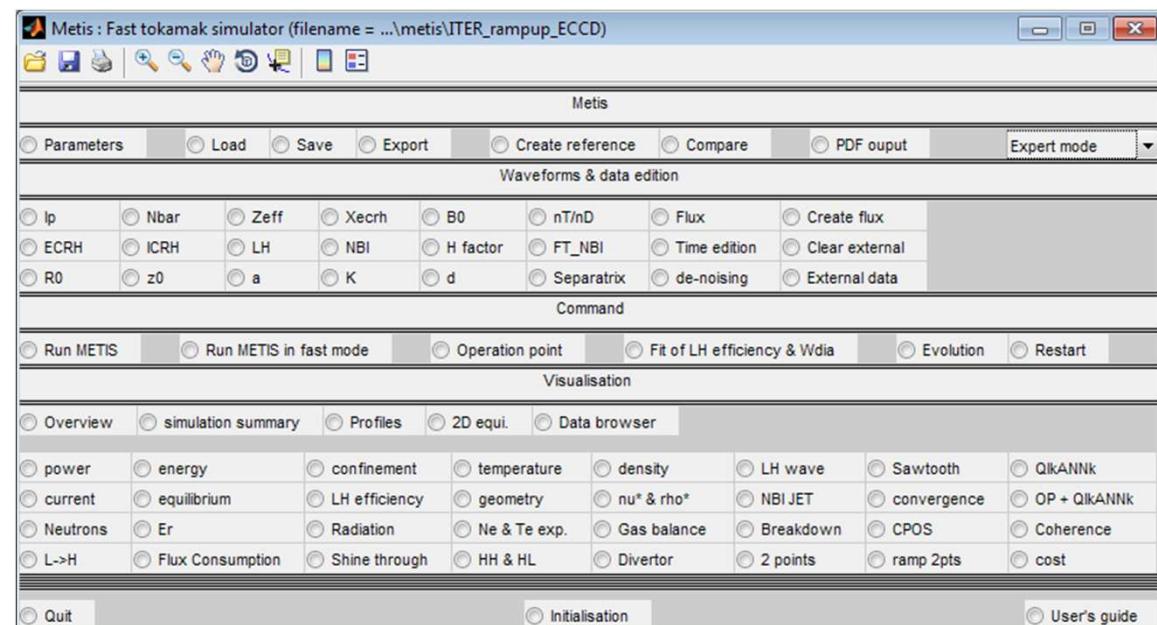


DE LA RECHERCHE À L'INDUSTRIE



[www.cea.fr](http://www.cea.fr)

# METIS HOWTO



Introduction to METIS | Jean-François Artaud

FRIDAY, 02 FEBRUARY 2018

- **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

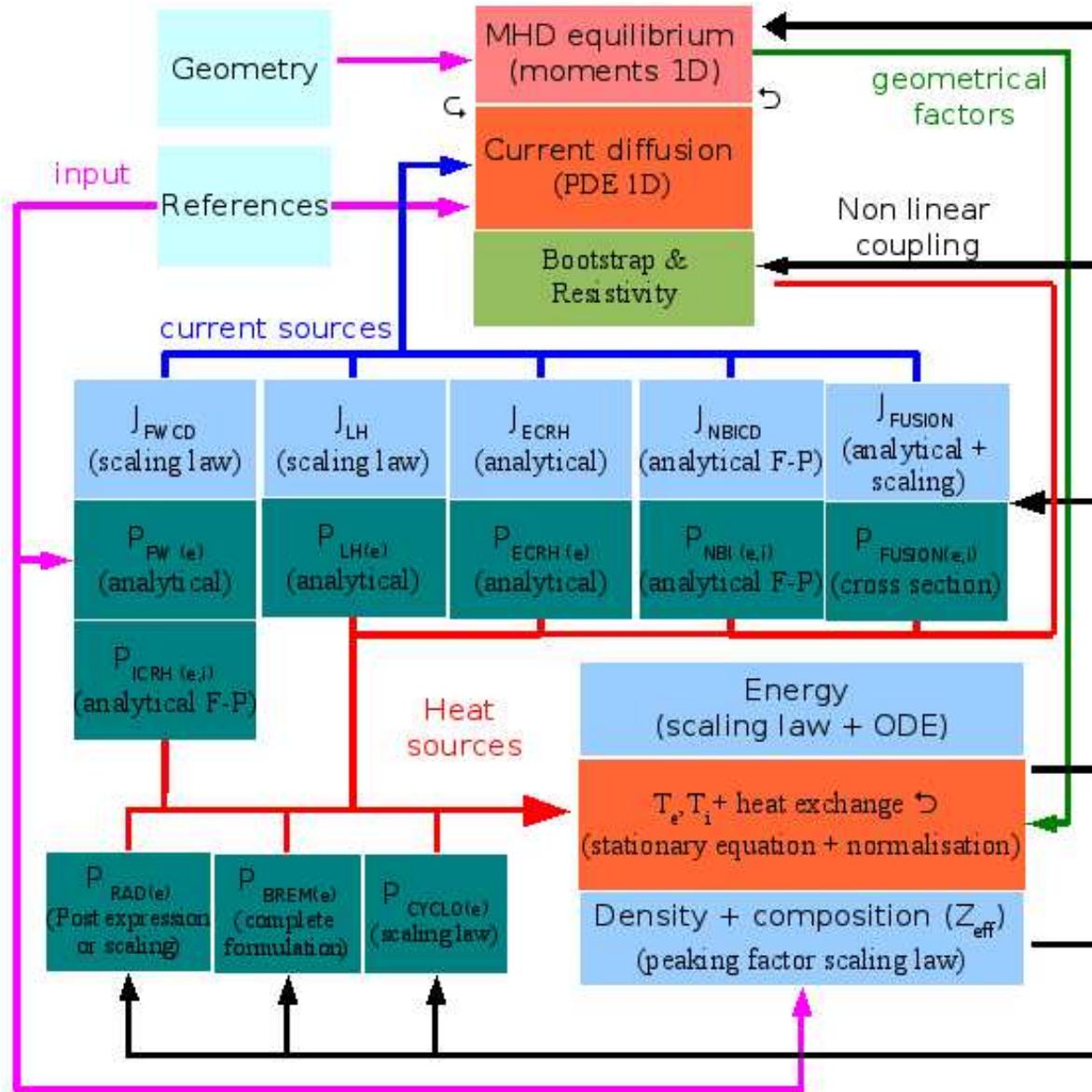
<b>METIS overview</b>	<b>slide 5</b>
<b>Launch METIS</b>	<b>slide 14</b>
<b>Overview of METIS GUI</b>	<b>slide 25</b>
<b>Use METIS with GUI</b>	<b>slide 29</b>
<b>Expert &amp; standard Mode</b>	<b>slide 44</b>
<b>LCFS generator</b>	<b>slide 47</b>
<b>Main Parameters for first use</b>	<b>slide 51</b>
<b>Inside METIS</b>	<b>slide 70</b>
<b>Advance features</b>	<b>slide 74</b>
<b>METIS in Simulink</b>	<b>slide 79</b>
<b>WEST scenario preparation</b>	<b>slide 87</b>
<b>JT-60SA scenario preparation</b>	<b>slide 99</b>
<b>METIS &amp; IMAS</b>	<b>slide 111</b>
<b>Runaway electrons in METIS</b>	<b>slide 122</b>
<b>METIS &amp; qualikiz Neural Network</b>	<b>slide 124</b>
<b>Other features</b>	<b>slide 129</b>

# METIS OVERVIEW

- **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**

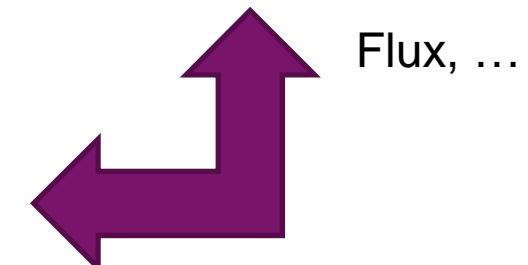
- ✓ Mixed 1D and 0D equations
  - ✓ Current diffusion 1.5D with moment equilibrium
  - ✓ Source profiles deduced from simple models
  - ✓ Global energy content from 0D ODE (scaling, transients)
  - ✓ Temperature profiles : stationary 1D solution,  $\chi$  scaled to  $W_{th}$
  - ✓ All non-linearities solved (dependence of sources on profiles, fusion power, He ash transport)
  - ✓ Bootstrap and resistivity :O. Sauter et al, Phys. Plasmas 6 (1999) 2834
- ✓ 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



2 points model

W radiation  
and  
impurity  
accumulation



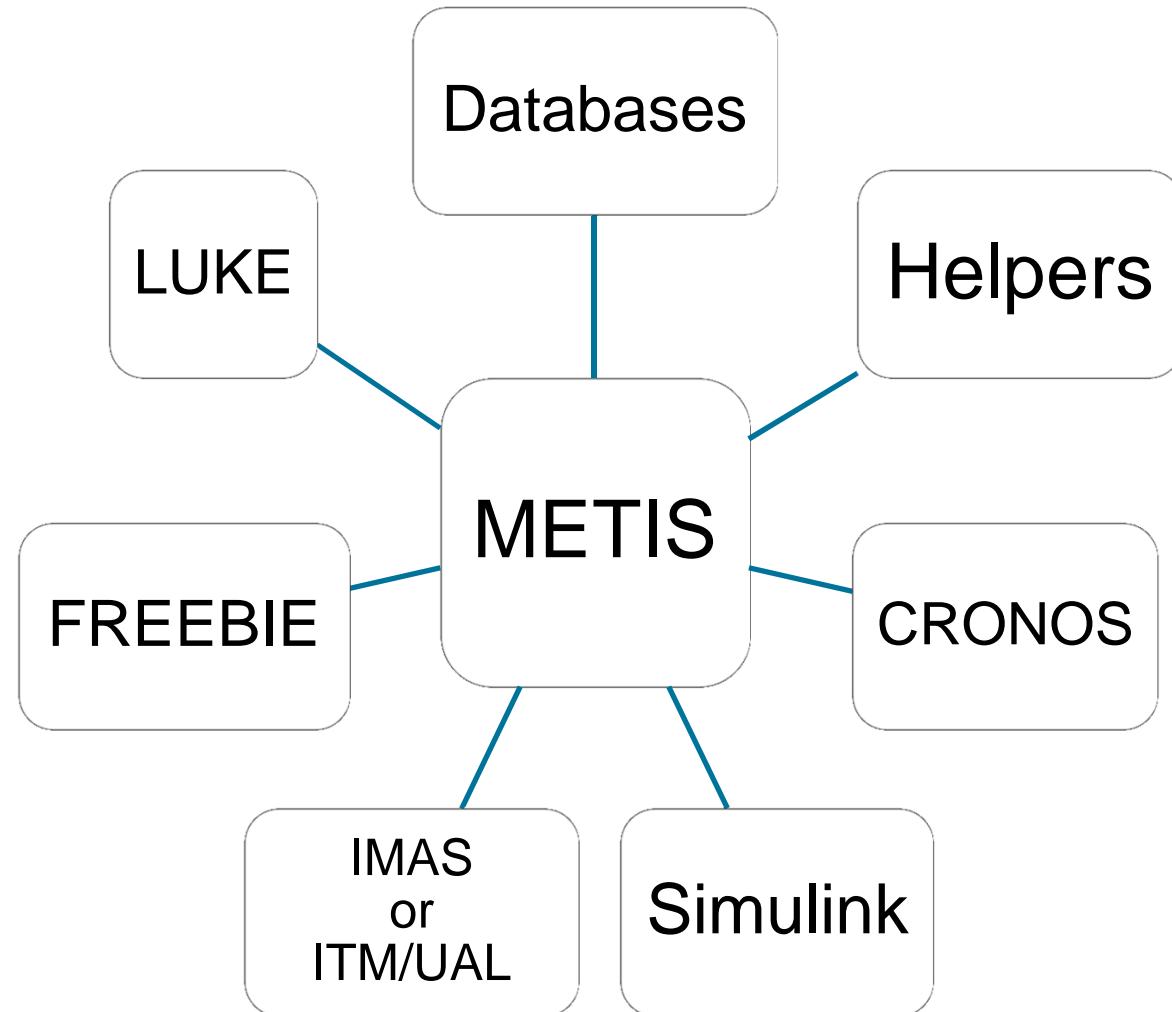
## METIS has 2 main use cases:

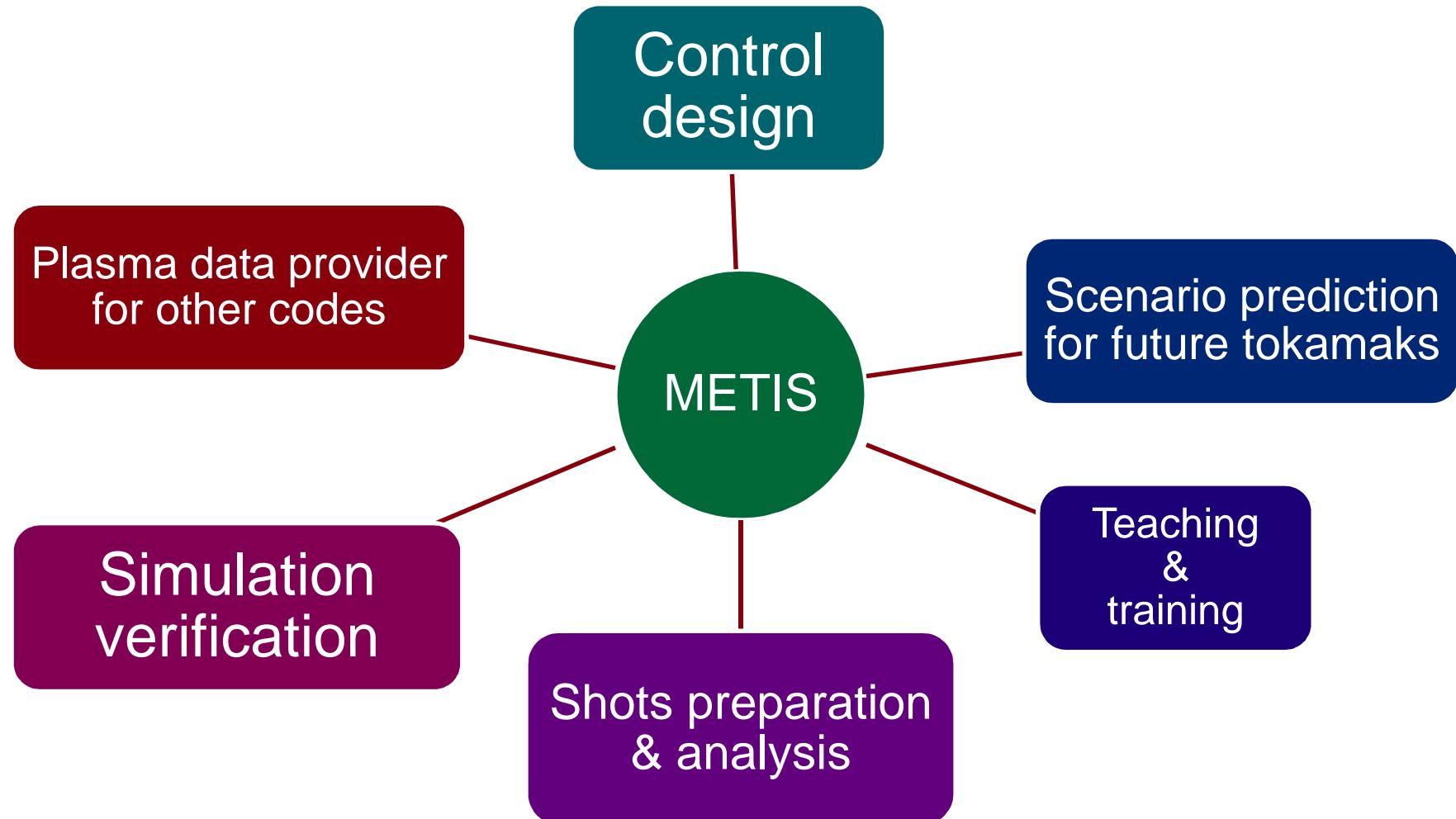
- **Stand-alone full scenario simulation**
  - CRONOS module
  - Matlab function with data base access or UAL connection
  - Standalone runtime (no Matlab license need) with data base access or UAL connection
- **One time step solver in a workflow**
  - Use inside Simulink workflow (simmetis)
  - Use inside Kepler workflow through Matlab actor

- Direct connection:
    - Tore Supra / WEST: pre and post shot access (Tslib)
    - JET: MDS+ access
    - 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**

- **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
- **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)

- **Pre-installed version:**
  - On zone intra:  
**any server (but Sirrah is faster)**
  - On zone partenaires IRFM servers:  
**Cephee & Andromede**
  - On EU-IM servers
  - ITER servers

- **Source of the code:**

- **On zone intra:**

**/ZONE\_TRAVAIL/JA132999/public/metis4itm/trunk**

- **On zone partenaires:**

**/donnees/JA132999/public/metis4itm/trunk/metis**

- **In EU-IM Gforge server:**

**<http://gforge.efda-itm.eu/gf/project/metis4itm>**

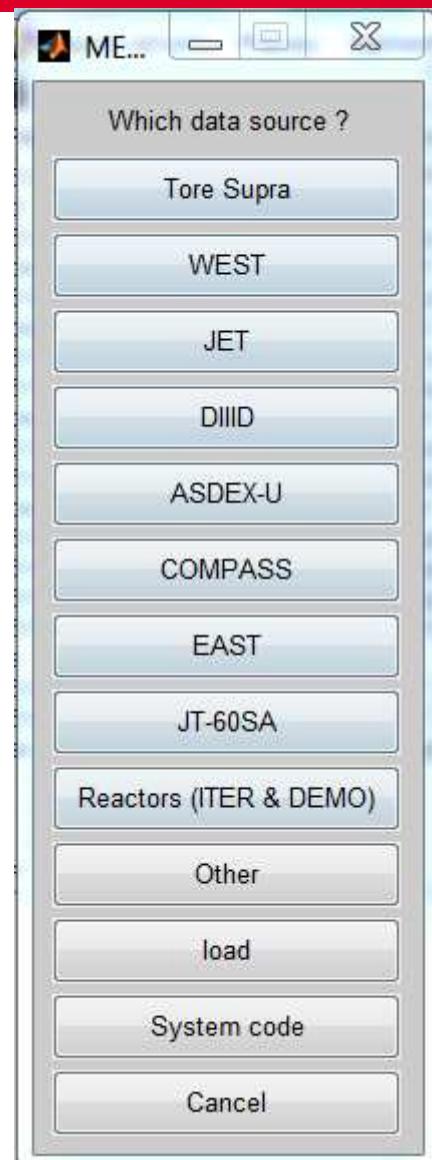
- **Compiled versions (Windows):**
  - **On Erakis server :**  
**C:\Users\JA132999\Documents\Metis64**
  - **Request the installer file:**  
send me a email: [jean-francois.artaud@cea.fr](mailto:jean-francois.artaud@cea.fr)  
need a license for non IRFM user (but it is free)
  - **First installation:**  
**Need to have administrator right for the first installation**

## Pre-installed version:

- **Local PC version :**
  - Launch: “metisPC64.exe” (Windows 7, ...)
- **Intra version**
  - Load module: module load matlab/2012B
  - Launch: /ZONE\_TRAVAIL/JA132999/public/metis4itm/trunk/metis
- **Andromede version**
  - Load module: module load python/3.3
  - Launch: /donnees/JA132999/public/metis4itm/trunk/metis

- Two ways:
  - outside matlab : just launch **metis** script  
**inside directory .../metis4itm/trunk**
  - Inside matlab :  
**addpath to metis4itm**  
**addpath .../metis4itm/trunk**  
**and launch metis**

# RUNNING COMPILED VERSION OF METIS



METIS_HELP.pdf	26/02/2013 14:25	Adobe Acrobat D...
METIS_JET_73344	18/05/2017 15:24	Microsoft Access T...
Metis_splash_screen3.png	04/06/2012 14:51	Image PNG
<b>metisPC64.exe</b>	18/05/2017 10:22	Application
MetisPC64.log	19/05/2017 09:33	Document texte



## How to run it:

- 1) Source IMAS environment:

```
module use /work/imas/etc/modulefiles  
module load imas/3.9.1/ual/3.5.3
```

- 2) Select a device:

```
imasdb WEST
```

- 3) Launch METIS script (public version):

```
/donnees/JA132999/public/metis4itm/trunk/metis
```

## How to run it:

- 1) Source IMAS environment:

```
module load imas
```

- 2) Select a device:

```
imasdb WEST
```

- 3) Launch METIS script (public version):

```
/ZONE_TRAVAIL/JA132999/public/metis4itm/trunk/metis
```

## How to run it:

- 1) Source UAL environment:

```
$ITMSRIPTDIR/create_user_itm_dir WEST 4.10b
```

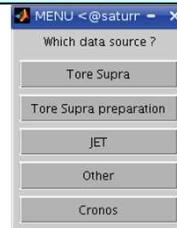
- 2) Select a device:

```
source $ITMSRIPTDIR/ITMv2 WEST
```

- 1) Launch METIS script (public version):

```
/afs/eufus.eu/g2itmdev/user/g2jfa/metis
```

# **OVERVIEW OF METIS WITH GUI**

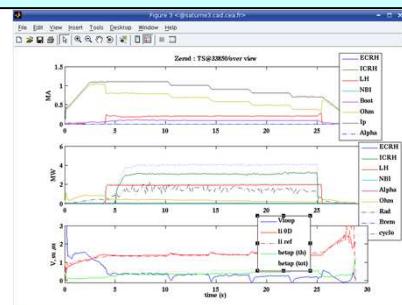
**Data source****Shot choice**

Access to Tore Supra Data <@saturn>

shot number :  
33850

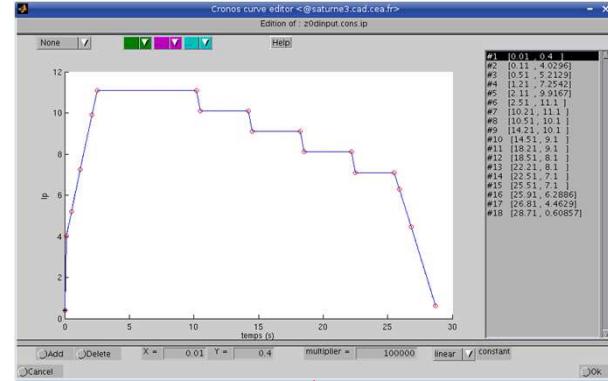
reference shot number :  
33850

Cancel Reset Ok

**Visualisation****Parameters**

module interface zero'd <@saturne1.cad.cea.fr>

gaz	2							
measser	0	✓						
pir	0.7		(integer)					
scaling	0	✓						
l2hslope	0		(real) [0 1]					
kishape	3		(real) [0 10]					
runaway	1	✓						
vref	0		(integer) [-3 3]					
zmax	8		(integer) [3 100]					
frad	1		(real) [0 1 10]					
angle_ecc	90	✓						
angle_nbi	0		(real) [-90 90]					
ejin	1e+06		(real) [10000 10000000]					
nparo	1.8		(real) [1 10]					
xih	0.2		(real) [0 0.8]					
min_H	H	✓						
freq	57.05		(string) [20 80]					
smd	100		(real) [-10 100]					
signe	1	✓						
effinj	0.7		(integer) [0 1]					

