Optimization Results for Consistent Steady-State Plasma Solution

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GENERAL ATOMICS

Progress Made in Implementing Planned Self Consistent Simulation for ARIES-AT Baseline

- **Recent progress in implementing first steps:**
  - New ARIES baseline ACT 1 substituted for original 2006 ARIES
  - First simulation found collapse of temperature profile
  - Steady state found with large Ar reduction and increased density
  - Newest ACT 1b baseline obtained
    - Beginning simulation
- **Recent code improvements:**
  - Diagnostics implemented to diagnose individual species fluxes
  - Newest NFREYA Neutral Beam module included
  - GENRAY multiple ray option released in public version and IMFIT
- **Main Result:**
  - ACT 1 baseline density too low:
    - Profiles collapse
    - Increase density factor 1.85 prevents core collapse
    - Edge collapse only prevented so far by imposed boundary condition
- **Future plans**

Previous Progress Through June 2011: Pedestal and Transport Models Incorporated in 2006 ARIES Baseline

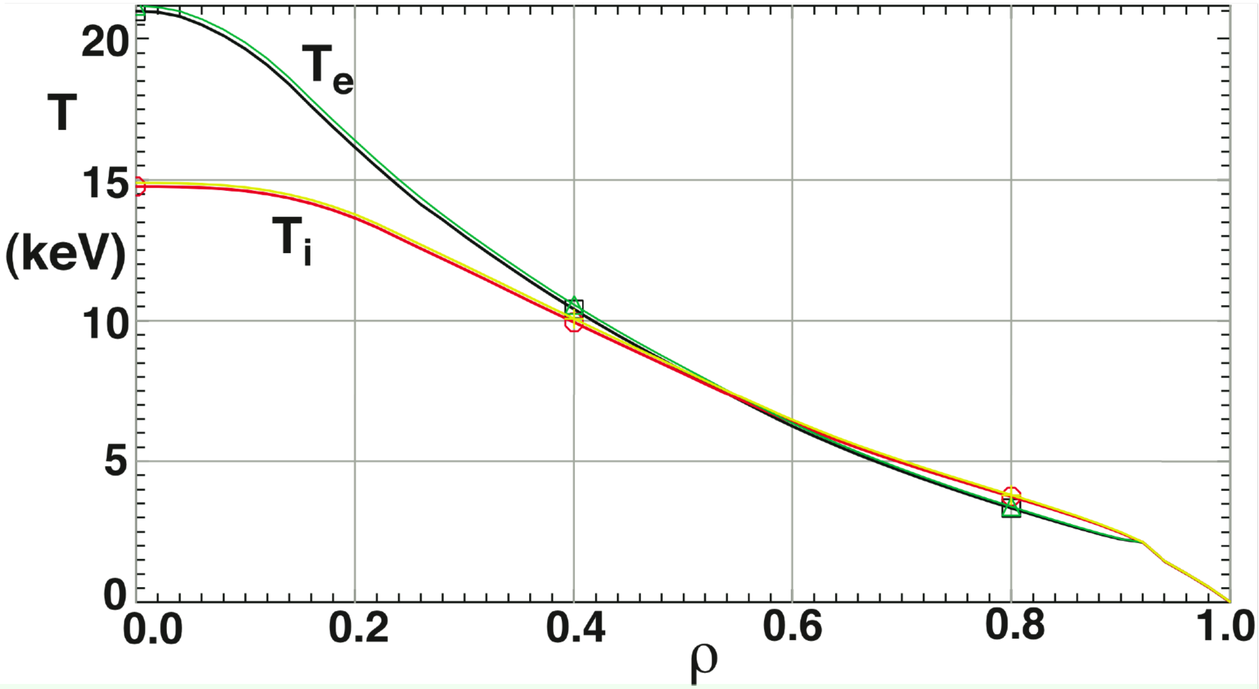
- **EPED1 pedestal model incorporated in profiles consistent with model for peeling-ballooning stability:**
  - Predicted H-mode pedestal height and width at ELM threshold
  - In place of the *ad-hoc* pedestal imposed on the published ARIES-AT base configuration
  - Pedestal β_N of 1.0 near $\rho = 0.93$
- **GENRAY code modified to allow multiple frequency waves launched from different launcher**
- **Self consistent transport simulation implemented:**
  - Initially using previous GLF23 model
  - Using TGLF model with real geometry
- **Main Result:**
  - Self consistent transport simulation using new TGLF model is significantly more pessimistic:
    - Unable to find steady state solution with TGLF due to profile collapse

Previous Results Obtained using GLF23 and TGLF Transport Models with Lower Hybrid Current Drive

- **Steady state result achieved using GLF23 after one second:**
  - Fixed density and RF heating profiles
  - Shifted circle geometry assumed by the GLF23 model

