TF 04: ITER TBM Error Field Mock-up Experiments in DIII-D

by

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for the International TBM Team

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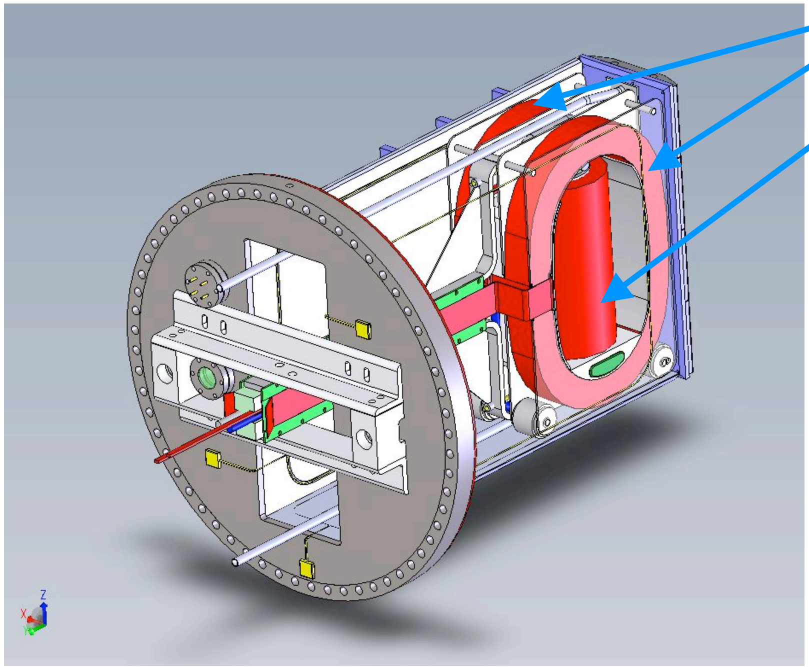
DIII-D Year End Review 2010

General Atomics, San Diego 2010 June 8 – 9

GOAL: Measure Effects of Test Blanket Module (TBM) Ferromagnetism on Plasma for ITER

