Update on integral closures

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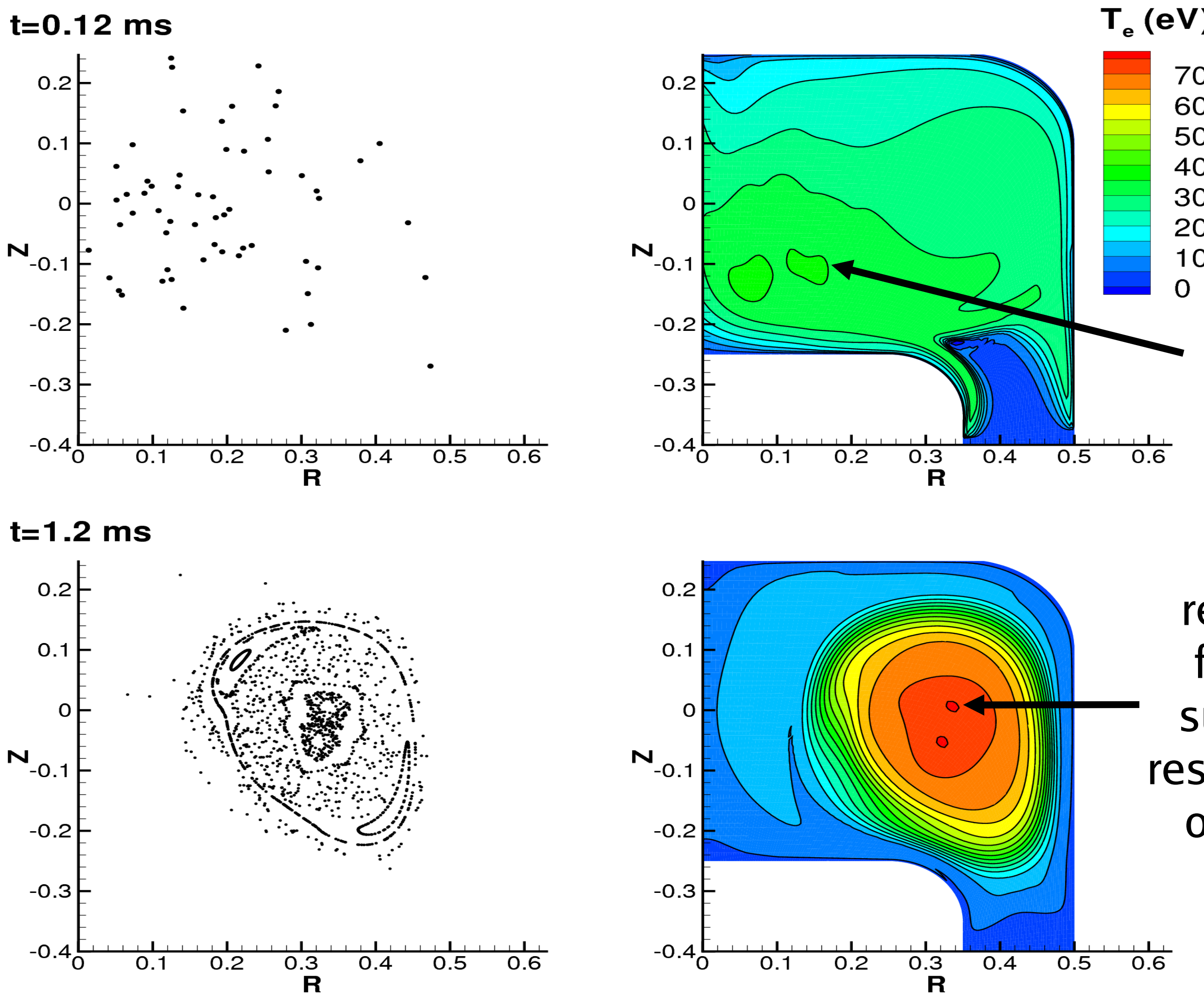
Analytical developments for parallel closures

- Derived complete form for collisional closures with higher-order corrections and comparison to Braginskii.
- Derived small-mass-ratio form for collision operator in moment expansion with arbitrary flow speeds.
- Derived complete closure model for slab geometry including off diagonal terms using CEL approach.
- Developing neoclassical forms for closures with trapping in tent wells. M. Sharma working on more complicated |B| wells.
- Deriving parallel stress in higher-order moment model including precise conservation laws.

