

# Time-Dependent Integrated Modeling of Burning Plasmas

R. Budny, R. Andre, and C. Kessel (PPPL)

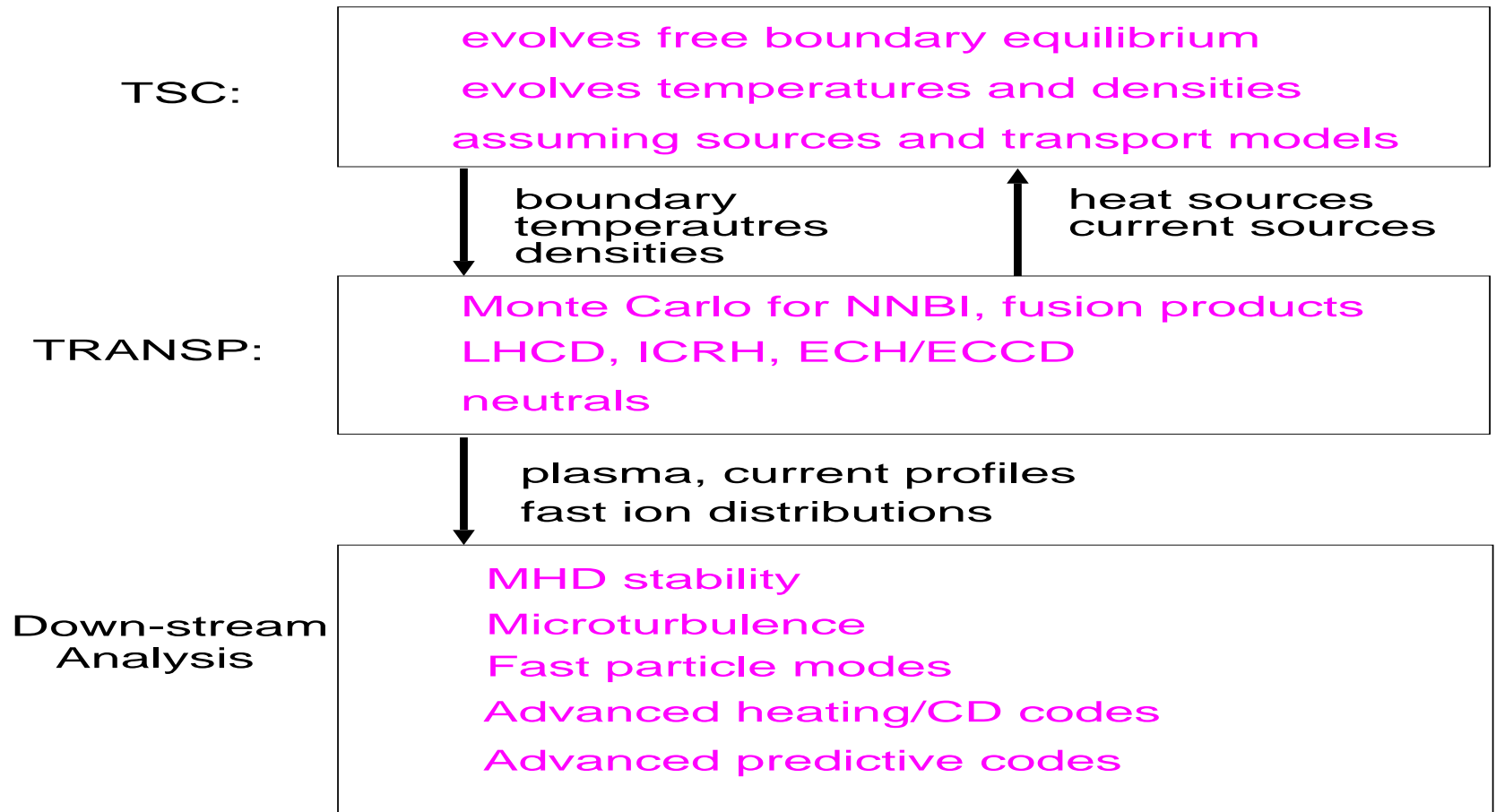
IAEA meeting W60 for Burning Plasma Physics, Tarragona, Spain, July 4-5, 2005

