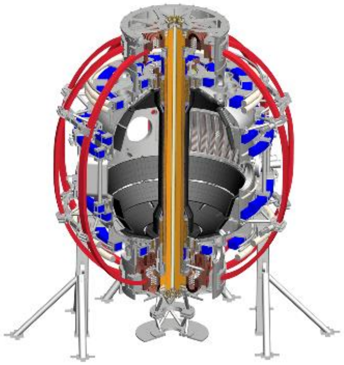
NSTX-U L-mode transport & turbulence analysis and simulations

W. Guttenfelder, R.E. Bell, A. Diallo, S. Ethier, S.M. Kaye, B.P. LeBlanc, M. Podesta, Y. Ren, S.A. Sabbagh, D.R. Smith, W.X. Wang, …

NSTX-U Results Review
9/22/2016



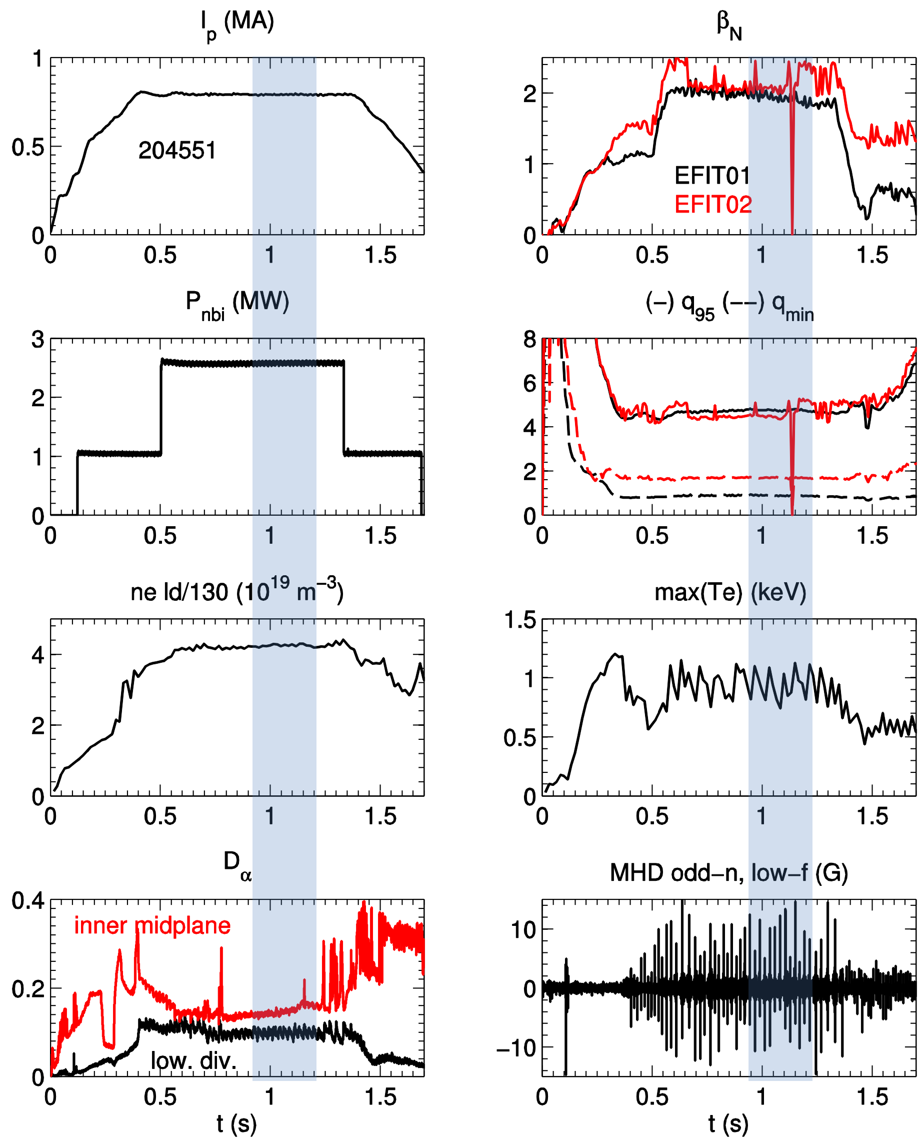
Motivation for L-mode transport studies

- Previous NSTX L-mode analysis using local and non-local gyrokinetic codes predict different results from relatively large $\rho_*=\rho_i/a\sim1/120$
  - Local GYRO ion-scale simulations predicts wide variation of predicted fluxes compared to exp. (Ren, Nucl. Fusion 2013)
  - Global GTS ion-scale simulations get close to predicting $Q_{i,exp}$; $Q_{e,sim}$ is far too small (Wang, Phys. Plasmas 2015)
  - GENE group working on similar global simulations (Bañón-Navarro, 2016)

