QOS Plasma Transport Analysis

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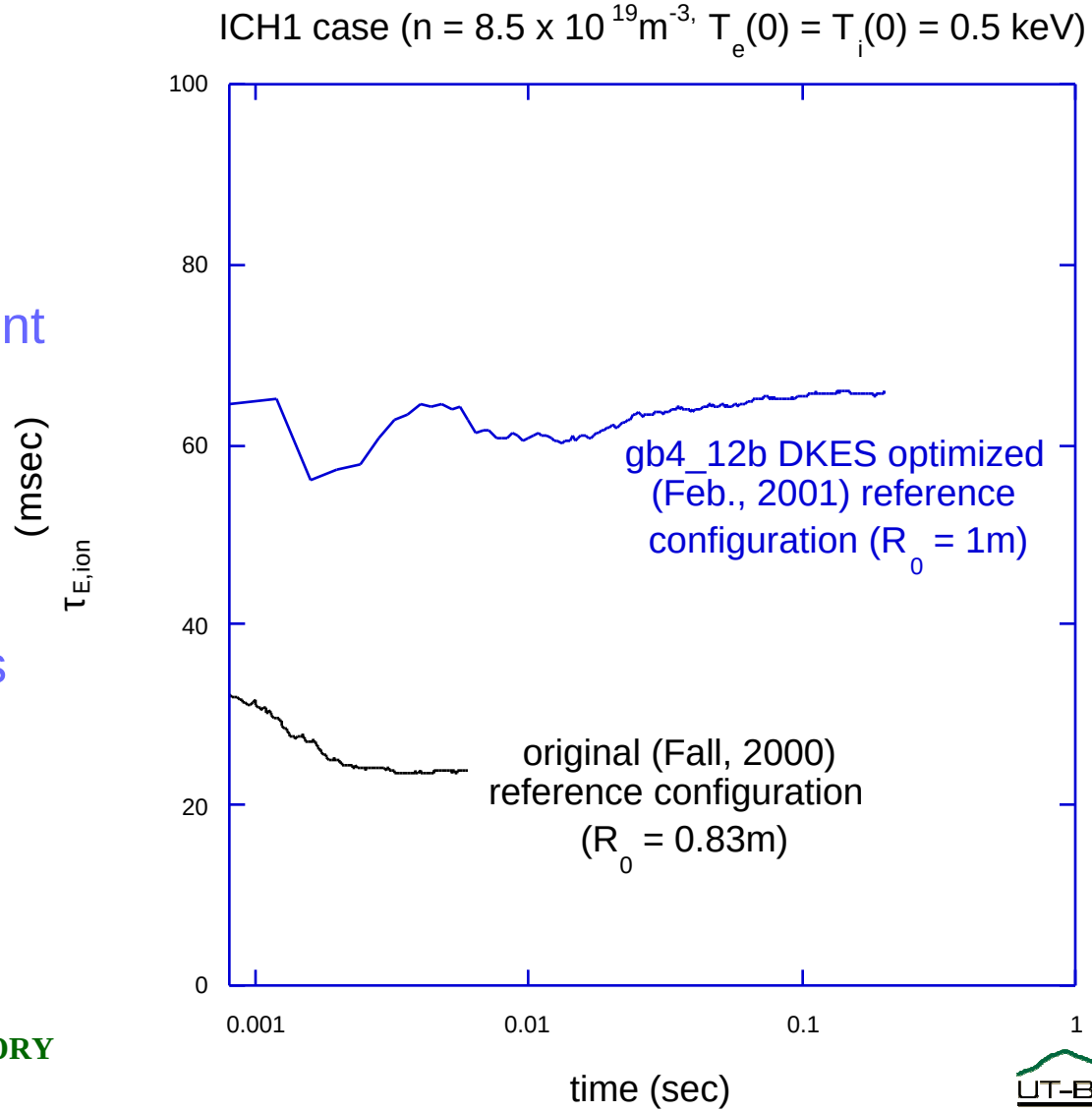
Significant gains in ion confinement have been made since our earlier reference configuration:

- DKES transport targets have led to improved confinement
- R_{min}, R_{max} targets have allowed more open area in center and higher R_0
- NESCOIL target has decreased coil complexity

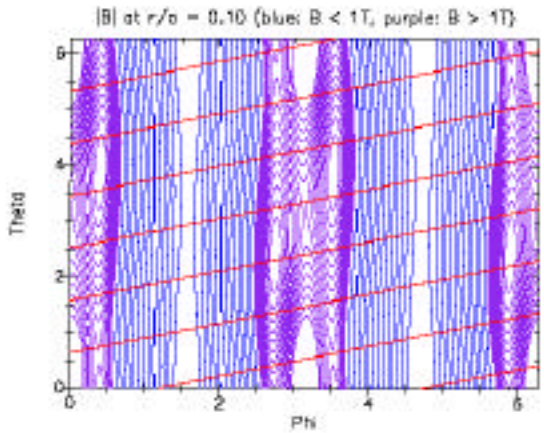


Plasma transport in recent 2 field period QOS devices is being analyzed using:

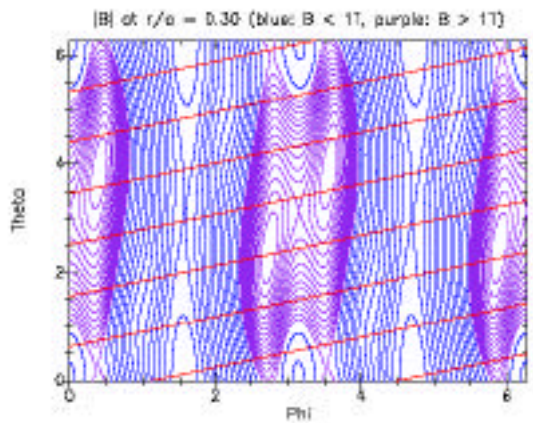
- Orbits, |B| structure, J invariant contours
- NEO code: $1/\nu\ \varepsilon_{eff}^{3/2}$ coefficient
  - V. V. Nemov, S. V. Kasilov, W. Kernbichler, M. F. Heyn, Phys. Plasmas **6**, 4622 (1999).
  - Applicability to quasi-poloidal systems, comparison to DKES
- DKES (drift kinetic equation solver)
  - Electric field, collisionality, radial dependence
  - Applications: ambipolar electric field, bootstrap current, diffusive lifetime
  - Convergence issues
- Global Monte Carlo energy lifetimes
  - Heating scenarios, comparison to ISS95
  - Electric field effects, steady-state issues

The |B| spectrum achieves its highest degree of quasi–poloidal symmetry closest to the magnetic axis

