Cross-verification and validation of tokamak plasma evolution models

Joe Abbate[1,2]

with E. Fable[3], A. Pankin[1], G. Tardini[3], E. Kolemen[1,2]

[1]PPPL,
[2]Princeton University,
[3]Max-Planck-Institut

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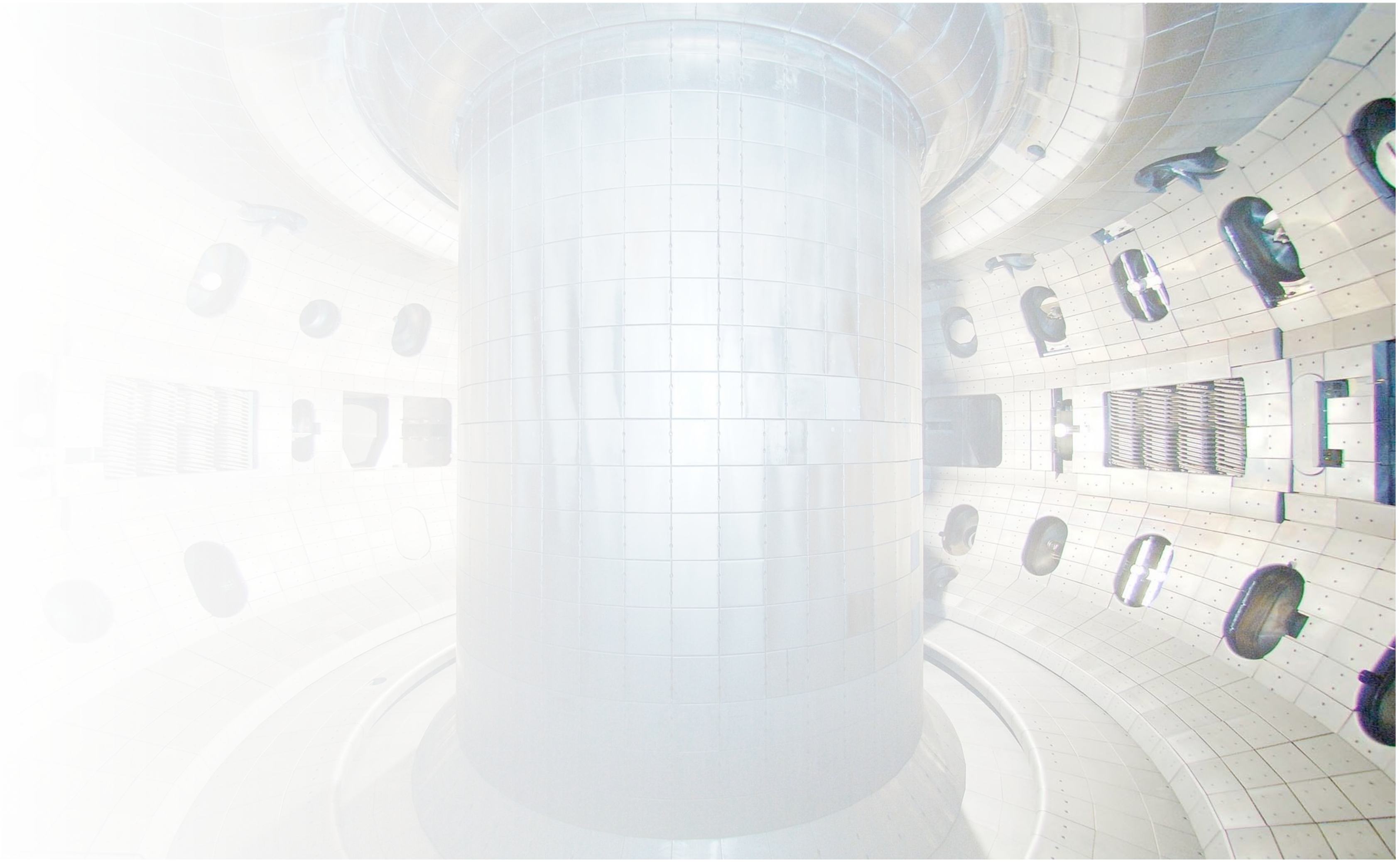
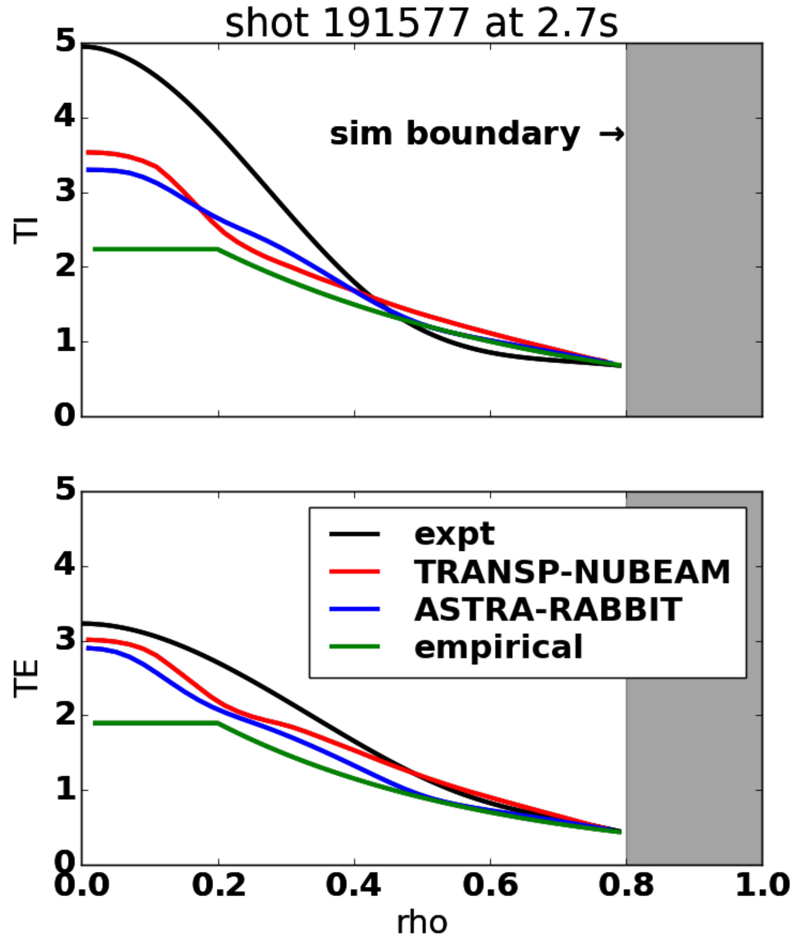