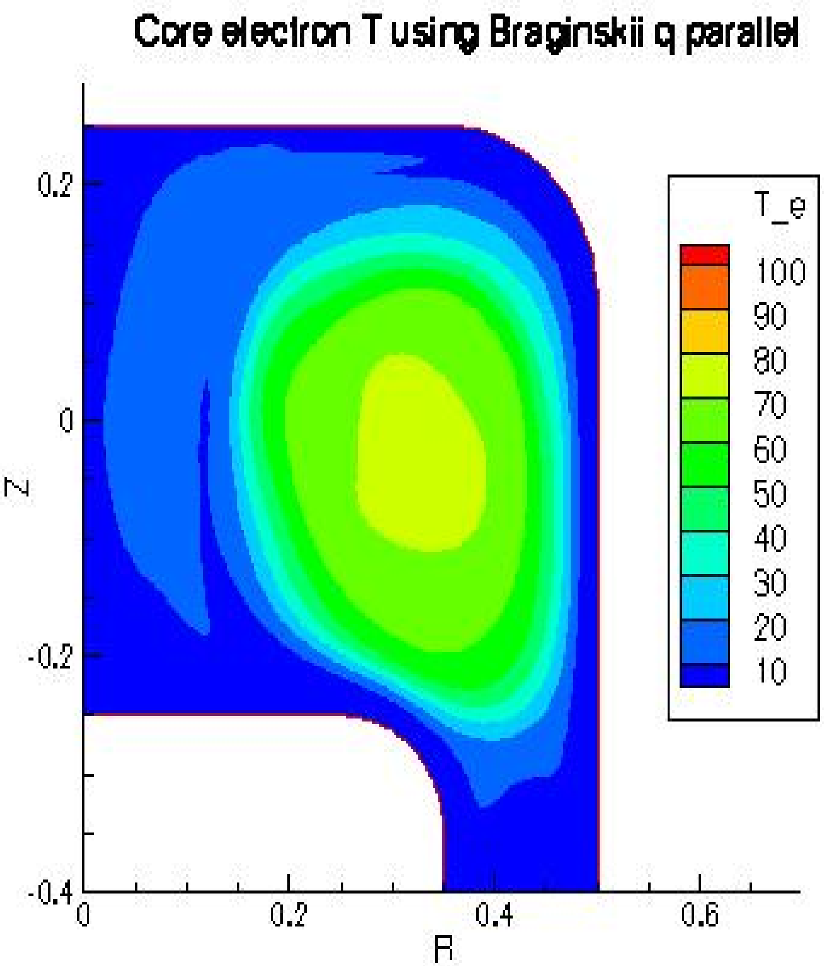
Enhanced confinement observed in experiment and NIMROD simulations of SSPX during decay phase.