- **Steady state profiles using GLF23**

- **No steady state reached using more sophisticated full geometry TGLF model**



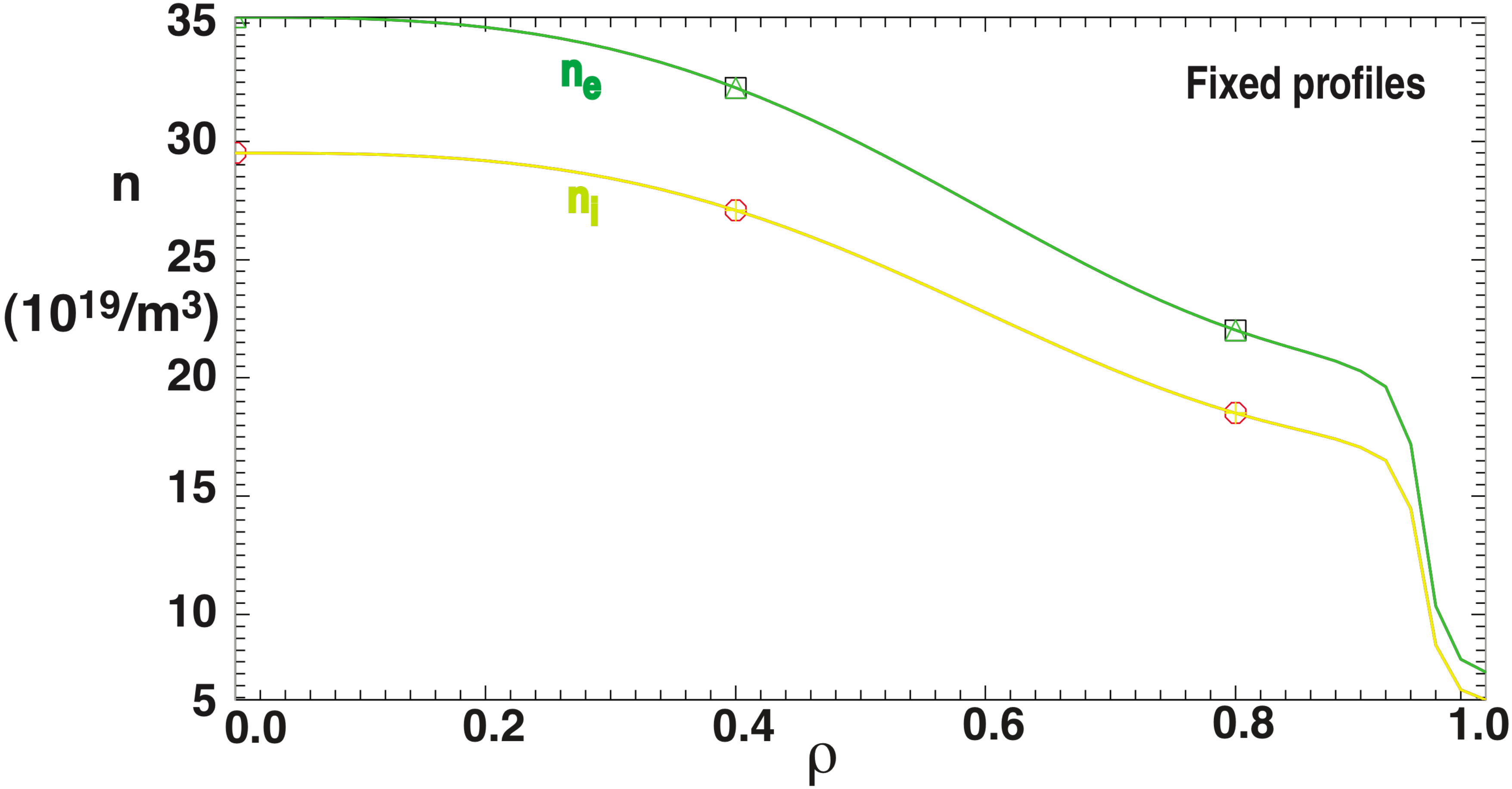
- **Next step is to reproduce this for the newest ARIES ACT 1 and ACT 1b scenarios**

Initial Simulation With New ARIES ACT 1 Found Collapse of Temperature Profile Using Initial Baseline Profiles

