The OMFIT integrated modeling tool STEP for predicting performance of NSTX(-U)

presented by

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in collaboration with

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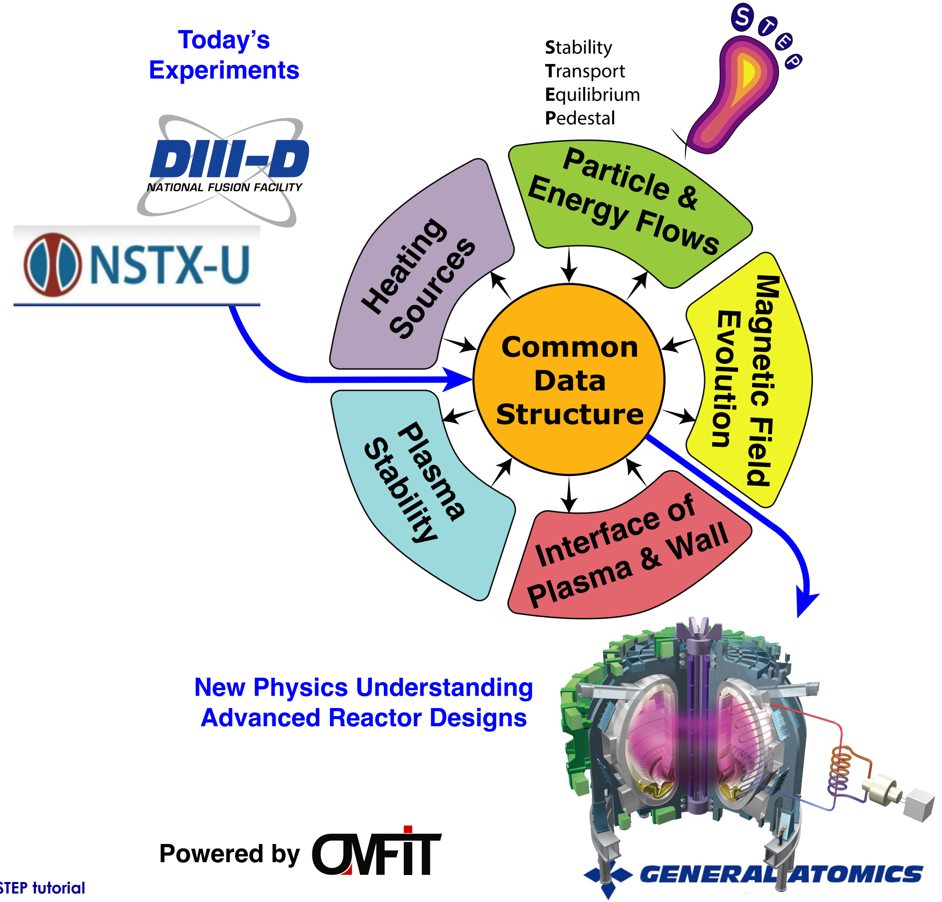
Presented at the NSTX-U Monday Physics meeting

STEP developed to predict stable tokamak equilibria self-consistently with core-transport & pedestal calculations

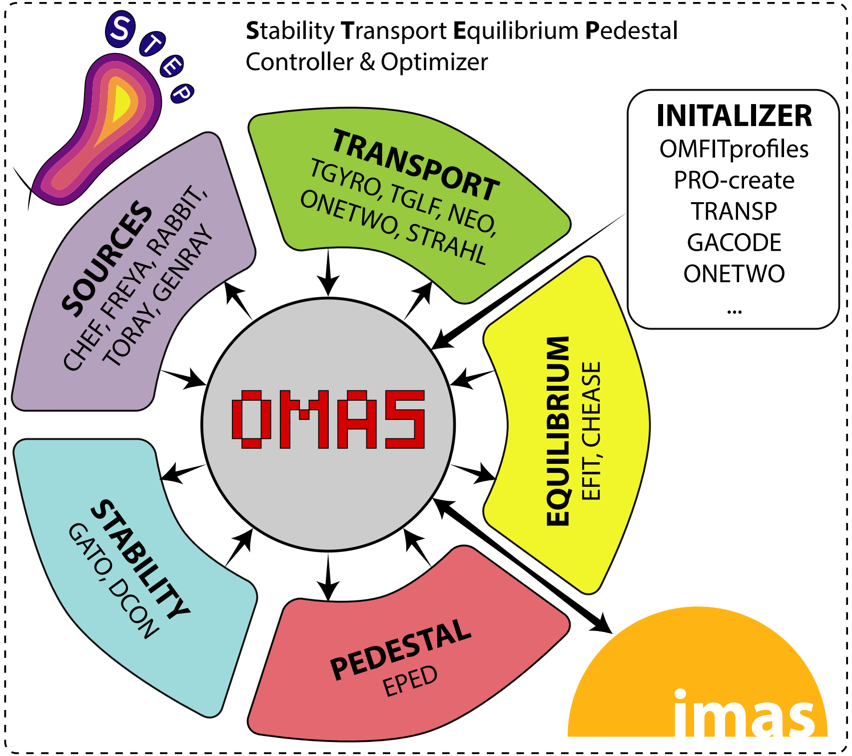
- **Couples theory-based codes for different physics to analyze experiments and predict reactors**
- **Uses centralized data structure for communication**
  - Highly flexible workflow development
- **Created in OMFIT for user-friendliness and wide access**

Lyons et al. Phys. Plasmas 30, 092510 (2023)



STEP module in OMFIT couples Stability, Transport, Equilibrium, & Pedestal codes to predict tokamak scenarios

- **Each physics code is wrapped into a "step" that reads from & writes to centralized data structure**
- **Steps are interchangeable, permitting a variety of workflows**
  - **Open-loop:** given these parameters, what does my plasma look like?
  - **Closed-loop:** given a desired plasma, what parameters do I need?
  - **Optimization:** what parameters maximize a desired plasma metric?
- **Initialize simulations from:**
  - Experimental data
  - Existing simulations
  - Data in ITER IMAS format
  - 0D parameters (via PRO_create)



