Gyrokinetic simulations of electron density fluctuations and comparisons with measurements

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- Nonlinear gyrokinetic simulations can predict turbulent-driven energy, momentum, and species transport and fluctuations
- Comparisons of simulations with transport and fluctuation measurements help verify the simulations
- This talk compares simulations of a JET L-mode using the GYRO code with transport analysis and reflectometry measurements
- Encouraging agreement is achieved

Reflectometry measurements

- Tunable microwave reflectometers operating in X-mode ($\boldsymbol{E \perp B_{TF}}$)

  1. JET: 92-96 and 100-106 GHz

- Density fluctuation $\tilde{n}_e(r)$ RMS levels
- Radial correlations of $\tilde{n}_e(r)\tilde{n}_e(r')$ and correlation length λ_r
- Power spectra Fourier Transform of $\tilde{n}_e(t)\ \tilde{n}_e(t')$
- Refs:

  1. Mazzucato and Nazikian, Phys. Rev. Lett **91** 045001 (2003)
  2. Mazzucato, Nazikian, Scott, 22 EPS (Bournemouth, 1995)
  3. Valeo, Kramer, Nazikian, Plasma Phys. Control. Fusion **44** L1 (2002)
  4. Fonseca *et al.*, Poster NP8.00103

Analysis and simulation tools

- TRANSP

  1. analyze plasmas for transport analysis and plasma profiles

- TRGK $\equiv$ TRANSP-postprocessor $\equiv$ GYRO-preprocessor

  1. generates inputs for GYRO

- GYRO

  1. time evolution of potential and distribution functions of kinetic species
  2. 3 spatial and 2 phase space dimensions

- SCHRADO2

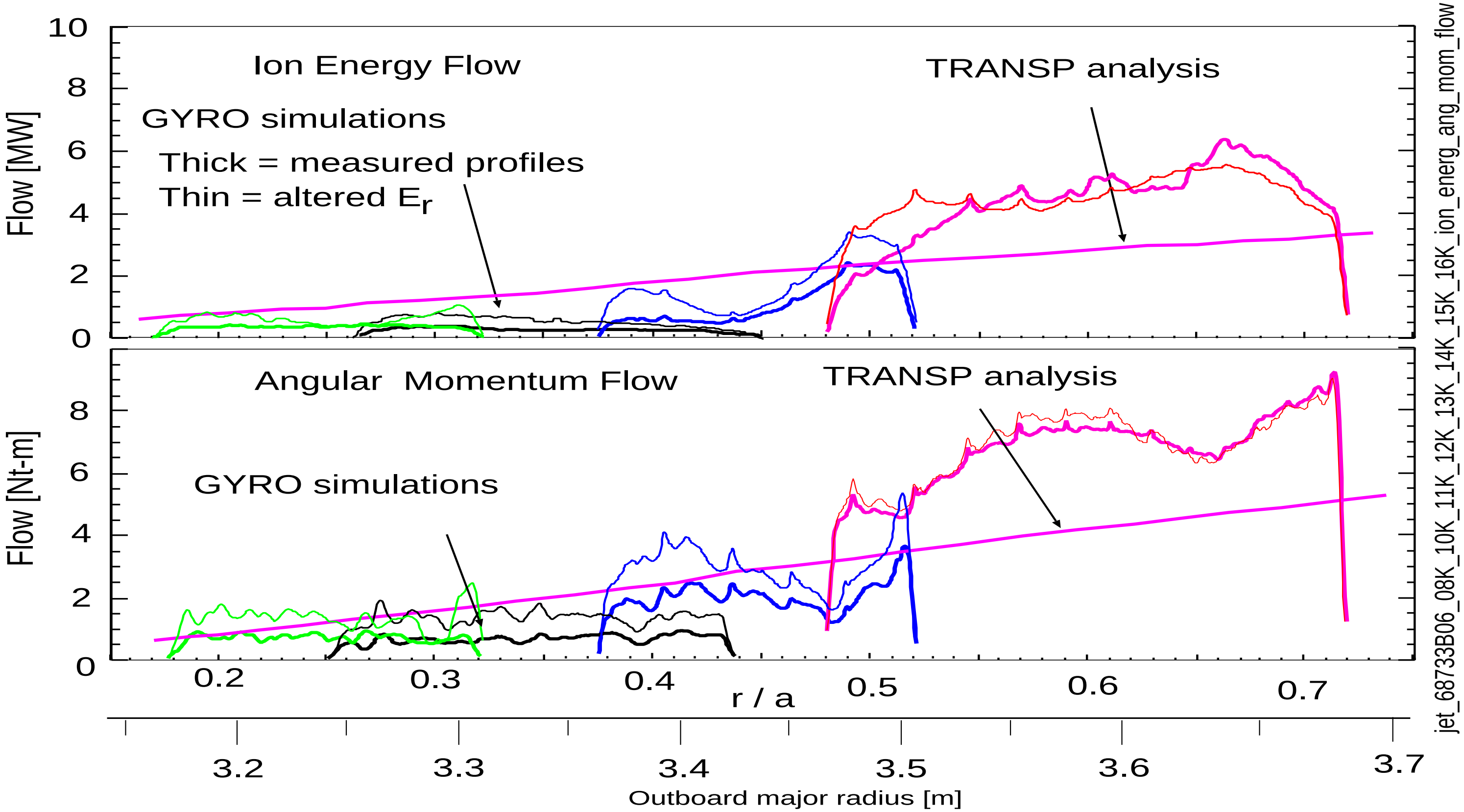
  1. Full-wave 2D scattering from density cut-off region