- Need better understanding of burning plasmas to increase the chances of practical fusion power
- Time-dependent integrated modeling will help meet this goal
  1. Check the ITER design (ex,  $P_{aux}$  sufficient? rotation sufficient? ash removal sufficient? will the diagnostics work?)
  2. Provide quality data for theoretical studies (ex, TAE)
  3. Will need to certify each plasma before it is tried

- ITER plasmas generated using a prototype of PTRANSP
- Examples of uses of the modeling
  1. distributions of the fast alpha and NNBI ions
  2. estimates of toroidal rotation and  $E_r$  profiles
  3. gyrokinetic simulations of energy, momentum, and particle flows
  4. estimates of alpha ash profile
- Introduction to PTRANSP

# Prototype Integrated Modeling using the TSC and TRANSP codes

---



# ITER Plasmas studied

---

- Steady-State plasma: low current, fully non-inductive
- Day-one hybrid plasma:  $q(0) \simeq 1.0-2.0$ , low  $\beta_n$  (2.1)
- Sawtoothing ELMy H-mode

	$I_p$	$I_{boot}$	$I_{nnbi}$	$I_{Oh}/I_p$	$n_e(0)$	$f_{GW}$	$T_e(0)$	$P_{DT}$	$\beta_\alpha(0)$
units	MA	MA	MA		$10^{20}/m^3$		keV	MW	per cent
Steady-State	9	4.3	4.3	0.0	0.6	0.63	33	305	1.3
Hybrid	12	2.8	2.4	0.50	0.8	0.64	24	333	1.0
ELMy	15	2.7	1.1	0.70	1.1	0.80	22	403	0.6

# Examples of Findings

---

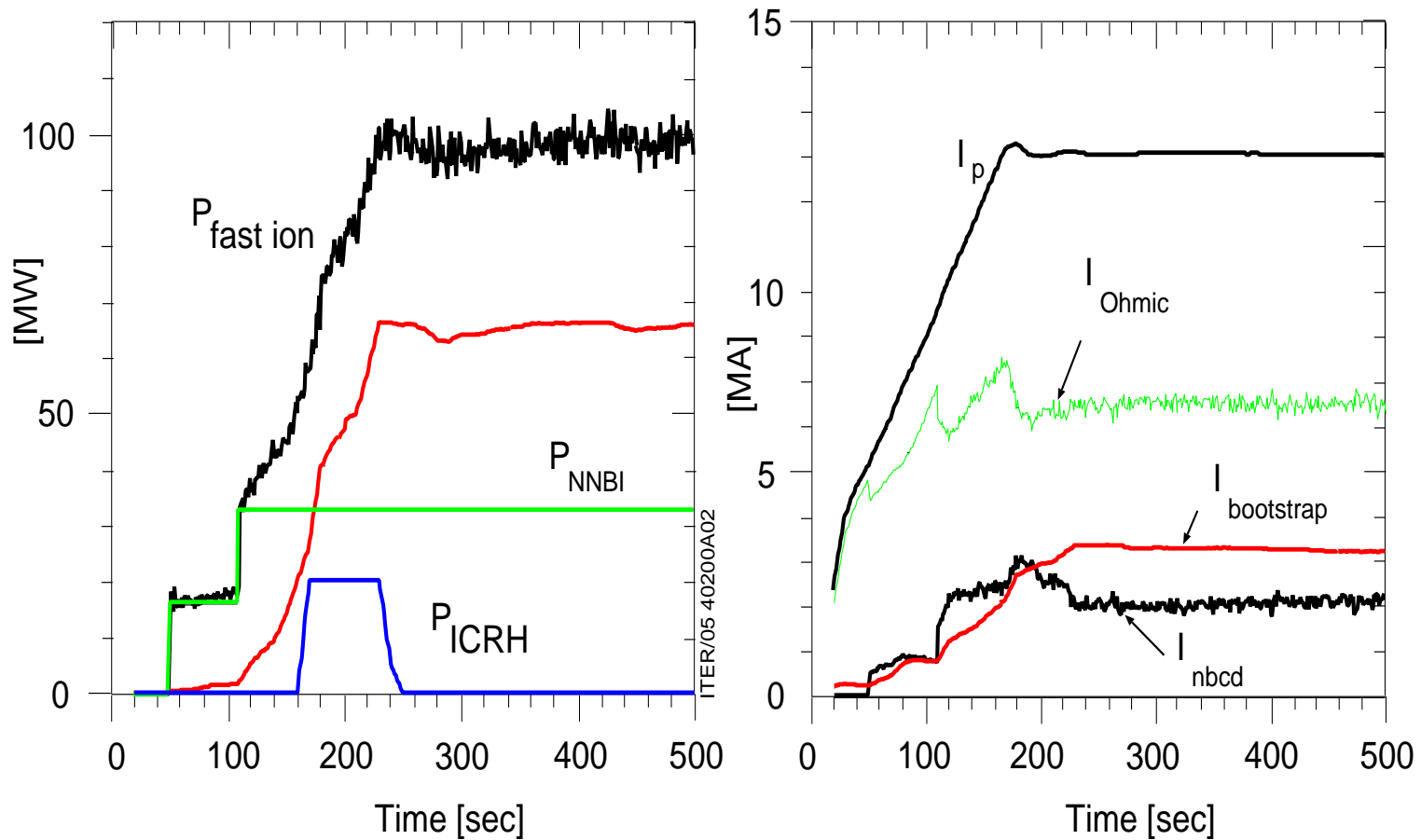
- High pedestal temperatures appears required by GLF23 (in TSC) to achieve  $P_{DT} \simeq 400\text{MW}$  with the planned ITER auxiliary heating
- Good NNBI penetration and current drive
- Modest toroidal rotation from NNBI torques if  $\chi_{mom} \approx \chi_i$
- Intense TAE activity predicted

