EFDA

EUROPEAN FUSION DEVELOPMENT AGREEMENT

Task Force
INTEGRATED TOKAMAK MODELLING

Remote meeting 26 Sept 2012

INTEGRATED SCENARIO MODELLING, Introduction

Presented by X LITAUDON & I VOITSEKHOVITCH

TF Leader : G. Falchetto
Deputies: R. Coelho, D. Coster
EFDA CSU Contact Person: D. Kalupin

Agenda

1) **Introduction: X. Litaudon**
2) **The European Integrated Tokamak Modelling (ITM) Effort: Achievements and First Physics Results: G. Falchetto et al**
3) **The European Transport Solver: an integrated approach for transport simulations in the plasma core: D. Kalupin et al**
4) **Modelling of Hybrid Scenario: from present-day experiments toward ITER (ISM) X. Litaudon**

Other related contribution to 2012 FEC-IAEA conf.

Contribution already reviewed & discussed

- **Model validation and integrated modelling simulations for the JT-60SA tokamak G. Giruzzi et al**
- **Integrated Magnetic and Kinetic Control of Advanced Tokamak Scenarios on DIII-D Based on Data-Driven Models D. Moreau (mainly ITPA DIII-D + ISM for ITER modelling)**
- **Other proposals not strictly related to ISM: Self-consistent simulation of plasma scenarios for ITER using a combination of 1.5D transport codes and free boundary equilibrium codes** V Parail (F4E Grant 255)

Remote meetings, WS and CC

Regular remote meeting on Wednesday morning 10h30-12h00 CET (09h30-11h00 GMT) :

- 26 Sept 2012
- 08-18 Oct FEC IAEA & ITPA San Diego
- 24 Oct 2012
- 7 Nov 2012 (??)
- Thrid ISM Working session 19-23 Nov.
- GOTiT training 12-23 November, JET
- IMP3 + ISM-ACT1 Code Camp and ITM General meeting 3-14 Dec., Innsbruck
- 19 Dec 2012

Foreseen talks for remote meeting

- **Integrated Modelling of WEST scenario F. Imbeaux**
- **JET – JT-60U modelling J. Garcia**
- **Current ramp-down modelling F. Koechl, J. Bizarro**
- **report on the status of Act 1 T1 support to the ETS validation : Benchmarking of new modules coupled with ETS workflows V. Basiuk**
- **Emilia Barbato on LHCD simulations for JET**
- **Short reports on the status of publications (Irina, Florian, Luca ...)**
- **Other proposals?**

ISM mobility visits

- **António Figueiredo is visiting JET September 17 – 28 working on WP12-ITM-ISM-ACT1 (Support to the validation and physics application of the ETS and ITM tools): predictive (Te, Ti, current diffusion) modelling of JET 77922 with ETS and comparison to experimental data**

2012 ISM Working session

- **First ISM working session**
  - 26 - 30 March at EFDA-Garching

- **Second ISM working session**
  - Monday 21 – Friday 25 May (13:00) Vienna

- **Third ISM working: Culham**
  - **Monday 19 (09:00)– Friday 23 Nov. (13:00) JET Culham**
  - **invitation letter for mobility support: 15 October**
  - **Our local host is Irina irina.Voitsekhovitch@ccfe.ac.uk Many Thanks !**

Participation to third ISM Working 19-23 Nov. Culham

- **CCFE**
  - **I. Voitsekhovitch, L Garzotti**
- **CEA**
  - **X. Litaudon , E. Joffrin,**
- **IST**
  - **F. Nave , J. P. S. Bizarro , A. Figueiredo , F. Nabais, J. Ferreira, P. Belo**
- **ÖAW/ATI: F. Koechl**
- **FOM**
- **ENEA-Frascati**
  - **E. Barbato**
- **TEKES**
  - **Paula Siren**

Modelling of Hybrid Scenario: from present-day experiments toward IT

- X. Litaudon[1], I. Voitsekhovitch[2], J.F. Artaud[1], P. Belo[3], J.P.S. Bizarro[3], T Casper[4], J. Citrin[5], E. Fable[6], J. Ferreira[3], J. Garcia[1], L. Garzotti[2], G. Giruzzi[1]J. Hobirk[6], G.M.D. Hogeweij[5], F. Imbeaux[1], E. Joffrin[1], F. Koechl[7], F. Liu[1], J. Lönnroth[8], D. Moreau[1], V. Parail[2], P.B. Snyder[9], M. Schneider[1], ASDEX Upgrade Team, JET-EFDA contributors, and the EU-ITM ITER Scenario Modelling group See the Appendix of F. Romanelli et al., Proceedings of the 23rd IAEA Fusion Energy Conference 2010, Daejong, Korea

Outline

- **Integrated modeling of ASDEX-U and JET hybrid scenario**
  - Current diffusion
  - q-profile influence on transport
  - Self-consistent modelling of hybrid scenario (current, thermal, particle and rotation): *ExB* shear influence on transport
  - Modelling of hybrid termination
- **Predictive integrated modeling of ITER hybrid scenario**
  - ITER hybrid operational domain from 0-D modeling
  - Current profile optimization during current ramp-up phase
  - Consistent core and pedestal integrated modeling
  - Model-based Magnetic and Kinetic real time Control

