SWIP *HL-2A*

Present Progress of Plasma Transport Study on HL-2A

X.T.Ding, Yi Liu, W.W.Xiao, H.J.Sun, X.L.Zou+, W.Chen, L.H.Yao, J.Rao, B.B.Feng, Z.T.Liu, J.Zhou, Y.Zhou, L.W.Yan, Q.W.Yang, J.Q.Dong, X.R.Duan

Southwestern Institute of Physics, Chengdu, Sichuan, China

+ CEA/IRFM, Cadarache, France

dingxt@swip.ac.cn

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E-mail: dingxt@swip.ac.cn Tel: 028-82850307

OUTLINE

- **Present Status of the HL-2A Tokamak**
- **Diagnostics for transport Study on HL-2A**
- **Improved Confinement during Off- Axis ECRH**
- **Observation of a Spontaneous Particle ITB**
- **Non-local transport phenomenon with SMBI**
- **Summary**

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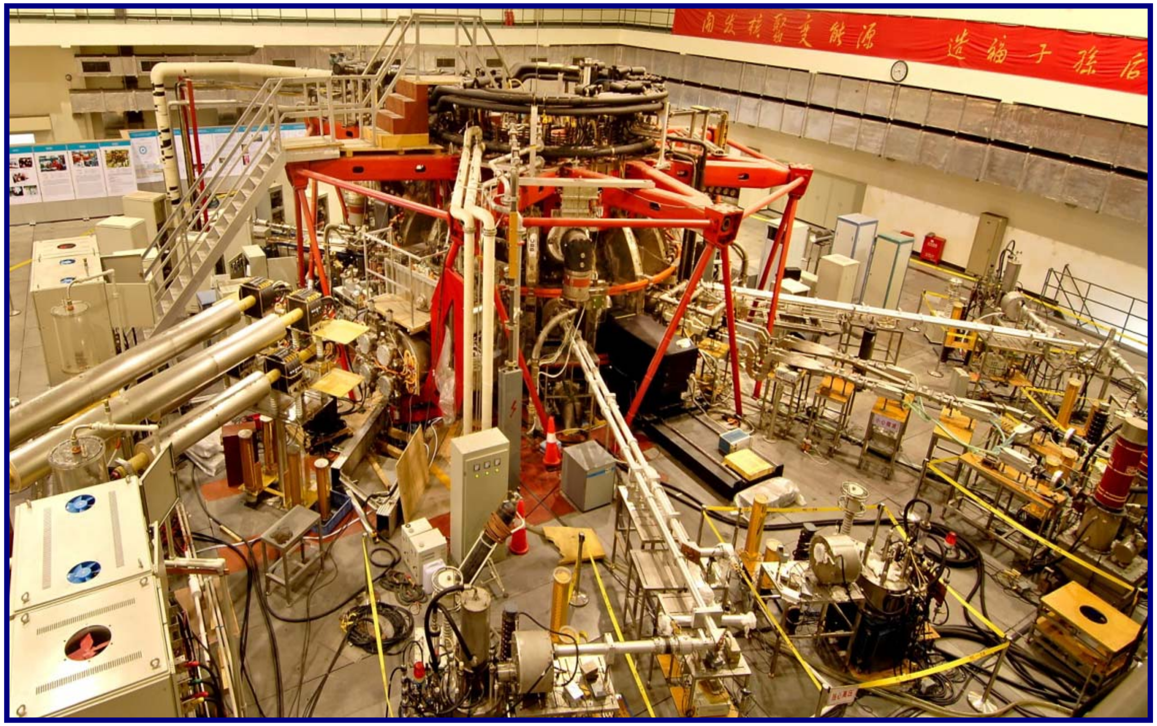
Present Status of the HL-2A Tokamak



The main parameters:

R =1.65m

a = 0.4m

Ip =350kA~450kA

B_T = 1.2~2.7T

Ne =1~8x10^{19} m^{-3}

Te ~ 5.0 keV

Ti ~ 1.5 keV

Auxiliary heating:

ECRH/ECCD: 2 MW

(4/68 GHz/500 kW/1 s)

modulation: 10~30 Hz; 10~100 %

NBI(tangential): 1.5 MW

LHCD: 1 MW

(2/2.45 GHz/500 kW/1 s)

Fueling system *(H_2/D_2)*:

Gas puffing (LFS, HFS, divertor)

Pellet injection (LFS, HFS)

SMBI (LFS,HFS)

LFS: f =1~60 Hz, pulse duration > 0.5 ms ms, gas pressure < 3 MPa

Present Status of the HL-2A Tokamak

Physics subjects

Transport study

- Spontaneous particle transport barrier
- Non-local transport triggered by SMBI
- Impurity transport

Zonal flow & turbulence

- Low frequency zonal flow
- GAM density fluctuation
- Two regime fluctuations

MHD activities under ECRH

- E-fishbone instability
- Tearing Mode control

Diagnostics for transport Studying on HL-2A

Diagnostics with high resolution：

- Scanning Microwave Reflectometry： time resolution：1ms， Spatial resolution： ~1.5cm, frequency range: 24-60GHz
- Multi – Channel ECE：16 Channels, time resolution： 0.005ms
- Scanning ECE receiver: 20 Channels, time resolution： 4ms
- Soft x ray arrays：5 arrays， 100 Channels，time resolution：0.005ms
- HCN Interferometer： 8 channels： time resolution 0.1ms，
- Microwave Doppler Reflectometer: 8 spatial points

