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NSTX

NSTX Contributions to Burning Plasma Studies

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U Maryland
U Rochester
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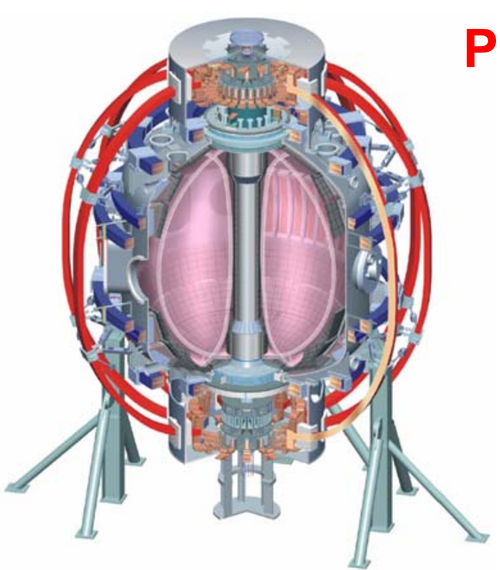
U Wisconsin

Martin Peng
ORNL, UT-Battelle
For the NSTX Team

Workshop (W60) on "Burning Plasma Physics and Simulation"

4-5 July 2005
University Campus
Tarragona, Spain

Under the Auspices of
The IEA Large Tokamak
Implementing Agreement



Culham Sci Ctr
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NSTX Is Contributing Actively to Physics Topics of Interest to Burning Plasmas

NSTX

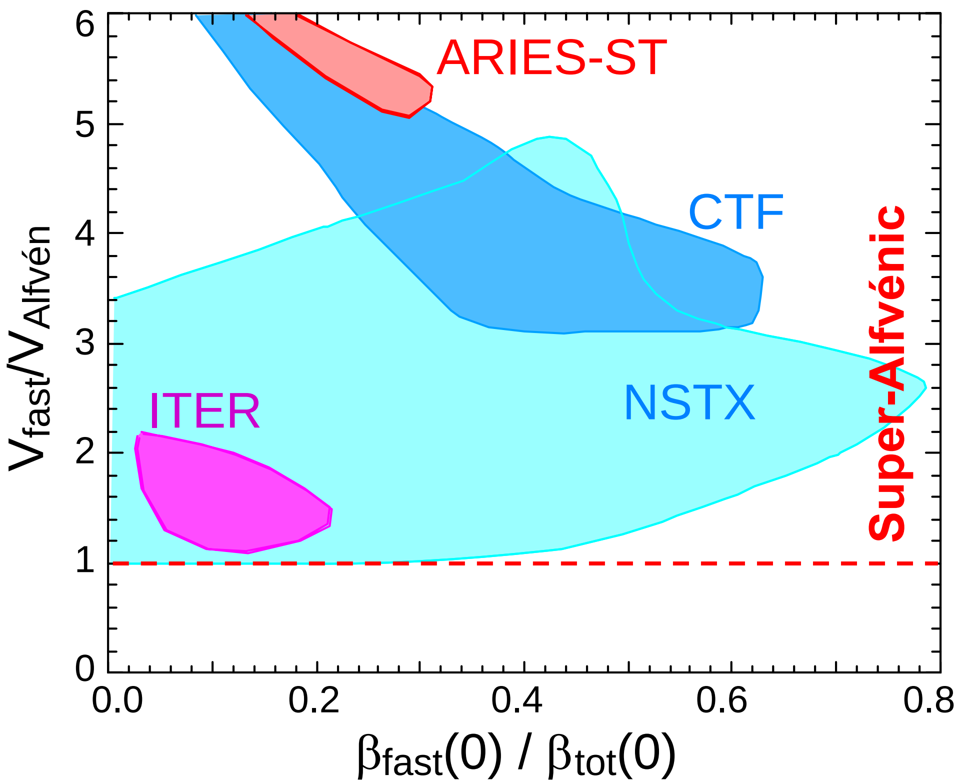
- **Super-Alfvénic ion driven modes and associated losses**
- **Co-linearities in confinement scaling**
- **Active MHD mode control to raise β limit**
- **2-D x-ray crystal spectrometer**

Low-A Studies of Super-Alfvénic Ion Driven Modes and Associated Losses Are of Interest to ITER

- ***ITER Topic****: Prediction of fast particle induced instabilities and associated fast particle losses*
- **High priority for 2005-2006**: Understand intermediate-n AEs; losses of fast particles from AEs; and perform theory-data comparisons on damping and stability.
- NSTX operating conditions overlap ITER in normalized fast particle velocity and β
- New modes by super-Alfvénic ions were discovered and identified– likely important in ITER
- Diagnostics & modeling readied to elucidate modes and transport of super-Alfvénic ions

NSTX Operating Conditions Overlap ITER in Normalized Fast Particle Velocity and β

