Predictions of fast ion parameters in ITER

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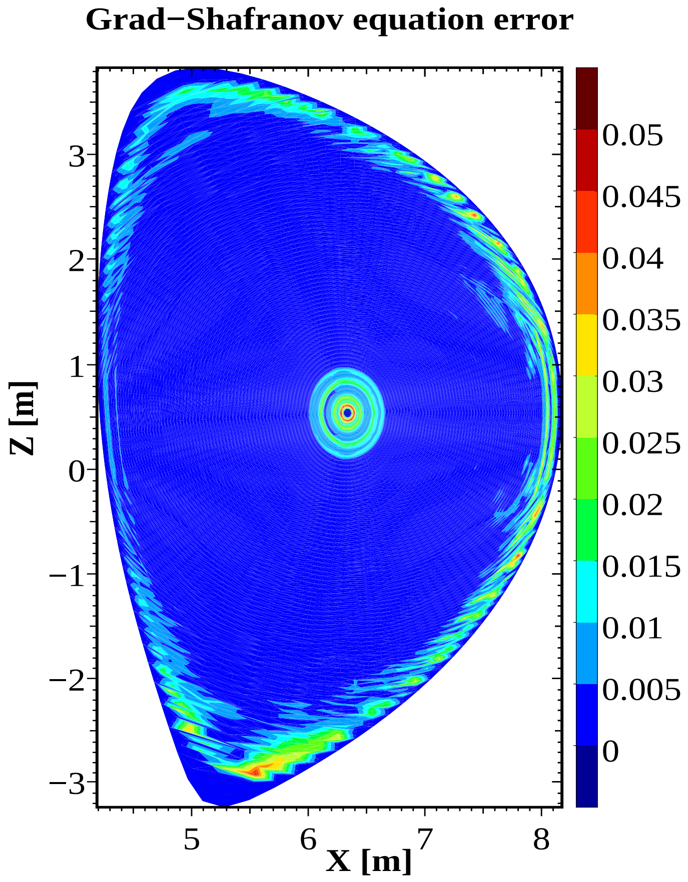
- Time-dependent integrated modeling is needed for educated guesses of fast ion parameters in ITER (and beyond)
  - Time-dependent for transients, e.g., startup, sawteeth, slow approach to flat top, post $P_{\mathbf{aux}}$
  - Integrated modeling for coupling: heating, current drive, and plasma response
- This talk presents time-dependent integrated modeling predictions for ITER using PTRANSP

PTRANSP predictions of ITER plasmas

- PTRANSP $\equiv$ new version of TRANSP with improved predictive capabilities
- Collaboration among PPPL, Lehigh Univ, LLNL, Tech-X, GA
- PTRANSP modules used for self-consistent ITER predictions
  - TSC for plasma boundary, startup, feedback control, termination
  - TEQ for equilibria
  - NUBEAM for NNBI and fusion ions
  - TORIC for ICRH
  - TORAY for ECCD, ECH
  - LSC for LHCD
  - GLF23 for predicting T_i, T_e
- $\Longrightarrow$ Detailed predictions of ITER H-mode and Hybrid plasmas including:
  - sawteeth
  - alpha ash accumulation
  - plasma rotation

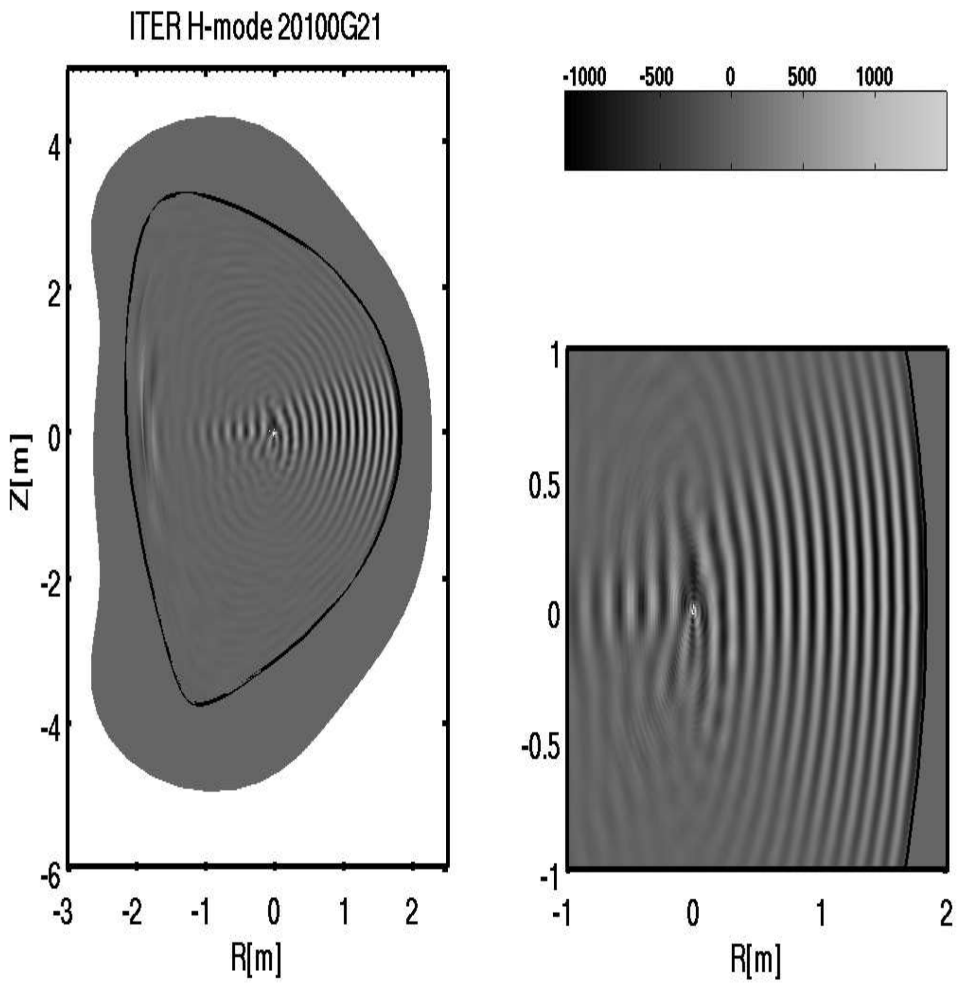
Accurate time-evolving equilibrium solutions using TEQ

