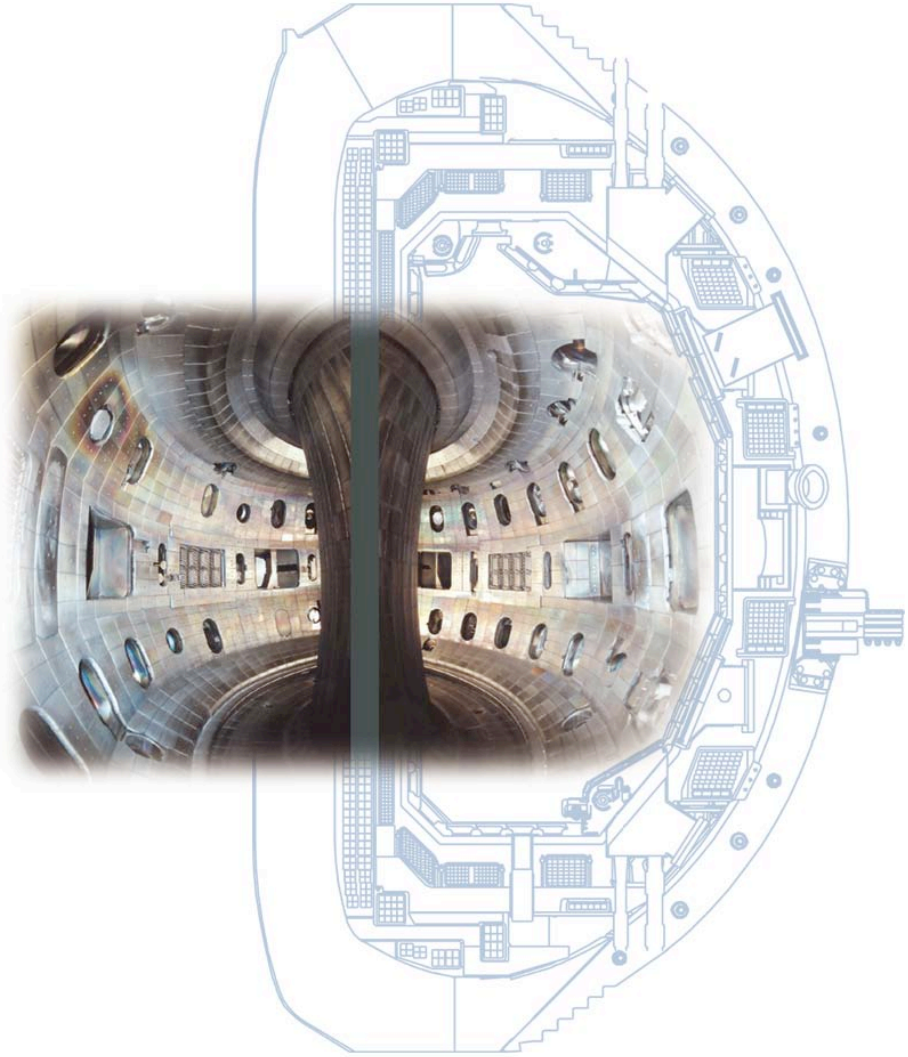
System Upgrades to the DIII-D Facility

A.G. Kellman for the DIII-D Team



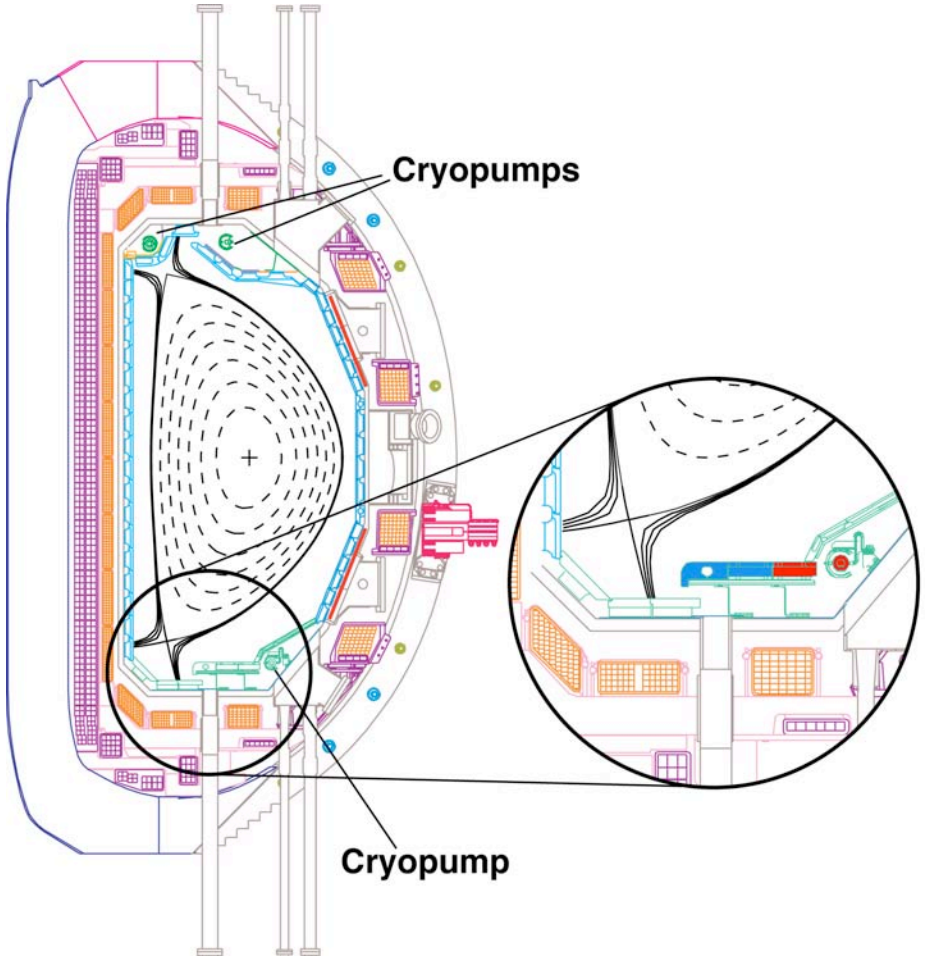
24th Symposium on Fusion Technology
Warsaw, Poland

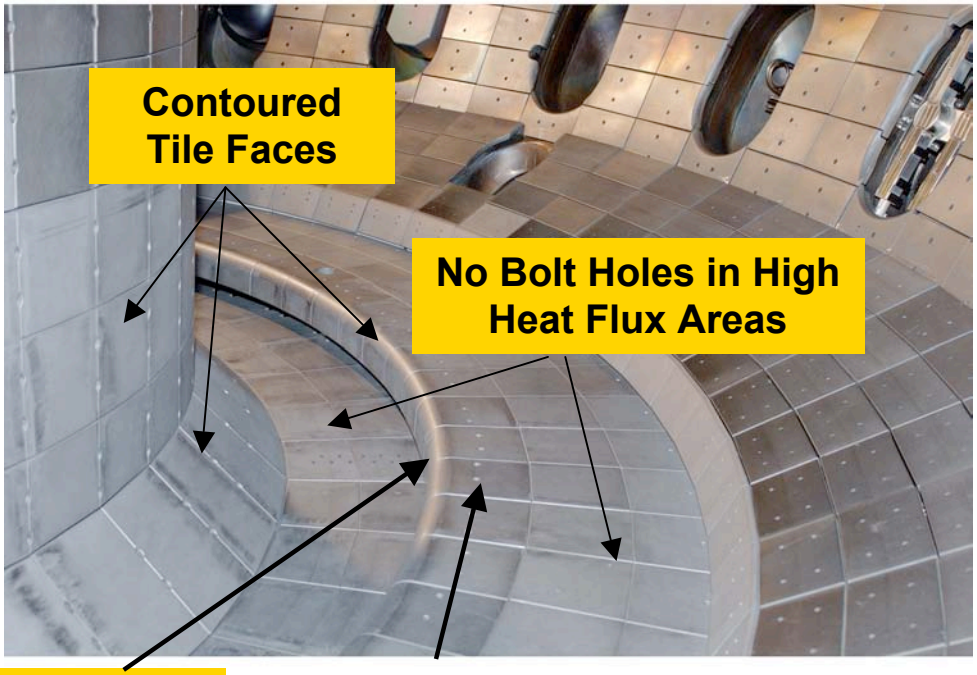
September 11-15, 2006

Upgrades Performed During the Long Torus Opening (LTOA) Significantly Enhance The DIII-D Facility Capability

