P6-29

Soft X-ray emission profile and mode structure during MHD events in the TST-2 spherical tokamak

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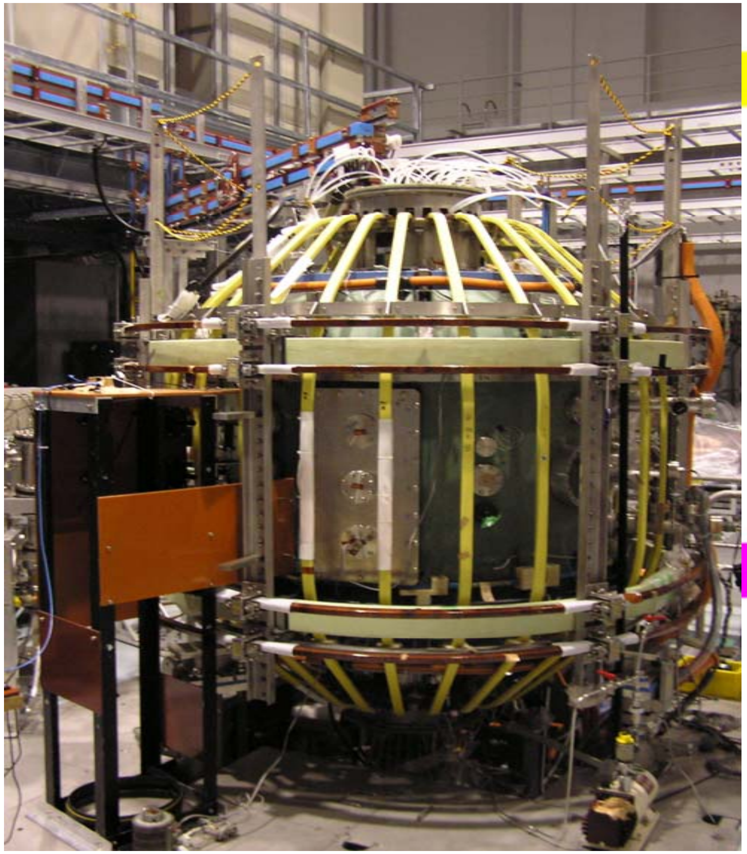
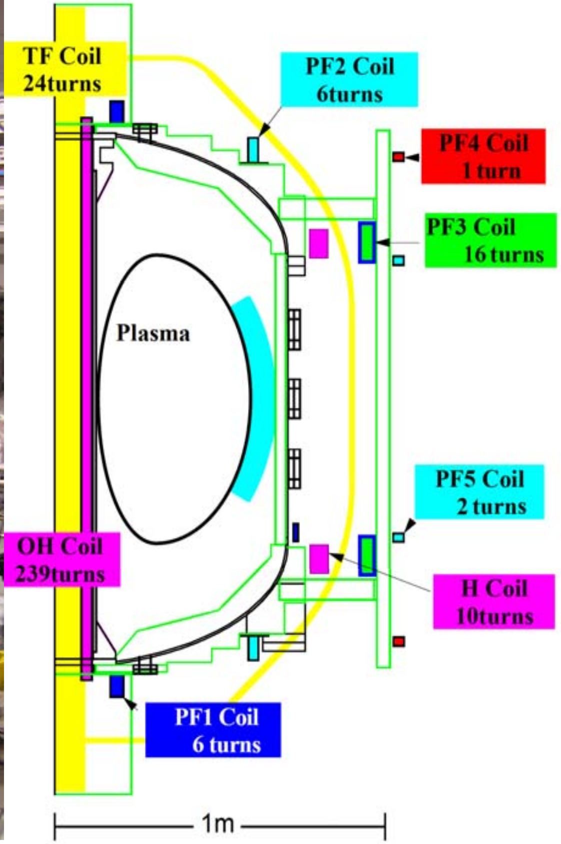
Outline

- TST-2 device
- MHD events (Reconnection Event) and objective of this study
- Measurements
  - SX detectors and evaluation of curved filters
- Experimental results
  - Evaluation of SX profile
  - Mode Analysis by Singular Value Decomposition
  - Correlation with SX gradient
  - Ion temperature increase
- Summary

Tokyo Spherical Tokamak-2(TST-2)





- Major Radius R_0 ∼0.38 m
- Minor Radius a ∼0.25 m
- Aspect ratio R/a ∼1.5
- Toroidal field BT ∼0.3T
- Electron density ne∼$10^{19}/m^3$
- Plasma current Ip ∼ 0.1MA

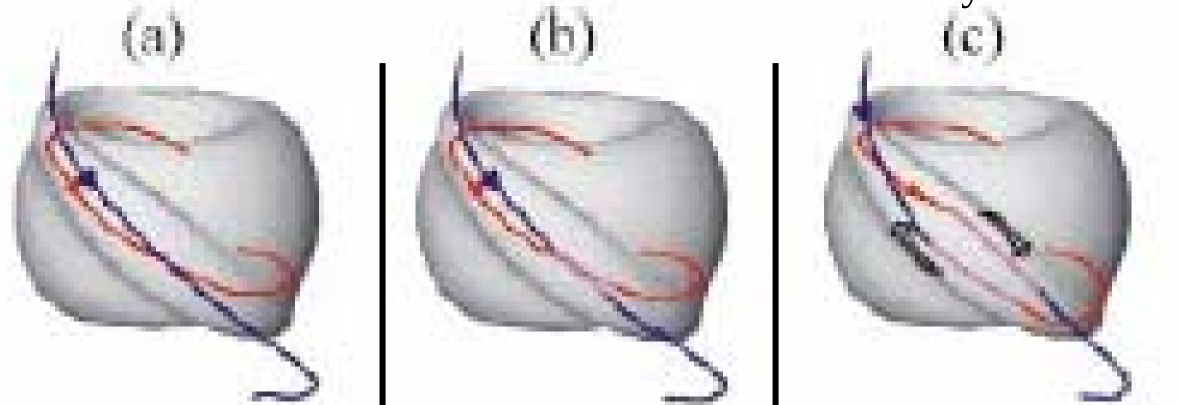
Simulation results of Reconnection Event

Previous study by MHD simulation

Naoki Mizuguchi et al,.
Phys. Plasmas **7**, 940(2000)

Magnetic lines

- **Inner -RED**
- **Outer -BLUE**



time

Simulation results

Growth of (m, n) = (1, 1), (2, 2)
(initial state)
→ non-linear coupling
(late state)
→ local deformation

