THE DIII–D NATIONAL PROGRAM SCIENTIFIC RESEARCH PLANS

by
T.S. Taylor

Presented at
Office of Fusion Energy Sciences
FY03 Budget Planning Meeting
Washington, DC

March 14, 2001

DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

GENERAL ATOMICS

047–01/TST/ci

DIII–D INTERNATIONAL RESEARCH TEAM

U.S. Labs

ANL
INEL
LANL
LLNL
ORNL
PNL
PPPL
SNL

Japan

JAERI
  JT–60U
  JFT-2M
NIFS
  LHD
Tsukuba U.

European Community

Cadarache (France)
Culham (England)
Frascati (Italy)
FOM (Holland)
IPP (Garching)
Joint European Torus
KFA (Germany)
Lausanne (Switzerland)

Russia

Ioffe
Keldysh
Kurchatov
Moscow State
Troitsk

U.S. Universities

Alaska	MIT
Cal Tech	RPI
Columbia	Texas
Georgia Tech	UCI
Hampton	UCLA
Johns Hopkins	UCSD
Lehigh	Washington
Maryland	Wisconsin

Other International

ASIPP (China)
CCFM (Canada)
Chalmers U. (Sweden)
Helsinki U. (Finland)
KAIST (Korea)
KBSI (Korea)
SWIP (China)
U. Alberta (Canada)
U. Toronto (Canada)
U. Wales (Wales)

Industry

CompX
CPI
Creare
FAR Tech
Gycom
HiTech Metallurgical
IR&T
Orincon
Surmet
Thermacore
TSI Research

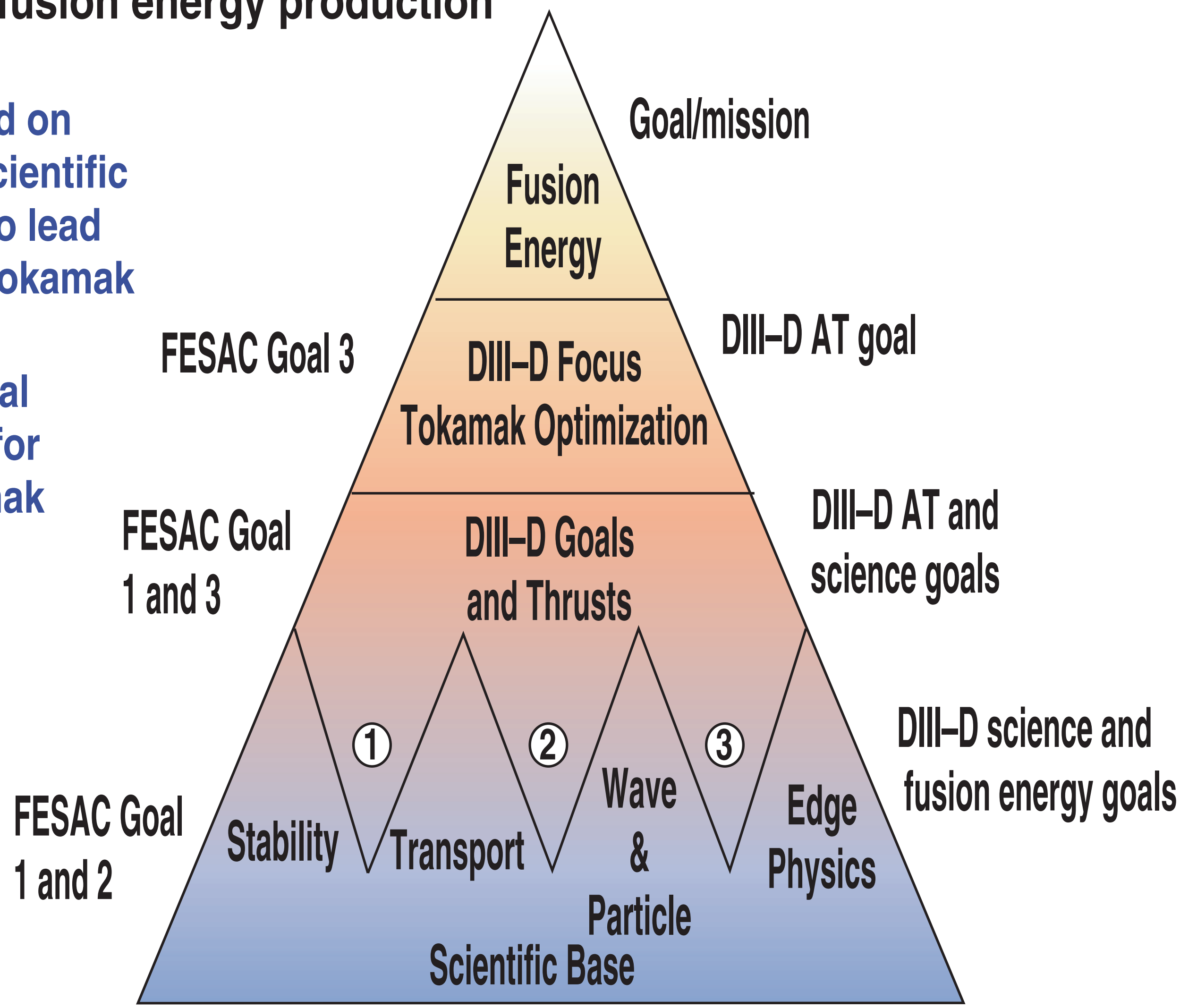
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

150-00/RDS/wj

THE DIII–D PROGRAM IS A SCIENCE PROGRAM AIMED AT AN ENERGY GOAL

Mission: to establish the scientific basis for the optimization of the tokamak approach to fusion energy production

- Research thrusts are based on (and contribute to) solid scientific base – they are expected to lead to the optimization of the tokamak
- Broad scientific base (topical science) forms foundation for research thrusts and tokamak optimization, as well as contribute to advancing plasma and fusion science on a broad front



DIII–D NATIONAL FUSION FACILITY

047–01/TST/wj

FOCUS OF DIII–D RESEARCH IS ON ADVANCED TOKAMAK PHYSICS

FESAC Goal #3

- Innovative concept improvement of the tokamak concept toward
  - High power density
    - ★ Improved stability
  - Compact (smaller)
    - ★ Improved confinement
  - Steady state
    - ★ High bootstrap fraction $\Rightarrow$ high β_N
    - ★ Current drive and divertor optimization

Simultaneously integrated

FESAC Goal #1

- A self-consistent optimization of plasma physics through
  - Magnetic geometry (plasma shape and current profile)
  - Plasma profiles (pressure, density, rotation, radiation)
  - MHD feedback stabilization

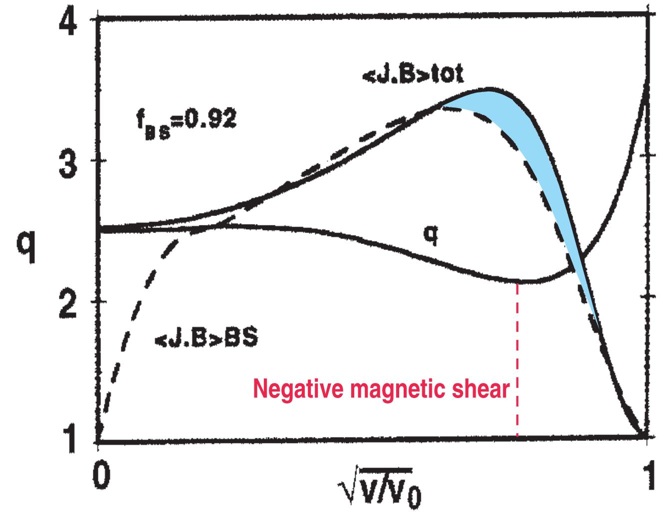
- Requires strong coupling between theory, simulation and experiment
  - Challenging and rich scientific research
  - Improved and new physics measurements (DIII–D diagnostic initiative)

ULTIMATE POTENTIAL OF THE TOKAMAK
VISION: HIGH BOOTSTRAP FRACTION NCS SCENARIO

SCIENTIFIC CHALLENGES FOR ADVANCED TOKAMAK

- Density and impurity control
- Current profile evolution and control
  - Electron cyclotron current drive
- Resistive wall mode stabilization
- Neoclassical tearing mode stabilization
- Transport barrier control
- Pedestal optimization and control