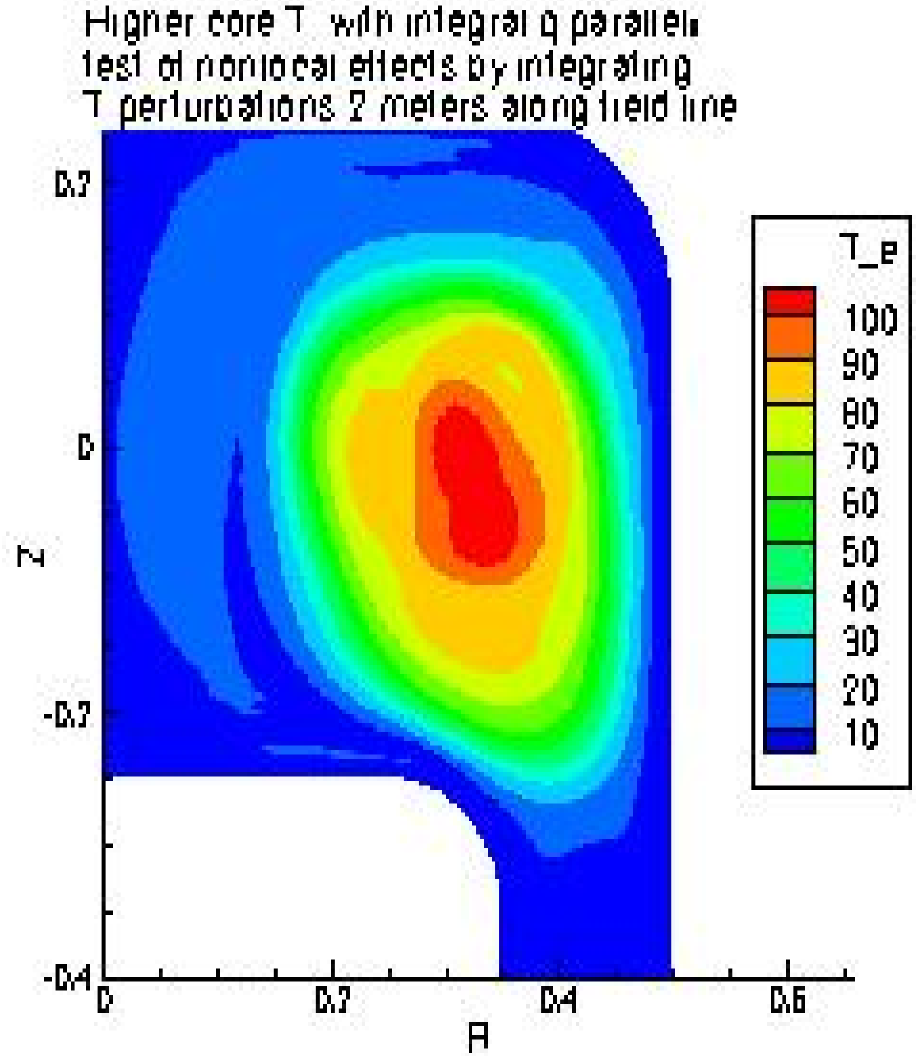


small volume of close flux after formation pulse = little confinement

reduced magnetic fluctuations after sustainment pulse result in large volume of closed flux and enhanced confinement

Initial thought was that integral heat flow closure would lead to higher core temperatures.





Integral $\mathbf{q}_{||}$ from higher order moment method developed and implemented.

- For ease of implementation, used $\mathbf{b} \bullet \nabla T$ in kernel of heat flow integral (as opposed to integrating by parts and using T directly): $\mathbf{q}_{||}(L) = \int dL' \, K(L',L) \, \mathbf{b} \bullet \nabla T$.

