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Modelling of JET hybrid scenarios with the GLF23 model

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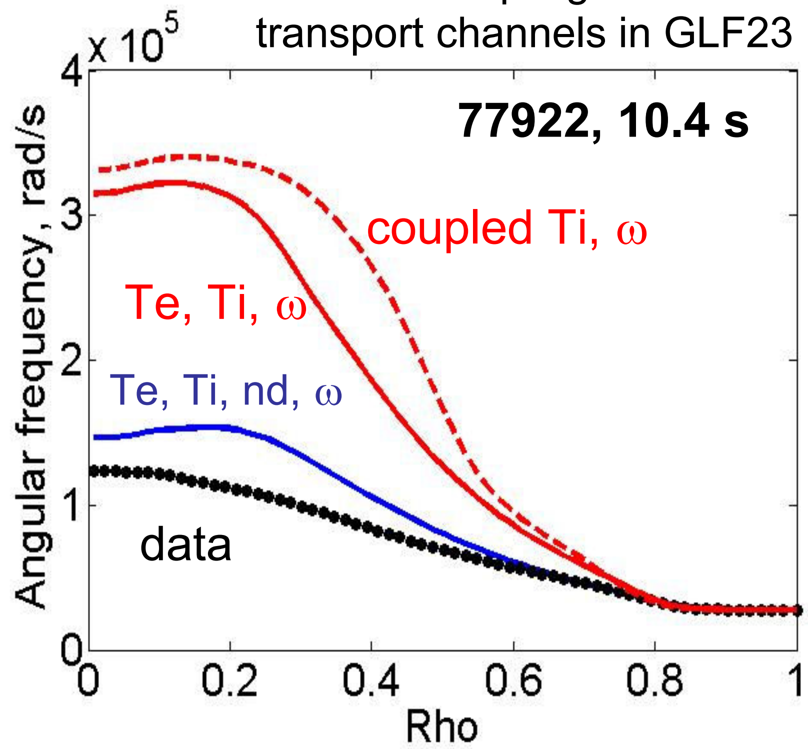
Objectives:

- ***increase the database for GLF23 validation on JET hybrid discharges: various shapes, Ipl waveforms, H98y***

- ***self-consistent simulations of toroidal rotation, temperatures and density (started with the momentum simulations with GLF23, expanded to four transport channels)***

Effect of coupling of various transport channels in GLF23



8 discharges with different H98y, torque per particle, Ipl waveform, shape have been selected for modelling

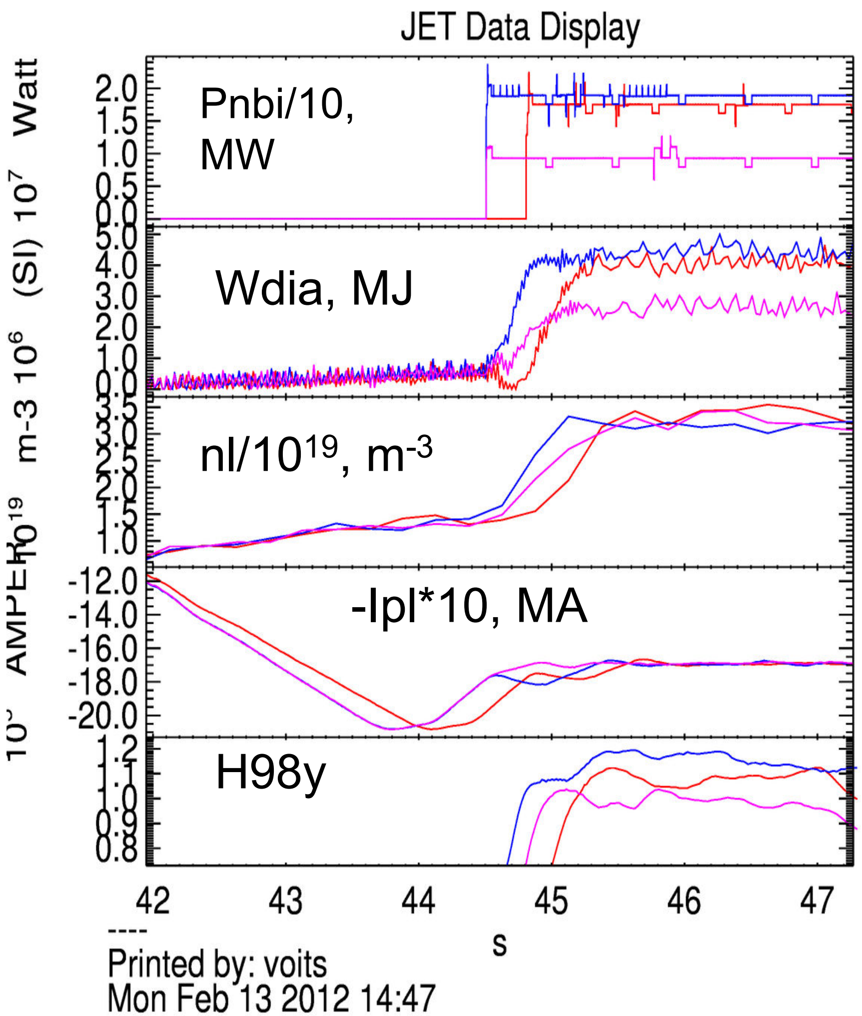
Pulse #	Time, s	PNBI MW	nl/10^{19} m-3	Omega at 3 m, rad/s	H98y (SCAL)	<Press.at ρ=0.8>, Pa	Torque per ptcl. at ρ<0.8, Nt-m
74641	6-6.5	9.3	3.4	0.79e5	1	0.9e4	4.47e-21
74634	5.6-6.1	17.5	3.4	0.95.e5	1.05	1.3e4	6.97.e-21
74637	6-6.5	18.9	3.2	1.37e5	1.17	1.2e4	7.05e-21
74826	6-6.5	19.2	3	1.06e5	1.05	0.97e4	8.72e-21
75225	6-6.5	18	3.2	1.27e5	1.35	1.33e4	8.12e-21
79635	5.5-6	6	2.5	0.6e5	1.23	0.49	4.27e-21
75590	5-5.5	10	3.1	1.06e5	1.38	1.23e4	6.11e-21
77922	7.5-8	17	4.77	1.16e5	1.37	2.07e4	7.08e-21

