NSTX

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Effect of non-axisymmetric magnetic perturbations on divertor heat and particle flux profiles

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Joon-Wook Ahn, ORNL

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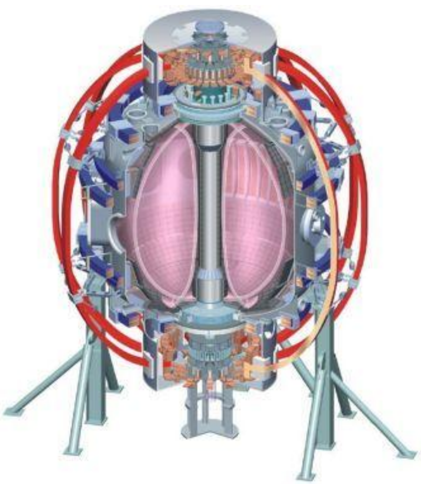

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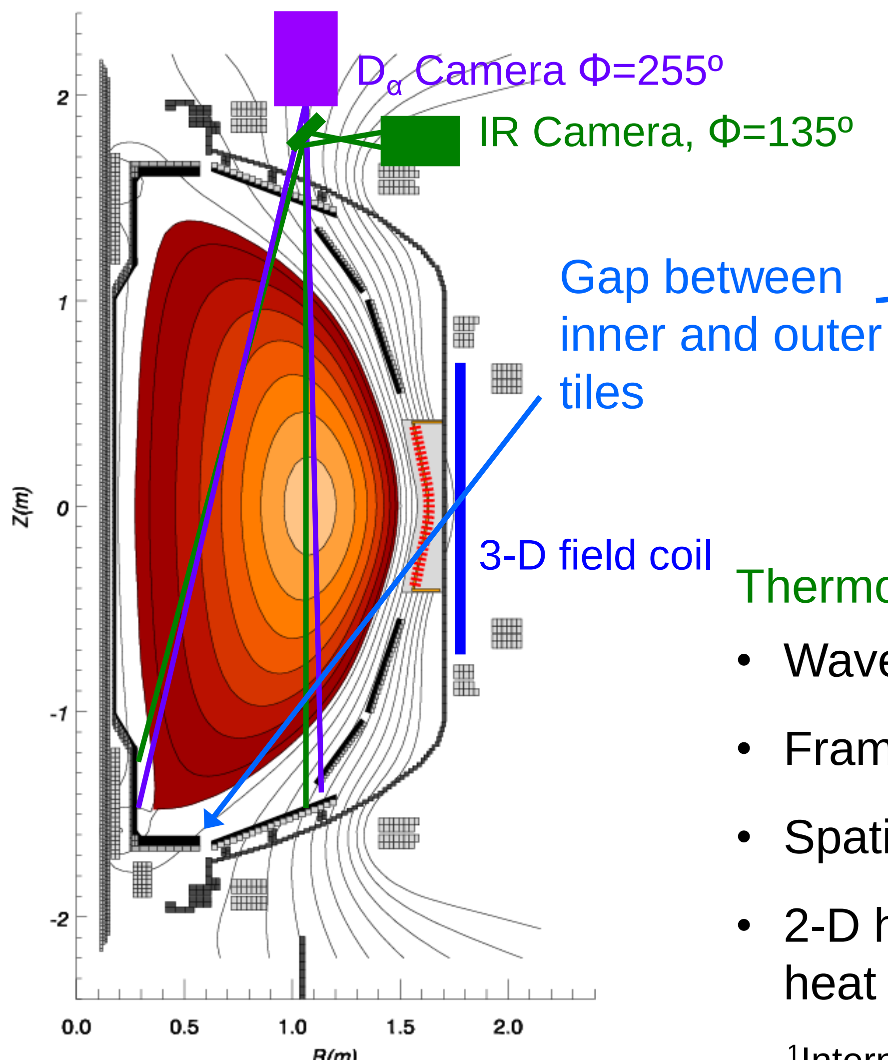
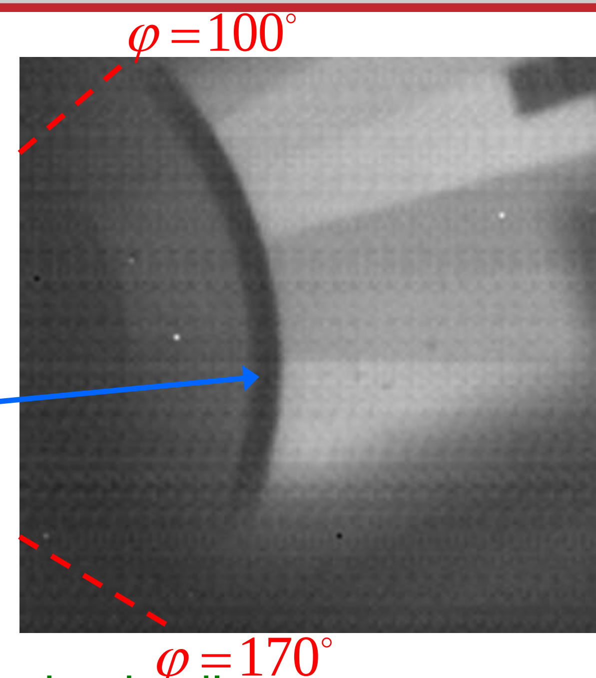
Motivation and outline

- Small external magnetic perturbations used for ELM control
  - ELM suppression (DIII-D) and mitigation (JET)
  - ELM triggering (NSTX, MAST)
- The 3-D nature of RMP application can cause toroidally asymmetric heat and particle deposition
- Understanding of heat and particle transport in the presence of 3-D fields, both externally applied and/or internally arisen, is important for divertor performance projections
- The proposed use of 3-D field triggered ELMs in a controlled manner requires detailed understanding of heat and particle deposition pattern during the ELMs