GYRO simulations

- Nonlinear runs to saturation of ITG/TEM turbulence ($k_\theta \rho_s$ < 1.0)
- Kinetic electrons and 2 kinetic ion species (bulk and combined impurities)
- Extended radial domain
- Most runs in the electrostatic approximation
- Achieved mixed success simulating radial flows of energy, species, and toroidal angular momentum in DIII-D, JET, and TFTR plasmas
- Here we focus of simulations of transport and density fluctuations $\tilde{n}_e$
- JET 68733 with B_{TF}=3.4T, I_p=2MA, P_{NB}=5.9MW, P_{RF} < 2MW

Approximate agreement for ion energy and angular momentum flows

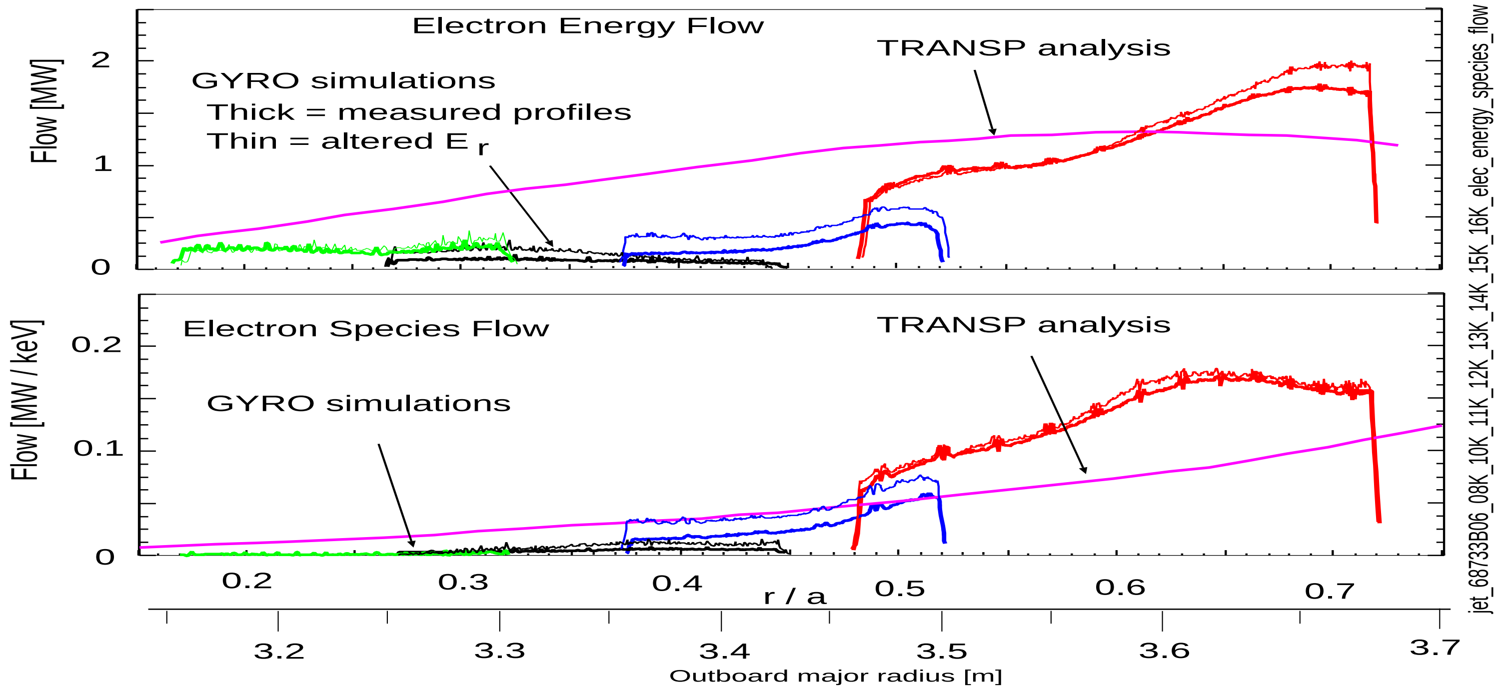
- TRANSP analysis for ion energy and angular momentum flows
- Varied E_r flow shearing and up/down 20 percent to study sensitivity



