EBW-driven current ramp-up at 10 times the plasma cutoff density in the LATE device

M. Uchida, T. Maekawa, H. Tanaka, F. Watanabe,
Y. Noguchi, K. Kuroda, S. Omi

Graduate School of Energy Science, Kyoto University

Non inductive startup of ST by EB waves

- Non inductive startup and formation of spherical tokamak by electron Bernstein (EB) waves has been investigated in the LATE device by using 2.45 and 5 GHz microwaves.
  - Ip = 20 kA by 5GHz, 190kW, 70ms
  - Ip = 10 kA by 2.45GHz, 60kW, 250ms

- EB waves can have a parallel refractive indices ($N_{||}$) larger than 1, which is advantageous for current ramp-up, as shown in the previous results, where the current carrying fast electrons tail is driven by high $N_{||}$ EBW at the density level typically a few times the plasma cutoff density. [Phys. Rev. Lett. 104, 065001 (2010)].

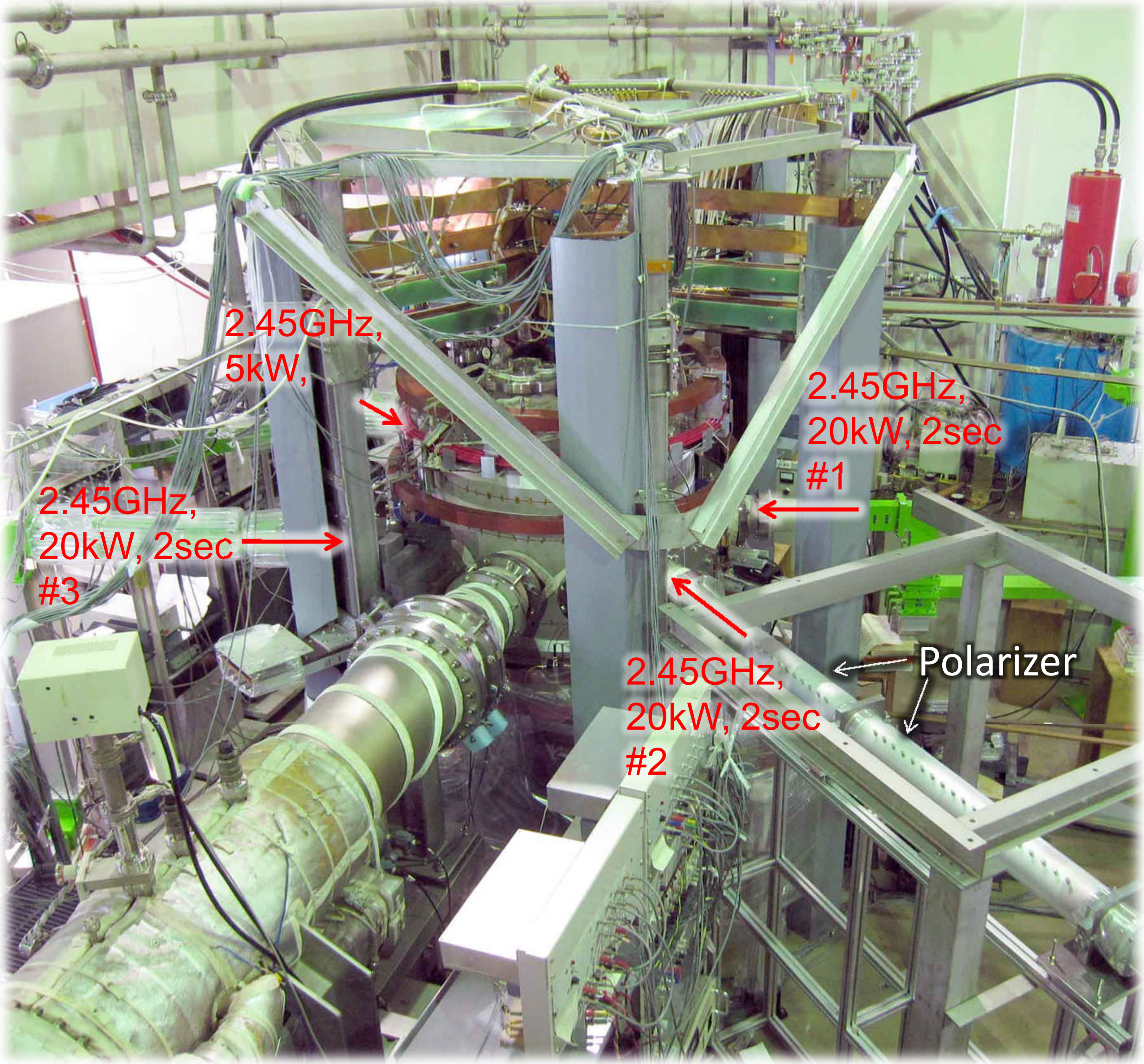
- EB waves can heat plasmas without the density limit. Higher density will be favorable to the target for NBI. Is it possible to increase the bulk electron density, keeping the current carrying fast electrons?

[This presentation]

- In the recent experiments using 2.45 GHz microwave up to 60 kW, where dependence on ECR location was investigated to seek the better coupling to EB waves.

- ST Plasma having Ip ~10kA with ~10 times the plasma cutoff density is obtained.

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



LATE Parameters:

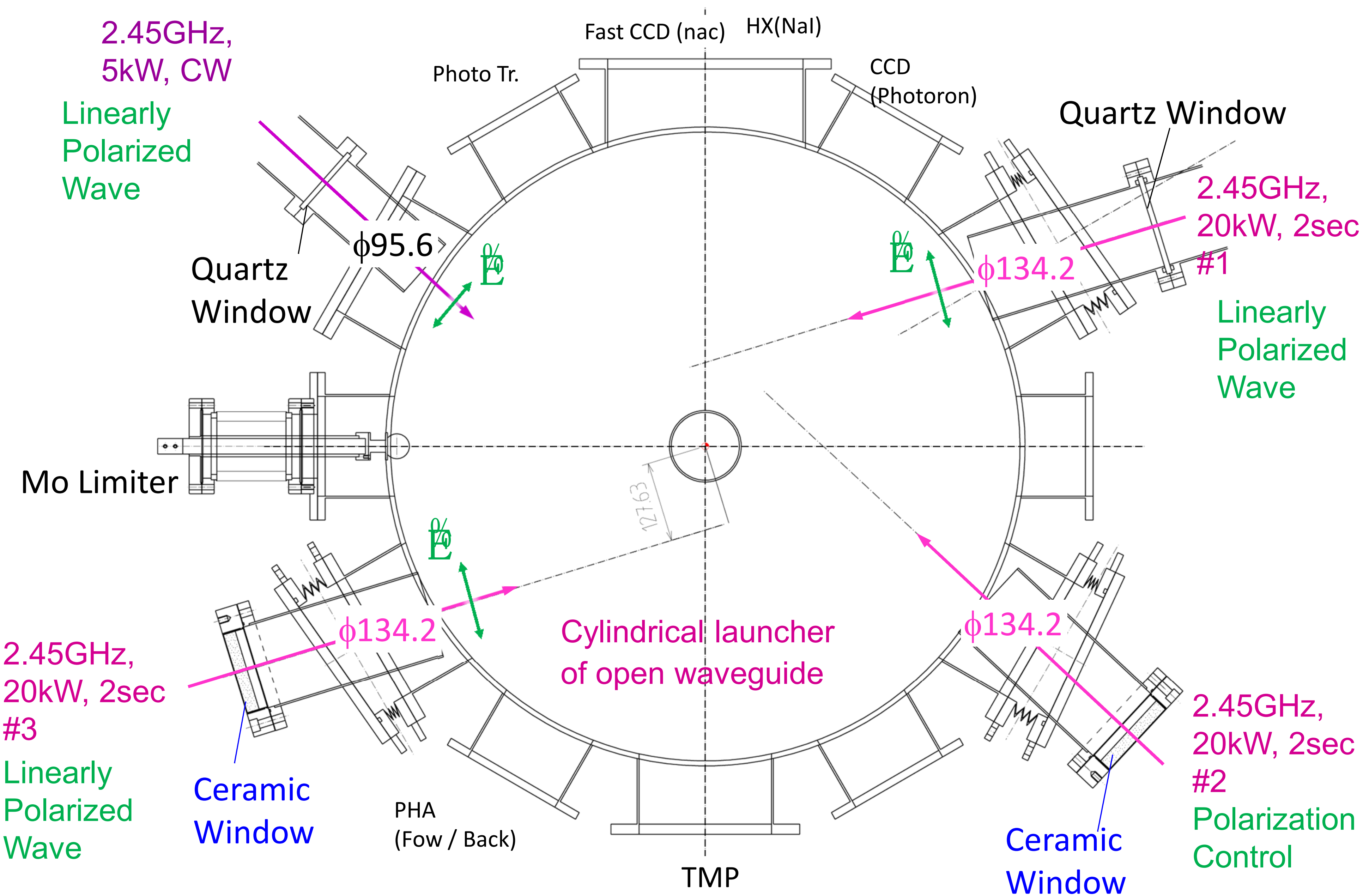
Vacuum vessel: diameter = height = 1m
Center post : diameter = 11.4 cm
Toroidal coils : 60 kAT (Bt ~ 0.5 kG), 10 s. or 120 kAT(Bt ~ 1 kG), 0.3 s.
Vertical coils: 3 sets, Vertical position control coils: 1 set

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

Diagnostics:

