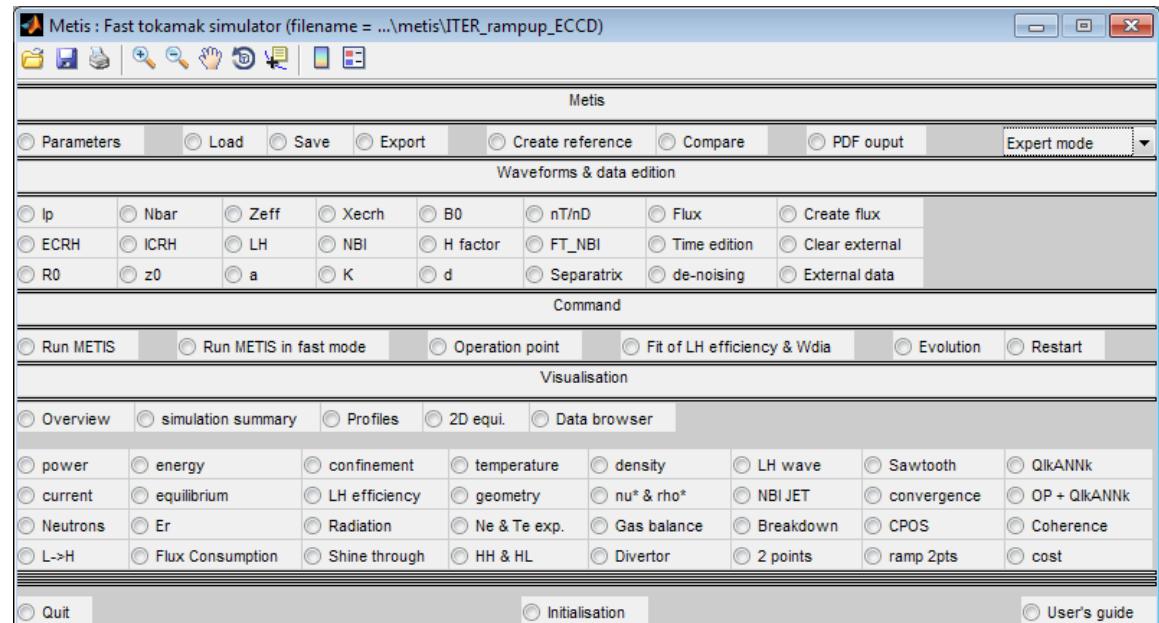


DE LA RECHERCHE À L'INDUSTRIE



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# METIS HOWTO



Introduction to METIS | Jean-François Artaud

FRIDAY, 27 JANUARY 2023

# METIS: A FAST INTEGRATED TOKAMAK MODELLING TOOL FOR SCENARIO DESIGN

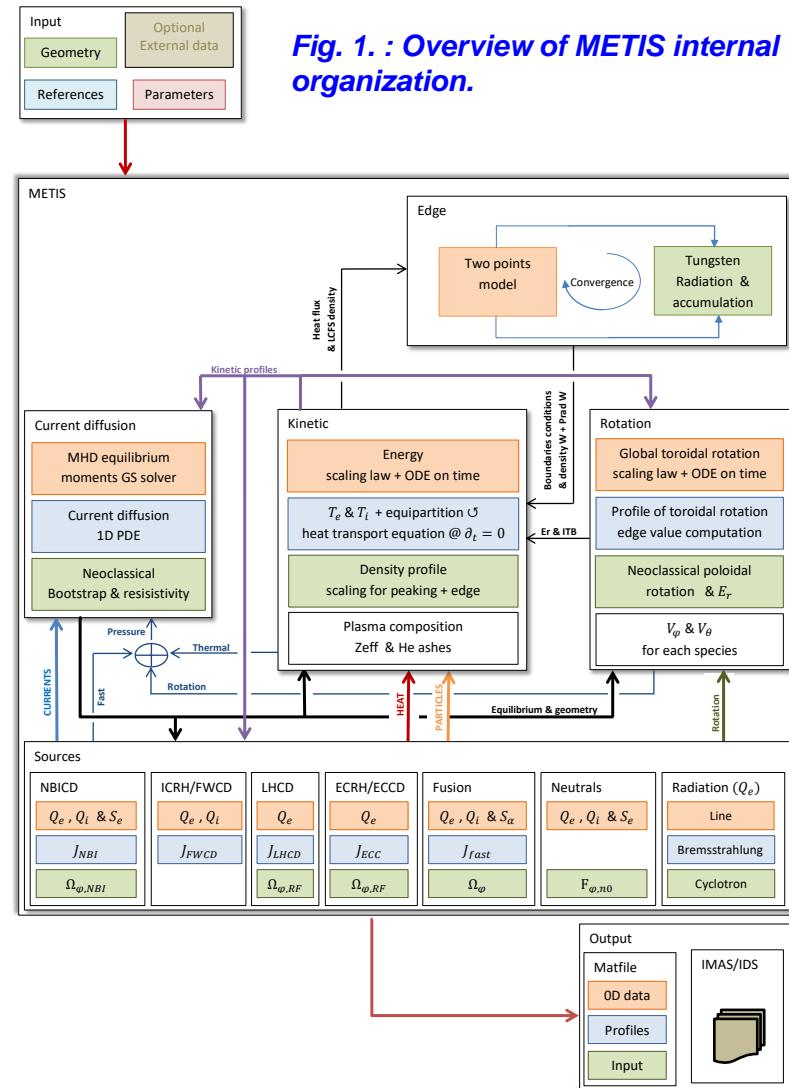
METIS is a numerical code aiming at fast full tokamak plasma analyses and predictions:

- It combines 0D scaling-law normalised heat and particle transport with 1D current diffusion modelling and 2D equilibria.
- It contains several heat, particle and impurities transport models, as well as heat, particle, current and momentum sources
- It allows faster than real time scenario simulations for reactor simulations.

METIS applications and use cases:

- Tokamaks discharges analysis (WEST, Tore Supra, JET, TCV, DIII-D, EAST, HL2A, COMPAS, ...)
- Scenario predictions (JT-60SA, DTT, HL2M)
- Reactor studies (ITER, DEMO, CFETR, ...)
- Data provider for other codes (as CRONOS)
- Plasma plant simulator in control workflow
- Students teaching and training

*Fig. 1. : Overview of METIS internal organization.*



# FOREWORD

- The goal of this HOWTO is to learn how to run METIS:
  - Connected to database or with scenario generator
  - Compiled or inside Matlab
  - With or without IMAS interface
  - Inside Simulink
  
- The HOWTO explains what METIS is but does not provide a detailed training on METIS Physics applications

# OUTLINE

<b>METIS overview</b>	<b>slide 6</b>
<b>Launch METIS</b>	<b>slide 15</b>
<b>METIS documentation</b>	<b>slide 18</b>
<b>Overview of METIS GUI</b>	<b>slide 21</b>
<b>Use METIS with GUI</b>	<b>slide 25</b>
<b>Expert &amp; standard Mode</b>	<b>slide 40</b>
<b>LCFS generator</b>	<b>slide 43</b>
<b>Main Parameters for first use</b>	<b>slide 47</b>
<b>Inside METIS</b>	<b>slide 66</b>
<b>Advance features</b>	<b>slide 70</b>
<b>METIS in Simulink</b>	<b>slide 75</b>
<b>METIS &amp; IMAS</b>	<b>slide 83</b>
<b>Runaway electrons in METIS</b>	<b>slide 94</b>
<b>METIS &amp; qualikiz Neural Network</b>	<b>slide 96</b>

# **METIS OVERVIEW**

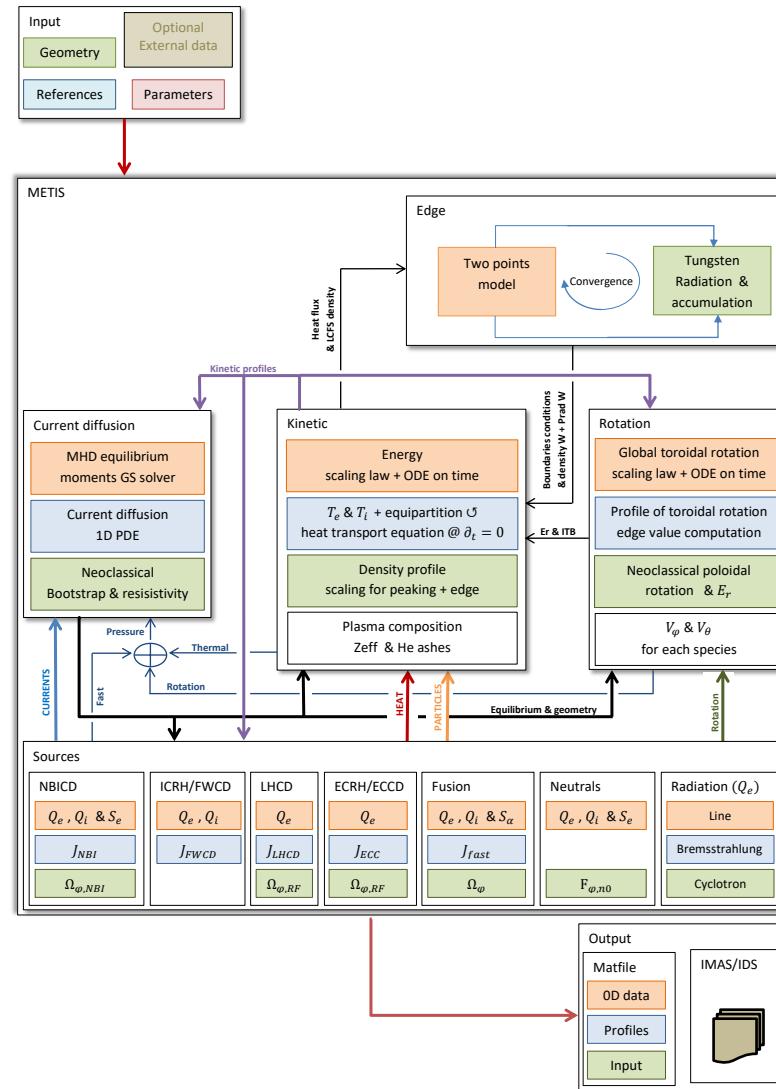
# WHAT IS METIS

- METIS is a fast Integrated Transport Code with simplified assumptions
- All parameters of an ITER discharge calculated in 1 minute (300 time slices)
- Designed for
  - Scenario Design
  - Flight Simulator
  - First analysis of a discharge
- Mixture of 0D and 1.5D equations
- Highly convergent computing scheme
- Originally part of CRONOS

# MAIN METIS FEATURES

- ✓ 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,  $\chi$  scaled to  $W_{th}$
  - ✓ All non-linearities solved (dependence of sources on profiles, fusion power, He ash transport)
  - ✓ Bootstrap and resistivity : Sauter O. et al 1999 Phys. Plasmas 6, 2834; ibid. 9 (2002)
- ✓ 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
- Global time convergence (wave form relaxation)

# METIS INTERNAL WORKFLOW



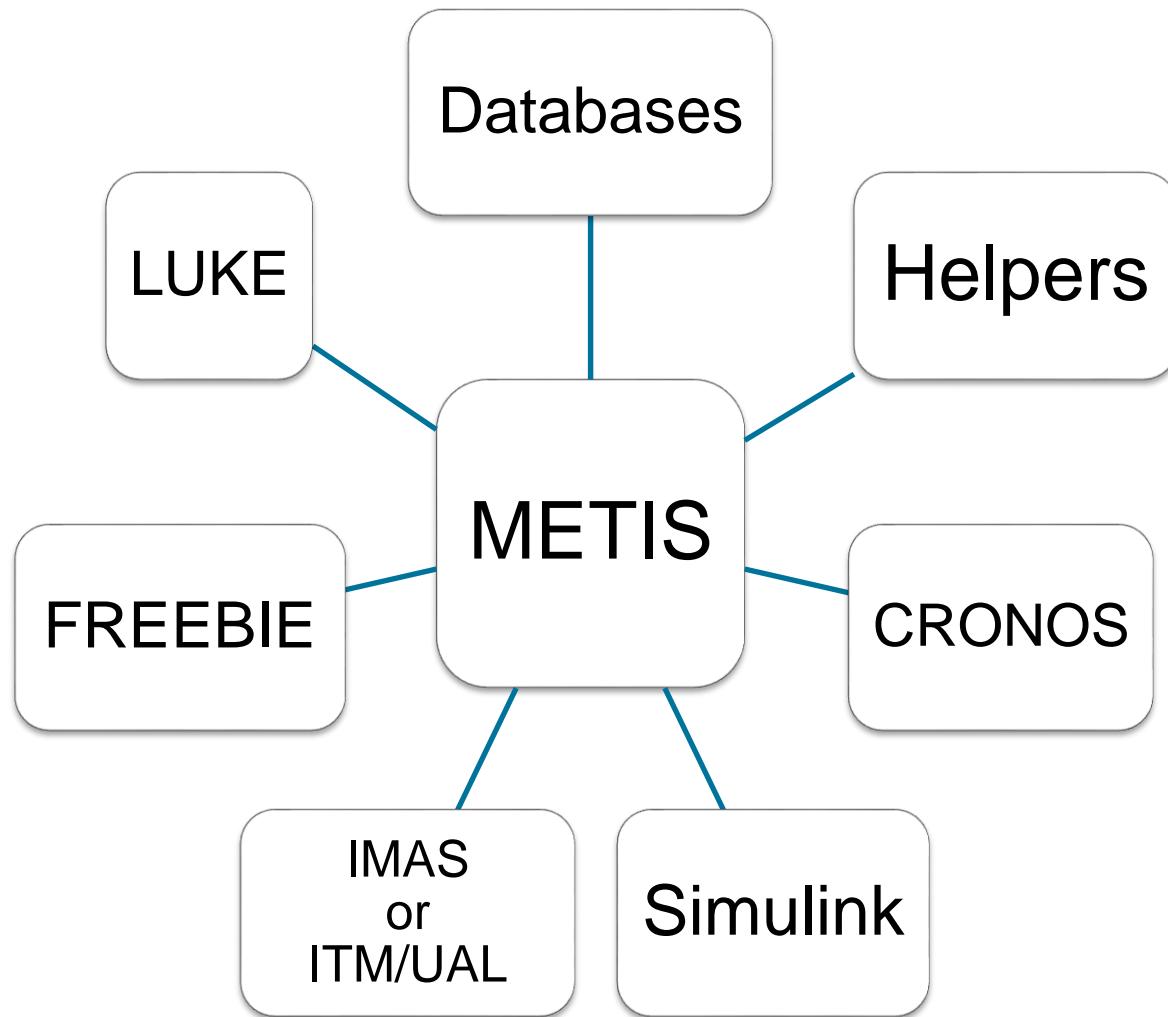
# DIFFERENCE BETWEEN VERSIONS

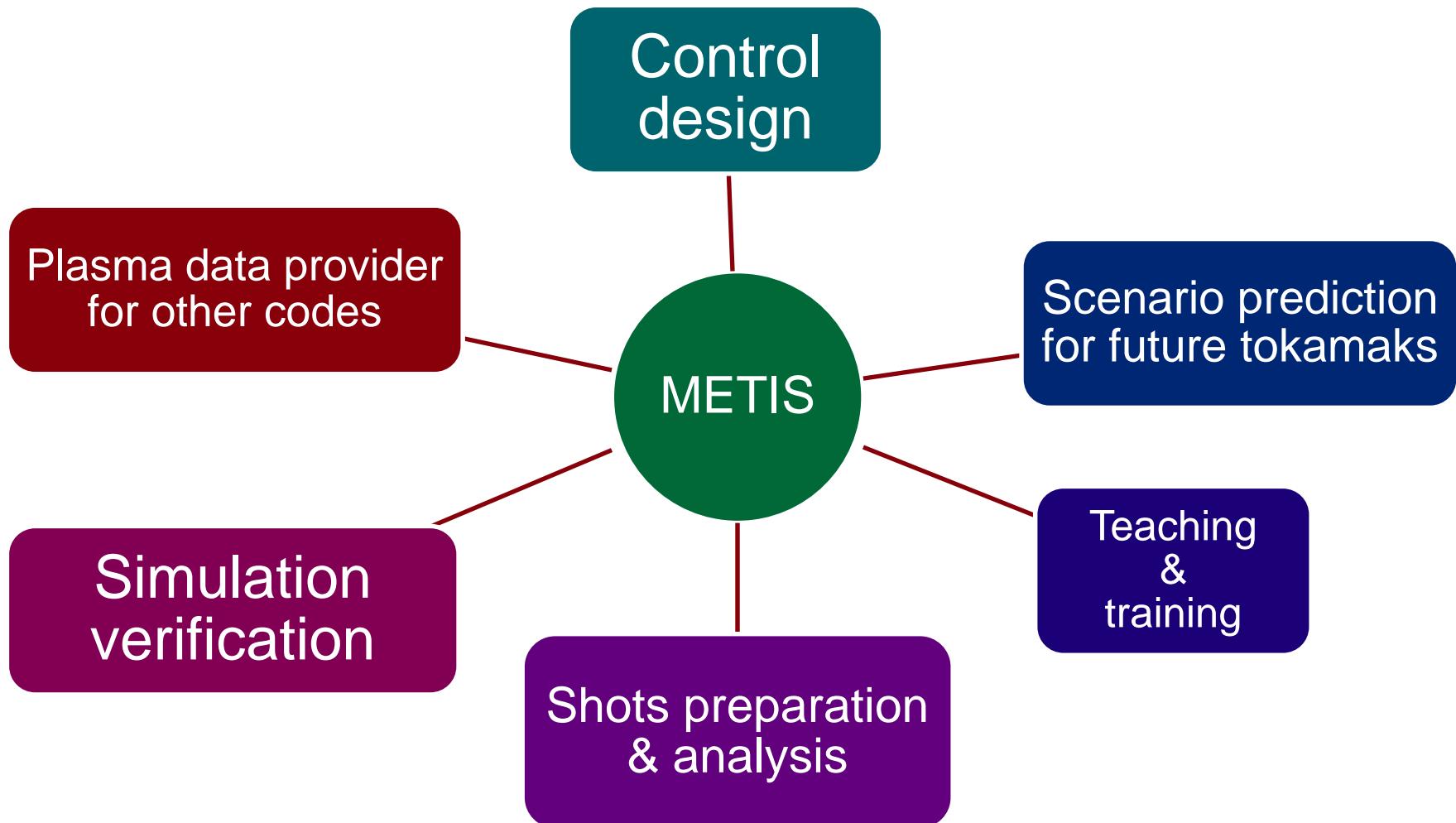
- **METIS as a CRONOS module:**
  - Exchange data between CRONOS↔ METIS
  - Access to more data bases : DIII-D, ...
  - Complementary tools : HELENA, NCLASS direct call
- **METIS for IMAS or ITM:**
  - Access to UAL
  - Coupling with Kepler and Python workflow
- **METIS standalone:**
  - Simpler installation
  - Can be called from Simulink
- **METIS runtime (compiled version):**
  - No Matlab license needed (= no Matlab workspace)
  - Work on many OS  
(available for Windows, on demand for Mac OS/X and Linux)

- Direct connection:
    - Tore Supra / WEST: pre and post shot access (Tslib)
    - JET: SAL access to JET data
    - Compass: dedicated library
    - IMAS & ITM databases: UAL
  - Indirect connection:
    - DIII-D: dedicated tool (to be run on DIII-D computers)
    - EAST: dedicated tool (to be run on EAST computers)
    - Asdex-U: still incoming
    - TCV: MDS + access from SPC
- Allows comparison to experimental data.

