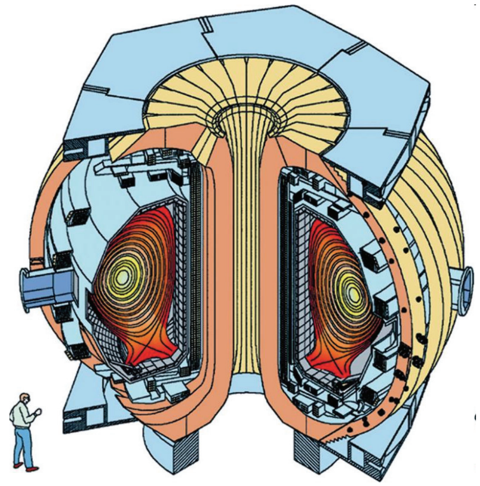
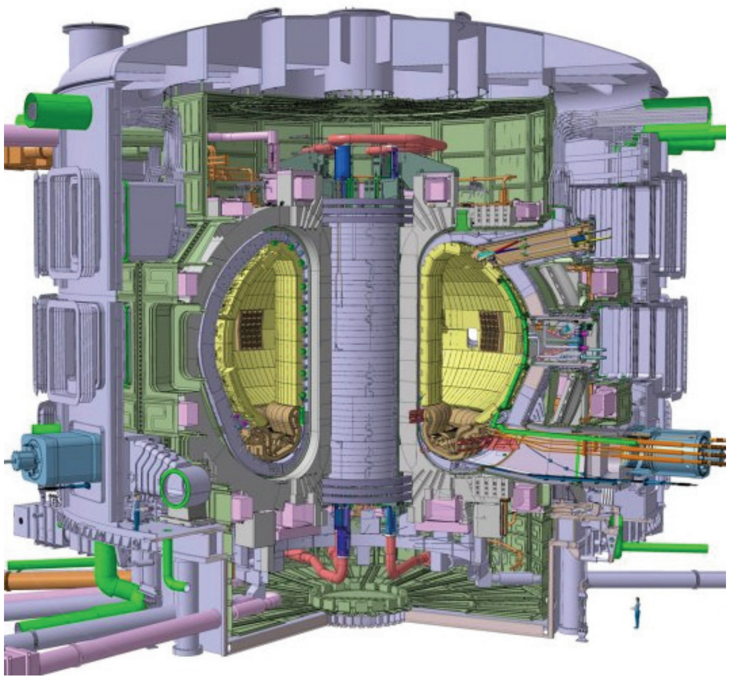
ITER Test Blanket Module Error Field Simulation Experiments at DIII–D



by
M.J. Schaffer



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A Large International Team Participated

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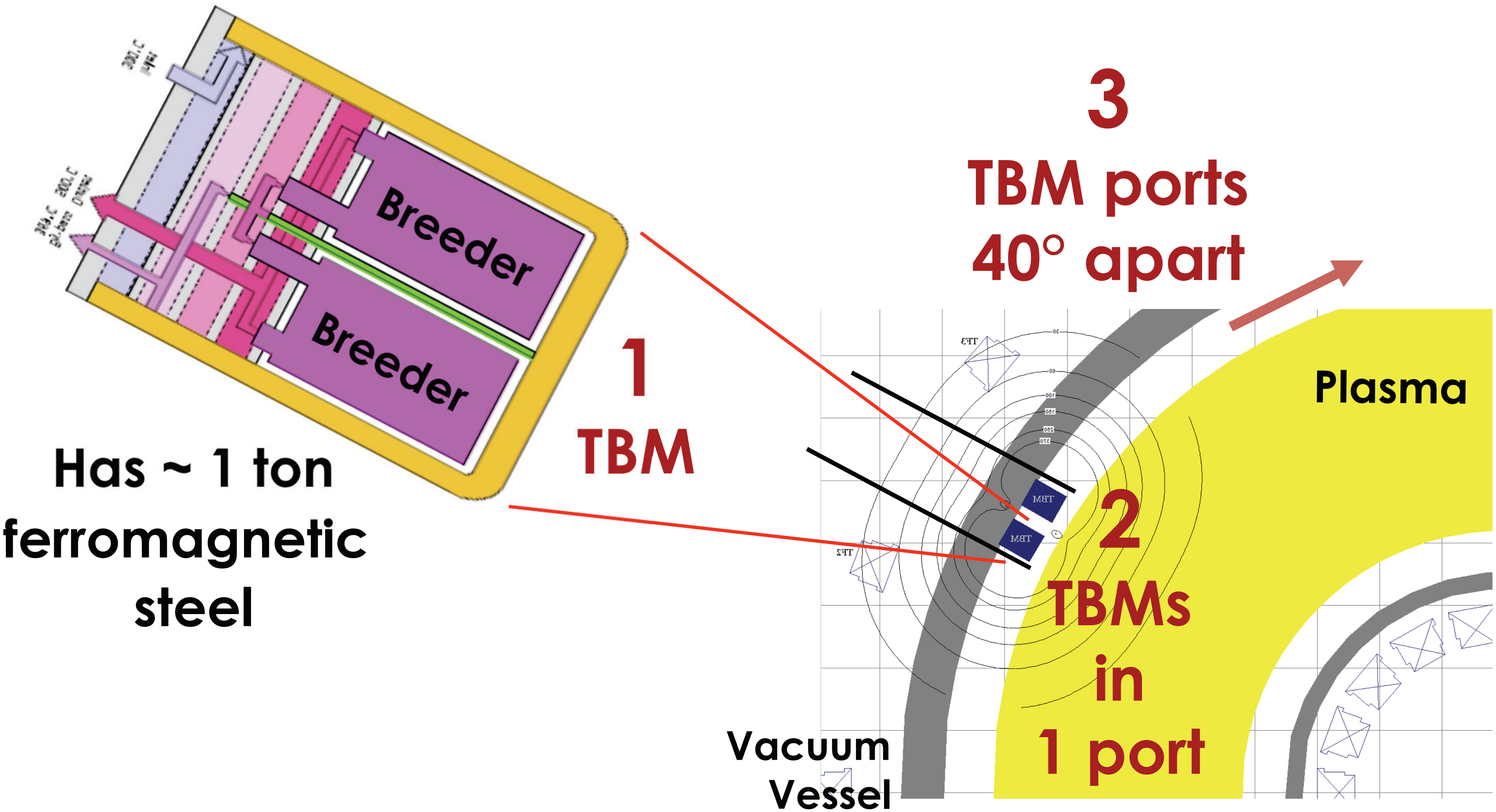
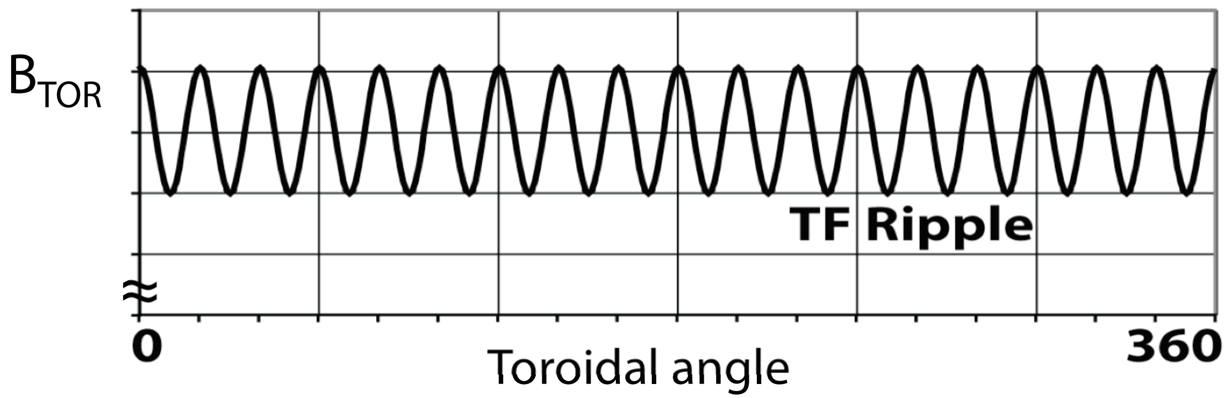
Concern Raised About the Impact of Ferromagnetic Test Blanket Modules (TBMs) on ITER Performance



