NSTX-U

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Progress and Plans for Macroscopic Stability

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PPPL – B318
June 11-13, 2014

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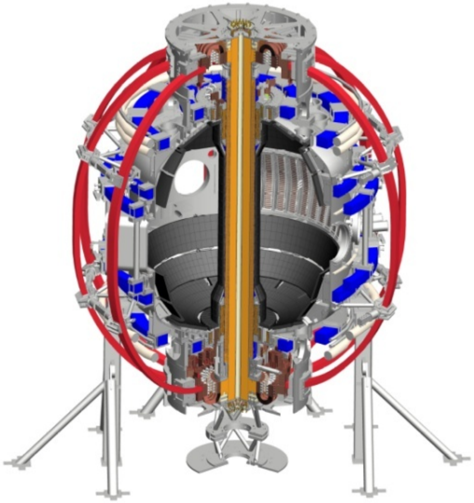

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Outline

- Introduction
  - Macroscopic stability (MS) group research in stability, 3D fields, and disruptions is key for NSTX-U, ITER, and FNSF
  - MS research is prominent in NSTX-U milestones as well as JRTs
- Progress in the last year – in preparation for upcoming run
  - Collaborations at KSTAR and DIII-D
  - Three main areas: Stability, 3D fields, and disruptions
  - Non-axisymmetric control coil (NCC) design
- MS research goals and plans for FY15
- MS research goals and plans for FY16
- Key results expected by the end of the FY16 run, and how they will impact further NSTX-U operation and future devices

Macroscopic stability research is crucial for the successful sustainment of high performance in future devices

1. Demonstrate 100% non-inductive sustainment at performance that extrapolates to ≥ 1MW/m^2 neutron wall loading in FNSF

5. Access reduced ν* and high-β combined with ability to vary q and rotation to dramatically extend ST physics understanding

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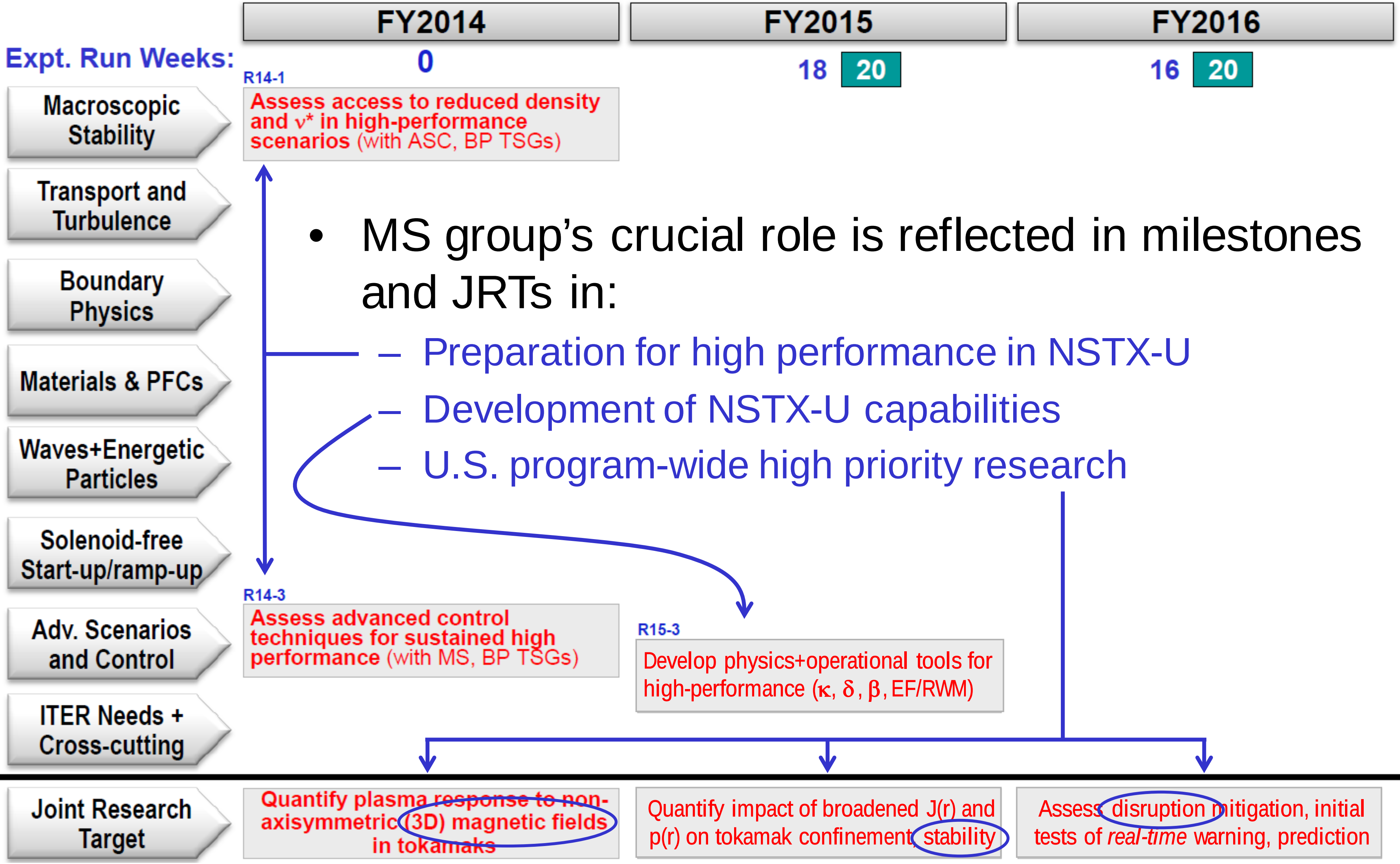
- Macroscopic stability research is in three key areas:
  - Thrust 1, Stability:

    Understand and advance passive and active feedback control to sustain macroscopic stability at low collisionality
  - Thrust 2, 3D Fields:

    Understand 3D field effects and provide physics basis for optimizing stability through equilibrium profile control by 3D fields
  - Thrust 3, Disruptions:

    Understand disruption dynamics and develop techniques for disruption prediction, avoidance, and mitigation in high-performance ST plasmas

Macroscopic stability research and capabilities play an instrumental role in the success of NSTX-U



FY2014 | FY2015 | FY2016

Expt. Run Weeks: 0 | 18 **20** | 16 **20**

Macroscopic Stability

Transport and Turbulence

Boundary Physics

Materials & PFCs

Waves+Energetic Particles

Solenoid-free Start-up/ramp-up

Adv. Scenarios and Control

ITER Needs + Cross-cutting

R14-1
Assess access to reduced density and ν^* in high-performance scenarios (with ASC, BP TSGs)

- MS group's crucial role is reflected in milestones and JRTs in:
  - Preparation for high performance in NSTX-U
  - Development of NSTX-U capabilities
  - U.S. program-wide high priority research

R14-3
Assess advanced control techniques for sustained high performance (with MS, BP TSGs)

R15-3
Develop physics+operational tools for high-performance (κ, δ, β, EF/RWM)

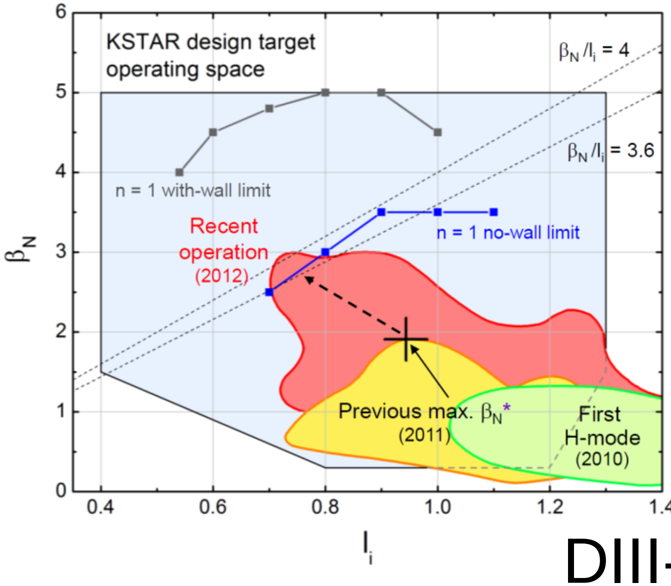
Joint Research Target

Quantify plasma response to non-axisymmetric (3D) magnetic fields in tokamaks

Quantify impact of broadened J(r) and p(r) on tokamak confinement, stability

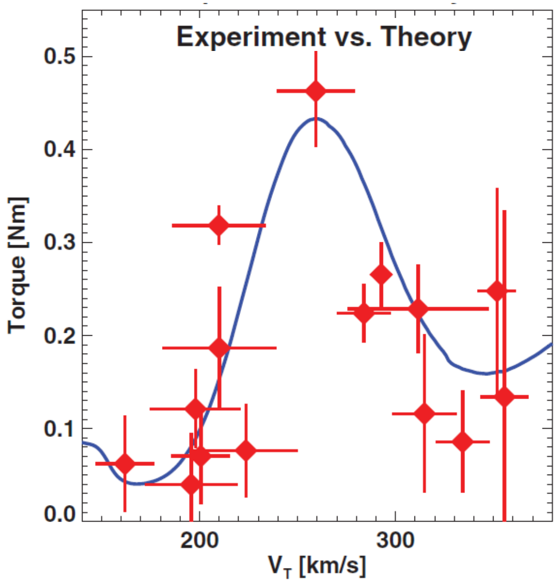
Assess disruption mitigation, initial tests of *real-time* warning, prediction

Collaborations at KSTAR and DIII-D support macroscopic stability research thrusts on NSTX-U

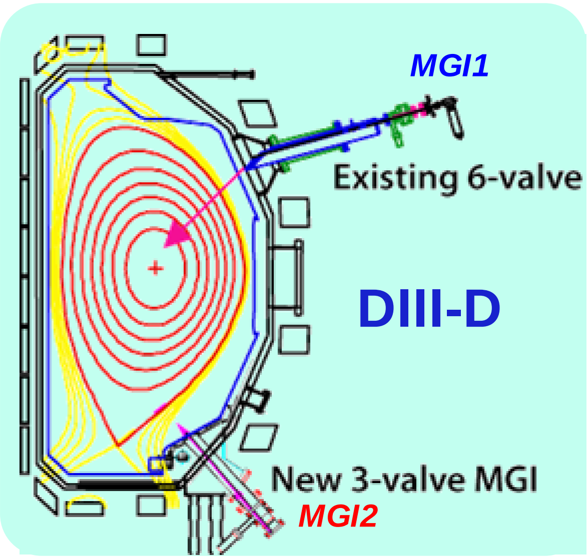


KSTAR collaboration

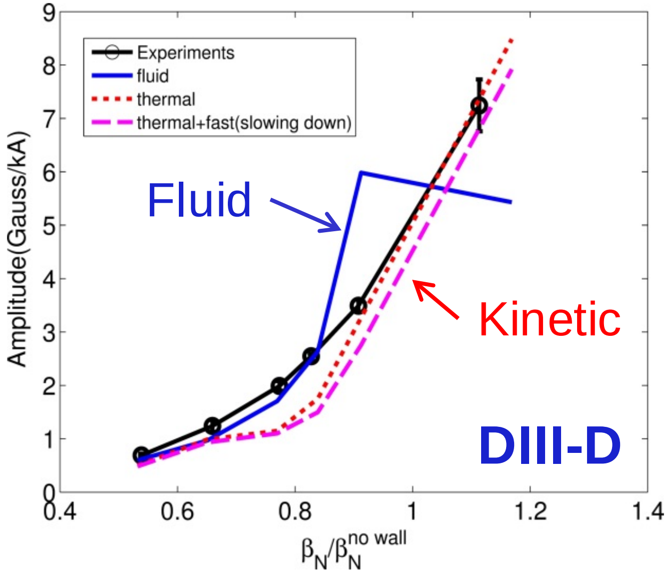
- Improved control and ran XPs accessing $\beta_N^{\text{no-wall}}$
- Pitch-crossing field drives n=1 NTV with bounce harmonic resonances
- Non-resonant NTV slows ω_φ (no hysteresis)



DIII-D collaboration



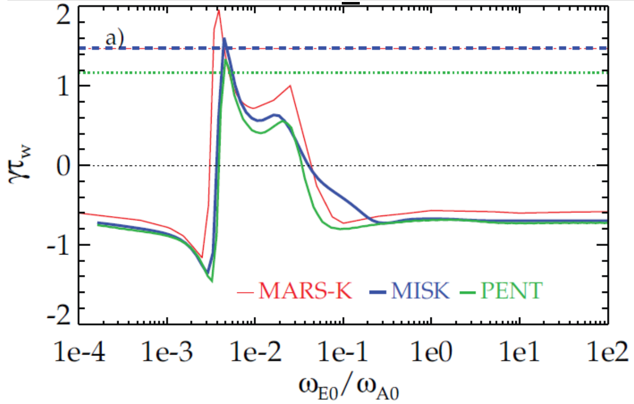
- Participated in radiation asymmetry campaign: # of injectors had little effect on TQ/CQ P_{rad} asymmetry
- Kinetic effects explain RFA experiments (MARS-K)
- XP and MISK calcs. to understand kinetic RWM stability and enable high β



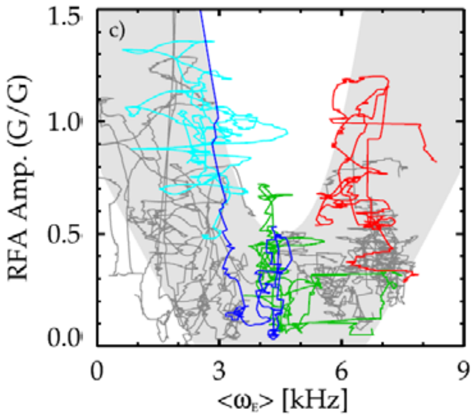
Kinetic stability theory and comparison to NSTX is setting the stage for practical use in NSTX-U for disruption avoidance

– Moving kinetic RWM stability theory from successful theory/experiment comparison to actual implementation
  - MISK (perturbative) benchmarked with other leading codes
  - A simplified model based on these results will be implemented in the NSTX-U disruption avoidance algorithm

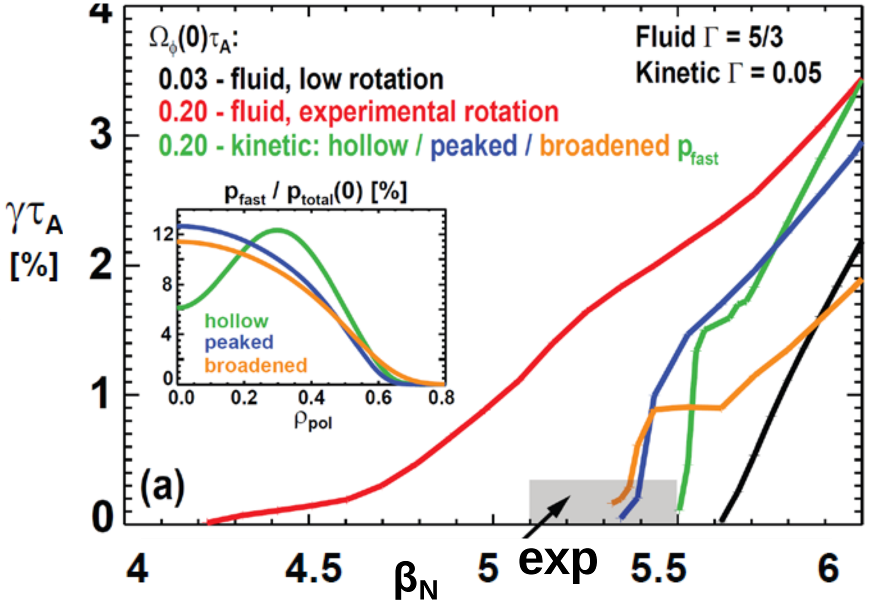
Growth rate vs. ω_E for ITER case



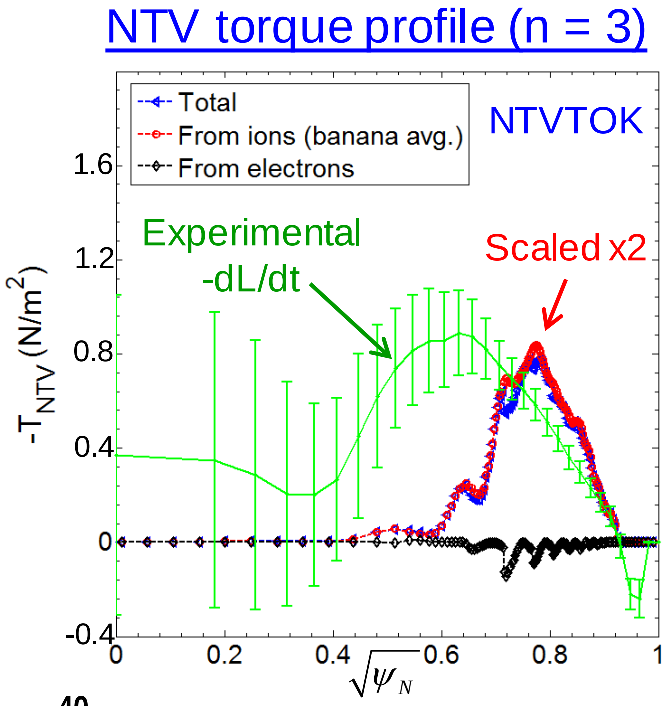
Instability measure (RFA) vs. exp. ω_E for NSTX

