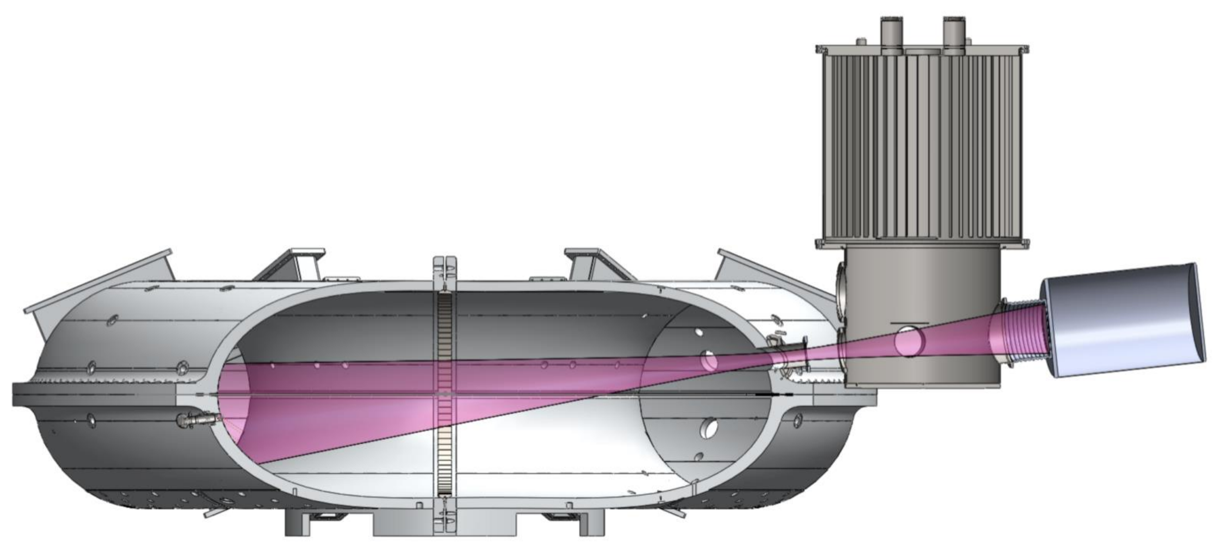
Abstract

Fast ion orbits in the reversed field pinch (RFP) magnetic configuration are well ordered and have low orbit loss, even considering the stochasticity of the magnetic field generated by multiple tearing modes. Purely classical TRANSP modeling of a 1MW tangentially injected hydrogen neutral beam in MST deuterium plasmas predicts a core-localized fast ion density that can be up to 25% of the electron density and a fast ion beta of many times the local thermal beta. However, neutral particle analysis (NPA) of an NBI-driven mode (presumably driven by a fast ion pressure gradient) clearly shows transport of core-localized fast ions and a saturated fast ion density. The TRANSP modeling is presumed valid until the onset of the beam driven mode and gives an initial estimate of the volume-averaged fast ion beta in the range of 1-2% (local core value up to 10%). Distinguishing between an experimental fast ion number limit or fast ion beta limit is performed by scanning both the magnetic field strength and the NBI energy while observing conditions at the onset of the beam driven mode.

