EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT
Task Force
INTEGRATED TOKAMAK MODELLING

T&C ITPA meeting, 5-7 October 2011

Update on current ramp up modelling

*I Voitsekhovitch, G.M.D. Hogeweij, T. Casper (IO), M. Beurskens, T. Gerbaud, C. Giroud, J. Hobirk, E. Joffrin, X. Litaudon and ITM/ISM contributors**

Acknowledgement:
for the DIII-D data in the ITPA database: R. Prater, D. Mikkelsen, JM Park, C. Petty and the JET data contributors

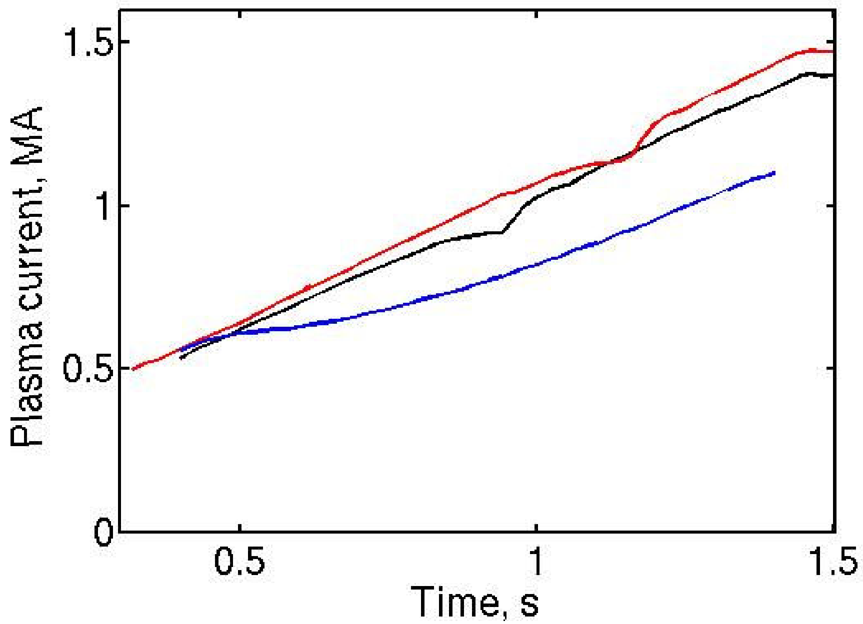
**See talk of X. Litaudon, ITM General Meeting, IPP-Garching September 12-16 2011*

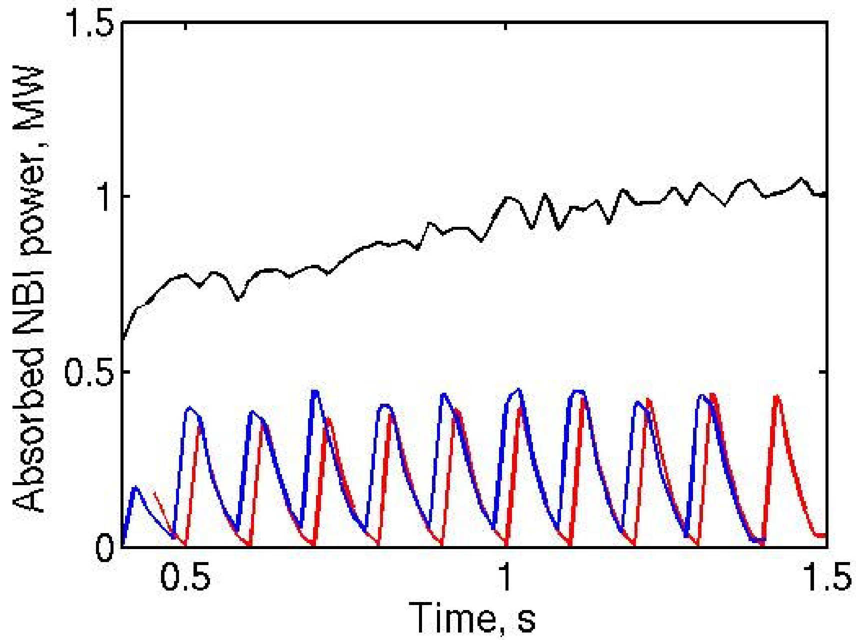
Outline

- ***DIII-D 136303 (ISM - T&C ITPA collaboration):***
  - benchmarking of Bohm-gyroBohm model in ASTRA and CRONOS
  - modelling with Coppi-Tang (ASTRA) and empirical scaling based (CRONOS) transport models
- ***Current ramp up in JET hybrid scenarios***
- ***Update on T&C ITPA modelling activity in 2012 (added for this ISM meeting)***

DIII-D current ramp up discharge submitted to the ITPA database

132411 (B_t=2.1 T, κ=1.86, δ=0.5), 136303 (B_t=1.86 T, κ=1.8, δ=0.5), 136779 (B_t=1.85 T, κ=1.75, δ=0.48)

