NSTX

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

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and the NSTX Research Team

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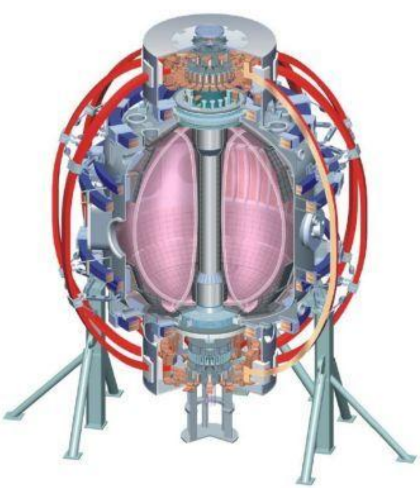

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Motivation

- Small external magnetic perturbations used for ELM control
  - ELM suppression (DIII-D) and mitigation (JET)
  - ELM triggering (NSTX, MAST)

- 3-D magnetic perturbations can cause toroidally asymmetric heat and particle deposition

- The formation of 3-D magnetic field structures, and the transport of heat and particles through those structures are poorly understood

Understanding the 3-D field effects on the divertor profile is crucial for future machines, where such 3-D fields are probably unavoidable and likely to be imposed intentionally

Outline

- Background and diagnostics

- 3-D fields cause divertor profile splitting, largely consistent with vacuum field line tracing
    - Intrinsic 3-D fields
    - Applied 3-D fields
    - Toroidal periodicity of profiles (n=3)
    - q95 dependence
- Ideal plasma response does not change calculated splitting patterns substantially
- ELM heat flux follows imposed 3-D field patterns
- Effects of 3-D fields on divertor detachment

- Summary and conclusion

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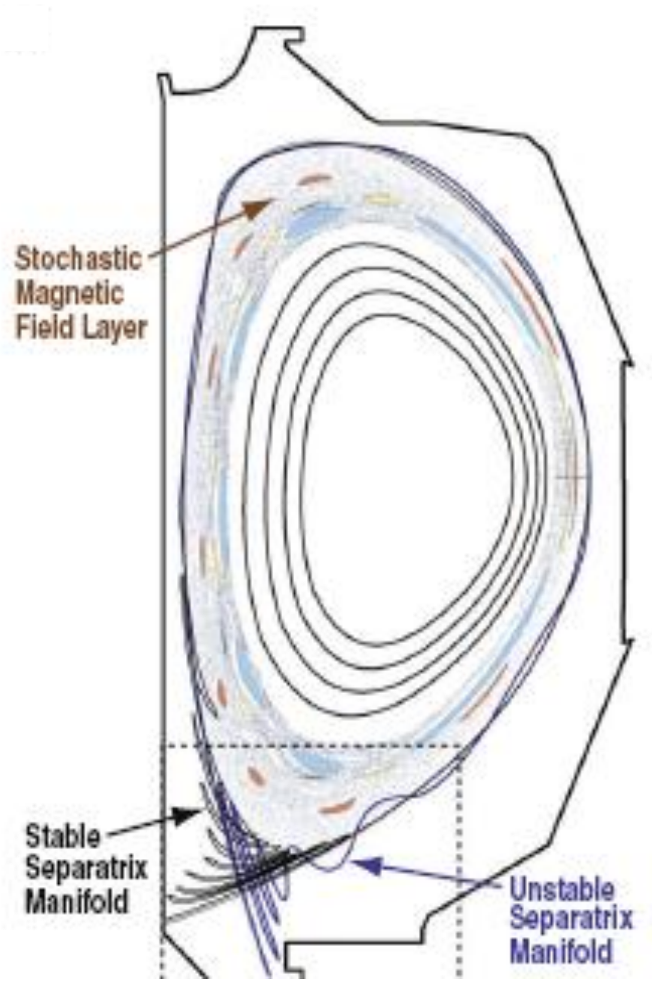
How do non-axisymmetric magnetic perturbations modify divertor heat and particle flux profiles?



- Interaction of non-axisymmetric magnetic perturbation with 2-D equilibrium field → 3-D topology of perturbed field lines in the edge[1]
- Stochastic plasma boundary and enhanced radial transport due to high diffusivity of magnetic field lines
- Poloidal magnetic flux is organized by complex topological structures known as homoclinic tangles