Reconnection

Loss of heat and particles along the lines outside of the plasma

Experimental results

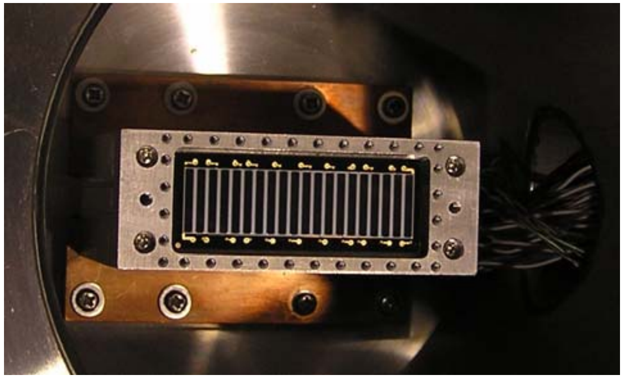
SX and magnetic fluctuation

I_p, T_i increase

Objective of this study

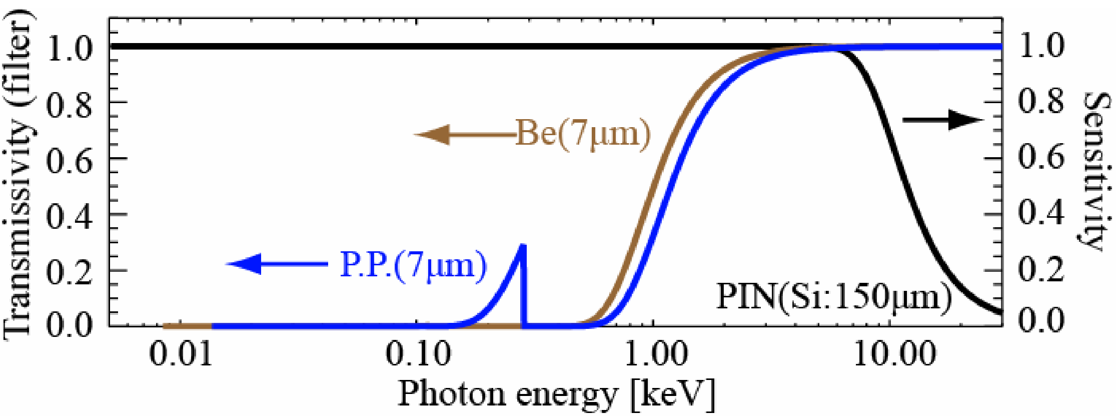
- **Comparison with MHD simulation**
  - **To understand flow of heat and particles in plasma (slow behavior) by SX radiation profile**
  - **To determine the mode number in the initial state by…**
    - **SX radiation profile (internal) and magnetic signals (external)**
  - **To decide which modes grows by…**
    - **Special technique to know the each modes of time evolution and its spatial distribution. (Singular Value Decomposition)**
  - **To get supportable evidence of magnetic reconnection by…**
    - **Determination of ion temperature (T_i) by spectroscopy**
  - **Identification of non-linear coupling (late state)**
- **Experimental understanding of the source.**
  - **To determine whether pressure gradient causes RE to know the difference of gradient on SX profile in RE and non-RE discharges**
  - **n_e profile**
  - **Current profile(q_0/q_a)**

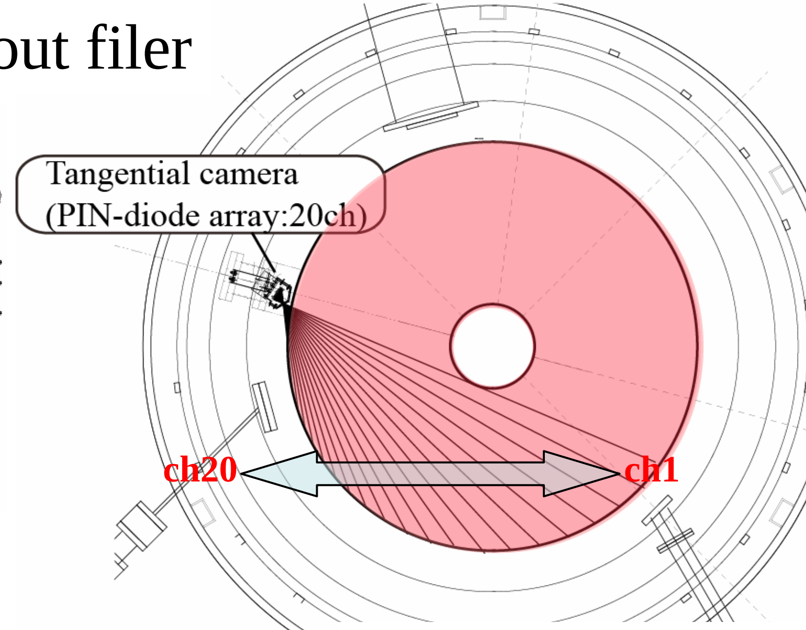
Tangential SX camera



- Semi-conductor detector (P-I-N type)
- Pin-hole camera with 20ch
- Frequency response < 50kHz
- Curved filter
  - Polypropylene(P.P.):7 μ m
  - Beryllium(Be):7 μ m

From visible to soft X-ray(〜10keV) without filer



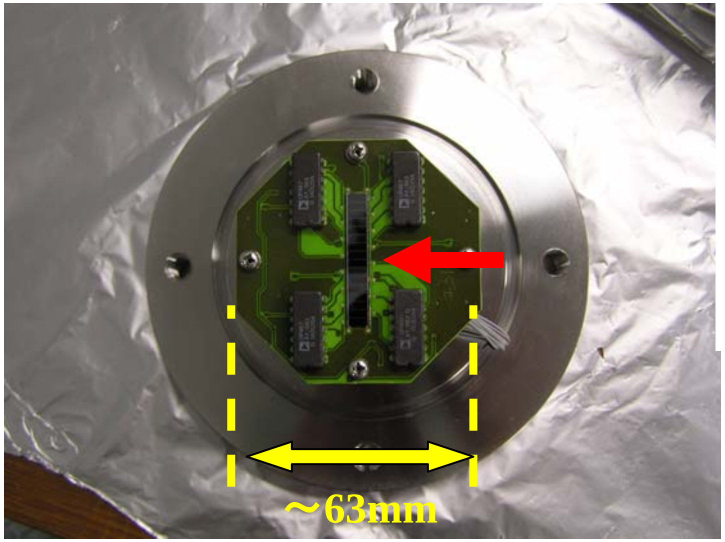


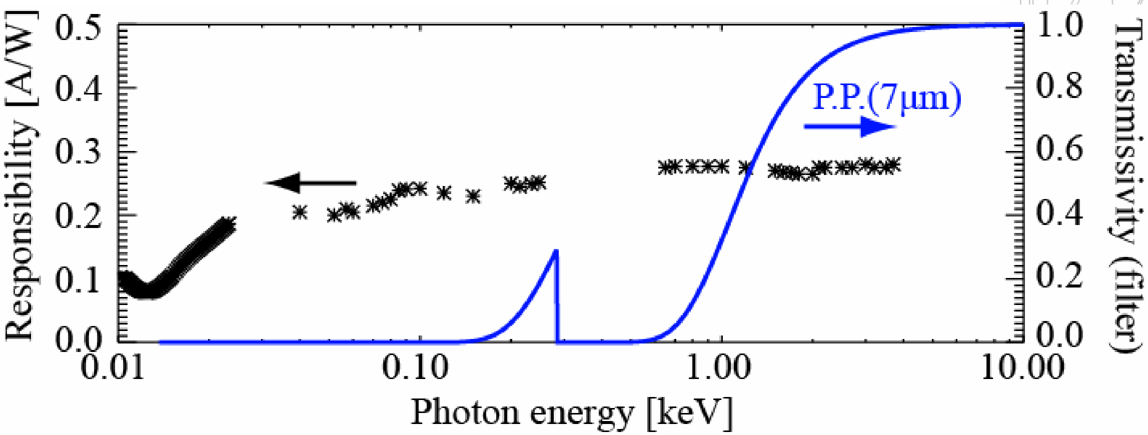
Equatorial plane (Z=0)

The sensitivity is calculated by effective thickness of Si (150 μ m).

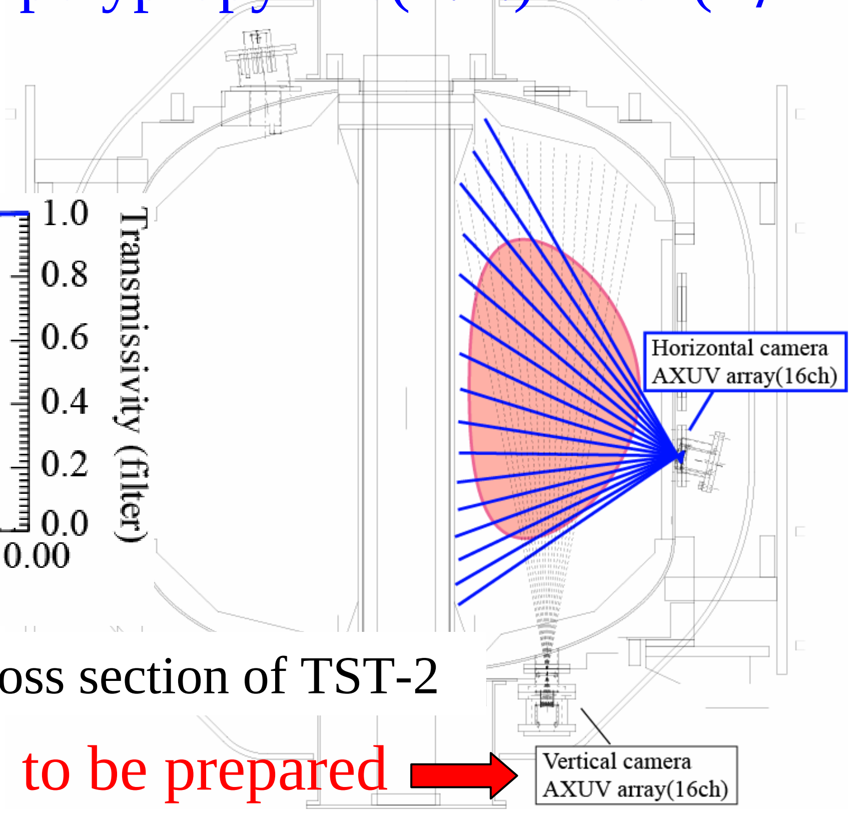
Horizontal SX camera

- AXUV16ELOHYB1(IRD Inc.)
- Frequency response～300kHz
- Pin-hole camera with 16ch
- Compact size
- Curved polypropylene(P.P.) filter (7 μ m)