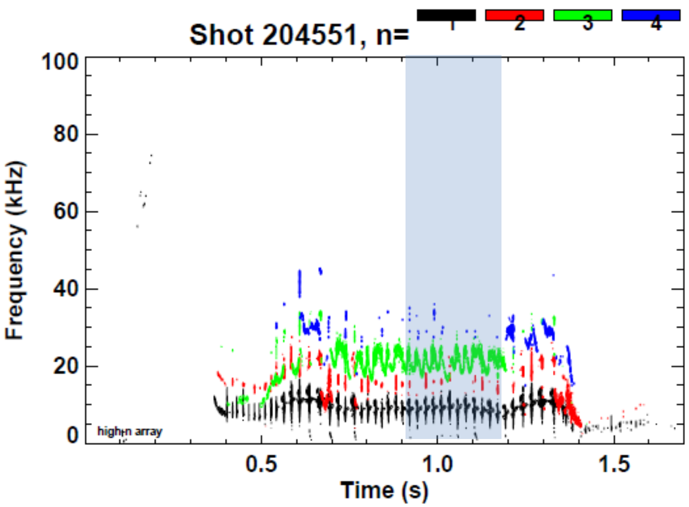
- Goal is to develop an NSTX-U L-mode shot for benchmarking and validating finite-ρ_* (non-local) effects in the electrostatic limit using numerous global gyrokinetic simulations (GTS, XGC1, GENE, GYRO, GEM, …)
  - Approved XP-1521 (Y. Ren)
  - Ultimately want to do the same with global EM predictions (significantly more challenging)

- **Using results from XMP-151 (L-mode development) for initial scoping**

Focusing on stationary, 800 kA L-mode (204551) $n_e \approx 4\times10^{19}$ m^{-3}, P_{NBI}=2.5 MW



- Long, stationary, sawtoothing discharge
  - No L-H-L transitions
  - No inner wall MARFE-like activity (as found in other L-modes)
- n=2 develops after 1.35s
  - Using time-average between 0.9-1.2 s for transport analysis and simulations