Summary

- **Validate Te/Ti predictors using state-of-the-art but general settings**
  - **Run on ~hundreds of cases automatically**
  - **Compare multiple independent implementations (TRANSP and ASTRA)**
  - **Compare against empirical (linear regressed) models to contextualize error**

- **Find no significant statistical difference in Te/Ti predictions between TRANSP, ASTRA, and empirical model**

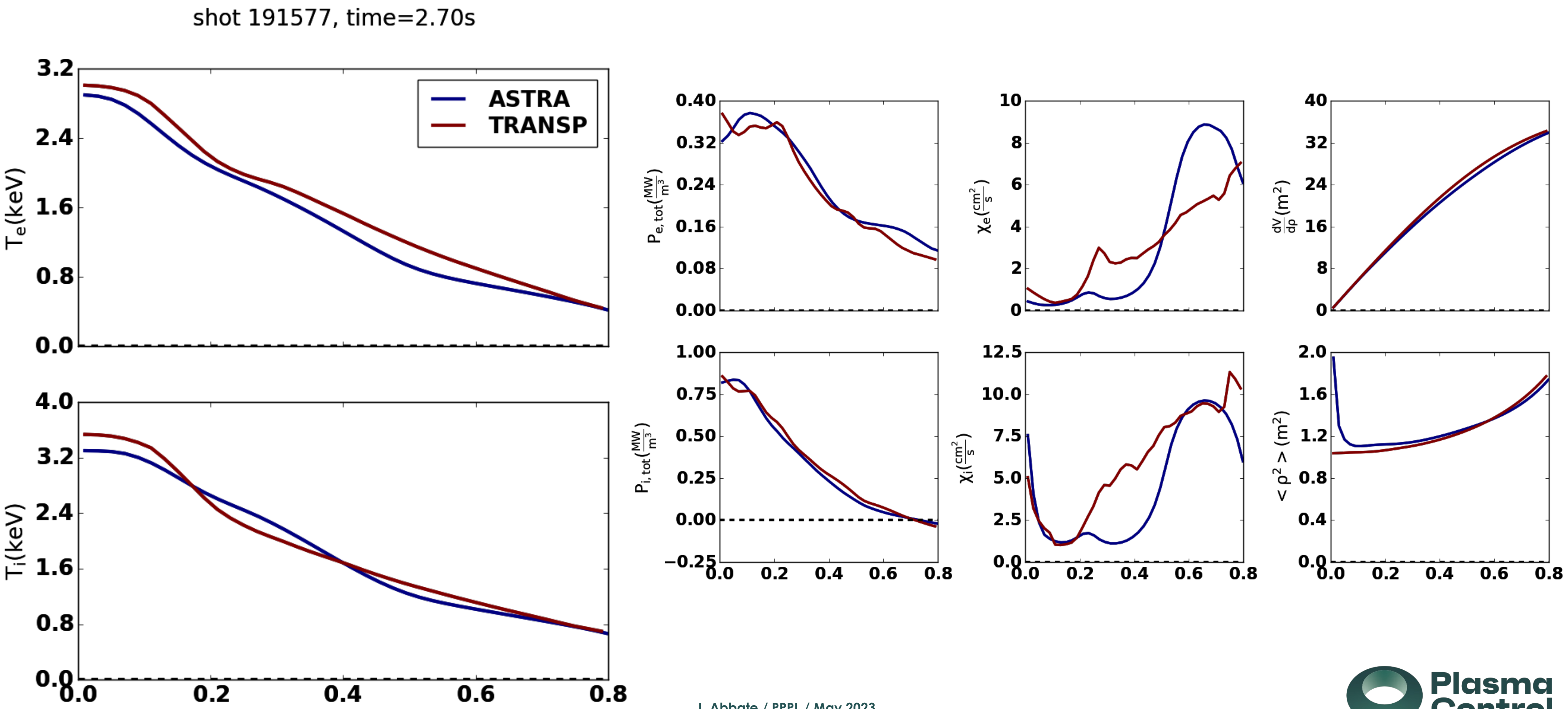


Predict core Te+Ti using ASTRA and TRANSP (w/ similar settings)

- **Inputs:**
  - **EFIT01 (no kinetic constraint) q**
  - **ZIPFIT ne, rotation, Zeff profiles**
  - **Te and Ti boundary at $\rho = 0.8$**
- **900ms simulation**
- **TGLF SAT2, same settings except nky**

	TRANSP	ASTRA
Fast ions	NUBEAM	RABBIT
Equilibrium	(input directly)	SPIDER
Ion heat	+viscosity +cold-neutral CX	
Neoclassical diffusion	Modified Chang-Hinton	Angioni-Sauter (e) Galeev-Sagdeev (i)
TGLF nky	12	19

