LMP (integral) closures

Eric Held, Jeong-Young Ji and Mukta Sharma
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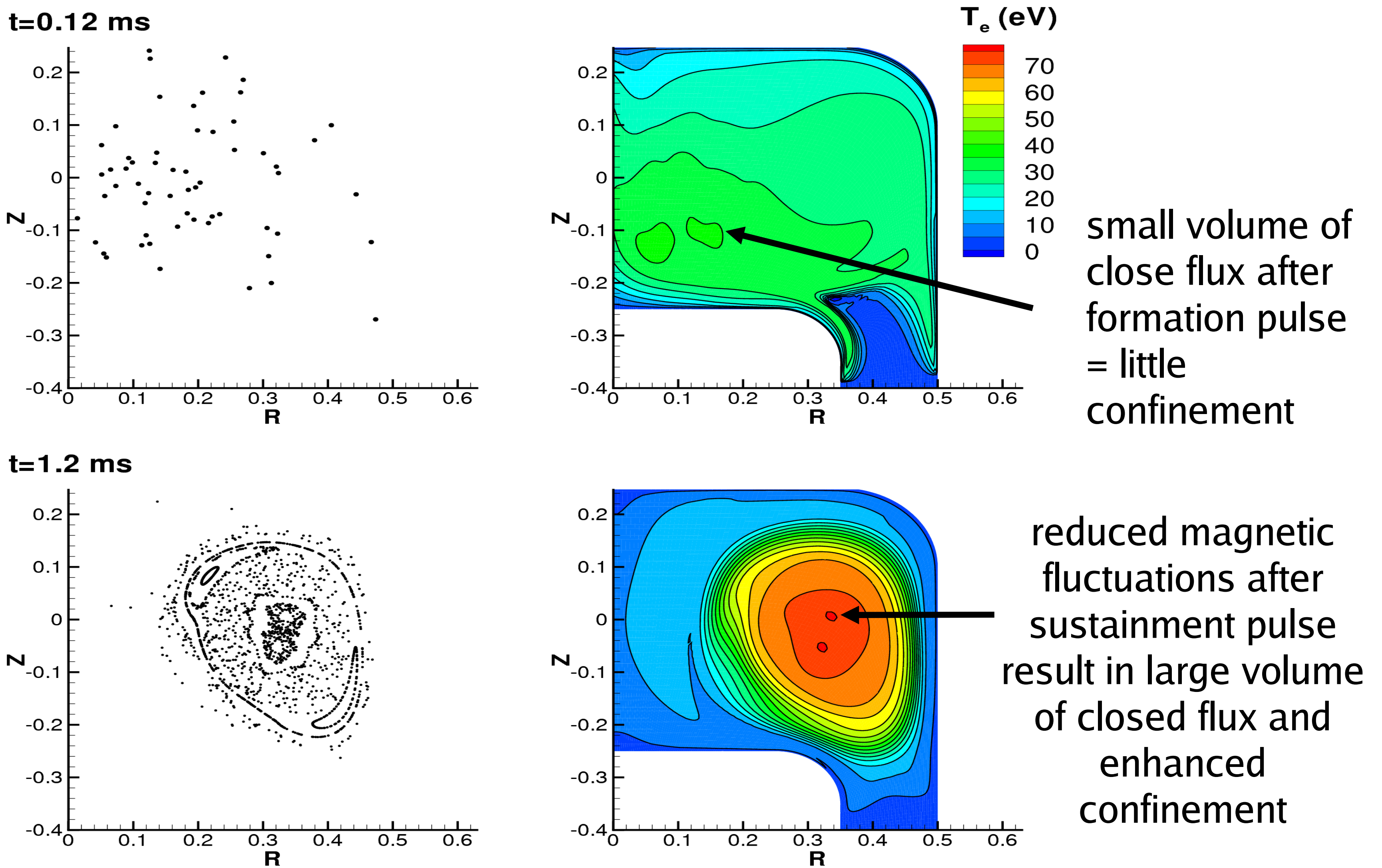
Analytical developments for integral closures

