ECC Program on EAST and HT-7

Baonian Wan, Bili Ling, Ti Ang, Liu Yong, Li Erzhong, Han Xiang,
Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China

Changxuan Yu, Wandong Liu Yizhi Wen， Jinlin Xie, Xiaoyuan Xu, Jun Wang， Ming Xu, Binxi Gao
University of Science and Technology of China

N. C. Luhmann, C. W. Domier, Benjamin John Tobias, Jian Wang, Zhenggang Xia, Zuowei Shen,
UC. Davis, USA

Perry Philippe , Kenneth Gentle , William Rowan , He Huang ,
Fusion Research Center, UT at Austin, USA

Ron Prater
General Atomic, San Diego, USA

Gary Taylor2
Princeton Plasma Physics Laboratory, USA

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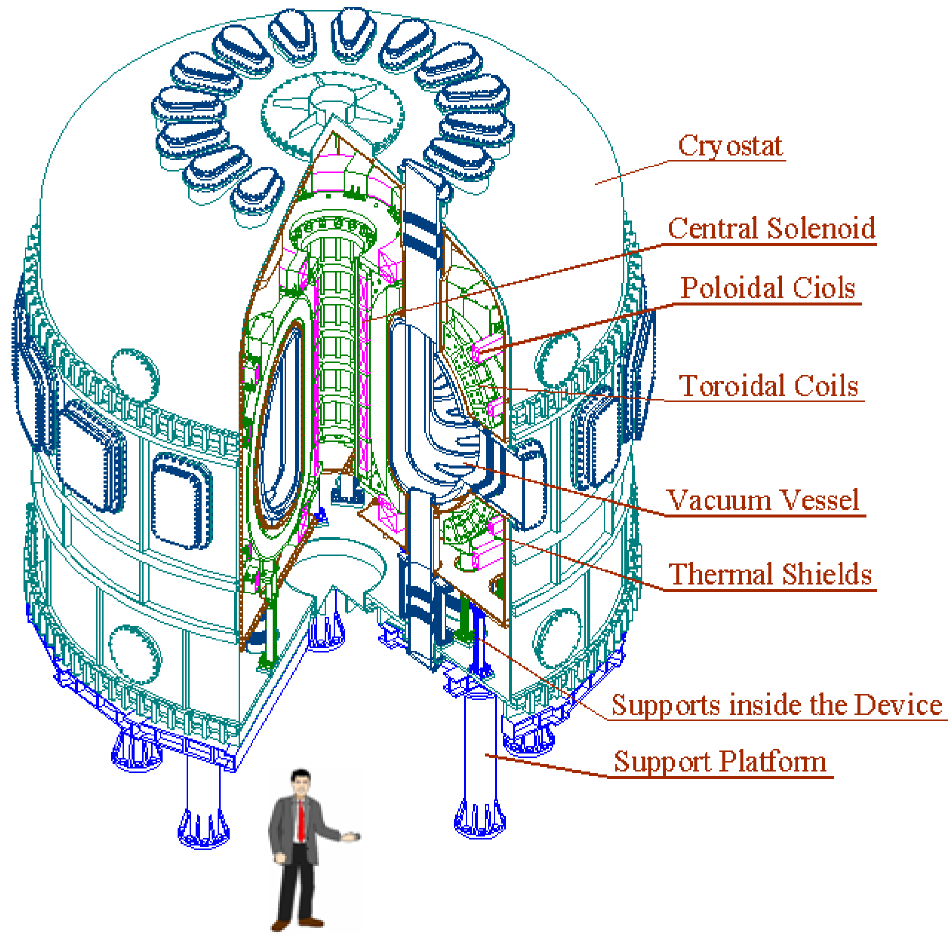
outline

- EAST features
- ECH program on EAST
- ECE systems on HT-7
- ECE program on EAST
- Summary

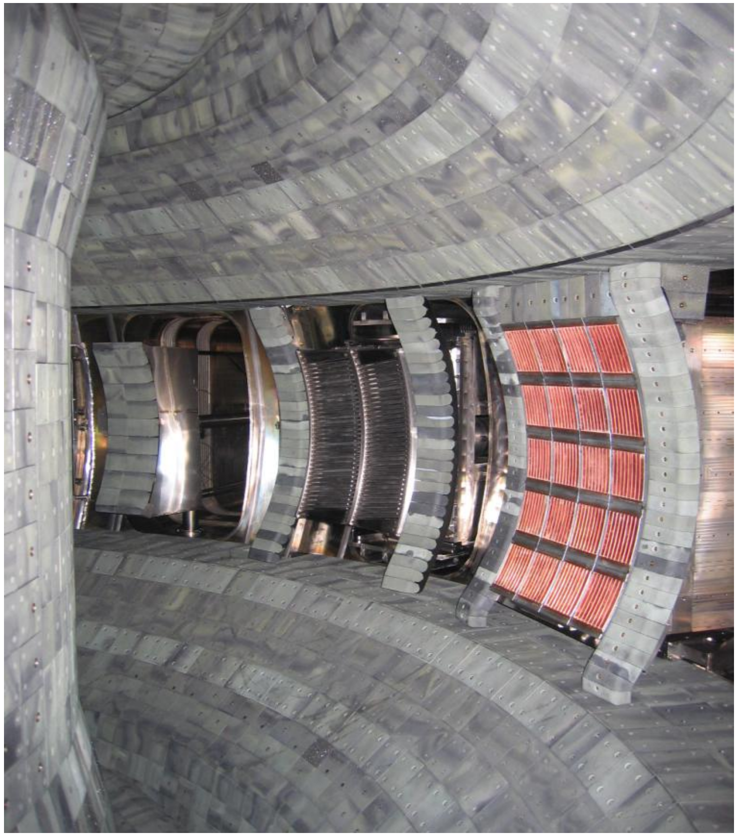
Main Parameters of the EAST

	Nominal	Upgrade
B_o	3.5 T	4.0 T
I_P	1 MA	1.5 MA
R_o	1.7~1.9 m	1.7~1.9 m
a	0.4~0.45 m	0.4~0.45 m
κ_x	1.0-1.9	1.0-1.9
δ_x	0.2-0.6	0.2-0.6
Cryo	4.5 K	3.8 K
Heating and Driving:		
ICRH	4.5 (6) MW	9 MW
LHCD	2.0 (4) MW	10 MW
ECRH	4.0 MW	4.0 MW
NBI	4.0 MW	8 MW
Pulse length		1000 s
Configuration:		DN, SN, Limiter

grey under construction



EAST features



- Full superconducting magnets
- Actively cooled Plasma facing components
- Flexible configurations
- CW Heating and current Driving powers

These features allow steady-state and high efficient operation

The available power within next 3 years could provide:

- fully non-inductive plasma
- flexibility for manifold current and density profiles

Allow to approach advanced regime

(scale from DIII-D discharge: Bt=2.2T, Ip=0.8MA, q_{95}~5.0 β_N>3.5, f_{bs}>40% MHD instabilities maybe a concern)

ECCD become particularly important for control of such high beta plasma under steady-state condition.

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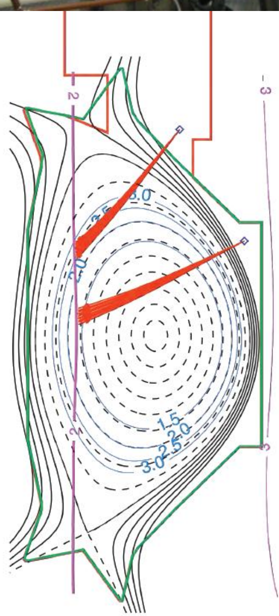
ECH/ECCD program

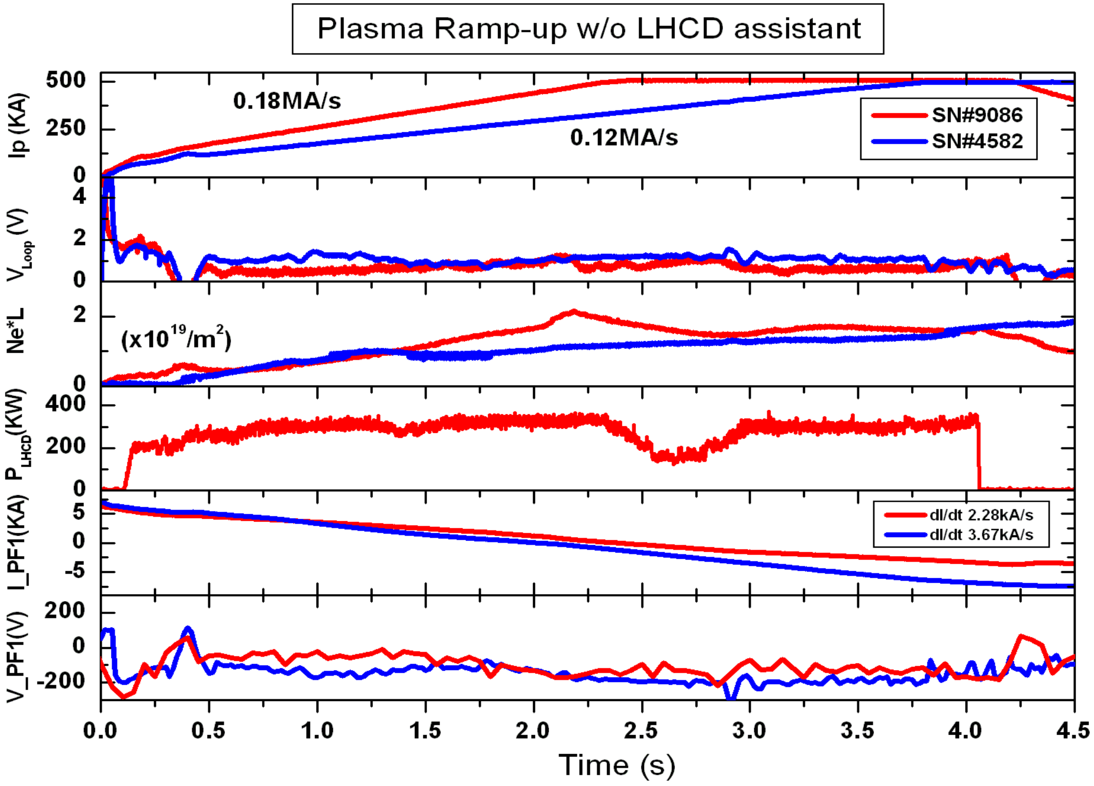


Potential injection locations

- Scenario development for high performance steady-state discharges.
- Studies of transport of energy or momentum.
- Off-axis current drive for current profile control.
- MHD control.
- Start-up → **compatible with ECH/ECCD (particularly benefit for SC device due to limited current ramping rate in PF coils)**

Based on above consideration, expected operation regime and availability:
2~4MW at 140 GHz in CW is considered in next 3 years for Bt=1.9~2.6T, P_{total} ~20MW