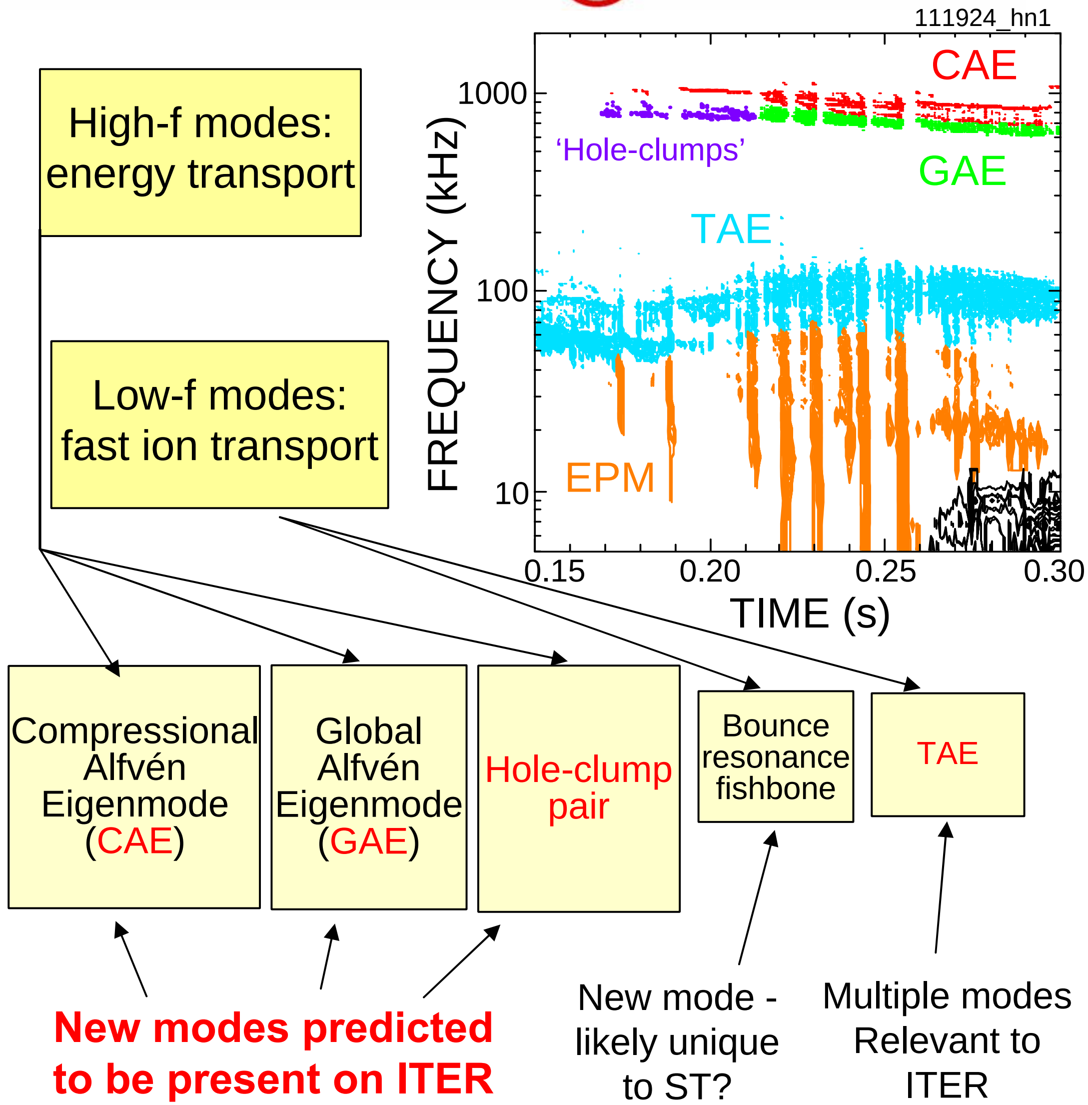
- NSTX overlaps with ITER in v_{fast}/v_{Alfven} (≥ 1) and β_{fast}/β_{tot}(≤ 0.2)
- Identify and characterize modes unique to super-Alfvénic ions
- Large β_{fast} reveals potential nonlinear physics of wave-particle resonance overlap
- Strong test bed for simulations and validations of fast ion physics models by going beyond ITER parameters
- Caution: ρ^*_{fast} different from ITER



New Modes by Super-Alfvénic Ions Were Discovered and Identified – Likely Important in ITER

ITER-Relevant Modes

- Multiple TAEs with resonant overlap / chirping
- Super-Alfvénic driven:
  - CAEs (nonlinear heating of thermal ions?)
  - GAEs
  - Hole-Clump
- **Fisch** (α-channeling)
- **Gorelenkov** (ITER beam and α profile relaxations)



Diagnostics & Modeling Are Readied to Elucidate *AE Modes and Transport of Super-Alfvénic Ions

Measurements

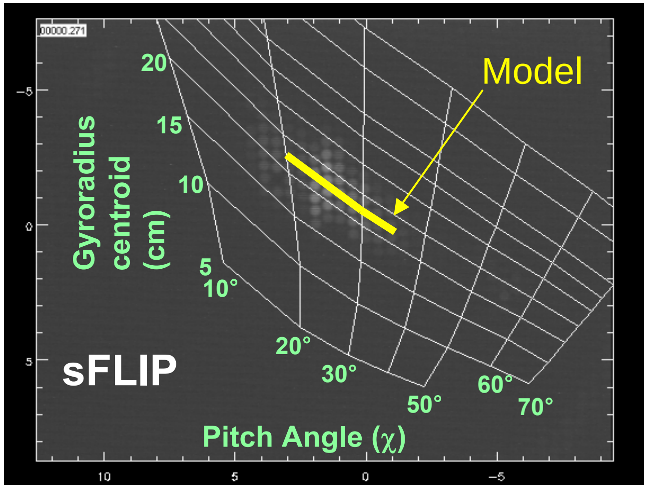
- Fast particle loss
  - Fast Lost Ion Probe
  - Scanning FLIP
  - Neutral Particle Analyzer
  - Solid State NPA
- Fluctuations
  - Reflectometer
  - Tangential FIR polarimeter
  - High-freq Mirnov coils ($\omega \sim \omega_{ci}$)
  - Fast soft x-ray camera