It Is Well-Known That Toroidal Field Ripple Has Undesirable Effects on Plasmas

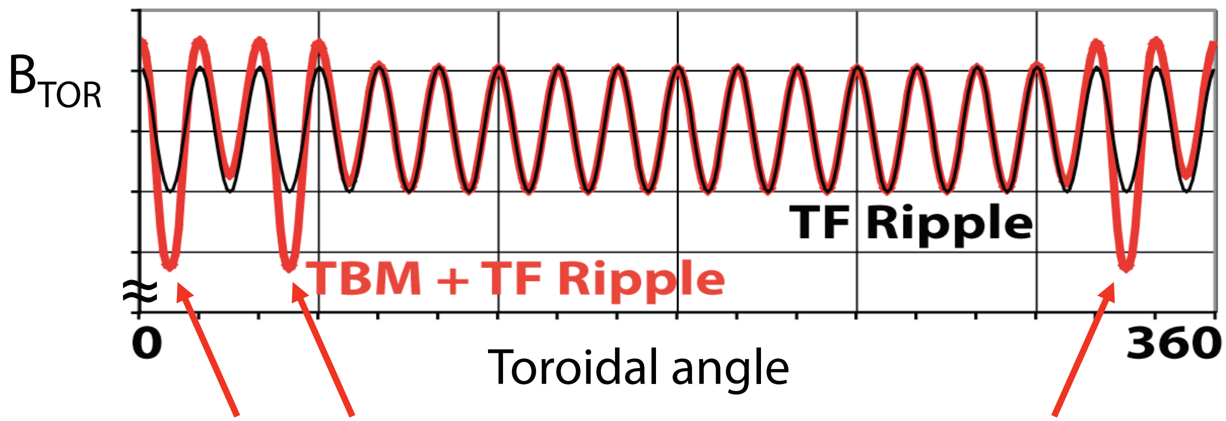
- **Common magnetic field ripples made by toroidal field coils are uniformly periodic**



- **DIII-D matched ITER TF coil ripples for most of the TBM experiments**
  - 0.35 ~ 0.4% ripple for both

TBMs Complicate Ripple Geometry

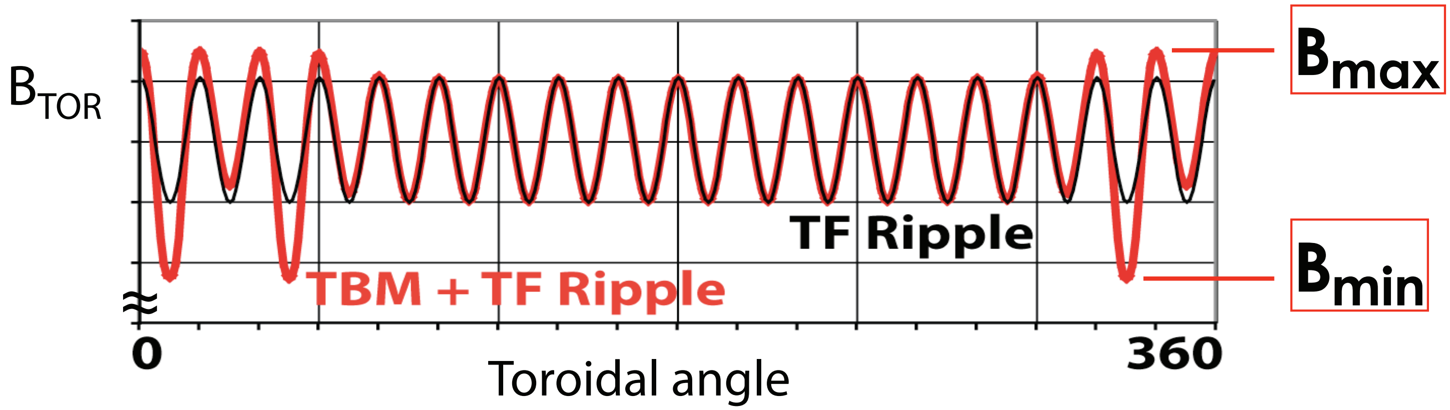
- **Larger perturbations**
- **Broken periodicity**



- **Magnetized TBM steel makes 3 local "dips"**
- **Cannot predict consequences, NEED EXPERIMENTS**