- Lower Divertor Modification
- Rotation of neutral beam line from co- to counter injection
- Upgraded Resistive Wall Mode Stabilization system
- Upgraded Electron Cyclotron System
- Reduced error field of Toroidal Field feedpoint
- Improved cooling of TF return bus for longer pulse operation
- Expanded Diagnostic Set
- New cooling towers, transformers for 10 sec full power operation

New Lower Divertor with Extended Shelf Has Been Installed for Pumping High Triangularity Double Null Discharges

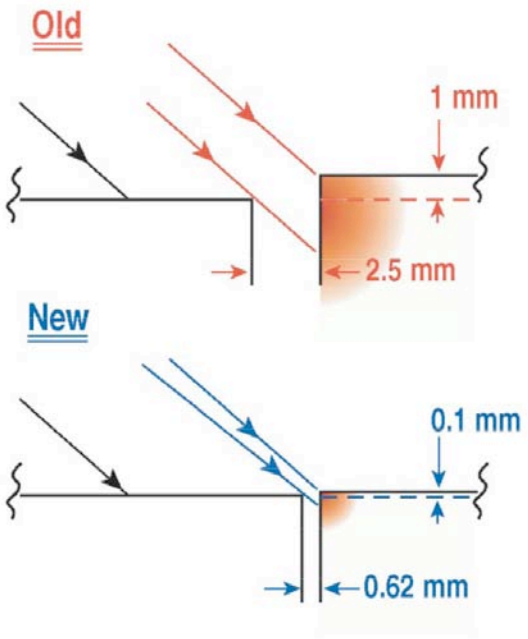




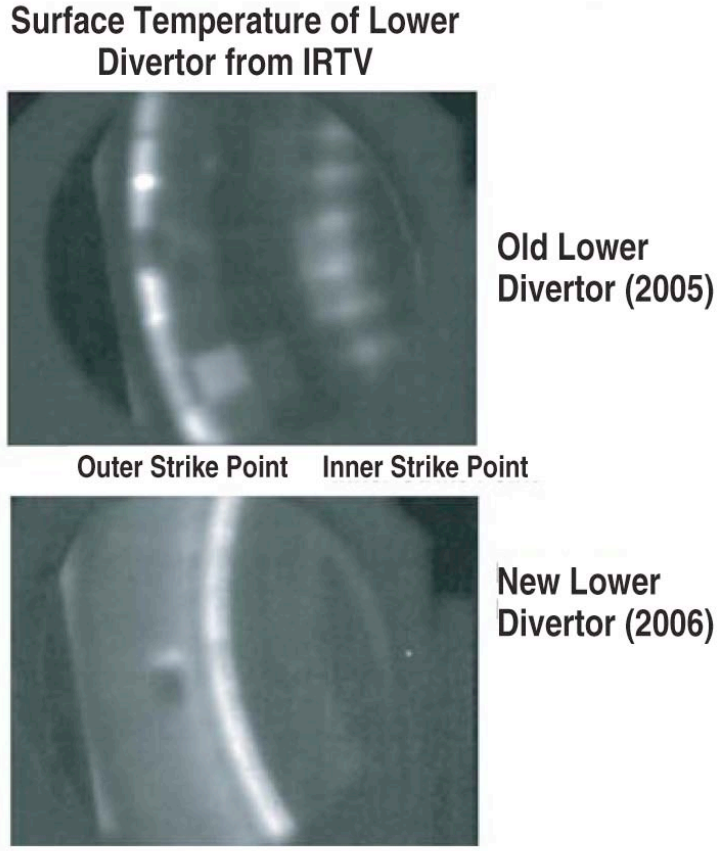
- **DESIGN FEATURES: 316 SS, water cooled, low gas leakage to main chamber, no bolt holes in high heat flux areas, contoured tiles**

Tile Design of New Lower Divertor Improves Toroidal Symmetry and Reduces Material Erosion

- **New design features**
  - Reduced gaps between tiles
  - Improved alignment of tiles
  - Elimination of bolt holes in high heat flux area

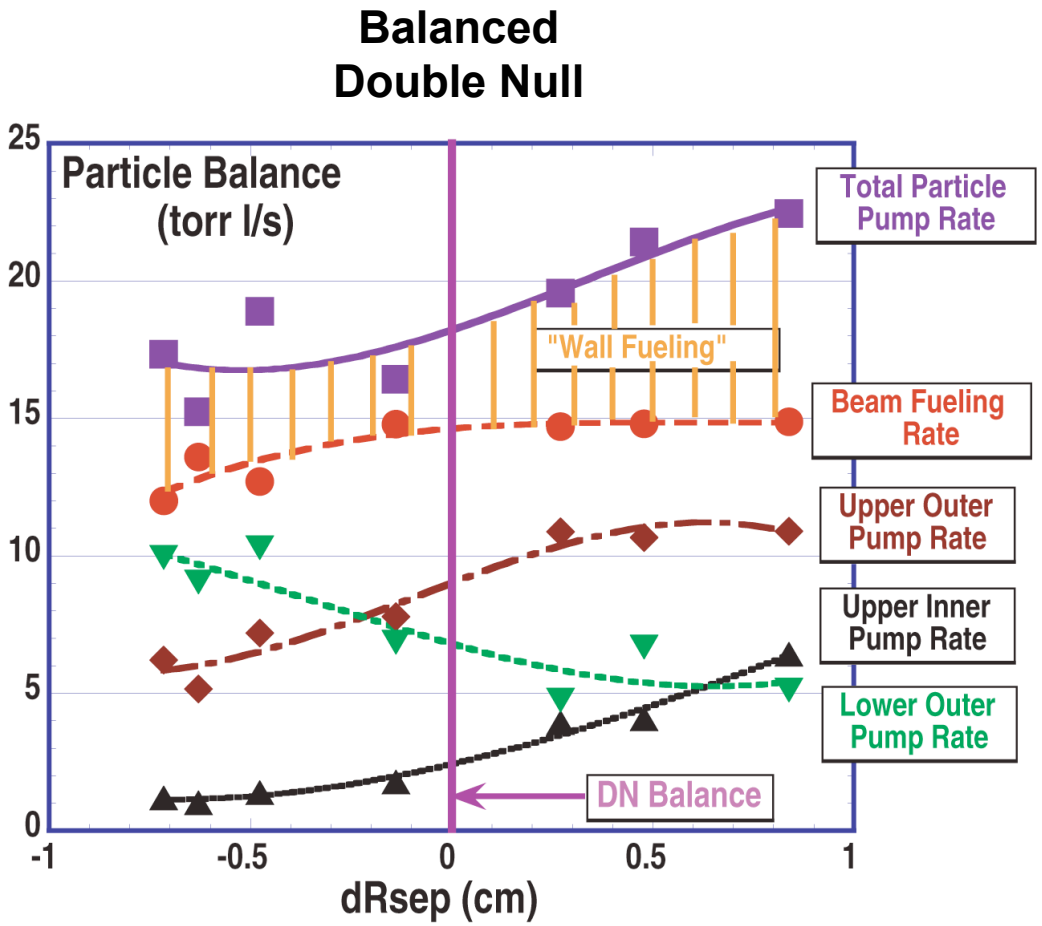


- **Clear reduction in toroidal asymmetries in tile heating**



New Lower Divertor Has Improved Density Control in Double Null, Advanced Tokamak Plasmas

- Measured pumping speed of lower pump is S~35,000 l/s
- Effective pumping speed is reduced ~50% by the restrictive conductance under the shelf S~18,000 l/s
- In high triangularity balanced double nulls, the lower pump provides 50% additional pumping over the upper two pumps.