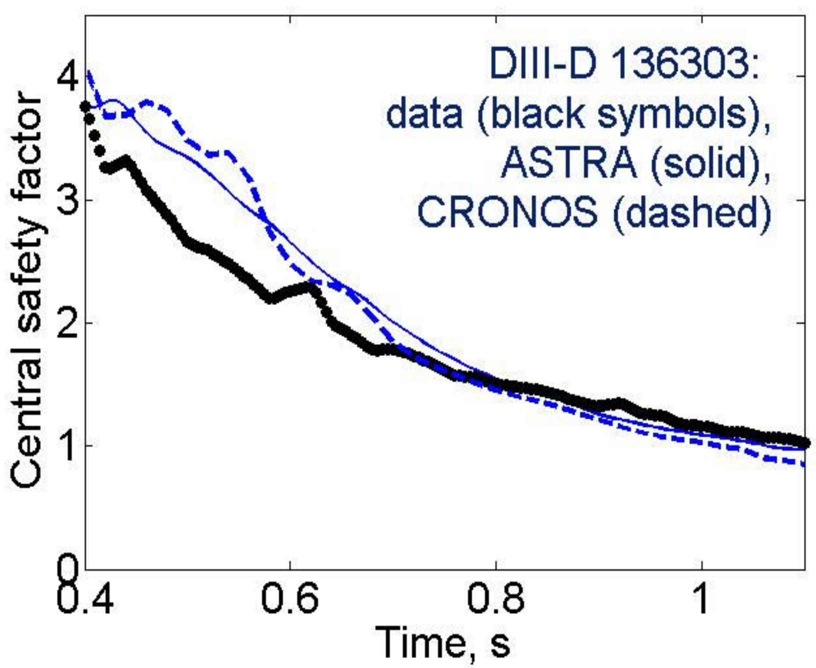


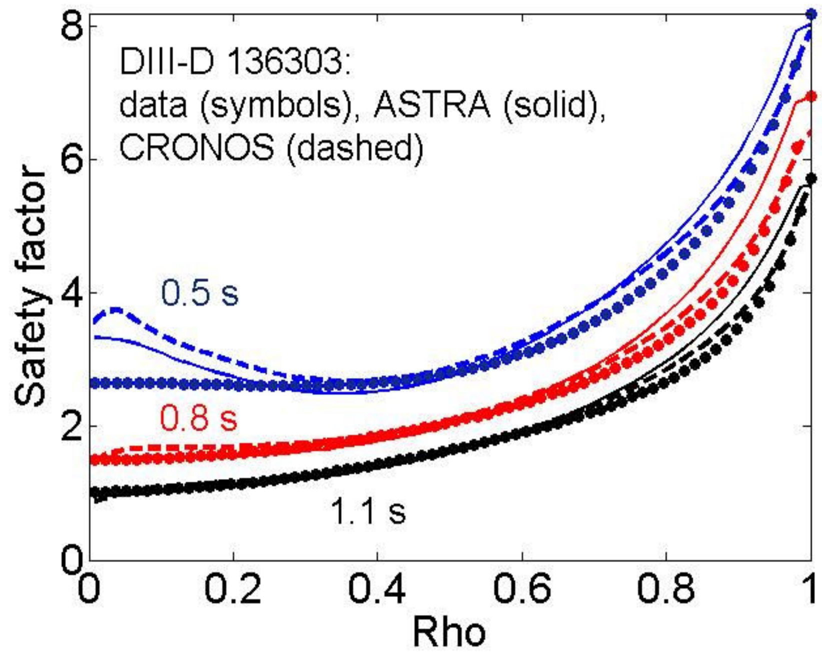


- discharge with continuous NBI heating is selected here for benchmarking

- the whole current ramp up phase is simulated

Current diffusion simulations with measured electron temperature





- ***NCLASS model for current conductivity and bootstrap current***

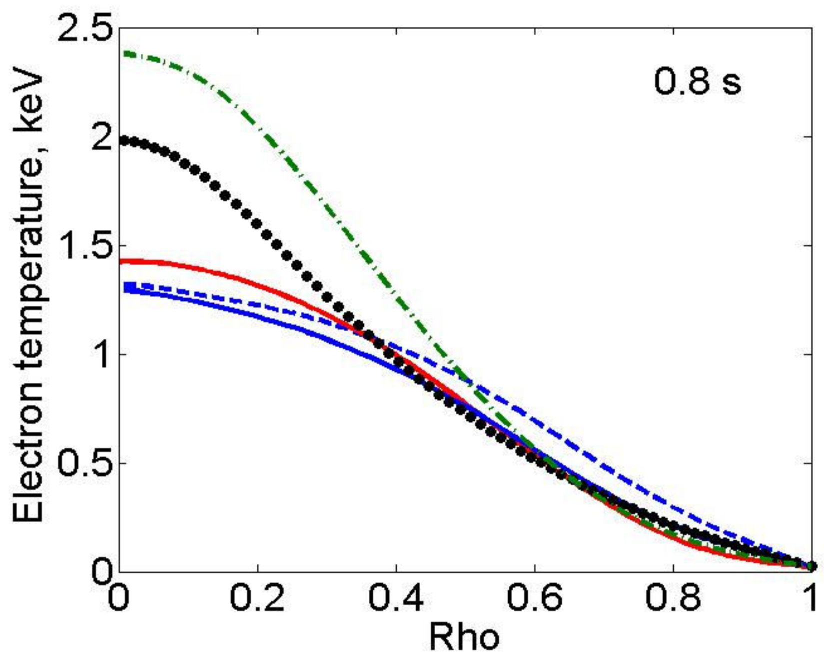
- ***ASTRA: 3 moment equilibrium, CRONOS: HELENA equilibrium module***

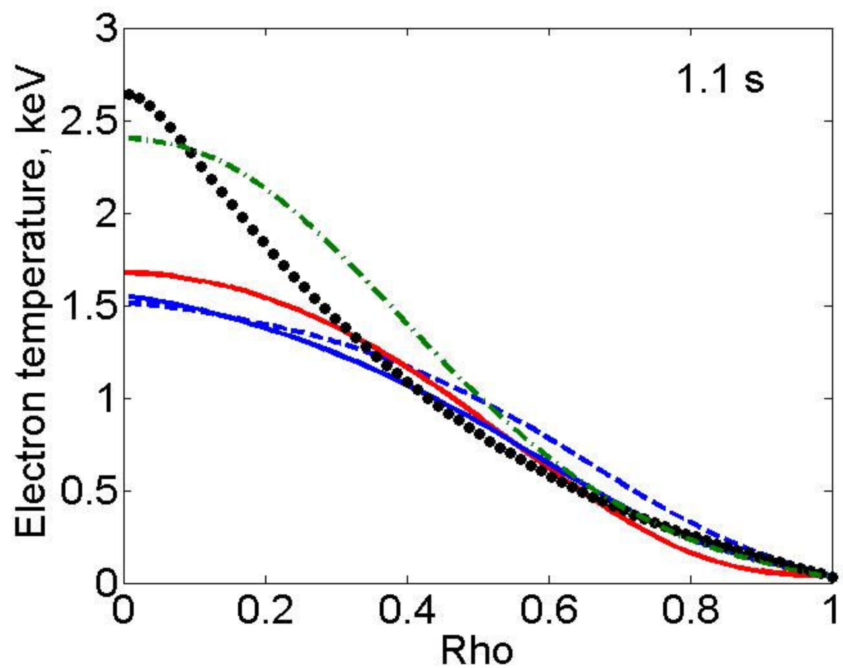
- ***ASTRA and CRONOS simulations show that current diffusion is reasonably predicted with NCLASS.***

- ***Craig Petty checked the MSE data for 136303 after this talk. According to the the MSE data the q-profile should be reversed around 0.4 - 0.5 s and close to CRONOS and ASTRA q-profile***