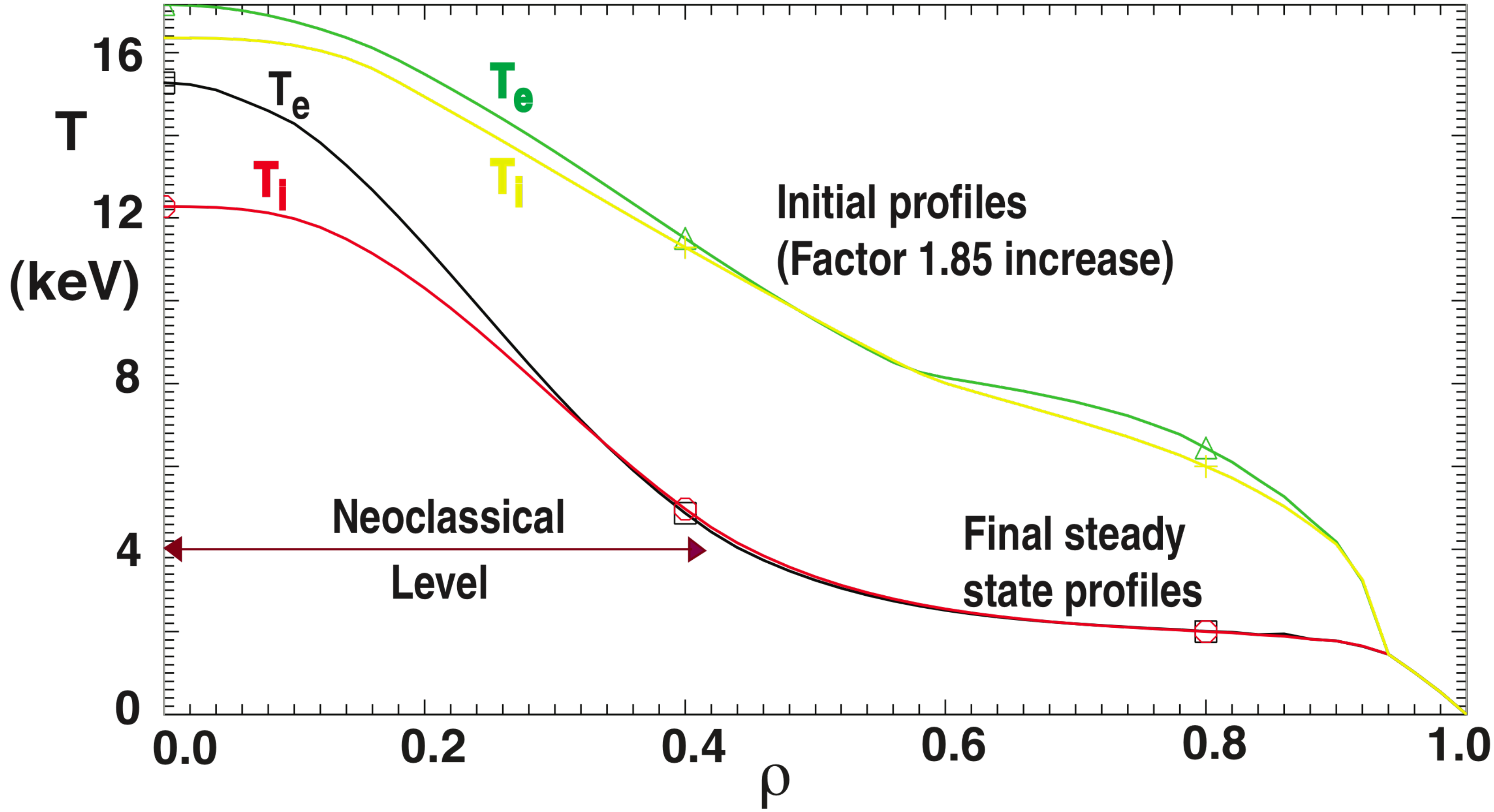
- **Profiles collapsed below the imposed boundary condition value on first simulation:**
- **Ar fraction reduced to 10% of original value to prevent complete collapse from core to edge boundary condition:**
  - Zeff ~ 1.2
  - No self consistent pedestal in this simulation
    - Previous (2006) pedestal boundary condition imposed
- **Core region still collapsed with GLF23 transport model:**
  - Edge region outside core held at boundary condition value
- **Increased density by factor 1.85 prevented core collapse and yielded a steady state:**
  - Neoclassical transport inside core
  - Partial radiative collapse outside
  - Density factor has a small range for steady state solutions:
    - Factor below 1.8 leads to collapse
    - Factor above 1.9 leads to runaway core peaking

Density Profile Fixed in Simulation at $n_e = 3.5 \times 10^{20}\ m^{-3}$ on Axis: Factor 1.85 Above Systems Code Value

- **Pedestal boundary condition set to earlier ARIES 2006 values:**
  - Not yet set to EPED1 prediction for this equilibrium



