EFDA

EUROPEAN FUSION DEVELOPMENT AGREEMENT

Task Force
INTEGRATED TOKAMAK MODELLING

MODELLING of JET HYBRID SCENARIOS

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Warm acknowledgements to P. Buratti for MHD analysis

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Outline:

I. IOS/ITPA talk

- *Experimental scenarios and parameter space (variation in plasma shape, Ipl waveforms, H98y)*
- *GLF23: self-consistent simulations of toroidal rotation, temperatures and density*
- *TGLF simulations (preliminary results)*
- *Validation of Bohm-gyroBohm model*
- *IOS/ITPA summary*

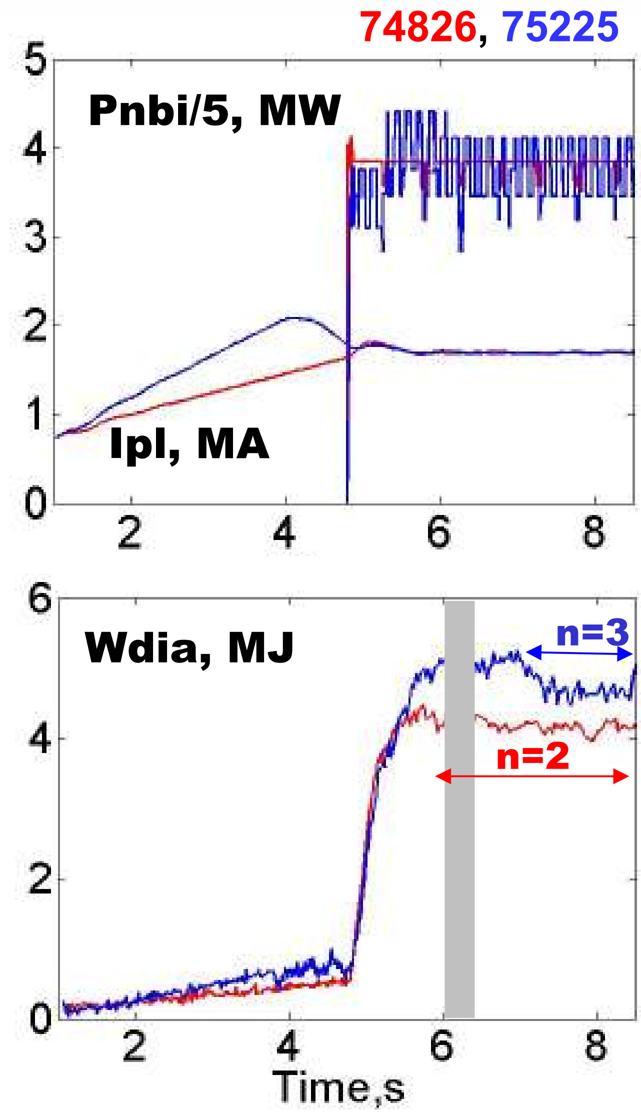
II. Discussion of remaining work for EPS 2012

III. Update on the status of some work (EDGE2D, GYRO, edge MHD, LHCD in JET steady-state scenario)

8 JET discharges (different shape, NBI power, plasma, current, H98y) have been selected

Pulse #	P_{NBI} MW	NI / 10^{19} m-3	Central Ω, rad/s	H98y	P(ρ=0.8), Pa
74641	9.3	3.4	0.79e5	1	0.9e4
74634	17.5	3.4	0.95.e5	1.05	1.3e4
74637	18.9	3.2	1.37e5	1.17	1.2e4
74826	19.2	3	1.06e5	1.05	0.97e4
75225	18	3.2	1.27e5	1.35	1.33e4
79635	6	2.5	0.6e5	1.23	0.49
75590	10	3.1	1.06e5	1.38	1.23e4
77922	17	4.77	1.16e5	1.37	2.07e4

J. Hobirk et al, submitted to PPCF



- Low triangularity discharges: 1.7 MA / 2T

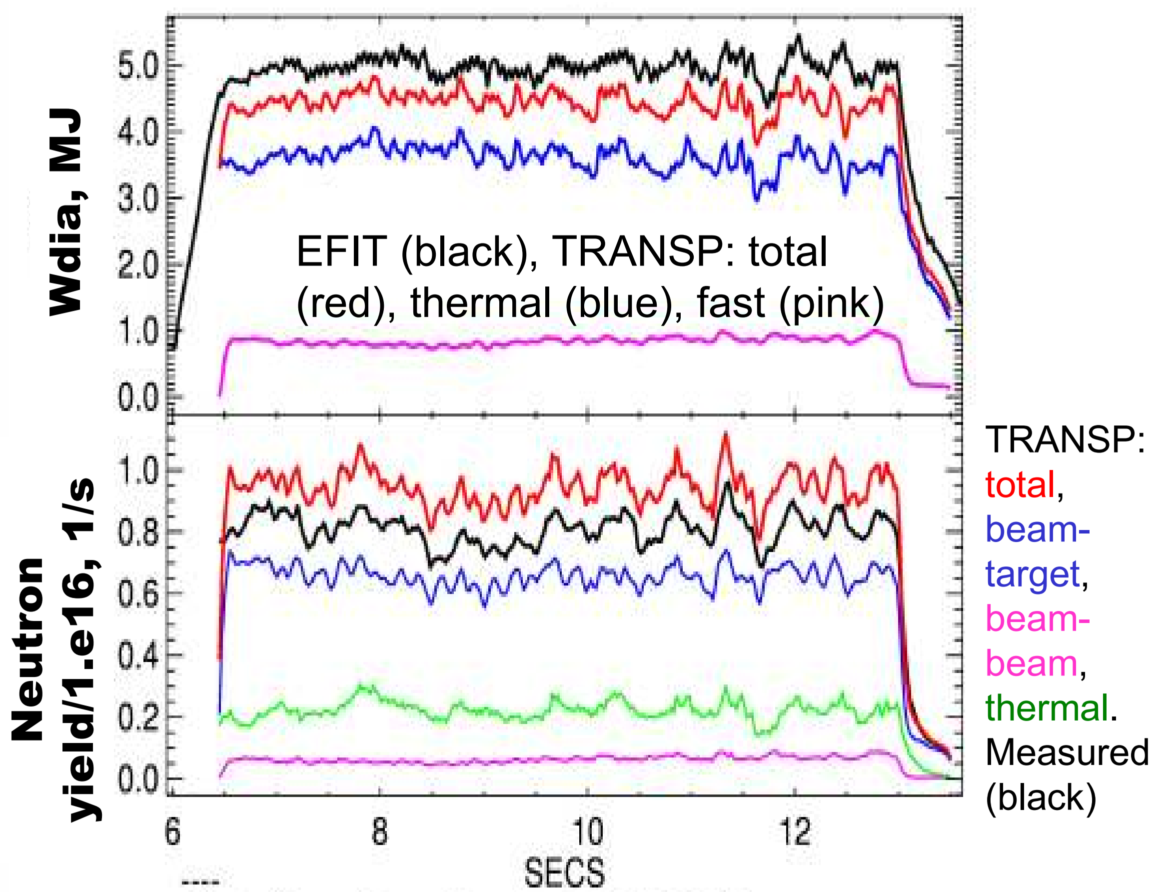
- High triangularity: 0.8MA/1.1 T (79635), 1.3MA/1.7 T (75590), 1.7MA/2.3T (77922)

