EX/P2-11

東京大学
THE UNIVERSITY OF TOKYO

Non-inductive Plasma Initiation and Plasma Current Ramp-up on the TST-2 Spherical Tokamak

Y. Takase, A. Ejiri, H. Kakuda, T. Oosako, T. Shinya, T. Wakatsuki, O. Watanabe[3], T. Ambo, H. Furui, T. Hashimoto, J. Hiratsuka, H. Kasahara[1], K. Kato, R. Kumazawa[1], C. Moeller[2], T. Mutoh[1], A. Nakanishi, Y. Nagashima[3], K. Saito[1], T. Sakamoto, T. Seki[1], M. Sonehara, R. Shino, H. Togashi, T. Yamaguchi

The University of Tokyo, Kashiwa 277-8561 Japan

[1)] National Institute for Fusion Science, Toki 509-5292 Japan

[2)] General Atomics, San Diego, CA 92186 U.S.A.

[3)] Research Institute for Applied Mechanics, Kyushu University, Kasuga 816-8580 Japan

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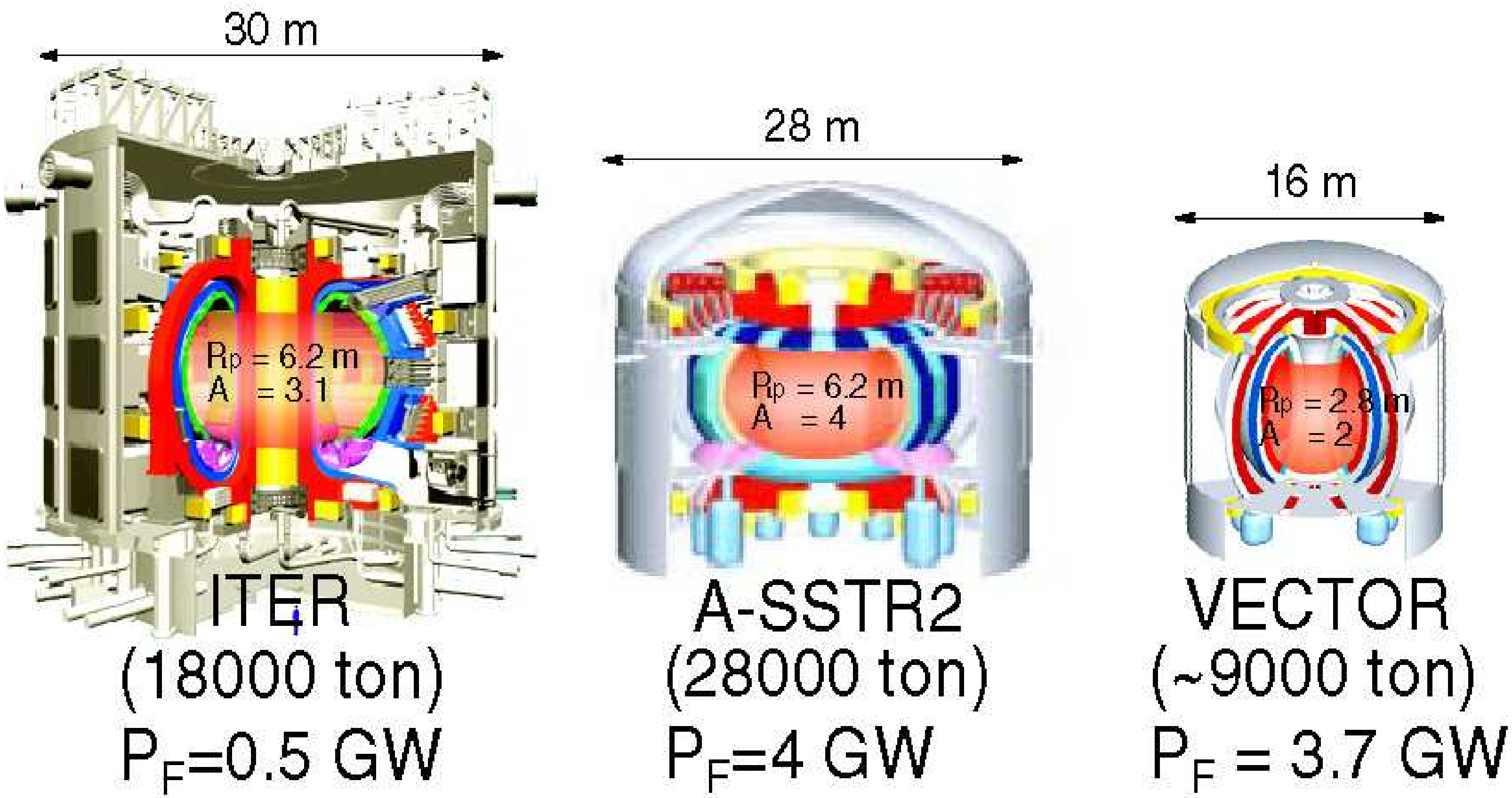
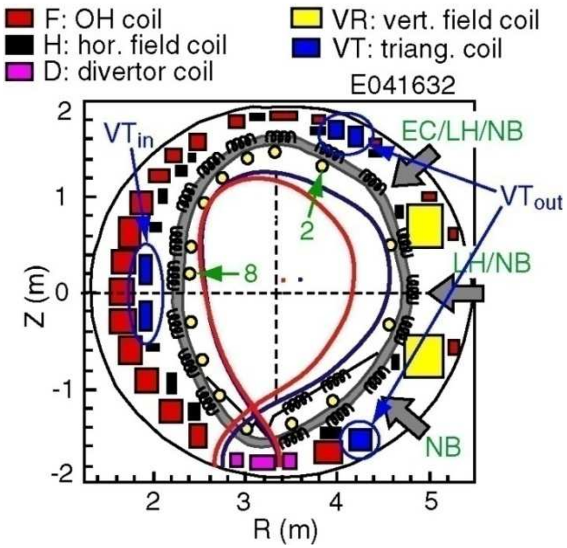
Motivation and Goal of Research

