NSTX

Supported by

U.S. DEPARTMENT OF ENERGY Office of Science

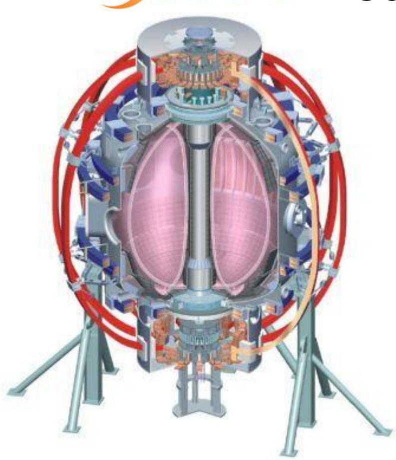
Effect of 3-D fields on divertor detachment in NSTX and DIII-D

J-W. Ahn[1]

R.E. Bell[2], A.R. Briesemeister[1], J.M. Canik[1], A. Diallo[2], T.E. Evans[3], N.M. Ferraro[3], S.P. Gerhardt[2], B.A. Grierson[2], T.K. Gray[1], S.M. Kaye[2], M.J. Lanctot[3], B.P. LeBlanc[2], J.D. Lore[1], R. Maingi[2], A.G. McLean[4], D.M. Orlov[5], T.H. Osborne[3], **T.W. Petrie**[3], A.L. Roquemore[2], F. Scotti[2], O. Schmitz[6], M.W. Shafer[1], V.A. Soukhanovskii[4], E.A. Unterberg[1], and A. Wingen[1]

[1]ORNL, [2]PPPL , [3]GA, [4]LLNL , [5]UCSD, [6]UW-Madison

IAEA FEC Meeting
St. Petersburg, Russia
October 13-18, 2014



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

Motivation

Key questions for ITER:

- Would 3-D fields to be applied for ELM control in ITER be compatible with detachment and highly radiative divertor as required for stationary power flux control in ITER ?

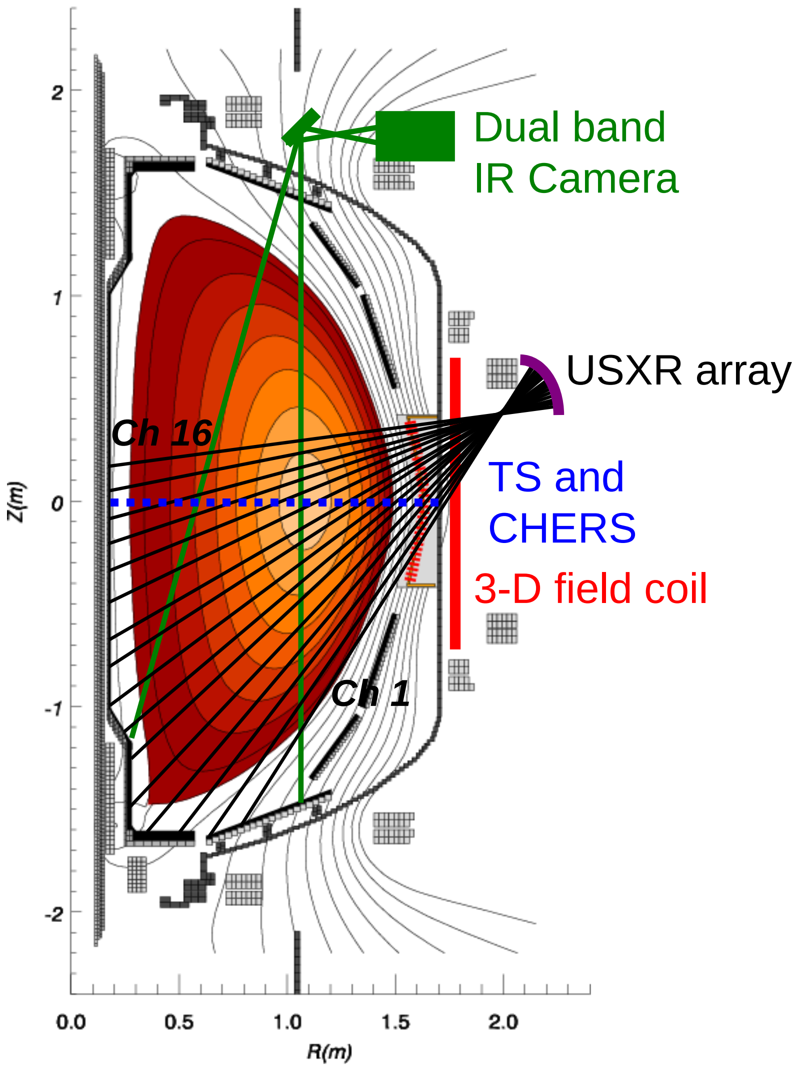
- Can one maintain the pedestal plasma as required for fusion performance and at the same time keep the divertor heat flux under control along with 3-D field?

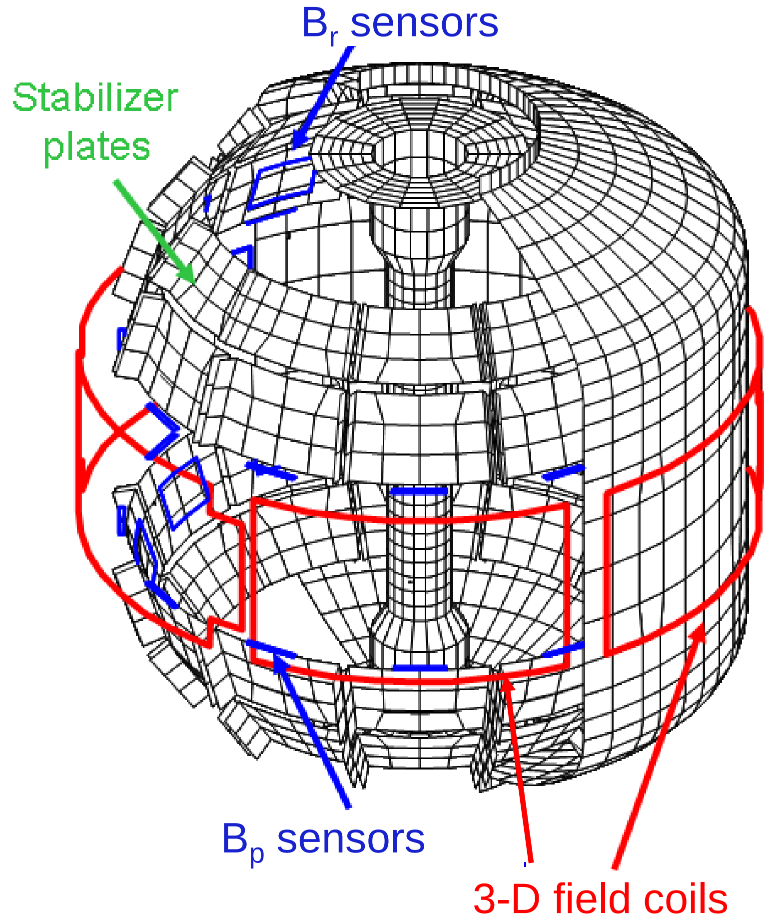
– NSTX has no pump-out by the applied 3-D fields, therefore experiment at constant collisionality is possible
– DIII-D has a suite of magnetics data for the investigation of plasma response to applied 3-D fields

Effect of 3D fields on detachment in NSTX

- Diagnostics and experiments overview:
  - Divertor detachment with various gas puff levels and applied 3-D fields
- Effects of detachment and 3-D fields on the divertor plasma:
  - Heat flux profile at the divertor surface by IR camera
  - Both for inter-ELM period and ELM peak times
- Effects on the pedestal plasma characteristics:
  - Mid-plane T_e, n_e , T_i, V_t profiles by Thomson scattering and CHERS
  - TRANSP modeling