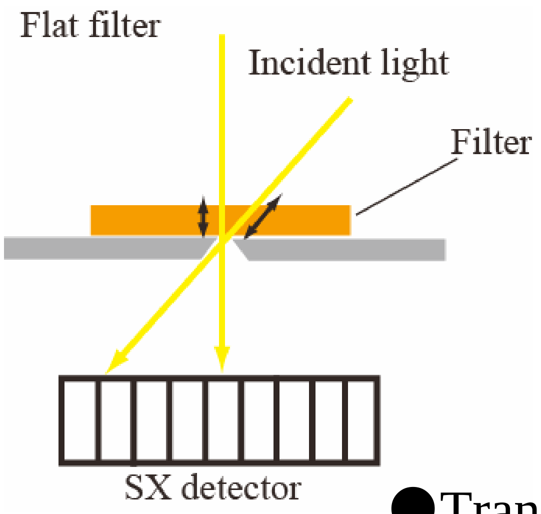


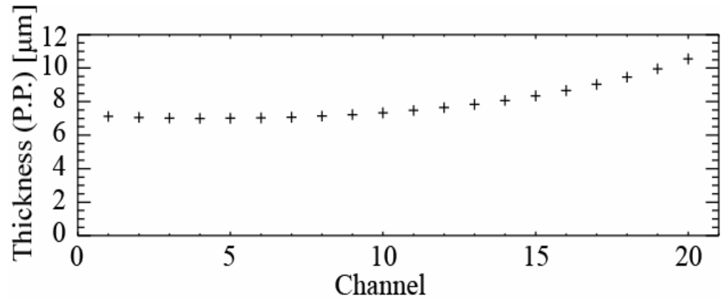
International Radiation Detectors Inc.
(http://www.ird-inc.com/axuvope.html)



Poloidal cross section of TST-2

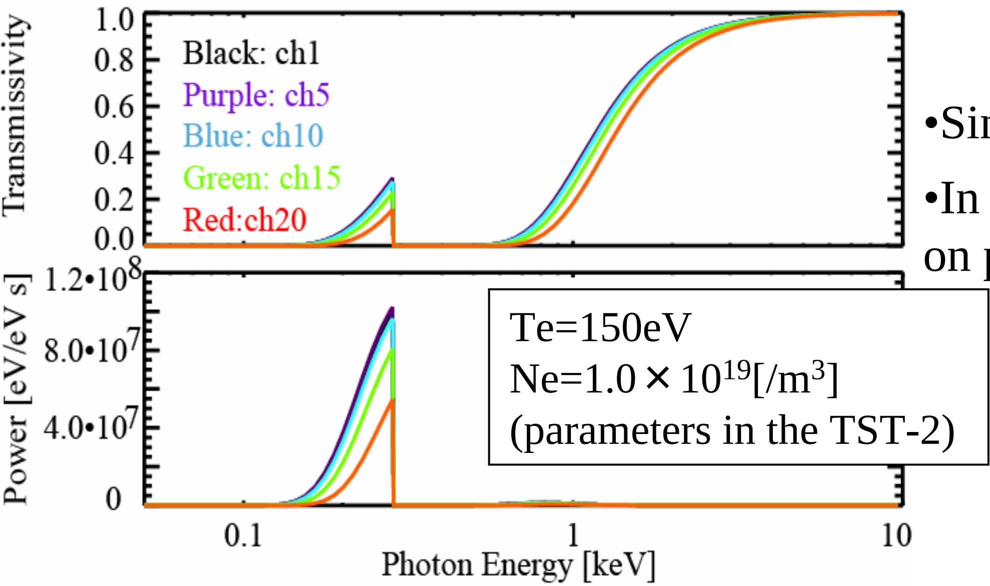
Disadvantage of flat filter





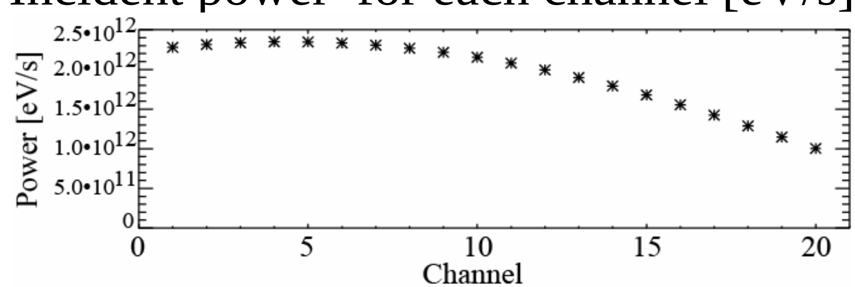
- P.P. thickness is different for each channel.
- It breaks quantitative evaluation of signal.

● Transmissivity of Be and expected incident power by bremsstrahlung

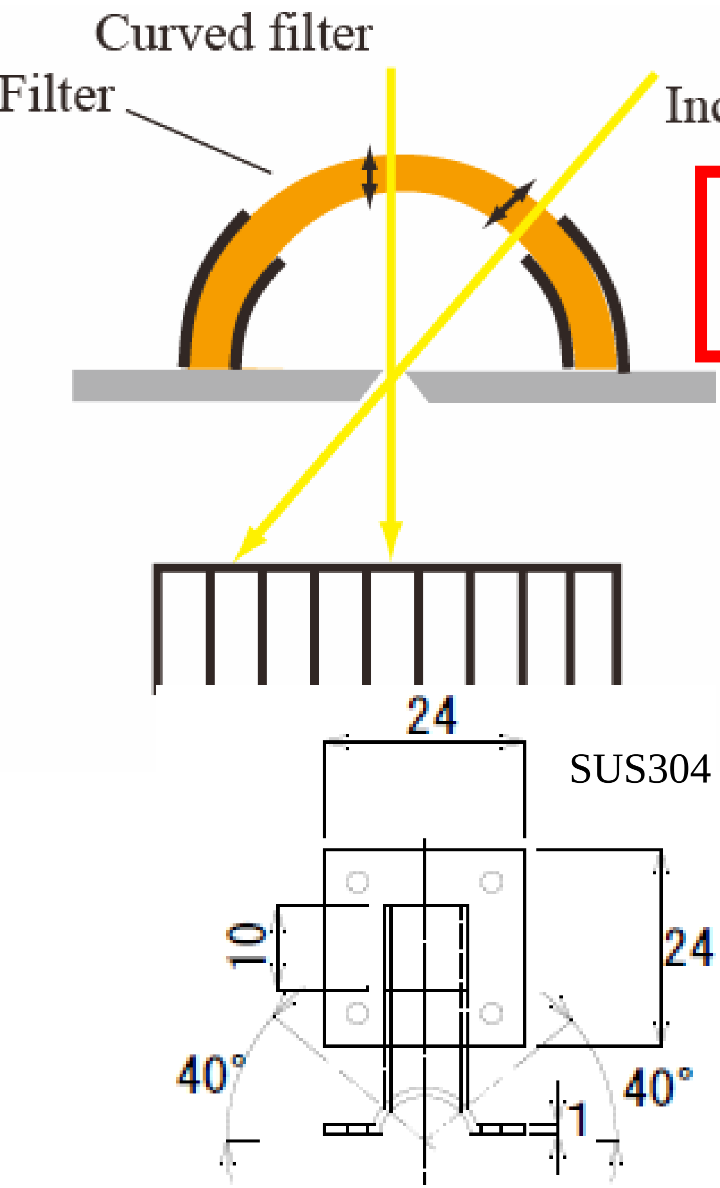


- Since Te～150eV, thick P.P. filter reduce power.
- In the case of Be filter,it changes peak position on photon energy.