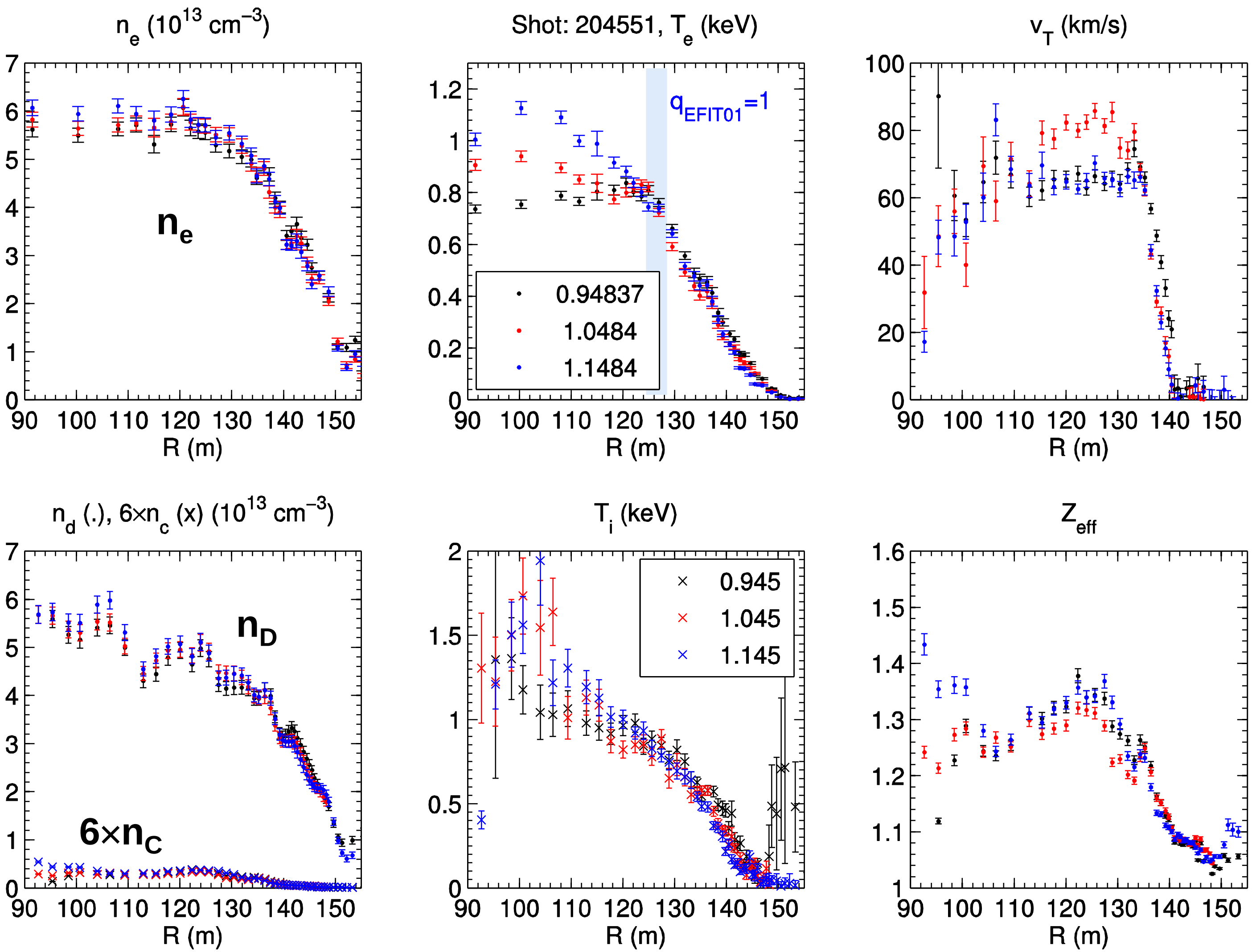


Example profiles during averaging window

- Effect of sawteeth obvious in T_e
  - Inversion radius ~125 cm consistent with EFIT01
- n_e, $v_{Tor,c}$, n_c all relatively flat inside inversion radius
- Rotation locked outside 140 cm? (from 2/1 mode?)

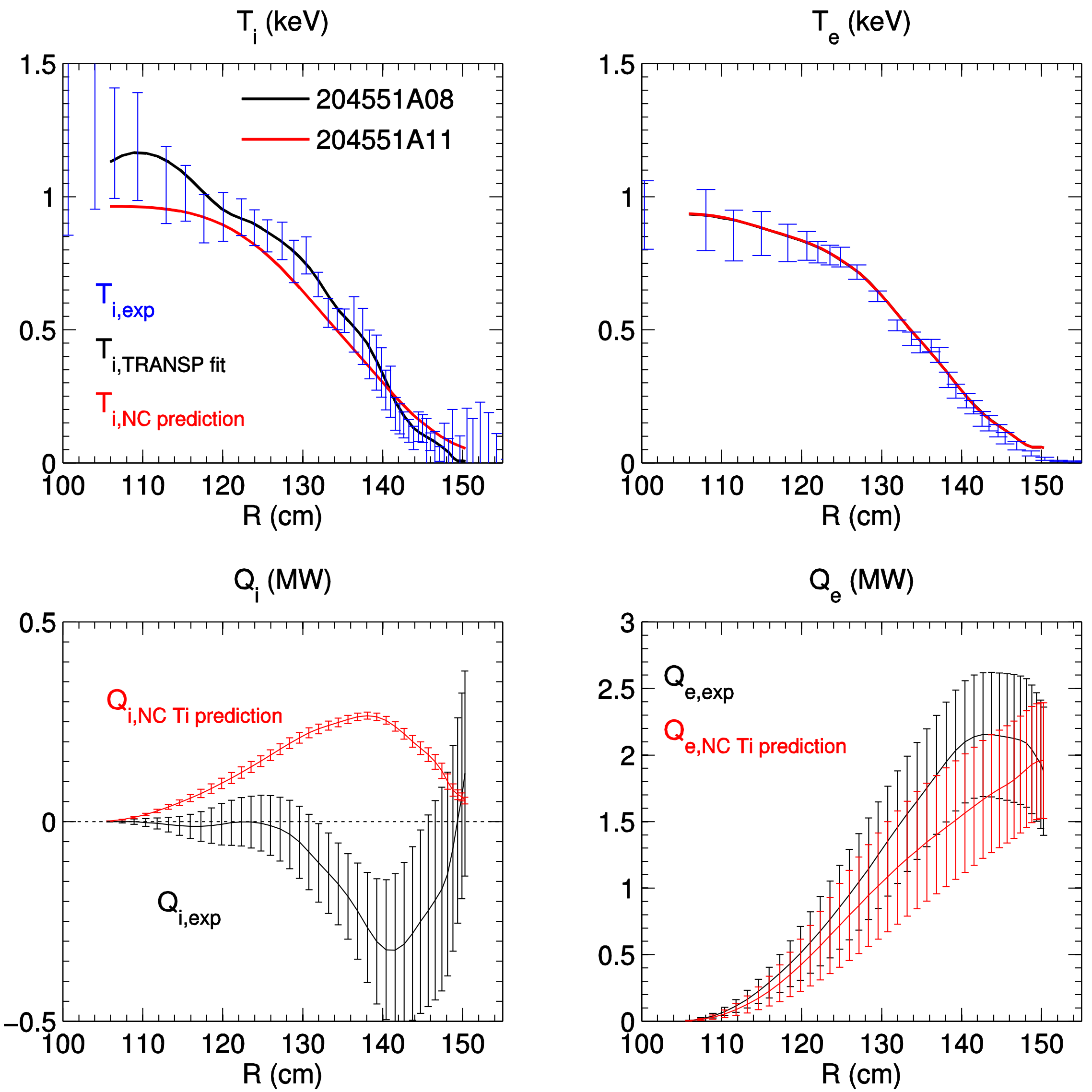
⇒ Very strong local flow shear

- Relatively low $Z_{eff,c}$~1.1-1.3 from carbon, but at P_{NBI}=2.5 MW reasonable CHERS signal over most of profile



