NBI Modulation Experiments to Study Magnetic Field Induced Ripple Torque and Momentum Transport on JET

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*See the Appendix of F. Romanelli et al., Fusion Energy 2010 (Proc. 23rd Int. Conf. Daejeon, Korea), paper OV/1-3

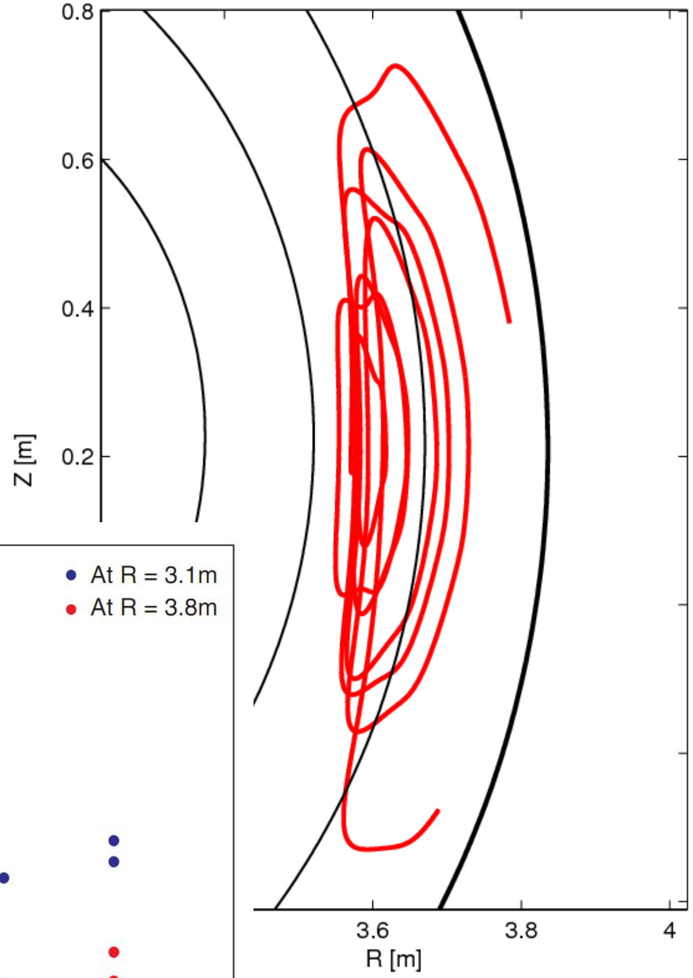
Association Euratom–Tekes

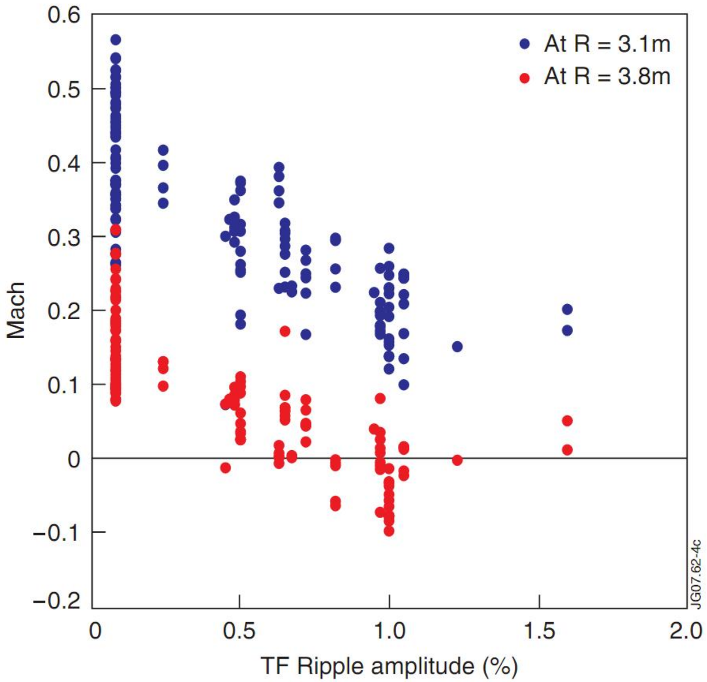
Outline

- NBI modulation experiment to validate the torque calculation due to lost fast ions in JET ripple experiments using the Monte-Carlo guiding centre code ASCOT

- Parametric dependencies of the momentum pinch and Prandtl number on R/L_n, collisionality and q-profile on JET

Ripple Causes Increased Non-ambipolar Diffusion and Trapping of Fast Ions



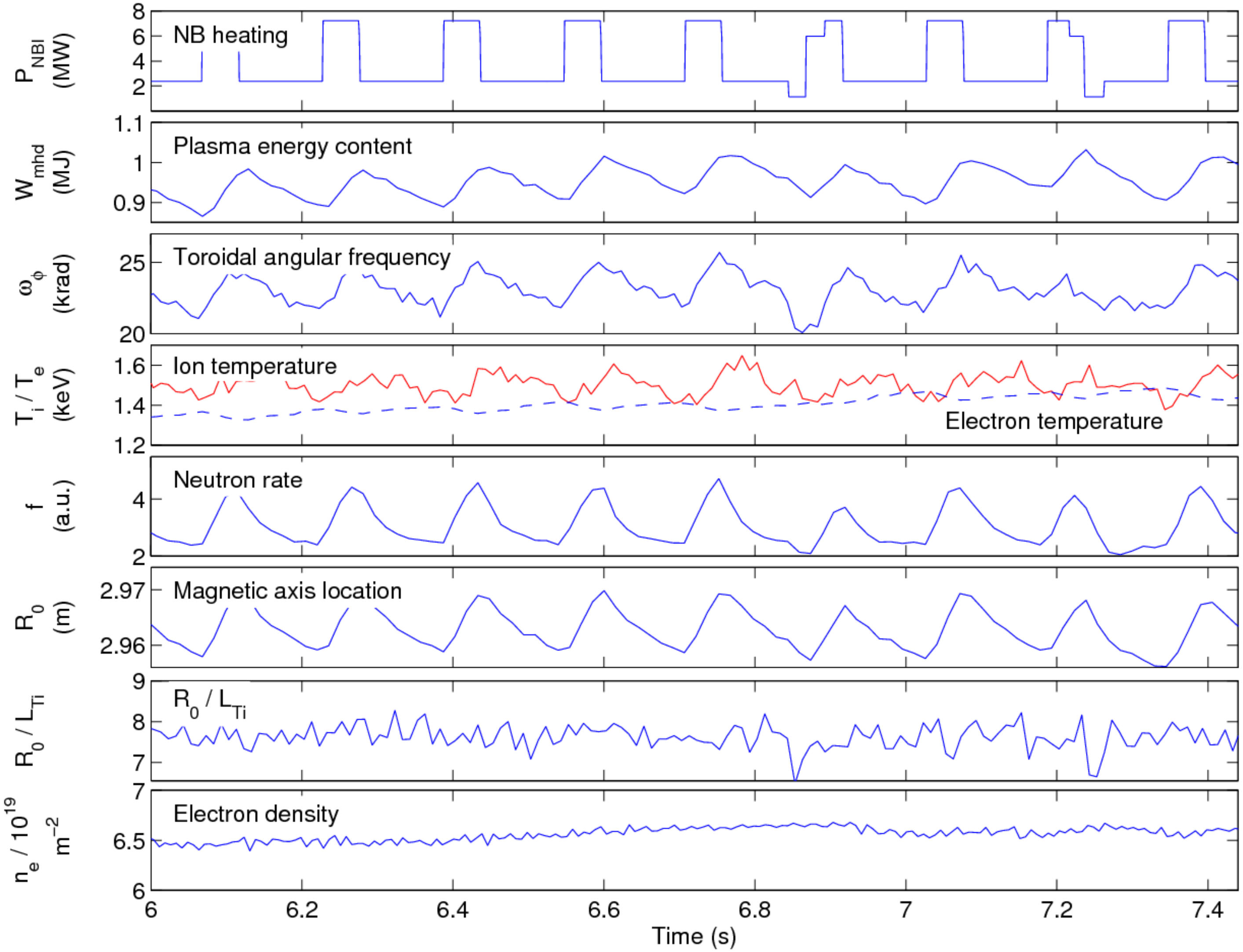


- An extra torque in the counter-I_p direction created
- Can drag the toroidal rotation to counter-I_p with 20MW of co-NBI power at the plasma edge (r/a>0.7)
- The calculation of this torque produced by the ripple lost fast ions has not been validated against the experimental data
- This talk presents experimental data from JET to benchmark the ripple torque calculation in the ASCOT code