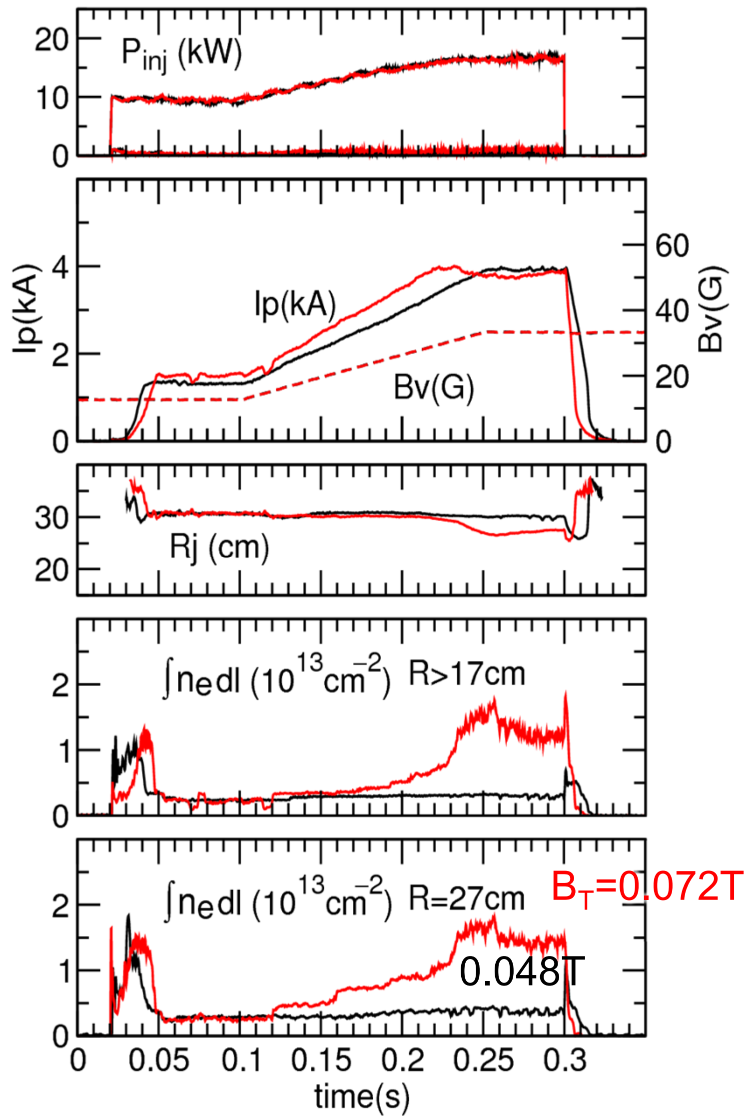
70GHz interferometer (4 chords),
Fast visible camera, Flux loops,
Langmuir probes, Spectrometer,
SX cameras (1-poloidal)
AXUV cameras (1-poloidal, 2-toroidal)
4-chord PHA system (2-tangential, 2-vertical),

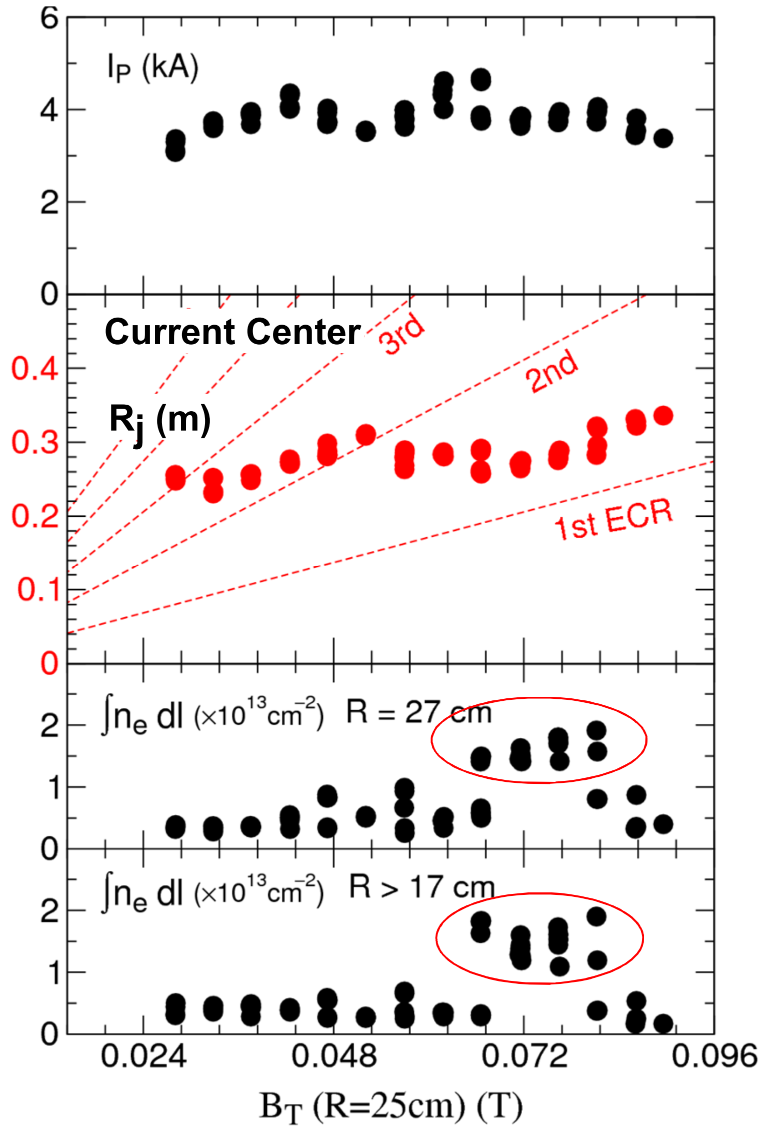
Four launching ports for 2.45 GHz injection

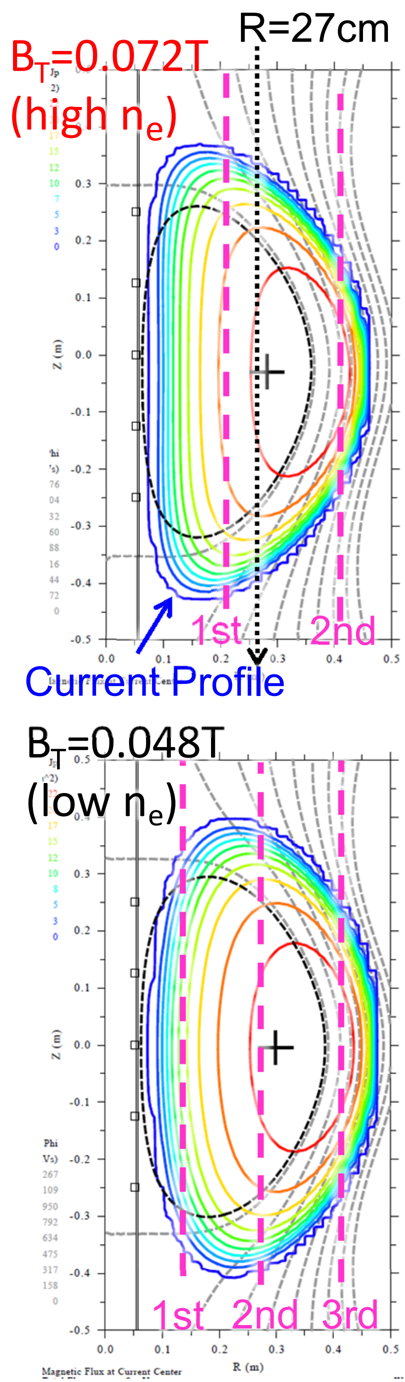


Electron density depends on ECR location

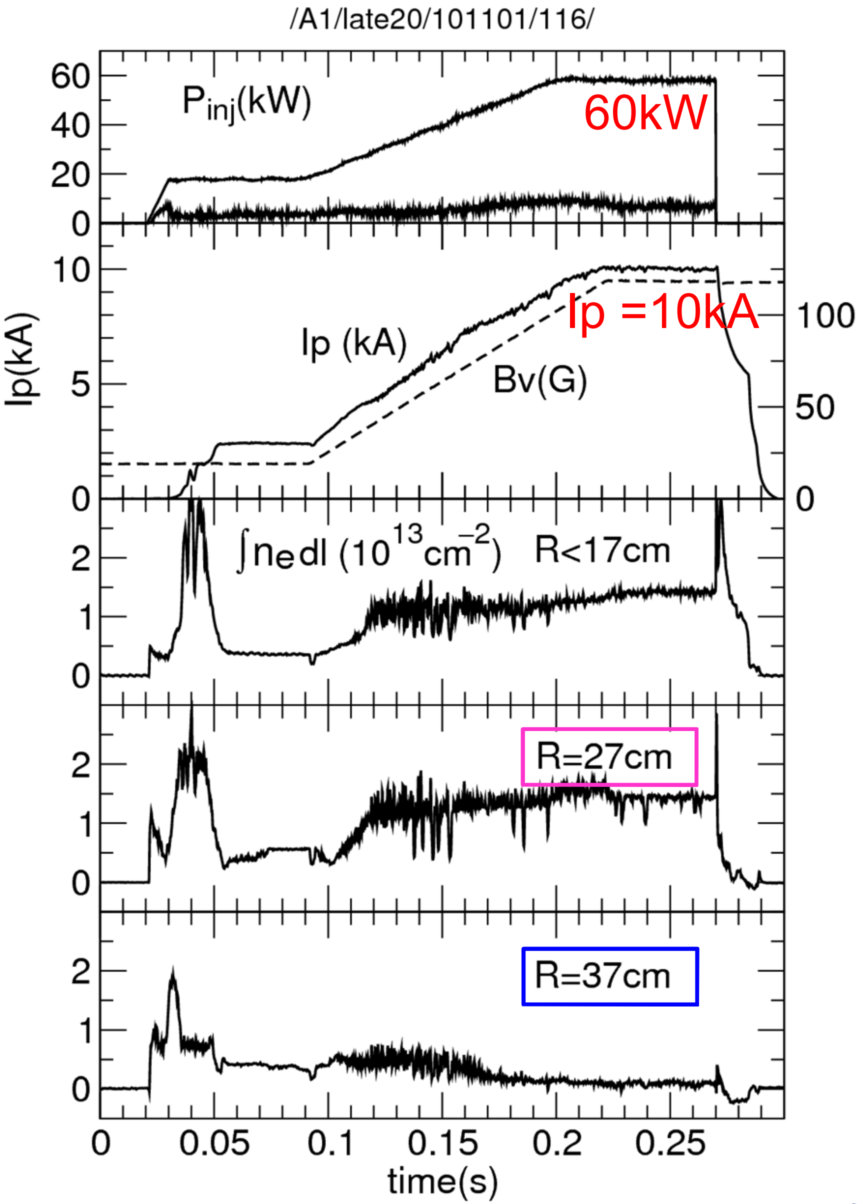
- Plasma current is roughly the same (Ip~4kA)
- Current center (Rj) slightly depends on the resonance location but stays near the vessel center of R~25 cm
- Electron density significantly increases when the 1st ECR locates R~20-22cm
  → effective heating of bulk electrons by EBW is expected in this configuration

