Time-dependent Integrated Predictive Modeling of ITER Plasmas

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- **Outline**

  1. **Motivation**
  2. **pTRANSP (predictive TRANSP)**
  3. **Examples of ITER plasmas**
  4. **Developments and efforts to Validate and Verify**

Motivation

- **Need accurate modeling of ITER plasmas**
  1. Estimate performance
  2. Aid in design of systems
  3. Investigate plasma regimes
  4. Data for Theory
- **Need time-dependent modeling**
  1. Successful startup, control, and termination
- **Need integrated modeling**
  1. Strong nonlinear couplings in burning plasmas

Integrated modeling using the TRANSP and TSC codes

- **TSC to sketch the plasma**

  1. Free boundary consistent with control circuits
  2. Temperature predictions, ex from GLF23
  3. Feedback on desired plasma performance

- **TRANSP for more detailed study**

  1. multiple plasma species n_j with Maxwellian T_j
  2. variety of heating and current drive packages
  3. distributions in energy and pitch angle for multiple fast ion species

- **Iterate TRANSP heating and current sources back to TSC**

Modules available for modeling

- **Suite of equilibrium solvers**
- **Power deposition, current drive, and torque**

  1. **Monte Carlo alpha heating and NNBI (NUBEAM)**
  2. **low harmonic ICRH with TORIC or SPRUCE**
  3. **high harmonic RF with CURAY**
  4. **ECH/ECCD with TORAY-GA**
  5. **LHCD with LSC**

- **Predictive models**

  1. **GLF23, MMM, neoclassical, etc**

Applications to ITER

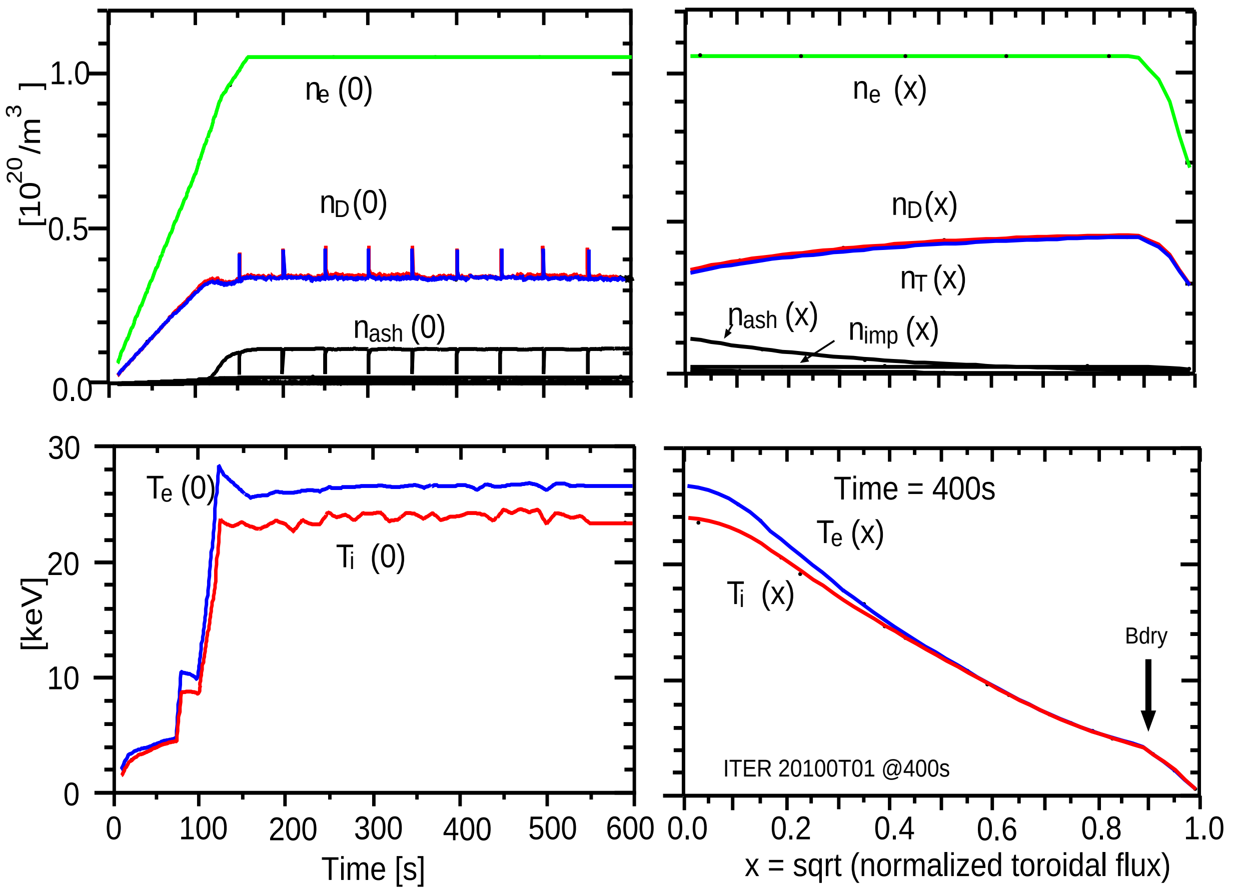
- **Plasma regimes studied**
  1. **Standard ELMy H-mode $I_p = 15$MA**
  2. **Hybrid Scenario with reduced $I_p \simeq 12$MA**
  3. **Steady State Scenario with $I_p \simeq 9$MA**
- **Providing ITER plasmas to the ITPA profile database**
- **Code benchmarking**
- **Improving design of ITER systems**
- **checking consistency of diagnostics**
- **bridge to theory**
  1. **inputs to MHD, TAE, microturbulence codes**

Modeling outputs of interest

- Power densities such as $P_{ICRH}(x, t)$
- Current densities and q-profile
- $f_j(x, t, E, pitch - angle)$ for each fast ion species
- predictions of NNBI plasma rotation and current drive
- sawtooth mixing
- He ash accumulation
- ripple loss estimates

