NSTX

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Active Control of Rotating Edge Modes using HHFW Antenna in NSTX

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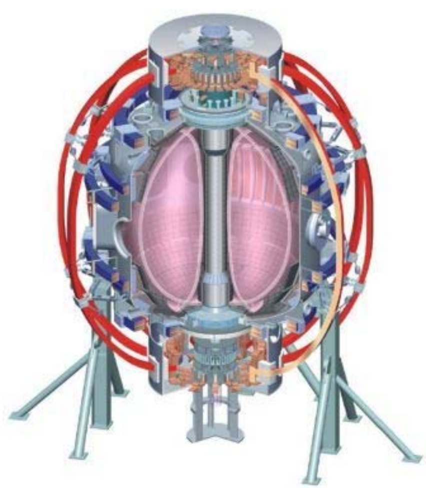

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Motivation (I)

- A problem with impurity control in NSTX
  - Lithium is effective at holding the deuterium density constant
  - But the carbon density keeps rising [*Maingi, PRL 103, 075001 (2009)*]
  - Core radiation rises
  - This is not good, but it is not because the lithium is not pumping deuterium
  - In the absence of ELMs the plasma does not unload impurities

- Are EHOs the answer?
  - DIII-D has found QH modes both for counter and co-injected cases [*Greenfield, PRL 86, 4544 (2001)*] [*Burrell, PRL 102, 155003 (2009)*]
  - The density does not rise in these plasmas, despite absence of ELMs
  - It is believed that the Edge Harmonic Oscillations (EHOs) are the reason

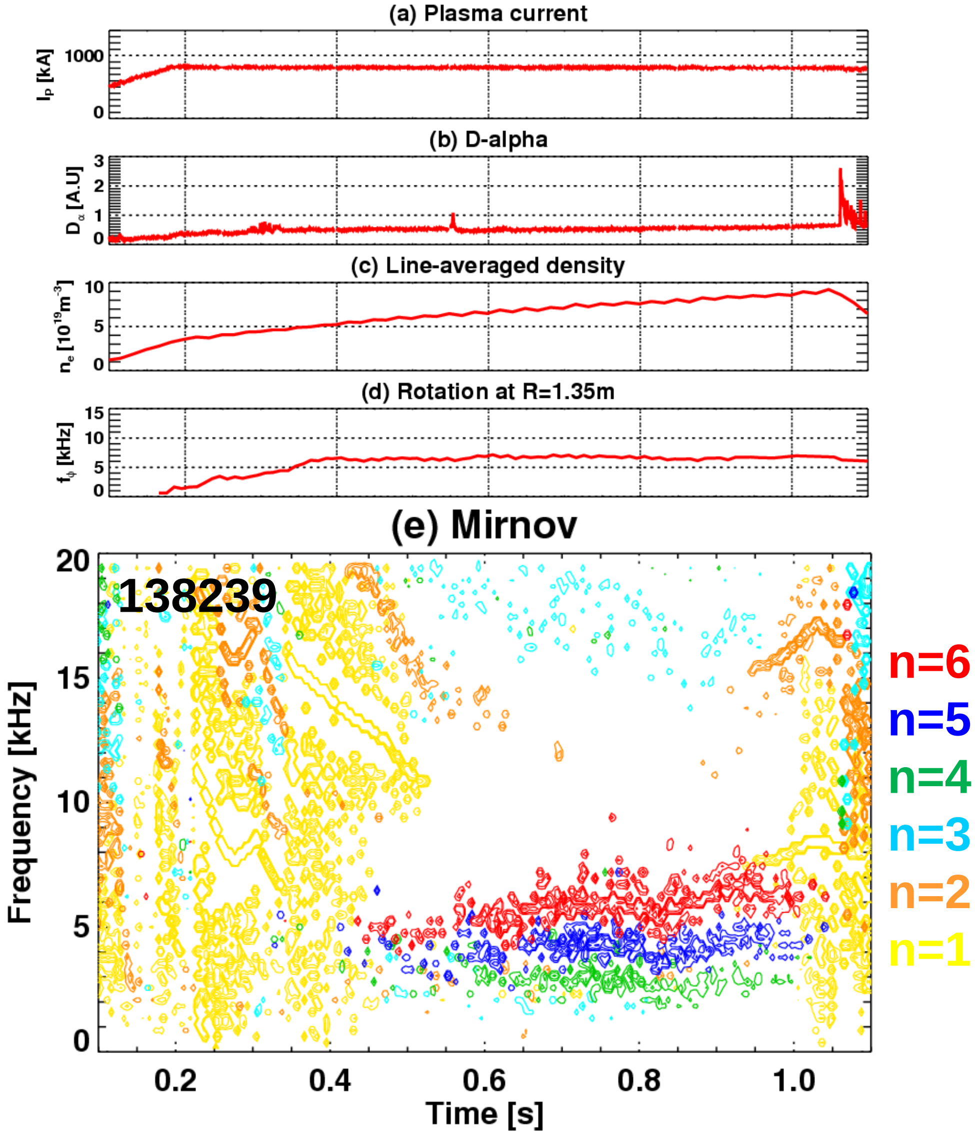
Motivation (II)

- EHOs have been observed in NSTX ELM-free periods
  - 2-8kHz and n=4-6 EHOs have been observed (PEST and ELITE codes showed n=3 is most unstable in NSTX)
  - EHOs were weak in amplitudes and did not pump density out

- Direct coupling to EHOs to increase amplitudes has been discussed, by utilizing HHFW antenna as 3D coils
  - Present Error Field Correction (EFC) coils are not effective for n>3
  - HHFW antenna straps are localized within $\Delta\varphi<90$ and perhaps would be effective for n>3

- This will be proposed for NSTX-U again in the future, but study showed the possibility of HHFW straps for 3D coils

