NSTX-U

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RWM active control performance analysis using NCC actuators and realistic sensors

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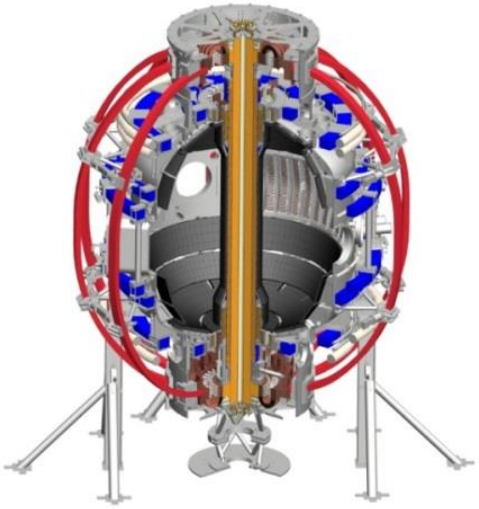
PPPL



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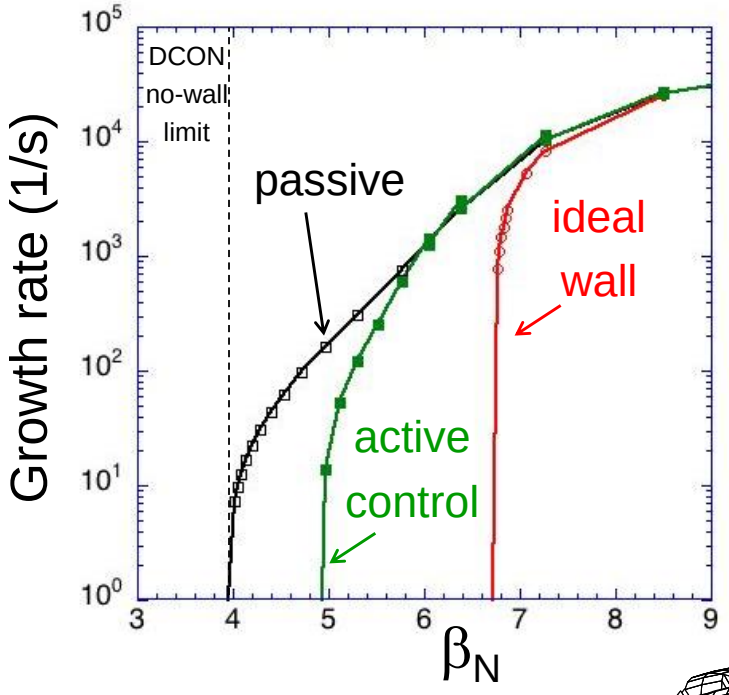
V1.2

RWM active control performance analysis using NCC actuators now performed with realistic sensors

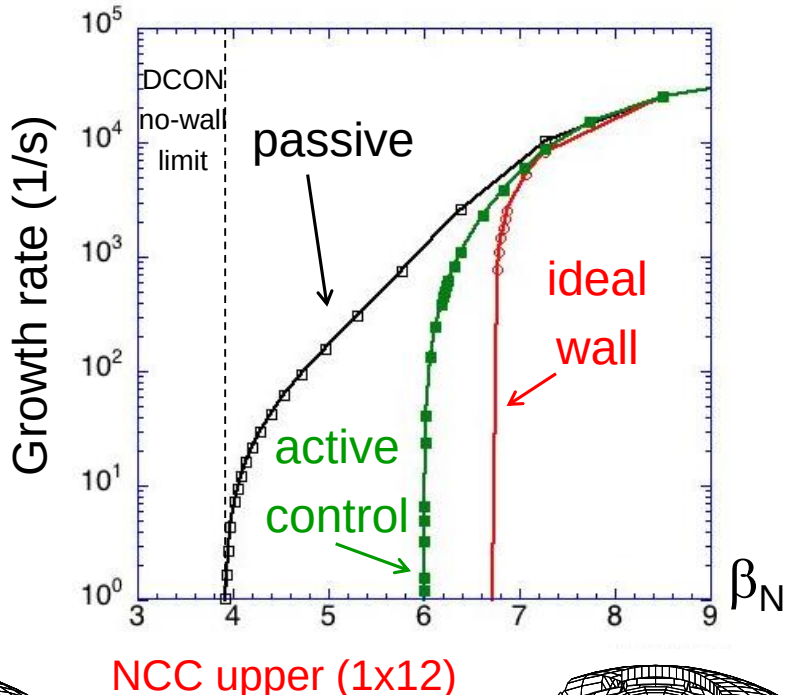
- Motivation
  - Past analysis considered several NCC options, compared to present RWM coils, but with idealized sensors
- Outline
  - Review of RWM active control performance with idealized sensors
  - Control performance of NCC using existing sensors
  - Control performance of NCC using newly-considered sensors
  - Comparison of NCC configurations using best-performing sensors

Review: RWM active control capability increases as partial NCC coils are added (calculations using idealized sensors)

