(Partial) summary of ISTW-2011

J. Menard

October 17, 2011

The Joint Meeting of:

5th IAEA Technical Meeting on Spherical Tori

16th International Workshop on Spherical Torus (ISTW2011)

2011 US-Japan Workshop on ST Plasma

September 27-30, 2011

National Institute for Fusion Science, Toki, Japan

U.S. ST research well represented at ISTW2011

Sep. 27 (Tue.)	Sep. 28 (Wed.)	Sep. 29 (Thu.)	Sep. 30 (Fri.)
9:00 Opening Chair: Nagayama 3 speeches	Session 28-1 Chair: Peng	Session 29-1 Chair: Lloyd	Session 30-1 Chair: M.Ono
9:30 Group Photo	9:00 YOno 28-1-1i	9:00 Menard 29-1-1i	9:00 Peng 30-1-1i
10:00 Registration	9:40 Fonck 28-1-2i	9:40 Yamada 29-1-2	9:40 Majeski 30-1-2
		10:05 Maingi 29-1-3	10:05 Gates 30-1-3
	10:20 Coffee Break	10:30 Coffee Break	10:30 Coffee Break
Session 27-1 Chair: Takase	Session 28-2 Chair:Tan	Session 29-2 Chair: Yamazaki	Session 30-2 Chair: Hanada
	10:50 Nishino 28-2-1	11:00 Tritz 29-2-1	11:00 Nagayama 30-2-1i
11:10 MOno 27-1-1i	11:15 Tanaka 28-2-2	11:25 McClements 29-2-2	11:40 Yamazaki 30-2-2
11:50 Lloyd 27-1-2i	11:40 Wakatsuki 28-2-4	11:50 Nagashima 29-2-3	12:05 Ban 30-2-3
		12:15 Garzotti 29-2-4	
12:30 Lunch	12:05 Lunch	12:40 Lunch	12:30 Lunch
Session 27-2 Chair: Fonck	13:30 Session 28-3P poster 28-3P-1~21	Session 29-3 Chair: Menard	13:30 Session 30-3 Chair: Peng (ST Review Paper Disc) (Summary & Closing)
13:30 Hanada 27-2-1i		13:40 Tan 29-3-1i	
14:10 Idei 27-2-2		14:20 Hasegawa 29-3-2	
14:35 Uchida 27-2-3		14:45 Hwang 29-3-3	
15:00 Watanabe 27-2-4		15:10 Chung 29-3-4	15:00
15:25 Coffee Break	15:45	15:35 Coffee Break	15:00 US-J collaboration discussion Chair: Takase
Session 27-3 Chair: McClements		Session 29-4 Chair: Sato	16:00
15:55 Raman 27-3-1	16:00 Excursion hot spring	16:05 Mutoh 29-4-1	
16:20 Nagata 27-3-2		16:40 Suzuki 29-4-2	
16:45 Victor 27-3-3		17:05 Kobayashi 29-4-3	
17:10		17:30 Dinner	
17:30 Japan ST Committee 20:00	19:00 Banquet	18:30 LHD Tour 20:00 18:00 IEA IA ExCo 20:00	
	21:00	LHD Tour	

Selected highlights

- Transport
  - TS-3, UTST, MAST – merging for heating
- H-mode physics
  - MAST BES data
- MHD
  - MAST disruption mitigation
- Next-steps
  - Japanese ST reactor studies

TS-3 Spherical Torus Merging Device

The first merging ST device since 1985

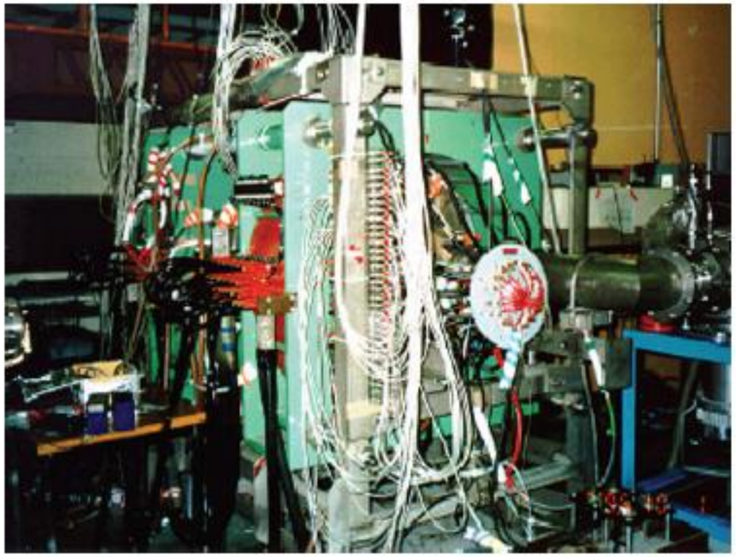
U. Tokyo, Nihon-U, Osaka-U., NAOJ, ISAS

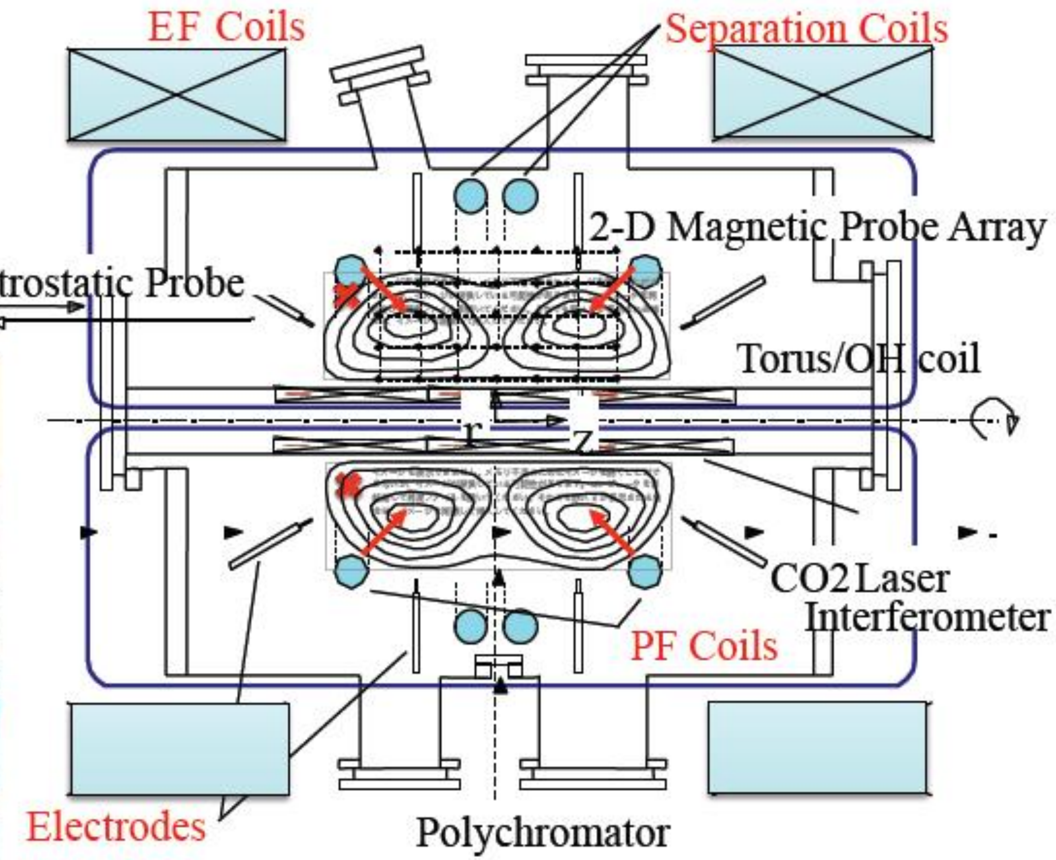
$R=0.15\text{-}0.22\text{m}$, $R/a=1.6$

$B_0\sim.5\text{kG}$, $T_i=10\text{-}100\text{eV}$,

$T_e=10\text{-}30\text{eV}$,

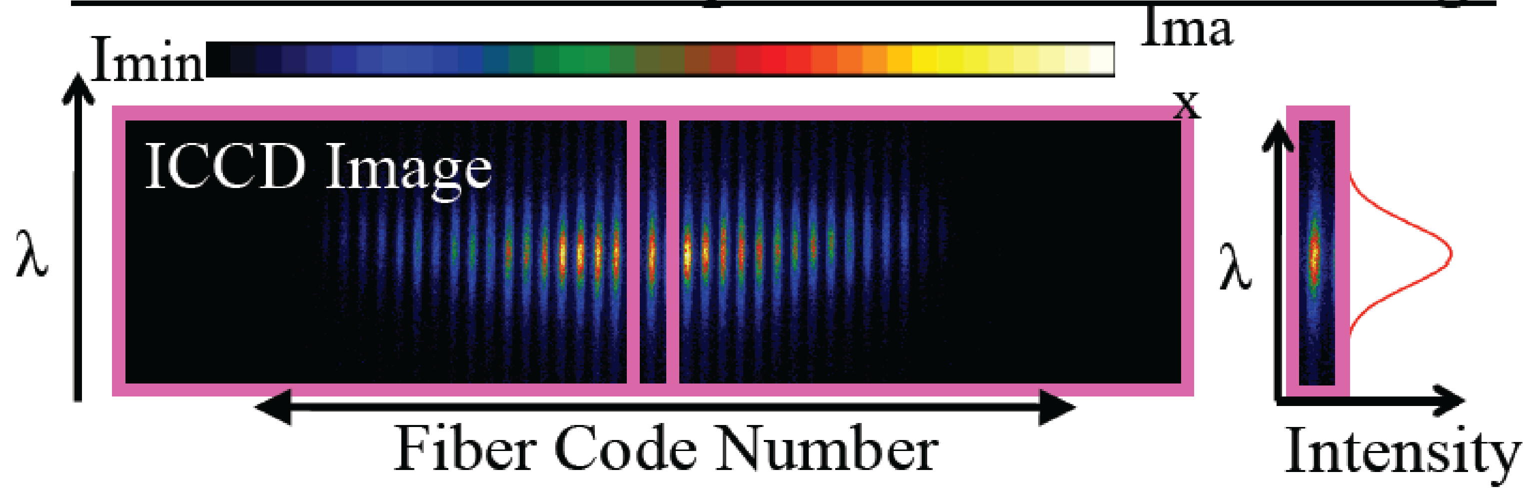
$n_e=0.5\text{-}1.\times10^{20}\text{m}^{-3}$

