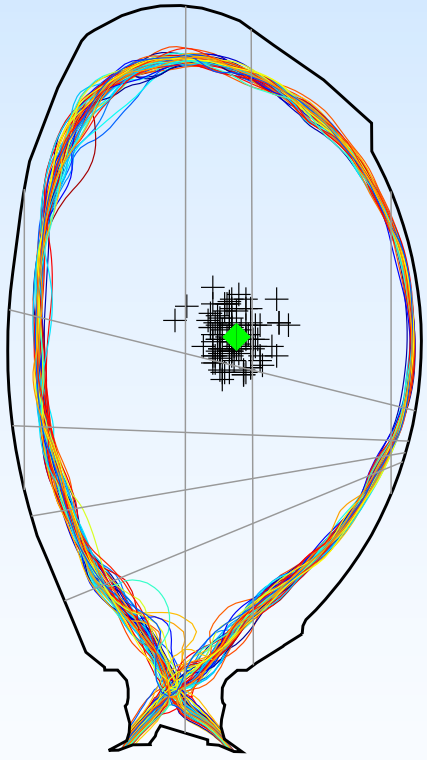

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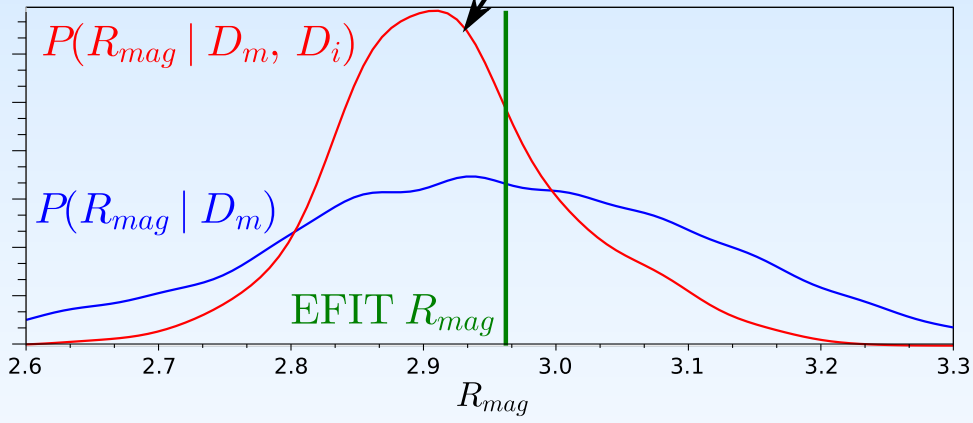
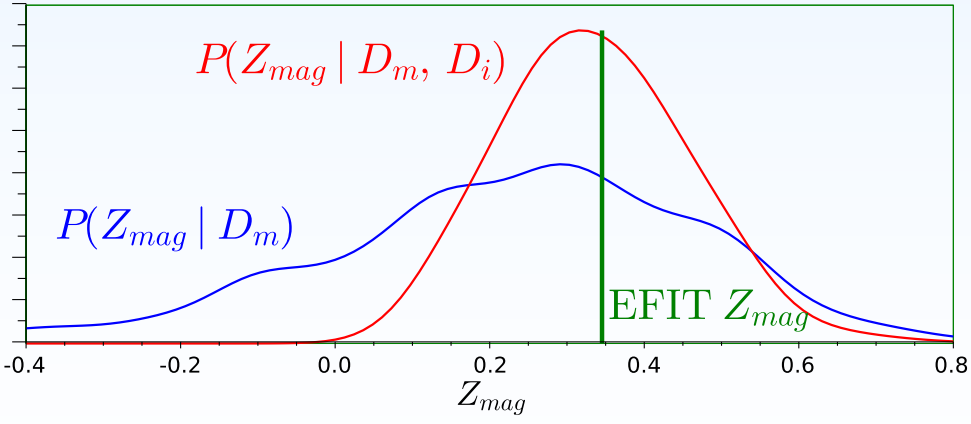
Less obviously, gives higher certainty magnetic axis

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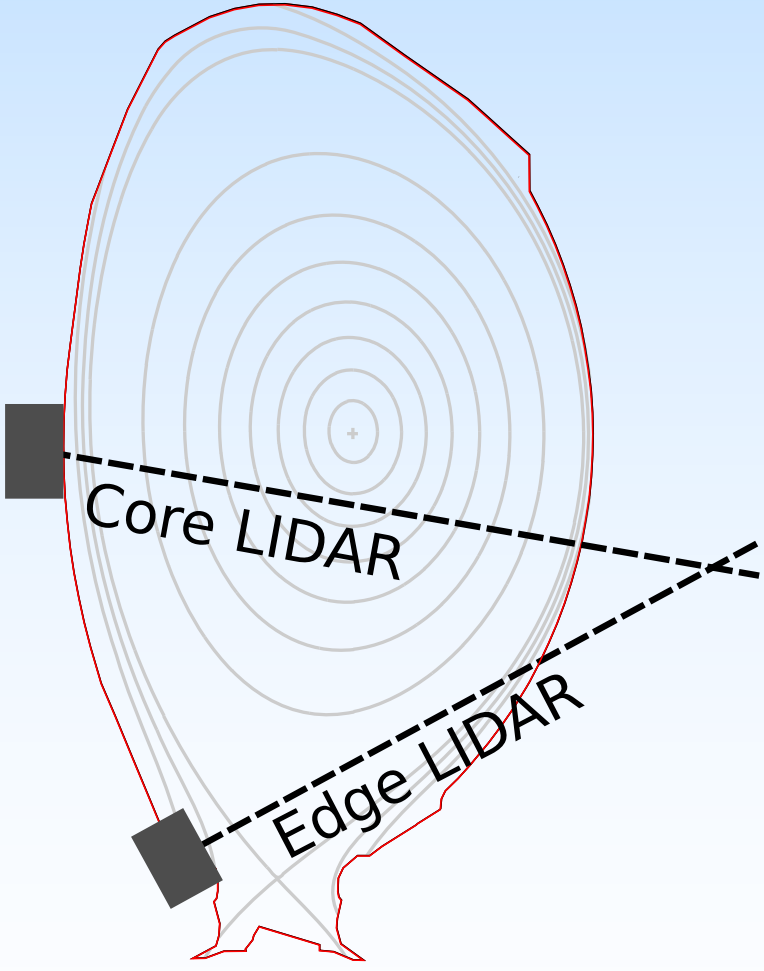

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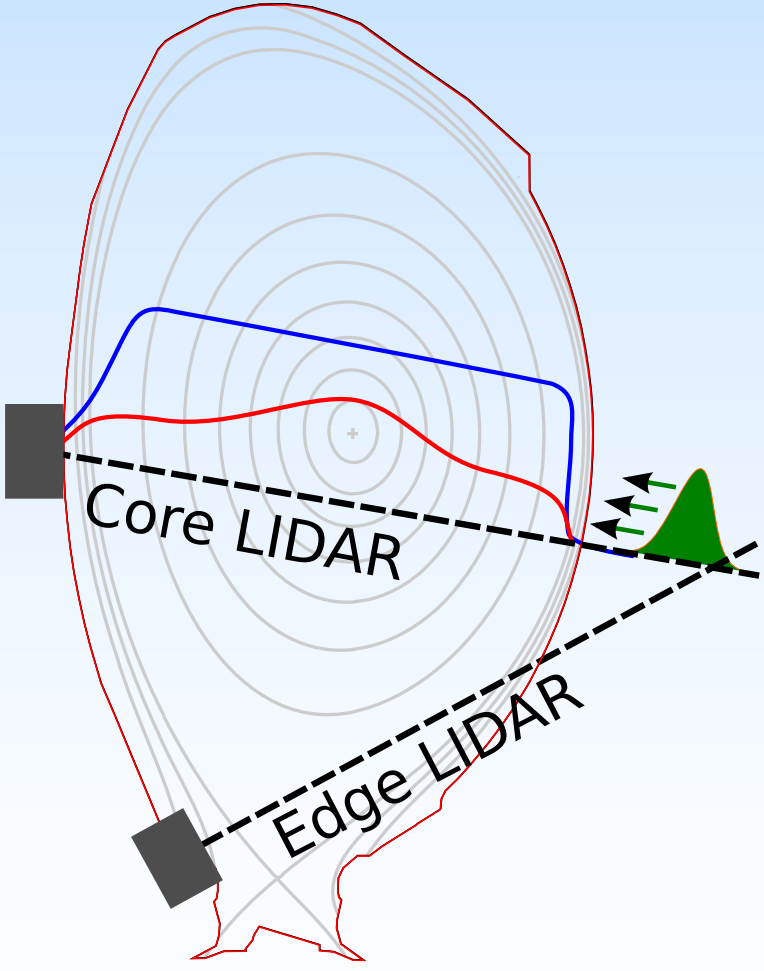

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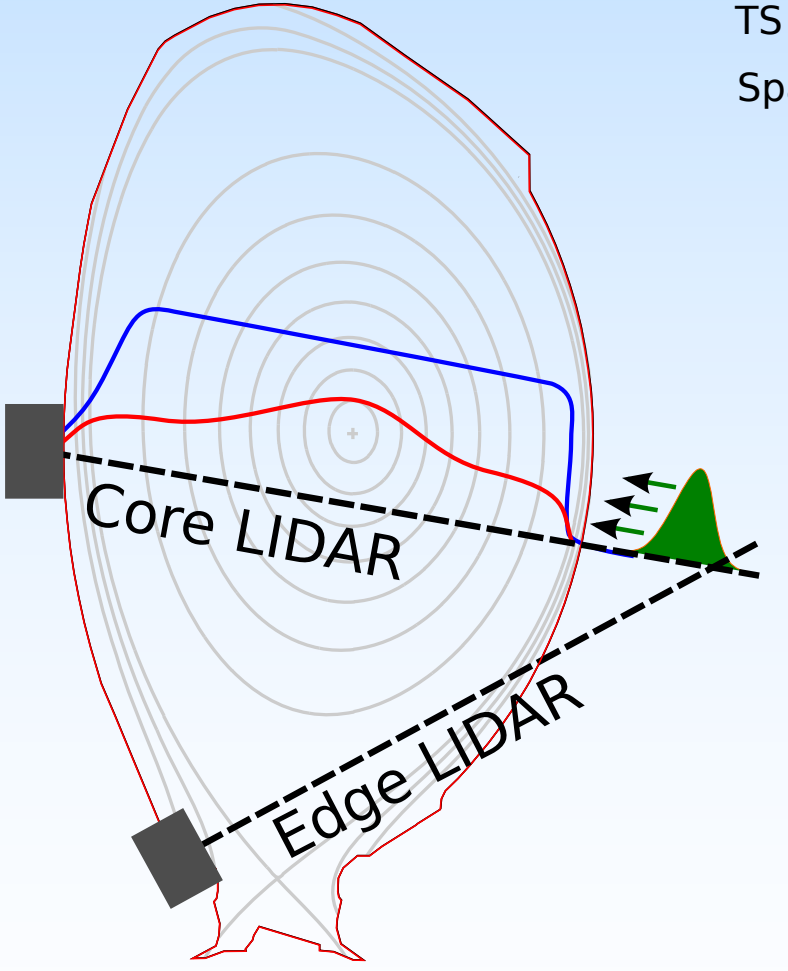


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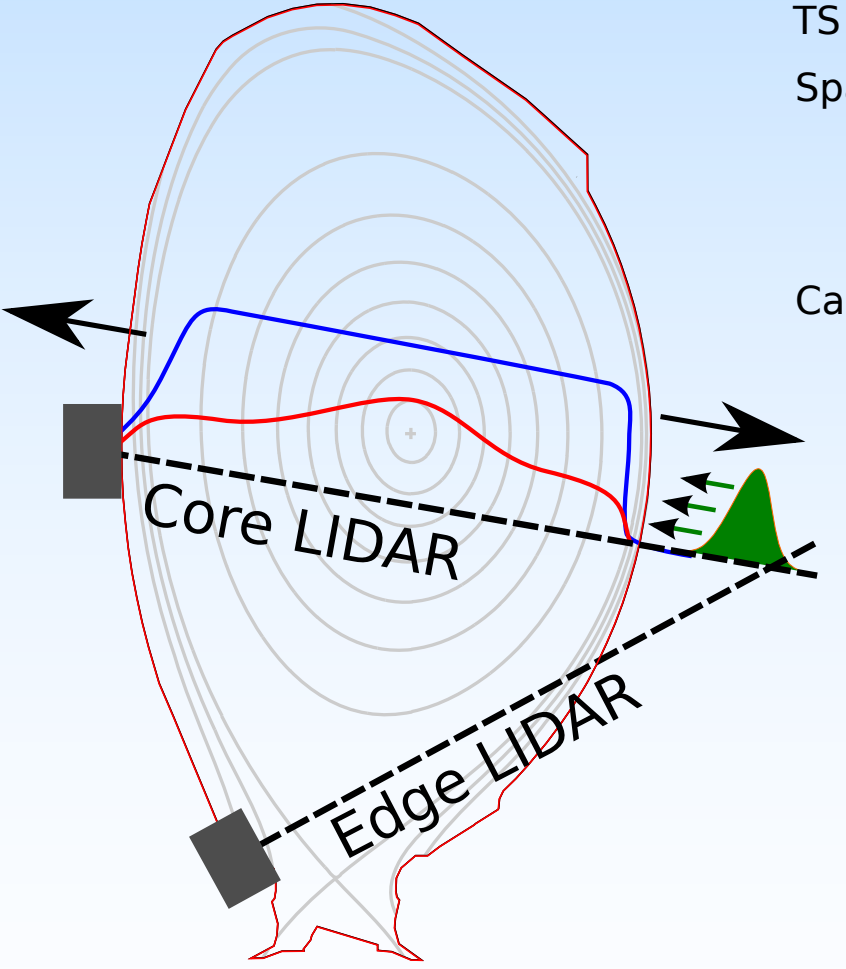


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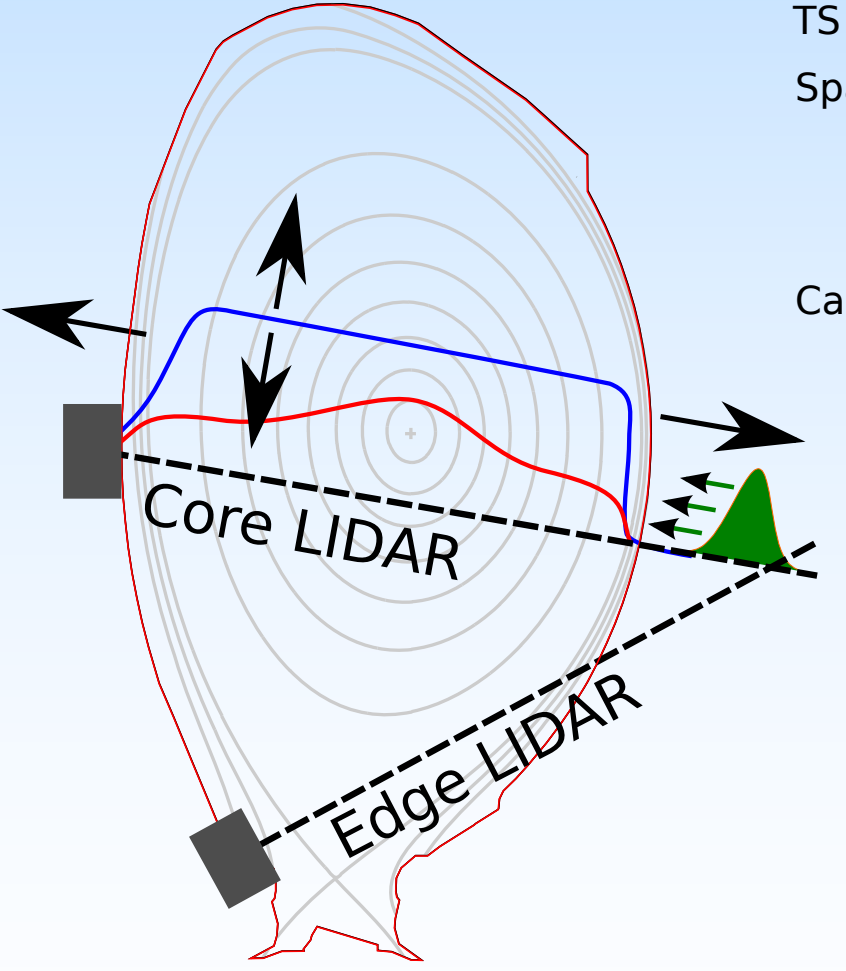


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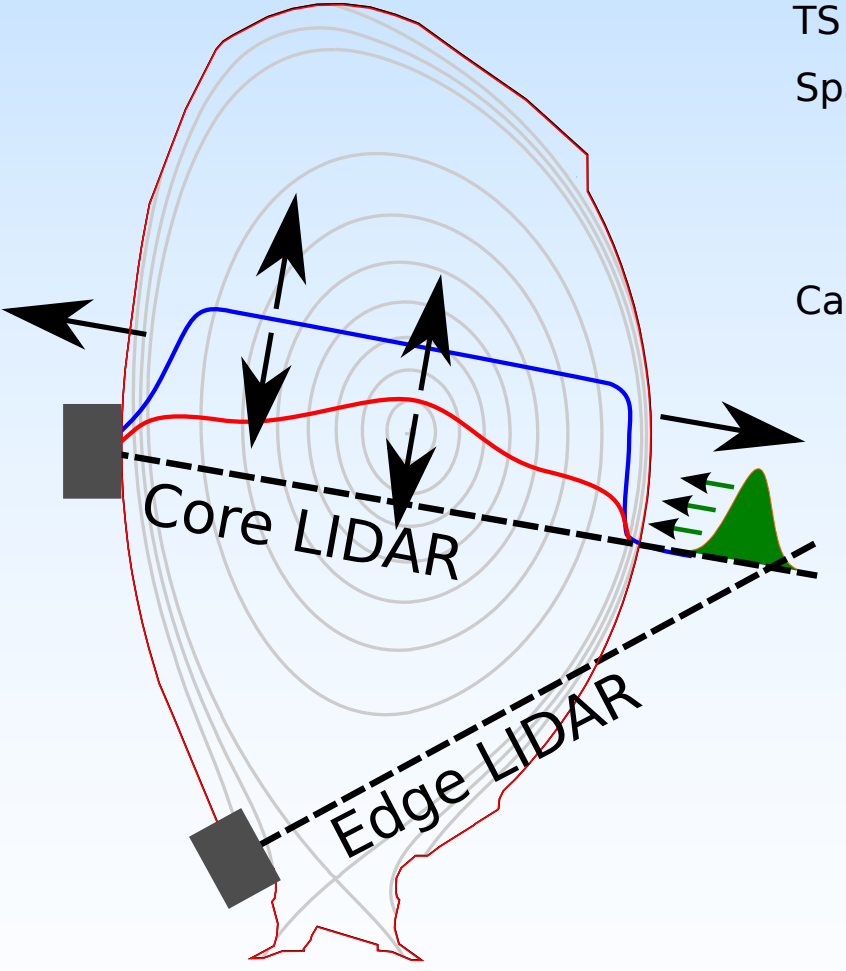


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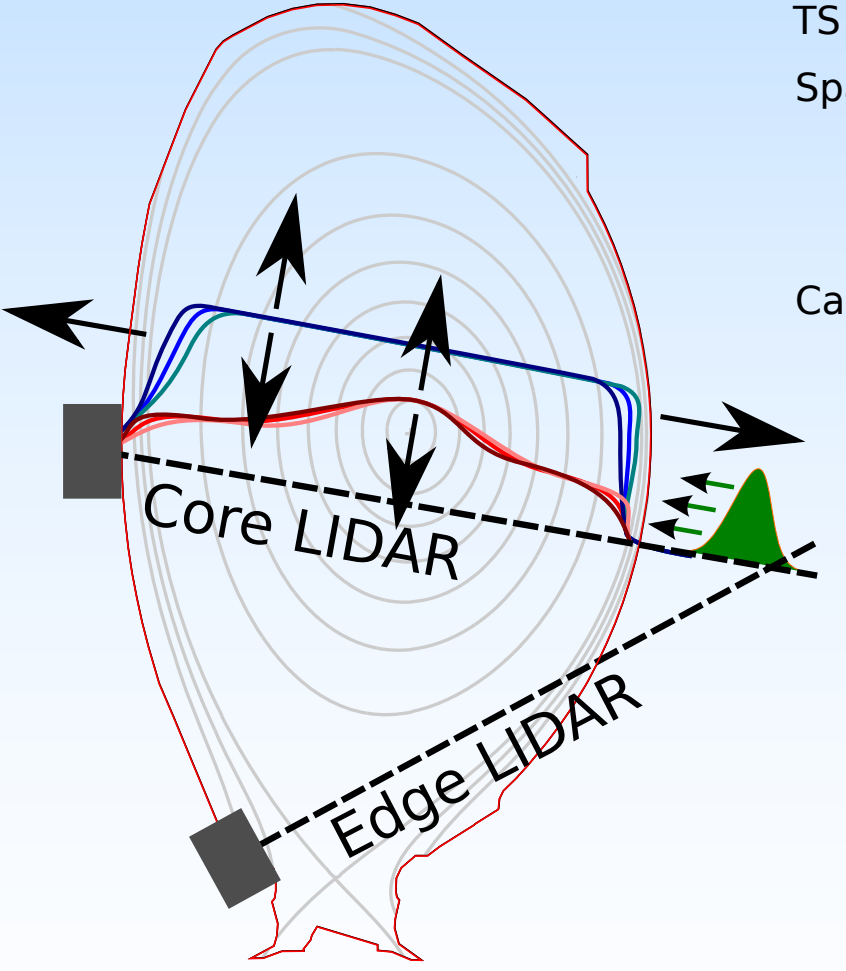


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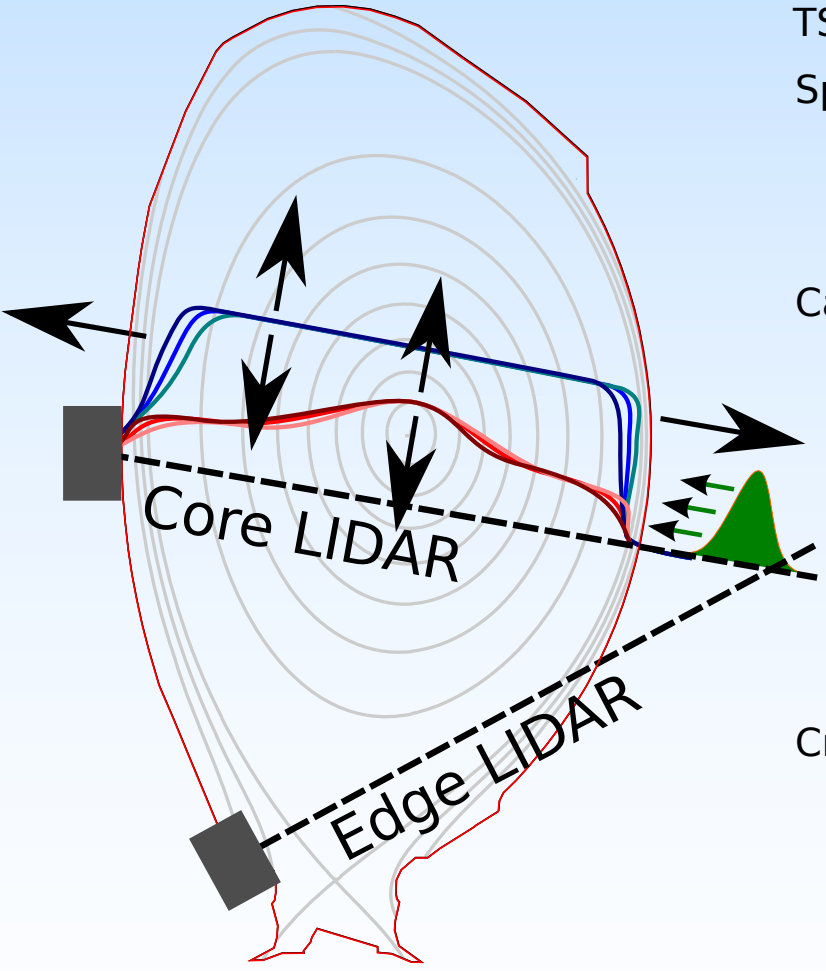


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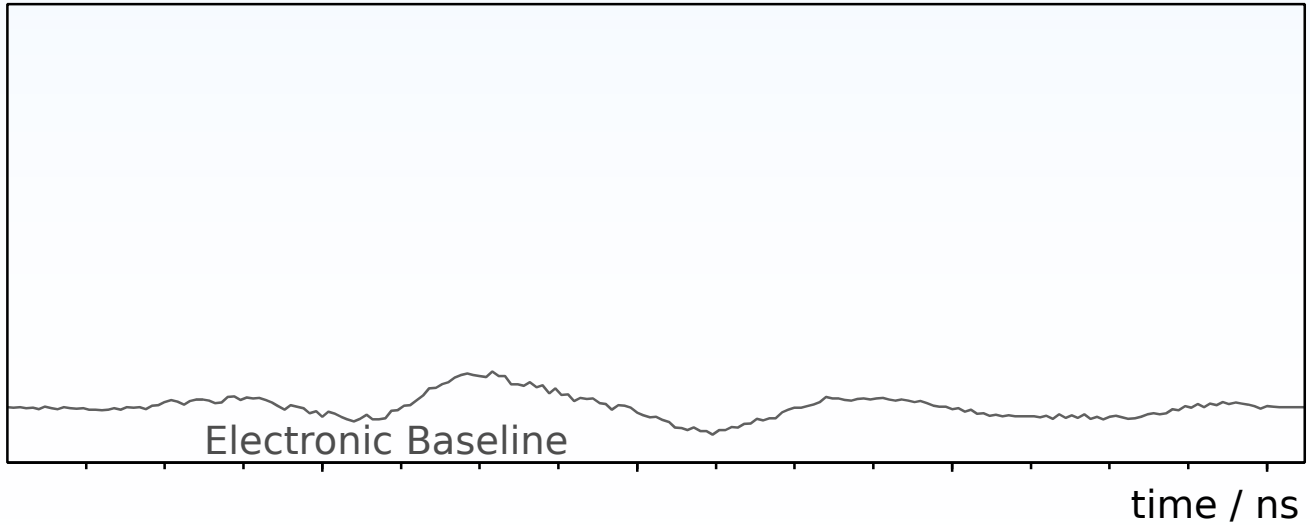

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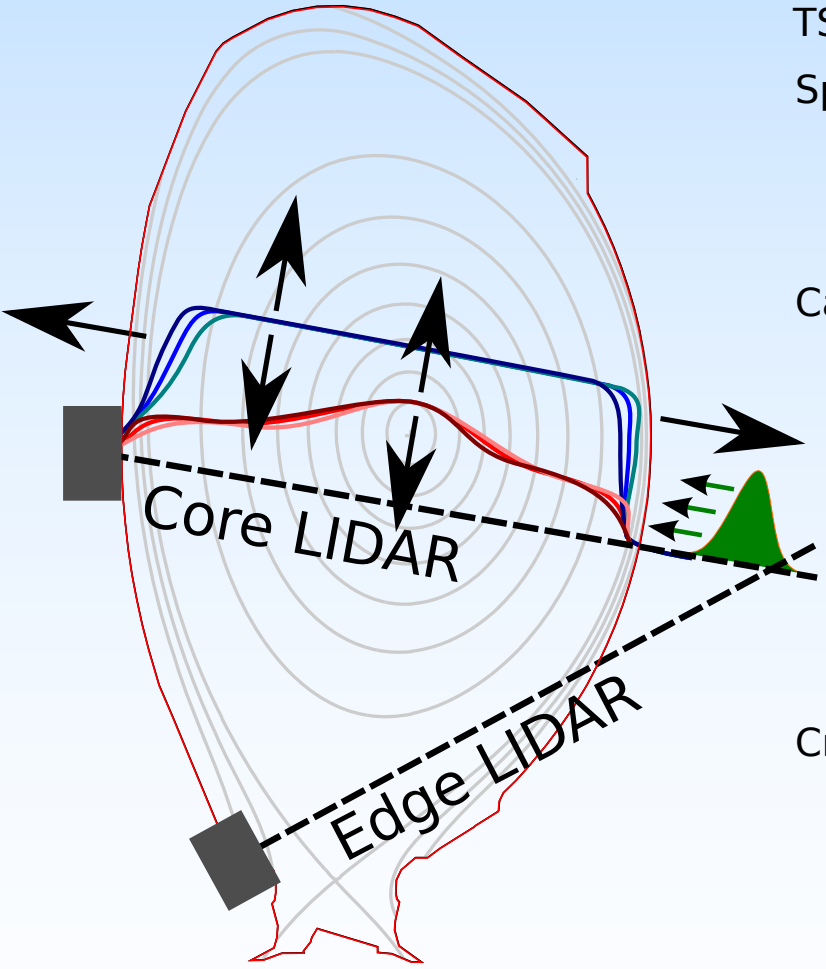


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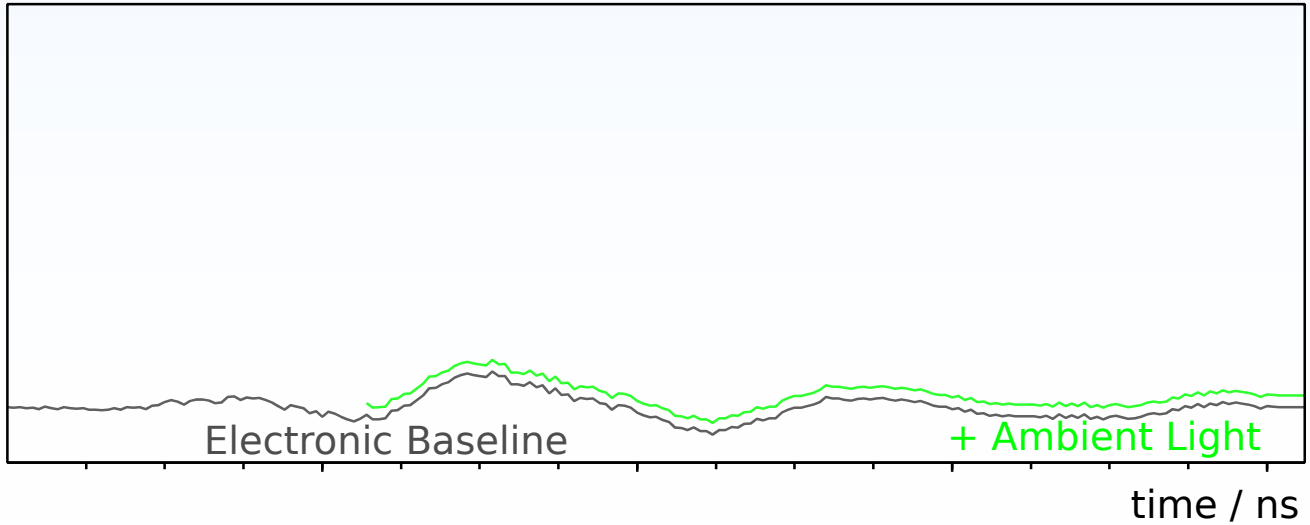

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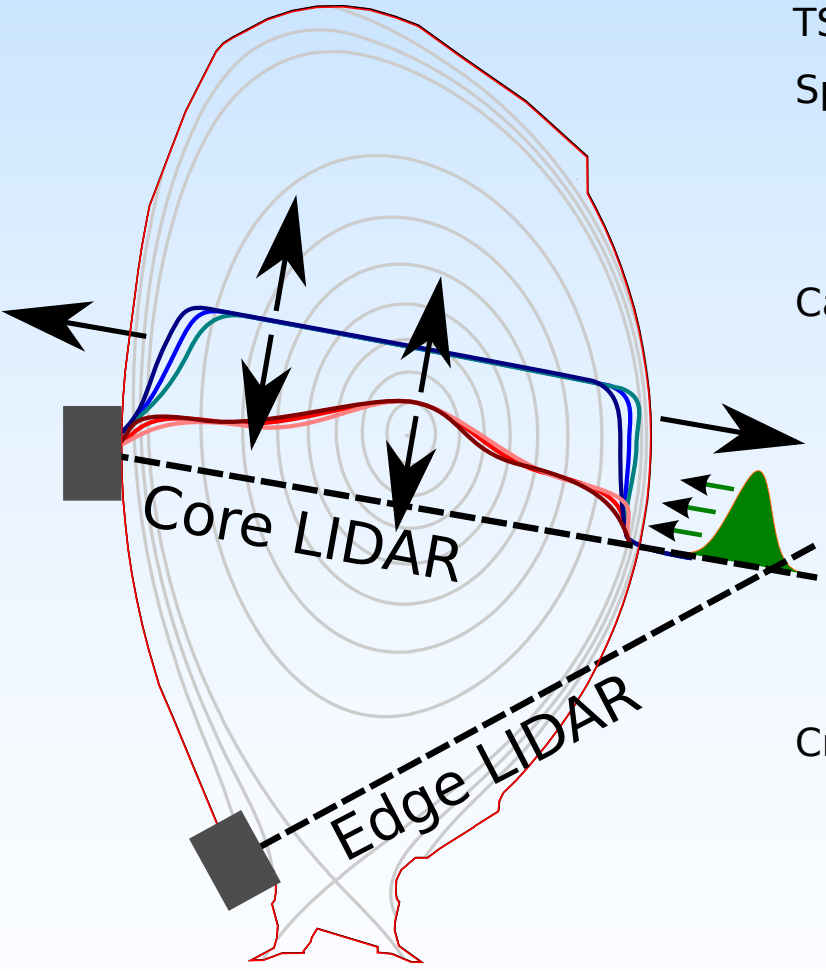