Use the Combined "Local Ripple" δ

$$\delta = \frac{B_{max} - B_{min}}{B_{max} + B_{min}}$$

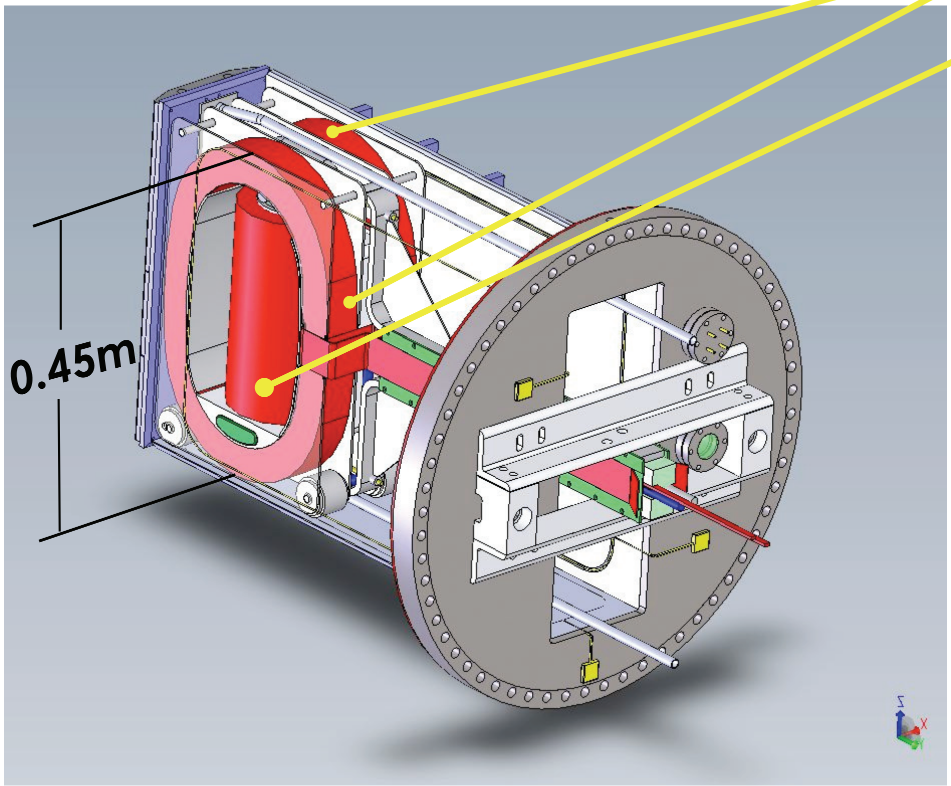


We Designed a Mock-up of the TBM Field to Measure Its Effects on DIII-D Plasmas for ITER

Mock-up Approximates the Magnetization at One ITER Port

Racetrack coils ~ M_{TOR} TBM

Vertical solenoid ~ M_{POL} TBM



- **Matches ITER TBM field well**
- **Moveable, ΔR = 0.28 m**
  - 1.0 m in ITER
- **Up to ~3 x ITER local ripple**
  - To match **surface-average amplitude** of **3 ITER** TBM ports

Experimental Results Showed that Most TBM Effects Were Small, and the Remainder May Be Correctable

Nil or Small Effects on

Plasma Startup

L-mode Confinement

L-to-H Transition

ELM Characteristics

ELM Control by RMP

Global Fast Ion Loss

Divertor Power

Of Concern* if Scaling is Unfavorable

Braking of plasma rotation

Reduction of H-mode confinement

(both at high ß)

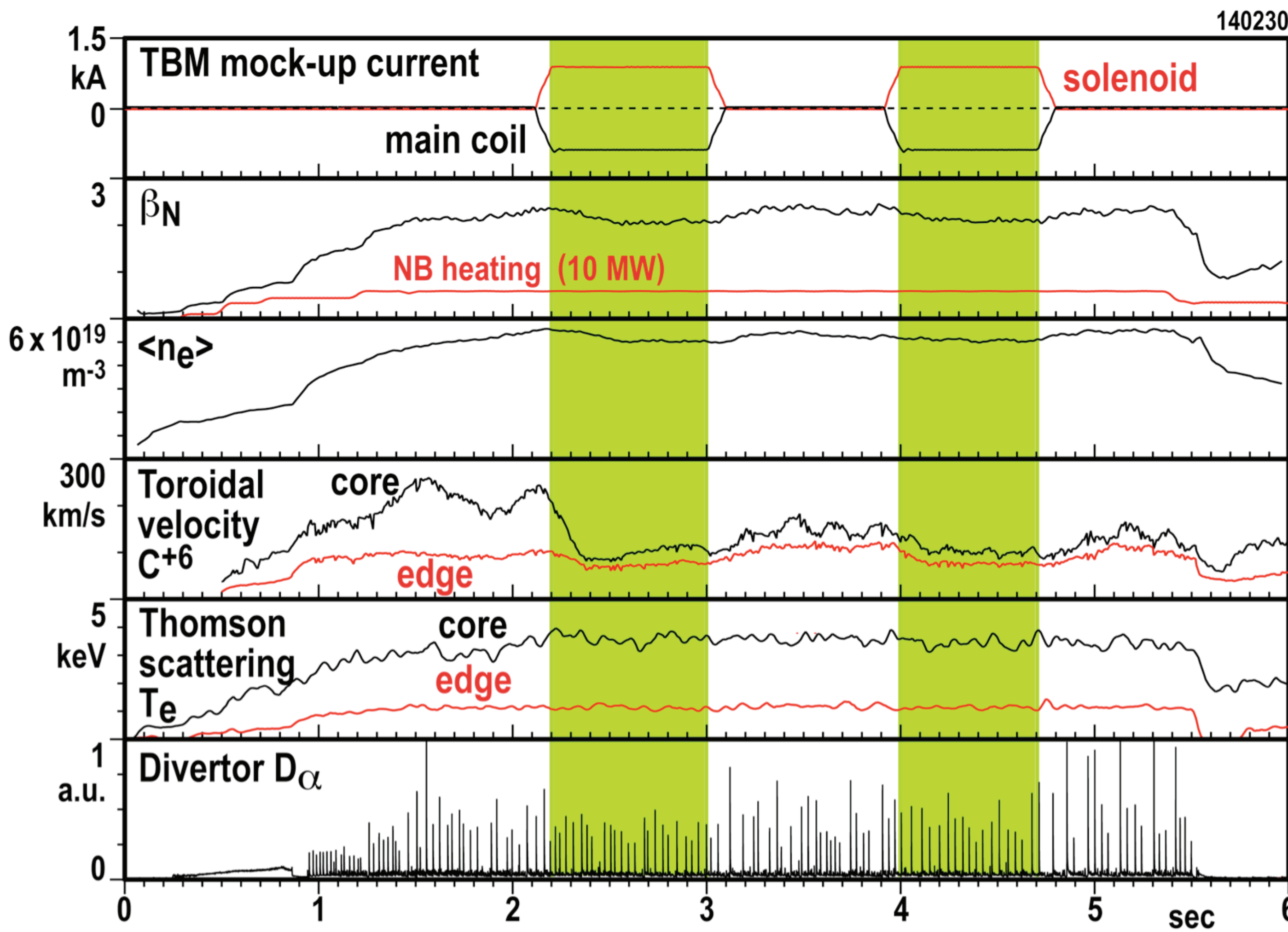
* to ITER High-Gain Mission

May Be Correctable

n=1 error compensation eliminated TBM contribution to *locking* in *L-mode* experiments