JET and ASEDX-U database

	JET					ASDEX-U	
	77922	79626	79630	79635	77280	20993	20995
R_o[m],a[m]	3.1,0.9	3.1,0.9	3.1,0.9	3.1,0.9	3.1,0.9	1.6,0.7	1.6,0.7
k , δ	1.7, 0.4	1.6,0.2	1.6,0.2	1.7, 0.3	1.7,0.4	1.6,0.2	1.6,0.2
B_T [T]	2.3	2	2	1.4	1.7	2.4	2.4
I_p [MA]	1.7	1.7	1.7	0.9	1.1	1.0	1.0
q_{95}	4.2	3.9	3.9	4.8	4.9	4.8	4.8
P_{tot} [MW]	18	17	17	7	10	8	8
$H_{IPB98(y,2)}$	1.3	1.3	1.1	1.3	1.25	1.0	1.2
β_N	2.8	2.8	2.6	2.4	2.5	1.9	2.3
n_{eo}, $\langle n_e \rangle$	5.5,3.9	4.6,2.7	4.3,2.7	2.9,2.1	3.7,2.6	6.1,4.8	6.9, 4.9
$\langle T_i \rangle$, $\langle T_e \rangle$	3.2,2.4	3.6,2.3	3.5,2.2	1.3,1.1	2.1,1.6	2.0,1.7	2.3,1.9
ρ^*_i x 10^{-3}	3.9	4.8	4.7	4.1	4.3	4.0	4.3
ν^*_e	0.13	0.09	0.1	0.37	0.2	0.1	0.09
M_Φ	0.5	0.5	0.6	0.8	0.4	0.4	0.5

Current diffusion

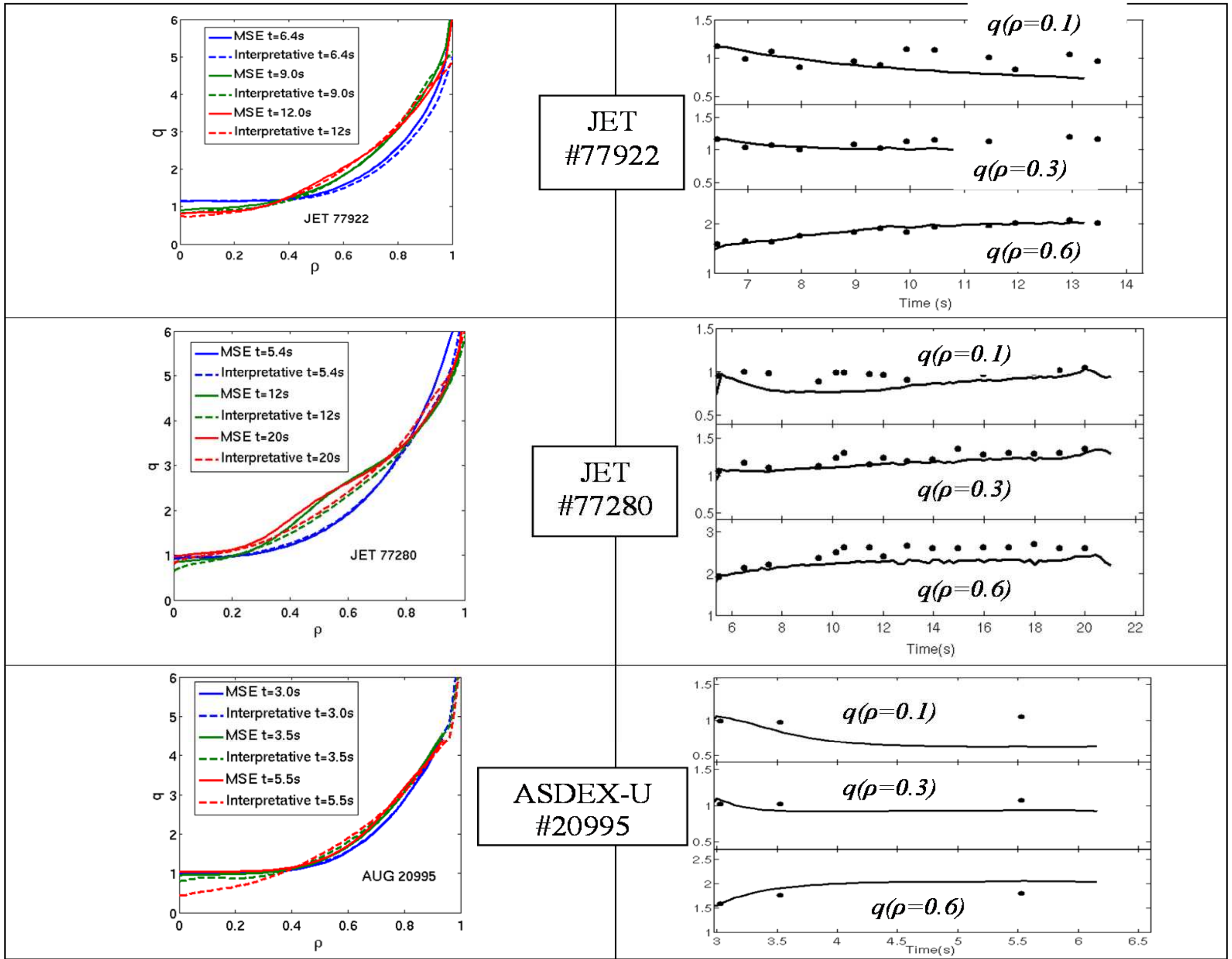


***Fig. 1:** Measured q-profiles (EFIT for JET and CLISTE for AUG reconstruction constrained by MSE data) and the ones simulated by CRONOS JET #77922 (top), JET #77280 (middle), ASDEX-U #20995 (bottom). (left) radial profiles at different times; (right) time evolution: experimental data (full circles) and CRONOS simulation (solid line) at ρ=0.1, ρ=0.3 & ρ=0.6*