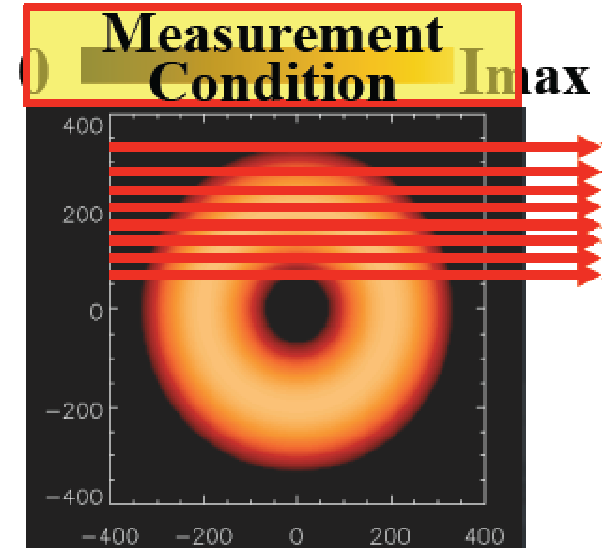




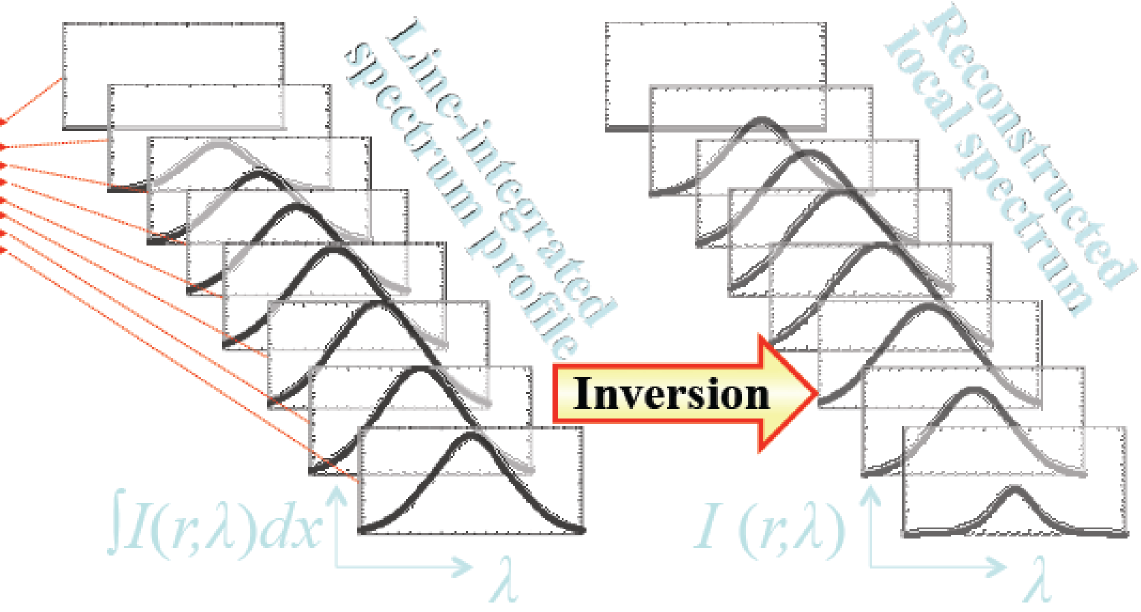
ICCD Image Reconstruction to measure 2-D T_i Profile