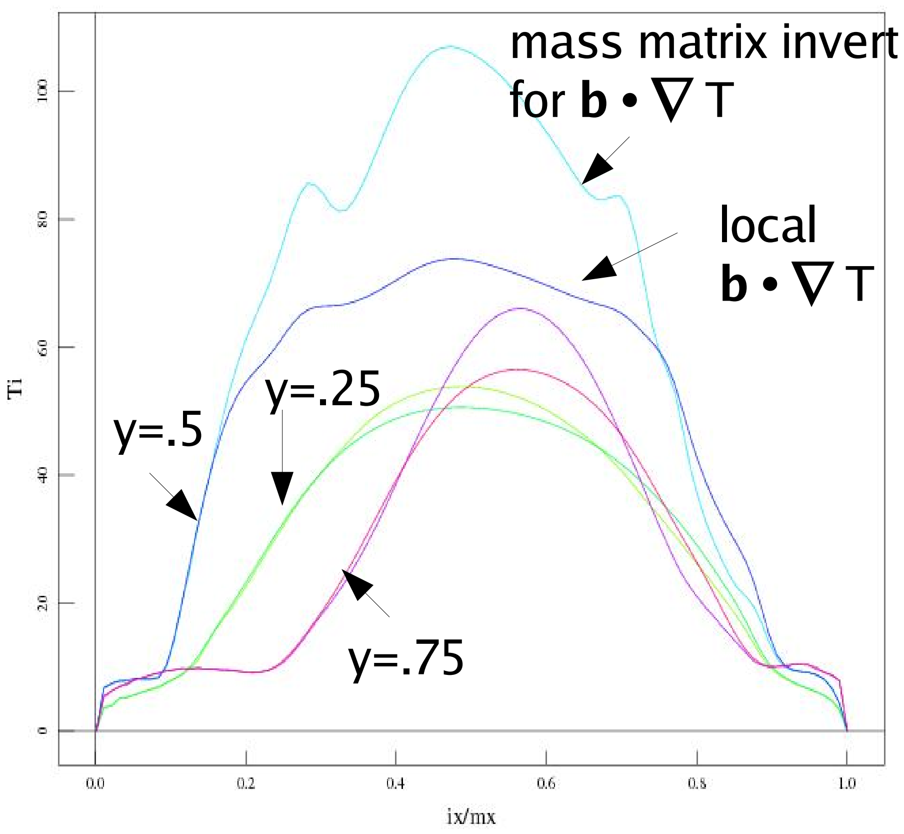
- $\mathbf{b} \bullet \nabla T$ formulated via mass matrix inversion.
(can also evaluate it locally by requesting derivative information when evaluating T, a little noisier).

- To test parallelism, ran cases that computed Braginskii $\mathbf{q}_{||}$ using CEL machinery and got different results.

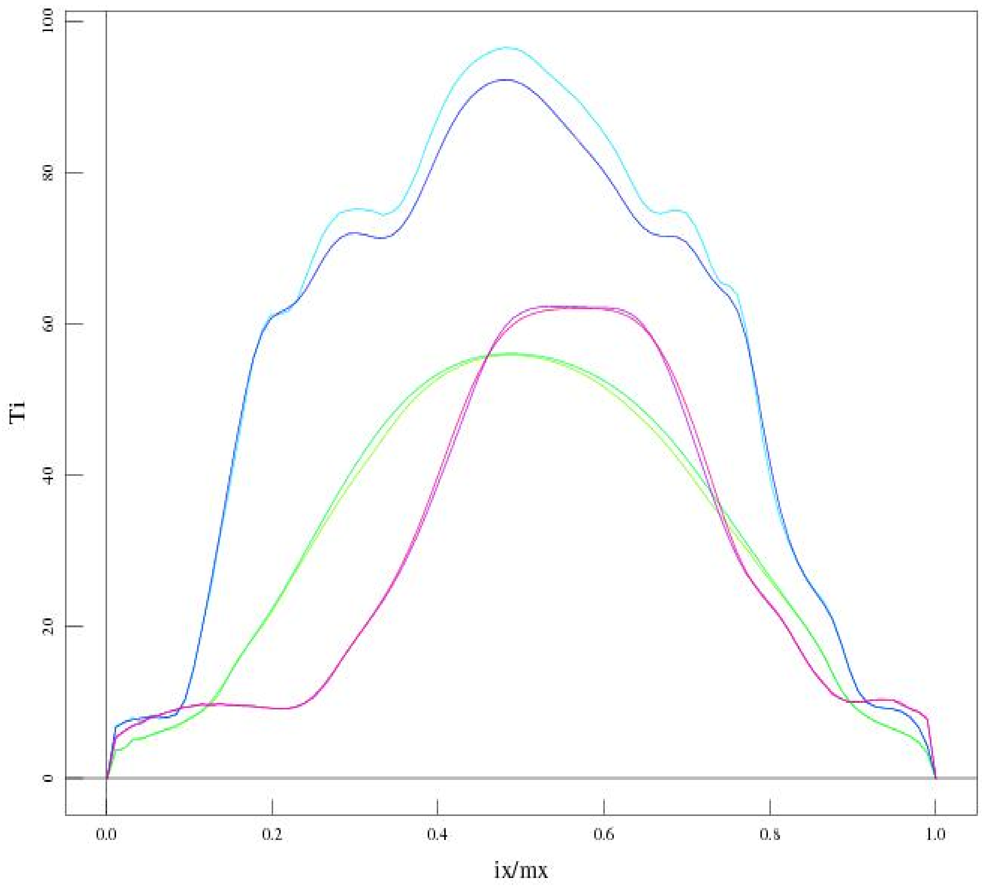
$\mathbf{b} \bullet \nabla T$ evaluated locally at quadrature points in tirhs $\neq$ **$\mathbf{b} \bullet \nabla T$ mass matrix inversion**

