Plasma Visualization Diagnostics for KSTAR: ECEI and MIR

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University of California at Davis

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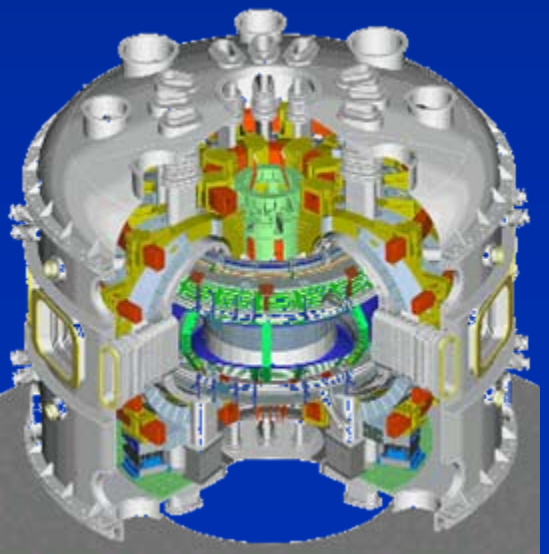

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DIAGNOSTICS
GROUP

Outline

- Introduction and Overview
- Diagnostic Principles
  - T_e Measurements via ECEI
  - n_e Measurements via MIR and MDIR
- Experience on Previous and Current Systems
- Ongoing Development Activities
- Low Field (~2 T) and High Field (3-3.5 T) Conceptual Designs
- Diagnostic Development Plan

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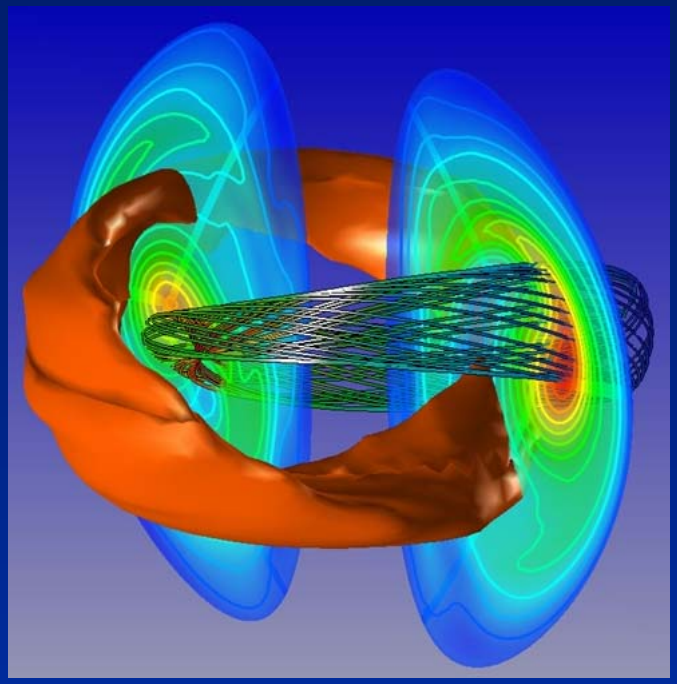
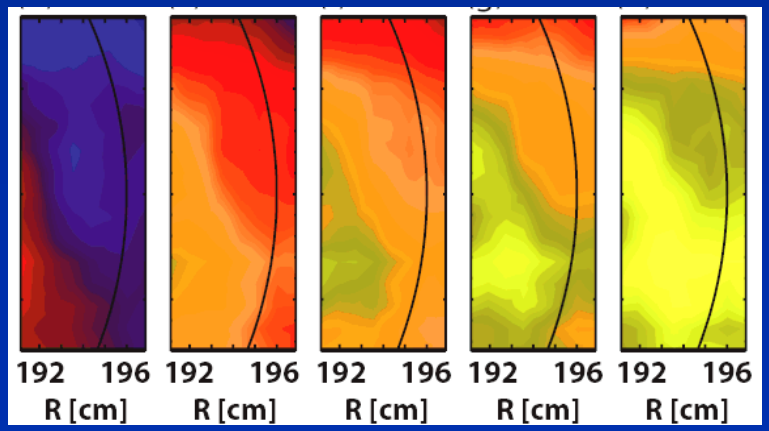
Introduction and Motivation





- A unique window of opportunity exists on KSTAR for fundamental understanding of MHD and turbulence not possible with ITER and future burning plasma experiments
  - Excellent port access
  - Advances in 3-D simulation capability
  - Advances in imaging diagnostics capability
- 2-D plasma microwave imaging tools
  - Electron Cyclotron Emission Imaging (ECEI)
  - Microwave Imaging Reflectometry (MIR)
  - Microwave Doppler Imaging Reflectometry (MDIR)

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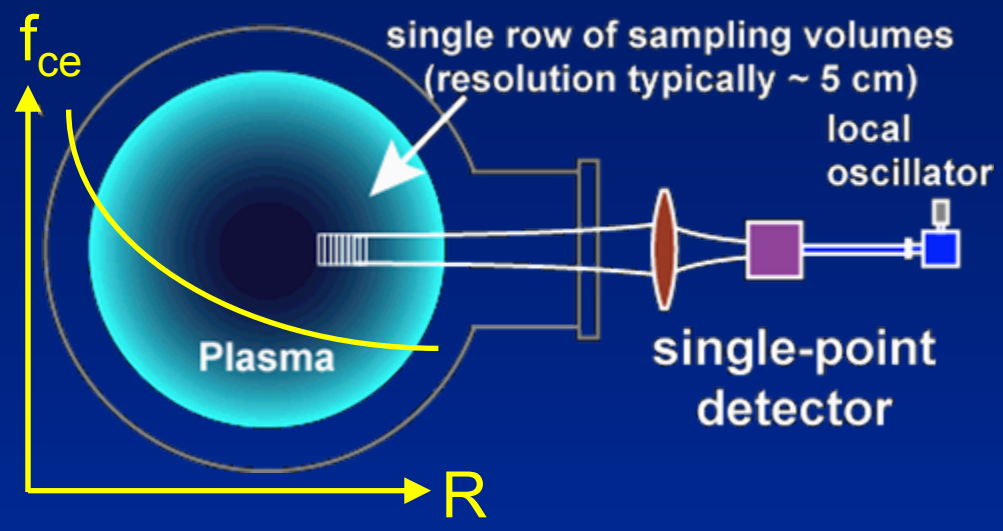
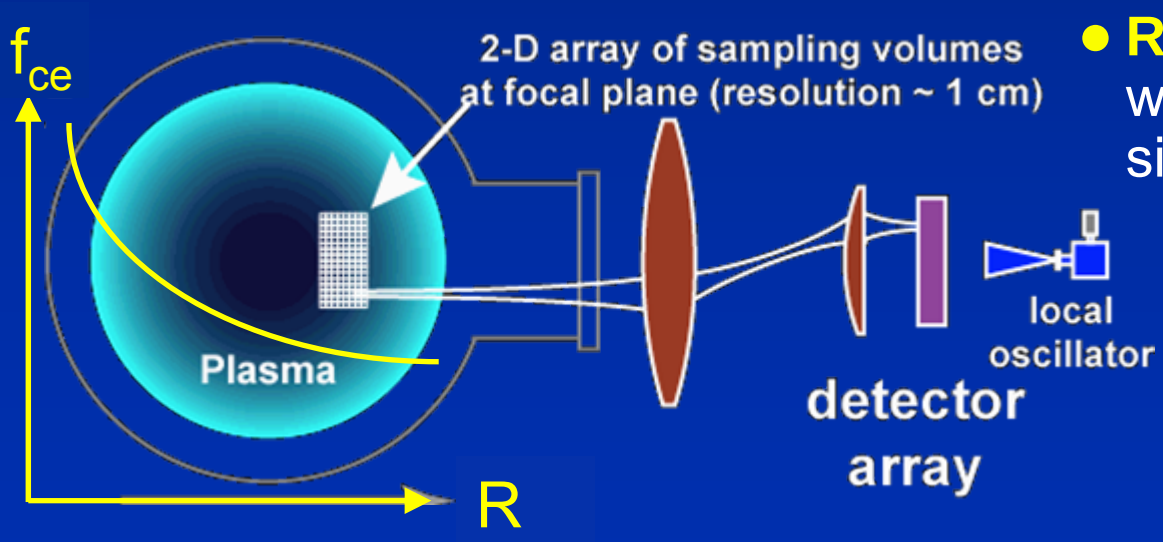
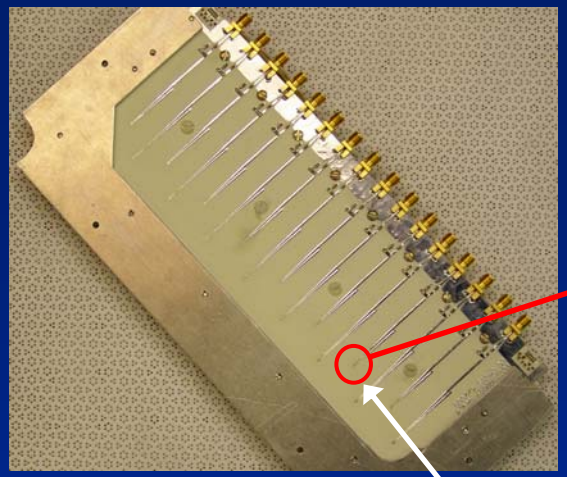
2-D ECE Imaging (ECEI)

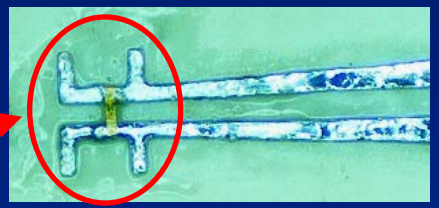


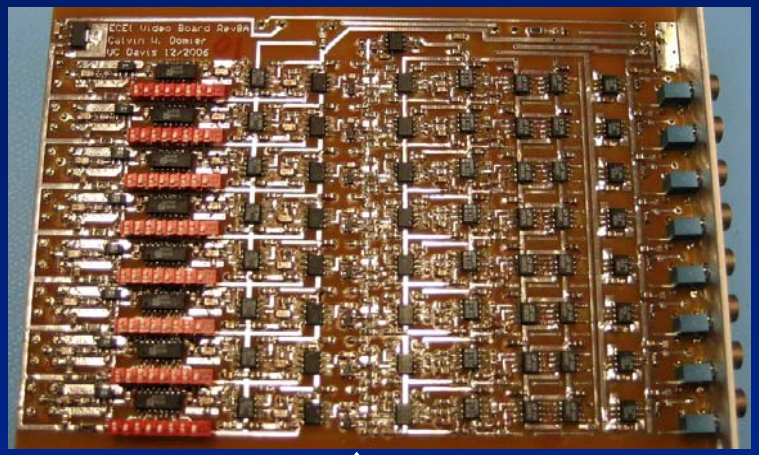


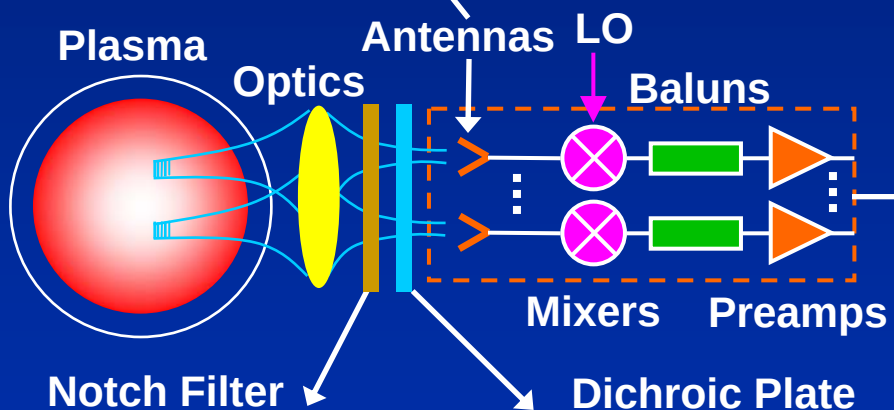
- In conventional 1-D ECE radiometry, a single antenna receives all frequencies. In ECEI, a vertically aligned antenna/ mixer array is employed as the receiver.
- Advantages: **high spatial and temporal resolution, 2-D correlation.**
- **Real time 2-D imaging** using wideband IF electronics and single sideband detection.
  - 16×8=128 channels on ASDEX-UG
  - 20×16=320 channels on DIII-D
  - 24×32=768 channels envisaged for KSTAR

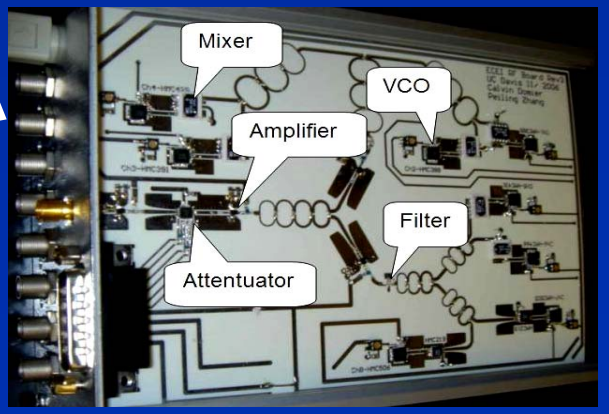
ECEI System Overview – TEXTOR



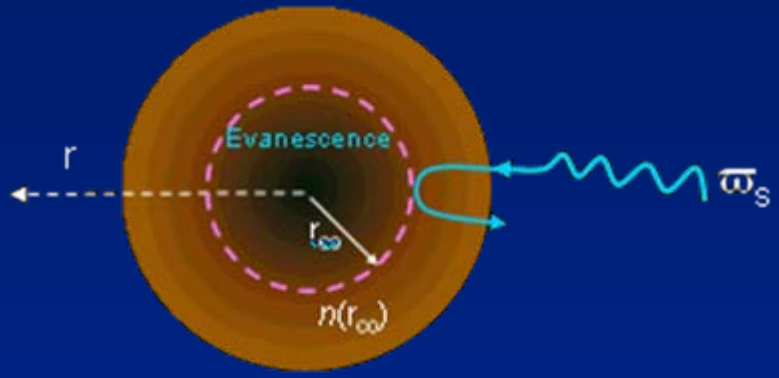




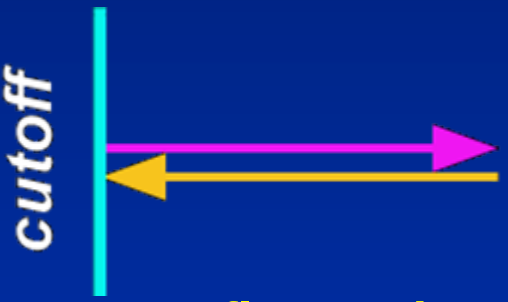




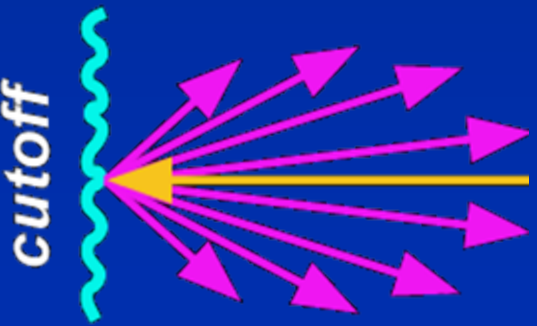
Imaging Fluctuation Reflectometry



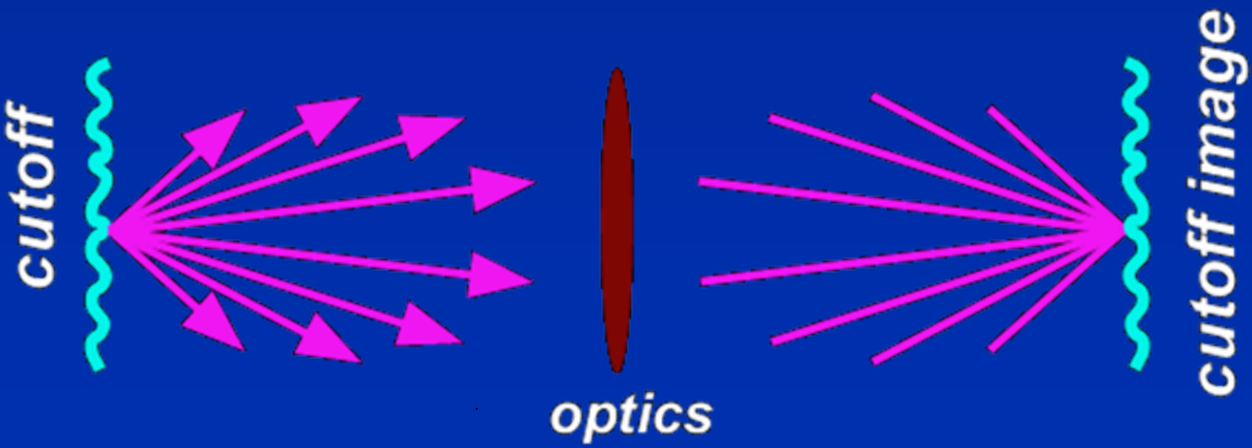
- Microwave reflections from plasma cutoffs contain information on density fluctuations near the cutoff layer
- 1-D fluctuations: simple mirror-like interpretation
- 2-D fluctuations: the received signal is corrupted by interference from multiple reflected waves
- Imaging can restore phase fronts!



