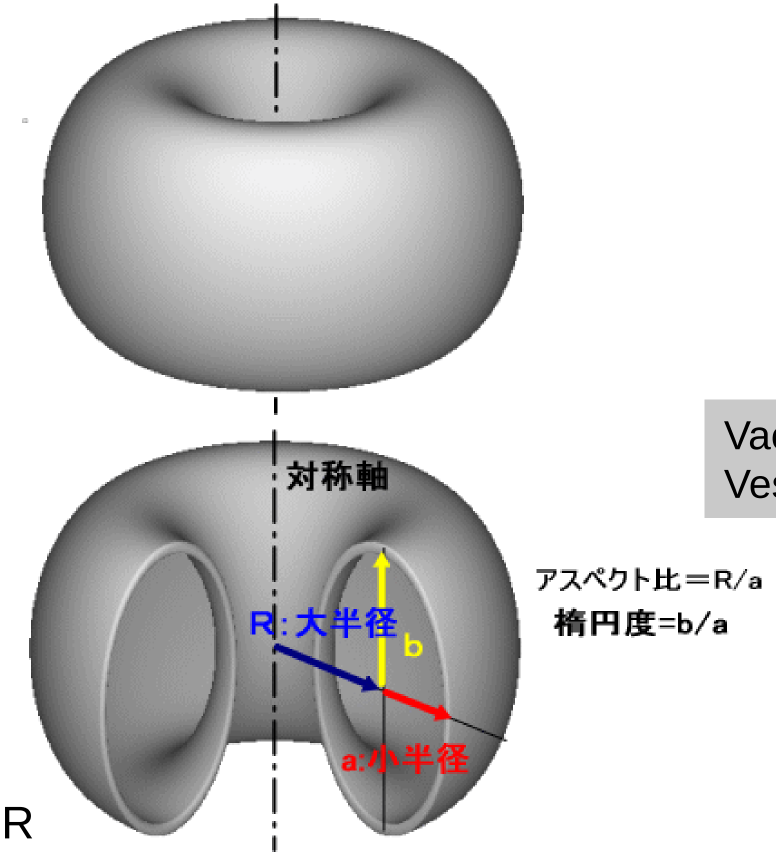
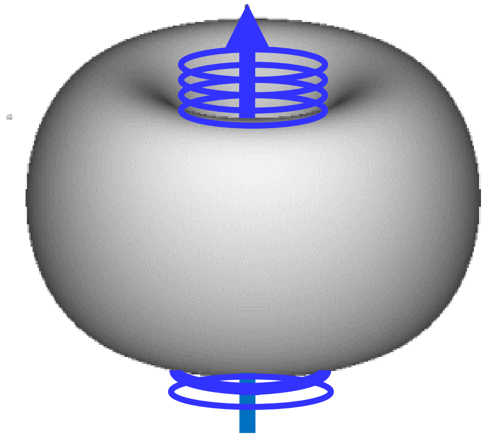
TST-2 device

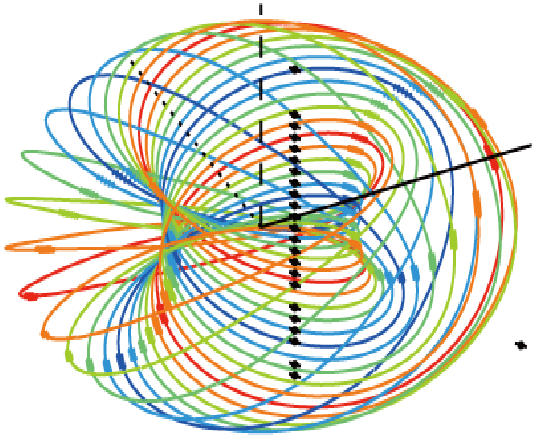
Outline

- Tokamak
- TST-2 device
- Typical plasma parameters
- Pumping and gas feeding system
- Coils and typical discharge waveforms
- Shaping experiment
- Breakdown
- Spontaneous ST formation
- AC Ohmic coil operation

Plasma has a torus shape

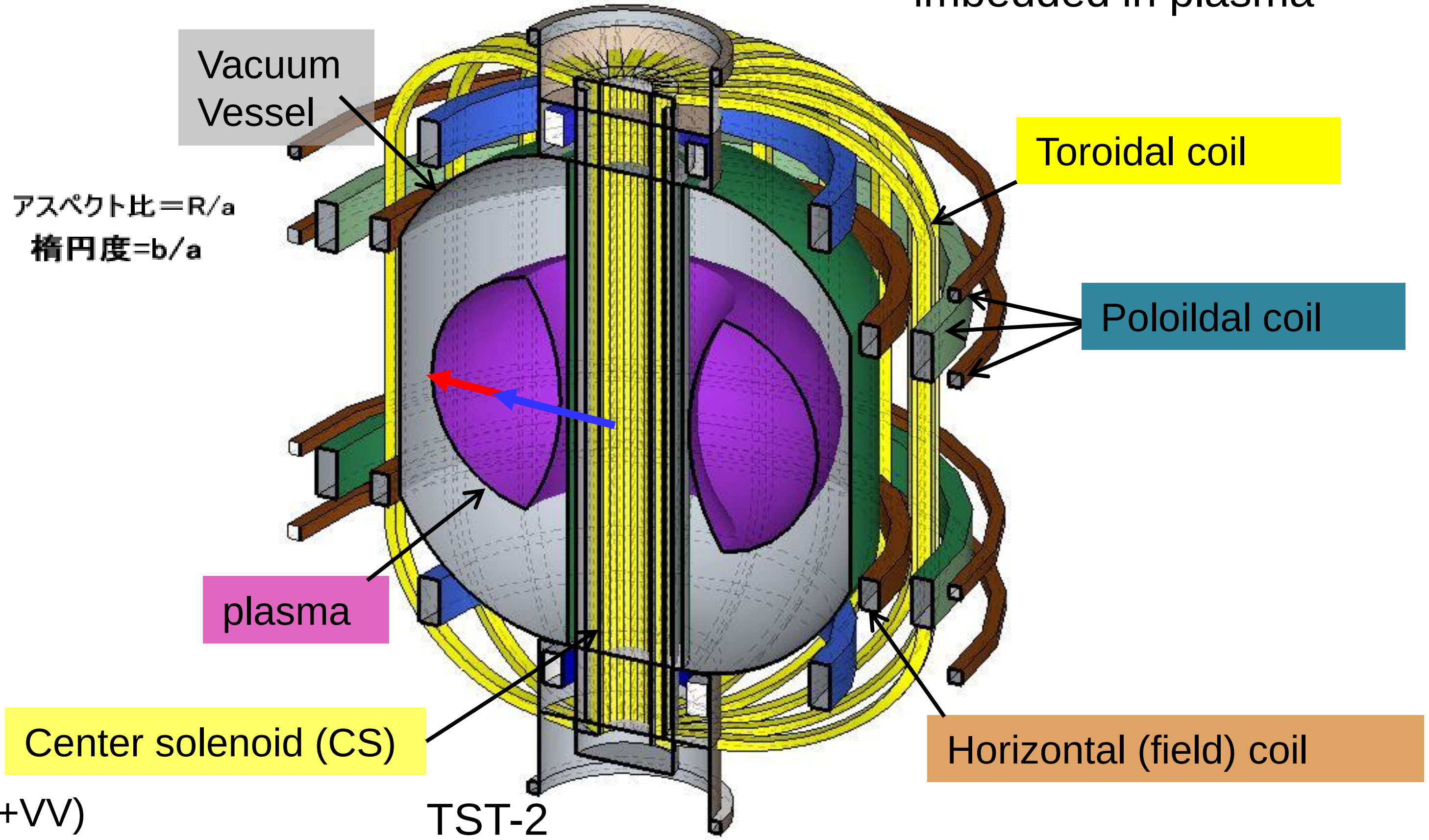






Magnetic fields imbedded in plasma

Sizes
major radius: R
minor radius: a
aspect ratio R/a
ellipticity k=b/a



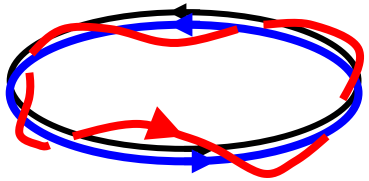
TST-2

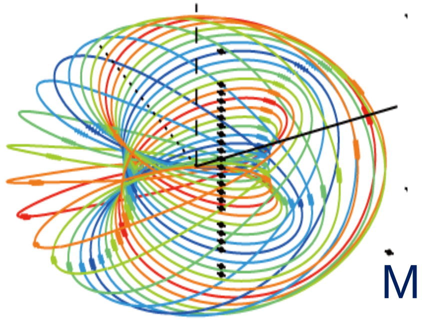
Note: center stack=central part (CS+TF+VV)

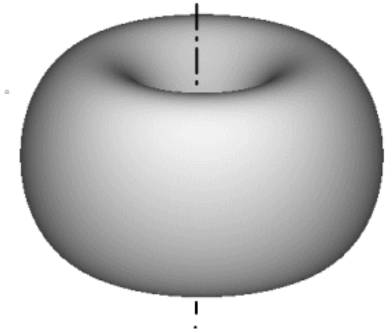
Current drive is a critical issue in tokamak

tokamak configuration

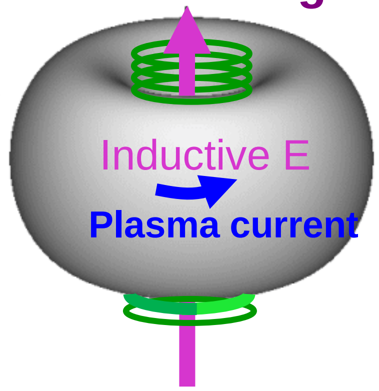
- External toroidal field
- Plasma current driven by inductive field or by noninductive methods, like RF (radio frequency)