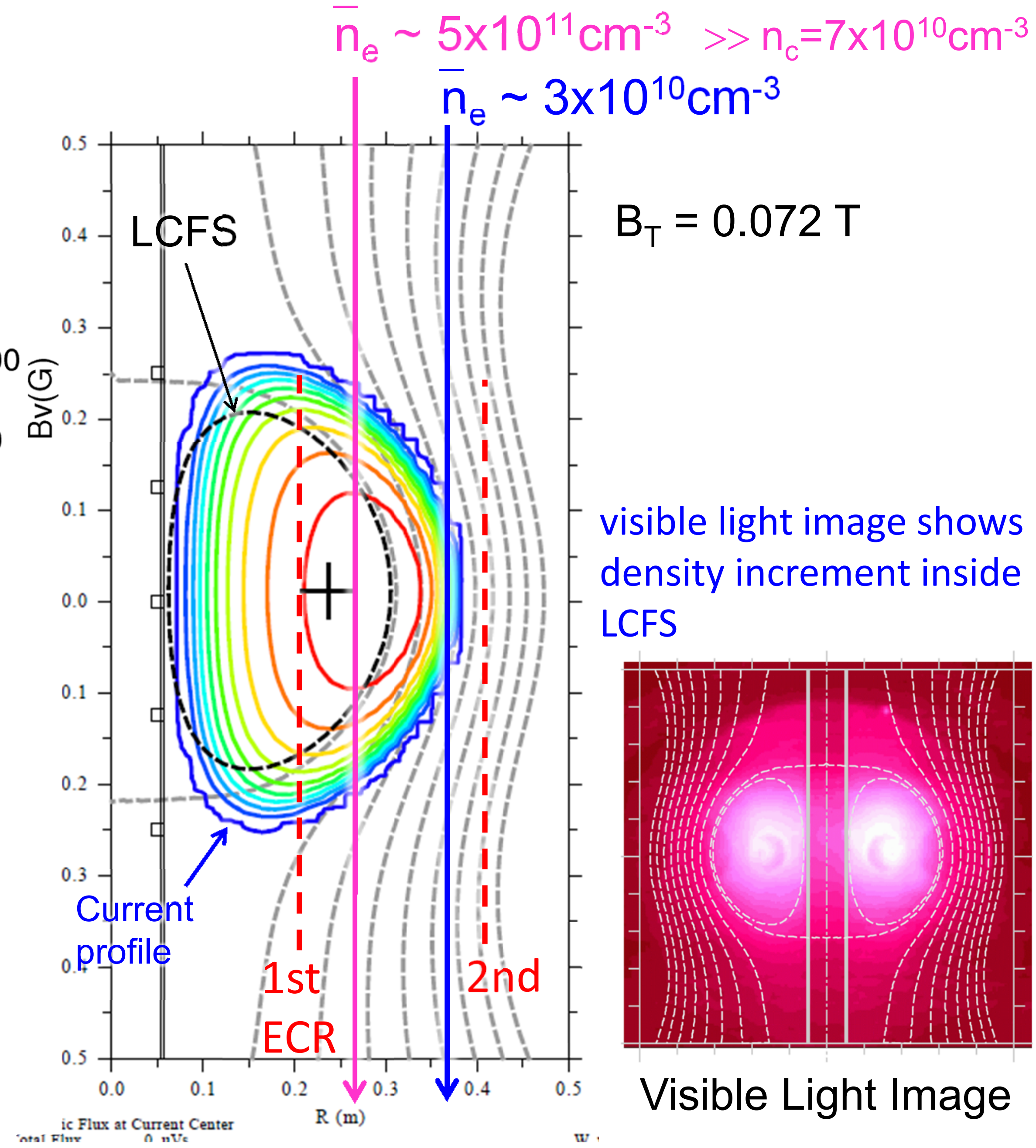






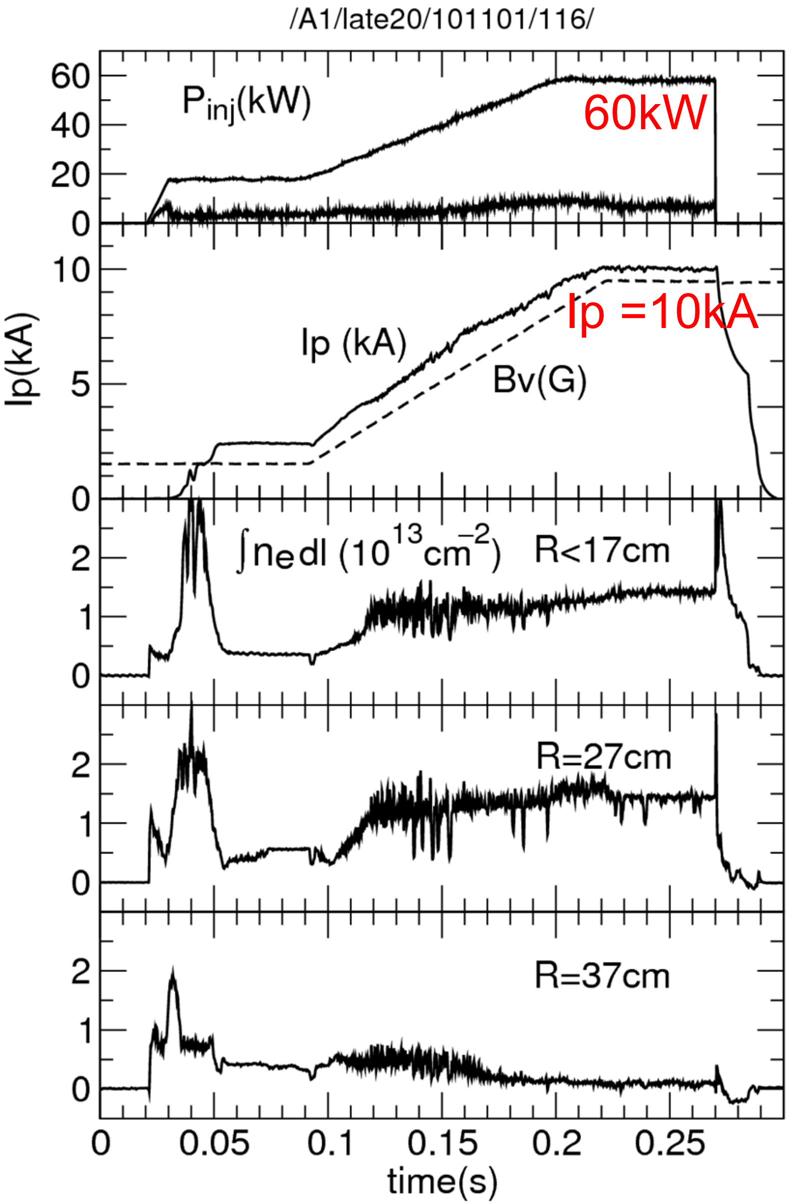
Electron density increases up to ~10 times the plasma cutoff density as Ip increases to 10 kA

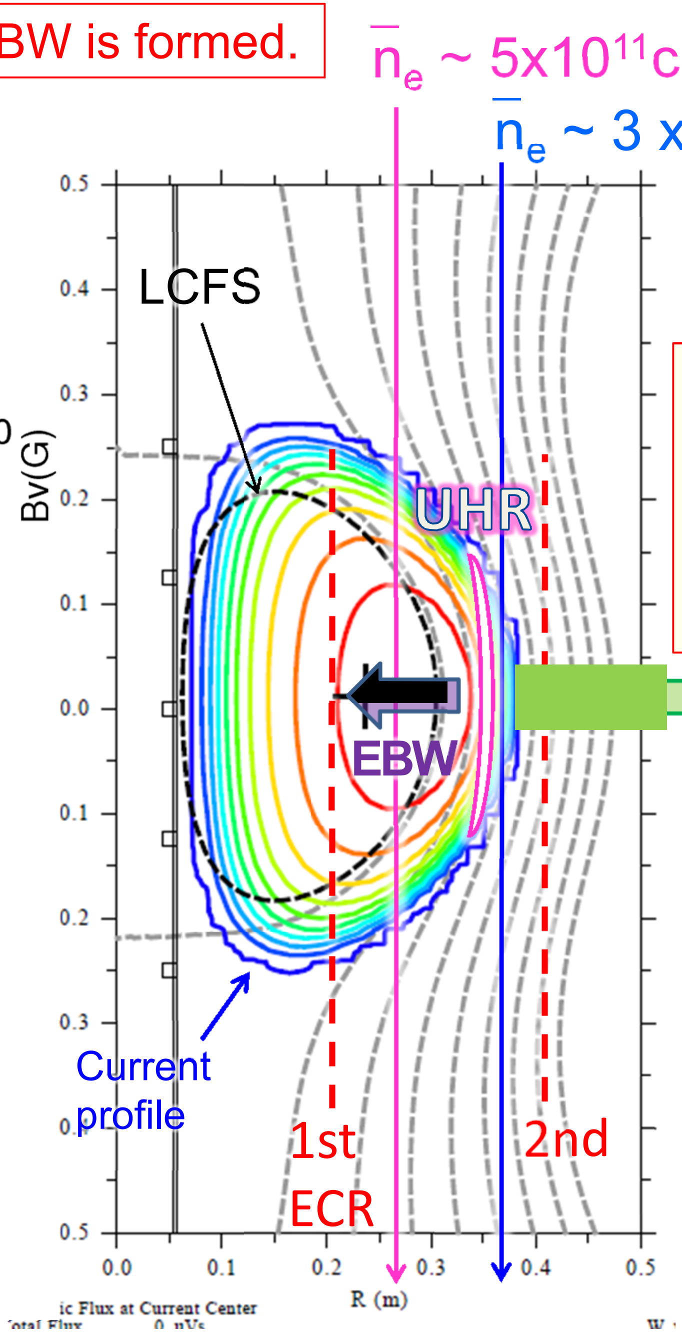




Effective heating of the bulk electrons at the plasma core is expected

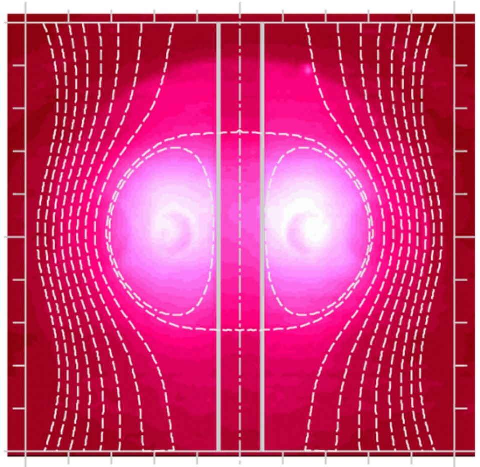
ST plasma solely maintained by EBW is formed.