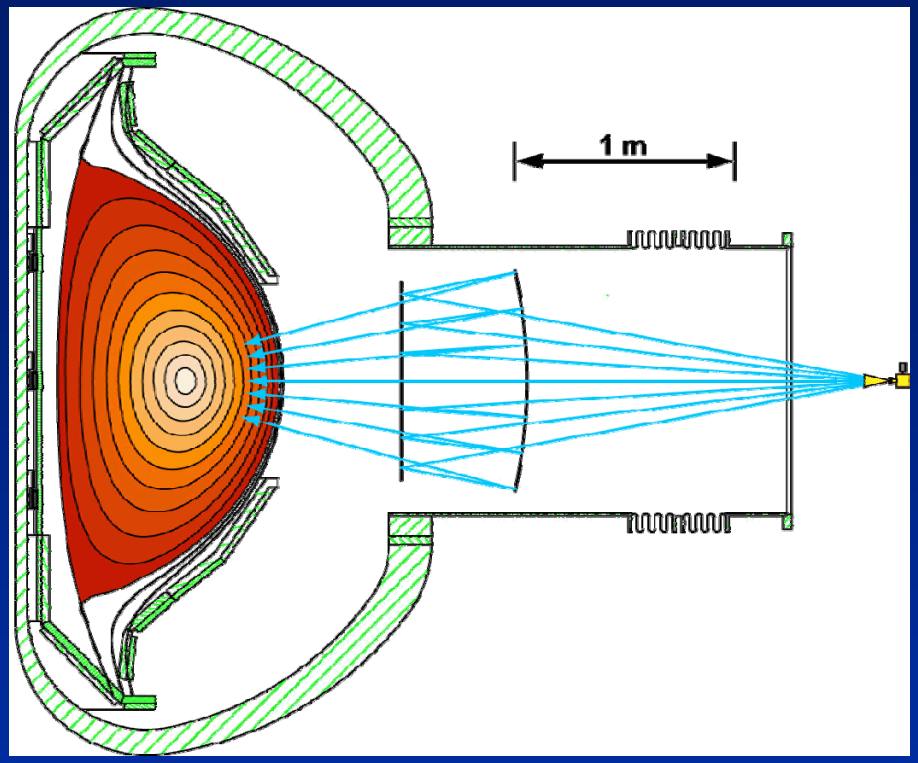
1-D fluctuations

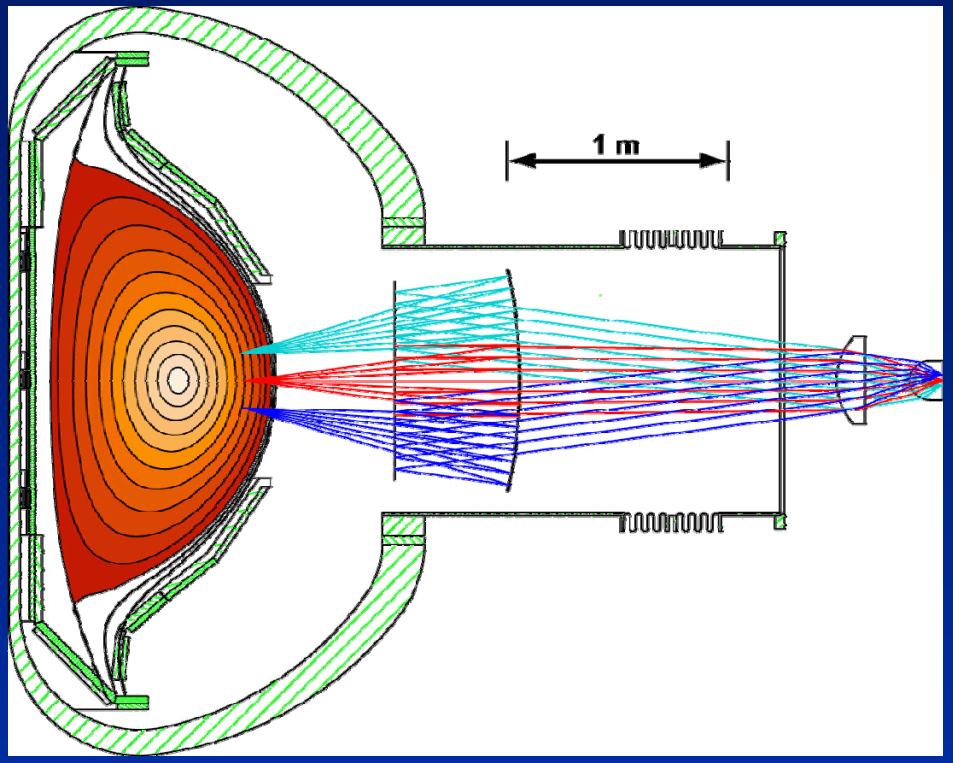


2-D fluctuations



Microwave Imaging Reflectometry (MIR)

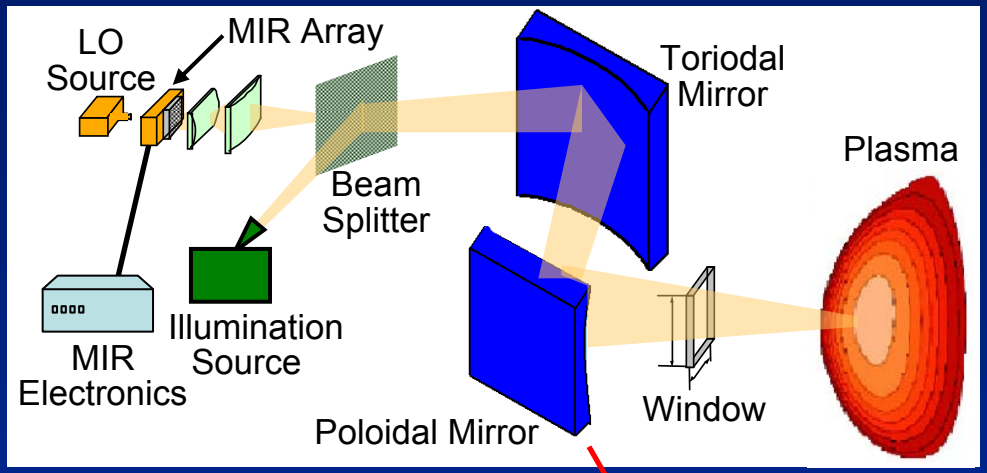


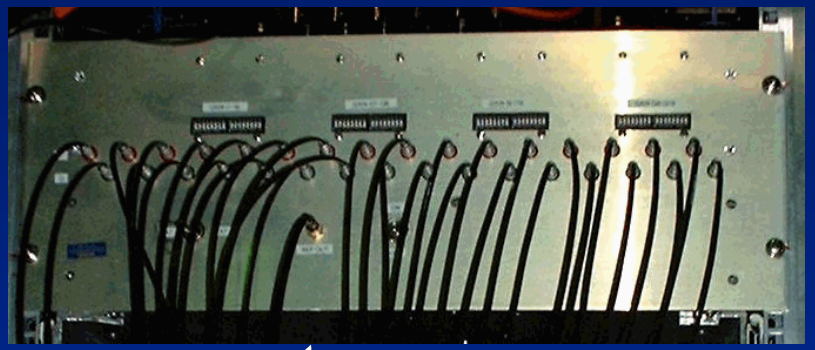


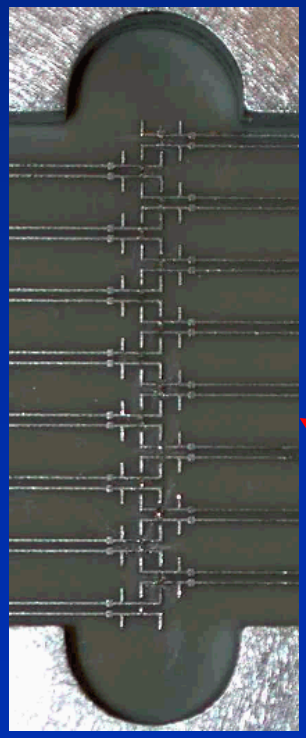
- Probing beam illuminates extended region of cutoff layer
- Beam curvature matched (toroidal and poloidal) to that of the cutoff surface

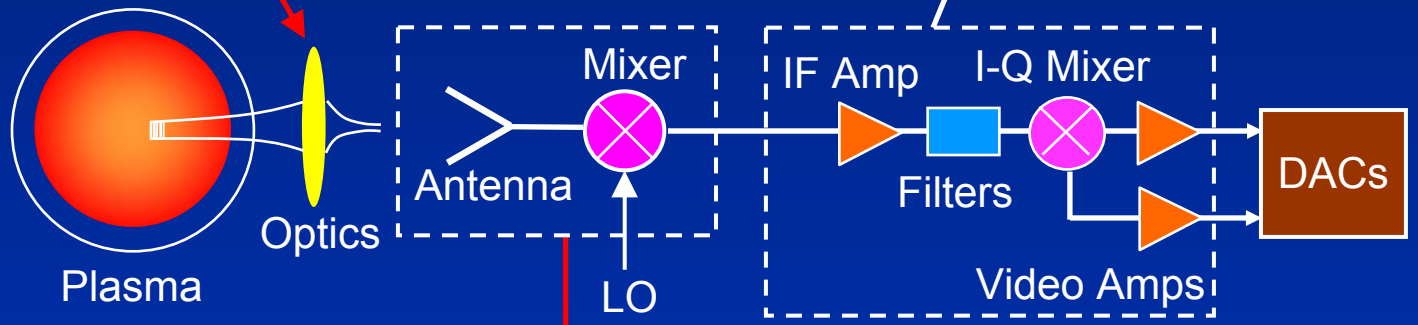
- Cutoff layer imaged onto array of detectors (3 elements shown), eliminating interference effects
- Detection system shares the same plasma-facing optics

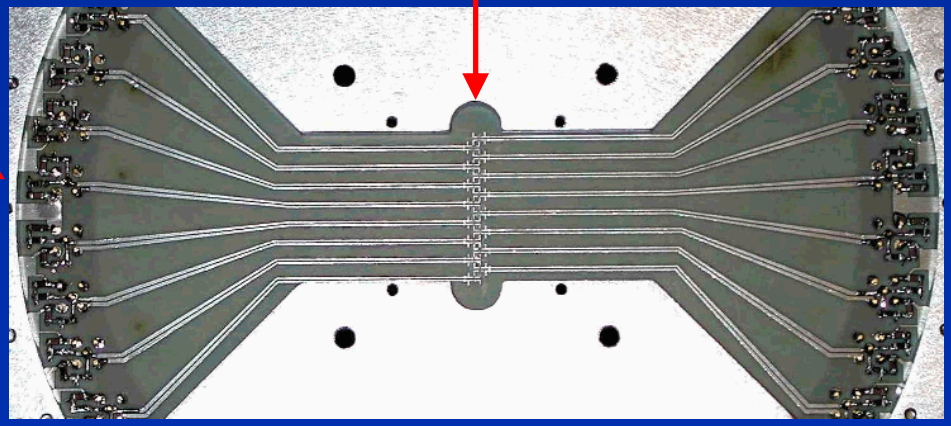
MIR System Overview - TEXTOR



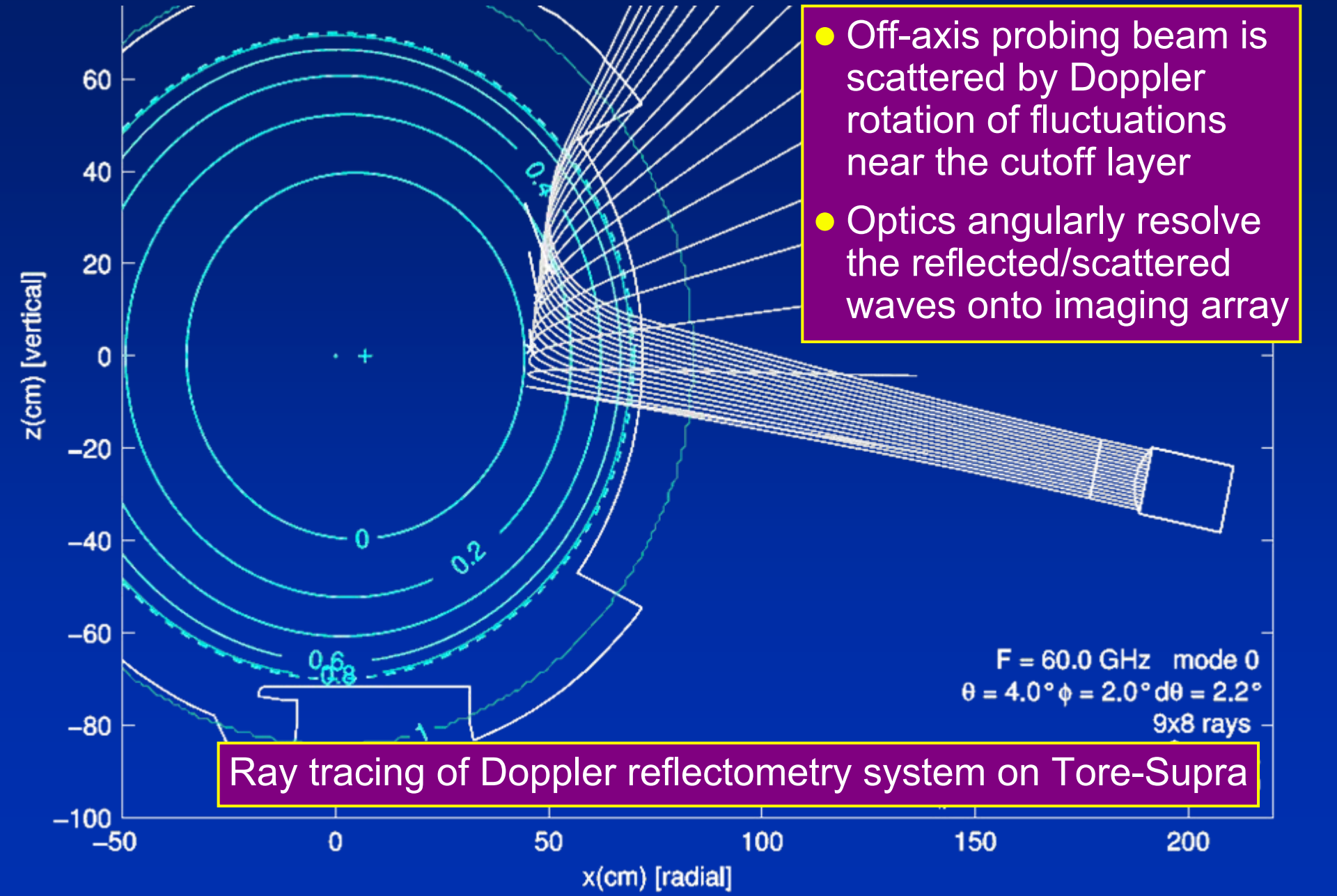








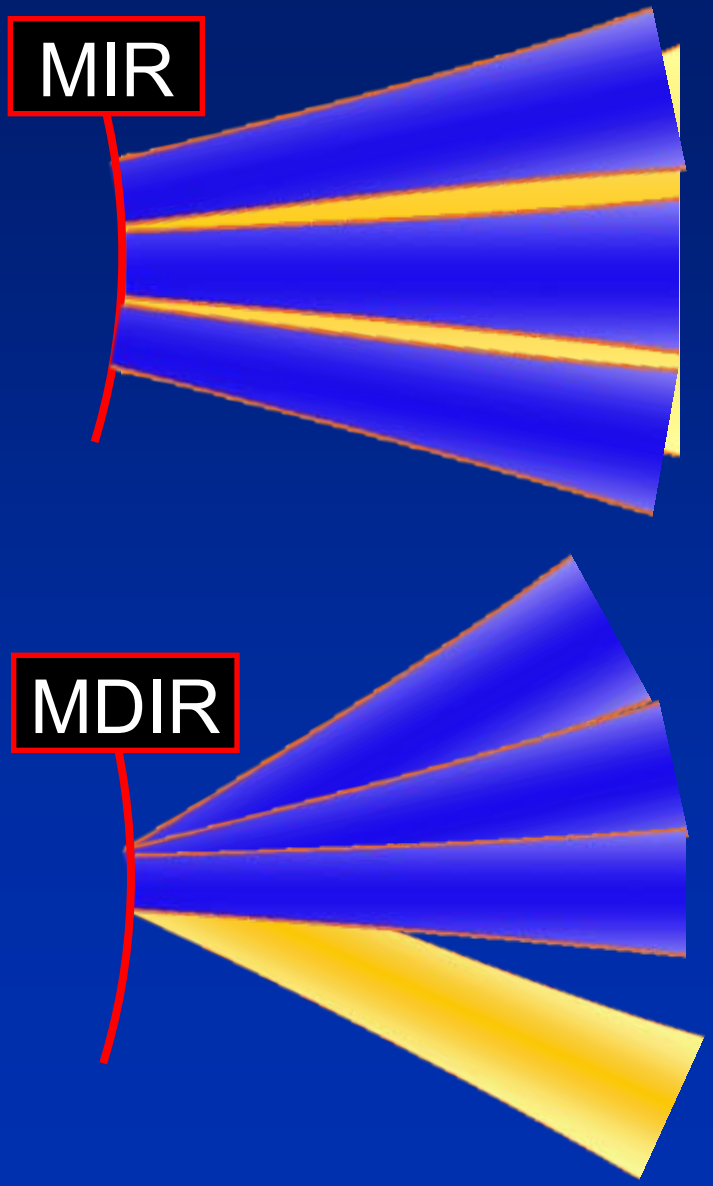
Microwave Doppler Imaging Reflectometry



- Off-axis probing beam is scattered by Doppler rotation of fluctuations near the cutoff layer
- Optics angularly resolve the reflected/scattered waves onto imaging array

Ray tracing of Doppler reflectometry system on Tore-Supra

Comparison Between MIR and MDIR



- Common features
  - Planar imaging array
  - Large aperture optics
  - Multiple frequencies to probe multiple cutoff layers
- Major differences
  - MDIR illumination beam is narrower, and tilted with respect to plasma midplane
  - MDIR probes poloidal scattering angle rather than vertical position

