EFDA

EUROPEAN FUSION DEVELOPMENT AGREEMENT

Task Force
INTEGRATED TOKAMAK MODELLING

ITPA-IOS, 11-14 April 2011

ITER SCENARIO MODELLING activities within ITM-TF

Presented by X LITAUDON & I VOITSEKHOVITCH on behalf of the ISM group

Work in progress – the materials of this presentation should not be used

TF Leader : G. Falchetto
Deputies: R. Coelho, D. Coster

EFDA CSU Contact Person: D. Kalupin

ITER SCENARIO MODELLING (ISM) project

- **The objective of the ISM project within the Integrated Tokamak Modelling EU Task Force**
  - **Provide support to interpretative and predictive integrated scenario modelling on existing EU experiments**
  - **Provide support to scenario modelling activities to cover the preparation of operational scenario for ITER, JT60-SA, DEMO and new EU facilities**
- **2011**
  - **47 participants (~7 ppy) from 10 associations together with ITER-IO strong involvement**
  - **Regular remote meeting (once every 2 weeks)**
  - **Three working sessions per year**

Scientific activities:

- **Activity-1 : Support Validation of the European Transport Solver (ETS)**

- **Activity-2 : Developing and validating plasma scenarios: simulations for existing devices**

- **Activity-3 : Support to predictive scenario modelling for future devices (ITER , JT60SA, etc)**

2011 : main focus on the hybrid scenario for JET, ASDEX-U and ITER

Suites of codes involved: ASTRA, CRONOS, JETTO, METIS, HELIOS (0-D), ETS (European Tokamak Solver), TRANSP + edge code : SOUL 1D, EDGE2D

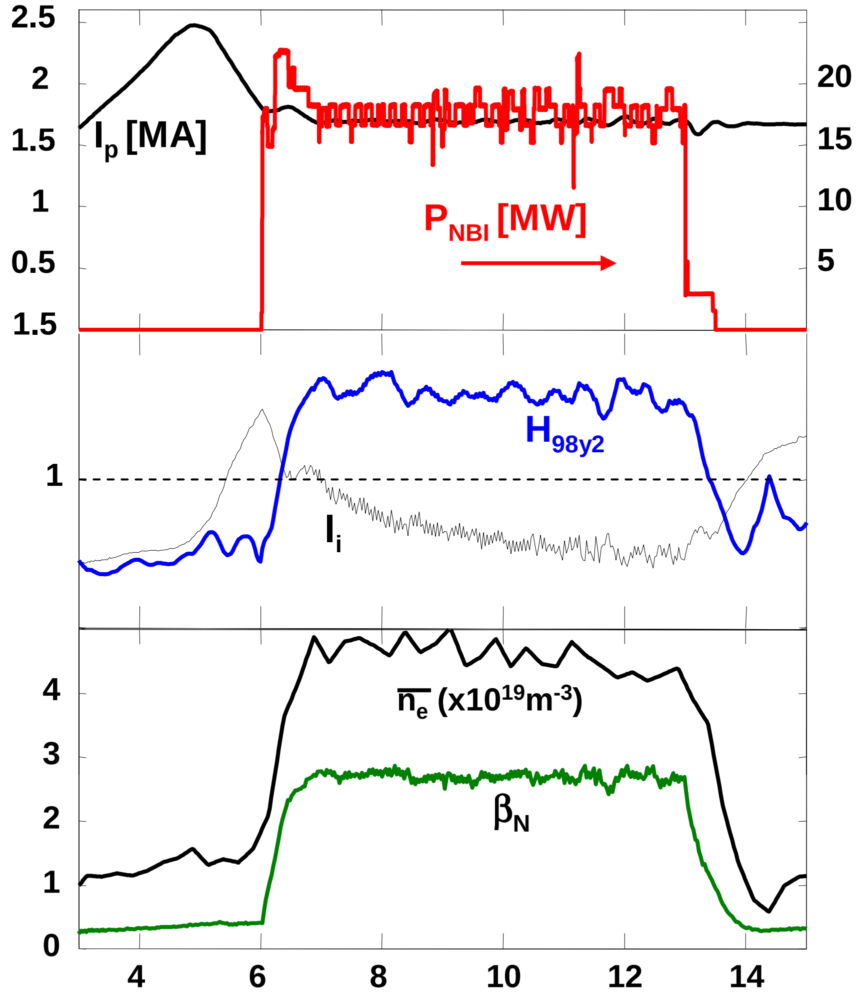
Acknowledgment & 2011 participation

- 2011-ACT1 team: V. Basiuk, E. Fable, I. Ivanova-Stanik, J. Ferreira, J. Bizarro, P. Strand, S. Moradi, I. Voitsekhovitch
- 2011-ACT2 team: I Voitsekhovitch, D Keeling, I Jenkins, Y Baranov, L Garzotti, M Romanelli, M Valovic, J-F Artaud, J Garcia, J Bucalossi, R Goswani, C Guillemaut, X. Litaudon, P. Belo, D Hogeweij, J Citrin, J Hobirk, E Fable, C Angioni, M Wischmeier, P Lauber, C Konz, D Coster, H Nordman, F Koechl
- 2011-ACT3 team: I Voitsekhovitch, M Valovic, L Garzotti, R Kemp, G Corrigan, V Parail, J-F Artaud, F Imbeaux, M Schneider, G Giruzzi, J Johner, J Bucalossi, B Pegourie, P Maget, E Nardon, D Moreau, F. Liu, X. Litaudon, T Bolzonella, M Baruzzo, E. Barbato, D Hogeweij, J Citrin, S Wiesen, D Harting, J Hobirk, C Konz, D Coster, J Lonnroth, F Koechl
- Together with the ITER-IO team T. Casper, W. Houlberg, S H Kim A. Polevoi J. Snipes

Interpretative & predictive of JET/ASDEX-U Hybrid discharges

IP overshoot

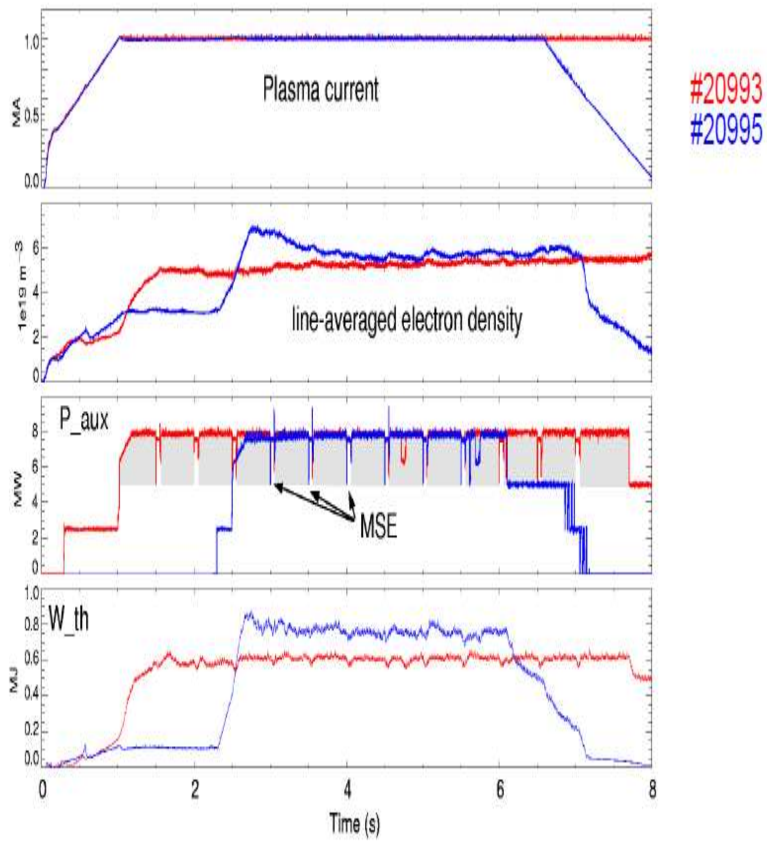
JET pulse 77922 (B_T=2.3T)



E. Joffrin IAEA 2010

Time [s]

Early and late heating



Confinement significantly better with late heating scheme

J. Stober *et al*, Nucl. Fusion 47 (2007) 728–737

Activity-1

- **validate ETS Kepler workflow* using a high performance hybrid JET pulse #77922**

- **run JETTO /CRONOS/ASTRA/TRANSP #77922 with the same sources terms and transport model , Bohm/Gyro-Bohm**

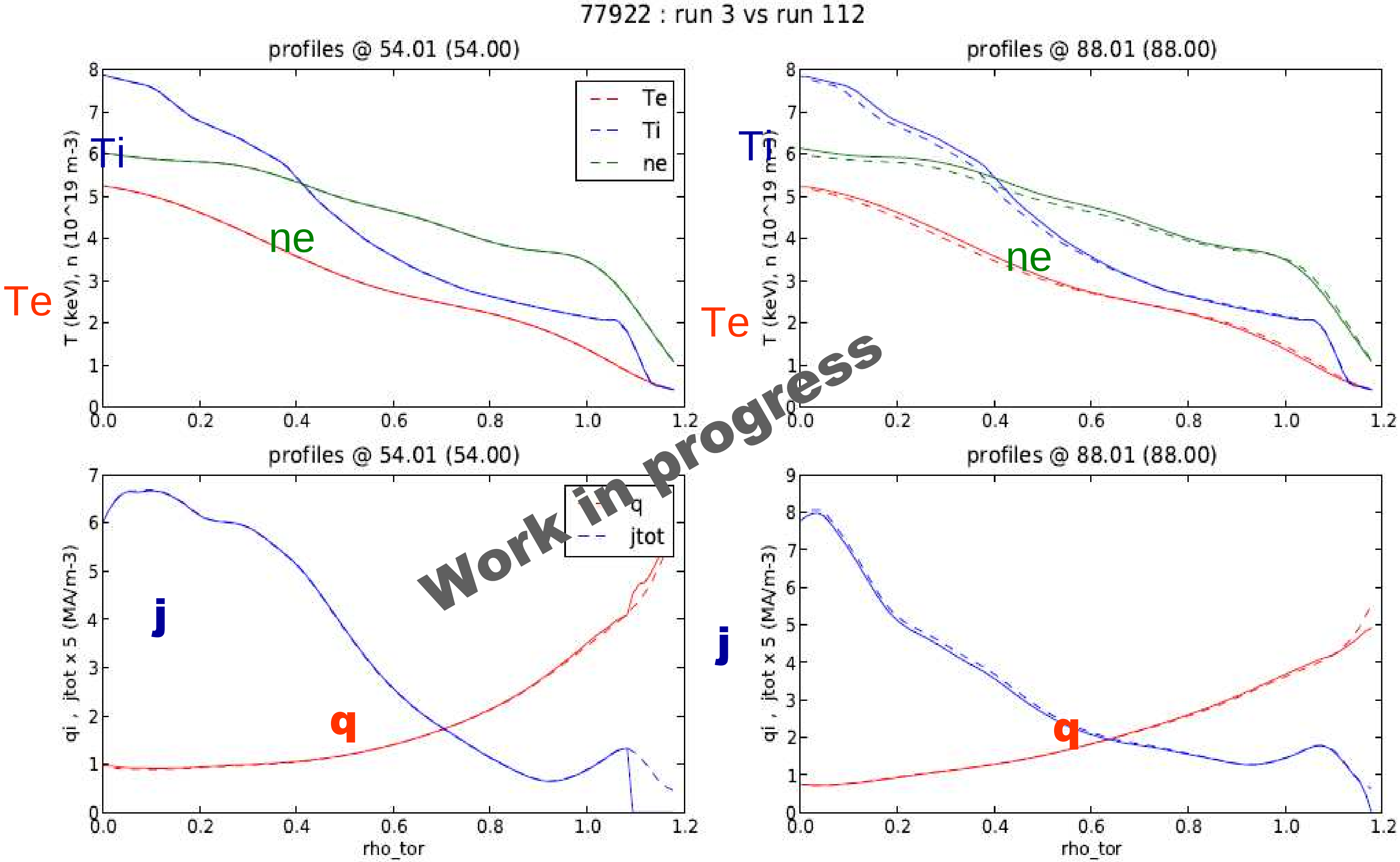
- **ETS reads the heating source terms, share the transport model with CRONOS/JETTO /ASTRA/TRANSP**

- **ETS runs # 77922 and comparison with CRONOS/JETTO/ASTRA/TRANSP**
  - **Benchmark transport model**
  - **Benchmark Spitzer and neoclassical resistivity /bootstrap**

