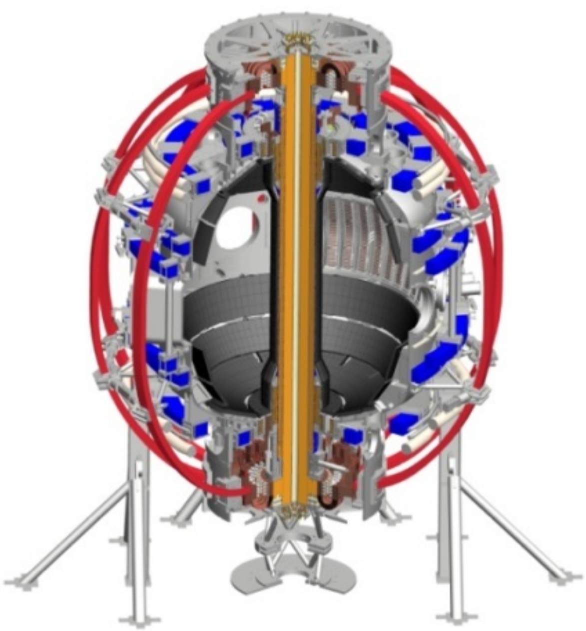
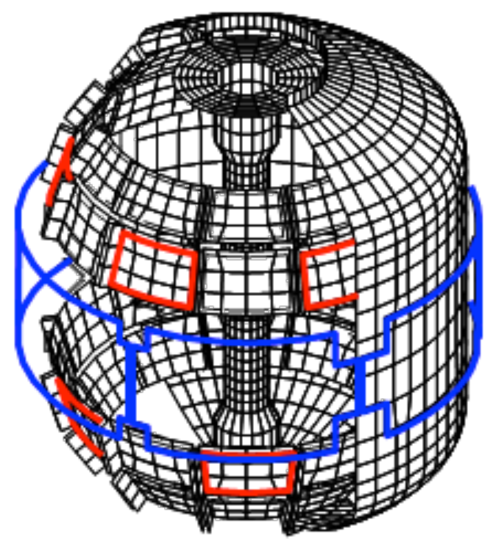
Summary of goals for NCC WG and previous physics analysis

Jong-Kyu Park
For NCC Working Group

NSTX-U NCC WG Meeting

January 30th, 2015





Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

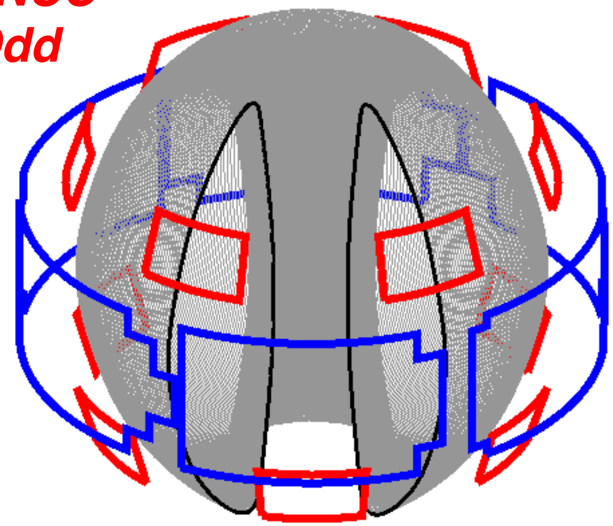
Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

