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Neoclassical Rotation Theory Simulations & Comparison with Experiment

Original title:
Transport Simulations of DIII-D Discharges with Impurity Injection

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THEORY

The extended neoclassical theory includes the effects of the gyroviscous component of the Braginskii viscosity tensor in the radial momentum transport equation[3]

$$\text{gyro}$$

Since gyro $\text{gyro}/$ 10^{4} gyro the toroidal viscous force in toroidal geometry is

$$\left\langle R^{2} \quad {}_{34} \right\rangle \left\langle \frac{1}{Rh_{p}} \frac{}{I} \; R^{3} h_{p} \; {}_{4} \frac{V \; R^{1}}{I_{p}} \right\rangle \frac{1}{2} \; G \frac{nmT}{eB} \frac{V}{R} \; O^{3} \quad R_{0} mnV_{d}$$

where,

$$G \quad \frac{r}{{}_{4}V} \frac{}{r} \; {}_{4}V \quad r \; L_{n}^{1} \; L_{T}^{1} \; L_{V}^{1}$$

is a factor depending on the gradient scale lengths of the density, temperature and toroidal velocity profiles, and the poloidal asymmetry factor is defined as:

[3] W.M. Stacey, Phys. Plasmas **8** (2001) 158.

$$4\ \frac{n^c}{}\ \frac{V^s}{}\quad 1\ \frac{V^c}{}\ \frac{n^s}{}$$

$$4\ \frac{n^c}{}\quad \frac{B}{B}\frac{V}{V}\ \frac{}{}^{s}\ \frac{n^s}{}\ \frac{}{}^{s}$$

$$\frac{n^s}{}\quad \frac{B}{B}\frac{V}{V}\ 2\ \frac{}{}^{c}\ \frac{n^c}{}\ \frac{}{}^{c}$$

The coefficients of the poloidal variations $n^{c/s}$, which arise from a Fourier expansion of the form $x(r,) = x^0(r)(1+x^c\cos + x^s\sin)$ as well as the poloidal velocity V, are evaluated by solving a set of nonlinear coupled equations for the (1, cos, sin) components of the poloidal momentum balance equations for each species.

Central Rotation Velocities and Momentum Confinement Times

Assuming a fixed profile shape for the toroidal velocity and using the measured background plasma properties, the central toroidal velocity and the theoretical momentum confinement time can be calculated. Notice that only the shape of the toroidal velocity profile is assumed and <u>not</u> the amplitude(V_0) which is calculated by the theory:

$$\sqrt{\frac{2m_b}{E_b}} P_b R_{tan} \frac{2\pi R \int_0^a \left\langle R \sum_j^{ions} n_j m_j V_j \right\rangle 2\pi r dr}{th} \frac{V_0 2\pi R \sum_j^{ions} \int_0^a \left\langle R n_j m_j f_v \right\rangle 2\pi r dr}{th}$$

where

$$th \frac{2 \sum_j^{ions} \int_0^a \left\langle \quad j \quad j \quad j \right\rangle 2}{2 \sum^{ions} \int_0^a \left\langle \quad 2 \quad \right\rangle 2_{34} \int_0^a \left\langle \quad j \quad j \quad \hat{} \right\rangle 2 \quad 8}$$

COMPARISON WITH EXPERIMENT

We compared predicted and measured momentum confinement times and central toroidal rotational velocities in a number of different types of DIII-D discharges.

Good agreement is obtained between theory and experiment for both the velocities and the momentum confinement times.

A possible exception is the ITB shot 102942 where the theory underpredicts the momentum confinement time and the central rotation velocity. This is consistent with the Mikhailovskii-Tsypin drift correction to the gyroviscous stress tensor[4] which is important when the parameter (/ L_{pi})/(V_i / V_{thi}) > 1. The combination of the strong density gradient at the ITB and the peaked T_i profile makes 1.5 at the ITB location, which could reduce the gyroviscous momentum transport rate by an order of magnitude[5].

[4] A. B. Mikhailovskii and V. S. Tsypin, Sov. J. Plasma Phys., **10**, 51 (1984).

[5] H. A. Claassen, et al., Phys. Plasmas, **7**, 3699 (2000).