Perturbation Source：

- Pulsed Molecule Beam Injection（SMBI）

Modulation frequency： 10 –30 Hz；pulse number：30； ： width of pulse > 5ms

- Modulated ECRH（MECRH）

Modulation frequency：10 – 30Hz；10%-100%；Power： 0-2MW

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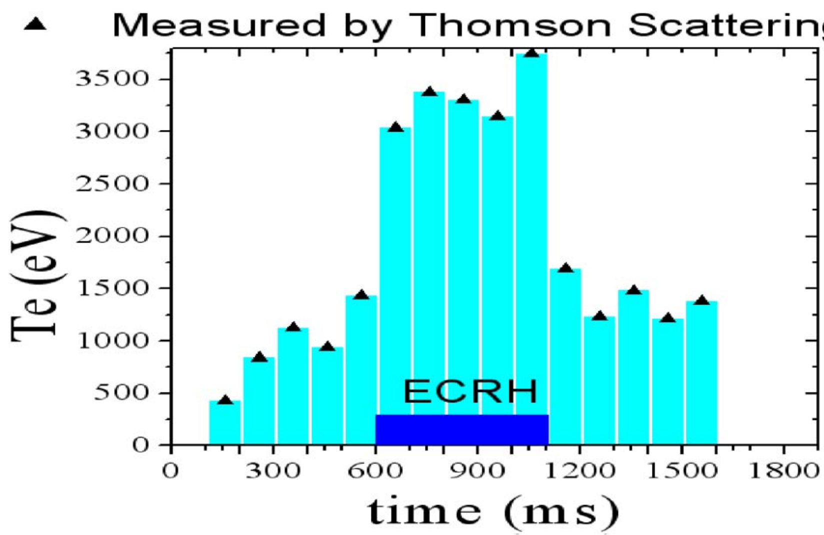
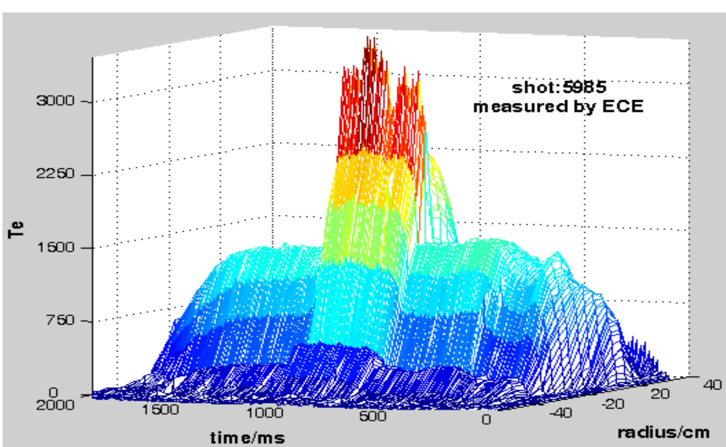
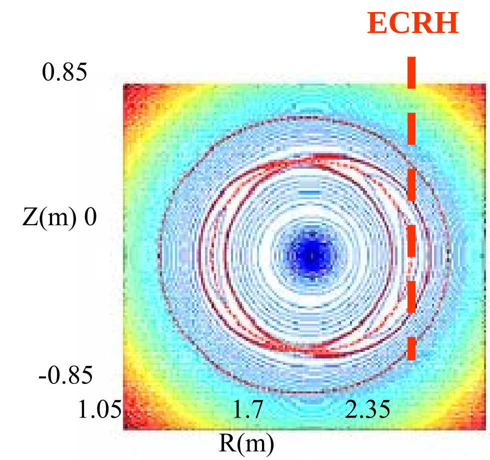
ECRH & MHD Control

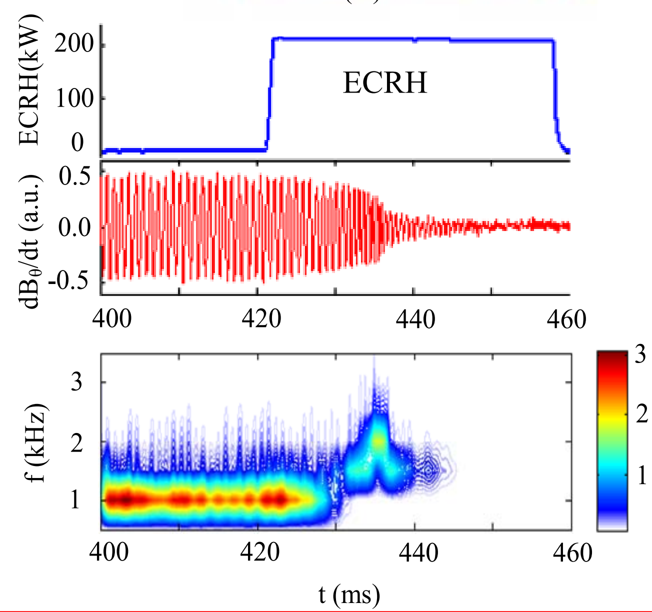
The temperature measured by
ECE and Thomson Scattering Diagnostics





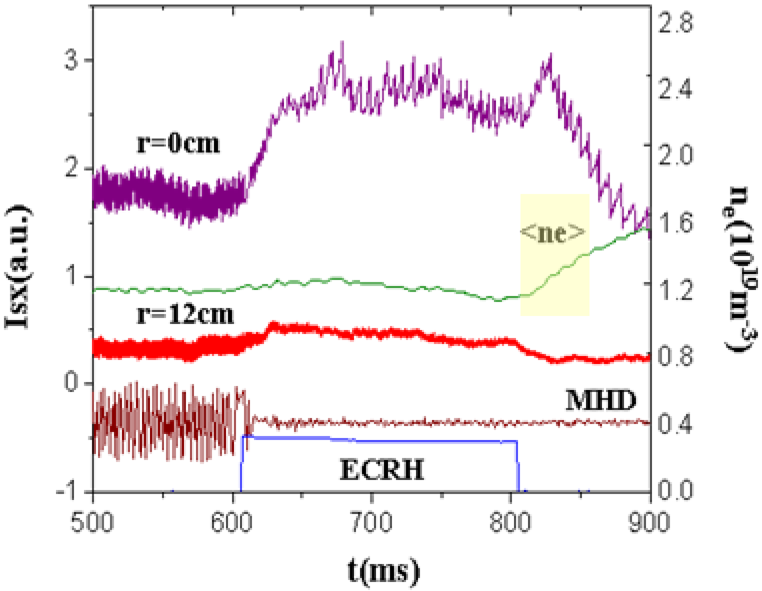
The suppression of m=2/n=1 tearing mode has been realized with off-axis heating located around q=2 surface.