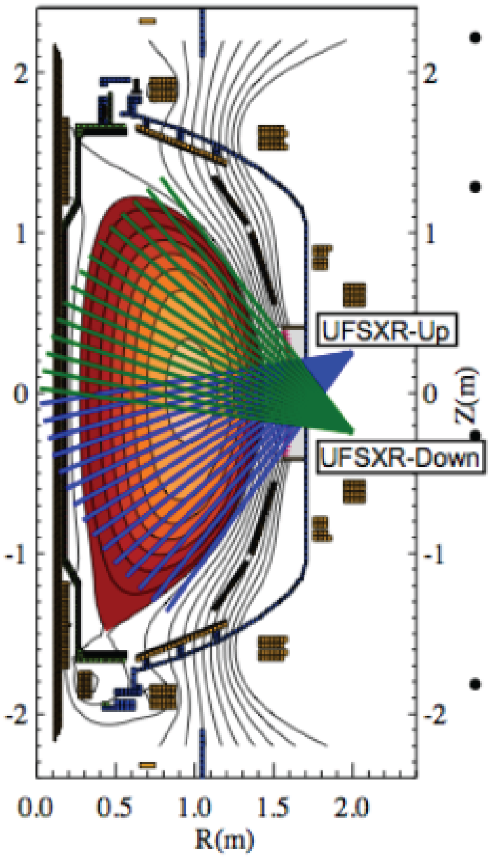
EHOs were seen on NSTX Mirnov coils



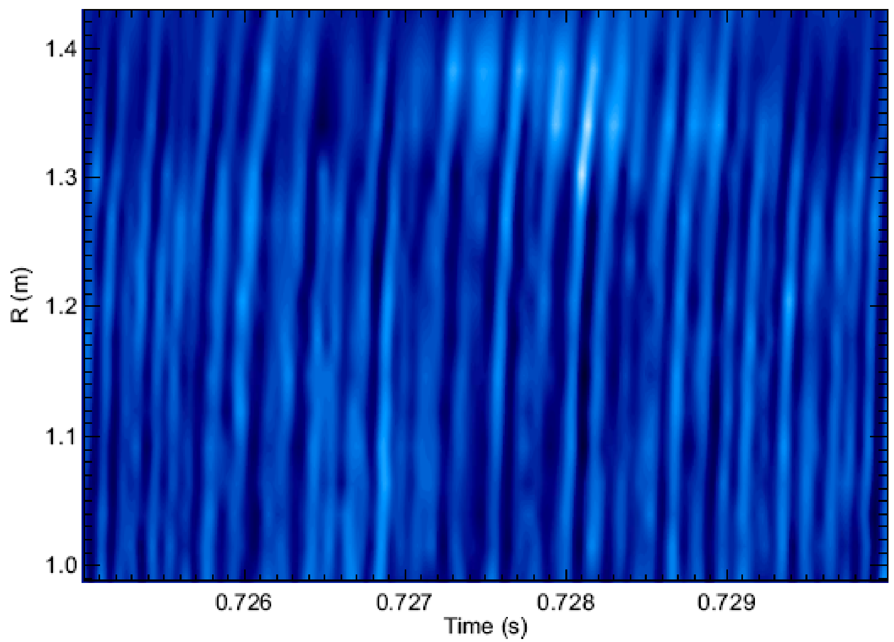
- n=4-6 EHOs were observed in the edge by Mirnov coils tuned for low frequency and low amplitude
- EHOs are clearest in some optimal operating regimes
  - 4MW, 0.8MA, 0.4T
- Generally amplitudes of EHOs are very low, without reduction of density increase
- Amplitudes may be able to be increased by active driving for EHOs

EHOs were also seen on UFSXR

- n=4-6 EHOs were observed in the edge by Ultra-Fast Soft X-Ray (UFSXR) diagnostics
- Such clear signals were not seen without EHOs

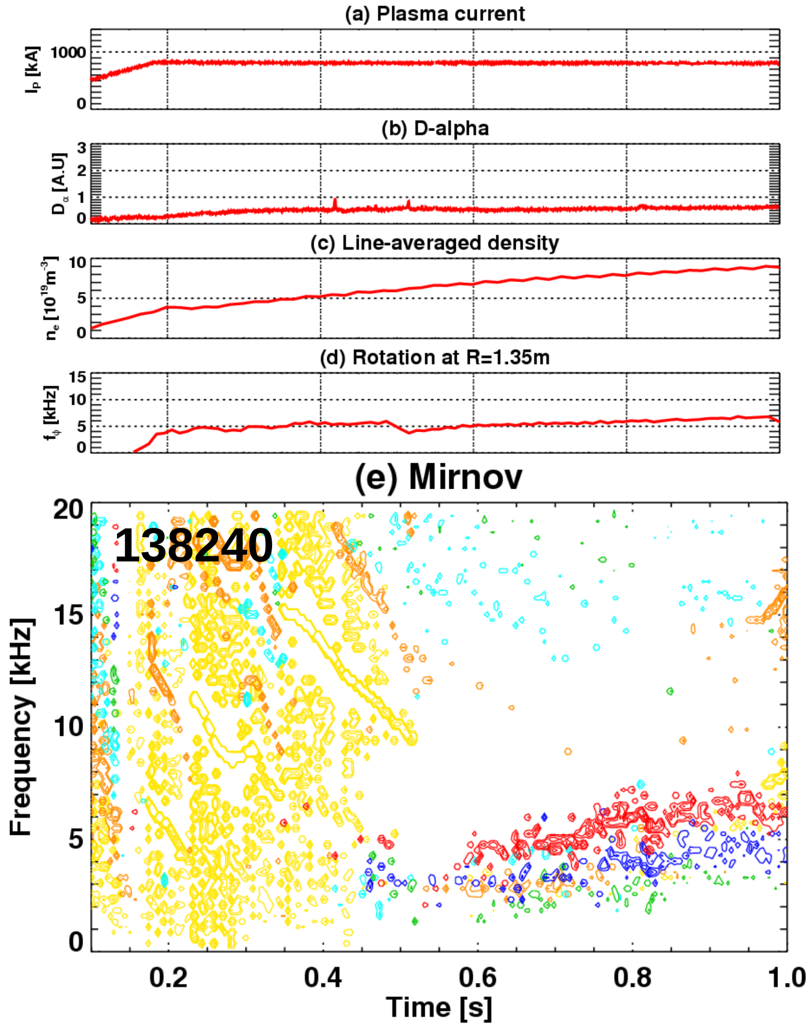


#138239, UFSXR-Up, 5um Be filter

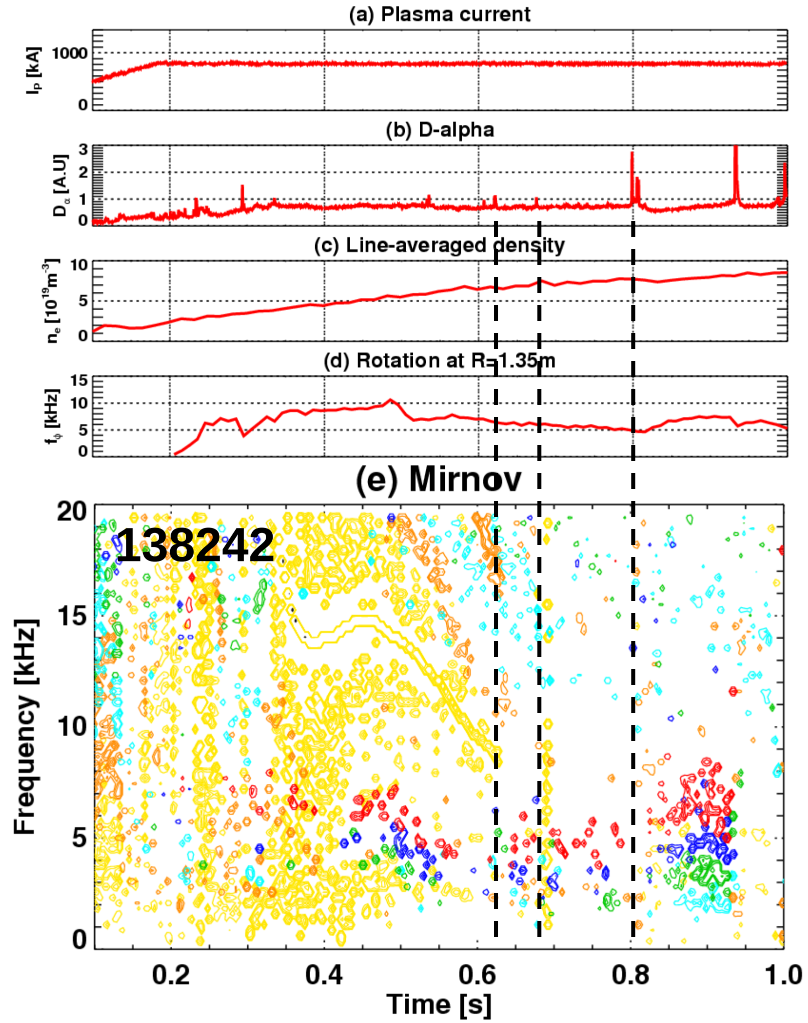


EHOs in NSTX were however found in only limited operational domains (I)

