Feasibility of an ECRH system for JET: Project Overview

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IAP GYCOM Kurchatov

Project overview

- **The E4J project**
  - context and motivation
  - functions of ECRH on JET
  - project objectives

- **Physics studies**
  - beam tracing → ***D. Farina*** *(oral)*
  - MHD control → ***S. Nowak***
  - scenario simulations

- **System design elements**
  - gyrotrons
  - transmission line → ***S. Garavaglia***
  - launcher → ***C. Sozzi*** *(oral)*
  - power supplies → ***H. Braune***
  - system layout, auxiliaries, buildings → ***M. Lennholm***
  - diagnostics → ***T. Gerbaud***

- **Cost, manpower, time**

ECRH on JET: motivations

- **JET programme for the future years:** *F. Romanelli, FST **53**, 1217 (2008)*
  - → consolidation of ITER physics basis and design choices
  - → a noticeable example: D-T discharges
  - → integrated preparation of the three main ITER scenarios

- **ITER scenarios:**
  - → ELMy H-mode: requires ECCD for NTM and sawtooth control
  - → Hybrid: very likely to require off-axis CD → ECCD
  - → Steady-state: definitely requires off-axis CD → ECCD + LHCD
  - → upgrade of ITER ECRH system possible

⇓

- **Difficult to think of preparing ITER scenarios without ECCD**

- **No other tokamak can fully replace JET for this preparation**
  - → size and confinement: the closest to ITER
  - → normalised parameters, in particular ρ^*
  - → wall
  - → tritium experiments

Main functions of an ECRH system for JET

- Electron heating
  - → more ITER-relevant scenarios ($T_e \sim T_i$)
  - → impurity control
- Central CD
  - → to contribute to low loop-voltage scenarios
  - → to control the central q profile (co- or counter-CD)
- off-axis CD for scenario control
  - → q profile tailoring (e.g. to trigger and sustain ITBs)
  - → real-time scenario control
- MHD control
  - → sawtooth period real-time control
  - → NTM real-time control
- Other functions
  - → plasma breakdown, start-up, ramp-up assistance
  - → transport studies by power modulations