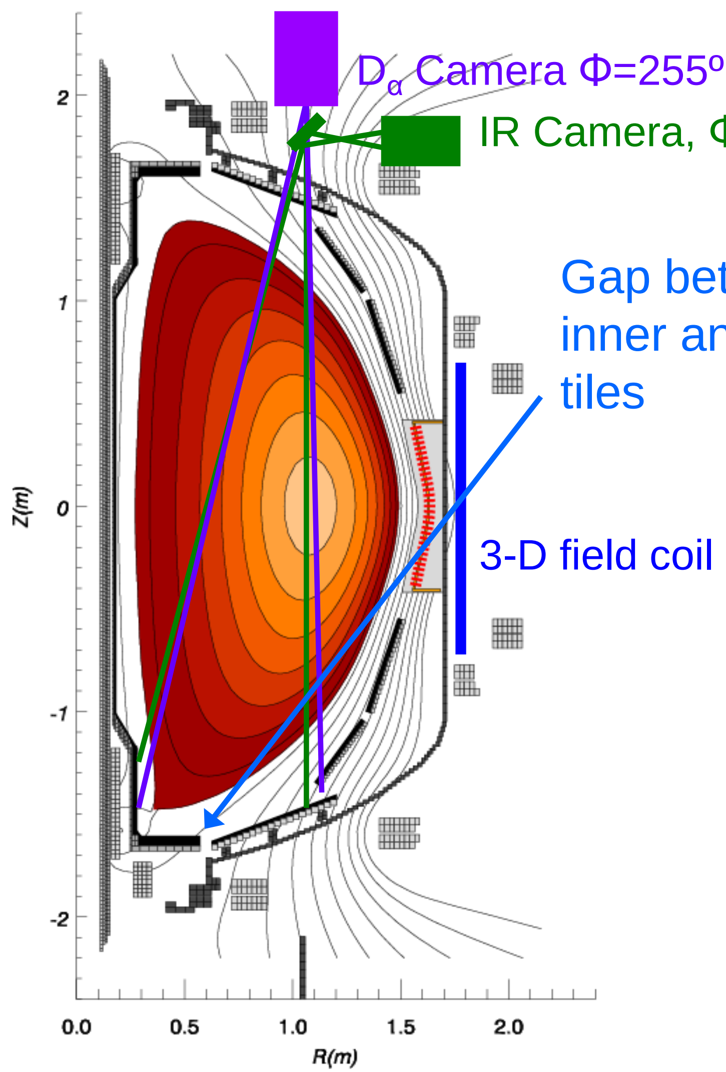
  → Strike point splitting

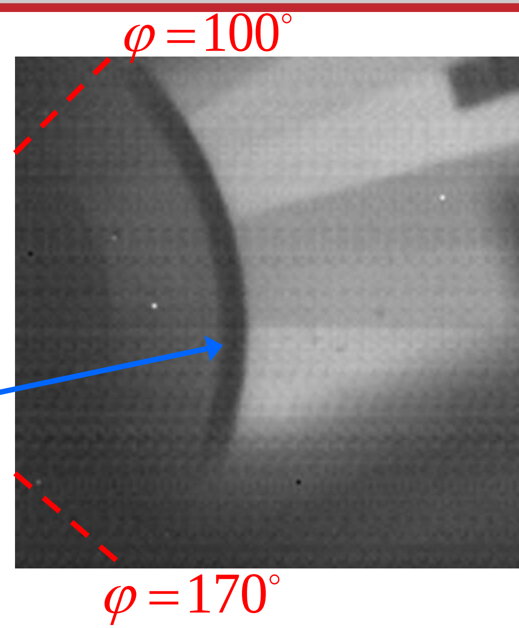
  → Modification of divertor profiles

T.E. Evans, J. Nucl. Mater. 390-391 (2009), 789

[1]T.E. Evans, Contrib. Plasma Phys. 44 (2004), 235

Divertor heat flux and D_α measurement in NSTX



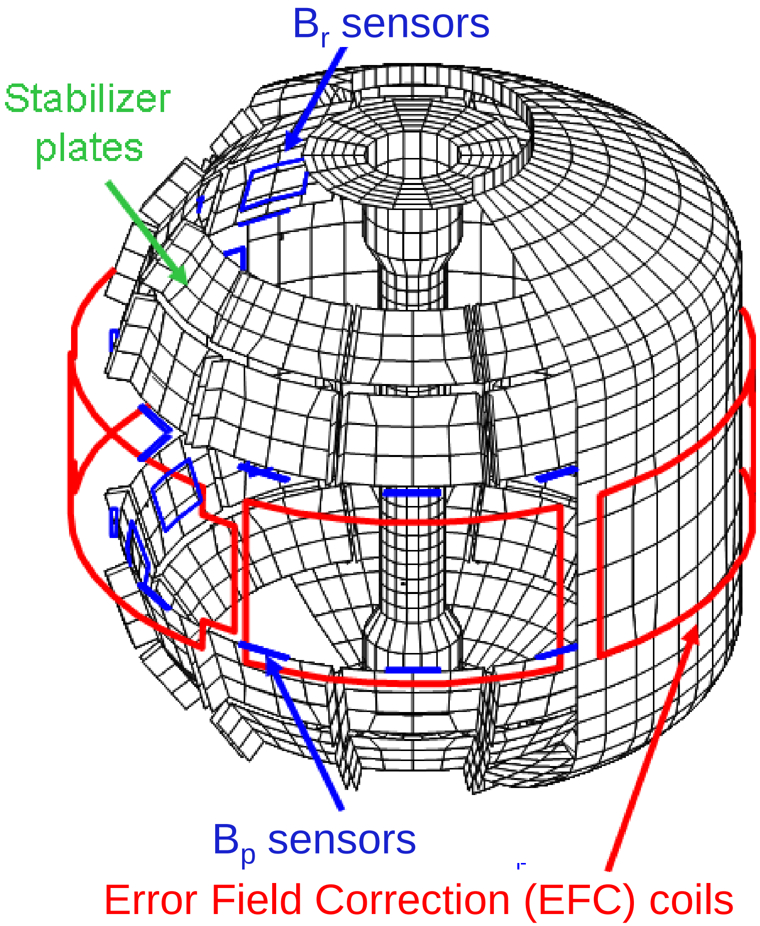


Thermography details: J-W. Ahn. RSI (2010), 023501

- Wavelength range: 8-10μm → 3-10μm
- Frame speed: 1.6 (128x128) – 6.3 (96x32) kHz
- Spatial resolution : 5-7mm
- 2-color IR data becoming available (A. McLean, RSI (2011))
- 2-D heat conduction model (THEODOR)[1] for heat flux calculation

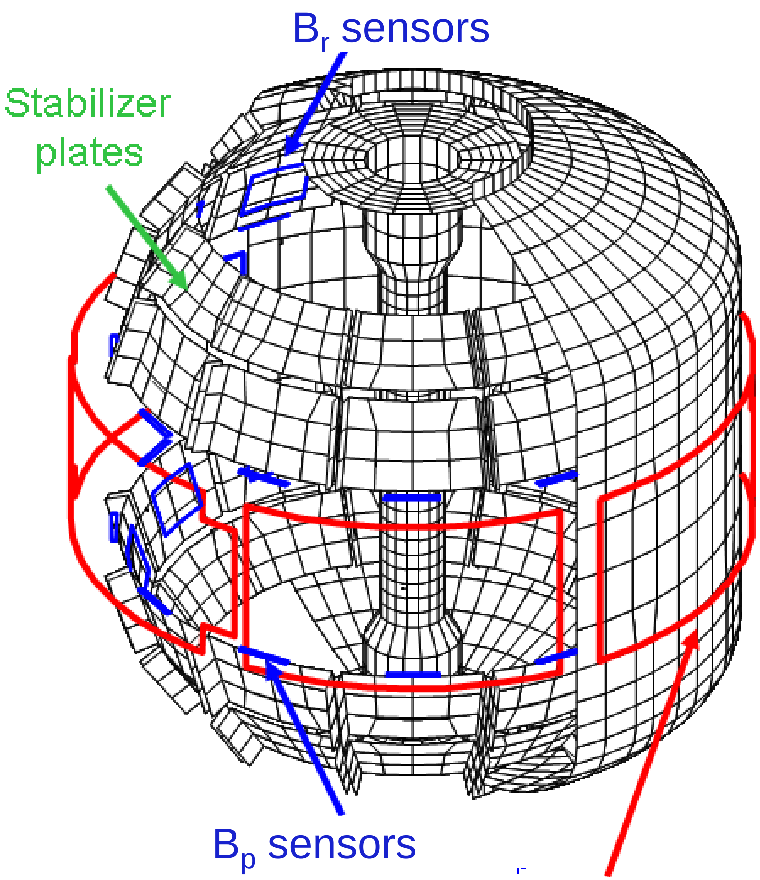
[1]Collaboration with IPP Garching, A. Herrmann

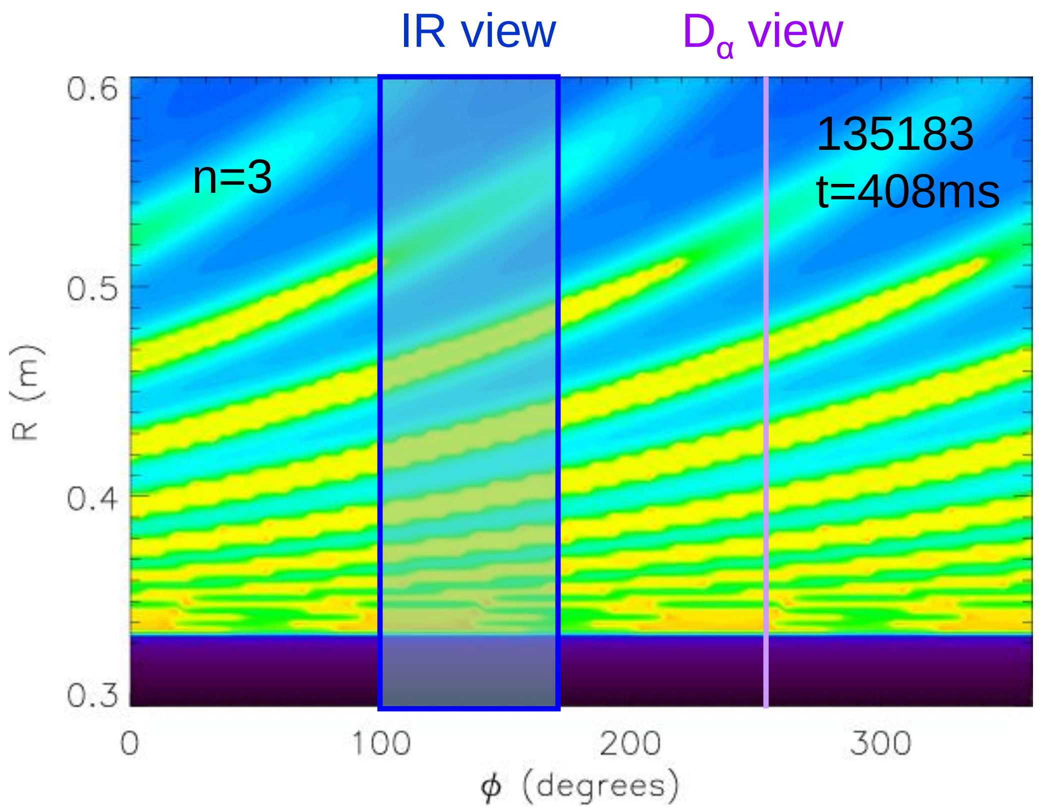
Strike point splitting is predicted by 3-D field application



- 3-D fields (n=1, 2, 3) applied by midplane EFC coils

Strike point splitting is predicted by 3-D field application





- 3-D fields (n=1, 2, 3) applied by midplane EFC coils

- Connection length for field lines at divertor target, computed by vacuum field line tracing
- Field line tracing uses superposition of vacuum n=3 fields and 2-D equilibrium fields

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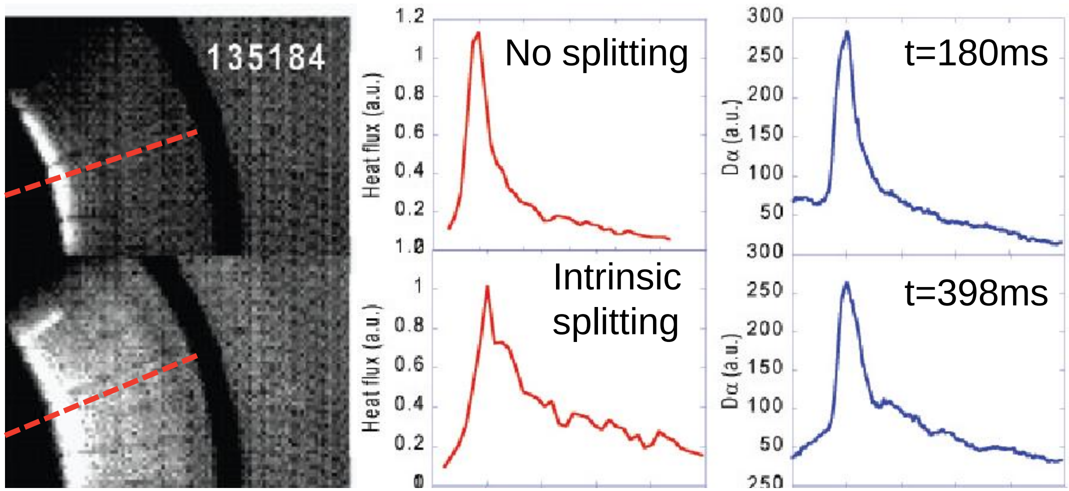
Divertor profile is modified by intrinsic and applied 3-D magnetic perturbations

