TRANSP for Integrated Tokamak modeling

Francesca Poli

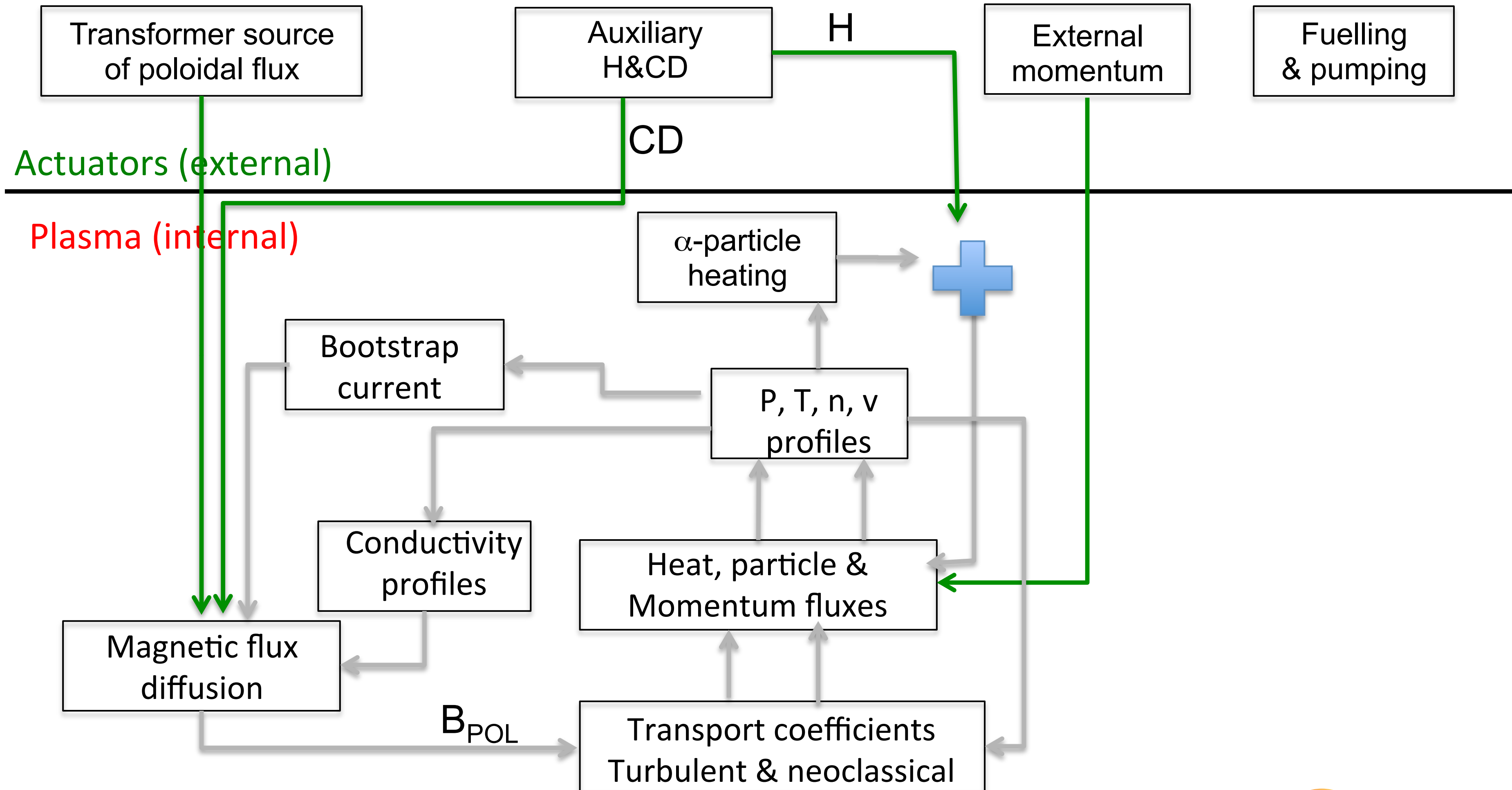
Princeton Plasma Physics Laboratory

Outline

- Integrated modeling, the golden goal
  - what should be included in a tokamak simulator?
- What do I use TRANSP for?
    - predictions, scenario modeling
    - analysis and interpretation
- What could I do better?
  - what upgrades would I like to see and how to facilitate this?