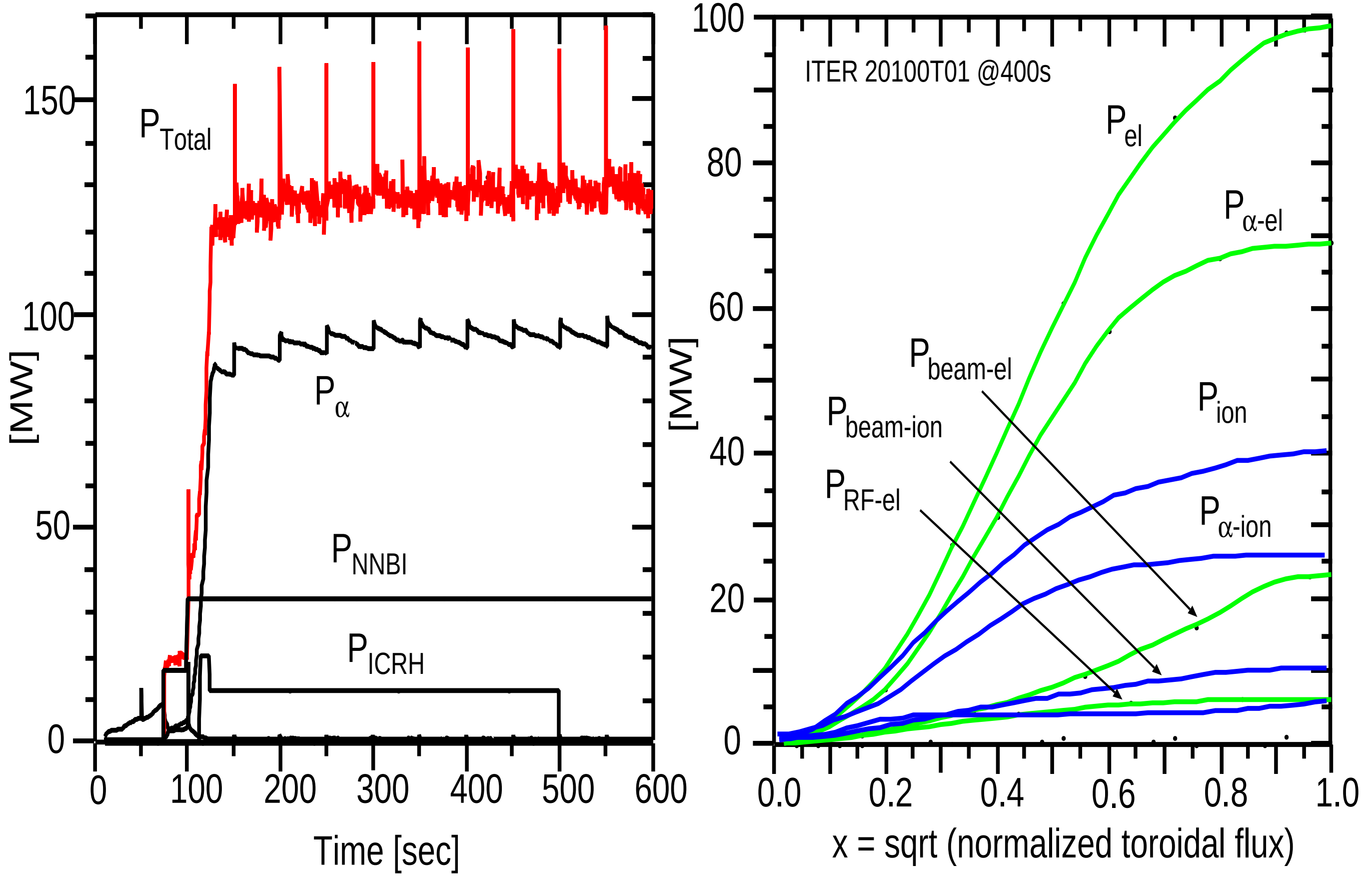
Standard ITER ELMy plasma (Scenario 2)

- **Assume electron density, GLF23 for temperatures**



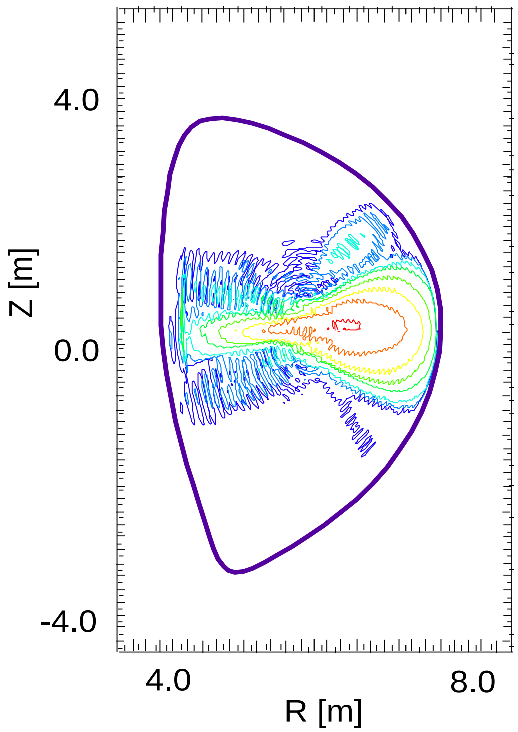
Rampup plasma to steady state

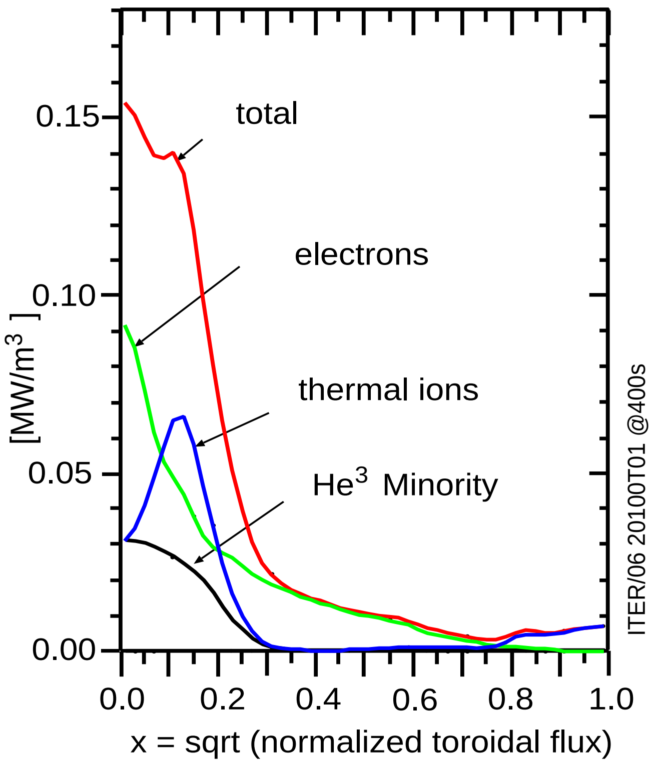
- **Adjust control coils to maintain steady state**



