EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT
Task Force
INTEGRATED TOKAMAK MODELLING

T&C ITPA group meeting, 4-6 April 2011

ISM modelling activity on current ramp up

Presented by I VOITSEKHOVITCH on behalf of ISM group

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

ISM Leader: X. Litaudon
ISM Deputy Leader: I. Voitsekhovitch

EFDA CSU Contact Person: D. Kalupin

Outline

- **ISM group & activity: general information**
- **Validation of transport models for current ramp up plasmas**
- **Current diffusion and li simulations**
- **Projection to ITER**

ISM: general information

- **Created in 2007 as ITM cross-project. Status of ITM project since 2010**

- **Resources in 2010/2011:**

  - 47 participants, 6.86 PPY (basic and priority support)

  - CCFE, CEA, ENEA, IPP-Garching, IST-Portugal, FOM, FZJ, RFX, OAW, VR, EFDA-CSU

  - coordinated by X. Litaudon (Leader) and I. Voitsekhovitch (Deputy)

- **Meetings: 3 working sessions per year + regular remote meetings (~every two weeks).**

- **Suites of codes involved: ASTRA, CRONOS, JETTO, TRANSP, SANCO, SOUL 1D, EDGE2D, EMC3-EIRENE, MISHKA, METIS, HELIOS.**

  ETS (European Tokamak Solver) at the user test phase.

- **Close collaboration with IO, ITPA groups (T&C and IOS) and experimentalists (JET, AUG, Tore Supra)**

Scientific activities:

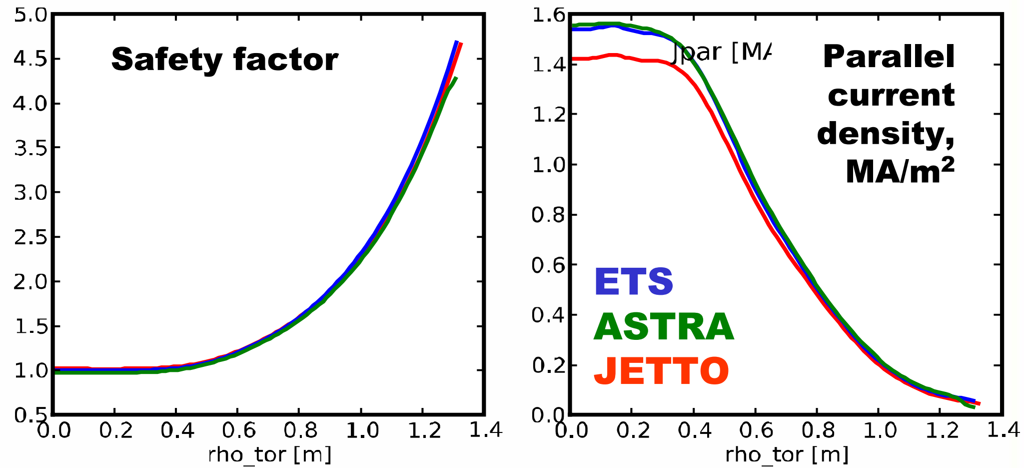
- **Activity-1 : Support Validation of the ETS**
- **Activity-2 : Developing and validating plasma scenarios: simulations for existing devices**
- **Activity-3 : Support to predictive scenario modelling for future devices (ITER , JT60SA, etc)**

The modelling of current ramp up phase is addressed within all three activities

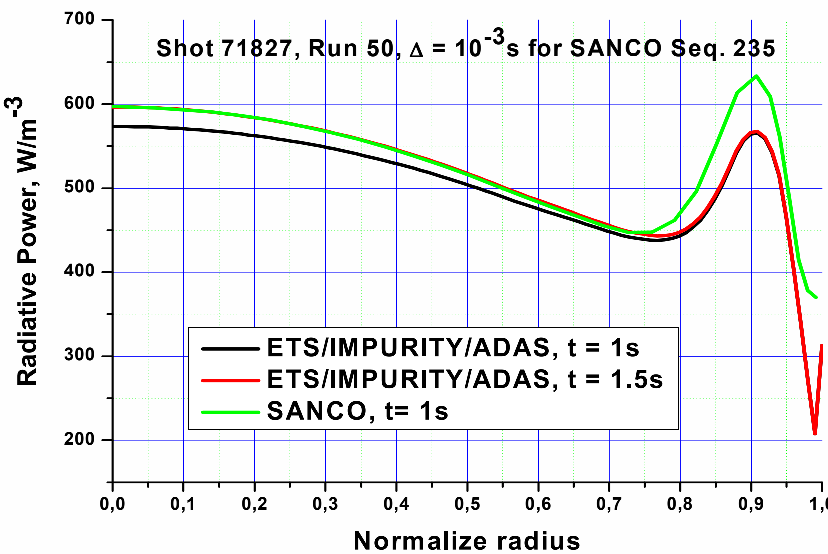
ACT1: benchmarking of the ETS code against ASTRA/CRONOS/JETTO/SANCO for JET OH current ramp up discharge (#71827)

- **ETS development:**
  - **- input data: scripts converting the JET PPFs, CRONOS & TRANSP output into the input CPO for ETS**
  - **- 2 Kepler WFs for equilibrium+ current diffusion+Te+Ti**
  - **- Bohm-gyroBohm & Coppi-Tang models are implemented in WFs**
  - ***- over 20 H&CD codes ported on the Gateway, 11 Kepler actors delivered, their implementation in WFs is in progress***

- **Examples of ETS benchmarking for #71827:**
  - **- steady state equilibrium and current diffusion after 100 s of simulation time obtained with measured plasma profiles (ne, Te, Ti)**
  - **- impurity simulations with ADAS cross-sections: benchmarking of radiative power in ETS & SANCO**