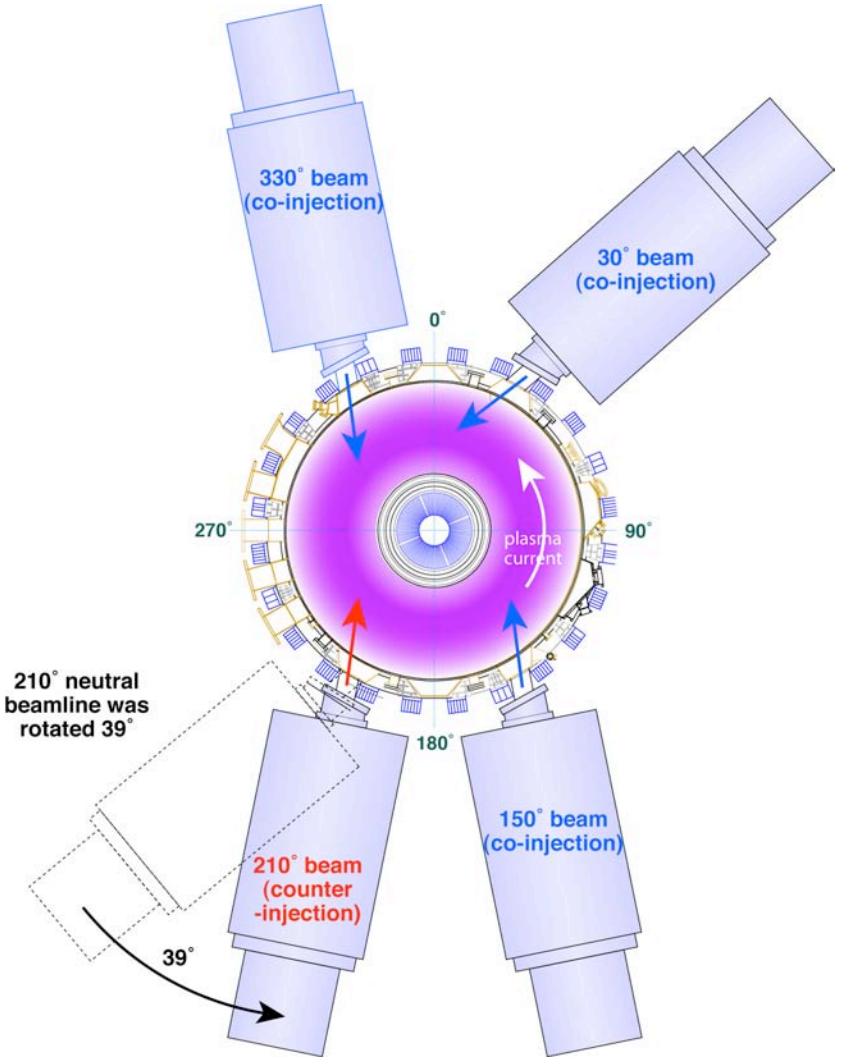
Rotation of Neutral Beam Enables Both Co and Counter Injection and Provides Significant New Research Capability

ENABLES

- Physics at low rotation, more ITER relevant
- Physics of Rotation, NBCD
- RWM stability at low rotation
- NTM stabilization with modulated ECCD
- Transport barrier control
- Fast ion distribution control

DIAGNOSTICS

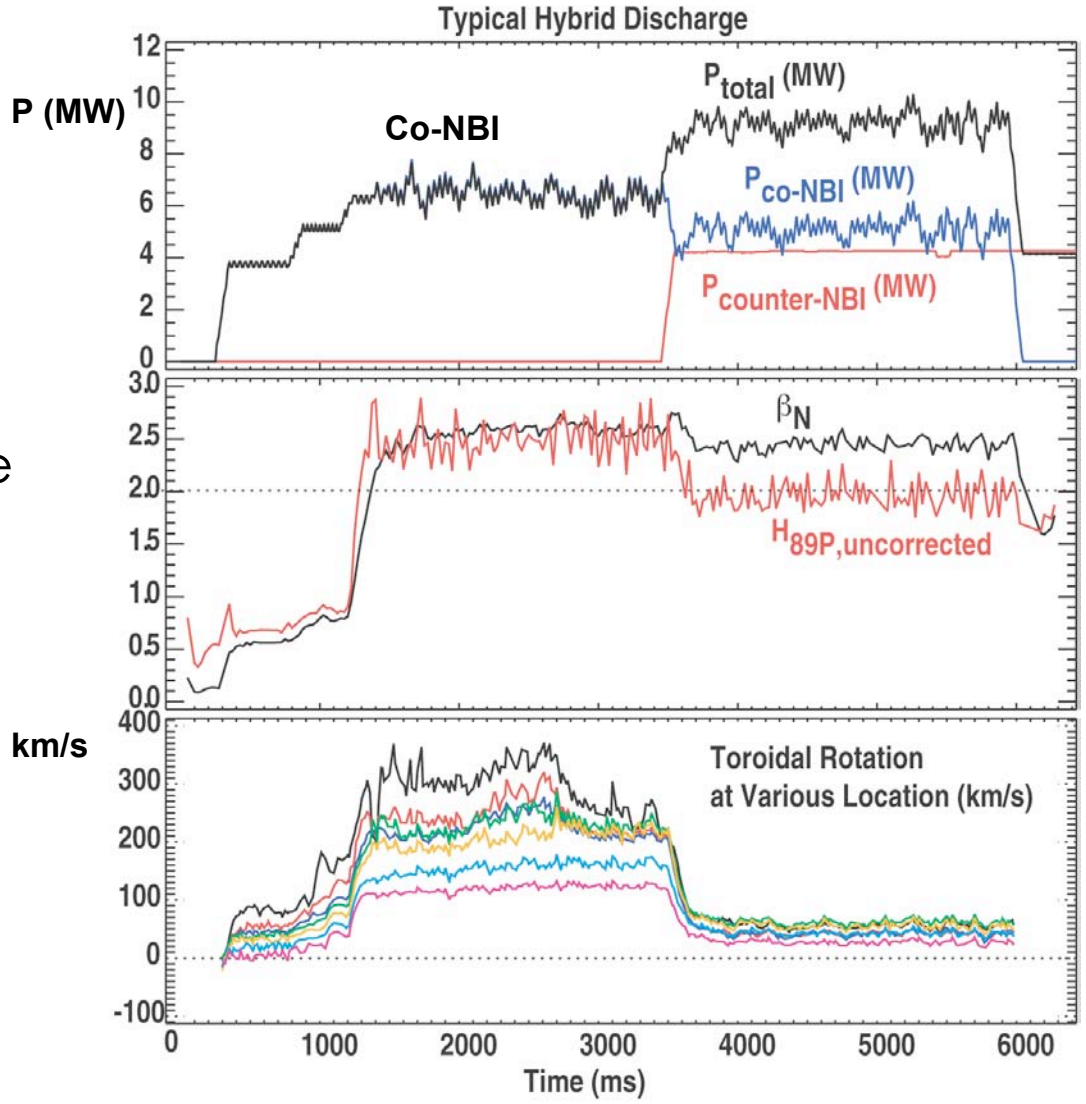
- Co plus counter viewing MSE, J(ρ) and Er with high resolution
- Co plus counter CER, improved poloidal and toroidal rotation



