Toroidal and poloidal momentum transport studies at JET

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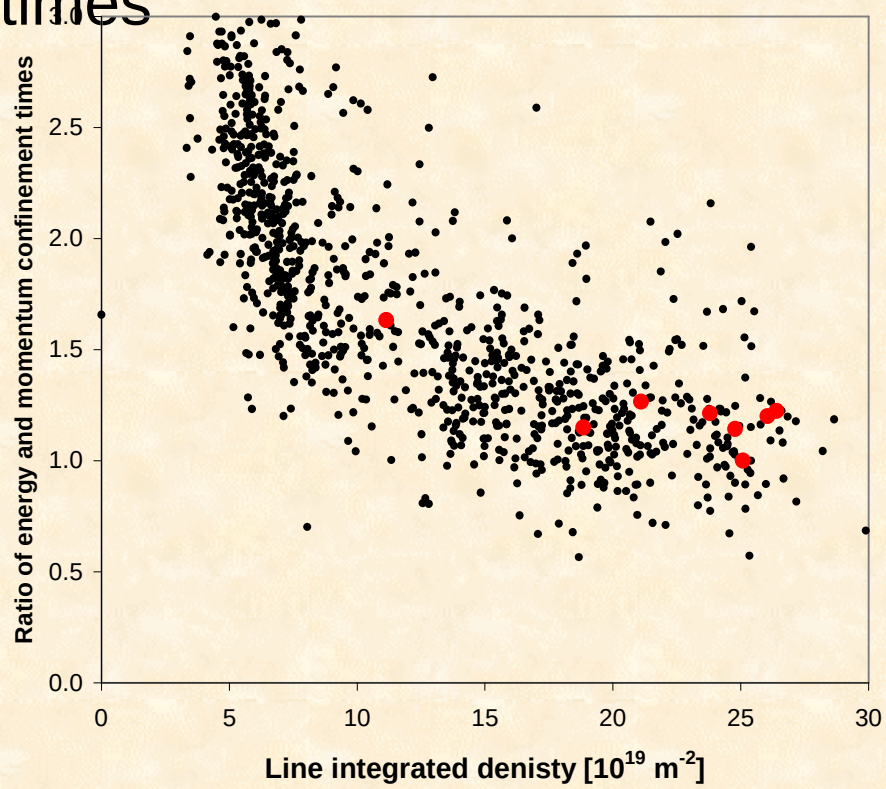
INTRODUCTION

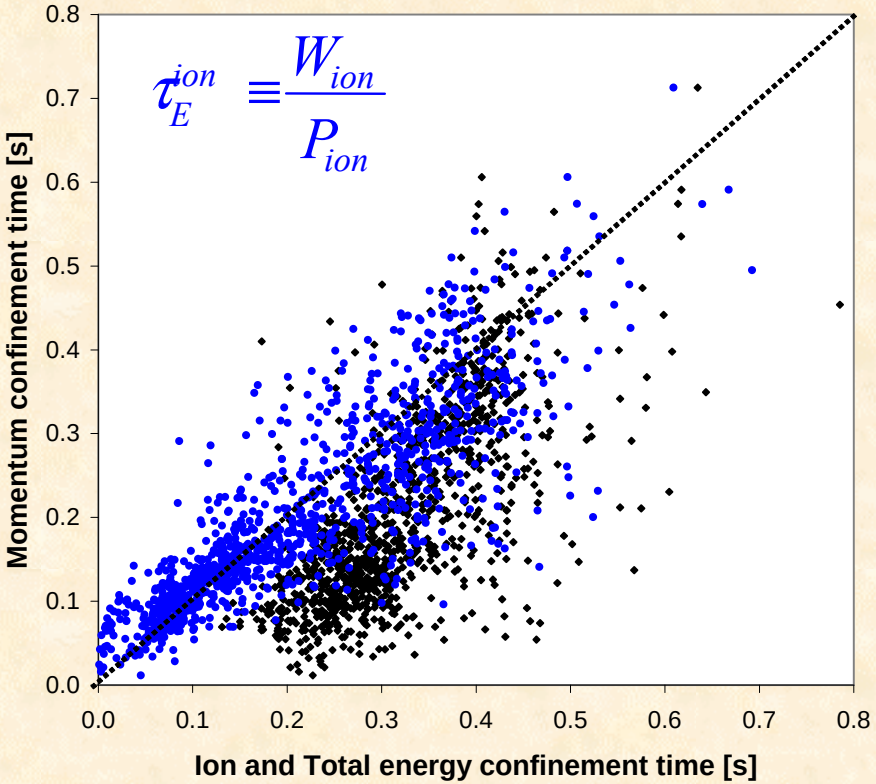
- Intense work on JET on momentum transport
- Experimental work
  - creation of a database for toroidal rotation studies from JET past data
  - measurements of poloidal velocity in H-mode and ITB plasmas
- Theoretical work
  - New version of Weiland model developed
  - Weiland and GLF23 tested for toroidal rotation
  - Weiland model and turbulence simulations with TRB and CUTIE for poloidal rotation

