ＬＨＤ周辺プラズマ揺動計測

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Introduction

Particle and heat transport in the SOL //B ⊥B

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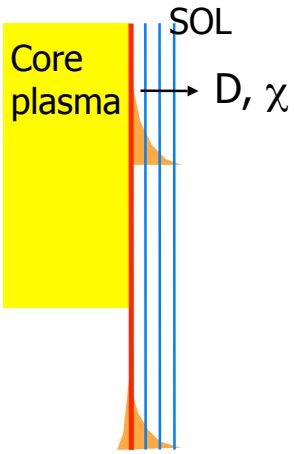
Particle and heat loads profile on the divertor plates



Fluctuation phenomena affect the transport.

Intermittent transport (Blobs) is found to affect the cross-field transport in tokamaks SOL.

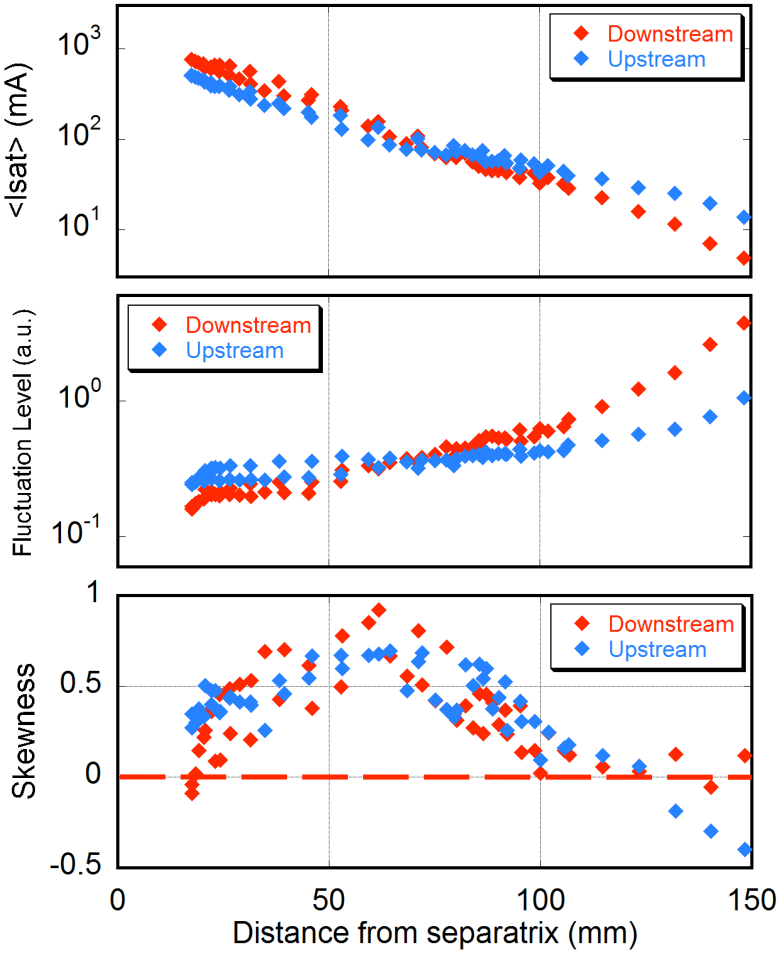
In the LHD, magnetic structure in SOL is complicated in comparison with tokamak SOL.

--- How fluctuation phenomena affect the transport in the LHD SOL?

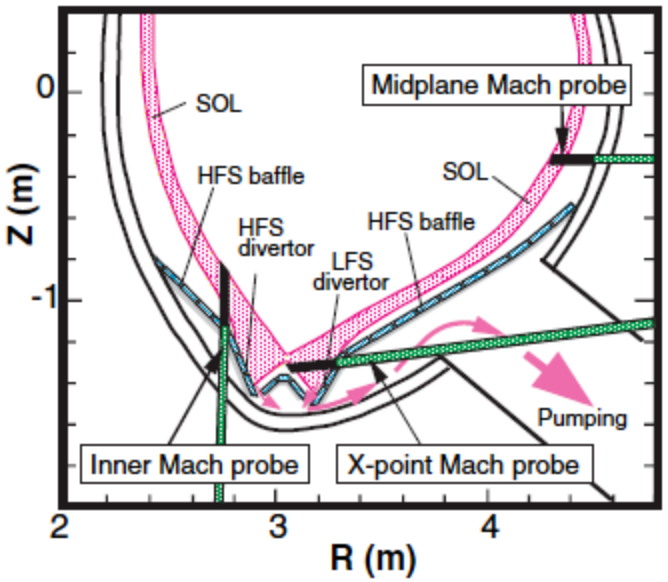
--- Is is different from that in tokamak SOL?

Comparison between the intermittent bursty fluctuations in the edge plasma of tokamaks and helical devices makes it possible to understand the essential physics of the blob transport.

Typical Fluctuation Properties of Isat in Tokamak



L mode discharge in JT-60U
Shot Number : 44421 ,
time = 5200-5800 ms



- Slope of averaged Isat varies with radial position
- The p.d.f of Isat is strongly skewed.
- Skewness peaks at 60-70 mm

Fluctuation property is different in H- and L-modes

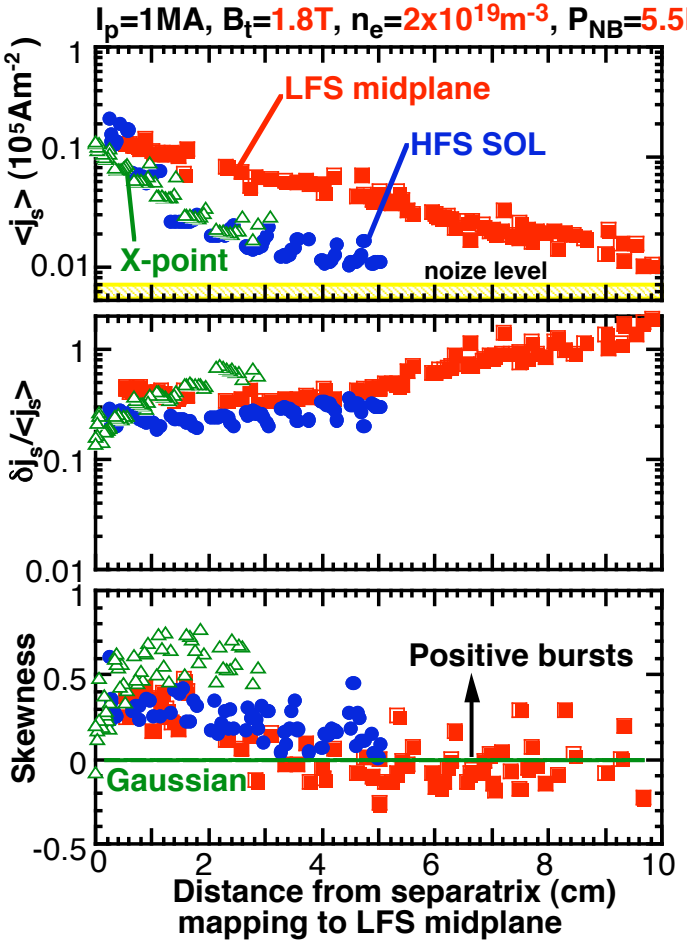
ELMy H-mode (between ELMs):

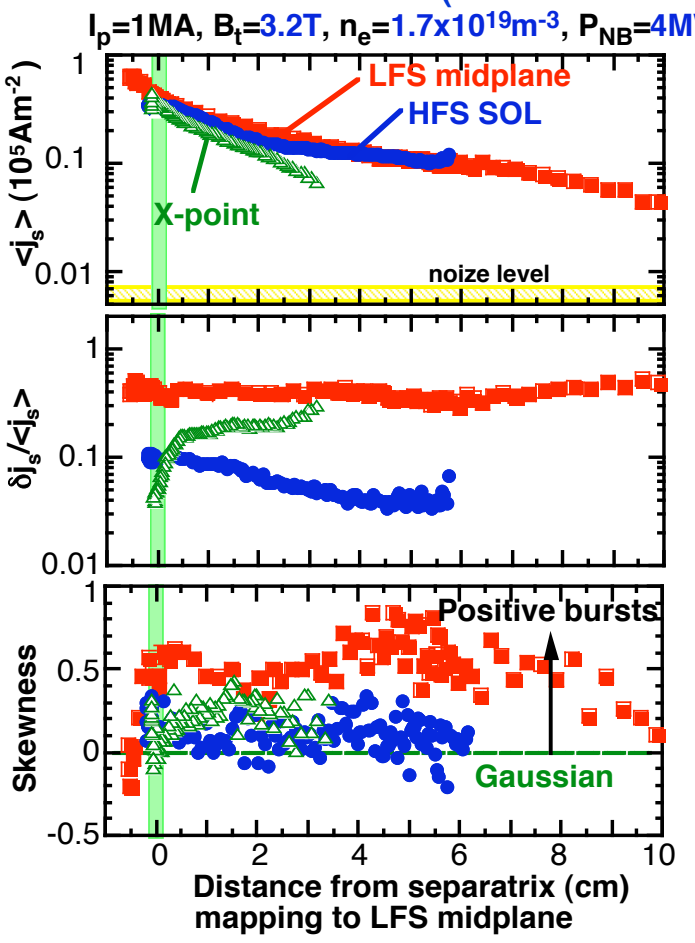
$\delta j_s/\langle j_s\rangle$ near separatrix (20-30%) is similar.

bursty events are localized in near-SOL ($\Delta r^{mid} < 3$ cm).