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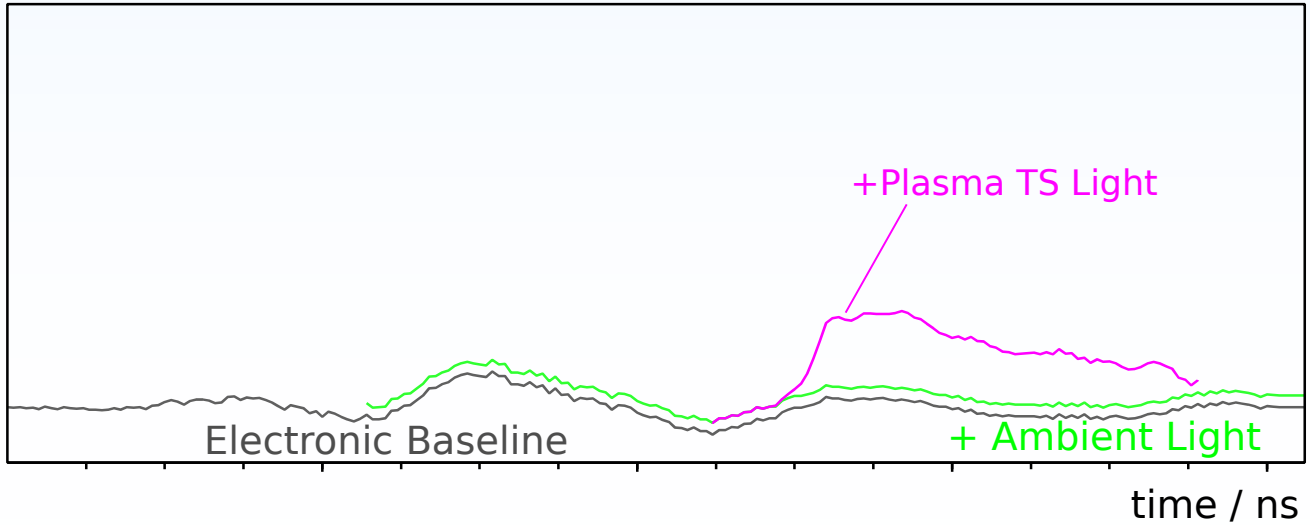

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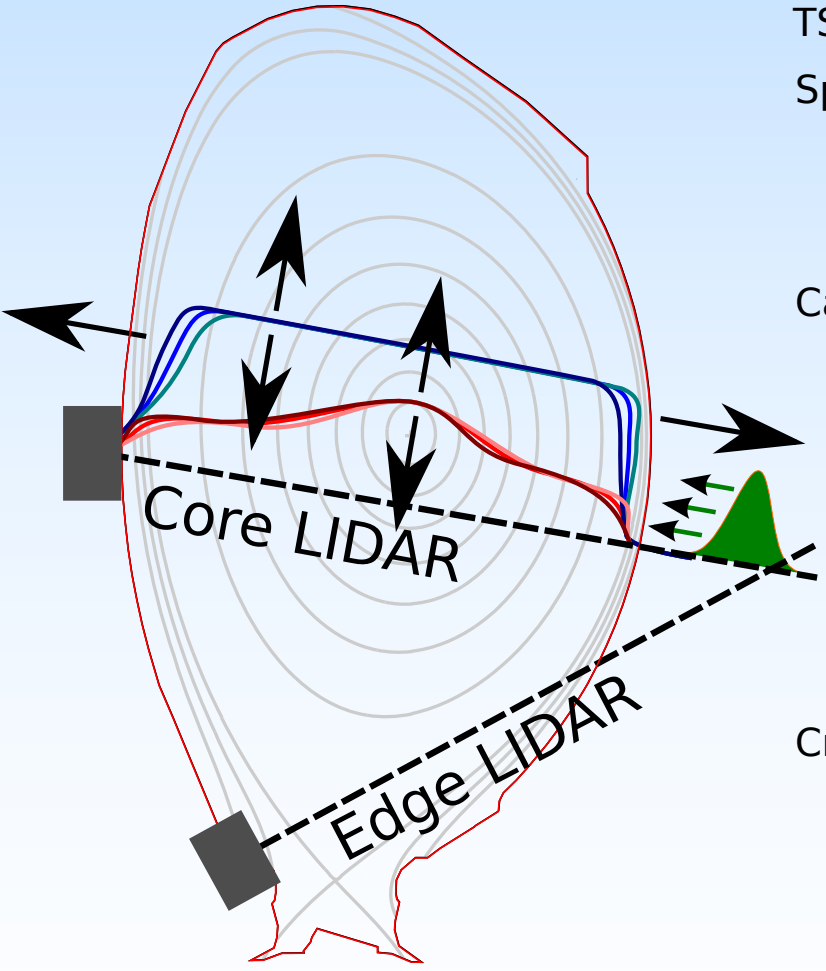


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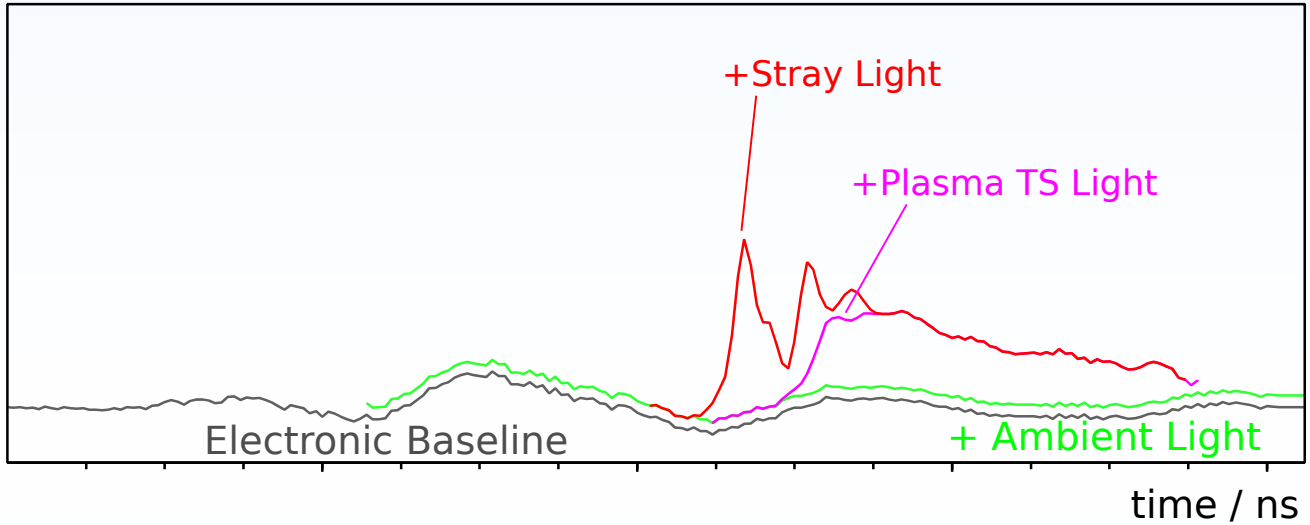

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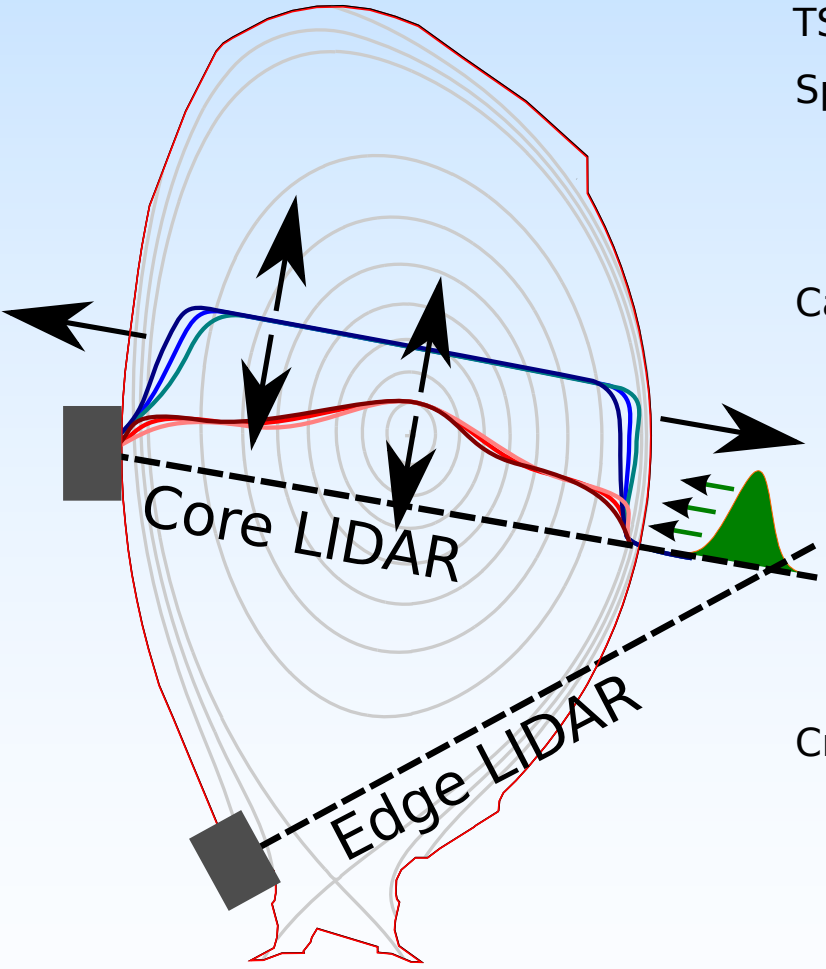


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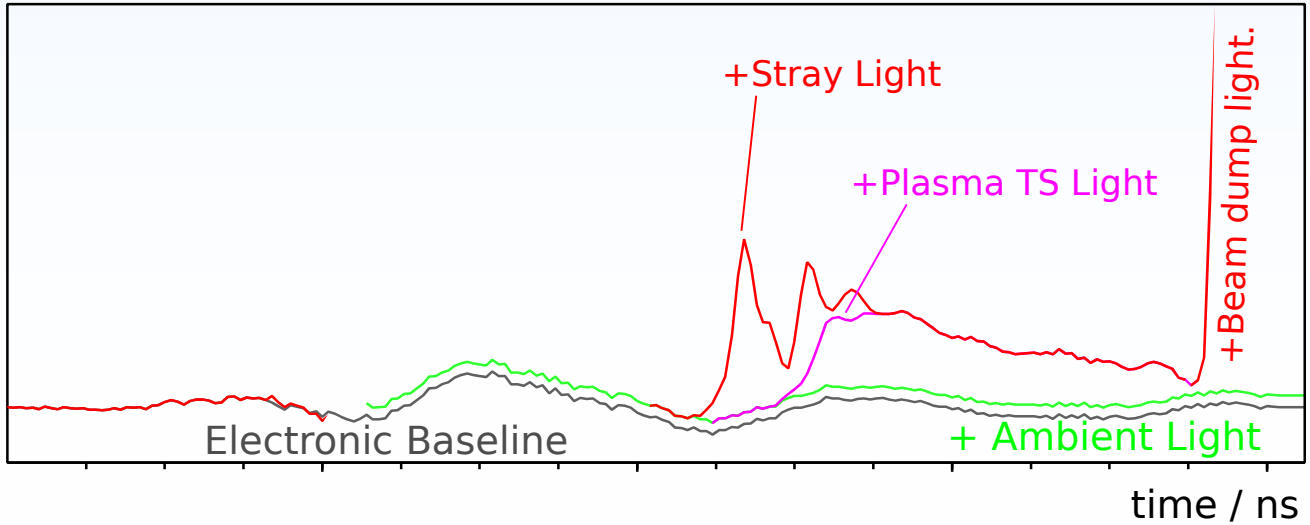

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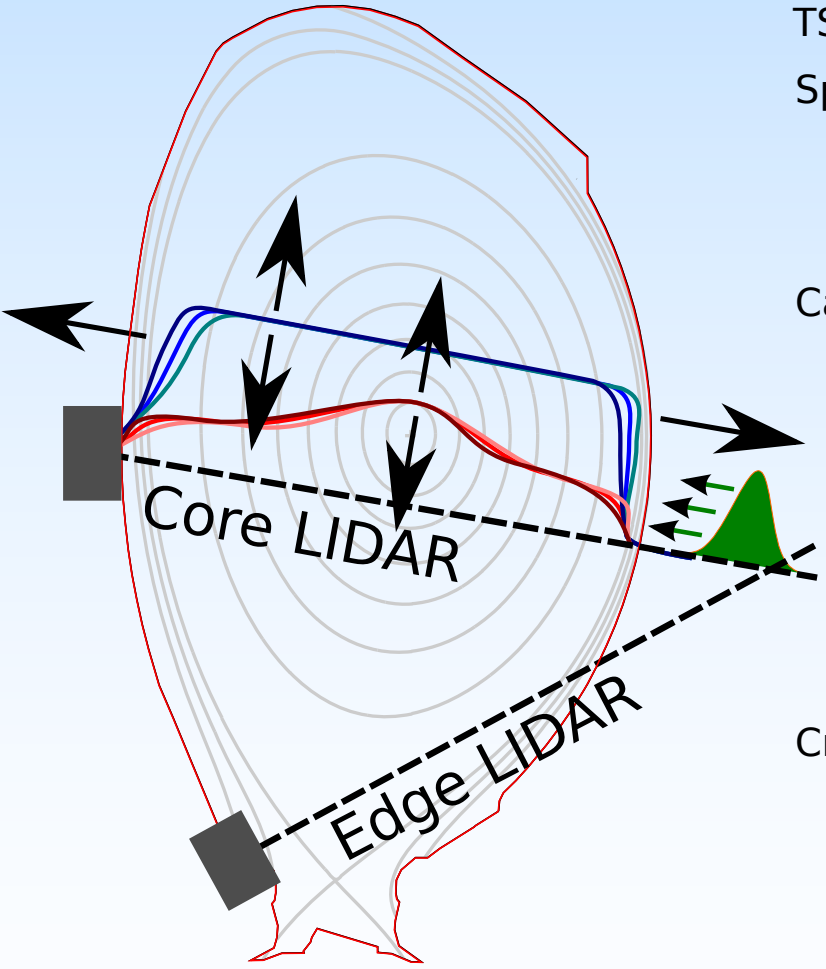


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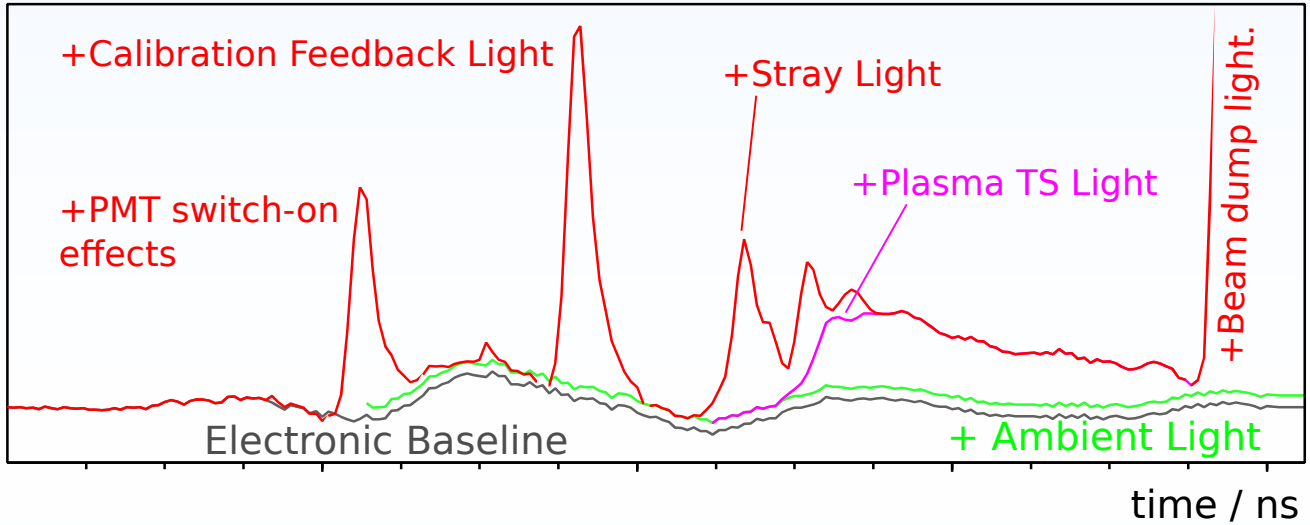

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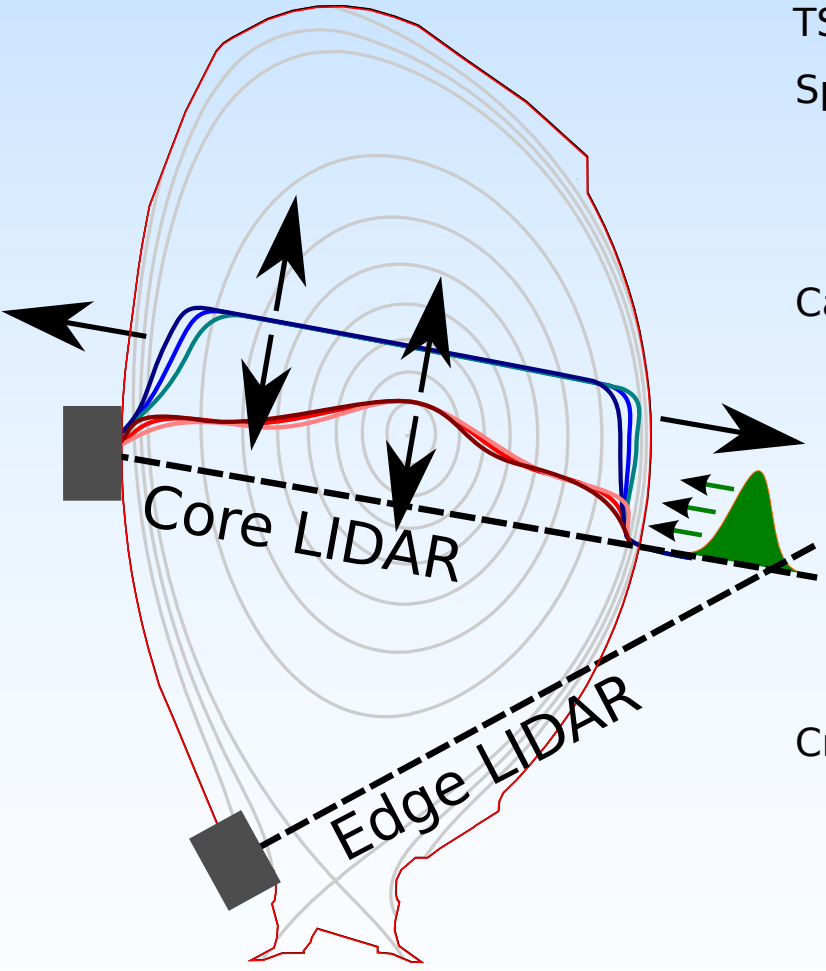


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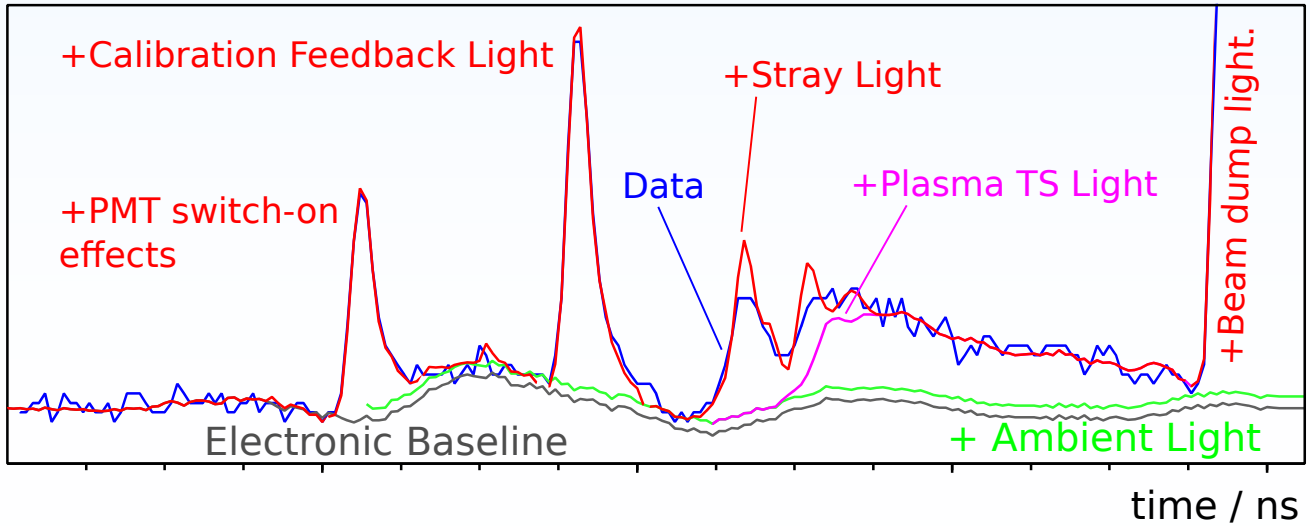

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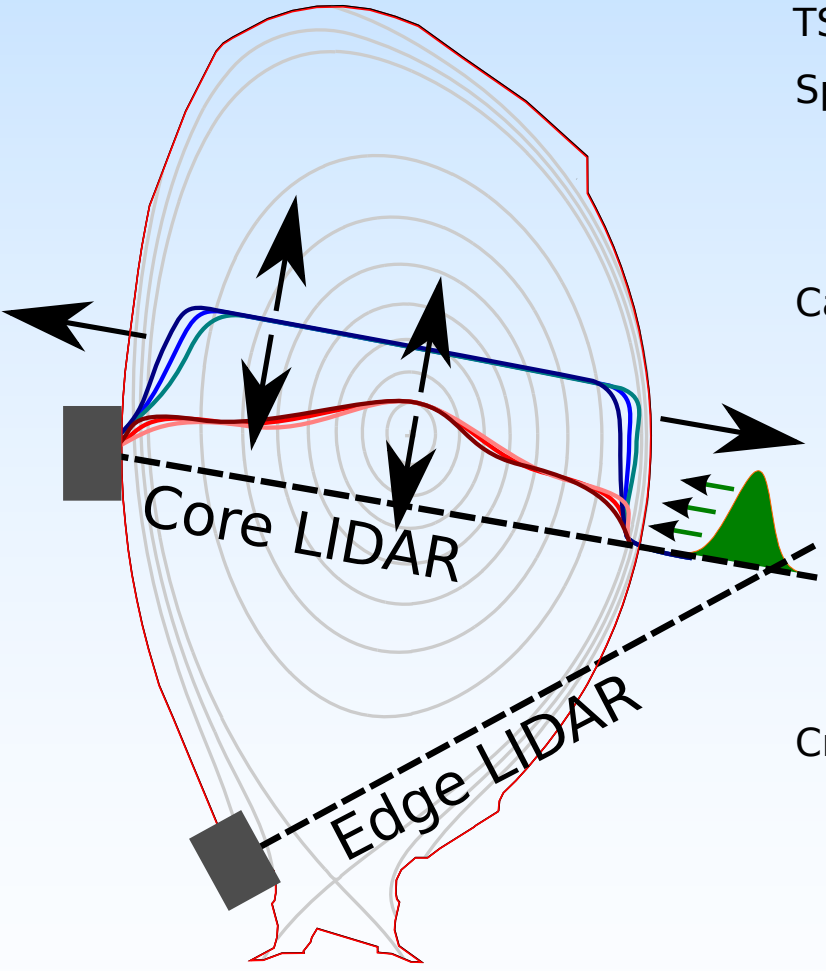


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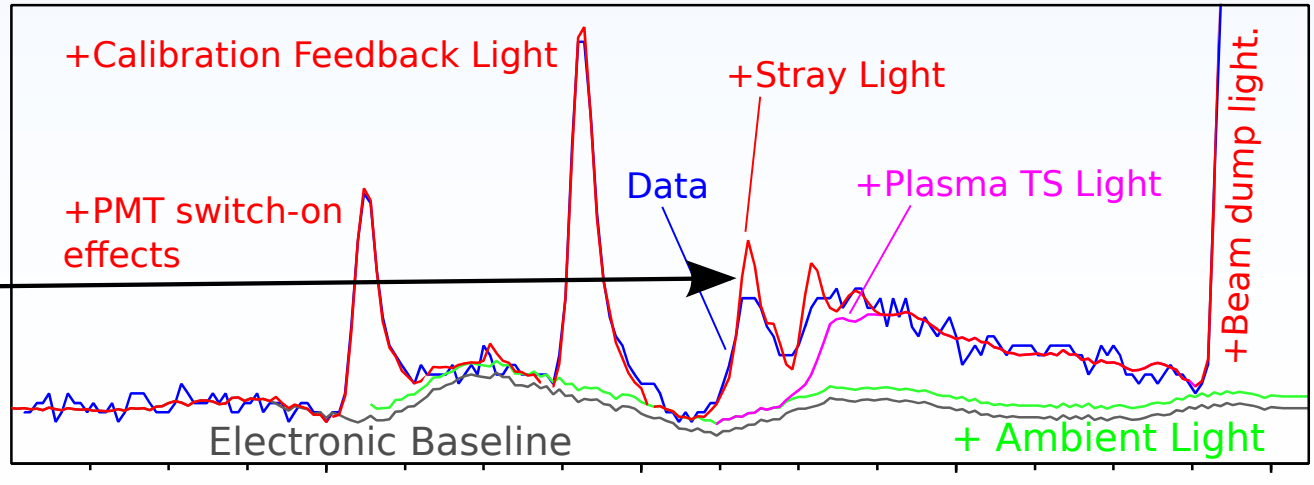


Stray light effects low signal (low $ne$) data on both systems but is **vital** for proper edge LIDAR analysis.

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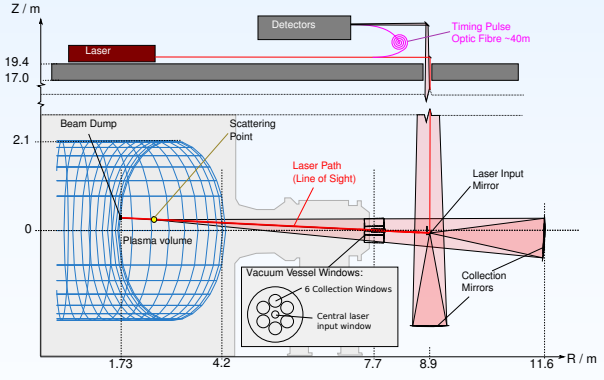


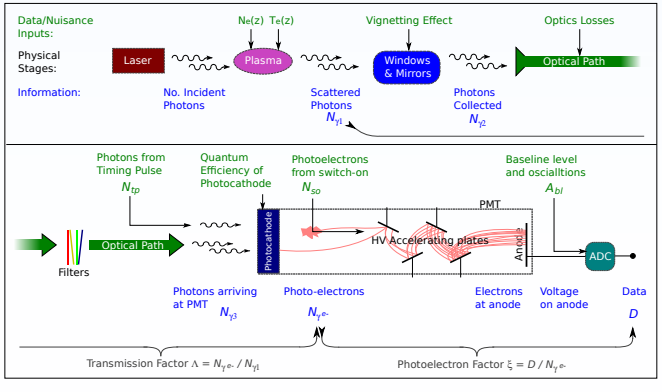


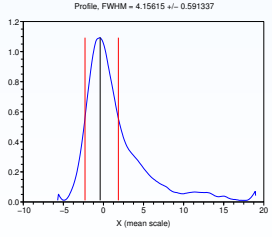


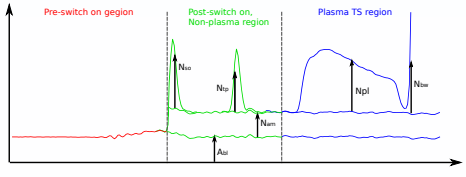

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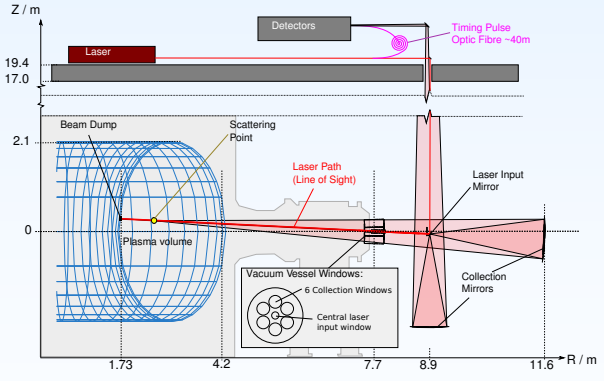


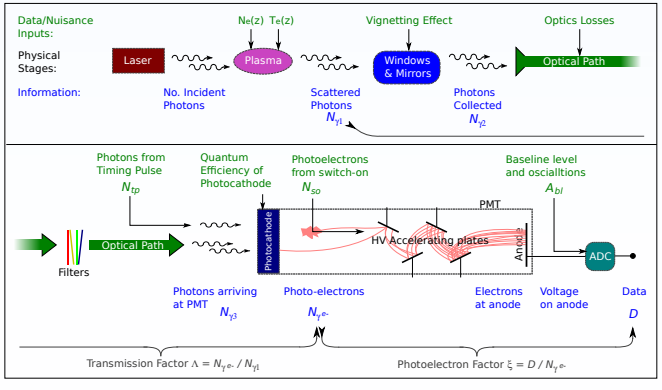


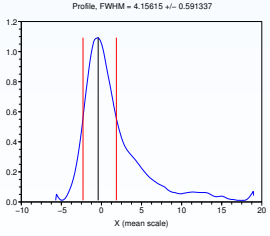


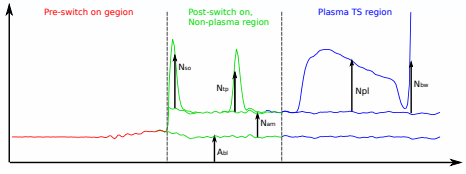


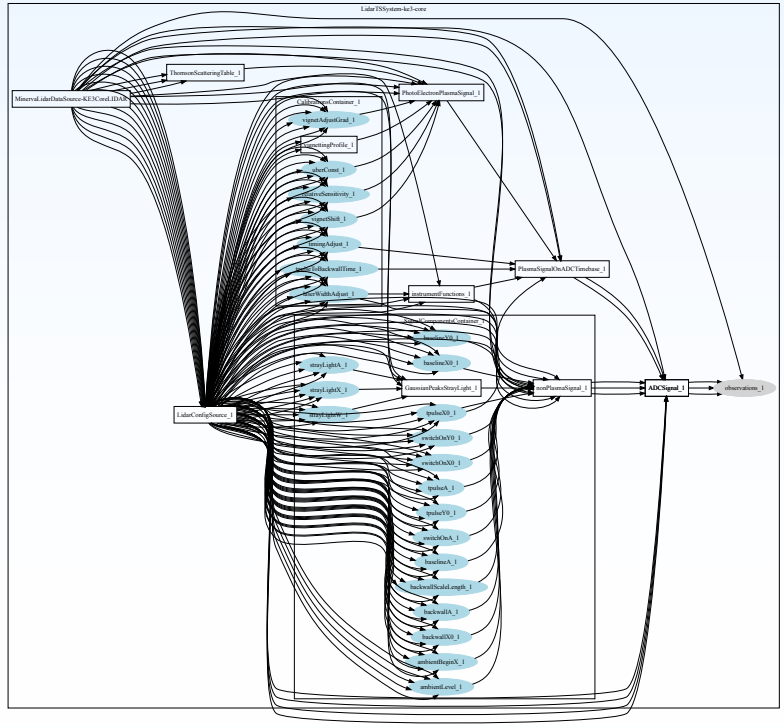

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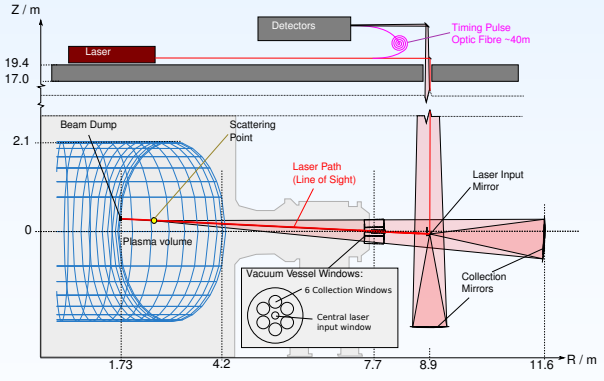