NCC WG goals and deliverables

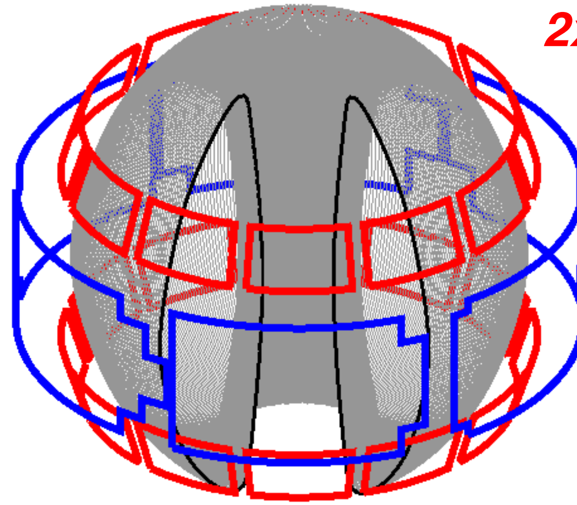
- Charges:
  - Specify required coil current, frequency, and location for NCC
    - Consider full set (24 coils) and partial set (12 coils)
    - Consider range of applications: NTV, EFC, RWM, RMP, ELM pacing, etc...
  - Specify required number of independent SPA channels vs. applications and requested capabilities
- Deliverables:
  - Organize summary presentation(s) on IPECOPT analysis results
  - Give presentation(s) making recommendations on NCC and SPA performance requirements, gather and incorporate team input
  - Generate written report (5-20pp Word file) documenting NCC and SPA requirements for use in developing engineering requirements document (GRD) to drive engineering design
- Due dates:
  - Initial written report April 2015 if possible (no later than May)
  - Consult with Project/engineers/designers as needed until implementation

Coil shape and locations are largely fixed now, but inverse approach through optimization is yet on

Partial NCC 2x6 Odd



Full NCC 2x12



- Action item for group: Perform physics analysis to see if these options can achieve what to be expected or required
  - Should provide kA-turns and a range of frequency needed
  - Priority 1. Partial NCC 2x6 Odd, 2. Partial NCC 2x6 even, 3. Full NCC
- Action item for limited group members: Optimize coil shape/location by performing physics analysis without constraints
  - Should provide coil capability to drive optimized 3D fields

Physics analysis with partial/full NCC options

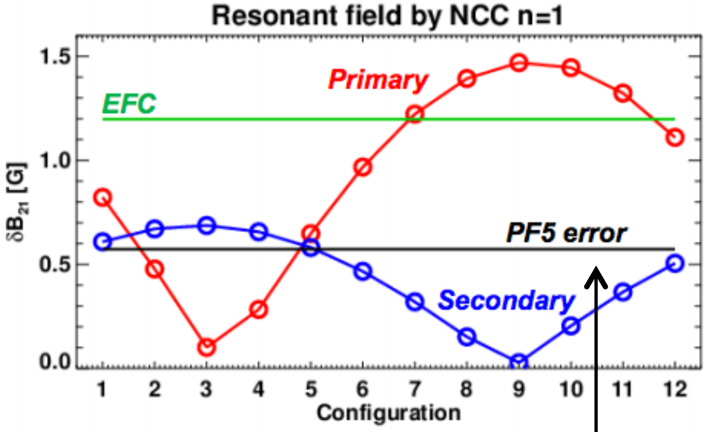
- Two equilibrium targets + TRANSP kinetic profiles were used
- Figures of merit were defined for EF, RWM, NTV, RMP, and analyzed using readily available tools (IPEC, PENT, VALEN3D, TRIP3D, POCA) for NCC alone, compared to midplane alone

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 $F_{N\text{-}R}$**	**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 $\Delta F_{N\text{-}N}$**	**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 $F_{N\text{-}C}$**	**0.25~0.30**	**0.31~1.04**	**0.43~0.77**	**1.18~3.53**
	Wide $\Delta F_{N\text{-}C}$	**1.00**	**2.20~12.3**	**10.4~17.4**	**888~14400**

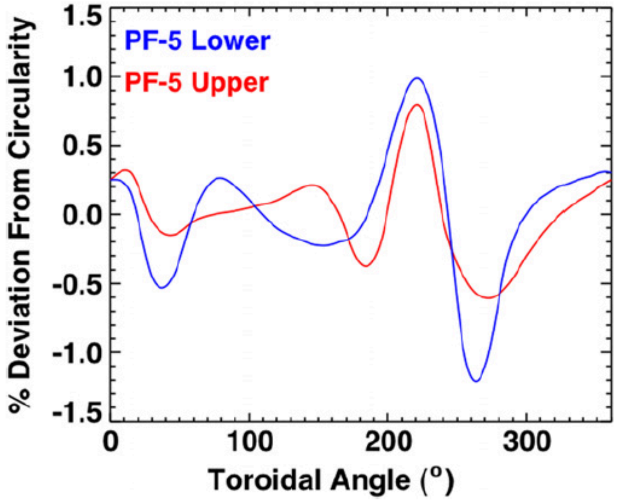
Partial or Full NCC for n=1-3 error field correction