P. de Vries NF 2008, A. Salmi, Contrib. Plasma Phys. 2008

NBI Modulation Experiments to Study Torque Induced by Ripple Lost Fast Ions

Reference shot without a ripple (ripple level 0.08%): 77089



Clear modulation in the rotation signal

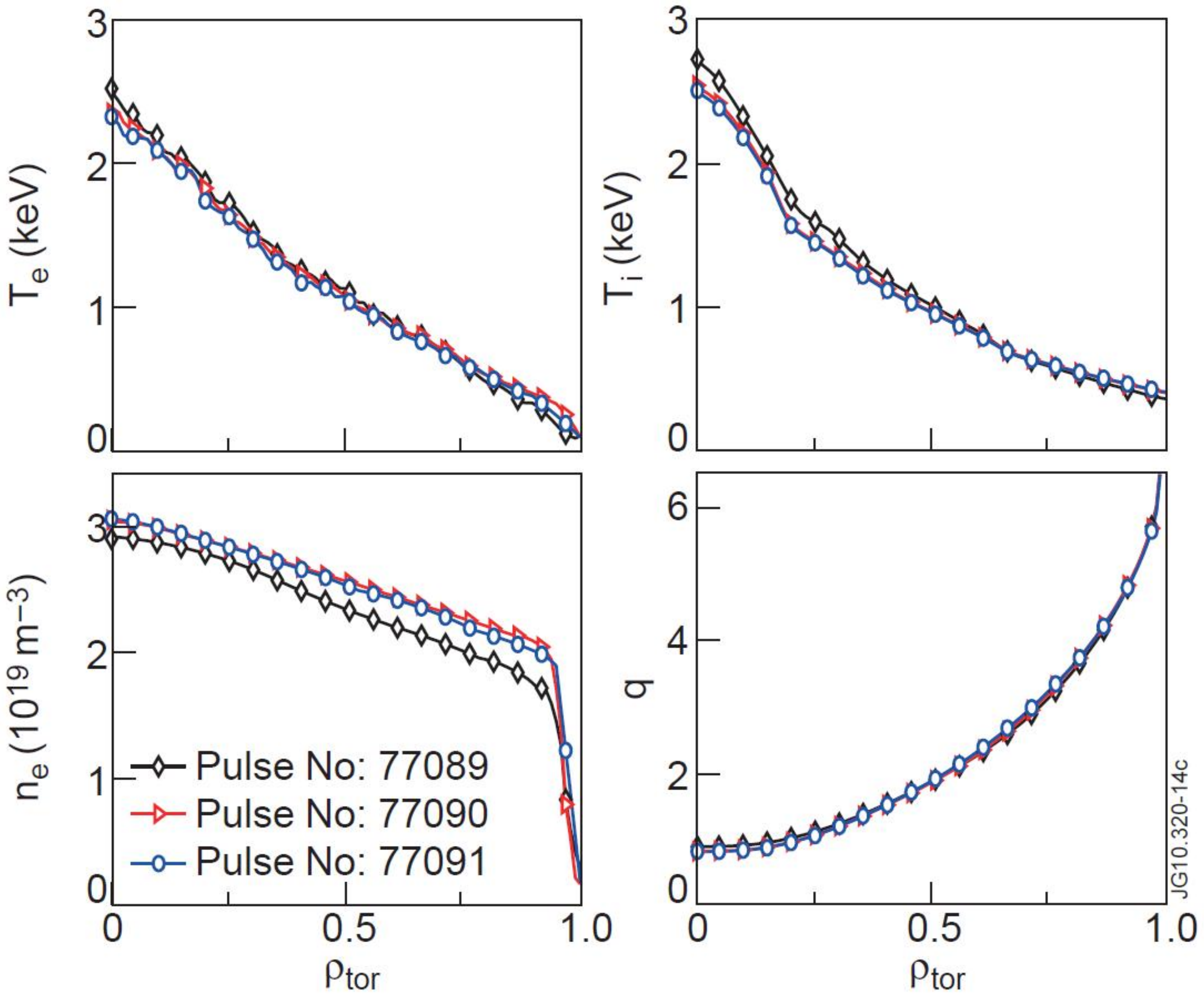
Density and R/L_{Ti} independent of time – no correlation with the NBI modulation

Justifies the assumption of constant momentum transport in time

L-mode discharge

3 Very Similar Shots Chosen; Reference (w/o ripple), Normal NBI (w ripple), Tangential NBI (w ripple)

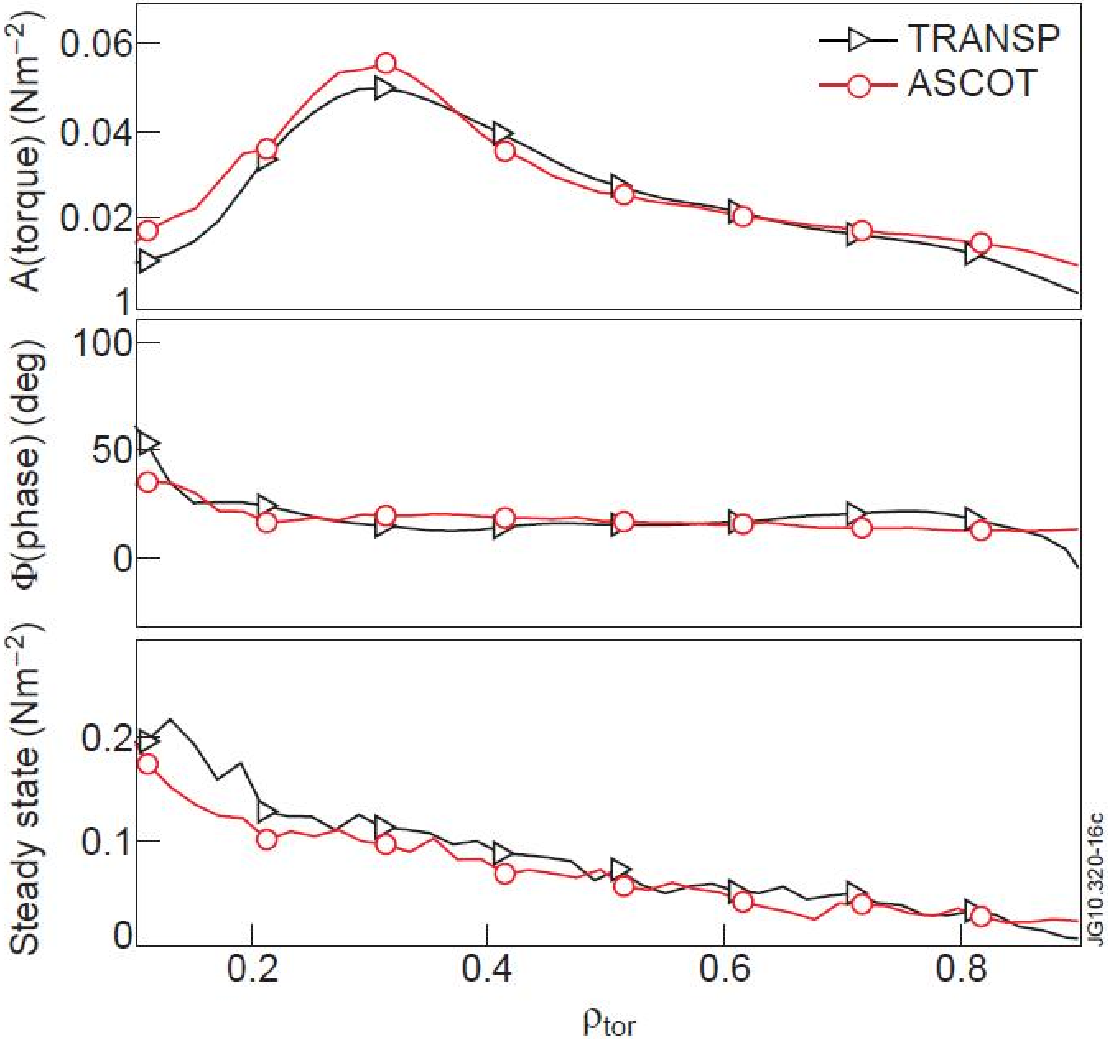
77089 reference without ripple
77090 normal NBI with 1.5% ripple
77091 tangential NBI with 1.5% ripple