O. Meneghini et al. Nucl. Fusion **61**, 026006 (2021)

Many Physics Steps Already Available

Stability

- DCON – Ideal MHD
- GATO – Ideal MHD

Equilibrium

- EFIT – Free-boundary
- CHEASE – Fixed-boundary

Pedestal

- EPED – Balances stability and transport

Transport

- TGLF – Quasilinear gyro-Landau-fluid model
- NEO – Neoclassical drift-kinetic solver
- TGYRO – Runs multiple instances of TGLF & NEO to balance fluxes
- ONETWO – Current evolution
- STRAHL – Impurity transport

Sources

- CHEF – Runs NBI, RF, and fueling models
- FREYA & RABBIT – NBI heating & current drive
- TORAY & GENRAY – RF heating & current drive

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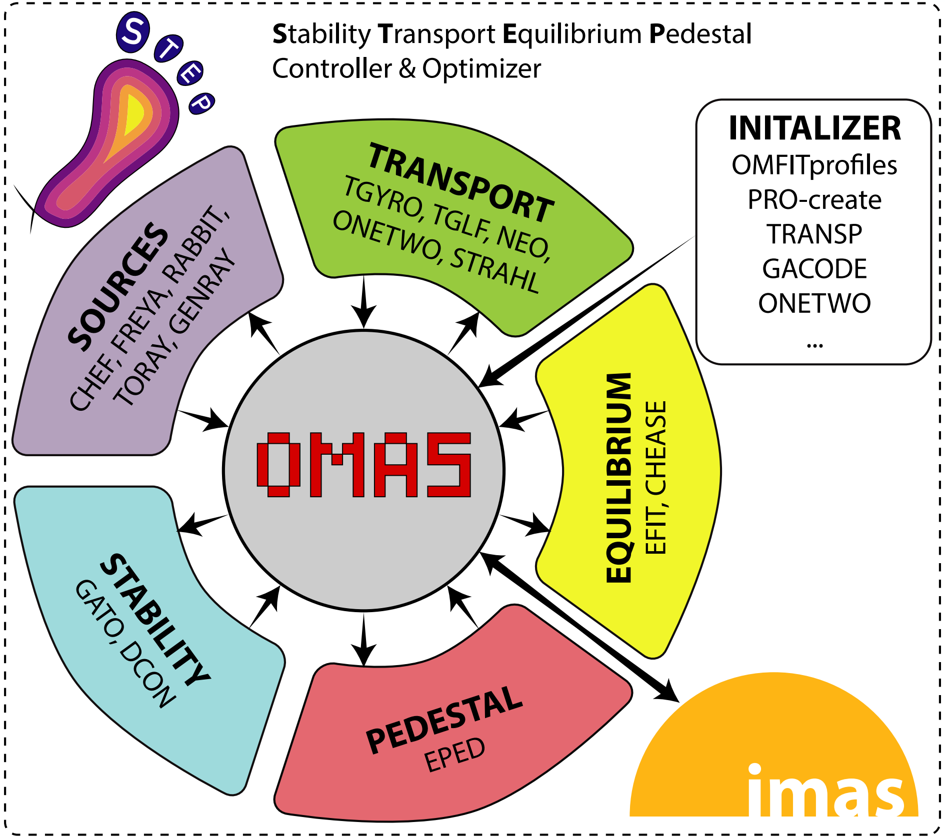
That's STEP! What Can We Do With It?

- Design your own workflow based on physics need
- *Manually* iterate through codes
- Define custom convergence conditions
- Define custom actuators and targets

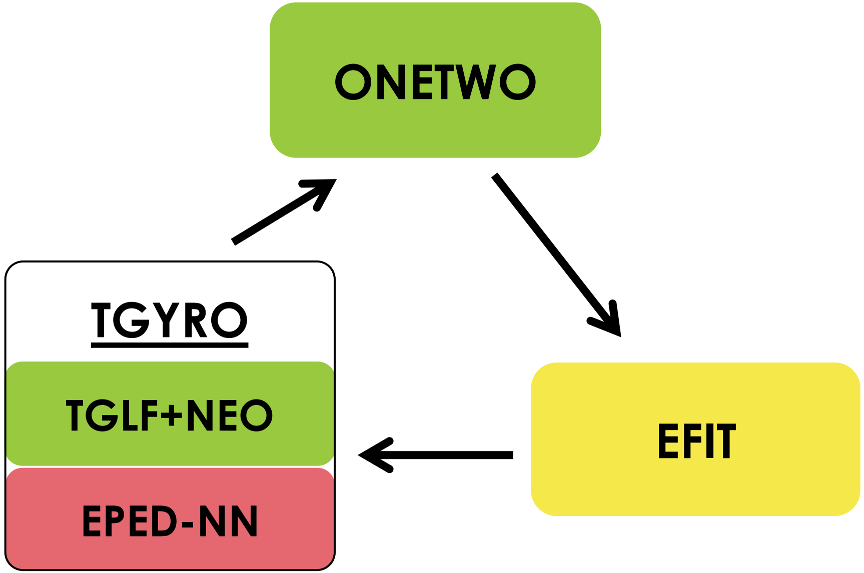


GENERAL ATOMICS

STEP Open-Loop, Self-Consistent Workflow Allows Prediction of Stationary Tokamak Plasmas

- **In general, for open-loop predictions we use:**
  - ONETWO for sources & current evolution
  - EFIT for equilibrium calculations
  - TGYRO (with neural nets)
    - TGLF/MMM for stationary transport
    - EPED for pedestal height/width
- **Many variations are possible**
  - CHEASE for fixed-boundary equilibria (e.g., for future devices)
  - Full codes when neural nets not applicable
    - TGLF+NEO
    - EPED
  - CHEF for additional or increased control over sources

