Effect of low frequency MHD instability on fast ion distribution in NSTX

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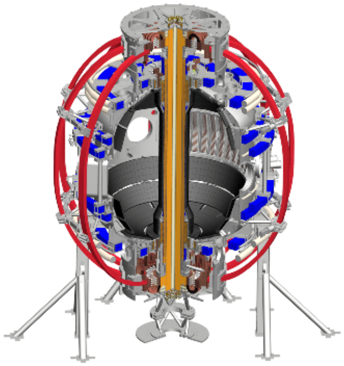


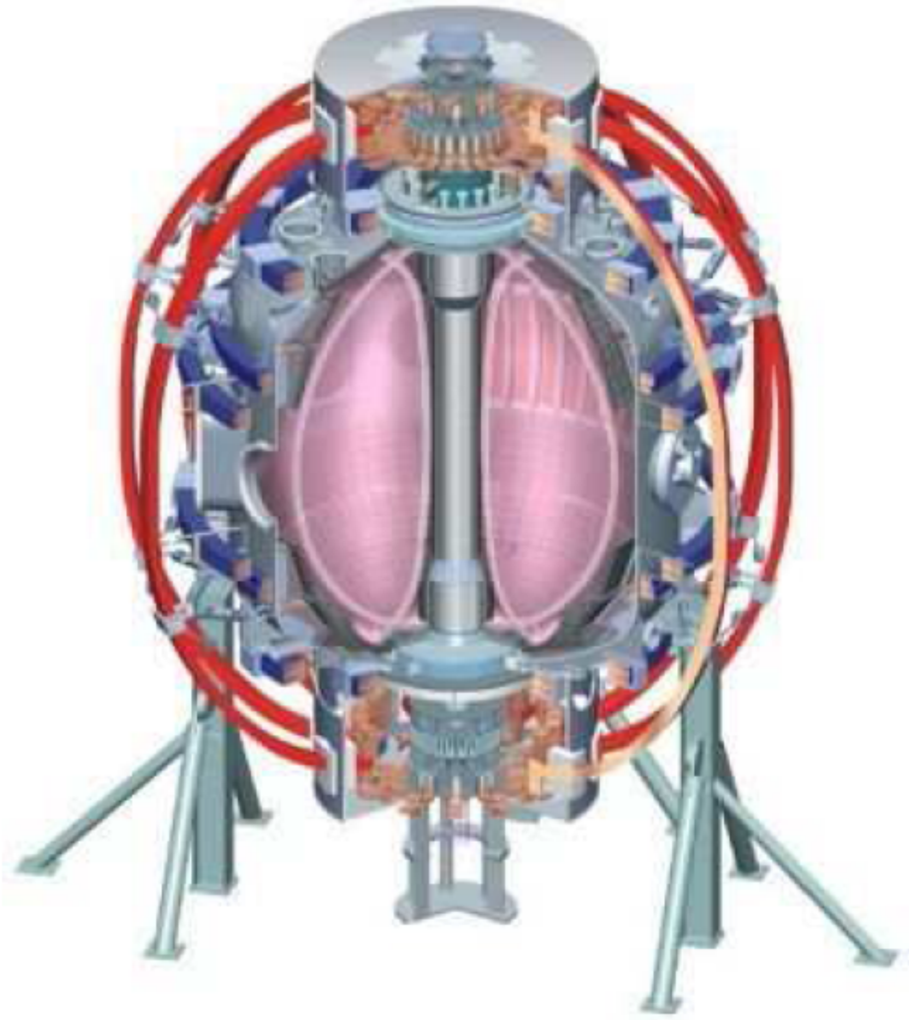
Introduction

- The fast ion confinement is an essential issue for plasma heating and current drive in magnetic controlled fusion devices

- Numerous instabilities have strong influence on fast ion confinement in NSTX
  - Toroidal Alfven Eigenmodes (TAE) and TAE avalanches
  - Energetic Particle Mode (EPM)
  - Low frequency instability (kink/tearing)

- Recent focus on the low-frequency instability and on its effect on fast ion confinement (A.Bortolon APS 2012)
  - Low-frequency mode strongly affects fast ion population
  - Significantly reduces fast ion (FIDA) signal in the core plasma region
  - The mechanism of onset of the instability & its effect on fast ion confinement is not clear yet

NSTX parameters



Major radius	0.85 m
Aspect ratio	1.3
Elongation	2.7
Triangularity	0.8
Plasma current ~	1 MA
Toroidal field	<0.6 T
Pulse length	<2 s

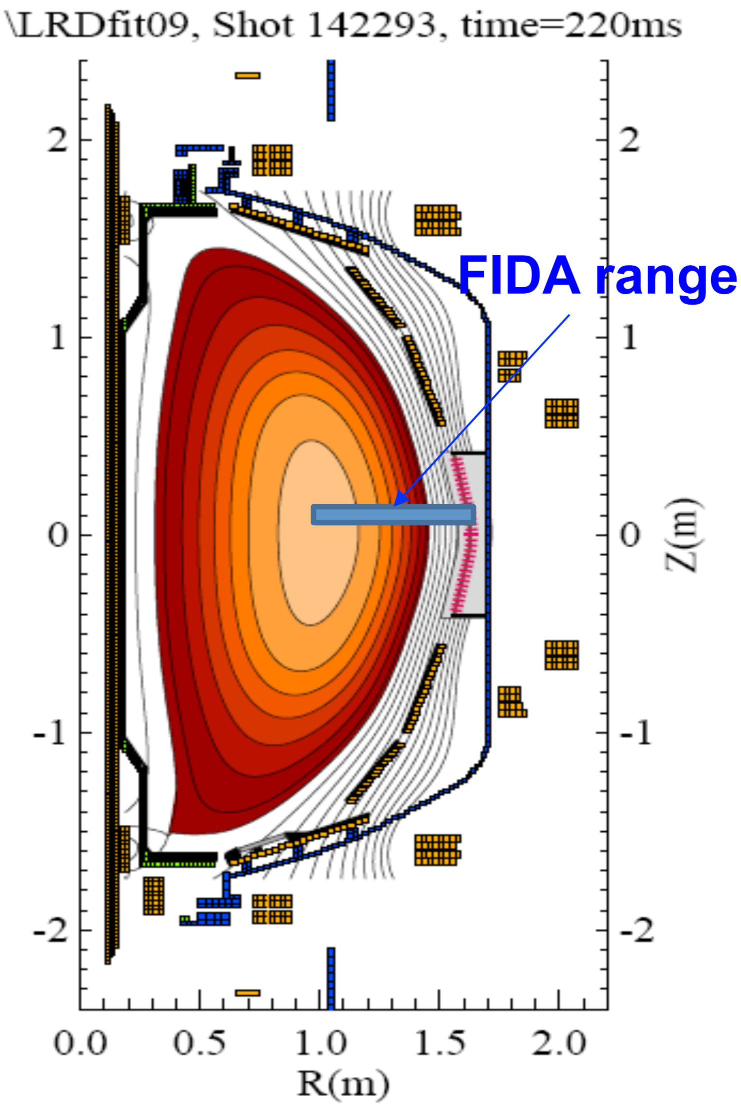
3 Neutral Beam sources

$P_{NBI} \leq 6$ MW

$E_{injection} \leq 95$ keV

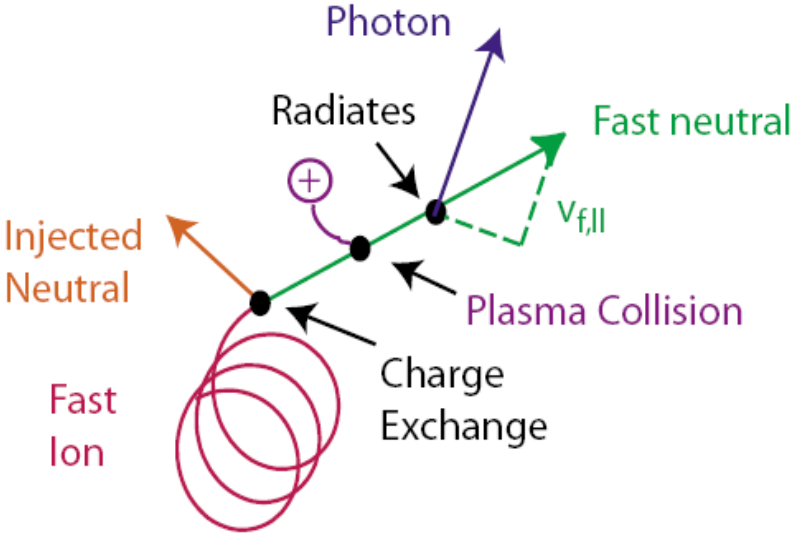
$1 < v_{fast}/v_{Alfven} < 5$

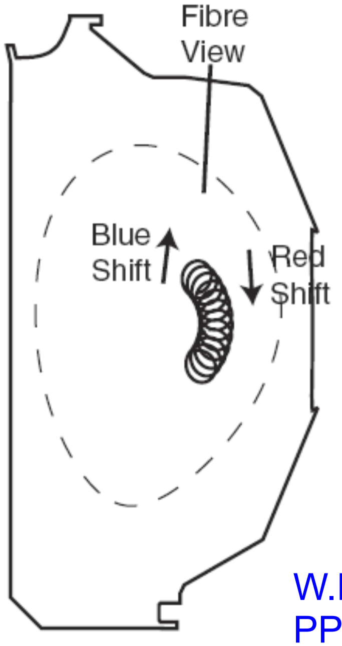
Main fast ion diagnostics in NSTX



- Mirnov Coils
  - Magnetic perturbation; up to 2.5MHz
- Fast Ion D-Alpha(FIDA)
  - Fast ion profile through active charge-exchange recombination spectroscopy
- SSNPA: Fast ion profile
- FLIP: Fast ion Lost