NCS Scenario



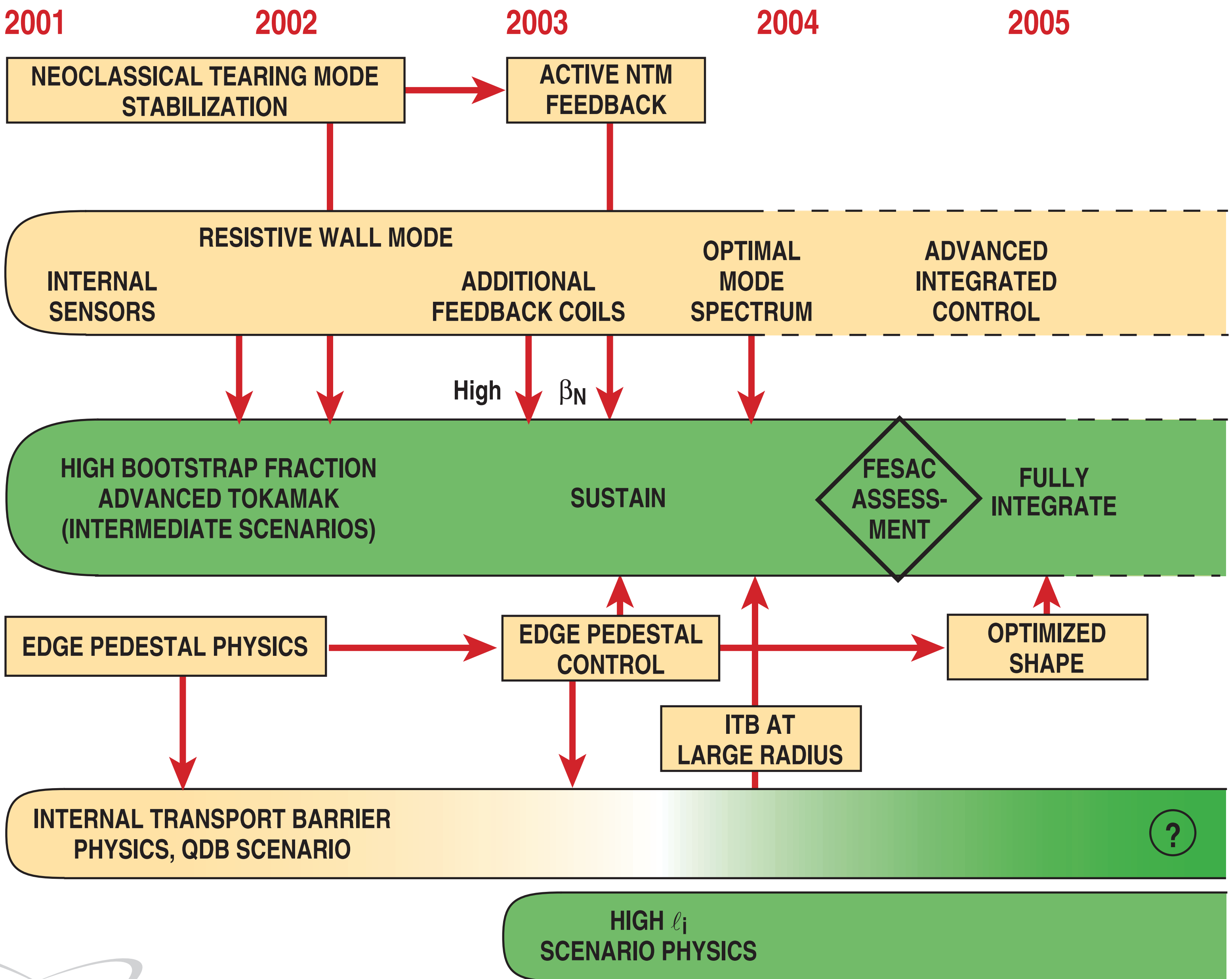
⇒ These are important "building blocks" for high-performance AT plasmas

⇒ Each represents an important and rich scientific area of investigation

⇒ Each contributes immensely to the science base of MFE

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

ADVANCED TOKAMAK RESEARCH THRUSTS (2001–2005)



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

325-00 jy

FESAC GOAL 2: RESOLVE OUTSTANDING SCIENTIFIC ISSUES AND ESTABLISH REDUCED-COST PATHS TO MORE ATTRACTIVE FUSION ENERGY SYSTEMS BY INVESTIGATING A BROAD RANGE OF INNOVATIVE MAGNETIC CONFINEMENT CONFIGURATIONS

- The Advanced tokamak vision of the ultimate potential of the tokamak is a new and innovative magnetic confinement configuration. Studies have shown that these modes, if realized, can halve the cost of electricity in tokamak fusion power systems

- DIII–D research elements of generic value across magnetic confinement concepts:
  - Micro-turbulence suppression
  - Wall stabilization
  - Energetic particle density gradient driven instabilities
  - Current drive by waves and beams
  - Parallel field line physics

FESAC GOAL 4: DEVELOP ENABLING TECHNOLOGIES TO ADVANCE FUSION SCIENCE; PURSUE INNOVATIVE TECHNOLOGIES AND MATERIALS TO IMPROVE THE VISION FOR FUSION ENERGY; AND APPLY SYSTEMS ANALYSIS TO OPTIMIZE FUSION DEVELOPMENT

- The DIII–D will deploy, and thereby foster, the development of a number of enabling and innovative technologies:
  - Advanced methods for plasma heating and current drive (microwave ECRF)
  - Disruption mitigation by solid, liquid, or gas injection
  - Plasma fueling (inside pellet launch)
  - Plasma flow control (neutral beam, ECRF, ICRF)
  - Investigation of novel divertor concepts
  - Feedback technologies for wall stabilization
  - Studies of surface erosion
  - Small-sample testing of low activation materials in plasma environment

THE DIII–D PROGRAM HAS HAD A SUCCESSFUL YEAR !

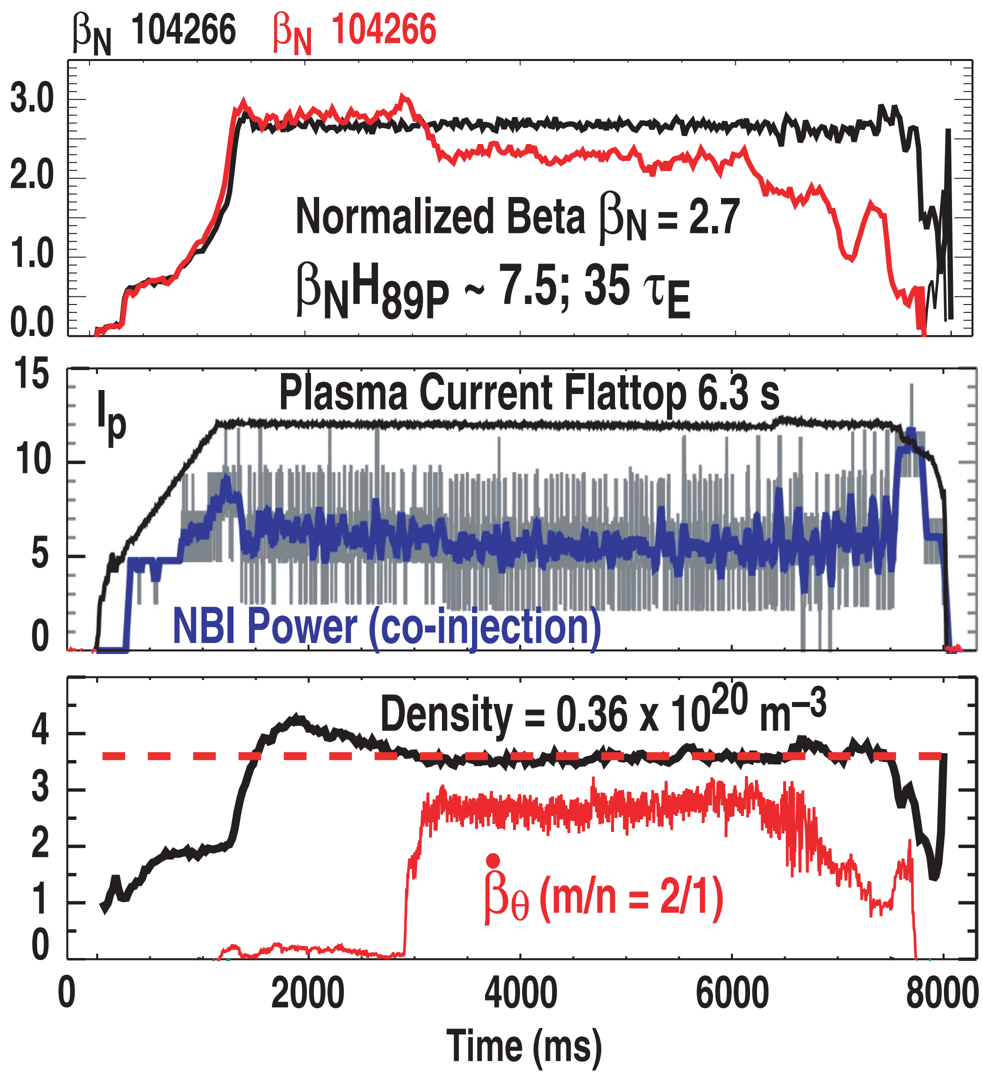
— A number of excellent conference presentations/papers —

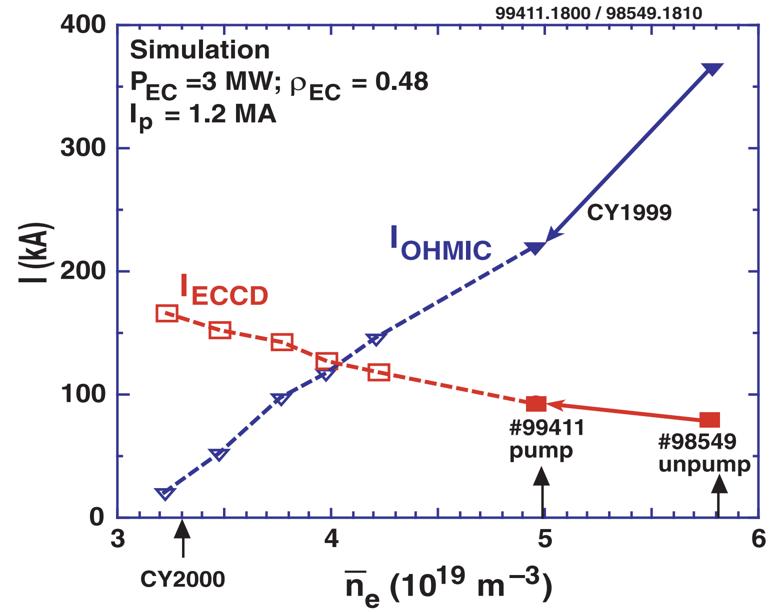
- APS
  - Tokamak Review (Stambaugh)
  - 7 invited presentations
  - 14 orals, 65 posters
- ANS
  - Invited AT (Petersen)
  - 7 presentations
- EPS
  - Invited AT (Petty)
  - 15 presentations
- HTPD
  - Invited (Burrell)
  - 8 presentations
- IAEA
  - Overview (S. Allen)
  - 20 presentations
- SOFT
  - Advanced Tokamak (Kellman)
  - 6 presentations
- PSI
  - 2 invited (Allen, Schaffer)
  - 14 presentations