Divertor heat flux and D_α measurement in NSTX



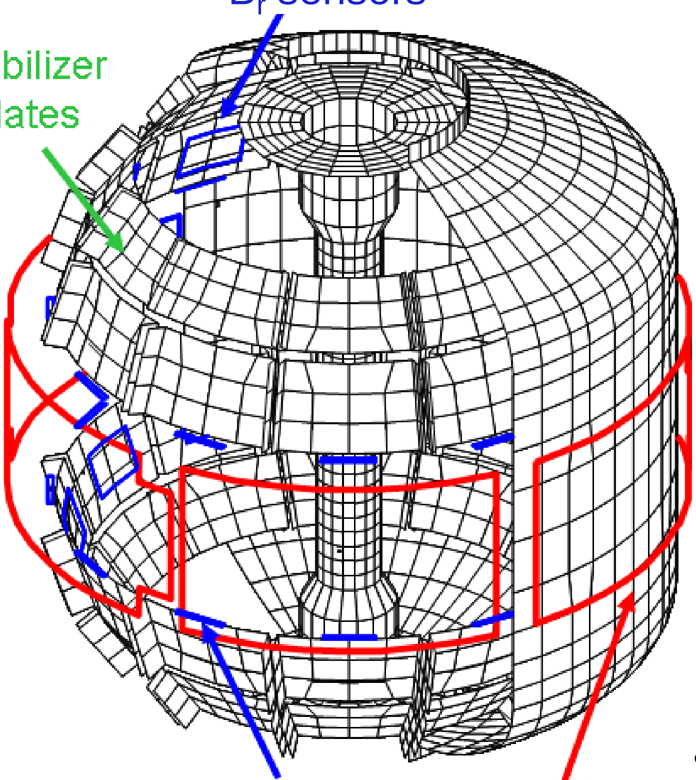


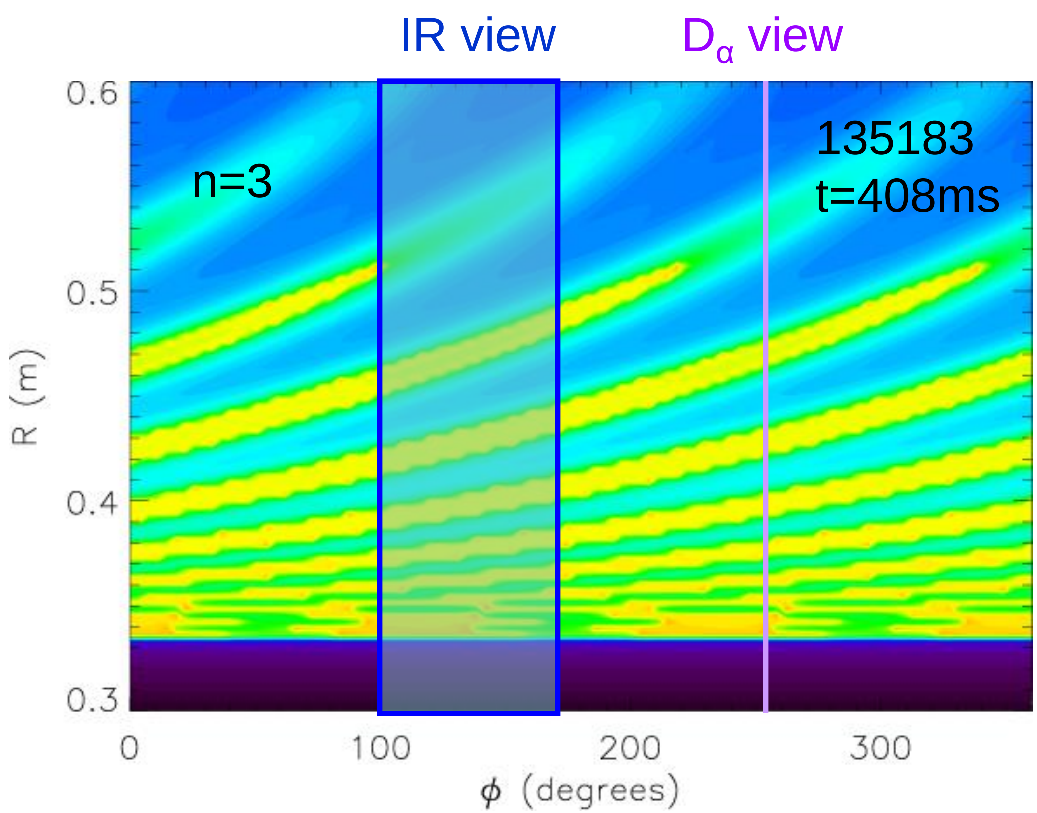
Thermography details: J-W. Ahn. RSI (2010), 023501

- Wavelength range: 8-10μm → 3-10μm
- Frame speed: 1.6 (128x128) – 6.3 (96x32) kHz
- Spatial resolution : 5-7mm
- 2-D heat conduction model (THEODOR)[1] for heat flux calculation $q(t) = -k\nabla T$

[1]International collaboration with IPP Garching, A. Hermann

Strike point splitting is predicted by 3-D field application

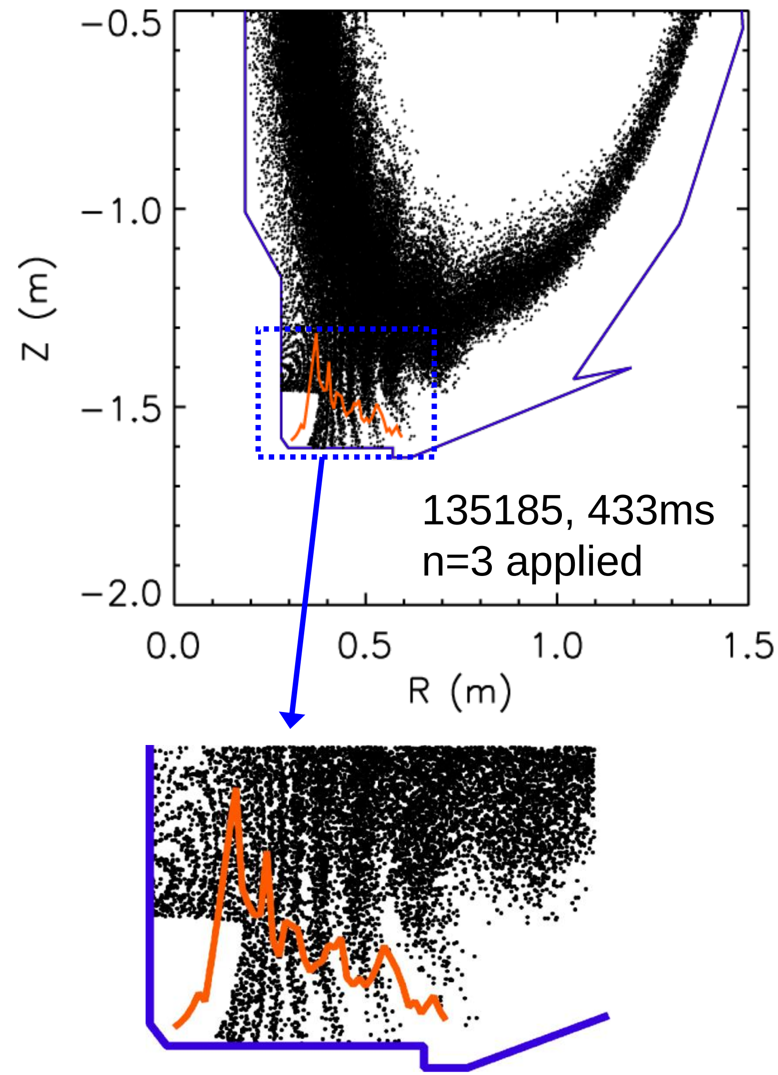




J-W. Ahn, Nucl. Fusion (2010), 045010

- 3-D fields (n=1, 2, 3) can be applied externally
- Connection length for field lines at divertor target, computed by vacuum field line tracing (J.M. Canik)
- Field line tracing uses superposition of vacuum n=3 fields and 2-D equilibrium fields

