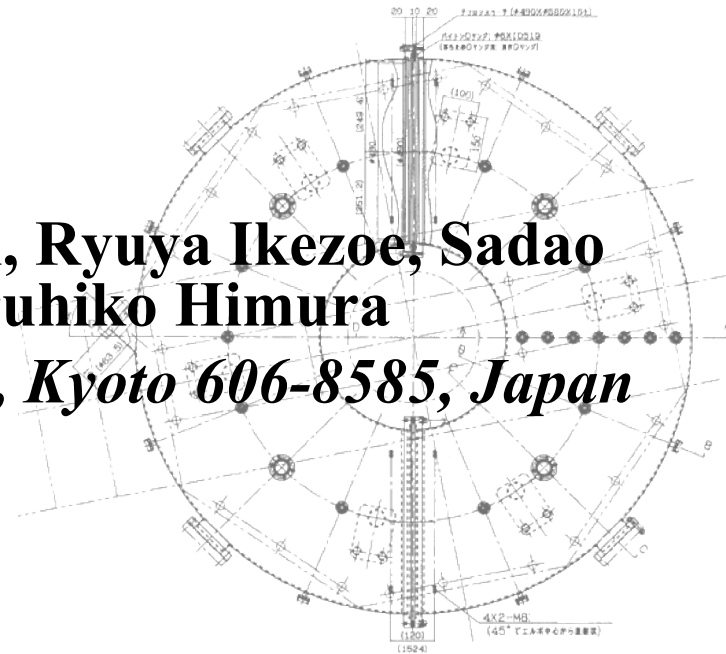


Development of a soft-X ray imaging system for MHD studies in an RFP plasma

**Akio Sanpei, Takumi Onchi, Ryuya Ikezoe, Sadao
Masamune and Haruhiko Himura**
Kyoto Institute of Technology, Kyoto 606-8585, Japan





Abstract

The measurement of bremsstrahlung soft-x ray (SXR) radiation is a very useful means for diagnosing high-temperature plasmas without material insertion.

In the reversed field pinch (RFP), studies on the behavior of magnetic islands due to the tearing modes are quite important in understanding confinement.

Since the safety factor $q \ll 1$ in the RFP, toroidal pitch of the equilibrium field is relatively short, and therefore, the SXR diagnostic system which can provide 3D magnetic structures with relatively simple components is desirable.

We are developing a SXR imaging system in which a pinhole camera provides a high-resolution two-dimensional (2D) luminosity distribution on a phosphor plate through a microchannel plate (MCP).

The experiment for the principle verification was executed on STE-2, which has aspect ratio of 4, and we have gotten the SXR images.



Outline

**Characteristics of Reversed Field Pinch (RFP)
plasmas**

Motivations

Experimental arrangement

Sample data of experimental result for $A=4$ RFP

Design for application to Low-Aspect Ratio RFP

Reversed Field Pinch (RFP)