Added spatial resolution (mainly Fourier modes) brings reasonable convergence in T profiles.

6 Fourier modes, pd = 4, uniform

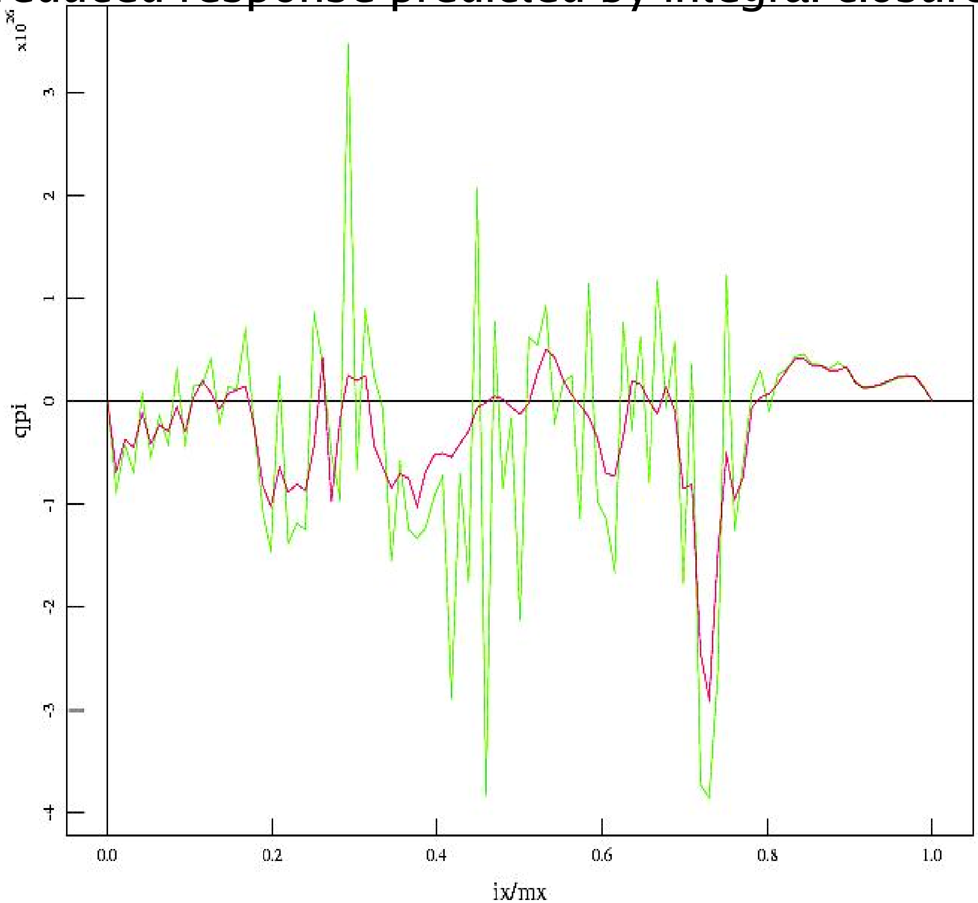


22 Fourier modes, pd = 4, gll