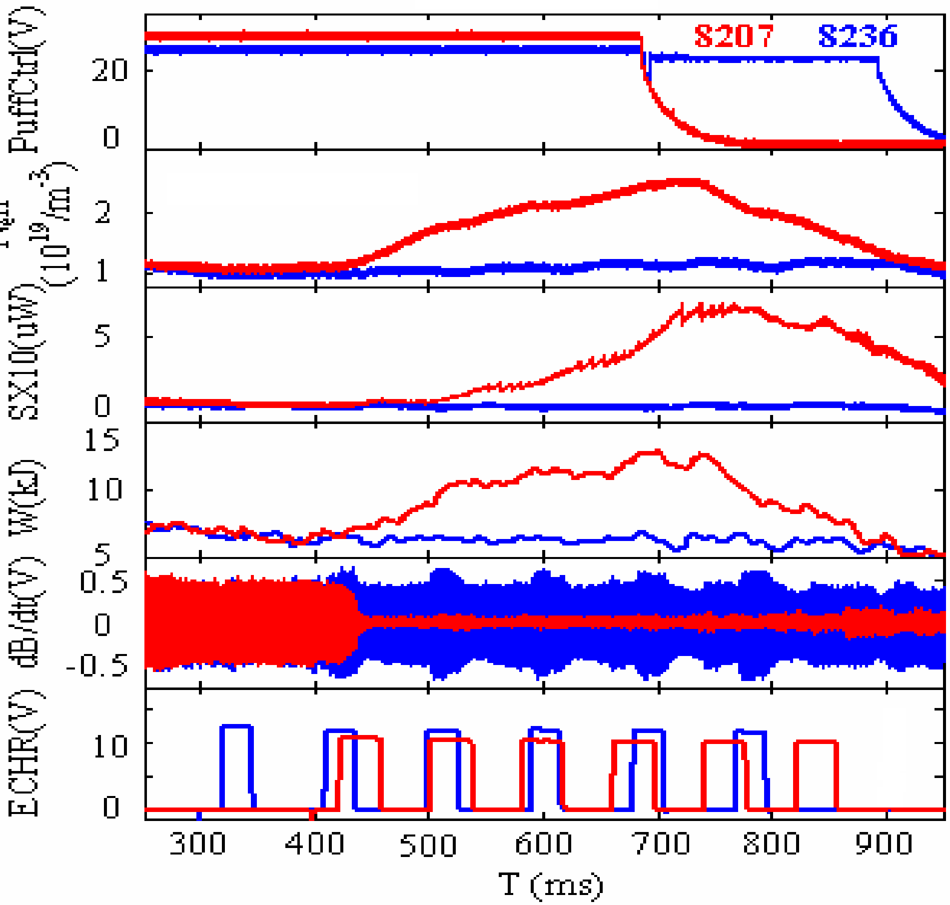


Improved Confinement during Off- Axis ECRH

- The m=2 activity does not resume even after the ECRH is turned off .
- After ECRH switch-off central SXR intensity can be increased subsequently.



- The effect can be additive by applying successive ECRH pulses.
- MHD-free phase and a continuous confinement improvement have been achieved.



The continuous improvement of confinement, i.e. the plasma density, temperature, stored energy and energy confinement time increase steadily throughout the successive ECRH period.

The Spontaneous Particle Transport Barrier

- **Observation of the spontaneous particle transport barrier**
- **Simulation Results of the transport barrier**
- **Poloidal velocity profiles measurement**

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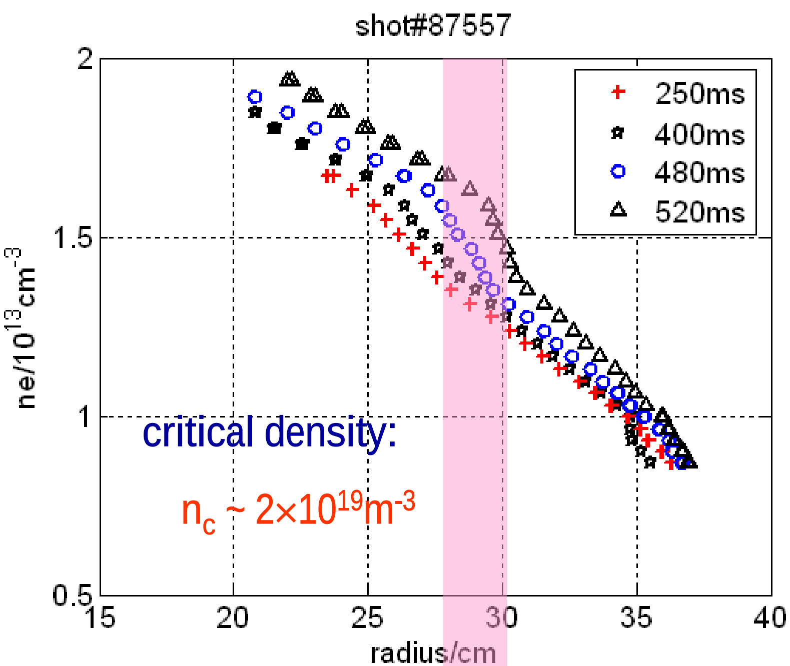
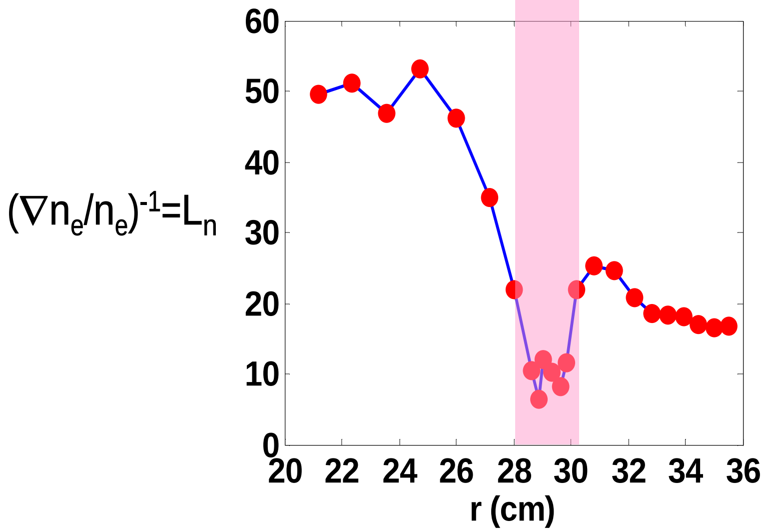
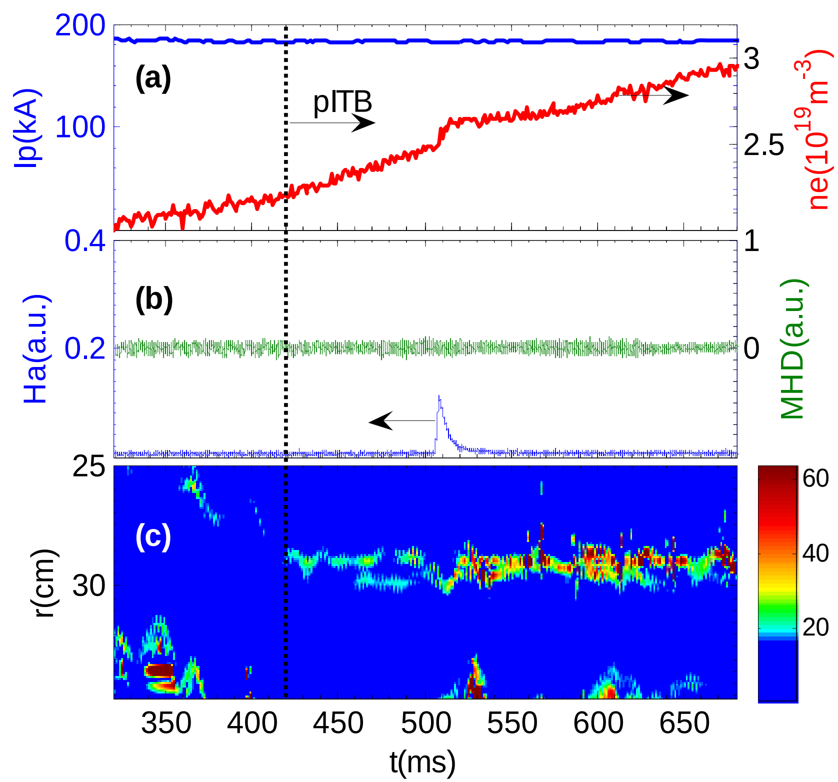
Observation of the spontaneous particle transport barrier