- It was more than enough when previous PF5 coil errors (with 20kA) were assumed
  - Needed only a few hundred A-turns in midplane coil or NCC to minimize PF5-driven n=3 NTVs and n=1 error field
- However, there are expectations for n=2 error field, and possibly larger n=1 error field in NSTX-U
  - Can any assessment or model be arrived in the next 2 months (Myer)?
  - Need to estimate how many coils and how much kAt from midplane and NCC are needed to correct n=1-3 simultaneously

Each by 1kAt

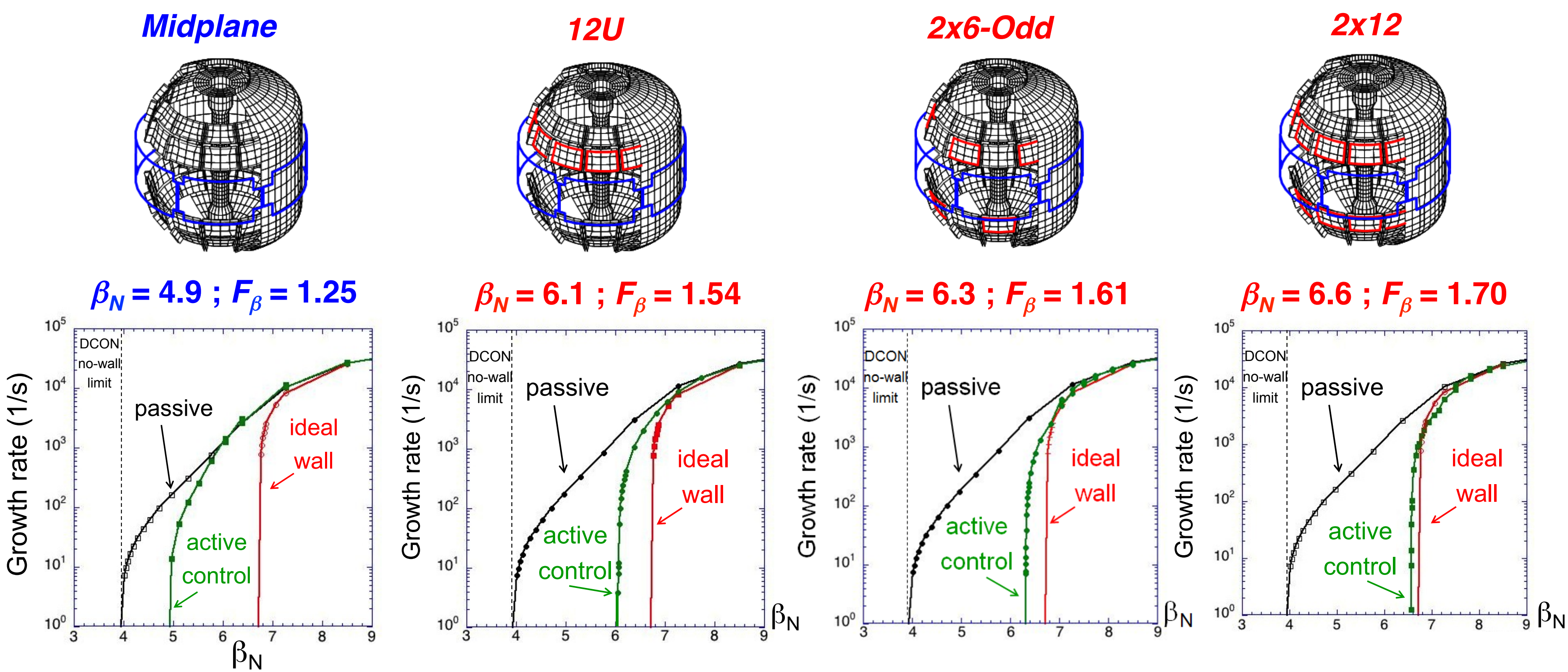


Present PF5 filamentary model



RWM active control capability with partial/full NCC

- VALEN3D showed enhanced RWM control capability by NCC



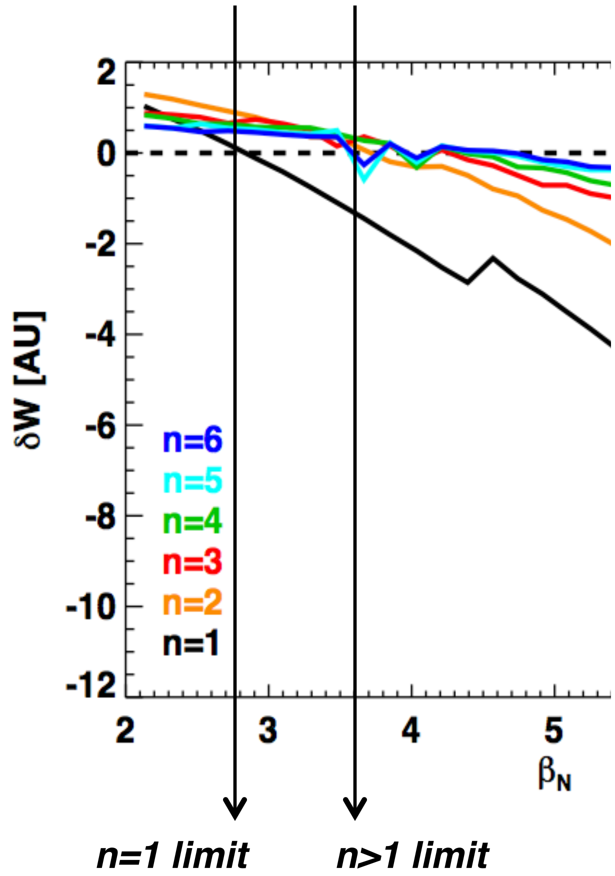