Plasma Ramp-up w/o LHCD



LHCD→I_p →Te
Coupling issue

ECRH→Te→$l_i dI_p/dt$
No coupling problem

LHCD applied at plasma ramping up phase can significantly reduce the current ramping rate in PF coils or voltage applied at PF coils, which increases the safety margin of SC magnets and provide larger margin for plasma control

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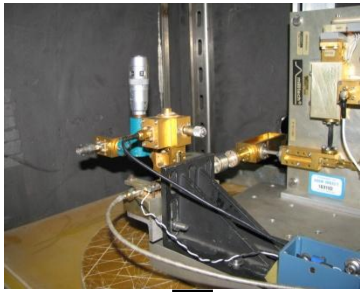
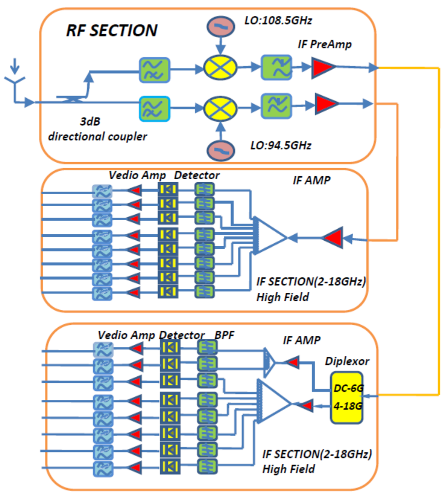
ECEI/ECE on HT-7





•ECEI: similar to those used on other tokamak (collab. With USTC and UC Davis)

•Heterodyne Radiometer of ECE (Collsb. With UT-FRC)

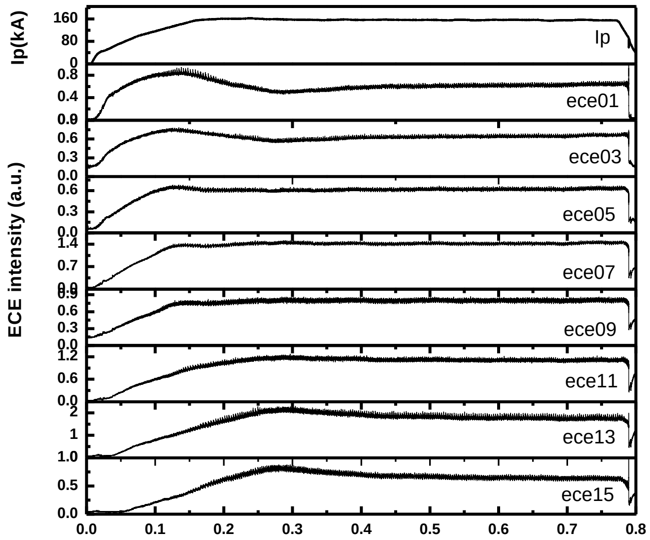
- Gaussian antenna
- Oversized waveguide
- 98.5~125.5GHz in 16chs with two mixers
- Tem. res. 50μs, spt. res. ~2cm

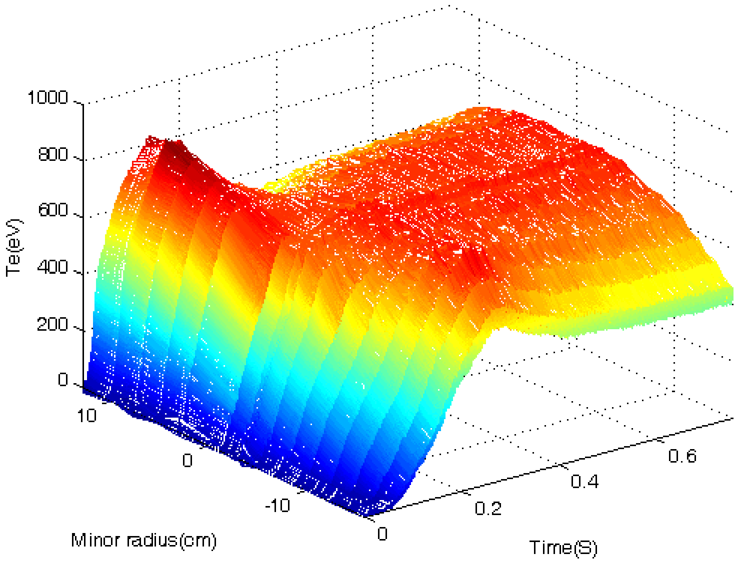
•These two systems are toroidally separated by 135°

•These two systems can be synergically operated

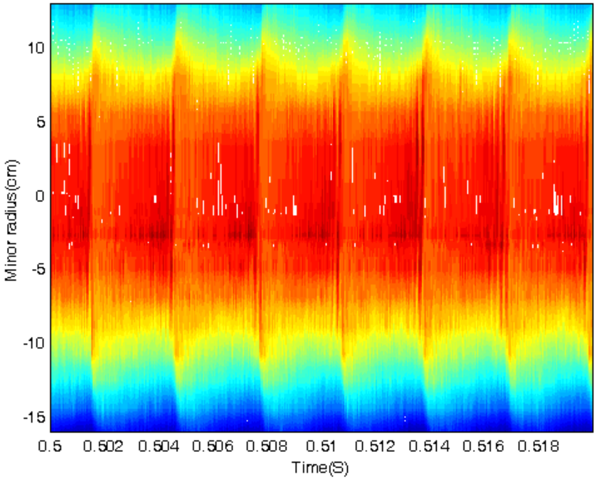
Post session I, 13 Ti. A

ECE on HT-7





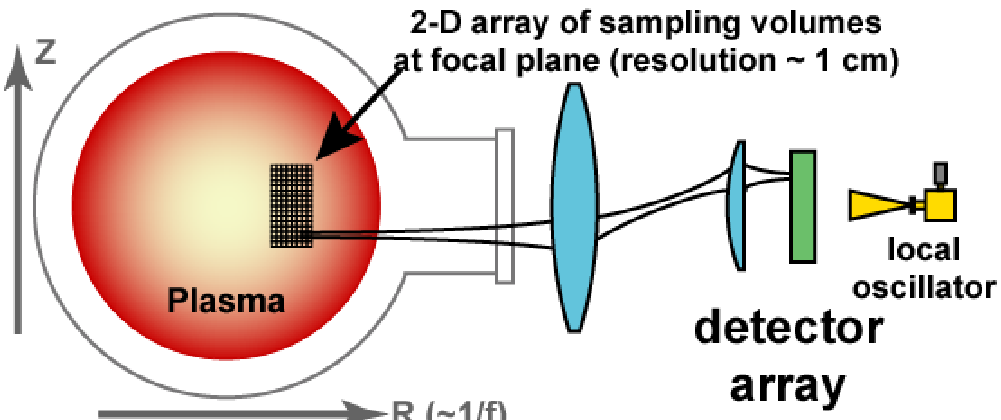
Reliable operation with good S/N ratio
Te fluctuation in ST plasma show clear heat propagation pattern



ASIPP

EAST

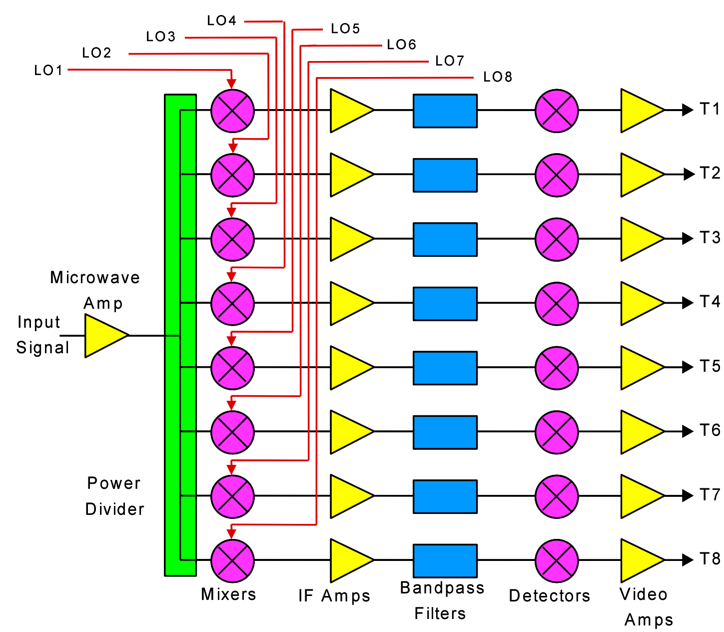
ECEI on HT-7



Optical System

- Two E-plane lens and one H-plane lens.
- 2D Image 5.6cm × 22.4cm on the LFS in the HT-7 tokamak with 8 × 16 channels.
- pixel sizes: 0.9– 1.2cm × 1cm, vertical channel spacing ~1.4 cm.

- 1st mixer at about 100GHz downconverts to IF in (DC-18GHz)
- Intermediate Frequency(IF) System(2nd mixing)
- Temporal resolution 4μs
- the magnitude of the signal noise ratio :1% level



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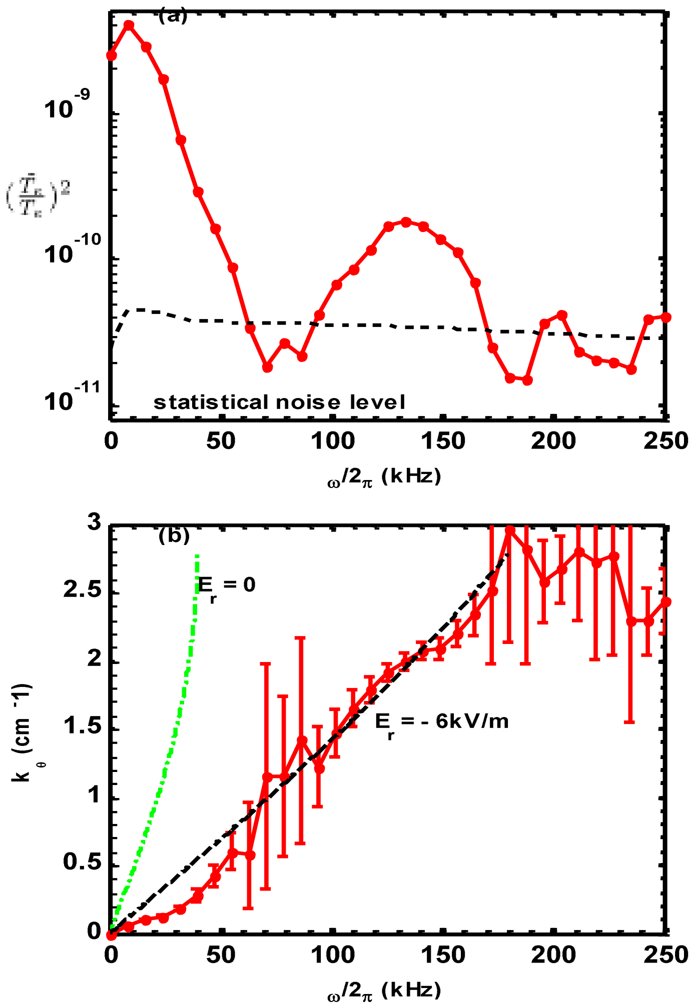
Electron mode in plasma with low density