$$B_{\text{toroidal}} \approx B_{\text{poloidal}}$$

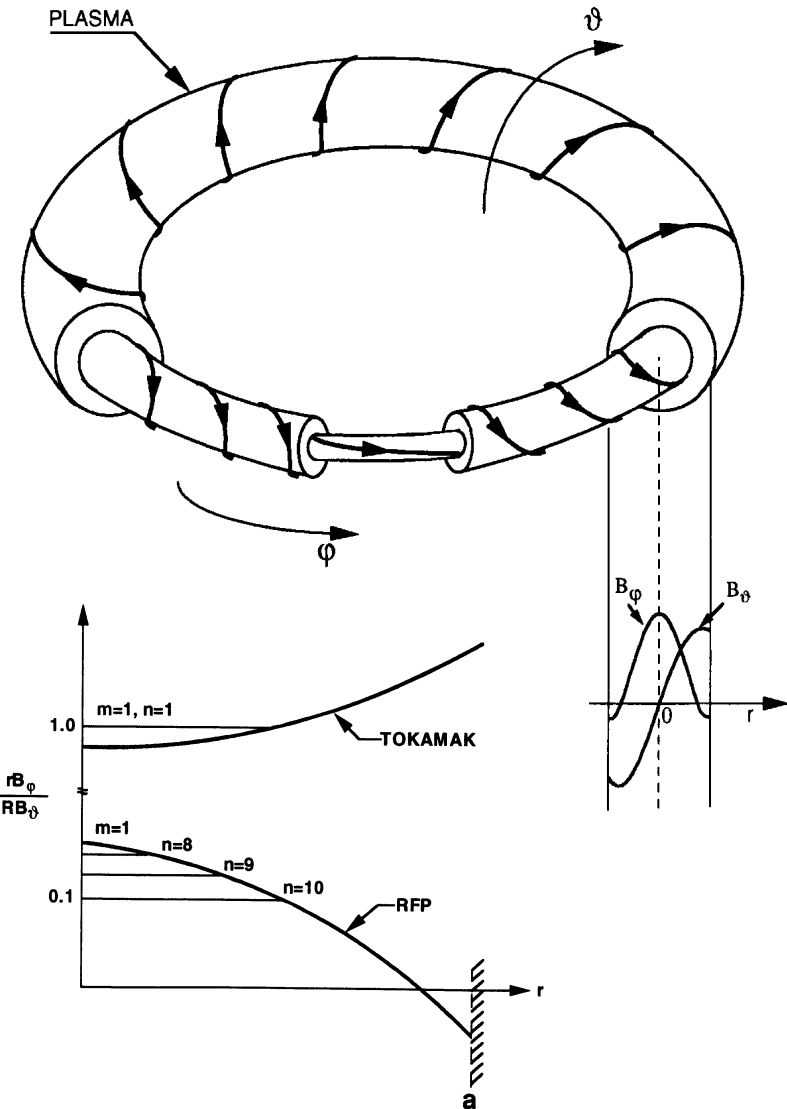
$$q \ll 1$$

Peaked current profile

→tearing unstable

Dense mode rational surfaces

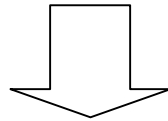
→ mode coupling





Motivations

Since the safety factor $q \ll 1$ in the RFP, toroidal pitch of the equilibrium field is relatively short, and therefore, the SXR diagnostic system which can provide 3D magnetic structures with relatively simple components is desirable.



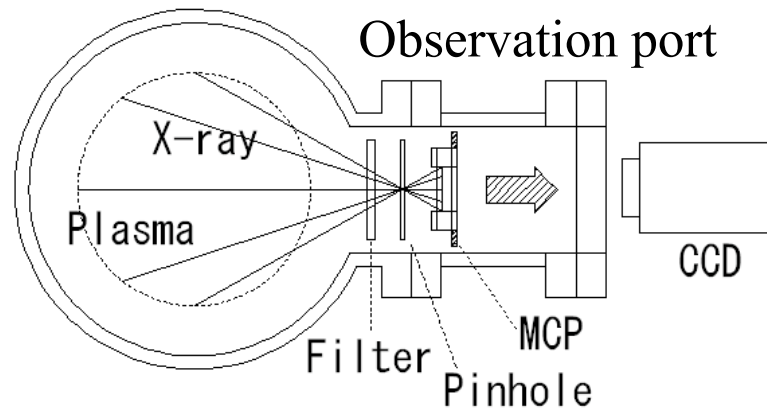
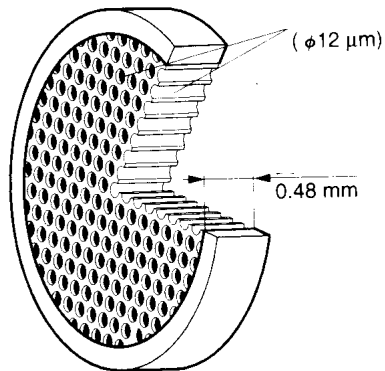
We are developing the SXR imaging system consist of the pinhole, MCP, phosphor plate and ICCD camera.