HIGHLIGHTS OF THE 2000 DIII–D RESEARCH PROGRAM

- Progress on long pulse improved performance discharges ($\beta_N H_{89P}$ = 7.5 for 6 s)
- Long pulse operated reliably ~5% below known stability limit
- Stabilization of the resistive wall mode verified in accordance with modeling predictions
- Complete stabilization of neoclassical tearing modes with electron cyclotron current drive
- Off-axis current drive in ELMing H–mode discharges
- Development of an understanding of transport barriers in the electron channel (Shafranov shift stabilization) (electron cyclotron heating and current drive)
- Density control demonstrated with new private flux baffle and cryopump; with low plasma impurity
- New discovery: quiescent double barrier mode — edge (H–mode) and internal transport barrier, without ELMs
- Developing an understanding of the role of the benign edge harmonic oscillation in avoiding large ELMs
- Measurement of sheared flow of turbulence in the plasma edge
- Improved understanding of the synergistic effect of impurity injection and sheared flow in the stabilization of microturbulence
- Measured nondimensional scaling characteristics of turbulence behave consistently with the gyrokinetic equation

STABLE OPERATION WITHOUT DISRUPTION ~5% BELOW KNOWN LIMIT (m/n = 2/1) NTM





- Density is controlled with divertor pumping

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

047–01/TST/wj

FESAC (IPPA) GOAL 1: ADVANCE FUNDAMENTAL UNDERSTANDING OF PLASMA, THE FOURTH STATE OF MATTER, AND ENHANCE PREDICTIVE CAPABILITIES, THROUGH COMPARISON OF EXPERIMENTS, THEORY AND SIMULATION

- Turbulence and transport
- Macroscopic stability
- Wave-particle interactions (heating and current drive)
- Multi-phase interfaces

TURBULENCE AND TRANSPORT (IPPA)

- Five-Year Objective: Advance the scientific understanding of turbulent transport, forming the basis for a reliable predictive capability in externally controlled systems

- Progress will be measured by the evolving level of agreement between theory, simulation and experimental measurements of transport phenomena

- Implementation approaches
  - Predictive capability
  - Understanding transport barriers
  - Integrated models of core and edge physics

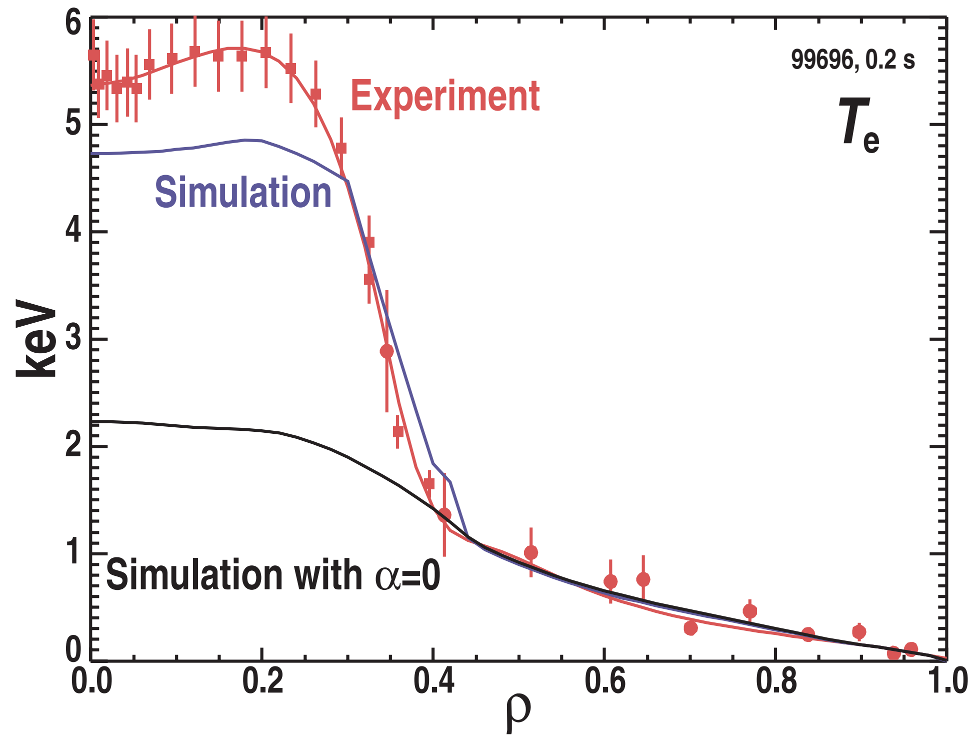
NEAR TERM GOALS/PLANS FOR CONFINEMENT AND TRANSPORT

- **Core Transport**
  - Develop improved physics understanding and control of reduced core transport regions, especially in advanced tokamak plasmas (also FESAC Goal 3)
    - ★ Investigations of quiescent double barrier H–mode plasmas
  - Investigate fundamental nature of turbulent transport in tokamaks
    - ★ Measure zonal flows and compare to theory (needs new measurement capability)
  - Carry out innovative experiments to make quantitative tests of predictions of (theory-based) transport models
    - ★ Modulated transport studies using ECH (Is ETG important? — needs new measurement capability)
- **Edge physics**
  - Test theories of edge and divertor conditions needed to get H–mode
    - ★ Results from ∇B drift experiments compared with BOUT model
  - Study H–mode edge pedestal and investigate key physics controlling edge gradients and pedestal values
    - ★ Nondimensional identity comparison with C-Mod
- **Modeling**
  - Develop modeling capability in parallel with experimental tests

Extremely active area of research — many more proposed experiments than can be done — 11 experiments out of 50 in 2001 campaign

MEASUREMENT OF HIGH k TURBULENCE IS NEEDED TO VALIDATE ROLE OF ETG MODES IN ELECTRON TRANSPORT

- ITB observed with ECH, co-ECCD, counter-ECCD
- Transport modeling indicates Shafranov shift (α) stabilization of ETG modes
- Future plans
  - — Simultaneous e-ITB, i-ITB
  - — Evaluate χ with localized modulated ECH
  - — Dependence of ITB on q, $\hat{S}_n$
- Added value — measurement of turbulence in ETG range (high k)