*https://kepler-project.org/

ETS/TRANSP benchmarking for JET HS 77922

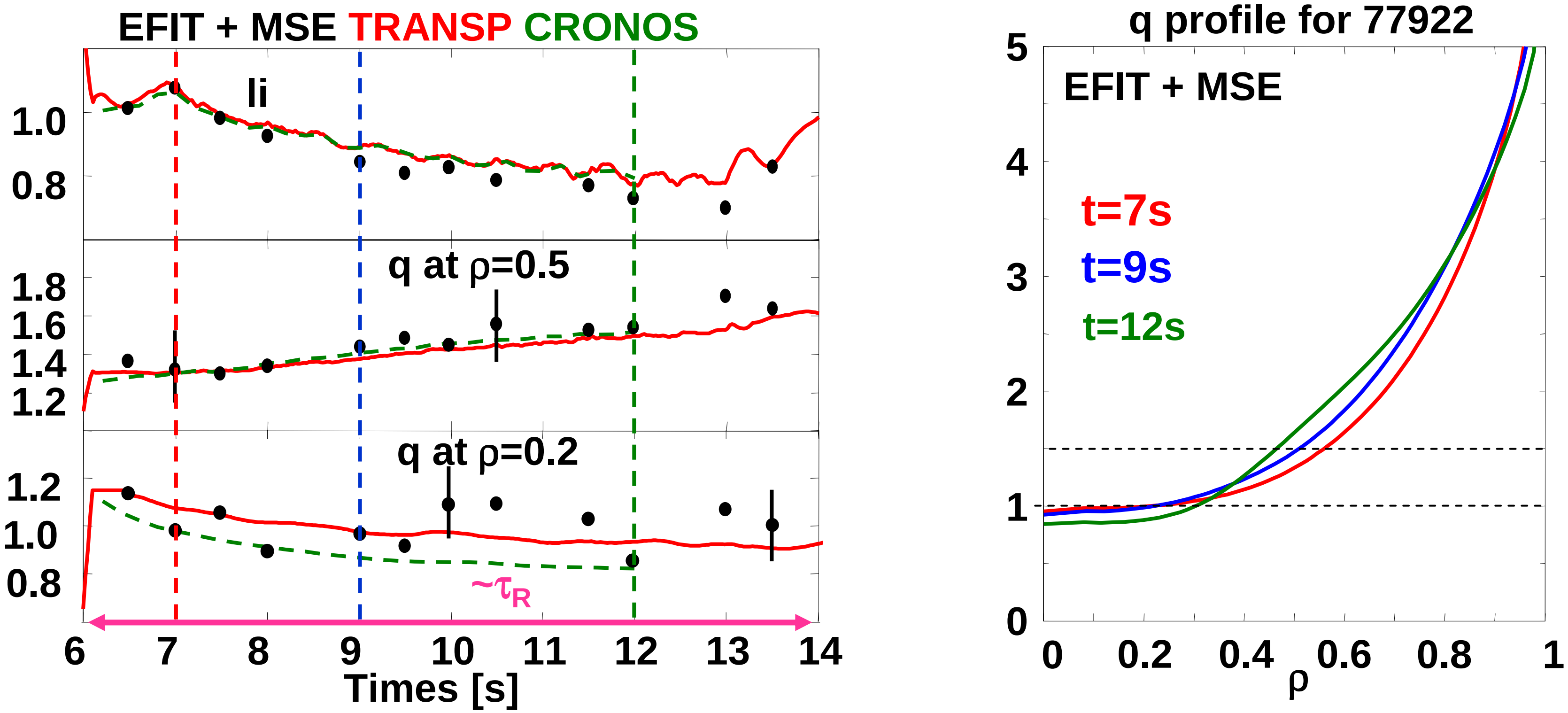
ETS (solid)/TRANSP (dashed): current diffusion with NCLASS resistivity & bootstrap current taken from TRANSP



J. Ferreira, I Voitsekovitch

Current diffusion in JET hybrid regime ?

q profile evolution for 77922 after the current overshoot

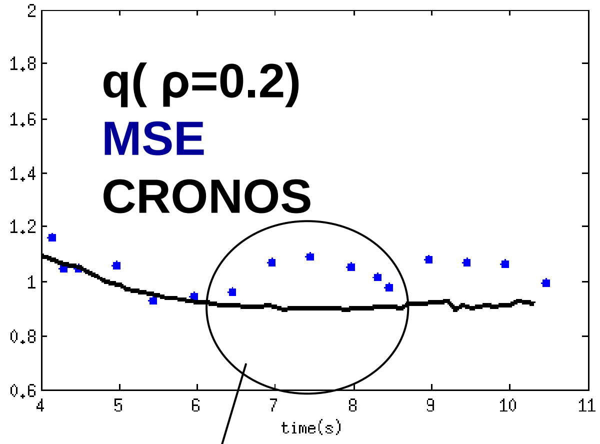


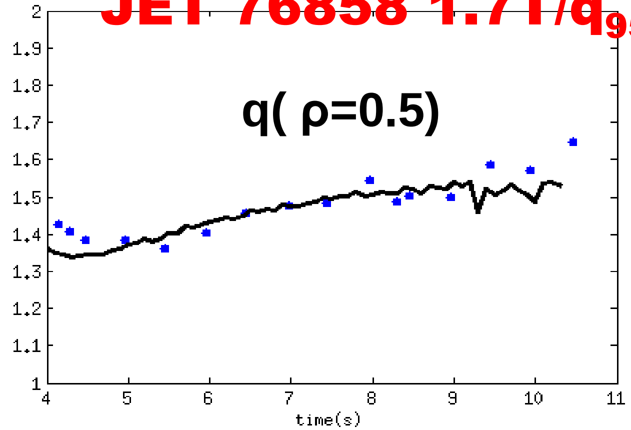
- ❑ q profiles are characterised by a broad region of low magnetic shear in the core with q~1.
- ❑ The “broadening” is progressively lost as the current profile diffuses over ~1 τ_R.
- ❑ Both TRANSP and CRONOS are consistently reproducing the experimental q reconstruction data ➔ no anomaly is found with respect to neoclassical theory