Numerical model predicts n=1 compensation will reduce *braking* in *H-mode* plasma

Greatest TBM Effect Was Toroidal Velocity Reduction – β, n_e, T_e Were Less Affected



Making local ripple δ = 3%

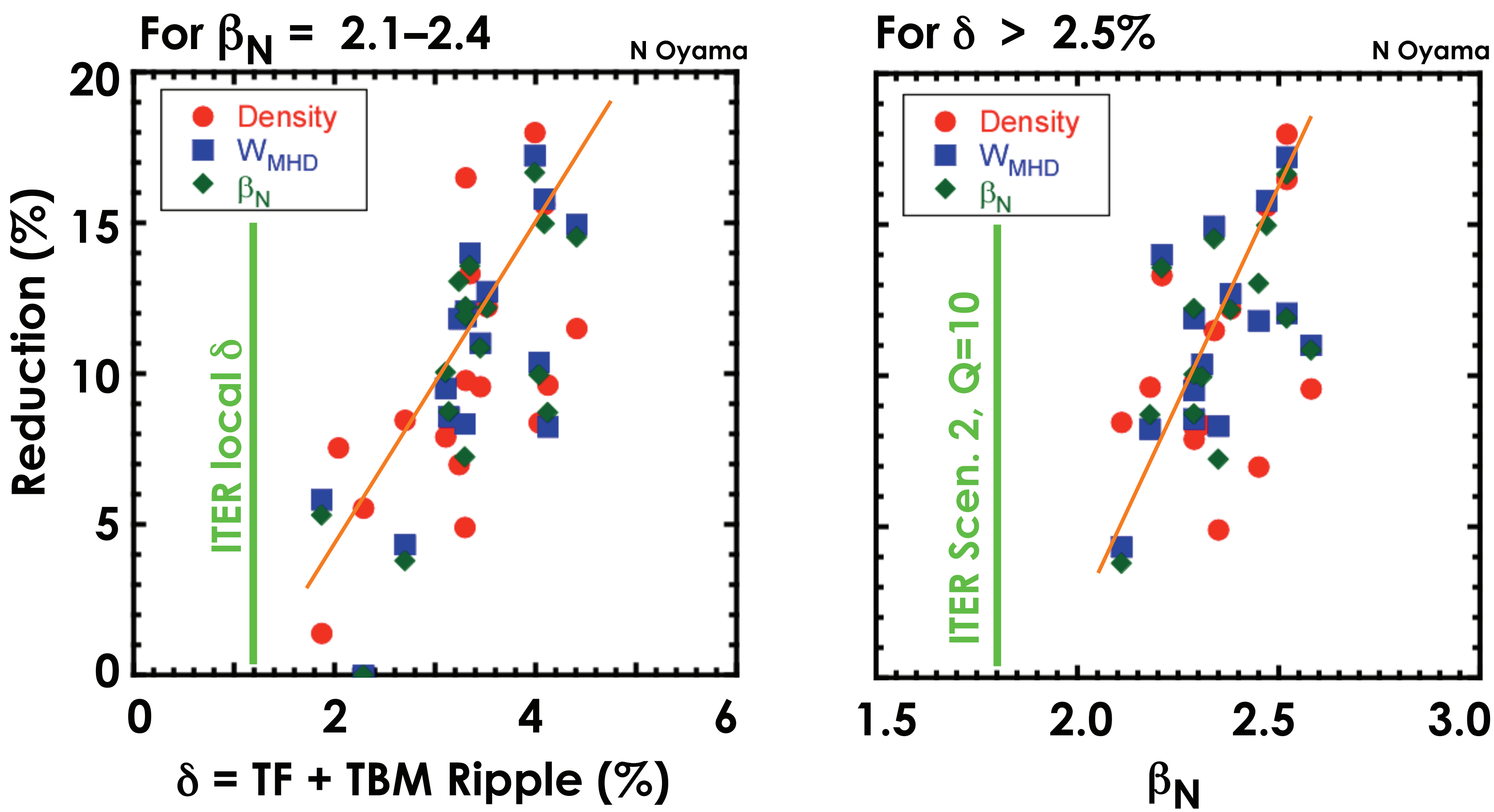
Moderate reductions

Large velocity reduction

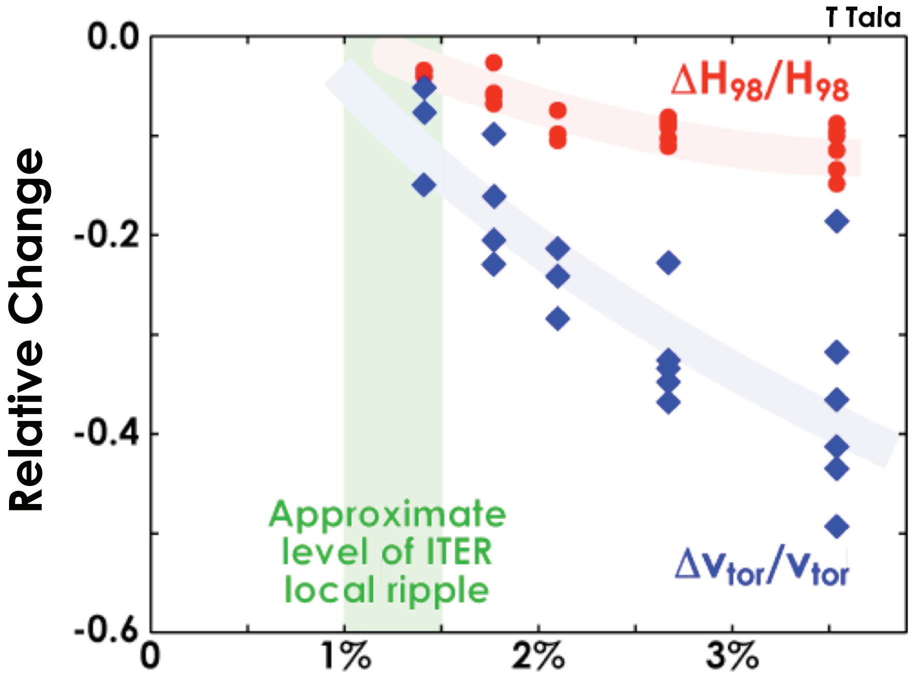
No effect on T_e

TBM Effects Were Small at ITER Baseline Parameters. – We Did Systematic Scans at Higher Ripple and β.