● Incident power for each channel [eV/s]

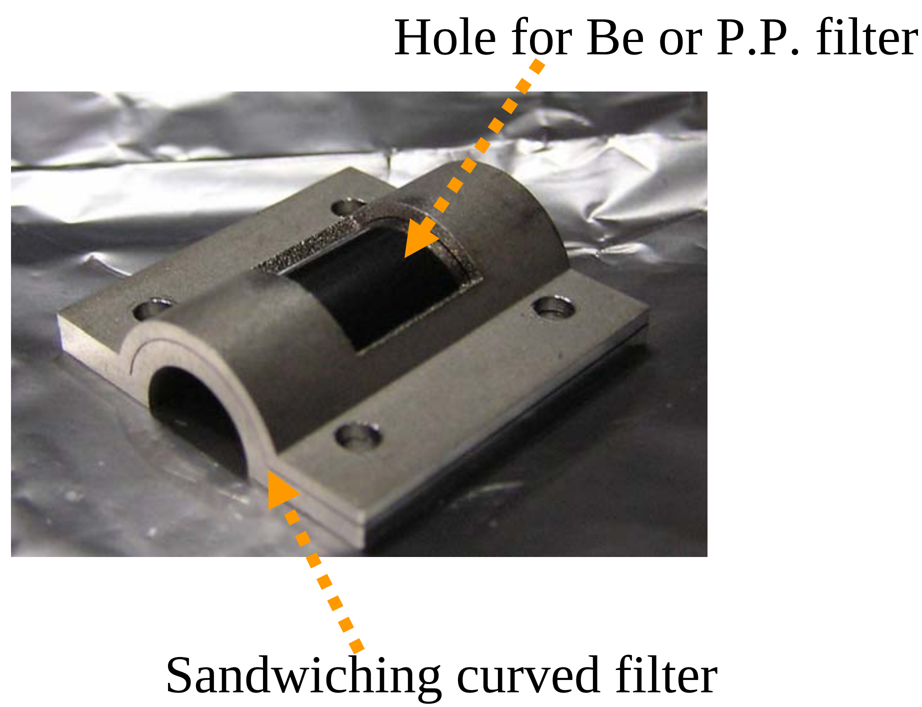


Curved filter

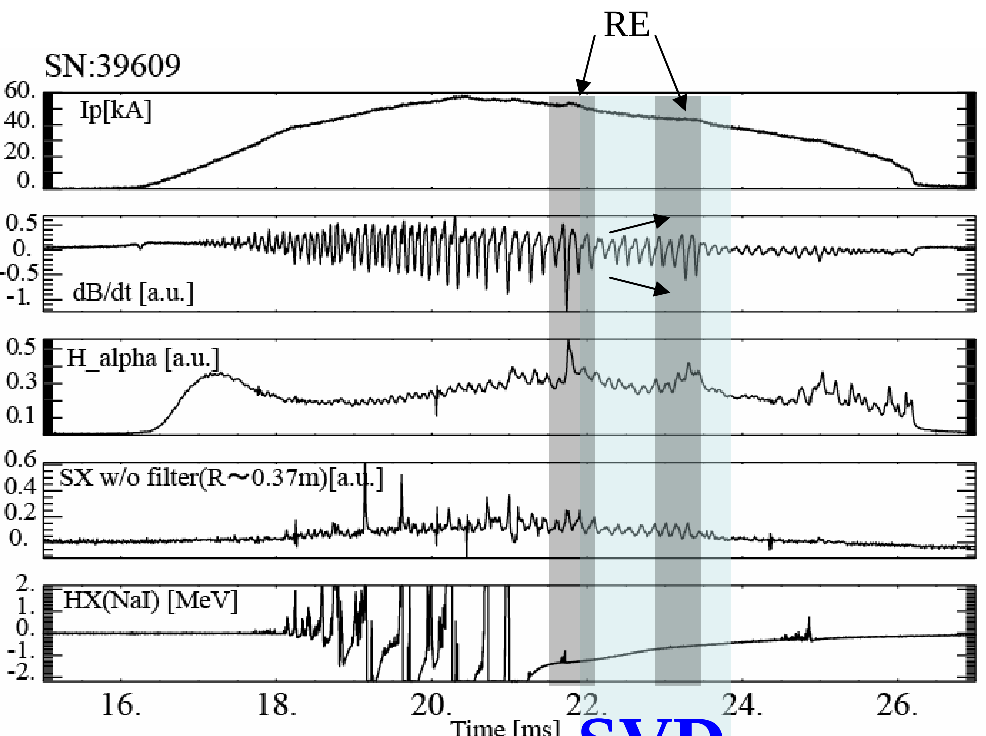


Same thickness(7 μ m) by curving

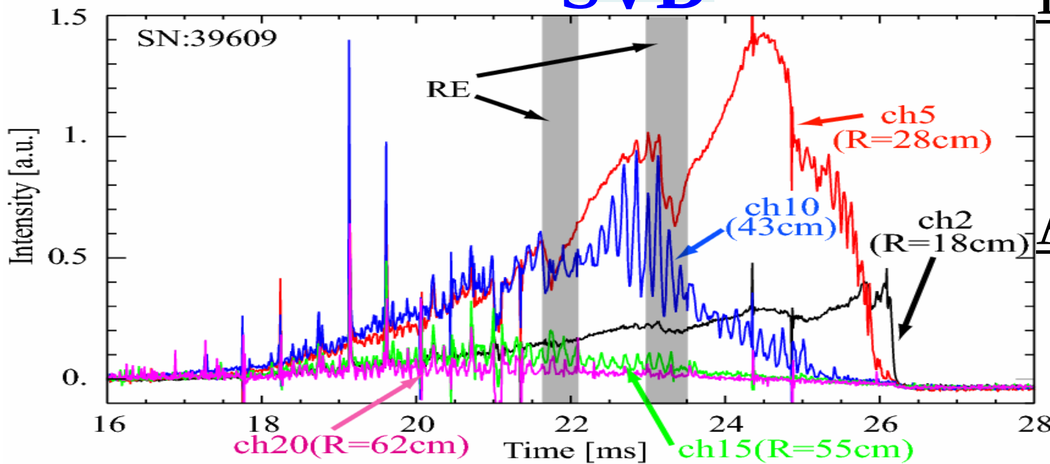
● Picture of filter-cover



Typical discharges with RE



SVD



- I_p increased slightly during the events
- Fluctuation of dB/dt and SX
- Interaction between plasma and V.V. (enhanced emission of H_α and HX)