- I_P=0.8MA, B_T=0.4T, P_{NBI}=**4MW**

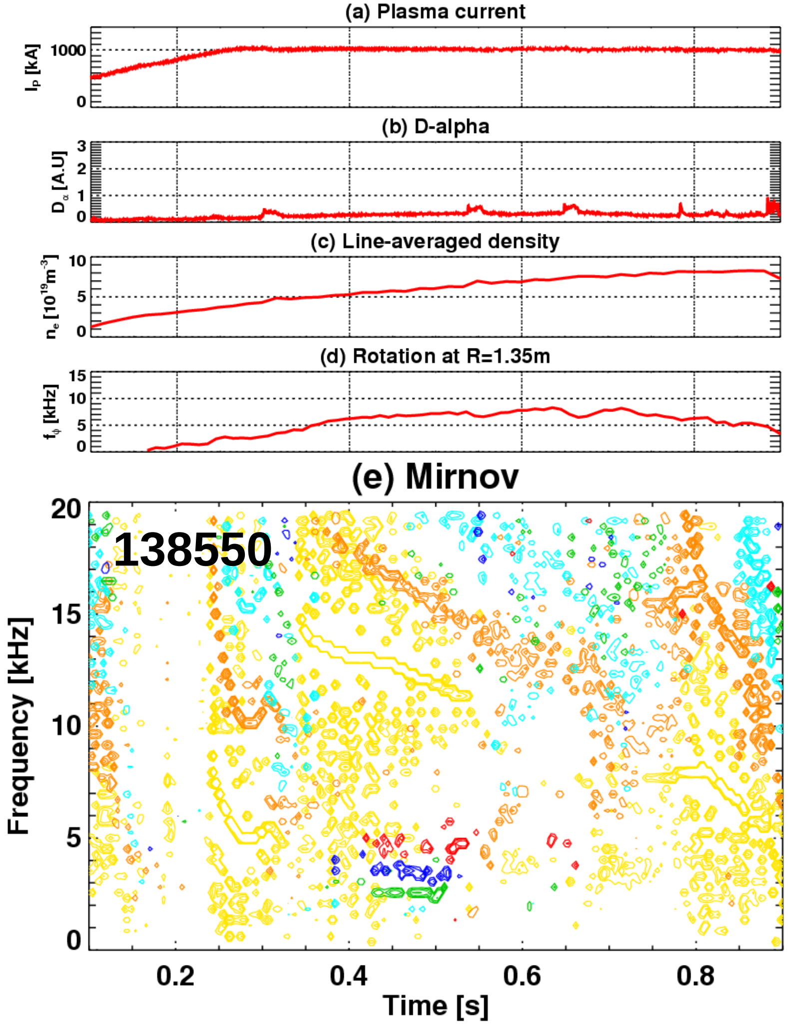


- I_P=0.8MA, B_T=0.4T, P_{NBI}=**6MW**

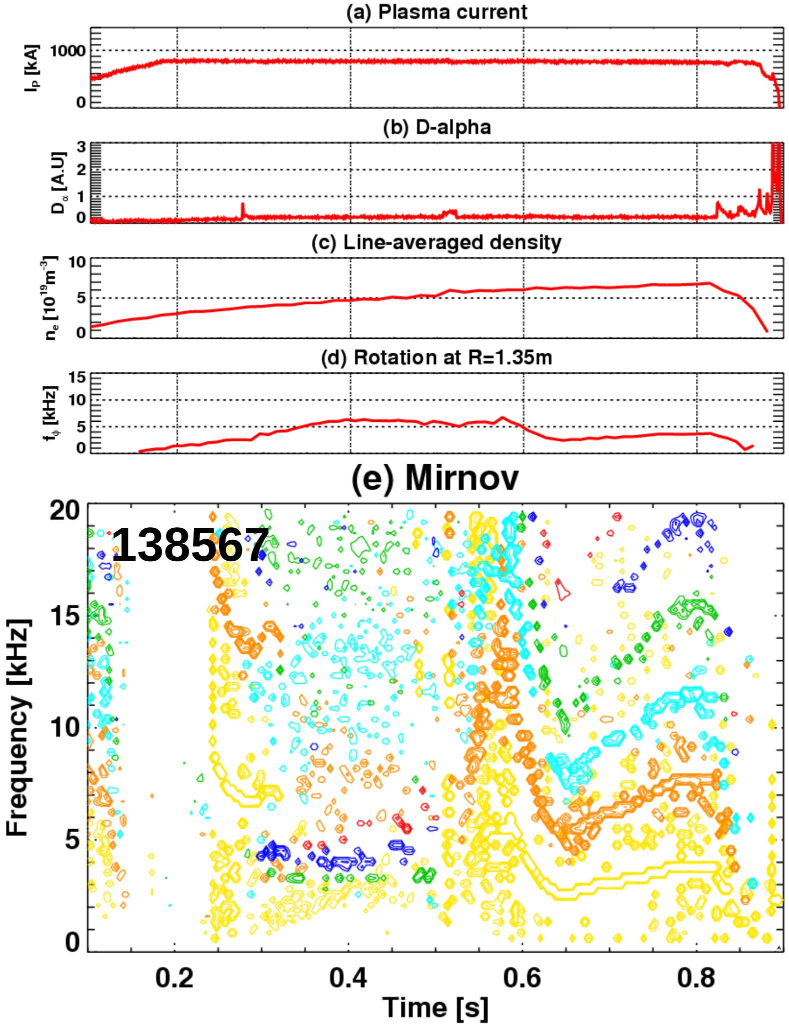


EHOs in NSTX were however found in only limited operational domains (II)

- I_P=1.0MA, B_T=0.45T, P_{NBI}=**4MW**



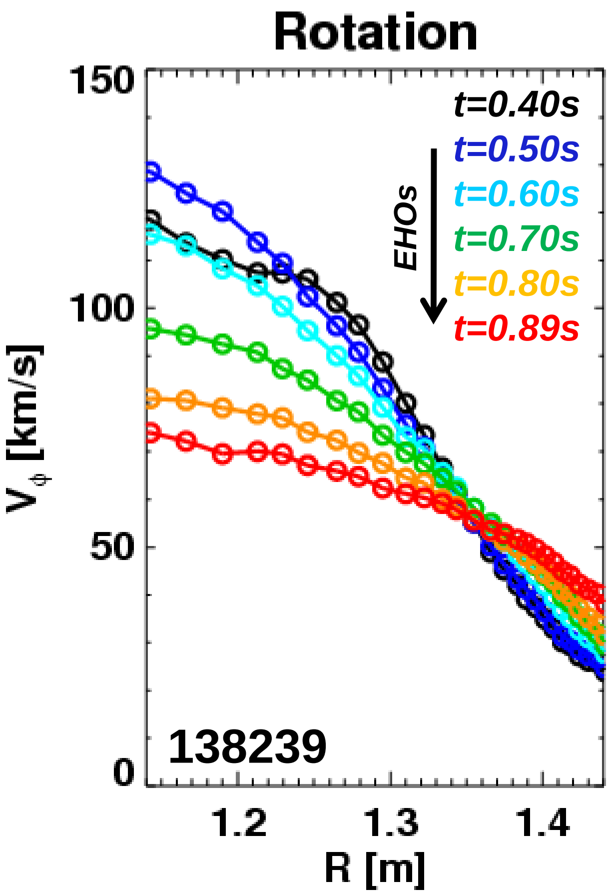
- I_P=0.8MA, B_T=0.33T, P_{NBI}=**4MW**



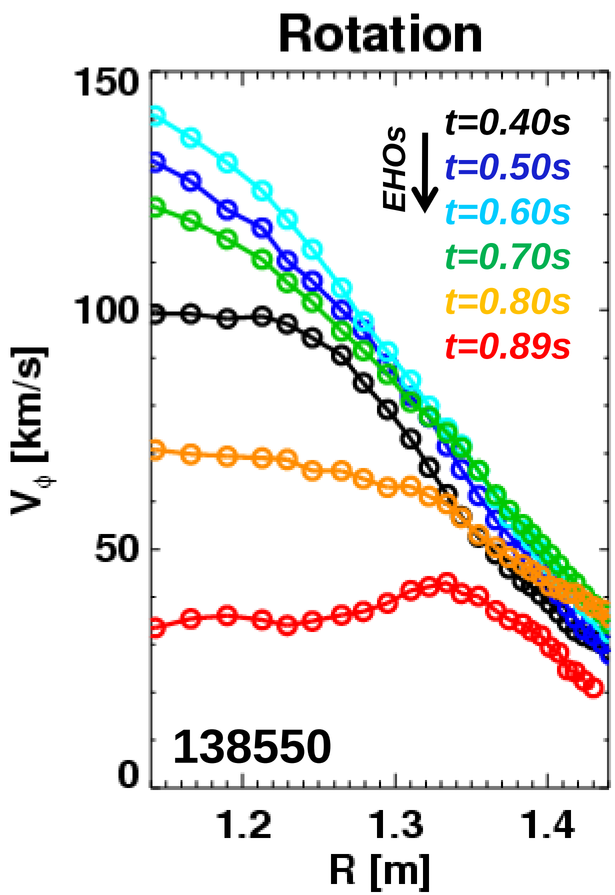
Edge rotational shear is strong in NSTX, perhaps in a consistent way as expected for EHOs