Approximate agreement for electron energy and species flows

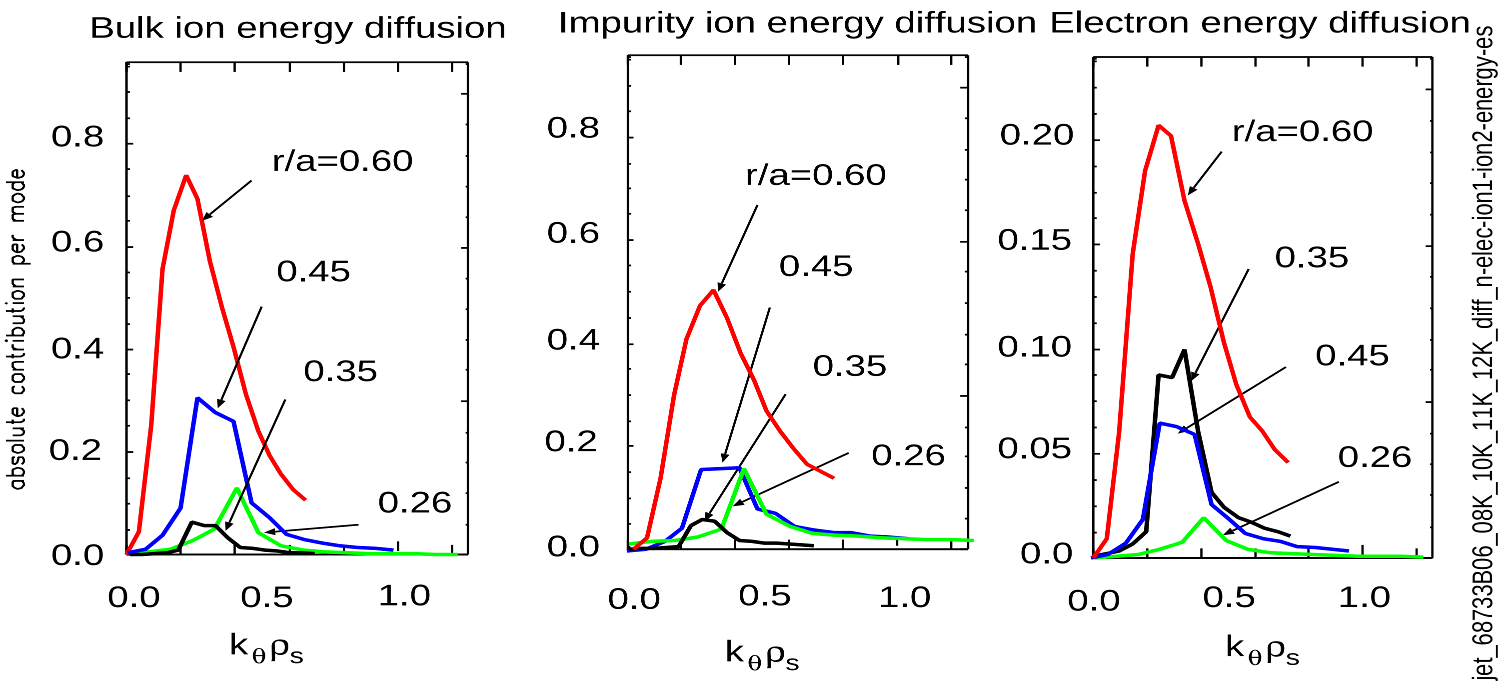
TRANSP analysis for electron energy and species flows

- Again varied results from inferred E_r flow and scaled up/down 20 percent



Why are simulated flows low in interior, high outside?