- 3 L-mode shots chosen
- I_p=1.5MA, B_t=2.2T, $n_{e,0} \approx 3\times10^{19}m^{-3}$, $T_{i0}=T_{e0}\approx 2.5$keV
- Plasma profiles nearly identical among the 3 shots
- NBI power the same
- Justifies the assumption that transport is the same for each shot (keep P_r and v_{pinch} constant)

Torque Calculation Benchmark between ASCOT and TRANSP without Ripple

Reference shot without a ripple: 77089

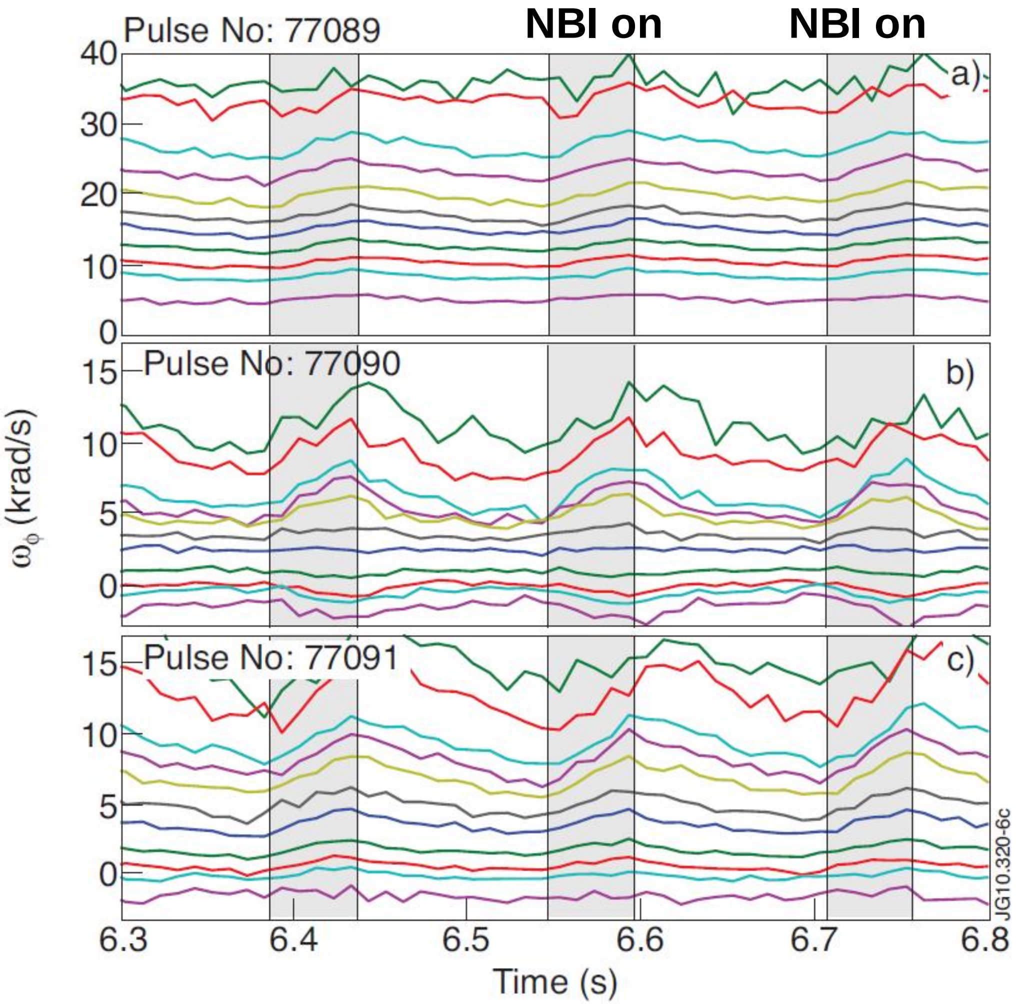


- The agreement of the calculated torque between TRANSP and ASCOT is very good
- This includes both the amplitude, phase and steady-state
- The scope in this presentation is to benchmark the ASCOT torque calculation in plasmas with a large fraction of lost fast ion induced torque at the ripple level of 1.5%

Time Traces of Rotation Reveal Already Significant Differences among the 3 Shots

77089 reference without ripple
77090 normal NBI with 1.5% ripple
77091 tangential NBI with 1.5% ripple

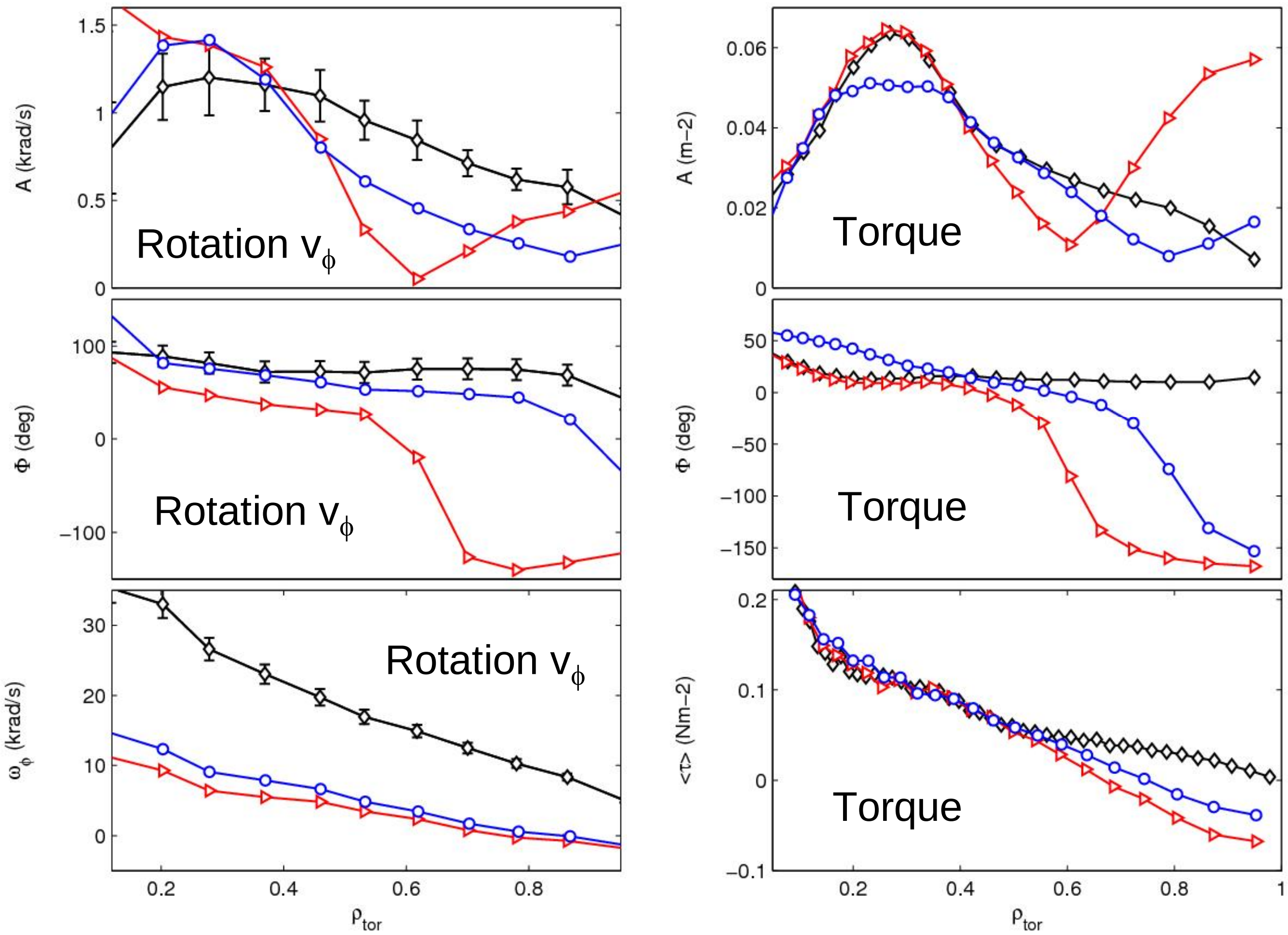
grey shaded bars show when NBI is on



- With co-NBI and without the ripple (77089), rotation increases throughout the radius during the NBI ON phase
- With co-NBI with normal injection angle at ripple of 1.5% (77090), rotation goes toward more counter-I_p direction at r/a>0.6
- With co-NBI with tangential injection angle at ripple of 1.5% (77091), no change in rotation at the edge