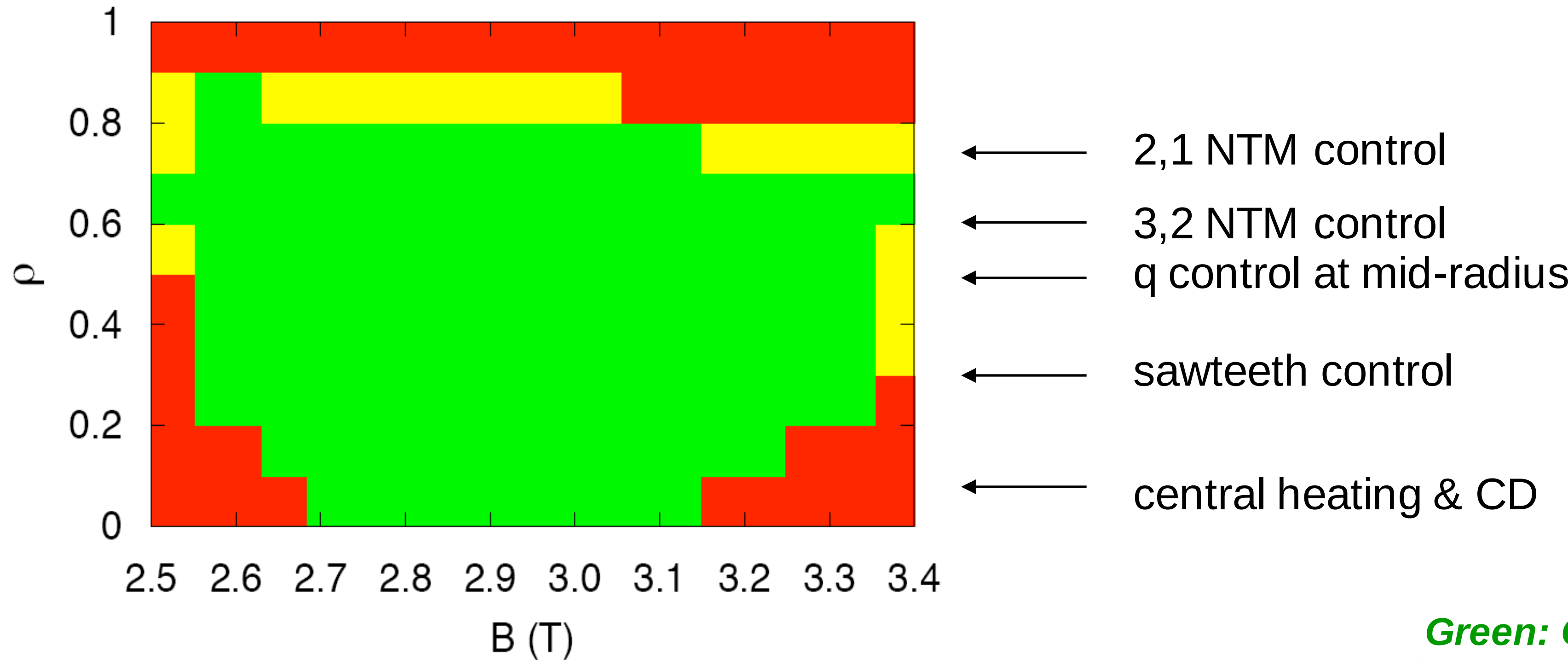
Project objectives

- To define the physics requirements of an ECRH system
  - → with respect to the main JET **scenarios**
  - → with respect to the main **functions**
  - → taking into account **priorities** of the JET programme

- To assess the feasibility of an ECRH system
  - → with respect to **time**
  - → with respect to resources (**cost** and **manpower)**
  - → with respect to the present JET layout (**ports**, **buildings**)
  - → with respect to **risks**
  - → in coherence with the future JET **programme**

- Main boundary conditions
  - → **time:** system ready by ~2014/2015
  - → **power:** ~ 10 MW in the plasma
  - → **strategy:** strong synergy with **ITER** ECCD system development; partnership with Russian Federation

170 Ghz operation diagram (H-mode)



Green: OK
Yellow: marginal
Red: not OK

Conclusions:

- **2.7 < B < 3.1 T: full performance (all functions achieved)**
- 3.1 < B < 3.3 T: central H&CD limited, (2,1) control marginal
- 2.5 < B < 2.7 T: central H&CD limited by 3rd harmonic
- **advanced scenarios**: diagram displaced to the right → + 0.1 T

Istituto di Fisica del Plasma "Piero Caldirola" Consiglio Nazionale delle Ricerche

