RMP Mitigation and Suppression of ELMs in KSTAR

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with KSTAR Research Team

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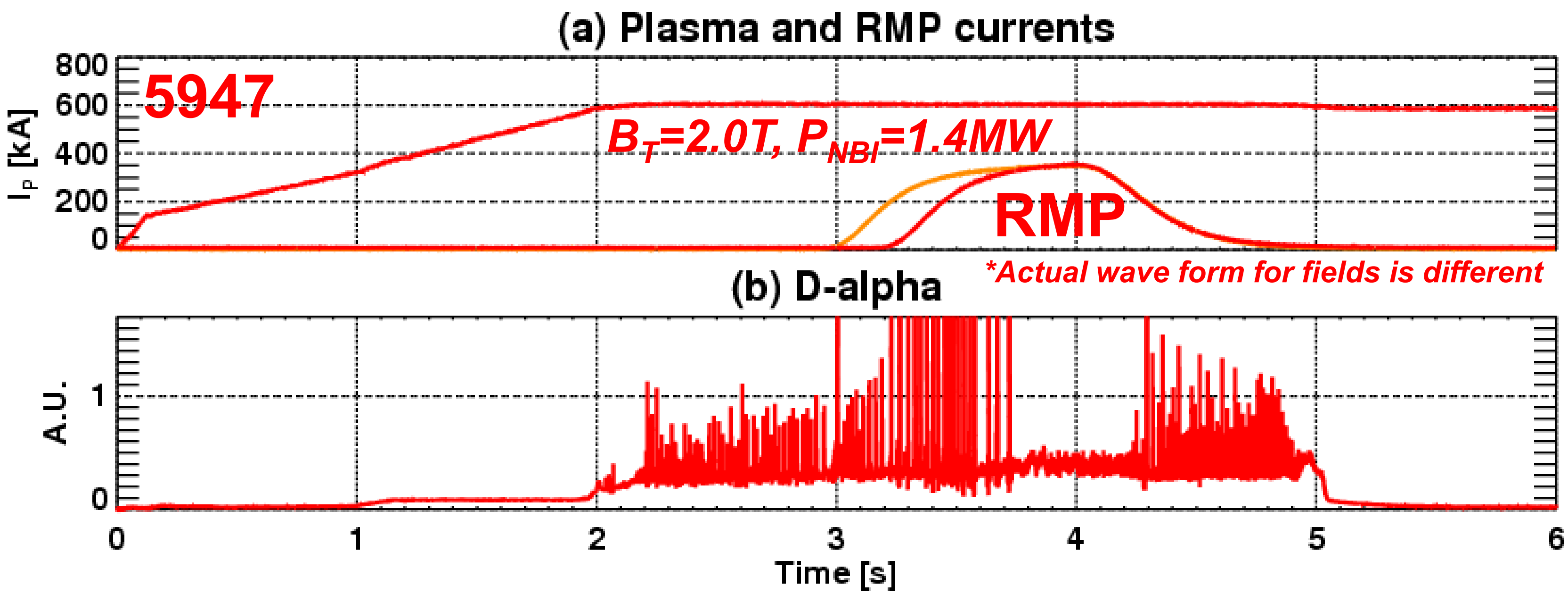
PPPL Research Seminar
September 19, 2011

n=1 RMP suppressed ELMs in KSTAR



<u>CCD Video</u>

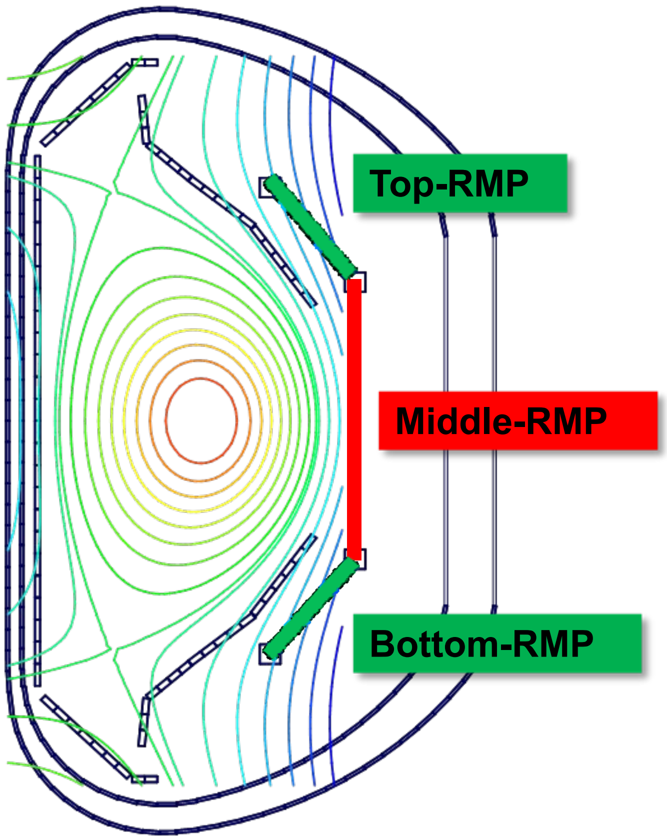
005947tv01.avi

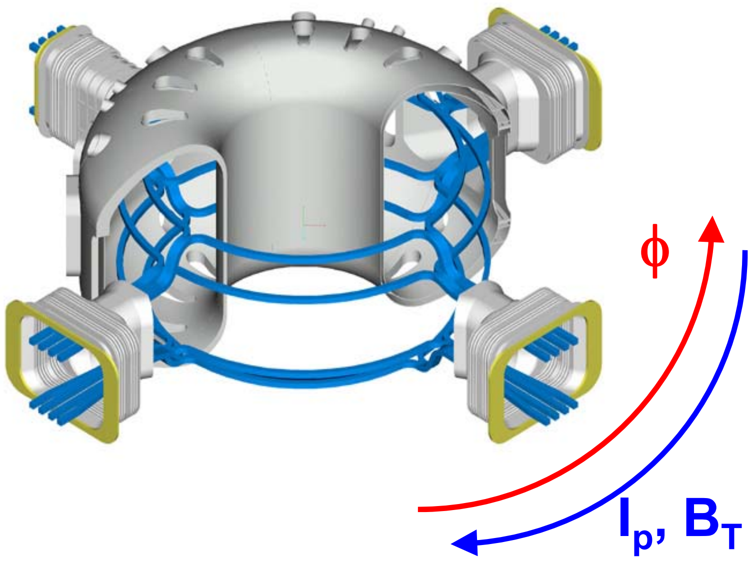
Overview

- KSTAR 3D field coil configurations
- n=1 RMP applications to ELMs
  - ELM mitigations and suppressions by 90 phasing
  - ELM excitations with midplane alone
  - Locking by 180 phasing
  - ELM mitigations by 0 phasing
- Preliminary vacuum, plasma, NTV analysis
- n=2 RMP applications to ELMs
- Other observations and considerations
- Summary

KSTAR can produce various n=1 field spectra using three rows of internal coils

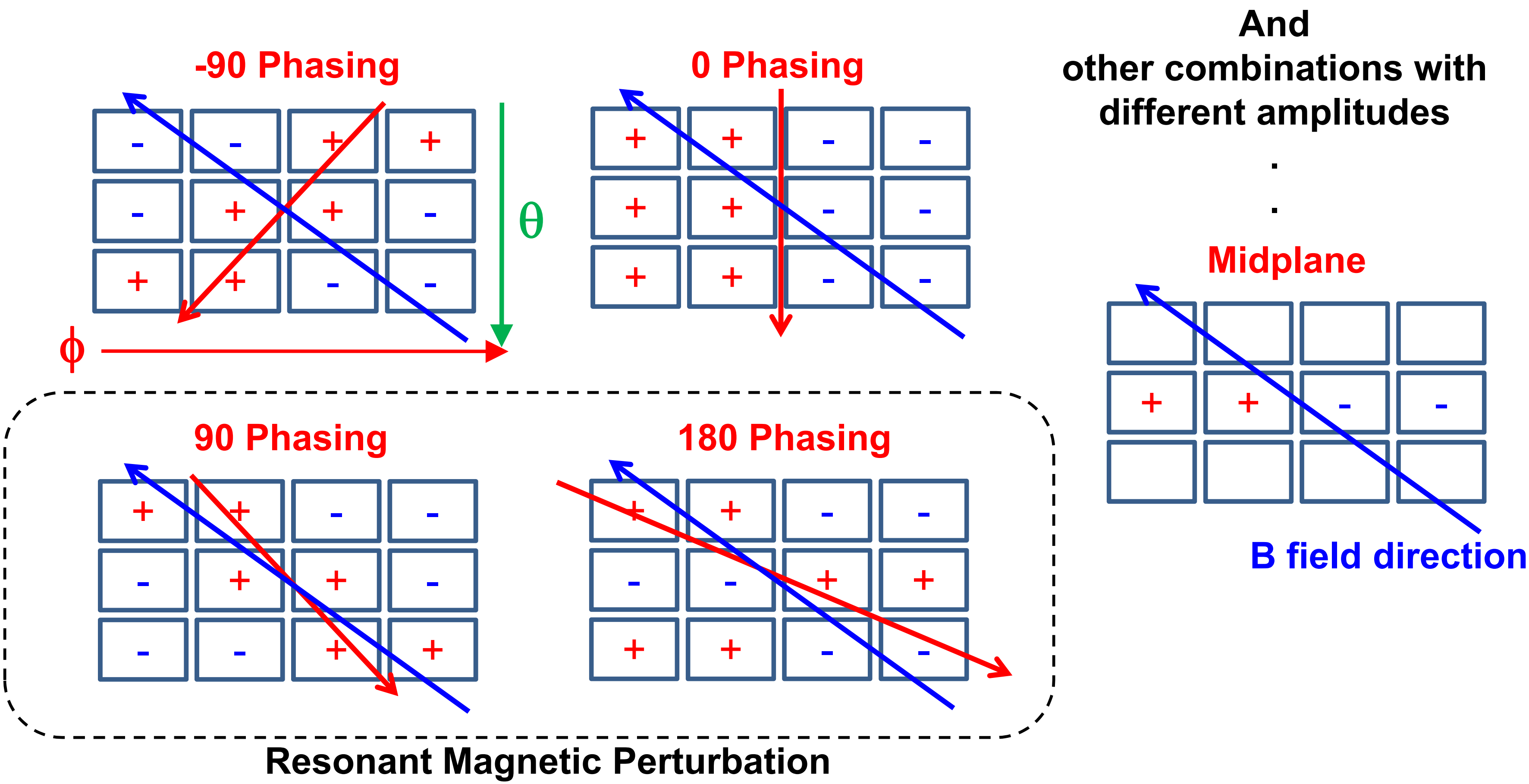
- KSTAR 3D field coils have 3 rows of coils, with 4 toroidal array for each
- Various n=1 spectra are possible, and a few n=2 configs. are available