- Edge rotational shear is often strong in NSTX, and perhaps there may be a correlation between rotation shear and NSTX EHOs' amplitudes

Strong EHOs

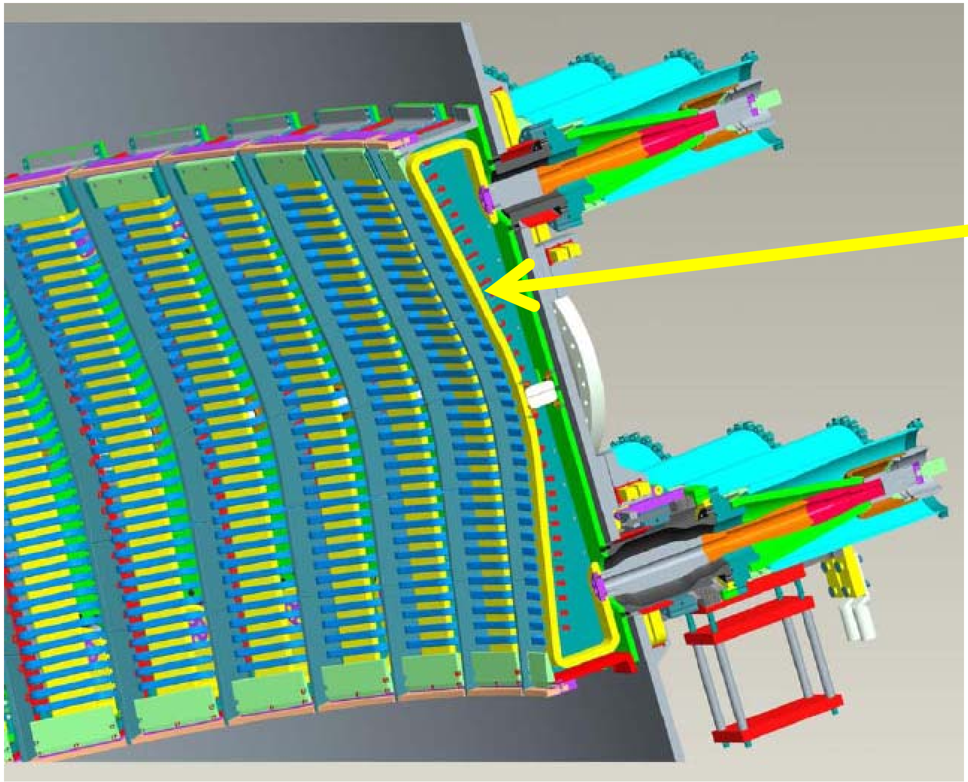


Weak EHOs



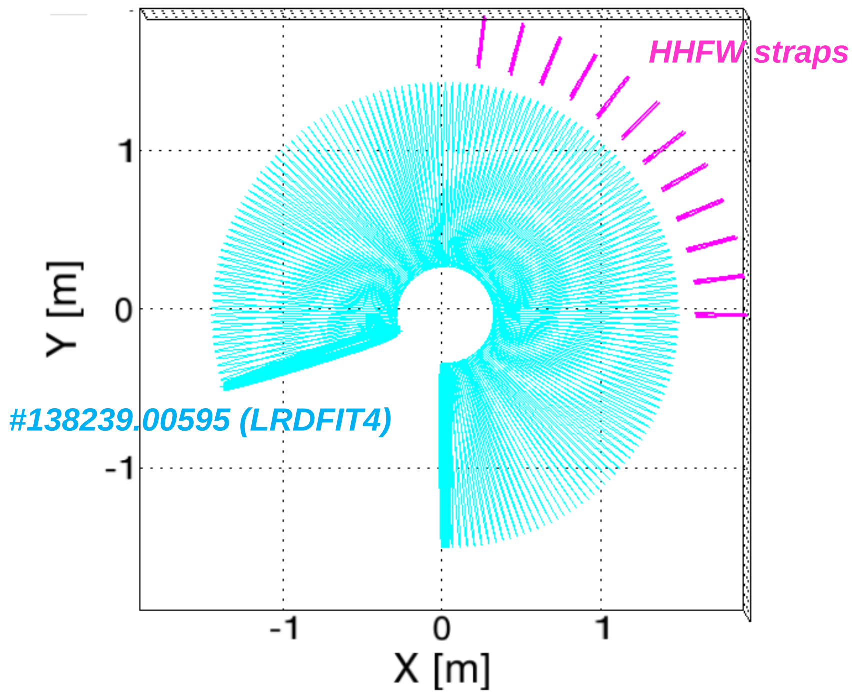
Active control of EHOs using HHFW antenna has been proposed by R. Goldston

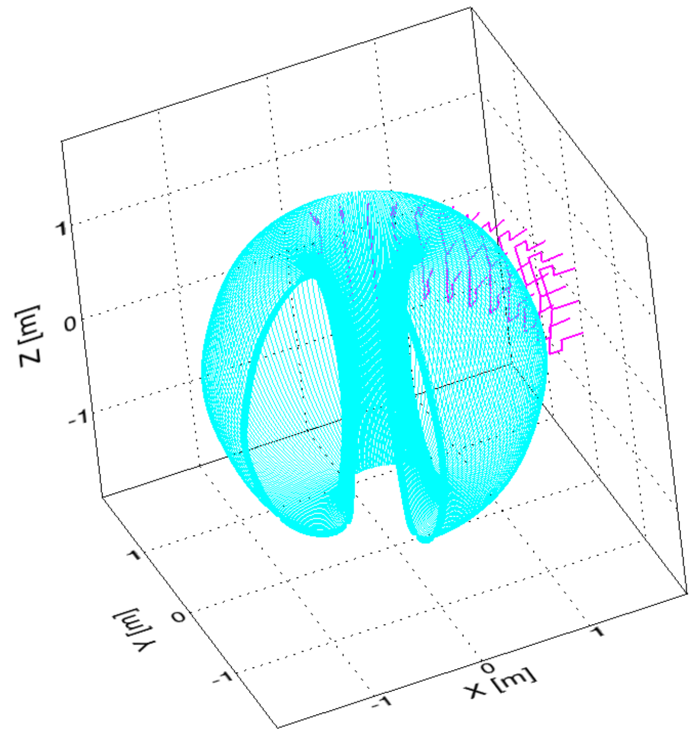
- Maybe we can use HHFW to drive EHOs and even control impurity influx
- Easy to modulate HHFW amplitude in high frequency 2-8kHz