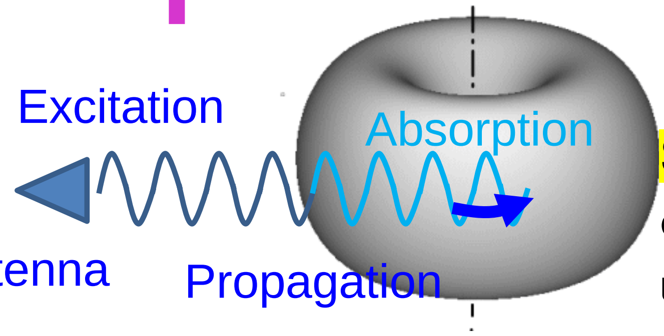




Current drive method



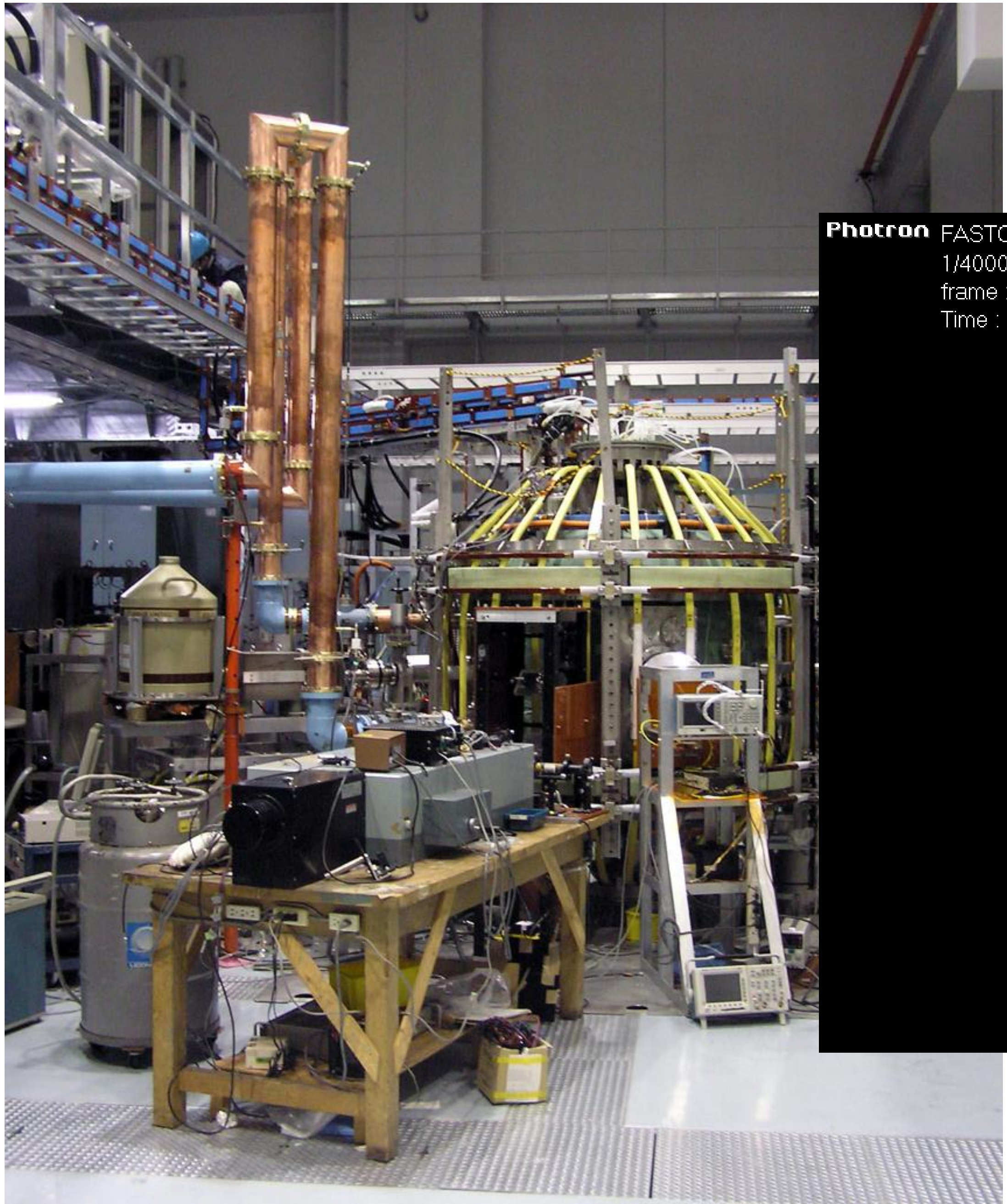
Present main method
Pulse discharge

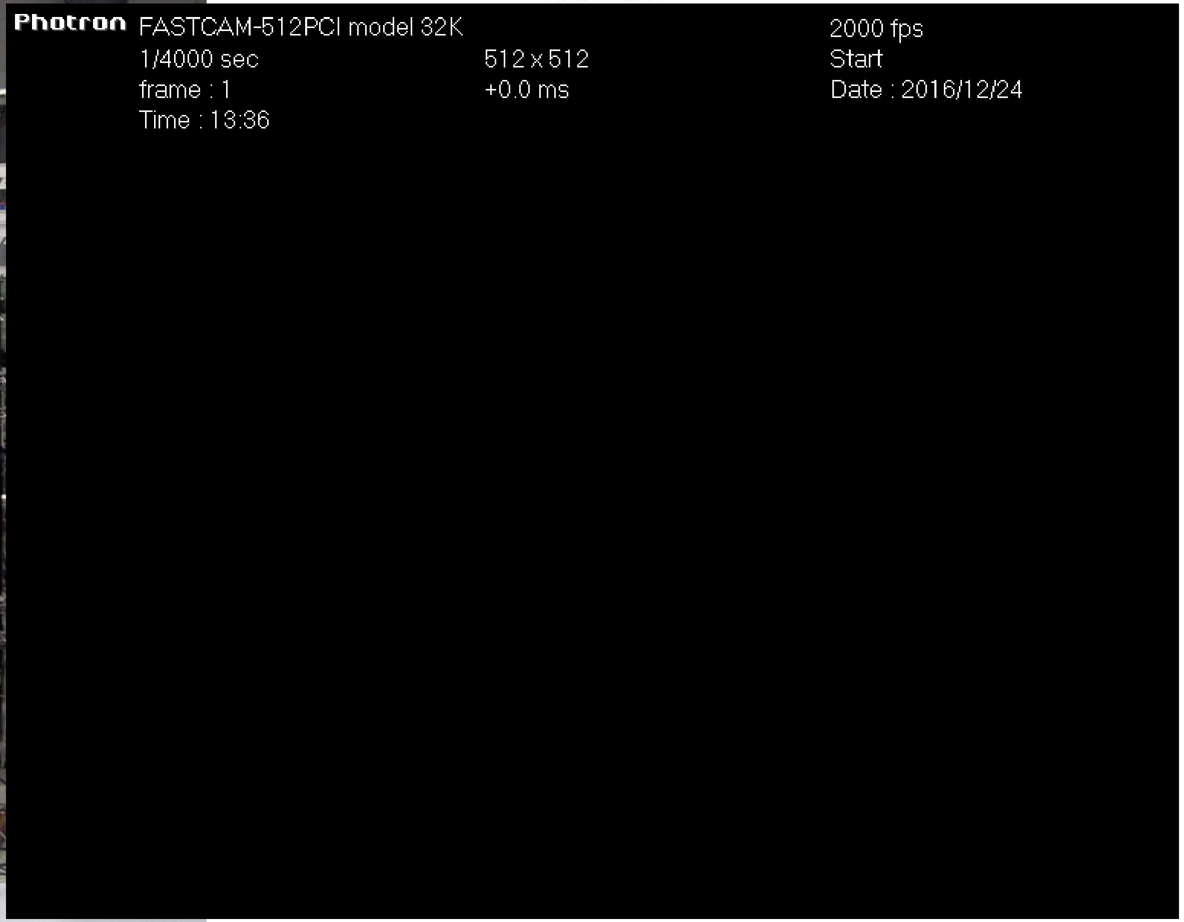


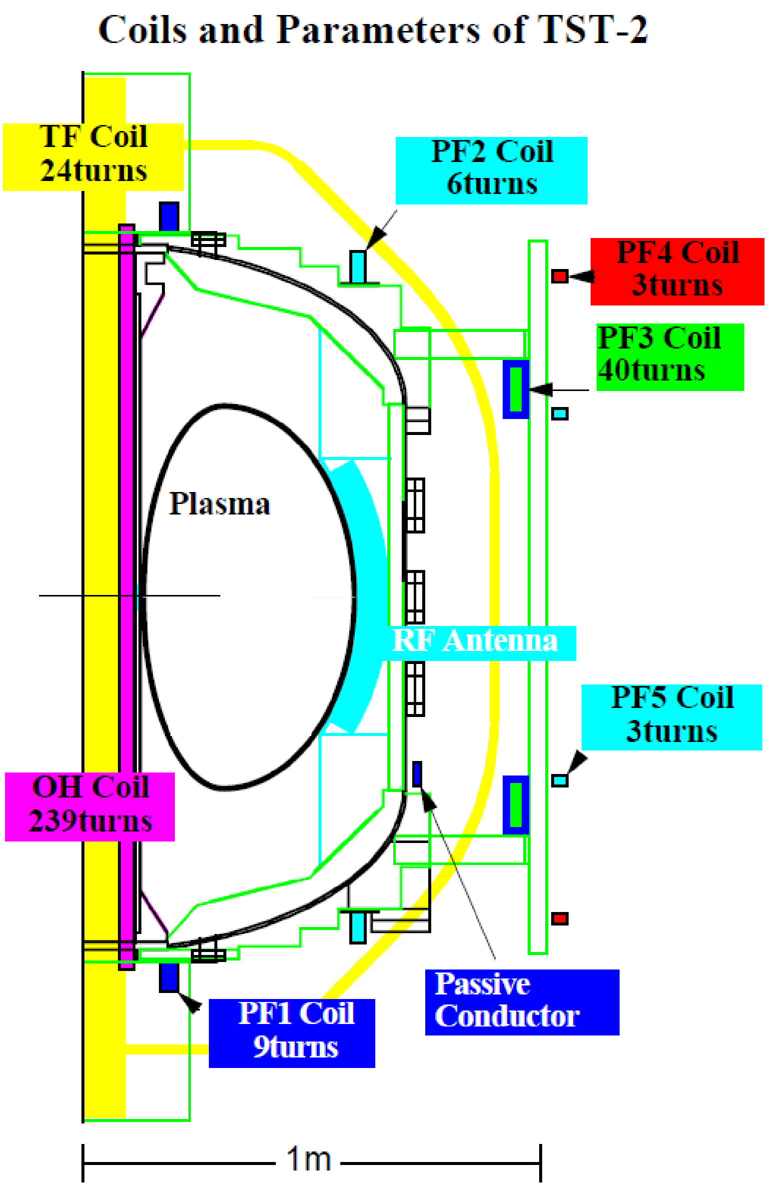
Steady state operation (discharge) requires an efficient current drive method. We have to understand the interaction between the plasma and the wave

TST-2球状トマカク装置@Kashiwa Campus

東京大学　新領域創成科学研究科　複雑理工学専攻
江尻晶･辻井直人研







Spec. of the TST-2 spherical tomakak

Major radius : ~0.36 m

Minor radius : ~0.23 m

Toroidal field : < 0.3 T

Plasma current : 25 kA/120 kA

Discharge duration : 0.1 s/ 0.025 s

Electron temperature : 10 eV/ 400 eV

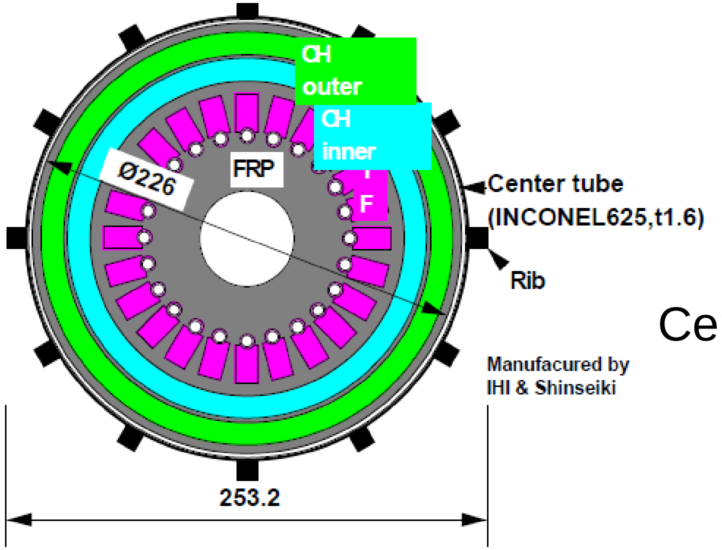
Electron density : $>1x10^{17}$ m^{-3}/< $2x10^{19}$ m^{-3}