- Extended RWM control analysis with new sensors are underway

Will presented by S. Sabbagh in this meeting

High-β plasma response analysis with kinetic effects

- For IPEC modeling, target was chosen below no-wall limit, as ideal model is quantitatively unreliable beyond the stability limit
  - For n=1, target β_N = 2.5
  - For n>1, target β_N = 3.4

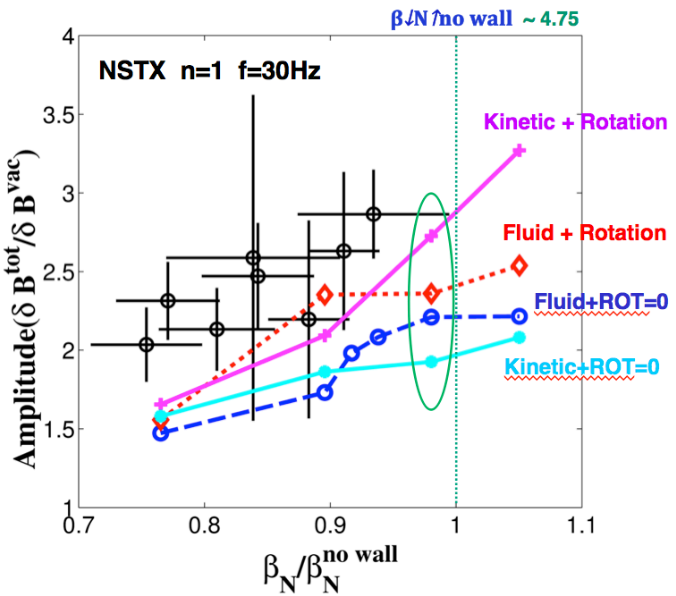
- This relied upon the assumption on the rigid dominant response mode, but recently it was shown that kinetic effects can significantly change the mode structure
  - Investigation of kinetic plasma response in high-β targets will be important especially for lower n (n=1)



MARS-K shows fluid and kinetic plasma response to NCC can be substantially different