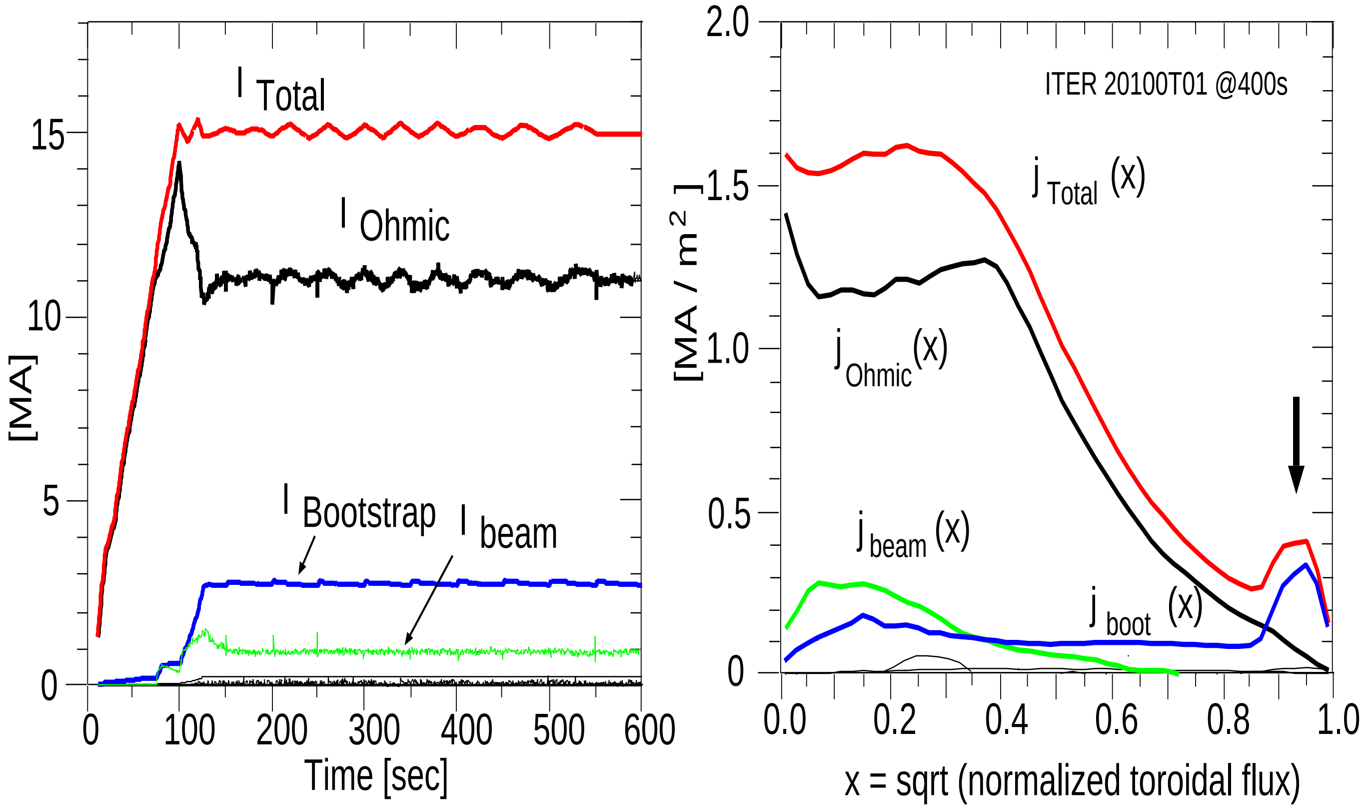
ICRH computed with TORIC

- **TORIC better than SPRUCE**



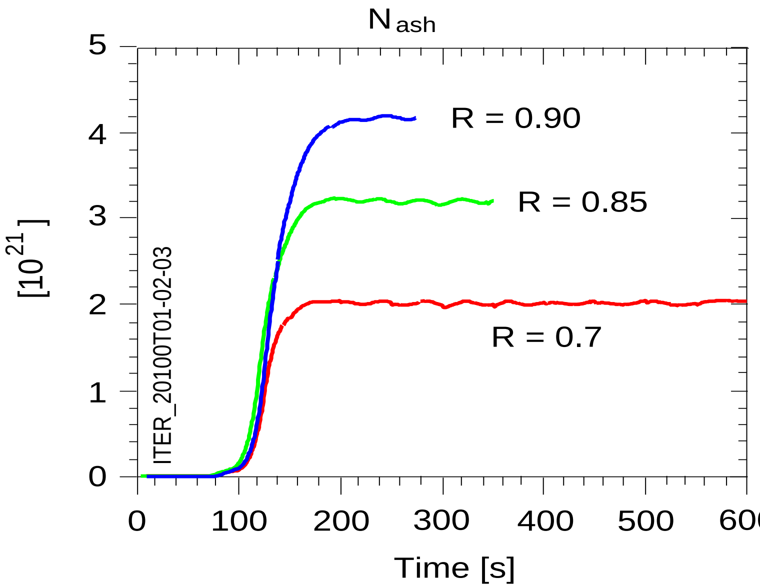


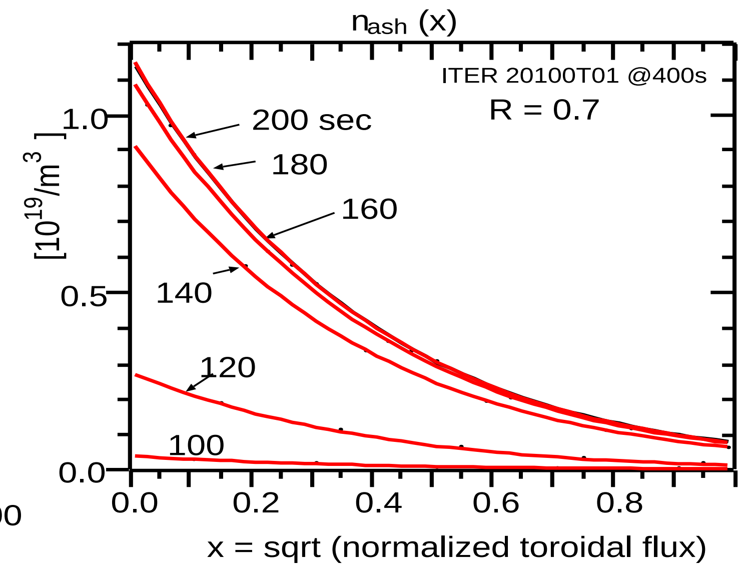
Plasma currents



Alpha ash modeling

- **Sensitive dependence of ash profile on recycling**





Sources

He^4 thermalization

Ash recycling = R

Transport

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

$D = 1.0\ m^2/s$

$V = -1.0\ m/s$

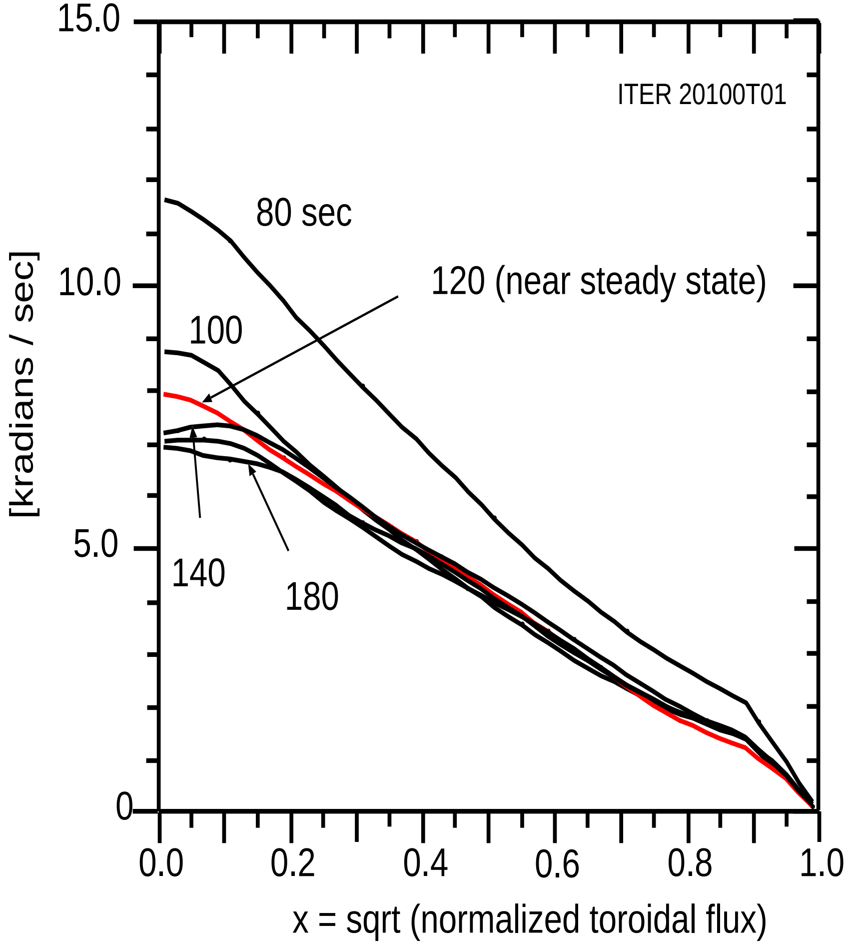
Confinement if R=0.7

