TC-15 Dependence of momentum and particle pinch on collisionality

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| **TG priority:** High | **Start date:** 2009 | **Status:**  On-going | **Personnel exchange:**  Yes |
| **IO priority:** | **End date:** 2018 | **Motivation:** Physics Basis | |

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| --- | --- | --- | --- | --- | --- | --- |
| **Device /**  **Association** | **Contact**  **Person** | **2016 TG Request** | **Activity (from JEX/JA spreadsheet)** | | | |
| **2013** | **2014** | **2015** | **2016** |
| JET | T. Tala | Desirable | Considering | Committed | Considering |  |
| DIII-D | W. Solomon  S. Mordick | Desirable | Not doing | Analysis | Considering |  |
| NSTX-U | S. Kaye | Desirable | Analysis | Analysis |  |  |
| C-Mod | J. Rice | Desirable | Analysis | Analysis | Considering |  |
| AUG | R. McDermott | Desirable | Committed | Committed | Considering |  |
| MAST | W. Guttenfelder | Desirable | Committed | Analysis |  |  |
| JT-60U | M. Yoshida | Desirable | Analysis | Analysis | Analysis |  |

**Purpose:** Collisionality scans will be performed in various devices in order to develop an understanding of the relationship between momentum and particle pinches, and to develop an understanding of the underlying physics by testing theoretical predictions for pinches driven by low-k turbulence. Another collisionality related quantity to be scanned is R/Ln which is believed from theory to be the key quantity determining the magnitude of the momentum pinch in low-k turbulence plasma. Further dependencies to be studied are the one on q and β.

**Results for 2015**

**JET:** *Momentum pinch part:* No activity.

*Particle pinch part*: The session on the collisionality scan in 2014 was analyzed in detail and presented at the EPS conference. The 3-point collisionality scan at fixed q95, ρ\* and βN (2.3T, 2.7T, 3.4T versus 1.7MA, 2.0MA, 2.5MA) at constant ne=4.3e19m-3 at and NBI power levels of 5MW, 12MW and 23MW, respectively was executed very well. The collsionality υ\* was scanned about a factor of 5 within the scan βN and ρ\* (and q) were kept constant within a few %. Even temperature gradient length R/LTe was pretty much constant within the scan.

Density peaking increases in the inner core (r/a=0.3) from 0.3 to 2.7 and in the outer core (r/a=0.8) from 1.6 to 3.5 when υ\* decreases from 0.47 to 0.09 in JET H-mode plasmas while density peaking does not depend on υ\* in JET L-mode plasma. For this particular scan, experimental evidence indicates that a dominant part of this peaking originates from NBI fuelling and inward pinch is a subdominant fraction. This is supported by the simple linear runs with GYRO although much more work is needed here to make a conclusion. This result is based only on one discharge where the HRTS data is good enough for a reliable ne modulation phase profile. More discharges are needed to quantify more precisely the fractions of these two contributions and also much more work is required on the modelling front to make exact comparisons.

**AUG:** *Momentum pinch part:* Many of the NBI modulation shots for TC-15 were rerun in TRANSP to improve the data mapping and improve the accuracy of NBI torque calculation. The result shows that the changes in the deduced Prandtl and pinch number profiles are well within the error bars. Therefore, all the previous results can be regarded valid for the final report or Nuclear Fusion paper. The new TRANSP runs are still probably changing the result of intrinsic torque (TC-17) and thus useful work.

**DIII-D:** *Momentum pinch part:* Finished.

*Particle pinch part*: New experiment to scan υ\* in H-mode drafted and proposed. This was motivated on one hand by the contradicting result between DIII-D and JET and on the other hand by the observation that NBI fueling may be responsible for the density peaking to large extent in JET.

**NSTX:** Walter Guttenfelder has written a paper with the title "Quasilinear predictions of momentum pinch in NSTX" where the main results concerning TC-15 active work are summarized.

**C-Mod:** TC-15 particle transport experiment proposed but not yet accepted to study density peaking and particle transport on C-Mod. This proposal covers both the experiment in I-mode and H-mode.

**MAST:** MAST TC-15 experiment was performed in autumn 2013. The scope of the experiment was to measure perturbative momentum transport in ST H-mode and L-mode plasmas, and thereby to contribute to ITPA TC-15. The MAST experiments were performed with n=3 fields applied to perturbatively brake plasma rotation in low-beta L-mode plasma. Analysis implies that the NTV torque profile is peaked in core. Assuming diffusion & convection is all that matters, the (vpinch, χφ) response after removal of NTV torque indicates inward momentum pinch, -Rvpinch/χφ ~ 2 – 11. There are limitations in interpretation due to unsteady conditions, correlation between ωφ - ∇ωφ is significant. The next step is to try to improve analysis by fitting to modeled ωφ from integrating momentum transport equation. Gyrokinetic predictions are proceeding to predict -Rvpinch/χφ and other possible effects that may be important (centrifugal, finite ρ\*).

**Plans for 2016**

**JET:** *Momentum pinch part:* Collect all the material for the Nuclear Fusion paper. Check the L-mode pulses again with the newest optimization scheme.

*Particle pinch part*: Repeat part the υ\* scan in Deuterium as the data quality from reflectometry nor HRTS was not good enough in the 2014 scan. In JET Hydrogen campaign, a proposal on a dimensionless 3-point collisionality scan at fixed q95, ρ\* and β (2.3T, 2.7T, 3.4T versus 1.7MA, 2.0MA, 2.5MA) is put forward. This would be a very nice comparison with the Deuterium collisionality scan executed in 2014-2016.

