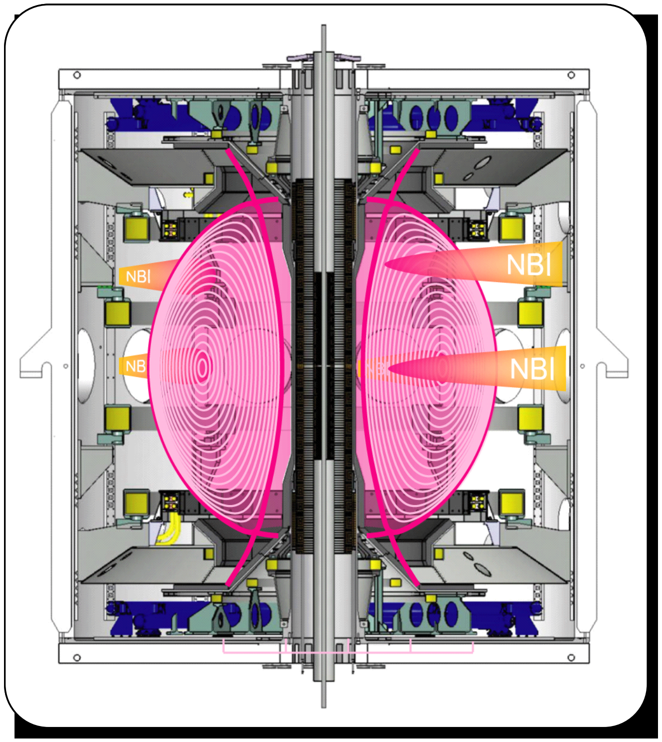
MAST Upgrade

Goals

- Demonstrate physics viability of a ST– based Component Test Facility
- Contribute to the ITER/DEMO physics base
- Demonstrate effectiveness of a flexible Super-X divertor



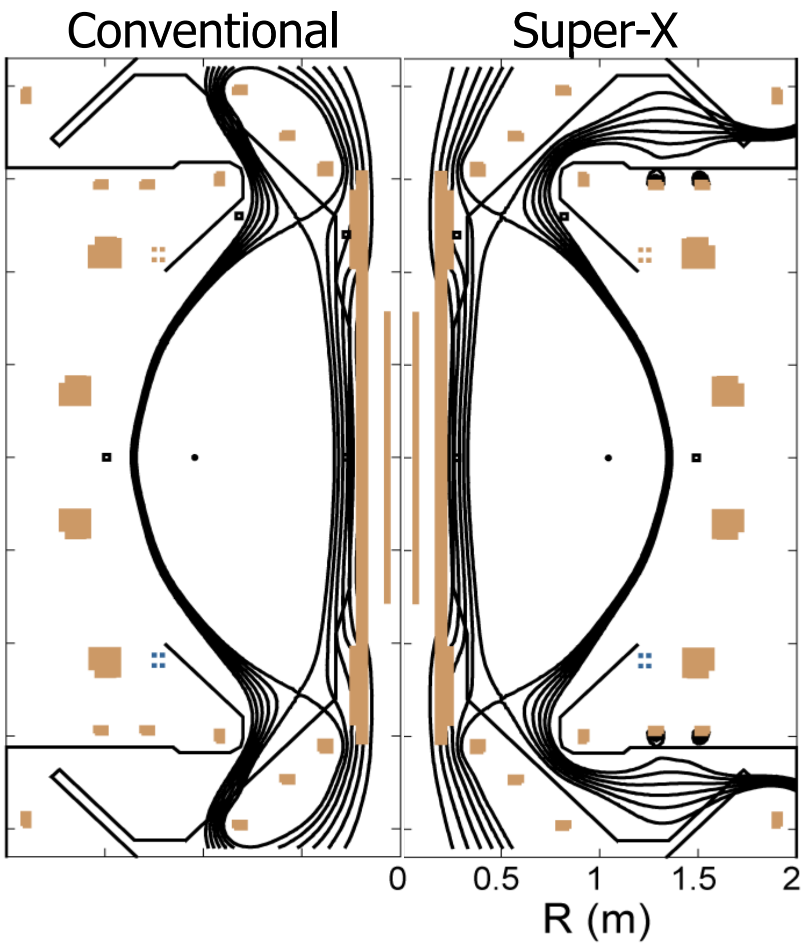
- Increased heating power (NBI, EBW)
  - adaptable system providing control of j(r), p(r), v(r)
- Relaxed current profile
  - fully non-inductive operation possible
- Increased TF, increased solenoid flux
  - higher current, longer pulse routine operation
- Improved exhaust and density control
  - closed cryopumped divertor

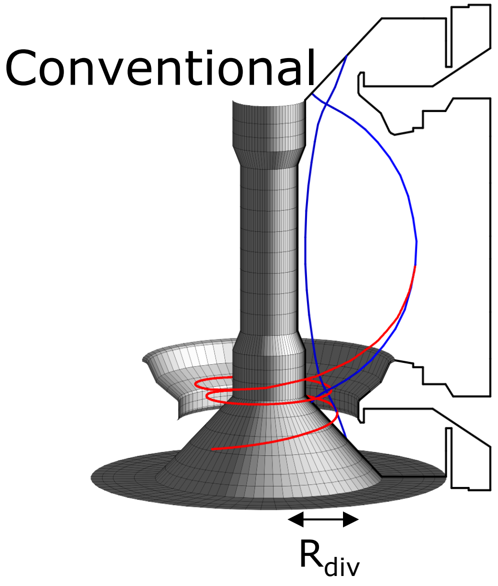
MAST Upgrade – stage 1 and full compared

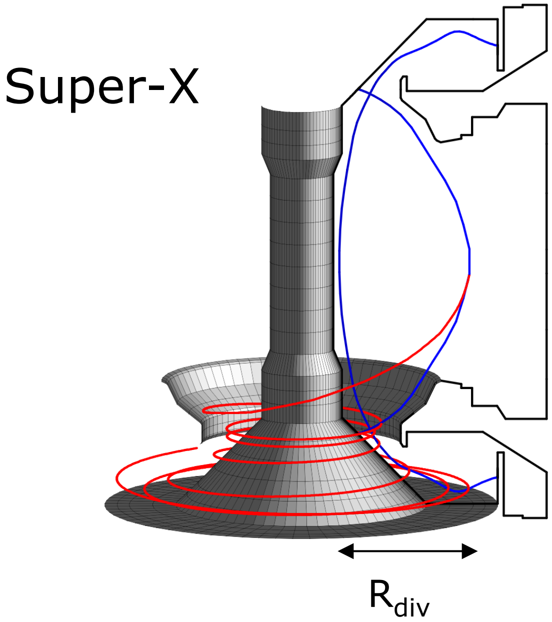
	MAST	**MAST-U** Stage 1	Stage 2 (proposed)
Power injected (NBI)	~5 MW	**~7.5 MW**	12.5 MW
Power injected (RF)	< 0.3 MW	**<0.3 MW**	1-2 MW
Toroidal field (R=0.8m)	0.55 T	**0.84 T**	
Energy deposited at I_P=1 MA	~5-10 MJ	**< 30 MJ**	< 63 MJ
Pulse length at I_P=1 MA (B_t>0.5T)	> 0.5s	**~2-4s**	< 5s
Plasma current flat-top	1.2 MA	**~ 2 MA**	
Profile control (J, p, flow)	~none	**moderate**	extensive
Particle control	~none	**active**	
'Routine' high elongation^2	1.8-2.1	**2.5-2.7**	
Divertor design	open	**closed + SXD**	

MAST Upgrade divertor

Both super-X and conventional divertor operation are possible.







