NSTX-U

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Recap of RWM magnetic sensor upgrade plan for NSTX-U (from 5 Year Plan)

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U Tulsa
U Washington
U Wisconsin
X Science LLC

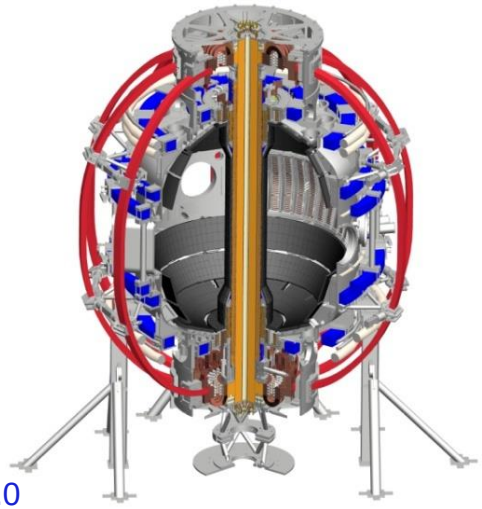
S. A. Sabbagh, J.W. Berkery, J. Bialek, S.P Gerhardt et al.

Columbia University, PPPL

Macrostability Topical Science Group Meeting

February 8th, 2015

PPPL



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V1.0

Discussion of magnetic sensor upgrade plan for NSTX-U

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J.W. Berkery, S. A. Sabbagh, J. Bialek, A. Diallo, S.P. Gerhardt, N. Logan, J-K Park, R. Raman, V. Soukhanovskii, et al.

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NSTX-U 5 Year Plan Meeting

January 11th, 2013

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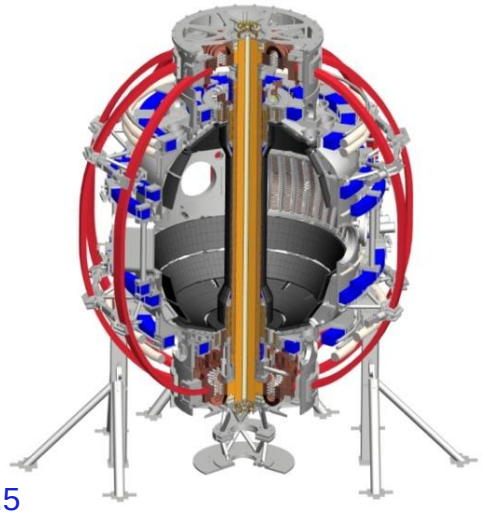


V1.5

RWM active control performance analysis using NCC actuators and realistic sensors

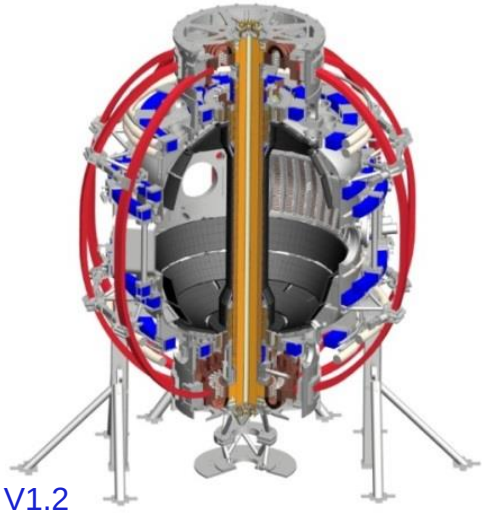
S. A. Sabbagh and J.M Bialek

Department of Applied Physics, Columbia University, New York, NY

NSTX-U NCC Working Group Meeting

January 30th, 2015

PPPL



V1.2

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Upgraded magnetic sensor plan status discussed at recent meeting

- Global mode diagnosis
  - Measure theoretically expected mode alteration at high β_N
- RWM physics and control
  - Improve RWM state space active control and observer
  - Enhance input to disruption warning system

- Disruption characteristics
  - Expanded shunt tile set for halo current diagnosis, etc.
  - Do questions remain re: specs for halo current meas. / shunt tile set?
- Snowflake divertor and ELM characteristics
  - Additional requests / detail needed for probes to run snowflake?
  - Further extensions of magnetics for ELM research?
- CHI
  - Additional flux loop positions requested – what about B probes?

1) These elements to be discussed here

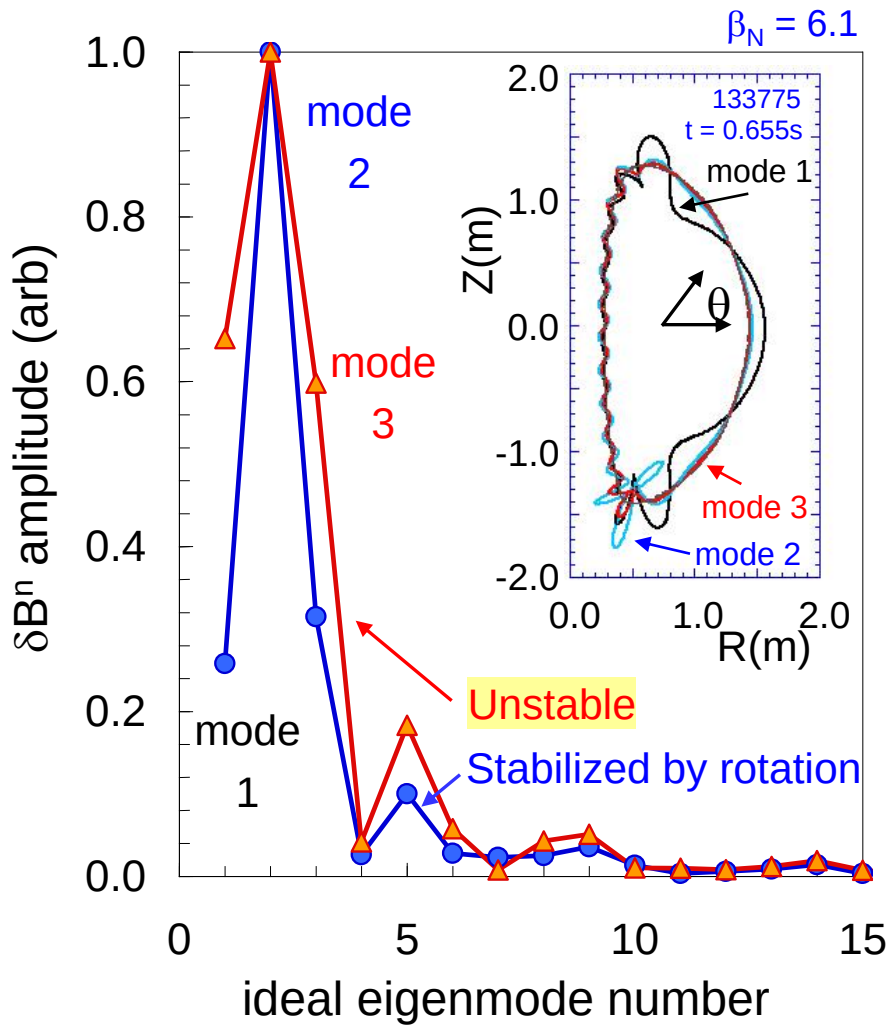
2) Further discussion on topical cross-cutting, improvements

3) Status of these elements discussed yesterday

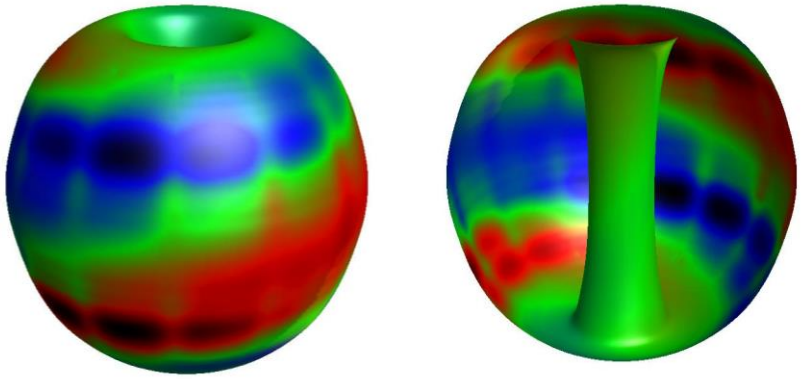
- Additional detail not needed for today's discussion