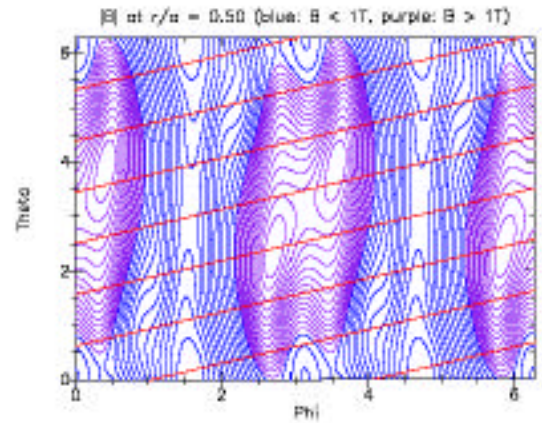
r/a = 0.1

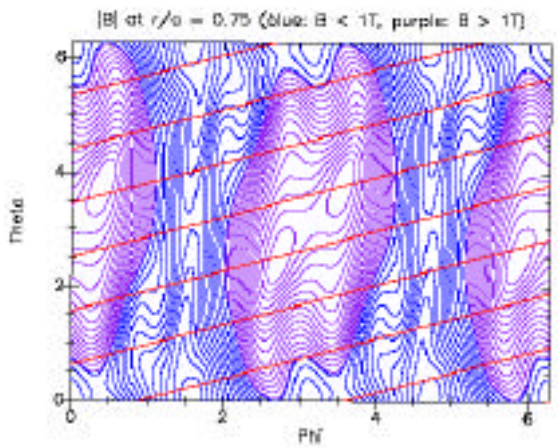


r/a = 0.3

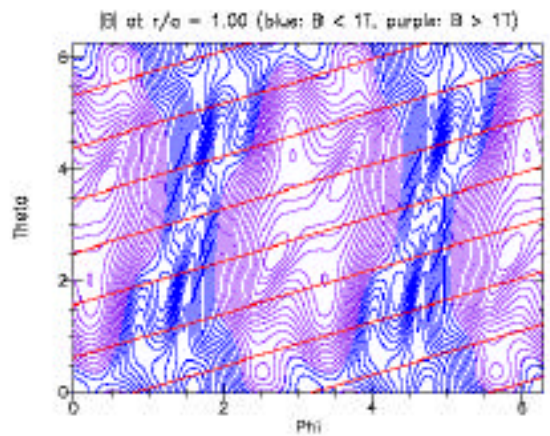


r/a = 0.5



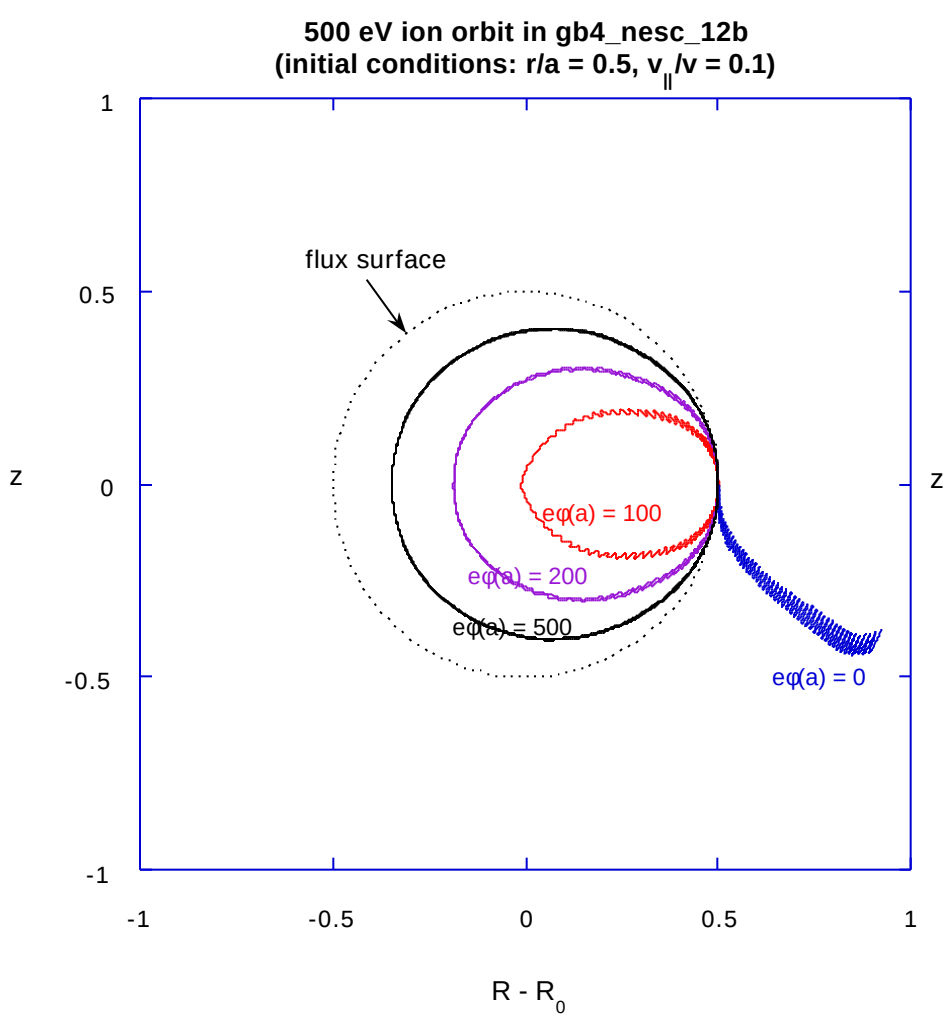


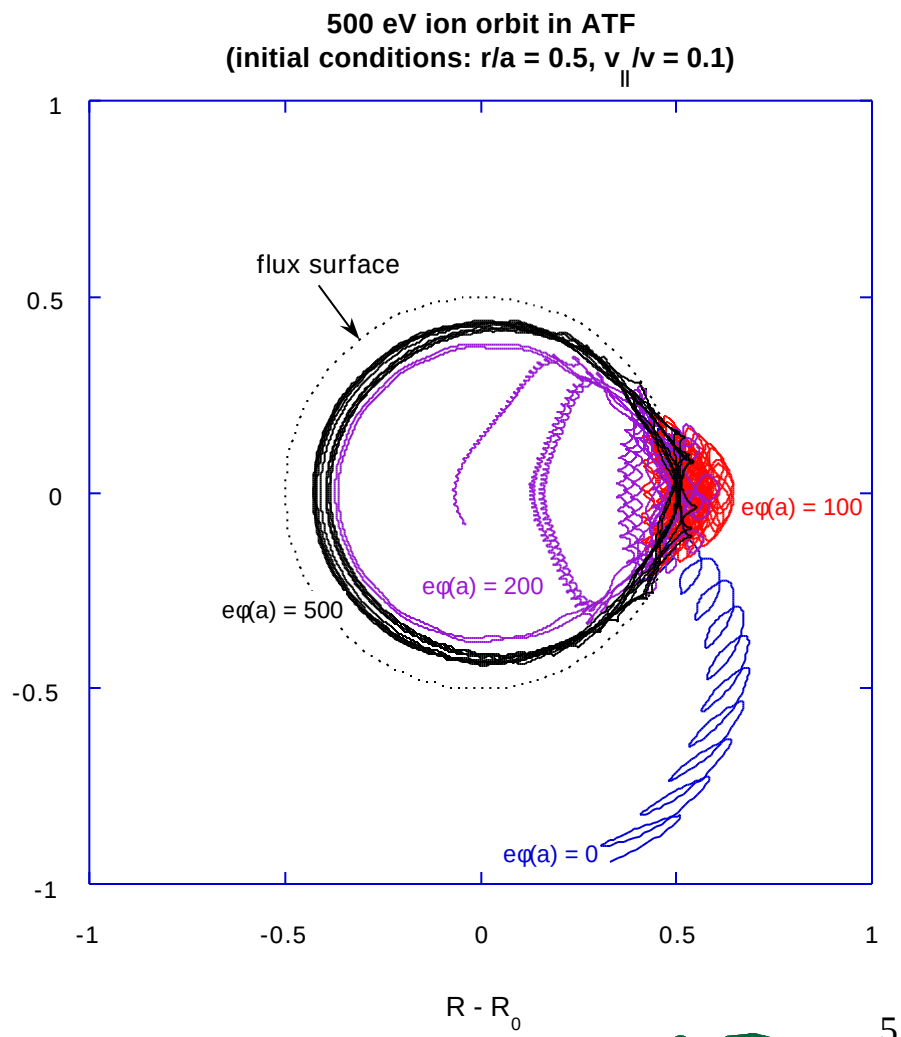
r/a = 0.75



r/a = 1.0

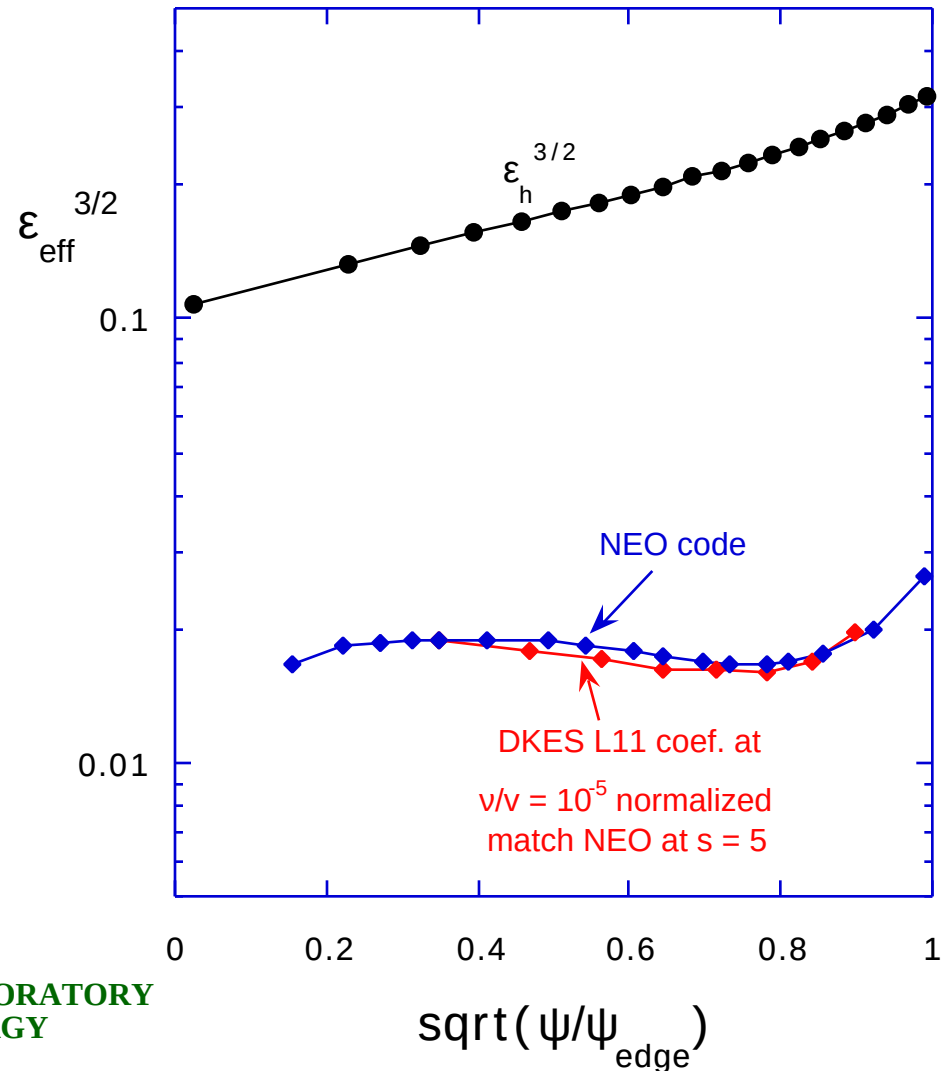