NSTX HHFW antenna system can be used to produce high-n magnetic perturbations

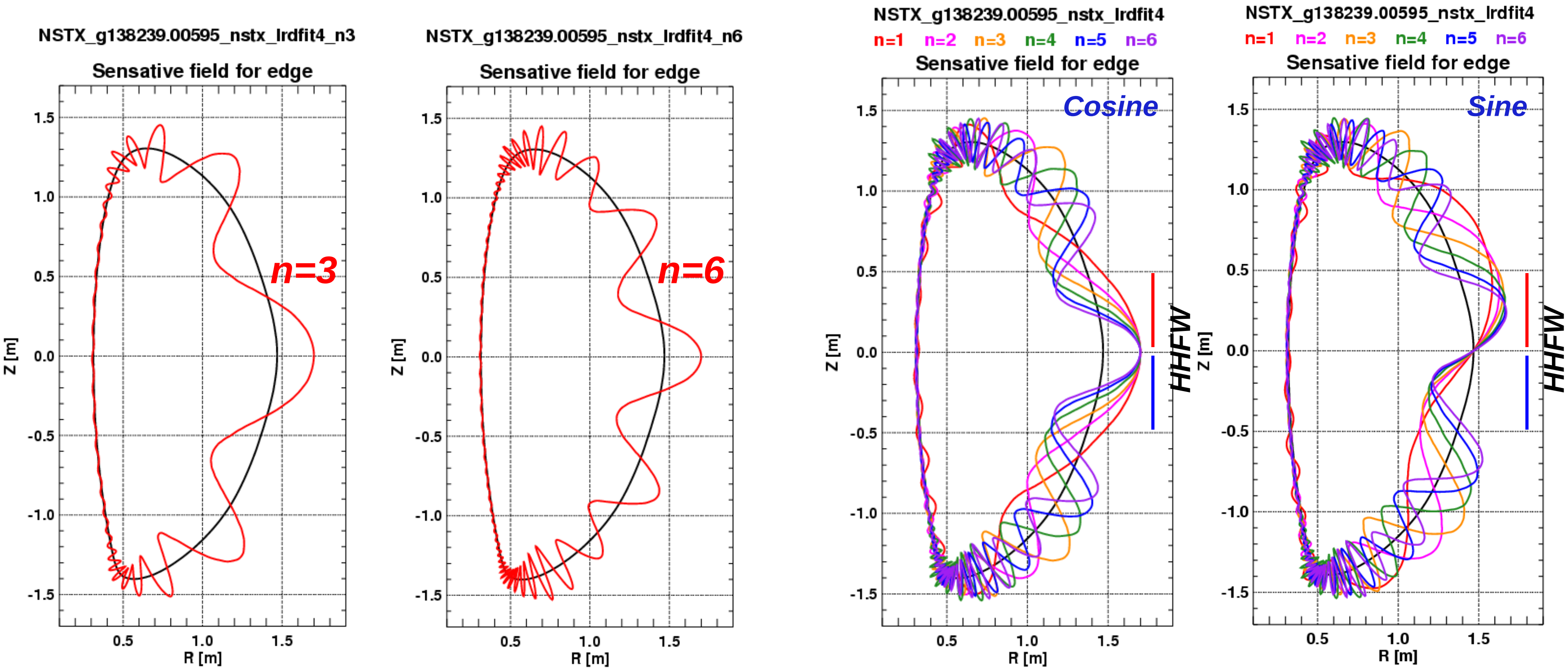
- NSTX HHFW antenna system has 12x2 straps covering 90 toroidal angles at the midplane
  - Each strap is modeled with a open filament (model can be improved)
- HHFW can produce n=1-6 (spatially tangential) perturbations





High-n perturbations from HHFW may be able to excite dominant fields in NSTX plasmas

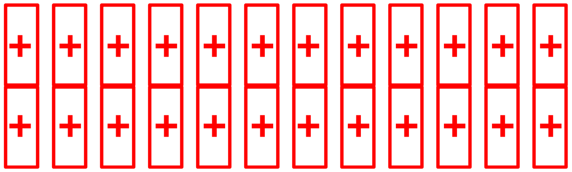
- Dominant fields for high-n's in NSTX are localized at the midplane, and so may be well coupled with HHFW driven perturbations
  - Dominant field is defined as the field maximizing total resonant field at ψ_N=0.8~0.95 for each n
  - As known, wavelength of dominant field becomes shorter for higher n

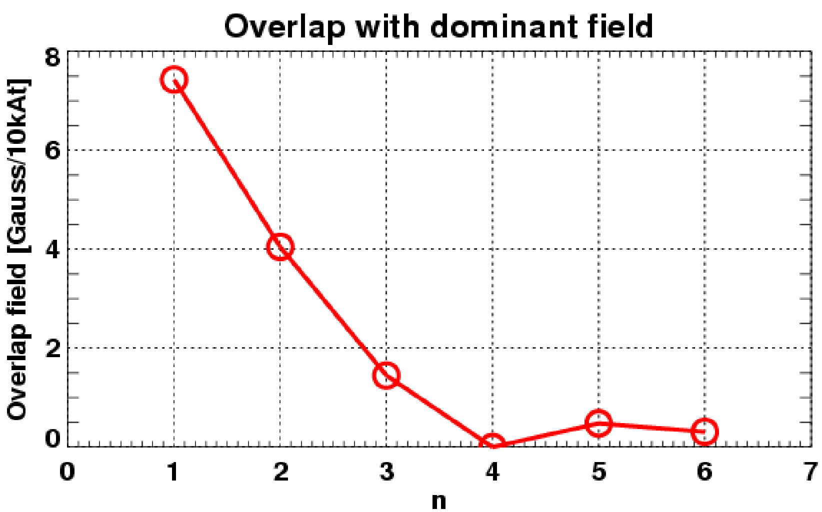


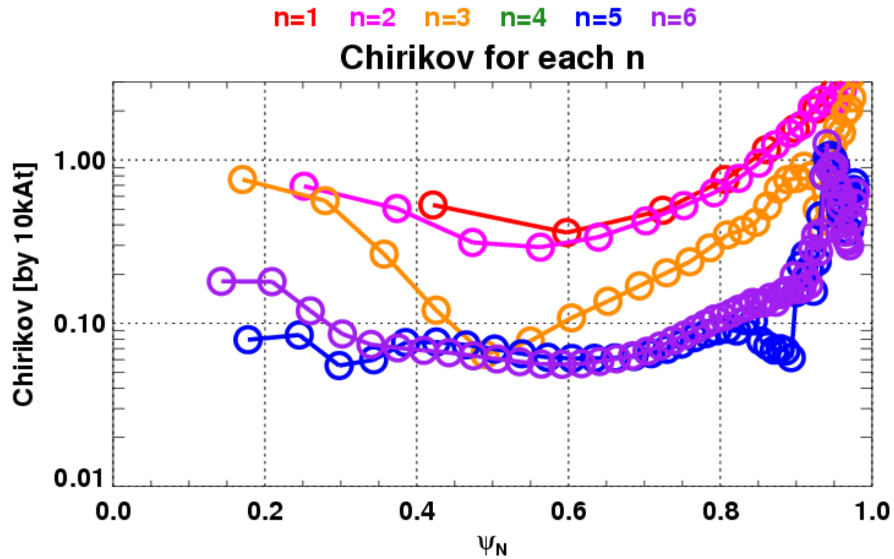
Overlap with dominant field and Chirikov (I)