Low triangularity: 1.7 MA / 2T

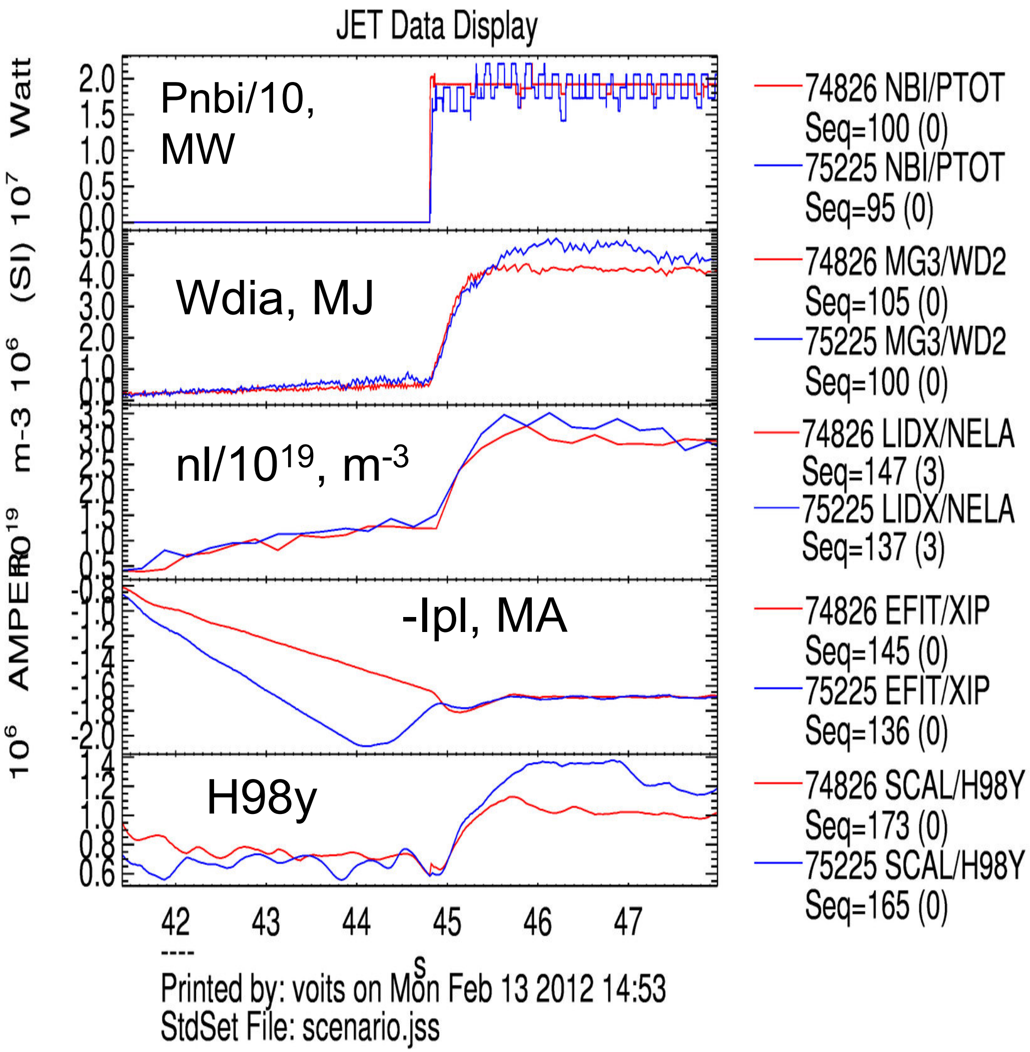
High triangularity: 0.8MA/1.1 T (79635), 1.3MA/1.7 T (75590), 1.7MA/2.3T (77922)

