Methods for Modeling Burning Plasmas and Validation using TFTR and JET DT Plasmas

APS, Denver, October, 2005

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and the TFTR and JET-EFDA teams

- Need reliable burning plasma predictions for successful fusion power
- Need methods to test and assess these predictions
- Gyrokinetic turbulence simulations offer the possibility of checking the predicted transport
- This talk describes time-dependent integrated modeling predictions of ITER plasmas, and GYRO gyrokinetic simulations of ITER, TFTR, and JET DT plasmas

Goals of this talk

- Describe progress in time-dependent integrated modeling of ITER plasmas
- Describe nonlinear gyrokinetic simulations using the GYRO code
- Assess the level of accuracy of GYRO assessment of ITER simulations by simulating DT plasmas from TFTR and JET
- Discuss ways to improve the gyrokinetic assessment of ITER predictions

Prototype Integrated Modeling using the TSC and TRANSP codes

TSC:

- evolves free boundary equilibrium
- evolves temperatures and densities
- assuming sources and transport models

↓ boundary
temperautres
densities

↑ heat sources
current sources

TRANSP:

- Monte Carlo for NNBI, fusion products
- LHCD, ICRH, ECH/ECCD
- neutrals

↓ plasma, current profiles
fast ion distributions

Down-stream Analysis

- MHD stability
- Microturbulence
- Fast particle modes
- Advanced heating/CD codes
- Advanced predictive codes

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ITER Plasmas studied

- Sawtoothing ELMy H-mode (Easy)
- Hybrid plasma: q(0) $\simeq$1.0-2.0, β_n (2-3) (Hard)
- Steady-State plasma: low current, fully non-inductive (Very Challenging)

units	I_p MA	I_{boot} MA	I_{nnbi} MA	I_{Oh}/I_p	$n_e(0)$ $10^{20}/m^3$	f_{GW}	$T_e(0)$ keV	P_{DT} MW	$\beta_\alpha(0)$ per cent
ELMy	15	2.7	1.1	0.7	1.1	0.80	22	403	0.6
Hybrid	12	3.3-5.6	1.5-2.1	0.4-0.5	0.8-0.94	0.64-0.93	24-30	333-528	0.7-1.0
Steady-State	9	4.3	4.3	0.0	0.68	0.63	33	305	1.3