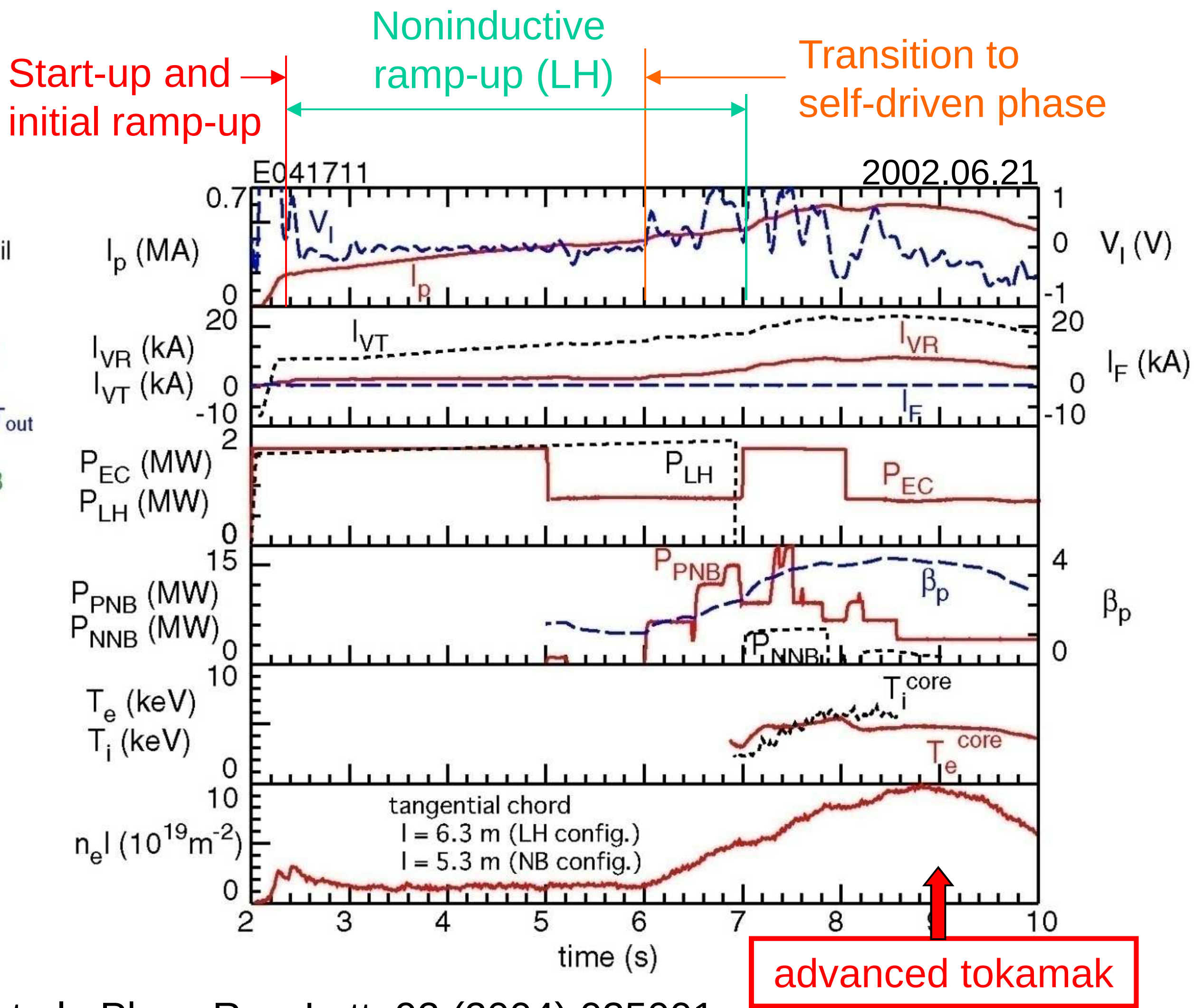
- Economically competitive tokamak reactor may be realized at low aspect ratio by eliminating the central solenoid (CS)