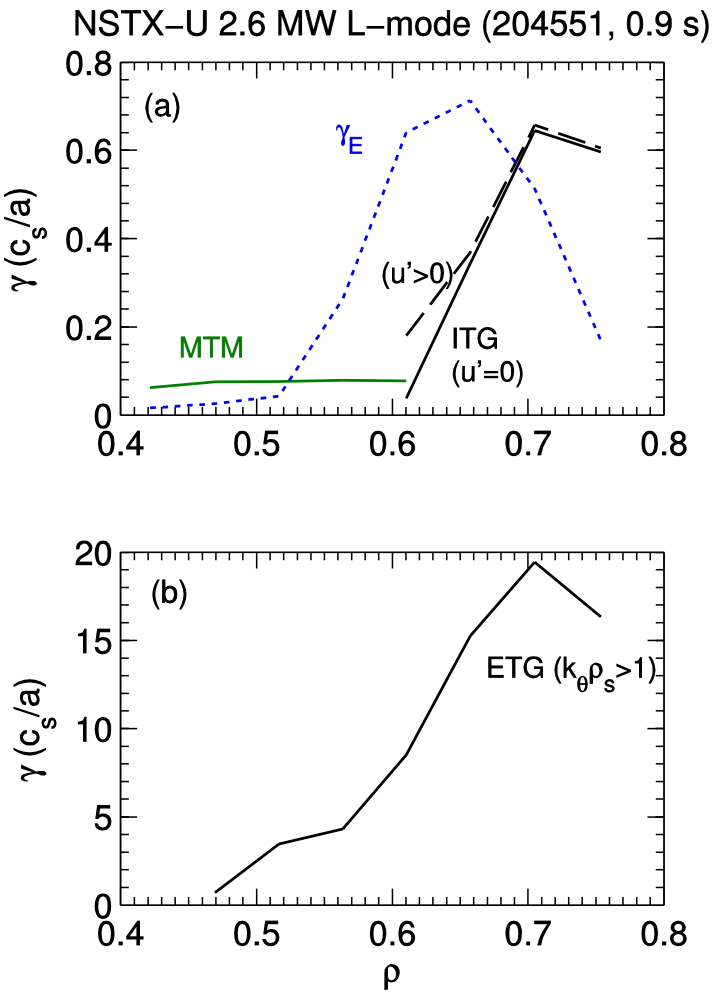
Ion transport likely neoclassical, Uncertainty in heat fluxes from strong collisional coupling

- Note: all quantities averaged over 0.9-1.2 s
  - "Error bars" represent statistical variation from sawtoothing, etc…
- Inferred ion heat flux is negative (up the T_i gradient), consequence of collisional coupling & $T_i/T_e>1$
  - Small tweaks in average T_e fit might resolve this
- Assuming purely neoclassical Q_i predicts T_i ~ 90% exp. T_i
  - ~0.5 MW uncertainty in Q_e, Q_i from strong e-i collisional coupling



Linear GK stability shows unstable MTM in core ($\rho\approx0.4$-0.6), unstable ITG and ETG farther outer ($\rho>0.6$)

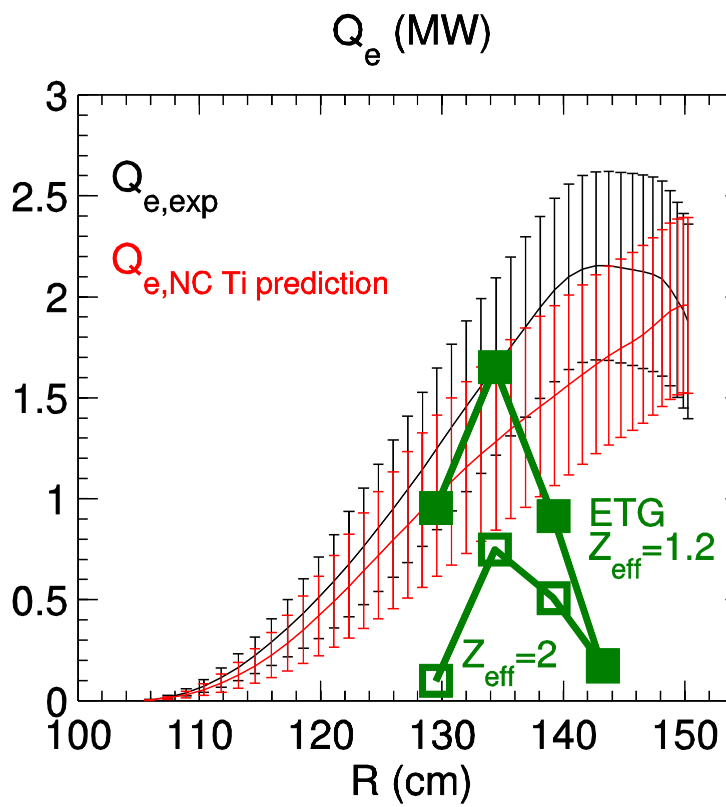
- Initially surprised to find MTM unstable ($\rightarrow$non-neglible EM effects in L-mode, $\beta_N\approx2$)
  - Large collisionality enhances MTM (Guttenfelder, PoP 2012)
- E$\times$B shearing rates (γ_E) bigger than ITG growth rates ρ=0.5-0.7 (R=131-141 cm)
  - Insignificant destabilizing influence of parallel velocity gradient (PVG, $u'=qR/r\cdot\gamma_E>0$)
- ETG linearly unstable across region of strong E$\times$B shear