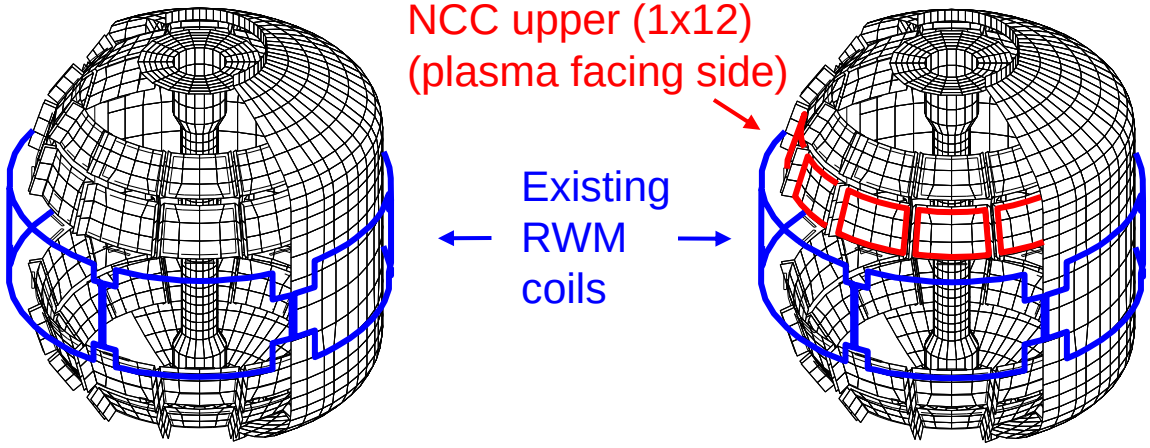
Using present midplane RWM coils



Partial NCC 1x12 (upper), favorable sensors

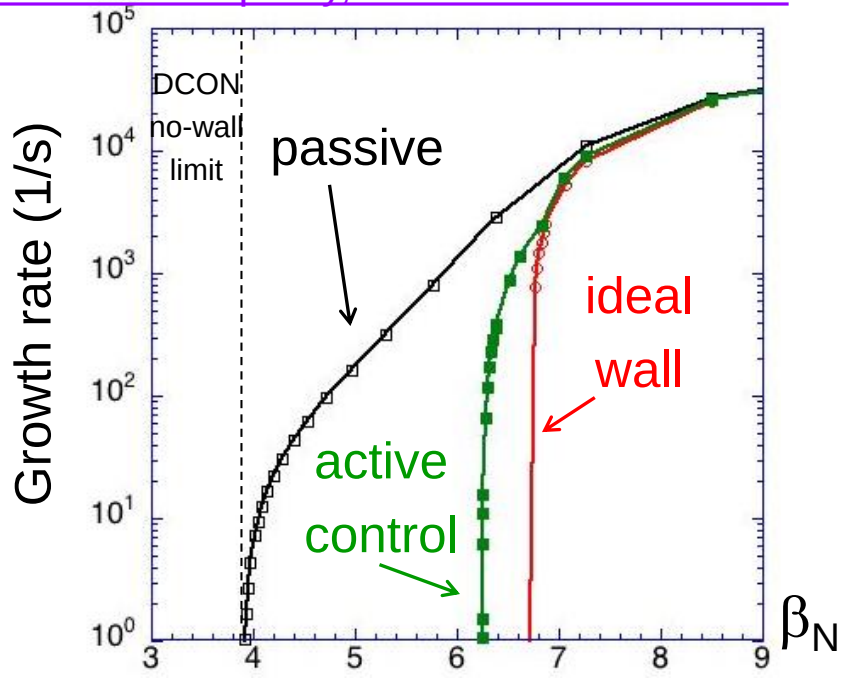


- Partial 1x12 NCC coil set significantly enhances control
  - Present RWM coils: active control to $\beta_N/\beta_N^{no\text{-}wall} = 1.25$
  - NCC 1x12 coils: active control to $\beta_N/\beta_N^{no\text{-}wall} = 1.52$

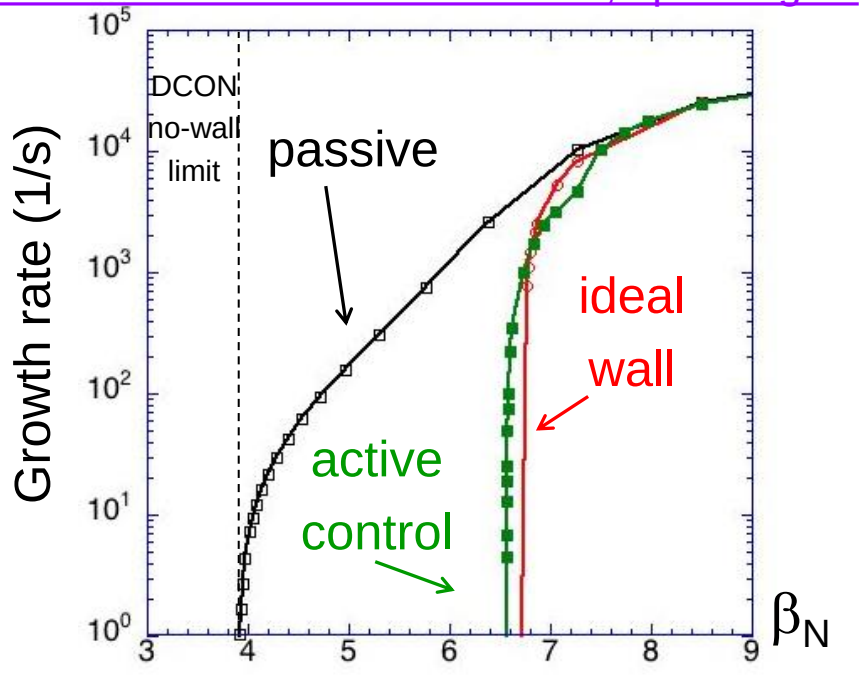


Review: RWM active control capability increases further with full NCC (calculations using idealized sensors)

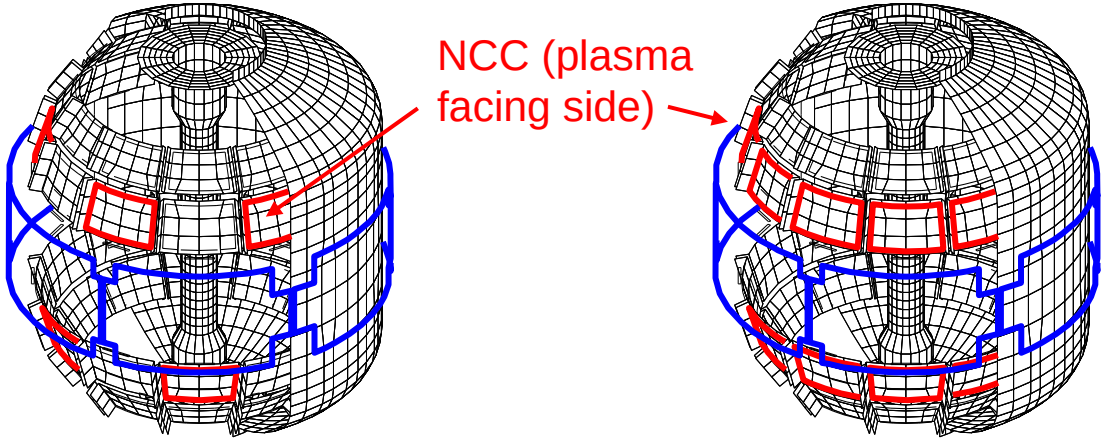
NCC 2x6 odd parity, with favorable sensors



NCC 2x12 with favorable sensors, optimal gain

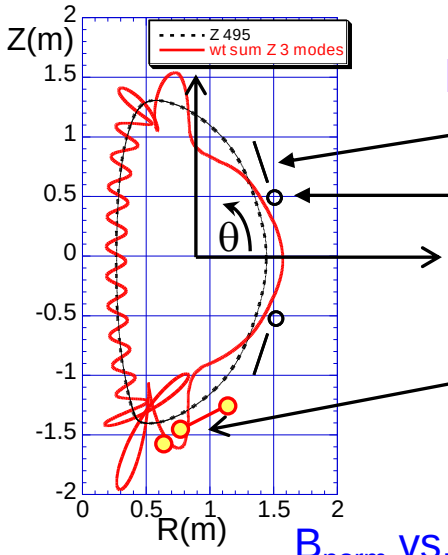


- Full NCC coil set allows control close to ideal wall limit
  - NCC 2x6 odd parity coils: active control to $\beta_N/\beta_N^{no\text{-}wall} = 1.58$
  - NCC 2x12 coils, optimal sensors: active control to $\beta_N/\beta_N^{no\text{-}wall} = 1.67$