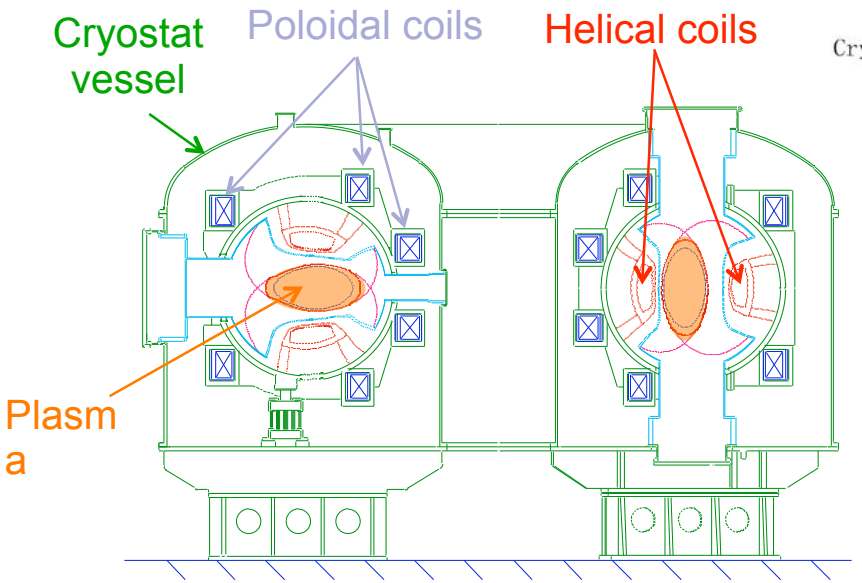
L-mode:

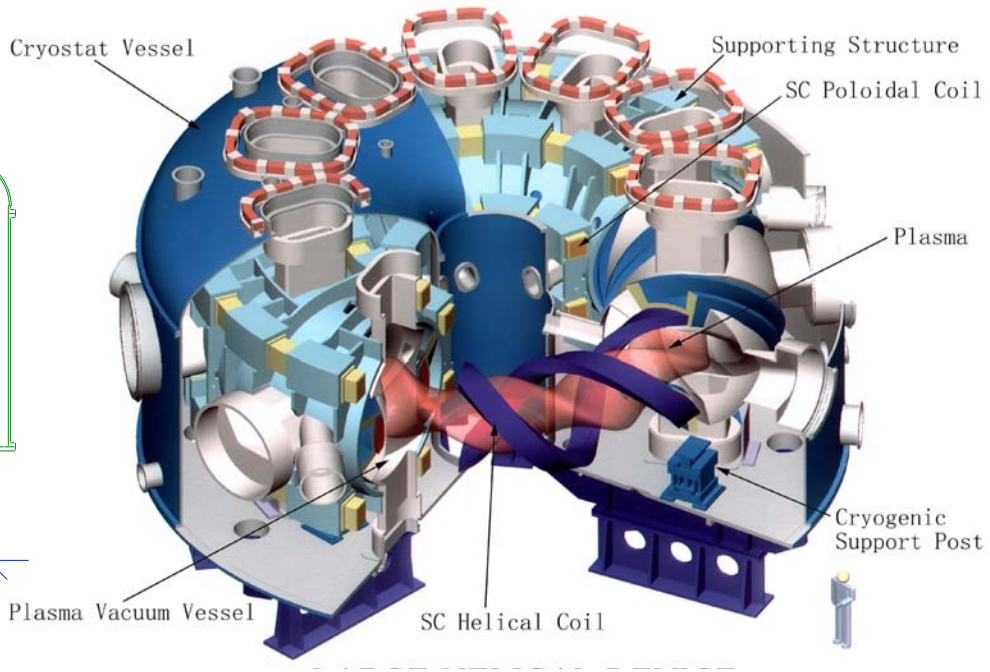
Large asymmetry in $\delta j_s/\langle j_s\rangle$: 30~40% at LFS midplane, and bursty events extend to far-SOL ($\Delta r^{mid} < 10$ cm).





Large Helical Device (LHD)





Specifications of LHD

Plasma Major radius	3.5 – 4.0 m (mainly 3.6m)	Heating power	
Plasma Minor radius	~ 0.6 m (average)	ECH	2.1 MW
Plasma Volume	~ 30 m^3	N-NBI	10.0 MW
Coil minor radius	0.975 m	ICRF	2.4 MW
Magnetic field	~ 2.9 T (at R_{ax}=3.5m)		

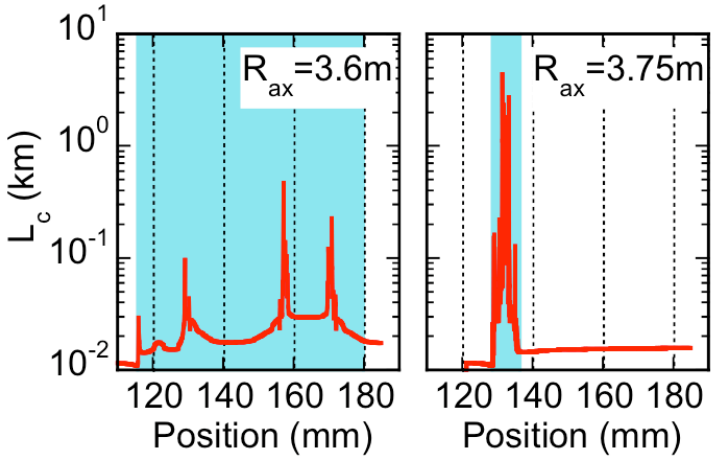
Edge Magnetic Structure in the LHD

Edge magnetic structure can be divided roughly three regions.

