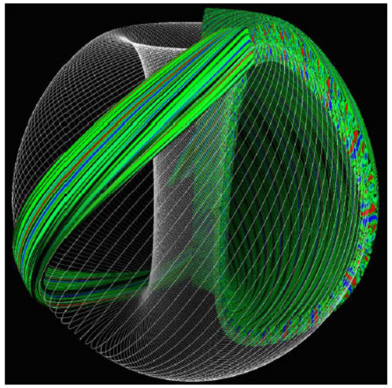
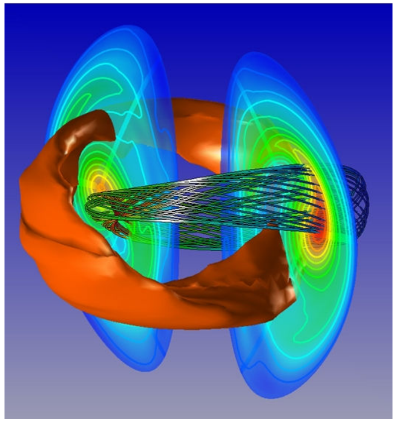
2D ECE Imaging Program for Fluctuation Studies on the KSTAR and DIII-D Tokamaks





Hyeon K. Park

POSTECH, Pohang, Korea

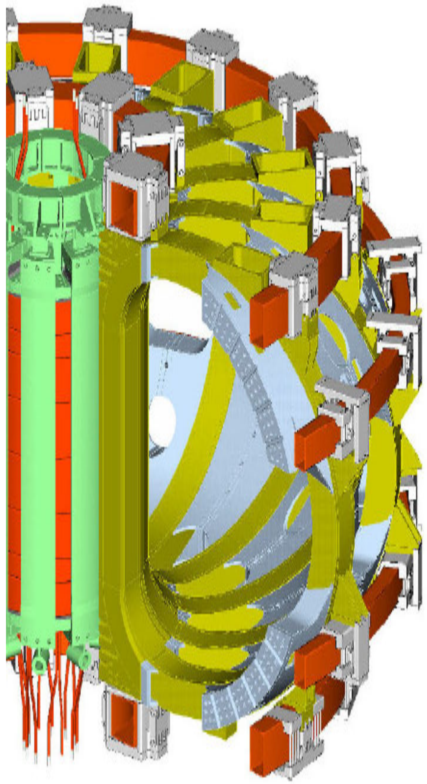
at

16th joint workshop on

ECE and ECRH

April 12 – 15, 2010

Sanya, China



Collaborators

B. Tobias, G.S. Yun, W. Lee, M.J. Choi, I.G.J. Classen, C.W. Domier,
A.J.H. Donné, J.C. Kim, X. Kong, T. Liang, N.C. Luhmann, Jr., T. Munsat and L. Yu.

Center for Fusion Plasma Diagnostics & Steady-State Operation

CPDS²O UCDAVIS FOM Colorado University of Colorado at Boulder

Introduction

- Innovative 2-D Imaging Diagnostics
  - Visualization of T_e and n_e fluctuations in high temperature plasmas ("ultimate diagnostic system",1998 APS)
  - Principle of ECE imaging system
  - Review of the "Sawtooth oscillation"
- Advances in Visualization Tools and New Findings
  - Improved ECEI system and its application
  - New physics of sawtooth crash and other MHDs
  - New measurement in DIII-D – 2-D Alfven wave study (ASDEX-U)
  - Status of the KSTAR ECEI system

Evolution of Plasma Diagnostics

Conventional Diagnostics | Computer simulation | Imaging Diagnostics

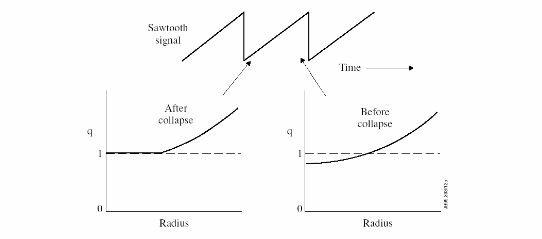
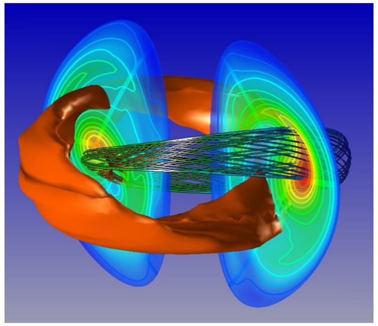
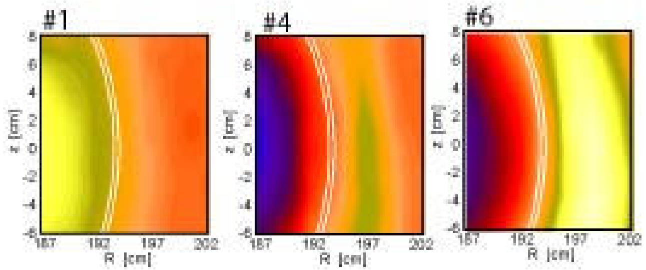


Figure 10.12. Kadomtsev's model predicts a flattening of the q-profile at the sawtooth collapse and the development of an unstable profile with $q < 1$ during the ramp phase.





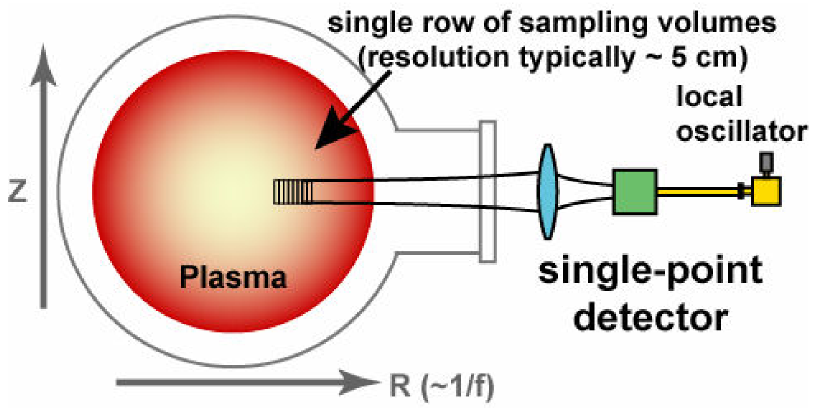
Improve predictive capability of MHD physics (Sawtooth, NTM, and RWM)

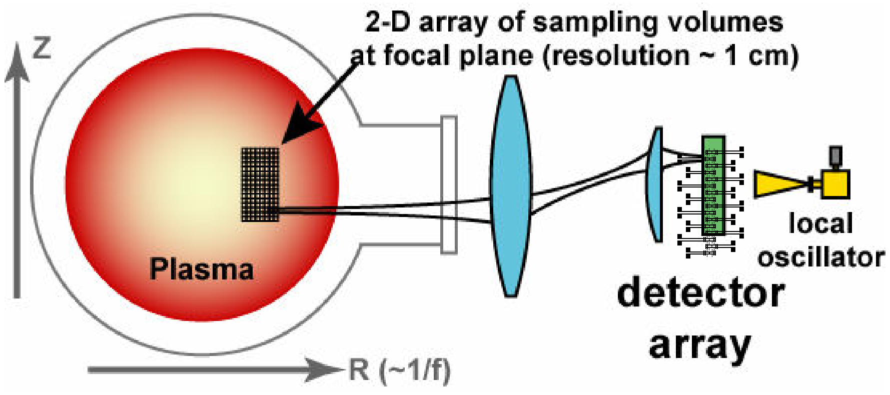
Analogous to evolution of diagnostic capabilities from Stethoscope to MRI