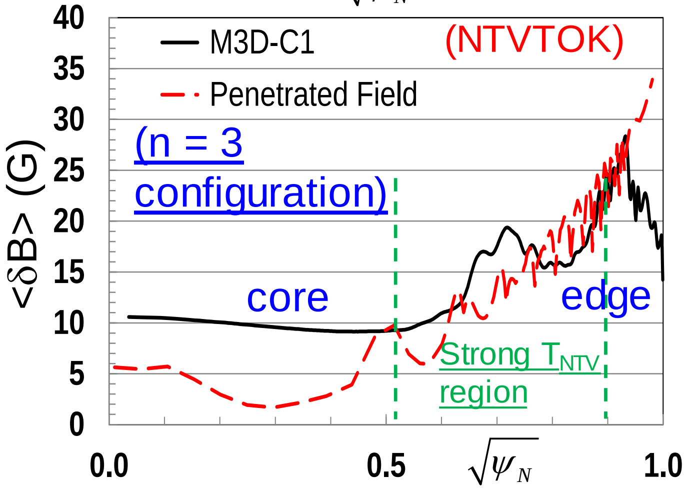


– Ideal Wall Mode destabilization by rotational shear vs. stabilization by kinetic effects explained with MARS-K
  - Also may help explain low-density/ramp-up disruptions in NSTX in prep for low ν operation (fast ions important)



Non-resonant Neoclassical Toroidal Viscosity (NTV) physics analysis progresses, will be used for rotation feedback control





- Leading theory/codes under active development
  - IPEC-PENT, MARS-K, MARS-Q, and POCA (δf guiding-center particle code) have been benchmarked

- NTVTOK code analysis
  - NTVTOK modified, incl. Shaing's connected NTV model, covers all ν, superbanana plateau regimes (like MARS-Q)
  - Full 3D geometry and coil, ion & ele. effects
  - Plasma response from penetrated 3D field used in exp. analysis matches M3D-C^1 single fluid model
  - FY14: Analyzing NTV data from 6 experiments on ν dependence and other NTV characteristics

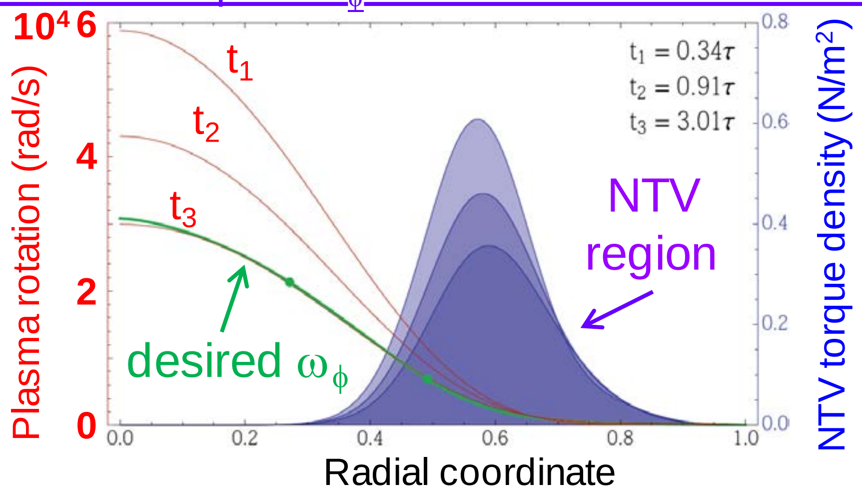
(Columbia U., GA)

JRT-14

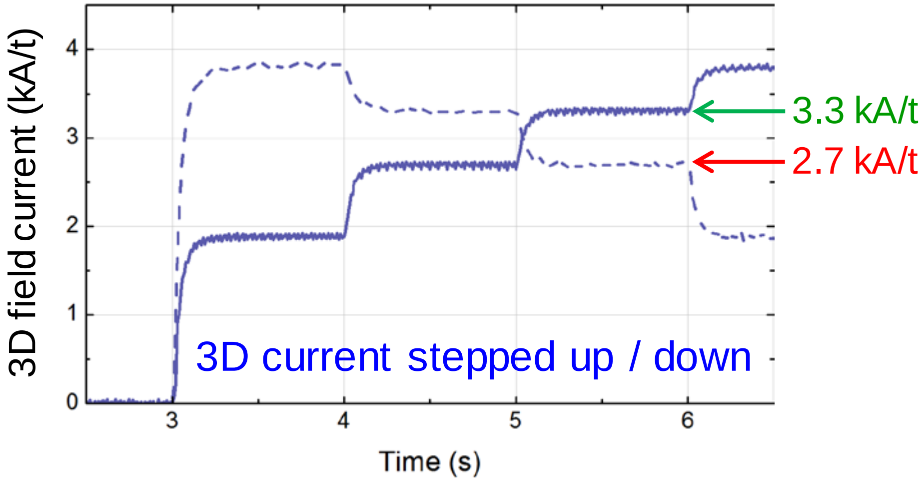
Rotation feedback controller using NTV designed; supported by key results from international collaboration research

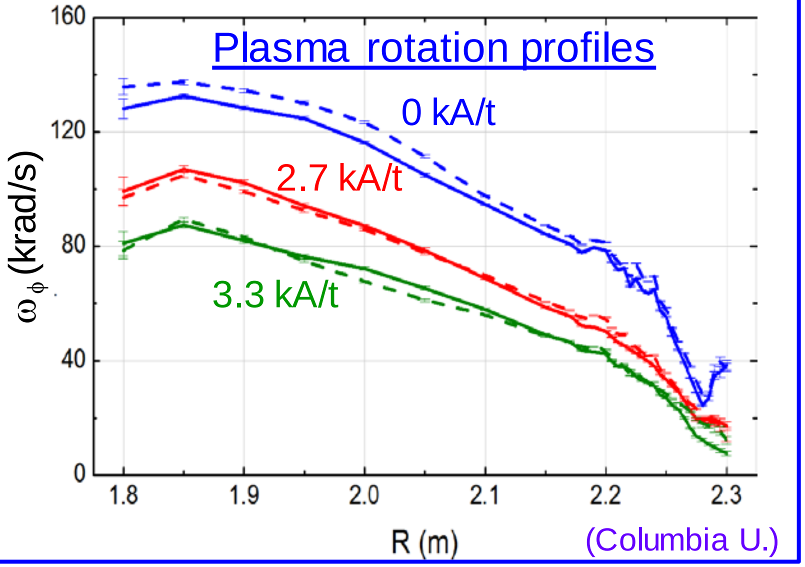
- NSTX-U controller will use Neoclassical Toroidal Viscosity (NTV) physics for the first time in rotation feedback control
- Dedicated long-pulse KSTAR experiments show no hysteresis in ω_ϕ profile vs. applied 3D field strength (important for control)

NSTX-U state-space ω_ϕ controller w/NTV as actuator



KSTAR non-resonant ("n = 2") NTV experiments

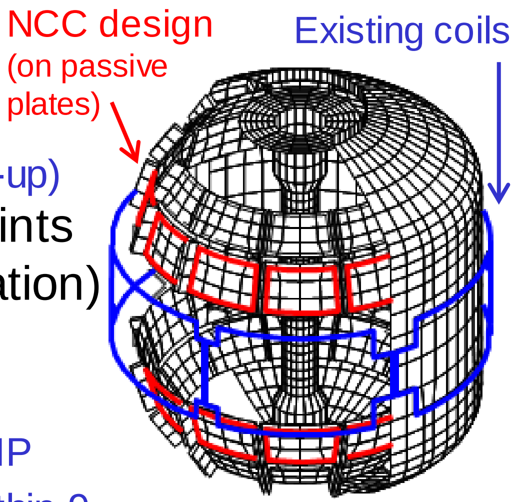



Plasma rotation profiles

(Columbia U.)

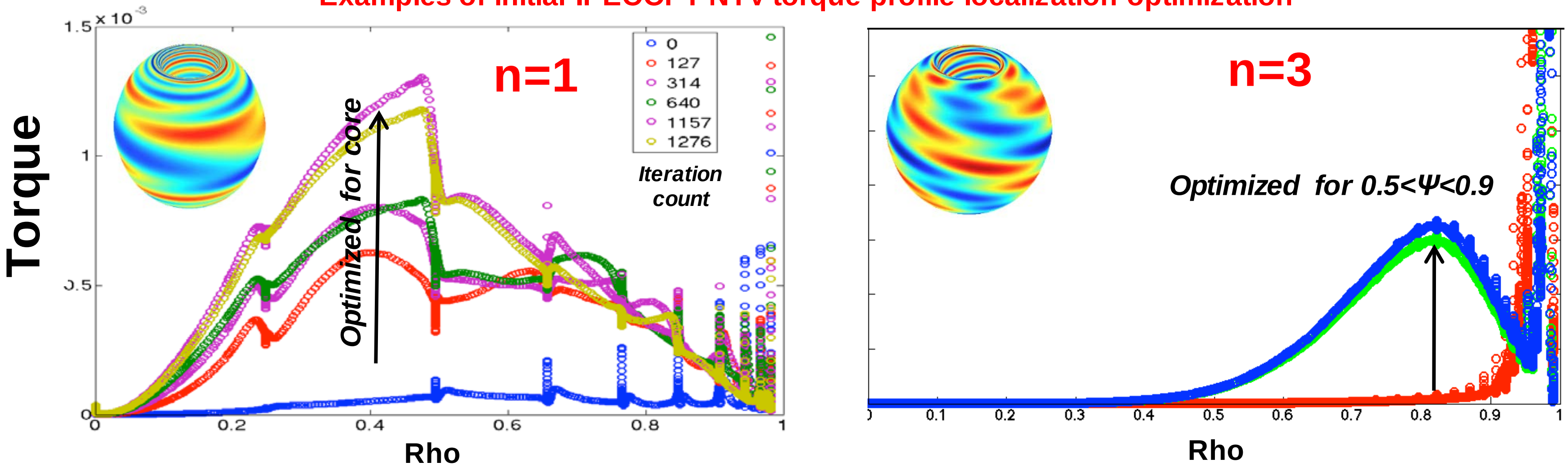
Non-axisymmetric control coils (NCC) (incremental) will enhance physics studies and control

- NCC designed with multiple physics metrics for error field, RWM, rotation control by NTV, and RMP characteristics
  - Analysis updated with IPEC-PENT and more NSTX-U targets (see back-up)
- Now utilizing stellarator optimization tools without coil constraints to determine theoretical max performance (PAC recommendation)
  - The IPECOPT code developed (from STELLOPT) to optimize IPEC equilibrium for core and edge NTV Torque
  - IPECOPT will be extended to analyze additional figures of merit: EF, RMP
  - Deliverable: assess physics benefits of potentially improved coil sets within 9 months to drive subsequent engineering analysis



PPPL Theory Partnership, JRT-14

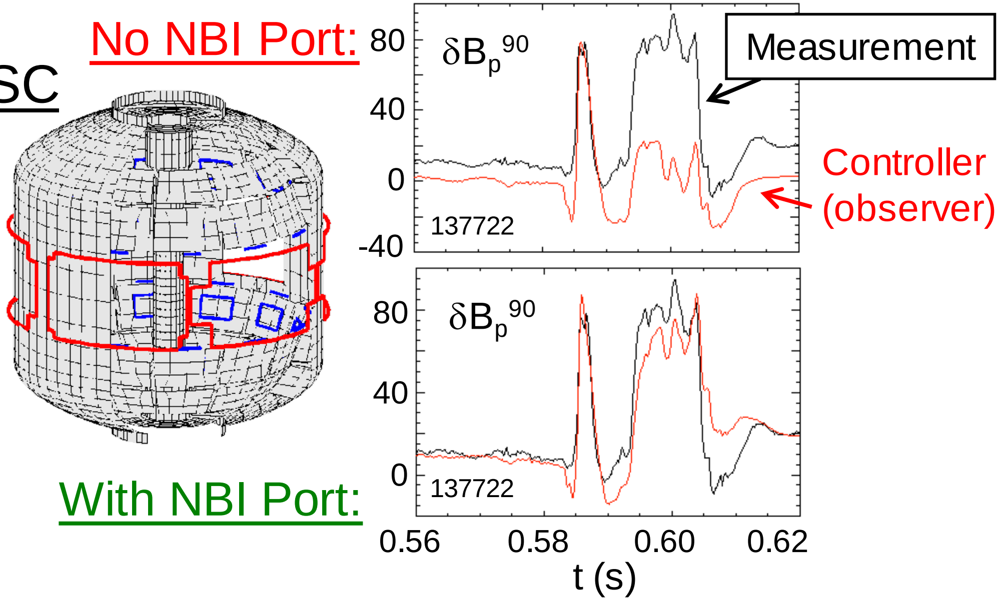
Examples of initial IPECOPT NTV torque profile localization optimization

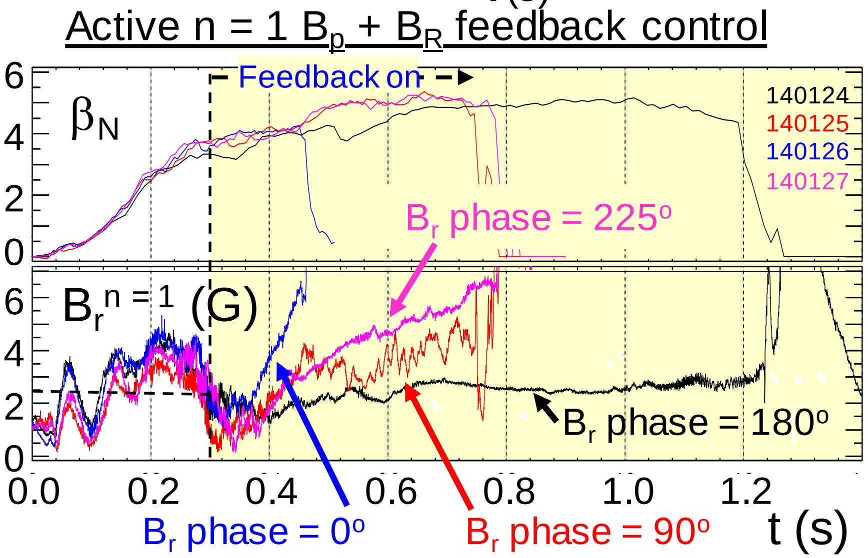


Active control techniques ($B_r + B_p$, RWM state-space (RWMSC)) will enable long pulse, high β operation

- FY14:
  - Offline RWMSC already expanded for 6 coil control and n > 1 physics
    - Now comparing past 3 coil algorithm with open-loop 6 coil tests in generalized code
- Stability plans, FY15:
  - EFIT, available Day 0
    - New parallel CPUs implemented, increased between-shots spatial / time resolution
  - Examine RWMSC with:
    - six control coils and multi-mode control with n up to 3
  - Establish $B_r + B_p$ active control capability in new operational regime

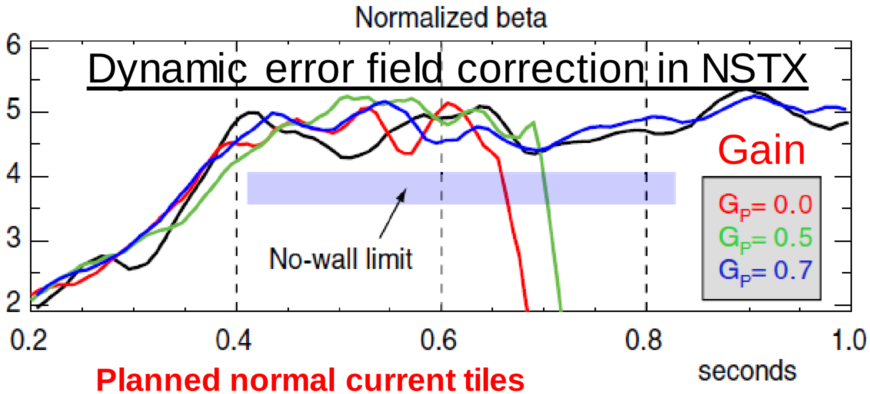
JRT-16



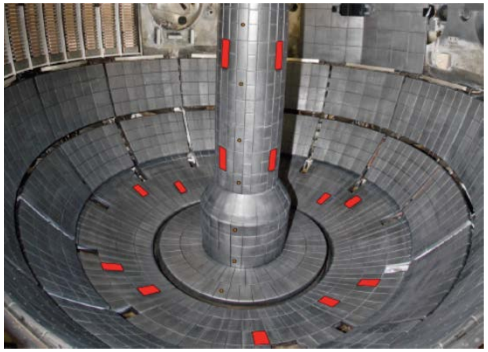


Correction of intrinsic error fields is critical for performance; NSTX-U will have new disruption research capabilities