The Modulated Rotation and Calculated Torque Profiles Look Similar to Each Other

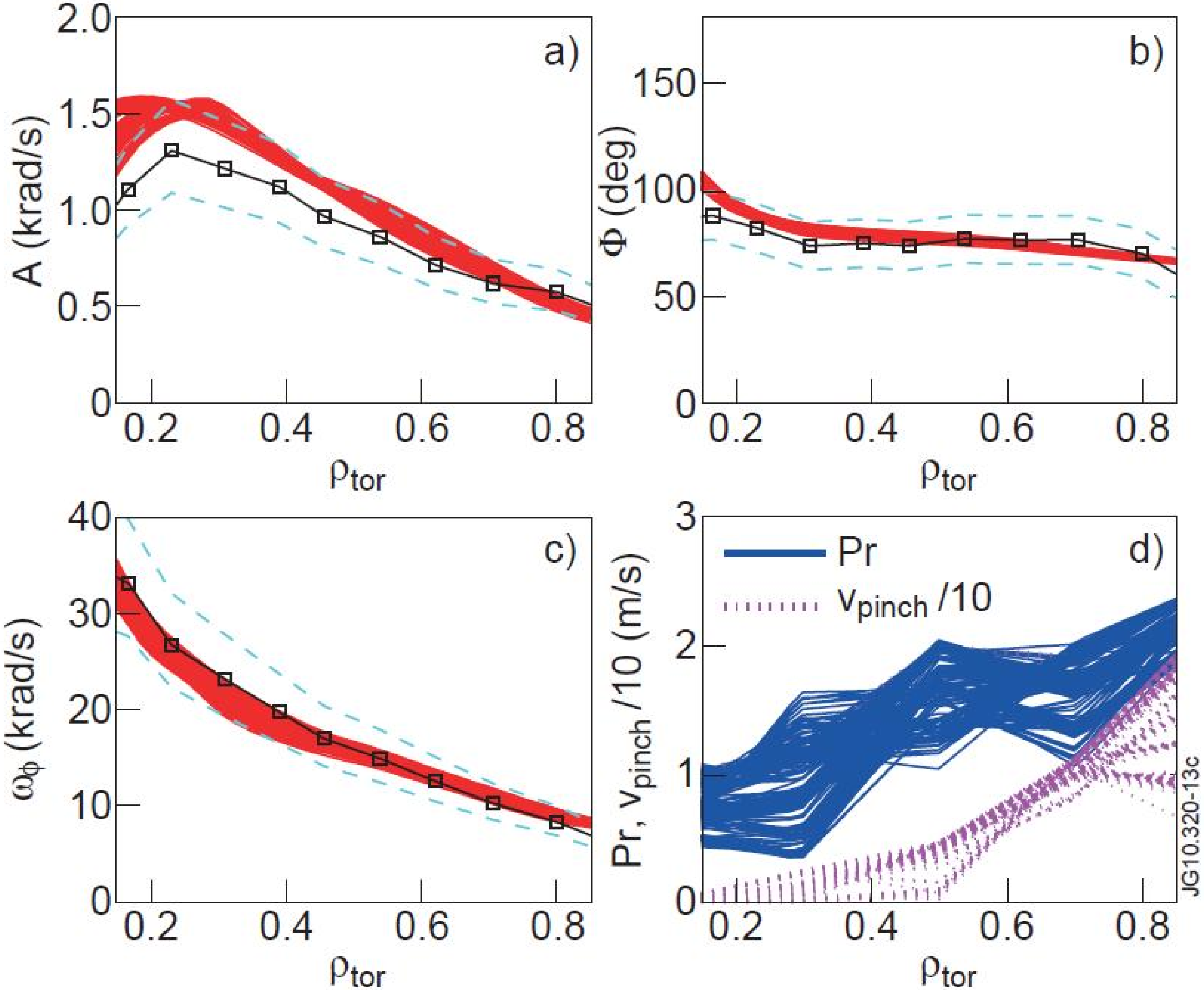
77089 reference without ripple
77090 normal NBI with 1.5% ripple
77091 tangential NBI with 1.5% ripple



- The amplitude and phase profiles between the measured rotation and calculated torque strikingly similar (ASCOT torque calculation independent of rotation)
- From the steady-state torque profiles, one can see the counter-torque induced by the ripple lost fast ions
- Ripple effect much stronger with normal NBI (lower pitch angle + turning points at high ripple region)

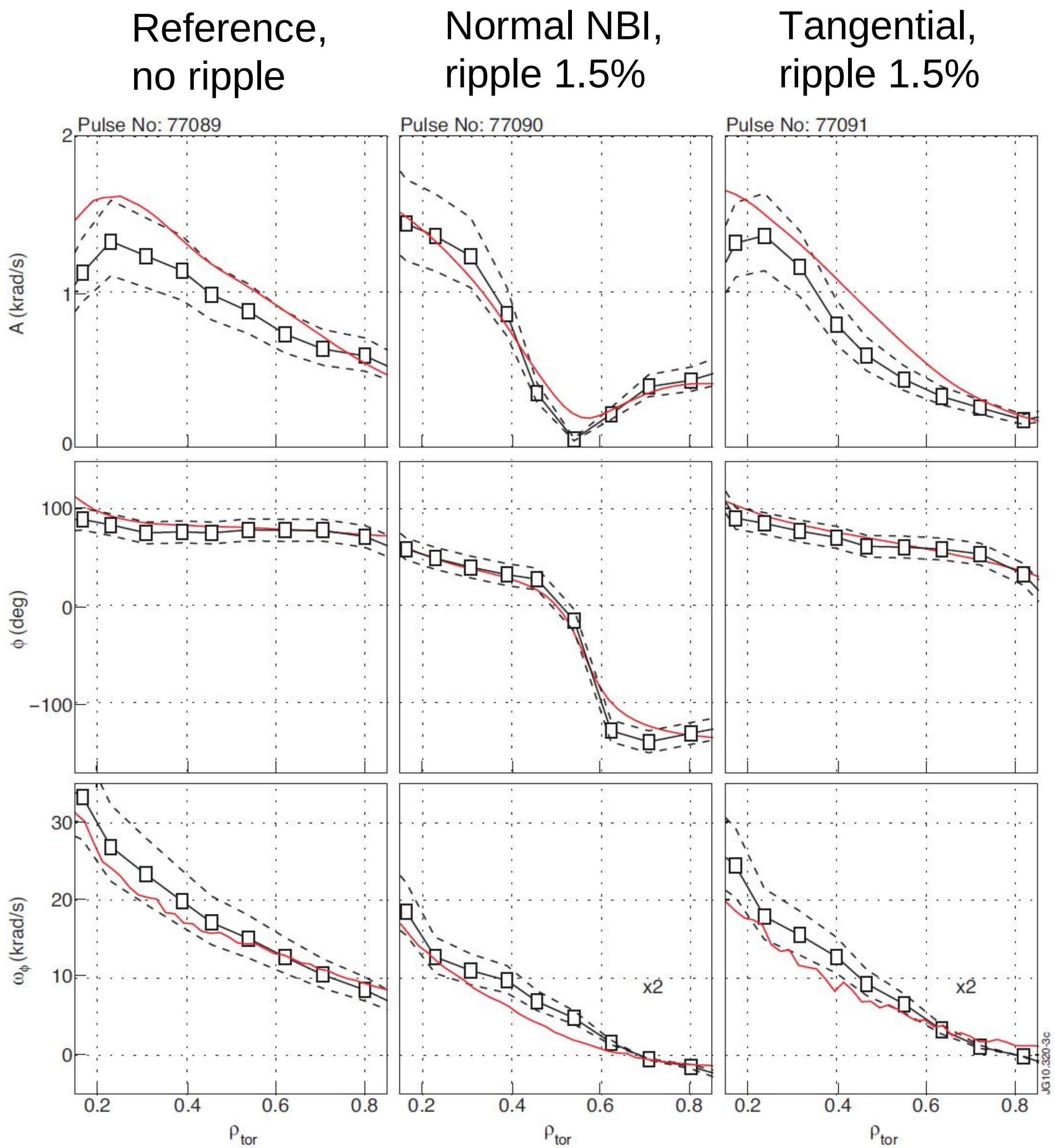
Momentum Transport Coefficients Determined from the Reference Shot