Equilibrium Modeling

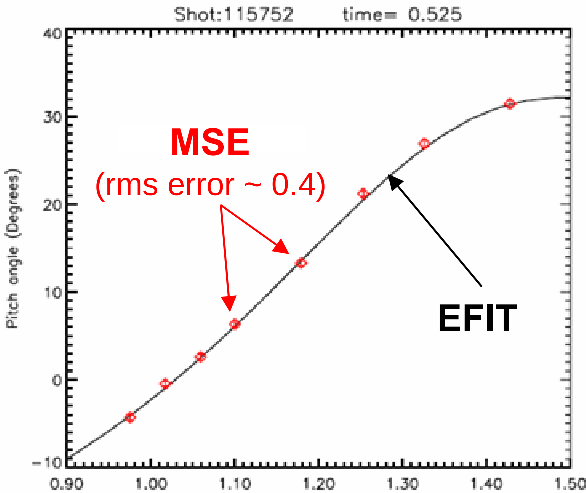
- EFIT + MSE at low B

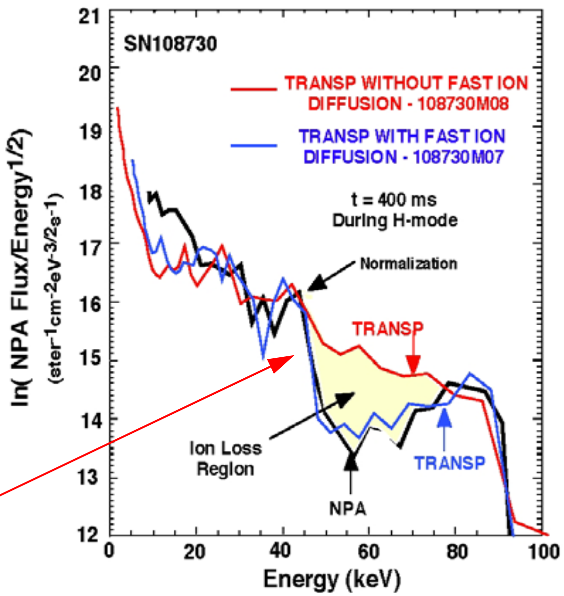
sNPA & TRANSP Measure & Model Distribution

Identify Lost Ions

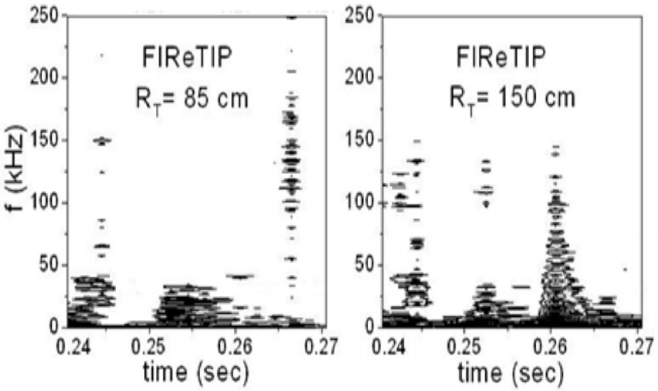


MSE + EFIT ⇒ J(r,t) + q(ψ)