- Small error $\equiv$ (RHS - LHS) / < RHS >



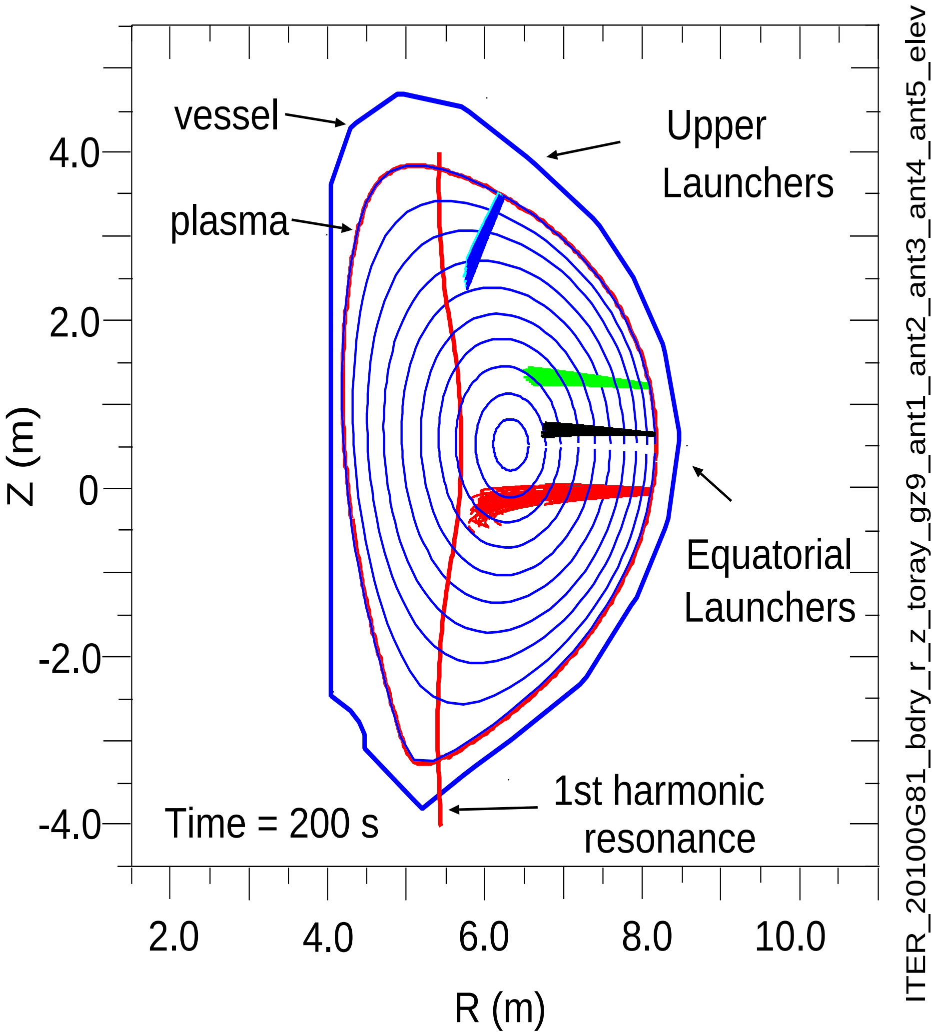
Detailed ICRH predictions using TORIC

- TORIC has been benchmarked with AORSA



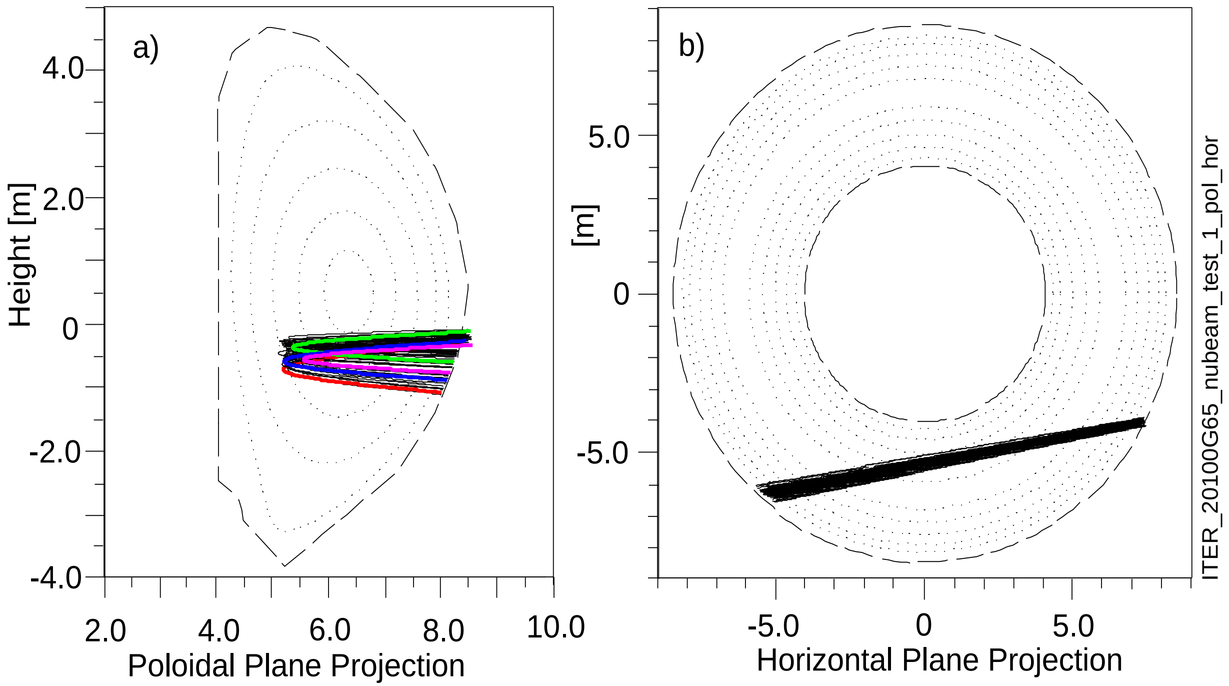
ECH / ECCD predictions using TORAY

- TORAY has been benchmarked with many other codes



Careful treatment of Negative Ion Neutral Beam Injection using NUBEAM

- 3D geometry modeled
- Example of Monte Carlo flights for case of below-axis NNBI



Fusion ion parameters also calculated with NUBEAM

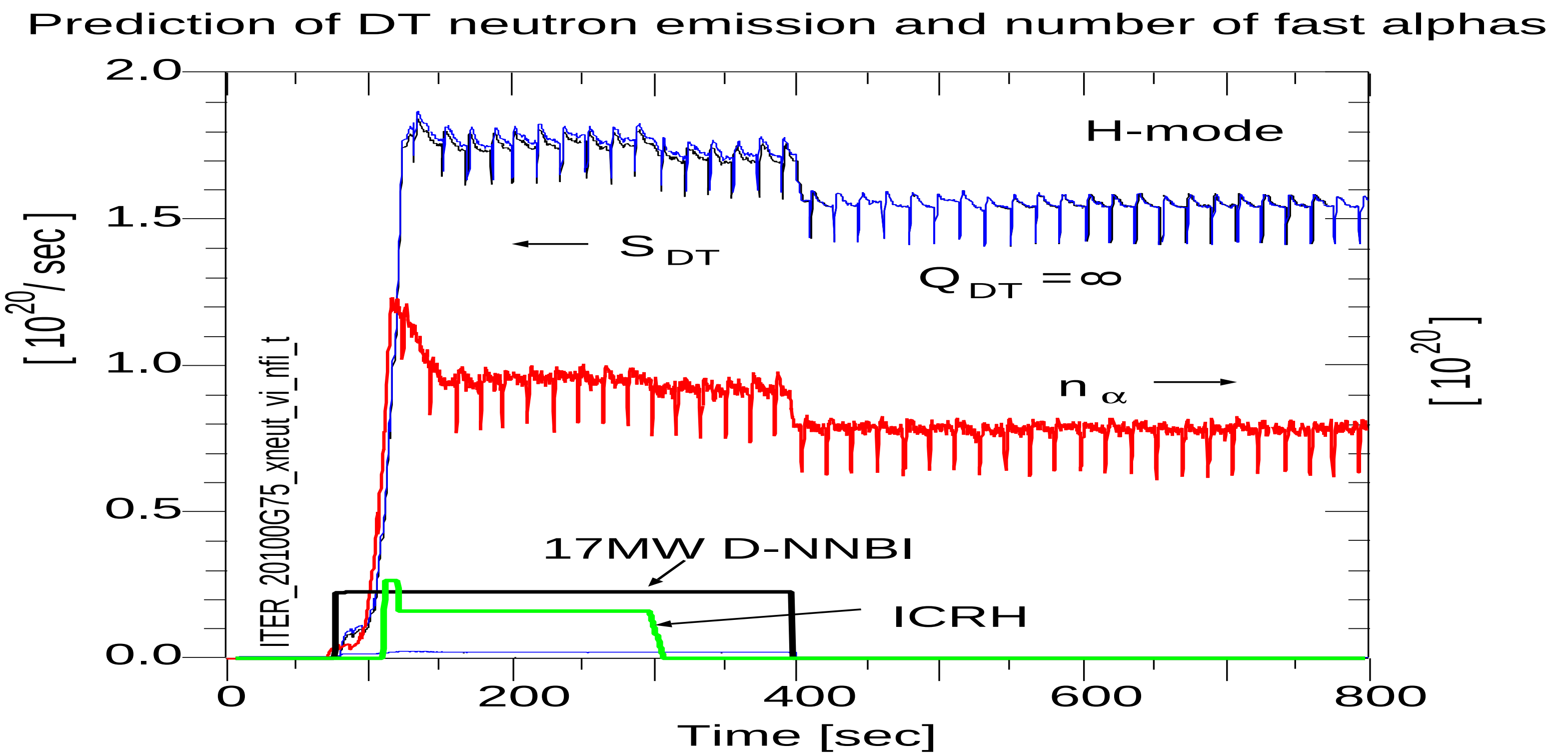
- Monte Carlo methods
- Phase space sampling predicts distributions
- Fast α's from DT
- Fast T from DD
- Fast He^{3} from DD

Caveats:

- Large uncertainties for predicting ITER performance
  - Power threshold for L⟶H (e.g., density, isotopic mass, heat source)
  - pedestal T_i, T_e, density
  - validity of GLF23 for T_i, T_e, and v_ϕ
  - density prediction
  - ash and impurity transport and recycling
  - Radiation predictions
  - MHD (e.g., sawteeth, ELMs, NTMs)
  - atomic cross sections (e.g., 1 MeV D^0)
  - anomalous fast ion transport
- Standard H-mode: predict range of $P_{DT} \sim$ 250 - 500 MW
- Predict range for $Q_{DT} \sim$ 2 - ∞ (after step down in P_{aux})

S_{DT}, n_α in a standard ITER H-mode

- Case with optimistic assumptions (peak P_{DT} = 500 MW)



