

VisualStart: GUI-Aided Unified Initialization Tool for Hybrid (MHD + Particle) Simulations

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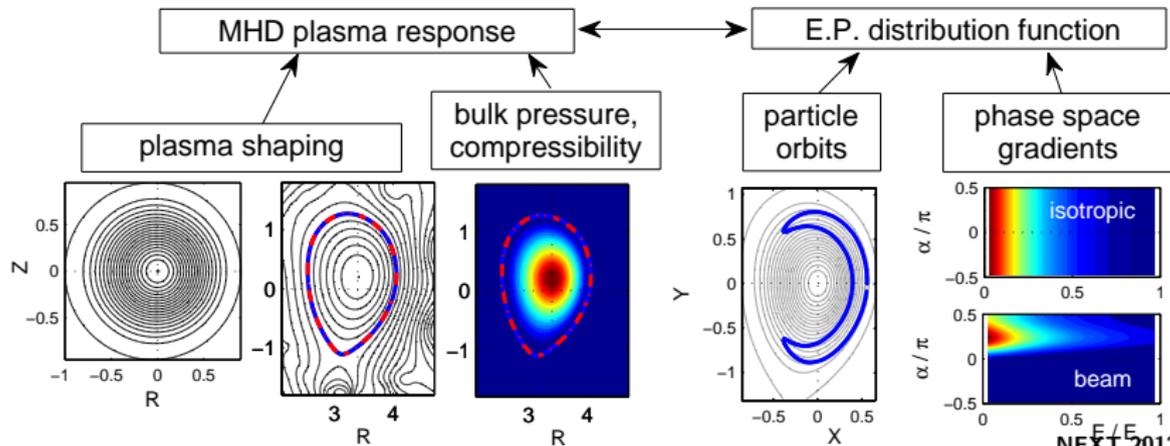
Japan Atomic Energy Agency, Aomori, Japan

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Introduction

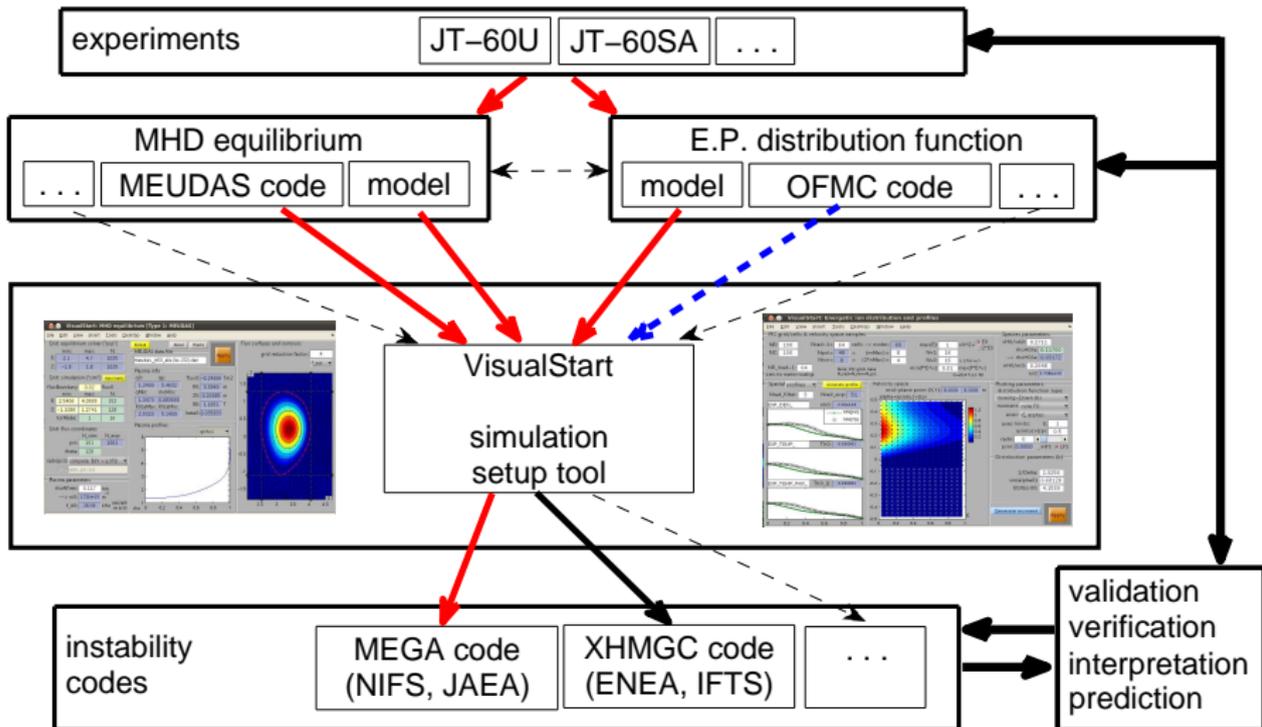
- **Motivation:** Predictive simulations ...
 - ▶ Require complex models for the initial state and dynamic evolution.
 - ▶ Amount of input data can be large and often requires preprocessing
 - ▶ Preprocessing such as data conditioning and matching of parameters require interaction with the user.
- **Approach and Scope:**
 - ▶ A GUI-aided software tool is developed that assists the user with the task of designing a simulation scenario.
 - ▶ Focus on global nonlinear hybrid codes used to study Alfvén mode and energetic particle (E.P.) dynamics in tokamaks.



