

# Issues of Plasma Start-up in Stellarator/Heliotron Devices

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Many thanks to E. Ascasíbar, Á. Cappa (CIEMAT), H. Laqua, M. Preynas (IPP) and Y. Yoshimura (NIFS)



# Why Study Plasma Start-up?

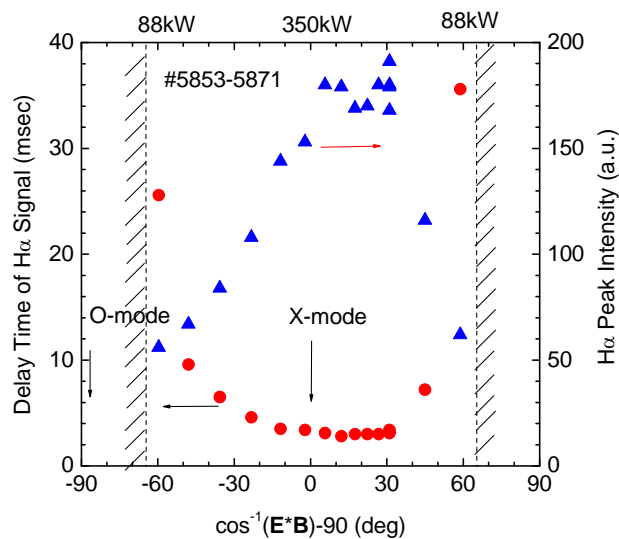
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- In stellarator/heliotron devices, current-free plasmas are produced by 1st /2nd harmonic ECH or tangential NBI.
- Successful start-up plasmas is required in W7-X.
- No successful plasma start-up by NBI only in the medium-sized devices such as TJ-II and Heliotron J.
- The physics for 2nd harmonic ECH breakdown is not fully understood.
- Reliable start-up at low toroidal electric field is an important issue in superconducting tokamaks such as ITER, JT-60SA and KSTAR.

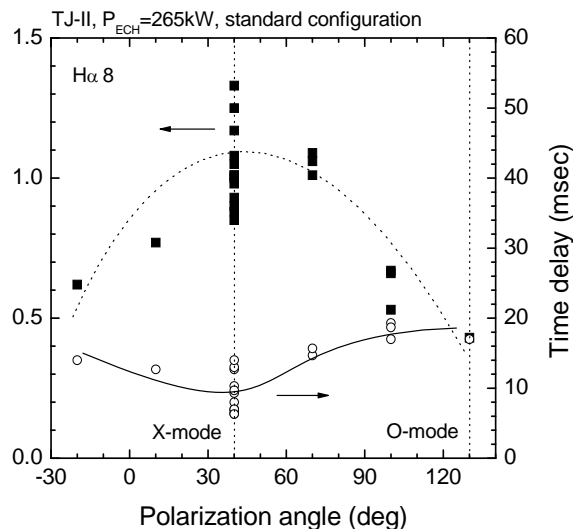
# Time delay Strongly Depends on Wave Polarization for 2<sup>nd</sup> harmonic ECH

- Breakdown time is shortest at X-mode polarization.
- This tendency is common in three devices.
- No plasma is produced or breakdown time is delayed at the O-mode polarization.