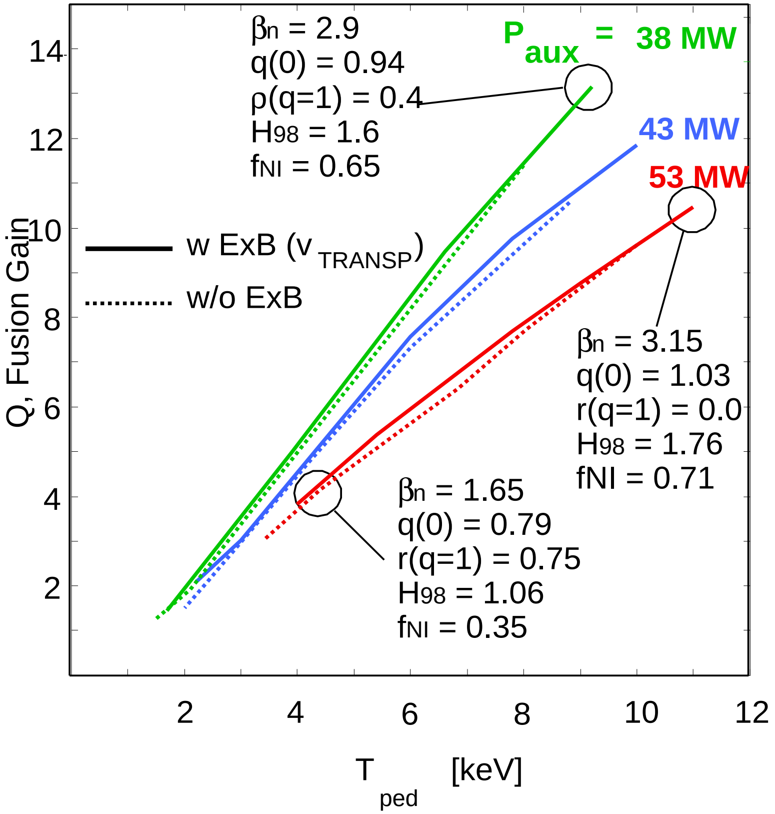
Examples of Findings for ITER

- ELMy H-mode from GLF23 (in TSC) with T_{ped} = 5.5keV, I_p = 15MA has $\beta_n \simeq 1.8, H_{98} \simeq 1.0, Q_{DT} \geq$ 10
- Hybrid plasmas with $\beta_n \geq 3$ require high pedestal temperatures using GLF23 and the auxiliary heating planned for ITER
- Good NNBI penetration and current drive
- Modest toroidal rotation from NNBI torques if $\chi_{mom} \approx \chi_i$
- modest E_r and very small flow shearing rates
- Intense TAE activity predicted in some regimes

High pedestal T_i needed for high performance

- Hold P_{NNBI} = 33MW for max CD, adjust P_{ICRH} to achieve β_n

Predictions using a flat n_e



GLF23
ρ(ped) = 0.9
P(aux) = P(NNBI, 33 MW) + P(ICRF, 20 MW)
$n_{20}(0)$ = 0.93 /m3
$n(0)/\langle n \rangle$ = 1.05
I_p = 12.0 MA
Z_{eff} = 2.2 (2% Be, 2% C, 0.12% Ar)
$\tau_{He} = 5\ \tau_E$

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- Find degraded performance with peaked n_e due to increased χ from GLF23

GYRO runs

- The GYRO Gyrokinetic code is thought to contain all the physics needed to understand ITG / TEM turbulence
- calculates time evolution of distribution fun'n of each species in 5D
- 2 ion species: 1) bulk hydrogenic, 2) lumped beam and impurity
- ITG/TEM with kinetic electrons ($k_\theta \rho_s < 1.0$)
- linear runs to study spectra in $k_\theta \rho_s$
- nonlinear runs to simulate transport and $\tilde{n}_e / n_e$
- include effects of E_r and Kelvin-Helmholtz ($v_{||}$) instability
- only electrostatic ($\beta_e = 0$) so far
- massive parallel processing (128-512 processors)

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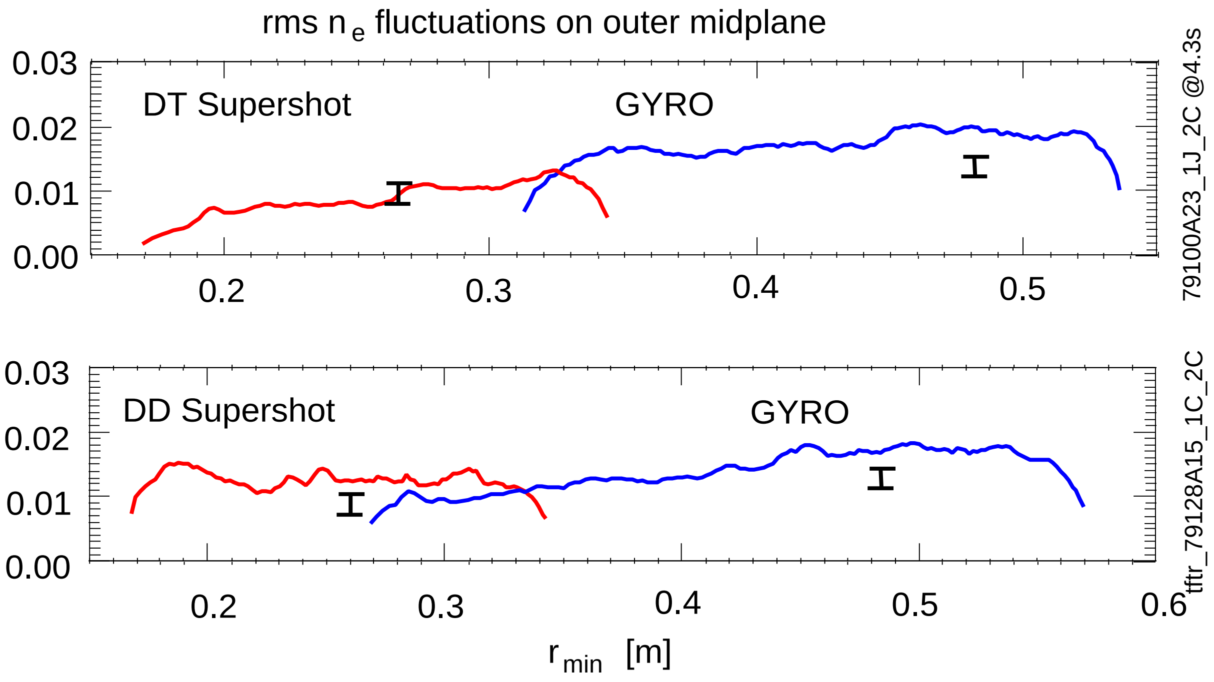
Nonlinear GYRO simulations of TFTR supershots

