Optimizing and Enriching Plasma Diagnostics with a Data Centric Approach for Fusion Reactors

Aza Jalalvand[1], S.K. Kim[2], J. Seo[3], Q. Hu[2], M. Curie[1], P. Steiner[1], A. O. Nelson[4], Y.S. Na[5], E. Kolemen[1,2]

[1]Princeton University, USA
[2] Princeton Plasma Physics Laboratory, USA
[3] Chung-Ang University, South Korea
[4] Columbia University, USA
[5] Seoul National University, Republic of Korea

DIII-D NATIONAL FUSION FACILITY

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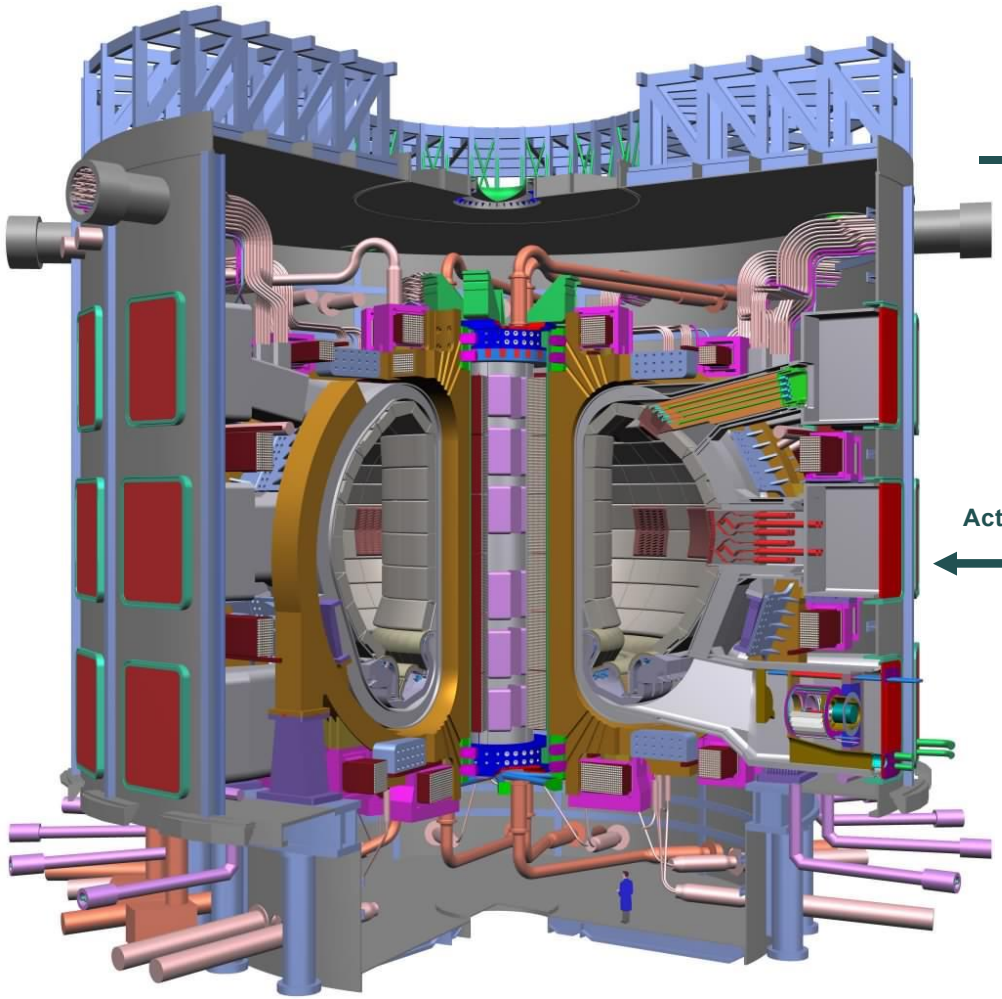
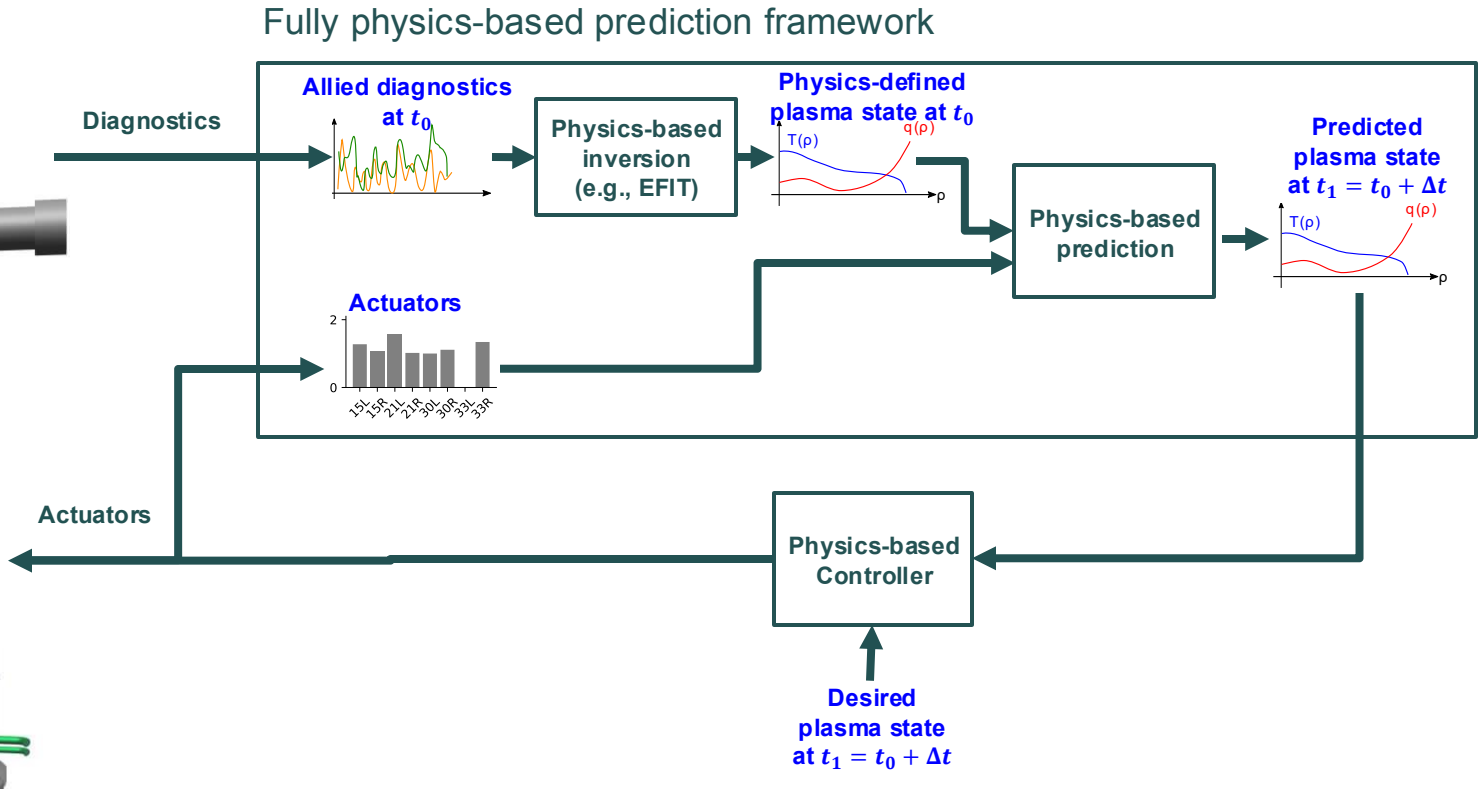
Control for Fusion





- **Physics-based inversion and prediction are sometimes slow and/or not much accurate**