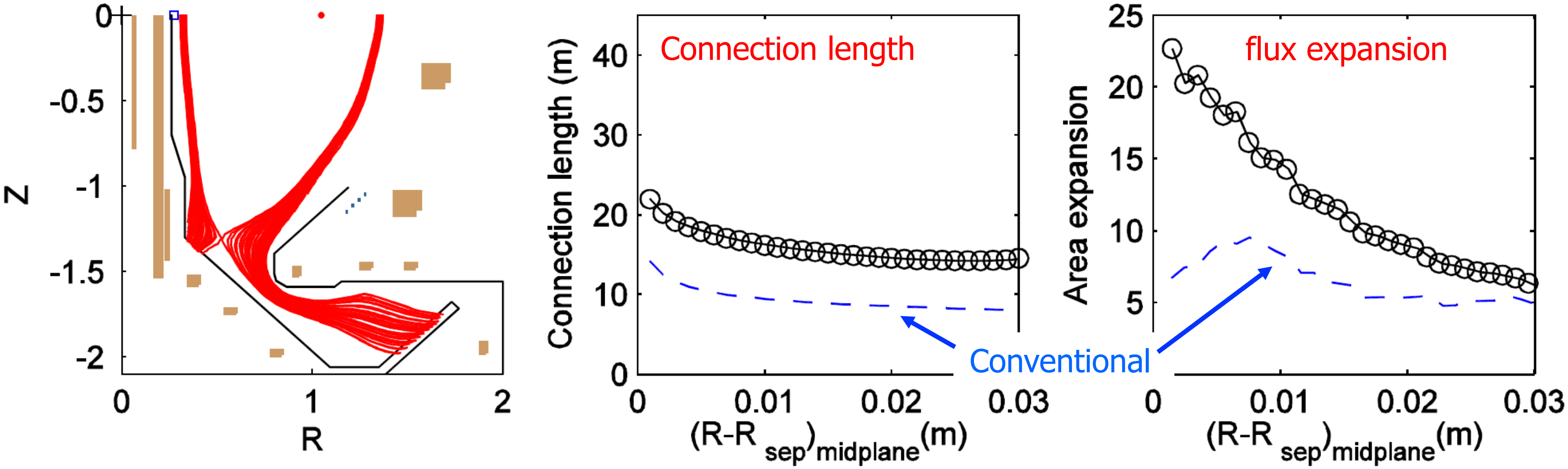
Valanju et al Phys. Plasmas 2009

MAST super-X divertor

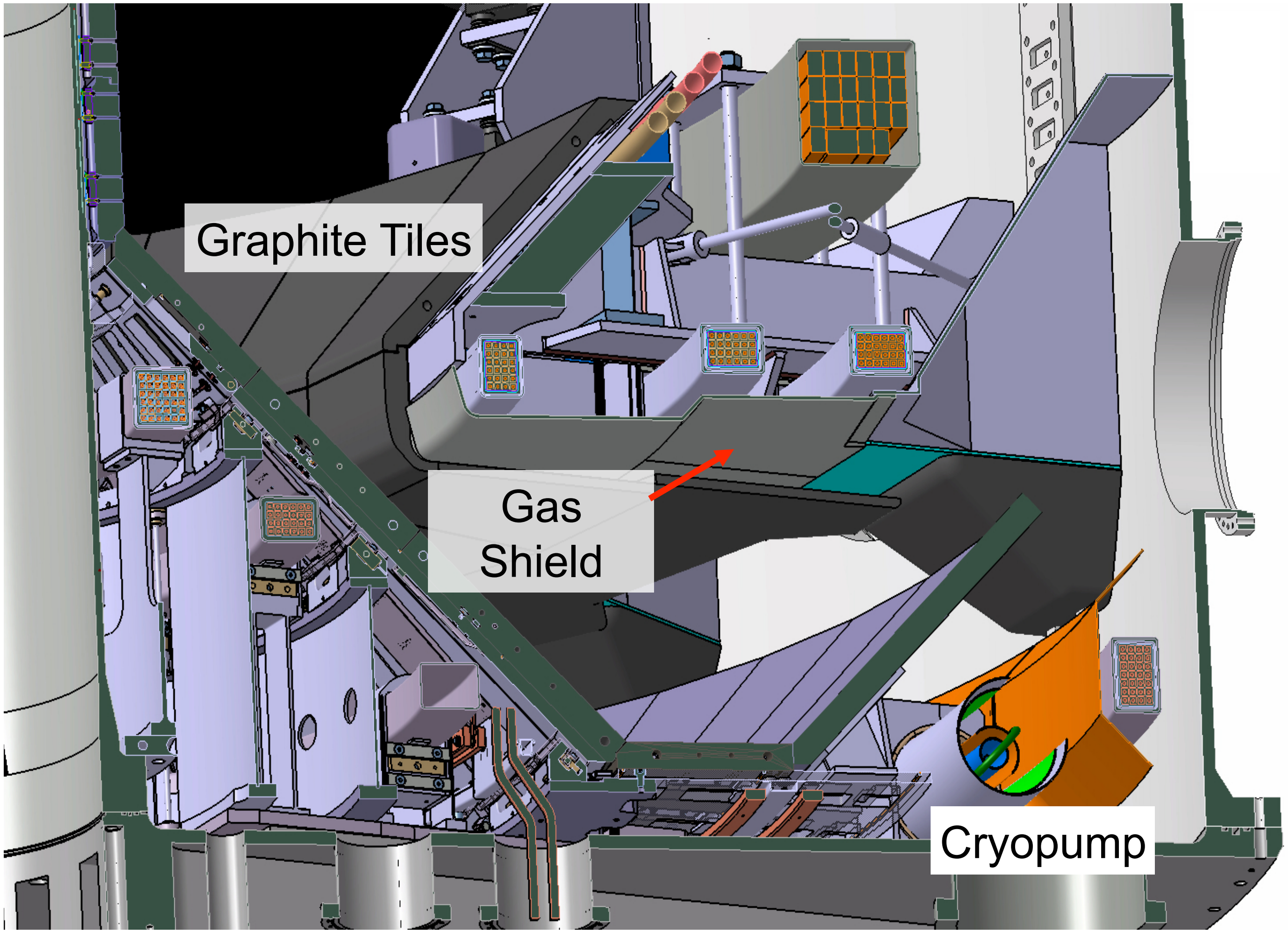
- ☐ Super-X combines
  - long connection length,
  - flux expansion and
  - large volume to radiate power

to get cold low power density plasma at target

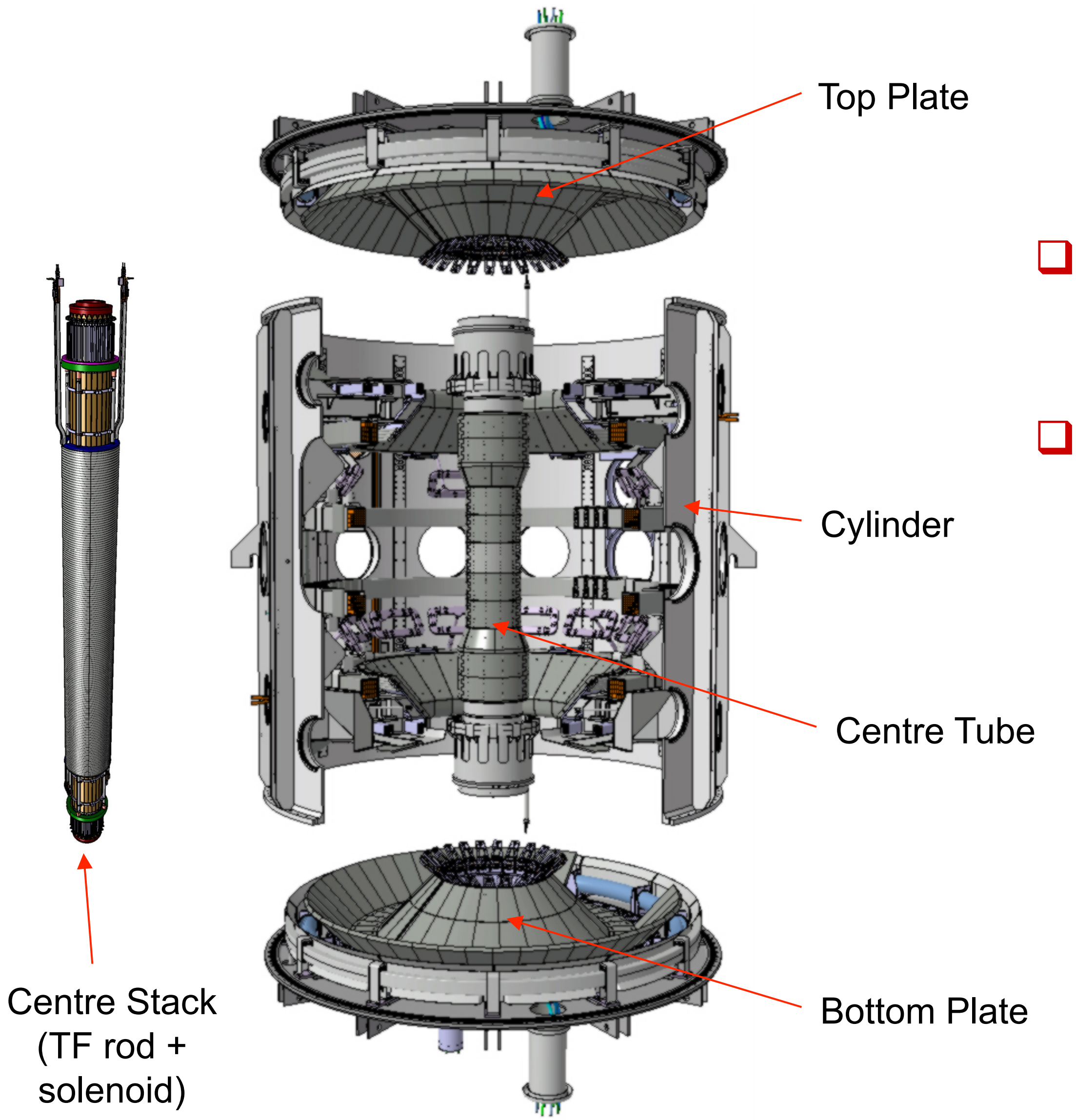
- ☐ MAST super-X has a low poloidal field region to increase connection length in limited space



Super-X mechanical design



MAST-U load assembly



- Modular design option for parallel assembly (keep shutdown short)
- Main engineering issues:
  - Centre rod+solenoid thermal + e.m. stresses
  - TF sliding joints – thermal + e.m. stresses
  - Super-X divertor assembly and maintenance
  - magnetic alignment of coils

SOL ion energy measurements

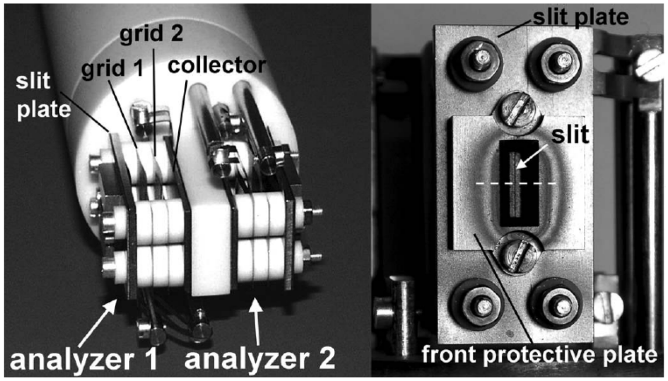
- Motivation:
  - – interpretation of probe data (n_e, P_{div})
  - – determines physical sputtering rates from plasma facing materials
  - – ELM ion energies in the far SOL unknown

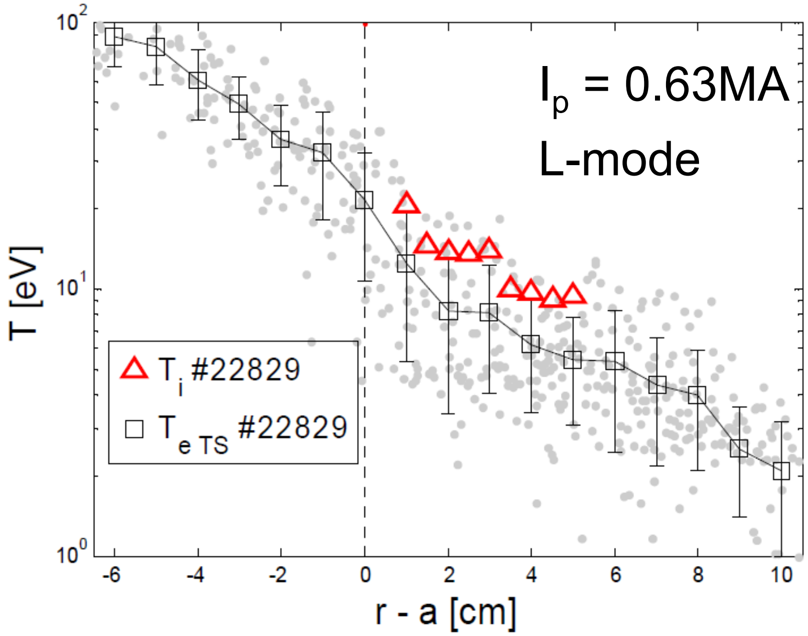
- First measurements show $T_i \sim (1 – 2.6) \times T_e$ at outboard mid-plane (much higher energies observed in fluctuations)