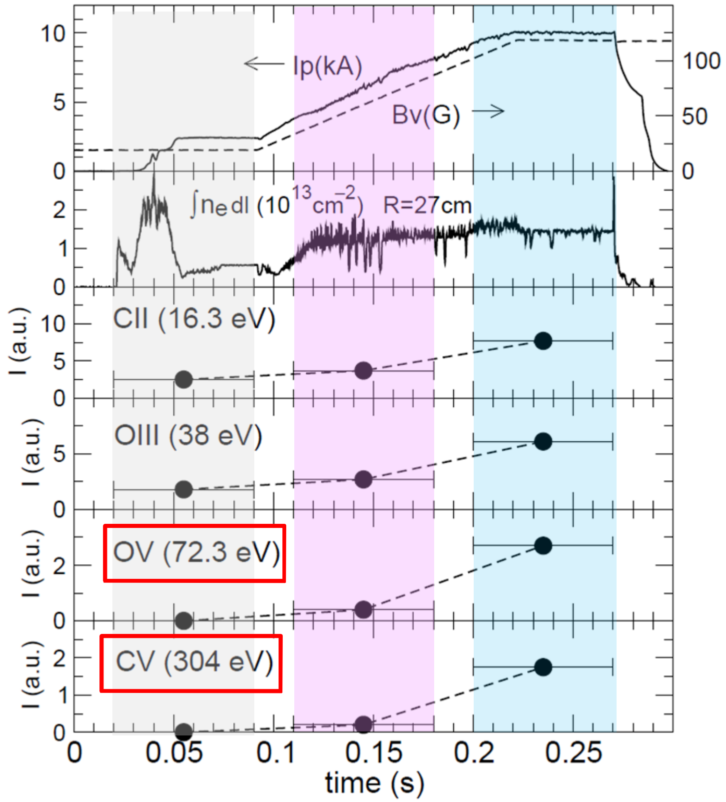
B_T = 0.072 T

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



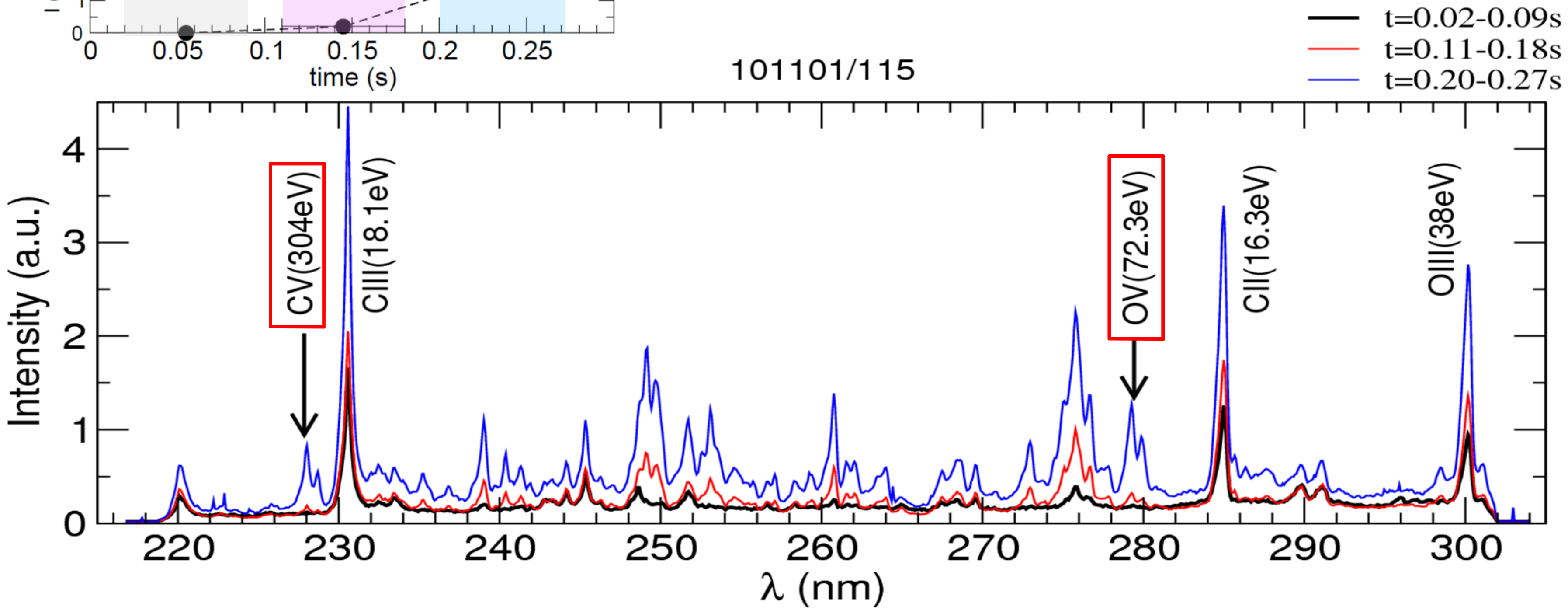
Visible Light Image

Impurity line radiations suggest T_e also increases

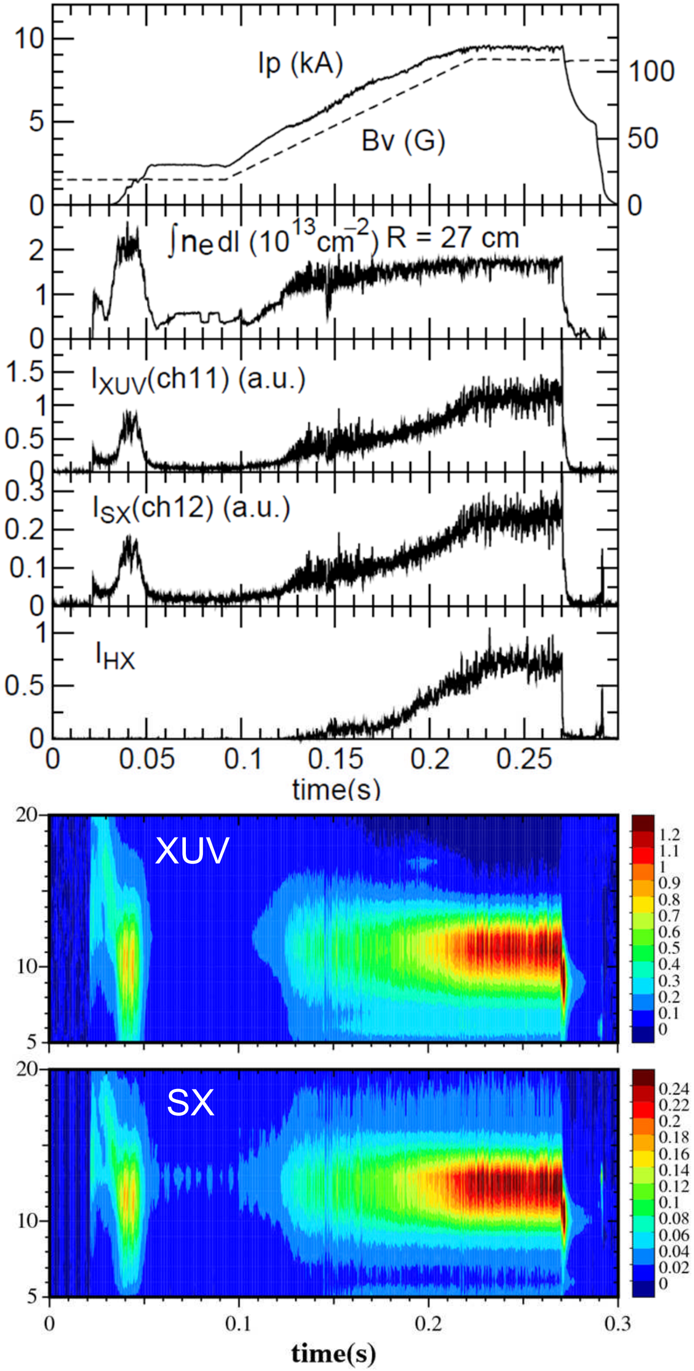


Impurity line radiations at higher excitation energy such as OV(72.3eV) and CV(304eV) appears and increases as Ip increases.

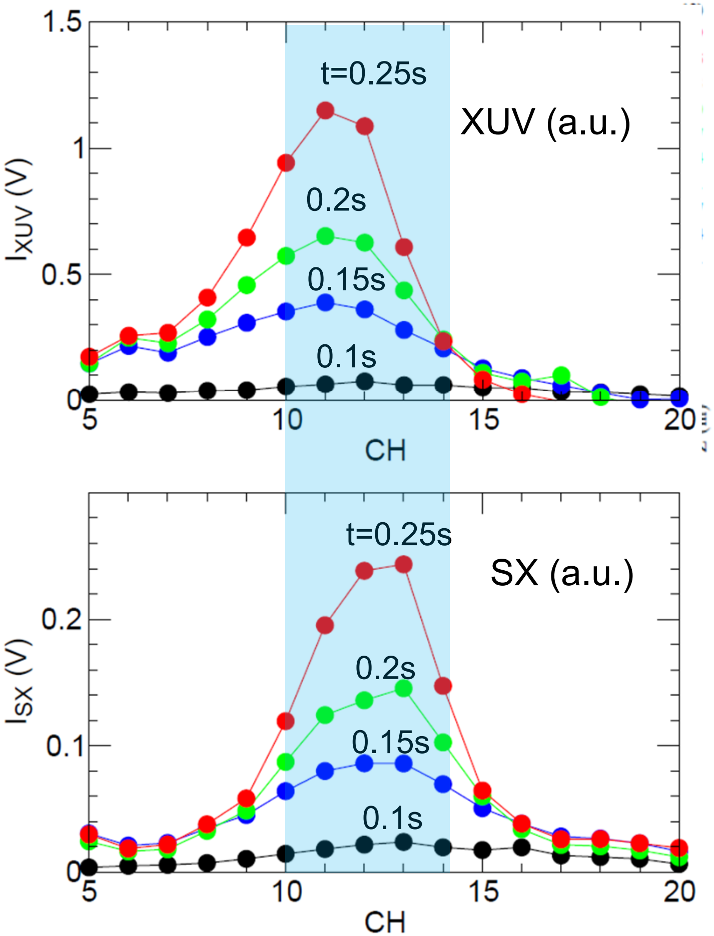
Strong increase compared with the density increment suggests that the bulk electron temperature increases.