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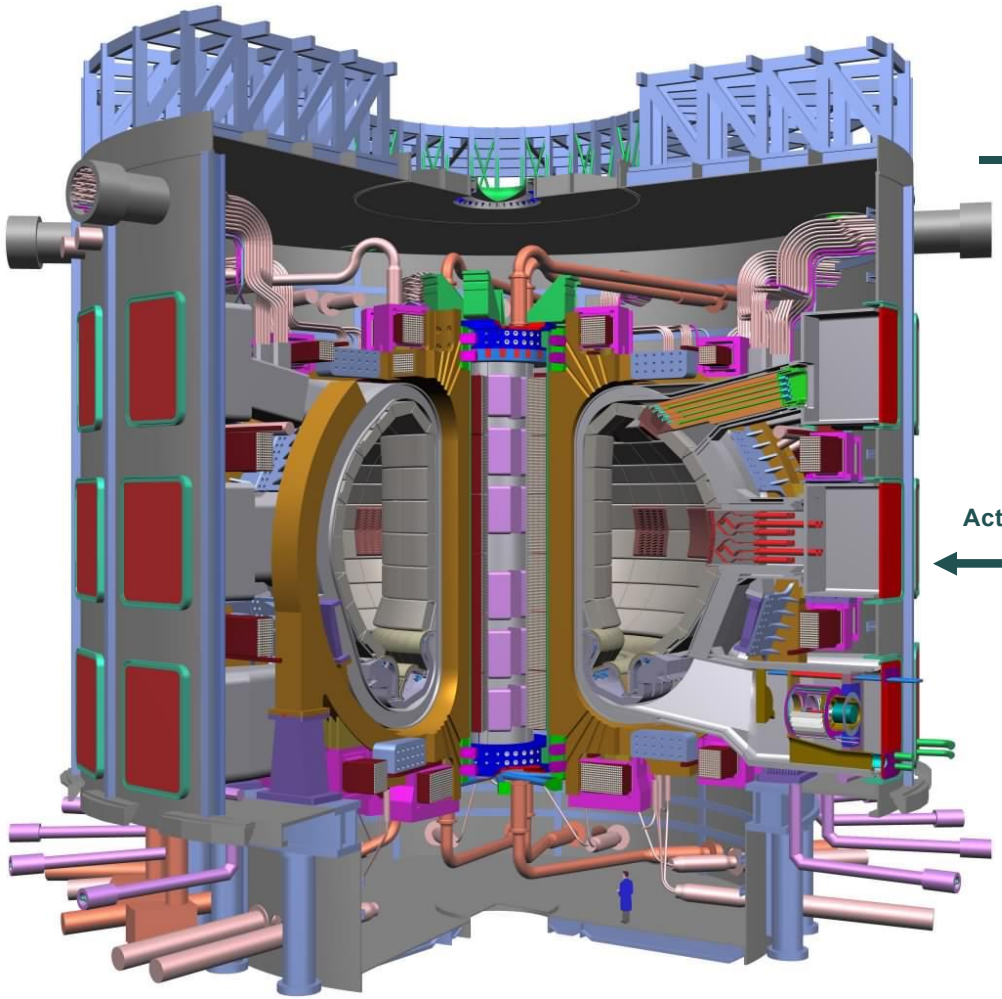
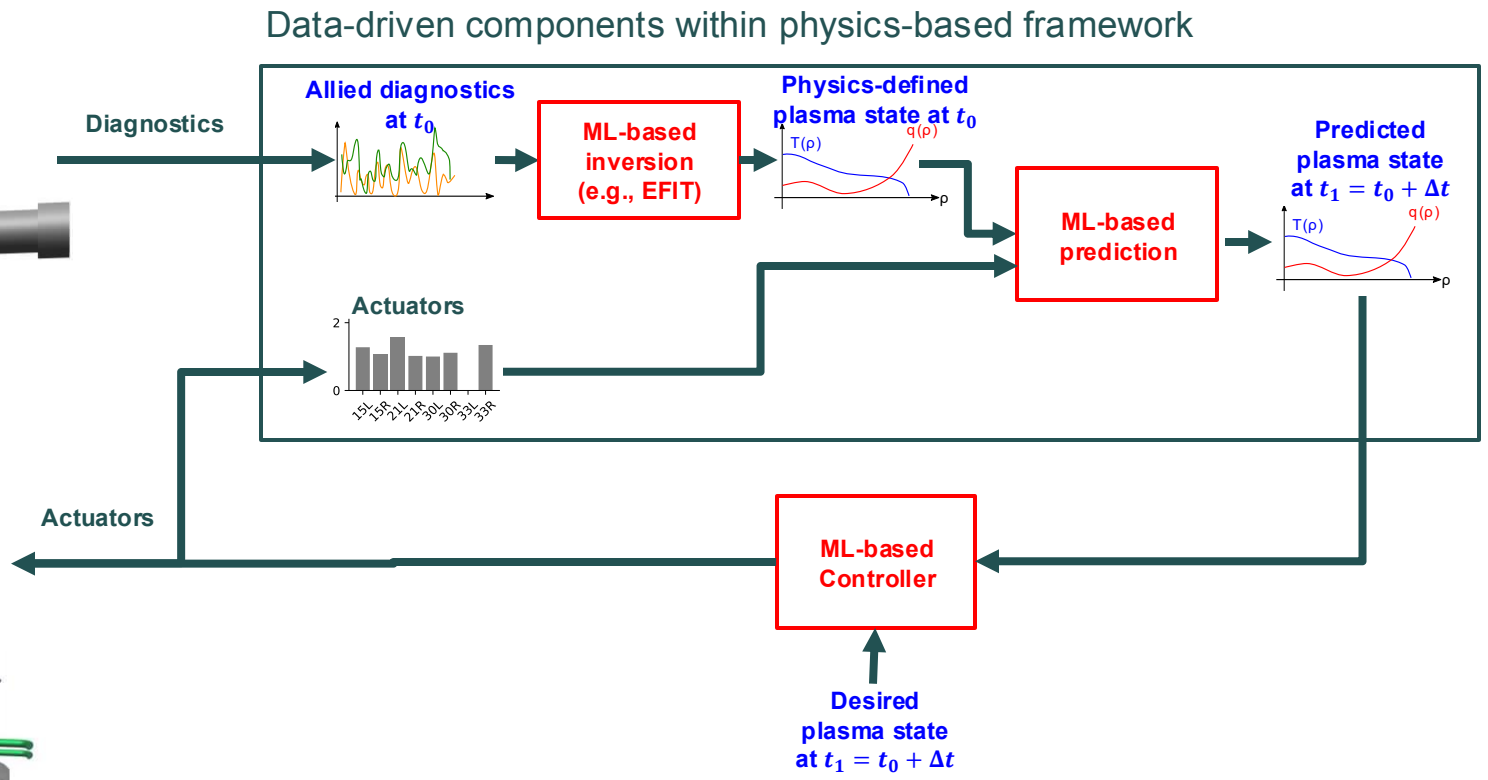
Control for Fusion





- **ML-based surrogate models speed up the process significantly. But they usually inherit the inaccuracy/uncertainty of physics-based inversion components.**

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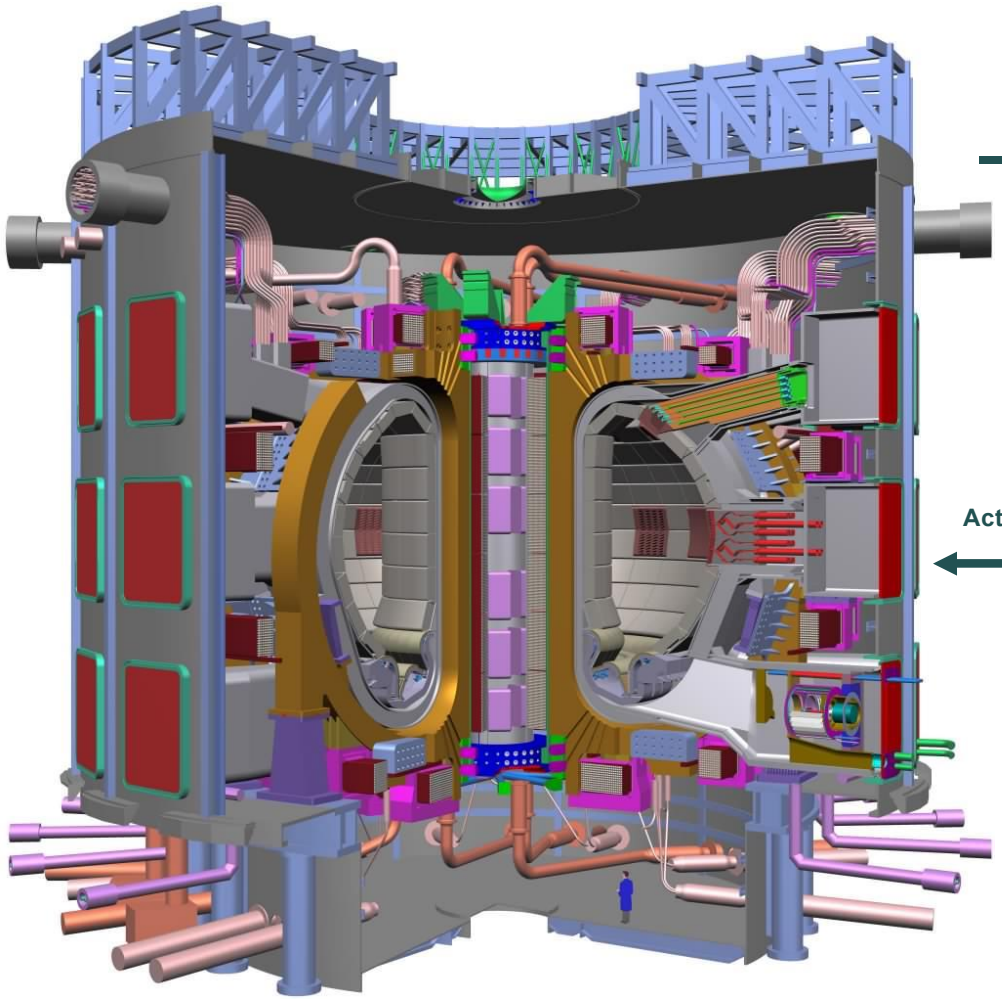
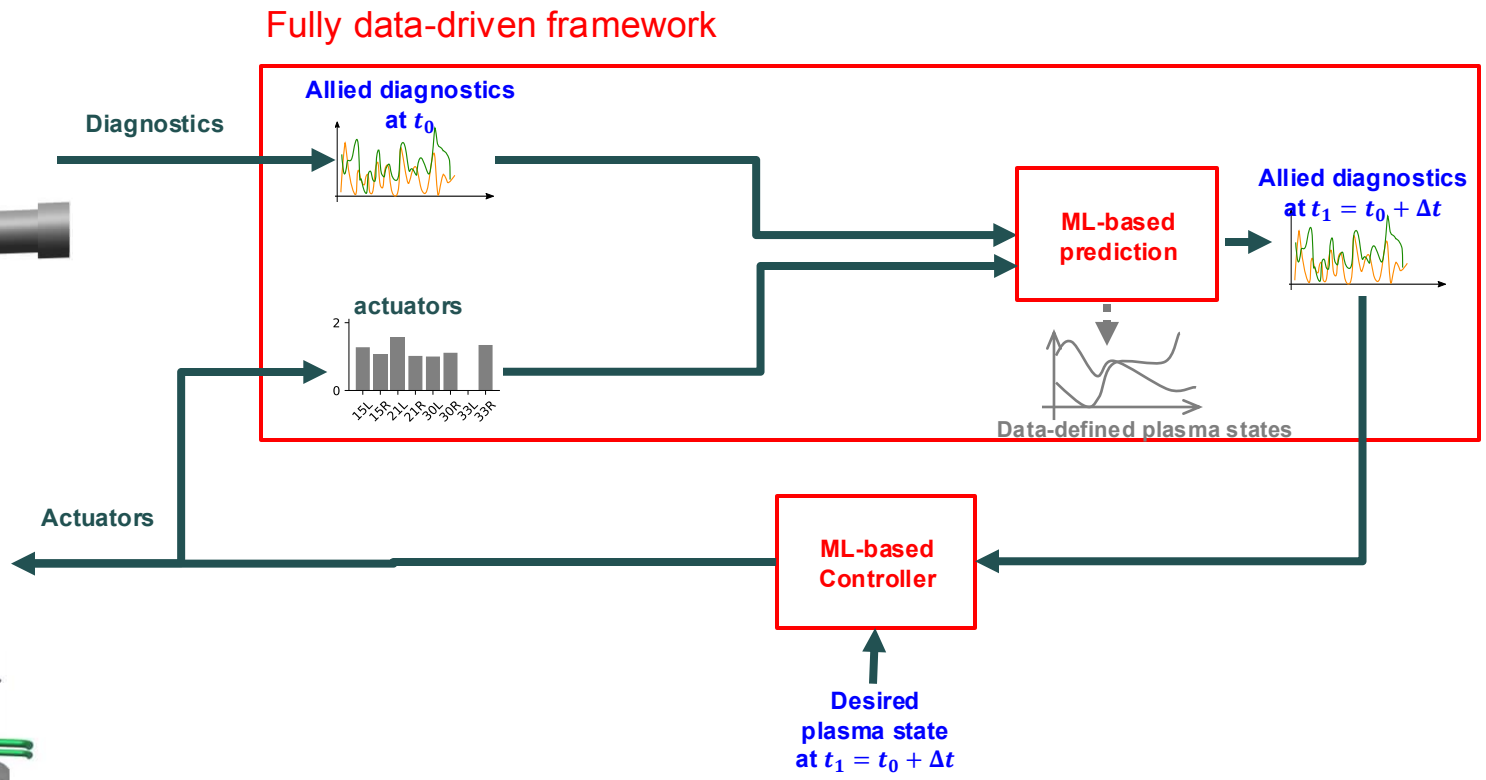
Control for Fusion