D. Kalupin, et al, General ITM meeting, September 2010



I. Ivanova-Stanik, ITM Code Camp, March 2011

ACT2: simulations of current ramp up on existing devices

- **Multi-machine database for modelling: AUG, JET, Tore Supra. Modelling for DIII-D & CMOD in collaboration with T&C ITPA group is in progress.**

- **Operational space:**
  - dIpl/dt = 0.19 - 0.36 (JET) -> 0.7 (AUG) -> 0.9 (TS) MA/s
  - q95 = 3 – 5 (TS)
  - n/nGW = 0.2 - 0.4
  - P_{aux} = 0.6 (TS) - 10 MW: ICRH, NBI, LHCD, ECCD

- **Tested models:**
  - empirical scaling-based model with prescribed radial shape of $\chi e = \chi i$ used for the whole plasma region
  - semi-empirical models: Bohm-gyroBohm and Coppi-Tang used for the whole plasma region
  - theory-based (GLF23) used for $0 \le \rho \le 0.8$

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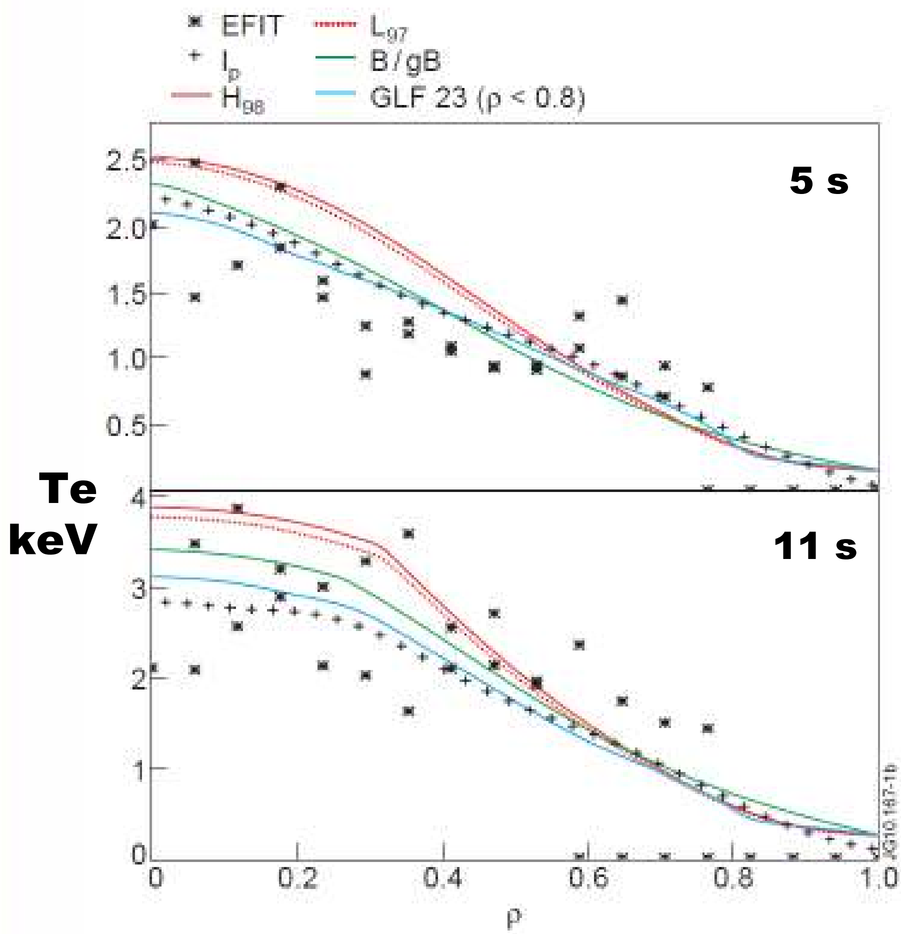
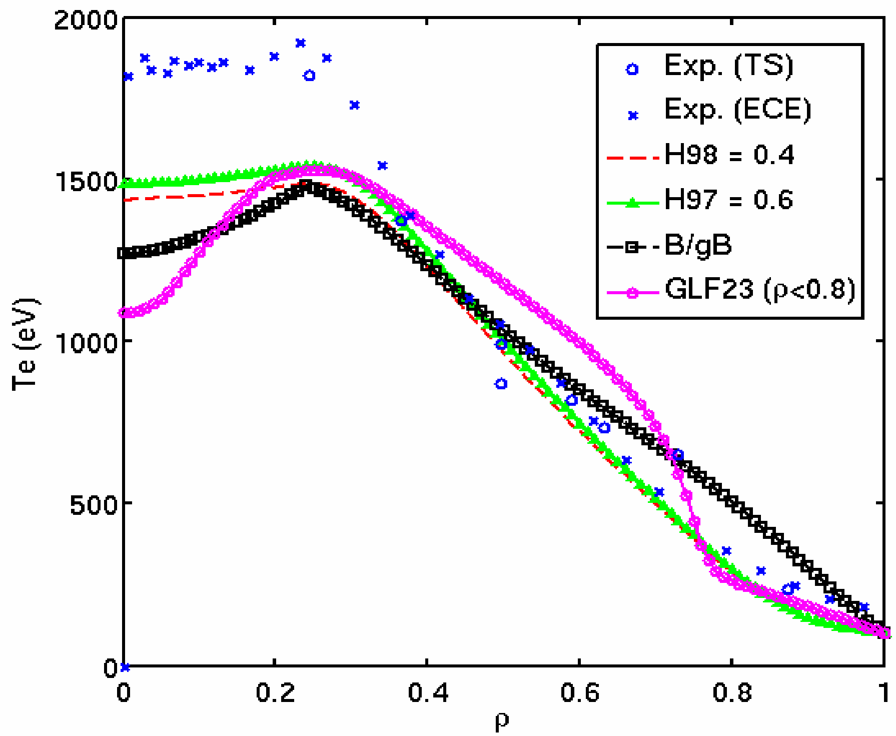
Validation of transport models (I): scaling based, Bohm-gyroBohm, GLF23