FIDA measures fast ion density profile through active charge-exchange spectroscopy



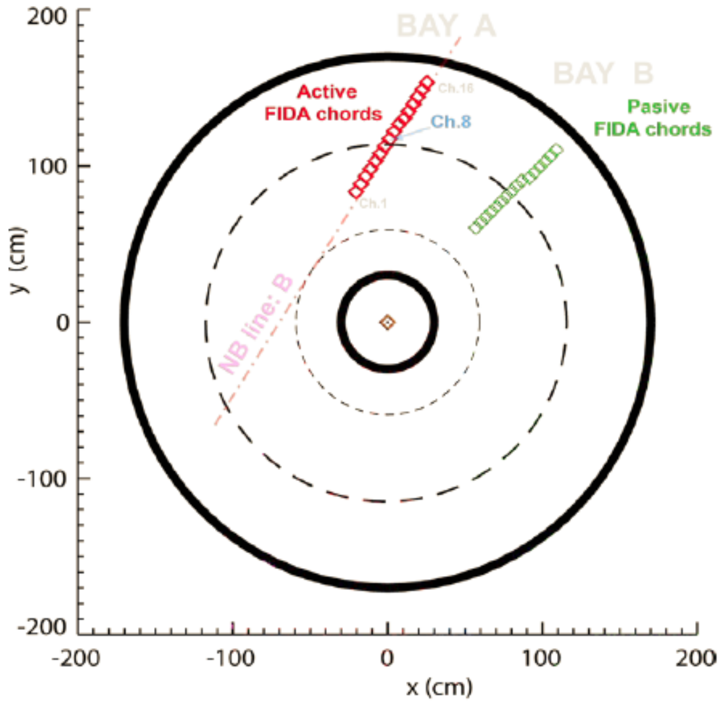


W.Heidbrink,RSI(2010), PPCF(2004)

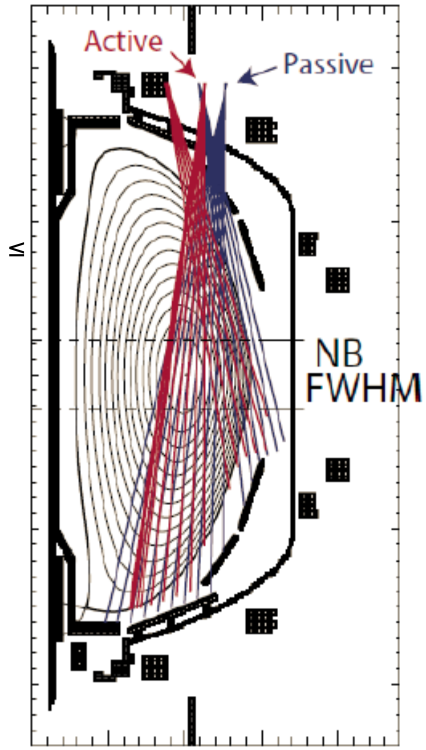
- Fast ion exchanges an electron with the injected neutral
- Doppler shift of the emitted photon depends on the fast ion velocity
- FIDA: collect the Doppler-shifted Balmer-alpha light of Hydrogen

Vertical-FIDA: measure fast ions that have large perpendicular velocity component