Verification: ASTRA and TRANSP yield similar results

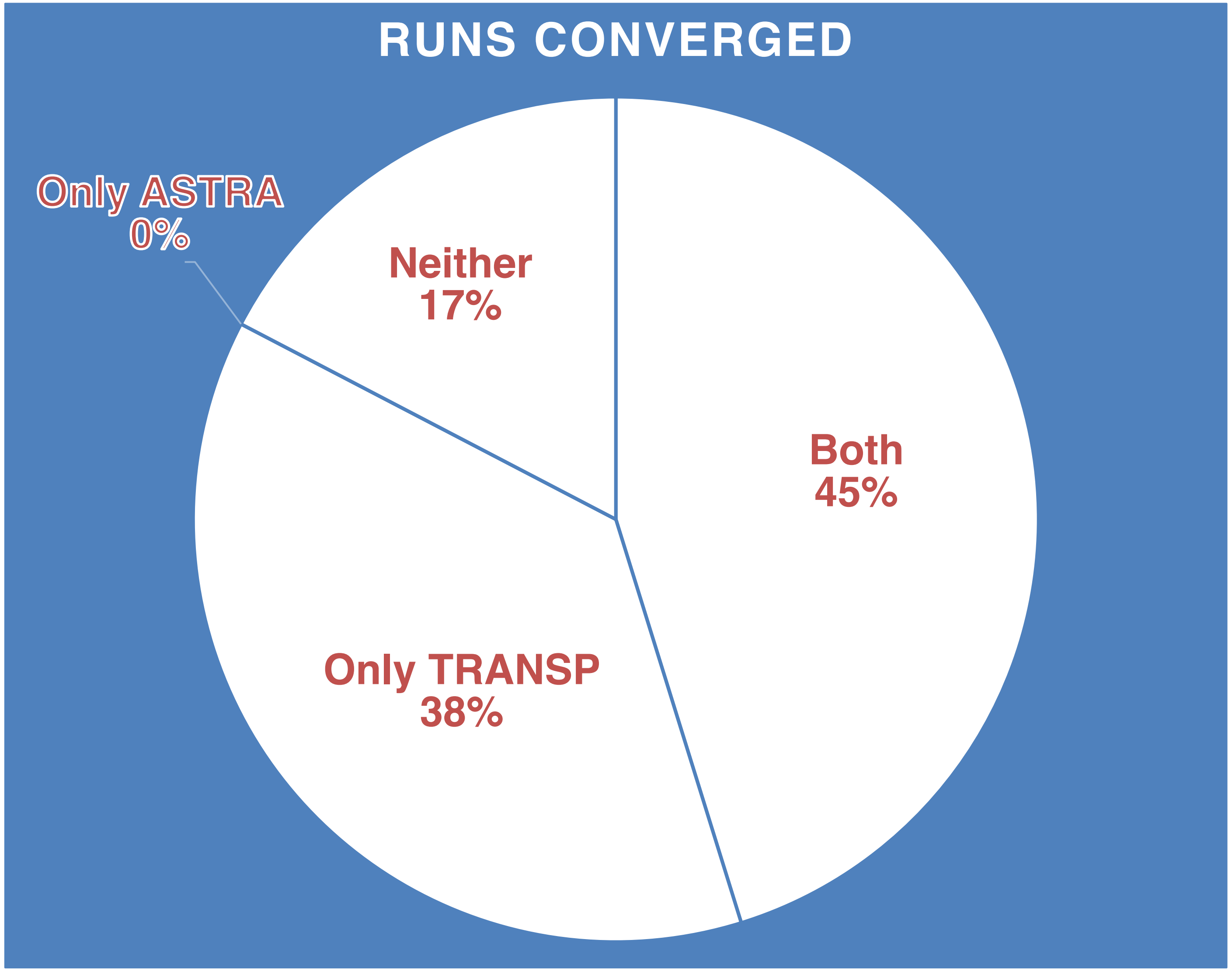


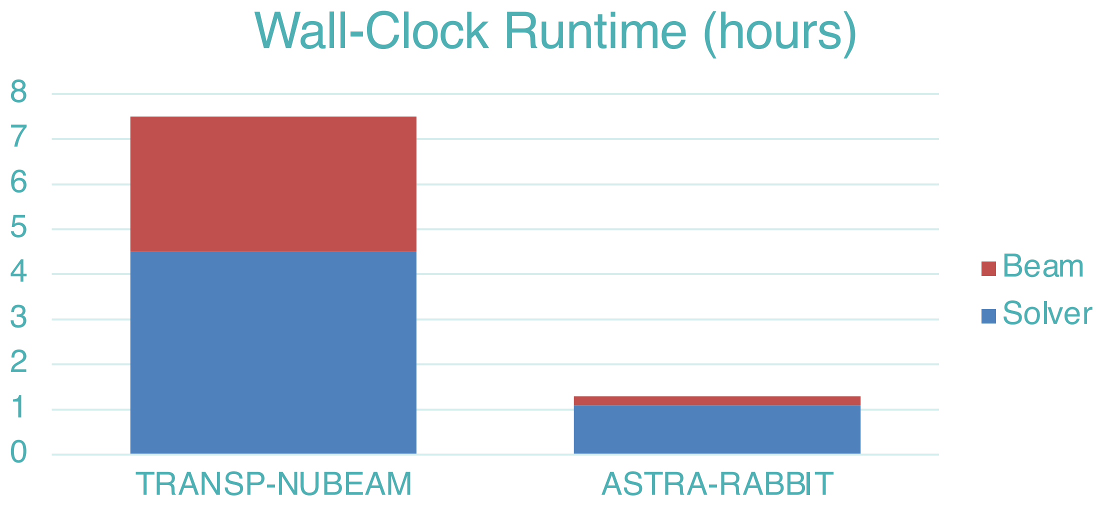
Plasma Control

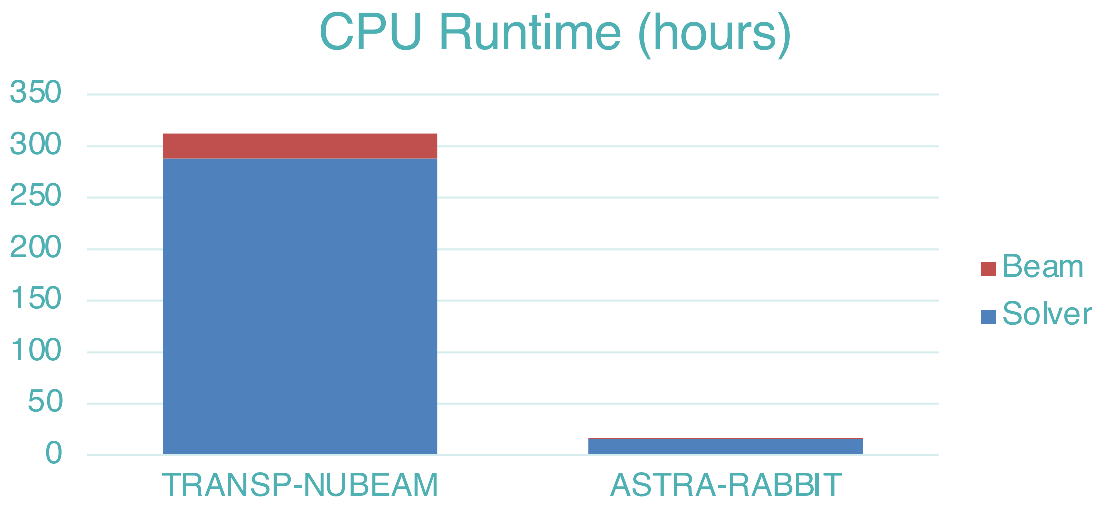
Semi-randomly selected 219 DIII-D shots, created automated workflow

- **Exclude**
  - wave-heating
  - 3D field perturbations
  - Non-D2 gas
  - Rampup and rampdown
  - Shots before year 2010
- **OMFIT modules**
  - ASTRA: compiled + debugged + user-interface for GA (Iris) cluster
  - AGGregate: automatically mass prepare + launch TRANSP/ASTRA jobs

ASTRA and TRANSP converge in ~half of cases, runs take ~hrs (wall-clock)
ASTRA less robust, TRANSP higher runtime







Metrics and figures of merit

Metrics to consider: Te, Ti, and W_{MHD}

$$W_{MHD} = \int \left(p_{thermal} + p_{fast\ ions}\right) dV$$

ITER standard figures of merit used to measure accuracy

Te and Ti

$$\epsilon(\rho) = T^{sim}(\rho) - T^{expt}(\rho)$$

$$\sigma = \frac{\sqrt{\sum_\rho \epsilon(\rho)^2}}{\sqrt{\sum_\rho T(\rho)^2}}$$