- Tool to prepare a complete scenario ab-initio:
  - Set waveforms and parameters
  - Including ramp-up, flattop and ramp-down
  - Take into account specificity of each device
  - Can be fine tuned from METIS GUI
- Available generators:
  - WEST
  - JT-60SA
  - Reactors (ITER, DEMO, ...)

# METIS ECOSYSTEM OVERVIEW





**LAUNCH METIS**

# HOW TO LAUNCH METIS ON FREIA

- In a terminal on freia:
  - Set the environment:  
**module purge**  
**module load matlab/2022a**  
**module load gcc/7/5.0**  
**module load gfortran/4.8**
  - Launch METIS:  
**/home/jartaud/Public/METIS\_INSTALL/metis/metis**
  - Simulation examples:  
**/home/jartaud/Public/METIS\_INSTALL/metis/certification/metis**
  - Documentation:  
**/home/jartaud/Public/METIS\_INSTALL/metis/doc**

- Two ways:
  - outside matlab : just launch metis script  
`/home/jartaud/Public/METIS_INSTALL/metis/metis`
  - Inside matlab :  
**addpath to metis installation**  
`addpath /home/jartaud/Public/METIS_INSTALL/metis`  
**and launch metis from Matlab CLI**

# **METIS DOCUMENTATION**

# AVAILABLE DOCUMENTATION

- In directory “doc” of METIS code
- Main documentation
  - Artaud\_2018\_Nucl.\_Fusion\_58\_105001.pdf  
→ Reference paper
  - Howto\_METIS\_FREIA.pdf  
→ user guide (this presentation)
  - METIS\_installation\_guide.pdf  
→ guide for METIS installation and compilation
  - description\_model\_ICRH\_Dumont-Vu.pdf  
→ ICRH model details
  - METIS\_Core\_edge\_coupling\_howto.pdf  
→ 2 point model and W source model configuration

# AVAILABLE DOCUMENTATION

- In directory “doc” of METIS code (see below)
- Parameters documentation
  - **metis\_documentation\_for\_parameters\_standard\_mode.pdf**  
→ documentation for METIS parameters available in standard mode
  - **metis\_documentation\_for\_parameters\_expert\_mode.pdf**  
→ documentation for METIS parameters (all, available in expert mode)
- Input/output data
  - **metis\_documentation\_for\_input\_data\_structure.pdf**  
→ description of input data of METIS
  - **metis\_documentation\_for\_output\_data\_structure.pdf**  
→ description of output data of METIS

# **OVERVIEW OF METIS WITH GUI**

# GUI OVERVIEW

## Data source

MENU <@saturn>

- Which data source ?
- Tore Supra
- Tore Supra preparation
- JET
- Other
- Cronos

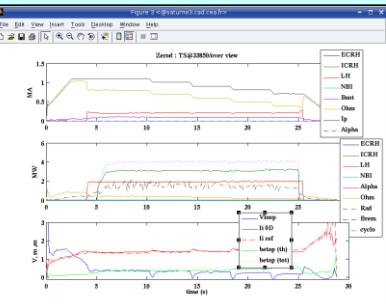
## Shot choice

Access to Tore Supra Data <@saturn>

- shot number : 33850
- reference shot number : 33850

Cancel Reset Ok

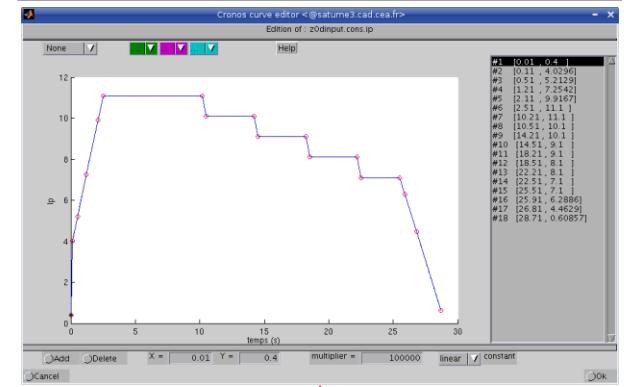
## Visualisation



## Parameters

module interface zerod <@saturne1.cad.cea.fr>	
gas2	2 (integer)
neaserr	0 (integer)
pix	0.7 (real [0..1])
scaling	0 (integer)
l2scaling	0 (integer)
l2histope	0 (real [0..1])
kshape	3 (real [0..10])
runaway	1 (integer)
modeshot	1 (integer)
ii	1 27441 (real [-3..3])
zimp	6 (integer [-3..100])
frad	1 (real [0..1..10])
angle_ecce	90 (real)
angle_nbi	0 (real [-90..90])
einj	1e+06 (real [10000000000..100000000000])
rpar0	1.8 (real [1..10])
xth	0.2 (real [0..8])
mino	H (string)
freq	57.05 (real [20..80])
smtid	100 (real [-10..100])
signe	1 (integer)
effinj	0.7 (0..1)
rmf0	0 (real [0..5..5])
ane	0 (integer)
piw	0.5 (real [0..3..3])
tprad	0.333333 (real)
moden	0 (integer)
toped	1 (real [0..1..10])
odds	0 (real [0..3..3])
tauhemul	0 (real [0..20..20])
tauhemul	0 (real [0..5..5])
pif	0 (real [0..1..1])
l2hmul	0 (real [-10..100..100])
kidds	1 (real [1..1000..1000])
vloop	0 (integer)
zeff	0 (integer)
rms	0.3 (real [0..1..1])
rv	0.7 (real [-1..1..1])
synergie	0 (real [0..10..10])
rtang	0 (real [0..100..100])
zext	0 (real [0..3..3])
etanh	0.8 (real [-3e+19..3e+15..15])
wfh	0.352 (real [0..3..3])
fwcd	0 (integer)
nphi	30 (real [1..100..100])
tau	0 (integer)
rip	1 (integer)
aux	0.05 (real [0..1..1])

## References



## METIS : main interface

Metis : Fast simulator coupled with CRONOS <@saturne3.cad.cea.fr>

Metis

Parameters Load Save Create reference PDF output

References

Op Obar OZeff OXece OBo OIso  
OECRH OICRH OLUH ONBI OAmelioration OFT\_NBI  
OR0 Oz0 Oa OK Od OSeparatrix

Compute Metis simulation Fast Metis simulation computation Fit of LH efficiency & Wdia

Visualisation

Opower Oenergy Oconfinement Otemperature Odensity Ocost  
Ocurrent Oequilibrium OLH efficiency Ogeometry Oconvergence ONe Profile  
Oneutron DD OEr ODDS TS OOverview OProfiles O2D equi.

Quit Initialisation Aide

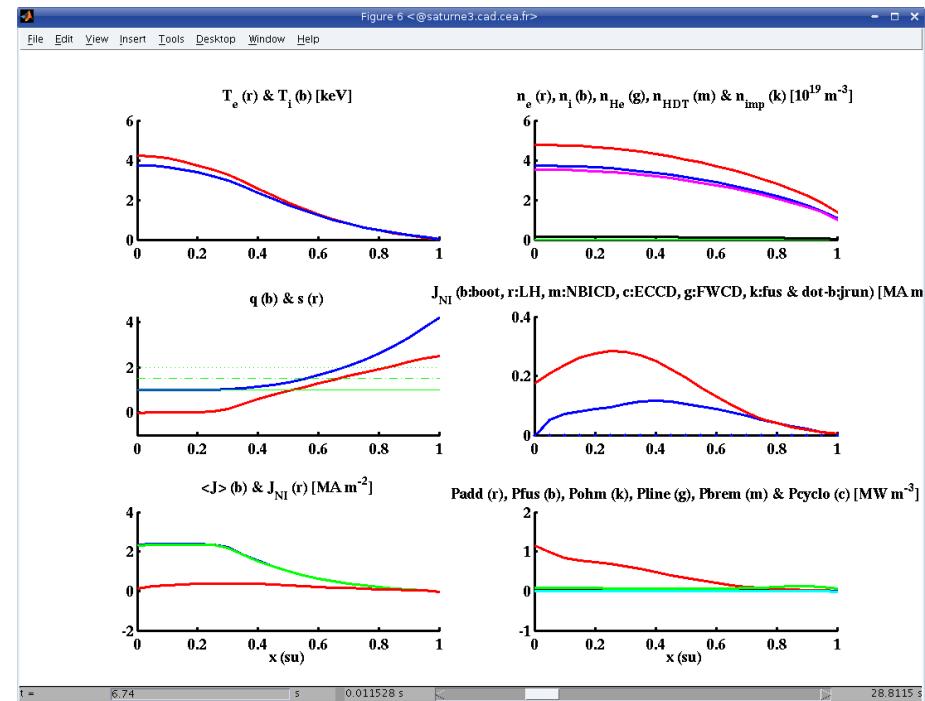
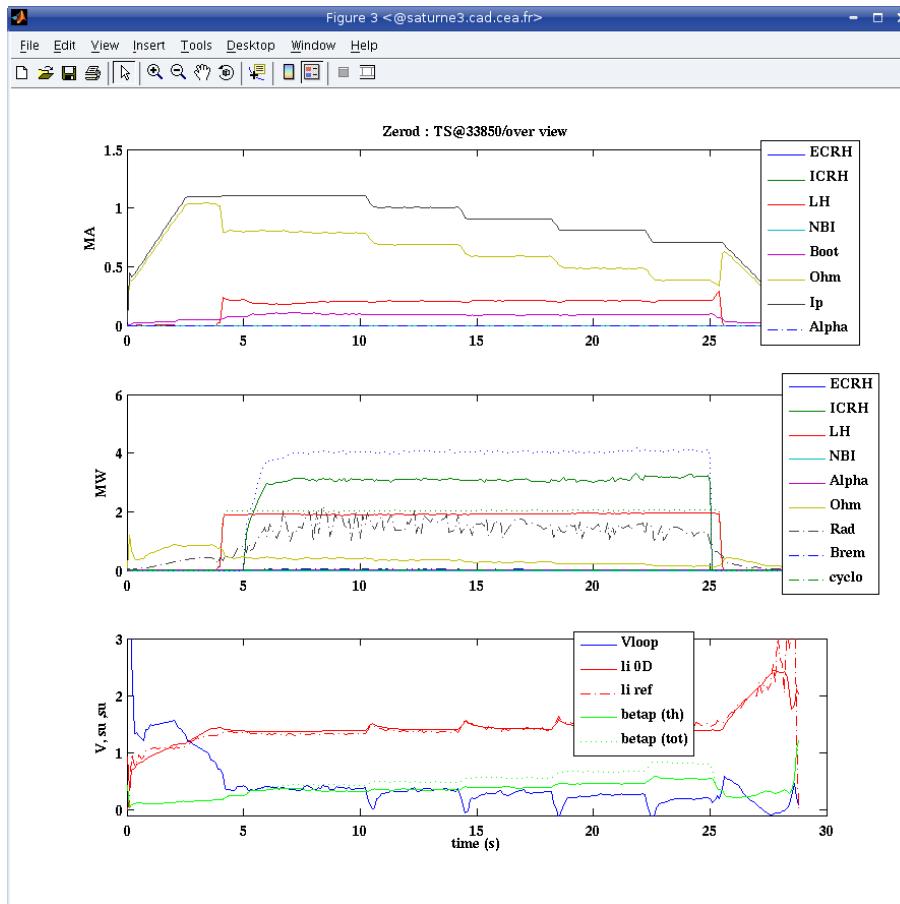
Run (~ 1mn)

Export to database

Results

# METIS OUTPUT EXAMPLE (1/2)

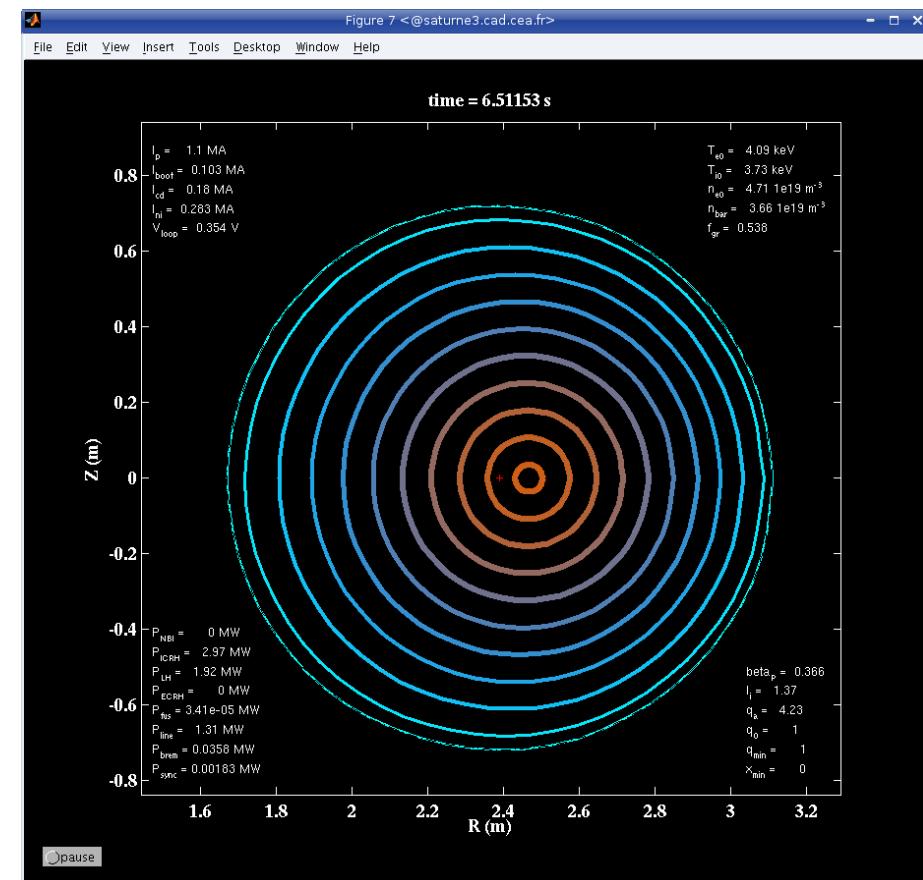
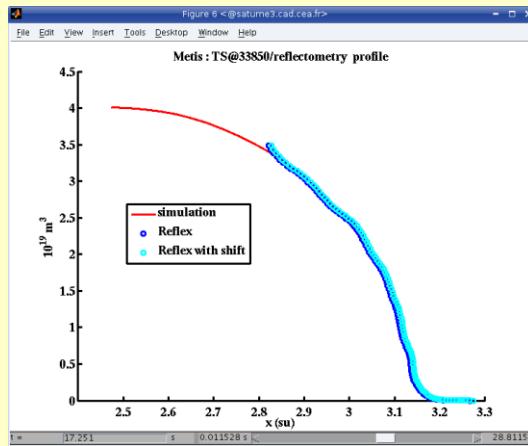
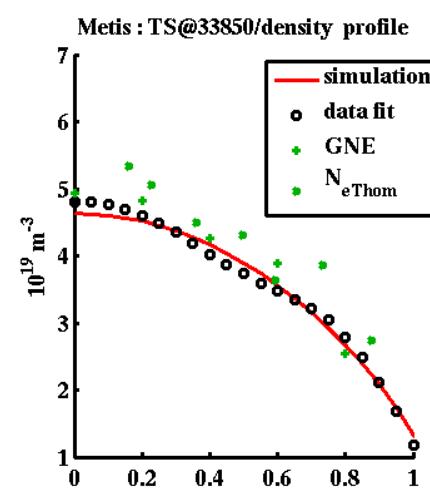
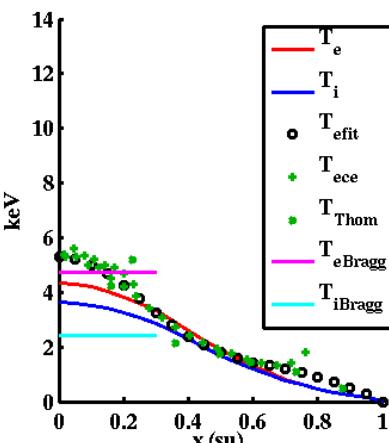
## Results: 0D data