q-profile influence on transport

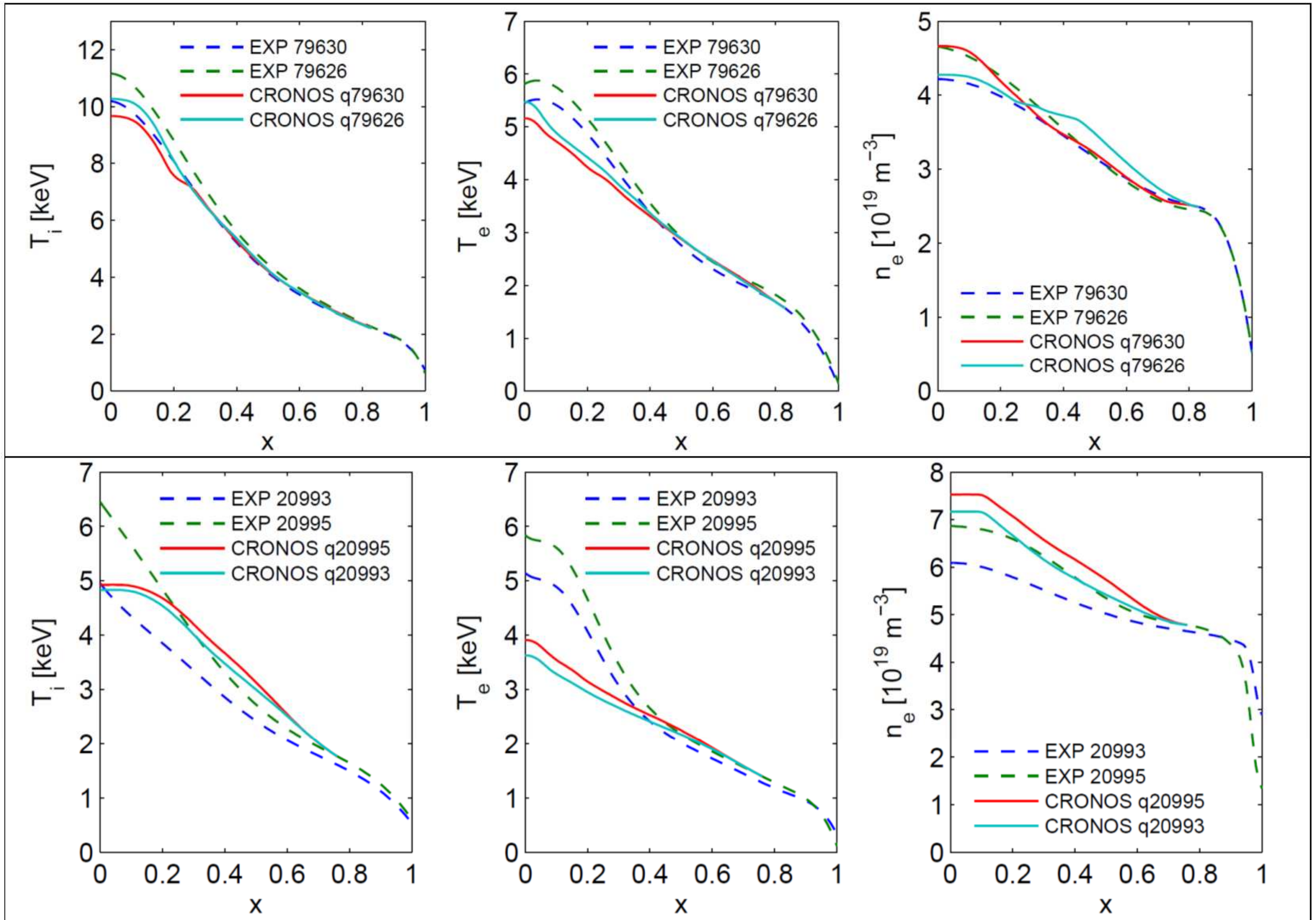


Fig. 2: *Results of combined heat and particle transport GLF23 simulations for JET (top) and AUG (bottom) without ExB stabilisation effect. (left column) T_i profiles. (center column) T_e profiles. (right column), n_e profiles. (top): JET 79630, comparing q-profile inputs from both 79630 and 79626. (bottom) AUG 20995, comparing q-profile inputs from both 20995 and 20993. (from Citrin 2012)*

Self-consistent modelling of hybrid scenario (current, thermal, particle and rotation): *ExB* shear influence on transport