Center for Fusion Plasma Diagnostics & Steady-State Operation

CFPDS²O UCDAVIS FOM Colorado University of Colorado at Boulder

2D ECE imaging system





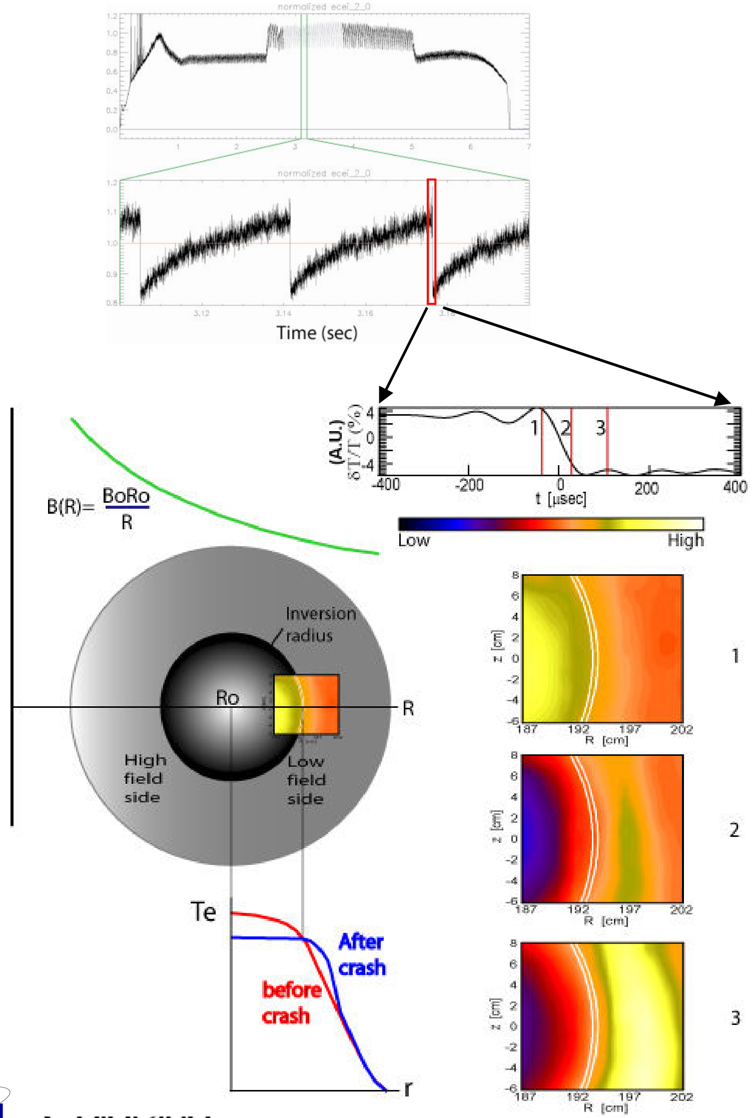
Conventional 1-D ECE system

2-D ECE imaging system

- ECE measurement is an established tool for electron temperature measurement in high temperature plasmas
- Sensitive 1-D array detector, imaging optics, and wide-band mm wave antenna, and IF electronics are required for 2-D imaging system
- T_e fluctuation measurement
  - Real time fluctuations can be studied up to ~1% level
  - Fluctuation studies down to 0.1 % level have been performed using long time integration

Sawtooth crash via composite 2-D views

- Core electron temperature (within the inversion radius) flattens after crash
- Frame 1: Hot spot (m/n=1/1 mode) is in the core before crash
- Frame 2: Cold flat area (Island) forms inside the inversion radius as crash starts
- Frame 3: Transported heat from the core builds up at the mixing zone (~10 cm layer surrounding the inversion radius)
- Accumulated heat in the mixing zone will symmetrically diffuse out in radial direction

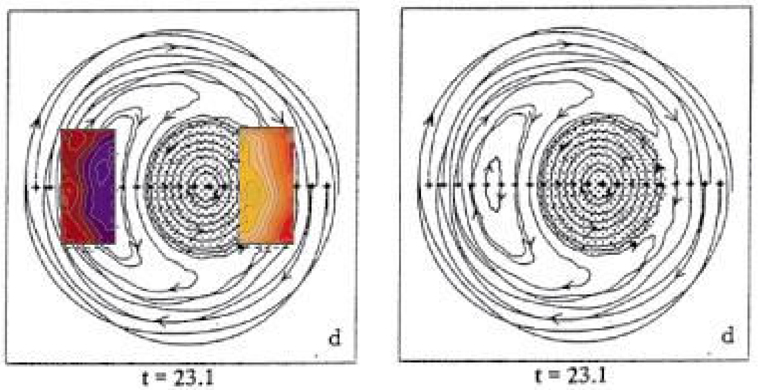


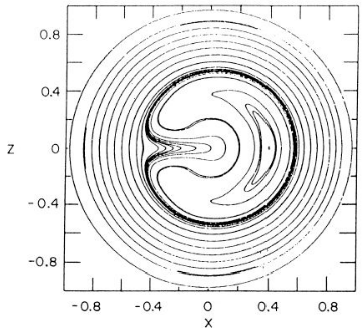
Center for Fusion Plasma Diagnostics & Steady-State Operation

Verification of theoretical models

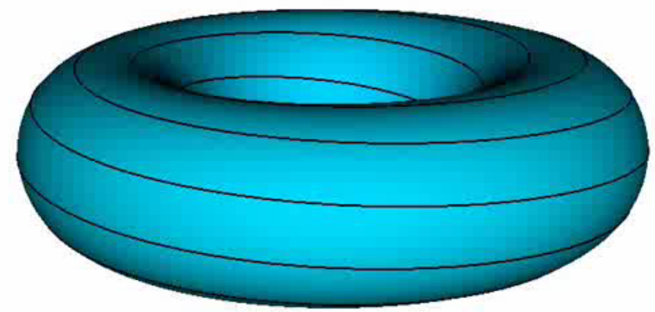
- Remarkable resemblance between 2-D images of the hot spot/Island and images from the matured stage of the simulation result of the full reconnection model (Sykes et al.)

H.K. Park *et al.*, *Physical Review Letters* **96**, 195003 (2006).
H.K. Park *et al.*, *Physical Review Letters* **96**, 195004 (2006).





Quasi-reconnection model (J. Wesson)



Comparative animation

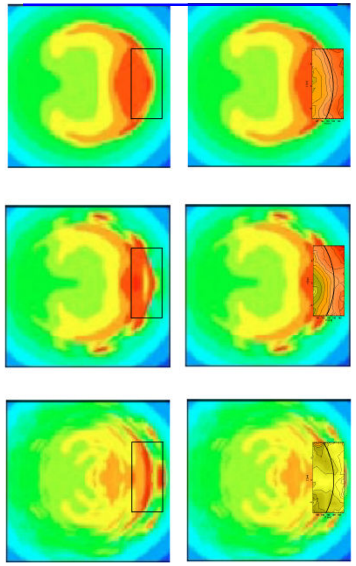
Initial and final stage agreement

with the full reconnection model is excellent but not in between

Center for Fusion Plasma Diagnostics & Steady-State Operation

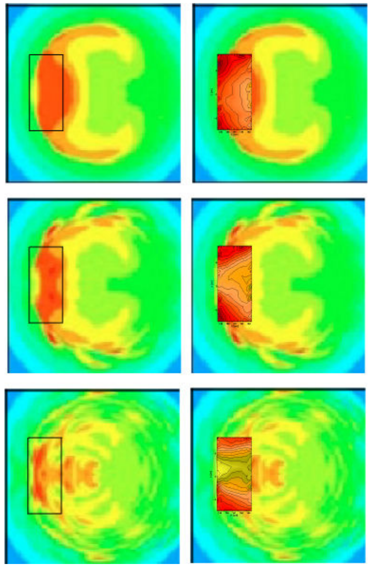
Comparison with the ballooning mode model

Low Field Side



- Similarities
  - Pressure finger in early stage of simulation at low field side (middle figure) is similar to those from 2-D images ("a sharp temperature point")
  - Reconnection zone is localized in the toroidal plane (1/3 of the toroidal direction is opened)
- Differences
  - Heat flow is highly collective in experiment and stochastic process of the heat diffusion is clear in simulation.

High Field Side

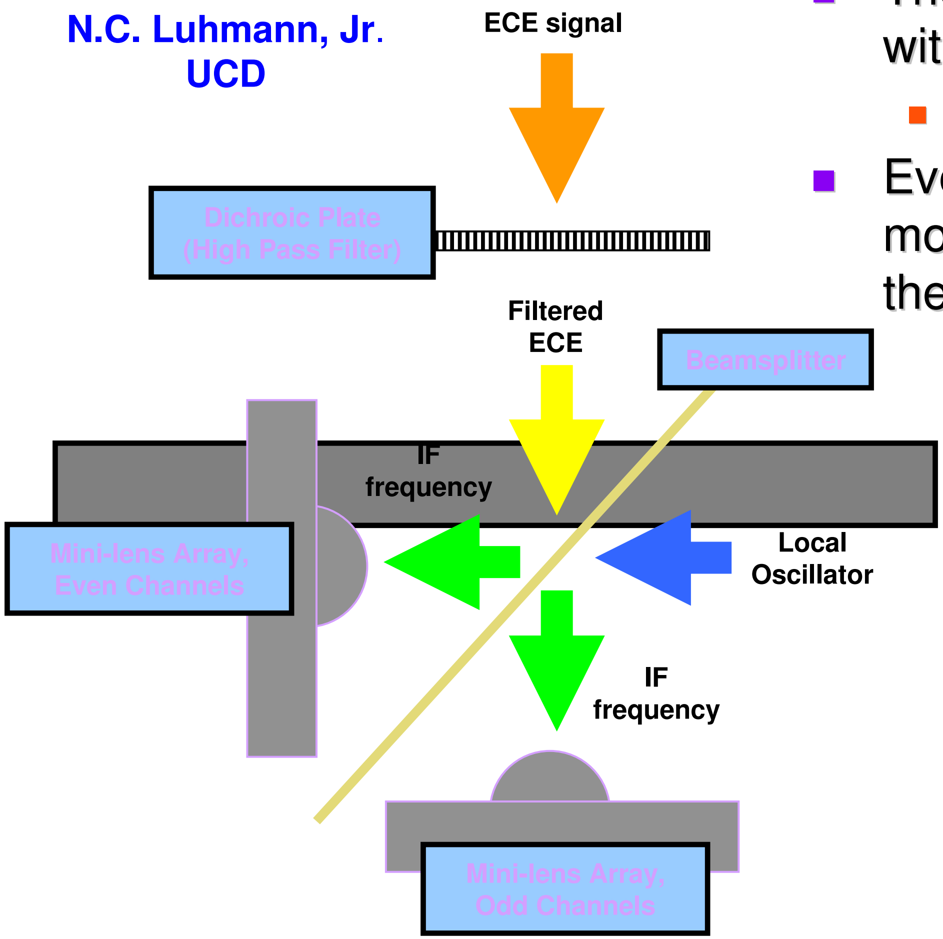


- Differences
  - Pressure bulge at the high field side is inhibited in simulation
  - Clear pressure finger at high field side from 2-D images but there should be weak (or no) activity of the ballooning mode at the high field side
  - Stochastic heat diffusion is clear in simulation but the heat flow is highly collective: stochastic process may not be the dominant mechanism for this case