Global energy and momentum confinement

Ratio energy / momentum confinement times

$$\tau_E \equiv \frac{W}{P} \qquad \tau_\phi \equiv \frac{\Omega_t}{T_\phi}$$





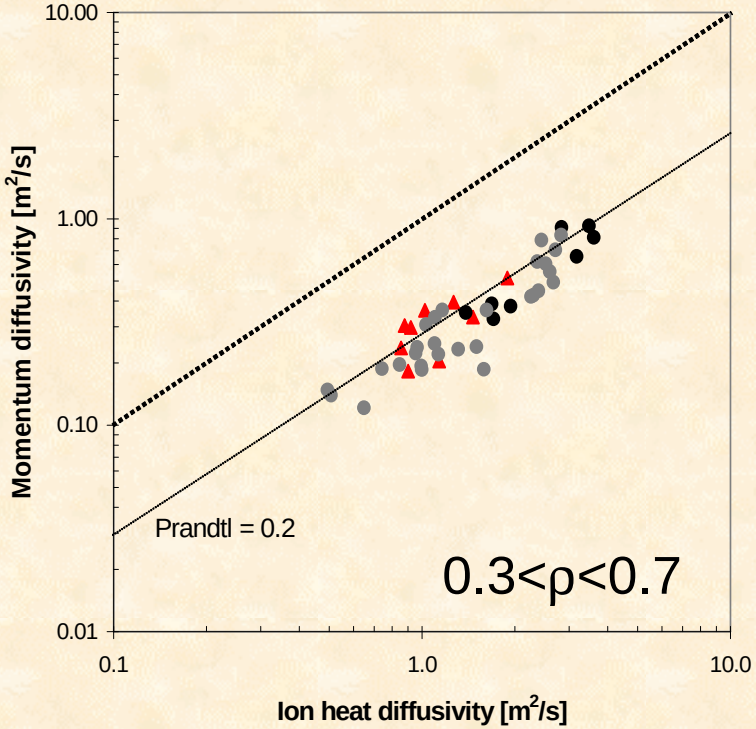
At high density: $\tau_\phi \sim \tau_E$
at low density: $\tau_\phi < \tau_E$

»Momentum confinement time scales with **ion energy replacement time**

Local ion heat and momentum diffusivities

Contrary to global confinement, local momentum diffusivity is always lower than ion heat diffusivity

$$\begin{cases} S_\phi = \chi_\phi^{eff} \nabla\Omega \\ Q_i = n_i \chi_i^{eff} \nabla T_i \end{cases}$$



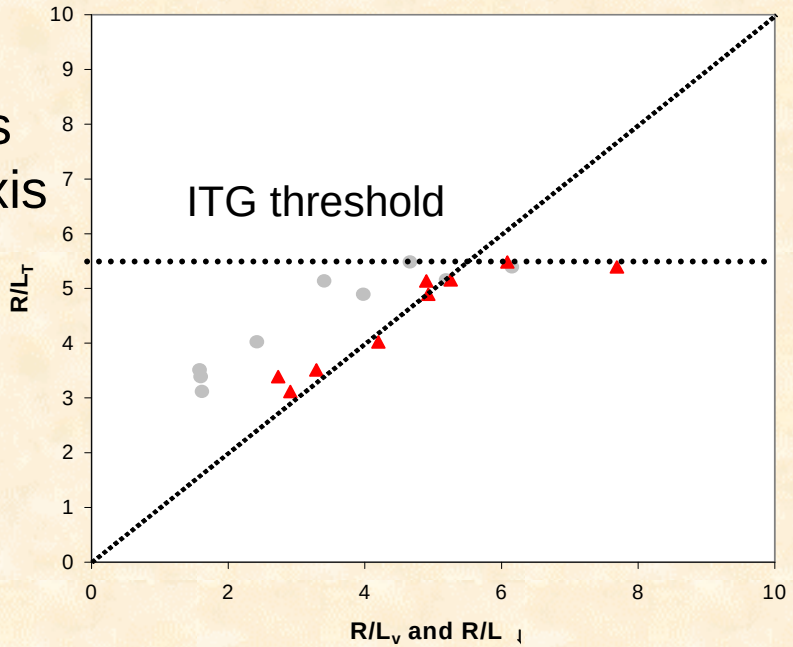
$$P_r \equiv \frac{\chi_\phi}{\chi_i} \approx 0.18 - 0.35$$