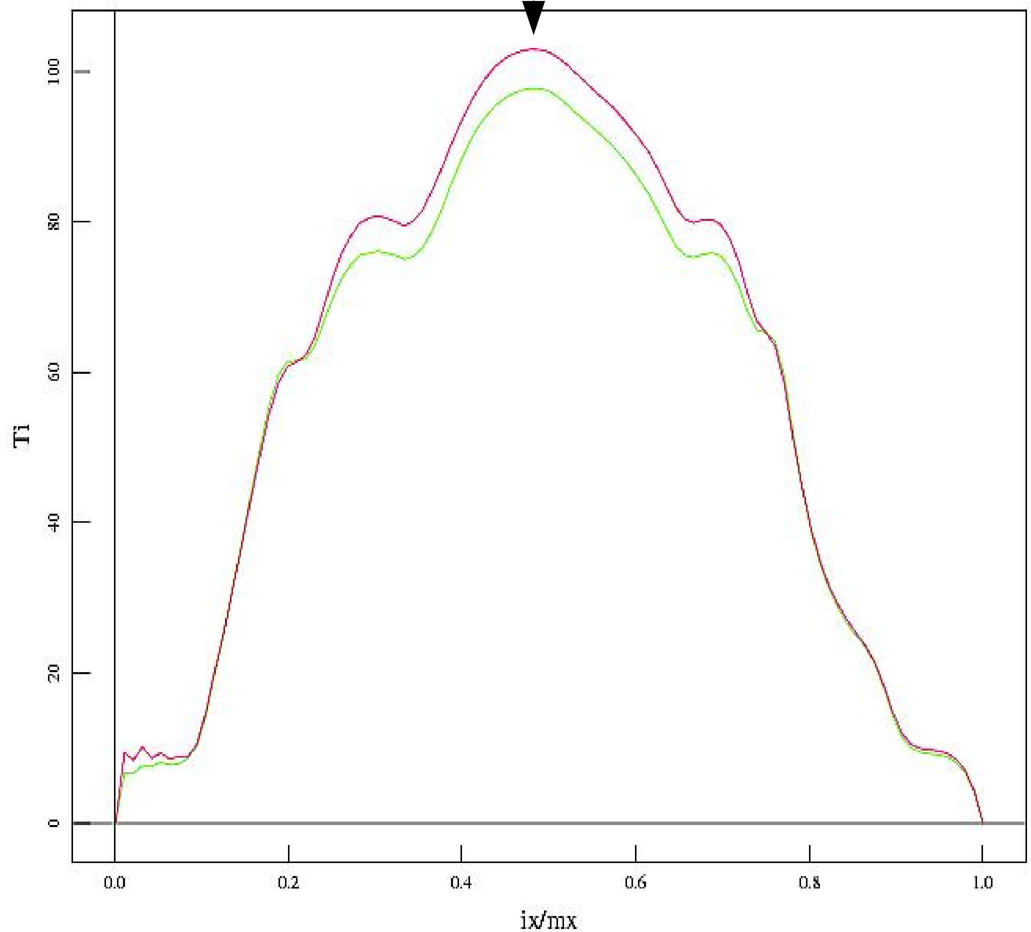


Compare steady-state $\mathbf{q}_{||}$ and T predictions from integral and Braginskii closure.

$\mathbf{q}_{||}$ plotted along chord through core shows reduced response predicted by integral closure.