- Alpha heating balances losses
  (convection, condustion, radiation, net charge exchange)

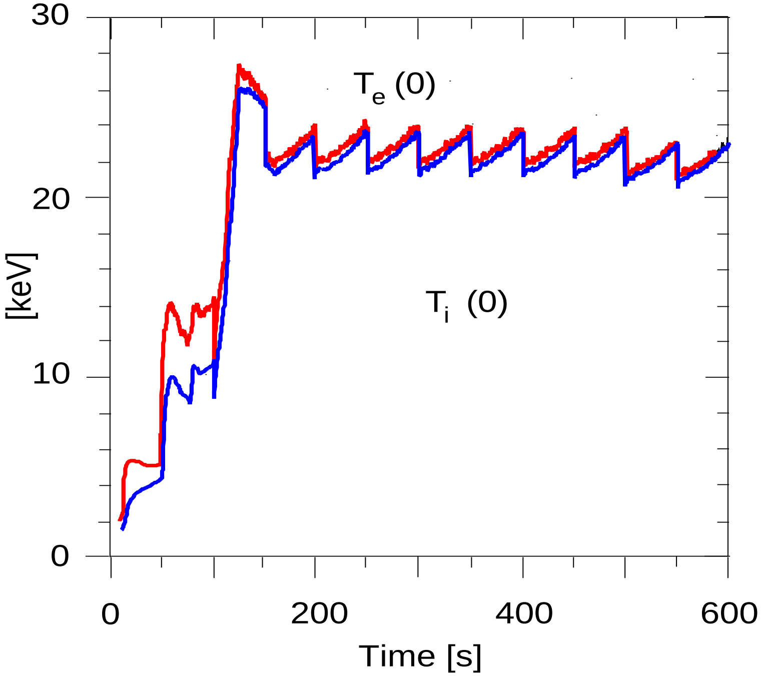
Examples of ITER Plasmas studied

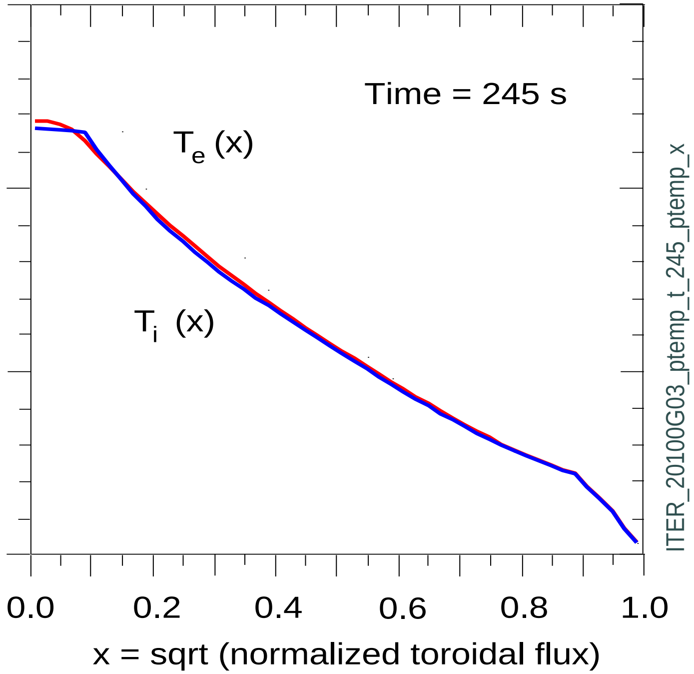
- Sawtoothing ELMy H-mode
- Hybrid plasma: q(0) ≃1.0-2.0

units	I_p MA	I_{Oh} MA	I_{boot} MA	I_{NNBI} MA	$n_e(0)$ $10^{20}/m^3$	f_{GW}	T_e keV	P_{DT} MW	$\beta_\alpha(0)$ per cent
Standard H-mode	15	11.5	2.5	0.50	1.05	0.86	25	250-500	1.2
High density H-mode	15	11.6	2.2	0.60	1.15	0.94	20	400-700	0.8
Hybrid $\beta_n \simeq 2.2)$	12	8.0	4.0	0.80	0.85	0.85	24	460	1.0
Hybrid $\beta_n \simeq 2.6)$	12	6.2	4.2	1.4	0.85	0.85	28	550	1.1
Hybrid $\beta_n \simeq 3.2)$	12	4.8	5.0	1.6	0.85	0.85	28	700	1.0