Mock-up Approximates Magnetization M of 2 ITER TBMs in One ITER Port

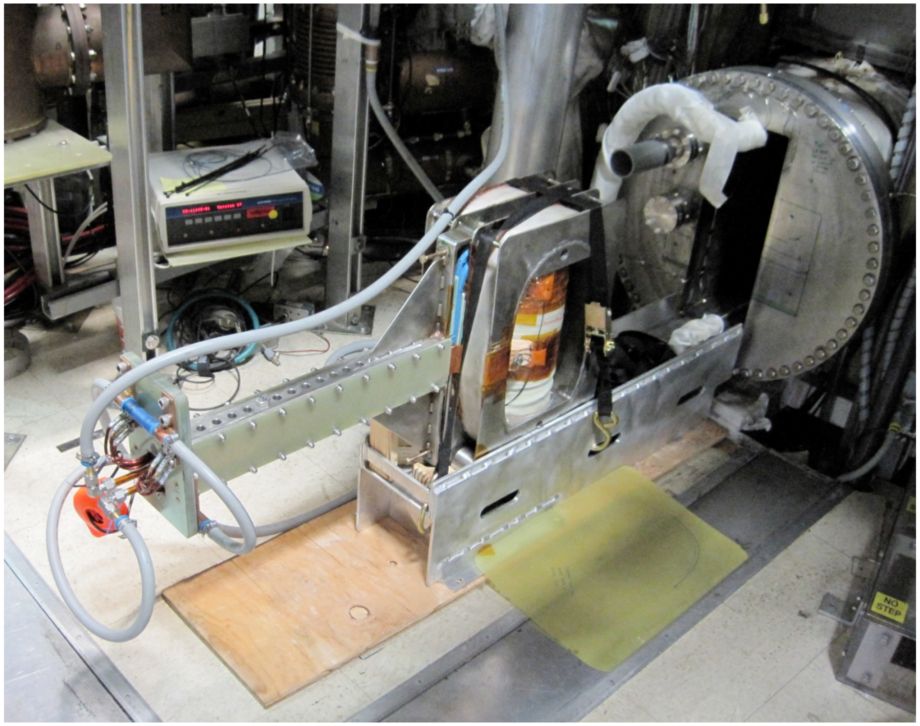


TBM mock-up coil assembly fits into custom re-entrant port

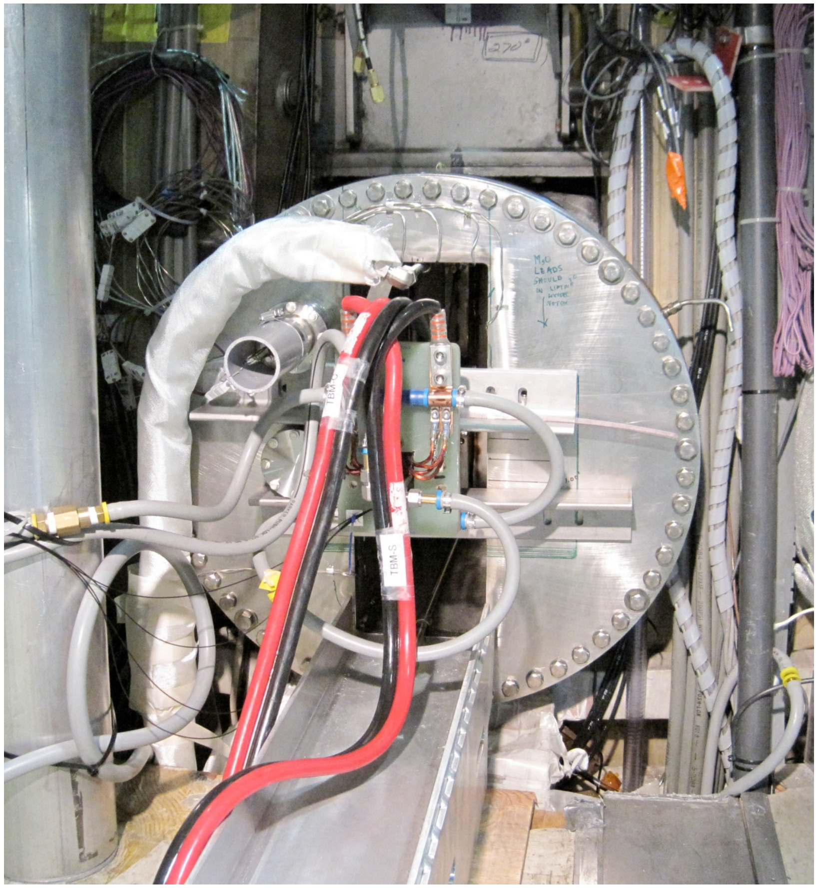
- **Racetrack coils ⇔ M_{TOR}**
  Vertical solenoid ⇔ M_{POL}
  - Separate power supplies for M_{POL} and M_{TOR}
- **Moveable, ΔR ≈ '1.0 ITER meter'**
- **Matches ITER TBM far field**
- **Capable of ~3x ITER $\Delta B/B_0$**
  - Matches surface-average amplitude of the **6 ITER** TBMs
  - Cannot match their spectrum