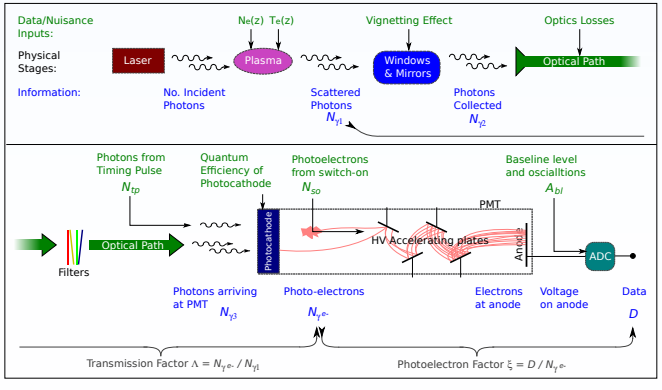


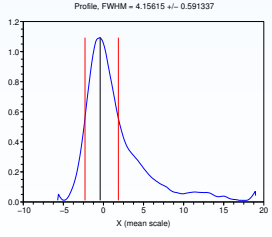


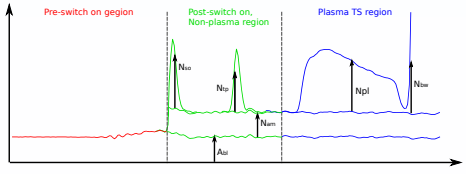


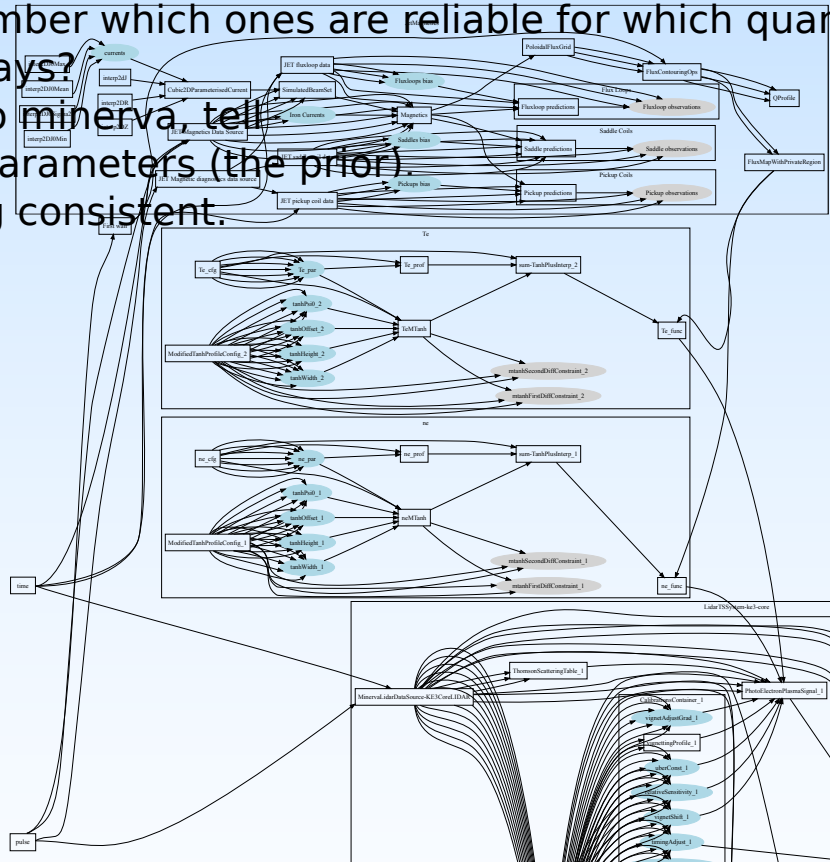

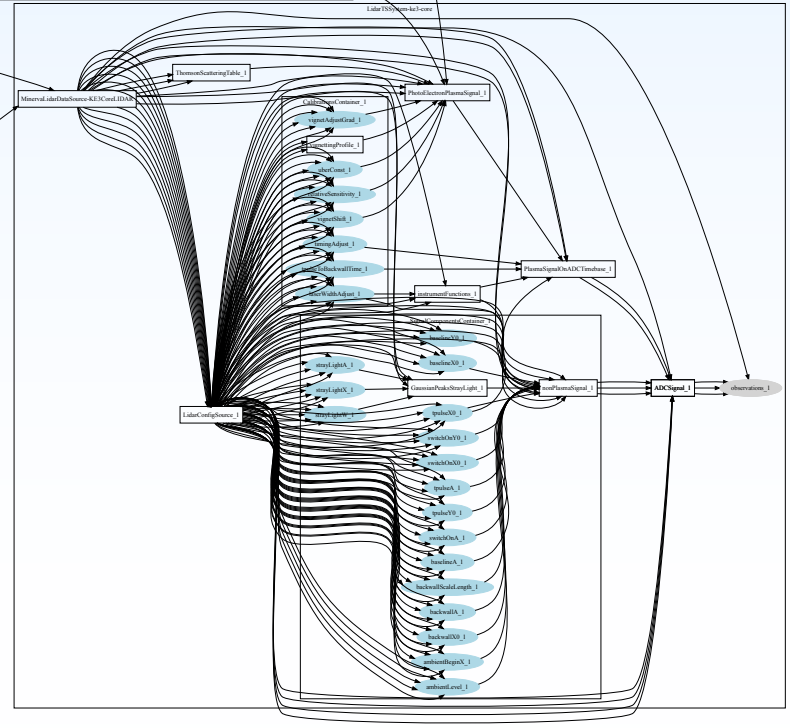

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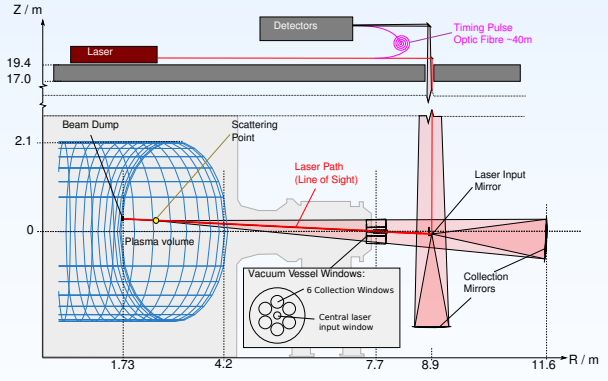


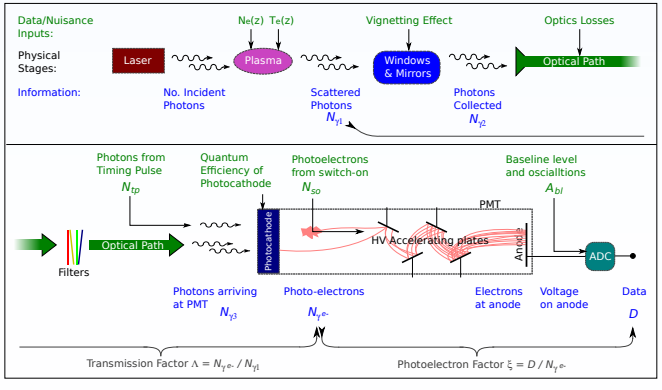


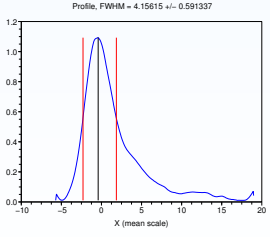


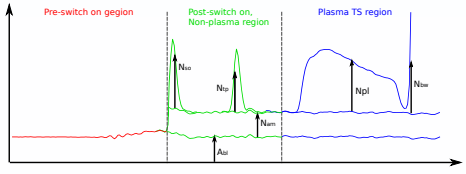


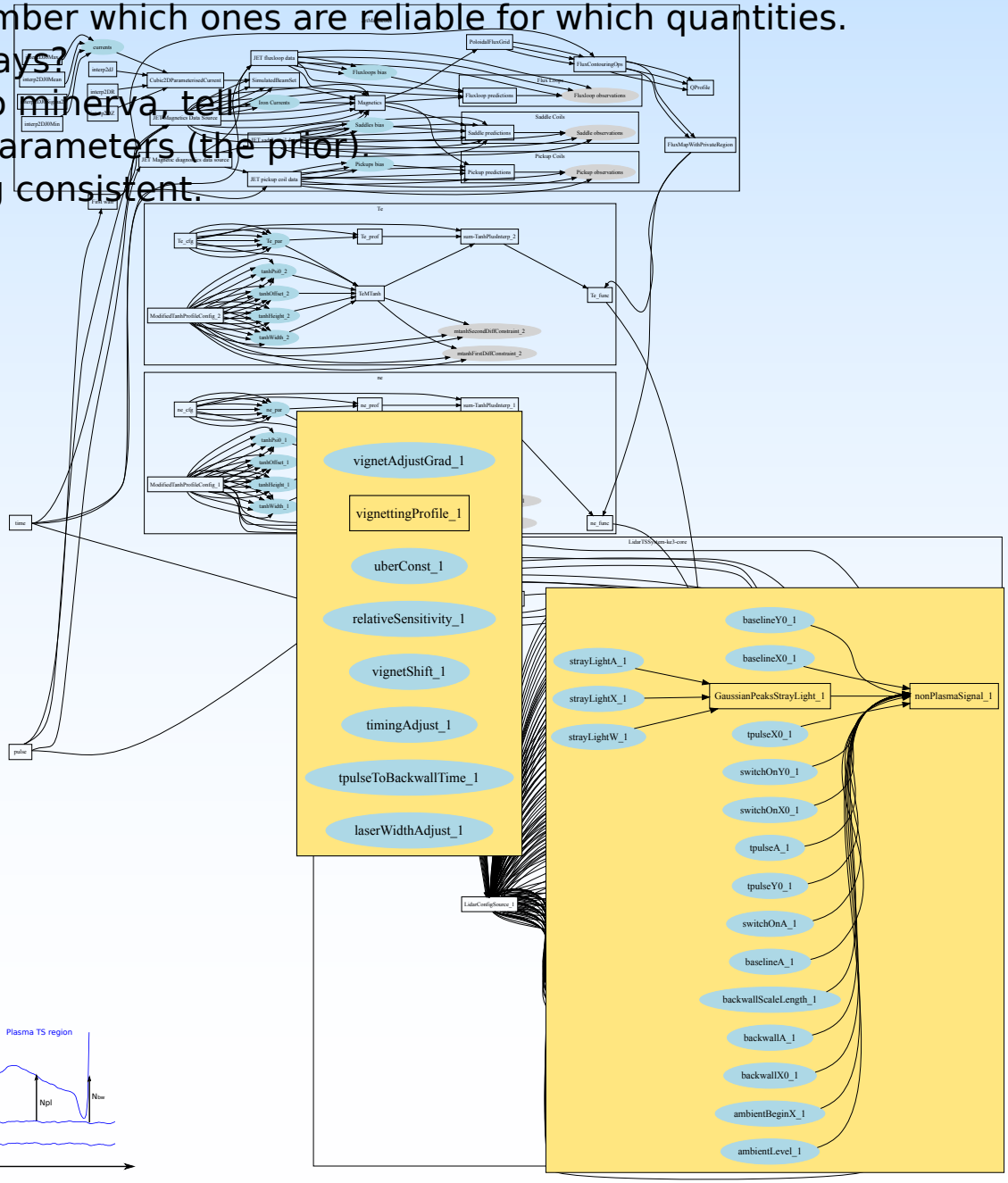

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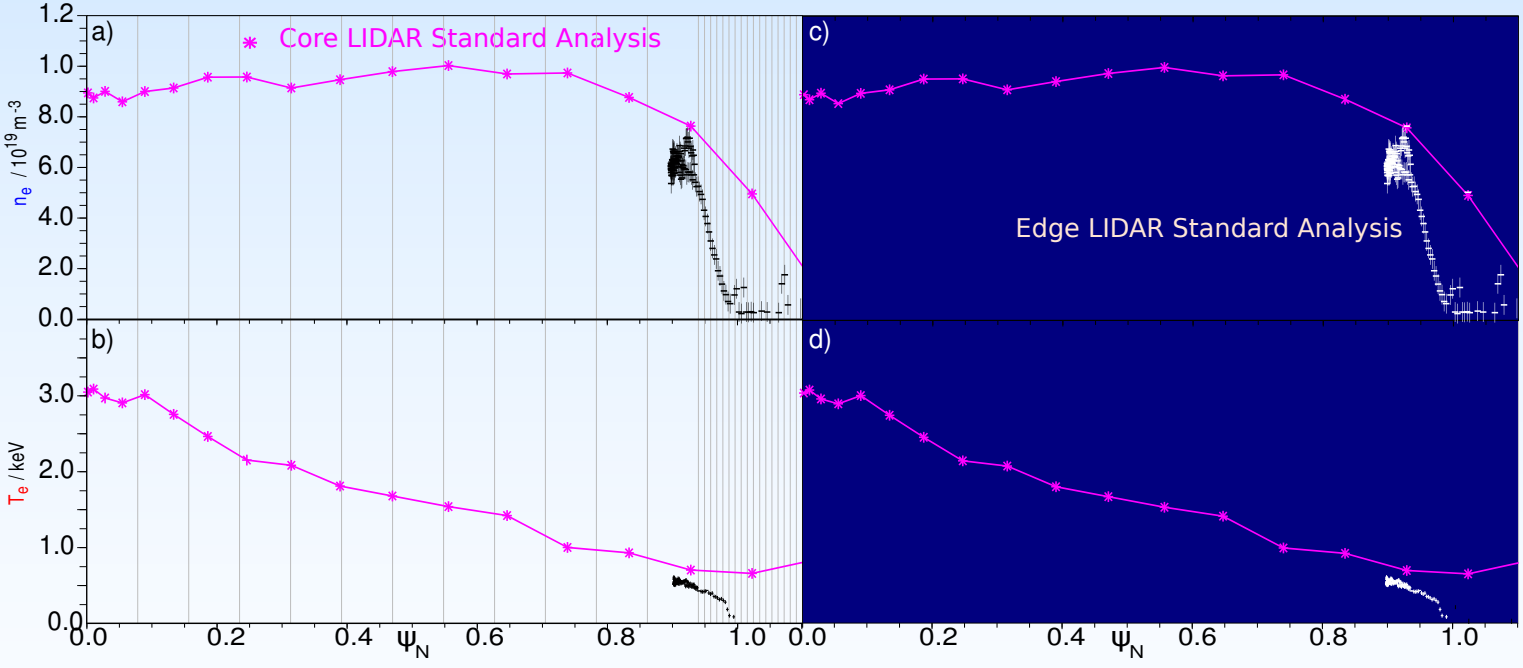


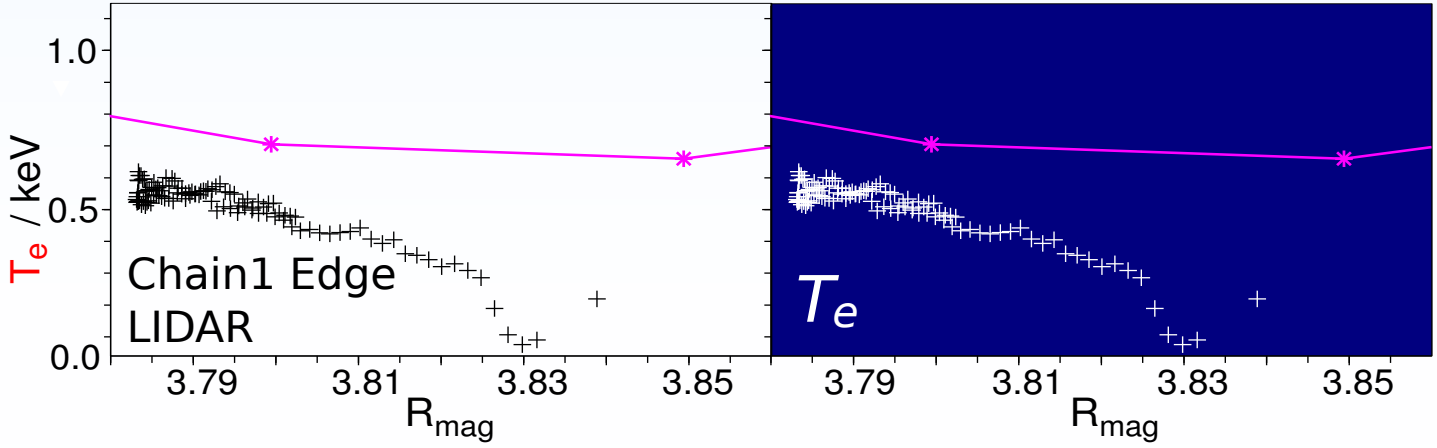

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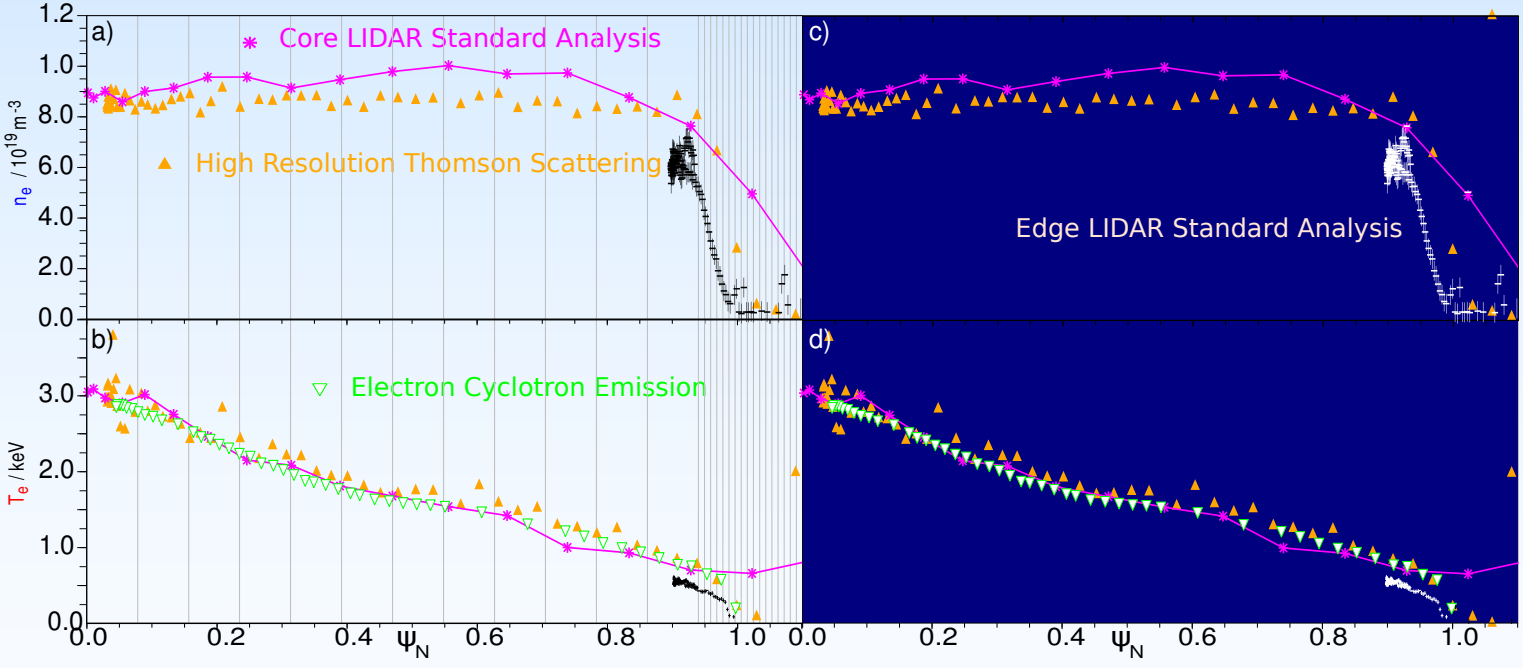


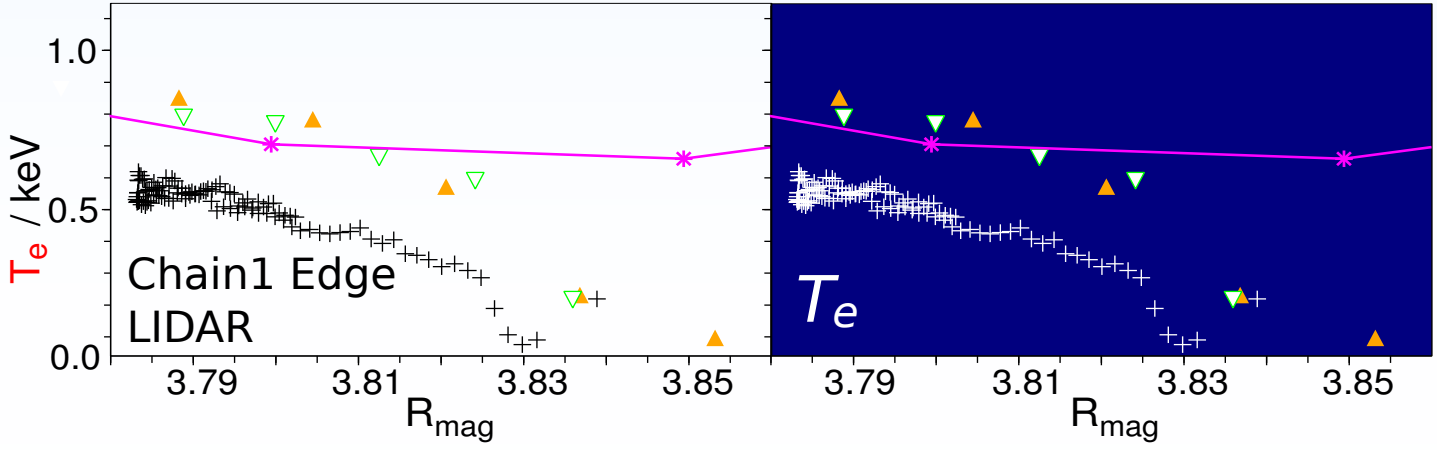

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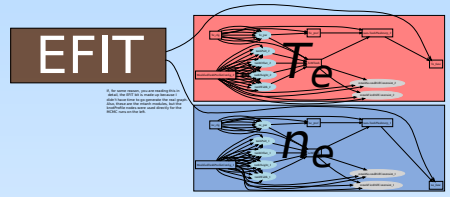


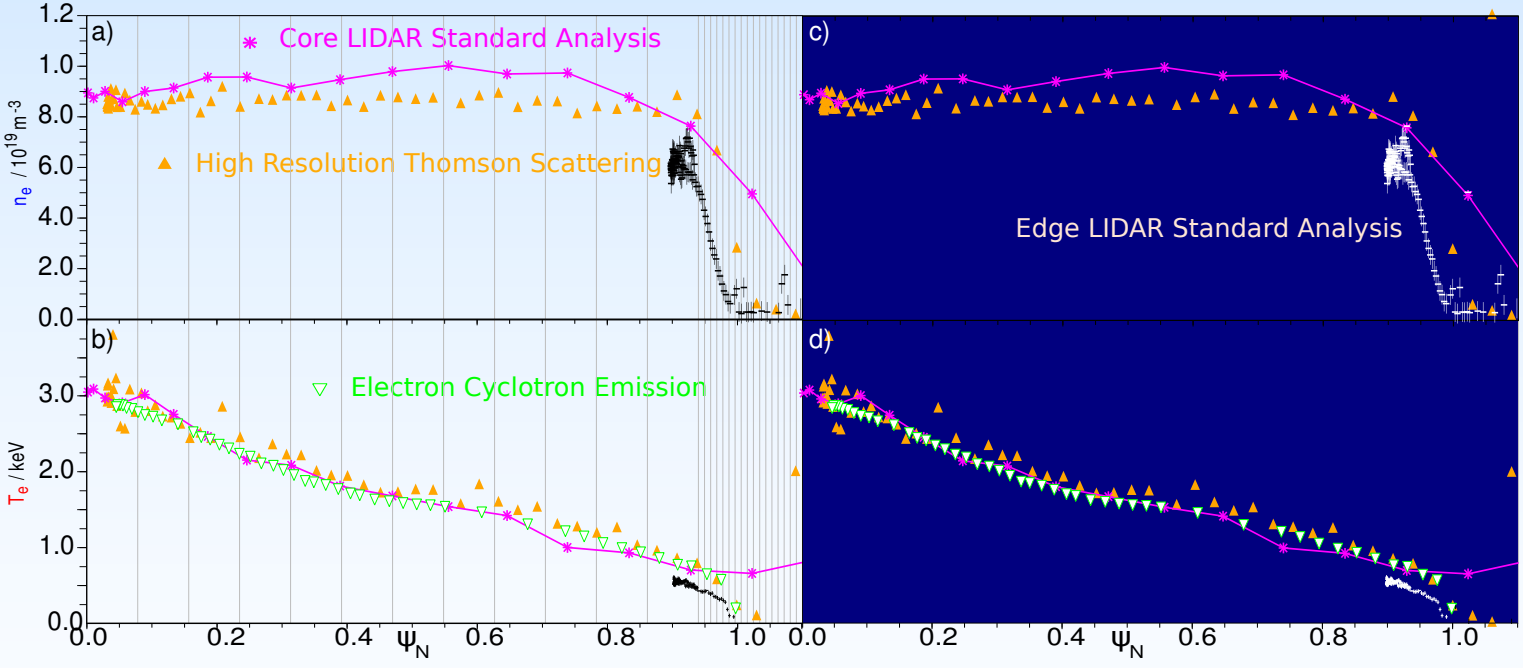


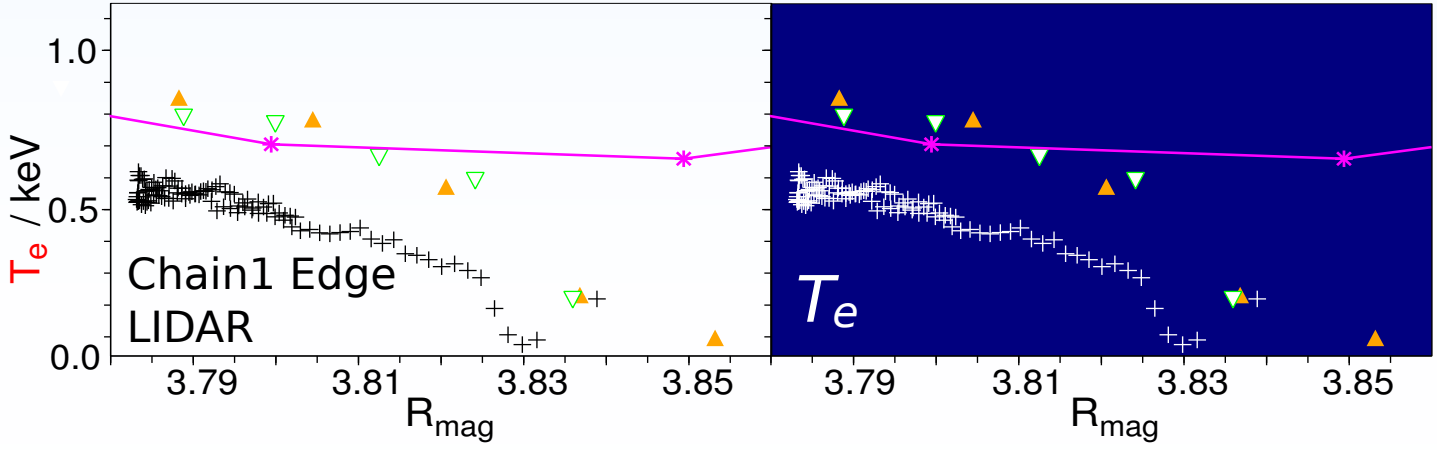

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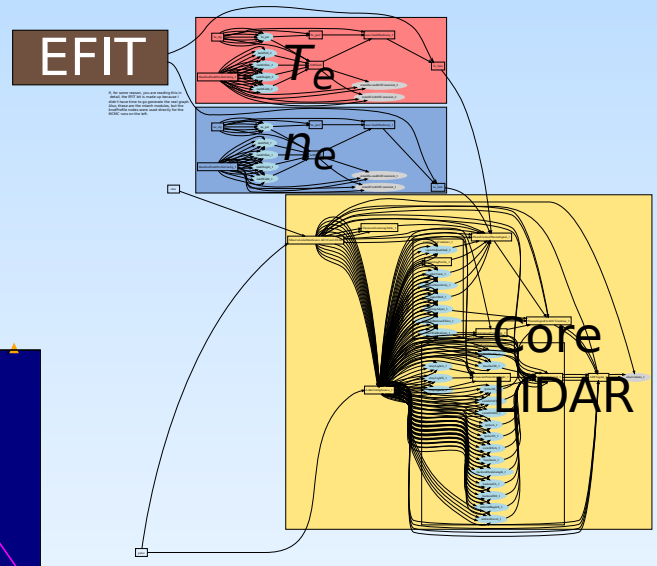


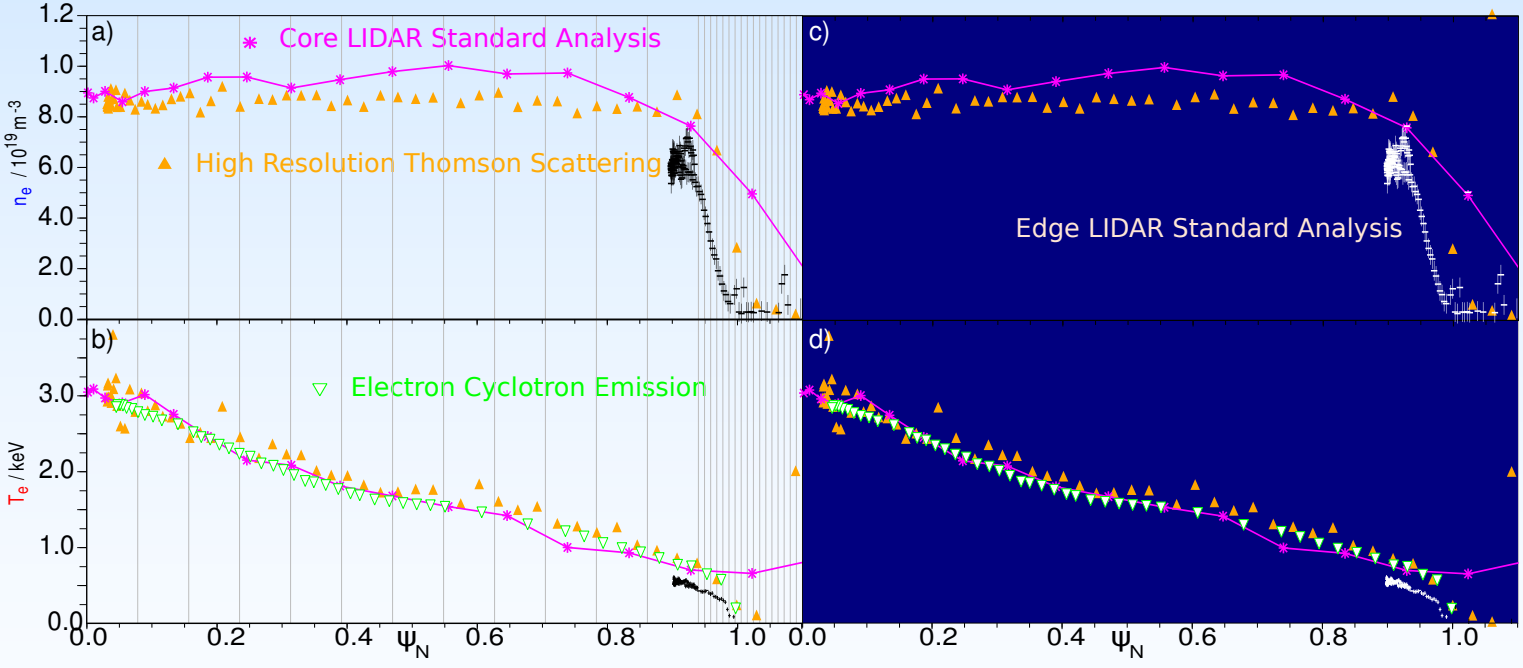


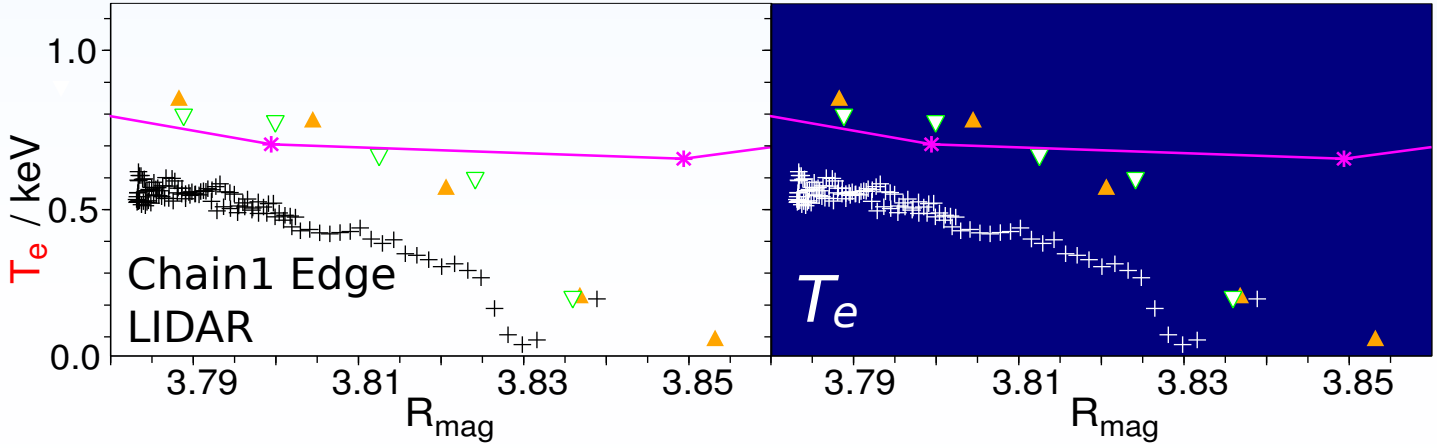

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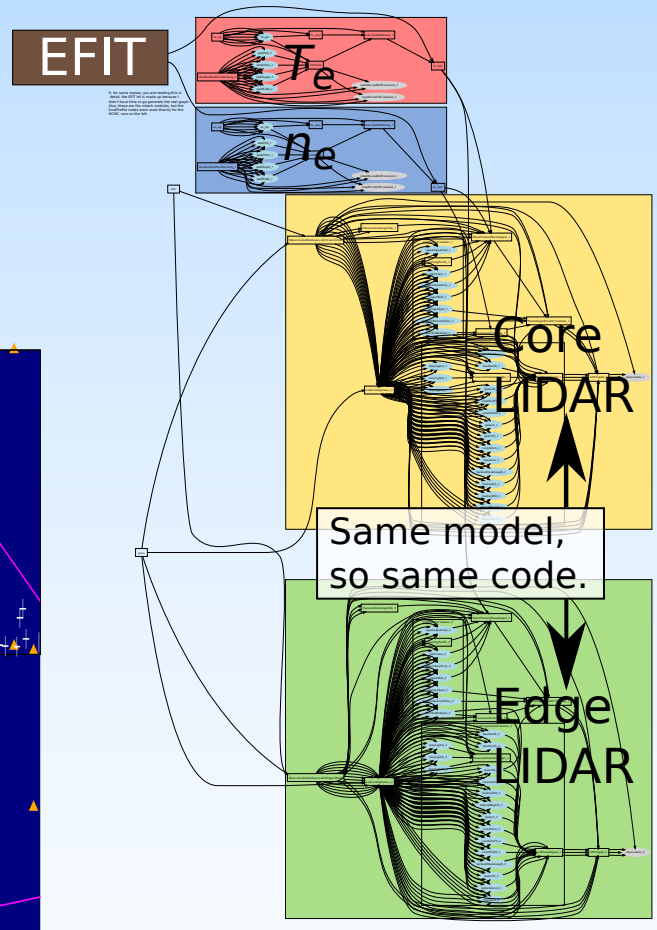