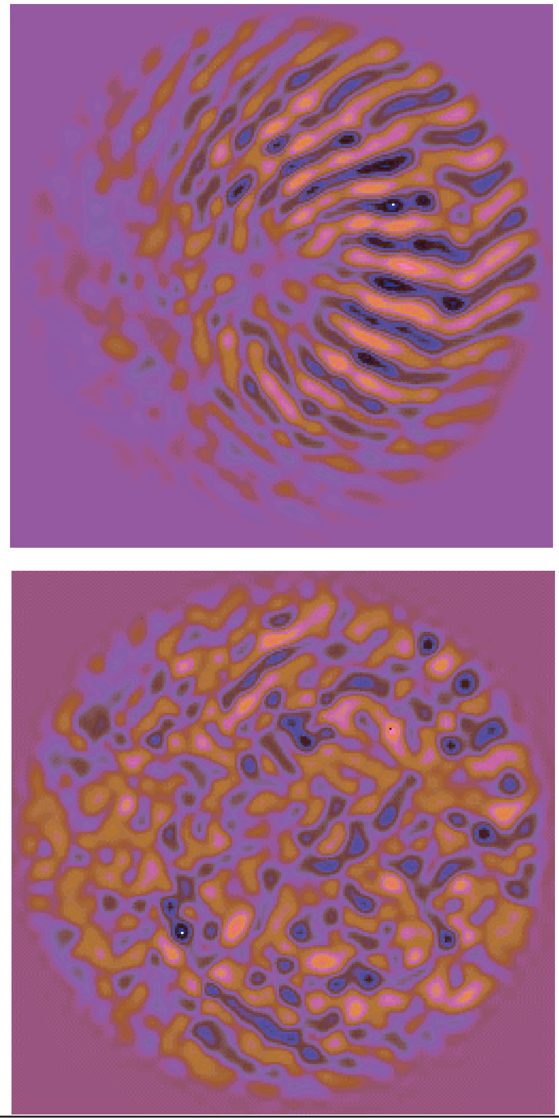


DIII–D NATIONAL FUSION FACILITY SAN DIEGO

047–01/TST/wj

EXAMPLE OF TOKAMAK TURBULENCE SIMULATION
— Self-Generated Zonal Flow —

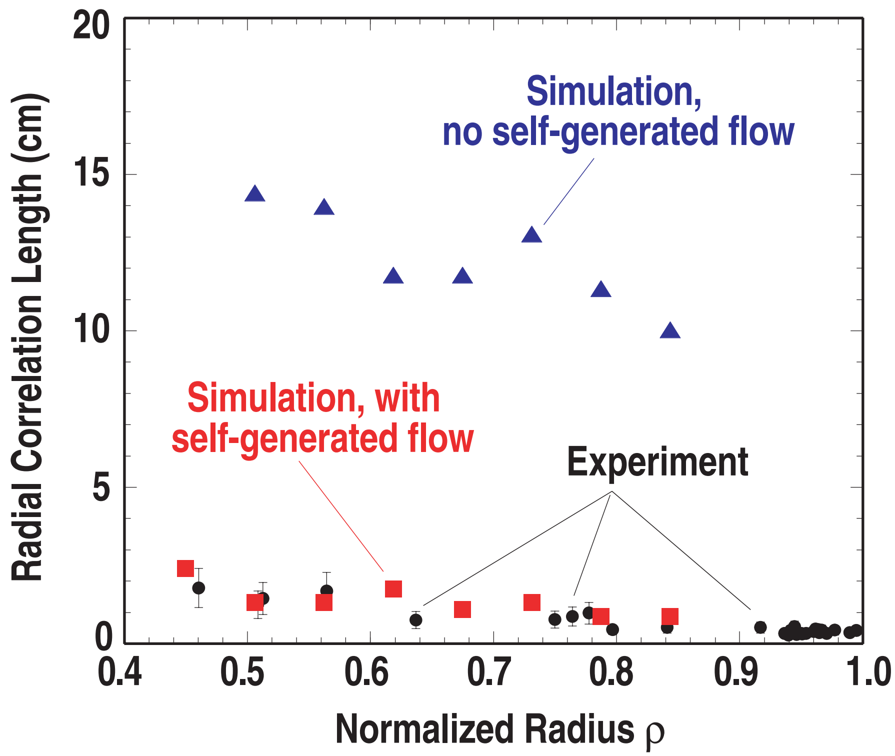
- Contour plot of potential fluctuations
- Early linear stage shows long radial structures
- Later, nonlinear stage shows much shorter radial structures
- Simulations performed by J.-N. Leboeuf, UCLA



Linear Phase

Nonlinear Steady State

DIII–D IS WORKING TO EXPERIMENTALLY VERIFY ZONAL FLOWS



- Theory: zonal flows limit turbulent driven transport, m = 0, radially localized
- DIII–D discharges/turbulence simulated by J-N. Leboeuf (UCLA) / R. Sydora (U. Alberta)
- Radial correlation lengths from correlation reflectometer (UCLA)
- Future work
  - Experimental measurements needed to identify and quantify zonal flows (BES, multiple correlation reflectometry)
  - Need detailed theoretical guidance on exactly what we should measure

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

047–01/ TST/wj

DIII–D'S EXCELLENT SUITE OF DIAGNOSTICS ENABLES SOPHISTICATED TRANSPORT AND TURBULENCE STUDIES

Profile Diagnostics:

- CER (T_i, V_ϕ, V_θ, n_{Imp})
- ECE (T_e)
- MSE (q profile)
- Thomson scattering (n_e, T_e)
- Bolometer (P_{rad})
- Bremsstrahlung (Z_{eff})
- Li Beam ($J(\rho)$, edge)

Fluctuation Diagnostics

- BES ($\tilde{n}(r)$, L_c)
- Correlation Reflectometer ($\tilde{n}$, $L_{c,r}$)
- FIR [$\tilde{n}(t)$]
- Langmuir Probes ($\tilde{n}$, $\tilde{\phi}$, $\tilde{T}_e$)
- PCI ($\tilde{n}(R,t)$ near edge)

Other Important Diagnostics

- Charge Exchange Neutral Analyzers
- Neutrons
- Magnetics (Shape)

- Frontiers of transport and turbulence research require new physics measurements

High Priority Measurement Needs

- Zonal Flows
- Turbulence of Electron Gyroscale (high k)

FUSION PLASMA PHYSICS IS NOW READY TO MAKE A SIGNIFICANT ADVANCE IN UNDERSTANDING TURBULENT TRANSPORT

- **Advances in computation over the past 10 years have created a revolution in our ability to simulate turbulence and calculate the resulting transport**

- **To further improve the models, we are testing them with several techniques**
  - Comparison of predicted and measured plasma profiles (n_e, T_e, T_i, v_ϕ) in both steady-state and time varying situations
  - Detailed comparison of theoretically predicted and experimentally measured turbulence characteristics (e.g. BES, FIR measurements)

- **To make further progress in testing the theories we need**
  - Theoretical calculations of what the existing diagnostics actually measure
    - ★ Include actual spatial and frequency response in calculation
  - Improved diagnostics to measure key theoretical predictions
    - ★ Short wavelength turbulence (high k) associated with electron transport
    - ★ Zonal flows which damp turbulence

- **We need a new, community-wide diagnostic initiative to fully realize the potential for improved predictive understanding of transport**

MACROSCOPIC STABILITY (IPPA)

- Five-Year Objective: Develop detailed predictive capability for macroscopic stability, including resistive and kinetic effects
- Progress will be measured by the level of agreement between predicted and observed stability regimes and by improvements in the stability of operating confinement devices
- Implementation approaches:
  - Understanding observed macroscopic stability limits
  - Understanding physics underlying external stability control
  - Extending MHD description

DIII–D RESEARCH ADVANCES THE UNDERSTANDING OF KEY MHD STABILITY ISSUES FOR TOROIDAL PLASMAS

- **Kink mode stabilization by a resistive wall** (additional coils, power supplies)
  - Validate models of stabilization by plasma rotation (FESAC 1 & 3)
  - Confirm the recently predicted phenomenon of error field amplification (FESAC 1 & 3)
- **Neoclassically-driven tearing modes** (ECCD ⇒ gyrotrons, steerable launchers)
  - Validate theories of threshold mechanism through detailed rotation measurements, and continue development of an international database (FESAC 1 & 3)
- **Edge-driven instabilities** (Li beam, polarimetry)
  - Validate role of edge bootstrap current density
  - Extend ideal and resistive stability modeling to intermediate range of mode numbers
  - Develop understanding of ideal and non-ideal stability properties of quiescent H–mode edge
- **Physics of non-ideal plasma instabilities** (ECE radiometer)
  - Investigate sawtooth reconnection physics and the role of the Mercier stability criterion through variation of flux surface shaping
  - Validate the predicted dependence of resistive interchange mode stability on pressure gradient and magnetic shear
- **Disruption physics** (FESAC 1 & 3) (Dis RAD)
  - Confirm the predicted avalanche process in runaway electron generation
  - Investigate the physics of disruption mitigation by injection of high pressure D_2 or impurity gas

WAVE-PARTICLE INTERACTIONS (IPPA)

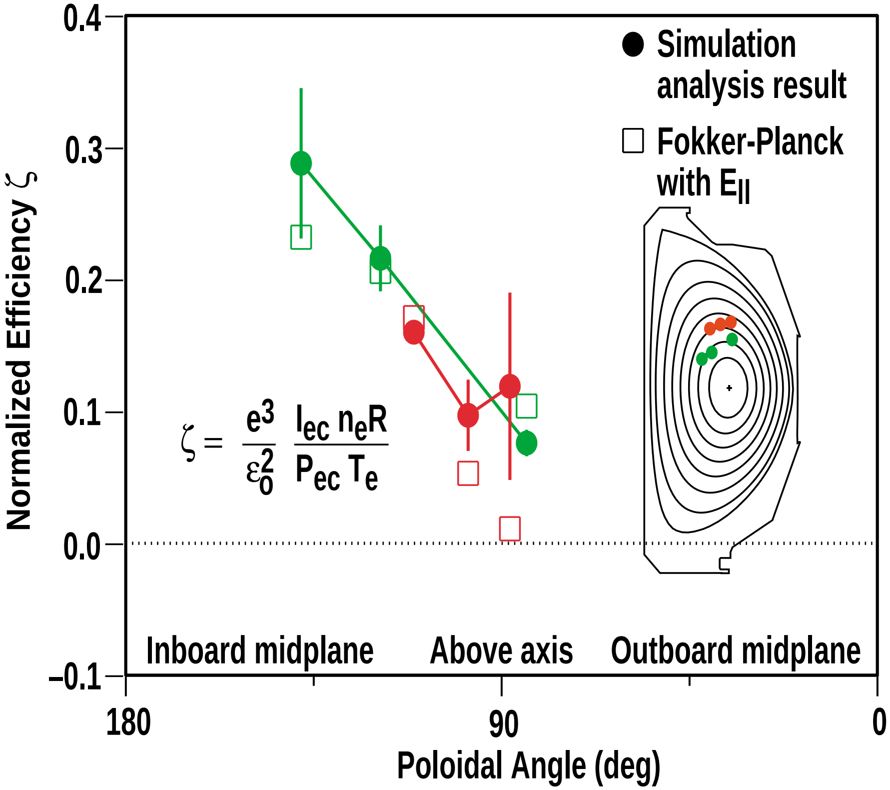
- **Five-Year Objective: Develop fundamental understanding of plasma heating, flow, and current drive, as well as energetic particle-driven instabilities, in a variety of magnetic confinement configurations and especially for reactor-relevant regimes**

- **Progress will be measured by increased level of agreement among theory, numerical simulation, and experiment for understanding and controlling wave-particle phenomena**

- **Implementation approaches:**
  - **Plasma heating and current drive**
  - **Energetic particle effects on radial profiles and confinement**
  - **Instabilities affected by energetic particles**

NEAR-TERM HEATING AND CURRENT DRIVE PLANS

- Validate the CQL3D Fokker-Planck code as a predictive tool for electron cyclotron current drive
  - Electron pressure
  - Collisionality
  - Magnetic well
  - Quasi-linear effects of high power density
- Develop current drive for sustainment of current profile in steady-state AT discharges
- Evaluate effects of nonthermal particle distributions on heating and current drive
- Validate physics model for NBCD
- Develop physics basis for FWCD



- Important tools
  - High power ECCD
  - Steerable launchers
  - X-ray camera

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

047–01/TST/wj

PLASMA BOUNDARY PHYSICS (IPPA)