Reference shot without a ripple: 77089



- Black lines with square markers are the experimental data, dashed lines the 20% interval around the measurements for rotation and rotation amplitude and 11.25 deg (5 ms equivalent in time) for phase
- Ensemble of red lines that give the rotation a) amplitude b) phase c) steady state of the simulations that yield a target error that is within 10% of the best fit. d) The corresponding Prandtl number and pinch velocity profiles

ASCOT Ripple Torque Benchmark against Experimental Data



- Momentum transport assumed to be the same for the ripple shots 77090 and 77091 (determined from the reference shot 77089)
- The ASCOT torque profiles including the ripple effects reproduce very well the amplitude, phase and steady-state of the rotation
- Demonstrates that the torque calculation with ripple in ASCOT is consistent with experimental data

Outline

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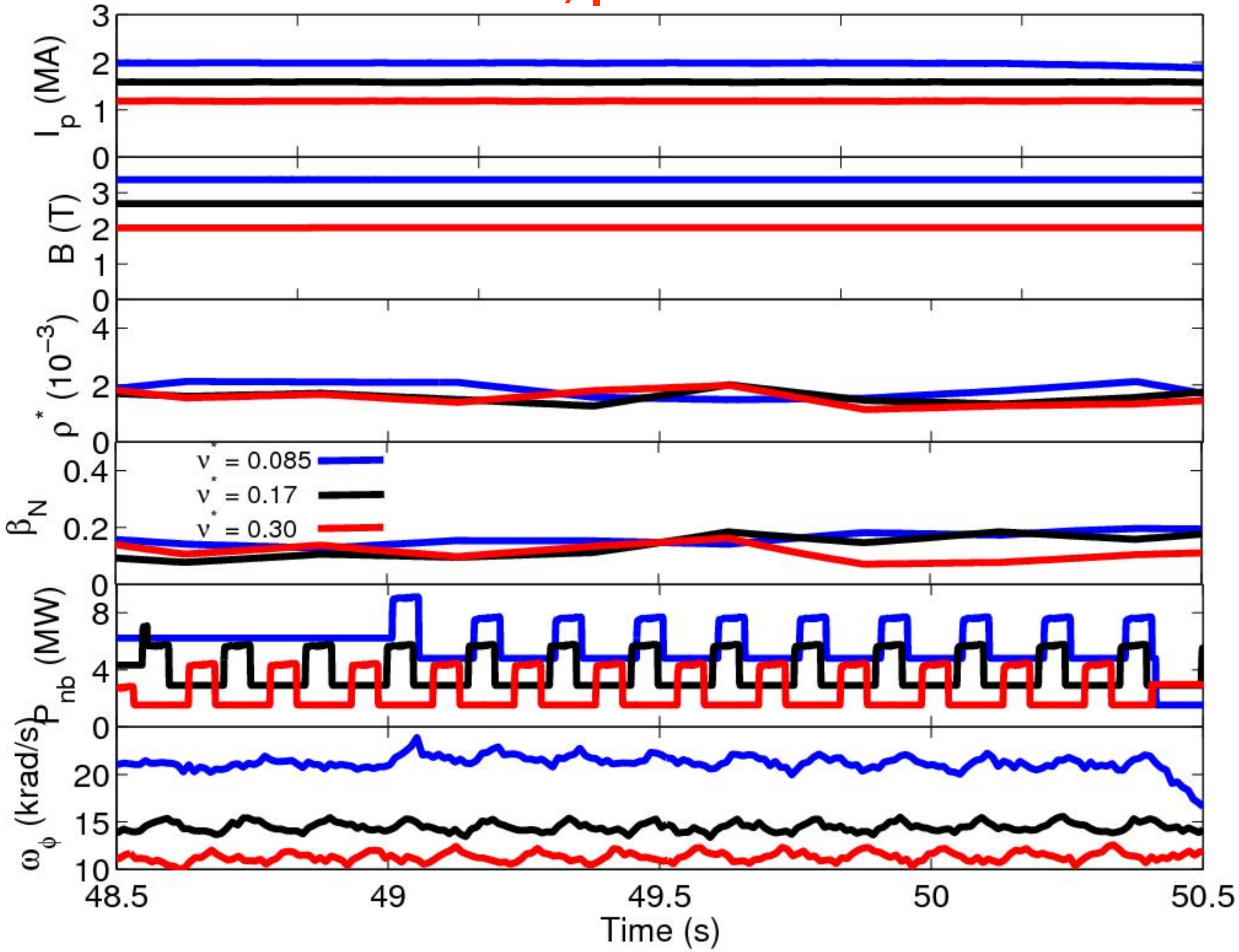
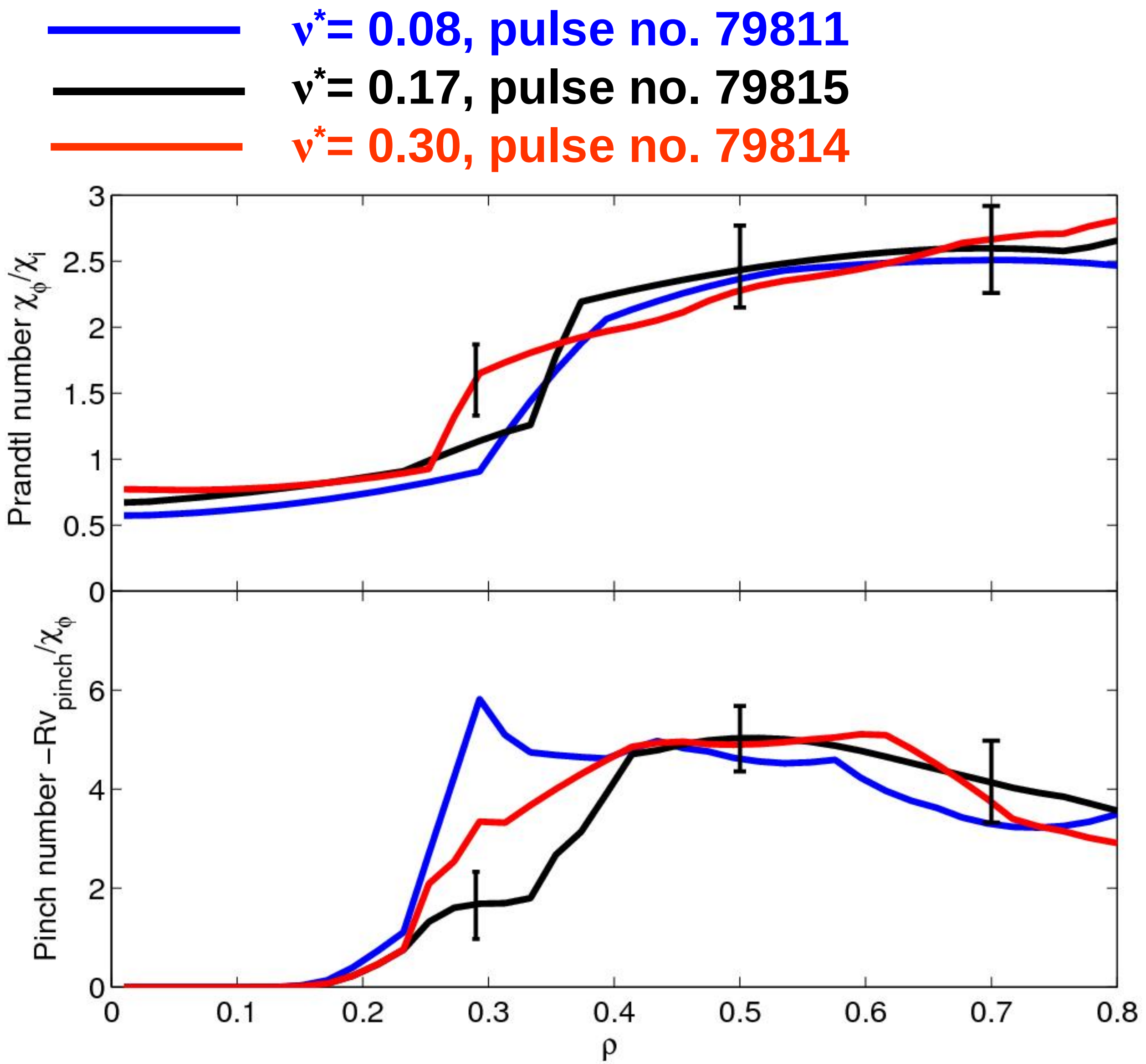
3-point Collisionality Scan to Study Momentum Transport on JET