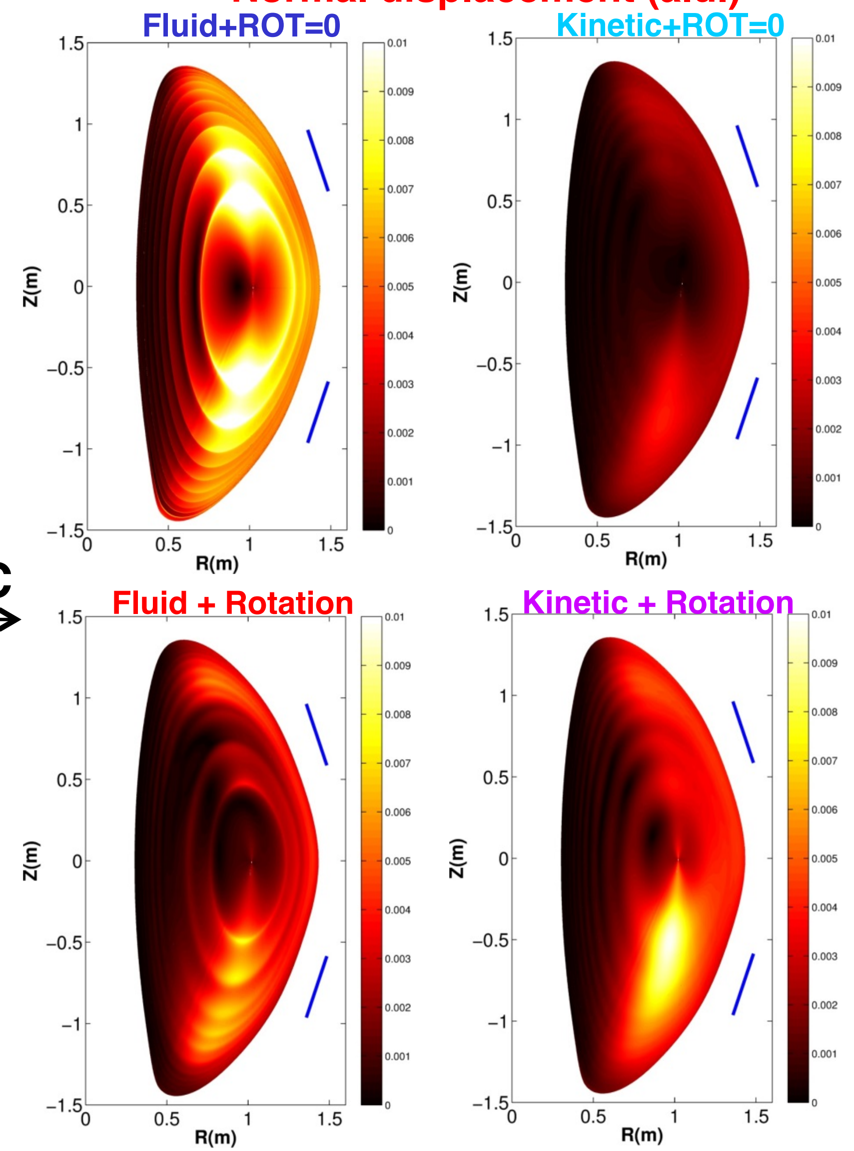
- MARS-K test for NSTX+NCC (240 phasing with 30kHz) shows strong up-down asymmetric modification of eigenmode structure
- Will be extended to NSTX-U high-β targets + NCC, at least for n=1(Wang)

NSTX+midplane (APS talk by Wang)



NSTX+NCC →

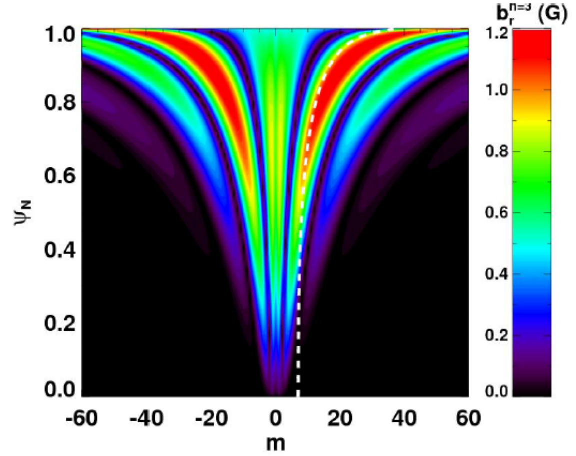
Normal displacement (a.u.)