Multi-mode computation shows 2nd eigenmode component has dominant amplitude at high β_N in NSTX stabilizing structure

δB^n RWM multi-mode composition



δB^n from wall, multi-mode response



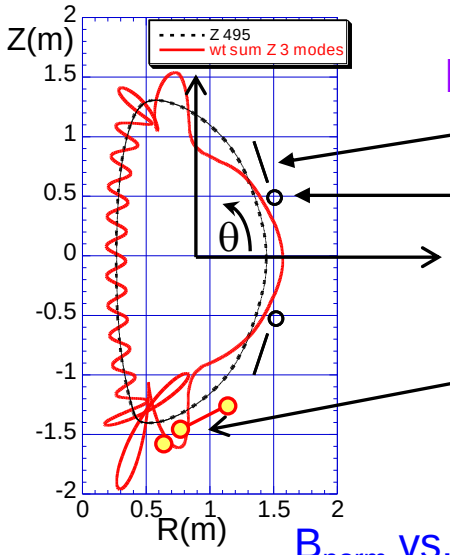
- The two primary global modes have increased amplitude in the divertor region
- This was also found theoretically for NSTX for single mode computations during the design of the present NSTX system S. Sabbagh, et al., NF 2004

mmVALEN code

S.A. Sabbagh, et al., IAEA FEC 2010 (Paper EXS/5-5)

Review: 3D analysis of extended MHD sensors show significant mode amplitude off-midplane, incl. divertor region

n = 1 ideal eigenfunction for high beta plasma (three mode sum)

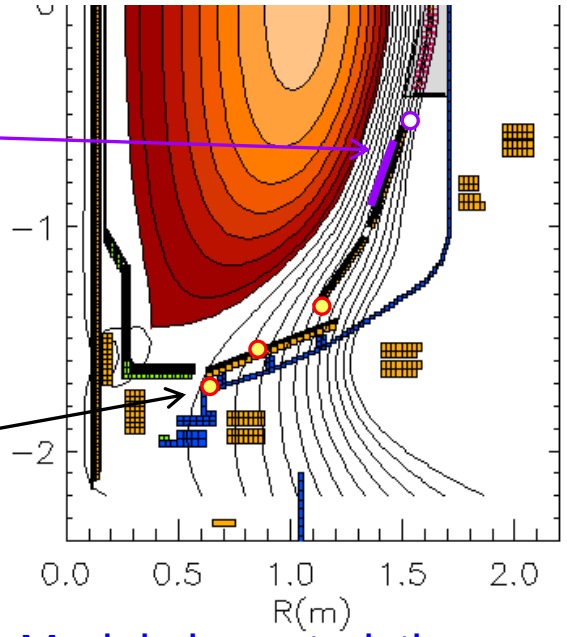


Present sensor locations

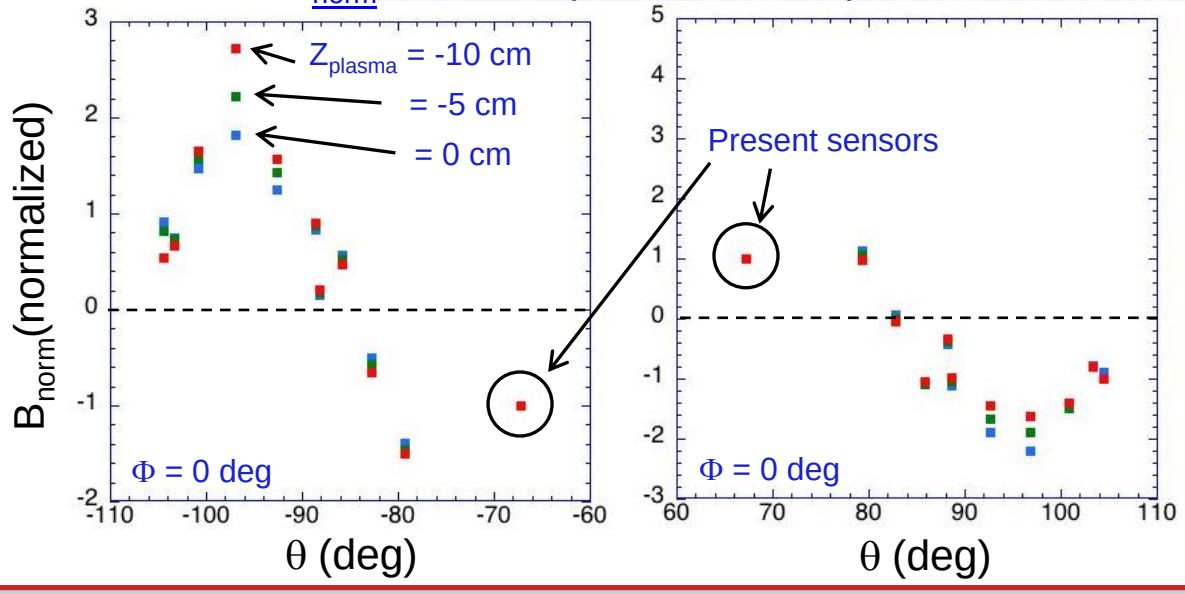
B_R sensors (nominally normal, B_{norm})

B_p sensors (nominally tangential, B_{tan})

New sensor locations (includes one new location above midplane)