JET low density OH pulse 71827: nl=10^{19} m-3, dI_{pl}/dt=0.19 MA/s



G.M.D. Hogeweij et al, EPS 2010

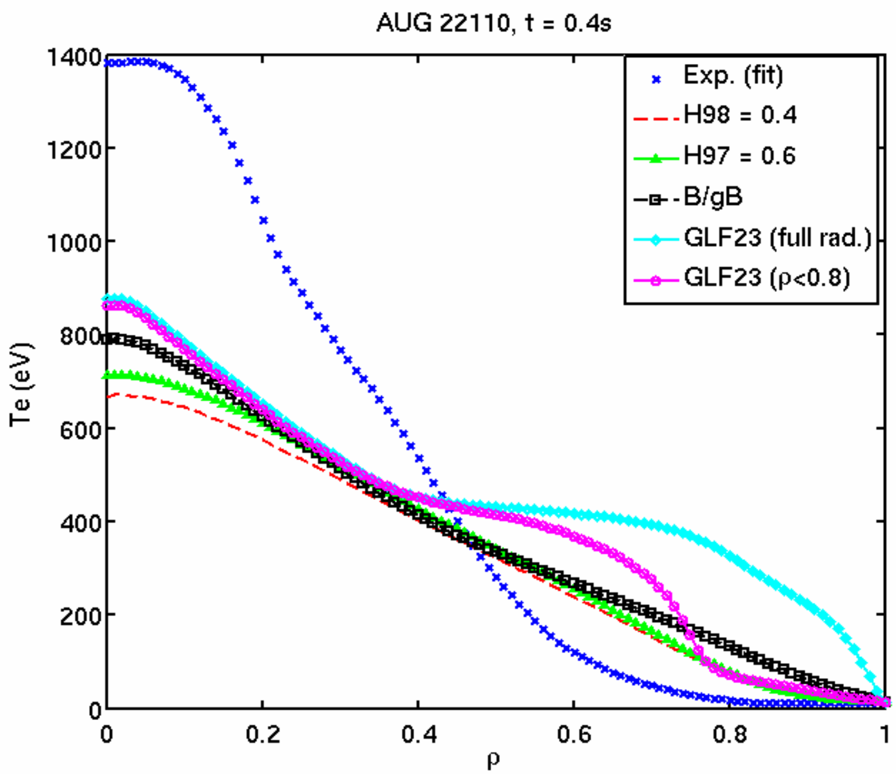
Tore Supra ECCD assisted current ramp-up (co-ECCD applied at ρ = 0.3) from 0.5 s (halfway the Ip ramp up)



F. Imbeaux et al, IAEA 2010, submitted to Nucl. Fusion

Validation of transport models (II): scaling based, Bohm-gyroBohm, Coppi-Tang, GLF23

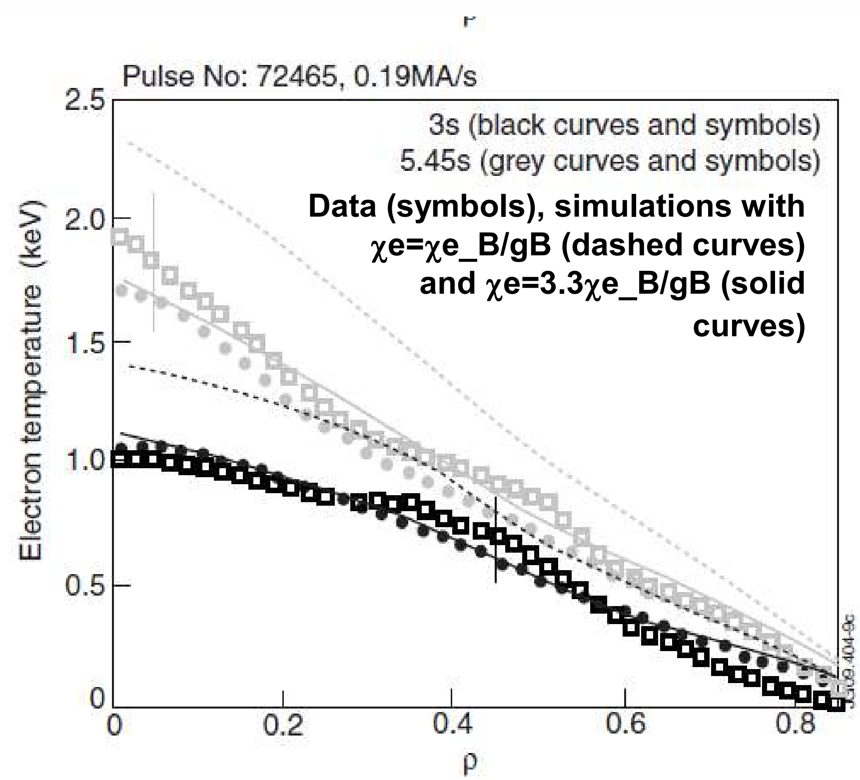
AUG OH shot. The plasma current is ramped up to 0.8 MA in 0.9 s. Edge radiation due to impurities (wall conditionning) -> edge cooling & low Te



F. Imbeaux et al, IAEA 2010, submitted to Nucl. Fusion

JET OH shot: nl=1.4*10^{19} m-3, dI_{pl}/dt=0.19 MA/s. Original Bohm-gyroBohm model over-predicts Te, accurate prediction with $\chi e=3.3\chi e$_Bohm-gyroBohm.

