Accurate ECH deposition with real-time TORBEAM and ECH mirror feedback control

A. Rothstein[1], K. Erickson[2], S.K. Kim[2], A. Bortolon[2], and E. Kolemen[1,2]

[1] Princeton University, [2] Princeton Plasma Physics Lab

DIII-D NATIONAL FUSION FACILITY

PPPL

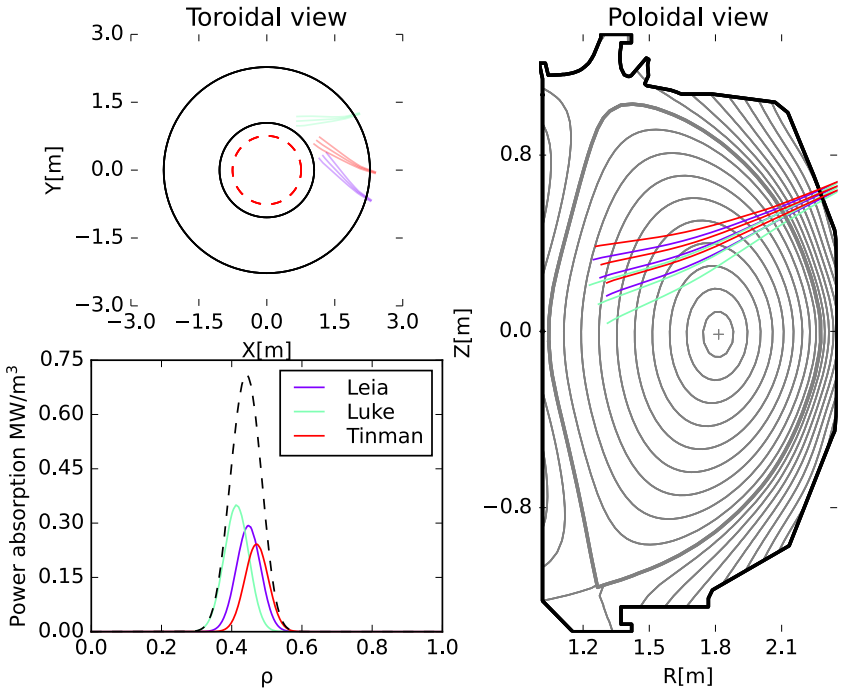
SET Meeting / July 24 2024

Mechanical & Aerospace Engineering

Plasma Control

TORBEAM Ray Trace Code

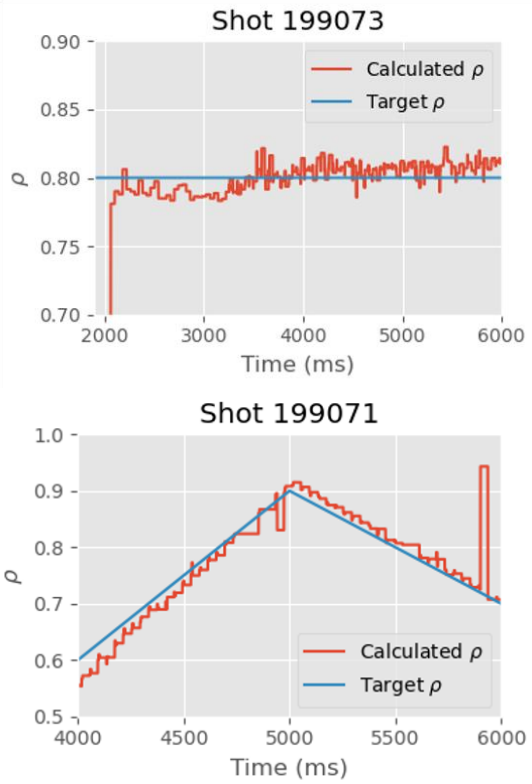
- TORBEAM[1] is a beam tracing code for electron cyclotron waves in fusion plasmas
  - Calculates ECH and ECCD deposition profiles
- Real-time version only traces center ray for maximum deposition location
  - Runs each gyro in parallel in <20ms
  - Real-time safe multithreading PCS library created
  - Can calculate CD at extra time cost