## Results: profiles

# METIS OUTPUT EXAMPLE (2/2)

## comparaison with diagnostics data



Internal 2D METIS equilibrium

**USE METIS WITH GUI**

# MAIN GUI WINDOWS (1/2)

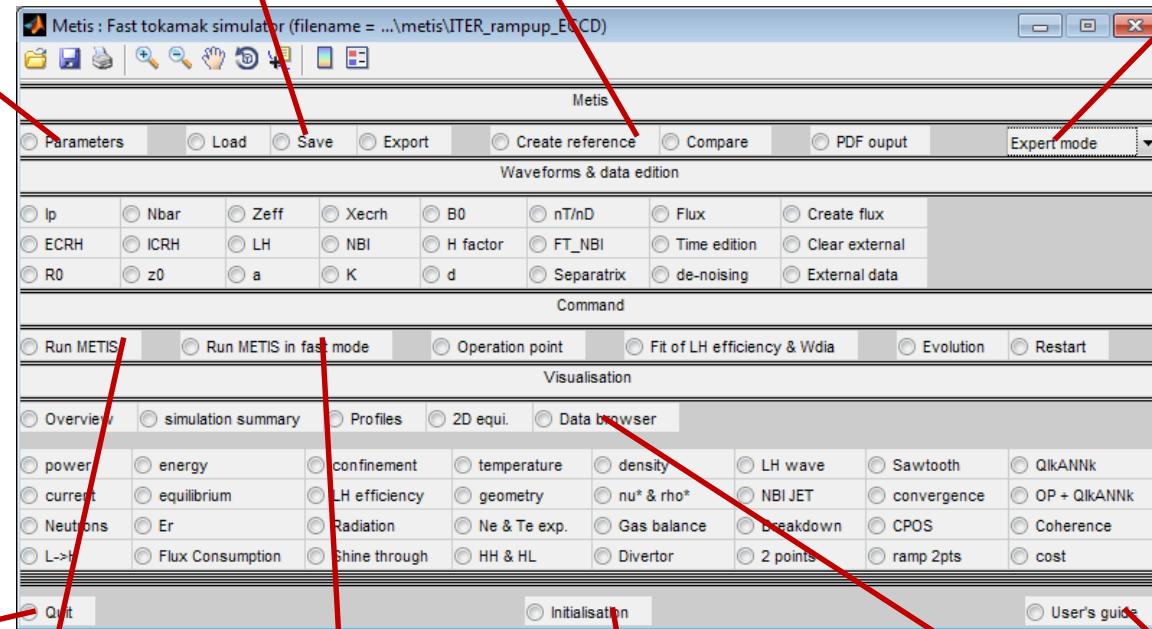
Edition of simulation parameters

Load & Save simulation

Create reference data set for comparison

Mode switching

Edition references



Pre-defined graphs

Quit METIS

Full simulation  
(all time slices, to be  
use for final result)

Fast simulation  
(selected time slices  
for overview)

Data browser  
(plot any METIS data)

Initialization  
(create a new simulation)

Open METIS manual  
(need a pdf reader installed)

# MAIN GUI WINDOWS (2/2)

Generate  
separatrix (LCFS)  
with X-point

Noise filter for references

Time resampling (input)

Handle external data  
(measurement, ...)

Edition  
references



Main graphs

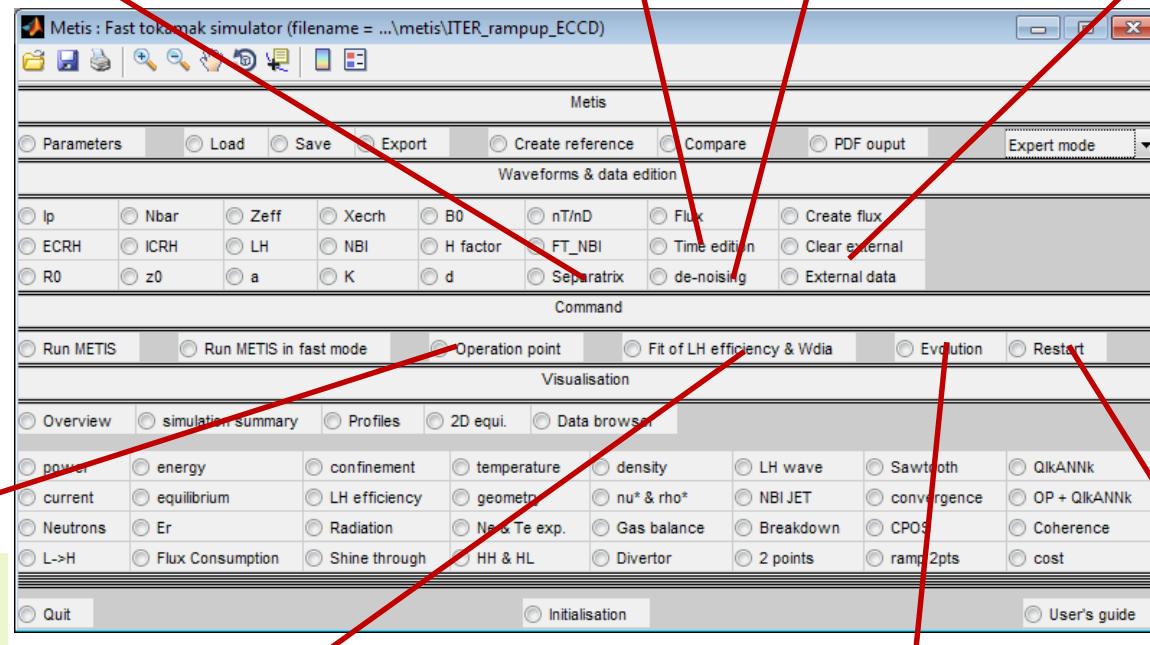


Steady-state  
fast  
computation

Fit experimental energy  
content and search LHCD  
efficiency (if present)

Run in evolution mode  
(for testing)

Restart evolution mode  
(to continue the simulation)



# SOME RECIPE FOR A SIMULATION

1. Create or load a data set
2. Edit and modify references
3. Optionally, edit the LCFS (if X-point)
4. Edit and modify parameters
5. Run the simulation in fast mode
6. Visualize results
7. Come back to 2, if changes are needed
8. Run complete simulation
9. Visualize and check results
10. Save results

# READ DATA FROM DATABASES

Which data source ?

Tore Supra

WEST

JET

DDIID

ASDEX-U

COMPASS

EAST

JT-60SA

TCV

Reactors (ITER & DEMO)

Other

load

Cronos

IMAS

System code

Cancel

- **From « initialization » :**
  - Access to databases
  - Possibility to create a simulation ab-initio
  - Create simulation with scenario generator for WEST, JT-60SA, Reactor (ITER/DEMO)
  - Create simulation from SYCOMORE or PROCESS run
  - Create a METIS dataset simulation from CRONOS data (if CRONOS available)
  - Read METIS input data from IMAS or ITM/UAL

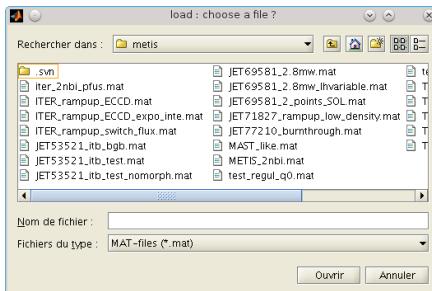
## ➤ Create a new simulation

✓ **Data are only in memory : must be saved (after first run) !**

## ➤ Menu change depending on context

- Button load open a file selector :
  - Just selected a file and open it
- METIS has unified file for input/output
- All METIS files are compatible with new METIS versions (ascendant compatibility)
- Some sample files (used for non-regression tests) are in the directory certification/metis :

.../certification/metis



# EDIT REFERENCE

- Time dependent reference can be edited with the help of graphic editor

Grid selector

Superimposes other reference

Add control points of other reference

Graphically  
editable points  
(right click for  
edition menu)

Add one point  
or delete  
selected point

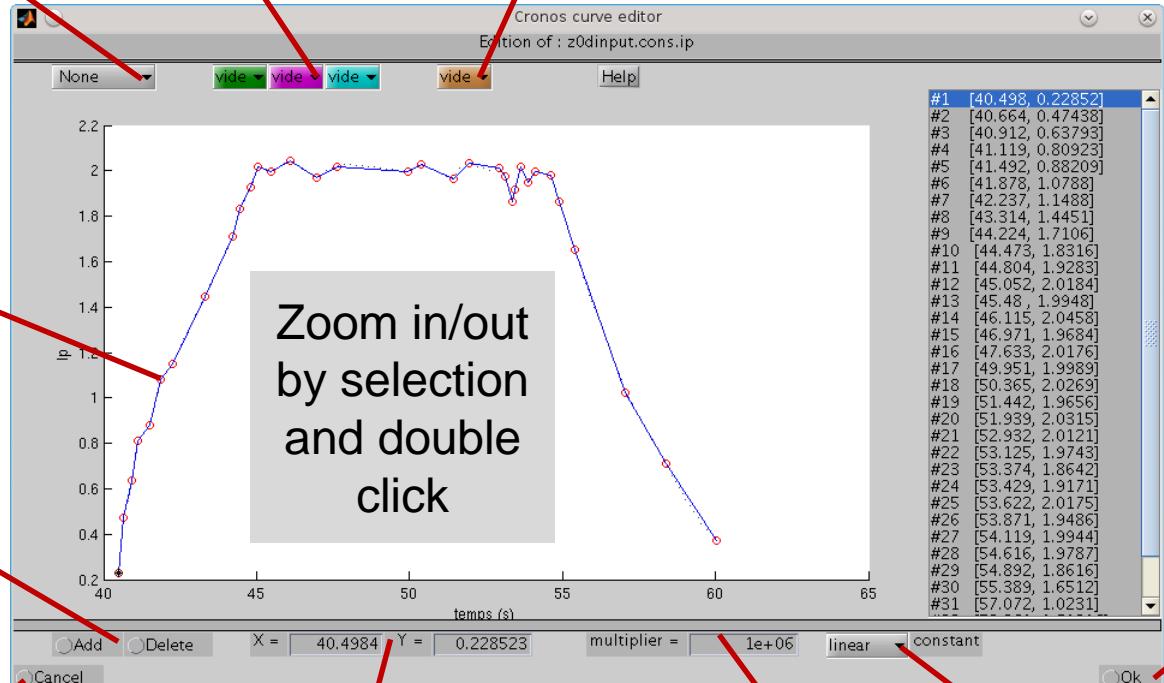
Cancel edition

Zoom in/out  
by selection  
and double  
click

Editable point coordinates

Exponent

Interpolation  
methods



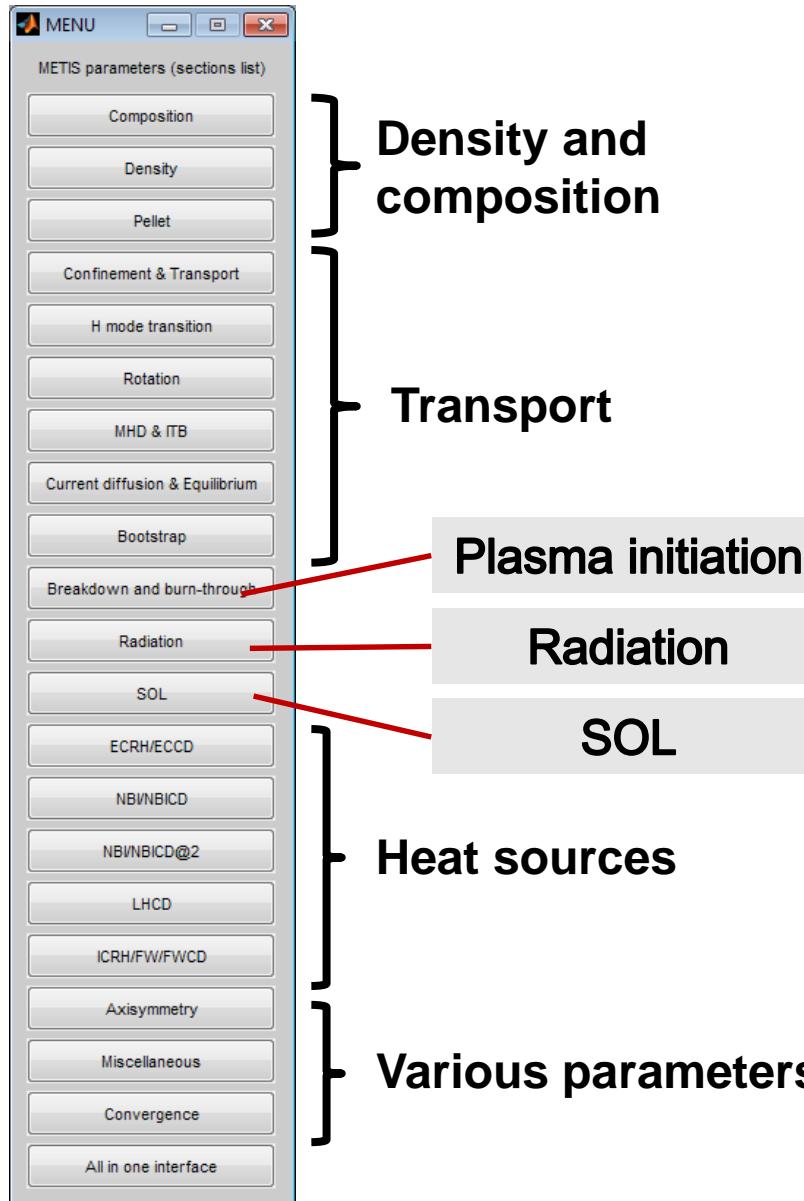
Selectable  
list of  
control  
points

Save  
new  
reference

# LIST OF REFERENCES

- Plasma parameters:
  - ip : plasma current
  - flux : edge poloidal flux
  - nbar : line averaged density
  - zeff : line averaged effective charge
  - iso : isotopic plasma composition ( $n_D/n_T$ )
  - picrh : ICRH/FW input power
  - plh : LFCD input power
  - pnbi : NBI input power (can open 2 reference editors)
  - pecrh : ECRH input power
  - hmore : enhancement factor
  - ftnbi : NBI composition
  - xece : ECRH maximum deposition position.
- Plasma geometry :
  - a : minor radius
  - R0 : major radius
  - z0 : vertical shift
  - K : elongation
  - d : averaged triangularity
  - b0 : toroidal magnetic field at the major radius
- LCFS generator:
  - More moments
  - Real X-point
  - For given interval of time

# EDIT MODEL PARAMETERS



- Parameters grouped by topic
- Each button opens a form
- Change the input parameters

- Main modes:
  - Fast: just to have a look and tune parameters and references
  - Compute: Full computation for final results
  - Fit: Compute energy using measurement  
(and optionally search for LHCD current drive efficiency)
  - Operation point: One time slice, steady state
- Other modes (for testing):
  - Evolution: test the simulation in evolution mode
  - Restart: restart a simulation in evolution mode

- At the end of the simulation overview graph is opened.
- Generic graph (0D) : just push the button
  - Power, energy, current, confinement, temperature density, equilibrium, geometry, convergence, ...
- 2D plot :
  - equi 2D, Profiles, Er, ...
- Specialize graphs :
  - L→ H, Consumed flux, LH wave , ...
- Machine dependent graphs :
  - Neutron DD, DDS TS, NBI JET, Ne profile
- Generic data browser and plotter.