S. Nishio, et al., in Proc. 20th IAEA Fusion Energy Conf., FT/P7-35 (Vilamoura , 2004).

- Formation of Advanced Tokamak Plasma without CS was Achieved on JT-60U





S. Shiraiwa, et al., Phys. Rev. Lett. 92 (2004) 035001.

- Is I_p ramp-up by LHW possible in ST? $\rightarrow$ Demonstrate on TST-2

LHCD Experiment on TST-2

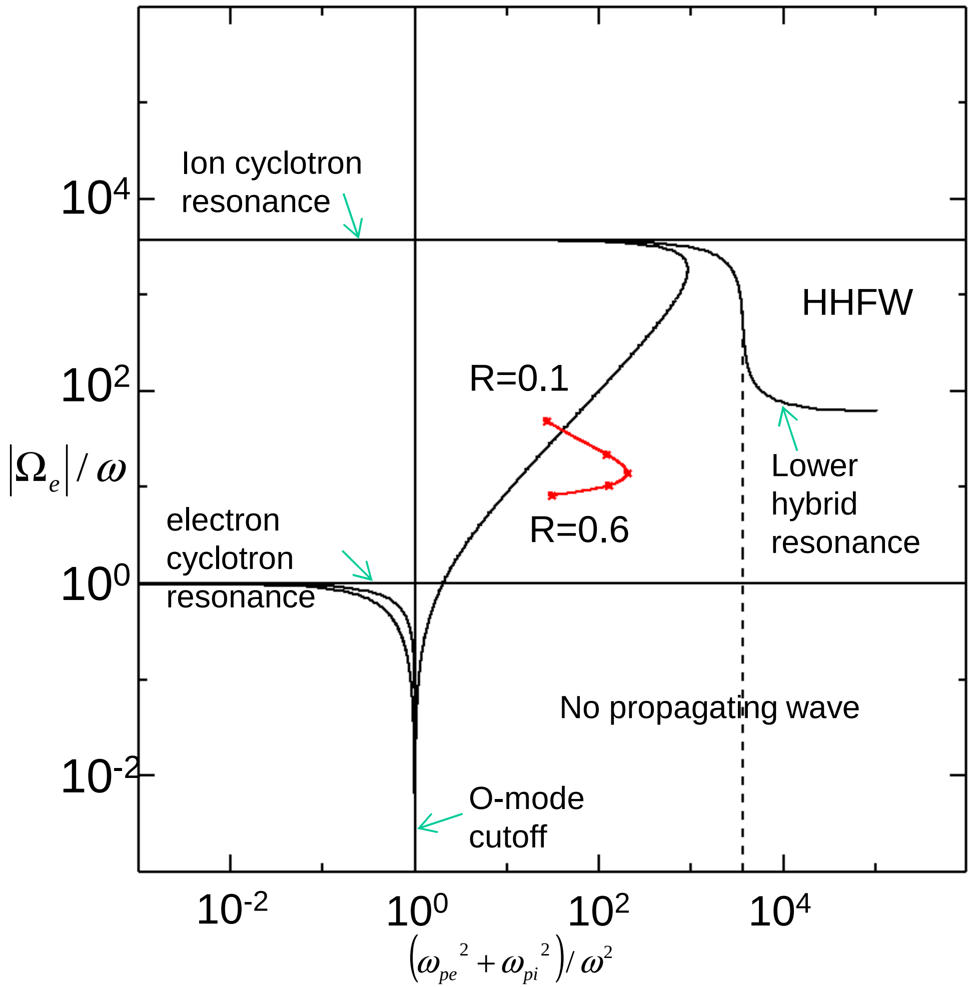
- LHCD experiments have started on TST-2.
  - The scenario is to ramp-up I_p from a very low current (~ 1 kA), very low density (< 10^{18} m^{-3}) ST plasma.
  - Up to 400 kW of power at 200 MHz is available. 8.2 GHz ECH (20 kW) installed to enable high B_t (0.3 T) operation required for LHCD.
  - Experiments using a combline antenna (FW launch) was completed, and initial experiments using a dielectric-loaded waveguide array (“grill”) antenna (SW launch) have begun.