- **Fully data-driven model can be an alternative to avoid uncertainties of physics-based models.**

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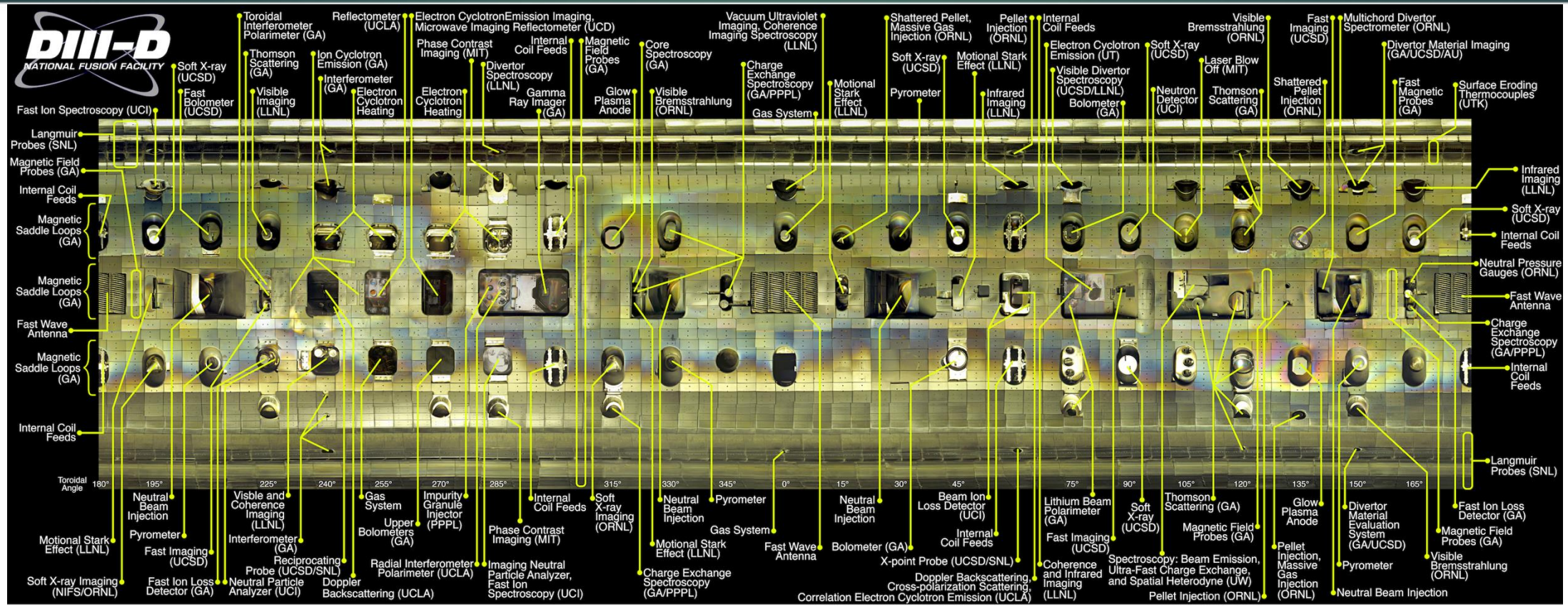
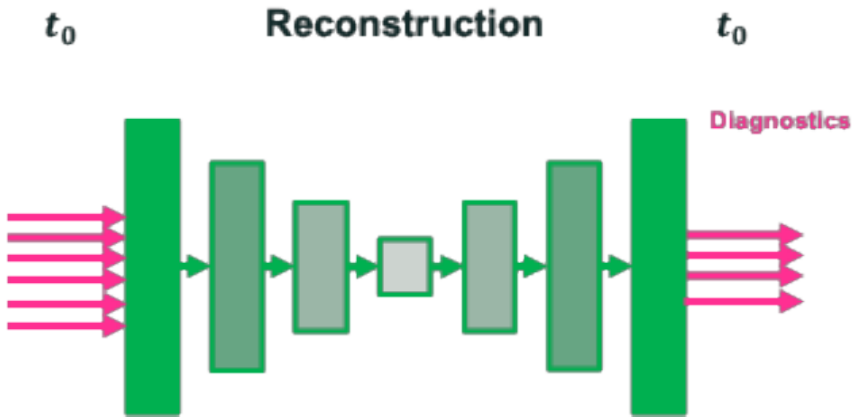
Fusion Has Huge Amounts of Data: How to Utilize This for Control?

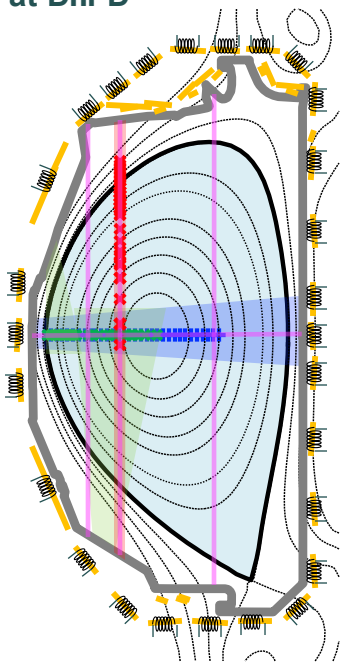


- **How can we bring this immense information into prediction and control?**
  - ***10's of diagnostics and actuators***
  - ***100's of channels***
  - ***Different time and spatial resolutions***
  - ***Missing data***

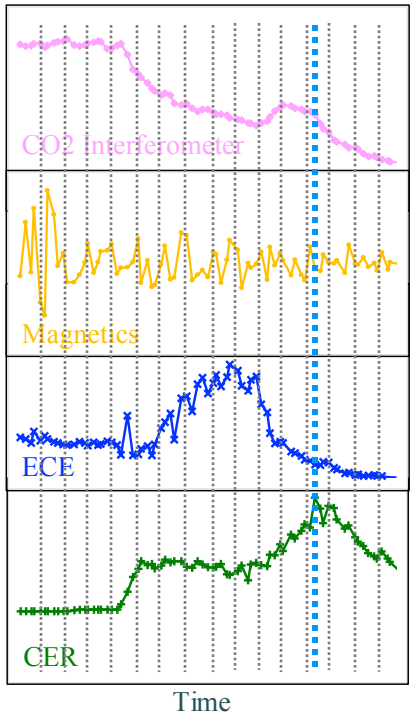
Multi-Modal ML for Synthetic "Super Resolution" Diagnostics