# DATA BROWSER

Matlab figure menu

0D data

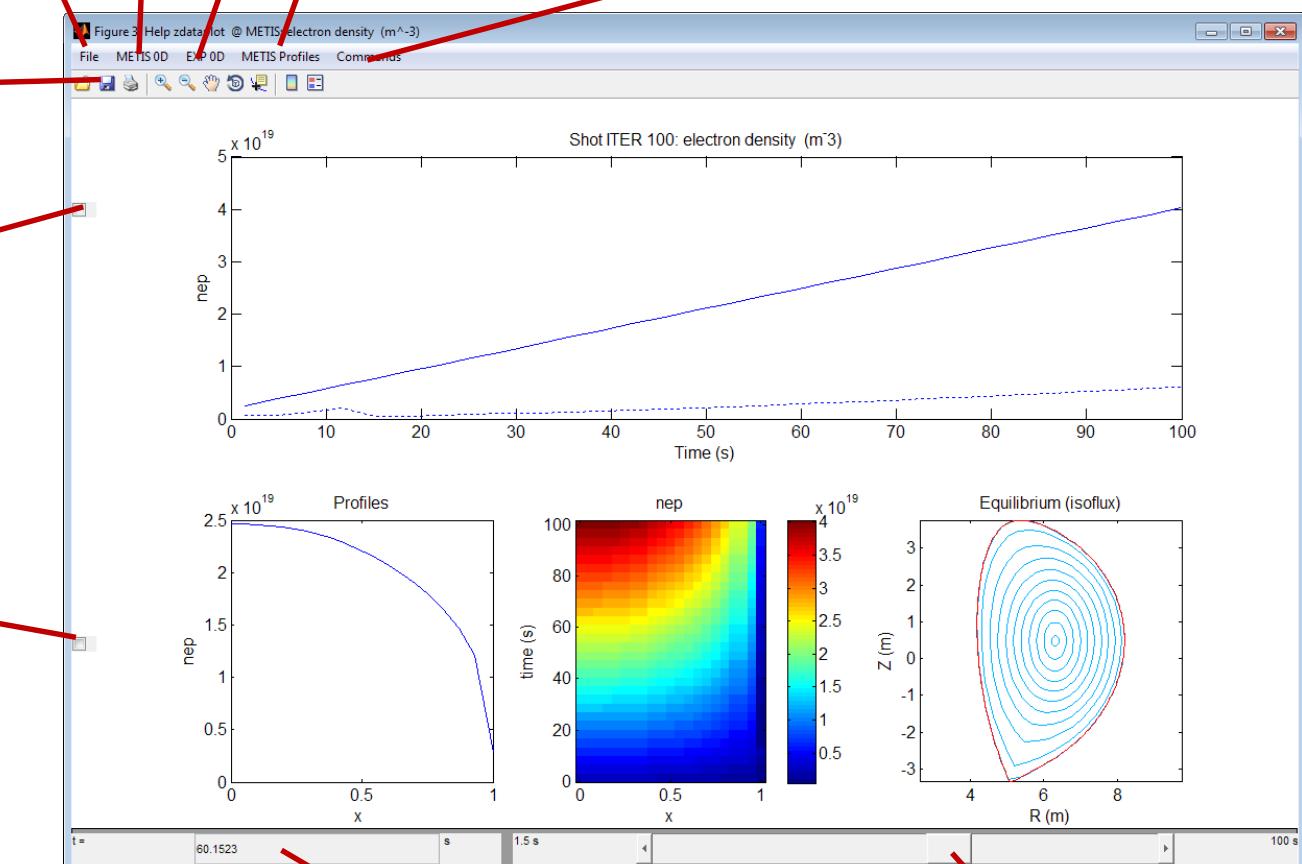
experimental data  
profile data

Graphs options  
(superimpose, ...)

Matlab figure  
toolbar

time selection  
With cursor

Memorize  
profile and  
superimpose

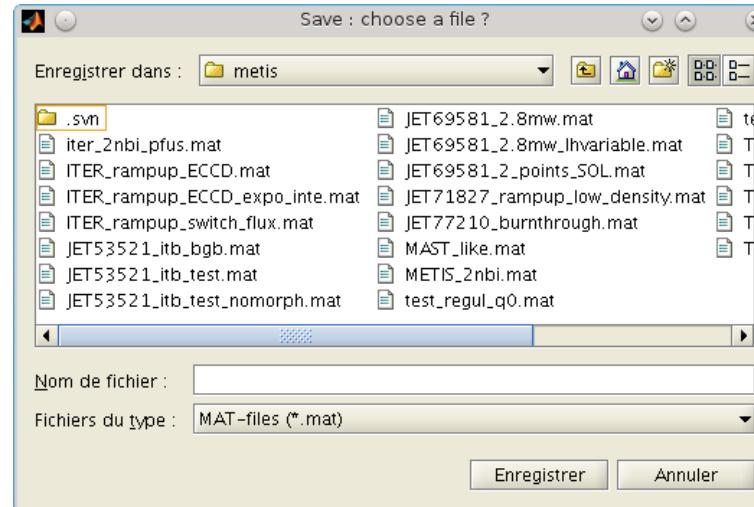


Time (edit field)

Time slider

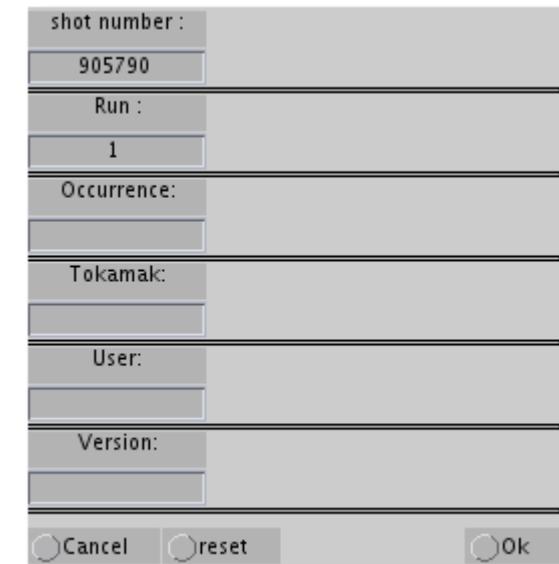
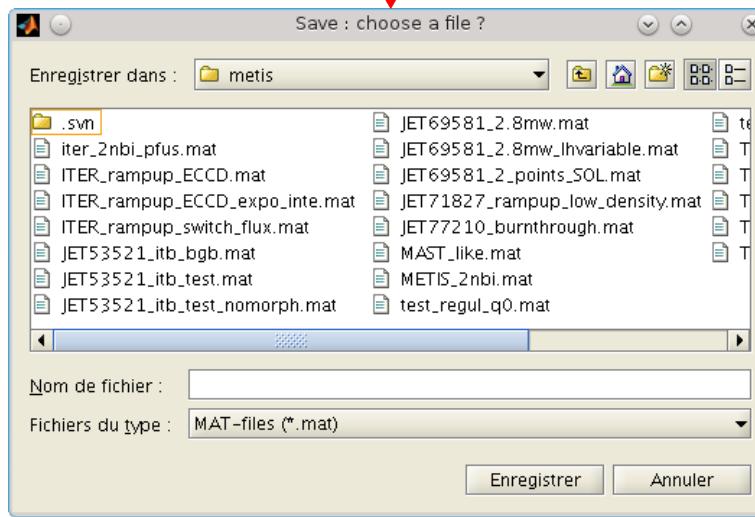
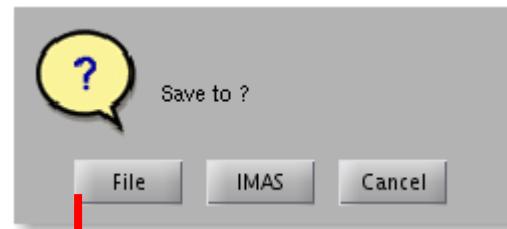
# SAVE DATA IN MATFILE

- Button save open a file selector:
  - Just select a file or enter a new name and save it
- METIS has unified file for input/output.



# SAVE DATA WITH IMAS OR ITM/UAL

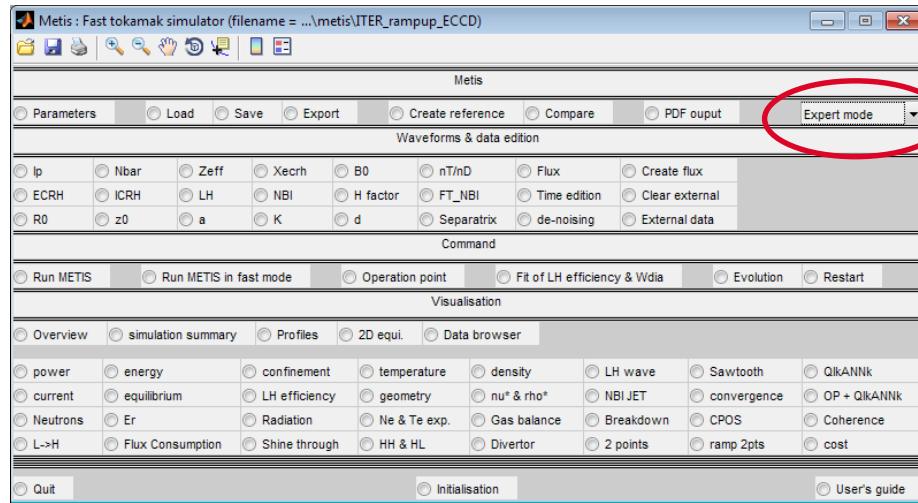
- If IMAS or ITM/UAL is available



- Button export:
  - Create IMAS data structure with all requested IDSs and store it in a matfile.
- Internal format depends on Matlab preferences:
  - See command “preferences” in Matlab.

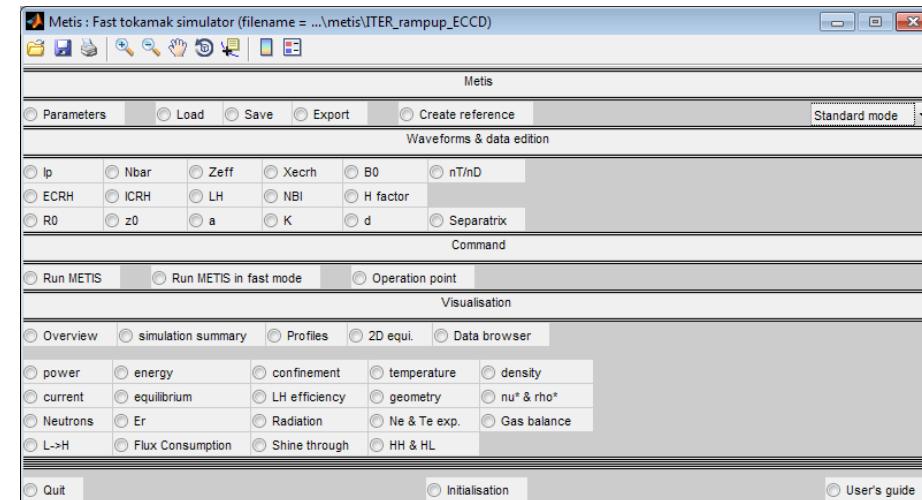
# **METIS GUI: EXPERT & STANDARD MODE**

# GUI HAS 2 MODES: STANDARD AND EXPERT (1/2)



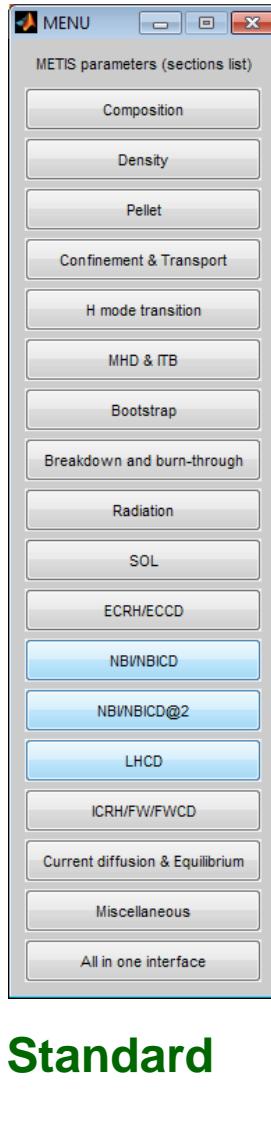
**Expert**

**Standard**



# GUI HAS 2 MODES: STANDARD AND EXPERT (2/2)

**Expert**



METIS parameters (section #SOL)						
METIS parameters (section #SOL)						
configuration	3	(integer)	lambda_scale	0	(real)	factor_scale
sol_lsclae	0	(real) [-0.1 0.1]	eioniz	25	(real) [0 1000]	de
alpha_e	0.82	(real) [0.15 3]	fresol	0.2	(real) [0 1]	sol_model
sol_rad	coupled	(string)	lcx	7	(real) [1 20]	scaling
fR_target	1	(real) [-3 3]	fcond	1	(real) [-1 1]	fpower
mach_corr	0	(integer)	yield_model	Javev	(string)	fmom
cw_factor	1	(real) [-10 10]	cw_offset	0	(real) [0 0.01]	ftweak
cw_icrh	0	(real) [0 0.01]	cw_lhcd	0	(real) [0 0.01]	cw_ecrh
cw_nb1	0	(real) [0 0.01]	fzmax_div	0	(real) [-100 100]	cw_nb1
cw_nb2	0	(real) [0 0.01]				carbonblow

**Expert**

SOL Parameters  
(one example)

**Standard**

METIS parameters (section #SOL)						
METIS parameters (section #SOL)						
configuration	3	(integer)	lambda_scale	0	(real)	
sol_lsclae	0	(real) [-0.1 0.1]	sol_model	scaling	(string)	
sol_rad	coupled	(string)	sol_rad	coupled	(string)	
cw_factor	1	(real) [-10 10]	cw_offset	0	(real) [0 0.01]	
cw_offset	0	(real) [0 0.01]				

Sections menu



**Standard**

# **LCFS GENERATOR**

# LCFS GENERATOR (1/3)

- LCFS parameters:

- rxup : upper triangularity (normalized)
- zxup : upper elongation (normalized)
- apup, amup : upper X-point angles
- ra : major radius
- za : vertical shift
- a : minor radius
- rxdo : lower triangularity
- zxdo : upper triangularity
- apdo, amdo : lower X-point angles
- b0 : maximum magnetic field on TF conductor
- delta : gap between TF and inner plasma point
- nbp : number points in LCFS
- mode : interpolation curve type
- filename : filename of LCFS given by point
- ton : first time for X-point LCFS
- toff : last time for X-point LCFS

Update or not  
 $B_0$

}

module interface z0dsepanew2		
rxup	0.466	(float) [-2 2]
zxup	1.687	(float) [0.05 5]
apup	0	(float) [0 90]
amup	0	(float) [0 90]
ra	6.2	(float) [0.1 100]
za	0.65	(float) [-10 10]
a	2	(float) [0.1 100]
rxdo	0.568	(float) [-2 2]
zxdo	2.001	(float) [0.05 5]
apdo	22.46	(float) [0 90]
amdo	67.92	(float) [0 90]
b0	13.6	(float) [0.0001 100]
delta	1	(float) [0.1 100]
update_b0	off	(string)
nbp	201	(integer) [35 250]
mode	elliptical	(string)
filename		(string) "
ton	1.5	(float) [1.5 99.999999999998]
toff	100	(float) [1.5 99.999999999998]

Cancel    reset

Ok

Before and after, use  
references R, a, K, d

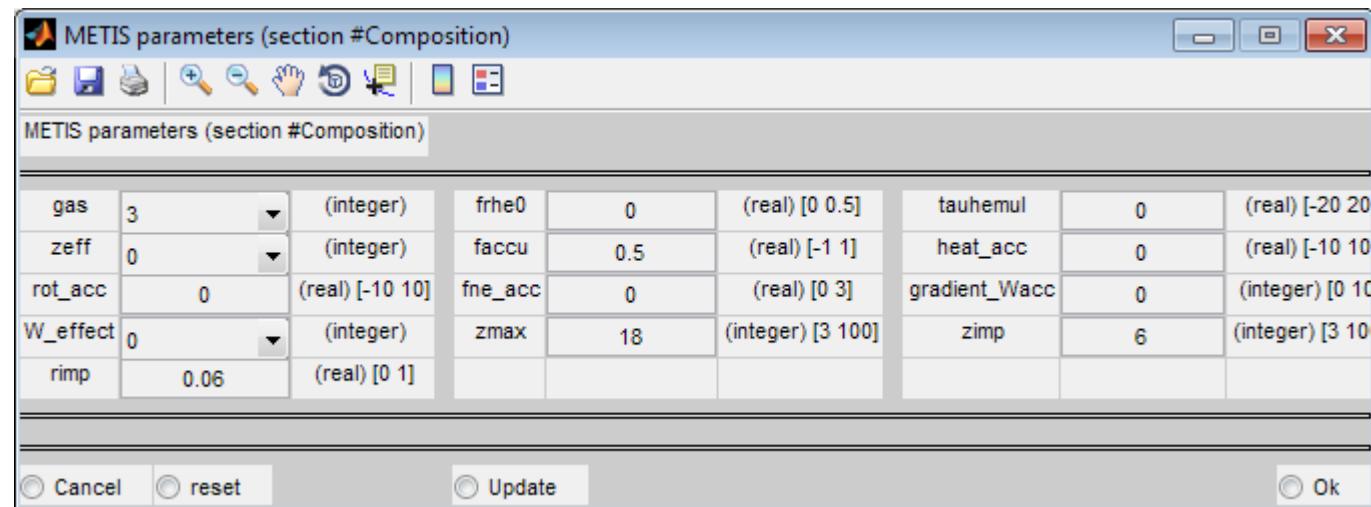
- LCFS GENERATOR:
  - Override references (R,a,K,d) between ton and toff
  - May re-computes B0 (you must check or reset B0 after)
- If you edit again any R, a, K or d reference:
  - LCFS is reset to moments only
  - You must restart the LCFS design
- Shared by HELIOS/SYCOMORE and METIS:
  - Same set of parameters

[HELIOS: A zero-dimensional tool for next step and reactor studies, J. Johner, FUSION SCIENCE AND TECHNOLOGY VOL. 59 FEB. 2011]

- Load a LCFS given by point:
  - Load file pointed by filename field, if field is not empty
  - If filename is invalid or “?”, open a file selector helping to choose the file
  - File must be a matfile containing R vector and Z vector of same length.
  - Override references (R,a,K,d) between ton and toff
  - Override LCFS given by parameters.
- If you edit again any R, a, K or d reference:
  - LCFS is reset to moments only
  - You must restart the LCFS design