$\tau_{He^4} = 3.6$ s

$\tau^*_{He^4} = 12$ s

Predict toroidal rotation

- **Rotation profile important for avoiding Resistive Wall Modes**



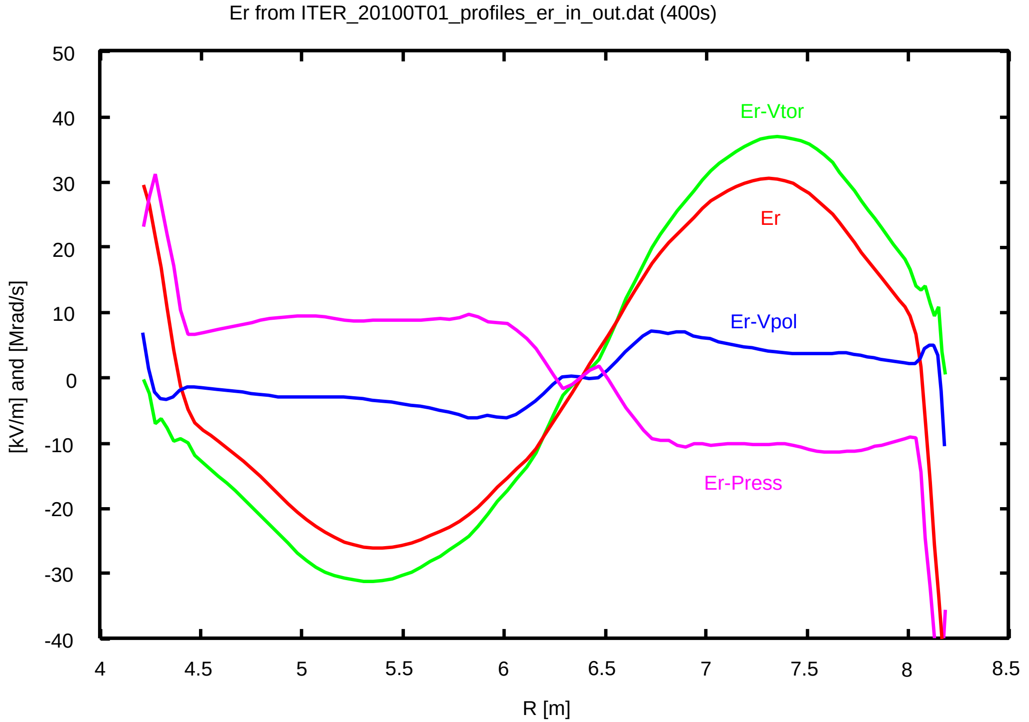
Assume:

Torques from NNBI

$\chi_{momentum} = \chi_{ion}$

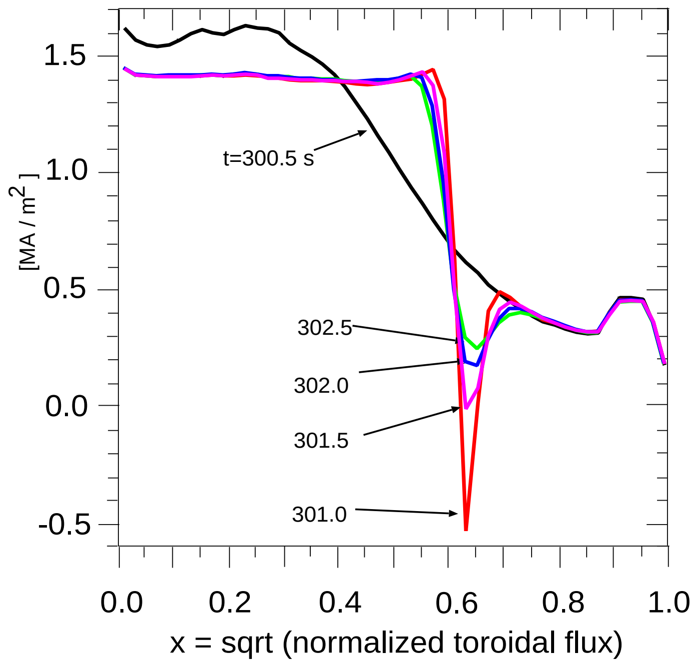
Radial electric field from force balance

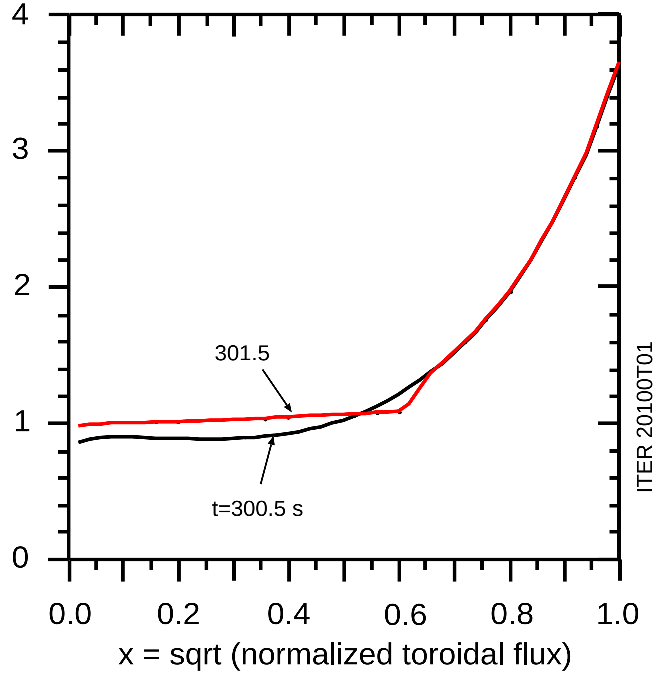
- E_r profile important for flow shear
- (flow shear $\propto \nabla(E_r)$)
- peak E_r similar to those in JET
- core flow shear much lower