**References****METIS : main interface**

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

Metis

Parameters Load Save Create reference PDF output

References

Qip QNbar Zeff Xece BO Iso  
OECRH OICRH OLH ONBI Oamelioration OFT\_NBI  
OR0 Ozo a OK Od Separatrix

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

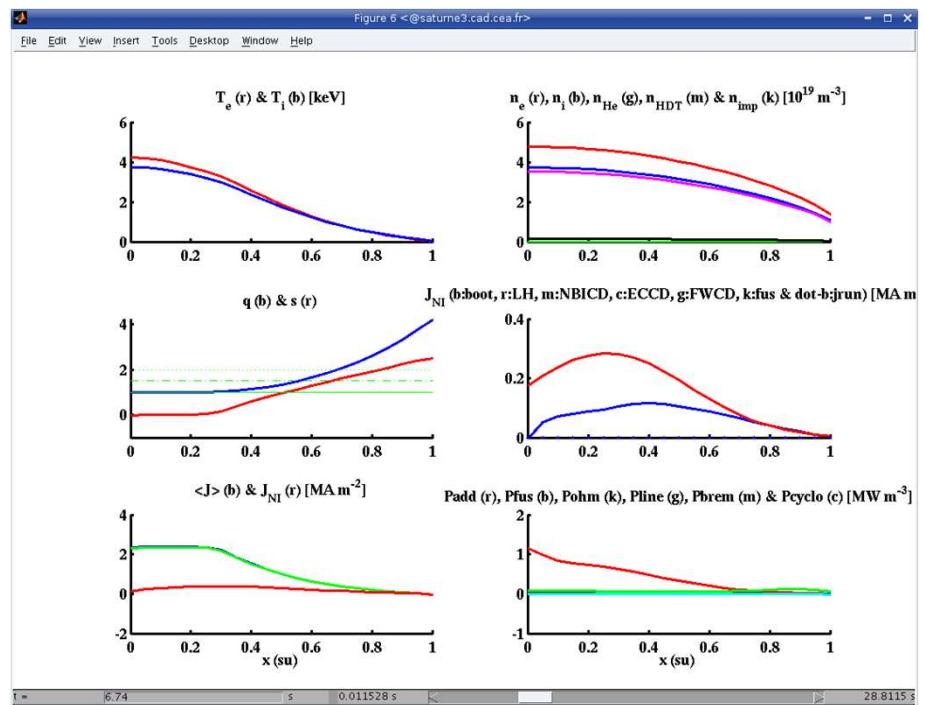
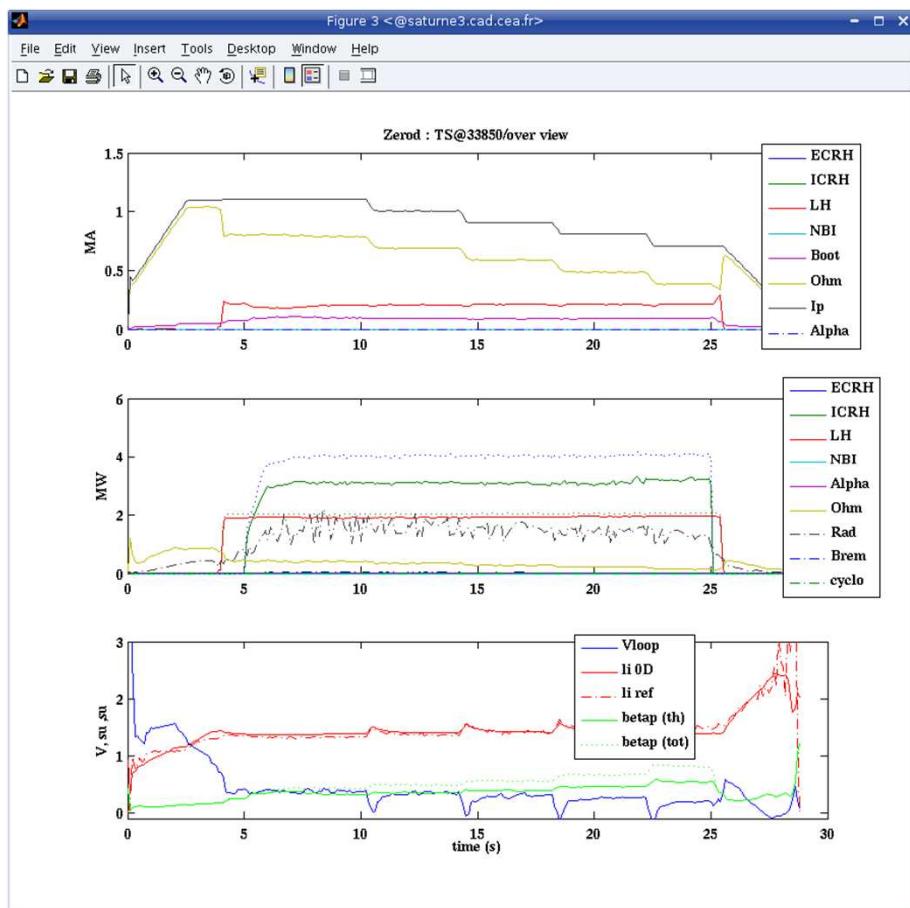
power energy confinement temperature density cost  
current equilibrium LH efficiency geometry convergence Ne Profile  
neutron DD Er DDS\_TS Overview Profiles 2D equi.

Initialisation Aide

**Run (~ 1mn)****Export to database****Results**

# METIS OUTPUT EXAMPLE (1/2)

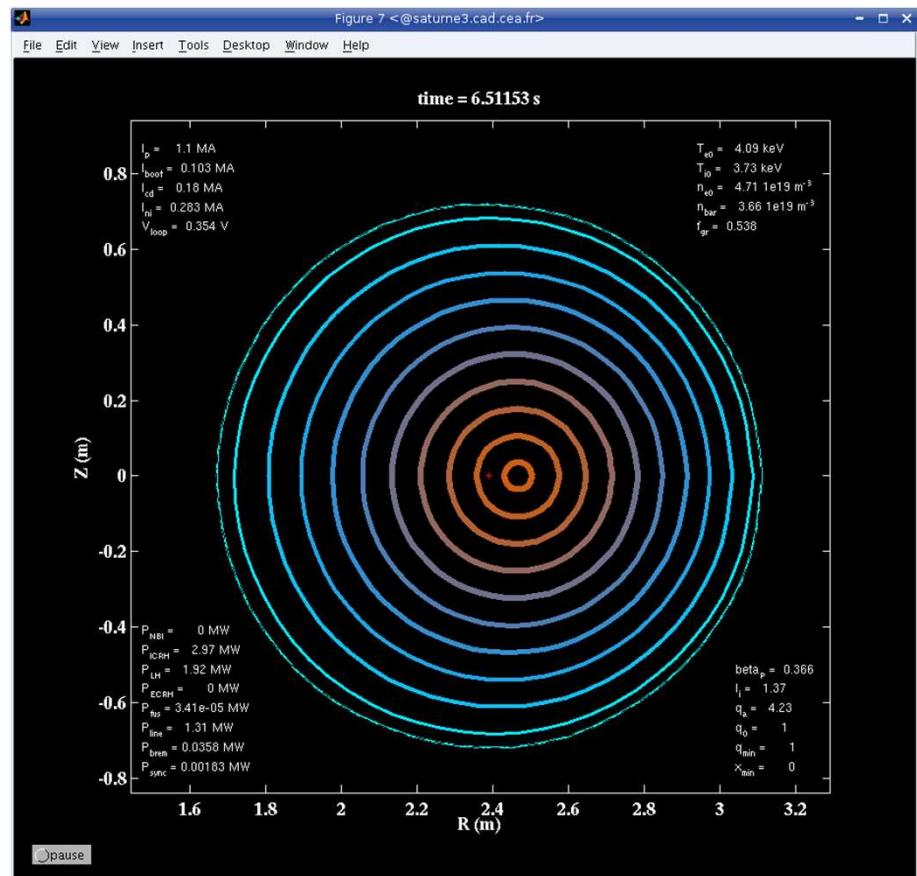
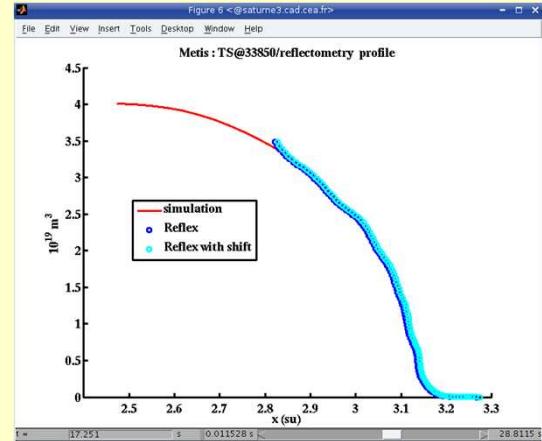
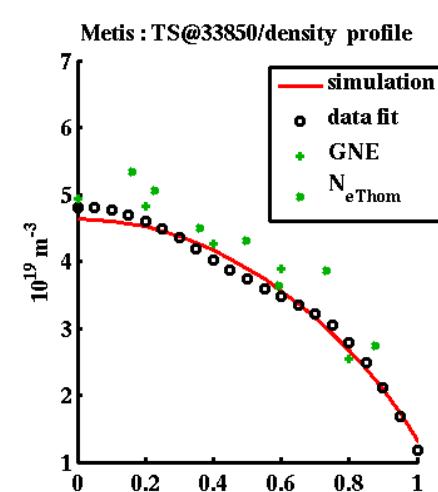
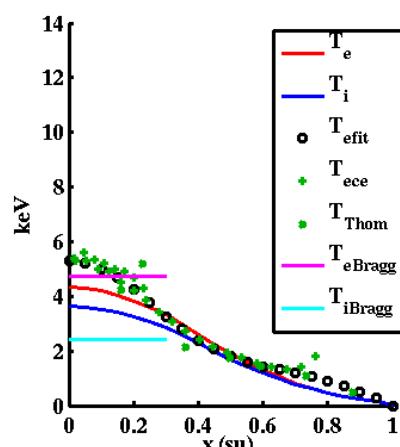
## Results: 0D data



## 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

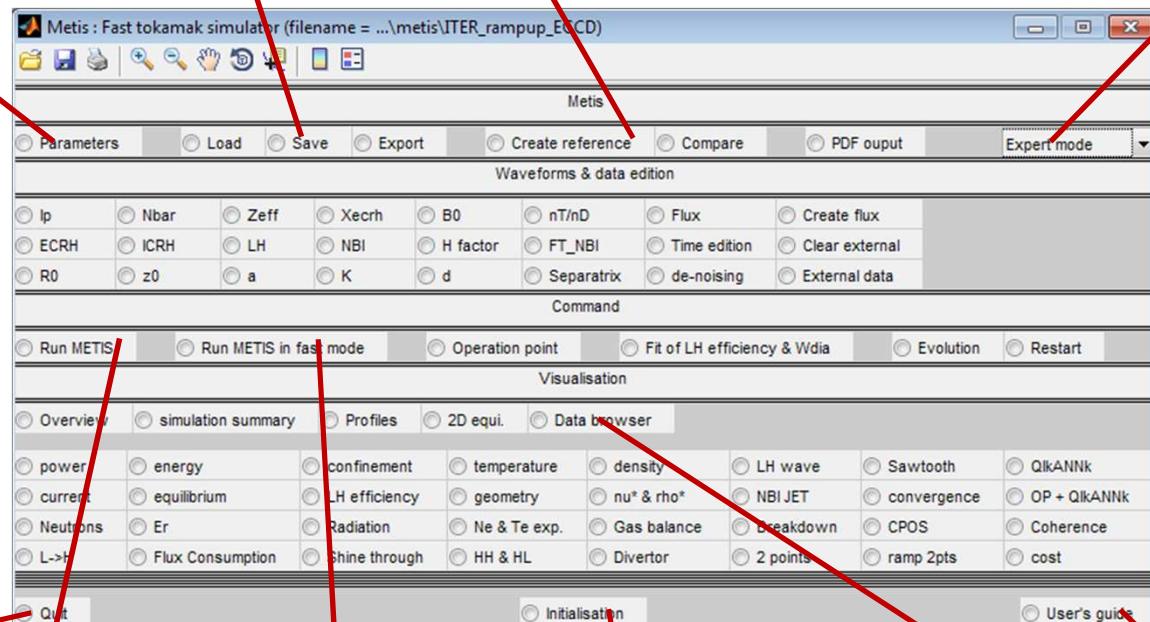
Full simulation  
(all time slices, to be  
use for final result)

Fast simulation  
(selected time slices  
for overview)

Initialization  
(create a new simulation)

Data browser  
(plot any METIS data)

Open METIS manual  
(need a pdf reader installed)



# MAIN GUI WINDOWS (2/2)

Generate  
separatrix (LCFS)  
with X-point

Noise filter for references

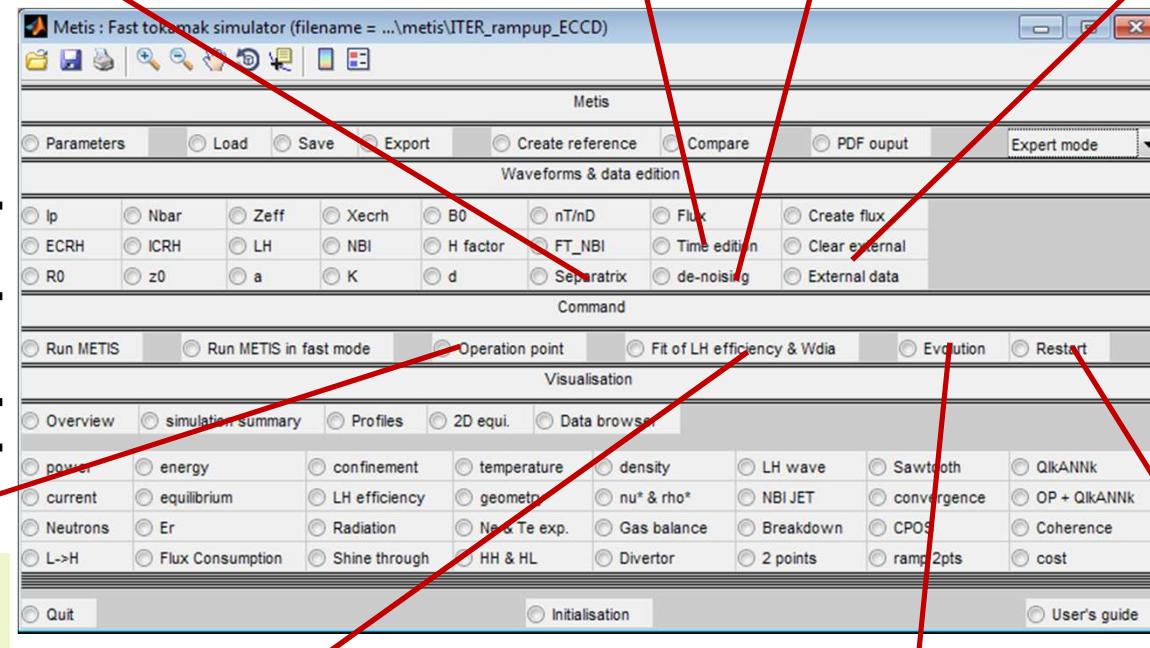
Time resampling (input)

Handle external data  
(measurement, ...)

Edition  
references

Main graphs

Steady-state  
fast  
computation

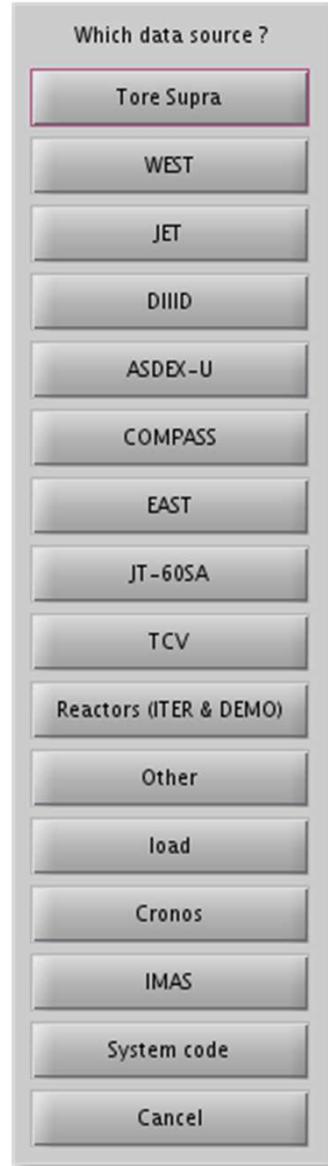


Fit experimental energy  
content and search LHCD  
efficiency (if present)

Run in evolution mode  
(for testing)

Restart evolution mode  
(to continue the simulation)

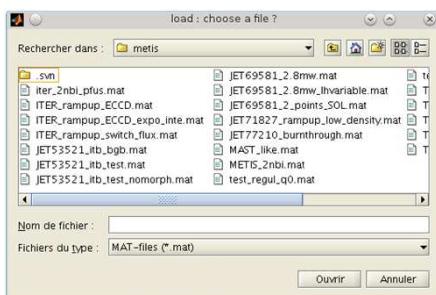
1. Create or load a data set
2. Edit and modify references
3. Optionally, edit the LCFS (if X-point)
4. Edit and modify parameters
5. Run the simulation in fast mode
6. Visualize results
7. Come back to 2, if changes are needed
8. Run complete simulation
9. Visualize and check results
10. Save results



- **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**

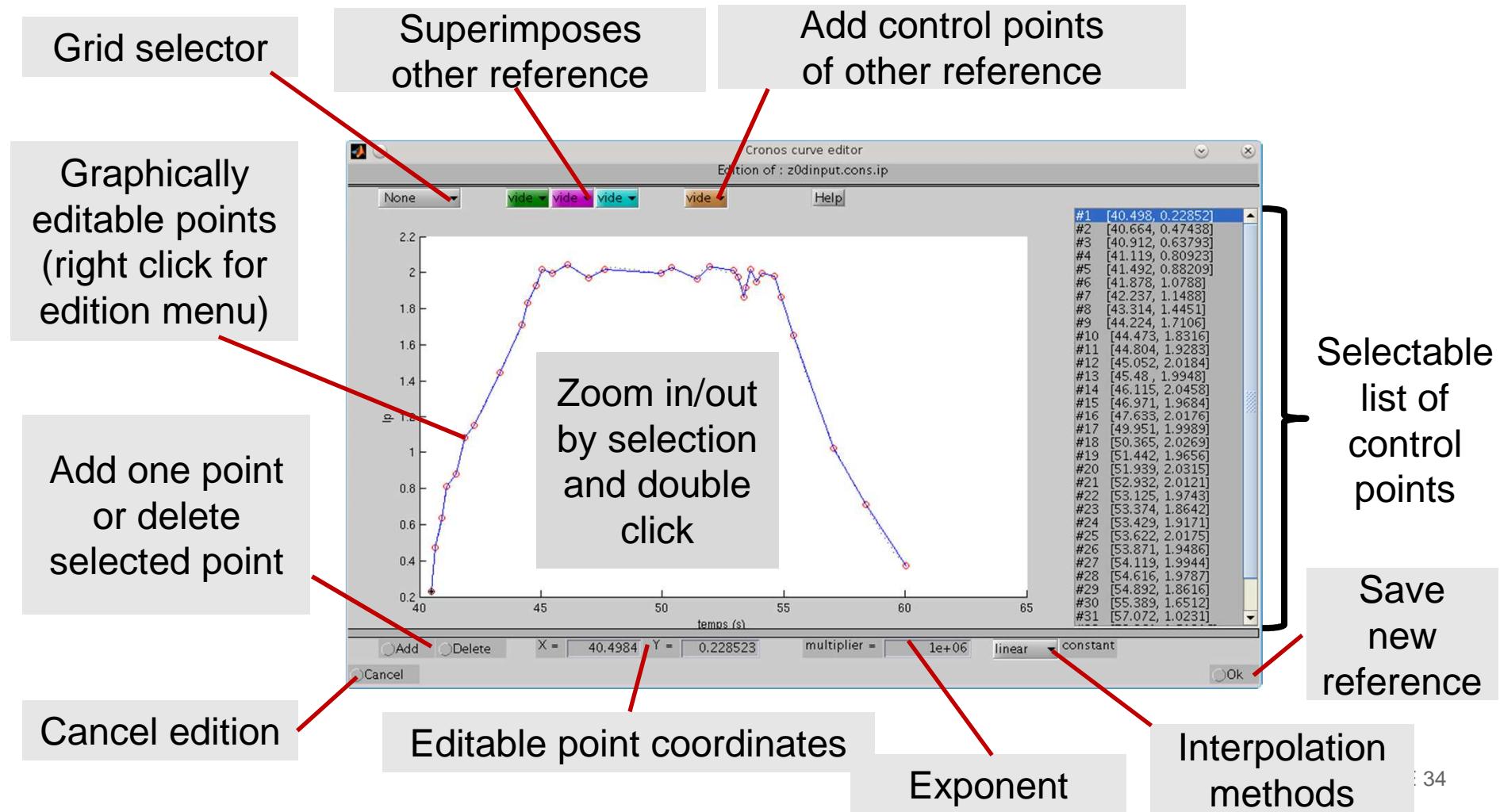
- Button load open a file selector :
  - Just selected a file and open it
- METIS has unified file for input/output
- All METIS files are compatible with new METIS versions (ascendant compatibility)
- Some sample files (used for non-regression tests) are in the directory certification/metis :