[1][Poli 2017]

Real-time Steering Applications

- Rho tracking
  - Give a rho target and mirror follow
  - Target can be constant or change throughout shot
- q-surface tracking
  - User picks rational surface value and will use MSE rtEFIT to find rho value
  - Tracks rho of rational surface location

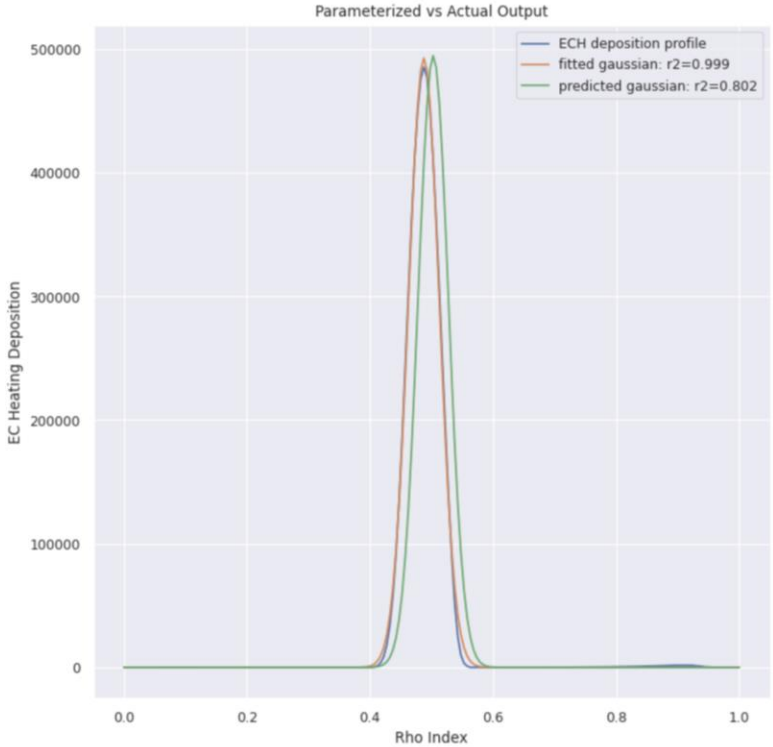


Quick FAQs

- What machine capabilities do I need to use rt-TORBEAM and EC steering?
  - rt-Thomson profiles, MSE, tell ECH team to enable mirror steering
- How quickly can the mirrors move?
  - Max angle rate of 4-5 degrees per 100ms
  - Qualitatively expect to travel ~0.1 in rho in <200ms
- Does this work for top launch ECCD?
  - No, with only single ray it won't give reasonable results
- What happens if rho location or q-surface is not reachable?
  - Controller minimizes distance, so goes to closest achievable rho or q-surface