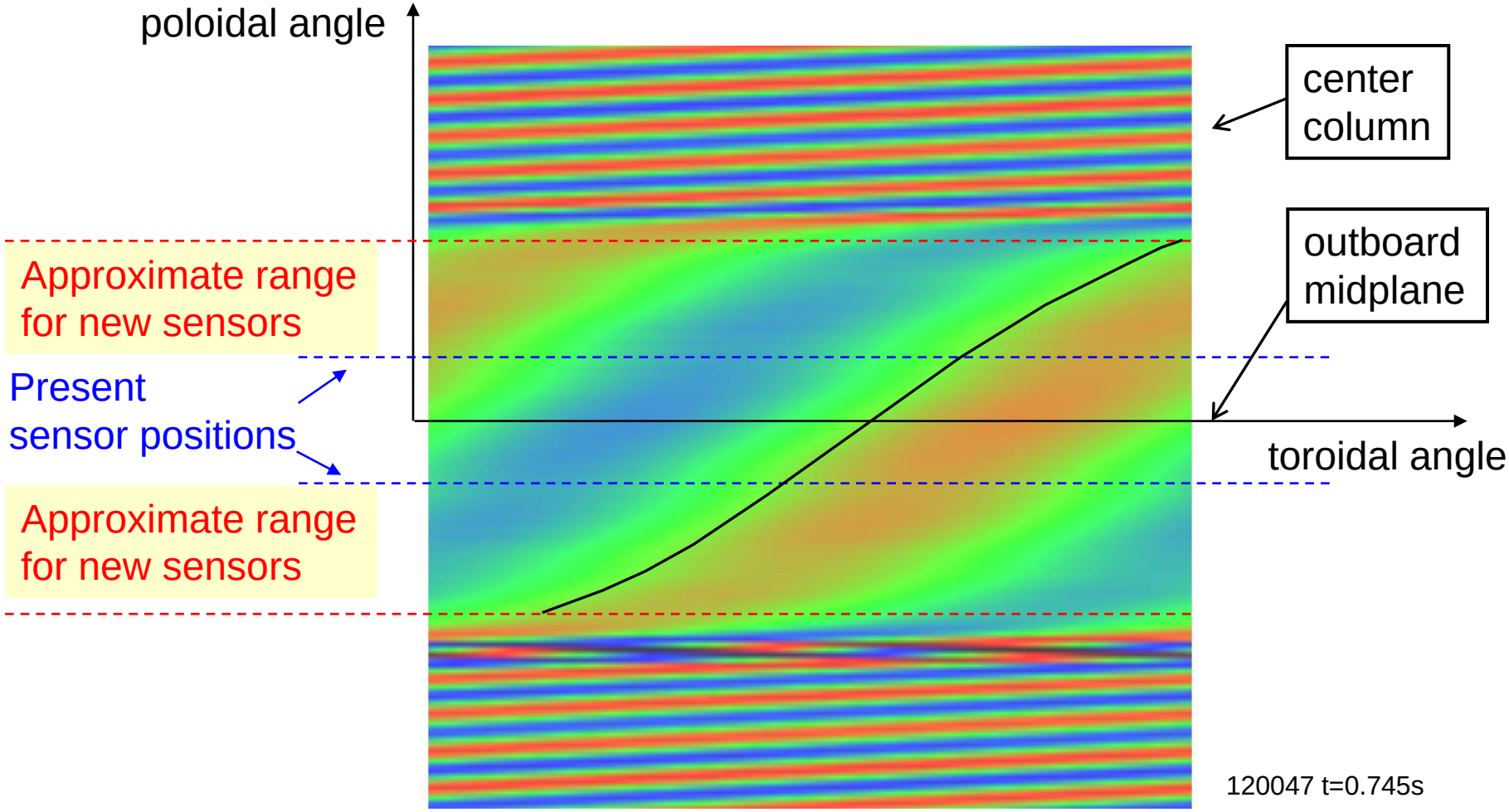


B_{norm} vs. theta (normalized to present Br sensors)



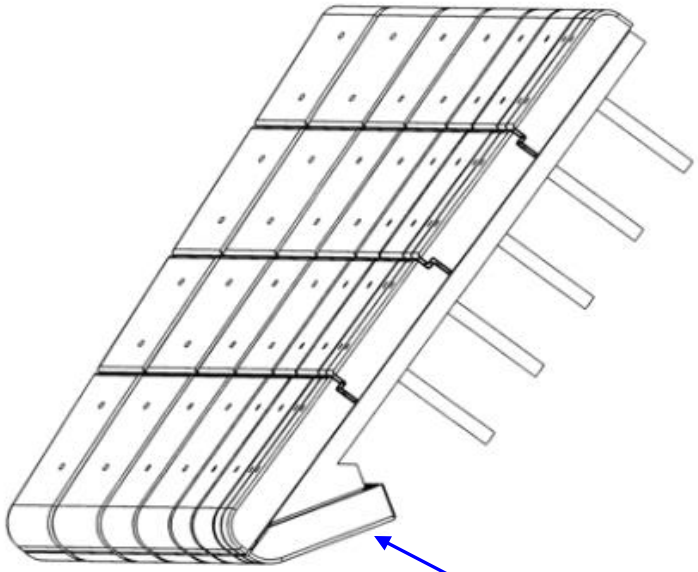
- Model characteristics
  - New 3D model of divertor plate
  - 3D sensors with finite toroidal extent; n*A of existing sensors
- Results summary
  - Field amplitude up to factor of 6 larger with new sensors
  - Perturbed field reversals observed with new sensors
  - Signals sufficient with plasma shifted off-midplane

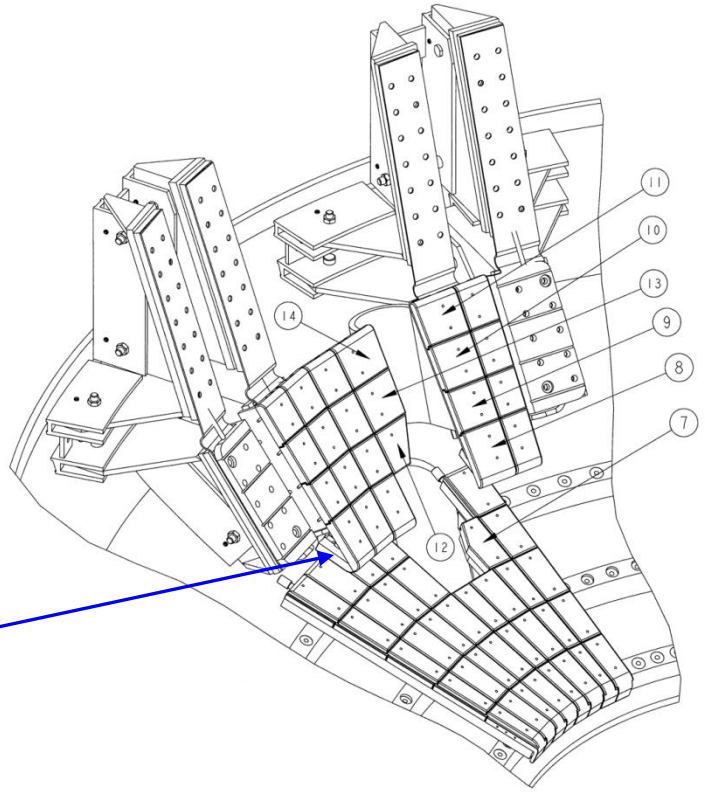
Significant change to toroidal phase (n = 1 mode shown) would be clearly measured in new sensor location range



- Due to significant field line pitch in this region
- Still have relatively long poloidal wavelength (vs. center column region)