**.../certification/metis**



# EDIT REFERENCE

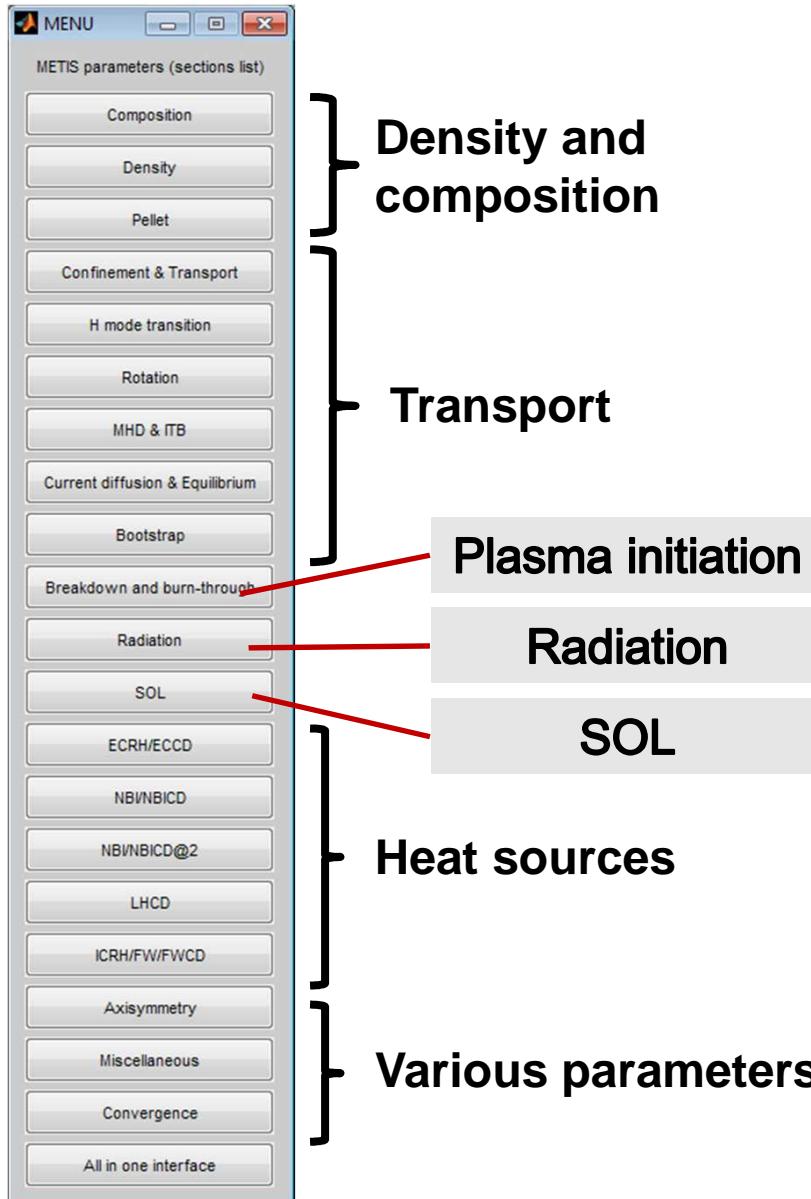
- Time dependent reference can be edited with the help of graphic editor



# 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 PARAMETERS



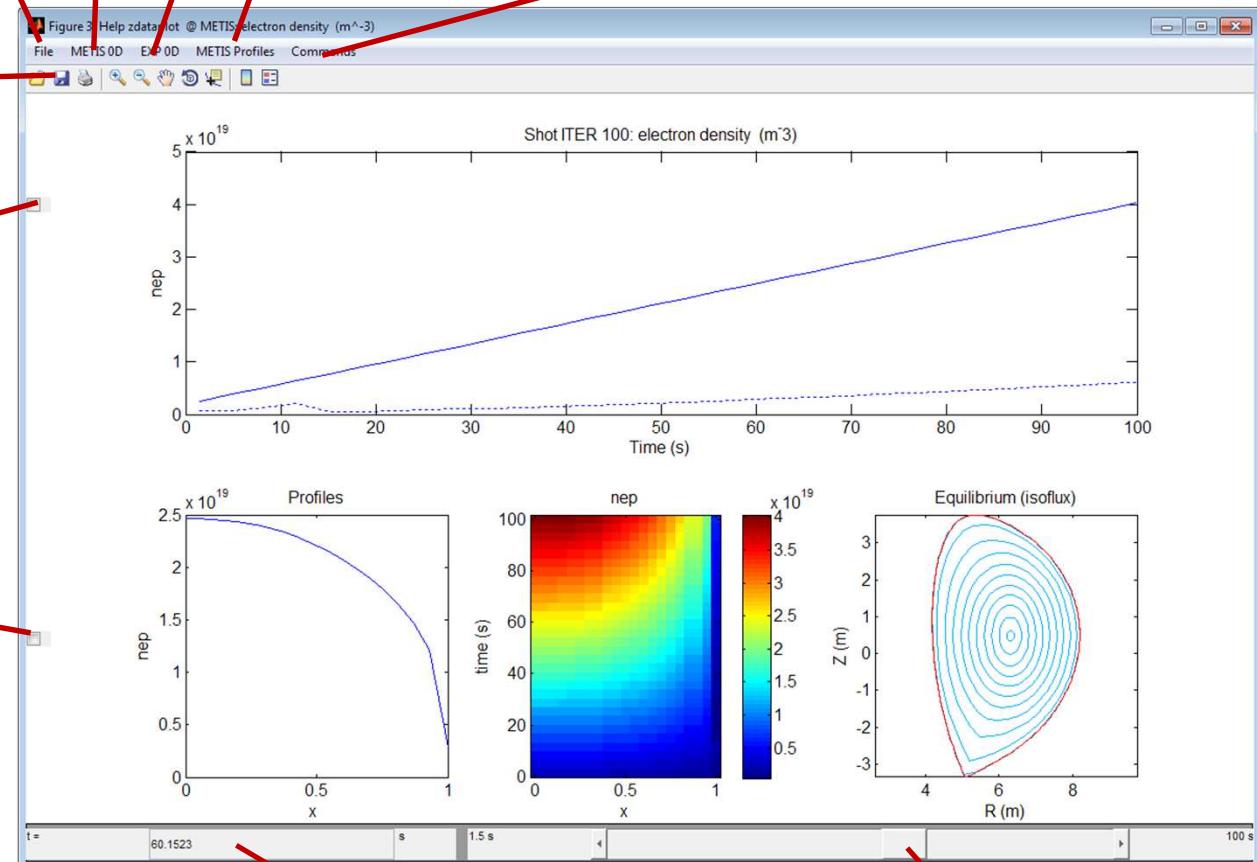
- Parameters grouped by topic
- Each button opens a form
- Change the input parameters

- 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.

Matlab figure menu

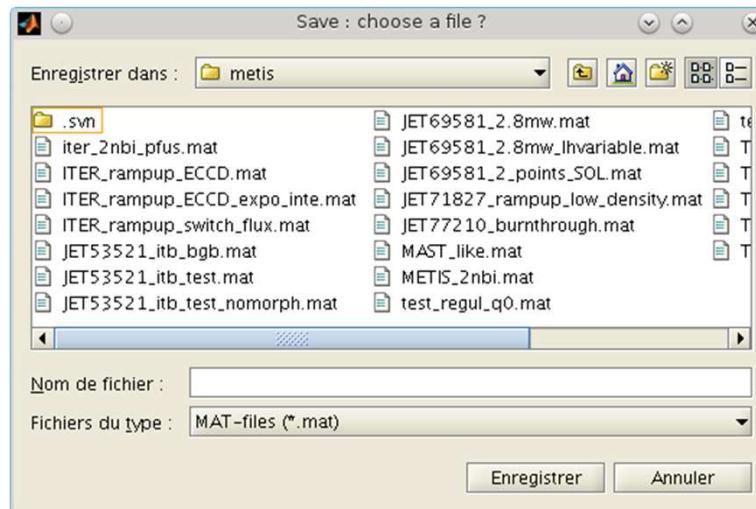
0D data

experimental data  
profile dataGraphs options  
(superimpose, ...)Matlab figure  
toolbartime selection  
With cursorMemorize  
profile and  
superimpose

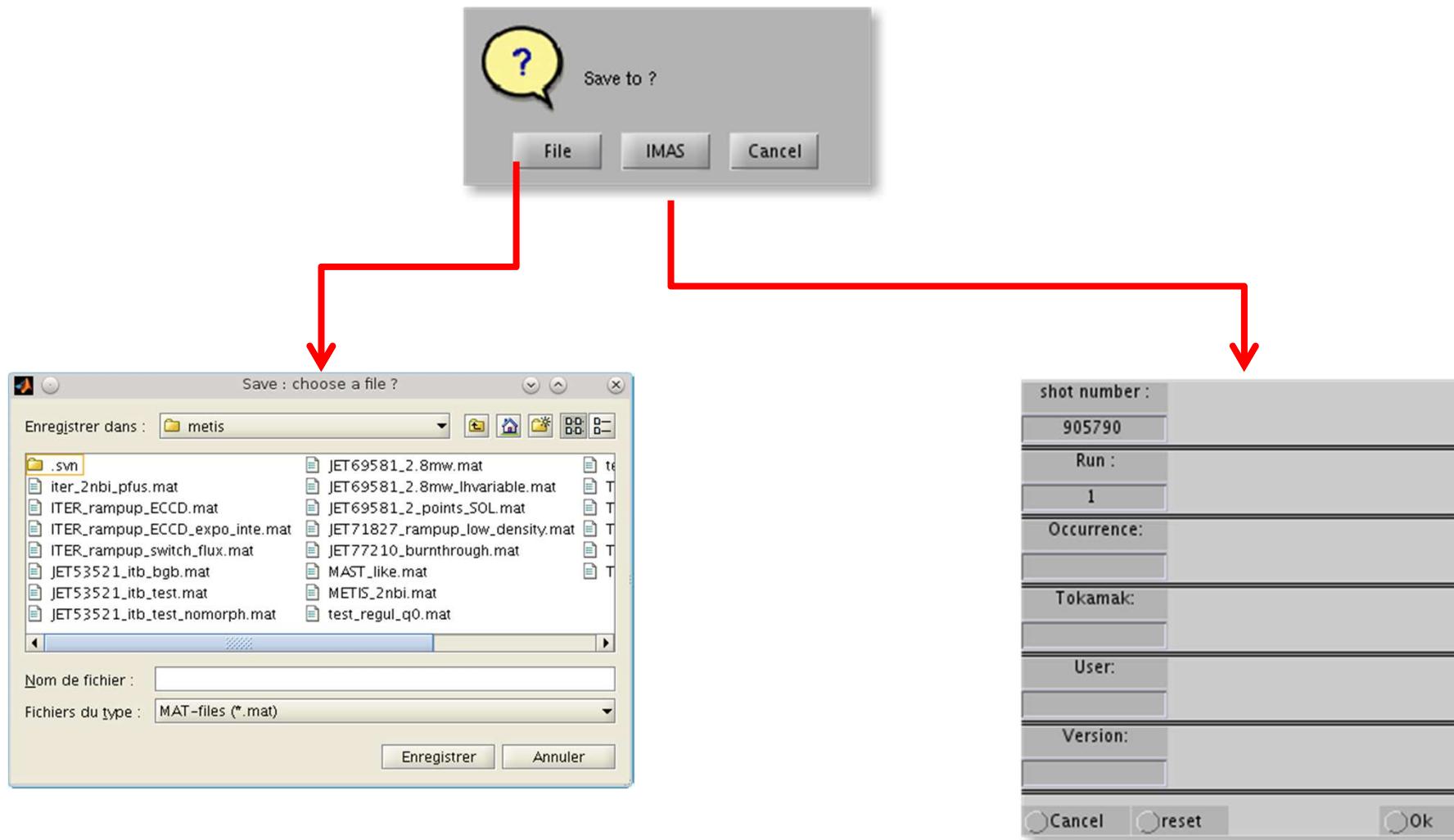
Time (edit field)

Time slider

- 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.



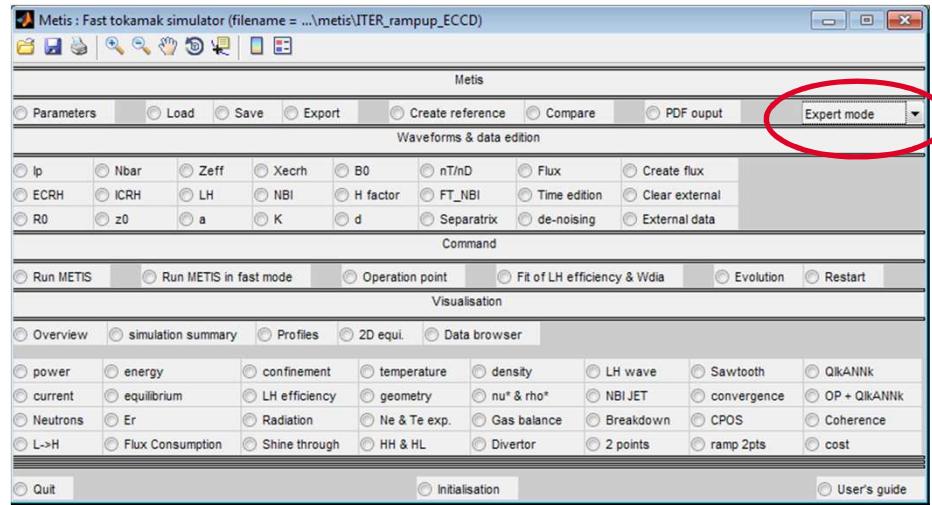
- If IMAS or ITM/UAL is available



- 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.

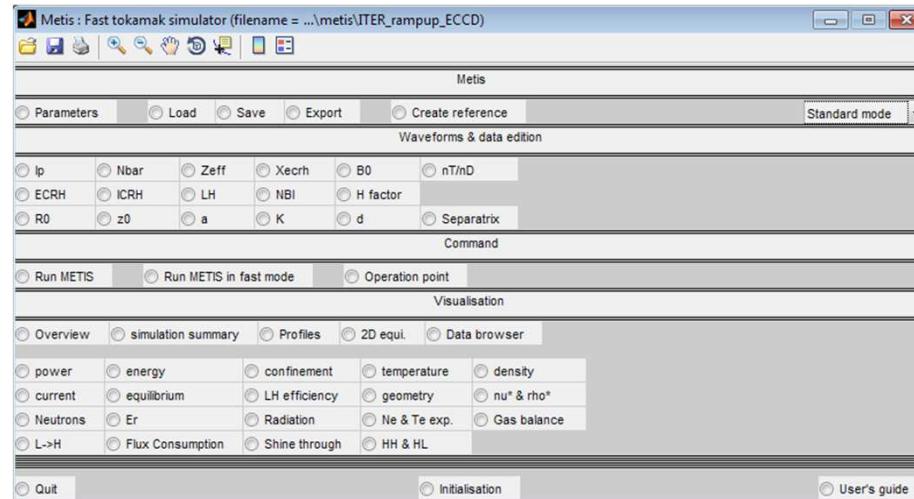
# **METIS GUI: EXPERT & STANDARD MODE**

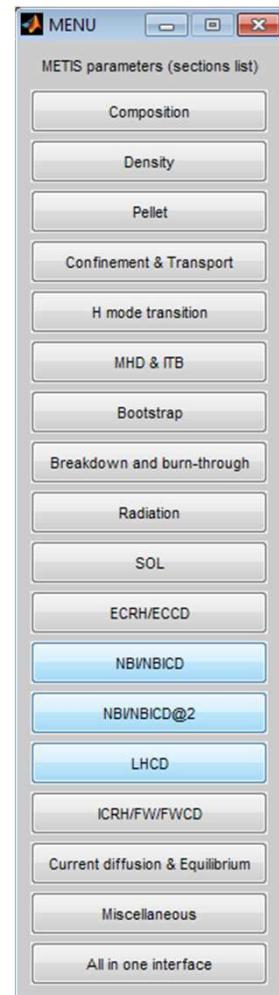
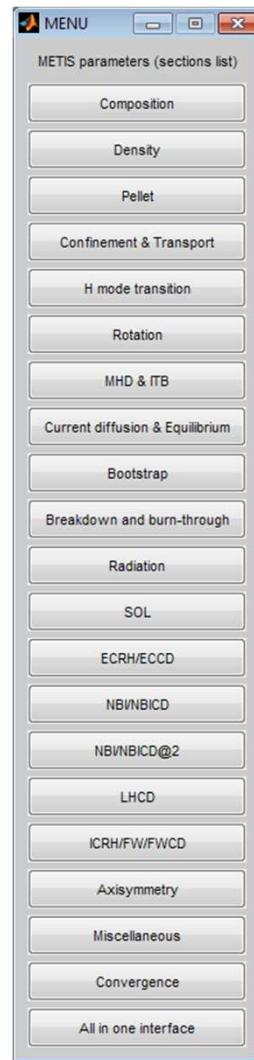
# GUI HAS 2 MODES: STANDARD AND EXPERT (1/2)



**Expert**

**Standard**



**Expert****Standard**

Sections menu  
←

**SOL Parameters  
(one example)**

**METIS parameters (section #SOL)**

configuration	3	(integer)	lambda_scale	0	(real)	factor_scale	1	(real)
sol_lscale	0	(real) [-0.1 0.1]	eioniz	25	(real) [0 1000]	de	0.5	(real) [0.1 10]
alpha_e	0.82	(real) [0.15 3]	fnesol	0.2	(real) [0 1]	sol_model	scaling	(string)
sol_rad	coupled	(string)	lcx	7	(real) [1 20]	fpower	0.6	(real) [0.1 1]
fR_target	1	(real) [-3 3]	fcond	1	(real) [-1 1]	fmom	1	(real) [0 1]
mach_corr	0	(integer)	yield_model	Javev	(string)	ftwleak	-0.5	(real) [-1 1]
cw_factor	1	(real) [-10 10]	cw_offset	0	(real) [0 0.01]	cw_ecrl	0	(real) [0 0.01]
cw_icrh	0	(real) [0 0.01]	cw_lhcd	0	(real) [0 0.01]	cw_nbi1	0	(real) [0 0.01]
cw_nbi2	0	(real) [0 0.01]	fzmax_div	0	(real) [-100 100]	carbonblow	0	(real) [-3 3]

Cancel    reset    Update    Ok

**Expert****Standard**

**METIS parameters (section #SOL)**

configuration	3	(integer)	lambda_scale	0	(real)	sol_lscale	0	(real)
sol_model	scaling	(string)	sol_rad	coupled	(string)	cw_factor	1	(real) [-10 10]
cw_offset	0	(real) [0 0.01]	sol_icrh	0	(real) [0 0.01]	sol_lhcd	0	(real) [0 0.01]

Cancel    reset    Update    Ok

# **LCFS GENERATOR**

- 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  
 $B_0$

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

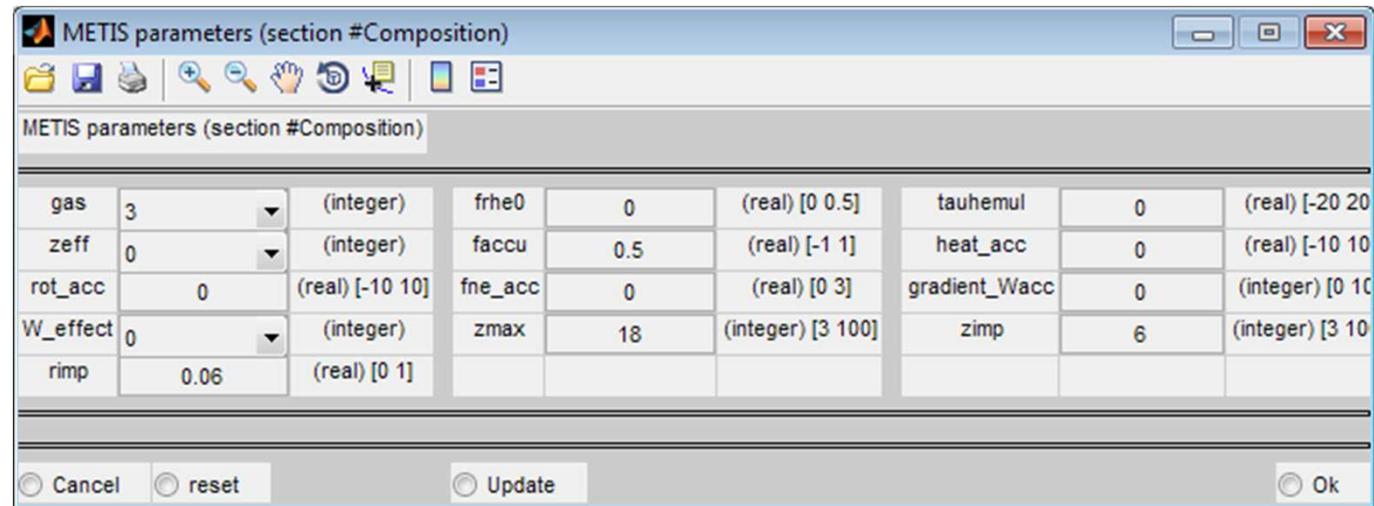
Before and after, use  
references R, a, K, d

- 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]

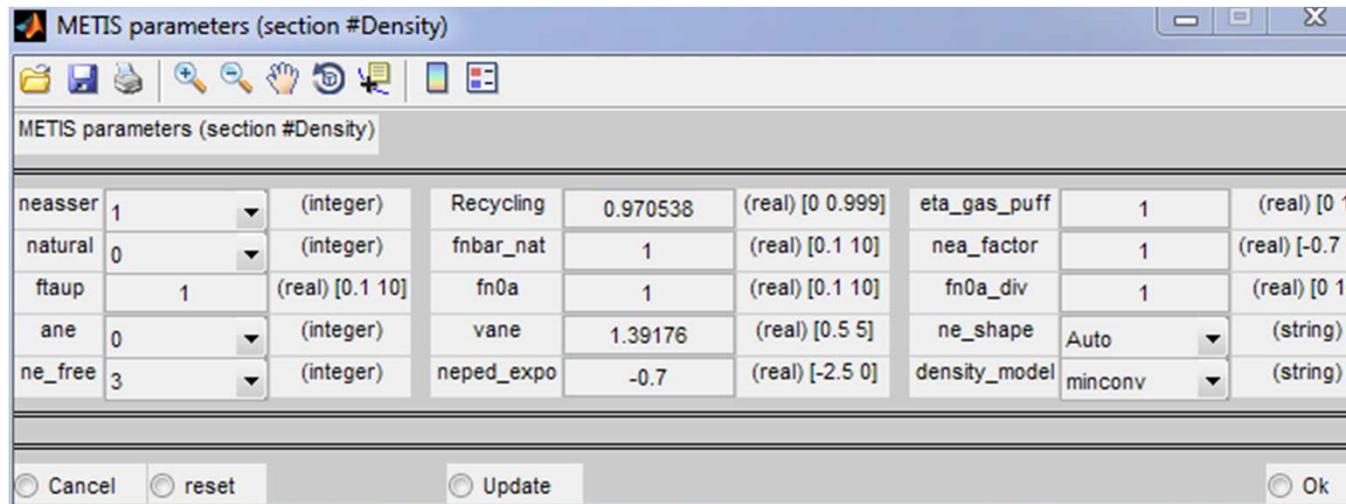
- Load a LCFS given by point:
  - Load file pointed by filename field, if field is not empty
  - If filename is invalid or “?”, open a file selector helping to choose the file
  - File must be a matfile containing R vector and Z vector of same length.
  - Override references (R,a,K,d) between ton and 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