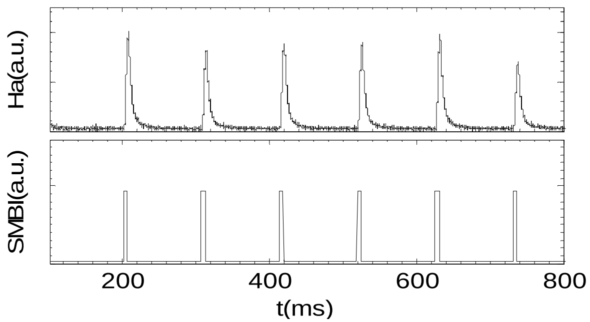


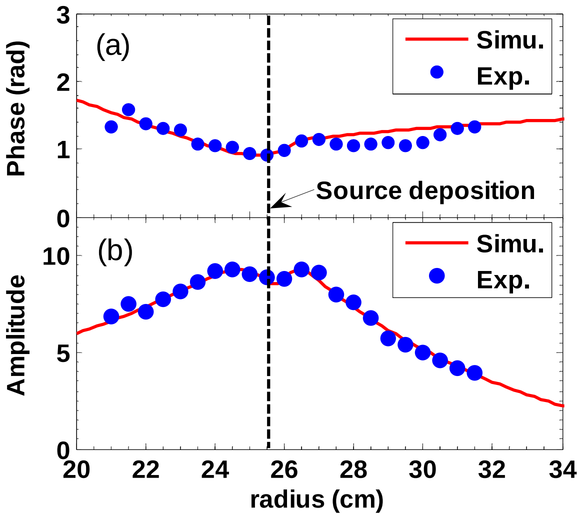
The phenomenon of particle transport barrier is perfectly reproducible, and characterized by a density threshold., the central linear density corresponding to this density limit is n_{el}=2.0x10^{19}m^{-3}. The effect of the barrier is most visible for n_{el}=2.5x10^{19}m^{-3}. The barrier is located around *r/a*= 0.6-0.7.

Simulation Results of the transport barrier

n_e modulation by SMBI

frequency: 9.6 Hz
pulse duration: 6 ms
gas pressure: 1.3 MPa





- phase very sensitive to the diffusivity
- amplitude very sensitive to the convection

Analytical model

[S.P.Eury Phys.Plasma 2005]

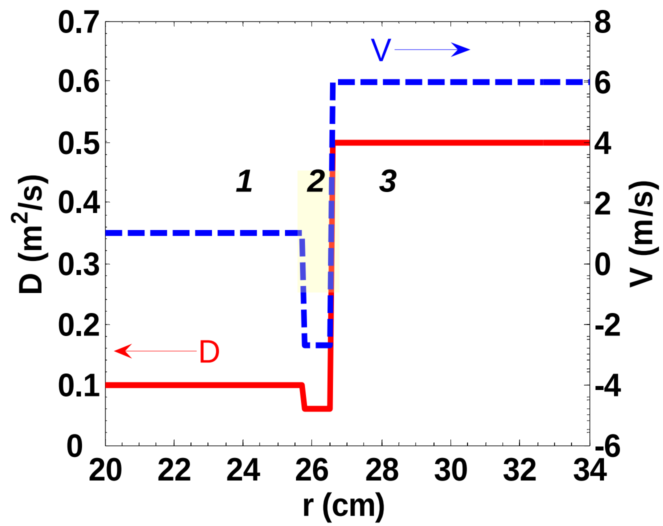
Domain 1: D_1=0.1 m²/s, V_1=1.0m/s

Domain 2: D_2=0.06m²/s, V_2=-2.7m/s

Domain 3: D_3=0.5 m²/s, V_3=6.0m/s

x1=0.257 m, (domain 1/domain 2)

x2=0.265 m, (domain 2/domain 3)



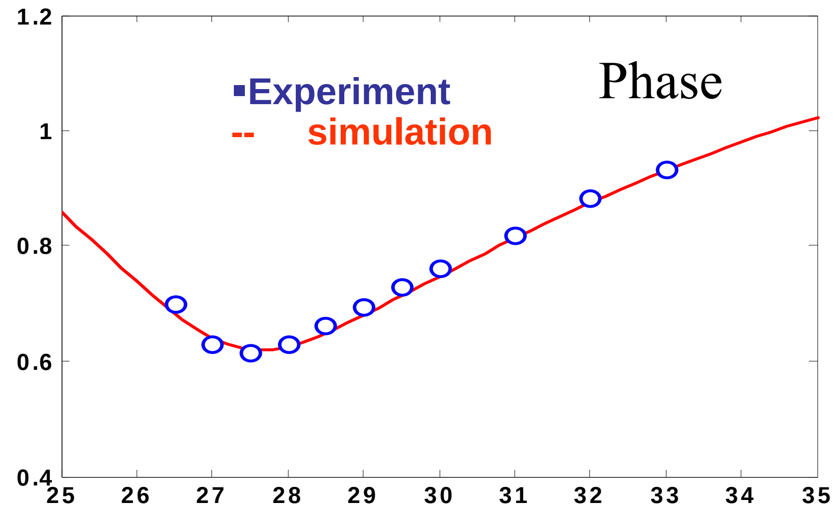
- **rdep=0.254 m, (particle deposition)**
- **Particle Source: w1=0.03*a=0.012 m, (width of the gaussian for the particle source)**