Many Experiments Have Utilized 4 MW of Counter NBI for Physics Studies

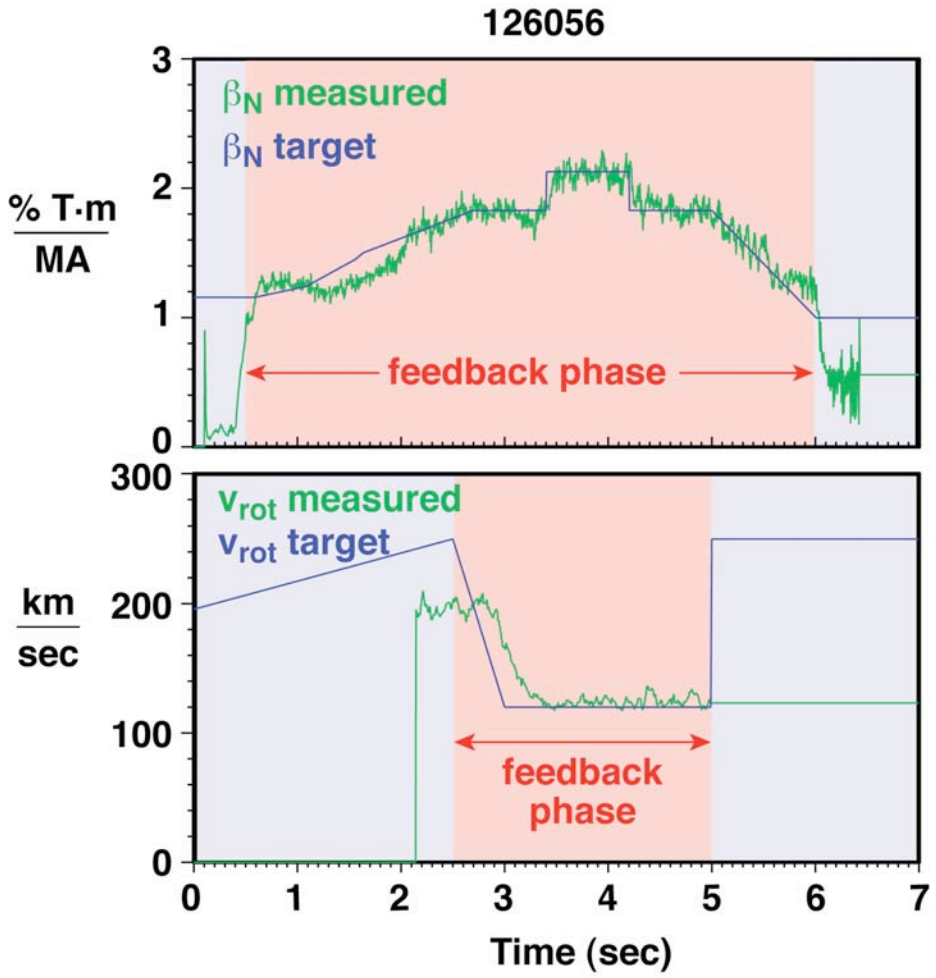
Example:

- **Applying 4 MW counter NBI in otherwise constant conditions results in:**
  - Sustained toroidal rotation near zero across entire profile
  - Modest reduction in plasma confinement



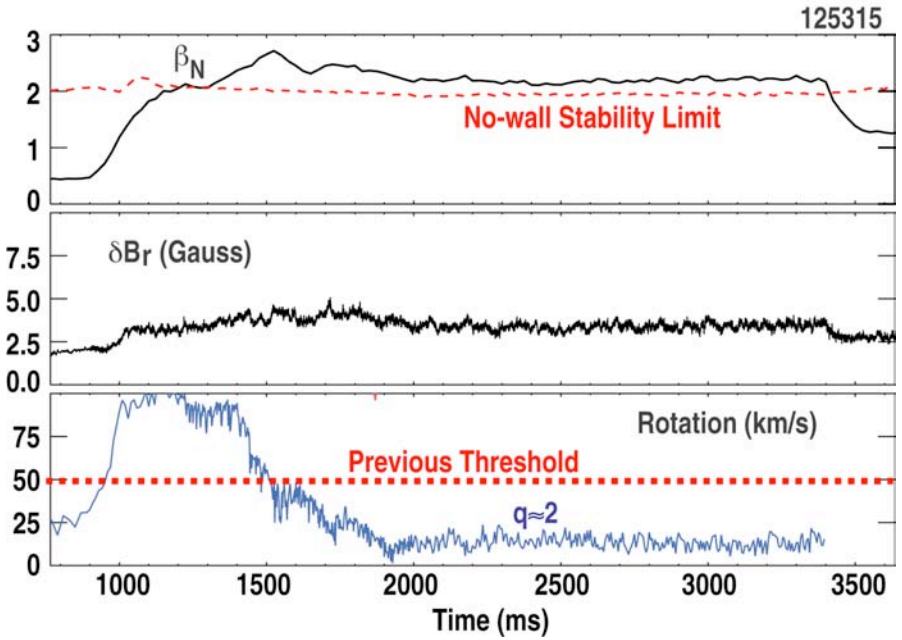
Simultaneous Feedback Control of Stored Energy and Rotation Velocity Have Been Achieved

- Feedback system adjusts mix of co and counter beams to provide required power and torque input.
- PID algorithm adjusts duty cycle of modulated neutral beams to enable smooth variation of energy and rotation

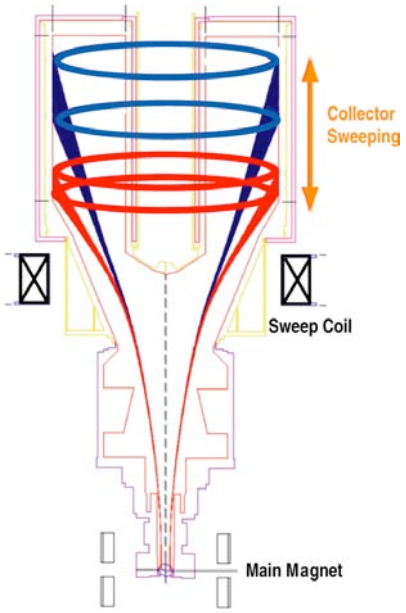


Co/Counter Injection Has Enabled ITER Relevant (low rotation) RWM Stabilization Research

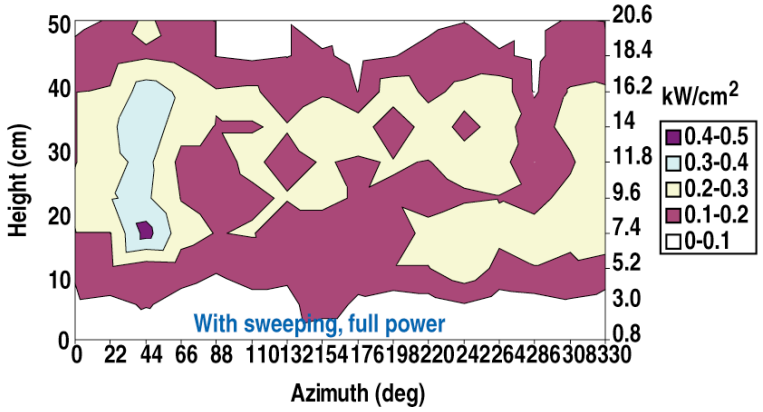
- **NB rotation control has shown that threshold for RWM stabilization is at lower rotation than previous observations.**
- **β_n sustained above no-wall stability limit at very low rotation.**
- **RWM Feedback System Upgrades have further enhanced research**
  - High bandwidth amplifier system enlarged from 6 to 12 (10 kW each). 24 amplifiers in Fall '06.
  - Feedback delay time reduced to 50 μs. CPU cycle time reduced from 50 to 11 μs.