## **MAIN PARAMETERS FOR FIRST USE**

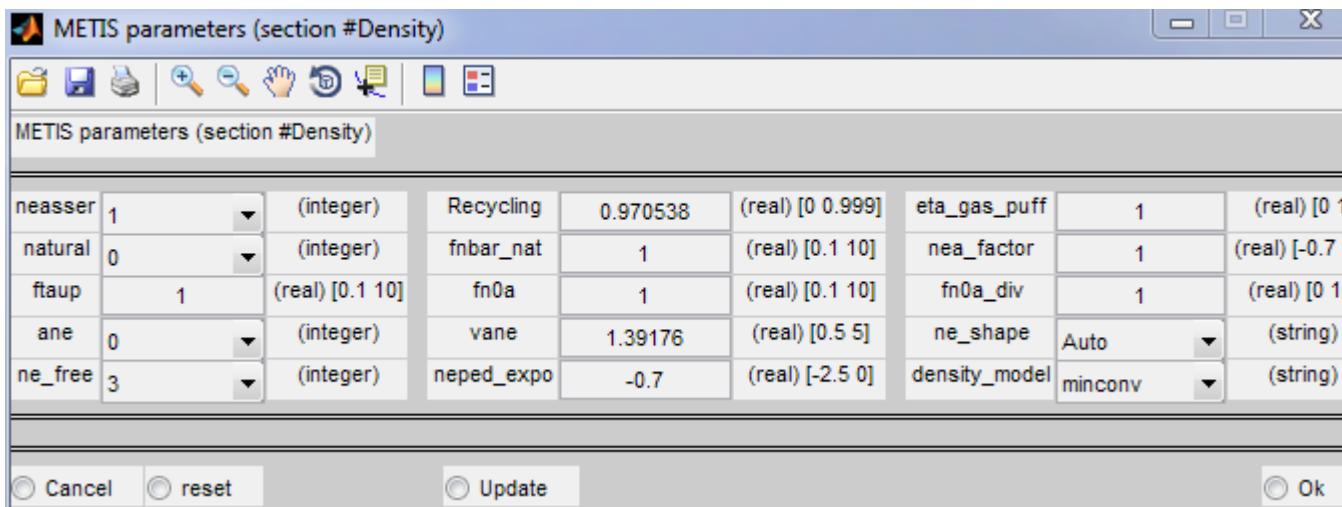
# PARAMETERS INTERFACES (COMPOSITION)



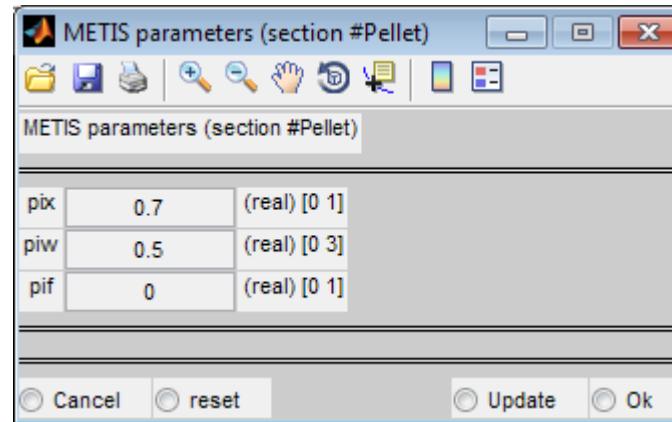
- Main Keys (for first use):
  - gas: main plasma ion species (H/D/He/DT)
  - zimp: charge of light/main impurity
  - zmax: charge of heavy/secondary impurity
  - rimp : density ratio of secondary over main impurity

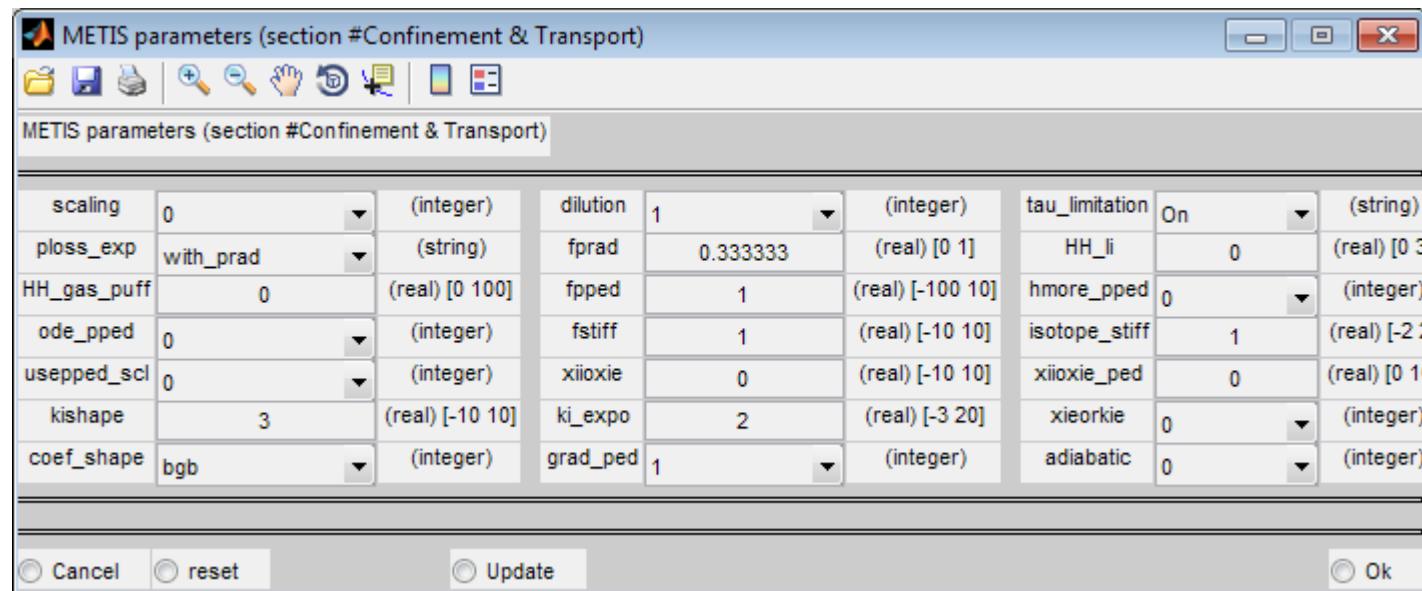
# PARAMETERS INTERFACES (DENSITY)

- Main Keys (for first use):
  - **ane**: model for density peaking factor
  - **vane**: value of density peaking factor if provided



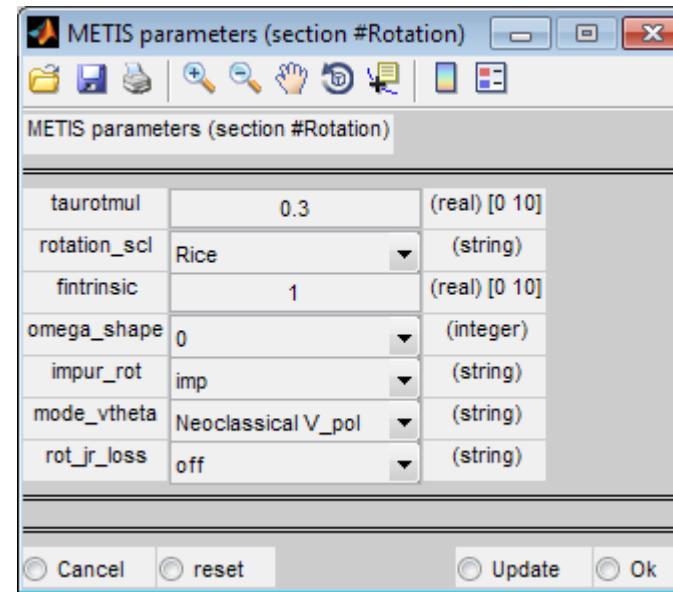
# PARAMETERS INTERFACES (PELLET)





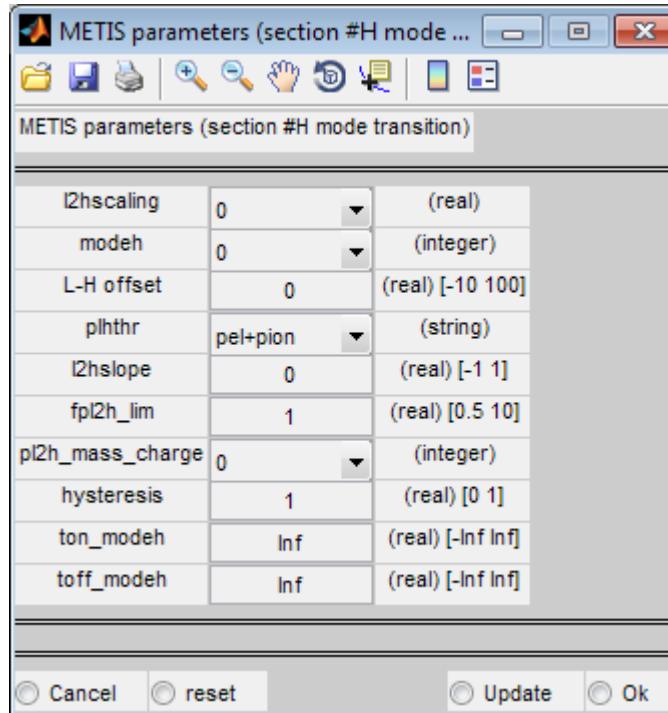
- Main Keys (for first use):
  - scaling: scaling law for energy content choice
  - fpped: pressure at the top of pedestal (factor)
  - usepped\_scl: set on scaling for pedestal pressure

# PARAMETERS INTERFACES (ROTATION)



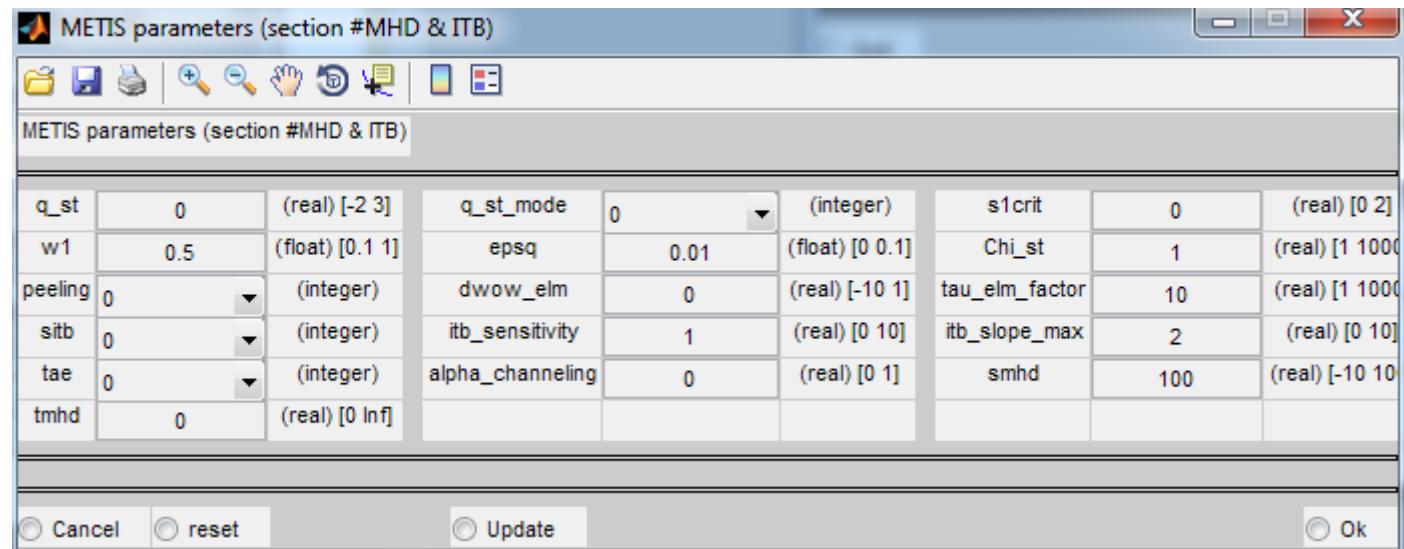
- Main Keys (for first use):
  - taurotmul:  $\tau_\varphi / \tau_E$
  - fintrinsic: fraction of intrinsic rotation taking into account

# PARAMETERS INTERFACES (H-MODE)

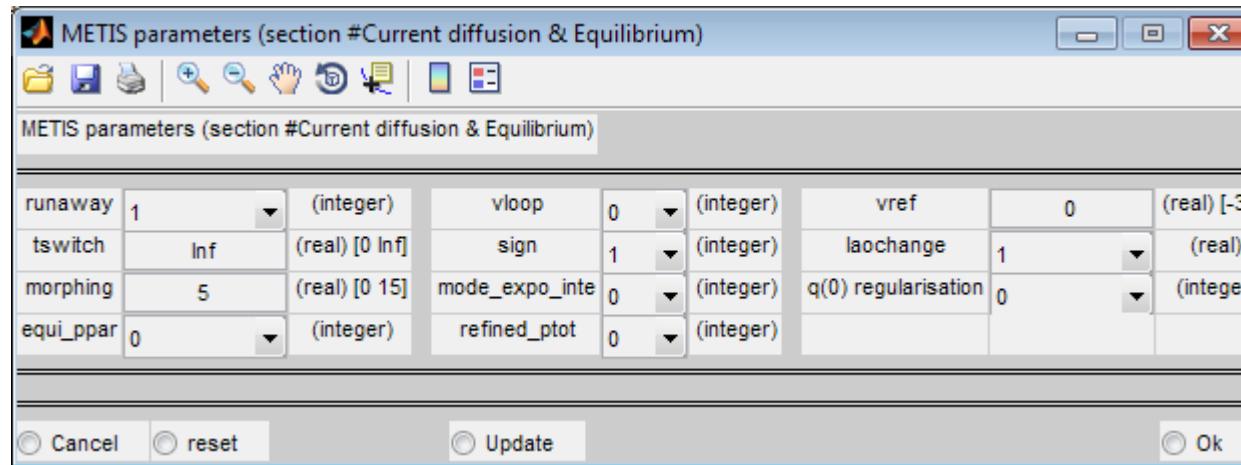


- Main Keys (for first use):
  - I2hscaling: scaling law for L->H transition
  - modeh: allow/force/prevent H-mode transition
  - I2hmul: offset for the transition

# PARAMETERS INTERFACES (MHD & ITB)

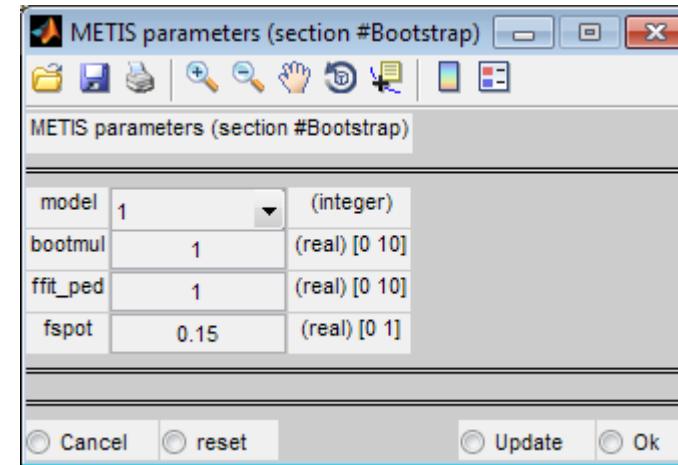


- Main Keys (for first use):
  - q\_st: set on sawteeth model
  - Chi\_st: effect of sawteeth on transport
  - smhd: limitation of  $\beta_N$



- Main Keys (for first use):
  - runaway: switch on/off runaway model (runaway can be a problem !)
  - signe: sign of  $I_p * B_{phi}$
  - Cronos\_regul: methode to compute safety factor @ magnetic axis

# PARAMETERS INTERFACES (NEOCLASSIC)



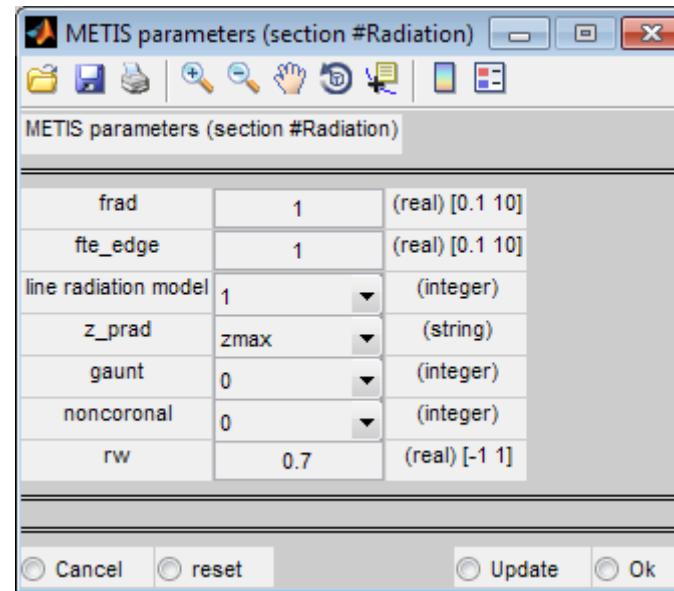
# PARAMETERS INTERFACES (BREAKDOWN)

METIS parameters (section #Breakdown and burn-through)

initial li	1.43632	(real) [0.1 10]	initial Vloop	0.03	(real) [-100 1]	berror	0	(real) [0 10]
L_eddy	0	(real) [0 1]	R_eddy	0	(real) [0 10]	C_eddy	1	(real) [0 1]
B_eddy	1	(real) [0 10]	PSI_eddy	1	(real) [0 2]	I_eddy	1	(real)
p_prefill	0.001	(real) [0 1000]	temp_vac	300	(real) [1.8 3000]	VV_volume	0	(real) [0.1 1000]
initiation_only	0	(integer)						