$$\bar{\sigma} = \sqrt{< \sigma^2 >}$$

W_{MHD}

$$R_W = \frac{W^{sim}}{W^{expt}}$$

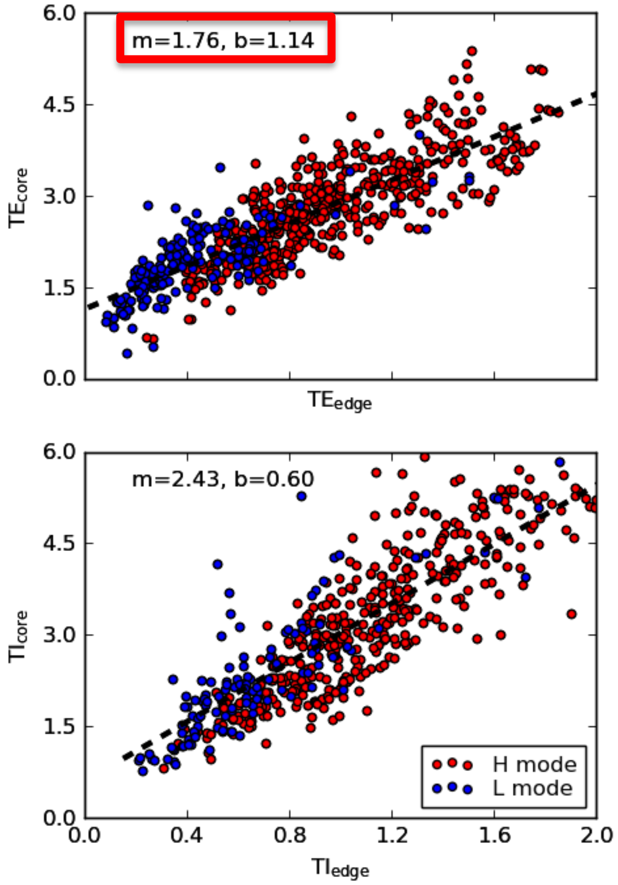
$$\Delta R_W = R_W - 1$$

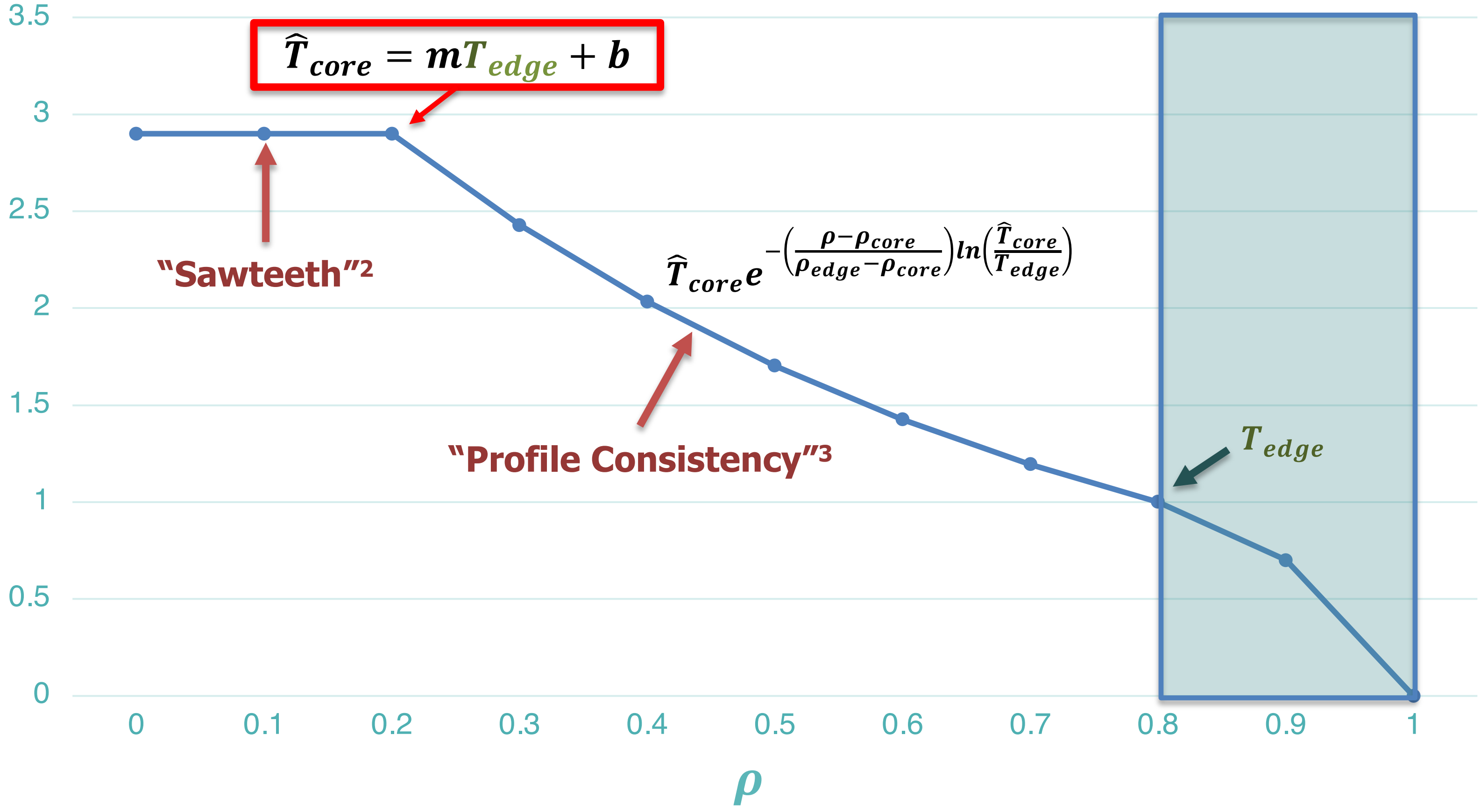
$$\Delta \bar{R}_w = \sqrt{< \Delta R_W^2 >}$$

Baselines for comparison:
W_{MHD} from H89/98 (w/ linear regression)
Te and Ti from profile consistency w/ linear regression

"Nondimensionalization"[1]