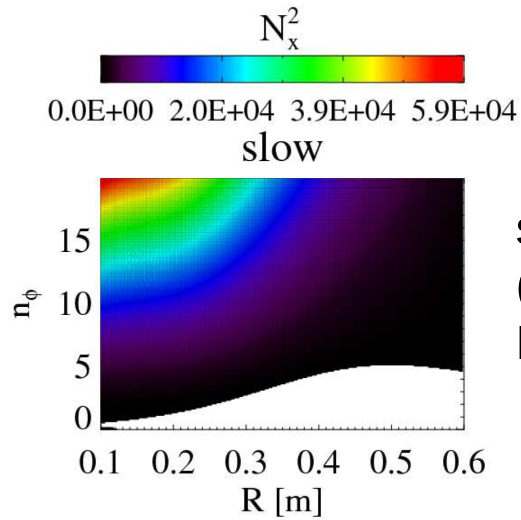
- Experimental results presented in this poster:
  - Efficiency of I_p ramp-up (FW launch vs. SW launch).
  - X-ray measurements.
  - Polarization-resolved wave measurements by RF magnetic probes.

- Improved antenna for direct SW excitation is being tested.
  - Capacitively coupled traveling wave antenna.

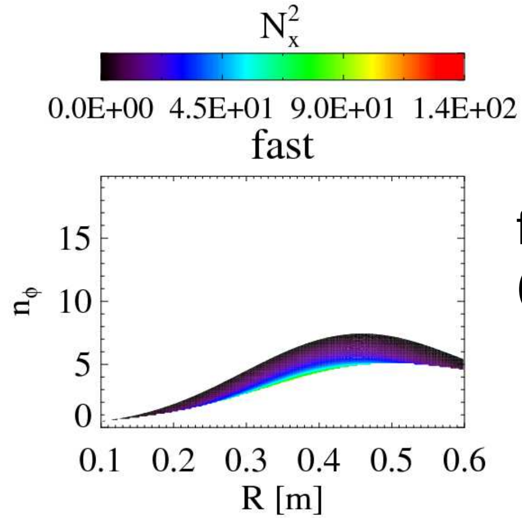
Cold Plasma Dispersion Relation

CMA diagram





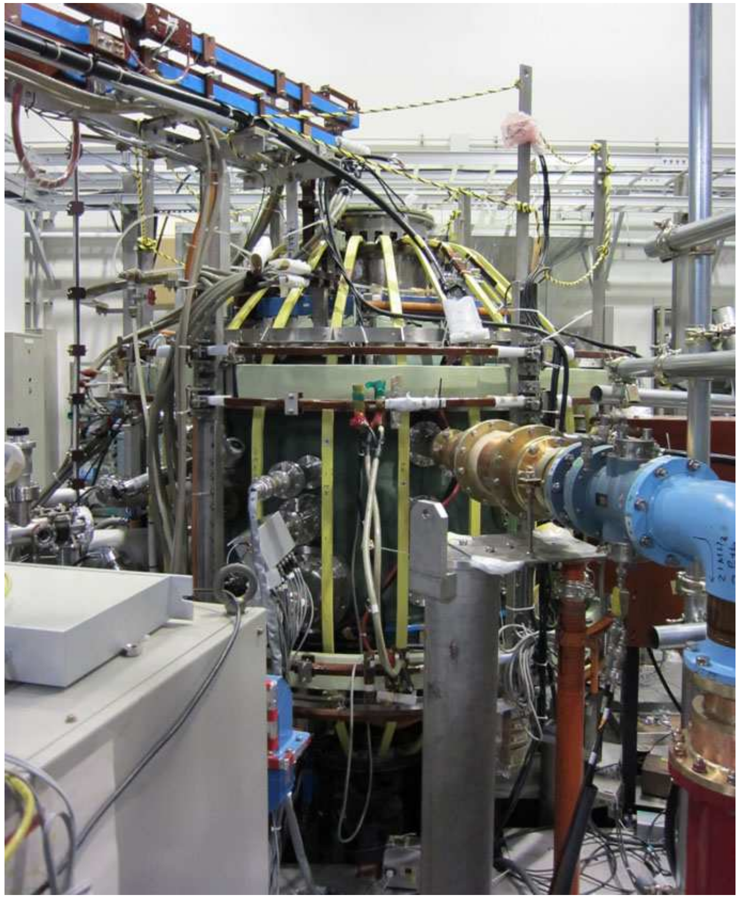
slow wave (SW) or LH wave



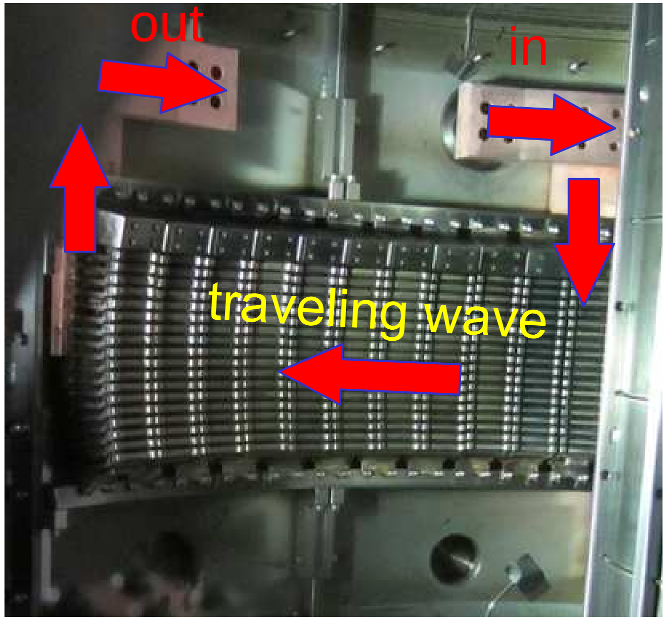
fast wave (FW)