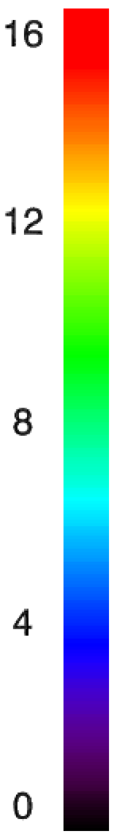
Various n=1 can be defined by toroidal phase shift between rows

- Phasing : Toroidal phase-shift from the top to the bottom
- Phase : Toroidal phase (would not give difference without intrinsic errors)

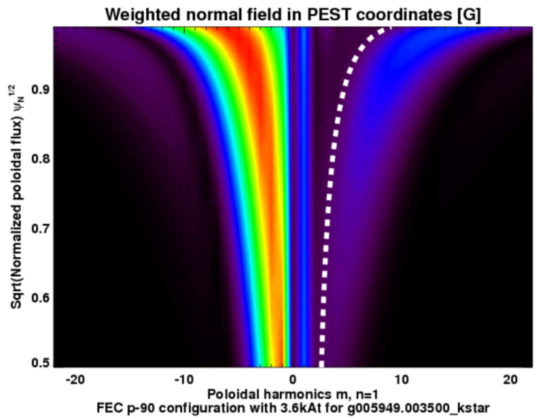


ELM changes were observed all differently for each phasing and field spectrum in RMPs

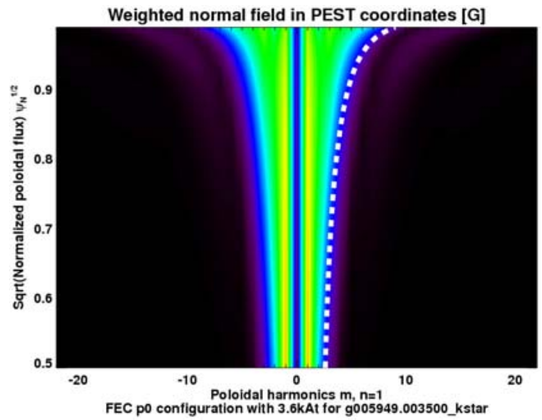
- Different phasing can produce various Chirikov conditions
- ELM changes were all different for each phasing in RMPs



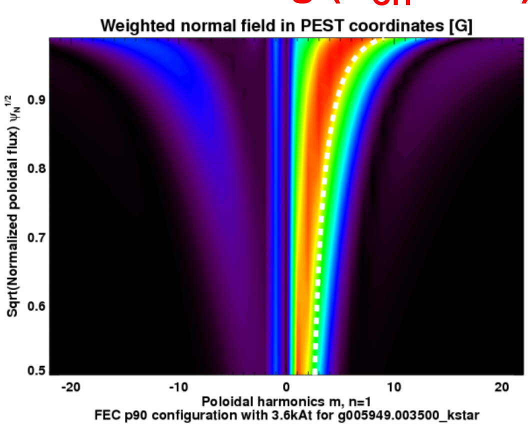
-90 Phasing (σ_{CH}~0.04)



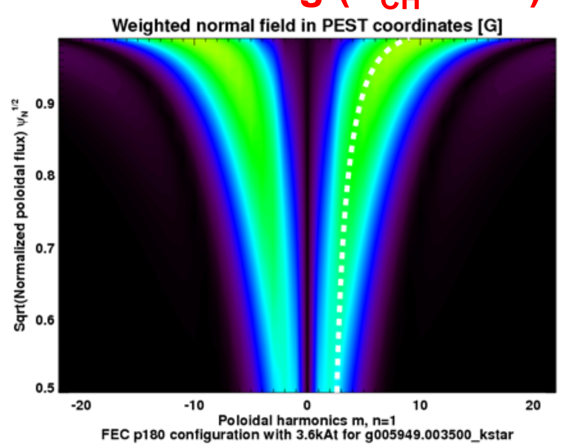
0 Phasing (σ_{CH}~0.08)



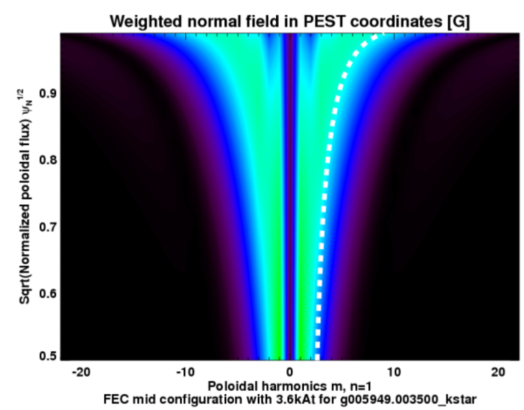
90 Phasing (σ_{CH}~0.27)



180 Phasing (σ_{CH}~0.22)



Midplane (σ_{CH}~0.17)



**By vacuum analysis*

**σ_{CH} = Stochastic layer width in the edge*

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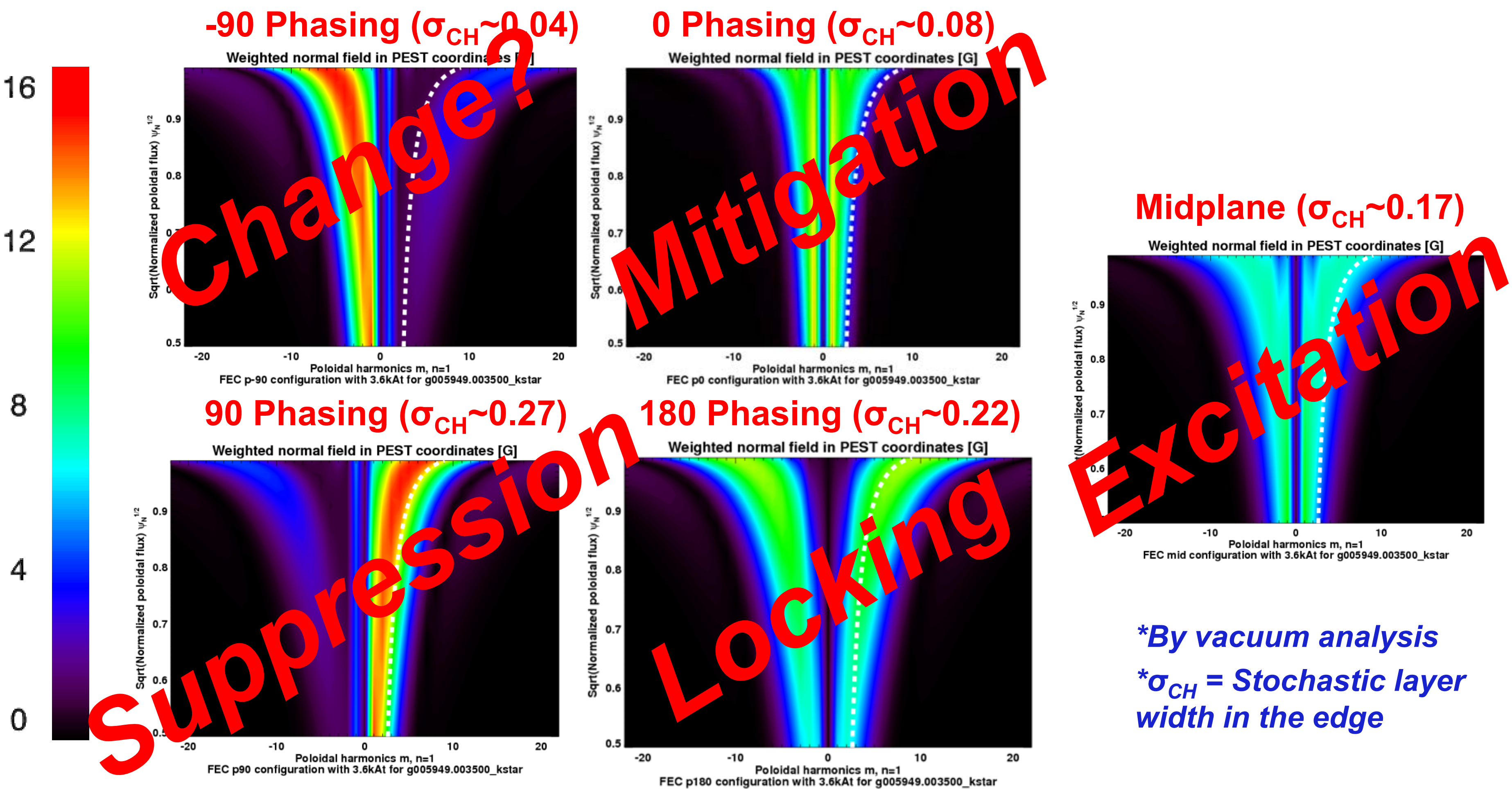