1. Extract each code spectrum from ICCD Image





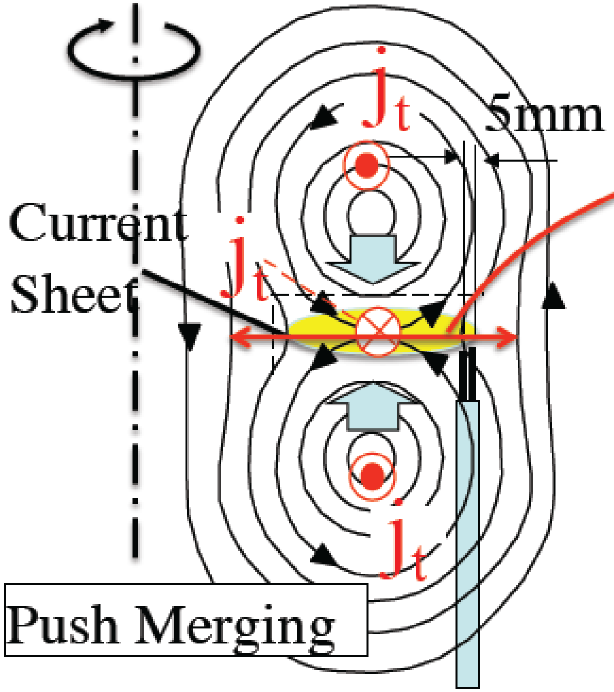
imitated emission profile

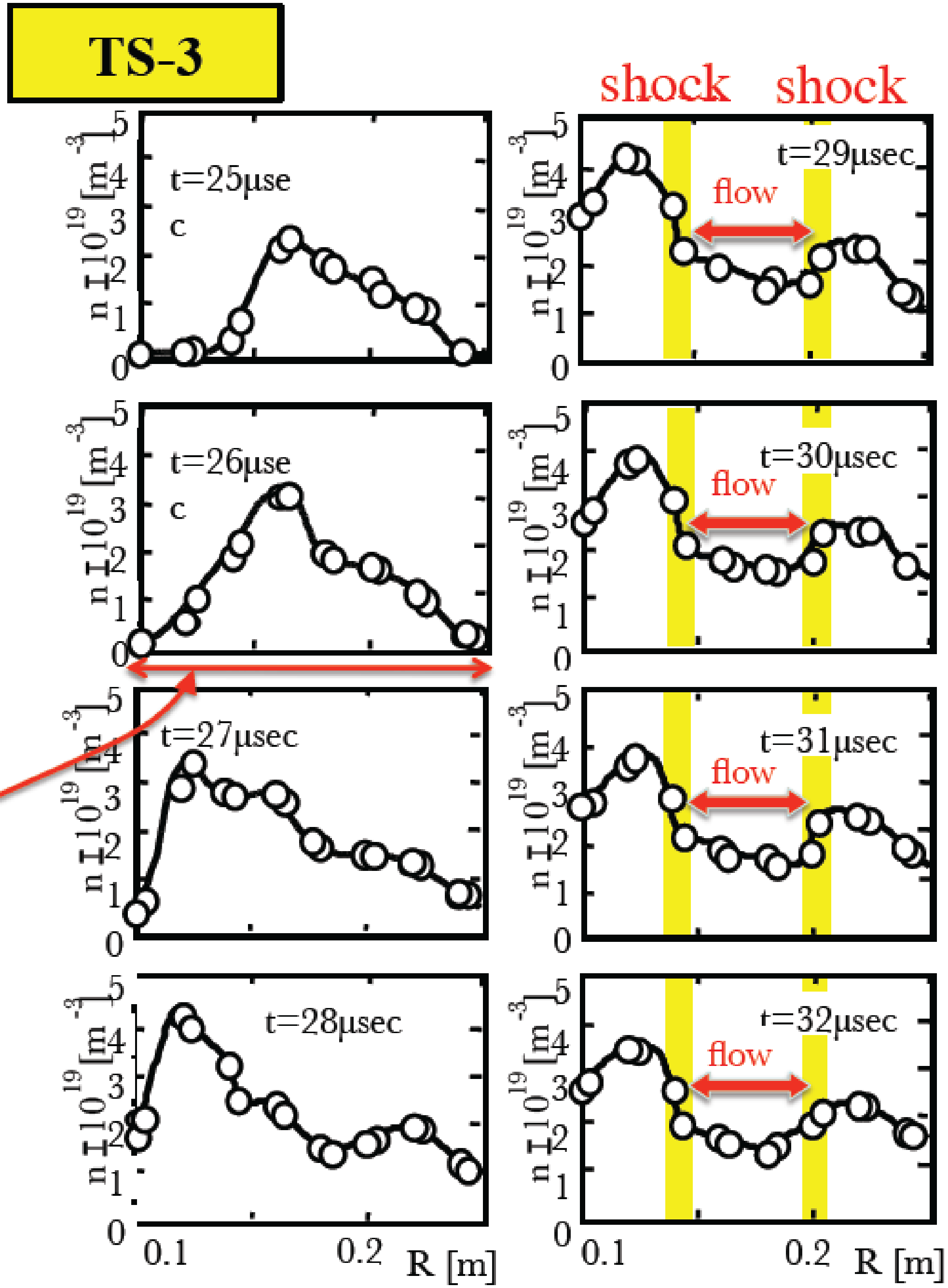


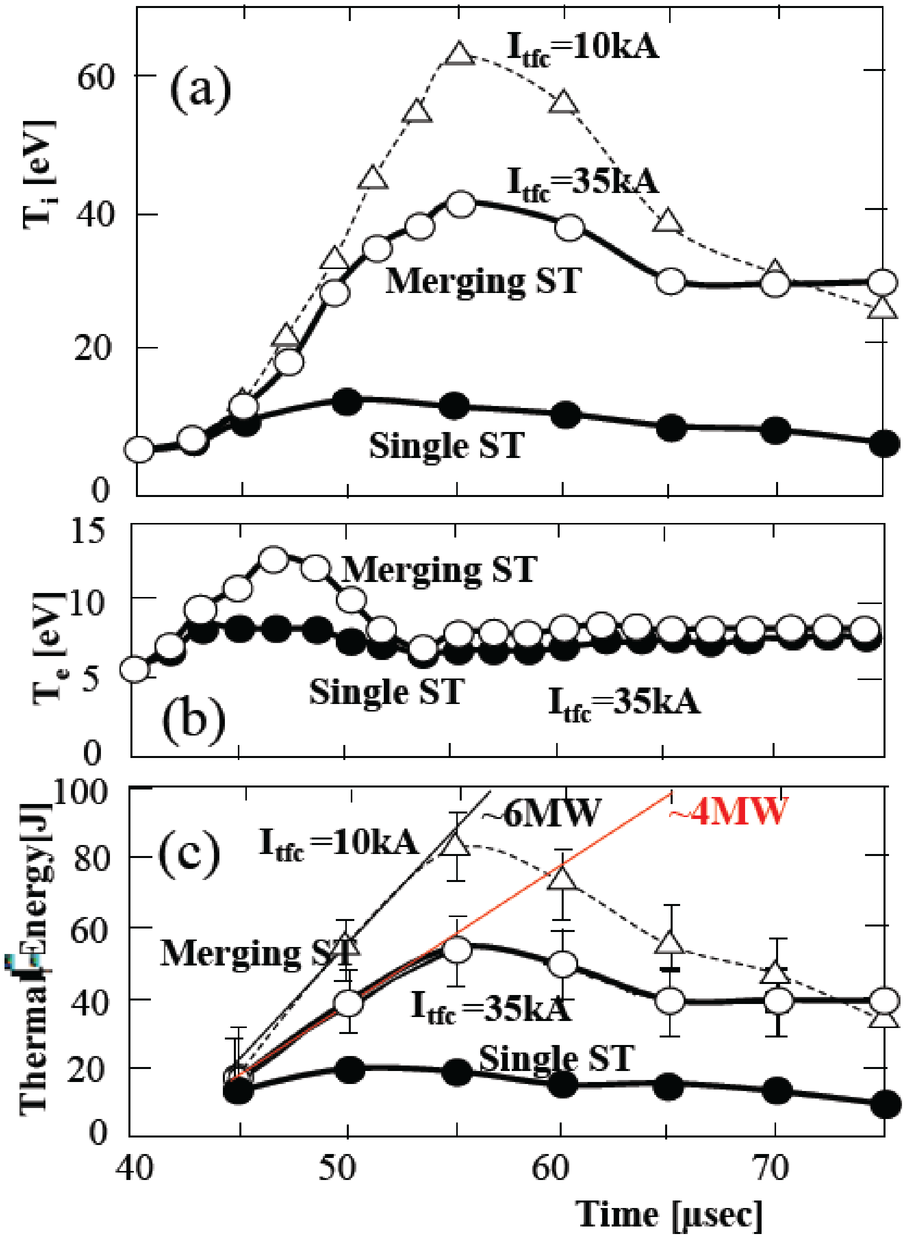
Evidence of Fast Shock

↑

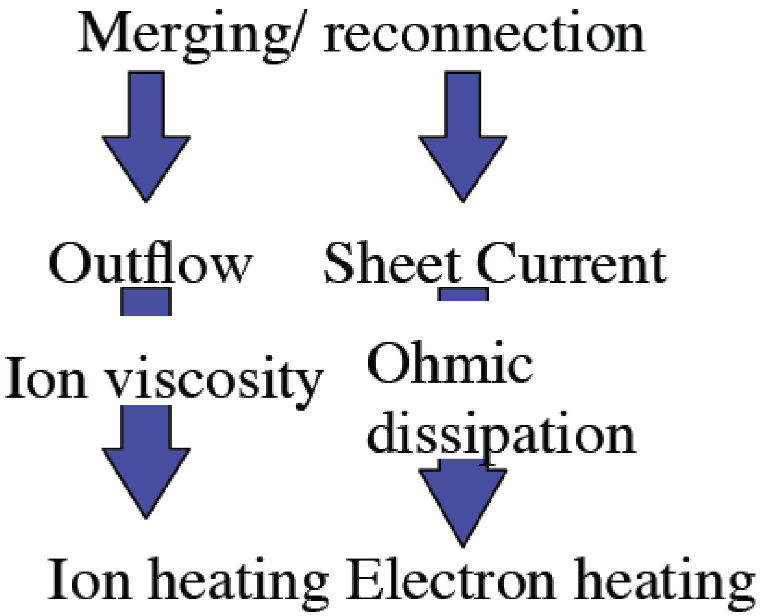
High resolution n_e measurement by pair double probes







Heating power of ST merging is as high as 10MW for half kG STs



Merging/ reconnection

Outflow

Sheet Current

Ion viscosity

Ohmic dissipation

Ion heating

Electron heating

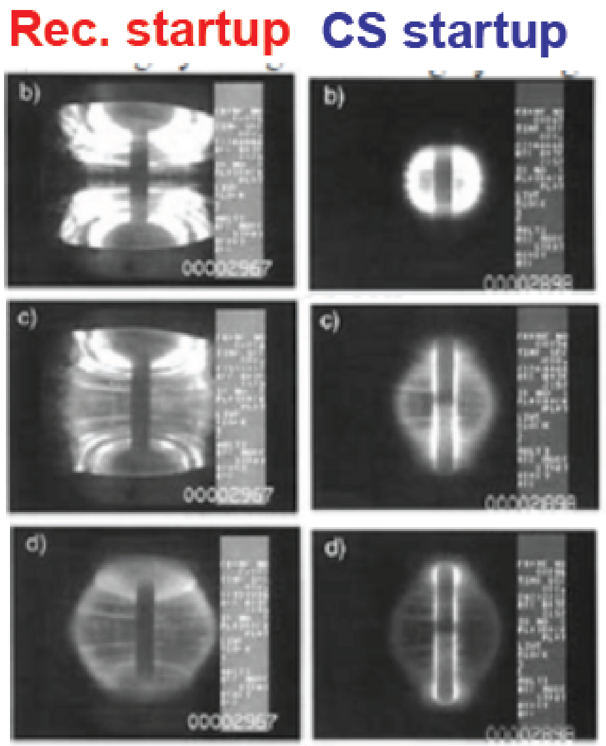
The ion heating power and energy decreases with tB

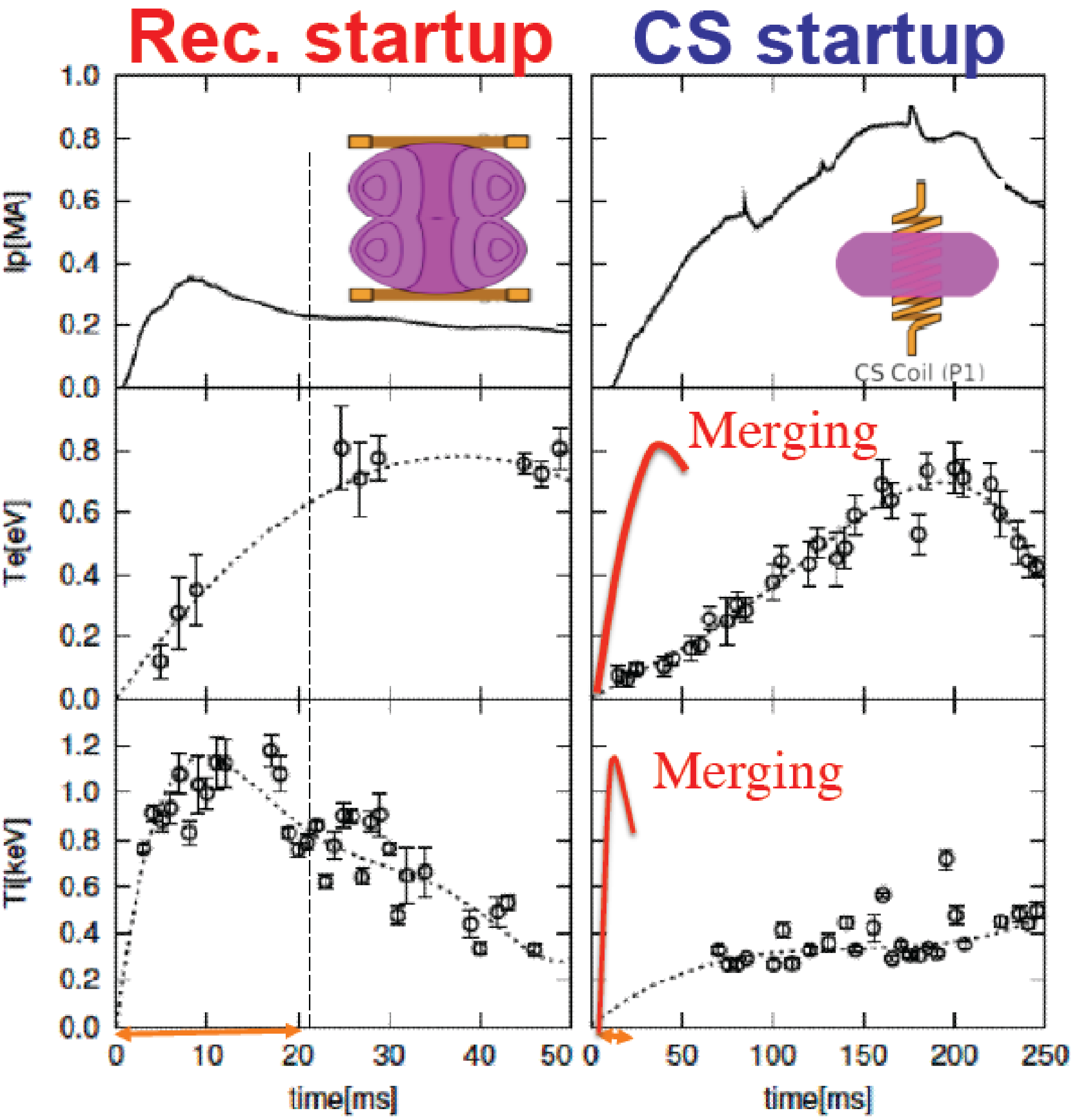
MAST

T. Yamada et al 29-1-1

MAST-TS Collaboration

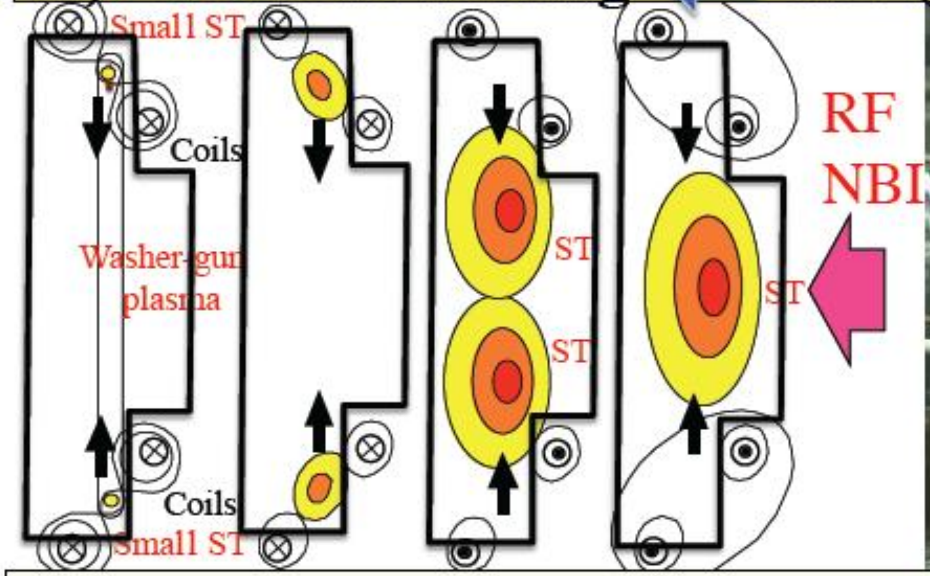
The reconnection start-up heats ions and electrons much faster than the conventional CS startup.