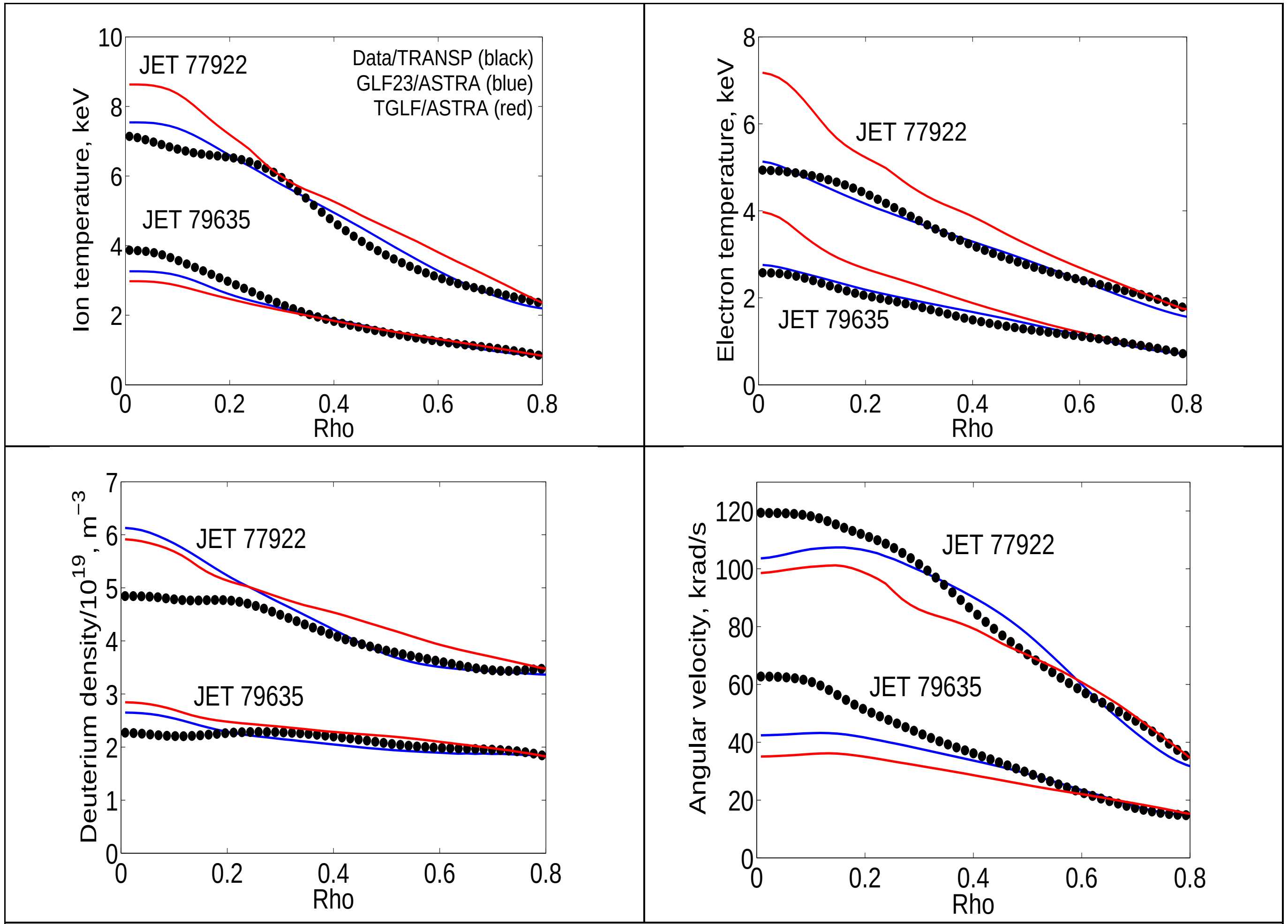


***Fig. 4**: ASTRA simulations with GLF23 (blue curves) and TGLF (red curves) models performed with α_E=0.5 and P_r = 0.5 for JET high triangularity hybrid pulses from Table 1*

Modelling of hybrid termination

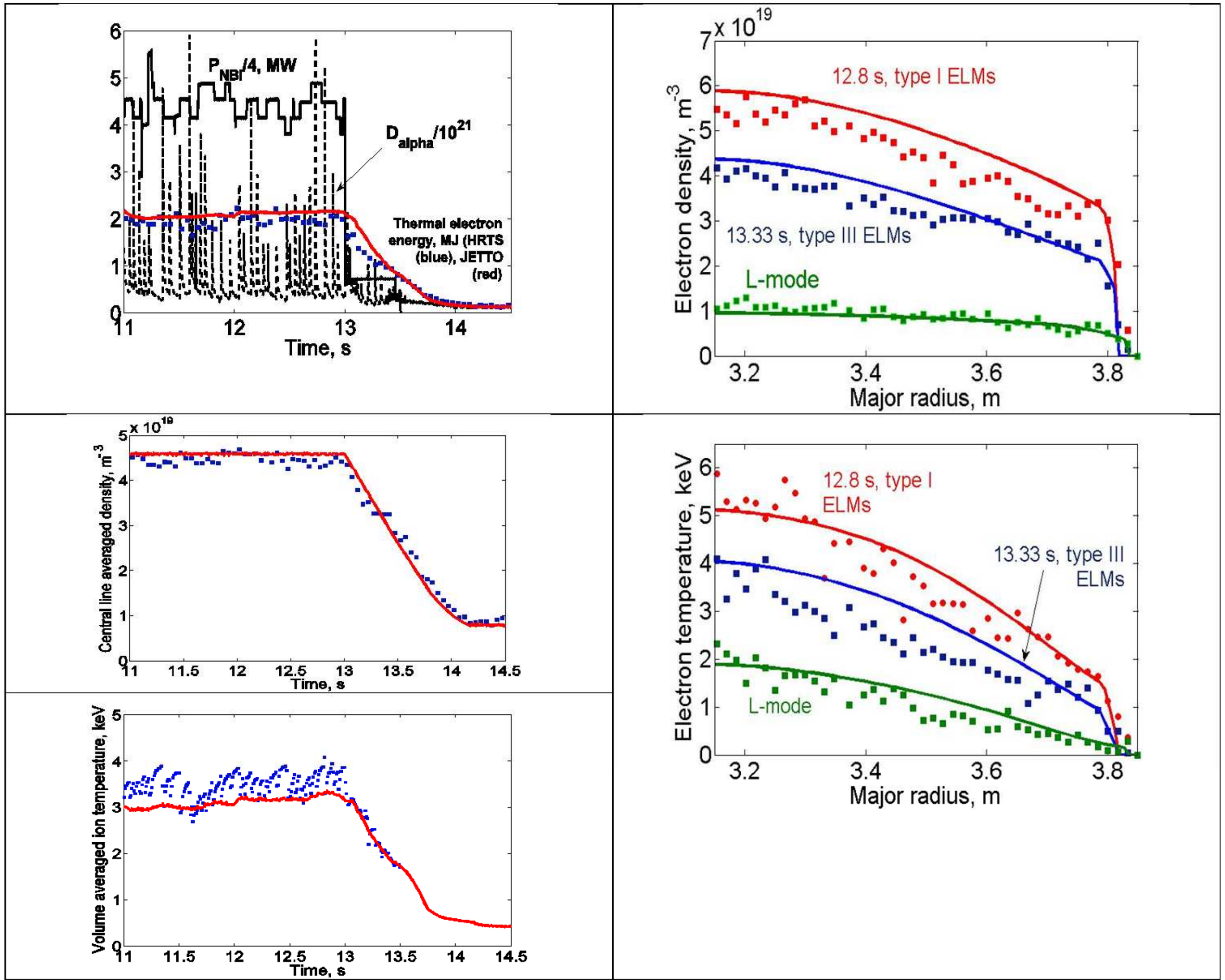


***Fig.5** Termination of JET #77922: (left) NBI power, D_α, thermal electron energy, central line averaged density, volume averaged ion temperature; (right) measured (High Resolution Thomson Scattering) and simulated n_e and T_e profiles. Measurements and simulations are shown by blue and red colours correspondingly.*