R ≈ 126 cm **145 cm**

Initial nonlinear ETG simulations give significant transport around ρ=0.45-0.65

- $Q_{e,etg}$ large enough to account for $Q_{e,exp}$ if $Z_{eff}=Z_{eff,c}\approx1.2$
  - Larger Z_{eff} (from other impurities) would lower $Q_{e,etg}$
  - Will also test sensitivity to variations in $R/L_{Te} \sim \nabla T_e$



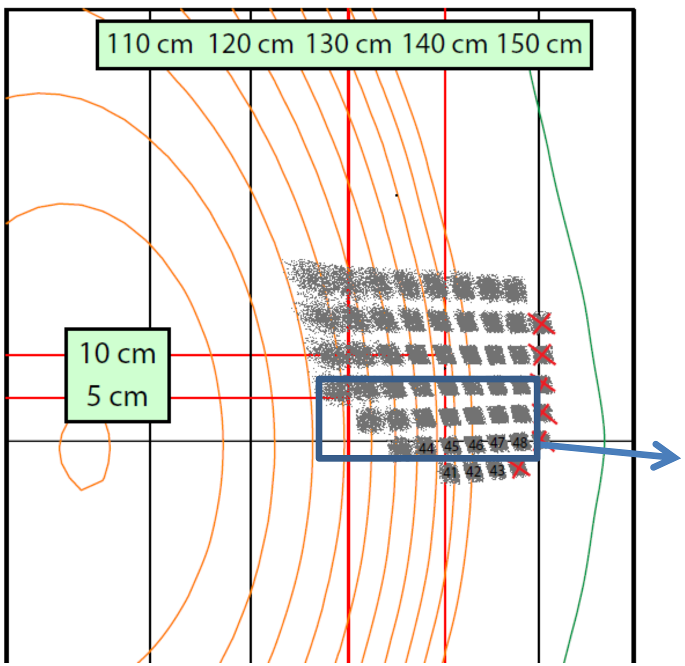
Local, nonlinear GYRO simulations

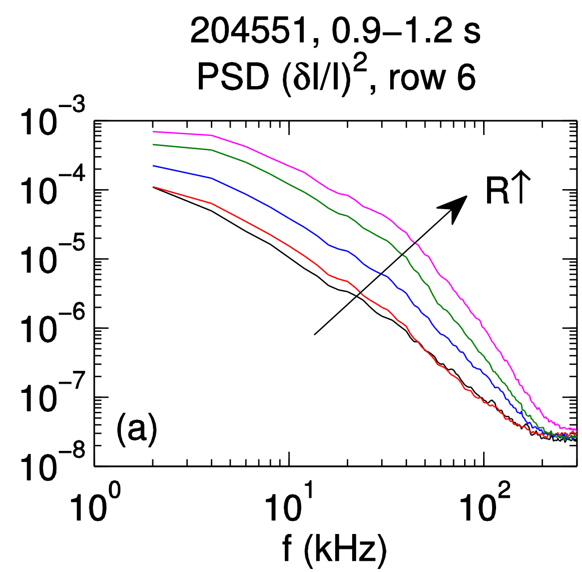
ρ ≈ 0.45 0.55 0.65 0.75

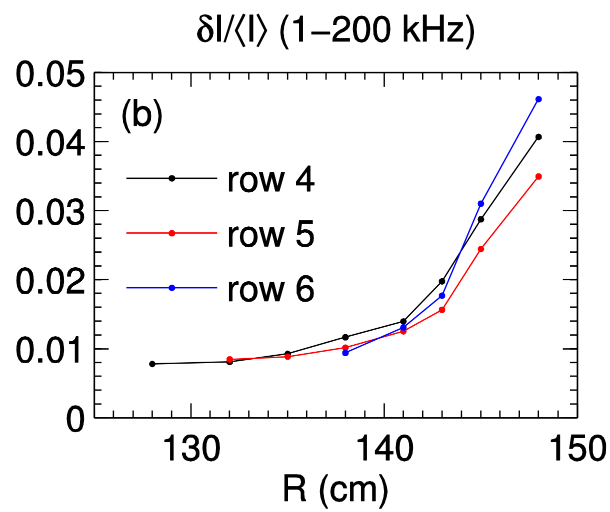
BES data shows broadband ion-scale fluctuations increasing in amplitude >140 cm

- Broadband fluctuations (f<200 kHz) with $\delta I/I$ = 1-4% (R≈128-148 cm, $\rho \approx 0.45$-0.9)
- Ion turbulence may be more important $\rho > 0.7$ (where $\gamma_{ITG} > \gamma_E$) → considering GTS runs

Smith (2016)