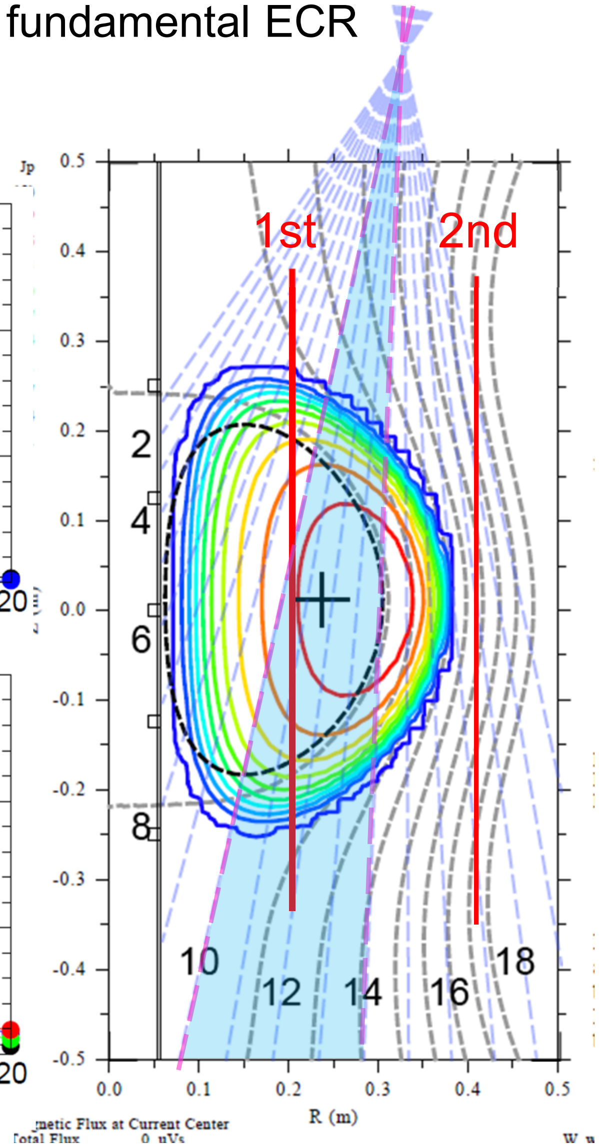


XUV and SX profiles show heating just before ECR layer



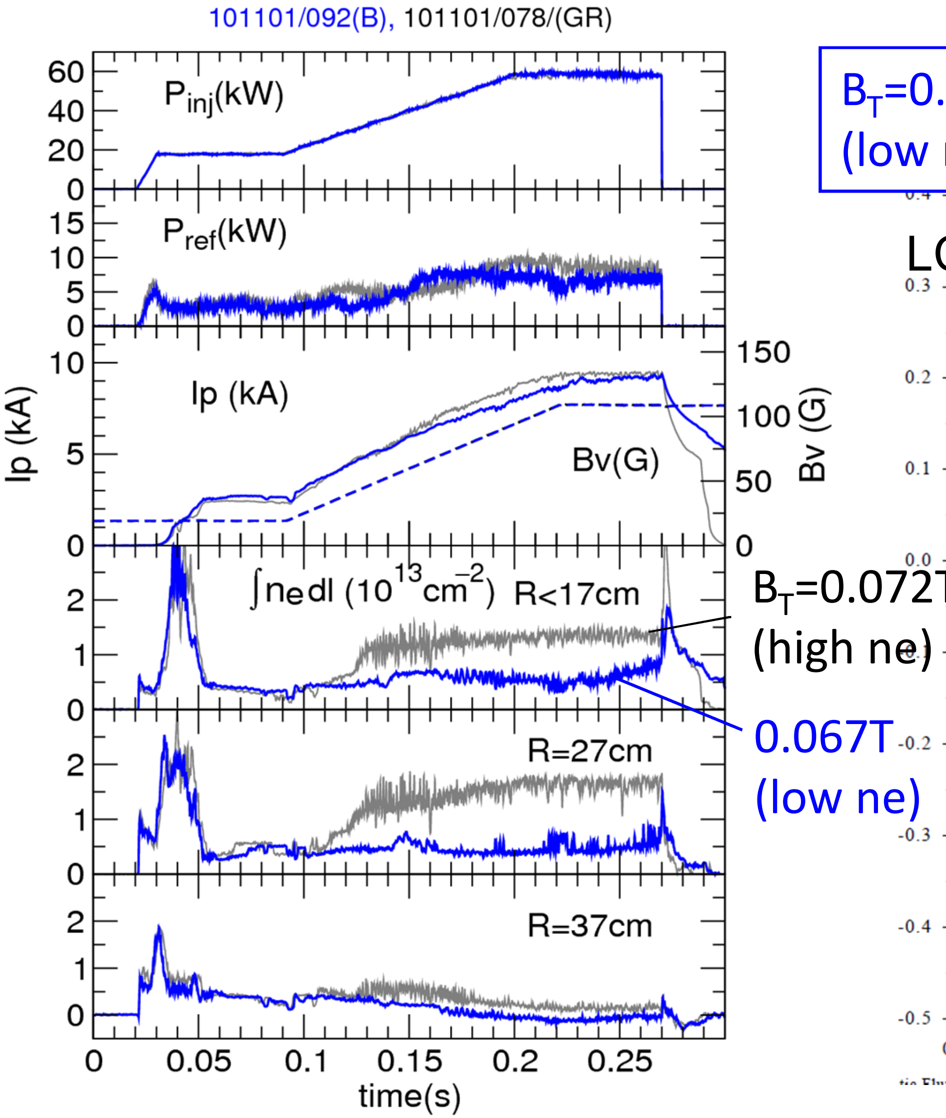
- XUV and SX increase as Ip increases from 5 to 10 kA, while the line density is nearly the same.
- The increment is significant just outside the ECR layer, indicating heating at the fundamental ECR by EBW.