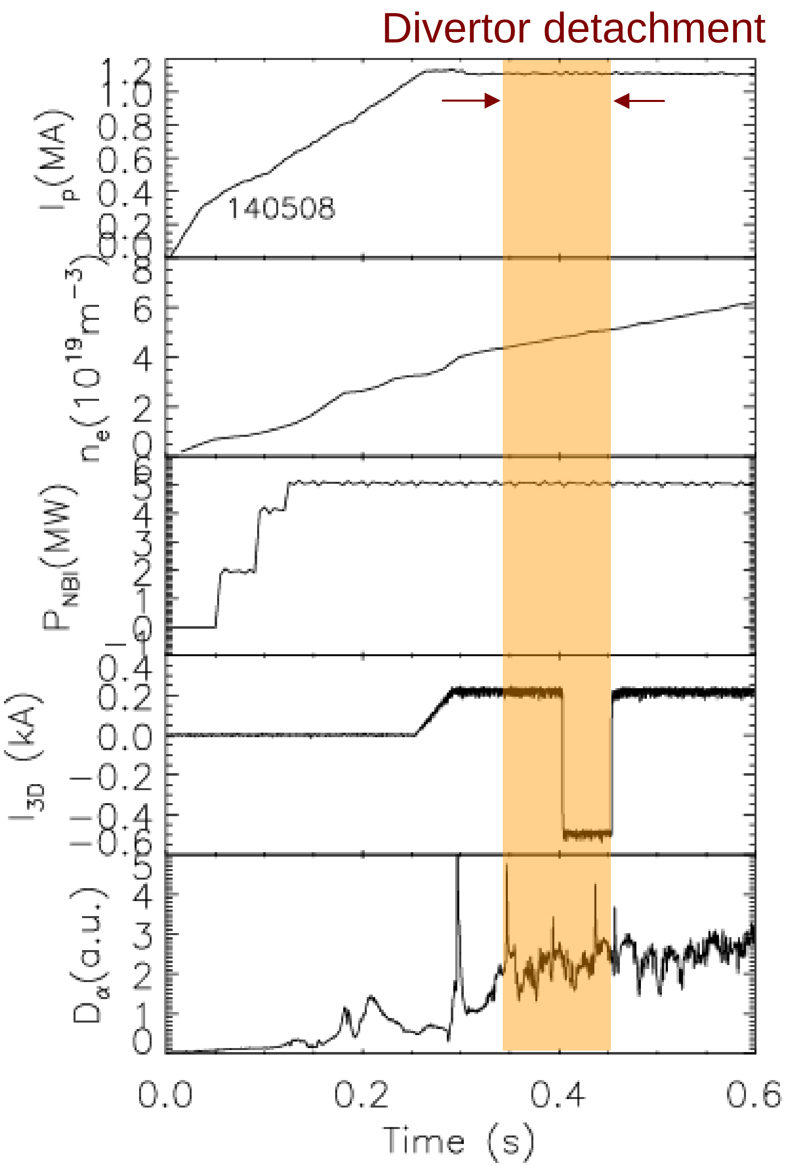
Diagnostics and 3-D coil arrangement at NSTX





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

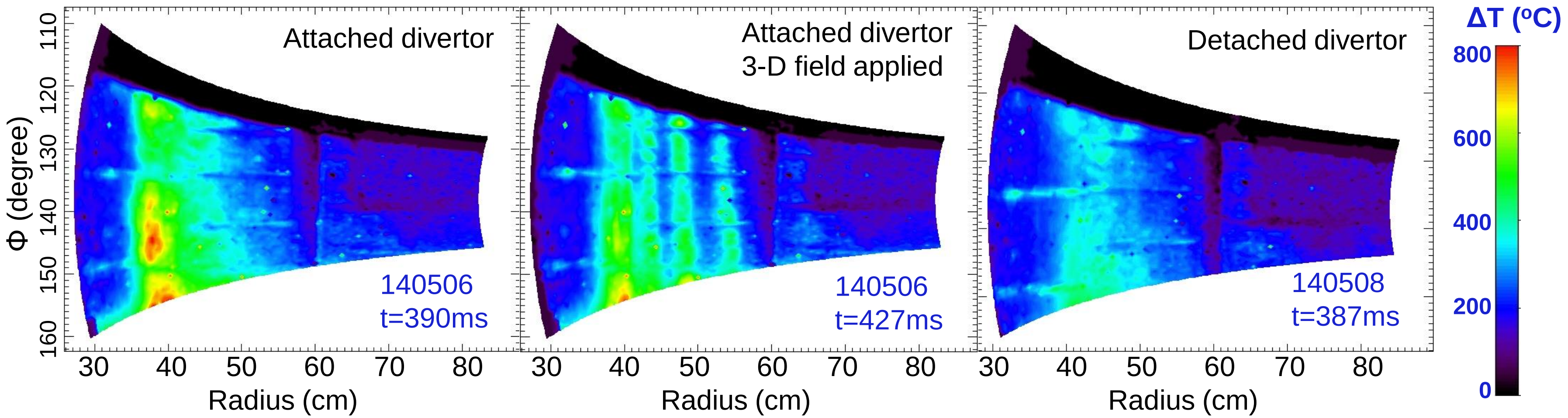
Experimental approach

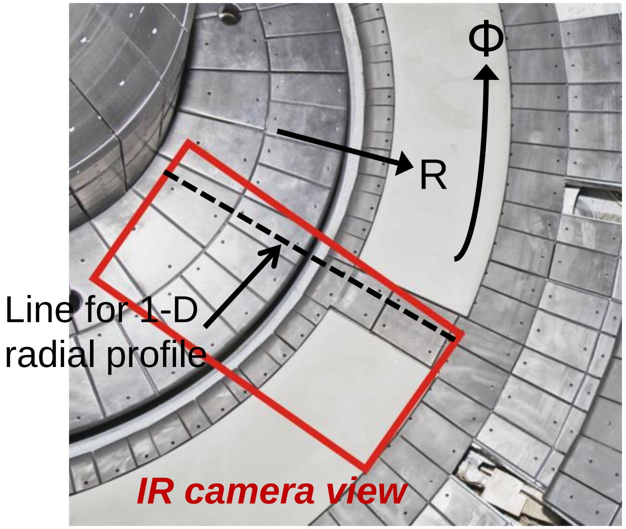


- Naturally ELMing H-mode with minimal lithium deposition as needed for discharge reproducibility and wall conditioning
- Step 1: Divertor gas puffing to produce partially detached divertor plasmas
- Step2: Apply 3-D fields (n=3) on top of the n=3 EFC field (~200A) below ELM triggering threshold to see the effect on the divertor and pedestal plasmas