DIII-D TBM Mock-up Is About as Tall as a Scaled-Down ITER TBM

DIII-D port is considerably narrower than a scaled ITER TBM port

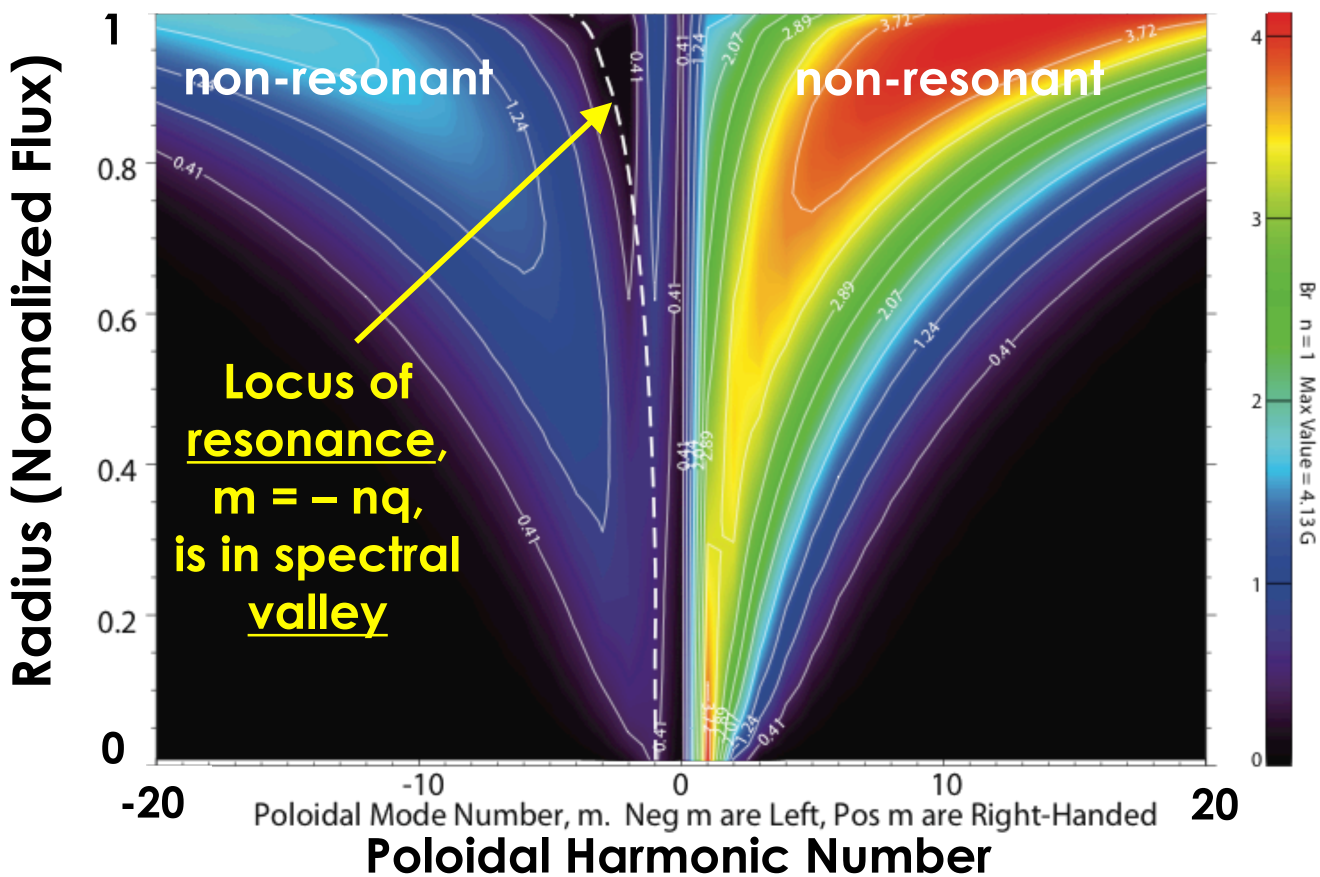


Mock-up secured in its channel with cooling water attached



Mock-up rolled into re-entrant port

The n=1 B_r Harmonic Spectrum of 6 ITER TBMs Is Dominantly NON-RESONANT



Largest helical harmonic ~ 4 G, *vs* peak local B ~ 800 G

TBM field contains hundreds of harmonics

Islands should be very small
Non-resonant torque may be large

Scientists from the 7 ITER Parties and the IO Participated in the DIII-D TBM Task

Michael Schaffer	USA
Joseph Snipes	IO
Punit Gohil	USA
Charles Greenfield	USA
Valery Chuyanov	IO
Alberto Loarte	IO
Naouki Oyama	Japan
Kouji Shinohara	Japan
Xiang Gao	China
Songlin Liu	China
Yanjing Chen	China
Guoyao Zheng	China
Gabriella Saibene	Europe
Peter de Vries	Europe
Tuomas Tala	Europe
Anti Salmi	Europe
Filomena Nave	Europe
Oliver Schmitz	Europe
Marcin Jakubowski	Europe
Ruth Laengner	Europe
Henning Stoschus	Europe
R. Srinivasan	India
R. Narayanan	India
Hogun Jhang	S Korea
Kwang-Il You	S Korea
V.D. Pustovitov	Russia
Donald Spong	USA
David Gates	USA
Jong-Kyu Park	USA
Gerrit Kramer	USA