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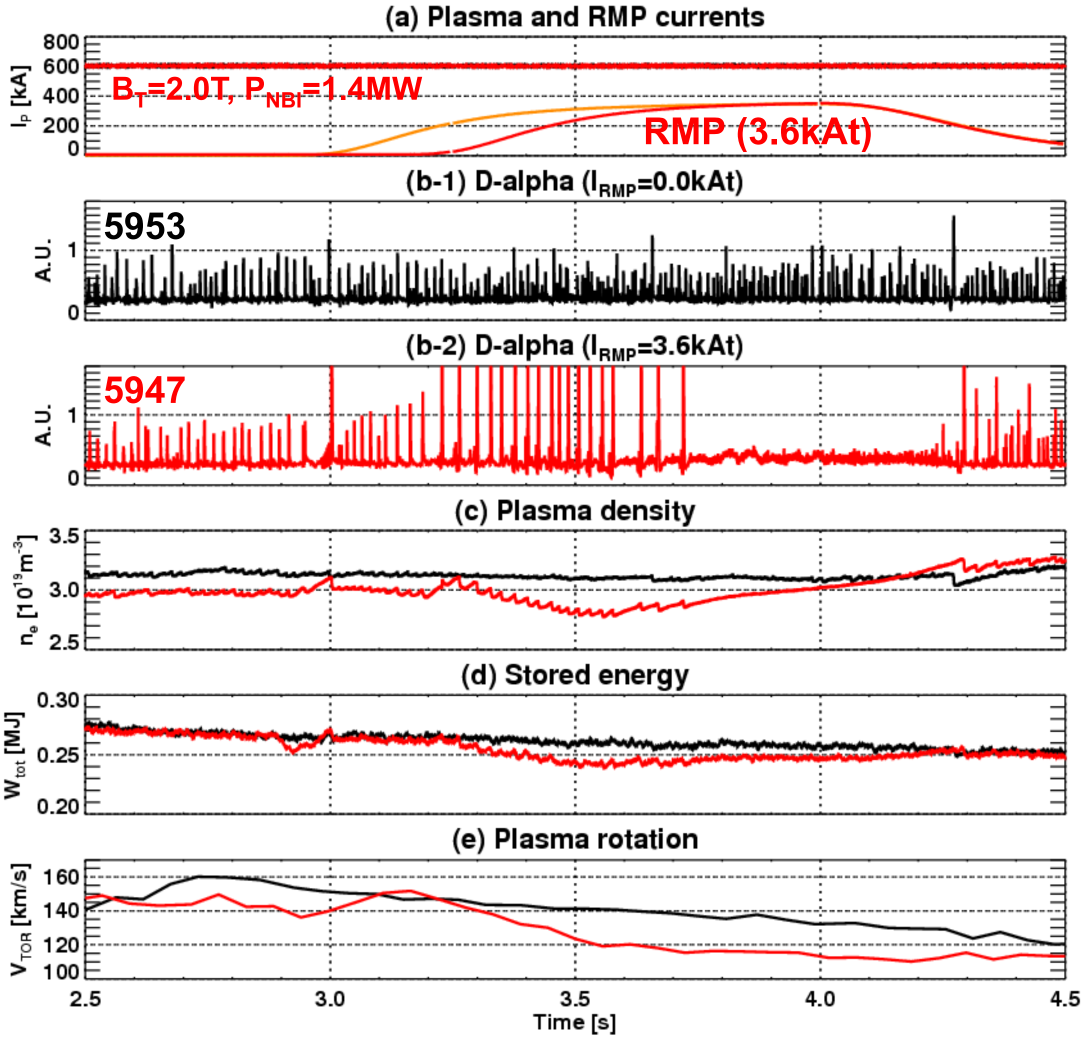
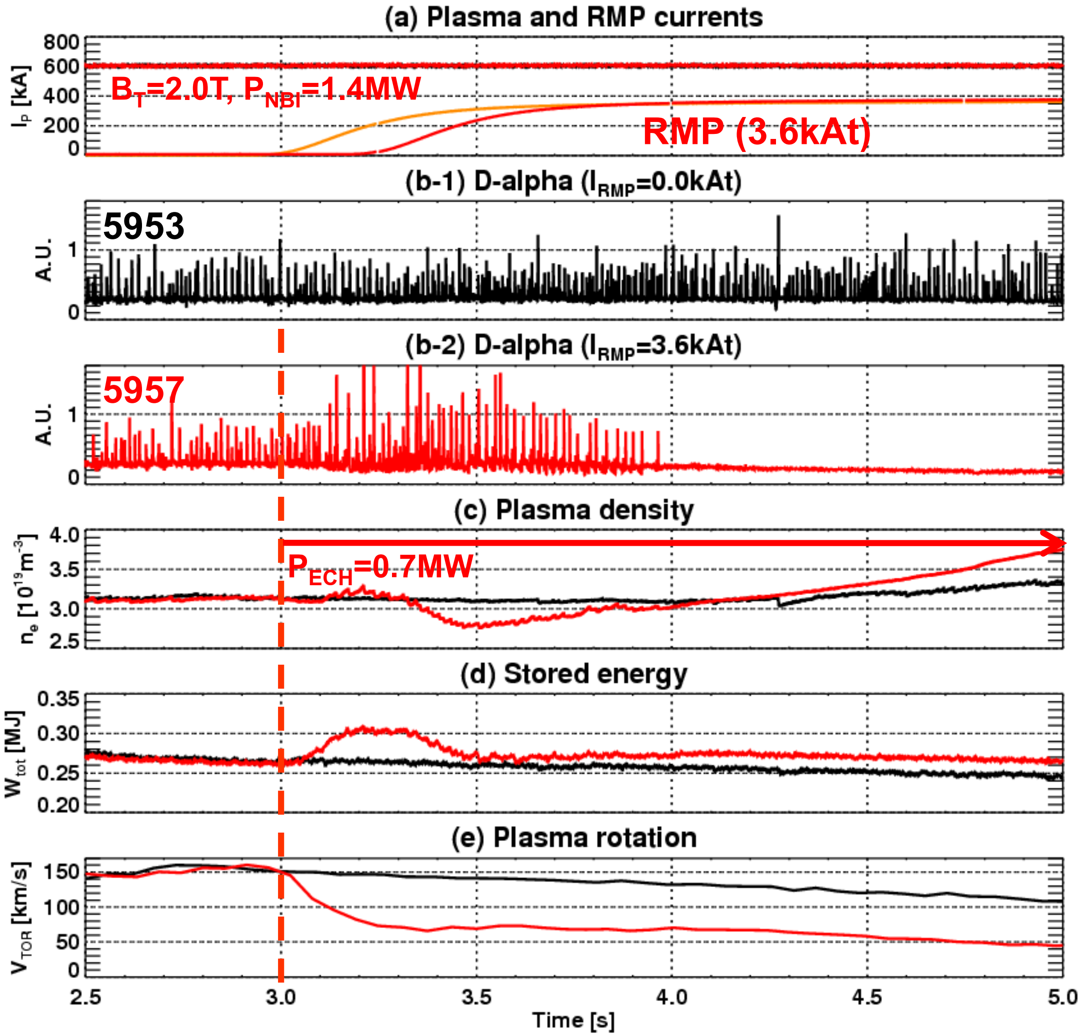
<u>90 phasing</u>: ELMs were suppressed, with density and energy changes, and rotation damping



- 90 phasing RMPs (excited ELMs first) strongly mitigated or suppressed ELMs
- Density pump-out was observed (probably not by large ELMs
- Density increased when ELMs were gone, probably due to impurity accumulation
- Stored energy was changed, similarly to density changes
- Rotation damping was observed (probably not by large ELMs)
- Ti (1.5~2.0keV) evolutions were similar to rotations