Effects of sawtooth mixing

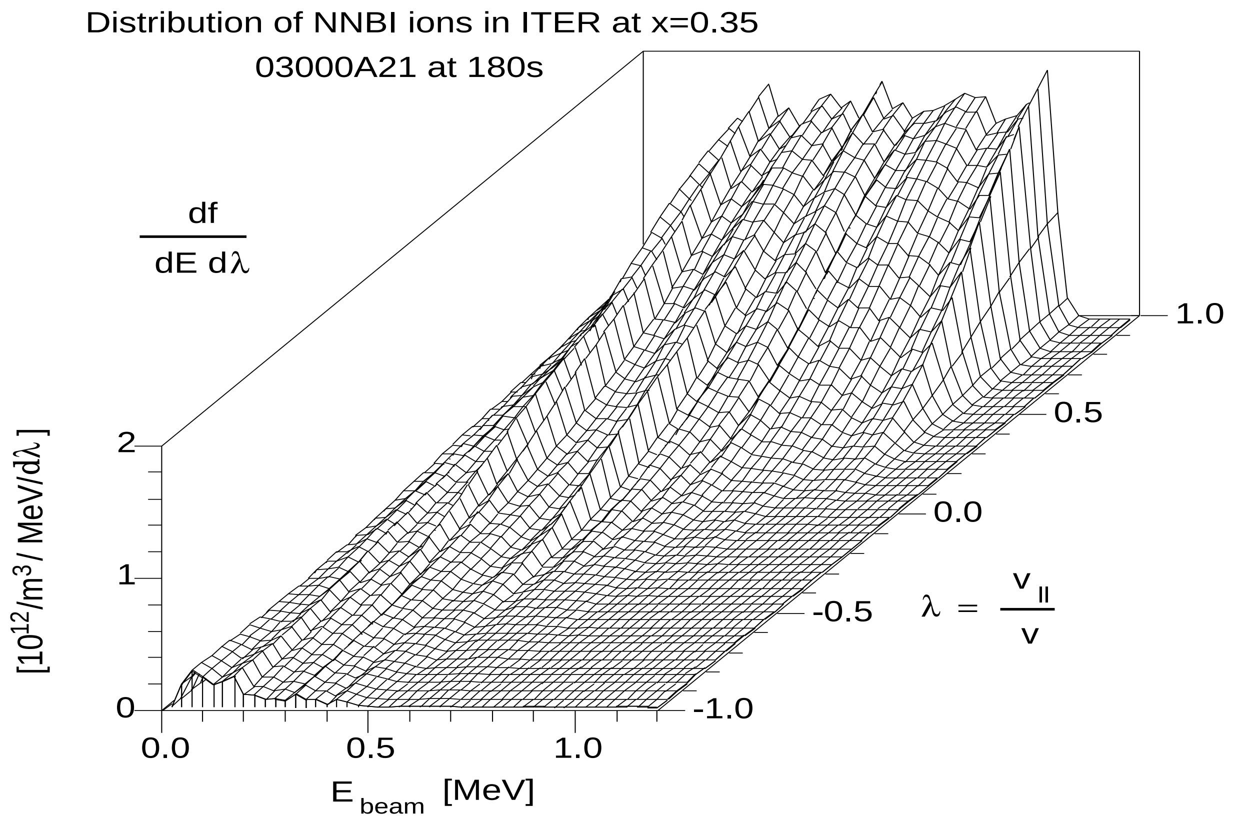
- **Assume Kadomstev mixing**
- **Infrequent sawteeth ⇒ large inversion radii**





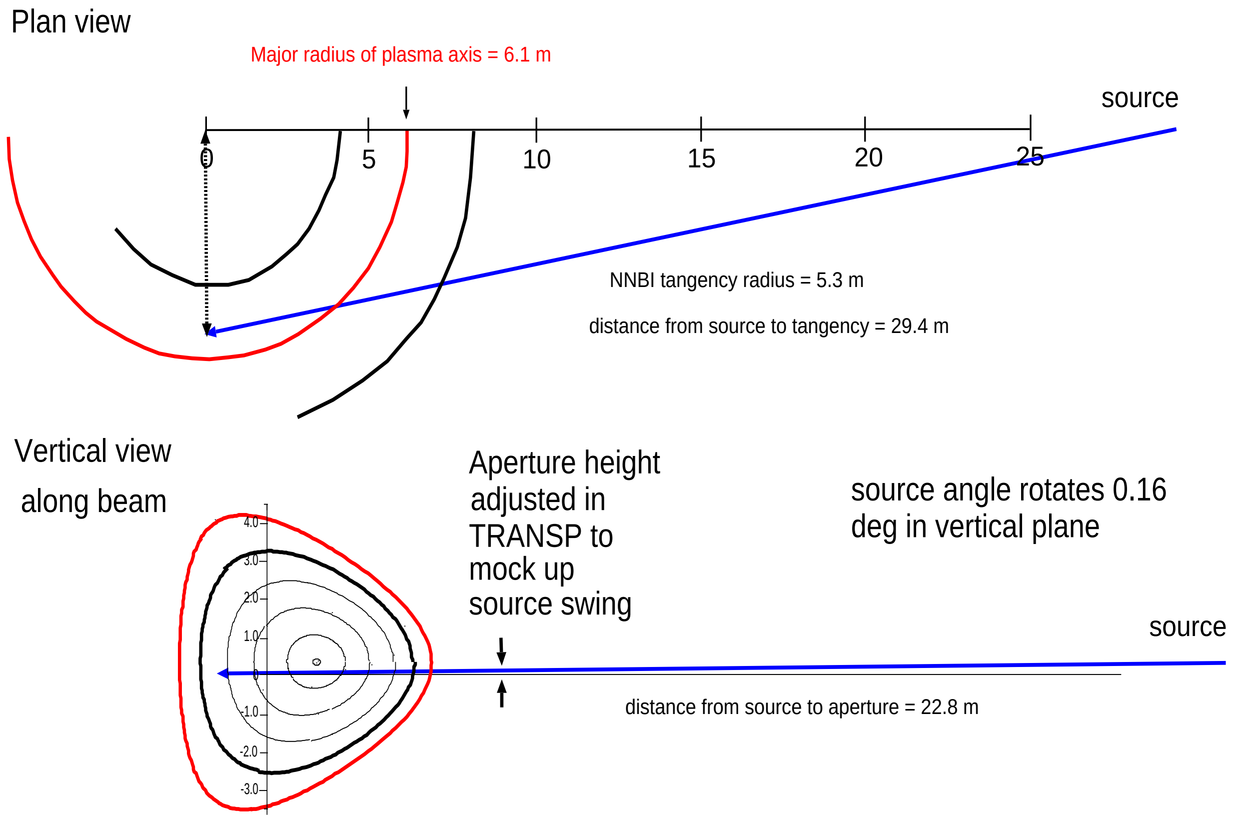
Distribution functions of fast ions

- **Computed using Monte Carlo techniques**
- **Important for TAE, MHD, sawteeth, etc**