Nondestructive, noncontact method for measurement

High spatial resolution

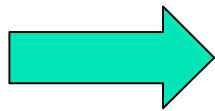
Lower number of Channels for measurement

Design of a detector

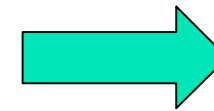


MCP: microchannel plate
(Hamamatsu Photonics F2222-21P)

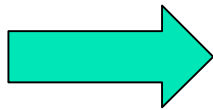
plasma
SXR radiation



Microchannel plate(MCP)
SXR is amplified, and
converted to electron

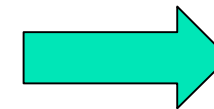


Phosphor screen



Electron is convert to visible light
(530~560[nm])

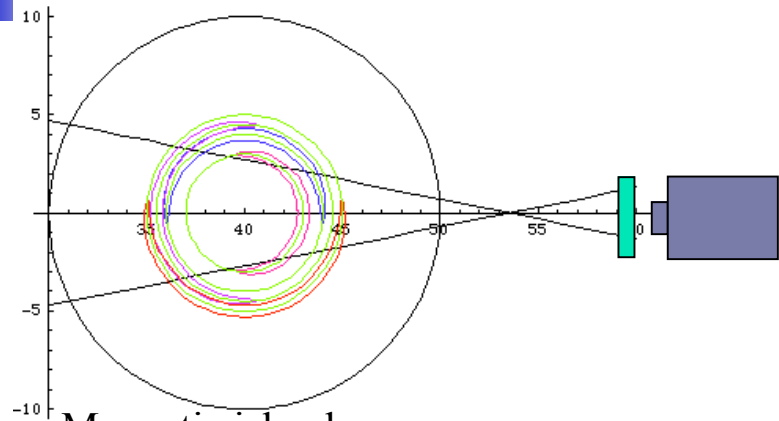
CCD camera



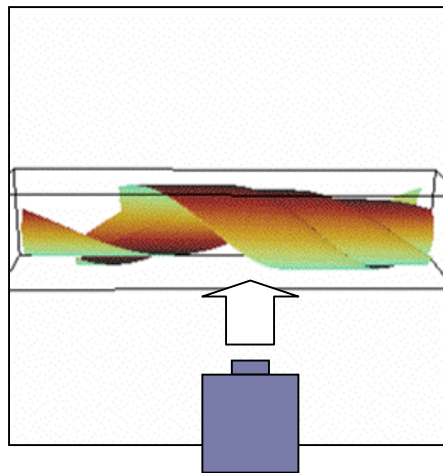
PC

2D luminosity distribution

Basic model

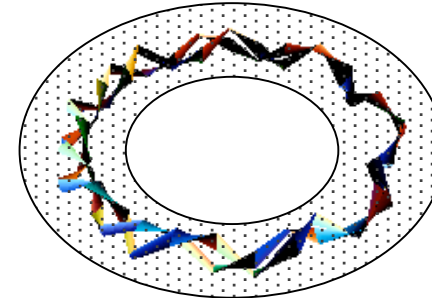


Magnetic islands
in poloidal cross section



3D magnetic structure

Since the safety factor $q \ll 1$ in the RFP, toroidal pitch of the equilibrium field is relatively short!



The line integrated temperature and density distribution along lines of sights are measured in terms of the 2D luminosity distribution on the phosphor screen.

2D SXR image may reflect the magnetic surface structure.

The experiment for the principle verification was executed on STE-2, which has aspect ratio of 4.

STE-2 (Separatrix Test Experiment-2)

Vacuum Vessel

Material : SS (2mm t)

Major radius R : 0.4 m

Minor radius a : 0.1 m

Field Penetration Time : 0.15 ms

Number of poloidal gaps : 2

Toroidal Field Circuit

Number of TF coils : 24 (6 turns/coil)