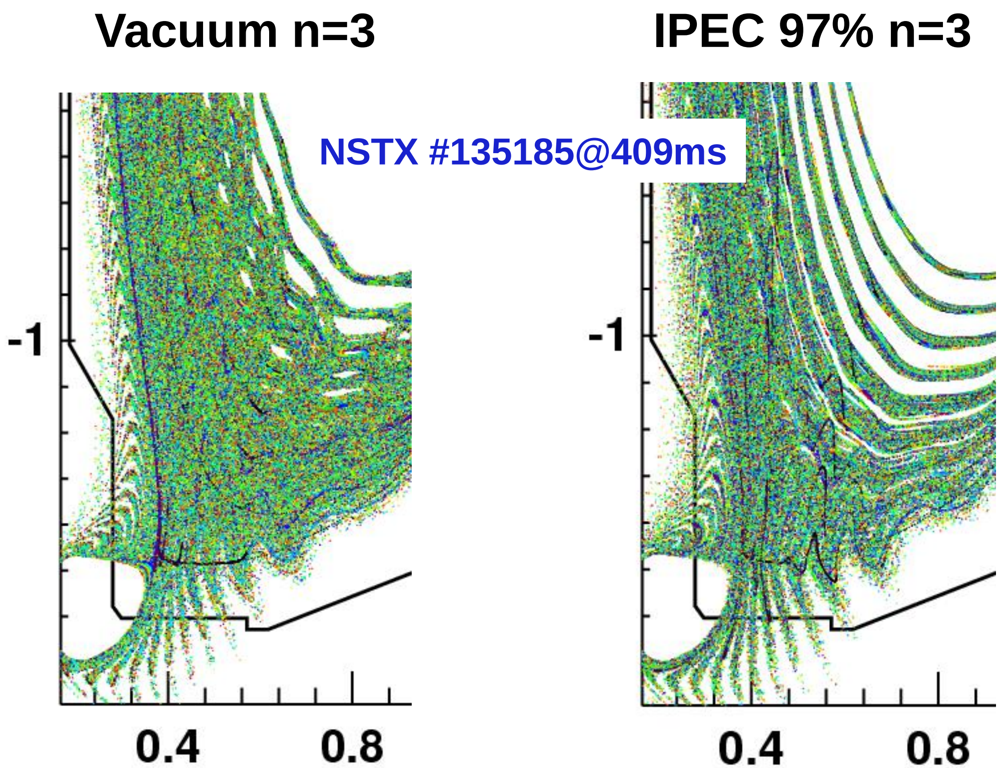
Distribution of lobe locations agrees well between measurement and vacuum field line tracing



- Measured heat flux profile (red) overlaid with vacuum field line tracing plot
- Dense regions in the puncture plot correspond to long connection length lobes, therefore expected to have higher heat and particle fluxes

J-W. Ahn, Nucl. Fusion (2010), 045010

Plasma response inside separatrix appears unimportant for the formation of lobe structure

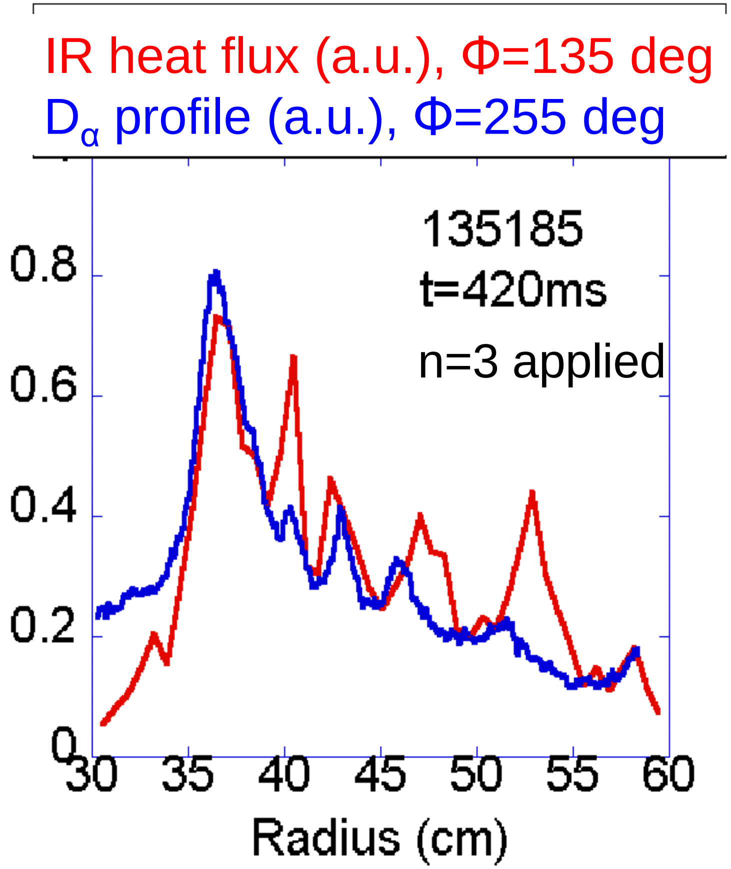


- Plasma response computed by Ideal Perturbed Equilibrium Code (IPEC)[1], an ideal MHD code capable of solving 3-D equilibrium with free boundary

- Radial location and spacing of generated lobes are little affected by the plasma response inside the separatrix

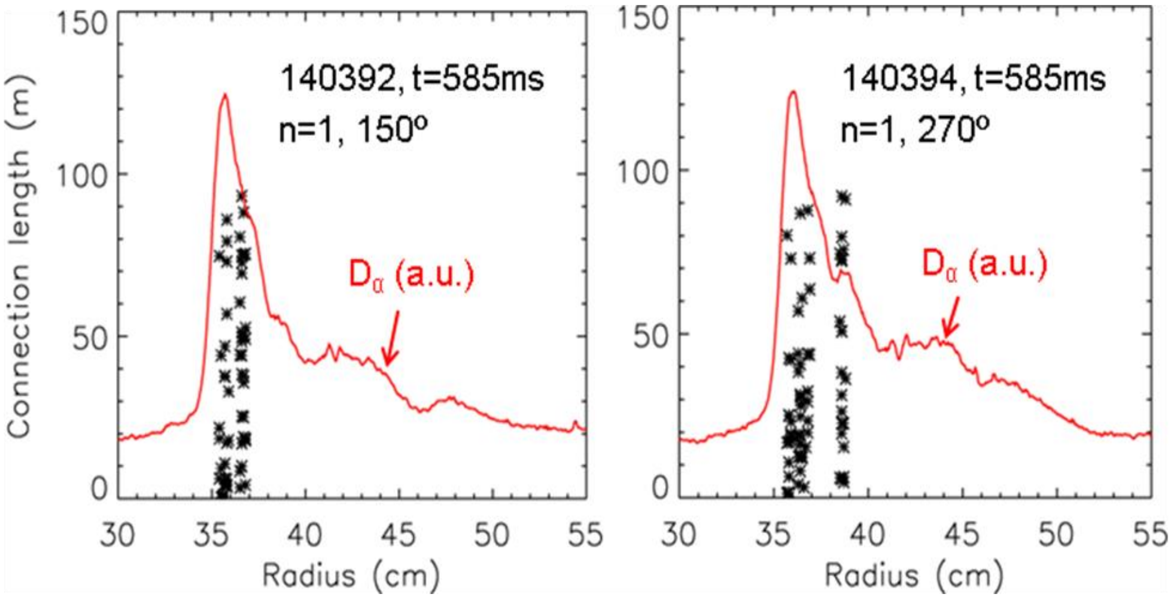
[1] J.-K. Park, Phys. Plasmas (2007), 052110