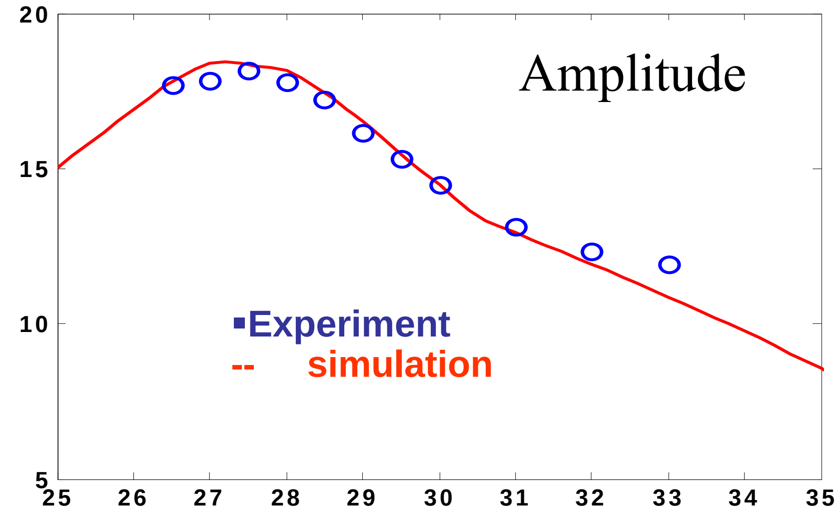
Simulation results of the amplitude and phase of the Fourier transform of density perturbation and density gradient length are in good aggrement with the experimental results with an analytical model for perturbative transport in order to characterize this barrier.

Simulation Results of the transport at lower density

- Parameters for simulation (shot 7543, 03/03/08)
- f0=9.6 Hz, (modulation frequency)
- rdep=0.275 m, (particle deposition)
- a=0.4 m, (minor radius)
- x1=0.275 m, (frontier domain 1/domain 2)
- x2=0.305 m, (frontier domain 2/domain 3)
- Particle Source:
- S0=1.9, (total particle injected per second Np=2*pi*R*S0)
- w1=0.025*a=0.01 m, (width of the gaussian for the particle source)

- Domain 1:D1=0.2, v1=-0.05
- Domain 2: D2=0.25, v2=-2.2
- Domain 3: D3=0.25, v3=-4.2





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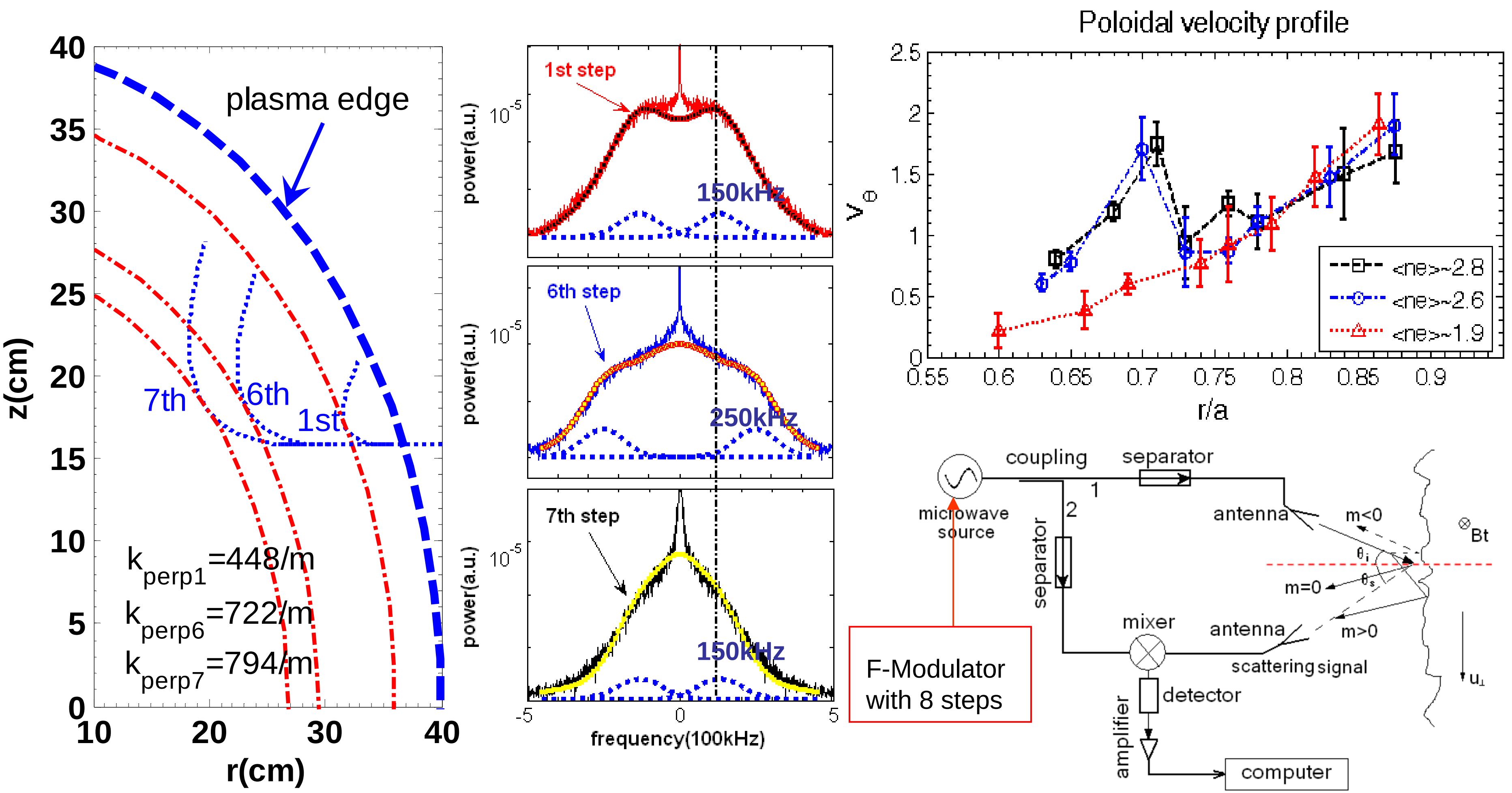
Poloidal Velocity Profiles