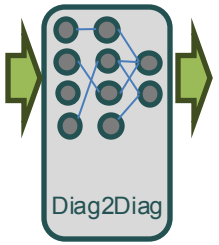


Diagnostics configuration at DIII-D

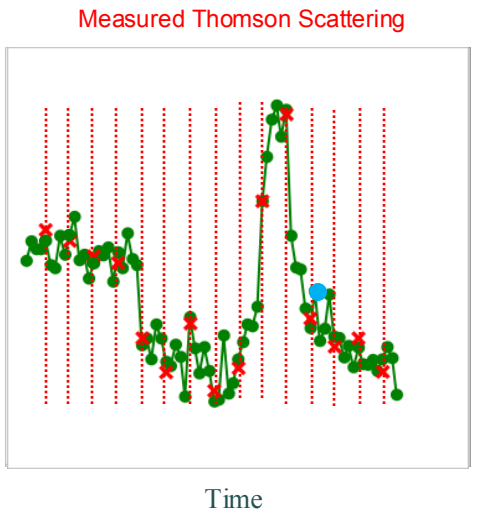


Diag2Diag processing pipeline





Reconstructed Thomson Scattering



ECE (500kHz)

Interferometer (1.6 MHz)

Magnetics (2MHz)

CER (200Hz)

Thomson Scattering

Electron density and temperature sampled at 20Hz-10KHz

R2 Score: 0.92

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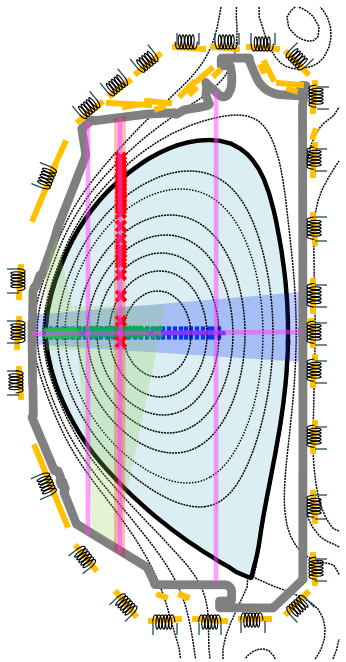
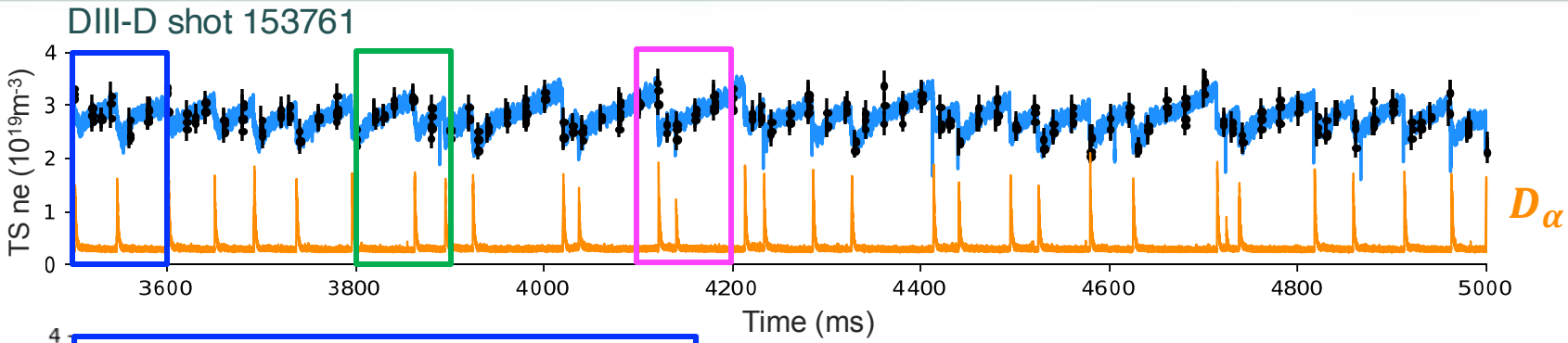
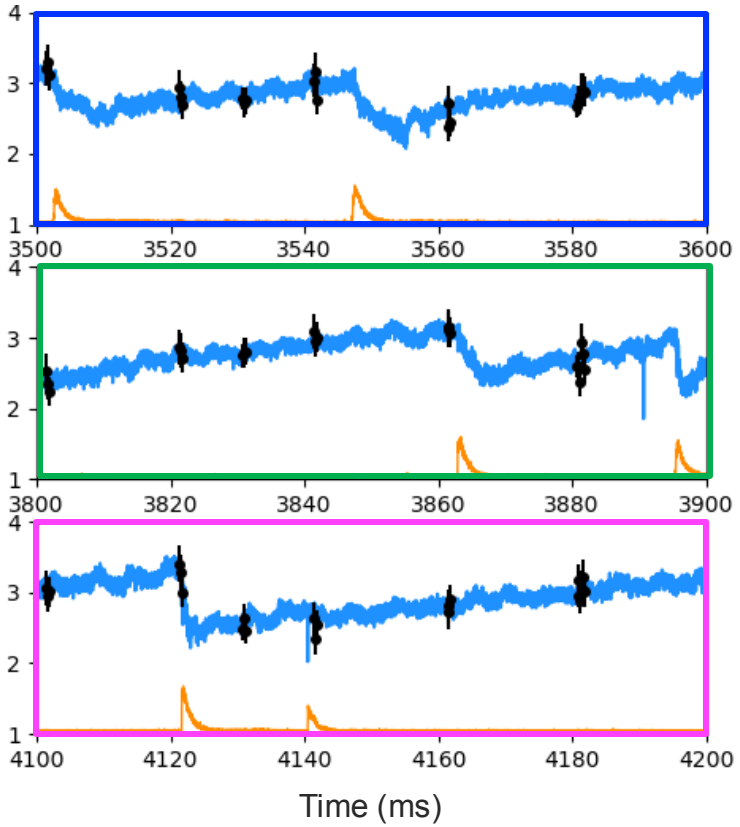
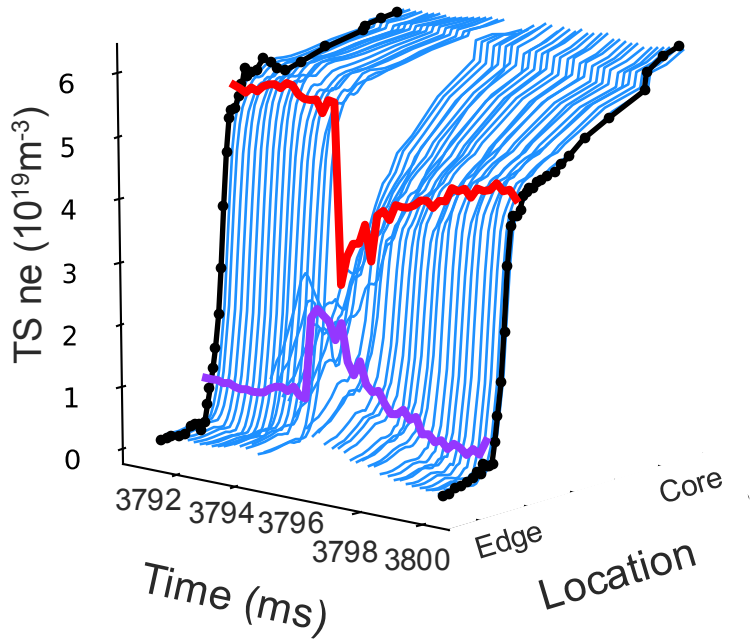
Validation: Capturing ELM with Super Resolution Thomson Scattering









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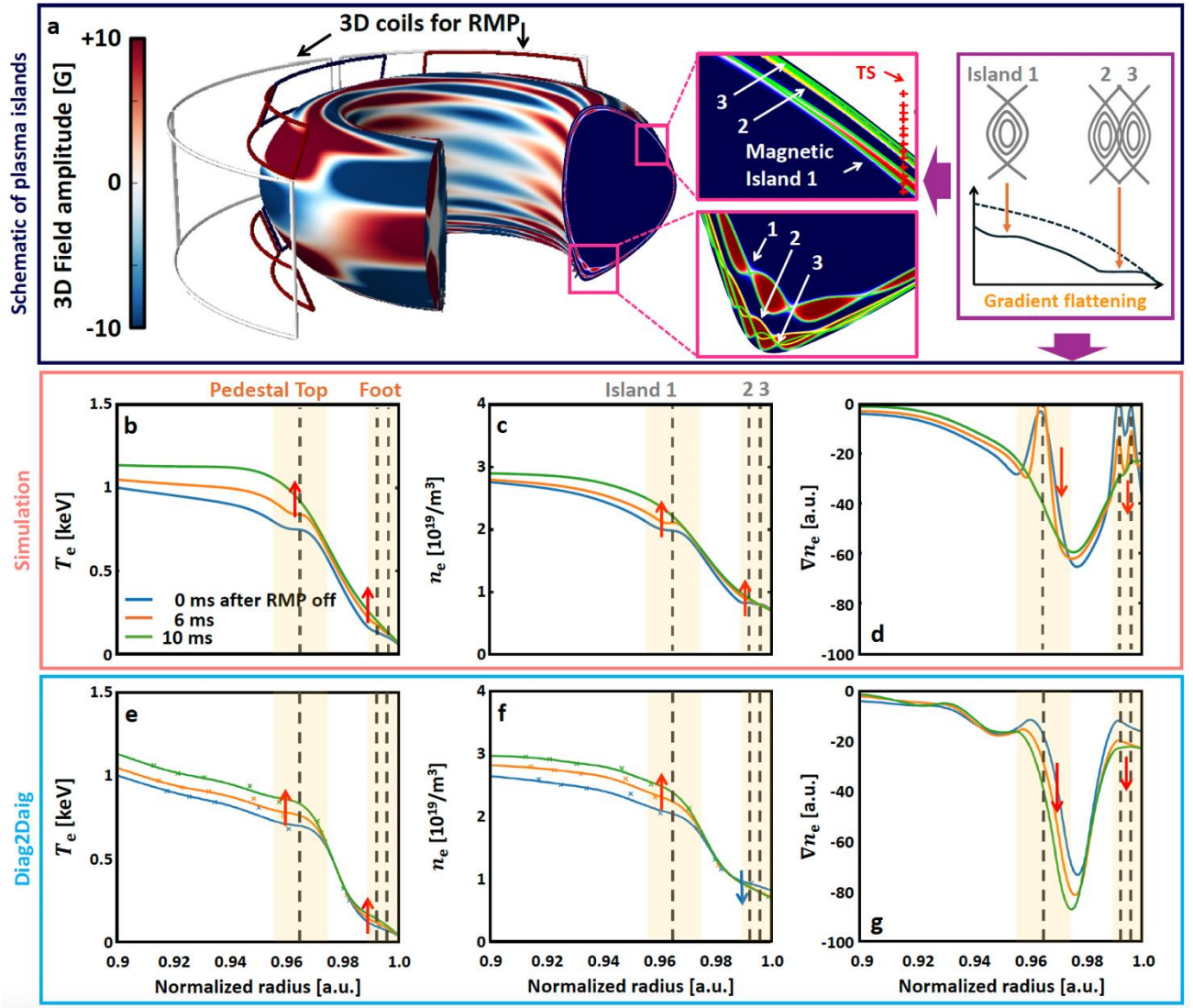
Discovery: Diagnostic evidence of RMP mechanism on the plasma boundary