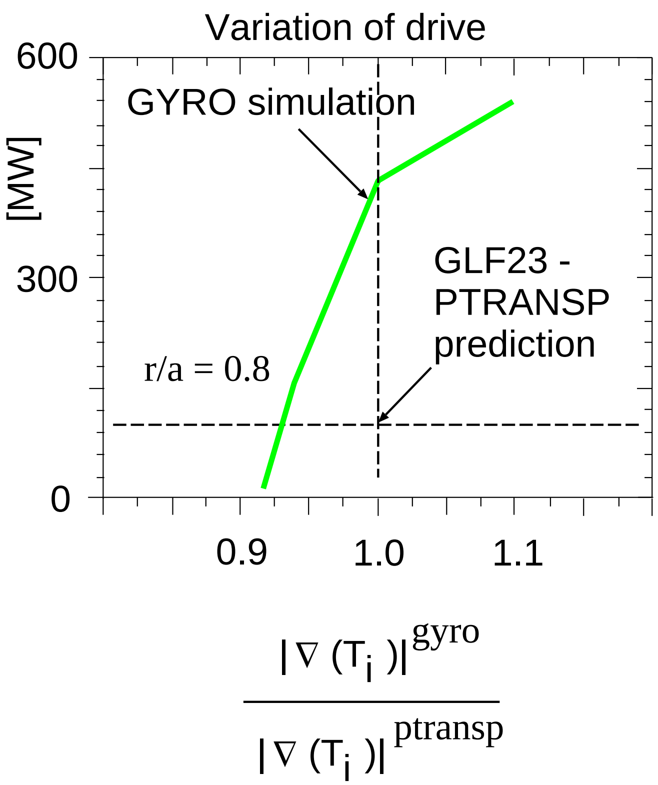
- TFTR DT supershot (and DD isotopic sister)
  1. Approx agreement with measured RMS $\tilde{n}_e$ fluctuations and correlation lengths
  2. But predicted energy flow 10x higher for DT and 3X for DD than TRANSP energy balance