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

n = 1 ideal eigenfunction for high beta plasma

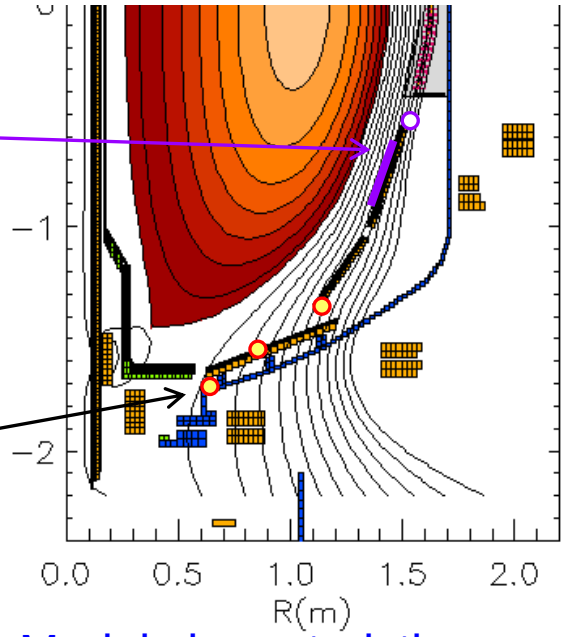


Present sensor locations

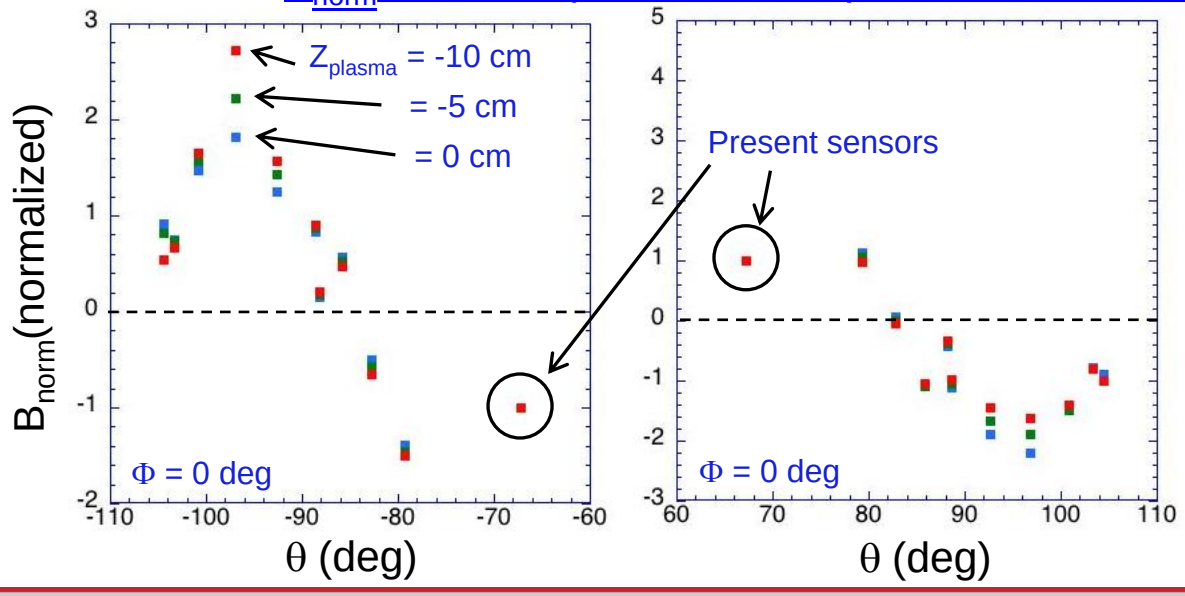
B_R sensors (nominally normal, B_{norm})

B_p sensors (nominally tangential, B_{tan})

New sensor locations (includes one new location above midplane)



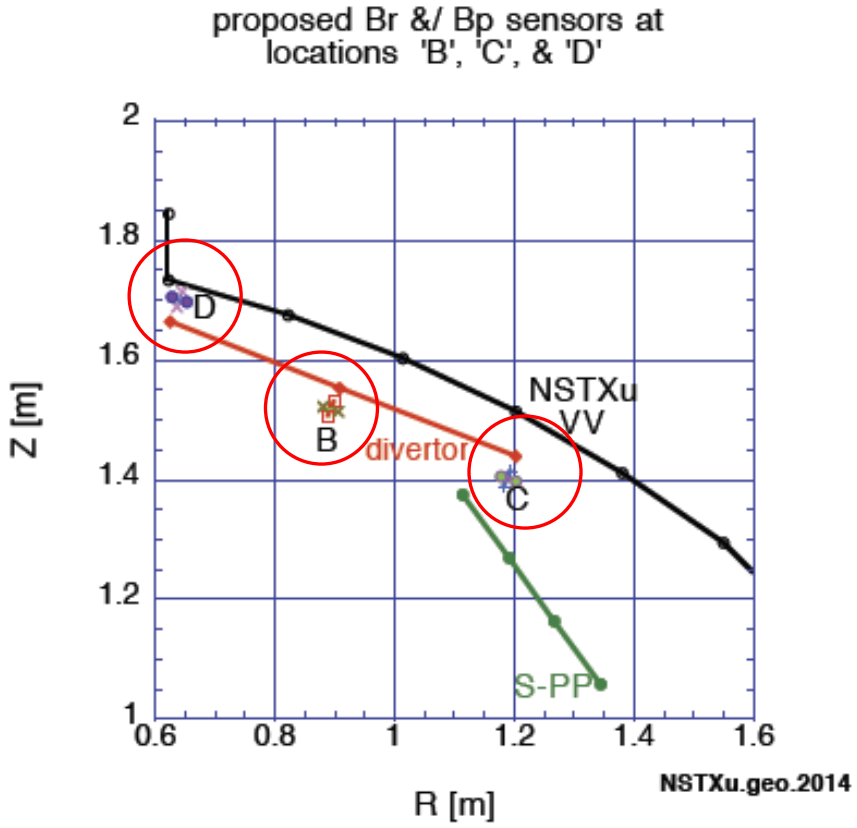
B_{norm} vs. theta (normalized to present Br sensors)