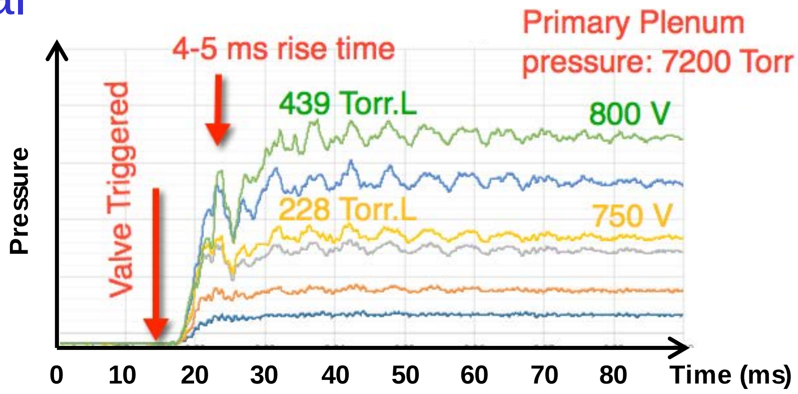
- 3D fields research plans, FY15:
  - Assess intrinsic EFs in NSTX-U
  - Optimize dynamic EF correction, including n>1 and using 6 SPAs and RWMSC
  - Resonant EF effects on tearing mode onset (+Resistive DCON)
- Disruption research plans, FY15:
  - FY14: substantial contributions to the ITPA disruption database
  - Investigate halo current toroidal asymmetry and loading on the center column, using 18 newly installed shunt tiles
  - Commission MGI system
    - ITER-like valves tested to pressure above spec: fast rise time



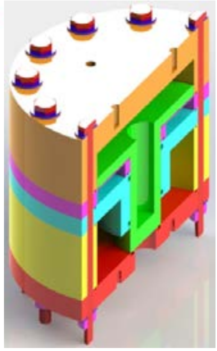
Planned normal current tiles



PPPL Theory: optimal sensor position/type

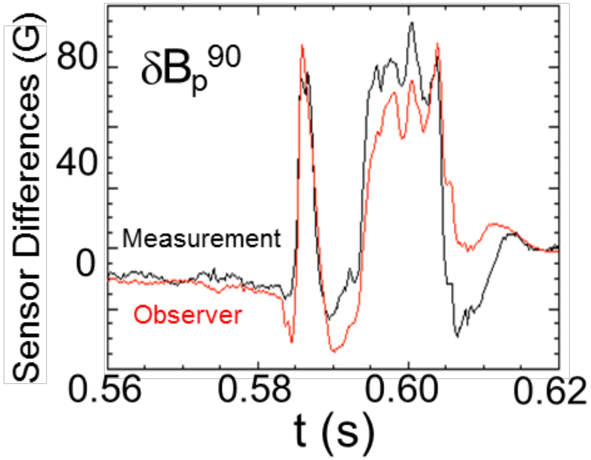


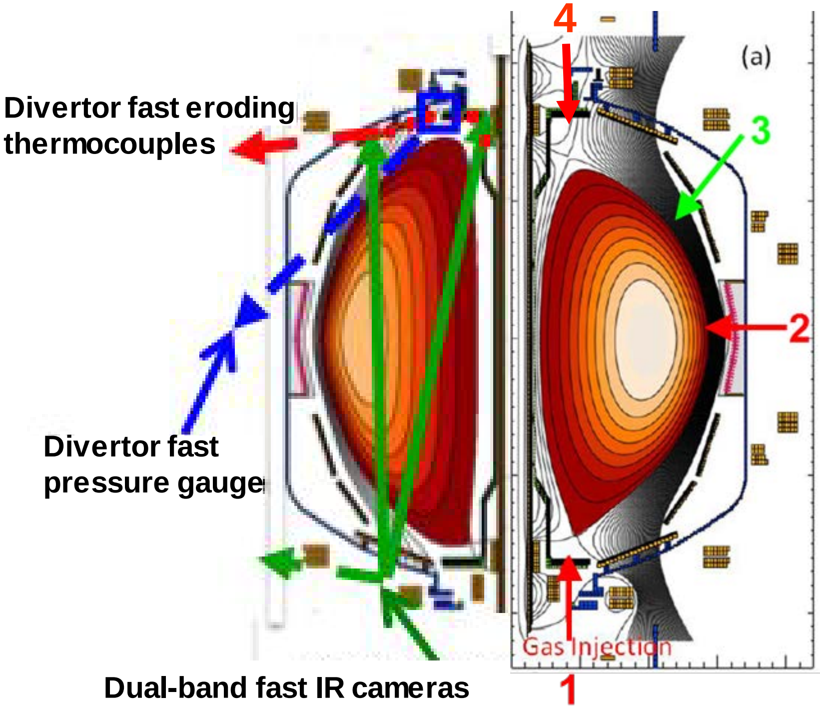
NSTX-U ITER-like MGI Valve



Disruption prediction by multiple means will enable avoidance via profile or mode control or mitigation by MGI

- Disruption research plans, FY16:
  - Compare the mismatch between the RWMSC observer model and sensor measurements, and disruption occurrence
  - Study spatial extent and timing of the heat deposition during VDEs
    - Eroding thermocouples and new IR cameras
  - Characterize density assimilation vs. poloidal location of MGI system
    - JRT-16 support, DEGAS-2 modelling
    - Valves in poloidal location 2 & 3 identical to location 1 or 4 (locations 1, 2 & 4 for FY15)
    - Injection into the private flux region is possible





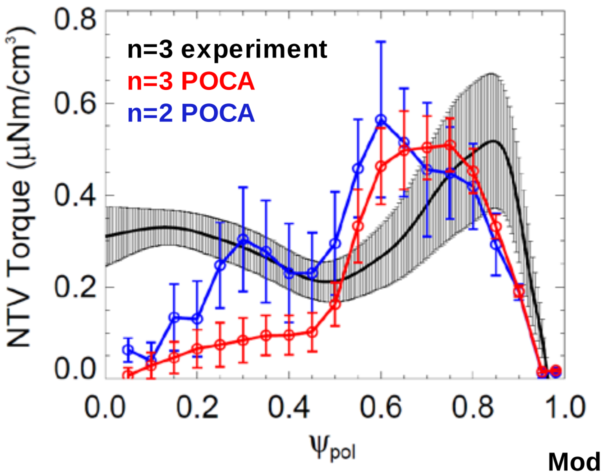
Divertor fast eroding thermocouples

Divertor fast pressure gauge

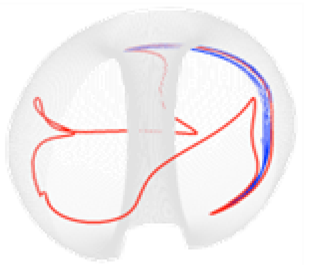
Dual-band fast IR cameras

NSTX-U will investigate NTV and stability theory in lower ν regime for implementation in active rotation control

- 3D fields plans, FY16:
  - Assess NTV profile and strength at reduced ν, examine NTV offset rotation at long pulse, at zero torque
  - Prepare an initial real-time model of NTV profile for use in initial tests of the plasma rotation control system **JRT-16**

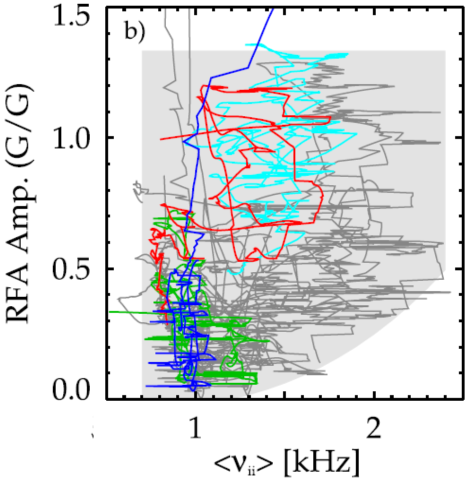


NSTX -> NSTX-U (Bounce freq. ↑, Collisionality ↓)



Modified bounce orbits may be strongly resonant at low collisionality

- Stability plans, FY16:
  - Examine RWMSC with rotational stabilization in the controller model
  - Investigate the dependence of stability on reduced ν through MHD spectroscopy; compare to kinetic stabilization theory



Summary: MS research during FY2015-16 will enable long-pulse high performance in NSTX-U and future devices

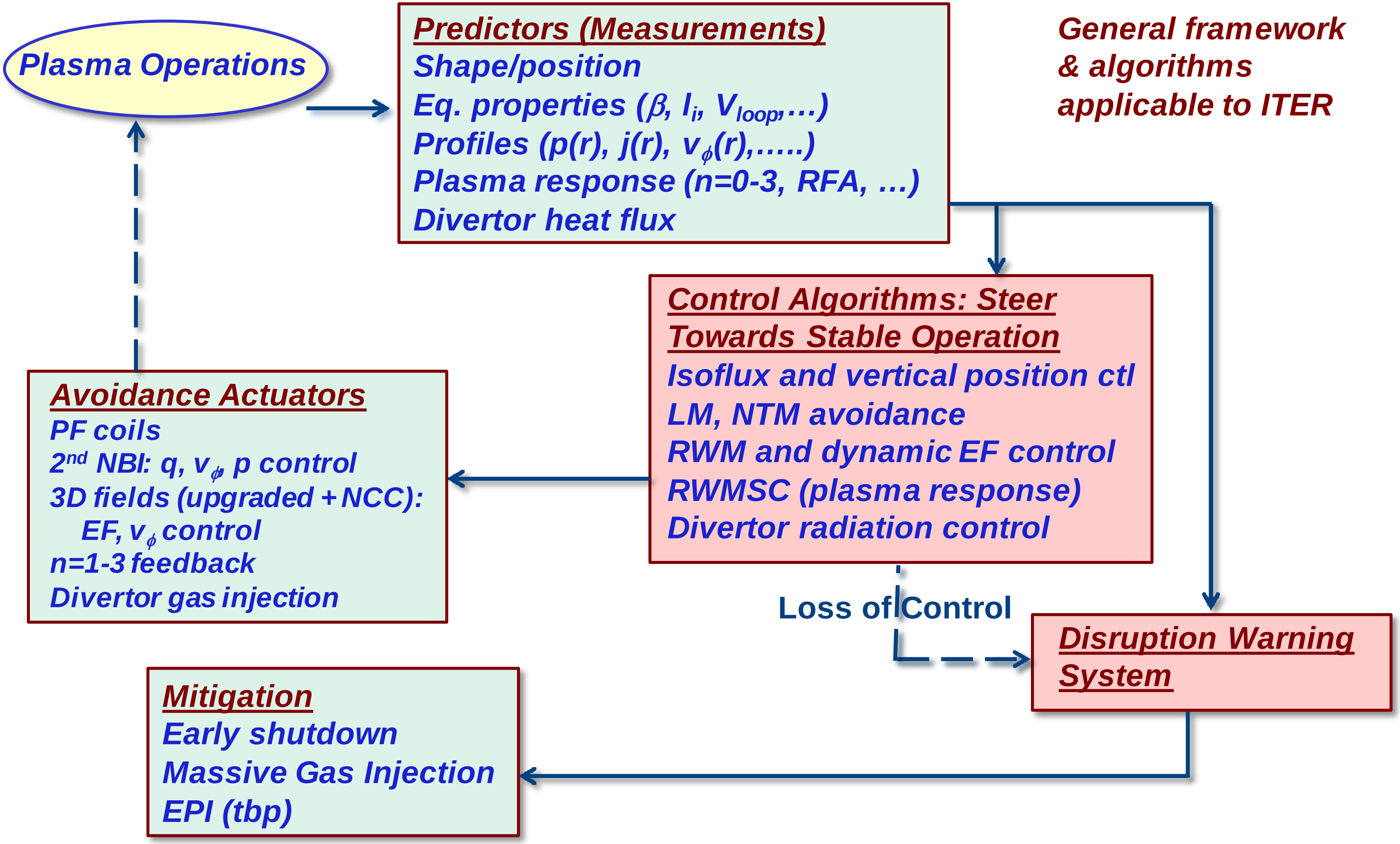
- Advancing passive stability and active feedback control will be integrated into a disruption avoidance system, allowing us to sustain macroscopic stability in the new low collisionality regime

- Understanding 3D field effects will provide a physics basis for optimizing stability through new capabilities of equilibrium profile control

- Understanding disruption dynamics, and development of techniques for disruption prediction, avoidance, and mitigation in high-performance ST plasmas will be greatly beneficial to future devices

Backup

Disruption prediction by multiple means will enable avoidance via profile or mode control or mitigation by MGI



Plasma Operations

Predictors (Measurements)

Shape/position

Eq. properties (β, l_i, V_{loop},…)

Profiles ($p(r)$, $j(r)$, $v_\phi(r)$,…..)

Plasma response (n=0-3, RFA, …)

Divertor heat flux

General framework & algorithms applicable to ITER

Control Algorithms: Steer Towards Stable Operation

Isoflux and vertical position ctl

LM, NTM avoidance

RWM and dynamic EF control

RWMSC (plasma response)

Divertor radiation control

Avoidance Actuators

PF coils

2^{nd} NBI: q, v_ϕ, p control

3D fields (upgraded + NCC):

EF, v_ϕ control

n=1-3 feedback

Divertor gas injection

Loss of Control

Disruption Warning System

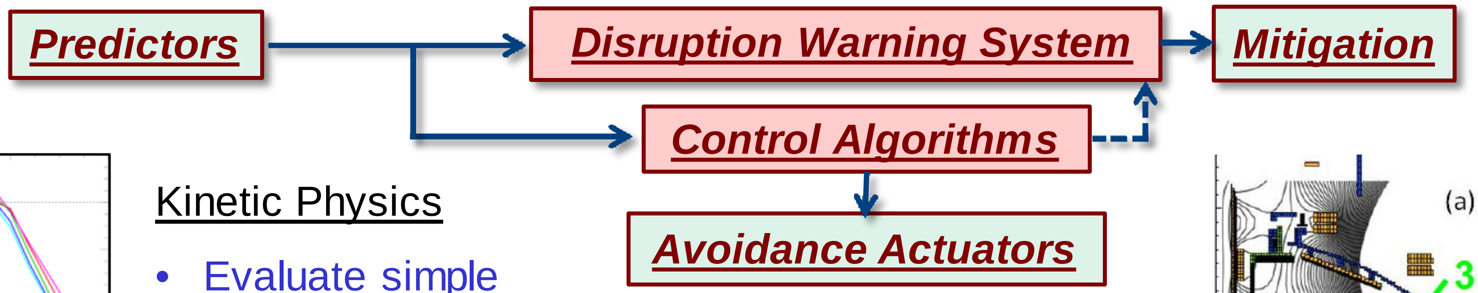
Mitigation

Early shutdown

Massive Gas Injection

EPI (tbp)

Disruption prediction by multiple means will enable avoidance via profile or mode control or mitigation by MGI (2)



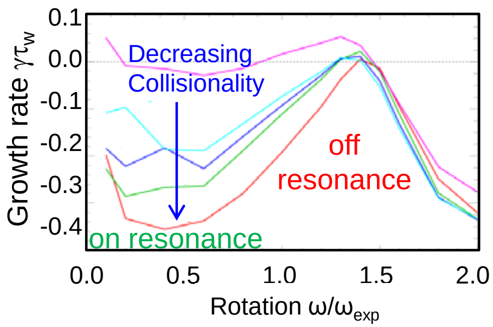
Predictors

Disruption Warning System

Mitigation

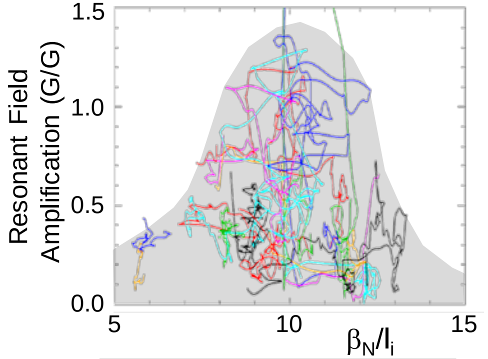
Control Algorithms

Avoidance Actuators



Kinetic Physics

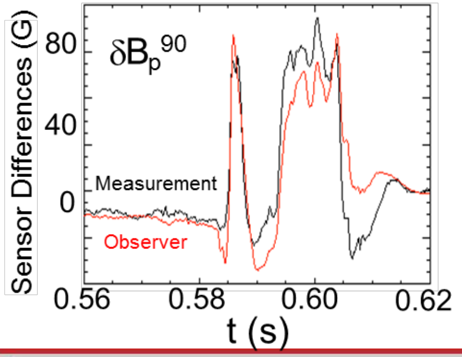
- Evaluate simple physics criteria for global mode marginal stability in real-time