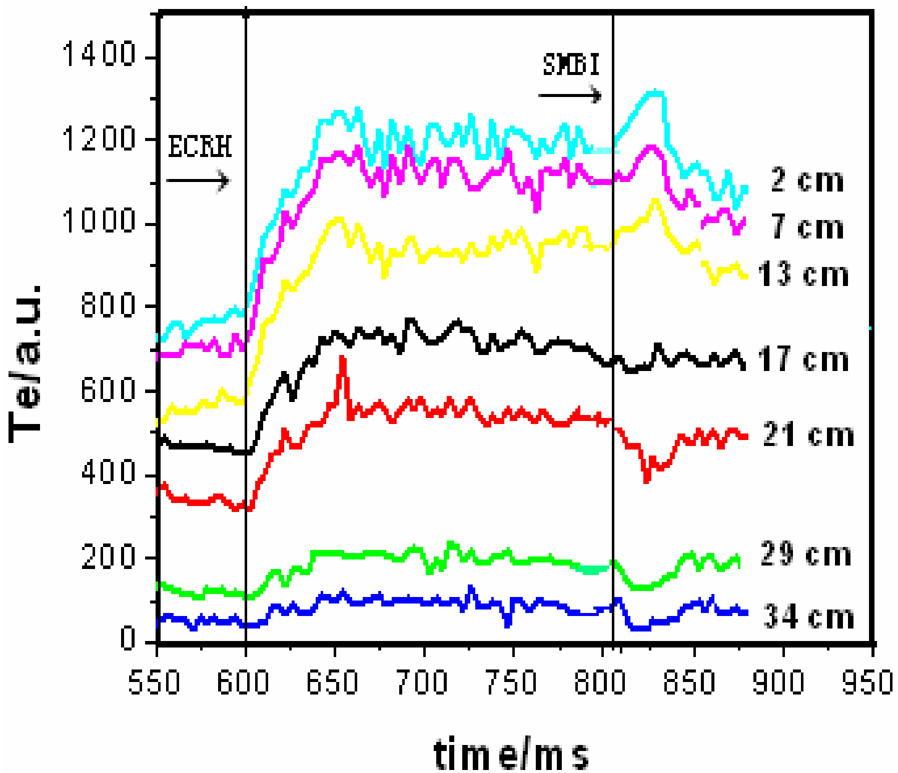


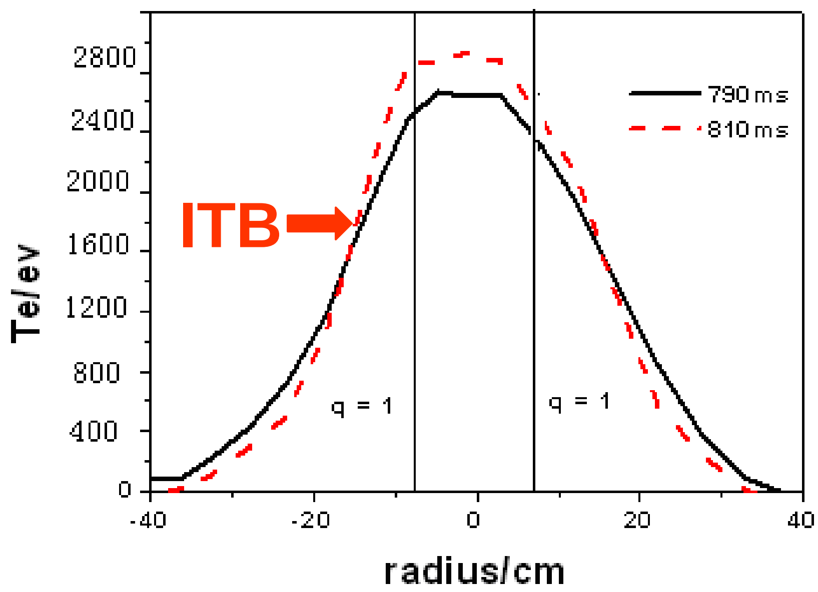
•Poloidal velocity profiles have been measured by scanning microwave Doppler reflectometry under different densities. Obvious velocity shear appears when the particle internal transport barrier formed.

The Non-local Transport Phenomenon with SMBI

- **The features of the Non-local transport phenomenon with SMBI**
- **Repetitive non-local effect triggered by SMBI**

Non local phenomena Induced by SMBI in HL-2A

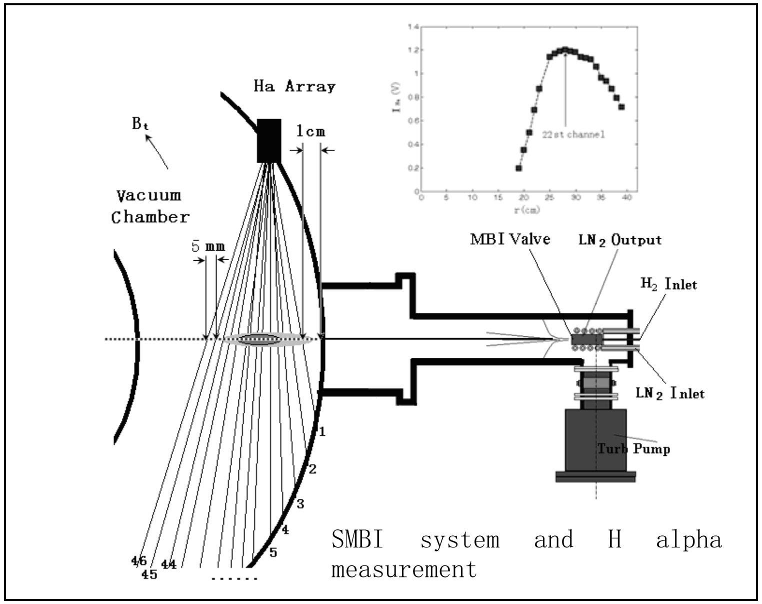




•The core temperature rise :18%→40%;

•As a new trigger method

The SMB injection has deeper penetration and better locality than conventional gas puffing