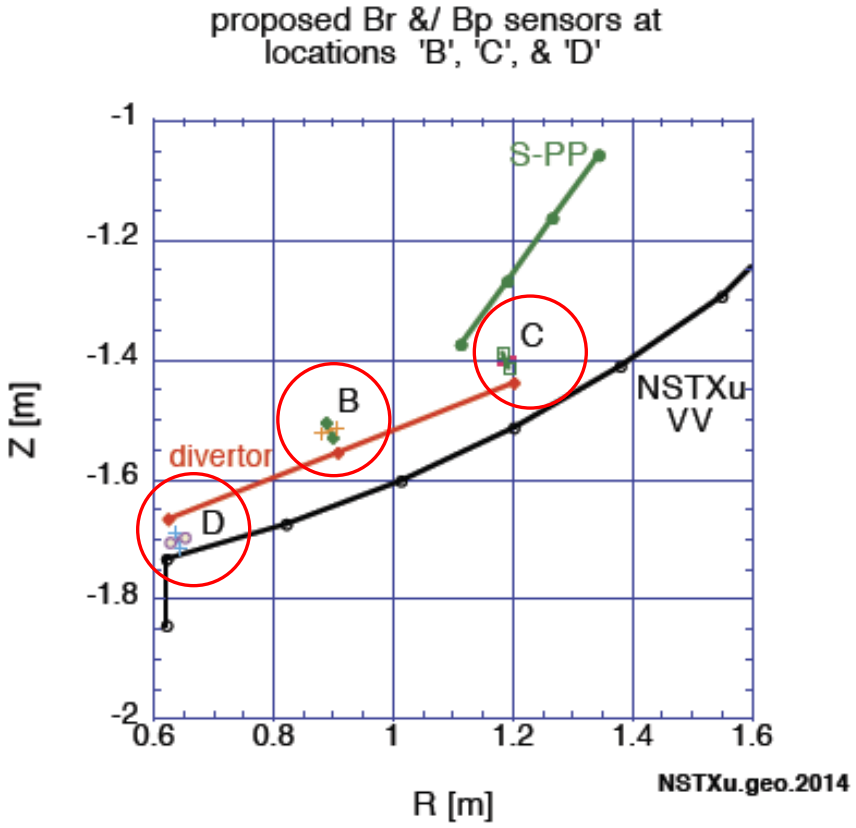


- Model characteristics
  - New 3D model of divertor plate
  - 3D sensors with finite toroidal extent; n*A of existing sensors
- Results summary
  - Field amplitude up to factor of 6 larger with new sensors
  - Perturbed field reversals observed with new sensors
  - Signals sufficient with plasma shifted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

Extended RWM sensors proposed – consider some new sensor positions closer to the divertor region

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

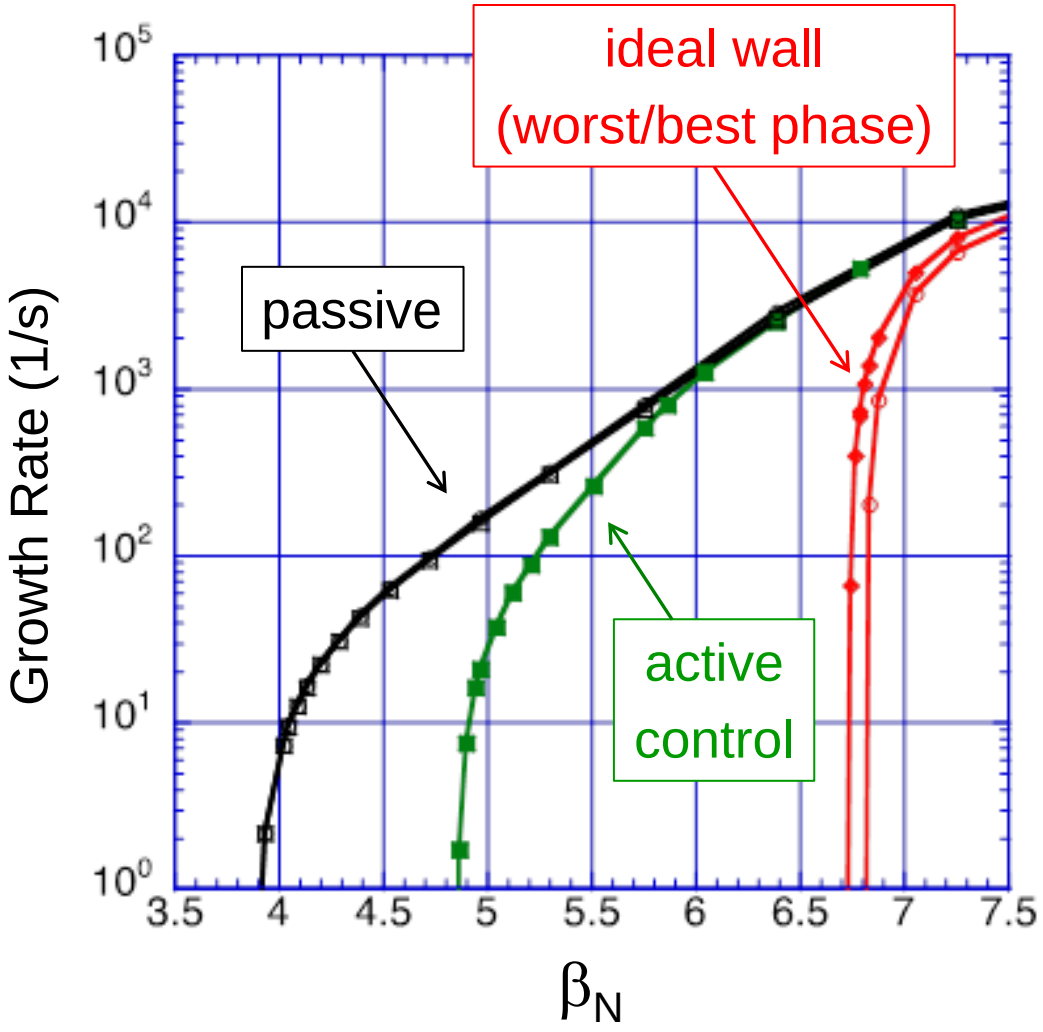




Extensive VALEN calculations of RWM active control performance considered several variations