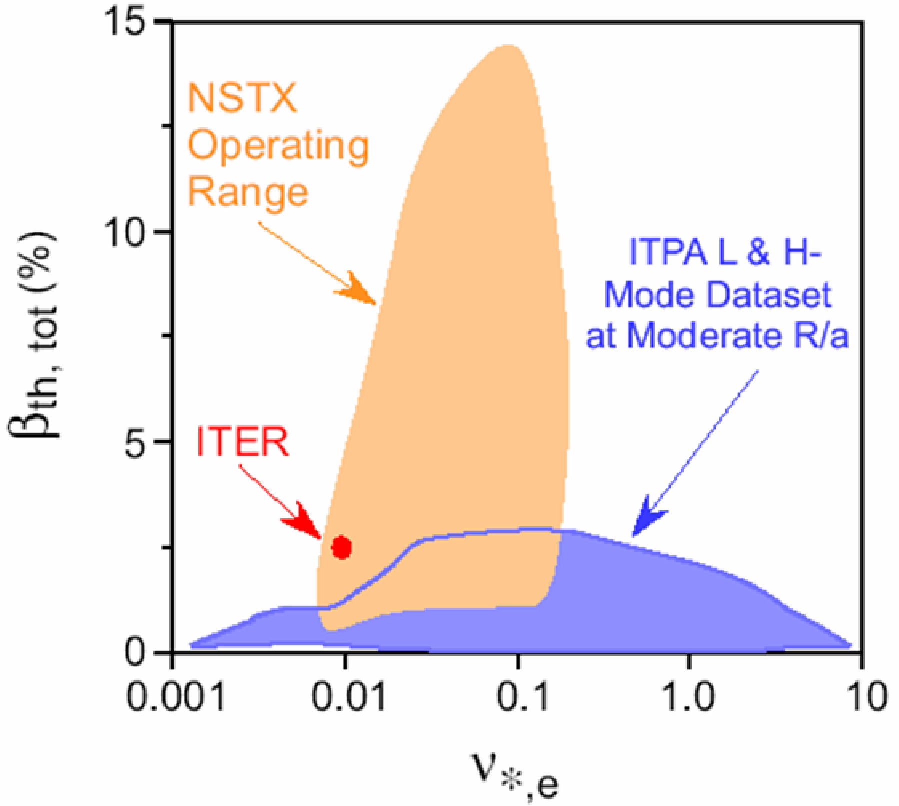
Locate *AE Mode



Low-A Database Can Shed New Light on Confinement Scaling Uncertainties in β and ν*

- ***ITER Topics**: Resolve differences in β scaling in H-mode confinement; resolve which is a more significant confinement parameter: ν* or n/n_{GW}.*
- **High priority for 2005-2006**: Joint experiments on the above topics; improve global scaling by adding Low A database.
- Low-A data provides leverage in determining scaling dependence for ITER
- Offers clarifying views into plasma transport and turbulence
- Initial analysis of NSTX data suggests favorable β exponent
- New and planned turbulence diagnostics will enable contributions, jointly with DIII-D and C-Mod

Low-A Data Provide Leverage in Determining Scaling Dependence for ITER

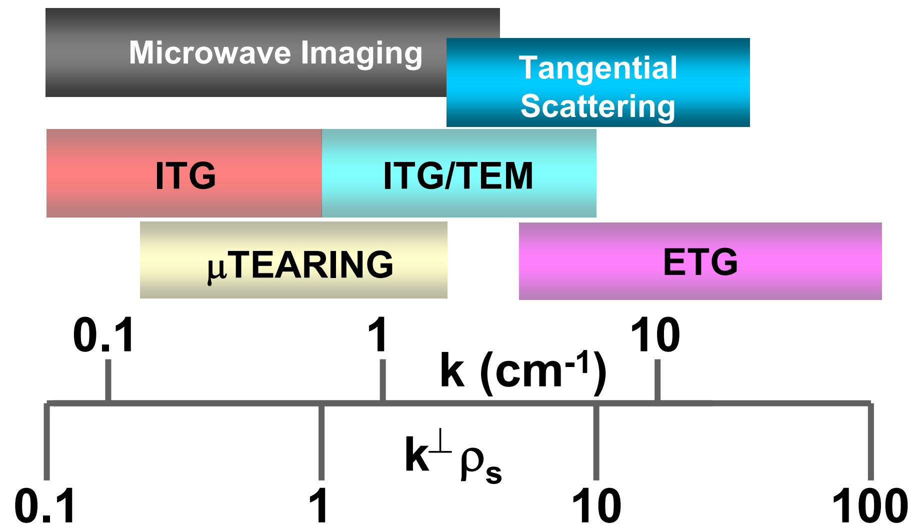


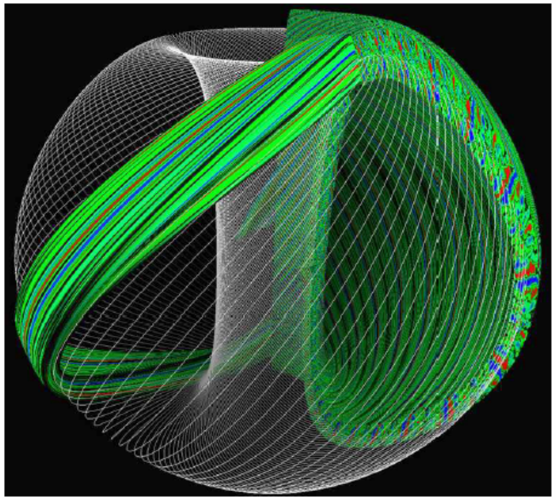
- *Firming up confinement scaling may expand ITER operating space and improve performance*
- *NSTX data helps remove co-linearities (β, $\rho*$, ν*) in moderate R/a data*
  - ITER operating point lies within range of NSTX data
  - NSTX provides a factor of 5 increase in range of β and will help resolve this issue

- *Probe and challenge toroidicity physics through expanded R/a*
  - Trapped particles, mode coupling, magnetic shear
  - Similarity experiments with DIII-D, identity experiments with MAST

Low-A Plasmas Offer Clarifying Views Into Plasma Transport and Turbulence Properties

- **Low B_T**
  - Larger scale sizes (ρ), turbulence amplitudes → *electron-scale turbulence more measurable*
  - Large rotational shear ($\propto E_r/B$) → *reduce or suppress long-λ μ-instabilities?*
- **Wide range in β_T ($\leq$ 40%)**
  - NSTX spans the range from *electrostatic* (low β_T) to *electromagnetic* (high β_T) → Impacts *electron transport?*
- **Greater toroidicity (lower R/a)**
  - Theory: non-linear saturation of short-λ (ETG) turbulence due to poloidal coupling, parallel variation → *generation of radial streamers?*





