NSTX-U

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Non-axisymmetric Control Coil (NCC) Options and Analyses

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For the NSTX research team

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NCC Meeting
LSB318, PPPL
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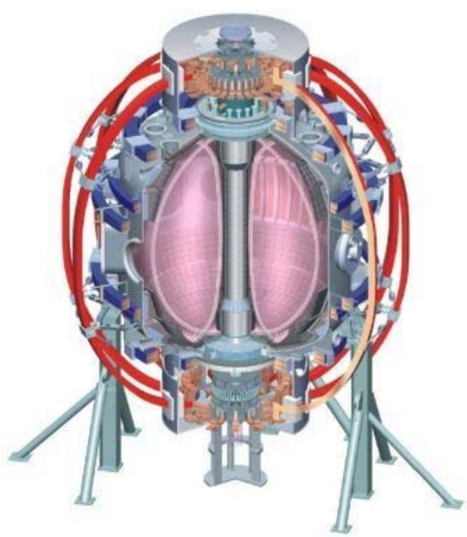

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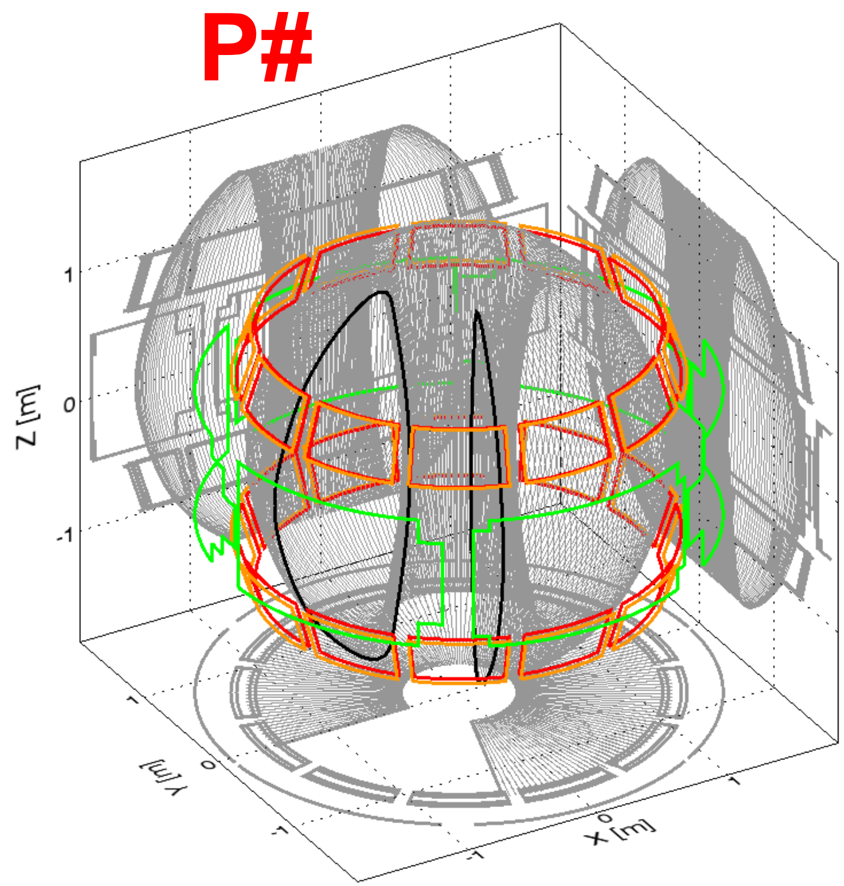
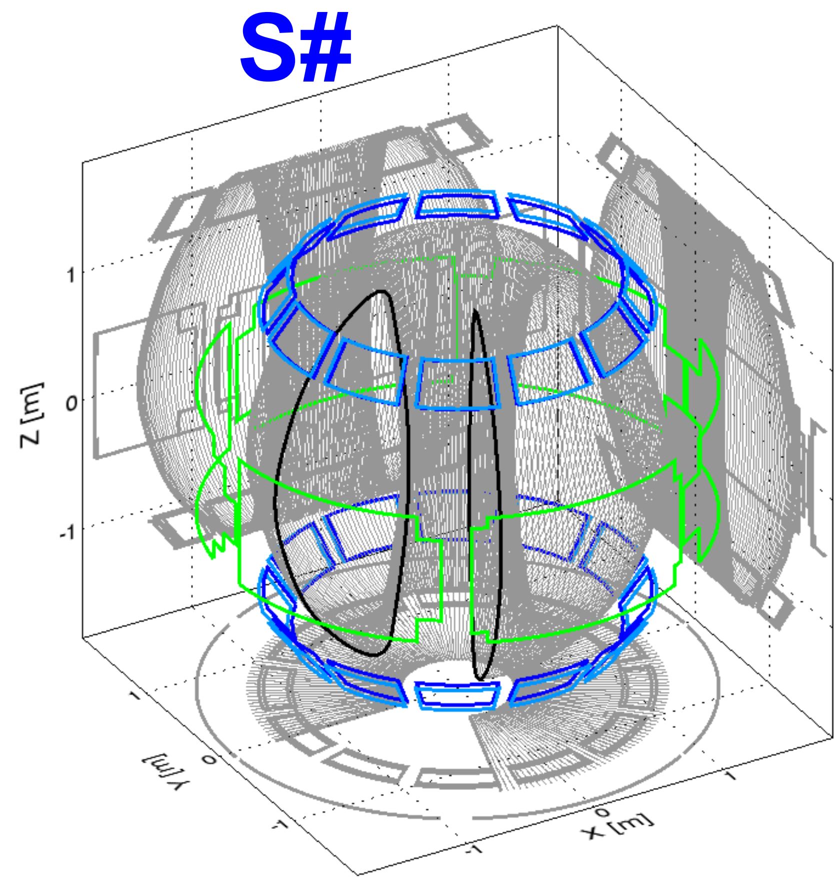
Motivation

- Non-axisymmetric control coil (NCC) is under consideration for the next 5-yr term of NSTX-U operation
- Many impacts on various TSG physics research
  - MS: Advanced control for macroscopic stability such as RWM, LM, TM
  - MS: Momentum transport (or rotation) control using 3D fields
  - TT: Microscopic stability control via rotation control
  - BP: Particle (or pedestal) control using 3D fields
  - ASC: Vertical control (n=0)
- 2 off-midplane NCC with 12-array has been proposed, but partial NCC is now also under consideration to reduce the cost and realize the plan for the next 5-yr
  - Plan development is needed for the 5-yr document and PAC

Full NCC option
(2 off-midplane coils with 12 arrays)

- Primary option: Closer to the midplane, better for EF correction, NTV, edge coupling (by Chirikov)
- Secondary option: Closer to the top and bottom, but no advantage has been found yet