Code framework

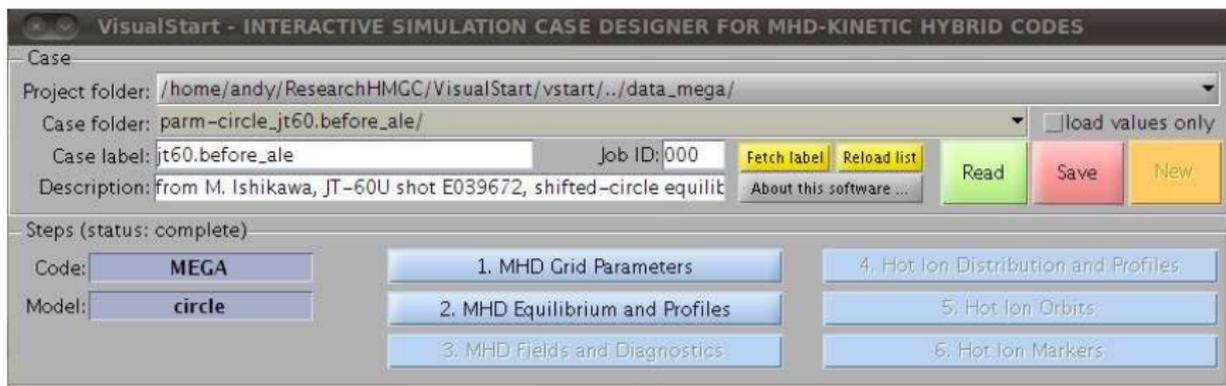
— active, --- planned
— here, --- underway

- **Modular simulation toolbox**

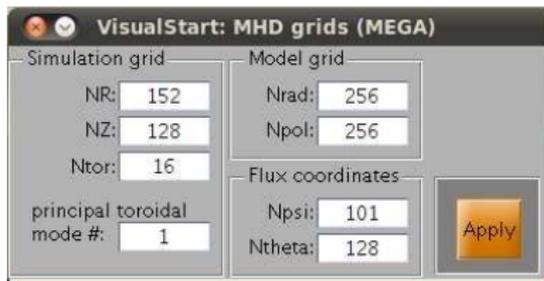


- The tool is capable of initializing different codes with the same initial state. This simplifies and improves benchmarking activities.

Main panel, Step 1: Grid setup



- Project file management
- Navigation



- Computational grid setup

Step 2: MHD equilibrium [Type 1: MEUDAS]

VisualStart: MHD equilibrium [Type 1: MEUDAS]

File Edit View Insert Tools Desktop Window Help

Grid: equilibrium solver ("exp")

min:	max:	N:
R: 2.1	4.7	1025
Z: -1.8	1.8	1025

Reload About Howto

MEUDAS data file

meudas_jt60_ale.(le-i32).dat Apply

Plasma info

q0:	qa:	flux0:	-0.24996	Tm2
1.3499	5.4632	R0:	3.3949	m
qMin:	rhoMin:	Z0:	0.20385	m
1.3473	0.083666	B0:	1.1661	T
R0/aMax:	R0/aMin:	beta0:	0.035833	
2.5323	5.1439			

Grid: simulation ("sim") Auto limits

fluxBoundary: 0.02 flux0

min:	max:	N:
R: 2.5406	4.0565	152
Z: -1.1086	1.2741	128

torMode: 1 16

Grid: flux coordinates

N_sim:	N_exp:
psi: 101	1001
theta: 128	

radn(psi) compute: \$dV \times q/(FJ)\$

file: radn_psi.txt

Plasma parameters

rhoAlfven:	0.117	a1fs	-3
ni0:	1.731e+19	m	
f_A0:	202.66	kHz	(wA/2piR on axis)