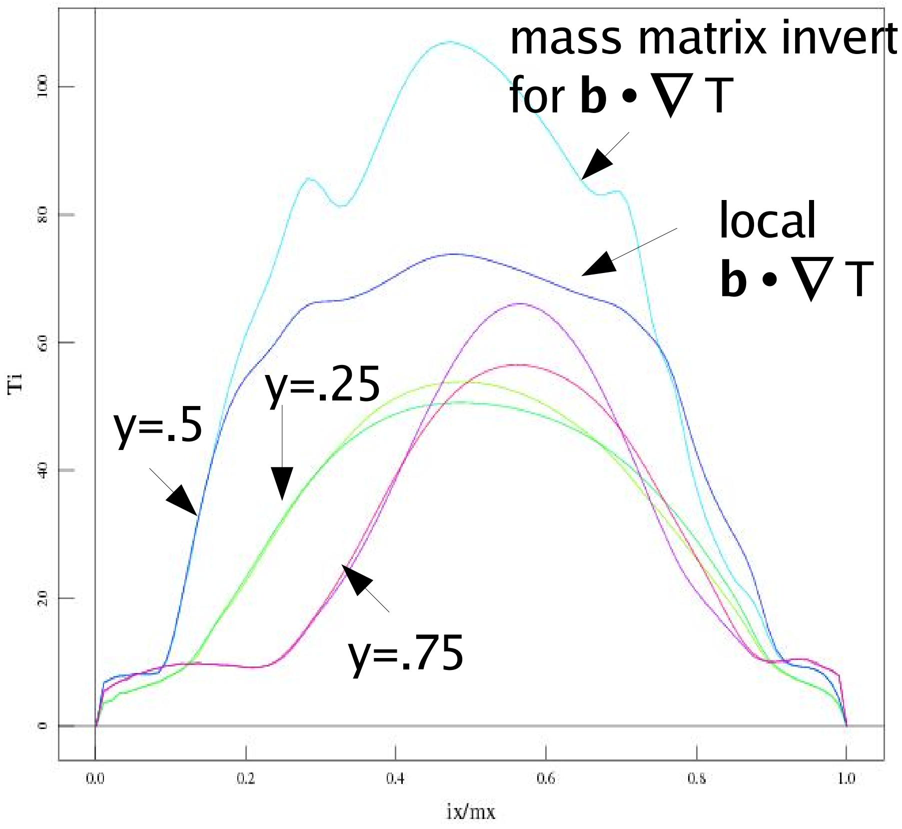
- Completed derivations:
  - collisional closures with higher-order corrections and comparison to Braginskii,
  - small-mass-ratio form for collision operator in moment expansion with arbitrary flow speeds,
  - complete CEL parallel closure model for slab geometry including off diagonal terms.
- Ongoing derivations:
  - neoclassical forms for CEL parallel closures with trapping in |B| wells,
  - parallel stress in higher-order moment model,
  - effect of RF on integral, parallel closures.