- SX(PIN-diode array) w/o filter

Before RE

Growth of the fluctuation

Emission ↑

After RE

Decay of the fluctuation

Emission ↓

Distribution of time derivative

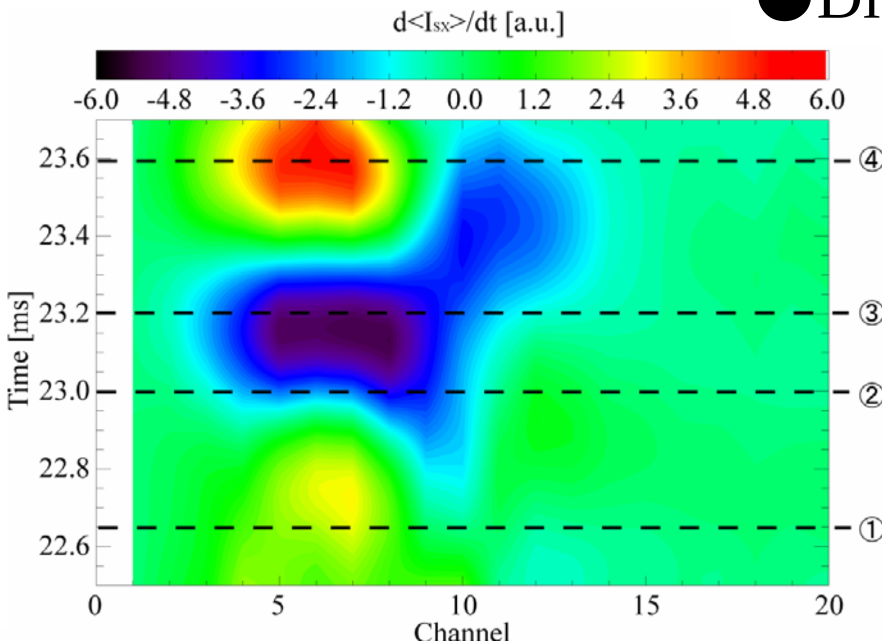
● Distribution of $d\langle I_{SX}\rangle/dt$ against the time

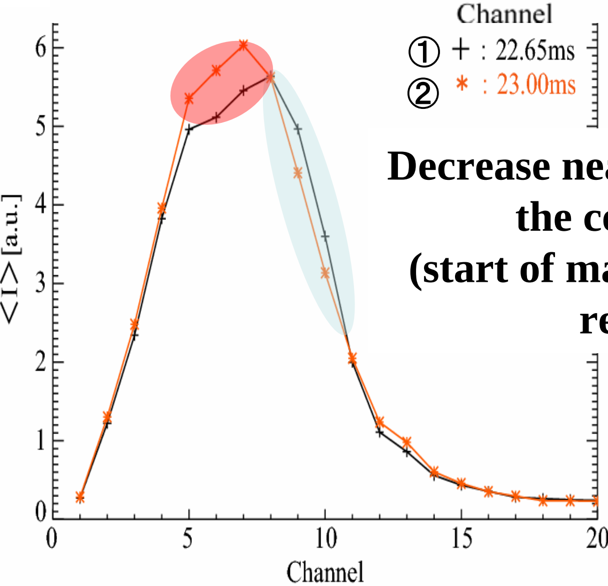
Signal from PIN

↓ Low-pass filter (<3kHz)

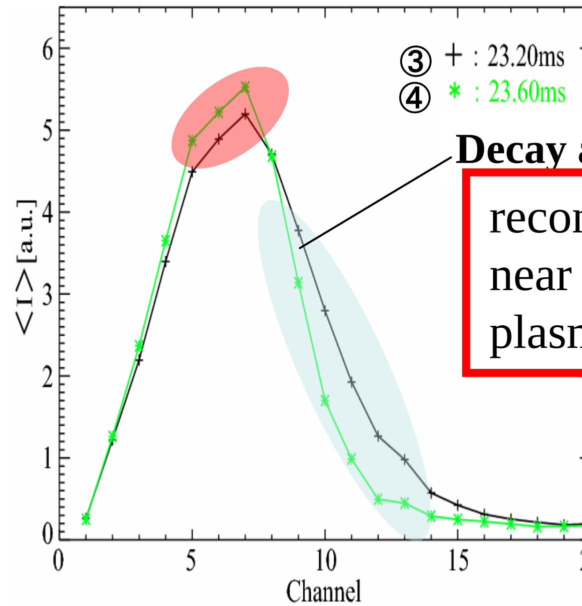
mean intensity $\langle I_{SX}\rangle$ (no fluctuation)

→ $\dfrac{d\langle I_{SX}\rangle}{dt}$ (derivative)





Decrease near the center of plasma (start of magnetic reconnection)



Decay area spread to outer

reconnection start near center of the plasma($\rho \sim 0.2$)

⇕

Outer of plasma (MHD simulation)

Mode Analysis by Singular Value Decomposition

TST-2 Tokyo Spherical Tokamak

$$A = U\Sigma V^T$$

Singular value

$$A = [u_1, u_2, \ldots, u_M] \begin{bmatrix} \sigma_1 & & 0 & \\ & \sigma_2 & & 0 \\ 0 & & \ddots & \\ & & & \sigma_M \end{bmatrix} \begin{bmatrix} v_1^T \\ v_2^T \\ \vdots \\ v_N^T \end{bmatrix}$$

A: N × M matrix

U: (Mth order) Orthogonal matrix

V: (Nth order) Orthogonal matrix

Σ : diagonal matrix

$$A = \sum_{i=1}^{p} \sigma_i u_i v_i^T$$

Ai

$\{u_i\}$ (**chrono**) , $\{v_i\}$ (**topo**) : **singular vector**

$$p = \min(M, N)$$

N.Iwama Journal of Plasma and Fusion Research, **74**, 1310 (1998)
C. Nardone, Plasma Phys. Controlled Fusion 34, 1447 (1992)

Considering experimental data…

Channel Number →

$$A = \begin{bmatrix} s_1(0) & s_2(0) & \cdots & s_N(0) \\ s_1(\Delta t) & s_2(\Delta t) & \cdots & s_N(\Delta t) \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ s_1((M-1)\Delta t) & s_2((M-1)\Delta t) & \cdots & s_N((M-1)\Delta t) \end{bmatrix}$$

↓ Time evolution

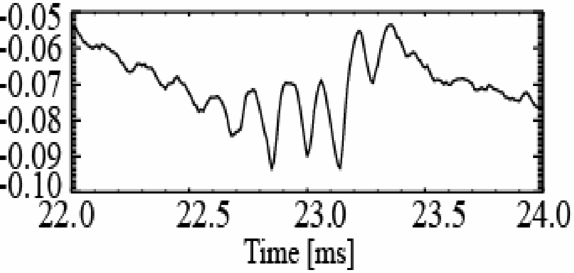
Not only SX signals
but also magnetic coils (n-coil) are used.

- To know the correlation between toroidal mode and fluctuation of SX

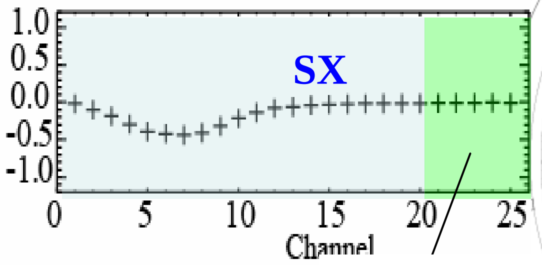
Results of SVD analysis with tangential chords and n-coils

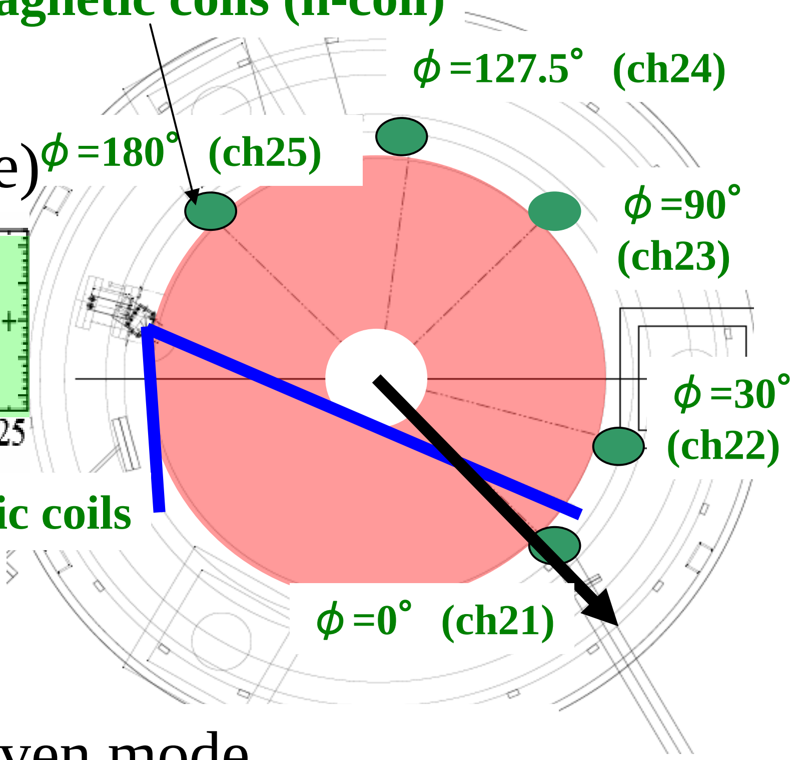
■i=1(mode number)