- All same currents for 24 straps give maximum power, but only to low n's

HHFW



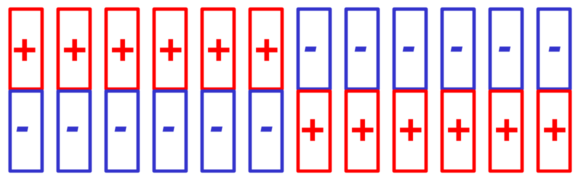


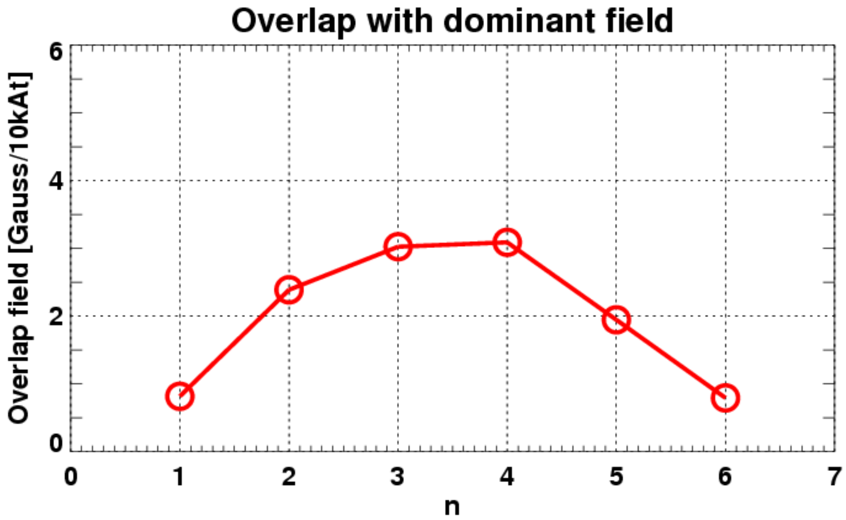


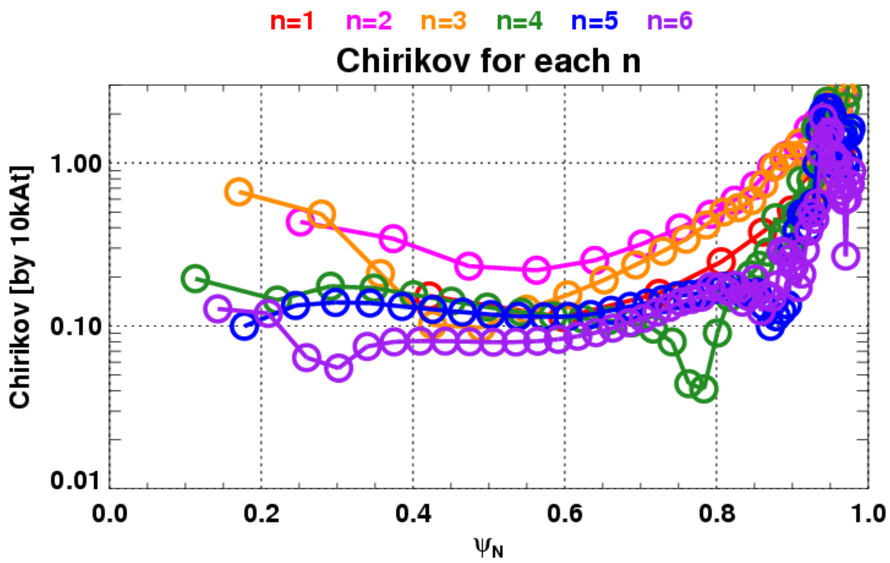
Overlap with dominant field and Chirikov (II)

- Up-down asymmetry for 24 straps can maximize middle n’s (n=3-4)

HHFW



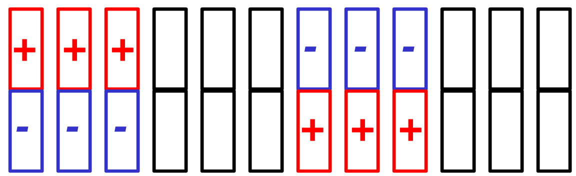


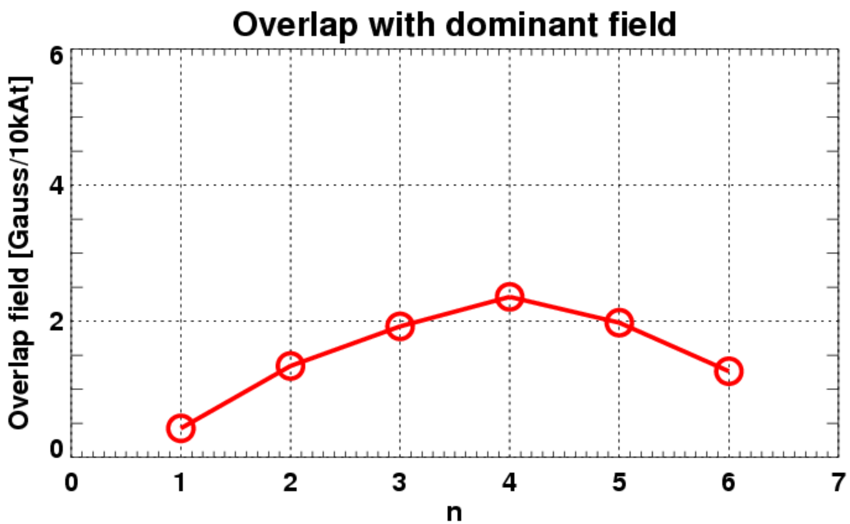


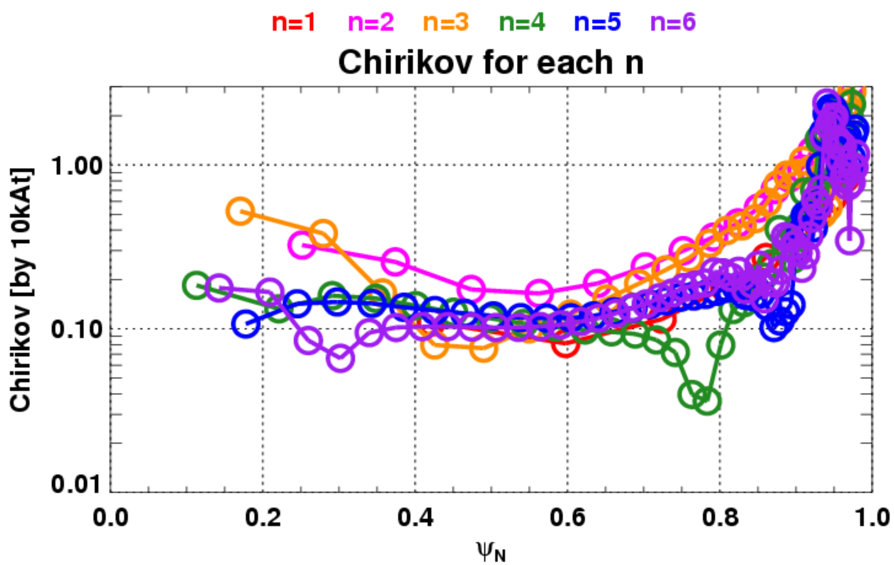
Overlap with dominant field and Chirikov (III)