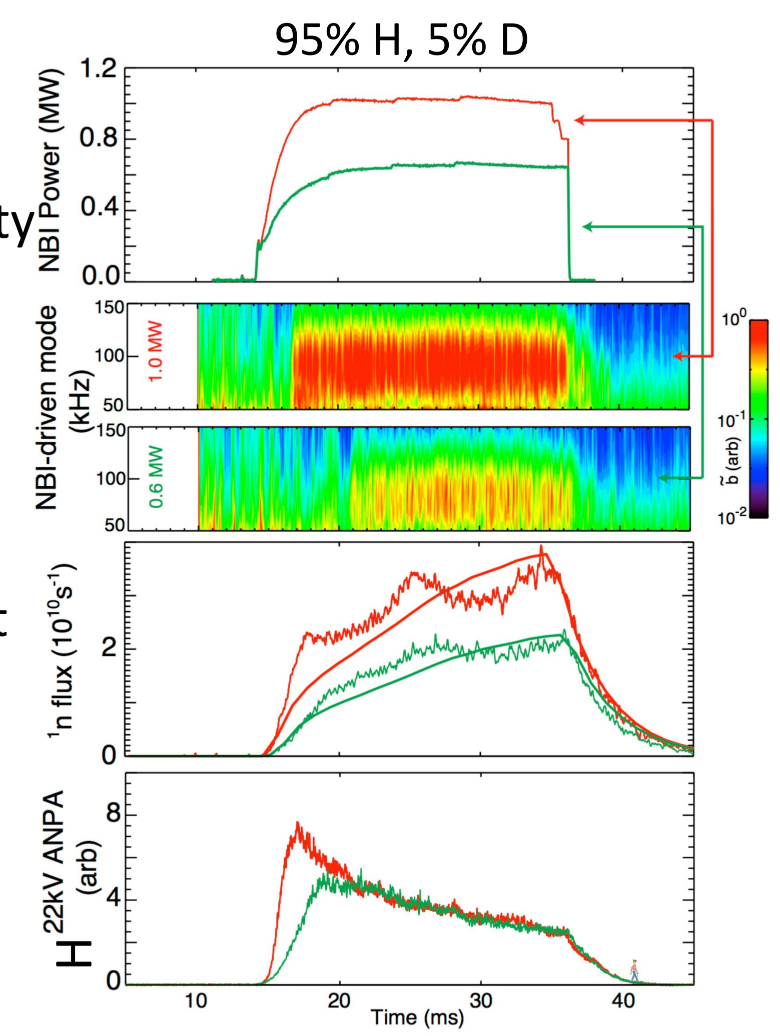


Madison Symmetric Torus
R=1.5 m; a=0.52 m
$I_p \sim 200 - 500$ kA
$\lvert B \rvert \sim 0.2 - 0.5$ T
$T_e(0) \sim 200 - 2000$ eV
$n_e \sim n_D \sim 10^{13}$ cm^{-3}
Pulse length ~ 60-100 ms

NBI Parameter	Specification
Beam energy	25 keV
Beam power	1 MW
Pulse length	20 ms
Composition	3-5% or 100% D
Energy fraction (E:E/2E/3:E/18)	86%:10%:2%:2%