•chrono: (temporal eigenmode)

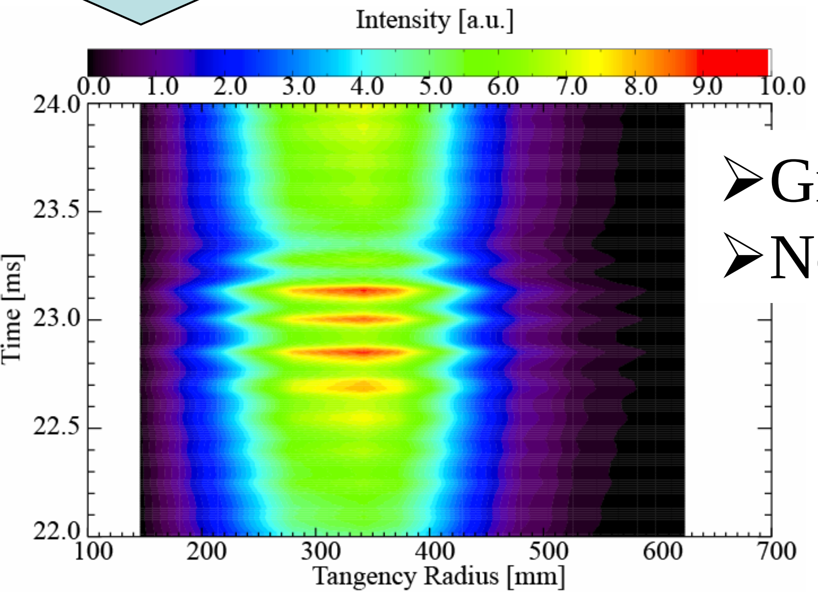


•topo: (spatial eigenmode)

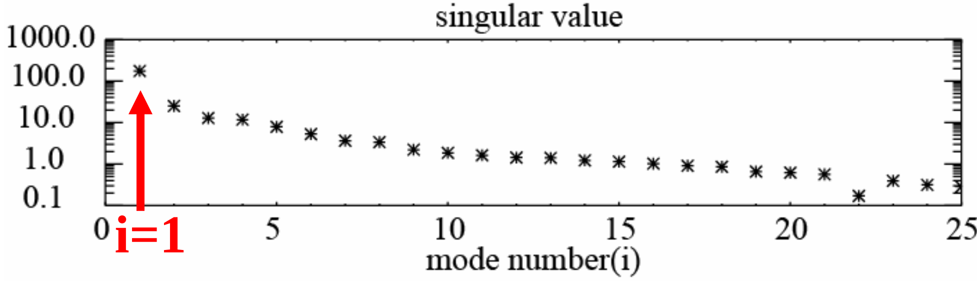




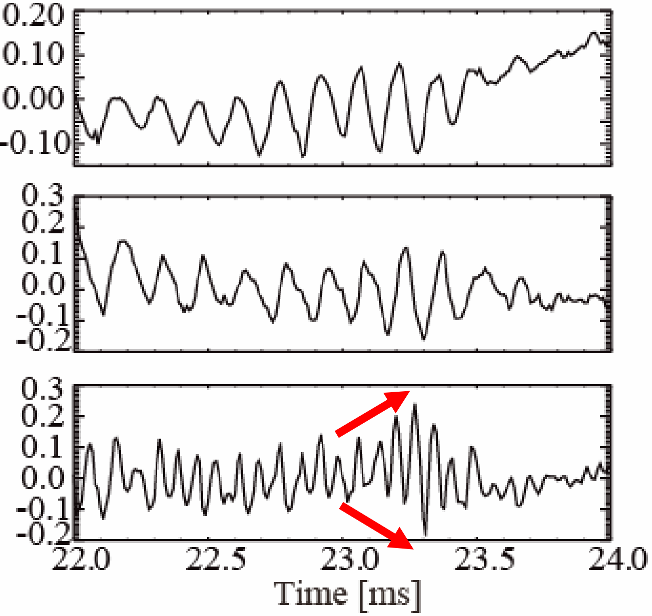
Contour plot of the SX channels

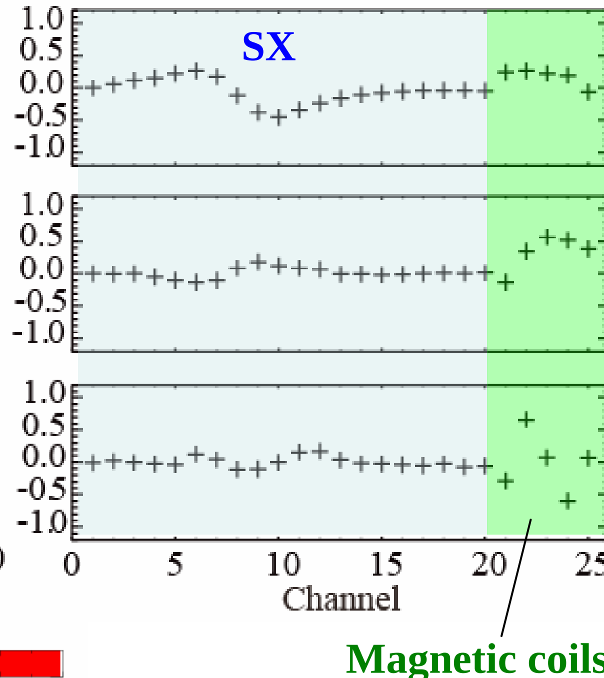


- ➢Growth of even mode
- ➢No component of toroidal mode



Results of SVD analysis with tangential Chords and n-coils

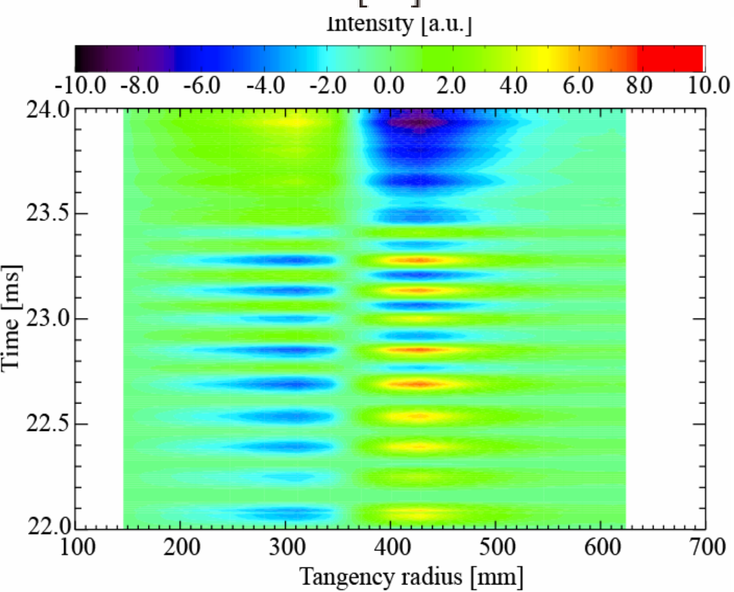




- ●i=2
  - ➢Odd mode (below Fig.)
  - ➢small effect by toroidal mode
- ●i=4
  - ➢n=1
  - ➢Small effect to SX signal
- ●i=7
  - ➢n=2
  - (frequncy in chrono ～20kHz)
  - ➢Growth of chrono

➢i=2 indicates existence of poloidal (Odd) mode.