Raw IR image **Heat flux profile** **D_{α} profile**

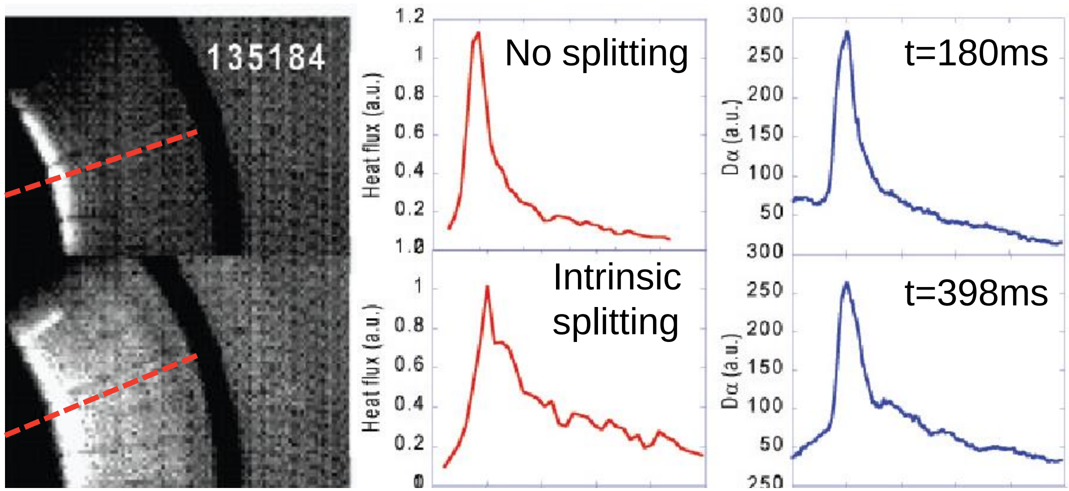


At earlier time slice

2ms before 3-D field application

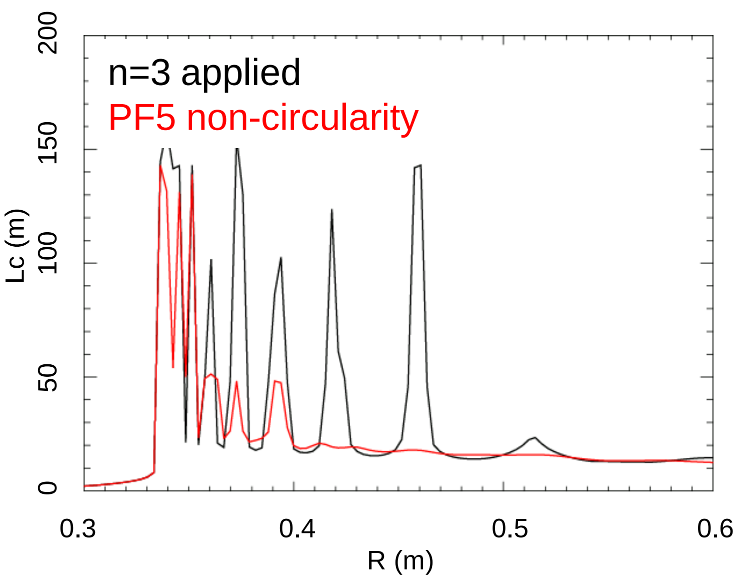
Divertor profile is modified by intrinsic and applied 3-D magnetic perturbations

Raw IR image **Heat flux profile** **D_α profile**



At earlier time slice

2ms before 3-D field application

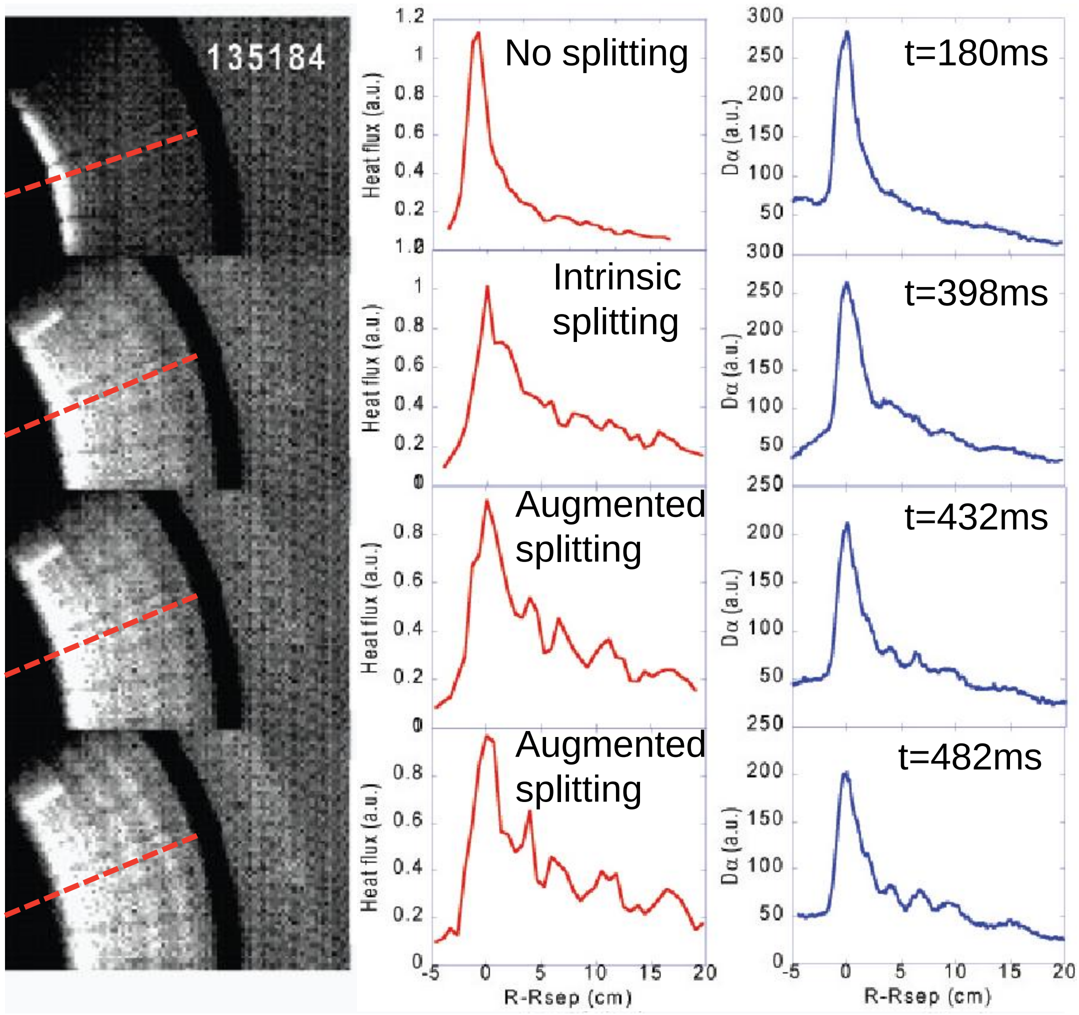


- Vacuum field line tracing modeling for intrinsic error fields from the non-circularity of PF5, n=3 component is known to be dominant component[1]
- Radial location of local peaks agree between PF5 and n=3 application cases