J-W. Ahn, PoP 18 (2011), 056108

2-D dual band IR image shows various divertor plasma conditions



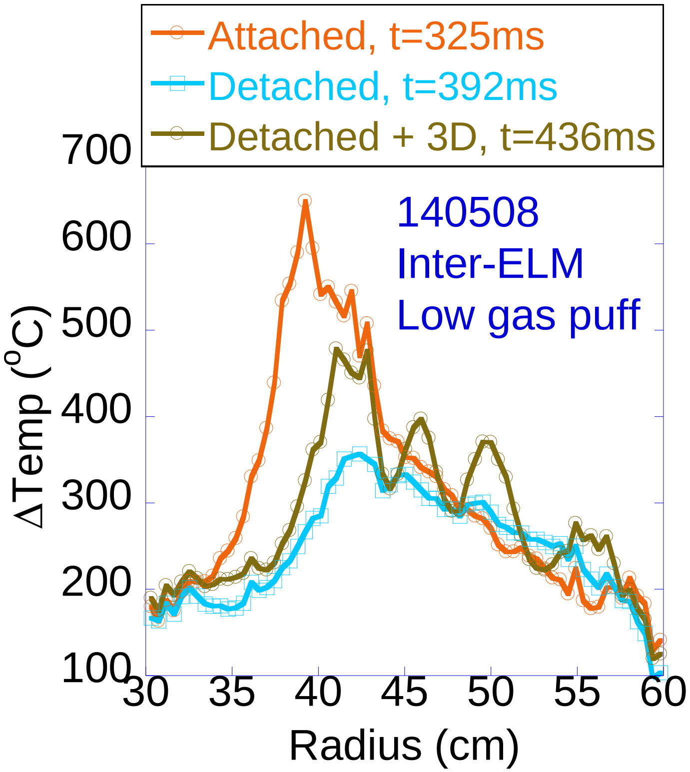


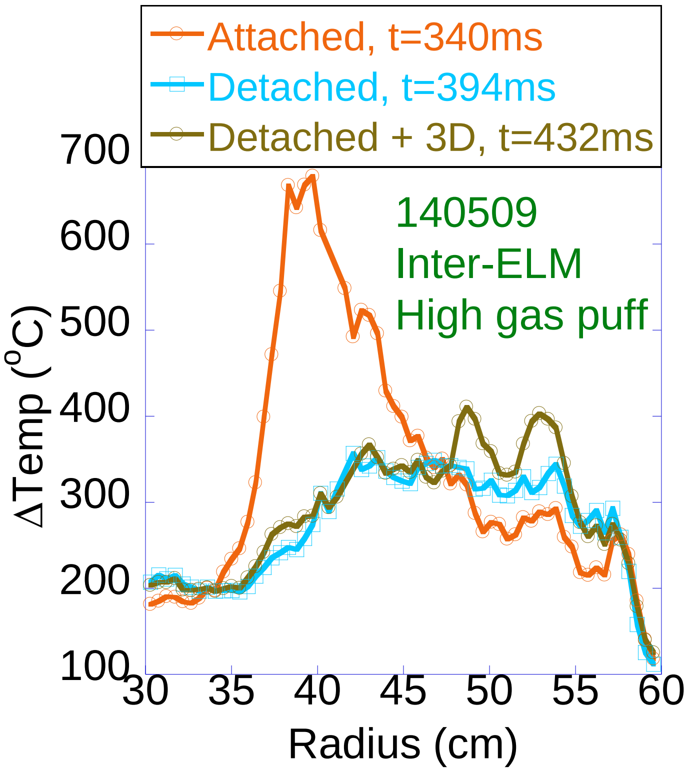
- Divertor surface temperature is monitored by dual band (4-6μm and 7-10 μm) IR camera[1,2]
  → 1.6kHz frame speed, 15-40° toroidal coverage
- Applied 3-D fields generates homoclinic tangles and causes strike point splitting
- Surface temperature shows significant reduction only near the strike point in case of divertor detachment → ‘Partial detachment’

IR Data analysis by A.G. McLean, ORNL

[1]A.G. McLean, to be published in RSI (2011)
[2]J-W. Ahn, RSI 81 (2010), 023501

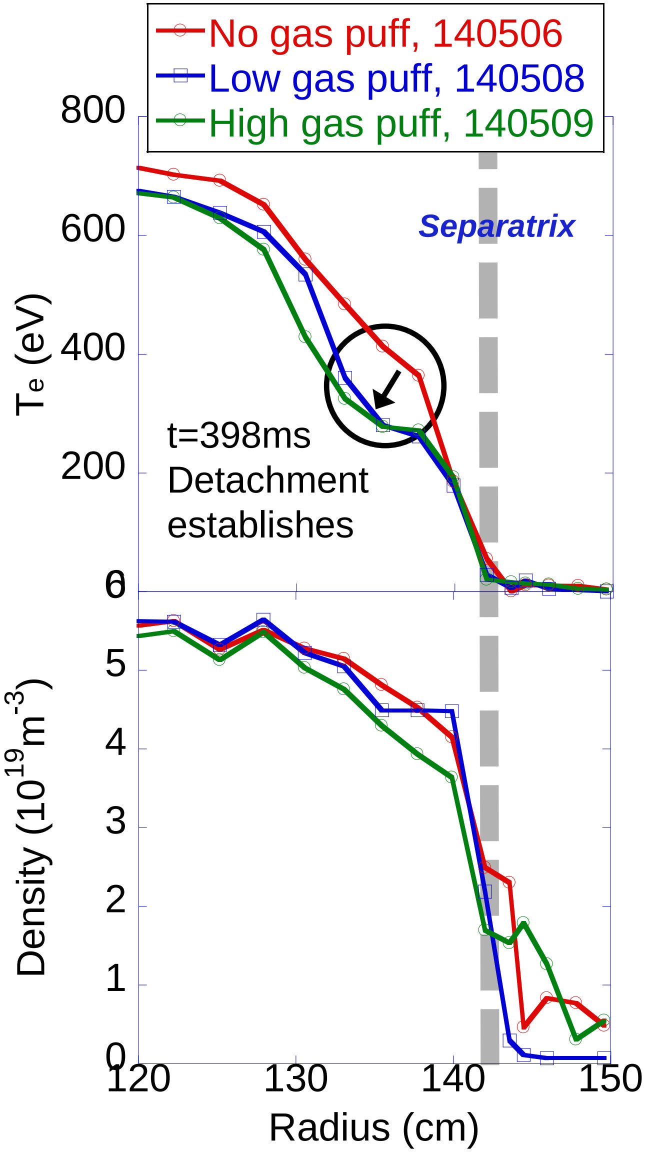
Applied 3-D fields can reattach weakly detached plasma but no effect on strong detachment

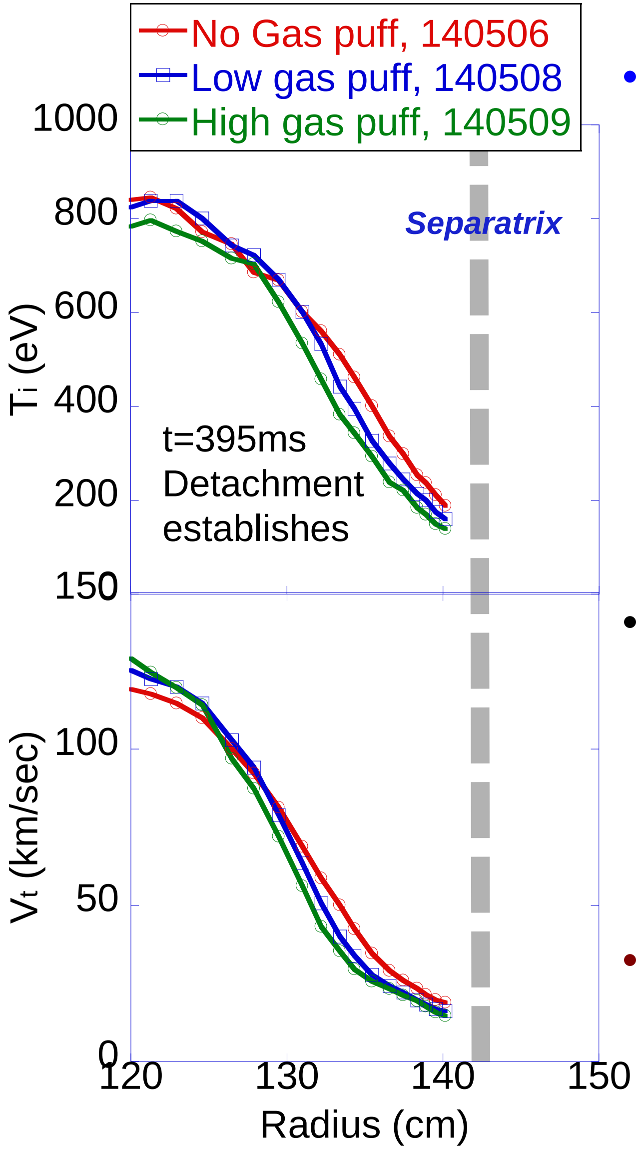




- Applied 3-D fields make the detached divertor plasma re-attach in low gas puff rate, leading to a peaked surface temperature profile again. The peak temperature in the re-attached plasma is lower than the original peak value
- If the divertor gas puffing is high enough, plasma stays in the partially detached regime even with 3-D field applied