Current diffusion, electron and ion energy equations with empirical transport models (DIII-D 136303): Te

L-mode Bohm-gyroBohm model (ASTRA: solid, CRONOS: dashed), scaling-based model with H98y=0.5 (CRONOS, red), Coppi-Tang model re-normalised as in CORSICA (ASTRA, green), data (black). Simulation boundary is taken at ρ=1



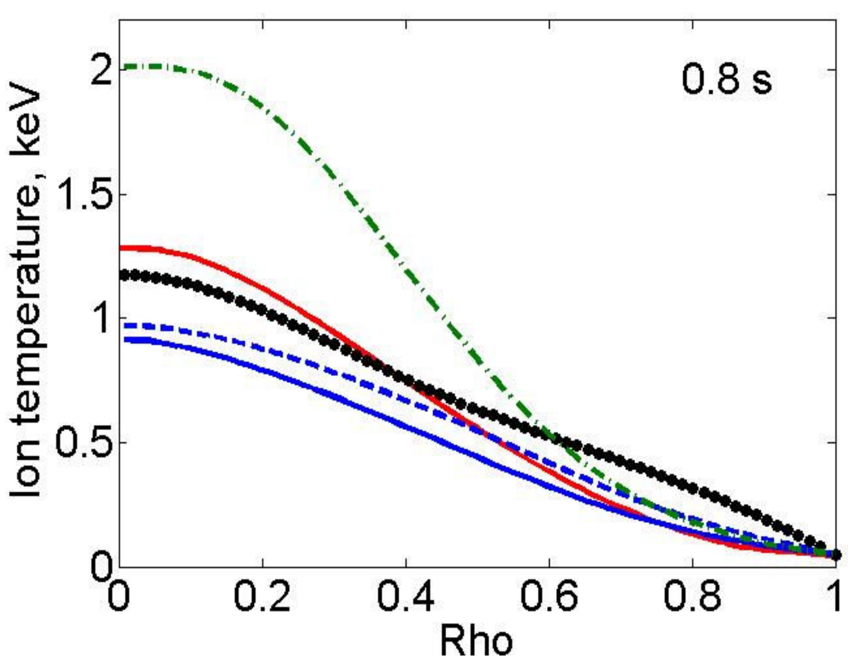


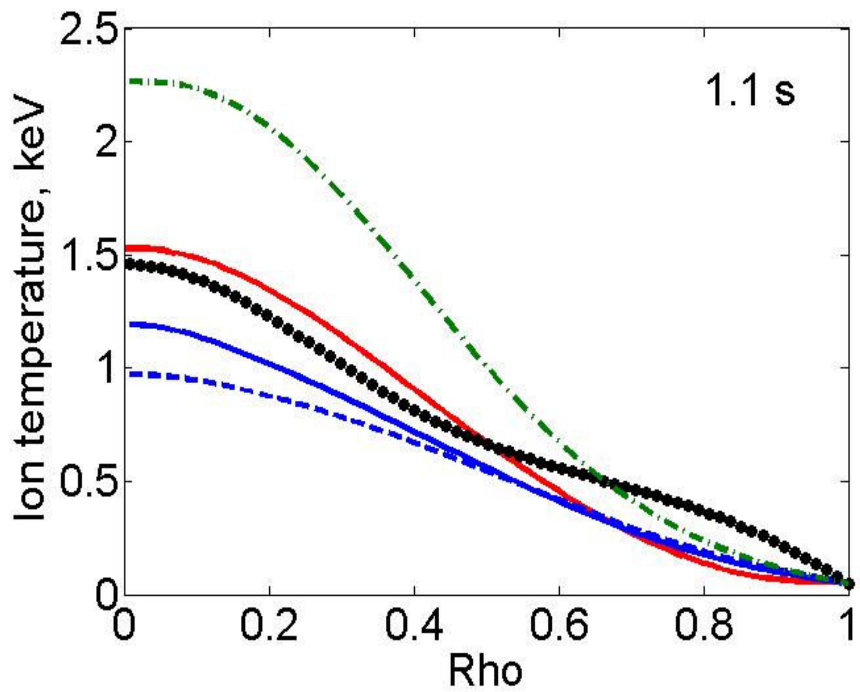
- systematic underestimation of core temperature with Bohm-gyroBohm and scaling-based model

- edge temperature is reasonably predicted with Bohm-gyroBohm and Coppi-Tang model

Current diffusion, electron and ion energy equations with empirical transport models (DIII-D 136303): Ti

L-mode Bohm-gyroBohm model (ASTRA: solid, CRONOS: dashed), scaling-based model with H98y=0.5 (CRONOS, red), Coppi-Tang model re-normalised as in CORSICA (ASTRA, green), data (black). Simulation boundary taken at ρ=1