D. Farina, L. Figini

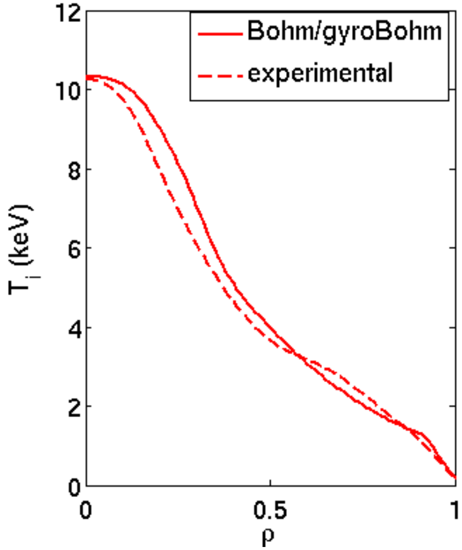
Integrated modelling of JET scenarios

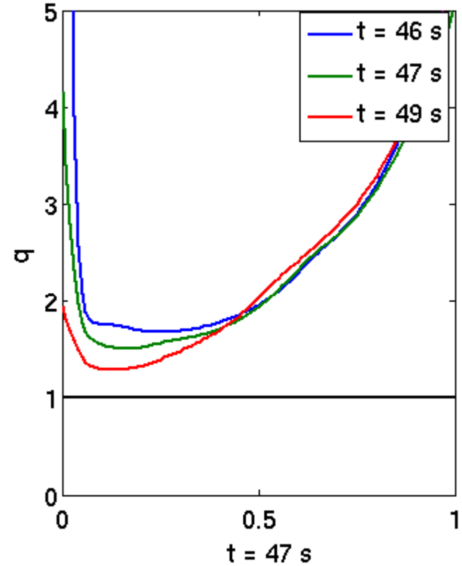
J. Garcia

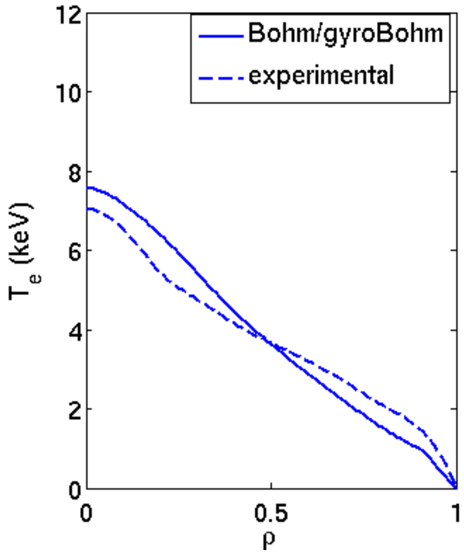
- Goal: to determine the EC power needed to:
  - → equilibrate T_e and T_i (mainly in the H-mode scenario)
  - → modify the q profile (mainly in the advanced scenario)
- Tools
  - → CRONOS (integrated modelling code)
  - → JETTO (runs to fine-tune the transport model) *V. Parail*
- Method
  - → current diffusion runs with exp. profiles, check of coherence with l_i, V_{loop}, flux, MSE, sawtooth inversion radius
  - → predictive runs with Bohm/gyro-Bohm model, check of coherence between predicted and exp. T_e and T_i
  - → predictive runs including ECRH / ECCD
- Applications (170 GHz)
  - → core heating for H-mode scenarios
  - → off-axis CD for advanced scenarios

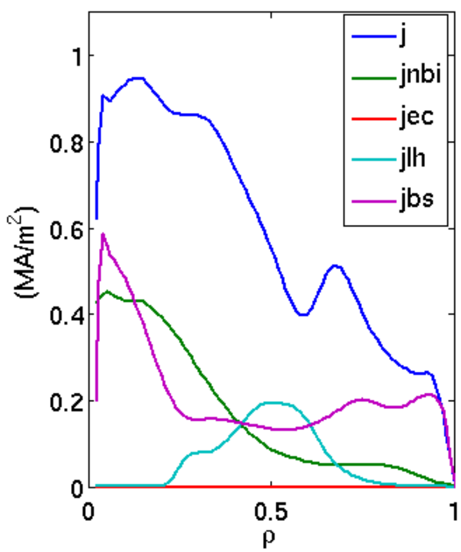
77895: advanced scenario

P_{NBI} = 22 MW, P_{ICRH} = 6.5 MW, P_{LH} = 2 MW









Predictive simulation

CRONOS

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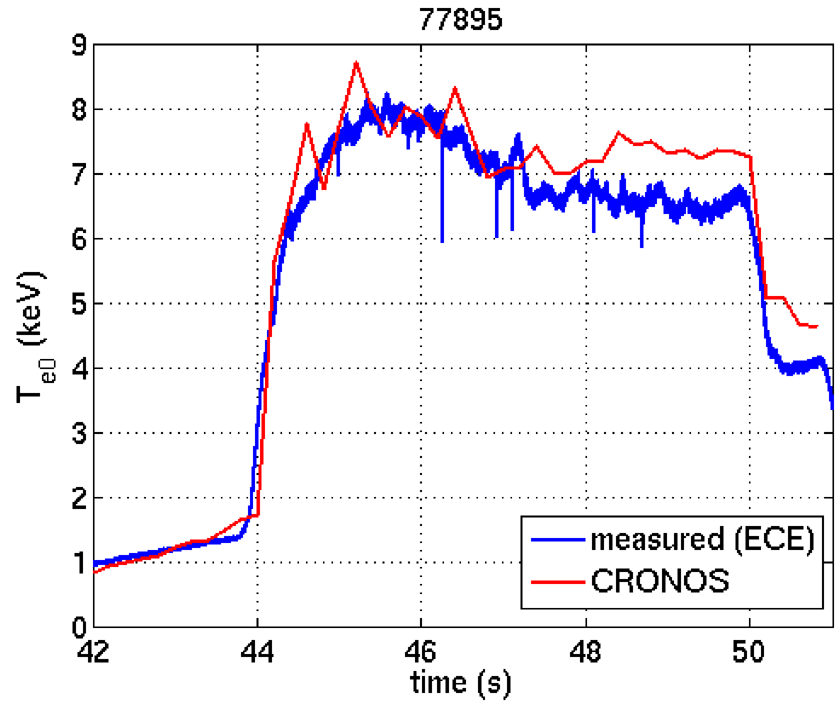

T_e in the current ramp phase well reproduced, using experimental pedestal and rotation