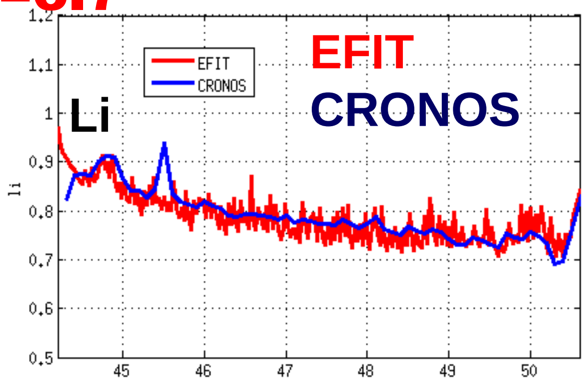
E. Joffrin et al IAEA 2010

Neo-classical current diffusion in JET hybrid regime

JET 76858 1.7T/q_{95}=3.7

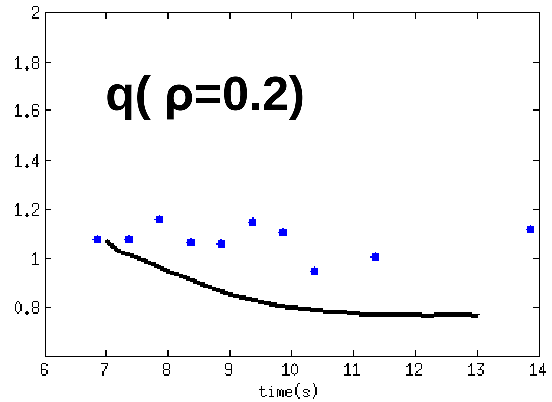


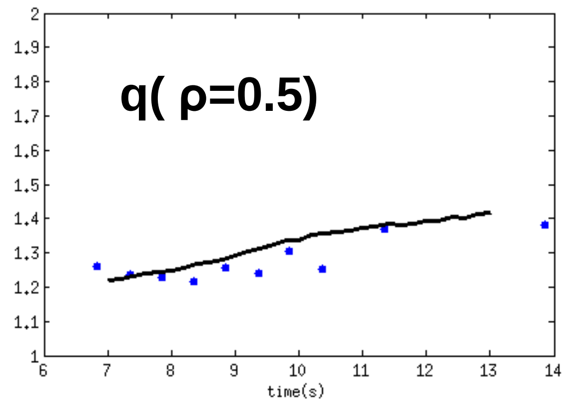


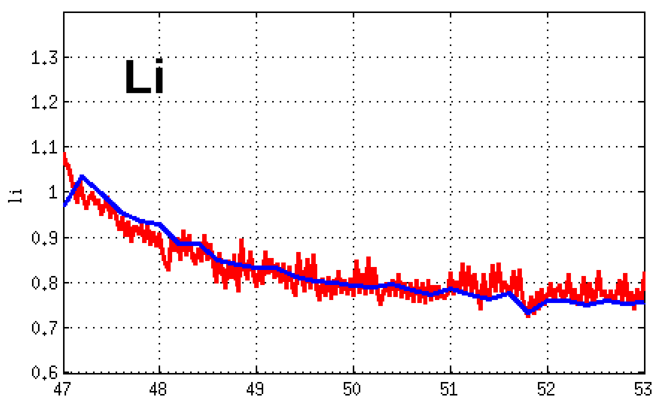


MHD event

JET 77933 2.3T/q_{95}=3.5





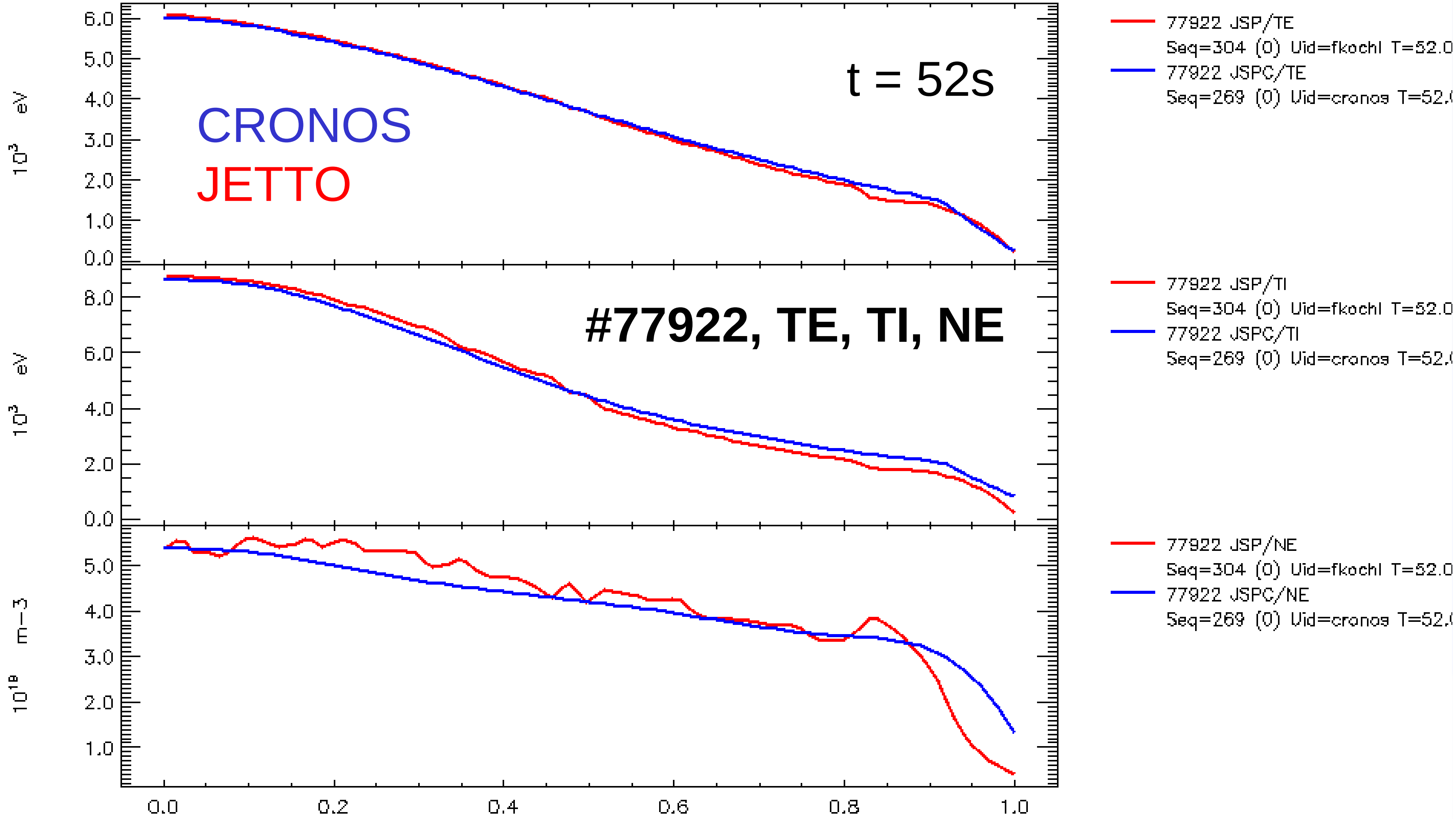


J. Garcia et al

Work in progress

Predictive modelling with the Bohm/gyro-Bohm model

prescribed Ne, predicted Te Ti and q



F Koechl, J. Garcia et al

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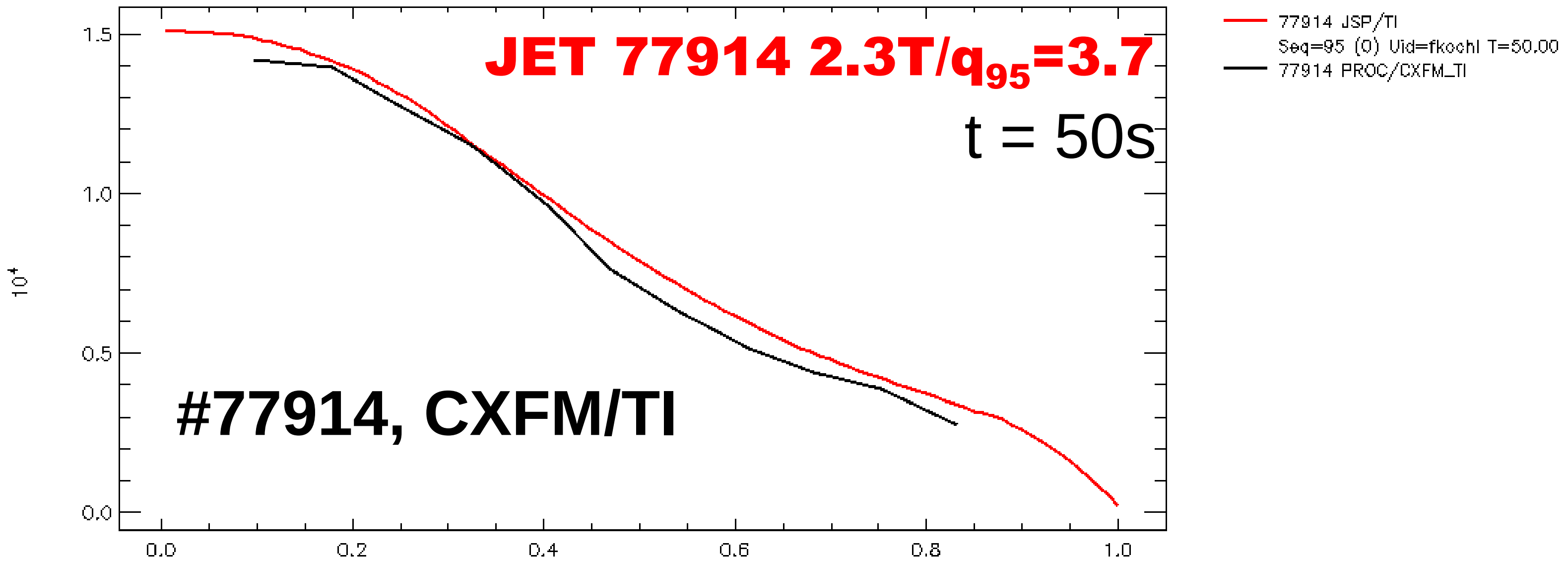
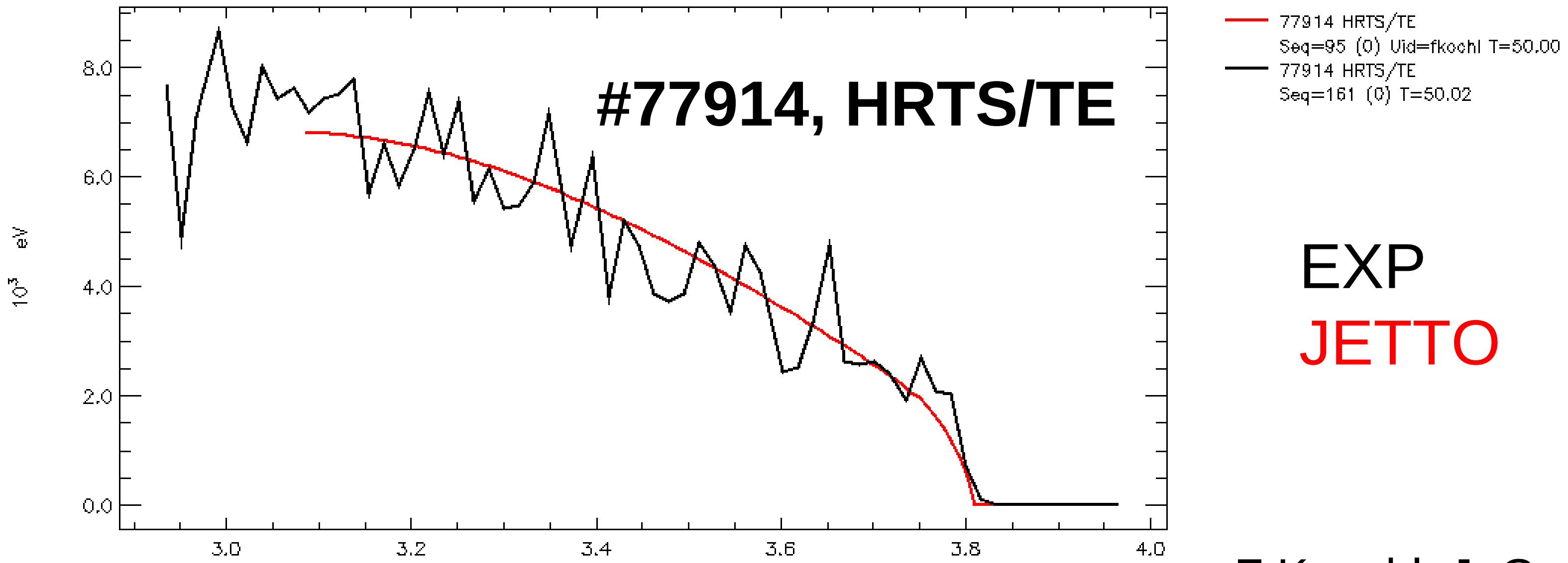
EFDA JET

Predictive modelling with the Bohm/gyro-Bohm model

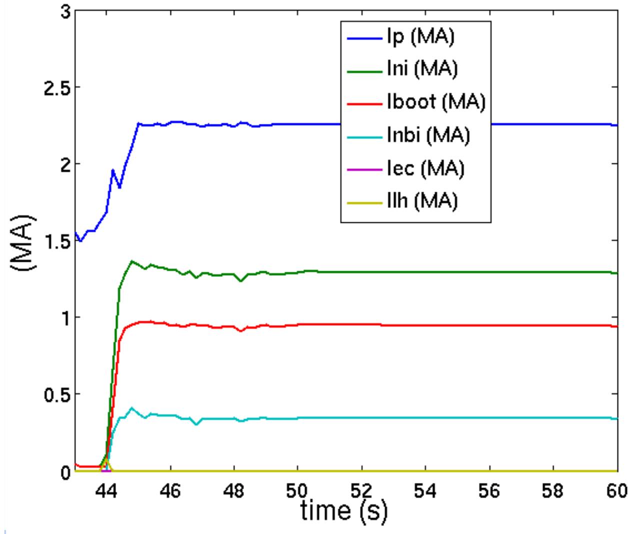


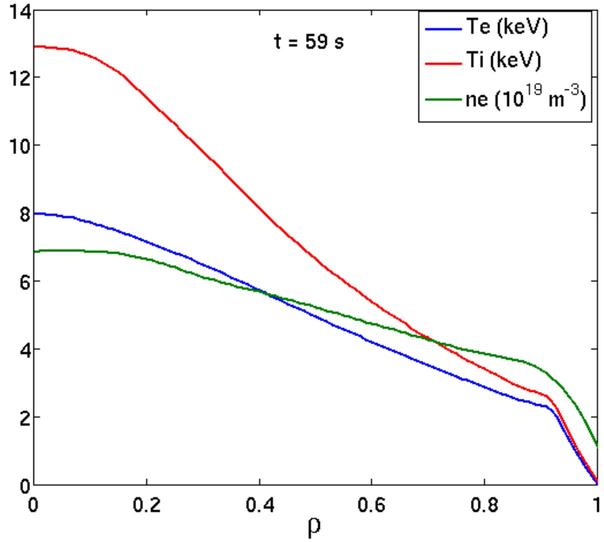


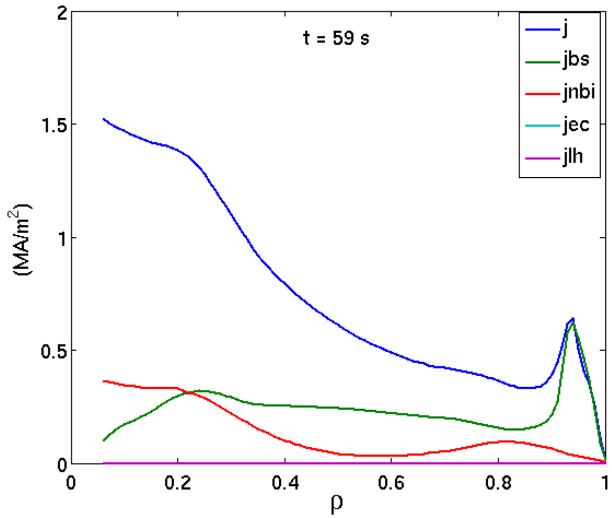
EXP
JETTO

F Koechl, J. Garcia et a

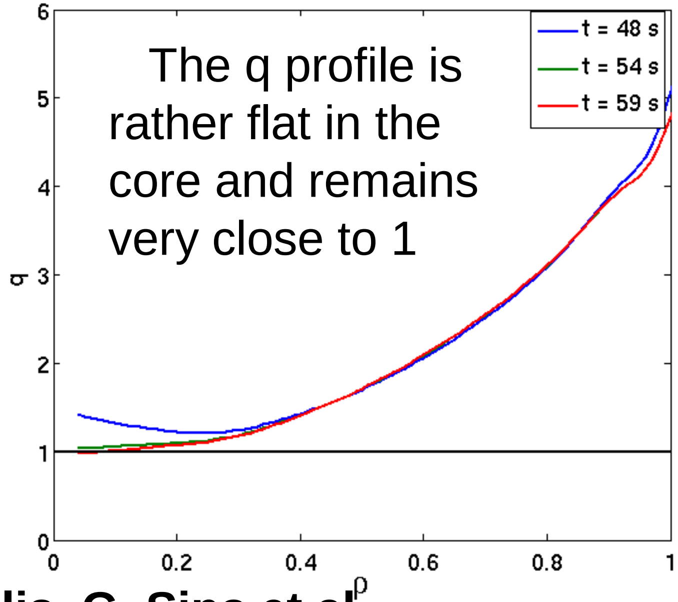
Extrapolation Hybrid like scenario at Ip=2.3MA and Pnbi=34.8MW (and q_{95}=4)







- Ip=2.3MA B_t=3T βN=2.8 H98=1.1 βp=1.8 fG=0.55
- Iboot=0.97MA fboot=42%
- Ini=1.25 MA fni=54%
- The q profile is rather flat in the core and remains very close to 1
- The pedestal temperatures are calculated with a scaling