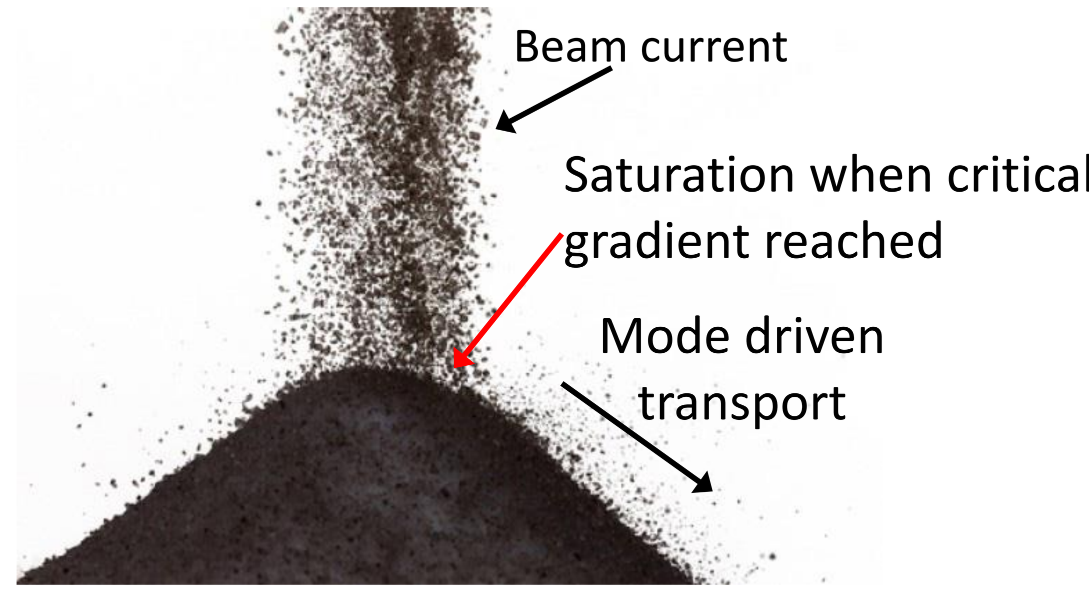
Motivation

- TRANSP shows steady fast ion density growth (and neutron signal) while experimental measurements show a saturated fast ion density
- Deuterium unaffected by Hydrogen ion driven magnetic activity
- ANPA signal hard to calibrate, so fast ion beta limit measured by finding neutron flux saturation value
- Repeated in 100% D beam



Computing Fast Ion Beta

- The fast ion density increases from beam turn on at a rate dependent upon beam current and confinement time
- At some point we observe a saturation at which point NBI driven magnetic activity increases fast ion transport
- Assuming classical behavior for the first few ms of the neutral beam we can predict the neutron flux from MST based on beam current, confinement time using:



$$n_{fi} = \int \left(\frac{I_b}{e * Vol} - \frac{n_{fi}}{\tau} \right) dt$$

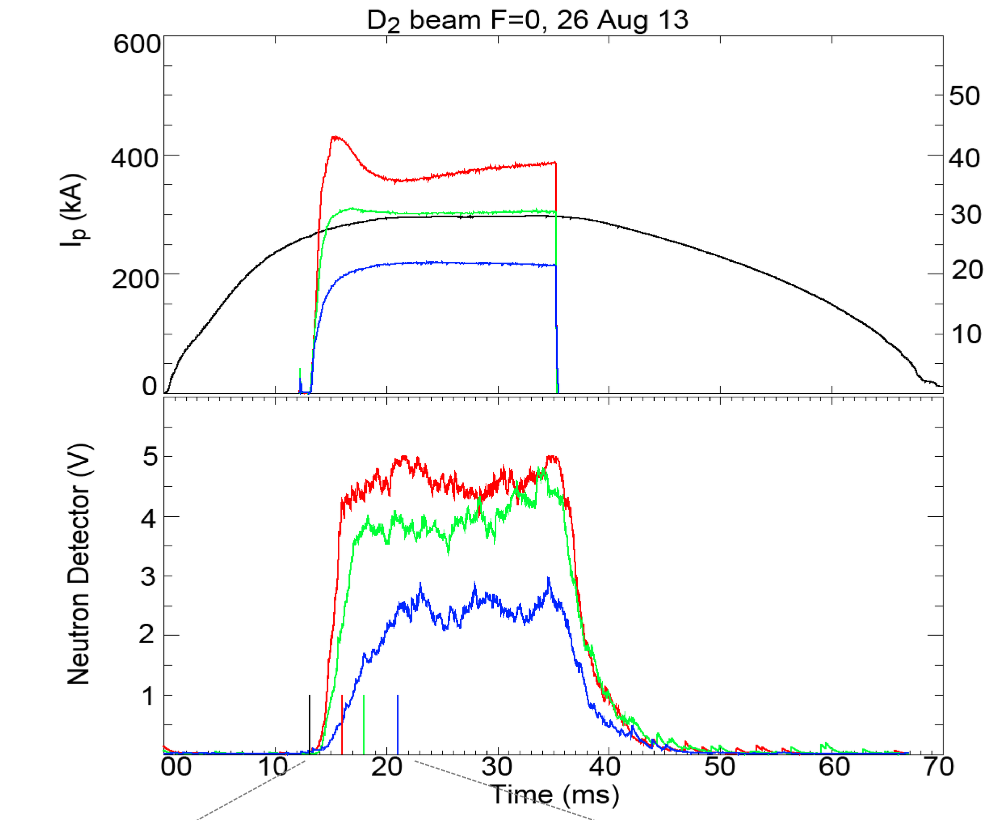
$$\Gamma_{MST} = n_{fi} n_i \sigma_{dd} v_{fi} Vol$$