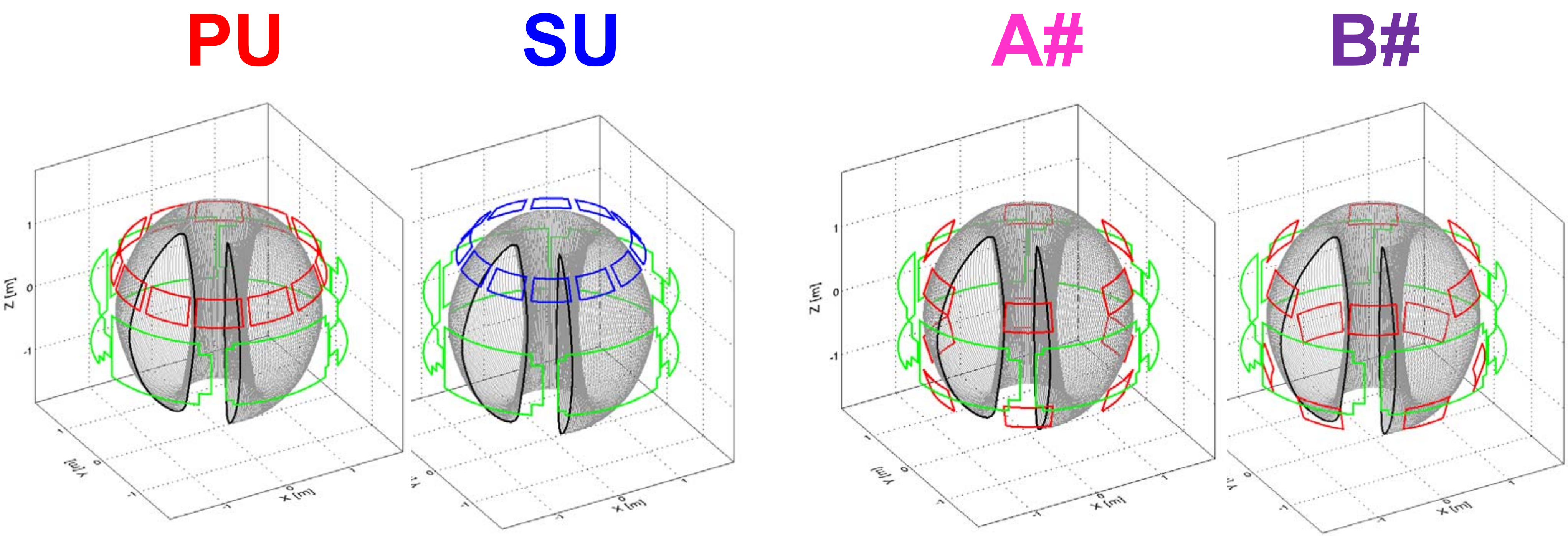




 # indicates different phasing between upper and lower coils
**** Only coils in front of the passive plates are analyzed***

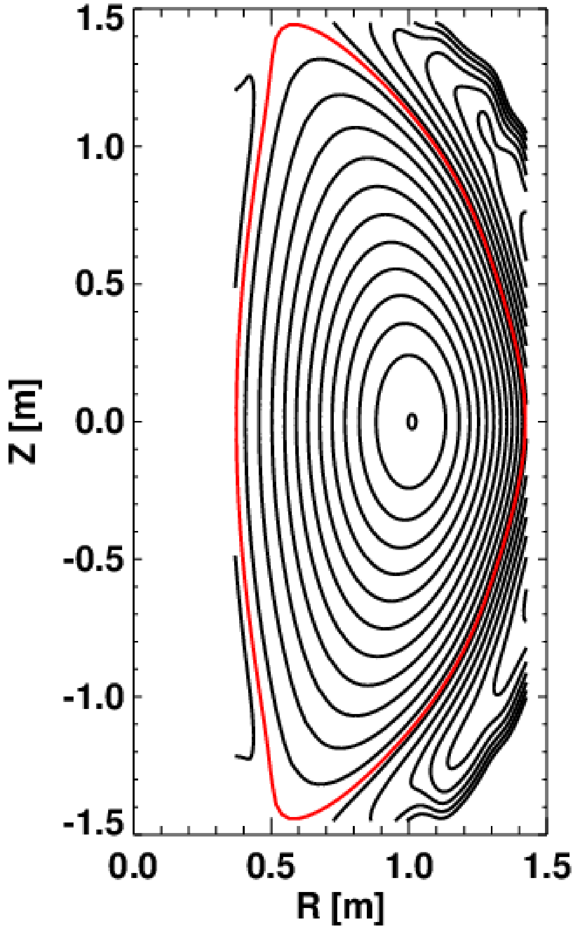
Partial NCC options (1 off with 12 arrays vs. 2 off with 6 arrays)

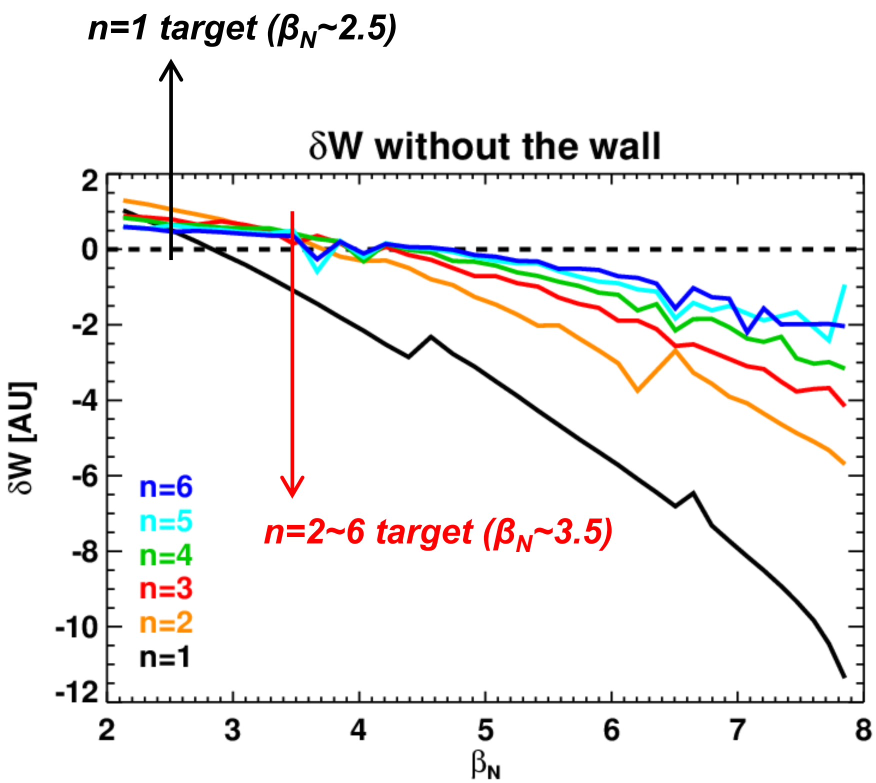
- 1 off with 12 arrays
  - n=1~6 can be produced, and n=3~4 rotation is possible (important for ITER and 3D diagnostics)
  - Synergy with RWMEF is not good
  - Analyses are done only with upper array (almost up-down symmetric)
- 2 off with 6 arrays
  - Only n=1~3 can be produced
  - Many possible combinations with RWMEF can be possible
  - Original NCC coil shapes are maintained in analyses, anticipating the full set upgrade



NSTX-U target plasmas and stability

- NSTX-U target plasmas are given by Gerhardt, Sabbagh
- Same shape and profiles but with different pressures (or β)
- For IPEC and NTV analysis, stable βs (without the wall) are selected