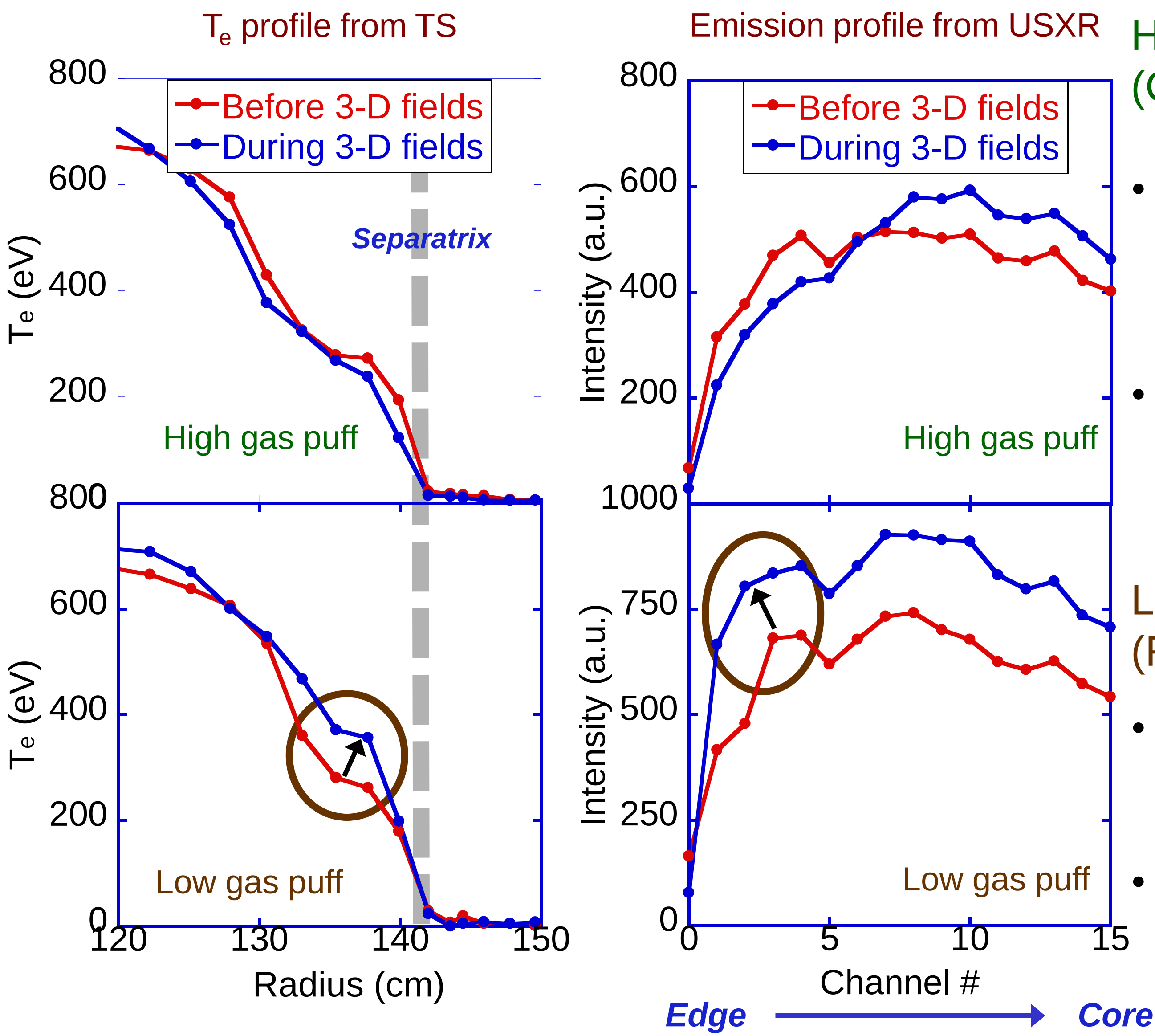
Pedestal T_e drop is prominently observed when divertor detachment is established





- T_e profile reduction near the pedestal top is most prominent. Pedestal density only slightly decreases
  → Correlated with divertor heat flux profile reduction
- Overall pedestal T_i and V_t profiles also decrease as the detachment is established but the change is relatively small
- This is commonly observed in detached plasmas in NSTX

Divertor re-attachment by applied 3-D fields is related with rise of pedestal T_e profile



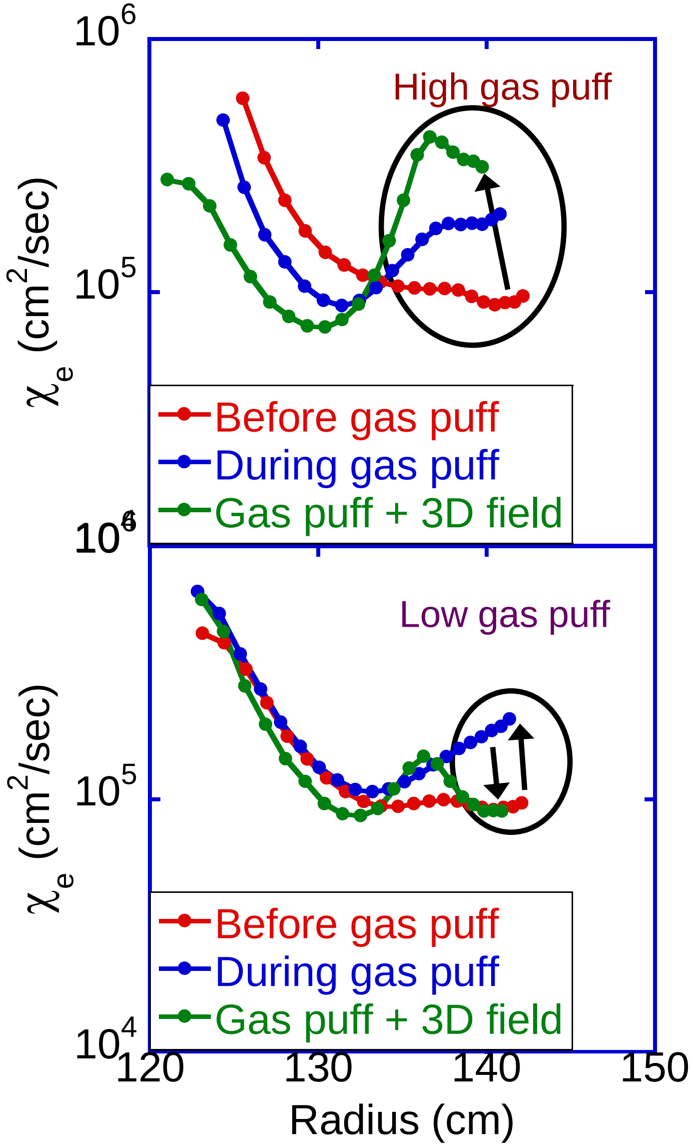
High gas puff
(Continued detachment)

- Pedestal T_e profile remains decreased, ie unaffected, after 3-D field application
- USXR edge data (toward channel 0) also continuously decrease

Low gas puff
(Re-attachment by 3-D field)

- Pedestal T_e rises back up by the applied 3-D fields
- Edge USXR data also shows increase

TRANSP modeling indicates change in the pedestal electron heat diffusivity



High gas puff (continued detachment)

- Pedestal χ_e continuously increases during the whole detachment and the later 3-D field application phases

Low gas puff (re-attachment)

- Pedestal χ_e increases during the detachment phase and then decreases again with the onset of re-attachment

Effect of plasma response in separatrix splitting by 3D fields in DIII-D

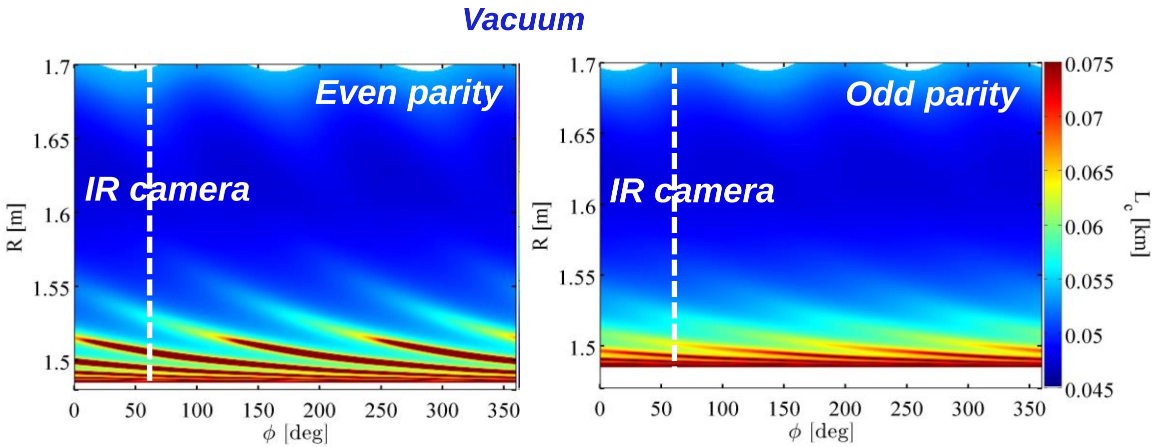
- Separatrix splitting is a signature of stochastic B-fields and the formation of 3D SOL
  - Hot and dense plasma particles from the pedestal can directly flow to divertor surface through tangles
  - 3D-ness of helical SOL changes characteristics of SOL transport (possible overlap with stellerator)
  - Impact on divertor plasma regime and detachment