- NTMs: 74826 (strong n=2), 74641 (weak 3/2, 4/3, 2/1), 74634 (weak 2/1, m3, n5), 74637 (4/3, 5/4 during last half of selected Δt), others are NTM-free during selected time interval

Data preparation and consistency

- **Fit of High Resolution Thomson Scattering and ECE for Te; HRTS and core Thomson scattering for ne.**
- **CX measurements of Ti and Zeff profiles**
- **q-profile: EFIT/MSE reconstruction or TRANSP simulated q-profile when it agrees with EFIT**
- **TRANSP for NBI heat, particle and momentum sources and wall particle source + ASTRA for transport modelling with GLF23 and TGLF**
- **JETTO & CRONOS for simulations with Bohm-gyroBohm model**

77922



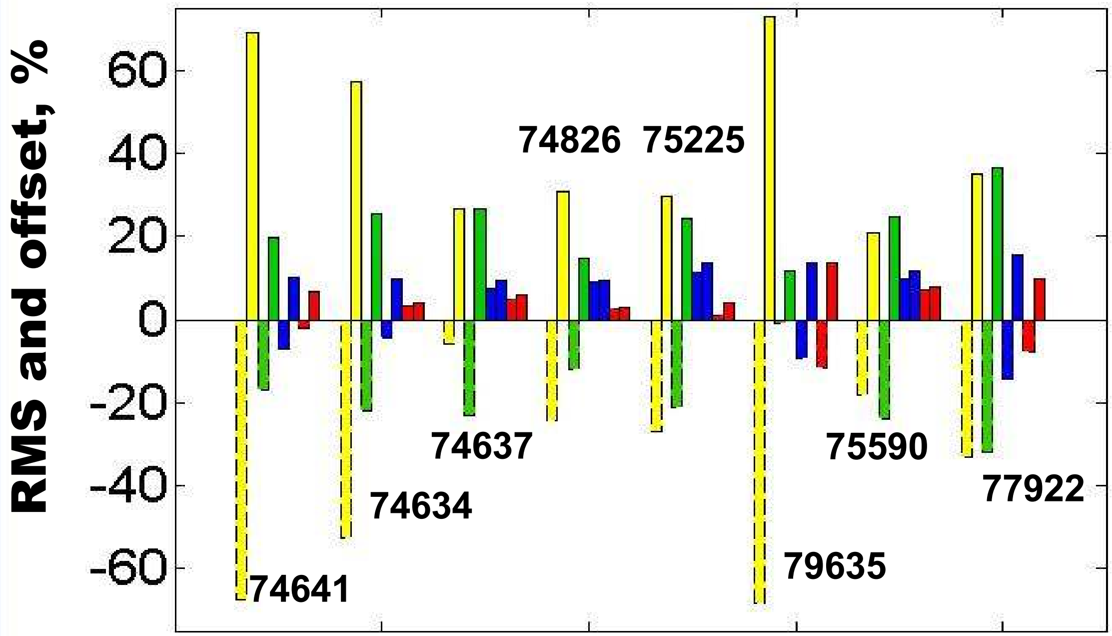
Typical agreement between EFIT/ TRANSP Wdia (top) and simulated/ measured neutron yield (bottom) obtained for 8 discharges

Validation of GLF23 model

- **JET hybrids are close to the stability threshold (QualiKiz, GLF23), modelling results may be sensitive to the ExB shear (or αE (= γmax / ωExB))**
- **αE =1 is used for JET H-mode plasmas**
- **Te, Ti, Vtor and density are simulated inside $\rho < \rho_{ped} = 0.8 - 0.85$**
- **χφ = χφ_GLF + χi_neocl, GLF23 + NCLASS for thermal χs and D**

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

$$\mathrm{offset} = \frac{1}{N+M}\sum_{t_n=t_1}^{t_N}\sum_{\rho_m=0}^{\rho_m=0.7}\frac{T_{\mathrm{exp}}(t_n,\rho_m)-T_{\mathrm{sim}}(t_n,\rho_m)}{T_{\mathrm{exp}}(t_n,\rho_m)}.$$