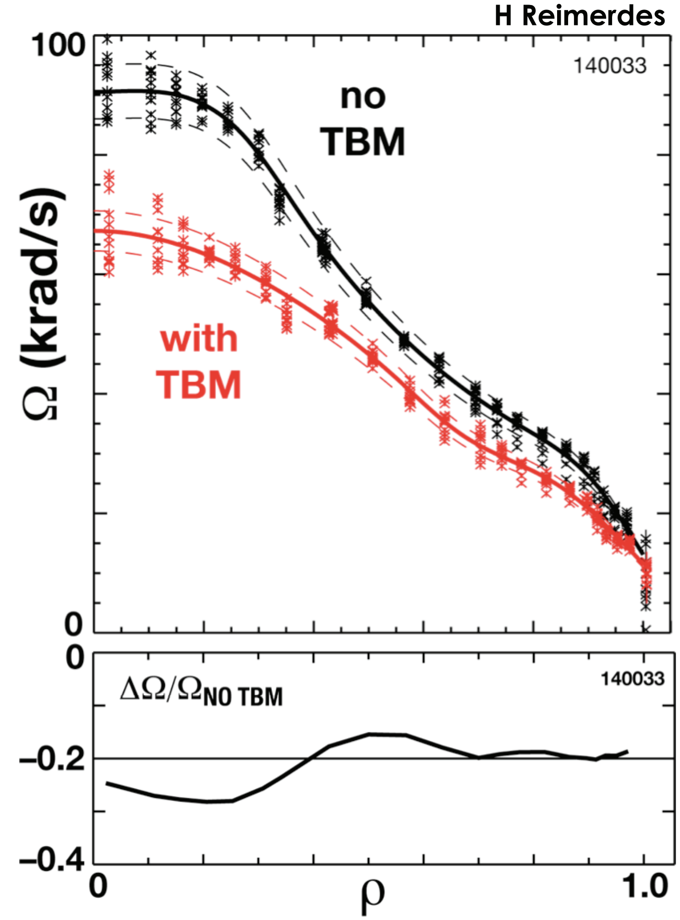
R_{midout} = 2.30 m q_{95} = 3.5 B_T = 1.7 T I_p = 1.4 MA



The TBM Field Reduced Toroidal Velocity Much More Than H-mode Confinement

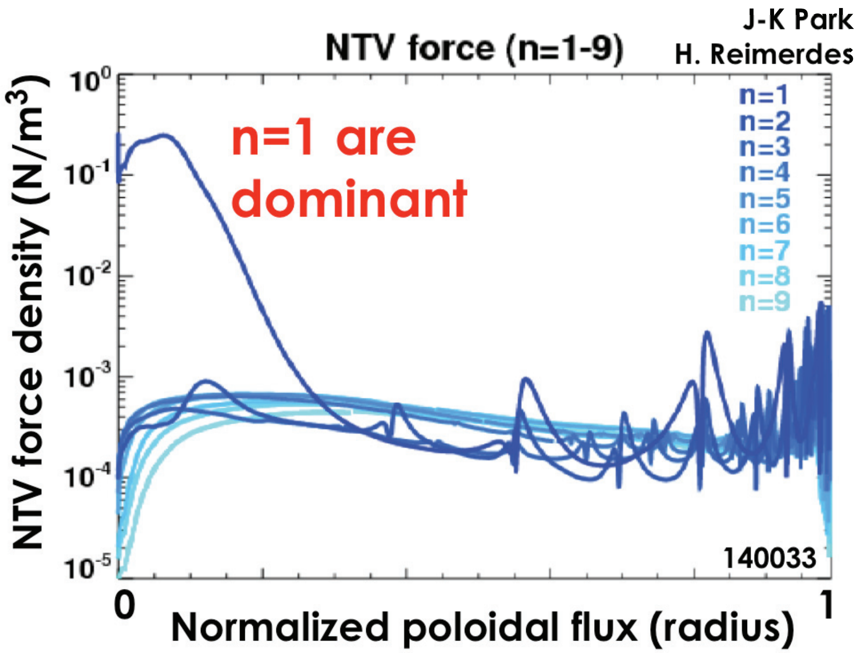


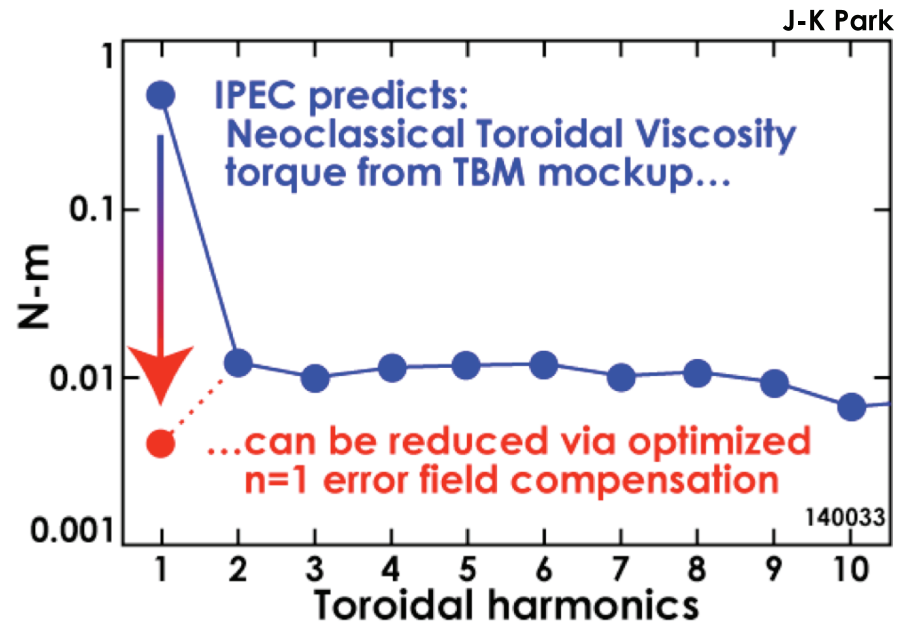
Relative
velocity change
was ~ 3 times the
confinement change