# Construction of the Hybrid plasma

---

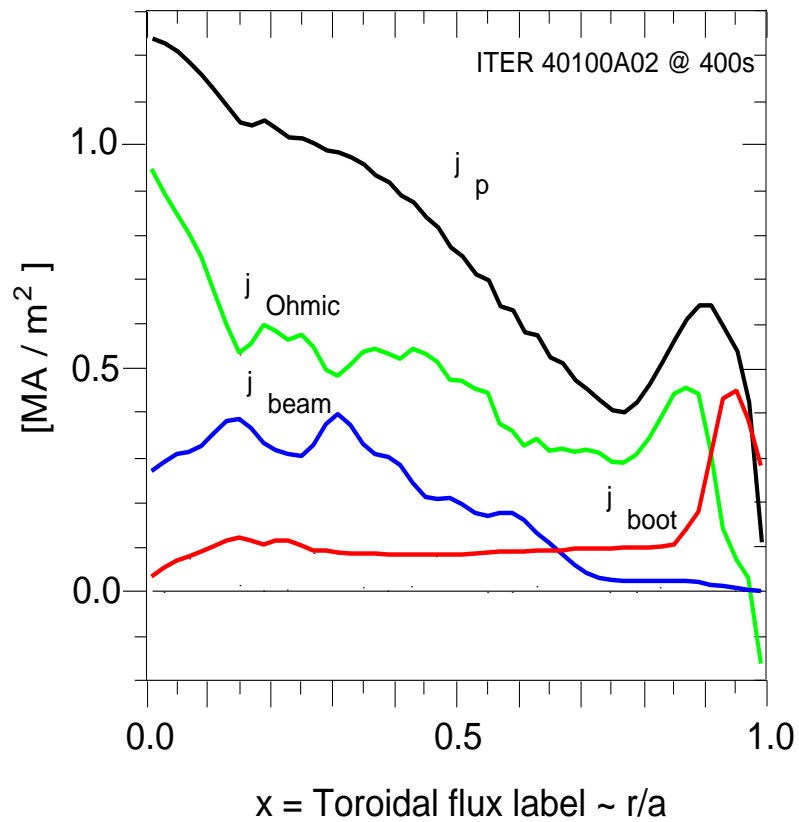
- Use GLF23 model to predict temperatures
- High pedestal temperatures to achieve  $P_{DT} \simeq 400$  MW
- Reduced  $I_p$  (12 MA) to decrease inductive-current fraction
- Moderate density for good NNBI penetration
- Sufficient current drive to keep  $q(0)$  above unity