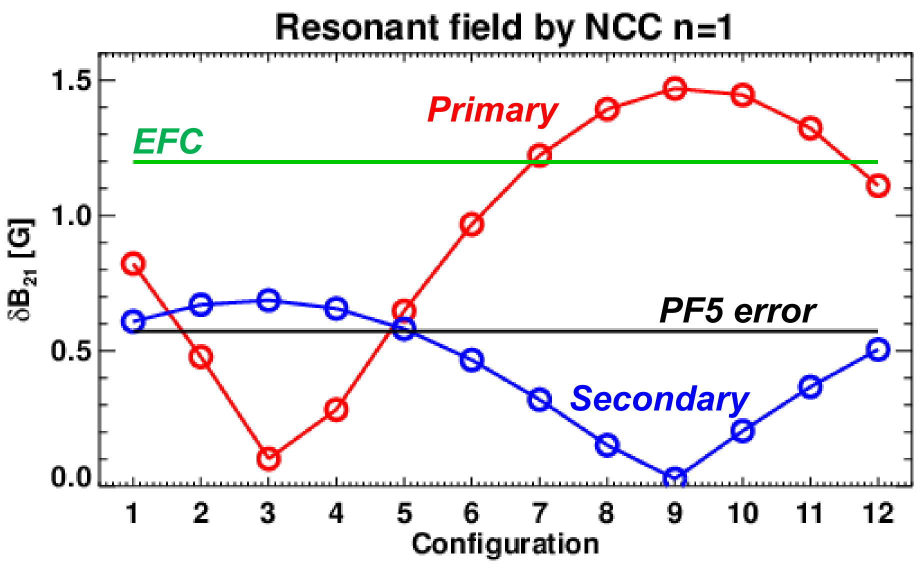




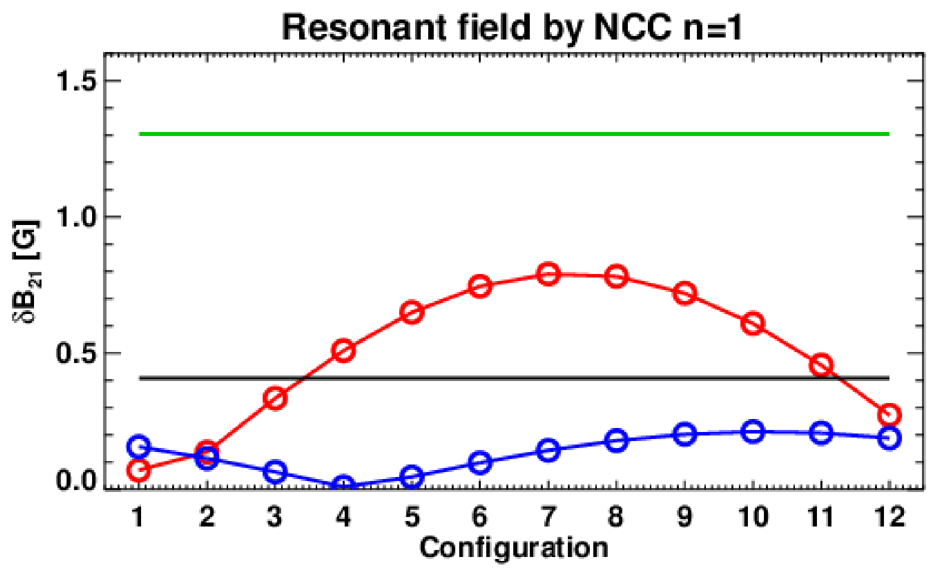
n=1 error field correction capability

- Full NCC with primary option provides good coupling with plasma and n=1 error field correction capability with high spectral flexibility
- Secondary option cannot effectively produce resonant field compared to RWMEF coils

IPEC



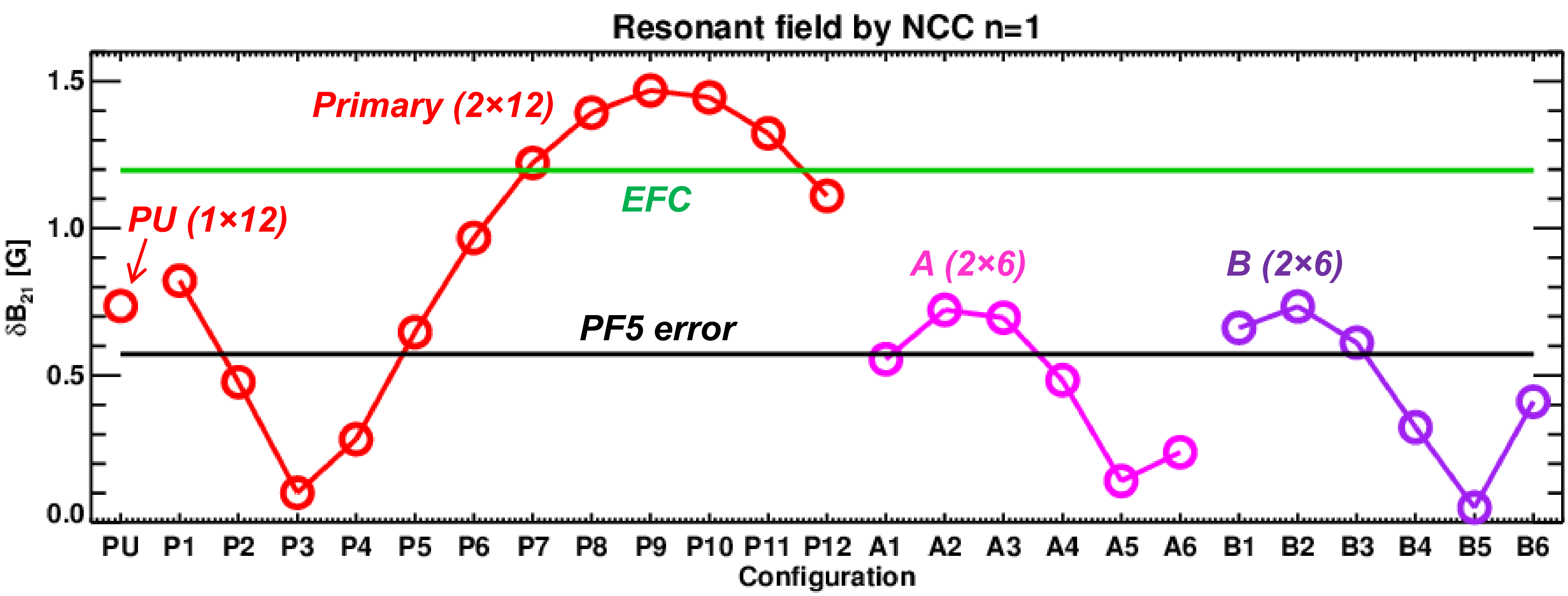
VACUUM



***** All analyses are done with 1kAt. If 6kAt is the maximum, note field can be 6 times larger, NTV can be 36 times larger, and Chirikov can be 2.5 times larger**

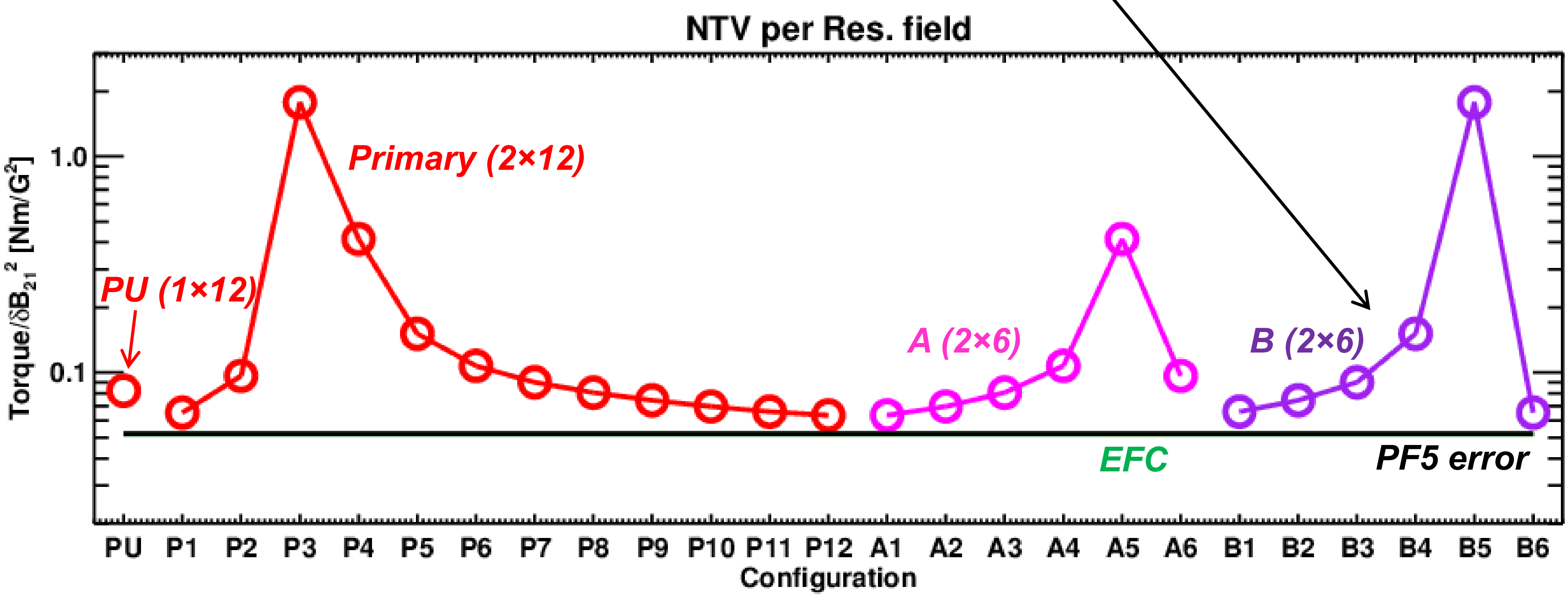
n=1 error field correction capability

- PU (1x12) is good enough for resonant error field correction
- SU (1x12) is bad (not shown)
- A and B (2x6) is also good enough with good spectral flexbility