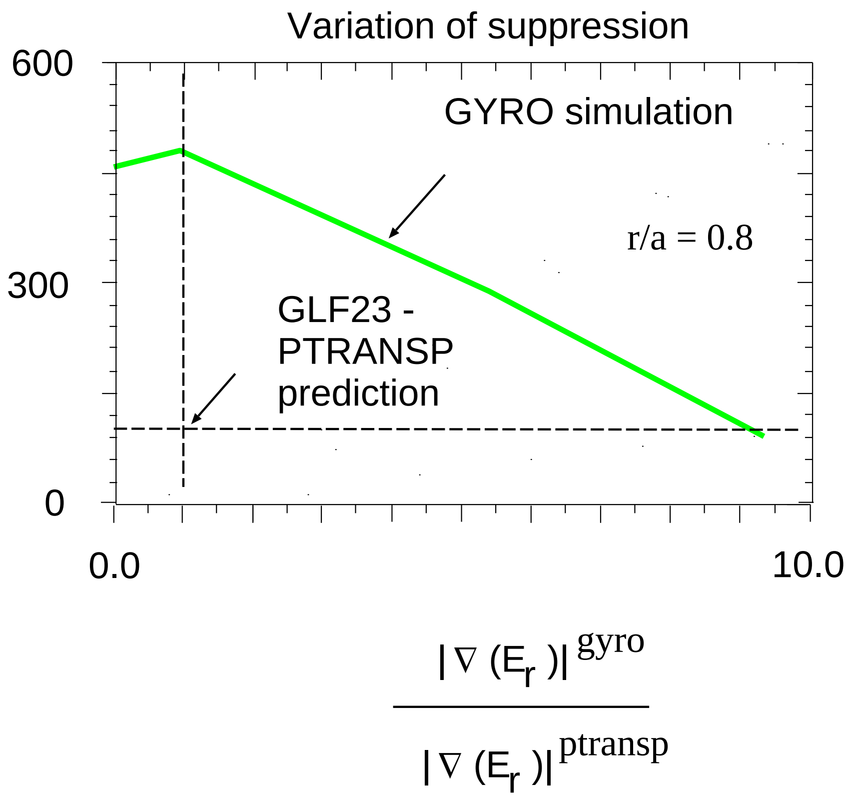


Reflectometry measurements from Mazzucato EPS '95

Sensitivity of GYRO simulations for ITER

- GYRO predicts energy transport too high near pedestal, too low in core
- Strong sensitivity to $\nabla(T_i)$
- Adjust $\nabla(E_r)$ to look for turbulence quench