- Ion energy in ELM filaments - large signals observed as far as 20cm from the LCFS and up to 500V of biasing

P. Tamain, S. Allan, S. Elmore (Liverpool U.)

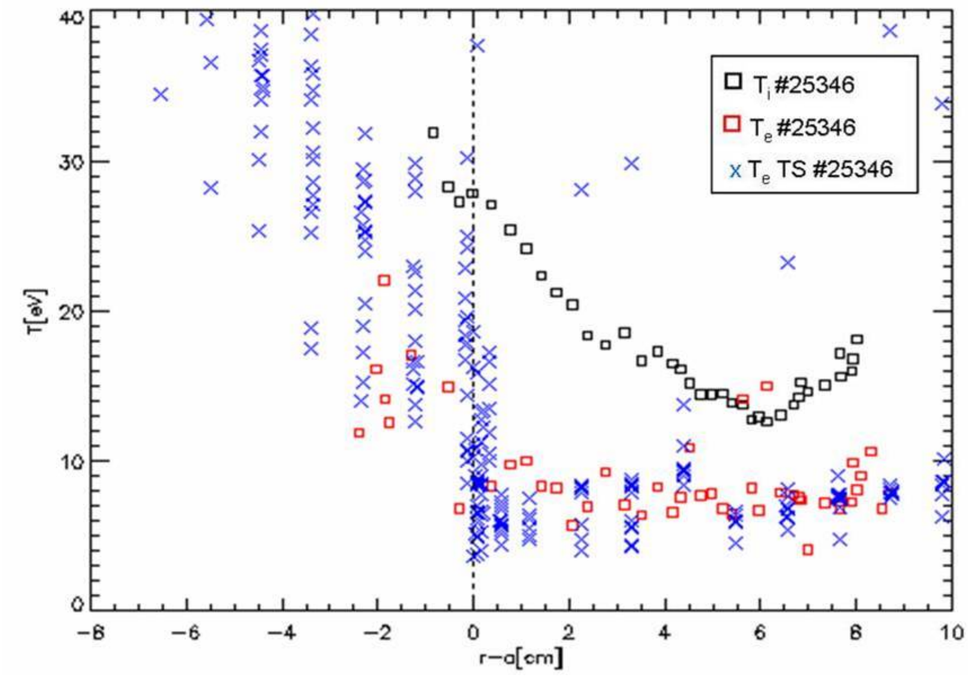
Retarding Field Analyzer (CEA)

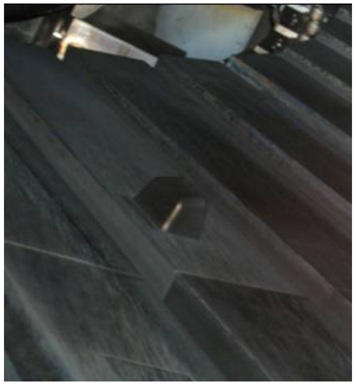




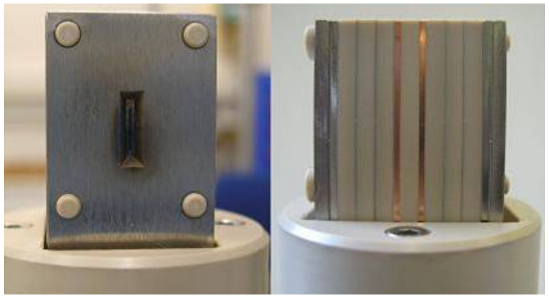
RFA supplied by CEA Cadarache

SOL ion energy measurements





Installation of two new retarding field energy analyzers now allows simultaneous ion energy measurements in the divertor and at the outboard mid-plane



Divertor RFEA

S. Allan, S. Elmore (Liverpool U.), P. Tamain (CEA), M. Kocan (IPP Garching)

Mid-plane RFEA

QUEST

QUEST

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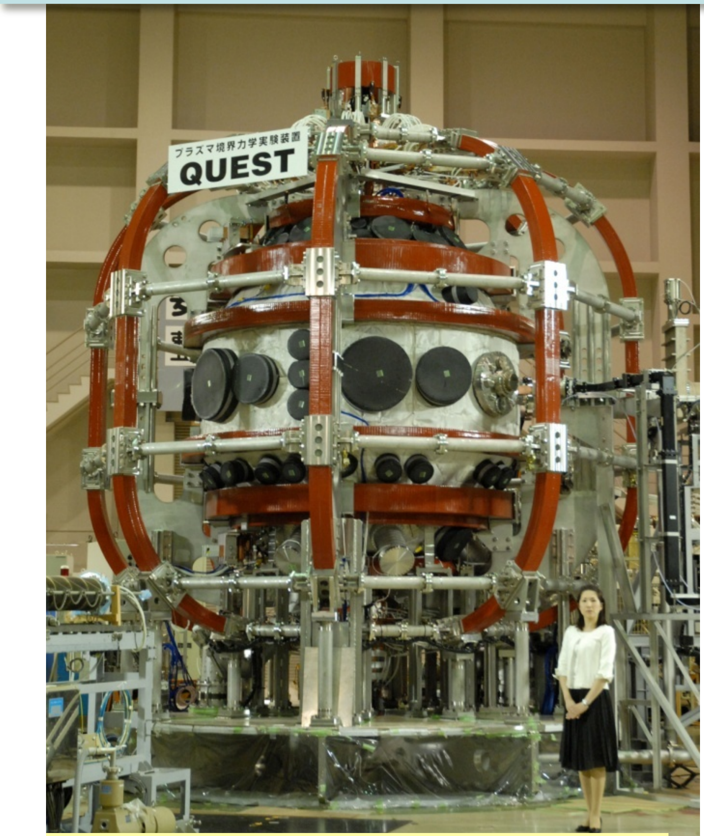
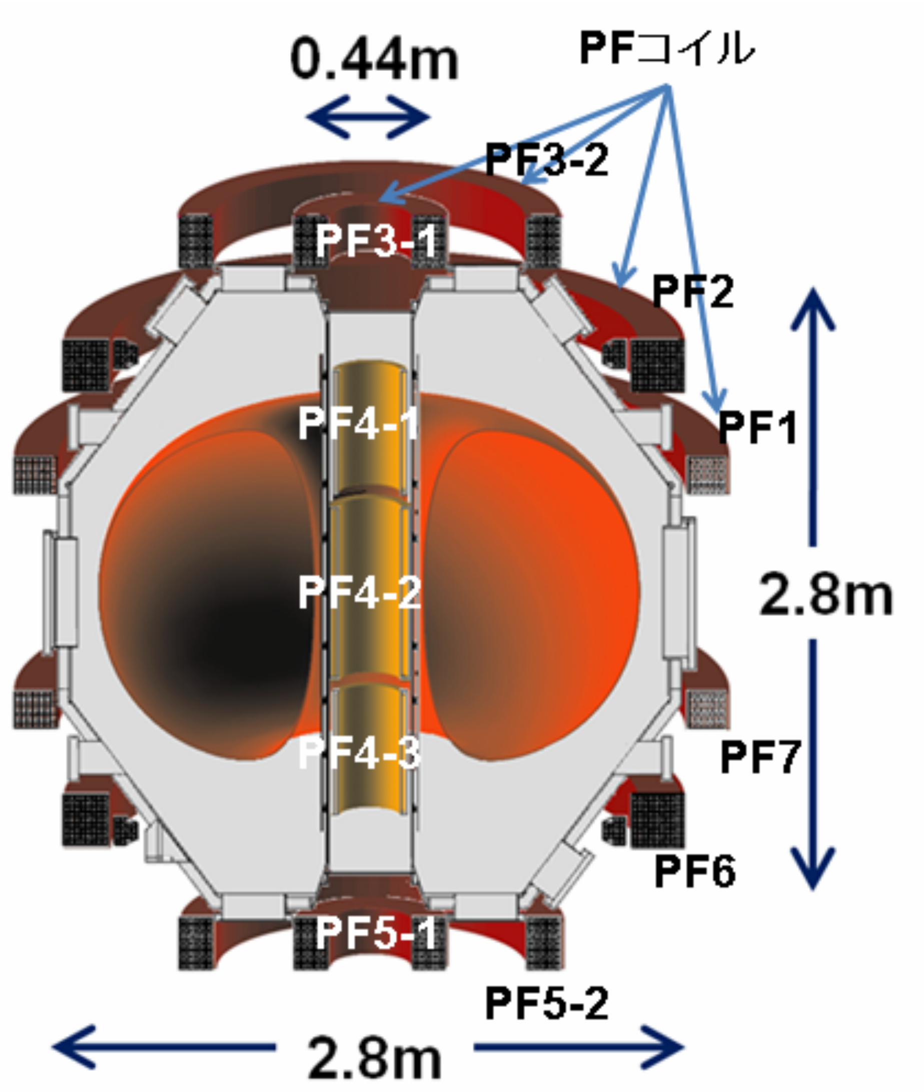


Bt	**0.25 T at R=0.64 m (CW)**	
PF	**4 pairs**	
CS	**3 coils**	
RF systems		
	2.45GHz	**50 kW(CW)**
	8.2 GHz	**400 kW(CW)**



Present status of QUEST

QUEST

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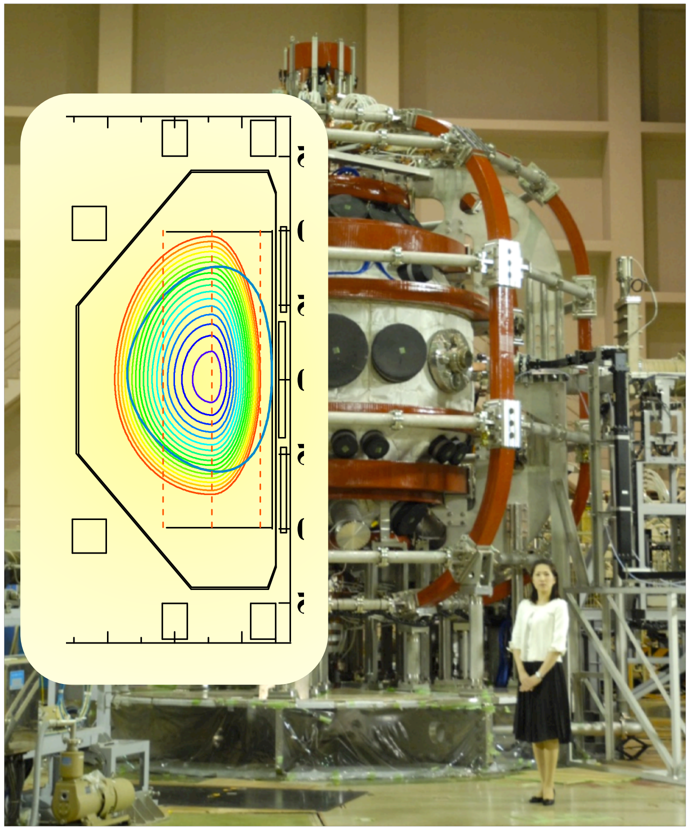

	Design	Achieved
R(m)	0.68	0.7
a(m)	0.4	0.48
A	1.6	1.47
I_p kA(OH)	300	110 (Bt=0.14T)
Ip kA (RF)	2~ 30(0.45MW) 100 (1MW)	25(60kW)
P_{rf} (kW)	400	~200
Bt(T)	0.25(CW)	0.25(CW)
n	4E18	<1E18
discharge	SS	37 s

Non inductive current driven plasma
R=0.7m, a=0.48m, A=1.47

What are issues to SSO?