Structure of 3D coils and islands by perturbed field and evidence of RMP-induced island mechanism on the plasma boundary in DIII-D shot 157545.

The Chebyshev filter is used to derive a statistically reliable time trace of the profile, leveraging the enhanced temporal resolution.



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Conclusion and Future Work

- We showed that ML can learn the correlations among diagnostics using historical data
- It was validated by capturing ELM events in selected DIII-D discharges
- Diag2Diag is (to our knowledge) the first implementation of multi-modal ML for generating temporal super-resolution diagnostics.
- Such approach can be used for discovering hidden physics
  - Diagnostic evidence of RMP mechanism on the plasma boundary →

arXiv:2405.05908

- Next steps
  - Temporal/Spatial super resolution of diagnostics at DIII-D and other machines
  - Minimum set of diagnostics (FPP-relevant)
  - Continue with Diag2Diag prediction
  - Use Diag2Diag for scenario design and control
  - Application on other fields (astronomy, health, robotics)

Thank you!

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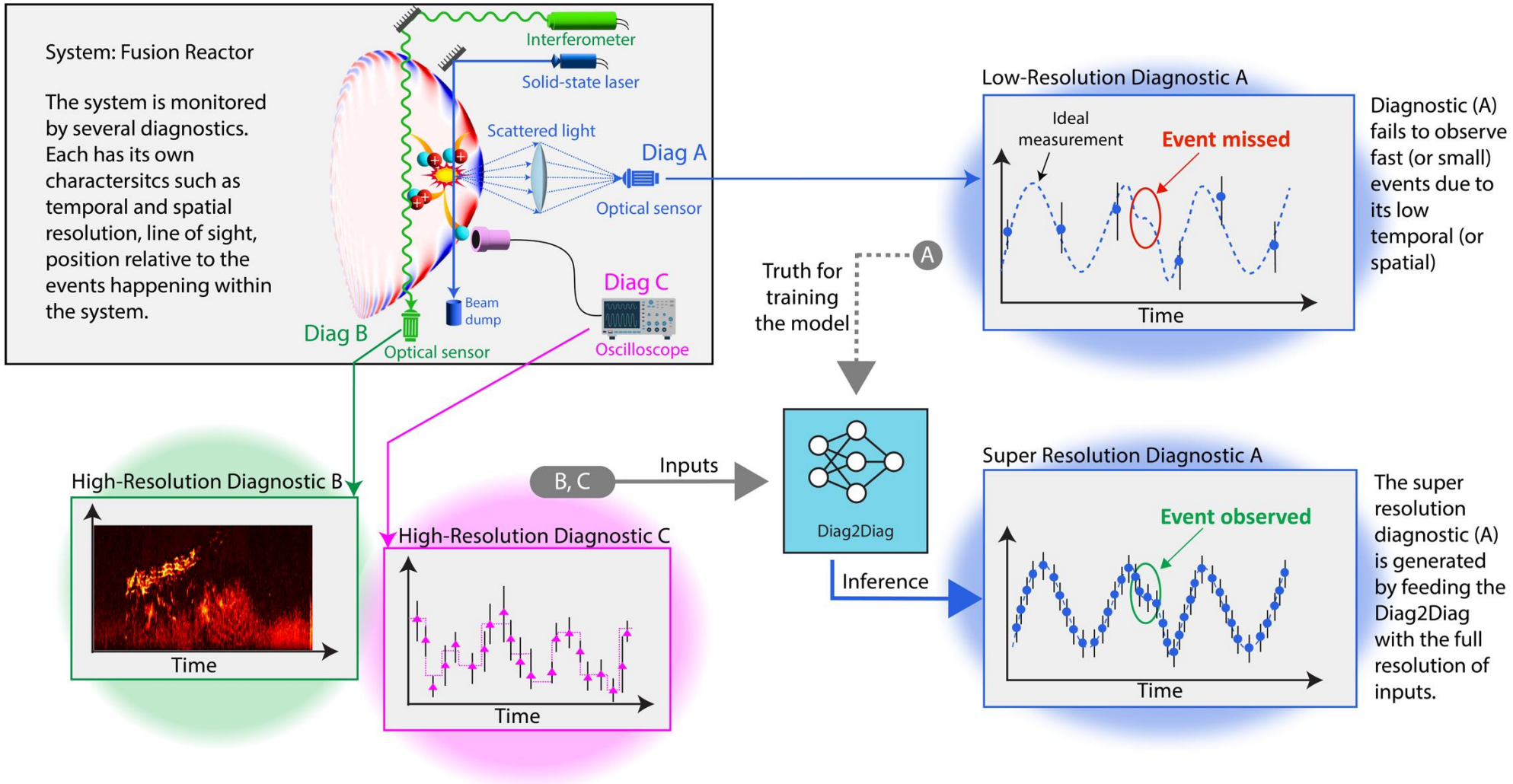

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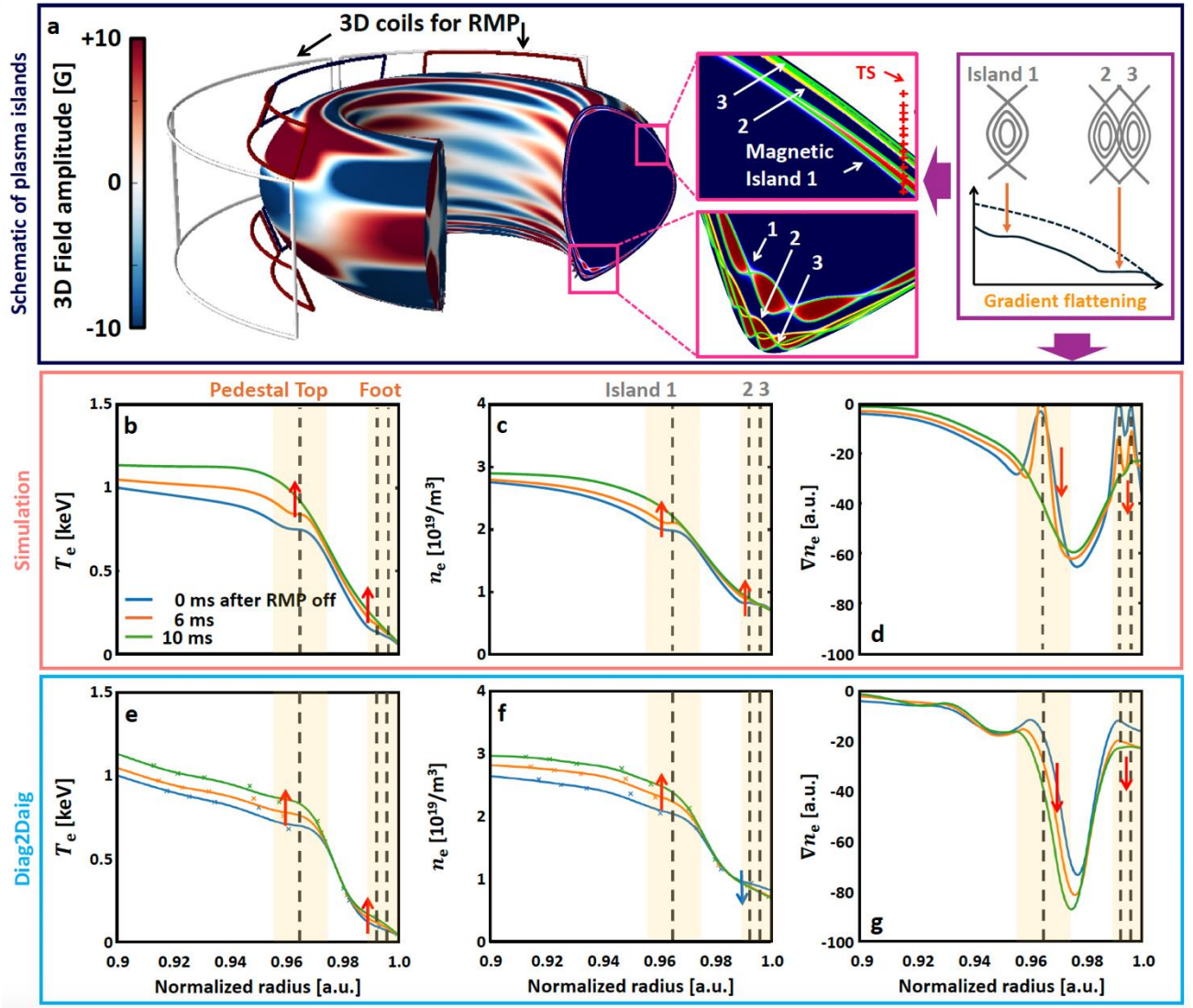