Low P_r comes from

$$\frac{\chi_\phi}{\chi_i} = \frac{S_\varphi}{Q_i}\frac{n_i T_i}{\Omega}\left(\frac{R/L_T}{R/L_\Omega}\right)$$

~0.7-1
Stiffness in ion heat but not in rotation

~0.21-0.38
torque off-axis
ion heat on axis

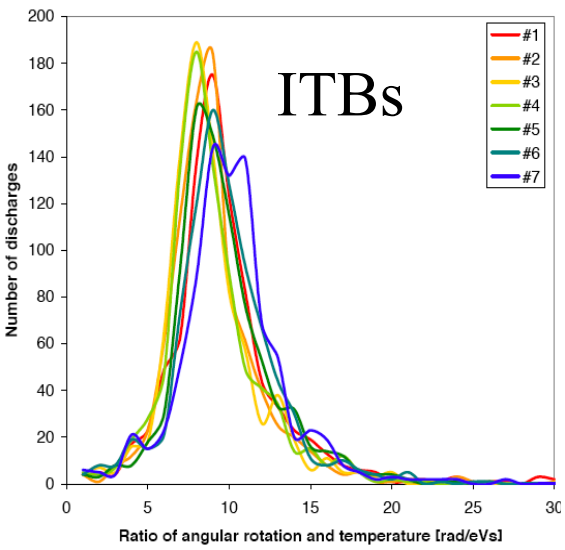


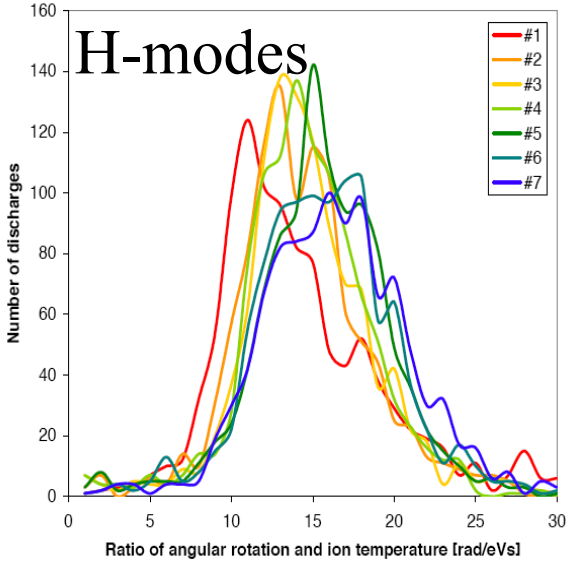
Edge confinement: pedestal momentum confinement worse ?