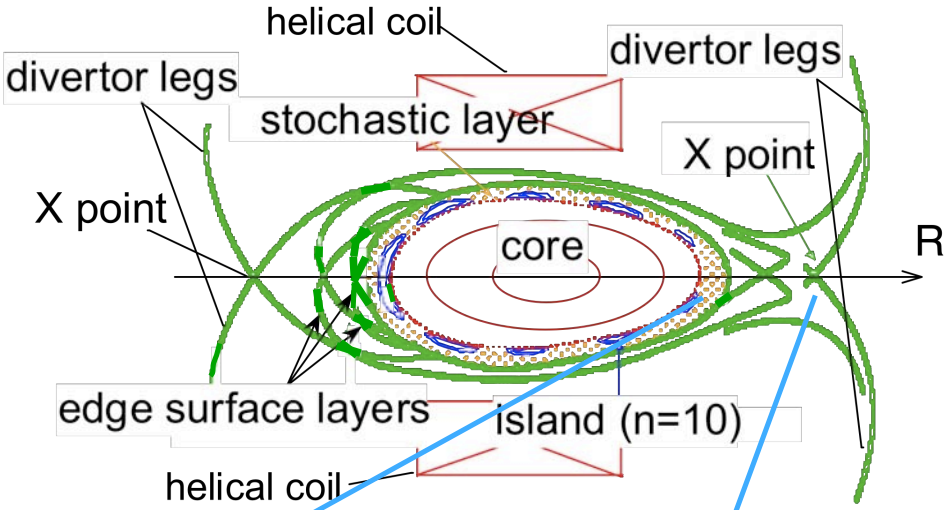
1. Island and stochastic layer region

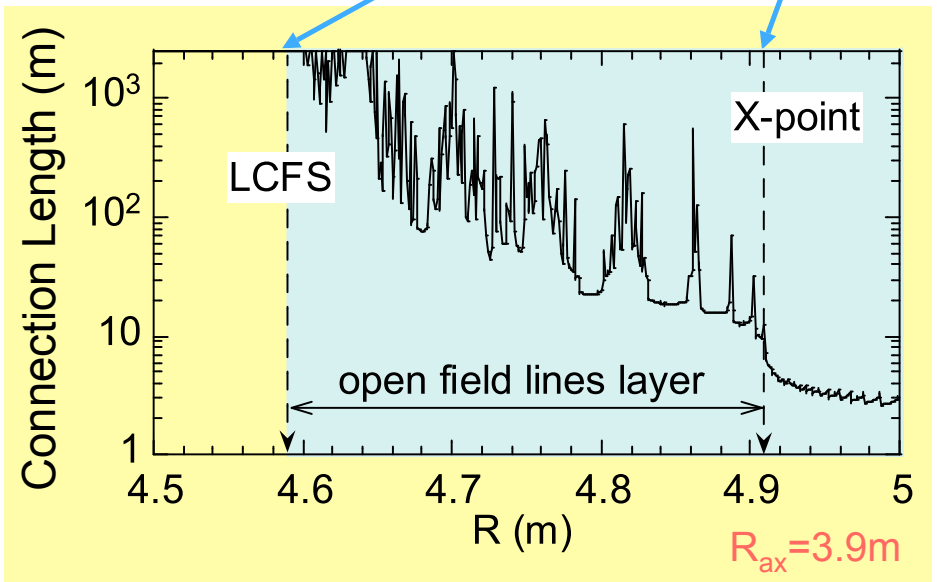
2. Edge surface layers region

3. Divertor

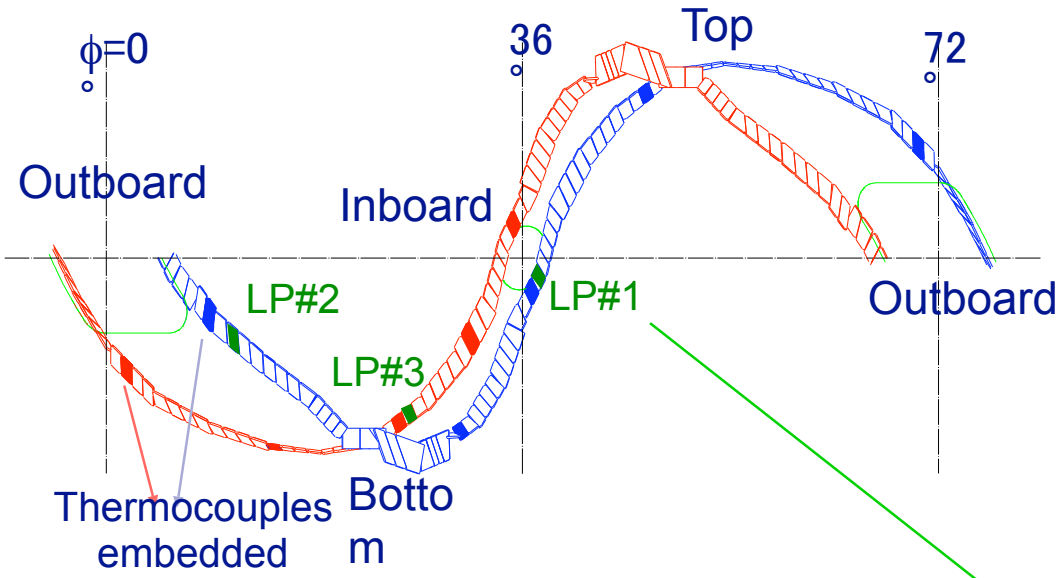


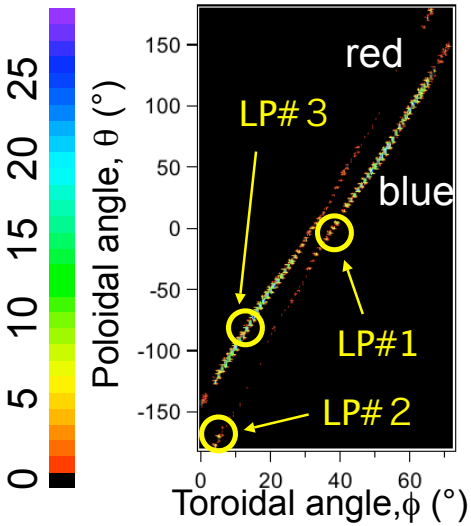
Profiles of connection length of field lines connected to a torus inboard side divertor plate.



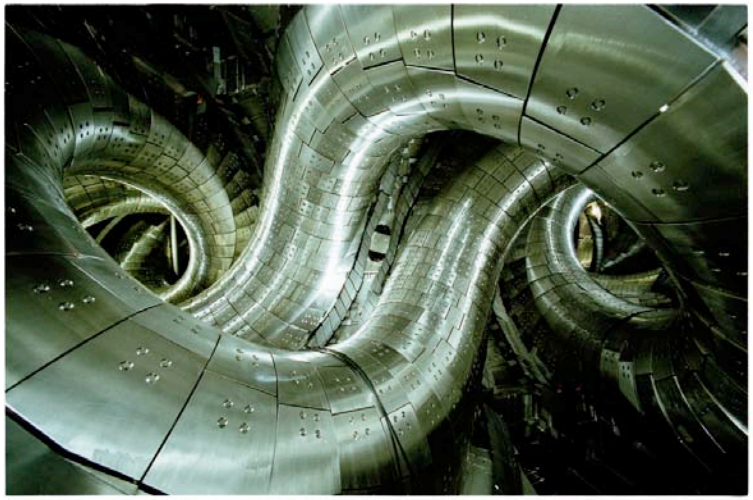


Langmuir Probe Array

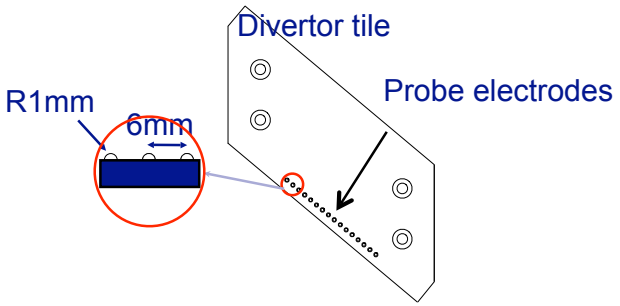




Particle deposition profile (cal.)

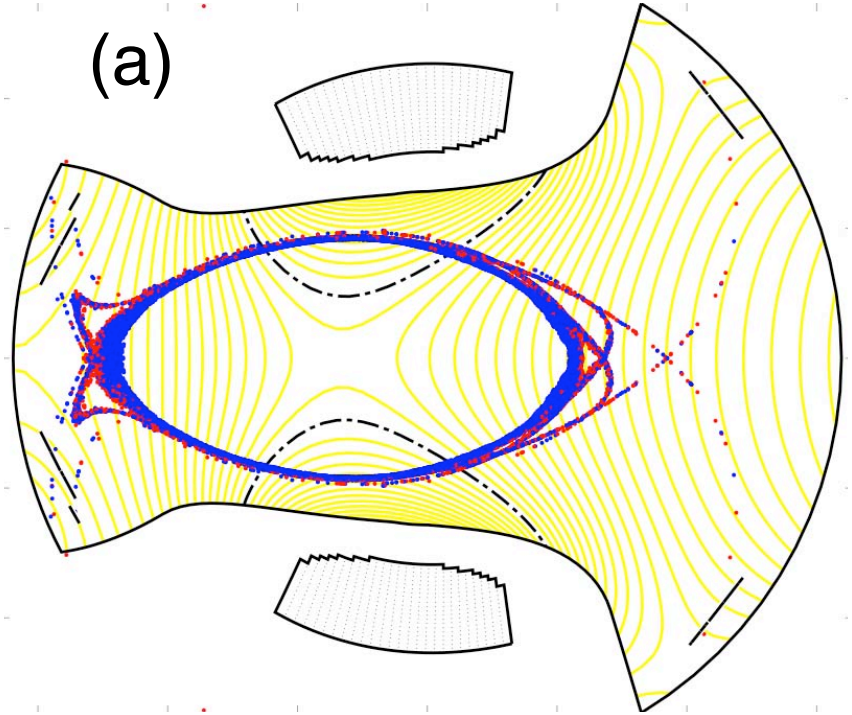


Inside of the LHD vacuum vessel (view from outboard port)