-Te and Ti are well predicted

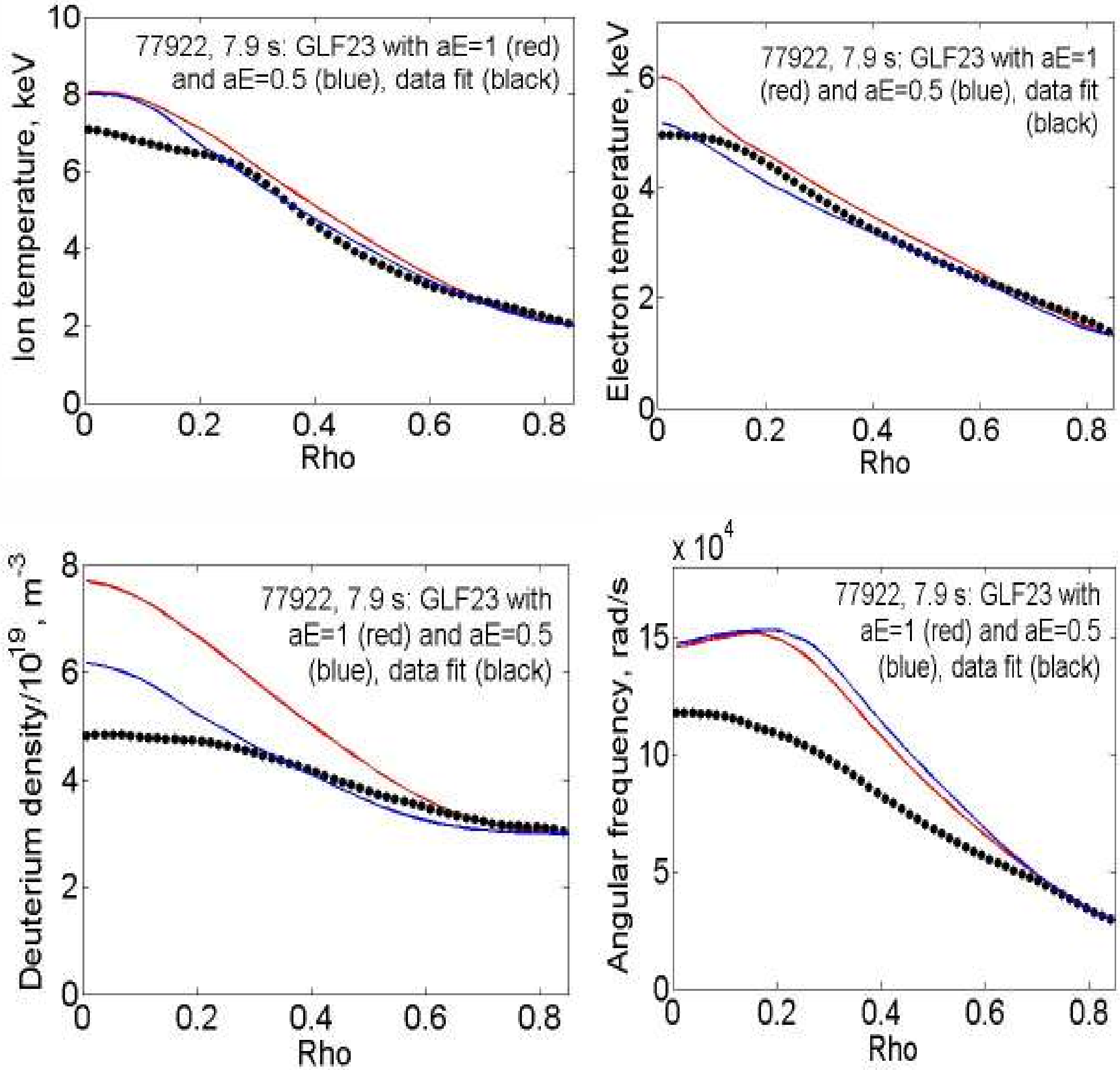
- density is over-estimated (too strong peaking)

- strongly over-predicted rotation

RMS (solid, right columns) and offset (dashed, left columns) for Te (red), Ti (blue), nd (green) and omega (yellow)

GLF23: effect of ExB shear stabilisation in HS

- **GLF23 [Waltz et al, PoP 1997]*: 0.5 < αE < 1.5***
- **Non-linear ITG gyrofluid: αE ≈ 1, circular ITG gyrokinetic: αE ≈ 0.6**
- **GYRO [Kinsey et al, PoP 2005]:**
  - αE ≈ 0.5 ± 0.1 without parallel velocity shear (lower at peaked density)
  - no transport quench by ExB shear at large q and parallel velocity shear
- **In our simulations αE is adjusted to improve the agreement with data**
- **Much better density prediction with *αE =0.5 for all shots (and shots simulated in J. Citrin et al, PPCF 2012 to appear)***
- **"Stiff" temperatures and rotation: reduction with *αE is compensated by increase via energy & momentum balance (reduced density)***
- ***Toroidal rotation is still strongly under-predicted***