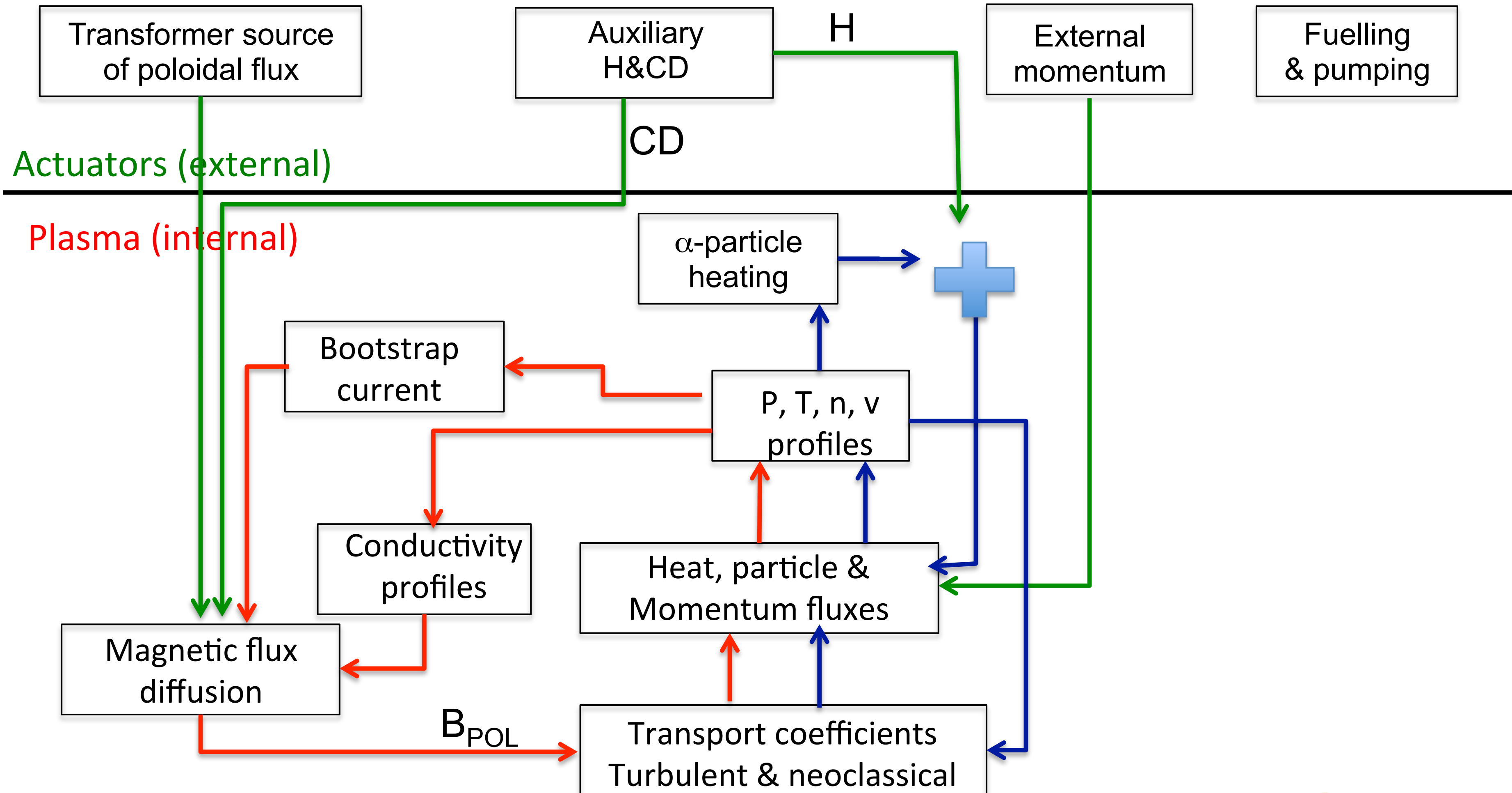
  (*do not ask what TRANSP can do for you, but what you can do for TRANSP*)

Integrated modeling is a complex task: evolve self-consistently plasma and actuators



adapted from Politzer NF 2005 and X. Litaudon, ITER summer school 2014

Integrated modeling is a complex task: combine fast (transport) & slow (current diffusion) time scales