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

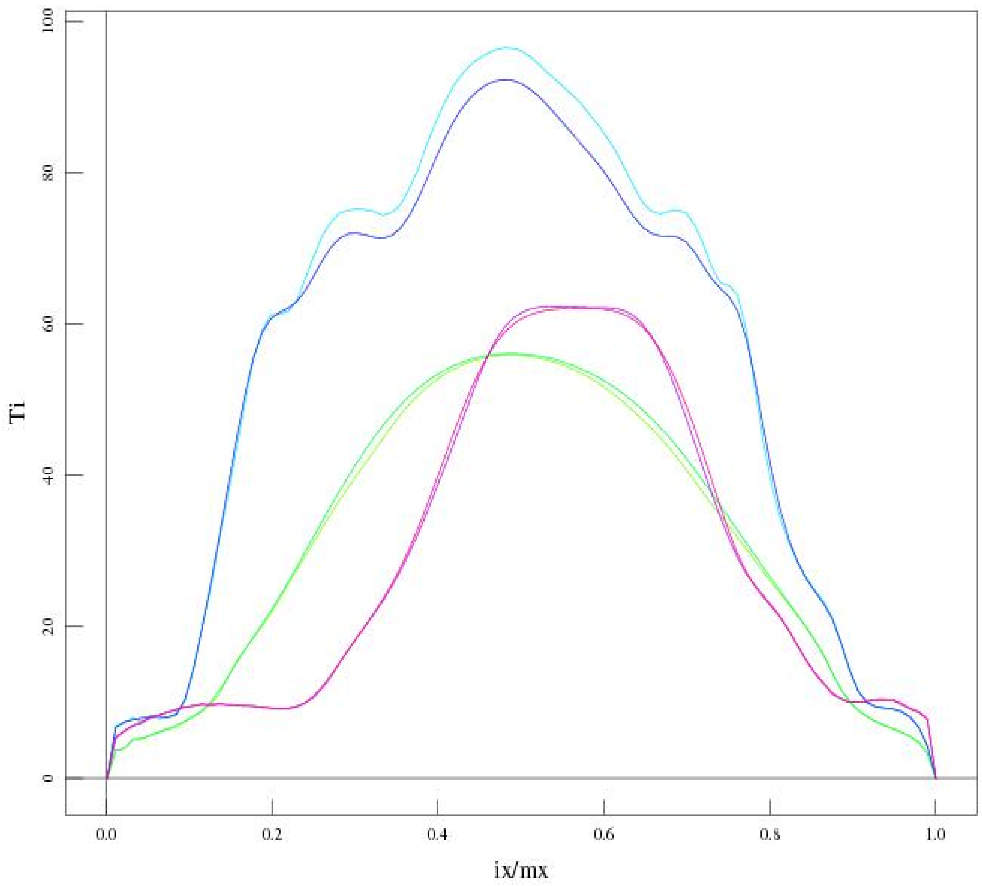


Added spatial resolution (mainly Fourier modes) brings reasonable convergence in T profiles.