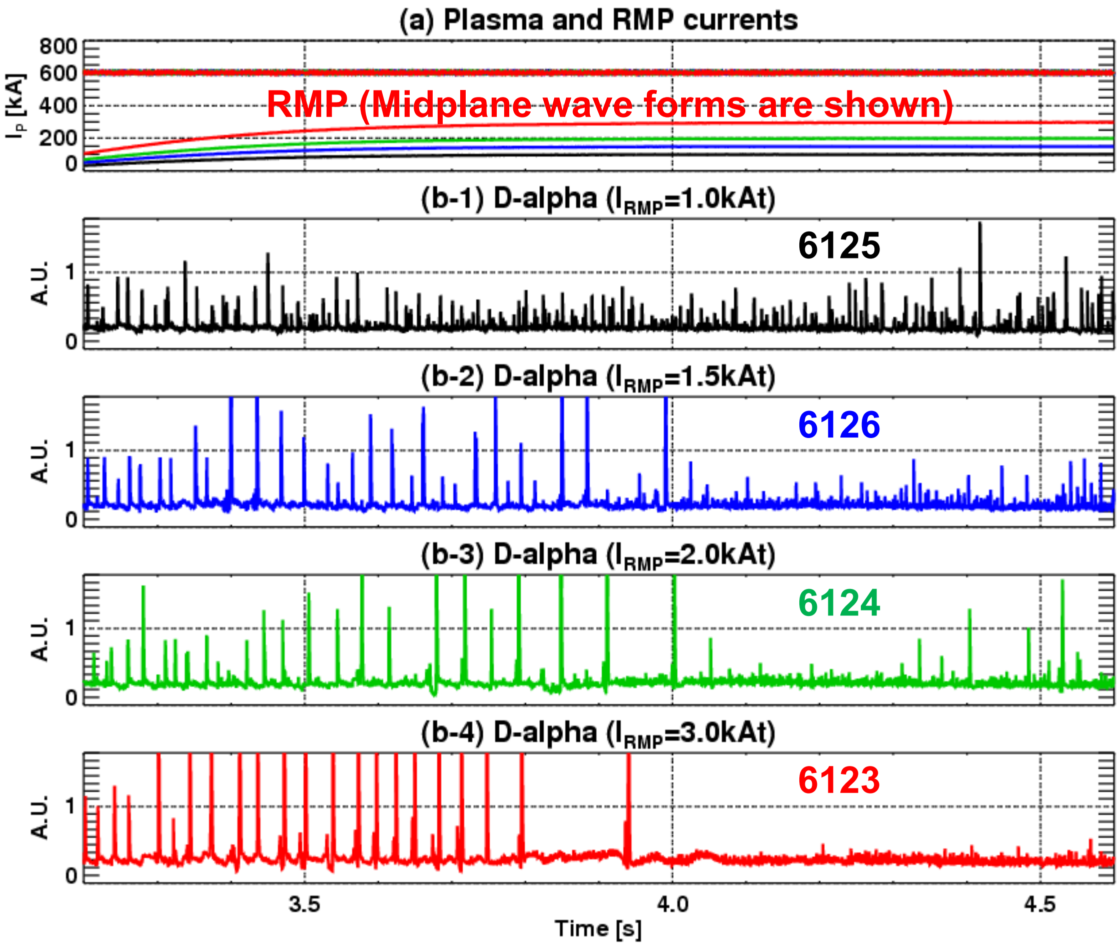
90 phasing: ELMs were completely suppressed for high power discharge



- 90 phasing RMP applications to higher power discharges (with $P_{ECH-110GHz}$=0.4MW, $P_{ECH-170GHz}$=0.3MW) completely suppressed ELMs
- Density pump-out was observed in the initial period
- Stored energy was increased by high power, but then decreased again with RMPs
- Rotation was damped strongly due to both ECHs and RMPs
- Ti evolutions were similar to rotations (will be omitted)

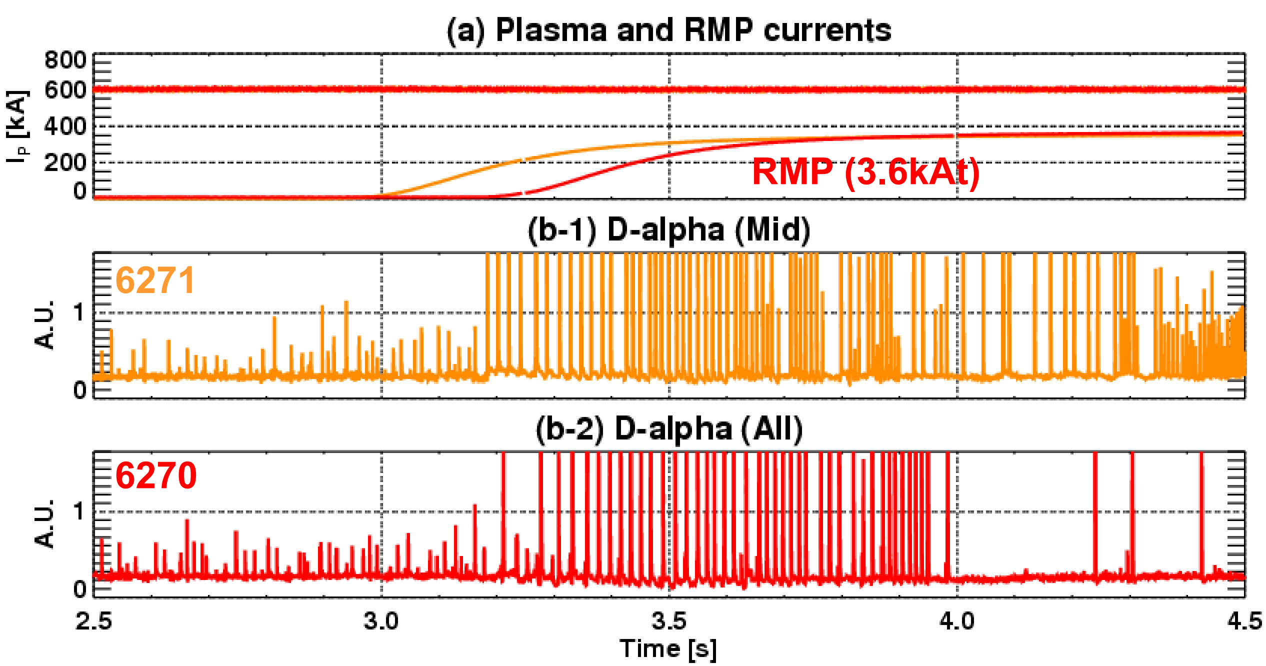
<u>90 phasing</u>: ELM mitigations and suppressions became stronger with higher RMP currents

- RMP effects became stronger for higher currents
- ELM mitigations and suppressions were observed for I_{RWM}>1.5kAt

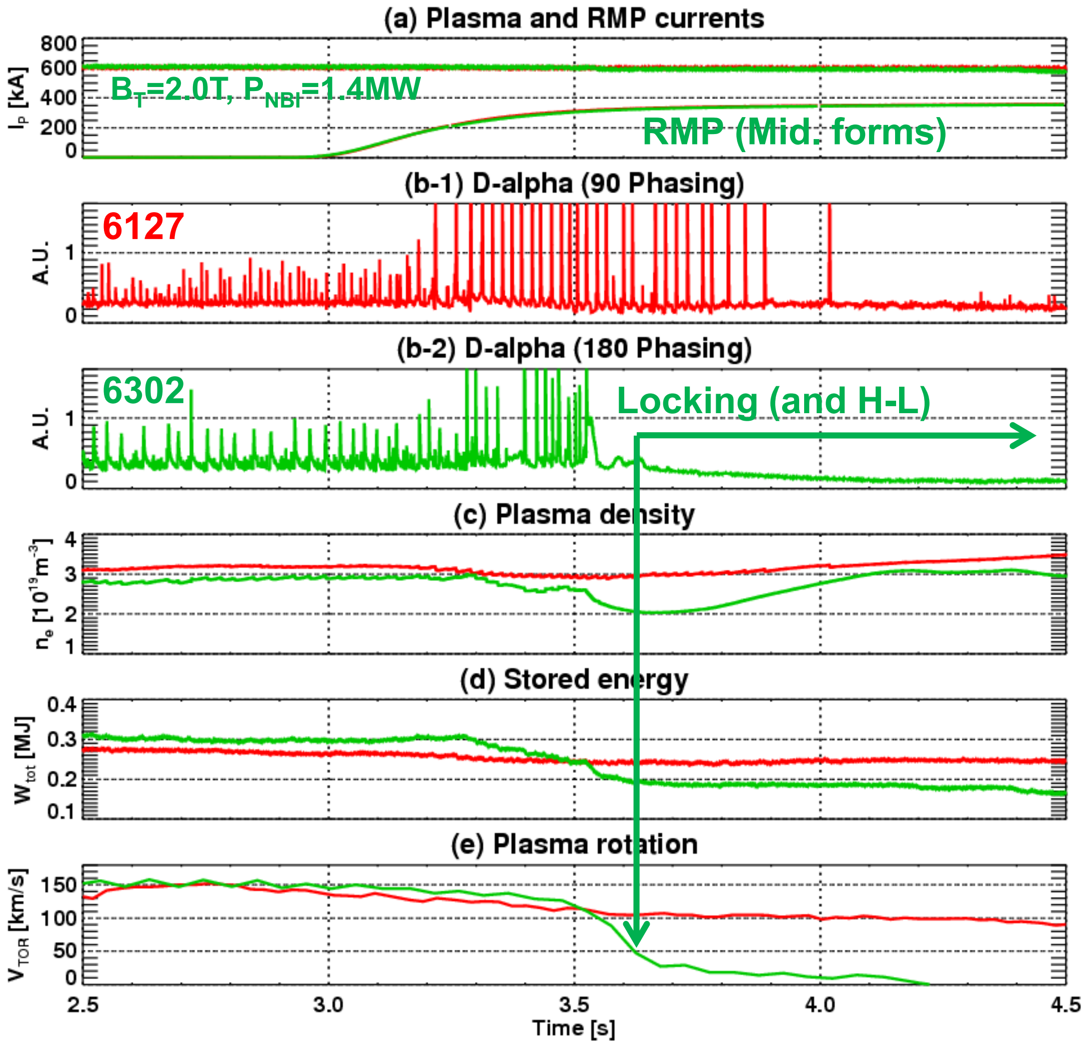


Midplane: ELMs were excited when only midplane coils were applied (like NSTX)

- Midplane coil (alone) applications showed ELM excitations
- This is similar to NSTX (n=1 excitations were speculated and proposed)
- However, the question "if ELM excitations were driven by plasma evolutions or different field spectra" was not fully addressed
  - **Precise RMP waveforms are needed!**
  - Off-midplane + later midplane coil applications will be needed