Low triangularity pulses

74634, 74637, 74641



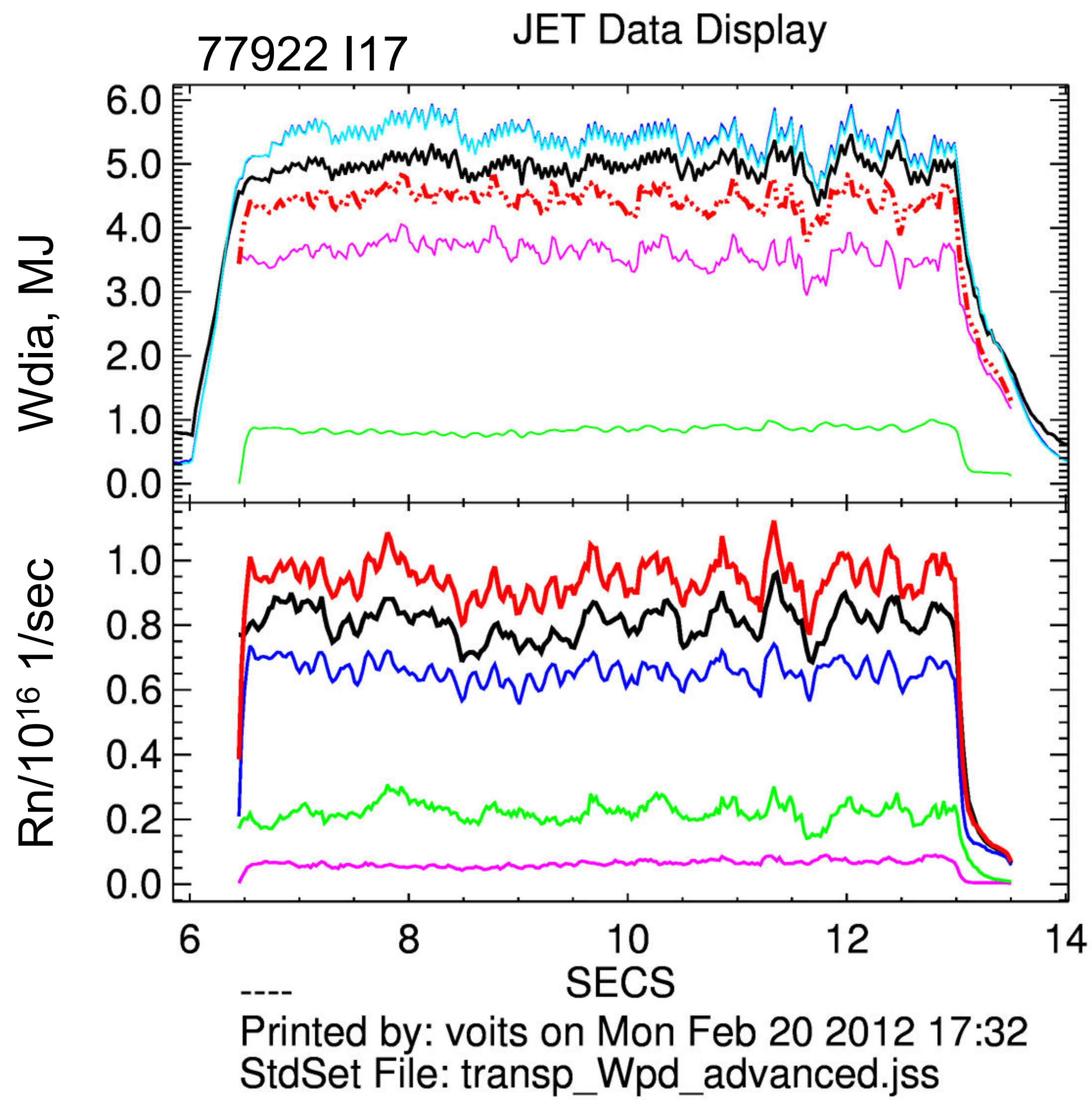
74826, 75225



Modelling assumptions

- Te and ne are prepared with Profile Maker (HRTS, LIDR, ECE)
- CX measurements for Ti and Zeff profiles (CXFM/TICR, ZFCX)
- EFTM/Q for all pulses except 74826 and 75225 where the TRANSP simulated q consistent with EFTM/Q was used [J. Hobirk et al, to be submitted to Nucl. Fus.]. Sensitivity to be assessed.
- NBI heat, particle and momentum sources are calculated by TRANSP
- Wall particle source is taken from TRANSP/FRANTIC using 10*Dα. Sensitivity study for 77922: same results with zero recycling source
- Pedestal values have been used as a boundary: $\rho_{ped,n}$ = 0.85, $\rho_{ped,T}$ = 0.8 - 0.85
- αE = 1 (calibration factor in front of the ExB shear term in GLF23)

Data consistency checked with TRANSP shows similarly good agreement for Wdia, neutron yield and KG1V in selected shots