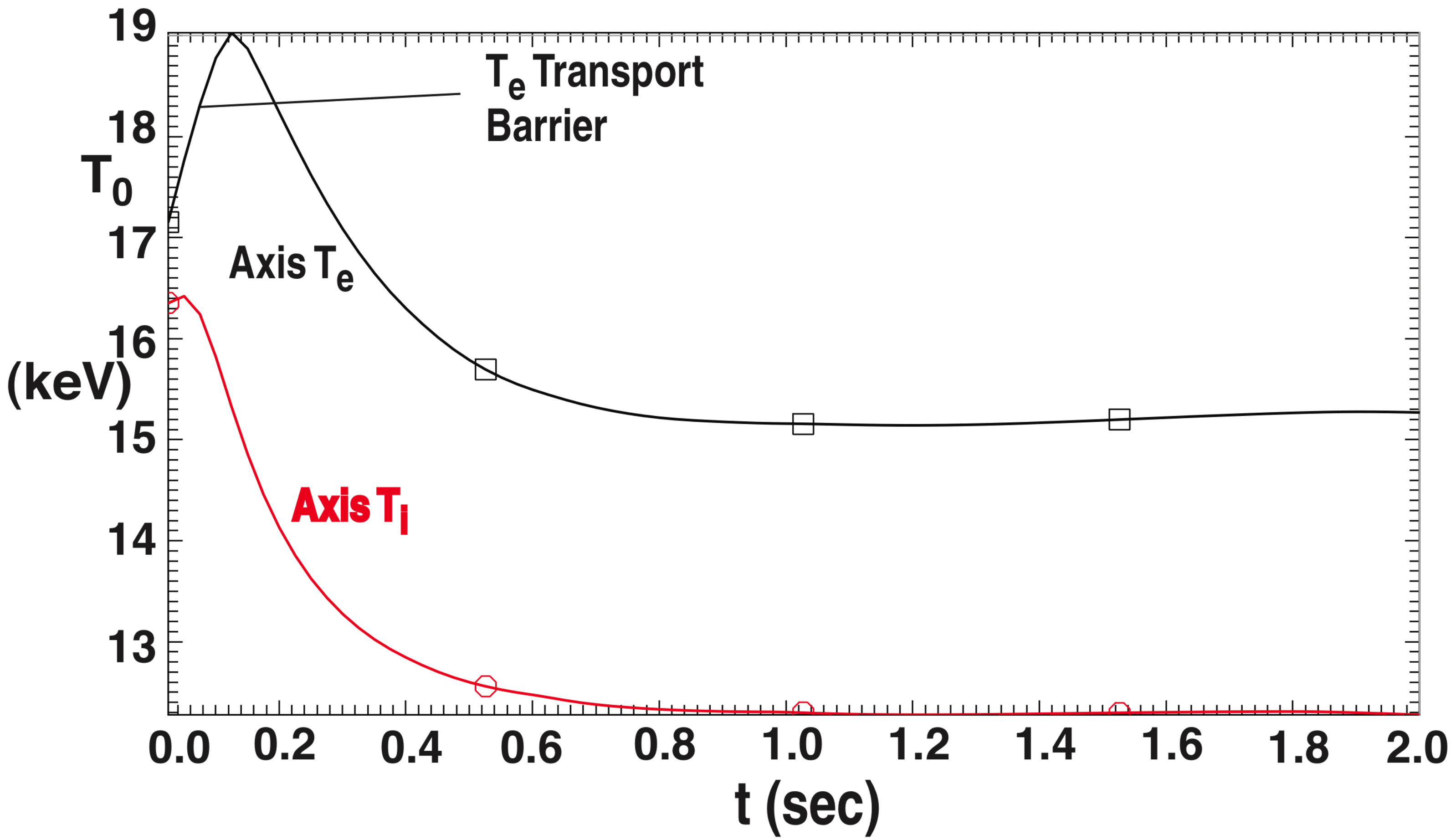
Steady State Temperature Profiles Obtained if Density Increased by Factor 1.85 Above Systems Code Value



- **Need additional heating to push outer region up:**
  - Currently maintained at imposed boundary condition value