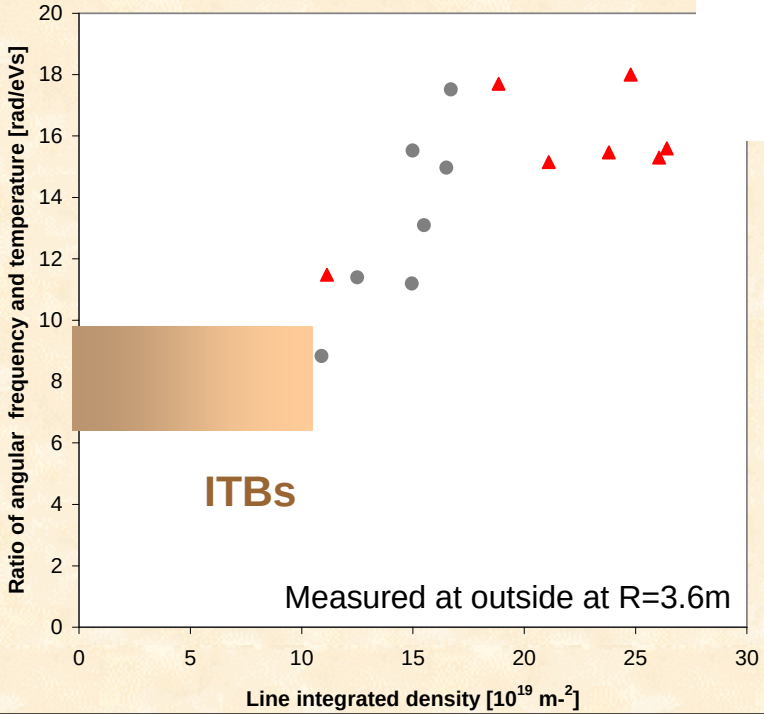
Rotation and ion temperature profiles

- many devices reported similarity of profiles : $v_\phi(r) \sim T_i(r)$

- This relationship does NOT generally hold in JET discharges





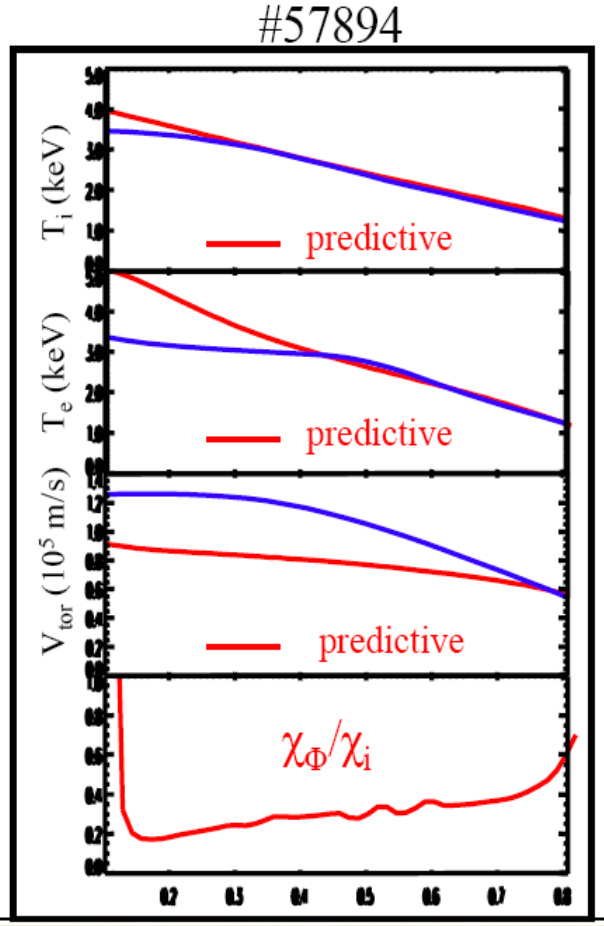


Rotation broader than Ti in H-modes especially at high density

Simulations with Weiland and GLF23 models

New Weiland model

The convective transport term is usually small in ordinary H-modes

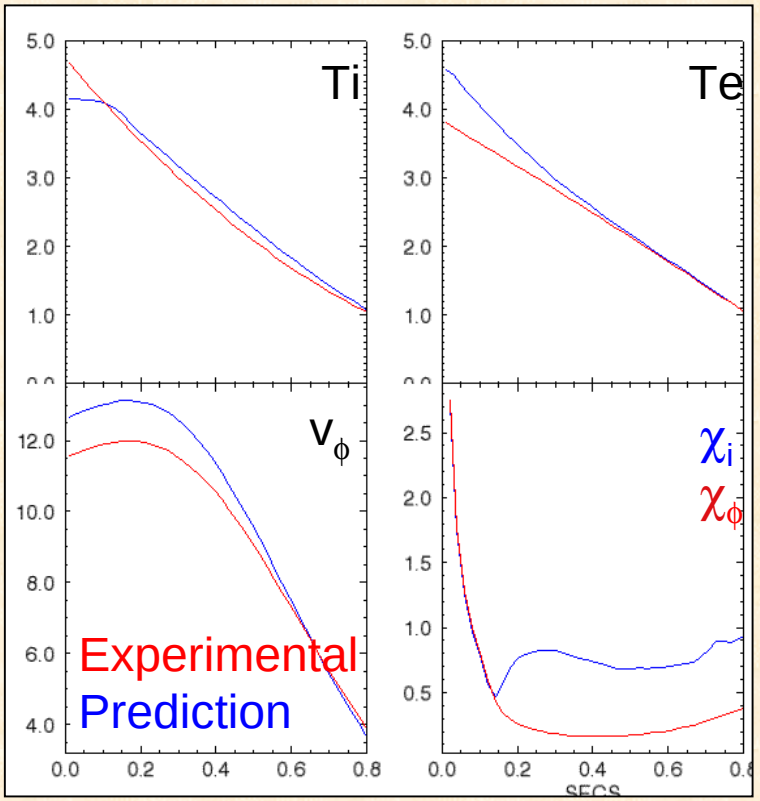


χ_ϕ/χ_i~0.1-0.5 in simulations

V_{tor} under-predicted by ~20% in ITG dominated cases but over-predicted in low n_e TEM cases