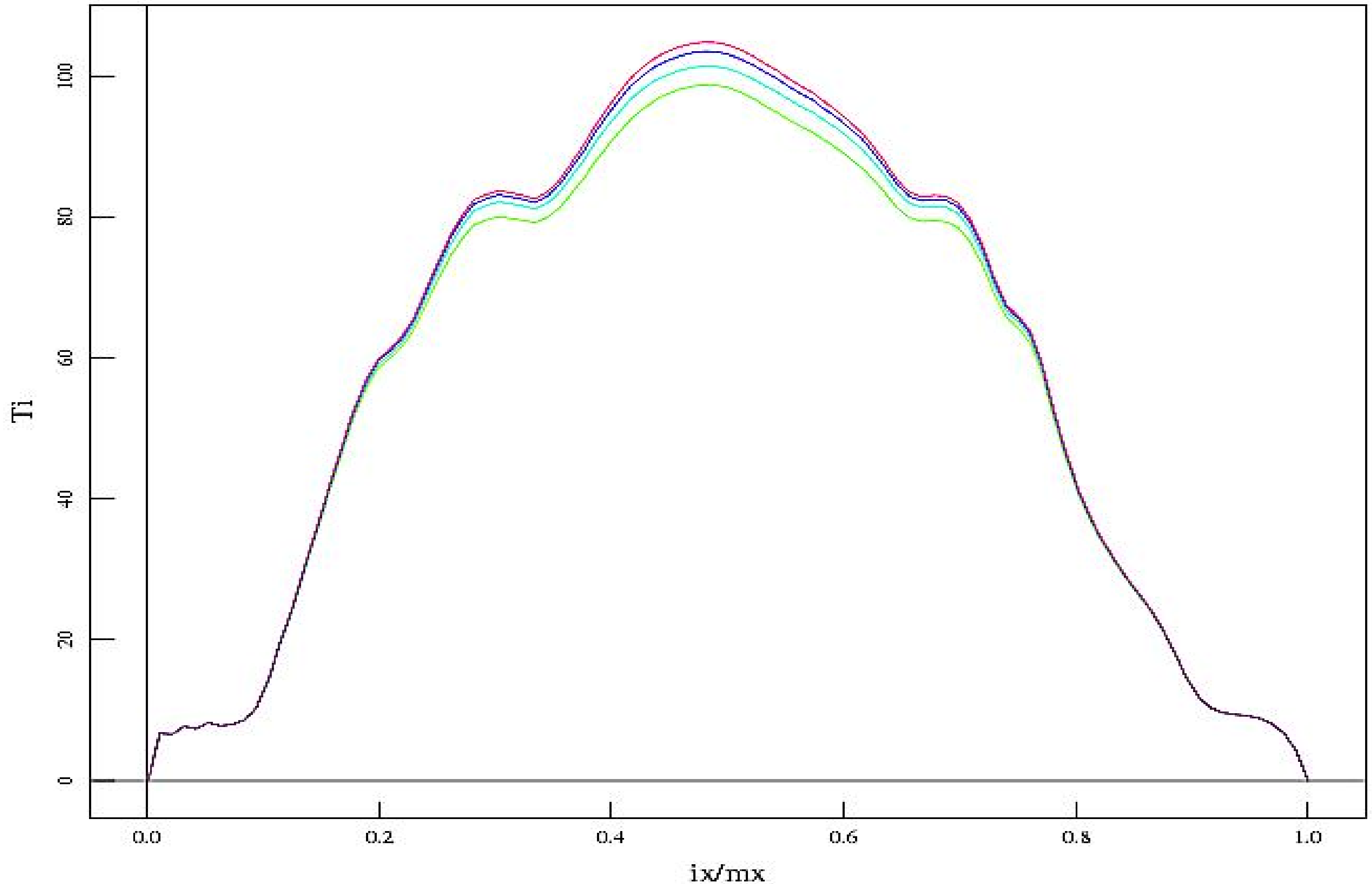


Predictions of core temperatures similar, however.



Evolution of T to steady-state stagnates due to high wave numbers in semi-implicit operator.

Lowering dt permits evolution to slightly higher temperatures. Still, core temperatures appear only slightly higher (~ 10%) than predicted by Braginskii.



More numerical effort needed to speed up closure calculation.

- For SSPX calculation, computed $\mathbf{q}_{||}$ at all nodal points by integrating several (~8 – 40) collision lengths, ~ 1 m at 100 eV.
- Solving steady state drift kinetic equation at
  24 x 48 grid * 16 (pd = 4) * 2^6 (lphi = 6) ~ 10^6 locations.
  1 step/30 minutes on seaborg using 1000 processors.
- Presently throwing away information about integral $\mathbf{q}_{||}$ which is known all along a field line.
- Developing Monte Carlo scheme for computing $\int dV\, \nabla\alpha \cdot \mathbf{q}_{||}$ that uses this information.