MHD Spectroscopy

- Use real-time MHD spectroscopy while varying rotation, q_{min}, and β_N to predict disruptions

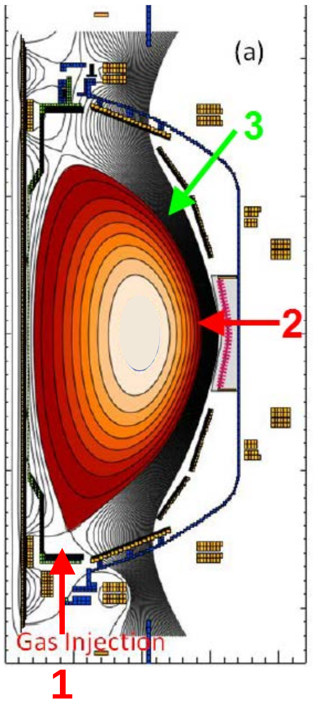
q, v_ϕ, β_N control



RWMSC observer

- Compare mismatch between the RWMSC observer and sensor measurements, and disruption occurrence

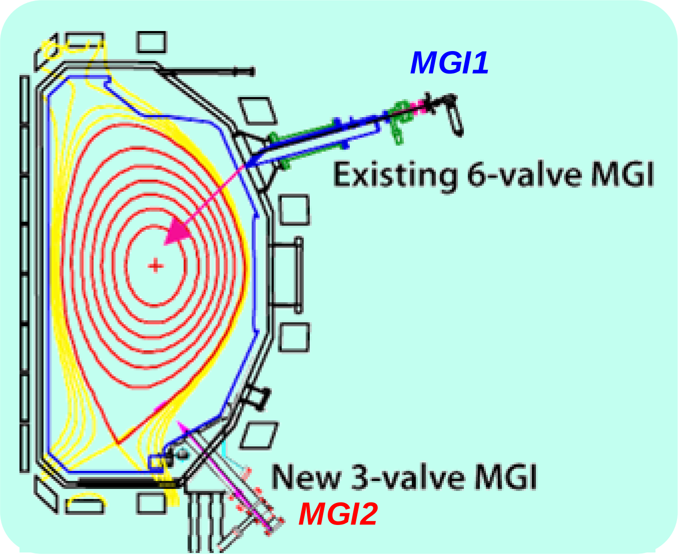
3D fields, feedback



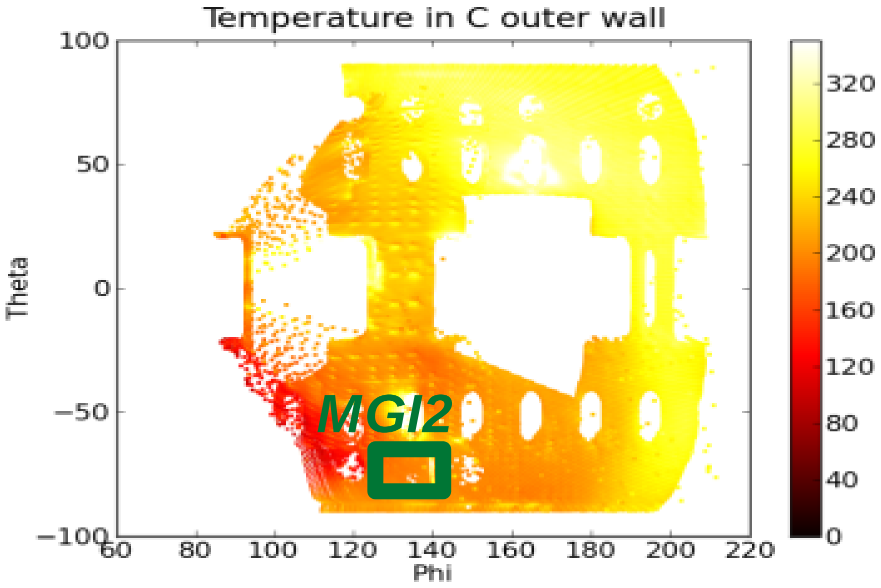
<u>ITER gas-loading :</u>

Injection into private flux region with higher assimilation efficiency?

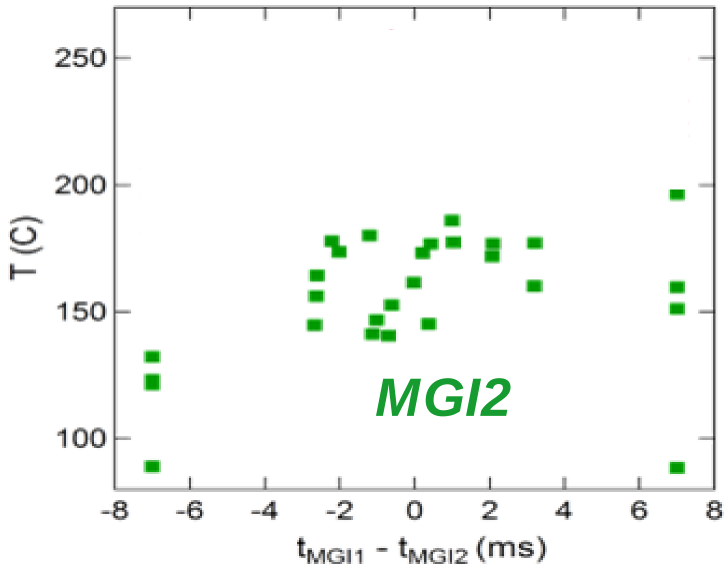
Participated in DIII-D National Campaign on Radiation Asymmetry XP



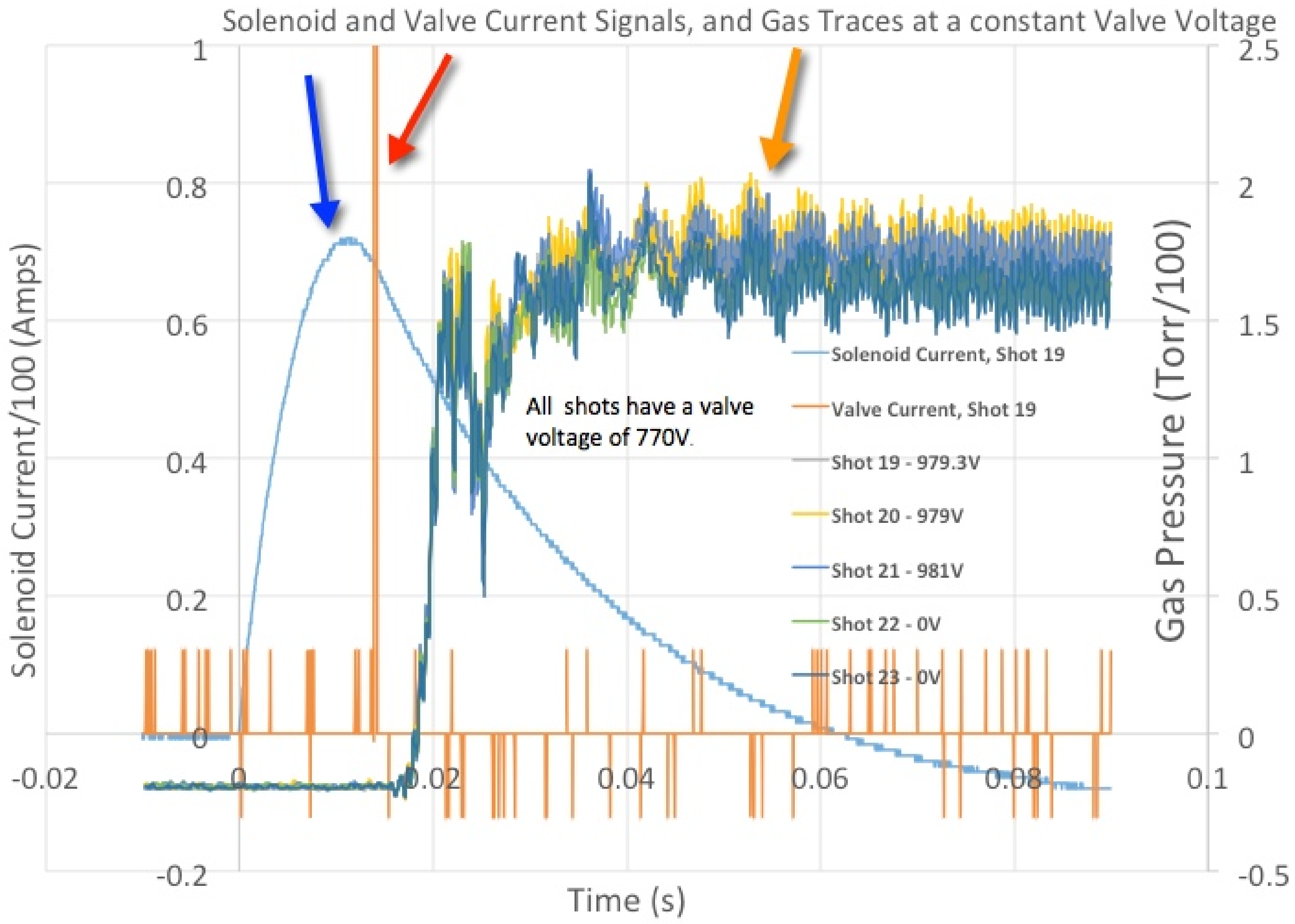
- Thermal imaging indicates MGI location cooler than nearby wall
  - ITER concerned about localized melting near gas injection port location
- # of injectors had little effect on TQ/CQ P_{rad} asymmetry
  - No significant variation with valve delay



N.W. Eidietis, et al, G04-2, APS2013



Valve has same time response for operation in <0.4T magnetic fields



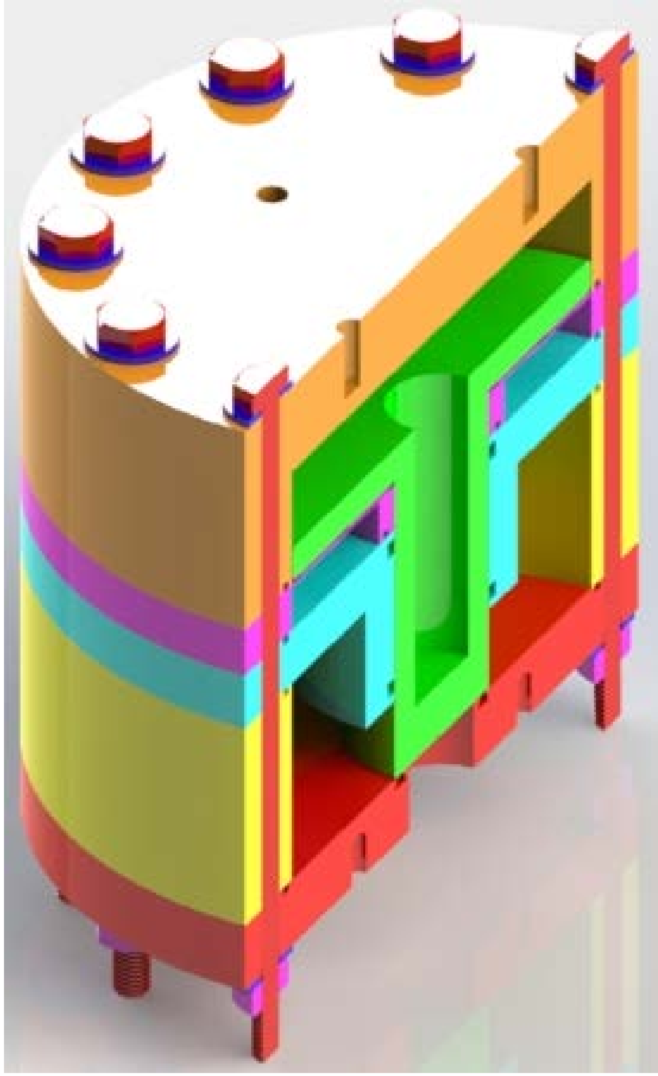
Shots 19,20, 21 are with solenoid energized

Shots 22 and 23 are comparison shots without solenoid

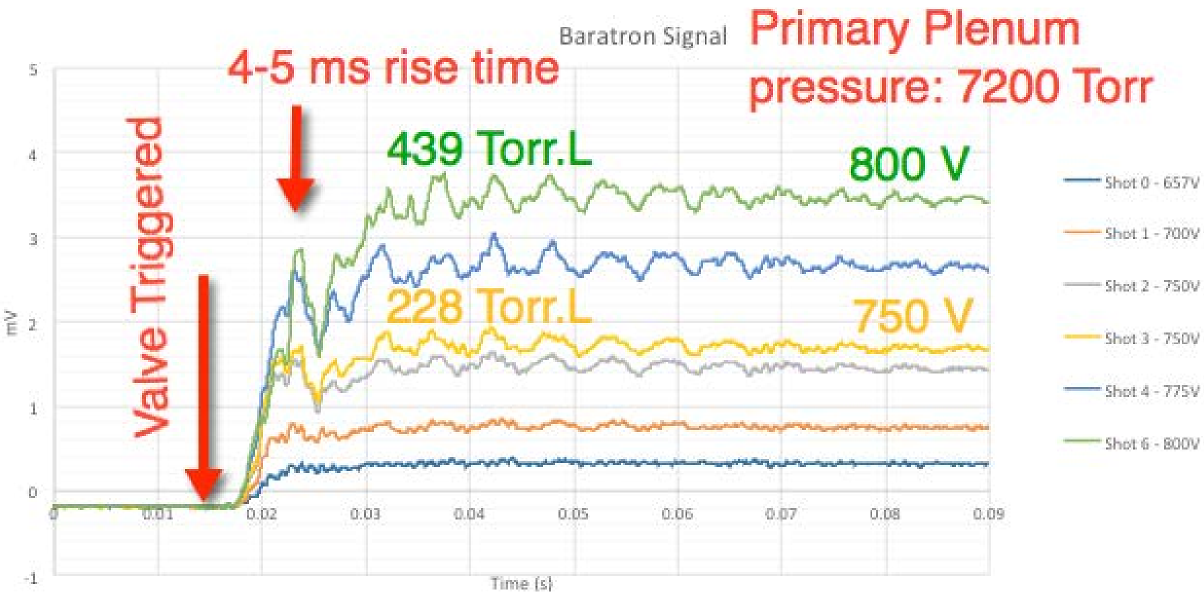
- **Vacuum solenoid field is 0.67T**
- **Skin depth in Al is 2.2cm, valve wall thickness is 1cm. Fields inside valve side wall ~0.4T**
- **Future tests will use SS304L valve and further slow down solenoid current waveform**