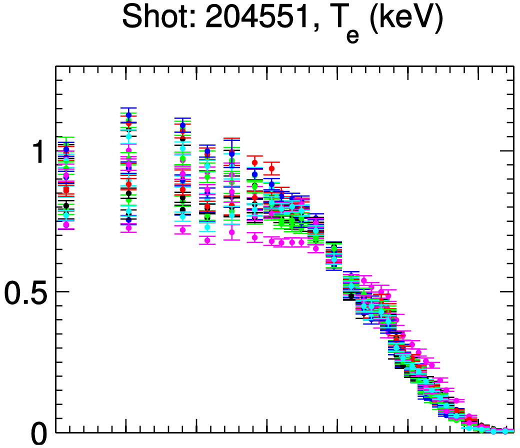


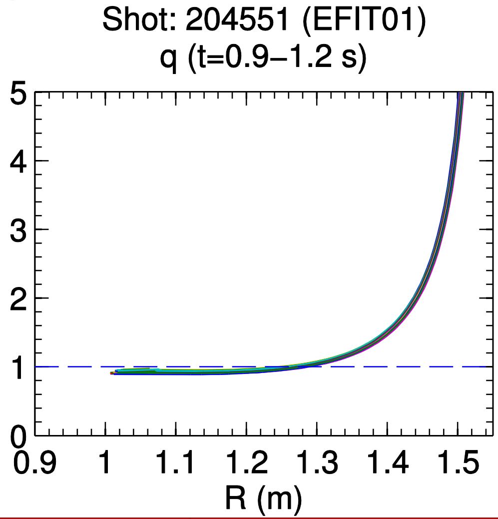


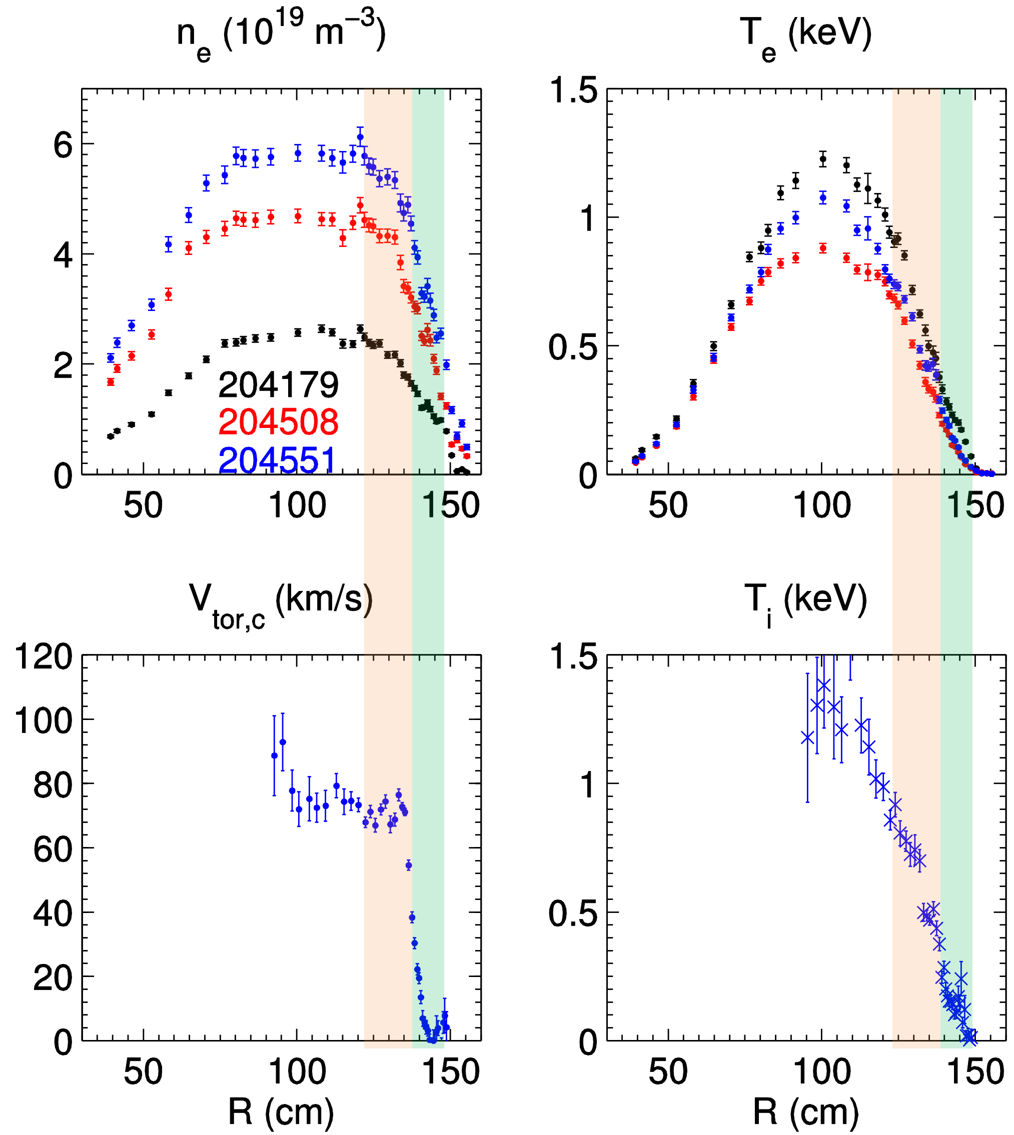


Profiles, sawteeth

- $Z_{eff,c} \approx 1.2$
- R=128-138 cm (r/a=0.5-0.7, ρ≈0.45-0.66)
- R=138-148 cm (r/a=0.7-0.95, ρ≈0.66-0.9)

