Upgrades Completed at the DIII-D Facility During the Long Torus Opening in FY05-06

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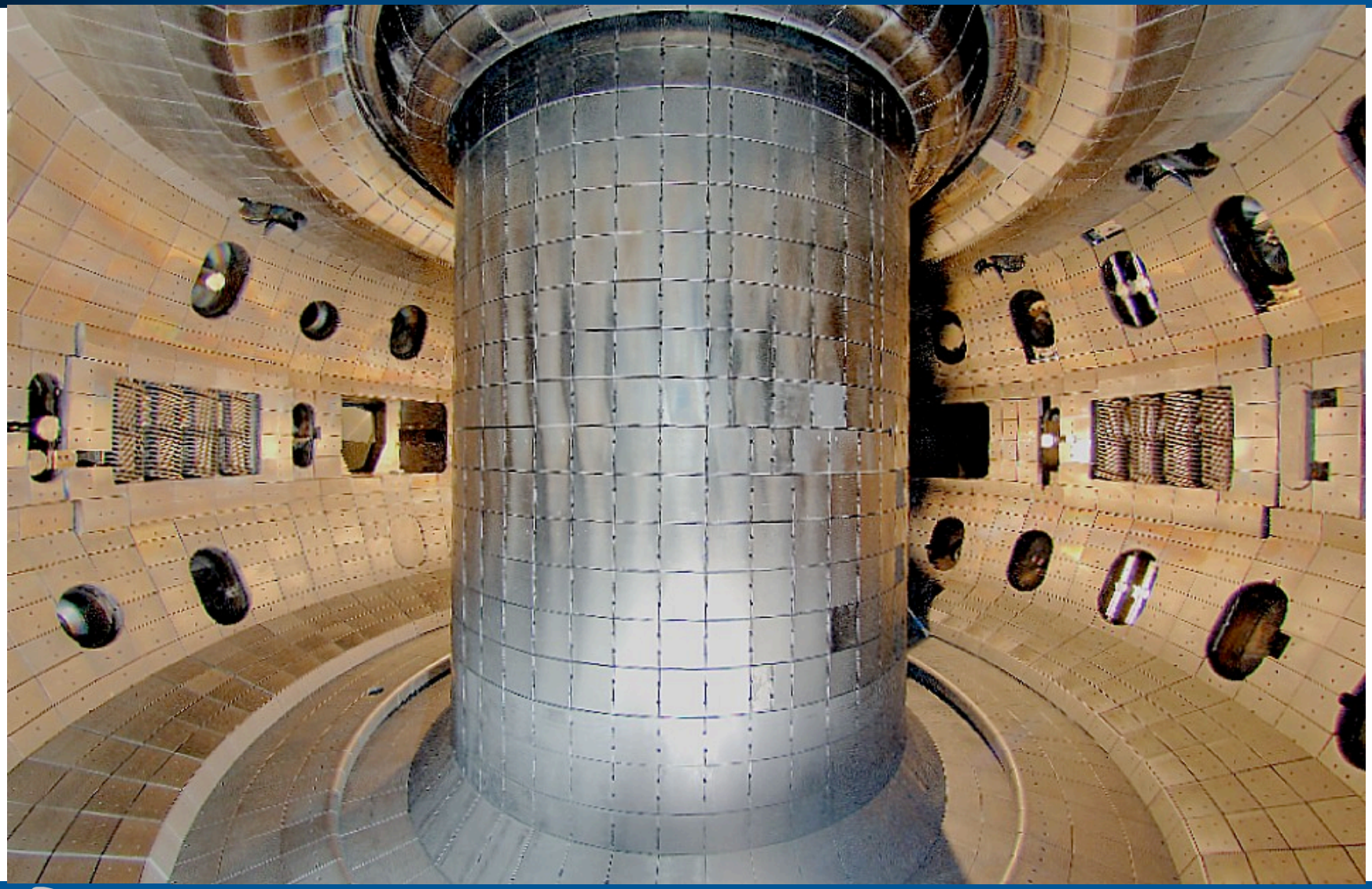
DIII-D NATIONAL FUSION FACILITY