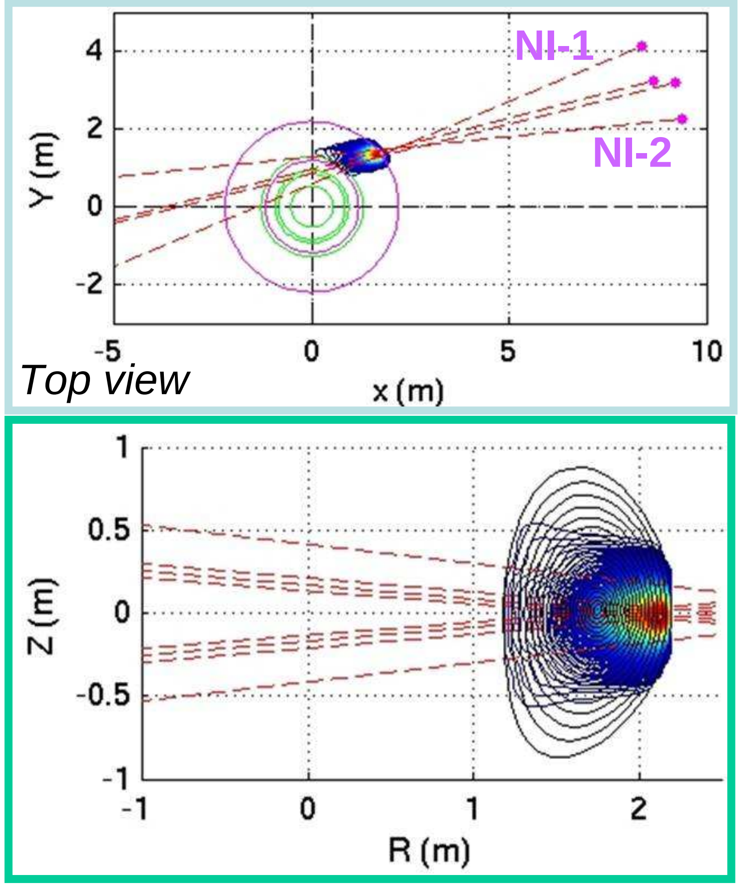


J. Garcia, C. Challis, G. Sips et al

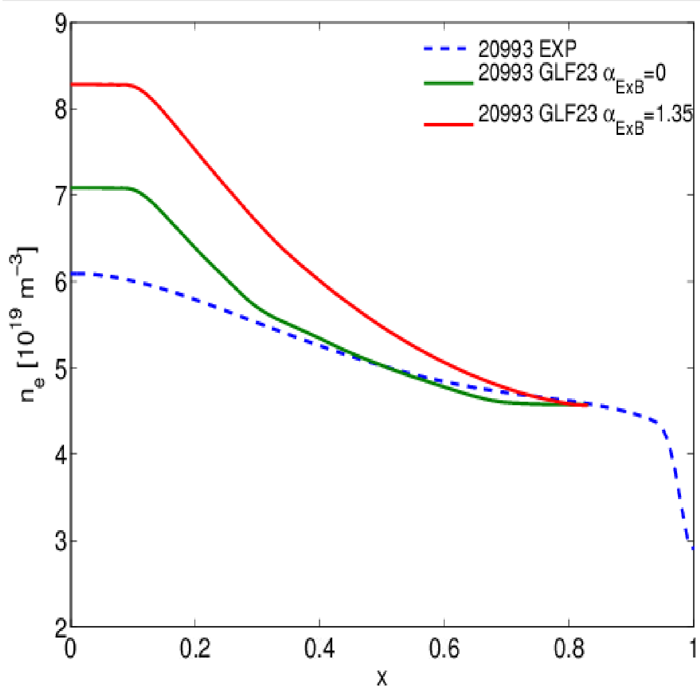
– WORK IN PROGRESS -

Predictive simulation of ASDEX-U hybrid scenario

- **ASDEX Upgrade NBI geometry implemented in CRONOS**
- **NBI sources calculated with NEMO, ICRH with PION**
- **Physics question being investigated with GLF23: Importance of q-profiles responsible in improved confinement ? (#20995 vs 20993)**
- **Simulations of ne, Te, Ti**



2D NBI deposition calculated with NEMO-RISK (#20993)



Predictive simulation of electron density using the transport model GLF23 (#20993)

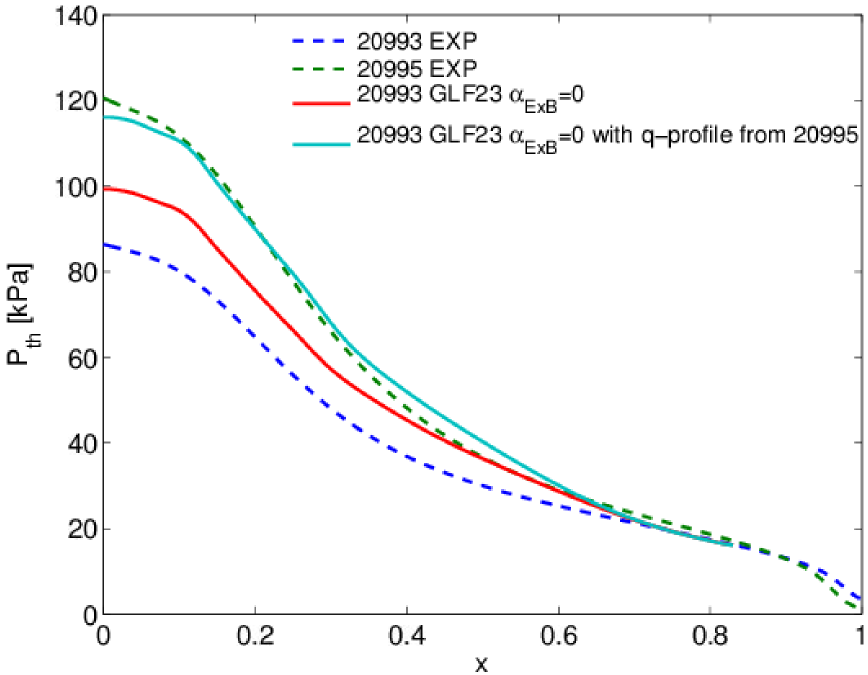
J. Citrin, M. Schneider, J. Hobirk et al

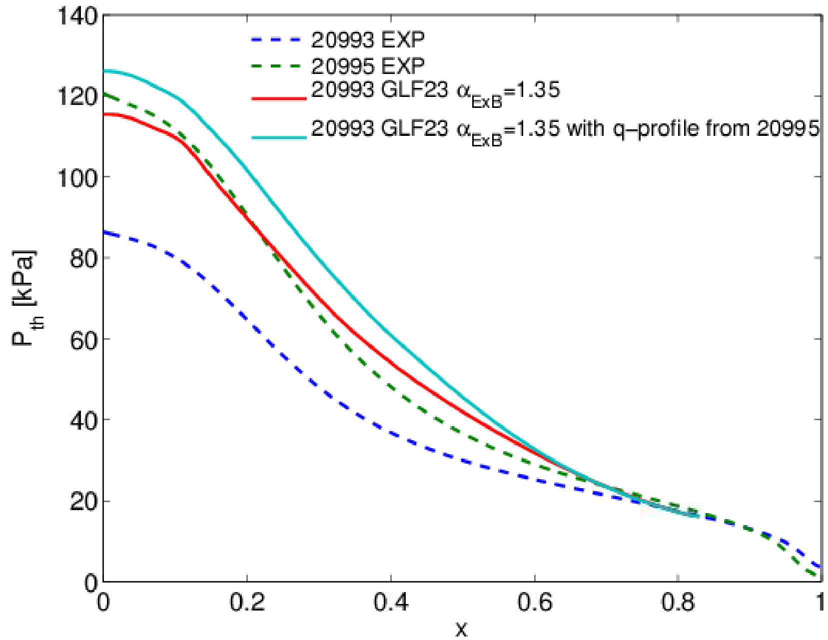
Predictive simulation of ASDEX-U hybrid scenario

J. Citrin et al EPS 2011

effect of switching the q-profile in a 20993 predictive run to the 20995 q-profile, attempt to isolate s/q effect on heat and particle transport prediction, with GLF23 (αExB=1.35 and 0)

CRONOS





Improvement due to s/q is up to 20% for the core pressure when α_{ExB}=0

J Citrin et al

ITER hybrid modelling

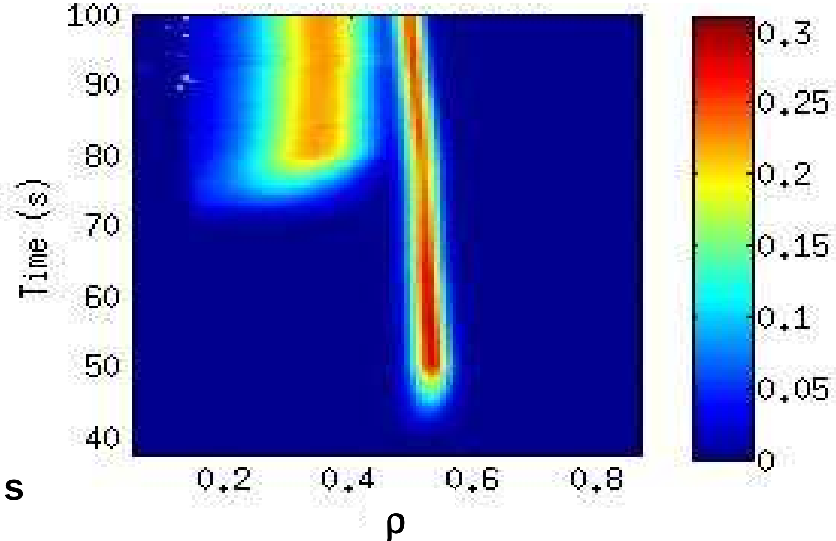
- **Optimisation of the current ramp-up phase at 12MA**
  - Find best scenario to arrive at hybrid q profile (q0~1, large low shear region) at L-H transition (varying ramp rate, density, settings of ECRH/ECCD, LHCD)
  - Assess sensitivity of results
- **current ramp-down modelling**
  - **Ongoing task : validation transport model on JET database**
- **Optimisation of ECCD during the burn phase**
- **Sensitivity studies : effect of density peaking**
- **Edge core integration**

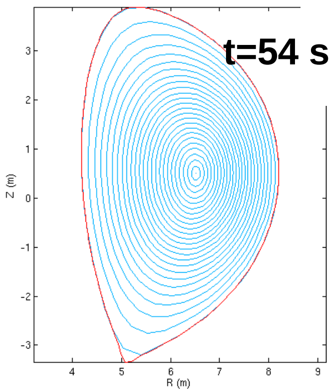
Modelling of ITER hybrid current ramp-up

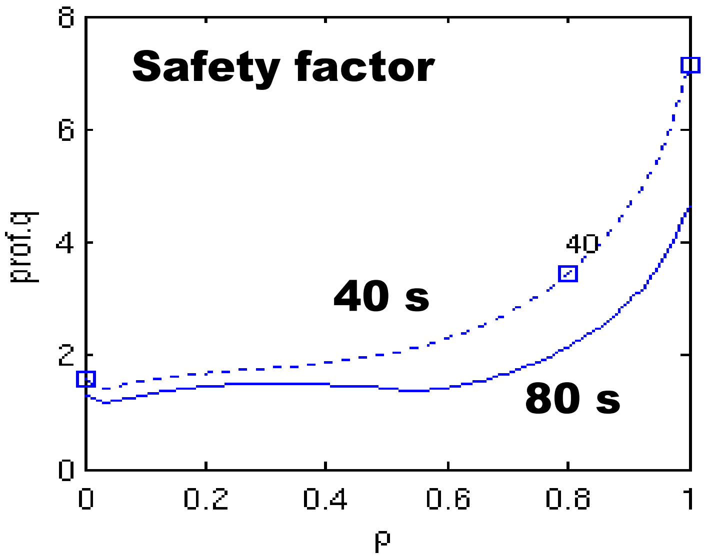
G.M.D.Hogeweij et al, EPS 2011

- **Modelling of current ramp up for JET, ASDEX-U, Tore Supra (Imbeaux et al IAEA 2010, Nuc. Fus 2010)**
- **Current ramp up simulations for DIII-D and comparison with JET (cf this meeting, I Voitsekhovitch)**
- **Optimisation of current ramp up for ITER HS:**
  - 12 MA
  - Shape from CORSICA (T Casper)
  - off-axis LHCD or ECCD