Various RF sources

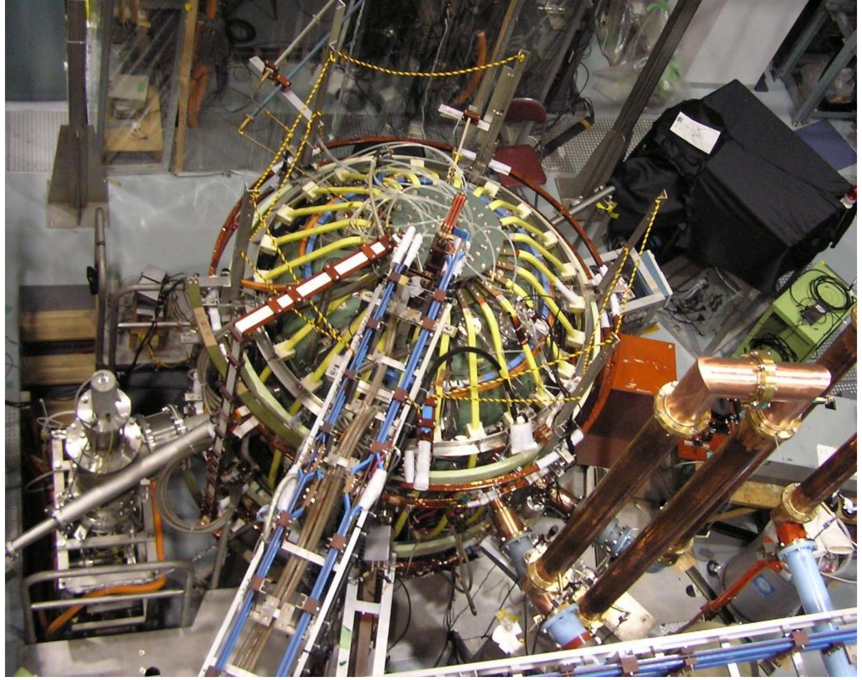
ECH : 2.45 GHz/5 kW, 8.2 GHz/ < 20 kW

HHFW: 21 MHz/ < 400 kW

LHW: 200 MHz/ < 400 kW

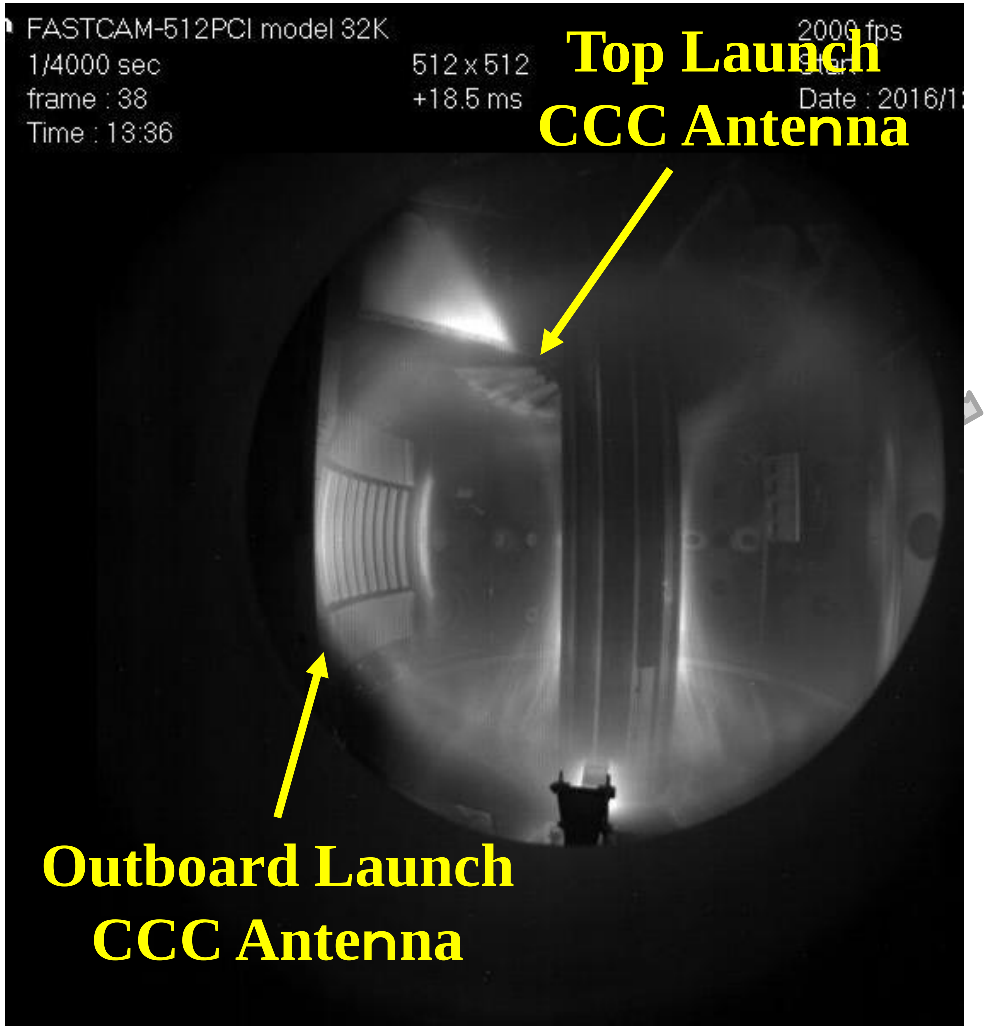


Center stack

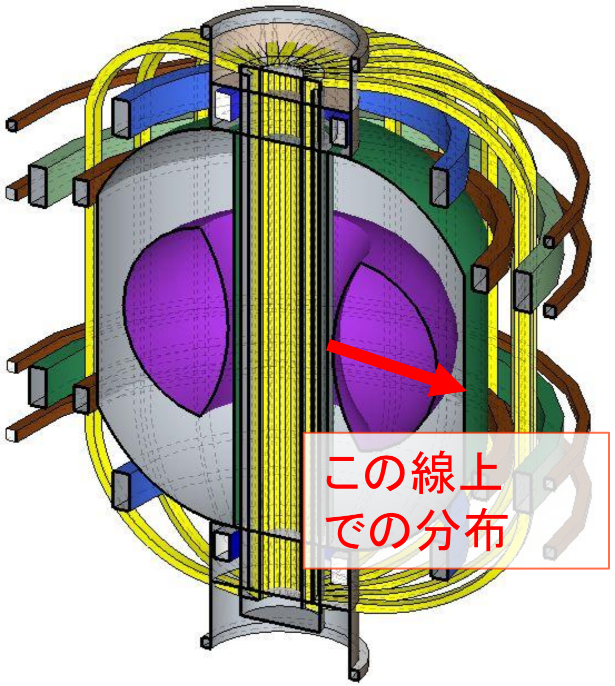


Research issues
RF current drive
High energy electron
Development of plasma diagnostics
Instabilities and turbulence

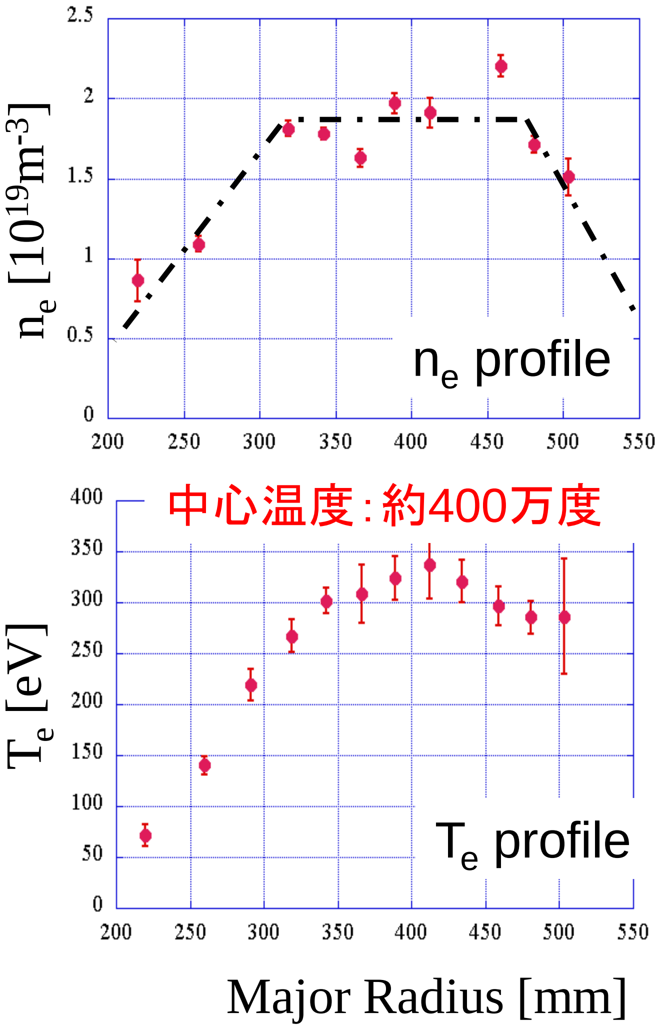
4 RF units of 200 kW/200 MHz



Typical density and temperature profiles in TST-2

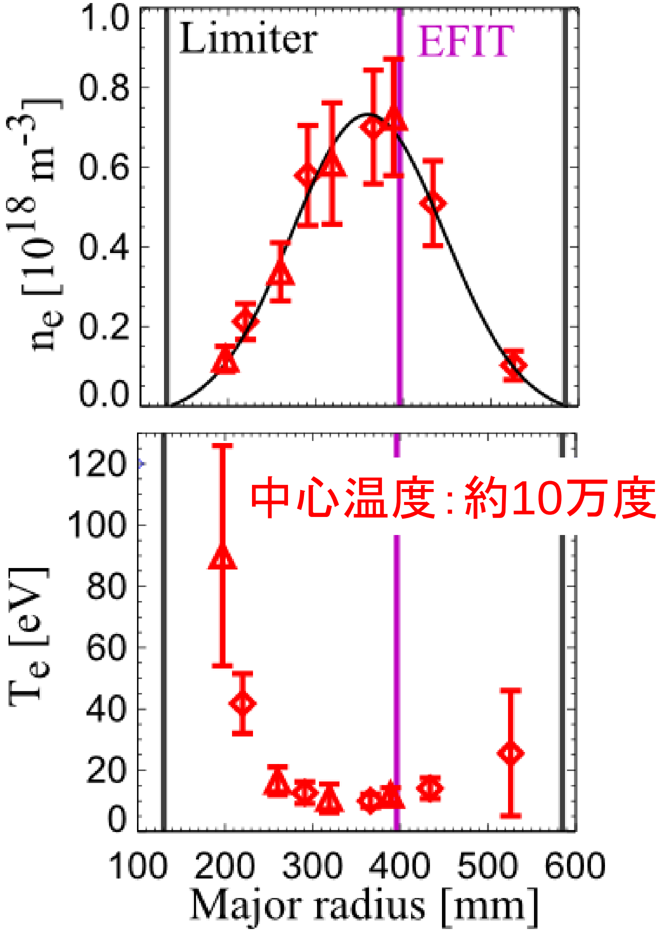


Joule (Ohmic) heating



J. Hiratsuka, et al.

Wave heating

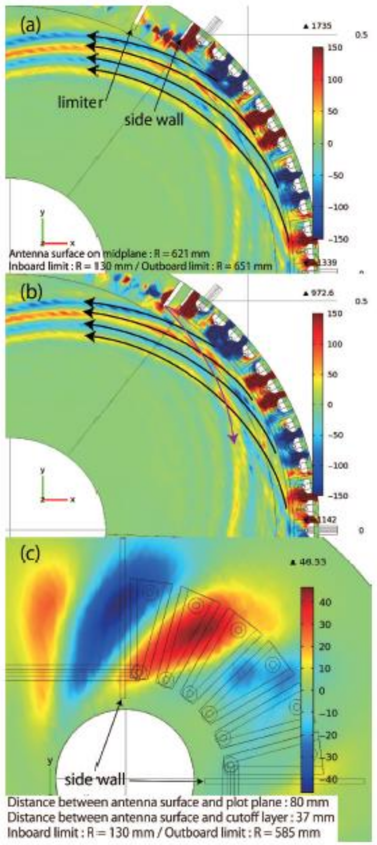


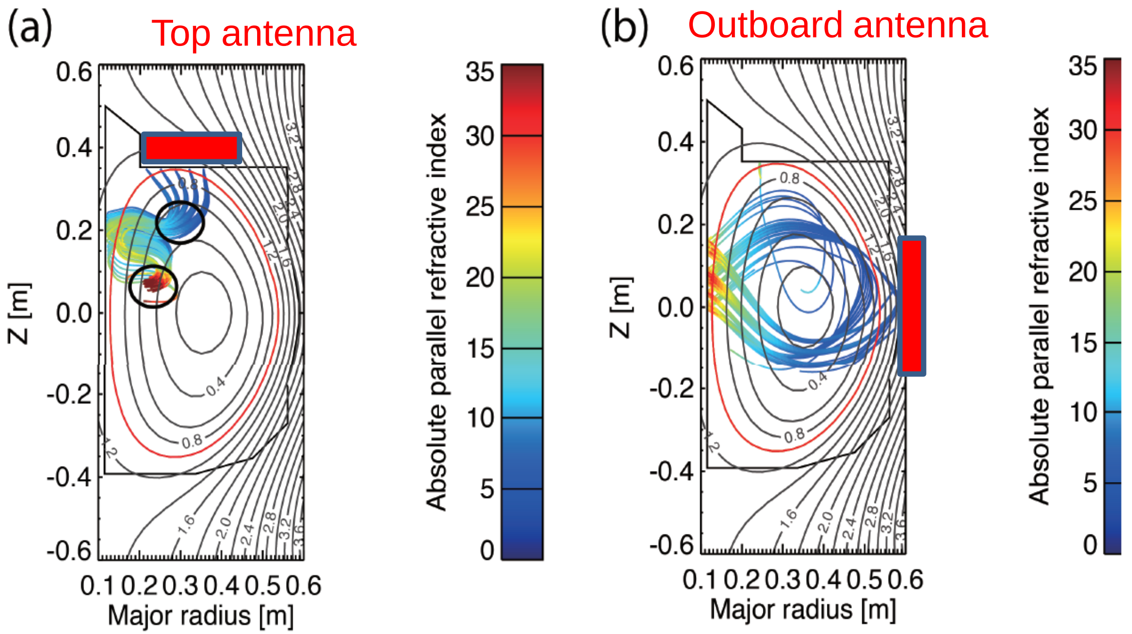
H.Togashi, et al.