Strike point splitting consistent with n=3 periodicity for n=3 applied fields



- The profile modification is expected to have n=3 periodicity (120º) due to the imposed n=3 field structure
- Locations of local peaks and valleys in the heat flux (IR camera at 135º) and D_α (at 255º) profiles are similar

Non-axisymmetric divertor deposition has been confirmed for n=1 perturbation

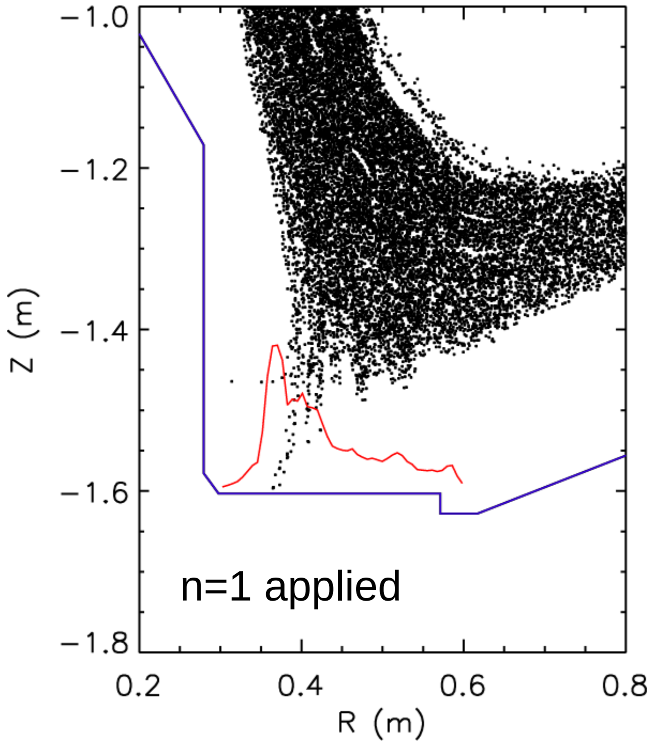


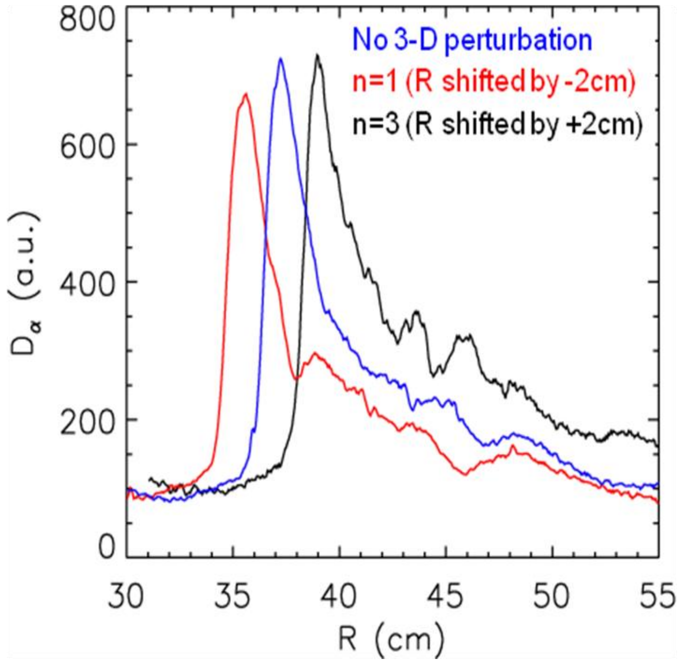
- Application of n=1 field is expected to produce different divertor profile patterns at different toroidal angles

  → Static rotation of applied n=1 field

- Field line tracing and measured D_α profile at different toroidal angle of 150º and 270º agrees with each other

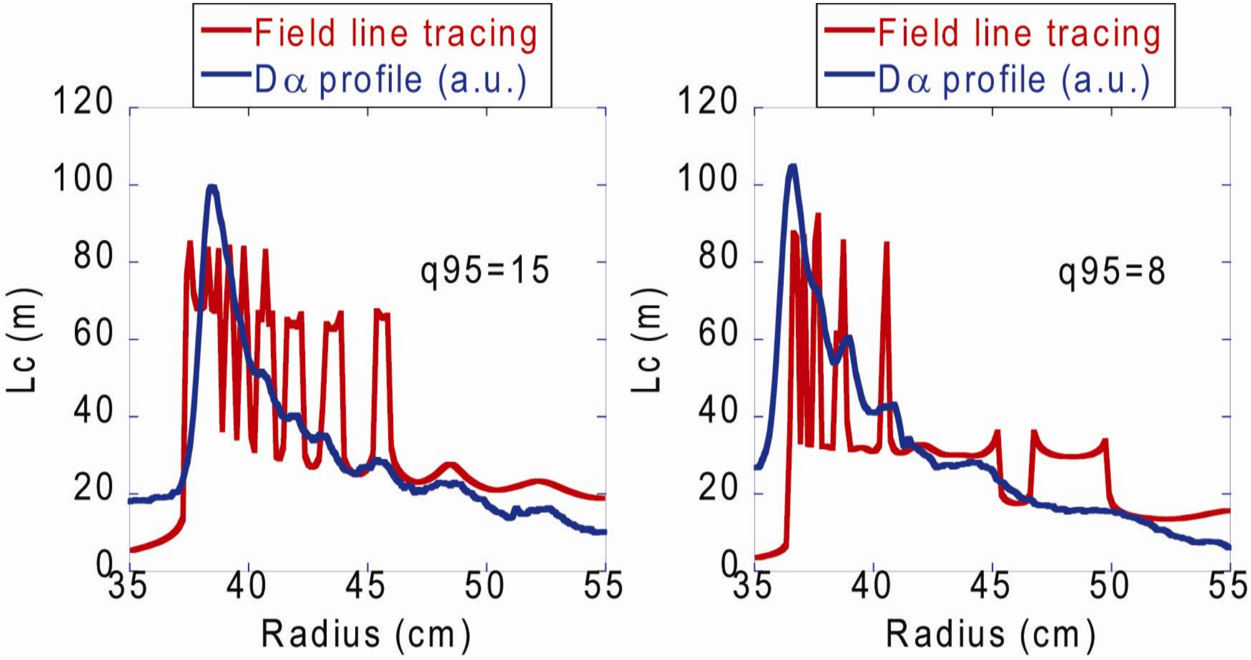
Modification of divertor profiles by both n=1 and n=3 perturbation fields has been singled out