# Heating powers and plasma currents in the Hybrid plasma

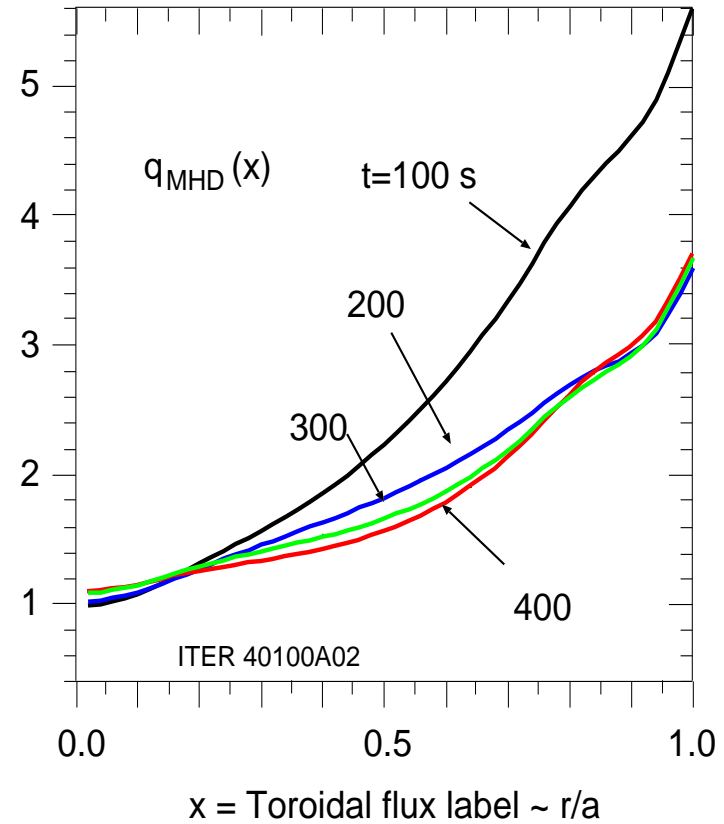


# Sustained $q_{MHD} > 1$ with evolving reversal in Hybrid plasma

Current profiles computed by TRANSP

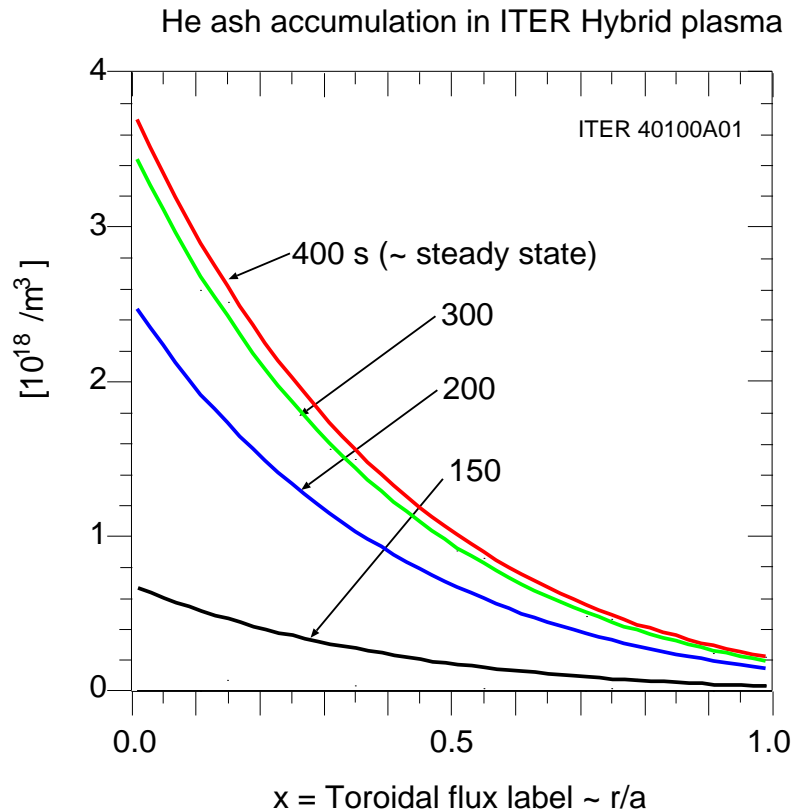


Slow evolution of  $q$  in ITER Hybrid plasma





# Integrated modeling needed for ash accumulation



Sources:

Core - Compute  $\text{He}^4$  thermalization

Edge - Assume ash recycl coeff  $R = 0.7$

Transport assumptions

$$\Gamma_{\text{He}^4} = -D \nabla n_{\text{He}^4} + V n_{\text{He}^4}$$

$$D = 1.0 \text{ m}^2 / \text{s}$$

$$V = -1.0 \text{ m} / \text{s}$$

Calculate confinement

$$\tau_{\text{He}^4} = N_{\text{He}^4} / \Gamma_{\text{He}^4} = 5 \text{ s}$$

$$\tau_{\text{He}^4}^* = \tau_{\text{He}^4} / (1-R) = 17 \text{ s}$$

- Need to get  $\Gamma_{\text{He}^4}$  from nonlinear gyrokinetic simulations

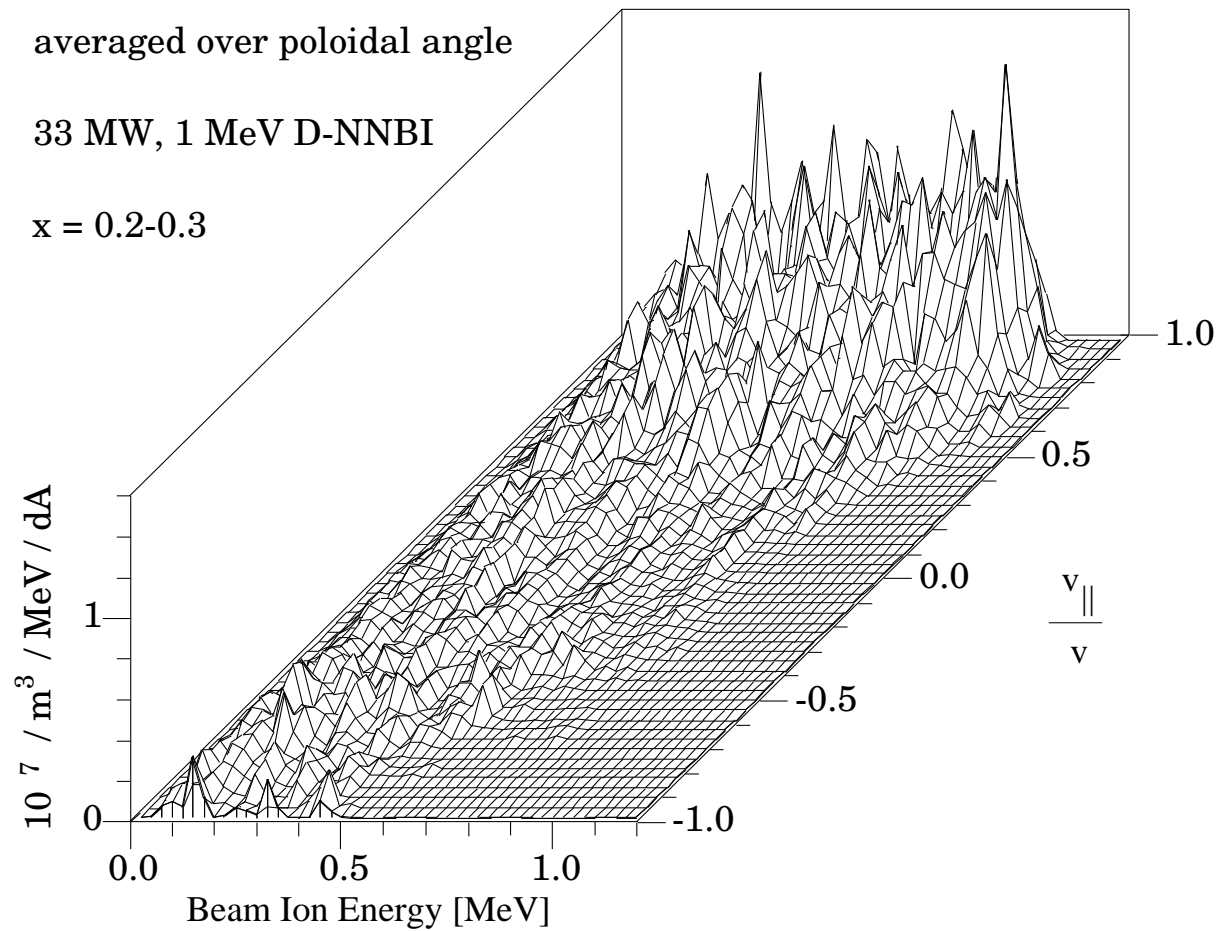
# TRANSP computes distributions of fast ions