GENERAL ATOMICS

Long Torus Opening Activities ended March 29, 2006



Long Torus Opening Period Minimized Impact on Physics Operation

- **Completed 15.6 weeks (14 weeks scheduled) of operation during the physics campaign of FY05**
- **Extensive work performed both inside and outside the vessel during the long torus opening period of 4/19/05 – 3/29/06**
- **Activities accomplished during torus opening**
  - Proceeded with upgrading the Electron Cyclotron System toward six long-pulse gyrotrons
  - Installed new lower divertor
  - Rotated one of four beamlines for counter injection
  - Upgraded diagnostics
  - Upgraded one Fast Wave system
  - Upgraded DIII-D water cooling system
  - Proceeded with upgrades in coil cooling and in AC power towards ten-second operation
- **Physics operation resumed on June 7th and 12.7 weeks of operation completed during second half of FY06**

Increases in EC System Power and Pulse-Length Enable New Physics Capability

- **Physics enabled**
  - Control current profile
  - Sustain high performance plasmas
  - Stabilize or avoid tearing mode
  - Perform transport barrier studies
  - Perform modulated transport and critical gradient studies
  - Perform electron heating

- **Prior to LTOA EC System supported physics campaigns with**
  - Three 1 MW, 10 second gyrotrons from CPI
  - Three 0.75 MW, 2 second Russian gyrotrons

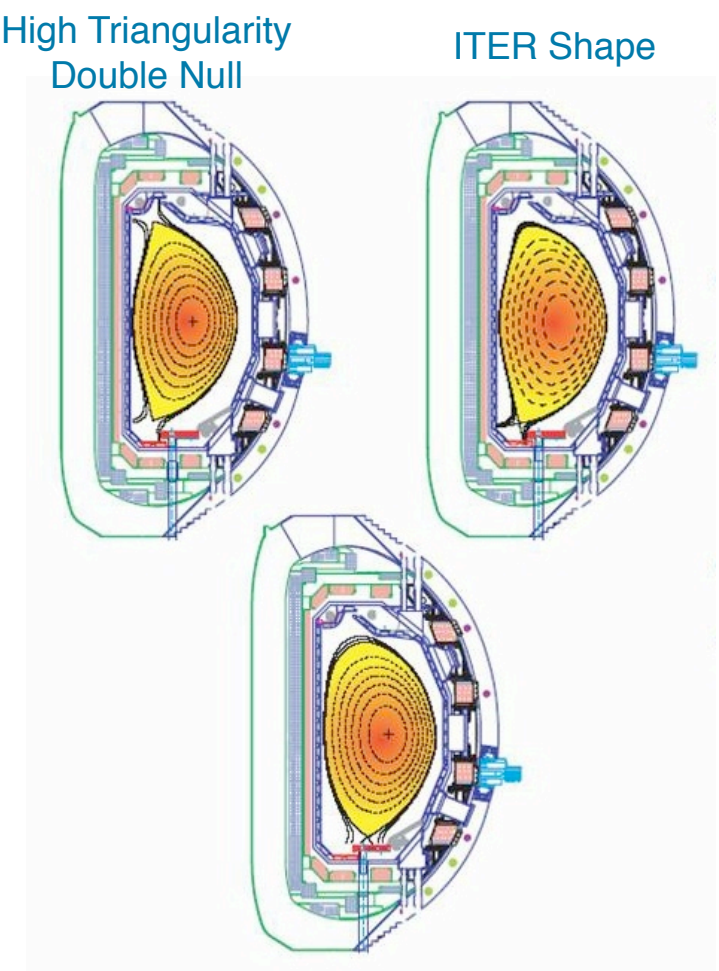
- **During LTOA**
  - Refurbished two Russian gyrotron "sockets" for CPI gyrotrons
  - Built new CPI gyrotron "socket"
  - Developmental depressed collector gyrotron installed in new "socket"
  - First CPI replacement gyrotron installed in refurbished "socket" and conditioned
  - Second & third gyrotrons arrived late

- **EC resuming support of physics with**
  - Two gyrotrons in FY06
  - Up to six 1 MW, 10 second gyrotrons from CPI in FY07
  - Plus developmental 1.2 MW depressed collector gyrotron if conditions up in power satisfactorily