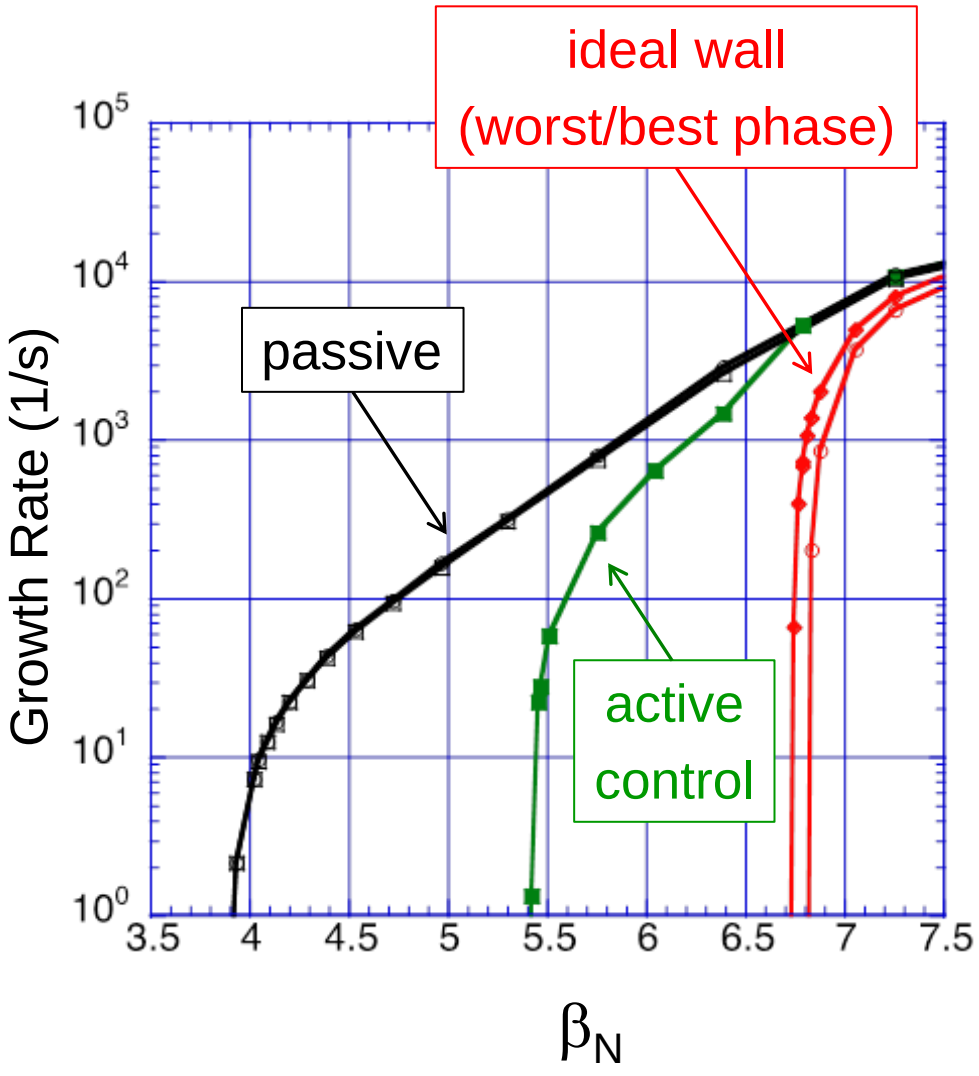
- Configuration variations (all using "full" NSTX-U model)
  - Sensor position variations
  - Partial and full NCC sets; midplane RWM coils added (or not)
  - NOTE: "intermediate β_N" equilibrium used
    - Higher β_N equilibrium shows greater mode amplitude deeper into divertor region (in poloidal angle), 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



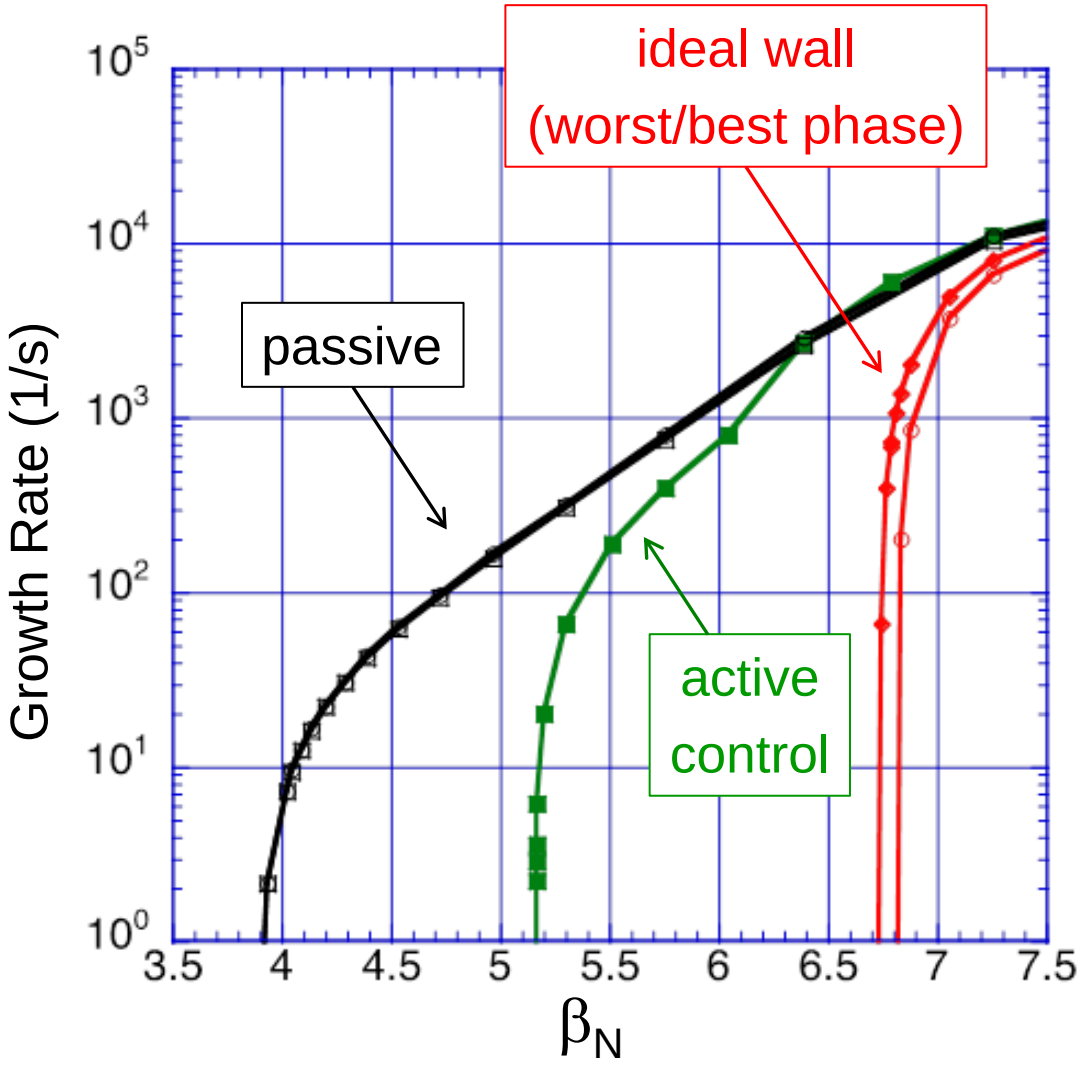
- Sensors
  - Present RWM sensors (bottom B_p), compensated
- Actuators
  - Midplane RWM coils
- Performance
  - Nearly identical to idealized midplane coils (as expected)