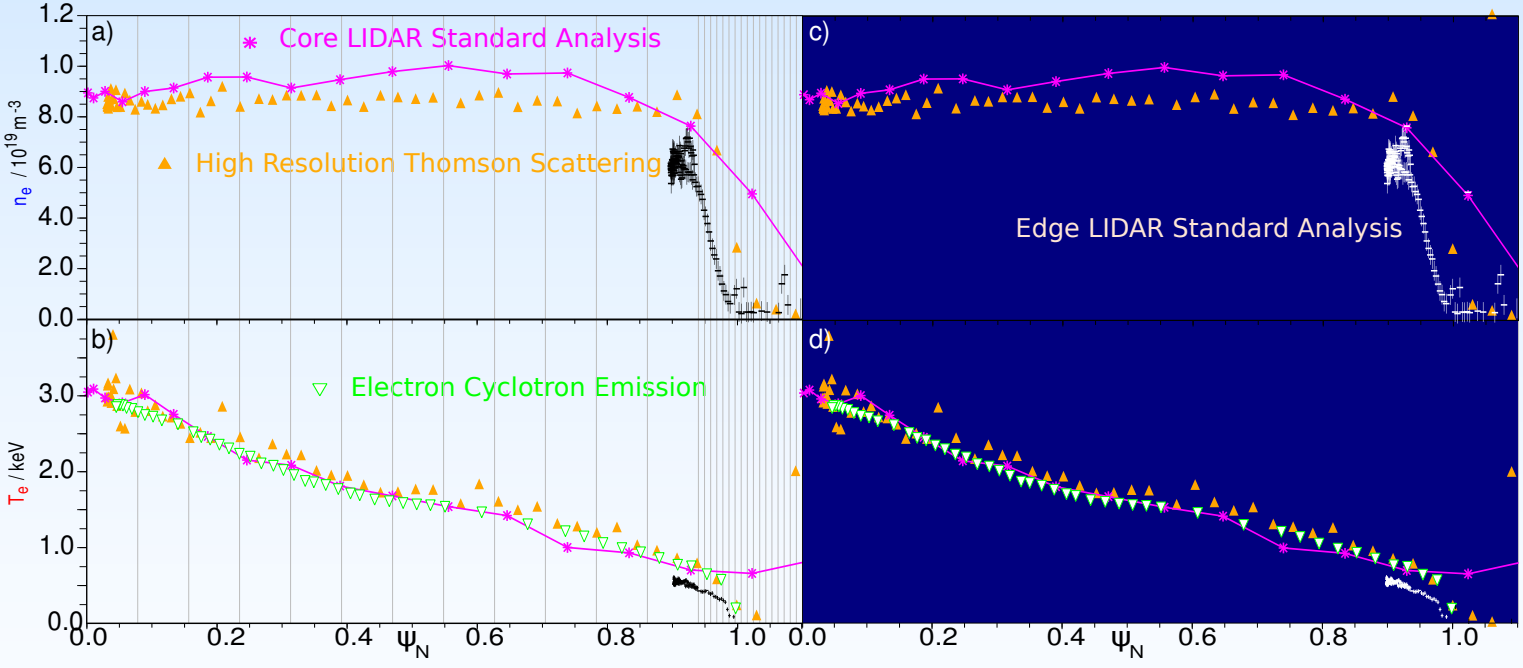


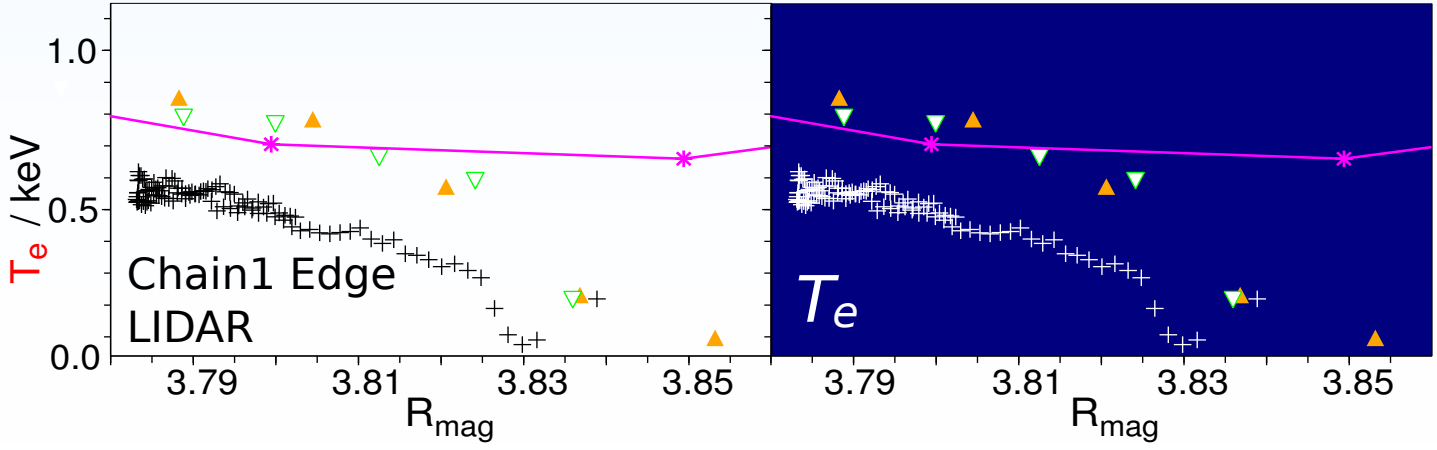

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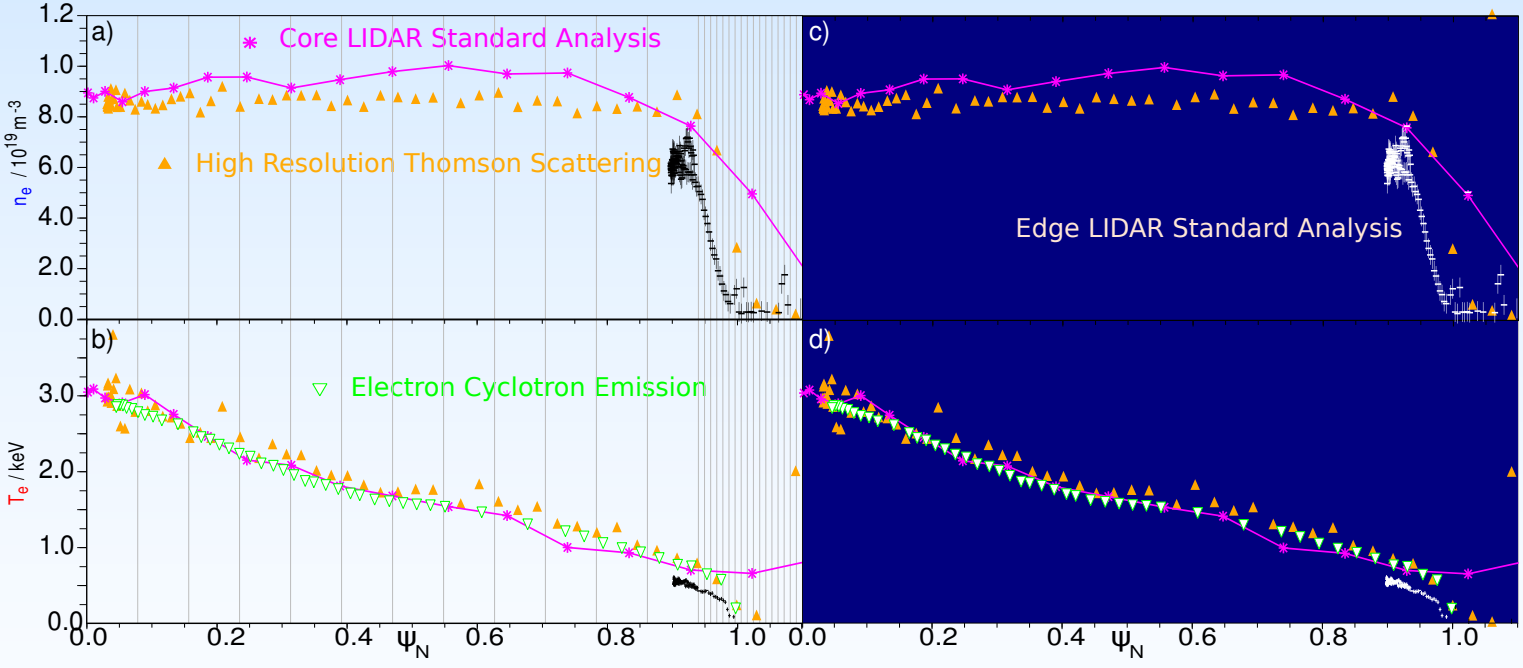


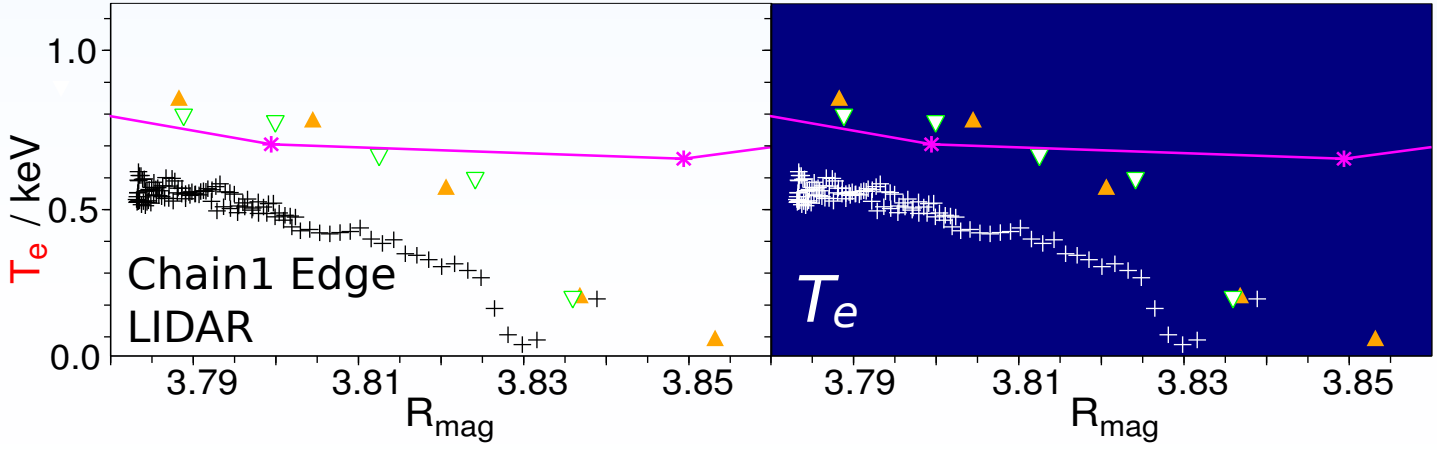


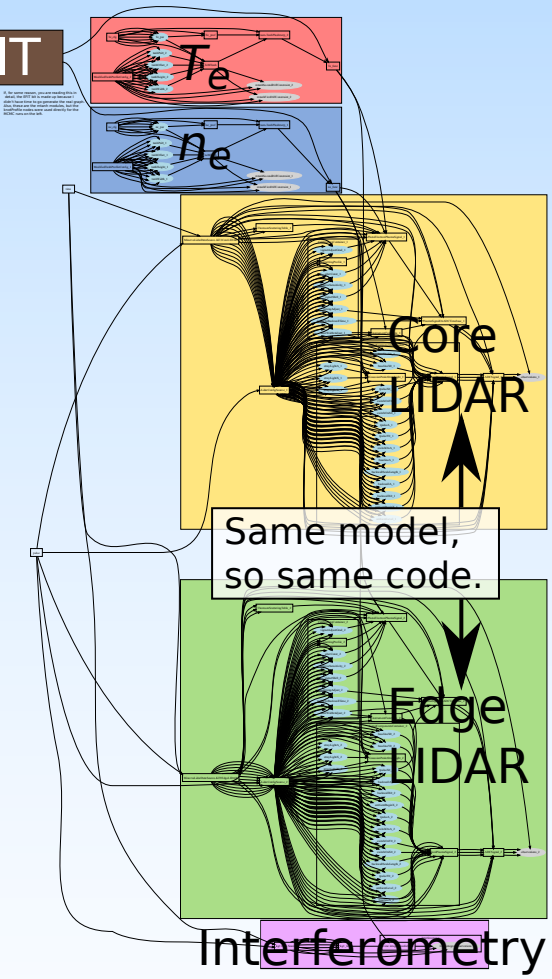

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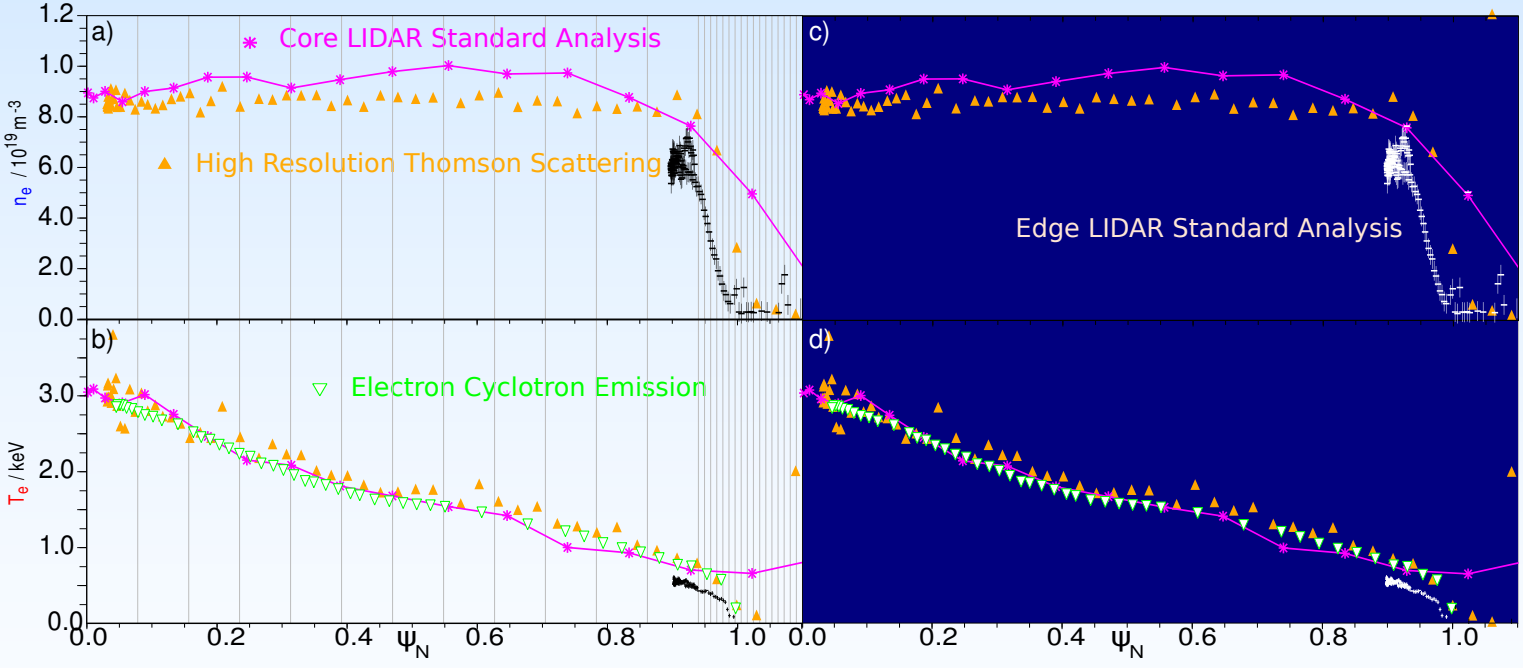


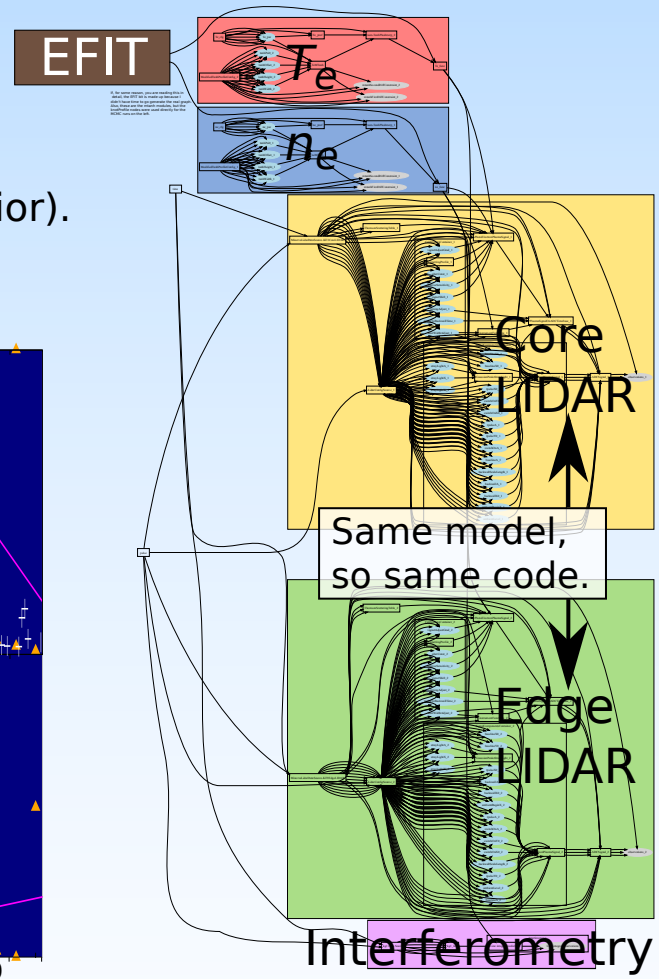


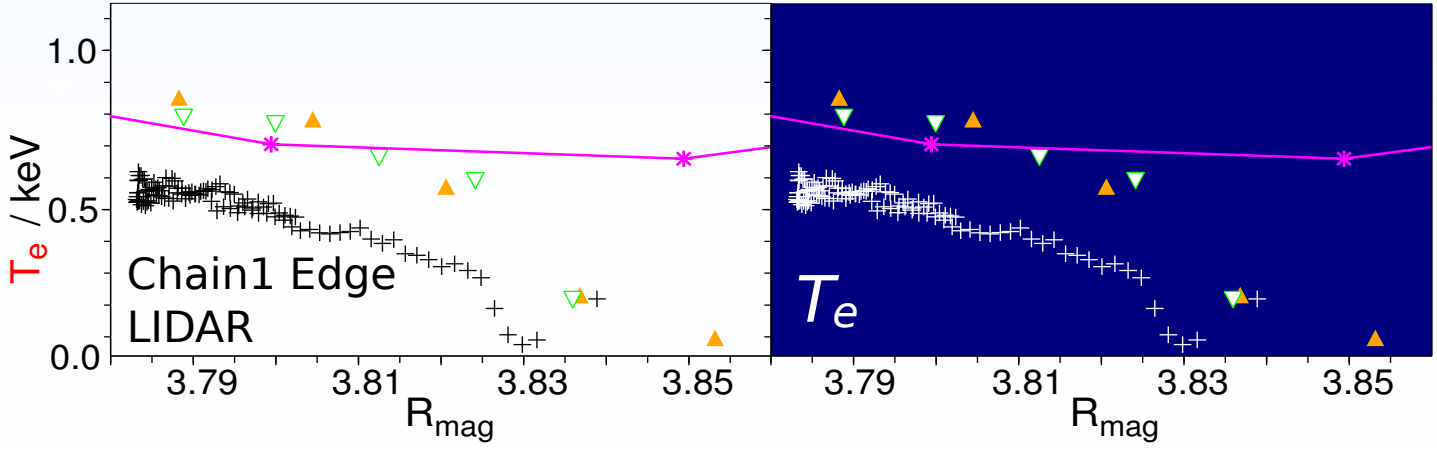

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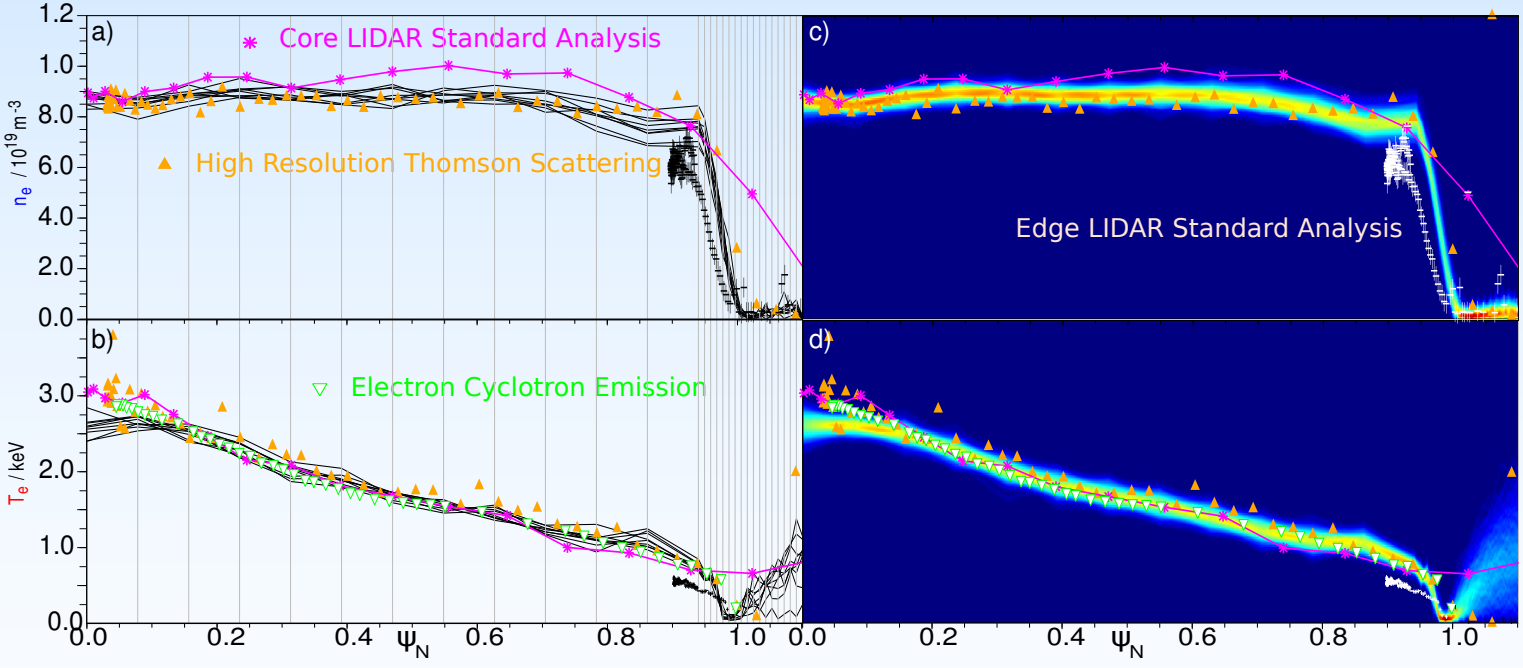


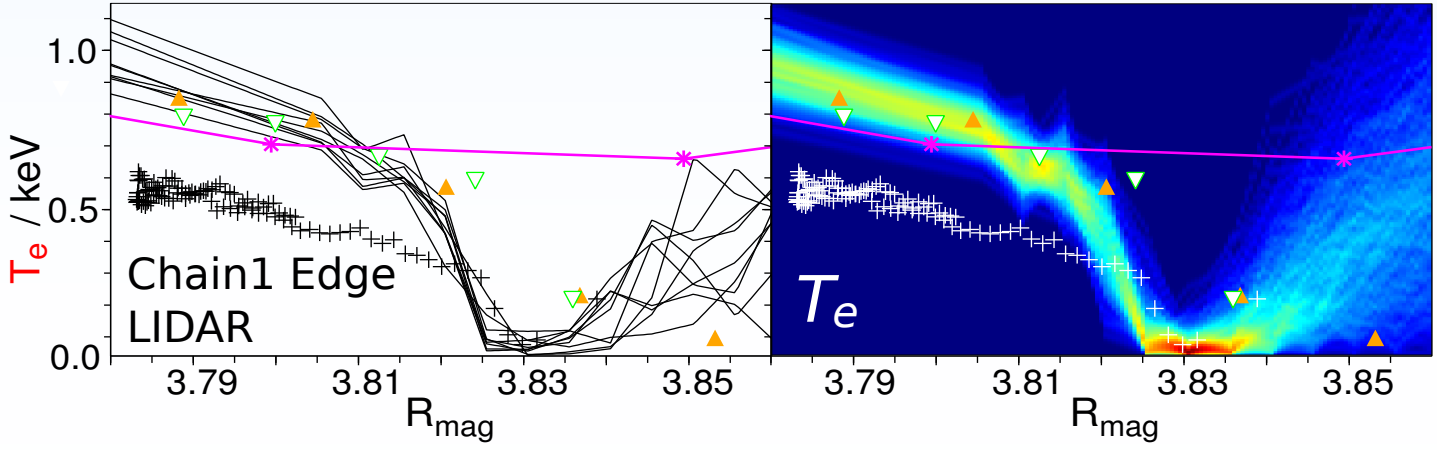


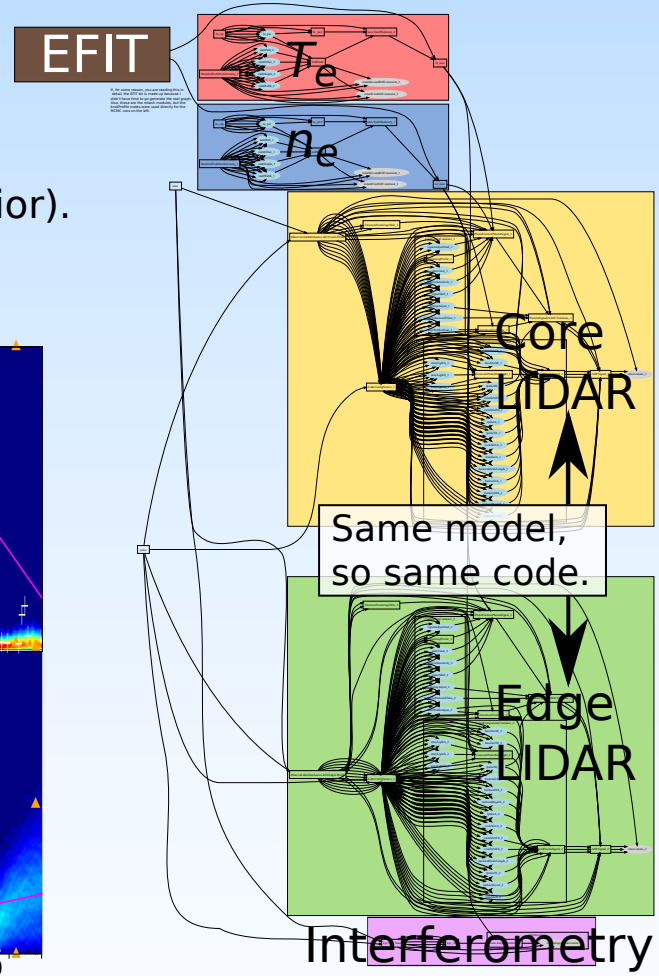

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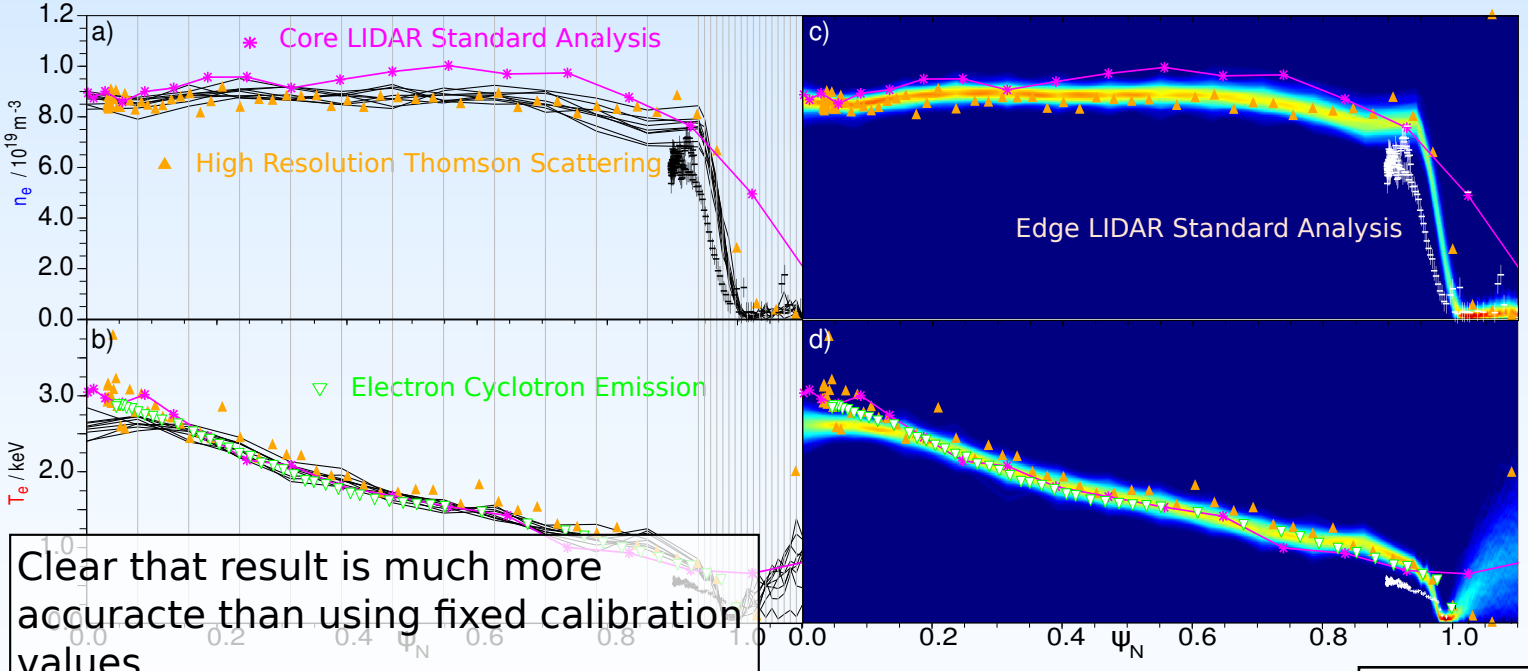