- **Non-inductive current drive**

  Ideally self-organized current such as BS current to alleviate less current drive efficiency

  neo-classical current in low n_e at present and EBWCD in near future on QUEST

- **Heat and particle handling**

  Heat handling; Detached divertor, Ar and Ne injection

  Particle handling; Closed divertor, Hot wall, Enhanced pumping, Advanced fueling

- **Integrated control including core plasma, PWI and wall.**

  Global plasma control, Turbulence control in core, Blob control in SOL, Wall conditioning

τ_W can be controlled by T_{wall}.

QUEST

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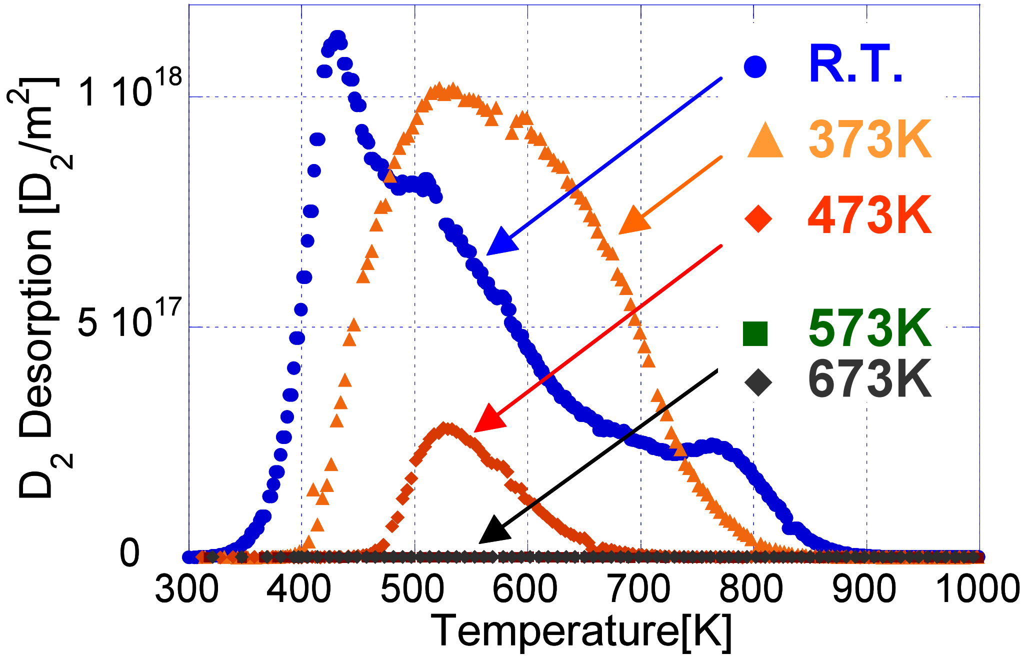

N.Yoshida et al.

- TDS spectrum for Mo implanted D (2keV-D+, $3\text{x}10^{21}$ D/m^2) at various temperature.
- At the high temperature region, D does not absorbed in the material.
- We consider the high temp. wall works as the reflector of the particle.

- **The number of stored particles depends on the targeted wall temperature.**
- **Hot wall around 673K could not have the property of pumping.**

Steady state operation

QUEST

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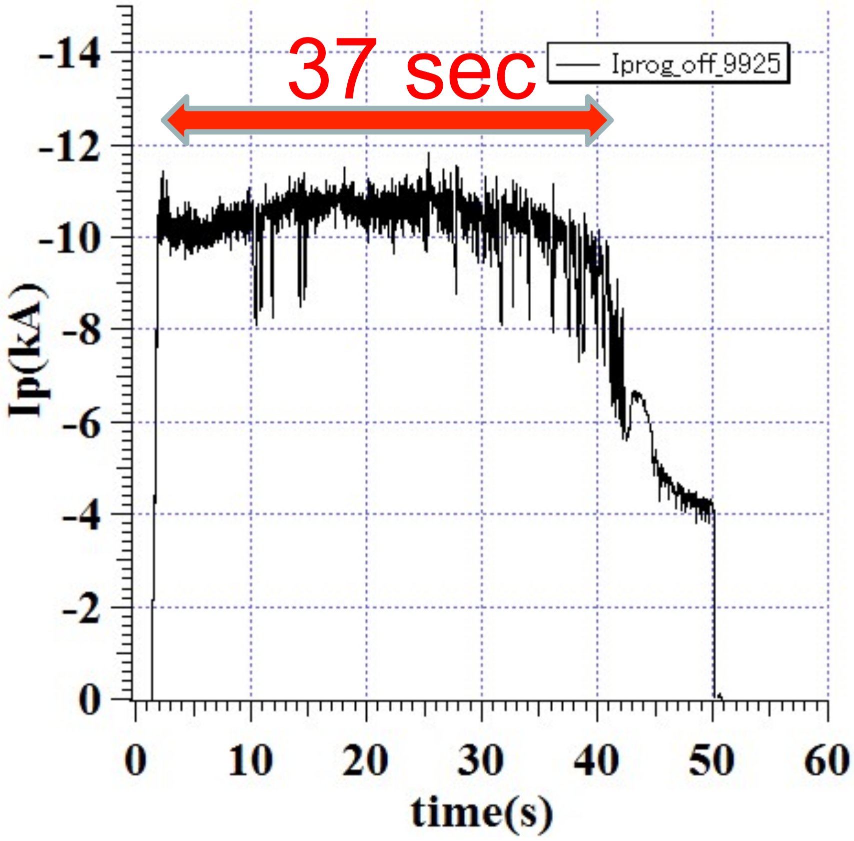
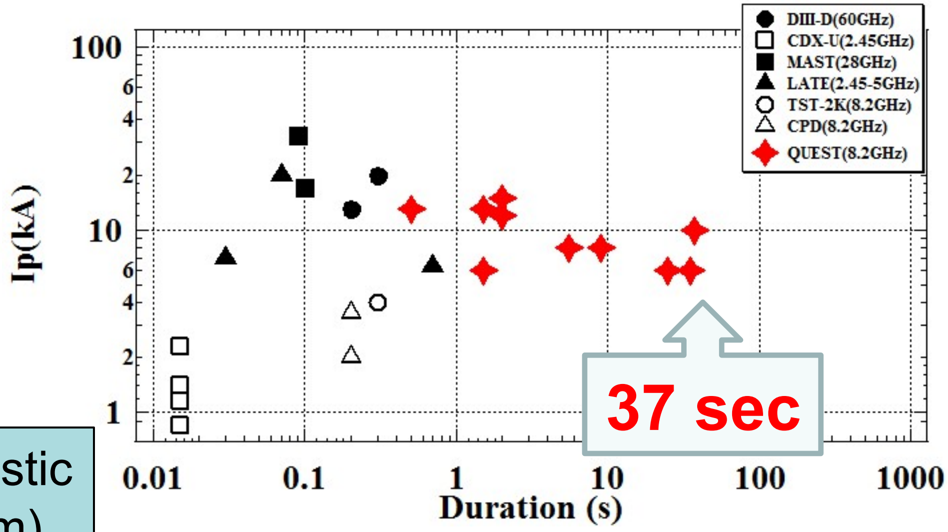


The plasma of more than 10kA, A~1.5 could be obtained by only 8.2GHz microwave on a limiter conf