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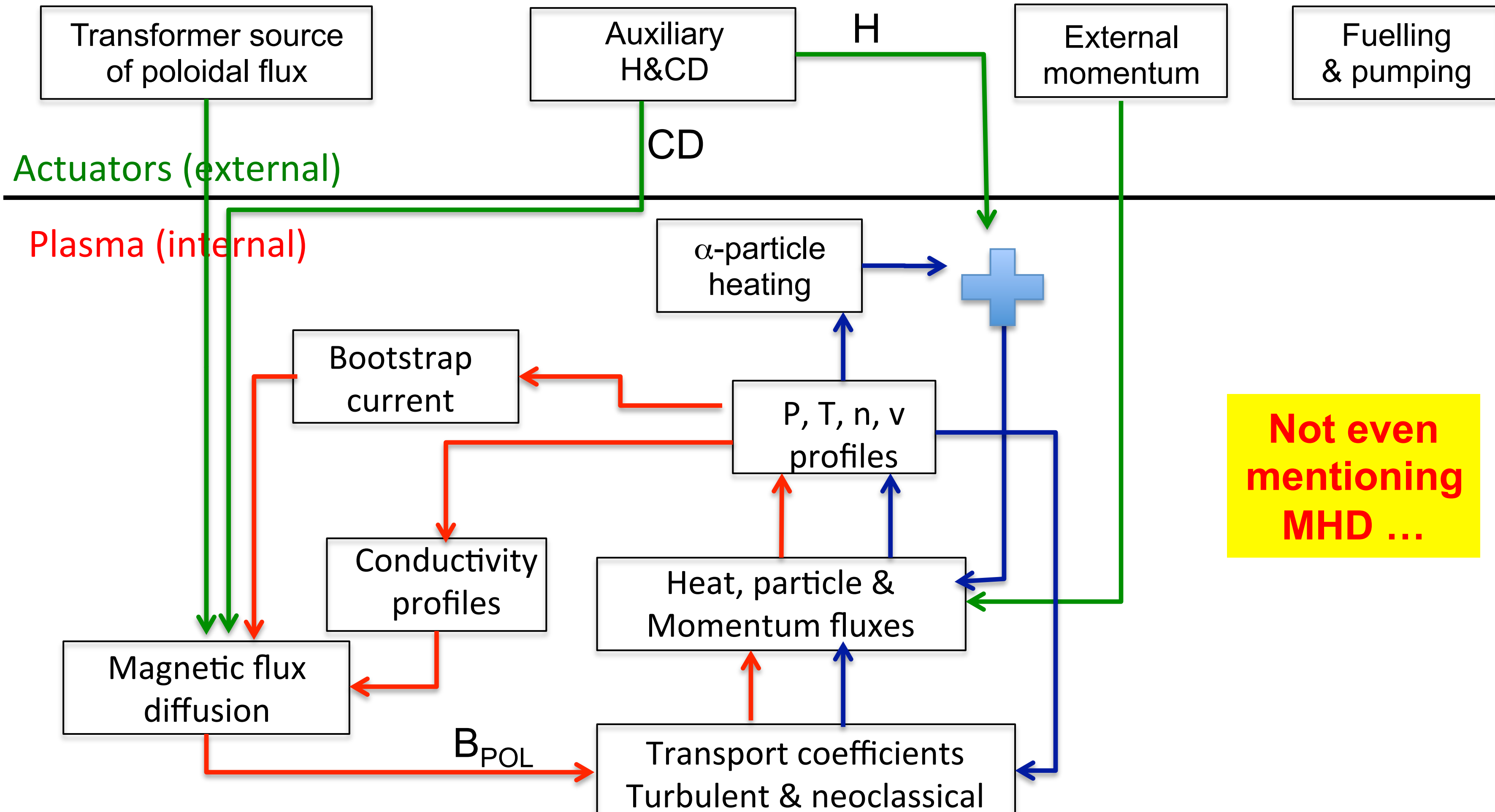
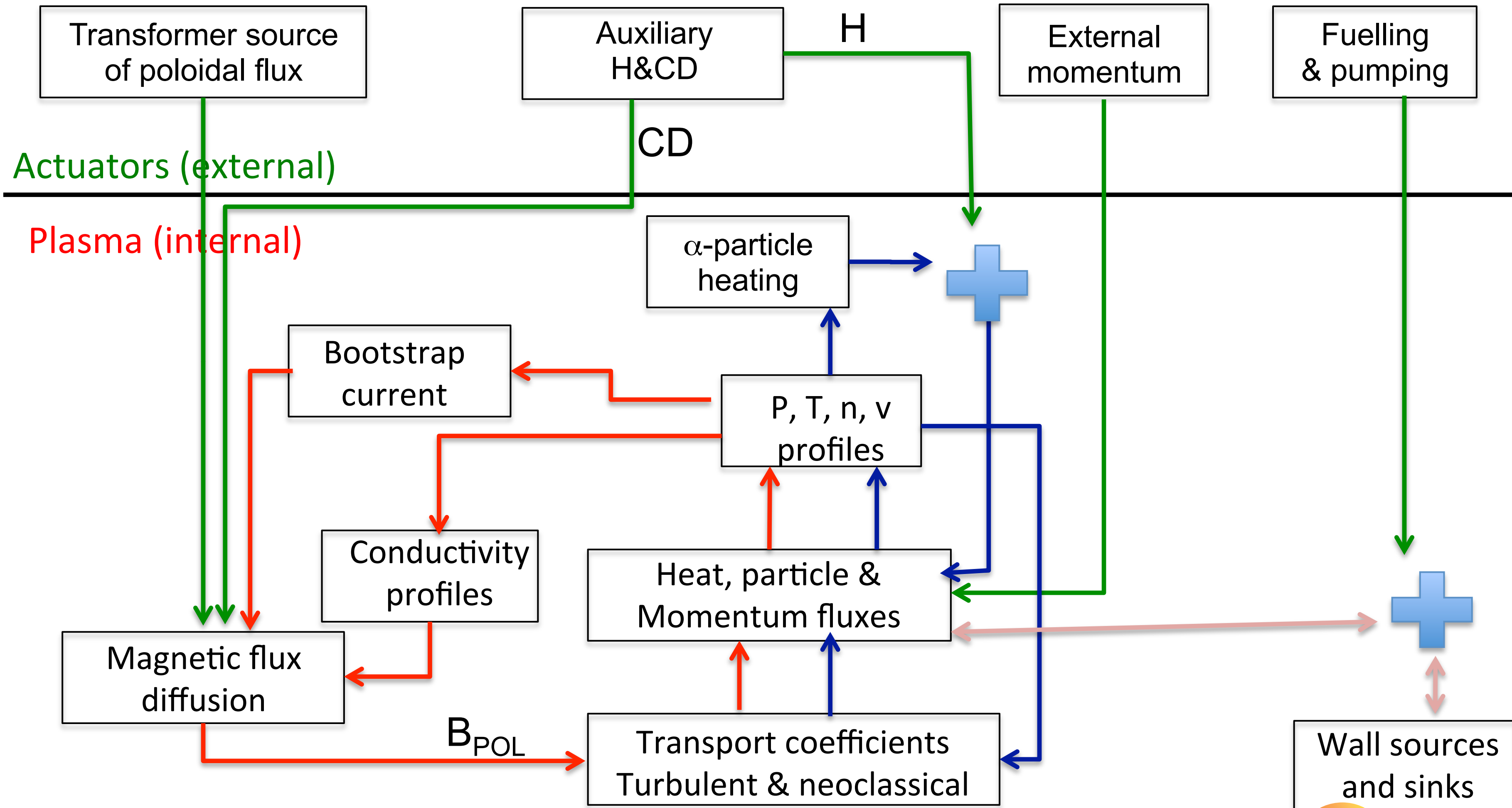