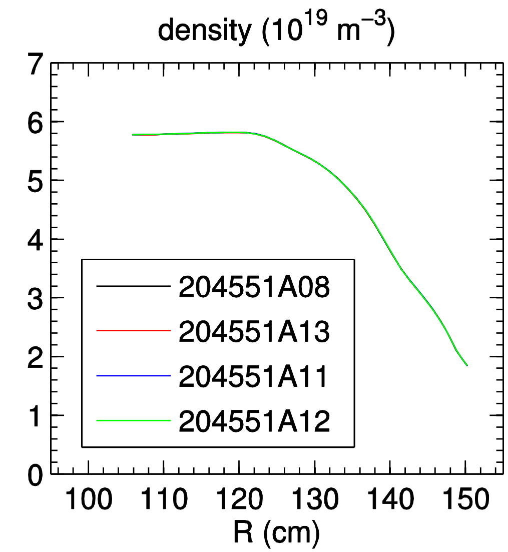


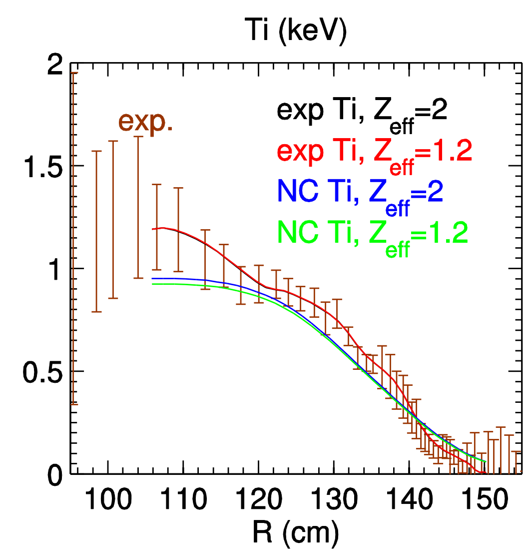


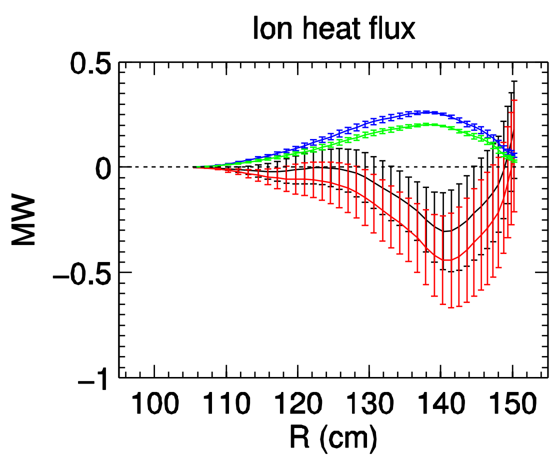


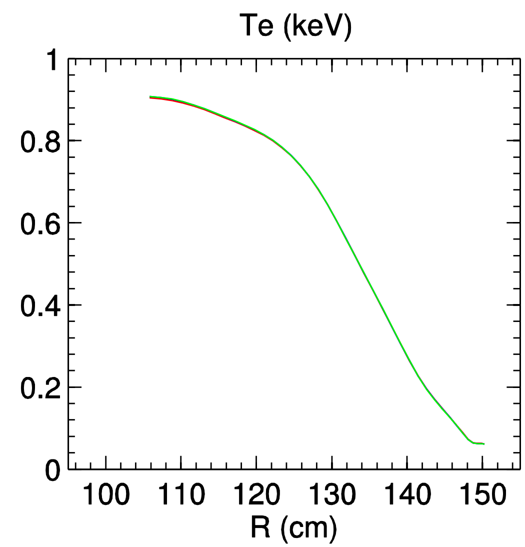
Comparing heat fluxes and T_i profiles (exp. and NC) from TRANSP (Z_{eff}=2 & 1.2; exp. & NC T_i)

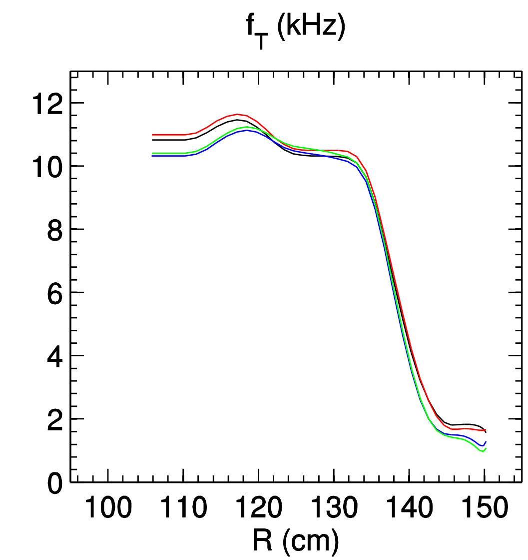
- All profiles are time-averaged 0.9-1.2 sec
- Reducing $Z_{eff}=2 \rightarrow 1.2$ changes heat fluxes more negative
- Neoclassical (Chang-Hinton) prediction of T_i is smaller than experiment by ~10-15%
- **(1) Try NEO Ti prediction**
- **(2) Try 0.85-0.9$\times\chi_{i,C\text{-}H}$**