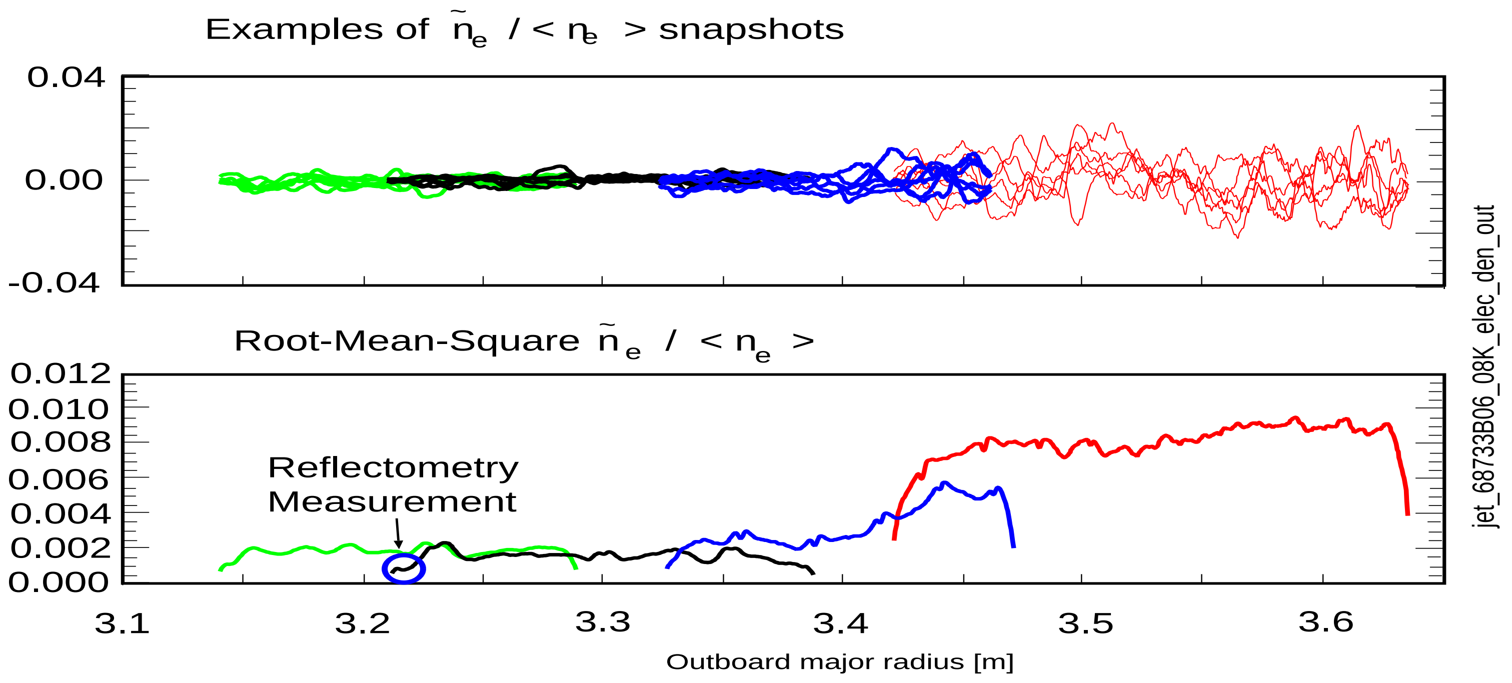
- Compare mode spectra at different radii



- Simulations very close to marginal near core
- Implies strong sensitivity to drive and suppression terms (plasma gradients and E_r flow shear)

Simulated $\tilde{n}_e$ fluctuations consistent with reflectometry

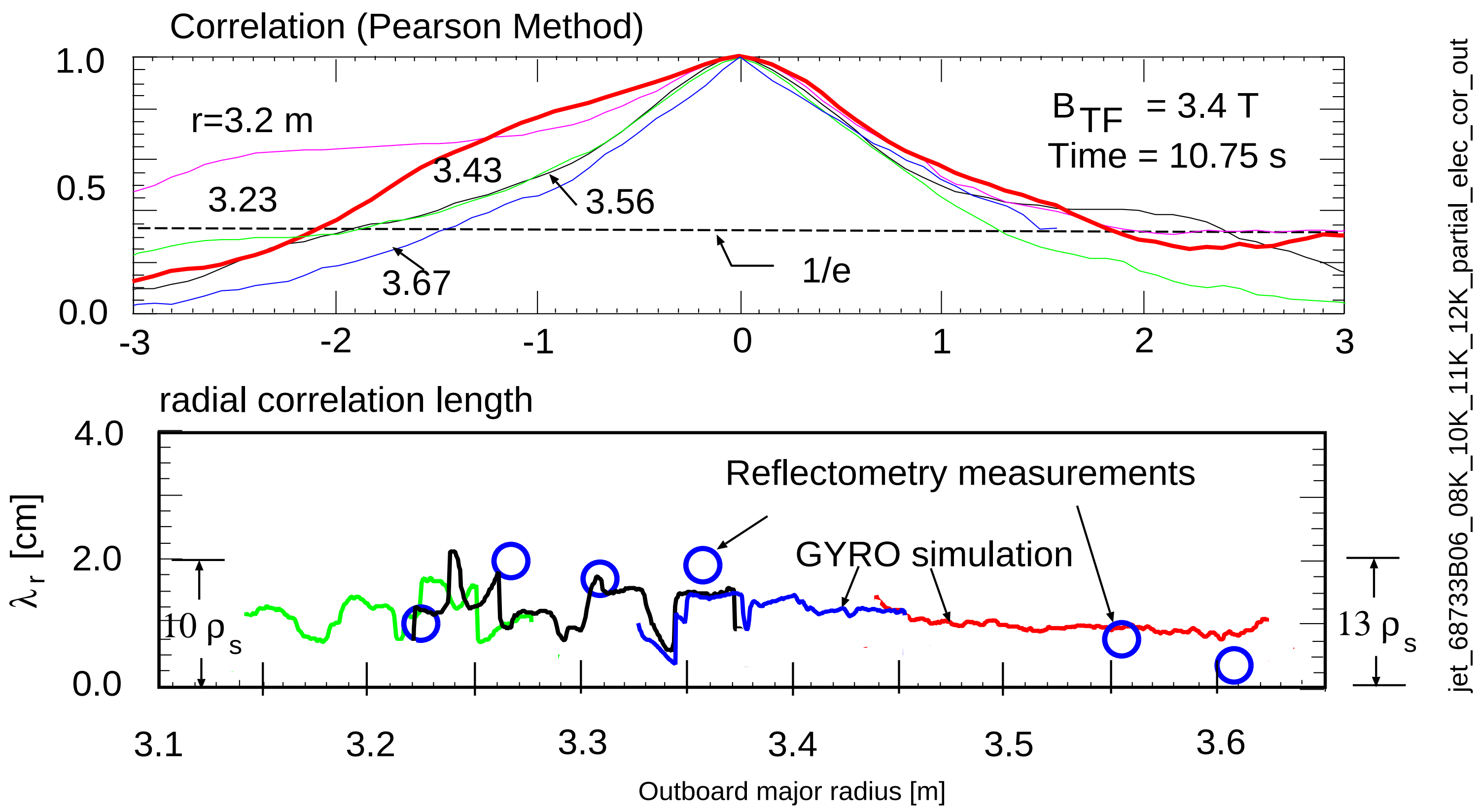
- Integrate electron distribution to get $\tilde{n}_e$ in 3D and time
- Use postprocessor to get $\tilde{n}_e(r, \theta, \phi = 0, t)$
- Compute Root-Mean-Square along outer mid-plane ($\theta = 0$)