Deeply trapped orbits in reference configuration and ATF





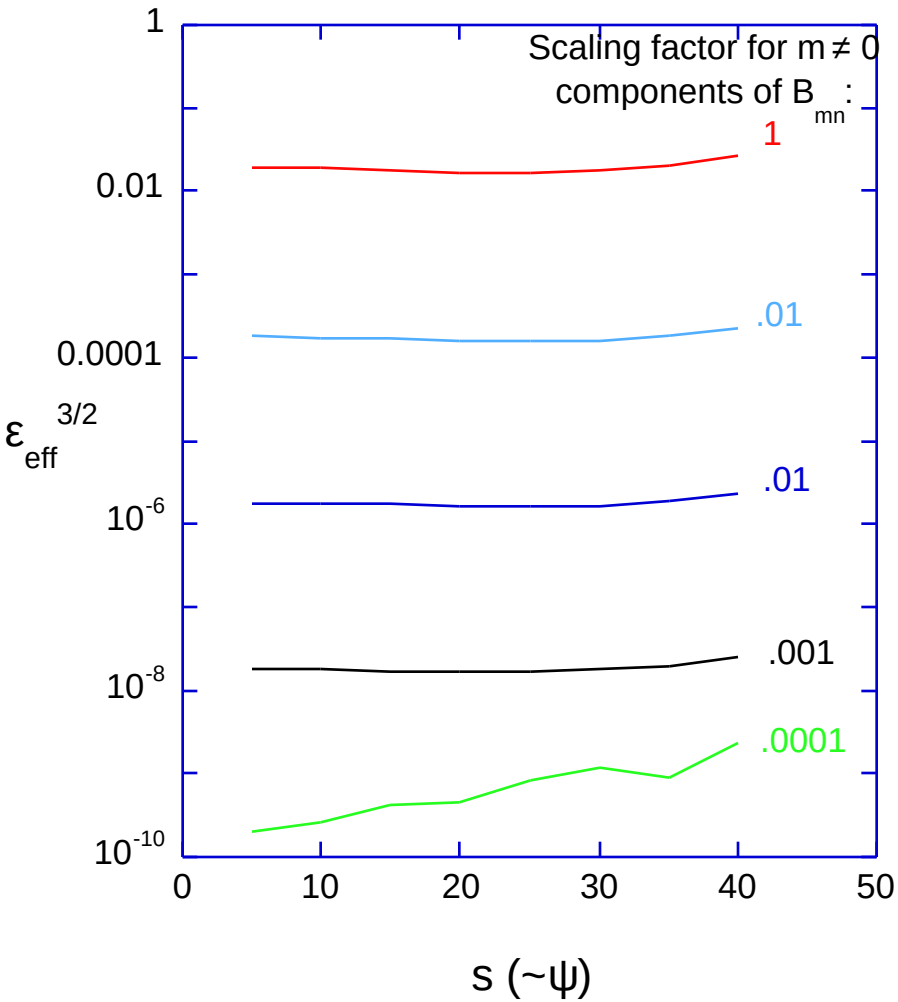
Comparison of $\varepsilon^{3/2}$ for our reference configuration using simple helical ripple $\varepsilon_h = (B_{max} - B_{min})/(B_{max} + B_{min})$ and $\varepsilon_{eff}^{3/2}$ from the NEO calculation shows significant reduction from ε_h:

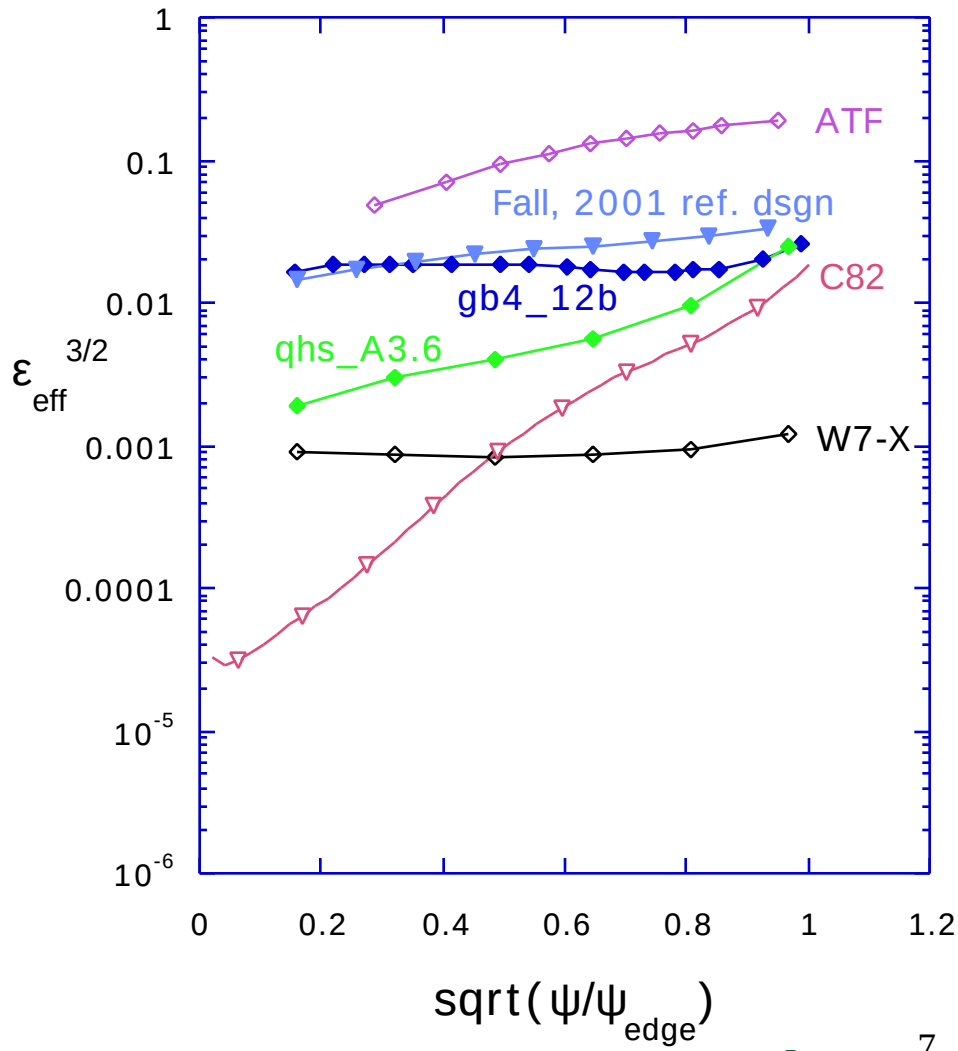
Kernbichler NEO code



Scaling of $\varepsilon_{eff}^{3/2}$ for our reference case with artificially improved QP symmetry/comparison among machines

Kernbichler NEO code





With selection of a reference configuration, the focus of transport calculations is shifting more to in depth studies of a single device

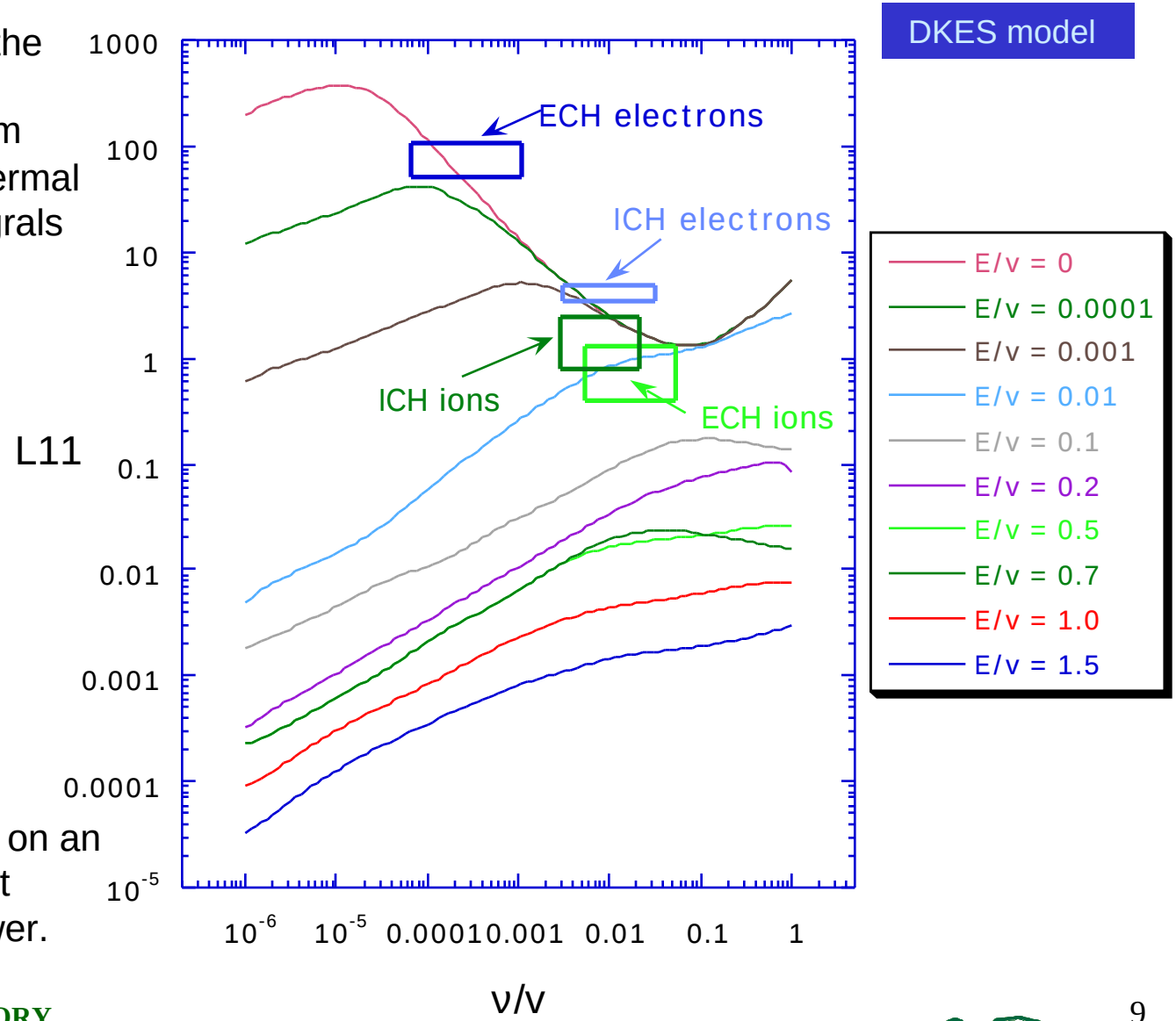
- DKES data base (flux surface, collisionality, electric field)
  - energy integration
  - self-consistent ambipolar electric field
  - bootstrap current dependence on collisionality
  - global lifetimes
  - comparison with Monte Carlo calculations of local diffusivities
- Explore the accessible parameter space
  - Heating scenarios: ECH, ICH
  - Magnetic field variations: 1 and 0.5 Tesla