**AUG:** Some final tests like on-axis versus off-axis NBI modulation within the same pulse is to be performed before the data is final for the Nuclear fusion paper.

Another scan to be further analysed in great detail is the ECRH power scan, the range spanning from PECRH= 0.6MW to PECRH= 3.4MW, giving useful data for momentum transport studies with respect to looking into the effect of the ECRH power on momentum transport.

**DIII-D:** *Momentum pinch part:* Collect all the material (final form already) for the Nuclear Fusion paper.

*Particle pinch part*: New experiments will performed on DIII-D in order to increase the υ\* range of the collisionality scan, and to include more points. JET was able to obtain a 3 point scan with a factor 5 increase in collisionality. New experiments on DIII-D are needed, to understand why the previous limited scan did not reveal a change in density peaking with υ\*. Core density peaking is a key ITER physics issue and DIII-D needs to resolve whether a larger scan would result in similar peaking scalings as JET and AUG. Or are the possible υ\* dependencies of density peaking different at different υ\* values. In addition, the relative contribution between NBI fueling and inward particle pinch to be quantified.

**NSTX:** Walter Guttenfelder is planning to write and submit a manuscript (probably to Nuclear Fusion) on the NSTX calculations (mainly gyro-kinetic analysis) from the earlier NSTX experiments. It's pretty much finished work. Once NSTX-U is operational, here is a plan to pursue further some NBI modulation experiments (but the υ\* scaling part is finished), but it is not sure if that will be 2015 or 2016.

**C-Mod:** To get approved and perform TC-15 particle transport experiment to study density peaking and particle transport on C-Mod. This proposal covers both the experiment in I-mode and H-mode.

**MAST:** Similar NSTX-U L-mode experiment to the MAST one in 2013 is planned for upcoming run campaign.

**OVERALL:** T. Tala gave a talk and final report on TC-15 joint experiment in the fall ITPA meeting. It is only final report concerning the momentum transport part. The particle transport part will stay open for quite some time (a couple of years) as it is very active field and high priority ITER physics topic as well.

The original scope of TC-15 was to perform collisionality scans in various devices in order to develop an understanding of the relationship between momentum and particle pinches, and to develop an understanding of the underlying physics by testing theoretical predications for pinches driven by low-k turbulence. The scans were extended to include R/Ln scan and q-scan. Total 5 tokamaks, JET, DIII-D, AUG, NSTX and C-Mod, participated in this JEX and recently MAST is doing very similar work. The main conclusions of the TC-15 are the following ones:

* Well matched dimensionless collisionality scan on JET and DIII-D showed no dependence of momentum transport on collisionality. This further confirmed with data from AUG and NSTX. This is also consistent with GK simulations.
* Prandtl number does not depend on inverse density gradient length. The pinch number shows a clear dependence on R/Ln in each device (JET, DIII-D, AUG and NSTX) separately and as a joint database: -Rvpinch/χφ ≈ 1.2R/Ln + 1.4
* The observed weak q-dependence of the pinch number (larger than 1 unit in -Rvpinch/χφ) in AUG and JET q-scans is larger than that originating from different R/Ln within the scan. The experiment cannot distinguish whether this comes from q- or s-dependence. The Prandtl number does not depend on q.

The full Nuclear Fusion draft will be ready for clearance after 2-3 weeks of work. However, there was a discussion whether further work should be included in the area of understanding why JET L-mode shots have such a high Prandtl numbers, typically above 2 while in all the other conditions and tokamaks it stays between 0.5-1.5.

**Background:** Recently, several tokamaks have shown that a significant inward momentum pinch exists. NBI modulation technique or NBI blips has been used on JET, JT-60U and DIII-D while plasma braking has been used on DIII-D and NSTX. Now, when the existence of the inward momentum pinch has been established, in order to be able to extrapolate its significance in ITER prediction for rotation, the parametric dependencies of the pinch must be clarified. The recent theory papers and gyro-kinetic simulations have shown that the most important parametric dependence of the momentum pinch is the density gradient length R/Ln. R/Ln (measure of density peaking factor), on the other hand, depends strongly on the collisionality, reported in several tokamaks. The electron trapping is expected to play an important role in the generation of the momentum pinch, indicating why collisions are important in determining the momentum pinch. It is possible that a higher collisionality will make the electrons more adiabatic and will remove the pinch effect. Here, similar physics is expected for the particle transport where the reduction of the trapped electron response removes the inward particle pinch. The central role of trapping shows the importance of including spherical tokamaks in the joint experiment where trapping is different. However, no experimental data exist to verify the dependence of the momentum pinch on either R/Ln or collisionality. Also, while the density peaking dependence on collisionality is reported on many tokamaks, the direct dependence of the particle pinch vpinch,part on collisionality has not been studied (partly due to diagnostics difficulties in measuring the density evolution accurately enough and partly due to challenges in inducing suitable density perturbation). According to gyro-kinetic simulations, the pinch number depends strongly on β at high enough values of β. At low β, ITG completely dominates and momentum pinch depends only weakly on β, but at higher β, kinetic-ballooning modes become significant and momentum pinch is decreased and eventually becomes an outward convection. One objective in this experiment is to verify this theory result and gyro-kinetic simulations with experiments, to be proposed on 3 different tokamaks suited best for the required high β studies. Furthermore, no attempts have been made to compare the similarity of the momentum and particle pinch although according to the theory they are linked. Quantifying the parametric dependence of the momentum and particle pinch on collisionality (and possibly some other parameters as well) consolidates the extrapolation of both the toroidal rotation and density profiles for ITER.