Modelling of hybrid termination

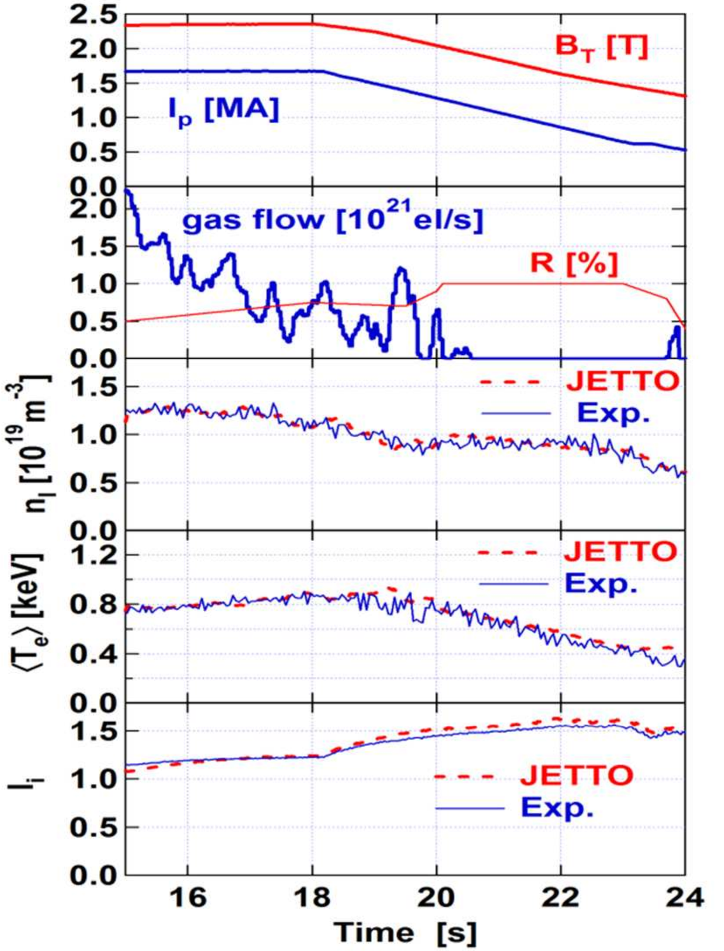


Fig. 6: Self-consistent current, temperature and density JETTO modelling of the JET hybrid discharge during the L-mode ramp down phase.

ITER hybrid operational domain from 0-D modeling

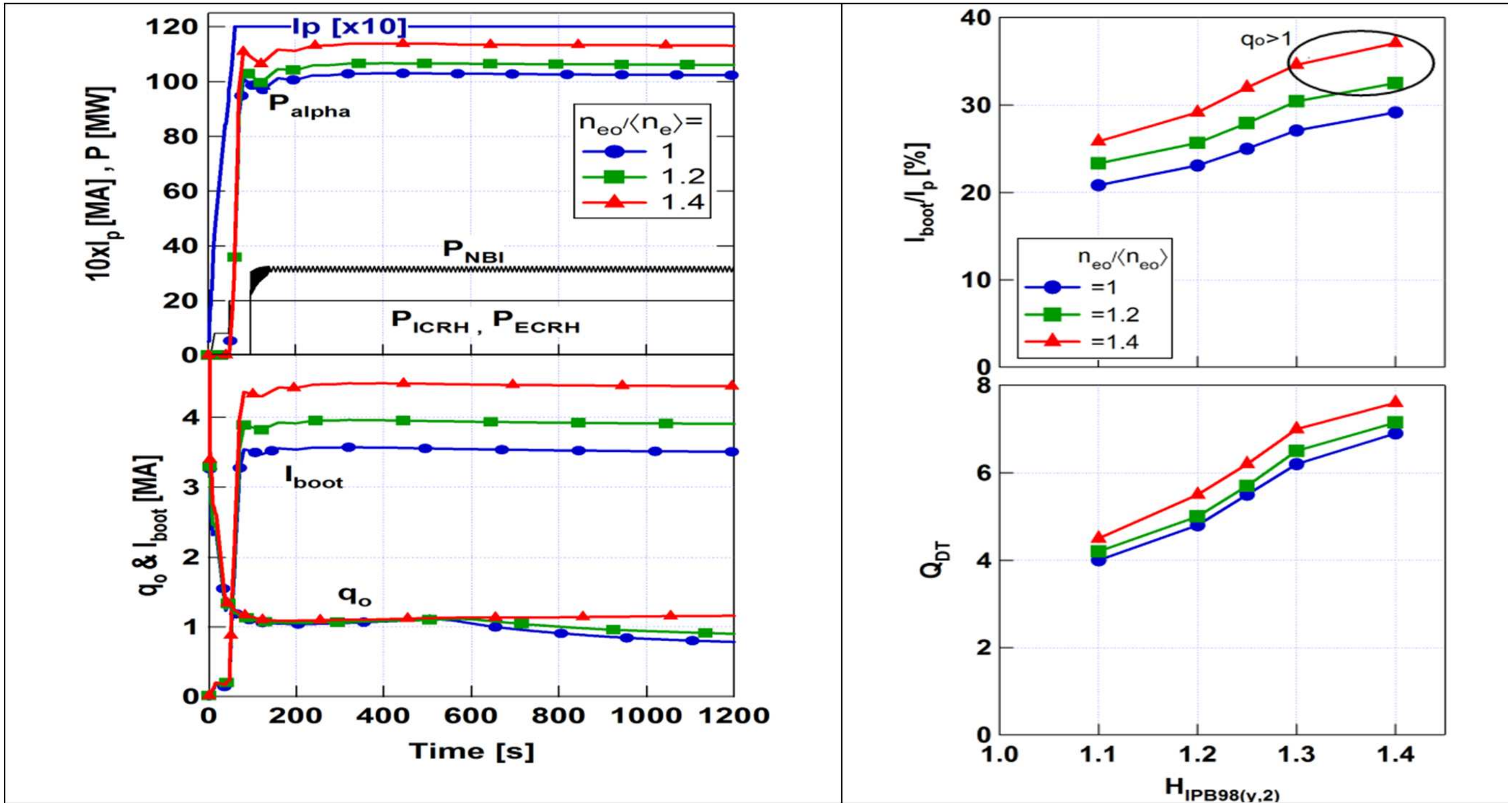


Fig. 7: 12MA ITER hybrid scenario as simulated by METIS (left) time evolution of the main parameters assuming $H_{98IPB(y,2)}$=1.4 with three different density peaking. (right) bootstrap current fraction and Q_{DT} versus $H_{98IPB(y,2)}$ for three different density peaking