Standard Self-Consistent Workflow



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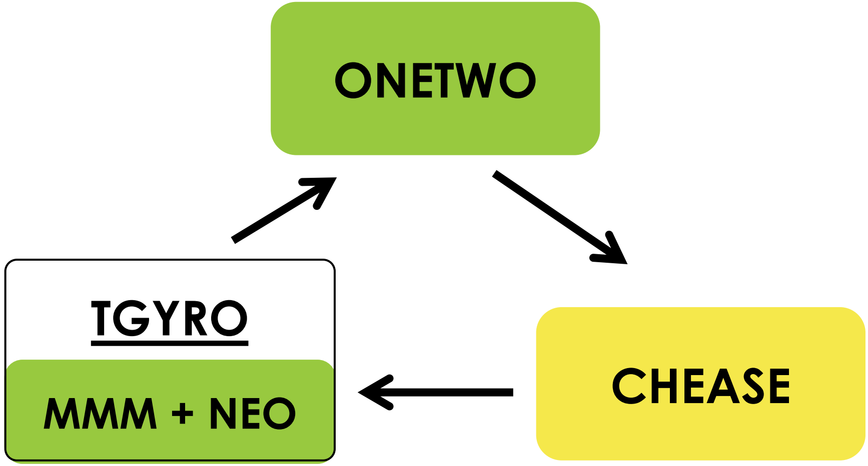

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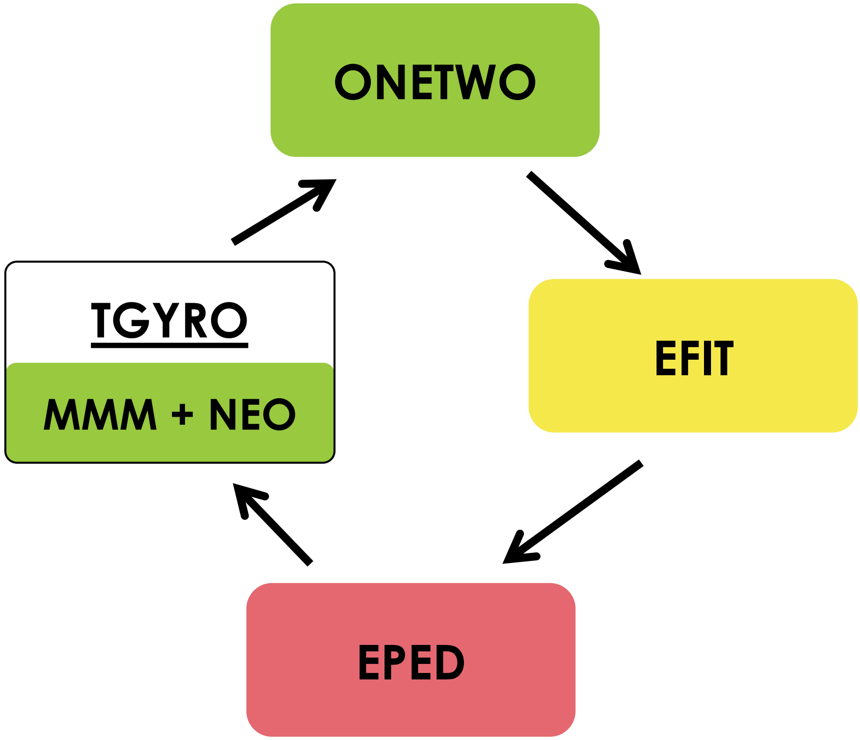

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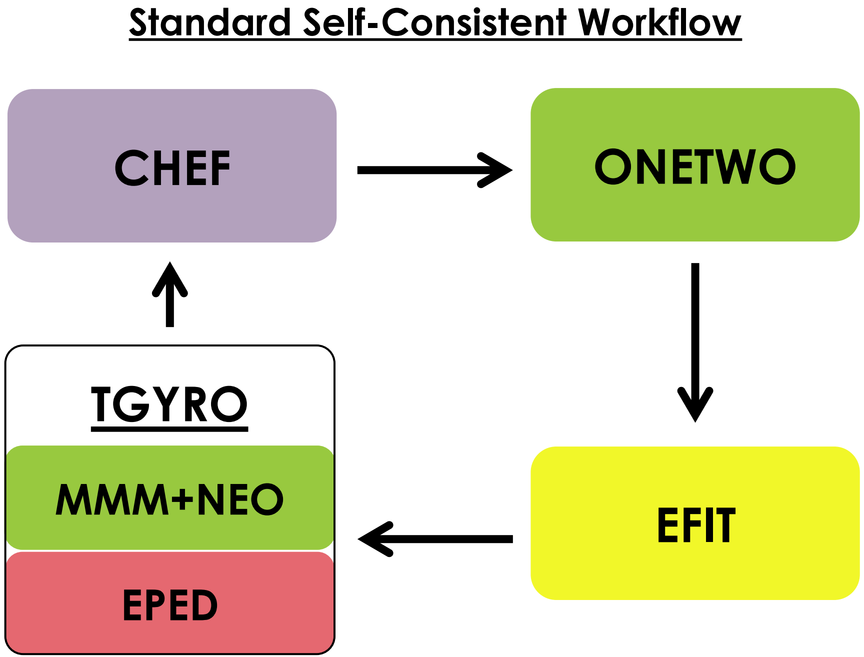
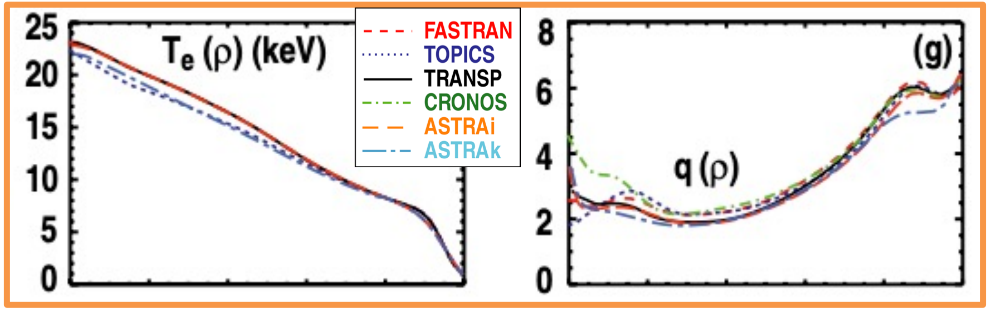
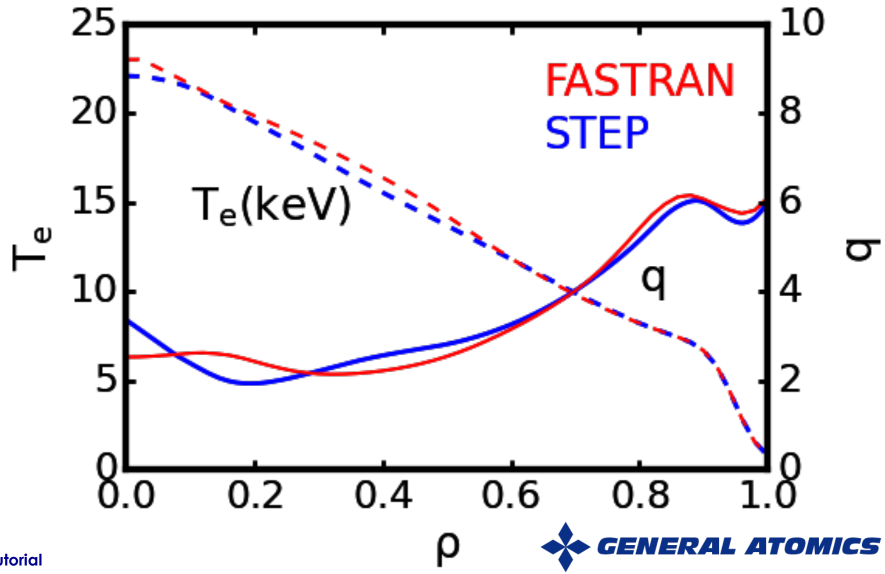