Upgraded EC System Will Provide Additional Power and Pulse Length for Enhanced Off-Axis Current Control



- Narrow beam sweeping in collector led to excessive heat loads and vacuum leaks in 2 earlier gyrotrons

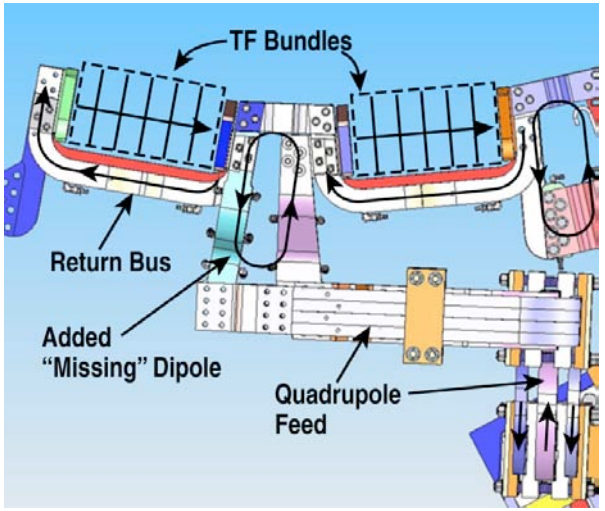


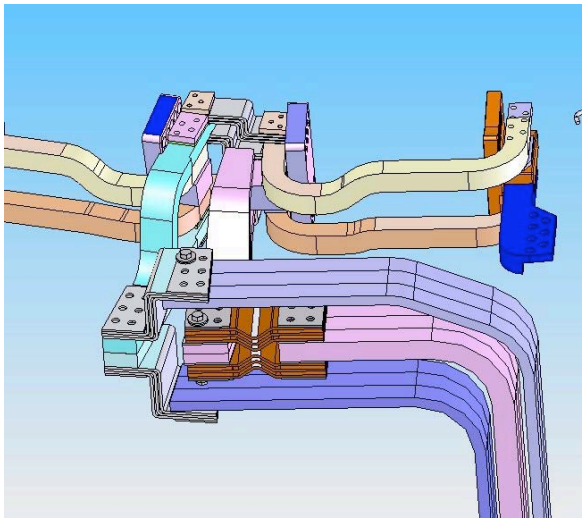
- Upgrade adds 3 new long pulse gyrotrons (6 MW total)
- First replacement gyrotron fully operational (1 MW, l0 s)
- Developmental "Depressed collector" 1.2 MW gyrotron installed and ready for testing

- Broader sweeping at a higher frequency (5 Hz) reduced loads by 40% and increased expected lifetime to 50,000, 5 s pulses

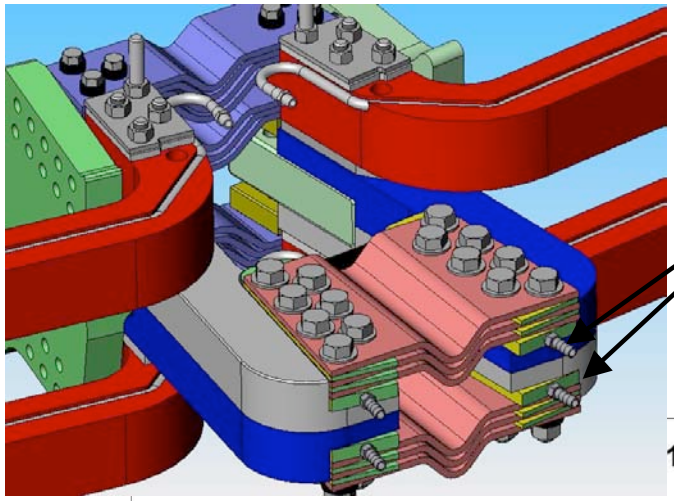
New Toroidal Field Feedpoint Significantly Reduced Magnetic Error Fields

- **TF Feedpoint was rebuilt to avoid rotated beamline port.**
- **New connections reduce error fields associated with old TF feedpoint by a factor of 10.**
  - Feed conductors changed from dipole to quadrupole
  - "Missing dipole" field added back in this new design.
- **Reduced field error has had a significant favorable impact on DIII-D experiments**
  - Expanded DIII-D operating space to lower density w/o locked modes
  - Reduced external torque aids in formation of low rotation plasmas

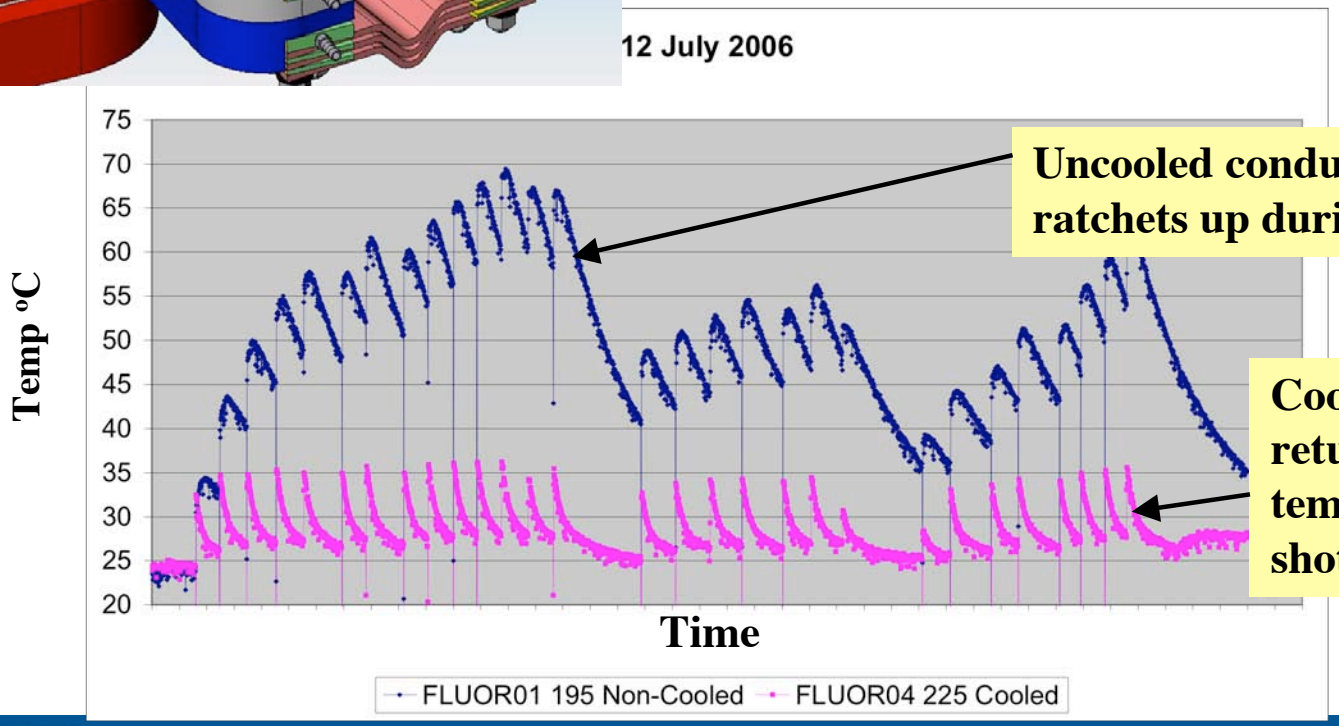




Addition of cooling plates to TF bus will double the long pulse capability of TF system