- **Fluctuation spectra characteristic:**
  - propagate in electron diamagnetic direction
  - wavenumber $\bar{k}_\theta \rho_s \sim 0.3$

$$\rho_s = \rho_i (T_e / T_i)^{1/2}$$

- **Comparison of experimental results and theory**
  - **Electron drift wave mode frequency(assume Ti=0)**

$$\omega_k = \omega_e^* [1/(1 + k_\theta^2 \rho_s^2)]$$

$$\omega_e^* = k_\theta c T_e / eBL_n$$

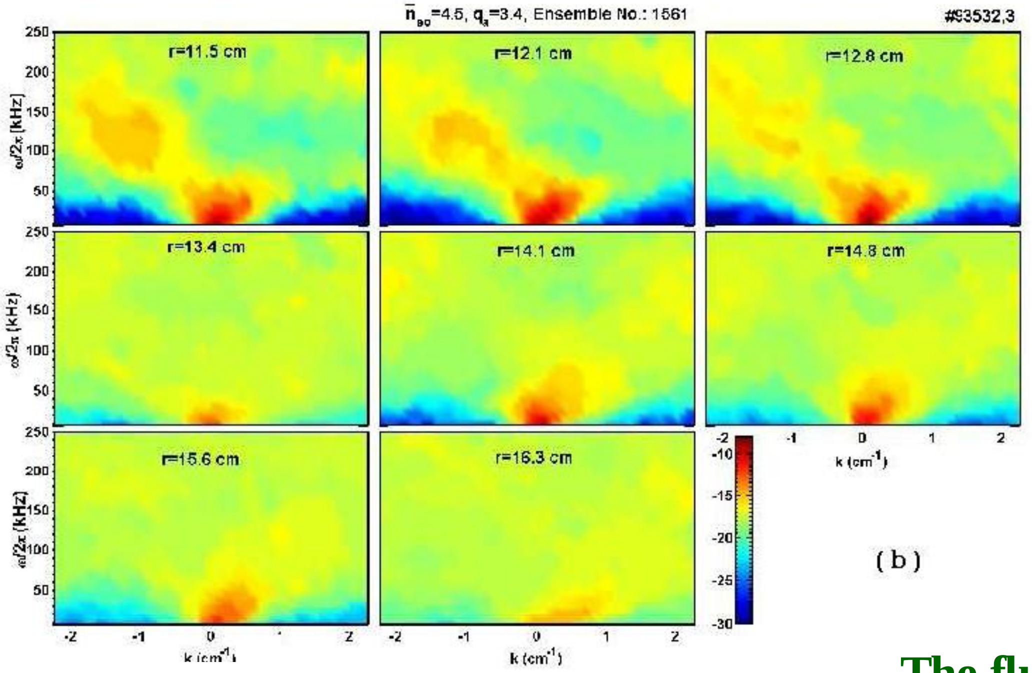
- **The statistical dispersion considering doppler shift :**

$$\omega = \omega_{edw} + \omega_{E\times B}$$

- **Fit the modified dispersion by considering Doppler shift with the measurement, derived Er~6kV/m**

r/a = 0.59, $\bar{n}_{e0} = 1.9 \times 10^{19} m^{-3}, q_a \simeq 3.8$

Coexistence of e- and i- modes in plasma at high density



$n_e = 4.5 \times 10^{19} m^{-3}$

, midplane on the HFS(Z~0)

The fluctuation with single electron mode evolves into electron and ion modes inward in radial direction

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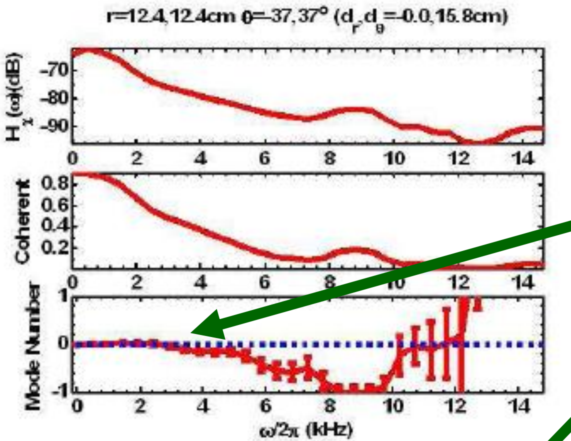
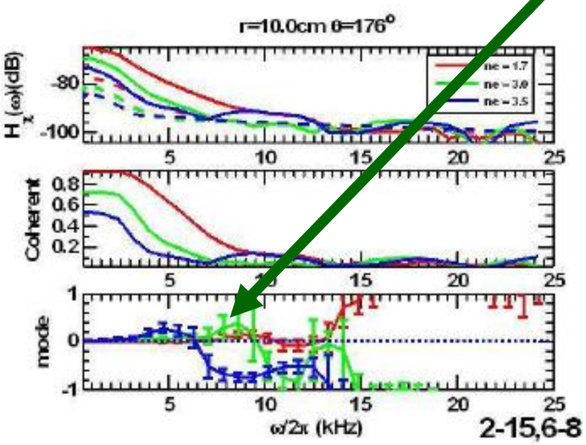
EAST

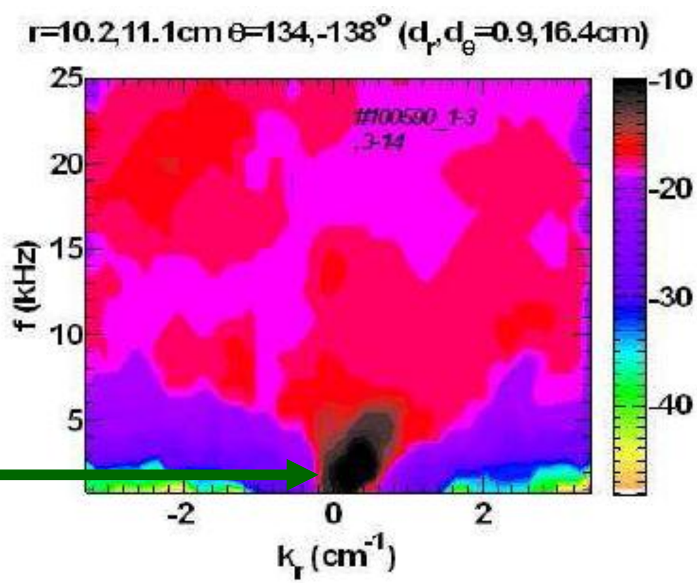
LFZF 3-D spectra character



The zero frequency mode in the electron temperature fluctuation is consistent with the character of the LF Zonal flow

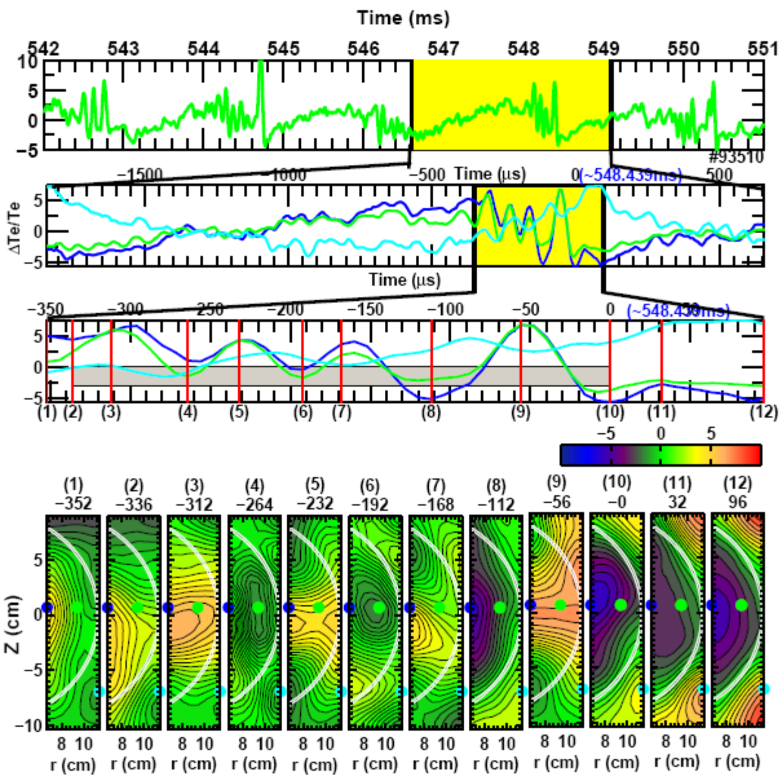
- k_θ~0 in 0-5 kHz (poloidal)
- k_ϕ~0 in 0~12kHz (toroidal) at density of $1.7\times10^{19}/m^{-3}$, the frequency range with kϕ~0 decreases as the density increases (this is measured by ECE and ECEI synergically)



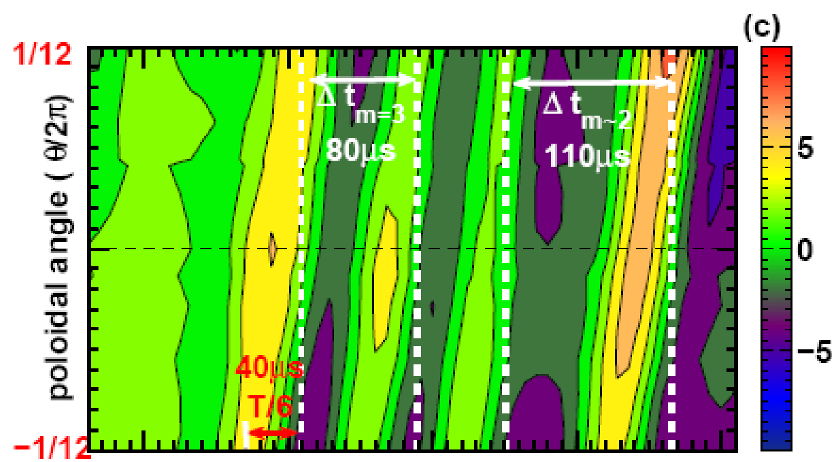


k_r~0 increases from 0 to 0.8 cm^{-1} in 0-5 kHz.
The propagation of the LFZF is outward

Magnetic reconnection and high-order harmonics



- Reconnection starts (Frame 2).
- Weak reconnection (Frame 3,5,7): only a few heat escapes out through the openings
- Strong reconnection (Frame 9): most of the heat escapes out.



$\bar{n}_{e0} = 1.5 \times 10^{19} m^{-3}, q_a = 3.3 (I_p$=170kA), $B_t = 1.9T$

- Azimuthal traces at about r=9.4 cm:
  - The poloidal mode number m = T /Δt, wher T~ 240 µs is the rotation period of the plasma.
  - Before the final crash, the harmonics evolve from m = 3(Δt ~ 80µs) to m ~ 2(Δt ~ 110µs).