ECCD [MA/m2], UPL 10 MW, starting at 40 s + EQL 10 MW, starting at 75 s

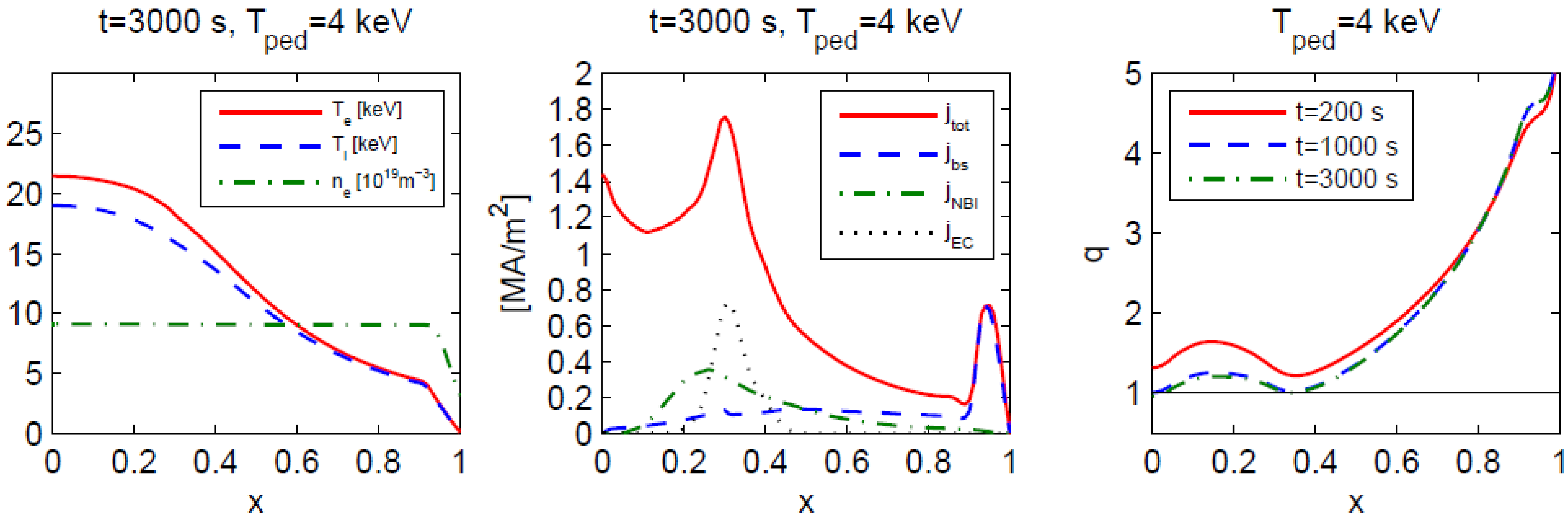






G.M.D.Hogeweij et al

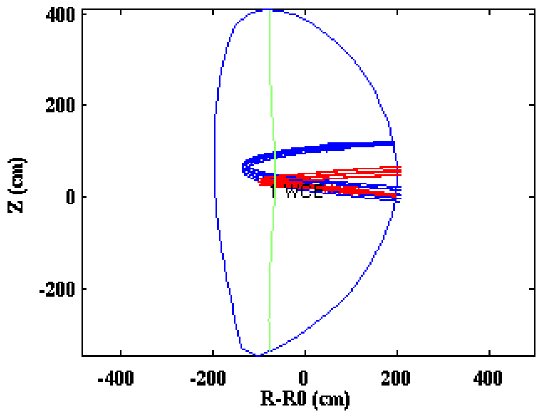
ITER hybrid

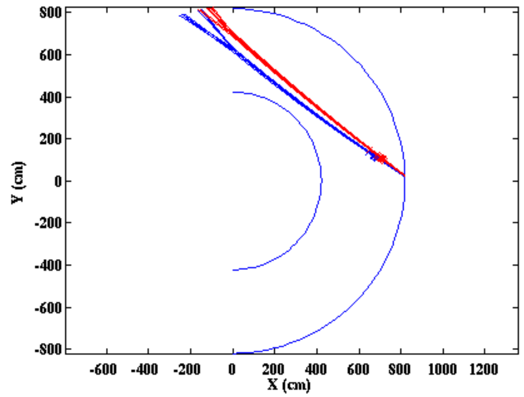


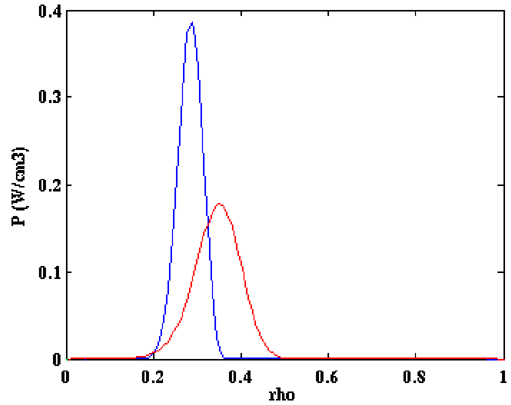
J. Citrin et al., Nucl. Fusion 50, 115007 (2010).

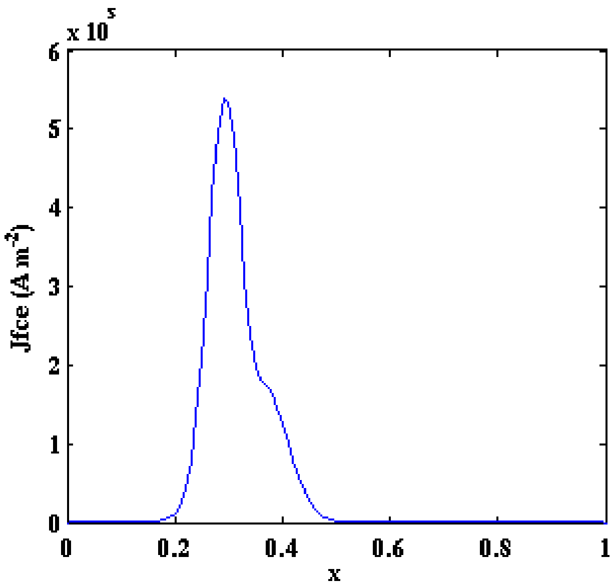
- The best ITER hybrid scenario, with reasonable pedestal Tped=4keV, was obtained with off-axis NBCD+ECCD
- Stationary state q-profile with qmin=0.96, x(q=1)=0.02
- High sensitivity of fusion power to q-profile shaping through s/q dependence on linear thresholds

ITER hybrid with revised ECRH configuration : removing middle row of equatorial launcher









Rant=8.5m
Zant=1.22,0.02m
Θ=-5°,5°
Φ=34°,37°
- **Middle row is removed**

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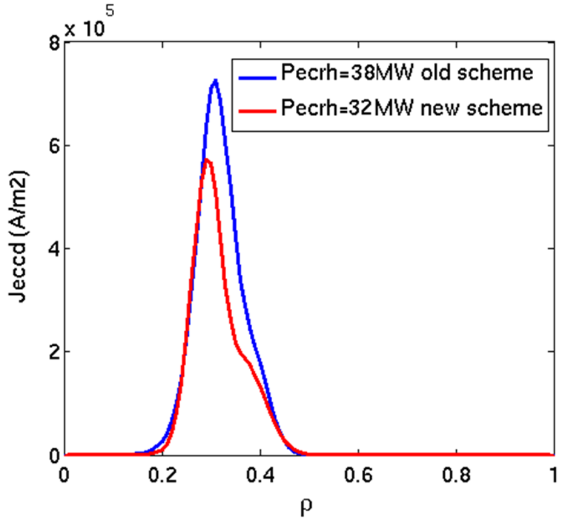
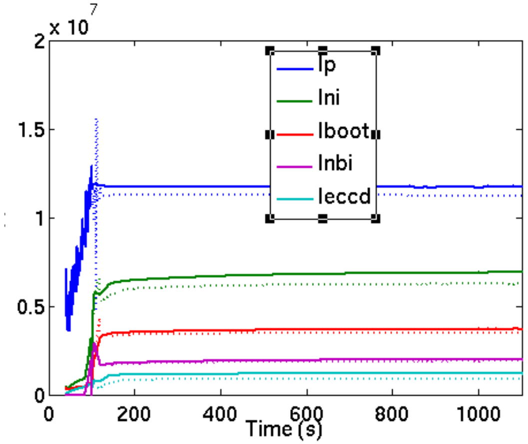
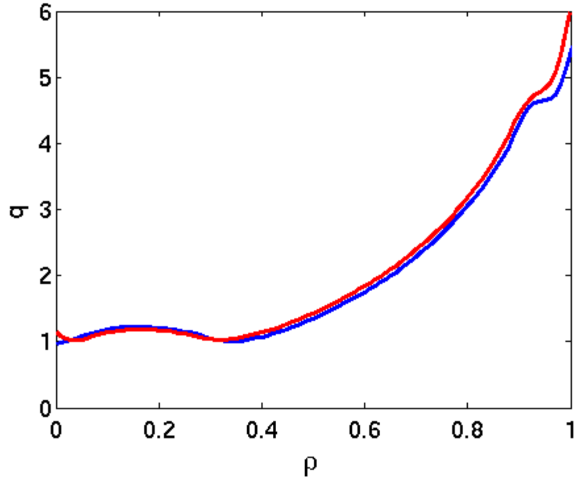
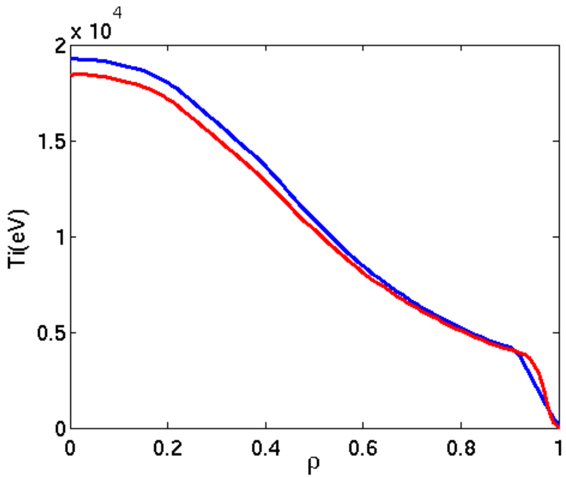
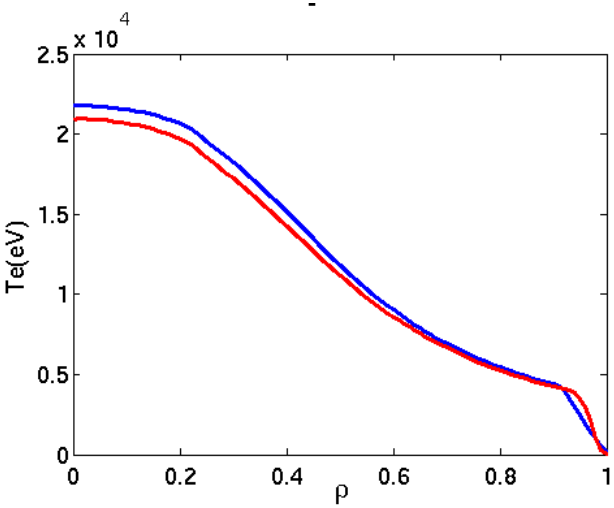
Modelling of ITER hybrid with GLF23 & revised ECRH constrains Q>5 and q0>1











- Pecrh=32 MW
- Iccd=0.85MA
- ρ_{ped}=0.94, Tped=3.9keV
- Ip=11.5MA B_0=5.3T

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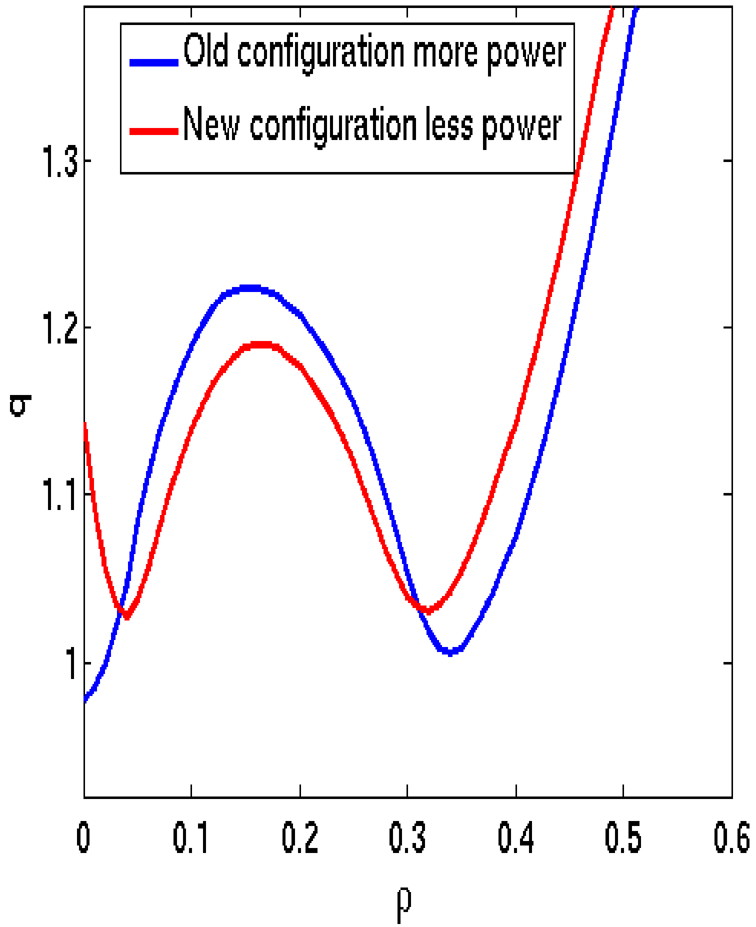
q profile shape in the core



- Q=5, β_N=2 H_{98}=1.05 in both cases
- I_{eccd}=0.85MA new case, I_{eccd}=1.2MA old case
- The impact of a new ECRH/ECCD configuration is low
- Less eccd increase the q profile at ρ=0.35
- The reduced input power and total current effects are counteracted by the pedestal assumptions
  - ρ_{ped}=0.94 as used by Kessel et al (instead of ρ_{ped}=0.92)
  - to confirm with EPED
- MHD analysis necessary