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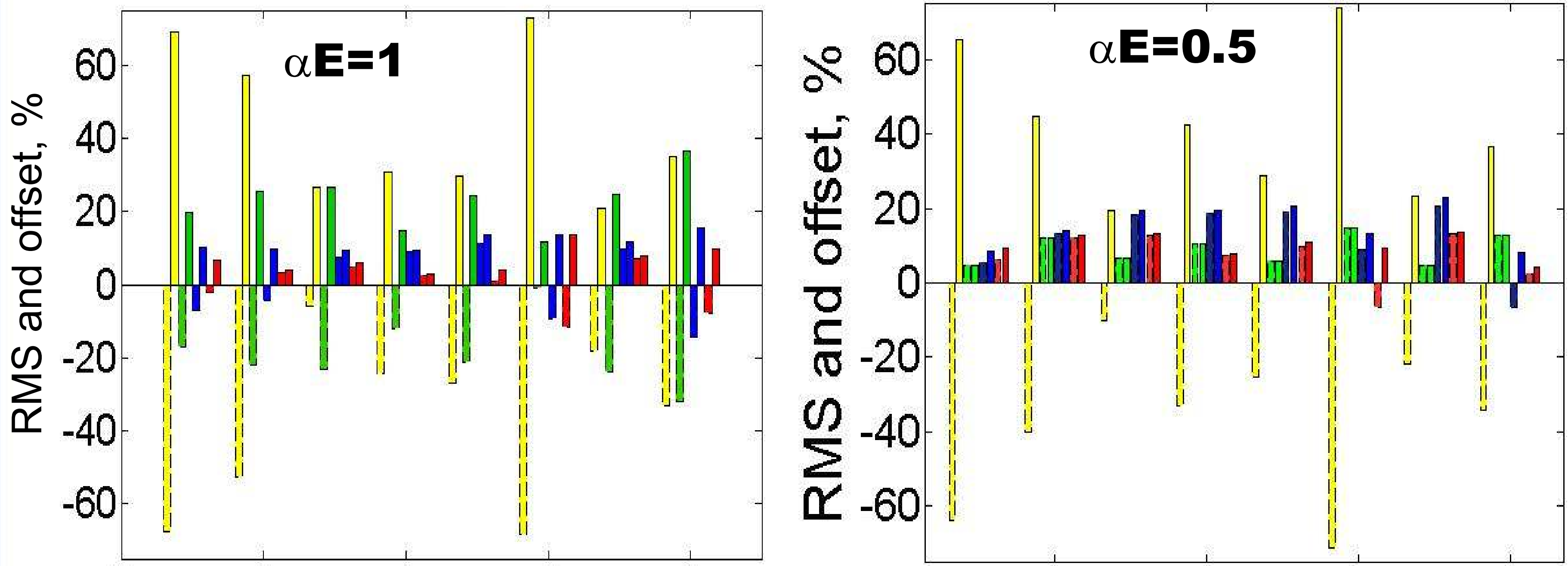
GLF23: weak ExB shear stabilisation in HS

RMS (solid, right columns) and offset (dashed, left columns) for Te (red), Ti (blue), nd (green) and omega (yellow)