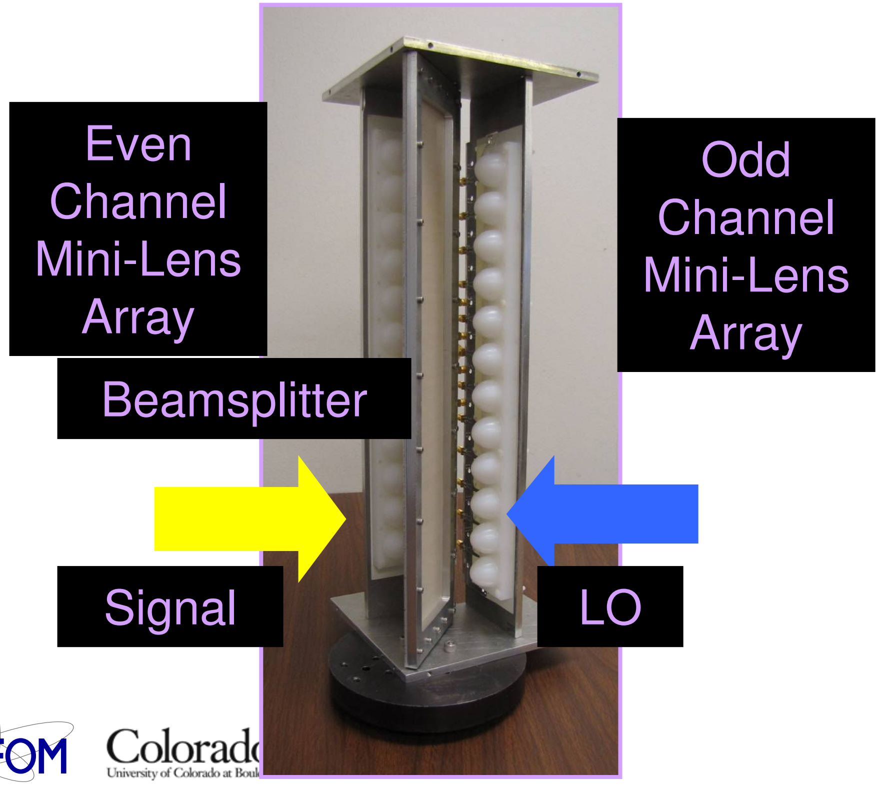
Y. Nishimura et. al.
W. Park et. al.

Mini-Lens based Array Detectors

N.C. Luhmann, Jr.
UCD

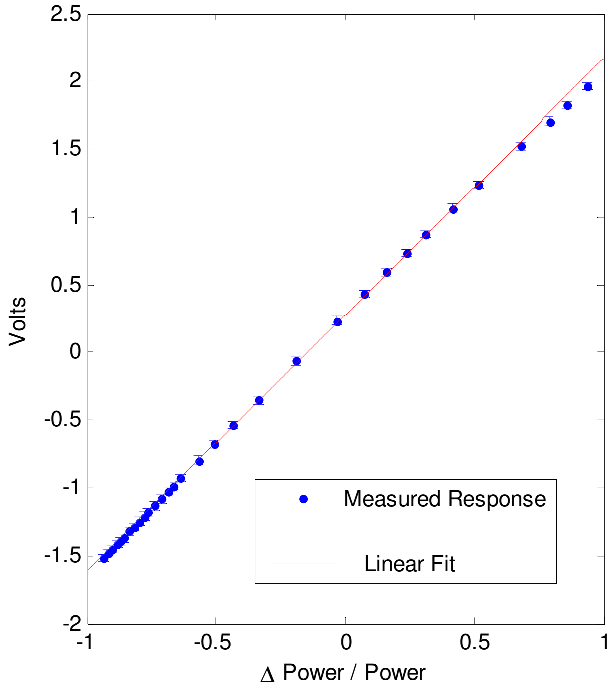


- The LO coupling beamsplitter is re-located within the array box
  - No wasted power, no LO beam dump
- Even and odd channels are separated for more relaxed vertical spacing, but imaged to the same plane

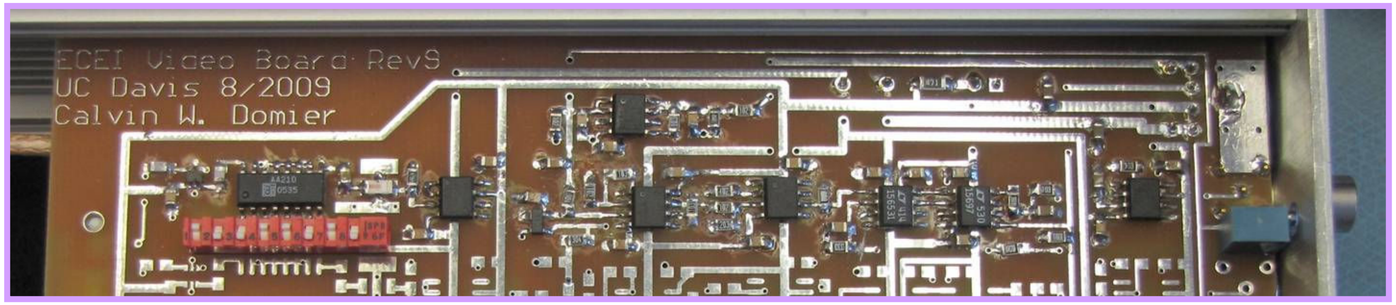


Improved Video Electronics

N.C. Luhmann, Jr.

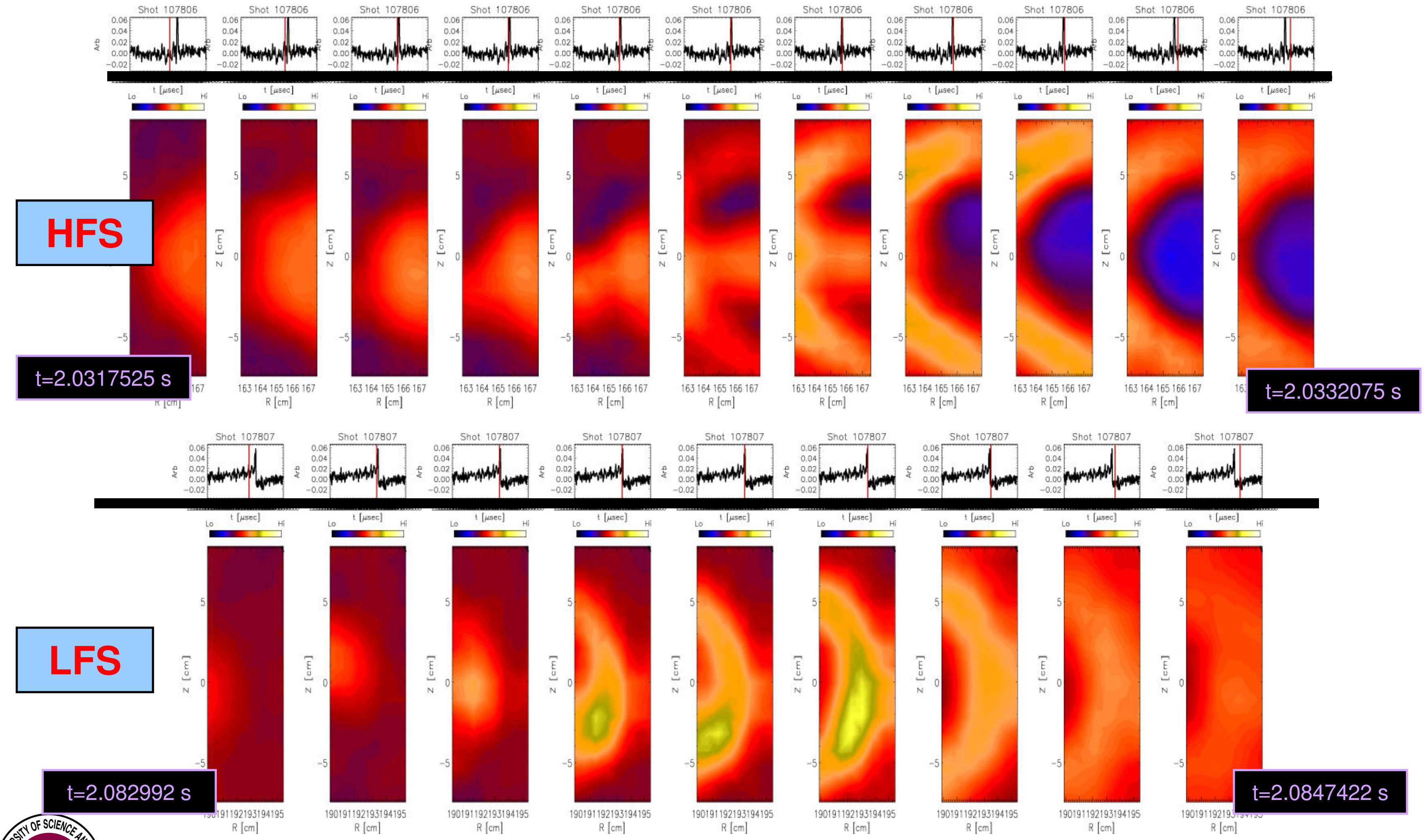


- Highly linear video response to temperature fluctuations up to 50%
- Video BW variable from 12.5 to 400 kHz and compatible with ±2.5 V digital acquisition
- Proprietary designs developed and tested at UC Davis