Effect of 10 MW ECCD at ρ = 0.5 or ρ = 0.6

ECCD at ρ = 0.6

→ $V_{loop} \approx 0$

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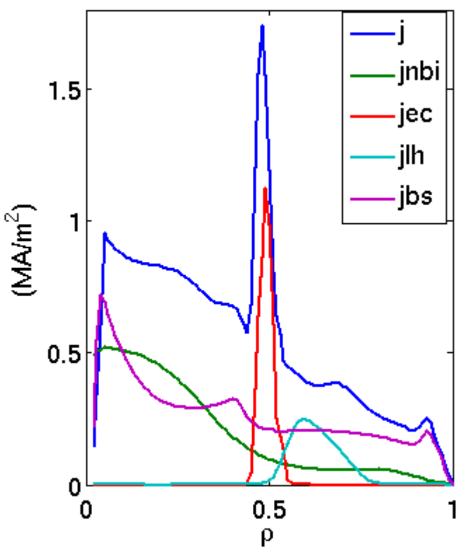

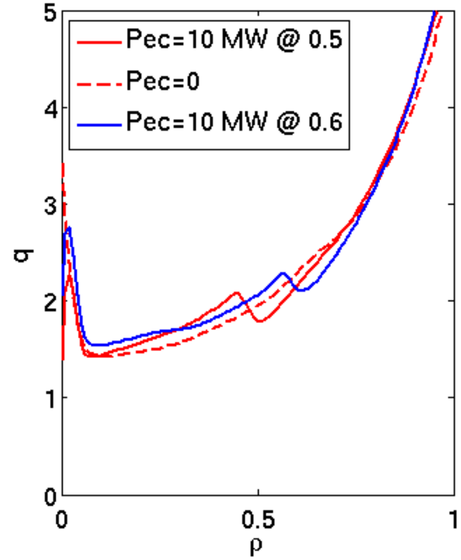

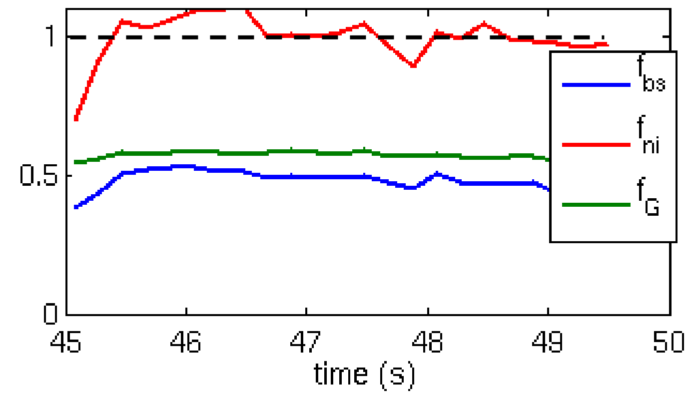

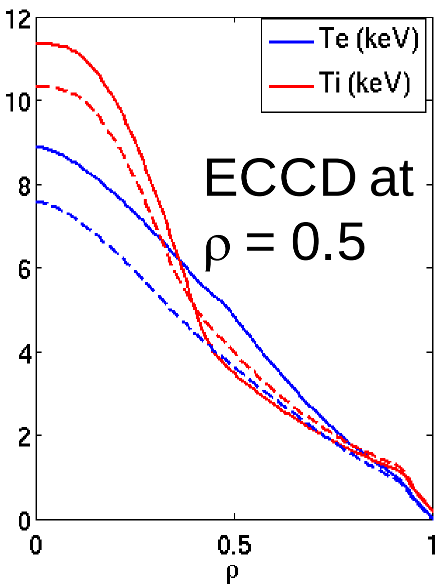

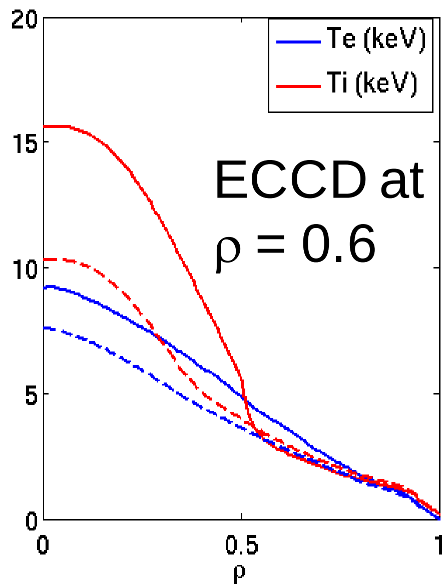

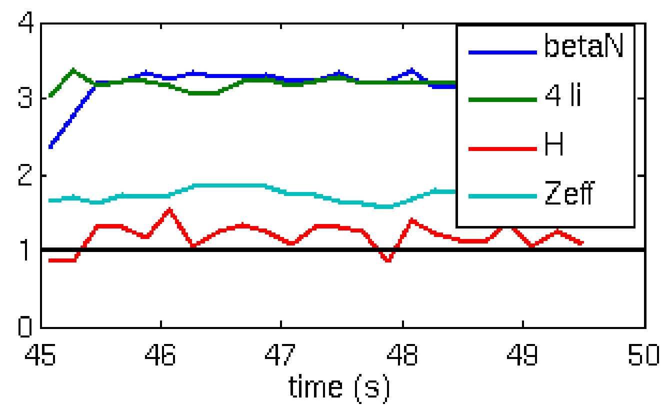

System design elements → posters

- gyrotrons (170 GHz, 20s → ITER gyrotron)
- transmission line
- launcher
- power supplies
- auxiliaries
- diagnostics
- system layout, buildings, controls

Manpower estimate

Tasks	Manpower (ppy)
GYROTRONS (installation – testing)	19
POWER SUPPLIES	30
ANTENNA (design – implementation)	16
TRANSMISSION LINES	4
WINDOWS	2
AUXILIARIES	16
CONTROL SYSTEMS	9.5
DIAGNOSTICS	2
BUILDINGS - INSTALLATION	2.5
SYSTEM COMMISSIONING (on plasma)	3
PROJECT MANAGEMENT	10
TOTALS	**114**

Cost estimates

Component	Total cost (M€)	Comments
GYROTRONS	15.6	12 GYCOM tubes
POWER SUPPLIES	16.5	8 MW refurbishement + 4 MW new
ANTENNA	1.6	
TRANSMISSION LINES	4.4 – 4.9	price range: TL options
WINDOWS	3.1 – 3.8	price range: F4E and GA estimates
AUXILIARIES	6.6	magnets: 4 M€ (GYCOM estimate)
CONTROL SYSTEMS	1.7	1.1 M€: PS controls - 0.6 M€: CODAS
DIAGNOSTICS	0.2	
BUILDINGS - INSTALLATION	2.0 – 2.4	price range: PS in containers or building
TOTAL	51.7 – 53.3	~ 4.4 €/W accuracy: ~ ± 6 M€

Acknowledgements: V. Erckmann (IPP, Germany), J. Lohr, R. Olstad (GA, USA)

Planning

Year	0	1	2	3	4	5
Project start. First calls for tender						
Gyrotron building						
Cooling plant						
Old PS refurbishment, installation and tests						
Gyrotrons manufacturing						
First gyrotron accepted						
Antenna design, manufacturing, installation and tests						
New PS manufacturing, installation and tests						