χ_ϕ/χ_i foreseen larger in TEM than ITG dominated plasmas

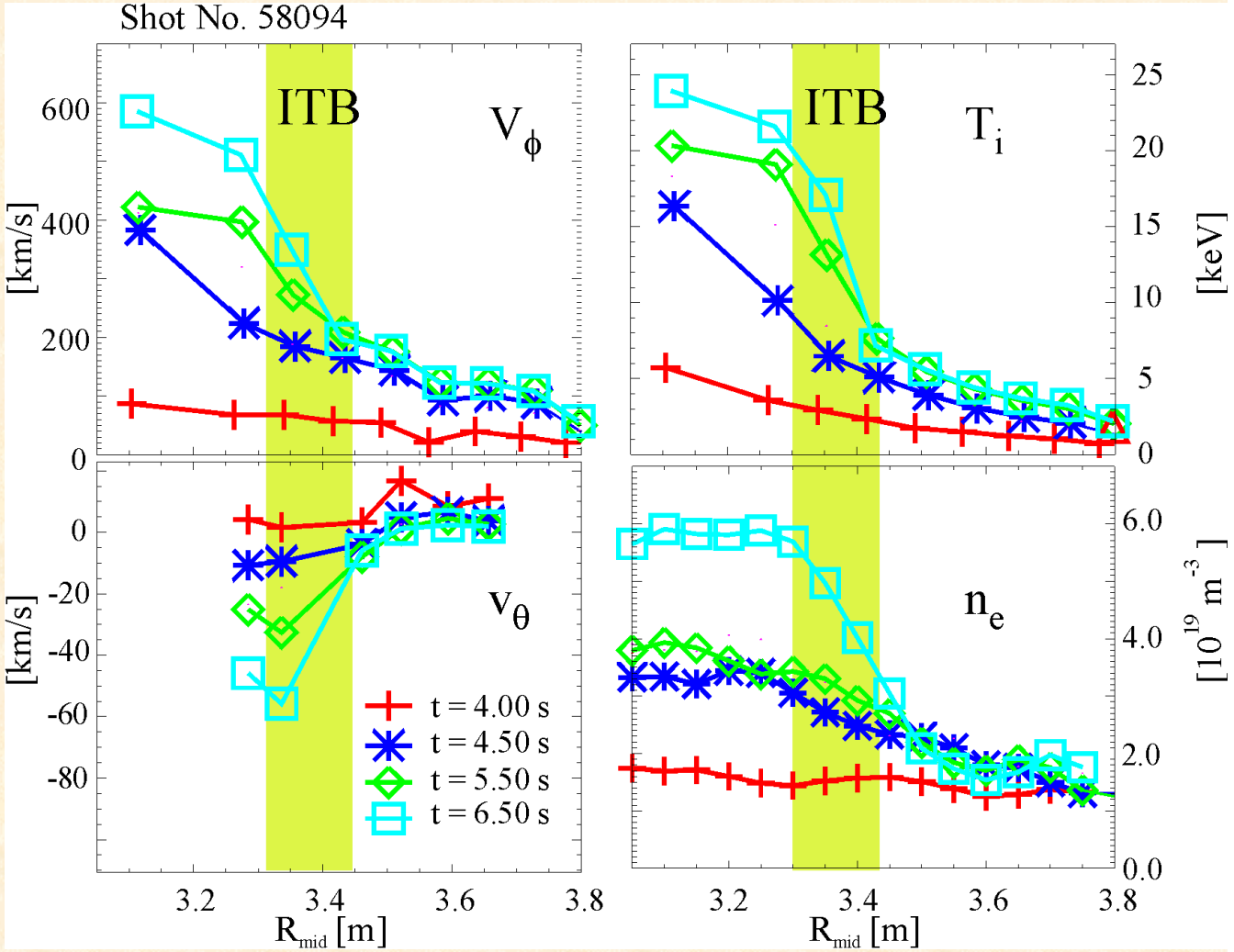
GLF23 shot 57894



GLF23 also predicts P_r~0.3. Slightly over-estimates V_{tor} in same ITG dominated case, but large overestimate in cases below ITG threshold

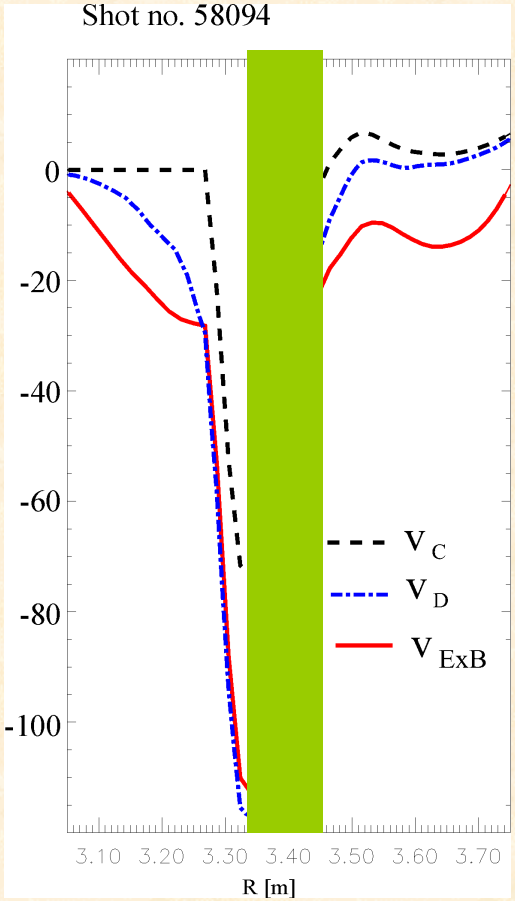
Poloidal rotation in ITB plasmas

- **Example with very strong T_i gradient**