Near-Future Extensions

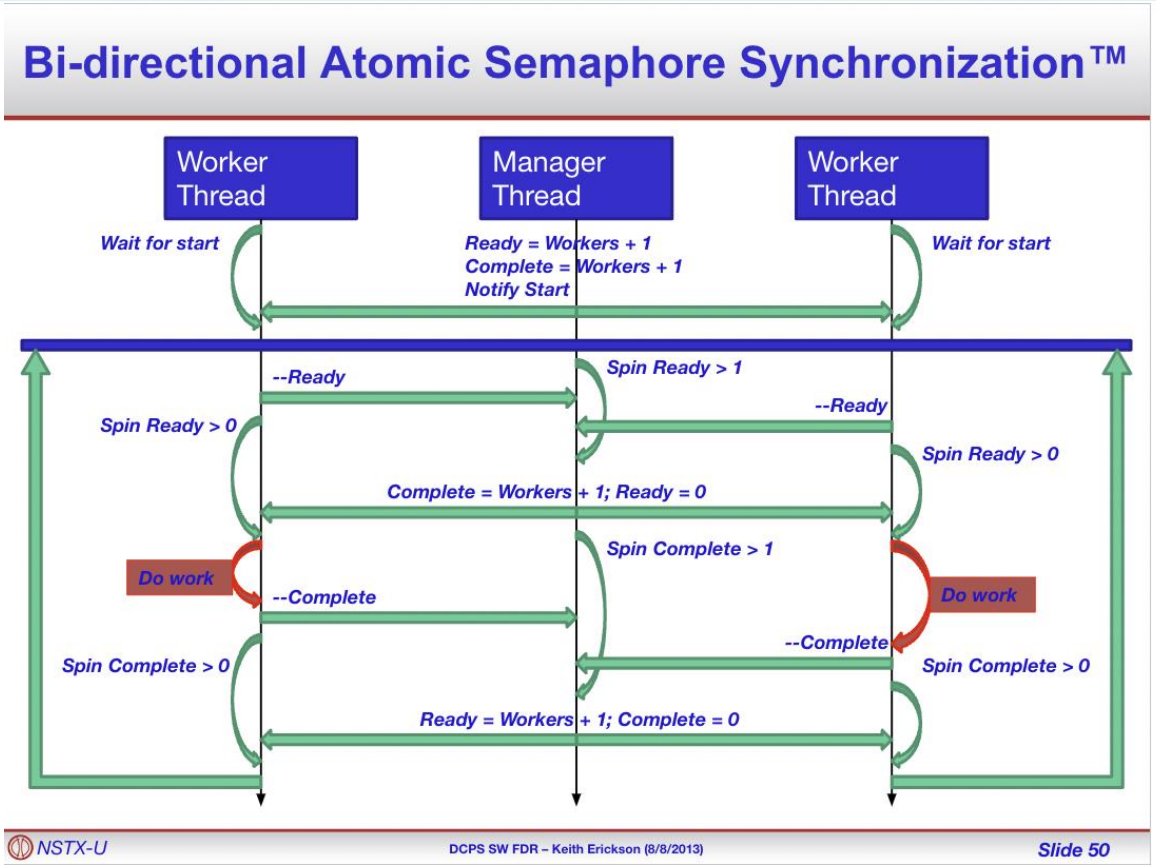
- TORBEAM ML surrogate model will predict full heating and CD profiles
- Will speed up steering convergence speed
  - Computationally search for exact angle will remove need for estimating derivatives or PID control
- Opens possibility for new EC control options:
  - Specify rho range and steer to max heating/CD
  - Specify rho range and optimize EC for flat heating/CD profile across range
  - Please share any ideas you would want!