Beam ion distribution in ITER Hybrid shot 40000B09

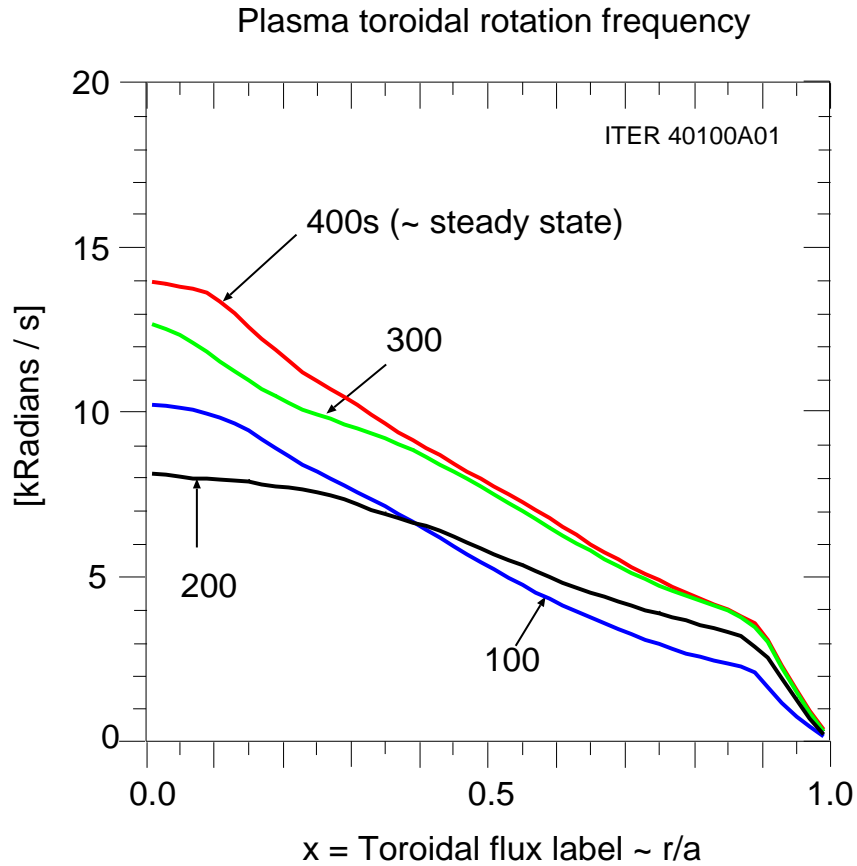
averaged over poloidal angle

33 MW, 1 MeV D-NNBI

$x = 0.2-0.3$



# Estimate modest toroidal rotation in the Hybrid plasma



Assume:

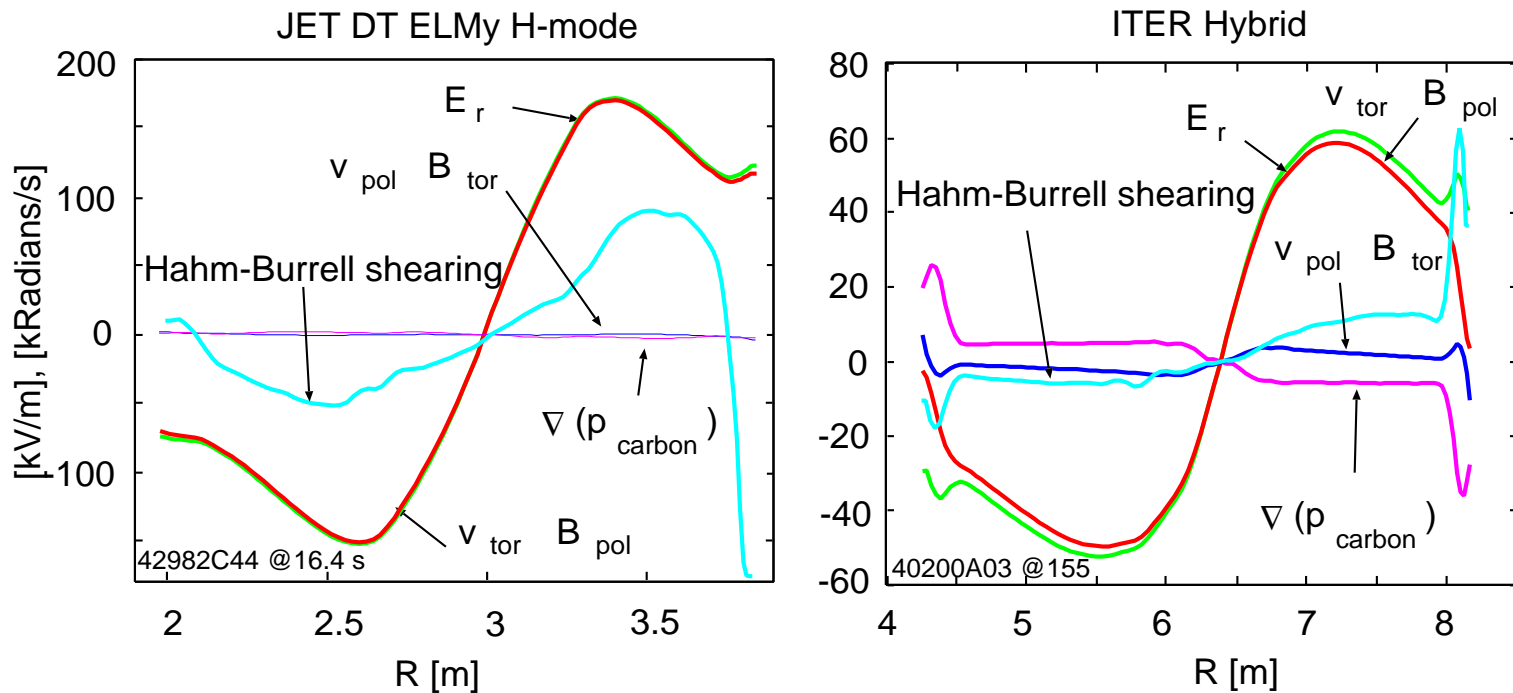
$$\chi_{\text{mom}} = \chi_i$$

$$P_{\text{NNBI}} = 33 \text{ MW}$$

Torques from NNBI

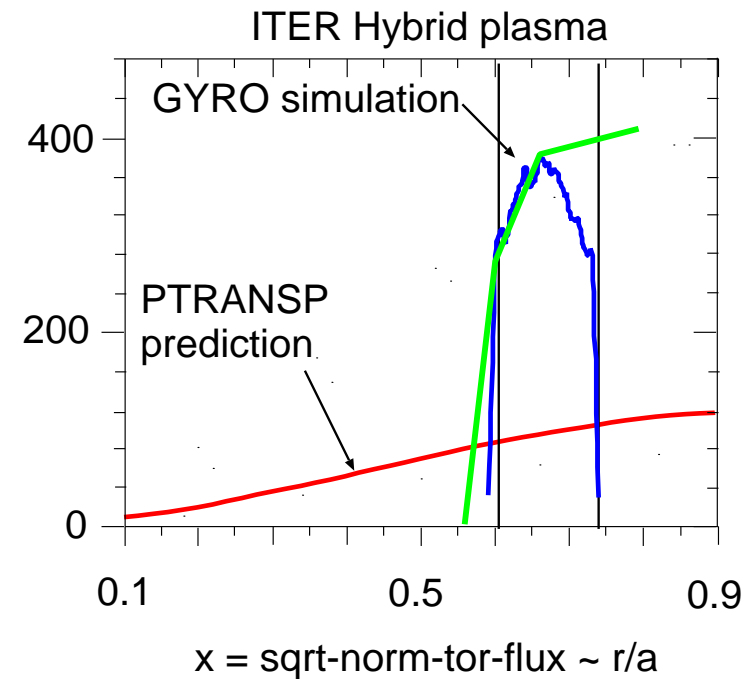
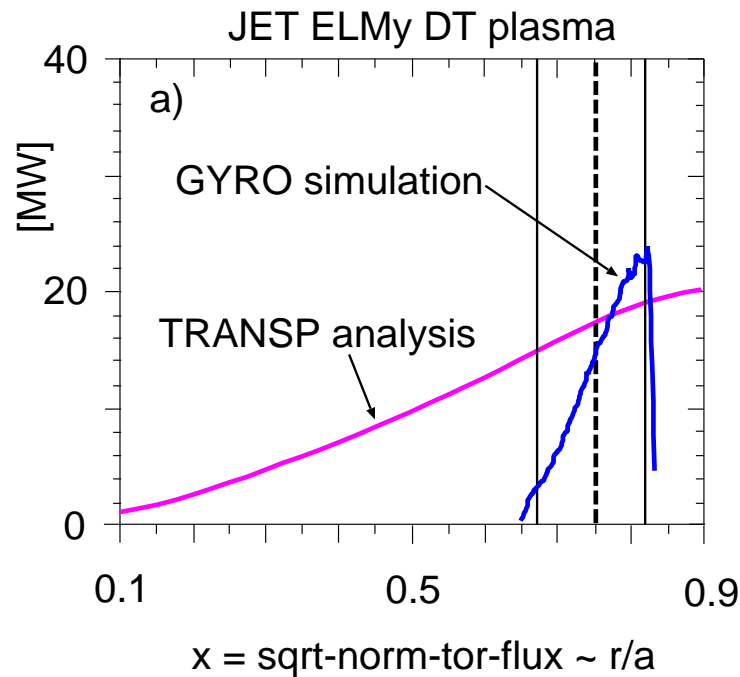
# Compare $E_r$ in JET DT ELM<sub>y</sub> and ITER Hybrid plasma