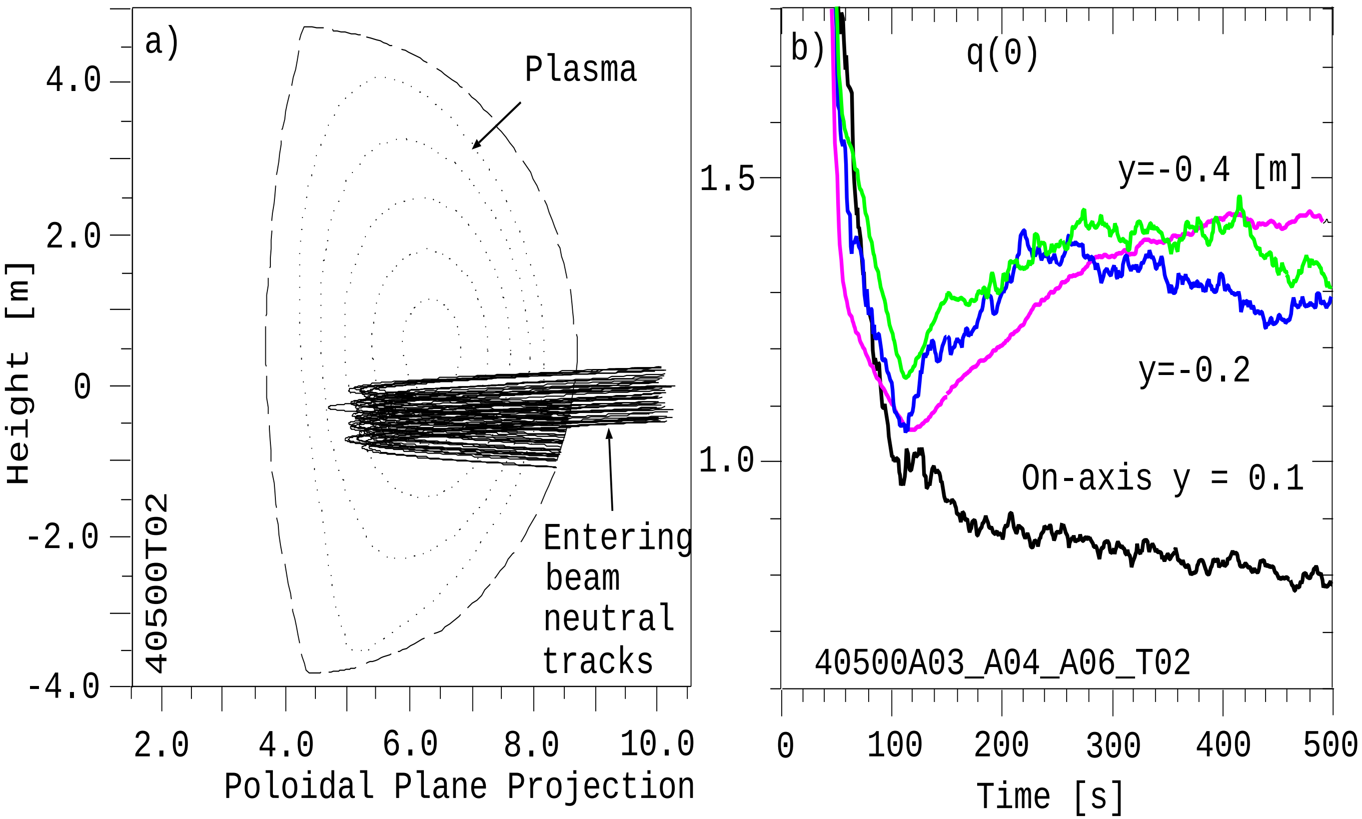
Schematic of planned NNBI aiming

- **capability to rotate NNBI sources vertically**



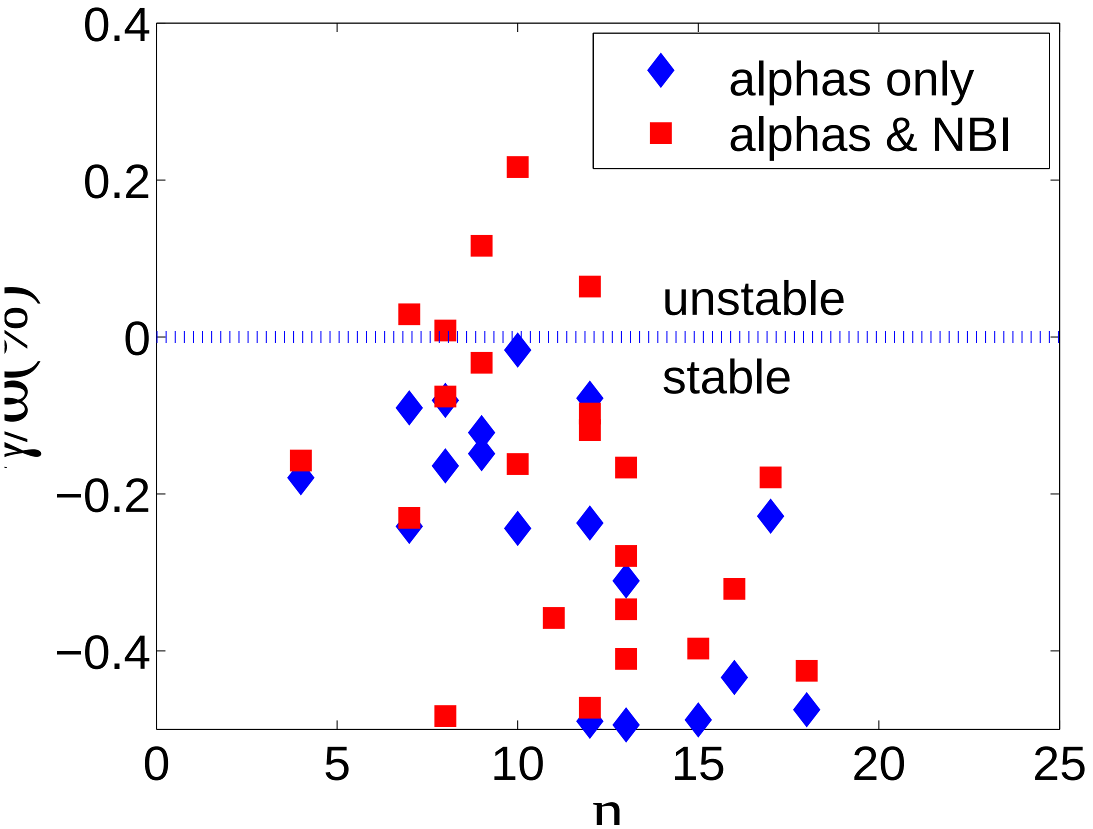
Below axis aiming ⇒ q(0) above unity in Hybrid plasmas