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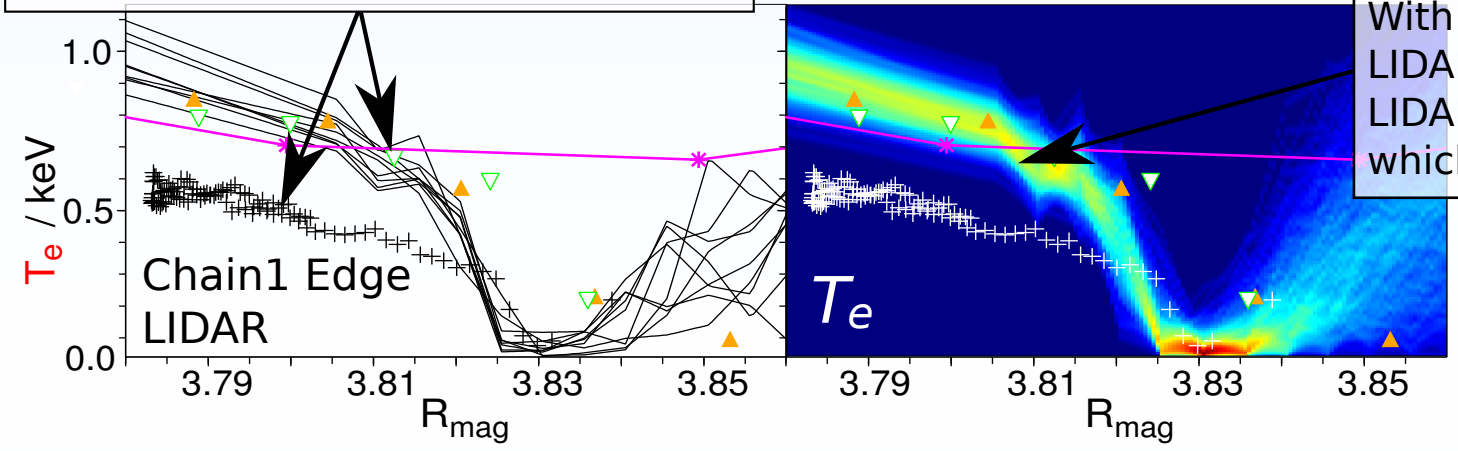


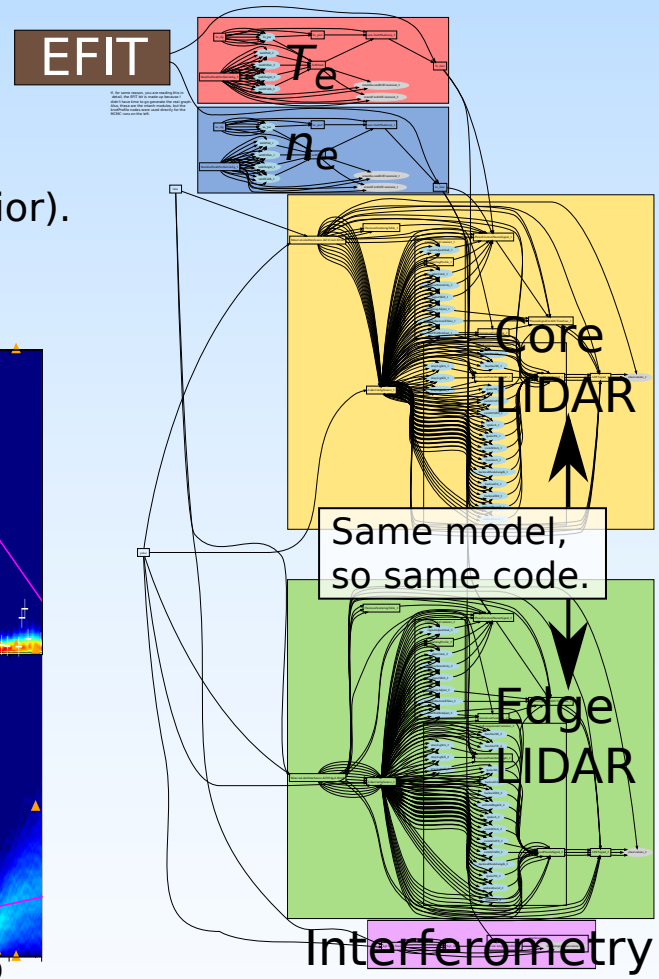


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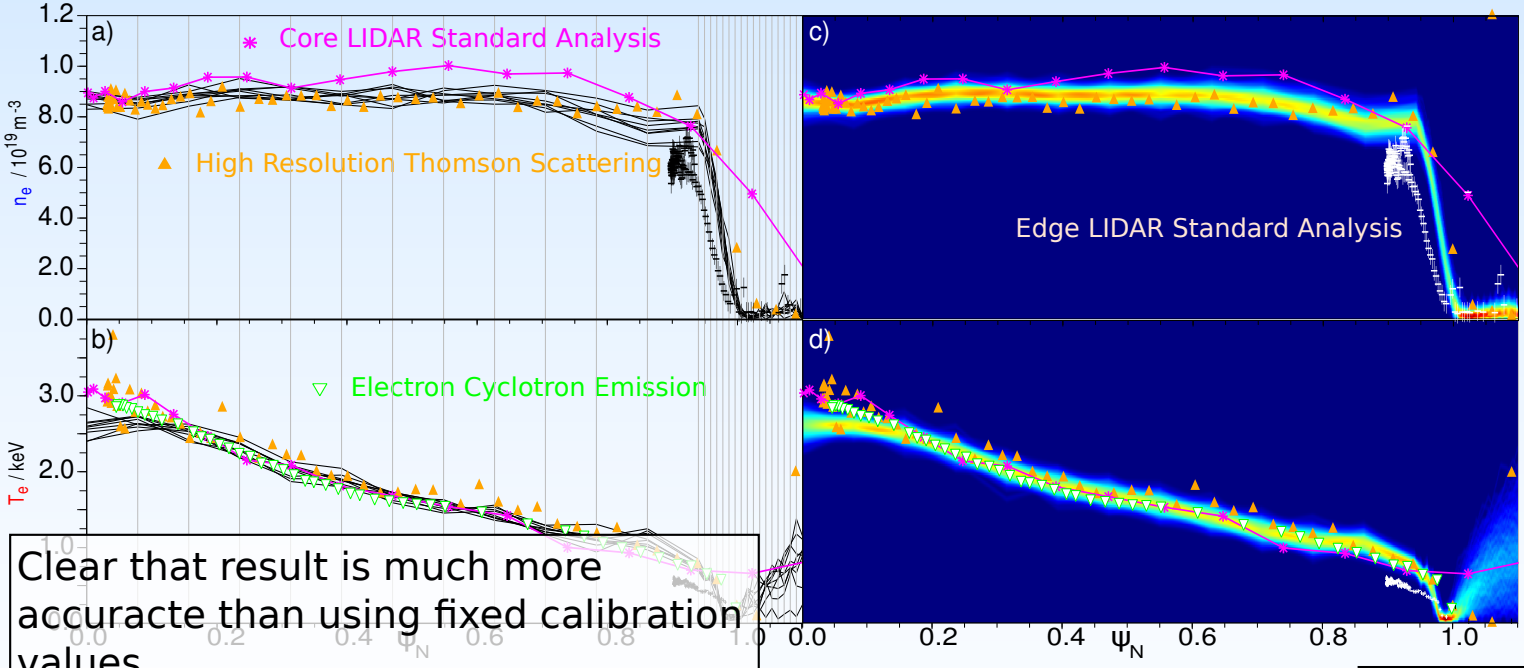


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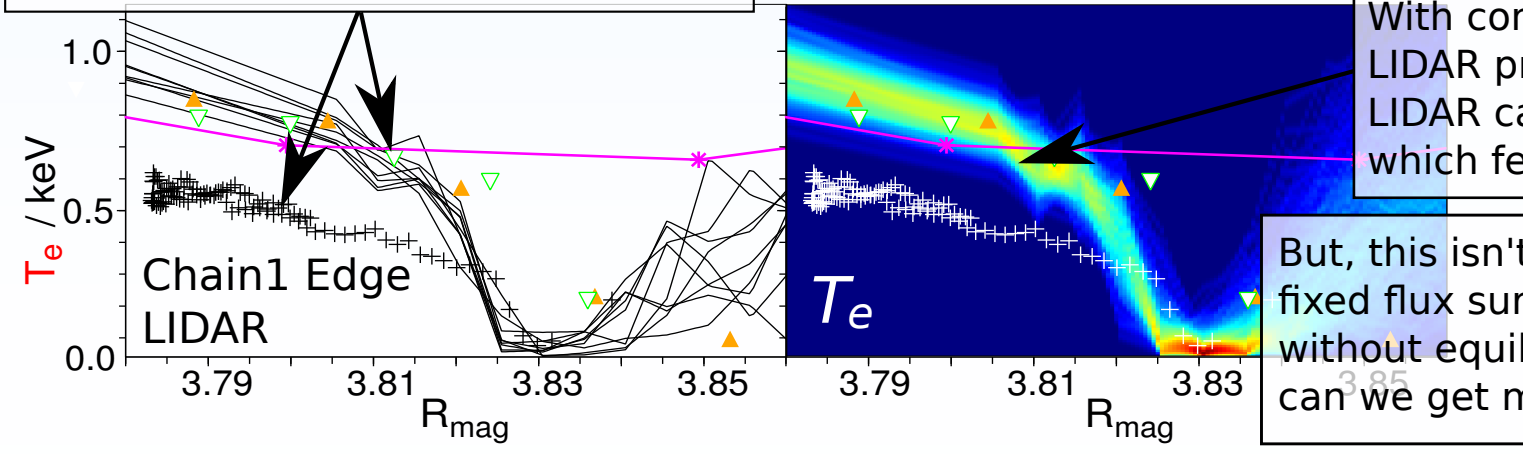


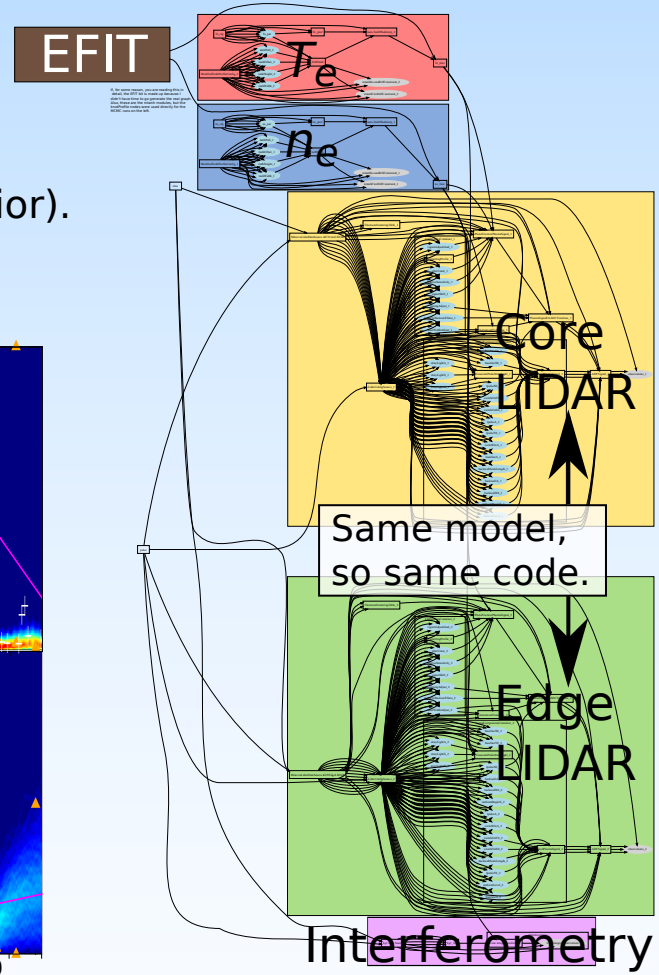


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But, this isn't complete - we are still using fixed flux surfaces. The Current tomography without equilibirum approach is useful but can we get more by assuming equilibrium...

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So mapping P( $\psi_N$ | ... ) is still the big problem.
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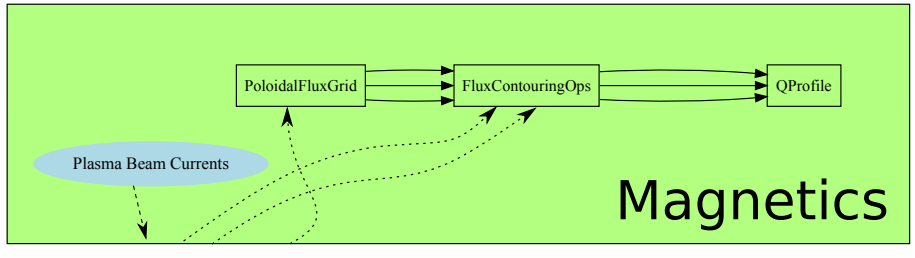

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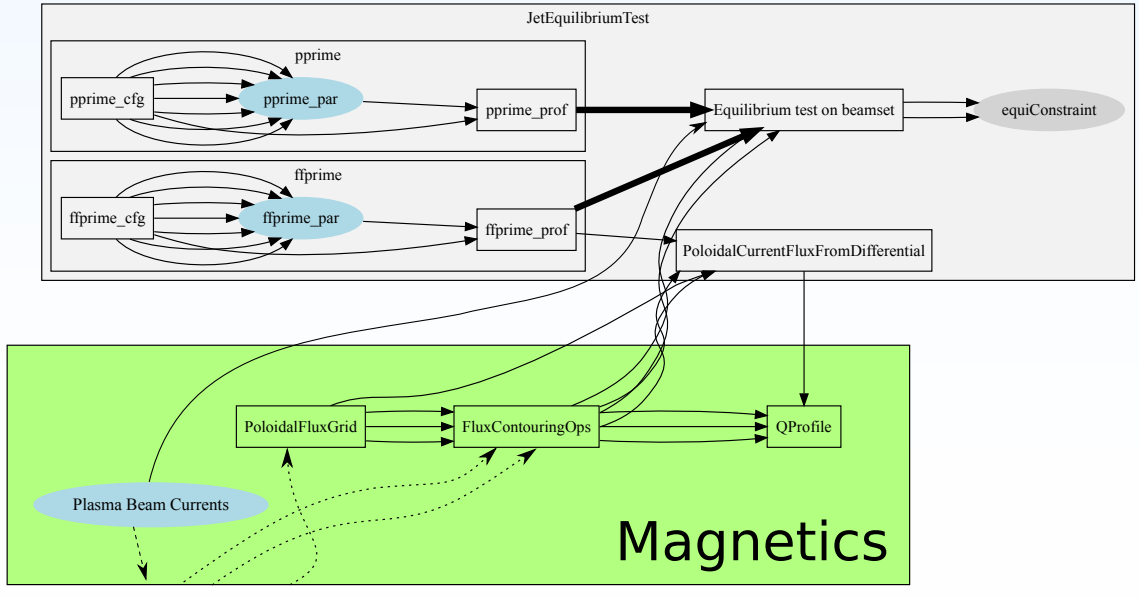

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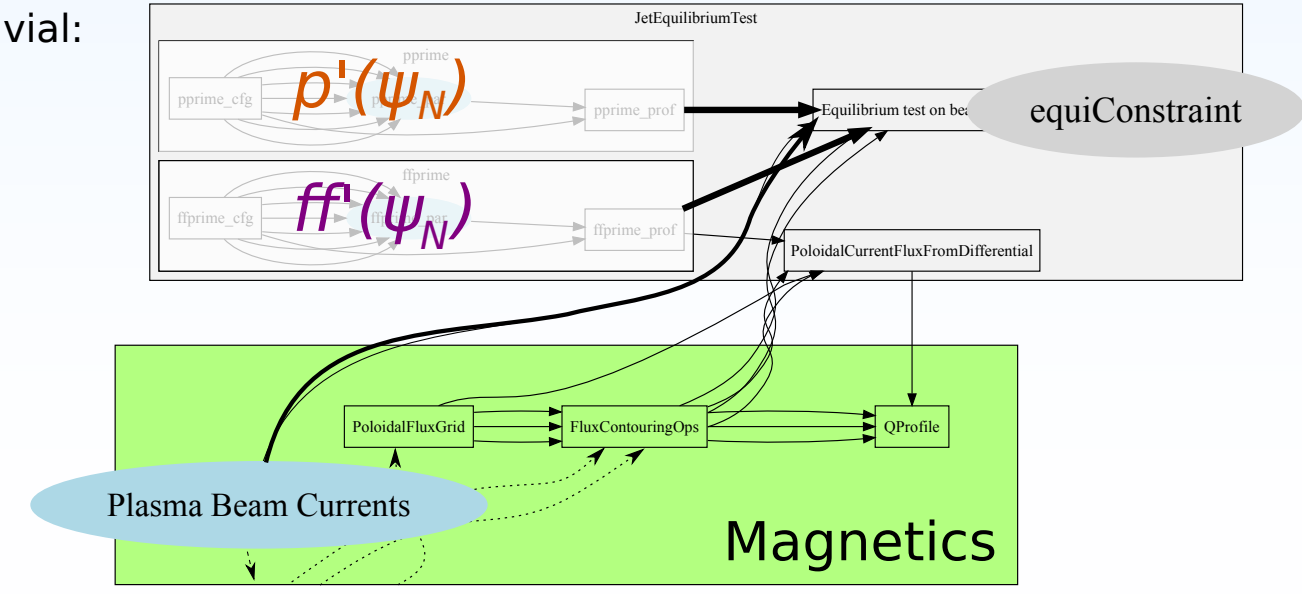

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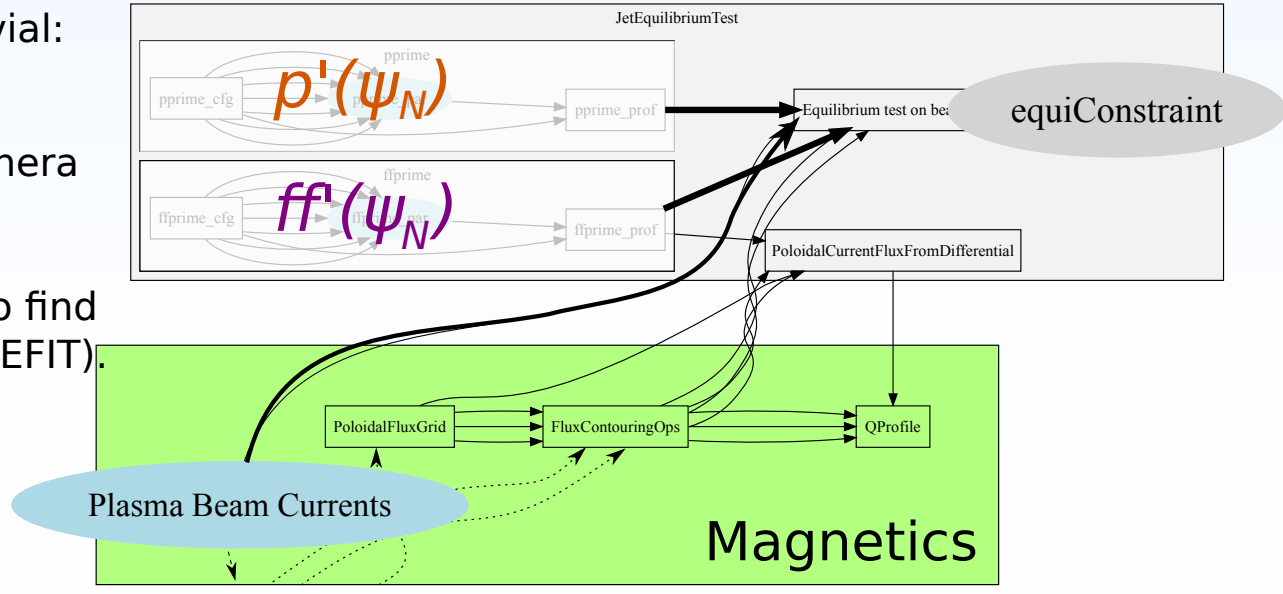
But, the problem is now very hard for the external algorithms to handle due to non-linera 1000D+ posterior.

1) Parallelise the linear solver and iterate to find MAP (much slower but more stable than EFIT).

2) Exporing the PDF only just possible (last week).



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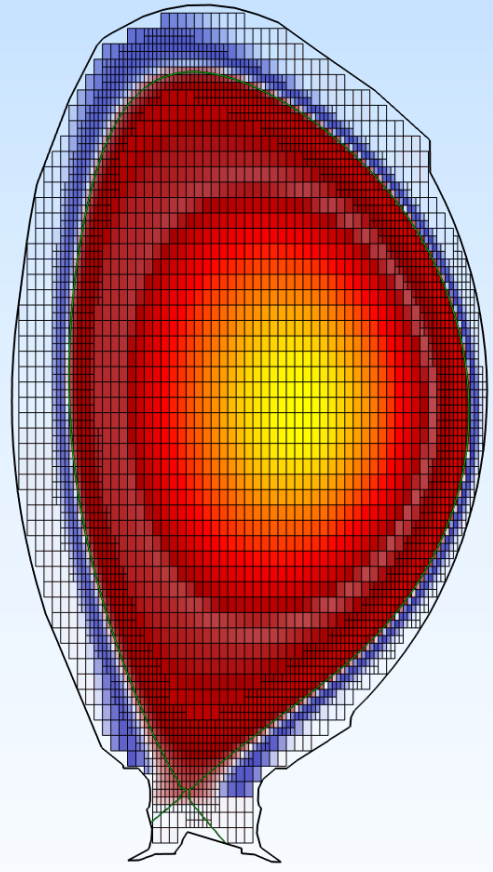

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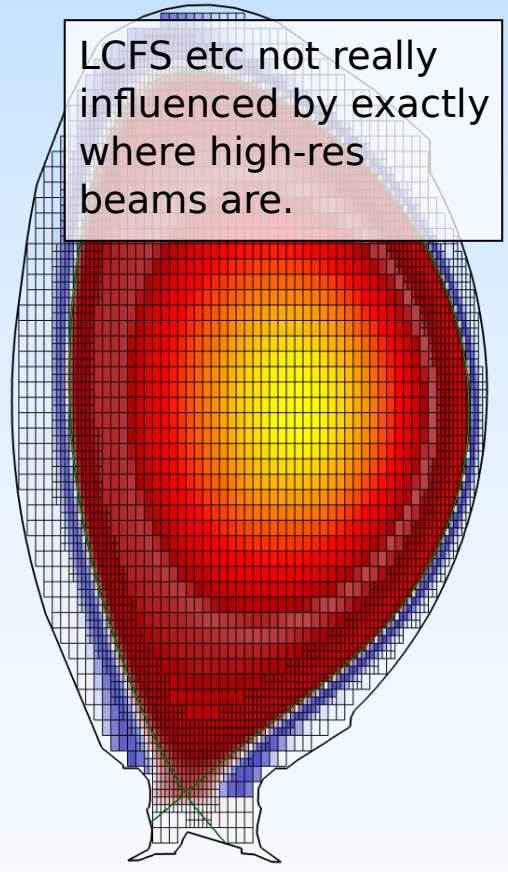

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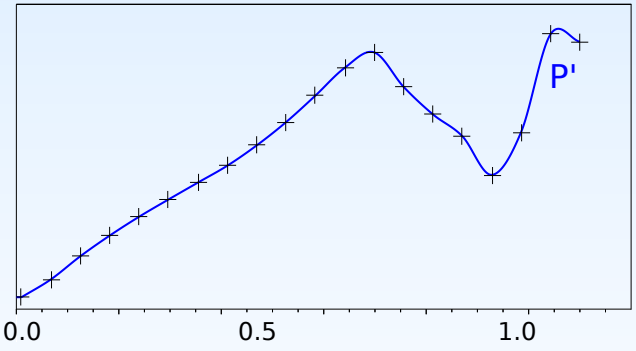


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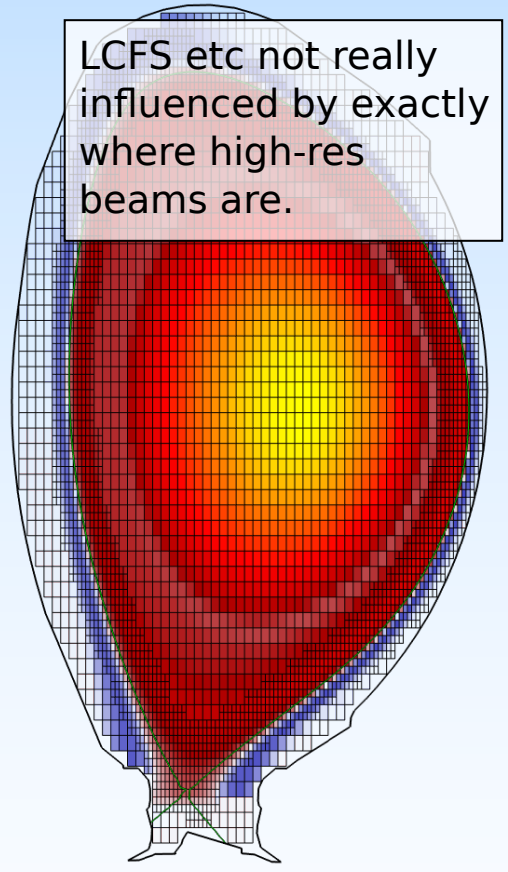

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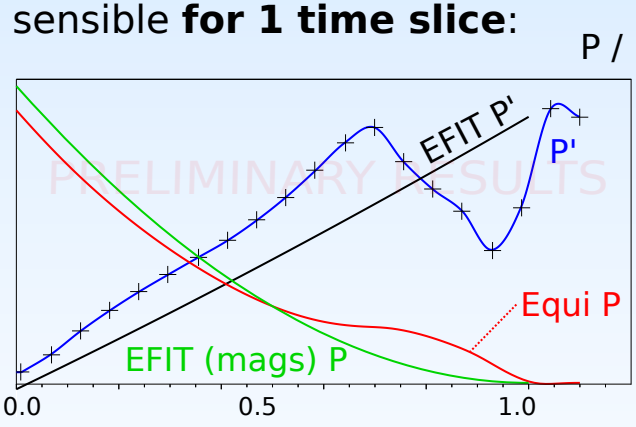


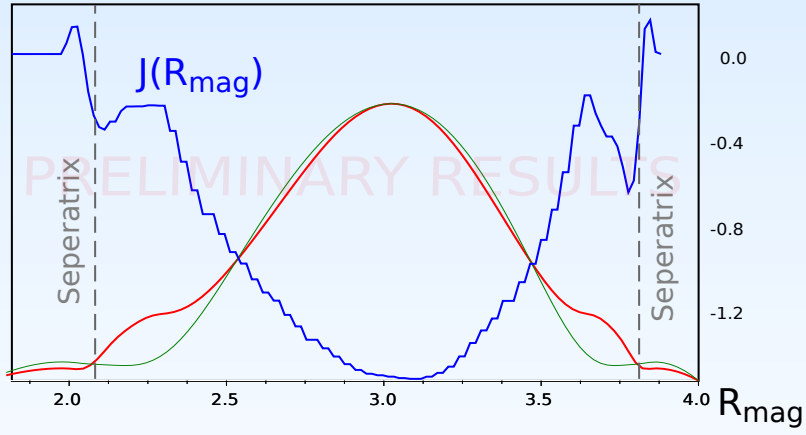


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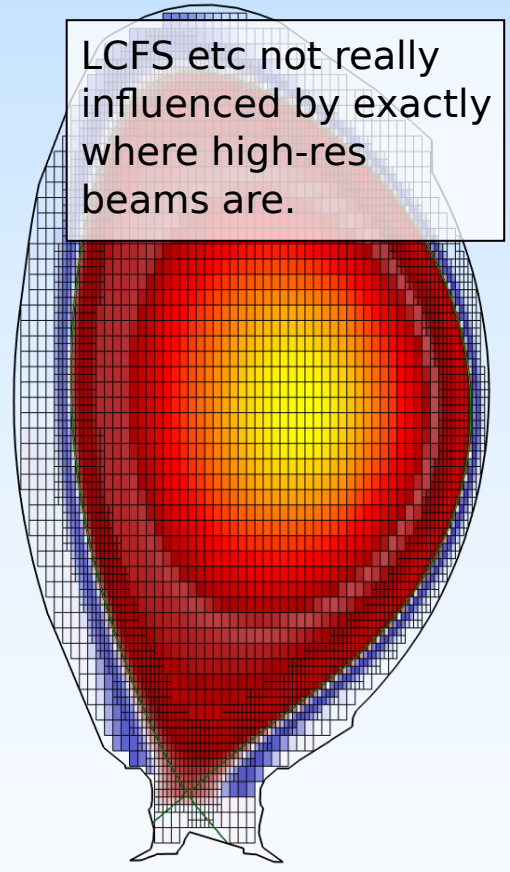

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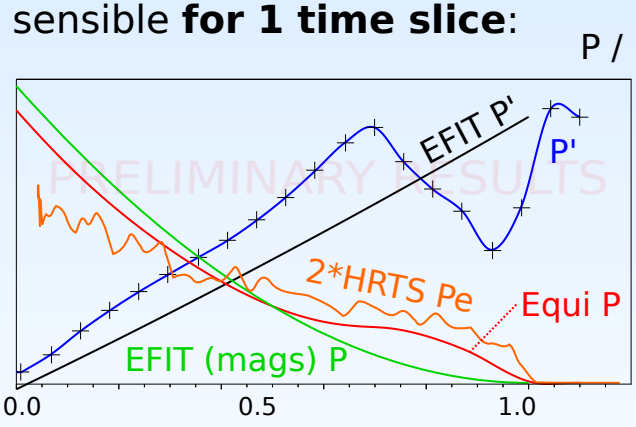


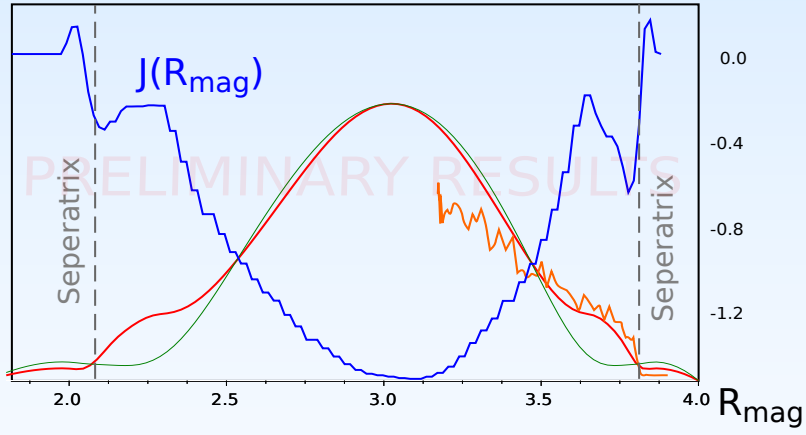




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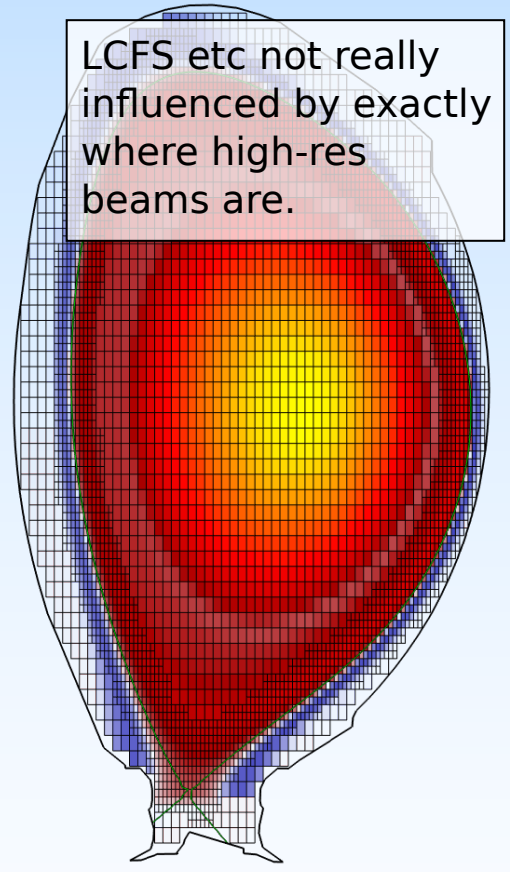

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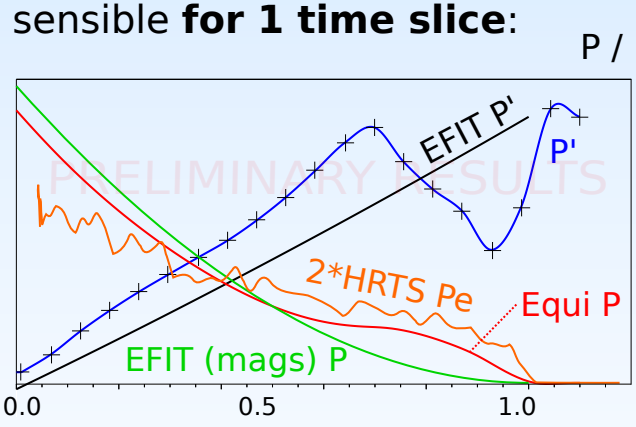