Current profile optimization during current ramp-up phase

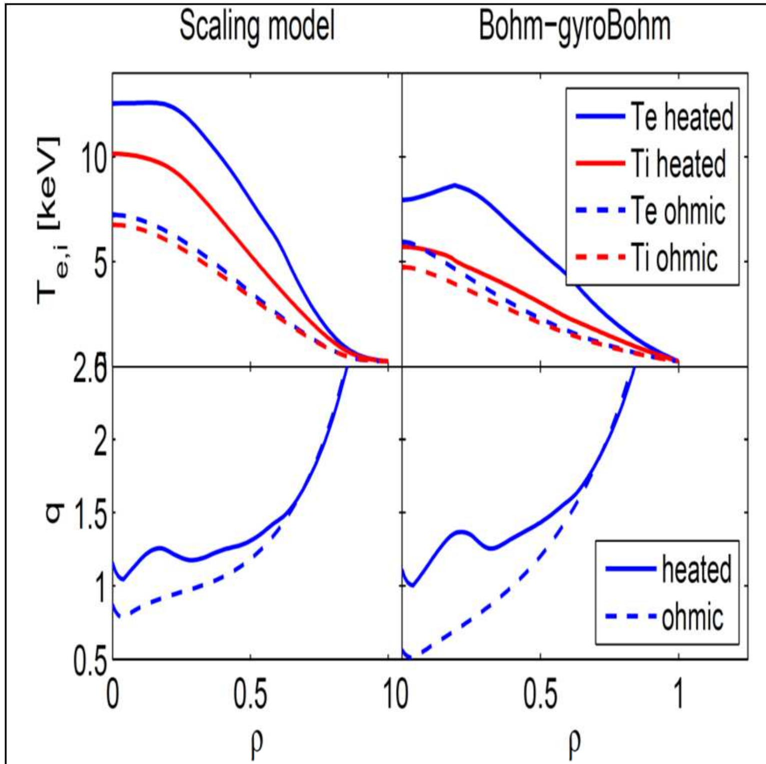


Fig. 8: Te,i and q profiles for the optimized L-mode current ramp-up scenario with current flat top 12MA at 80s. For comparison, the profiles without any additional heating are also shown (dashed lines).

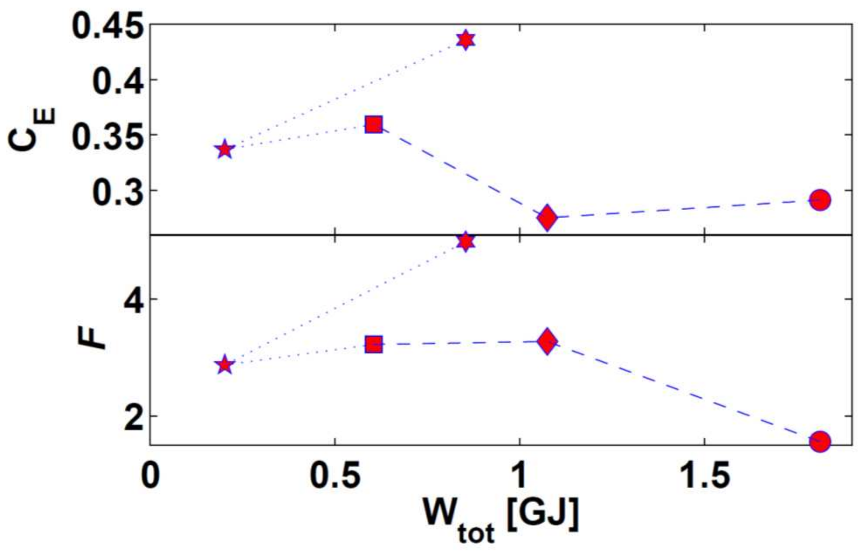
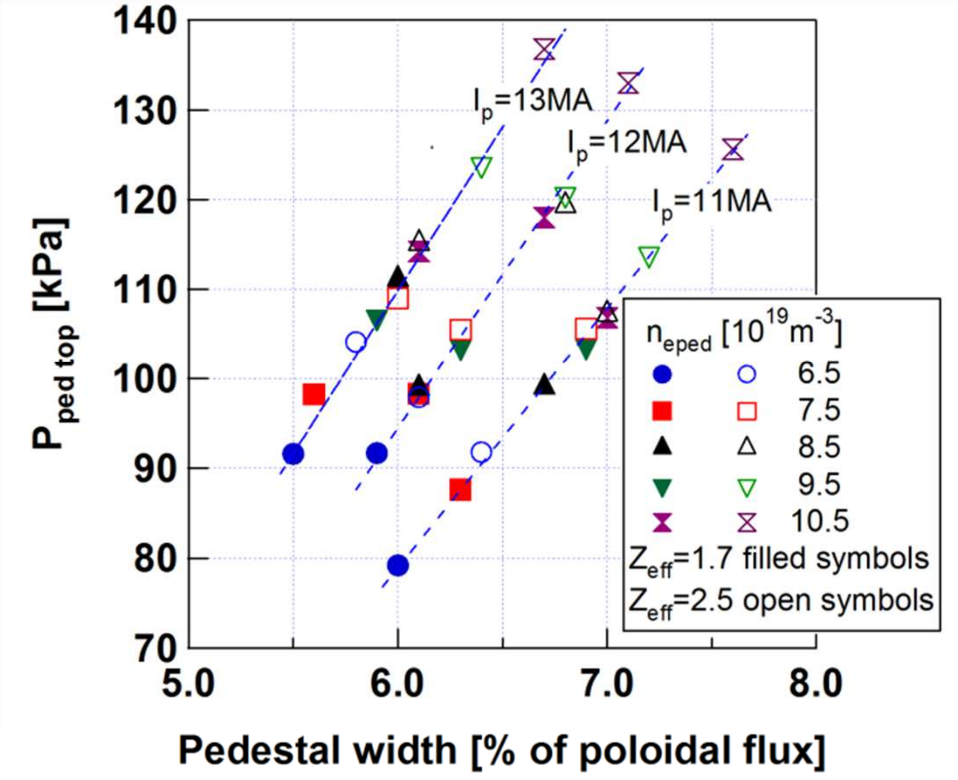