Not even mentioning MHD …

adapted from Politzer NF 2005 and X. Litaudon, ITER summer school 2014

Integrated modeling is a complex task: Integrate the core with the edge and the boundary



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Outline

- Integrated modeling, the golden goal
    - what should be included in a tokamak simulator?
- What do I use TRANSP for? Three examples
    - predictions, scenario modeling (NSTX-U, ITER)
    - analysis and interpretation (C-Mod)
- What could I do better?
    - what upgrades would I like to see and how to facilitate this?

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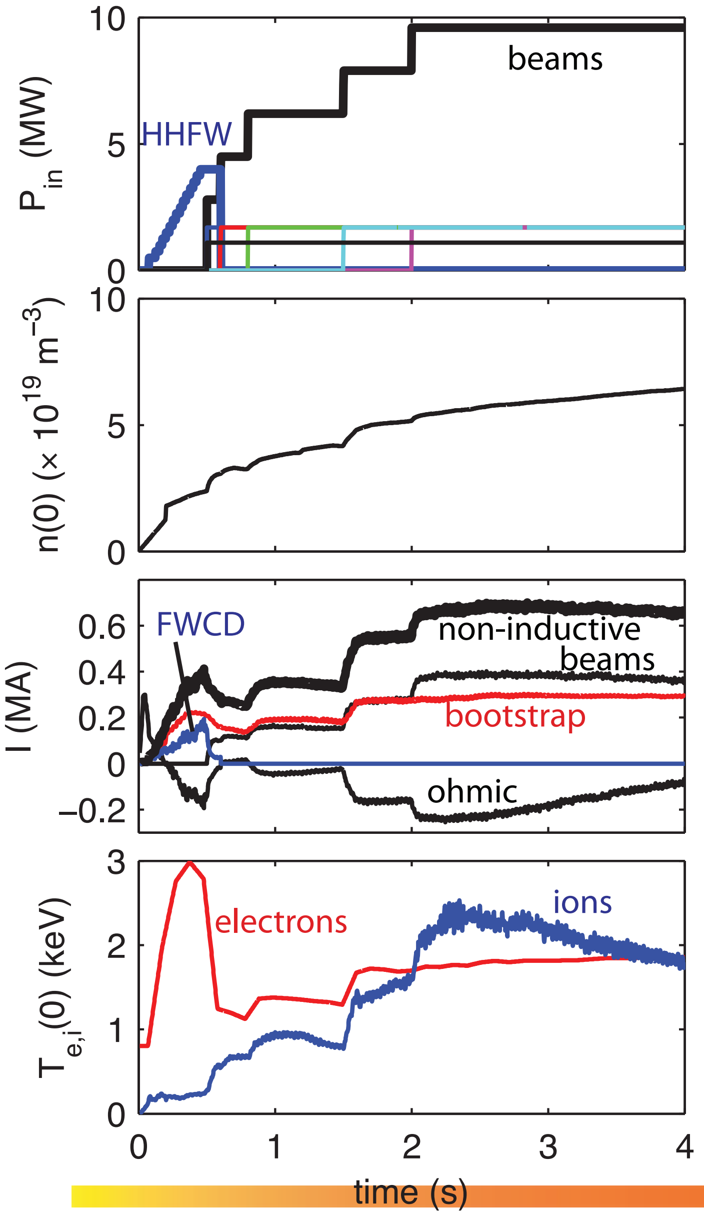
Free-boundary TRANSP is playing a critical role in predictive simulations of non-inductive current ramp-up on NSTX-U