Plan view



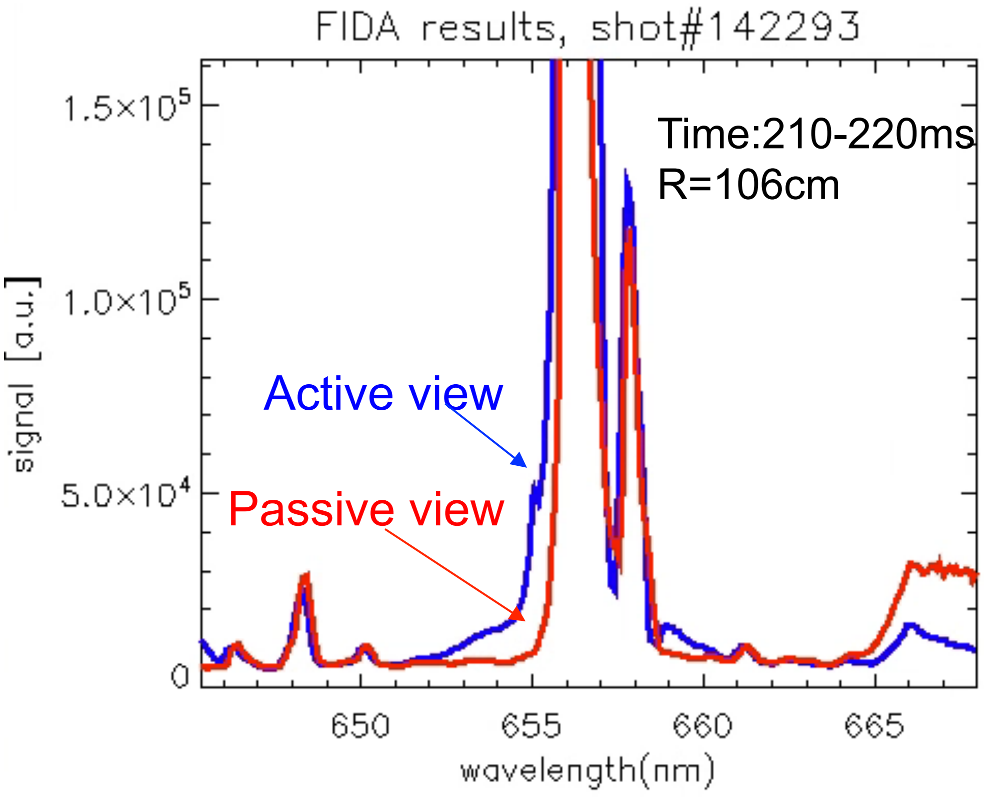
Elevation



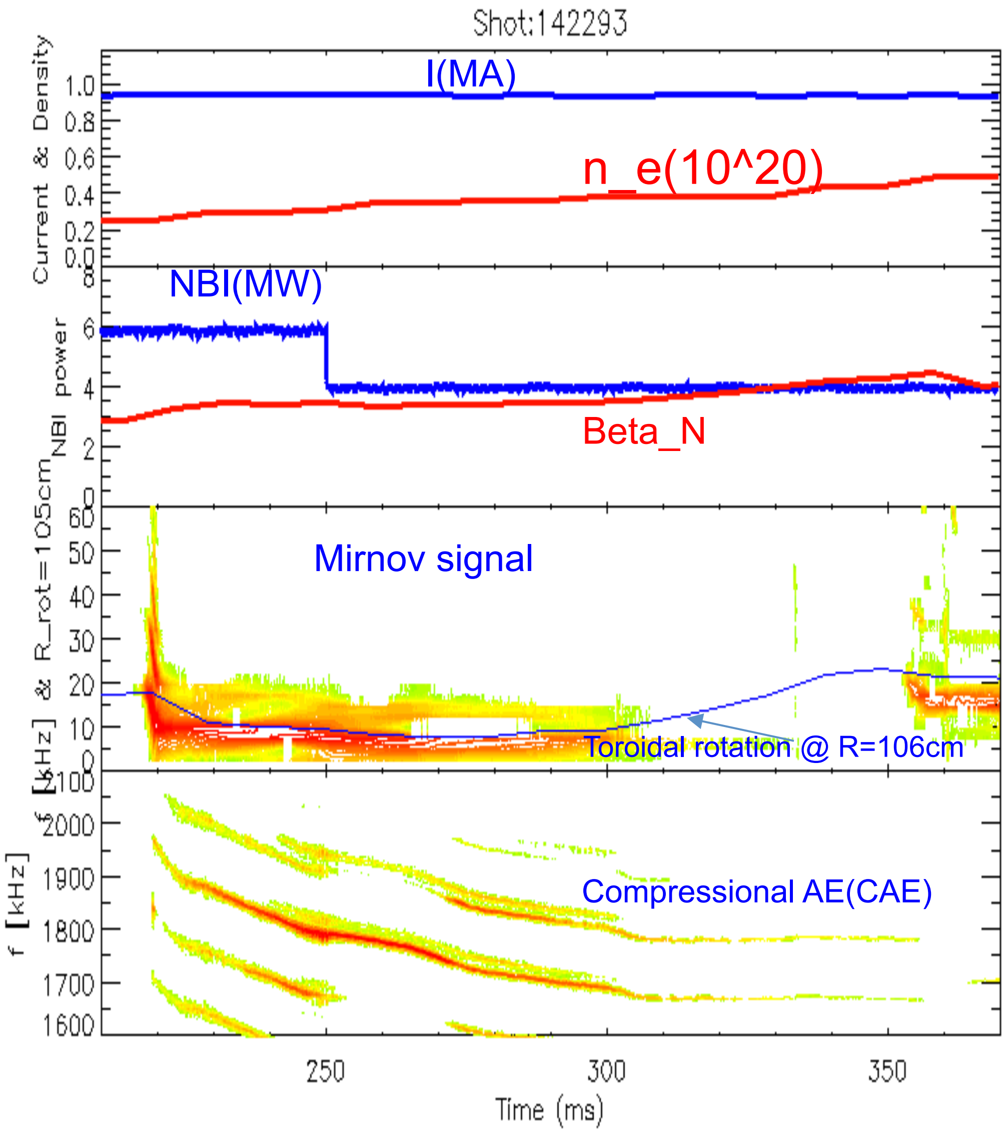
- 16 Channels:
  R=85cm->155cm
- Energy resolution ~ 10keV
- Temporal resolution: 10ms

Measure light in active view and passive view

- The FIDA signal is the difference between the active and passive views
- Wavelengths of interest : 650.1~654nm
- Only blue-shifted side is considered
- Integrate the signal over the selected wavelength for all of channels

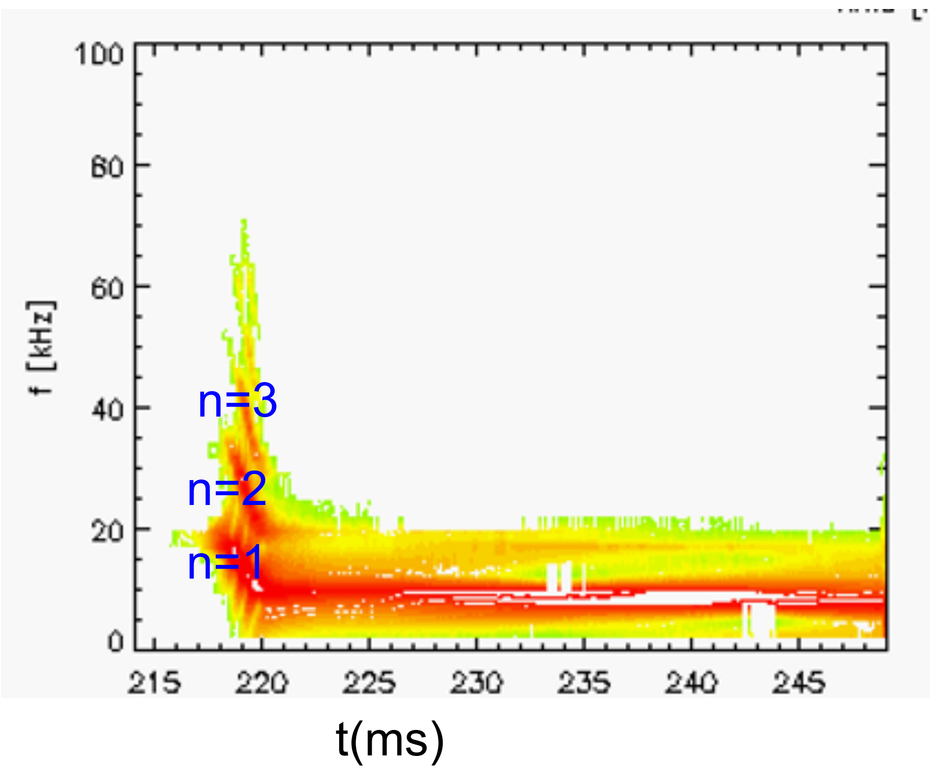


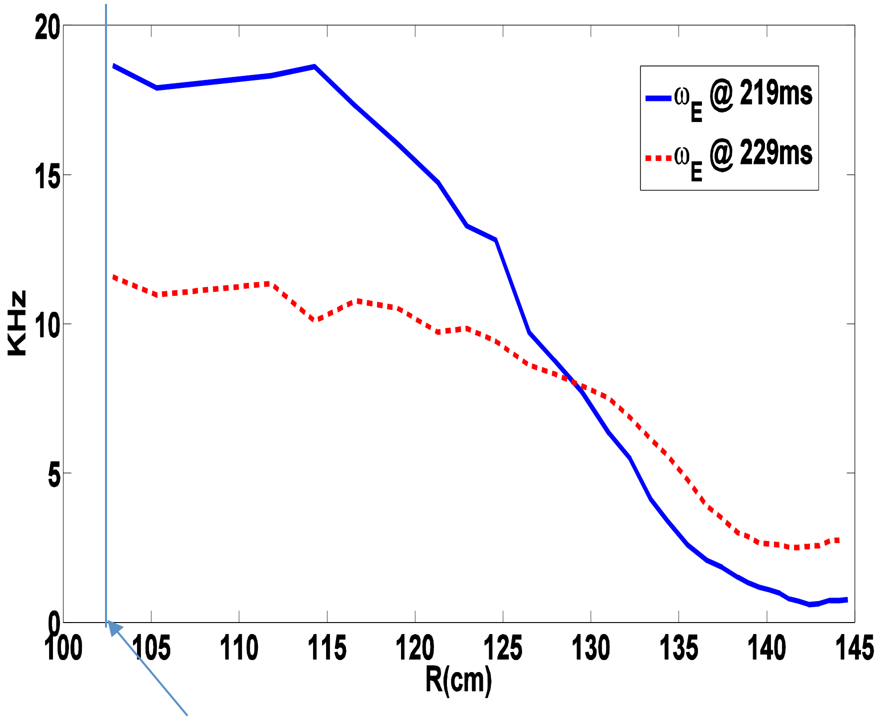
Low-frequency instability is almost static in plasma frame



- Plasma condition:
  - H-mode, B_tor=0.44T,Ip=0.9MA
  - n_e=3.12E19/m^3,P_NBI=6MW
  - Magnetic axis:R=102cm
  - Strong magnetic reverse shear(q_min~3)
- Onset of low-frequency instability at 218ms:
  - ~20kHz, which is close to toroidal rotation @ R=106cm
  - Static in plasma frame
  - Long life time:~70ms
  - Affect high frequency Alfven Eigenmode(CAE: 1.6MHz~2MHz)

Low-frequency instability is almost static in plasma frame(Cont'd)