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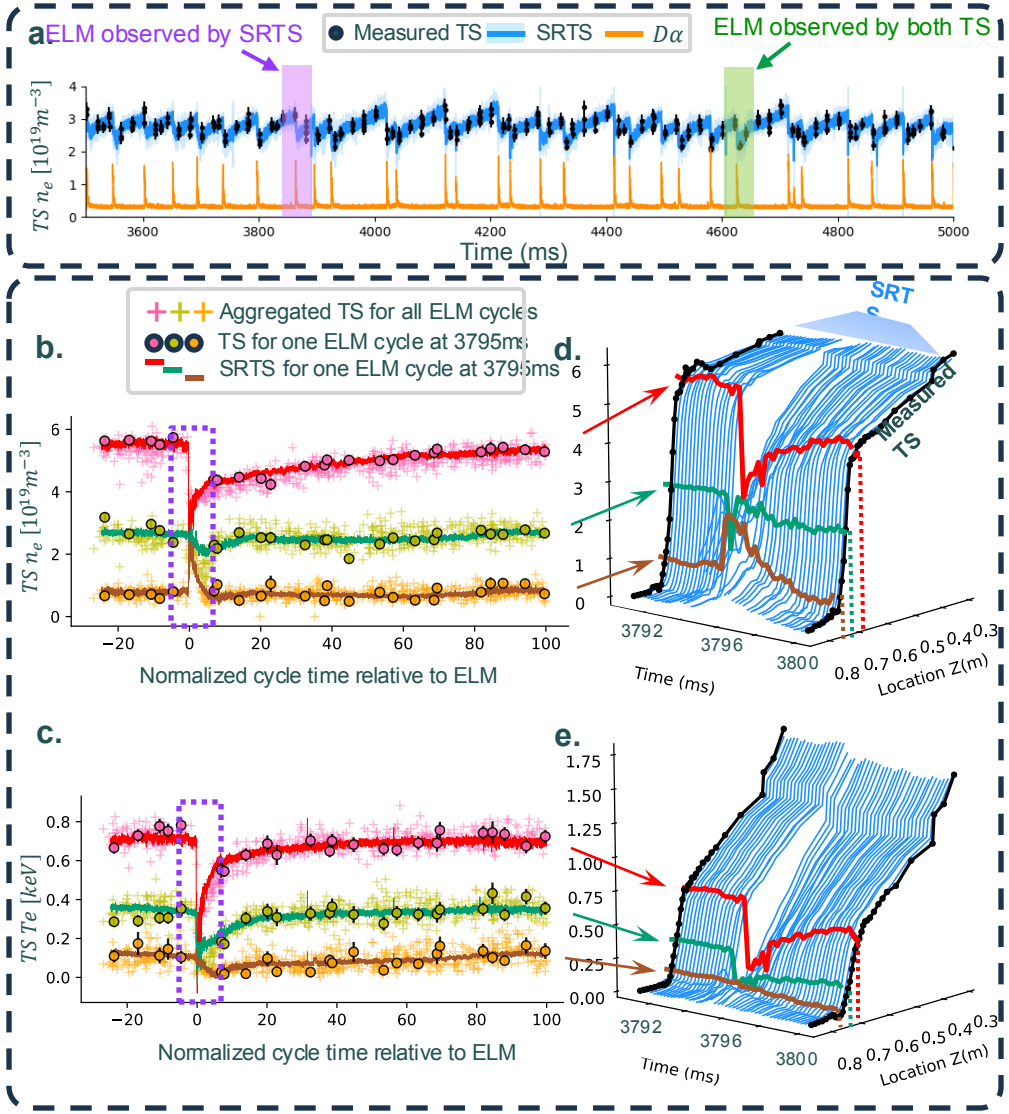

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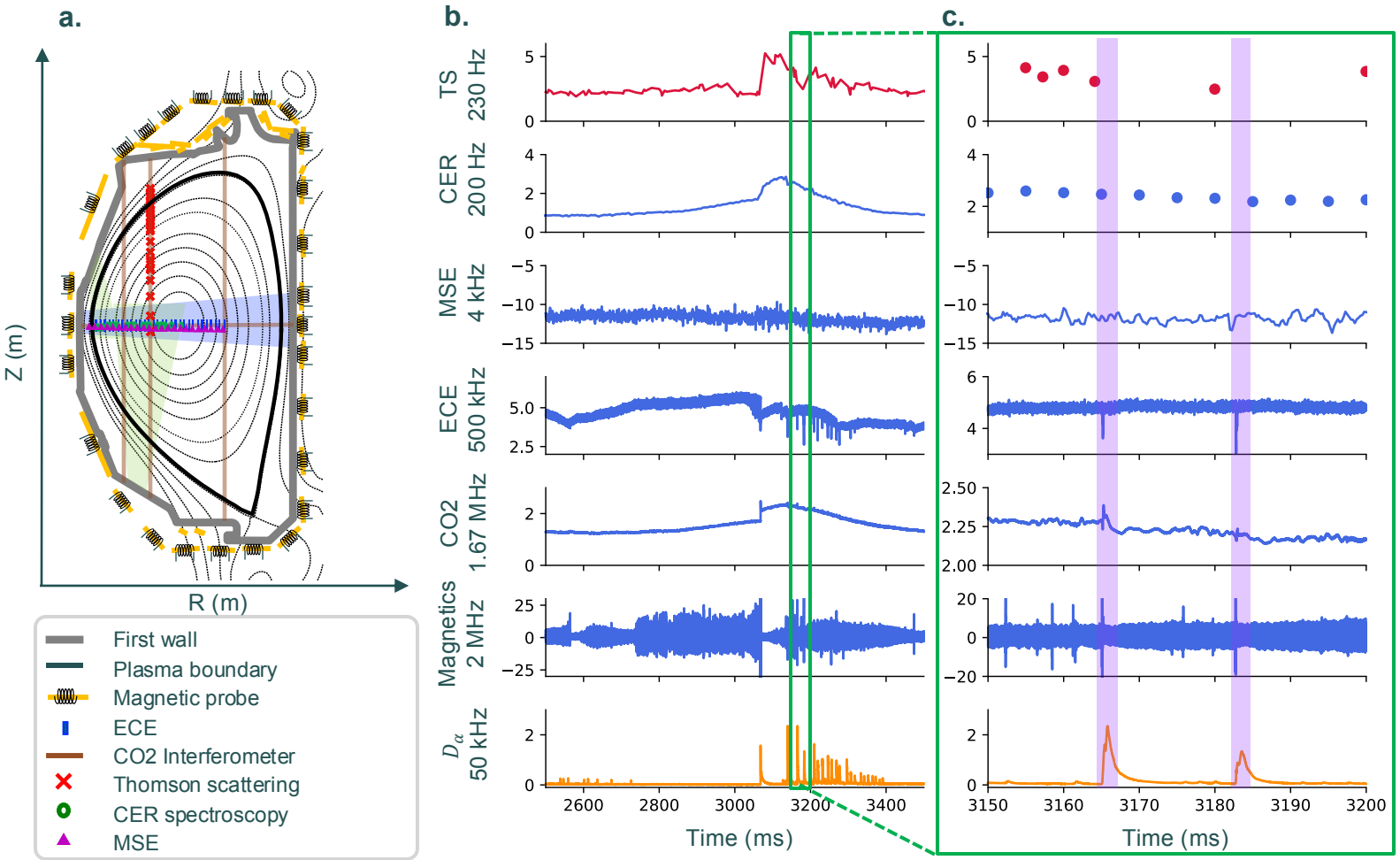