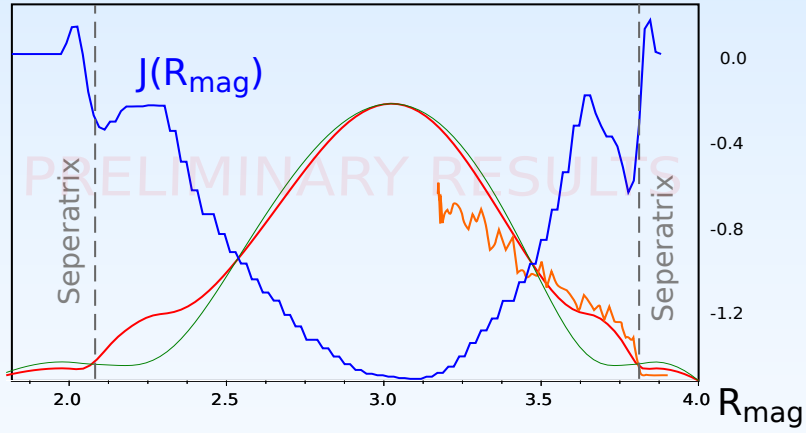




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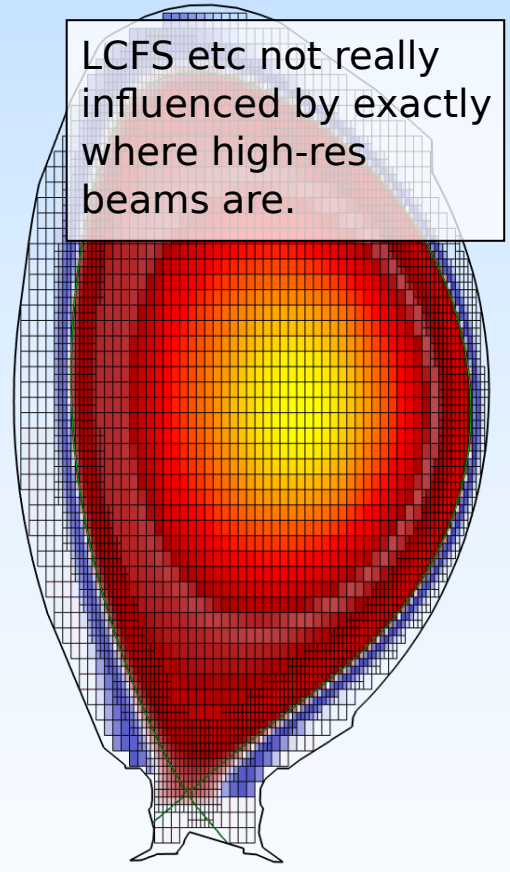

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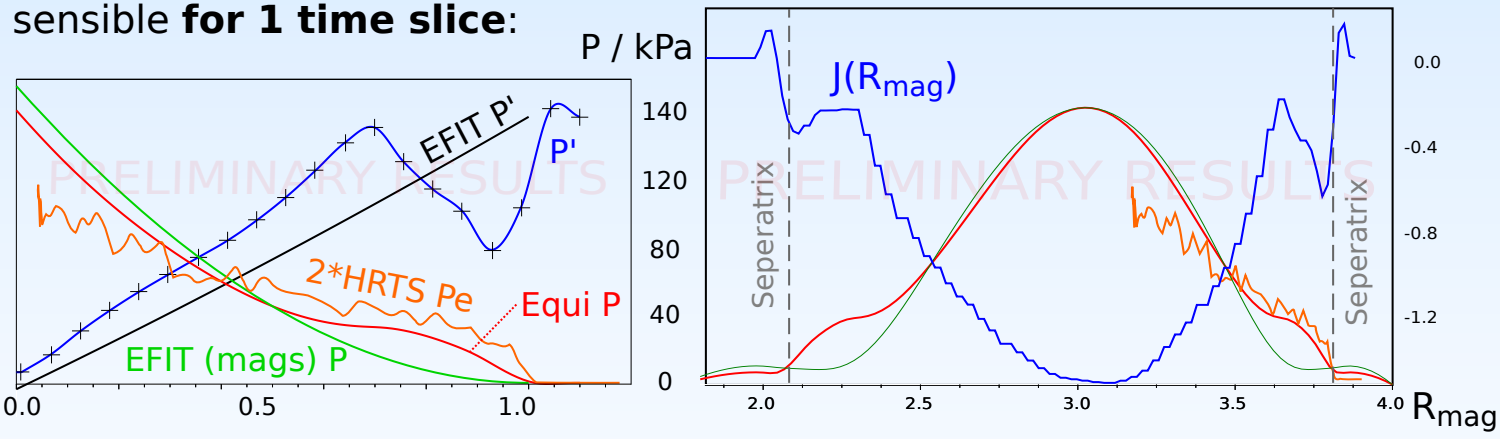


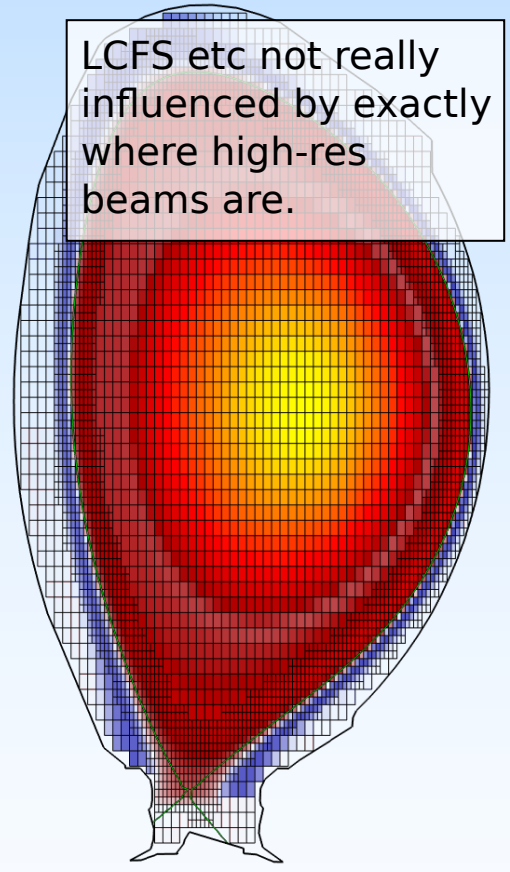


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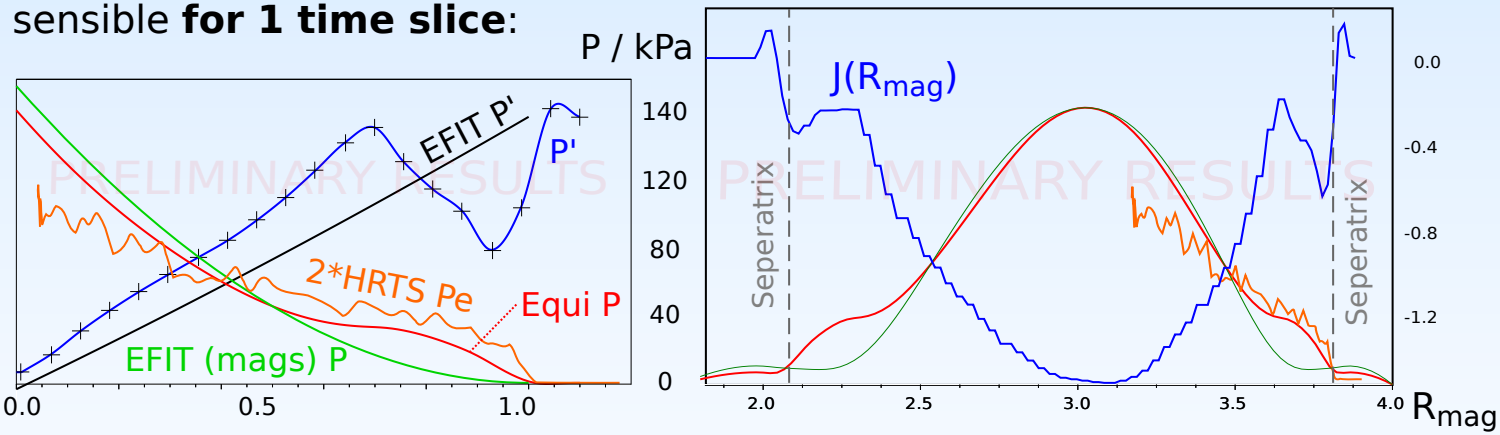


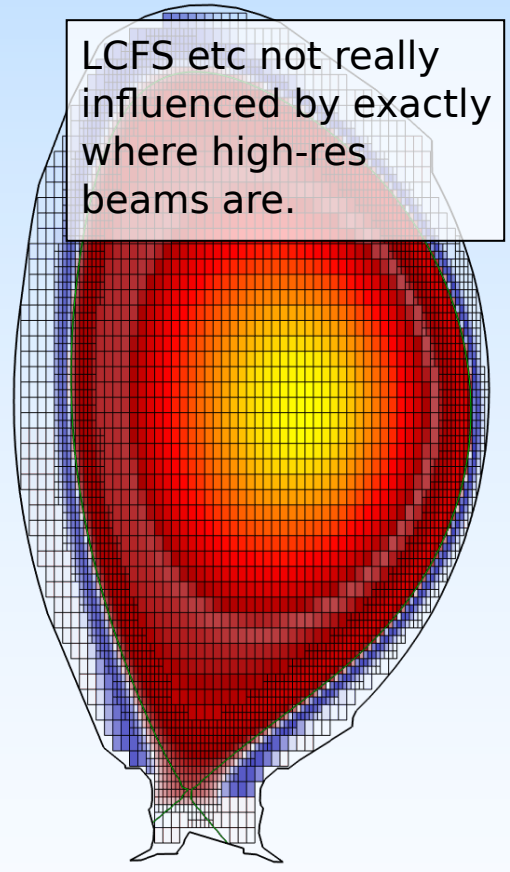


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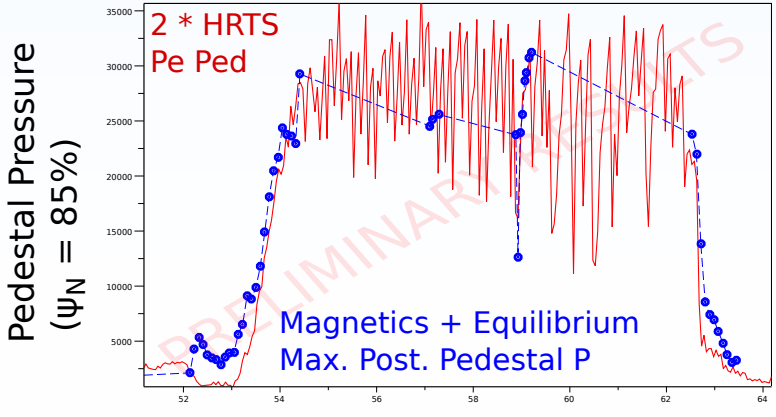

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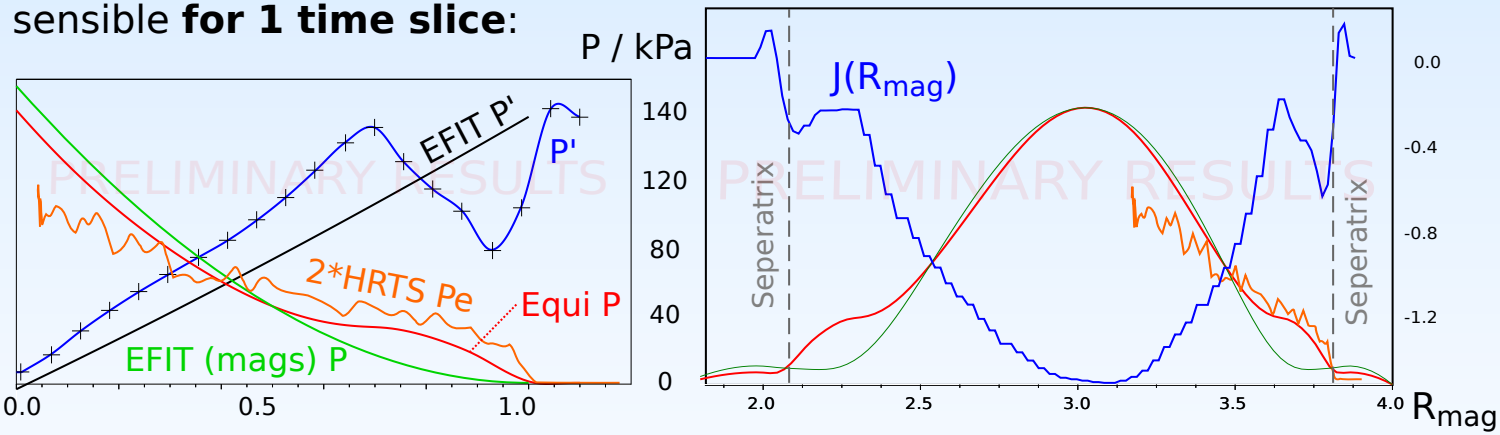


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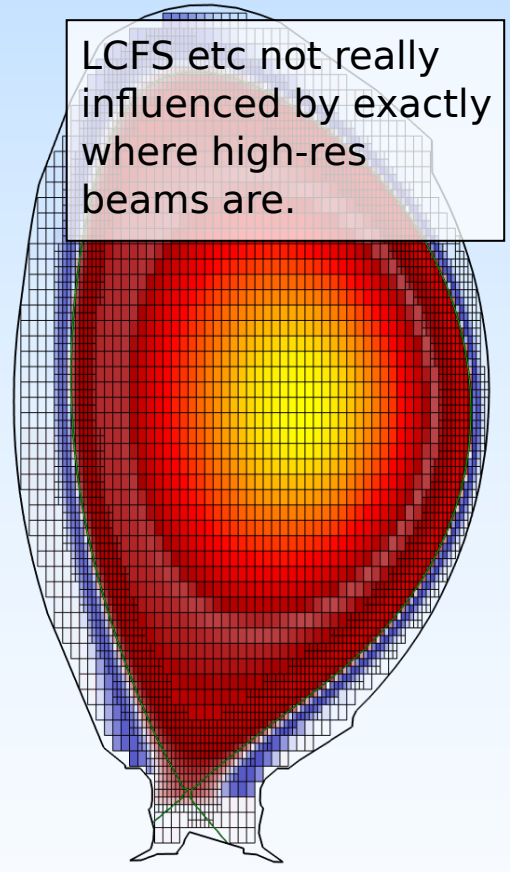

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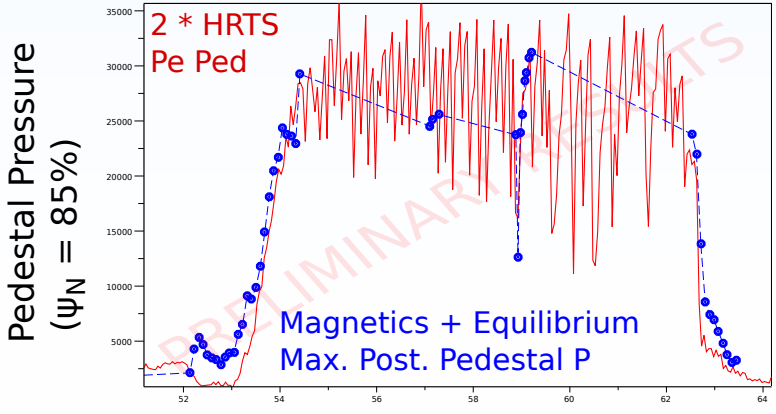


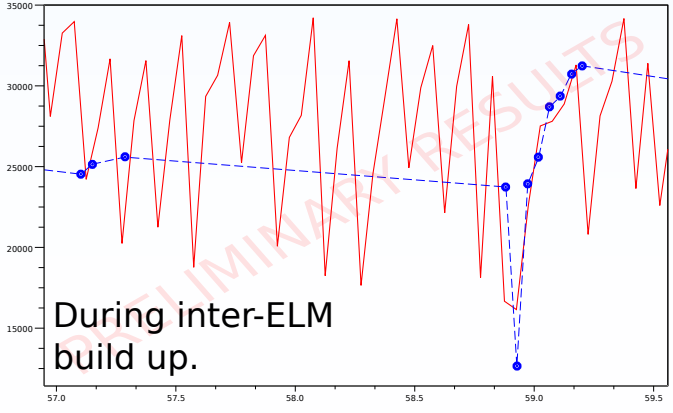

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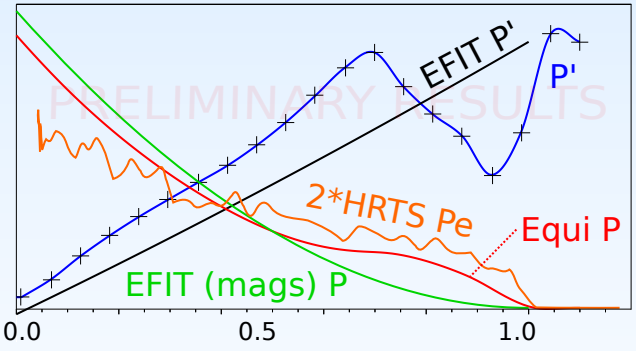


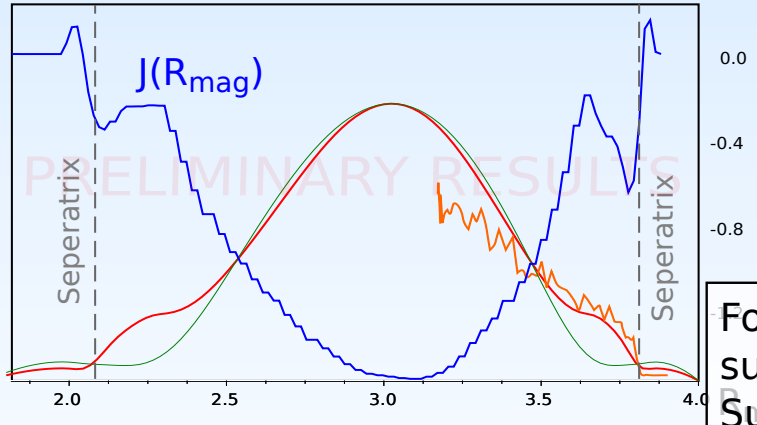


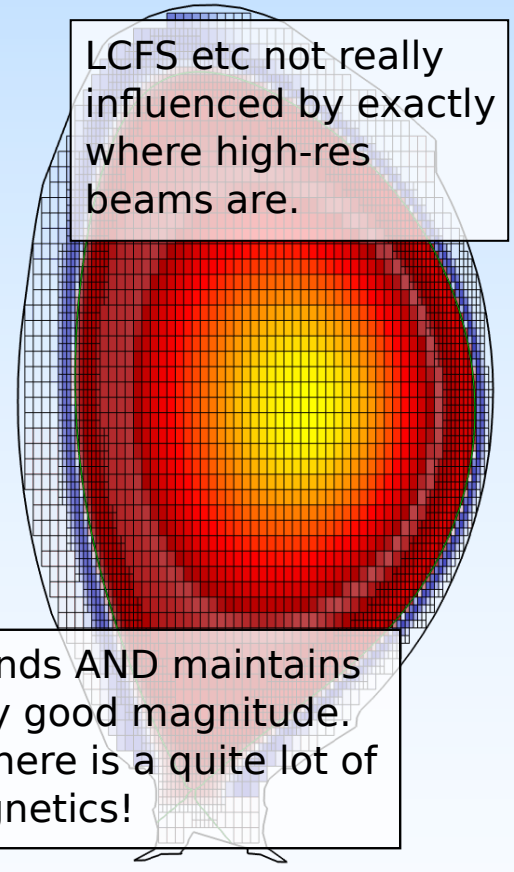

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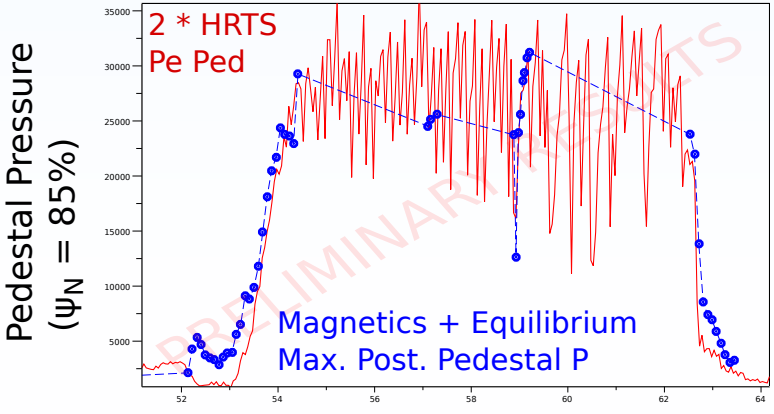


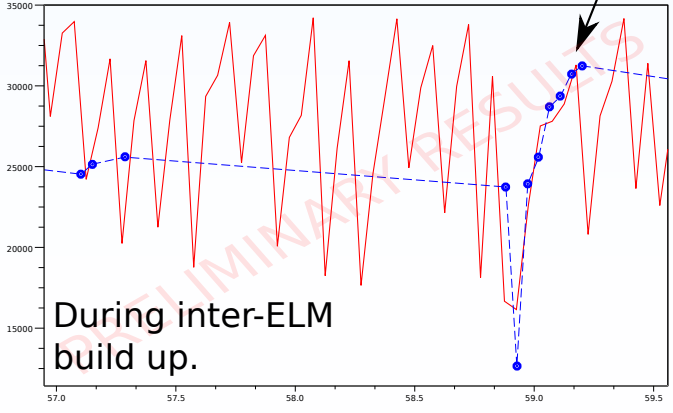

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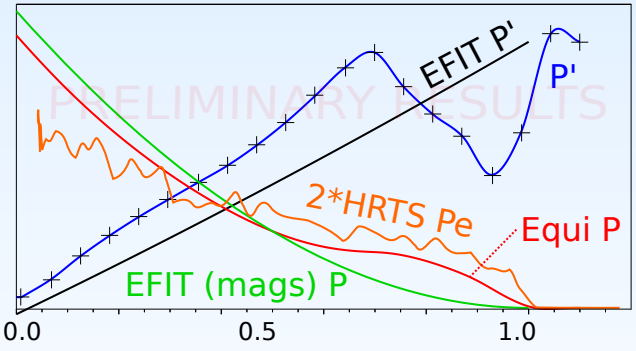


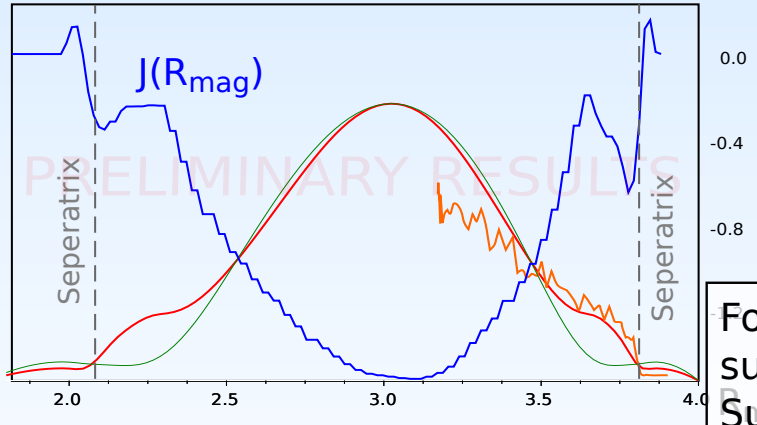


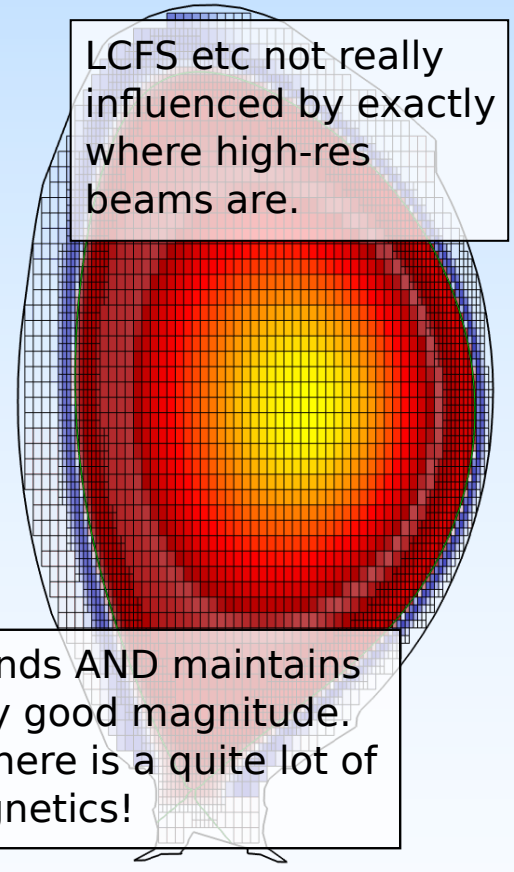

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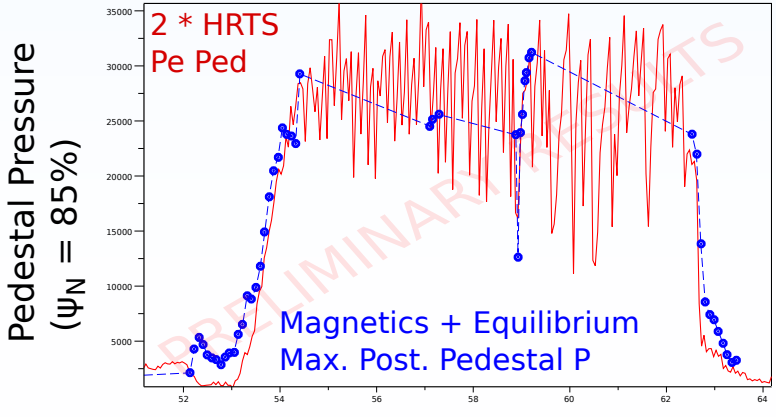


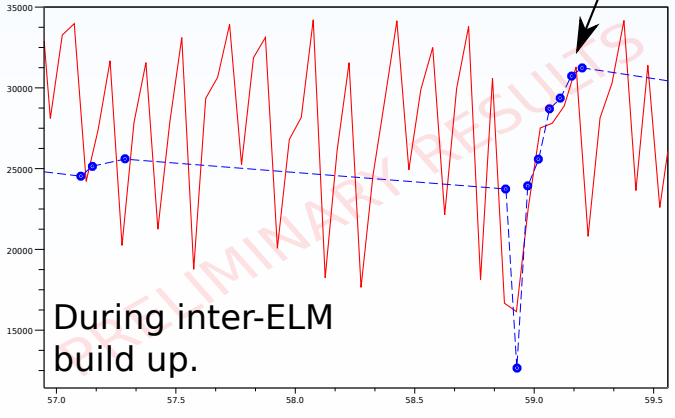


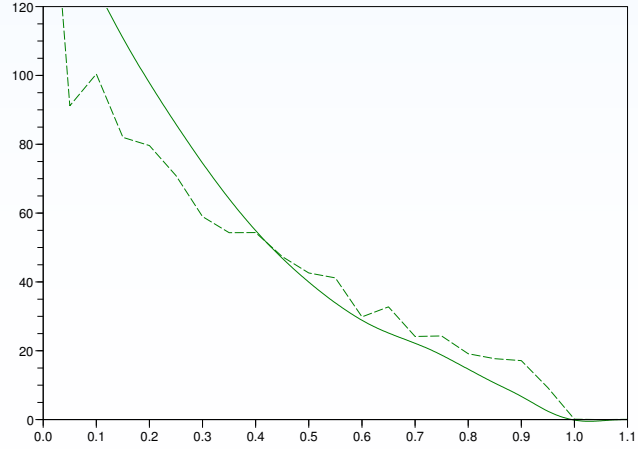

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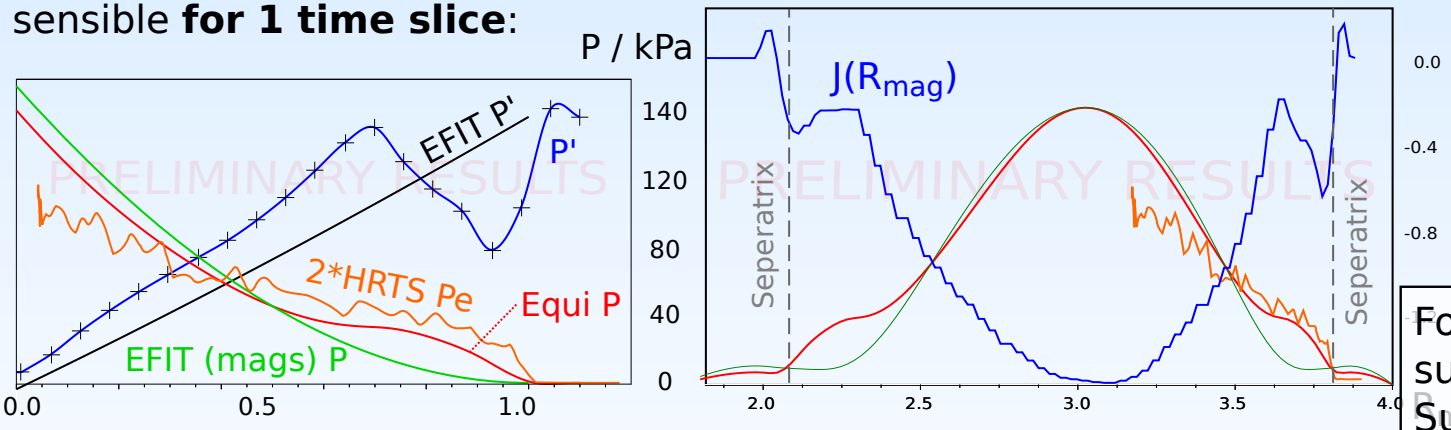


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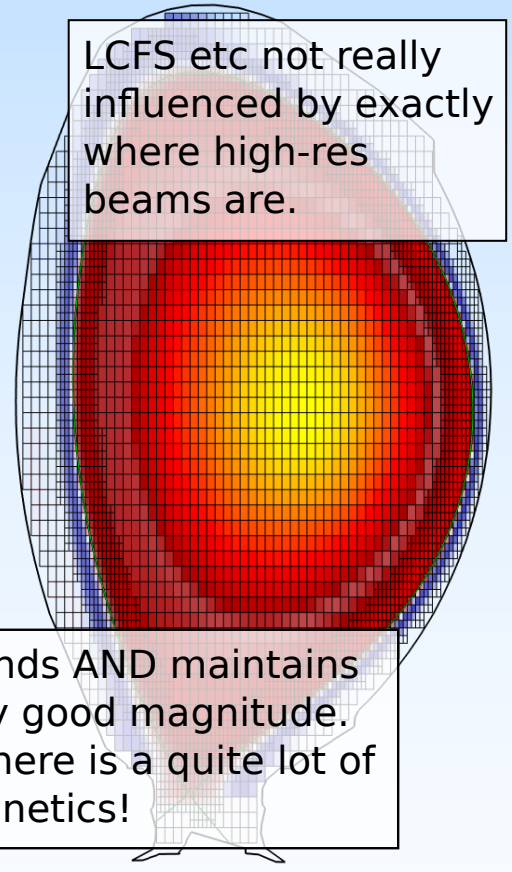

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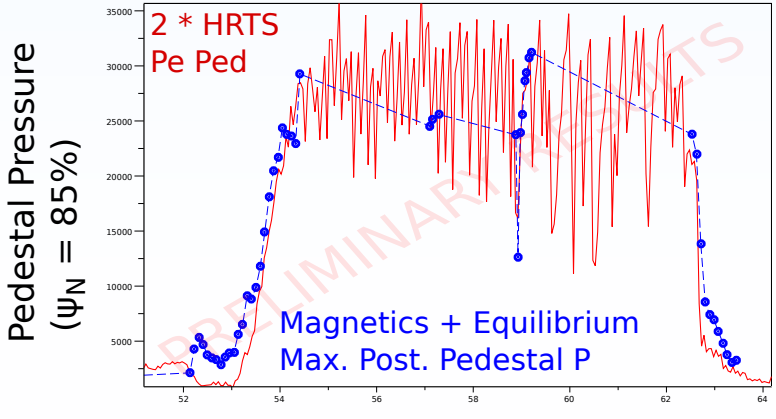


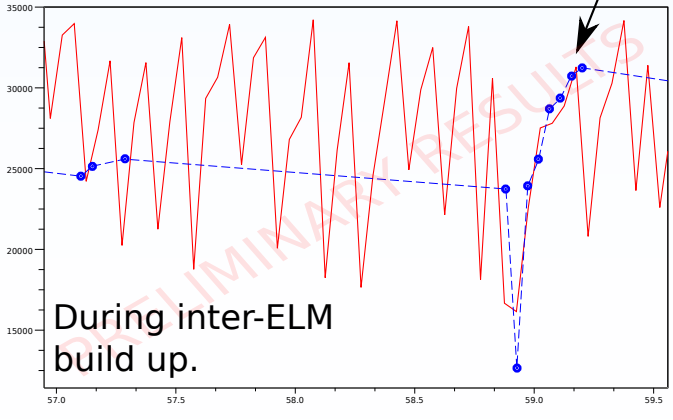


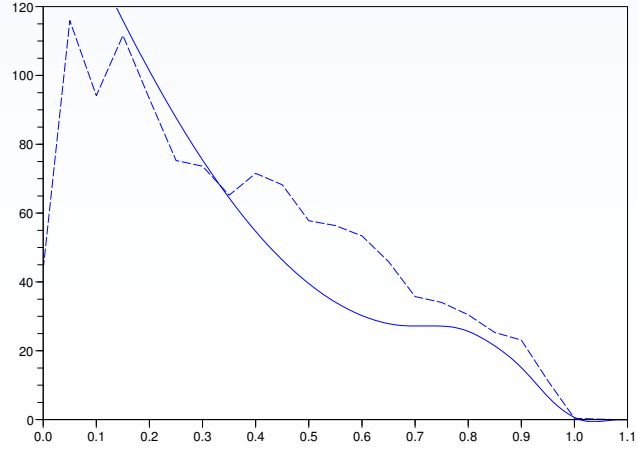

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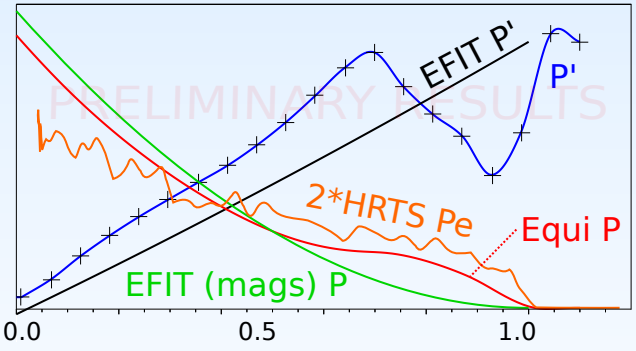