Wave physics

Heating and current drive

Prediction by ray tracing + Fokker Planck solver





S. Yajima, et al., Plasma Fusion Research 13 3402114 (2018)

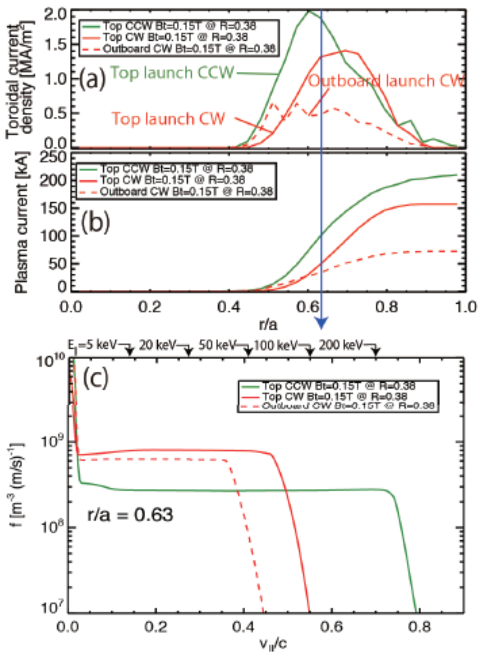


Fig. 4 (a) Plasma current density profile and (b) integrated plasma current, and (c) parallel electron velocity distribution function $f(v_\parallel/c)$ at r/a = 0.63 obtained by GENRAY/CQL3D [8]. Note that $v_\parallel/c$ corresponds to $1/N_\parallel$.

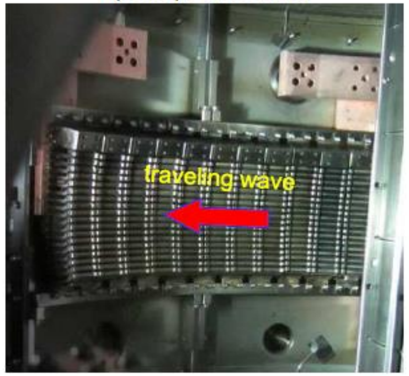
Antenna ⇨ Excitation ⇨ Propagation ⇨ Absorption ⇨ Velocity distribution ⇨ Current Magnetic field ⇨ Temperature and density

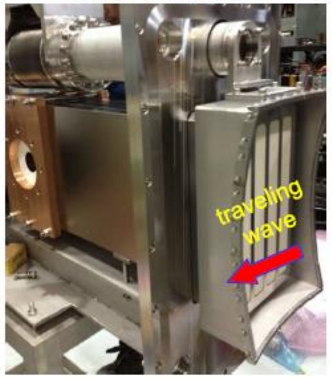
Change in wavenumber and direction

Landau damping
Cyclotron damping

Plasma heating and current drive using various antennas

Antennas in the past



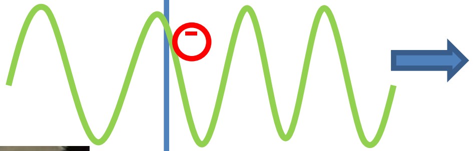


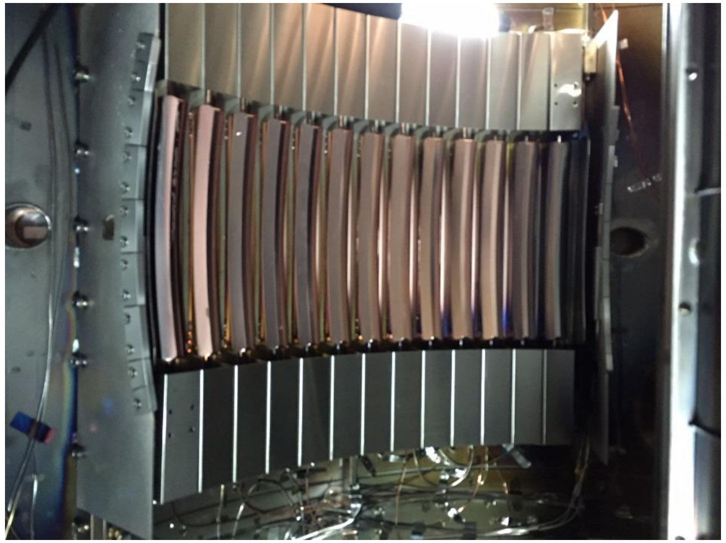
Present antennas

Capacitively coupled combline (CCC) antenna

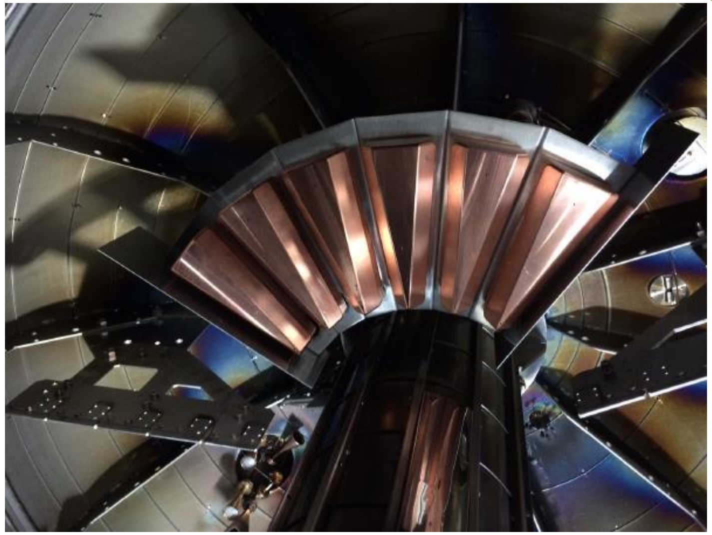
- Traveling SW is excited directly
- Sharp $n_{\parallel}$ spectrum & high directivity

travelling wave is necessary





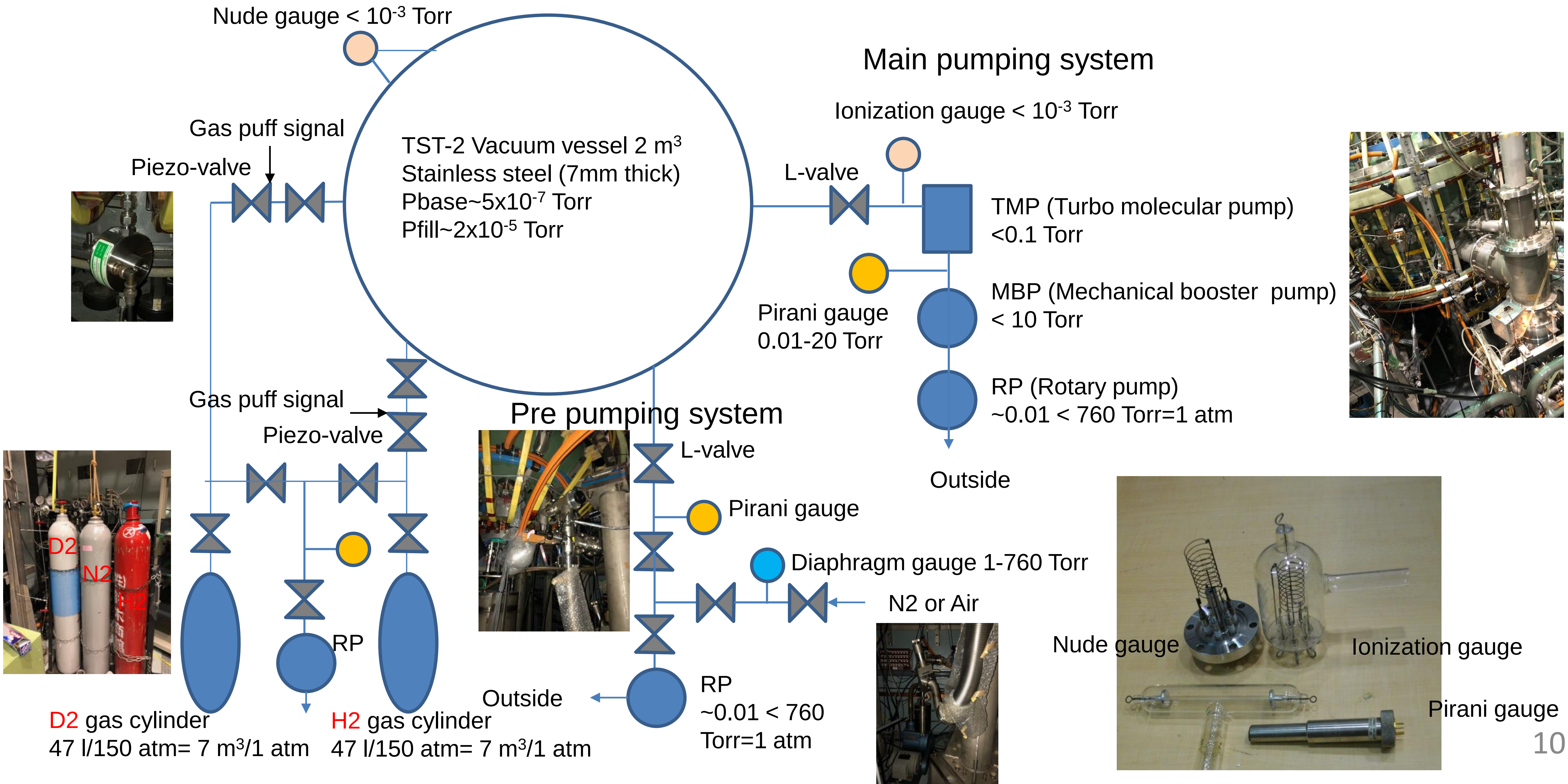
Outboard launch



Top-launch

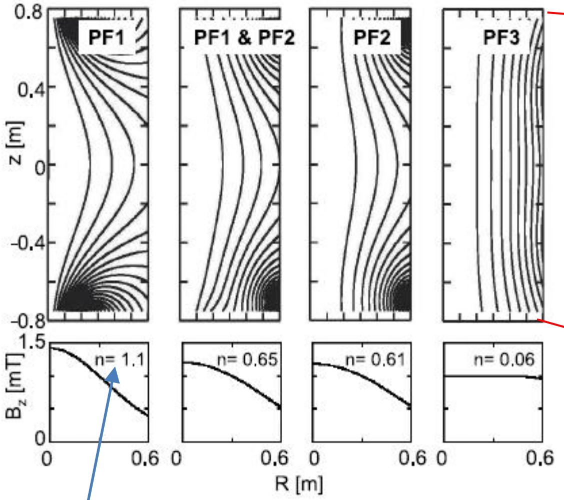
Developed in collaboration with C.P. Moeller (GA, US)