Example of ITER H-mode

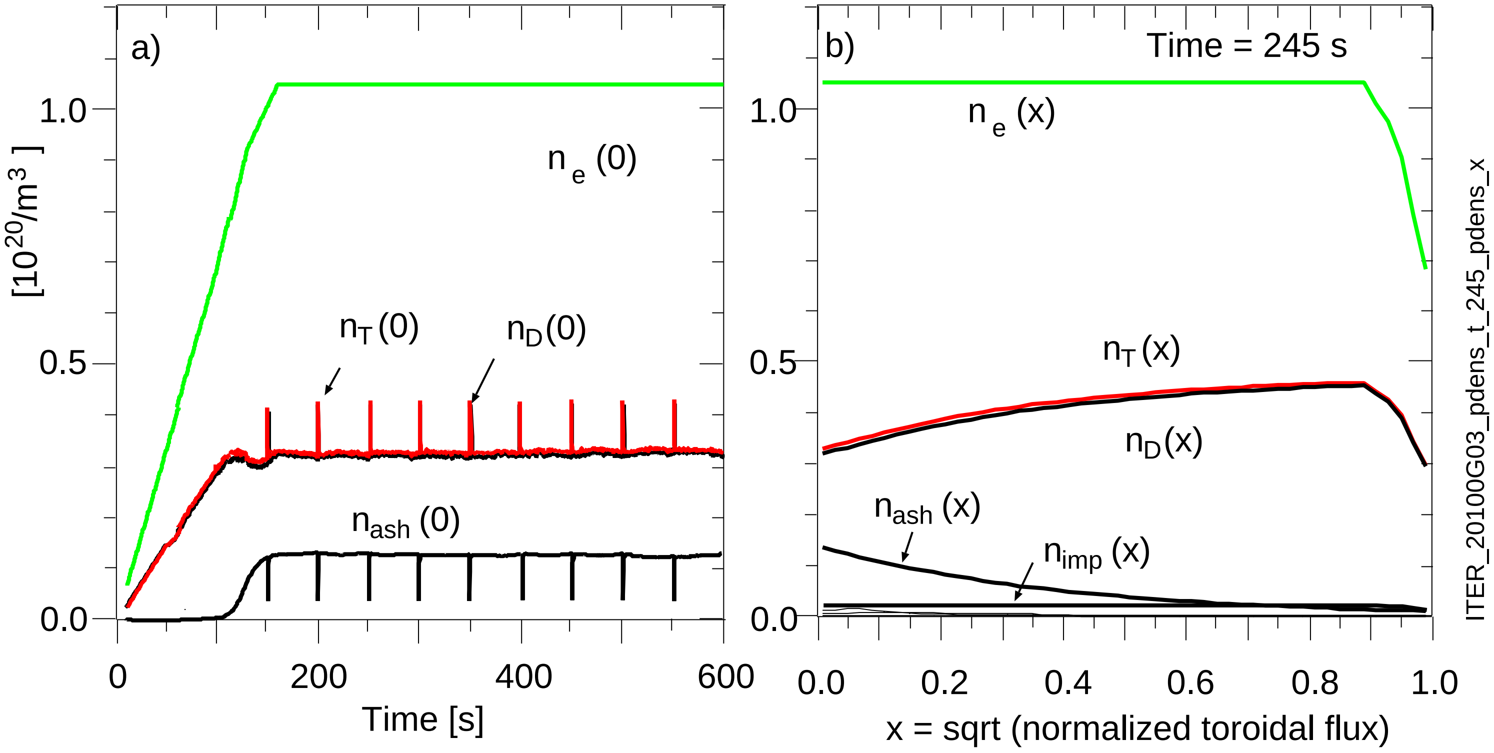
- $B_{TF} = 5.3$ T, $I_p = 15$ MA, κ_{98} =1.75, δ_{98} =0.5-0.6
- $P_{NNBI} = 33$ MW, P_{ICRH} = 20 MW, f_{GW} =0.86, β_n =1.7-1.8
- GLF23 predicts T_i and T_e out to assumed values at r/a=0.9





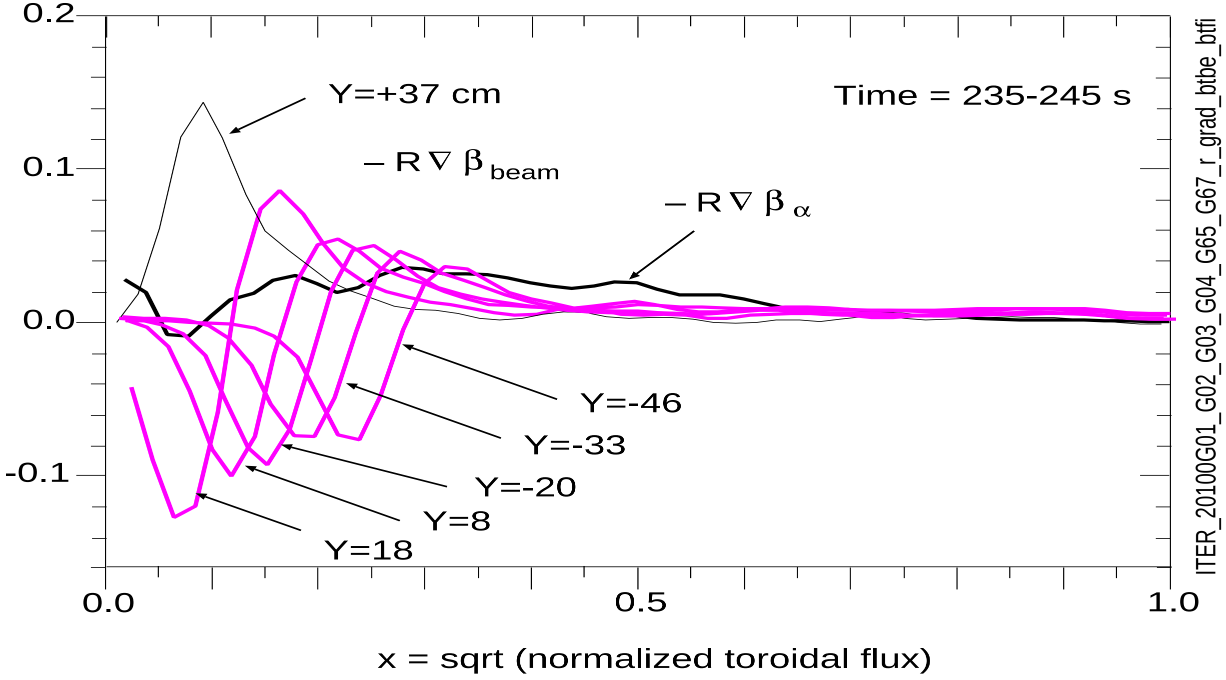
Densities in standard ITER H-mode

- Assume $n_e, n_{Be}, n_{Ar}, n_{He^3}$
- compute $n_D, n_T, n_{beam}, n_\alpha, n_{ash}$