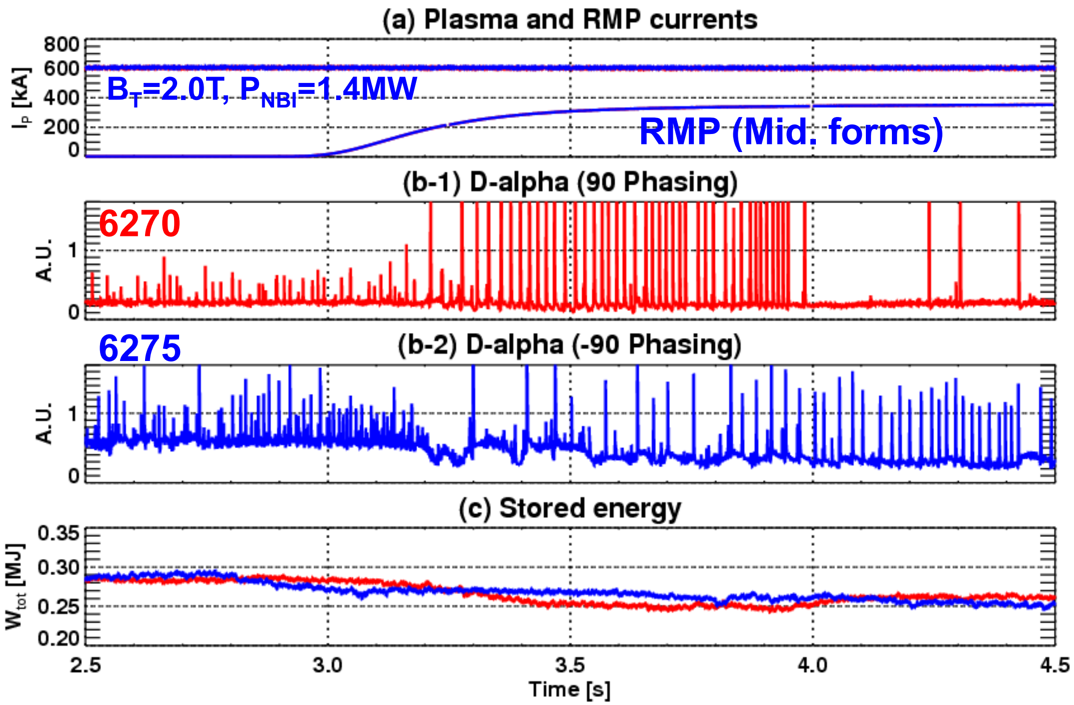


180 phasing: RMPs were strongly coupled to plasmas and produced locking



- 180 phasing RMP applications caused a locking without reliable ELM changes
- Locking was evident by fast drop of rotations
- This is consistent with usual expectations by n=1 fields and implies the subtlety between core and edge perturbations
- H-L back transition accompanied and L-mode was sustained with almost zero rotations

-90 phasing: RMP effects were unclear

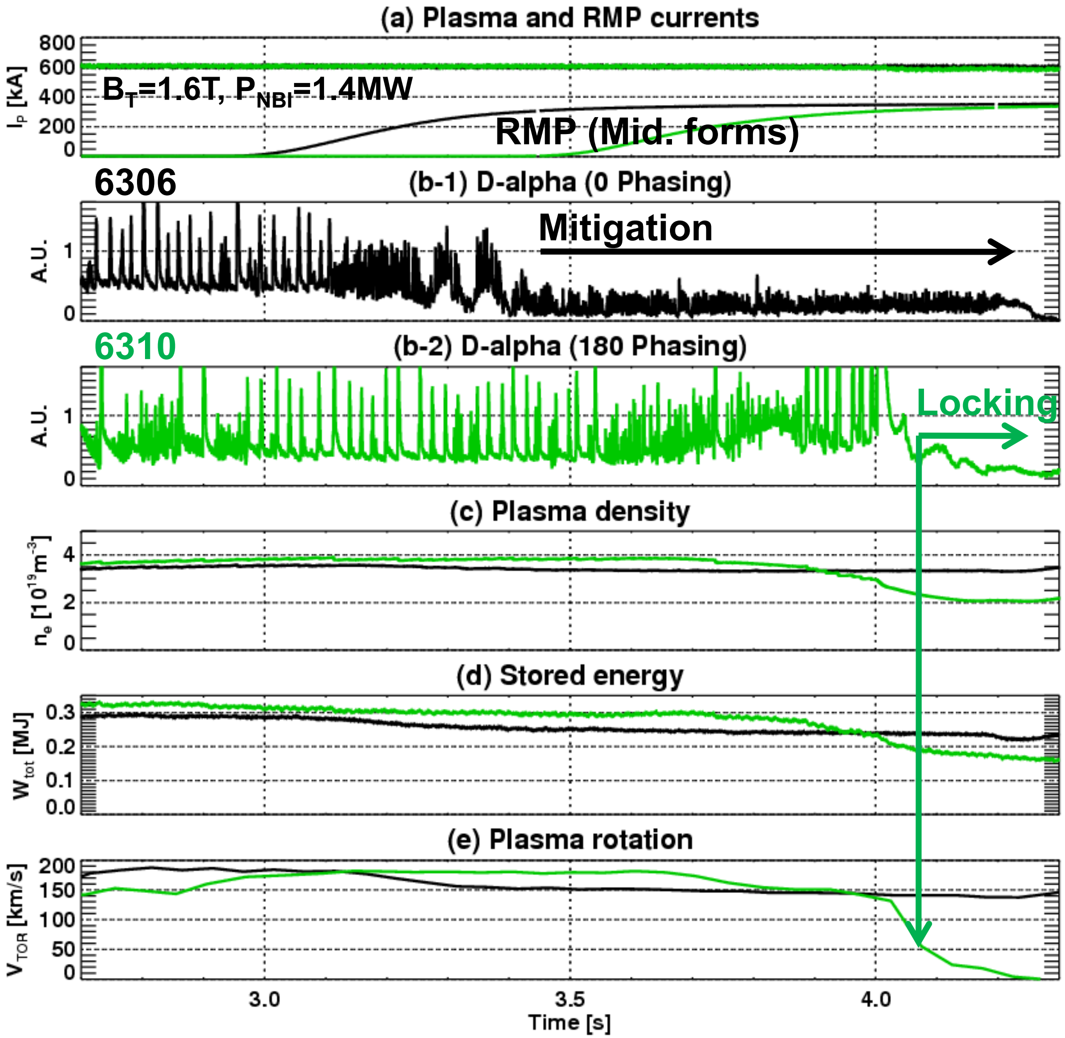


- -90 phasing RMP effects were unclear
- Other disturbances such as VDEs were involved and overlapped with RMPs…

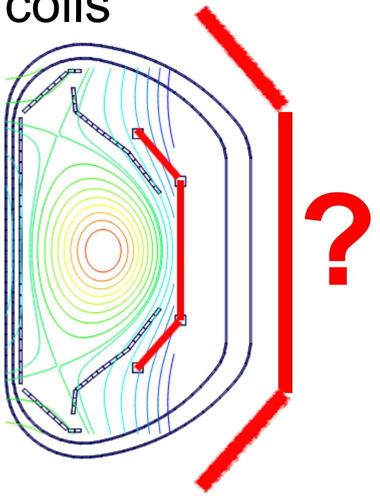
  In Ohmic experiments,

- -90 phasing was highly unfavorable (weakly coupled) to plasmas except small changes in rotation
- However, -90 phasing may be well coupled to plasmas in H-mode due to high m peaks

0 phasing: ELM mitigations were observed by this low (m,n) field (possible by external coils, like JET)



- 0 phasing RMP applications mitigated ELMs (or changed ELM types), like JET
- In B_T=1.6T, 0 phasing mitigated ELMs and 180 phasing locked plasmas similarly to B_T=2.0T
- 0 phasing fields may possibly be producible by external coils



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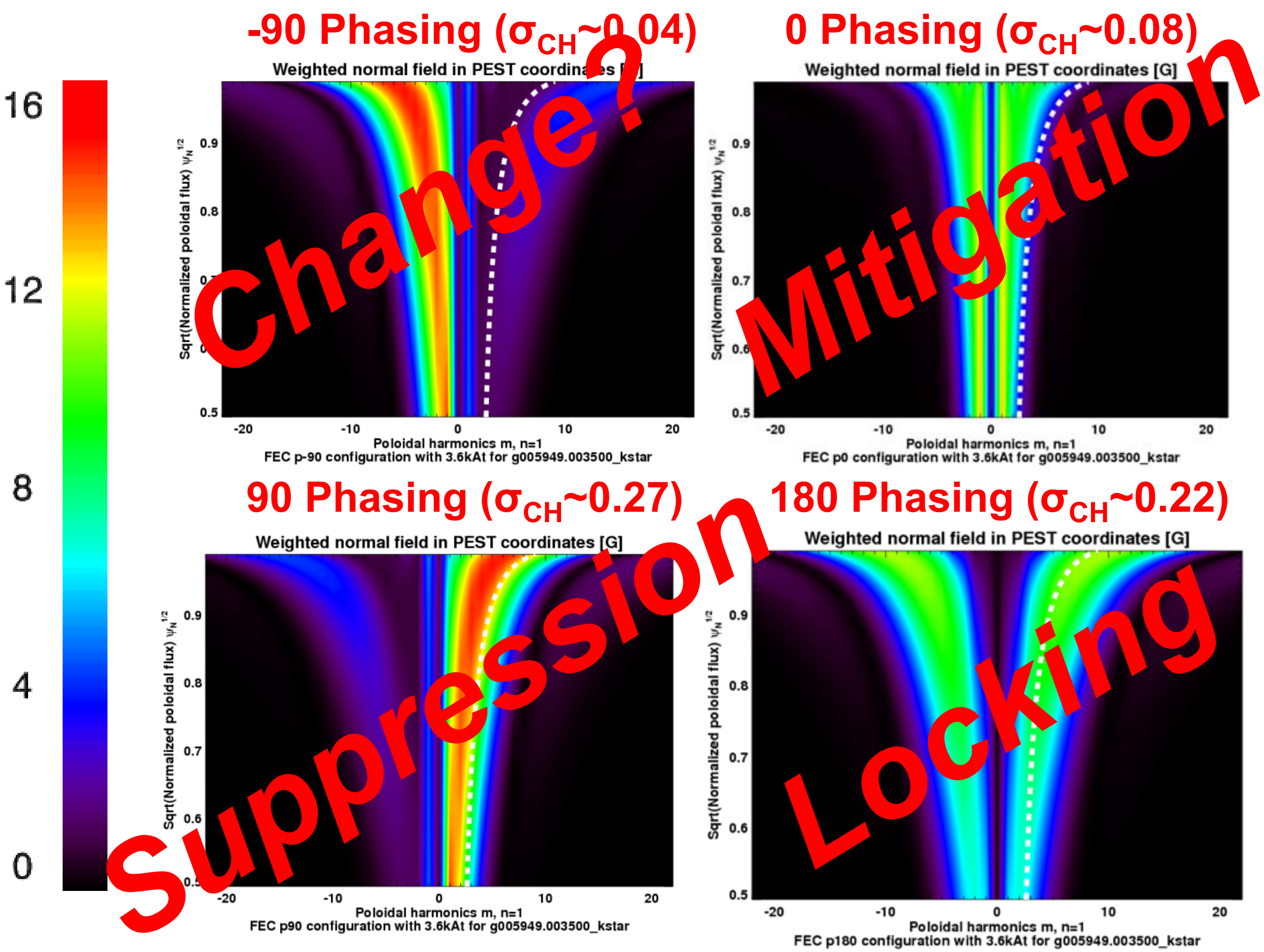