Table 1: Comparison of Predicted and Measured Toroidal Rotation Speeds and Momentum Confinement Times in DIII-D

Shot / Time	**Mode, NBI, impurity**	P_{nbi} **MW**	$\bar{n}$ m^{-3}	T_{i0}/T_{e0} **keV**	$V_{30}\div V_{thD}$	2_3^{th} **ms**	2_3^{exp} **ms**	V_{30}^{th} 10^5 **m/s**	V_{30}^{exp} 10^5 **m/s**
98777 1.6 s	L, Co Carbon	4.5	3.42	3.5 2.5	0.31	80	73	1.52	1.50
98775 1.6 s	L, Co Neon	"	4.05	6.3 3.3	0.37	147	152	2.90	3.06
99411 1.8 s	H, Co Carbon	9.2	4.80	8.3 3.9	0.32	93	84	2.90	2.64
106919 2.0 s	QH, Ctr Ni-Cu,	9.32	2.58	10.9 3.9	0.40	44	45	3.86	3.98
" 3.5 s	"	"	2.83	14.2 4.2	0.38	64	68	4.21	4.48
106956 3.1 s	QDB Ctr CuNi,	11.77	3.75	15.1 4.4	0.24	44	46	2.41	2.51
102942 0.85 s	H, Co Carbon	4.89	2.36	1.8 2.5	0.40	55	51	2.20	2.02
" 1.25 s	ITB, Co carbon	7.08	2.67	4.8 4.2	0.35				

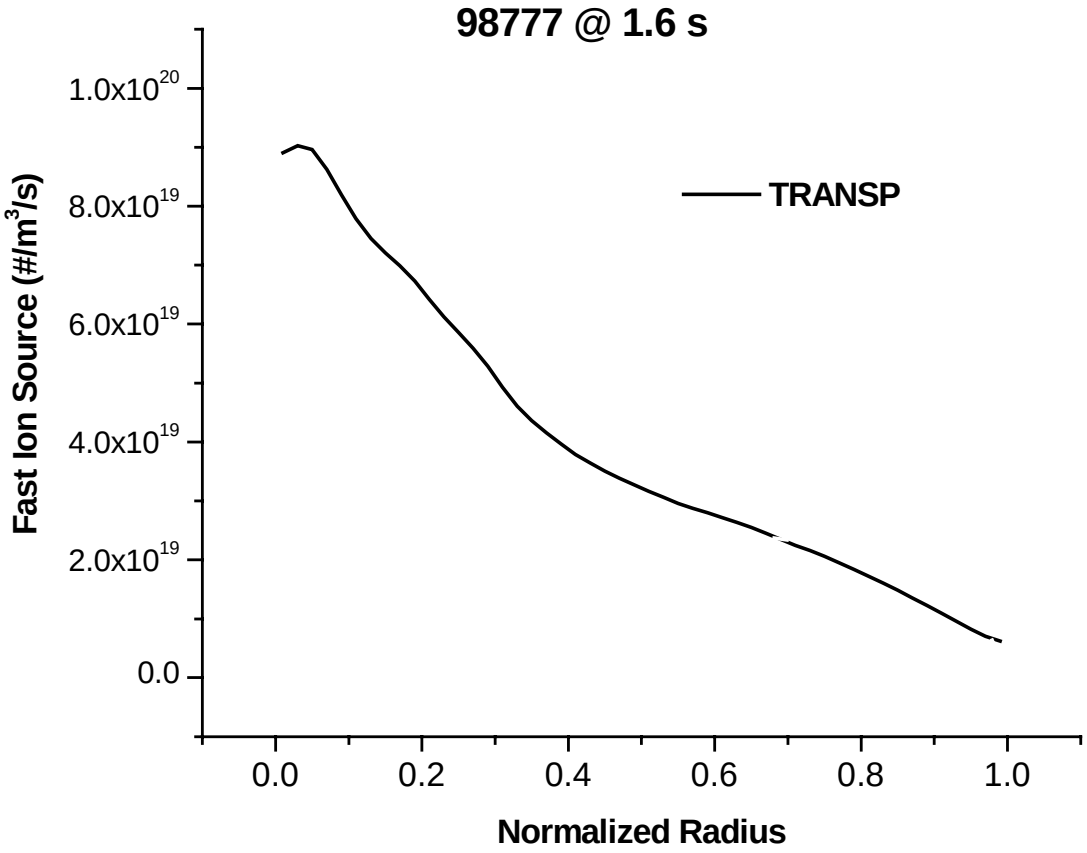
The predictions of the theory are compared with experiment for the DIII-D L-mode reference discharge 098777 with Carbon as the main impurity.

The theory is applied on each flux surface and fits to experimental profiles are used for the background plasma and impurity.

The beam momentum density input rate is calculated with our neutral beam deposition and fast ion slowing down code NBEAMS[6]. The predicted fast ion deposition source by NBEAMS agrees quite well with TRANSP.