GS2 Flux Tube Simulations of NSTX Turbulence

U. Maryland

Initial Analysis of NSTX Confinement Data Suggests Favorable β Dependence

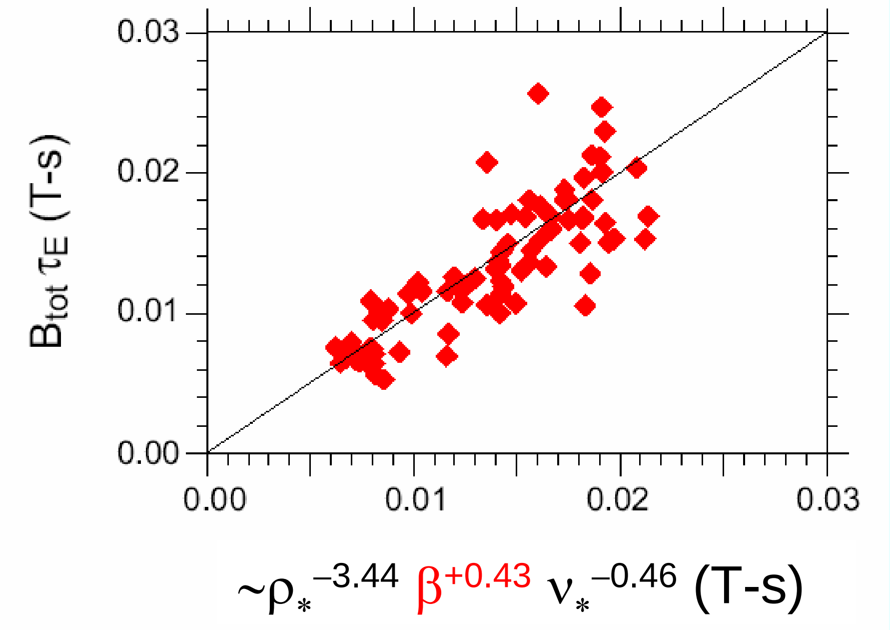
Dimensionless confinement scalings derived from normal R/a data contain some ambiguity.

Different assumptions and methods produce different β exponent:

$$B\tau_E \sim \rho_*^{-2.7}\ \beta^{-0.51}\ \nu_*^{-0.31}$$
$$\sim \rho_*^{-2.7}\ \beta^{0}\ \nu_*^{-0.15}$$
$$\sim \rho_*^{-2.83}\ \beta^{0.48}\ \nu_*^{-0.42}$$

(Cordey-IAEA '04)

NSTX data suggests a favorable dependence of confinement on β_T from statistical analysis



- Additional dedicated scans in β, ν_* are planned in NSTX
- Identity experiments with MAST

NSTX data submitted to ITPA database – full analysis underway

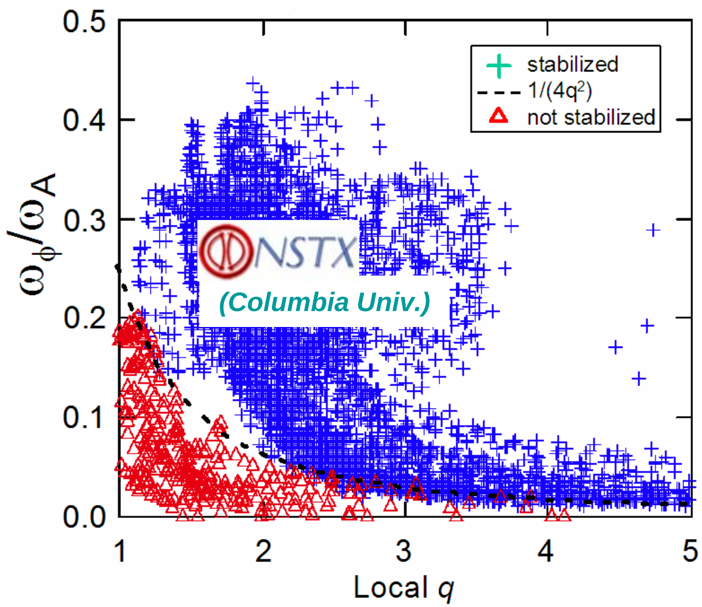
Active MHD Mode Control to Raise β Limit Can Substantially Improve ITER Performance