- Five-Year Objective: Advance the capability to predict detailed multi-phase plasma-wall interfaces at very high power and particle fluxes

- Progress will be measured by the level of agreement between models of physical processes in the edge region and experimental measurements, and by the capability to control energy and particle exhaust from a hot plasma

- Implementation approaches:
  - Plasma edge physics
  - Coupling between edge and core plasmas
  - Plasma-wall interaction

NEAR TERM BOUNDARY GOALS/PLANS
IMPROVED "PREDICTIVE CAPABILITY"

- **Understand SOL and divertor transport**
  - Evaluate effects of ∇B drifts, and local E$\times$B flows
  - Effect of neutrals on L–H transition
  - Far SOL transport and recycling
  - ELMs
- **Test turbulence and E$\times$B transport theories at near DN shape**
  - Turbulence and transport
  - Heat and particle flux asymmetries
- **Plasma materials interaction and first wall physics**
  - Measure interaction of plasma with liquid wall relevant materials
  - Evaluate carbon (impurity) source and penetration
- **High density at high confinement** (FESAC 1 & 3)
  - Evaluate core, SOL and divertor radiation limits to density
  - Edge and core transport at high density
  - Fueling and pedestal physics
- **Use physics understanding and modeling to extend the radiative divertor solution to lower core plasma density** (FESAC 1 & 3)
  - Impurity radiation in the divertor and SOL
  - Impurity and density control in the core

FESAC (IPPA) GOAL 3

- **Advance understanding and innovation in high-performance plasmas, optimizing for projected power-plant requirements; and participate in a burning plasma experiment**
  - Profile control
  - Stability feedback control
  - Burning plasmas, international collaboration

- **High-performance plasmas provide a research tool for extending our understanding of fusion plasmas**

PROFILE CONTROL (IPPA)

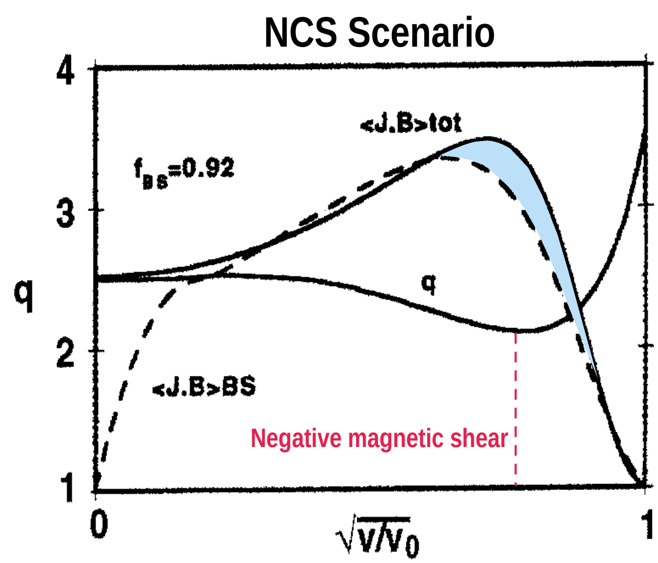
- Five-Year Objective: Assess profile control methods for efficient current sustainment and confinement enhancements in the advanced tokamak, consistent with efficient divertor operation, for pulse lengths much greater than energy confinement times

- Progress will be measured by the understanding of the physical processes that govern the plasma profiles and the confidence in the ability to control the plasma profiles in present and next-generation devices

- Implementation approaches:
  - Plasma current profile
  - Plasma pressure profile
  - Plasma flow profile
  - Plasma transport profile
  - Low density divertor operation

IMPORTANT FEATURES OF HIGH BOOTSTRAP FRACTION NCS

- **Broad or hollow current profile and broad pressure profile**
  - $q_{min} > 1 \rightarrow$ stability to central modes (ST, NTM, . . .)
  - q_0, $q_{min} >> 1 \rightarrow$ high bootstrap fraction, f_{BS}
  - Low magnetic shear allows high core pressure gradients (ITBs)
  - ITB gives good confinement
  - Strong coupling of external modes to wall
  - Well-aligned bootstrap current, edge current (H–mode)



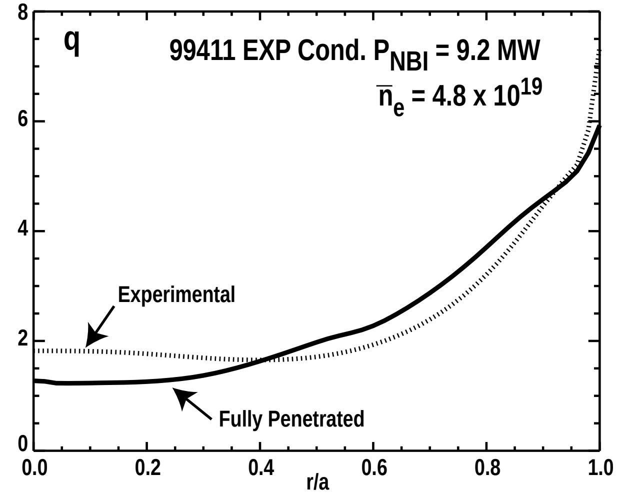
- **Promise of exciting new physics in NCS regime, high q_0, q_{min}**
  - Key is to maintain profile to investigate physics
  - High f_{BS} needed for high q_0, q_{min}
  - High β_N, β_p needed for high f_{BS}
  - Wall stabilization plays an important role

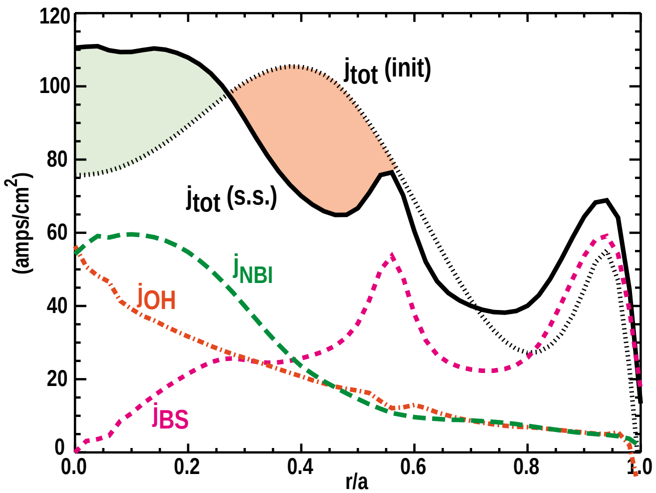
- **Key control tools for NCS sustainment**
  - Off-axis current drive (EC system $\rightarrow$ gyrotrons, steerable launchers)
  - Resistive wall mode stabilization to increase β_N (additional control coils, power supplies)

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

047–01/TST/ci

KEY TO MAINTAINING FAVORABLE q PROFILE: REDUCE AXIAL CURRENT DRIVE AND ADD OFF-AXIS CURRENT DRIVE





I_{tot} = 1.19 MA I_{NBI} = 0.31 MA I_{OH} = 0.25 MA

- Low ohmic drive (J_{OH} peaked on axis)

  $\Rightarrow$ High I_{BS}

  $\Rightarrow$ High I_{CD} (off-axis)

- Limited axial neutral beam current drive

  $P_{NBI} \Rightarrow P_{EC}, P_{FW}$

  $I_{NBI} \Rightarrow I_{ECCD}$

- High bootstrap fraction requires operation at high β_N, modest q

  $I_{BS}/I \propto \sqrt{A}\, q\, \beta_N$

  $\Rightarrow$ Optimize $\beta_N^{NO\ WALL}$

  $\Rightarrow$ Increase β_N by stabilization of resistive wall mode

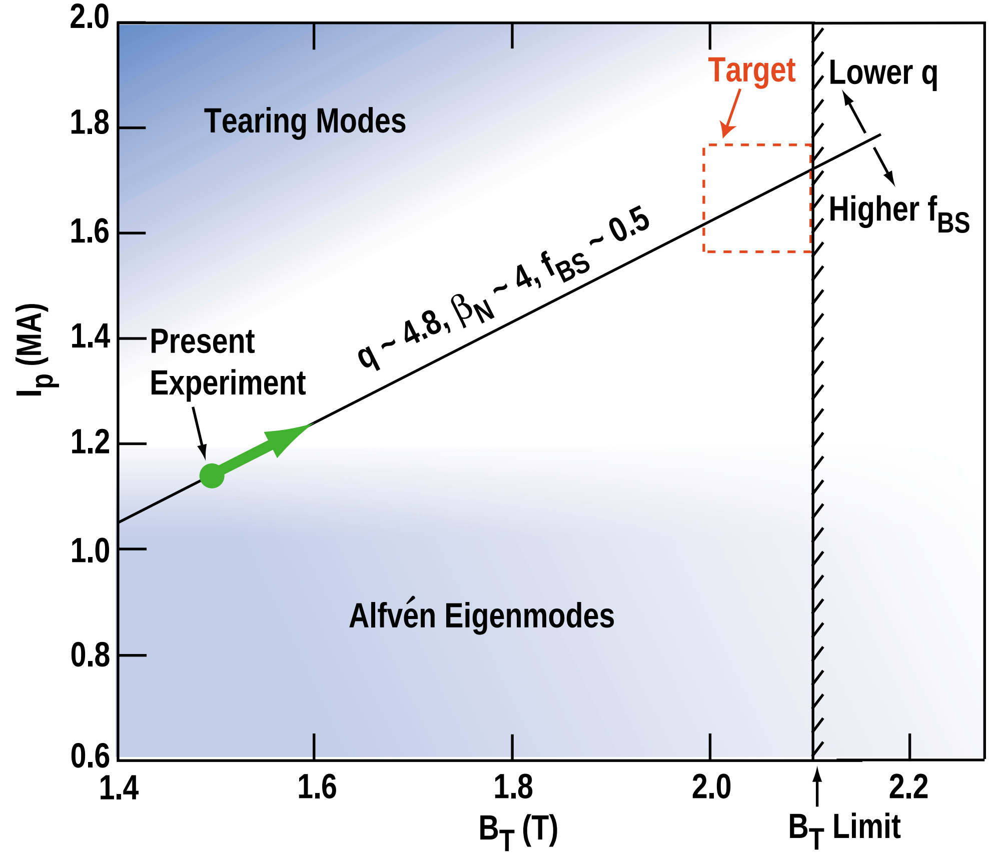
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