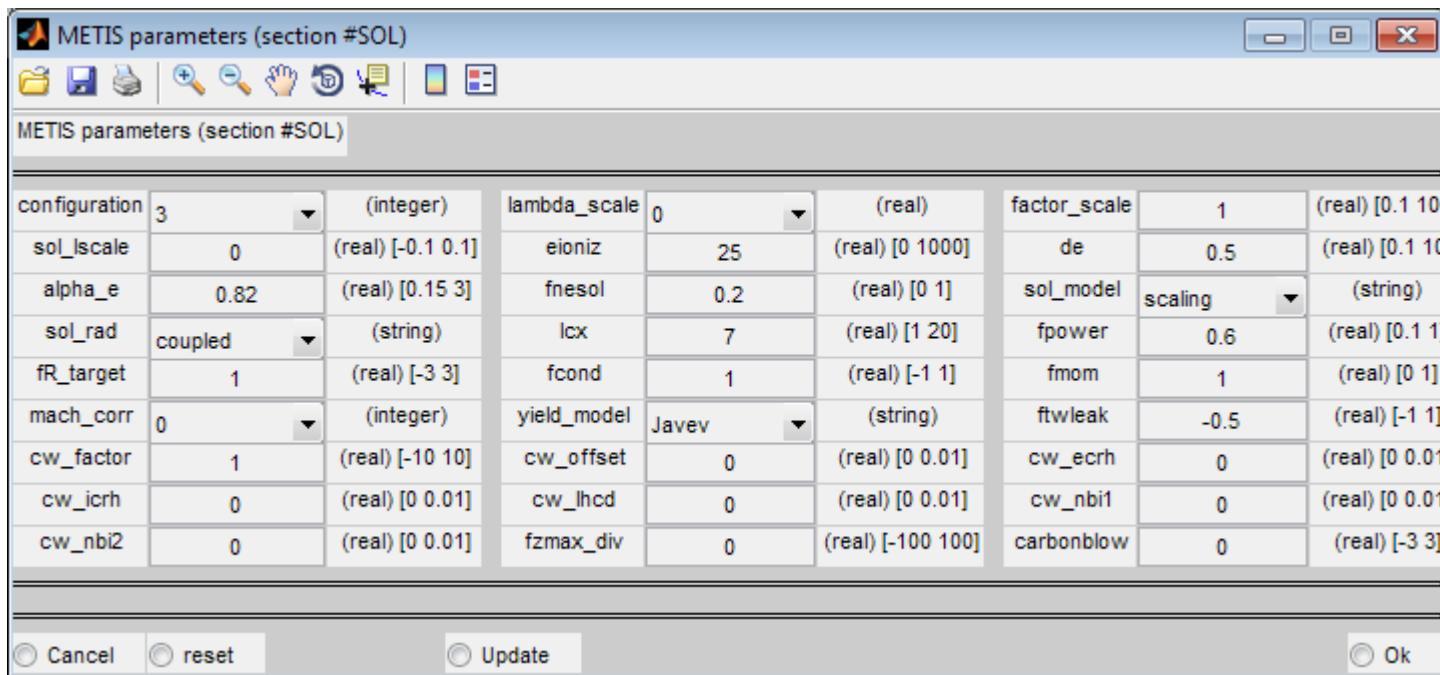
Cancel  reset  Update  Ok

# PARAMETERS INTERFACES (RADIATION)



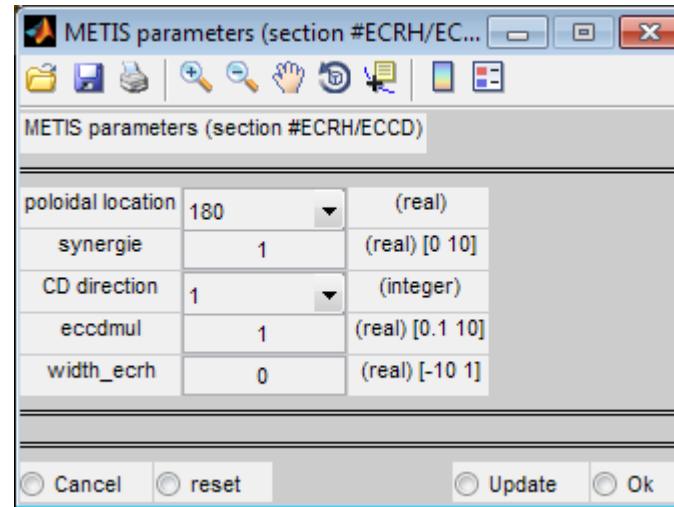
- Main Keys (for first use):
  - frad: factor applied to line radiative power
  - Line radiation model: use Matthews scaling or only cooling rate
  - rw: effective wall cyclotron radiation reflection fraction

# PARAMETERS INTERFACES (SOL)

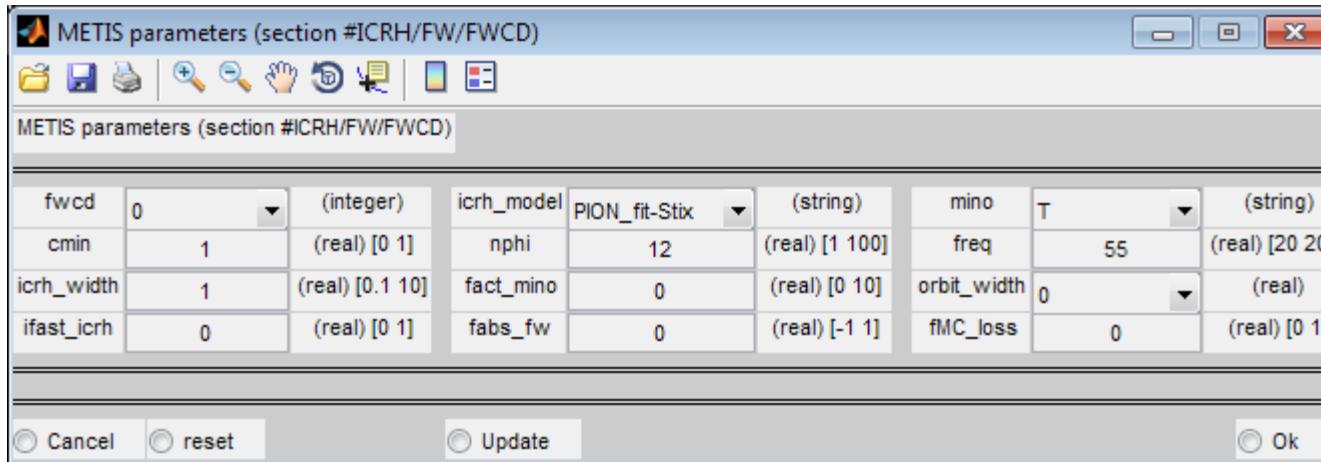


- Main Keys (for first use):
  - configuration: tokamak configuration (poloidal limiter, toroidal limiter, divertor, ...)

# PARAMETERS INTERFACES (ECRH/ECCD)

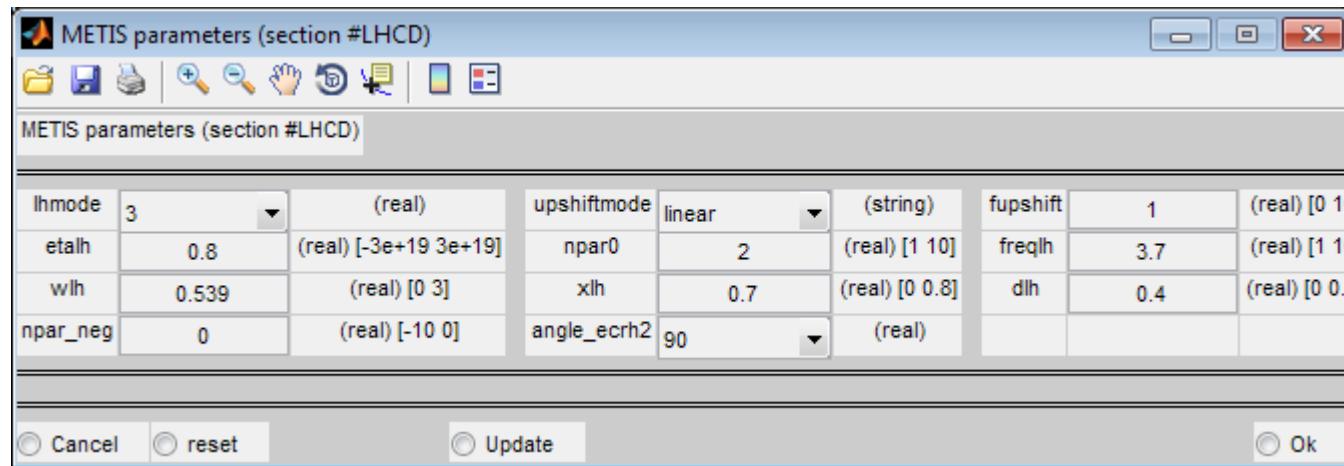


- Main Keys (for first use): all
  - angle\_ecrh: poloidal position of absorption
  - sens: co current, perpendicular or counter current



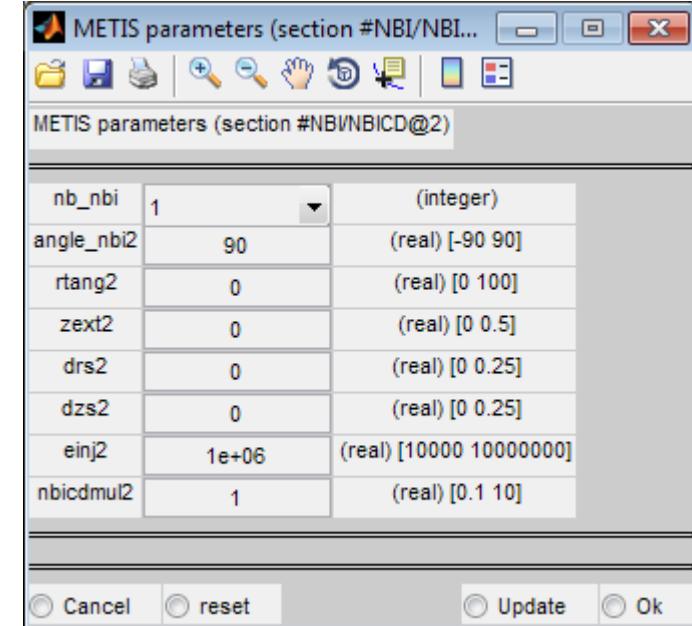
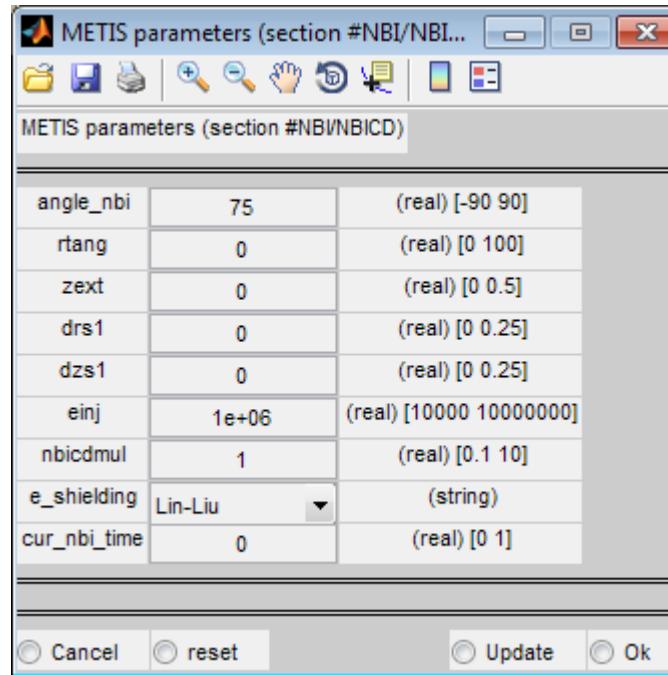
- Main Keys (for first use): all
  - fwcd: selection of heating scheme
  - mino & cmin : type and concentration of minority
  - nphi: toroidal wave number
  - freq : frequency of the injected wave (set to position of deposition)

# PARAMETERS INTERFACES (LHCD)



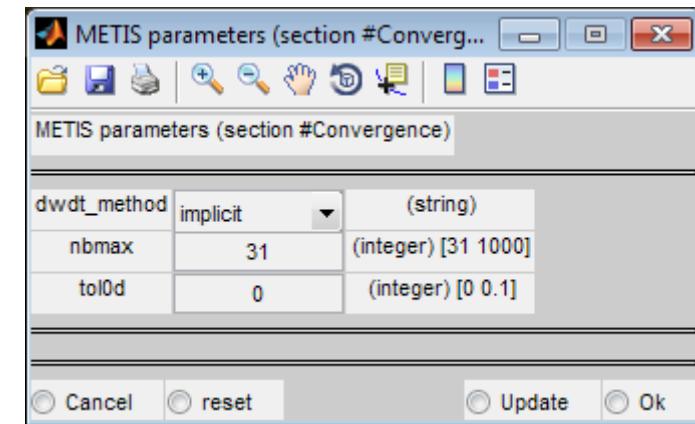
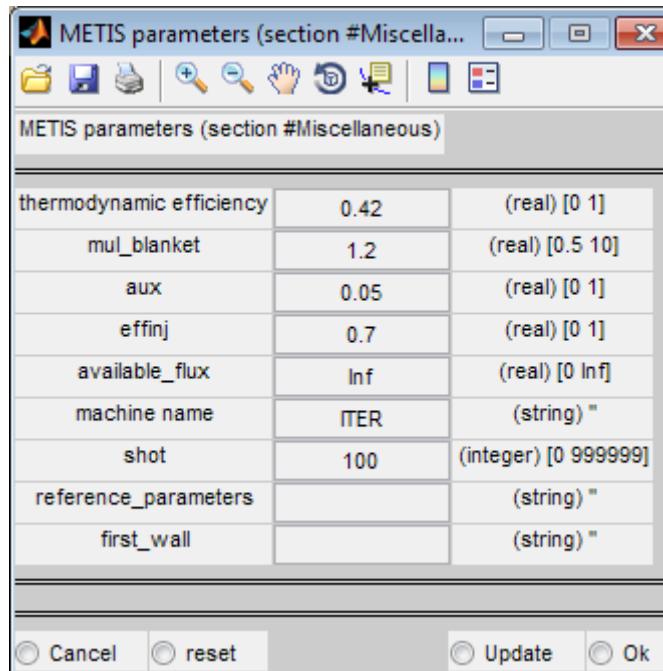
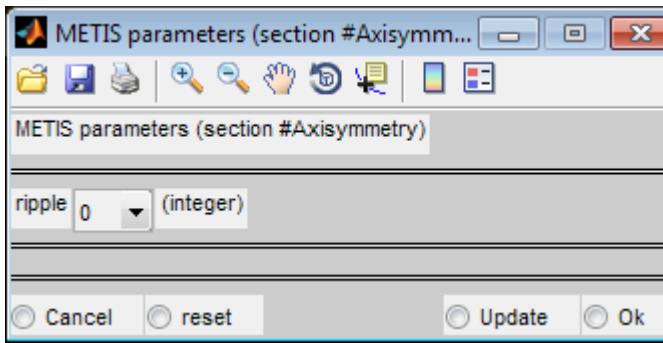
- Main Keys (for first use): all
  - Many mode: simpler to start from an example.
  - For Tore Supra can use hard X-rays bremsstrahlung data
  - Internal METIS model must be used cautiously

# PARAMETERS INTERFACES (NBICD1 & NBICD2)



- Main Keys (for first use): all
  - Standard use : provided rtang & set current direction with angle\_nbi
  - Set current direction with angle\_nbi  
(-90= counter, 0 = perpendicular, 90 = co)
  - Adjust deposition with zext

# PARAMETERS INTERFACES (OTHERS)



- Main Keys (for first use):
  - shot: shot number
  - machine: machine name
  - reference\_parameters : file name of METIS parameters as created with the button “Create reference”. **Override METIS internal tuning!**

# PARAMETERS INTERFACES (IMAS OR ITM/UAL)

METIS parameters (section #UAL)

init_output_ids	0	(integer)	restart		(string) "	summary	1	(integer)
core_profiles	1	(integer)	core_transport	1	(integer)	core_sources	1	(integer)
edge	1	(integer)	numerics	1	(integer)	equilibrium	1	(integer)
equi_extrap	1	(integer)	Convex_LCFS	1	(integer)	fixed_grid	0	(integer)
nb_points_pol	65	(integer) [35 255]	nb_points_radial	51	(integer) [33 301]	COCOS	11	(integer) [1 1]

METIS parameters (section #Occurrence UAL)

pulse_schedule_occurrence		(string) "
summary_occurrence		(string) "
core_profiles_occurrence		(string) "
core_transport_occurrence		(string) "
core_sources_occurrence		(string) "
edge_occurrence		(string) "
numerics_occurrence		(string) "
equilibrium_occurrence		(string) "