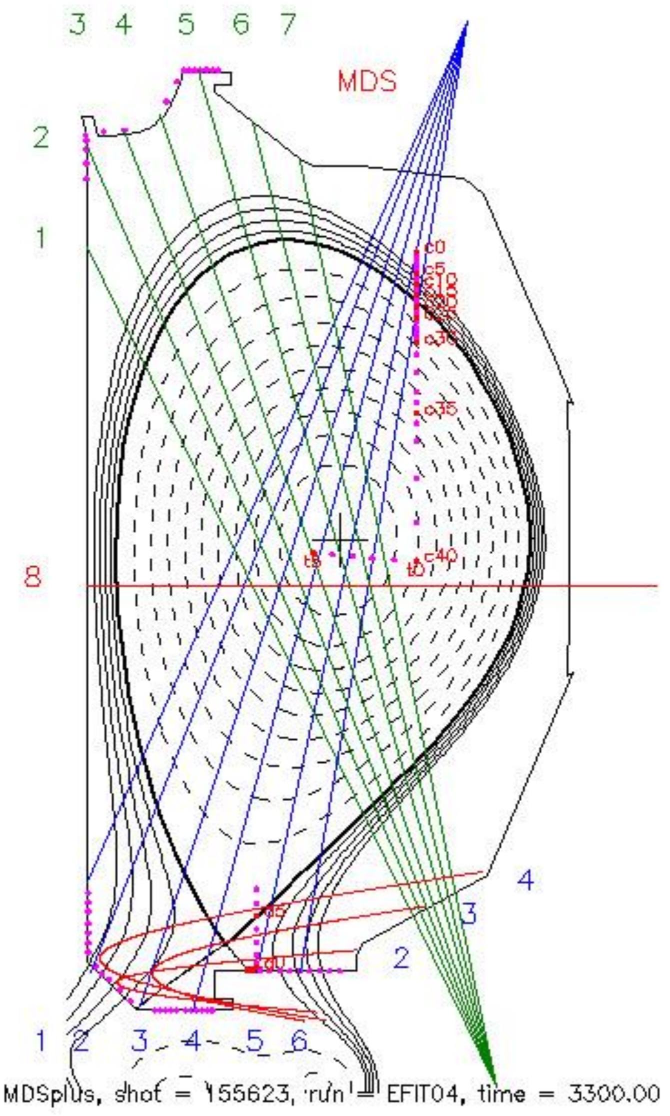
- Plasma response can affect the 3D structure of edge plasma and magnetic separatrix splitting

Clear splitting was expected from vacuum modeling for the even parity in 2013 experiment

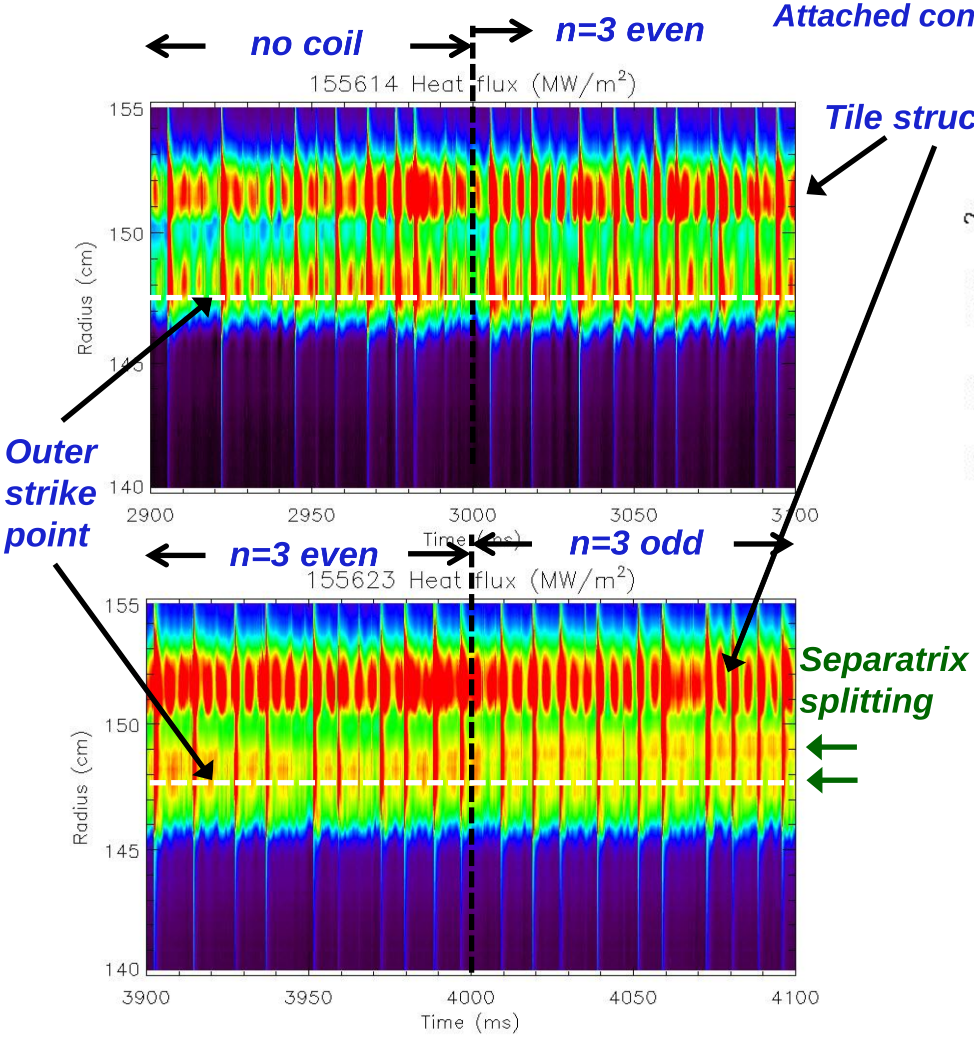
- Low δ shape was chosen for best diagnostic coverage (DTS and IRTV), a typical configuration for detachment study at DIII-D

- TRIP3D-MAFOT modeling for vacuum case predicted clearer splitting for the even parity configuration



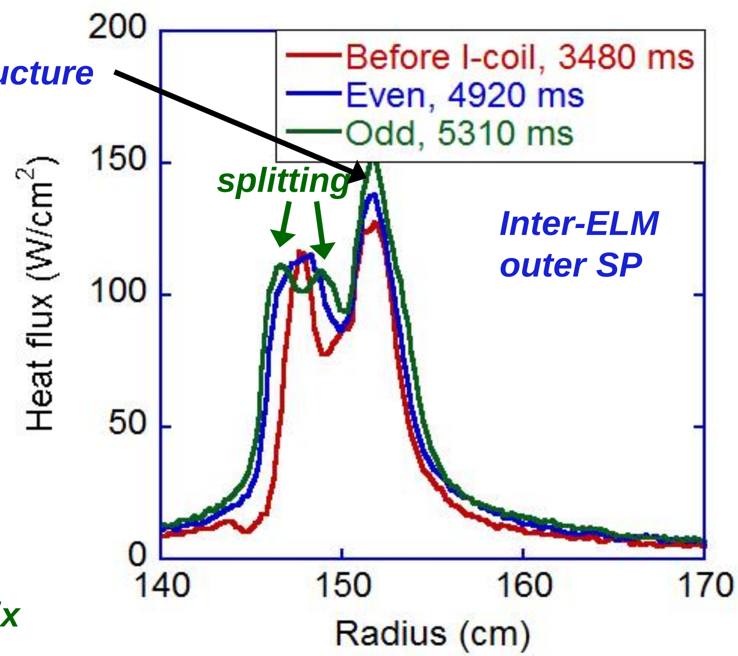


However, no splitting for even parity and very weak splitting for odd was observed