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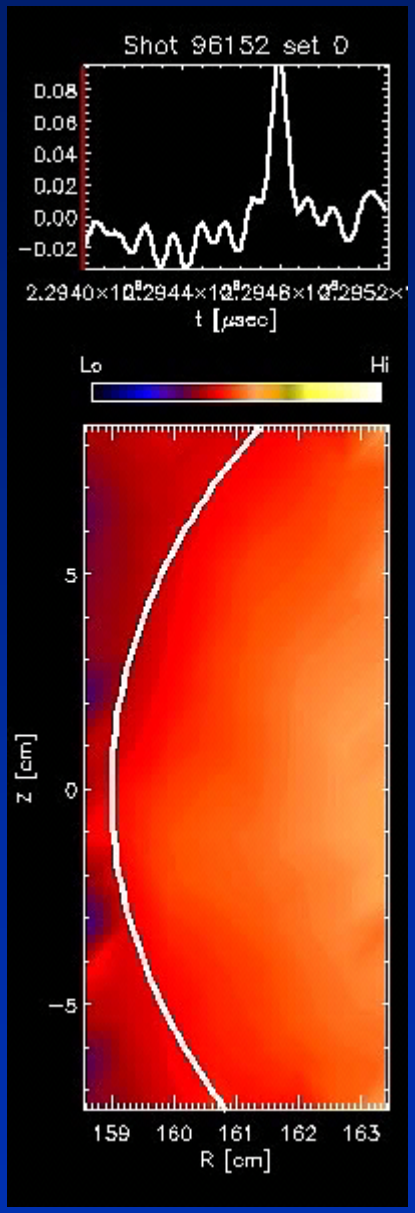
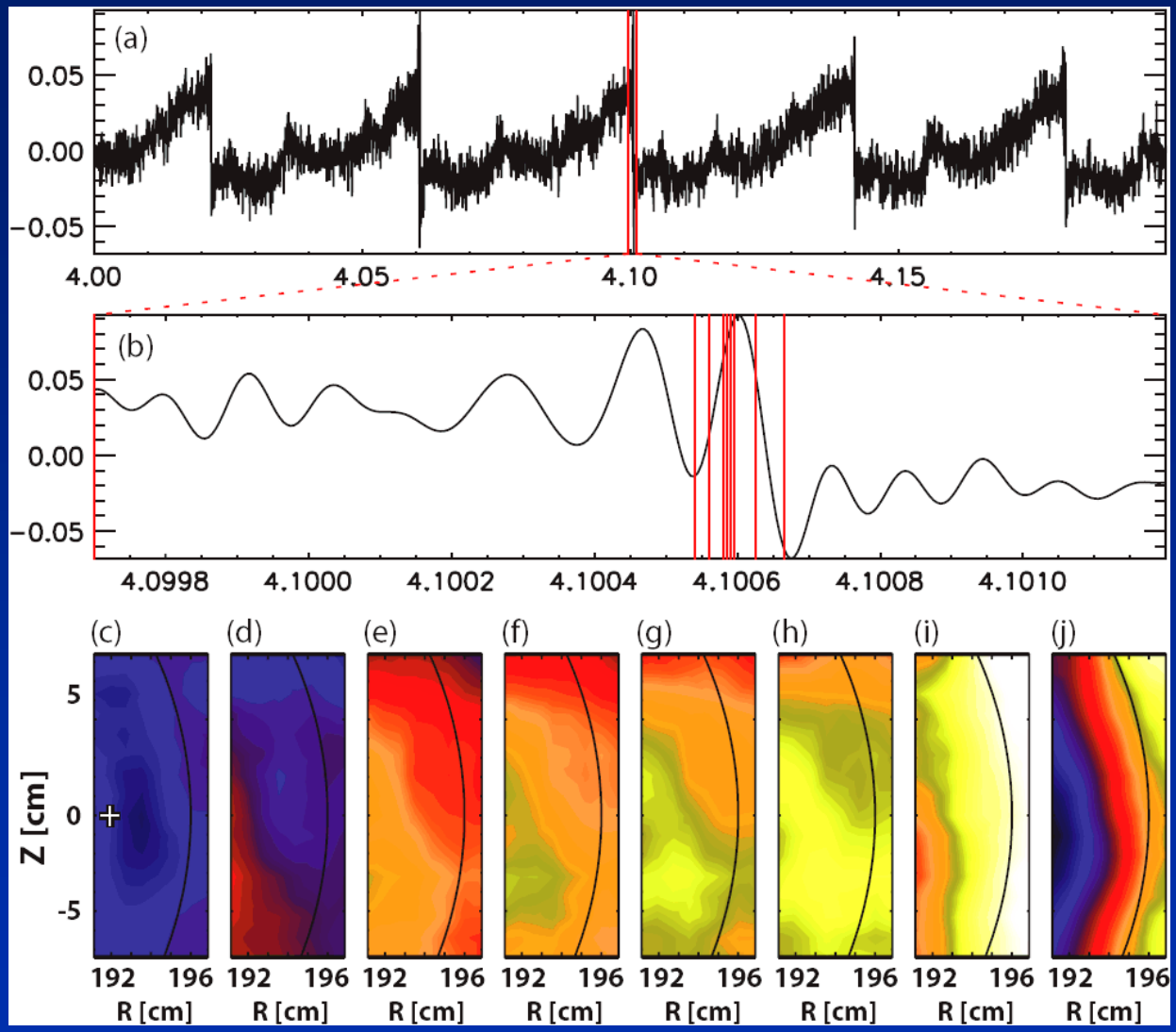
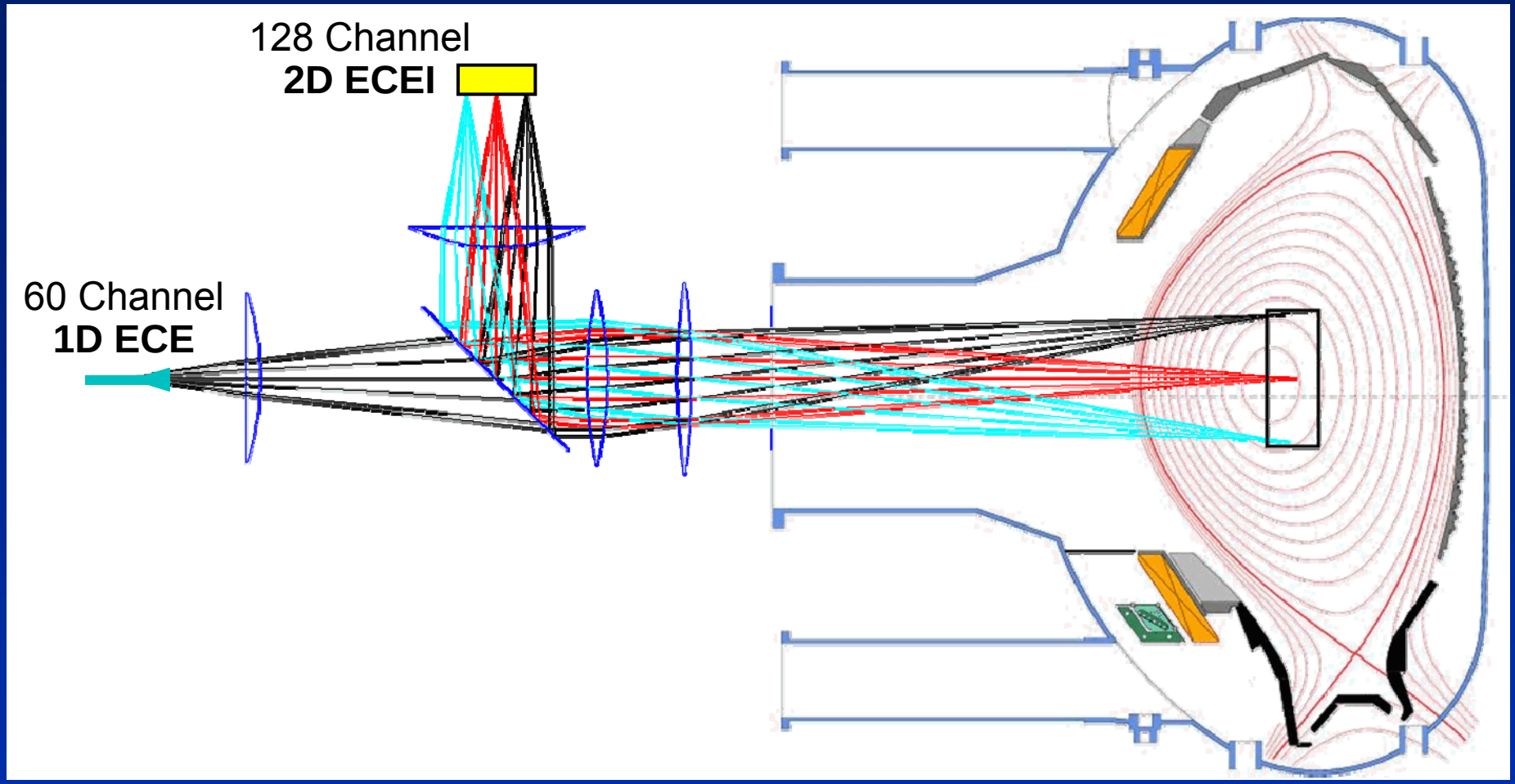
Single Array ECEI on TEXTOR





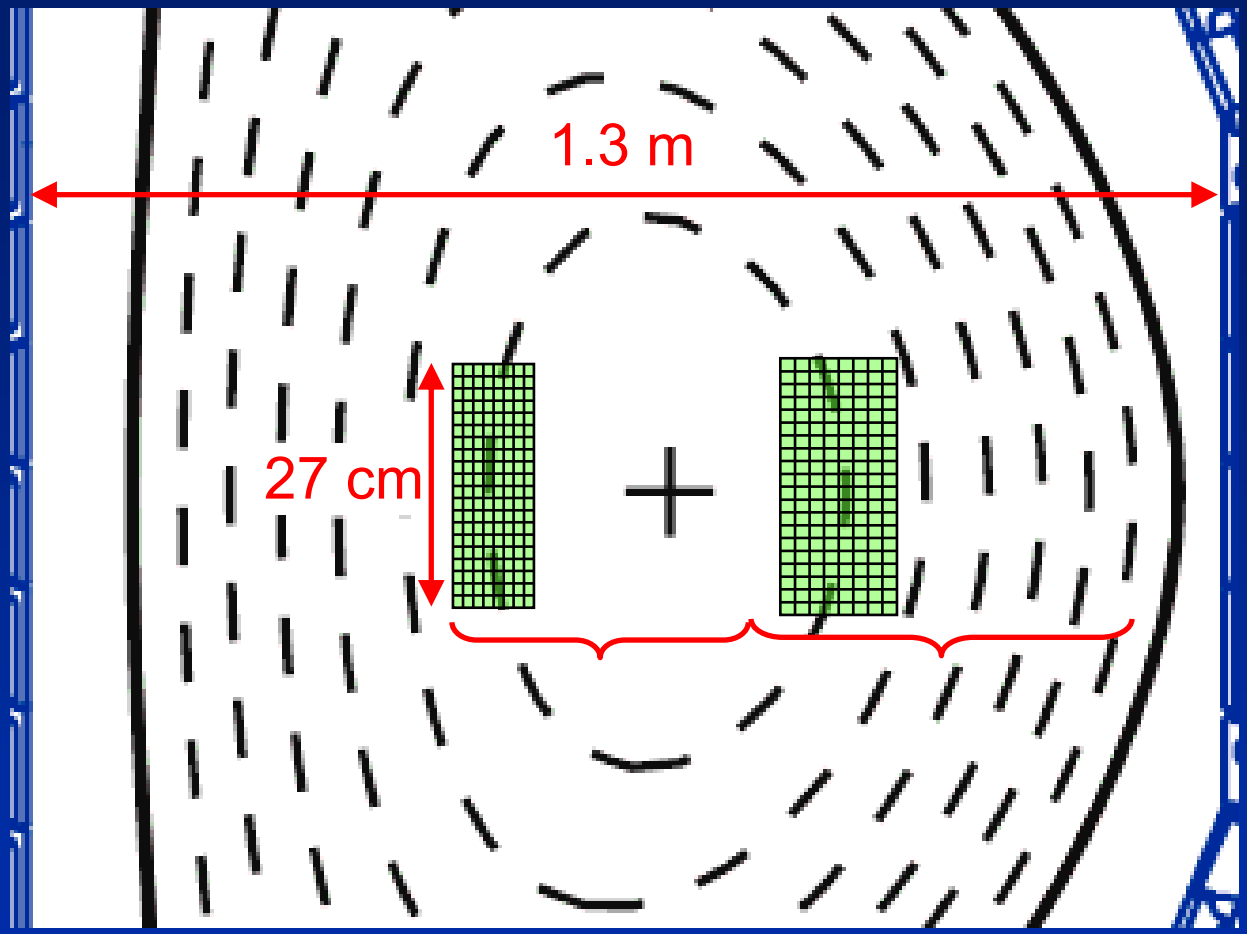
Single array implementation with 16×8 T_e image resolution (movie shown on left)

Single Array ECEI on ASDEX-UG



TEXTOR system transferred to ASDEX-UG in Jan. 2009, and will begin operation in May 2009

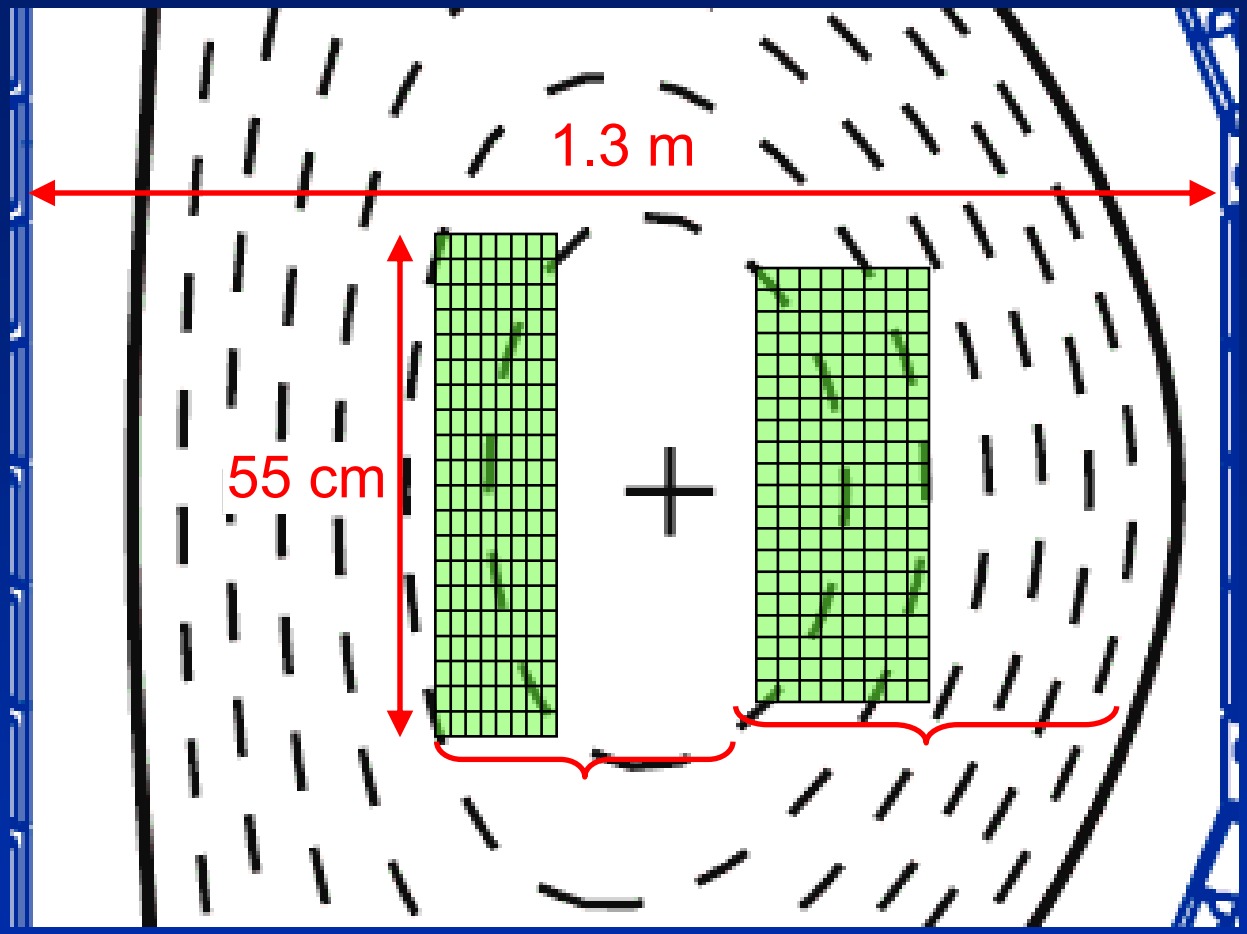
Dual Array ECEI on DIII-D



Narrow zoom
Narrow spacing

- Horizontal and vertical zoom control with full remote capability
- Two array system, each 20×8 channels expandable to 20×24
- Installation in Sept. 2009, with first results in Oct. 2009

Dual Array ECEI on DIII-D



Wide zoom
Wide spacing

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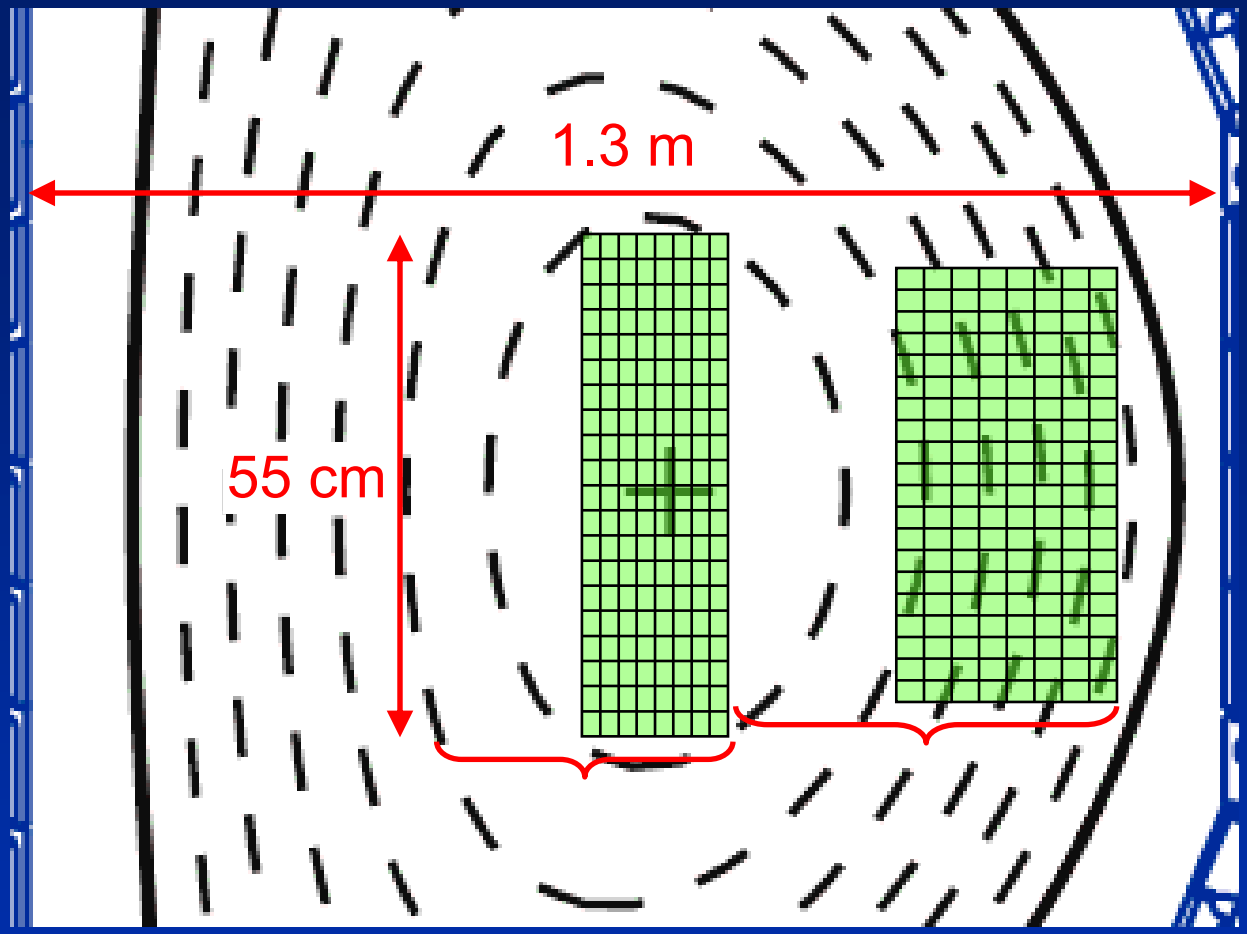
Dual Array ECEI on DIII-D