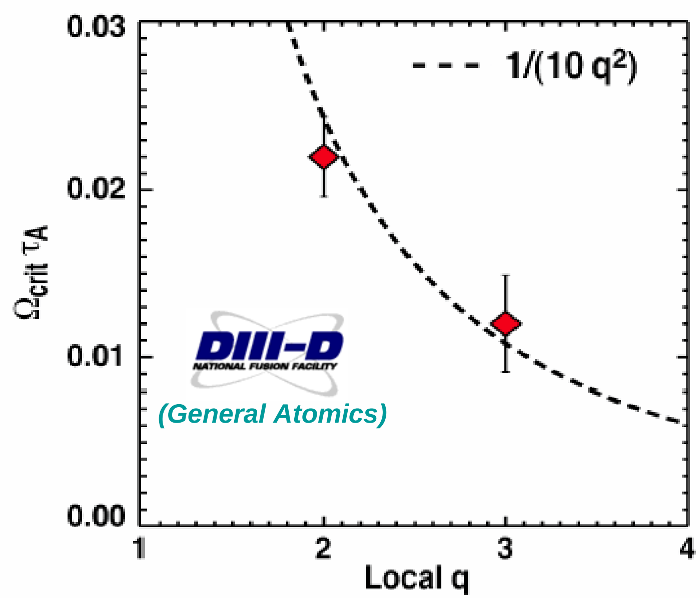
NSTX

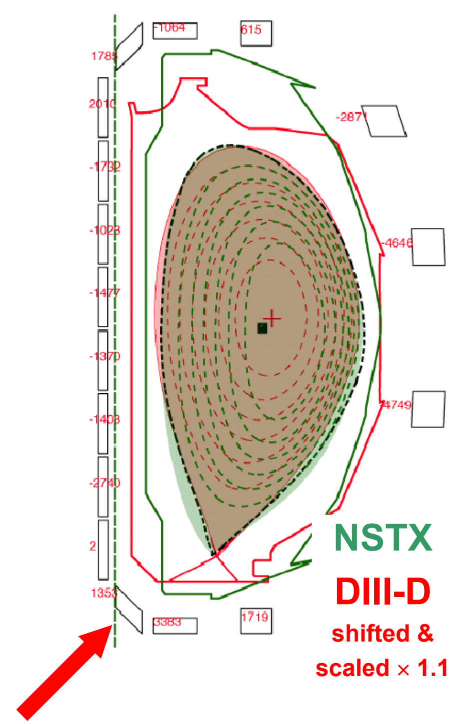
- ***ITER Topic****: Active control of MHD instabilities via conducting structures and additional coils*
- **High priority for 2005-2006**: Enhance understanding and mitigation of the effects of RWMs by analysis, experimental verification of control, determination of role of plasma rotation and error fields. Determine control system requirements for diagnostics.
- NSTX provides low-A data to help understand the dissipations that rotationally stabilize RWM
- Study of equilibrium, stability, and control of high β, q-shear & rotation plasmas can contribute
- ITER RWM model may also benefit from NSTX conductor configuration

NSTX Provides Low-A Data to Help Understand the Dissipations that Rotationally Stabilize RWM

- Insight from drift-kinetic theory:
  - Trapped-particle effects at finite ε significantly weaken ion Landau damping, but…
  - Toroidal inertia enhancement modifies eigenfunction when $\Omega_\phi / \omega_A > 1/4q^2$





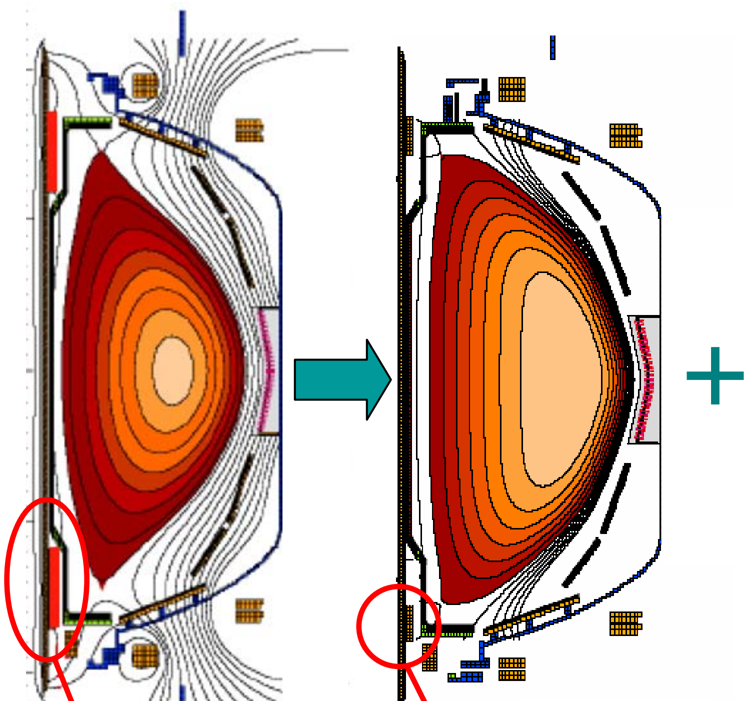


- Experimental Ω_{crit} consistent with scaling $\propto \varepsilon / q^2$ – why?
- Is dissipation localized to resonant surfaces, or more global?
  - Addressing questions above w/ NSTX / DIII-D similarity experiments, and hi-res CHERS
- ST has uniquely high $\omega_{sound} / \omega_A \rightarrow$ distinguish between ω_s and ω_A scaling

Needed for predicting control requirements for RWM stabilization in ITER

Study of Stability and Control of High β, q-Shear & Rotating Plasmas Can Contribute

- Sustained operation above the no-wall limit at high β motivates study of shape, RWM, and NTM control physics
  - **Potential for improving steady-state Q>5 scenarios in ITER**
  - Requires understanding + integration of both passive and active mode control
  - Important for achieving goal of non-inductive operation in NSTX