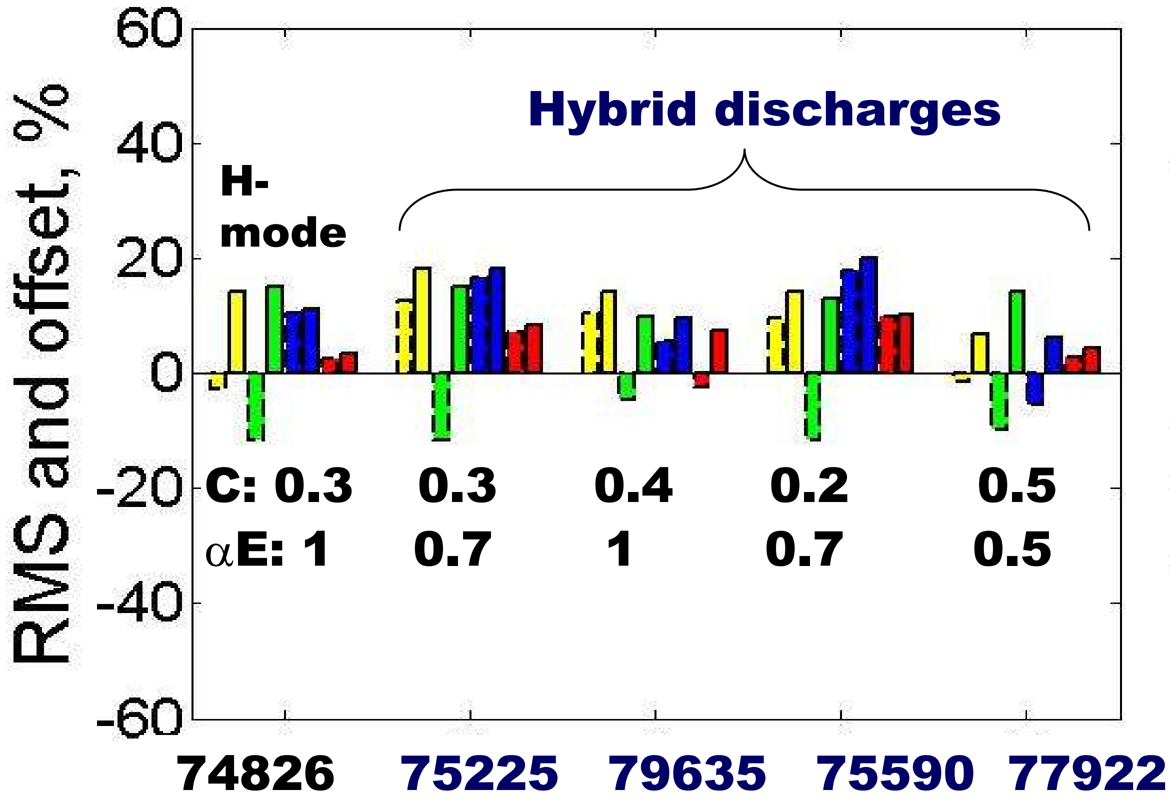


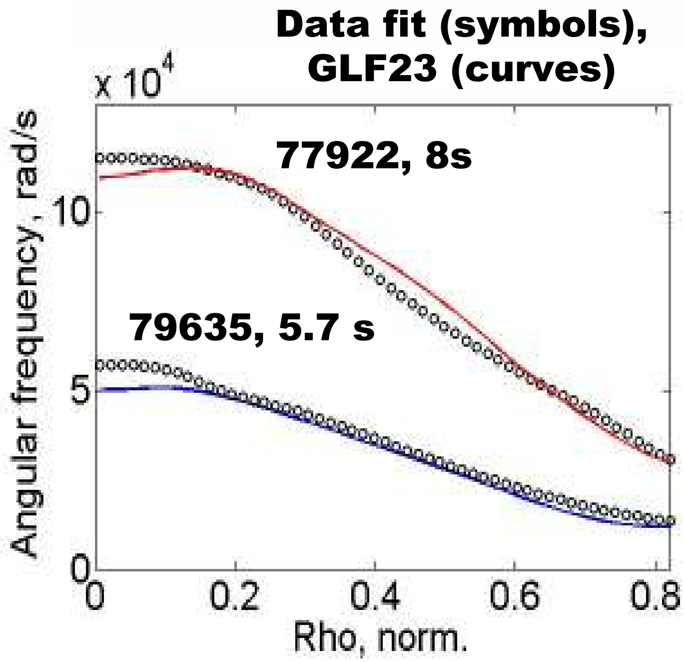
- **density is strongly affected by the ExB shear: better density prediction with αE=0.5**
- **temperature prediction is less accurate with αE=0.5, but still within 20% deviation from measurements**
- **strongly over-predicted rotation**

GLF23 for momentum: indications of momentum pinch

- **In previous simulations $\chi\varphi=\chi\varphi$_GLF23+χi_neocl**
- **$\chi\varphi$= Cχi_GLF23 + χi_neocl is tested, C is adjusted to match the data**
- **Indication of momentum pinch: C $\neq$1 (ITG modes give $\chi\varphi$= χi)**

RMS (solid, right columns) and offset (dashed, left columns) for Te (red), Ti (blue), nd (green) and omega (yellow)





GLF23: sensitivity to wall particle source and wall source validation (P. Belo)

- **In previous simulations wall source Swall was estimated as 10Dα+gas puff**
- **R=<Swall / (Swall+Snbi)> = 0.57-0.77 (high δ), 0.83-0.85 (low δ)**
- **Sensitivity of 2 high δ discharges (zero gas puff) to wall particle source has been tested in simulations with adjusted αE and C**

	R (Swall, part/s)	Te: rms, offset, %	Ti: rms, offset, %	ω: rms, offset, %	nd: rms, offset, %
79635	0.77	7.45, -2.38	9.45, 5.54	14.16, 10.52	9.97, -4.72
	0	7.95, -3.18	9.23, 4.68	13.1, 8.67	8.44, -2.01
	1 (6.e22)	13.72, 12.9	22.8, 21.42	48.29, 48.89	55.5, -50.07
77922	0.57	4.32, 2.62	6.09, -5.38	6.77, -1.55	14.15, -9.82
	0	4.21, 2.37	7.78, -6.41	7.43, -2.98	12.78, -7.98
	1 (1.e23)	11.13, 10.45	12.28, 11	32.66, 64.0	36.78, -34.33

- **Artificial constant in time gas puff has been added**
- **Weak sensitivity to wall source at high pedestal pressure (77822), strong sensitivity at low pedestal (79635)**
- **Validation of particle source in EDGE2D simulations is in progress**

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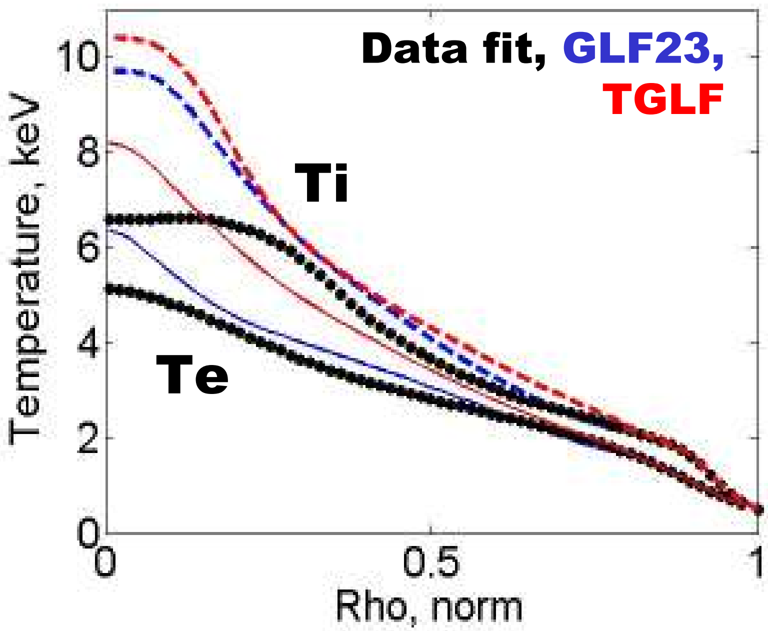
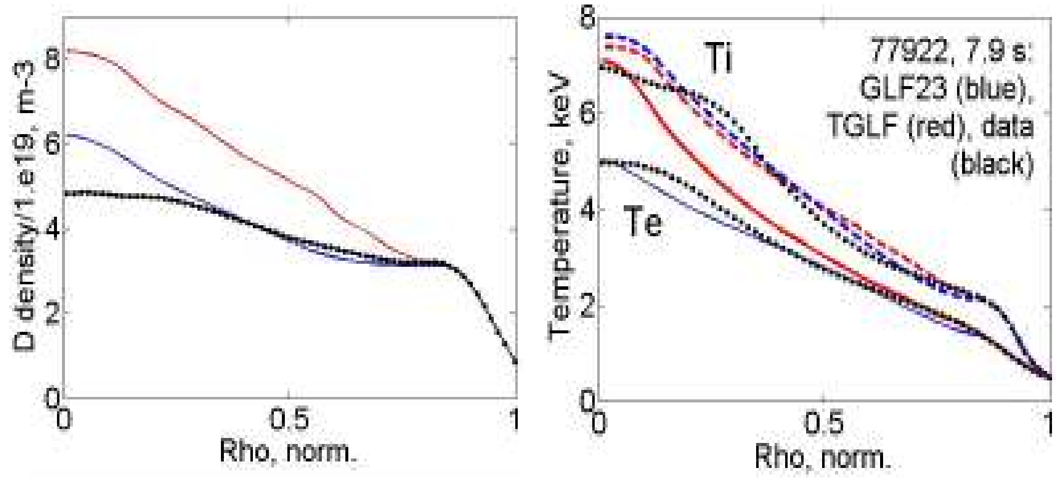
Modelling of JET 77922 with TGLF/ASTRA and comparison with GLF23 (E. Fable)