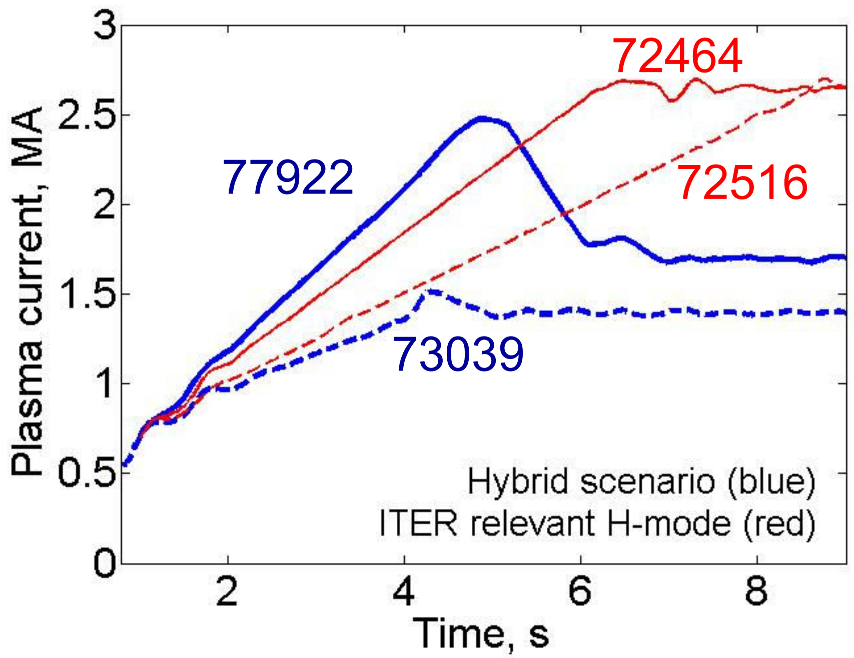


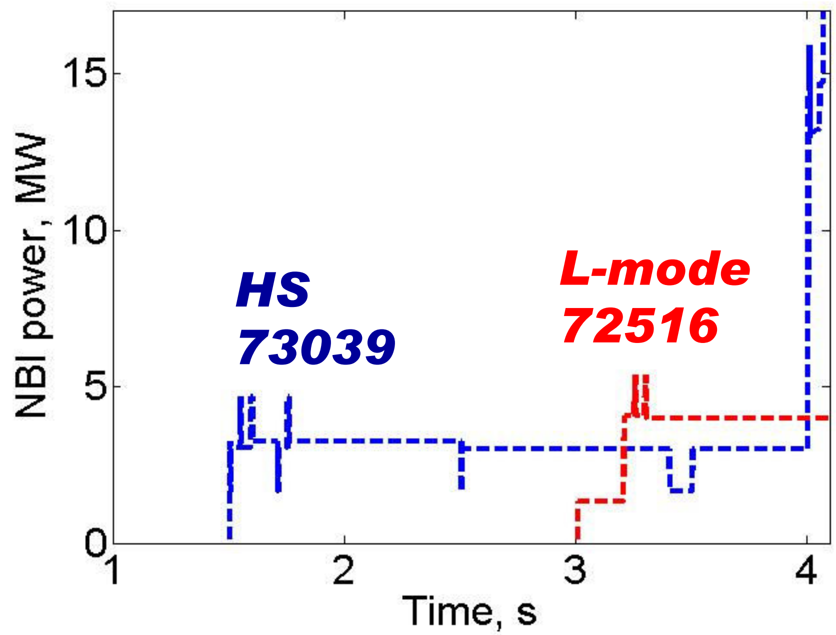


- ***underestimated Ti with the Bohm-gyroBohm model, overestimated core Ti with Coppi-Tang model***

- ***scaling-based model predicts too peaked profiles***

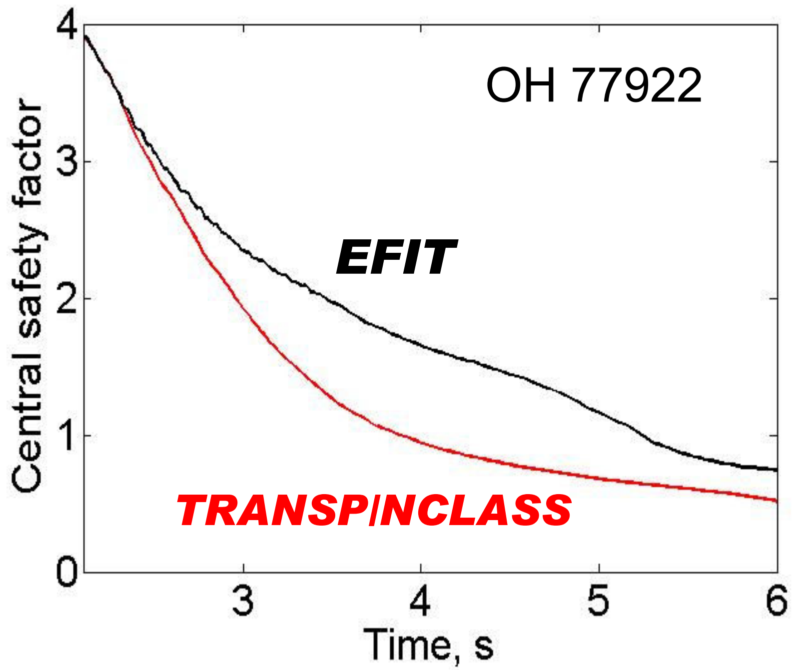
Current ramp up in JET HS

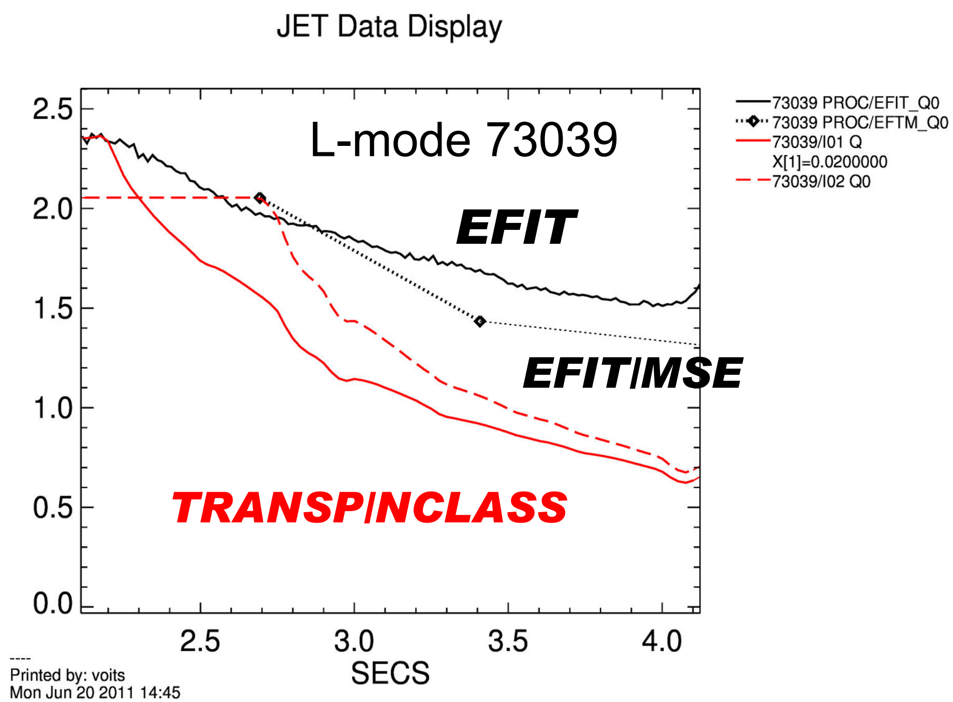




- *selected hybrid discharges: OH (77922), L-mode (73039)*
- *no sawteeth during current ramp up in HS*
- *no MHD in L-mode, short and weak n=1 (4.6-4.8 s) during ohmic ramp up*
- *measurements in HS: MSE for L-mode, HRTS and ECE for Te, HRTS for ne. KS3/ZEFV when CX data are not available*