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

Divertor profile is modified by intrinsic and applied 3-D magnetic perturbations

Raw IR image | **Heat flux profile** | **D_α profile**



At earlier time slice

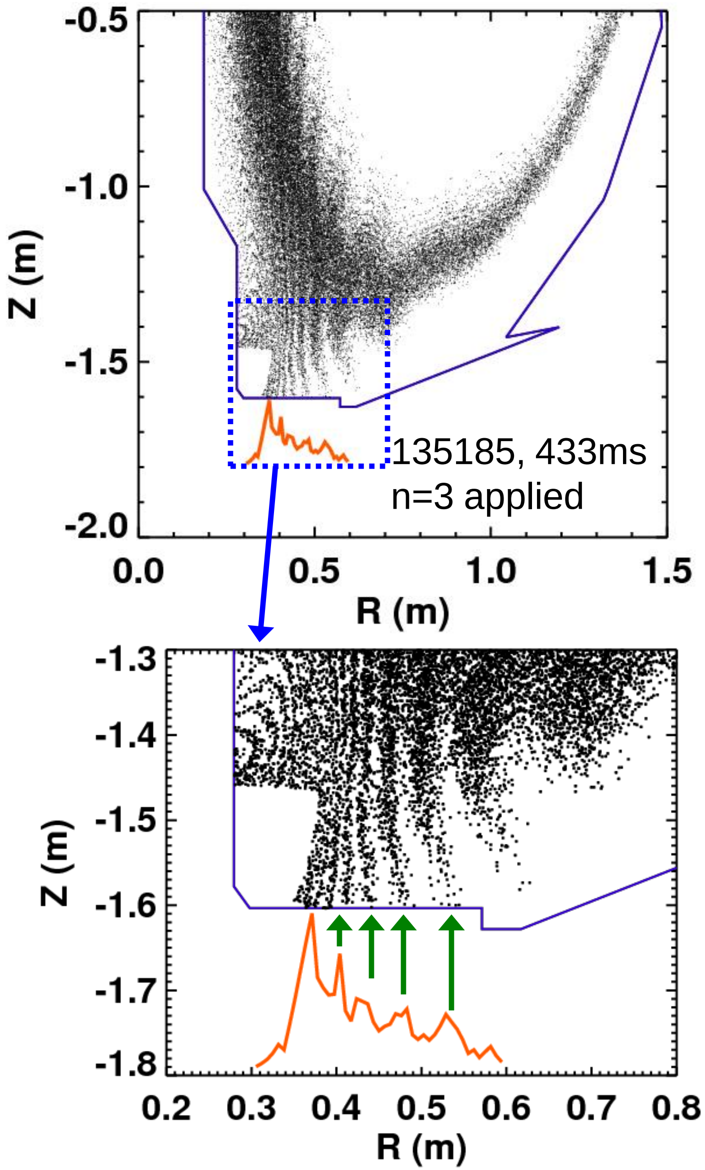
2ms before 3-D field application

32ms after 3-D field application

82ms after 3-D field application

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

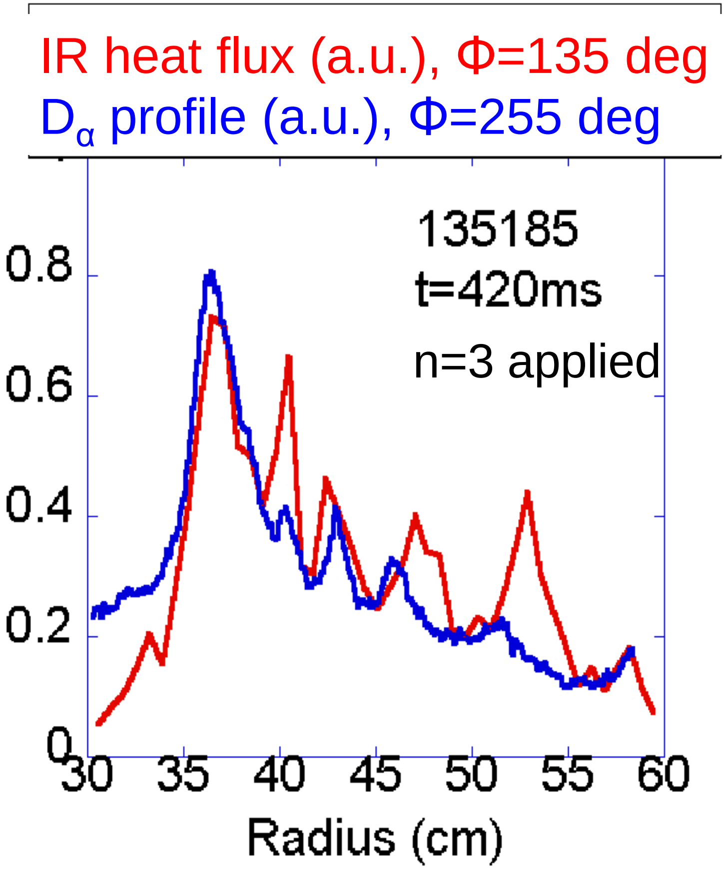
Distribution of splitting locations from measurement and vacuum field line tracing in good agreement



- Measured heat flux profile (orange) overlaid with vacuum field line tracing plot

- Dense regions in the puncture plot correspond to long connection length lobes from the pedestal region, therefore expected to have higher heat and particle fluxes

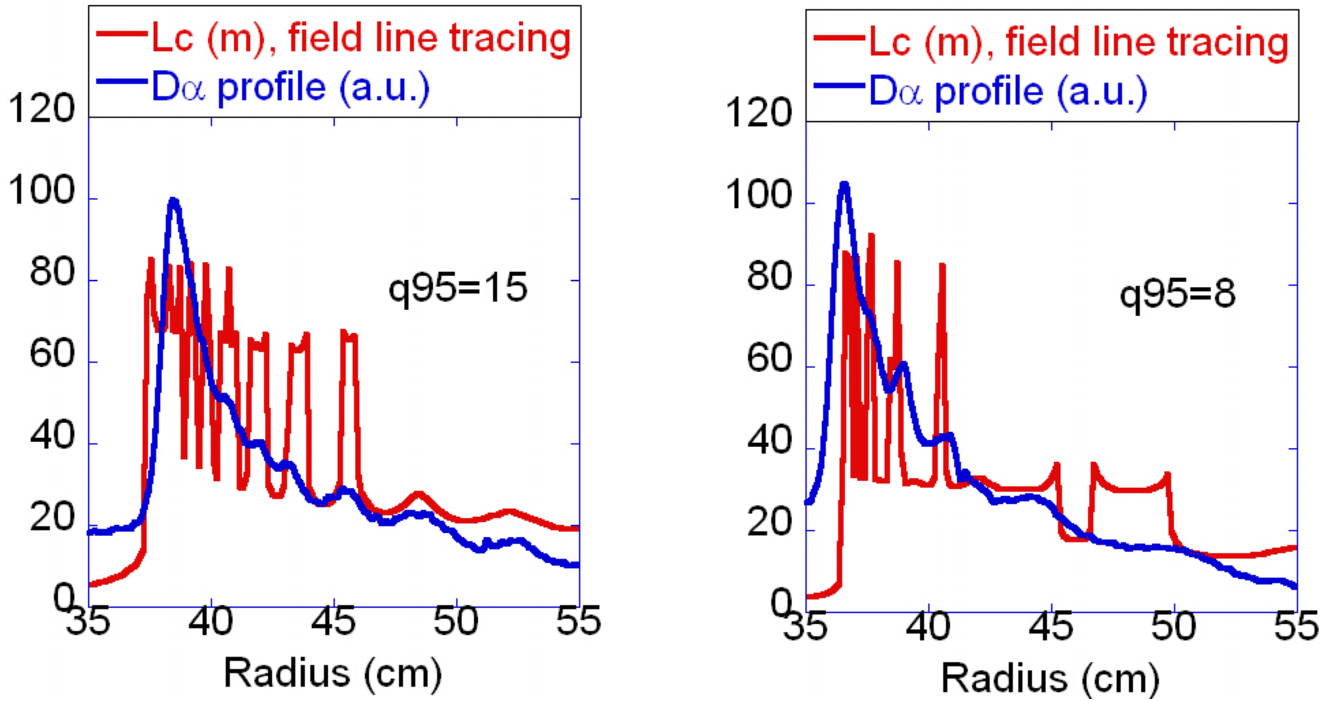
Strike point splitting is consistent with n=3 periodicity for n=3 applied fields



- The profile modification is expected to have n=3 periodicity (120º) due to the imposed n=3 field structure

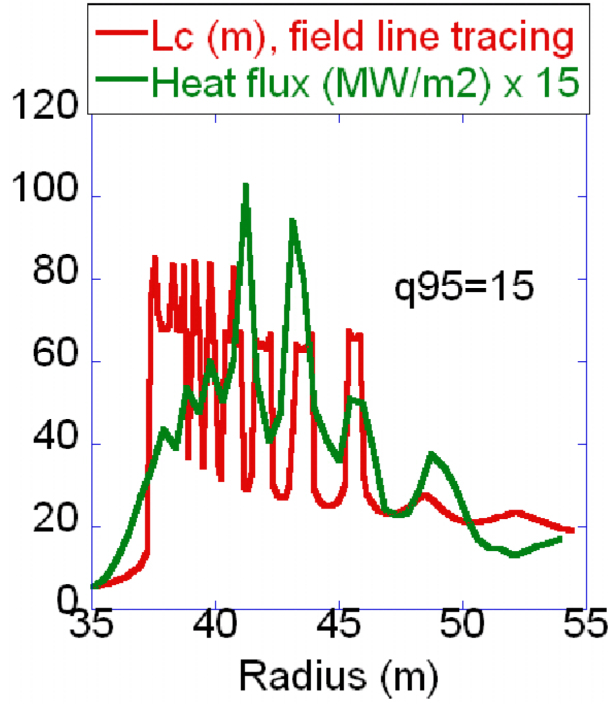
- Locations of local peaks and valleys in the heat flux (IR camera at 135º) and D_α (at 255º) profiles are similar