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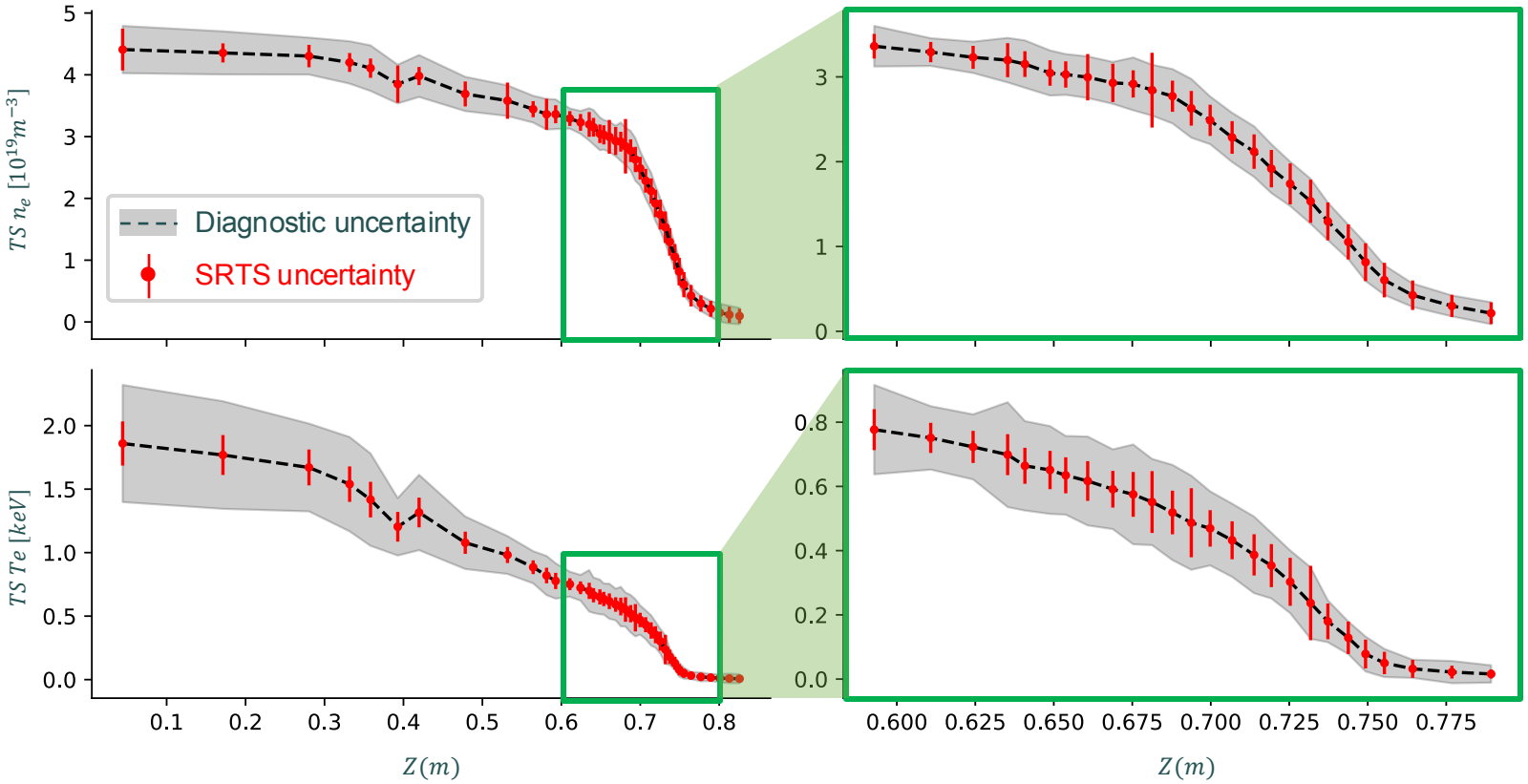

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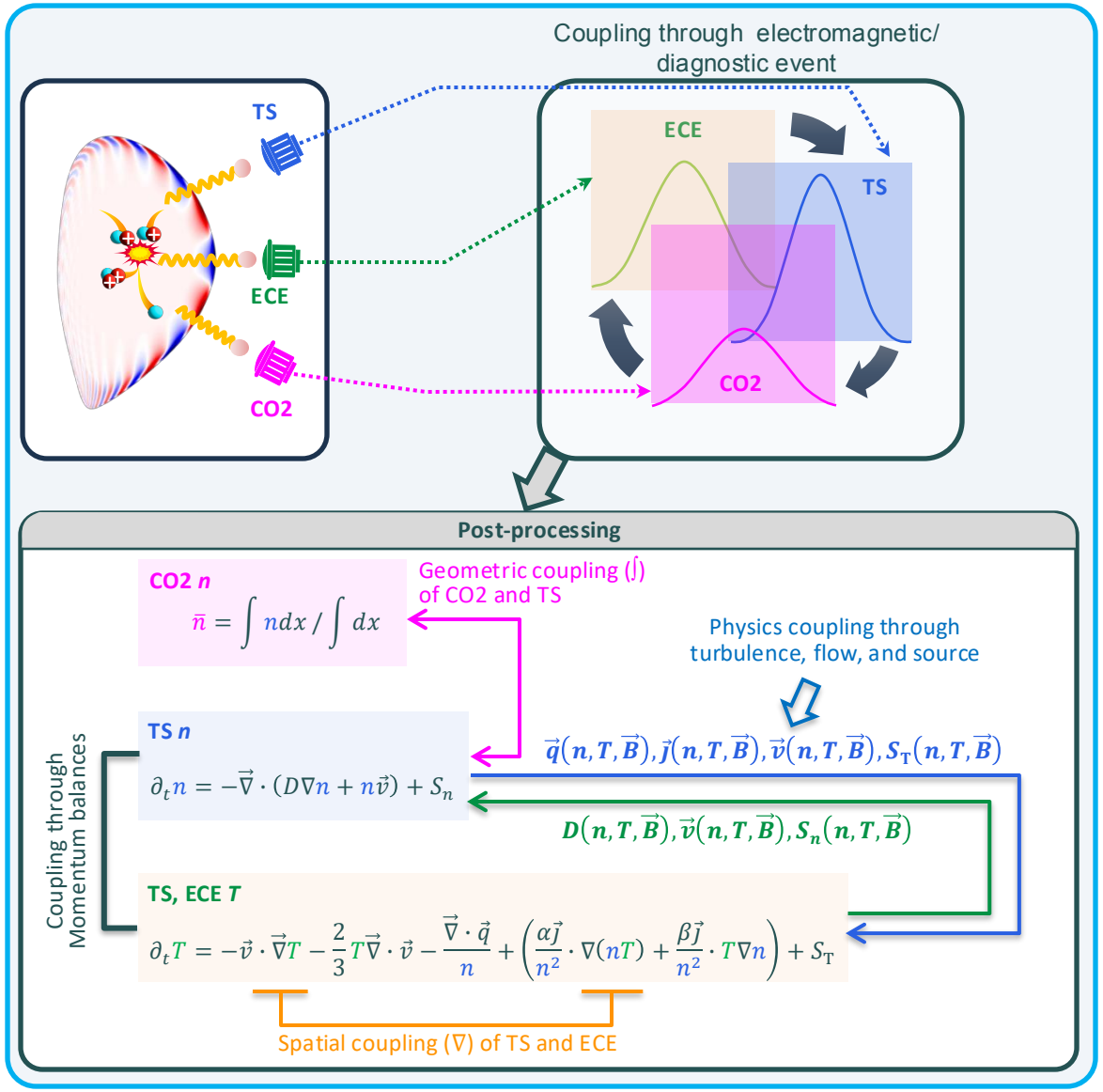
Coupling of diagnostics via events and physics



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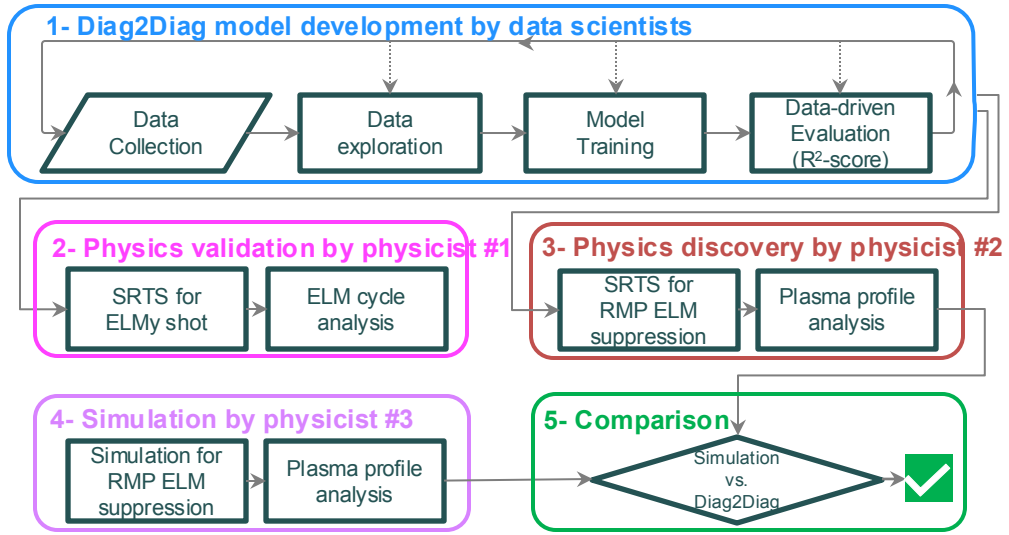