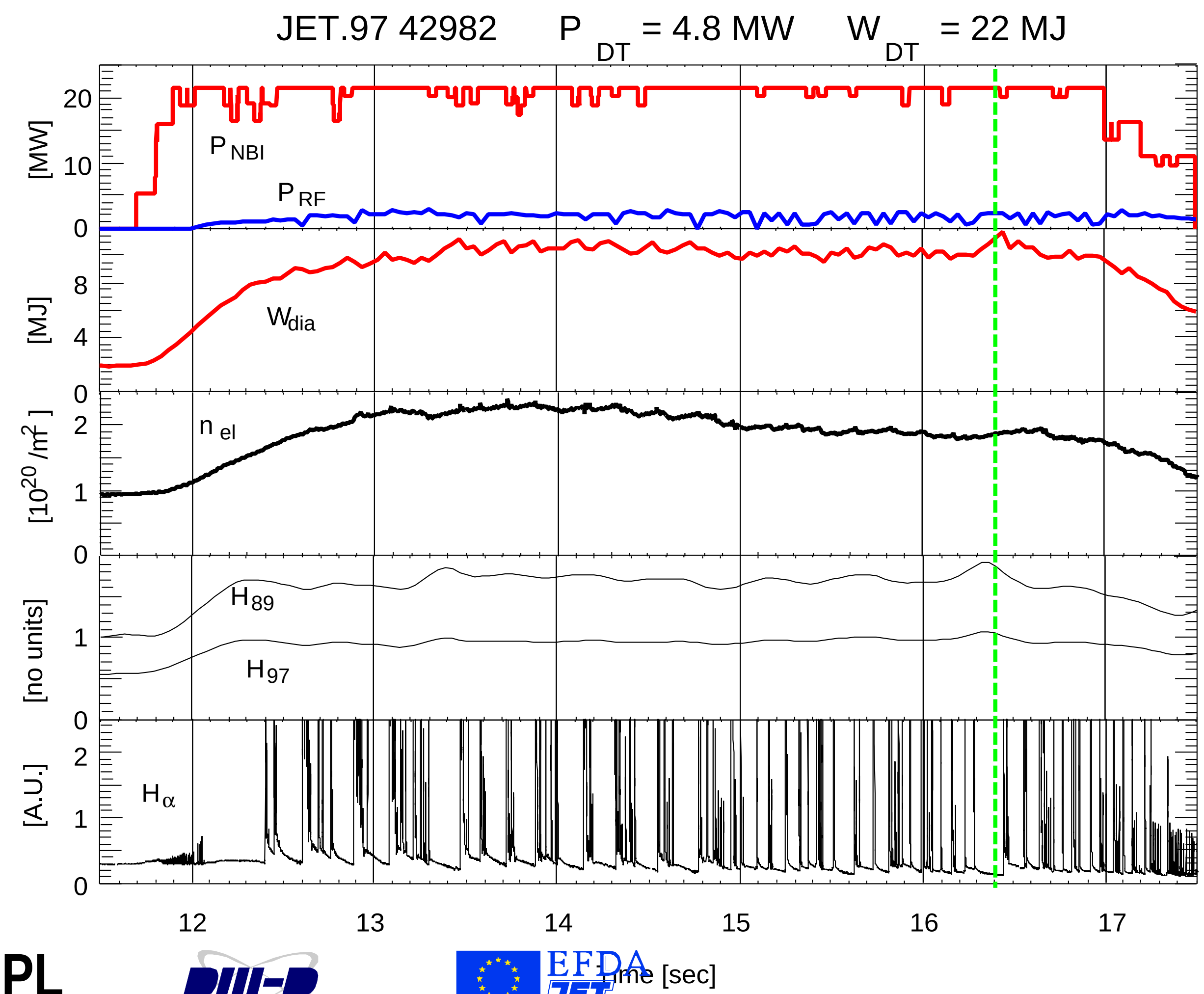


Discussion and Summary

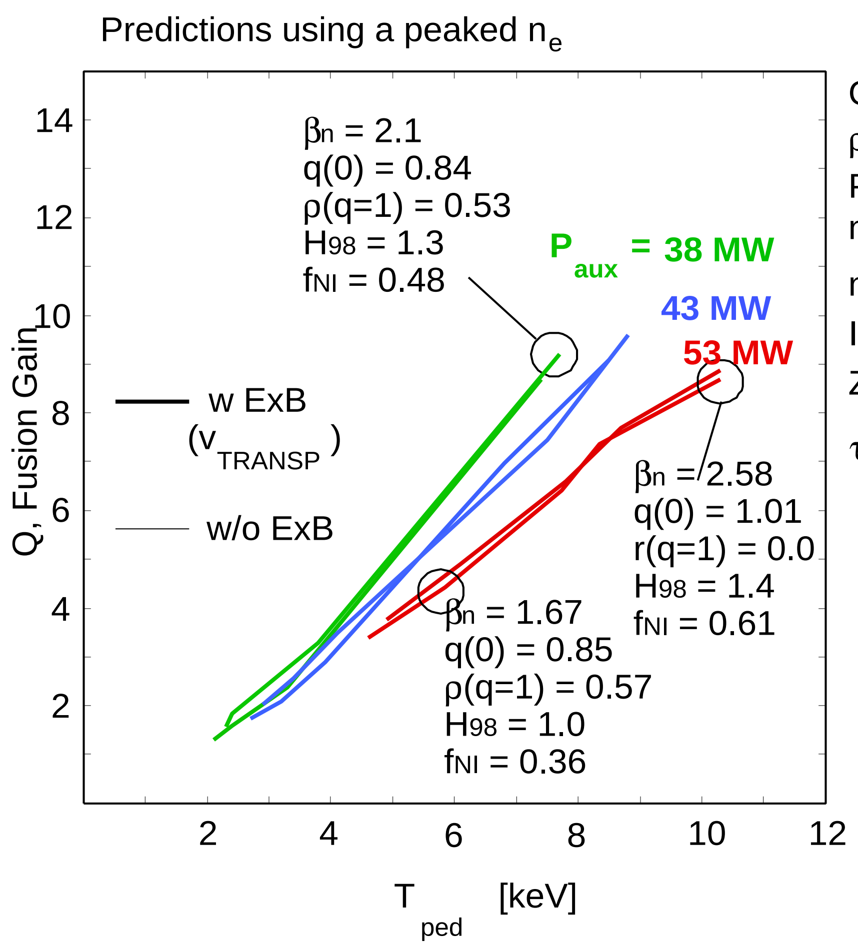
- Time-dependent integrated models of ITER ELMy and Hybrid plasmas have been archived in the ITPA profile database
- Very high T_{ped} appears needed for by GLF23 for ITER Hybrids with $\beta_n \geq 3$
- Scaling of transport with $\nabla(E_r)$: 10x more than expected is needed to quench transport
- Need to close the loop: GYRO $\Rightarrow$ GLF23 $\Rightarrow$ TSC $\Rightarrow$ TRANSP $\Rightarrow$ GYRO
- But find up to x10 differences between GYRO and energy flow rates
- Therefore more work needed to use gyrokinetic analysis to check ITER predictions
  - Problem: energy, momentum, and species flows depend sensitively on drive and suppression terms
  - Need to refine GYRO analysis (EM?, more kinetic species?)
  - Need to improve GYRO to predict temperatures from fluxes