Rec. startup **CS startup**

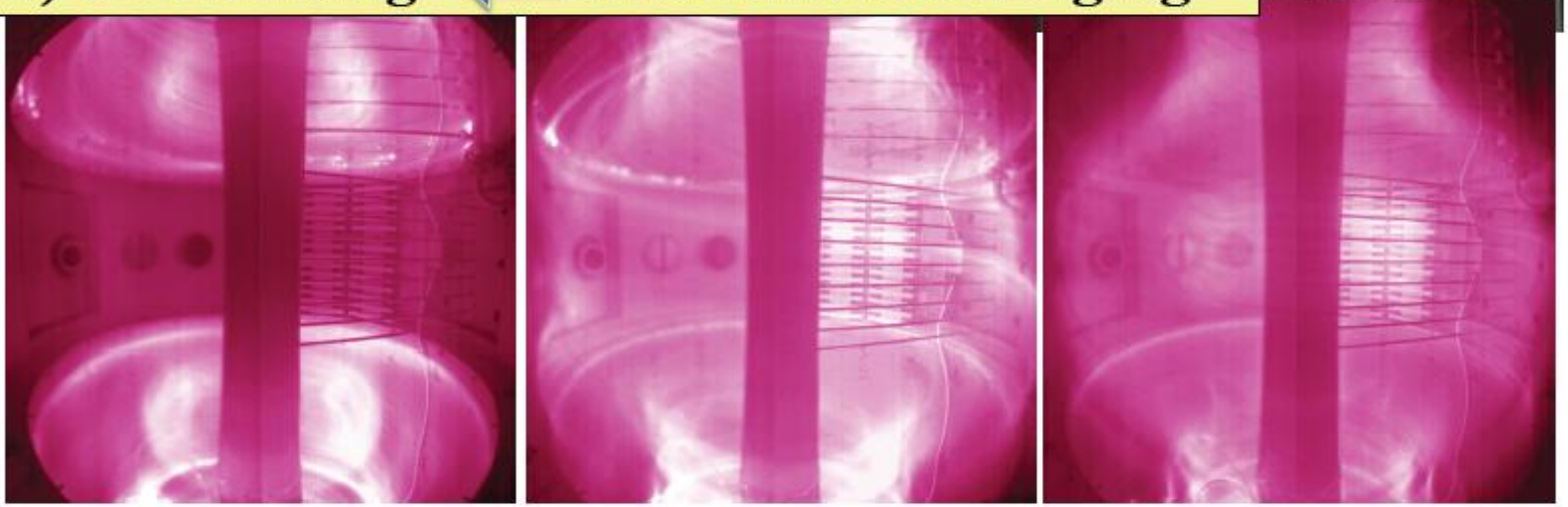

Rec. startup **CS startup**

High-ß ST Sustainment

2) Electron Heating ← NBI(0.7MW, 25kV), HHFW

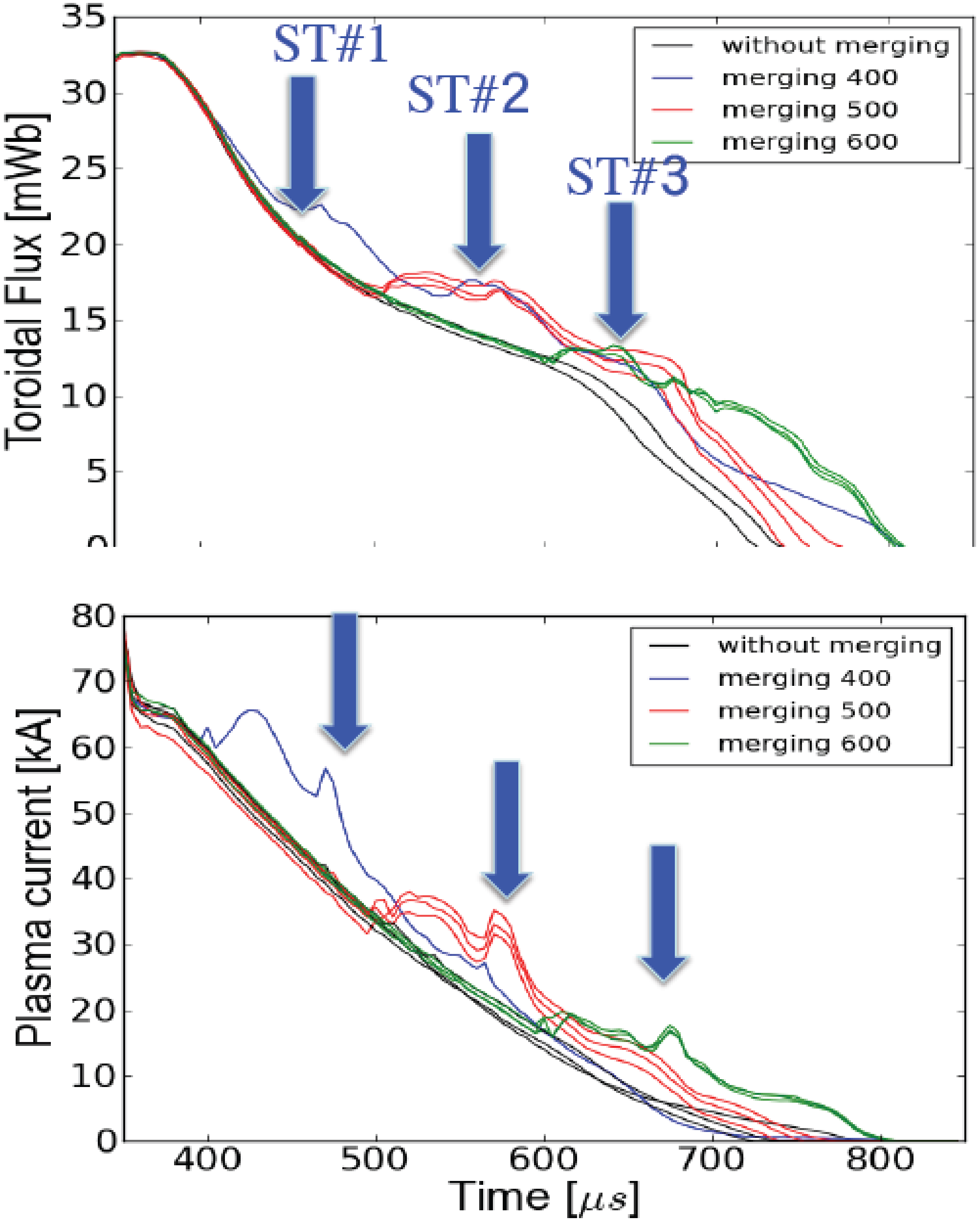


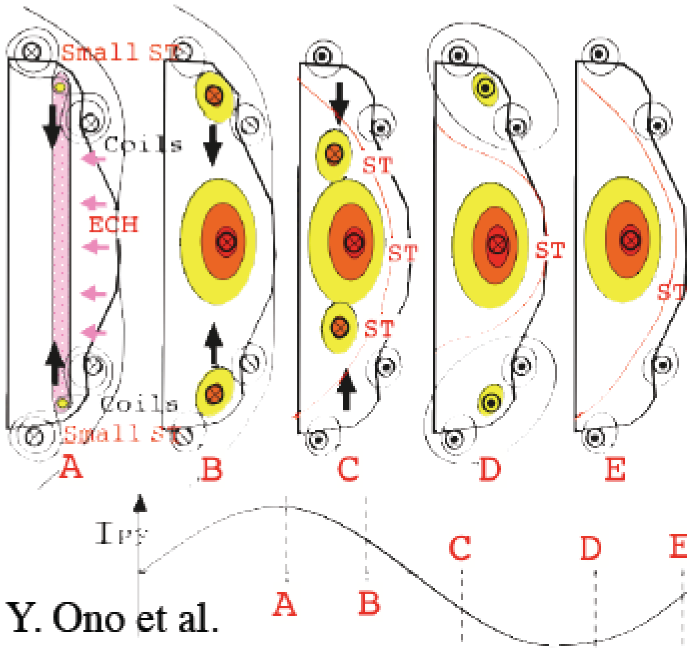
1) Ion Heating ← Intermittent Merging



1) Ion Heating
← Intermittent Merging

The intermittent ST merging increases both of toroidal flux and toroidal current.





Y. Ono et al.
Nuclear Fusion2003

16th ISTW & 5th IAEA Technical Meeting on Spherical Tori, NIFS, Toki, Japan, September 2011

Progress & Developments on MAST

Brian Lloyd for the MAST Team
& Collaborators

EURATOM / CCFE Fusion Association

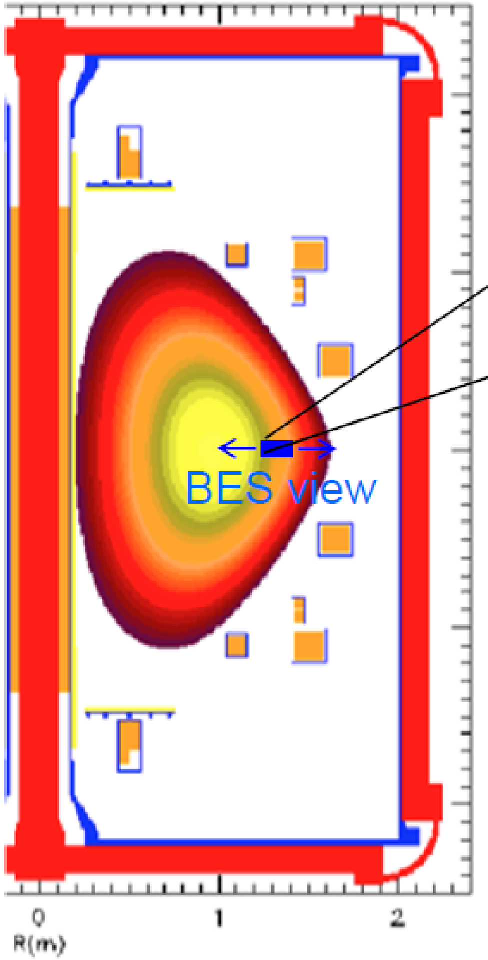
Research Councils UK
Energy
For a Low Carbon Future

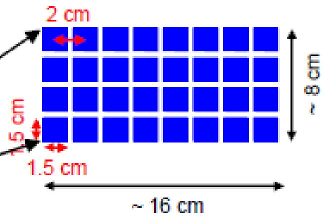
CCFE is the fusion research arm of the United Kingdom Atomic Energy Authority
Jointly funded by EURATOM & RCUK Energy Programme