- Water Cooled copper plates were added to TF bundle-to-bundle connections (55% complete)



Significant New Measurement Capability Will Be Available Following the LTOA

New Capability

- *MSE ($j(\rho)$) counter viewing
- CER (T_i,ω) counter viewing
- BES (δn) double high-sensitivity channels
- *SXR poloidal array
- MDS, under shelf spectral views
- MIMES (midplane)

ITER Relevant Diagnostics

- B-Stark - $|B|$ and B_θ/B_T
- Quartz microbalance
- Fast ion diagnostics
- Mirror testing

*will be completed in Oct. '06

Improved Capability

- FIR Scattering
- ECE Radiometer
- Langmuir Probes-floor
- Recycling camera
- Filterscope views
- Fast framing camera
- Divertor Thomson scattering
- Reflectometer
- Interferometer

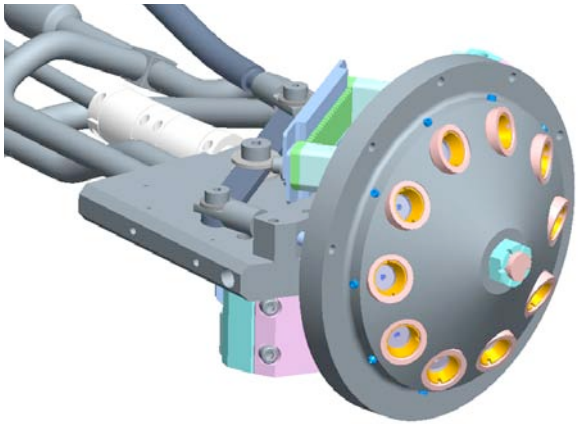
Significant New Diagnostic Capabilities Have Been Added

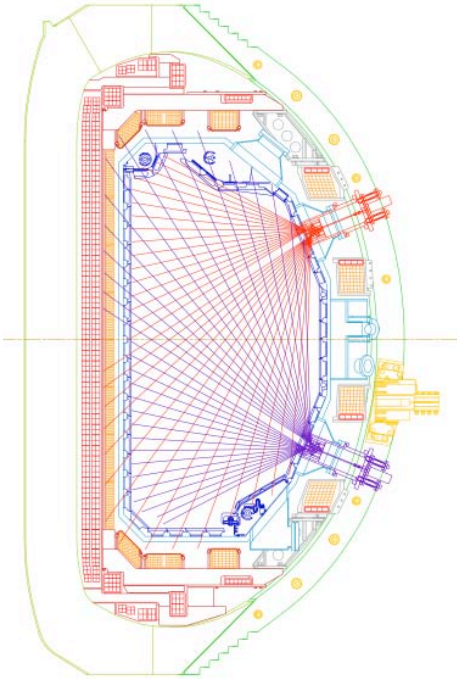
New Capability

- *MSE (j(ρ)) counter viewing
- CER (T_i,ω) counter viewing
- BES, (δn) double high-sensitivity channels
- ***SXR poloidal array**
- MDS, under shelf spectral views
- MIMES (midplane)

ITER Relevant Diagnostics

- B-Stark - |B| and B_θ/B_T
- Quartz Microbalance
- Fast ion diagnostics
- Mirror testing





- **Redesigned Poloidal arrays with flexible filter wheel will bring new capabilities for stability studies, including disruption characterization**

Additional Facility Upgrades will Expand Capabilities of DIII-D

138kV to 12.47kV Transformer for Auxiliary Heating

12.47kV to 4160V Transformer for MG#2 Motor

Two new cooling towers can handle expected heat loads for long pulse with auxiliary heating

FWCD antenna fitted with double-layer Faraday shield to investigate antenna rf voltage standoff during ELMs

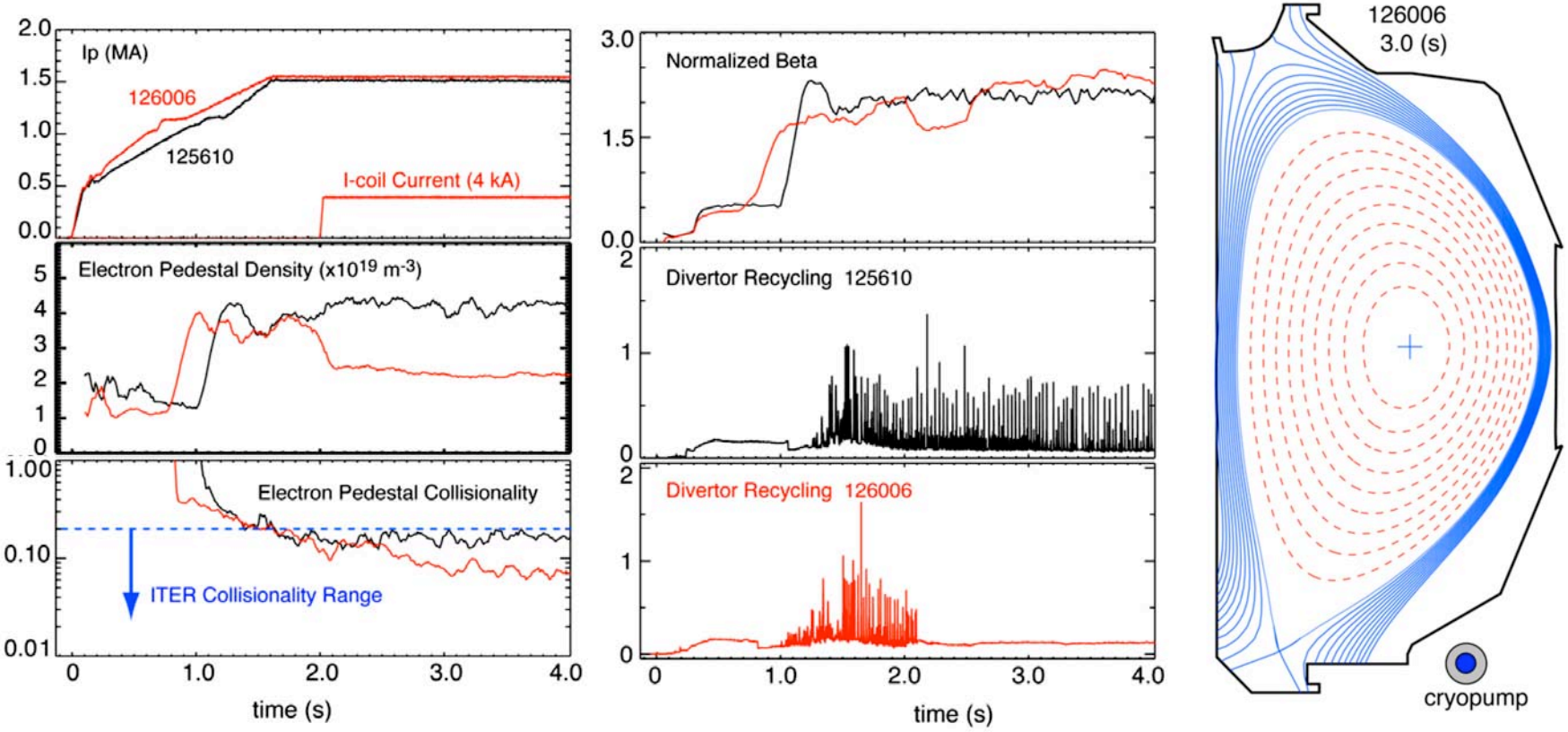
Major Upgrades Installed During the LTOA Significantly Enhance DIII-D Capabilities

- Many significant upgrades were completed during the recent LTOA: New lower divertor, counter injection neutral beam, new diagnostic systems, upgraded RWM feedback system, new long pulse gyrotron, cooling towers.