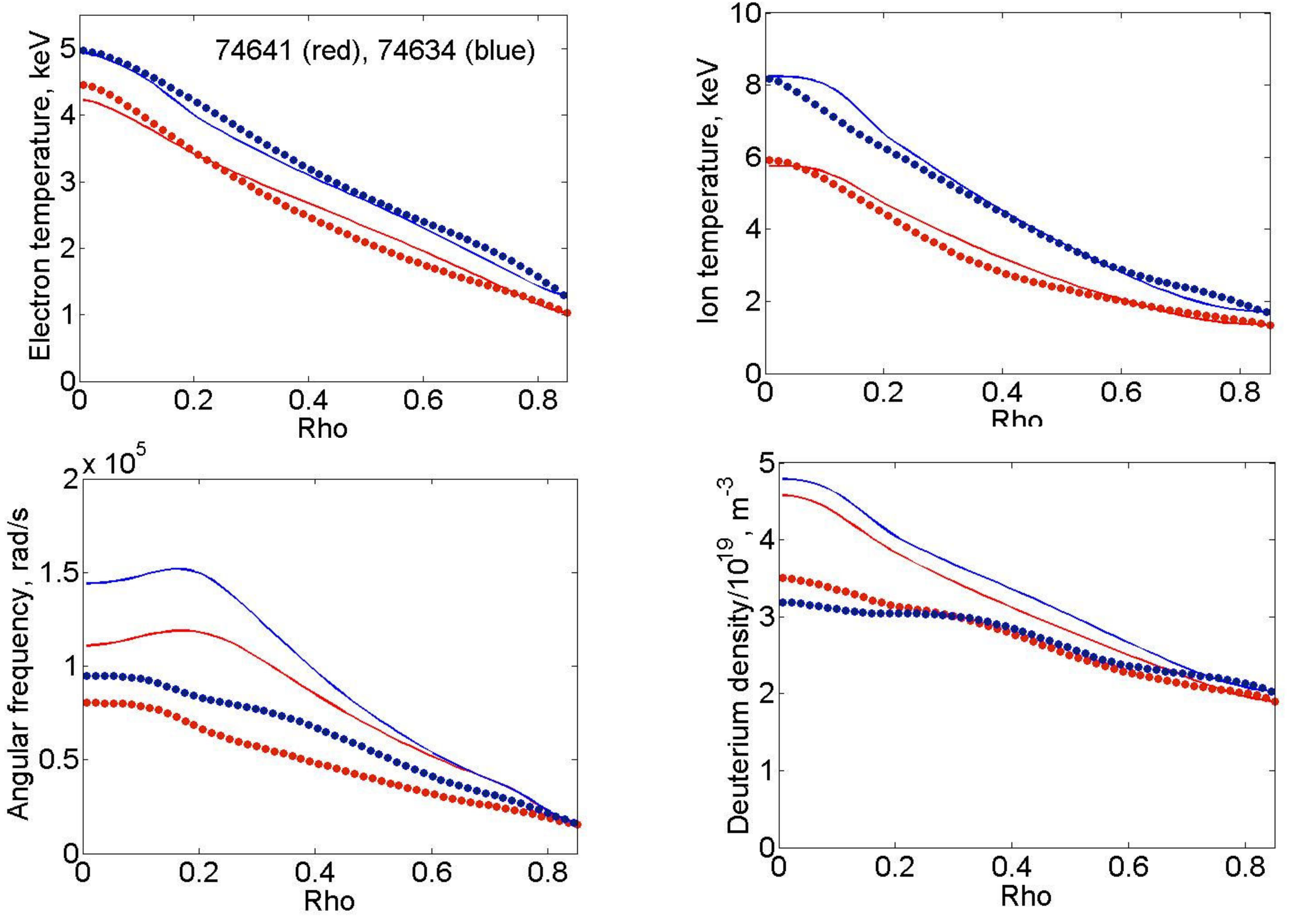
Wdia: EFIT (black),
TRANSP total (red),
TRANSP thermal (pink),
TRANSP fast (green)

Neutron yield:
TRANSP total (red),
beam-target (blue),
beam-beam (pink),
thermal (green)

Measured (black)