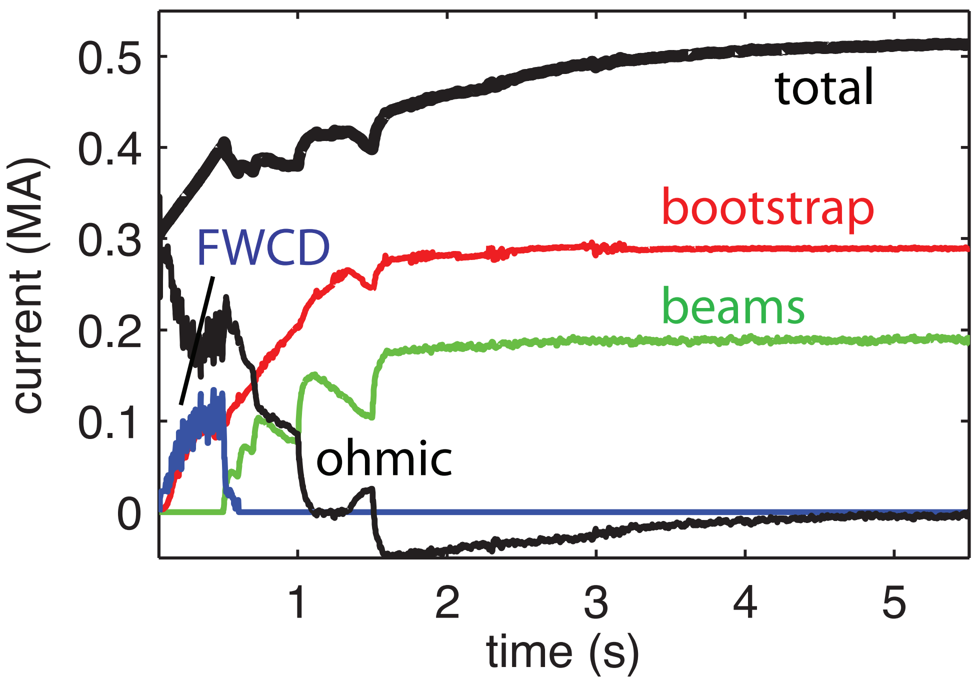


- free-boundary TRANSP with
  - HCD source module
  - bootstrap current and
  - thermal transport
  - combined with control algorithms

  is a great tool for scenario development

- Evolve self-consistently equilibrium and HCD
  - used here analytic density, BUT
  - predictive density evolution possible WITH
  - density feedback possible
  - shape control possible
  - beta control possible

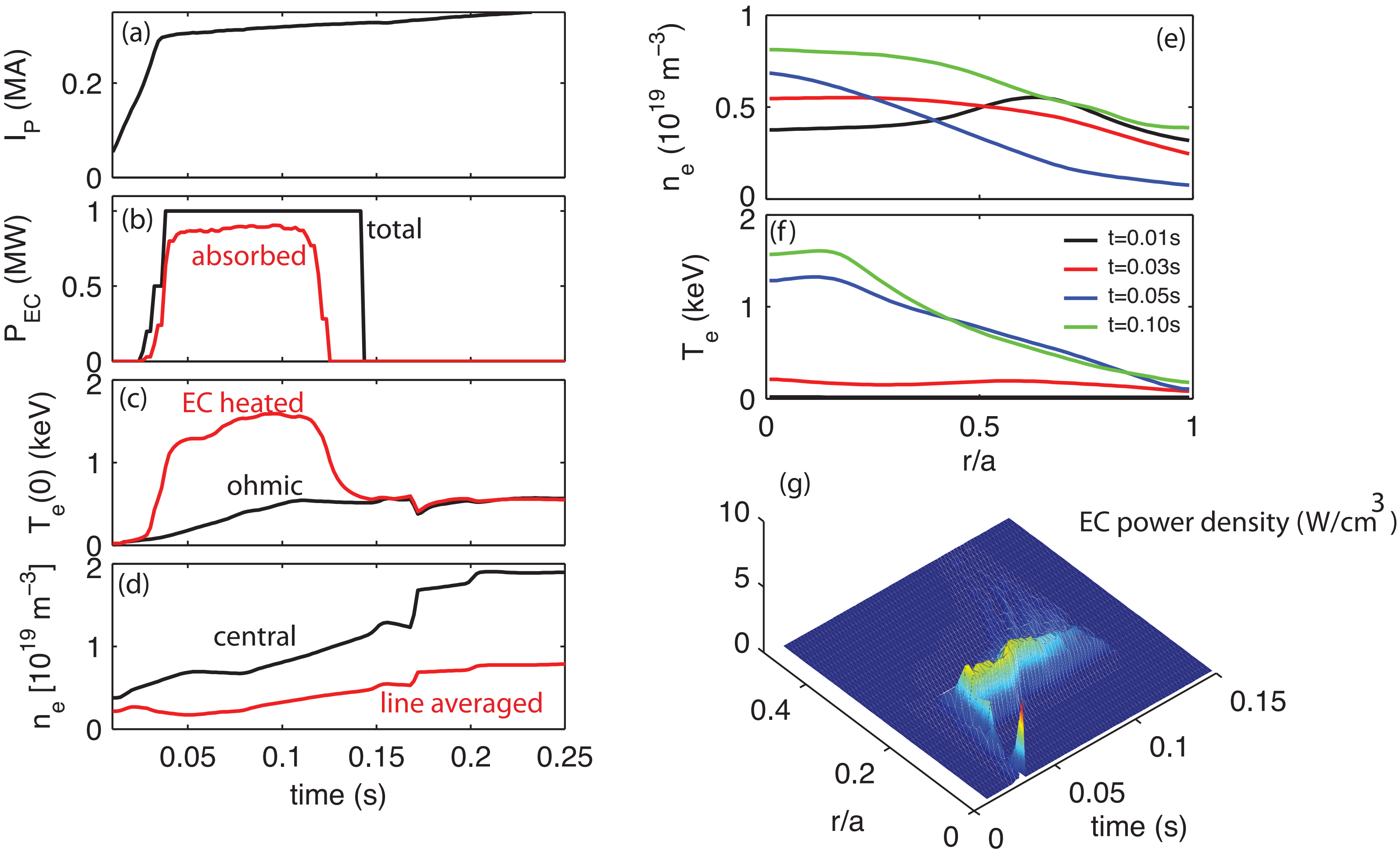
… and in the preparation of experiments towards the achievement of non-inductive ramp-up on NSTX-U