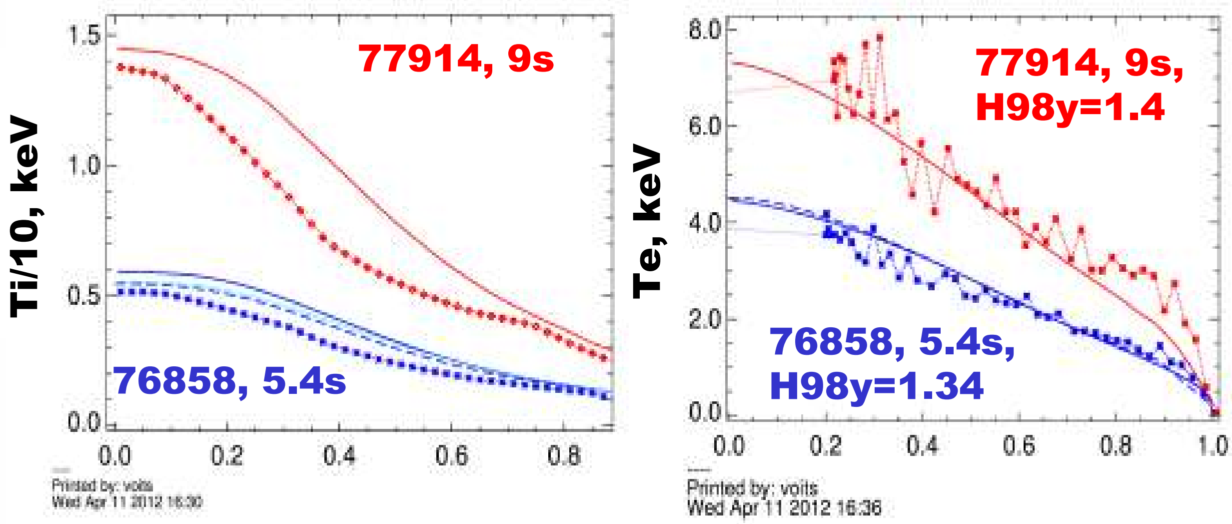
- ***Te, Ti, nd and Vtor are simulated self-consistently, αE=0.5, C=0.5***
- ***Fast numerical scheme, TGLF is called in ASTRA every 1 ms, computed in 10 radial grid points***
- ***Inward particle pinch and low diffusion near the edge, ITG-TEM bouncing (ITG and no pinch in case of GLF23)***
- ***Implementation of new TGLF version [G. Staebler, J. Kinsey, NF 2010] in ASTRA is in progress***

- **Te and Ti are simulated with prescribed density and rotation, αE=0.5, similar radial smoothing**
- **GLF23 and TGLF gives similar results for Ti, but Te is different**

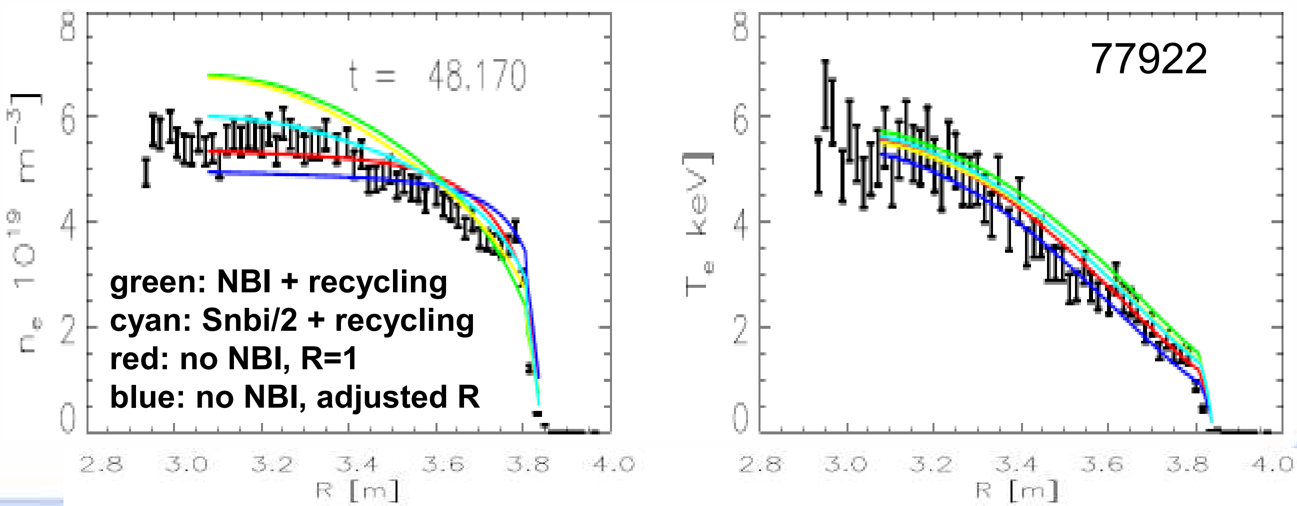
Validation of Bohm-gyroBohm model on JET HS