TST-2 Spherical Tokamak and Combline Traveling Wave Antenna

- R = 0.38 m, a = 0.25 m (A = 1.5)
- B_t = 0.3 T, I_p = 0.14 MA

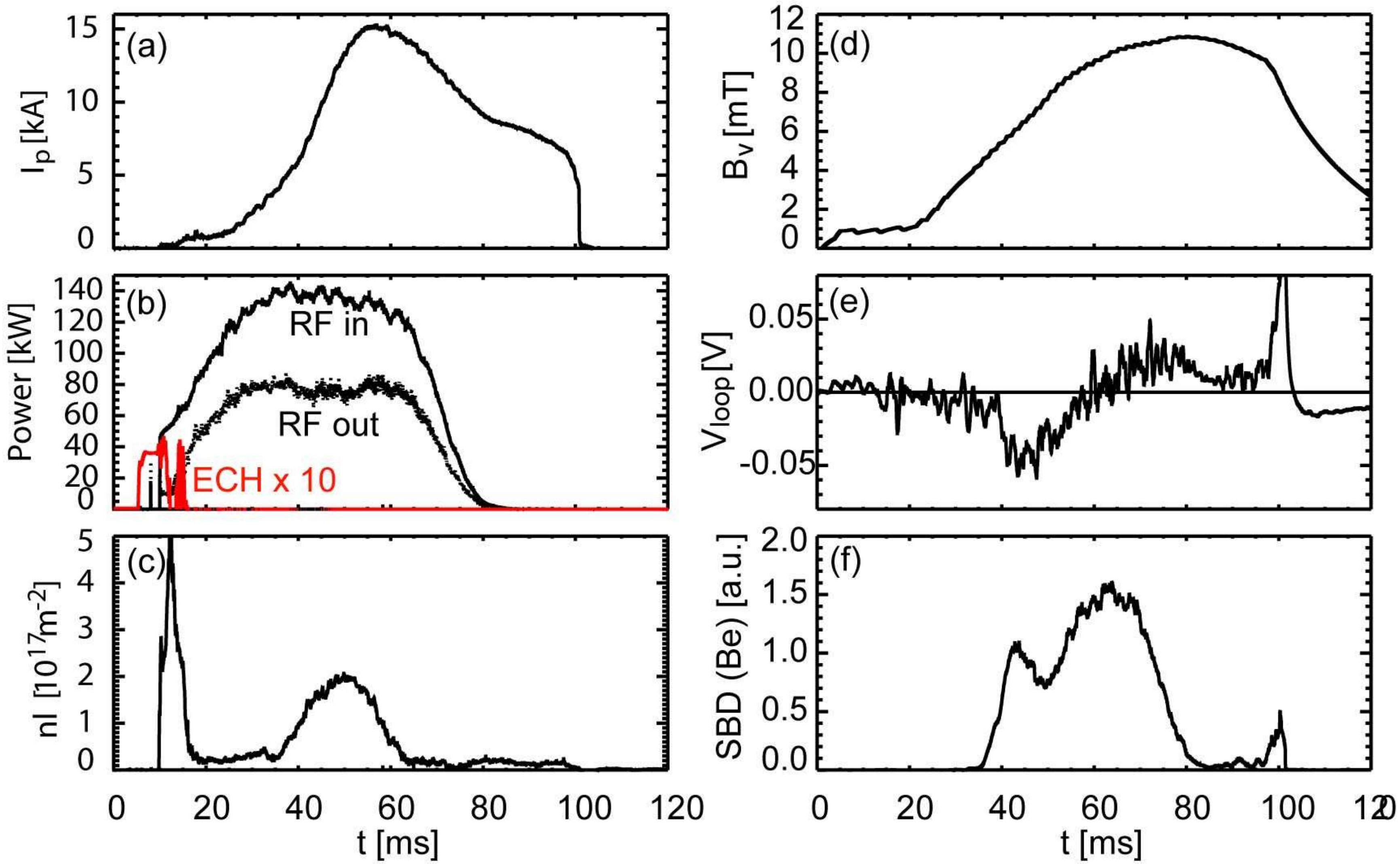


Combline antenna
(11 elements)