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



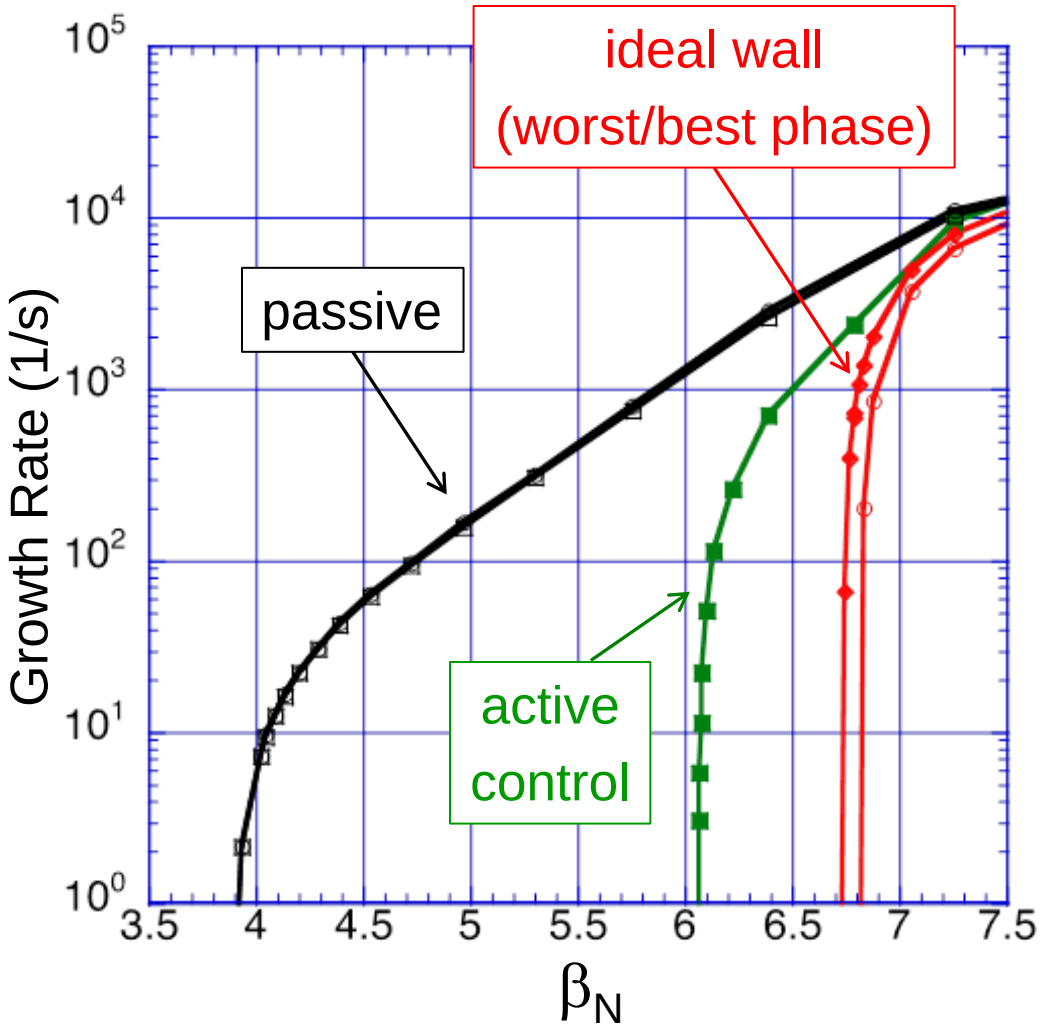
- Sensors
  - Present RWM sensors (bottom B_p), compensated
- Actuators
  - Top NCC coils (1x12)
- Performance
  - Superior to midplane RWM coils by $\Delta\beta_N \sim 0.5$
  - Uncompensated sensor results similar (bottom B_p driving upper NCC)
  - BUT: Present RWM sensors driving neighboring NCC results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

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



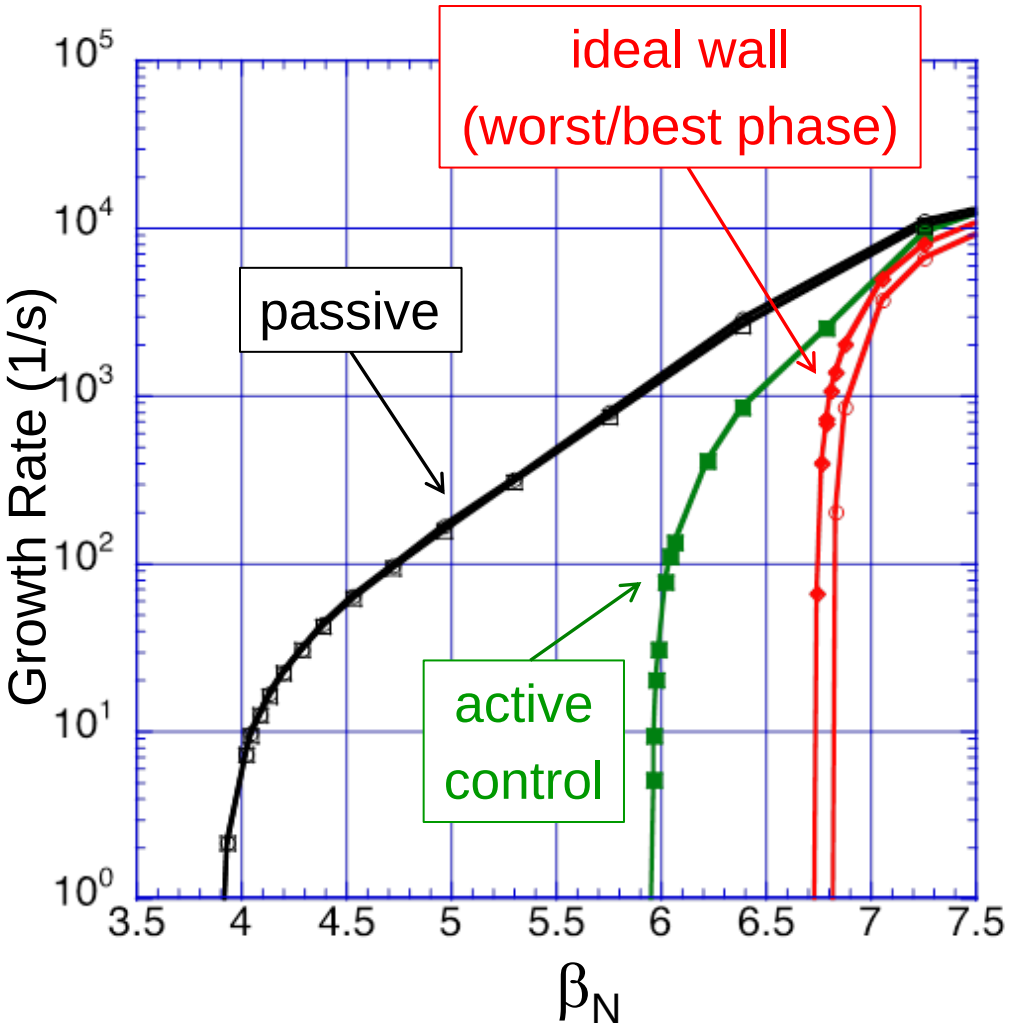
- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Midplane RWM coils
- Performance
  - Somewhat superior to existing RWM sensors ($\Delta\beta_N \sim 0.25$)