Examples of STEP usage (not NSTX)

STEP Verified Against Integrated-Modeling Benchmark

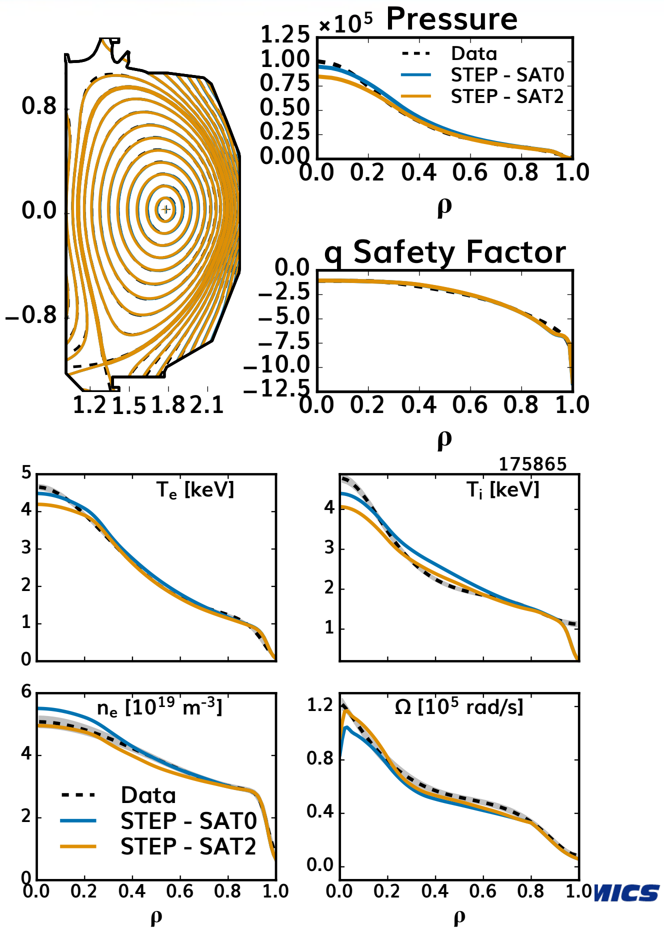
- Variety of integrated models used to simulate ITER weak-shear, steady-state scenario (*Murakami et al. 2011 Nucl. Fusion 51 103006*)
- Simulation profiles setup from ONETWO/FASTRAN simulations
- Standard, self-consistent STEP workflow with GLF23 used as transport model $n_{i,GLF23} = \sum_i n_i$
- Differences from FASTRAN within benchmark variations





STEP accurately reproduces standard H-modes in DIII-D

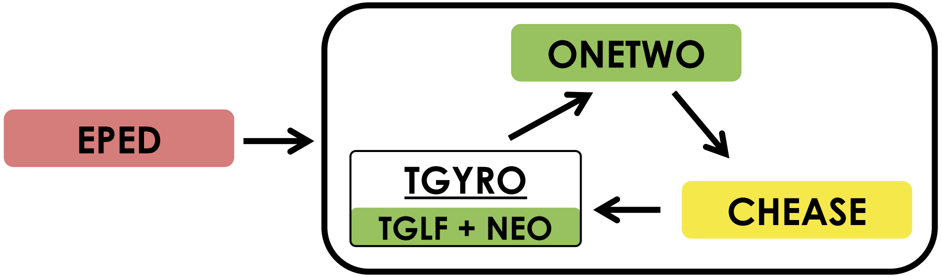
- **STEP initialized with experimental equilibrium and profiles from DIII-D standard H-mode**
  - 175865 @ 2100 ms
  - High-torque phase of torque-scan experiment
- **Self-consistent workflow to steady-state given experimental sources**
  - Full TGLF & NEO with EPED-NN
  - Predicts equilibrium and profiles with high accuracy