The End

JET ELMy H-mode DT plasma



Degraded performance with peaked n_e



GLF23

$\rho(ped) = 0.9$

P(aux) = P(NNBI, 30MW) + P(ICRF, 20 MW)

$n_{20}(0) = 1.12$

$n(0)/\langle n \rangle = 1.30$

$I_p = 12.0$ MA

$Z_{eff} = 2.2$ (2% Be, 2% C, 0.12% Ar)

$\tau_{He} = 5\,\tau_E$

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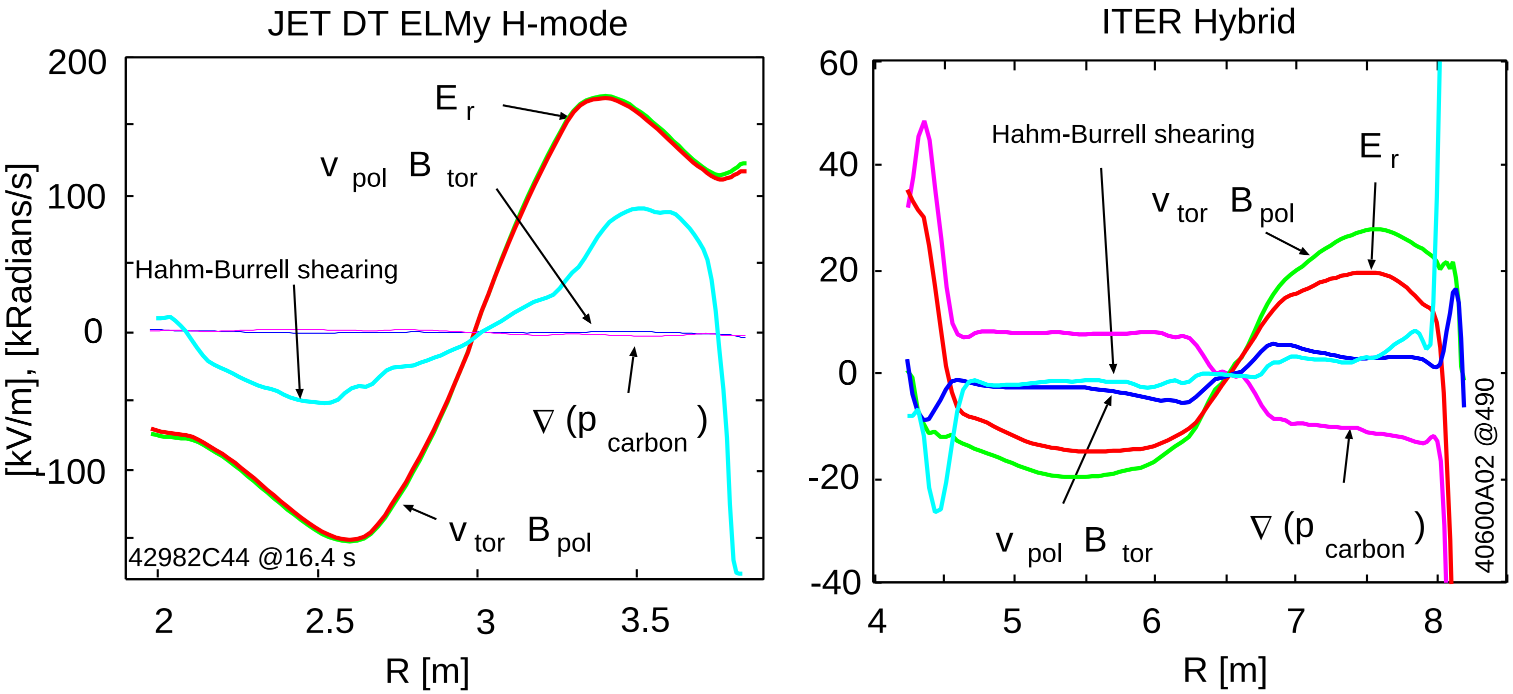
Modest E_r predicted in ITER high β_n hybrid