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



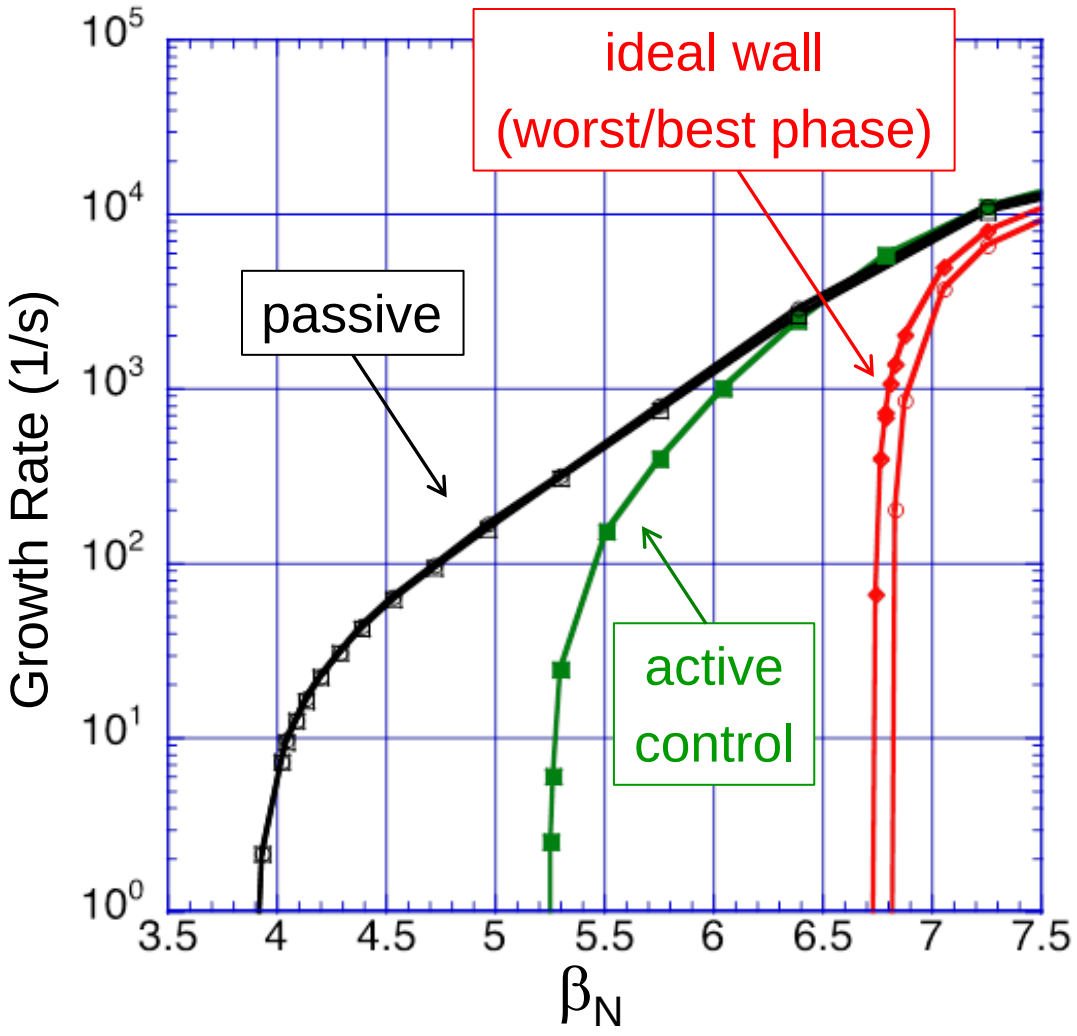
- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Top and bottom NCC (2x12)
- Performance
  - Uncompensated sensor results similar
  - Significantly superior performance to existing sensors/coils ($\Delta\beta_N$ ~ 1.25)