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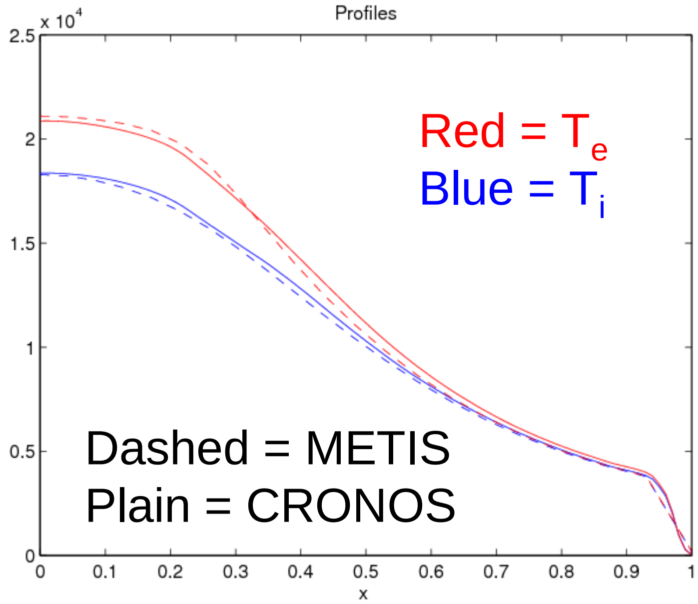
The METIS code: Fast Tokamak Integrated Simulation

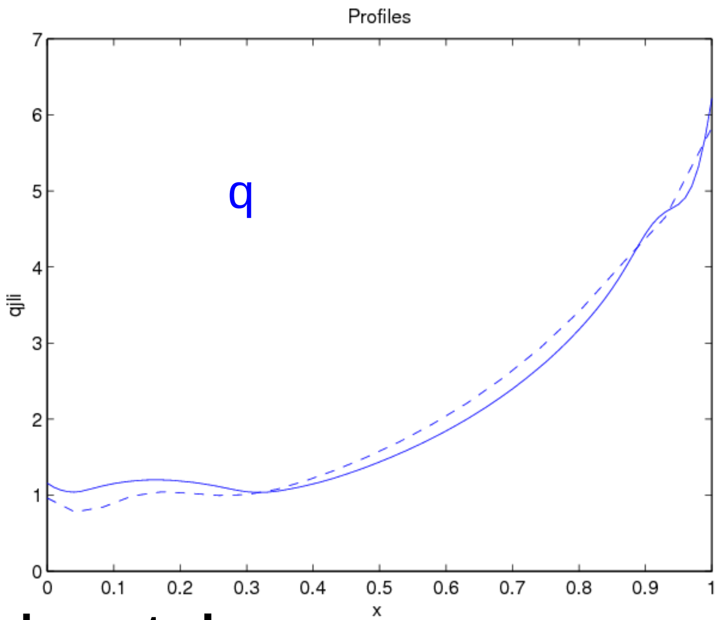
- ✓ **METIS : Integrated Transport Code with simplified assumptions**
- ✓ **METIS is fast :**
  - ➔ **~ 1 mn per simulation for 300 time slices (quite independent of the discharge duration)**
- ✓ **Mixed 1D and 0D equations**
  - ✓ **Current diffusion 1.5D with moment equilibrium**
  - ✓ **Source profiles deduced from simple models**
  - ✓ **Global energy content from 0D ODE (scaling, transients)**
  - ✓ **Temperature profiles : stationary 1D solution, χ scaled to W_{th}**
  - ✓ **All non-linearities solved (dependence of sources on profiles, fusion power, He ash transport)**
- ✓ **Input : Power references, I_P, plasma density, Z_{eff} , LCMS geometry**
- ➢ **Output : all standard 1D and 0D data that you would expect from a transport code**
- ➢ **METIS is included in the CRONOS suite of codes, preliminar scenario design to prepare full integrated modelling simulations**

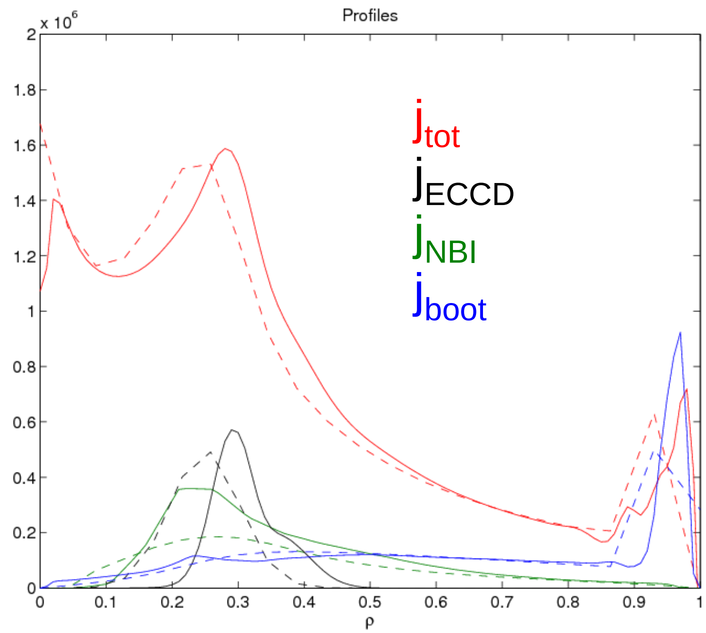
Parameter domain exploration with METIS for the ITER hybrid scenario

- METIS = companion tool to CRONOS 1 run ~ 1 minute
  - 32 radial points
  - Solves current diffusion
  - Simple models for heat transport, heating and current drive

- Use CRONOS run as a reference

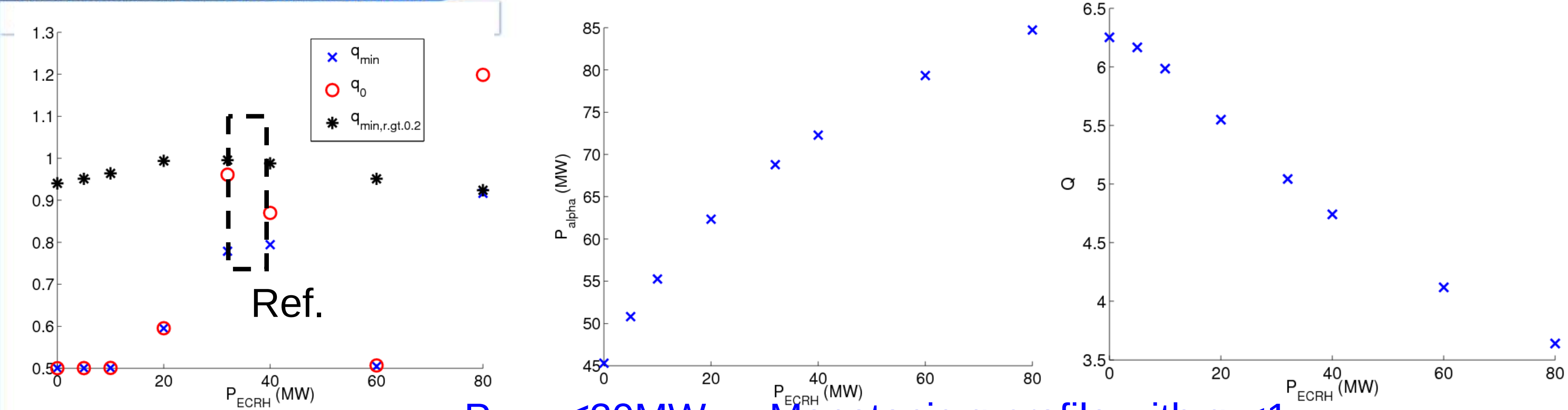






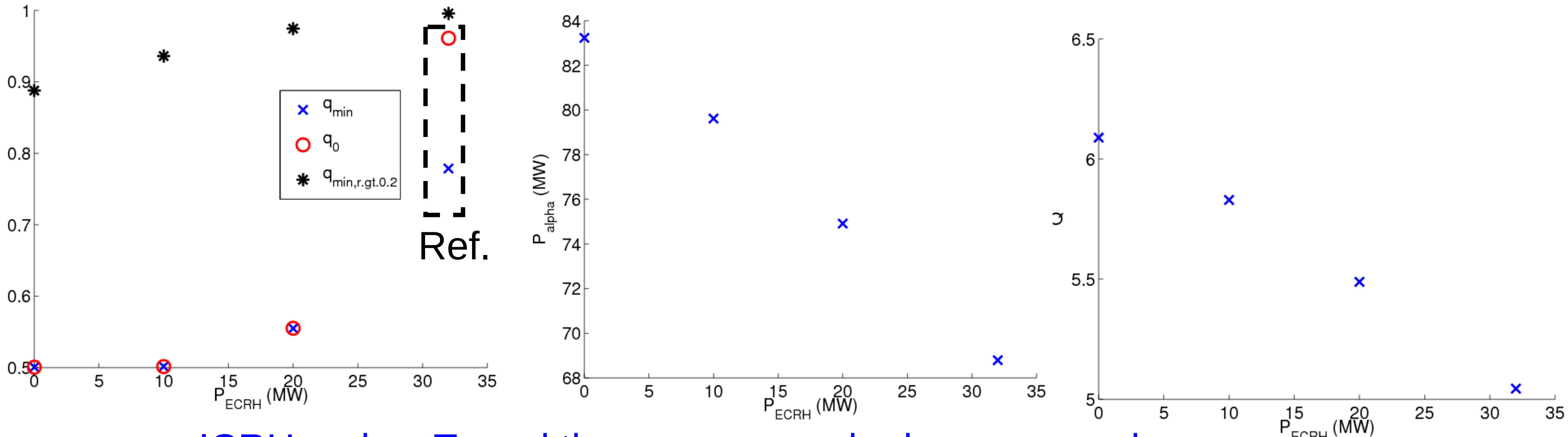
E. Nardon et al

P_{ECRH} scan (P_{add} not constant)



- $P_{ECRH} \leq 20$MW → Monotonic q profile with $q_0<1$
- Q goes up when P_{ECRH} goes down

P_{ECRH} scan adding ICRH power to maintain P_{add} constant



- ICRH makes T_e and thus σ more peaked → $q_{min,r>0.2}$ decreases
- Q goes up when P_{ECRH} goes down thanks to ion heating by ICRH

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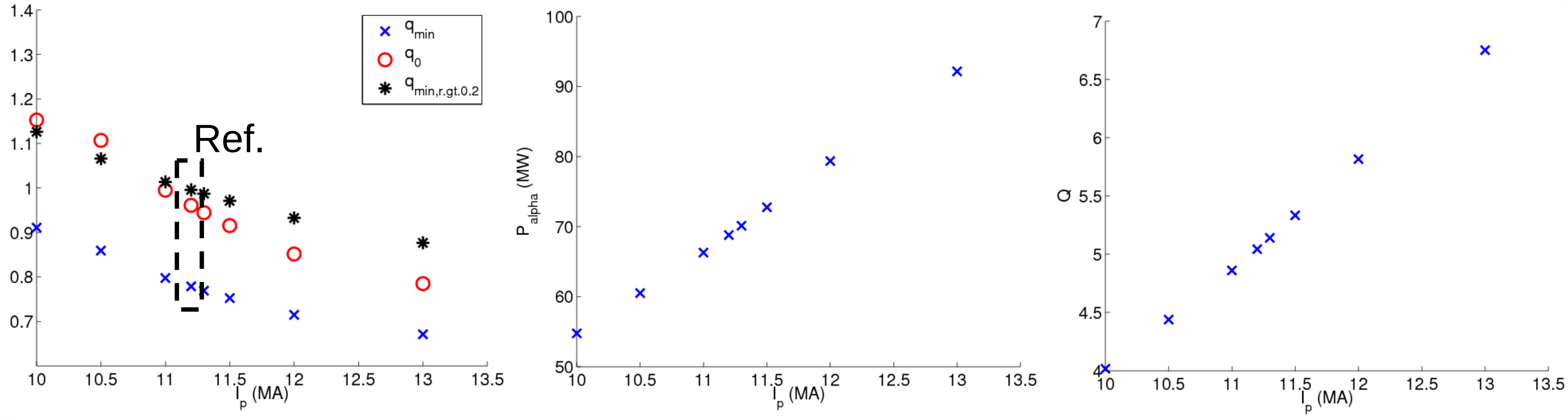
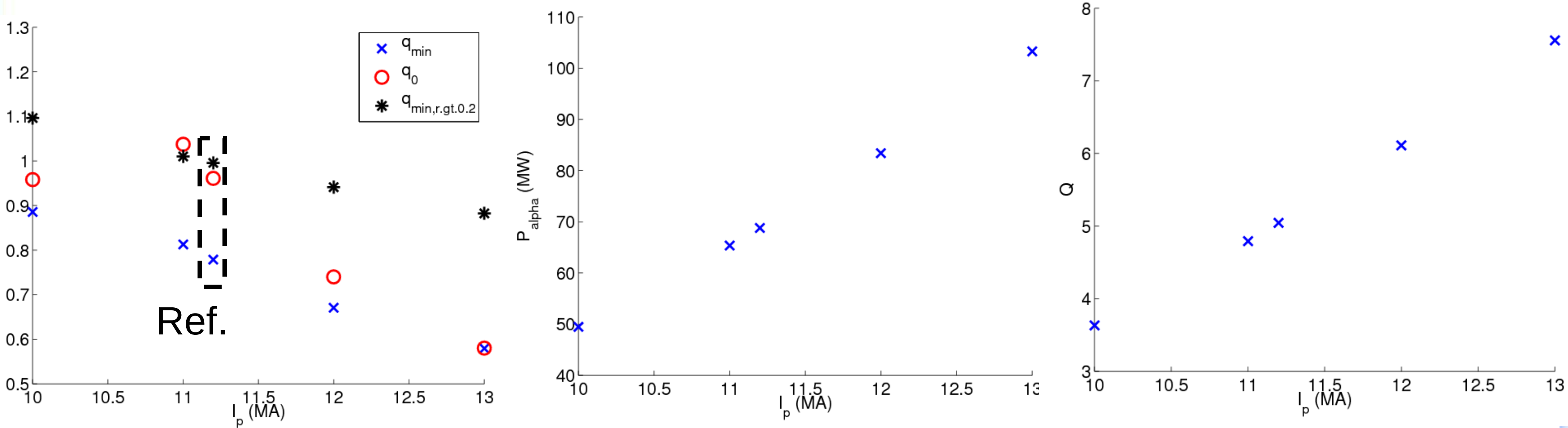
I_p scan at constant n_e