ν^*= 0.08, pulse no. 79811
ν^*= 0.17, pulse no. 79815
ν^*= 0.30, pulse no. 79814



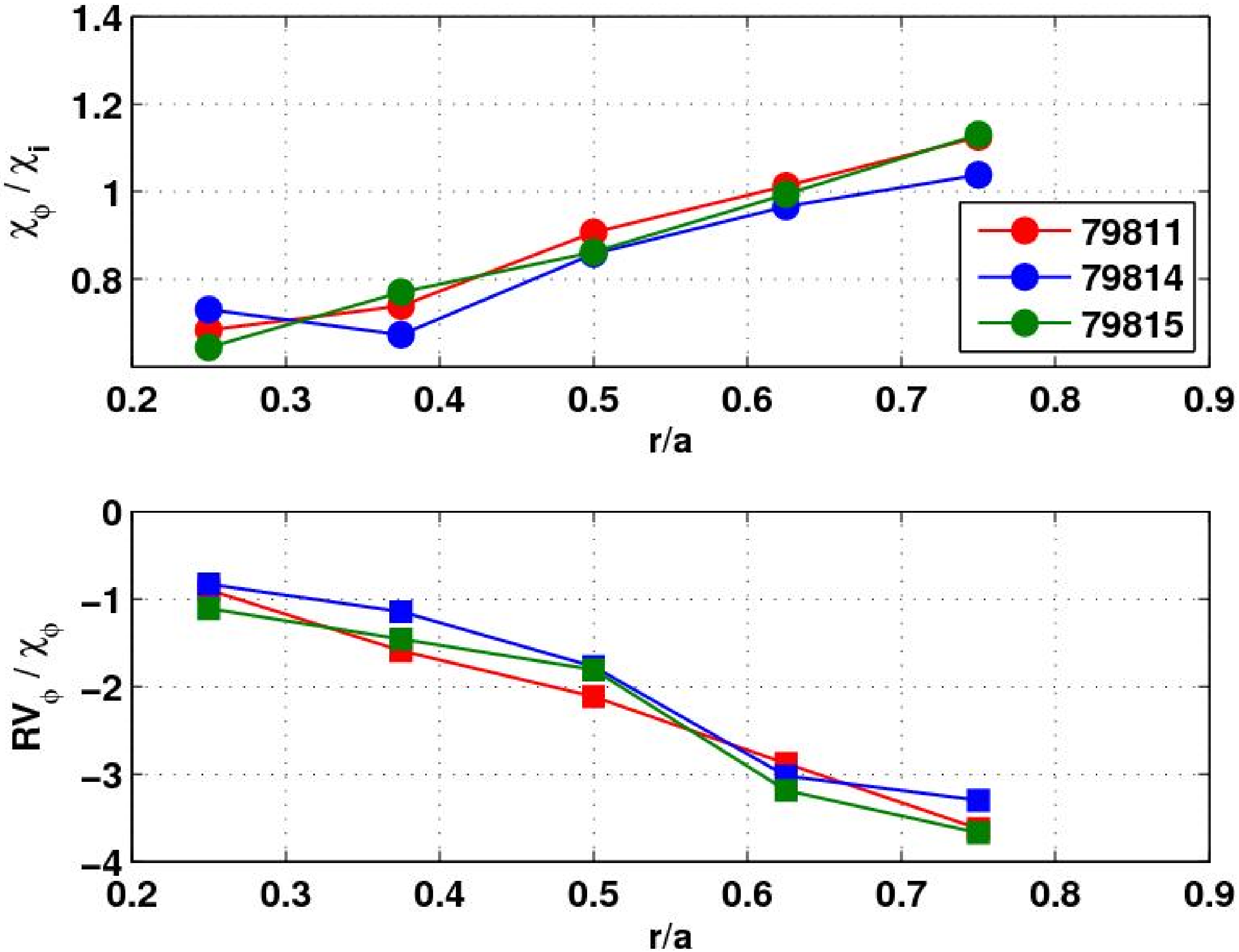
- 3-point collisionality ν^* scan performed by keeping other dimensionless parameters (ρ^*, β, q, R/L_n) constant within 10–20%
- Density profile the same among the 3 L-mode shots
- Factor of 4 variation in collisionality