First Replacement Gyrotron Supported Physics in FY06

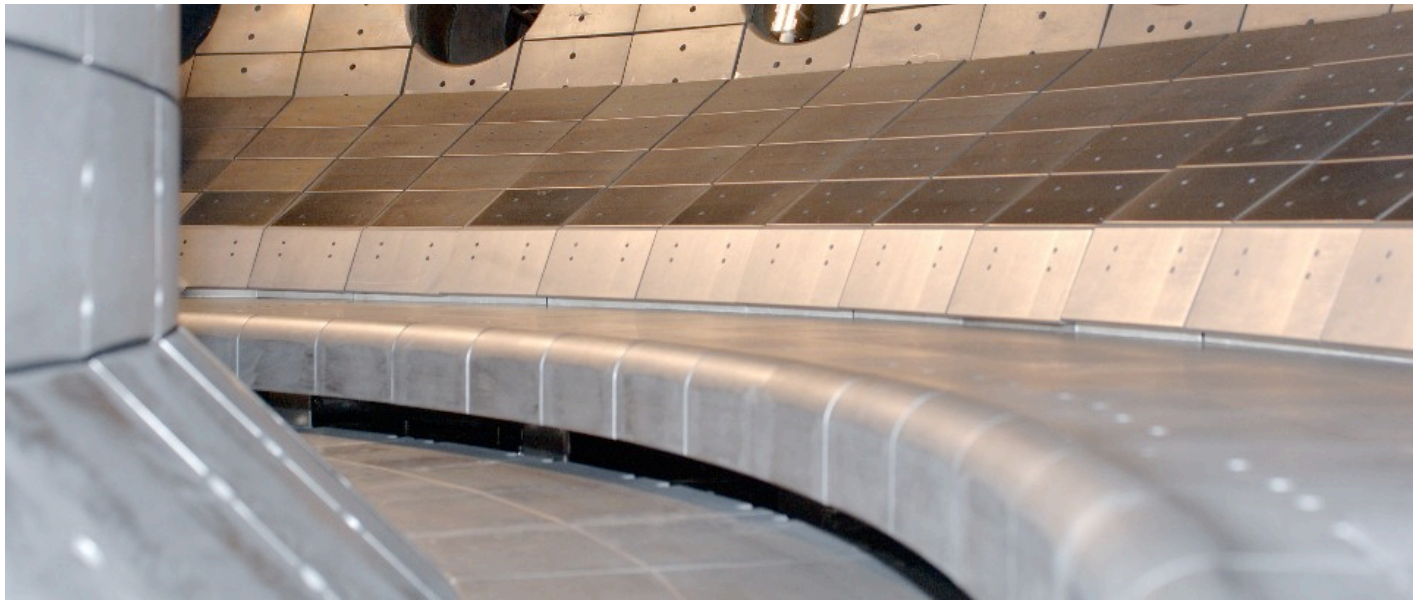
New Lower Divertor Provides New Capability and Maintains Shape Flexibility

- **Motivation**
  - Density control in high triangularity, high performance
    - Single-Null and Double-Null Advanced Tokamak plasmas
    - QH-mode plasmas
  - Comparison of long duration Single-Null and Double-Null plasmas
  - Pedestal physics with range of collisionalities
  - Mass transport physics
  - Optical access to inner divertor leg
  - Detachment control via pumping



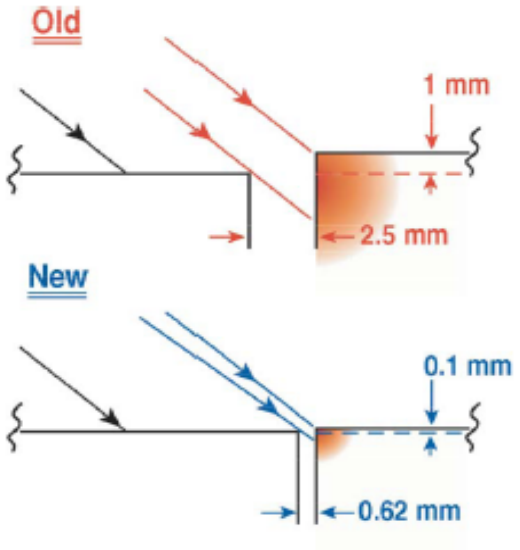
New Lower Diverter Installed and Supporting Plasma Operations

- Divertor cooling plate manufactured by ASIPP in China
- Divertor plate installed November 23, 2005
- 579 new tiles fabricated, cleaned, and installed
- Tiles leveled to within 4 mils
- Installation completed on March 27, 2006
- Plasma facing tiles conditioned during plasma start-up that began May 16, 2006
- Routinely running various high performance plasma configurations