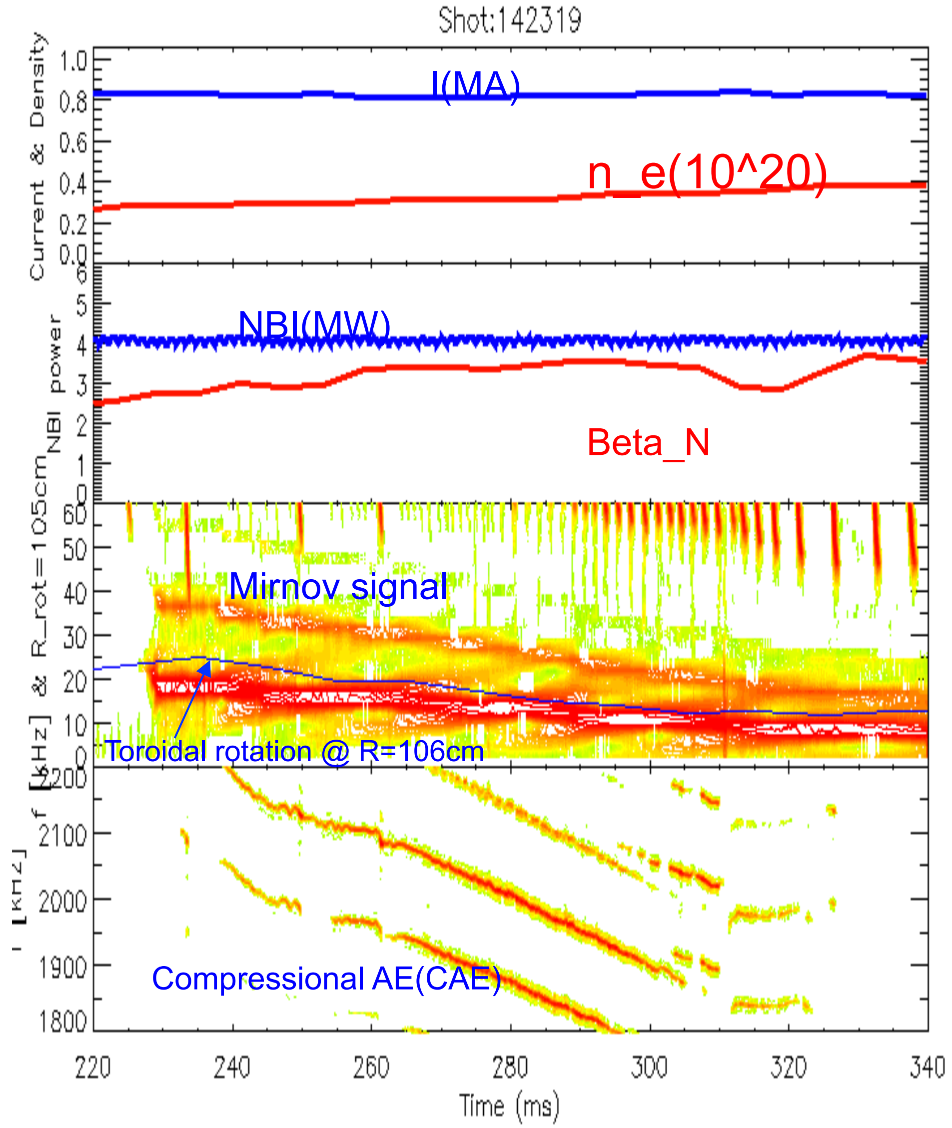




Magnetic axis

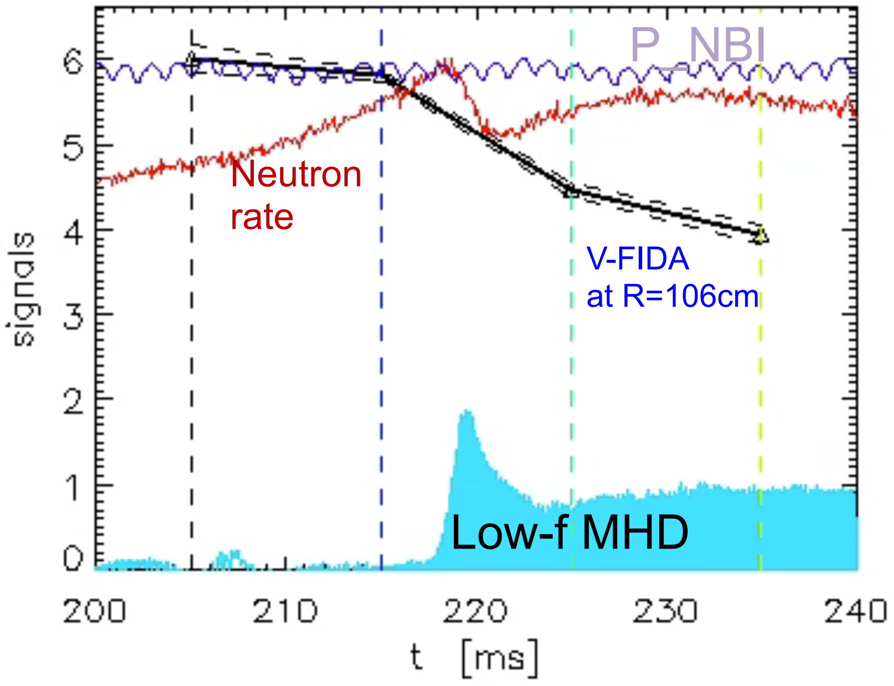
- Multi toroidal mode numbers: n=1,2,3
- Chirping time: ~3ms
- Mode frequency decreases from 20kHz to 10kHz
- Meanwhile, rotation drops from 19kHz to 10 kHz at R=106cm

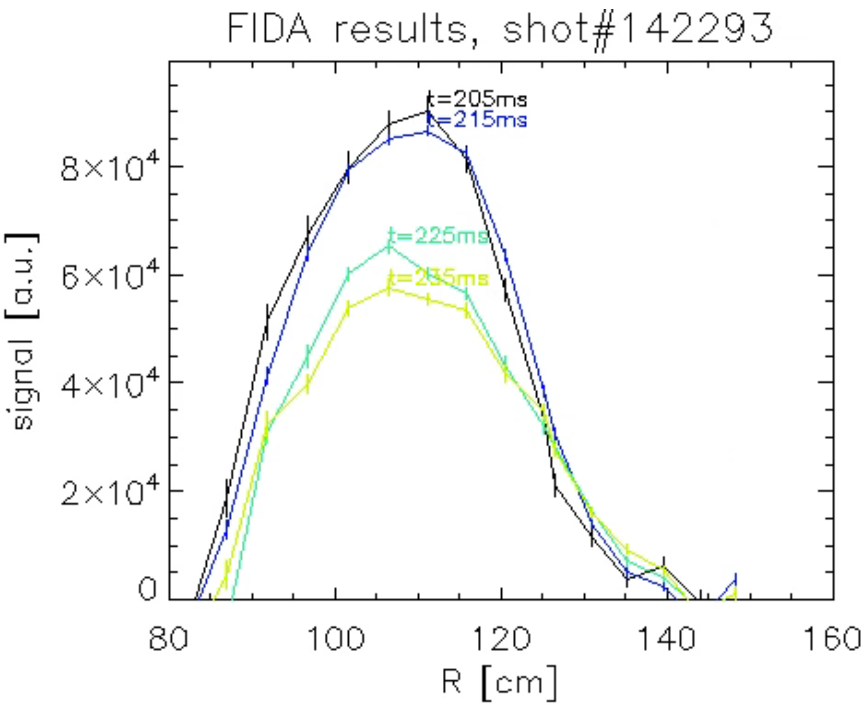
Low-frequency instability is almost static in plasma frame(Cont'd)



- In plasma frame, low-f mode is always static
- Suggests :
  - low-f mode is a kind of MHD mode rotating with plasma
  - Onset of low-f mode is correlated with toroidal rotation

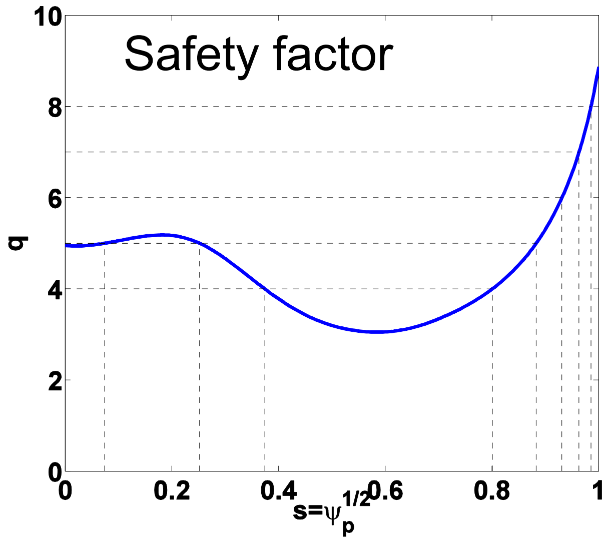
Low-f MHD mode reduces both the neutron rate and FIDA signal