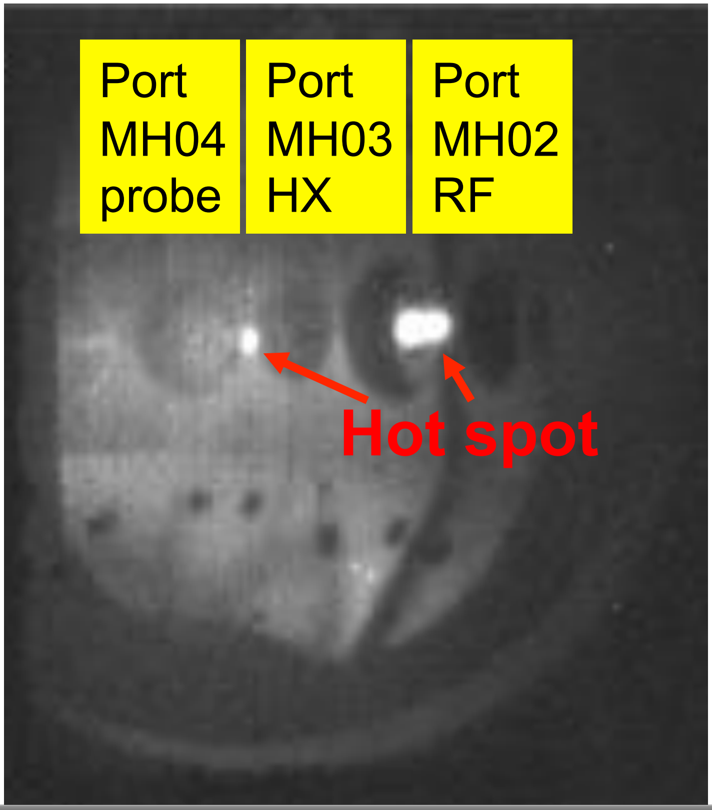


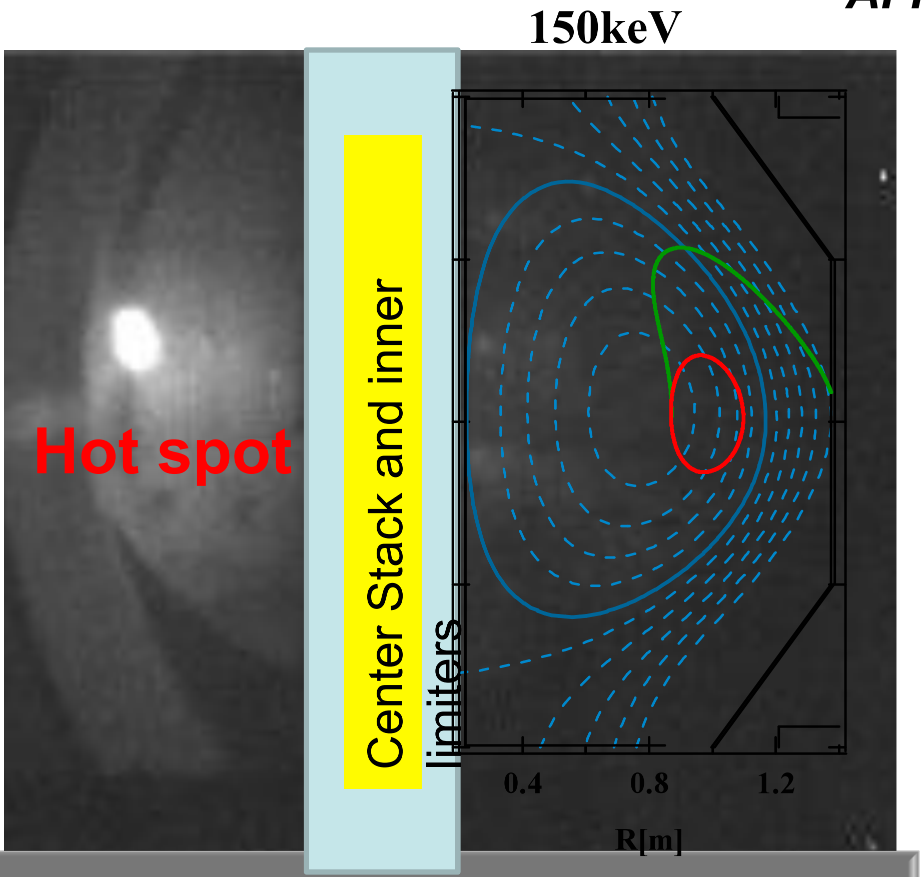
First data from SWIFT 2-D ion flow diagnostic (Nishino-san's seminar tomorrow, 11:00 am)

What is the reason of plasma termination? Hot spot on the outer wall

QUEST

AFRC





Hot spots mainly appeared on the outer wall, increasing P_{RF} and pulse duration. The plasma current was reduced by the increment of out-gassing caused by the presence of the hot spots.

Hot wall has been designed

QUEST

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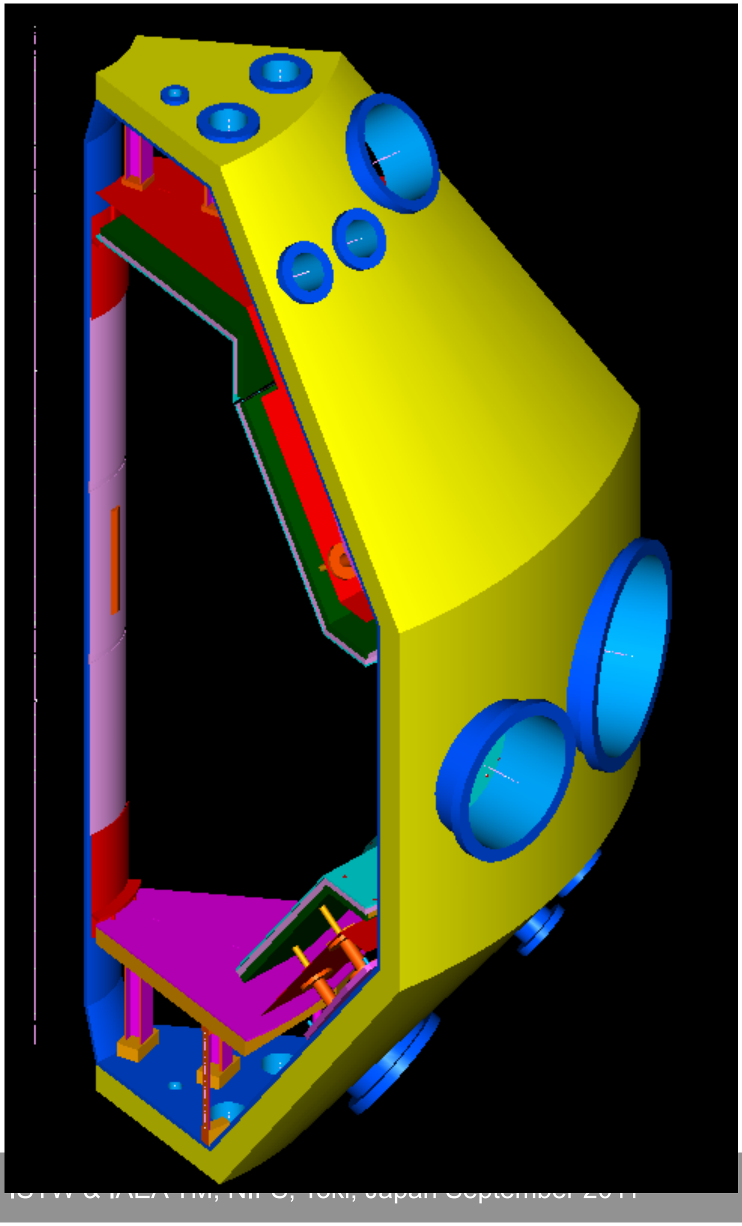
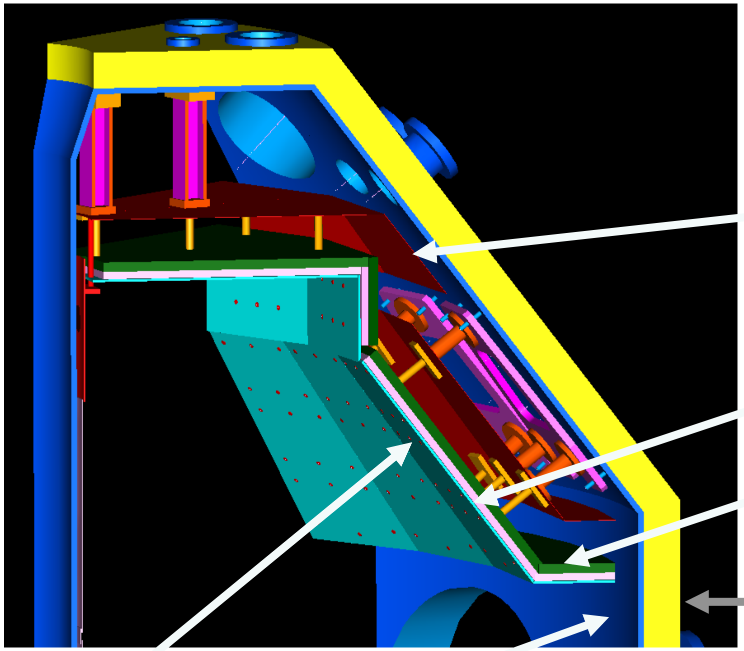




Radiation Shield

Heater

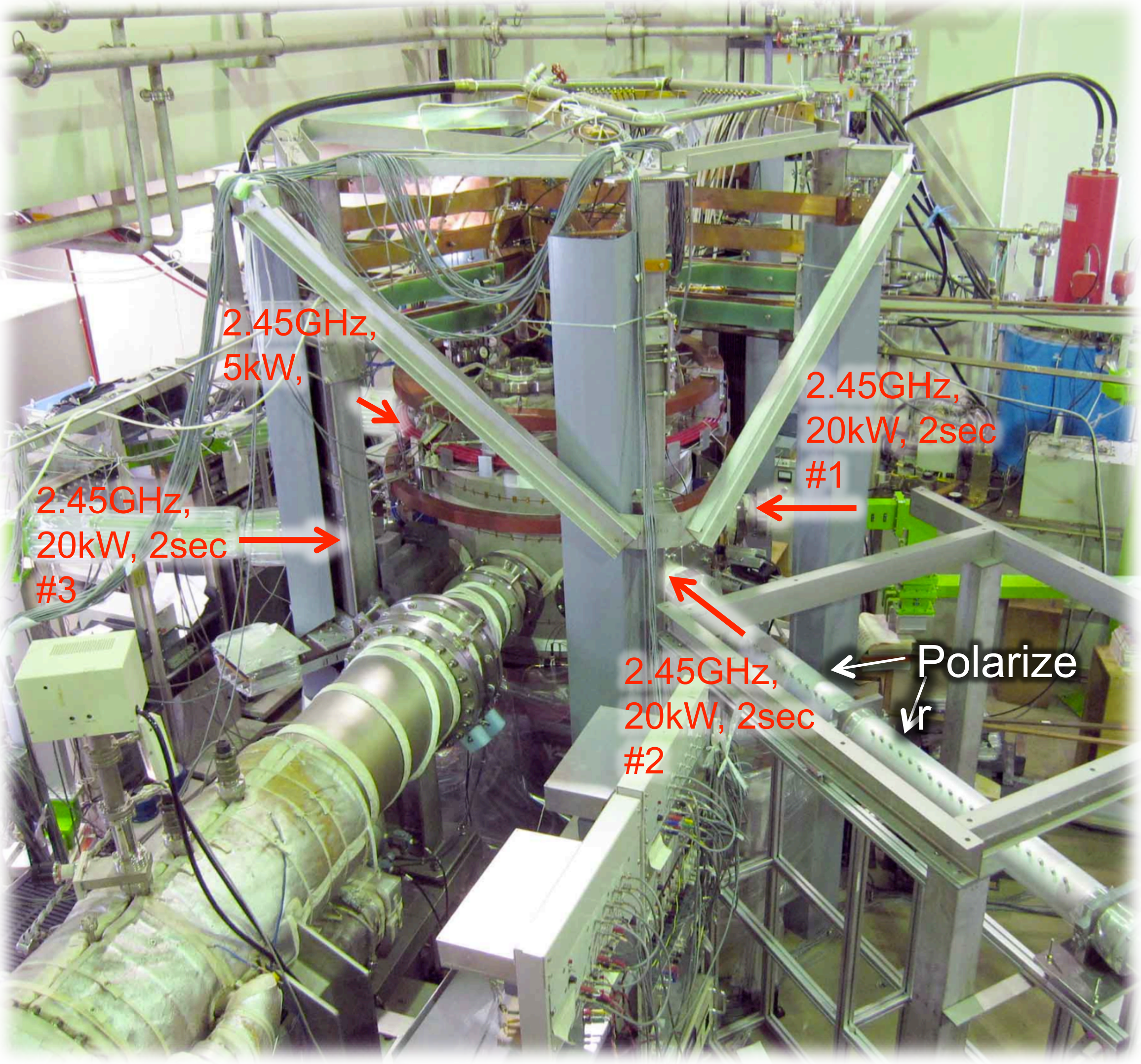
Cooling panel

Thermal Isolator

Hot wall

Vacuum Vessel

LATE is exploring non-solenoidal start-up by ECH/ ECCD



LATE Parameters:

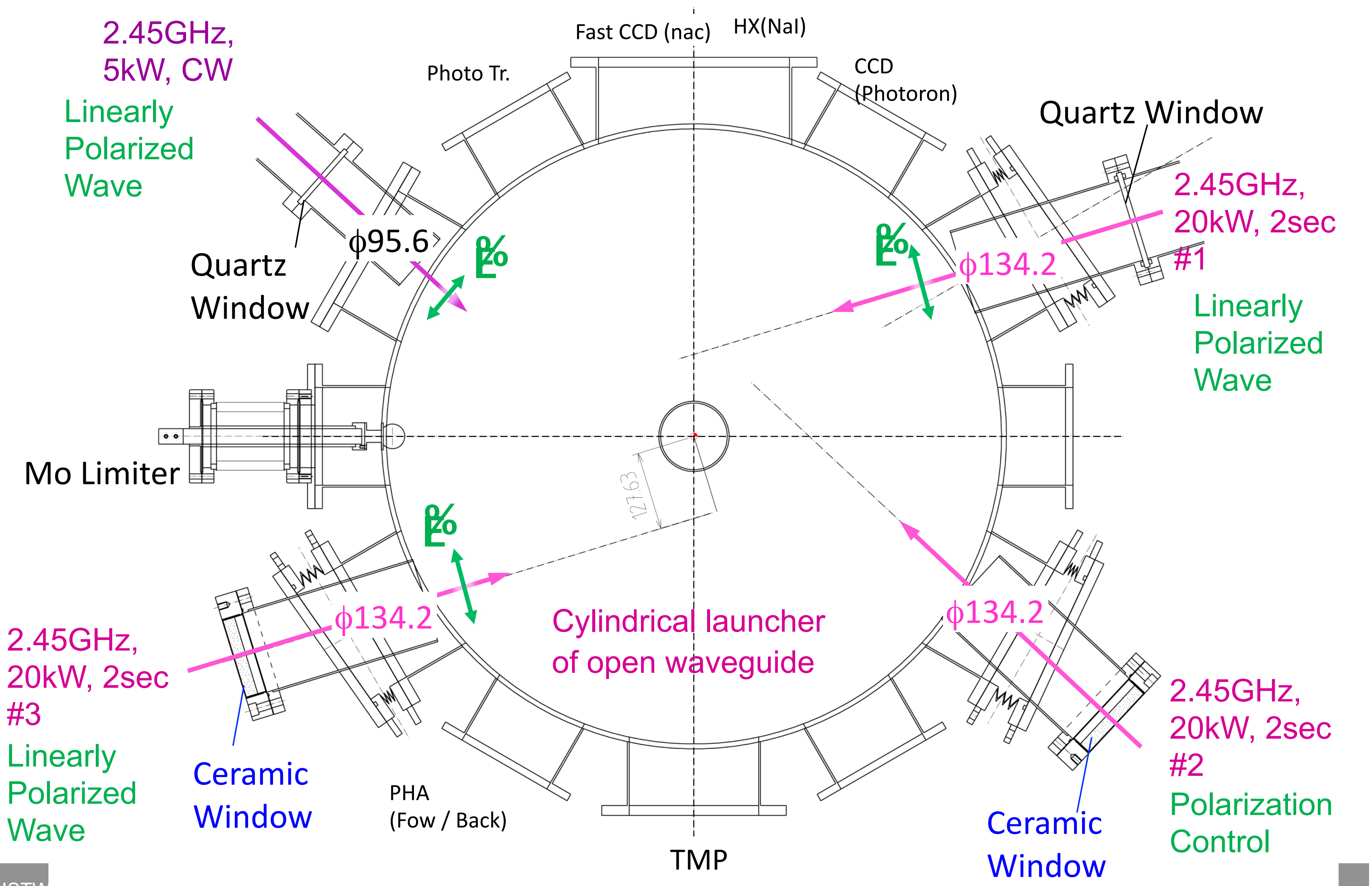
Vacuum vessel: diameter = height = 1m
Center post : diameter = 11.4 cm
Toroidal coils : 60 kAT (Bt ~ 0.5 kG), 10 s. or 120 kAT(Bt ~ 1 kG), 0.3 s.
Vertical coils: 3 sets, Vertical position control coils: 1 set

Microwave Power:
2.45 GHz (65kW 2sec.): 4 magnetrons
5.0 GHz (~200kW ~0.07 sec.)

Diagnostics:

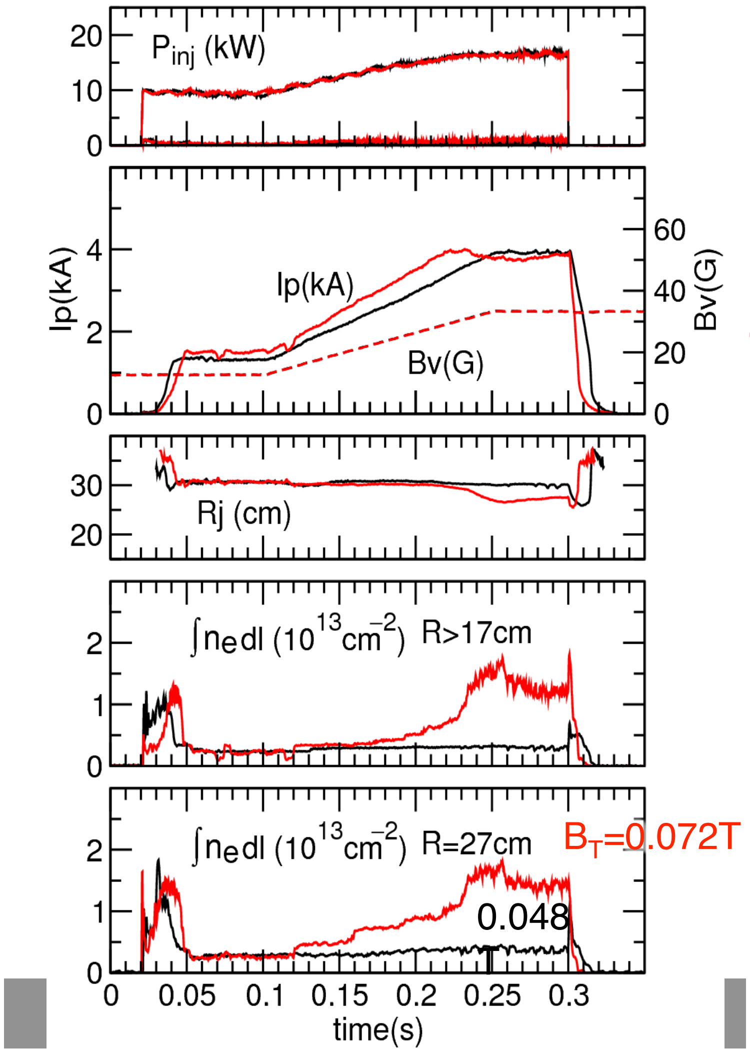
70GHz interferometer (4 chords),
Fast visible camera, Flux loops, Langmuir probes, Spectrometer,
SX cameras (1-poloidal)
AXUV cameras (1-poloidal, 2-toroidal)
4-chord PHA system (2-tangential, 2-vertical),

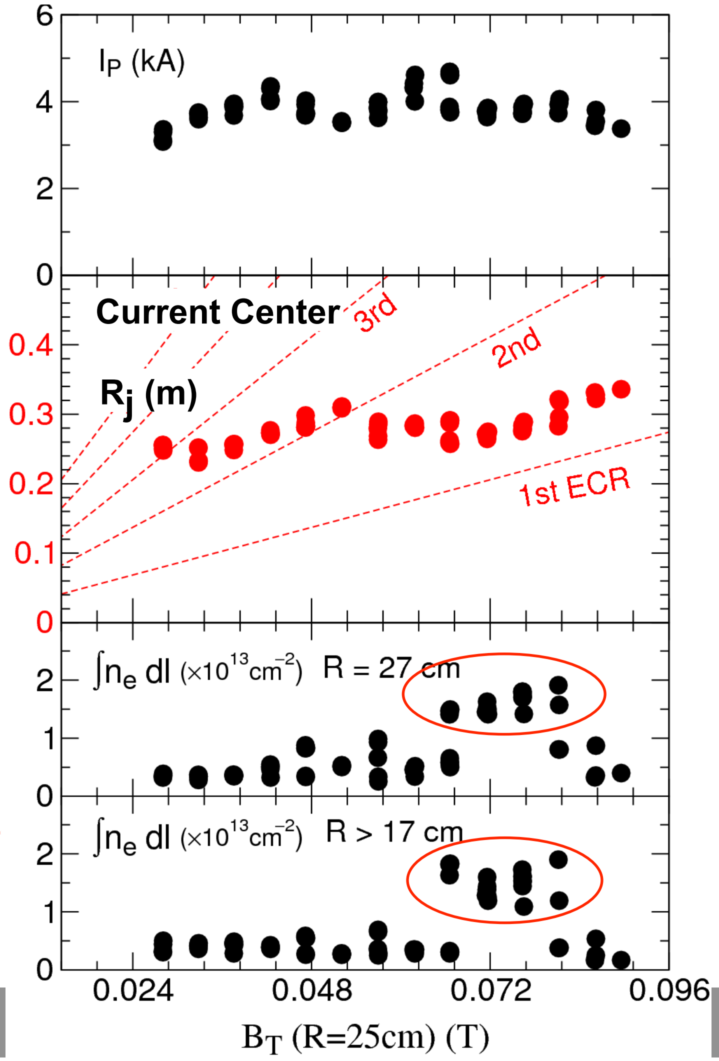
Four launching ports for 2.45 GHz injection