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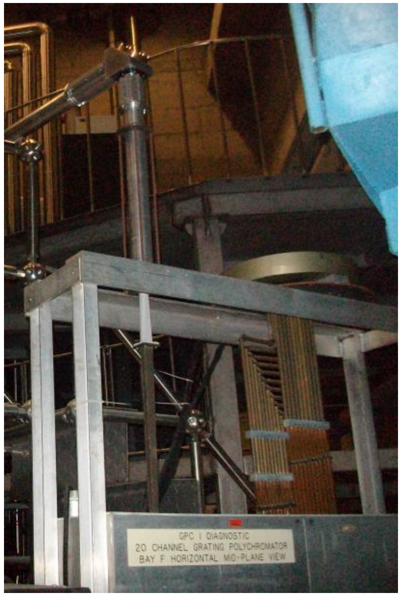
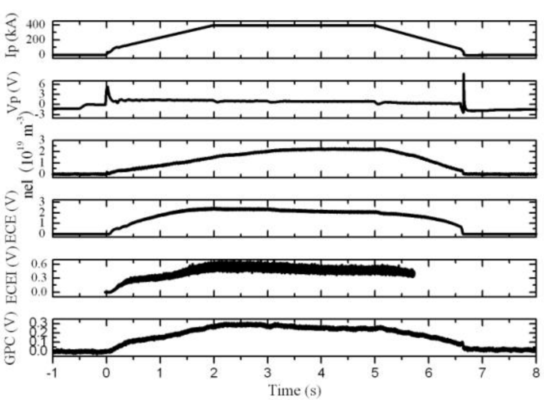
ECEI/ECE on EAST



GPC on EAST

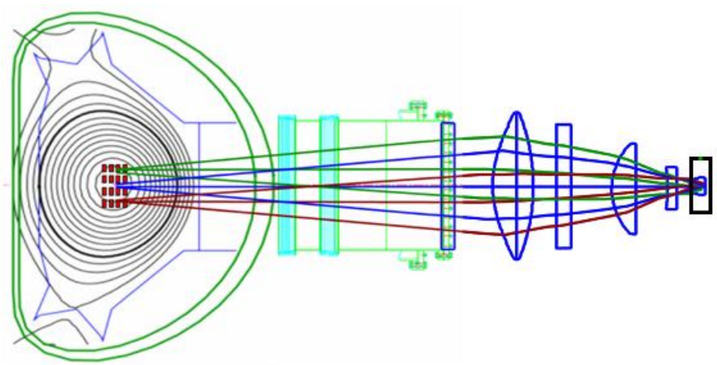


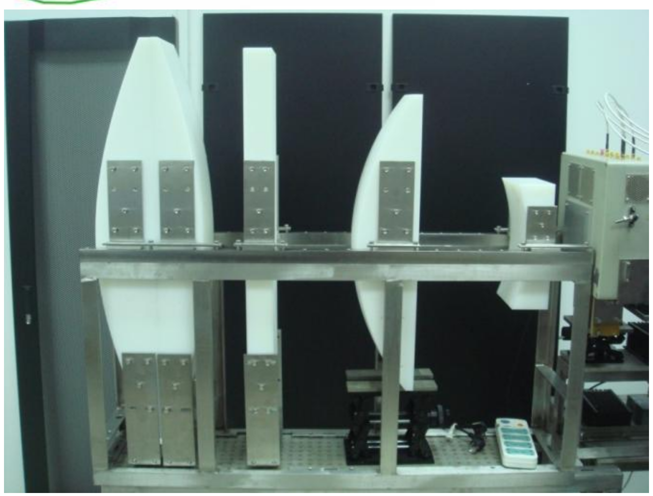
Mission

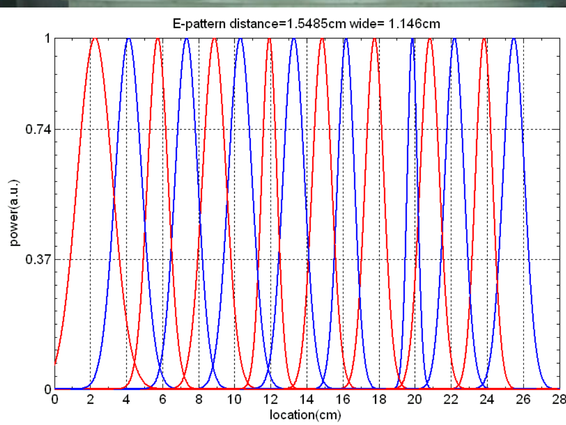
- **Te profile covering most radial region**
- **Kinetic equilibrium reconstruction**
- **Physically oriented:**
  - ➢ **Te fluctuation (spectra, coherence, long distance correlation…)**
  - ➢ **Electron thermal transport**
  - ➢ **Instabilities (ST, tearing mode…)**

- **Systems:**
- **Heterodyne radiometer ECE (modified from HT-7)**
- **2D ECEI (modified from HT-7)**
- **Grating polychromater (PPPL)**
- **Heterodyne radiometer ECE (collab. UC Davis)**
- **2D ECEI (collab. UC Davis)**

Modification of ECEI for EAST

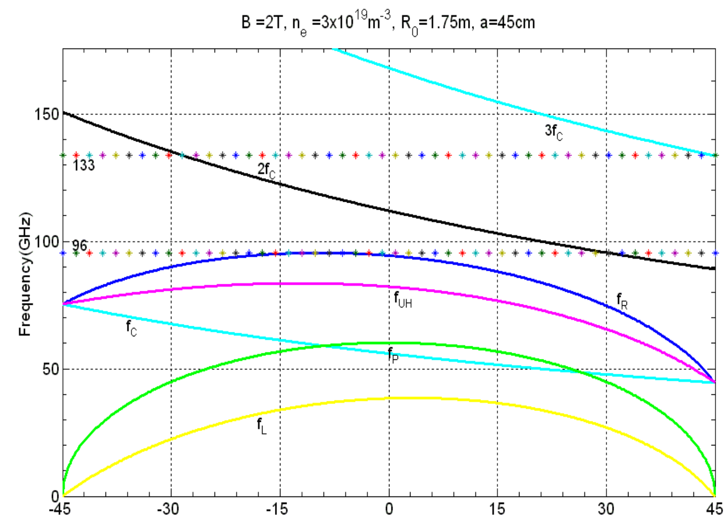




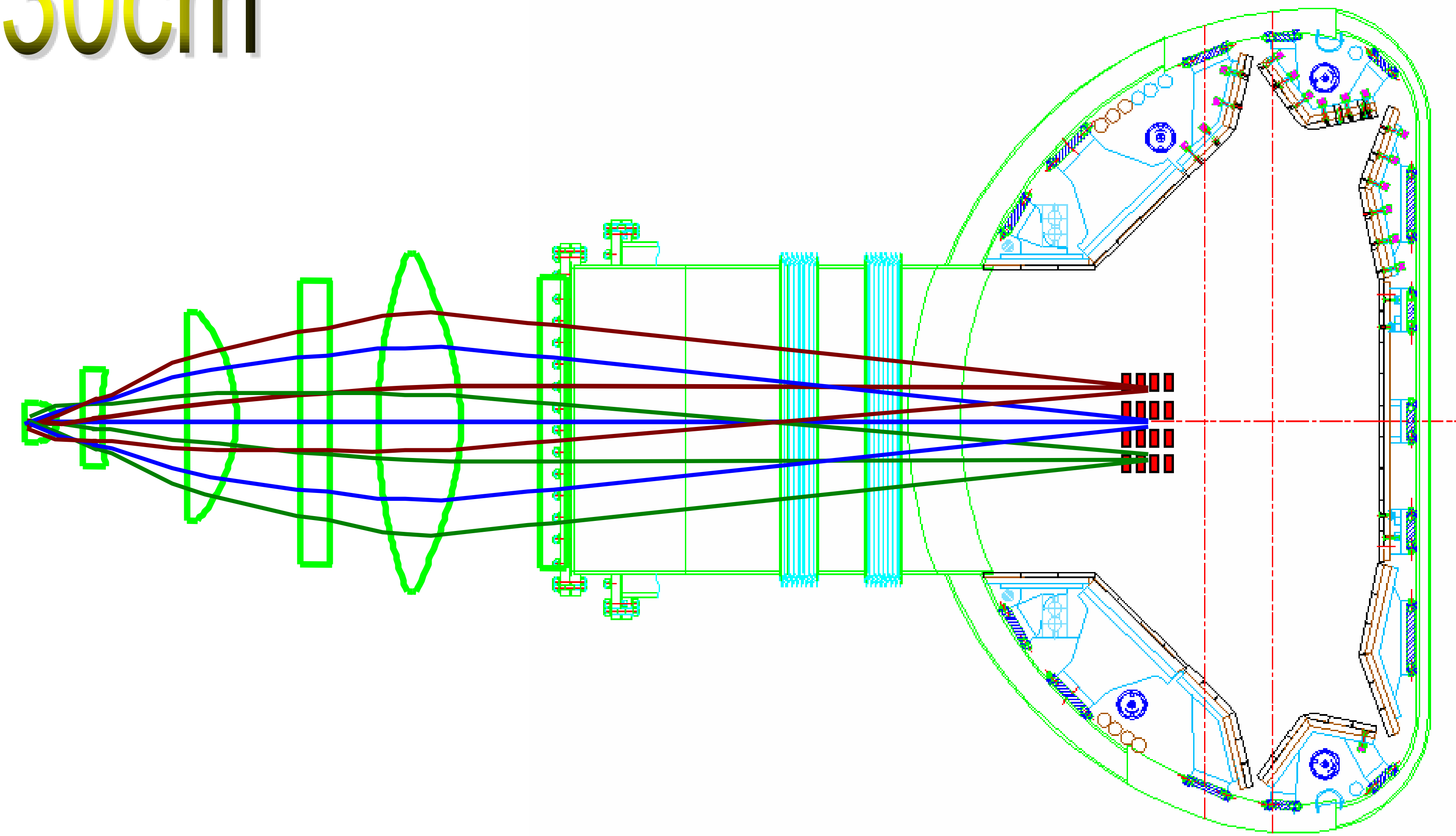


- New optical system and LO:
  - Three E-plane lens and one H-plane lens.
  - 2D Image 7cm × 23cm with 8 × 16 channels.
  - Extended frequency 96~133GHz, which can cover -30cm to 30 at B0=2T. (HT-7: 100.2~103.8GHz at f0=97GHz)