- **H-mode Bohm-gyroBohm model (without ExB or magnetic shear stabilisation)**
- **Pedestal region is simulated (continuous ELM model, ballooning stability limit)**
- **Good agreement for Te, over-estimated Ti**
- **Good agreement between JETTO (top, solid) and CRONOS (top dashed)**
- **Over-estimated density peaking with H-mode Bohm-gyroBohm model for diffusion (zero pinch) [L. Garzotti et al, EPS 2012]**

F. Koechl, J. Garcia, I. Jenkins: simulated Te and Ti (curves) with prescribed ne. Symbols show the measured temperatures



L. Garzotti, ISM WS, 22.06.2011: Ti, Te and ne are simulated

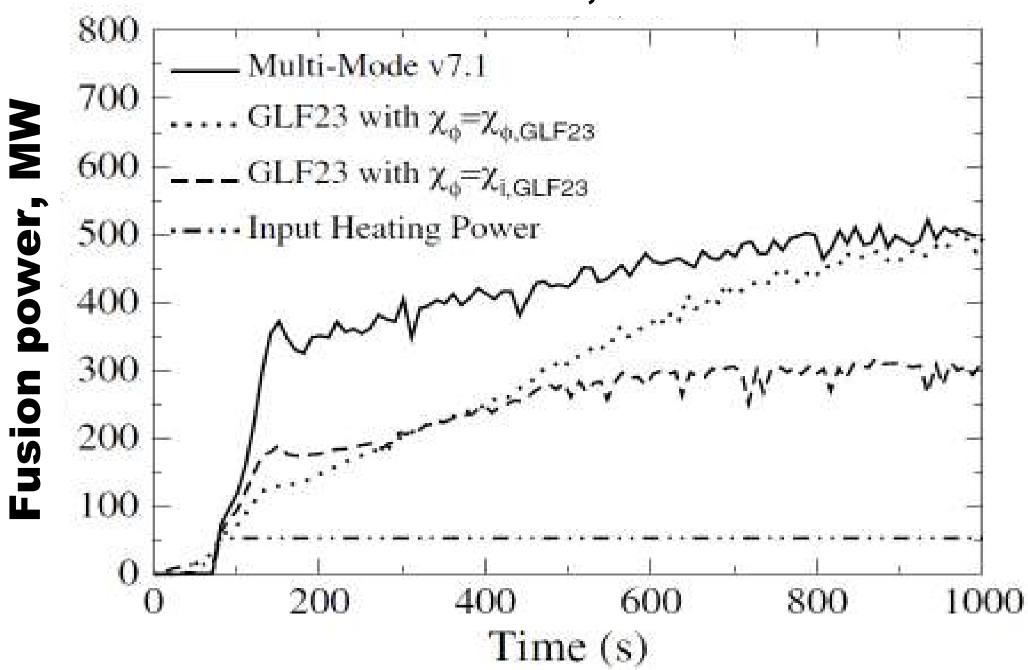


Summary and future work

- **GLF23 modelling of JET hybrids: less than 20% discrepancy with the data when αE = 0.5-0.7, $\chi\varphi = (0.2\text{-}0.5)\chi i$:**
  - *JET HS are in ITG dominant regime, close to the stability threshold*
  - *ExB shear stabilisation is not strong, αE is reduced by factor 2 as compared to its value used for JET H-mode plasmas*
  - *Other reasons for improved confinement in HS: s/q effect (~ 50% of confinement improvement, J. Citrin et al, PPCF 2012 to appear), stabilisation of tearing modes, better pedestal confinement…*
- **Bohm-gyroBohm:** *reasonable Te prediction, but over-estimated Ti and density peaking with H-mode model*

- **Impact on ITER hybrid scenario:** *uncertainty in fusion performance due to over-estimated ExB shear and scenario optimisation*

A. Kritz et al, NF 2011: ITER HS



EPS 2012: "Integrated modelling for tokamak plasma: physics and scenario optimisation"

- **Current diffusion in HS (***done for JET shots, questions remain for AUG***)**
- **Assessment of predictive capability of core transport models for existing experiments:**
  - *effect of the q-profile shaping on thermal transport [J. Citrin et al]*
  - *ExB shear effect on energy, particle and momentum transport in HS:*
    - *GLF23/JET (IOS/ITPA) + EDGE2D for particle source&bndry*
    - *GLF23/AUG (Te, Ti, ne) with the same αE – Jonathan or Irina*
    - *BgB/JET (Luca's EPS + previous simulations of Florian and Jeronimo)*
    - *AUG/BgB?*
- ***Turbulence simulations (GYRO):*** *ExB and beta effects (Sara + Chalmers group)*
- ***Pedestal studies:***
  - *edge MHD stability (ref. to P. Snyder, Johnny's work in progress)*
  - *ELM physics (Florian) – in progress*
- ***Bifurcation from high to low confinement state at the discharge termination*** *(Paula's EPS 2011 + work in progress)*

EPS 2012: "Integrated modelling for tokamak plasma: physics and scenario optimisation"

- **Hybrid performance on ITER based on predictive modelling:**

  - optimisation of the current ramp up phase [G.M.D. Hogeweij et al]

  - current profile and kinetic control during the burn phase [D. Moreau, F. Liu]

  - ITER fusion performance in H-mode [L. Garzotti,] and HS with the optimised heating and current drive mix [J. Citrin]