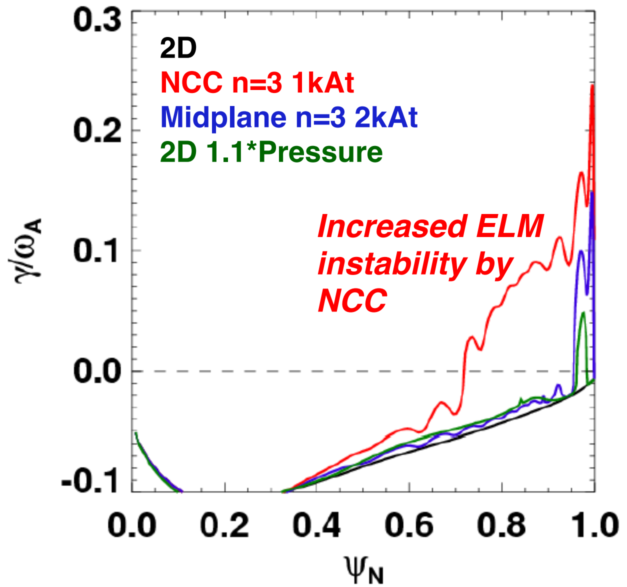


ELM stability analysis for 3D equilibrium by NCC

- Midplane coil applications in NSTX showed strong ELM triggering and pacing
- VMEC+COBRA analysis for NSTX-U shows NCCs may significantly increase this capability
  - NCCs can broaden ballooning unstable region by ~30% compared to midplane coils or 2D (benchmarked with BALL)
- Can this analysis be extended to partial NCC, or up-down asymmetric NCC applications, with relative phasing between upper and lower coils? (Canik)

Full NCC n=3 (Up-down symmetric)

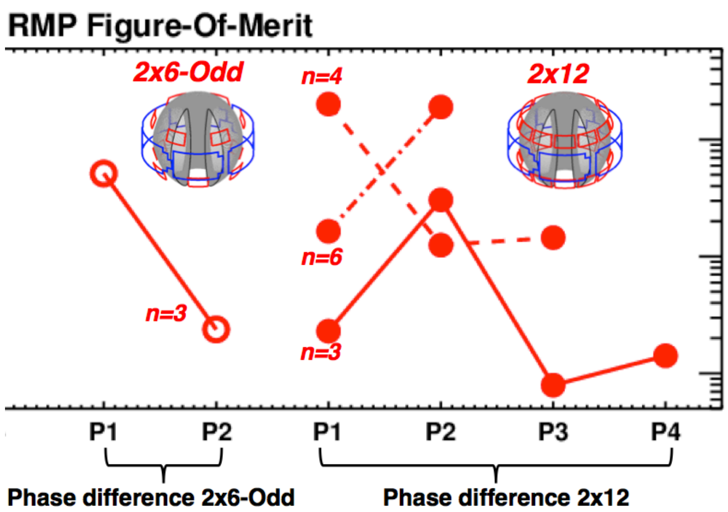




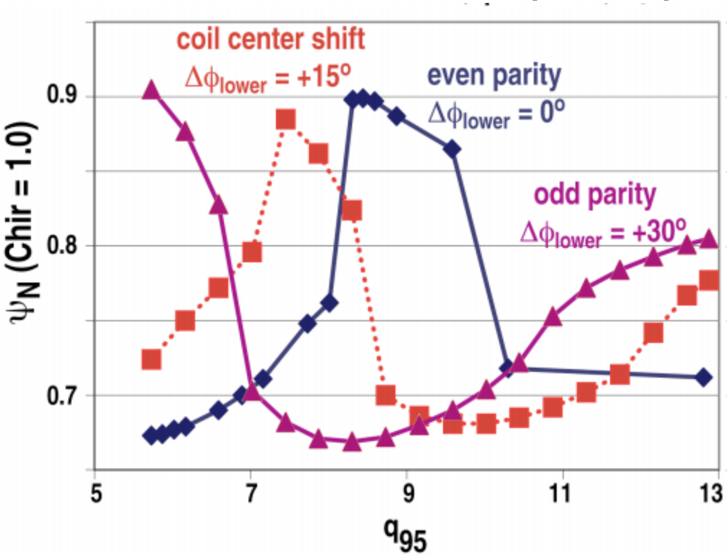
RMP characteristics beyond vacuum Chirikov

- Vacuum Chirikov, TRIP3D, POCA-FLT all showed Chirikov overlap conditions can be satisfied with enhanced NTV variability

Vacuum + IPEC-NTV



SURFMN + TRIP3D (Evans)



- Revision of vacuum Chirikov analysis with TRIP3D with NSTX-U (Evans)?
- Is it possible to deliver advanced non-linear modeling for NSTX-U + NCC using e.g. M3D-C1 (Evans, Nate)?