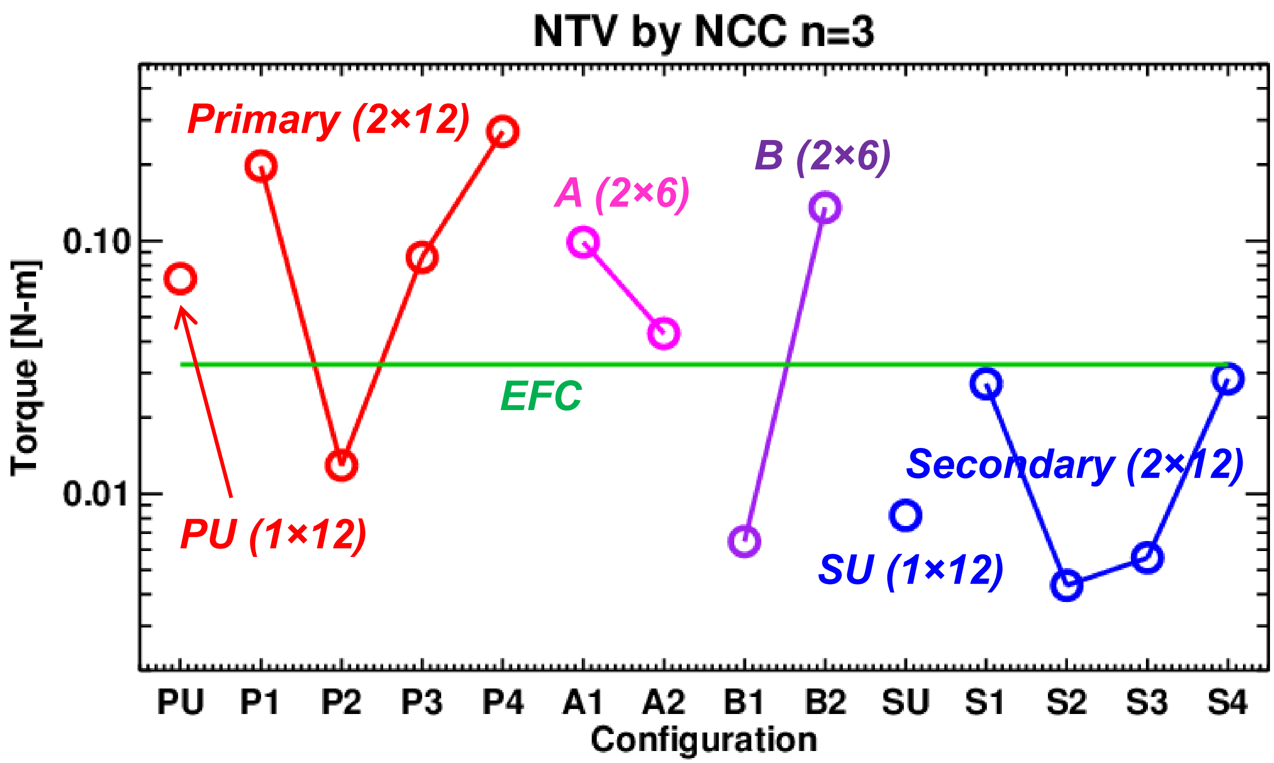
Selectivity for n=1 non-resonant field

- Selectivity of non-resonant field can be roughly seen by $S=NTV/\delta B^2$
  - Large S means that coils can produce NTV while minimizing resonant field
  - Small S means that coils can produce resonant field while minimizing NTV
  - Important in the study of non-res. Vs. res. error field effects
- **B (2x6) option gives much better selectivity than A (2x6)**



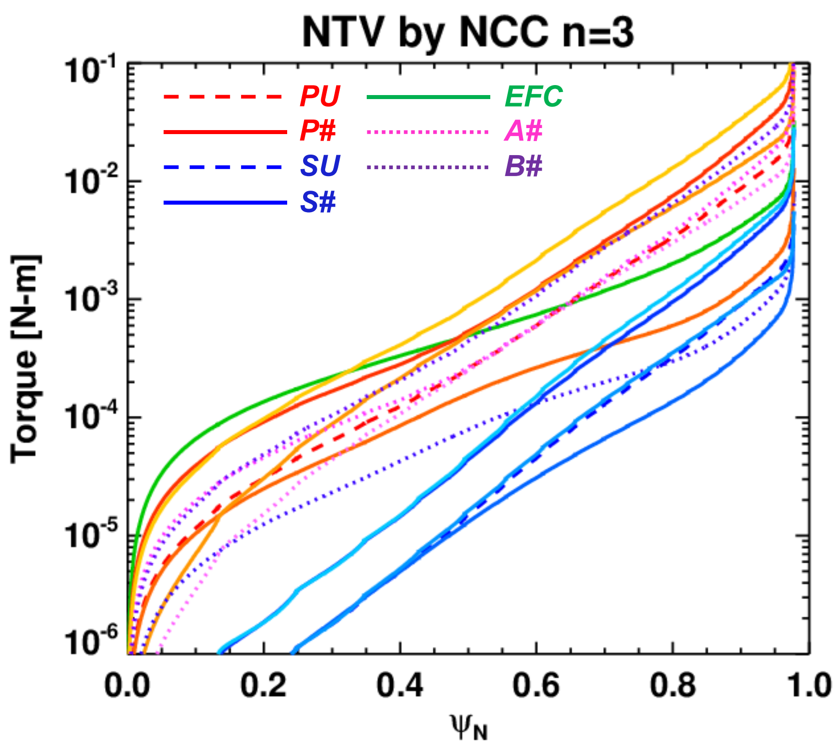
n=3 NTV braking capability

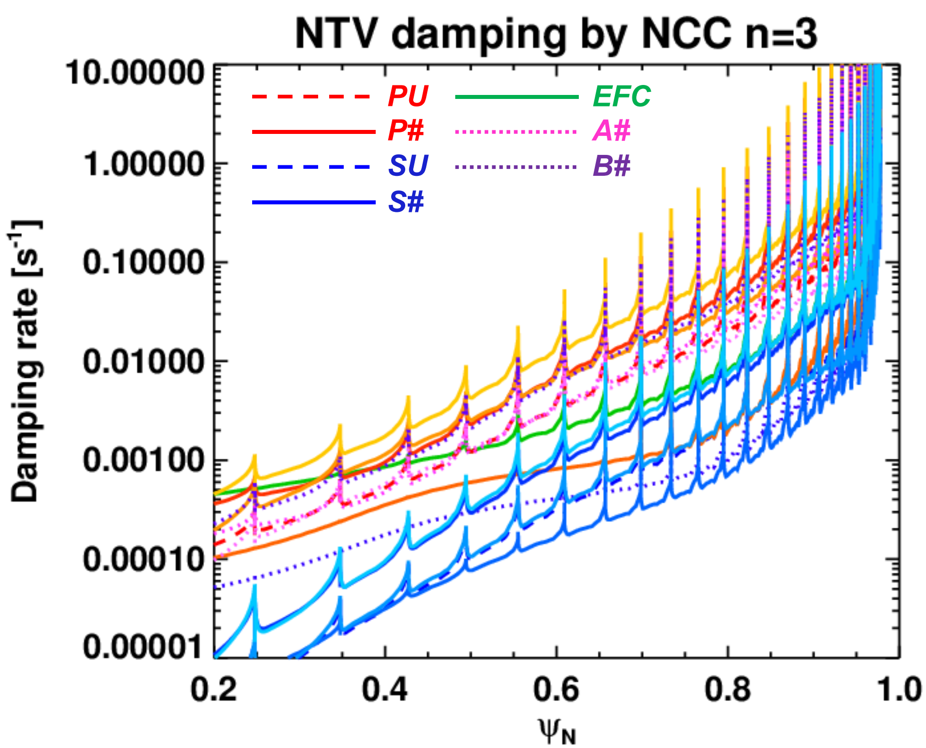
- Primary options, either with full or partial NCC, can provide better NTV braking capability than EFC
- **<u>Again B (2x6) option gives much better NTV variations than A (2x6)</u>**