047-01/TST/WJ

PROGRESS IN PHYSICS BASIS FOR STEADY-STATE HIGH PERFORMANCE AND CONFIGURATIONAL CONTROL GAINED THROUGH STAGED SCENARIOS

	Initial Scenario	Intermediate Scenarios		Full Scenario
P_{EC} (MW)	2.3	3.0	4.5	7.0
P_{FW} (MW)	0	0	3.0	6.5
P_{NBI} (MW)	6.9	6.2	4.5	6.5
B_T (T)	1.6	1.6	1.75	1.95
I_P (MA)	1.0	1.2	1.25	1.6
I_{BOOT} (MA)	0.55	0.57	0.85	1.07
I_{ECCD} (MA)	0.12	0.17	0.25	0.35
β_N	3.6	3.6	4.5	5.7
H_{89}	2.8	2.8	3	3.5
n/n_G	0.33	0.3	0.38	0.40
T_e (keV)	5	5.5	10	10
Wall Stabilization	6-coil	6-coil	18-coil	18-coil
Pulse Lengths (s)	5	5	8	10

STABLE OPERATION FAVORS HIGHER CURRENT AND CURRENT DRIVE POWER



- New tools
  - ECCD for current sustainment and profile control
    - ✶ Long-pulse gyrotrons (10 MW at B_T = 2 T)
    - ✶ Long-pulse launchers
  - RWM feedback coils

NEAR TERM DIII–D PLANS FOR PROFILE CONTROL

- **Current**
  - Develop stationary q-profiles with high q_0, q_{min} to avoid unstable boundaries, $q_{min} > 1.5$, $q_{min} > 2$; using n_e control, NBI, ECCD, $\dot{I}_p$
  - Validate ECCD off-axis CD models, in high beta H–modes (FESAC 1 & 3)
  - Integrate density control, current profile control, stability control, push scenarios to higher f_{BS}, higher current
  - Develop FW heating and CD in high beta
- **Pressure**
  - Evaluate use of ECCD/NBI, pellets, q(p), and L-H transiton to modify pressure profile
- **Transport**
  - Explore and understand formation and control of internal transport barriers (FESAC 1 & 3)
  - Evaluate QDB scenarios as possible alternate NCS scenario
- **Divertor**
  - Develop low n_e radiative divertor solutions

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

047–01/TST/ci

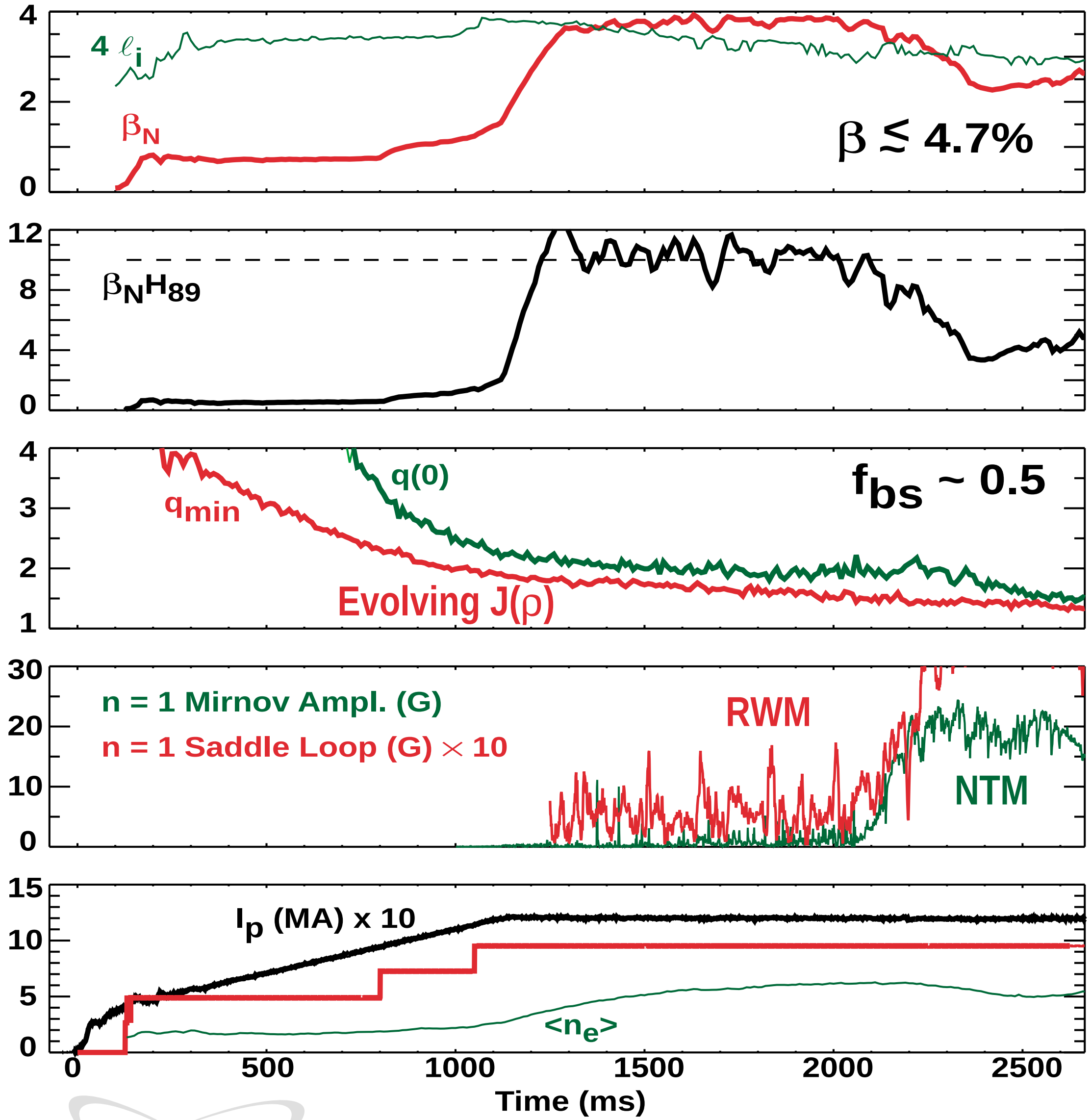
HIGH BETA STABILITY AND DISRUPTION MITIGATION (IPPA)

- Five-Year Objective: Develop and assess high beta instability feedback control methods and disruption control/amelioration in the advanced tokamak, for pulse lengths much greater than energy confinement times

- Progress will be measured by assessing improvements in
  - Physics understanding
  - Passive and active stability control
  - Amelioration of disruptions

- Implementation approaches:
  - Resistive wall mode control
  - Current drive inside magnetic islands
  - Active profile control to avoid unstable boundaries
  - Disruption control/amelioration