Why this result is different with 71827?



I. Voitsekhovitch et al, PPCF 2010

Different plasma conditions in #71827 as compared to analysed database of JET OH current ramp up discharges

Parameters of simulated discharges

Shot	dI_{pl}/dt MA s^{-1}	$n_l/10^{19}$ m^{-3}	n_l/n_{GW}	Z_{eff}	T_{e0} keV
72460	0.36	1.0	0.12	2	2.5
72464	0.36	1.45	0.2	2.2	2.2
72465	0.19	1.42	0.21	2.2	2.1
72467	0.28	1.44	0.2	2.11	2.1
72504	0.28	2.0	0.24	2.06	1.8
72723	0.28	2.63	0.33	1.8	1.6
71827	**0.19**	**1.05**	**0.13**	**2**	**2.9**

- **#71827: low current ramp rate, but also low ne, high Te and later sawteeth (after 9 s) -> slow current diffusion;**
- **current profile evolution is closer to low density #72460 (slow current penetration and later sawteeth- after 6 s)**

Bohm-gyroBohm predictive accuracy obtained under different assumptions

Shot #	rms/offset, % (peaked Z_{eff}, flat P_{rad})	rms/offset, % (peaked Z_{eff}, peaked P_{rad})	rms/offset, % (flat Z_{eff}, peaked P_{rad})	rms/offset, % (peaked Z_{eff}, flat P_{rad}, $C_{e,BgB} = 3.3$)
72460	21.6/−20.9	17.1/−16.1	19.4/−18.8	9.27/7.42
72464	32.3/−31.2	27.3/−26.3	29.7/−28.2	7.23/−1.73
72467	31.2/−31	27.7/−26.7	30/−28.2	5.03/1.2
	34.5/−33.5*	30.6/−29.5*	35.1/−33*	5.64/−0.5*
72504	40.3/−39	36/−34.9	34.2/−32.6	8.73/−5.75
	42.5/−41*	38.4/37.2*	39.7/−37.5*	10.7/−7.8*
72723	26.4/−25.3	24/−23	24/−22.2	4.86/1.07
	30.5/−28.6*	27.8/−26*	29.3/−26.7*	7.23/−2.47*
72465	40.2/−39	36.3/−34.8	38.4/−36.2	7.1/−2.8
	46/−44.9	42.3/−41.6*	45.3/−43.7	11.4/−8.5*

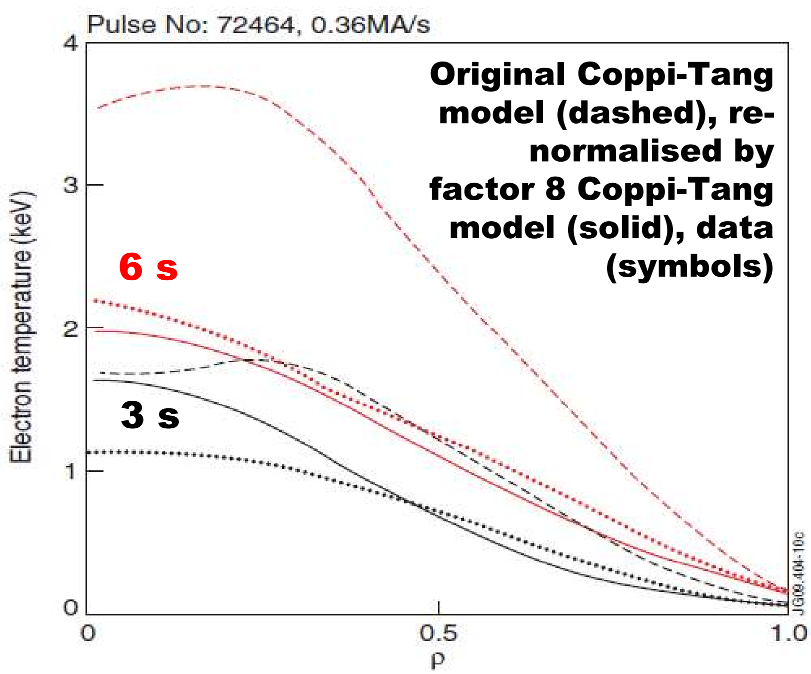
Bohm-gyroBohm model prediction:

- **relatively accurate at high Te/slow current diffusion: #72460 (rms < 22%), #71827**
- **low predictive accuracy at higher ne, lower Te and faster current diffusion**

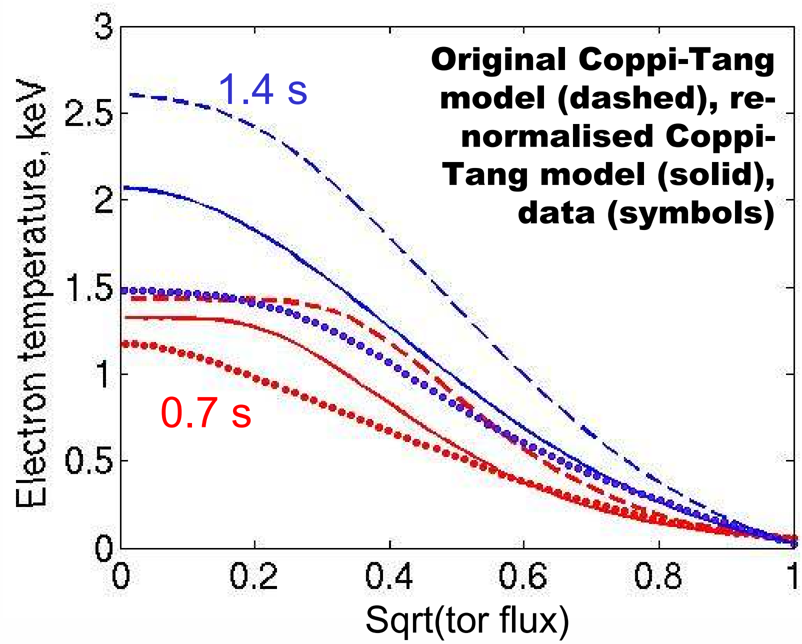
ISM – T&C ITPA collaboration: benchmarking of Coppi-Tang model in ASTRA & CORSICA for DIII-D discharge