ITER-like MGI Valve Designed, Built and Tested for Installation on NSTX-U

NSTX-U MGI Valve

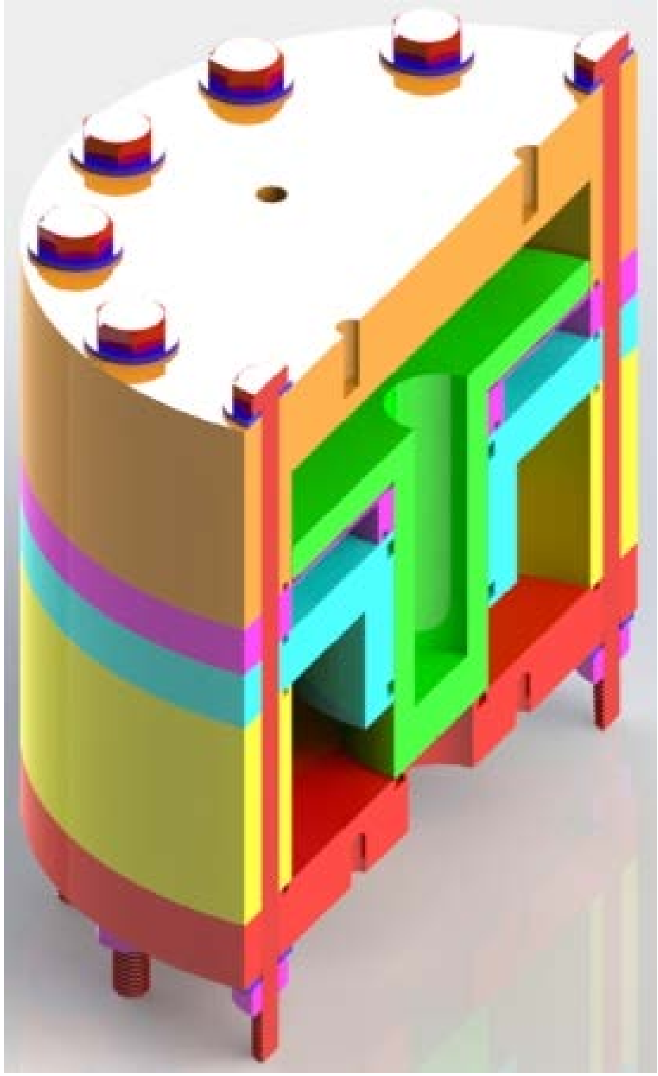


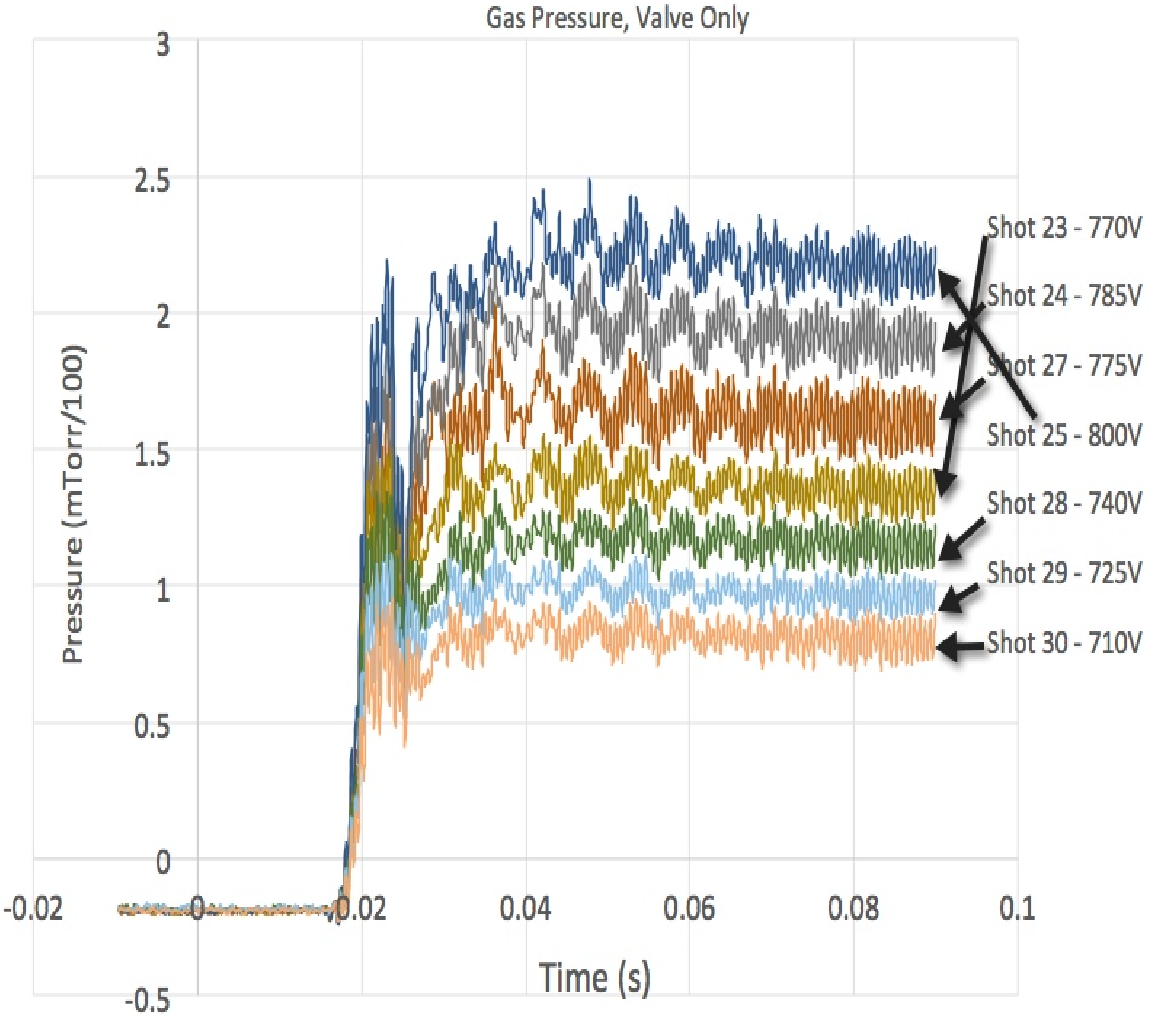
- FY15 MGI Research Plans
  - Operate valves at ~5000 Torr (200 Torr.L Neon)
  - Compare mid-plane and PFR locations for gas assimilations studies using identical gas injection set-up
  - Possible Poloidal injection effect on VDE (multi-machine experiment with DIII-D & C-MOD)
  - 3 valves to be installed for FY15 Experiments



Version 4 Valve evacuates into chamber in < 3ms, for gas injection amounts of 200 Torr.L N_2

NSTX-U MGI Valve





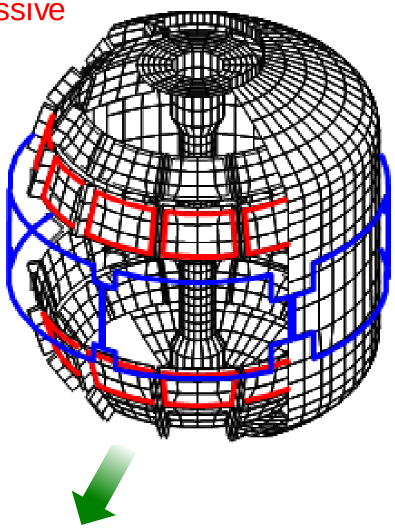
Physics analysis for Non-axisymmetric Control Coil (NCC) has been updated with IPEC-PENT and more NSTX-U targets

- NTV calculations are updated using IPEC-PENT, without previous large-aspect-ratio approximation and pitch-angle simplification
  - In NSTX and NSTX-U, PENT torque is typically larger than previous analysis by a factor of 2~3
- 1.5MA~2MA NSTX-U targets were studied
  - 2x6-odd is better than 12U or 2x6-even in general, but its advantages decrease when I_P= 1.5➔2MA
  - FOM table updated accordingly (Purple : 2MA)

Figures of Merit	**Favorable values**	**MID**	**12U**	**2x6-Odd**	**2x12**
EF (n=1) $F_{N-R} \equiv \frac{T_{NTV}}{\sum_{\psi_N<0.85} \delta B_{mn}^2}$	**High F_{N-R}**	**0.07**	**0.13**	**1.24**	**1.24**
RWM (n=1) $F_\beta \equiv \frac{\beta_{active}}{\beta_{no-wall}}$	**High F_β**	**1.25**	**1.54**	**1.61**	**1.70**
NTV (n≥3) $\Delta\left(F_{N-N} \equiv \frac{T_{NTV}(\psi_N < 0.5)}{T_{NTV}(\psi_N < 1)}\right)$	**Wide ΔF_{N-N}**	**1.00**	**1.44~6.08**	**1.75~11.33**	**6.38~59.4**
RMP (n≥3) $F_{N-C} \equiv \frac{\left(C_{vacuum,\psi_N=0.85}\right)^4}{T_{NTV}}$	**High F_{N-C}**	**0.25~0.30**	**0.31~1.04**	**0.43~0.77**	**1.18~3.53**
	Wide ΔF_{N-C}	**1.00**	**2.20~12.3**	**10.4~17.4**	**888~14400**

Non-axisymmetric Control Coil (NCC) capability on NTV braking has been successfully studied with STELLOPT

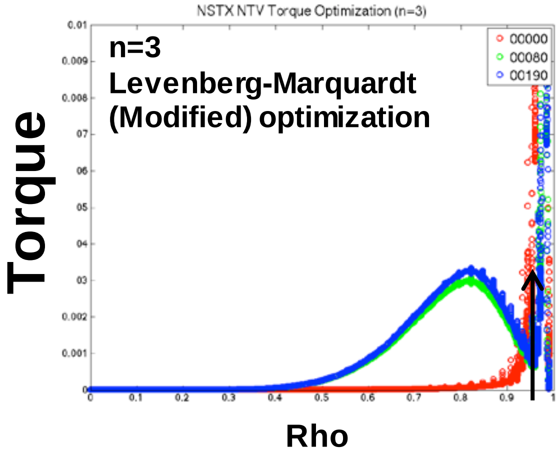
- The IPECOPT code has been developed from STELLOPT to optimize IPEC equilibrium for NTV Torque
  - Initial attempts focus on variation of boundary harmonics for core and edge torque
  - The applied n=1 spectrum shows the possibility to drive core (rho < 0.5) torque while minimizing edge torque
  - The applied n=3 spectrum shows the ability to drive a broad edge torque



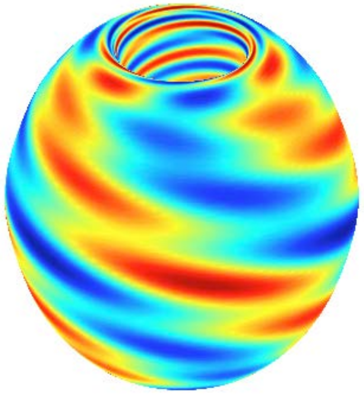
NCC design (on passive plates)

Existing coils

Unconstrained

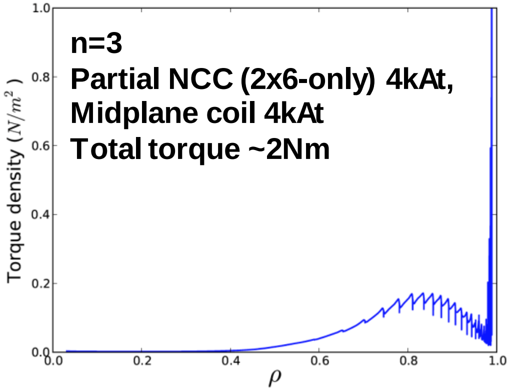


n=3
Levenberg-Marquardt (Modified) optimization

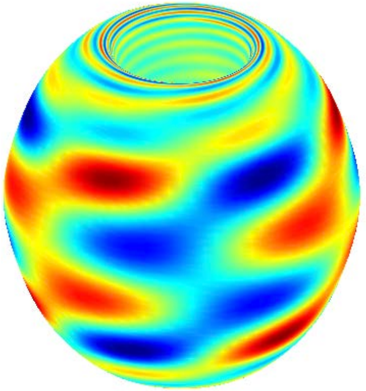


Total normal δB on the plasma boundary

Constrained to partial NCC + Midplane coil

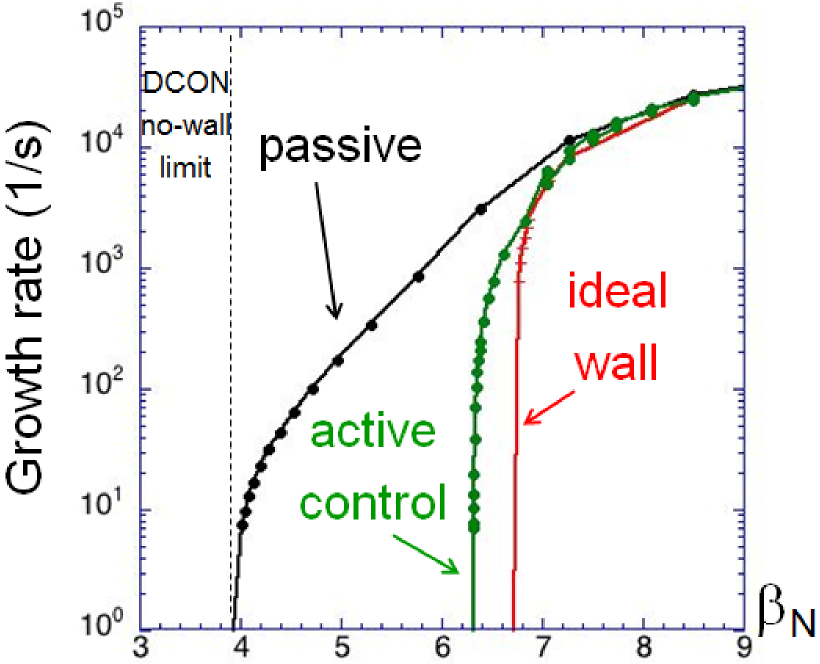


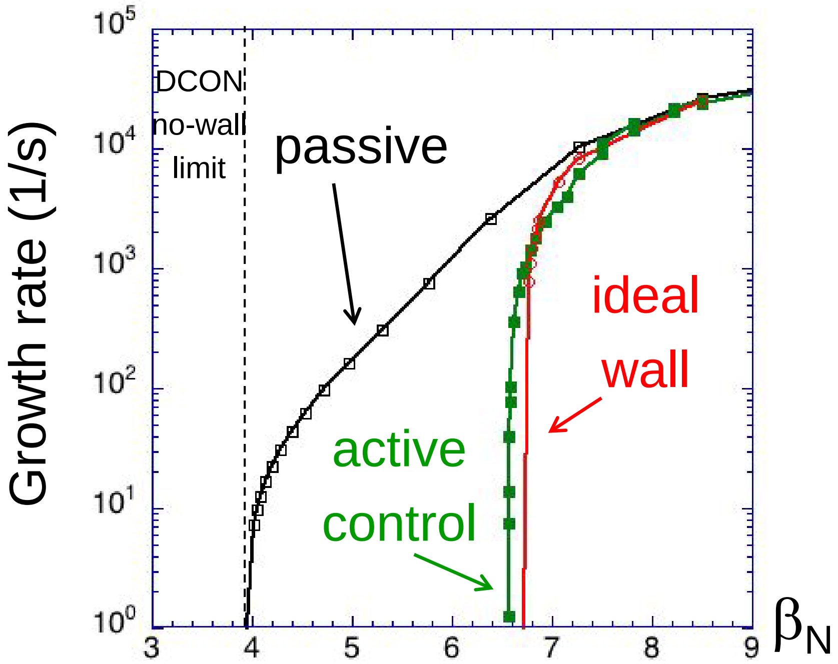
n=3
Partial NCC (2x6-only) 4kAt,
Midplane coil 4kAt
Total torque ~2Nm



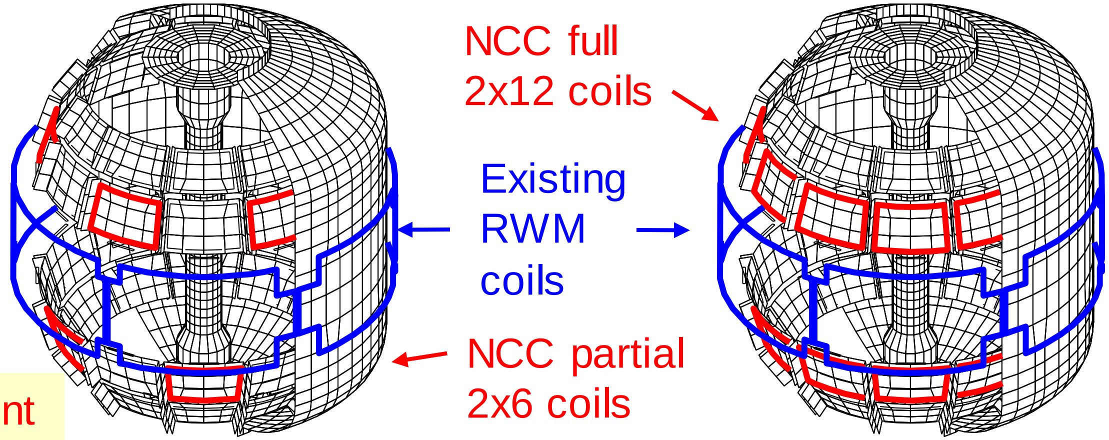
PPPL Theory Partnership, JRT-14

RWM active control capability of the NCC continues to be assessed


NCC 2x6 odd parity, with favorable sensors


NCC 2x12 with favorable sensors, optimal gain

- Full NCC coil set allows control close to ideal wall limit
  - NCC 2x6 odd parity coils: active control to $\beta_N/\beta_N^{\text{no-wall}} = 1.61$
  - NCC 2x12 coils, optimal sensors: active control to $\beta_N/\beta_N^{\text{no-wall}} = 1.70$
  - (RWM coil $\beta_N/\beta_N^{\text{no-wall}} = 1.25$)
- Design now needs sensor assessment