Field intensity < 0.1 T

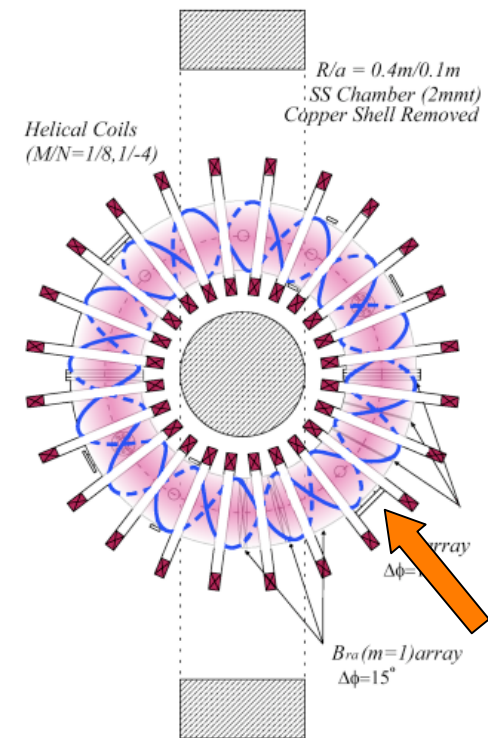
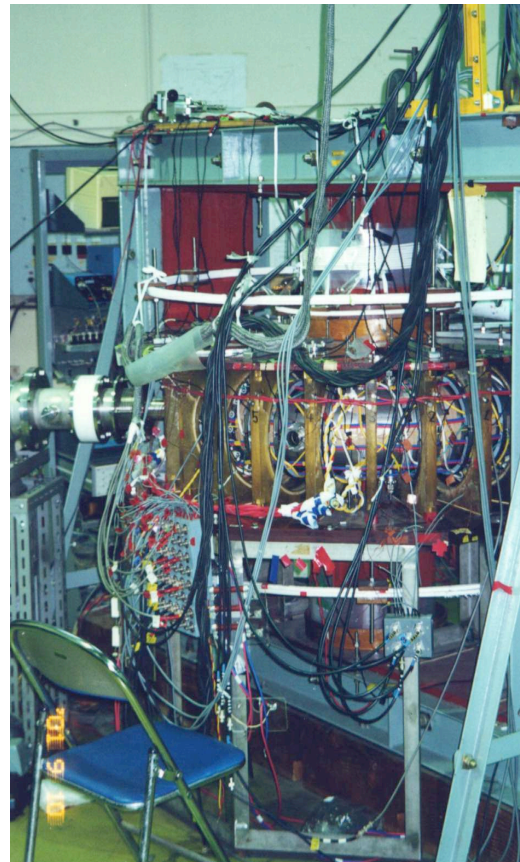
Mode Analysis

24 m=1 flux loops for B_r

Helical Winding for Rotating Field

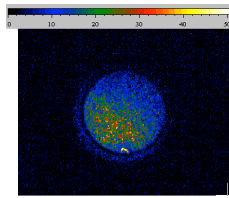
M/N=1/8 (core resonant)