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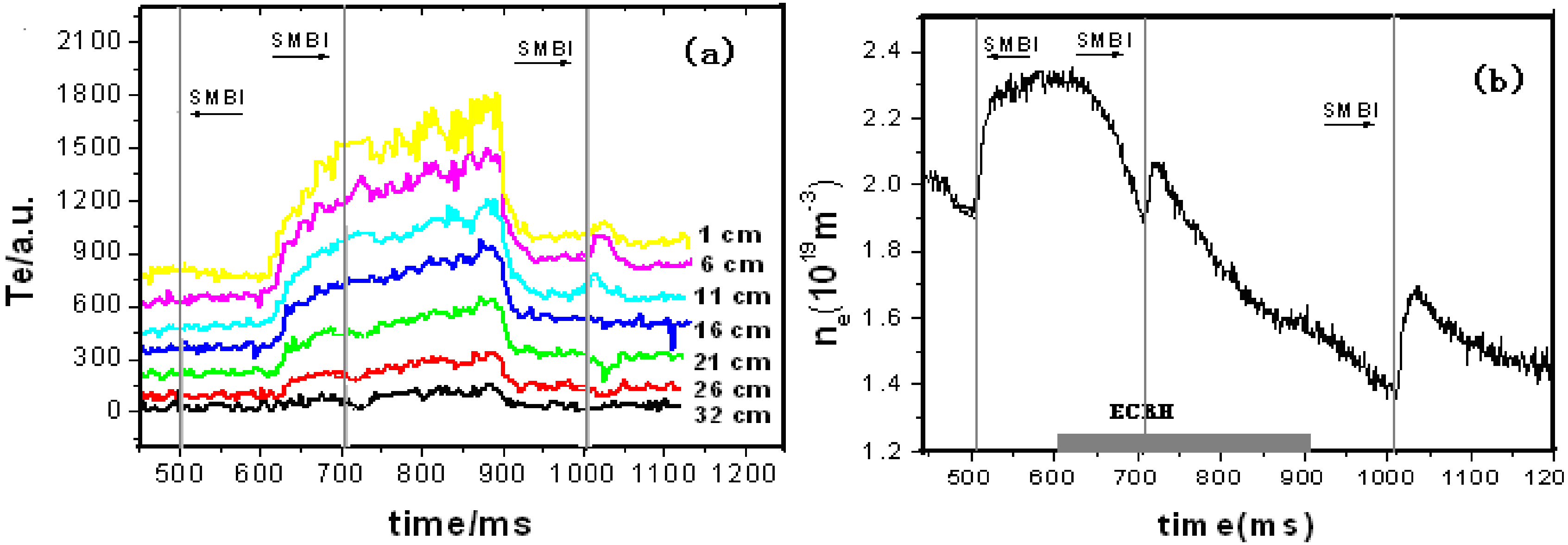
The features of the Non-local transport



- A strong dependence on plasma density is observed: the effect appears only in a low density plasma, the most discharges are around 1.0×10^{19} m^{-3} and it disappears when then density is larger than 2.0×10^{19} m^{-3}.
- The reverse position is several centimeters outside the $q = 1$ surface, it is estimated that the position should be inside the $q = 2$ surface.
- The non-local effect is enhanced by ECRH
- The duration is about 40 ms which is comparable with the energy confinement time.

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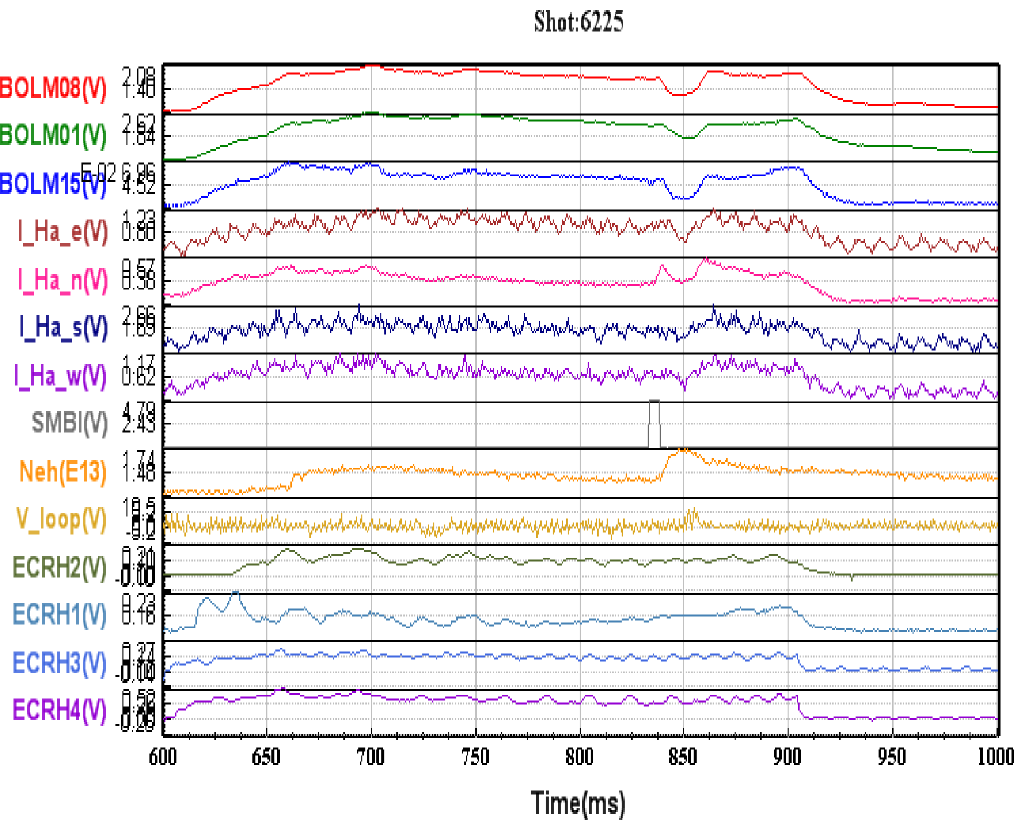
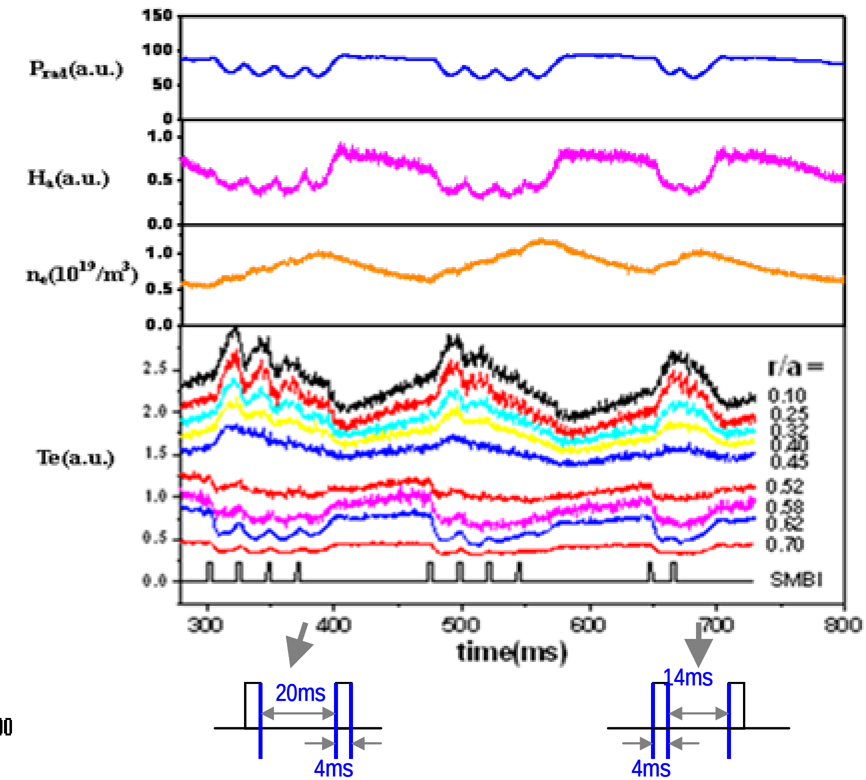
The features of the Non-local transport