DKES transport dependencies show that both L11 $\nu^{1/2}$ and L11 $1/\nu$ regimes are accessed.

These ranges are based on the maximum n, T in the profile, $e\phi/kT(a) = 1$, and looking from thermal energy to 9 times thermal (as sampled by velocity integrals for χ)

- **ECH electrons**:
  - $7\times10^{-5} < \nu/v < 10^{-3}$
  - $8\times10^{-5} < E/v < 2\times10^{-4}$
- **ECH ions**:
  - $6\times10^{-3} < \nu/v < 7\times10^{-2}$
  - $10^{-2} < E/v < 3\times10^{-2}$
- **ICH electrons:**
  - $3\times10^{-3} < \nu/v < 4\times10^{-2}$
  - $5\times10^{-5} < E/v < 2\times10^{-4}$
- **ICH ions:**
  - $2\times10^{-3} < \nu/v < 3\times10^{-2}$
  - $2\times10^{-3} < E/v < 6\times10^{-3}$

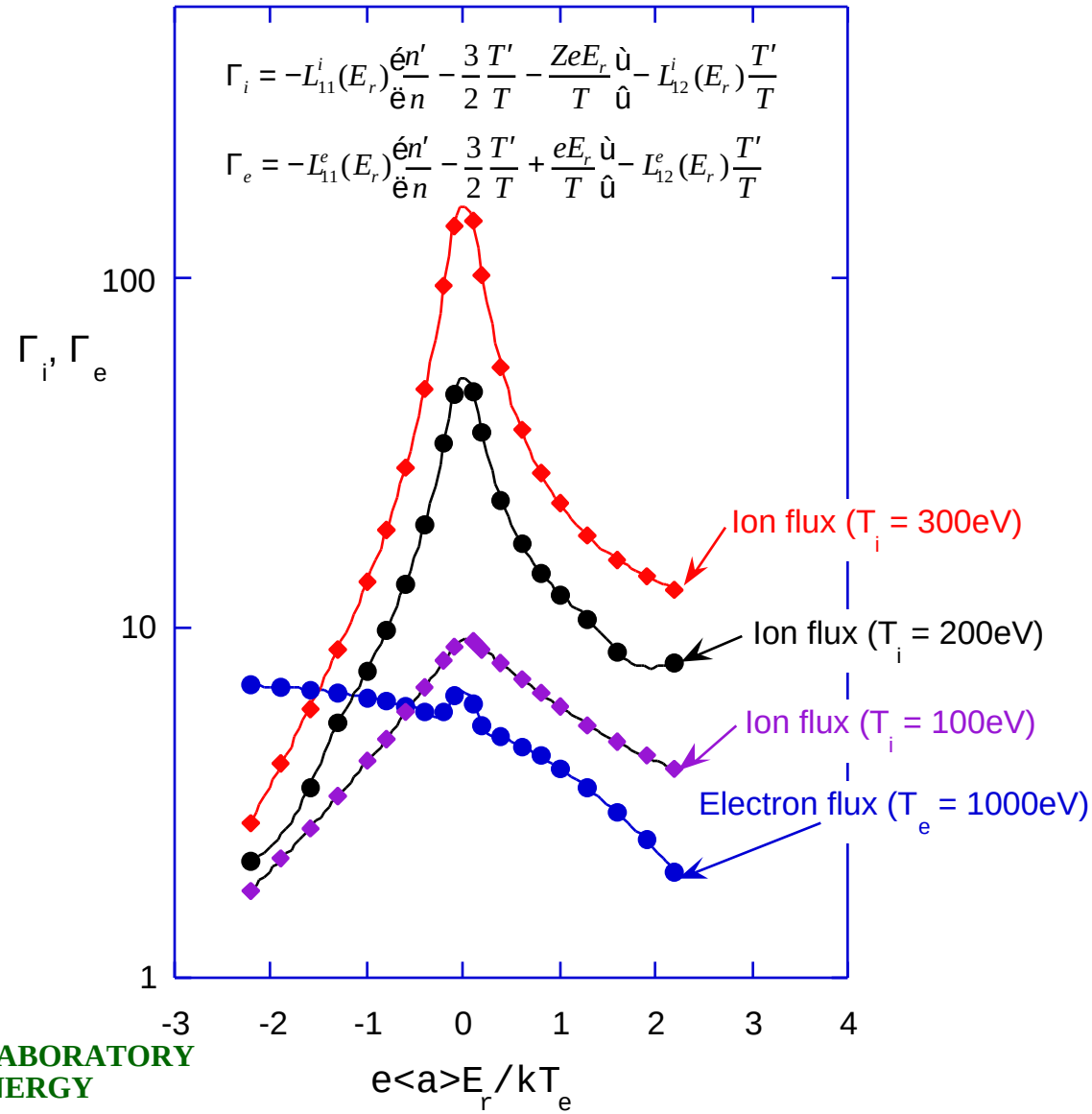
Note: these L11's are based on an earlier A=2.5 device. Current results are a factor of 2-3 lower.