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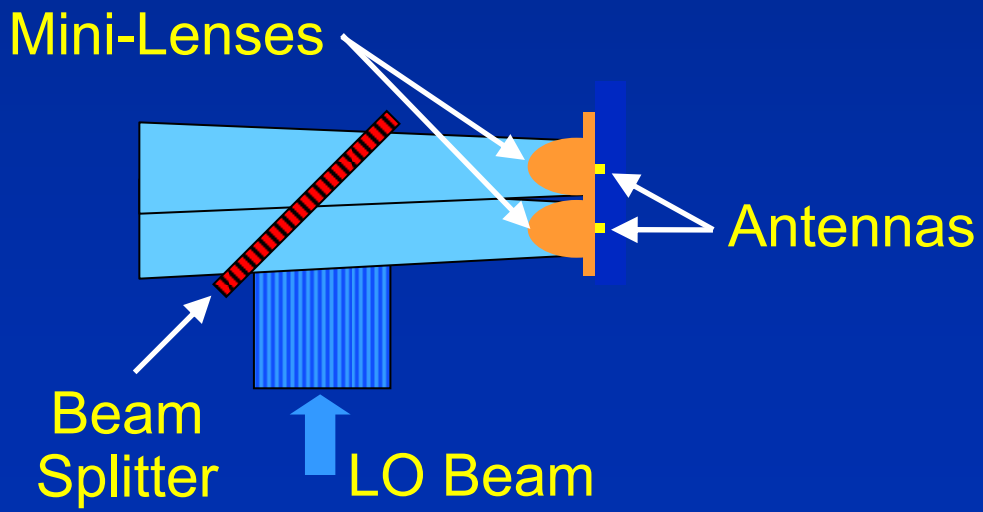
Ongoing Development Activities

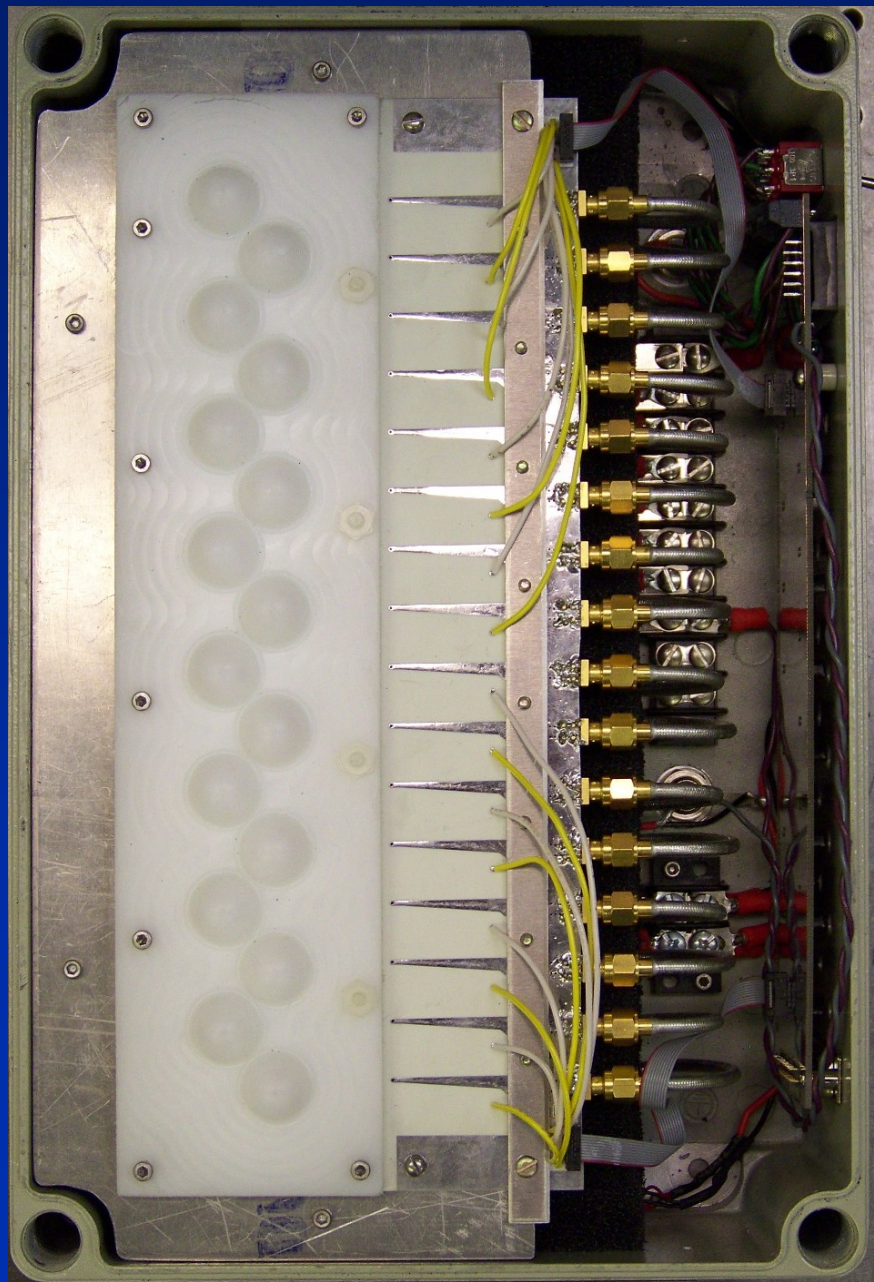
- Mini-lens imaging array concept and vertical zoom optics
- Horizontal zoom ECEI electronics and frequency extenders
- Quasi-optical notch filters
- High frequency imaging antennas
- Multi-frequency MIR sources

Mini-Lens Array Configuration

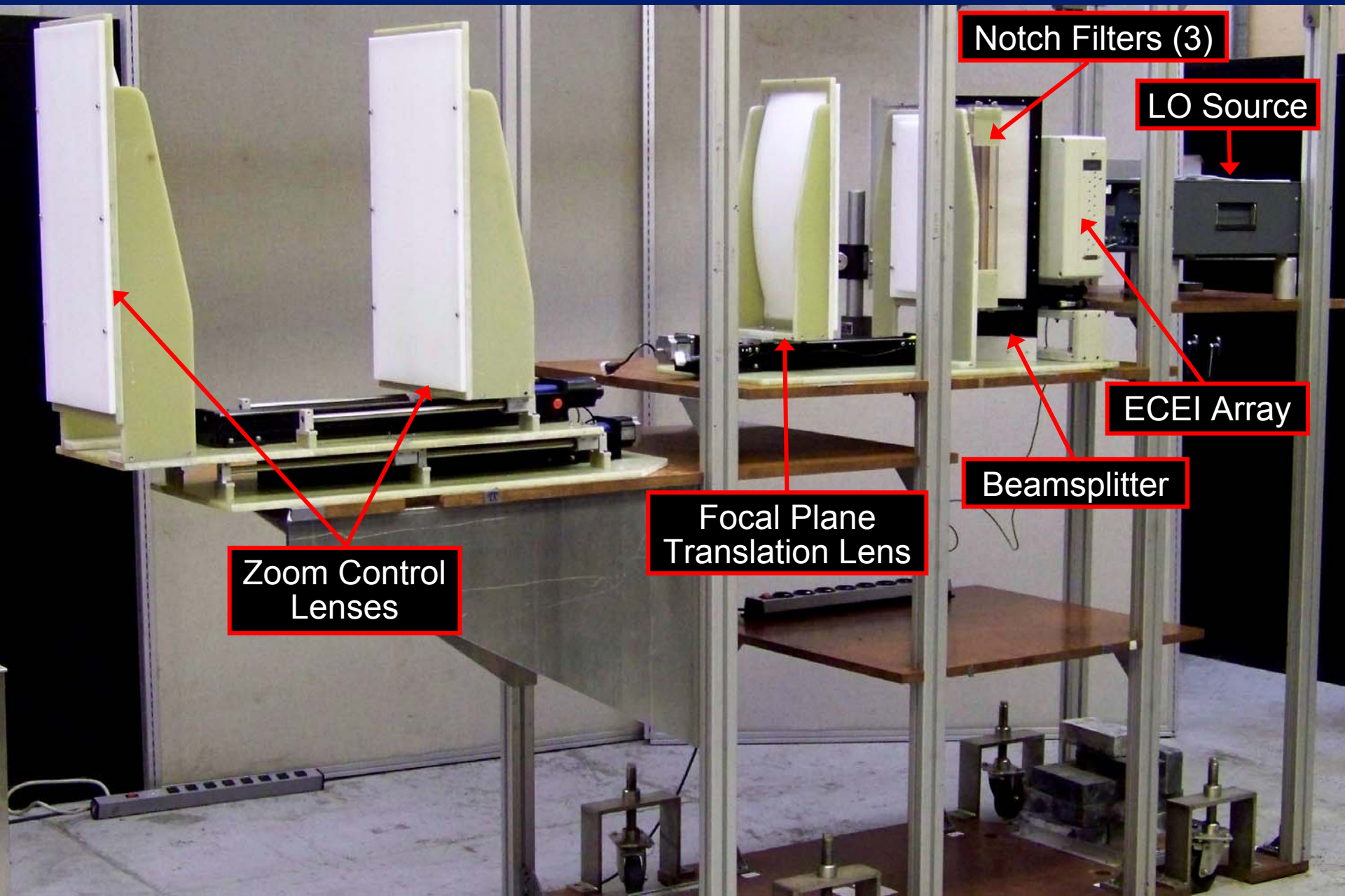
Advantages

- Elliptical substrate lens optimizes coupling and reduces sidelobes
- Eliminates off-axis aberrations
- Uses front side LO pumping for enhanced coupling, increased sensitivity and wide bandwidth (octave) operation