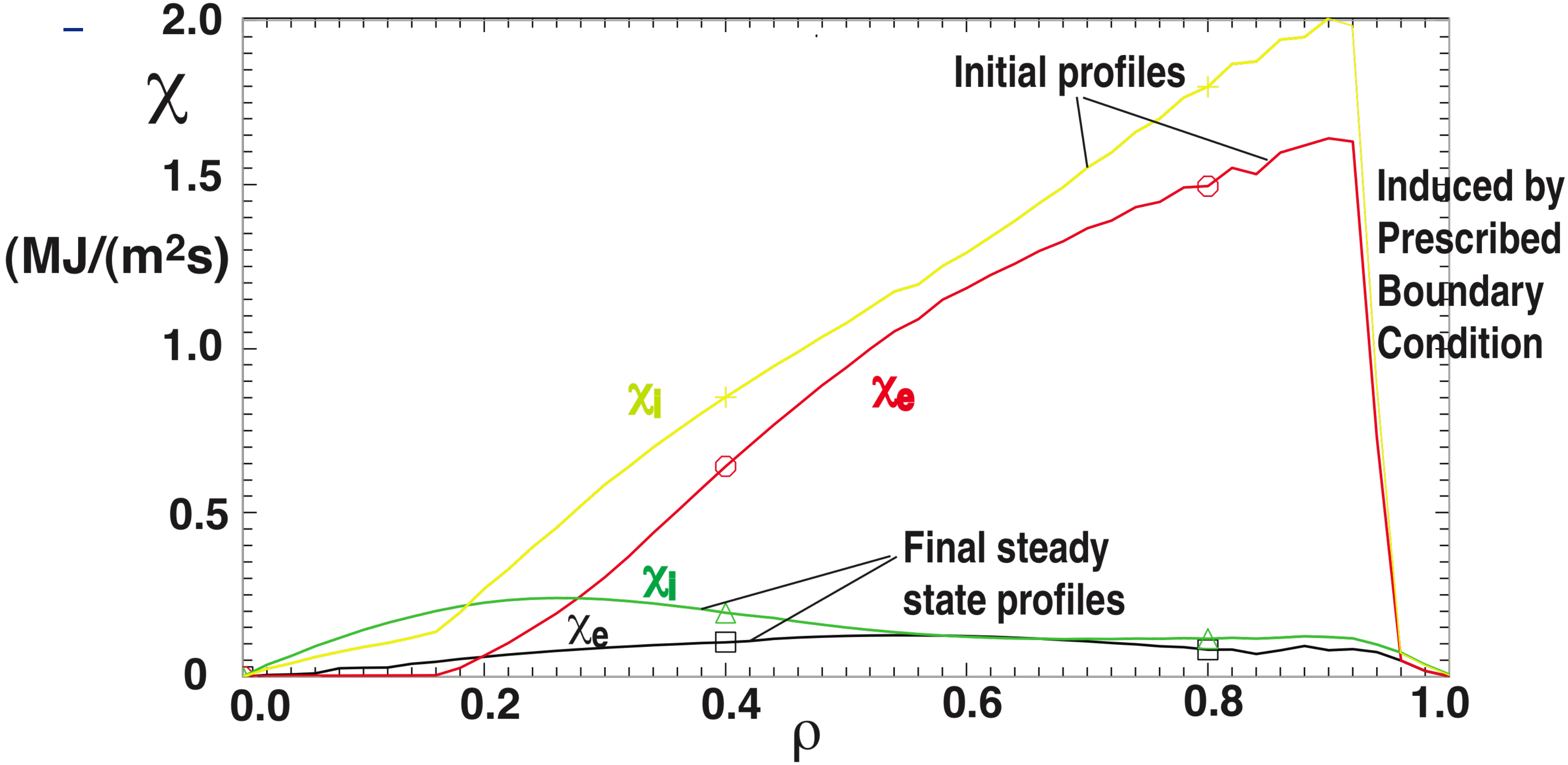
Time Dependent Simulation Shows Initial T_e Barrier Formation that Subsequently Decays

- **Time dependent simulation shows small long term oscillations:**
  - Often seen in other simulations