# **INSIDE METIS**

- **METIS is provided with documentation pdf files**  
→ in directory “doc” where METIS is installed
- In the GUI and in Matlab command line:
  - ✓ Parameters tooltip
  - ✓ Data description
- For evolution mode in Matlab command line:
  - ✓ Simulink help : simmetis, zerodevolution
  - ✓ IMAS help : metis4imas
- For external data used :
  - ✓ `external_data_rule_for_METIS.m`

- **Standalone METIS data structure:**
  - **Input data:** `z0dinput`
  - **Output data:** `post`
    - `post.zerod`: 0d data
    - `post.profil0d`: profiles
    - `post.z0dinput`: input data used during simulation

**Evolution mode data structure:**

**`z0dstruct`**

- **z0dinput structure:**
  - **Information:**
    - **z0dinput.info:** parameter tooltips
    - **z0dinput.zsinfo:** 0D data descriptions
    - **z0dinput.profinfo:** 1D data descriptions
  - **Data:**
    - **z0dinput.option:** parameters
    - **z0dinput.cons:** references (Ip, powers, ...)
    - **z0dinput.geo:** plasma geometry
    - **z0dinput.exp0d:** experimental data + LCFS pts

## **ADVANCED METIS FEATURES**

- METIS commands:

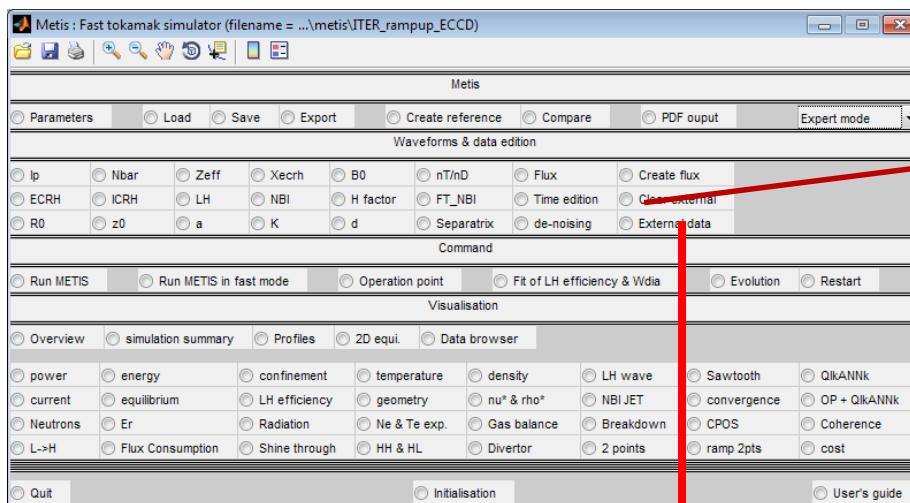
- metis\_load: load and update a simulation
- metis\_save: save a simulation (from workspace)
- metis\_fast: fast simulation (selected time slices)
- metis\_run: full simulation (all time slices)
- metis\_fitlh: search for LHCD current drive efficiency
- metis\_update\_tests: update non regression tests

- Call METIS functions in a mfile:
  - zerod\_init: initialise a simulation
  - zerod\_fast: fast simulation (selected time slices)
  - zerod: **full simulation (all time slices)**
  - zerodevolution: one time step simulation
  - metis4imas: run metis inside IMAS framework
  - metis4itm: run metis inside ITM framework

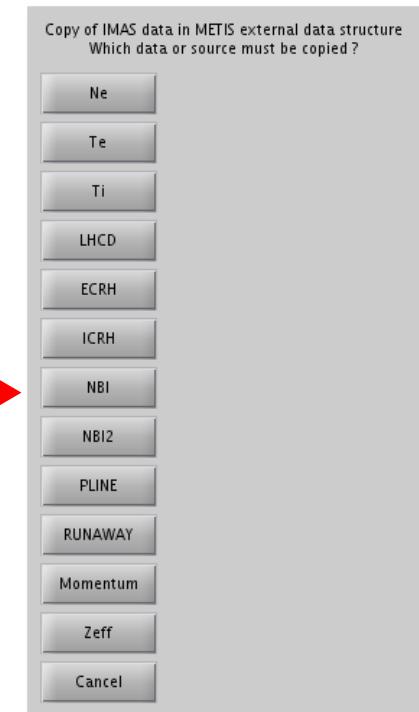
- METIS can use external data for:
    - Heat and current drive sources :  
LHCD, ICRH, ECCD, NBICD, Pline, Runaway
    - Kinetic profiles:  $N_e$ ,  $T_e$ ,  $T_i$ ,  $\Omega_\varphi$
  - External data override internal METIS computation
  - Heat sources are renormalized on references.
  - Density is renormalized on  $\bar{n}$  reference
- Details available in file:  
`.../zerod/external_data_rule_for_METIS.m`

# METIS & EXTERNAL DATA GUI

- METIS GUI for external:



Remove external data  
(METIS stops to use external data)



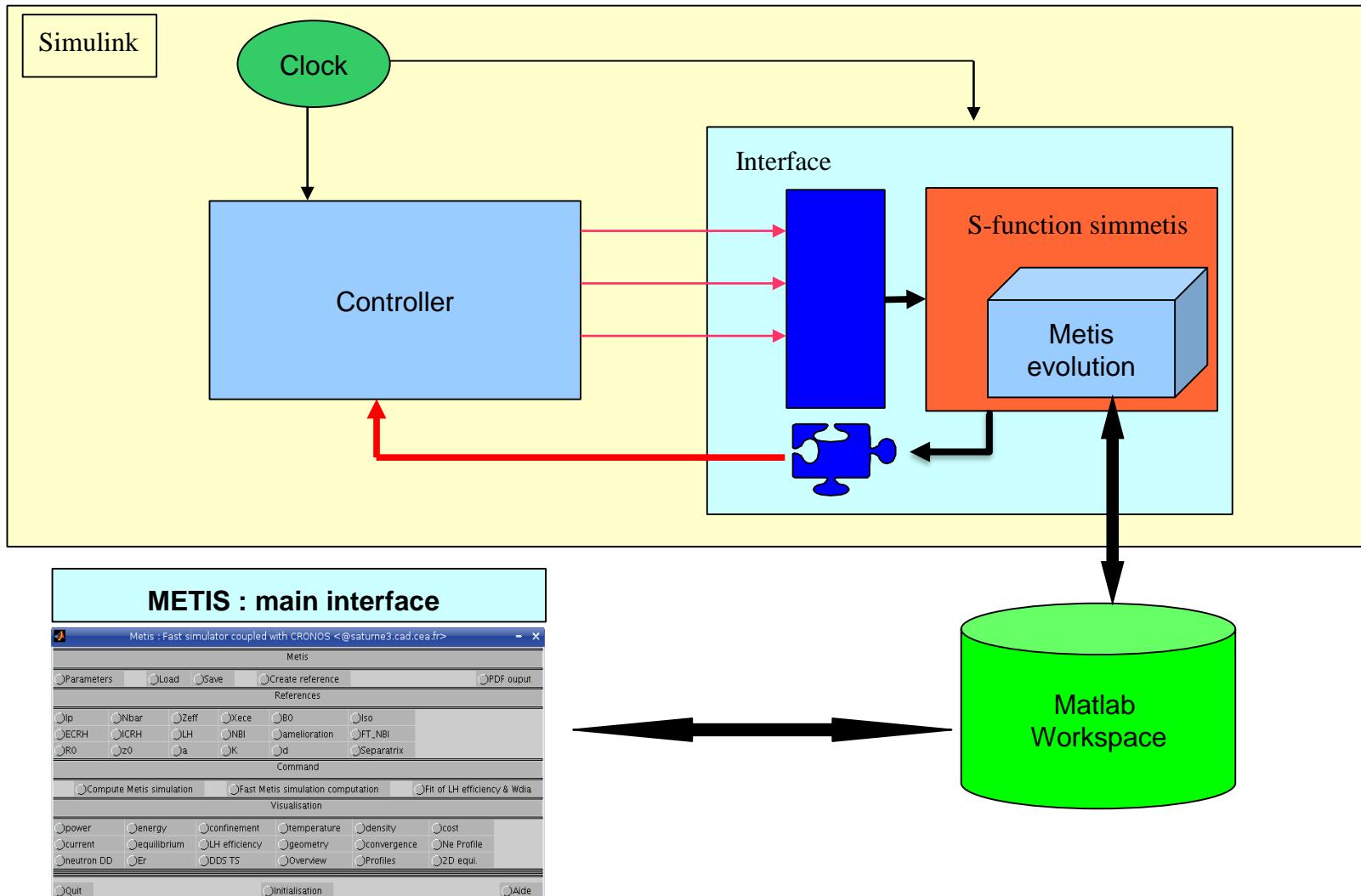
This menu depends on context

# **METIS IN SIMULINK**

- ✓ METIS call from Simulink = S-function `simmetis`
- ✓ Standard S-function Input & output
  - `simmetis` use one time step METIS computation:  
`zerodevolution`
- Some documentation is written inside functions
  - ✓ `help simmetis` or `help zerodevolution` (in Matlab)
  - ✓ S-function documentation :

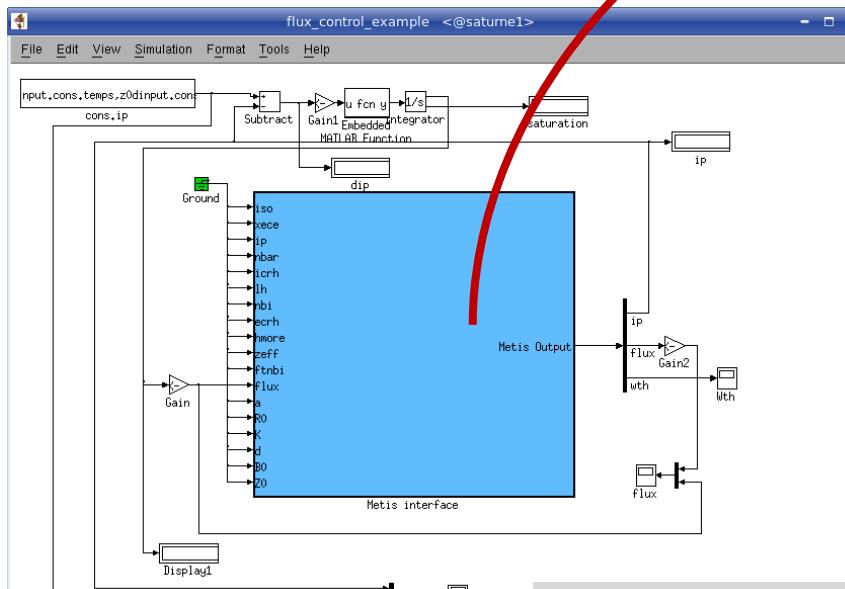
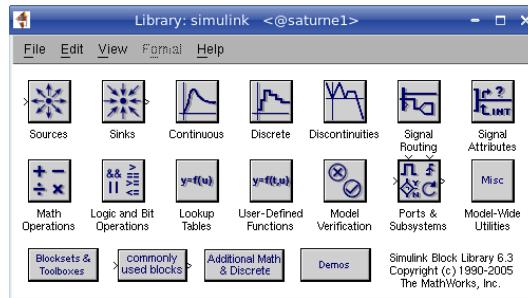
<http://www.mathworks.fr/fr/help/simulink/slref/sfunction.html>

# METIS EVOLUTION IN SIMULINK

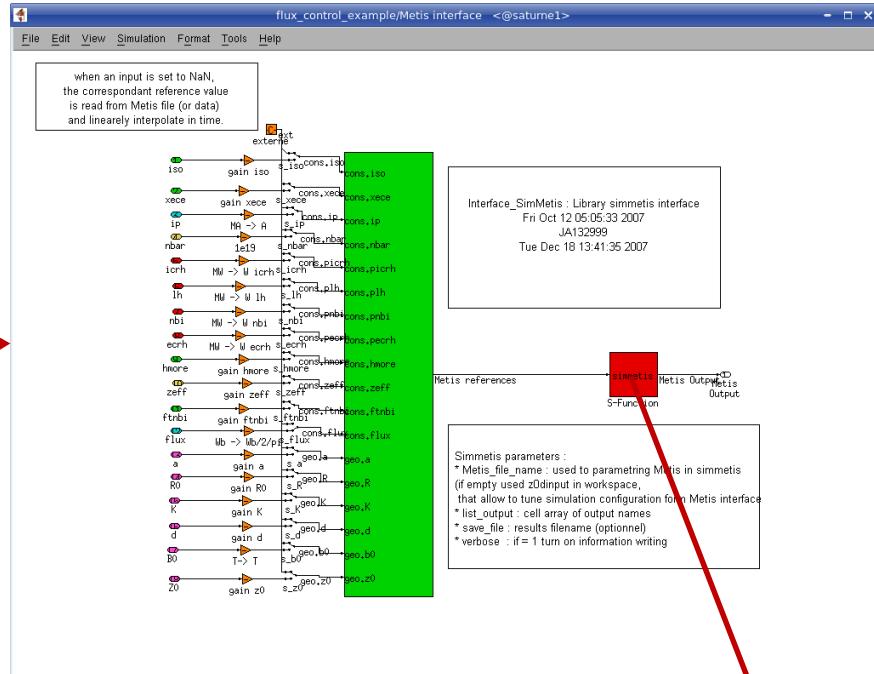


# METIS INTERFACE TO SIMULINK

## Simulink



Workflow with METIS



Interface to simmetis

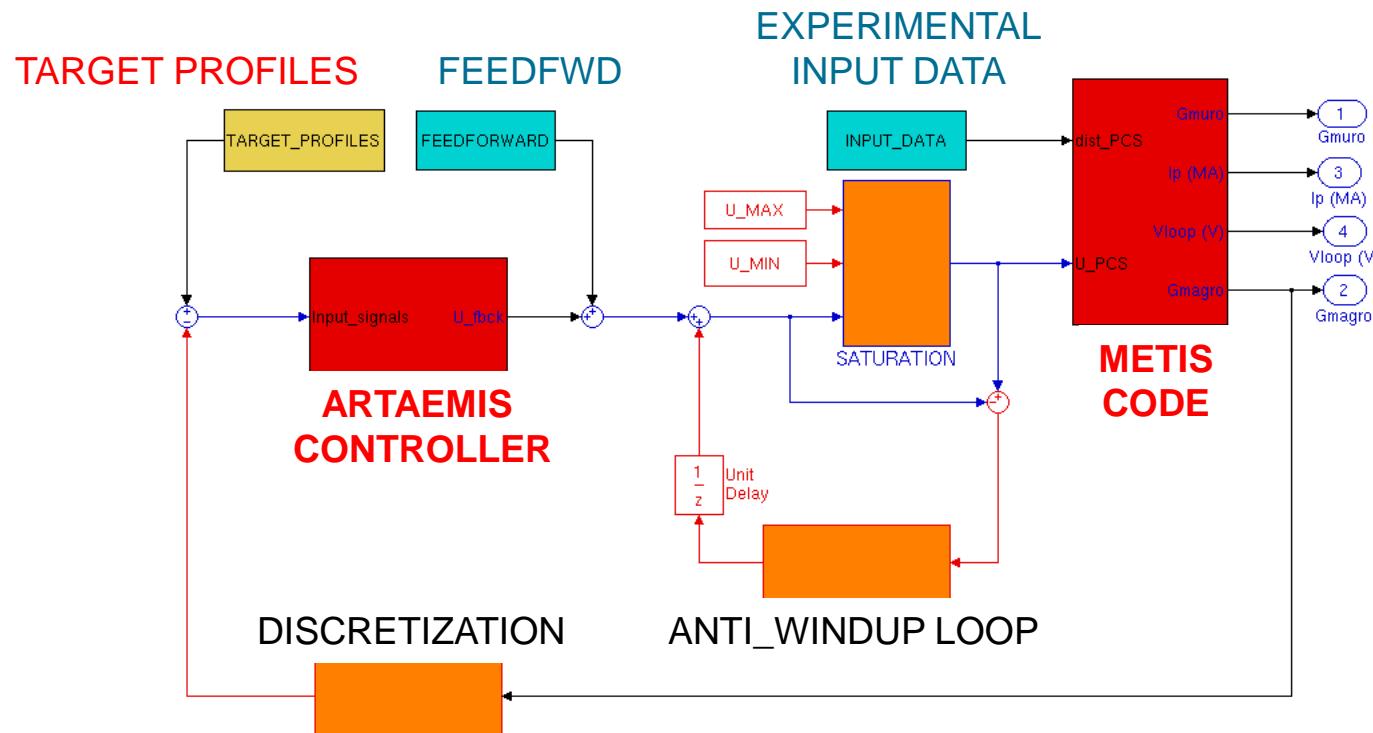
S-function simmetis

- Sample workflow for simmetis testing  
(under .../zerod/):
  - test\_simmetis.mdl : simple test
  - flux\_control\_example.mdl : poloidal flux feedback test
- Sample interface between Simulink and simmetis  
(under .../zerod/):
  - interface\_simmetis.mdl : switches, multiplexor + S-function call
- For testing:
  - Launch METIS + load a simulation
  - Open Simulink workflow, tune simulation parameters, and run it

- METIS takes default parameters and references in Matlab workspace
- METIS GUI still active with Simulink
- ✓ Only active selected references and parameters are override by Simulink data
- All METIS internal data copy in Matlab workspace
- Simulink can access to any METIS data

- Last (current time) METIS data are available in Matlab workspace from Simulink:
  - **zerod\_simmetis**: 0D METIS data
  - **profil0d\_simmetis**: 1D METIS data
  - **cons\_simmetis**: references (use by METIS)
  - **geo\_simmetis**: geometry (use by METIS)
  - **sepa\_simmetis**: if LCFS given by points
- More data available in global structure:  
see **simmetis** online help