- $E_r$  predicted for ITER Hybrid less than JET ELM<sub>y</sub> by factor of 3
- $E_r$  dominated by  $v_{tor}$  term



# Nonlinear GYRO simulations predict energy flow rates

- Agreement for the JET DT ELMy H-mode (with  $\nabla(E_r)$  reduced 10%)
- Factor of 3 too high for ITER Hybrid



## Discussion of gyrokinetic simulations

---

- Want to close the loop: GYRO  $\Rightarrow$  GLF23  $\Rightarrow$  TSC  $\Rightarrow$  TRANSP  $\Rightarrow$  GYRO
- EPS 2005 paper on GYRO nonlinear simulations of JET and DIII-D ELMy plasmas
  1. Energy, momentum, and electron species flows depend sensitively on  $\nabla(T_i)$  and  $\nabla(E_r)$
  2. Slight changes get approximate agreement for energy flow in 3 out of 4 plasmas studied
- Also find strong sensitivity to  $\nabla(T_i)$  in ITER
- For ITER Hybrid get  $\Gamma_E$  higher than TRANSP result by  $\times 3$  for  $r/a \simeq 0.7 - 0.8$
- Find turbulence suppressed for  $r/a \leq 0.6$
- Plan to explore sensitivity to  $\gamma_{E \times B}$
- Plan GYRO runs with more than 2 ion species to explore D, T, ash, and impurity transport

# Plans for Integrated Modeling using PTRANSP

---

- New PPPL - Lehigh - GA - LNL Collaboration
- Planned near-term upgrades to TRANSP
  1. Ability to stop, steer, and restart
  2. Free boundary adjusted by varying coil currents
  3. Improved temperature predictive capabilities
  4. Improved Verification and Validation
- Planned long-term upgrades to TRANSP
  1. Scrape-off model
  2. density prediction

- The TSC-TRANSP codes have been used to prototype time-dependent integrated modeling of burning plasmas
  1. Steady-State, Hybrid, and ELMy H-mode ITER plasmas
- Moderate toroidal rotation estimated from NNBI if  $\chi_\phi \simeq \chi_i$
- TAE activity is predicted for ITER
- High pedestal temperatures required by the GLF model in TSC
- ash accumulation modeled for various transport assumptions
- Upgrade (PTRANSP) in progress
- Nonlinear GYRO runs simulated energy, momentum, and electron flow in ITER



## Work needed

---

- Continued PTRANSP collaboration important for integration of more physics
- Submit more ITER plasmas to ITPA profile database
- Gyrokinetic studies
  1. verification and validation
  2. assess need for rotation
  3. predict particle transport