SPG Idea #1: Mount them under Secondary Passive Plate Lip

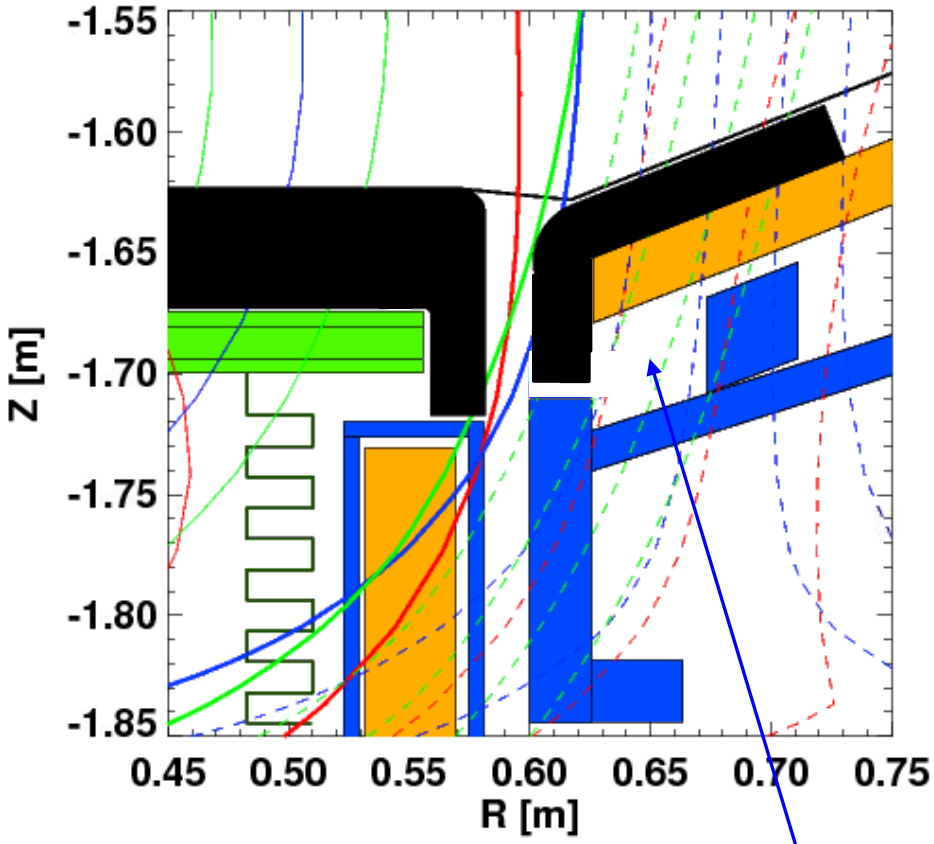


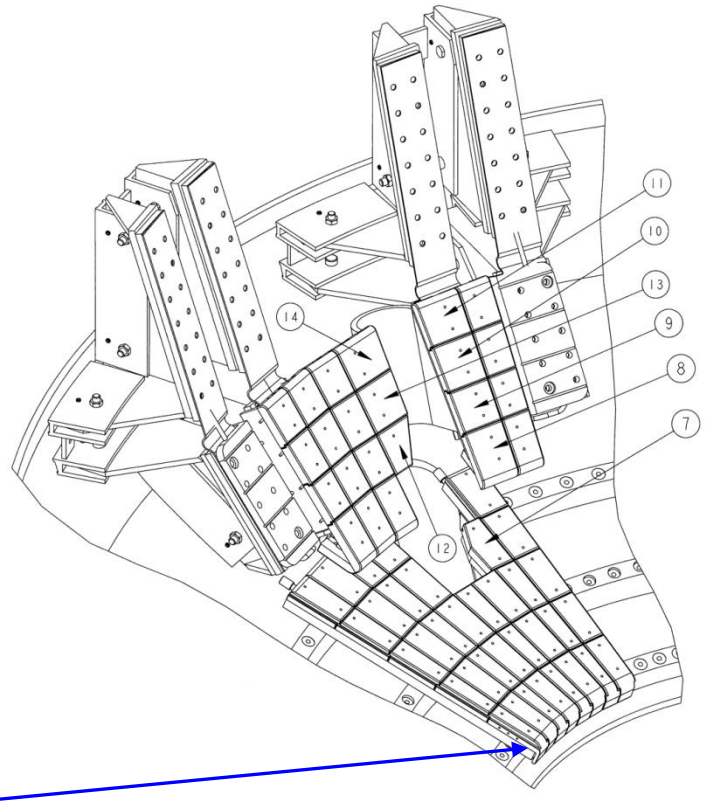


BAY "A" LOWER OPENING
DIVERTOR AND SECONDARY PASSIVE PLATE
TILE MODIFICATION ASS'Y
EXISTING HARDWARE TO BE USED
TO MOUNT TEE BARS AND TILES

- Replace this tile with sensor box.
- Would be partially shielded by SPP
- Might need to retain part of the front of the tile, but much could likely be eliminated.
- Wire extraction fairly simple.
- Boxes may need to be curved to follow outline of plate.

SPG Idea #2: Mount them under outer divertor bull nose tiles



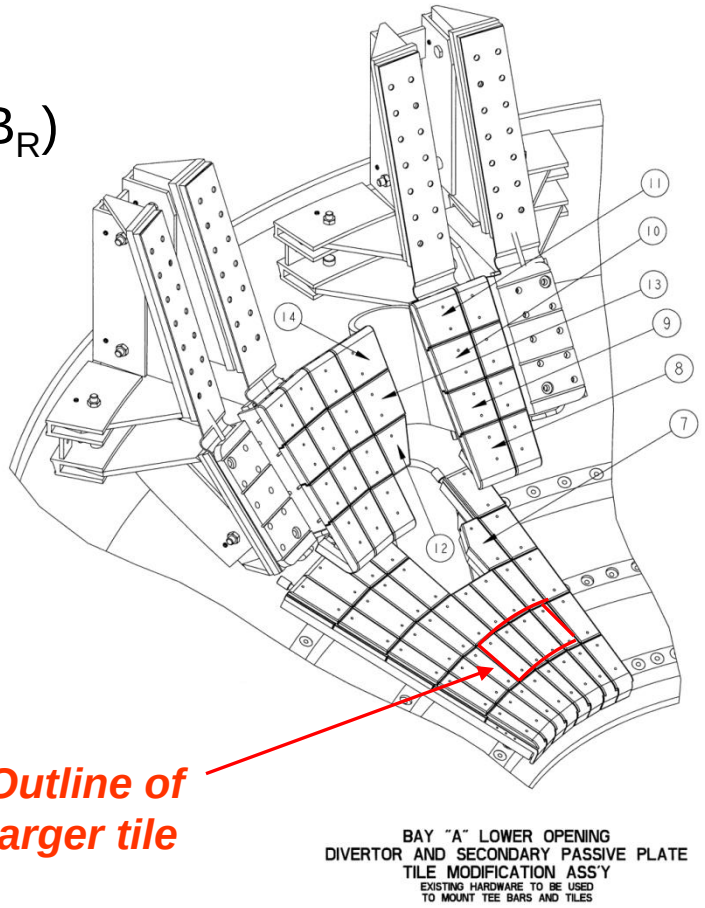


BAY "A" LOWER OPENING
DIVERTOR AND SECONDARY PASSIVE PLATE
TILE MODIFICATION ASS'Y
EXISTING HARDWARE TO BE USED
TO MOUNT TEE BARS AND TILES

- Place curved sensor box in this volume.
- Is reasonably well shielded from plasma by improved bull-nose tiles.
- Wire extraction likely to be difficult.
- Would be partially electromagnetically shielded by divertor.

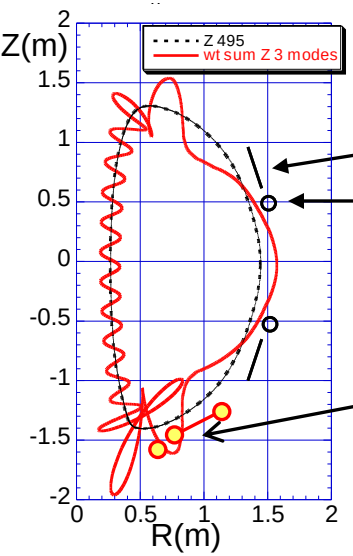
SPG Idea #3: Sensors in Tiles

- Tiles are only about 0.9” thick, and have a T-bar right down the center.
  - Makes installation of a traditional B_P (~B_R) sensor difficult.
  - Could imagine a very thin “Hiro” sensor mounted above the T-bar.
- Could fabricate a single larger tile, taking the area of 2-4 existing tiles.
  - Wrap a B_N (~B_Z) sensor around the tile edges.
    - Sort of like how the B_R sensors are mounted to the PPPs
  - Would likely trap the t-bars
  - Are there thermal issues with larger tiles?
  - Need to check the effective area.



Theory indicates that positioning new sensors closer to divertor will improve mode measurement

n = 1 ideal eigenfunction for fiducial plasma

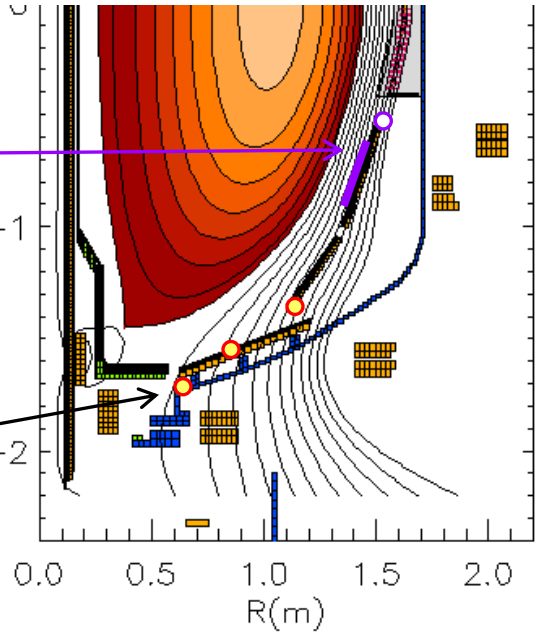


Present sensor locations

B_R sensors (nominally normal, B_{norm})