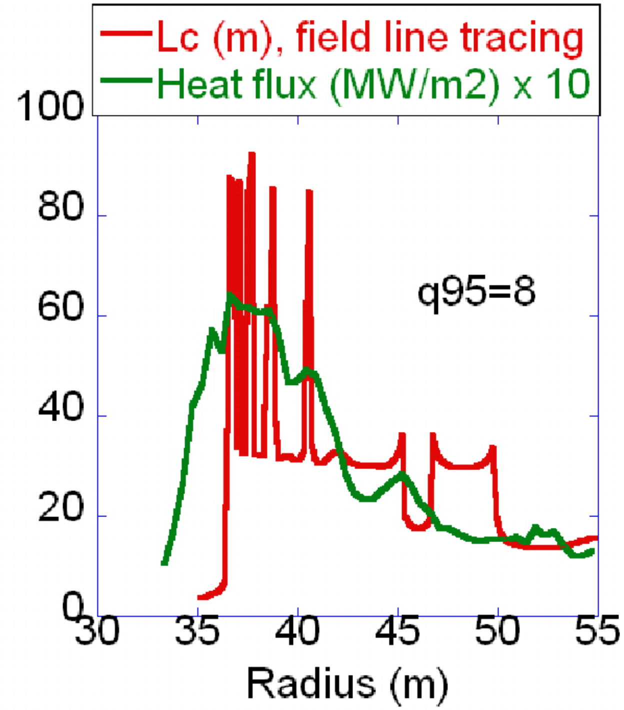
High q95 produces finer profile splittings



- Connection length profile from the vacuum field line tracing anticipates finer and more splittings for higher q95 for a given radial profile → Also confirmed in D_α and heat flux profiles

High q95 produces finer profile splittings





- Connection length profile from the vacuum field line tracing anticipates finer and more splittings for higher q95 for a given radial profile → Also confirmed in D_α and heat flux profiles
- Significantly higher fraction of heat flux through split profile channels in high q95

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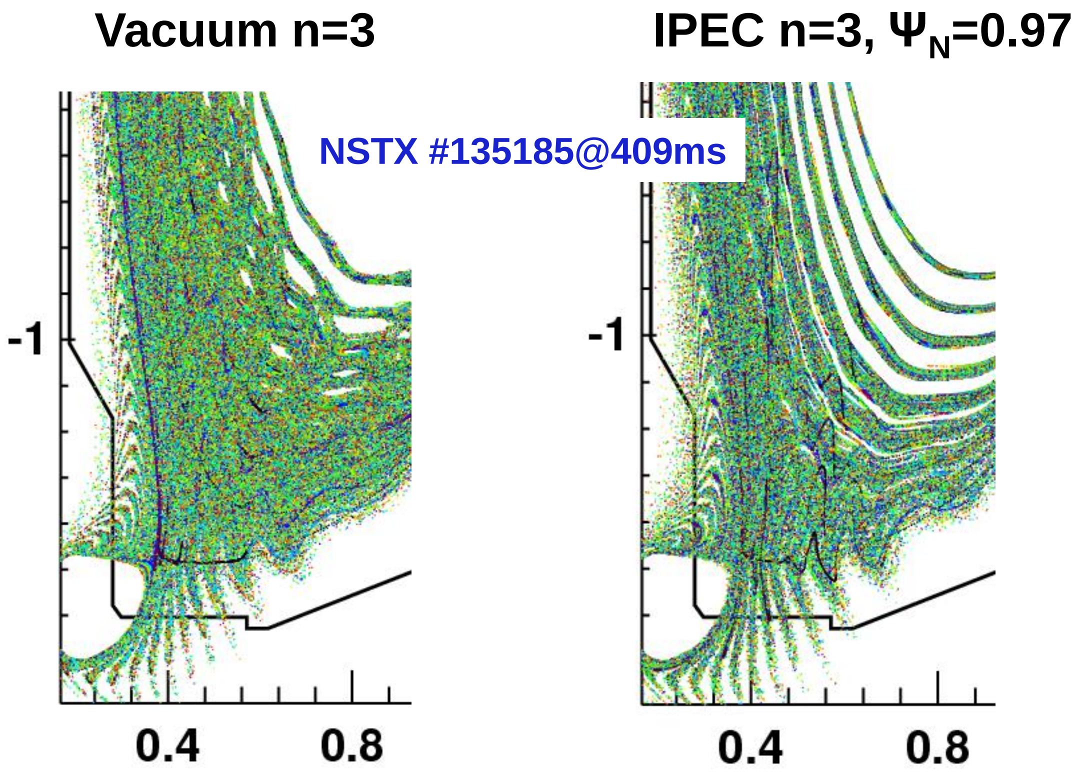
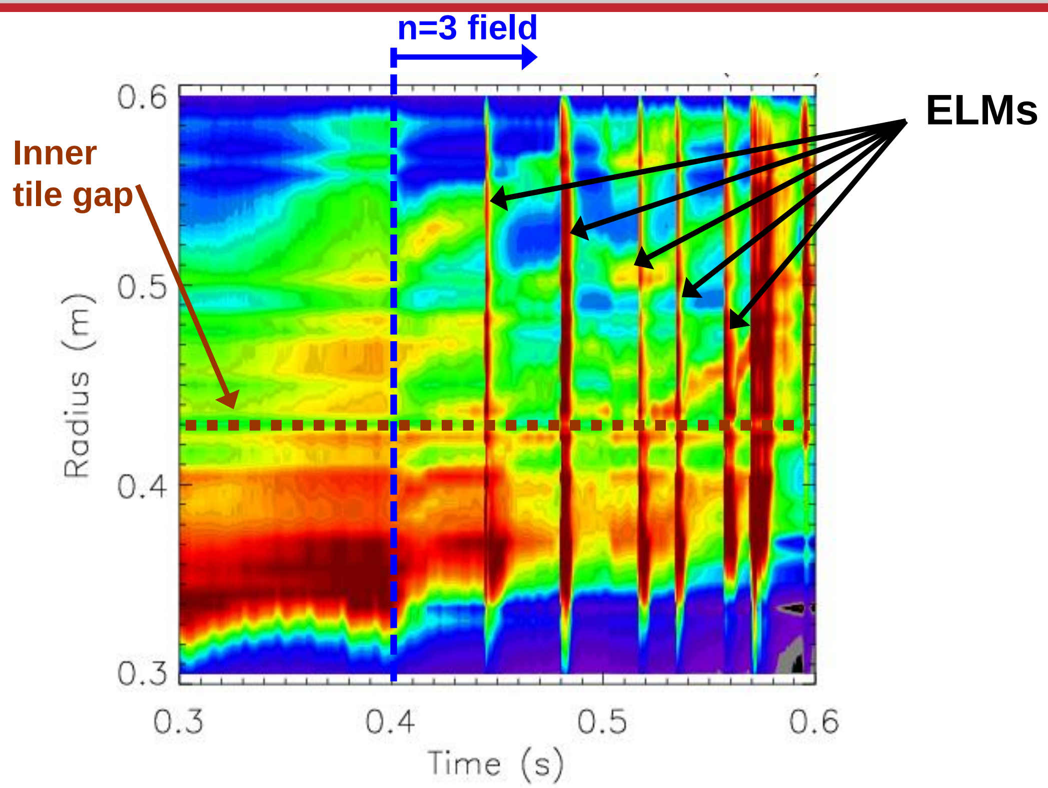
Radial location and spacing of profile splitting little affected by plasma response inside the separatrix