Plasma profiles

q(rho)

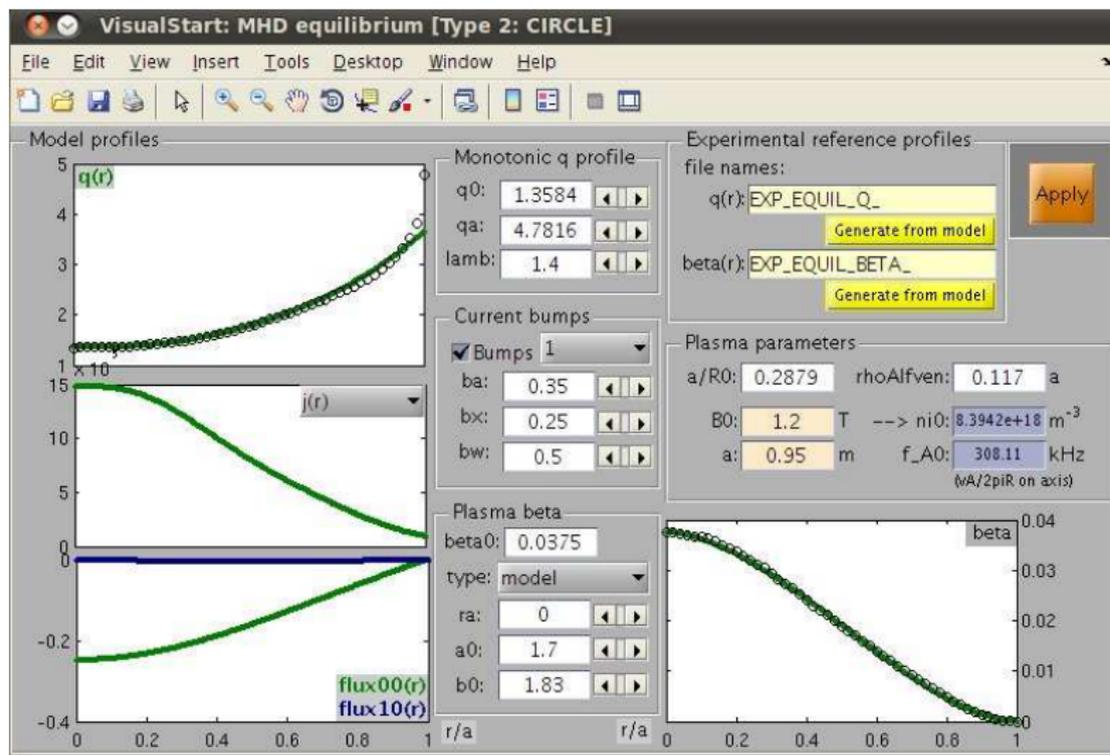
Flux surfaces and contours

grid reduction factor: 4

P_tot

- Import equilibrium files
- Set computational domain

Step 2: MHD equilibrium [Type 2: CIRCULAR]



- Match reference profiles
- Set model parameters

Step 3: MHD field analysis and solver parameters

The screenshot displays the VisualStart: MHD field solver interface, which is organized into several functional panels:

- Initial perturbation:** Includes input fields for amplitude (cos, sin) set to $1e-08$ and $1e-08$, and position/width (r, w) set to 0.3 and 0.6. A plot shows a red curve representing the perturbation profile.
- Dissipation:** Contains parameters for ν_0 ($1e-06$), η_0 ($3e-06$), and χ_0 ($1e-06$).
- Specific heat ratio:** Shows $c_P / c_V = 5 / 3$.
- Energetic ions:** Features checkboxes for 'enable P_hot', 'single n' (set to 1), 'smoothing', and 'include F0'.
- Field analysis:** Provides parameters for Fourier modes and radial probes, including qMin (1.347), qMax (3.882), and various mode selection options.
- Shear Alfvén continuum:** Displays a plot of the shear Alfvén continuum with green data points and a dashed line. The plot is labeled 'w/wA0'.
- Geometry and Harmonics:** Includes settings for 'finite betaBulk', 'geometry harmonics' (m(max): 6), 'wave harmonics' (m(max)/n: 12), and 'smoothing up to r(max)/a: 1'.