Center for Fusion Plasma Diagnostics & Steady-State Operation

Reconfirm “Crash” on Low and High Field Side

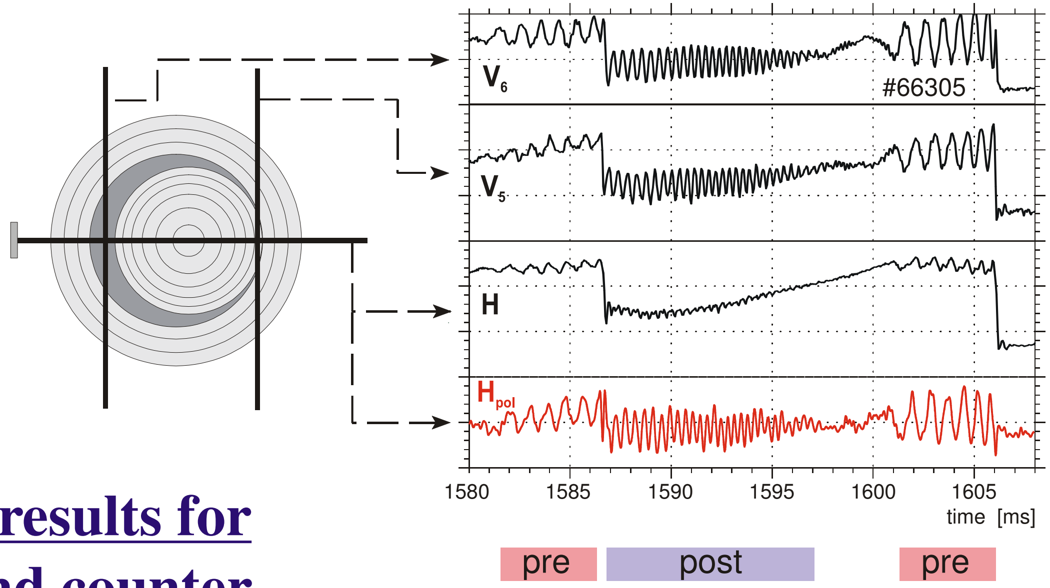


Center for Fusion
Plasma Diagnostics &
Steady-State Operation

T. Munsat

Sawtooth in NBI heated TEXTOR plasma

H. Soltwisch



Experimental results for balanced co- and counter-neutral beam injection

→ **large amplitude**
→ **low frequency**
of pre- and postcursor oscillations

mode characteristics appear to change rapidly (within <200 μs):

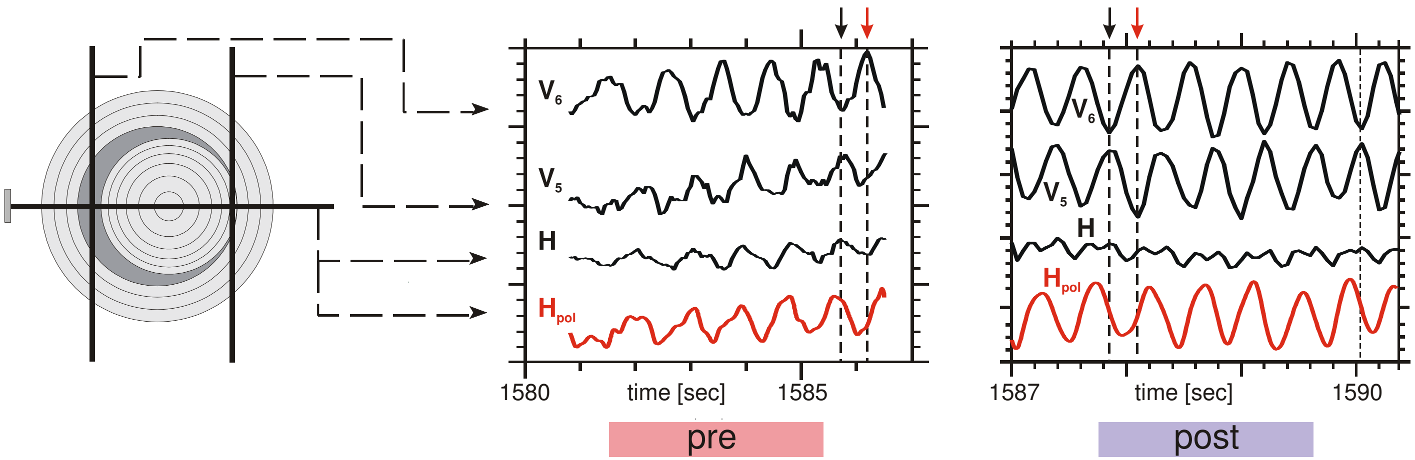
pre ***kink-like behaviour without indication of reconnexion***