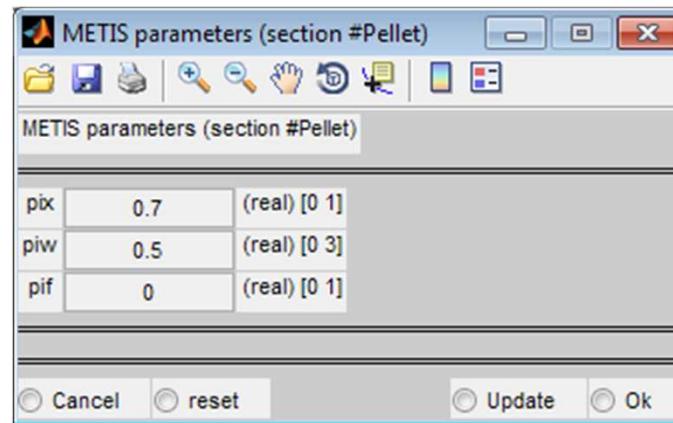
## **MAIN PARAMETERS FOR FIRST USE**

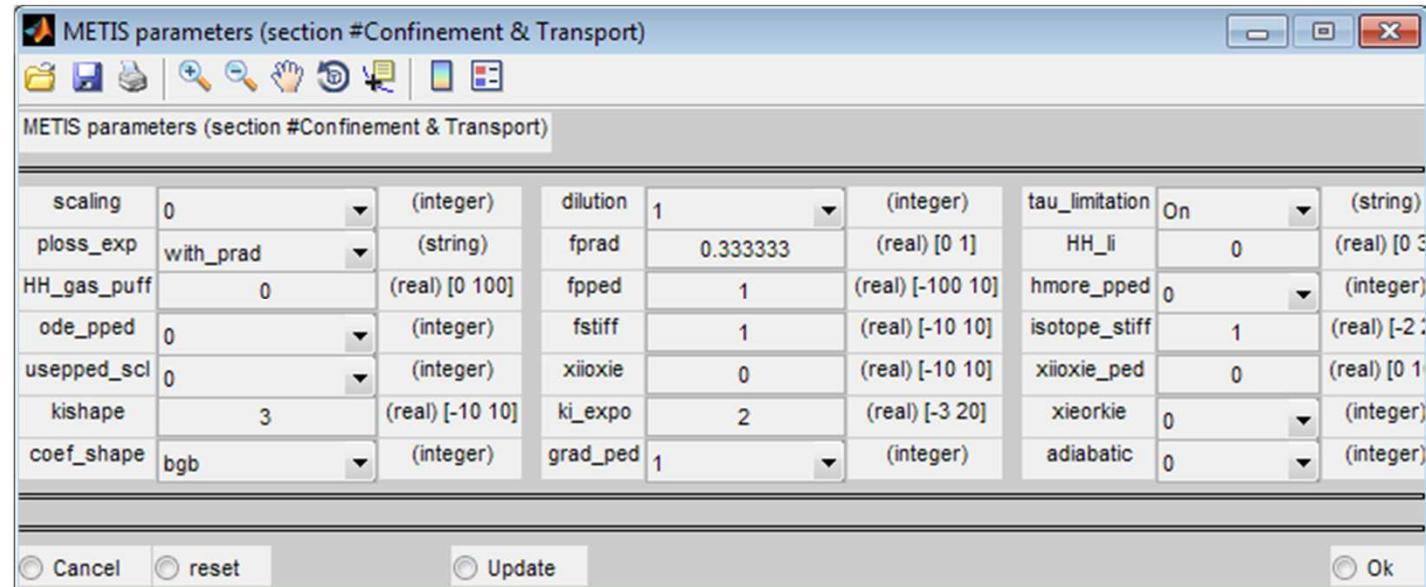


- Main Keys (for first use):
  - **gas**: main plasma ion species (H/D/He/DT)
  - **zimp**: charge of light/main impurity
  - **zmax**: charge of heavy/secondary impurity
  - **rimp** : density ratio of secondary over main impurity

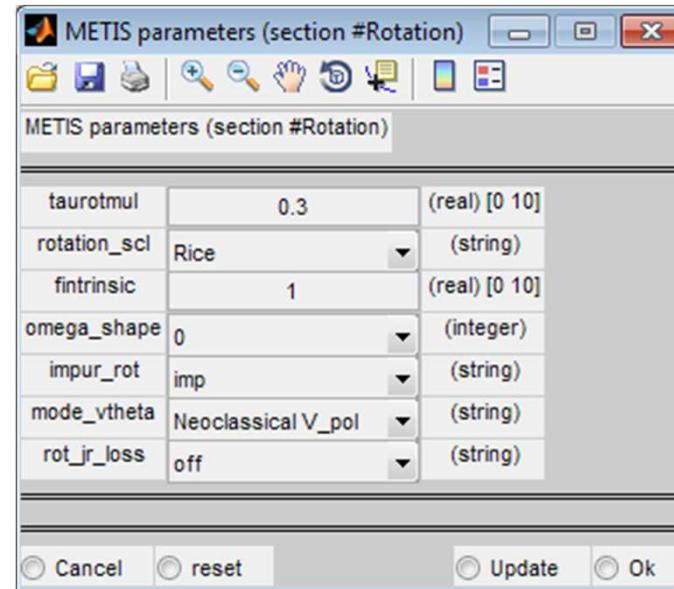
- Main Keys (for first use):
  - ane: model for density peaking factor
  - vane: value of density peaking factor if provided



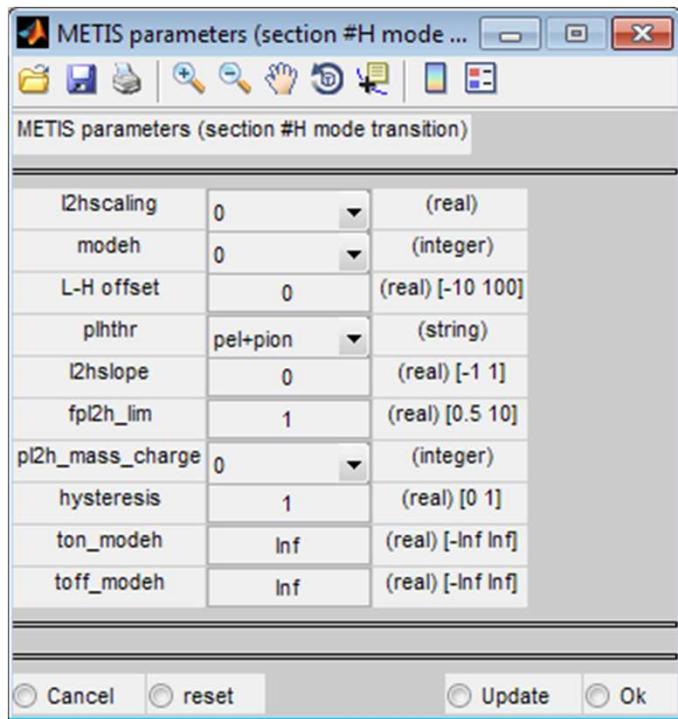




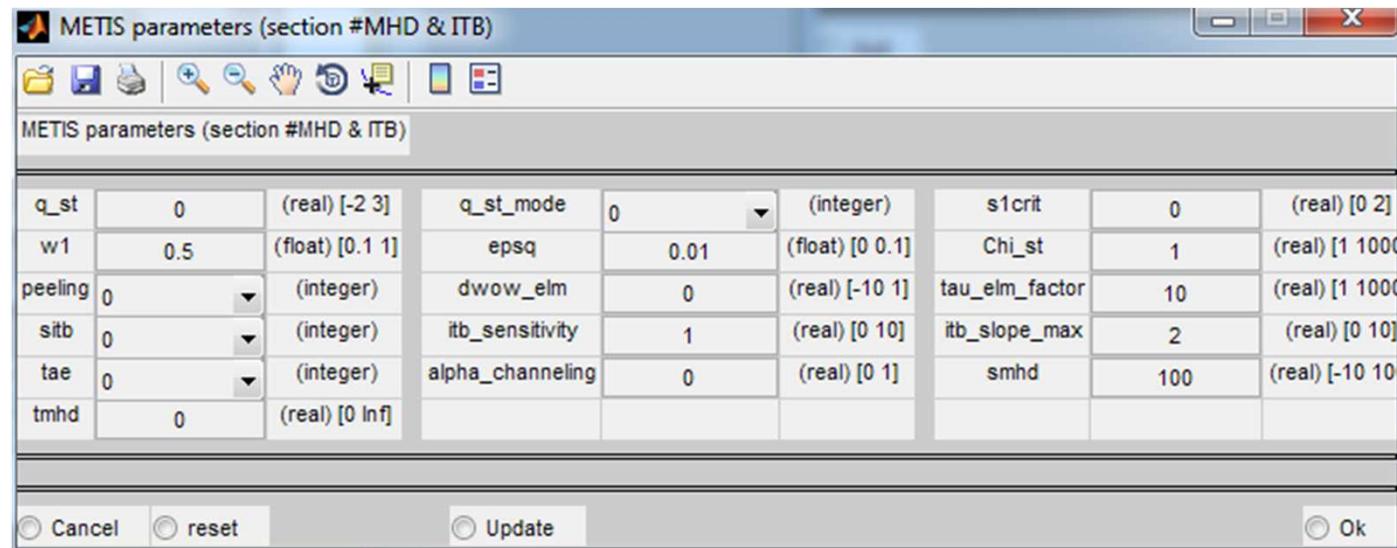
- Main Keys (for first use):
  - scaling: scaling law for energy content choice
  - fpped: pressure at the top of pedestal (factor)
  - usepped\_scl: set on scaling for pedestal pressure



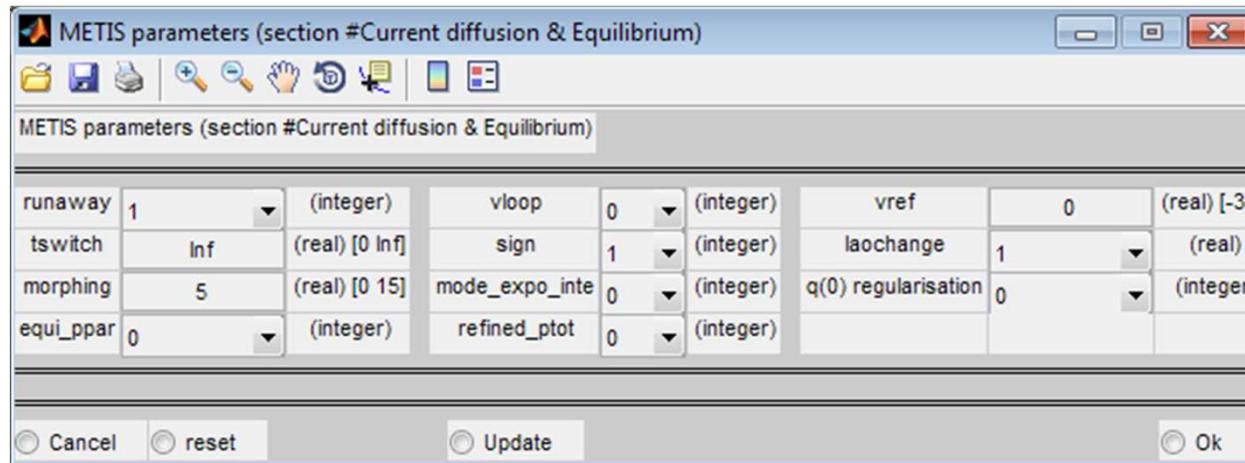
- Main Keys (for first use):
  - taurotmul:  $\tau_\varphi / \tau_E$
  - fintrinsic: fraction of intrinsic rotation taking into account



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

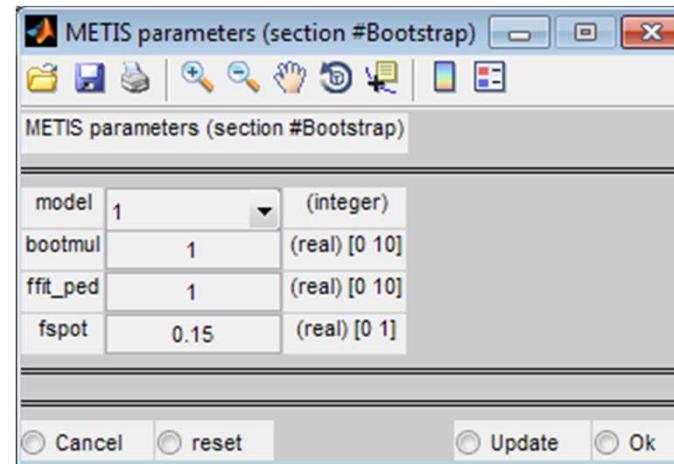


- Main Keys (for first use):
  - **q\_st:** set on sawteeth model
  - **Chi\_st:** effect of sawteeth on transport
  - **smhd:** limitation of  $\beta_N$

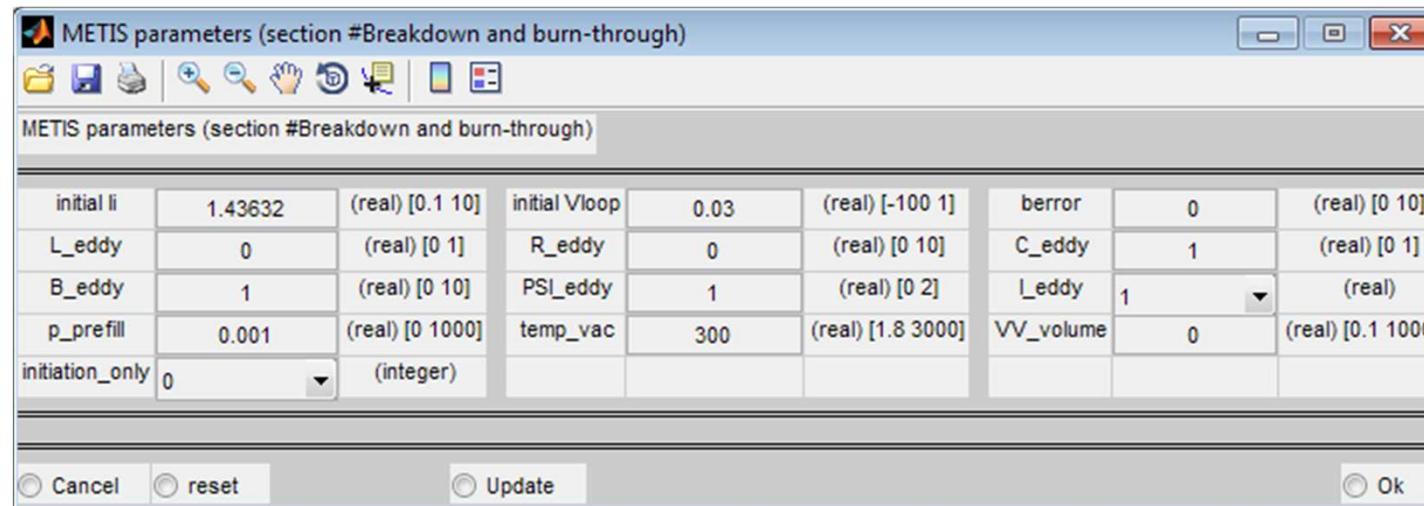


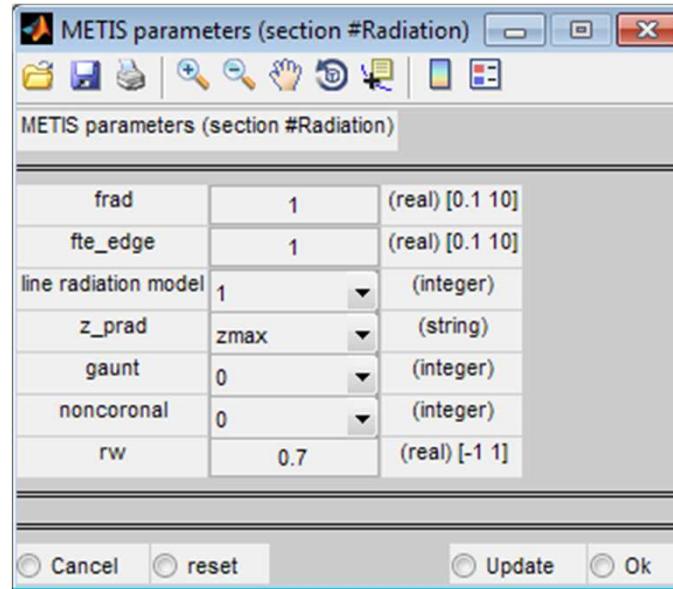
- Main Keys (for first use):
  - runaway: switch on/off runaway model (runaway can be a problem !)
  - signe: sign of  $I_p * B_{\phi i}$
  - Cronos\_regul: methode to compute safety factor @ magnetic axis

# PARAMETERS INTERFACES (NEOCLASSIC)

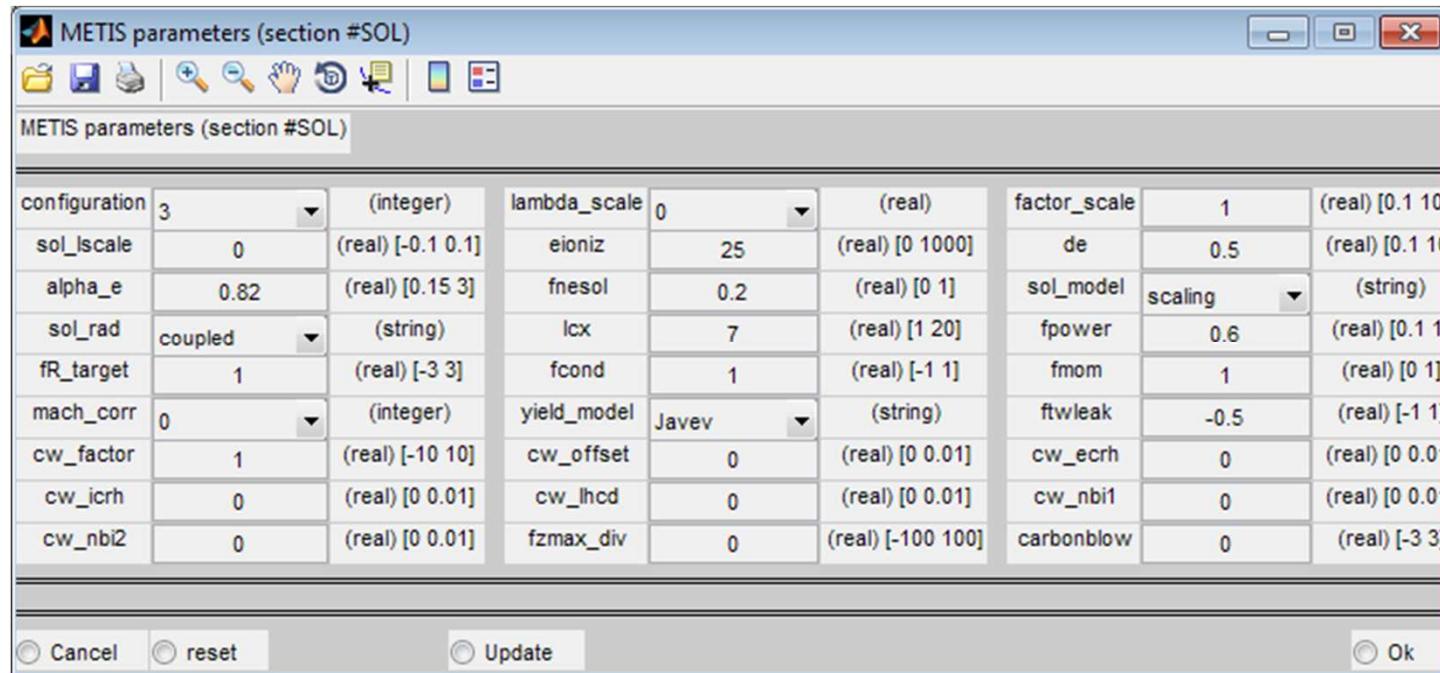


# PARAMETERS INTERFACES (BREAKDOWN)

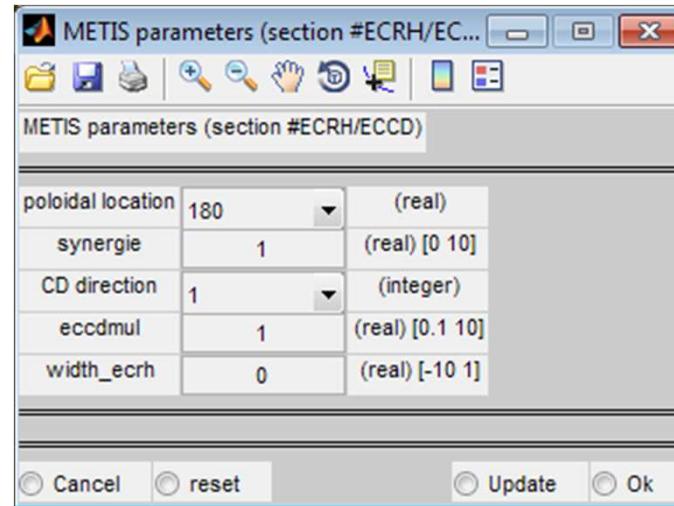




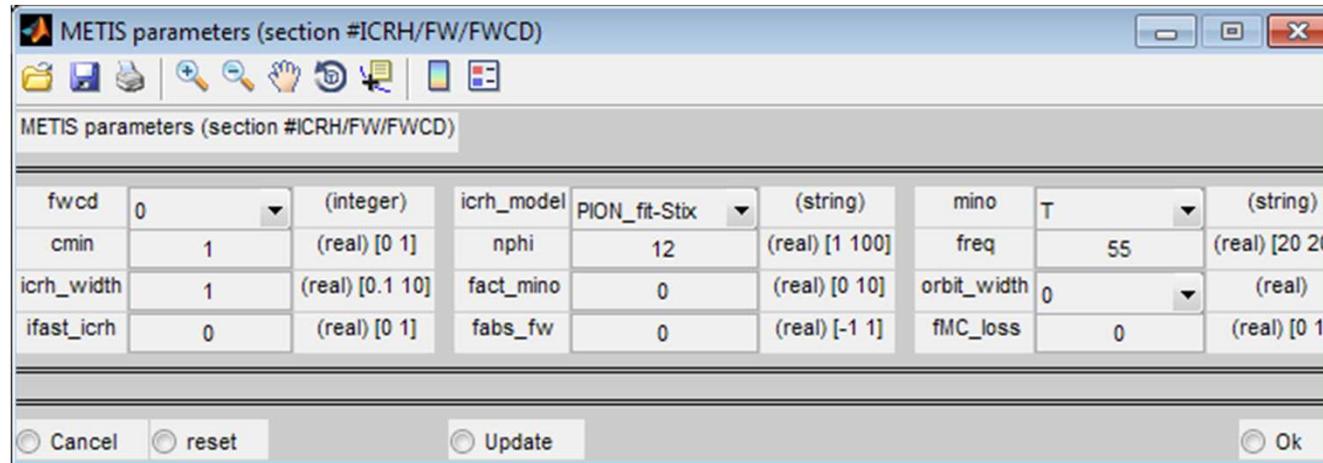
- Main Keys (for first use):
  - frad: factor applied to line radiative power
  - Line radiation model: use Matthews scaling or only cooling rate
  - rw: effective wall cyclotron radiation reflection fraction