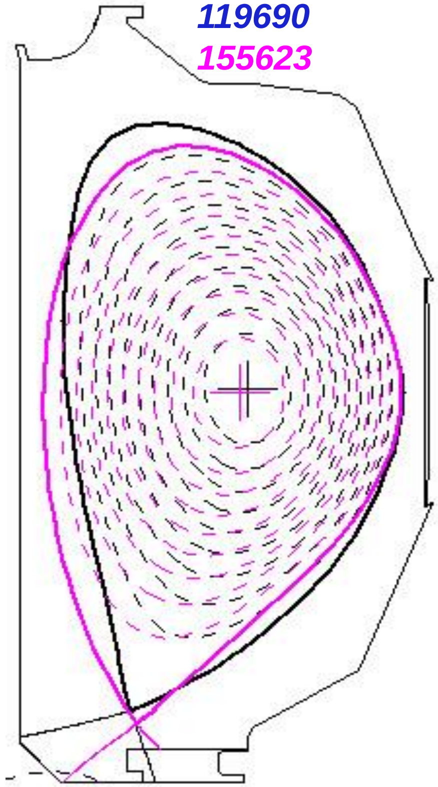
Heat flux data from C. Lasnier

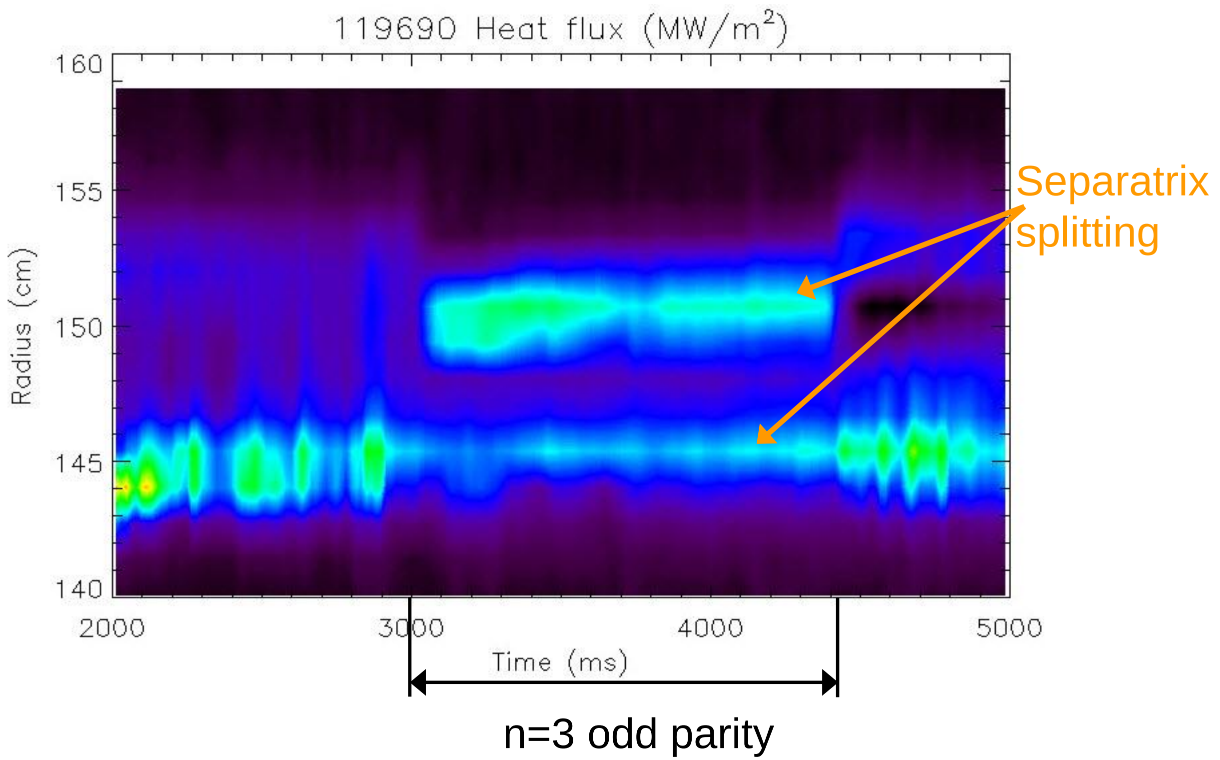
Attached condition



- Outer strike point reveals very subtle, but persistent splitting for the odd parity n=3
- Inner strike point remains unchanged

Clear heat flux splitting was observed for higher δ shape plasmas in the past

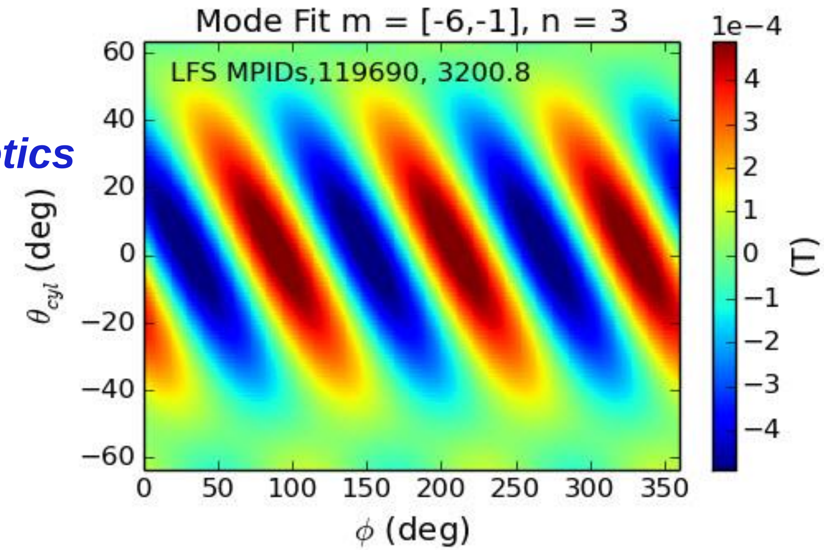




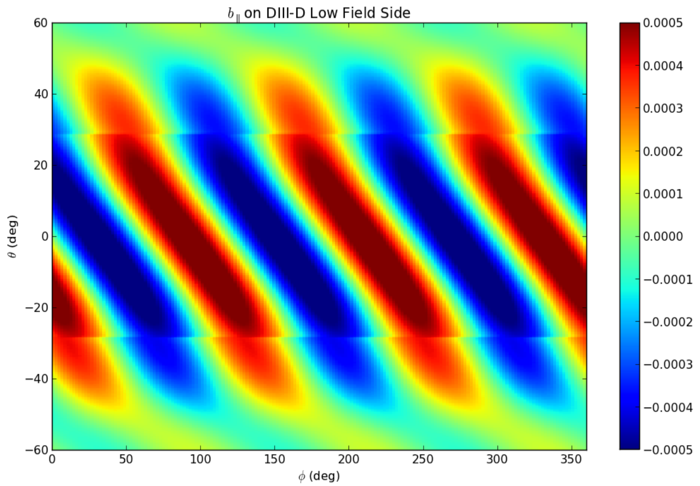
- Separatrix splitting clearly seen for high δ (δ_b=0.6 – 0.7) plasma shape, eg 119690, 115467, etc. β_N was also higher (2.0 vs 1.7)
  - Other plasma conditions are very similar to 155623, eg $\nu_e{}^*{}_{ped}$, density, q95, etc.