MHD INSTABILITIES LIMIT PERFORMANCE AND DURATION OF DIII–D ADVANCED TOKAMAK PLASMAS

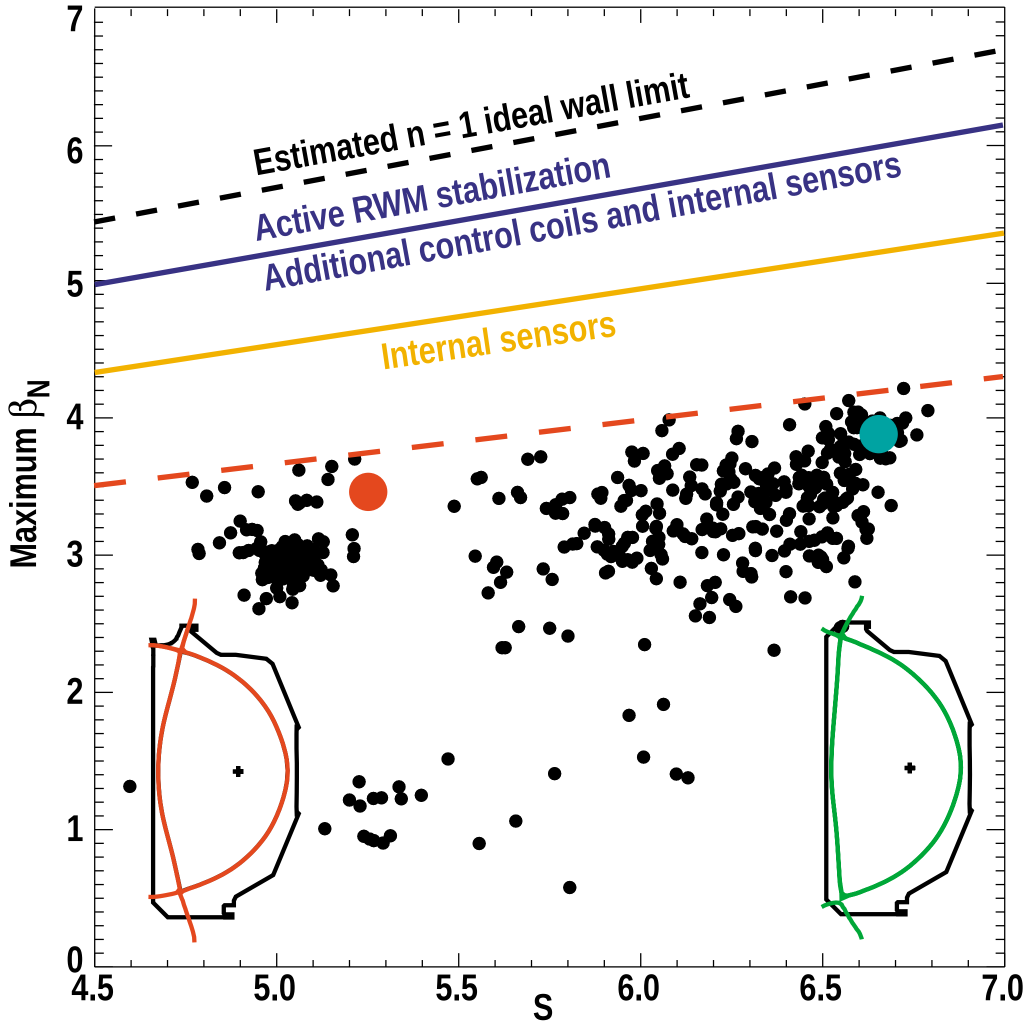


- $\beta_N H \sim 10$ for 5 τ_E
- Ideal kink/resistive wall mode limits maximum beta
  - Feedback stabilization with external coils
- Tearing mode limits high performance duration and current density profile evolves
  - Current profile control, off-axis ECCD
  - Stabilize NTM with localized ECCD

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

047–01/TST/wj

STABILIZATION OF n = 1 RESISTIVE WALL MODE OFFERS THE POSSIBILITY OF SIGNIFICANT GAIN IN MAXIMUM BETA



- Maximum beta slightly reduced for pumping shape
- Actual projected gains depend on details of equilibria and active feedback scheme
- Instabilities other than n = 1 RWM are likely to become important as beta is increased
  - NTM
  - Edge instabilities
  - n = 2 RWM?

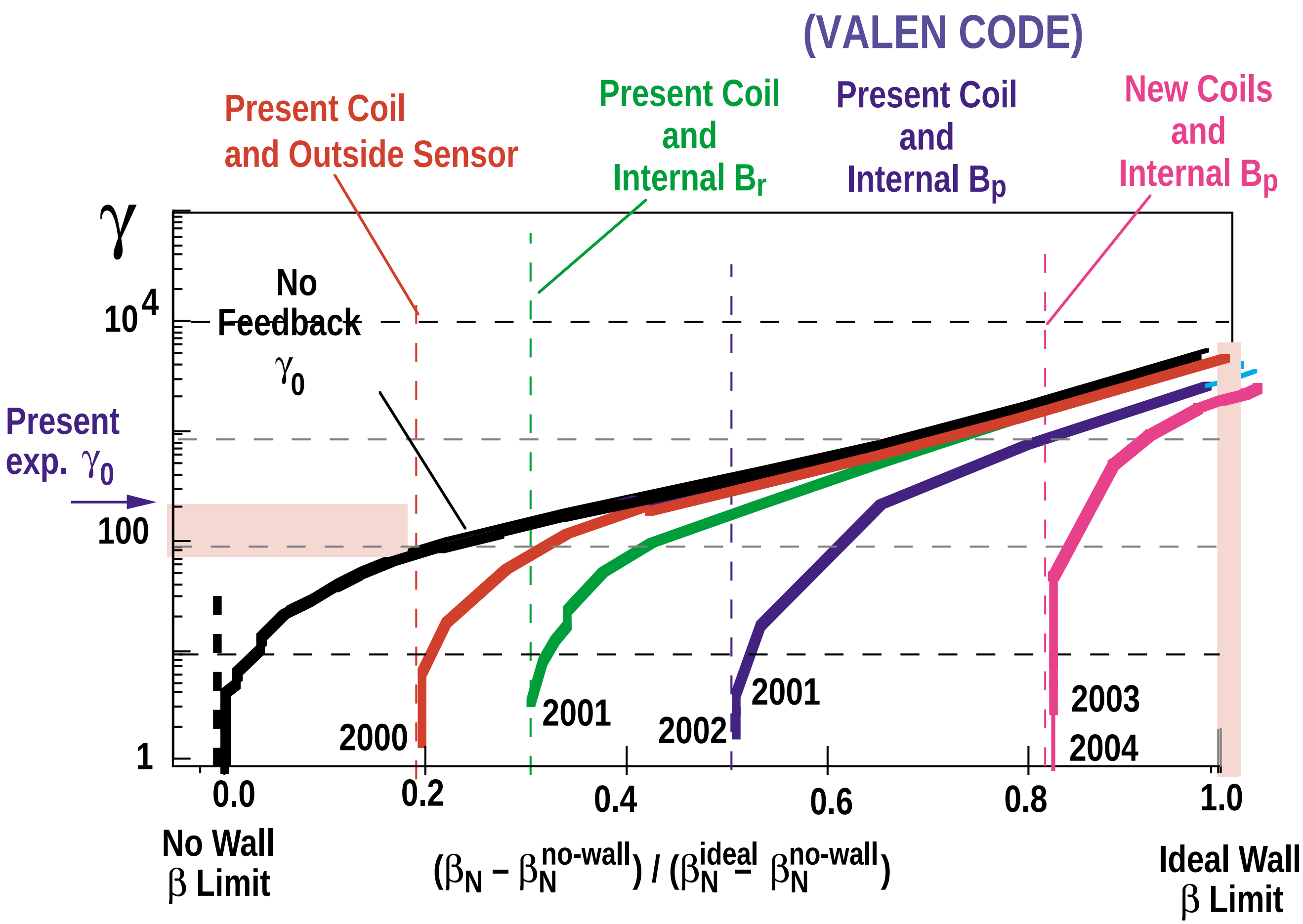
(Additional control coils, power supplies)

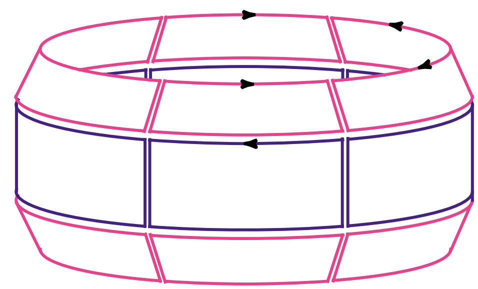
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

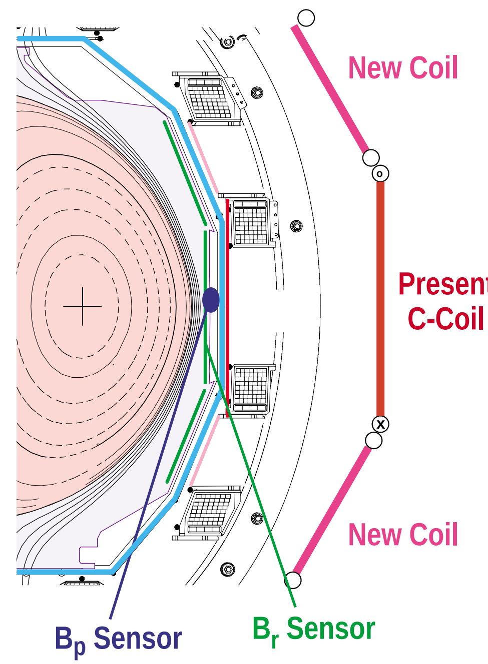
047–01/TST/wj

PHYSICS UNDERSTANDING AND PERFORMANCE CAN BE IMPROVED BY UPGRADED SENSORS AND ADDITIONAL ACTIVE COILS

- Six upper and six lower coil and internal B_p sensors increase achievable β within 20% of ideal MHD limit