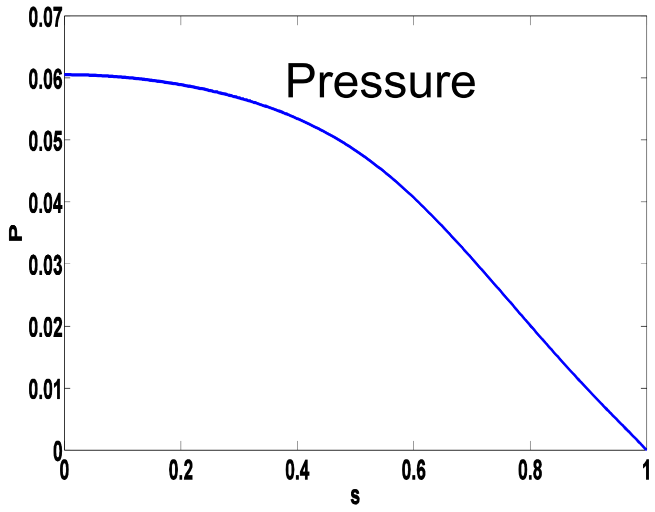


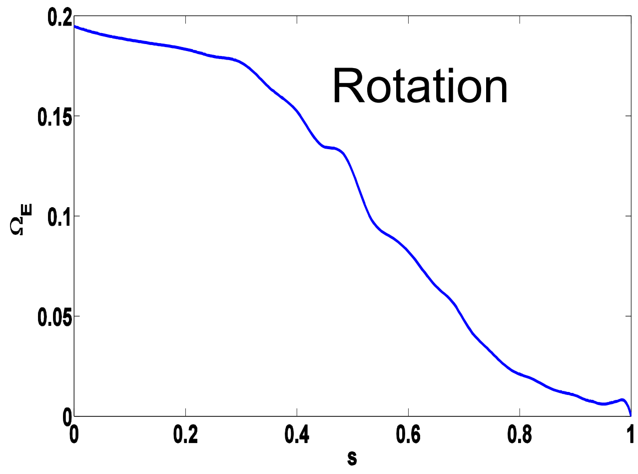


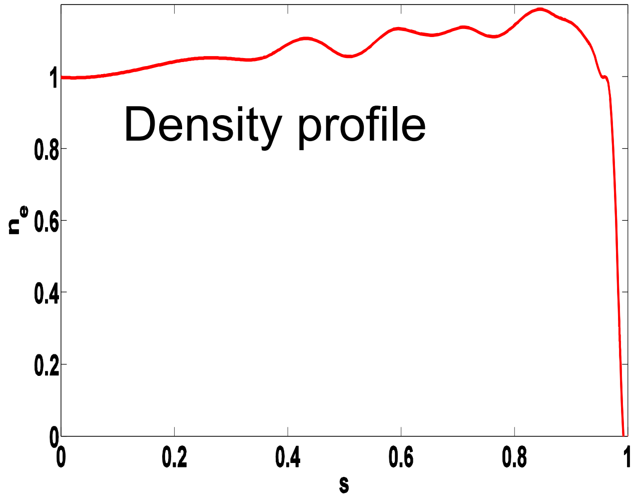
- Reduces neutron rate ~ 15%
- Reduces FIDA signal ~ 15 % at axis (R=102cm)
- Reduces FIDA signal in the core plasma region with R=[90cm,125cm]