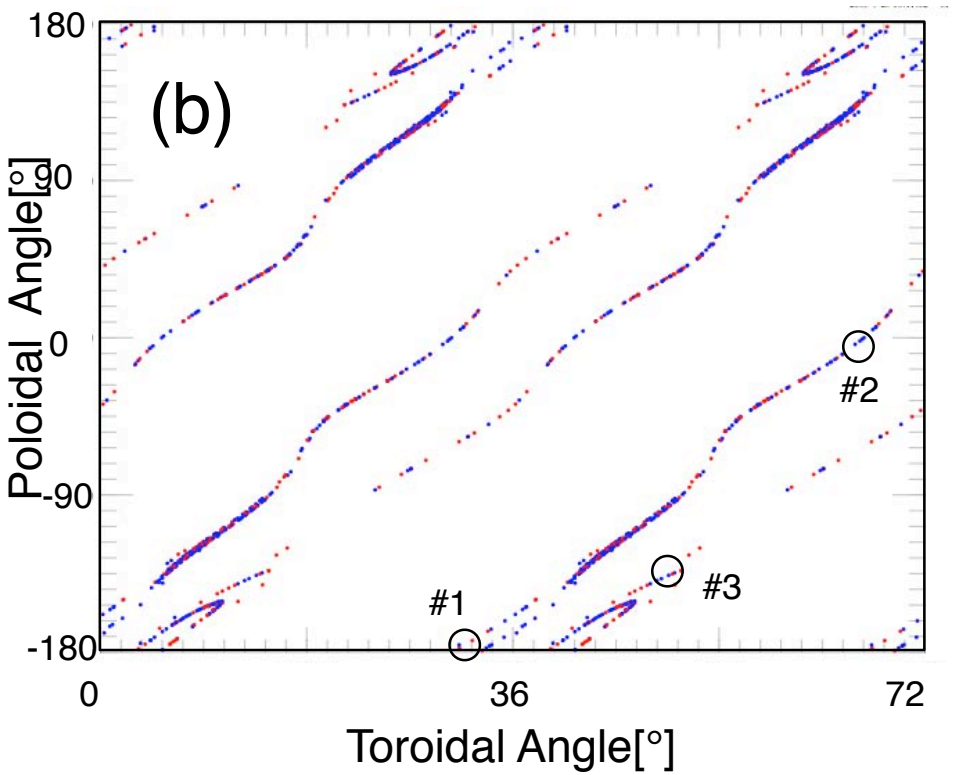


Langmuir Probe Array
（16ch.）
Sampling frequency: 250kHz

Calculated Magnetic Configuration

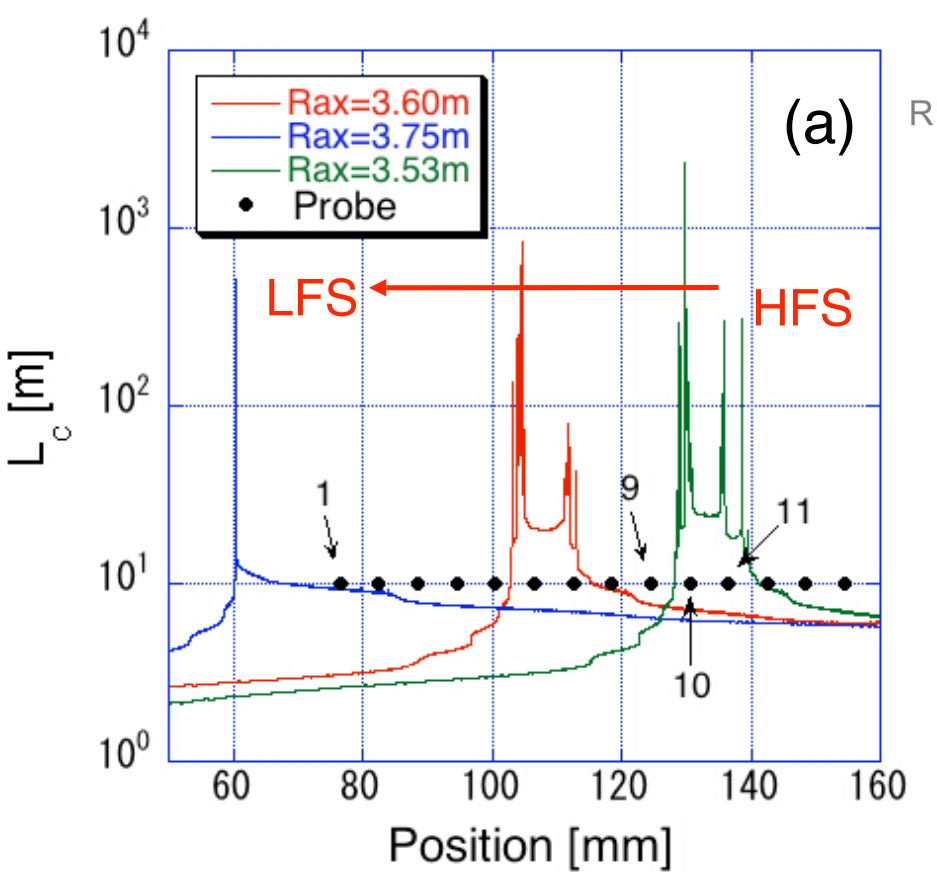


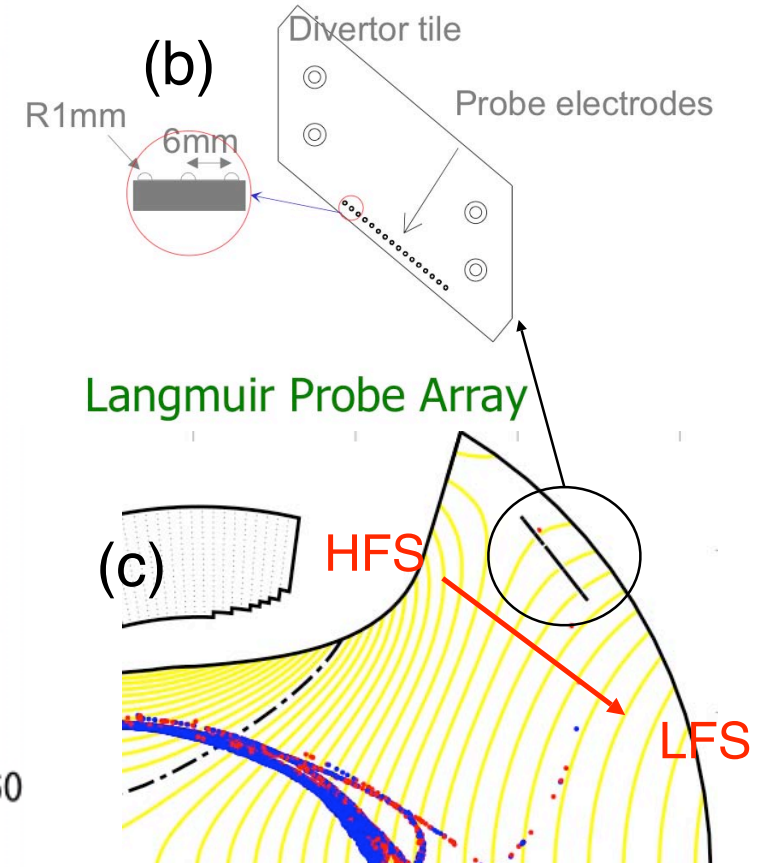
Schematics of calculated LHD magnetic configuration in horizontally elongated cross section for the magnetic axis of 3.53 m



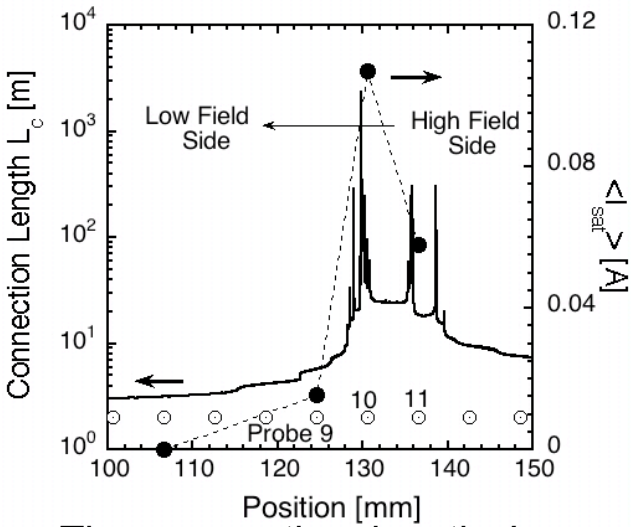
Deposition profile of magnetic field lines passing through the divertor plates

Edge Magnetic Structure near Probe Array





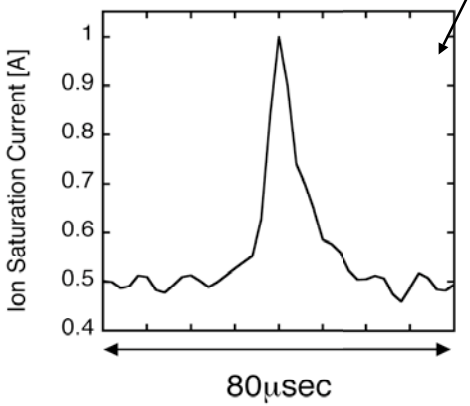
Fluctuation Properties at R_{ax}=3.53 m

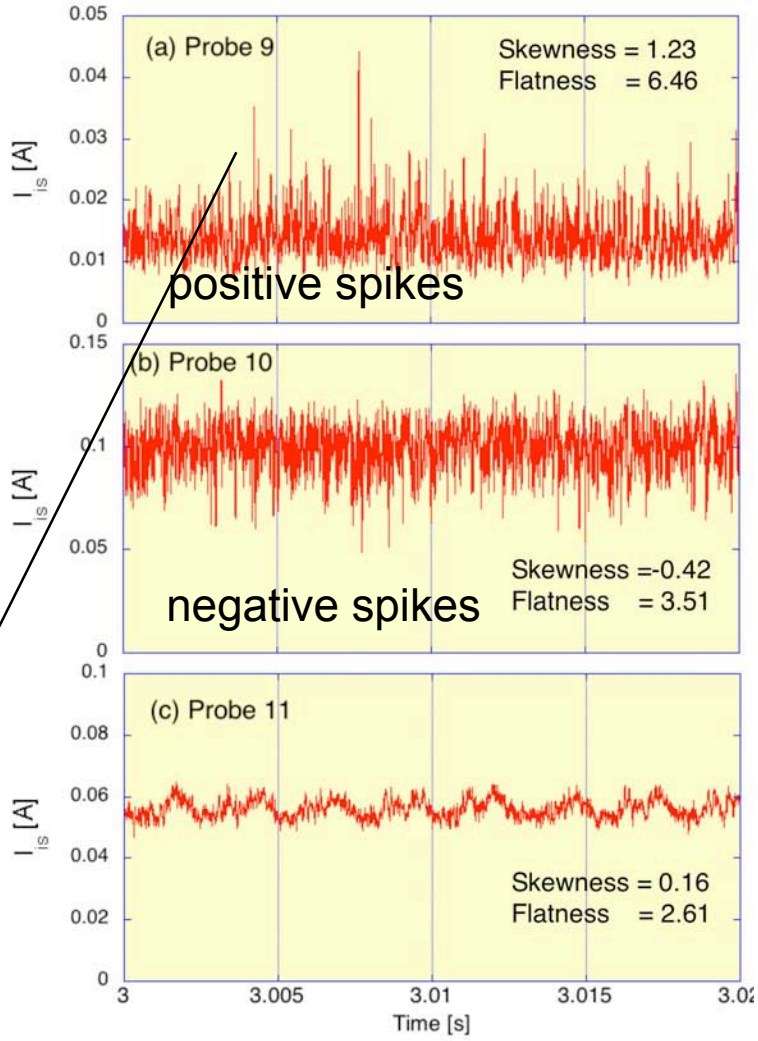


The connection length L_c of magnetic lines of force varies from less than a few meters to over a few kilometers.