- The half of the straps can give the similar efficiency in this configuration

HHFW



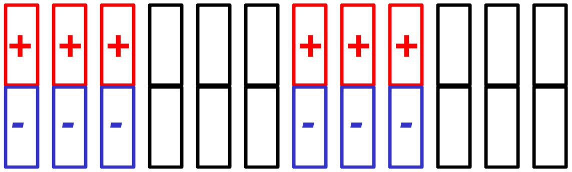


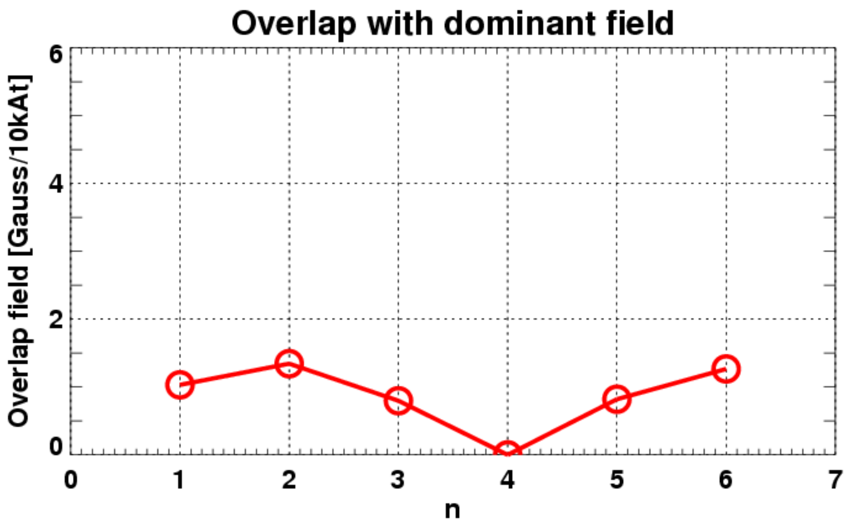


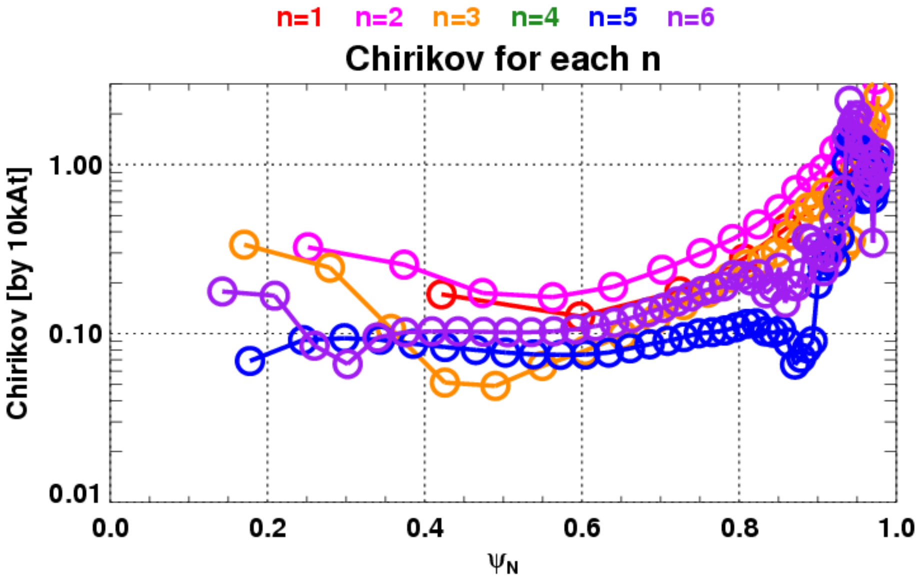
Overlap with dominant field and Chirikov (IV)

- This configuration can maximize n>=5, while minimizing n<=4

HHFW

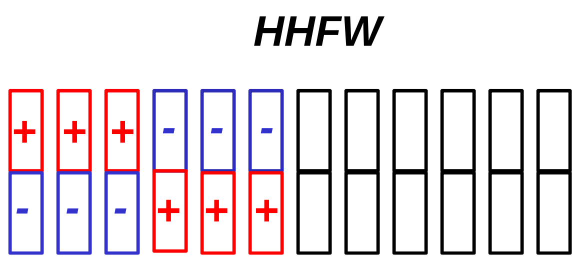


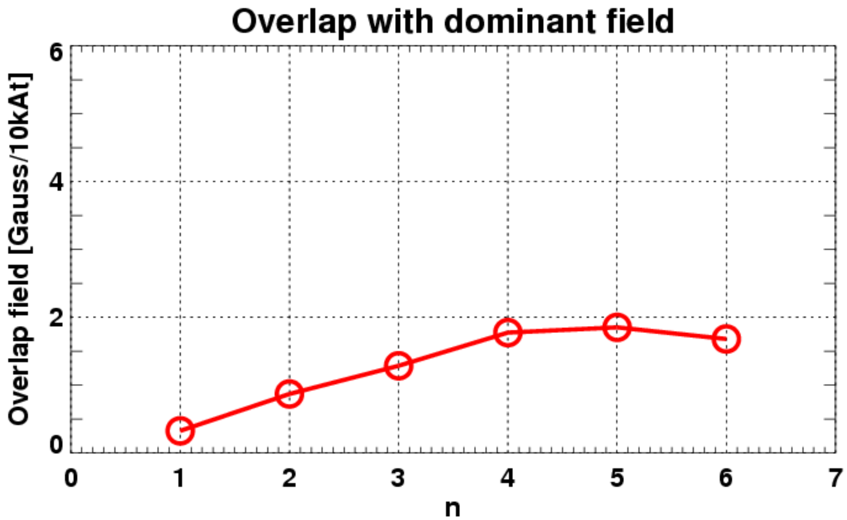


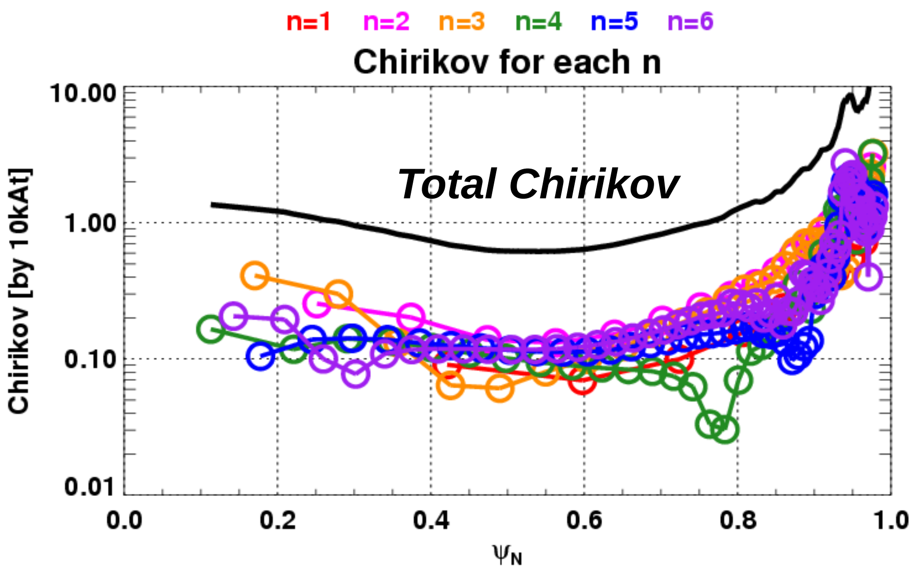


Overlap with dominant field and Chirikov (V)