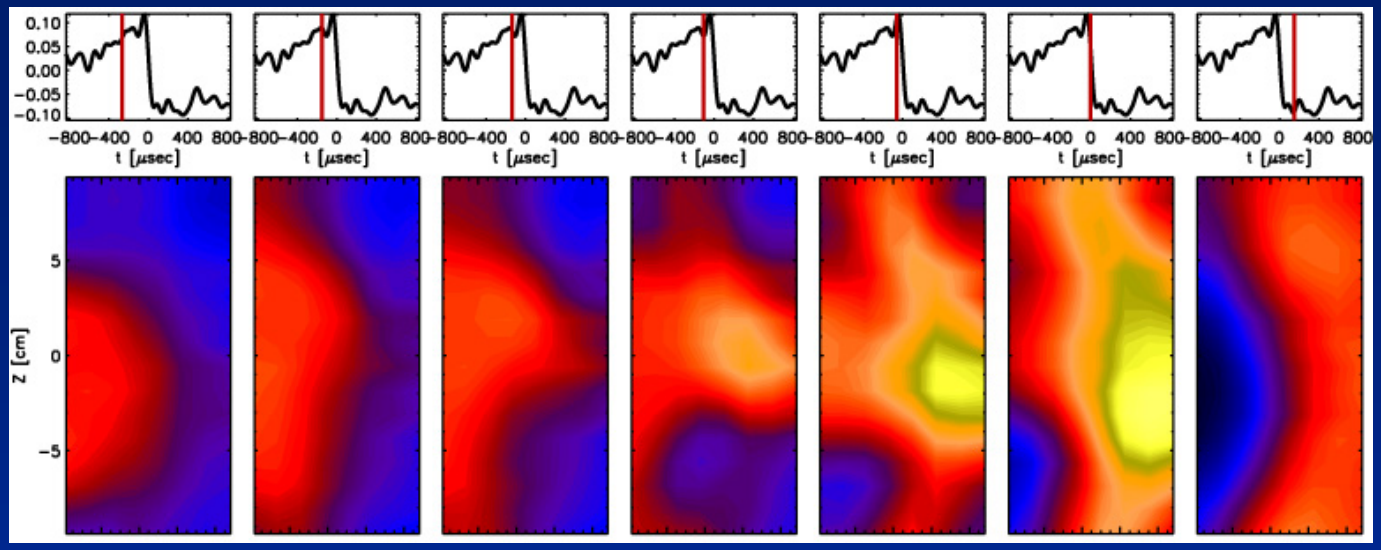




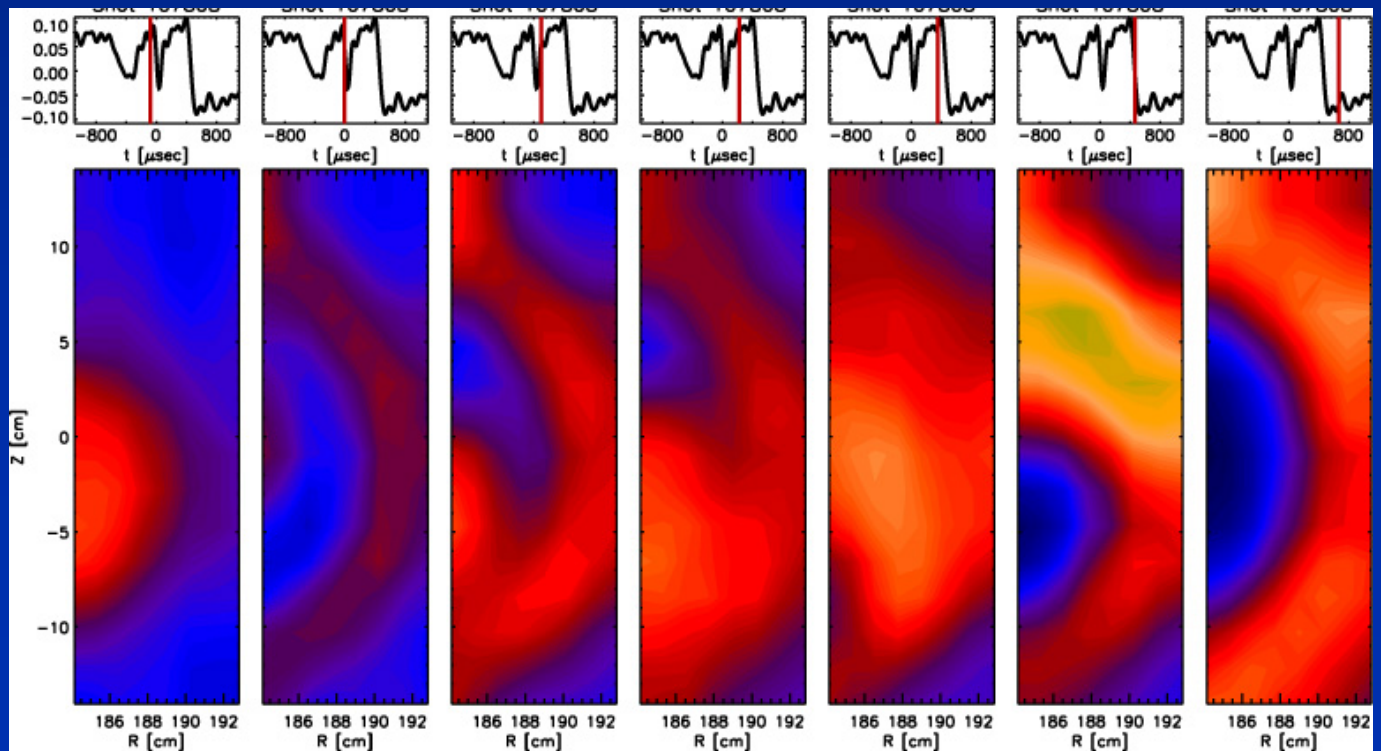
New Mini-Lens ECEI System Optics



New Vertical Zoom Optics



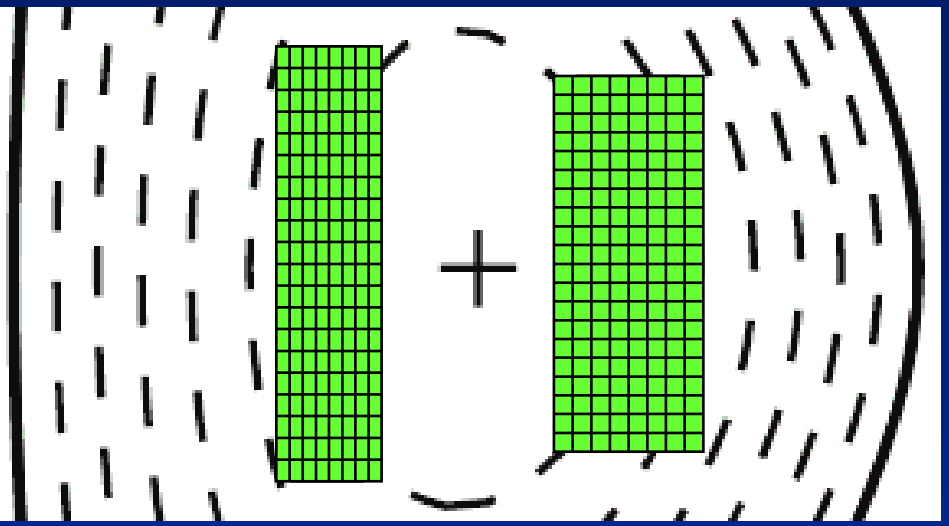
Narrow Zoom
Shot 107809

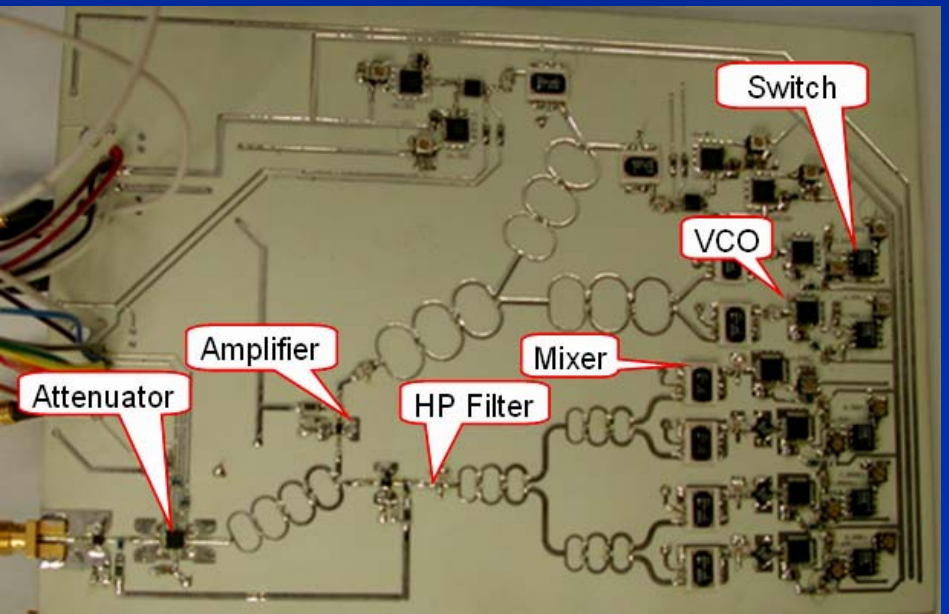


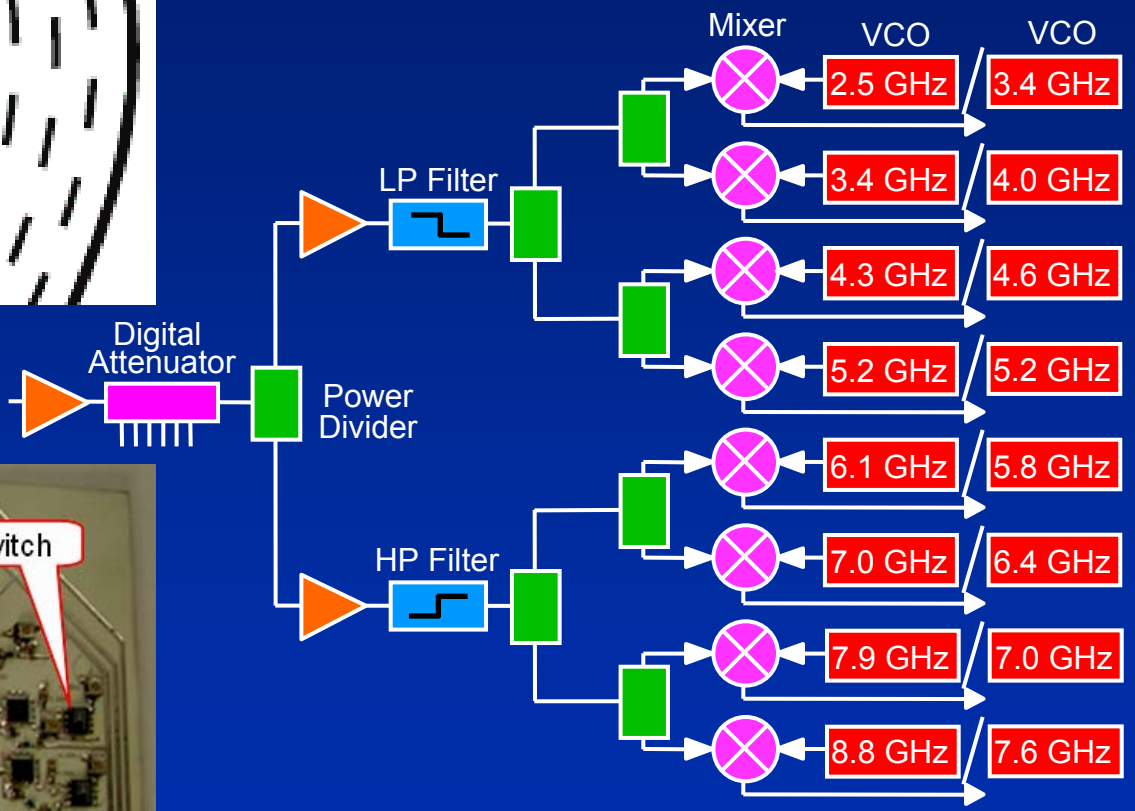
Wide Zoom
Shot 107808

T_e images courtesy of Prof. T. Munsat at the University of Colorado

New Horizontal Zoom Electronics

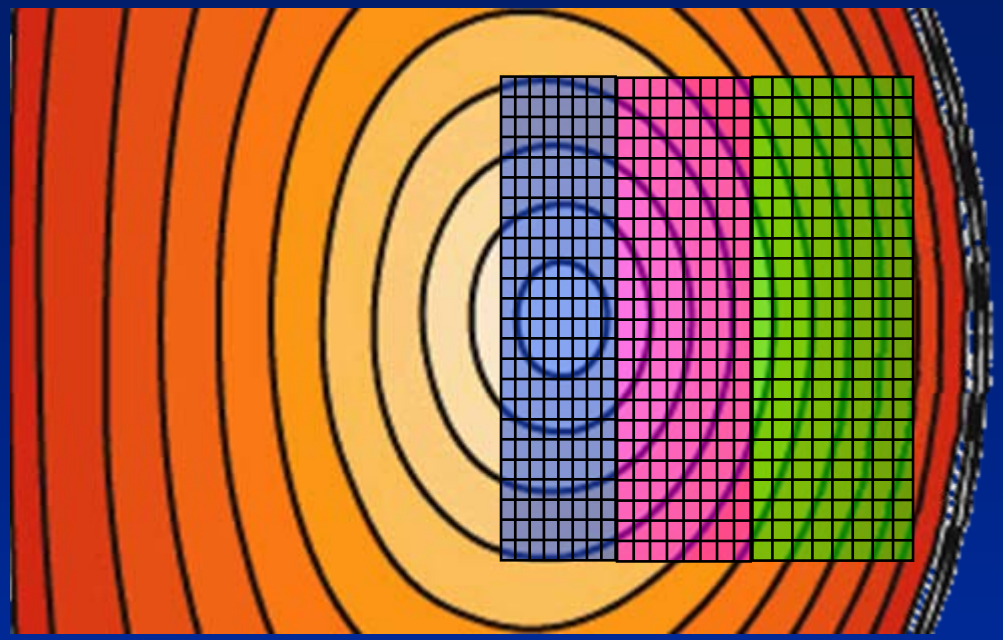






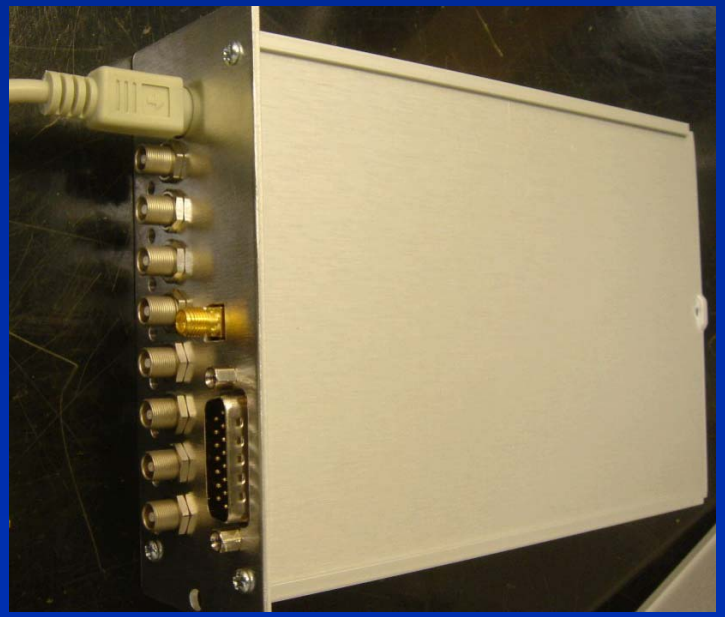
Horizontal spacing and spot size can now be independently and remotely-controlled

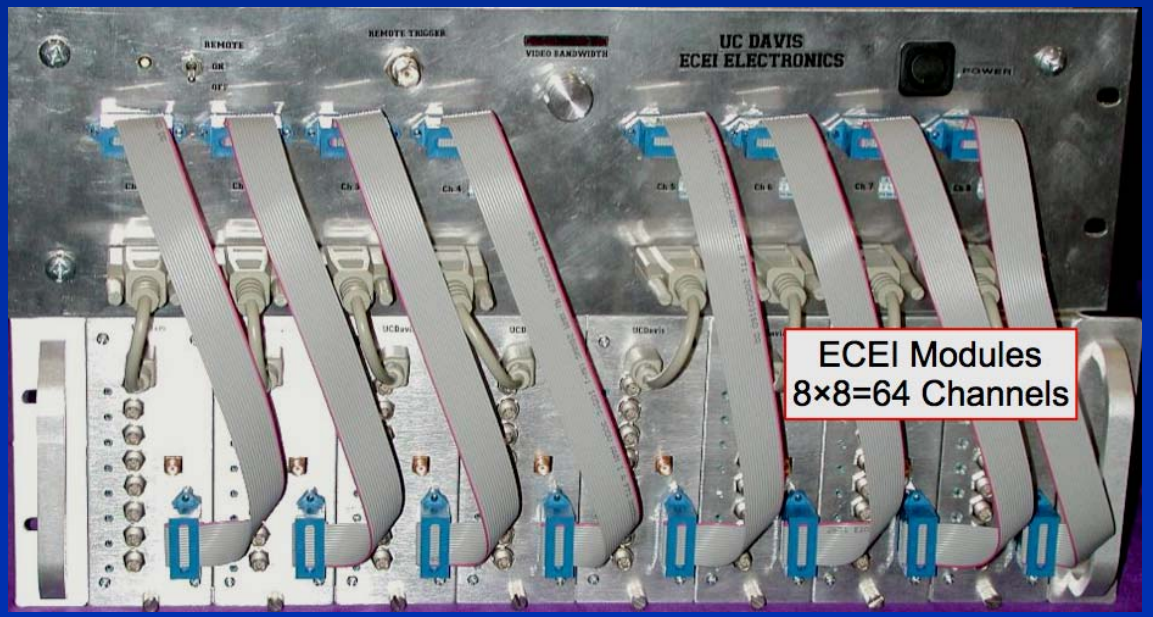
Multiple Modules for Increased Coverage



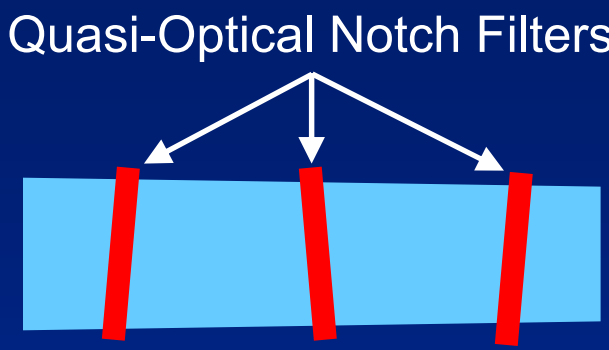
Standardized modules can be ganged together to extend RF coverage

- Two modules provide 16 GHz coverage
- Three modules provide 24.5 GHz coverage

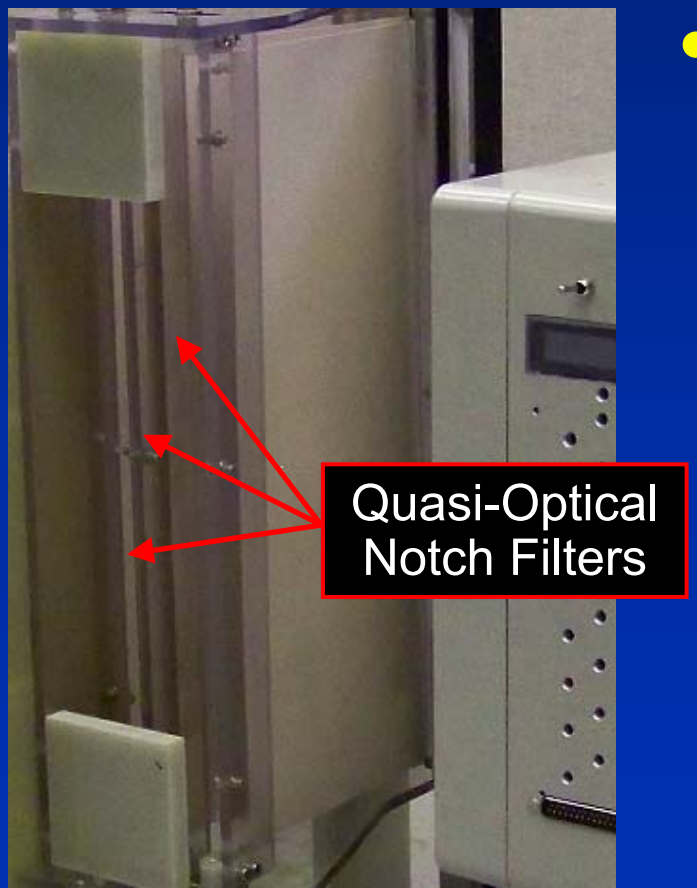


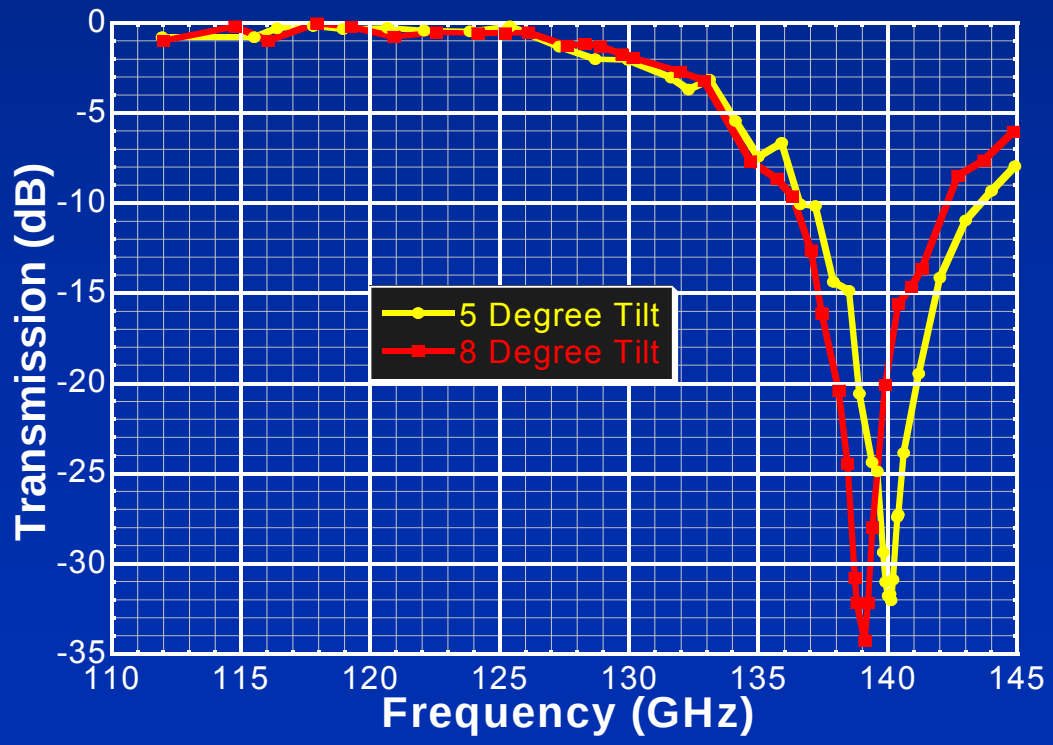


New “Stackable” Notch Filters

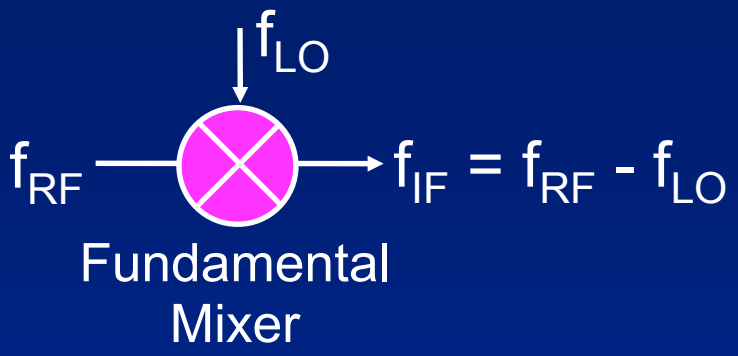


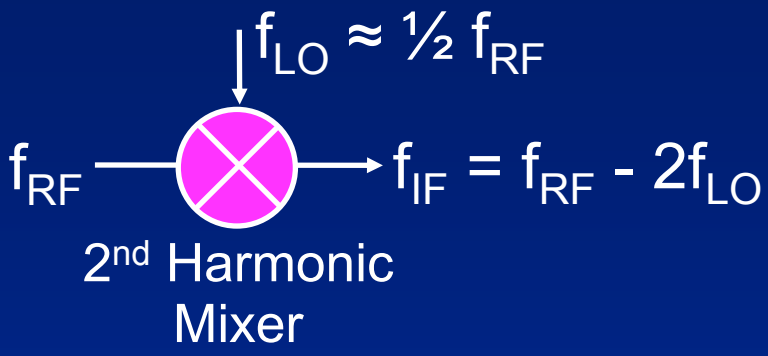
- Highly collimated mini-lens beams permit significantly improved ECRH shielding
  - Relaxed angular requirements (≤ 8°)
  - Stack up to 3 notch filters in series
- 140 GHz filter stack installed on TEXTOR (single filter results shown below)
- 170 GHz filter stack under development for KSTAR