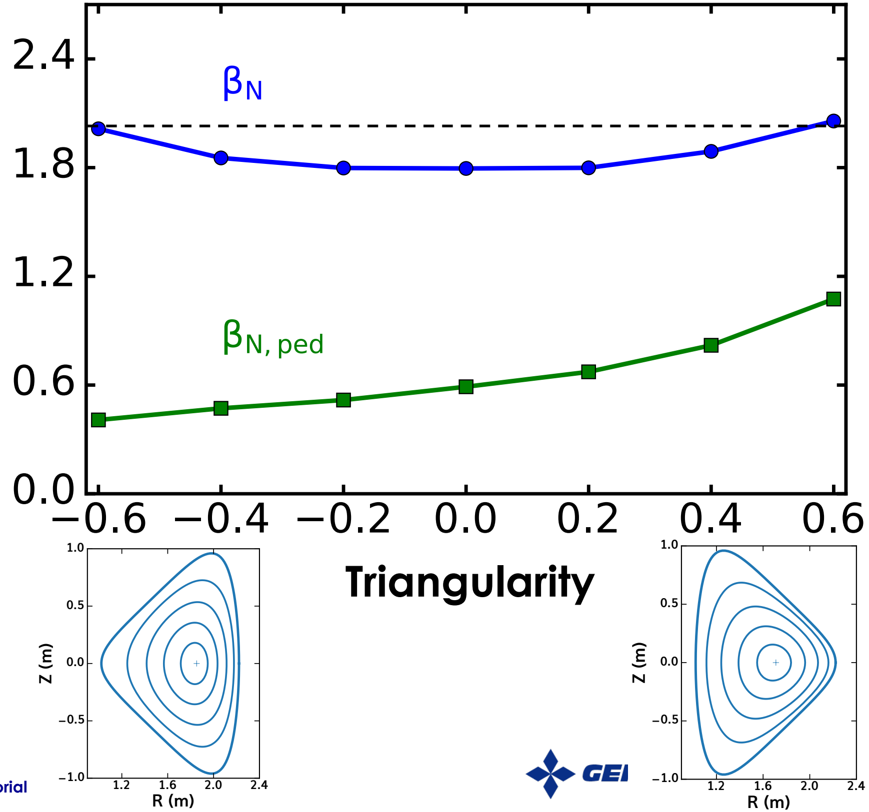


DIII-D NATIONAL FUSION FACILITY

STEP shows negative triangularity has similar performance to positive triangularity despite lower pedestals

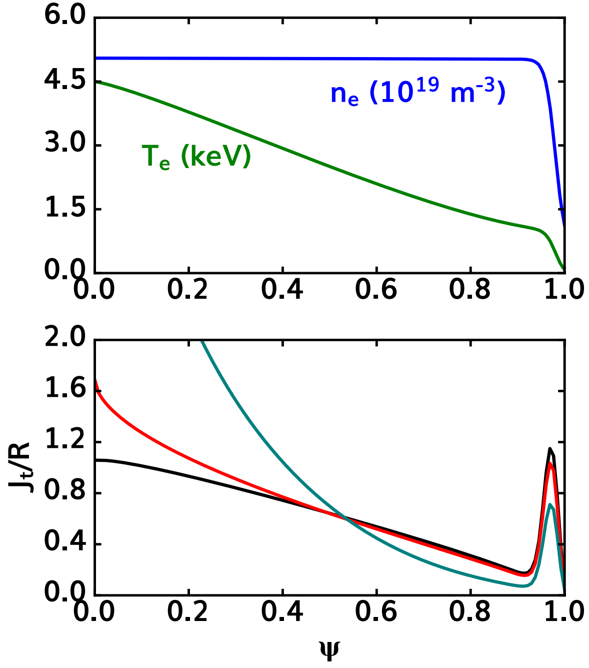
- STEP calculations performed using pre-computed EPED pedestals
- U-shaped dependence of normalized β
- Suppression of core turbulence offsets decreased pedestal height in negative δ

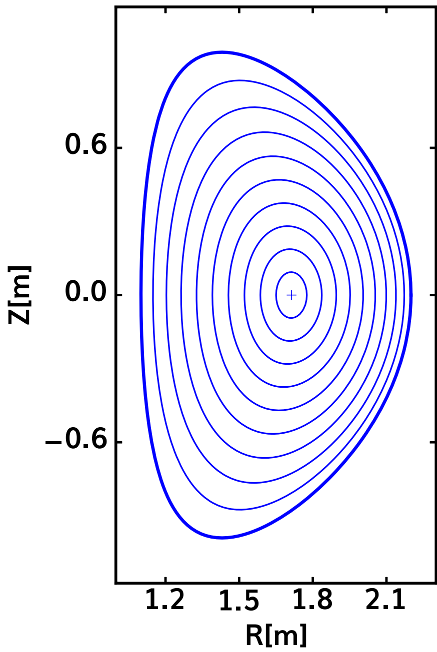




H-mode plasmas can be parameterized using OMFIT PRO_create module

- **Temperature and densities determined by EPED tanh + core polynomial**
- **$\langle J_t/R \rangle = J_0(1\text{-}psi^a)^b + J_{bs}$**
- **Approximate heating profiles can be specified in CHEF module**



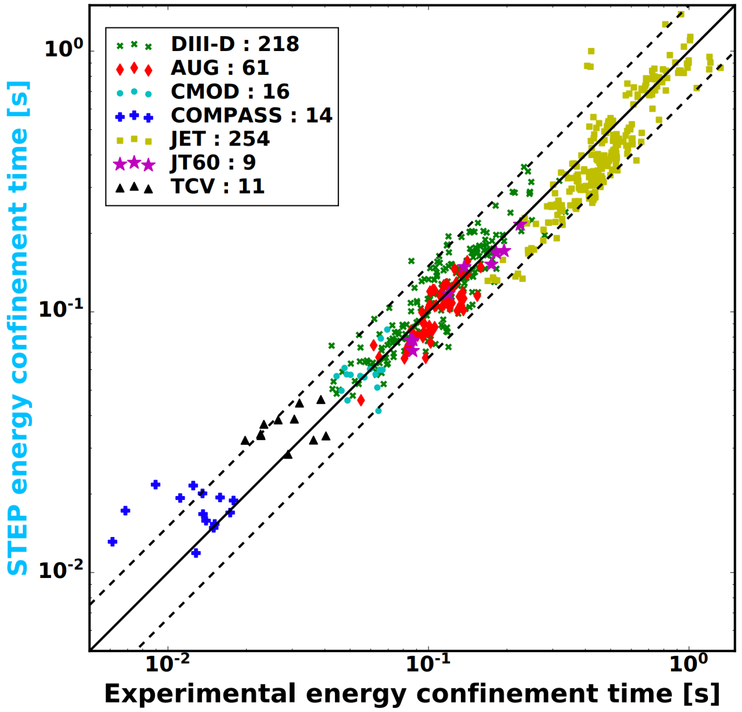


STEP show good agreement of energy confinement time on subset of $\tau_{98,y2}$ database