Simulation of a discharge on NSTX-U, with B_T=0.75 T, $n_{e,lin}$=0.75n_G
4 MW of HHFW and 10 MW of NBI

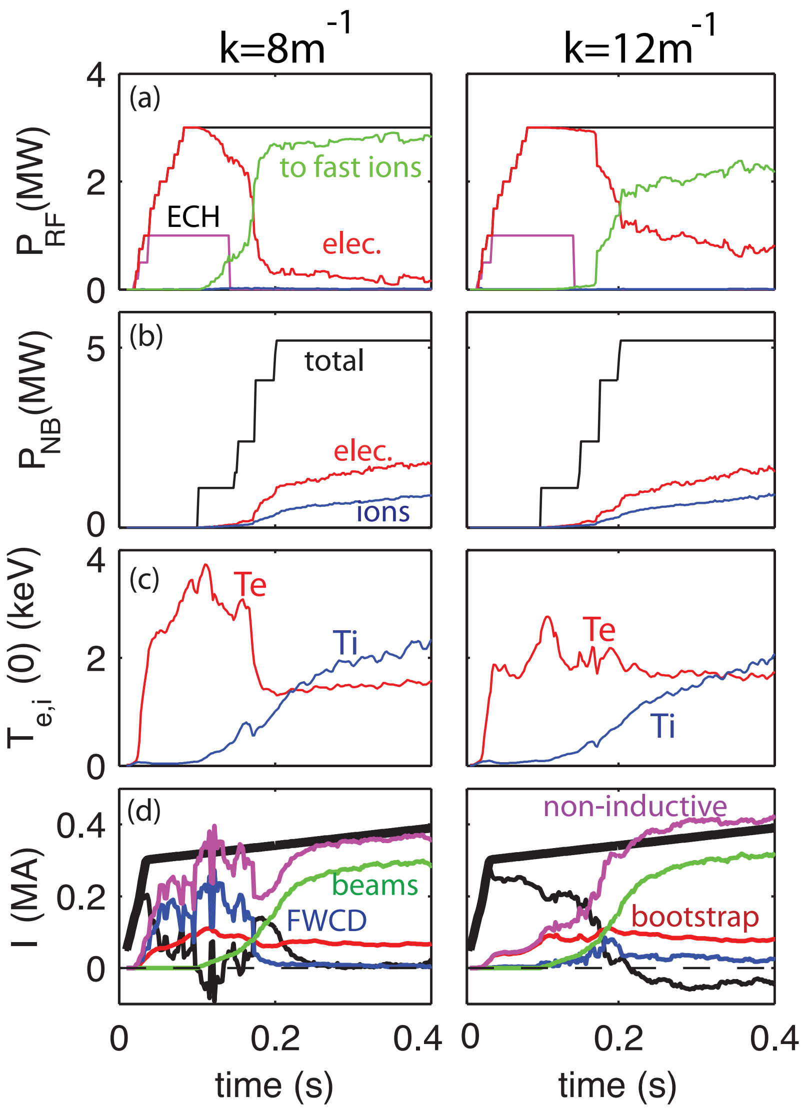
Combined with systematic validation activity, we are using free-boundary TRANSP to design experiments ahead of time and go "prepared" to the control room.

Self-consistent evolution of equilibrium and kinetic profiles are being used for assessing feasibility of EC upgrade



Simulation of 1 MW of Electron Cyclotron heating on NSTX-U start-up plasma

Assessing synergy and interactions between IC and NBI is important for experiments and for modeling



Correct inclusion of non-Maxwellian distribution function is a priority for fusion research