JET OH discharge – strong Te overestimation with Coppi-Tang model [Voitsekhovitch et al PPCF 2010]

Tom Casper, Irina Voitsekhovitch
ISM WS Nov 29 - Dec. 3 2010, Culham



DIII-D OH current ramp up discharge (136779)



- over-estimated Te with original Coppi-Tang model (as published in Jardin et al, Nucl.Fusion 1993)

- different implementation of Coppi-Tang model in ASTRA and CORSICA: original model in ASTRA, additional multiplier 2.5 is used in CORSICA for OH and L-mode plasmas

- better agreement with data has been obtained in ASTRA simulations after introducing this multiplier, but still there is an important deviation from measured Te

Validation of transport models - summary

- ***Empirical scaling-based model:*** *the optimal agreement between experiment and simulations is obtained using either H96-L = 0.6 or HIPB98 = 0.4.*

- ***Bohm-gyroBohm model:***
  - *OH discharges:*
    - *- good predictive capability for JET discharges with slow inward current diffusion*
    - *- over-predicted Te in JET discharges with fast current diffusion/low q.*
    - *- under-predicted Te for AUG discharge (large edge radiation)*
  - *auxiliary heating: relatively accurate prediction (except off-axis JET ICRH discharge)*

- **GLF23 model applied at $\rho \leq$ 0.8-0.85:** **close to the Bohm-gyroBohm model prediction for a number of cases. Not applicable near the edge. L*ess accurate at high NBI power.***

- **Coppi-Tang model:** **accurate prediction for DIII-D, but needs to be re-normalised for matching the JET discharges at least within 31% of rms deviation:**
  - **- increase by factor 8 is needed for OH plasmas**
  - **- increase by factor (4.7-4.9) is needed for NBI and ICRH heated discharges**
  - **- better agreement with data when factor 2.5 has been introduced, but still a larger multiplier is needed for JET discharges**

Current diffusion: is it consistent with neoclassical predictions?

- **I. Jenkins et al, EPS 2010: early MSE measurements (@~1s) after the breakdown at JET AT scenario: too fast reduction of q0**

- **G.M.D. Hogeweij et al, EPS 2010, I. Voitsekhovitch et al PPCF 2010 – too rapid reduction of q0 in JET ITER-like discharges with flat Zeff (Zeff≥2), but possible to match q0 by playing with Zeff profile**

- **Accurate NCLASS prediction of q profile evolution for 3 DIII-D discharges (Zef ≤ 1.5)**

I. Jenkins et al EPS 2010

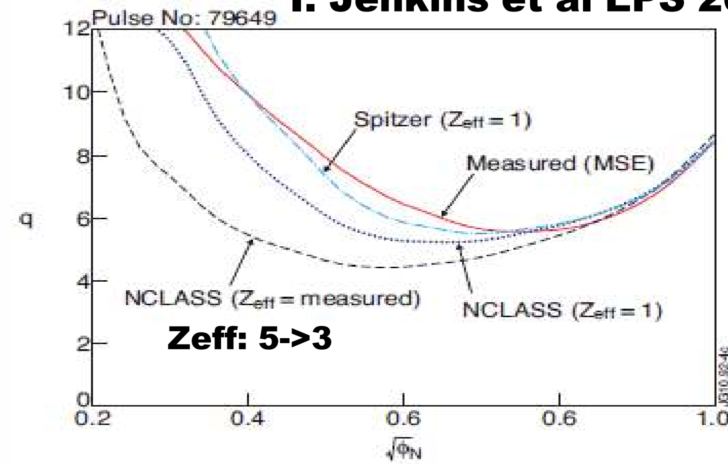
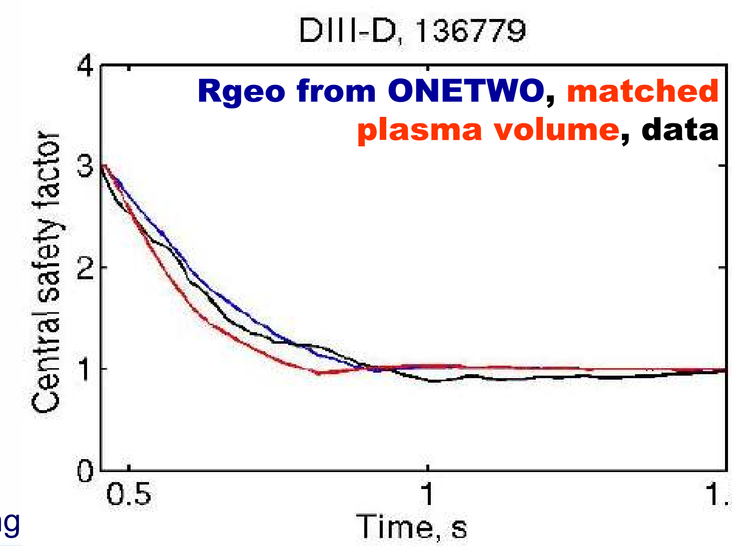


Figure 4: Comparison of measured and simulated q-profiles at t_{init}+1.4s for Pulse No: 79649 after 0.3s of modelled current diffusion. Z_{eff} is assumed to be flat across the plasma.