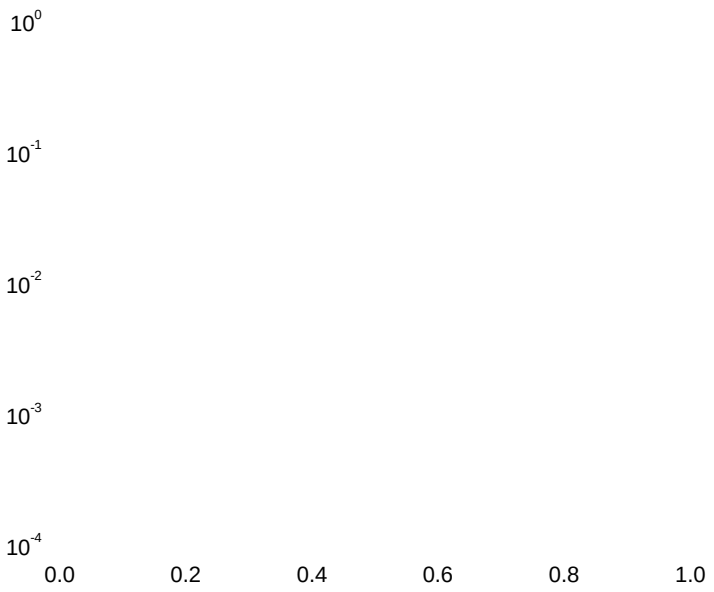
[6] J. Mandrekas, "Physics Models and User's Guide for the Neutral Beam Module of the SuperCode", **GTFR-102**, 1992.

Comparison of NBEAMS and TRANSP fast ion deposition profiles for 98777 @ 1.6 ms.



Poloidal Quantities

The density poloidal asymmetries and poloidal velocities for each species, calculated by solving a system of nonlinear equations on each flux surface[3], are shown below:



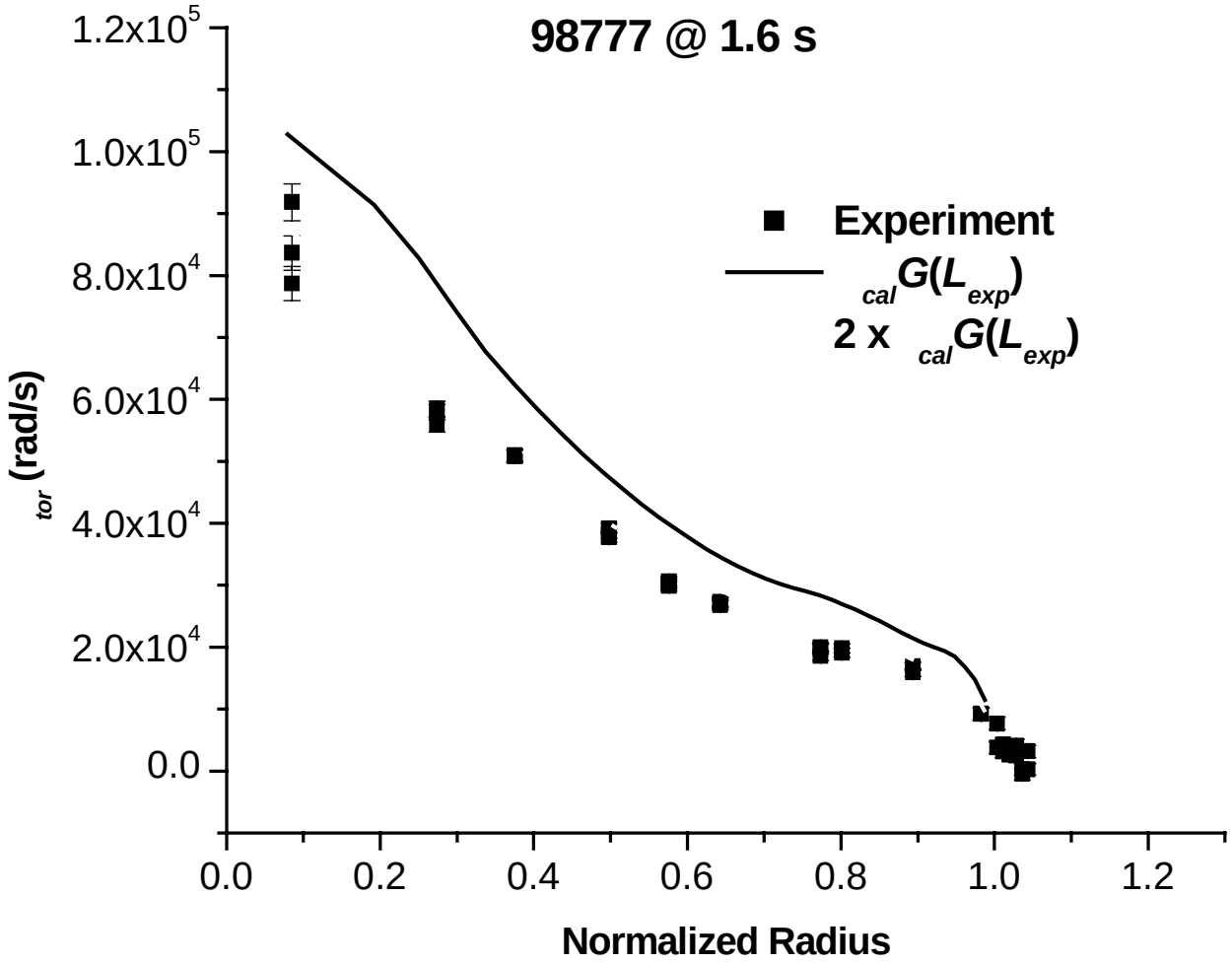
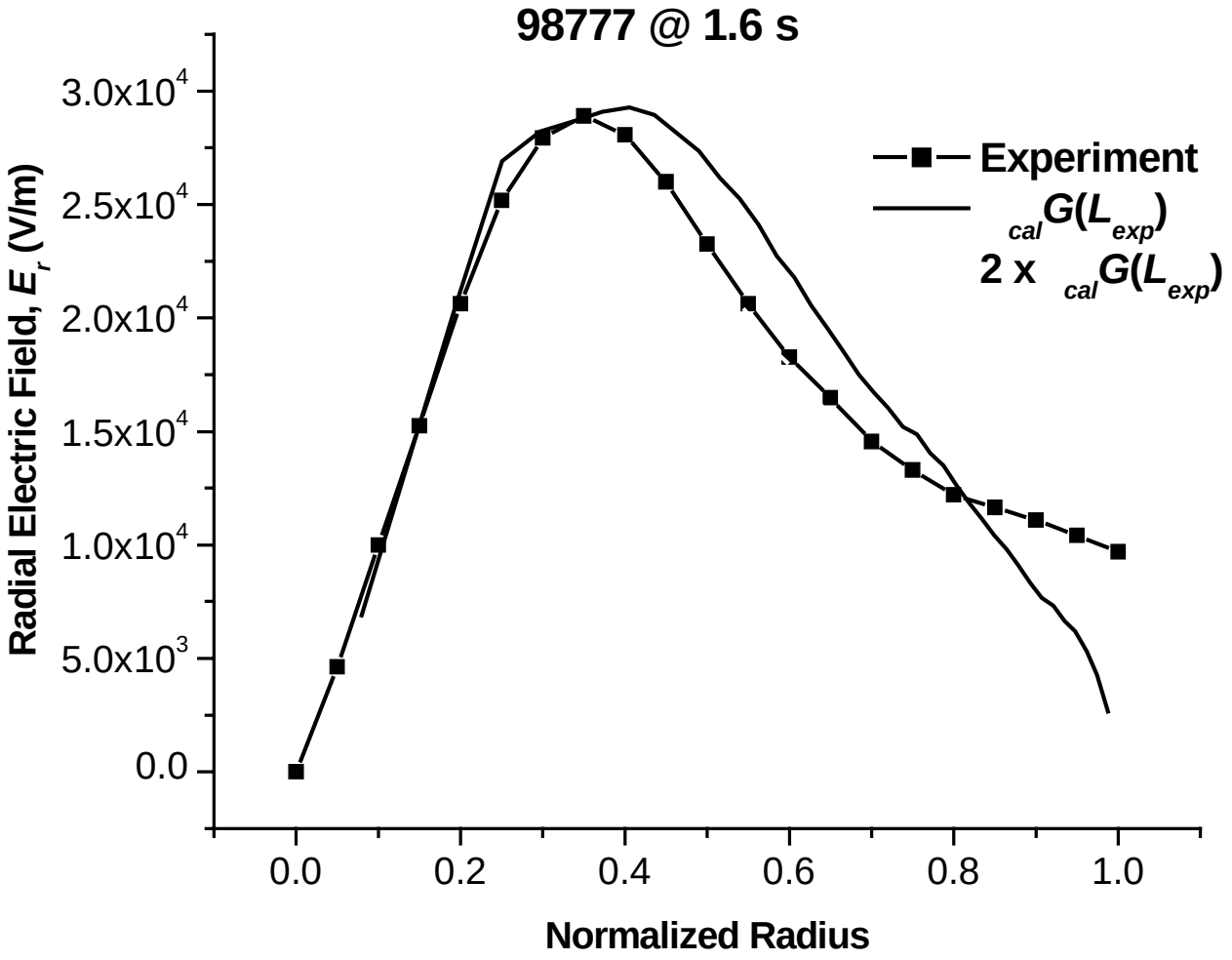
Comparison of toroidal angular velocity and radial electric field

Two simulations are shown for two different multipliers of the product G (1 & 2) in order to evaluate the sensitivity of our simulations to computational and experimental uncertainties.

The factor –calculated for analytic toroidal geometry with circular cross sections and using a low-order Fourier expansion—includes any approximation errors in the calculation of the poloidal velocities and density asymmetries

The factor G depends on the ion pressure and toroidal velocity gradient scale lengths, which we construct from the corresponding experimental profiles.

Comparison of toroidal angular velocities with experiment



Comparison of radial electric field with experiment