Vacuum pumping and gas feeding system



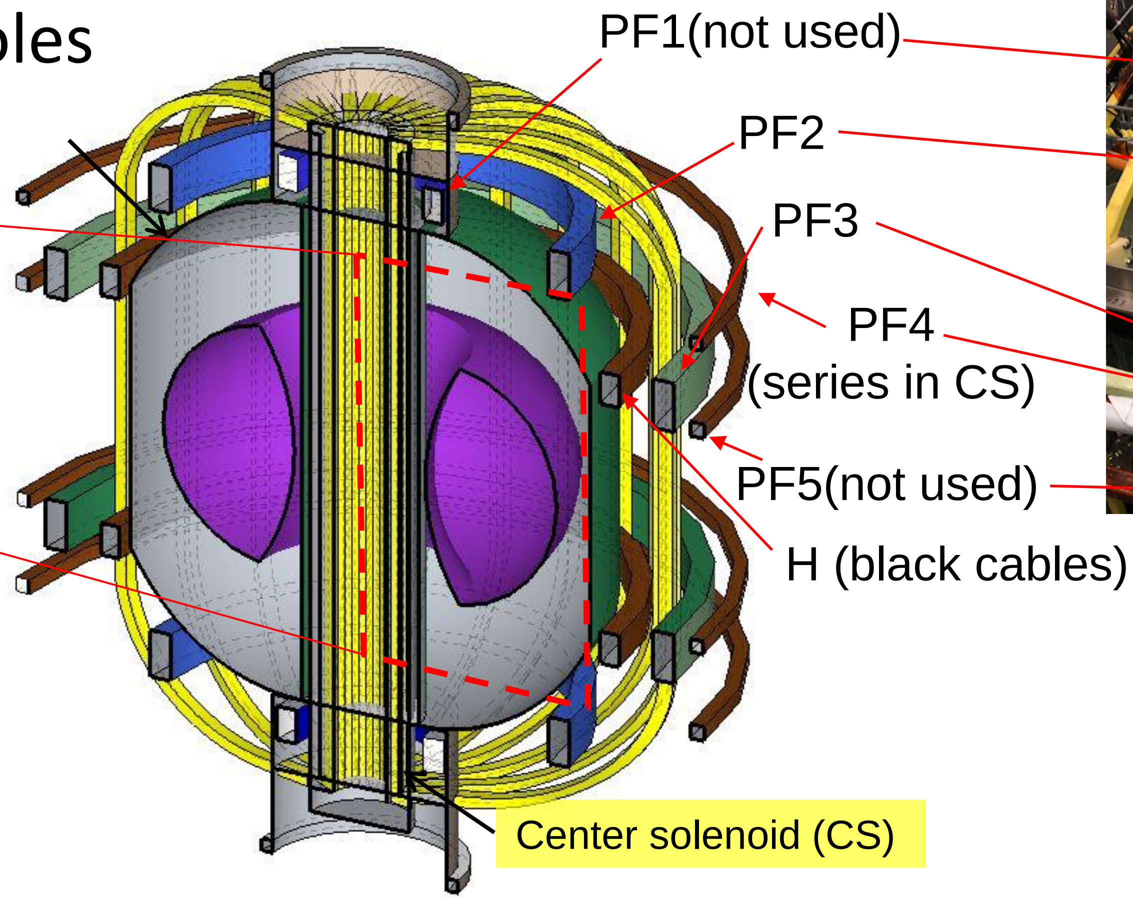
TST-2 coils and their roles

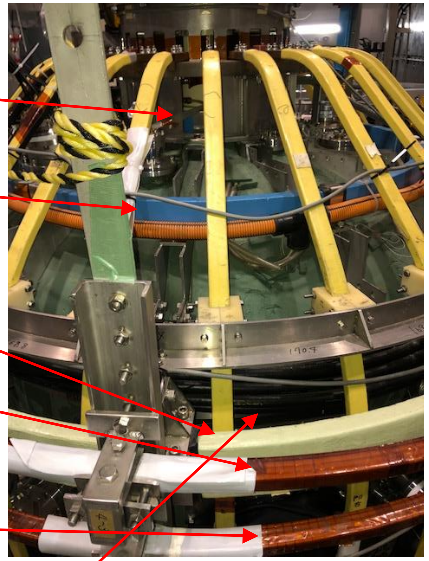
Various vacuum fields



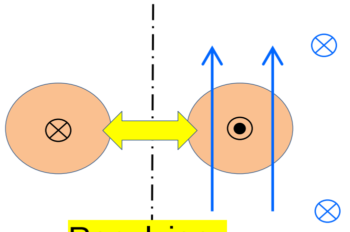
$$n_{index} \equiv -\frac{\partial B_z}{\partial R}\frac{R}{B_z}$$

measure of the shaping and vertical stability



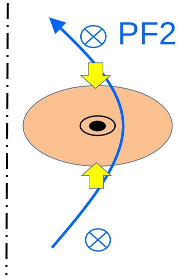


Main role of PF

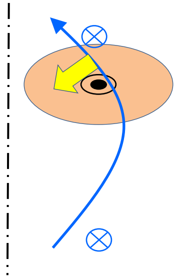


Equilibrium in tokamak represents mainly the force balance between the outward hoop force and the inward force by the external vertical field

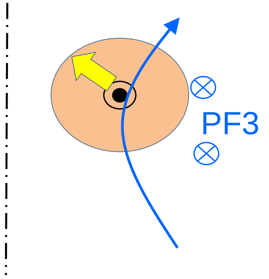
Vertical compress



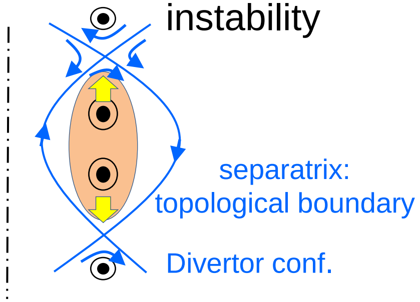
Vertical stability



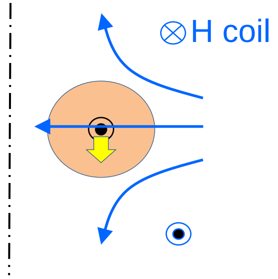
Vertical instability



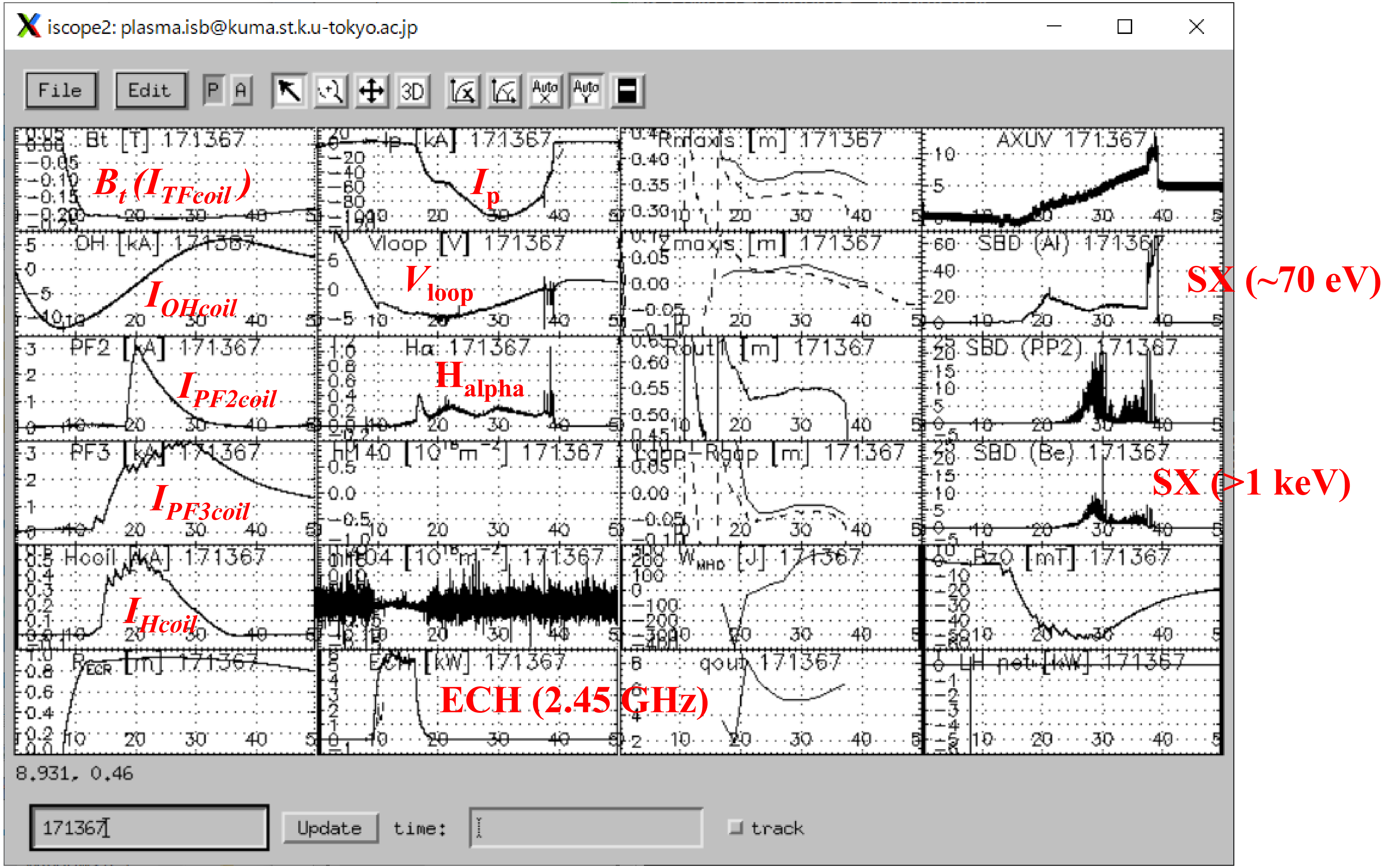
Vertical elongation, instability



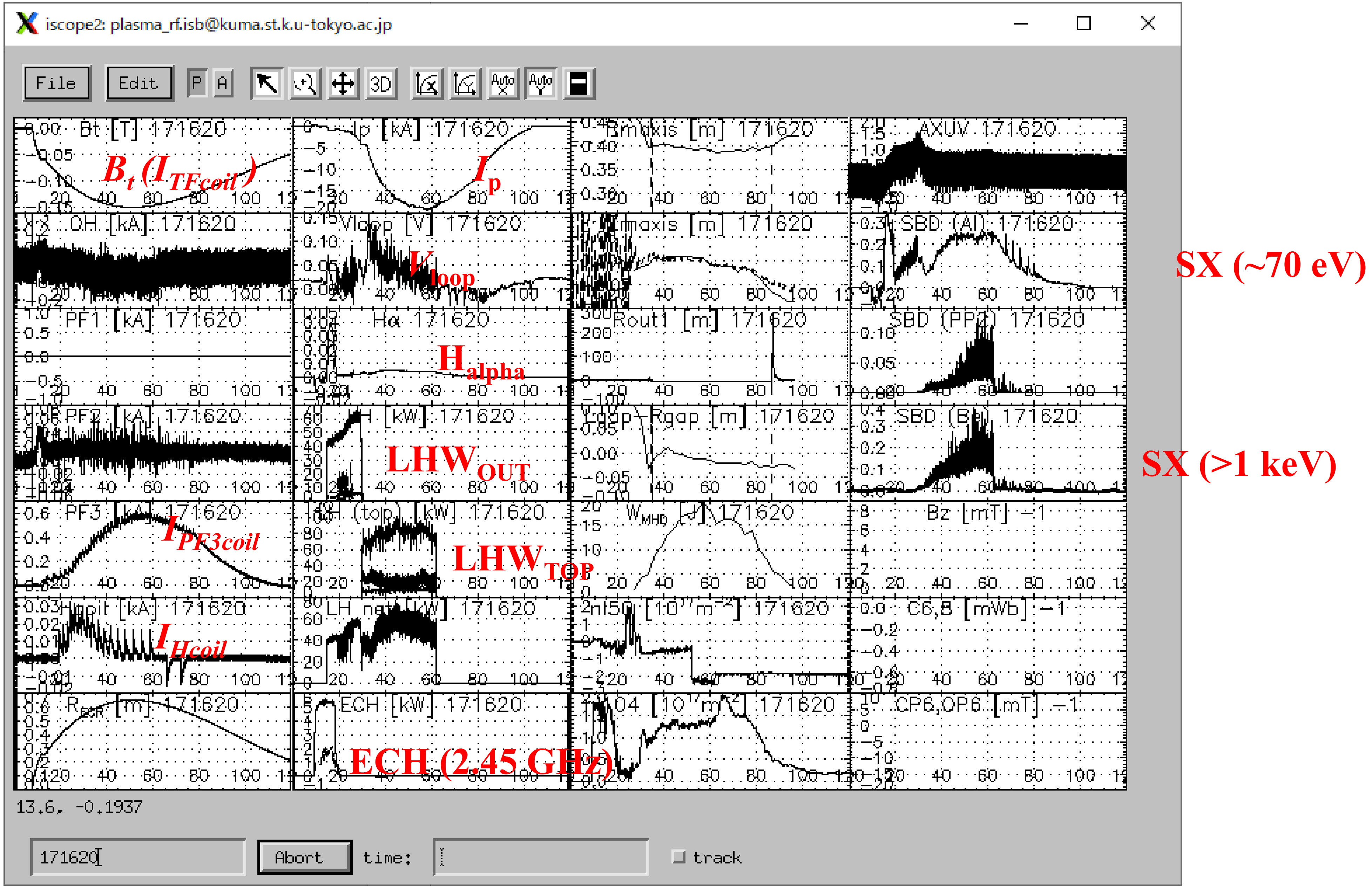
Vertical shift



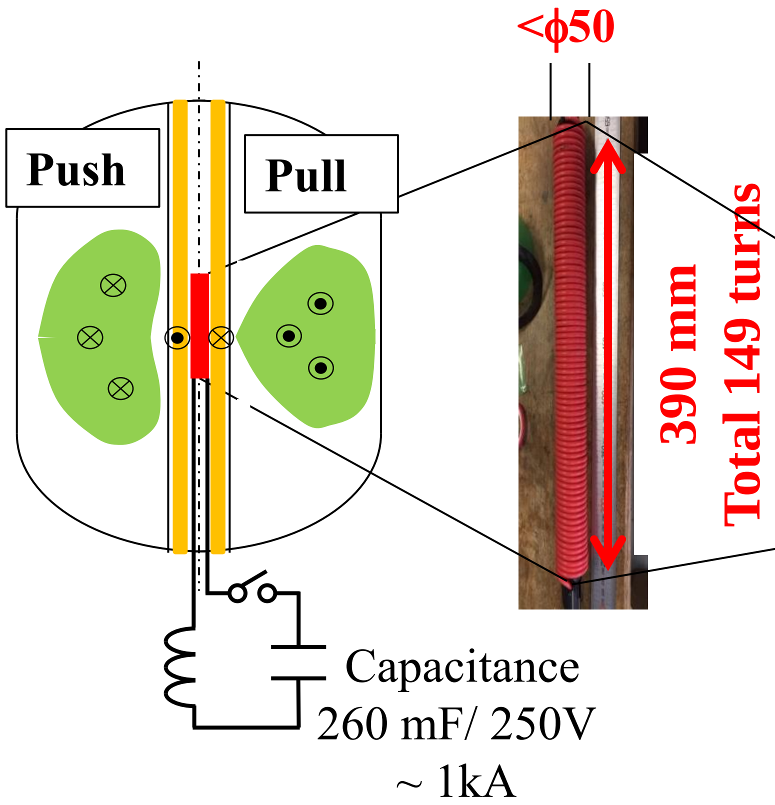
Ohmic discharge (inductive start-up)