CCFE
CULHAM CENTRE FOR FUSION ENERGY

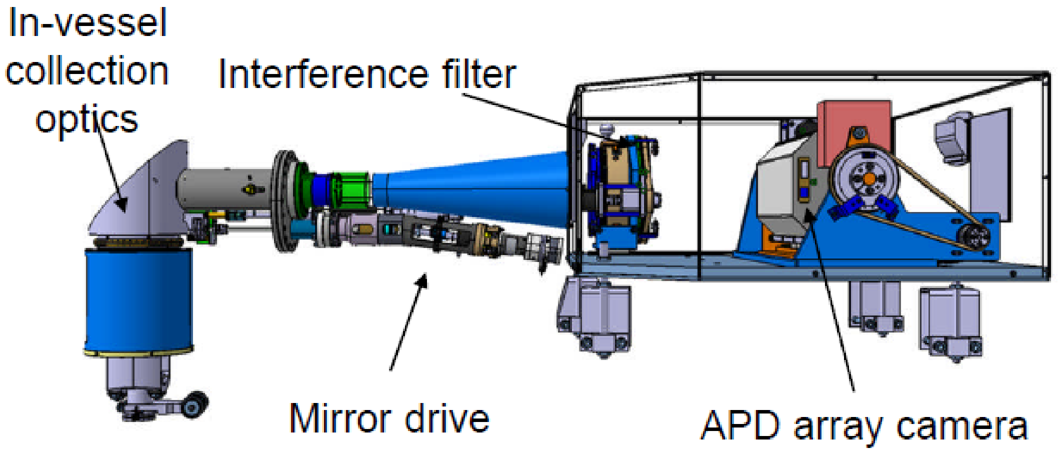
BES turbulence imaging system

- Views Doppler shifted D_α emission from heating beam
- APD array detector: 8 radial x 4 poloidal channels
- View location radially movable from R_m = 0.7-1.5 m



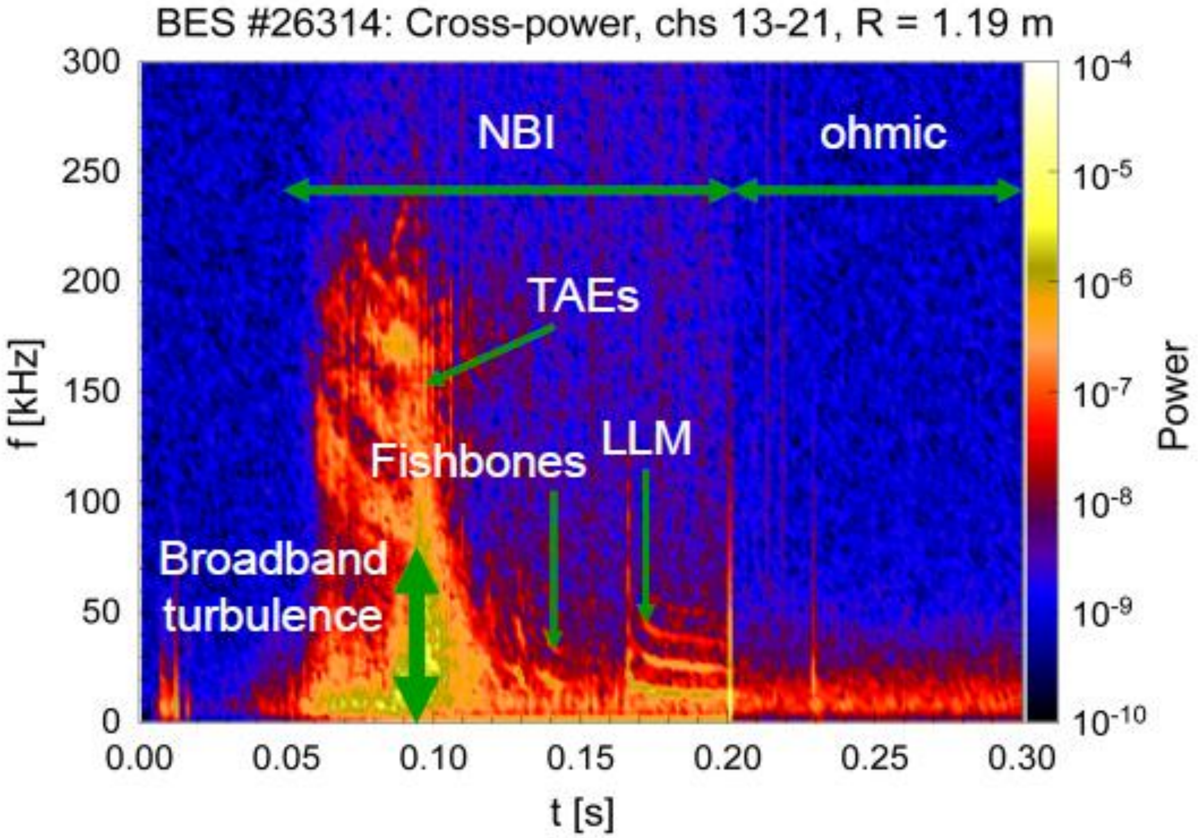


- 2 MHz digitization frequency, 0.5 MHz BW
- Resolution: $k_{r,\theta} < 2\pi/(2\text{cm}) \sim 1.6\ \text{cm}^{-1}$
- $k\rho_i < 1$ → ITG scale turbulence
- Sensitivity $\delta n/n \geq$ few 0.1% at a few 0.1 MHz



A. Field, D. Dunai (RMKI), Y-C Ghim (Oxford) et al

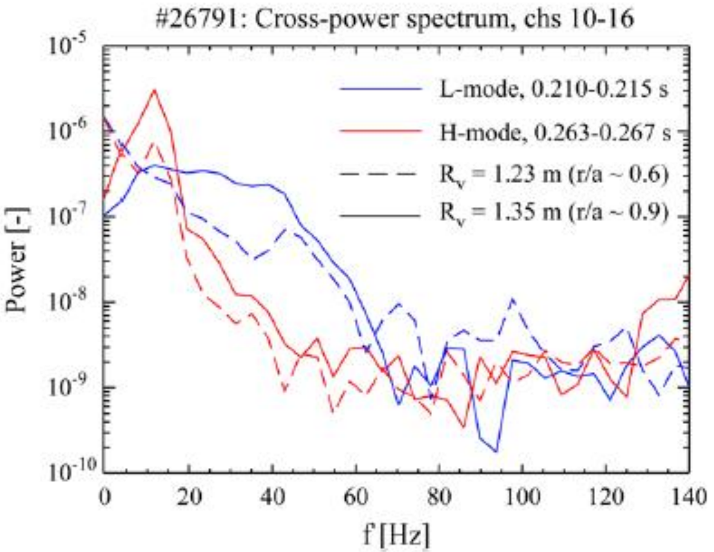
Characteristics of BES data



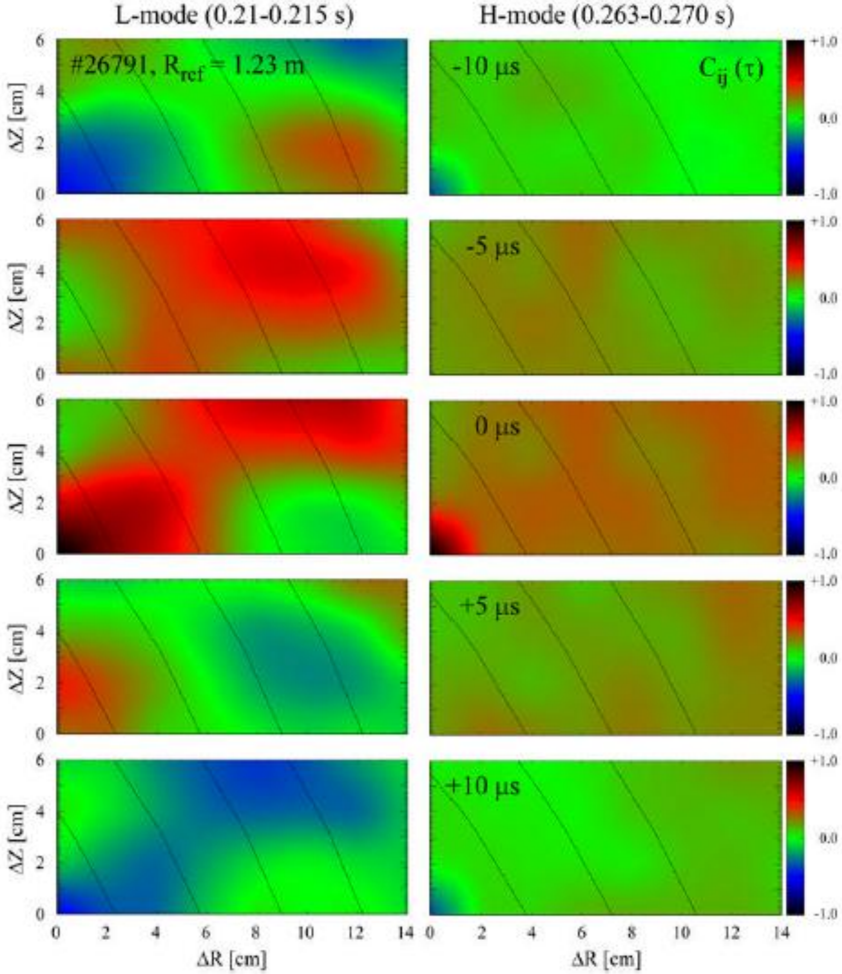
- ☐ Broadband turbulence in frequency range 0-100 kHz above noise floor
- ☐ Common mode component due to coherent MHD (TAE, fishbones, LLM, etc)
- ☐ Significant power from background signal during ohmic phase