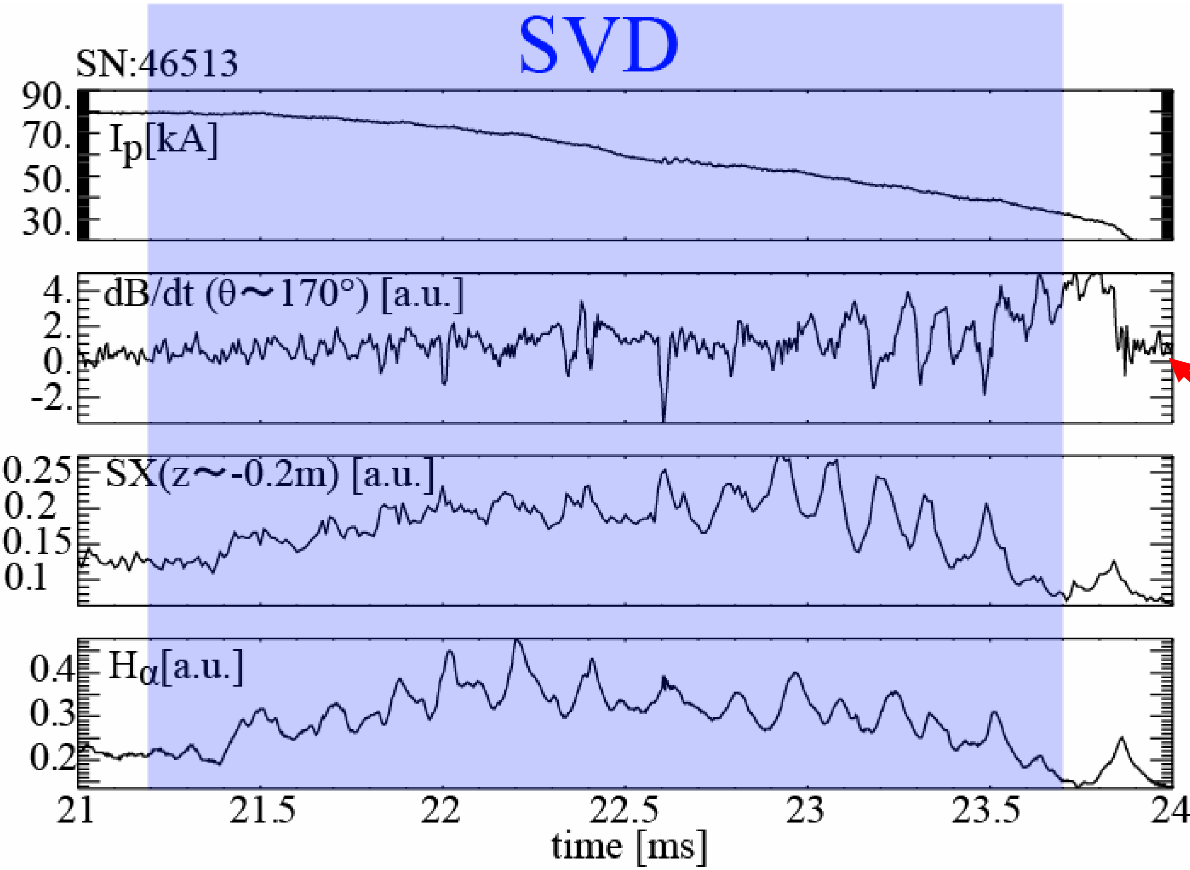
➢n=2 component is mixed with n=1 in SX and magnetic coils

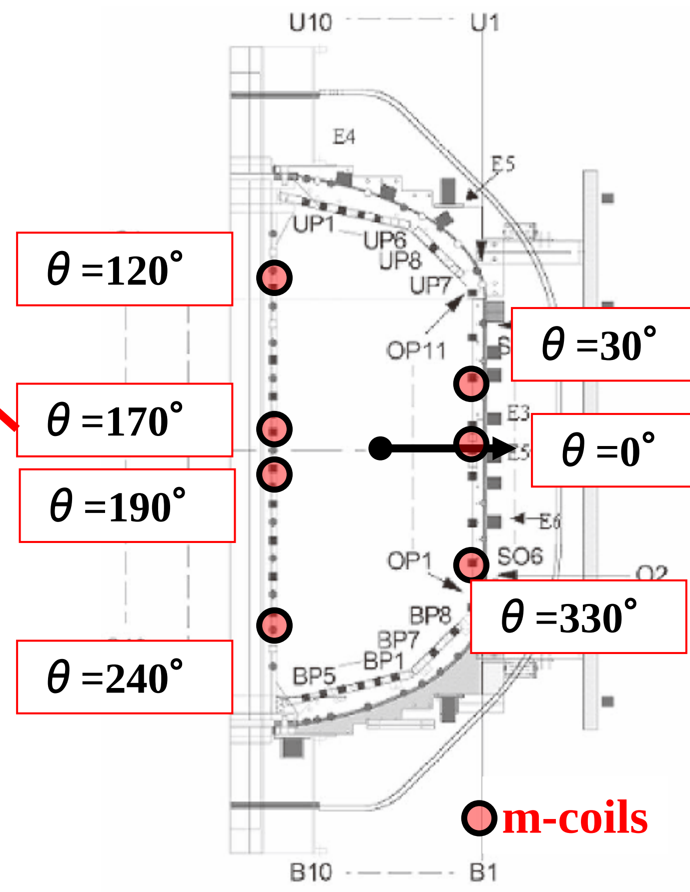


●Contour plot of only SX channels (i=2)

➢Growth of odd-mode is observed.

SVD analysis with horizontal chords and m-coils

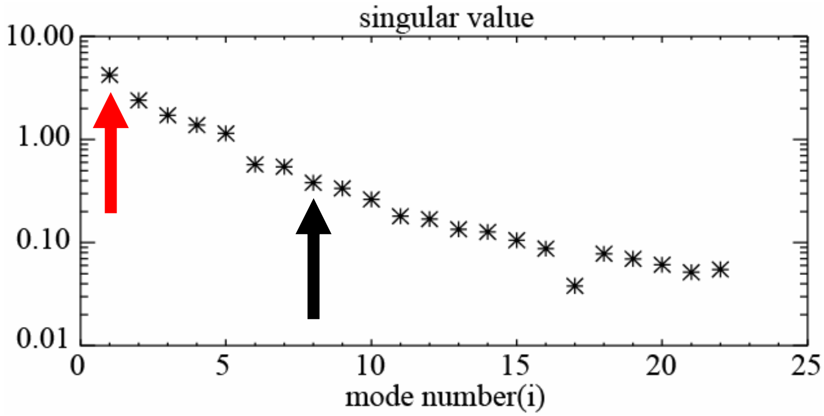




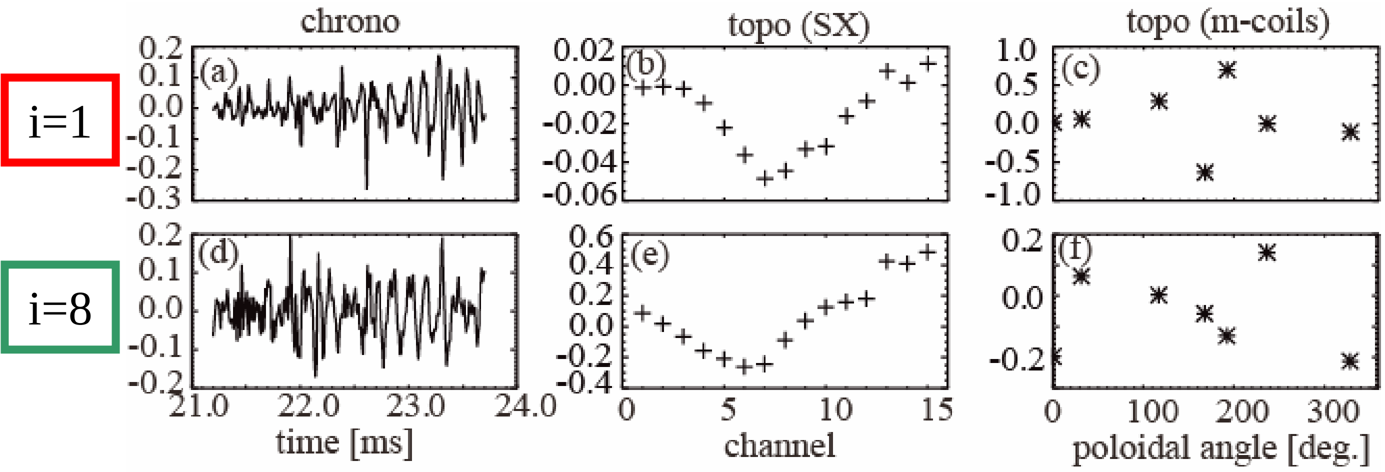
●Configuration of magnetic coils (m-coils)