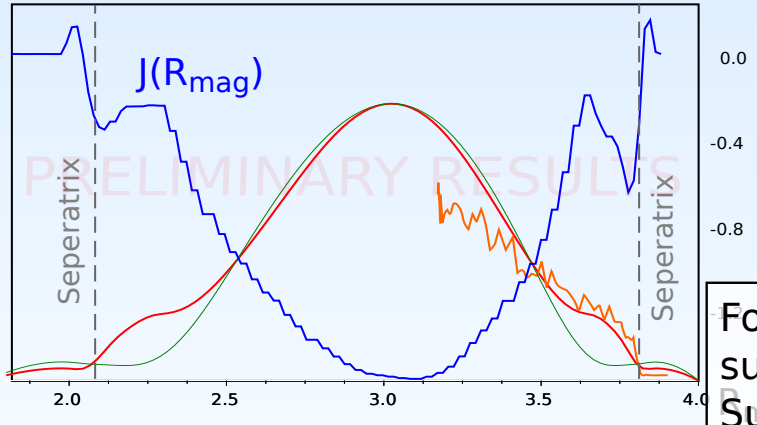


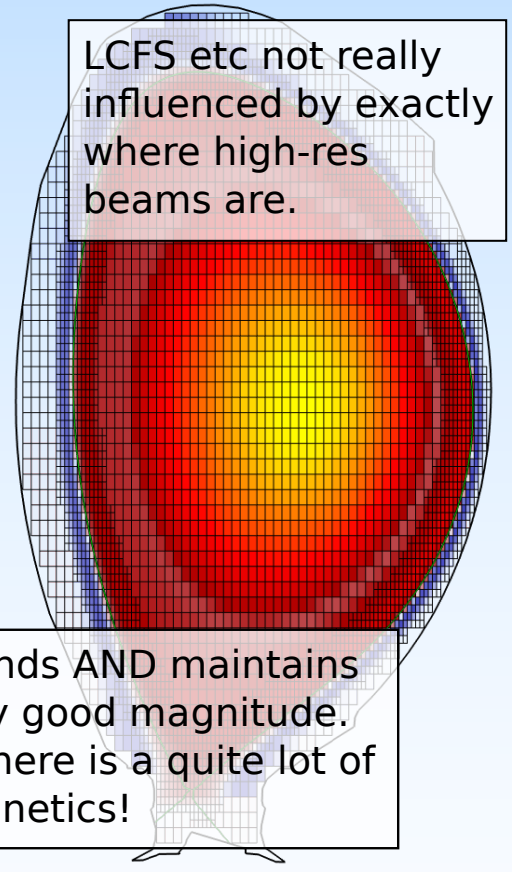

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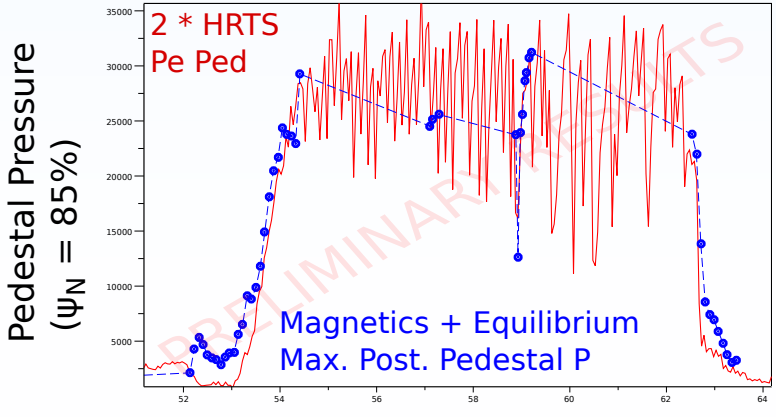


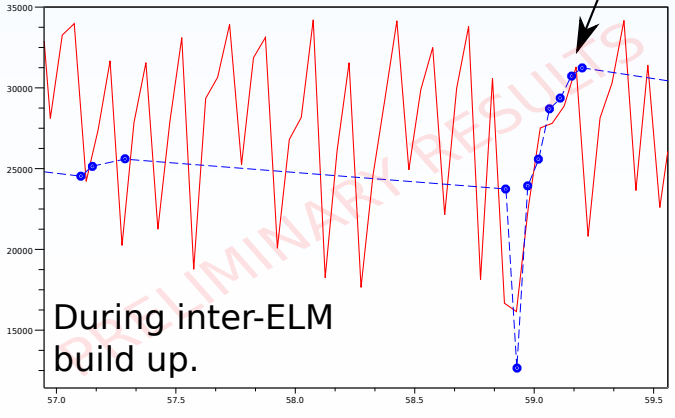


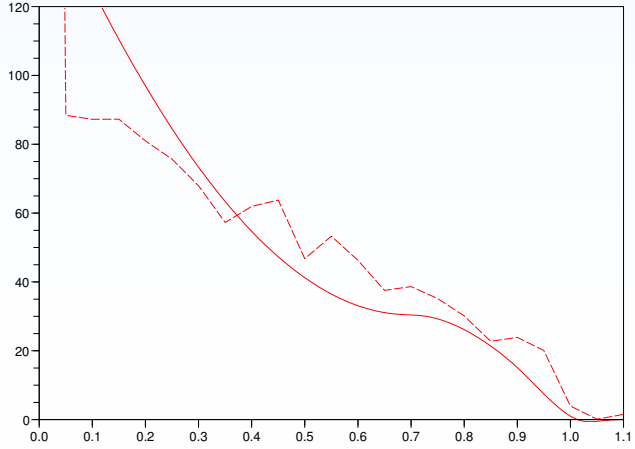

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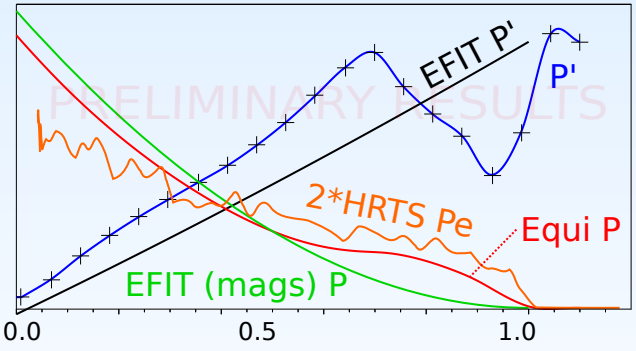


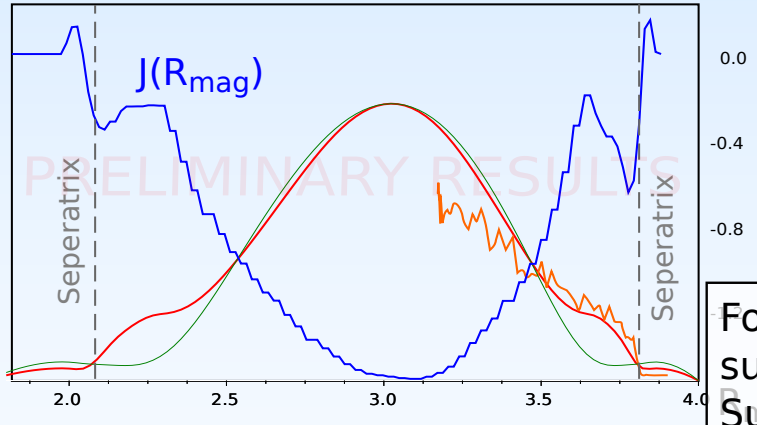


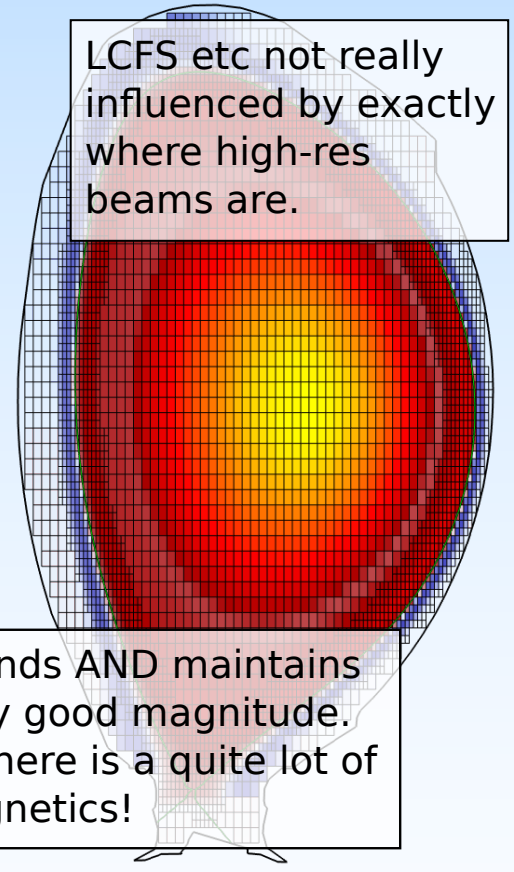

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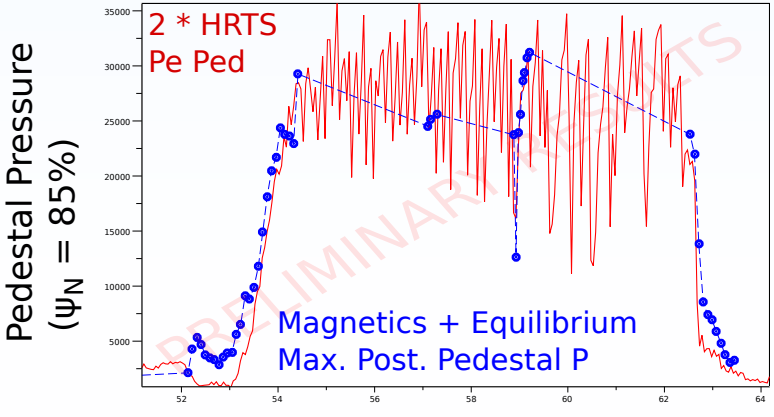


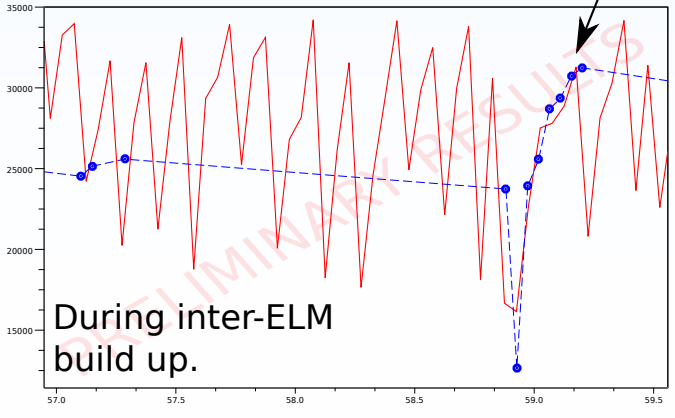


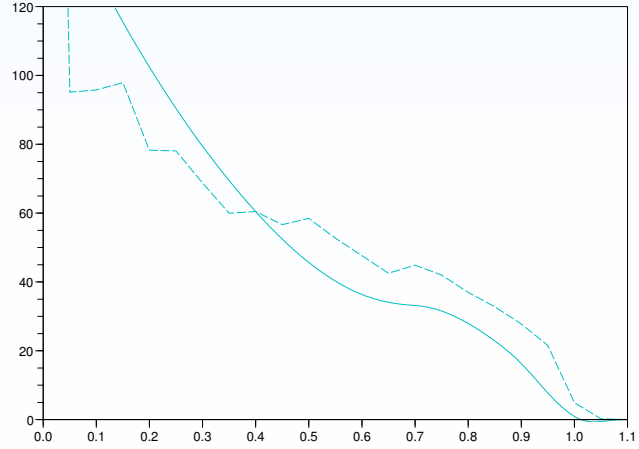

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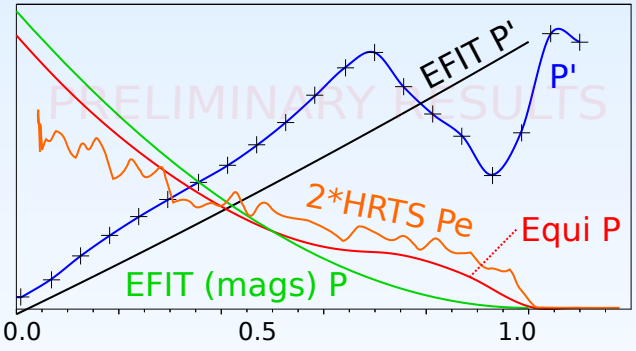


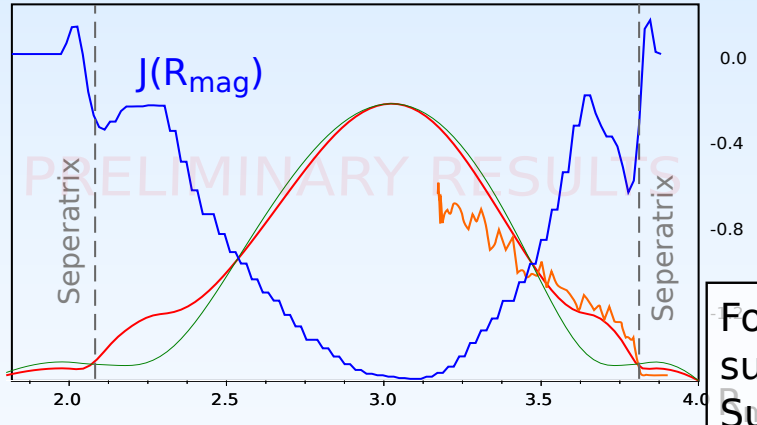


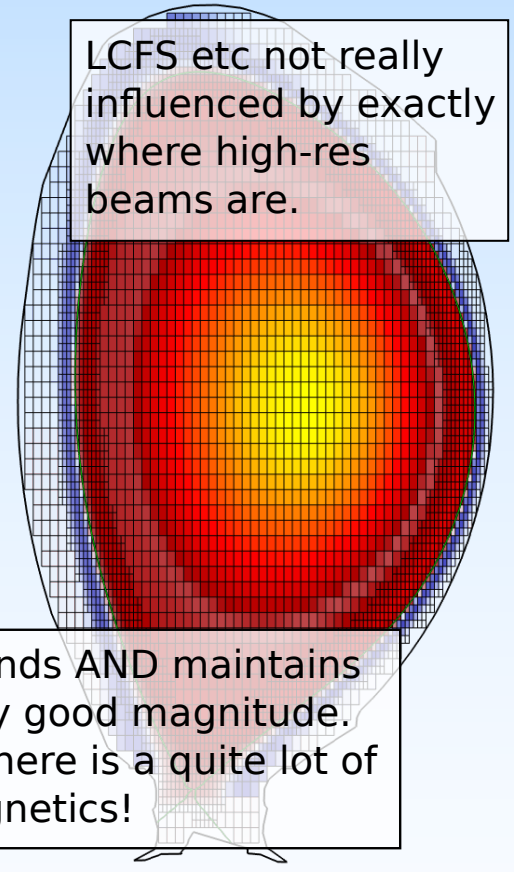

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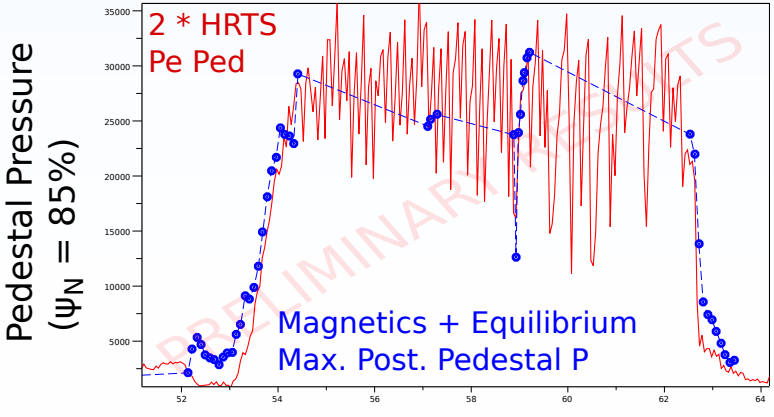


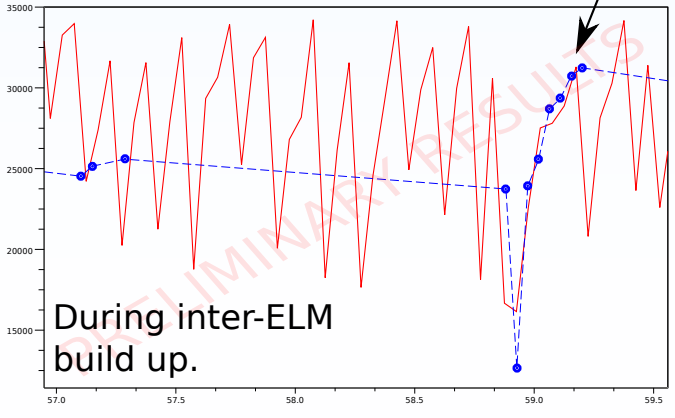


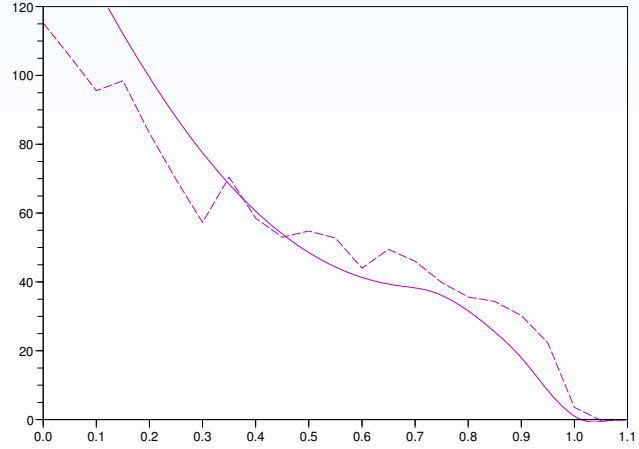

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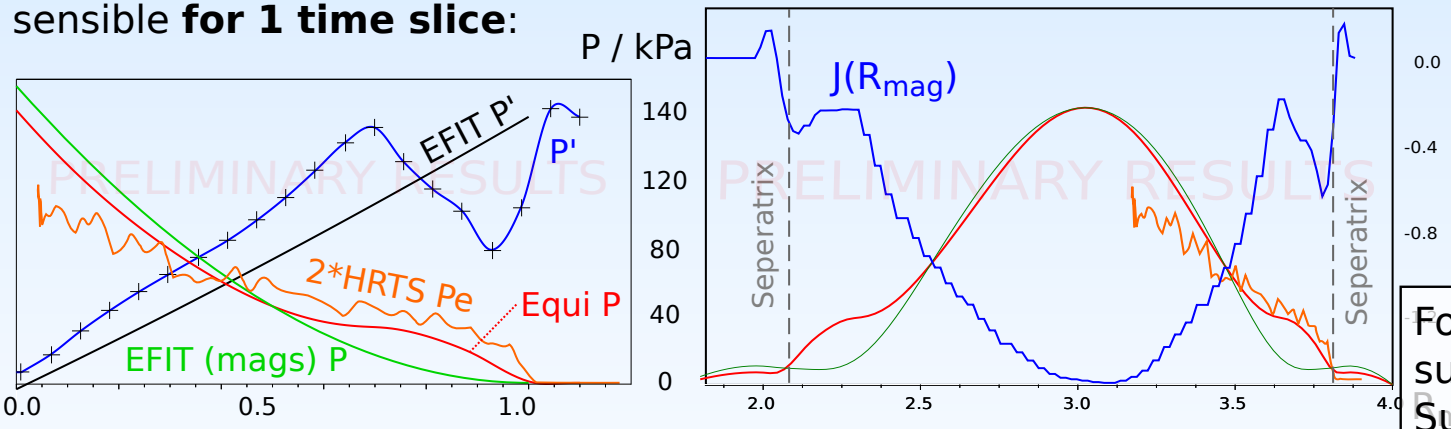


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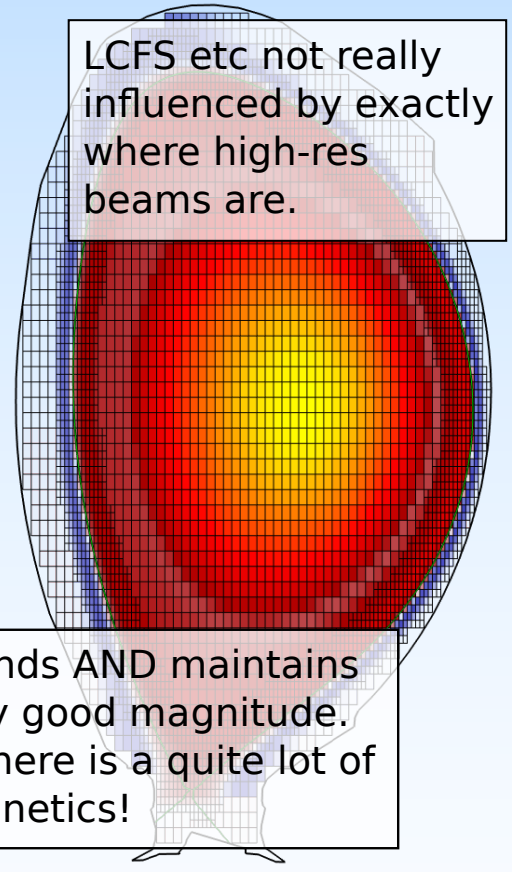

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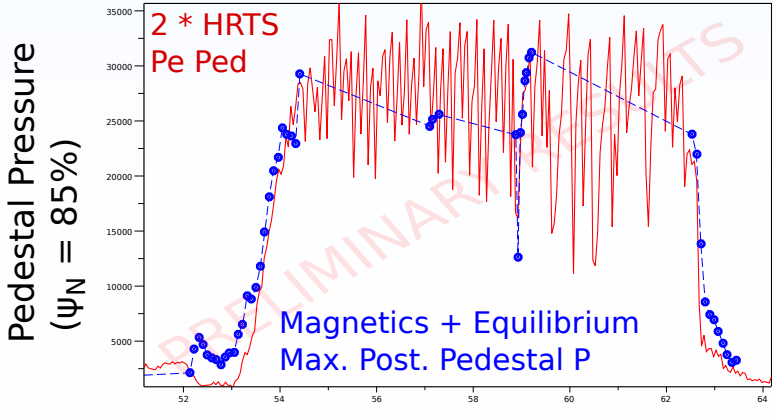


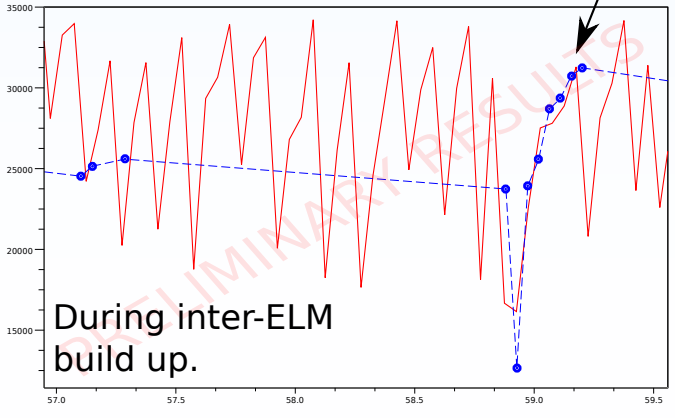


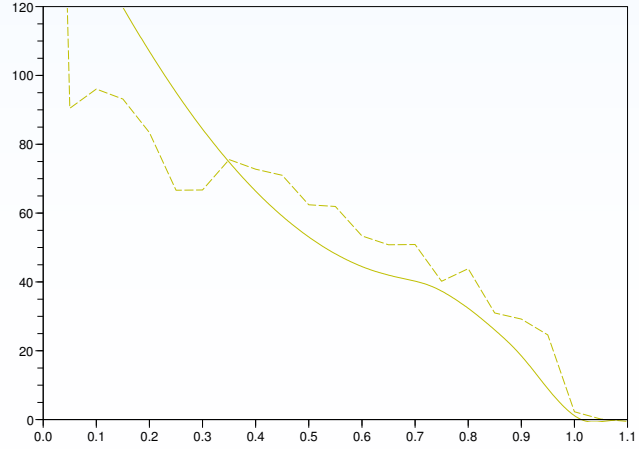

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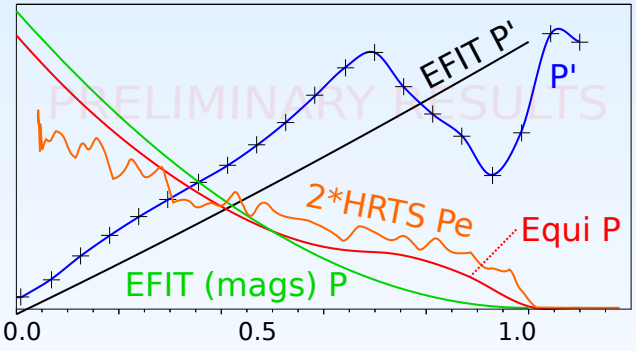


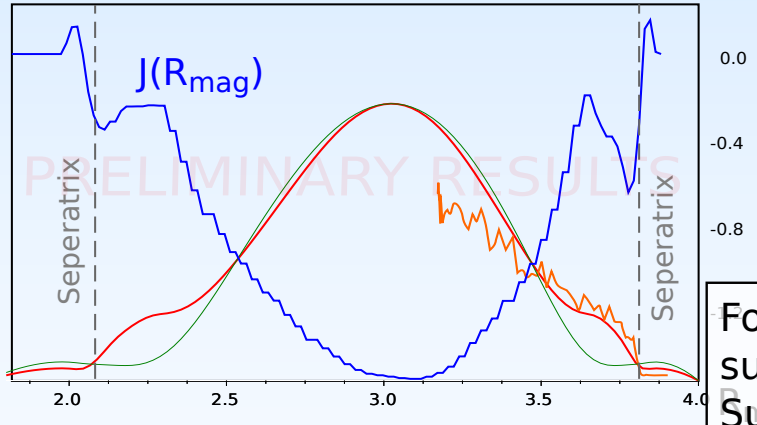


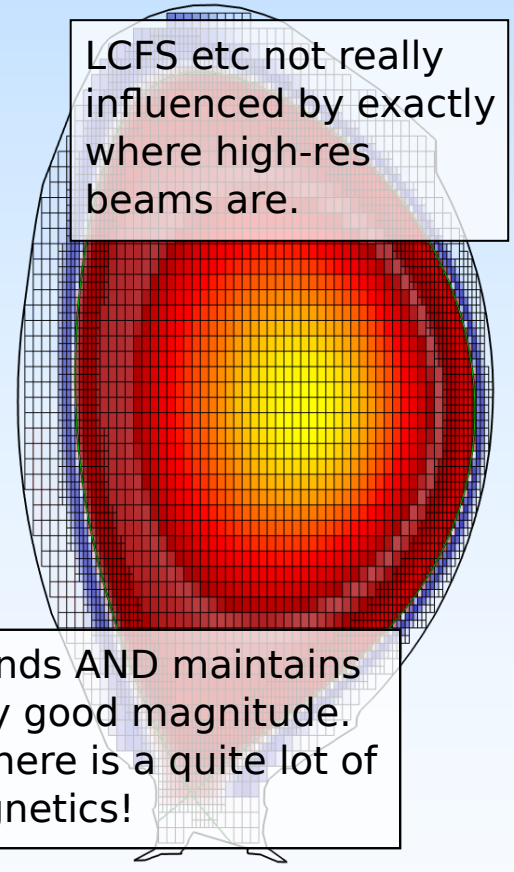

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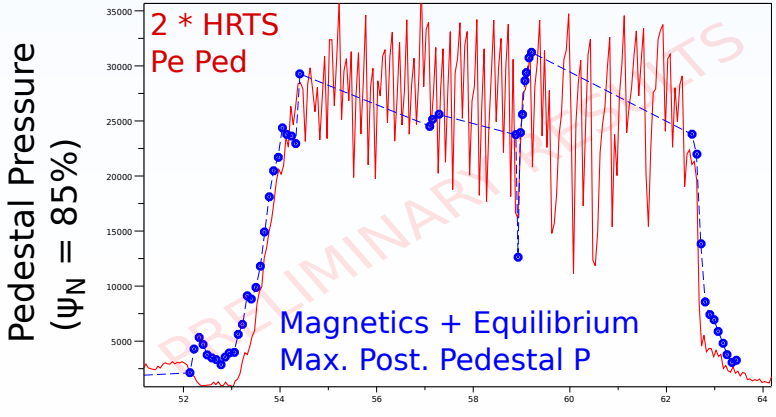


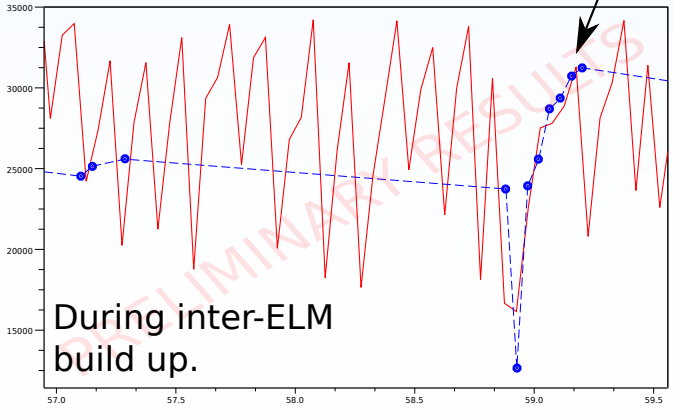


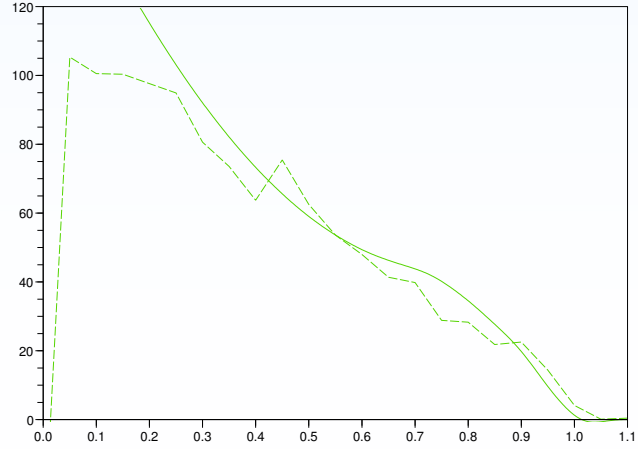

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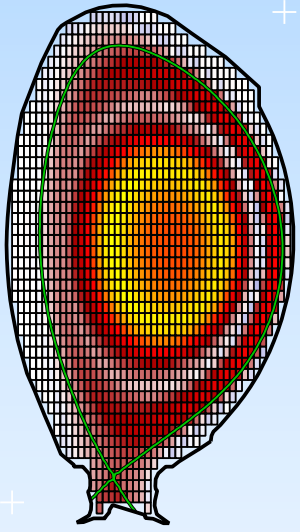

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VERY PRELIMINARY RESULTS

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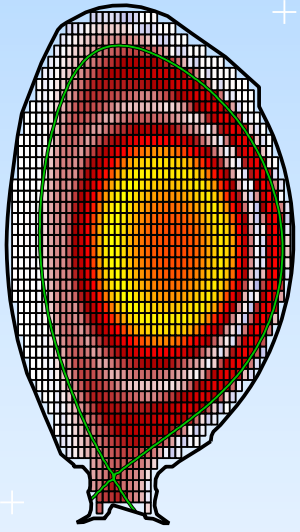

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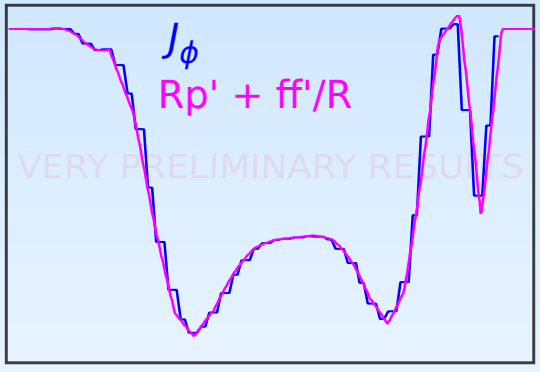