NCC full 2x12 coils

Existing RWM coils

NCC partial 2x6 coils

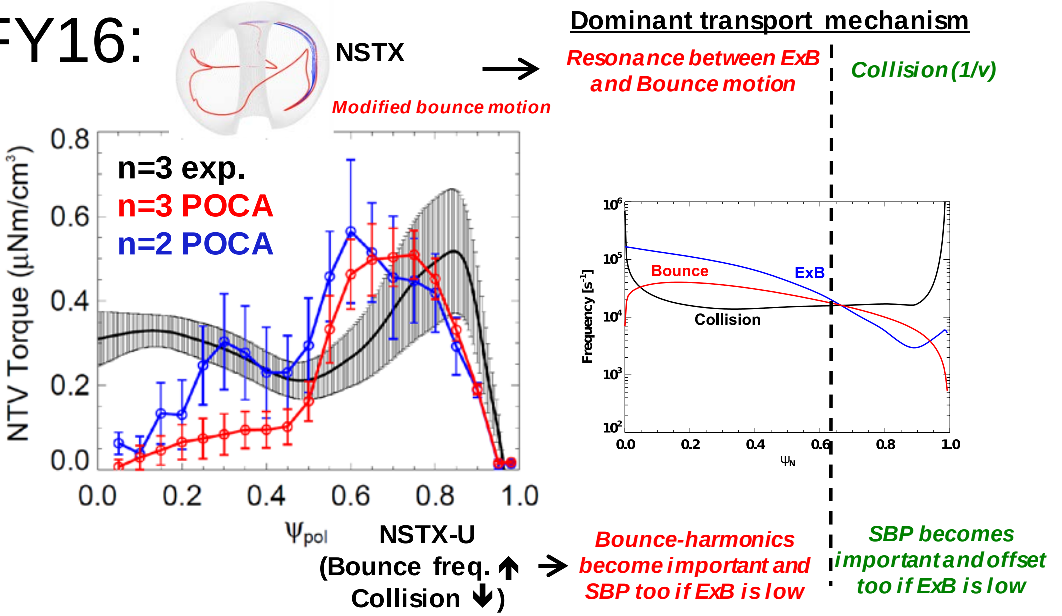
Extensive benchmark among various NTV codes has been active and successful

- There are three main branches in semi-analytic NTV codes as described in details below
- All three have been successfully benchmarked
- A particle code POCA also shows consistent trends with semi-analytic NTV codes, with some quantitative differences depending on regimes

Connected NTV formula	**Combined NTV theory**	**Drift kinetic energy theory**
• Analytic NTV formulation is derived in the collisionality regimes, SBP, ν-√ν regime and 1/ν regime separately. • Pade approximation to smoothly connect the formulations in different colisionality regimes.	• NTV torque due to different particle motions are combined by a generalized equation. • No need to separate the collisionality regimes	• Drift kinetic energy is studied to determine ideal MHD instabilities e.g. Resistive Wall Modes. • The torque is calculated based on the equivalence between NTV torque and drift kinetic energy. $T_\Phi=2in\delta W_K$
Precession resonance	Precession resonance + Bounce-harmonic resonance	
Pitch angle scattering collisional operator (accurate in the ν-√ν regime)	Krook collisional operator (allows to derive one generic equation of NTV torque and drift kinetic energy)	
Geometric simplification	Full toroidal geometry	
MARS-Q	IPEC-PENT	MARS-K
Liu and Sun, PoP **20** (2013) 022505 Sun et al, NF **51** (2011) 053015 Shaing et al, NF **50** (2010) 025022	Park et al, PRL **102** (2009) 065002 Logan et al, PoP **20** (2013) 122507	Park, PoP **18** (2011) 110702 Liu et al, PoP **15** (2008) 112503

In lower ν regime, NSTX-U will investigate NTV for rotation control and stability theory implemented in active control

- 3D fields research plans, FY16:
  - Assess NTV profile and strength at reduced ν and examine the NTV offset rotation at long pulse
  - Prepare an initial real-time model of NTV profile for use in initial tests of the plasma rotation control system



Dominant transport mechanism

NSTX →

Resonance between ExB and Bounce motion

Collision (1/ν)

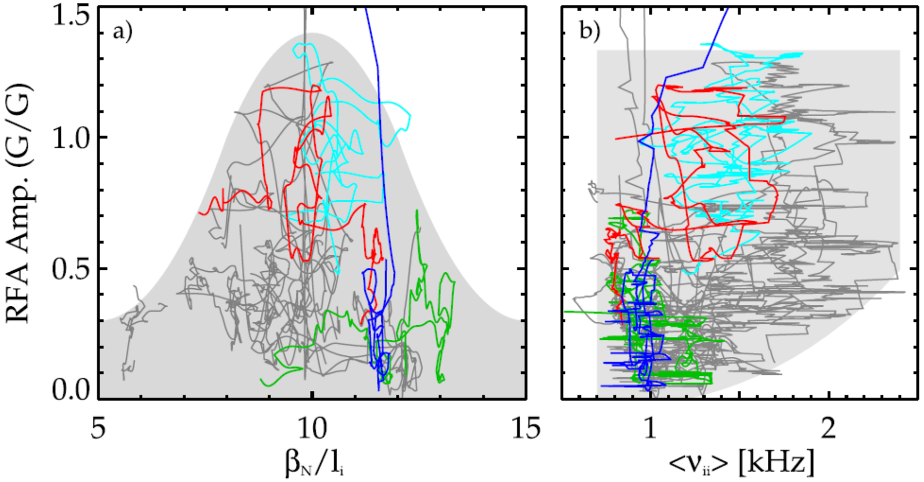
Modified bounce motion

NSTX-U (Bounce freq. ↑ Collision ↓) →

Bounce-harmonics become important and SBP too if ExB is low

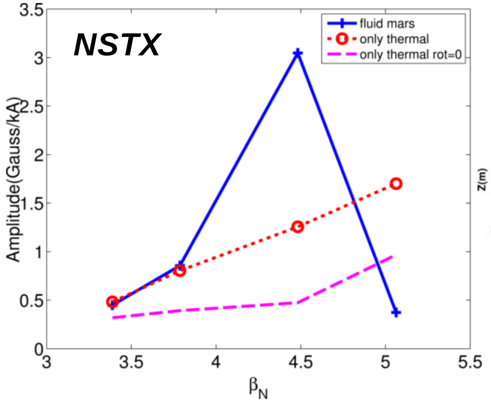
SBP becomes important and offset too if ExB is low

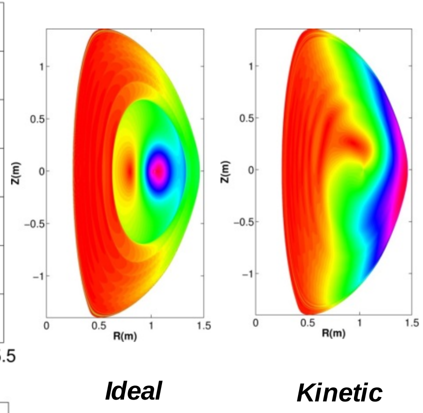
- Stability research plans, FY16:
  - Examine RWMSC with:
    - rotational stabilization in the controller model
  - Investigate the dependence of stability on reduced ν through MHD spectroscopy; compare to kinetic stabilization theory

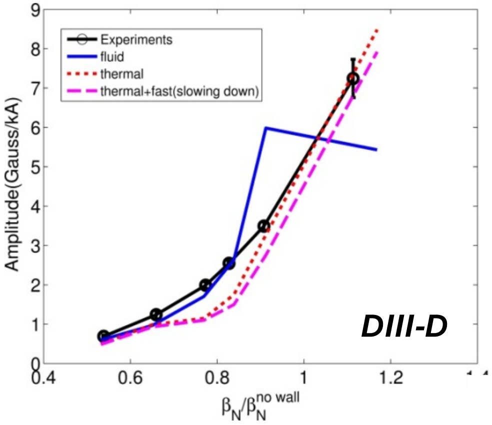


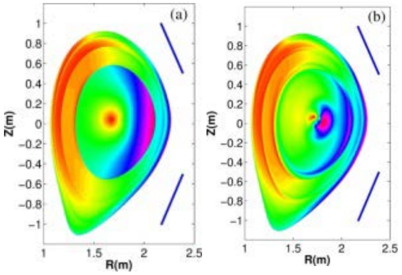
Drift-kinetic effects on 3D plasma response and non-resonant error field effects are being actively investigated

- Drift-kinetic 3D plasma response
  - MARS-K self-consistent calculations successfully compared with n=1 DIII-D RFA
  - Preliminary NSTX RFA calculations indicate kinetic stabilization effects important (especially near no-wall limit), and rotation can be destabilizing
- Res. and non-res. error field effects
  - Resonant-coupling schemes (IPEC-PENT) are being used to optimize n=2 error field correction in DIII-D and n=1-4 correction in TBM mock-up
  - Extremely small resonant errors were found so far in KSTAR, and non-resonant error field will be investigated
  - Non-resonant error field effects on locking/tearing are being investigated in NSTX, with newly developed resistive DCON

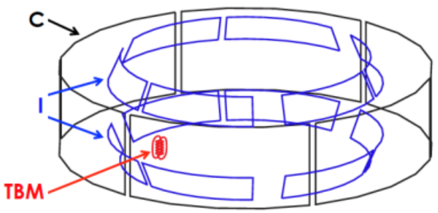


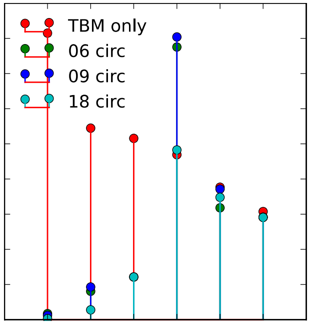






I+C-coil circuit optimization for TBM n=1-4 correction

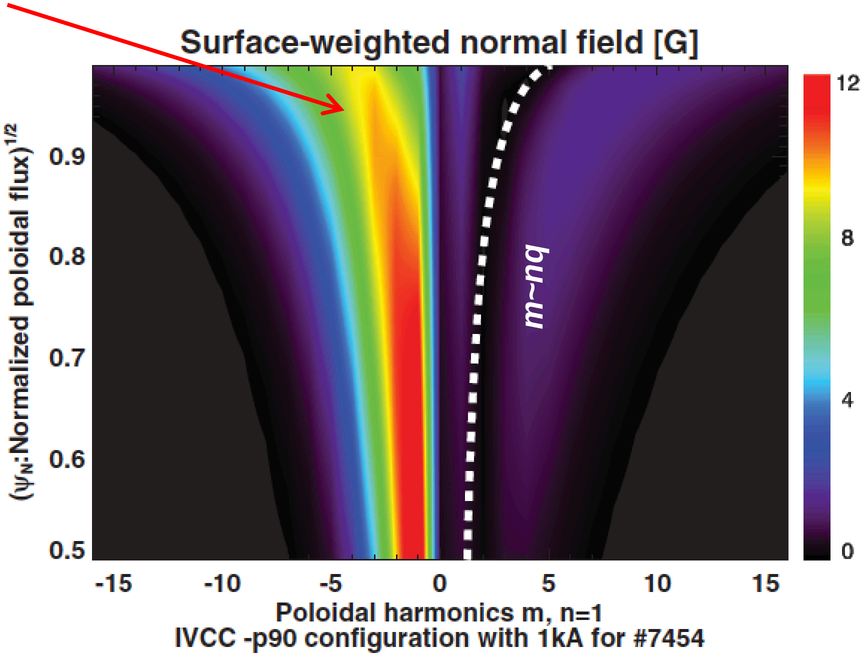




KSTAR 3 rows of internal coils were used to produce n=1 pitch-crossing field lines and to find rotational resonances

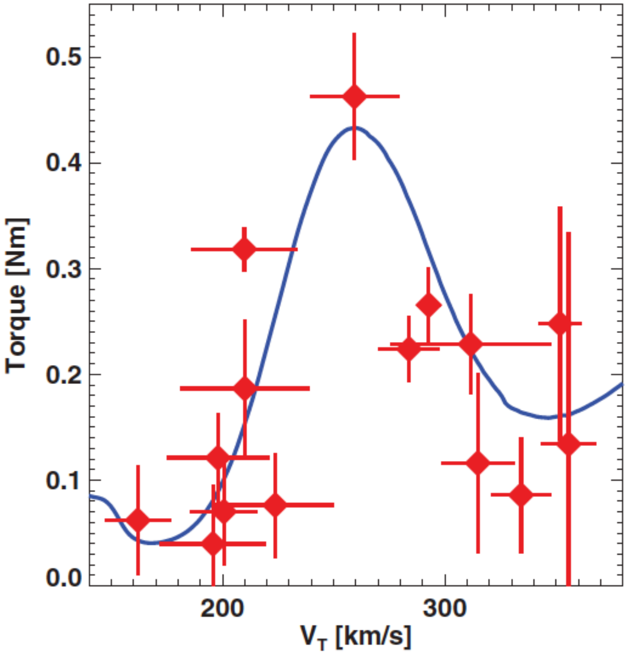
- The unique 3 rows of internal coils in KSTAR were utilized to produce pitch-crossing field lines (orthogonal to pitch-aligned field lines)
- This n=1 field is almost purely non-resonant :
  - Successfully induced NTV without n=1 resonant perturbation
  - Used to find the 1st bounce-harmonic rotational resonance, as the gap to 2nd resonance is the widest with n=1 (predicted by and agreed with theory and computation)

Mirror image to RMP



Surface-weighted normal field [G]

Experiment vs. Theory



J.-K. Park, PRL 111, 095002 (2013)

Non-resonant Neoclassical Toroidal Viscosity (NTV) physics will be used for the first time in rotation feedback control

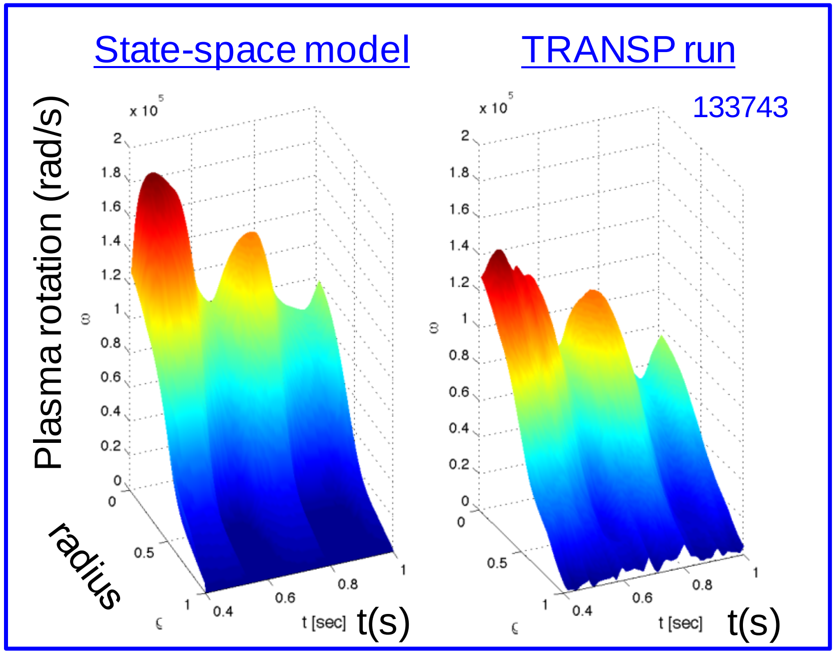
- Momentum force balance – ω_ϕ decomposed into Bessel function states

$$\sum_i n_i m_i \left\langle R^2 \right\rangle \frac{\partial\omega}{\partial t} = \left(\frac{\partial V}{\partial\rho}\right)^{-1} \frac{\partial}{\partial\rho}\left[\frac{\partial V}{\partial\rho}\sum_i n_i m_i \chi_\phi \left\langle \left(R\nabla\rho\right)^2\right\rangle \frac{\partial\omega}{\partial\rho}\right] + T_{NBI} + T_{NTV}$$

- NTV torque:

$$T_{NTV} \propto K \times f\left(n_{e,i}{}^{K1} T_{e,i}{}^{K2}\right) g\left(\delta B(\rho)\right)\left[I_{coil}{}^{2}\omega\right]$$