B_p sensors (nominally tangential, B_{tan})

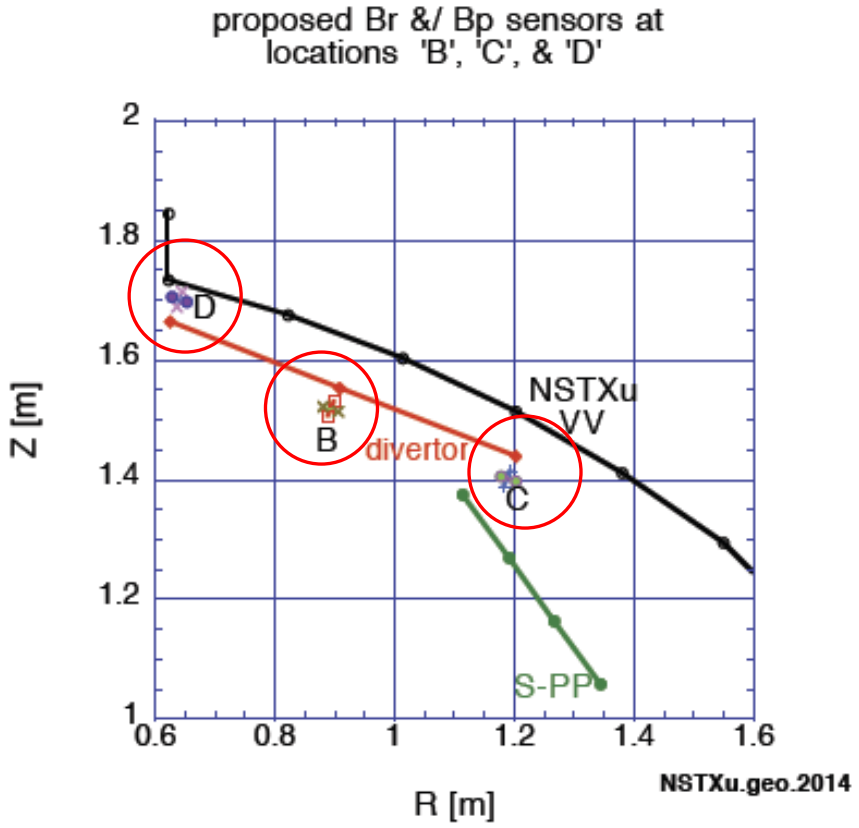
New sensor locations discussed (schematic) (includes possible locations in THIS range (+ one position above midplane)

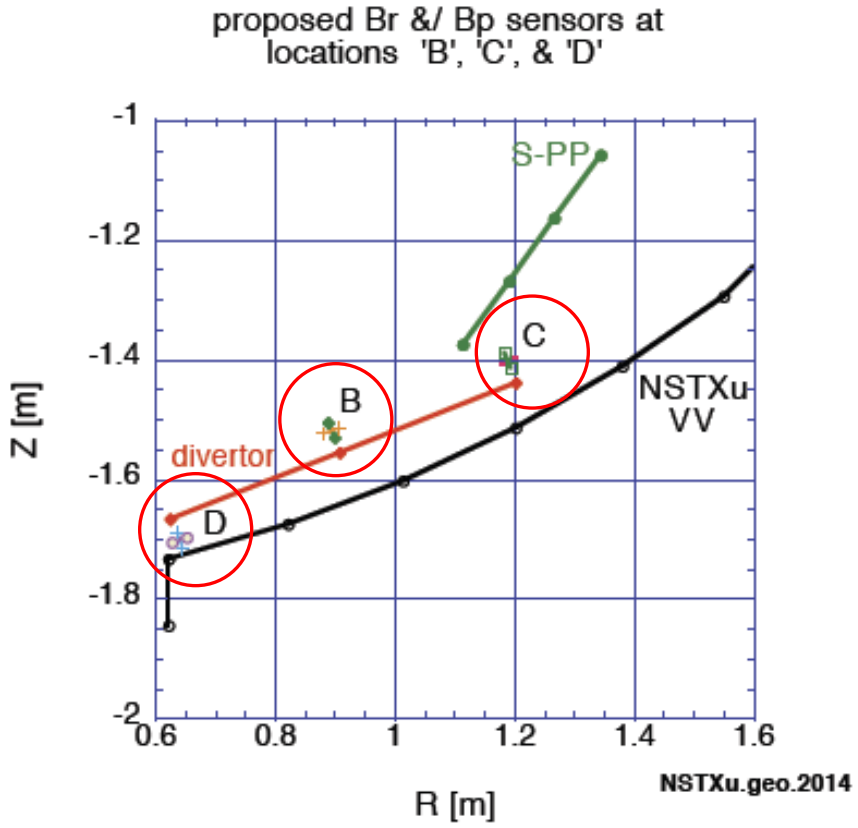


- Present suggestions (based on recent meeting – combination of physics needs, machine hardware constraints, and budget (discussion continues):
  - Consider 12 toroidal positions, 4 arrays (48 sensors) as "baseline"
  - 1st: B_{tan} or B_{norm} at smallest R (best accessible) in outer divertor region
  - 2nd: B_{tan} just below secondary passive plate (in Z position) – (B_{norm} possible here?)
  - 3rd: B_{norm} sensors in the lower divertor tiles (R position TBD)
  - 4th: B_{norm} or B_{tan} sensors at smallest R (best accessible), opposite Z in outer divertor
  - Are other positions possible to improve higher n (higher m) detection?

Extended RWM sensors proposed – consider use for RWM active feedback (RWM and NCC actuator coils)

- Motivation: Initial calculations using existing RWM sensors and NCC yielded inferior performance to idealized sensors
- Can new sensor positions improve active control performance?
  - New positions considered possible from past discussions to extend RWM sensor set