Ambipolarity condition using DKES coefficients

DKES model

Ion, electron fluxes from DKES

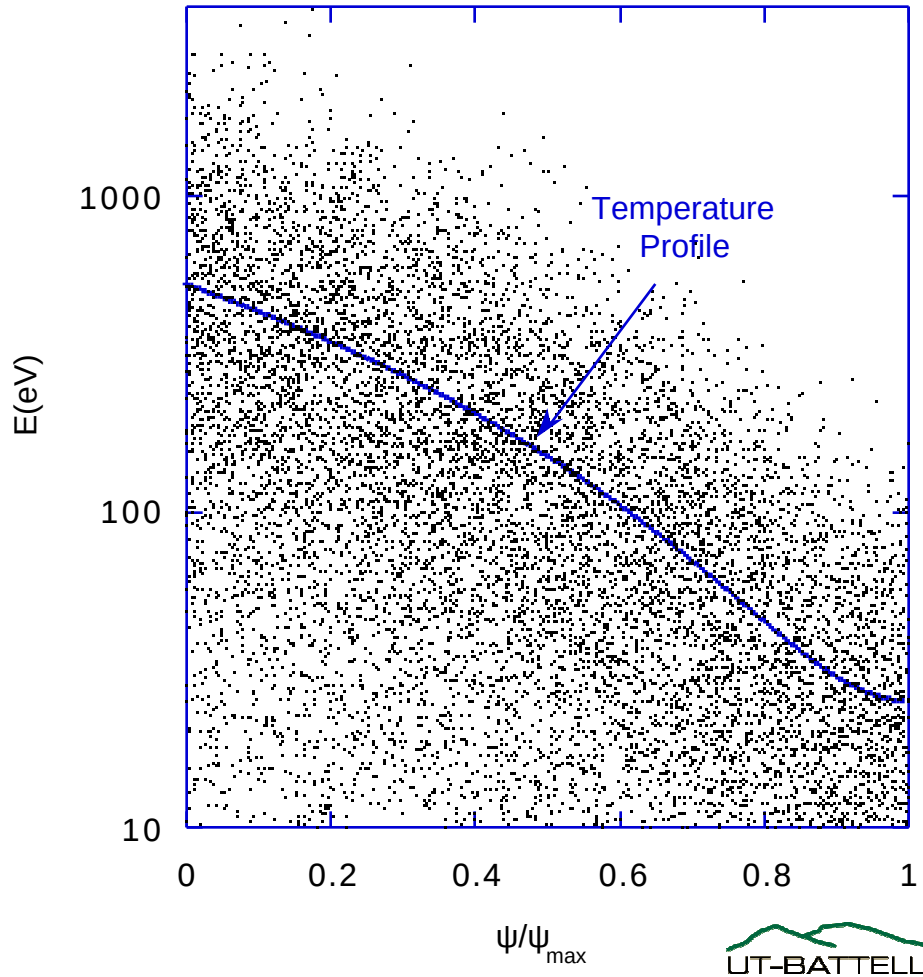


Monte Carlo procedure for estimating global energy lifetimes (DELTA5D code)

DELTA5D Monte Carlo

- start with particles distributed over cross section using PDF's consistent with assumed profiles and local Maxwellians
- follow ensemble in time, replacing particles (consistent with initial PDF's) as they leave outer surface
- Record energies of escaping particles - use to calculate τ_E
- Follow until approximate steady–state is achieved

Typical initial Maxwellian particle loading for T = 500eV $(1 - \psi/\psi_{max})^2$



Power flows for global single species test particle simulations:

- To achieve steady state, in a reasonable simulation time, terms (1) and (2) need to be balanced:
- For $E_r = 0$
  - can include pitch angle and energy scattering if $Q_{ii} + Q_{ei}$ is weak during particle confinement time
  - or can include only pitch angle scattering
- For $E_r \neq 0$
  - rely on $Q_{ii} + Q_{ei}$ term (1) to redistribute energy loss/gain from term (2)
  - or can remove kinetic energy loss/gain (due to $e\Delta\varphi$) each time step

DELTA5D Monte Carlo

$$\frac{dW_{test,ion}}{dt} = \int \left(Q_{ii} + Q_{ei}\right) d^3v \qquad (+/-) \quad (1)$$

$$+ \int \vec{J} \cdot \vec{E} \; d^3v \qquad (+/-) \quad (2)$$

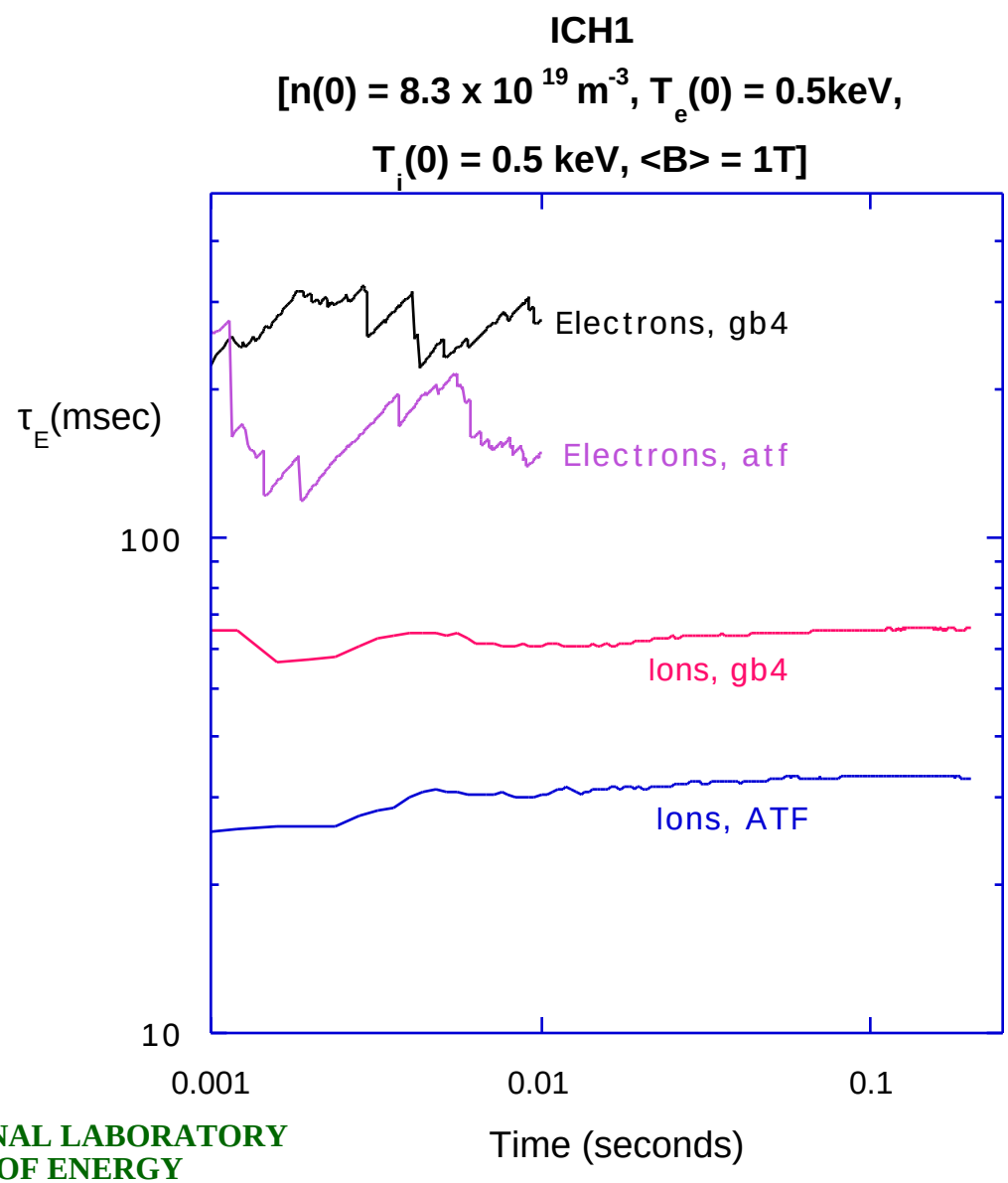
$$+ \int \frac{dW_{edge-loss}}{dt} dS \qquad (-) \quad (3)$$

$$+ \int N_{replacement} T(\psi) d^3v \qquad (+) \quad (4)$$

$$\frac{dW_{test,electron}}{dt} = \textit{Similar equations}$$

QOS reference case and ATF $E_r = 0$ energy lifetimes for higher collisionality ICH heated scenarios