# METIS & SIMULINK USE CASE

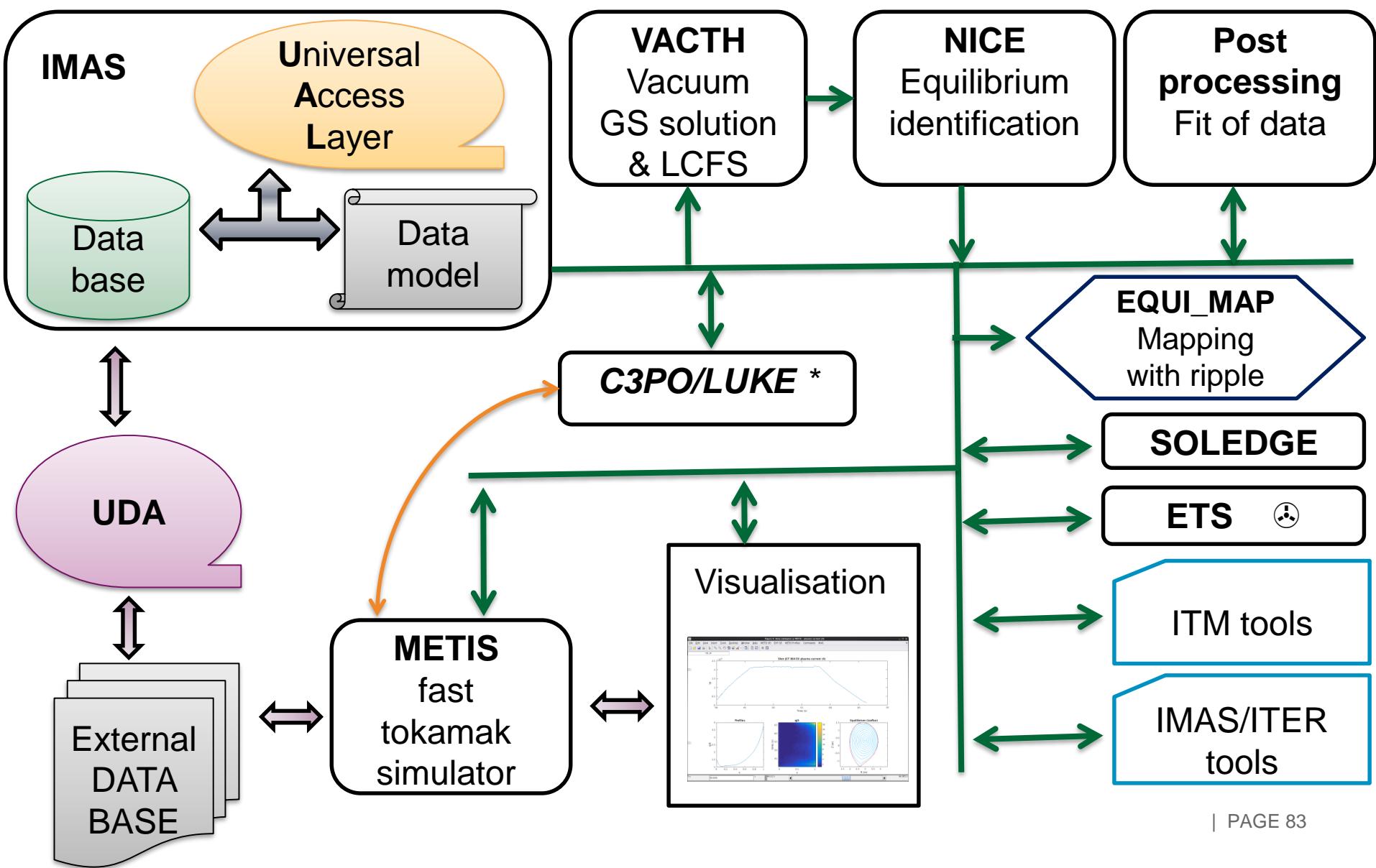


- ✓ Closed loop ARTAEMIS/ METIS simulations to extend control to steady
- ✓ Experimental input data is taken from DIII-D shot

[ITR/P1-20 Integrated Magnetic and Kinetic Control of Advanced Tokamak Scenarios Based on Data-Driven Models D. Moreau et al, 24th IAEA Fusion Energy Conference ]

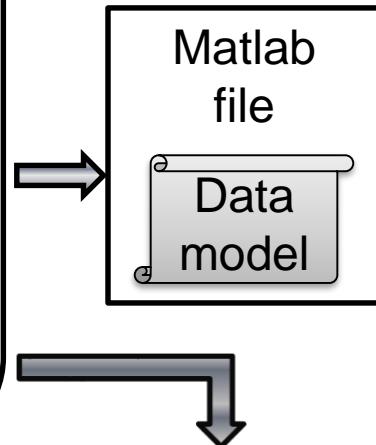
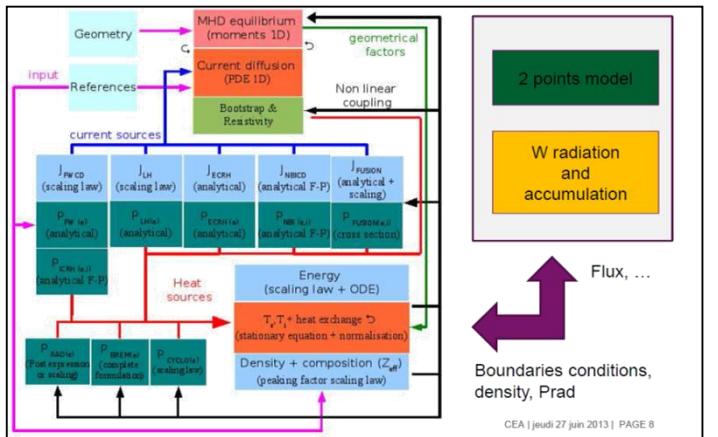
# **METIS AND IMAS**

# IMAS MODELING ARCHITECTURE FOR WEST



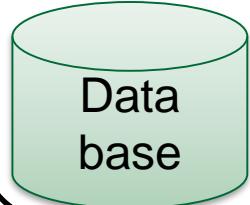
# METIS IS CONNECTED TO UAL

## METIS fast tokamak simulator



IMAS

**Universal  
Access  
Layer**



- Allows to call ITM or IMAS tools using METIS data set.
- Ready for analysis shot data, mixing both experimental data (fitted by ProfileMaker) and METIS prediction
- IDs:

  - Core\_profiles
  - Core\_sources
  - Core\_transport
  - Equilibrium
  - Pulse\_schedule
  - Summary
  - Dataset\_description
  - transport\_solver\_numerics

# METIS IS CONNECTED TO IMAS UAL (2/3)

## METIS & IMAS

- METIS is a fast tokamak plasma simulator.
- IMAS is the modelling infrastructure for ITER (data model + access layer named UAL).
- METIS can, both, read data from and write data into IMAS UAL.
- METIS can use data provided by other tools connected to IMAS infrastructure.
- METIS can export Matlab file (matfile) containing image of ITER data model for standalone use.
- METIS can display, for comparison purpose, both METIS native data and IMAS data.

# METIS IS CONNECTED TO IMAS UAL (3/3)

## ■ New capability interests for METIS:

- Modelling shots from data read directly into IMAS coming from machines not directly linked to METIS.
- Analysing shot data mixing both experimental data (fitted by ProfileMaker) and prediction (example: current diffusion) for data consistency.
- Feed IMAS data base (starting with ITER simulations) to provide data to others codes under IMAS infrastructure.
- Export IMAS formatted structures in a matfile.

## metis4imas.m = interface UAL ⇔ METIS

- ✓ Drives METIS (call methods)
- ✓ Handles input coming from Kepler and provides information to Kepler
- ✓ Reads and converts input IDS data
- ✓ Maps IDSs data and writes in database

### Remark:

use imasdb command under Matlab to set the default user, machine and version that will be used by metis4imas later.

**shot** = shot number.

**run** = run number for this.

**occurrence** = input IDS scenario occurrence in Kepler  
(default = 0).

**Method** = METIS command (see below).

**time** = time scalar or vector for which METIS must be run. If empty, read all time slices of the IDS and use IDS vector time as input.

**codeparam\_filename** = codeparam (see below).

**interpolation\_methode** = interpolation method used for data extraction (see UAL user guide ).

- **test** = test the function (use test data and create IDSs).
- **auto\_test** = complete test of metis4imas (whole functions)
- **full** = whole shot computation, full METIS mode
- **fast** = whole shot computation using fast METIS mode
- **Init** = initialization of the evolution mode of METIS.
- **one\_time** = compute plasma evolution for one time step.
- **read** = read UAL data and return in Matlab structure
- **<filename>** = load a METIS simulation and create associated IDS Matlab data structures.

## Codeparam contains:

- all standard METIS parameters
- UAL specific parameters that allow to control which IDS are written (+ occurrence choice)

## Sources of codeparam:

- XML string
- XML file
- Input IDS pulse\_schedule (if codeparam empty)
- Default values if not specified  
(no input IDS pulse\_schedule & codeparam empty)
- Matlab structure (for testing only)

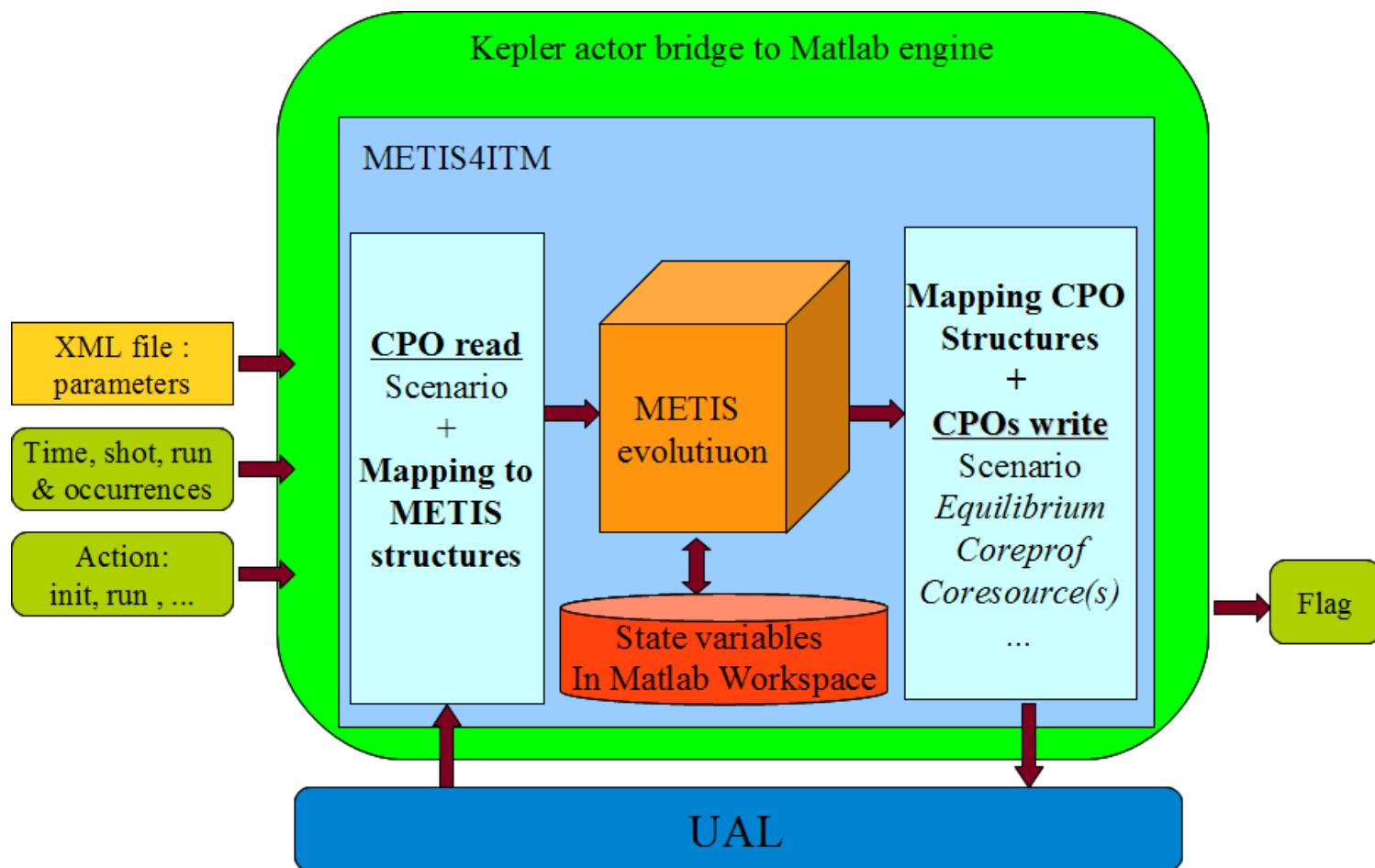
## Standard output:

- `err_flag` = error code, must be = 0 if no error
- `output_data` = Matlab structure containing the counterpart of IDSS structures in Matlab compatible format.

## METIS internal state:

- stored in appdata `IMAS_Z0DSTRUCT`
- allows to access to any METIS data and return it in Kepler

# METIS ACTOR (IMAS & ITM)



# **METIS INTERNAL RUNAWAY MODEL**

- METIS have already a simplified model for runaway
  - Total current is predicted:  
0D model for total runaway density/current  
[H. Smith et al, Physics of Plasma 13 (2006) 102502]
  - Current density shape given by seed shape  
(with exponential dependence):  
[F. Sourd, Phd, Université de Provence, 2004]
  - Taking into account as a source in current diffusion solver of METIS
  
- Mainly use for ramp-up:  
Change of effective resistivity during ramp-up

# **METIS & QUALIKIZ NEURAL NETWORK**

- Qualikiz neurak network:
  - Neural network interpolation of Qualikiz
  - 10D version in METIS:  
**limited capabilities, consider results with wariness**
- Run as a post processing of METIS:
  - Compute electron density and temperature and ion temperature
  - Predicted profiles can be used as METIS external data

Ref: J. Citrin et al 2015 Nucl. Fusion 55 092001

K. L. van de Plassche et al Phys. Plasmas 27, 022310 (2020); doi: 10.1063/1.5134126

# SOLVER = POWER BALANCE

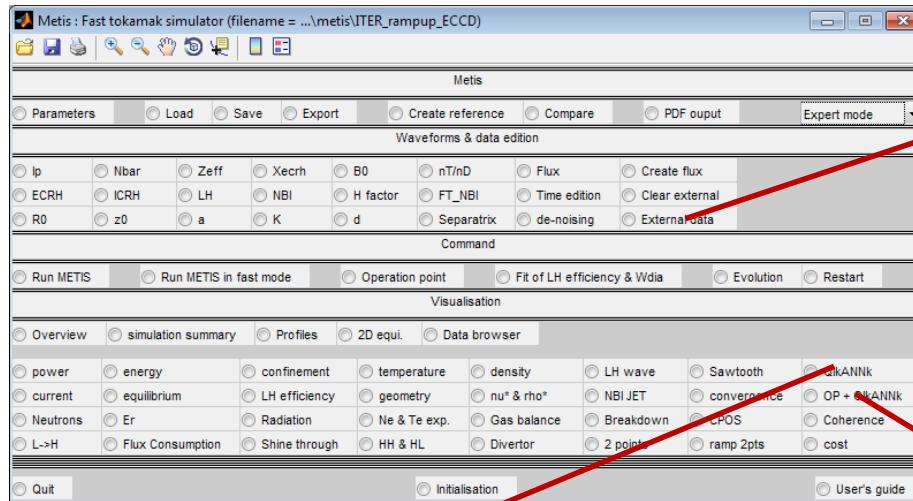
- Search for solution that equals flux computed from sources and from closure formula (transport coefficients).
- Steady state solution
- The solver uses simulating annealing for optimization/convergence (quite fast, very simple to implement, robust and no need of derivatives)
- Sources are got from Metis
- Equilibrium is got from Metis
- Neoclassical ion heat transport is computed using Chang-Hinton formula (ref: Tokamak, Wesson). It is added to Qualikiz NN flux.
- Ware pinch computed in Metis is added to particle pinch computed by Qualikiz NN
- Equipartition heat term (electron/ion energy transfer by collision) is updated in the convergence loop

# OPTIONAL TRICKS

- A factor can be applied to ion neoclassical heat transport
- Electron heat diffusivity can be clamped above some fraction of ion neoclassical heat diffusivity
- Particle diffusivity can be clamped above some fraction of ion neoclassical heat diffusivity
- Fast particle effect can be included using JETTO trick (reduction of  $\frac{R\nabla T_i}{T_i}$  as  $\frac{W_{th}}{W}$ )
- Flux ratio (ion/ electron or electron/ion) can be limited to some given value
- Threshold shift can be taken into account
- Time dependence can be mimicked by multiplying flux computed from sources by:

$$\frac{P_{loss} - \frac{dW_{th}}{dt}}{P_{loss}}$$

# TWO MODES: FULL SCENARIO OR SELECTED TIME SLICE



External data menu with item  
**QUALIKIZ**. Allows to select  
between Ne, Te and Ti

Full scenario prediction

Selected time slice

Remark: in selected time slice, a loop of convergence is performed between Qualikiz neural network prediction and METIS. Ne, Te and Ti are predicted by Qualikiz neural network and METIS predicts all other quantities.

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IRFM  
SPPF