Measured 2D plasma response in good agreement with ideal plasma response

Magnetics data



IPEC modeling



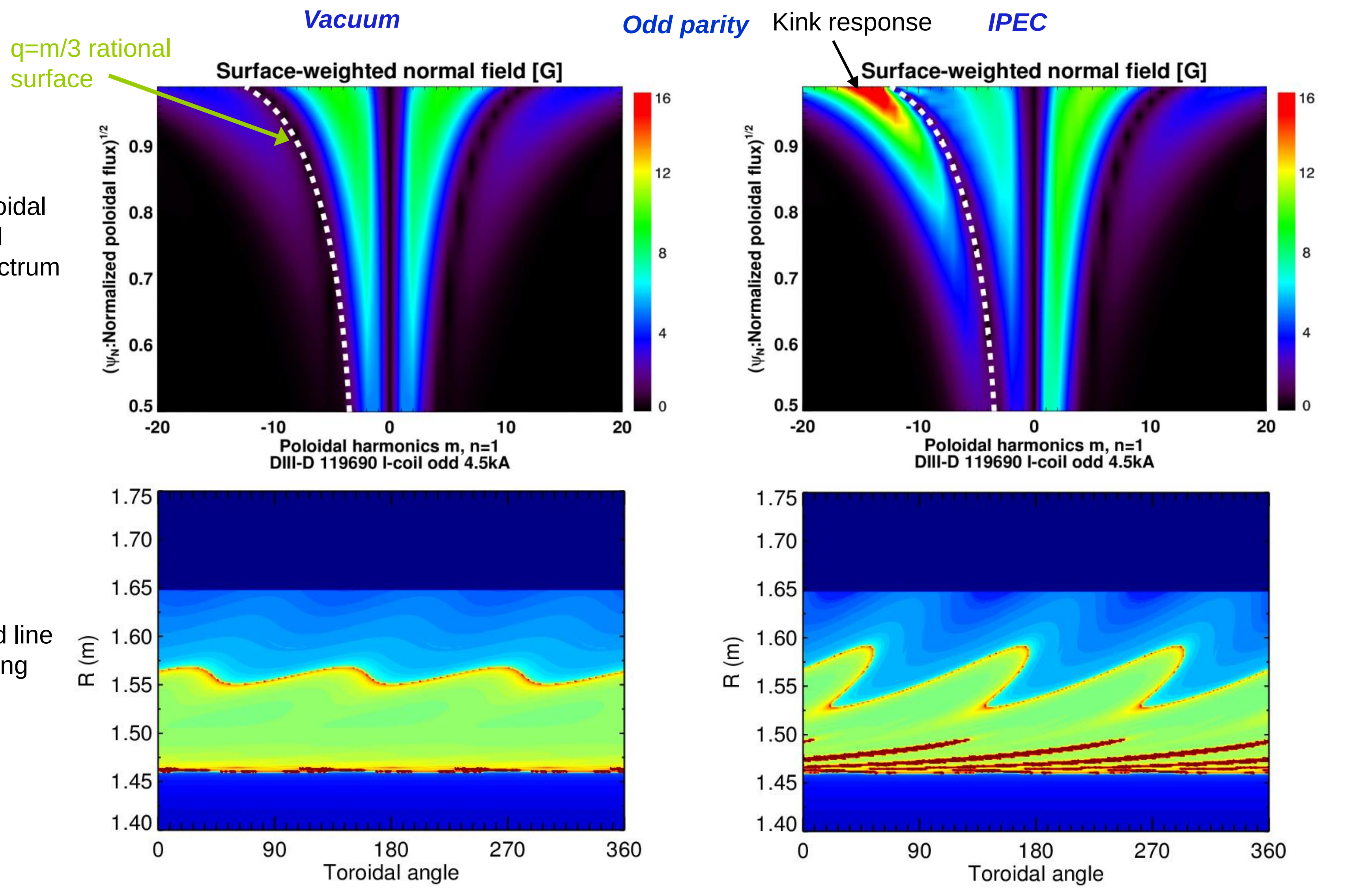
- 119690: odd parity, high density, clear separatrix splitting
- Fitting of magnetic sensor data to produce 2D data
- Both amplitude and phase of response fields agree well with the IPEC modeling
  → Ideal plasma response

Magnetic sensor data from N. Logan
IPEC data from J.-K. Park

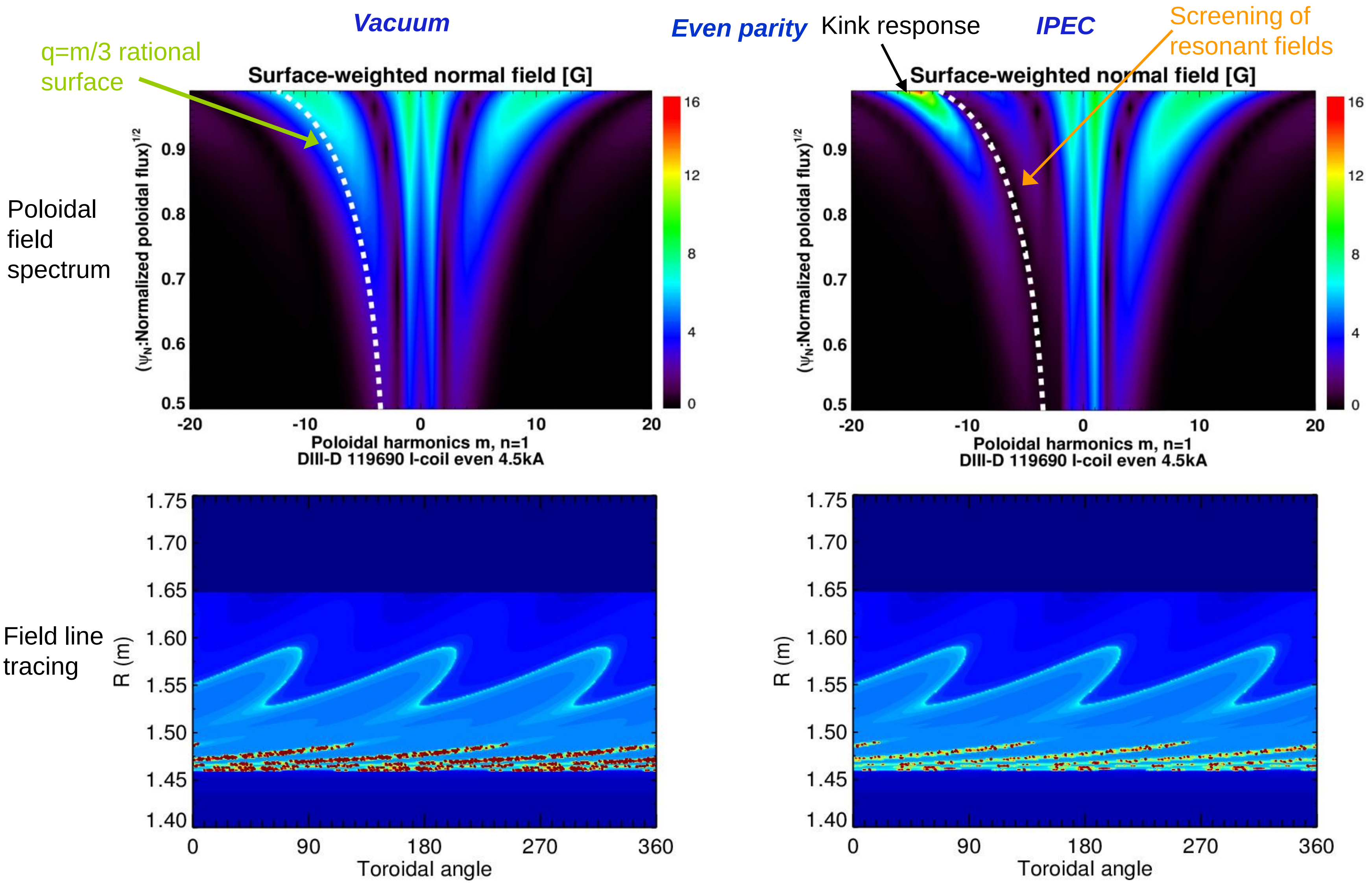
High δ shape shows strong amplification of lobes for odd parity by kink response