- This configuration may be the best by gradual weighting for higher n

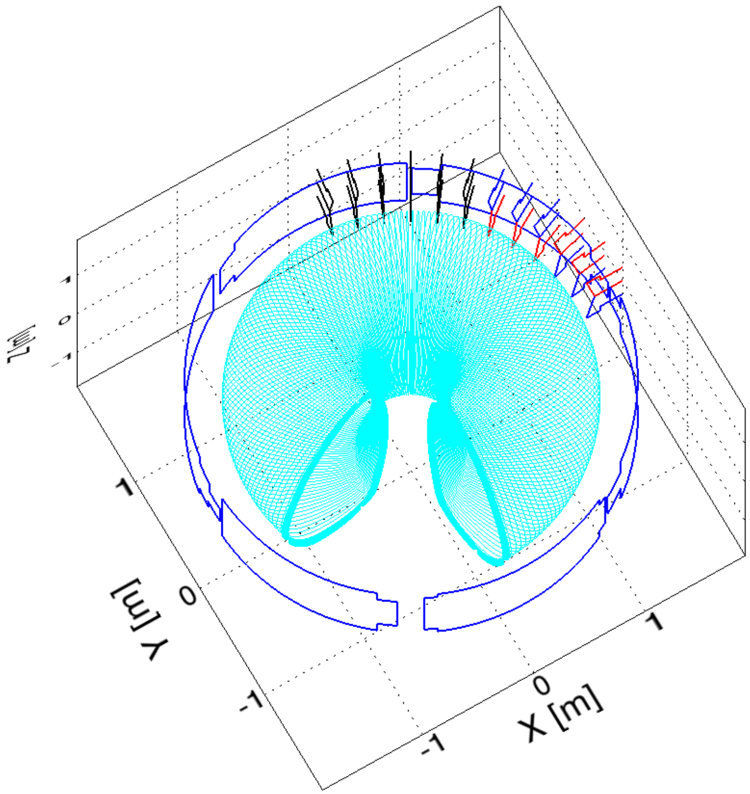


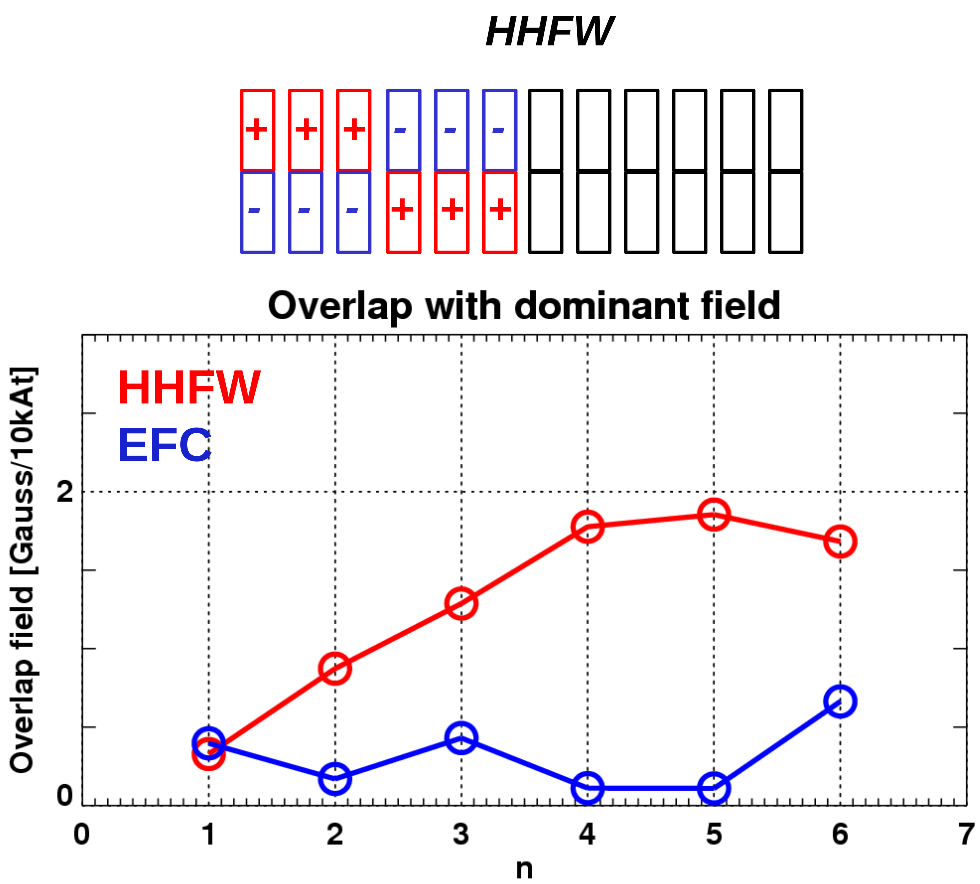




Comparison with EFC coils for n=6 (I)

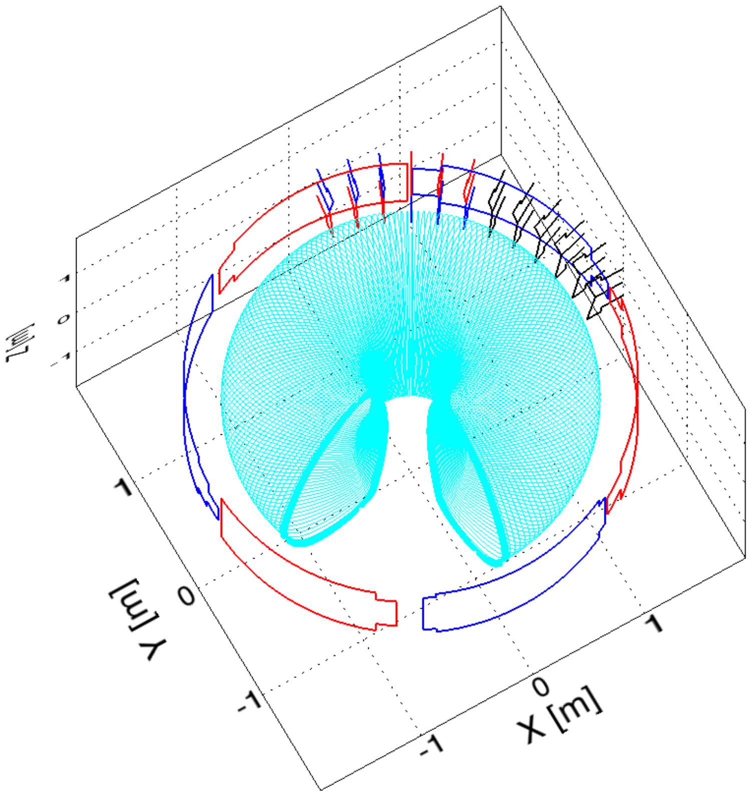
- HHFW is more efficient than EFC coils for higher n>3, even with same currents

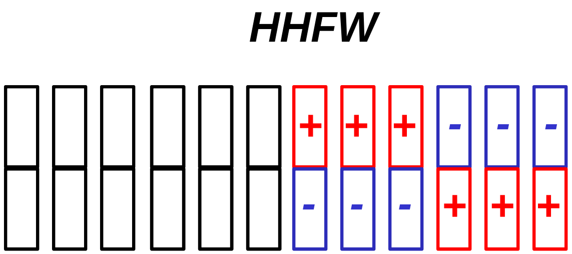


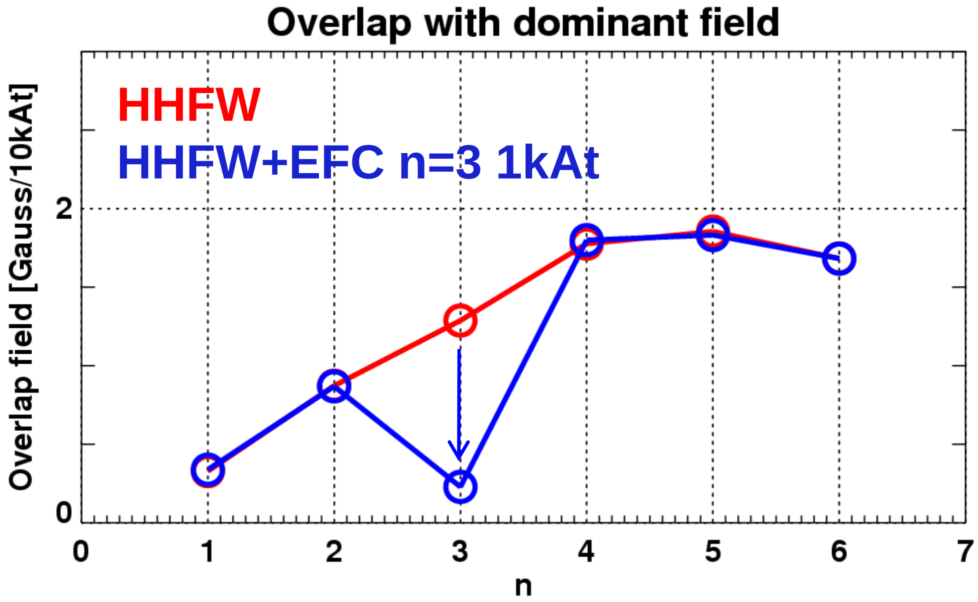


Comparison with EFC coils for n=6 (II)

- HHFW antennas are effective 3D coils with various combinations, and can be combined with EFC coils to maximize only higher n's







Summary and Future work

- EHOs with n=4-6, 2-8kHz have been observed in NSTX by Mirnov and UFSXR
  - Amplitudes are however low and density pumping was not observed
- EHOs were however found in limited operating regime
  - Edge rotational shear may be also the key to EHOs
- HHFW antennas can produce such harmonic perturbations and so perhaps can be used for active control of EHOs
- Dominant field, and Chirikov analysis showed HHFW antennas are indeed effective to produce high n>3, unlikely to EFC coils
- HHFW antennas are effectively 3D coils, and can be combined with EFC coils to control various n's
- This study will be extended and tested in NSTX-U
- We are open to the idea and to the collaboration in other tokamaks for active AC control of EHOs