Rotation control by n=3 NTV

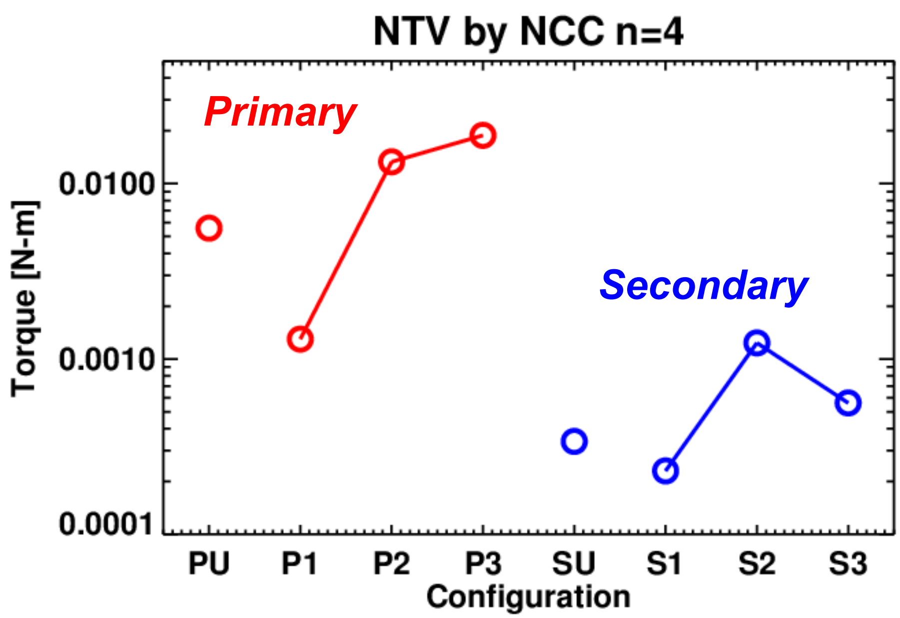
- Primary options, either with full or partial NCC, can provide better NTV braking selectivity (edge vs. core) than EFC
  - NTV selectivity (edge vs. core) is important to rotation profile control
- **In partial NCC, B (2x6) provides the best NTV selectivity**

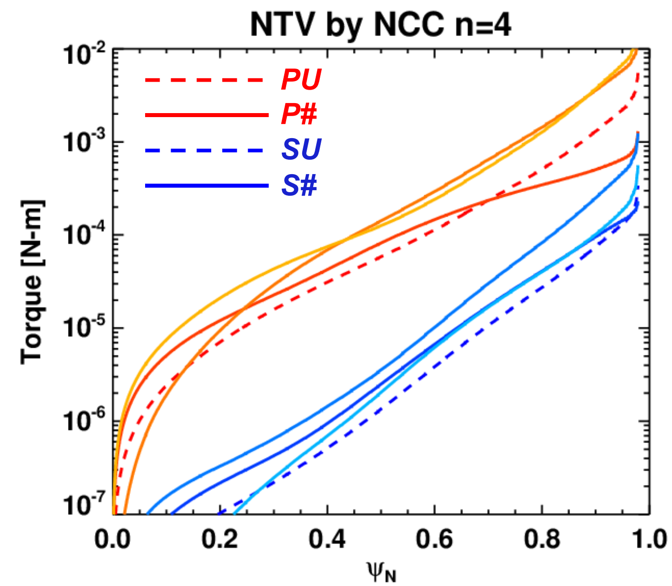


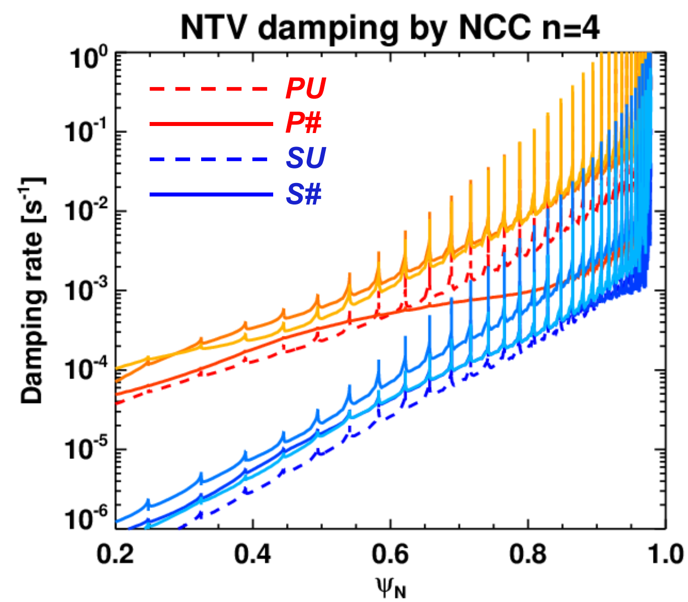


Rotation control by n=4 NTV

- Only 12 toroidal array can provide clean n=4 field
- Natural attenuation to the core gives good NTV selectivity compared to n=3, but NTV strength is too weak (This can be very good for RMP)