- Both simulation and measurement are less than about 0.2%

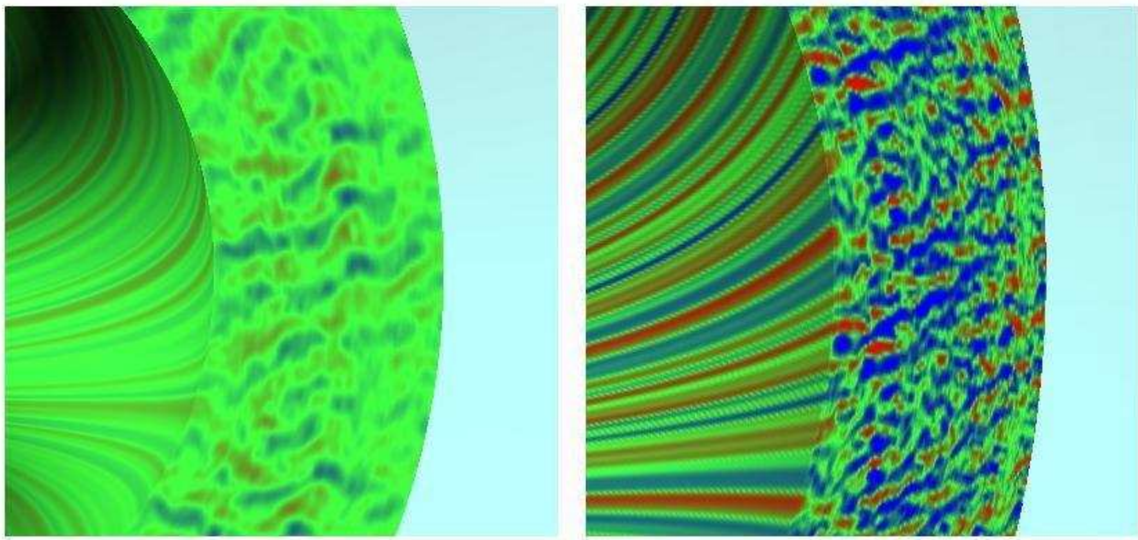
Radial correlation consistent with reflectometry

- Correlation of $\tilde{n}_e(r_1, t)$ and $\tilde{n}_e(r_2, t)$
- λ_r defined by Δr where correlation decreases below 1/e
- Magnetic axes at 2.97m and outboard separatrix at 3.85m