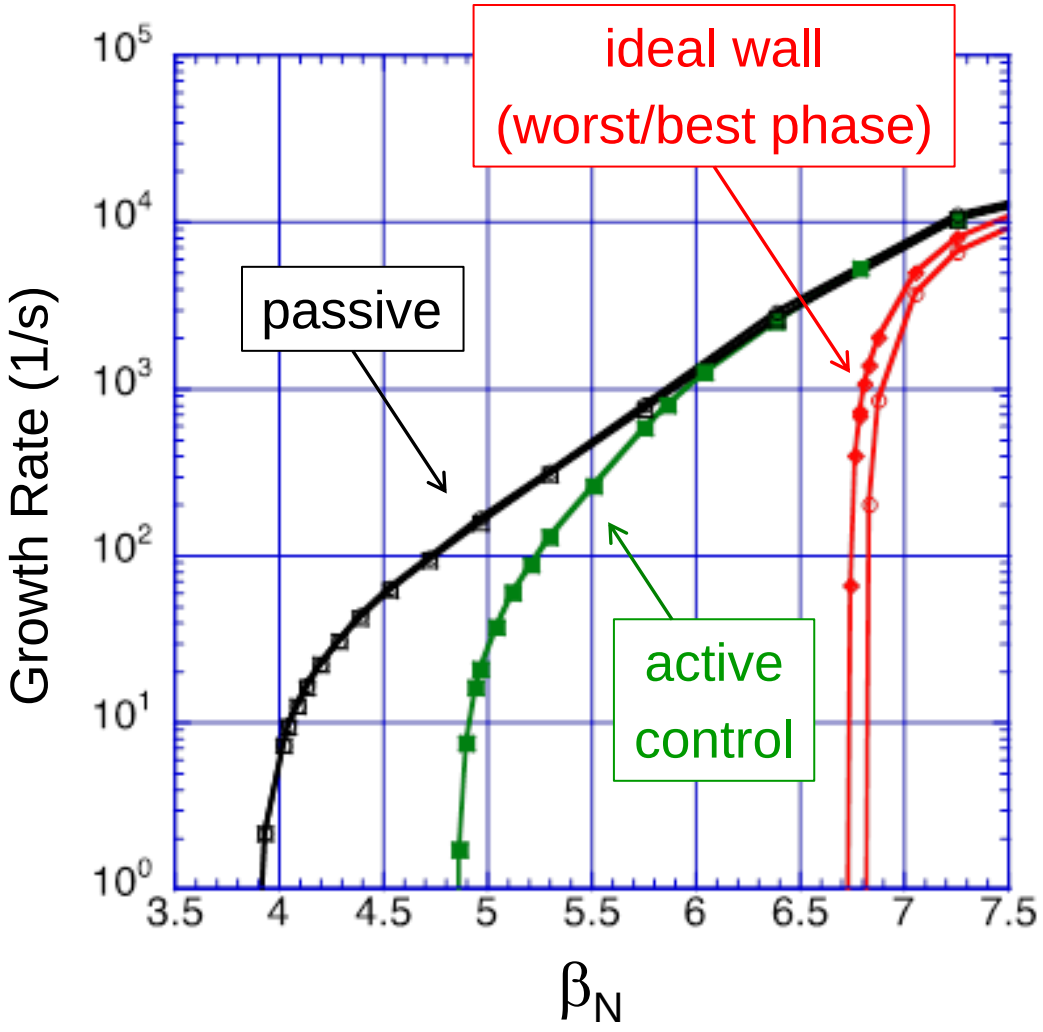




Extensive VALEN calculations of RWM active control performance with new sensors considered several variations

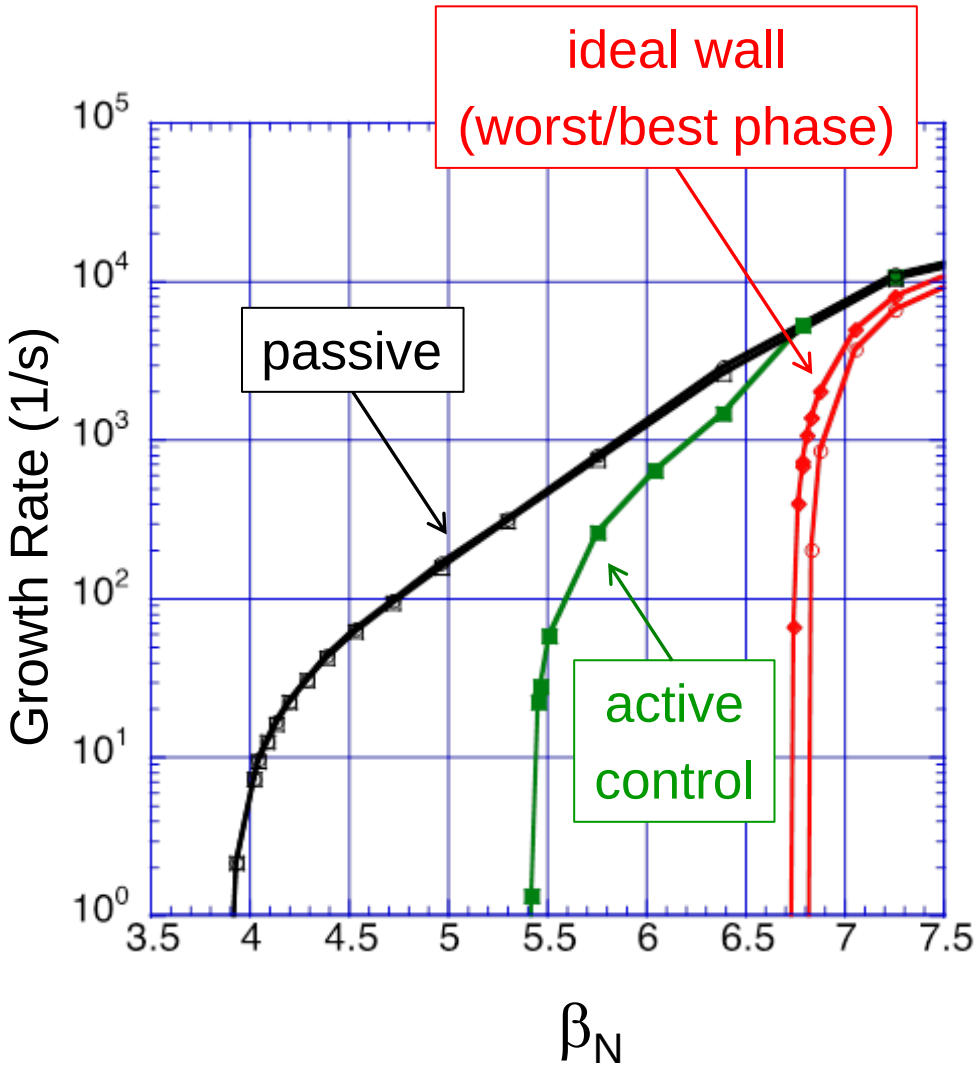
- Configuration variations (all using "full" NSTX-U model)
  - Sensor position variations
  - Partial and full NCC sets; midplane RWM coils added (or not)
  - NOTE: "intermediate β_N" equilibrium used
    - Higher β_N equilibrium shows greater mode amplitude deeper into divertor region (in poloidal angle), but control must work over full range of β_N
- Feedback parameter variations
  - Feedback phase scans
  - Feedback gain scans
  - "Smart shell" and "active control" analyses
    - The latter implements sensor compensation of the applied 3D field
- Extensive combinations of sensors and actuators, feedback phases and gains
  - Will only summarize "best" performance to compare configurations

Existing RWM sensors (Bottom B_p) driving Midplane RWM coils: calculation used for comparison



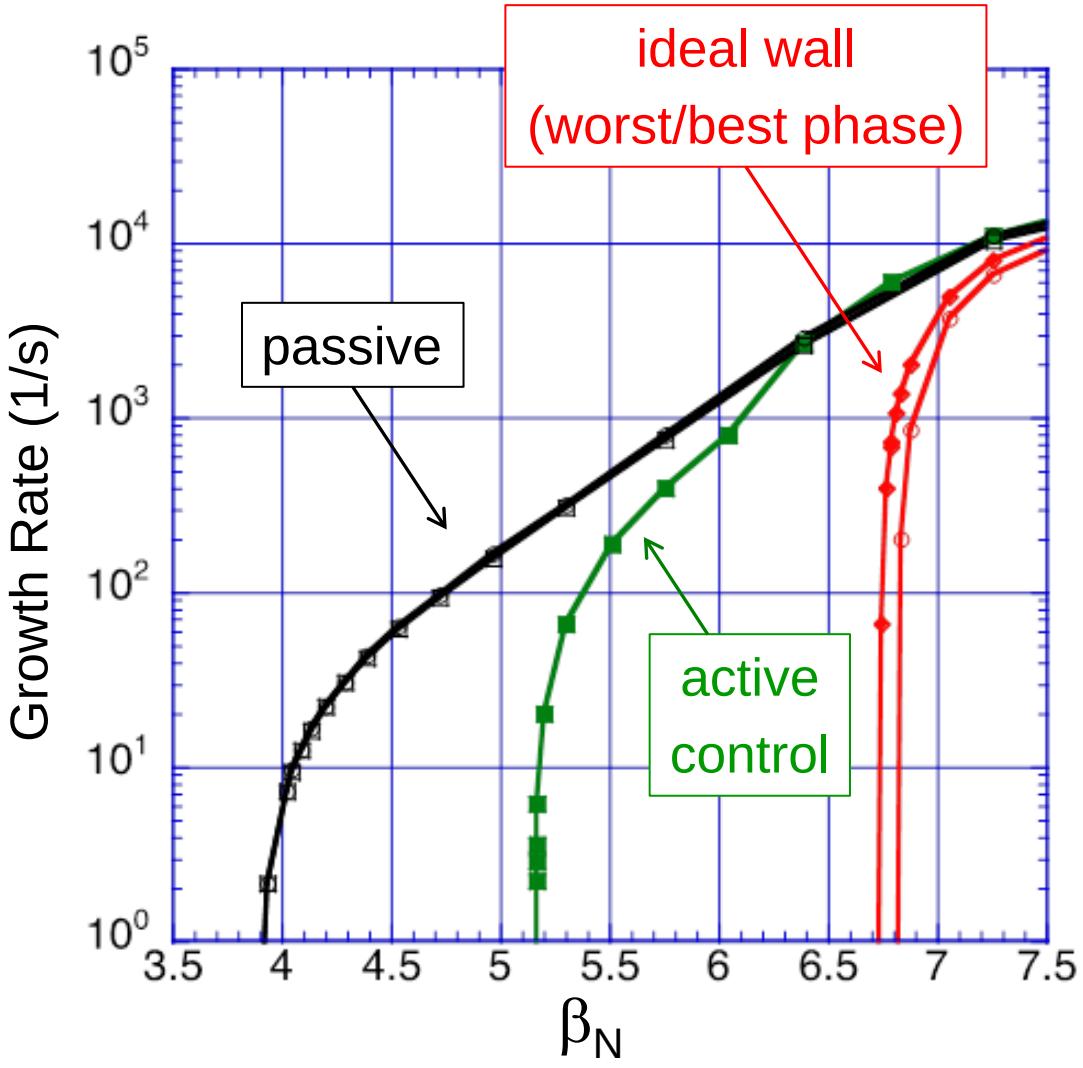
- Sensors
  - Present RWM sensors (bottom B_p), compensated
- Actuators
  - Midplane RWM coils
- Performance
  - Nearly identical to idealized midplane coils (as expected)