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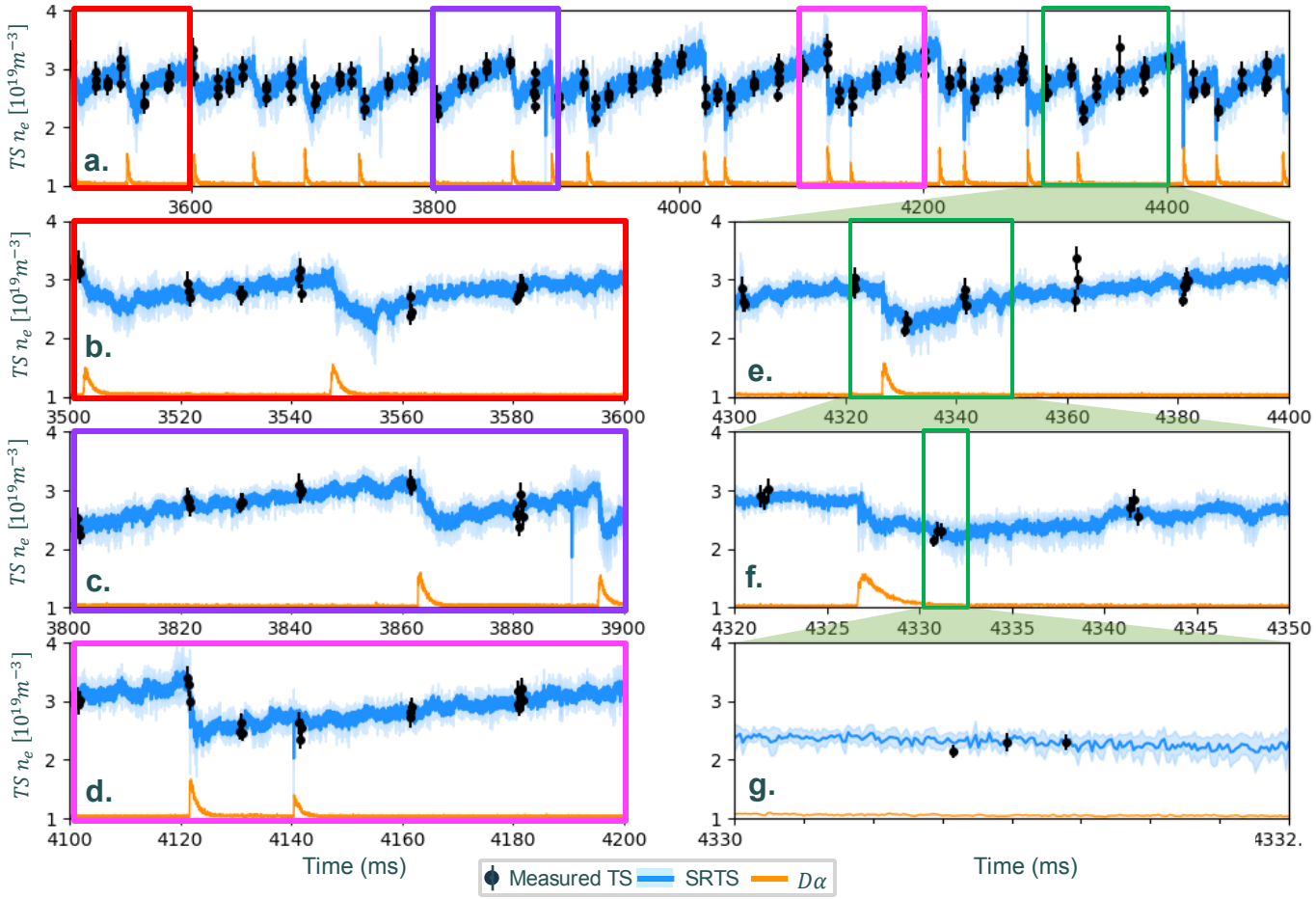

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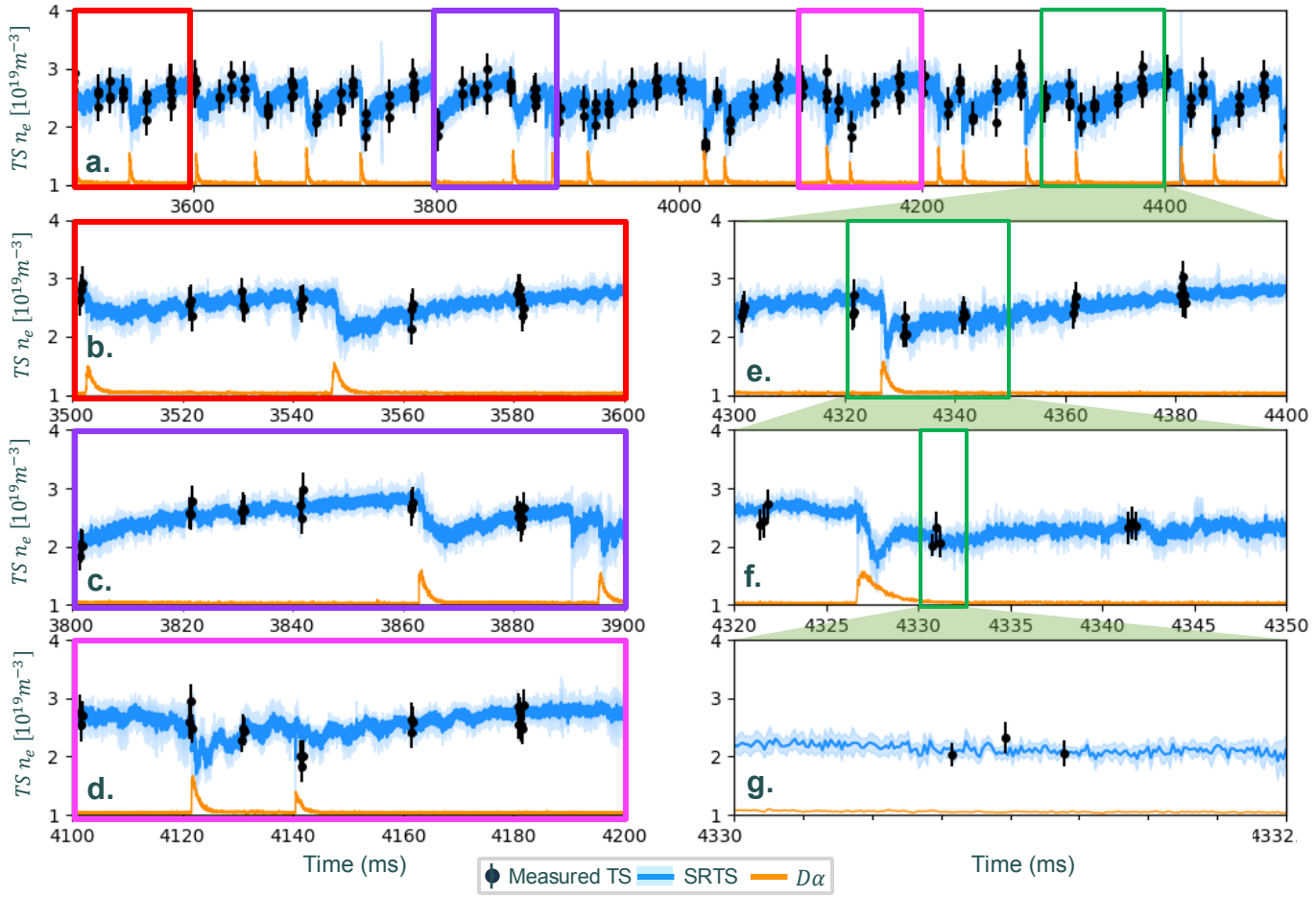

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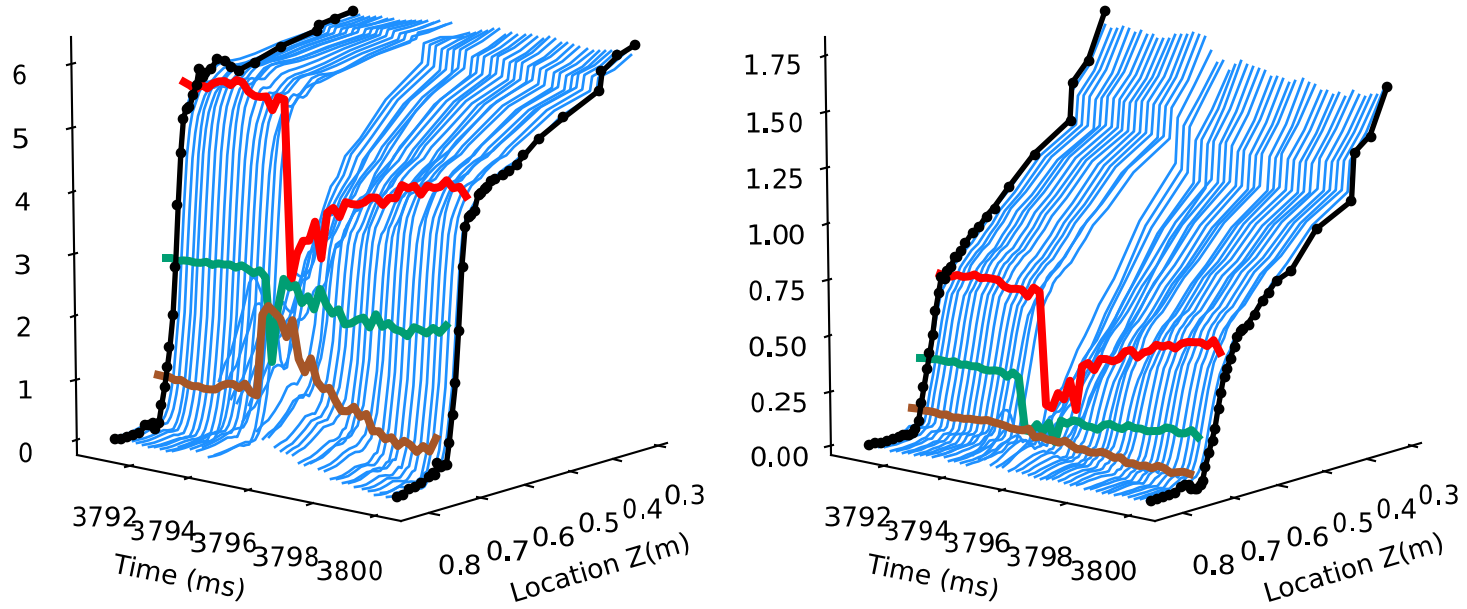

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