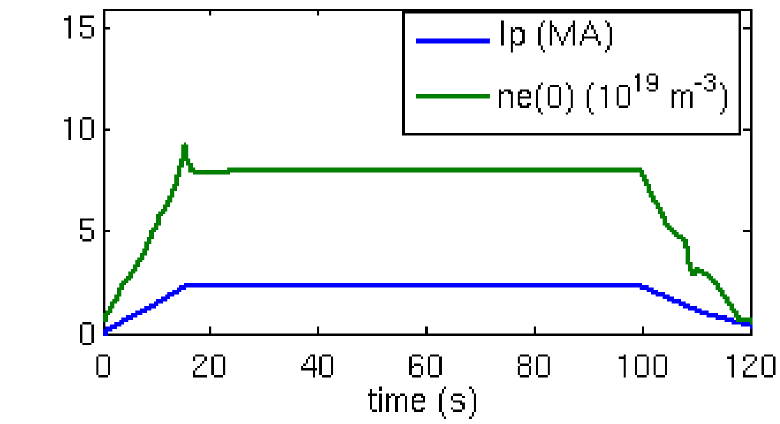


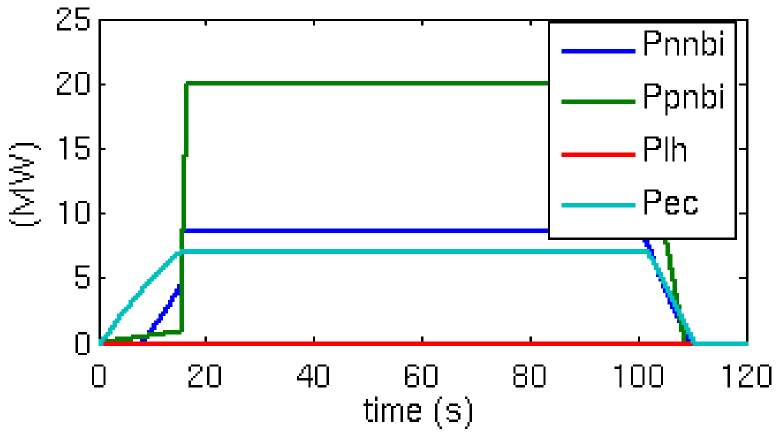
I_p scan at constant n_e/n_G

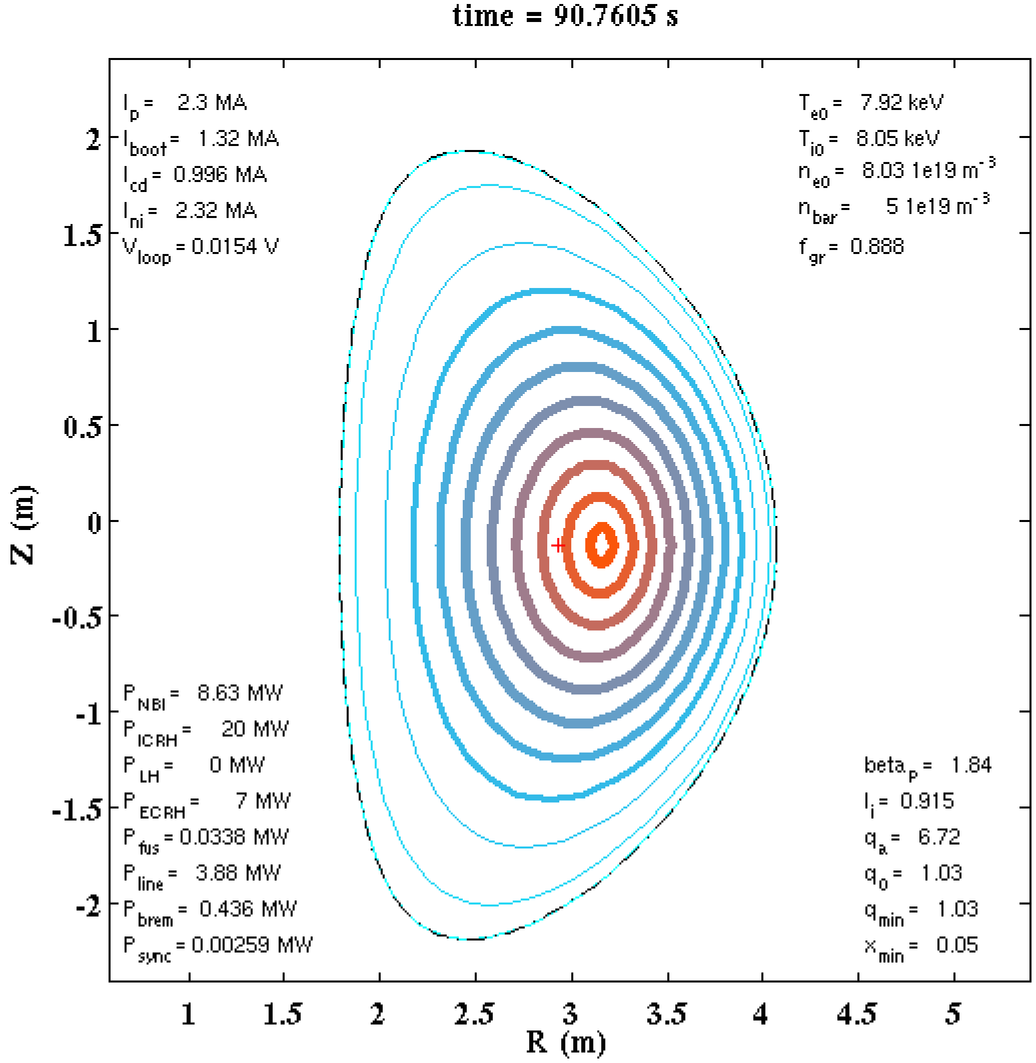


- At fixed n_e/n_G, $q_{min,r>0.2}$ decreases by ~0.05/MA while Q increases by ~1.25/MA
- At given I_p, $q_{min,r>0.2}$ decreases with n_e (more bootstrap gained than ECCD lost)

METIS simulation of JT-60SA Scenario 5-1 (high β_N, steady-state)







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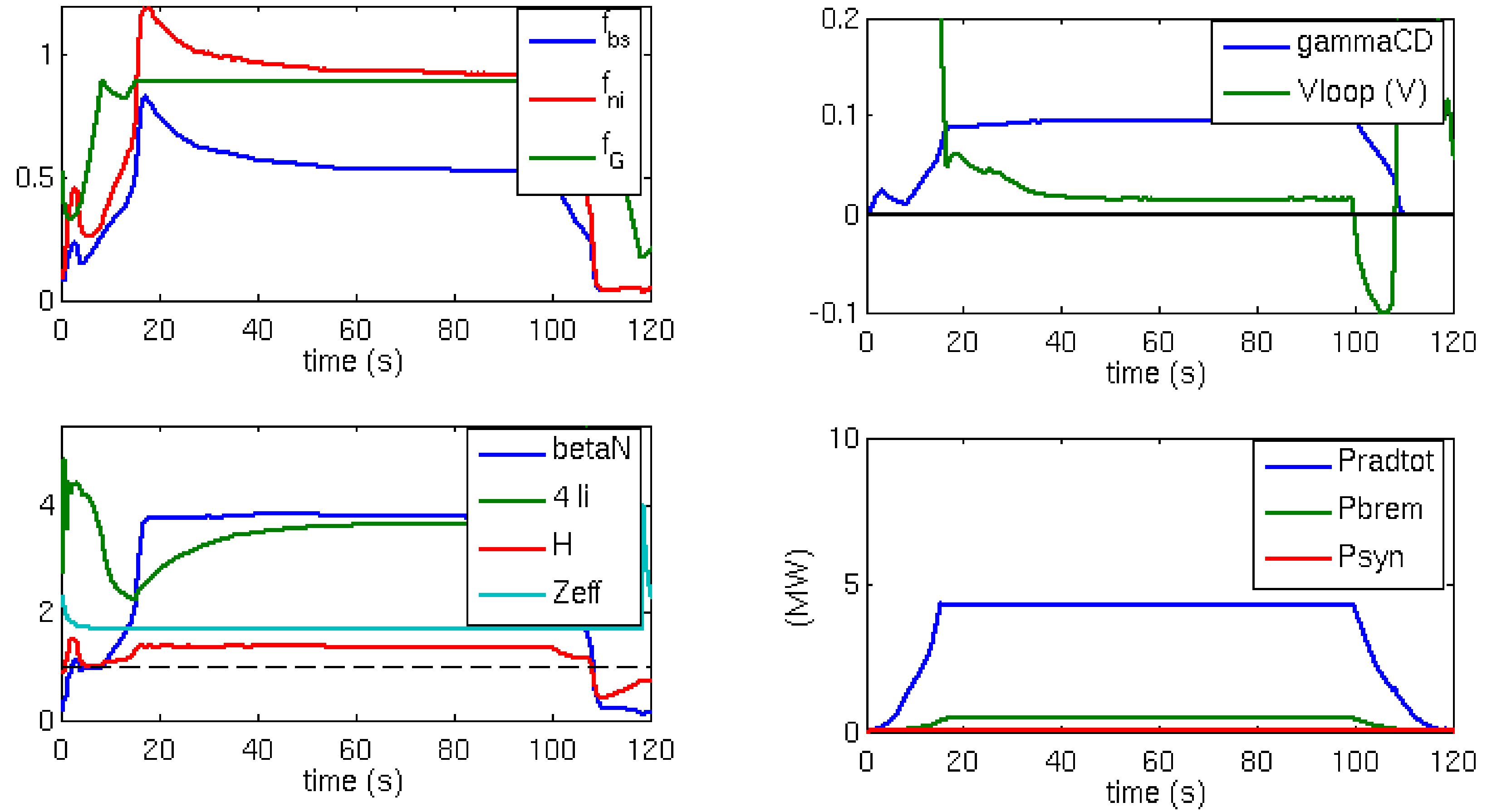
METIS simulation of JT-60SA Scenario 5-1 (high β_N, steady-state) /2