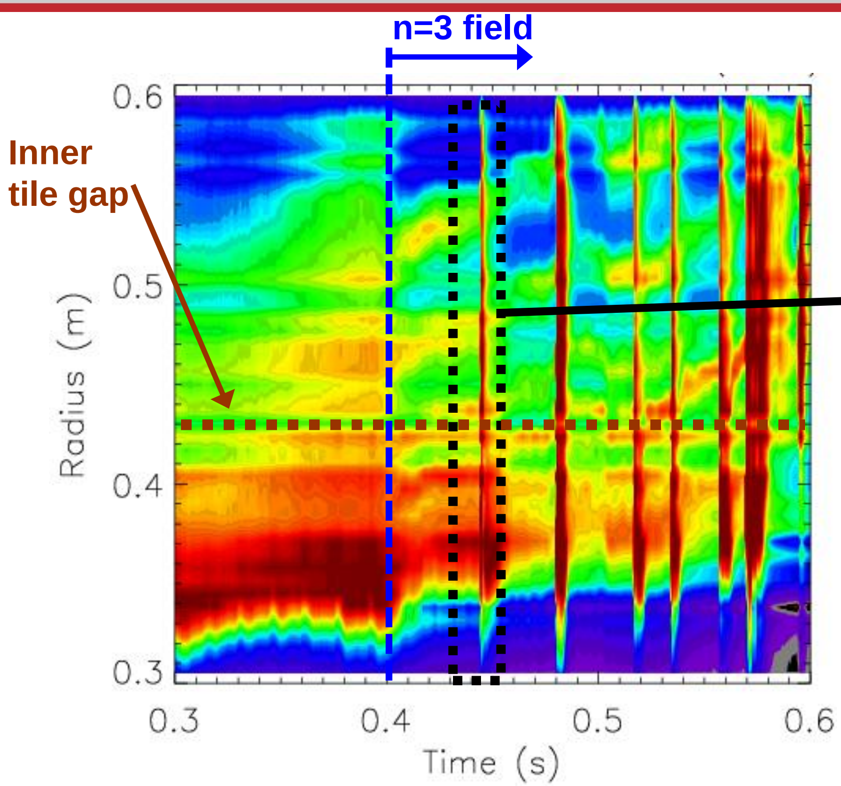
- Plasma response computed by Ideal Perturbed Equilibrium Code (IPEC)[1], an ideal MHD code capable of solving 3-D equilibrium with free boundary

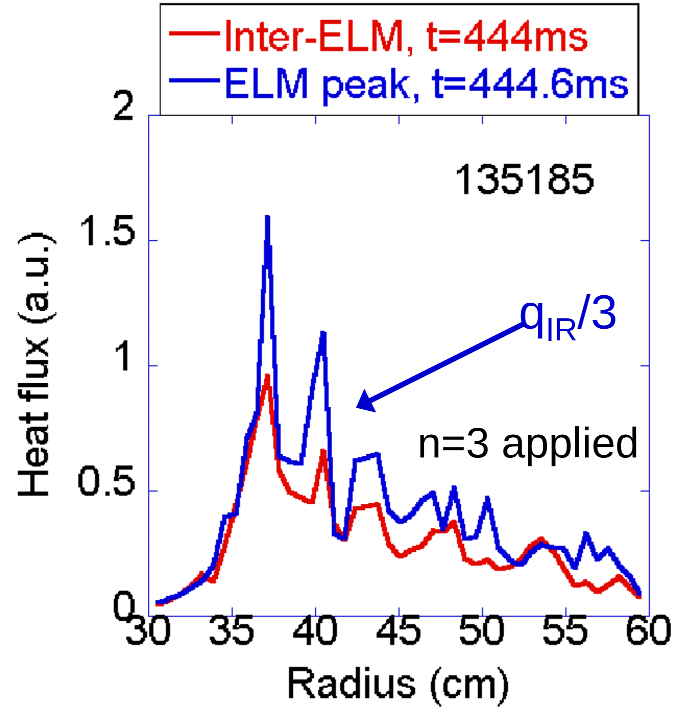
[1]J.-K. Park, Phys. Plasmas (2007), 052110

Heat flux from ELMs triggered by n=3 fields follows imposed field structure



Heat flux from ELMs triggered by n=3 fields follows imposed field structure

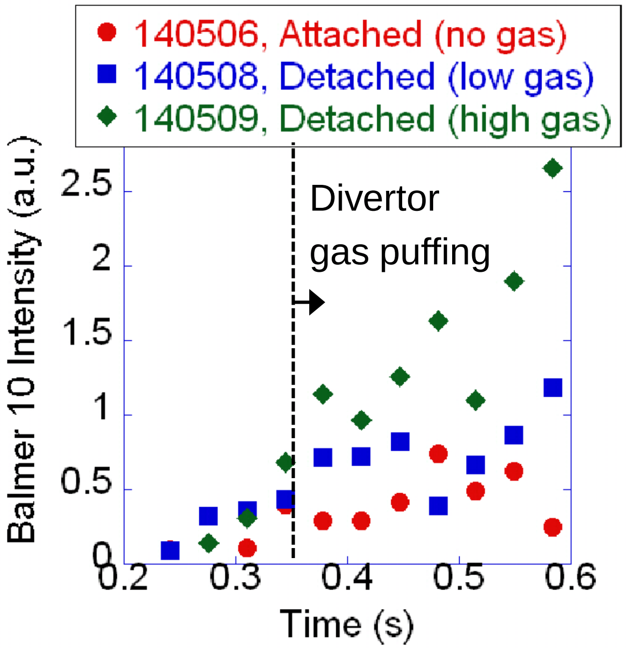




- Striations in the heat flux profile appear in the same locations as was before the ELM
- 3-D field (n=3) triggered ELMs are phase-locked to the externally applied perturbation structure (also seen in DIII-D[1])

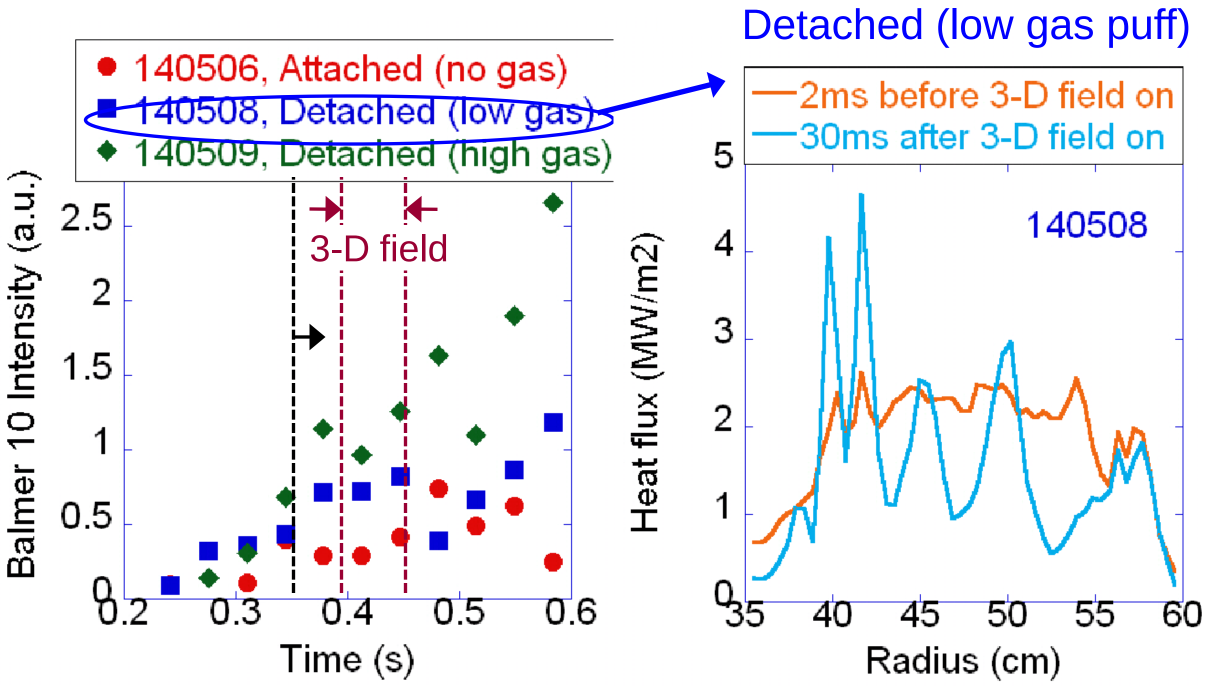
[1]M. Jakubowski, NF 49 (2009), 095013

Applied 3-D fields can reattach detached plasma but it can be avoided by high gas puffing