Current ramp up simulated with measured Te and flat Zeff profile consistent with measured <Zeff>



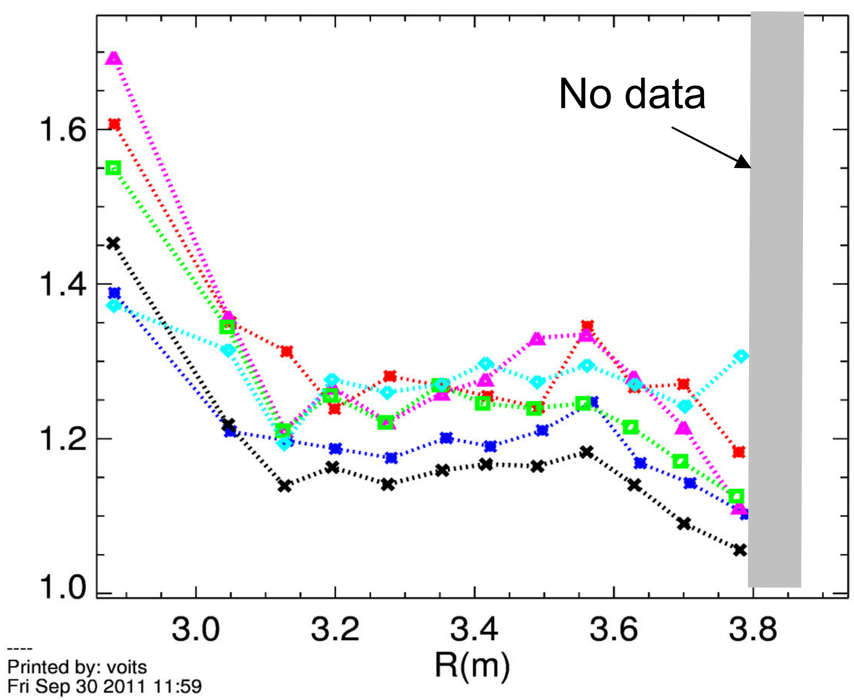


- *initial q-profile is taken at 2.3 s (EFIT, 77922 and 73039) or 2.7 s (EFIT/MSE 73039)*

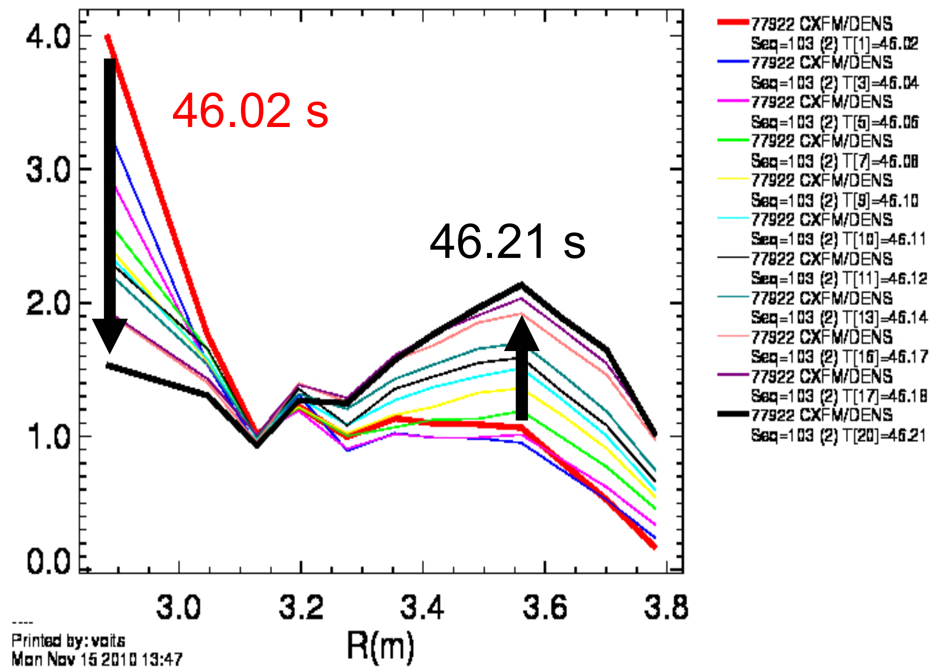
- *rapid reduction of simulated q0 is inconsistent with the absence of sawteeth (77922, 73039) and reconstructed (EFIT/MSE) q-profile (73039)*

Zeff profile in OH plasmas?

Initial Zeff(r) for 6 hybrid discharges measured close to the end of current ramp up phase or the end of Ipl overshoot