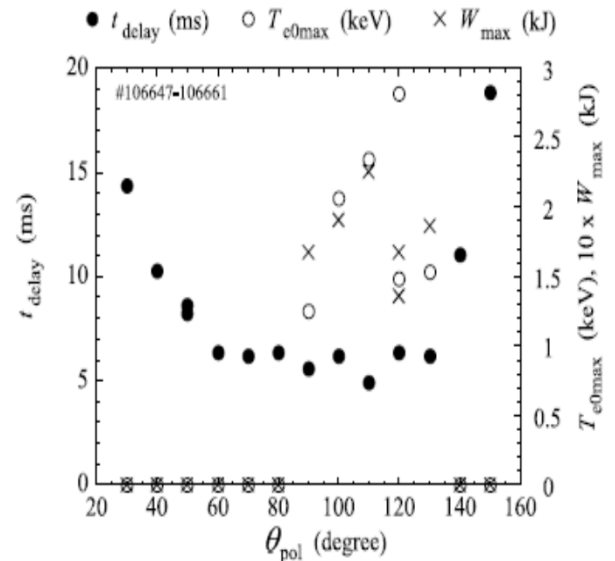
Heliotron J



TJ-II



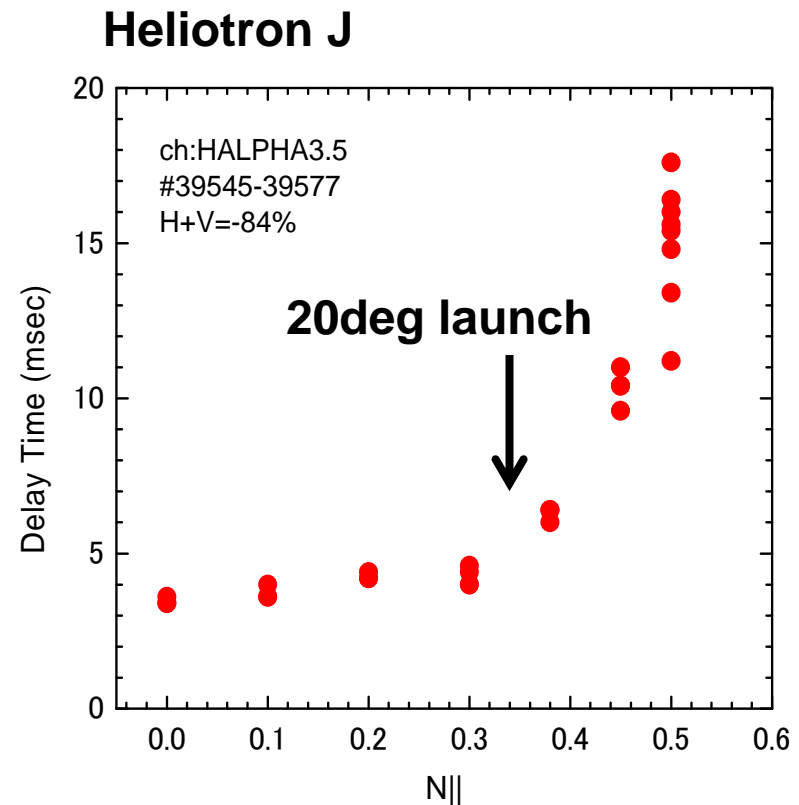
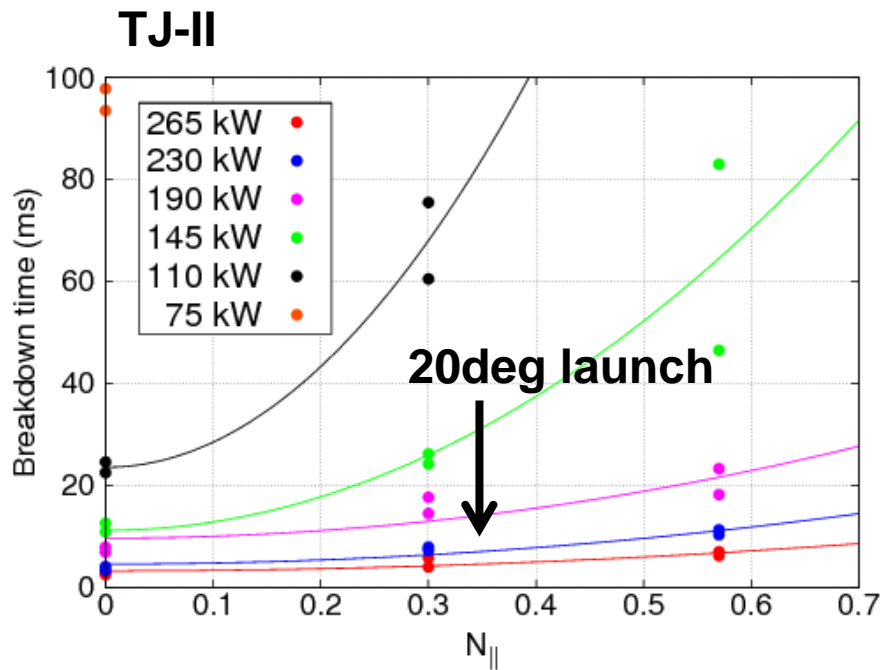
CHS



K. Nagasaki, Nucl. Fusion 45 (2005) 13  
 A. Cappa, 32<sup>nd</sup> EPS Conf., Tarragona (2005)  
 Y. Yoshimura, J. Plasma Fus. Res. 6 (2004)

# $N_{\parallel}$ Dependence of X2 EC Breakdown in TJ-II and Heliotron J

- 2<sup>nd</sup> harmonic ECH breakdown is dependent on  $N_{\parallel}$  at  $N_{\parallel} > 0.4$  at critical EC power (~190kW)