A few of the participants

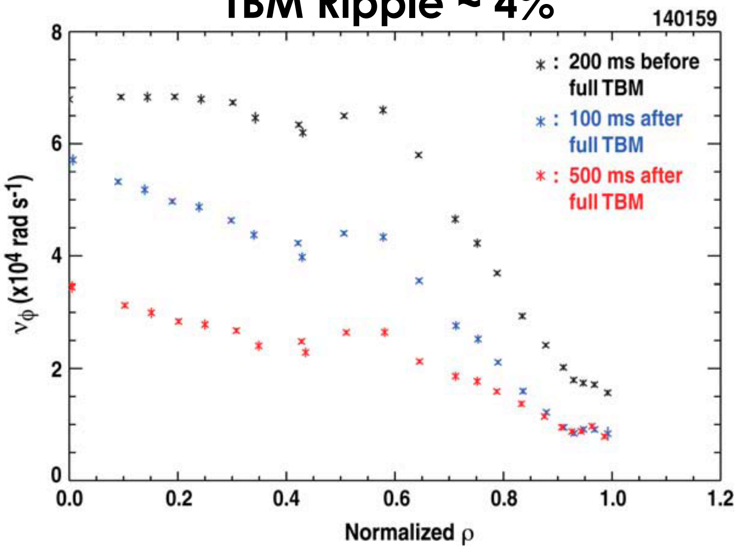
RESULTS (1)

- Designed and built TBM mock-up that reproduced many features of the error field from 2 ITER TBMs in 1 ITER port
  - Not having a 3-port mock-up was the greatest difference from ITER
  - Mock-up applied > 3 times ITER TBM ripple
  - “Ripple Theory” to extrapolate to ITER is not yet mature
- Used ITER-similar plasmas
  - Similar shape, edge collisionality, TF-coil ripple
- TBM had no significant effect on H-mode power thresholds
  - L-mode plasmas are little affected by TBM field
- Plasma initiation was unaffected

RESULTS (2)

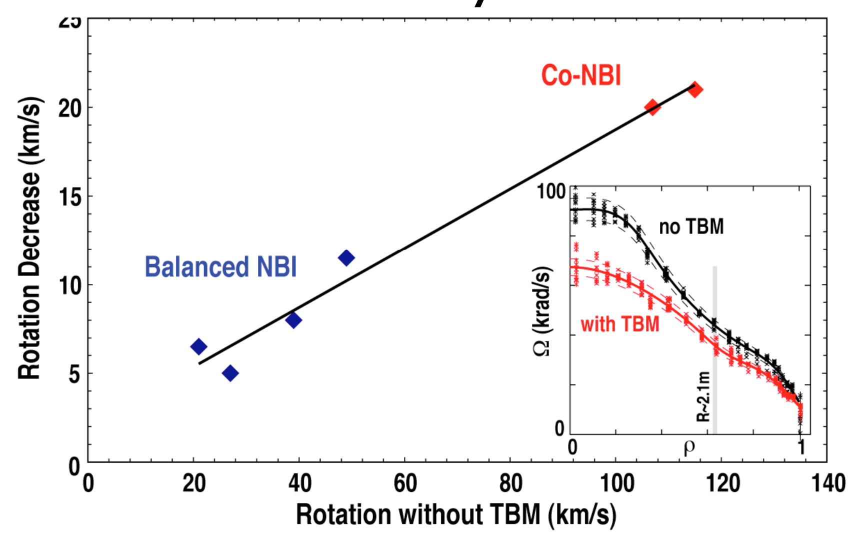
- Rotation reduction is the largest TBM effect
  - up to ~50% reductions
  - Has characteristics of a non-resonant braking torque