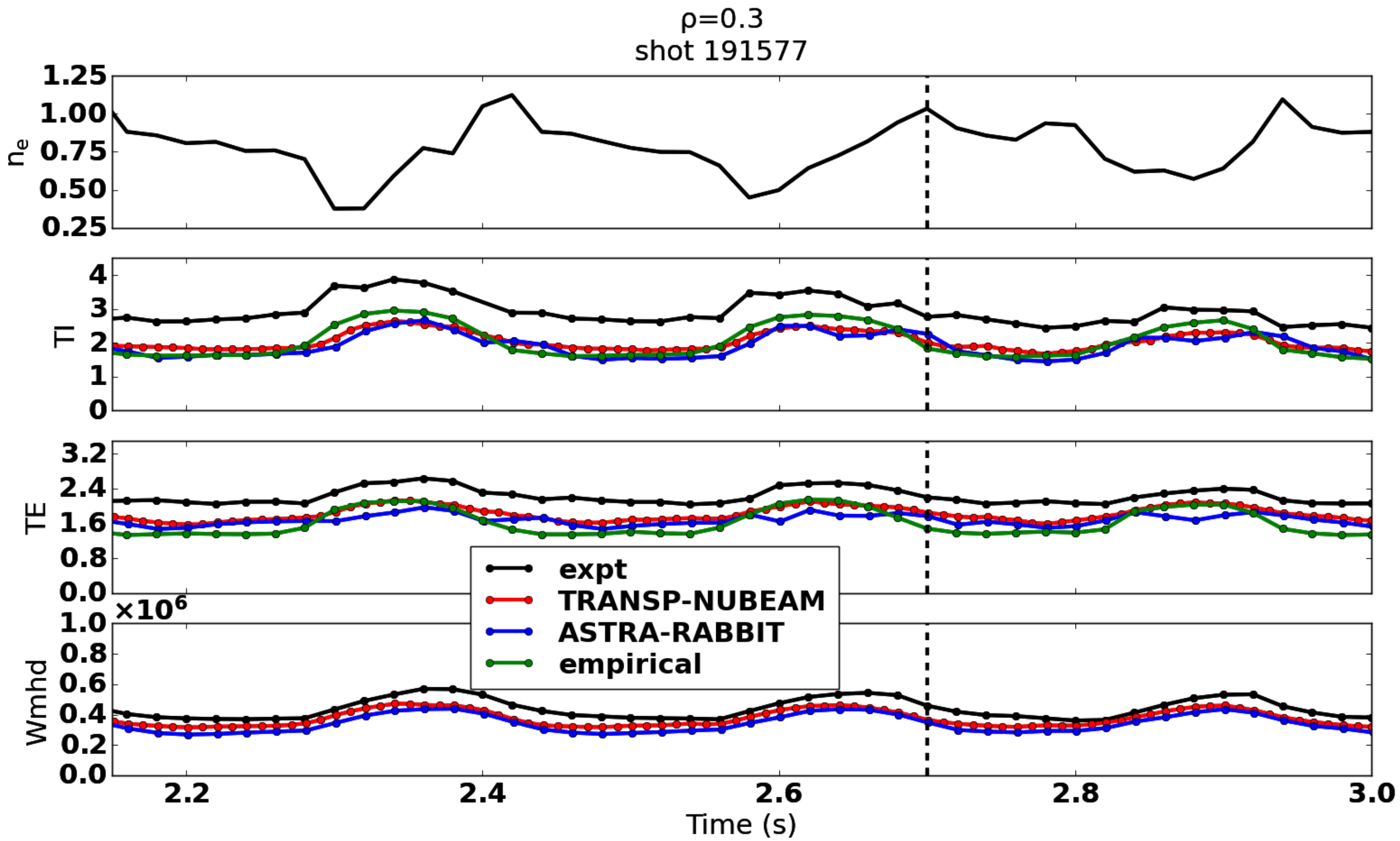
$$\widehat{W}_{MHD} = P_{tot}\tau_{H\{89,98\}}$$
$$P_{tot} = P_{NBI} + 0.55MW$$