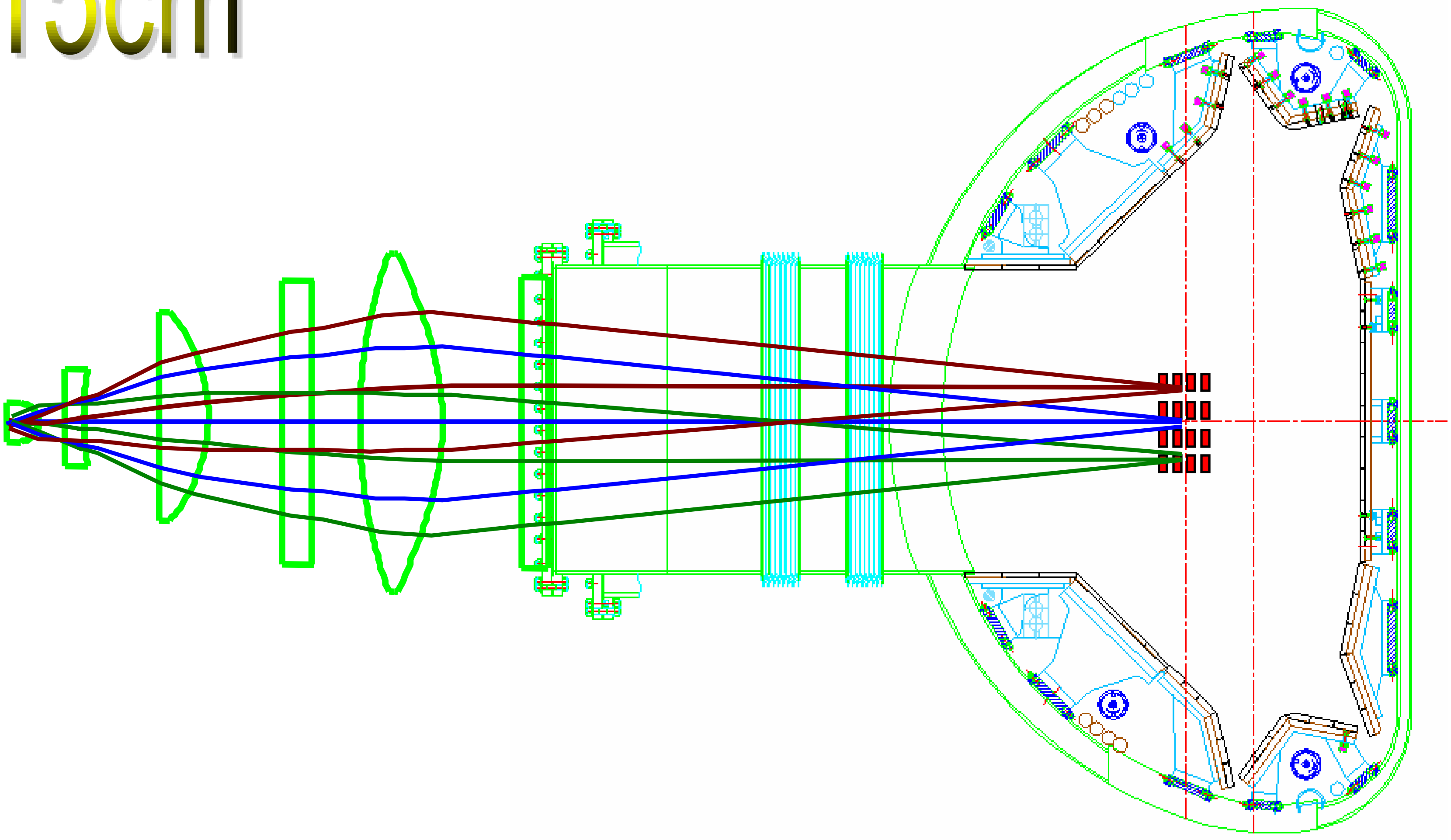
–Optimized optics can keep same sampling volume for large radial extension