Two plots are visible: 'Bulk ion density profile' showing a red curve and 'ni/ni0' showing a green curve with data points. The x-axis for both plots is r/a, ranging from 0 to 1.

- Match reference profile for bulk density
- Compute continuous shear Alfvén spectrum

Step 4: Energetic ion distribution function

VisualStart: Energetic ion distribution and profiles

File Edit View Insert Tools Desktop Window Help

PIC grid/cells & velocity space samples

NR: 100 Nrad-1= 64 cells -> nodes: 65 max(E): 0.5 v0^2 = E0 2*E0
NZ: 100 Npol= 48 = (mMax) x 8 Nv1: 16
Ntor= 8 = (2*nMax) x 4 Nv2: 16 x 2 for +/-
NR_load-1: 64 Note: PIC grids have N_rad=N_rho=N_psi. min(f*E^x): 0.01 max(f*E^x) (x={0,0.5,1,1.5})
(cells for marker loading)

Species parameters

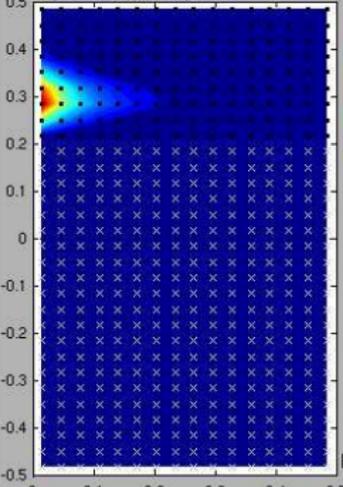
vH0/vA0: 1.391
rhoA0/a: 0.11700
-> rhoH0/a: 0.16275
nH0/ni0: 0.068
ni0: 1.738e+19

Spatial profiles

Nrad_filter: 3 Nrad_exp: 51

EXP_DEN_ nh0: 2.16e+18
EXP_TEMP_ Th0: 0.036903
EXP_TEMP_PAR Th0_II: 0.036903

Velocity space
mid-plane point (X,Y): 0.000 0.000 m
alpha=asin(u/v)/pi



Plotting parameters

distribution function type: Slowing-Down (b)

moment: pure F0

axes: (E, alpha)

axes limits: E: 0.5
asin(u/v)/pi: 0.5

radn: 0 HFS LFS

psin: 0.0000

Distribution parameters (b)

1/Delta: 10
sin(alpha0): 0.791
E0/Ecrit0: 11.678

- Set up phase space mesh and model distribution function

Step 5: Orbit analysis and database

VisualStart: Particle orbits and marker loading

File Edit View Insert Tools Desktop Window Help

Grid parameters: R_k(alpha=0) grid reduction fact.: 1 grid exponent: 1 Database: DB file prefix: ORBIT Build DB Check DB Apply

Phase space grids & initial position for test orbit: E/T0: 0.1

Solver & builder parameters: dt: 1 tA0 sample distance: 0.004 x plasma circumference tMax: 1000 tA0 min. # samples per orbit: 32 recorded # time samples: 16 (even # recommended)

model: drift kinetic (MEGA) randomization: 0: off

Orbit diagnostics: Compute Test Orbit status/type: banana #41 23deg mismatch dE: -2.8e-05 (relative err.) mismatch dR: 3.3e-05 (absolute err.)

(rad,pol) (X,Y)