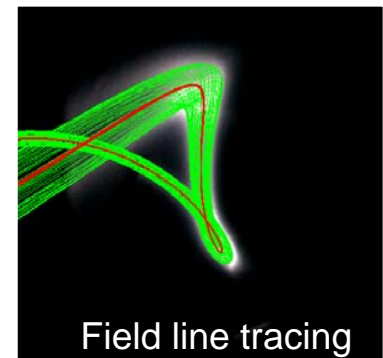
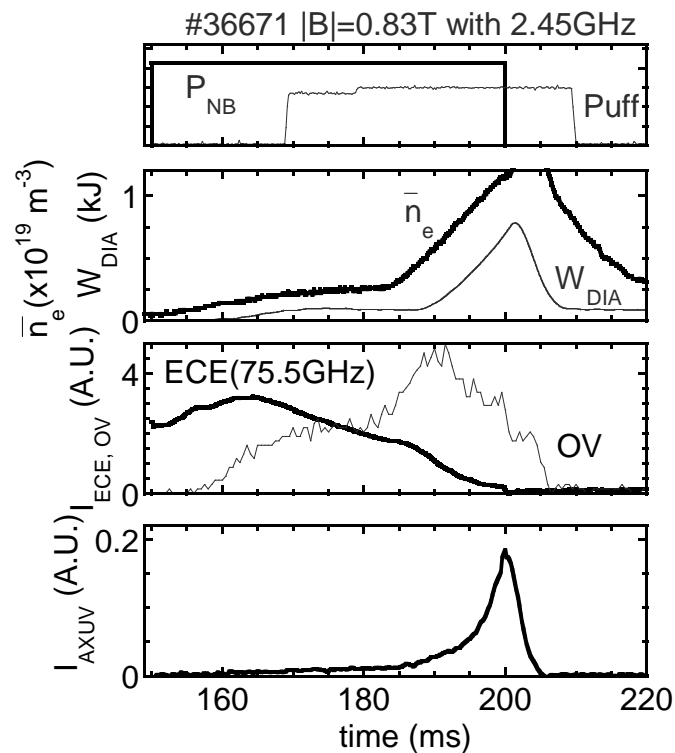
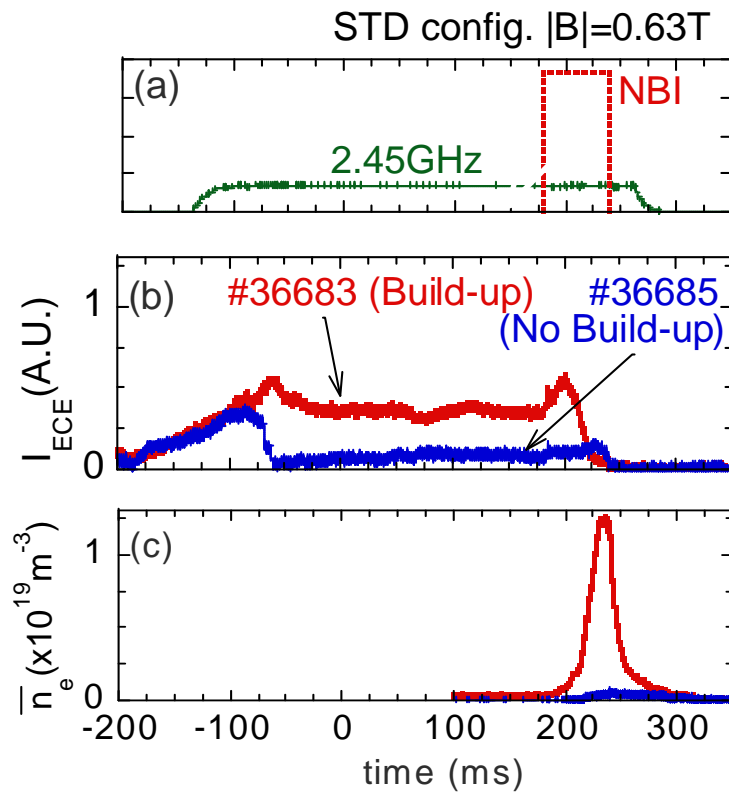