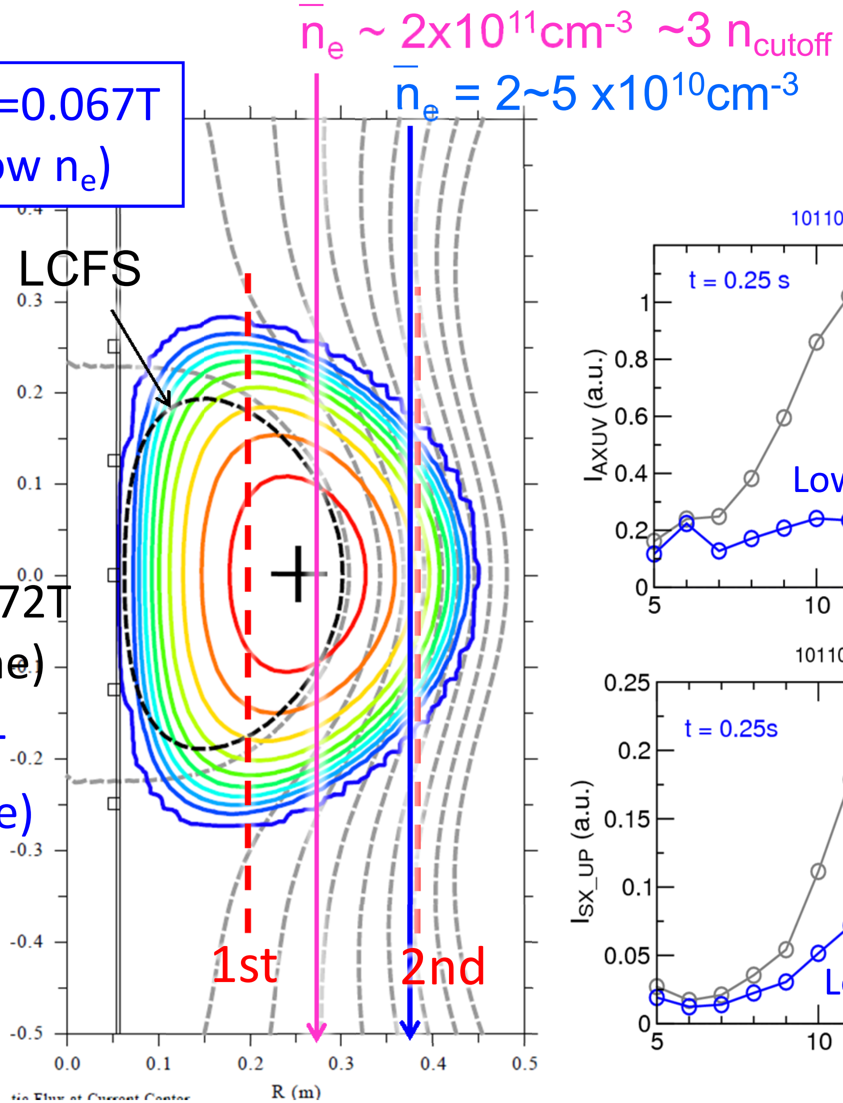


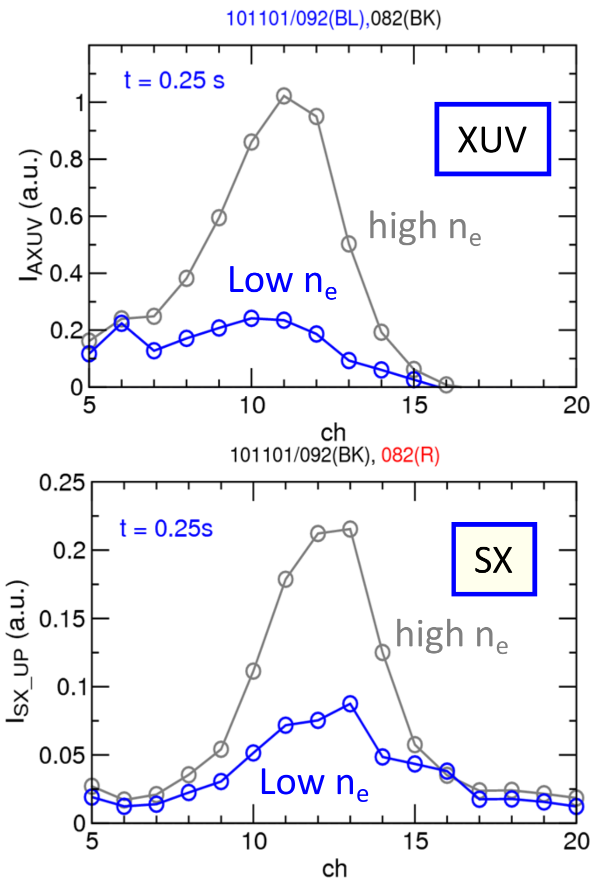


When we set the ECR layer at R<20cm, significant decrease in electron density is observed.

- When we set the R_{1st} < 20cm bulk density significantly decreased, while Ip ramps up almost the same value of Ip ~ 10kA.
- SX and XUV profile shows significant decreases in the core region.
- How such a large difference arises?

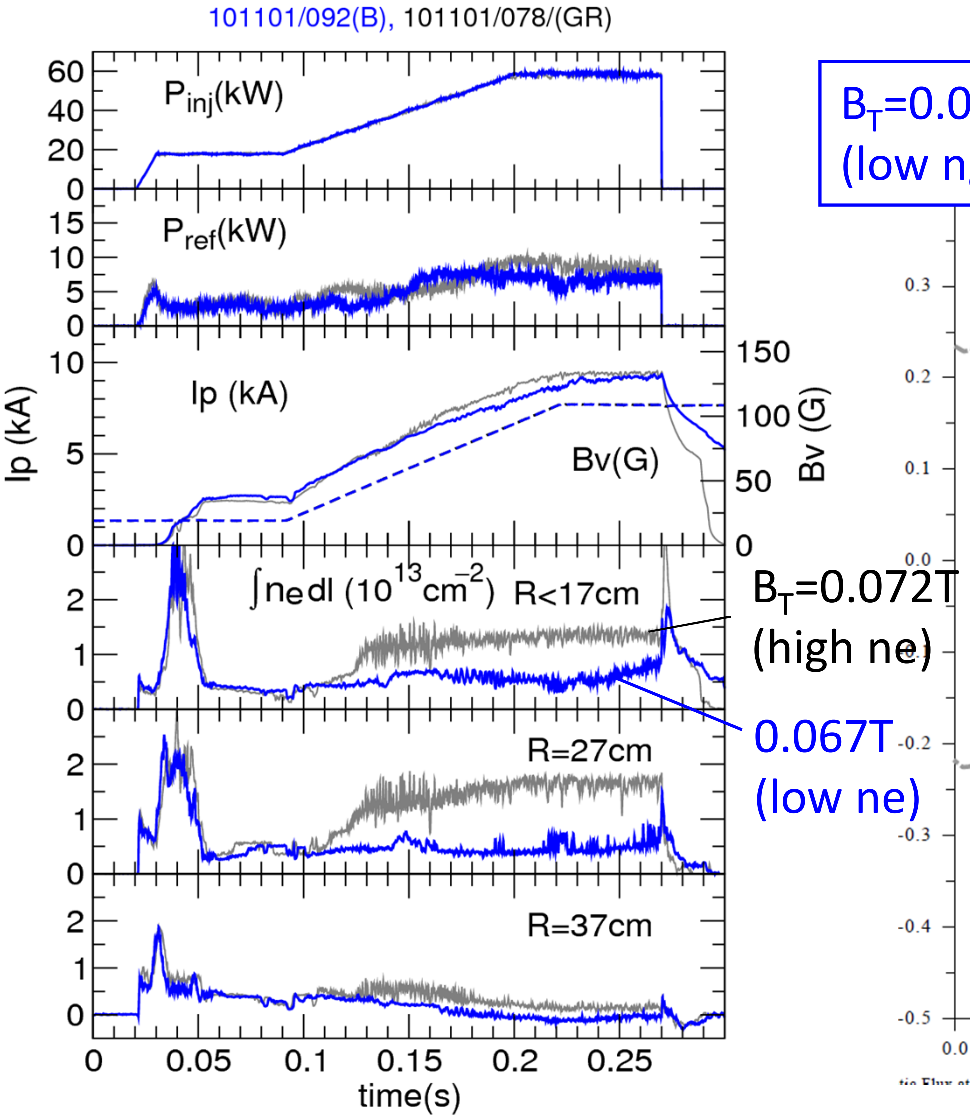


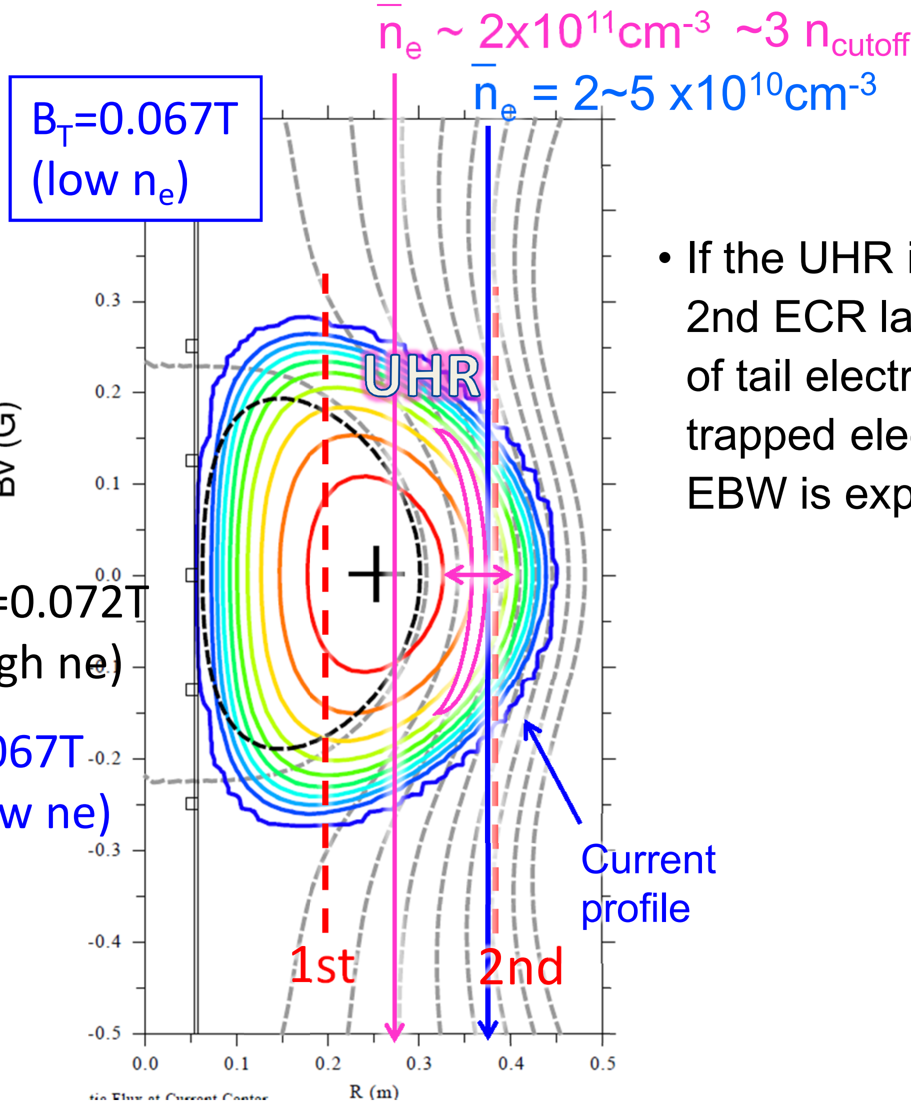




When we set the ECR located R<20cm, electron density significantly decreased

- UHR layer becomes closer to the 2nd ECR. Possibility that UHR is outside the 2nd ECR cannot be excluded.
- Current profile extends to the lower field side, across the 2nd ECR layer. 2nd harmonic heating by EB waves may take place.