Existing RWM sensors (Bottom B_p) driving upper NCC: sensors sufficiently decoupled from induced wall currents



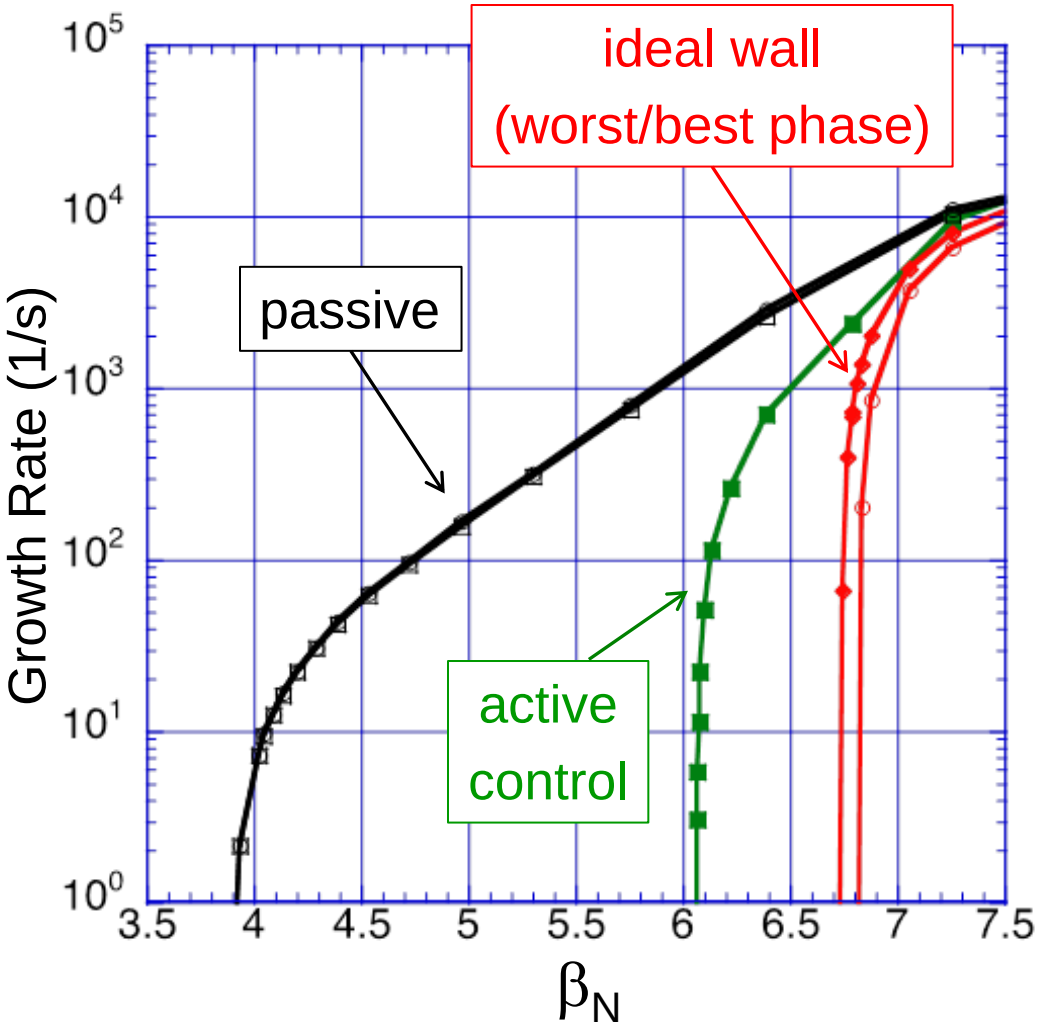
- Sensors
  - Present RWM sensors (bottom B_p), compensated
- Actuators
  - Top NCC coils (1x12)
- Performance
  - Superior to midplane RWM coils by $\Delta\beta_N \sim 0.5$
  - Uncompensated sensor results similar (bottom B_p driving upper NCC)
  - BUT: Present RWM sensors driving neighboring NCC results in decreased performance – consider new sensor positions

Proposed "B position" sensors in upper divertor driving midplane RWM coils close to present system performance



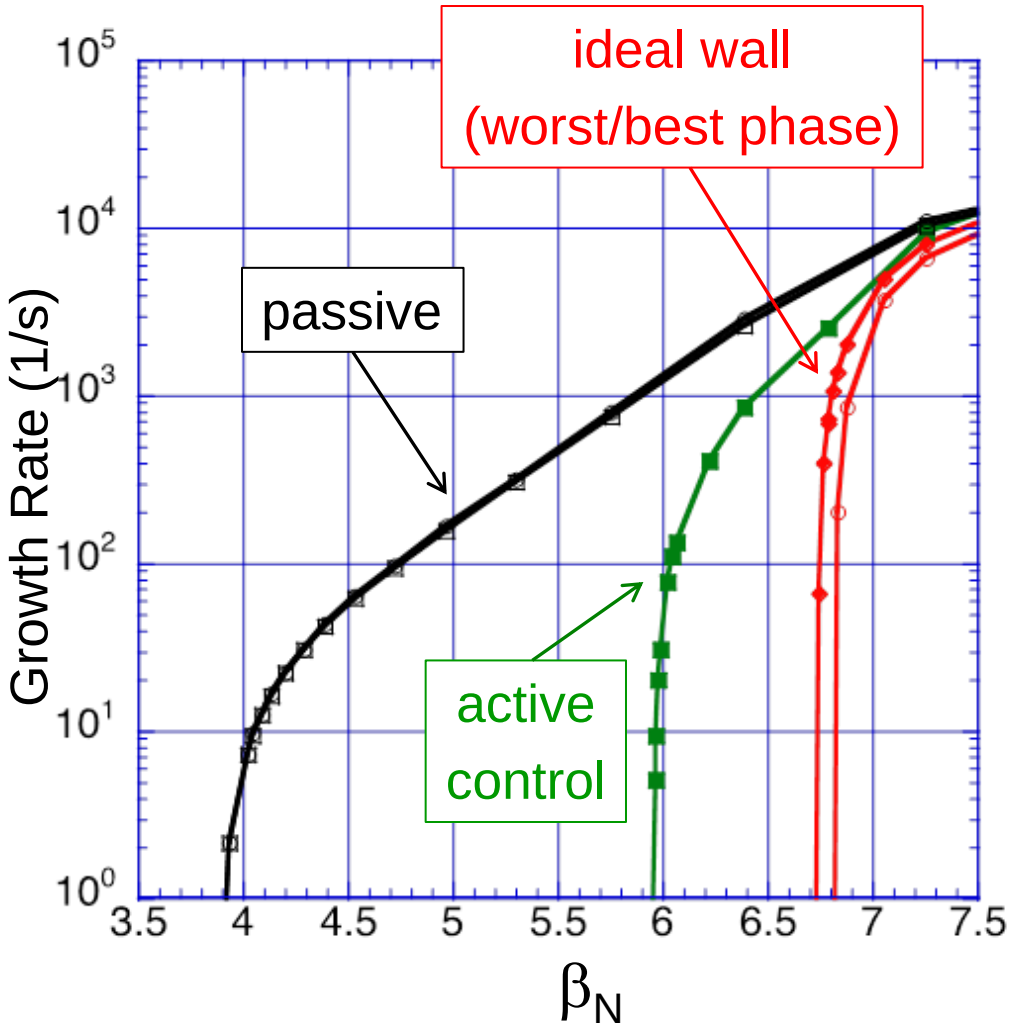
- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Midplane RWM coils
- Performance
  - Somewhat superior to existing RWM sensors ($\Delta\beta_N \sim 0.25$)