TBM Ripple ~ 4%



Slowing is across the whole plasma

Rotation Decrease by TBM at R ≈ 2.1 m

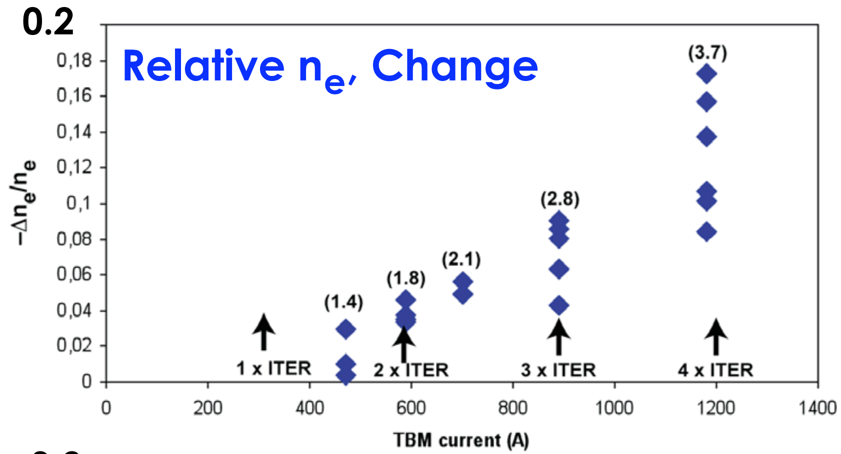


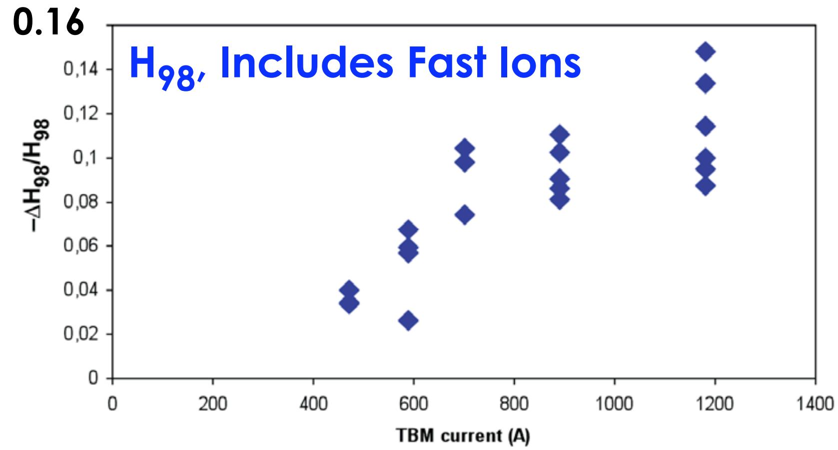
Decrease is proportional to initial velocity

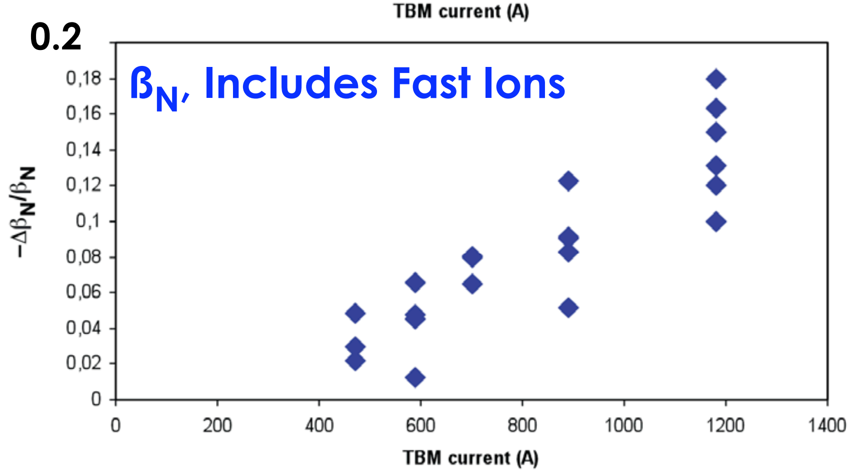
RESULTS (3)