A. Field, D. Dunai (RMKI), Y-C Ghim (Oxford) et al

L/H-mode comparison



Cross-correlation functions R_v = 1.23 m



Outer region of SND plasma: r/a ~ 0.6-0.9

MHD quiescent L- and H-mode phases

- **H-mode:**

Reduced power in 20-80 kHz band

Short correlation lengths < 2 cm

- **L-mode:**

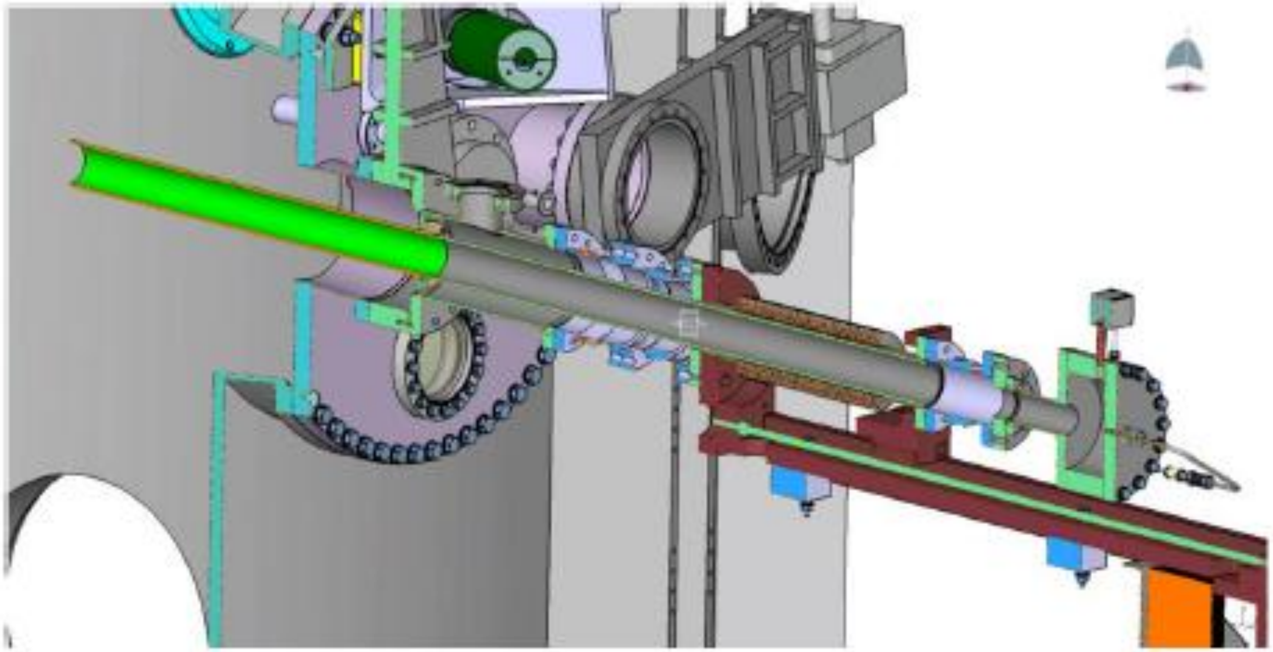
Longer radial correlation length ~ 4-6 cm

Propagation of eddies ⊥B due to ExB drift

A. Field, D. Dunai (RMKI), Y-C Ghim (Oxford) et al

Disruption mitigation

- **MAST disruption mitigation valve supplied via collaboration with FZJ**
  - 65ml injection volume
- **Gas delivered via 1.5m long, 50mm diameter pipe**
  - Pipe outlet located within 30cm of outboard midplane separatrix
- **Injection of a range of noble gas species and quantities:**
  - Ar(10%)/He mixture, Helium, Argon and Neon
  - 5 to 40 x10^{21} particles injected (10 – 300 times the plasma inventory)

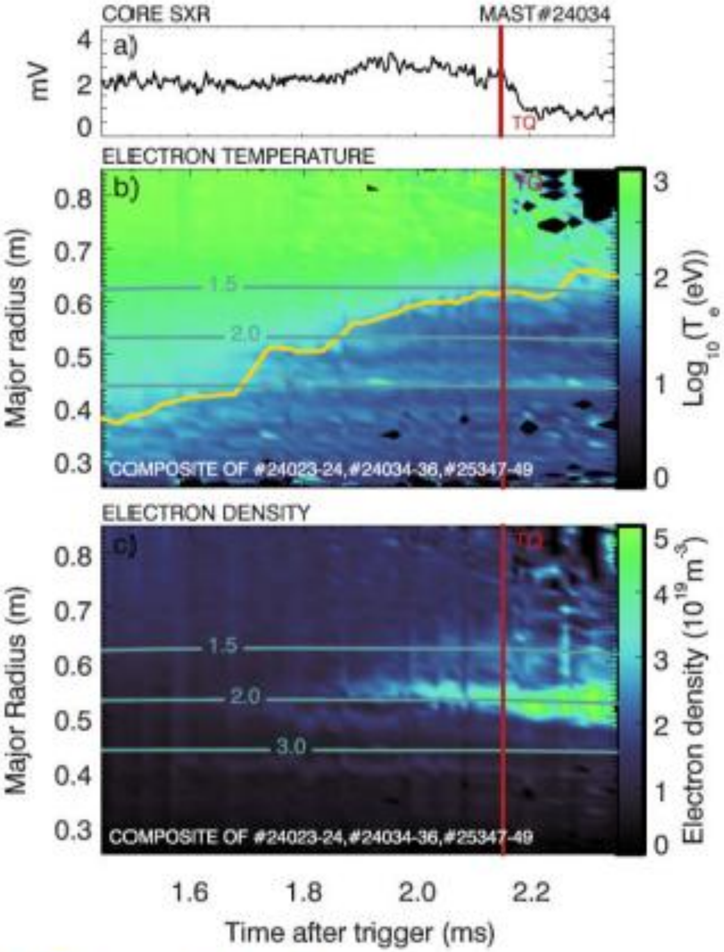


A. Thornton, M. Lehnen (FZJ) et al

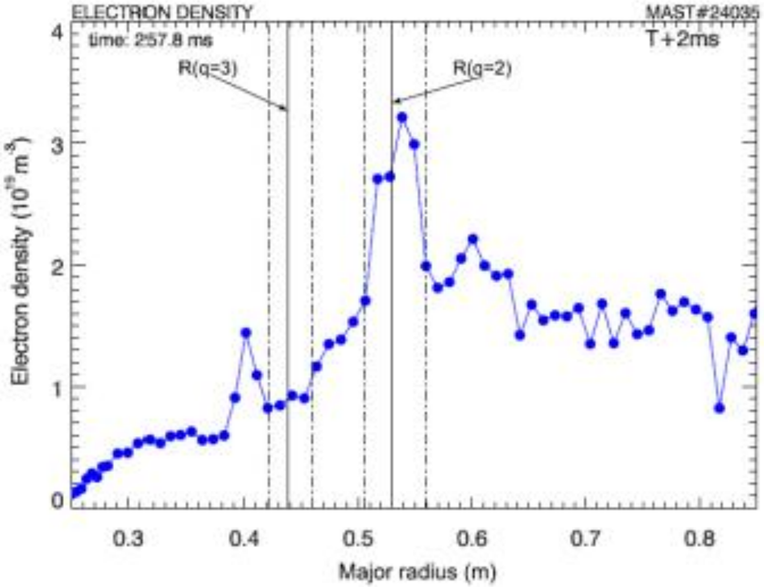
THE UNIVERSITY *of York*

Disruption mitigation

10% Argon 90% Helium



- Impurity ions penetrate to q = 2 surface prior to thermal quench (high speed imaging)
- Local density build-up and initiation of thermal quench when cooling front reaches q = 2 surface



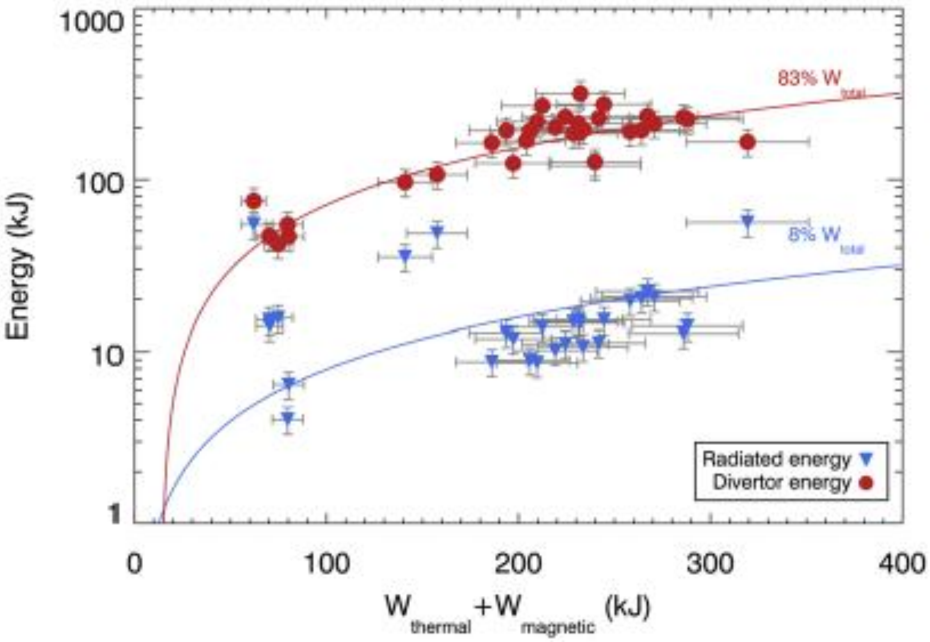
- 60 – 70% reduction in peak divertor power loads

A. Thornton et al

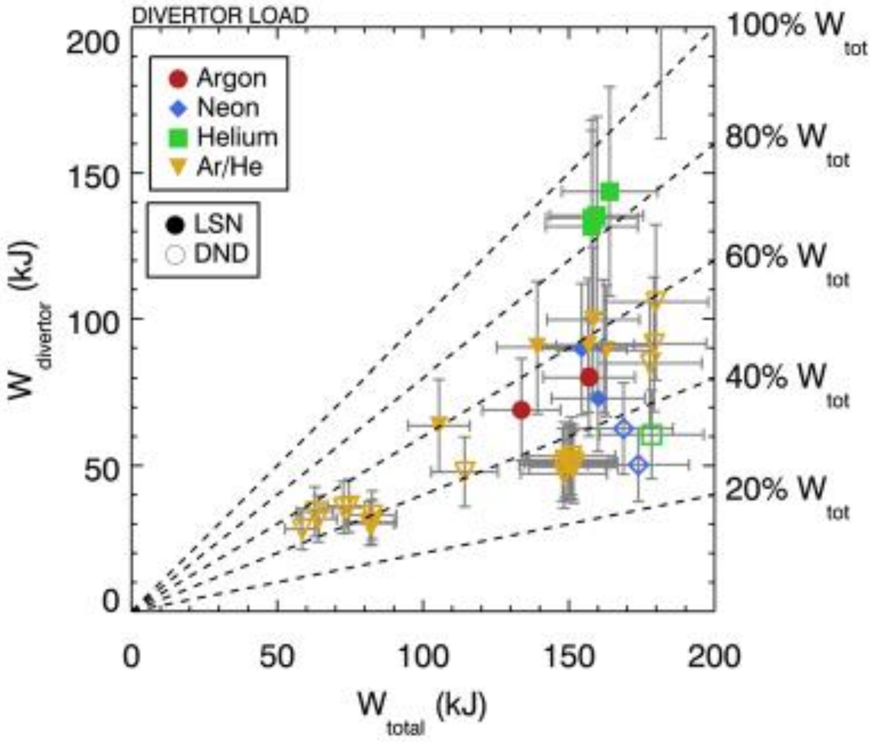
Disruption mitigation

Energy to divertor can be reduced by a factor ~ x2 to ~ 40% of the total stored energy