Animation

- Plan to place two 2D animations of $\tilde{n}_e$ at R=3.22 and 3.55m here



GYRO Simulation of $\tilde{n}_e$ in Jet 68733

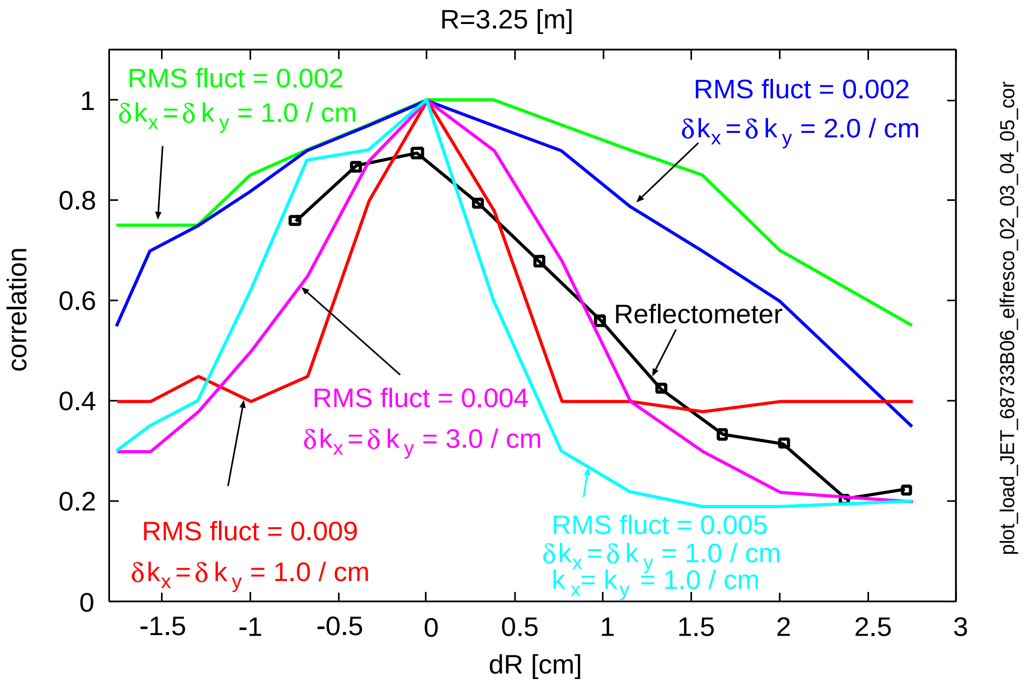
R = 3.22 m	R = 3.53 m
r/a = 0.26	r/a = 0.60
$n_e = 2.58 \times 10^{19}/m^3$	$n_e = 1.80 \times 10^{19}/m^3$
RMS($\tilde{n}_e/n_e$) = 0.002	RMS($\tilde{n}_e/n_e$) = 0.009
λ_r = 1.0 cm	λ_r = 0.9 cm

How to improve the measurements

- Calculate full wave reflections

  1. Simulate fluctuations near cut off
  2. Later: Input GYRO simulations of $\tilde{n}_e(r)$

- Simulate measurements assuming 2D scattering from Gaussian fluctuations



Summary

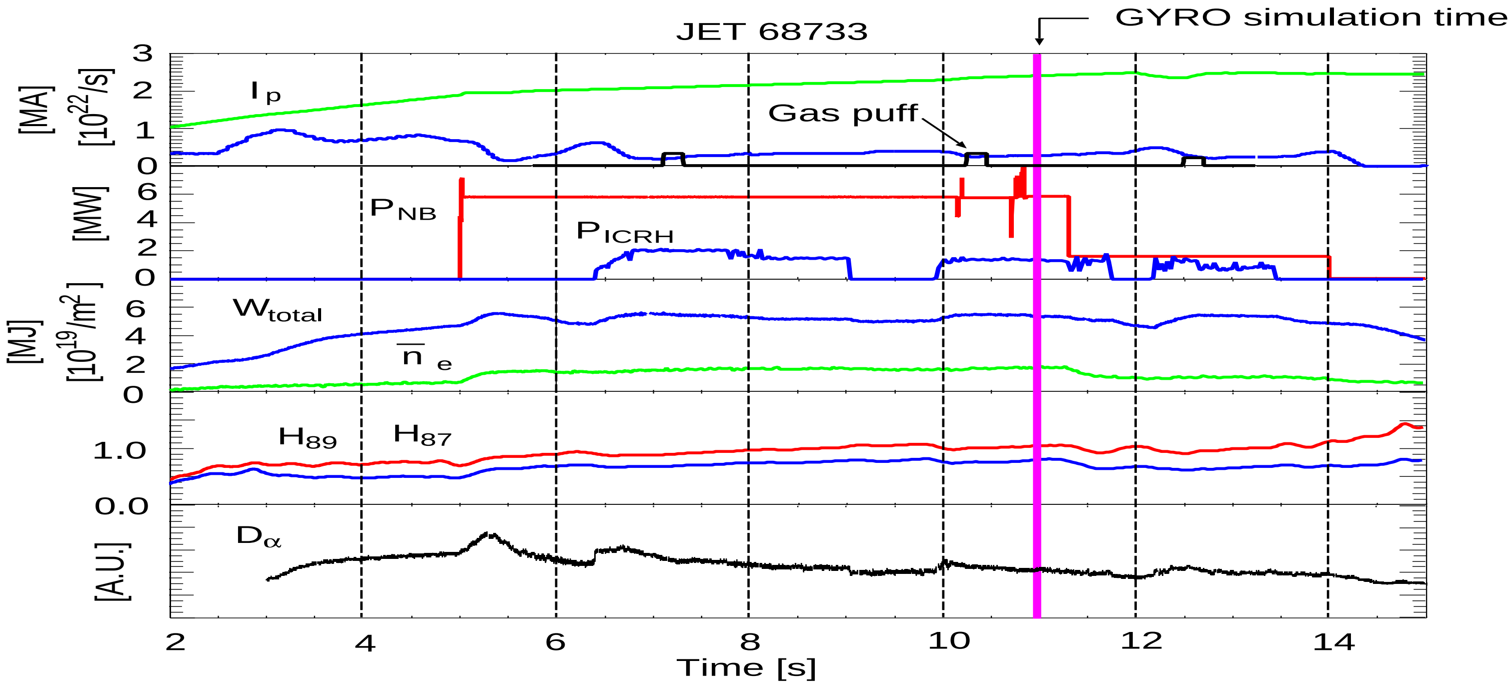
- Completed nonlinear gyrokinetic simulations of density fluctuations over extended radial domains
- Found approximate agreement between simulations and measurements of transport and $\tilde{n}_e$ in JET L-mode
- Also found similar agreement with companion shot at higher B_{TF} (3.8T) approximately consistent with ρ_* scaling
- Recent simulations using 2D full-wave scattering consistent with measurements