  - ITER hybrid performance with different αE and $\chi\varphi$

- **Status of European Transport Solver, first applications for physics study (Vincent)**

Validation of particle source with EDGE2D, self-consistent core-edge modelling (Paula, Irina, Luca, Florian)

- **Validation of wall source:**

TRANSP → EDGE2D (neutral influx) → TRANSP → ASTRA
→ JETTO

- **77922 (done, Γneut = 3.35*10^{21}), 79635 in progress (preliminary Γneut ≈ 3.7*10^{21}), 74826 & 75225 to be done**

- **Default TRANSP Dα calibration based on TFTR simulations 10*Dα is corrected to (16.8 – 18)*Dα**

- **Correction of wall source contribution**
  R=<Swall / (Swall+Snbi)> = 0.57→0.69 (77922), 0.77→0.86 (79635)

- **Particle confinement time (TRANSP+EDGE2D): τE=0.25 s, τp=0.54 s (old value 0.58s) (77922), τE=0.16, τp = 0.44 (old value 0.6s) (79635)**

- **Paula's talk on Friday for more details**

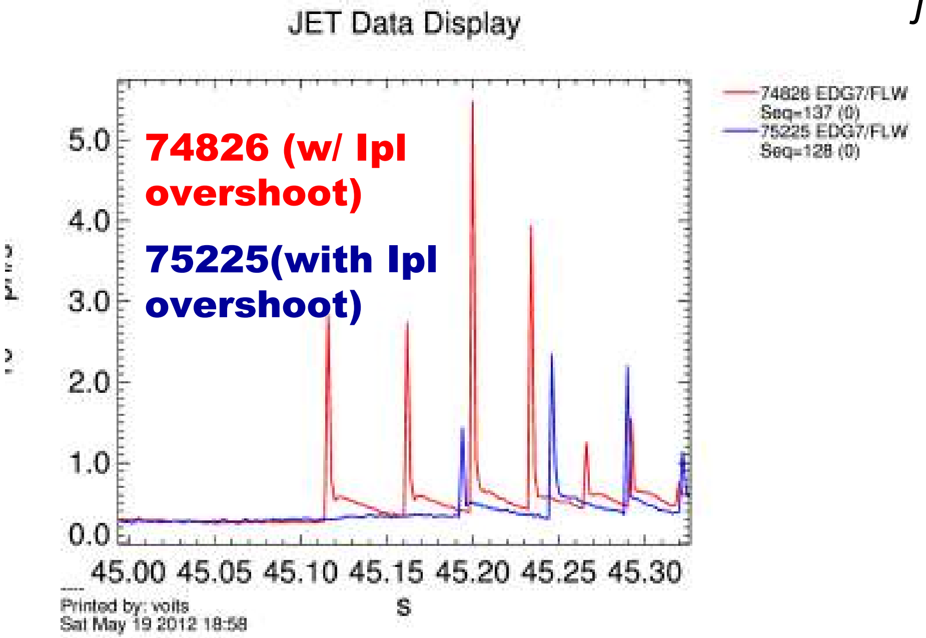
GYRO simulations for 77922: Sara Moradi

- **77922: simulations are in progress, 74825 & 75225 data to be prepared for GYRO**
- **Linear ES and EM GYRO simulations with and without ExB shear:**

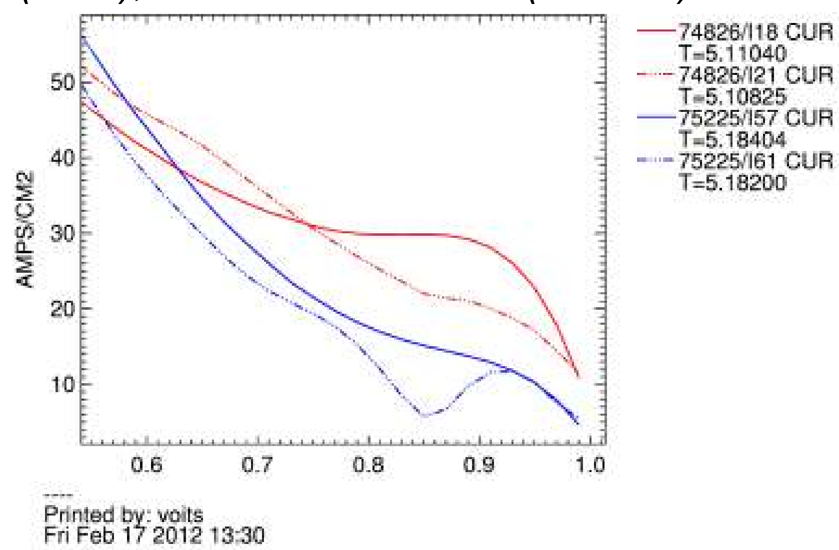
  - very weak effect of ExB shear on thermal transport coefficients and particle flux (but GAM and ZFs are not included)

  - βe scan: ExB shear strongly affects the transition from ITG to KBM
- **Non-linear simulations with subsequent comparison with TRANSP are in progress**
- **Results to be reported at the remote ISM meeting**
- **Sara's visits to JET: June 7-26 July9-27**

Edge MHD stability in discharges with & w/o current overshoot



j is recalculated by transp from EFTM/Q (solid), TRANSP/NCLASS (dashed)



- ***Slightly lower pressure and much higher edge current before the 1st ELM in discharge without current overshoot***

- ***instability triggering the 1st ELM in these discharges (peeling or ballooning)? Effect of Ipl overshoot on edge stability?***

- ***MISHKA simulations for 74826 are done: the plasma is unstable, with n = 10 the most unstable toroidal mode number***

- ***MHD analysis: exp.data → ESCO/JETTO + current diffusion eq. for 3 s → HELENA → MISHKA. Need to find a way to put experimental data to HELENA***