Measured (CX) nC6+, 10^{17} m^{-3}

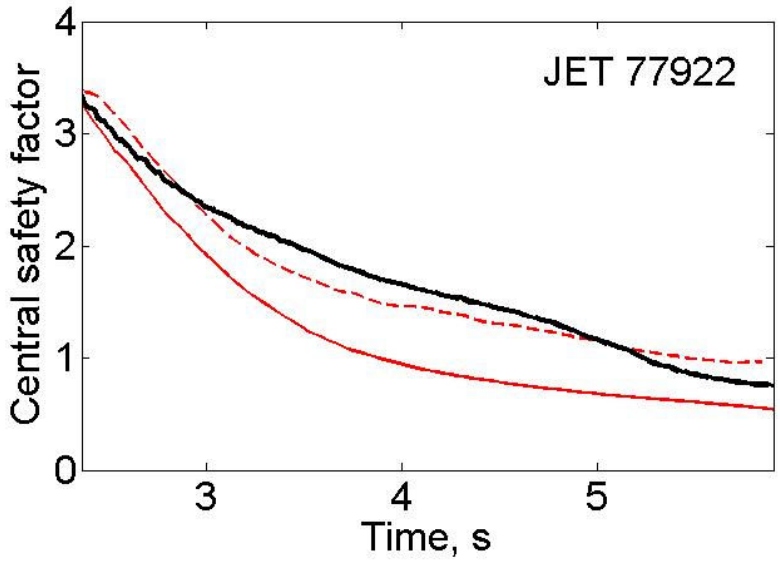


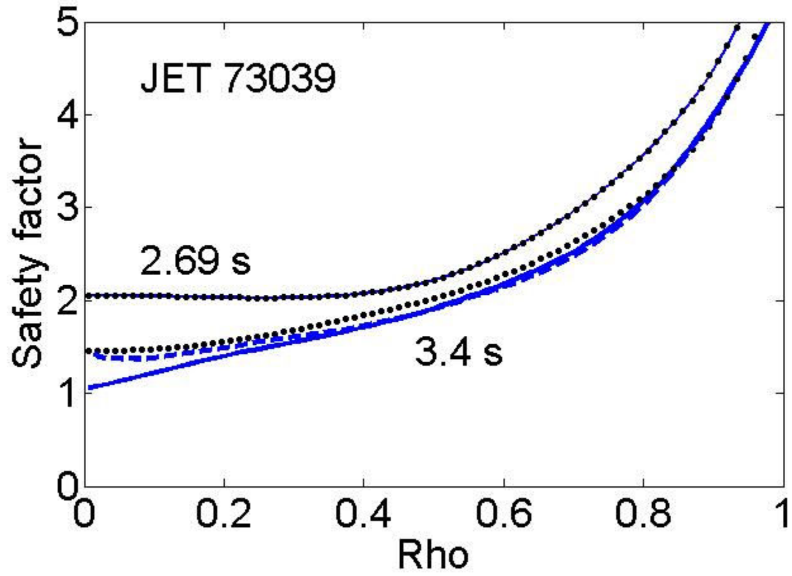
- measurements taken at 10 ms after the NBI start

- the outer part of plasma (R > 3.78 m) is not covered by the CX measurements

Evolution of C6+ impurity at the beginning of NBI heating in #77922

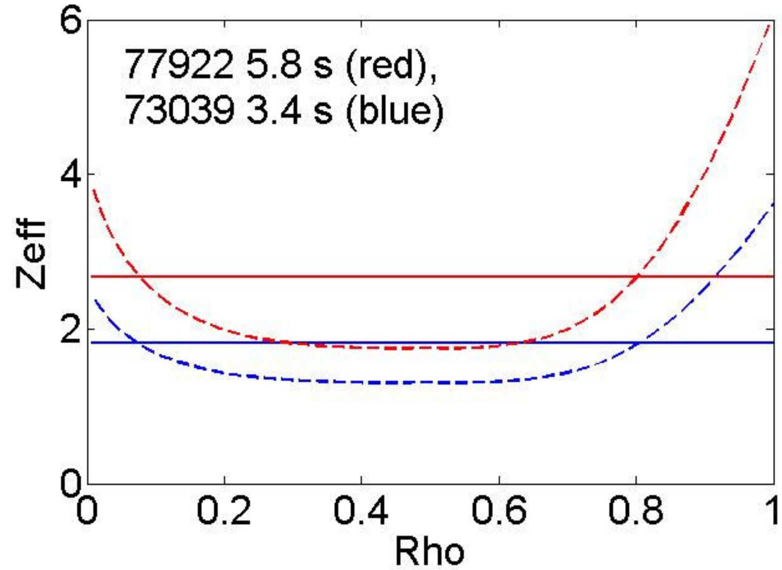
Effect of slightly peaked Zeff profile on current diffusion





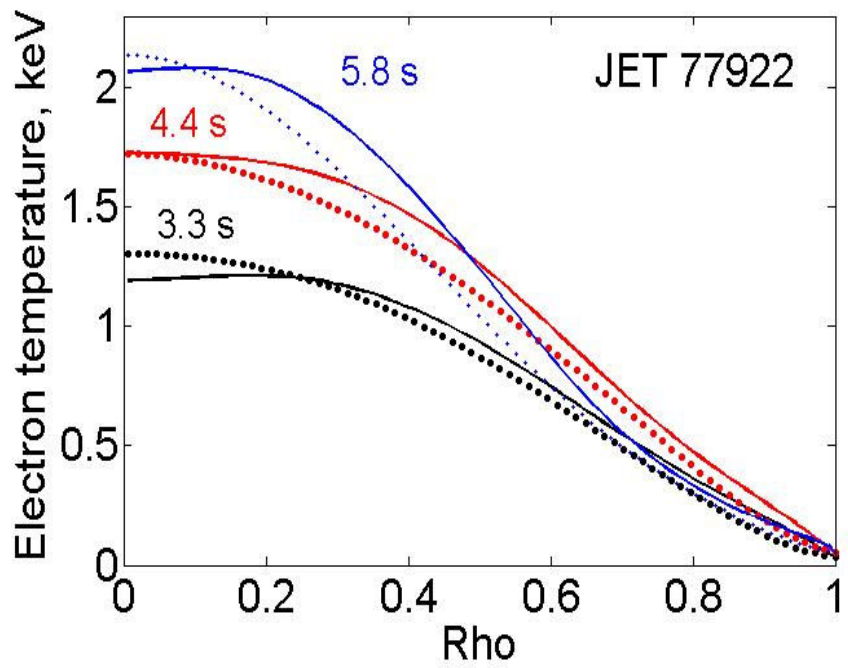
- *Zeff(r) is adjusted to provide q0 > 0.9 in OH discharge and q-profile matching MSE q in L-mode;*

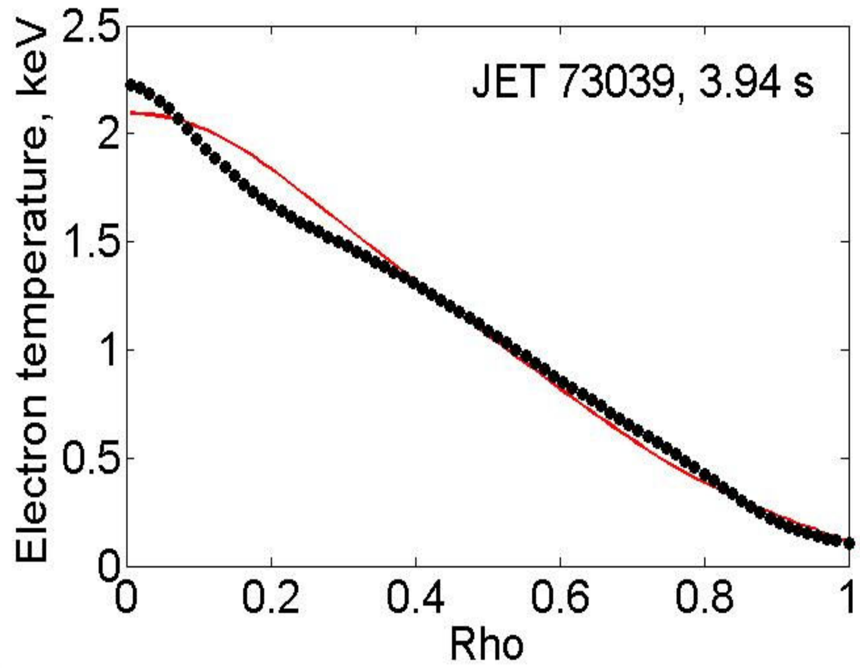
- *adjustment constrains: measured line averaged Zeff and initial Zeff shape*