$\Delta\Omega/\Omega \approx$ constant across plasma radius

The Ideal Perturbed Equilibrium Code (IPEC) Implicates n=1 Harmonics in Toroidal Rotation Braking

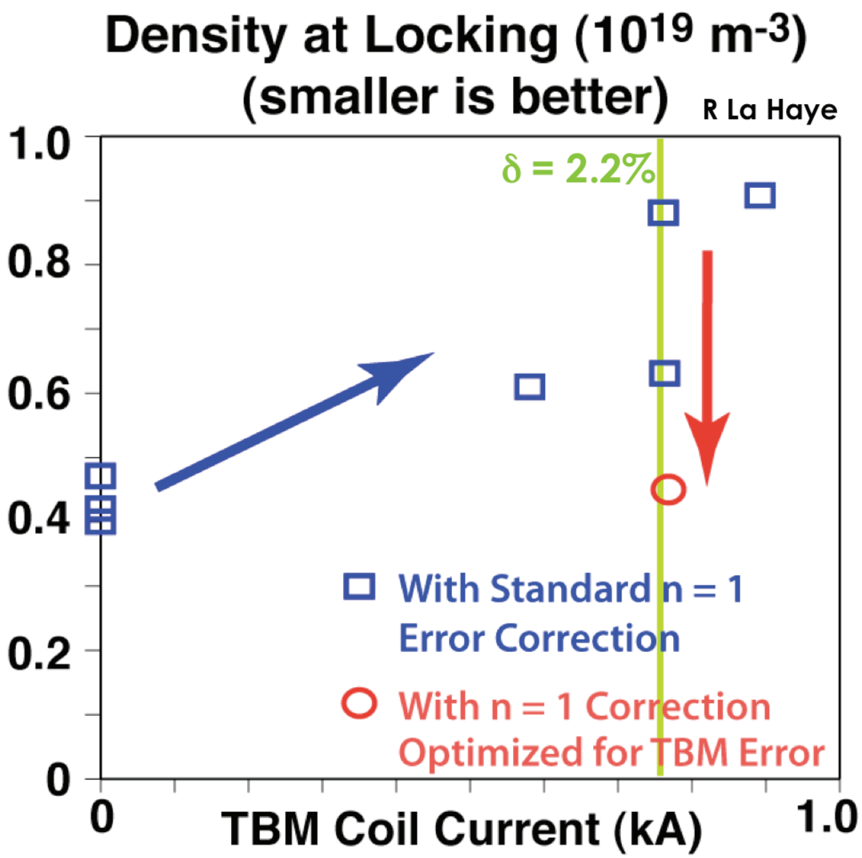




- **Mock-up <u>N</u>eoclassical <u>T</u>oroidal <u>V</u>iscous braking is mostly from n=1 harmonics in central core**
  - n=1 is **amplified** by H-mode

- **A great opportunity…**
- **One expects higher plasma speed and restored confinement**

n=1 Error Compensation Was Optimized for TBM, and It Restored Locked Mode Tolerance at low ß



Standardized Ohmic Low-Density Locking Test Plasmas

- TBM field raised the low-density threshold for locked mode avoidance
- n=1 compensation restored locked mode tolerance in *low-ß* test
- IPEC analysis and experiment ≈ agree
- Will n=1 compensation also restore H-mode confinement at *high-ß*?

How to Scale from 1Port in DIII-D to 3 Ports in ITER?

- **If TBM effects vary linearly with ripple mirror ratios, and they also sum linearly, then equivalence is $\delta_{DIII-D} = 3\,\delta_{ITER}$**
  - for case of 1 DIII-D vs. 3 ITER ports
- **If TBM effects $\propto \delta^{\alpha}$ and $\alpha > 1$, then $(\delta_{DIII-D})^{\alpha} = (3\,\delta_{ITER})^{\alpha}$ makes TBM effects 9 $(\delta_{ITER})^{\alpha}$ in DIII-D vs. 3 $(\delta_{ITER})^{\alpha}$ in ITER**
  - $\alpha \approx 2$ for DIII-D density reduction data (V Chuyanov)
  - DIII-D TBM experiments may be more pessimistic than ITER reality
- **A different view: ITER rotation may be too small for the TBM error to be important**