post ***tearing-like behaviour with large saturated island***

Continue

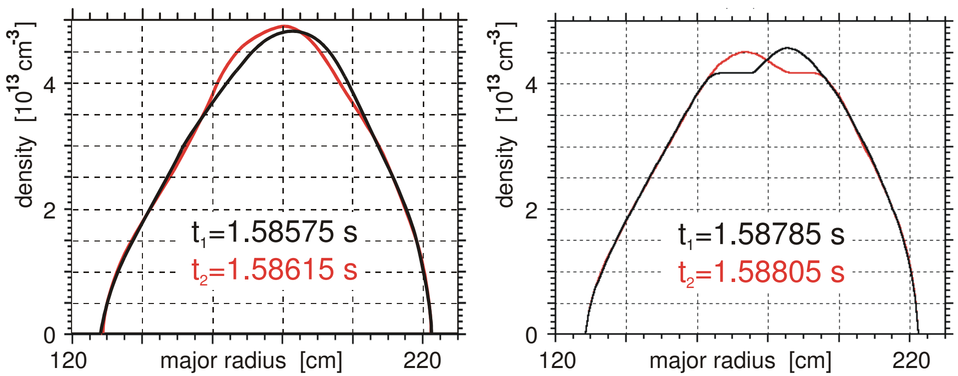
Expanded view of pre- and postcursors

H. Soltwisch

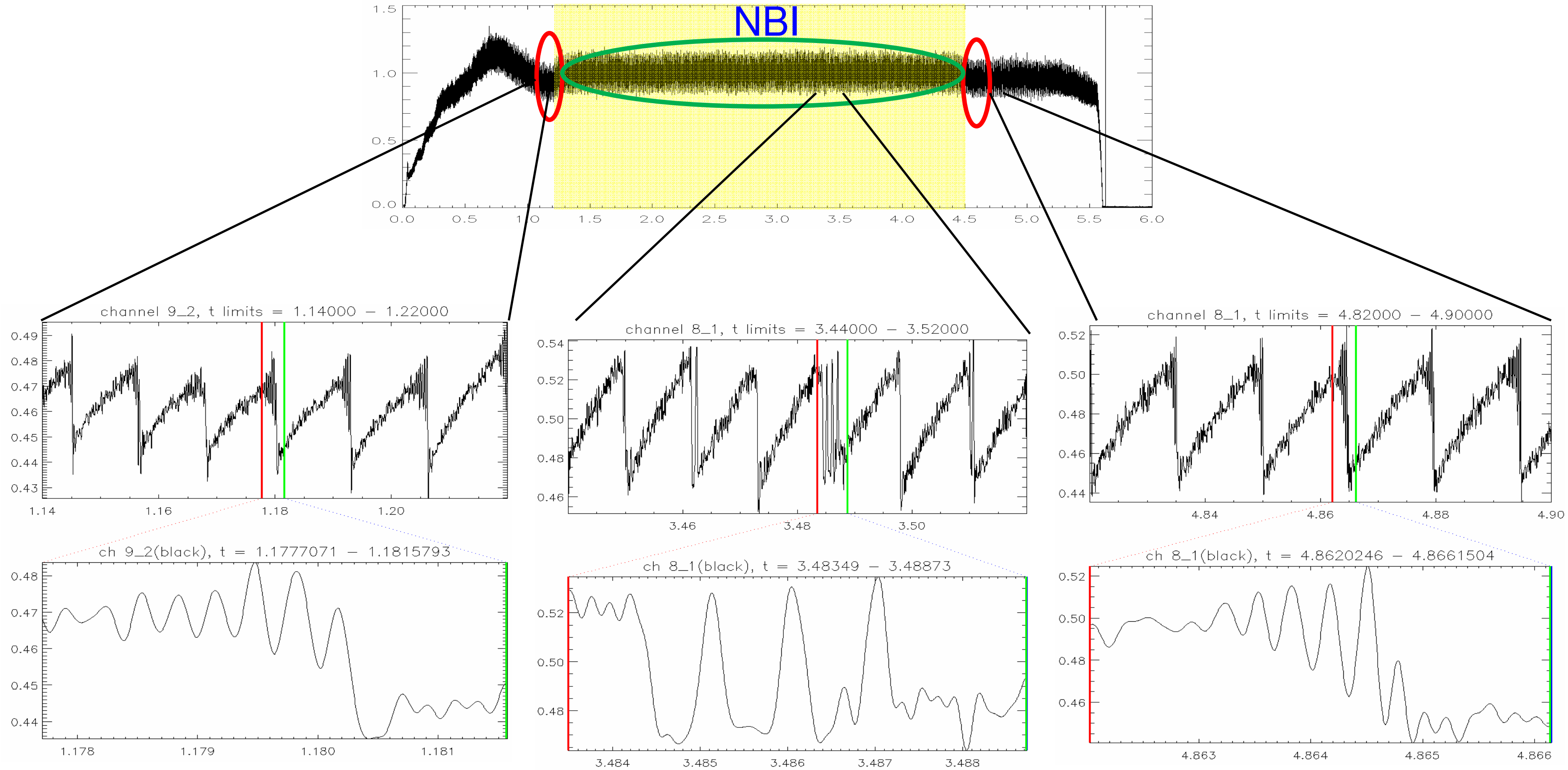


electron density profiles reconstructed by using all available channels of the interferometer

(assumption:
strictly circular contour lines)

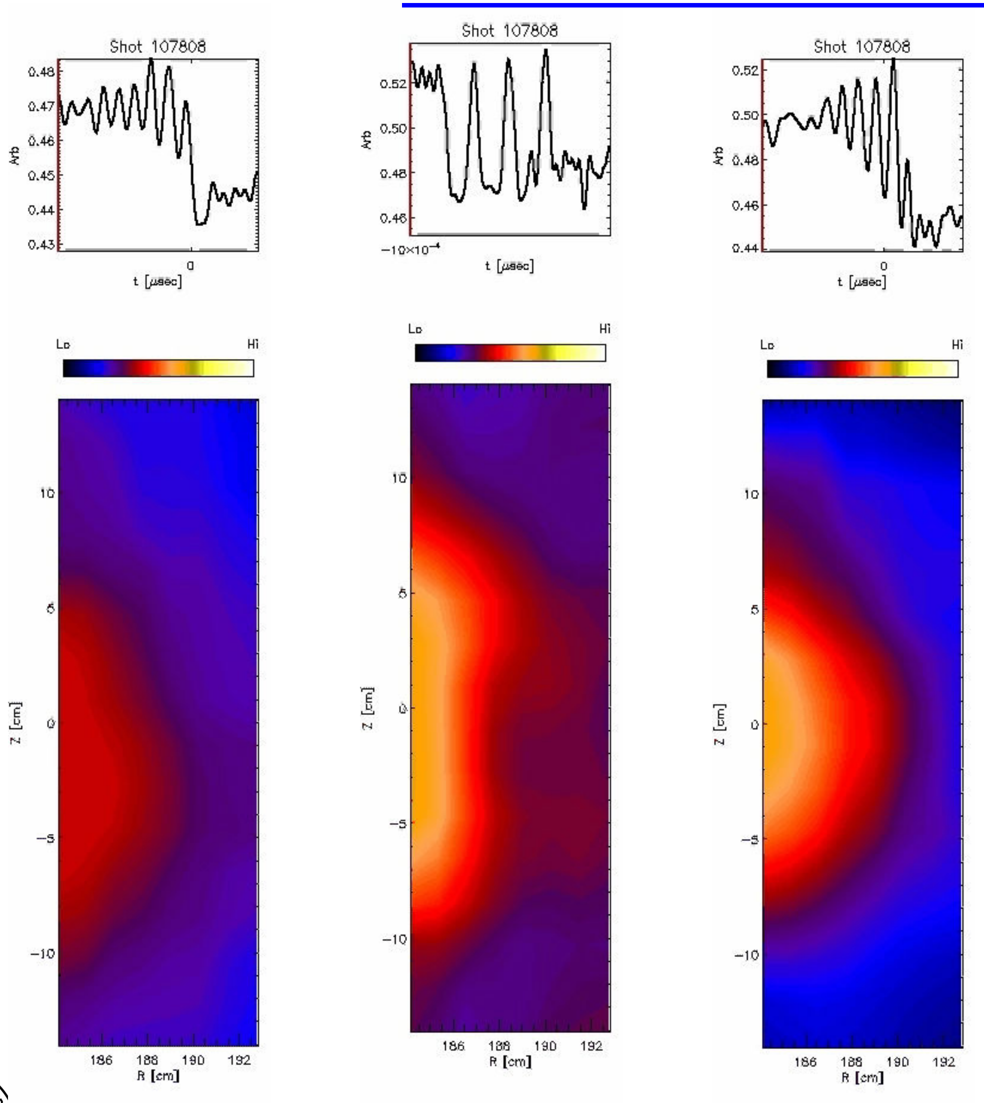


Precursor and Postcursor



Center for Fusion Plasma Diagnostics & Steady-State Operation

Low field side event



Core current density modification by NBI

Precursor phase

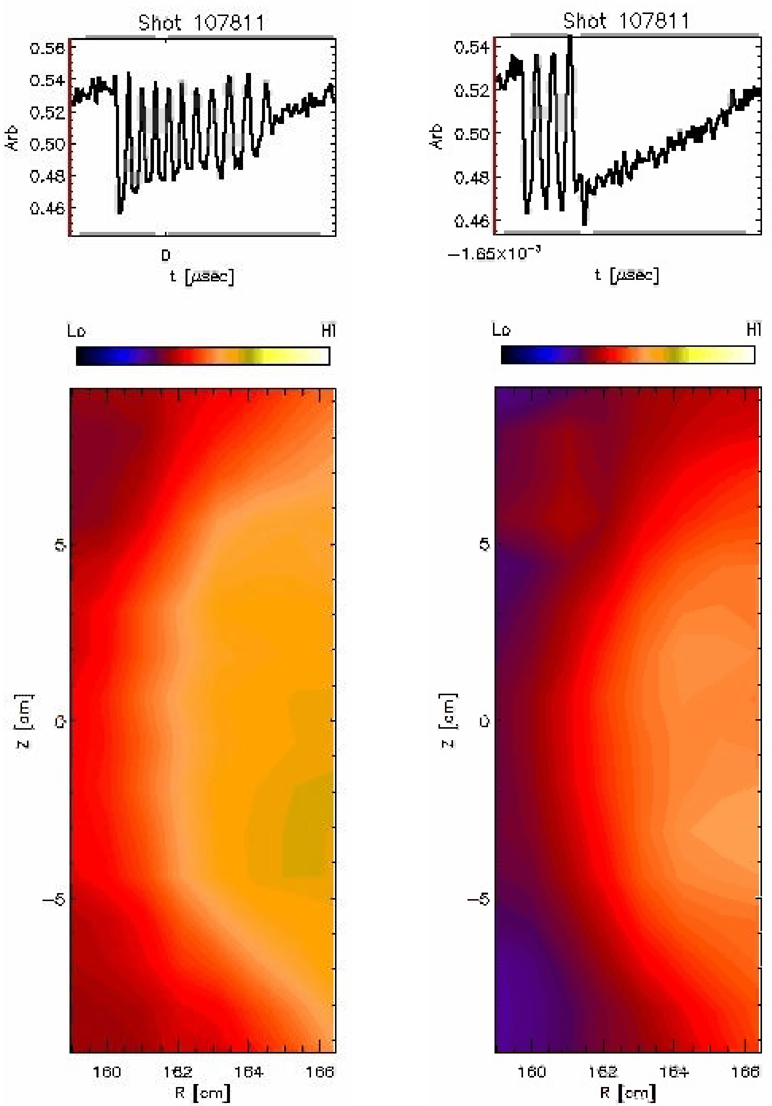
Rotation is CW with ~300 μsec. period

No clear reconnection Before crash time

Postcursor phase

Rotation is CCW with ~1 msec. period

Reconnection zone is reduced and heat leaks



High field side event

Core current density modification by NBI

Precursor phase

Similar to LFS

Postcursor phase

Rotation is CCW with ~1 msec. period

Reconnection zone is reduced and heat leaks through sustained but reduced reconnection zone