- ➢Using the P.P. filter for SX
- ➢taking fluctuation components by using frequency filter (5-40kHz)

SVD analysis with horizontal chords and m-coils

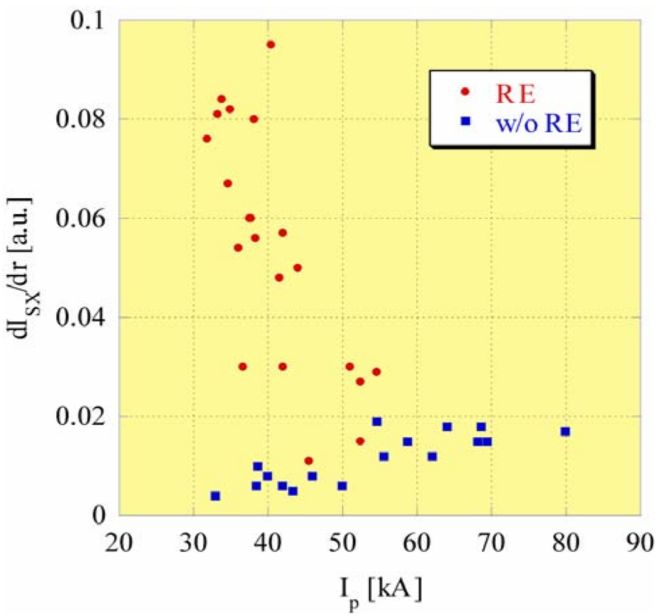


- Growth of SX mode were observed
- Signal of m-coils strongly depend on the position of plasma (It's difficult to determine poloidal mode number)



- growth against time (chrono wave form)
- SX profile-even mode
- w/o growth
- SX profile-odd-mode

Correlation between SX gradient and ΔI_p

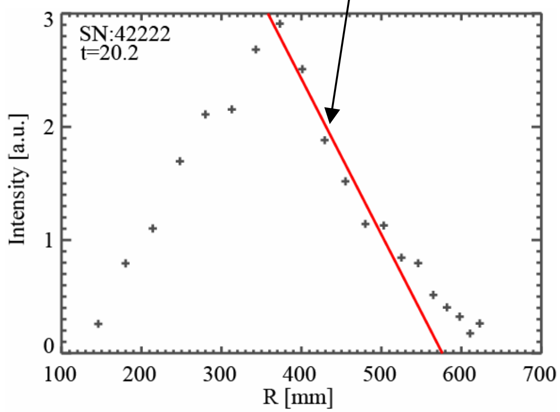


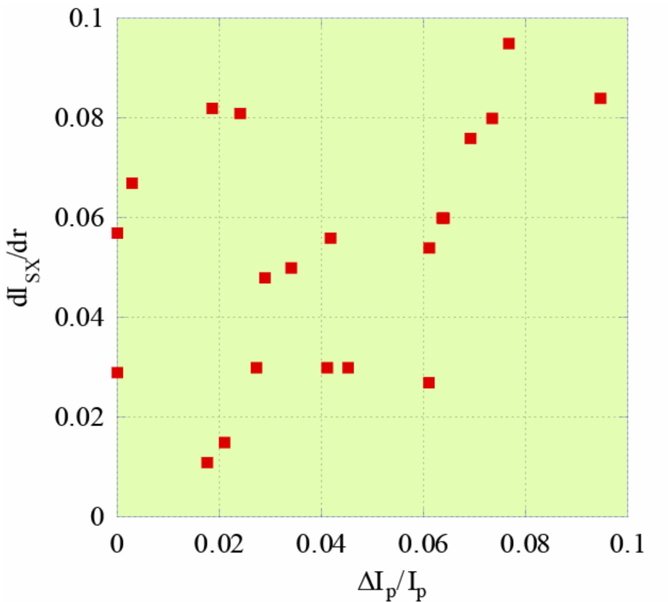
● Correlation between dI_{SX}/dr and I_p

(I_{SX}: SX intensity)

dI_{SX}/dr is determined by linear fitting

Steep profile have important role for RE ($dI_{SX}/dr>0.02$)





● dI_{SX}/dr and $\Delta Ip/Ip$

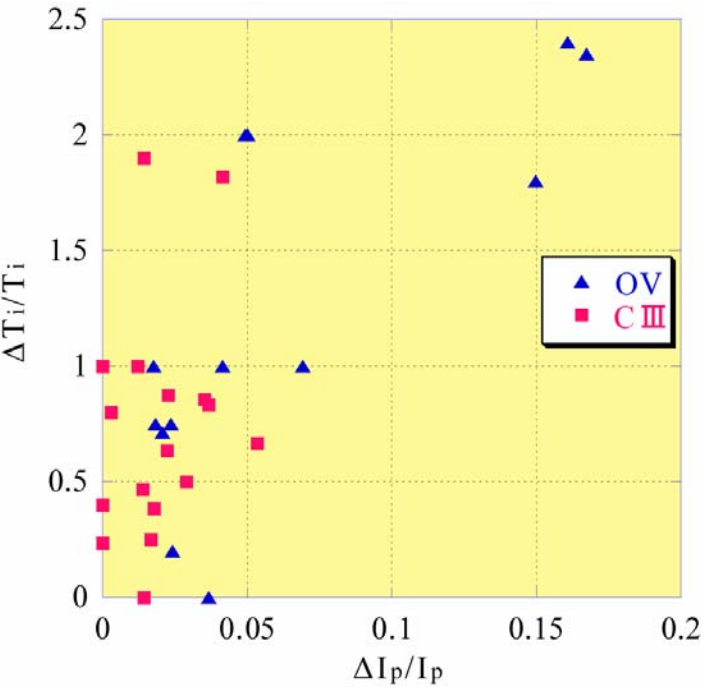
➢ positively correlated

Steeper profile enlarge scale ($\Delta Ip/Ip$) of RE

Ion temperature increase during the events

The resulting ion heating during the event

support release of magnetic energy



- Correlation between T_i (CⅢ and OV) and I_p
  - positively correlated
  - $\Delta T_i/T_i \sim 2.4$ at the maximum (OV)
  - w/o RE, $T_i \sim$40eV(OV) , 20eV(CⅢ)
  - The ion heating are also observed in other STs (MAST [1] TST-2 [2] HIT-Ⅱ[3])

[1] P. Helander et al., Phys. Rev. Lett 89, 235002 (2002).
[2] A. Ejiri, et al., Nuclear Fusion 43, 547 (2003).
[3] R. G. O'Neill Physics of Plasmas 12, 122506 (2005)

Summary

- Tangential and horizontal SX cameras
  - Curved filter has a flat sensitivity, while with a flat filter the difference of the detected power for the curved is up to a factor of two larger for edge channels.
- Slow behavior of SX profile shows position of crash was $\rho \sim 0.2$
- The results of SVD analysis is following
  - Using both SX and magnetic coils are effective to understand the correlation between toroidal mode and SX profile.
  - Growth of n=1 and n=2 were observed. (consistent with the MHD simulation)
  - m was difficult to determine because of effect of the plasma position.
  - Horizontal SX camera showed growth of even-mode.
- Steep profile ($dI_{SX}/dr > \sim 0.2$) is necessary for RE and can be a candidate of driving force of the instability.
- Ion temperature increase ($\Delta T_i/T_i \sim 2.4$ at the maximum (OV)) and its ΔT_i is positively correlated with ΔI_p (magnetic energy)