Extra Slides

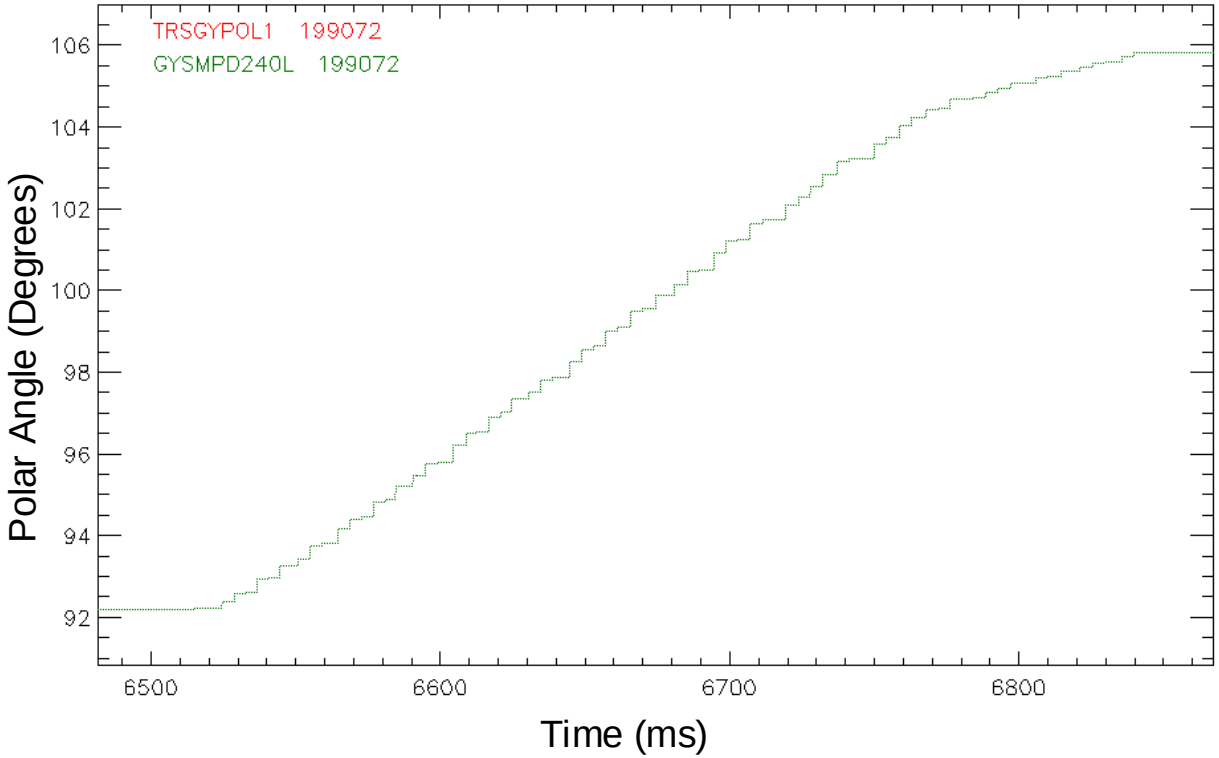
Plasma Control

Real-time Safe Multithreading



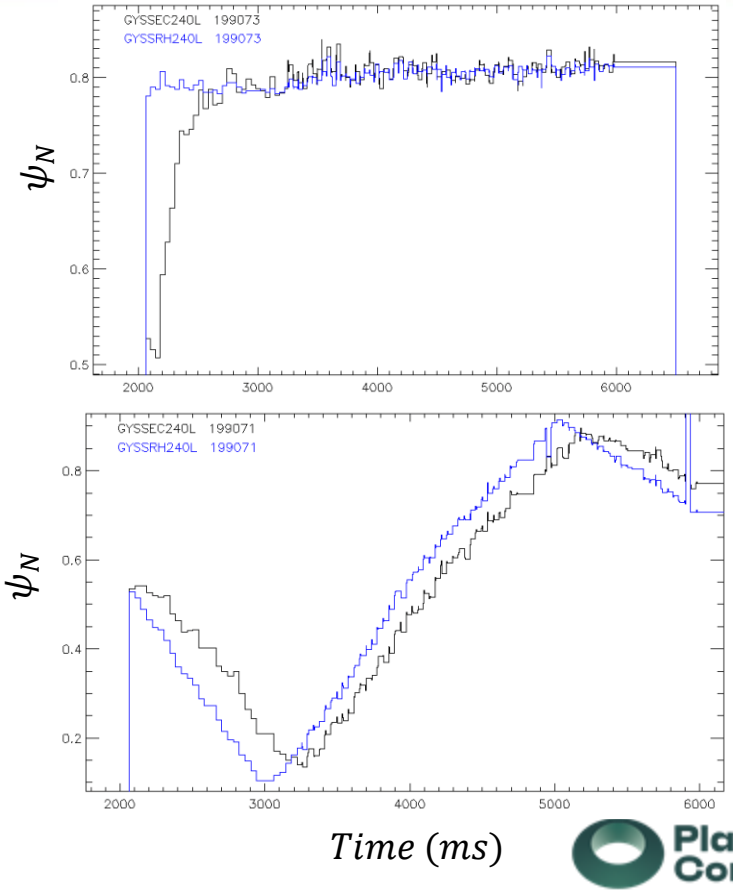
Plasma Control

Maximum Steering Rate



Caveats on steering plots

- In PCS, mirror tracking converts from ρ to ψ_N spatial coordinates
- In plots to right blue is the ρ target converted to ψ_N and black line is where mirror is currently steered in ψ_N
- Bottom plot gives sense of delay in steering when following a fast-changing target
  - ~100-200ms



Another shot example

- Equilibria changes throughout this shot, so while ρ target is a constant 0.41, because shot is dynamic the target ψ_N changes significantly