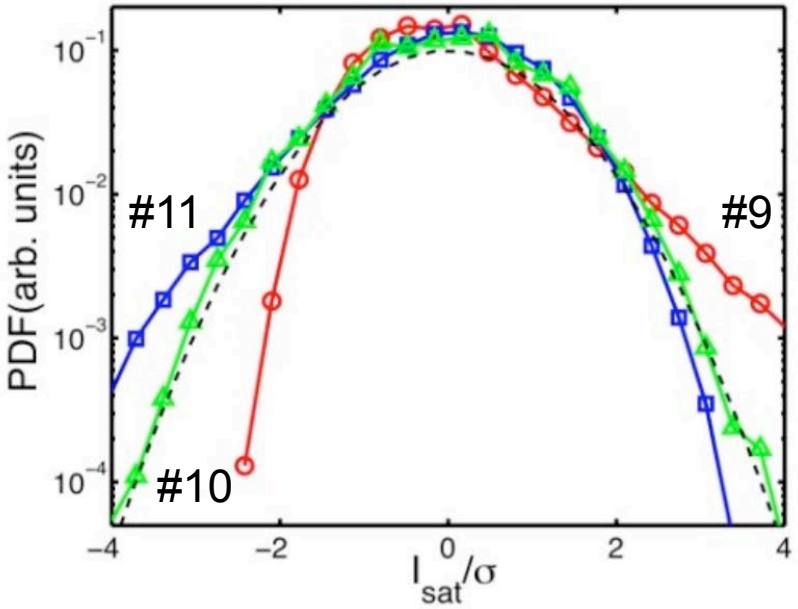
Condition averaging of the positive bursty events indicates the intermittent feature with a rapid increase and a slow decay is similar to that of plasma blobs observed in tokamaks.

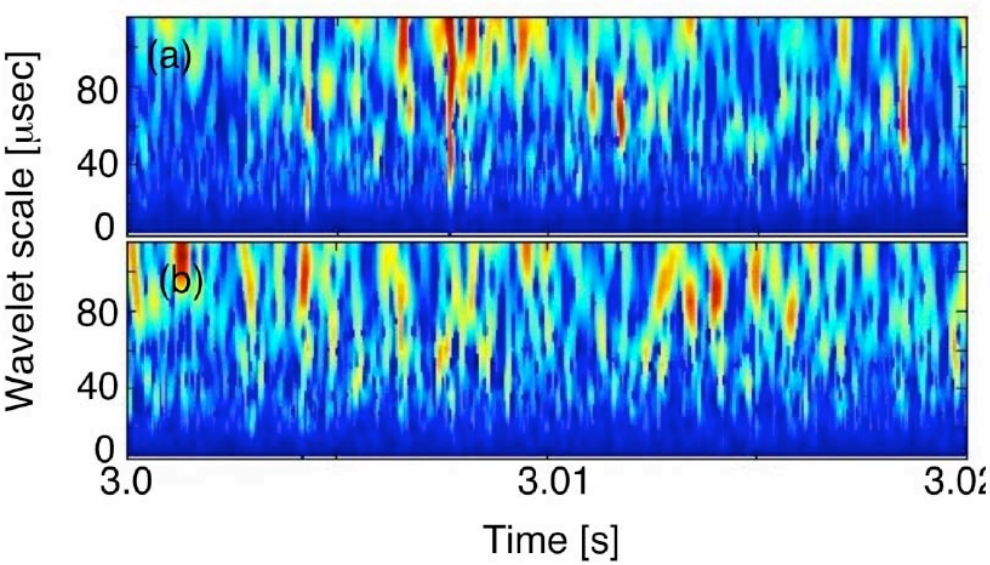
Large positive bursty events were often observed in the ion saturation current measured with a divertor probe near a divertor leg at which the magnetic line of force connected to the area of a low-field side with a short connection length.