I. Voitsekhovitch, ASTRA simulations of current diffusion for DIII-D discharge

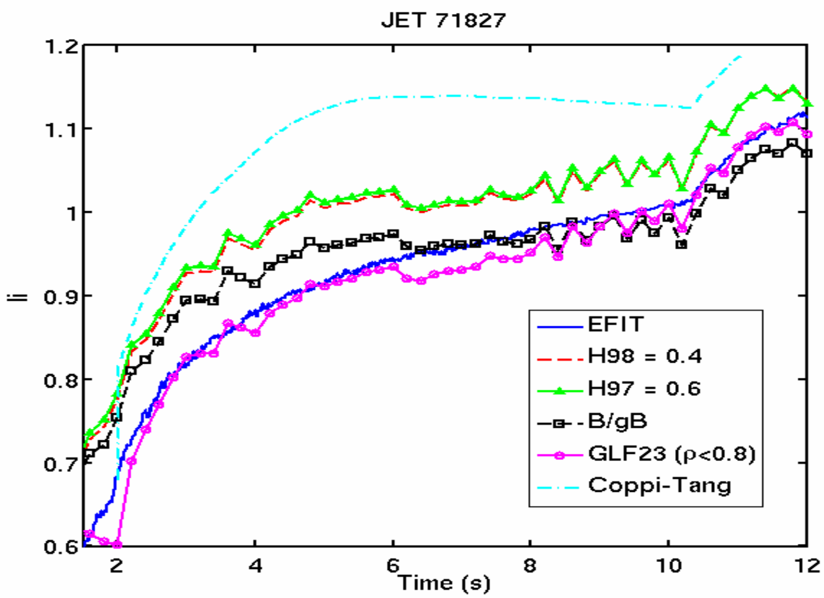


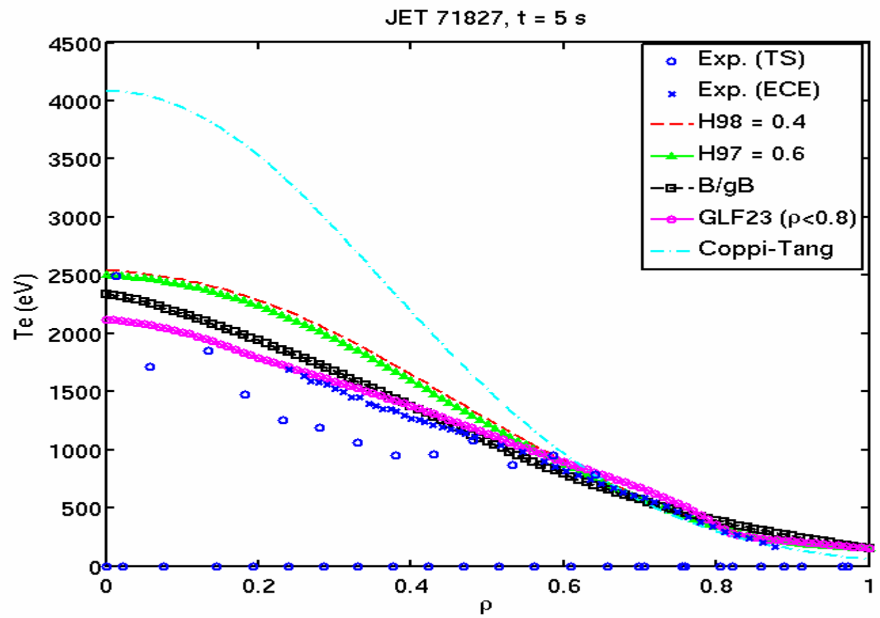
li simulations: sensitivity to Te profile

li simulations with different transport models:

- **empirical transport models (Bohm-gyroBohm and scaling based models): the *li* dynamics is predicted within +/- 0.15 accuracy**
- **Coppi-Tang or GLF23 models (applied up to the LCFS): overestimate or underestimate the internal inductance beyond this accuracy (more than +/- 0.2 discrepancy in some cases)**