- **High central Carbon v_ϕ (up to 600 km/s) Mach n ~0.55**
- **Carbon v_θ profiles show negative (ion diamagnetic velocity direction) dip in the steepest part of the T_i, v_ϕ and n_e profiles**
- **$v_{\theta C} >> V_{neoC}$**

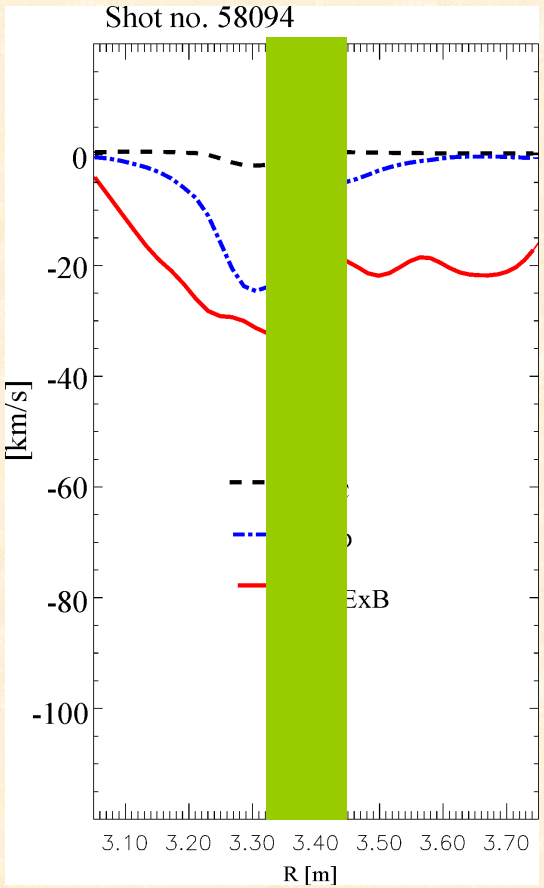


Comparison with neoclassical v_θ

Experiment



Neoclassical



Measured v_θ inside the ITB much higher than the neoclassical predictions both for carbon and main ions