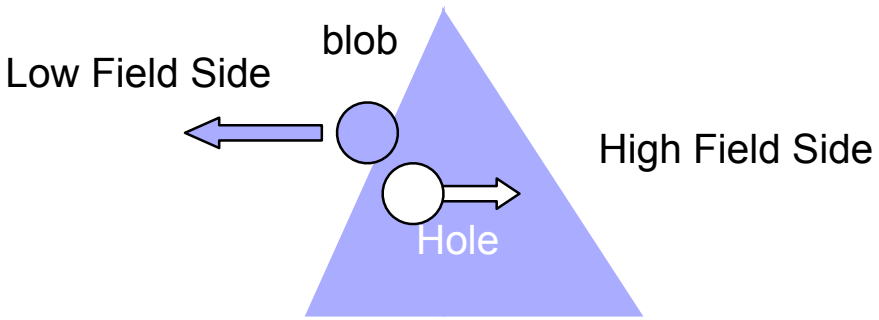


PDF and Wavelet Analysis



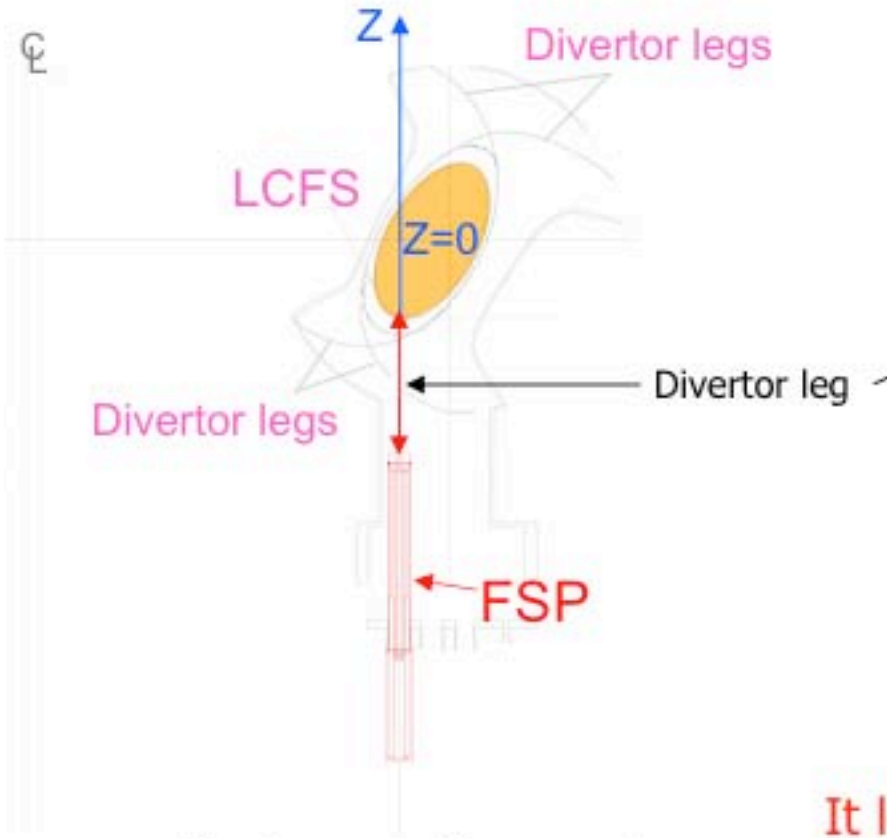


Intermittent positive spikes at probe tip 9
negative spikes at probe tip 10



Similar wavelet decomposition profile

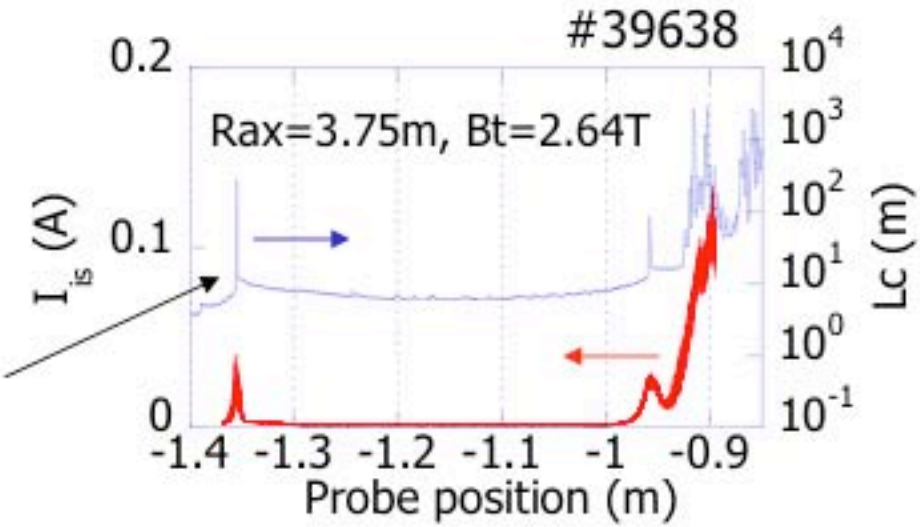
In the LHD SOL



Fast scanning probe

Stroke: 0.6 m

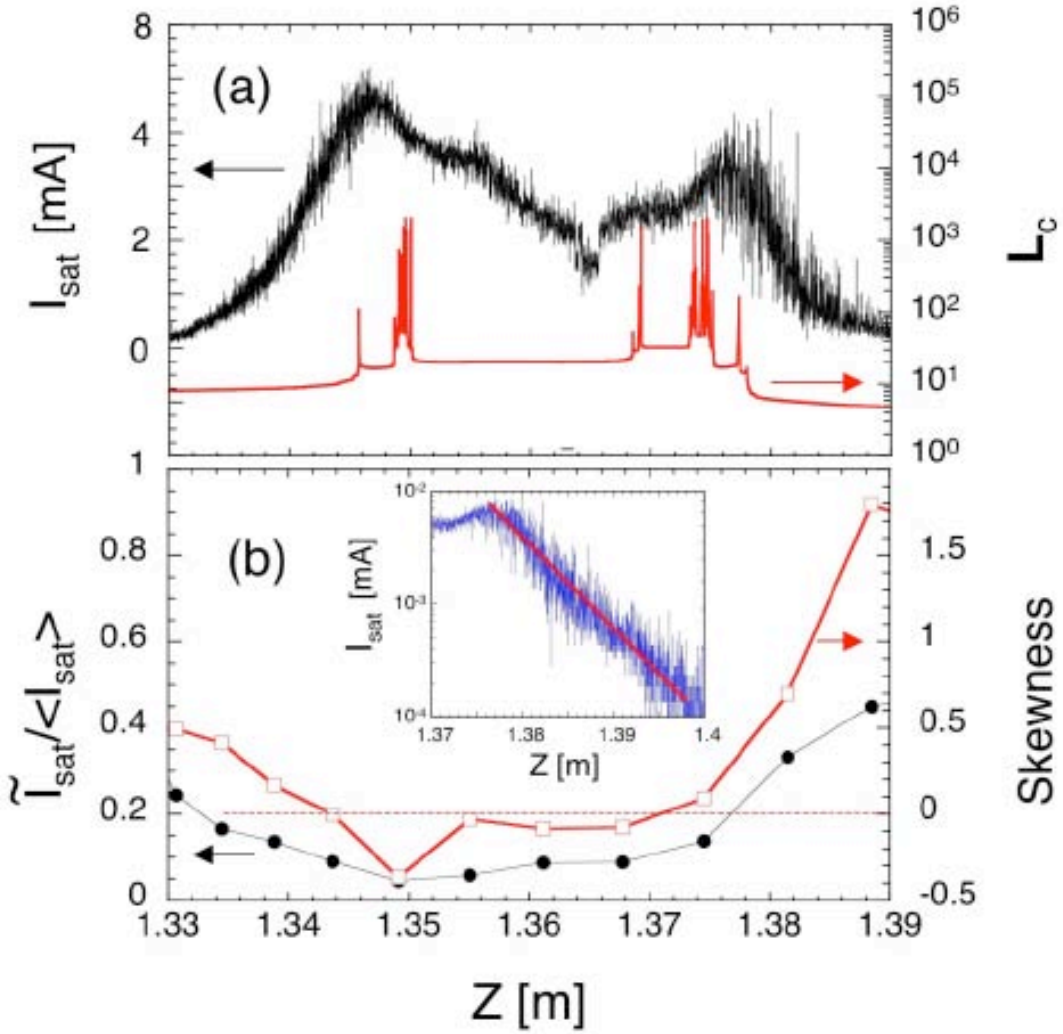
Velocity: 3 m/s



Field lines connection length and ion saturation current to probe

It looks that there is no Iis between divertor leg and outer Lc peak even spikes.

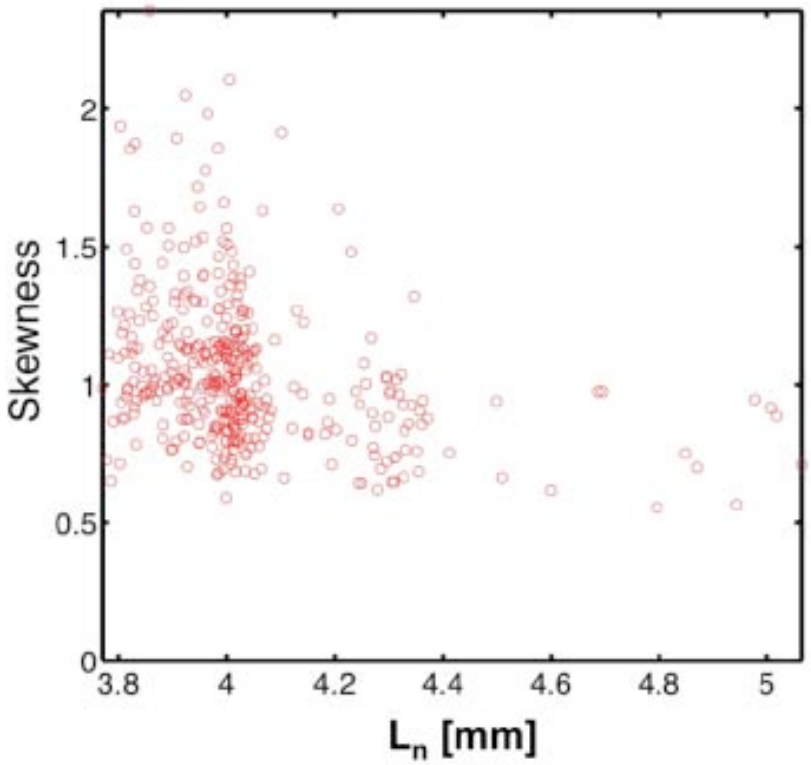
Profile of Isat and Fluctuation Characteristics In the LHD SOL



A reciprocating probe measurement also shows positive bursty events at a lower magnetic field side of the divertor leg.

These experimental results agree with the theoretical prediction of plasma blob transport although the second SOL region with a flat density profile was not clearly observed.

Density Dependence of Bursty Fluctuation

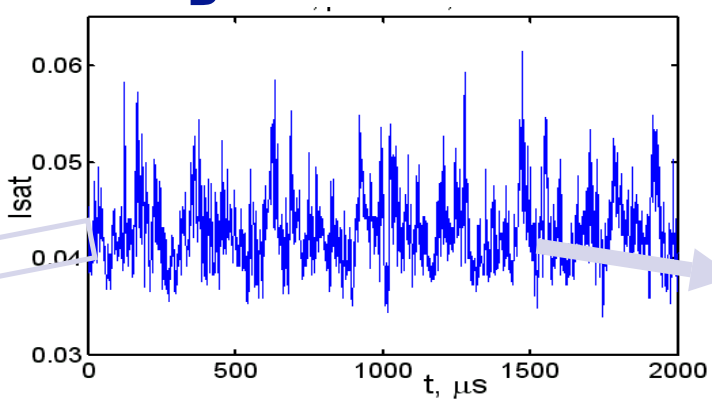


Bursty fluctuation characteristics is strongly influenced by the magnetic field structure around the probe tips, but has very weak dependence of plasma density and its gradient.

$$L_n^{-1} = \frac{2}{d_{9-10}} \cdot \frac{\langle I_{sat}^{10} \rangle - \langle I_{sat}^{9} \rangle}{\langle I_{sat}^{10} \rangle + \langle I_{sat}^{9} \rangle}$$

Multi-fractal Analysis

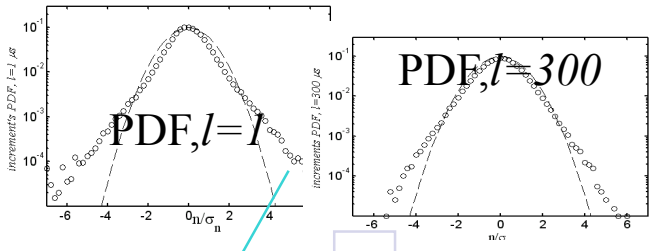
PDF of increments
$\delta_l X = X(t+l) - X(t)$

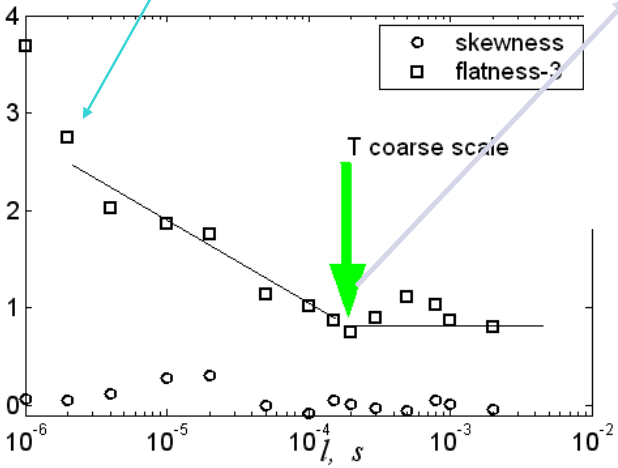


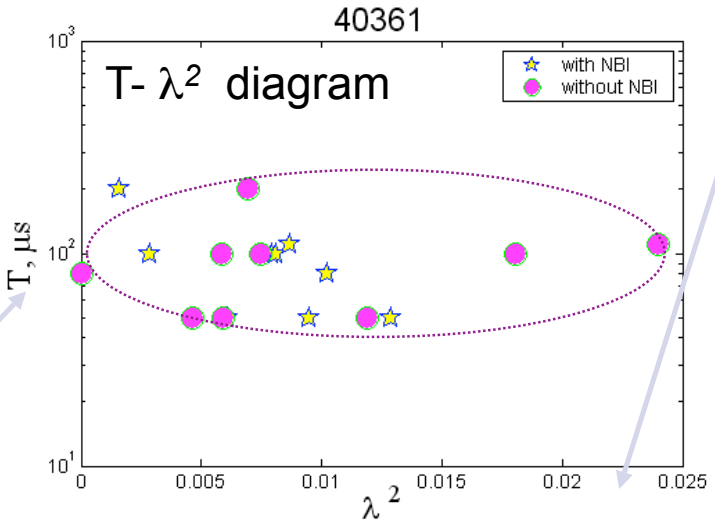
Not a Brownian-like process: structure function of increments has nonlinear scaling