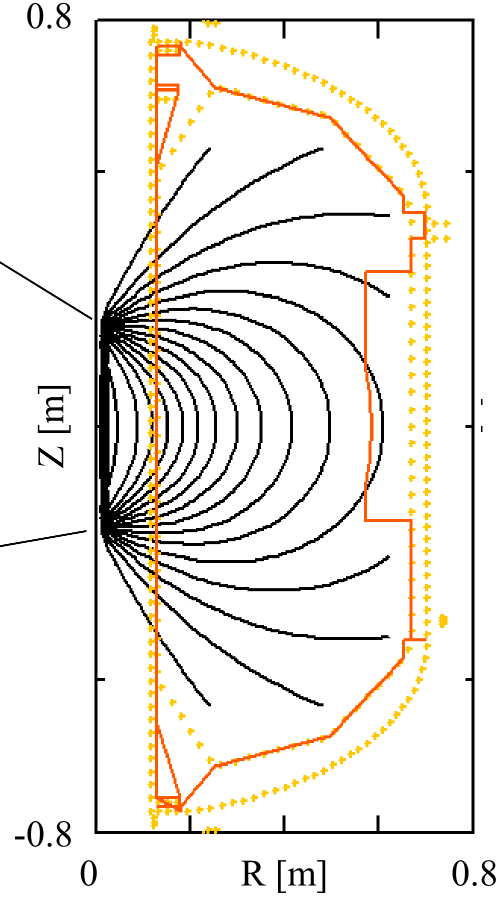


RF discharge (noninductive start-up)

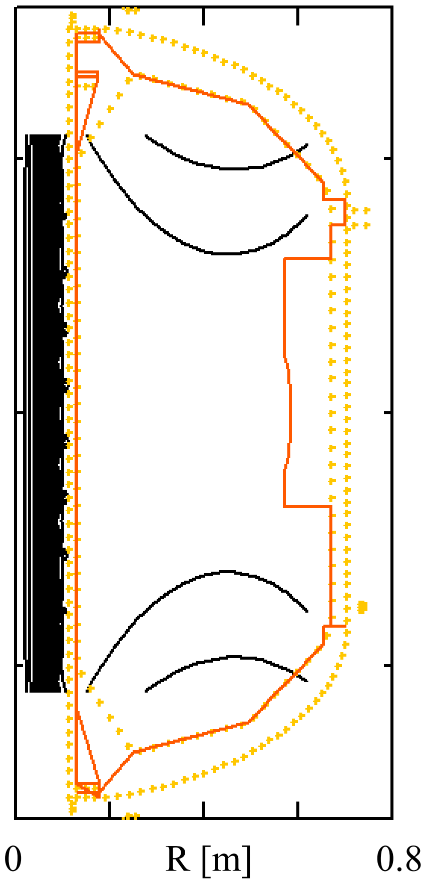


Shaping experiment using a compact center solenoid located at the center of the torus

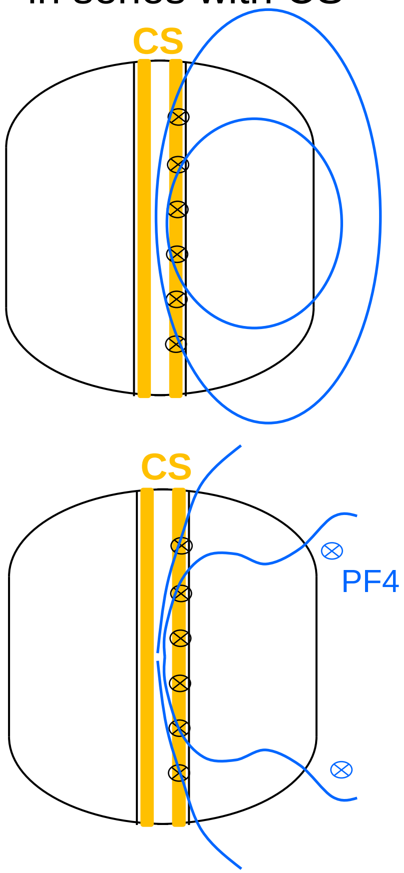


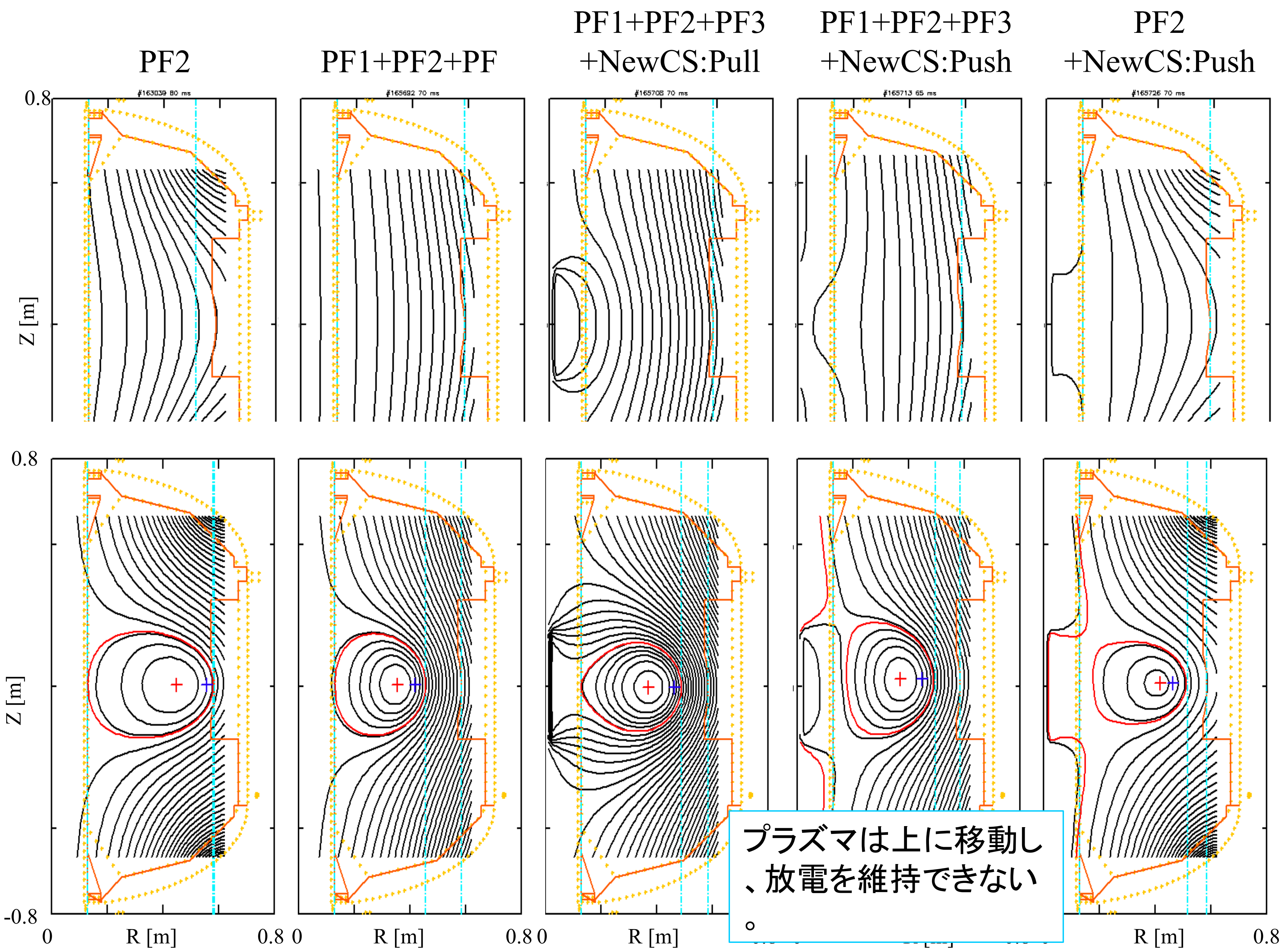


Cf.
Flux surface by the normal Ohmic coil



The role of PF4 connected in series with CS





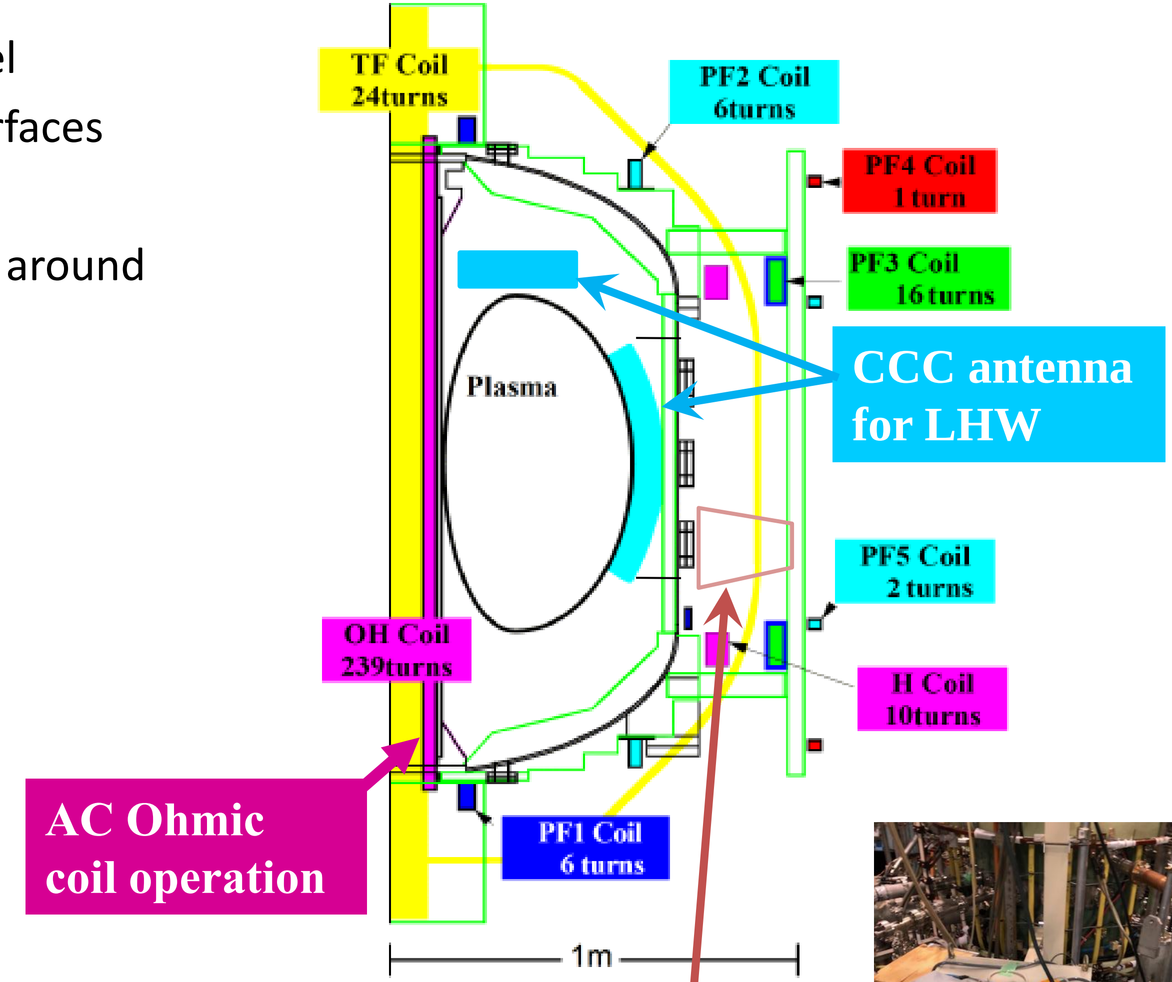
プラズマは上に移動し
、放電を維持できない
。

Breakdown in tokamak

1. Pre-ionization: increase the density to a certain level
2. Plasma current generation to make a closed flux surfaces
   -> enhance the confinement and heating efficiency
3. Burn through: overcome the radiation loss (barrier) around Te=10-50 eV
4. Plasma current ramp-up
   ->larger current implies higher Joule heating