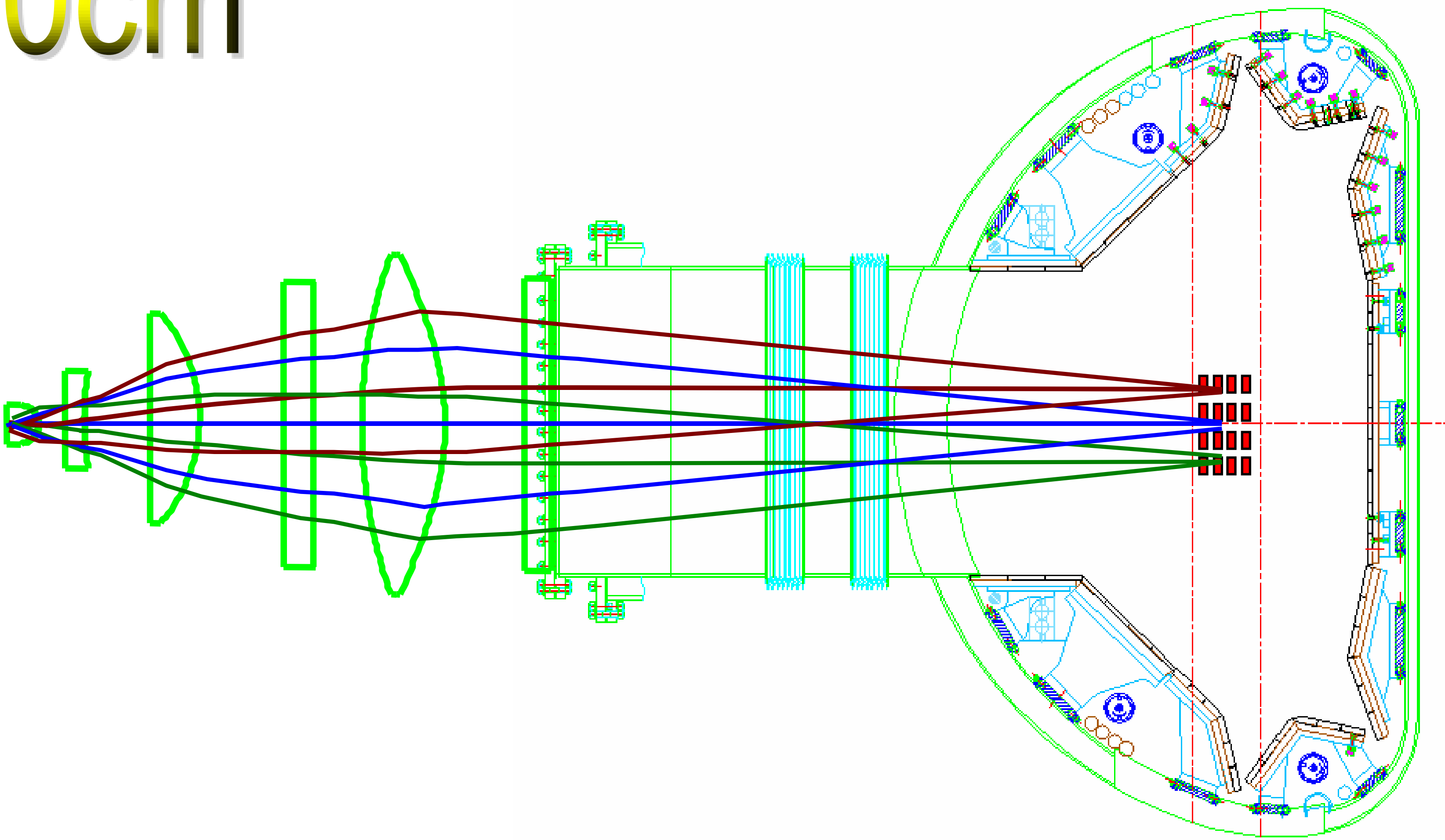
r=30cm



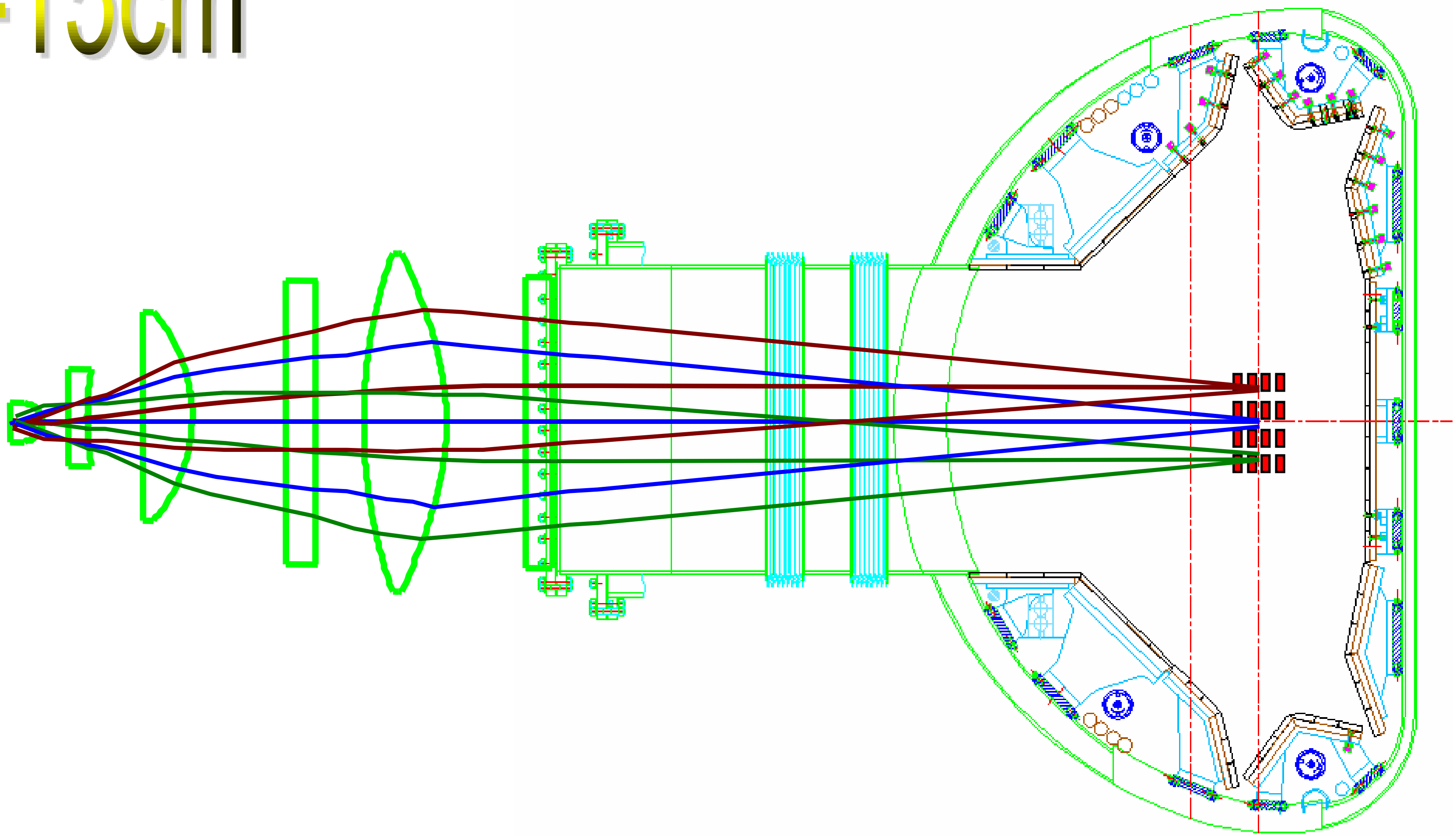
r=15cm



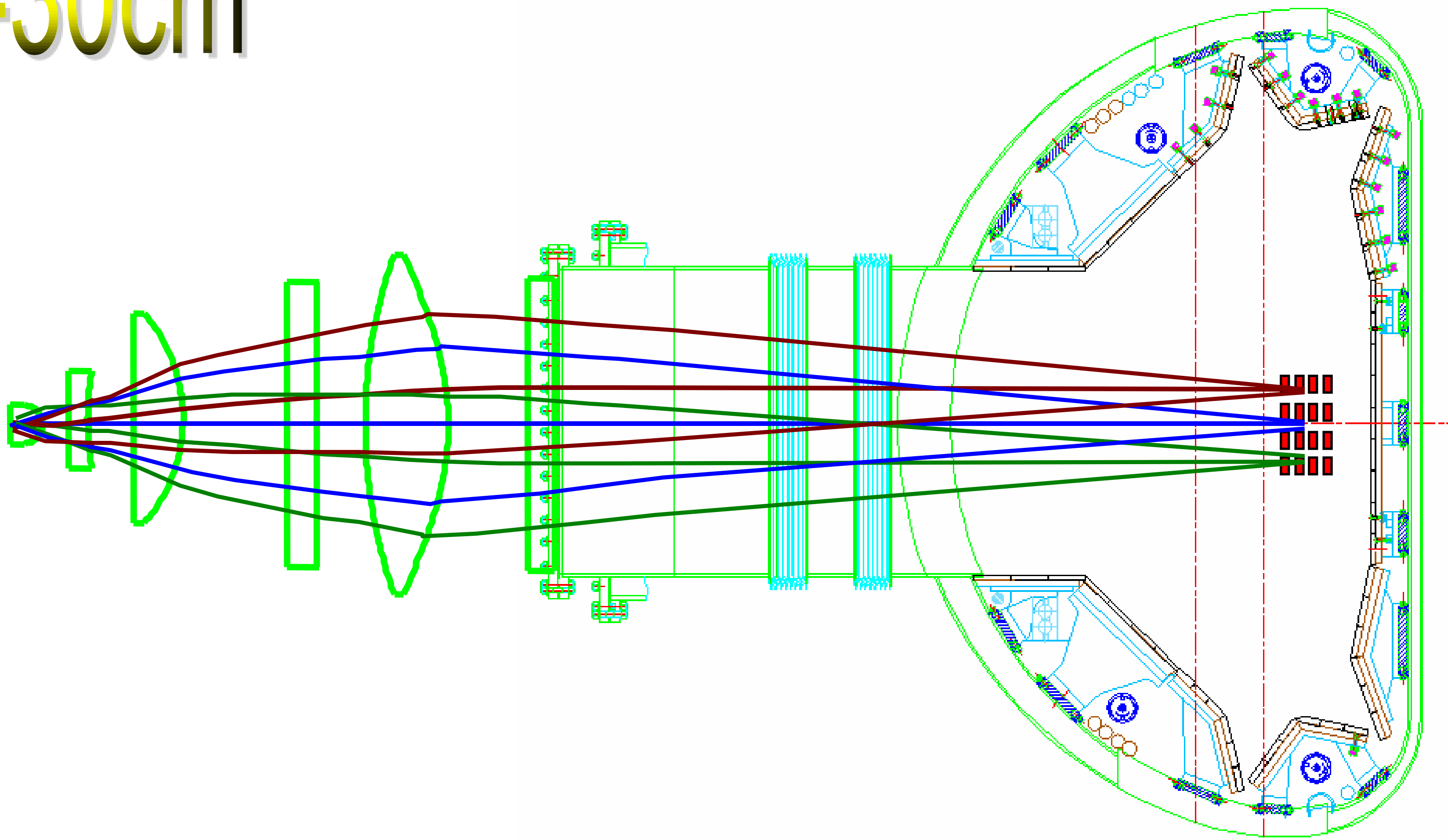
r=0cm



r=-15cm

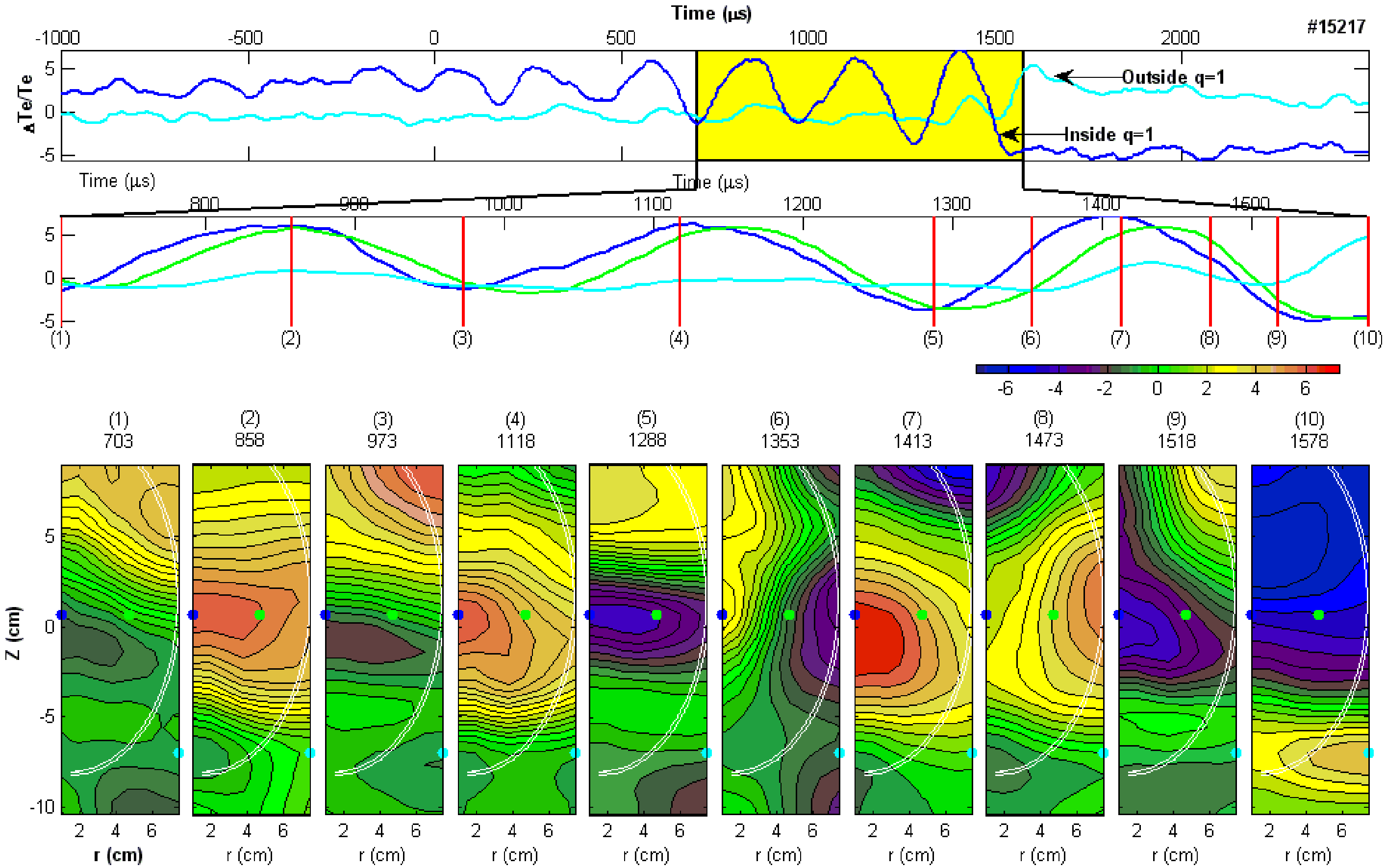


r=-30cm



Primary observation of ST on EAST

m/n=1/1 precursors



B0=2T, Ip=250kA, ne~2.0×10^{19}m^{-3}, R=1.80m

ECEI under development for EAST

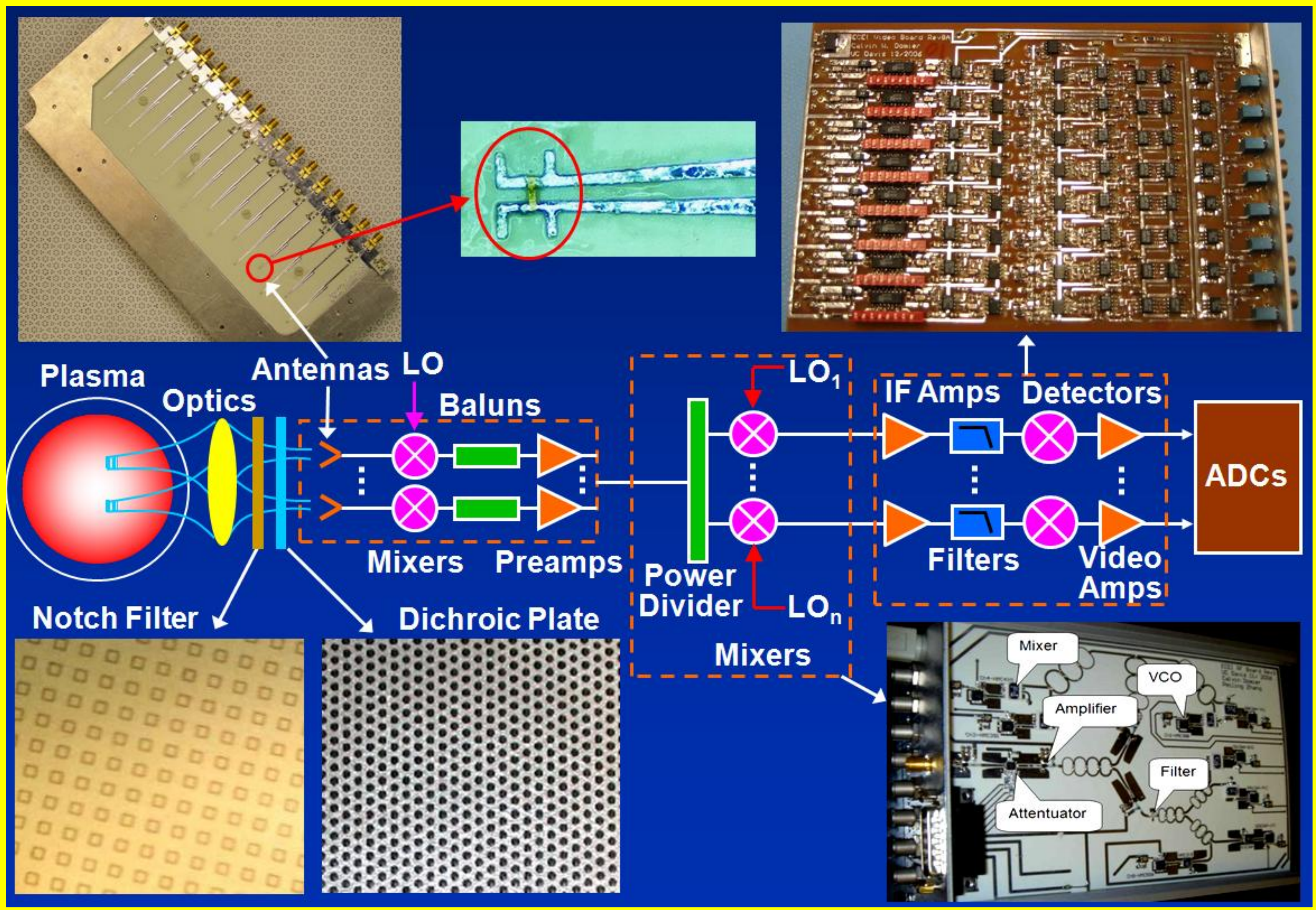
Similar to existing system, but adopt some new developed techniques