$M(q,l) = \langle | \delta_l X |^q \rangle \sim l^{\zeta(q)}$

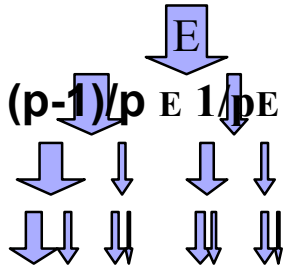
$\zeta(q) = qH - \lambda^2 q^2$







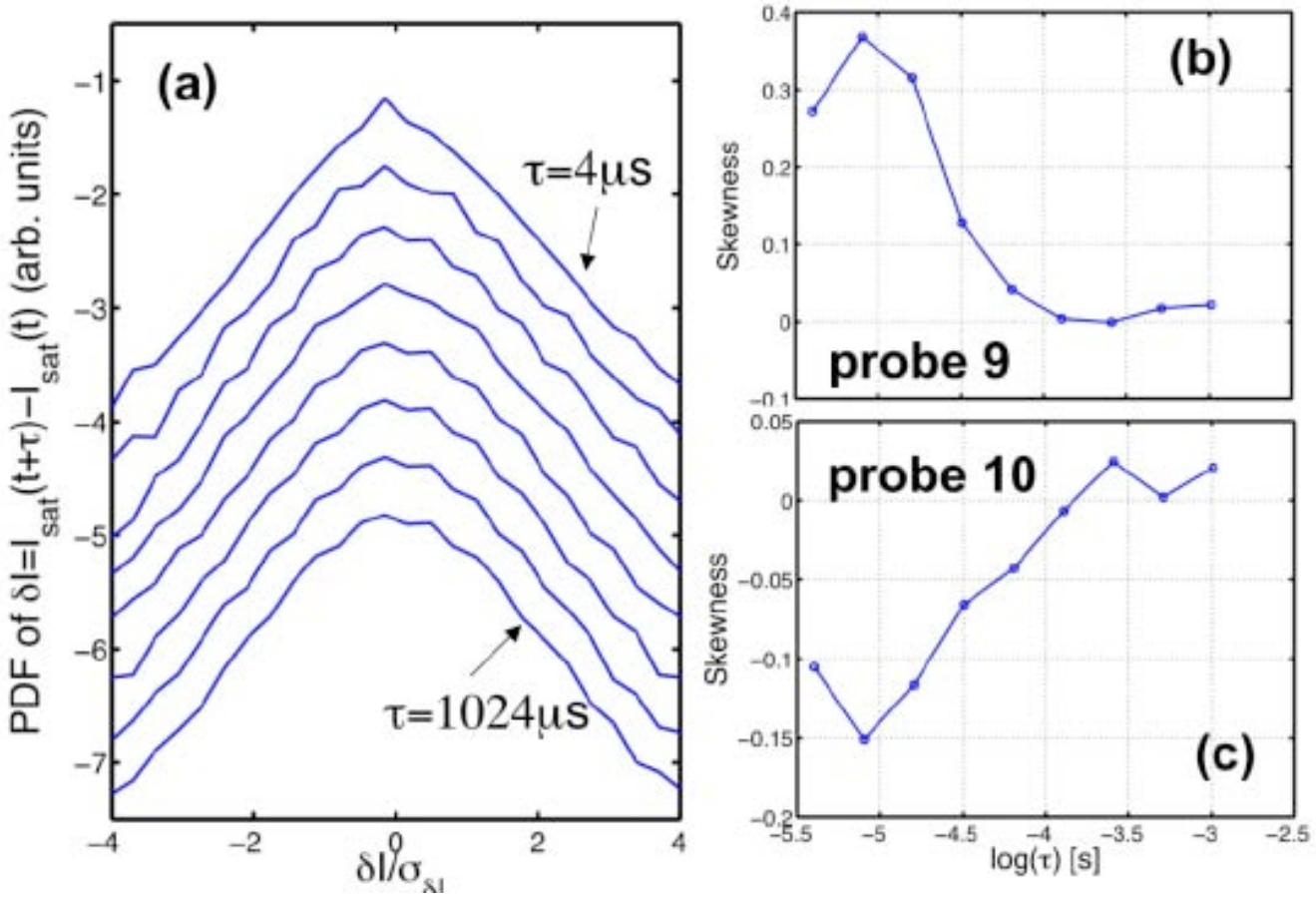
multifractality parameter λ^2



Multifractal cascading process – deviation from Kolmogorov's monofractal cascade

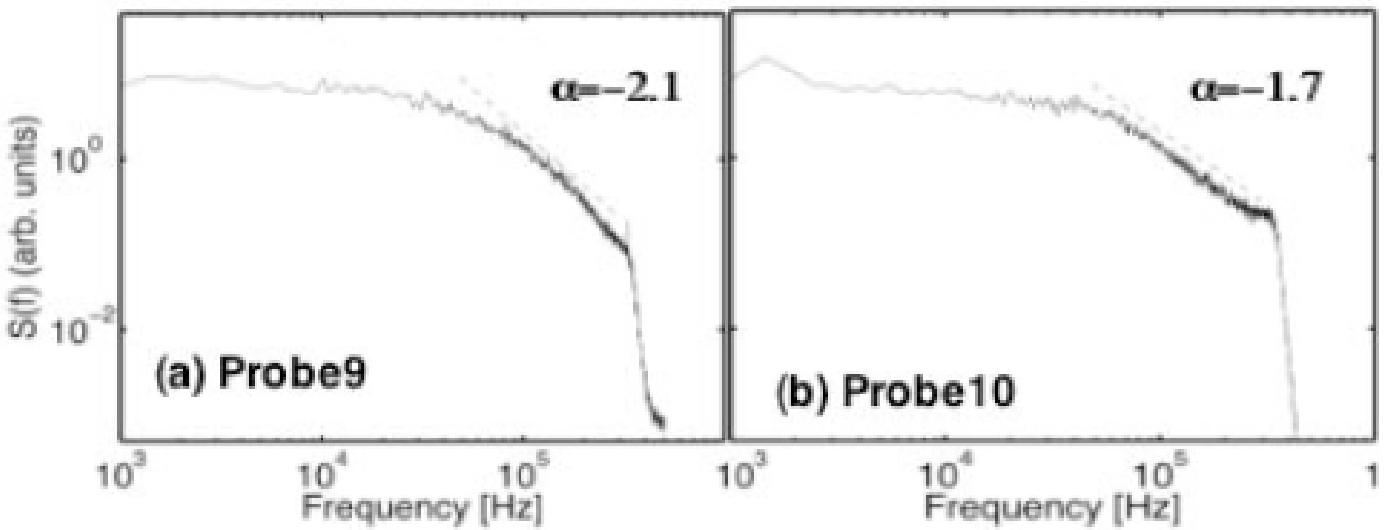
Coarse time scale of ~50-100 μs in the process: coherent structures scale