$$A=4$$

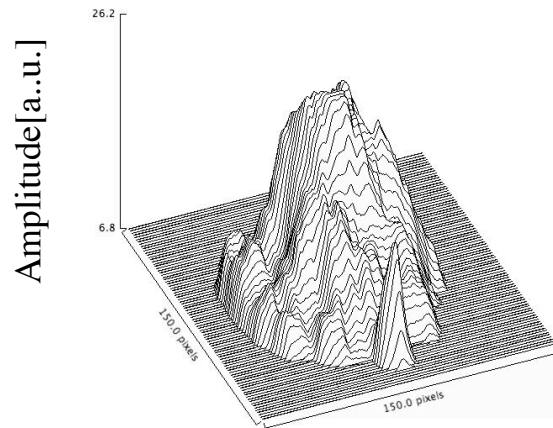


Sample Data

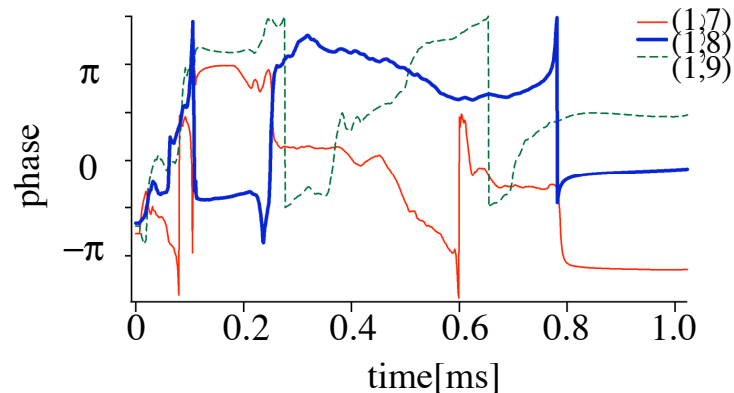
The experiment for the principle verification was executed on STE-2, which has aspect ratio of 4, and we have gotten the SXR images.



Raw Image



Surface Plot

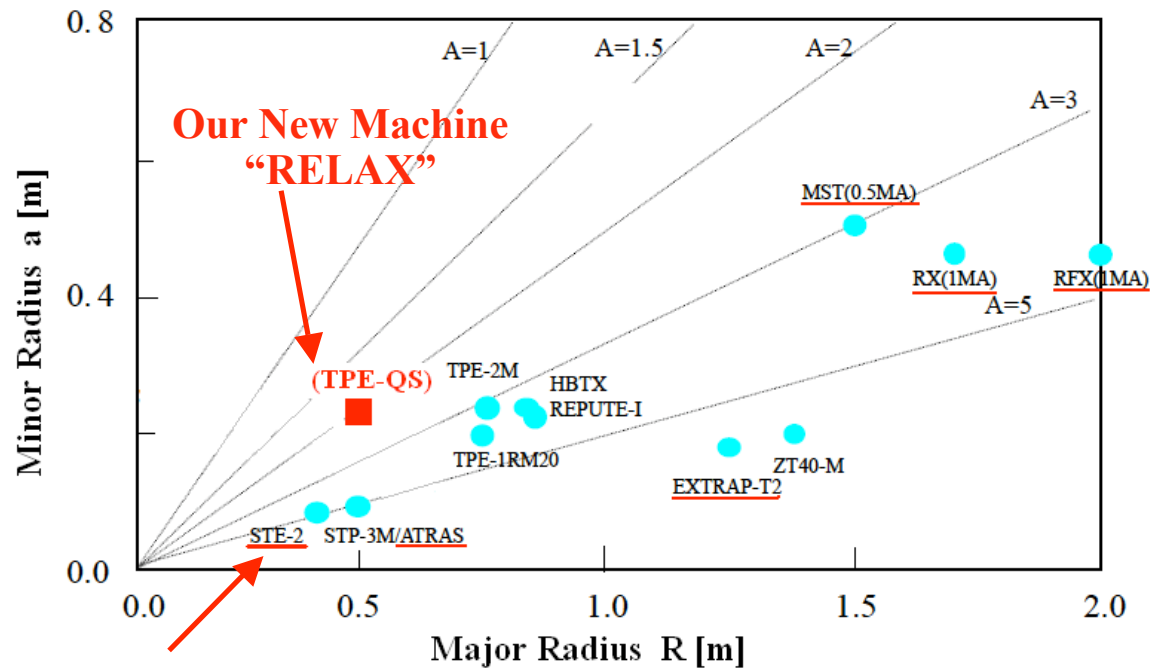


The dominant mode number of the $m=1$ mode is $n=8$, which is locked to wall.

Since the phosphor screen has long persistence, mode locking to wall causes stronger intensity.

Projection structure on SXR image is obtained, which may be corresponding with tearing mode measured from the outside of the vacuum vessel.

Application to Low-Aspect ratio RFP



We have constructed a low-A RFP device, called "RELAX" (REversed field pinch of Low Aspect ratio eXperiment), using a vacuum vessel with aspect ratio of 2 ($R/a = 0.51\text{m} / 0.25\text{m}$), with circular cross section, and are starting RFP experiment.