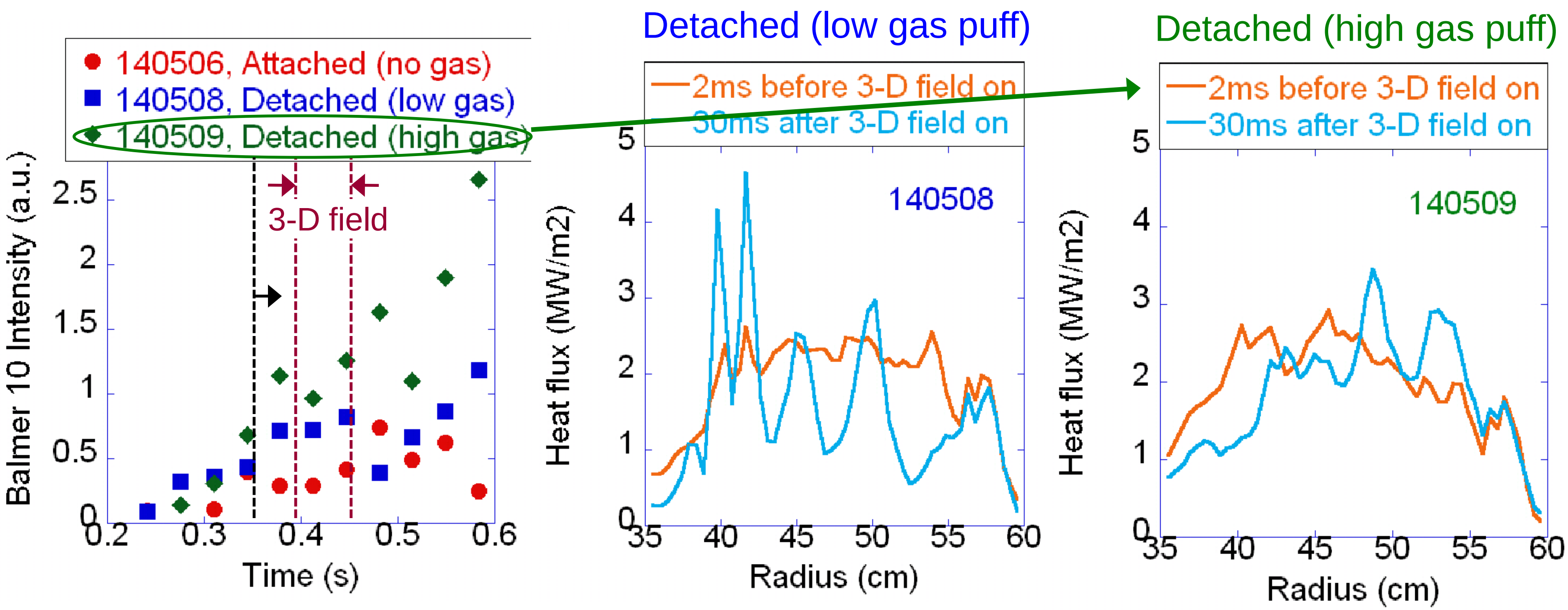
- Divertor plasma was made detached by raising divertor gas puffing
- Divertor plasma regime was monitored by multiple diagnostics (divertor spectroscopy, Langmuir probe, IR camera, etc)
- Balmer 10 line intensity: good indicative of volume recombination, characteristic of divertor detachment

Applied 3-D fields can reattach detached plasma but it can be avoided by high gas puffing



- Applied 3-D fields make the detached divertor plasma re-attach in medium divertor gas level, leading to a peaked heat flux profile again

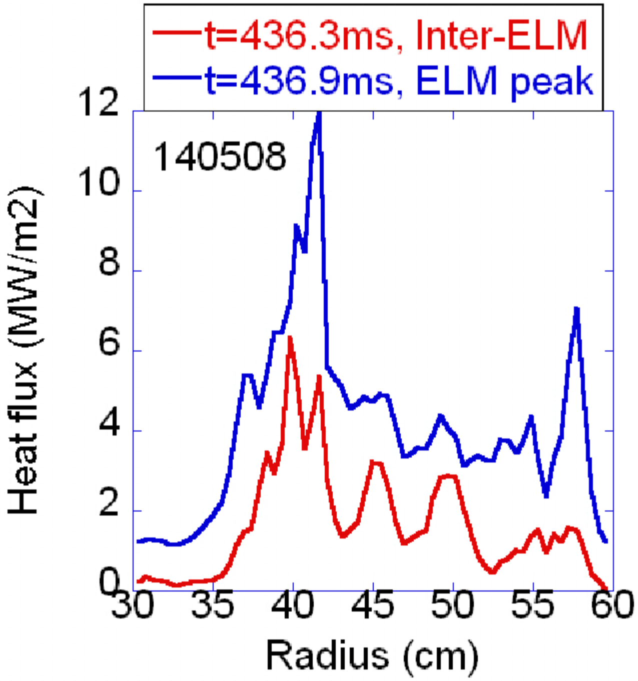
Applied 3-D fields can reattach detached plasma but it can be avoided by high gas puffing



- Applied 3-D fields make the detached divertor plasma re-attach 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

Divertor plasma can stay in the detached regime even during the ELM with strong gas puffing

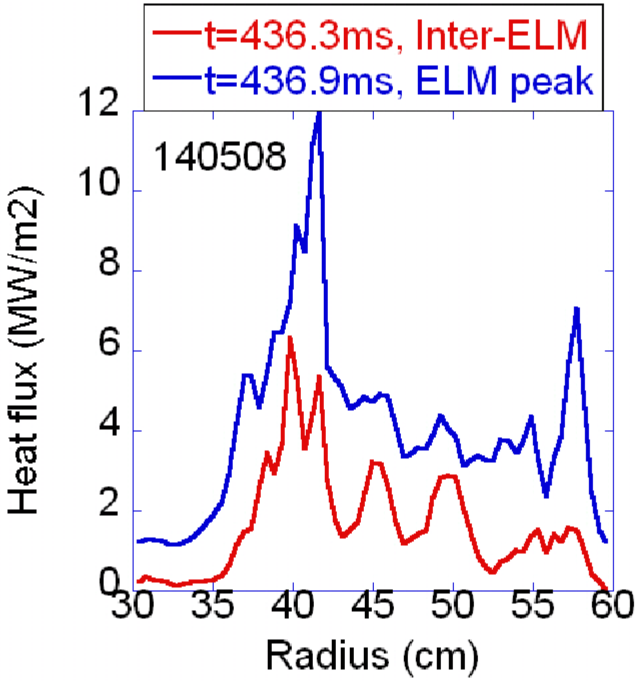
3-D field to detached plasma (low gas)



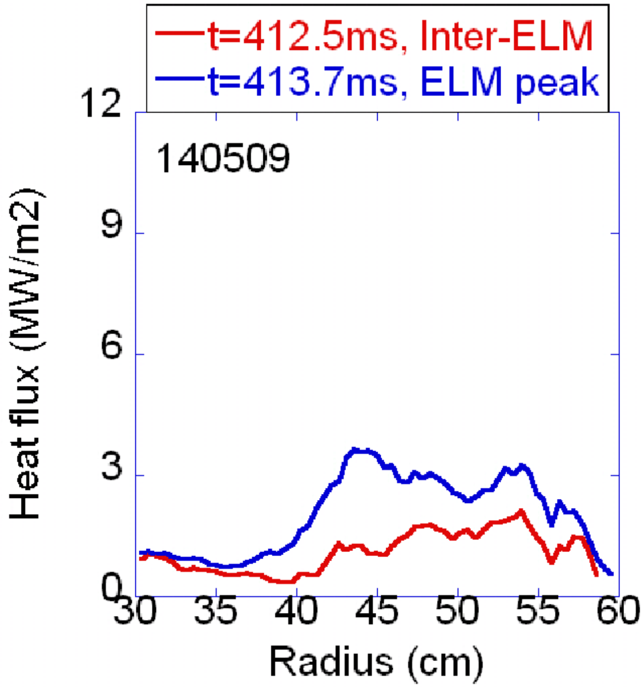
- Both the inter-ELM and ELM heat flux profiles show peaked deposition at the separatrix with lower gas puffing rate

Divertor plasma can stay in the detached regime even during the ELM with strong gas puffing

3-D field to detached plasma (low gas)



3-D field to detached plasma (high gas)