DELTA5D Monte Carlo



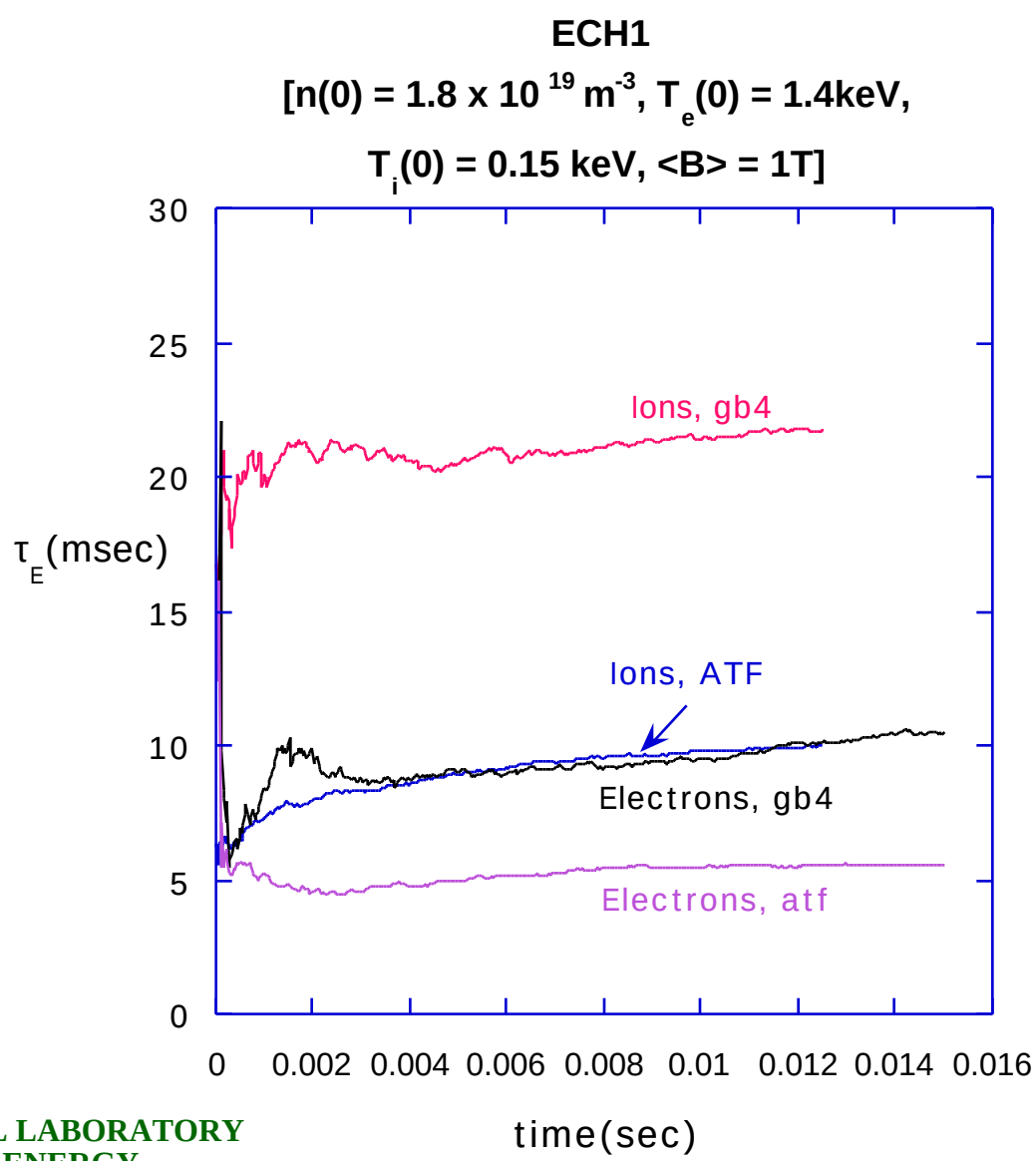
$$\tau_{gl}^{MC} \approx 6.5\tau_{gl}^{ISS95}$$

where τ_{gl}^{MC} is the global lifetime, taking into account electron and ion loss channels:

$$\tau_{gl}^{MC} = \frac{(T_e + T_i)\tau_e\tau_i}{T_e\tau_i + T_i\tau_e}$$

QOS reference case and ATF $E_r = 0$ energy lifetimes for low collisionality ECH heated scenario