(mu,A): 0.11185 1.1189 v_||/v0: 0.1382

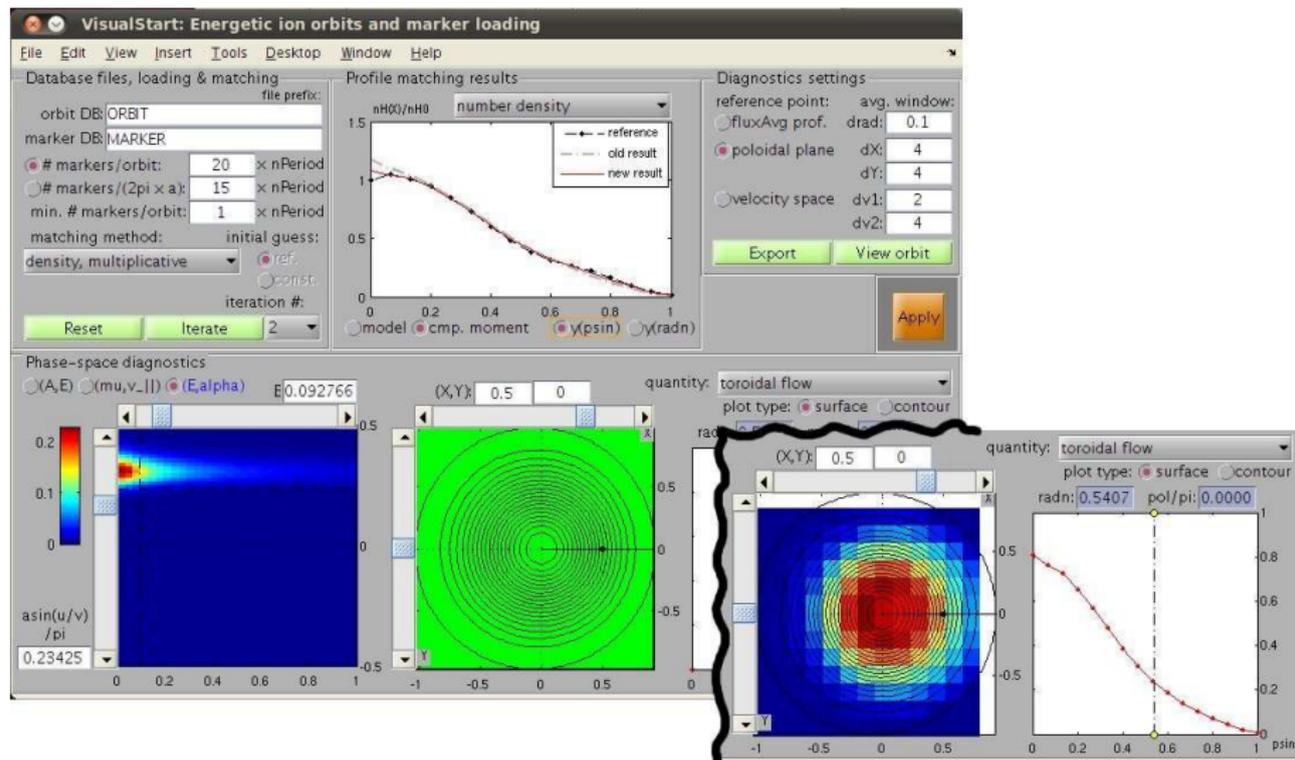
(r/a, pol/pi): 0.83735 0 (R,Z) (m): 4.16 0

radN: 0.9 polN[pi]: 0

The screenshot displays the VisualStart software interface. The top menu bar includes File, Edit, View, Insert, Tools, Desktop, Window, and Help. The main window is divided into several sections: 1. Grid parameters: R_k(alpha=0) grid reduction fact.: 1, grid exponent: 1. 2. Database: DB file prefix: ORBIT, with Build DB and Check DB buttons. 3. Phase space grids & initial position for test orbit: E/T0: 0.1, with a plot of alpha/pi vs X = R-R0. 4. Solver & builder parameters: dt: 1, tA0, sample distance: 0.004, tMax: 1000, tA0, min. # samples per orbit: 32, recorded # time samples: 16. 5. Model: drift kinetic (MEGA), randomization: 0: off. 6. Orbit diagnostics: Compute Test Orbit button, status/type: banana #41 23deg, mismatch dE: -2.8e-05 (relative err.), mismatch dR: 3.3e-05 (absolute err.). 7. Plots: (mu,A) plot, (r/a, pol/pi) plot, (R,Z) (m) plot, and a time series plot of Zeta/pi vs time.

- Sample constant-of-motion space and create orbit database

Step 5: Marker loading and weighting



- Load phase space markers along orbits
- Adjust weights to match reference profiles

Summary

Developed :

- Versatile tool to set up initial state hybrid simulation codes
- Design process supported by interactive GUI
⇒ provides convenient control, detailed information and feedback
- Steps 4+5+6: Implementation of new marker loading scheme:
Bierwage *et al.*, *Comp. Phys. Comm.* **183** (2012) 1107–1123
“Orbit-based representation of equilibrium distribution functions for low-noise initialization of kinetic simulations of toroidal plasmas”
 - ▶ Low noise initialization (time-independent marker distribution)
 - ▶ Exact equilibrium distribution function (fct. of constants of motion only)
 - ▶ Moments match given reference profiles (interactive iterative matching)
- Output files in portable and self-explanatory NetCDF format

Extensions underway:

- Step 4: Interface with OFMC solver to import and pre-process numerical distribution function

Planned extensions:

- Step 2: Interfaces with other MHD equilibrium solvers (e.g., for DIII-D tokamak)