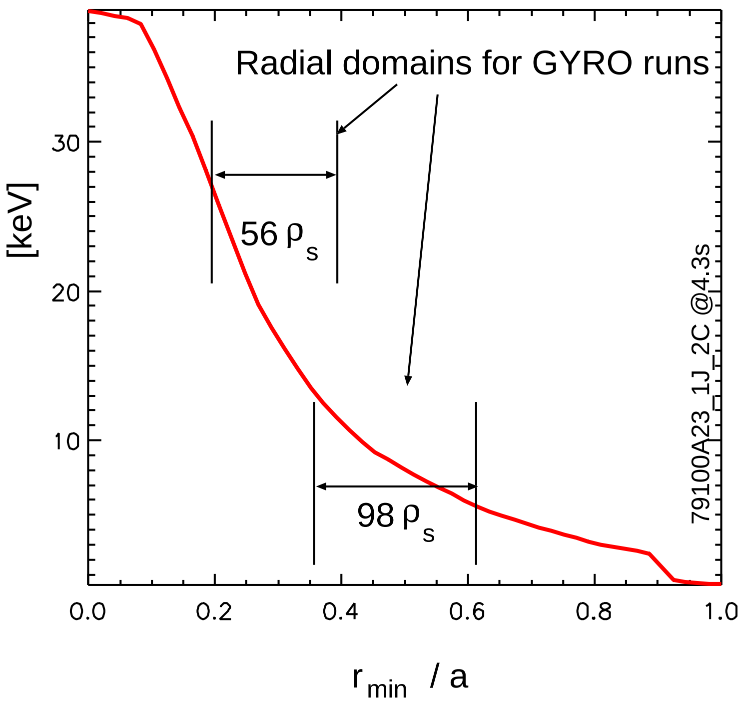
- E_r predicted for ITER Hybrid less than JET ELMy by factor of 7
- E_r dominated by v_{tor} term