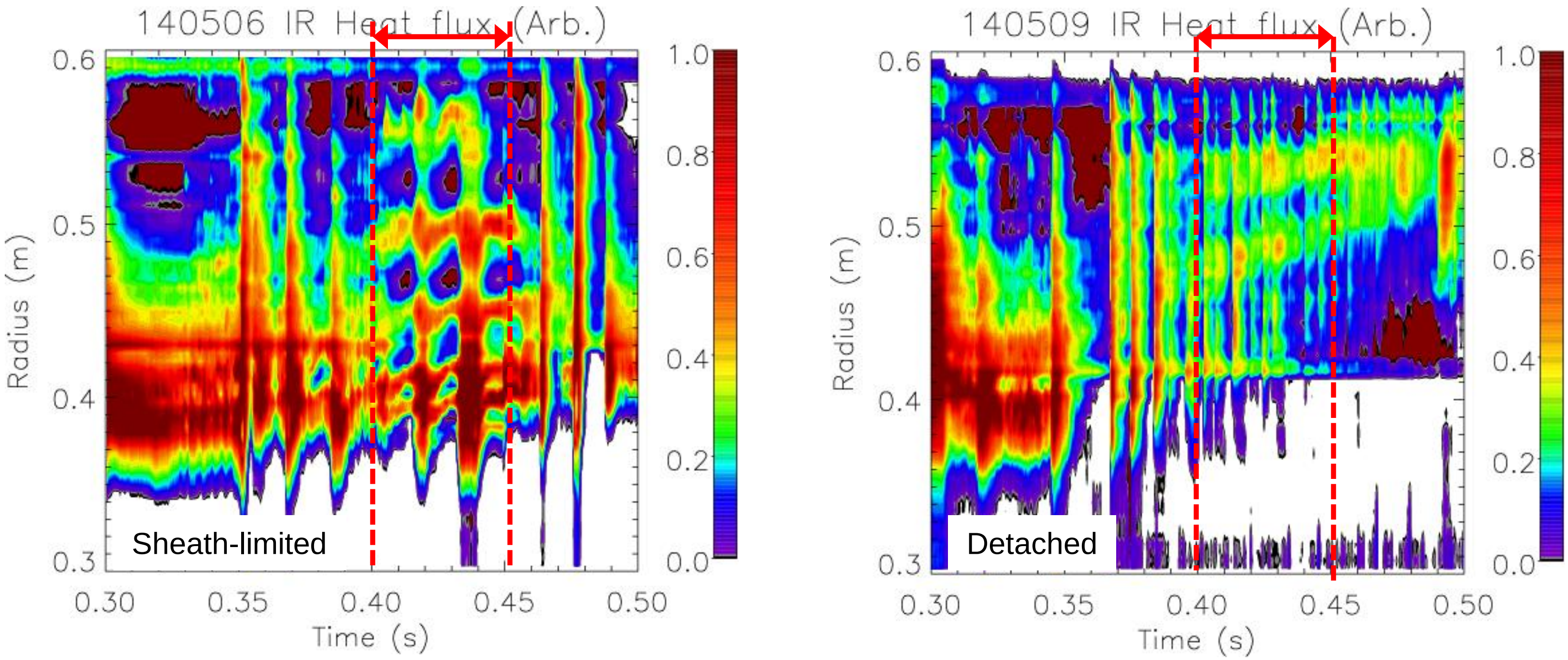
- Striation pattern is different between n=1 and n=3 cases. n=3 perturbation produces more striations than n=3
- Both heat flux and D_α profiles show good agreement with the vacuum field line tracing for n=1 and n=3

High q95 produces finer striations, reflecting more lobes generated by magnetic perturbation



- Connection length profile from the vacuum field line tracing anticipates finer and more lobe structure for higher q95 for a given radial profile
- Measured heat flux and D_{α} profiles agree with the modeling

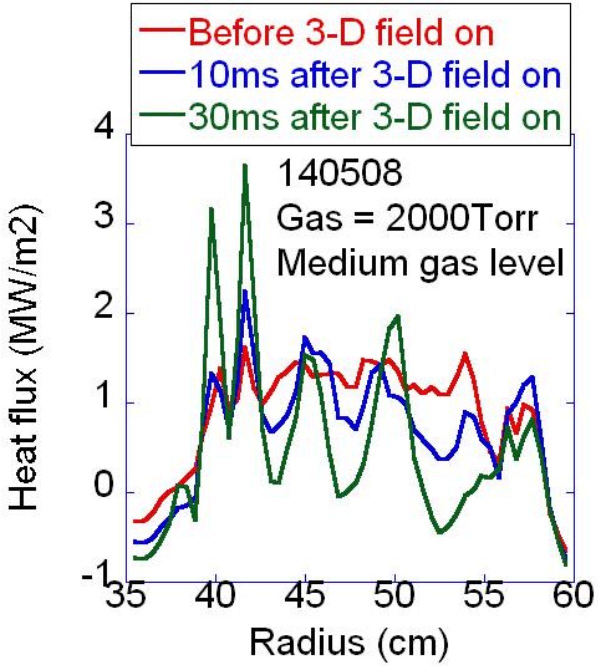
Applied 3-D field to different divertor plasma regime

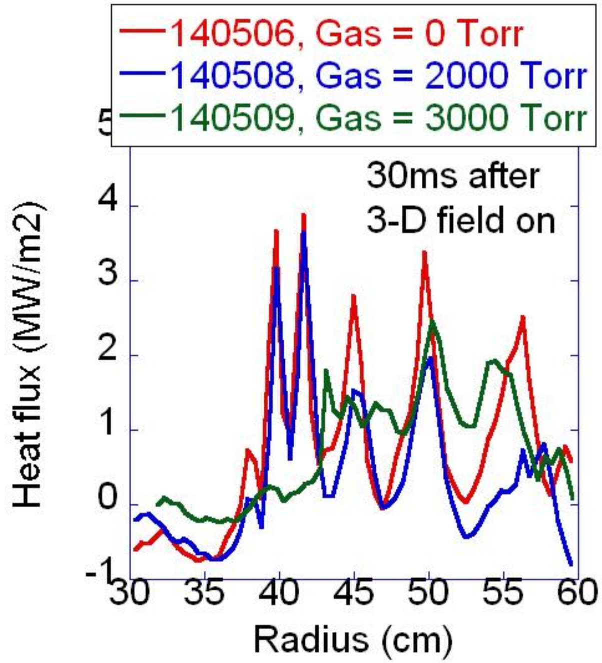


- In low divertor plasma collisionlity, ELMs are bigger and 3-D field application produces higher local peak values in the far SOL, keeping the peaked heat flux profile at the separatrix strike point location

- In high divertor plasma collisionlity, ELMs become smaller and the heat flux stays mitigated with no peaked profile at the separatrix strike point location. With 3-D field applied, more heat flux is deposited through the split strike points in the far SOL, with the whole profile much less peaked.