- New systems enhance the ability of DIII-D to address issues critical to ITER, to pursue Advanced Tokamak studies, and to advance basic fusion research.

- These systems are now operational and have been used successfully in the recent 12 week campaign.

ELM Suppression Using n=3 RMPs in the ITER Shape and Collisionality Enabled by New Lower Divertor



- **However, ELM control lost when rotation reduced by counter injection**

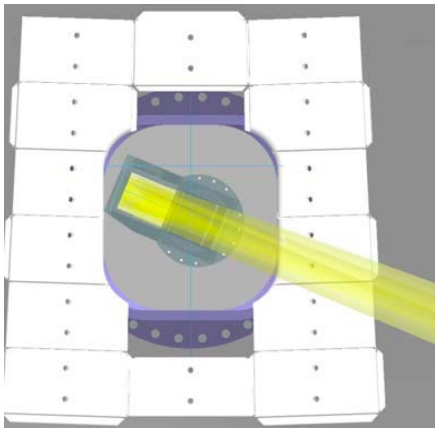
Significant New Measurement Capability Will Be Available Following the LTOA

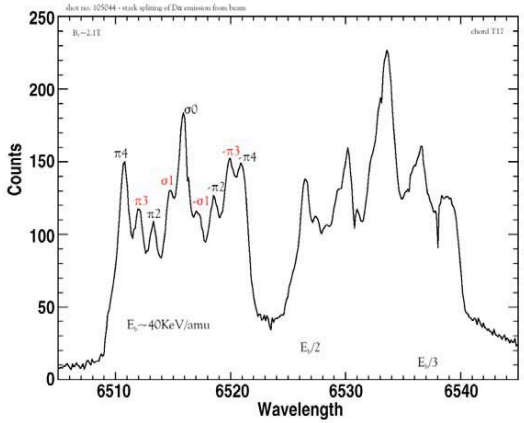
New Capability

- *MSE, counter viewing
- CER, counter viewing
- BES, double high-sensitivity channels
- *SXR poloidal array
- MDS, under shelf spectral views
- MIMES (midplane)

ITER Relevant Diagnostics

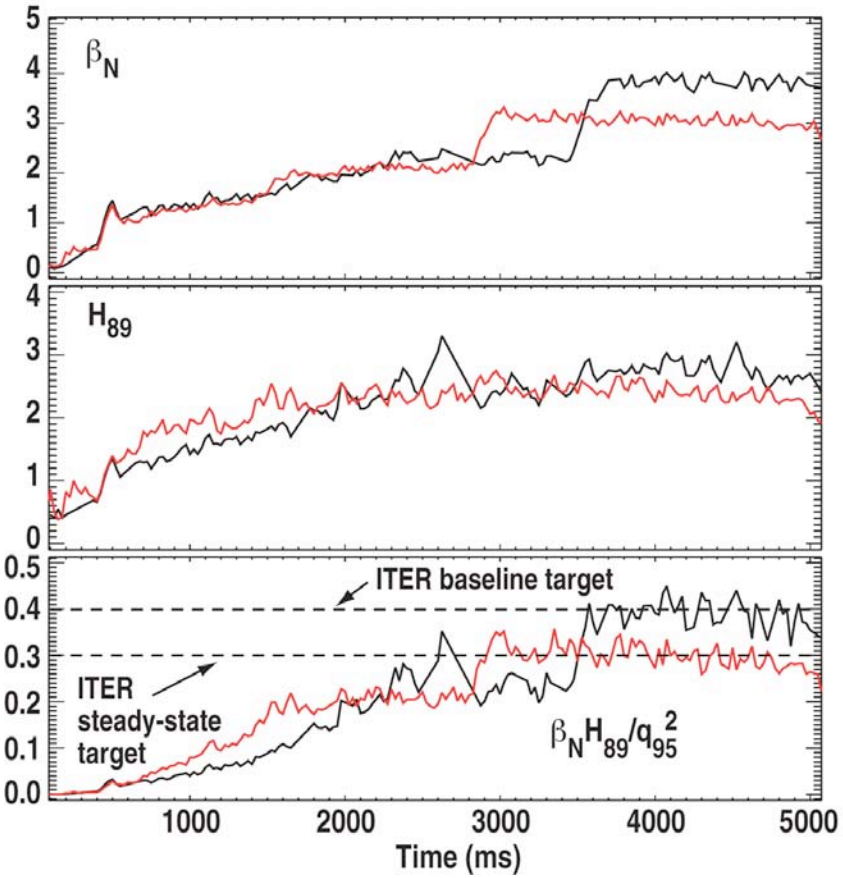
- **B-STARX - |B| and B_θ/B_T**
- Quartz microbalance
- Fast ion diagnostics mirror testing
- Complete installation in October

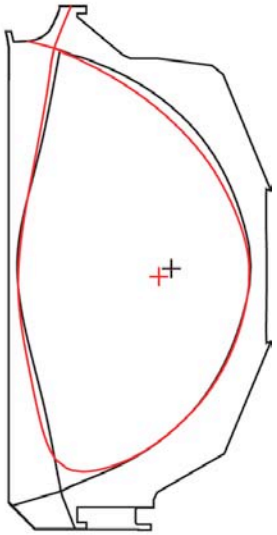




- **Stark Splitting of Dα provides B and Bθ/BT**
- **Potentially easier to implement on ITER**

Pumped Double Null Allows Significantly Higher Sustained Performance than Pumped Single Null