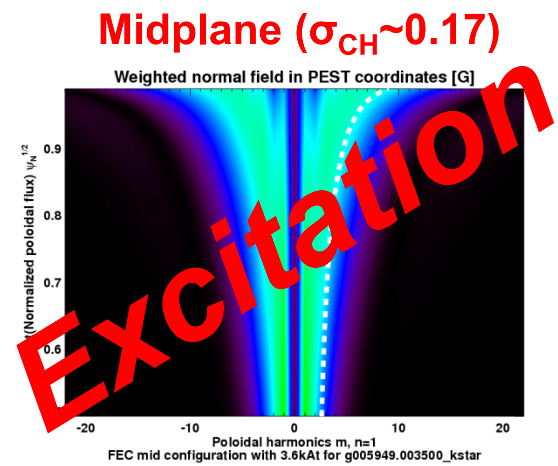

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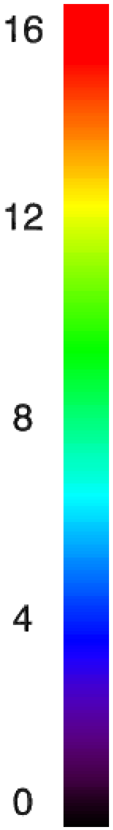

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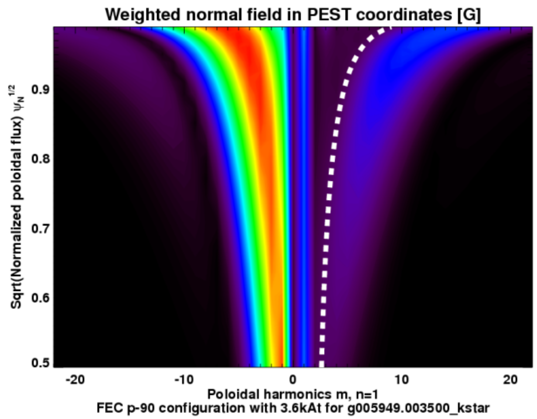

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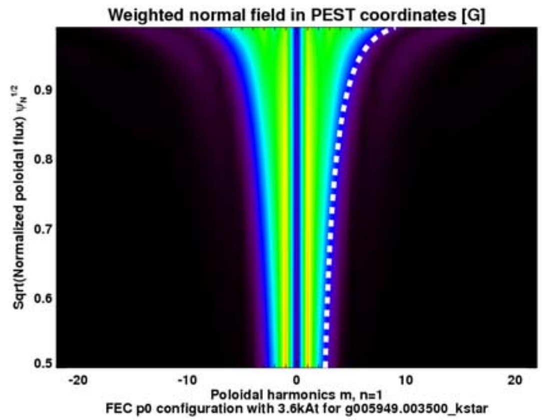
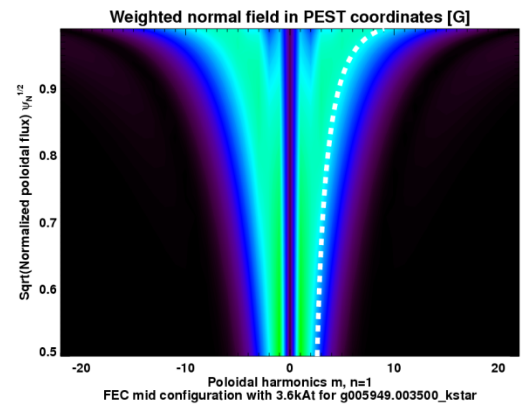


Midplane (σ_{CH}~0.17)



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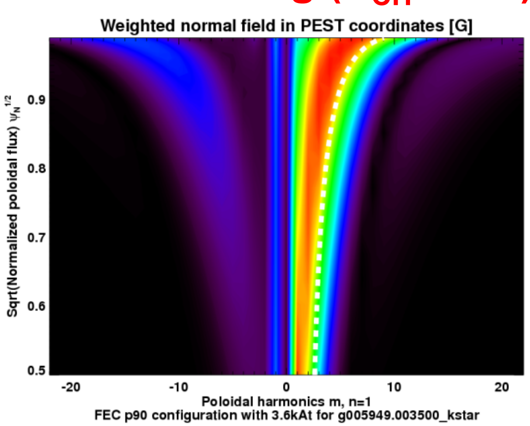

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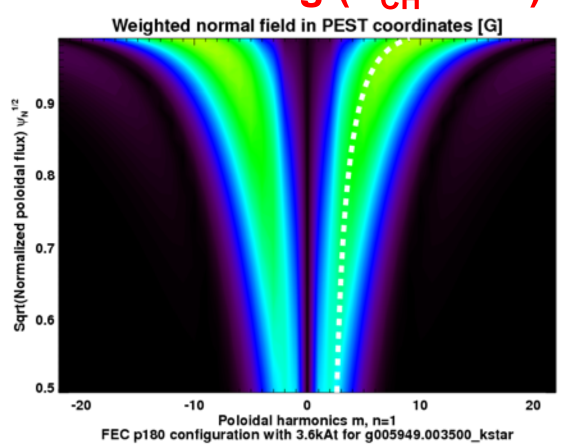
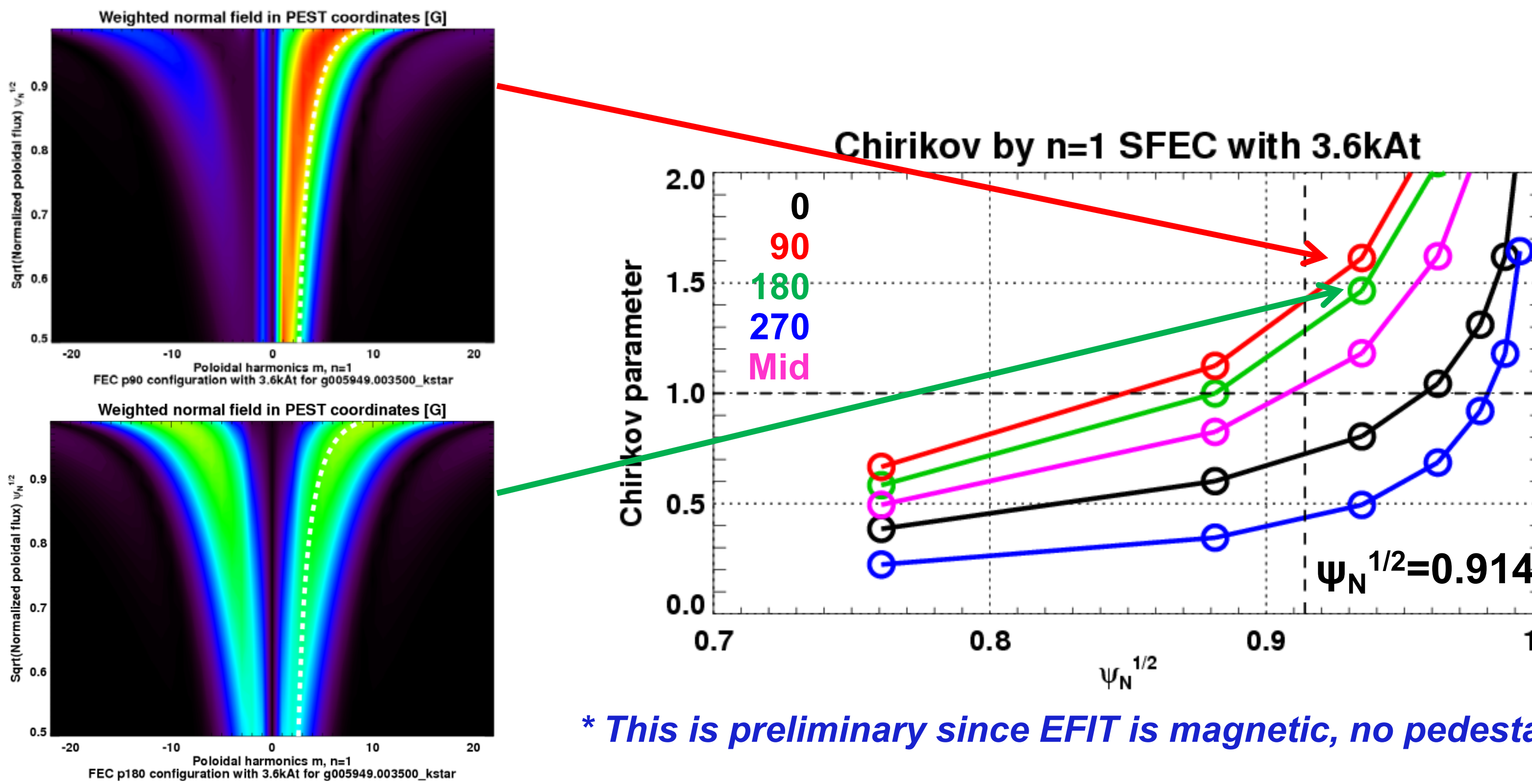