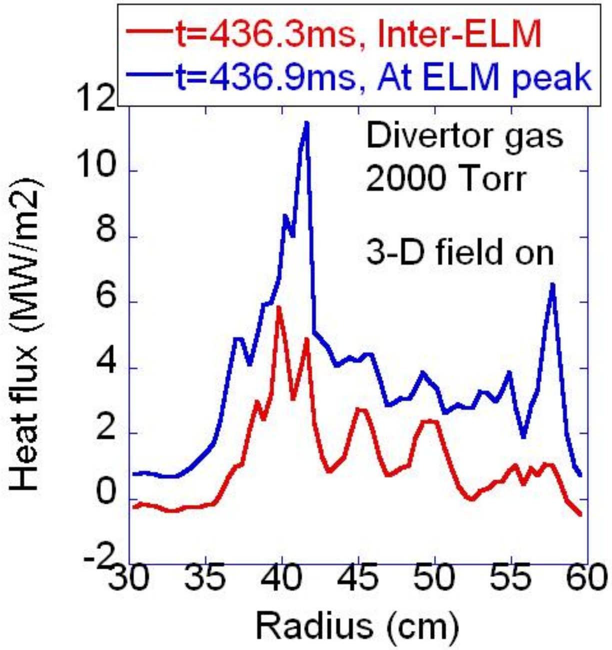
Effect of 3-D fields on inter-ELM heat flux profile in high divertor plasma collisionality

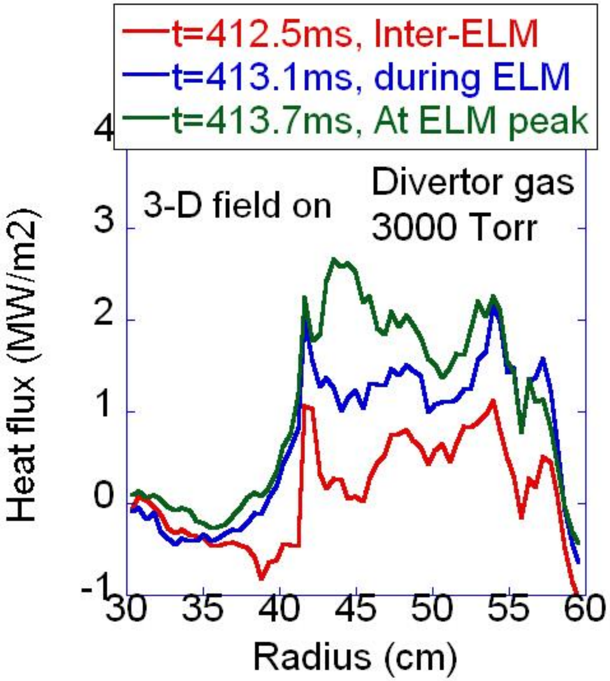




- Applied 3-D fields appear to make the divertor plasma re-attached in medium divertor gas level, leading to a peaked heat flux profile again
- If the divertor gas puffing is high enough, plasma stays in the detached regime even with 3-D field applied