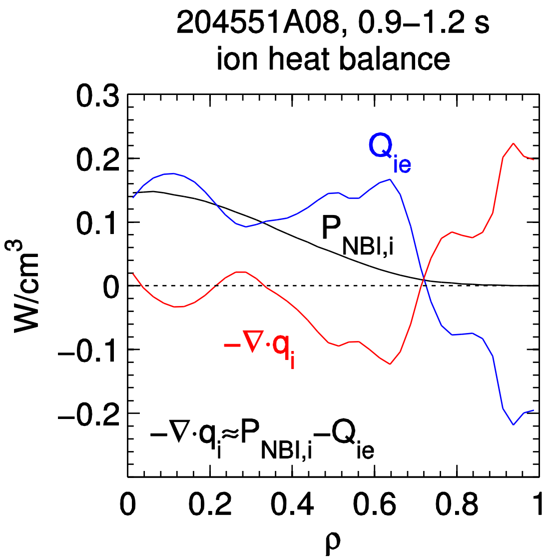


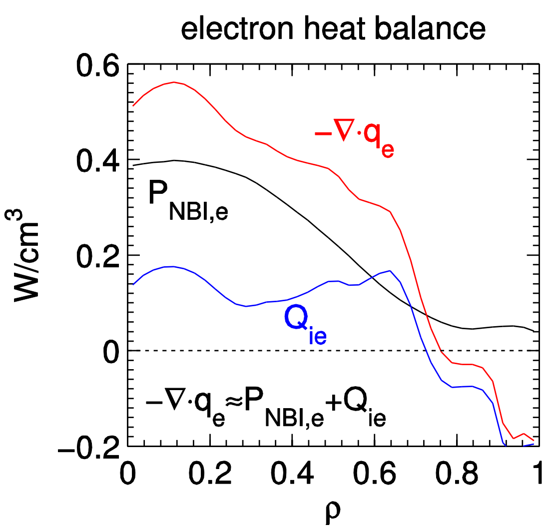


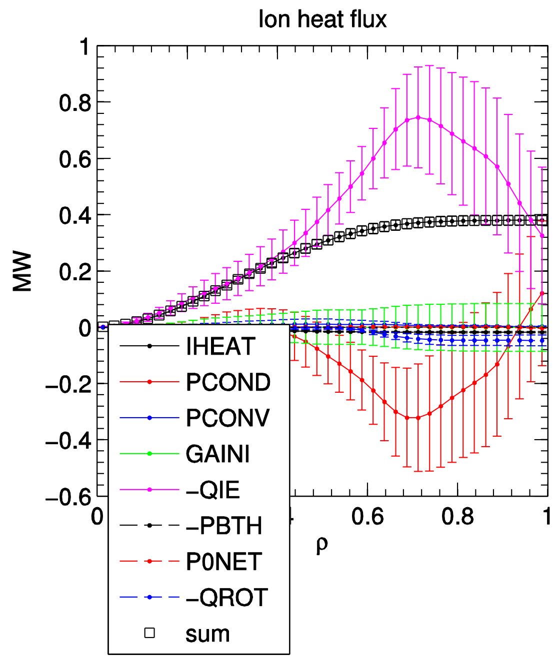


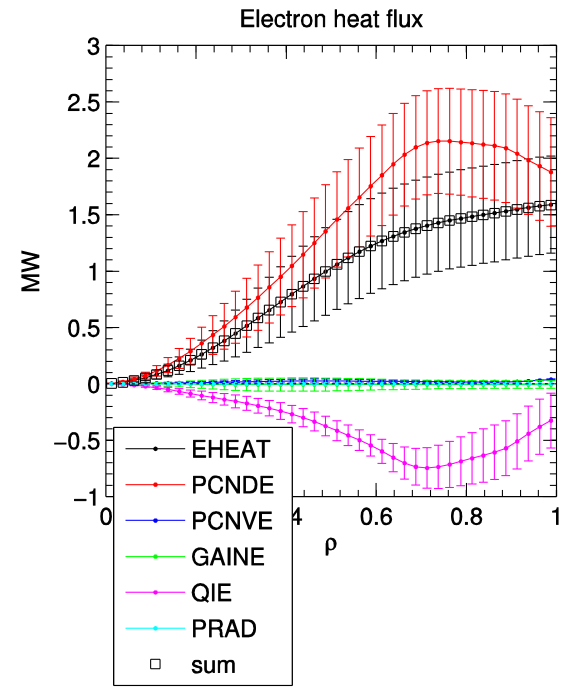


Power balance (204551, 0.9-1.2 sec)









Uncertainty in ETG $(R/L_{Te})_{crit}$ from Z_{eff}

-