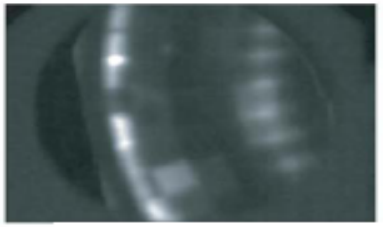
Tile Design of New Lower Diverter Improves Toroidal Symmetry and Reduces Material Erosion

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



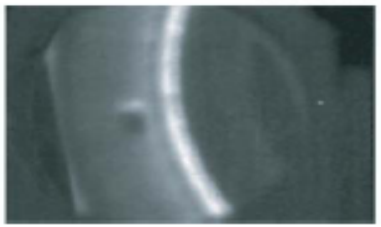
- **Clear reduction in toroidal asymmetries in tile heating**

Surface Temperature of Lower Divertor from IRTV



Old Lower Divertor (2005)

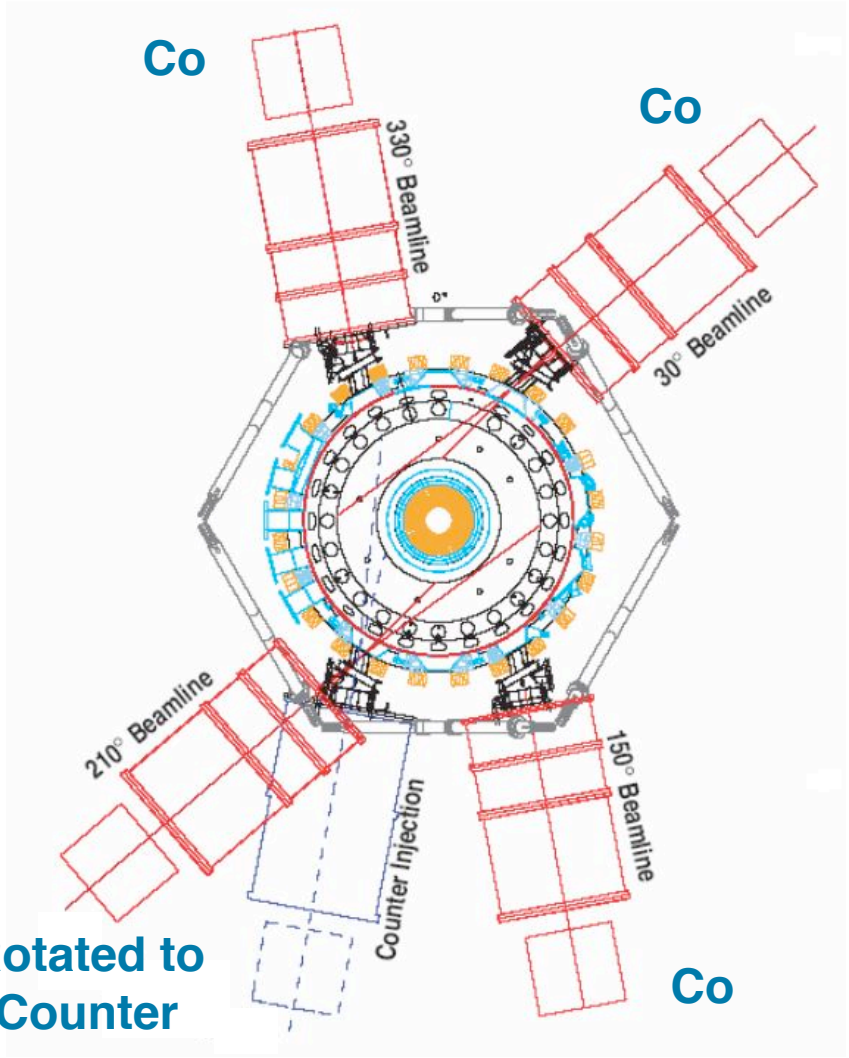
Outer Strike Point Inner Strike Point



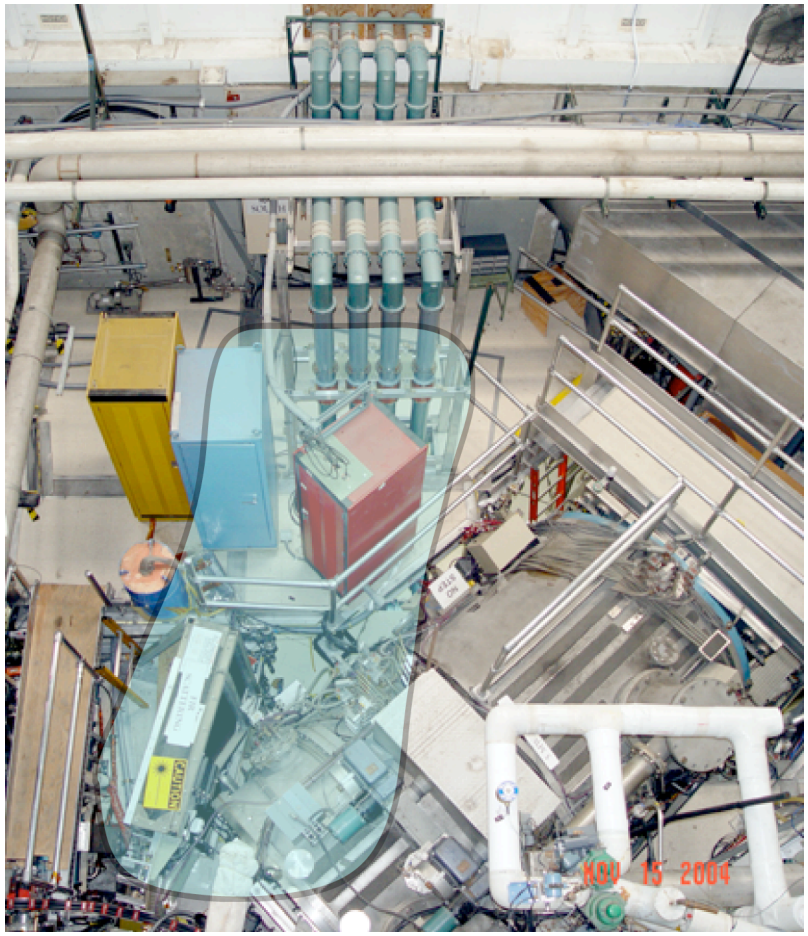
New Lower Divertor (2006)