Unmitigated disruptions



Mitigated disruptions



[Total stored energy ⇒ EFIT, radiated energy ⇒ bolometry, divertor energy ⇒ IR]

A. Thornton et al

A Conceptual Design of Super Conducting Spherical Tokamak Reactor

presented by **Yoshio Nagayama***

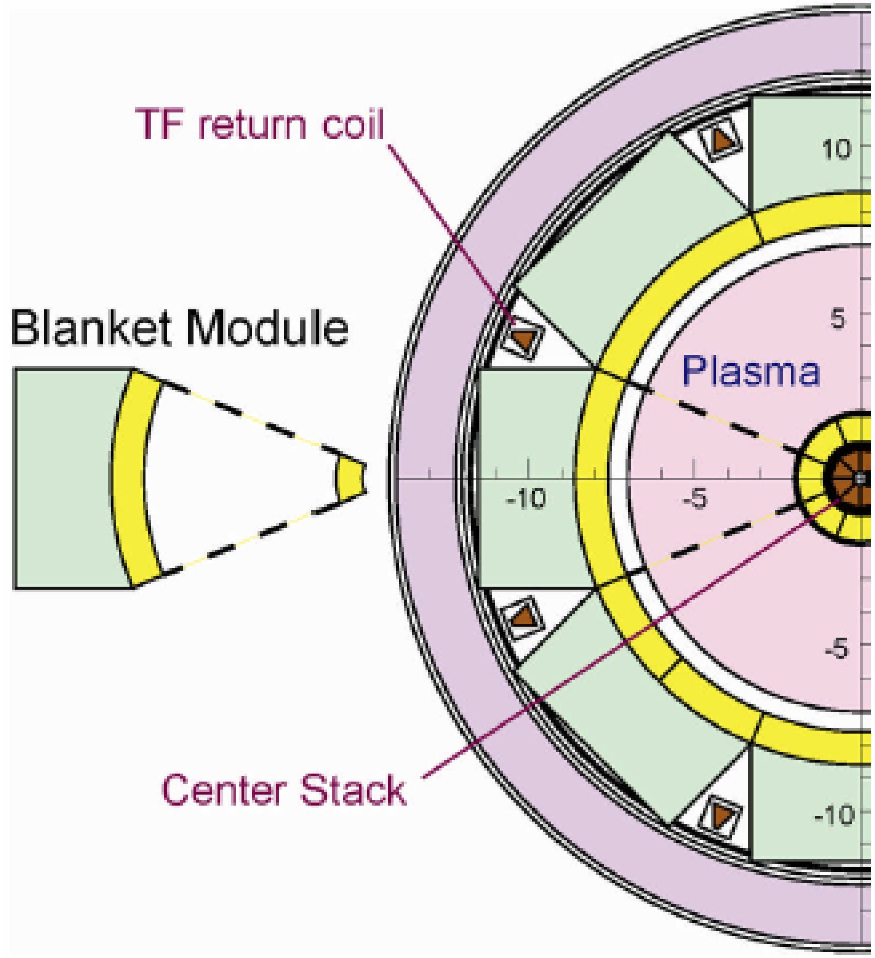
**National Institute for Fusion Science, 322-6 Oroshi, Toki-city 509-5292, Japan*

nagayama.yoshio@nifs.ac.jp

The Joint Meeting of 5th IAEA Technical Meeting on Spherical Tori, & 16th International Workshop on Spherical Torus (ISTW2011), & 2011 US-Japan Workshop on ST Plasma
National Institute for Fusion Science, Toki, Japan, September 27-30, 2011

Neutron damage problem can be solved in ST.

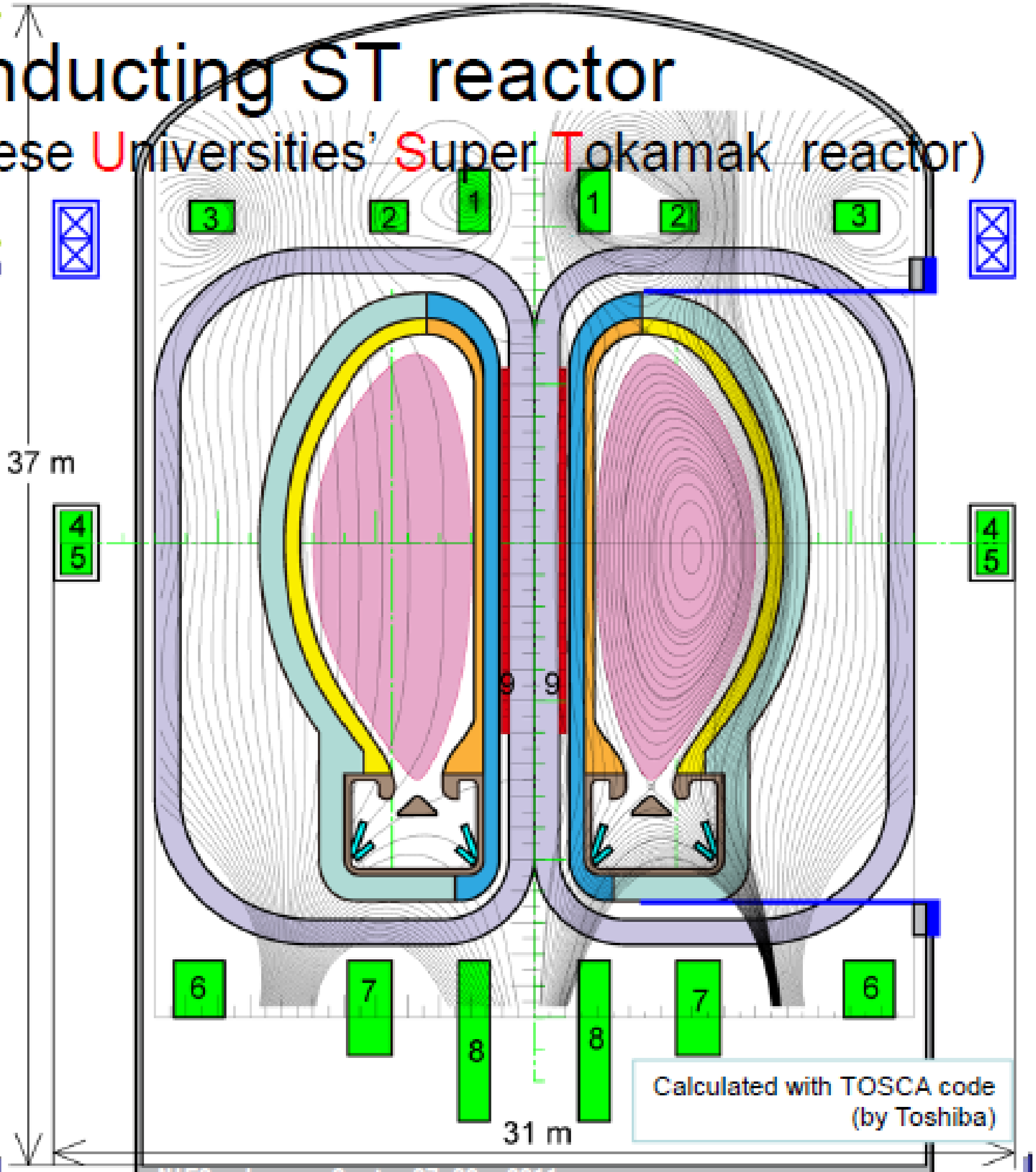
- Total (time integrated) neutron flux < 10 MW-year/m^2.
  - Life time of the first wall is 2-3 years, if the neutron wall load is 3-5 MW/m^2.
- Easy replacement of blanket module solves the neutron damage problem.
- The wide separation between TF return coils in ST enables the quick replacement of the blanket cassette.
- Large port is a weak point to support TF coils.



Superconducting ST reactor

JUST (Japanese Universities' Super Tokamak reactor)

R/a	4.5/2.5 (m)
κ/δ	2.5/0.35
B_{t0}/B_{coil}	2.36/12.7 (T)
U_{TF}	24 (GJ)
j_{coil}	24 (MA/m^2)
Φ_{OH}	20 (V-sec)
I_{BS}/I_{OH}	18/7 (MA)
T_{e0}/T_{i0}	15/15 (keV)
n_{e0}	17 (10^{19}m^{-3})
n_e/n_{GW}	1.5
β_t/β_N	0.22/7.2
τ_E/τ_p	2.7/11 (sec)
Neutron flux	4.4 (MW/m^2)
P_f/P_α	2.4/0.5 (GW)

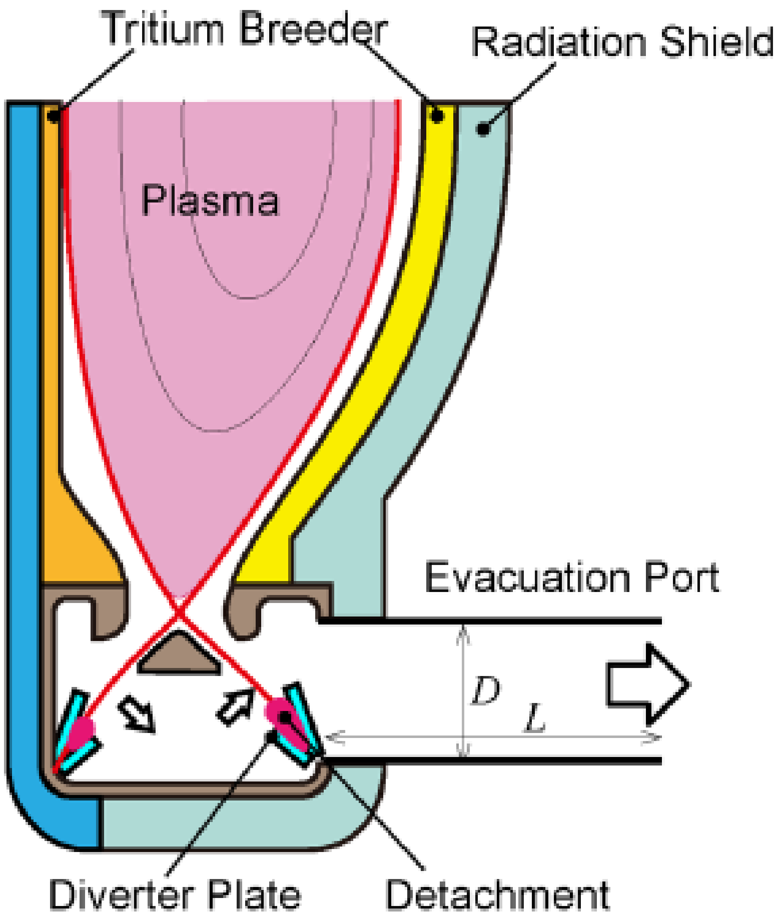


Calculated with TOSCA code
(by Toshiba)

Diverter

Heat load is received by the liquid diverter plate and detachment plasma.