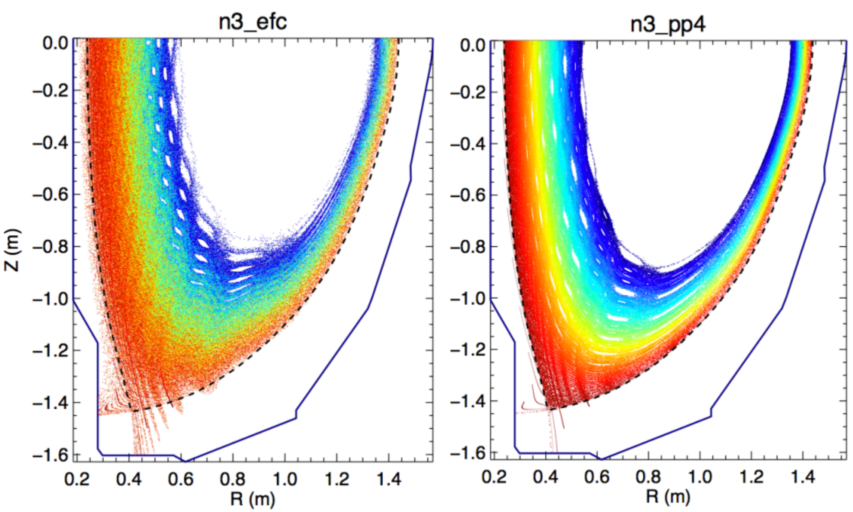
Particle, heat, and fast ion transport by NCC

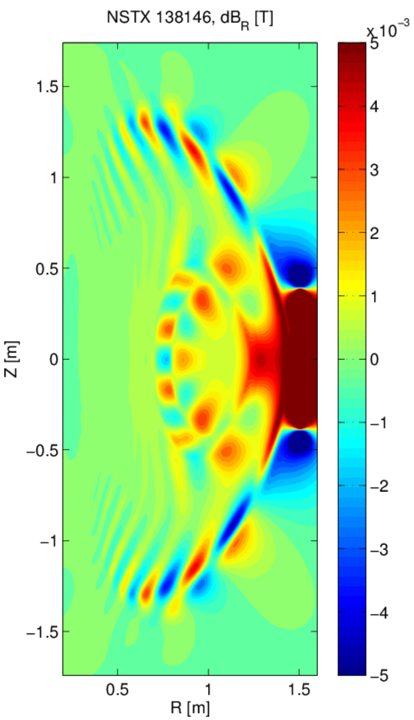
- POCA-FLT (vacuum) showed large modification of field line splitting is possible with NCC
- M3C-C1 analysis, if possible, can provide this information too

- Fast-ion distribution changes by NCC compared to midplane coils?
- M3C-C1+SPIRAL would be ideal, but IPEC+SPIRAL is alternative (by sacrificing some accuracies)