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



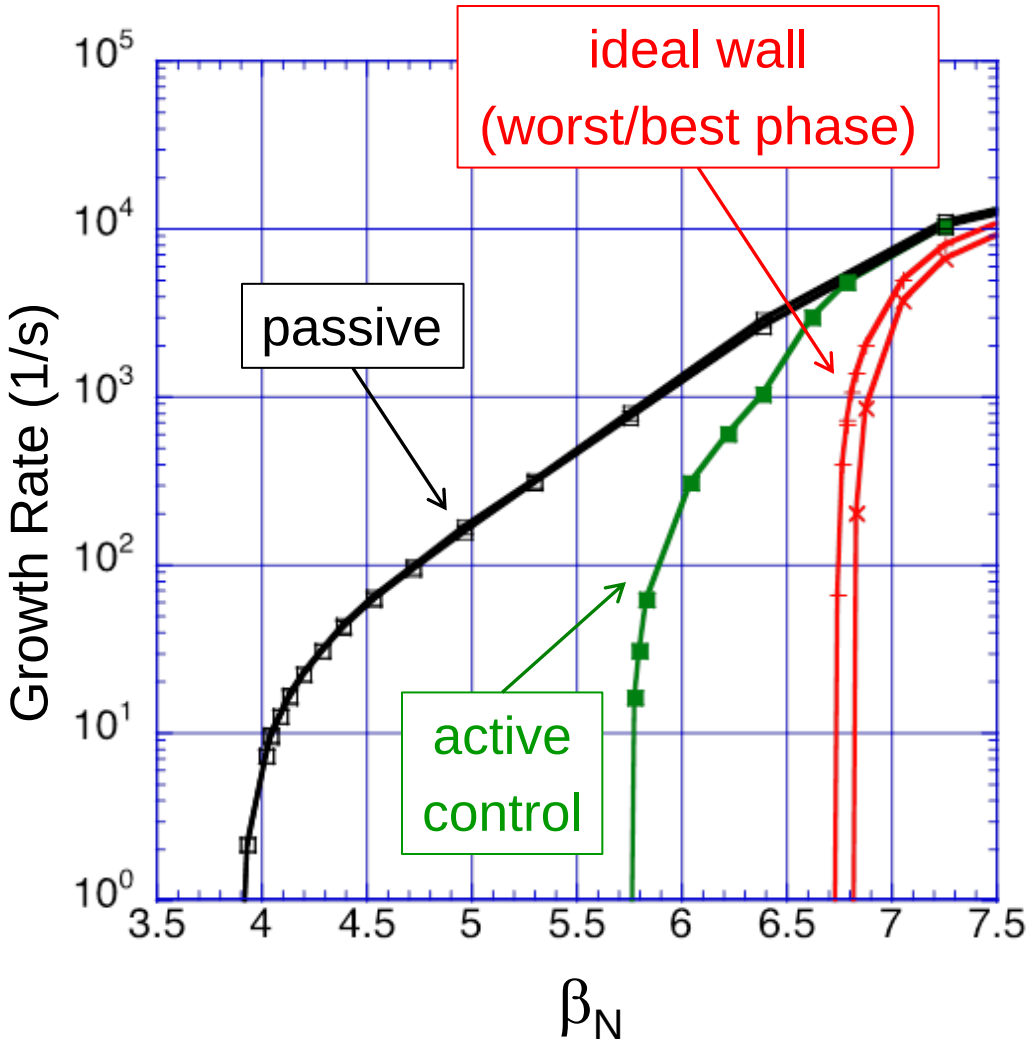
- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Top and bottom NCC (2x12), and RWM coils
- Performance
  - Uncompensated sensor results similar
  - Slightly inferior performance to upper/lower NCC alone ($\Delta\beta_N$ ~ -0.1)
  - In reality, w/midplane coil may be superior if mode "bulges"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

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



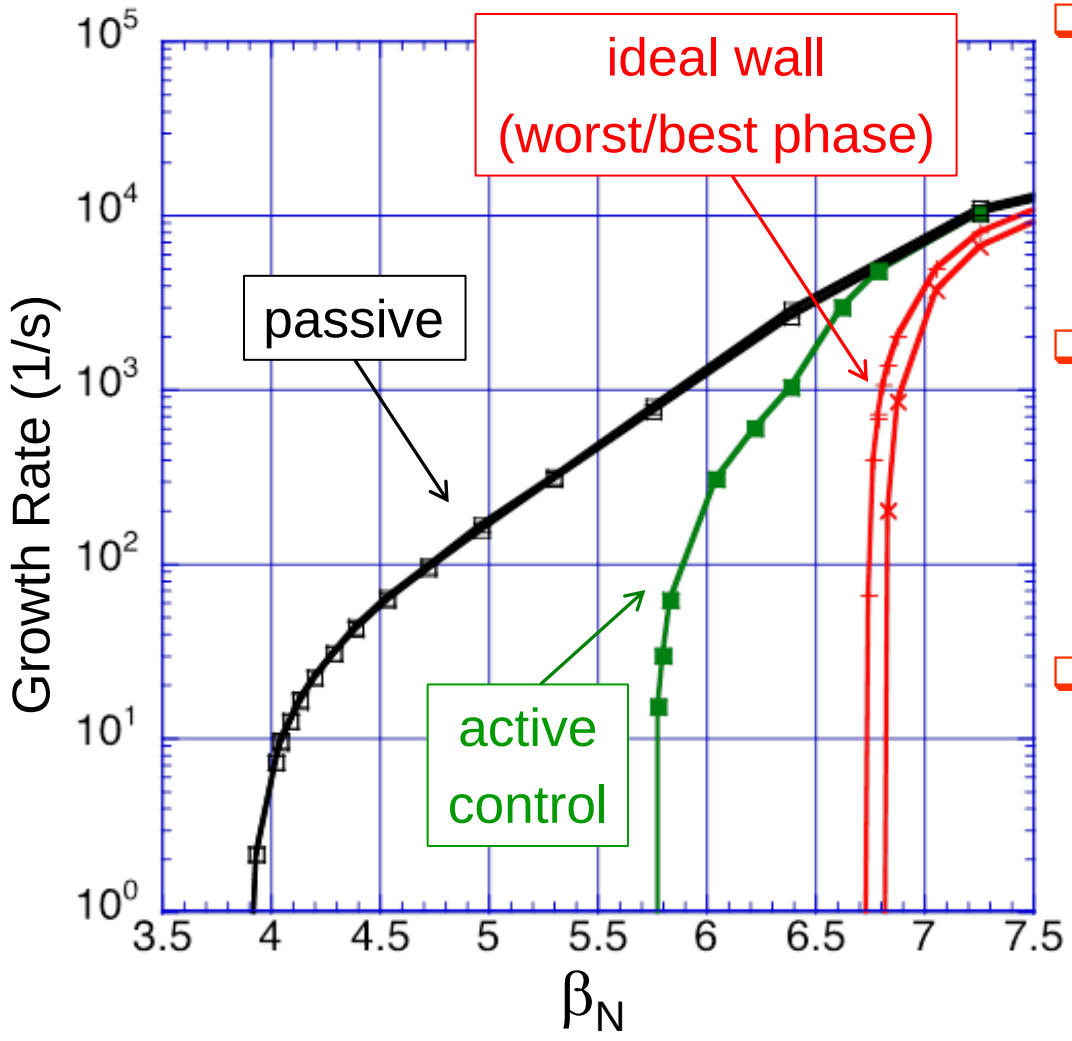
- Sensors
  - Top B_p, position C, compensated
- Actuators
  - Bottom NCC (1x12)
- Performance
  - Inferior to "Position B" sensor results by $\Delta\beta_N \sim -0.85$
  - NOTE: "Position D" sensor should not be considered for control at intermediate β_N
    - Need $\beta_N > 5$ for sufficient mode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

Proposed "B position" sensors in upper divertor driving "odd parity" partial NCC set also shows has good performance



- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Top and bottom odd parity partial NCC (2x6)
- Performance
  - Significantly superior performance to existing sensors/coils ($\Delta\beta_N$ ~ +0.9)
  - Full 2x12 NCC are still superior ($\Delta\beta_N$ ~ +0.35)

Proposed "B position" sensors in upper divertor driving "even parity" partial NCC set shows identical performance



- Sensors
  - Top B_p, position B; compensated
- Actuators
  - Top and bottom even parity partial NCC (2x6)
- Performance
  - Practically identical to odd parity partial NCC (2x6)

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 $\Delta\beta_N \sim +0.9$)