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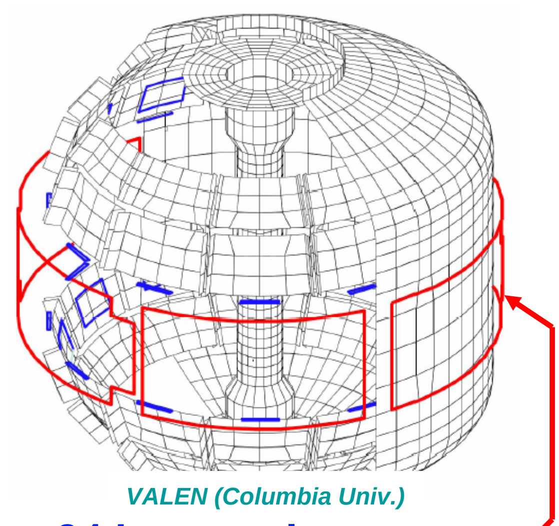
Effects of high β & edge *q*-shear may be important



24 in-vessel sensors
6 ex-vessel control coils

+

MSE: q profile;
CHERS: V_ϕ profile

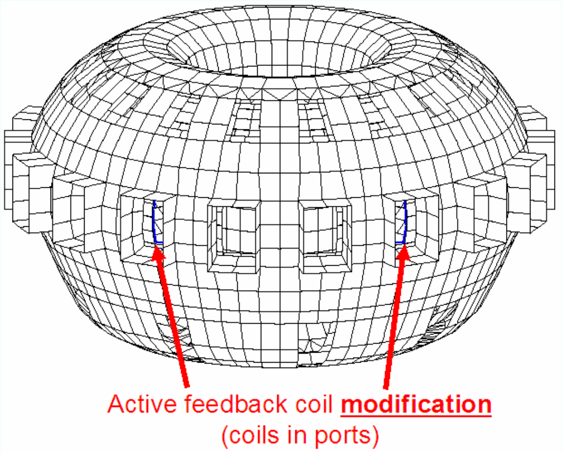
ITER RWM Feedback Models May Also Benefit from NSTX Conductor Configuration

ITER AT scenario requires stabilized n=1 RWM

Baseline external coils can only increase β_N from 2.4 to 3

U.S. proposal:
6 coils in ports

(VALEN – Columbia Univ.)



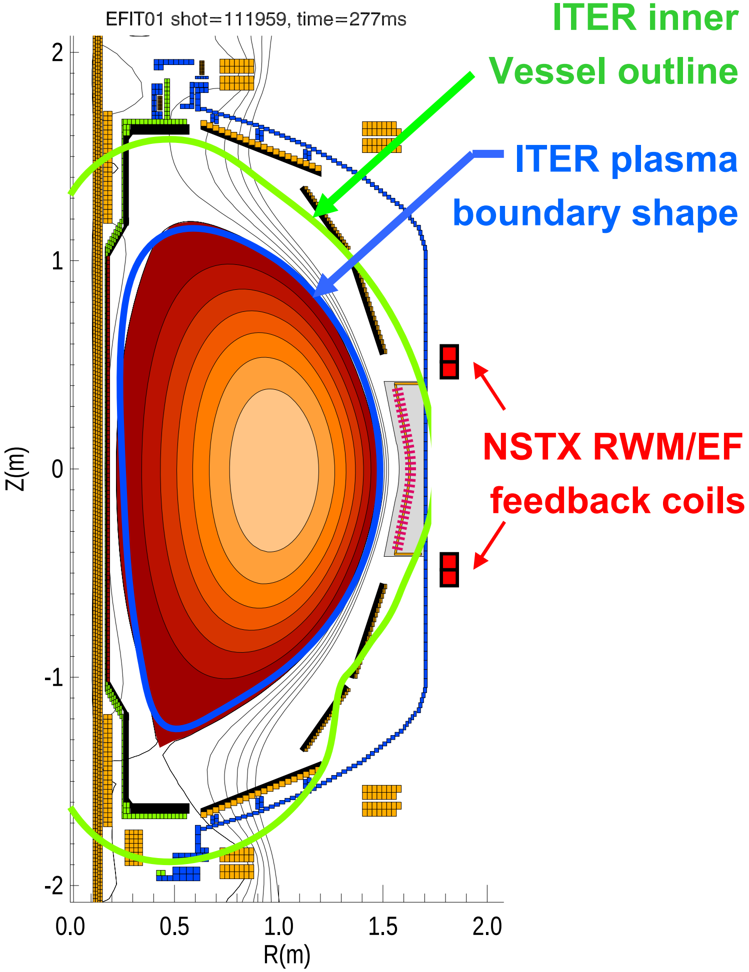
VALEN ⇒ blanket increases ideal-wall limit β_N from 3.5 to 5 (C_β = 0.9)

- **Possibility of higher β_N operation in ITER with active feedback control of RWM**