•Both the bolometer radiation and the $H\alpha$ emission decrease when the non-local effect appears in low density, especially in clean wall condition after silicatization.

•The duration of the process could be prolonged by changing the gap between SMB pulses

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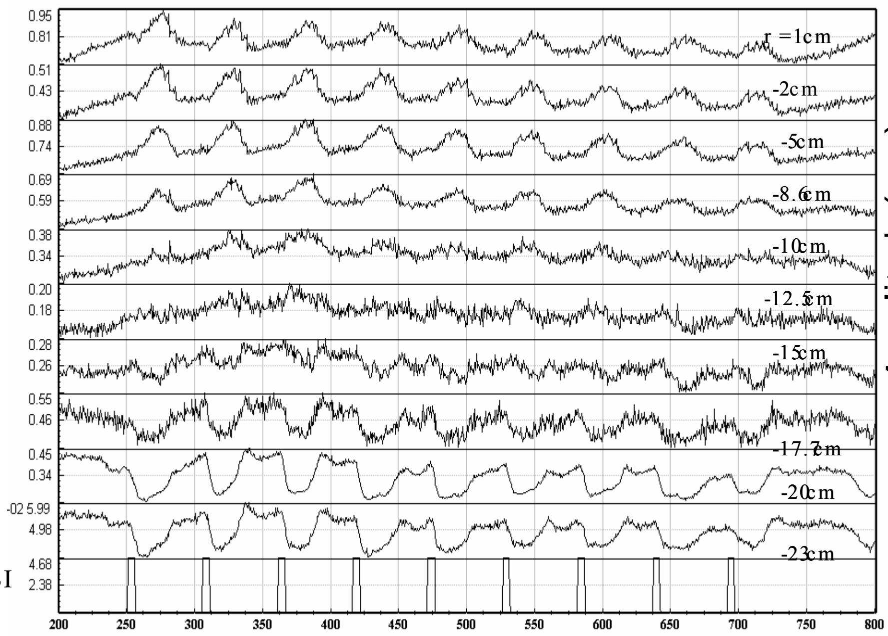
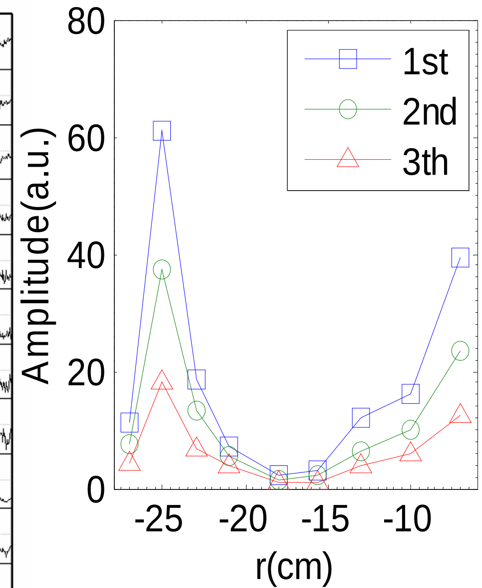
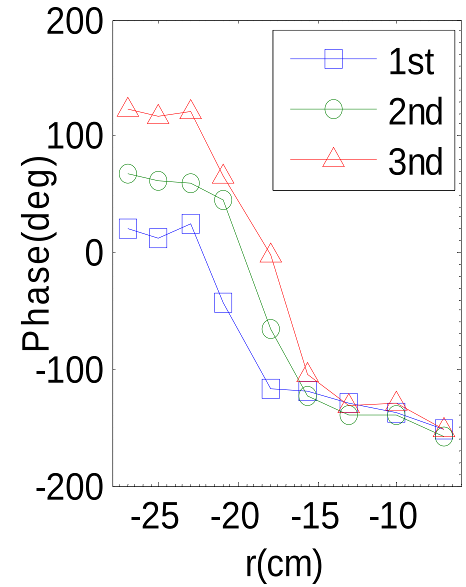
Repetitive non-local effect triggered by SMBI







Clear phase jump at the reverse position, *two peaks* in the amplitude may indicate *two perturbation sources* in the regions outside and inside the inversion radius.

Shot 7531
Bt=1.44T
Ip=185kA
,

Ne=0.5 - 0.92
Pulse duration: 3ms,
Pressure: 0.5MPa

Summary

- **2MW ECRH has been carried out on HL-2A. The m/n=2/1 tearing mode can be controlled with heating located around q=2 surface. The continuous improvement of confinement increase steadily throughout the modulated off-axis ECRH.**
- **The spontaneous particle transport barrier has been observed firstly in ohmic discharge. In the case of HL-2A, the central linear density corresponding to this density barrier is n_{el}= 2.0x$10^{19}$$m^{-3}$.**
- **A simulation is made with an analytical model for perturbative transport with modulated SMBI. The simulation results show that the diffusivity in the barrier decreases.**
- **Repetitive non-local effect induced by modulated SMBI, as a new trigger method, allows Fourier transformation of the temperature perturbation, yielding detailed investigation of the pulse propagation.**
- **Both the bolometer radiation and the H_α emission decrease when the non-local effect appears with SMBI, especially after silicatization.**

Thank you for your attention