Rotation of 210 Beamline

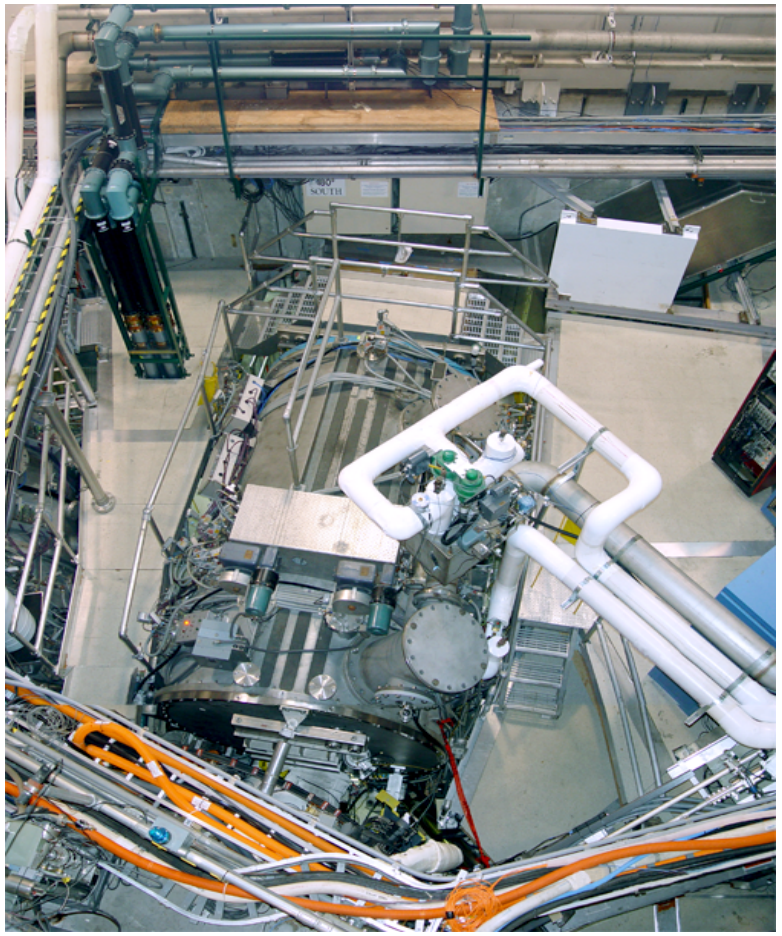
- **Opens new areas for physics**
  - QH-mode ELM-free regime with central co-rotation
  - Understanding physics of rotation
  - Resistive Wall Mode stability with low rotation
  - Transport barrier control
  - Fast ion physics
  - Understanding the physics of neutral beam current drive
- **Improved plasma measurements**
  - MSE measurement viewing counter beam allows separation of Er and J
  - Co and counter Charge Exchange Recombination