- **Uses PRO_create to start STEP specifying only global quantities**

$$\tau_{e\,h98,y2} = 0.0562 I_p^{0.93} B_0^{0.15} P_{heat}^{-0.69} \kappa^{0.78} M_{eff}^{0.19} (10 n_e)^{0.41} A^{-.58} R^{1.97}$$

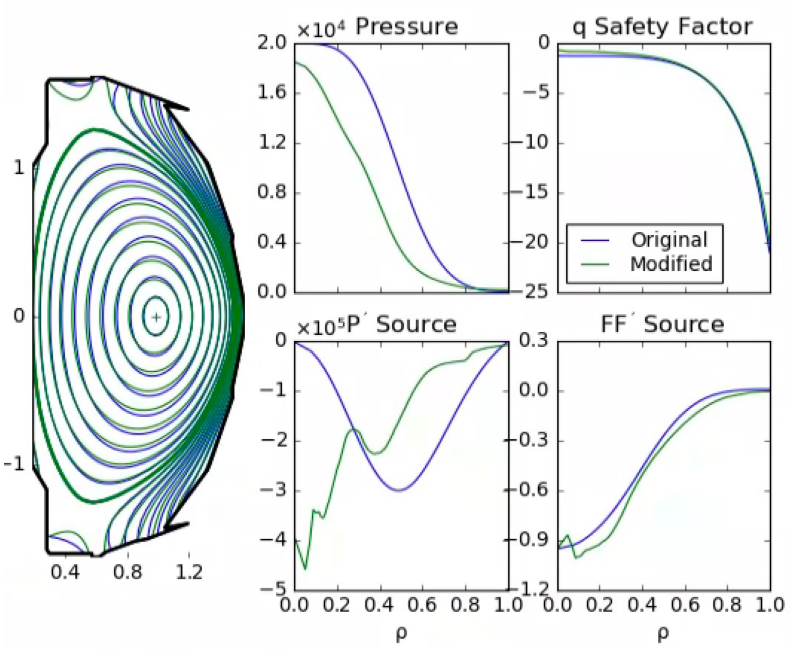
Slendebroek et al. PoP 2023

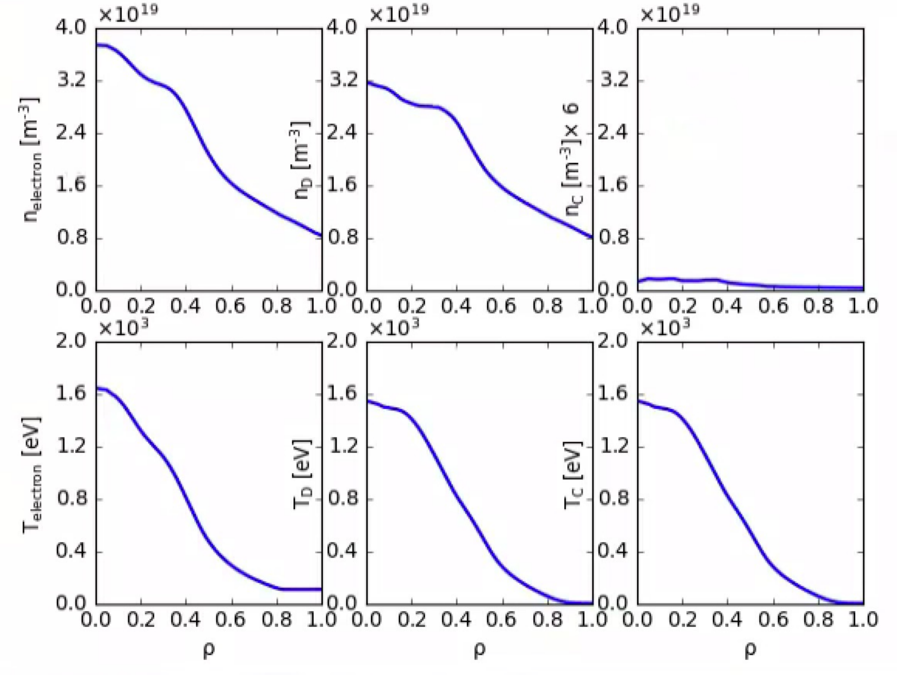


STEP NSTX example

PRO_create also has the option to start from TRANSP profiles and EFIT01

L-mode discharge 141716



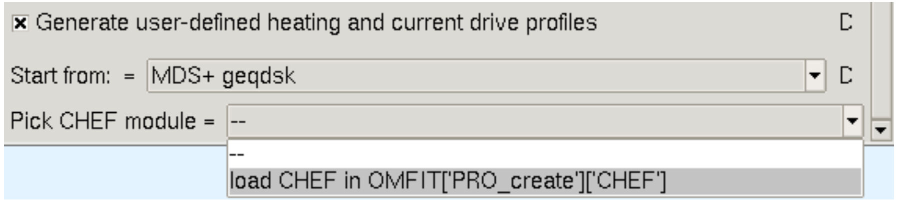


NSTX-U

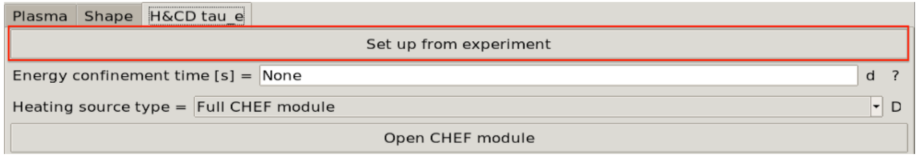