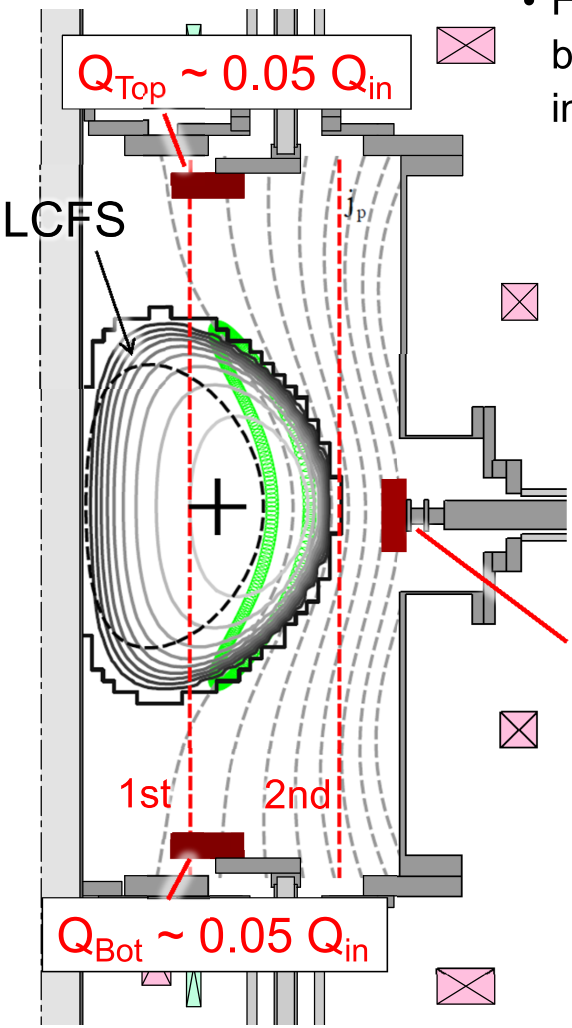




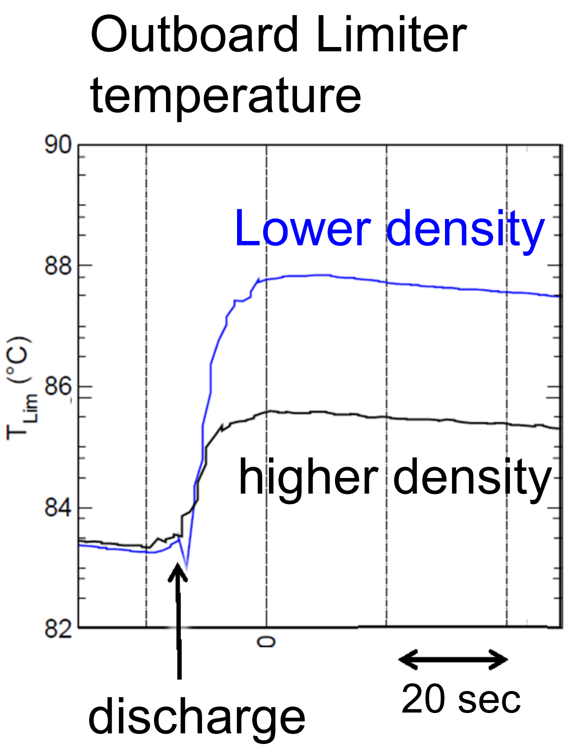
- If the UHR is outside the 2nd ECR layer, heating of tail electron (probably trapped electron) by EBW is expected.

Clear difference in the heat load to the outboard limiter shows that the better coupling to bulk electrons at the higher density.

Heat load to the limiter in one shot (Q_{in} ~ 8kJ)



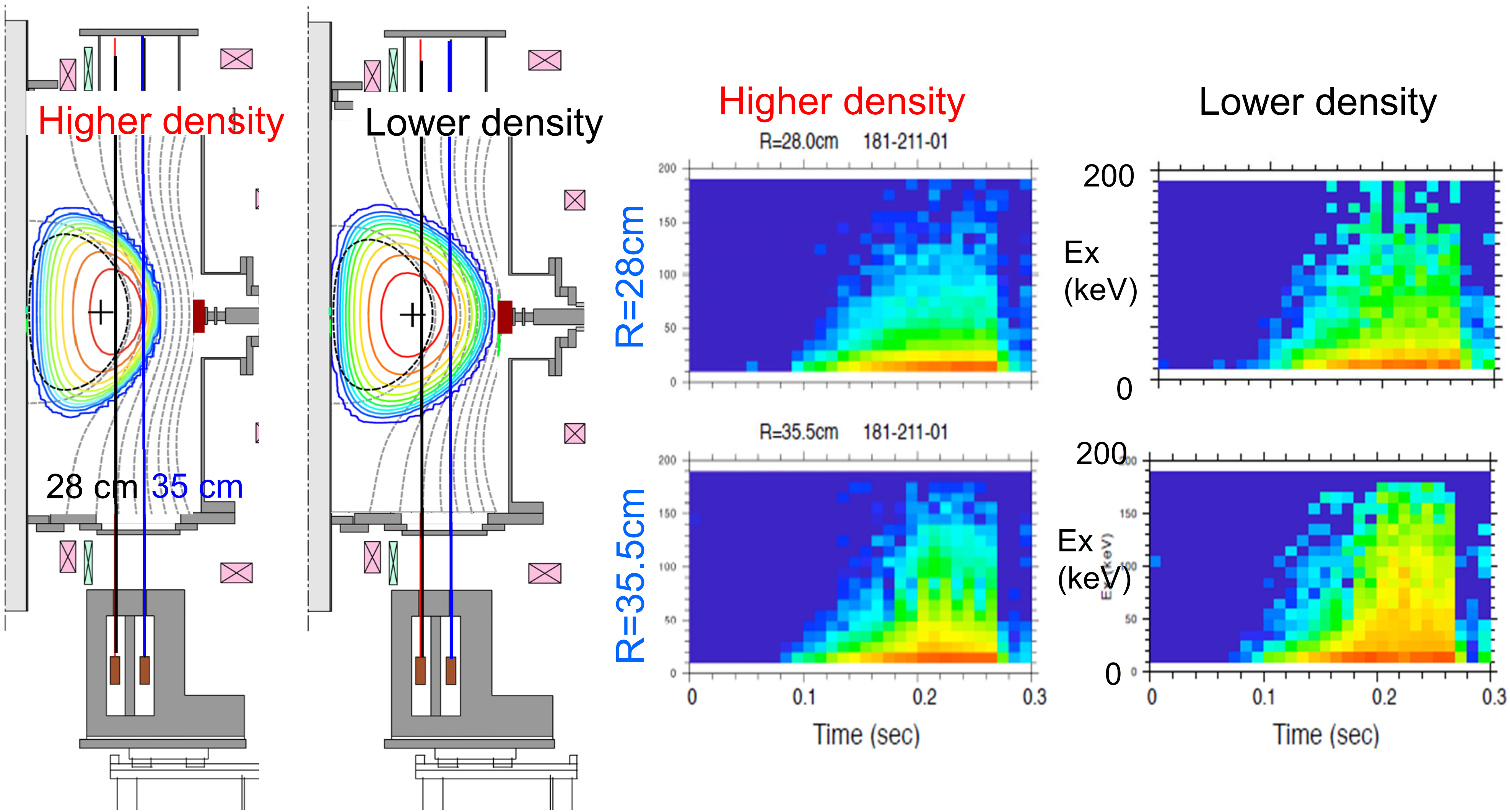
- Heat loads to the top and bottom limiter does not change in the two discharge



- At the lower density, heat load to the outboard limiters increases as $Q_{Lim(R)}/Q_{in}$ ~ 0.13 → 0.25 indicating larger loss.
- Since the outboard limiter is located far outside the LCFS, heat load is mainly from high energy trapped electrons.
- The results suggests that larger power is coupled to high energy trapped electrons and lost to the limiter at the lower density.
- 2nd harmonic heating by EBW may produce such electrons.
- Conversely, at the higher density, the 2nd harmonic heating is suppressed, better coupling to the bulk may be realized.

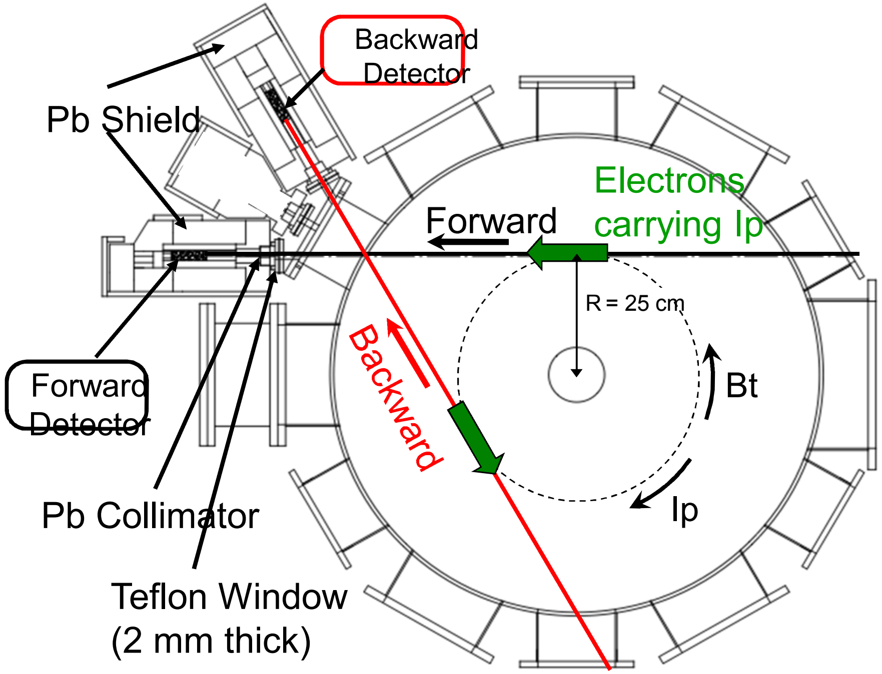
Evolution of HX spectra (vertical chords)