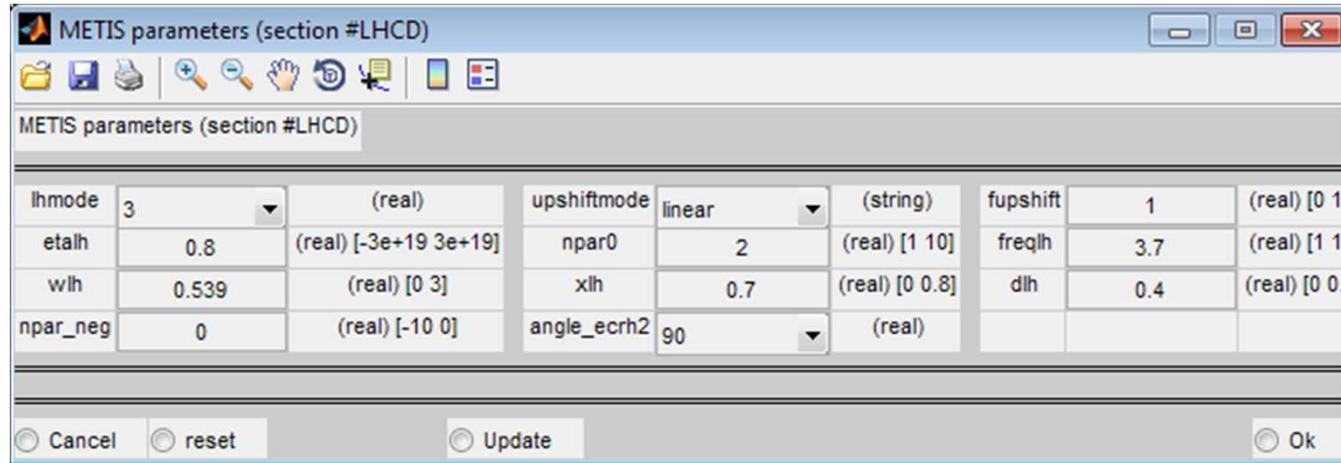
- Main Keys (for first use):
  - configuration: tokamak configuration (poloidal limiter, toroidal limiter, divertor, ...)



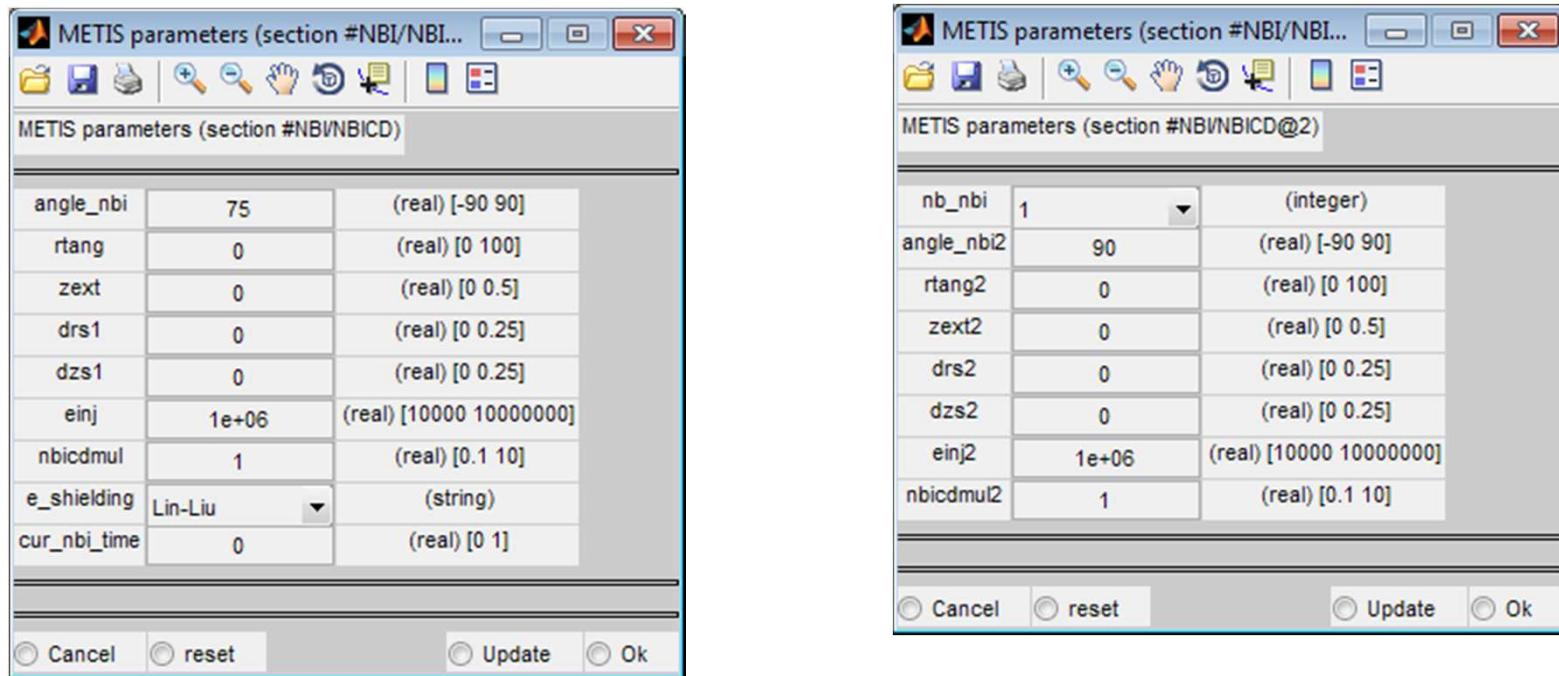
- Main Keys (for first use): all
  - angle\_ecrh: poloidal position of absorption
  - sens: co current, perpendicular or counter current



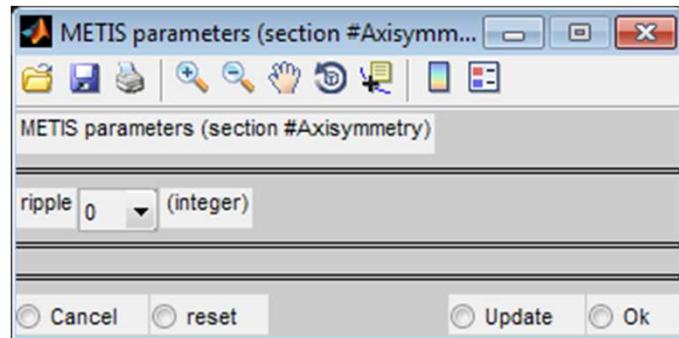
- Main Keys (for first use): all
  - fwcd: selection of heating scheme
  - mino & cmin : type and concentration of minority
  - nphi: toroidal wave number
  - freq : frequency of the injected wave (set to position of deposition)



- 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

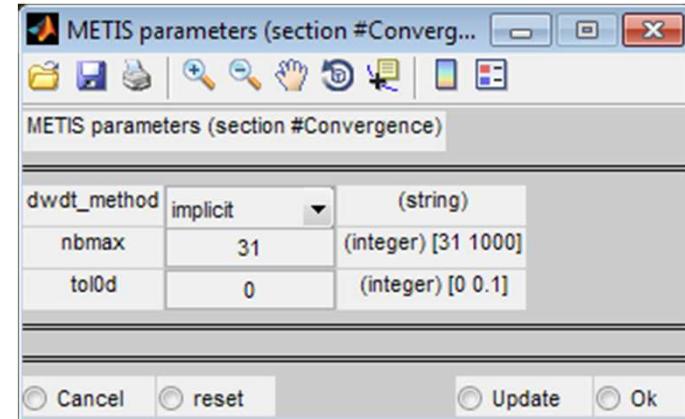


- Main Keys (for first use): all
  - Standard use : provided rtang & set current direction with angle\_nbi
  - Set current direction with angle\_nbi  
(-90= counter, 0 = perpendicular, 90 = co)
  - Adjust deposition with zext



METIS parameters (section #Miscellaneous)		
thermodynamic efficiency	0.42	(real) [0 1]
mul_blanket	1.2	(real) [0.5 10]
aux	0.05	(real) [0 1]
effinj	0.7	(real) [0 1]
available_flux	Inf	(real) [0 Inf]
machine name	ITER	(string) "
shot	100	(integer) [0 999999]
reference_parameters		(string) "
first_wall		(string) "

Buttons at the bottom: Cancel, reset, Update, Ok.



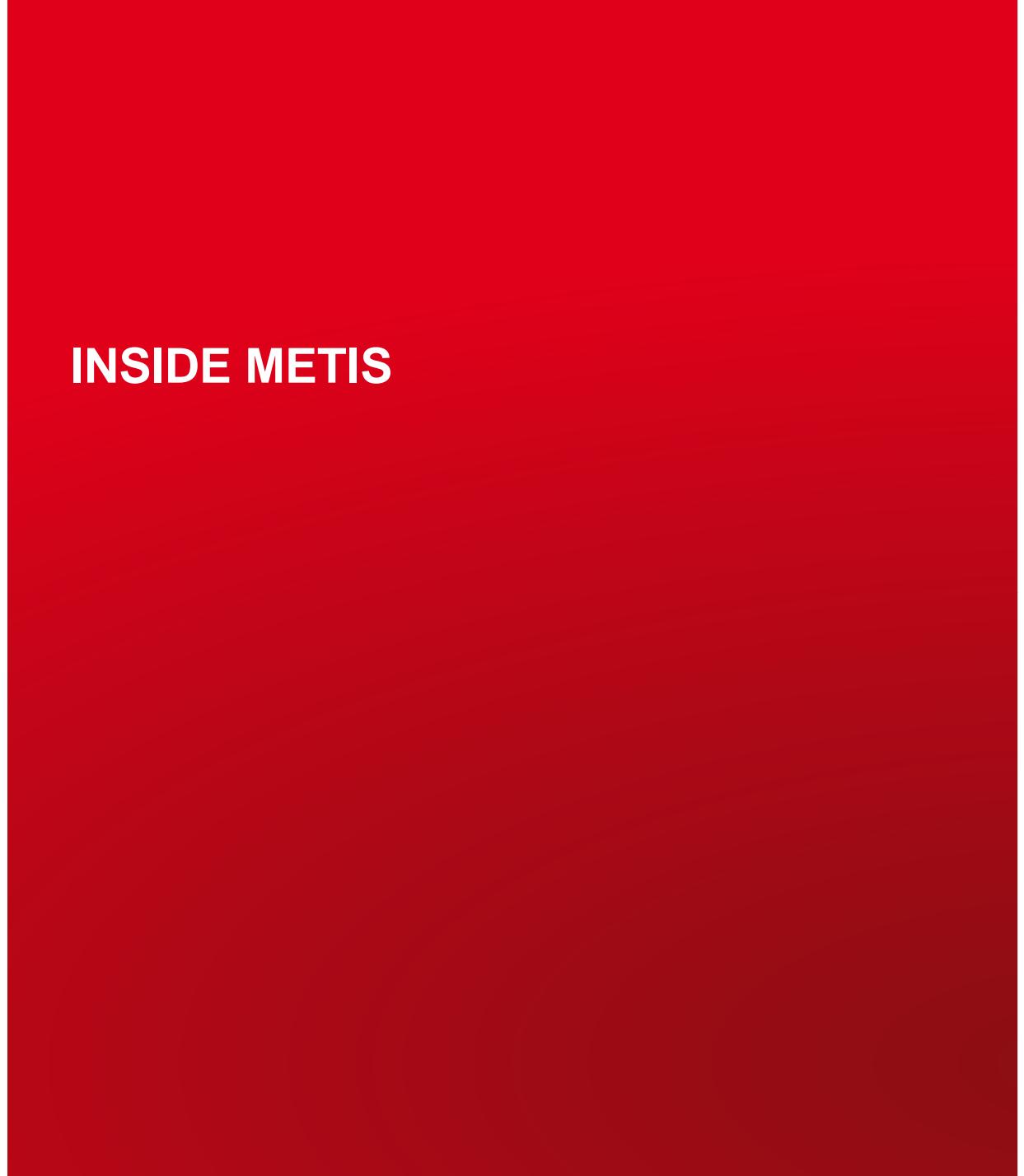
- Main Keys (for first use):
  - shot: shot number
  - machine: machine name
  - reference\_parameters : file name of METIS parameters as created with the button “Create reference”. **Override METIS internal tuning!**

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 **METIS\_HELP.pdf** file  
→ details technical manual and instruction  
**(not completely up-to-date with current METIS version)**
- 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

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

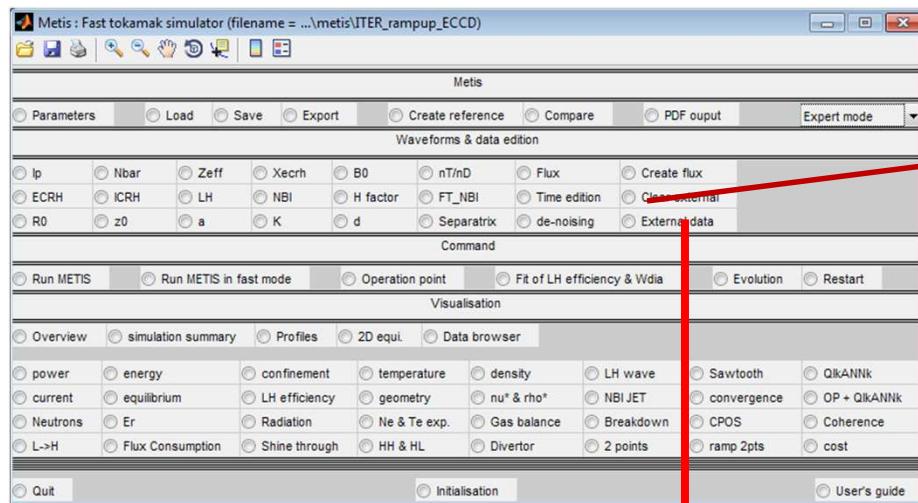
## **ADVANCED METIS FEATURES**

- 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

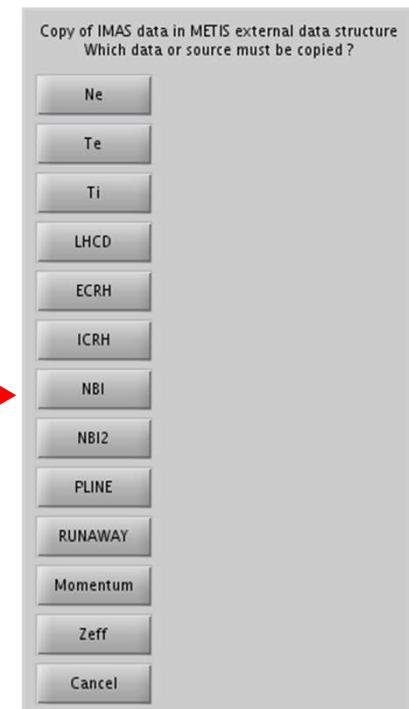
- Call METIS functions in a mfile:
  - zerod\_init: initialise a simulation
  - zerod\_fast: fast simulation (selected time slices)
  - zerod: full simulation (all time slices)
  - zerodevolution: one time step simulation
  - metis4imas: run metis inside IMAS framework
  - metis4itm: run metis inside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



Remove external data  
(METIS stops to use external data)



Select a source for external data:

Qualikiz NN

CRONOS

IMAS

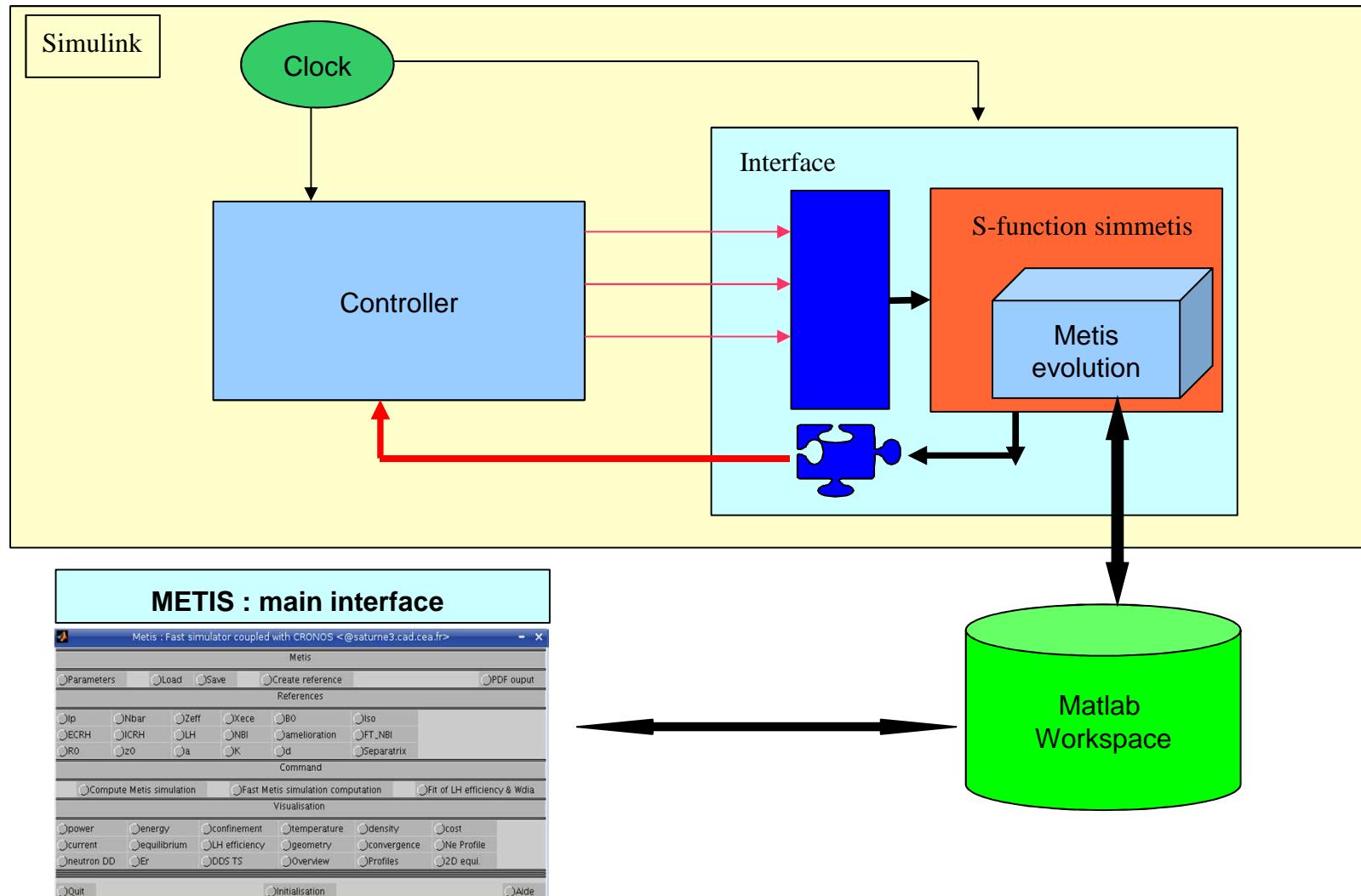
This menu depends on context

# **METIS IN SIMULINK**

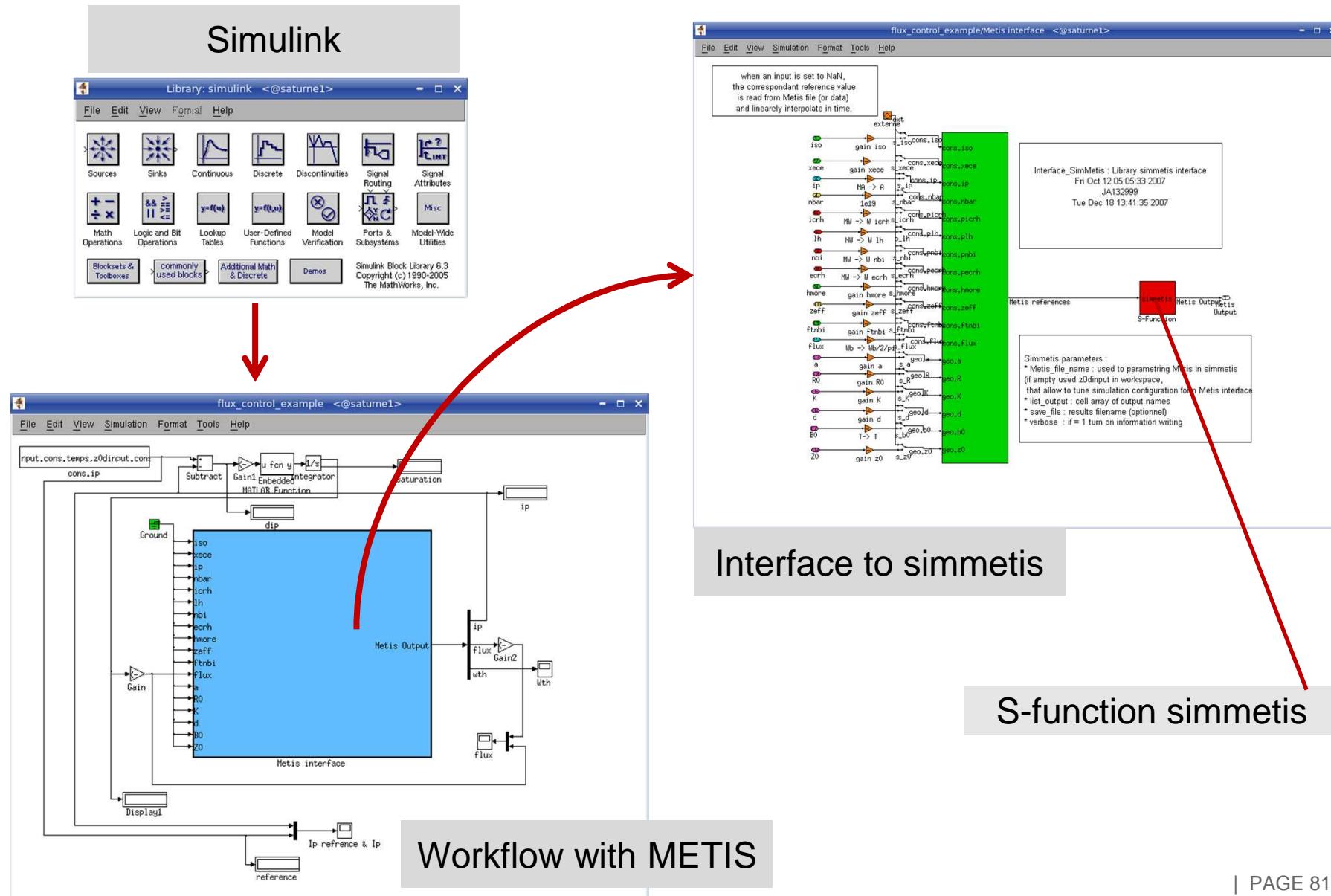
- ✓ METIS call from Simulink = S-function **simmetis**
- ✓ Standard S-function Input & output
  - simmetis use one time step METIS computation:  
**zerodevolution**
- Some documentation is written inside functions
  - ✓ help simmetis or help zerodevolution (in Matlab)
  - ✓ S-function documentation :