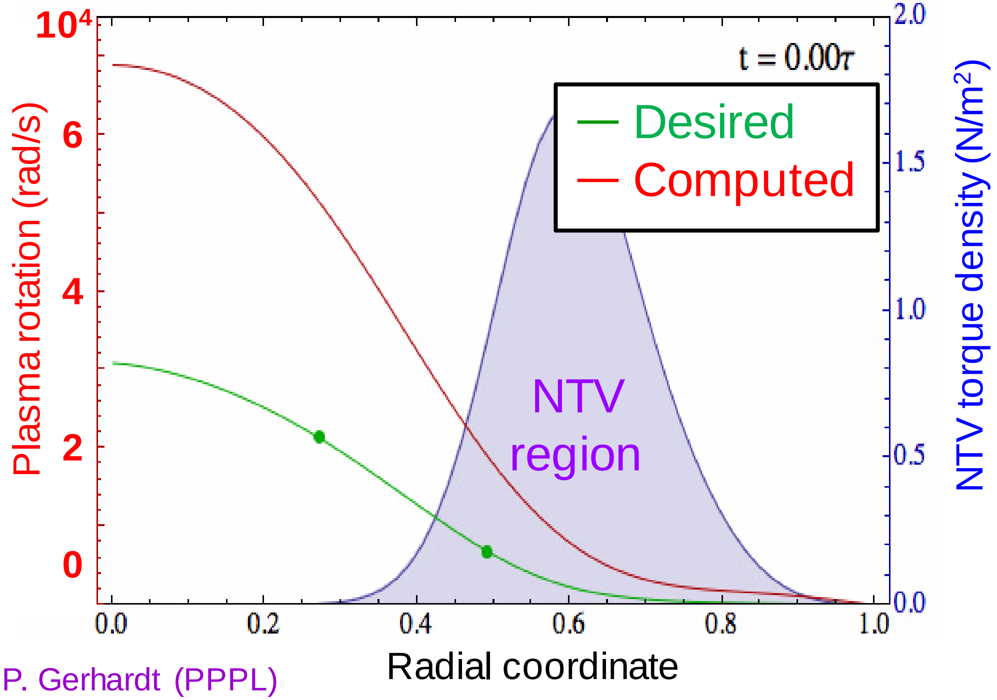
(non-linear)



State-space model

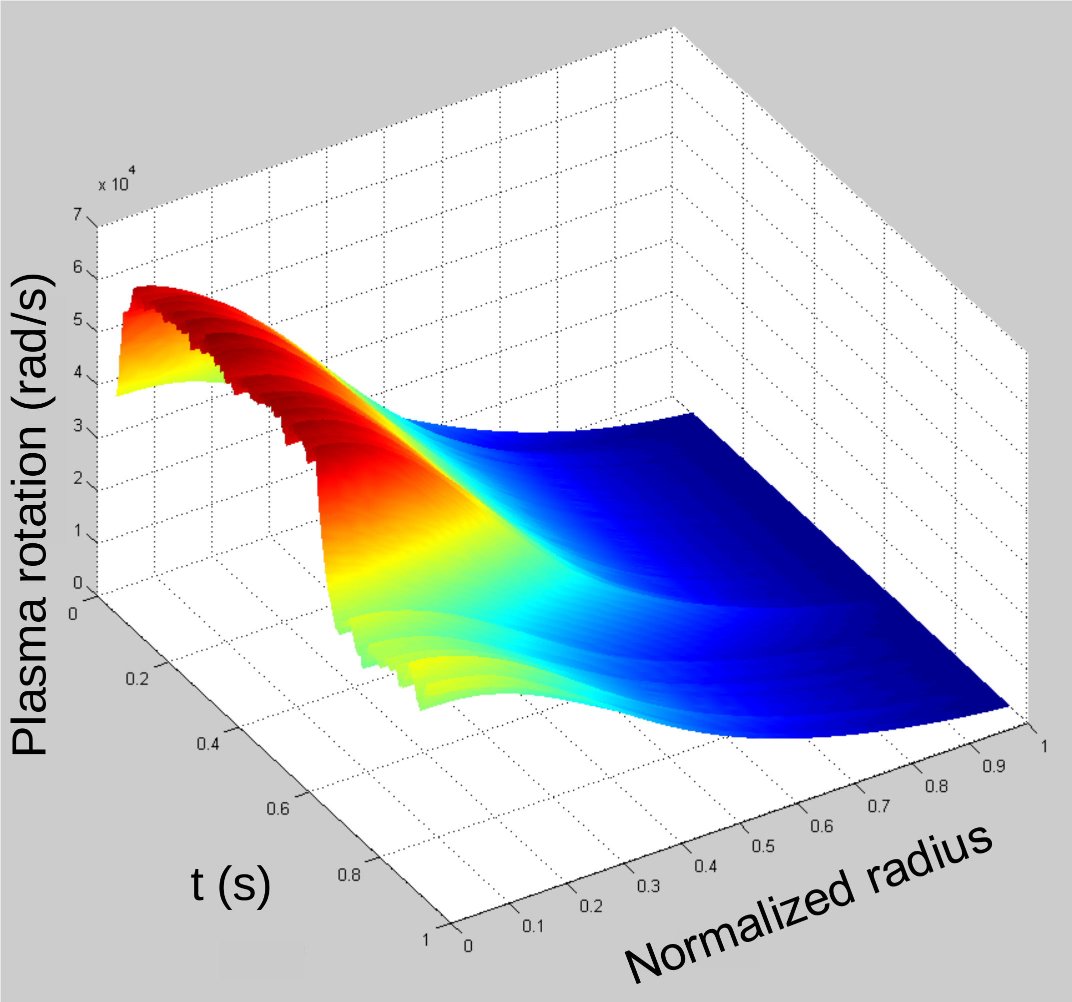
TRANSP run

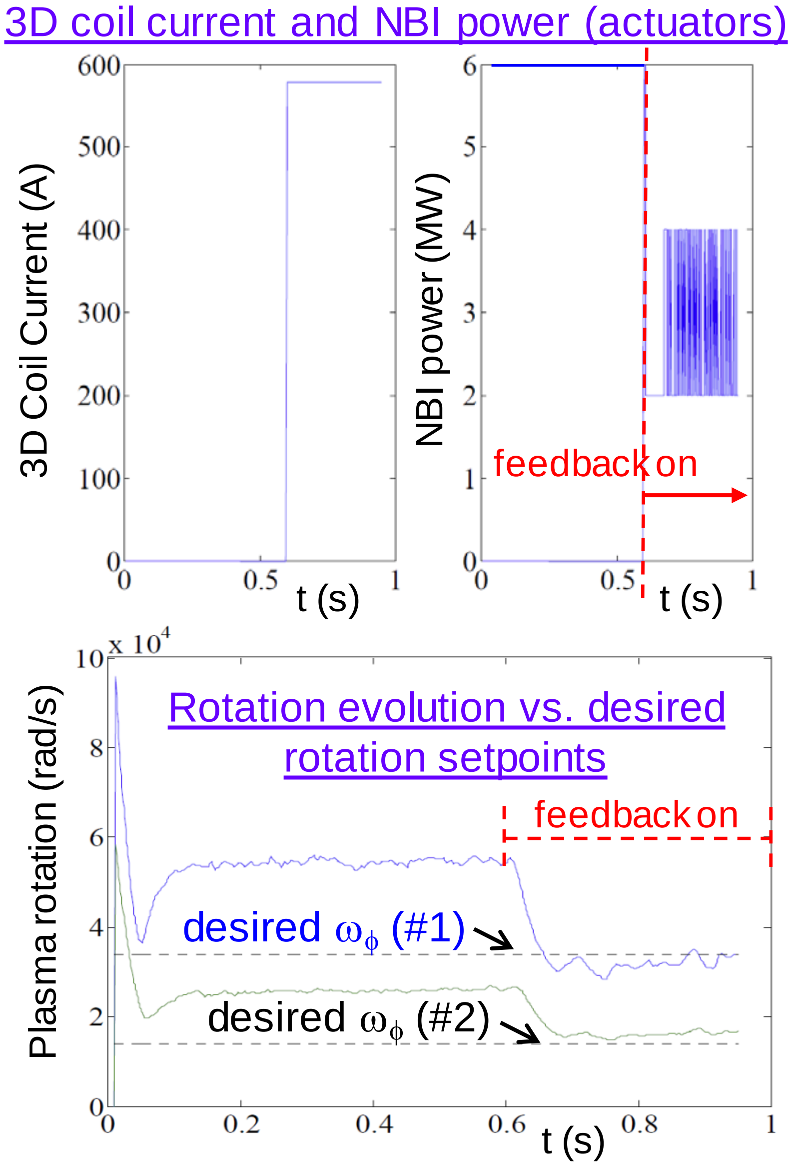
Feedback using NTV: "n=3" δB(ρ) spectrum



I. Goumiri (PU), S.A. Sabbagh (Columbia U.), D.A. Gates, S.P. Gerhardt (PPPL)

Plasma rotation control has been demonstrated for the first time with TRANSP using NBI and NTV actuators

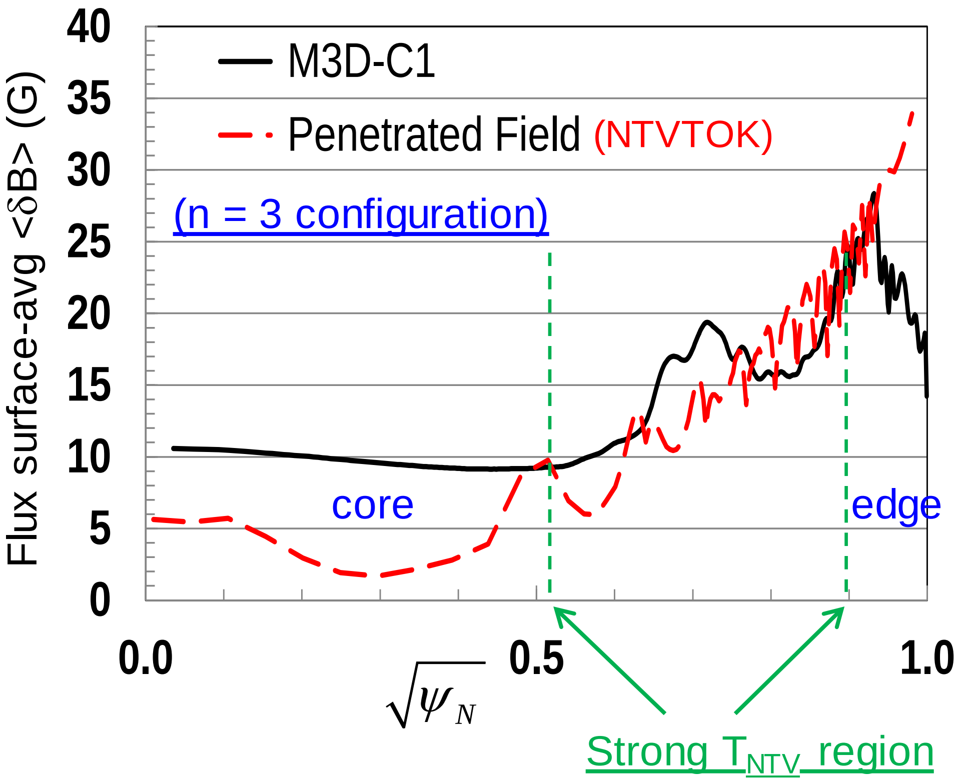




- This case uses pre-programmed 3D coil current and NBI feedback

Plasma response from fully-penetrated 3D field used in NTV experimental analysis matches M3D-C^1 single fluid model

Surface-averaged δB from fully penetrated model vs. M3D-C^1 single fluid model



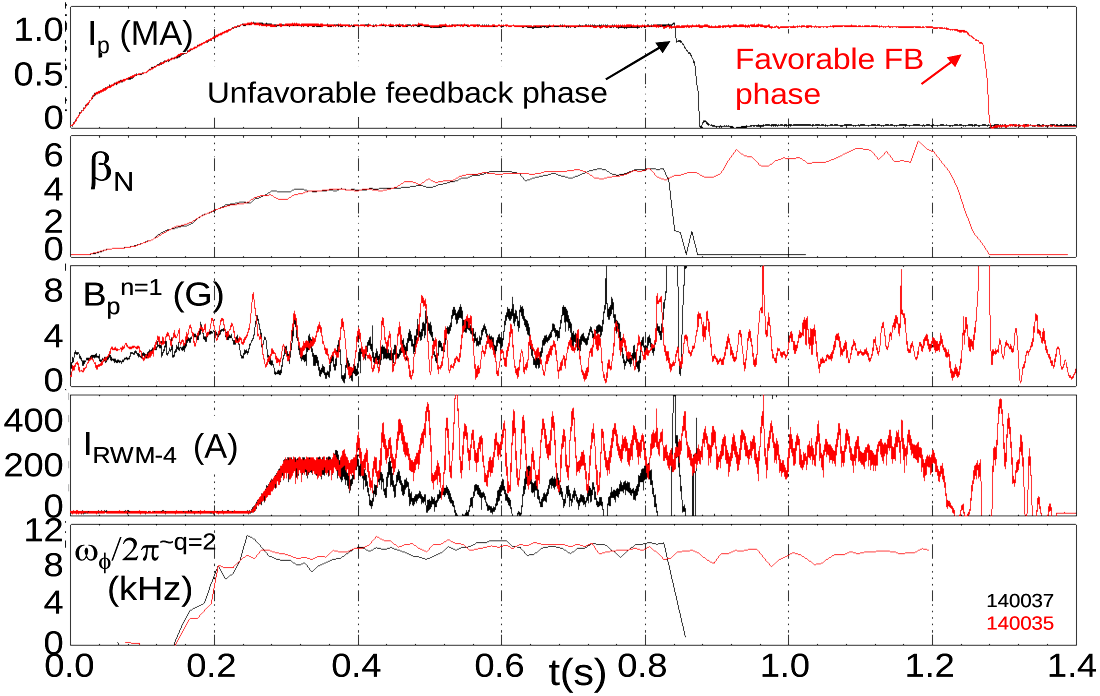
NTVTOK analysis (S.A. Sabbagh)

M3D-C^1 analysis (Evans/Ferraro (GA), Jardin (PPPL))

- NTV experimental data is a strong quantitative constraint on plasma response of δB
  - Because the measured NTV scales as $T_{NTV} \propto \delta B^2$,
- Level of agreement varies with profile
  - Good agreement between NTVTOK / M3D-C^1 single fluid models in strong NTV region
  - M3D-C^1 core <δB> larger than NTVTOK
    - Core mode in M3D-C^1
  - M3D-C^1 edge <δB> smaller
    - Experimental T_{NTV} too small in this region to constraint δB
- Analysis ongoing in 2014

Model-based RWM state space controller including 3D plasma response and wall currents used at high β_N in NSTX

RWM state space controller in NSTX at high β_N



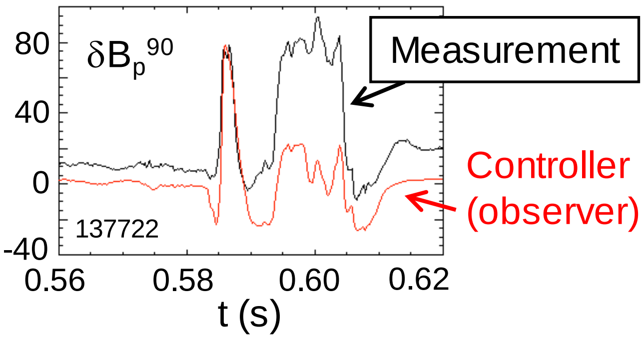
- Potential to allow more flexible control coil positioning
  - May allow control coils to be moved further from plasma, and be shielded (e.g. for ITER)

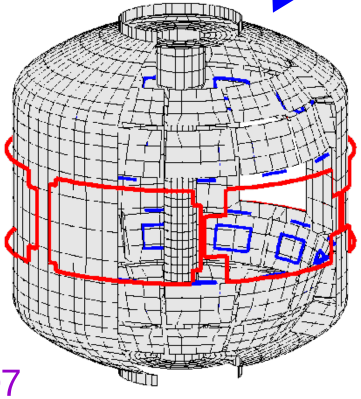
    Katsuro-Hopkins, et al., NF 47 (2007) 1157

S.A. Sabbagh, et al., Nucl. Fusion 53 (2013) 104007

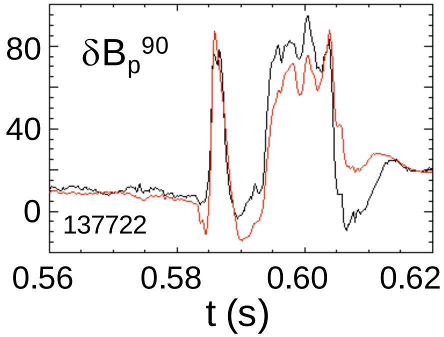
Effect of 3D Model Used

No NBI Port





With NBI Port

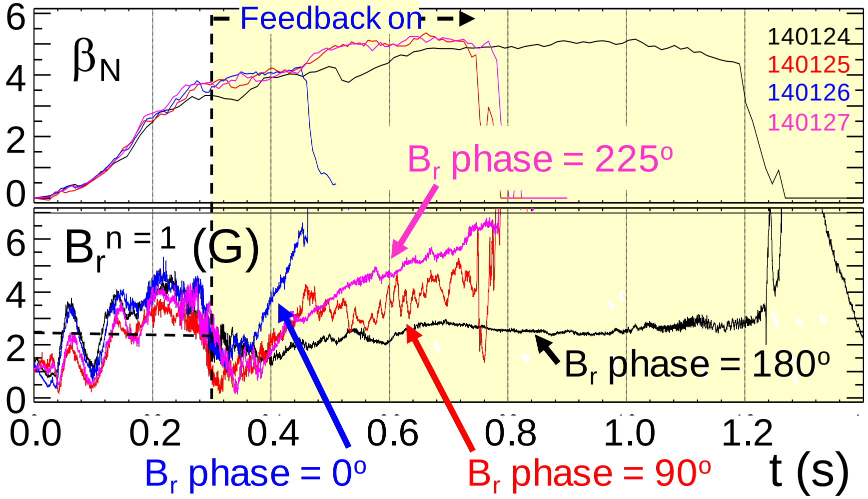


- 3D detail of model is important to improve sensor agreement

Dual-component PID (B_r + B_p) and model-based RWM state-space (RWMSC) active control will enable long pulse, high β operation