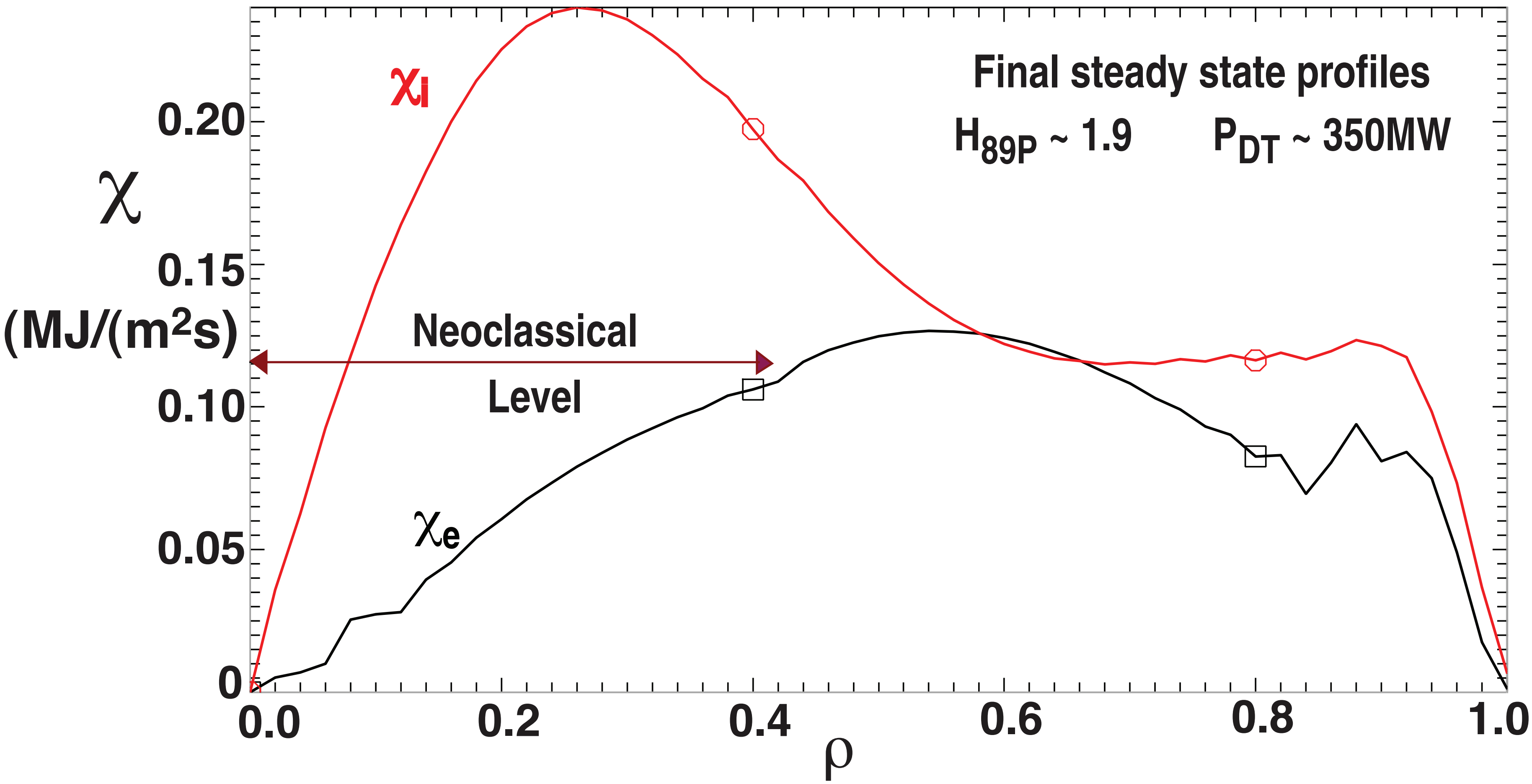
Diagnosis Of Initial and Final Steady State Energy Fluxes Show Large Reduction At Steady State

- Large initial transient fluxes drop when quasi-equilibrium steady state is established
  -



Steady State Fluxes Show Neoclassical Electron Heat Fluxes But Larger Ion Heat Fluxes