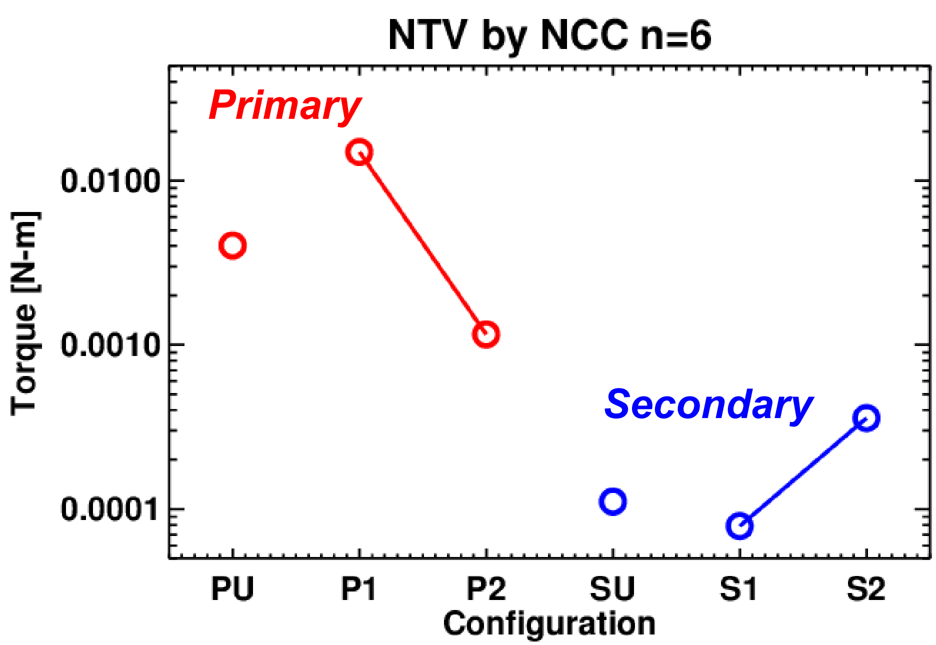


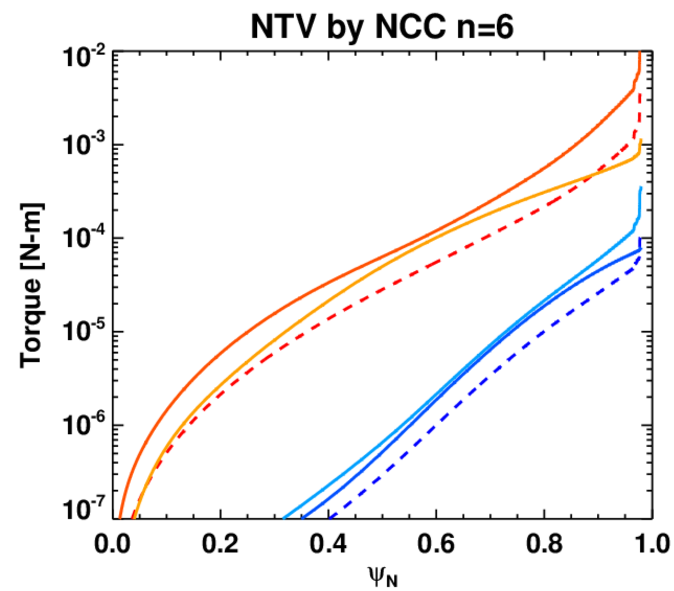


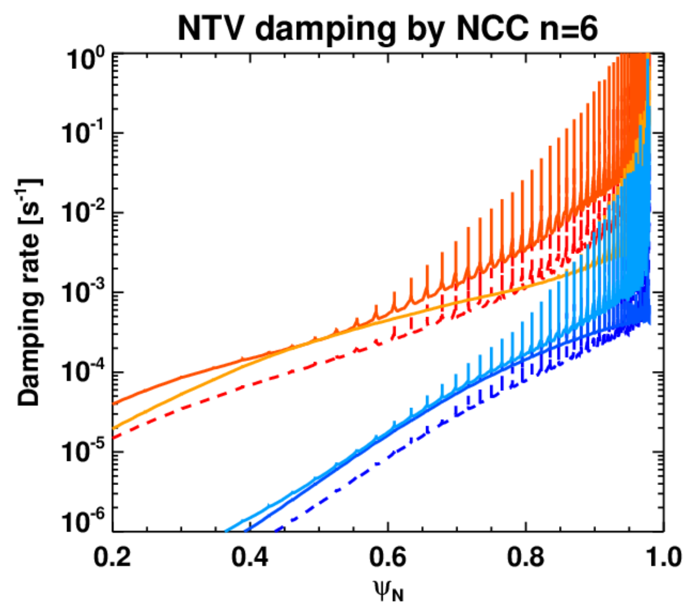


Rotation control by n=6 NTV

- Natural attenuation to the core is even better and so better NTV selectivity compared to n=3 or 4, but NTV strength is again too weak (This can be even better for RMP)

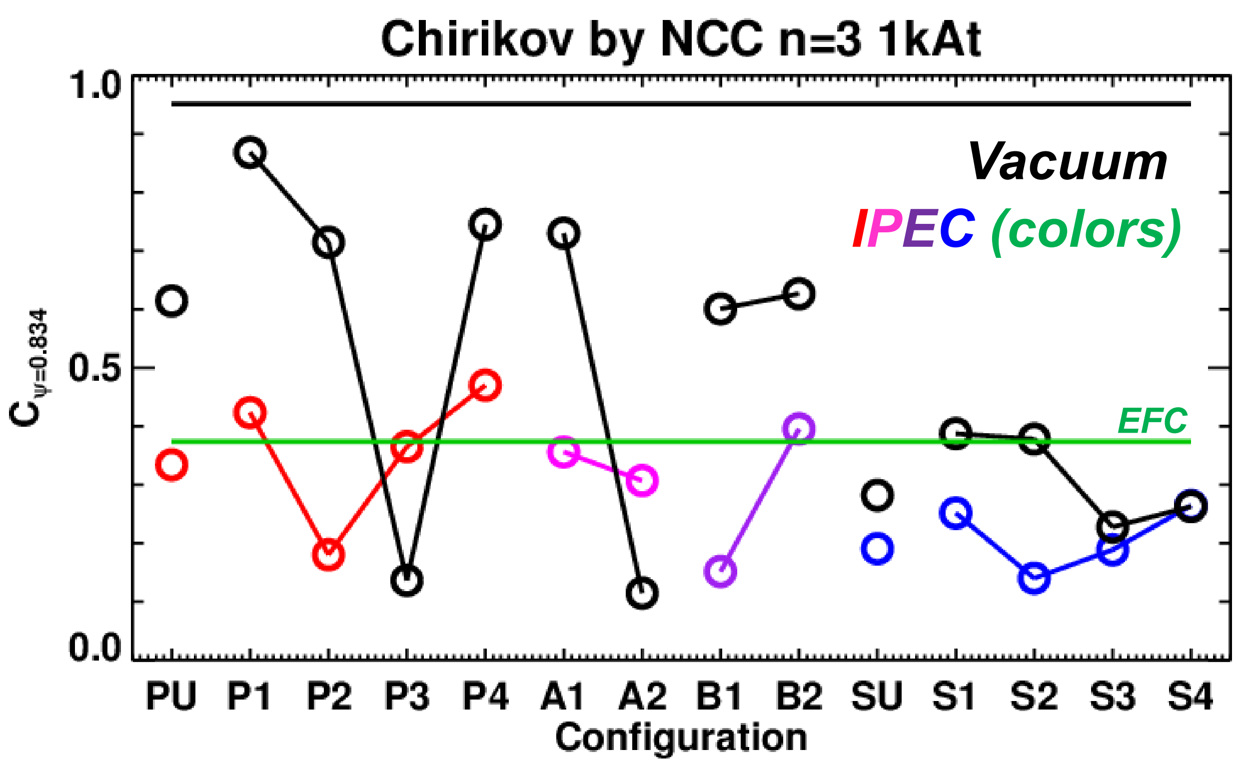






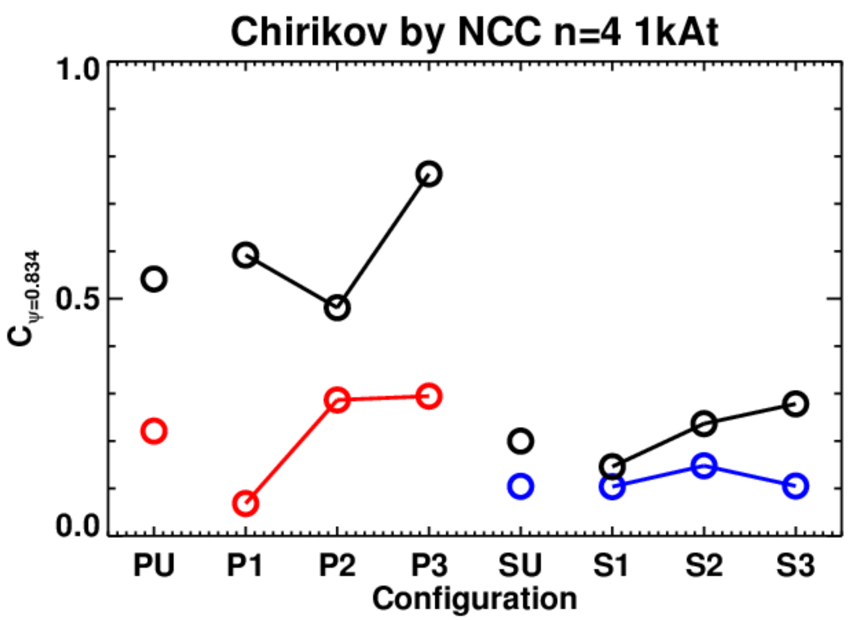
n=3 Chirikov overlap capability

- For RMP assessment, vacuum Chirikov overlap conditions are estimated (Chirikov=1 at ψ_N=0.834, as used for ITER)
- IPEC Chirikovs are also estimated but only for reference
- Primary options, either with full or partial NCC, can easily provide Chirikov>1 with maximum currents 6kAt



n>3 Chirikov overlap capability

- Primary options, either with full or partial NCC, can also produce sufficient n>3 field strength for Chirikov overlap condition
- Note Vacuum vs. IPEC Chirikov profiles become more separated in higher toroidal mode