GENERAL ATOMICS

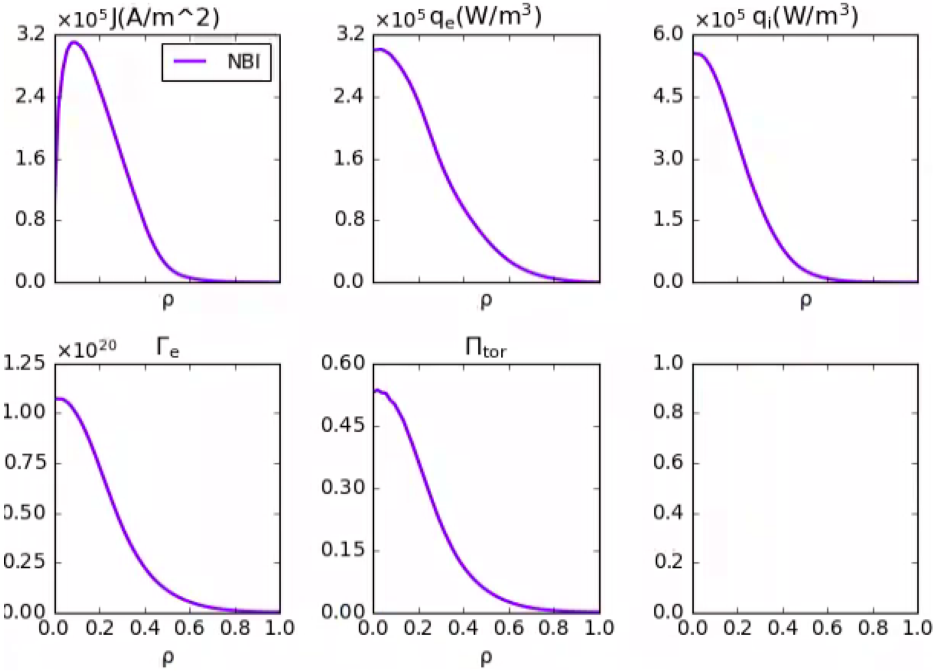
CHEF (Current HEating and Fueling) grabs beam geometry from TRANSP to run FREYA

- **Loading CHEF into PRO_create**



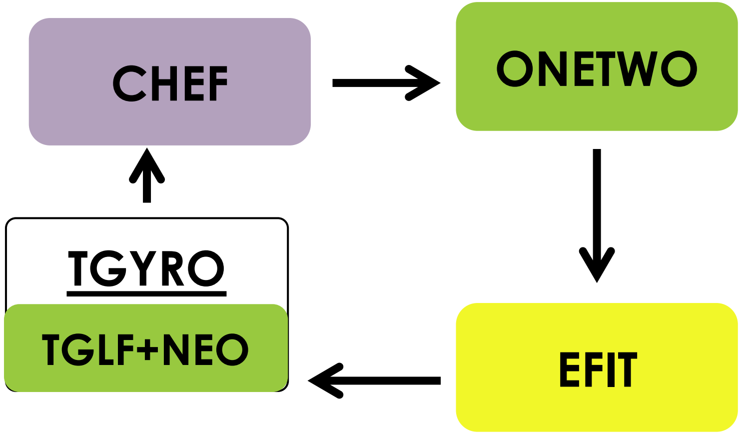
- **Setting up from experiment**





With PRO_create setup, then STEP can be run.

- **Standard iteration workflow**
- **Available transport codes**
  - MMM
  - **TGLF-SAT2**



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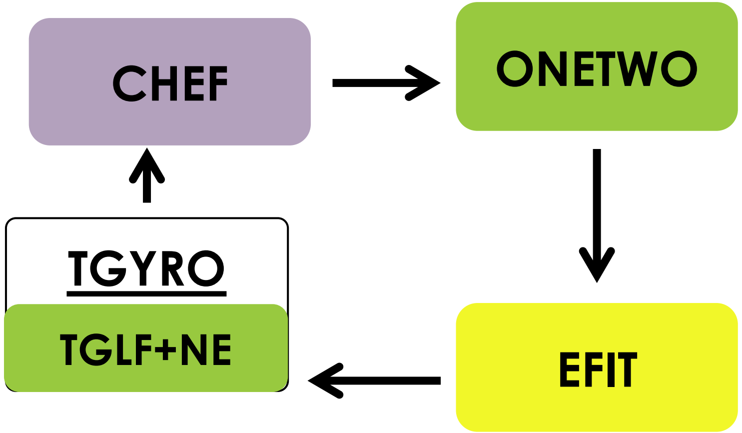
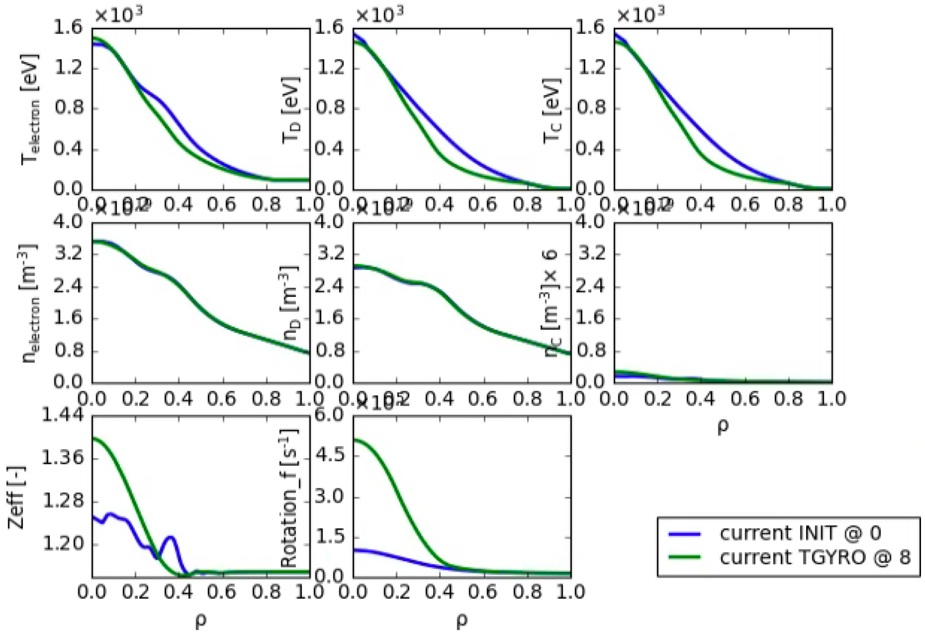