JET OH shot 71827: plasma current is ramped up to 2.5 MA in 10 s

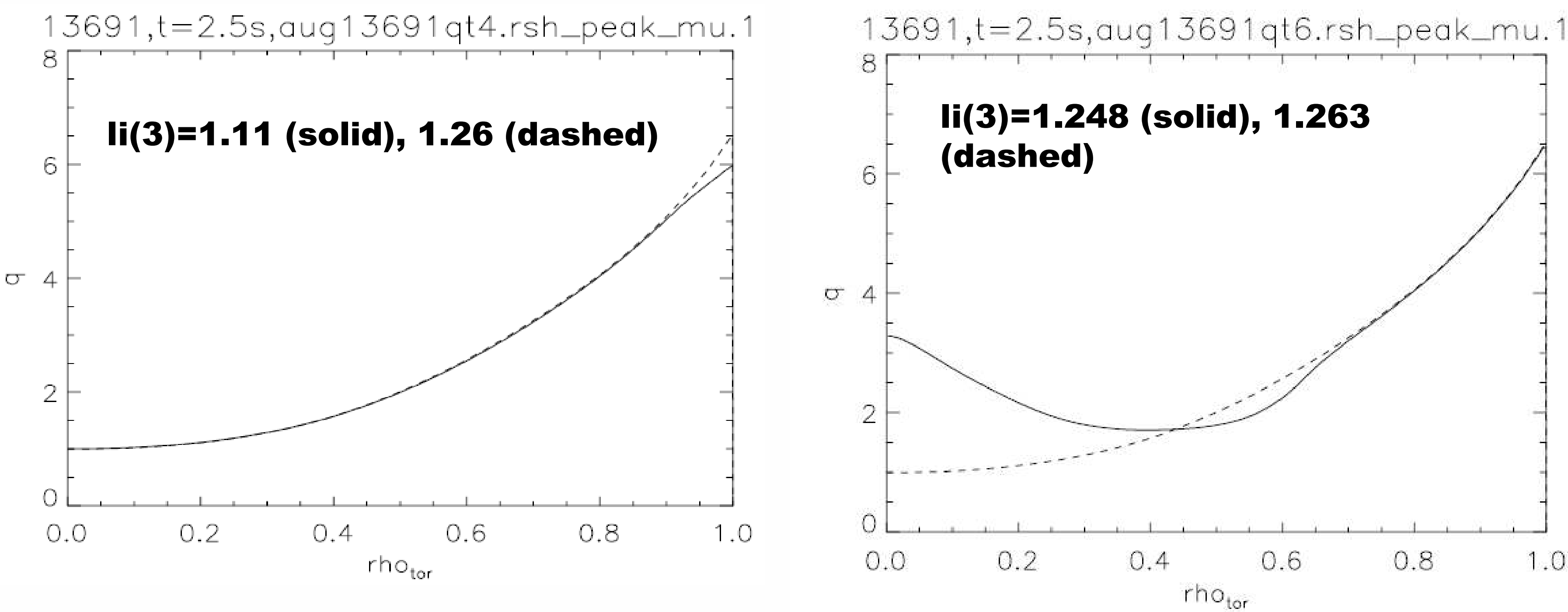




F. Imbeaux et al, IAEA 2010, submitted to Nucl. Fusion

li simulations: sensitivity to q at the edge

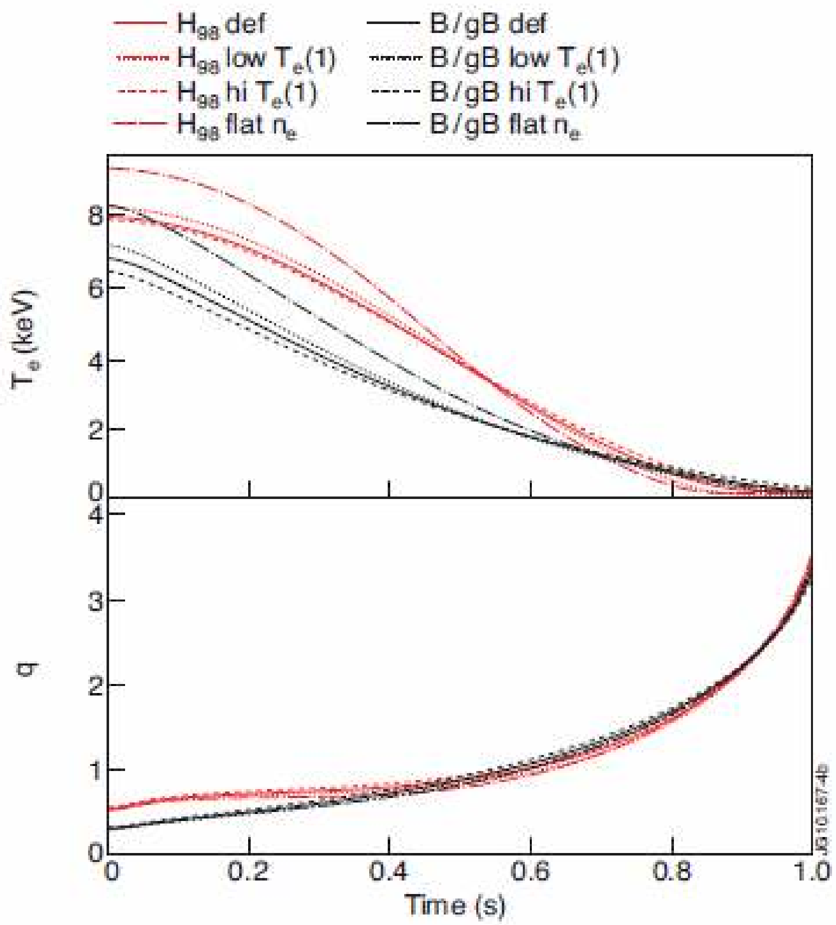
- Circular plasmas with prescribed q and pressure profiles, li is simulated
- li is strongly sensitive to q outside $\rho \geq 0.95$, while even significant changes in the central part of q-profile are not necessarily visible in li



J. Hobirk, private communication, ISM WS November 29-December 3 2010

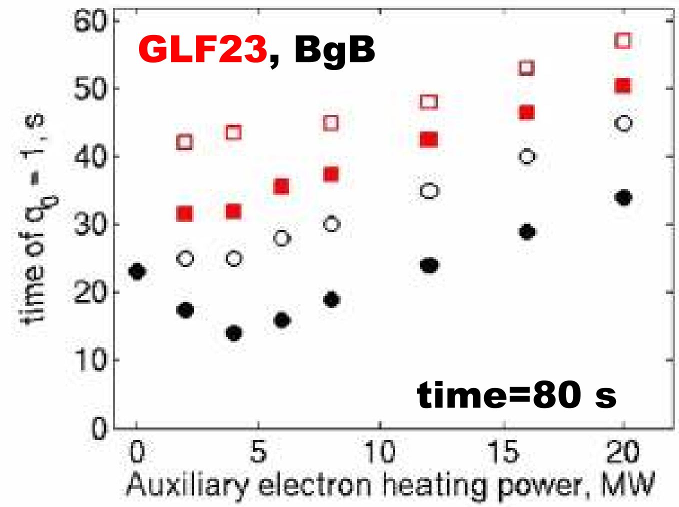
ACT3: projections to ITER, sensitivity to transport models, sawtooth oscillations and plasma density