No Dependence of Prandtl Number and Pinch Number on Collisionality



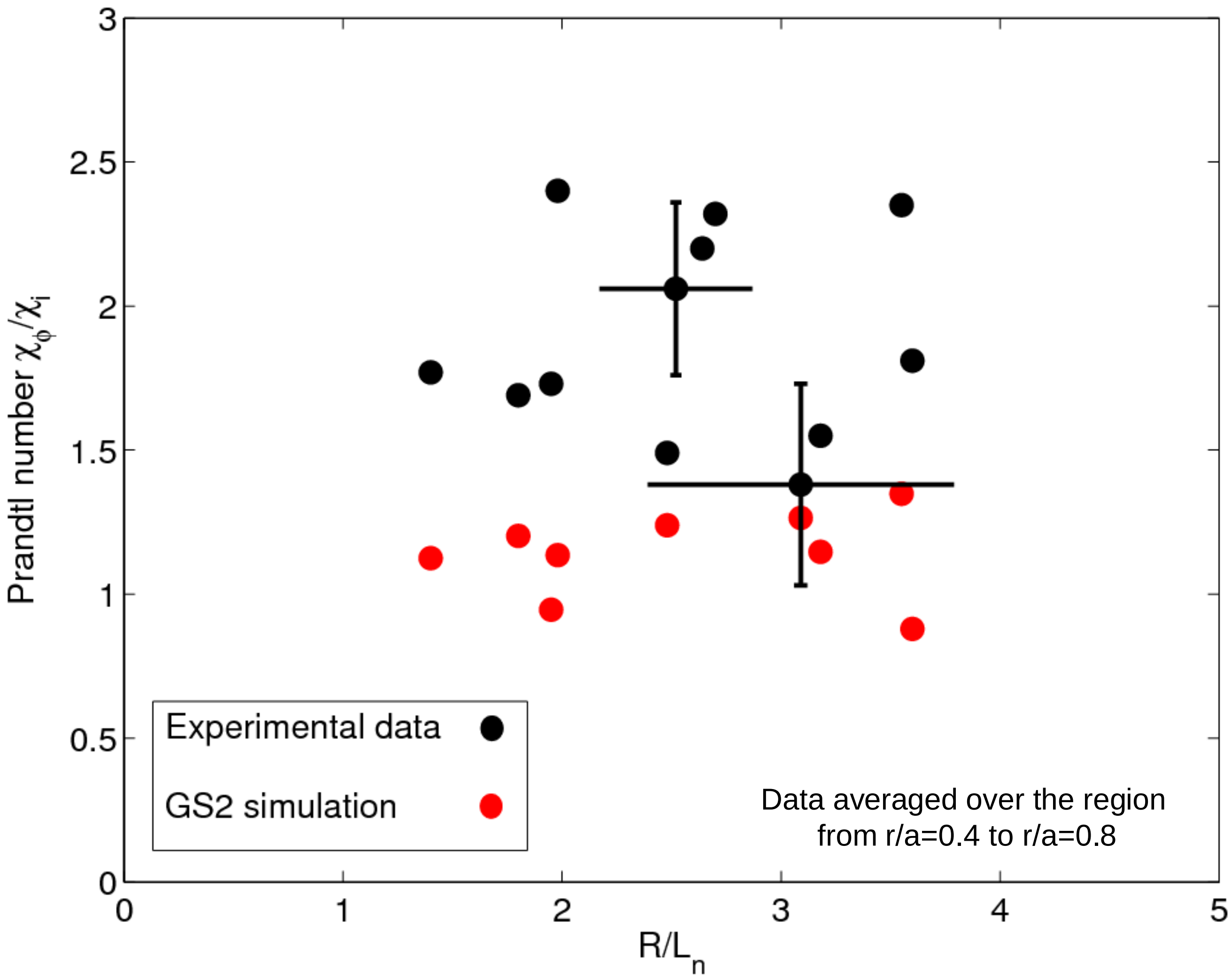
- Prandtl number $P_r = \chi_\phi/\chi_i$ profiles virtually the same within the scan
- No collisionality dependence in the pinch numbers Rv_{pinch}/χ_ϕ found

GS2 Finds No Dependence of Prandtl Number and Pinch Number on Collisionality



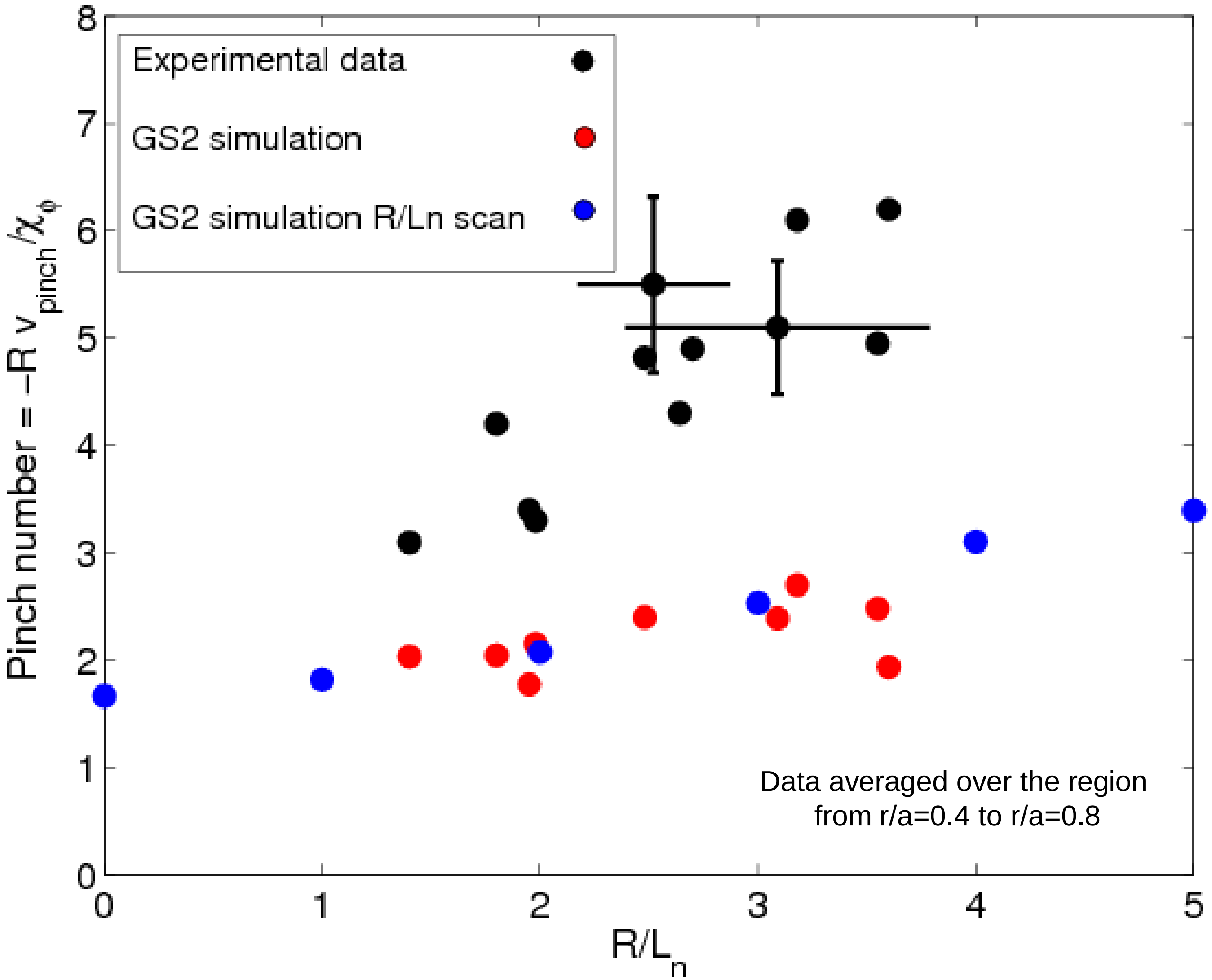
- GS2 linear simulations do not find any P_r or Rv_{pinch}/χ_ϕ dependence on ν^* in accordance with experiments
- The radial trends of both P_r or Rv_{pinch}/χ_ϕ are similar between the experiment and the GS2 simulations
- The magnitude of the P_r from GS2 is lower than the experimental one outside r/a>0.3
- The agreement of the pinch number Rv_{pinch}/χ_ϕ between the GS2 simulations and the experiment is fairly good

Prandtl Number Does Not Depend on the Density Gradient Length R/L_n



- Prandtl number is independent of R/L_n. Within this R/L_n scan, other parameters also changed, such as collisionality and density
- Prandtl number does not depend either on *q* or on density
- GS2 linear simulations predict no Prandtl number dependence on R/L_n in accordance with experiments
- GS2 gives lower Prandtl number than the experiments, a common observation in other scans as well. Non-linear simulations?