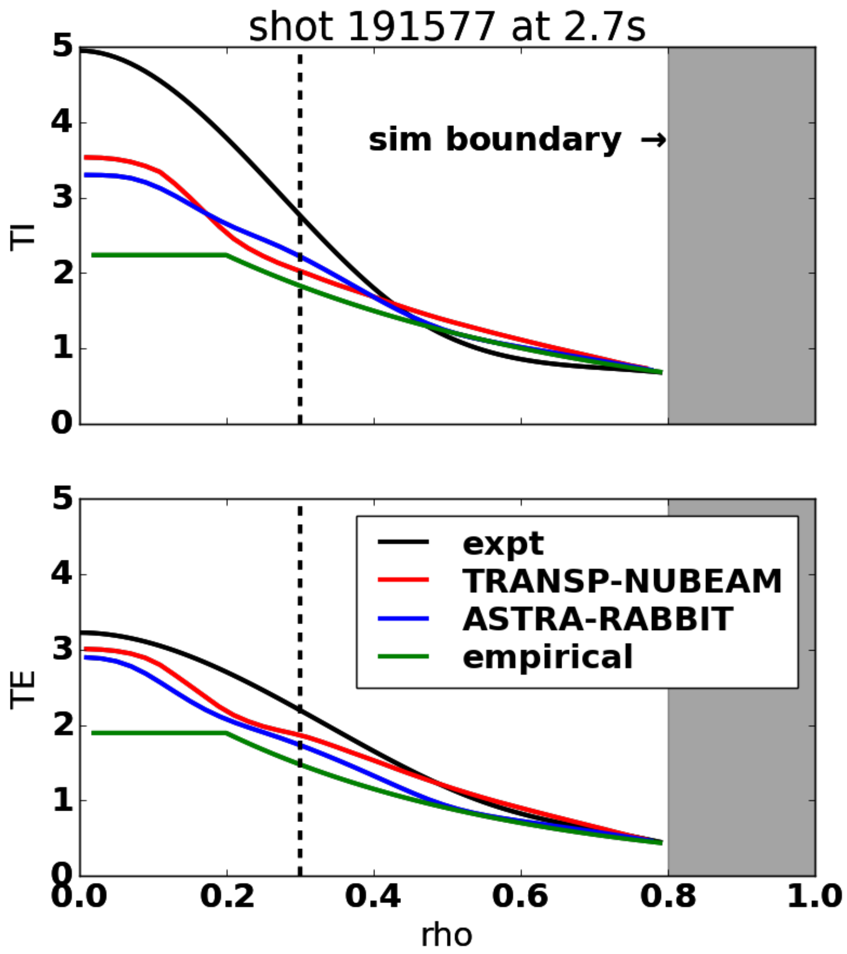




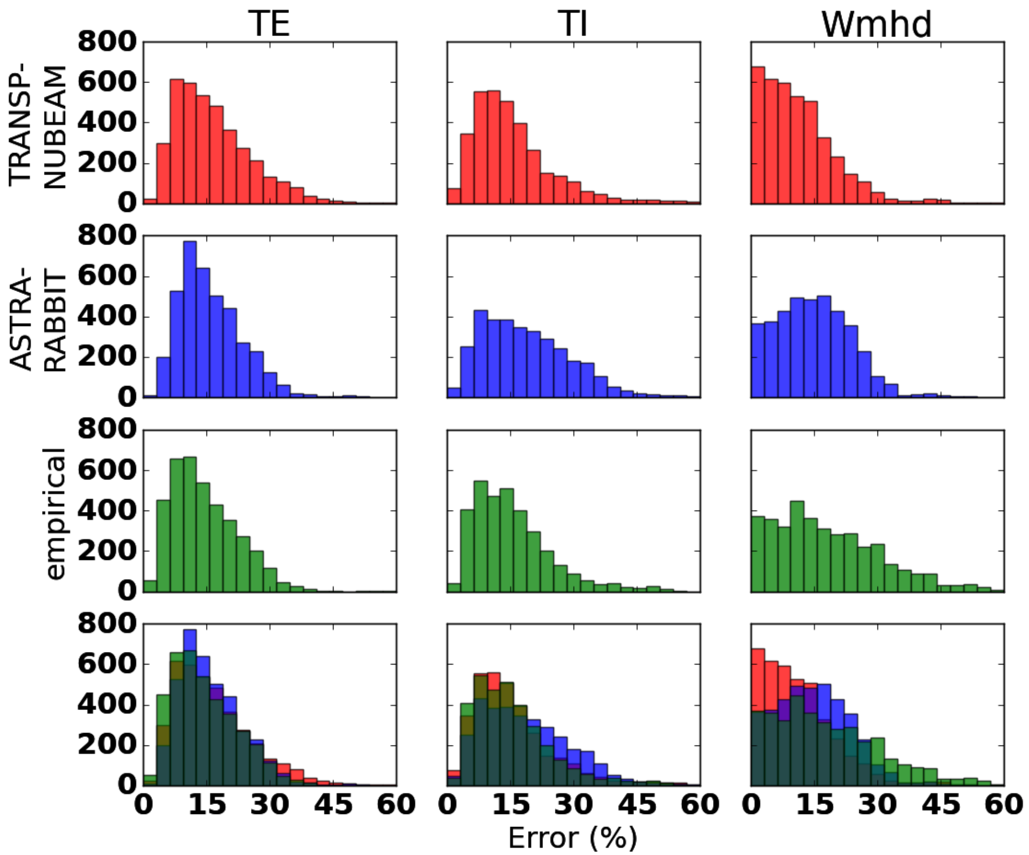
[1]Kadomtsev 1975 *Tokamaks and dimensional analysis*
[2]Kadomtsev 1975 *Disruptive instability in tokamaks*