6 Fourier modes, pd = 4, uniform

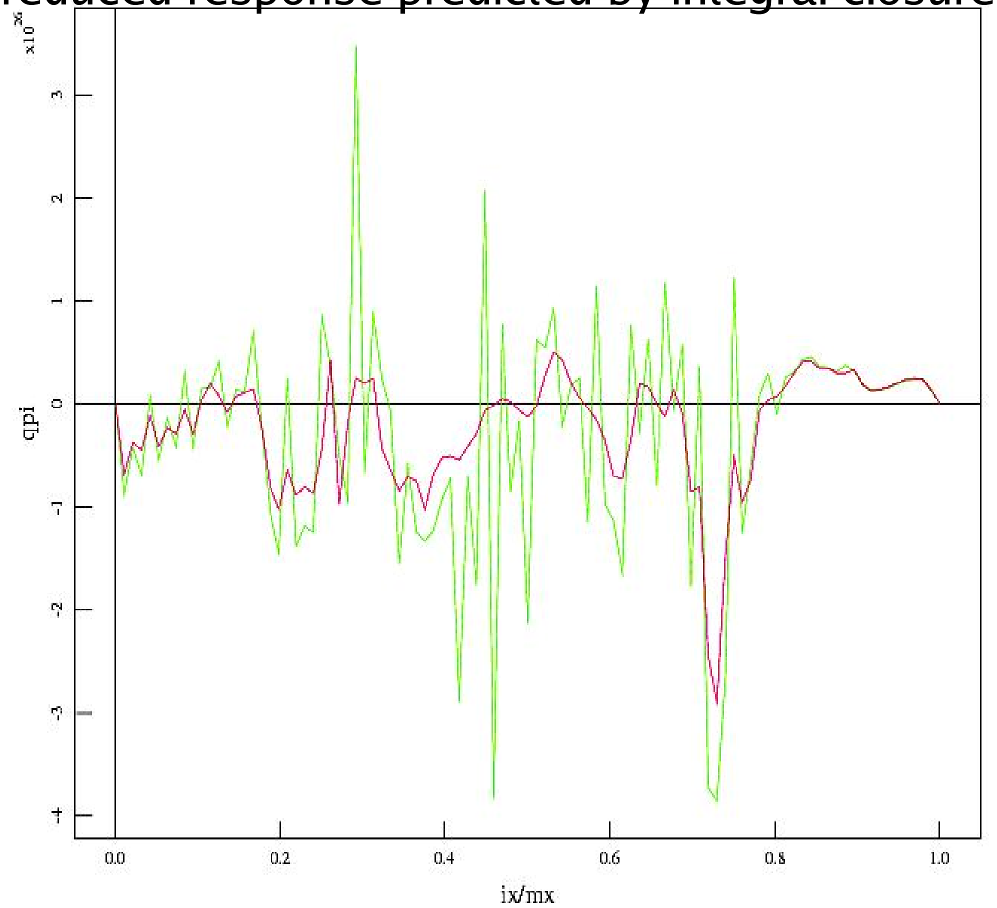


22 Fourier modes, pd = 4, gll

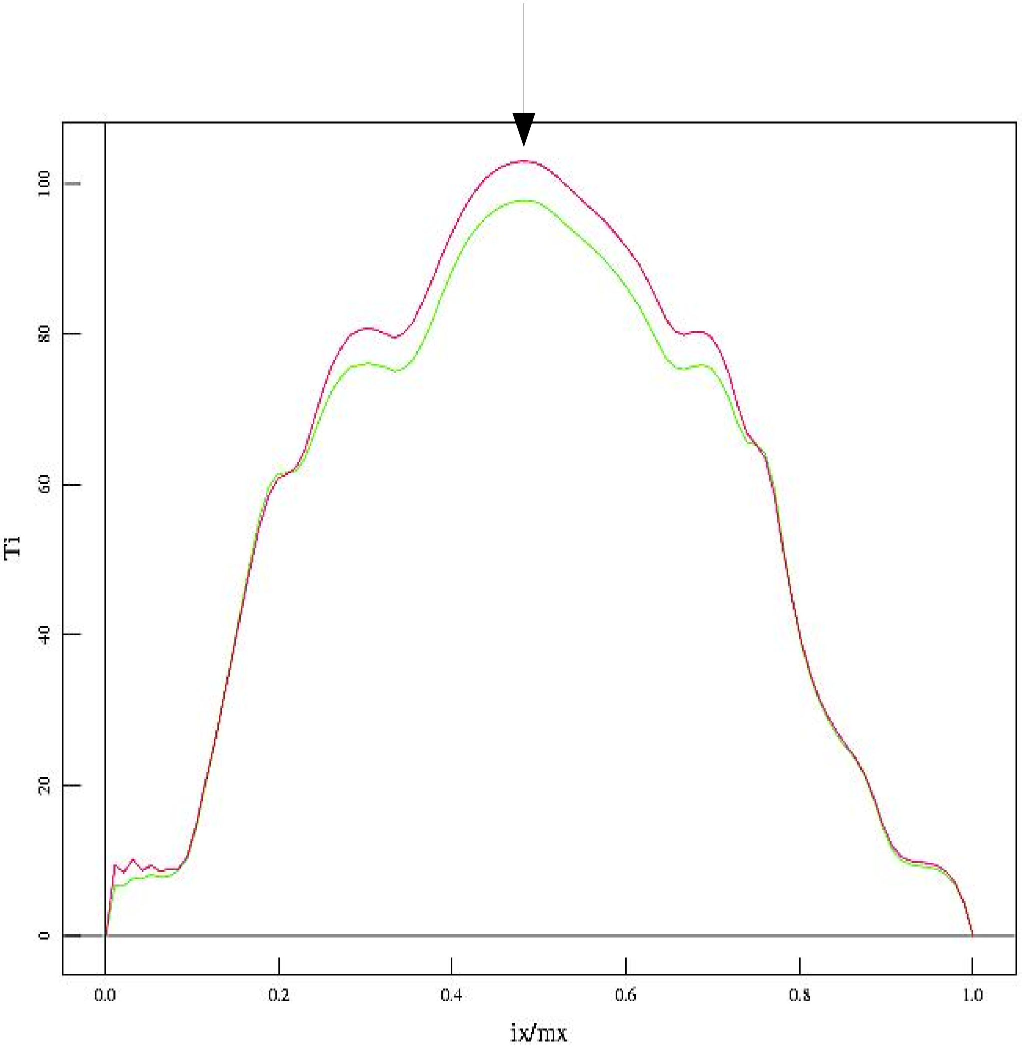


Compare steady-state $\mathbf{q}_{||}$ and T predictions from integral and Braginskii closure.

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



Predictions of core temperatures similar, however.



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.
- Develop Monte Carlo scheme for computing $\int dV\, \nabla\alpha \cdot \mathbf{q}_{||}$ or $\int dV\, \alpha\mathbf{q}_{||}$.

More on Monte Carlo approach...

- Multiply by test function, α, and integrate:
  $\int dx\ \alpha q_{||} \approx (1/N)\ \Sigma_{x} \left(\alpha q_{||}\right)|_{x}$.
- Use variance reduction techniques to reduce requisite number of closure calculations.
- Control variate method:
  $\int dx\ \alpha\ \left(q_{||} - \kappa_{||} \nabla_{||} T\right) + \int dx\ \alpha\left(\kappa_{||} \nabla_{||} T\right)$.
- Importance sampling:
  $\int dx\ \alpha\ \left(q_{||} / (\kappa_{||} \nabla_{||} T) - 1\right)\ d\left(\int dx'\ \kappa_{||} \nabla_{||} T\right)/dx$

Scaling of NIMROD with CEL closures needs improvement.

- Single root node collecting results from thousands of closure nodes.
- Synchronization issues with large group of closure nodes waiting for fluid advance.
- Constant set of root closure nodes exchanging global data with growing set of slave closure nodes.