to correctly study

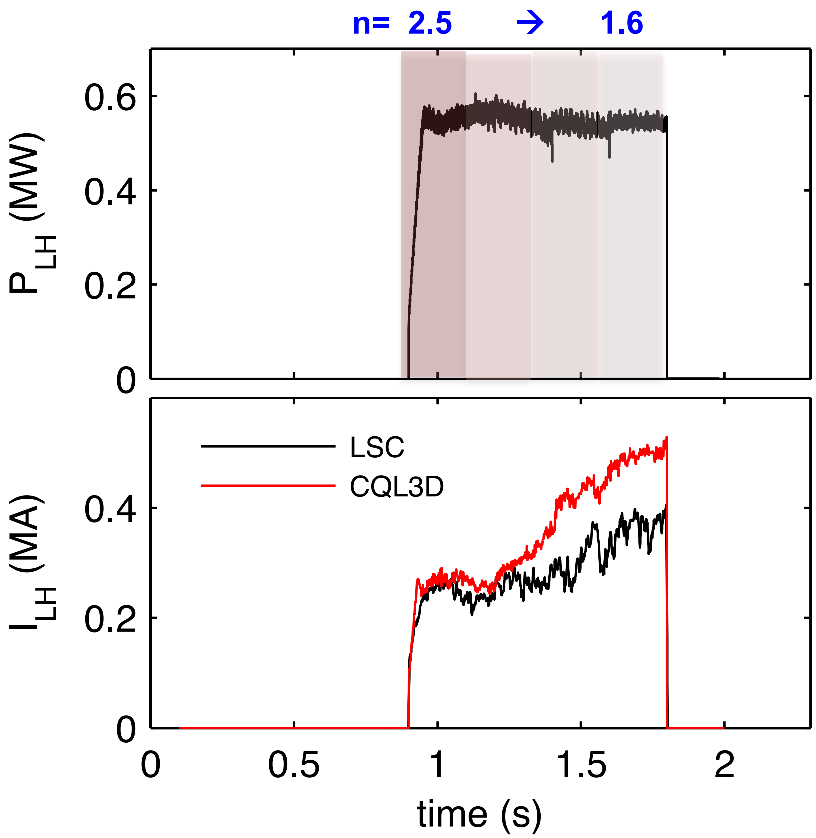
- interaction between RF and NBI

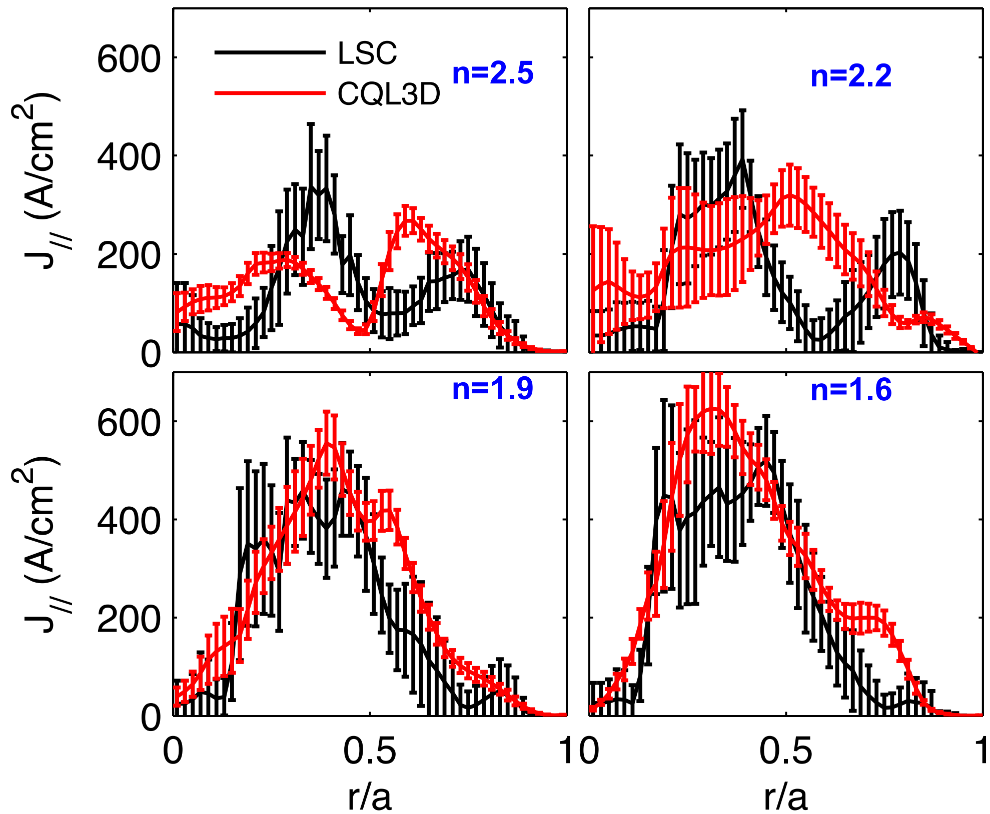
and for ITER and fusion devices

- correct treatment of minority heating
- treatment of alpha particles

Some upgrade needed here …

Implementation of 3D Fokker-Planck CQL3D represents a sensible improvement in the study of LHCD physics





decrease $n_{//}$ in discharge => expect inner LH wave damping

⇒ trend visible in GENRAY+CQL3D, not evident in LSC at large $n_{//}$

⇒ difference of about 20% in total LH current (acceptable, depending on purposes)

Sensitivity studies ongoing in TRANSP on C-Mod LHCD discharges

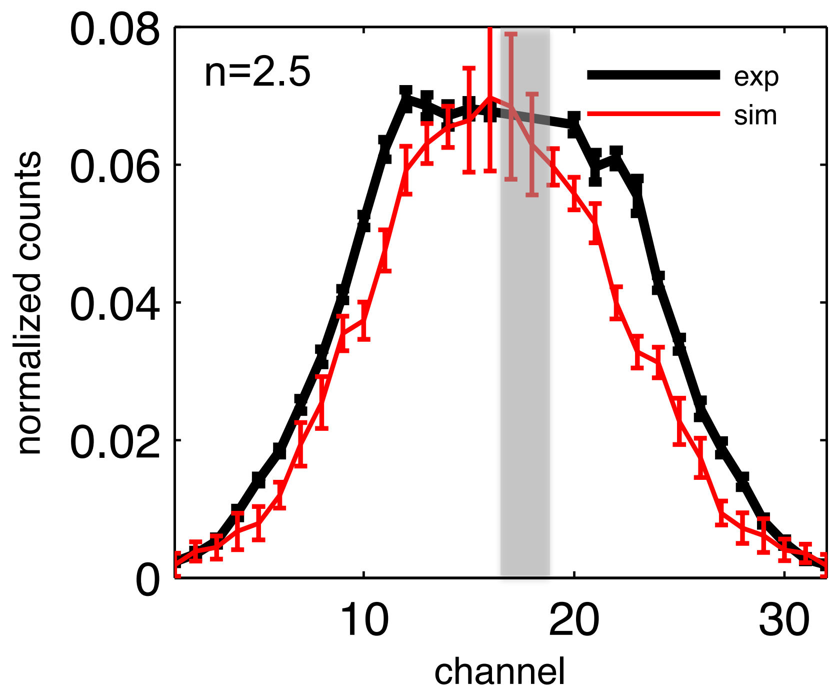
Using time-dependent calculations, LHCD model can be validated in experimental-like conditions