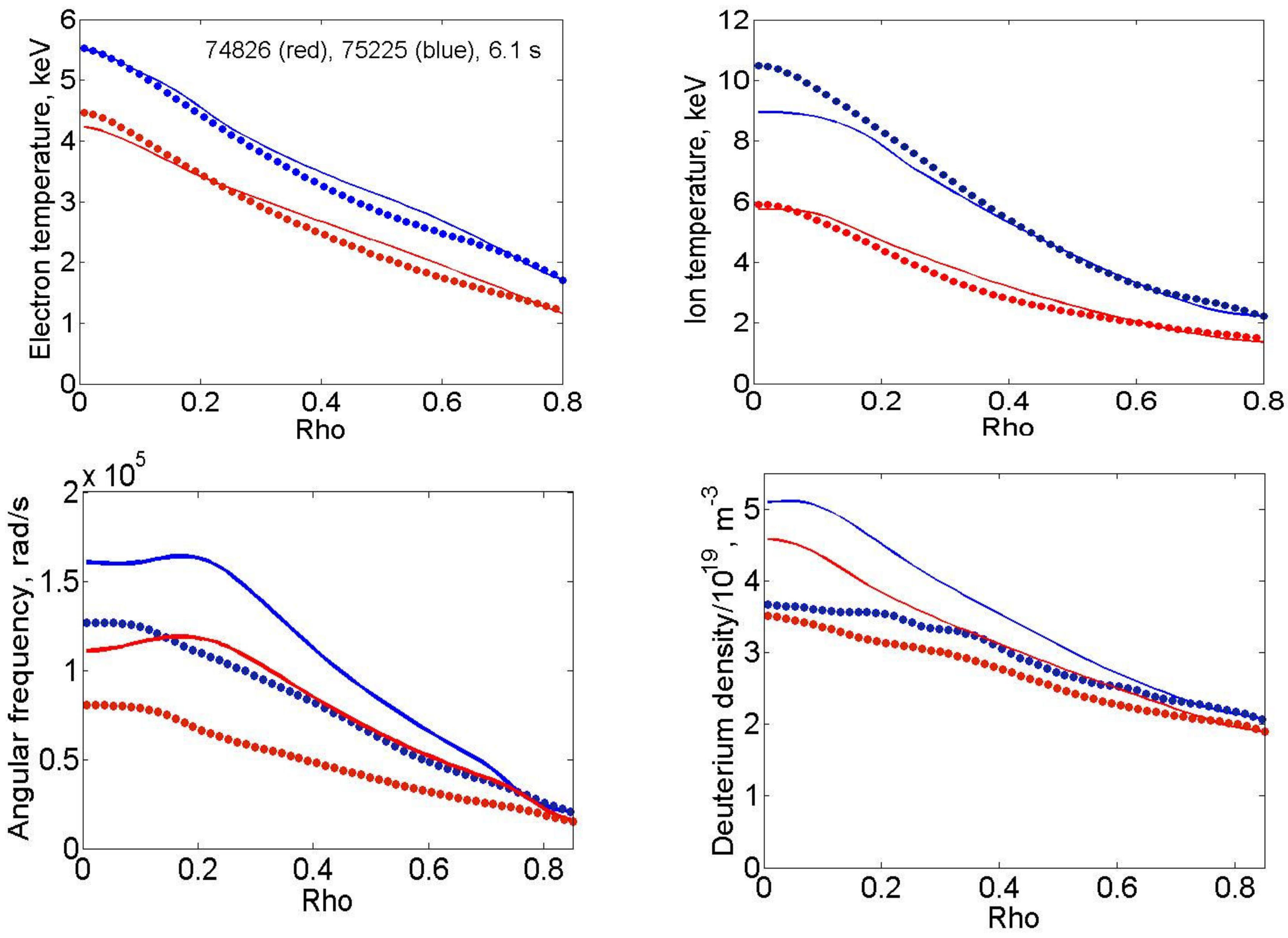
Low triangularity, "H98y scan" (74641, 74634, 6 s)

Data fit (symbols), GLF23/ASTRA (curves)