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

# METIS EVOLUTION IN SIMULINK



# METIS INTERFACE TO SIMULINK

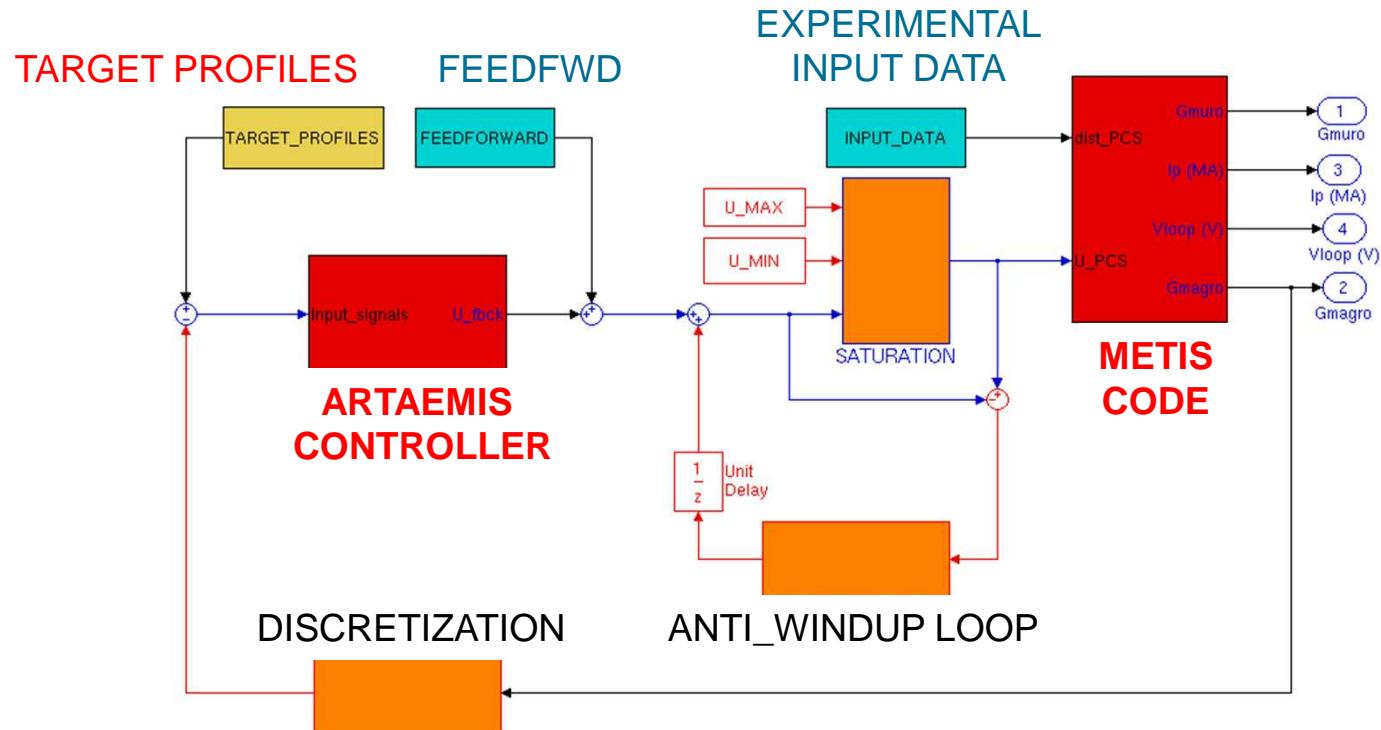


- Sample workflow for simmetis testing  
(under .../zerod/):
  - test\_simmetis.mdl : simple test
  - flux\_control\_example.mdl : poloidal flux feedback test
- Sample interface between Simulink and simmetis  
(under .../zerod/):
  - interface\_simmetis.mdl : switches, multiplexor + S-function call
- 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

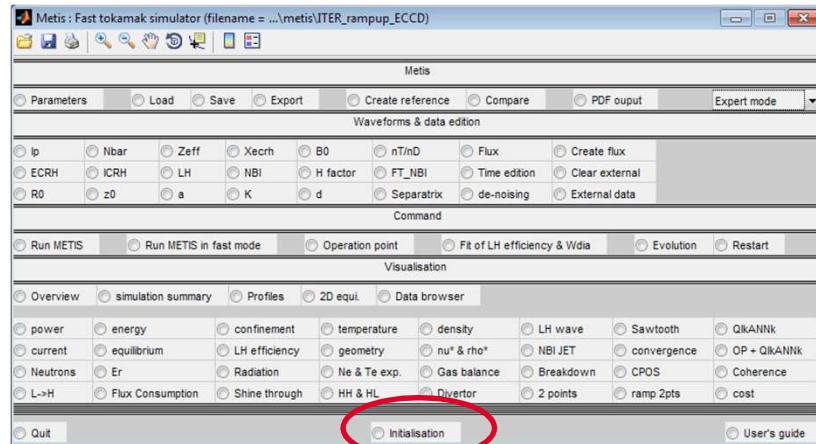


- ✓ Closed loop ARTAEMIS/ METIS simulations to extend control to steady
- ✓ Experimental input data is taken from DIII-D shot

[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 ]

# **WEST SCENARIO PREPARATION**

# ACCESS TO WEST SCENARIO PREPARATION



Menu for WEST

# METIS INITIALISATION MENU FOR WEST

Which data source ?

- Tore Supra
- WEST
- JET
- DIII-D
- ASDEX-U
- COMPASS
- EAST
- JT-60SA
- TCV
- Reactors (ITER & DEMO)
- Other
- load
- Cronos
- IMAS
- System code
- Cancel

**Read data in ARCAD database to prepare a METIS simulation**

**MENU**

WEST simulation: what kind of simulation ?

- Scenario generator
- Reference simulation
- Before shot
- After shot

**module interface westmetissimulation**

LCFS	WEST_Close_Xpoint.mat	(string)	configuration	default tuning of the scenario generator	(string)	gas	2	(integer)
ip	0.8	(float) [0.4 1]	b0	3.7	(float) [1.8 4.2]	ip_first	0.4	(real) [0.05 0.4]
f_Greenwald	0	(float) [0 1.4]	density	4.2	(float) [1 15]	edge_density_factor	1	(float) [0.1 10]
H_H	0.8	(float) [0.5 2]	ITB	on	(string)	PICRH	0	(float) [0 12]
PLHCD	0	(float) [0 7]	PECCD	0	(float) [0 0.6]	PBREAK	0	(float) [0 0.6]
PRAMPUP	0	(float) [0 0.6]	Recycling	0.7	(float) [0 0.9999]	radiation	Lz	(string)
Cw	0.0001	(float) [0 0.001]	Zeff	1.2	(float) [1.1 6]	SOL_model	scaling	(string)
runaway	off	(string)	breakdown	off	(string)	duration	30	(float) [10 100]
f_dipdt_rampup	0.6	(float) [0.1 1.5]	f_dipdt_rampdown	1	(float) [0.3 3]			

Cancel    reset    Ok

**Read PCS data before shot or to replay a shot as tune in PCS and prepare a METIS simulation**

**load : choose a file ?**

Organiser   Nouveau dossier

Bureau   Emplacements réservés   Téléchargements

WEST\_METIS\_10MV\_0d6MA\_1000s.mat   WEST\_METIS\_12MW\_0d6MA\_60s.mat   WEST\_METIS\_15MV\_0d8\_MA\_30s.mat

Bureau   Bibliothèques   Documents   Images   Musique   Nouvelle bibliothèque   TÉLÉCHARGER

Nom du fichier :    MAT-files (\*.mat)    Ouvrir    Annuler

■ Menu to choose between:

- Scenario generator
- PCS data (before shot)
- ARCAD data (after shot)

- Documents :

- WEST research plan

(WEST Physics Basis, C. Bourdelle et al 2015 Nucl. Fusion 55 063017)

- Data

- Snap shots of LCFS from CEDRES++.
  - References WEST simulations

- We have developed a scenario template generator:
  - Create a full discharge scenario including:
    - break-down & burn through (optional)
    - ramp-up
    - flat-top
    - ramp-down.
  - Pre parametrization with a dedicated GUI.
  - Fine-tuning from METIS GUI.
  - Take into account constraints described in documentation.
  - Actuators are pre-tuned (i.e. LH, ICRH, geometry, ...).

# WEST SCENARIO GENERATOR GUI

LCFS selection

Reference parameter configuration

Plasma composition

Plasma current

Toroidal magnetic field

ICRH power

LH power

Tungsten contamination

Zeff

Shot duration

The screenshot shows a MATLAB-style graphical interface titled "module interface westmetissimulation". The window contains a table with various plasma parameters. Red lines connect specific parameters in the table to labels at the bottom of the slide:

LCFS	WEST_Close_Xpoint.map	(string)	configuration	default tuning of the scenario generator	(string)	gas	2	(integer)
ip	0.8	(float) [0.4 1]	b0	3.7	(float) [1.8 4.2]	ip_first	0.4	(real) [0.05 0.4]
f_Greenwald	0	(float) [0 1.4]	density	4.2	(float) [1 15]	edge_density_factor	1	(float) [0.1 10]
H_H	0.8	(float) [0.5 2]	ITB	on	(string)	PICRH	0	(float) [0 12]
PLHCD	0	(float) [0 7]	PECCD	0	(float) [0 0.6]	PBREAK	0	(float) [0 0.6]
PRAMPUP	0	(float) [0 0.6]	Recycling	0.7	(float) [0 0.9999]	radiation	Lz	(string)
Cw	0.0001	(float) [0 0.001]	Zeff	1.2	(float) [1.1 6]	SOL_model	scaling	(string)
runaway	off	(string)	breakdown	off	(string)	duration	30	(float) [10 100]
f_dipdt_rampup	0.6	(float) [0.1 1.5]	f_dipdt_rampdown	1	(float) [0.3 3]			

Buttons at the bottom left include "Cancel" and "reset". A button at the bottom right is labeled "Ok".

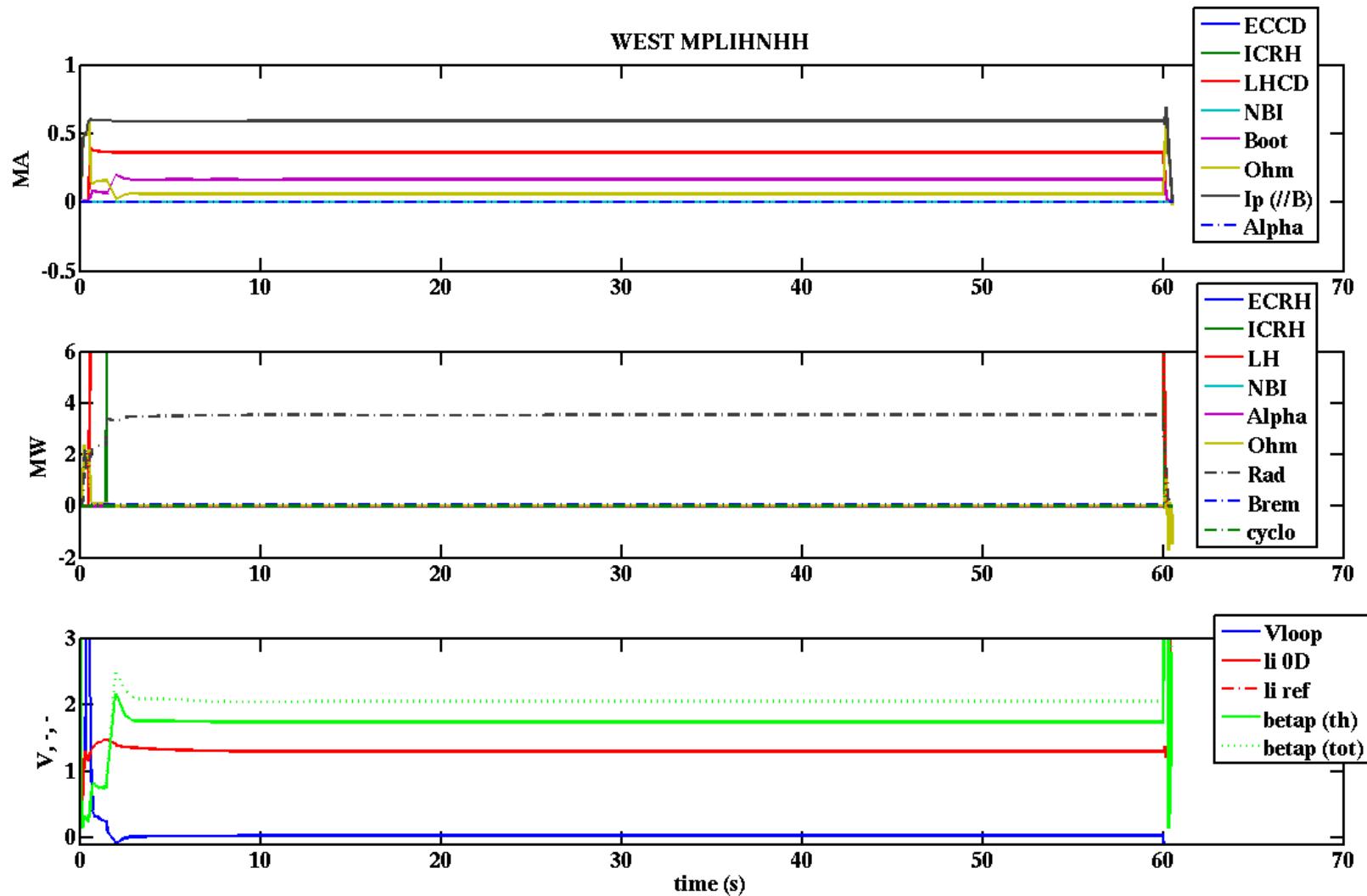
- **LCFS:** LCFS reference from CEDRES++
- **configuration:** initial parameter reference set;
  - if = none, use default tuning of the scenario generator.
- **gas:** main gas species: 1 -> H, 2 -> D, 4 -> He
- **ip:** plasma current (MA)
- **b0:** vacuum magnetic field @ R\_0 (T)
- **ip\_first:** plasma current at time when PCS take control
  - of ramp-up rate (MA)
- **f\_Greenwald:** Greenwald fraction.
  - If set to 0, generator uses density parameter
- **density:** line averaged electron density during flattop ( $10^{19} m^{-3}$ )

- **edge\_density\_factor:** edge density: multiplication factor applied to edge density scaling law:

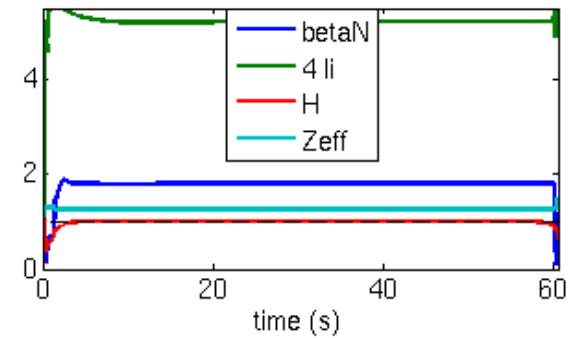
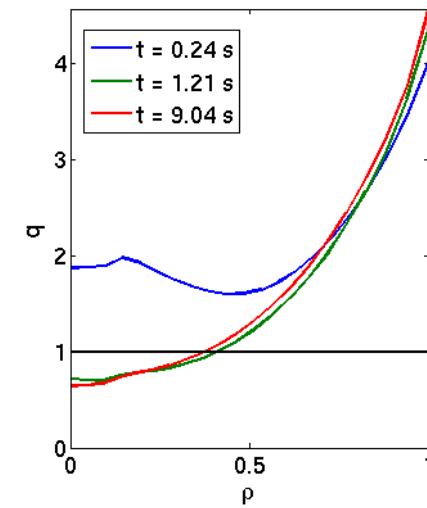
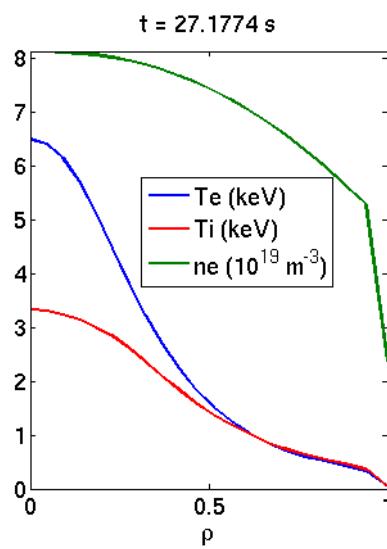
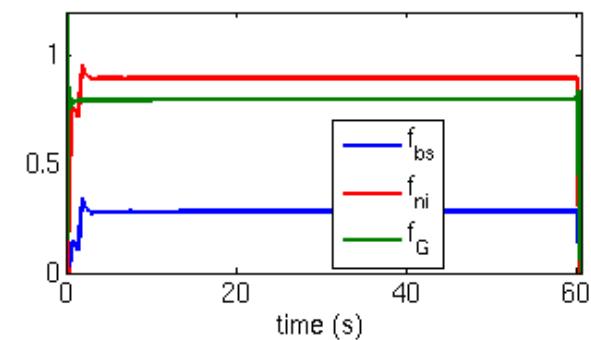
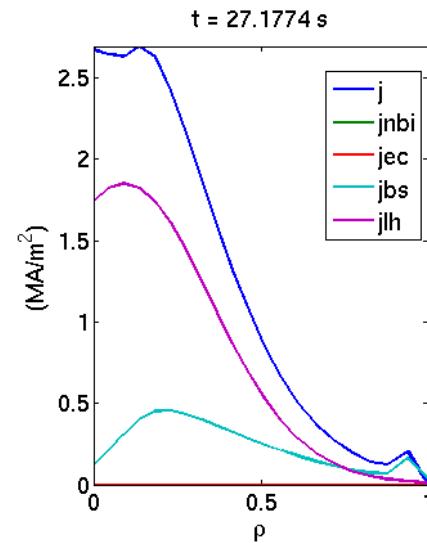
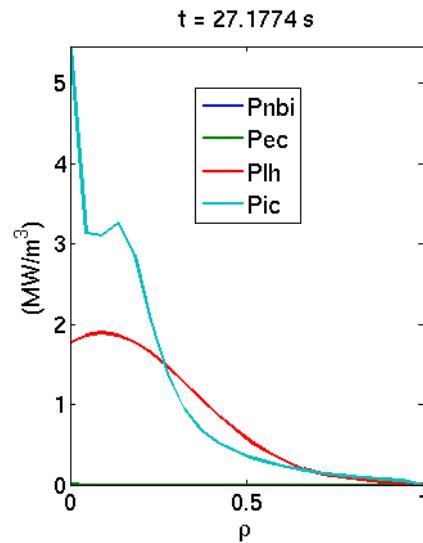
if  $> 0$ ,  $\text{ne\_edge} = \text{nea\_factor} * \text{LCFS\_denstity\_scaling\_law};$   
if  $< 0$ ,  $\text{ne\_edge} = \text{abs(nea\_factor)} * \text{n\_bar}.$

- **H\_H:** time confinement multiplication factor during H-mode phase
- **ITB:** allows or not ITB formation (on/off)
- **PICRH:** maximum power for PICRH during flattop (MW)
- **PLHCD:** maximum power for PLHCD during flattop (MW)
- **PECCD:** maximum power for ECRH/ECCD during flattop (MW);  
baseline maximum power is 0 MW.
- **PBREAK:** injected ECRH / ECCD power for assisted breakdown (MW);  
note that only a small fraction of this power is absorbed;  
baseline maximum power is 0 MW.