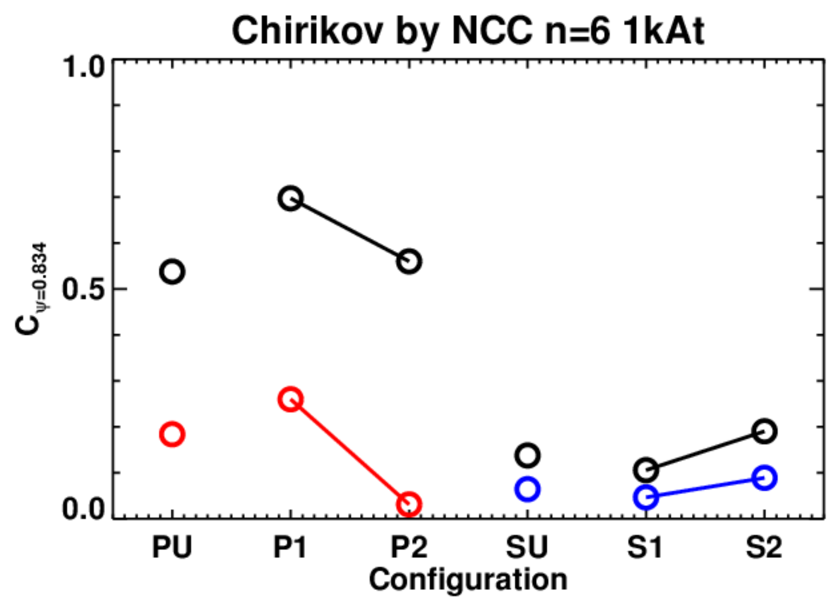
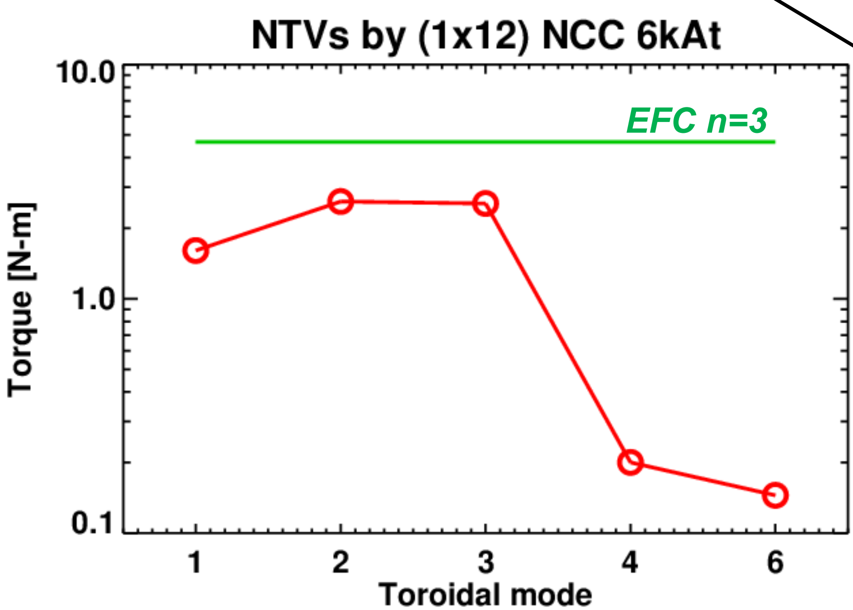


Figure of merit for 1x12 option

- Two figure of merits are used :
  - **Maximum NTV torque for rotation control**
  - **NTV torque when Vacuum Chirikov=1 at ψ_N=0.834 for RMP**
- Primary partial (1x12) can give large enough NTV torque with n=1~3 (still smaller than EFC n=3), but n=4~6 NTV torque is very small
- However, this may be good for RMP, as Chirikov condition can be satisfied with smaller NTV for higher n



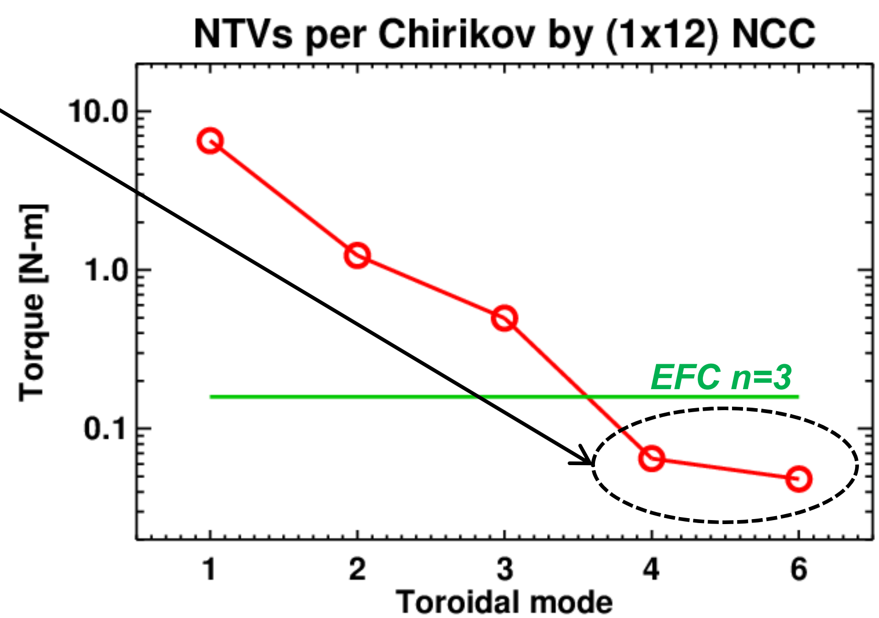
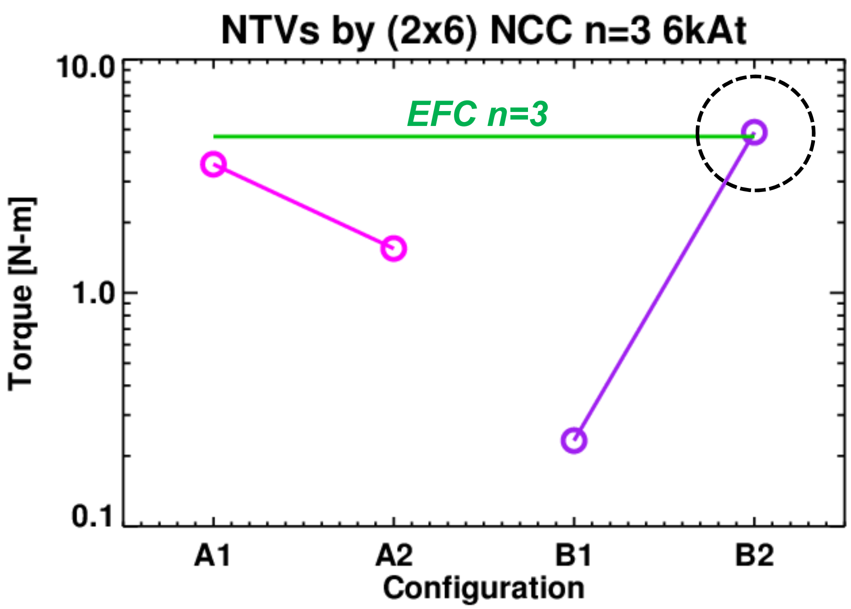
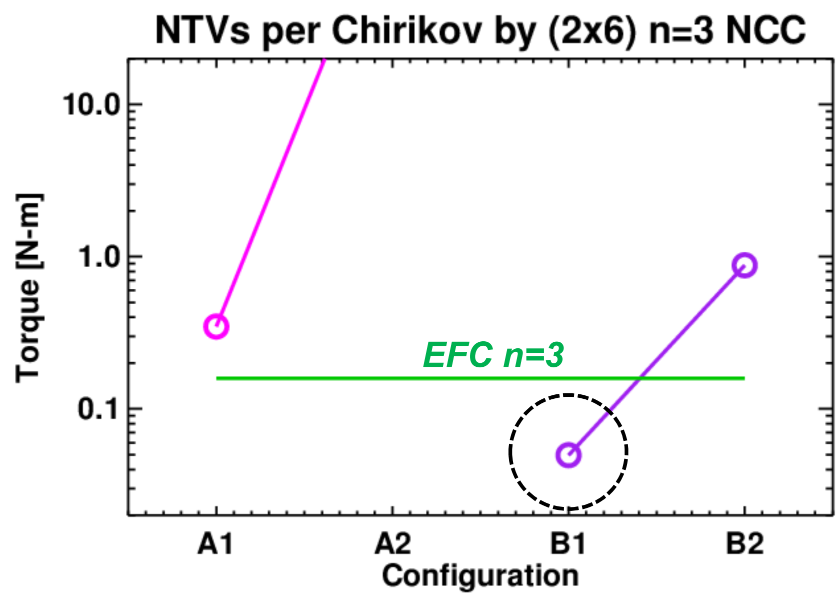