[3]Coppi 1988 *Profile Consistency: Global and nonlinear transport*

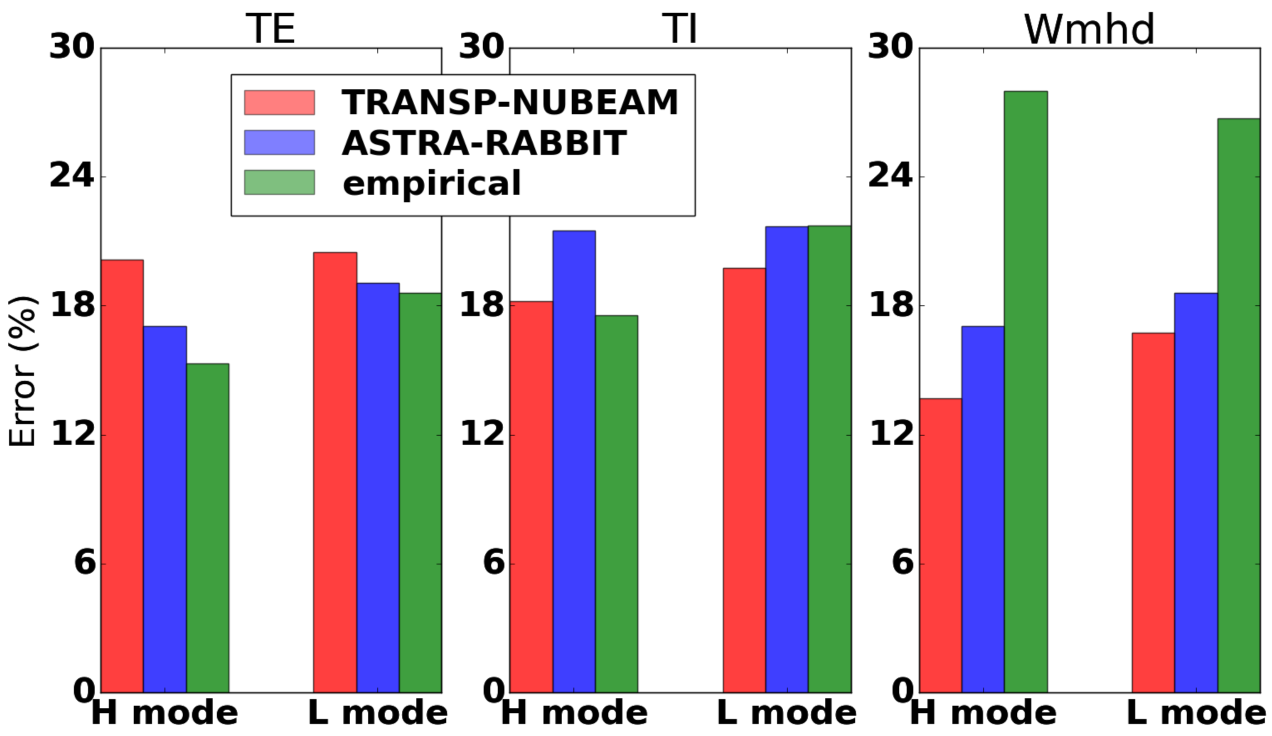
TRANSP and ASTRA qualitatively capture time-dependent changes