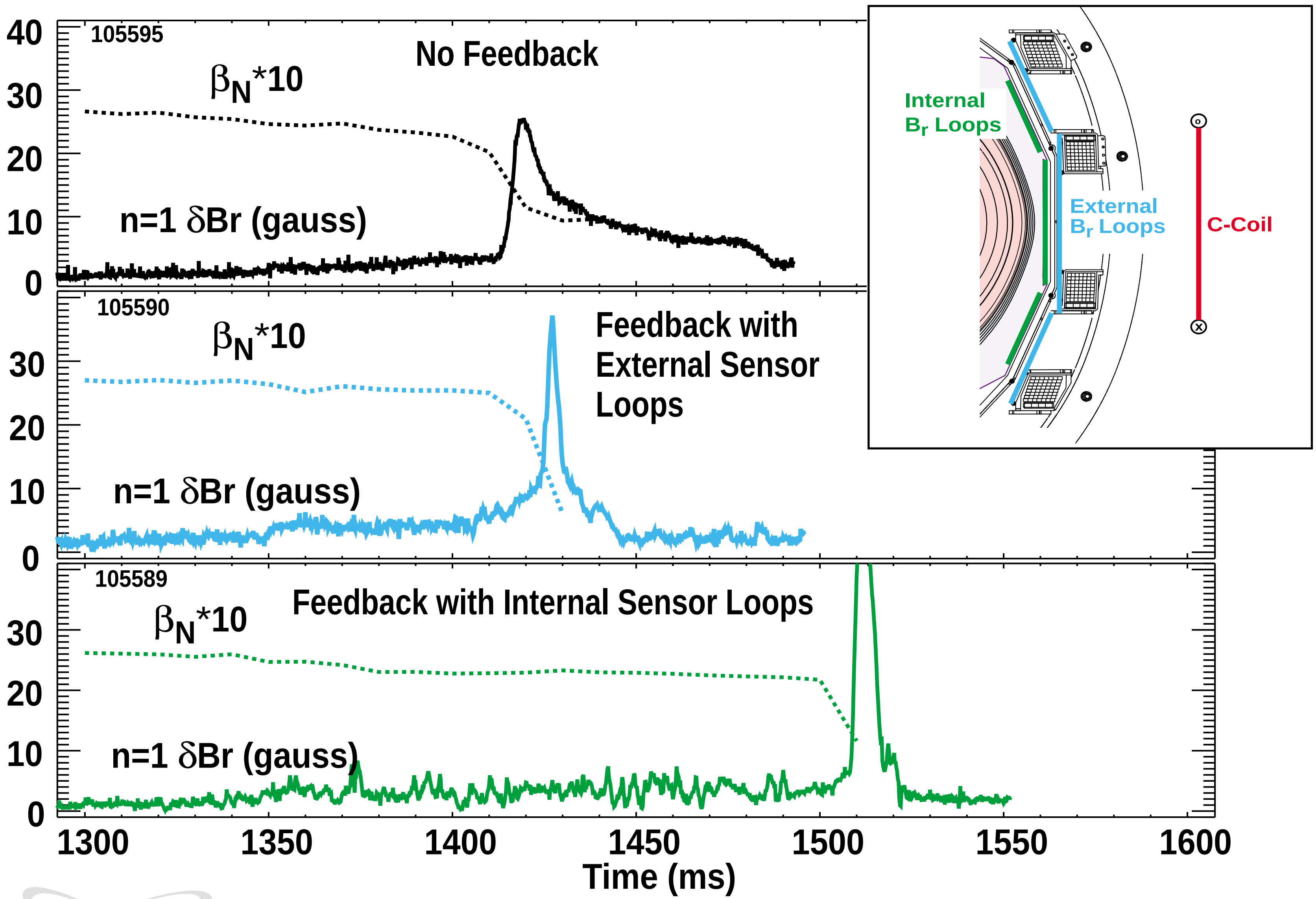




DIII–D NATIONAL FUSION FACILITY SAN DIEGO

047–01/TST/wj

INTERNAL LOOPS ARE MORE EFFECTIVE THAN EXTERNAL LOOPS FOR STABILIZATION OF RWM; CONSISTENT WITH VALEN PREDICTIONS



DIII–D
NATIONAL FUSION FACILITY

047–01/TST/wj

DIII–D PLAN FOR HIGH BETA STABILITY

- **Resistive wall mode**
  - Evaluate higher passive stability by reducing error field (FESAC 1 & 3)
  - Optimize feedback stabilization with new internal sensors; evaluate maximum achievable beta, validate model
  - Design and install 18 coil system
  - Evaluate impact of mode structure on effectiveness of feedback
    - ★ Evaluate maximum steady-state beta

- **Neoclassical tearing mode stabilization**
  - Test stabilization with non-resonant field (FESAC 1 & 3)
  - Develop active feedback of NTM
  - Evaluate gain in beta with ECCD stabilization, with and without sawteeth

- **Edge instabilities**
  - Develop measurement of edge current density; validate MHD model (FESAC 1 & 3)
  - Minimize ELMs and coupling to the core
  - Evaluate and understand edge harmonic oscillation; explore control methods

BURNING PLASMA (IPPA)

- Five Year Objective: Develop and assess burning plasma scenarios and potential next step burning plasma options utilizing domestic resources and working in concert with international collaborators

- Progress will be measured by the technical readiness of next step options for a burning plasma experiment

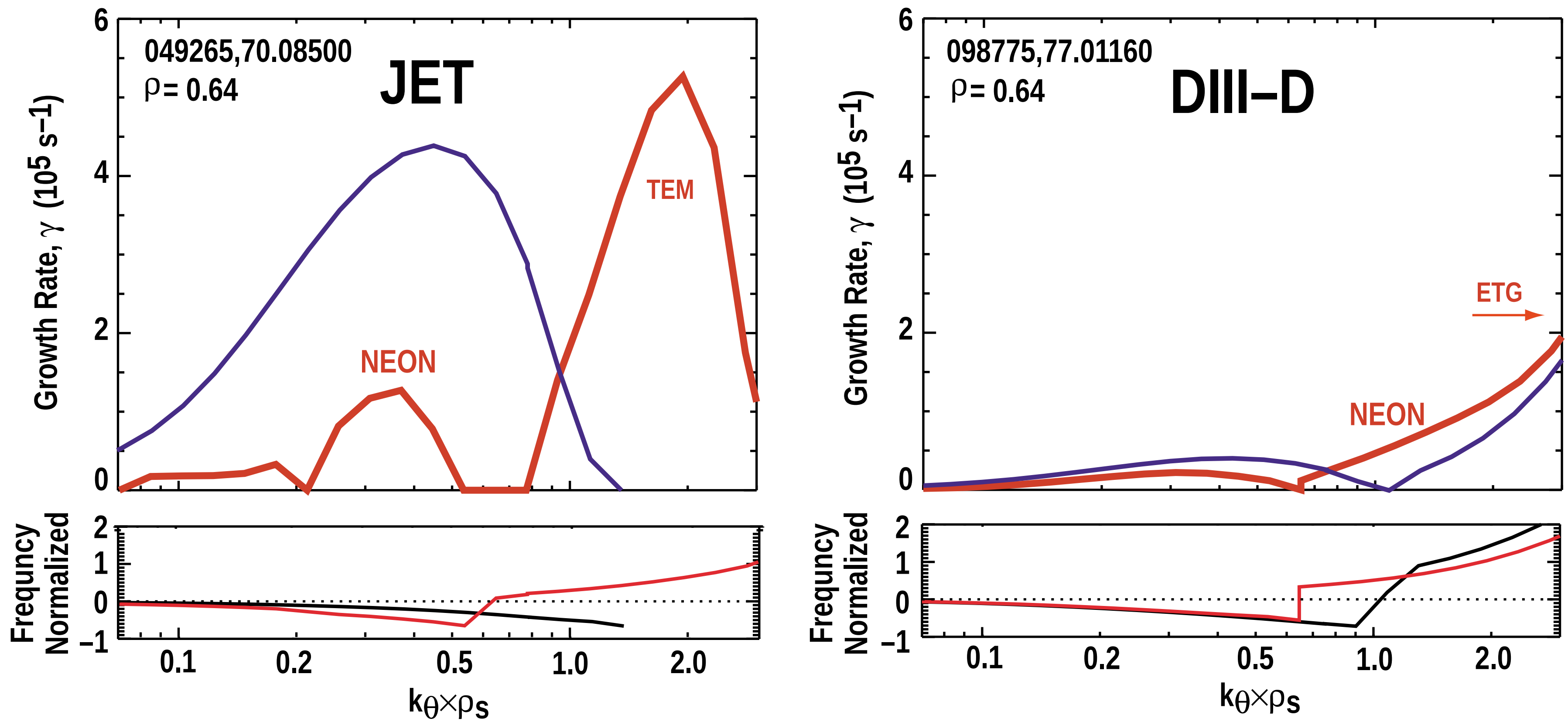
- Implementation approaches:
  - Coordinated and joint experiments
  - Prepare for DT experiments to be carried out on the enhanced JET
  - Continue conceptual design work and trade-off studies for next-step devices

INTERNATIONAL COLLABORATION IS AN IMPORTANT ELEMENT OF THE DIII–D SCIENCE PROGRAM

- Aimed at addressing outstanding scientific issues
- Extremely productive for developing physics understanding and predictive capability of common physics models
- International collaboration has several forms
  - Joint experiments to address outstanding physics issues
    - ★ Similar experiments on multiple devices
    - ★ Joint planning, execution, analysis
    - ★ Expands parameter range for physics evaluation, e.g. ρ_*
  - Participation and cooperation on experiments
  - Cooperation on analysis and modeling tools
    - ★ Equilibrium reconstruction (JET, JT–60U, START, MAST . . .)
    - ★ Determination of localized current drive (ASDEX–U, JT–60U, . . .)
  - Detailed experimental comparisons
    - ★ Steady-state high performance, edge stability (DIII–D/JT–60U)
    - ★ Radiative improved modes (DIII–D/JET/TEXTOR)
    - ★ High density, high confinement H–modes (DIII–D/JET)
    - ★ NTM physics and stabilization (DIII–D/JET/ASDEX-U)
    - ★ Helium plasmas to understand impurity sources and transport (DIII–D/JET)
  - Contribution to international databases

GKS ANALYSIS SHOWS COMMON PHYSICS ON JET AND DIII–D LEADING TO CONFINEMENT IMPROVEMENT

- Reduction in γ_{max} due to:
  - (1) Dilution; (2) Density profile effects; (3) Direct impurity stabilization
- Synergistic effects of $\omega_{E\times B}$ shear stabilization
- Different features observed: JET ⇒ TEM ; DIII–D ⇒ ETG



- A joint U.S./EFDA-JET abstract on these results has been submitted for 2001 EPS

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

CONCLUSIONS/SUMMARY

- DIII–D program is strong science-based program with a focus on the Advanced Tokamak

- DIII–D program and goals are well-aligned with the FESAC (IPPA) goals; mainly in the areas of:
  - Development of predictive capability (FESAC #1)
  - Understanding and optimization of high performance plasmas (FESAC #3)

- The DIII–D program is positioned to make large contributions to the science of plasmas and to the scientific basis for fusion energy

  ⇒ Significant added value can be obtained with modest investments in
  - ★ Diagnostics
  - ★ Plasma control tools
  - ★ Run time