Antennas/Mixers for High-Field ECEI



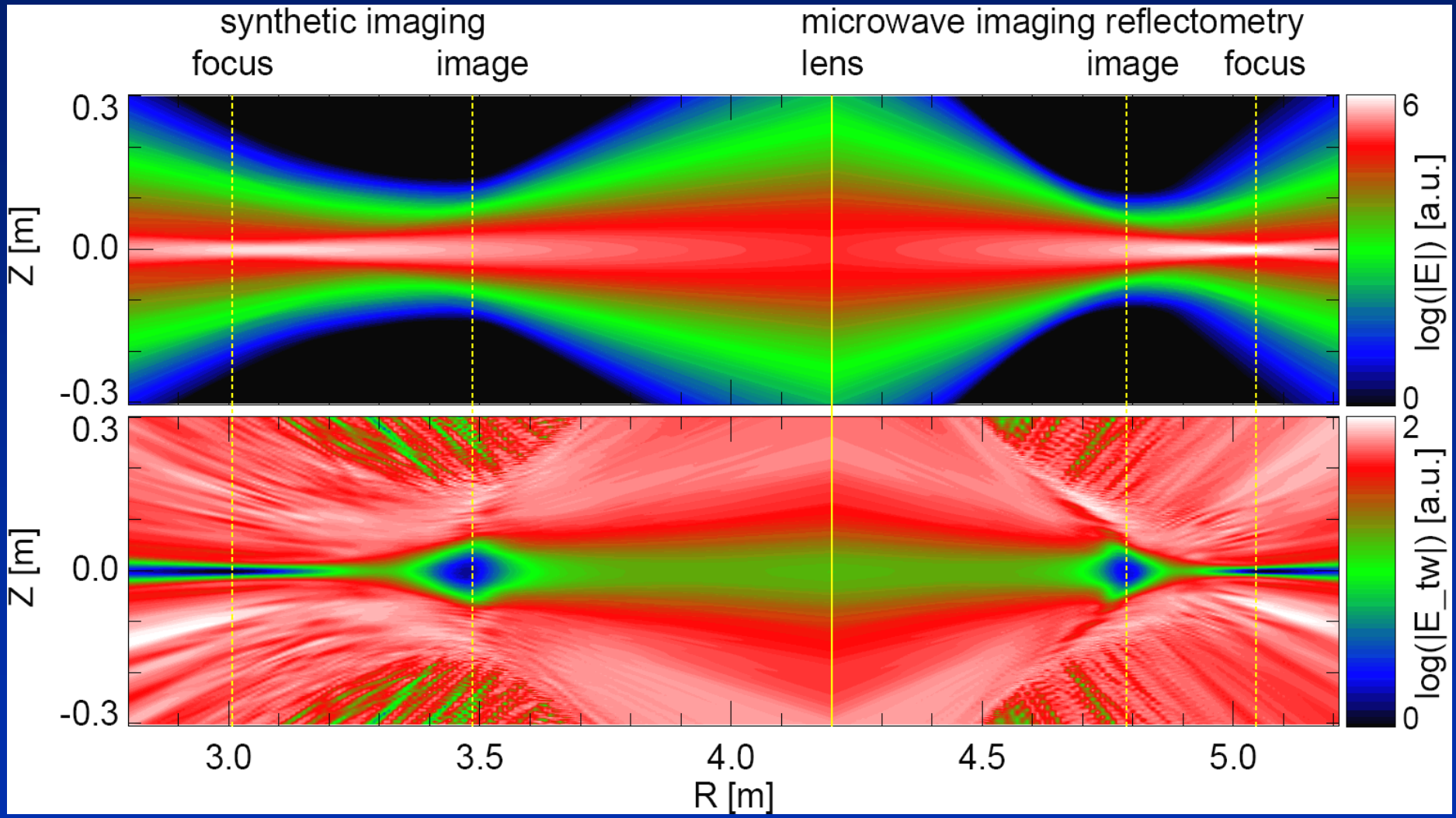


- Two approaches under investigation to realize imaging antennas for ECEI on KSTAR under high-field (3-3.5 T) conditions
- Fundamental mixers require high frequency (150-220 GHz) sources with >40 mW output power ⇒ difficult to obtain!
- 2nd harmonic mixers have 2-3 dB worse conversion losses, but can use lower frequency (75-110 GHz) sources ⇒ readily available!

POSTECH Collaboration (Prof. Hyeon Park) on MIR Characterization

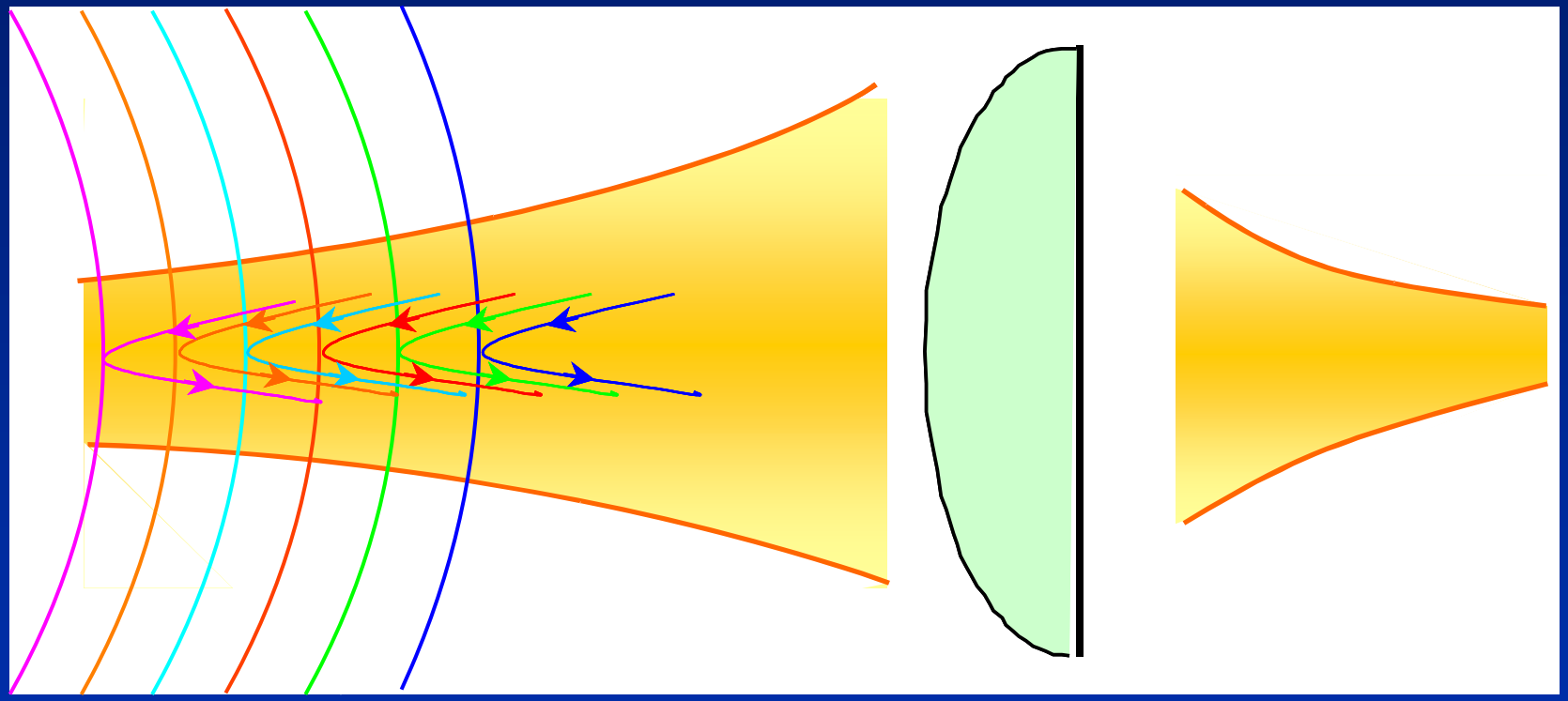
TEXTOR MIR system now set up at POSTECH for detailed laboratory measurements and characterization

PPPL Collaboration (Dr. Gerrit Kramer) on MIR Modelling



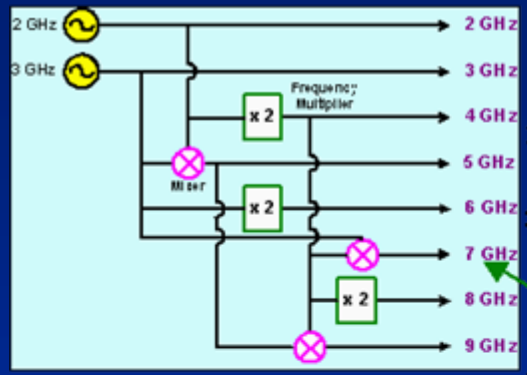
2-D simulations of microwaves reflected from a circular plasma, with an illumination beam curvature-matched to the plasma

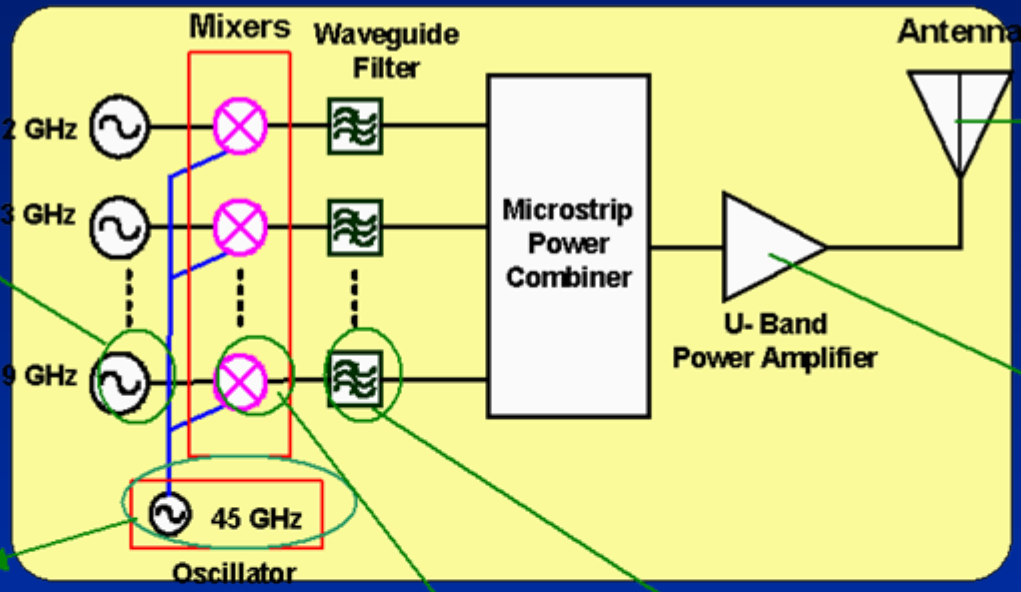
Kyungpook National University Collaboration (Prof. Kangwook Kim) on MIR Illumination Sources

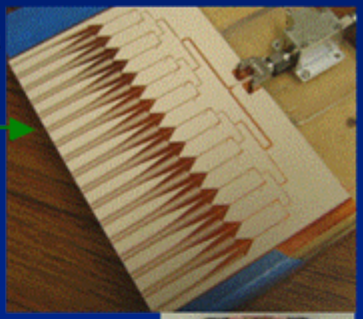


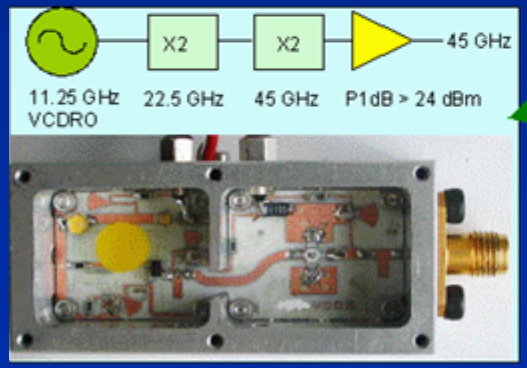
Schematic illustrating how a simultaneous “comb” of illumination frequencies can probe multiple cutoff layers, as each frequency reflects from a distinct cutoff layer

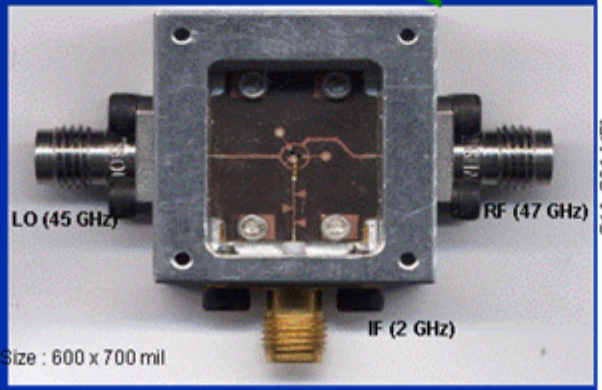
Kyungpook National University Collaboration (Prof. Kangwook Kim) on MIR Illumination Sources

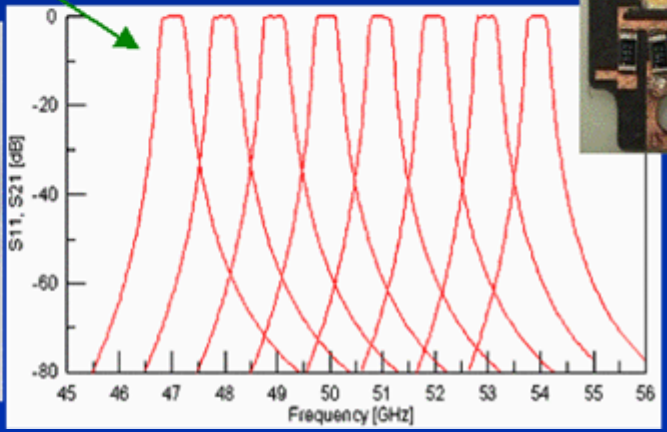


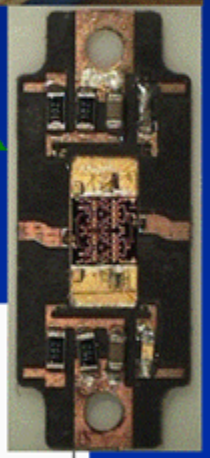










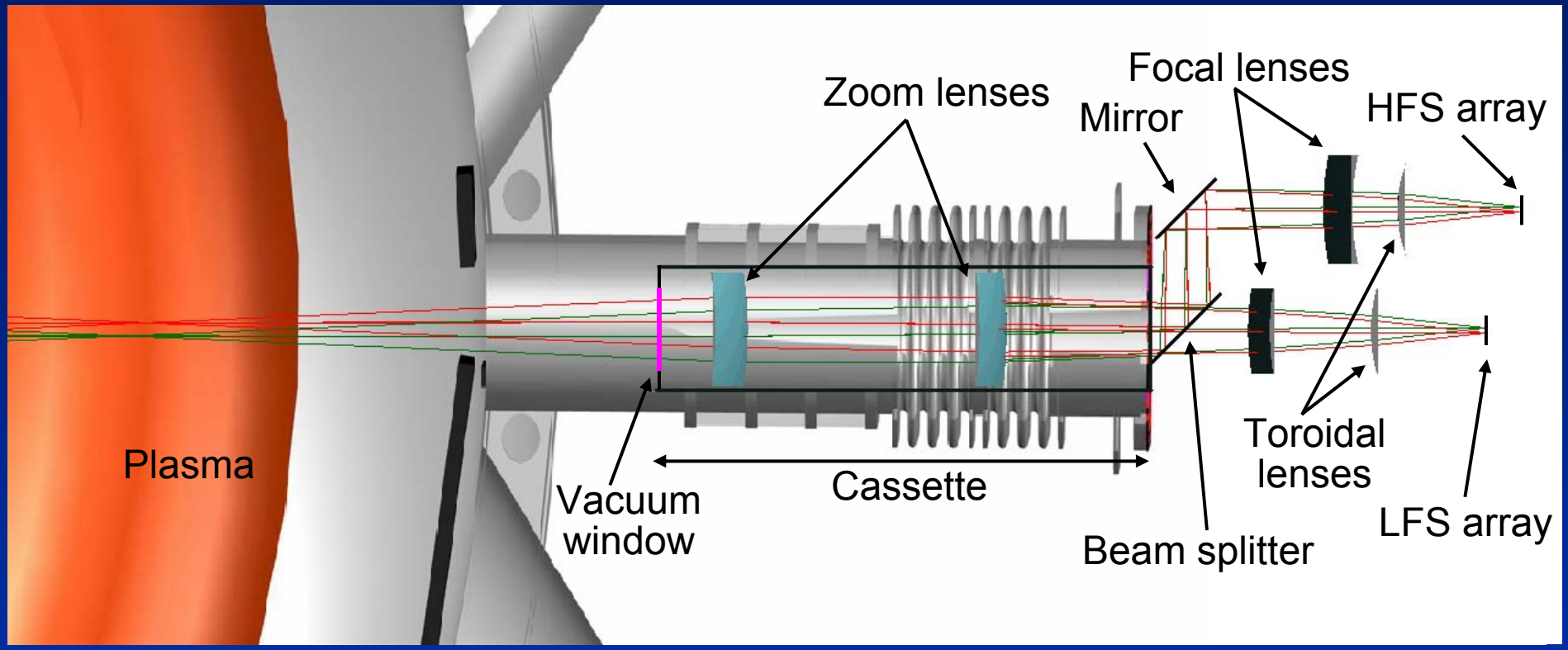


Outline

- Introduction and Overview
- Diagnostic Principles
  - T_e Measurements via ECEI
  - n_e Measurements via MIR and MDIR
- Experience on Previous and Current Systems
- Ongoing Development Activities
- Low Field (~2 T) and High Field (3-3.5 T) Conceptual Designs
- Diagnostic Development Plan