- 2014:
  - Expand/analyze RWMSC for 6 coil control and n > 1 physics
- 2015 and 2016:
  - Establish B_r + B_p active control capability in new machine, use with snowflake divertor
  - Examine RWMSC with:
    - independent actuation of six coils
    - multi-mode control with n up to 3
    - rotational stabilization in the model

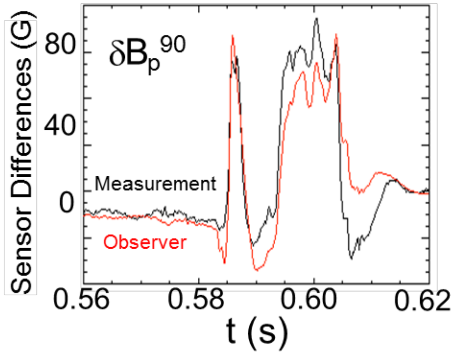
Active n = 1 B_p + B_R feedback control



RWMSC

Advantages:

potential for use of external coils with less power



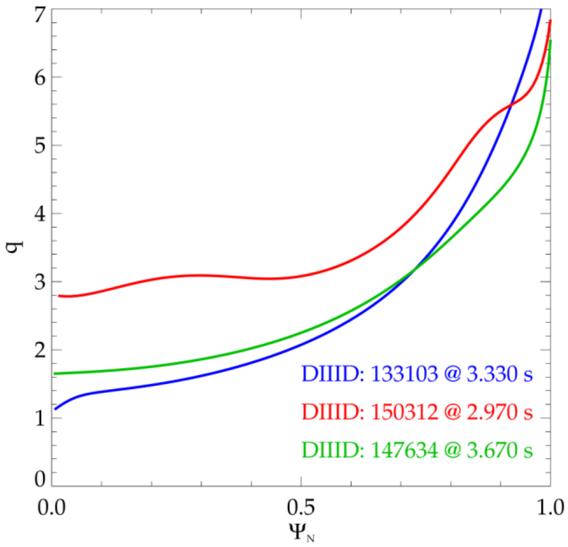
- 2017 and 2018:
  - Upgrade for NCC, utilize model-based active control with the new NCC to demonstrate improved global MHD mode stability and very low plasma disruptivity, producing highest-performance, longest-pulse plasmas

Research plans and needs for this year (FY2014) in preparation for NSTX-U operations in FY2015

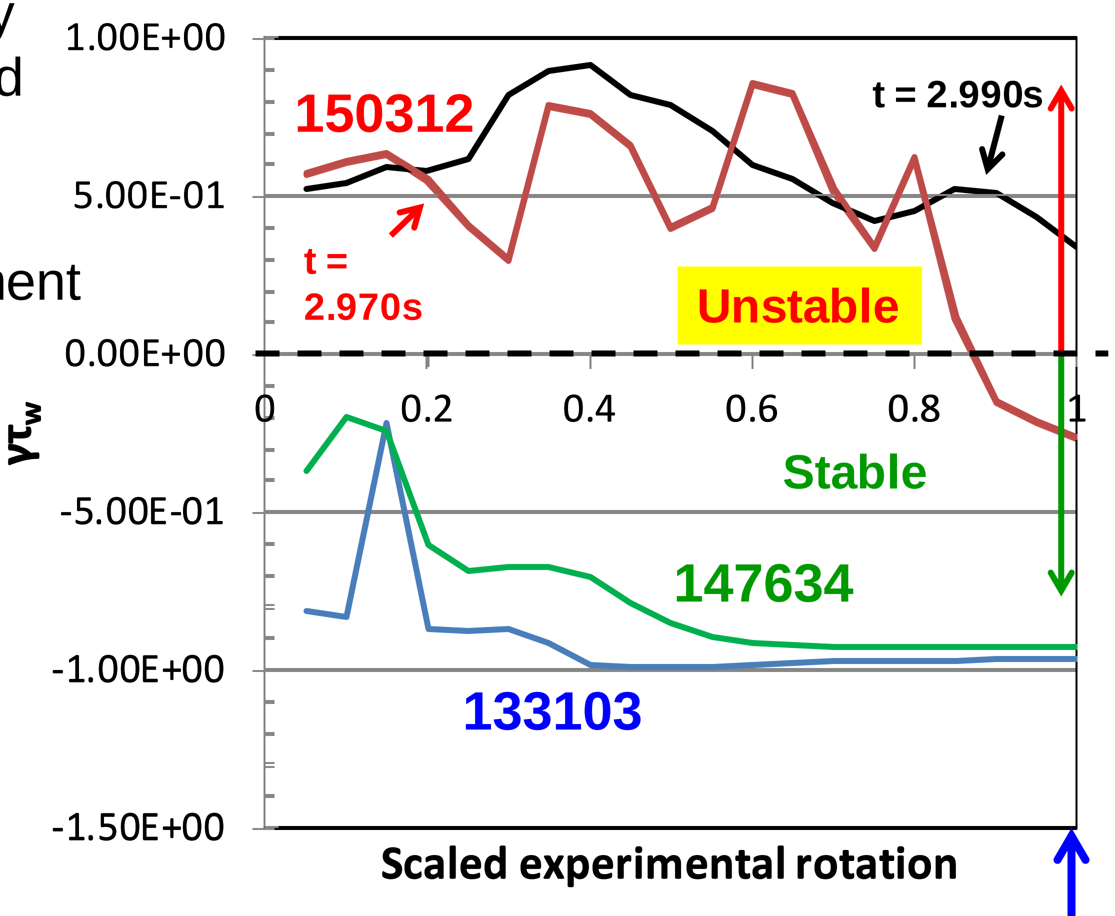
- RWM State-space Controller generalization – available “Day 0”
  - Offline IDL version of code already generalized
  - Changes to r/t version to be made. Small PCS programming support will be needed
- NSTX EFIT (of course, “Day 0”)
  - Plan to upgrade to faster processing to support increased between-shots spatial resolution / time resolution (eta 2014-2015); present code available as default
  - New code components acquired Dec 2013; new dedicated prototype 32 core CPU computer online at PPPL (planned to be expanded); consistent with PPPL IT plan
- NSTX rotation control
  - Continuing work with PU student (I. Goumiri) on rotation control algorithm
  - Present quantitative NTV analysis of Columbia U. NSTX experiments supports this

MISK analysis of DIII-D discharges is helping to enable their path to high beta operation

- High β_N, high q_{min} shots with similar, relatively high plasma rotation have varied stability due to q profile variation and related changes to bounce resonance stabilization
- Educated follow-on experiment forthcoming

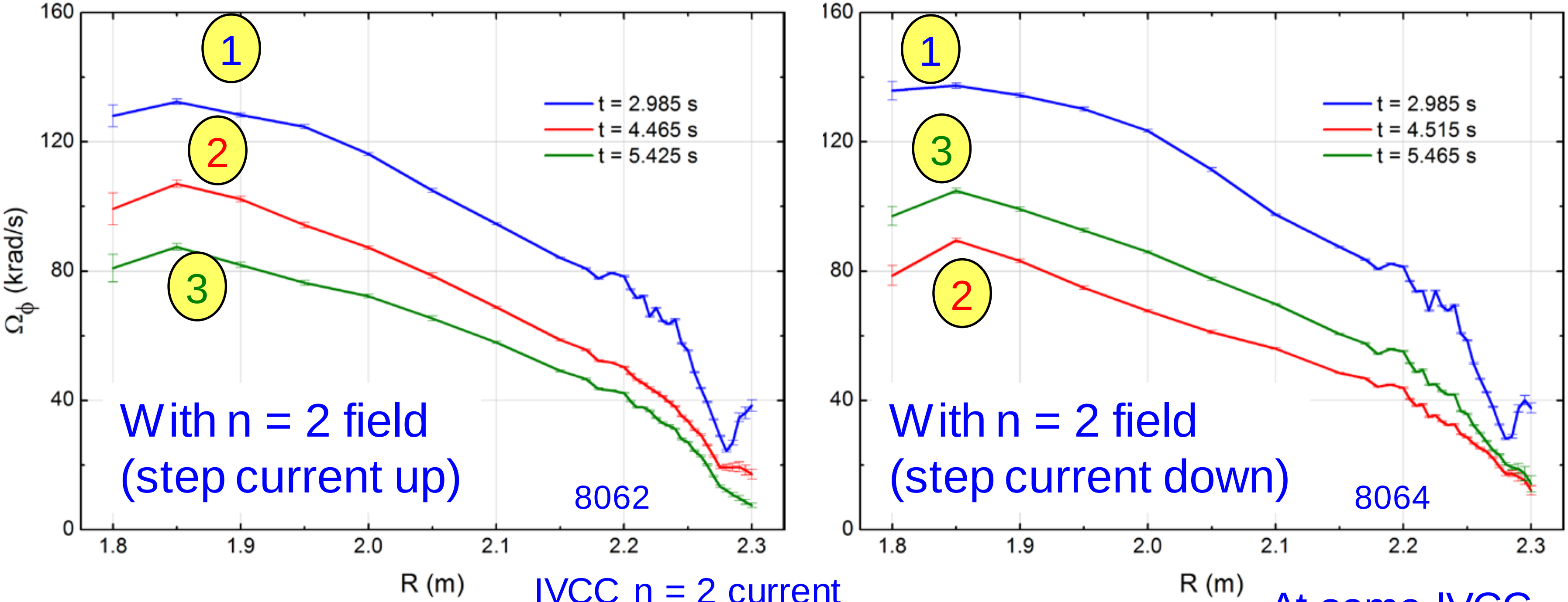


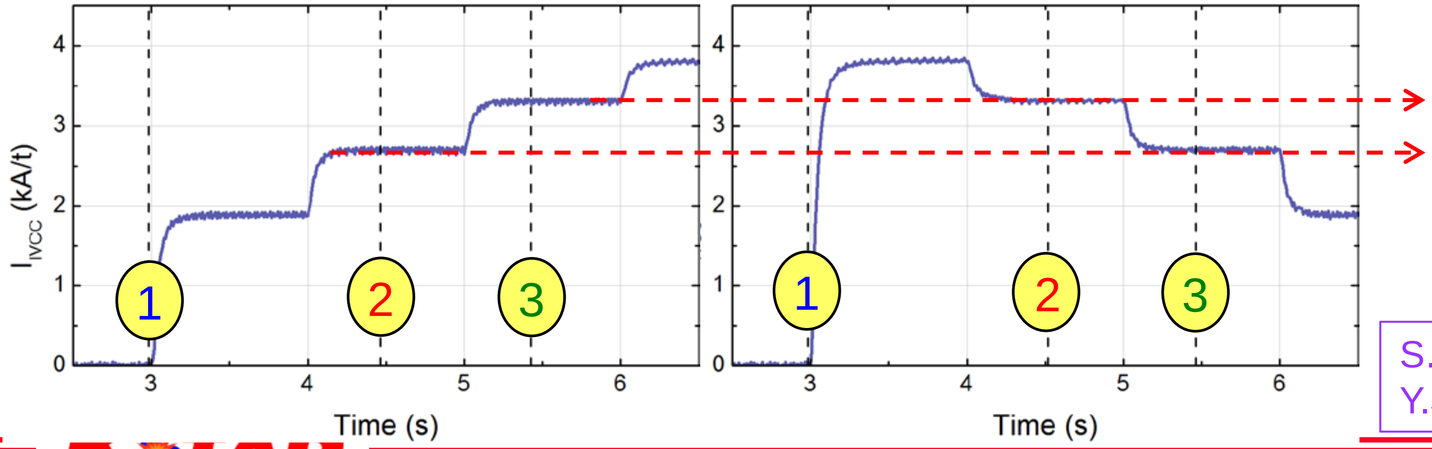
MISK stability vs. rotation



Experimental rotation magnitude

Measured toroidal plasma rotation profile shows non-resonant NTV rotation control using n = 2 field

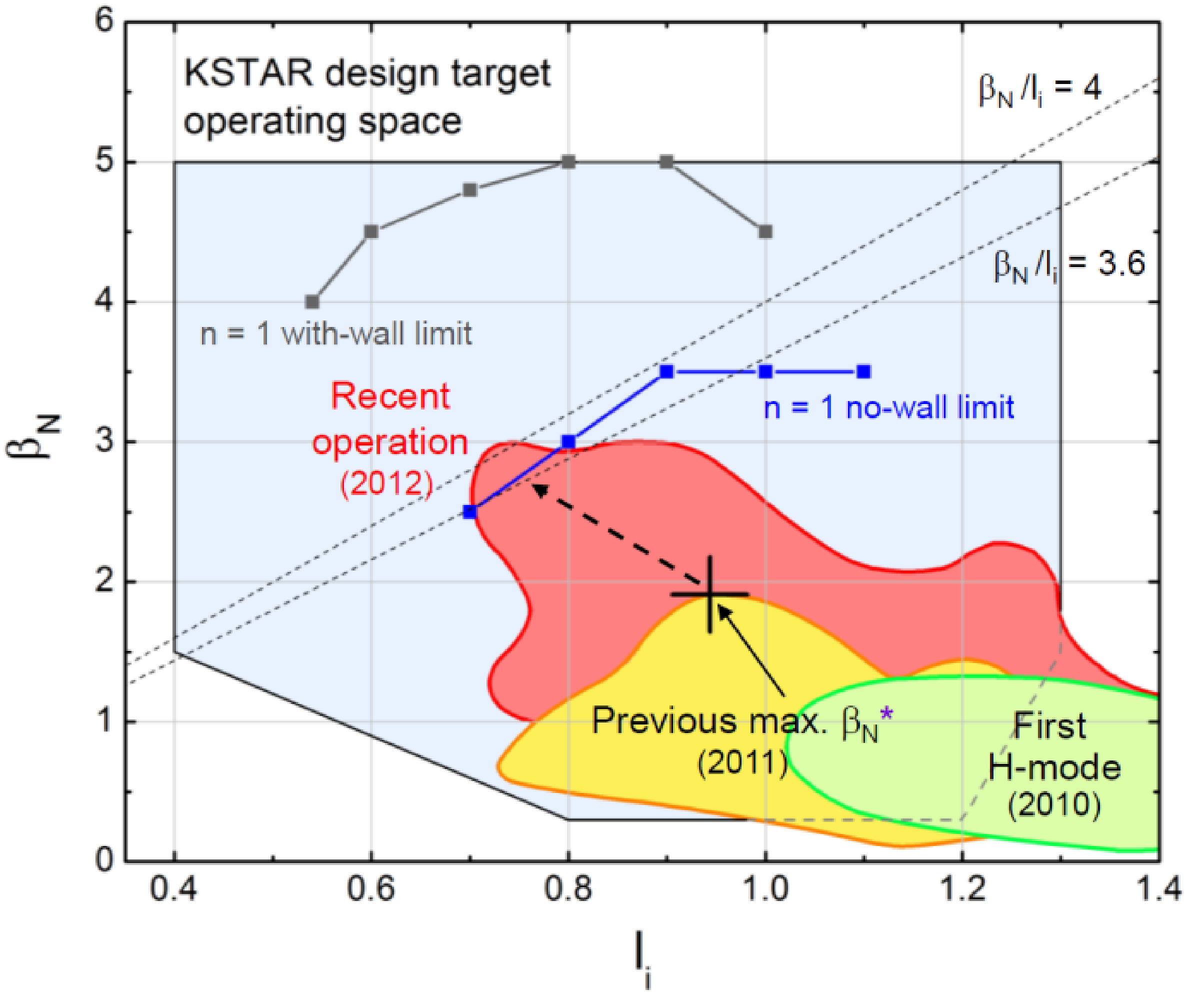




At same IVCC current, rotation profile shows no hysteresis – important for control

S.A. Sabbagh, Y.S. Park (Columbia U.)

Collaborations at KSTAR have aided high beta operation



KSTAR collaboration

- High β_N, over no-wall limit has been achieved