Modelling of electron temperature with Bohm-gyroBohm model

ASTRA simulations (solid curves), measurements (symbols)

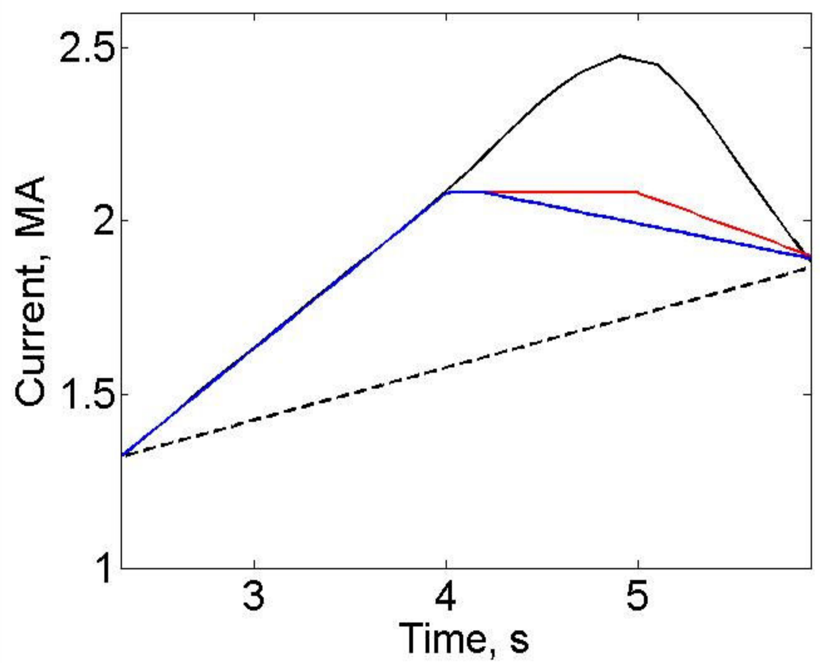


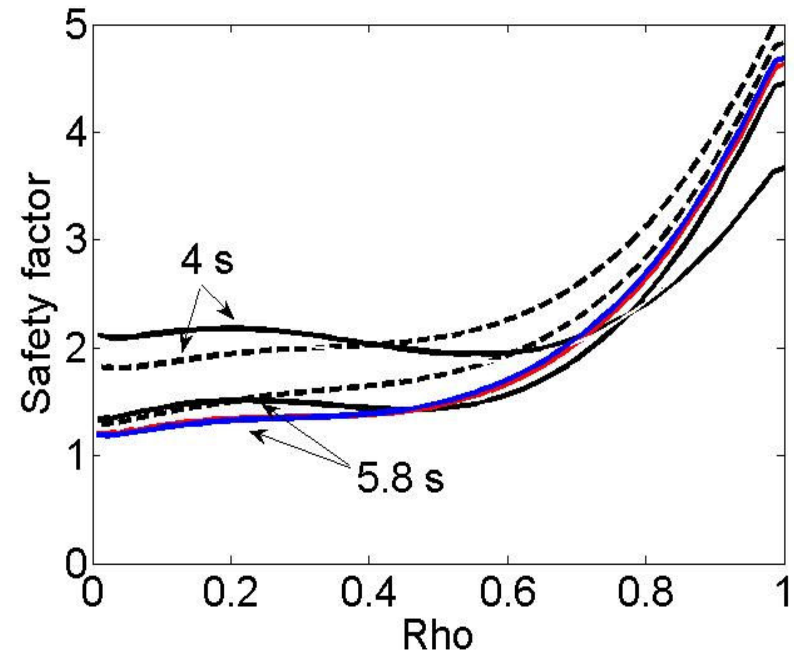


- simulated j, Te and Ti. Boundary condition at ρ =1

- slightly broader simulated profiles in OH plasma, good agreement with measurements for L-mode discharge

Optimisation of current overshoot scenarios





- ***Predictive simulations for 77922 based on validated models: NCLASS, adjusted Zeff, Bohm-gyroBohm transport model. Other parameters (ne, line averaged Zeff, …) taken from 77922***
- ***Plasma current waveform has been varied***
- ***Fast current ramp up -> flat q-profile, but at high central q values (4 s), subsequent delay results in the reduction of flat core q profile***
- ***The target q-profiles obtained with strong and weak overshoot are not very different***

Summary

- ***ISM – T&C ITPA activity - benchmarking for DIII-D discharge 136303:***

  - Bohm-gyroBohm model in ASTRA and CRONOS: good agreement for the core Te between two codes, some difference around mid-radius

  - simulations with H98y=0.5 (CRONOS) and Coppi-Tang (ASTRA) models are available for comparison with other codes

- ***Current ramp up in JET HS: consistently with previous modelling of JET ITER relevant H-mode discharges***

  - current diffusion is well predicted with NCLASS within the uncertainty on Zeff measurements