Proposed "B position" sensors in upper divertor driving upper & lower NCC significantly improves performance



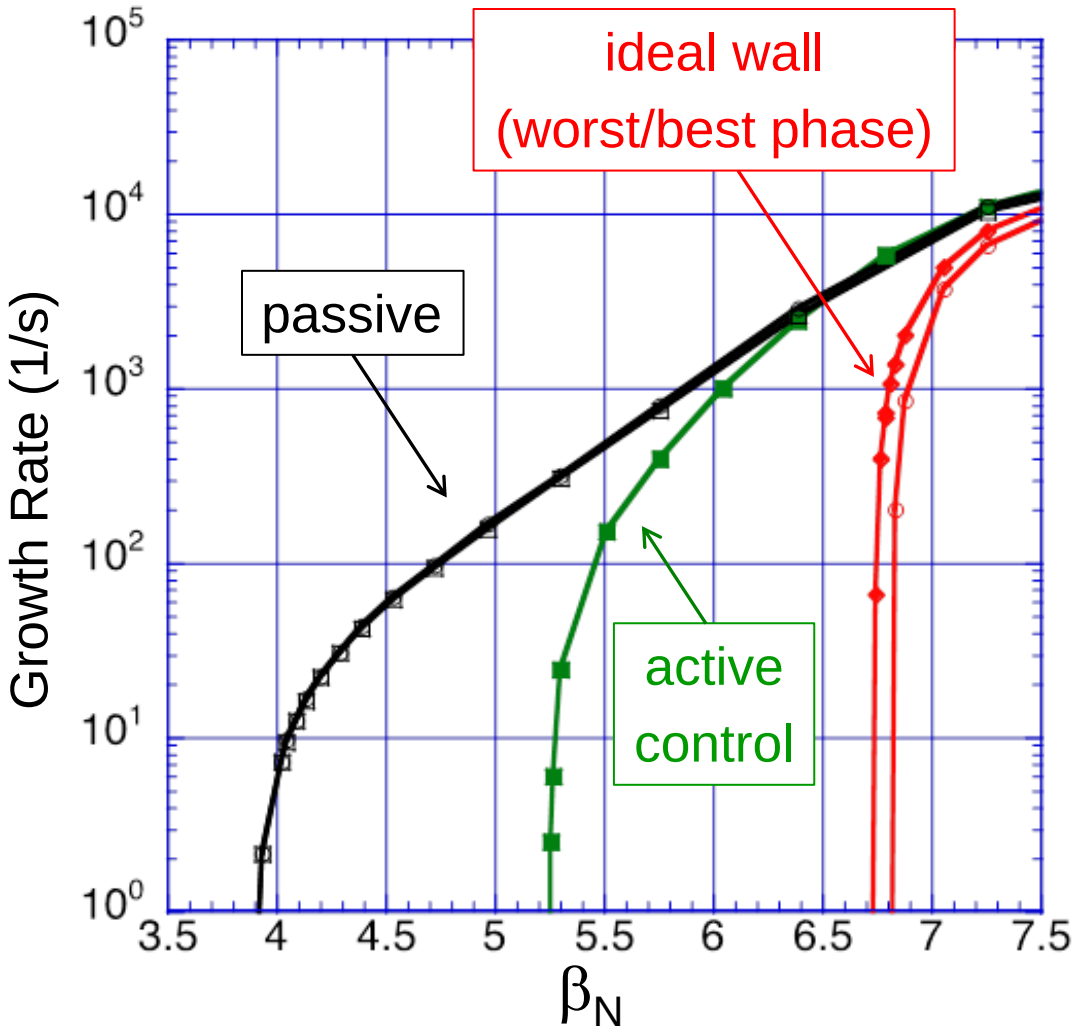
- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Top and bottom NCC (2x12)
- Performance
  - Uncompensated sensor results similar
  - Significantly superior performance to existing sensors/coils ($\Delta\beta_N$ ~ 1.25)

Proposed "B position" sensors in upper divertor driving upper & lower NCC and midplane RWM coils also works well



- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Top and bottom NCC (2x12), and RWM coils
- Performance
  - Uncompensated sensor results similar
  - Slightly inferior performance to upper/lower NCC alone ($\Delta\beta_N$ ~ -0.1)
  - In reality, w/midplane coil may be superior if mode "bulges" (Sabbagh, PRL 2006)

The other potential "new" sensors (Positions C and D) tested are inferior to the "B position" sensor results



- Sensors
  - Top B_p, position C, compensated
- Actuators
  - Bottom NCC (1x12)
- Performance
  - Inferior to "Position B" sensor results by $\Delta\beta_N \sim -0.85$
  - NOTE: "Position D" sensor should not be considered for control at intermediate β_N
    - Need $\beta_N > 5$ for sufficient mode amplitude at high poloidal angle

Positions have been found for new RWM sensors to allow superior RWM feedback performance with NCC

- Past result: Active RWM control calculations showed superior performance to RWM coils with NCC and idealized sensors
- Issue: Further calculations showed existing RWM B_p sensors driving neighboring NCC coils yielded relatively poor performance
- Present calculations
  - Existing RWM B_p sensors driving NCC on the opposite side of the midplane can improve feedback performance ($\Delta\beta_N \sim +0.5$)
  - Sensors in correct positions near the divertor plates driving the full 2x12 NCC yield significant performance improvement ($\Delta\beta_N \sim +1.25$)
  - Partial NCC (2x6) also show significant performance improvements: (odd, or even parity options yield $\Delta\beta_N \sim +0.9$)

Stefan's Comments/Questions re: extended RWM sensors (+ SAS replies)

- Is it necessary that these be up/down symmetric?
  - Maybe focus on LSN discharges for the first installation?
    - SAS comment: Up/down asymmetric ok – also has advantage of higher m resolution (helps address comment by Jong-Kyu regarding higher n's)
- Is likely premature to consider the details:
  - Is lower divertor going to be modified for pumps or lithium systems?
    - Suggested locations need changes if a cryopump placed in lower divertor.
    - But, cryopump would also allow for opportunities for sensor integration
    - Reply: Sensors to be installed at same time / must be compatible w/cryo.
  - How many years of operating with these sensors is required to make them worth the effort?
    - SAS: Even one year would provide key data, and results might argue to keep them in (e.g. for improved operation of RWM state-space controller)
- Who will do this work?
  - SPG not likely to have time (if accepted in plan, person would be found)