Difficulties

High spatial resolution ⇒large aperture optics

High power ECRH ~10^{+6}W

Very weak ECE power ~10^{-8}W



ECEI parameters and schedule

24 (poloidal) × 16 (radial) = 384 channels;

Coverage: >24 cm (vertical)， ρ≅0~0.5 (radial), (105~156GHz) ;

Spatial resolution: ~1cm； temporal resolution: 1us;

Te fluctuation <1%

2010/03： ECEI design

2010/04～2010/11： ECEI components and testing

2010/12： assembling in Hefei， system testing

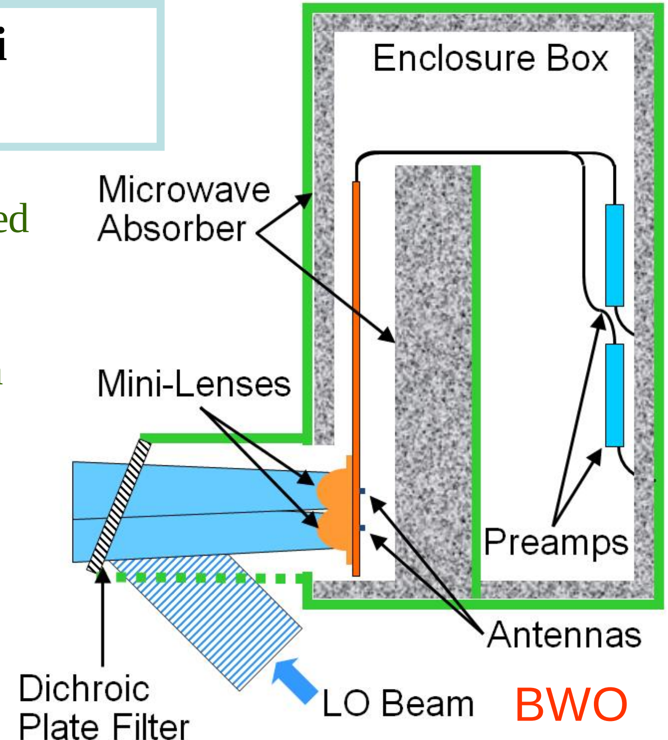
2011/01： install system on EAST

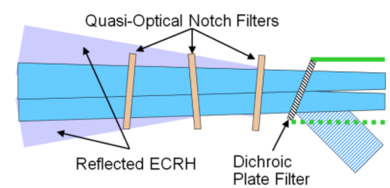
2011/03： primary experiments on EAST

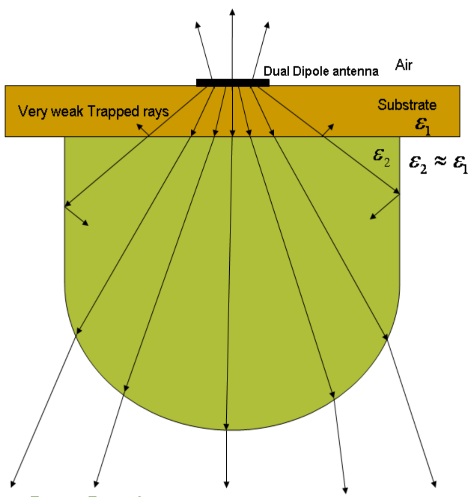
New optics

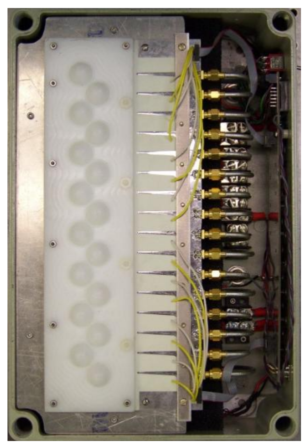
Hyperhemispherical lens:⇒ Elliptical lens:⇒ mini Elliptical lens array

shape optimized to collimate radiation from focus plane on back surface







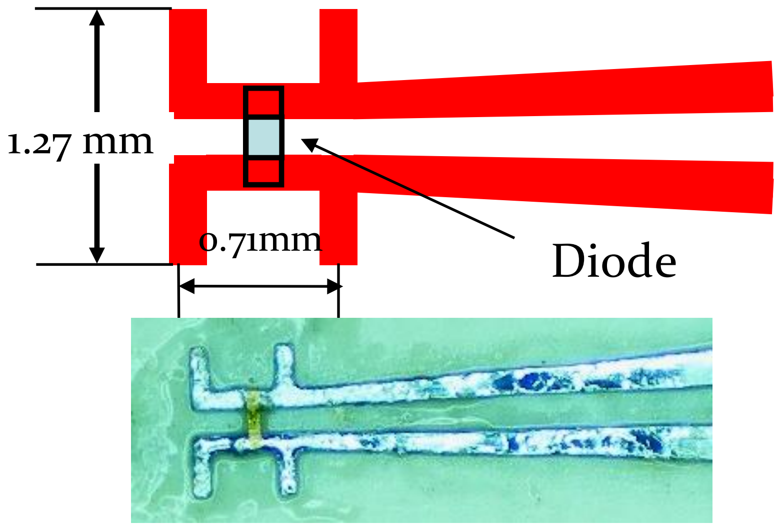


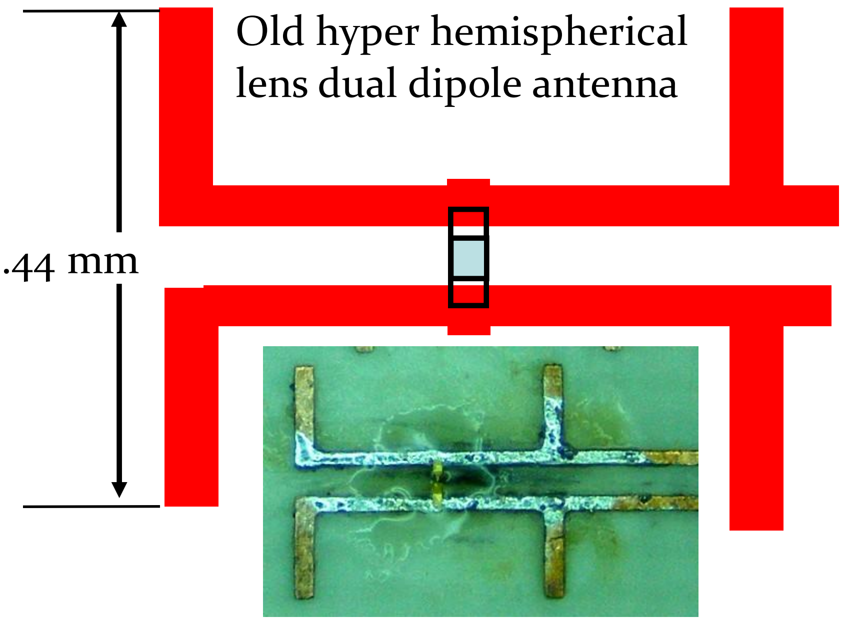
simple design;
easy to fabricate;
Trade-off between sensitivity and sidelobe levels

mini Elliptical lens array: 1. No need to trade-off sensitivity and antenna patterns!; 2.improved coupling efficiency by combination with front-side pumping (5~10); 3.increased gaps between antenna and lens arrays allow insertion of more ECRH filter for improved S/N ratio…

Antenna array

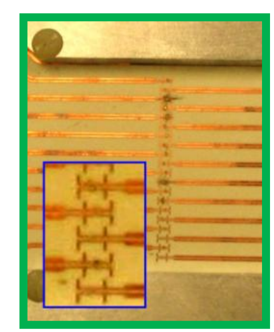
- New mini lens dual dipole antenna



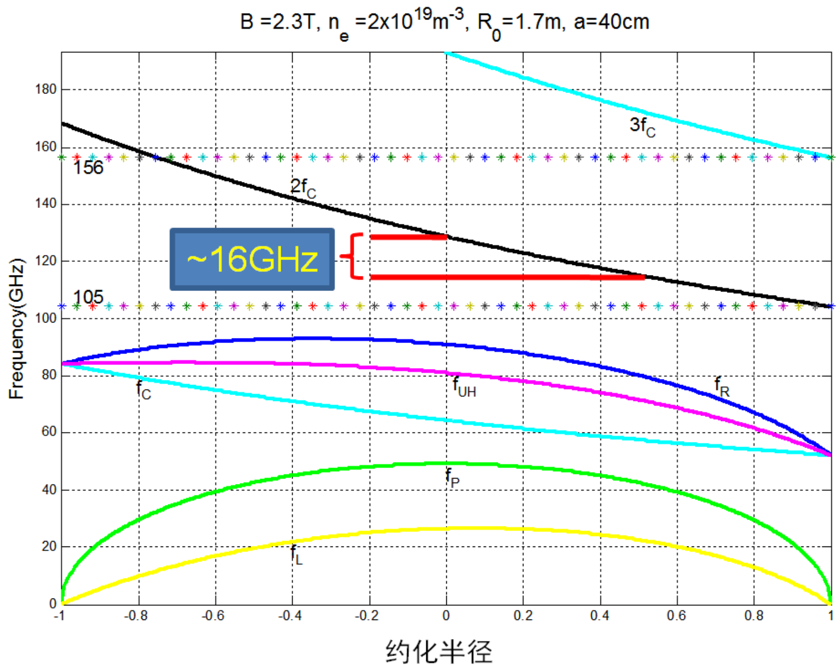


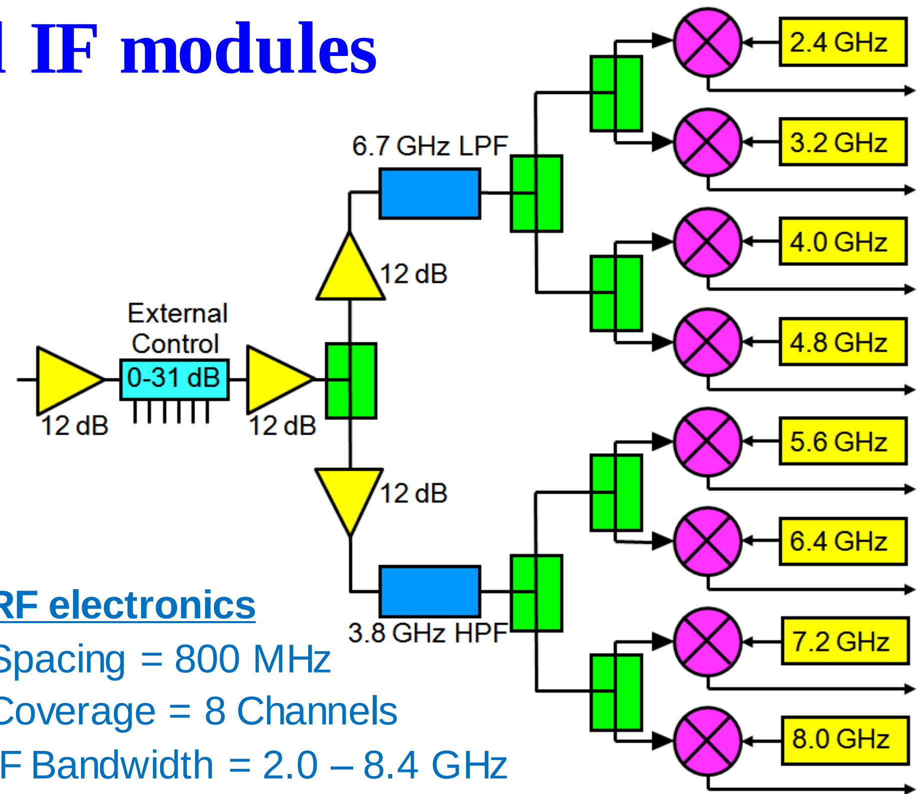
- Decreased antenna dimension, improved RF receiving efficiency
- Front-side pumping improved antenna mixer performance