Backup info

- For questions

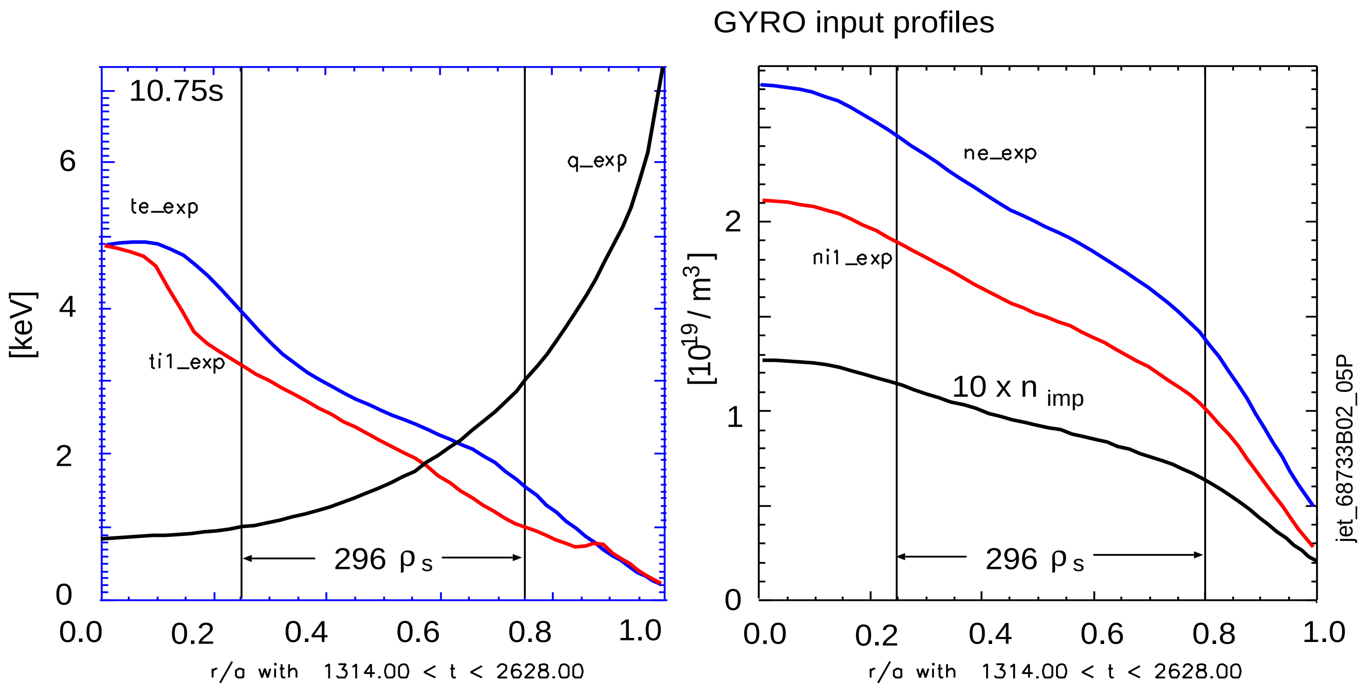
Example of JET shot

- L-mode heated by NBI and fundamental D-ICRH
- $B_{TF} = 3.4T$, $I_p = 2.0MA$, $\kappa = 1.6$, $\delta = 0.2$,
- $P_{nbi} = 5.9MW$, P_{ICRH} < 2 MW, $f_{GW} = 0.3$, $\beta_n = 0.45$