Estimation of Correlation Time

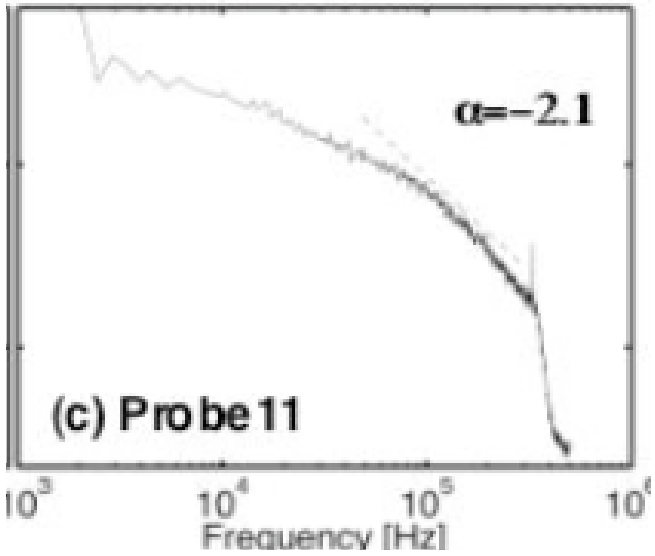


PDF for $\delta I = I_{sat}(t) - I_{sat}(t-\tau)$ $\tau_c = 100$ μs

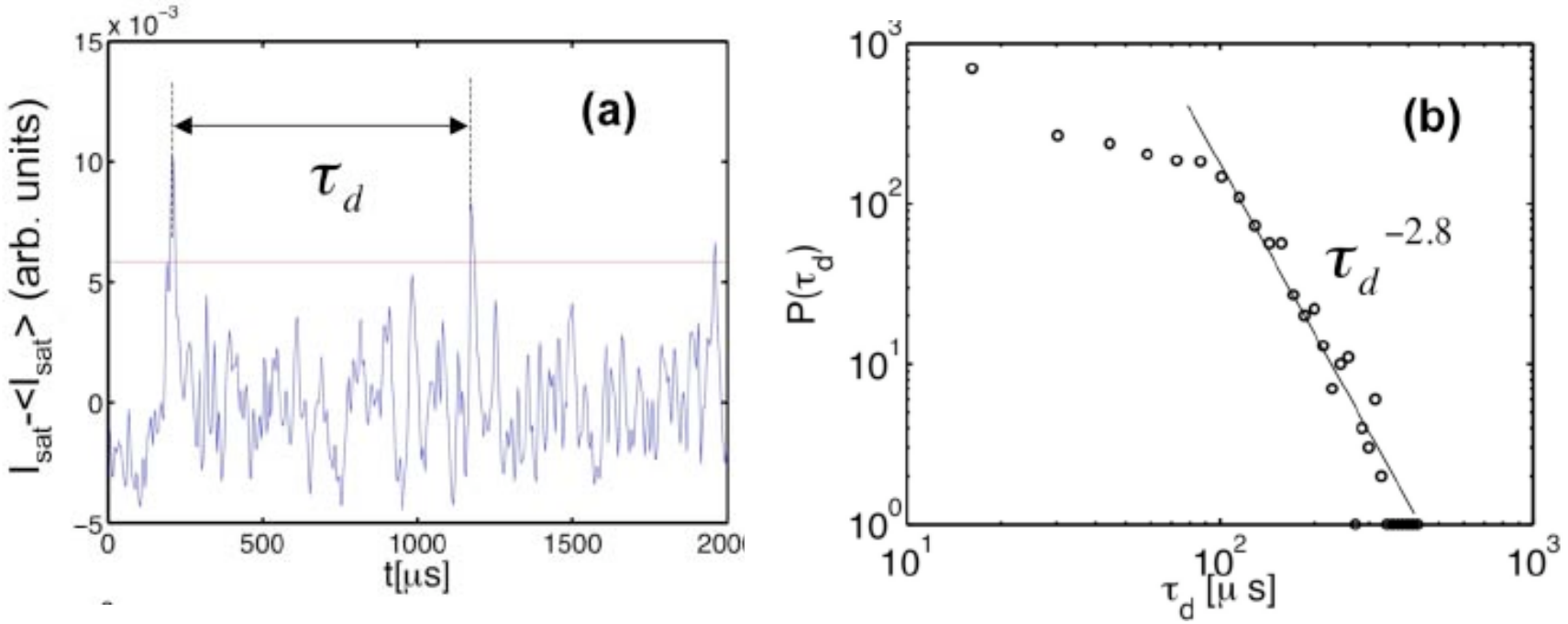
FFT of Isat in the LHD



No Apparent peaks
No SOC property



Waiting Time Statistics



self-organized criticality SOC model predicts $P(\tau_d) \propto \exp(-\tau_d)$

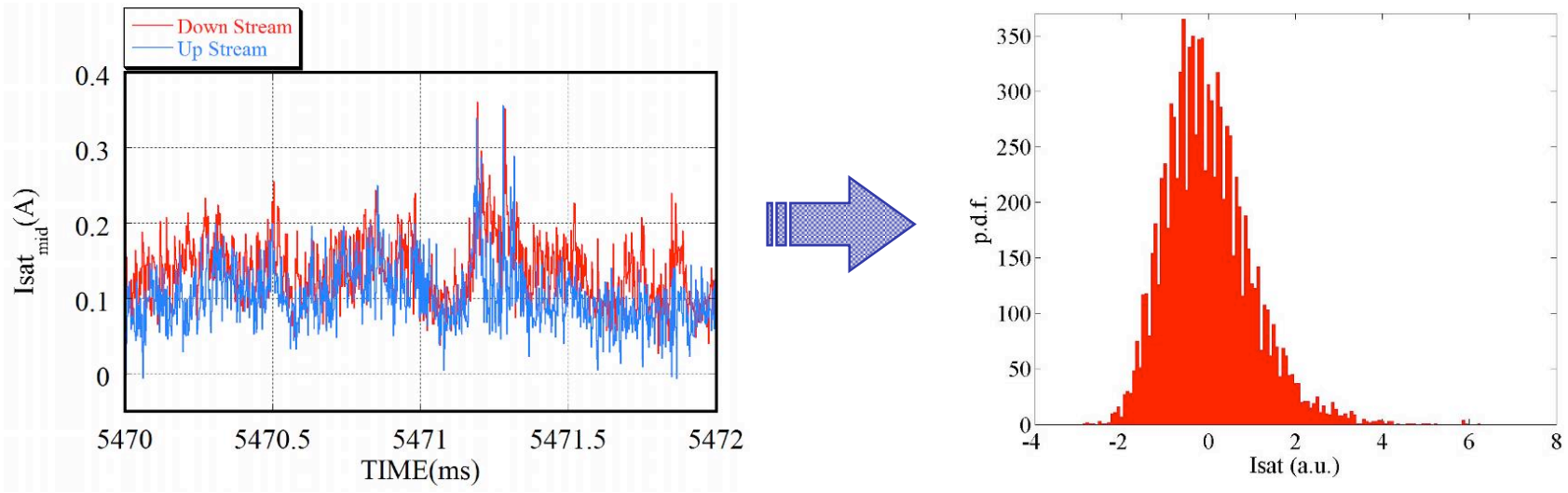
No SOC property

Summary

- We have investigated relation between edge magnetic structure of LHD and fluctuation properties of ion saturation current.
  - The edge magnetic structure was calculated by KMAG and Watanabe codes. .
  - Large positive skewness was obtained from measured ion saturation currents at lower magnetic field side of diveror leg and the negative skewness was observed at striking point of the divertor leg.
  - The fluctuation characteristics has very weak dependence of plasma density and its gradient.
  - A reciprocating probe measurement alsoshows positive bursty events at a lower magnetic field side of the divertor leg.
  - Waiting time statistics was analyzed to indicate that the waiting time statistics is not Poisson process and there is no clear signature of SOC paradigm.

Statistical Analysis Based on P.D. F.

- Reconstruction of p.d.f. from Isat signal



- Calculation of moments from the p.d.f.
  - 1st moment → Averaged value
  - 2nd moment → Fluctuation level
  - 3rd moment → Skewness(S) : Asymmetry of p.d.f.

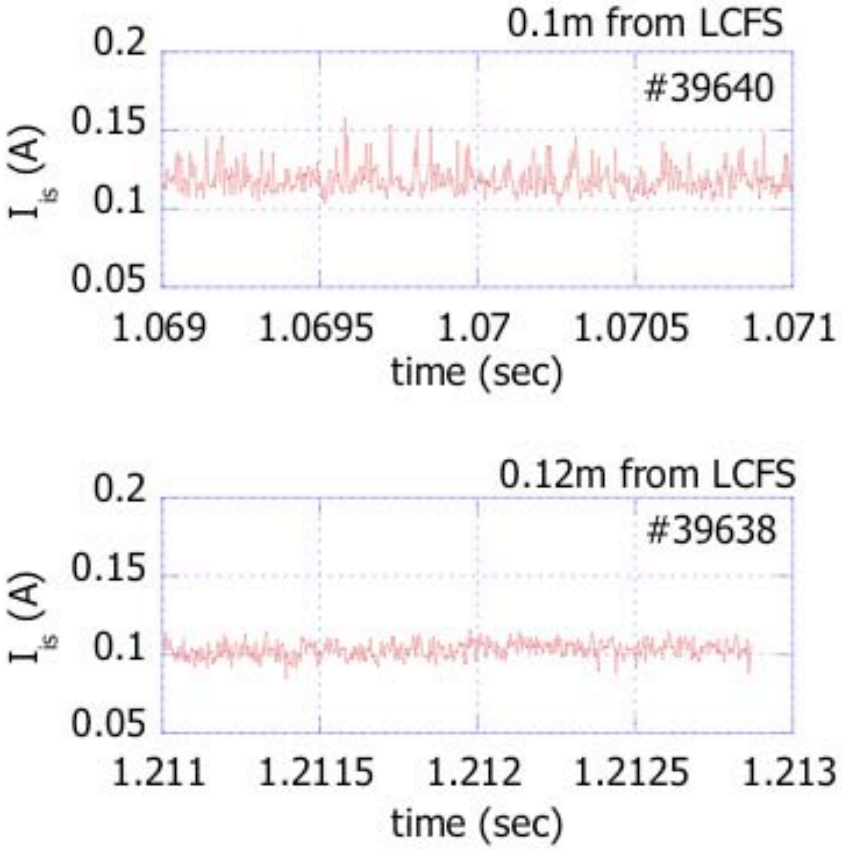
$$\frac{\left\langle \tilde{x}^3 \right\rangle}{\left\langle \tilde{x}^2 \right\rangle^{3/2}}$$

Gaussian→S=0

Positive spikes → S>0

Negative spikes→ S<0

In the LHD SOL



Time evolution of ion saturation current in the LHD SOL.

These data obtained with stopping the movable probe at the top of its trajectory.

These two shots were conducted with same conditions.

The I_{is} fluctuation at difference position show different properties.

The detail investigation to reveal the relationships between such fluctuation properties and magnetic structure will be done near future.