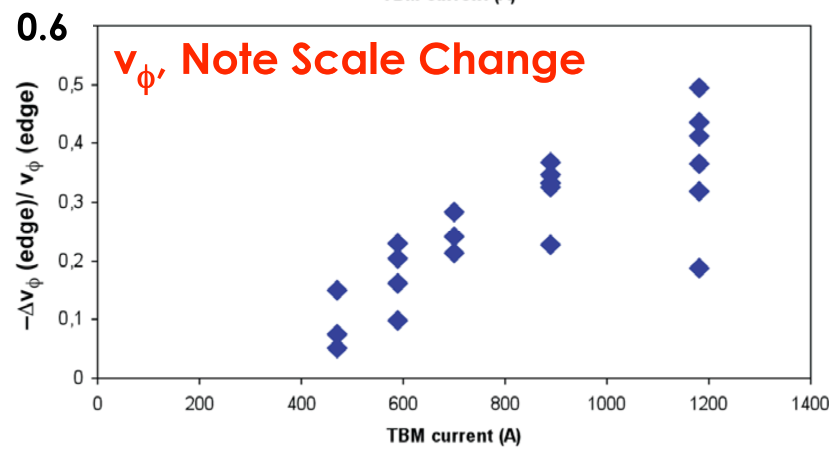
- **TBM mock-up ripple affects H-mode confinement**
  - **Density, ß, stored energy, H98, energy confinement times were reduced as much as ~20%**
    - **for local ripple up to ~4 times ITER level**
  - **TBM effects increase with ß**
  - **Less than 10% changes for $ß_N < 2$**
  - **H-mode confinement reductions showed no strong dependence on edge collisionality**

Reductions of Density, Beta, Confinement Factor and Toroidal Rotation Increase with TBM Ripple









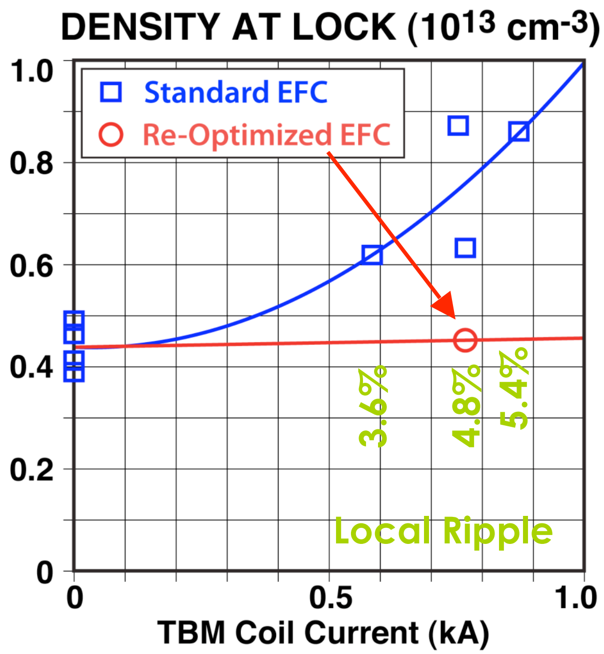
RESULTS (4)

- TBM ripple had no significant effect on suppression of ELMs by n=3 resonant magnetic perturbations
- TBM ripple sometimes enhanced amplitude of MHD, especially in high-performance plasmas
- Effects on <u>global</u> fast ion losses were less than diagnostic error bars
  - Consistent with numerical predictions
- <u>Local</u> heating of TBM enclosure tiles for small plasma-wall gap and maximum TBM ripple

RESULTS (4)

- TBM Mock-up field increased plasma sensitivity to locking by an n=1 error test field
  - At both low- and high-ß
- Low-ß (Ohmic L-mode) Locking Experiments Showed:
  - Re-optimization of empirical n=1 error correction, to compensate TBM field, restored previous error tolerance
  - n=1 errors, though small, are the most important to correct
    - Consistent with IPEC prediction

Re-Optimized n=1 Error Compensation Restored Most of the Locked Mode Tolerance



- **J-K Park's IPEC predicted that the weak TBM n=1 harmonics would have observable effect on Ohmic locked modes**
  - **Semi-quantitative agreement with experimental 'Standard EFC' results**
- **When n=1 error compensation was empirically 're-optimized' to include TBM, the locking threshold returned to the best no-TBM level**

RESULTS (5)

- High-ß (ELMy H-mode) Locking Experiments Showed:
  - TBM torque slowing the plasma rotation is the initial cause
  - Acts like neoclassical toroidal viscosity (NTV)
    - > Measured braking torque ~ 0.2 N•m
    - > IPEC-NTV calculates ~ 0.6 N•m

- **Future experiments are needed to determine if n=1 error correction alone is also effective in H-mode for locked mode amelioration**