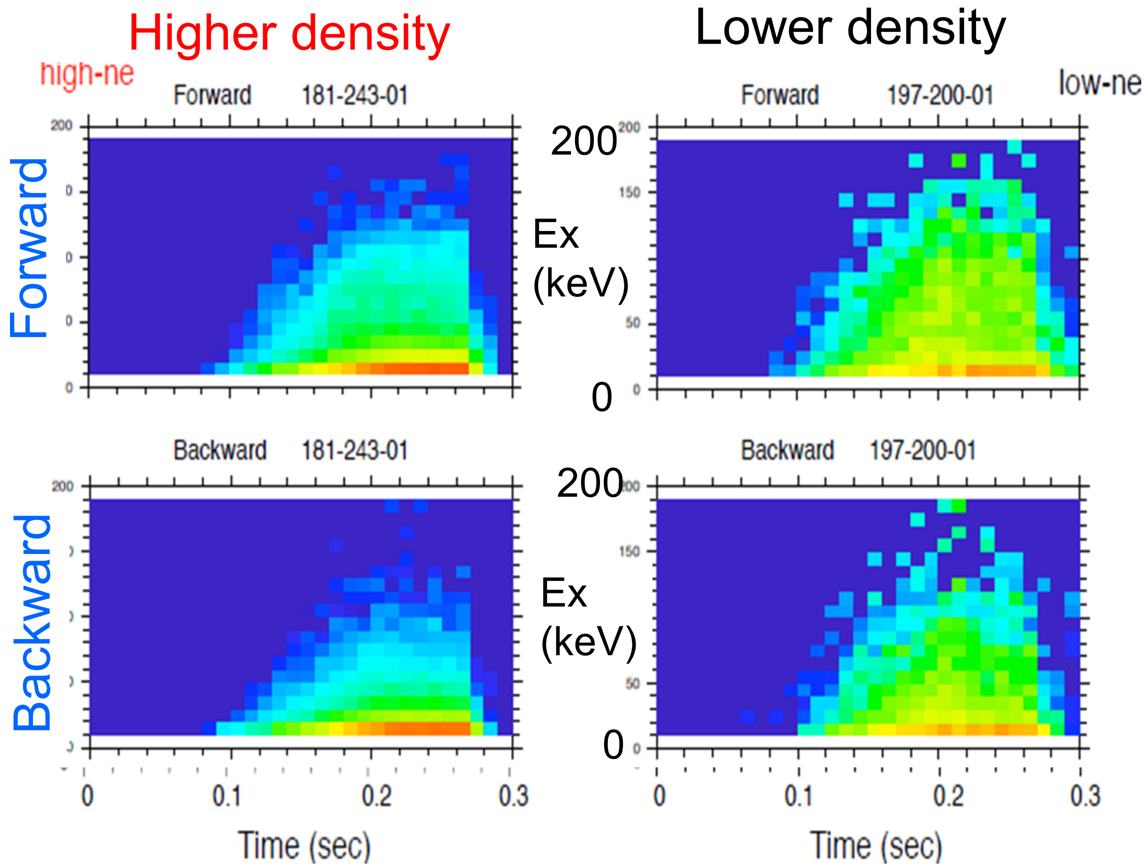
- This suggests that higher energy of trapped electrons exist outside LCFS at the lower density.
- At the higher density, X-ray energy becomes lower suggesting the production of trapped electrons are suppressed.



The difference forward and backward HX spectra exists for the both modes

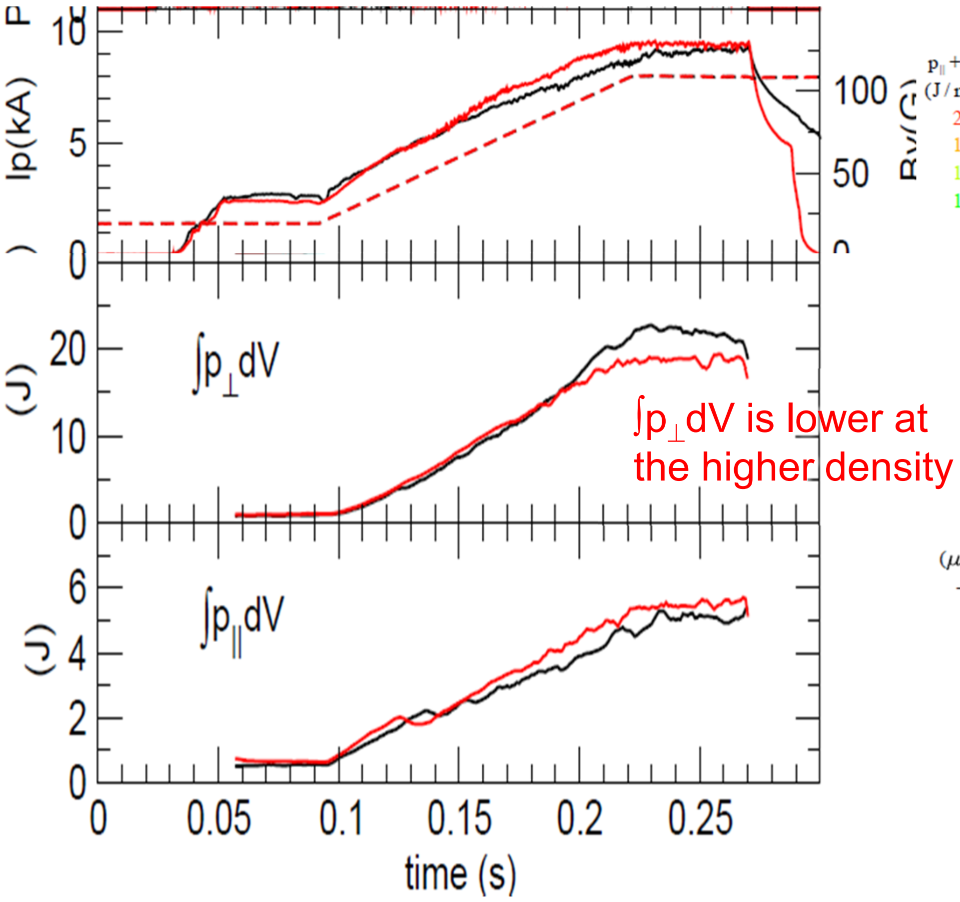
- For both the modes, difference between forward and backward emission can be seen, suggesting that current carrying tail electrons are produced similarly, in spite of the trapped electrons.





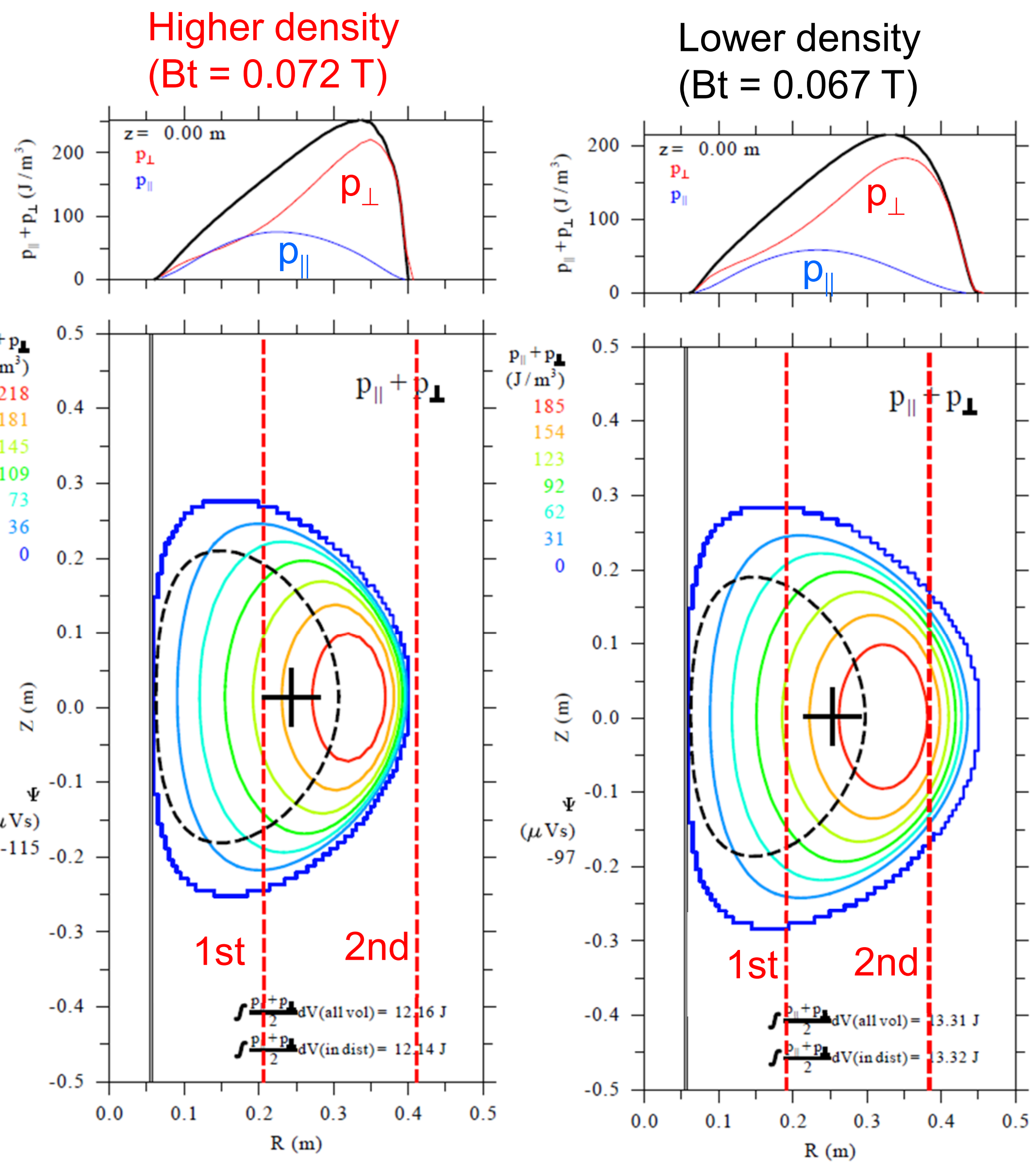
Equilibrium analysis show that $p_\perp$ is slightly lower at the higher density

- At the lower density, large $p_\perp$ region across the 2nd ECR suggest the production of trapped electrons by 2nd harmonic heating.
- At the higher density, power absorption by such electrons are suppressed, and the better coupling to the bulk electron is realized.



Pressure profile is estimated from equilibrium analysis

$j \times B = \nabla \cdot P \quad (P = P_\perp I + (P_{//} - P_\perp) bb)$ and $\nabla \cdot j = 0$



Summary

- Dependence on the EC resonance location for the EB driven current ramp-up discharge have been investigated. It is indicated the bulk electron density significantly increases when the ECR layer locates slightly inside the vessel center and UHR locates well inside the 2nd harmonic ECR layer.
- A plasma current is ramped up to Ip = 10kA with ~10 times the plasma cutoff density with 2.45GHz power of 60kW, solely maintained by EBW. Increase in T_e also indicated.
- When the UHR layer locates close to (possibly outside) the 2nd ECR layer, it is observed that the bulk electron density significantly decreases (~3 n_{cutoff}) and the loss to the outboard limiter increases. It is likely that the 2nd harmonic heating by EBW take place and larger portion of injected power heat the trapped electrons and lost to the limiter.
- These results suggest that preventing the 2nd EC heating by EBW leads to suppress the “useless” power to trapped electrons and improve the bulk density and temperature.