Complex passive conducting structures that require 3D modeling

→ NSTX – good test-bed for this research

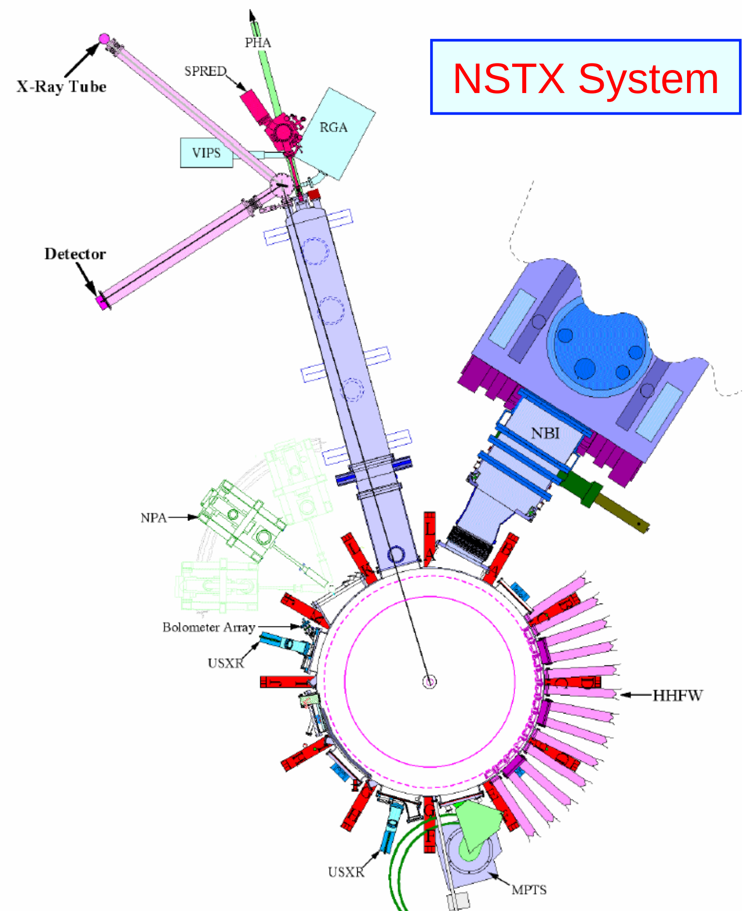
NSTX



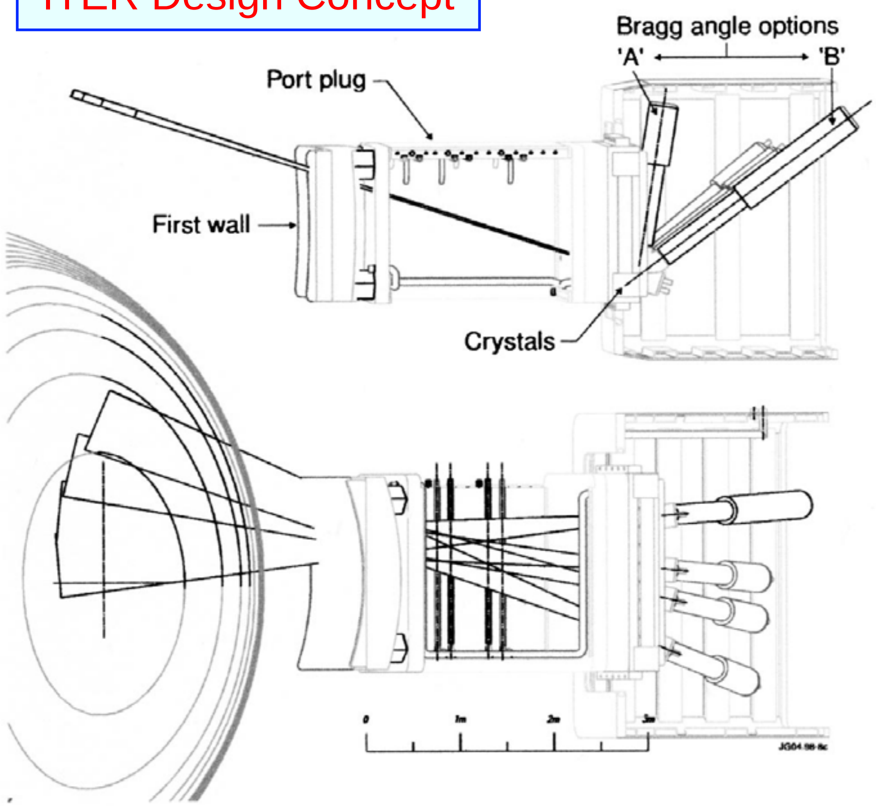
Present NSTX RWM coil will validate stabilization model up to C_β = *0.68*

2D X-Ray Crystal Spectrometer on NSTX for T_e and T_i Profiles Are Being Considered for Use in ITER

NSTX System



ITER Design Concept



- R. Barnsley et al., Rev. Sci. Instrum. **75**, 3743 (2004): spectrometer design for ITER
- M. Bitter et al, Rev. Sci. Instrum. **75**, 3660 (2004) & PRL 2003: validity of concept & resolved spectral issues of interest for comets and stellar flares
- Collaboration: NSTX, C-Mod, KSTAR, LLNL, Columbia U

NSTX Is Contributing Actively to Physics Topics of Interest to Burning Plasmas

- **Low-A studies of super-Alfvénic ion driven modes and associated losses are of interest to ITER**
- **Low-A database can shed new light on confinement scaling uncertainties in β and ν^***
- **Active MHD mode control to raise β limit can substantially improve ITER performance**
- **2-D x-ray crystal spectrometer to measure T_e and T_i on NSTX are being considered for use on ITER**