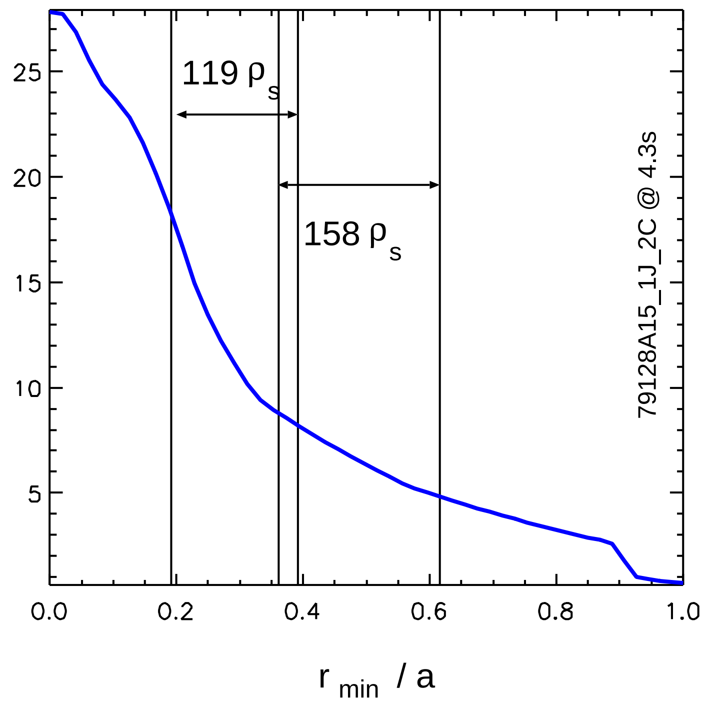
Compare a TFTR DT and DD supershot

- Equal P_{NBI} but different T_i due to isotopic effects

Input T_i profile for TFTR DT supershot



Input T_i profile for TFTR DD supershot



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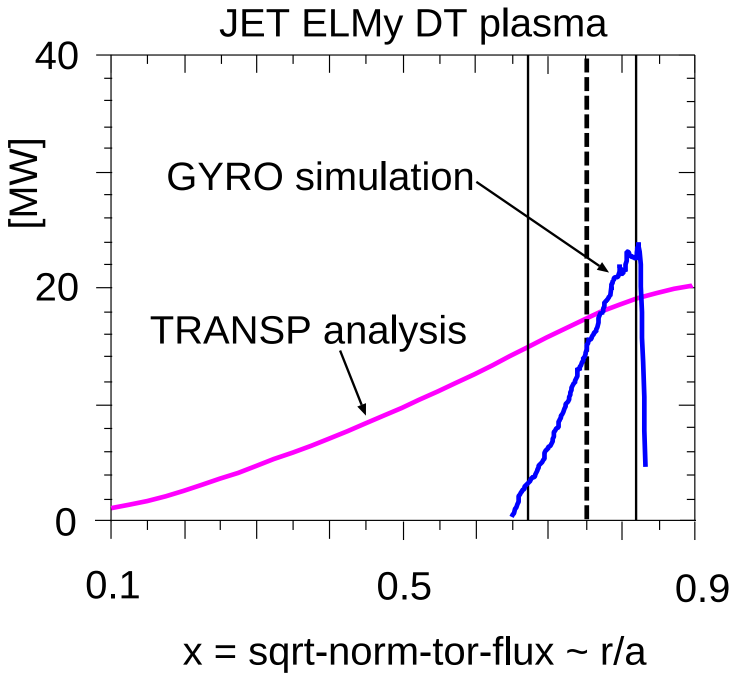
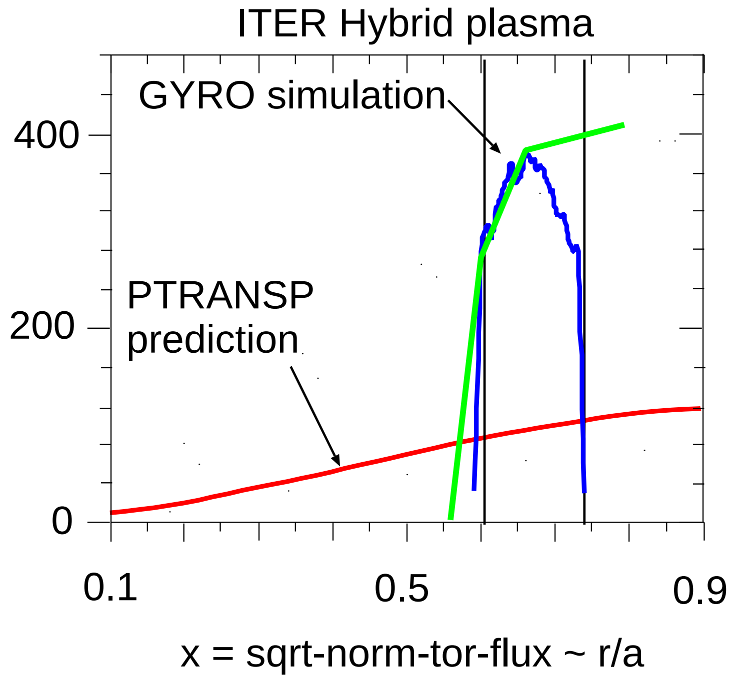
Nonlinear GYRO simulations predict energy flow rates

- Agreement for the JET DT ELMy H-mode with $\nabla(E_r)$ reduced 10%
- Factor of 3 too high for ITER Hybrid at r/s $\geq$ 0.7





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