Three operational scenarios

- Pure inductive breakdown (and tokamak formation)
- ECH assisted inductive breakdown
- Noninductive (RF) start-up

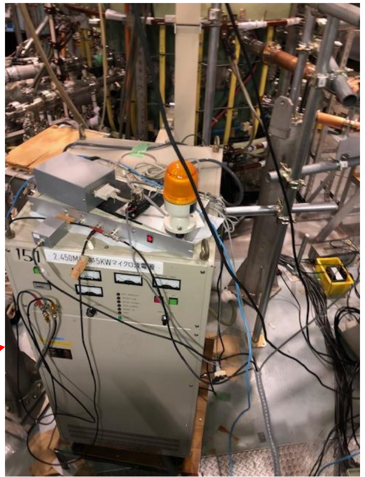


Less inductive or noninductive breakdown or start-up is very important because

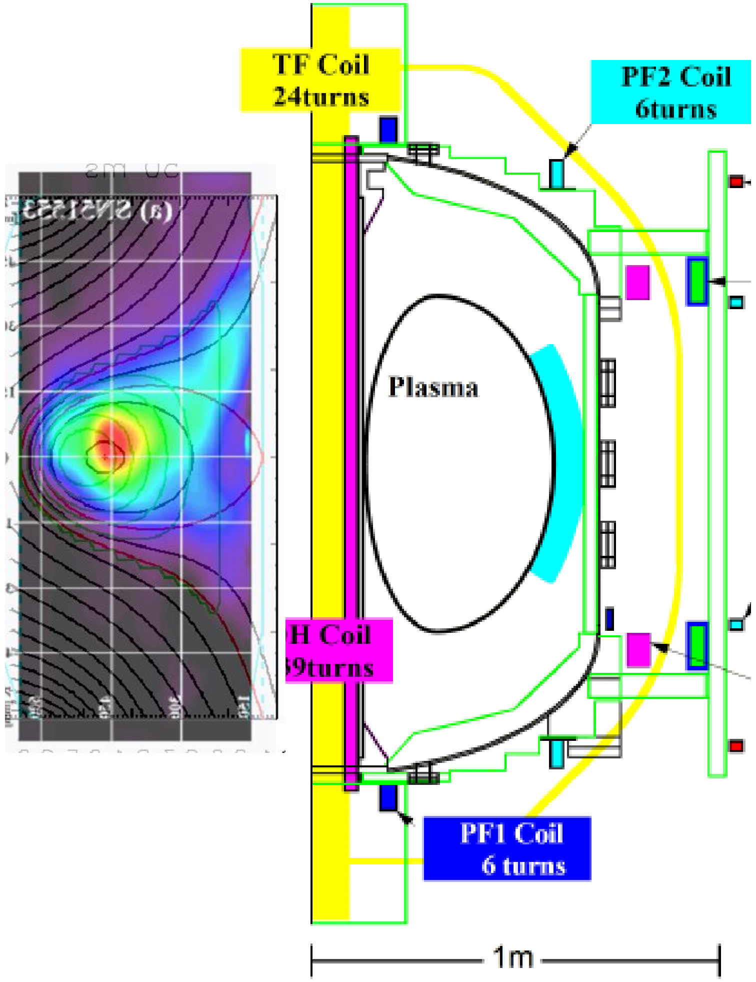
- Central space is limited in STs
- Loop voltage is very low in superconducting coil devices

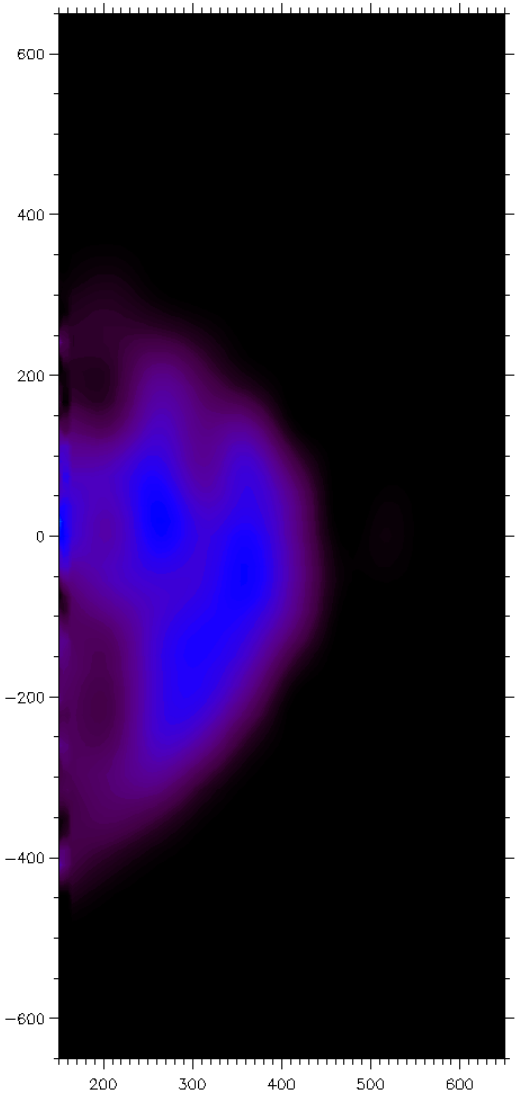
< 0.4 V/m in ITER

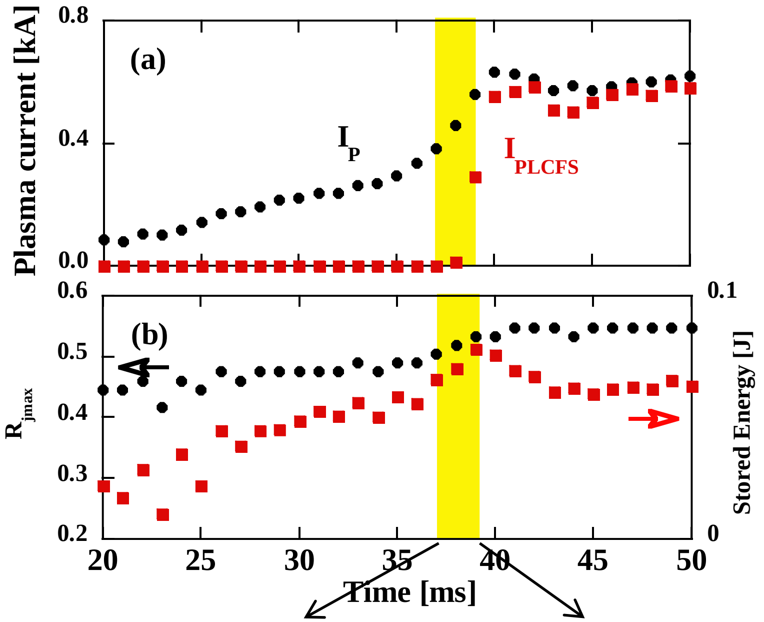
X/O-mode horn for ECH
2.45 GHz, Up to 5 kW
using magnetron



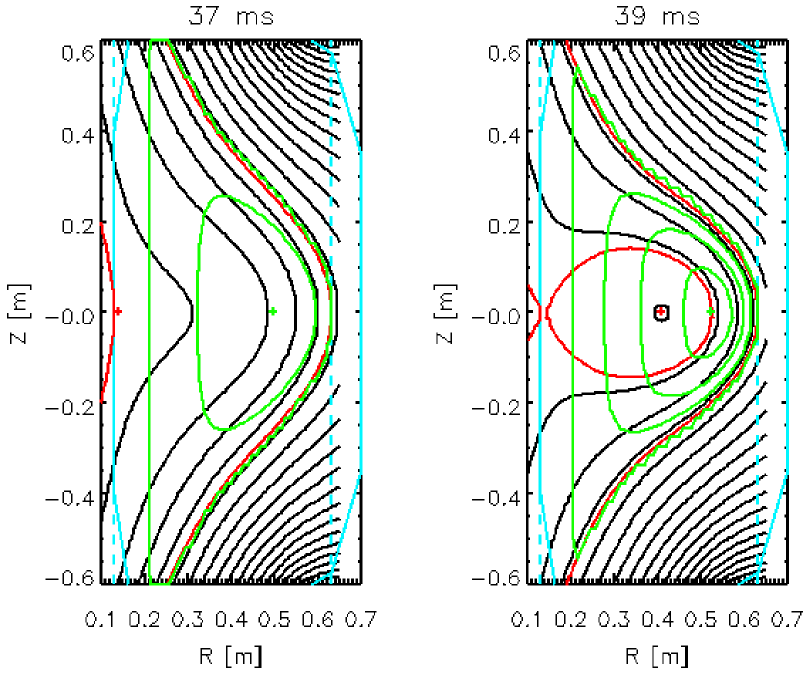
Spontaneous ST formation using non-directive ECH