Poloidal field spectrum

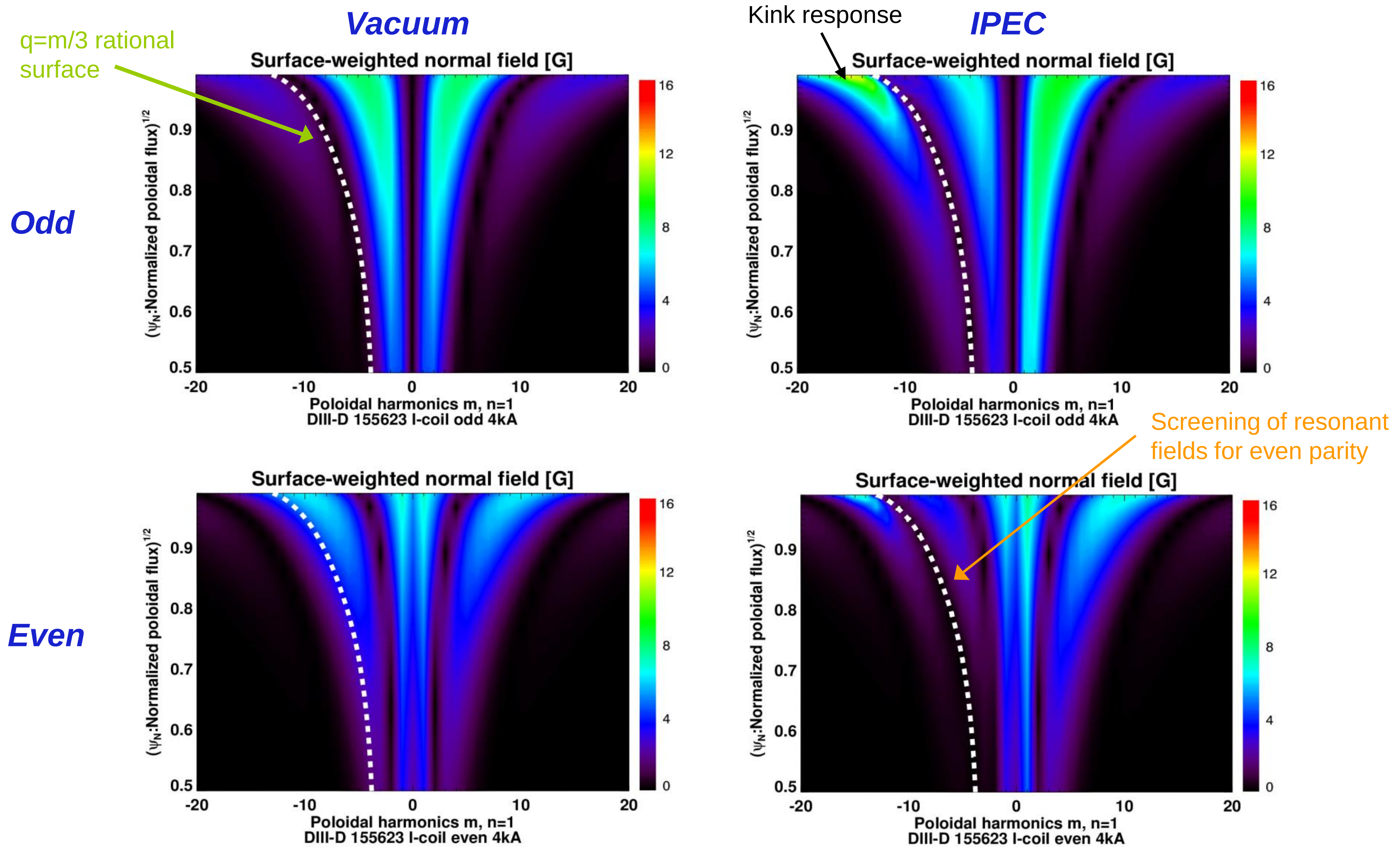
Field line tracing



Even parity shows screening of resonant fields with weaker kink response

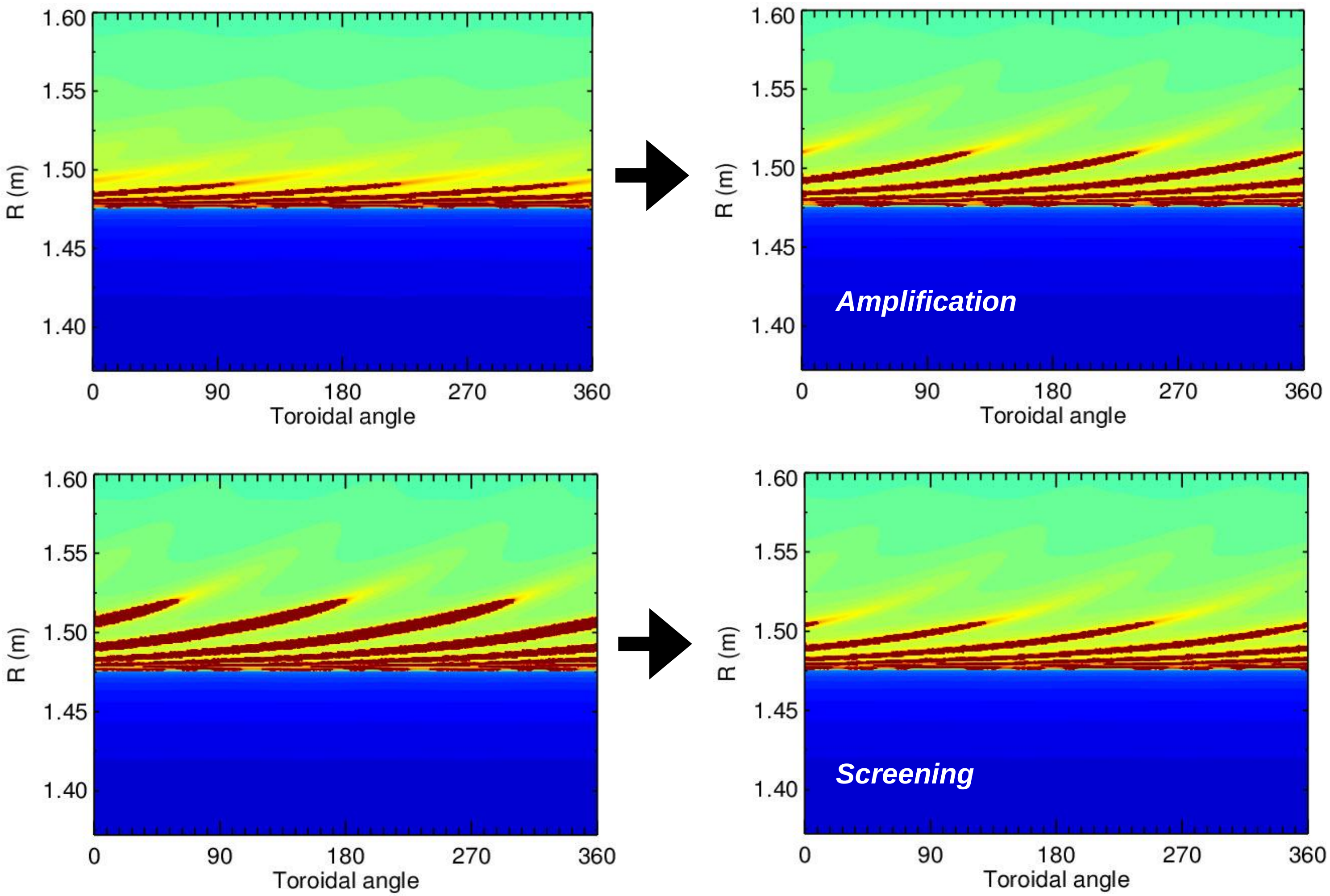


Low δ shape also shows similar trend but with much reduced kink response



Amplification (odd parity) and screening (even parity) of splitting by plasma response

Vacuum Field line tracing ***IPEC***



Summary and conclusion

- The applied 3-D field can burn through weakly detached divertor plasma to re-attachment and this process is primarily associated with the pedestal T_e profile increase
- Sufficiently high gas puff can prevent 3-D fields from raising pedestal T_e and the divertor plasma remains detached, including ELMs
- Pedestal χ_e from TRANSP modeling shows consistent change with the experimental observations
- Plasma response can either screen (even parity) or amplify (odd parity) lobes formed by applied 3D fields
- Strong plasma shape (δ) is beneficial for strong kink response that can lead to amplification of lobes → non-resonant effect
- Plasma response is a key factor in determining separatrix splitting pattern and therefore should be taken into account for the prediction of 3D effects on divertor plasma and detachment