Equilibrium used for modeling low-f mode



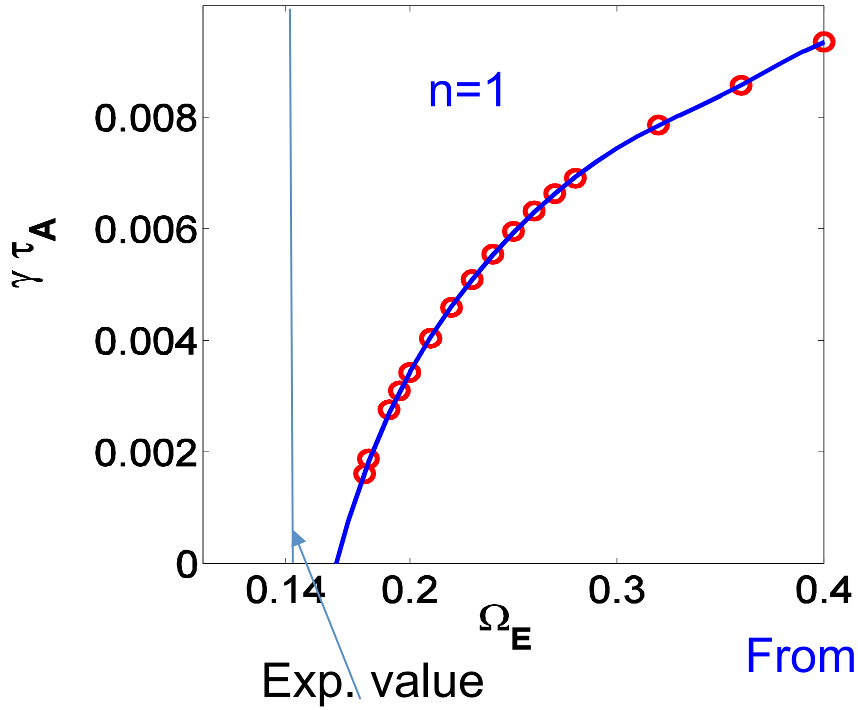




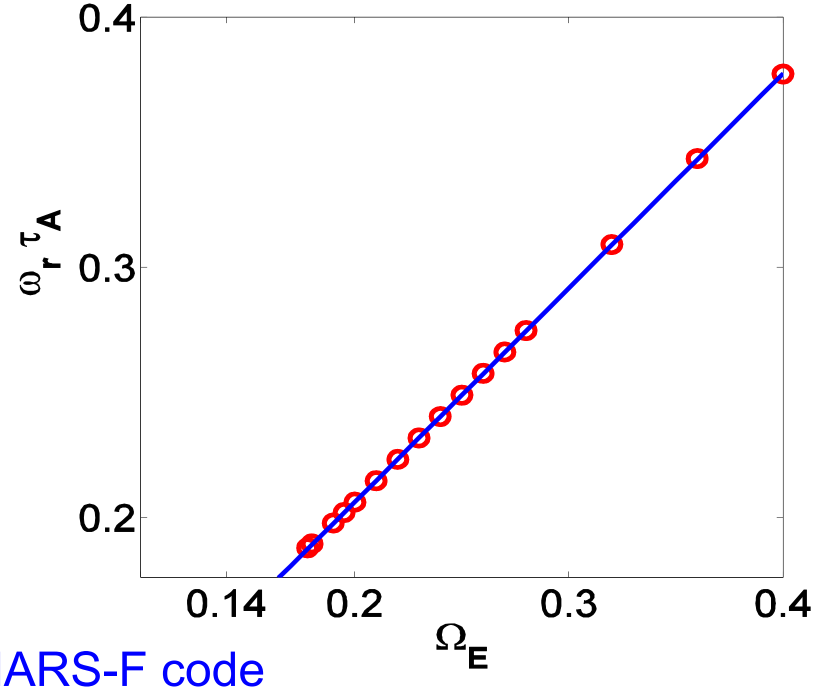


Rotation drives a kind of internal MHD instability

Growth rate



Real frequency

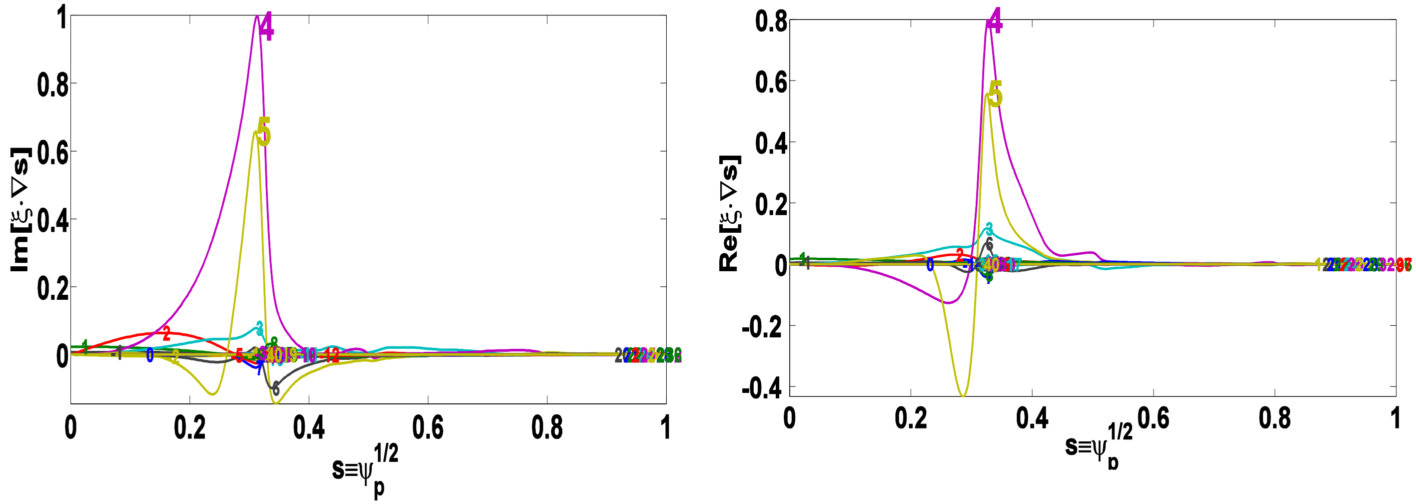


From MARS-F code

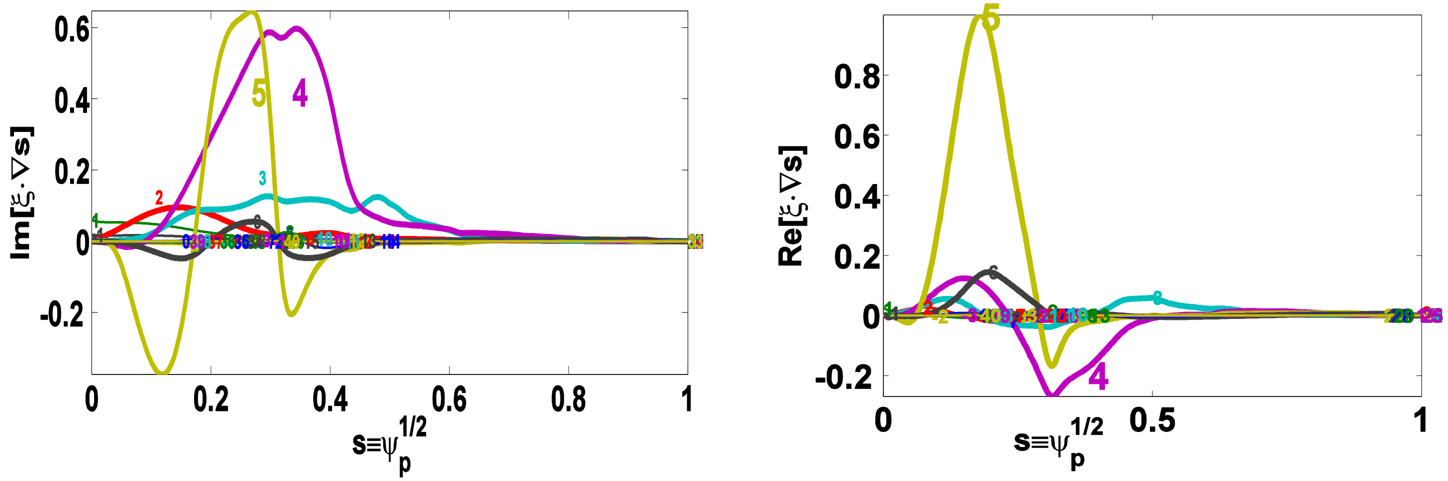
- As rotation exceeds a critical value, it drives a kind of internal MHD instability
- The inertial/compression term increases/decreases the rotation threshold, respectively. Actual threshold value depends on the combination effects of these terms. This case does not include inertial term and uses adiabatic factor $\Gamma = 5/3$
- Mode's frequency mode ~ rotation frequency, which agrees with experiment measurement

Resistivity extends the mode structure to core region

- IDEAL case: Mode localized in the region: $0.2 < \sqrt{\psi_p} < 0.4$



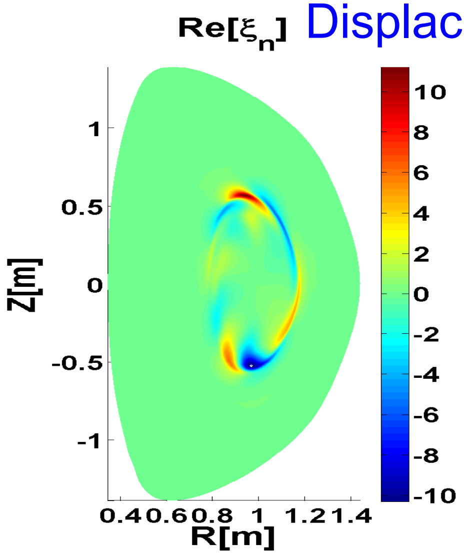
- Includes plasma resistivity: extends the mode to core region

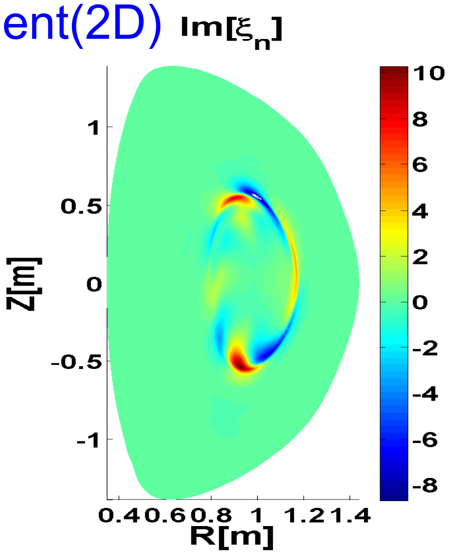


Resistivity extends the mode structure to core region(Cont’d)

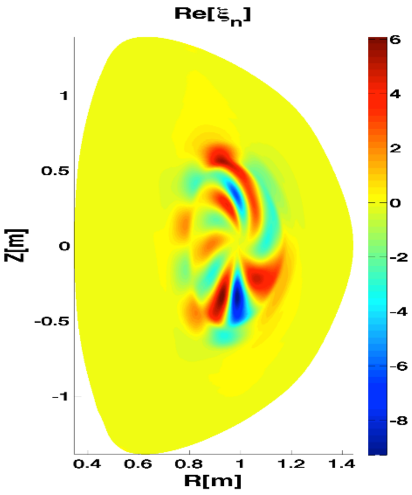
IDEAL

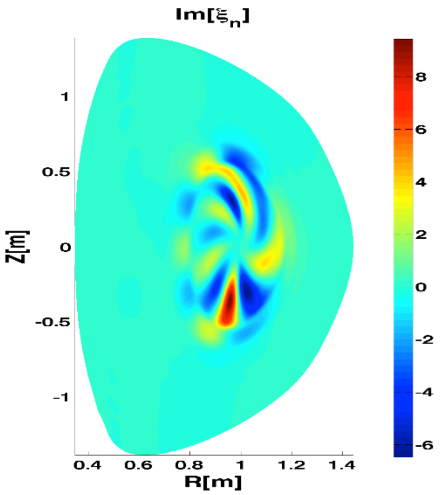
Displacement(2D)



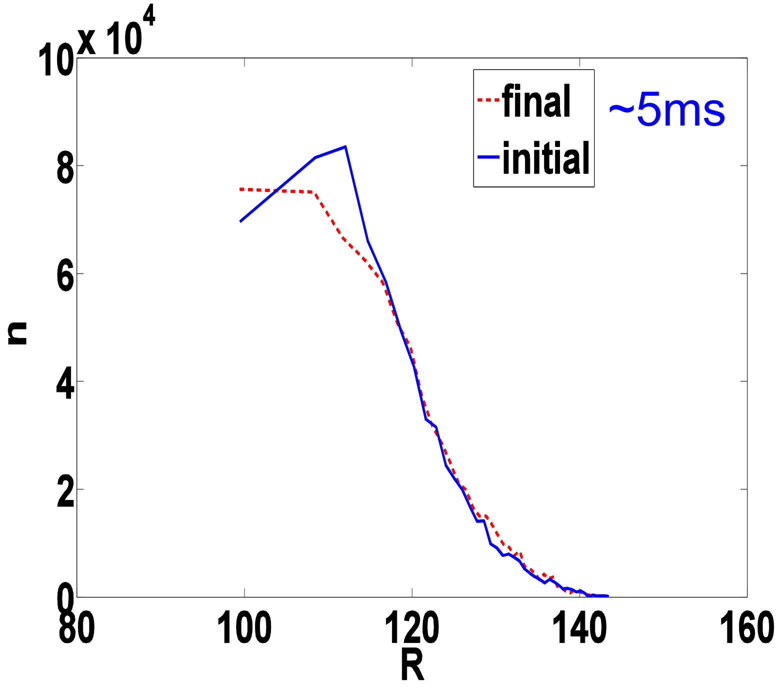


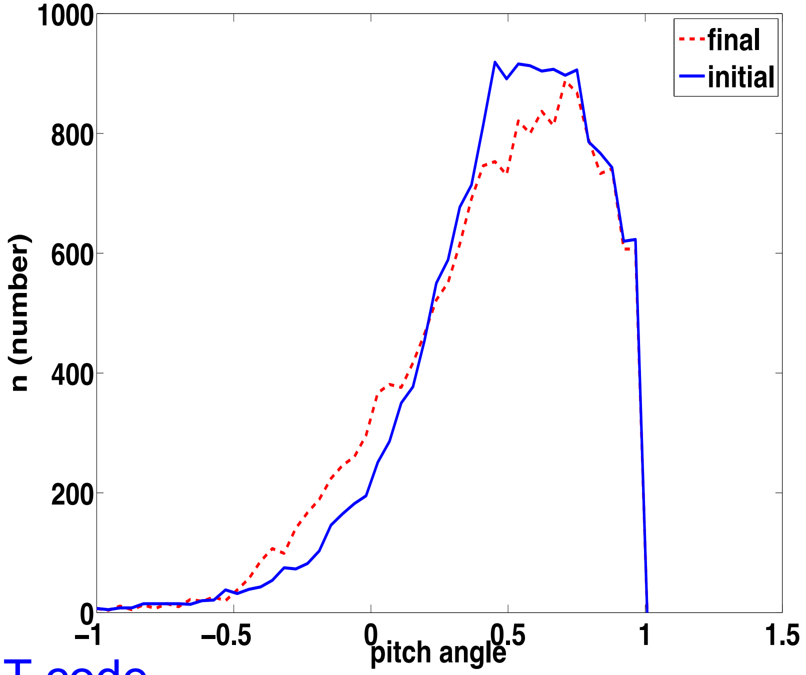
Includes plasma resistivity:





Low-f MHD instability modifies fast ion distribution function





From ORBIT code

- The mode decreases the fast ion density inside of R=120cm; slightly increases the density in the region 120cm<R<140cm
- After 5ms mode-particle interaction, more particles with smaller pitch angle
- This change could contribute to the decrease of FIDA signal in experiment
- This case uses the ideal internal MHD instability

Mode-particle resonance occurs in phase space

- Equation of particle motion in Hamiltonian form***:

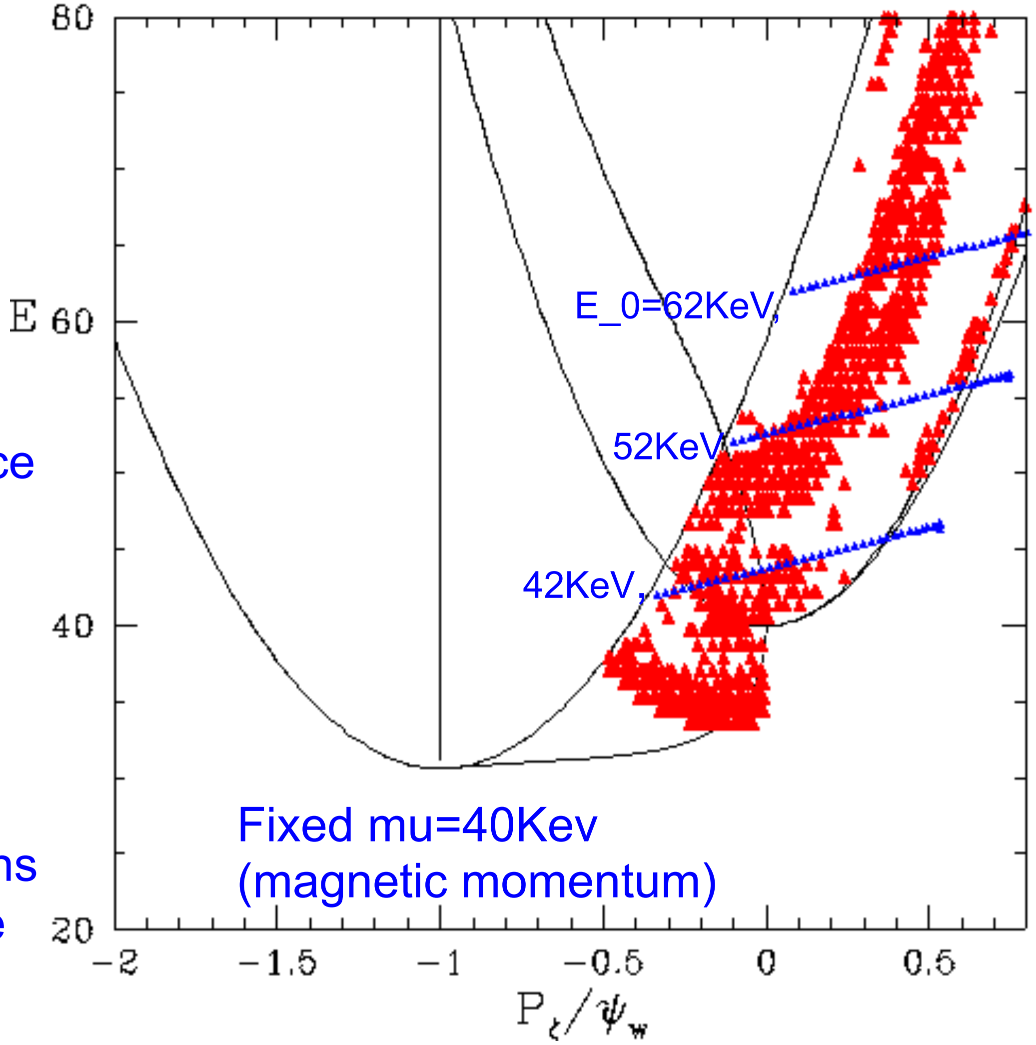
$$\dot{\theta} = \frac{\partial H}{\partial P_\theta} \quad \dot{P}_\theta = -\frac{\partial H}{\partial \theta},$$
$$\dot{\zeta} = \frac{\partial H}{\partial P_\zeta} \quad \dot{P}_\zeta = -\frac{\partial H}{\partial \zeta}.$$

- Red points indicate mode-particle resonance positions in phase space

- Blue points indicates the particles that satisfy $\omega_n P_\xi - nE = \omega_n P_{\xi 0} - nE_0$

  ω_n : mode frequency

- Overlaps between the blue points and red ones indicates the positions where the kinetic Poincare surface is broken

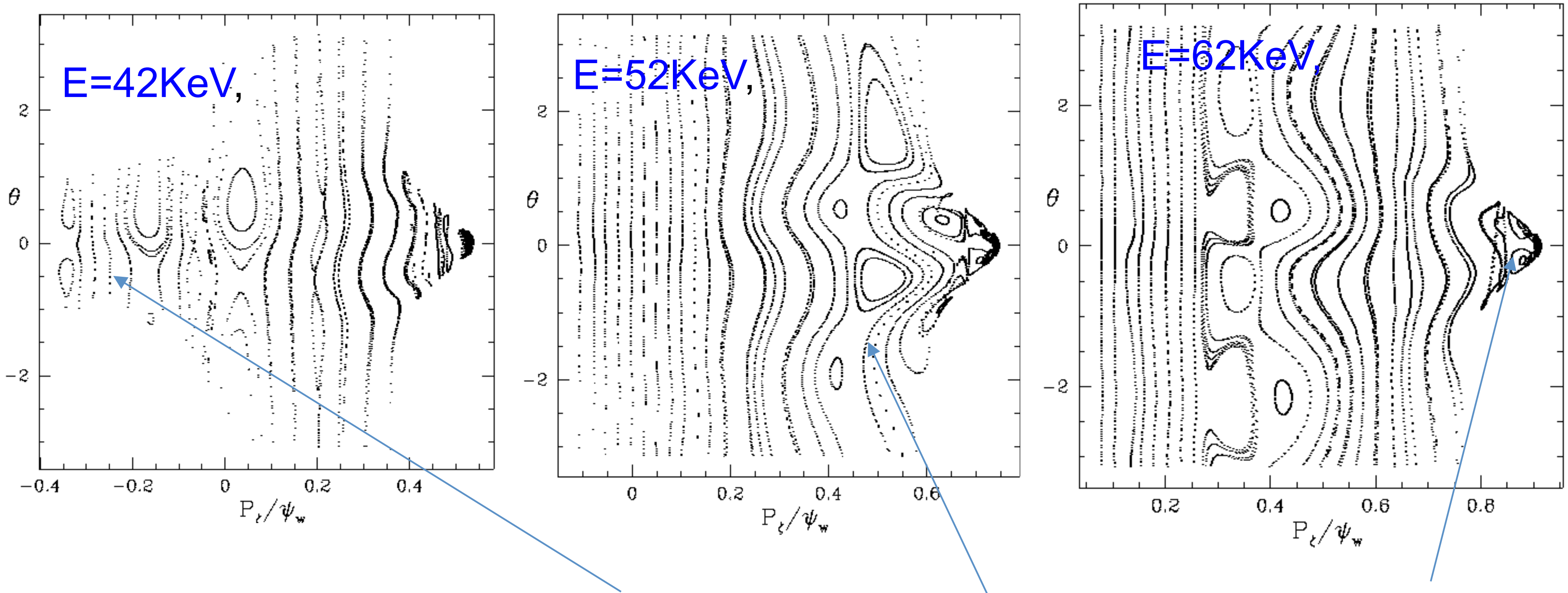


Fixed mu=40Kev
(magnetic momentum)

***White,Phys.Fluids.B 1989

Mode-particle resonance occurs in phase space

Kinetic Poincare Surface($n\varsigma - \omega_n t = 2\pi k$)



Mode resonances with trapped particles, passing particles and with stagnation particles

Summary

◆Experiment

- Low-frequency mode seems to be always static in plasma frame

◆Modelling indicates:

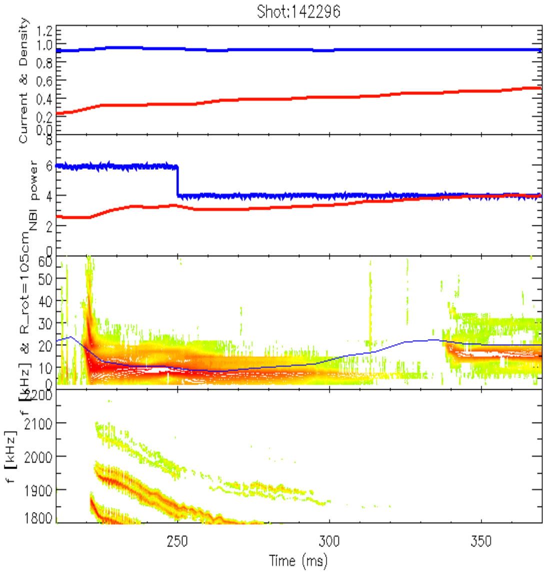
- When toroidal rotation exceeds a threshold, it drives a kind of internal MHD instability
- The rotation threshold is very close to the measured rotation value at the onset of low-frequency mode; Rotation threshold strongly depends the inertial force and compression term
- Plasma resistivity extends the mode structure, but it has negligible effects on mode's growth rate
- Through mode-particle resonance, ideal internal MHD mode modifies the fast ion density profile near the magnetic axis

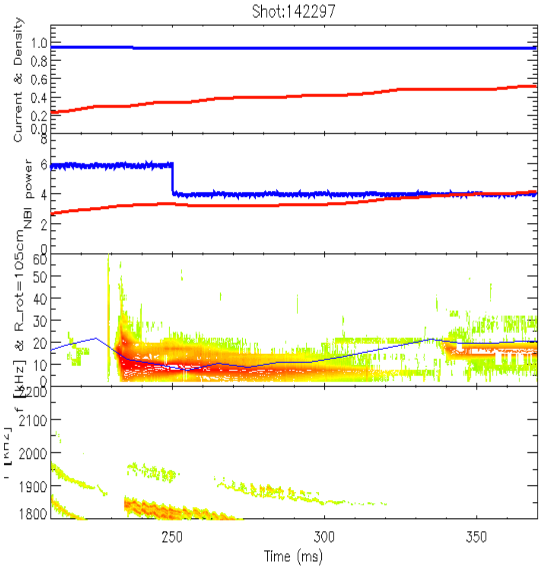
➢Outlook

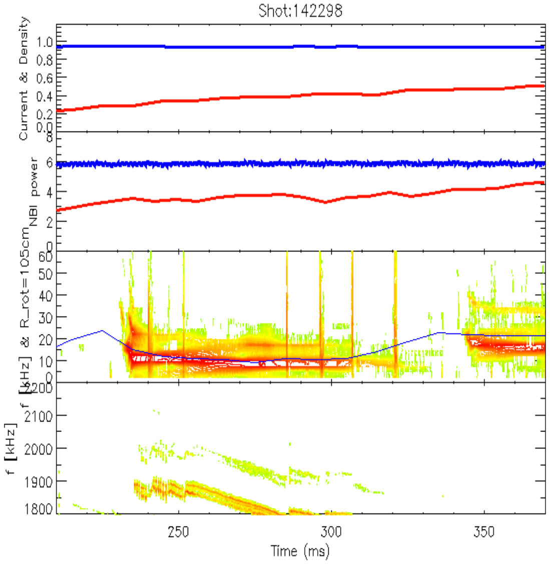
- FIDASIM simulation: to compare the predicted FIDA signal with experimental measurement
- ORBIT simulation : to study the effects of resistive perturbation on fast ions re-distribution

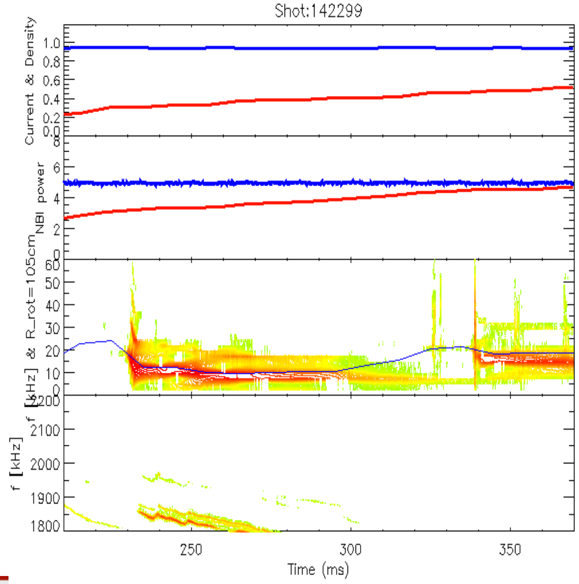
Backup slides

Low-frequency mode is static in plasma frame



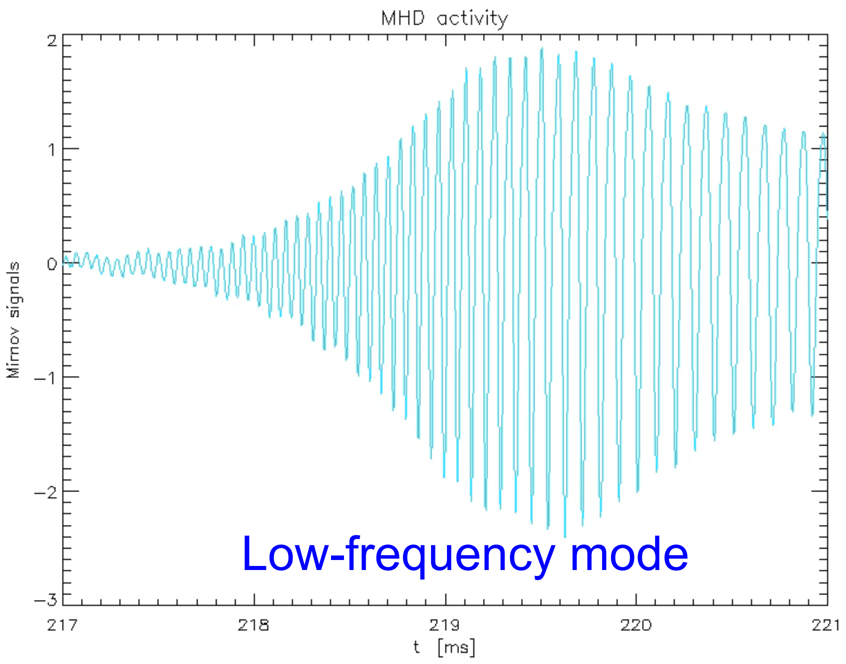






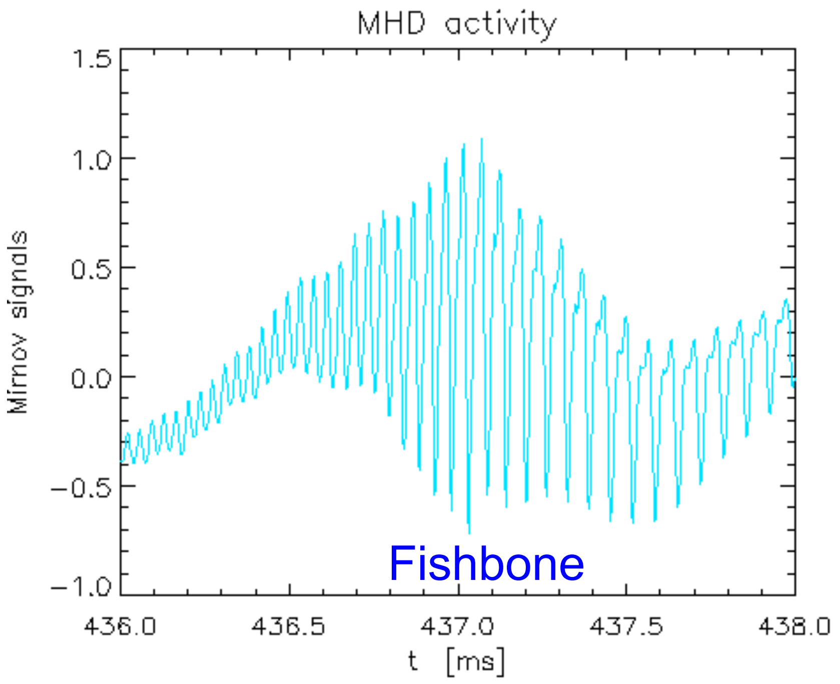
Mirnov signal of low-f mode is different with that of fishbone

Shot#142293



Low-frequency mode

Shot#138872



Fishbone

Fishbone slightly damps toroidal rotation

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