- Important for controlling q profile
- good news for chances of Hybrids in ITER



Application to TAE instability

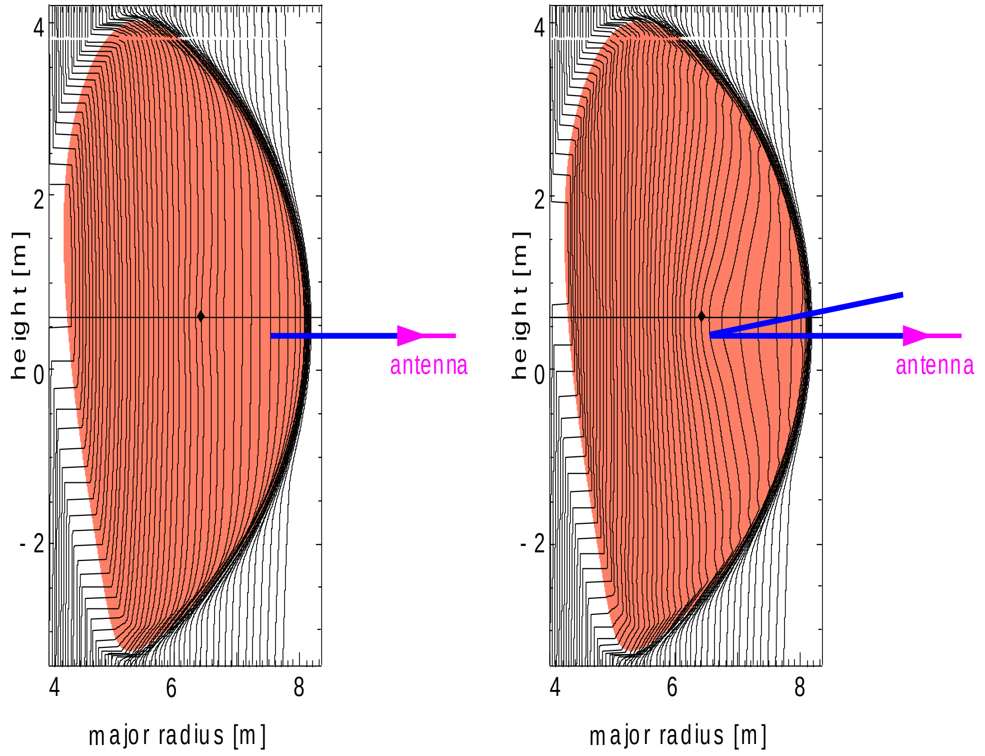
- **Important NNBI contributions to TAE instability**



Design of reflectometry diagnostic

• Relativistic effects in microwave scattering

microwave propagation for reflectometry in hot ITER plasma

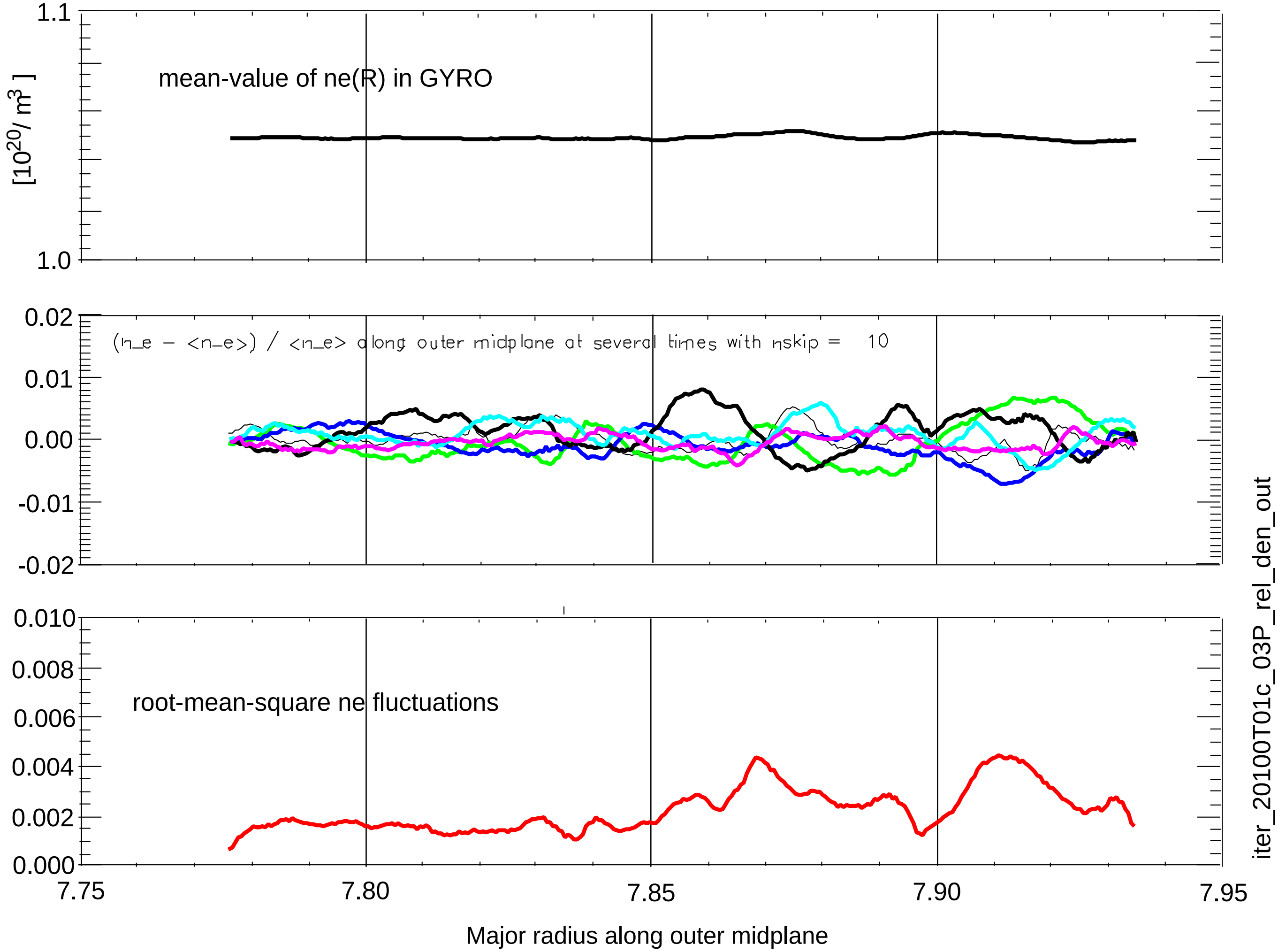


low electron temperature (5 keV)   high electron temperature (25 keV)

G.J. Kramer et al. to appear in Nuclear fusion August 2006

Gyrokinetic prediction of electron density fluctuations

- **GYRO results using 3D space + 2D phase space**



Improvements to the TRANSP / TSC tools (pTRANSP)

- **Near-term goals (within year)**
  1. robust solvers of stiff predictive models (GA, PPPL)
  2. robust fixed / free equilibrium solvers (LLNL, Tech-X)
  3. NTM model (Lehigh)
  4. pedestal model (Lehigh)
  5. improved sawtooth model (PPPL, Lehigh)

- **Long-term goals**
  1. density prediction
  2. scrape off
  3. parallelization of Monte Carlo fast ion package
  4. Monte Carlo ICRH

Collaboration possibilities

- The TRANSP / TSC codes have powerful capabilities for predicting and simulating ITER plasmas
- Intensive program for improvements (pTRANSP)
- collaborations are welcome