Similar evidence in DIII-D for H-modes

Solomon PoP 2006

In plasmas with outer barriers also high rotation (order 10^4 m/s) in the electron diamagnetic velocity has been observed

Poloidal rotation in TRB simulations

Non-linear 3D electrostatic collisionless fluid turbulence code

$$\partial_t V_D = -\nu_{neo}\left(V_D - k_{neo} V_{*Ti}\right) - r^{-2}\partial_r\left[r^2 \left\langle \tilde{v}_r \tilde{v}_\theta \right\rangle\right]$$

Viscous damping

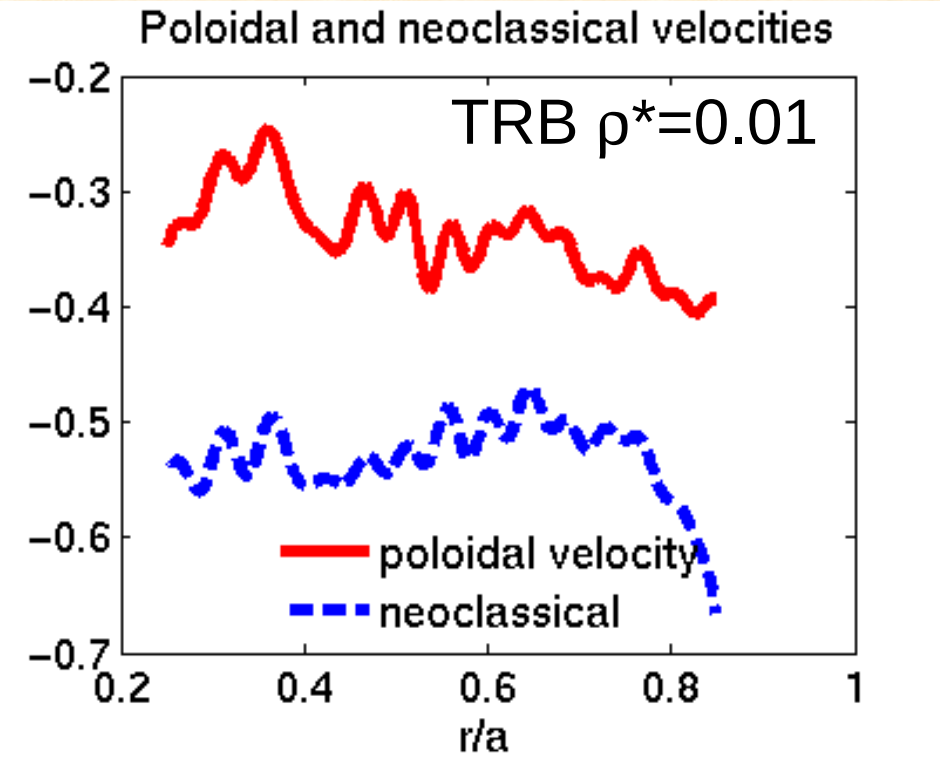
Reynolds stress ==> negative viscosity effect ==> flow amplification