****By vacuum analysis***

****σ_{CH} = Stochastic layer width in the edge***

Preliminary Chirikov analysis is partially consistent with vacuum criterion

- Chirikov width : **90 > 180 > Mid >** Criterion > 0 > -90 phasing
  Supp. (90) *Locking* (180) *Excit.* (Mid) *Miti.* (0) *?* (-90)
- However, 180 phasing is the best for pitch-alignment, although 90 phasing is the best for res. to nonres. ratio



***** This is preliminary since EFIT is magnetic, no pedestal, etc*

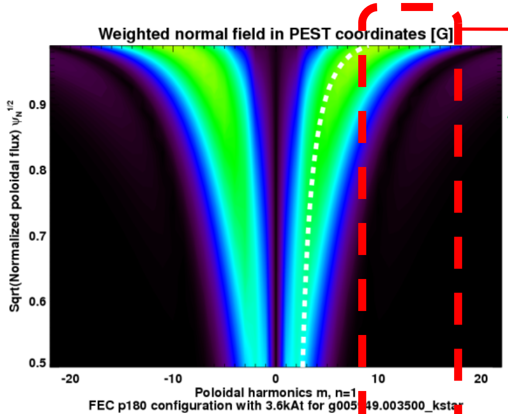
Preliminary IPEC analysis is also only partially consistent for locking

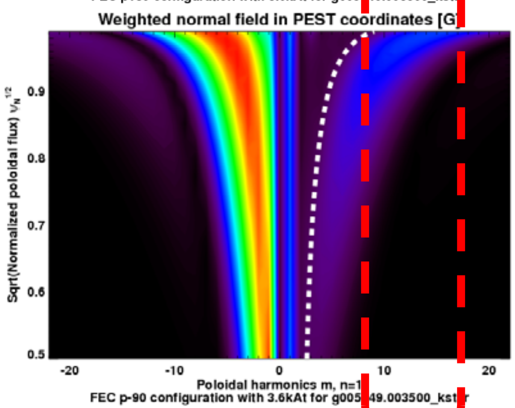
- IPEC Chirikov width: 180 > 90 > Mid > -90 > 0 phasing

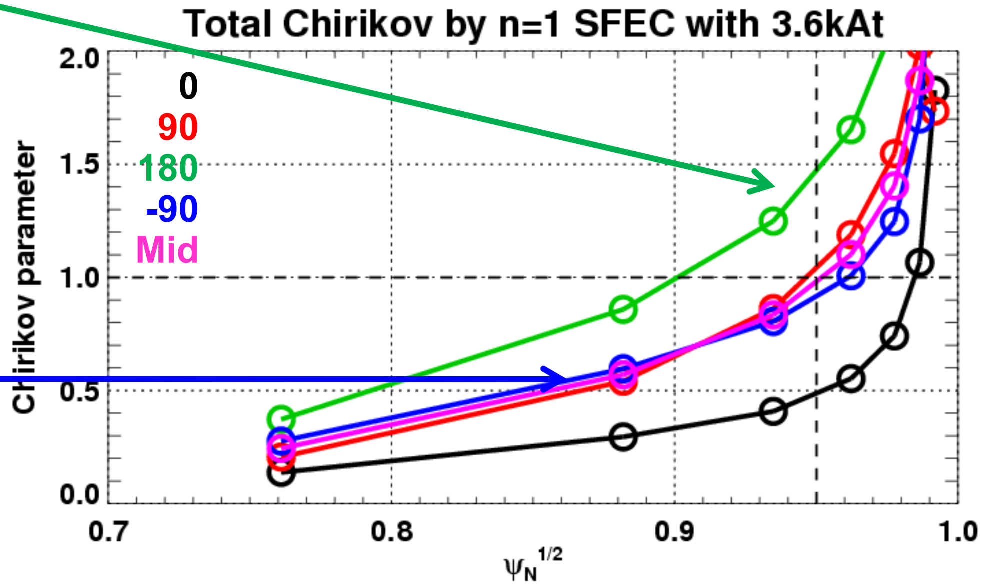
  Locking (180) *Supp.* (90) *Excit.* (Mid) *?* (-90) *Miti.* (0)

  – Note IPEC results only show field penetration strength
- Plasma response is determined by higher m's than resonant pitch

High m components maximize plasma response



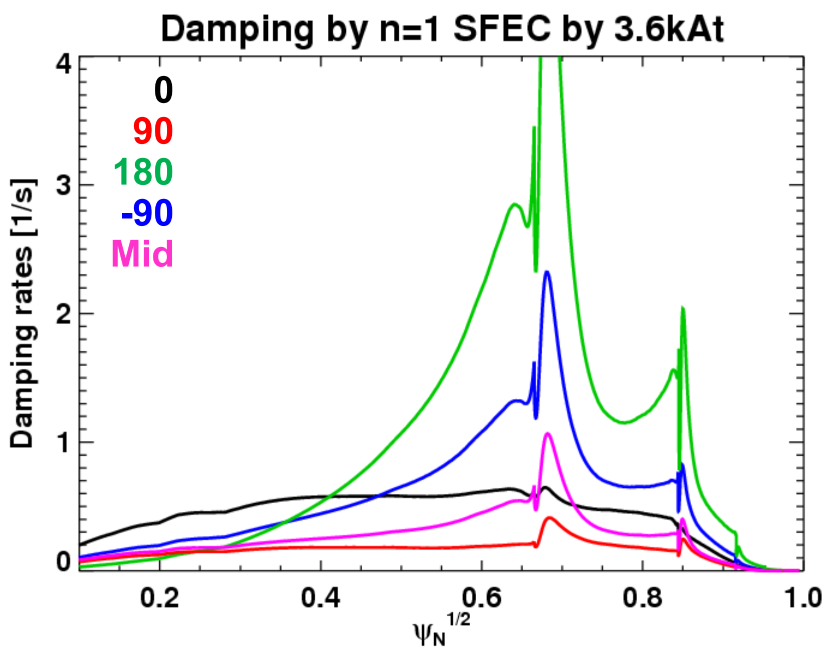




****** This is more preliminary since EFIT is magnetic, no pedestal, no precise q_0 and q-profiles, etc***

Preliminary IPEC+NTV analysis is also only partially consistent with observations

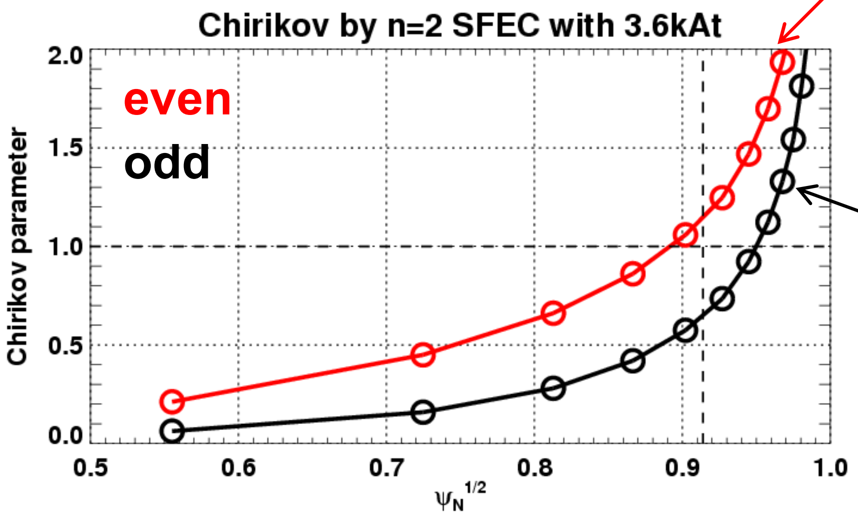
- IPEC+NTV predicts observable rotational damping (1/s damping rates)
  - If NBI + intrinsic torque is larger than NTV, then it may not be observable
- 180 phasing gives the largest damping with possibility of locking
- 90 phasing gives the highest figure of merit for Chirikov to NTV