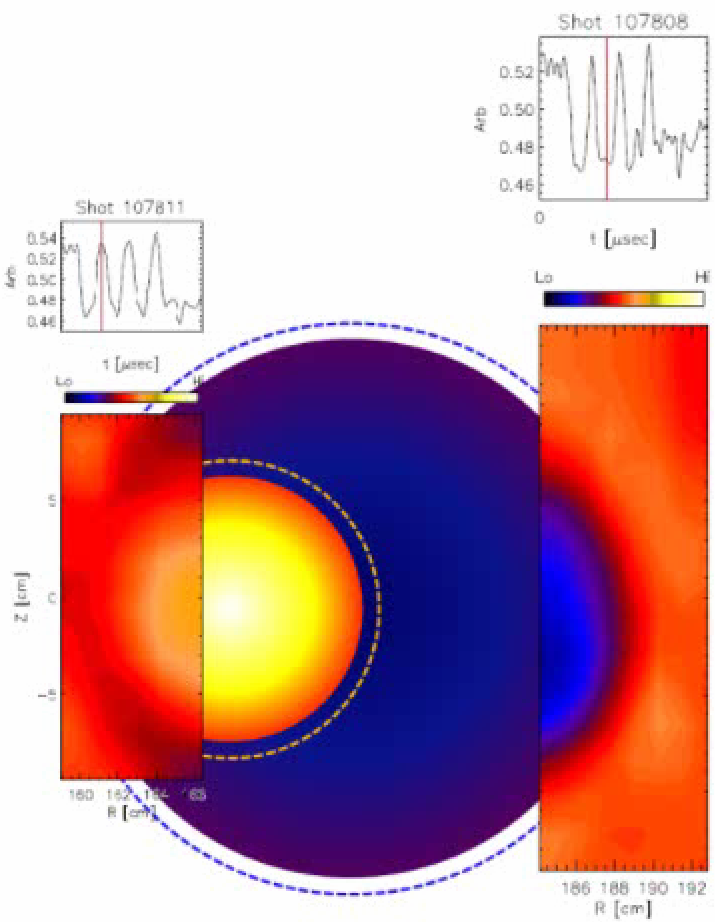
Reconstruction the post-crash phase

High Field Side

First reconnection is not complete

First crash is toward top

Remnants of the m=1 mode survives for ~1.5 msec while the reconnection zone Is reduced.



Low Field Side

First reconnection is not complete

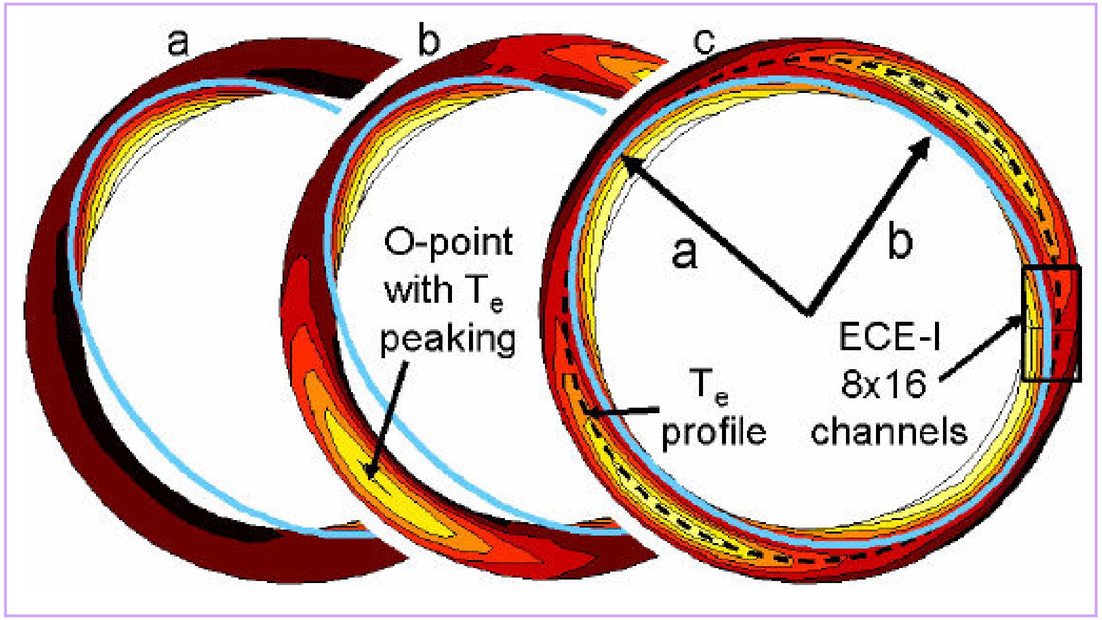
First crash is away from this view

Remnants of the m=1 mode survives for ~1.5 msec while the reconnection zone Is reduced.

Center for Fusion Plasma Diagnostics & Steady-State Operation

UCDAVIS FOM Colorado University of Colorado at Boulder

Imaging and Control of Magnetic Islands

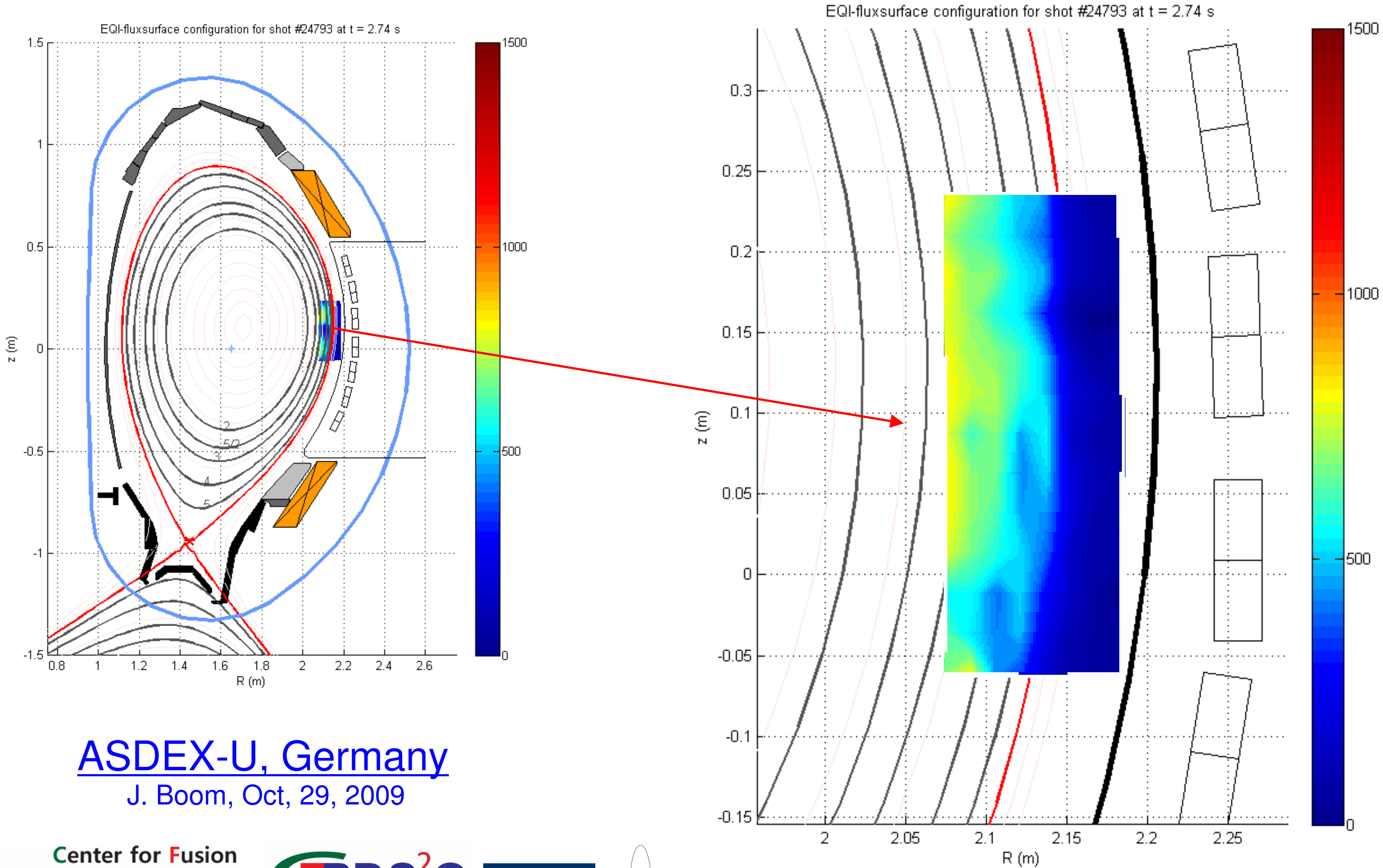


I. Classen et al., PRL 98, 035001 (2007)

- More recently, similar techniques have been used to reconstruct magnetic islands in TEXTOR plasmas.
- ECEI enables extraction of island parameters and helps to demonstrate the effects of ECRH on these structures.

Observation of ELMS with ECE-Imaging

Preliminary result !