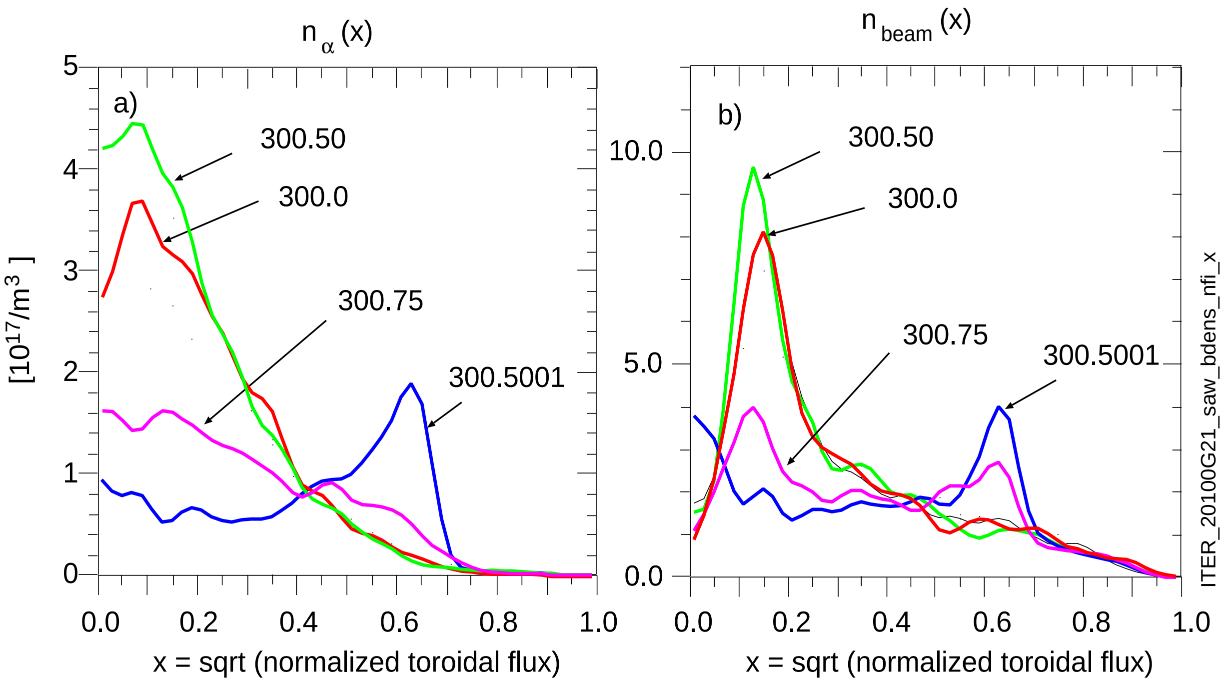
Effects of NNBI steering on fast ion pressure

- $R\nabla(\beta)$ measures TAE drive
- $R\nabla(\beta_{beam})$ altered by NNBI steering
- $R\nabla(\beta_{beam})$ can dominate $R\nabla(\beta_{\alpha})$