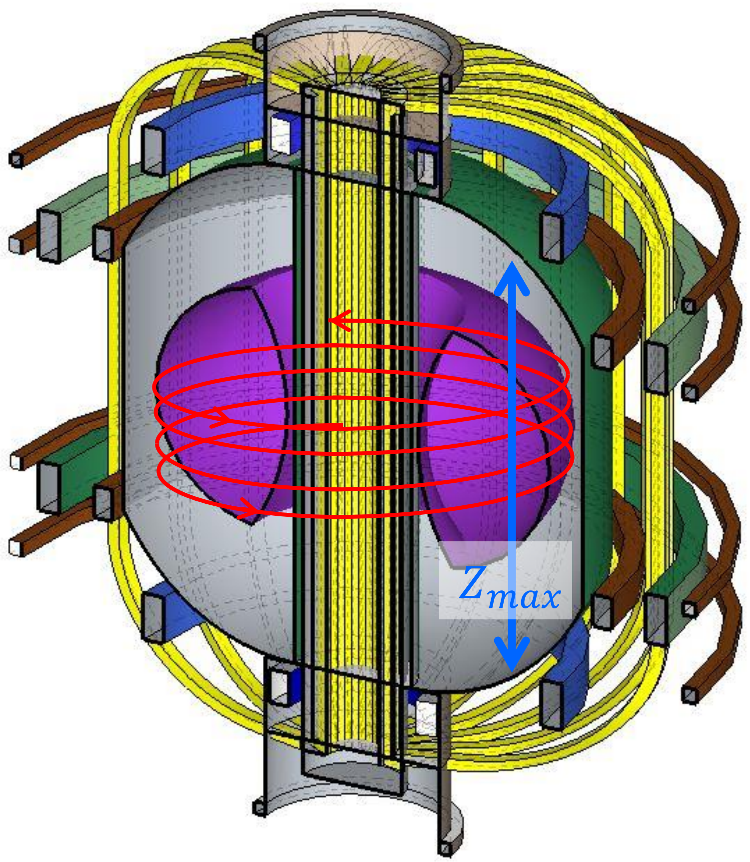


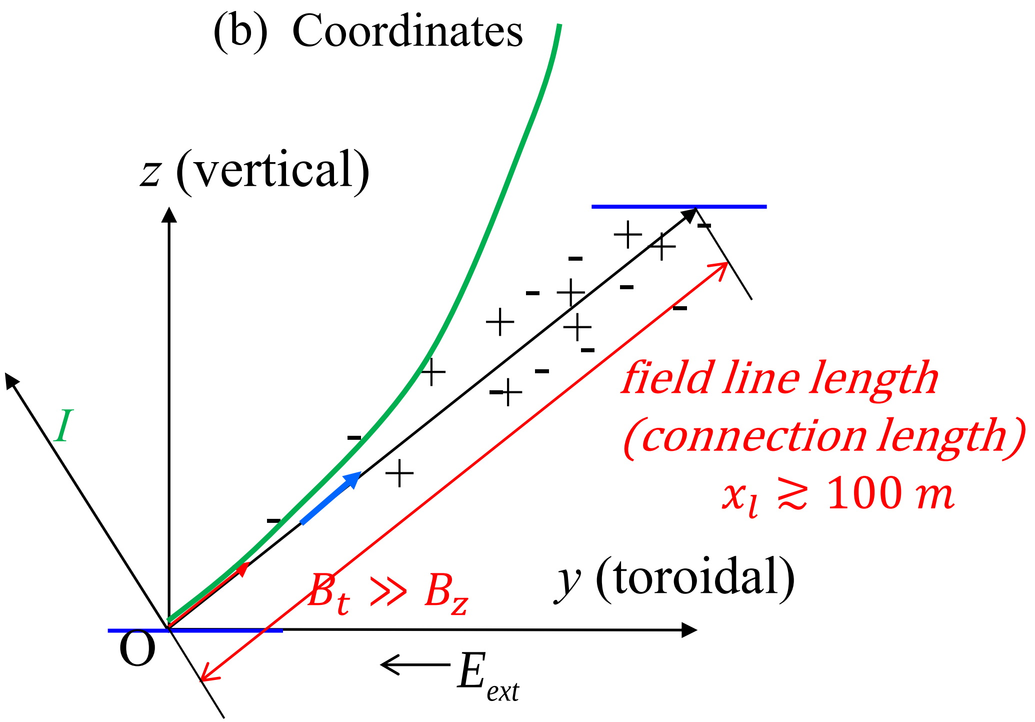


Just before and after the initial closed flux surface formation



(Standard) inductive preionization



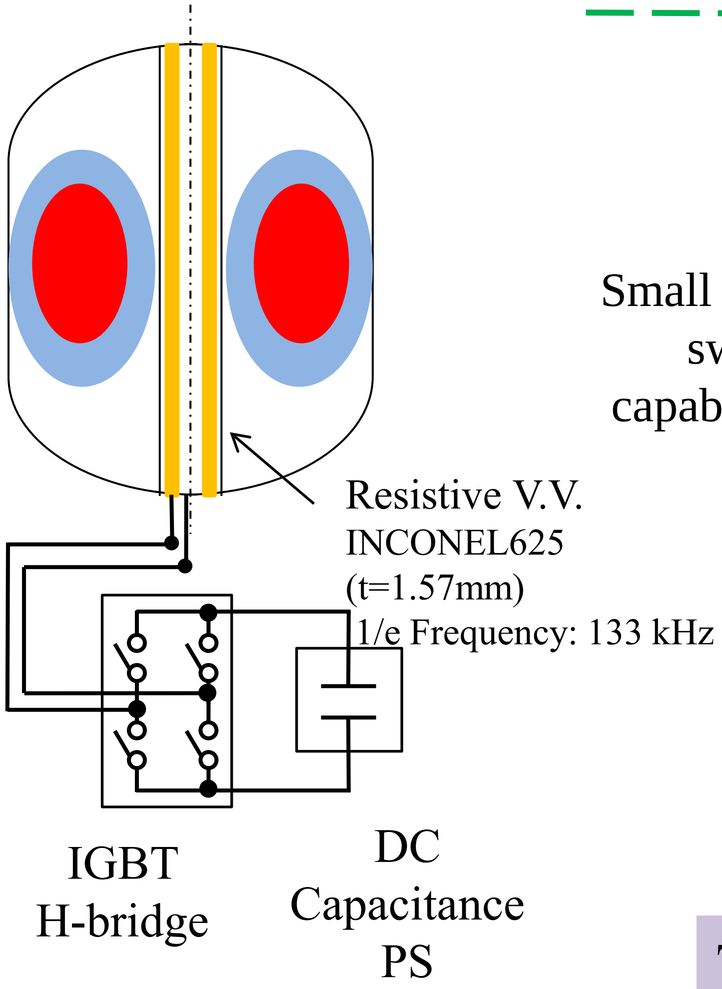


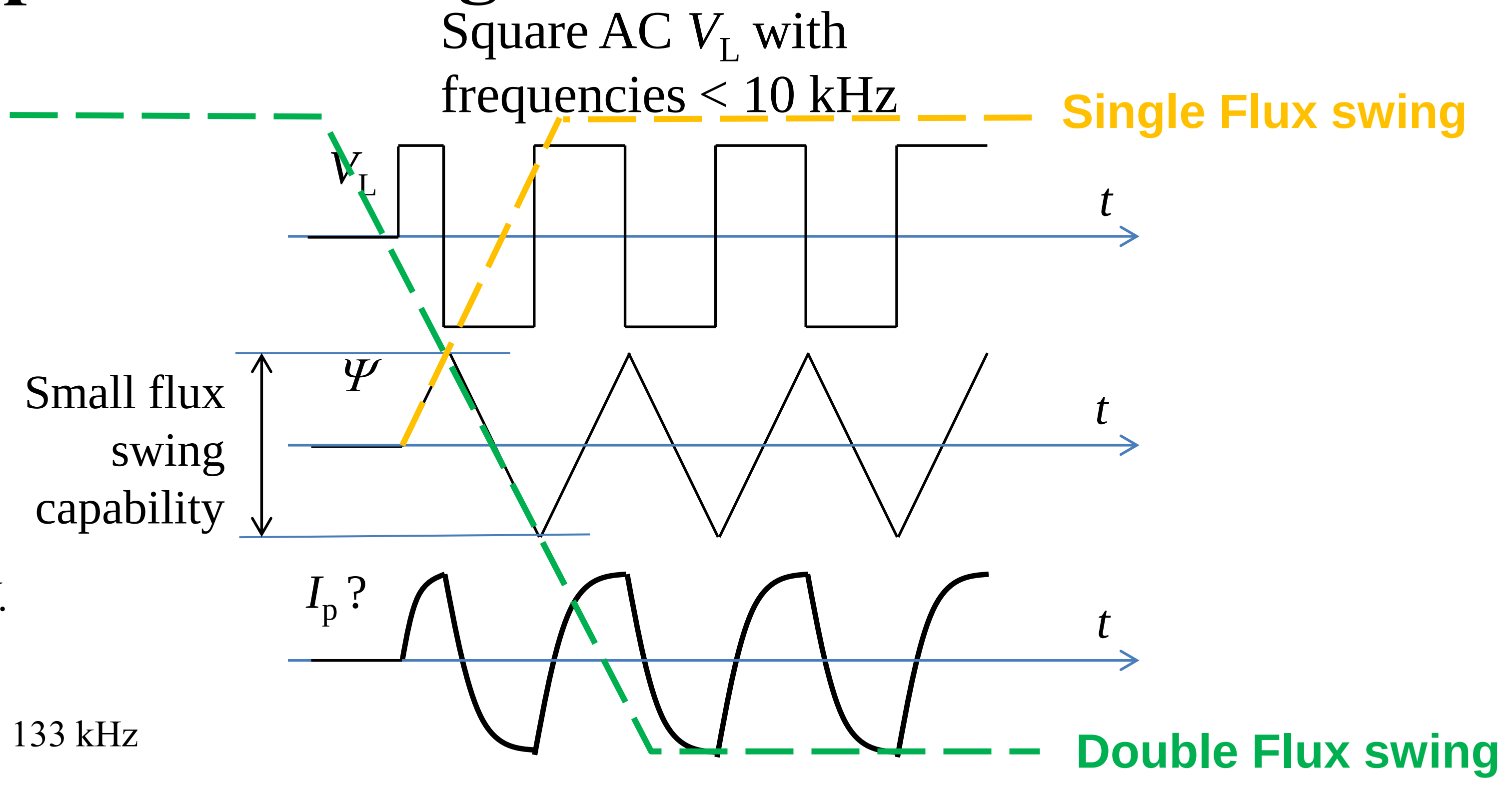
Townsend avalanche
alpha effect

$\frac{I}{I_0} = e^{\alpha x}, \quad \alpha(p_{fill}, E) = 510 p_G \times \exp\left(-1.25 \times 10^4 p_G / |E_{\|}|\right).$

Poloidal field null configuration: $B_z \sim 0, (B_R \sim 0) \ll B_t$
is important because the connection length $x_l \sim Z_{max} \times B_t / B_z$

AC Ohmic coil operation for pre-ionization, current ramp-up and heating





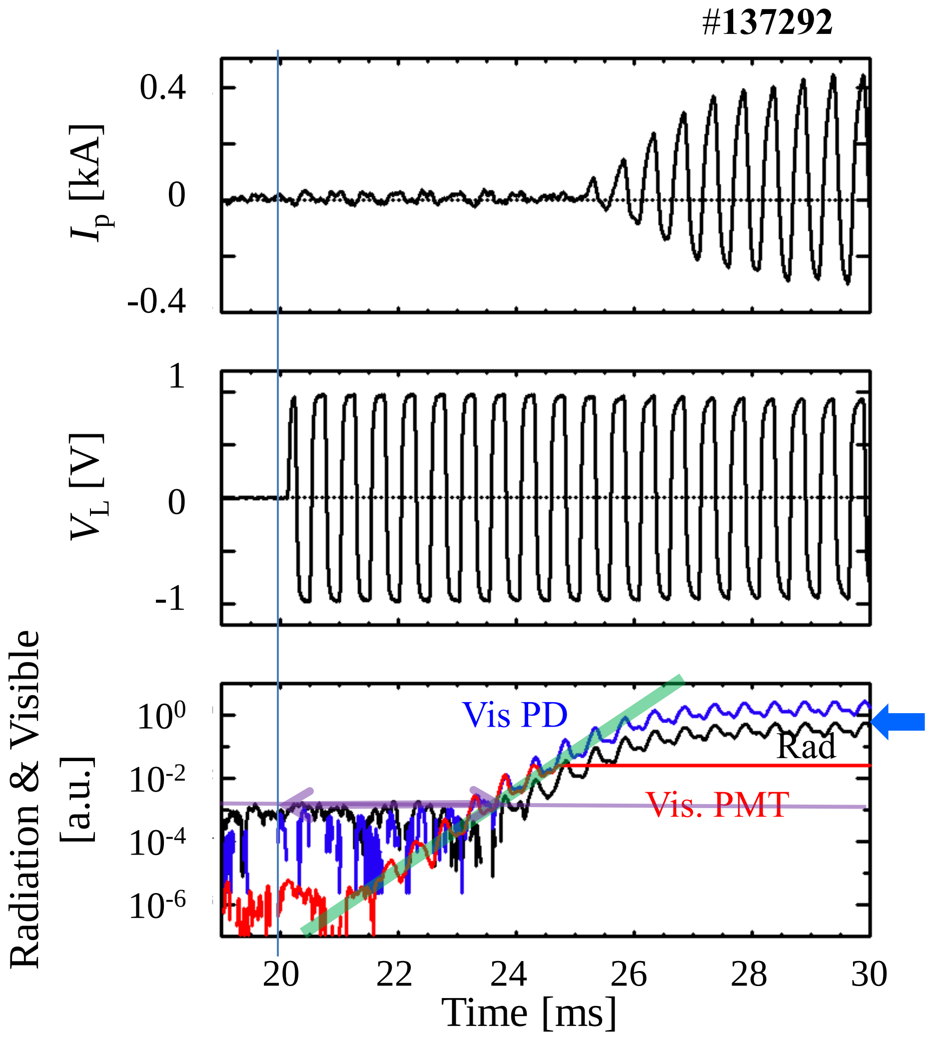
- Cumulative effect to increase n_e (i.e., pre-ionization)?
- Heating power: $\langle I_p V_L \rangle$ → DC current drive?

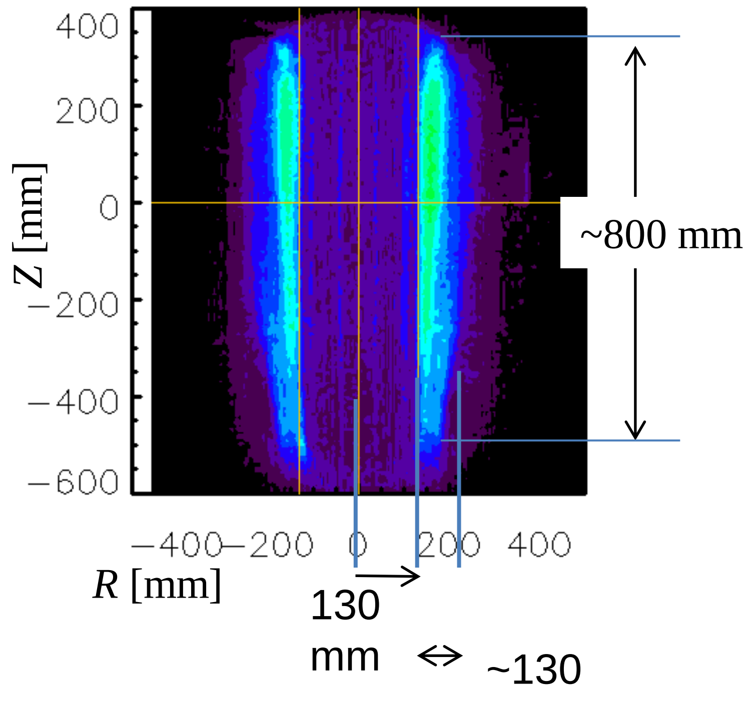
Targets:

- a reliable pre-ionization method for reactors
- a new current start-up tool

Discharges without vertical field ramp-up to study pre-ionization

After a certain time, I_p, n_e, light emissions grows exponentially and saturate at a level. A thin plasma attached to the inboard wall is formed





Visible emissions, radiation n_e are nearly proportional.

Growth rate, appearance time and saturation level of visible emissions characterize the pre-ionization.