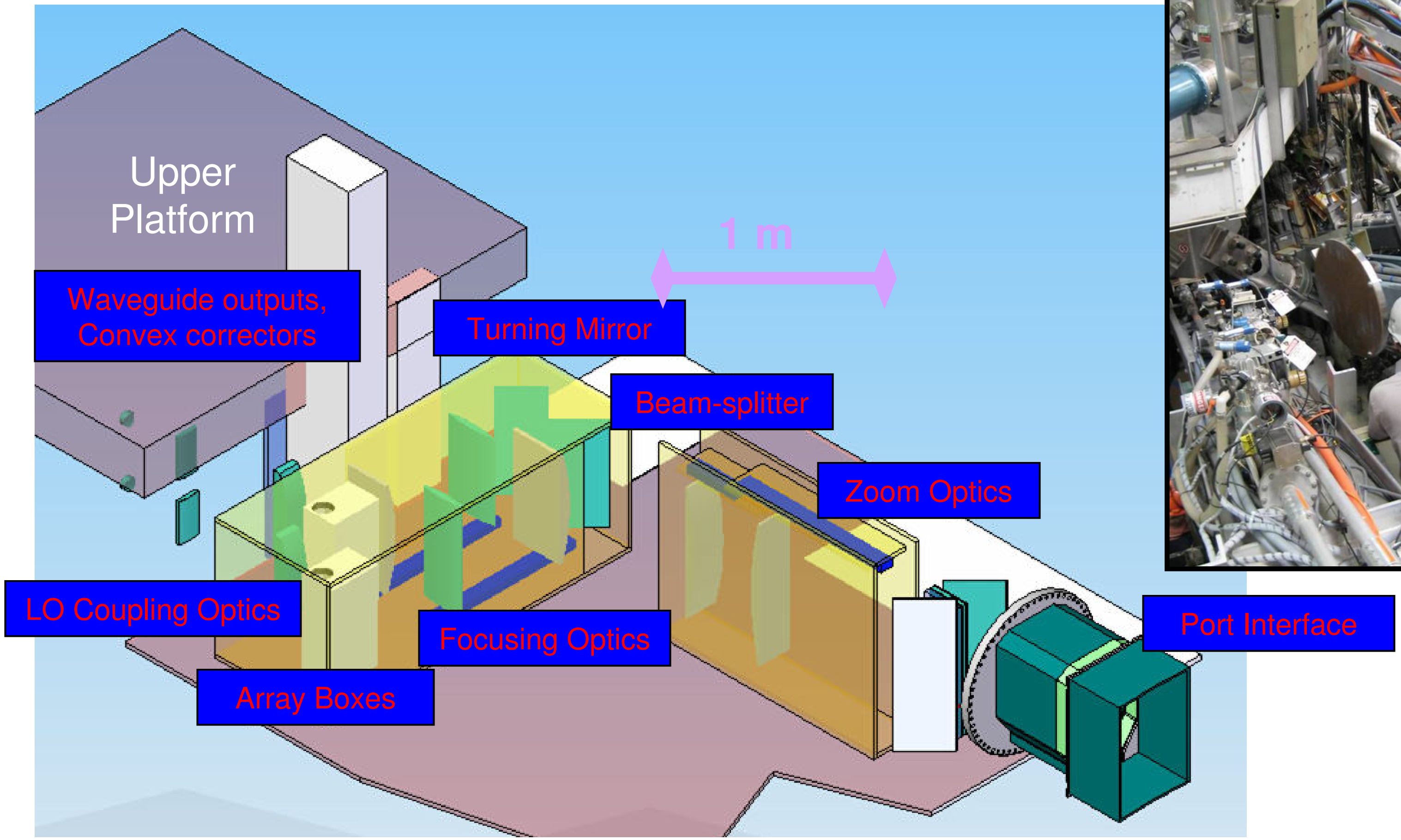


ASDEX-U, Germany

J. Boom, Oct, 29, 2009

Center for Fusion Plasma Diagnostics & Steady-State Operation

Dual-Array ECEI on DIII-D

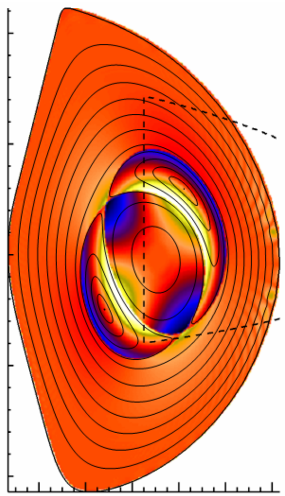


Commissioned in March 2010

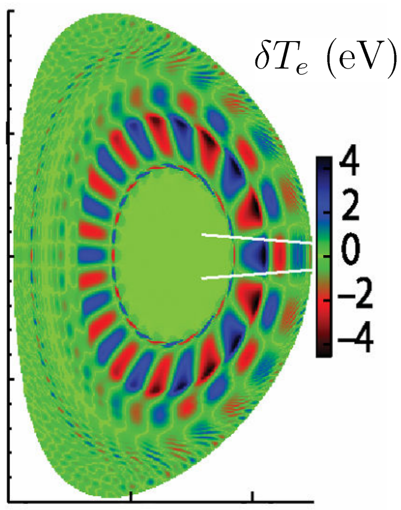
Center for Fusion Plasma Diagnostics & Steady-State Operation

Imaging of 2D Alfven waves

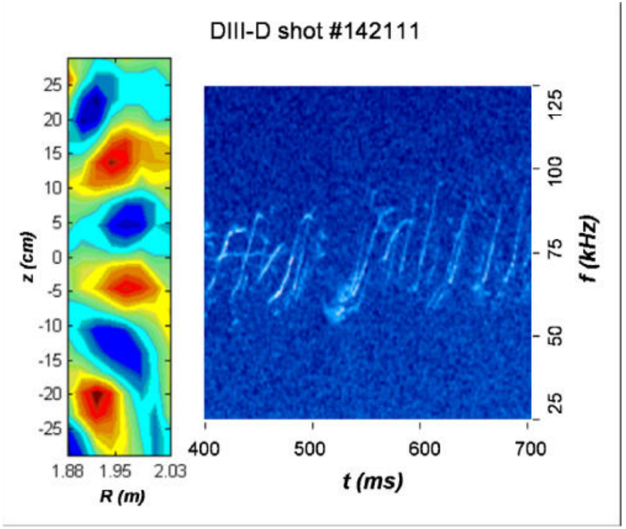
- Direct 2D visualization of core MHD perturbation structures
- Smaller amplitude perturbations (<10 eV) such Alfven eigenmodes may be possible to image by integrating the ECEI signal over time.



Tearing mode structure at DIII-D
M.A. Van Zeeland et al, Nucl. Fusion 48 (2008) 092002



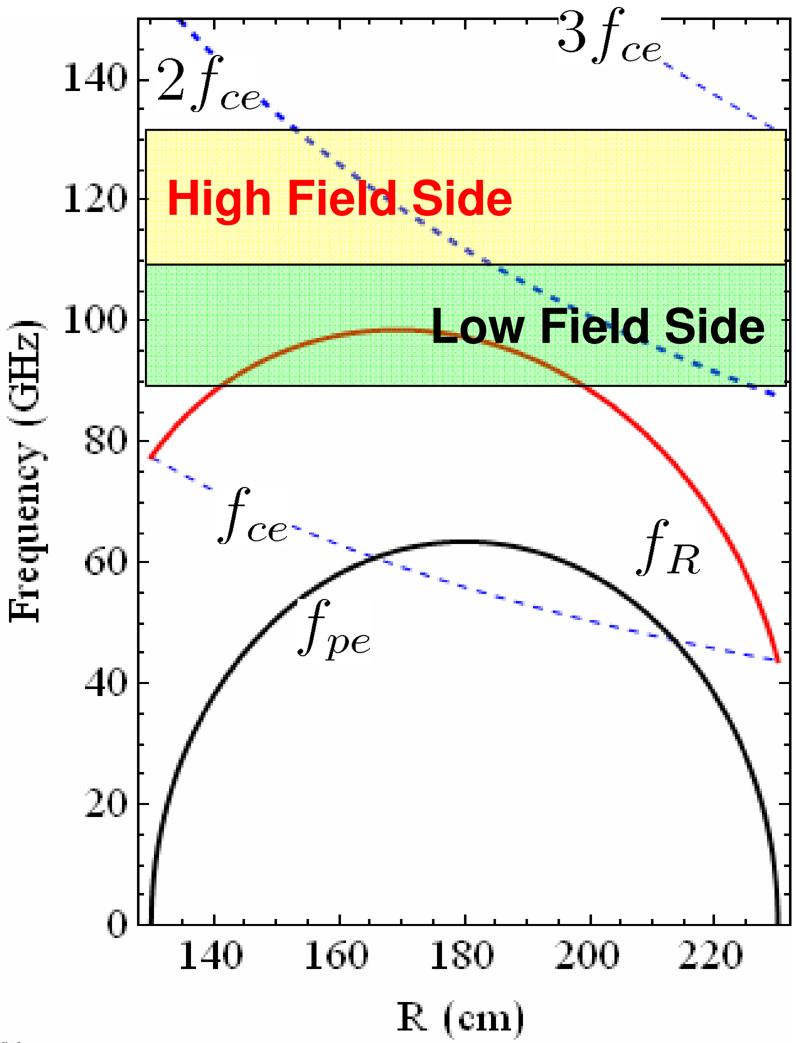
n=3 Toroidal Alfven eigenmode
M.A. Van Zeeland et al, PRL 97, 135001 (2006)