Fig. 9: *C_E and q-profile figure of merit, **F**, at the end of the 12MA ramp-up phase for the reference case on Fig 8 (square), the examples with early heating at 30s (diamond), with transition to H-mode at 55s (circle), with fast current ramp 12MA at 60s (pentagram), with a 10s/14MA current overshoot (hexagram).*

Pedestal prediction with first principle predictive model



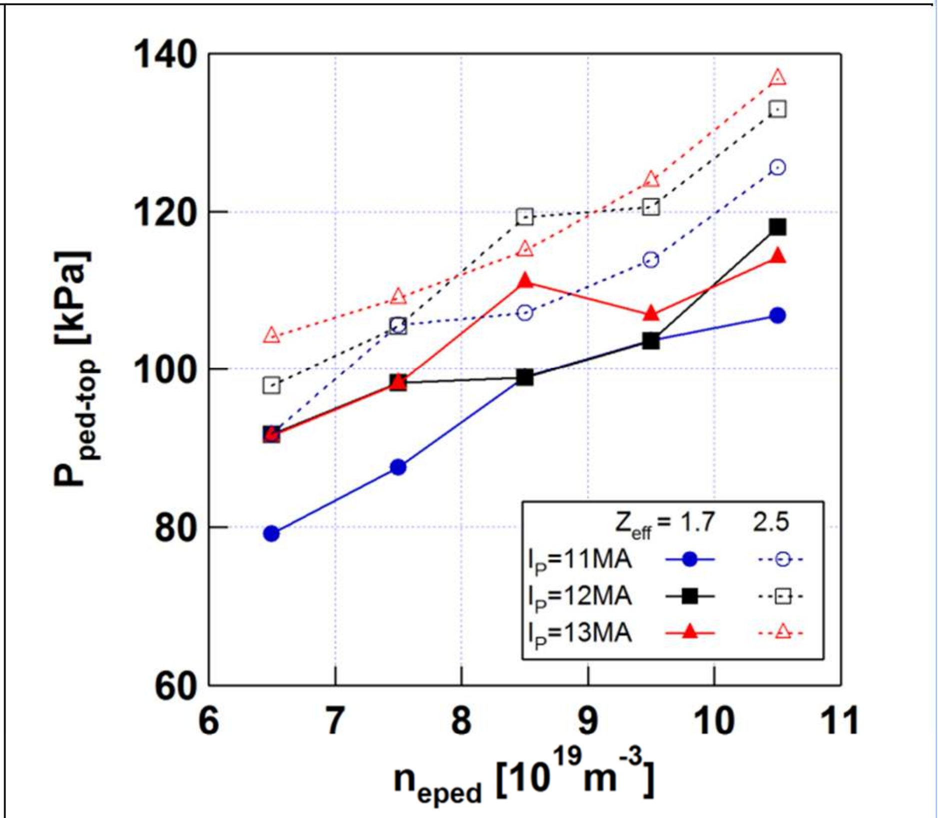


Fig. 10: *EPED prediction of the pedestal width and height for the range of parameters of the ITER hybrid scenario (left)Pressure at the top of pedestal versus pedestal width for different pedestal densities, n_{eped}, Z_{eff} and plasma current. (right) Pressure at the top of pedestal versus pedestal density for different plasma current and Z_{eff} values.*

Consistent core and pedestal integrated modeling

CRONOS simulation: GLF23 (core) with EPED constrains

Prescribed density profile scan at fixed $n_l = 8.8 \times 10^{19} m^{-3}$ $n_{eo}/n_l = 1, 1.25, 1.5$

consistent core & edge simulations n_{eo}/n_l ↑ at n_l=cst:

- Edge confinement ↓
- Core confinement ↑

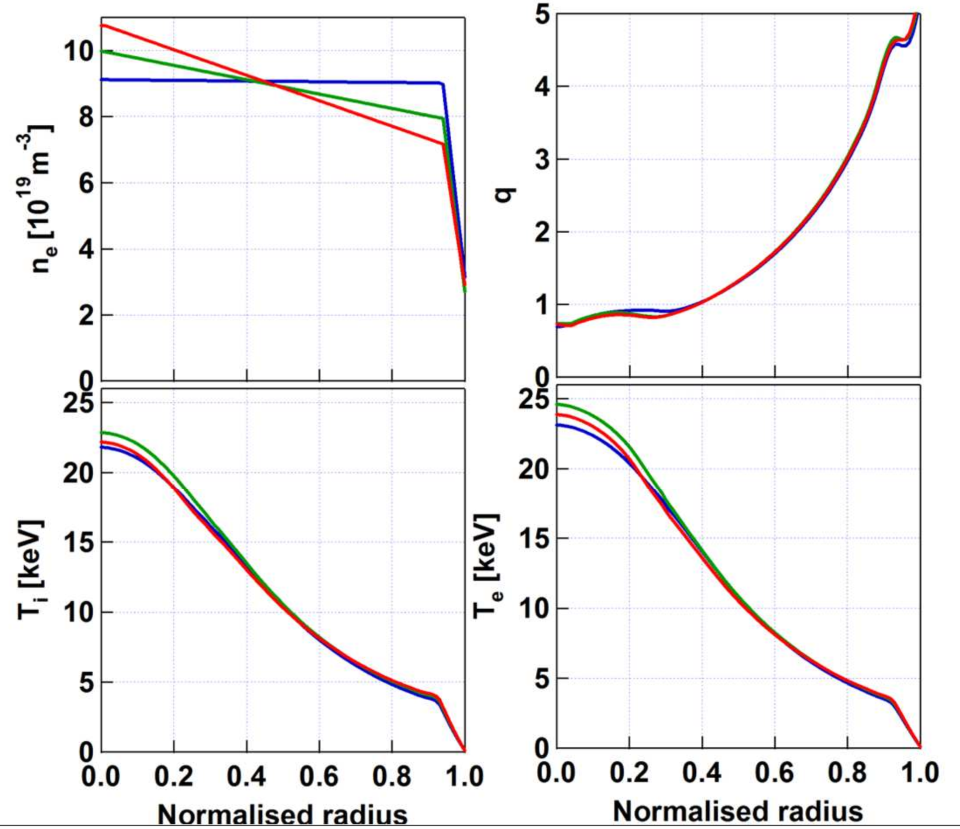


Fig. 11: *ITER hybrid scenario- CRONOS predictive modeling of T_e, T_i and q with three different imposed density profiles (top left), simulated q-profiles (top right), T_i (bottom left) and T_e (bottom right) profiles. All profiles are plotted at 1200s*

Consistent core and pedestal integrated modeling

- **Summary of results for CRONOS modelling of ITER hybrid scenario with GLF23 and pedestal parameters calculated with EPED for three density peaking. All evolving parameters are quoted at 1200s.**

n_{eo}/n_l	$n_{e,top}$ $[10^{19} m^{-3}]$	$T_{i,top}$ [keV]	P_{top} [kPa]	Δ_{top} [ψ_{norm}]	Q	I_{boot}/I_P	β_N	$H_{IPB98(y,2)}$
1	9.02	3.67	96.3	0.064	4.71	30%	1.91	1.06
1.25	7.99	3.9	90.2	0.064	5.06	33%	1.97	1.08
1.5	7.24	4.02	84.4	0.064	5.06	33%	1.93	1.05

Model-based Magnetic and Kinetic real time Control

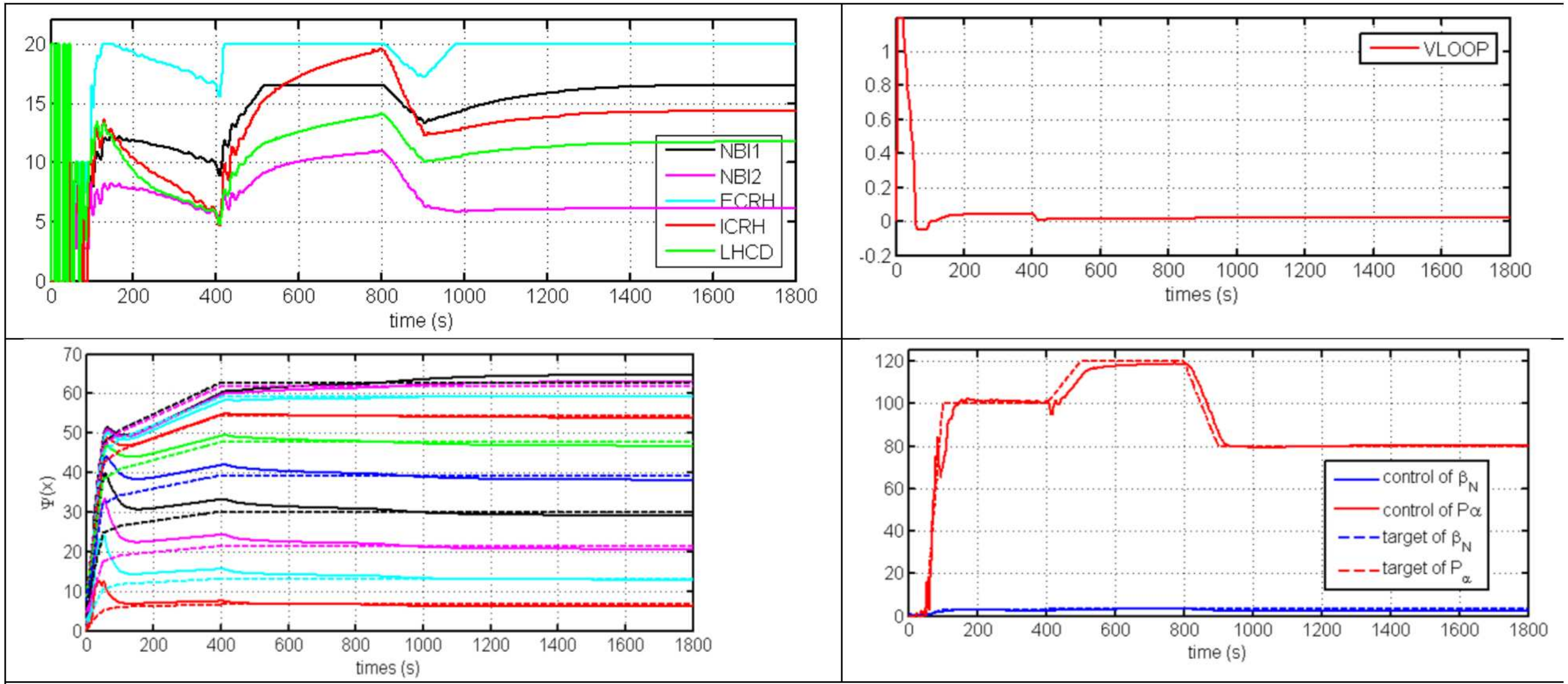


Fig. 12: *12MA ITER hybrid scenario METIS simulation of closed loop control of the poloidal flux profile $\Psi(x, t)$, β_N and P_α using 6 actuators. (top left) time evolution of the powers ; (top right) time evolution of the loop voltage; (bottom left) Control of ψ profile (solid line) at normalized radius from 0.1 to 0.9 using 6 actuator; target values are represented by dashed lines (bottom right) Control of $P\alpha$ (solid red line) and β_N (solid blue line) using 6 actuators; target values are represented by dashed lines. β_N be re-scaled ?*