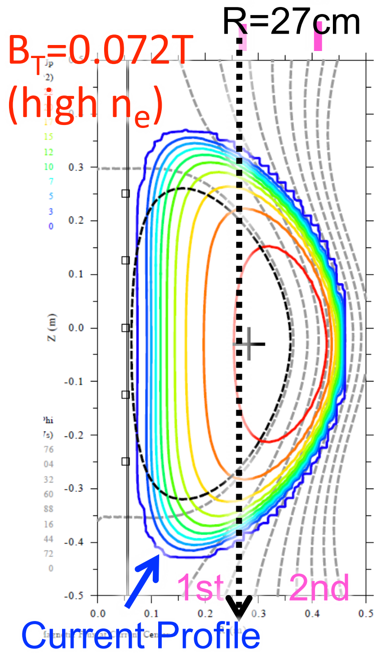


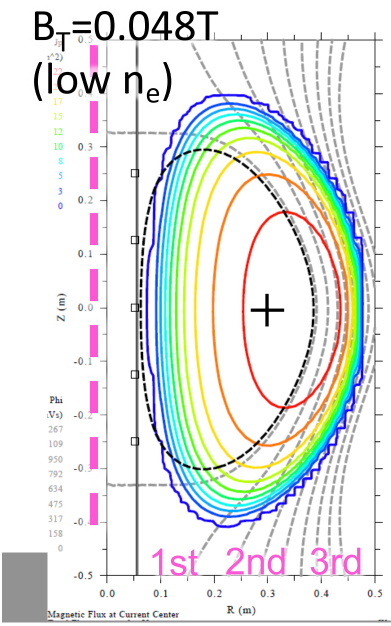
Electron density depends on ECR location

- Plasma current is roughly the same (Ip~4kA)
- Current center (Rj) slightly depends on the resonance location but stays near the vessel center of R~25 cm
- Electron density significantly increases when the 1st ECR locates R~20-22cm
  → effective heating of bulk electrons by EBW is expected in this configuration



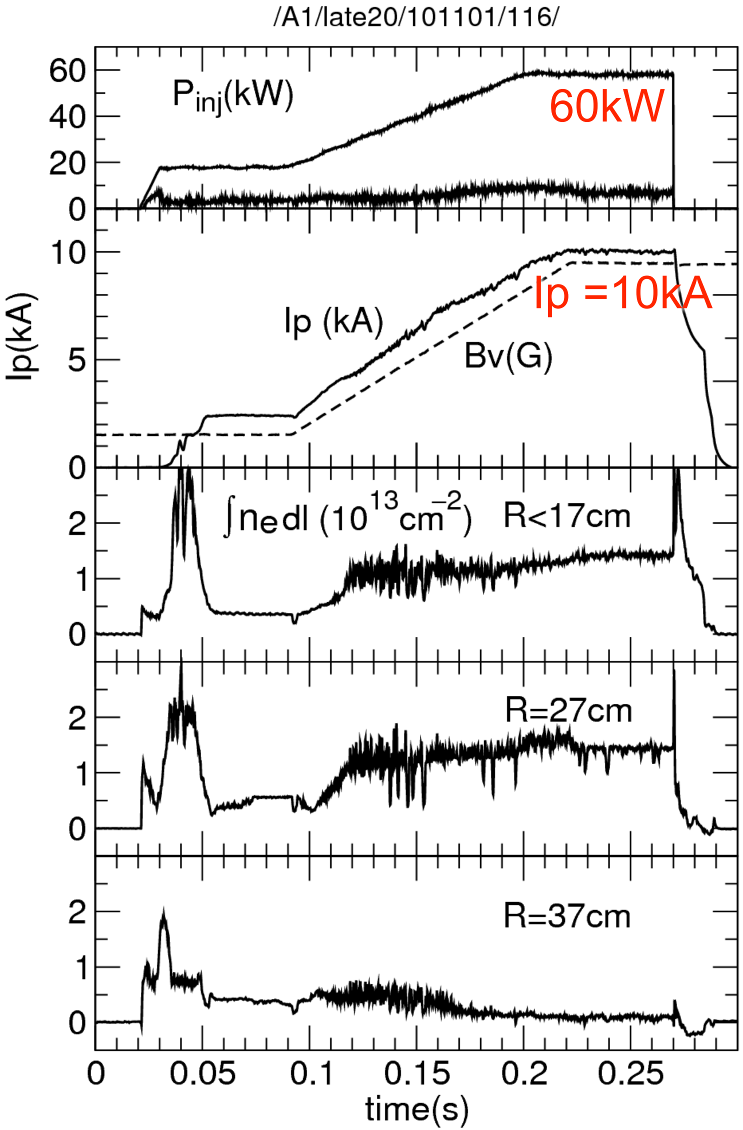






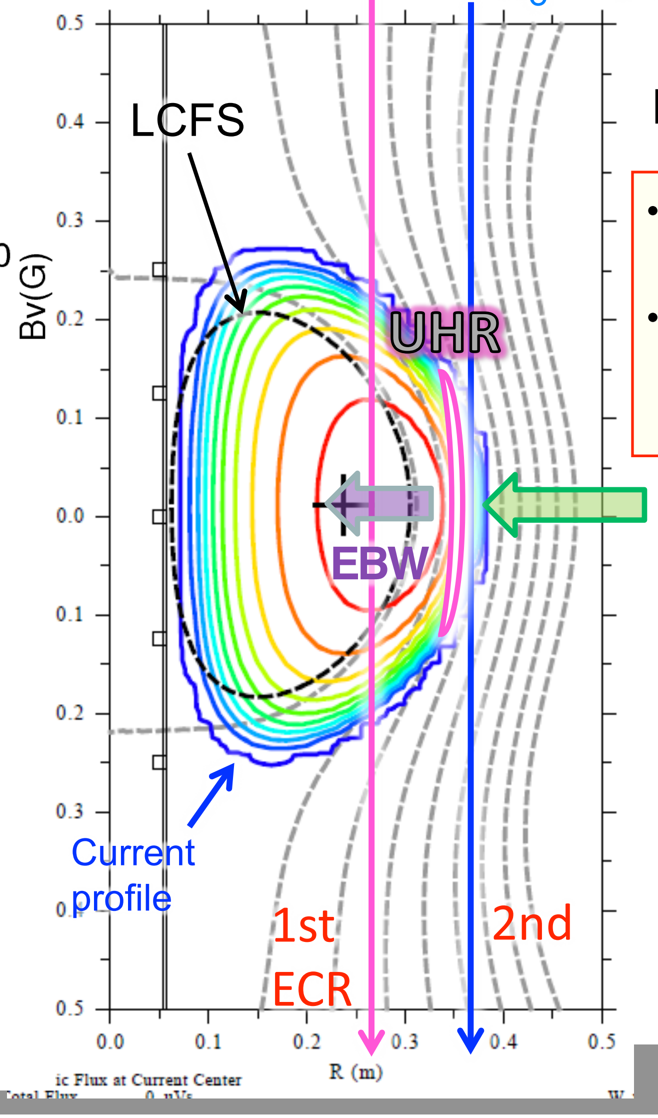
Electron density increases up to ~10 times the plasma cutoff density as Ip increases to 10 kA

ST plasma solely maintained by EBW is formed.



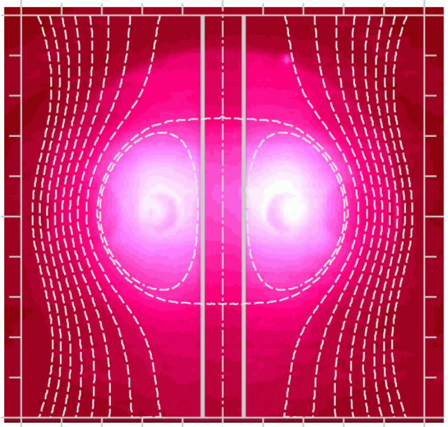
$n_e \sim 5\text{x}10^{11}\text{cm}^{-3} >> n_c=7\text{x}10^{10}\text{cm}^{-3}$

$n_e \sim 3\ \text{x}10^{10}\text{cm}^{-3}$



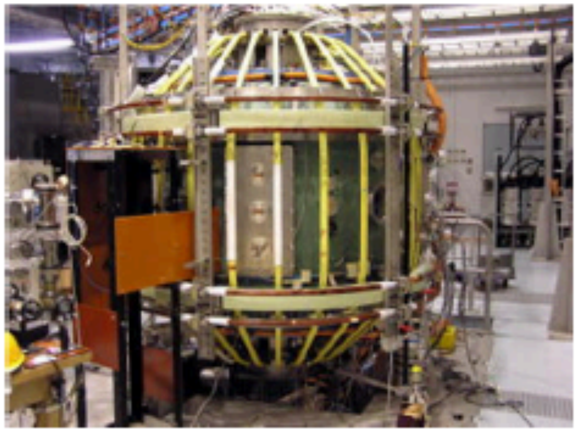
B_T = 0.072 T

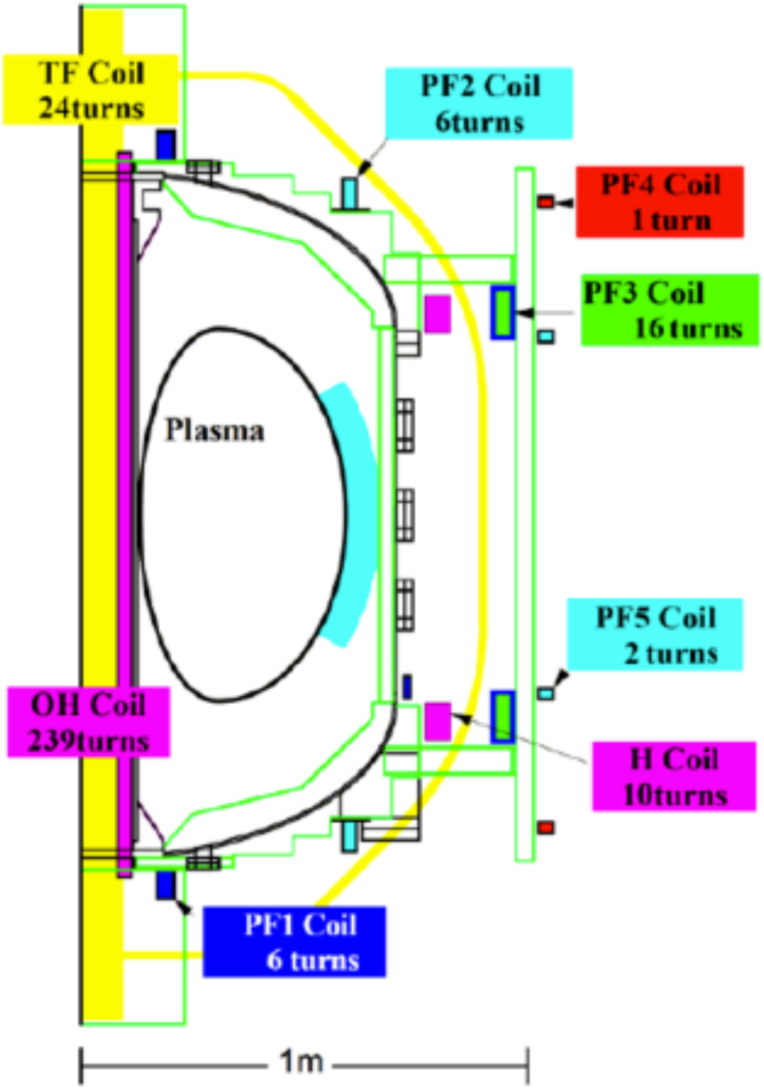
- UHR is located between 1st and 2nd ECR
- Good coupling to EBWs at their first propagation band is realized.