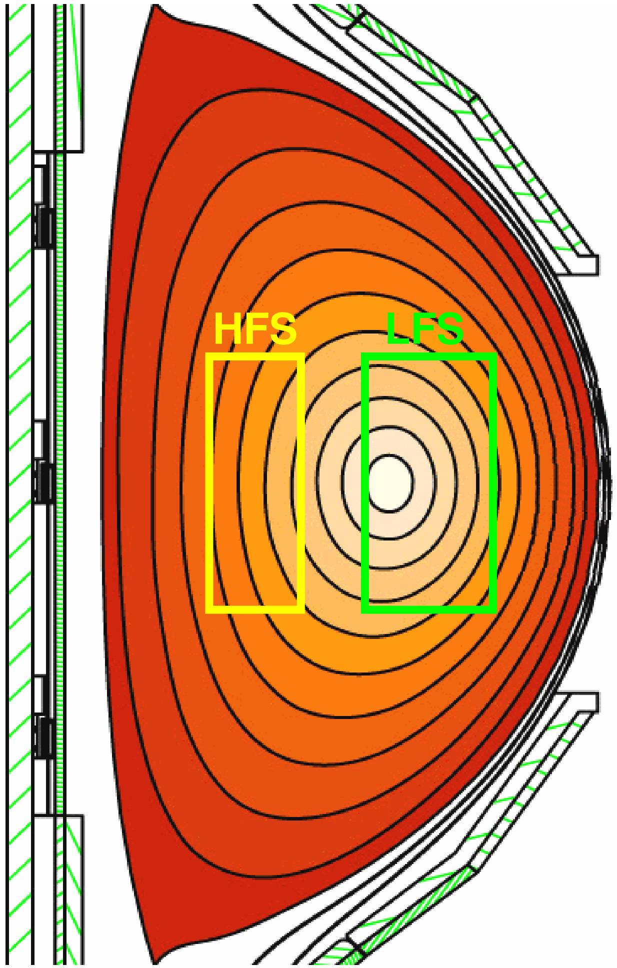


2D structure of RS Alfven eigenmode by ECEI system from DIII-D (similar measurement was achieved in ASDEX-UG

Center for Fusion Plasma Diagnostics & Steady-State Operation

KSTAR ECEI View Window (B_0=2.0 T)

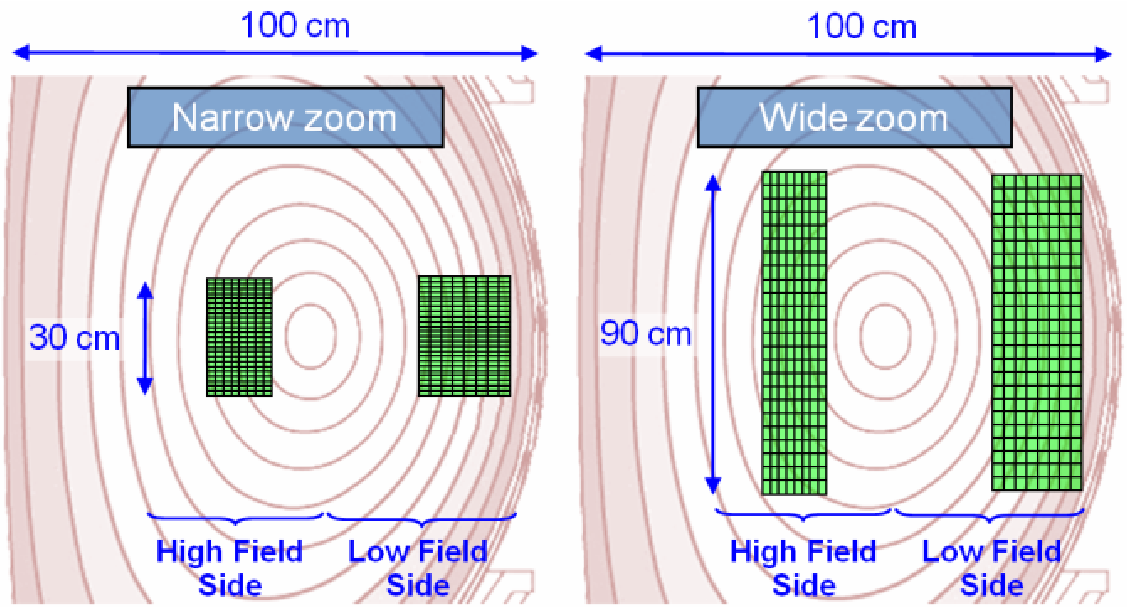




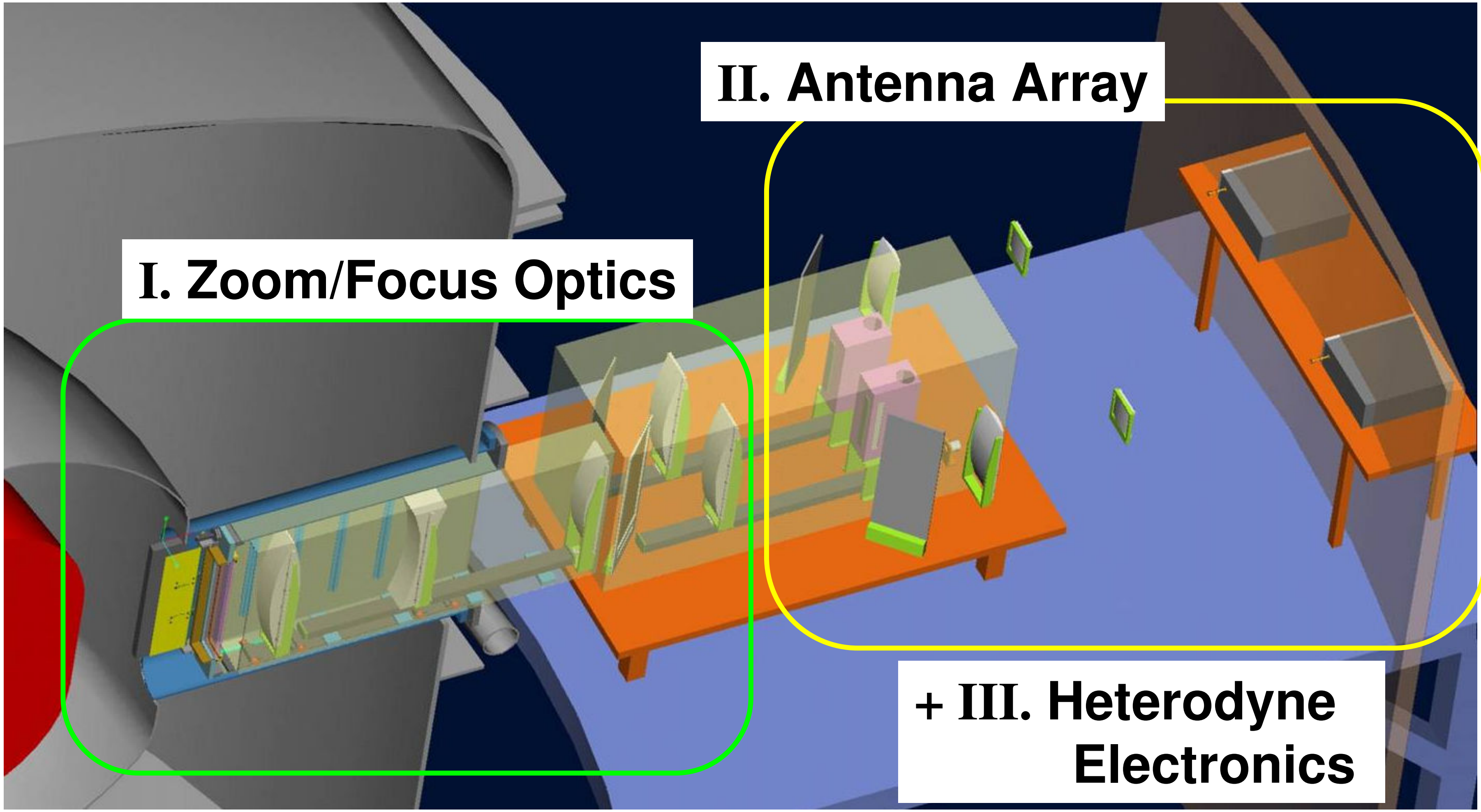
Operation Scenario

- Simultaneous imaging of LFS and HFS
  - Vertical zoom selection: 30—90 cm
  - Radial focus selection:
    - 90—110 GHz (R = 220—180 cm) for LFS
    - 110—130 GHz (R = 180—155 cm) for HFS

- Video bandwidth (Bv) selection: 12.5 – 400 kHz (digitizer sampling rate will be ~3xBv)



KSTAR ECEI System



Installation is in progress

Center for Fusion Plasma Diagnostics & Steady-State Operation
UC DAVIS FOM Colorado University of Colorado at Boulder

Summary

- New and comprehensive visualization diagnostics
  - ECE Imaging for T_e fluctuation
- Sawtooth physics and MHDs
  - Comprehensive comparison with theoretical models demonstrates shortcomings of each models (TEXTOR)
  - Counter NBI - effect of core current density on the growth rate and plasma rotation change due to external toroidal momentum (TEXTOR)
  - Study of m=2 mode (TEXTOR)
  - Example of edge application (ELMs via ECEI system on ASDEX-UG) – optical thickness issue will be imposed in interpretation.
- Improved technology and new experiments
  - New detection system and improved electronics tested on TEXTOR
  - DIII-D system has been commissioned (2D Alfven waves, e.g. ASDEX-UG)
  - KSTAR system will be commissioned in August, 2010