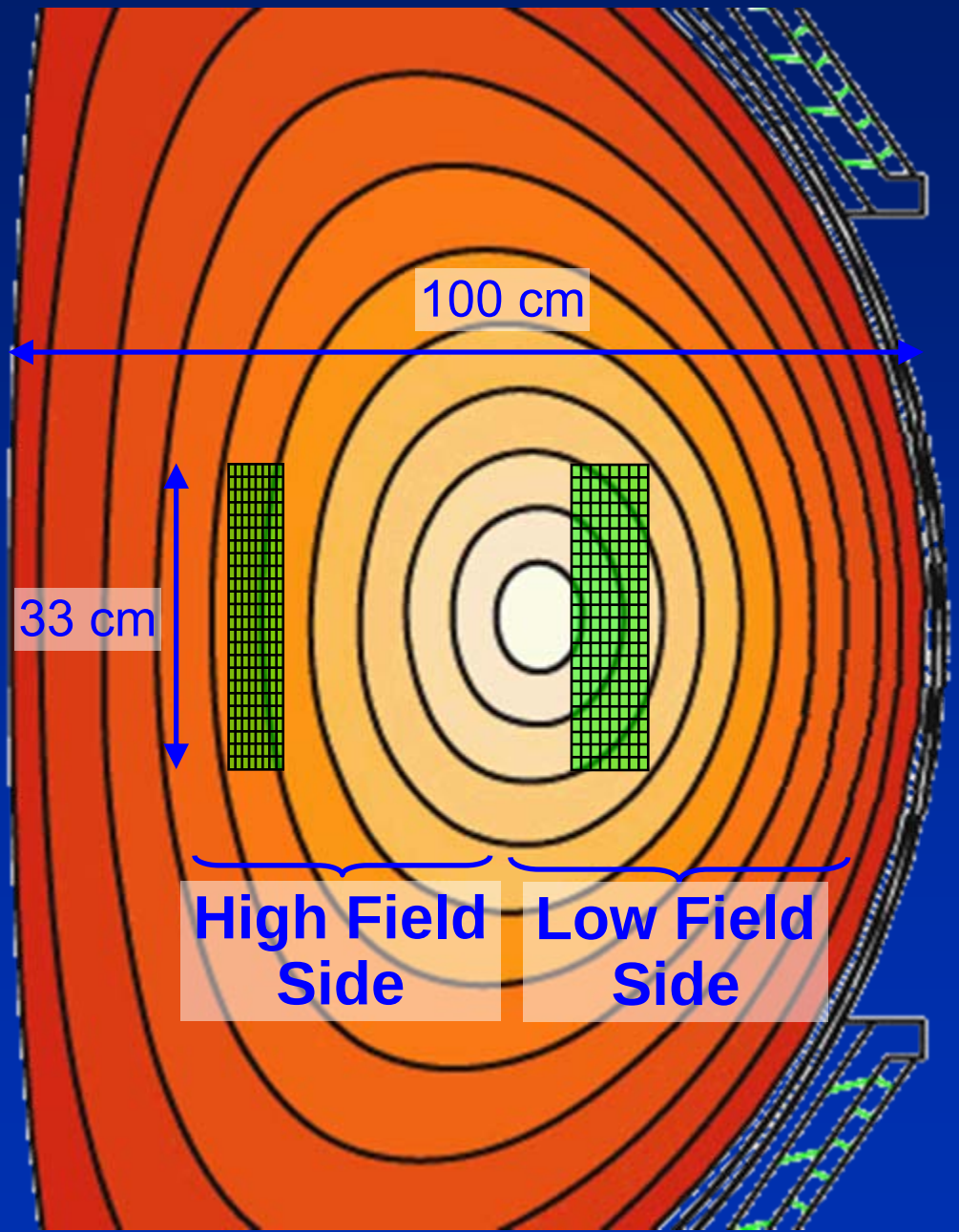
KSTAR Diagnostic Layout

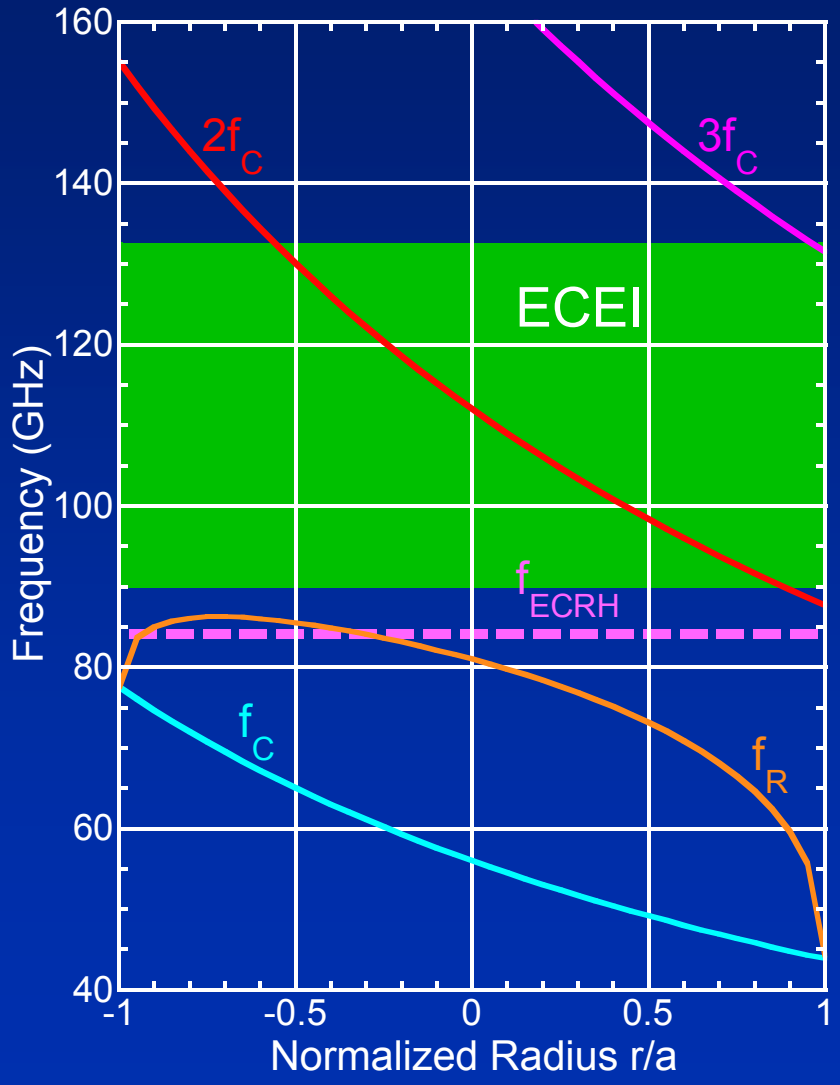
ECEI Configuration: ~2T



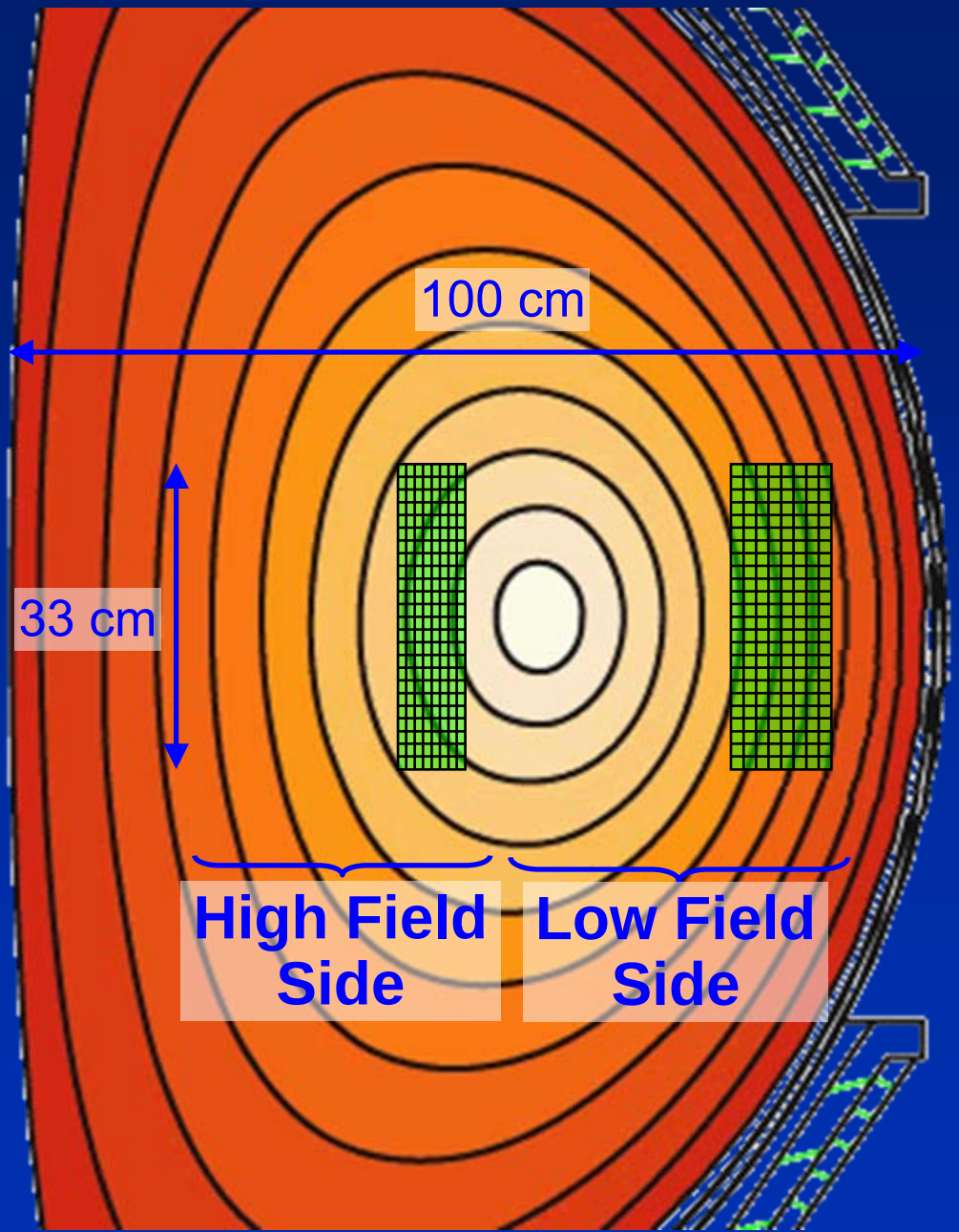
- Low field (~2 T) design for ECEI only
- High field side (HFS) and low field side (LFS) systems share the same zoom optics (inside cassette)
- Two array configuration per port, each generating 24(v)×8(h) T_e images expandable to 24×24 images