Effect of 3-D fields on ELM heat flux profile in high divertor collisionality

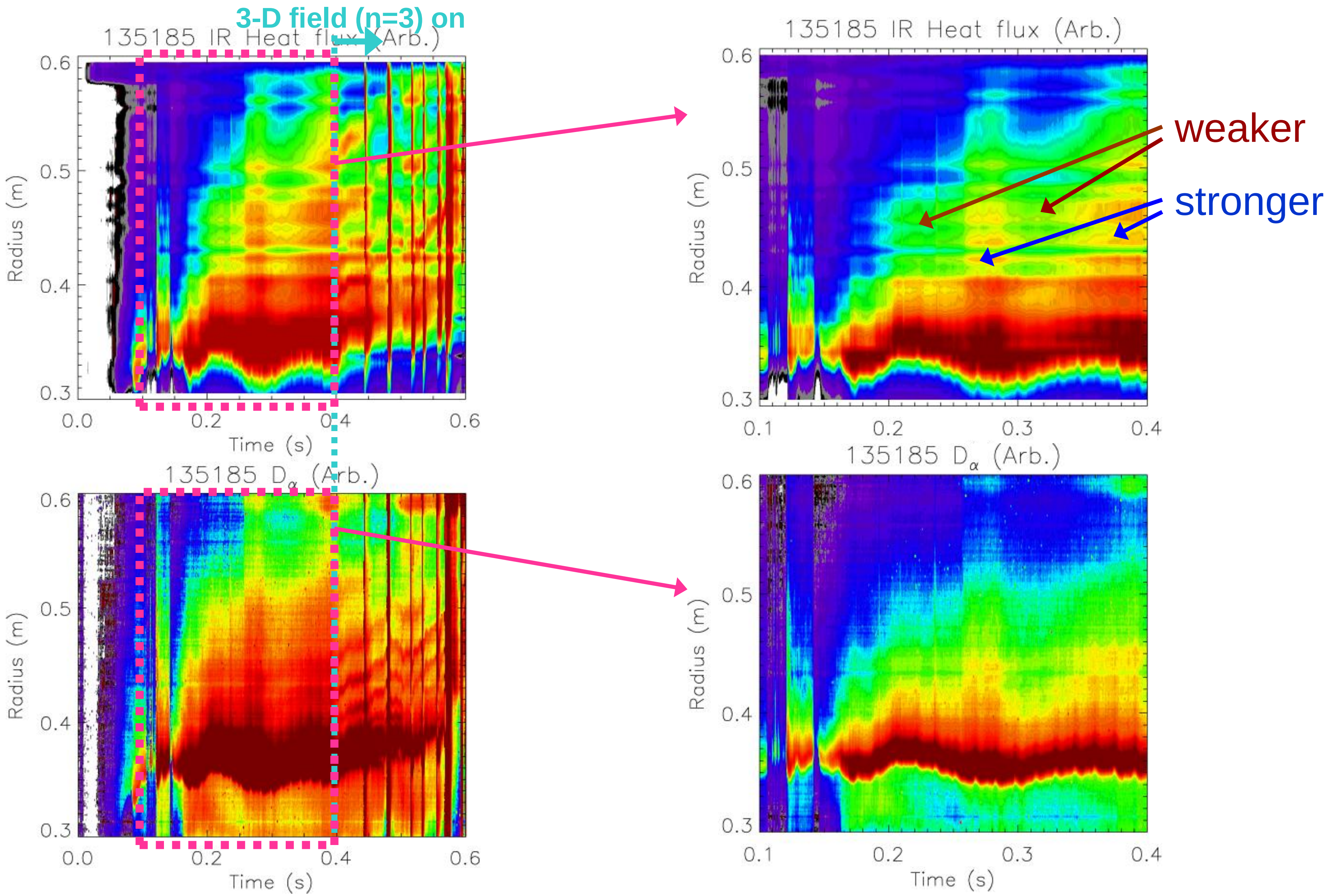




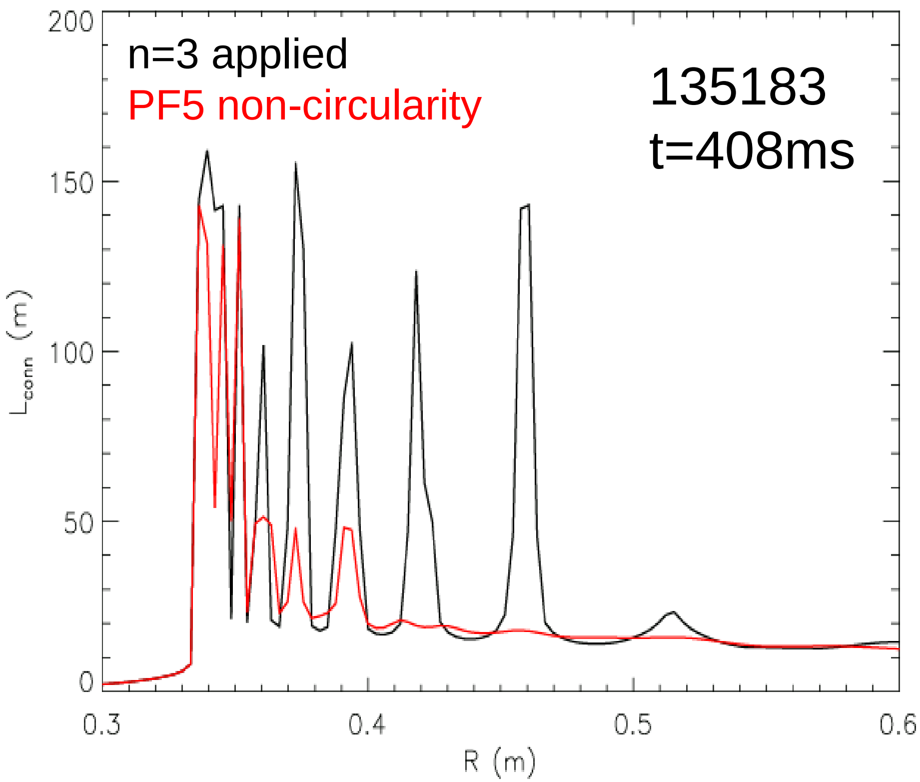
- Both the inter-ELM and ELM heat flux profiles show peaked deposition at the separatrix strike point in medium collisionality

- More highly detached divertor plasma produces significantly lower and flat heat flux profiles and makes the ELM size smaller, 3-D field produces striations in the far SOL

Intrinsic strike point splitting observed before 3-D field application with varying degree in time



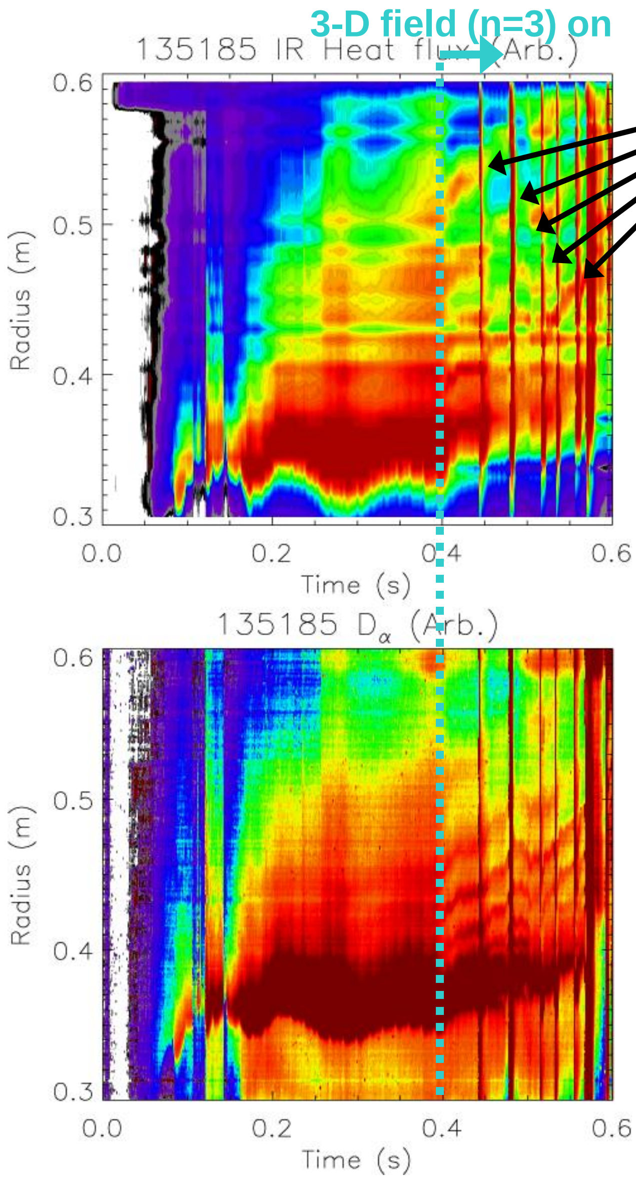
Intrinsic error field may be one of the sources for intrinsic strike point splitting