Visible Light Image

TST-2 spherical tokamak



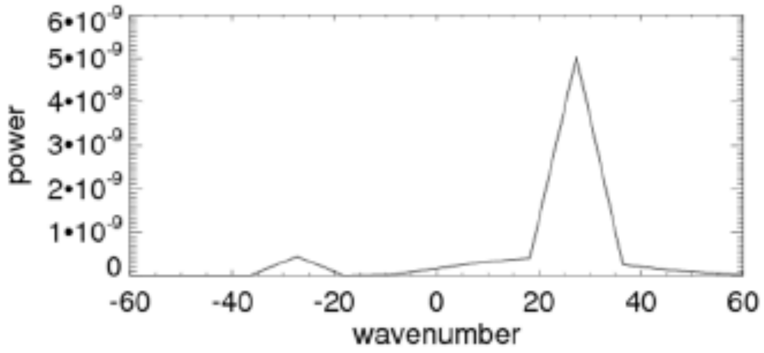


- Major radius R ~ 0.35 m
- Minor radius a ~ 0.23 m
- Aspect ratio A = R/a > 1.5
- Toroidal field B_t ~ 0.1 T

For LHCD ramp-up operation

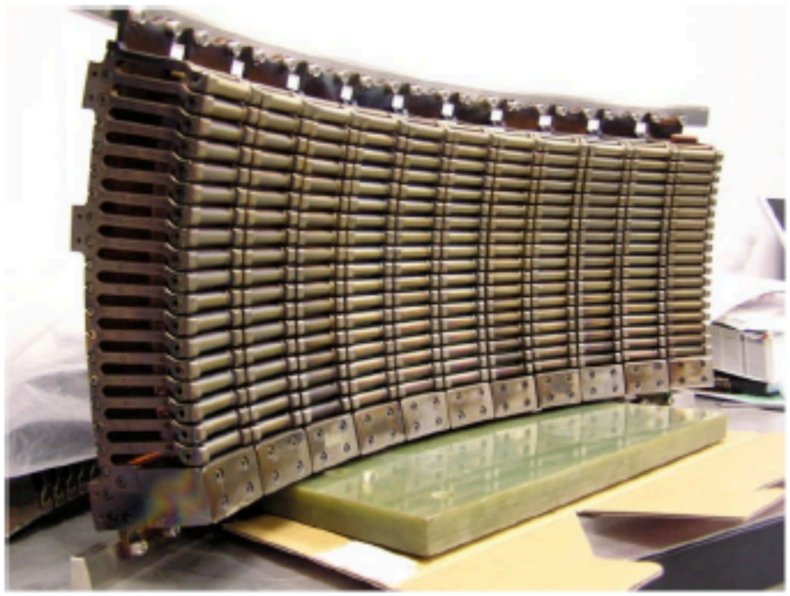
- Plasma current
  - $I_p < 15$ kA
- Discharge duration
  - $\Delta t < 120$ ms

Combline antenna

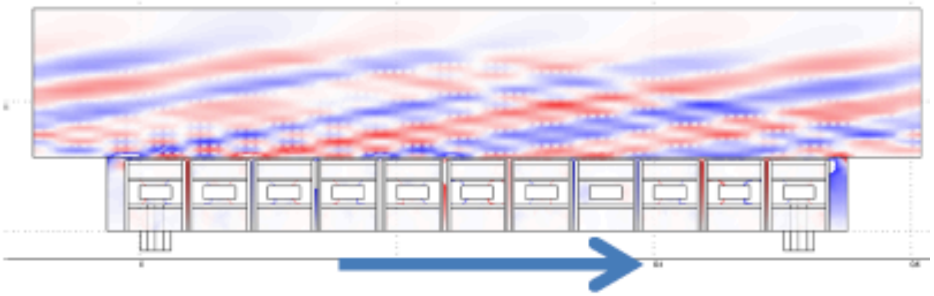


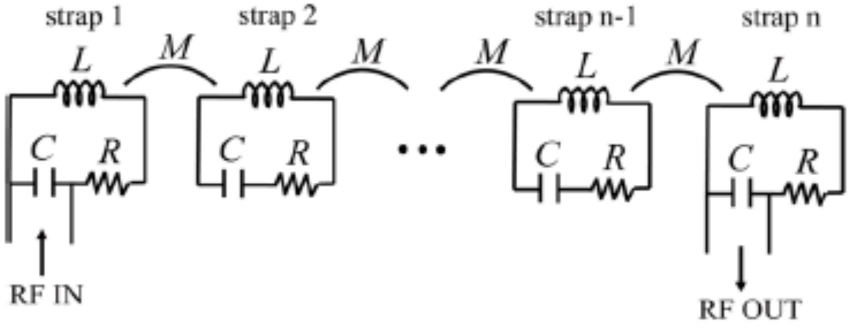
$n_{||} \sim +7.2$

(travelling wave)

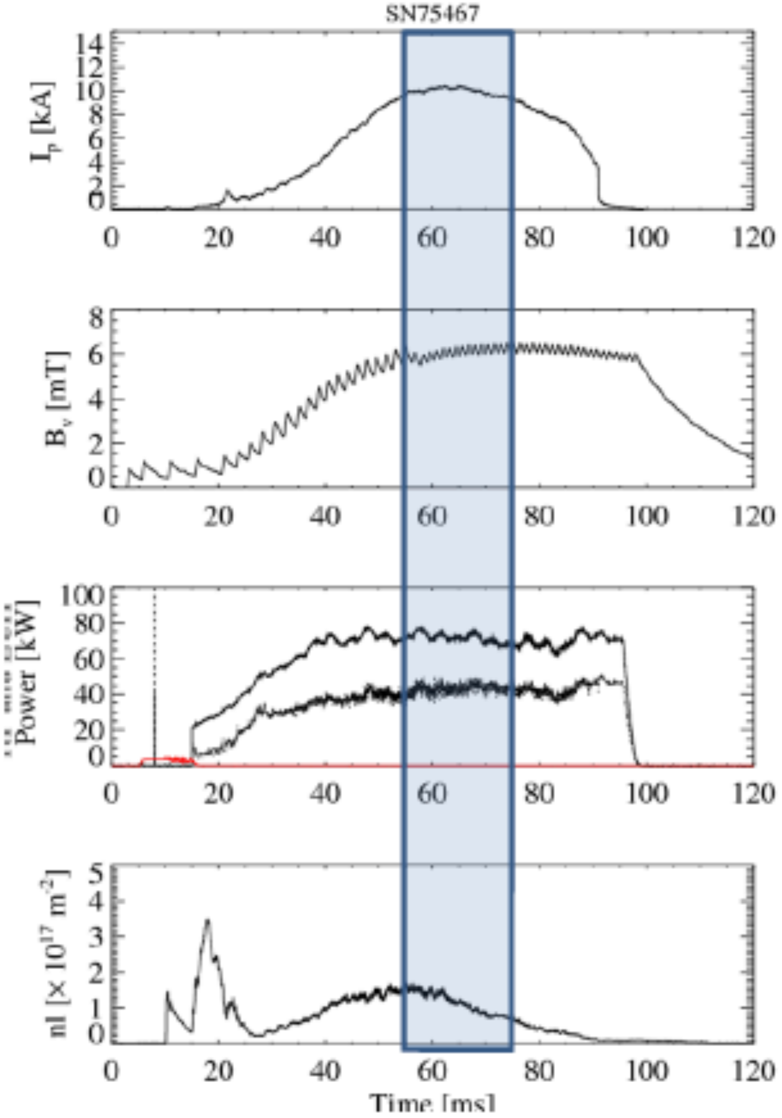


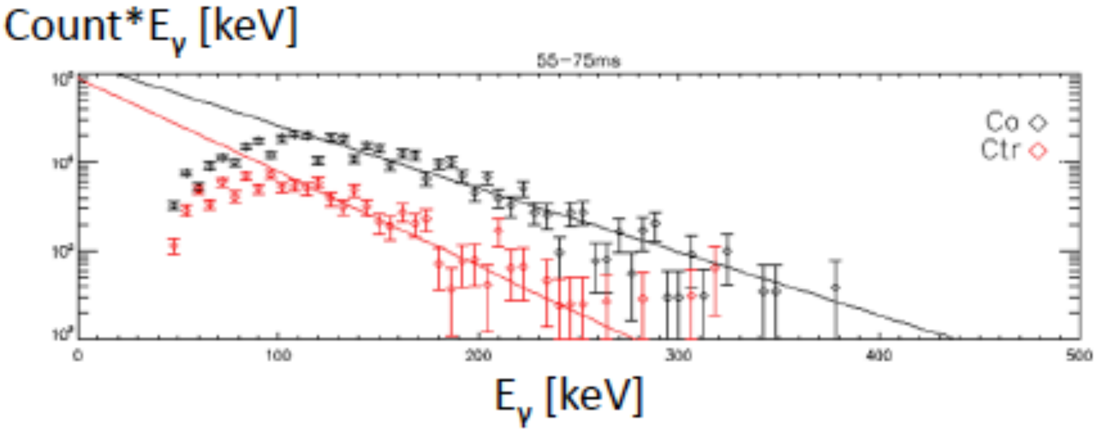
- This antenna is originally designed for fast wave excitation. However, FEM simulation predicts slow wave excitation.
- This is because the fast wave is cutoff for the density we consider.





Fast electron build up





- A slight difference in effective temperature of Hard X-ray can be seen.

T_{eff_Co}	T_{eff_Ctr}
61±6 keV	41±5 keV