Stober, Nucl. Fusion (2011) **51** 083031  
Bo Lu, PFR 7 (2012) 1202153

# NBI Plasmas Have Been Successfully Started Up by Assist of 2.45GHz Microwaves in Heliotron J

## Heliotron J

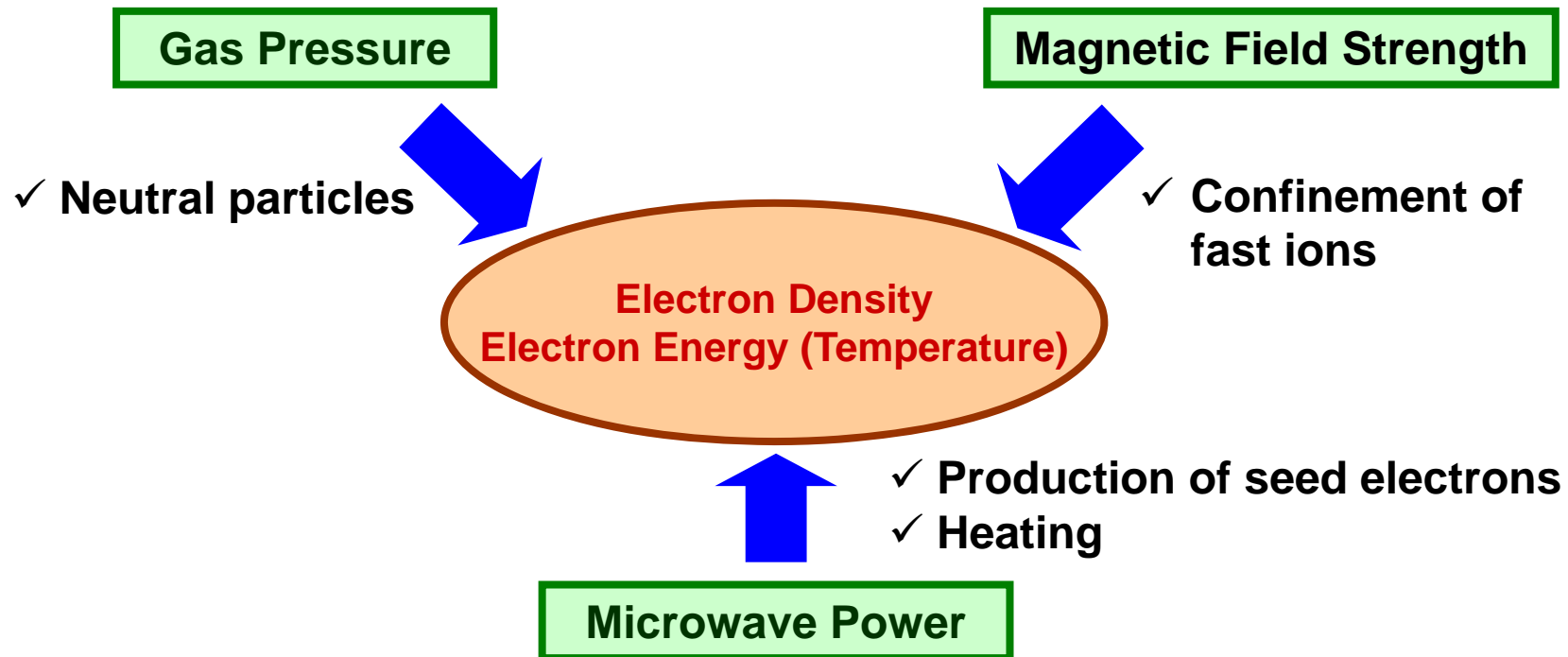
- 2.45 magnetron power  $P_{\text{mag}}=5\text{kW}$
- No ECH is applied



Kobayashi, Nucl. Fusion 51 (2011) 062002

# What Are Important for NBI Plasma Start-up?

- A small number of fast ions ionize the background neutrals and heat low-density seed plasma
- The electron temperature should be high enough to ionize background neutrals



- Large volume and/or high magnetic field strength are required for plasma startup by NBI alone

# Issues To Be Resolved

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1. How much ECH power is required for plasma start-up in W7-X?
2. Is plasma production by 3rd harmonic ECH possible?
  - No successful experiment has been demonstrated
3. Damage of in-vessel components by unabsorbed ECH power
  - Long delay of plasma breakdown might cause damage in in-vessel components
4. Extension of the magnetic field regime for 2nd harmonic ECH breakdown
5. Plasma start-up by perpendicular NBI
6. Modeling of plasma production to predict necessary conditions

# Presentations in This Session

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1. M. Preynas (IPP, VC)

**Plasma start-up experiments using ECRH on LHD, Heliotron-J and WEGA**

2. D. Gradic (IPP, VC)

**Plasma start-up in stellarators and heliotron with NBI**

3. E. Ascasibar (CIEMAT, VC)

**ECH startup**