NSTX exp. profiles
STEP predicted



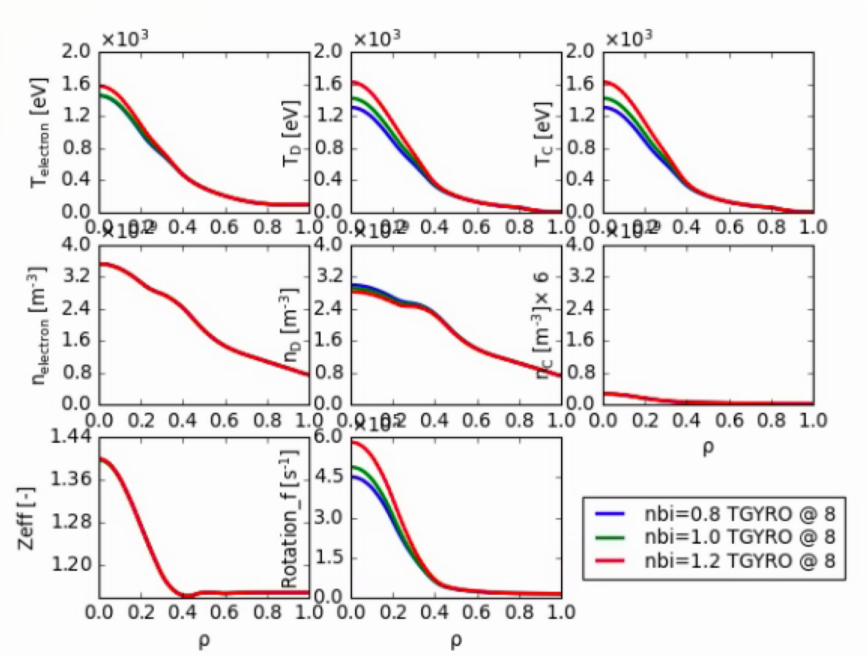
NSTX-U

GENERAL ATOMICS

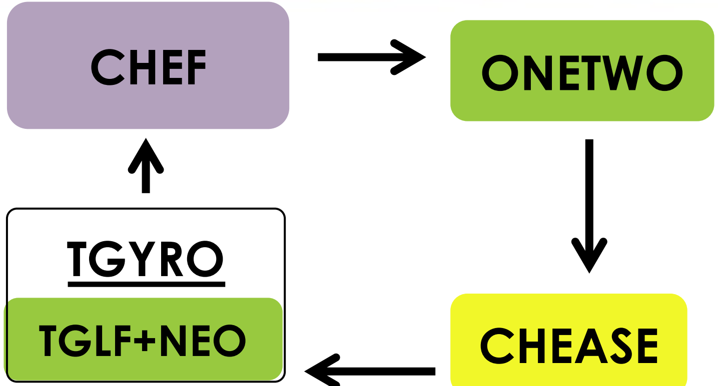
STEP can also be used to parameter scans

- **NBI injected power scan**
  - 80%, 100%, 120% power

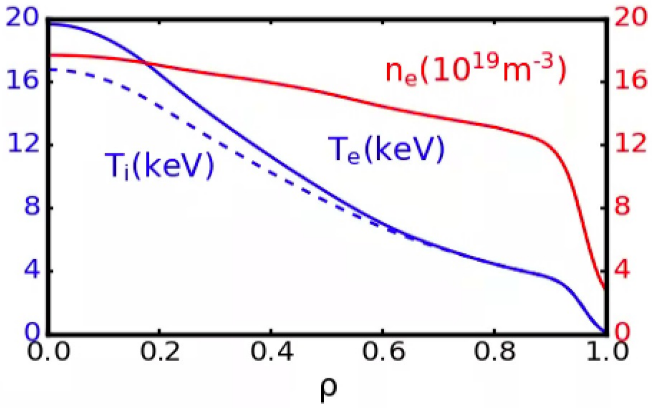
- **Other thing such B_t, I_p, $n_{e,line}$, p_{ped}, turbulence model can also be scanned.**

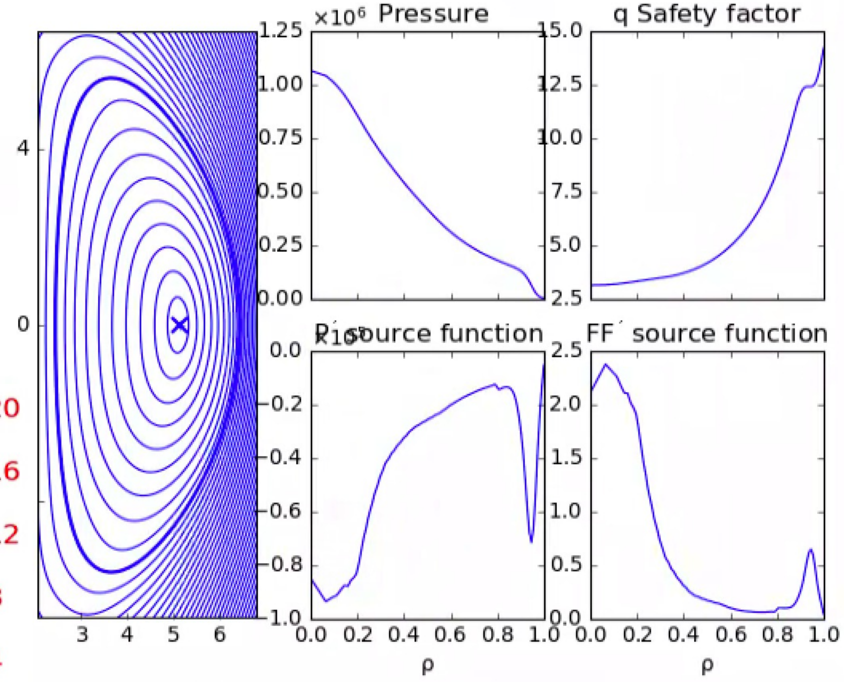


STEP ST reactor test example



κ	2.8
P_{aux} (MW)	100
A	2.2
I_P (MA)	14.5
B_T (T)	5.0
β_N	2.5
f_{gw}	1.2
P_{fus}(MW)	928
f_{bs}	0.78





McClenaghan STEP tutorial

GENERAL ATOMICS

Conclusions

- STEP (Stability, Transport, Equilibrium, & Pedestal) provides a flexible tool for theory-based, predictive, integrated modeling

- STEP has been setup for NSTX(-U) and is available on portal.

- Written tutorial available online and detailed video tutorial will be given on Oct. 5 2 pm ET