RELAX

(REversed field pinch Low Aspect ratio eXperiment)

Vacuum Vessel

Material : SS (4mm t)

Major radius R : 0.51 m

Minor radius a : 0.25 m

Number of poloidal gaps : 2

Toroidal Field Circuit

Number of TF coils : 16 (4 turns/coil)

Field intensity < 0.1 T

OH Circuit

OH coils : 16 turns

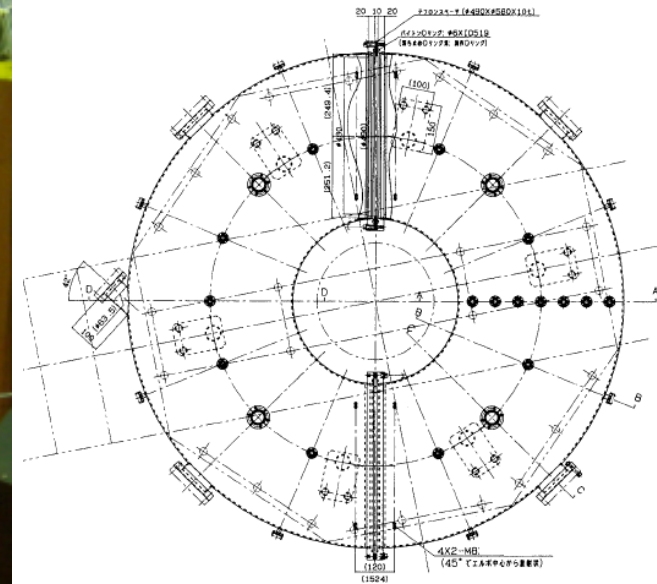
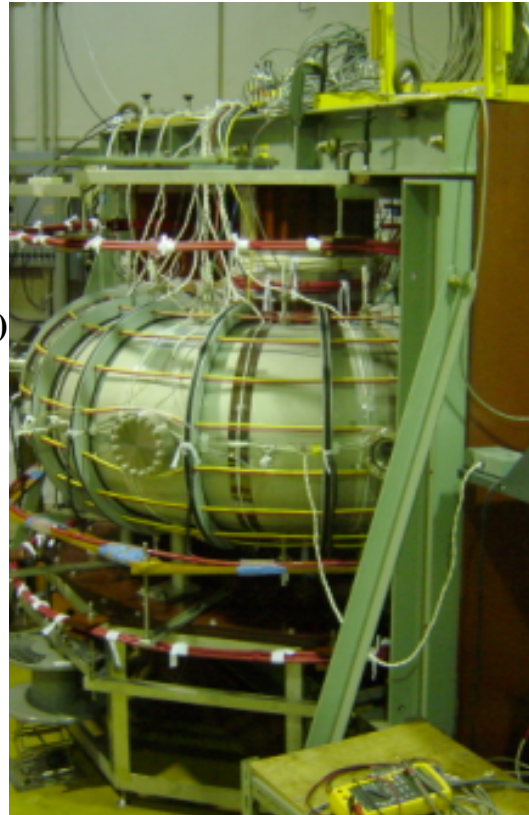
Mode Analysis

16 m=1 flux loops for B_r

16 m=0 flux loop

(and magnetic probes)

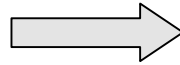
$$A=2$$



Top view

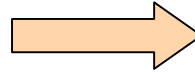
Q-profile

A=4 STE-2 : MH (Multi Helicity)