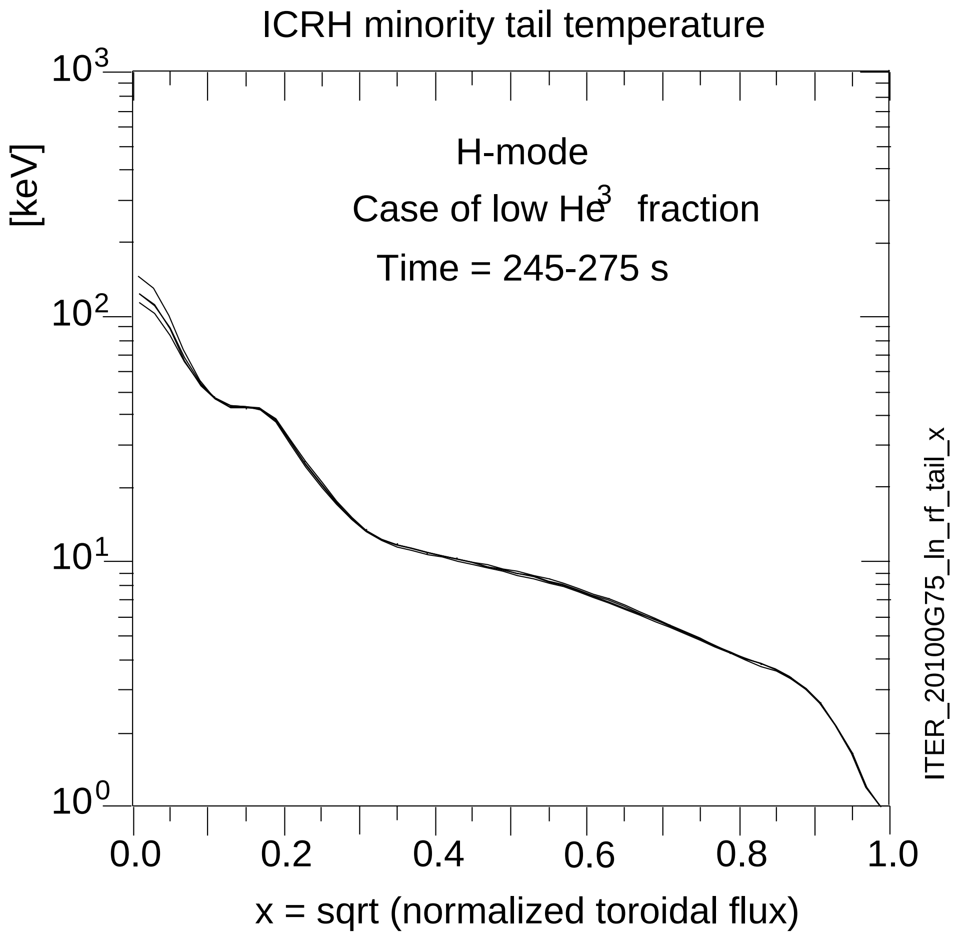
Sawteeth effects

- Generalized Kodemstev mixing model
- Porcelli trigger module available



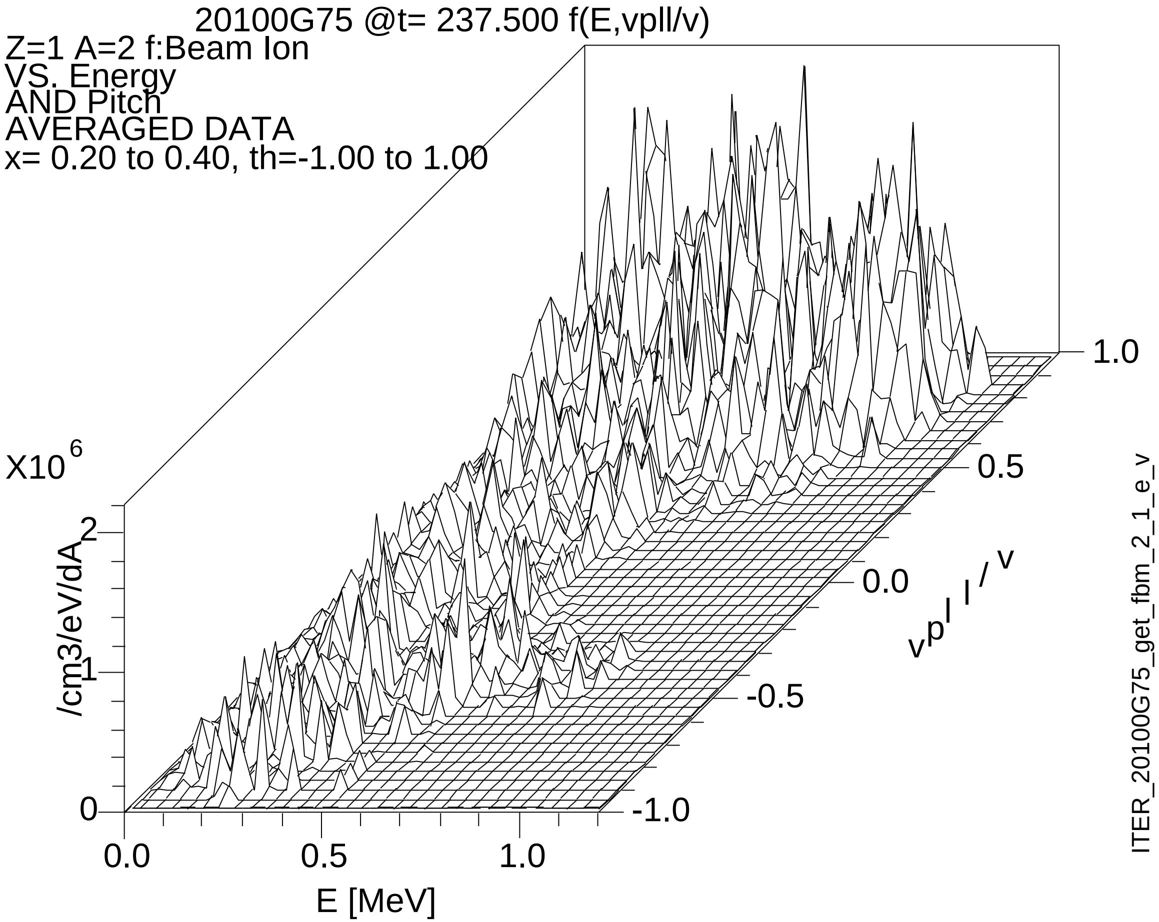
Energetic ICRH minority tail temperatures

- High T$_{RF}(0)$ if n_{He^3} / n_e is small (e.g., = 0.001)
- Distribution of RF minority ions not modeled accurately



PTRANSP computes distributions of fast ions

- Predict NNBI pitch angle scattering to negative $v_{||}/v$
- Predict α pitch angle asymmetries even near r/a $\simeq$ 0.5



Plans for improving integrated modeling capabilities

- Near-term (upgrades to PTRANSP):

1. Improved automatic TSC - PTRANSP coupling
2. Use TGLF in place of GLF23
3. density prediction
4. Free boundary equilibrium in PTRANSP via TEQ / ISOLVER
5. Use GENRAY in place of TORAY and LSC
6. Use CQL3D in place of ICRH Fokker Planck module
7. RF Monte Carlo operator

- Long-term (FACETS):

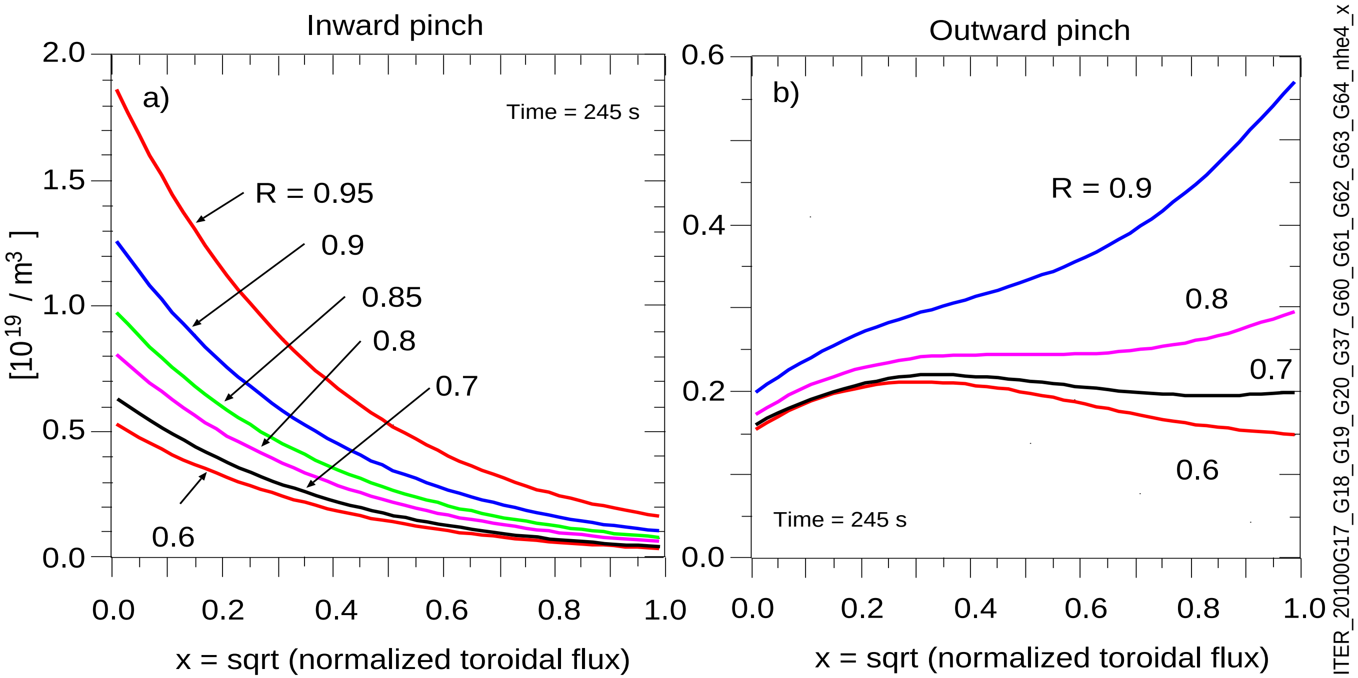
1. Advanced computing techniques
2. Edge-Core coupling