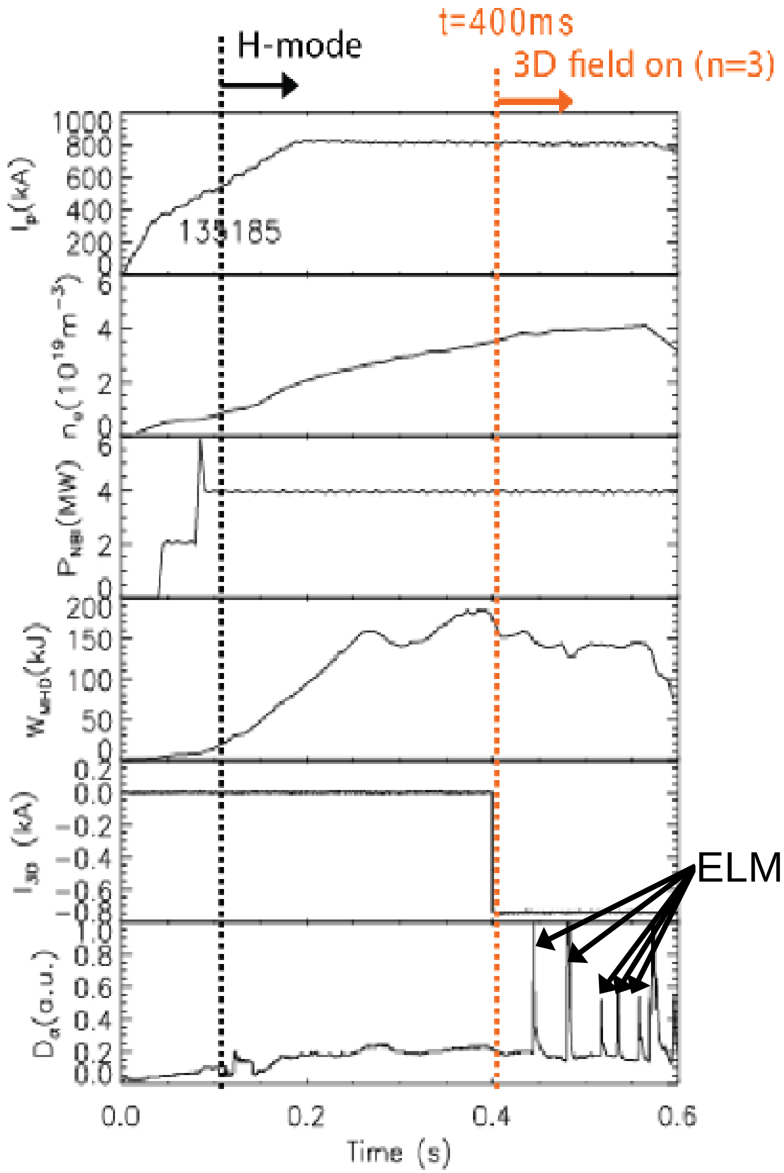


- Vacuum field line tracing modeling for intrinsic error fields from the non-circularity of PF5, n=3 component is known to be dominant component[1]
- Radial location of local peaks agree between PF5 and n=3 application cases, consistent with experimental observations in NSTX

[1]J.E. Menard, Nucl. Fusion (2010), 045008

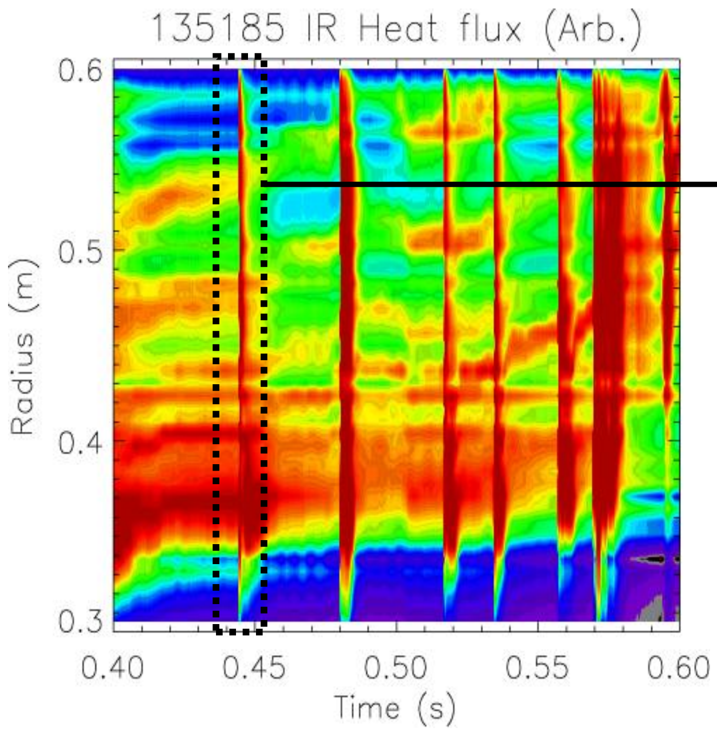
Imposed n=3 fields cause strike point splitting and trigger ELMs

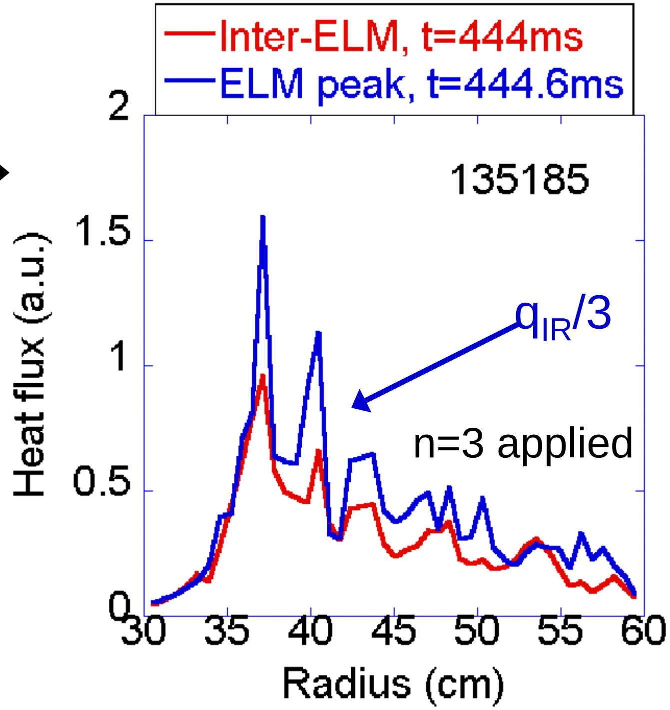




[1]J.M. Canik, PRL (2010), 045001

Heat flux profile from ELMs triggered by n=3 fields appears to follow imposed field structure





- Striations in the heat flux profile appear in the same locations as was before the ELM
- 3-D field triggered ELMs appear to be phase-locked to the externally applied perturbation structure

Summary and conclusion

- Measured heat and particle flux profiles show striations at the divertor target with the effect of both,
  - Intrinsic 3-D fields, intrinsic error fields may be one of the sources
  - Imposed 3-D fields by external coils
- The expected toroidal heat and particle deposition pattern for imposed 3-D fields (n=1 and n=3) was confirmed experimentally
- Inclusion of plasma response does not affect the structure of split strike point significantly
- 3-D field triggered ELM heat flux appears to largely follow split strike point channels
- High q95 produces more striations and agrees with the modeling
- We need sufficiently high divertor plasma collisionality to avoid the re-occurrence of peaked heat flux profiles with 3-D field application