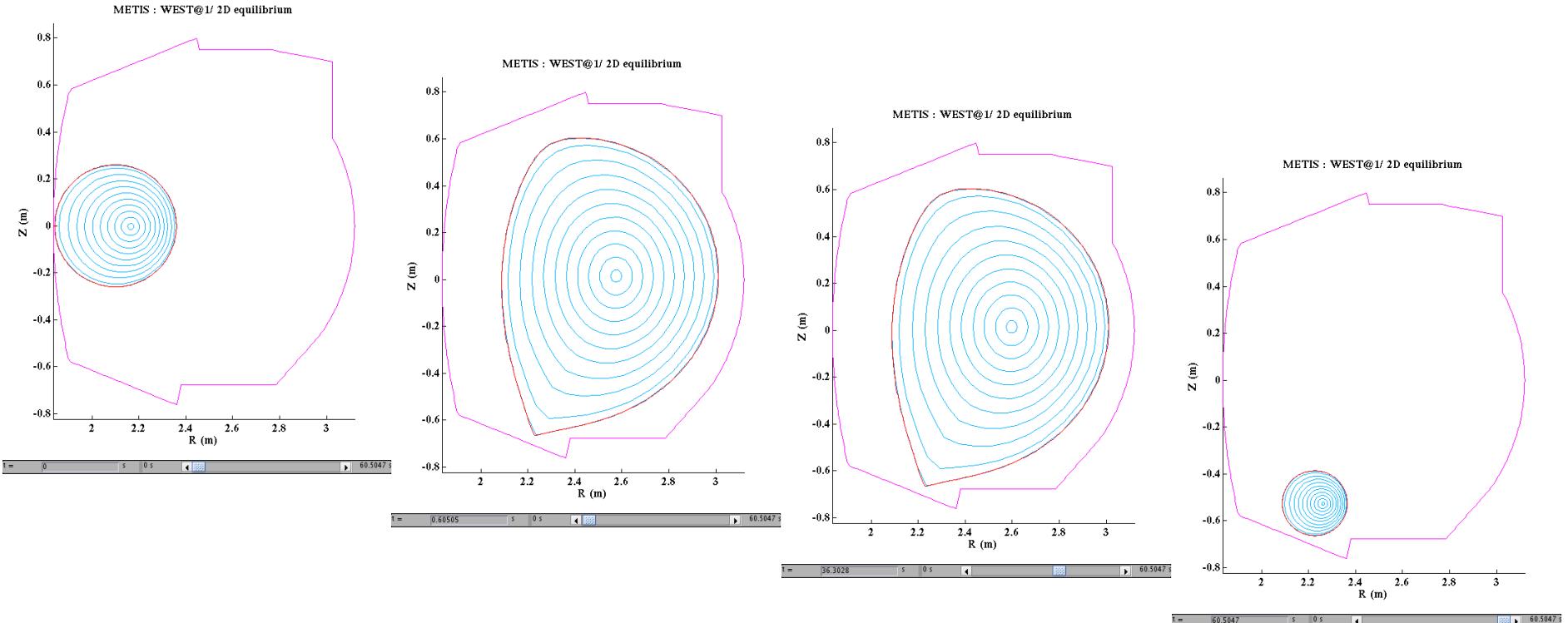
- **PRAMPUP:** ECRH / ECCD assisted ramp-up: power during ramp-up (MW);  
baseline maximum power is 0 MW.
- **Recycling:** Recycling coefficient
- **radiation:** model for line radiative power in core plasma  
(Lz = cooling rate or Matthews = Matthews scaling law)
- **Cw:** Tungsten concentration with respect to electron density
- **Zeff:** Effective charge during flattop
- **SOL\_model:** scaling law or 2 points model
- **runaway:** allows or not runaway electrons in the discharge (on/off)
- **breakdown:** turn on or off the breakdown model for plasma initiation
- **duration:** shot duration: time of end of flat-top (s)
- **f\_dipdt\_rampup:** Ramp-up rate (MA/s)
- **f\_dipdt\_rampdown:** Ramp-down rate (MA/s)

**EXAMPLE OF WEST SIMULATION (1/3)**

# EXAMPLE OF WEST SIMULATION (2/3)

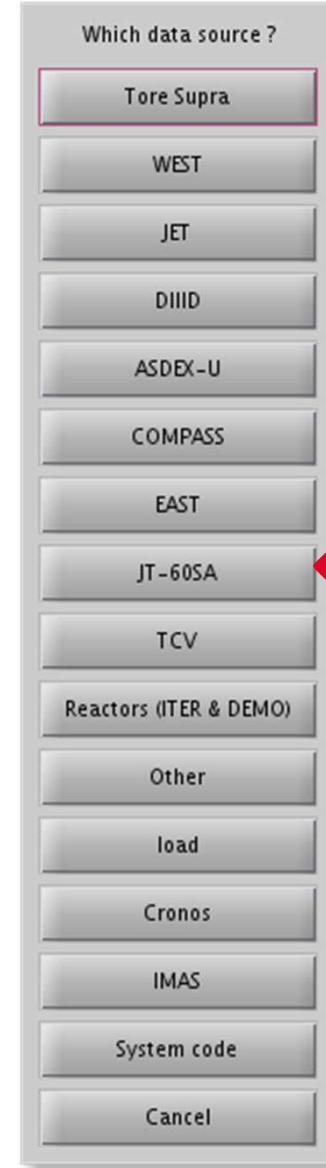
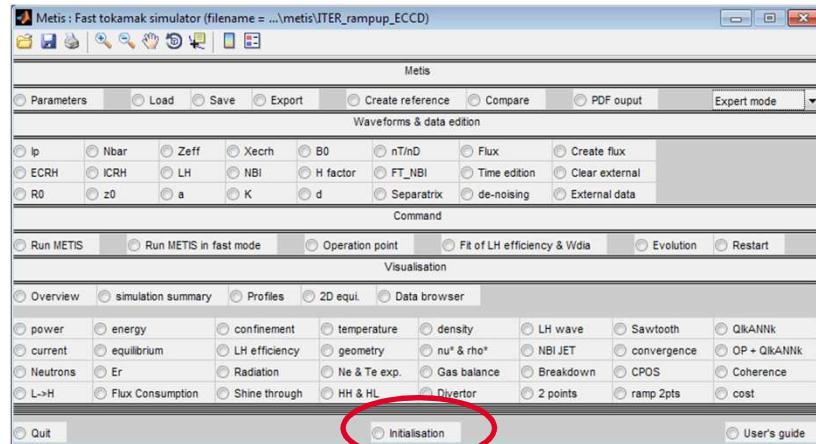


# EXAMPLE OF WEST SIMULATION (3/3)



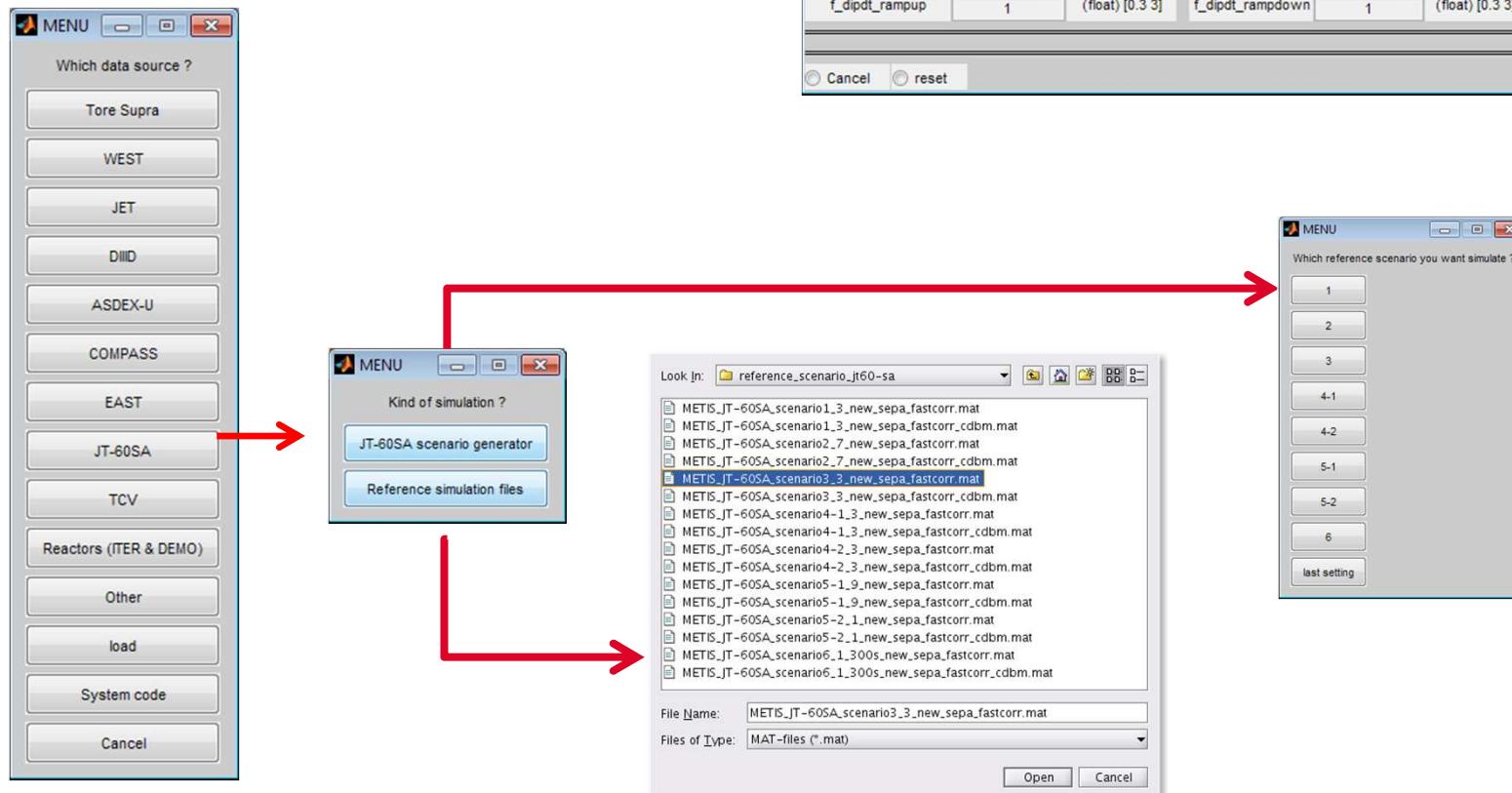
# **JT-60SA SCENARIO PREPARATION**

# ACCESS TO JT-60SA SCENARIO PREPARATION



Menu for JT-60SA

- Added menu to choose between:
  - reference scenario files
  - scenario generator



## ■ Documents :

- JT-60SA Research
- Development of operation scenarios for plasma breakdown and current ramp-up phases in JT-60SA tokamak , H. Urano et al,  
Fusion Engineering and Design 100 (2015) 345–356
- Simulation of plasma current ramp-up with reduced magnetic flux consumption in JT-60SA, T Wakatsuki et al,  
Plasma Phys. Control. Fusion 57 (2015) 065005 (12pp)

## ■ Data

- Snap shots of LCFS during scenario 2 from CREATE team.

- We have developed a scenario template generator:
  - Create a full discharge scenario including:
    - break-down
    - burn through
    - ramp-up
    - flat-top
    - ramp-down.
  - Pre parametrization with a dedicated GUI.
  - Fine-tuning from METIS GUI.
  - Take into account constraints described in documentation.
  - Actuators are pre-tuned (i.e. NBI geometry, ...).

- **sepa\_option:** reference scenario for LCFS parametrisation  
(JT-60SA Research Plan, Version 3.3, 2016, March)
- **sepa\_create:** if = Yes, use LCFS provided by CREATE team (available for scenario 2); if = No, use LCFS generated by the program
- **gas:** Plasma composition: main gas species: 1 -> H, 2 -> D, 4 -> He
- **ip:** plasma current (MA)
- **b0:** vacuum magnetic field @ R\_0 (T)
- **voltage\_first:** Plasma initiation: burn through Vloop: high or low  
(H. Urano et al, Fusion Engineering and Design 100 (2015) 345-356)
- **flux:** available flux from pre-magnetisation: half CS current or full CS current  
(H. Urano et al, Fusion Engineering and Design 100 (2015) 345-356)
- **density:** line averaged electron density during flattop ( $10^{19} m^{-3}$ )

- **edge\_density\_factor:** multiplication factor applied to edge density scaling law:

if  $> 0$ ,  $\text{ne\_edge} = \text{nea\_factor} * \text{LCFS\_density\_scaling\_law};$

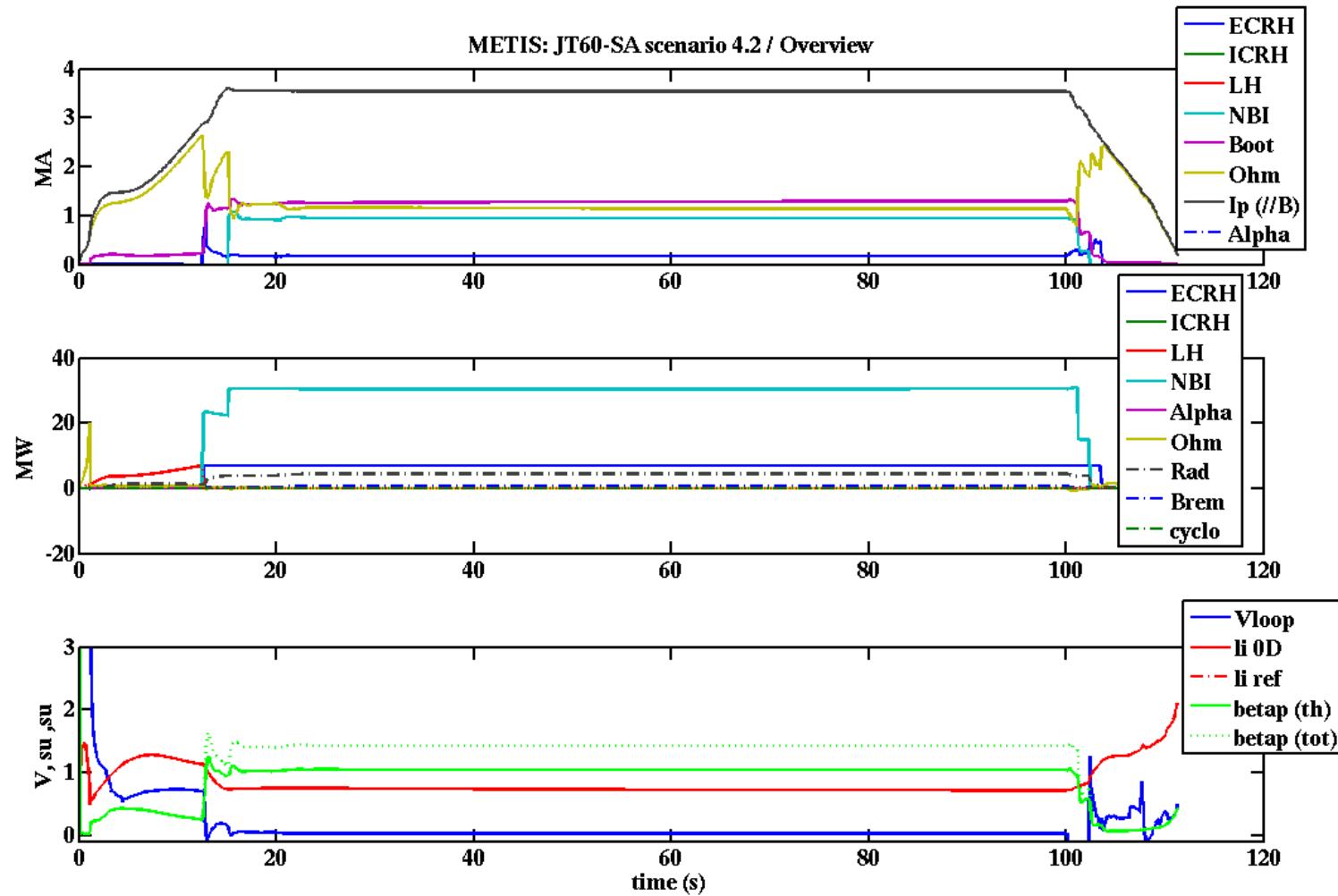
if  $< 0$ ,  $\text{ne\_edge} = \text{abs(nea\_factor)} * \text{n\_bar}$

- **H\_H:** time confinement multiplication factor during H-mode phase
- **ITB:** allows or not ITB formation (on/off)
- **PNBI\_N:** maximum power for NNBI during flattop (MW)
- **PNBI\_P:** maximum power for PNBI during flattop (MW)
- **PICRH:** Optional ICRH source; maximum power for PICRH during flattop (MW); must be 0 by default (this source can be used for scope studies)
- **PECCD:** maximum power for ECRH/ECCD during flattop (MW); baseline maximum power is 7 MW

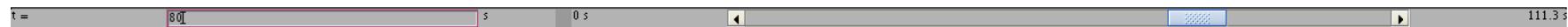
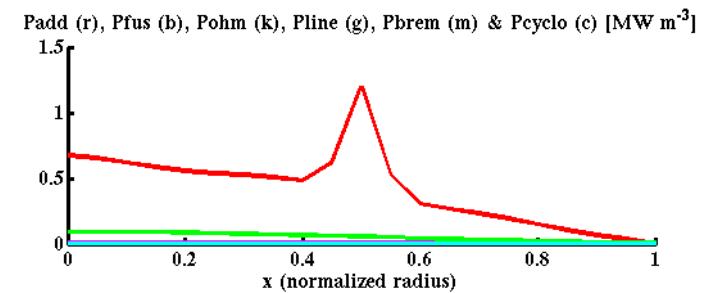
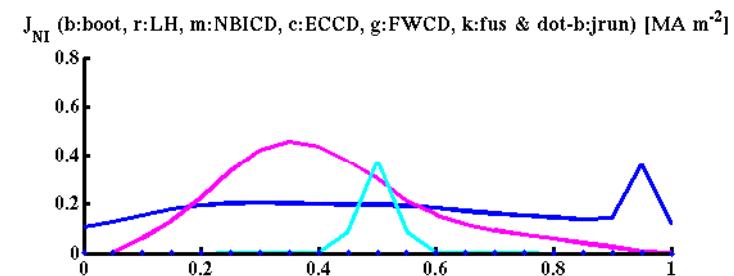
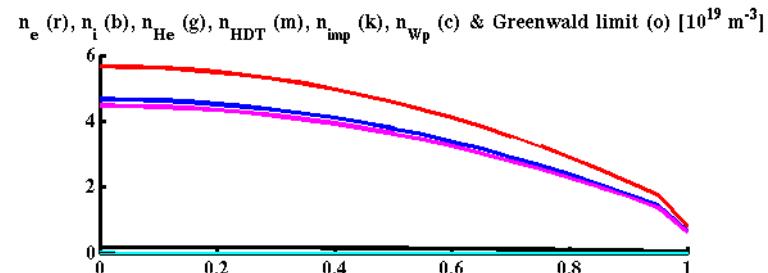
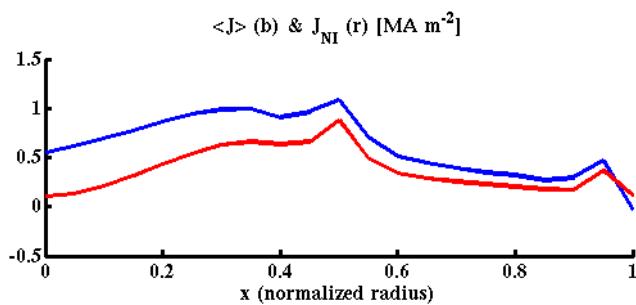
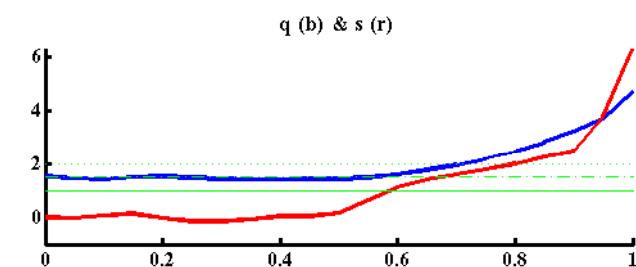
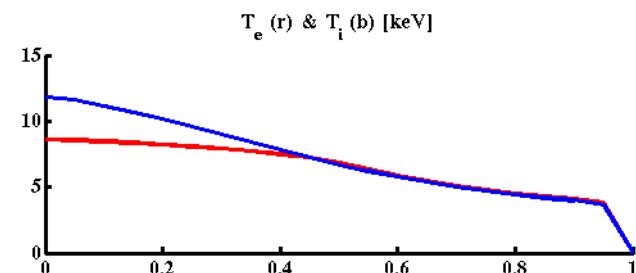
- **PBREAK:** injected ECRH / ECCD power for assisted breakdown (MW);  
note that only a small fraction of this power is absorbed
- **PRAMPUP:** ECRH / ECCD assisted ramp-up: maximum power at the end of ramp-up (MW): power increases in time depending on density and plasma current
- **Recycling:** Recycling coefficient
- **radiation:** model for line radiative power in core plasma  
( $L_z$  = cooling rate or Matthews = Matthews scaling law)
- **SOL\_model:** scaling law or 2 points model
- **runaway:** allows or not runaway electrons in the discharge (on/off)
- **breakdown:** turn on or off the breakdown model for plasma initiation
- **duration:** shot duration: time of end of flat-top (s)

- **f\_dipdt\_rampup:** Ramp-up rate; multiplication factor applied to dlp/dt for plasma current ramp-up with respect to reference case  
(H. Urano et al, Fusion Engineering and Design 100 (2015) 345-356)
- **f\_dipdt\_rampdown:** Ramp-down rate; multiplication factor applied to dlp/dt for plasma current ramp-down with respect to reference case  
(H. Urano et al, Fusion Engineering and Design 100 (2015) 345-356)
- **reference\_parameters:** file name that contains Parameters that will overwrite user defined Parameters (if empty, it is not used)