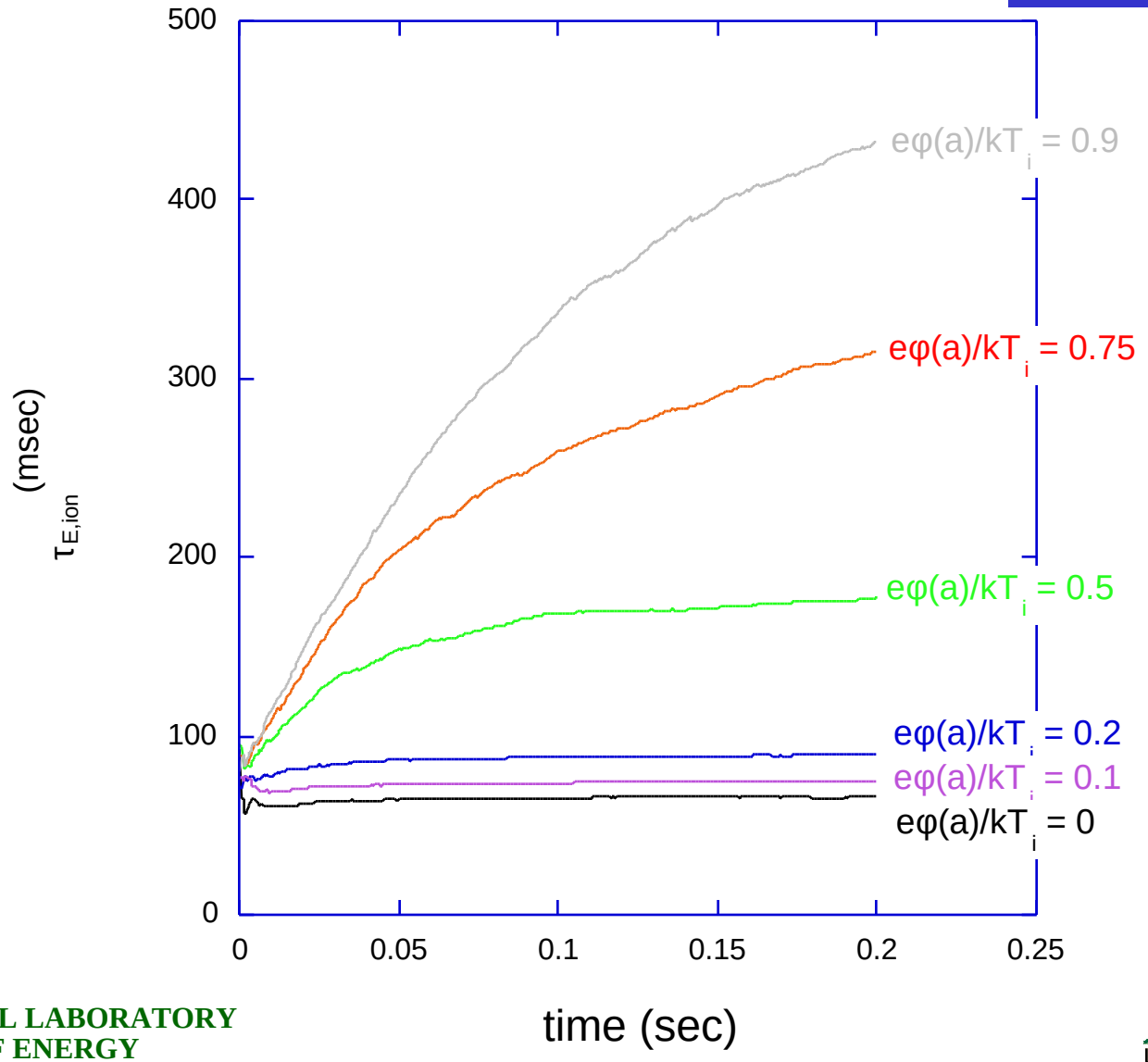
DELTA5D Monte Carlo



$$\tau_{gl}^{MC} \approx \tau_{gl}^{ISS95}$$

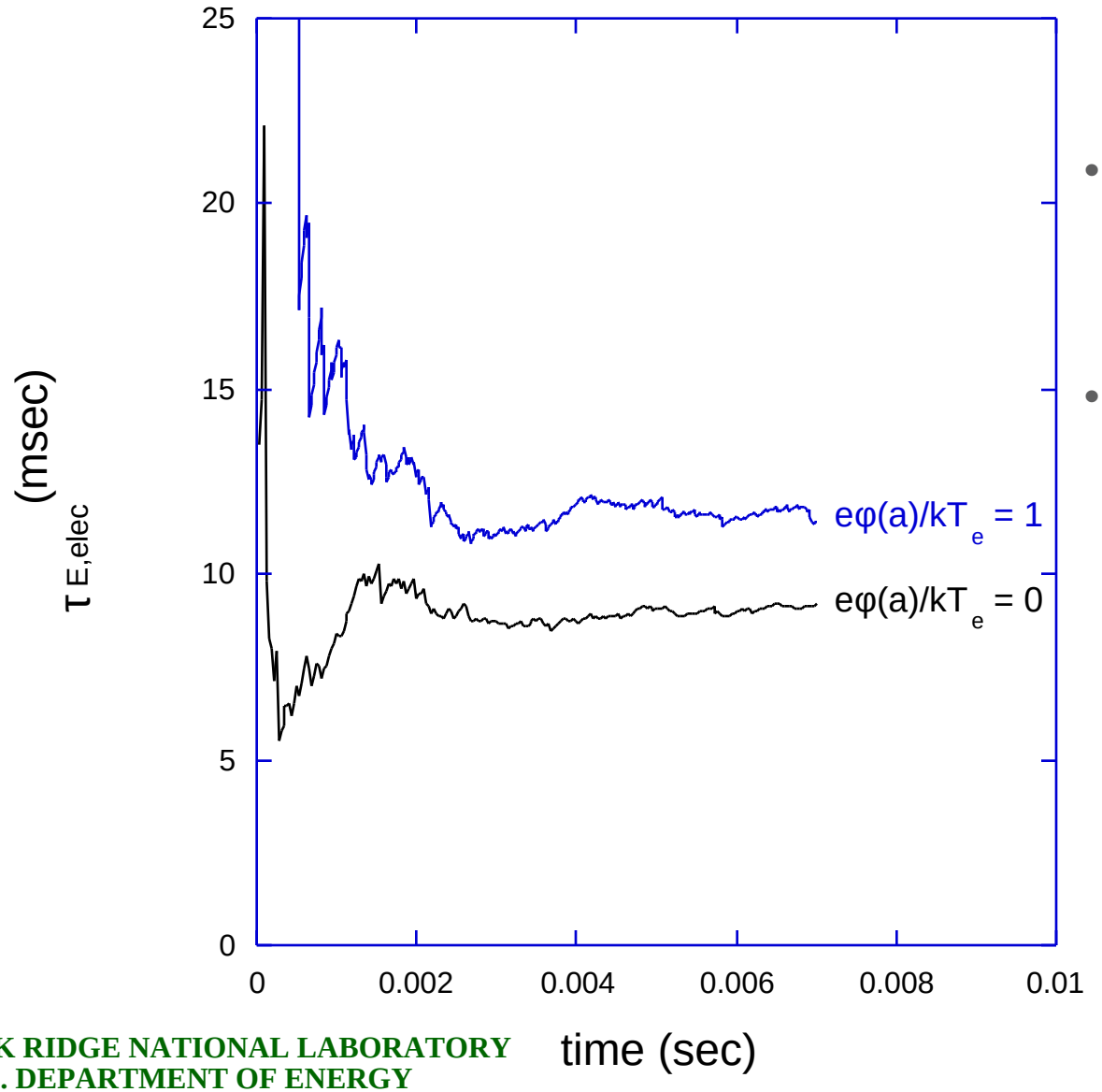
High collisionality ($\nu^{1/2}$ regime) ICH heated ions show strong sensitivity to the electric field

DELTA5D Monte Carlo



Low collisionality (1/ν regime) electrons show less sensitivity to E_r in similarity to DKES calculations

DELTA5D Monte Carlo



- These results are based on the ion root. Future calculations will examine the electron root.
- Here we have balanced terms (1) and (2) on slide 12 by keeping the kinetic energy constant. Higher confinement times result if energy scattering is included and total energy is fixed, but a steady state has not yet been achieved.

Conclusions and Summary

- Good progress has been made in developing quasi-poloidal configurations
  - improved transport
    - factor of 2-3 since Fall, 2000
    - Higher weight on DKES targets -> core transport most relevant for a CE device
  - accomplished while lowering coil complexity and avoiding “thin waist” region
- New tools applied and existing methods refined
  - Nemov, Kernbichler NEO code
  - DKES
  - Monte Carlo
- Selection of a reference allows more in depth transport analysis
  - DKES database (flux surface, collisionality, electric field)
    - ambipolar condition, global τ, comparison with Monte Carlo local D’s, bootstrap current
  - Explore different heating regimes (ECH, ICH)
  - Electric field effects
- CE device with ECH and ICH can explore a range of transport regimes
  - ECH: 1-2 times ISS95 (with E_r) -> electrons dominate losses
  - ICH: 6-20 times ISS95 (with E_r) -> ions dominate losses