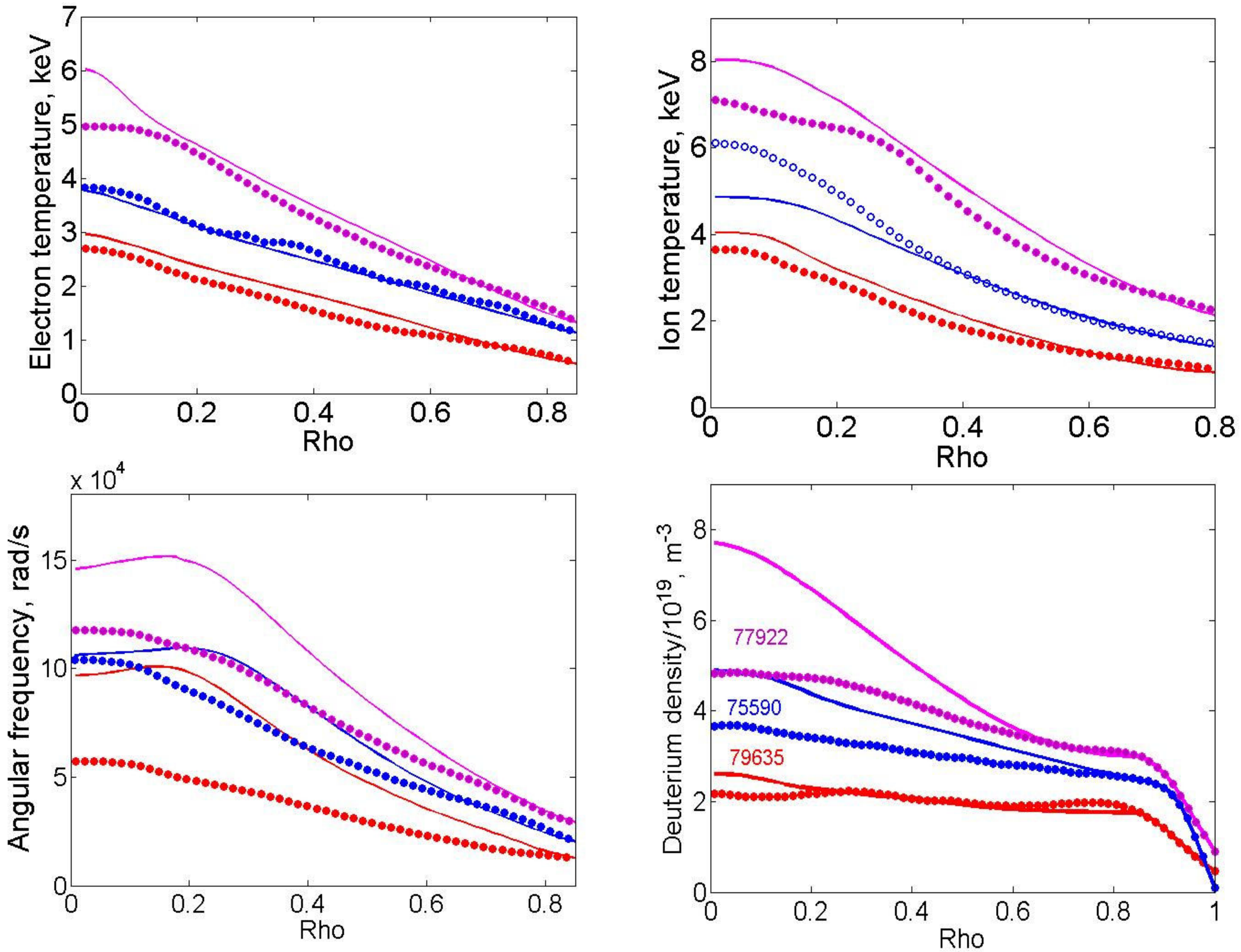


Low triangularity: H-mode (74826), HS (75225)

Data fit (symbols), GLF23/ASTRA (curves)



High triangularity, Ipl overshoot: 79635 (0.8 MA/1.1 T), 75590 (1.3 MA/1.7 T), 77922 (1.7MA/2.3 T). Data fit (symbols), GLF23/ASTRA (curves)