Time-dependent analysis accounts for:

- evolution of poloidal field diffusion
- including the coil current evolution
- use of self-consistent profile of Vloop
- can read equilibrium from EFIT-MSE for

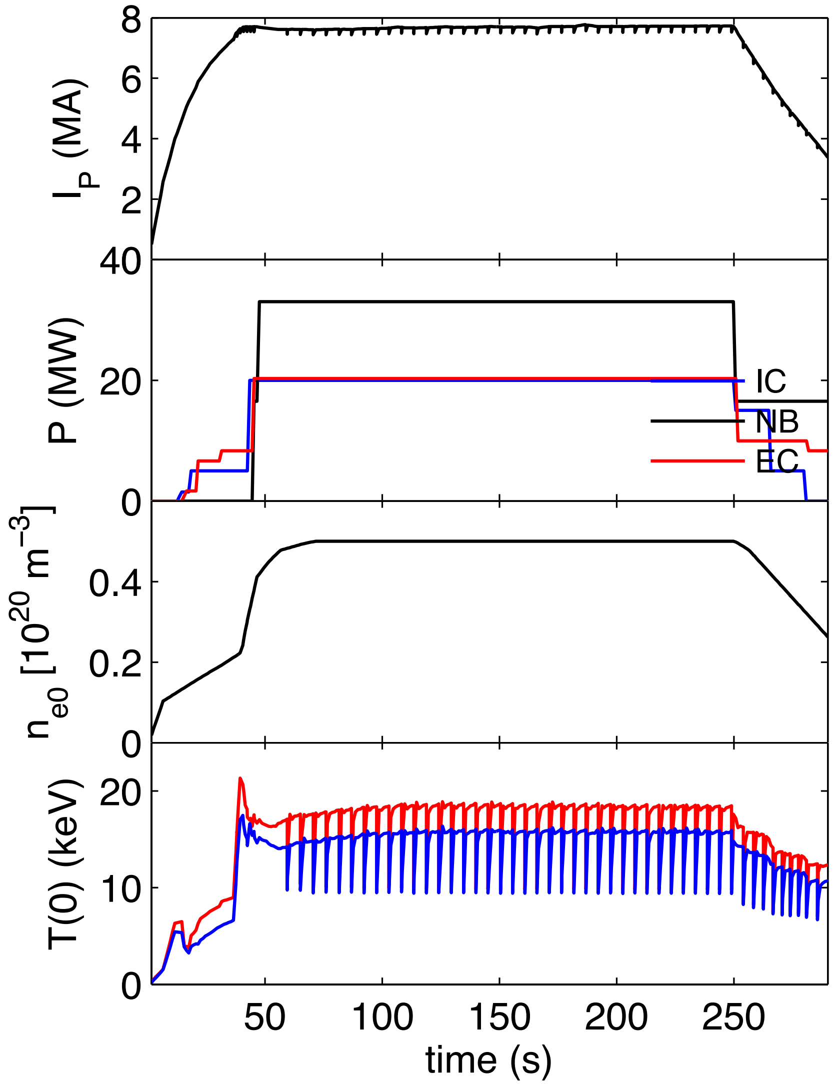
cross-check accuracy of diagnostics

Exp. HXR integrated over 80 ms
Synthetic HXR integrated over 80 ms



TRANSP very good tool for model validation and for diagnostics cross-consistency

Prediction of ITER operational scenarios needs high fidelity HCD source models, thermal transport, fast ion transport …



Simulate plasma evolution from startup to termination

Combine heating and current drive source
Assist L-H transition
Entry to burn
Ramp-down, H-L transition, termination
density evolution (prediction)
feedback control (shape, density, beta)

Evolve temperature and equilibrium self-consistently, including MHD (here sawteeth with Porcelli trigger).

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  - what do we need to model a tokamak ?
- What do I use TRANSP for?
    - predictions, scenario modeling
    - analysis and interpretation
- What could I do better if we had …

Upgrades wishing list …

Short term (1-2 years) **CORE PHYSICS**

- RF synergies and interactions with fast ions (beams, alphas) [high priority ITER, NSTX-U]
- reduced pedestal model and consistent core-pedestal coupling [in progress]
- core impurity transport [in the pipeline]
- reduced MHD (NTMs, fast ion stabilization in STs) [in progress, ITA]
- fast ion transport physics

Medium term (>5 years) **EDGE PHYSICS**

- reduced models for SOL, PMI, ELMs

Long term (> 10 years) start now **MODULARITY, SPEED** (more ITER oriented)

- fast algorithms/reduced models/more efficient modules
  - Ex: TORBEAM 5s/1CPU – replaces GENRAY 25s/48CPU
  - Ex. EPED1 lookup table and parametrization
- Ability to run in 'control' mode for inter-shot predictive runs