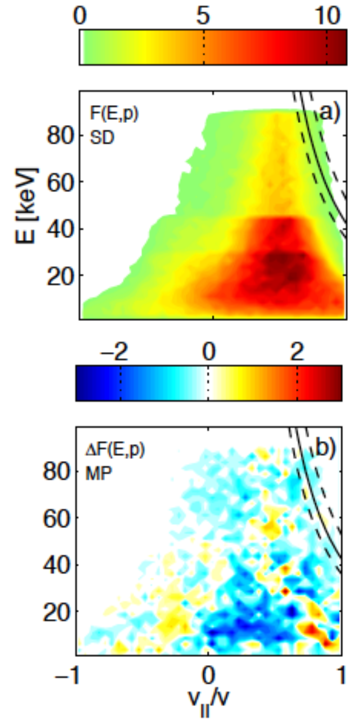
Midplane n=3

Less resonant n=3 using NCC





Before 3D field

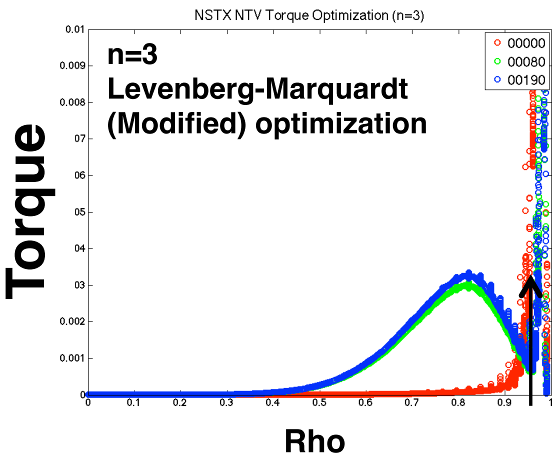


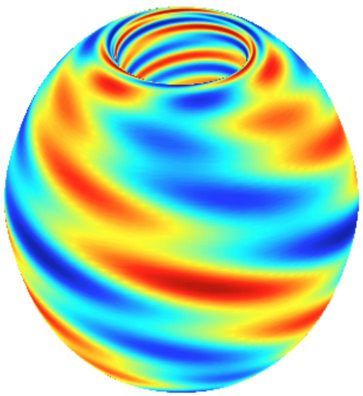
After 3D field

Coil optimization for NTV and RMP characteristics

- IPECOPT found the best field driving n=3 NTV and partial NCC has reasonably good coupling to the theoretical optimum

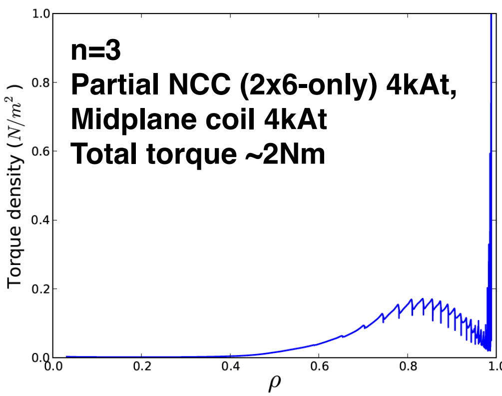
Unconstrained

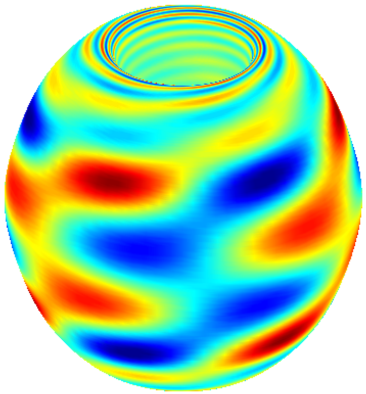




Total normal δB
on the plasma boundary

Constrained to partial NCC + Midplane coil





- Coil amplitude and phase optimization has also been done for full NCC
- Can this work extended to partial NCC, and also for RMP characteristics?

Will be presented by S. Lazerson in this meeting

Discussion and action items

- Follow-up meeting will be held in the middle of Feb and March
- Action items to be discussed (with Partial NCC and midplane)
  - Additional input for error fields (Myer) and corresponding n=1-3 correction analysis (Park)
  - RWM control analysis with new sensors (Sabbagh, Bialek)
  - Kinetic plasma response studies for n=1 (Wang)
  - 3D stability analysis with up-down asymmetric configuration (Canik)
  - Field line tracing and RMP characteristics using linear codes (Park, Kim)
  - RMP analysis using non-linear codes (Evans, Ferraro)
  - Study of fast ion distribution modification by 3D fields
  - …
- Target equilibria, kinetic profiles, coil information, will be all updated and placed in NCC D&D area
  - http://nstx.pppl.gov/DragNDrop/Five_Year_Plans/2014_2018/design_studies/ncc/
- Deliverables will be prepared by early April (Park, Canik)