TRB shows that turbulence can generate anomalous $V_D \sim 0.5\, V_{*e}$ ==>

$$V_C \approx V_D - \frac{\partial_r p_D}{n_D e B_T} >> V_{C,neo}$$

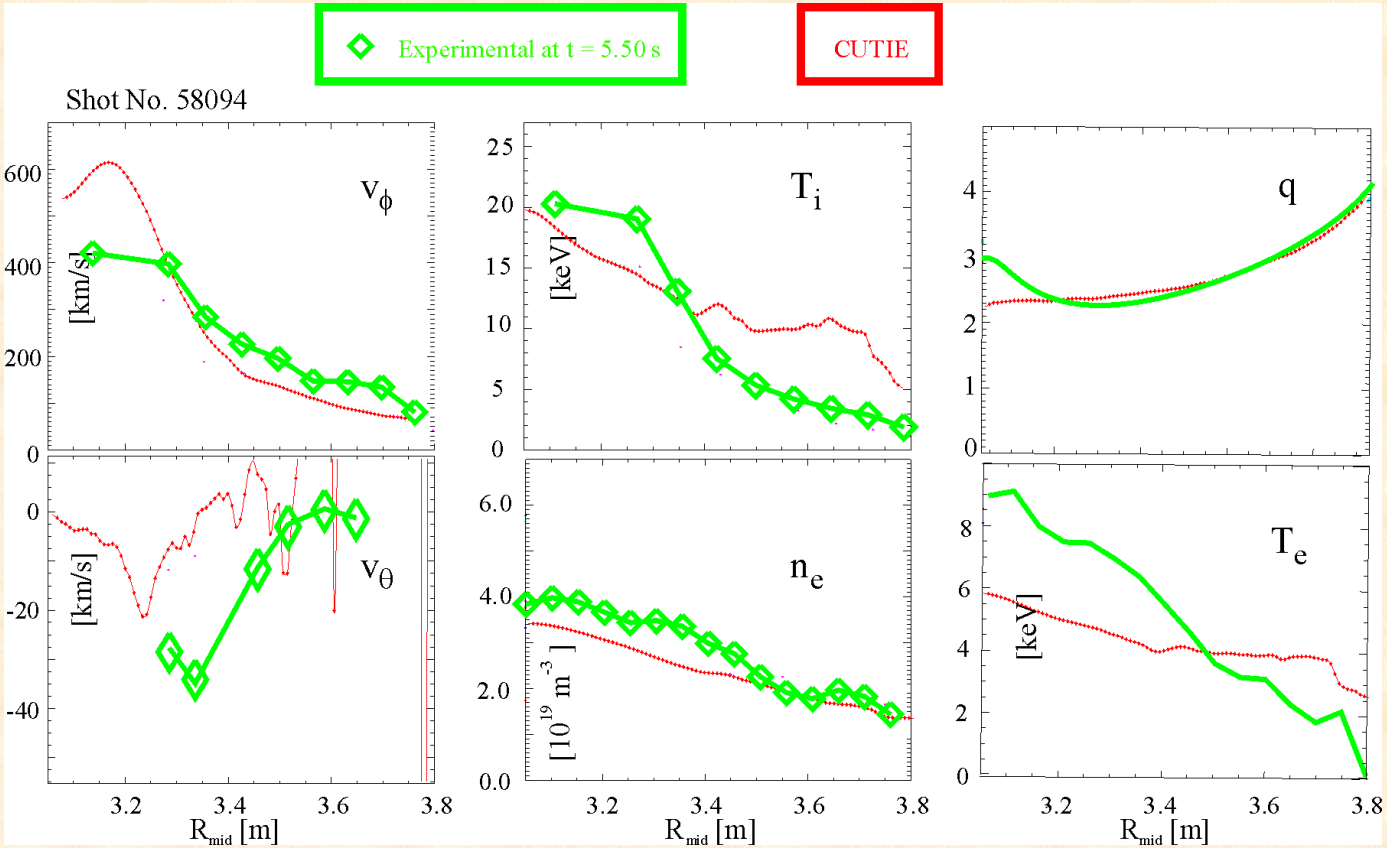
V_C is shifted in the electron diamagnetic direction

Under investigation effect in ITB regions



Poloidal rotation in CUTIE simulations

- Non-linear 3D global electromagnetic fluid turbulence code
- Takes into account both Reynolds and Maxwell stresses as sources of poloidal momentum



- Significant v_θ in ion diamagnetic direction in the ITB region, reversing towards the outer plasma region

Conclusions/Discussion

• In predictive modelling of toroidal rotation DO NOT assume $v_\phi(r) \sim T_i(r)$ or $\chi_\phi \sim \chi_i$ … also for ITER!
Existing models are not perfect but far better assumptions.

•Poloidal rotation: further measurements to confirm the picture! High impact of results on theoretical understanding and strong implications on ITB formation physics.

•Fluid turbulence simulations predict anomalous v_θ generation. However many questions:
-How can v_θ be maximum in the ITB where turbulence is suppressed?
-Dominant effect Reynold or Maxwell stress?
-What is causing the v_θ sign reversal from inner to outer plasma regions?