TL design, manufacturing, installation and tests						
Windows manufacturing						
All gyrotrons accepted						
System commissioning on plasma						

JET vs ITER ECRH system

		ITER	JET
FUNCTIONS	central electron heating	→ H-mode, impurity control	→ $T_e \sim T_i$, impurity control
	NTM control	yes	yes
	sawteeth control	yes	yes
	q profile control	yes	yes
	start-up, ramp-up assistance	yes	possible
COMPONENTS	gyrotron	1 MW, 170 GHz, cw	1 MW, 170 GHz, t > 20 s
	harmonic / polarisation	1^{st}, O-mode	2^{nd}, X-mode
	power supplies	solid-state based	solid-state based (Type 2 part)
	antenna	equatorial → tor. steering + top → pol. steering	equatorial, poloidally and toroidally steerable
	mirrors	actively cooled	actively cooled
	mirror movement	frictionless, backlash free steering mechanism	poloidal: ITER mechanisms toroidal: ITER mech. or rods/cables
	transmission lines	evacuated, corrugated alum. WG63	evacuated, corrugated alum. WG63
	windows	diamond, 1.11mm thick, 63.5mm diametre	diamond, 1.11mm thick, 63.5mm diametre
	magnets	cryogen free	cryogen free
	control systems	ITER-CODAC standards	ITER-CODAC standards

Conclusions

- **Usefulness** and **feasibility** of ECRH in JET confirmed
- The functions envisaged can be achieved for **2.7 < B < 3.1 T**
- **Technical issues**: launcher design, gyrotrons, windows, steering

  → **risk reduction** for the ITER ECRH system
- **Partnership with Russia**: very productive,opening exiciting prospects
- **Synergies with ITER, F4E**: broad and solid basis for common work
- Feasibility study: **good basis** for decision and for conceptual design
- **Timing critical:** in order to meet the 2015 deadline →
  - **Work for system specifications continues in 2010**
  - **Project go-ahead decision must be made in 2010**
  - **Negociations with partners should advance (new partners ?)**