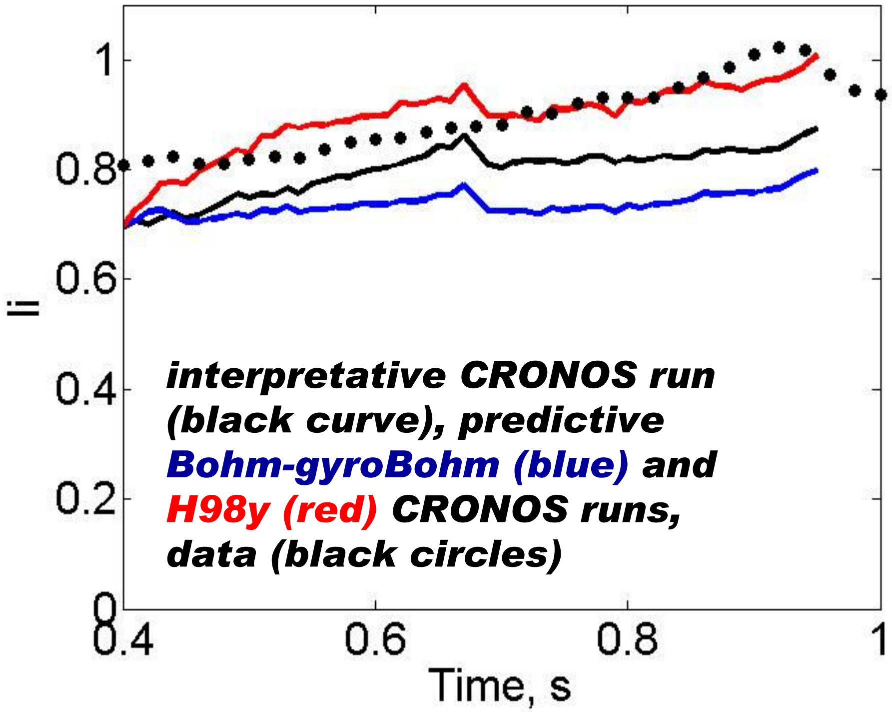
  - Bohm-gyroBohm model predicts well the electron temperature evolution in OH plasmas at high current ramp rate (*factor 3.3 in the BgB models comes from the averaging over the shots with fast and slow Ipl ramp rates****) and in NBI heated plasmas***

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

This slide with Dick's question has been prepared for discussion

li evolution simulated by CRONOS is inconsistent with li in provided data while the q-profile is well reproduced. Which li has been provided?



- in CRONOS li definition as in Sips et al NF 2009 has been used:

$$l_i(3) = 2\int B_p^2 dV / (\mu_0^2 I_p^2 R_0)$$

R_0 is the major radius

- li provided via ITPA DB (http://tokamak-profiledb.ccfe.ac.uk/DOCS/pr08_variables.htm):

li=2 &int Bp2dV / (&mu02 Ip2 Rgeo)

- li3 is appropriate for quantifying internal magnetic energy while the 'usual' li ($[\psi_{bndry}$ - $\psi(0)]$/Ipl?) is appropriate for quantifying the internal poloidal flux;

- on-going discussion: ITER cares about both flux consumption and energy/power issues -> use of both li in the ITPA DB in future?

T&C ITPA modelling work in 2012-2013 (I)

- **Edge transport (C. Bourdelle):**
  - QualiKiz can not predict OH and L-mode profiles (including the Ipl ramp up) outside ρ>0.8 -> search for edge transport
  - RBM as a candidate
  - Actions:
    - investigate/exclude (if possible) the radiative losses as a reason for discrepancy at the edge
    - collect the multi-machine database and characterise the condition where ITG-TEM based models fail (high q and collisionality, ...)
    - find a patch for the edge (DRBM as developed by T. Rafiq can be tested on this database)

T&C ITPA modelling work in 2012-2013 (II)

- ***Proposal for a new Joint Activity on transport after the L-H and H-L transition (D. McDonald):***
  - multi-machine database (JET, Cmod, AUD data has been collected)
  - 0D analysis
  - 1D modelling based on BgB/GLF23/MMM

- ***Proposal for new activity: I-mode (improved L-mode) plasma profiles as ITER-like simulator (A. Polevoi):***
  - I-mode: ETB on temperatures, but not density, SOL is opaque for wall neutrals (like on ITER);
  - assessment of "natural" (transport, but not peeling-ballooning) ETB height and width
  - control of pedestal density by pellet fuelling in H-mode
  - EPS paper by F. Ryter – AUG experiments – can be a starting point

T&C ITPA modelling work in 2012-2013 (III)

- ***Modelling of impurity transport (C. Angioni): collection of the multi-machine impurity database for modelling is in progress***

- ***3D effects on tokamaks and helical devices: effect of RMP on transport and confinement (gyrokinetic simulations)***

Discussion on GLF23 implementation in transport codes

- ***Short informal discussion during the T&C ITPA: G. Staebler, J.M. Park, R. Budny, I. Voitsekhovitch***

- ***Has been triggered by the ISM – ITPA momentum benchmarking exercise***

- ***Information obtained: GLF23 calculates the flux to be used in equation:***

$$\frac{d\left(M_i n_i V_\varphi\right)}{dt} = -\frac{1}{V'}\frac{\partial}{\partial\rho}V'\Pi_\varphi$$

no separate term with particle flux (decoupled ni and V φ ***equations)***

- ***GLF23 Fortran file in NTCC: metric should be included in*** $\Pi\varphi$ ***- to be checked and clarification to be distributed (G. Staebler)***

GLF23 equations for rotation

[R. E. Waltz et al, Phys. Plasmas 4 (1997), 2482]

$$M_i n_i \, \partial V_\phi / \partial t = -1/V' \; \partial/\partial\rho \; V' \langle |\nabla\rho| \rangle \times \left[(d\rho/dr) M_i n_i \eta^\phi_{\rm eff} \, \partial V_\phi / \partial\rho + M_i v_\phi \Gamma \right],$$

Γ is the ion particle flux

- *this equation is different with momentum equation implemented in ASTRA, CRONOS/JETTO/TRANSP*
- *if TRANSP torque is used it should be recalculated to rotation source*
- *$\chi\varphi$ has to be re-defined to match the GLF23 equation. For example, for ASTRA*

$$\chi\varphi = (\langle|\nabla\rho|\rangle / \langle(\nabla\rho)^2\rangle)(d\rho/dr) M_i n_i \eta^\phi_{eff}$$

- *if ion density $n_i(t,\rho)$ is evolving, the source term should be re-defined to take it into account*

GLF23 Fortran file

```
c       M ni d v_phi/ dt =
c error found 5/12/98  should be d (M ni v_phi)/ dt =
c -1/V(rho)_prime d /d rho V(rho)_prime
c      |grad rho|**2 ( M ni eta_phi_hat (c_s rho_s**2/a) (-d v_phi/ d rho)
c                  +    M v_phi ne d_hat (c_s rho_s**2/a) (-d ne/ d rho))
c        + toroidal momentum source density
```