$\Rightarrow$ maximum sensitivity, minimum noise temperature



Standardized IF modules



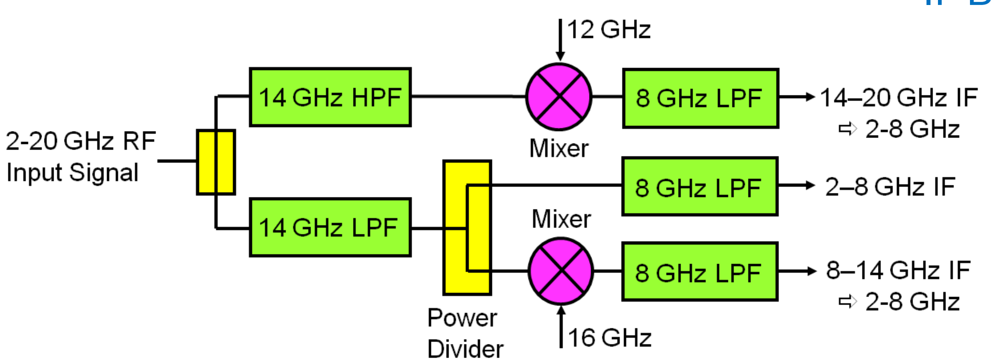


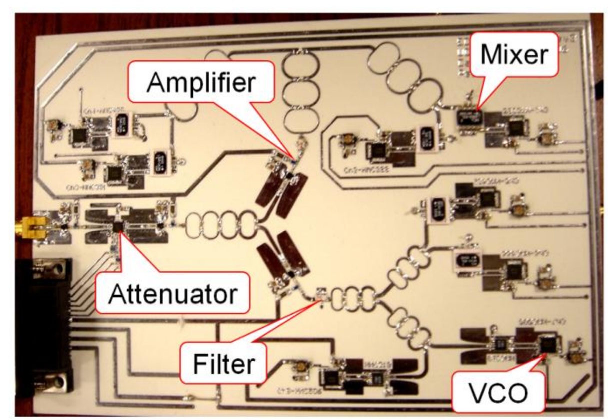
RF electronics

Spacing = 800 MHz

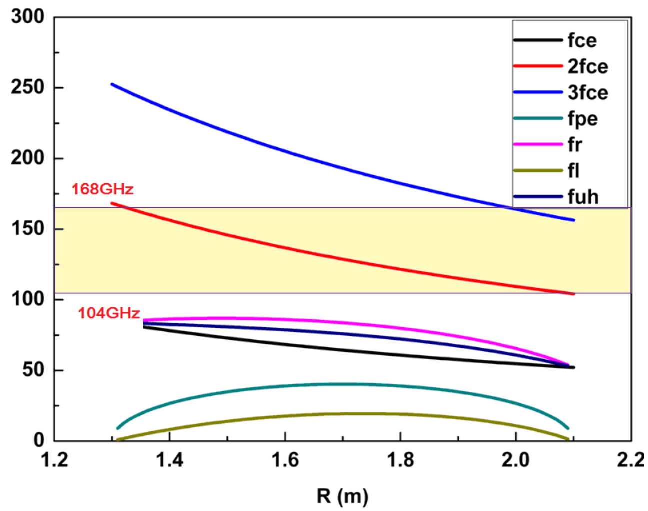
Coverage = 8 Channels

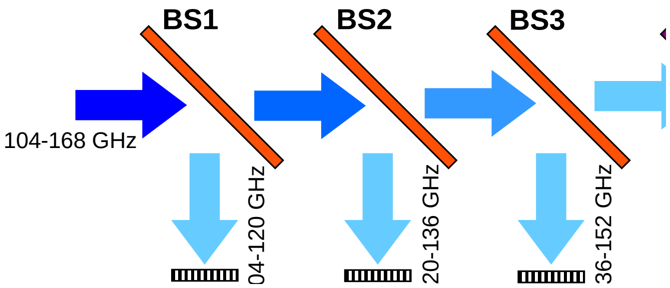
IF Bandwidth = 2.0 – 8.4 GHz



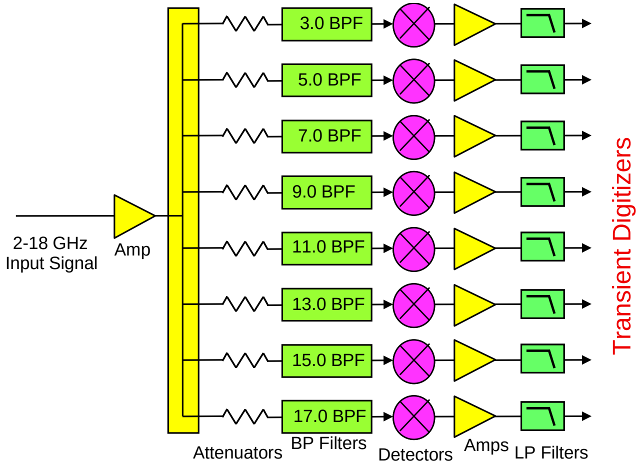


ECE under development for EAST





32 channels optimized for B0=2.3T
Single side band
high density polyethelene (HDPE) lenses



Poster session I, 14, Ling B

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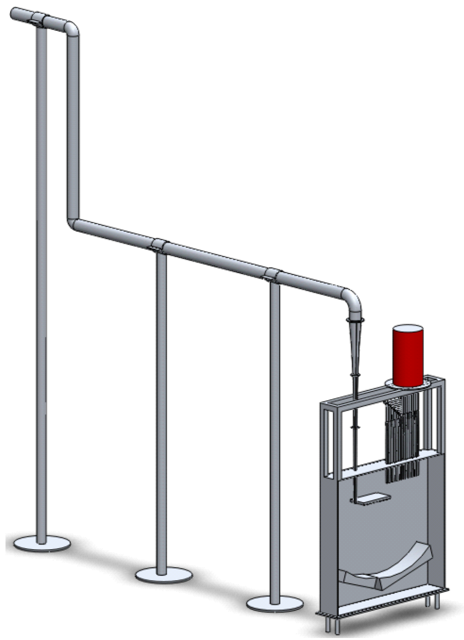
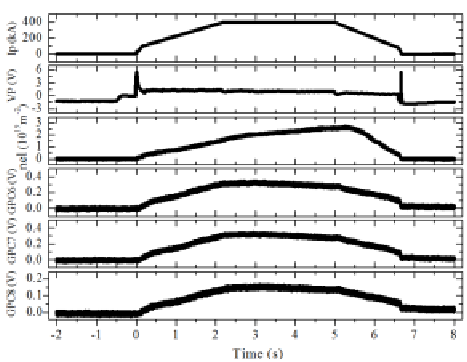
GPC from PPPL for EAST





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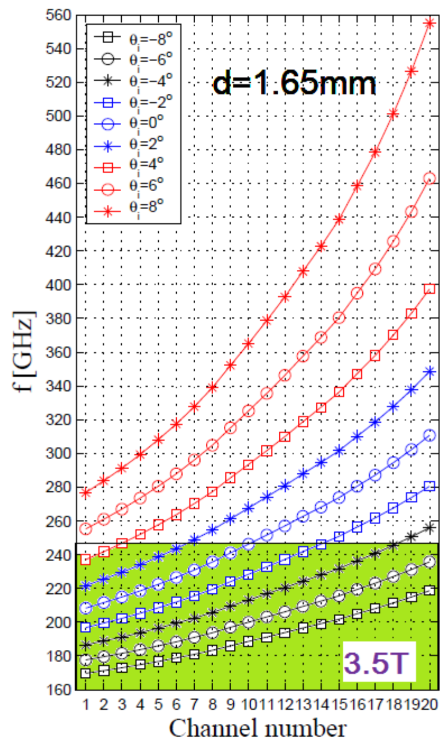

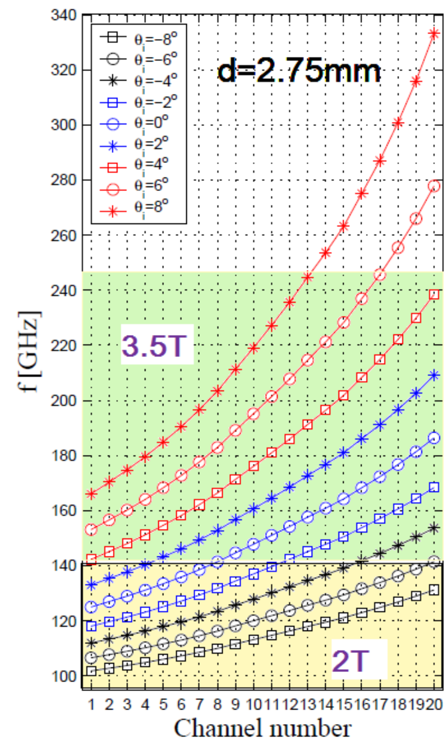

Two grating, 20 channels can covering most plasma for B0>2T

Transmission: Corrugated waveguide

Detector: Hot electron indium antimonide bolometers at 4.2K

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Summary

- EAST features allow plasma operation into high performance regime under long pulse condition.
- ECH program has been launched on EAST for various physical issues and start-up assistant
- ECE and ECEI systems on HT-7 have produced a lot of interesting observations
- ECE program on EAST focus on physics of the electron temperature profiles (equilibrium, transport, etc) and fluctuations
- International collaborations support the EC program on EAST

Thank you for your attention!