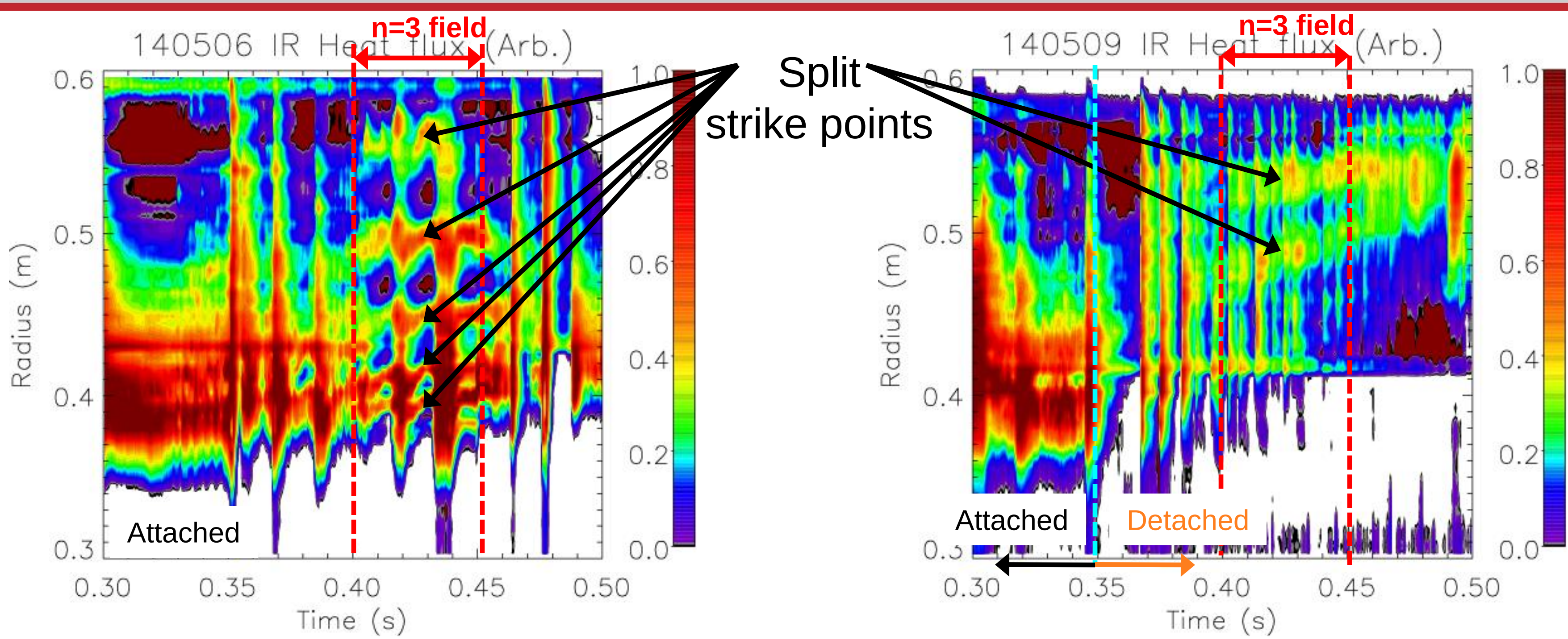
- Both the inter-ELM and ELM heat flux profiles show peaked deposition at the separatrix with lower gas puffing rate
- Higher gas puffing produces significantly lower and flat heat flux profiles and makes the ELM size smaller, 3-D field produces striations only in the far SOL

Summary and conclusions

- Splitting of divertor profiles caused by 3-D fields was measured for applied and intrinsic 3-D fields, and for different q95. Comparison with vacuum field line tracing shows good agreement
- The expected toroidal heat and particle deposition pattern for imposed 3-D fields was confirmed experimentally
- Inclusion of plasma response does not affect the structure of split strike point significantly
- 3-D field triggered ELM heat flux follows split strike point channels
- 3-D fields can reattach detached divertor plasma but it can be overcome by additional gas puffing.

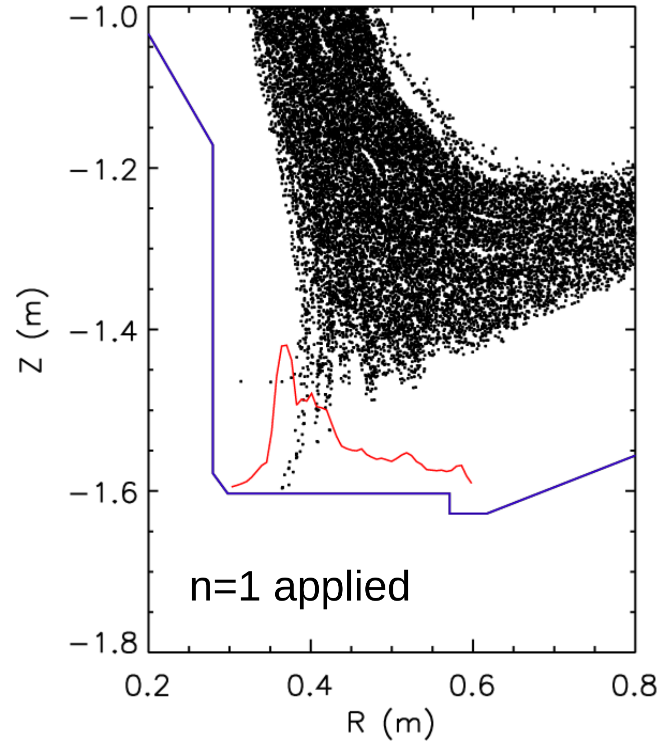
Backup slides

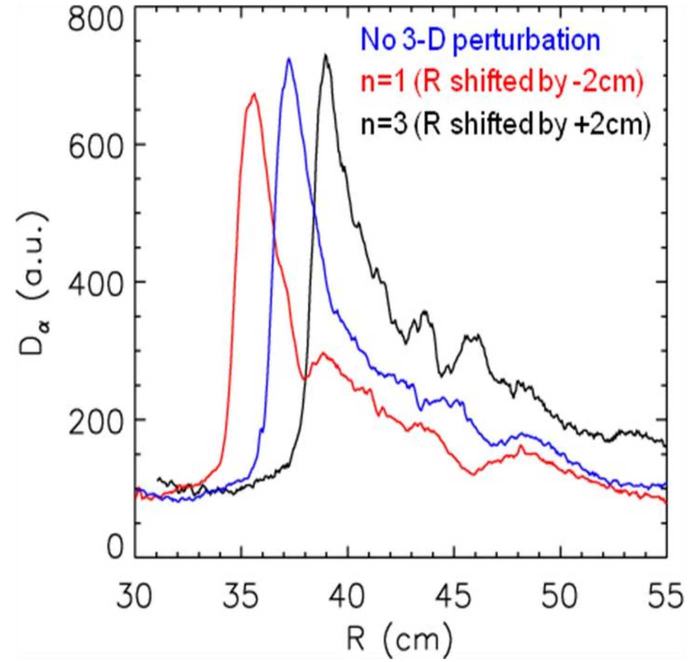
Effect of applied 3-D fields on natural ELM heat flux



- In attached divertor plasma regime: ELM size big; peaked heat flux profile at the separatrix; local peaks and valleys by 3-D fields
- In detached divertor plasma regime: ELM size smaller; mitigated heat flux with no peaked profile at the separatrix; local peaks and valleys in far SOL by 3-D fields

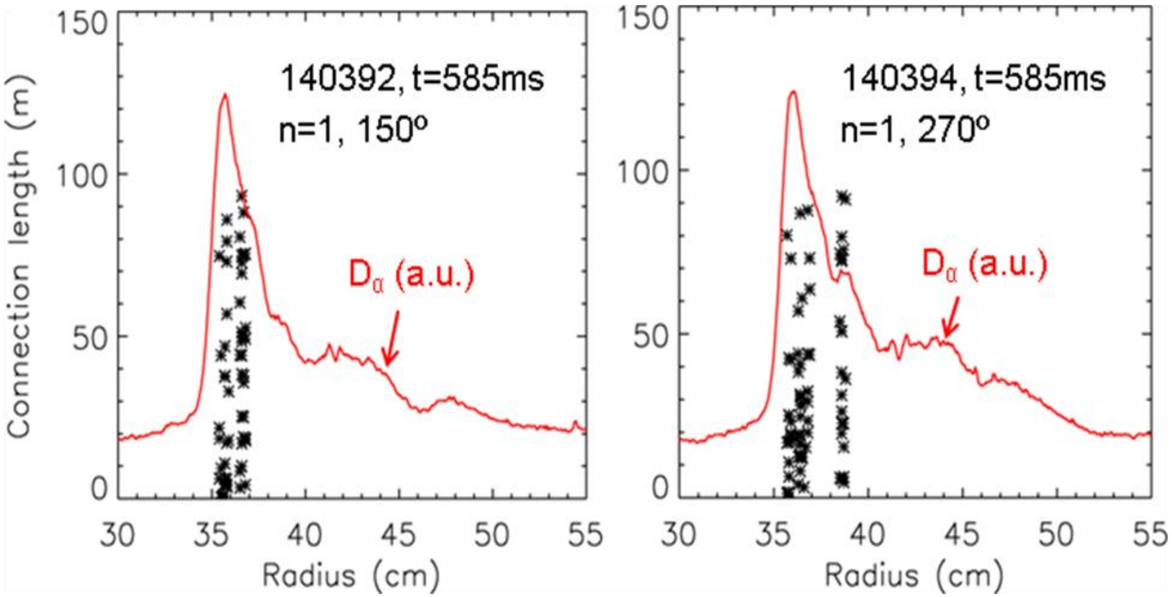
Modification of divertor profiles by both n=1 and n=3 perturbation fields has been singled out





- 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

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