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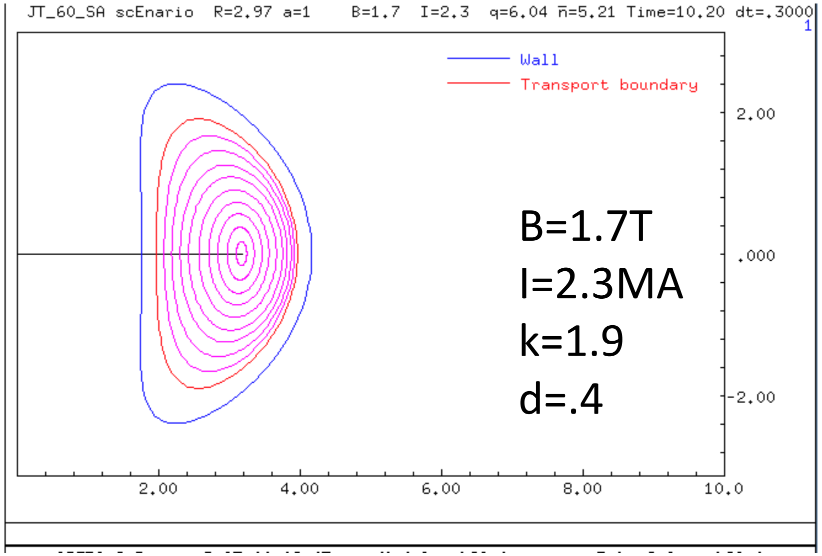
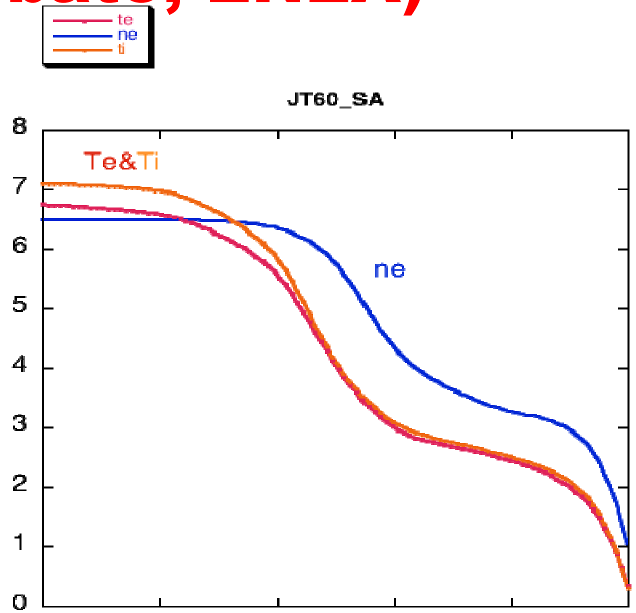
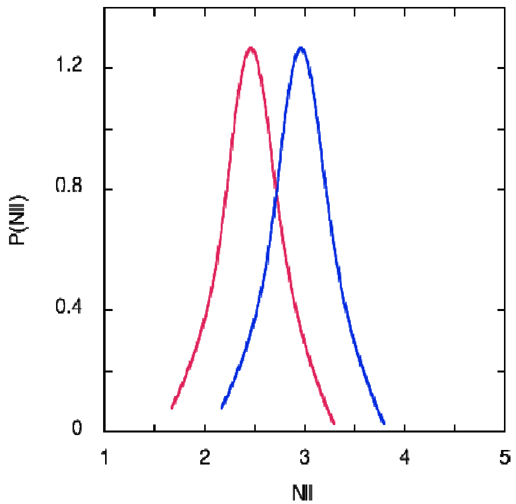
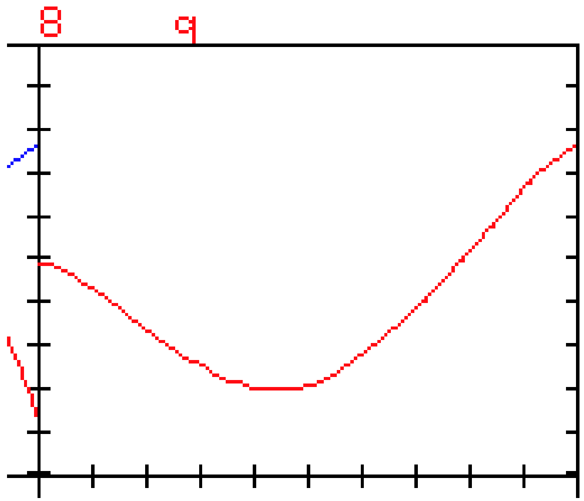
LHCD calculations (E. Barbato, ENEA)





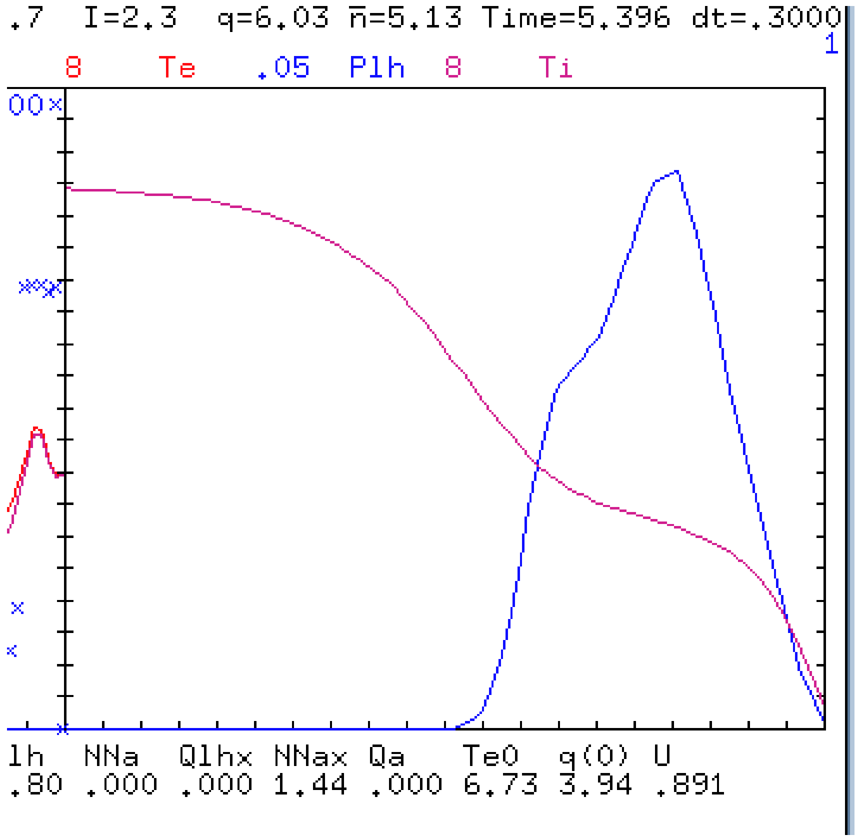


f=3.7Ghz
$n_{||}$ = 2.5-3
PL = 2MW



High β_N- full CD scenario $n_{||Launch}$=3, P_{ABS}=1.8MW

P_{LH-ABS}=1.8MW
I_{LH}= 219kA
n=5 $10^{19}m^{-3}$
R=2.97m
γ= 1.64 x 10^{19} m^{-2} A/W



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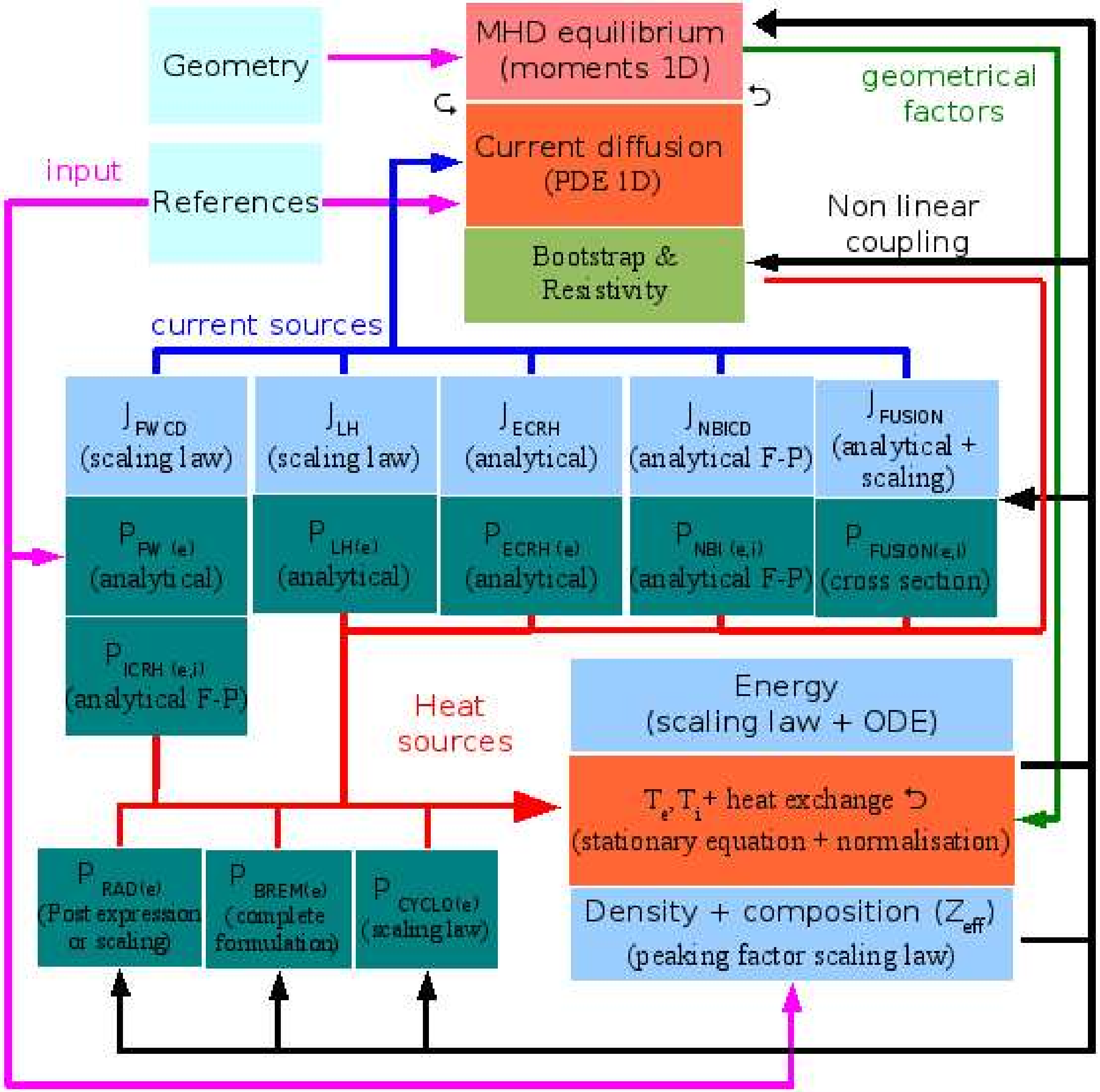
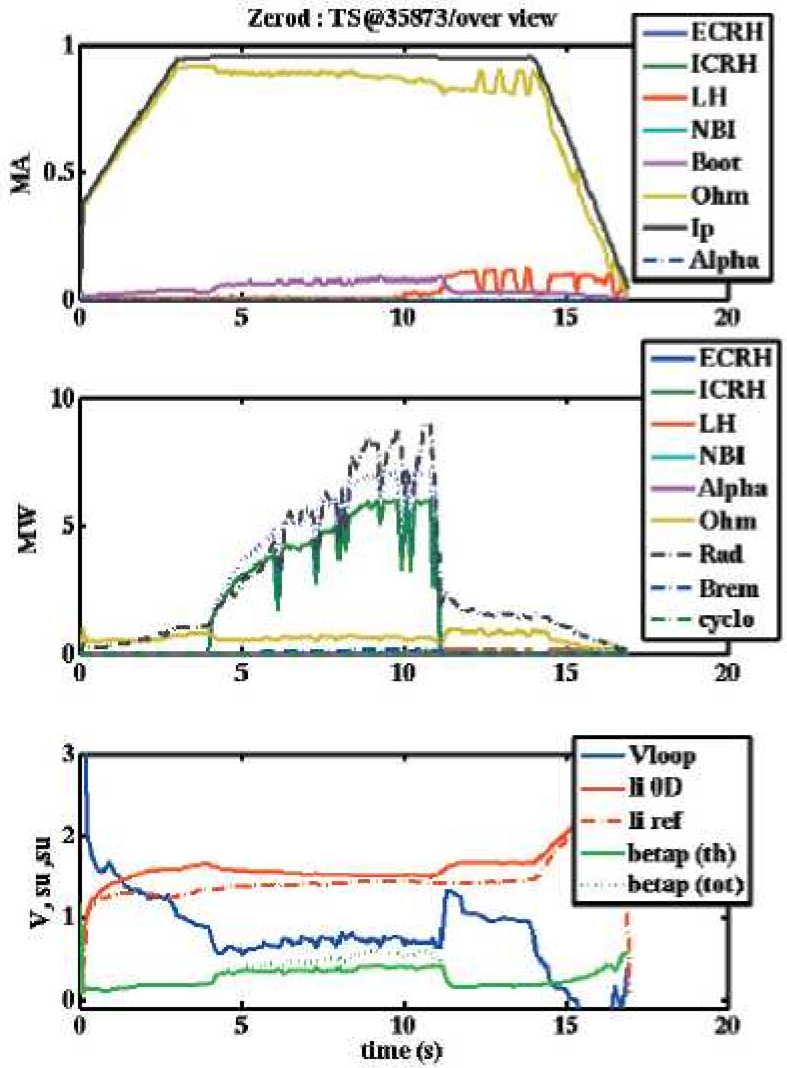
METIS internal workflow



The METIS code: Minute Embedded Tokamak Integrated Simulation

- Fast Integrated Modelling code
  - Scenario Design
  - Flight Simulator
- Mixture of 0D and 1.5D equations
- Highly convergent computing scheme
- All parameters of an ITER discharge calculated in 1 minute
- Part of CRONOS



Overview of a METIS simulation for the Tore Supra shot 35873