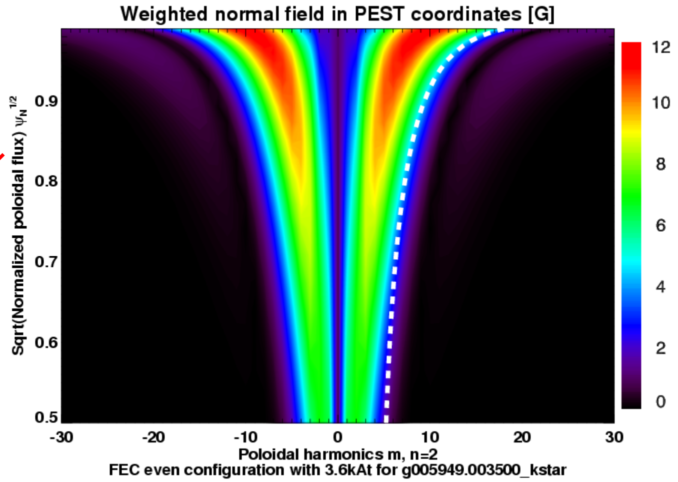


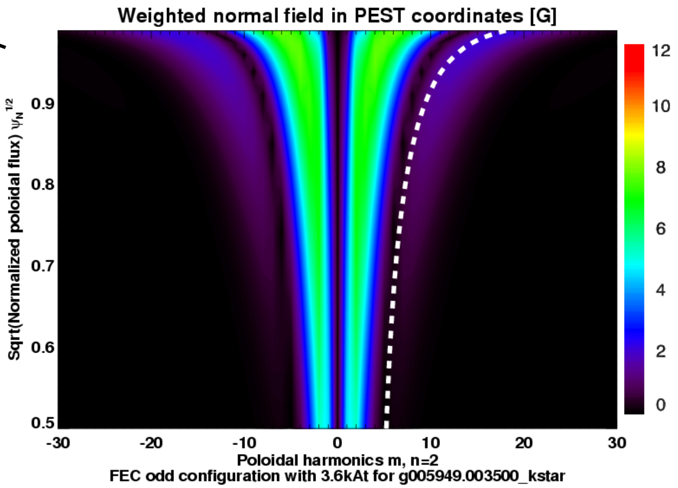
This is even more preliminary since EFIT is magnetic, no pedestal, no precise q_0 and q-profiles, and largely simplified kinetic parameters : Te, Ti, V_{rot} profiles are assumed using pressure profiles, and $T_{e0}=T_{i0}=1.5keV$, $V_{rot0}=150km/s$, $n_e=n_i$, $Z_{eff}=1$

n=2 RMP was also tested based on vacuum calculations showing marginal possibility

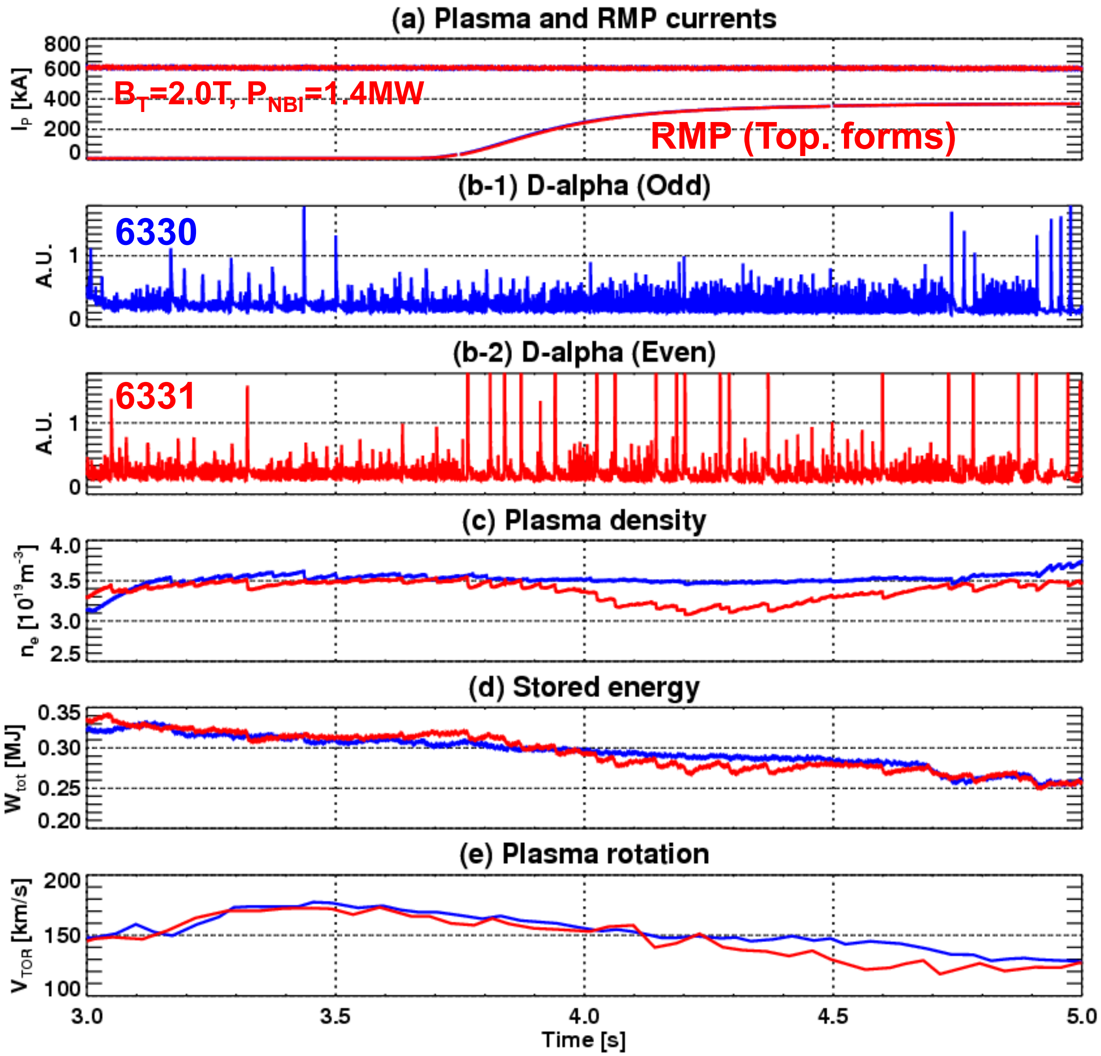
- Vacuum calculations showed n=2 even configuration can meet Chirikov criterion, with marginal pitch-alignment (IPEC gives the opposite trend)







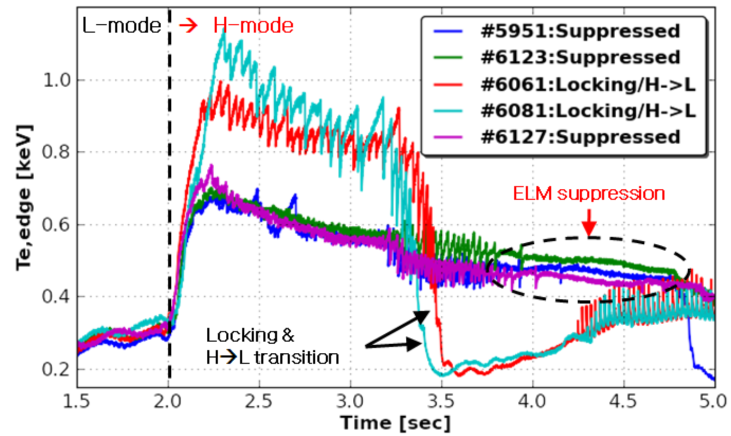
However, n=2 RMP effects were not clear for both even and odd configurations

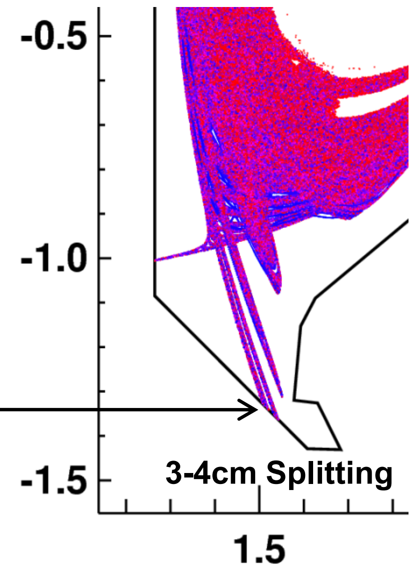


- n=2 RMP applications did not show any clear effects on ELMs
- Possibility of ELM excitations was speculated for n=2 even configuration, but observations were not reliably reproduced
- Rotation damping was not observed by RMPs, as consistent with preliminary IPEC+NTV (smaller damping rates by an order of magnitude than n=1)

Other observations and considerations

- Collisionality : Rough estimation gives ν_e^*= 0.5~1 at the pedestal
- ECE (~ 40Ch) and ECEI clearly showed ELM changes →
- ECEI showed island structures when plasma is unlocked and starts to rotate, but not clearly during ELM mitigation or suppression
- CERS (when NBI modulated) showed rotation collapse when plasma is locked
- Other D-alpha bolometer signals are available with no saturation (unlike signals shown in this presentation)
- BES measurements showed clear changes in fluctuations when RMP is applied
- Field-line tracing predicted one lobe, which is being under investigation with probes →
- Intrinsic error field was weak when measured in one direction





Summary and future work

- KSTAR n=1 RMP experiments demonstrated
  - ELM mitigations and suppressions (with 90p)
  - ELM excitations (with midplane alone, like NSTX)
  - ELM mitigations with broad spatial field (with 0p, like JET)
  - Locking without ELM changes (with 180p, like other n=1 applications)
  - Non-resonant response? (with -90p)
- This shows powerful controllability of RMPs on ELMs
  - For fixed n(=1), one can control m's to produce useful RMPs
  - However, consistent picture (vacuum or plasma) is not yet available across various spectra and plasma regimes (e.g. collisionality)
- In the next campaign, KSTAR is planned to have
  - P_{NBI}=3MW, possibly doubled I_{RMP} currents (for further test of n=2), MPTS, BES, SXR, etc,