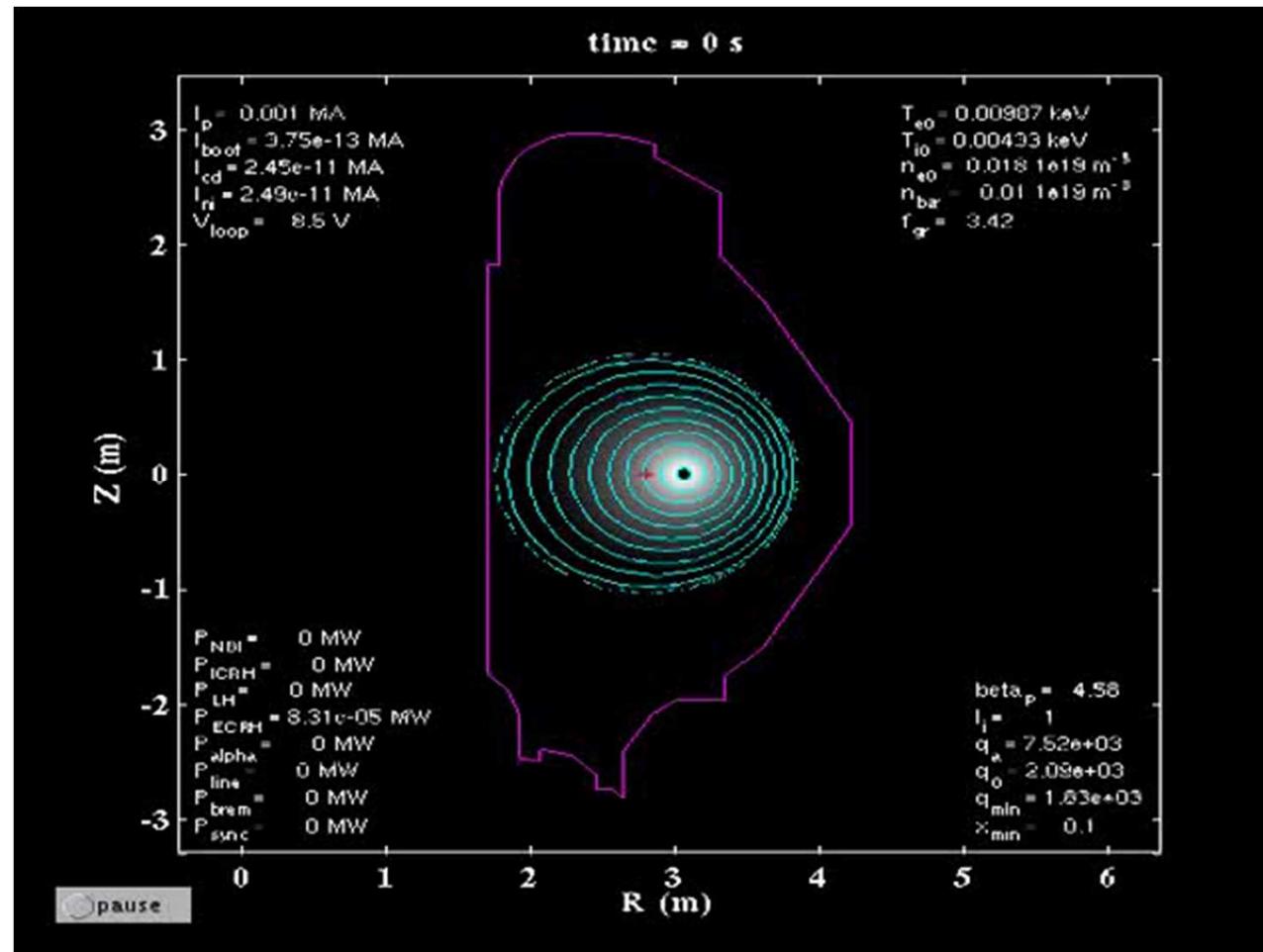
# ONE EXAMPLE: SCENARIO 4.2



# ONE EXAMPLE: SCENARIO 4.2 (2/3)

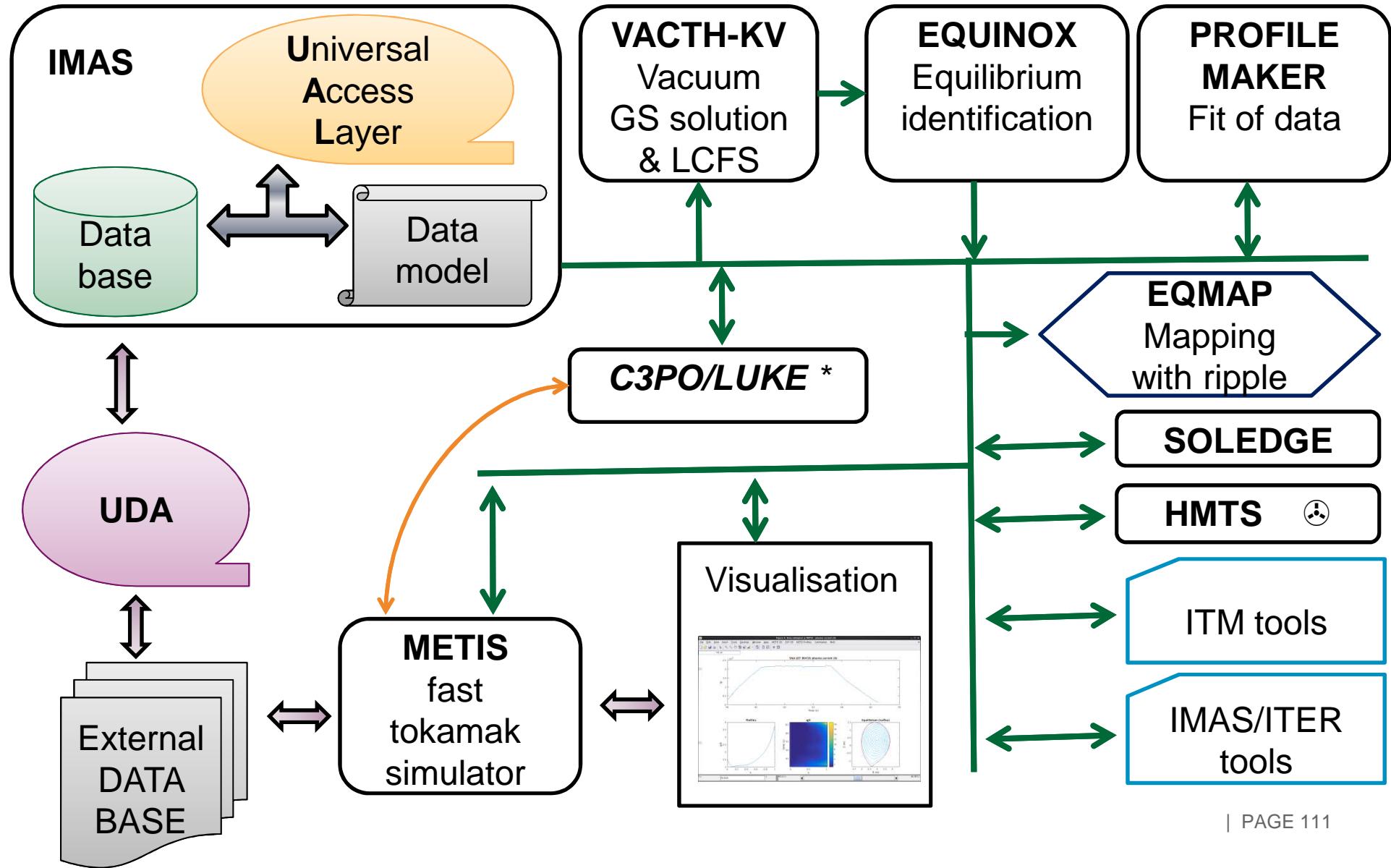


# ONE EXAMPLE: SCENARIO 4.2 (3/3)

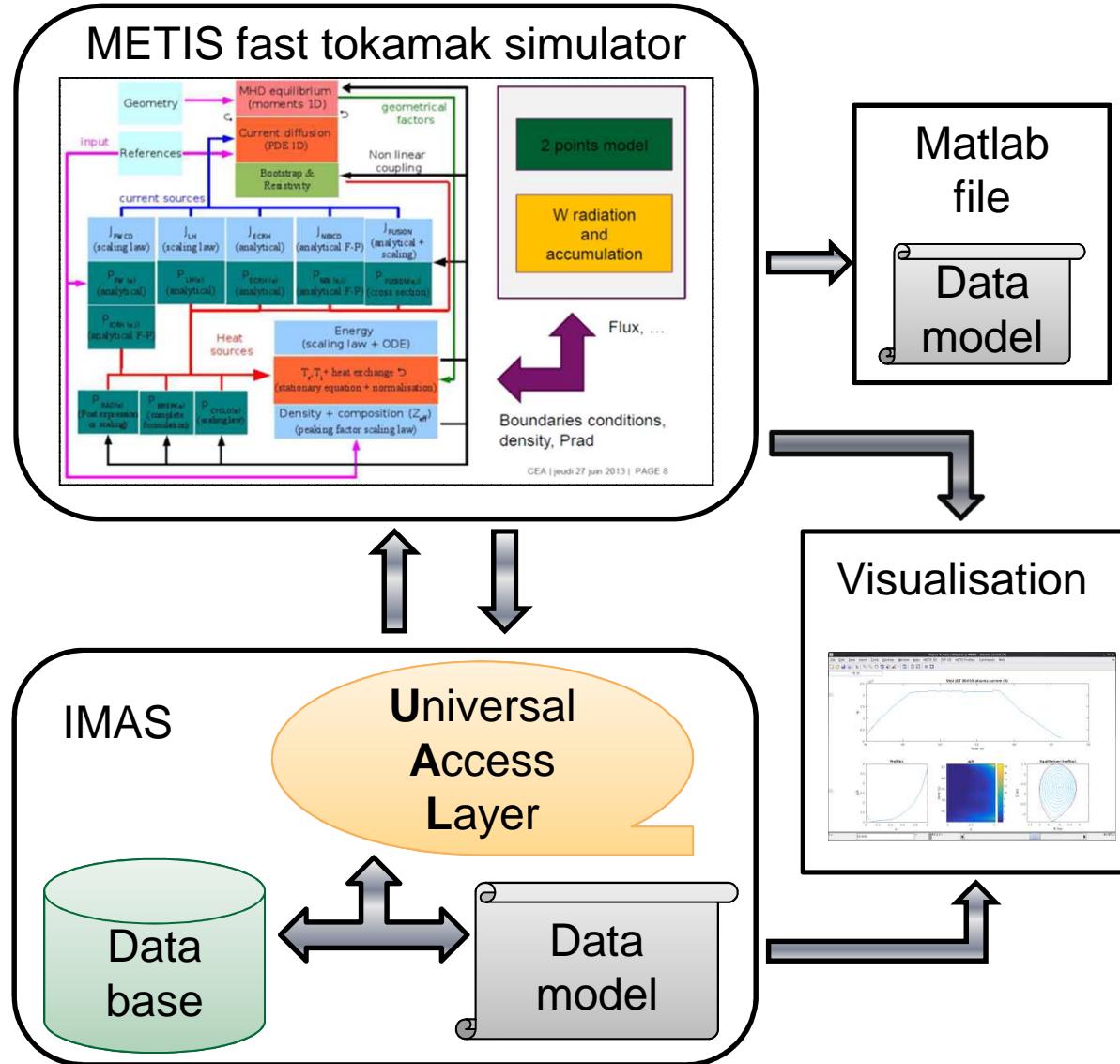


Time is not linear in this video !

# **METIS AND IMAS**



# METIS IS CONNECTED TO UAL



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

## ■ 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.

## ■ 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.

# METIS4MAS OVERVIEW

**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**

**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)

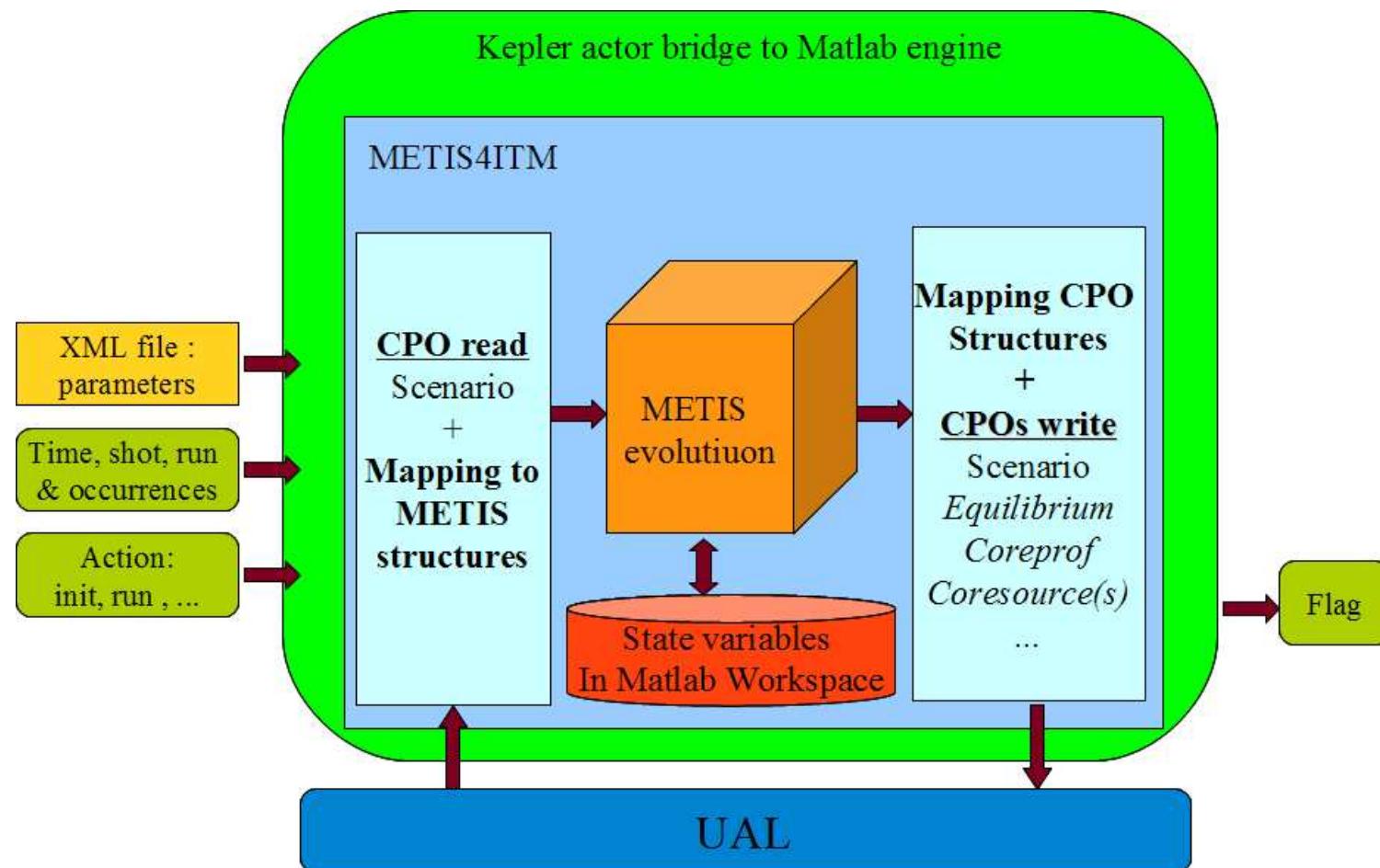
## Standard output:

- `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
  - 5D 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

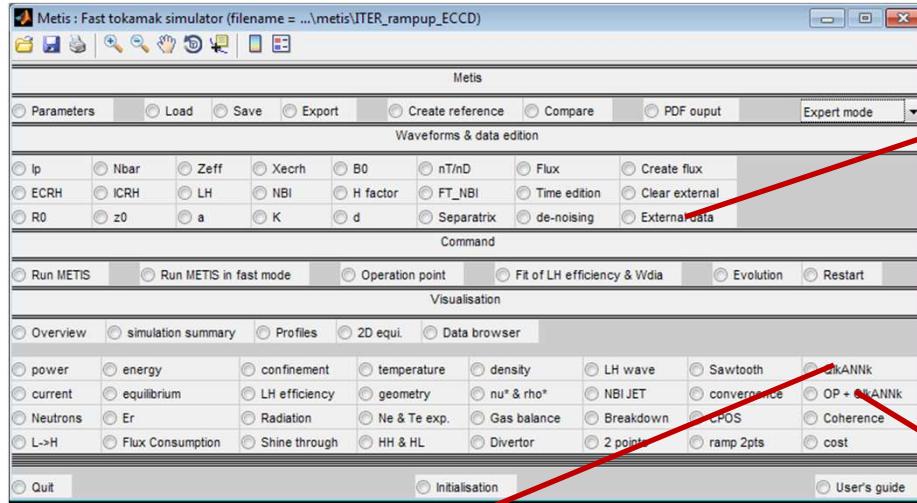
Ref: J. Citrin et al 2015 Nucl. Fusion 55 092001

# 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

- 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**

Full scenario prediction

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

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.

## **METIS: OTHER FEATURES**

- External codes interfaced to METIS
  - Call for one time slice
  - Tuning or validation of METIS models
- ✓ Available helpers:
  - HELENA/NCLASS: bootstrap current
  - Qualikiz neural network: (Te, Ti & Ne)

- Originally METIS was a module of CRONOS
  - CRONOS data set can be used to prepare a METIS simulation
  - METIS simulation can be used to fulfil a CRONOS data set
- Integration is complete between CRONOS GUI and METIS GUI
- Useful to check a CRONOS simulation
- Use to prepare CRONOS simulation for future tokamak
- Allows to rapidly run a module of CRONOS from a METIS simulation.

- FREEBIE (FBE) and METIS have been coupled  
= full tokamak simulator for scenario and controller design
- ✓ METIS: fixed boundary solver for FREEBIE
- ✓ FREEBIE provided LCFS + moments to METIS
- ✓ Interfaced to Simulink

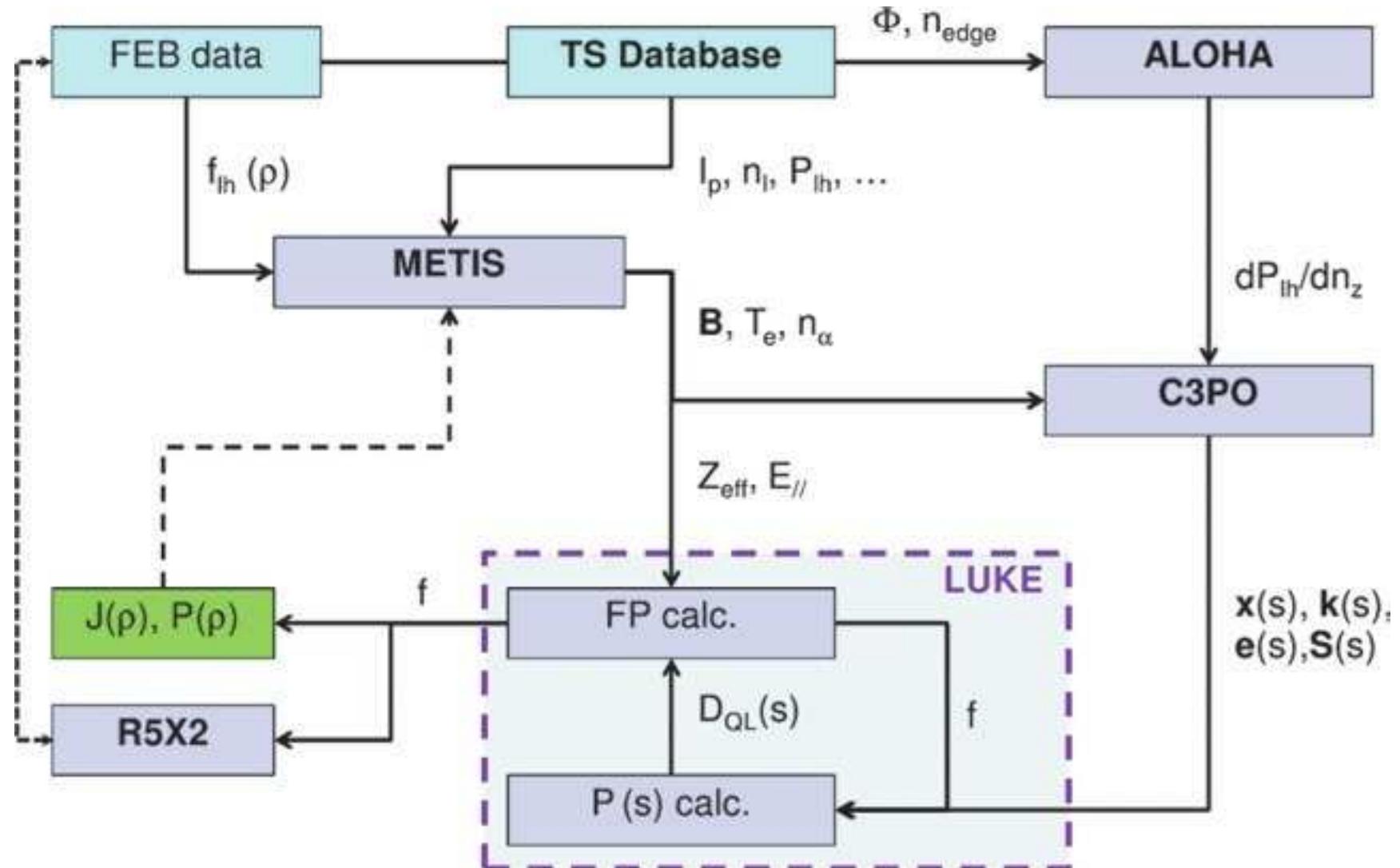
- C3PO/LUKE module compute sources from RF electron resonant waves:
  - LHCD
  - ECCD
- C3PO: ray-tracing code
- LUKE: relativistic Fokker-Planck solver
- R5X2: synthetic diagnostic for fast electron bremsstrahlung

[Y. Peysson et al, Plasma Phys. Control. Fusion, 54:045003, 2012]

[Y. Peysson and J. Decker, Calculation of rf current drive in tokamaks,  
CEA/IRFM, Association Euratom-CEA, 2007]

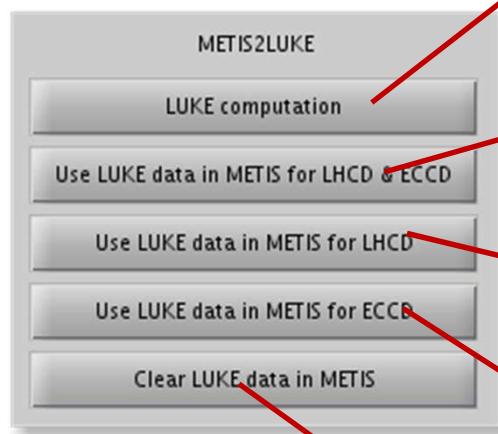
[Y. Peysson and J. Decker, Physics of Plasmas, 15, 2008].

# LUKE/METIS COUPLING



- ✓ METIS provides core plasma data to LUKE/C3PO (kinetic profiles and MHD equilibrium)
- ✓ LUKE provides LHCD and ECCD sources to METIS
- ✓ LUKE will provide runaway current to METIS that in return will provide  $E_{\parallel}$

[E. Nilsson et al 2013 Nucl. Fusion 53 083018 doi:10.1088/0029-5515/53/8/083018]



Prepare LUKE data from METIS simulation  
and call LUKE interface

Use LUKE results in METIS as external  
data for LHCD and ECCD

Use LUKE results in METIS as external  
data for LHCD

Use LUKE results in METIS as external  
data for ECCD

Remove LUKE data from external  
data used by METIS

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