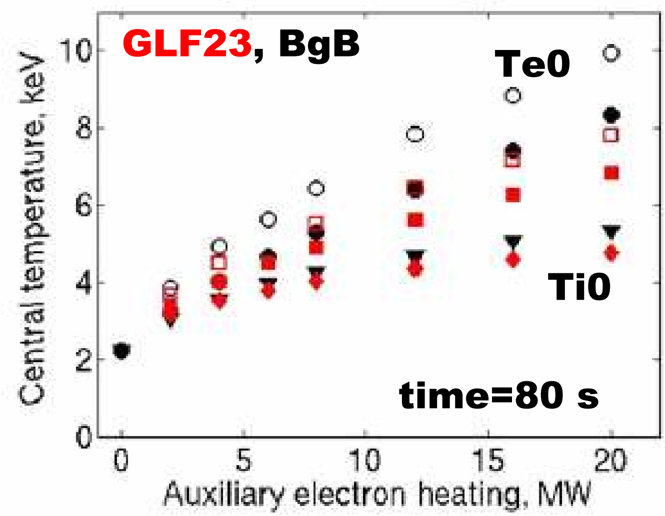
OH current ramp-up with ne/nGW=0.25: profiles at 100 s (end of Ip ramp-up), as calculated by 2 transport models, under different assumptions on Te(edge) and ne profile shape. No sawtooth mixing.



G.M.D. Hogeweij et al, EPS 2010

ECRH assisted current ramp up: scan in ECRH power and power deposition at ne/nGW=0.5. Sawtooth mixing maintains q0 close to 1.





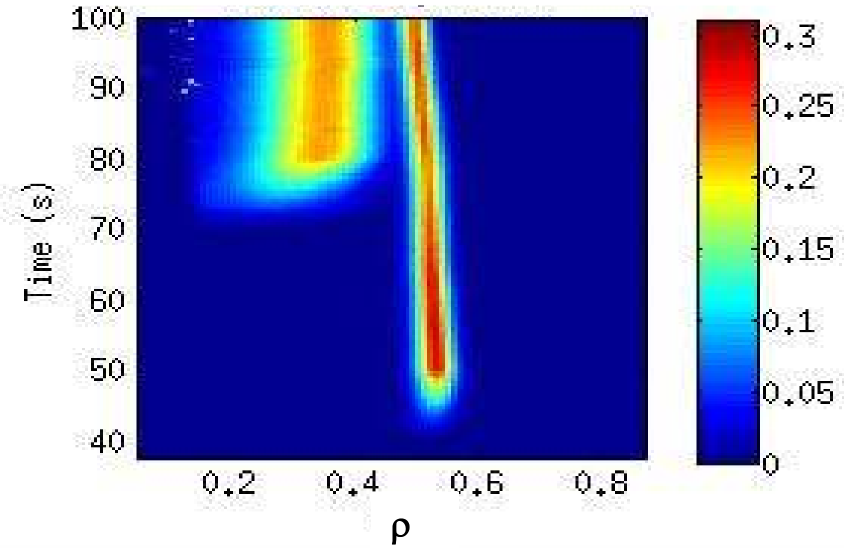
I. Voitsekhovitch et al, PPCF 2010

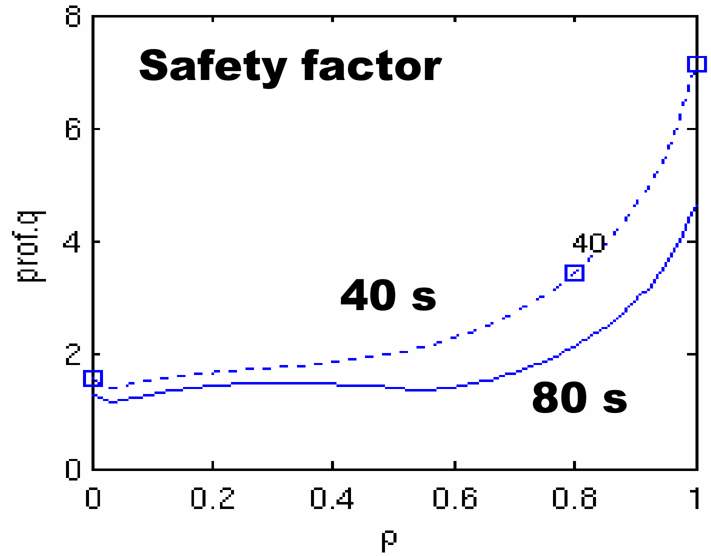
Work in progress:

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

- **Modelling of current ramp up for JET HS**
- **Optimisation of current ramp up for ITER HS (G.M.D. Hogeweij et al, EPS 2011): 12 MA, off-axis LHCD or ECCD**
- **Current ramp up simulations for DIII-D and comparison with JET – in preparation for IOS ITPA group meeting, April 11-14 2011**

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





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Publications and presentations used in this talk:

1. G.M.D. Hogeweij et al, EPS 2007
2. V. Parail et al, Nucl. Fusion 49 075030 2009
3. G.M.D. Hogeweij, J. Citrin, J. Garcia et al, EPS 2010
4. F. Imbeaux et al, 23rd IAEA Fusion Energy Conference (ITR/P1-20), Daejon, Republic of Korea, October 10-16th 2010, submitted to Nuclear Fusion
5. I. Voitsekhovitch et al, PPCF 52 105011 2010
6. I. Jenkins et al, EPS 2010
7. G.M.D. Hogeweij et al, ISM working session, March 7-11 2011, Cadarache, to be presented at EPS 2011
8. T. Casper, I. Voitsekhovitch, ISM working session, November 29 - December 3 2010, Culham