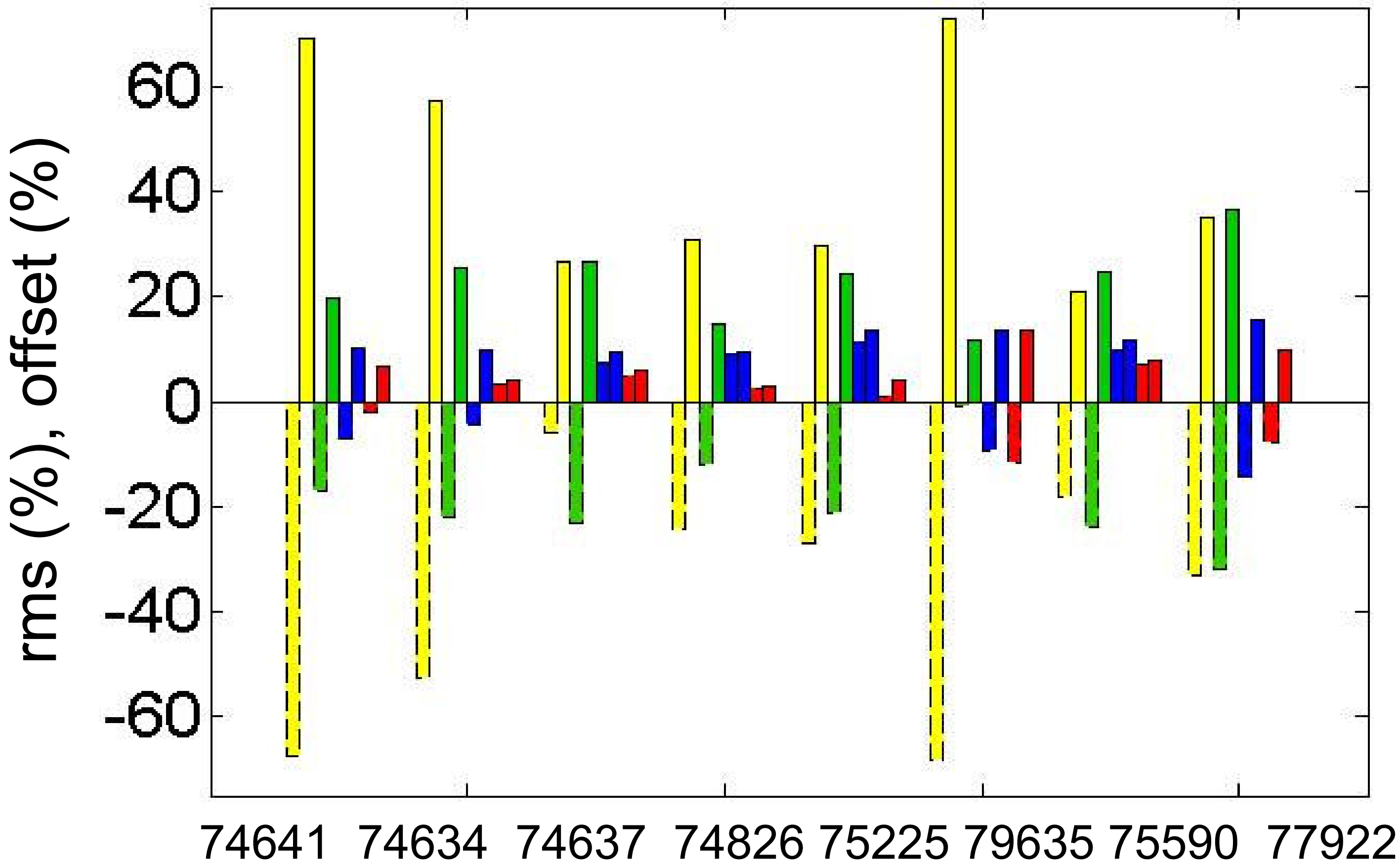


GLF23 predictive accuracy for Ti, Te, nd and omega

$$\mathrm{rms} = \left[\frac{1}{N+M} \sum_{t_n=t_1}^{t_N} \sum_{\rho_m=0}^{\rho_m=0.7} \frac{\{T_{\mathrm{exp}}(t_n,\rho_m) - T_{\mathrm{sim}}(t_n,\rho_m)\}^2}{T_{\mathrm{exp}}(t_n,\rho_m)^2} \right]^{1/2} \qquad \mathrm{offset} = \frac{1}{N+M} \sum_{t_n=t_1}^{t_N} \sum_{\rho_m=0}^{\rho_m=0.7} \frac{T_{\mathrm{exp}}(t_n,\rho_m) - T_{\mathrm{sim}}(t_n,\rho_m)}{T_{\mathrm{exp}}(t_n,\rho_m)}.$$

	Time, s	Te: rms, offset, %	Ti: rms, offset, %	**omega: rms, offset, %**	**nd: rms, offset, %**
74641	6-6.5	6.63, -2.18	10.15, -6.97	**69.12, -67.61**	**19.83, -17.09**
74634	5.6-6.1	4.17, 3.38	9.67, -4.32	**57.32, -52.43**	**25.58, -21.86**
74637	6-6.5	6.01, 4.86	9.35, 7.44	**26.45, -5.99**	**26.45, -23.32**
74826	6-6.5	2.99, 2.31	9.43, 9.1	**30.8, -24.46**	**14.67, -12.11**
75225	6-6.5	3.87, 0.98	13.61, 11.18	**29.53, -26.9**	**24.37, -21.2**
79635	5.5-6	13.64, -11.78	13.58, -9.39	**72.96, -68.2**	**11.51, -0.91**
75590	5-5.5	7.74, 7.06	11.65, 9.86	**20.68, -18.03**	**24.58, -23.78**
77922	7.5-8	9.68, -8.03	15.36, -14.52	**35.13, -33.14**	**36.59, -31.88**

GLF23 predictive accuracy for Te (red), Ti (blue), nd (green) and omega (yellow): rms (right columns), offset (left columns)



Choice of ExB calibration factor (α_E) in GLF23

- Waltz et al, PoP 1997: "*…based on nonlinear 3D GLF simulations ... the ITG turbulent transport vanishes at a critical ExB shear rate $\gamma E = \gamma max / \alpha E$ where* ***$0.5 < \alpha E < 1.5$.*** *The general parametric dependence of* ***αE*** *is uncertain...*"
- Non-linear ITG gyrofluid: **$\alpha E \approx 1$**
- Waltz et al, PoP 2002: circular ITG gyrokinetic: **$\alpha E \approx 0.6$**
- Non-linear gyrokinetic, ITG/TE modes, toroidal geometry (GYRO) [Kinsey et al, PoP 2005]:

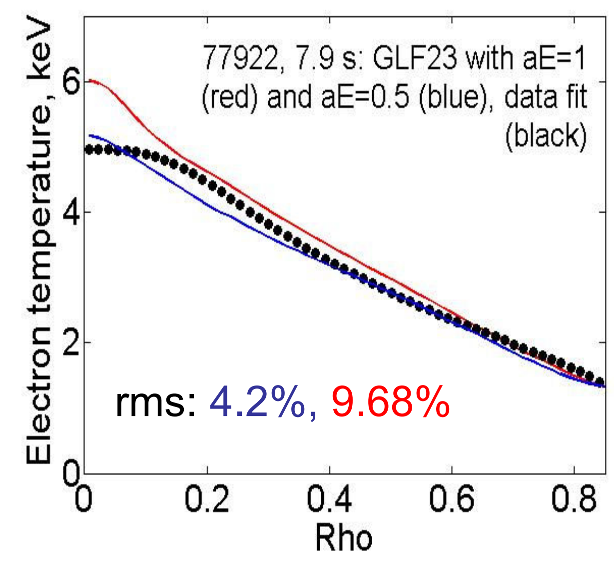
  - ***$\alpha E \approx 0.5 \pm 0.01$*** *adiabatic & kinetic electrons, w/o parallel velocity shear*