The Pinch Number Depends Linearly on R/L_n



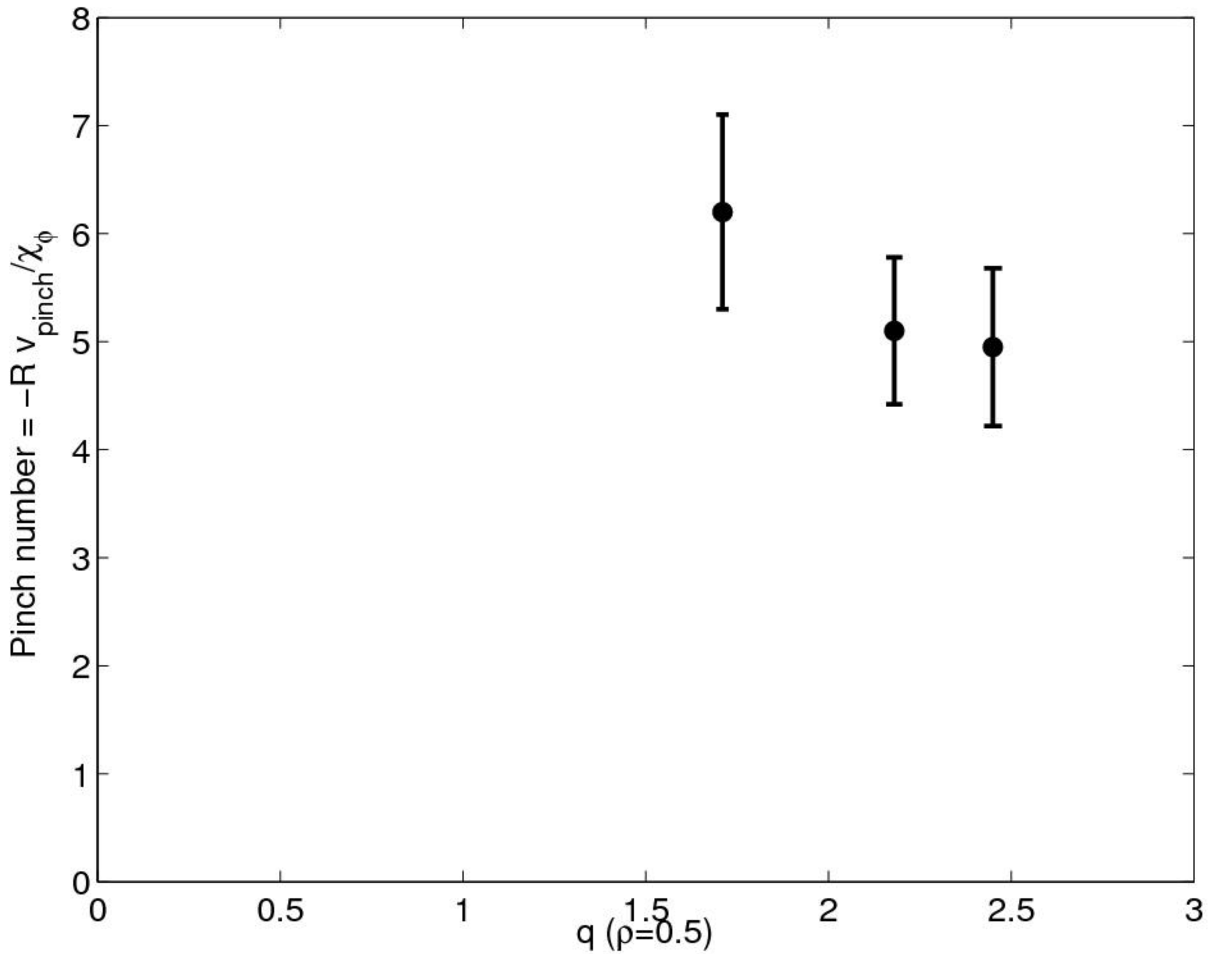
- Pinch number Rv_{pinch}/χ_ϕ depends strongly on the density gradient length R/L_n

  $-Rv_{pinch}/\chi_\phi \approx 1.2R/L_n + 1.4$

- Similar dependence of the pinch on R/L_n also found in JET rotation database studies [P. de Vries, PPCF 2010, H. Weisen, EU-US TTF 2010]

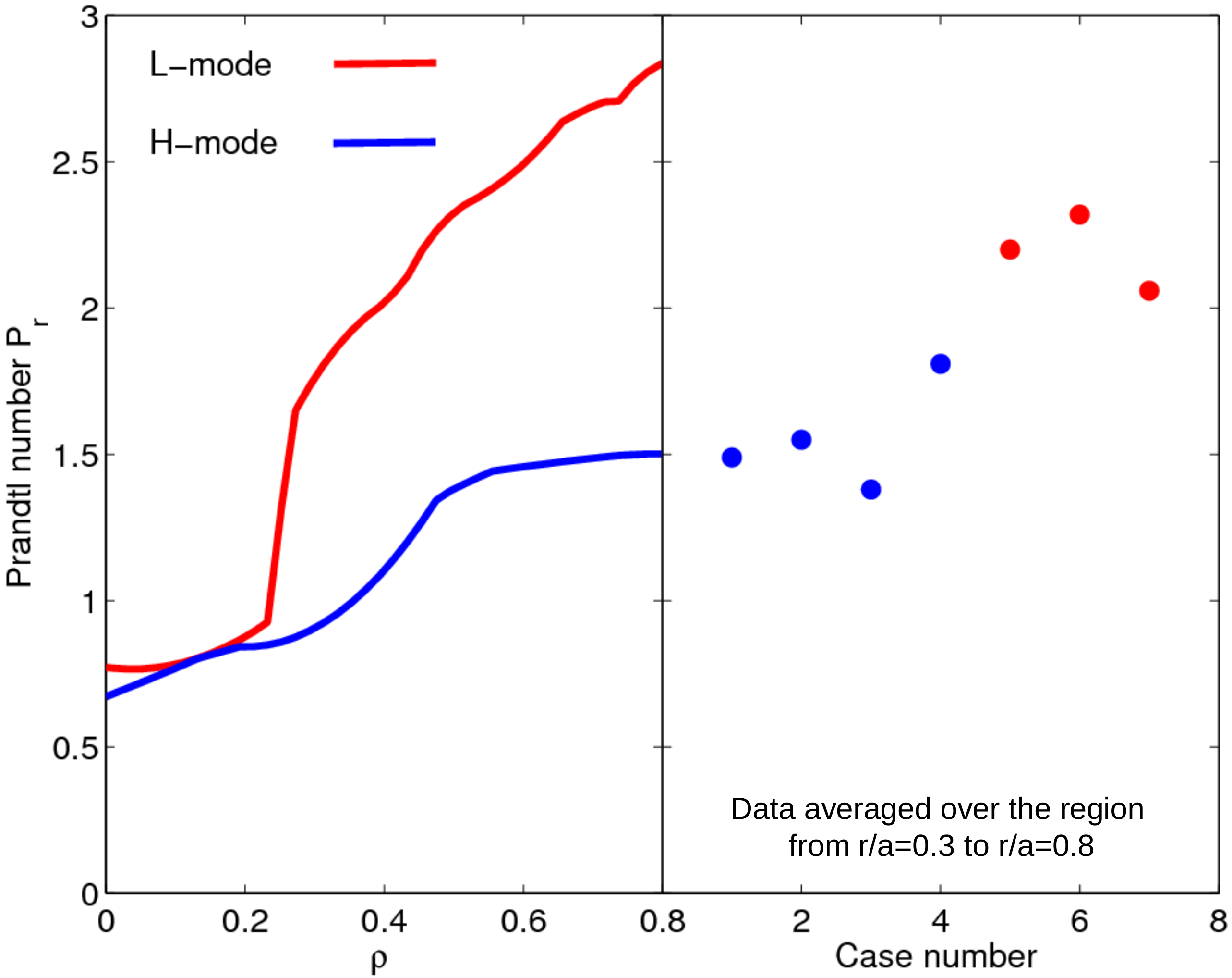
- GS2 simulations find similar positive trend with R/L_n, but it is weaker and very dependent on the value of R/L_n (note the large error bars in R/L_n)

The Dependence of the Pinch Number on q Is Weak



- q-scan performed by varying I_p and using the slow current diffusion time
- R/L_n variation minimized
- Magnetic shear also scanned inevitably
- The possible q-dependence of the momentum pinch is still within the error bars of the analysis
- Prandtl number does not depend on q

Prandtl Number Different in L-mode and H-mode Plasmas in JET



- L-mode plasmas tend to have higher Prandtl numbers than the H-mode ones
- Theory and simulations give typically P_r~0.7–1.5
- Is transport different between L-mode and H-mode plasmas (ITG versus TEM)?
- Are we missing some torque that in low momentum L-mode plasmas shows more distinctly?

Summary

- Torque calculation in plasmas at high magnetic field ripple in the ASCOT code validated against JET NBI modulation data

- Prandtl and momentum pinch numbers do not depend on collisionality

- Pinch number depends on R/L_n: $-Rv_{pinch}/\chi_\phi \approx 1.2R/L_n + 1.4$

- GS2 linear simulations tend to give lower P_r than in the experiments and often also lower pinch number