- Core electron confinement is at approximately neoclassical levels

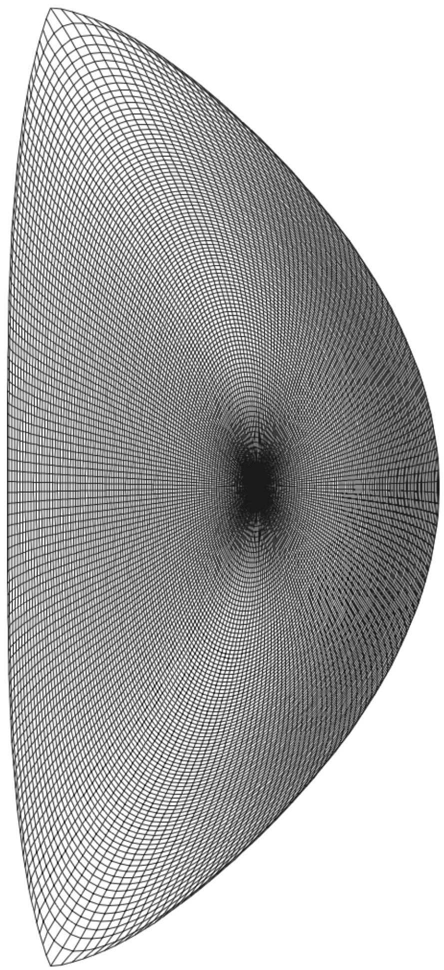


Initiated Simulations Using Updated ARIES ACT 1b

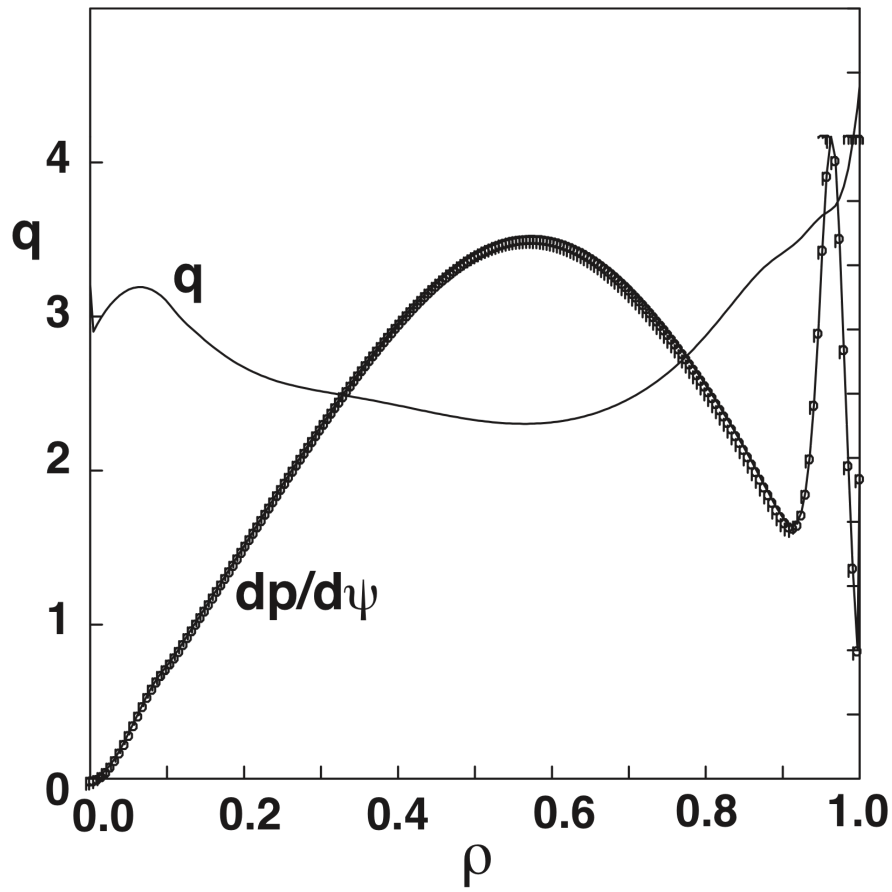
- **Significant enough change requires repeat simulations:**
  - Updated profiles and boundary
- **Requires new equilibrium:**
  - ONETWO simulation requires consistent force balance equilibrium
  - **Initial guess constructed for EFIT equilibrium calculation:**
  - Profiles obtained directly from JSOLVER inverse equilibrium:
    - No divertor
  - Boundary obtained from direct equilibrium:
    - With divertor
- **New F90 version developed and ported to Linux Cluster:**
  - EFIT Greens Function table reconstructed for new GA computers
  - Reproduced previous case correctly
- **New equilibrium constructed**

ACT 1b Boundary From Direct Equilibrium TSC Code and Profiles From JSOLVER Inverse Equilibrium Code

- Boundary:

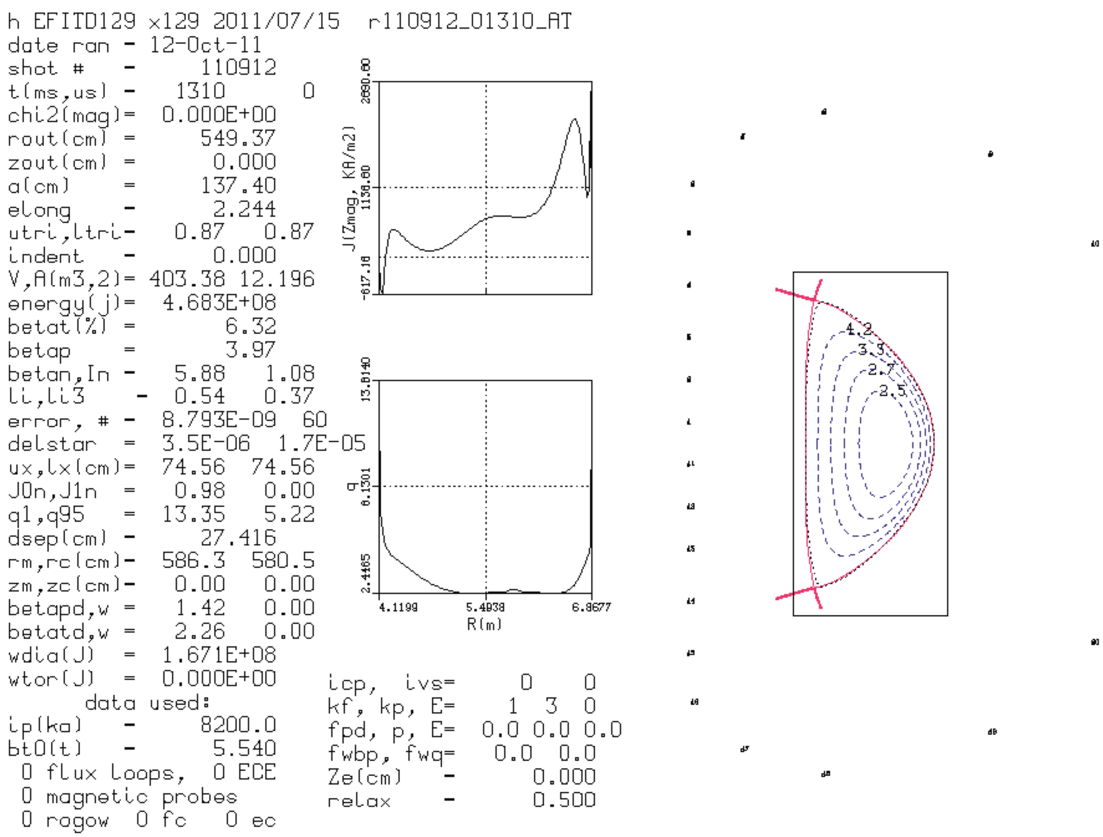


- Profiles:



Reconstructed Equilibrium From Updated ARIES ACT 1b

- Screen Shot from successful equilibrium calculation:



Future Steps Intend to Complete Self Consistent Optimization of ARIES-ACT 1b Design Point

- **Rerun simulation with newest iteration of ACT 1b baseline:**
  - Determine if same issues of collapse ensue
  - Does density still need to be increased
- **Include consistent pedestal in updated ACT 1b Scenario:**
  - Equilibrium pedestal set for consistency with peeling-ballooning (ELM) stability of ACT 1b equilibrium:
    - EPED1 model to provide pedestal height and width for given pedestal β_{pol}
- **Run self consistent steady state scenario iteration:**
  - Heating and current drive optimization using GENRAY and GLF23 transport model
  - Test TGLF transport model to determine if large differences
- **Iterate**

- **Diagnose simulation using new tools to document individual fluxes**

Backup slides

Future Steps Intend to Complete Self Consistent Optimization of ARIES-AT Design Point

- **Include consistent pedestal in updated ACT 1b Scenario :**
  - Consistent with equilibrium H-mode pressure pedestal
  - Equilibrium pedestal modified for consistency with peeling-ballooning (ELM) stability:
    - EPED1 model to provide pedestal height and width for given pedestal β_{pol}
- **Self consistent steady state scenario iteration:**
  - Heating and current drive optimization using TGLF transport model
  - Pedestal optimization for β_{pol} consistent with transport simulation and EPED1 model
- **Iteration on β, q profile, and ultimately cross section:**
  - Varied around design point as needed
  - Resistive wall mode stability considered

Future Plans Intend to Complete Optimization for Self Consistent Steady State Scenario

- **β optimization:**
  - Initialize with $\beta_N = 5.7$
  - Check ideal stability
  - Optimize to converge to maximum stable β_N
- **q profile optimization:**
  - Adjustment of q profile to improve stability and current drive potential
- **Shape and size optimization:**
  - Elongation, triangularity and aspect ratio
  - Size adjustments as needed
- **Aim to use IMFIT for automation of core loop of transport self consistently optimized with heating and current drive**

- **In the initial steps of the subsequent optimization, the GLF23 transport model will be used:**
  - Considerably faster than the more accurate TGLF model
  - Utilize TGLF once simulations are partially converged

Pessimistic TGLF Result May be Due to Full Geometry or to Other Features of the Model

- **Run one iteration to obtain individual diffusive and convective fluxes:**
  - Calculate individual fluxes and sources and compare with:
    - TGLF with shifted circle geometry
    - GLF23 (shifted circle geometry)
- **Run to steady state:**
  - If TGLF reaches steady state with shifted circle geometry then the shaping is the culprit:
    - Determine sensitivity to small tweaks in shape and profiles
  - Otherwise it may be simply higher accuracy of the TGLF model
  - May need rotational shear stabilization from neutral beams
- **TGLF and GLF23 are known to fail to predict experiments for $\rho > 0.85$ even in L-mode:**
  - Present boundary condition taken to be at pedestal ($\rho = 0.93$)
  - Option to move this boundary condition in and apply at $\rho = 0.85$:
    - Steady state was reached with boundary arbitrarily moved to $\rho = 0.82$
  - Need to properly match profiles between $\rho = 0.85$ and $\rho = 0.93$