Full database: TRANSP/ASTRA within ~5%
Empirical Te/Ti also within ~5%, but W_{MHD} >~10% worse





Conclusions and next steps: as we know, codes just one component to predict

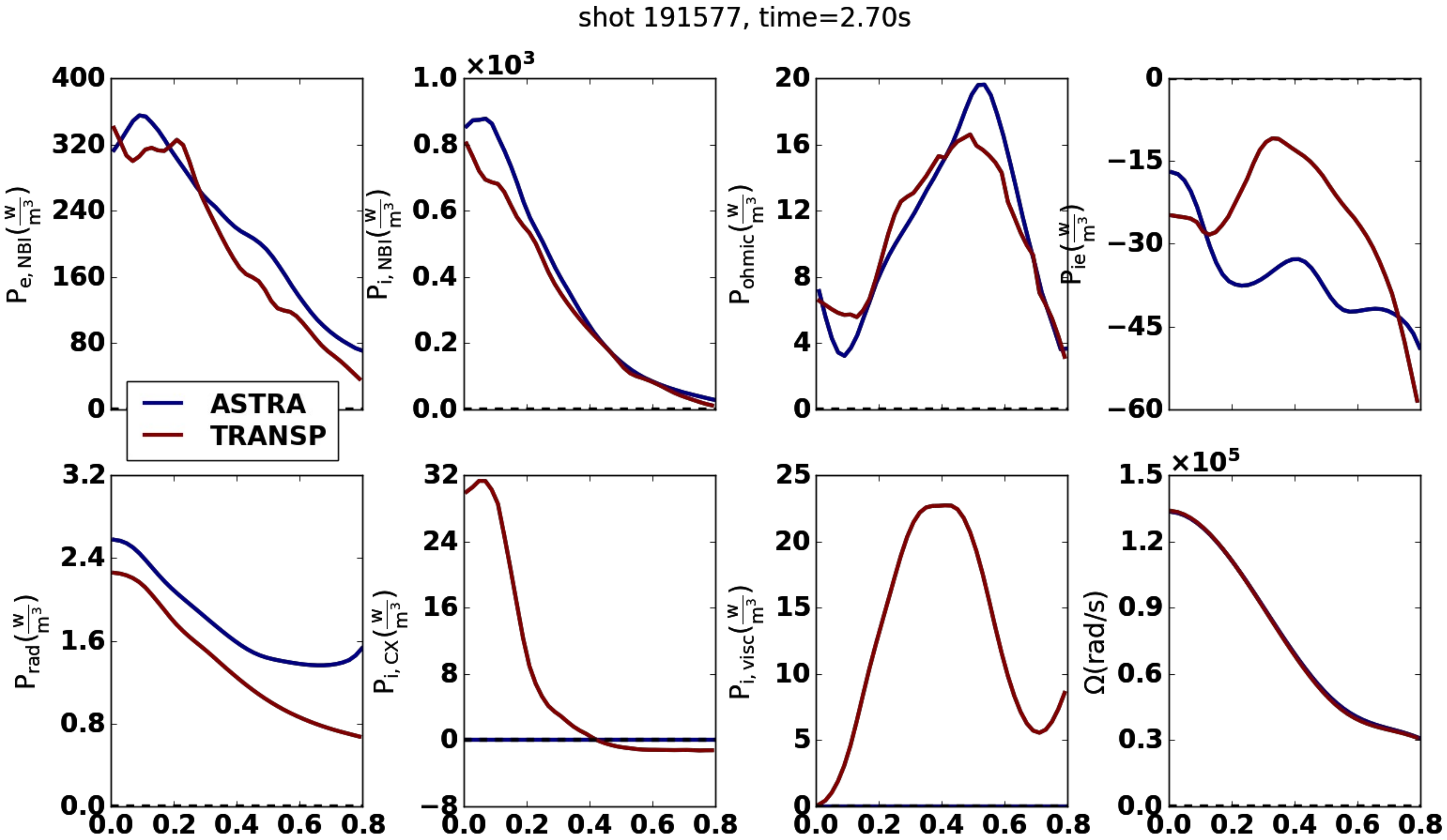
- **Developers are aware of models' limitations: primarily used not predictively but for**
  - **Qualitative scaling**
  - **Physics understanding**
  - **Extrapolation to unexplored regimes**
- **BUT similar transport prediction workflows still used to plan**
  - **Reactors**
  - **Scenarios**
  - **Machine upgrades**
- **In practice, code outputs are combined with experience + empirical scalings**
- **Use machine learning to try a task humans have always done:**
  - **More rigorously understand where and when to trust codes vs empirical data**
  - **Maintain extrapolability to new regimes with power of empirical models**

- **Start by predicting difference from code to experiment value (w/ database we made)**

What is shot 191577?

- **Expt title: "Effects of upstream power and heat flux width on the SAS-VW heat flux profile; influence of radiative and neutral heating"**
  - **Detachment studies**
- **Al Hyatt (shot log): "Very strange behavior. betan and density and li all seem to oscillate at a few hertz until the plasma density reaches about 4-5+13. Strike is almost perfect, maybe a little (~1 mm) too far out."**

Detailed heat source comparison



Detailed TGLF settings

- sat_rule: 2
- use_bper but not bpar
- kygrid_model: 1
- wdia_transp: 1
- xnu_model: 3
- alpha_quench: 0
- n_species: 3 (electrons, ions, impurity)
- n_modes: 3
- ibranch=-1
- etg factor: 1.25
- gaussian width: 1.65
- growth rate search for max width from 0.3 to 21
- units: cgyro