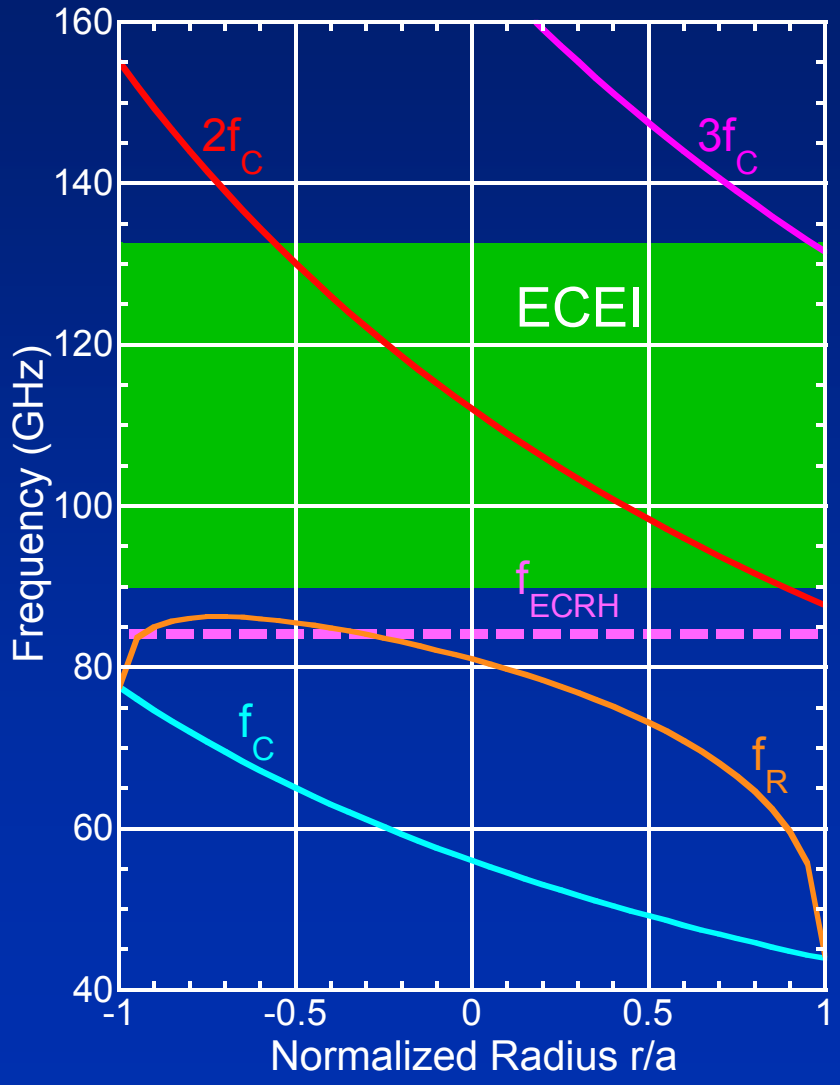
ECEI on KSTAR at 2.0 T



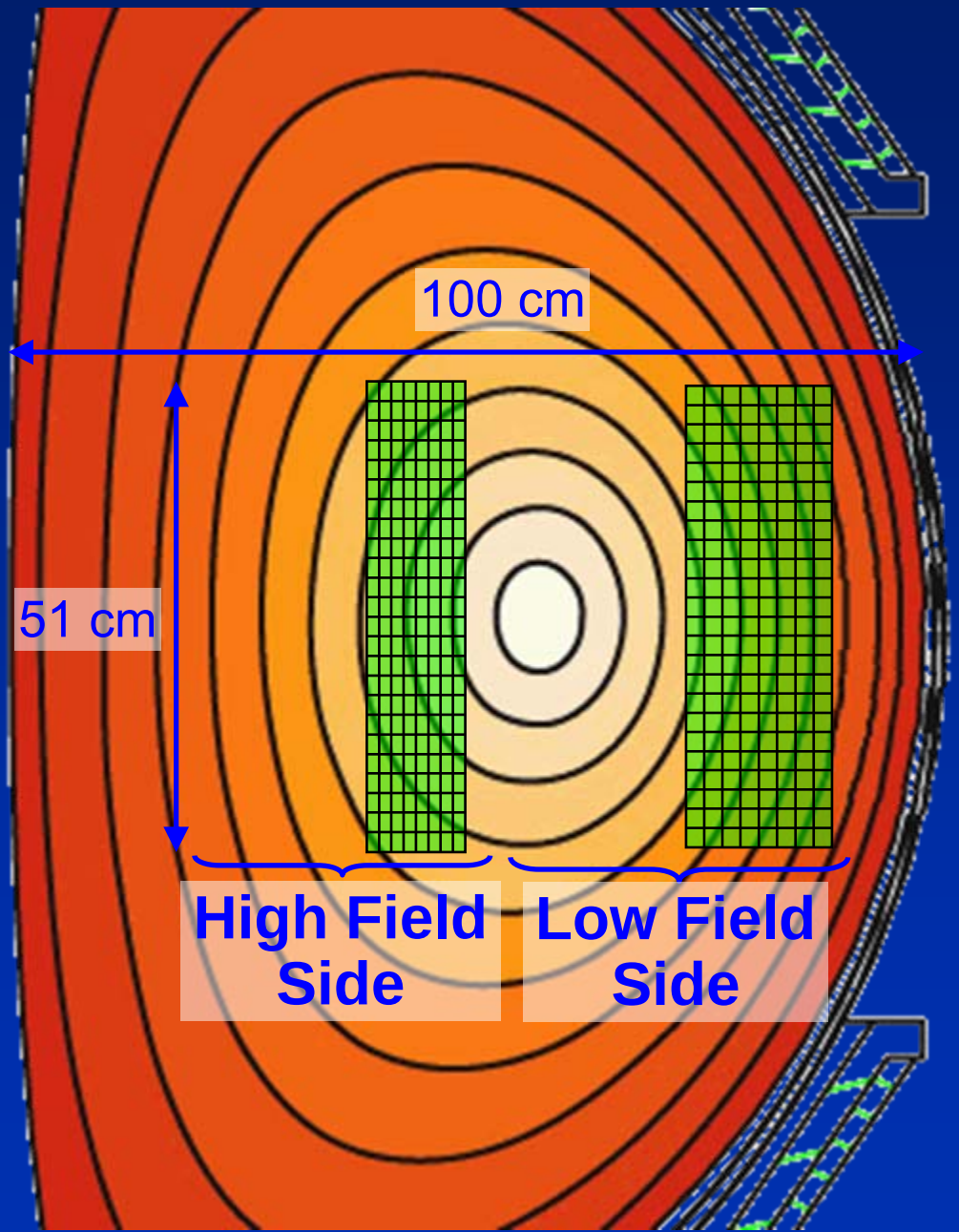


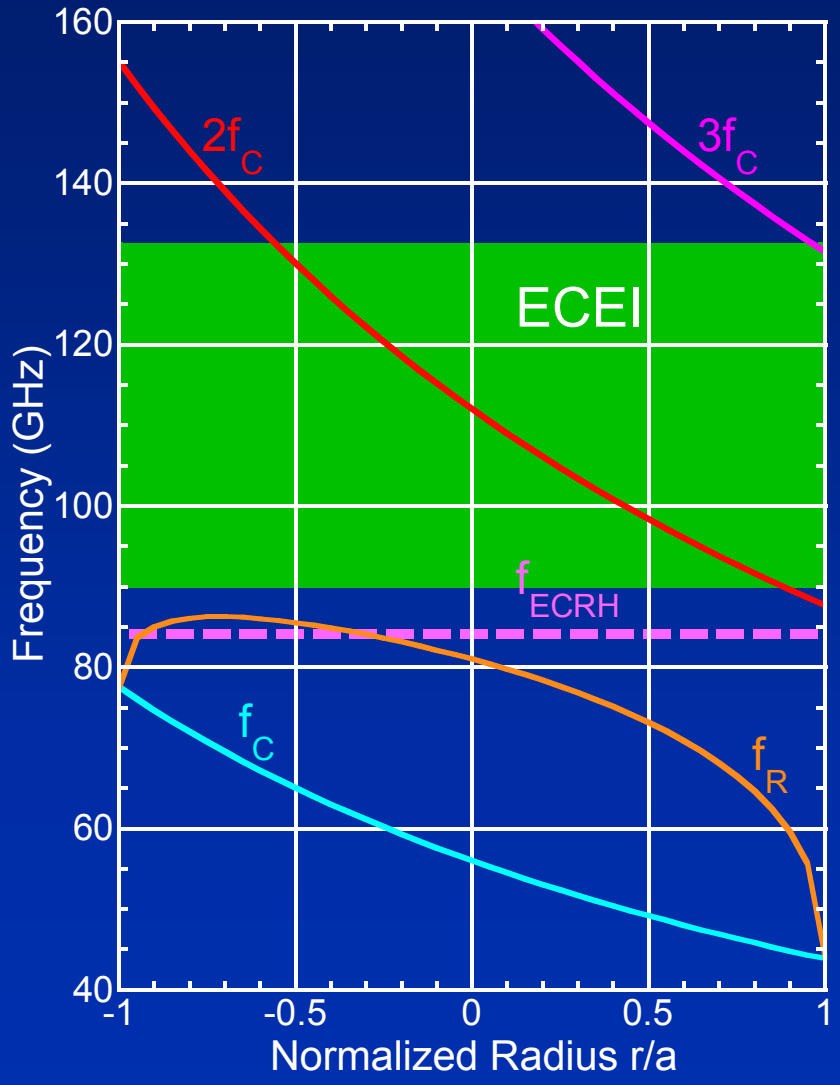
ECEI on KSTAR at 2.0 T



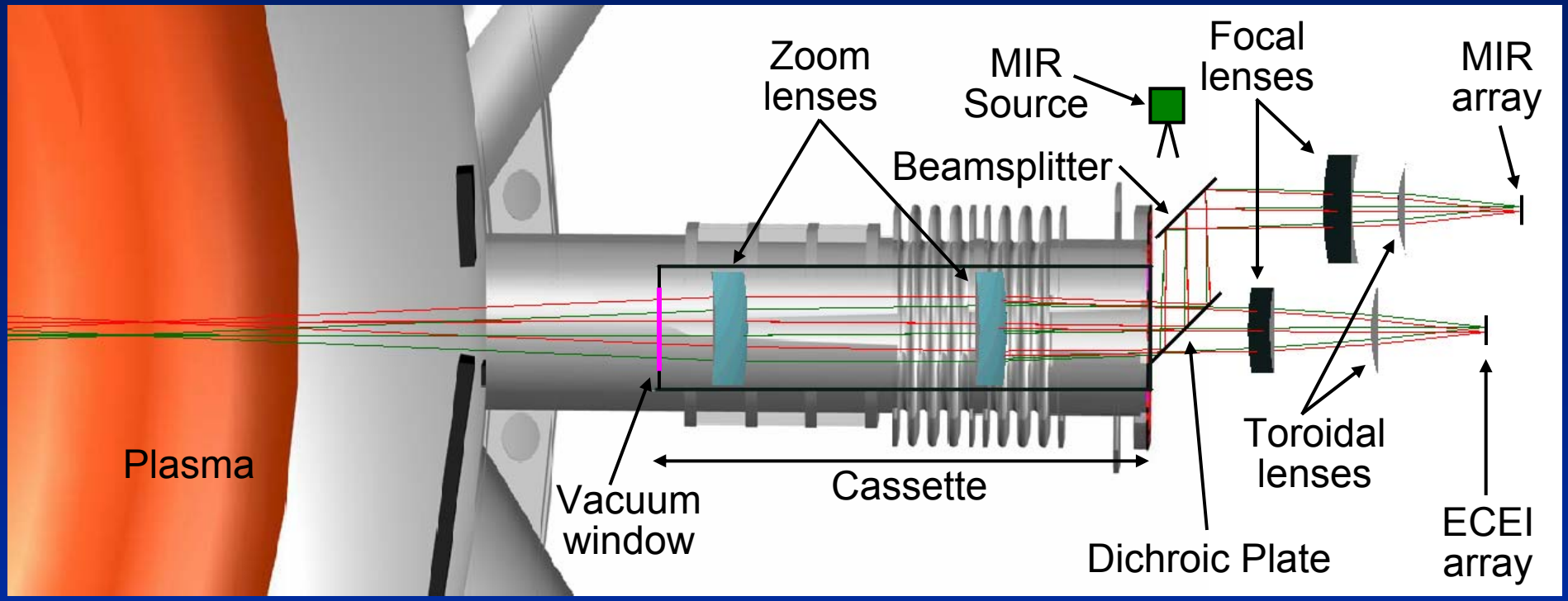


ECEI on KSTAR at 2.0 T



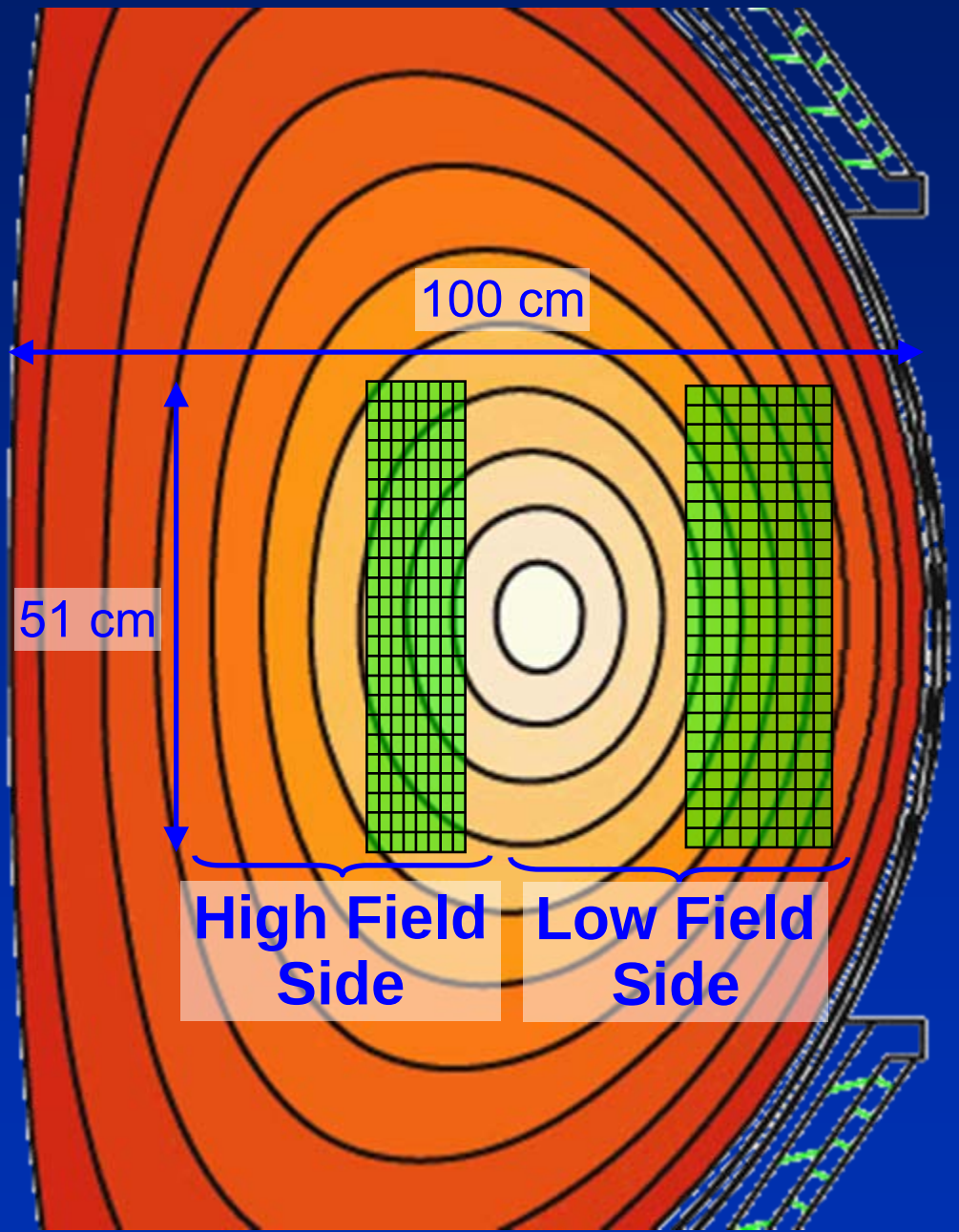


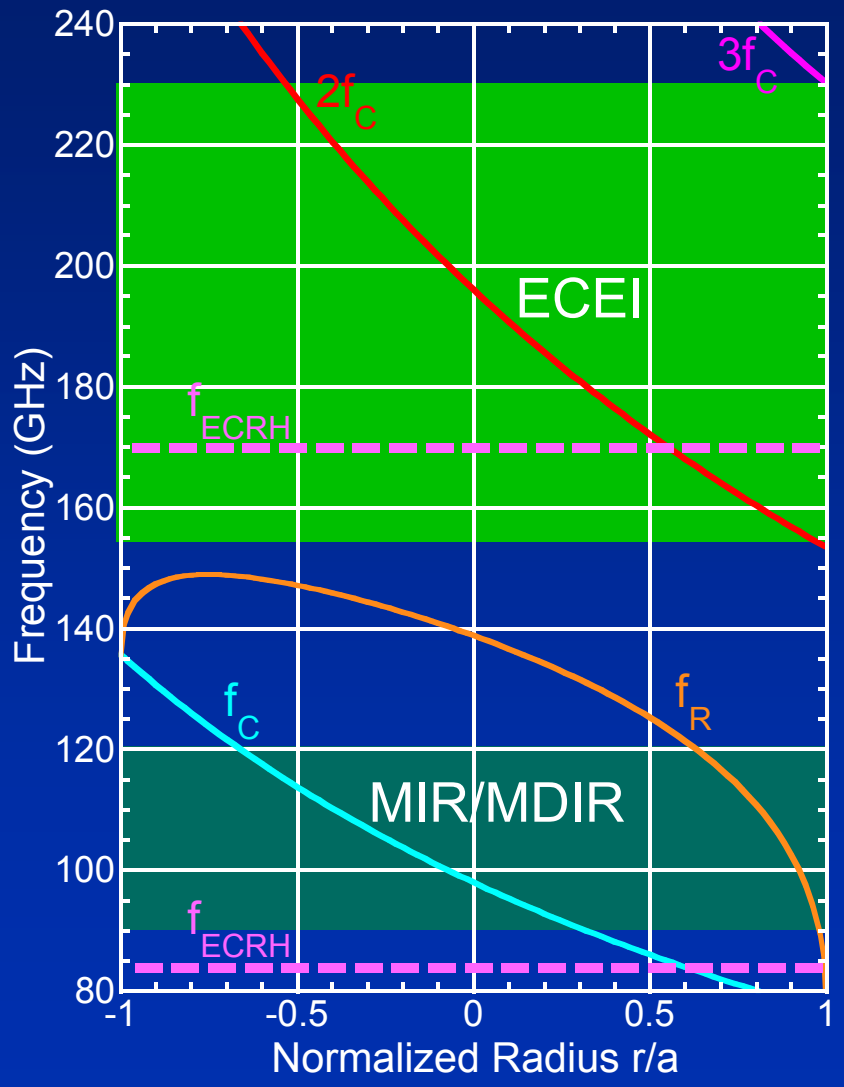
ECEI/MIR Configuration: 3-3.5 T



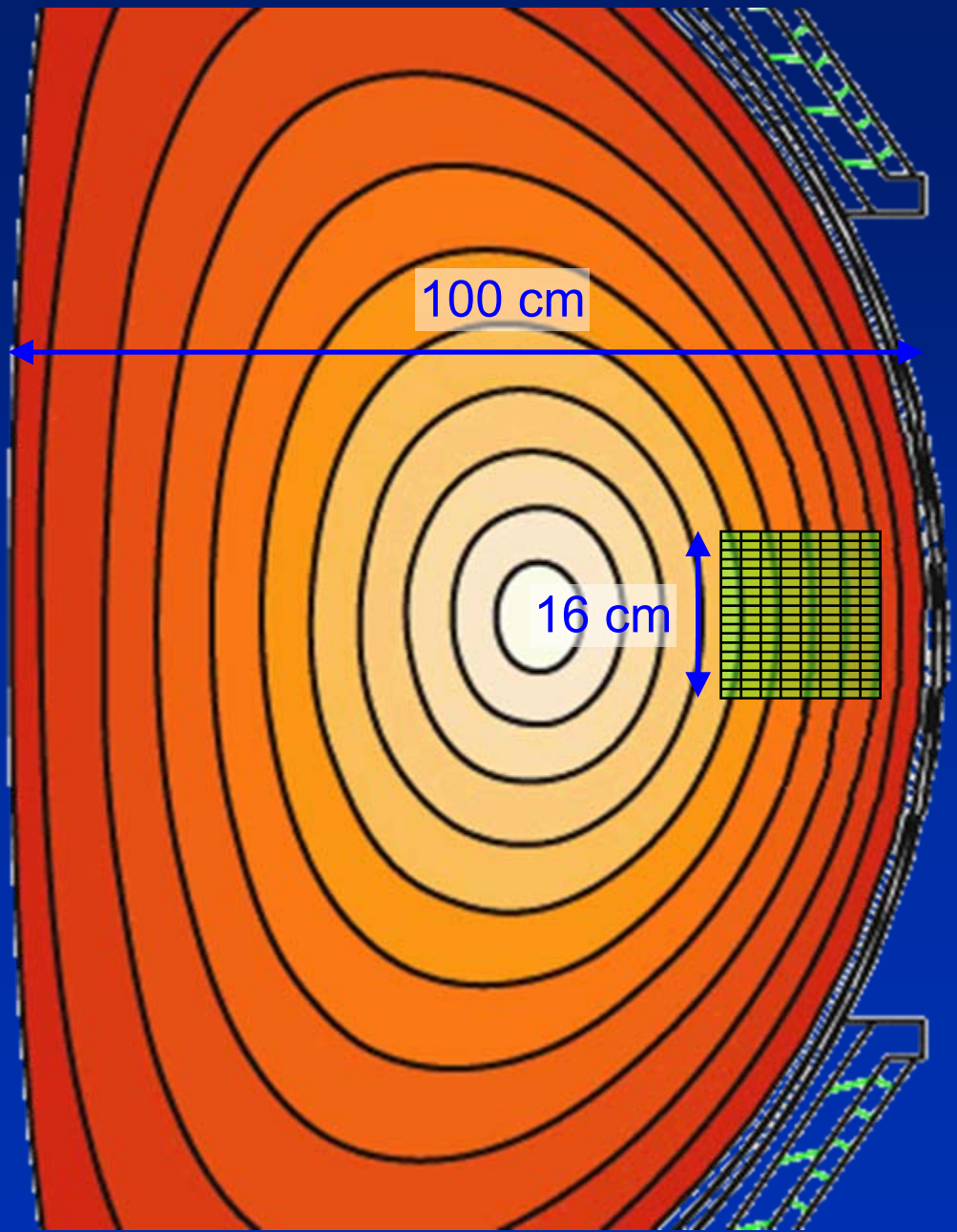
- High field design for simultaneous ECEI and MIR/MDIR
- Two array ECEI configuration, each generating 24×8 T_e images expandable to 24×24 images
- Single array MIR/MDIR configuration with a 14 element array and up to 8 simultaneous frequencies/cutoff layers
- Decision to implement MIR or MDIR (or both) dependent upon results from joint POSTECH and PPPL study into MIR physics

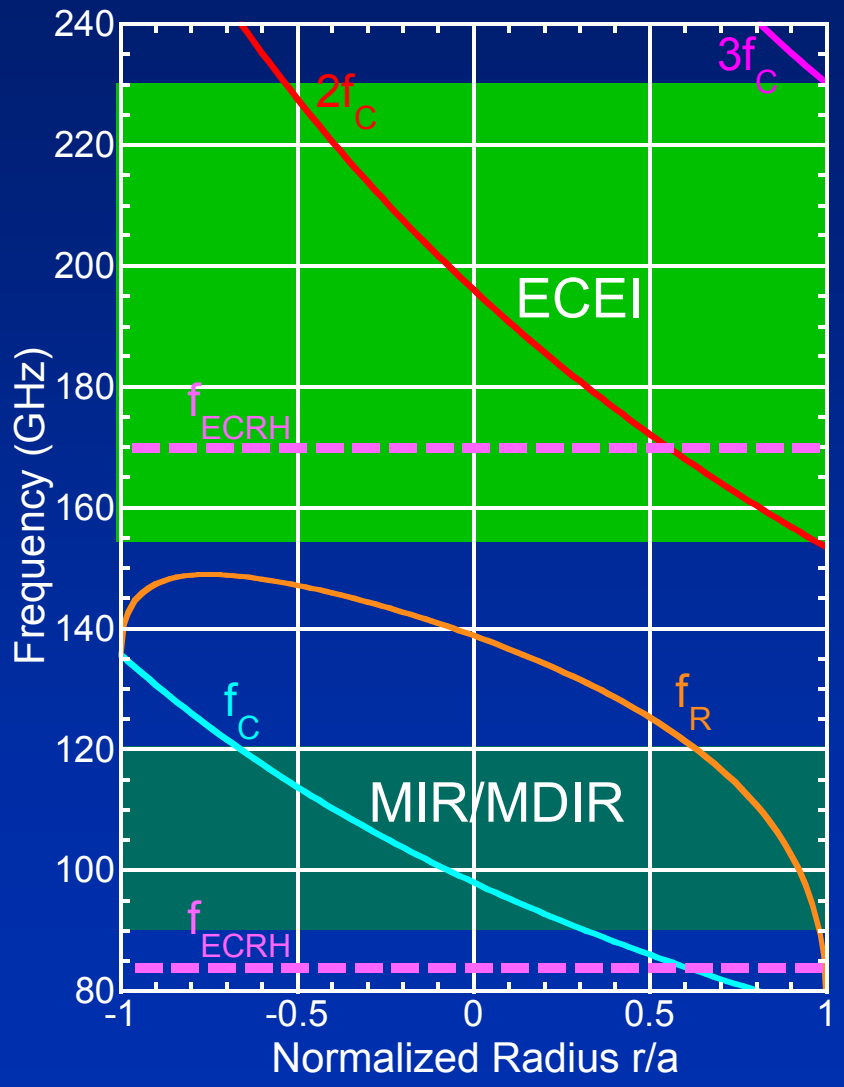
ECEI at High Field (3-3.5 T)





MIR/MDIR at High Field (3-3.5 T)





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Diagnostic Development Plan

FY2009

- Design multi-array low field (~2 T) ECEI system
- Develop multi-frequency source technology for MIR/MDIR (collaboration with Kyungpook National University)
- Fabricate and test high performance 170 GHz notch filters

FY2010

- Fabricate and characterize multi-array low-field ECEI system
- Install multi-array low-field ECEI system on KSTAR
- Fabricate and test prototype high-field (3.0-3.5 T) ECEI antennas
- POSTECH and PPPL to complete MIR system tests; results to be used to design optimum MIR and/or MDIR optical configuration

FY2011

- Operate and maintain low-field ECEI system on KSTAR
- Design high field (3-3.5 T) simultaneous ECEI and MIR/MDIR system

Thank you for your attention