Example of GYRO inputs

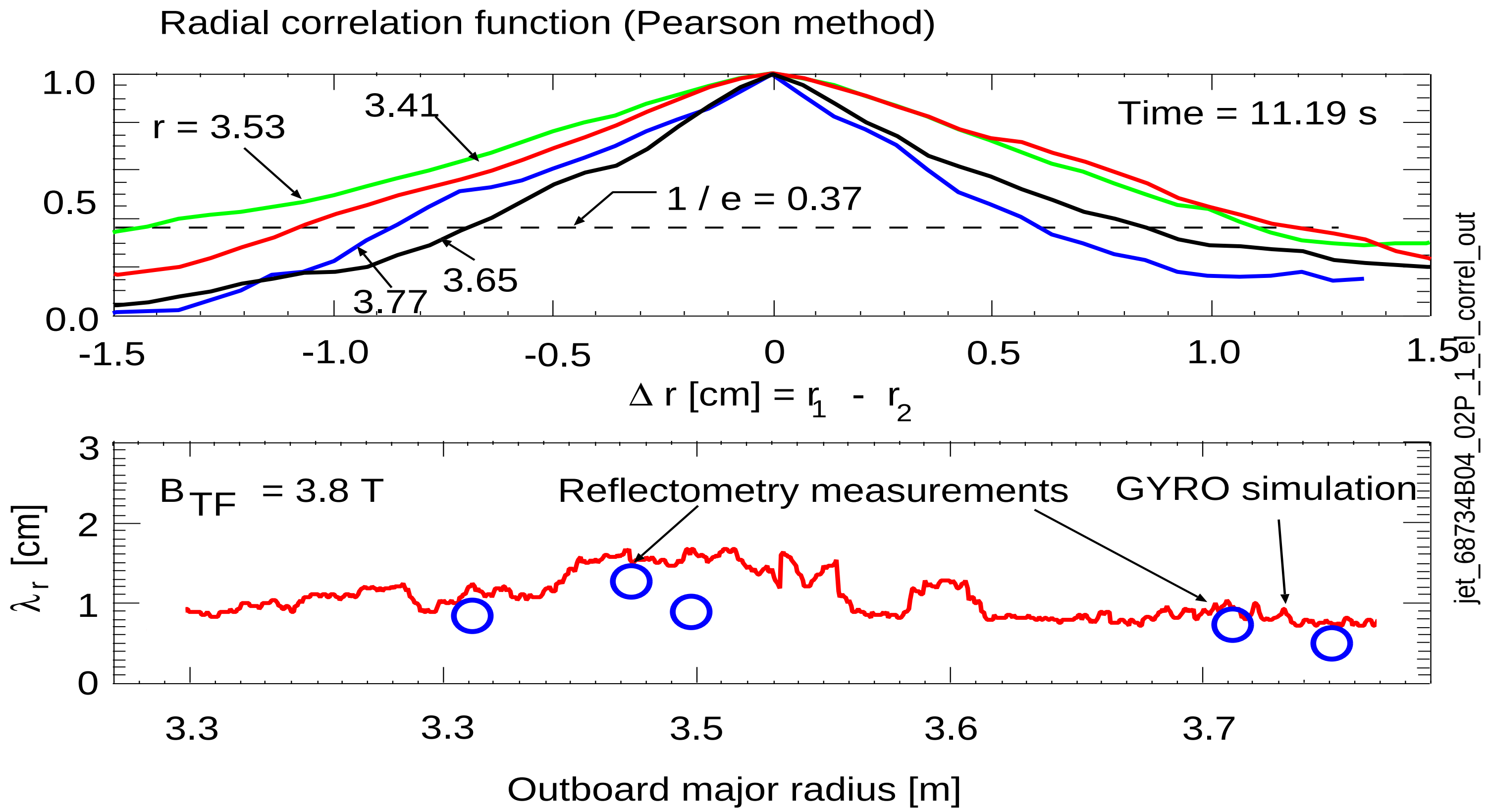
- Measured profiles mapped by TRANSP



- Simulate extended radial domain to allow turbulence room to saturate
- Domain width > > ρ_s (ion sound speed gyro-radius)

Similar levels of agreement in another JET L-mode

- Similar to previous shot, but B_{TF}: 3.4 $\longrightarrow$ 3.8 T



- Note smaller λ_r at higher B_{TF}

How to improve the measurements

- Calculate full wave reflections

  1. Simulate fluctuations near cut off
  2. Input GYRO simulations of $\tilde{n}_e(r)$

- Simulate measurements