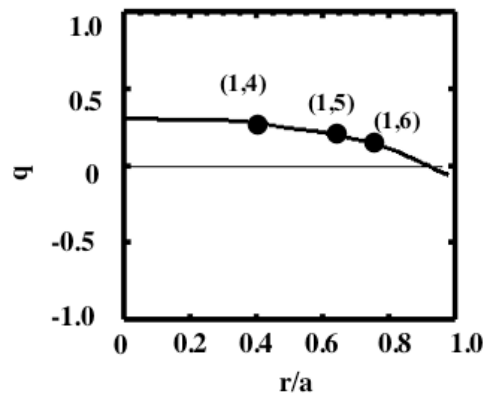


Complex structure of magnetic surface

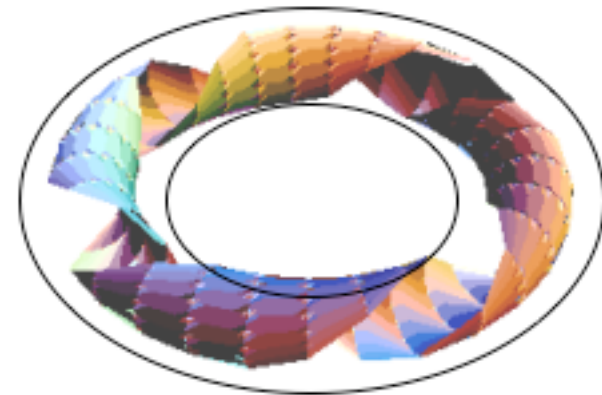
A=2 Low-Aspect ratio RFP : QSH



**Relatively simple structure
⇔ Simple distribution of SXR**



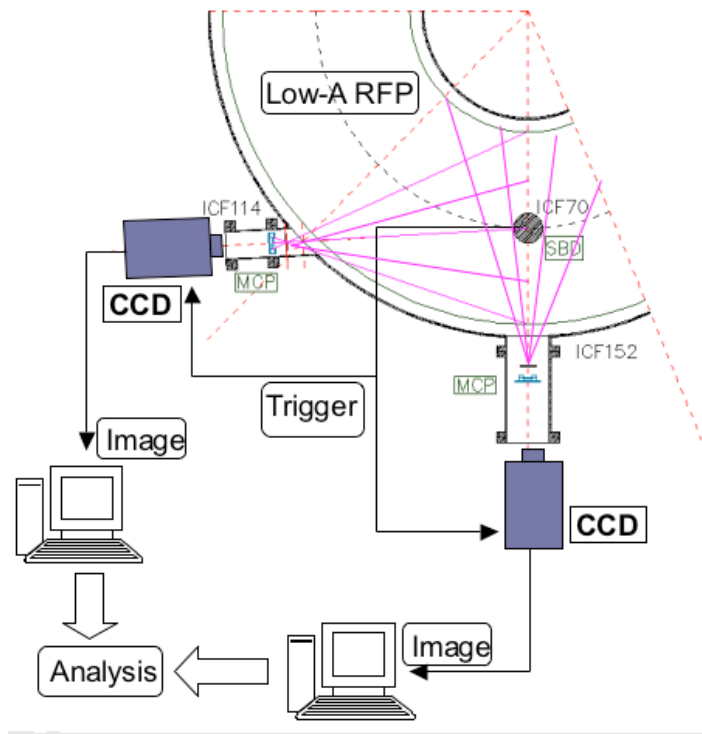
Safety factor for Low-Aspect ratio RFP



QSH (m=1/n=4)

When the aspect ratio of the machine is lowered, the equilibrium analysis shows that the q-profile tends to become flat in the core region and steeper in the edge region. Simpler MHD mode dynamics with less densely spaced mode rational surfaces expected, which may allow us to expect easier access to the QSH RFP state, in which a large magnetic island is immersed in an otherwise stochastic field.

2way measurement system



The sensitivity of the SXR images to the change in aspect ratio from 4 to 2 is of our major interest with a view to installing the system in our low-aspect ratio RFP experiment.

In RELAX, 2-way measurement system are being constructed.

3D structure of magnetic islands are reconstructed from resulting data of this 2-way imaging system making use of inversion algorithm such as CT.



Summary

- **We are developing a SXR imaging system, for MHD studies in an RFP plasma, in which a pinhole camera provides a high-resolution two-dimensional (2D) luminosity distribution on a phosphor plate through a microchannel plate (MCP).**
- **The experiment for the principle verification was executed on STE-2, which has aspect ratio of 4, and we have gotten the SXR images.**
- **2-way imaging system have been designed and is being constructed in order to study the 3D structure of magnetic surface and magnetic islands in Low-Aspect RFP machine RELAX.**