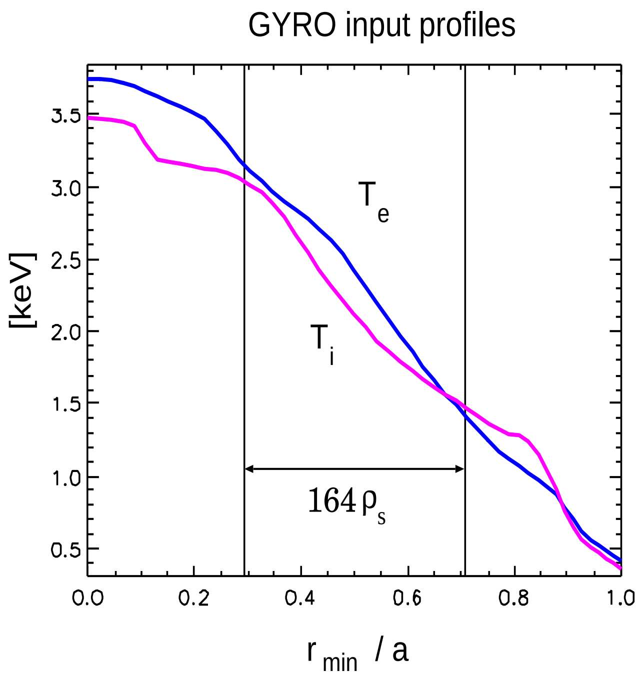
1. open sources of code
2. possible to run codes via the FusionGrid
3. modules in the NTCC code library
4. potentials for long term visitors at PPPL

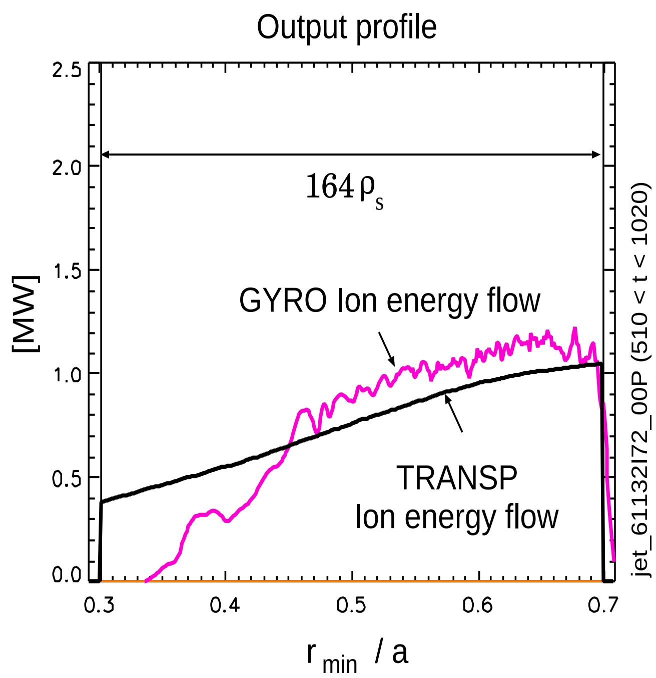
Recent work since Beijing talk

- **How to validate ITER predictions?**
  1. **Best predictions from GLF23, MMM, etc**
  2. **Mixed success predicting present experiments**
  3. **Some physics effects important for ITER are not included**
  4. **e.g., shaping, multiple species**
- **How to improve:**
  1. **Test self-consistency of predictions with gyrokinetic calculations**
  2. **Use GYRO on ITER models**

Check GYRO validity in present plasmas

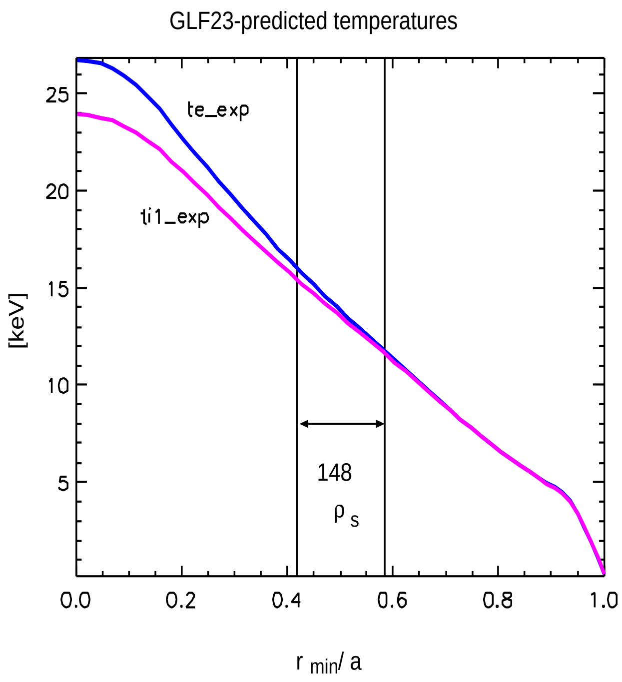
- nonlinear, 1-2 kinetic ion species, kinetic el's
- collisions, trapping, Electrostatic approx
- turbulence-driven ion energy flow $\simeq$ measurement in a JET H-mode plasma

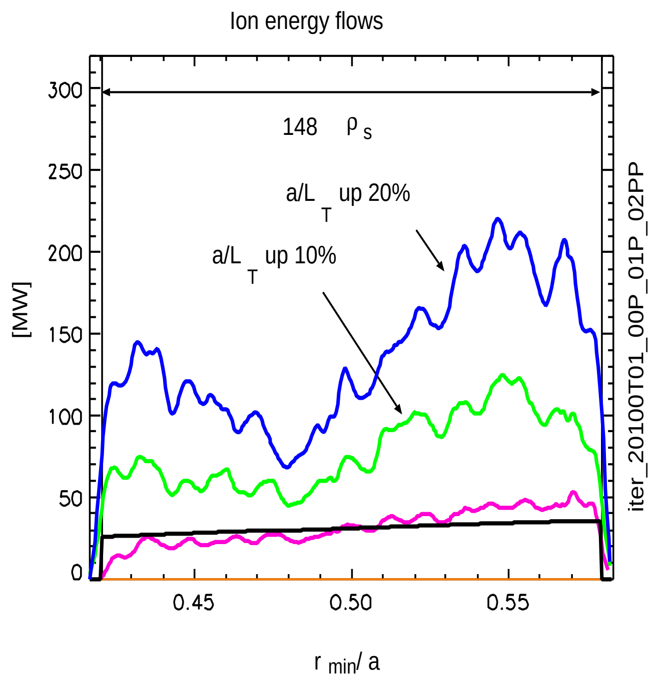




Use same GYRO procedures for ITER

- T_i close to marginal
- Need to adjust a/L_{T_i} to get self-consistent ion energy flow
- Increase a/L_{T_i} for small r/a, decrease for larger r/a
- suggests supershot-like T_i profiles





Conclusions

- **The TRANSP / TSC combination (pTRANSP) is a powerful tool for predicting ITER plasmas**
- **Much work is needed to substantiate these predictions**
- **Collaborators are welcome**