210 Beamline Rotated from Co-Injection to Counter-Injection



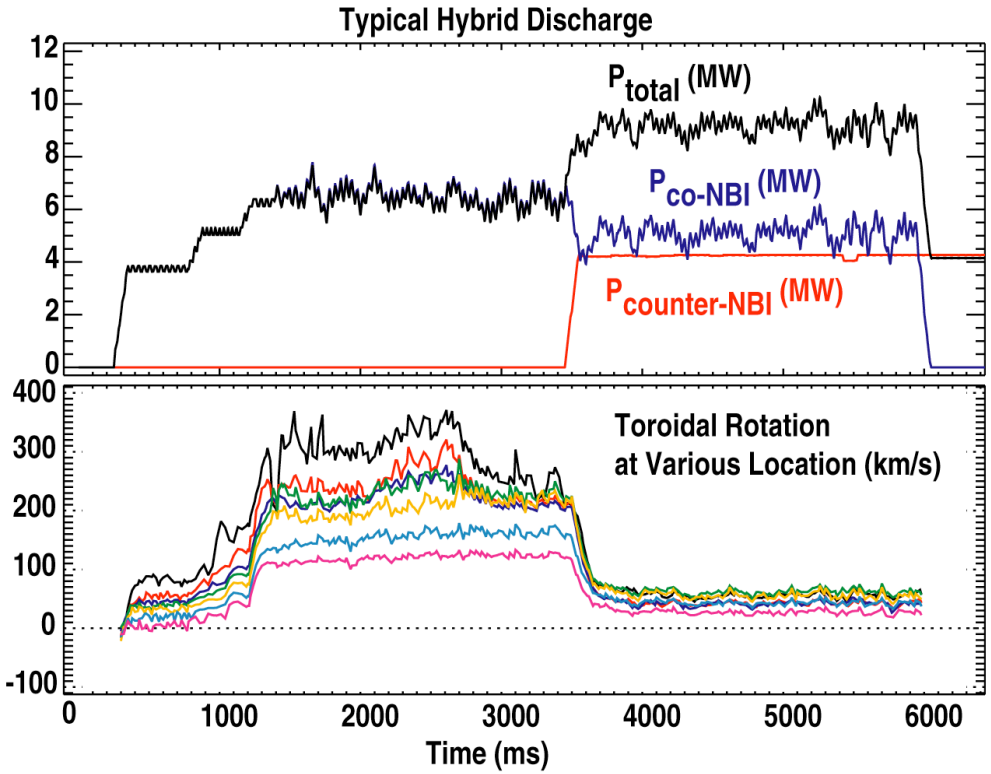
Co-Injection Orientation
prior to LTOA



Counter-Injection Orientation
after LTOA

Modification of Rotation Demonstrated using New Counter Neutral Beam Injection Capability

Plasma goes from rapid co-rotation to near zero rotation with introduction of counter beams



Other Activities Performed During Long Torus Opening (Partial List)

- **Fast Wave**
  - Refurbish 285/300 antenna
  - Converted ABB #1 transmitter to EIMAC tube (1MW → 2MW)
- **Restive Wall Mode**
  - Installed six additional high bandwidth amplifiers for I-coils (6 →12)
- **ECH**
  - Installed long-pulse launcher with fast steering
- **Pellet Injector for ELM pacemaking**
- **Plasma Control System**
  - Control algorithm improvements
  - Hardware upgrades
- **Maintenance**
  - Motor generator bearing inspection and balancing
  - General maintenance

High Bandwidth Amplifiers Energize I-coils during Resistive Wall Mode Experiments

- **12 amplifiers installed and tested**
  - Capable of further expansion to 24 amplifiers
- **New audio amplifier patch panel was installed**
- **System returned to operation in June 2006**

Increased Capability of DIII-D Water Cooling System

- Installed two higher capacity, higher efficiency cooling towers for increased future heat loads
- Upgraded heat-exchanger and pumps in ECH cooling loop to improve heat rejection