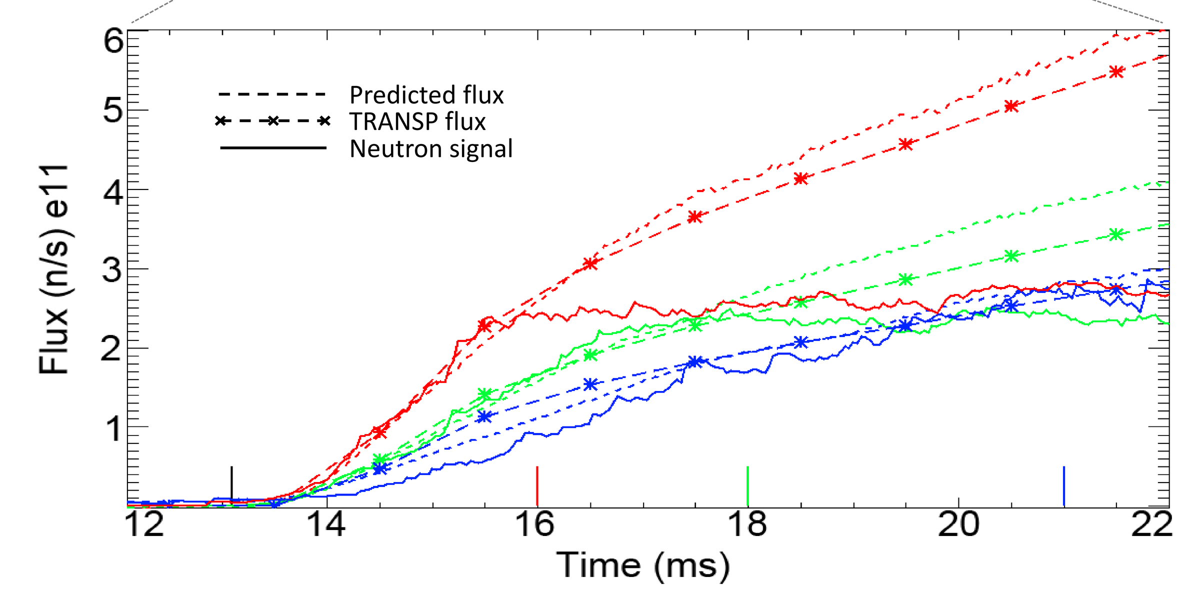
- Fitting the neutron detector data to the predicted flux during this classical period we see saturation around

$$\Gamma_{MST} \cong 2.5e11\ n/s$$

Resulting in

$$n_{fi} \cong 1.1e18\ m^{-3} \qquad \beta_{fi} \cong 0.123$$





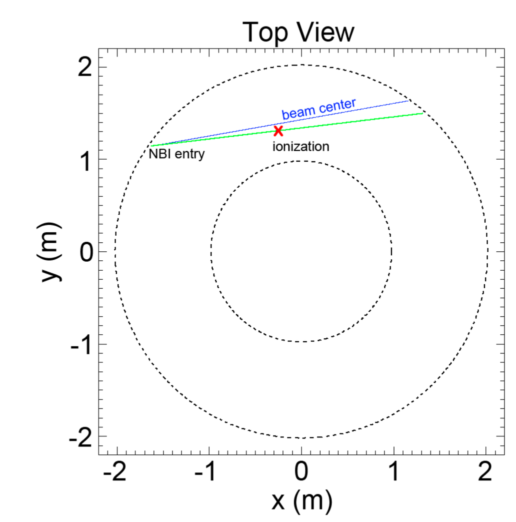
The full slowing calculation of TRANSP agrees with predicted flux, to within a factor of 1-2 (corrected above)