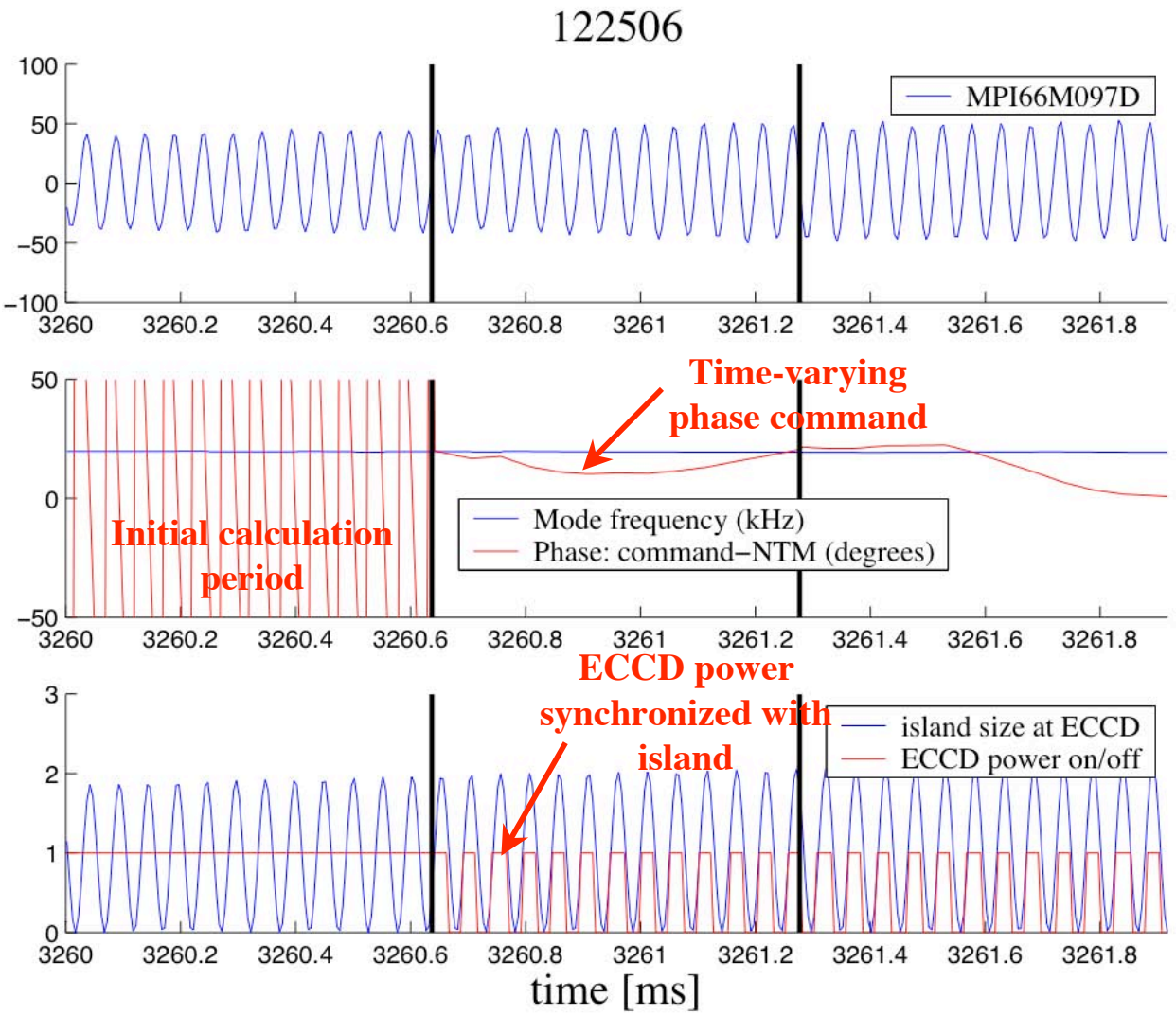




- Sustained higher β operation is demostrated
- Higher confinement quality is obtained at higher β
- Both shapes yield fusion fusion gain parameters at or above the ITER steady-state target
- Density control from new divertor enables better ECCD efficiency

NTM Control System Upgraded to Enable Gyrotron Modulation

- Detection algorithm extracts mode frequency and phase from Fourier analysis of midplane prove array
- After initial calculation period, algorithm identifies ~constant frequency, time-varying phase
- Command to dedicated cpu produces modulation signal for gyrotrons phase locked to island at ECCD location



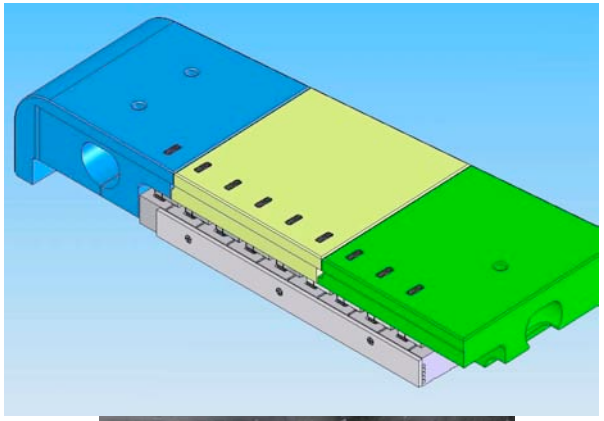
Significant New Measurement Capability Will Be Available Following the LTOA

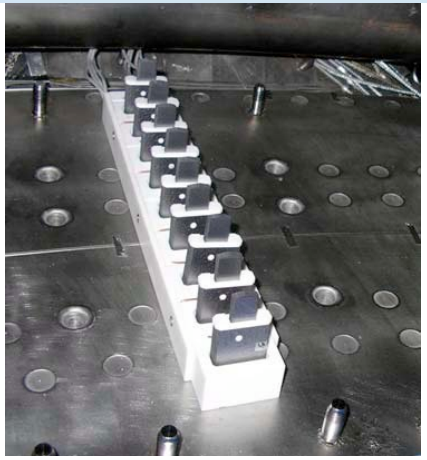
New Capability

- *MSE, counter viewing
- CER, counter viewing
- BES, double high-sensitivity channels
- *SXR poloidal array
- MDS, under shelf spectral views
- MIMES (midplane)

ITER Relevant Diagnostics

- B-Stark - $|B|$ and B_θ/B_T
- Quartz microbalance
- Fast ion diagnostics
- Mirror testing





- **20 New shelf and Floor Langmuir probes**
- **Modular design for easy installation**

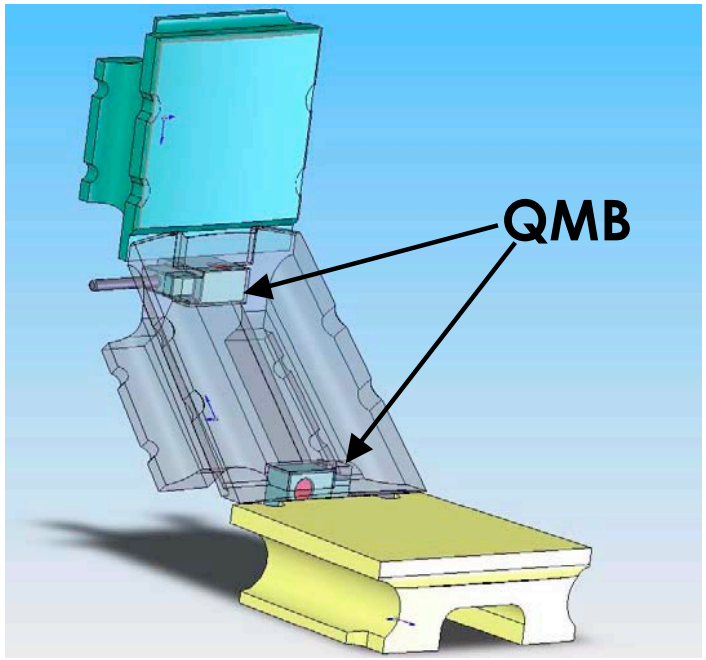
Significant New Measurement Capability Will Be Available Following the LTOA

New Capability

- *MSE, counter viewing
- CER, counter viewing
- BES, double high-sensitivity channels
- *SXR poloidal array
- MDS, under shelf spectral views
- MIMES (midplane)

ITER Relevant Diagnostics

- B-Stark - $|B|$ and B_θ/B_T
- **Quartz Microbalance**
- Fast ion diagnostics
- Mirror testing



- **Quartz Microbalance measures material deposition (e.g. Carbon) in real time**
- **2 locations installed near lower inner corner tile**