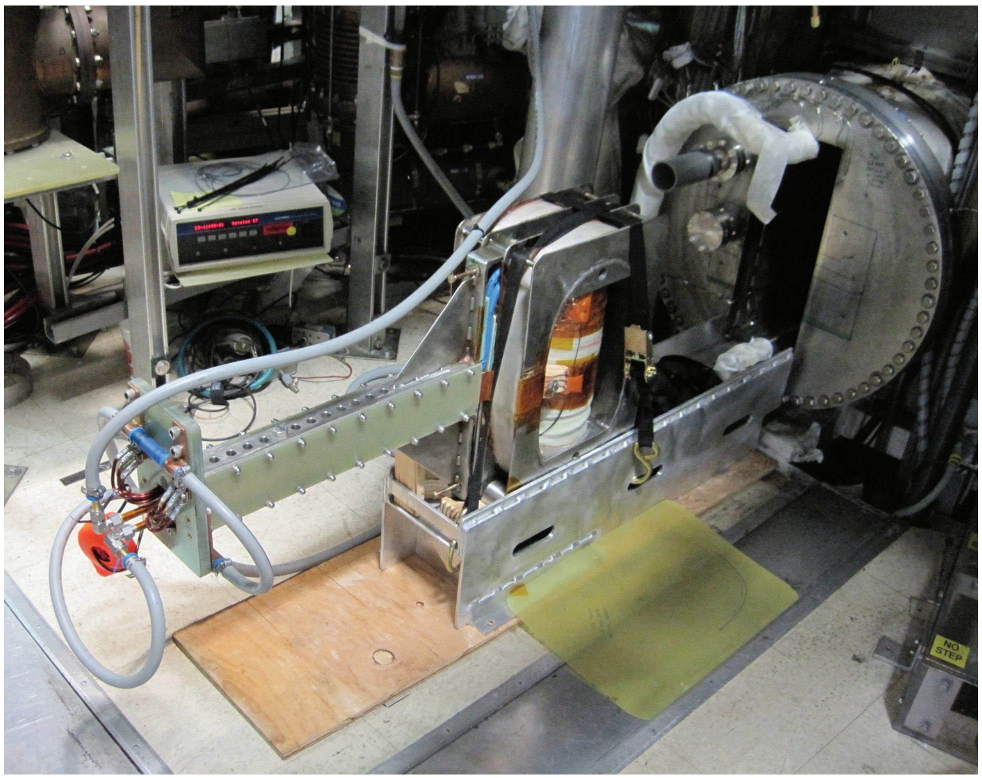
Summary

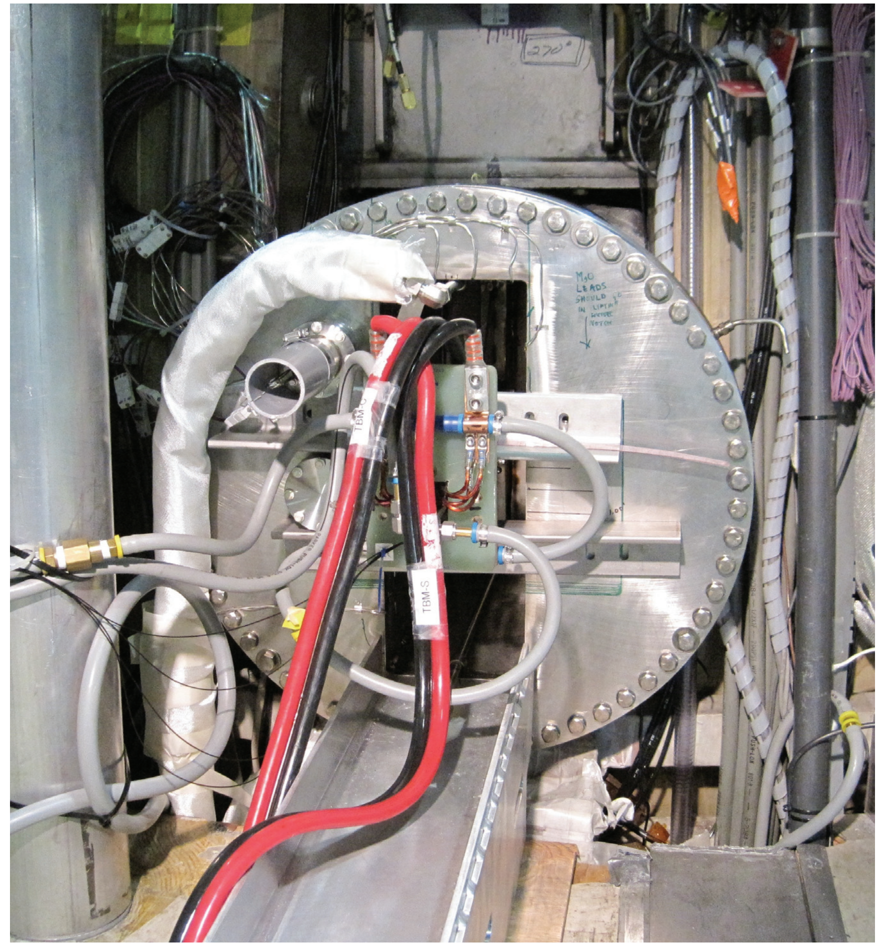
- **DIII-D experiments did not reveal any reason why a TBM-like error field would seriously limit ITER plasma performance objectives**
- **IPEC numerical analysis indicates that NTV braking is dominated by plasma-amplified n=1 TBM error field**
  - IPEC predicts rotation recovery by n=1 compensation
- **A DIII-D experiment demonstrated n=1 compensation of the TBM contribution to locking in OH plasmas**
- **DIII-D plans experiments in 2011 to test if n=1 re-compensation can obviate rotation and confinement degradations in high-ß H-mode plasmas**

Backup Slides

TBM Mock-up at its DIII-D Port

Mock-up secured in its channel with cooling water attached





Mock-up rolled into port

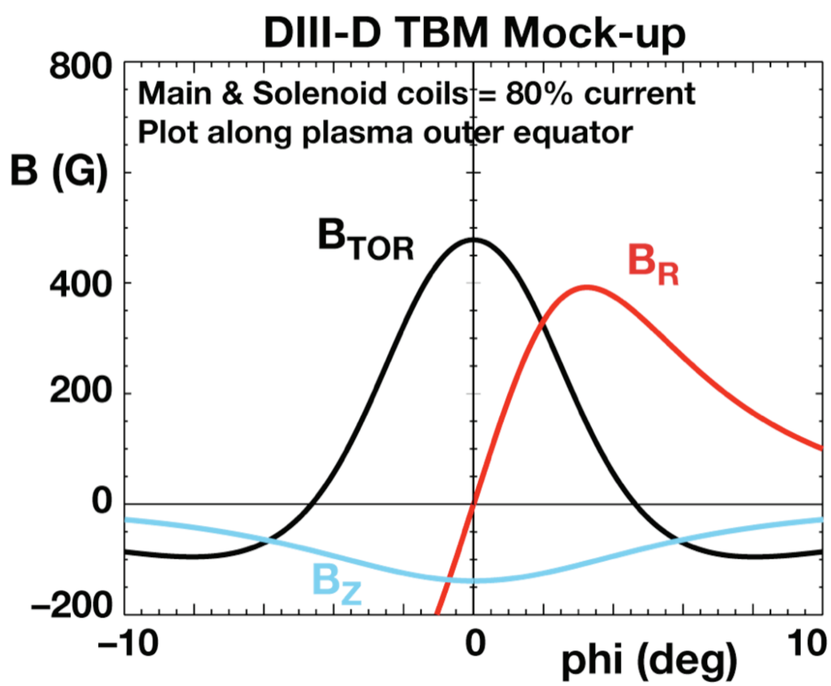
Two Main Differences Between DIII-D and ITER:

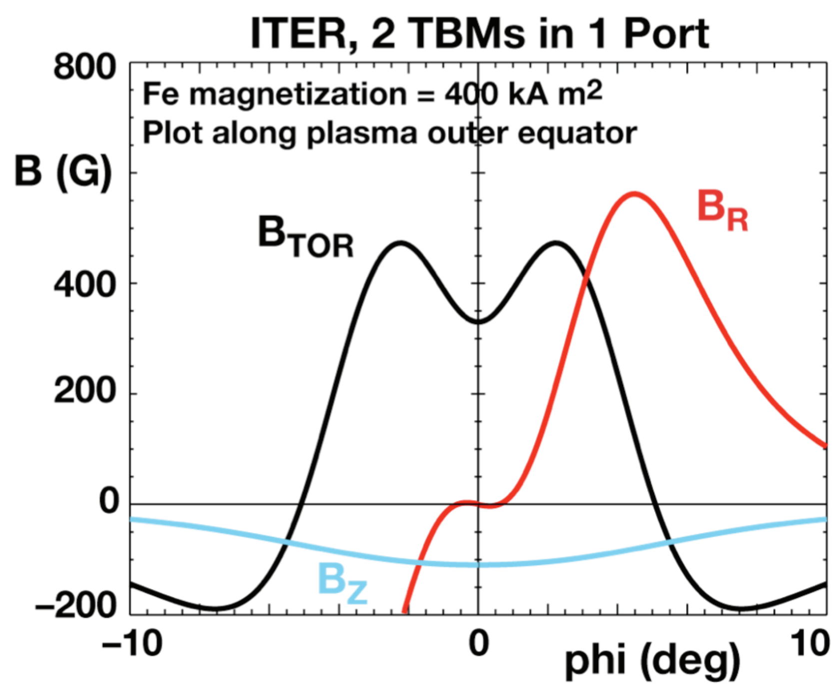
- **1 DIII-D TBM port vs. 3 ITER TBM ports**

  No validated theory for extrapolation

- **Near-field details**

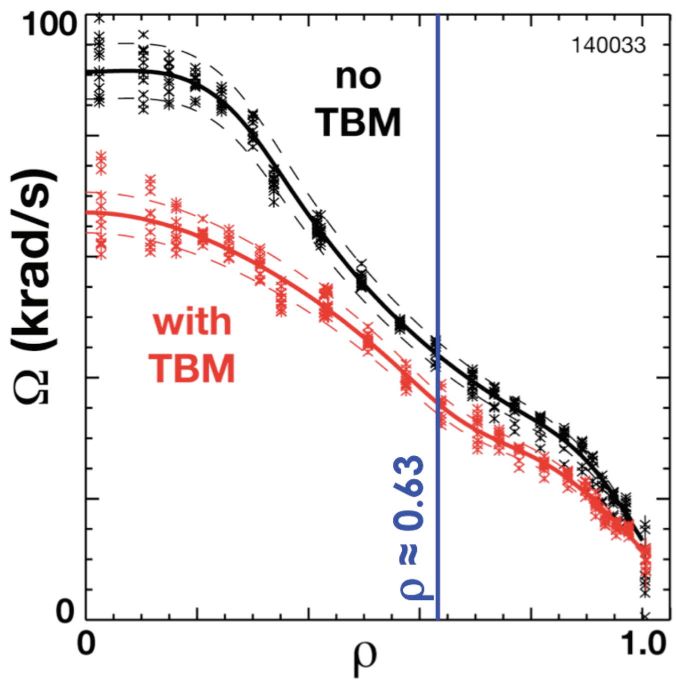
  Limited by DIII-D port width

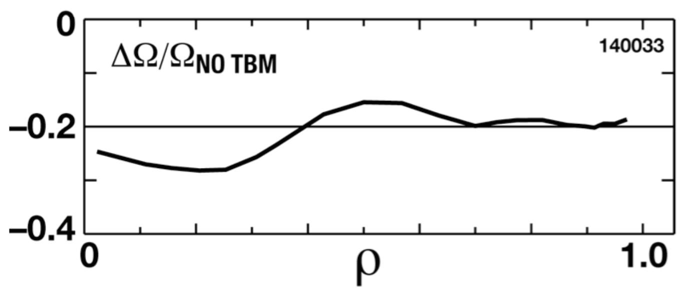




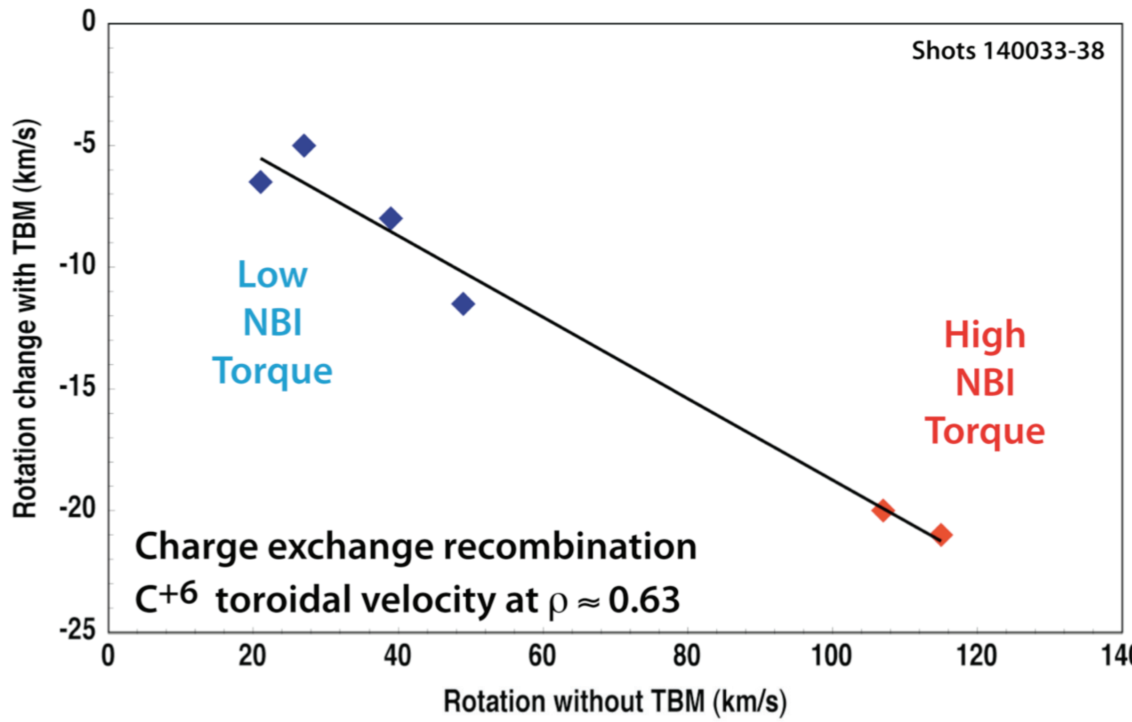
Mock-up Field Exerts Non-Resonant Braking on Plasma Toroidal Rotation, $v_T = \Omega R$

H Reimerdes





H Reimerdes



- $\Delta\Omega/\Omega$ is ≈ constant, either way