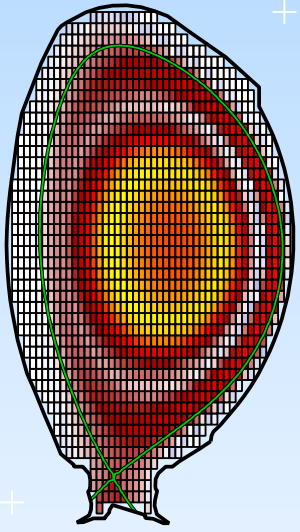

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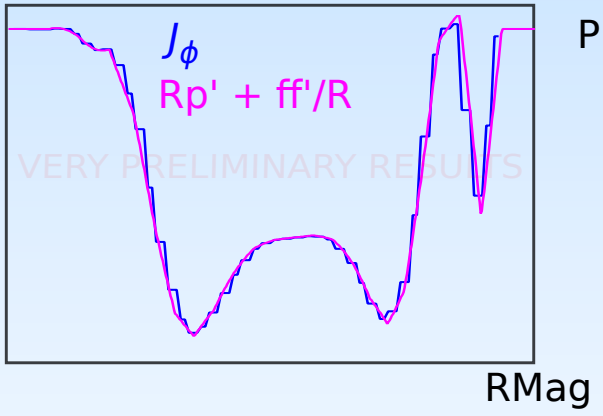


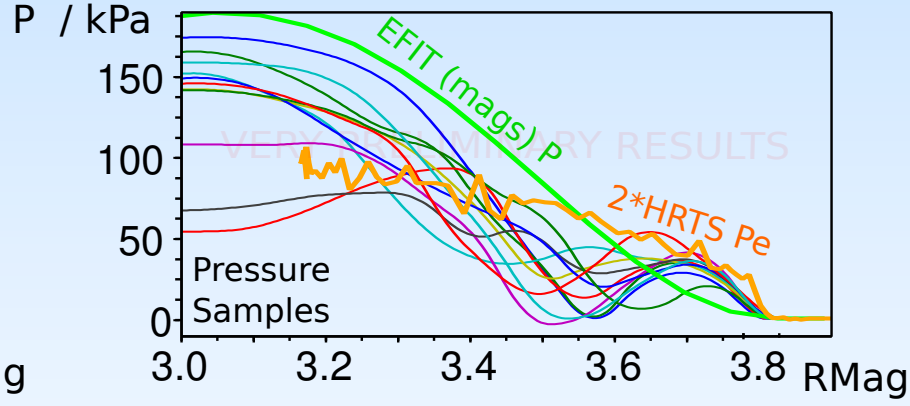

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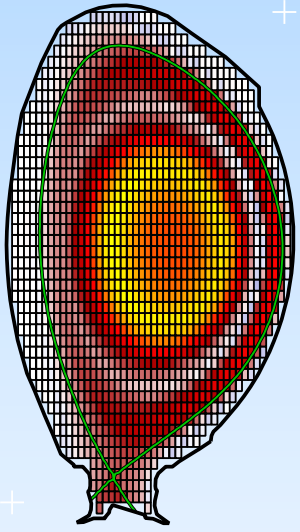

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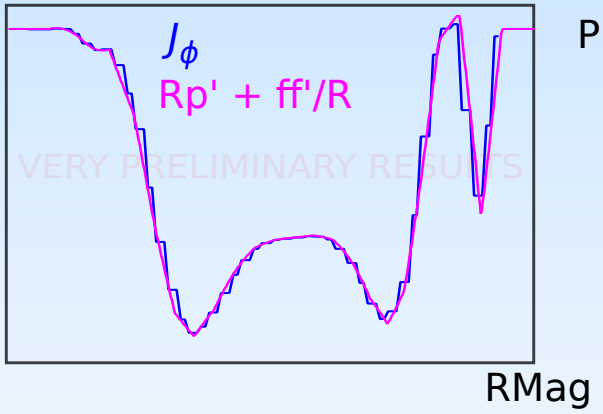


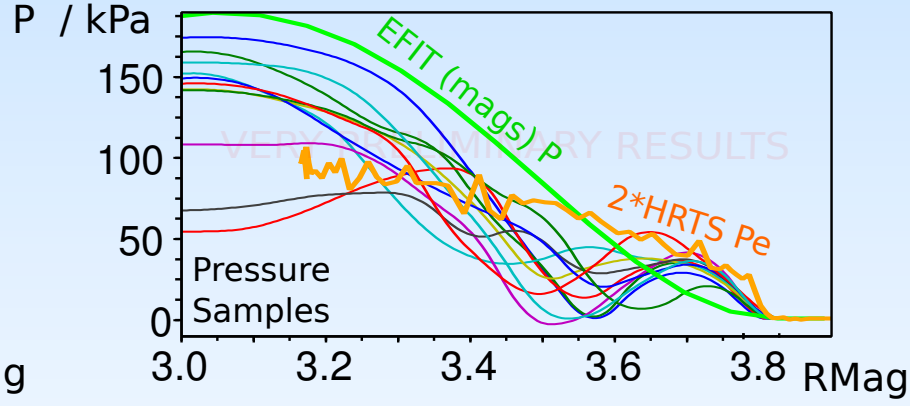


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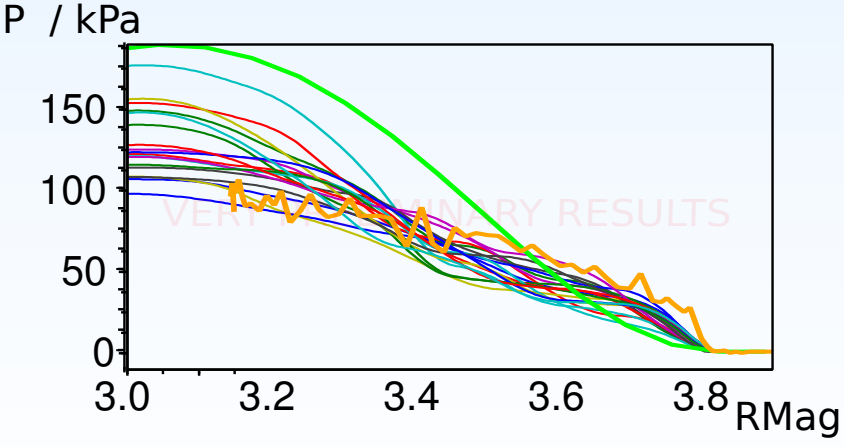

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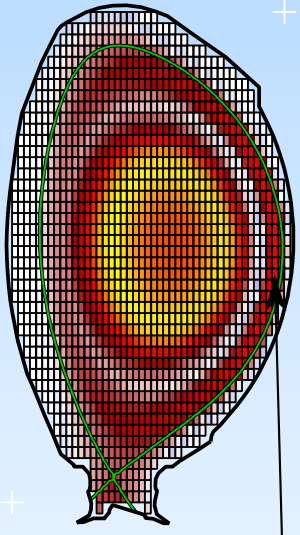

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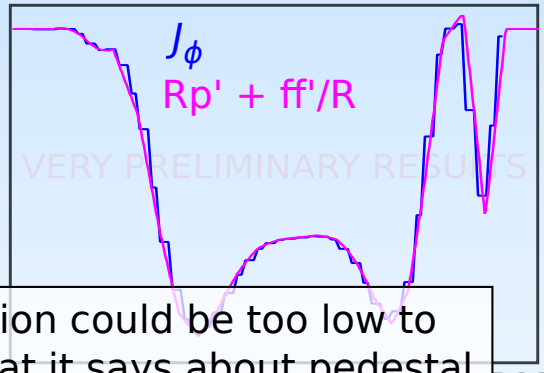


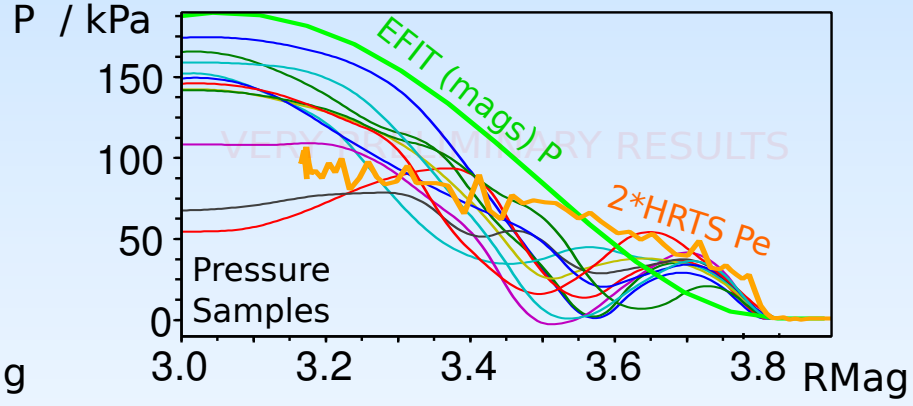


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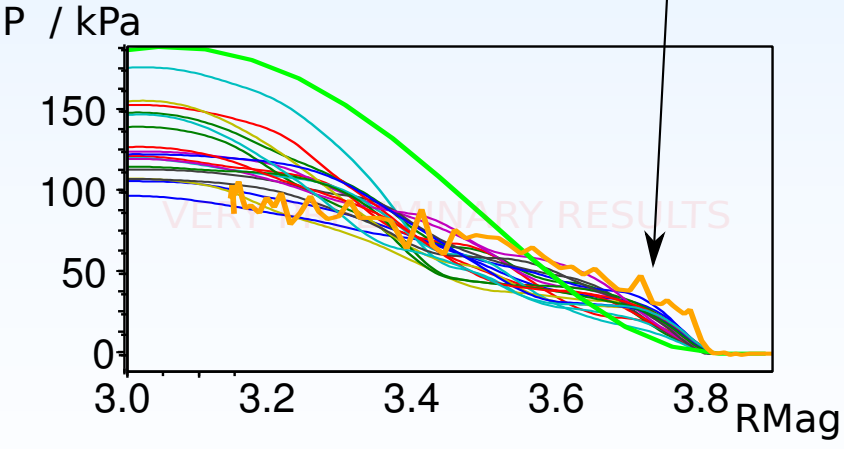

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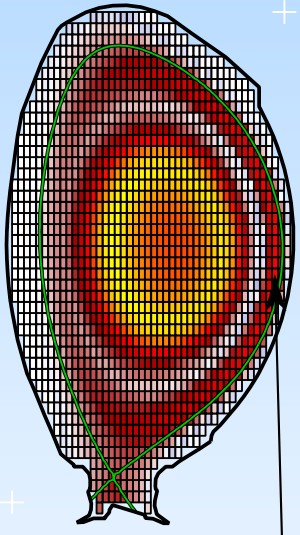

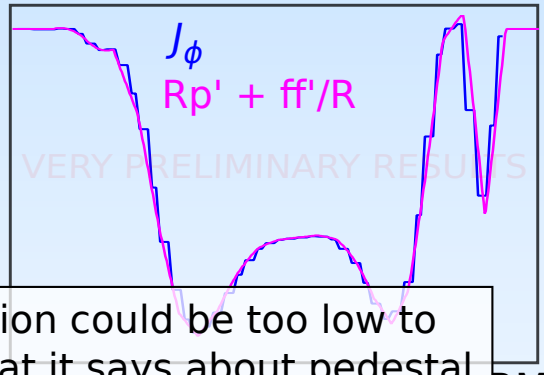


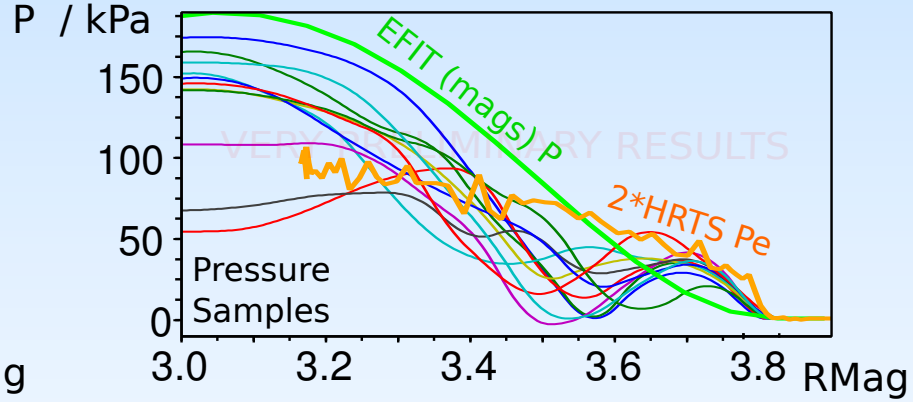


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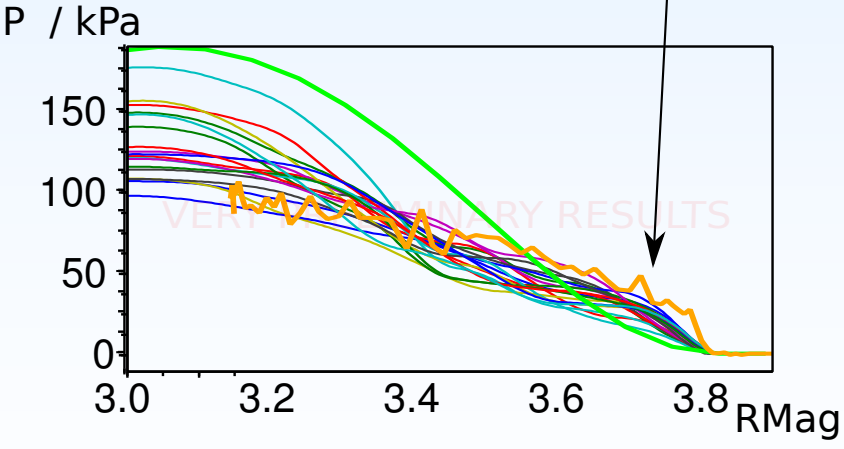


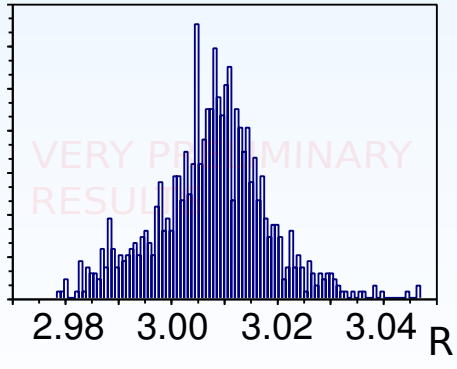


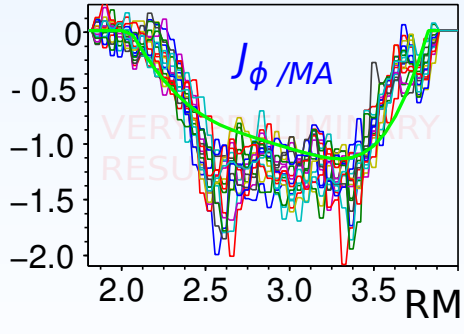


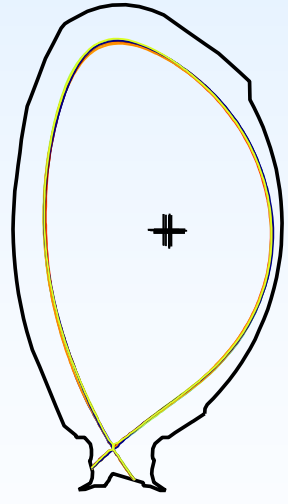

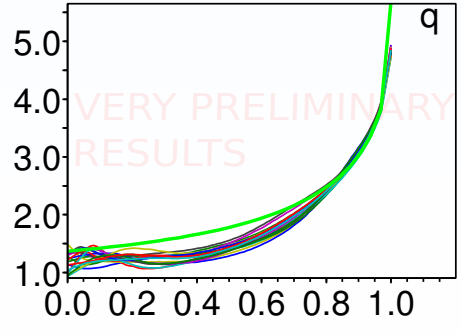

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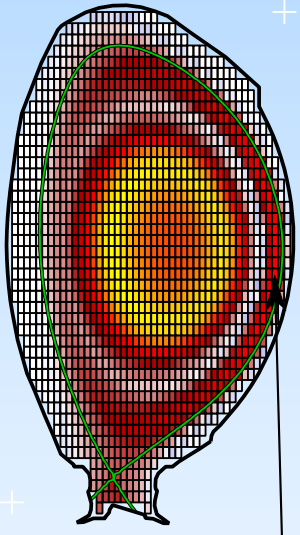

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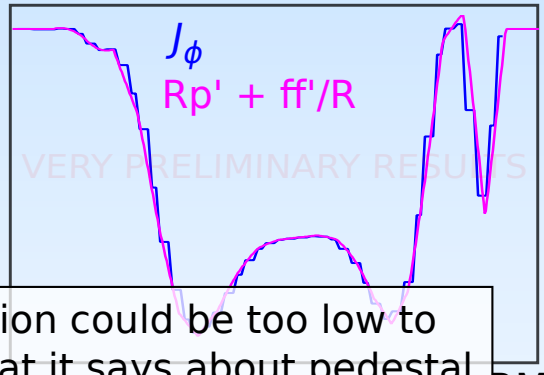


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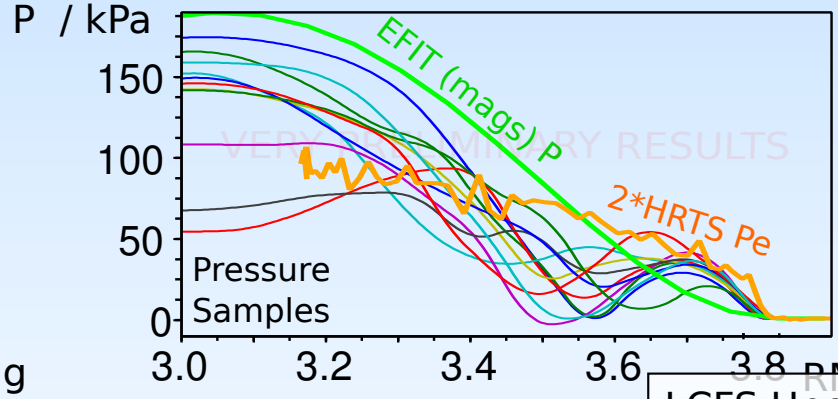


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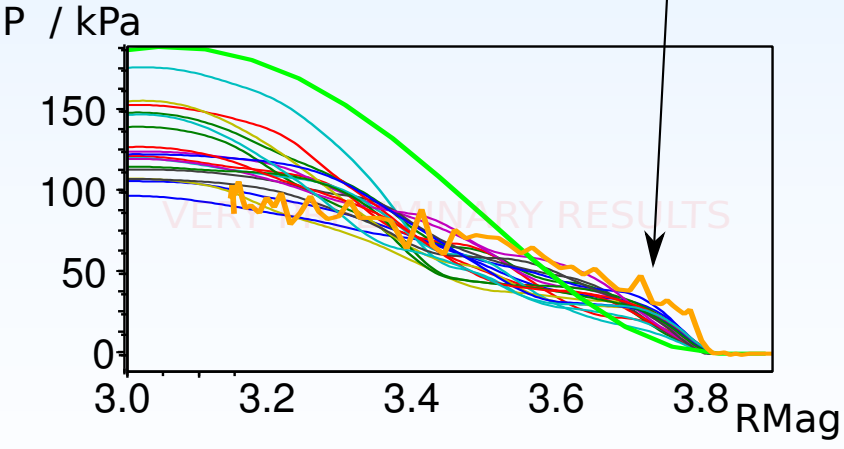


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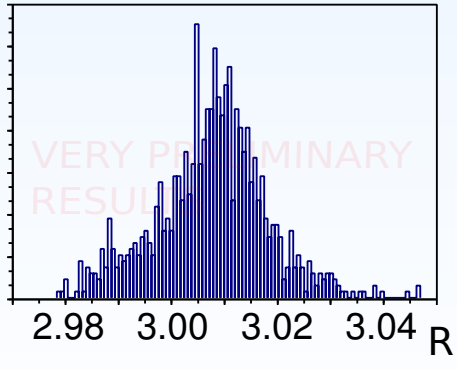


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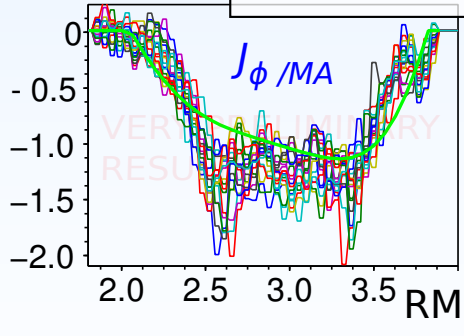


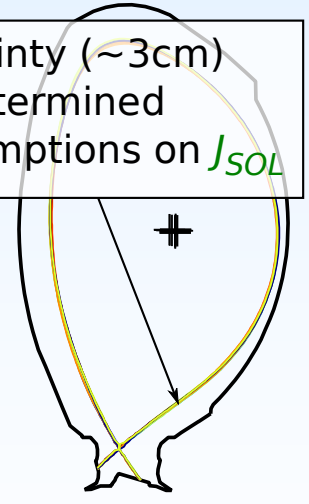

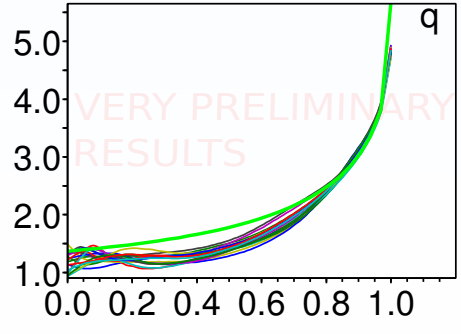

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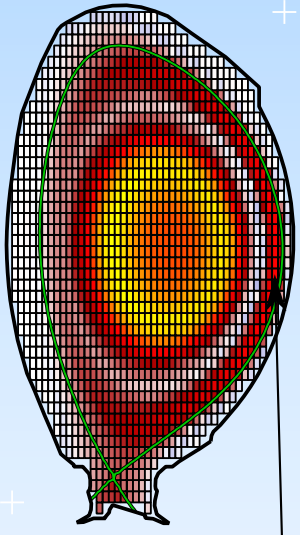

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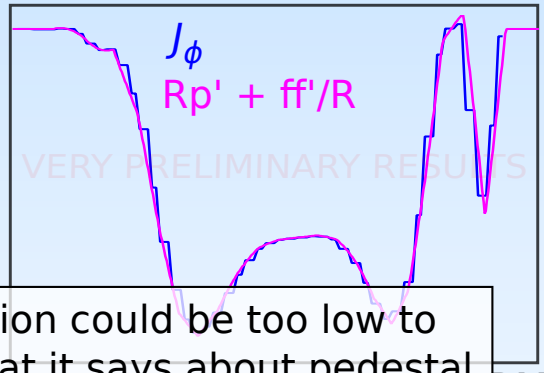


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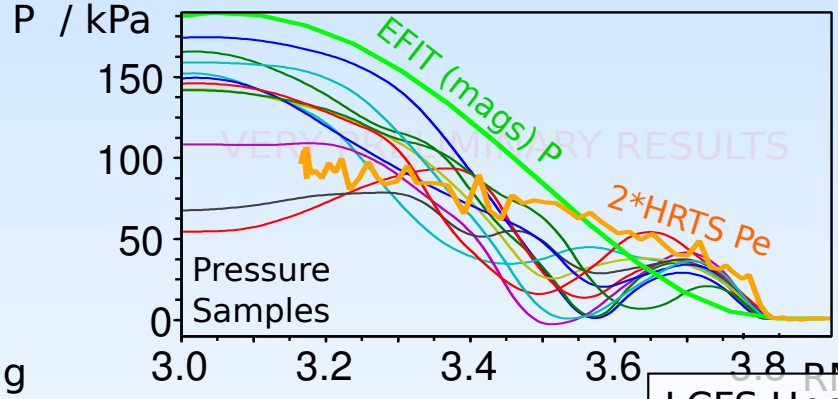


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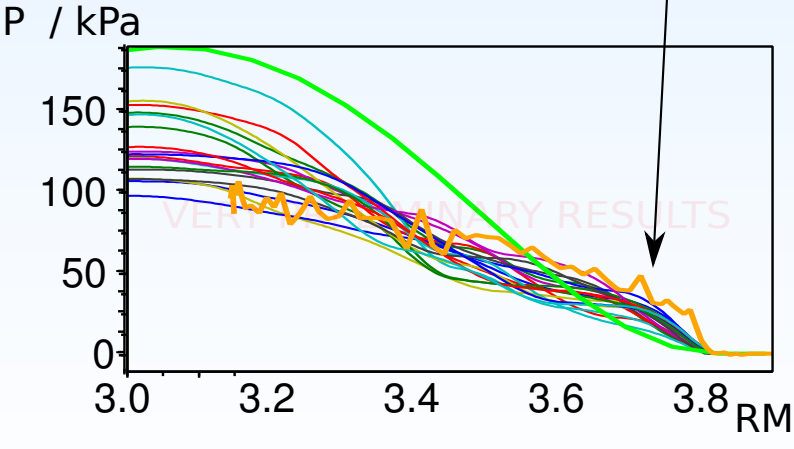


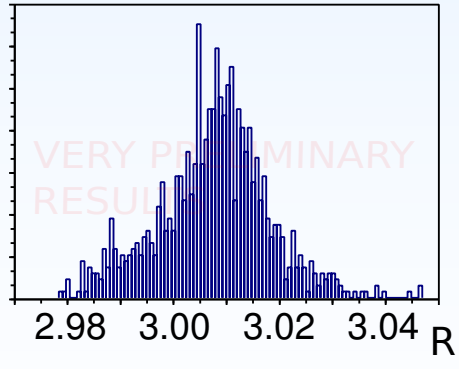


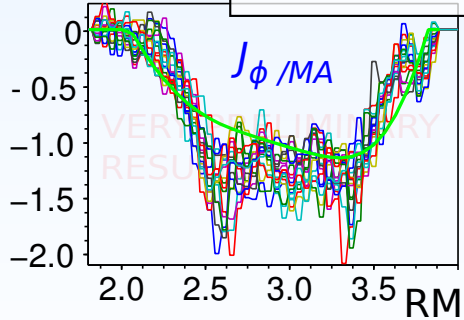


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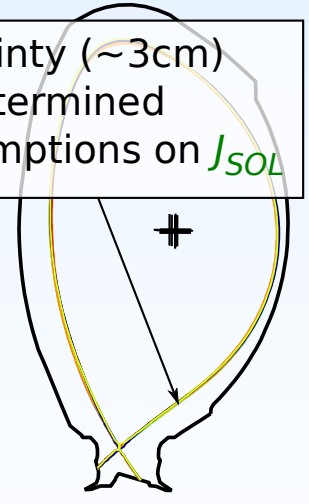

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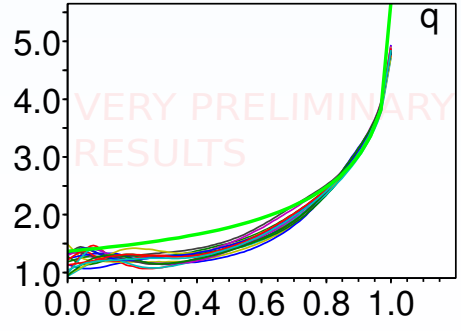

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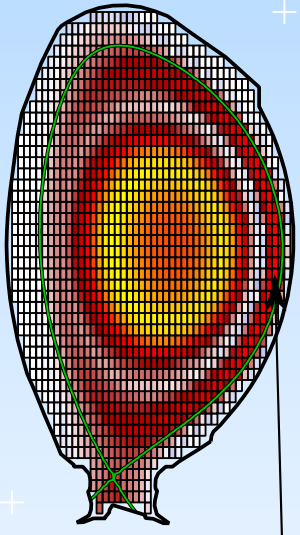

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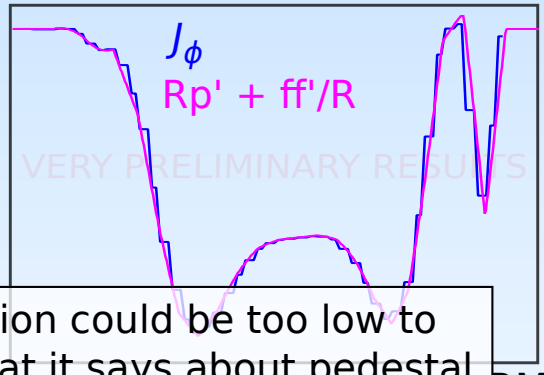


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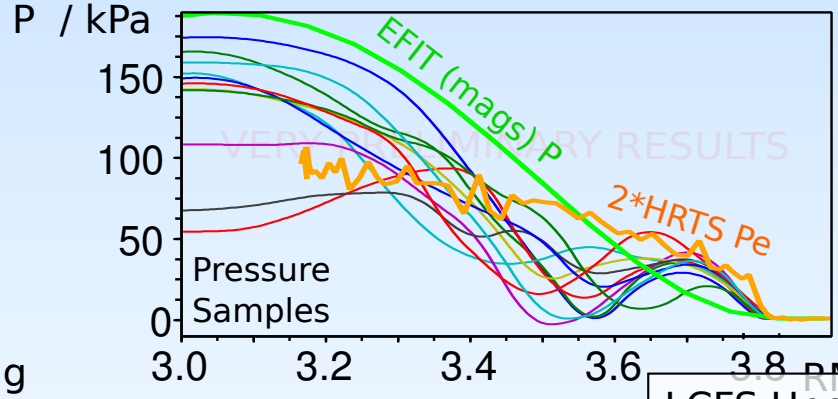


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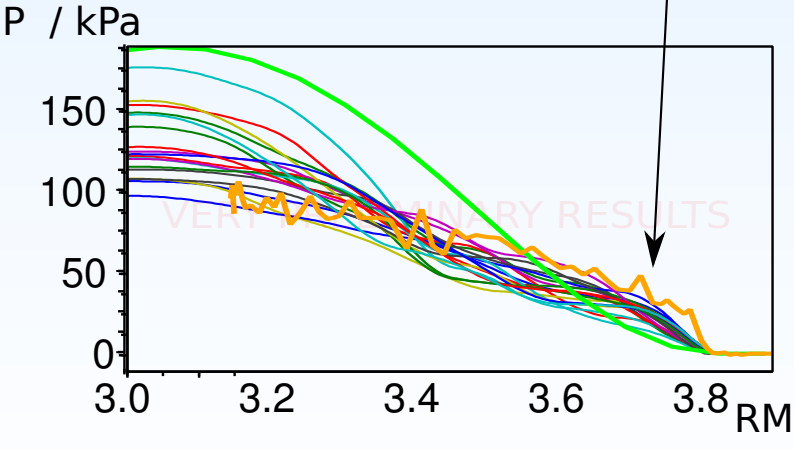


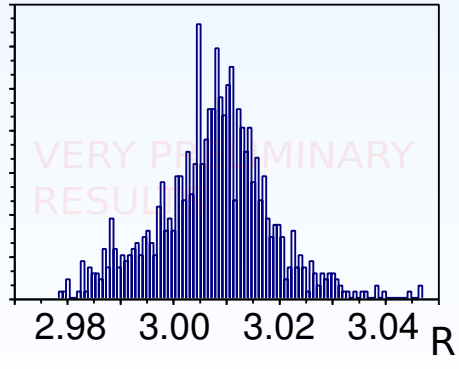


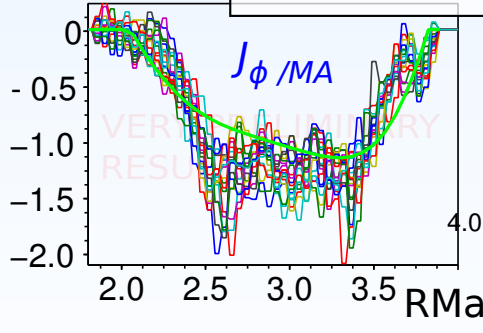


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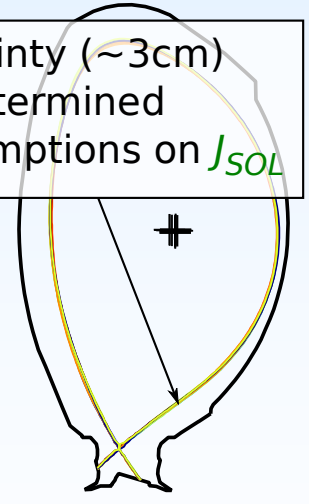

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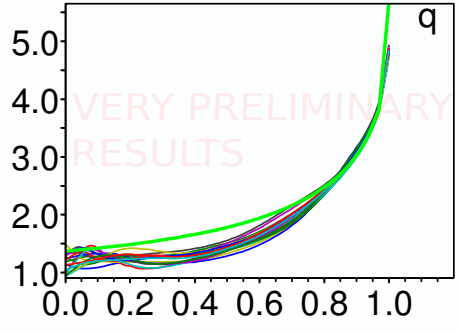
All of this still needs lots of investigating and validating...



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  P( $\boldsymbol{J}$, $n_e$ , $T_e$ | Magnetics + Core LIDAR + Edge LIDAR + Interferometry + Polarimetry + Force Balance + MSE + Reflectometry + ECE + Strike Points)

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- ••• Can we test pedestal scaling from edge LIDAR just with uncertain mapping (CT).
  - ✓ [Have 7000 time points, type-I ELMy H-Mode, marked and clear of ELMS since Edge LIDAR upgrade C20-C27 ]
- ••• Do we get enough info to test current models at edge?