Cooling towers installed

Upgraded ECH HX and Pumps

Progress in Upgrades Towards 10-Second Operation

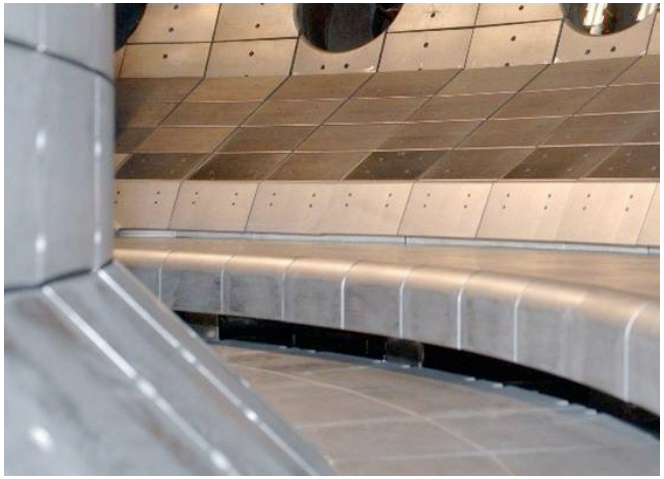
- **Improved cooling of toroidal coil return bus**
  - Added water-cooled plates to bus in 24 of 48 locations
  - Installed in locations prior to reinstallation of other equipment
  - Addressed other locations with difficult access
- **Increasing AC power for auxiliary heating systems**
  - Existing transformer rated at 84 MVA for one second
    - Sized in 1979 for eight ½ second neutral beams
  - New transformer coming from China rated at 110 MVA for 10 seconds enables simultaneous operation of
    - Eight neutral beams for 5 seconds
    - Six 1 MW and two 1.5 MW gyrotrons for 10 seconds
    - Three 2 MW fast wave systems for 10 seconds
  - Transformer to be installed at earliest opportunity

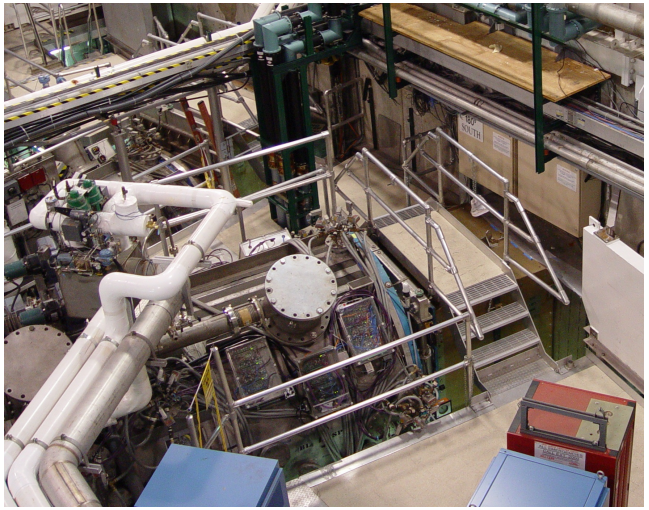
DIII-D Returned to Physics Operation in 2006

- **Completed installation of lower divertor on March 27, 2006**
- **Counter beamline**
  - Completed installation of beamline on January 9, 2006
  - Completed installation of support systems on March 30, 2006
- **Performed diagnostic calibrations**
- **Closed DIII-D vessel on March 29, 2006**
- **Completed system check-out and plasma start-up**
- **Resumed plasma physics operation on June 7, 2006**
- **Completed 12.7 weeks of physics operation in FY06**
  - Results highlighted in presentations made earlier this year at
    - 21st IAEA Fusion Energy Conference
    - 48th Annual Meeting of the APS Division of Plasma Physics

Conclusion

- Completed upgrades to DIII-D during LTOA and successfully resumed physics operation
- Completed a 12.7-week physics campaign in FY06 during which many exciting new results were obtained by exploiting the new capabilities of DIII-D
- Upgraded DIII-D well positioned to continue advanced tokamak research over the next decade





Additional Presentations

- Graphite Tile Thermal Performance in New DIII-D Lower Divertor, C. Murphy, November 14, In-Vessel Component Session
- A Network Based Telemetry Upgrade for the DIII-D Neutral Beam Power Diagnostics, H.H. Chiu, November 14, Poster Session
- Rotation of a Neutral Beamline to Obtain Counter-Injection on the DIII-D Tokamak, J. T. Scoville, November 15, Plasma Engineering, Heating and Control Session
- Diagnostic Developments on DIII-D, R. Boivin, November 15, Diagnostic Session