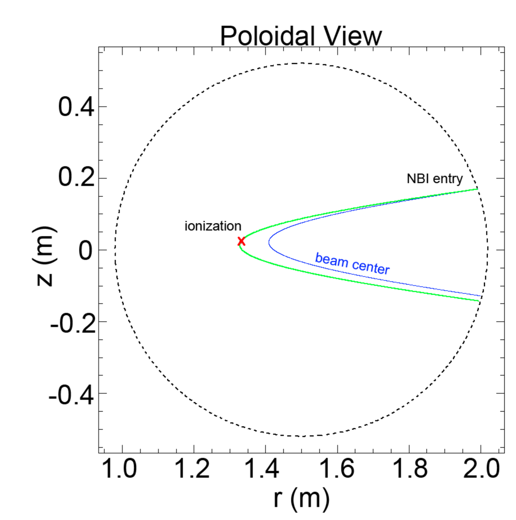
Resonant conditions met independently by species

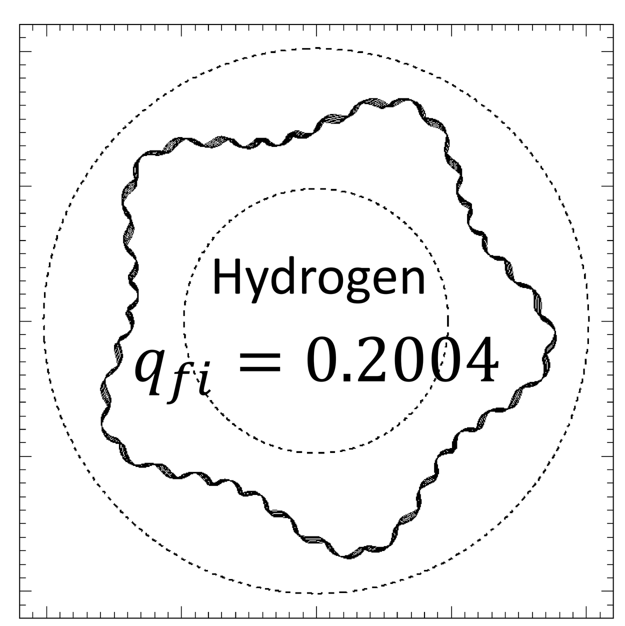
- Beam–driven instabilities transport fast ions when wave/particle resonance is satisfied

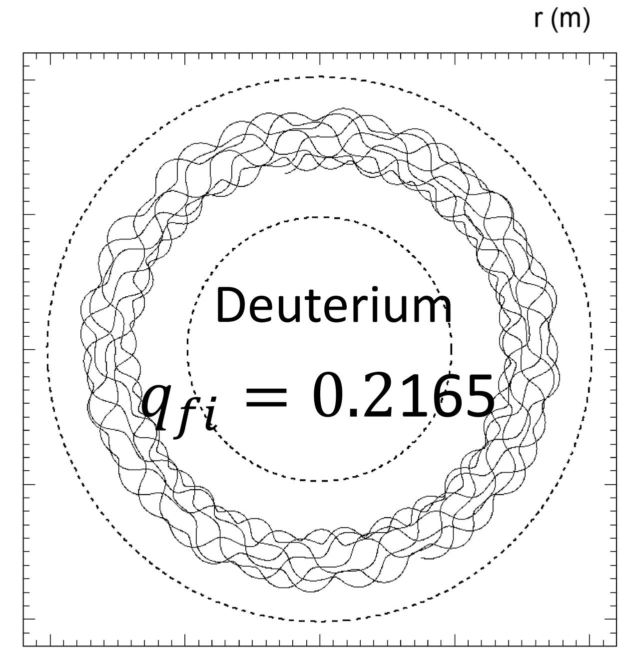
$$\omega = n\omega_\phi - (m + l)\omega_\theta$$

- Using particle orbit tracing we can see the resonant conditions for NBI driven modes are species dependent
- In this case, we ionize a neutral beam particle at 11 degrees toroidal, off axis and inboard of beam center
- Mass of ions alters orbit and resonance









$$\omega_\phi = 9.73e5\ rad/s \qquad \omega_\phi = 7.28e5\ rad/s$$

$$\omega_\theta = 4.85e6\ rad/s \qquad \omega_\theta = 3.36e6\ rad/s$$

Future Work

- Incorporate energy distribution into modeling
- Scan I_p, n_e space to vary B and n_0 to verify β scaling
- Incorporate radial profiles
- Improve neutron diagnostic suite