Conclusions

- PTRANSP is being used to predict ITER H-mode and Hybrid plasmas
    1. benchmarked NNBI, ICRH, LHCD, ECH/ECCD, and Fusion ion modules
    2. accurate plasma equilibria
    3. GLF23 for temperature evolution
    4. Sawteeth, ash accumulation, rotation
    5. time-dependent, self-consistent, integrated modeling
- Detailed predictions of fast ion parameters
    1. large effects of sawtooth mixing beam RF minority, and fusion ions
    2. beam and fusion ion distributions in 2D space and 2D phase space

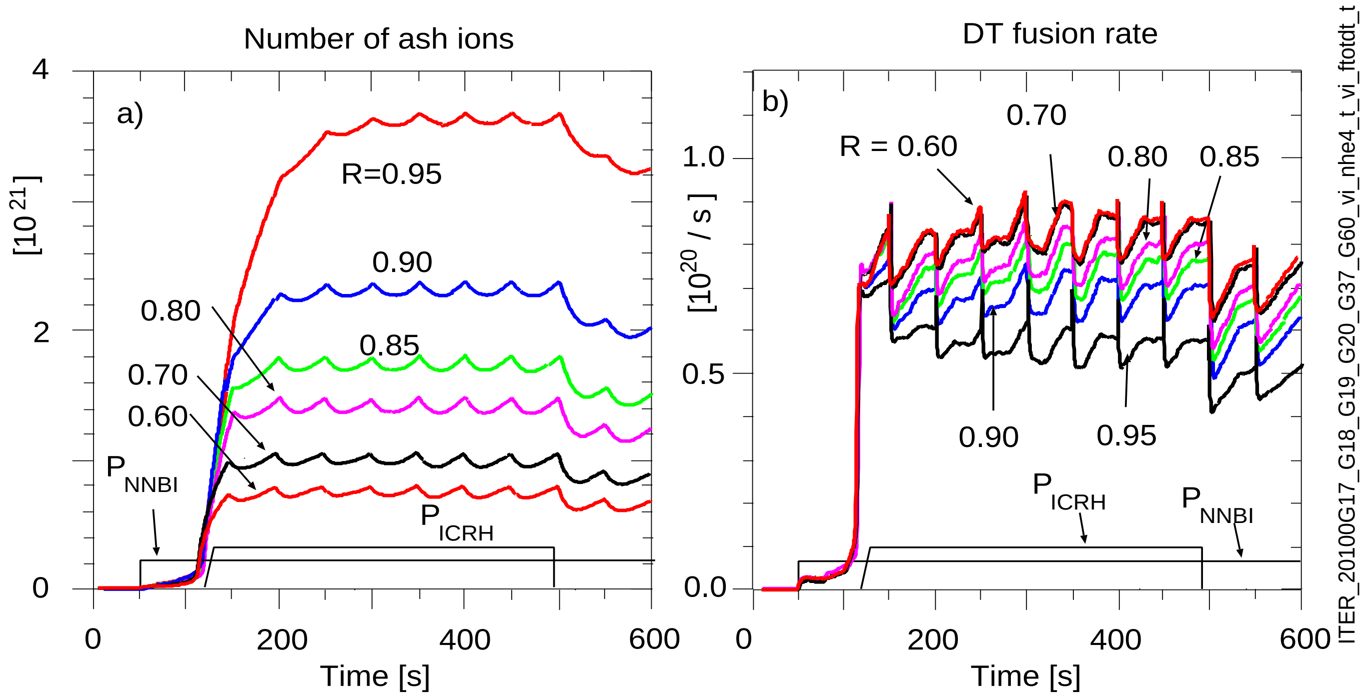
Effects of ash recycling on profiles of ash

- a) case with an inward ash pinch: increasing R causes depletion of DT in core
- b) case with an outward ash pinch: increasing R causes little depletion of DT in core



Uncertainites in ash transport and recycling

- Presence of inward pinch for ash makes He recycling important



Sharp decrease of P_{DT} with B_{TF}

- Simulations with reduced B_{TF} and constant q and β_n
- β_n scales as $n \times T/B_{\mathrm{TF}}^2$
- Scale I_p with B_{TF} to maintain constant q profile
- Scale n_e with I_{p} to maintain constant Greenwald fraction
- Find B_{TF}^4 dependence of P_{DT}