- Heat load
  - Area of diverter plate ($A=2\pi Rw$)
  - $R=5$ m, $w=0.03$m then $A=0.9$ m^2
  - 50% of alpha heating = 270 MW.
  - Heat flux = 300 [MW/m^2]
- Liquid Diverter plate
  - Li (Hydride)
  - LiSn (Effect to Plasma)
- Detachment
  - V-shape diverter target limits the volume and makes high density diverter plasma.
  - Large area (100 m^2: $w=1.5$ [m])
- Intense development is required!



Life Cycle Assessment for Energy Payback of Spherical Tokamak Reactors

US-Japan Workshop on ST Plasma

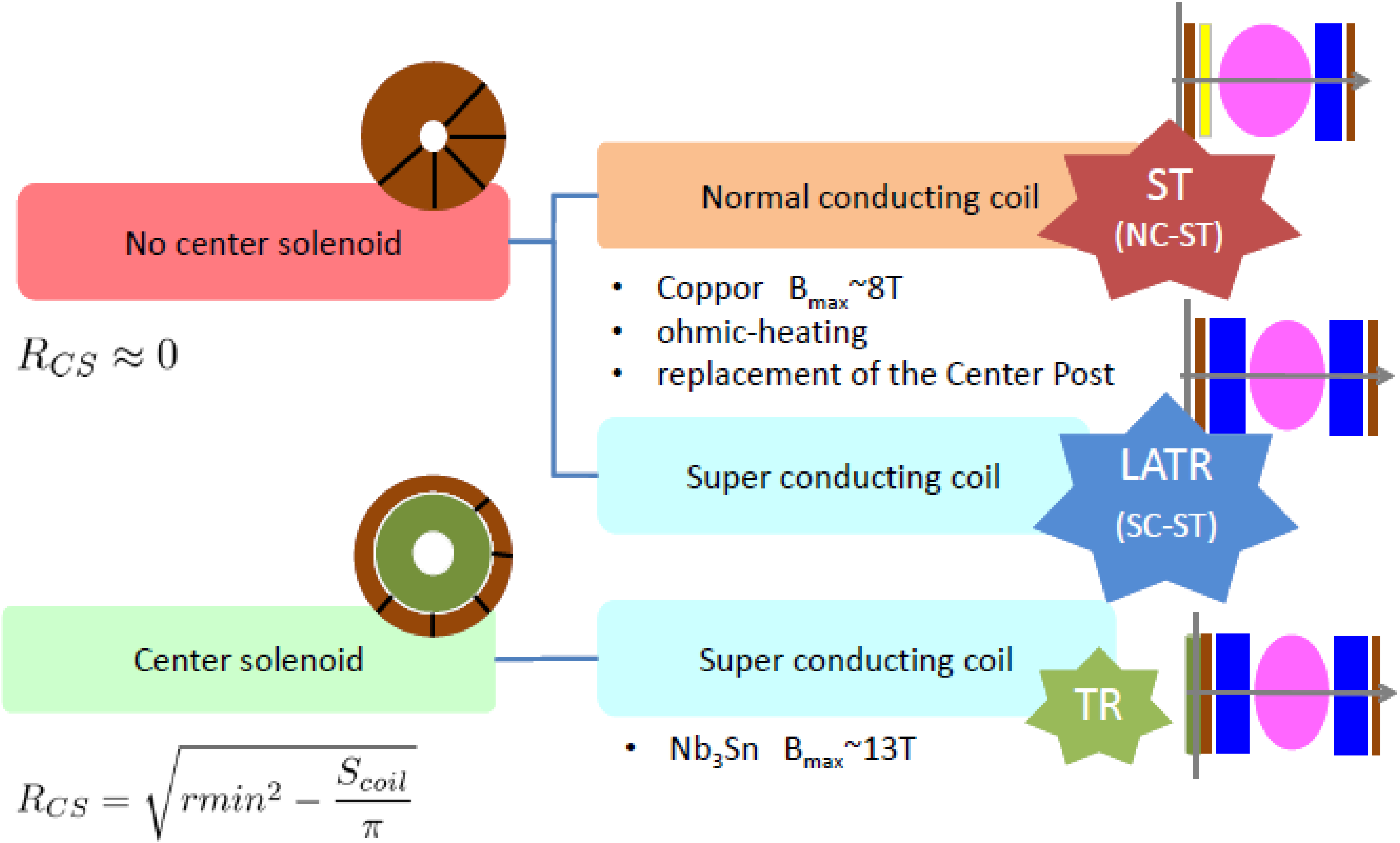
Sep 27th-30th ,2011

Kanae Ban , Kozo Yamazaki, Hideki Arimoto, Tetsutarou Oishi, Tatsuo Shoji

Dept. of Energy Engineering and Science

Nagoya Univ.

Classification of reactor types



No center solenoid

$R_{CS} \approx 0$

Normal conducting coil

ST
(NC-ST)

- Coppor B_{max}~8T
- ohmic-heating
- replacement of the Center Post

Super conducting coil

LATR
(SC-ST)

Center solenoid

Super conducting coil

TR

- Nb_3Sn B_{max}~13T

$$R_{CS} = \sqrt{rmin^2 - \frac{S_{coil}}{\pi}}$$

$$EPR = \frac{E_{output}}{E_{const.} + E_{operation} + E_{fuel} + E_{replace} + E_{Decon.}}$$

Operation

The energy requirements for operation including fixing and maintenance is evaluated.

The operation energy is assumed as **5% of input construction energy every year**.

Replacement

- The energy requirement for **blanket, divertor, and a part of the NBI** exchanges is evaluated. Only the case of ST has to replace the **center post**.
- The frequency of replacement is decided with the neutron wall load.

Fuel

The fusion reactors in this study use the deuterium-tritium reaction.

The tritium is bred in the blanket. Thus we consider the amount of deuterium consumed in fusion reaction.

Energy intensity of Deuterium is 140 [TJ/t].

Decommission&Decontamination

We assumed that the decommission cost is 0.5M$.

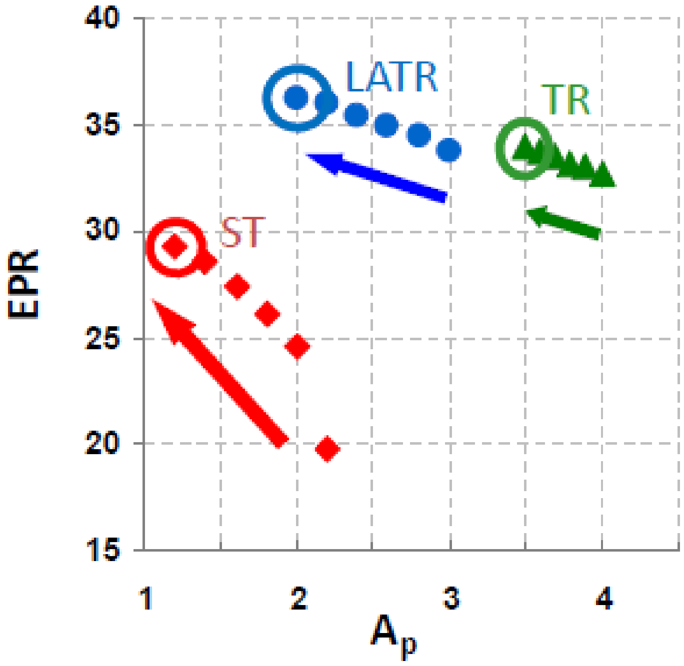
We multiply the decommission cost by energy intensity of industry waste disposal .

Results

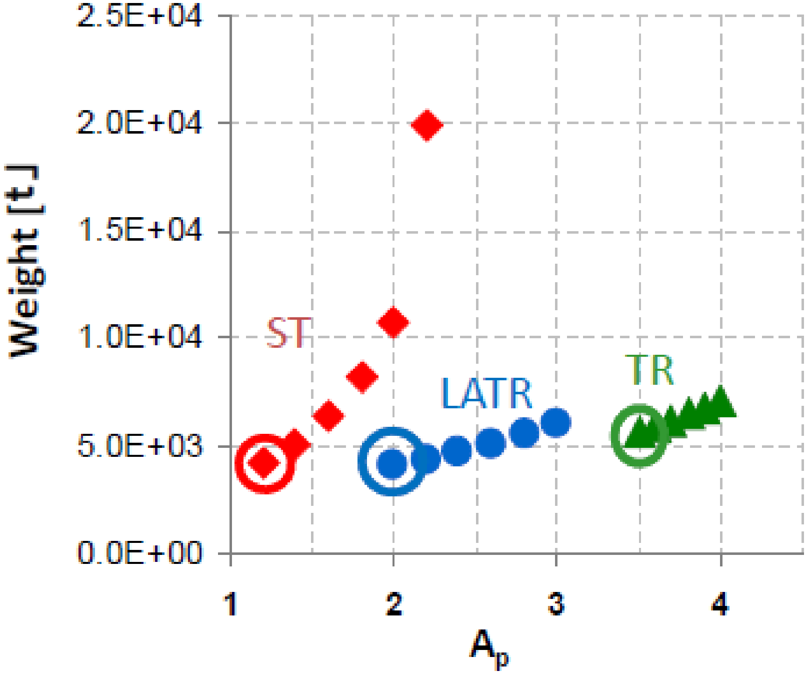
Aspect ratio dependence of the EPR

We show you that the relationship of aspect ratio and the EPR. We use the parameter, aspect ratio ,elongation, and normalized beta which evaluated in the previous slide.

Aspect ratio dependence of the EPR.



Aspect ratio dependence of the fusion island weight.



In the case of all reactors the lower aspect ratio is, the higher EPR is. The fusion island weight increase with increase of aspect ratio. And then, the lowest fusion island weight of each reactor are almost same. But the EPR of each reactor is different. In the next slide, we describe the reason with three typical reactor models.