Figure of merit for 2x6 option

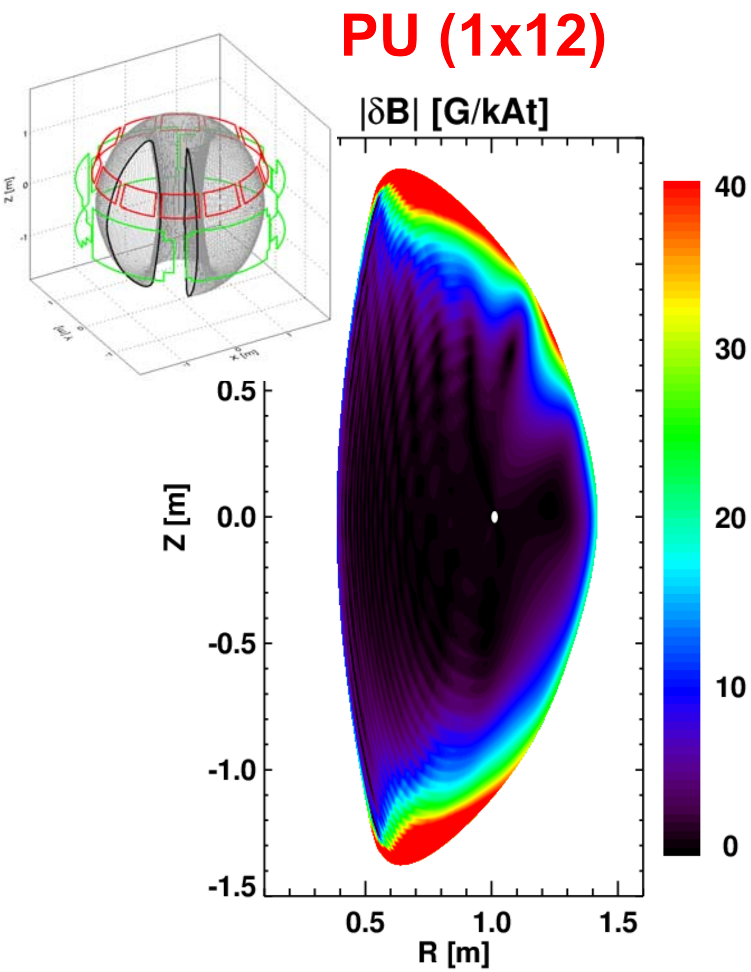
- B (2x6) partial option provide the largest NTV (comparable to EFC n=3)
- Also, B (2x6) option can produce the smallest NTV with Chirikov conditions if the phasing between upper and lower set of coils is optimized
- **Based on NTV, Chirikov, resonant error field correction capability, B config. is better than A config. for (2x6) partial NCC**

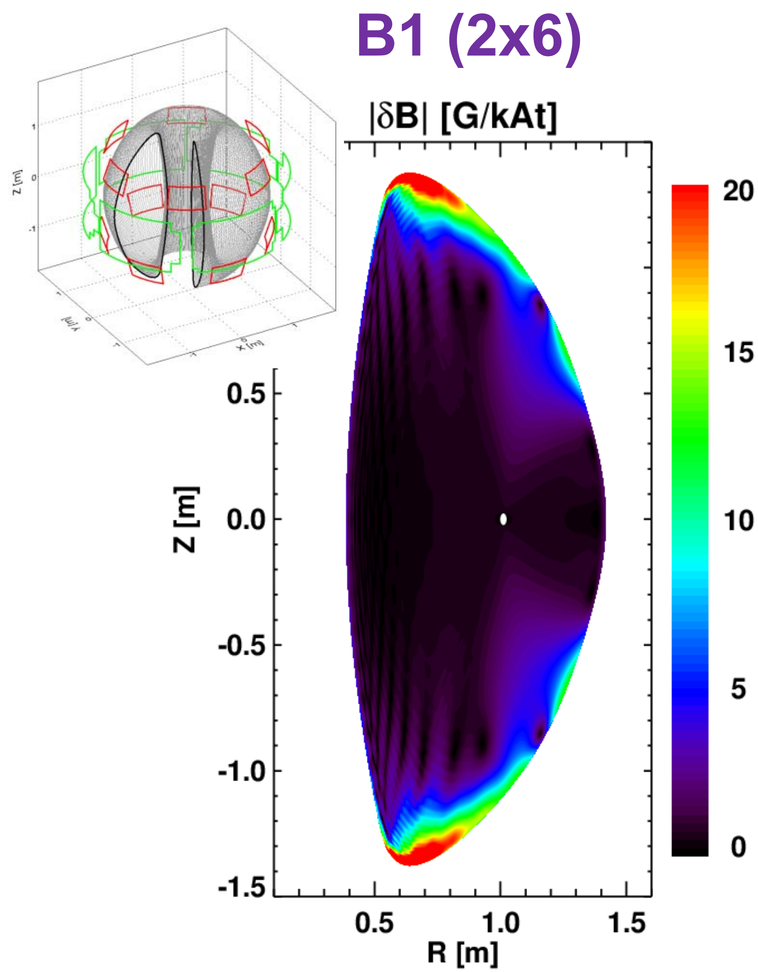




Primary (1x12) vs. B (2x6)

- B (2x6) may be the best for NTV, RMP, EF studies
- Primary (1x12) can provide n>3 (rotating) capability with sufficient NTV and RMP characteristics, but no flexibility for poloidal spectrum is allowed





Summary and future work of NCC analysis

- EF, NTV, RMP analyses for partial and full NCC showed:
  - Primary option is always better than secondary option
  - Partial (1x12) can provide sufficient NTV and RMP selectivity with high n, much better than EFC alone, but no flexibility for poloidal spectrum is provided
  - **Partial B (2x6)** can provide various NTV, RMP, EF selectivity, much better than EFC alone, with flexibility of field spectrum as well as synergy with EFC

- Further analysis plan:
  - Partial B (2x6) will be combined with EFC, and (3x6) combinations will be tested with finer tuning for phasing among three rows of coils
  - Possibly, POCA or TRIP3D calculations for several important cases

- For 5-yr plan and PAC:
  - MS: Analyses presented here will be included
  - TT: Extended descriptions with NTV braking for edge vs. core?
  - BP: Chirikov analyses can be included
  - ASC: n=0 controllability, but may be not good with (2x6)

Discussion for 5-yr plan