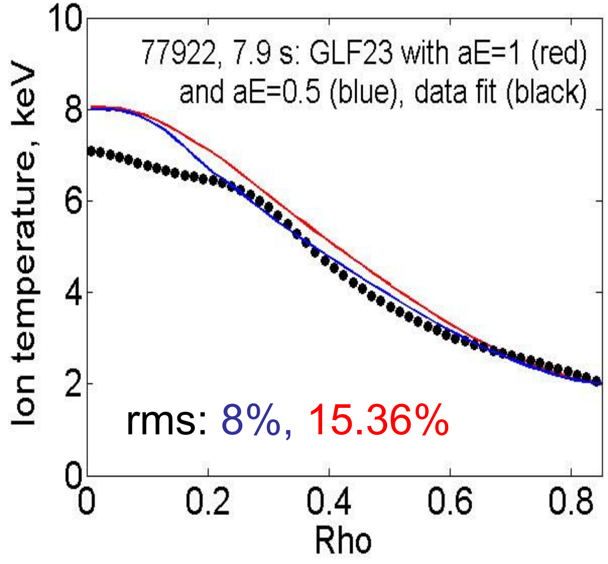
  - ***$\alpha E \approx 0.4 - 0.48$*** *kinetic electrons, peaked density, w/o parallel velocity shear*

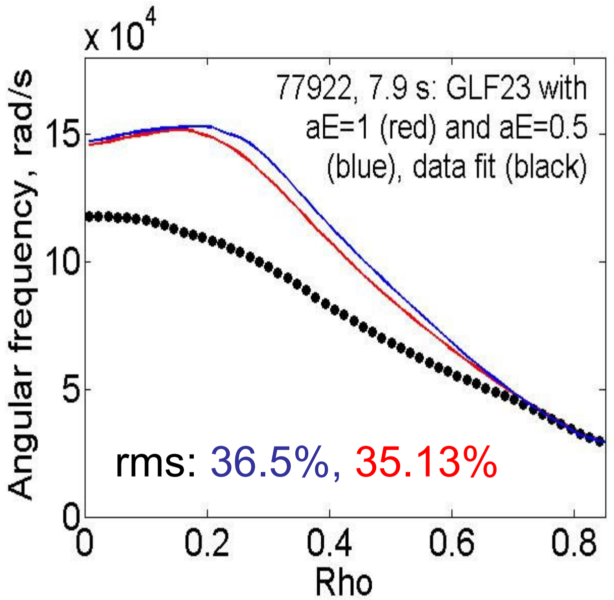
  - ***no transport quench by ExB shear*** *at large q due to destabilising effect of (large) parallel velocity shear (both adiabatic and kinetic electrons)*

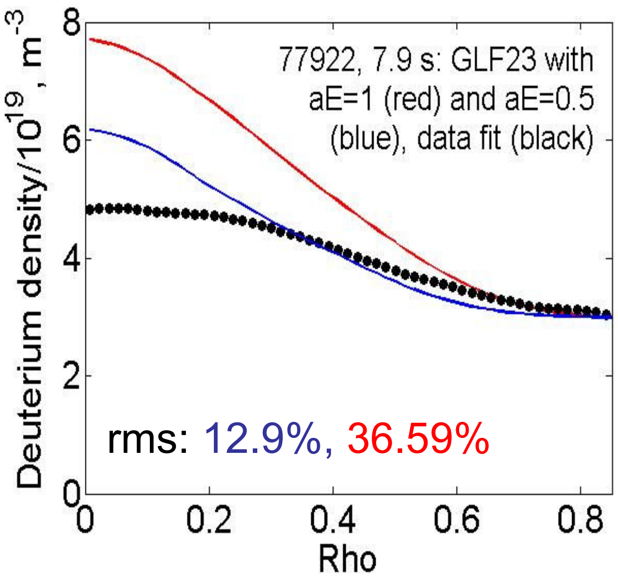
  These results are obtained for a given set of local parameters

Simulations with αE = 0.5 (blue) and αE = 1(red) for 77922









The agreement for density is better with αE=0.5, but the profile shape is not properly predicted

Simulated Te and Ti are weakly affected by αE (reduction of ExB shear is compensated by reduced ∇n drive and density → stiffness of temperature profiles)

Toroidal rotation is equally over-predicted with αE=0.5 and 1 (ExB shear reduction is compensated by reduced nd and ∇n destabilisation)

Summary and plans

Self-consistent temperature, density and toroidal velocity simulations with GLF23:

- *Te is well predicted (rms < 10% in the majority of cases)*
- *Ti prediction is slightly less accurate (but still rms < 16%). Larger discrepancy at high triangularity*
- *Over-predicted density peaking (by 11.5 - 36.6% of rms deviation) Discrepancy increases with power (density) at high triangularity*
- *Poor prediction of momentum (rms = 21-73%)*

Further work:

- *GLF23: adjustment of αE for selected discharges → parametric dependence/trend of αE → gyrokinetic simulations in support of αE choice under different plasma conditions*
- *TGLF: consistent four-field simulations to compare with GLF23*
- *Other (not included in GLF23) transport mechanisms for momentum and particles to be added?*

Prediction to ITER as an outcome of this validation – sensitivity of fusion performance to αE