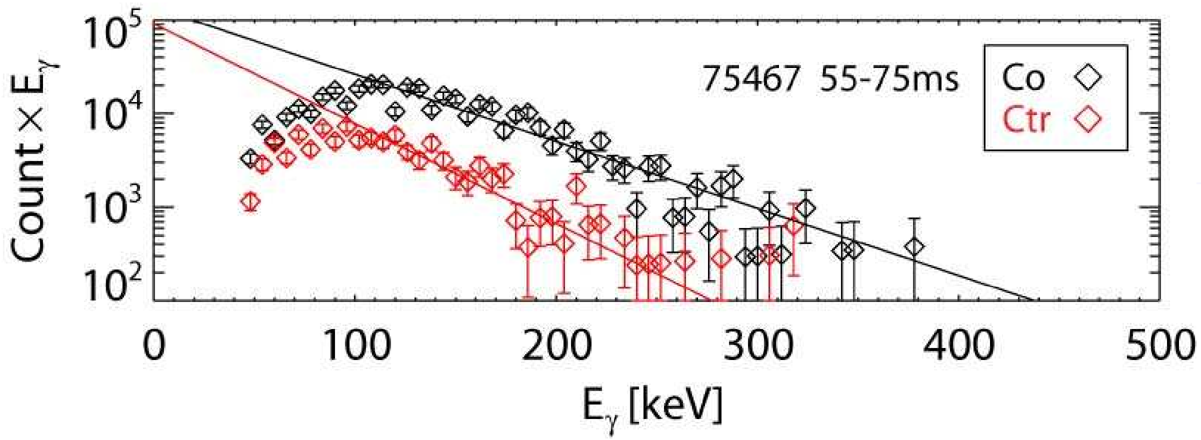


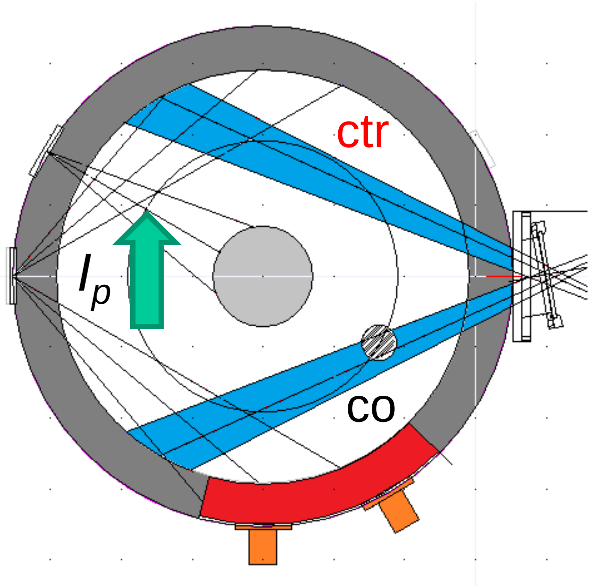
- excites traveling FW
- I_p driven by SW (LHW)
(requires mode conversion)

I_p Ramp-up to 15 kA Achieved by 200 MHz RF Power (Combline Antenna)



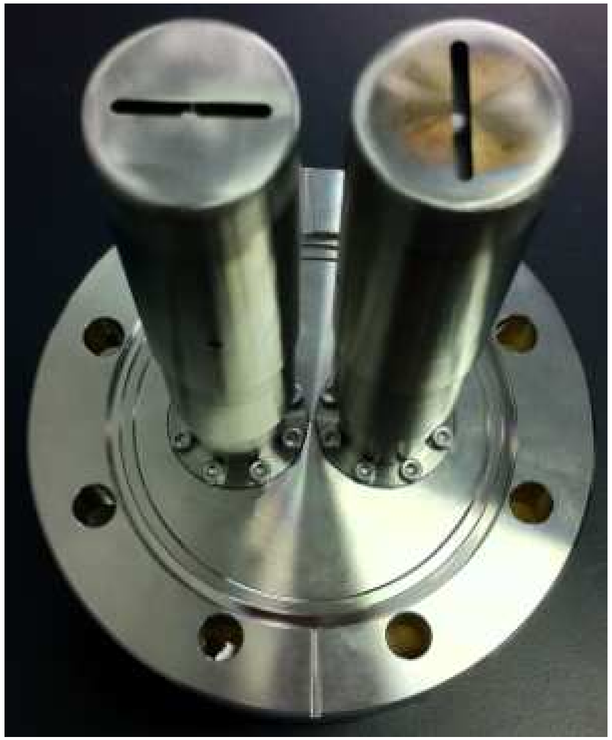
Hard X-ray Spectra for Co/Ctr Current Drive Directions (Combline Antenna)

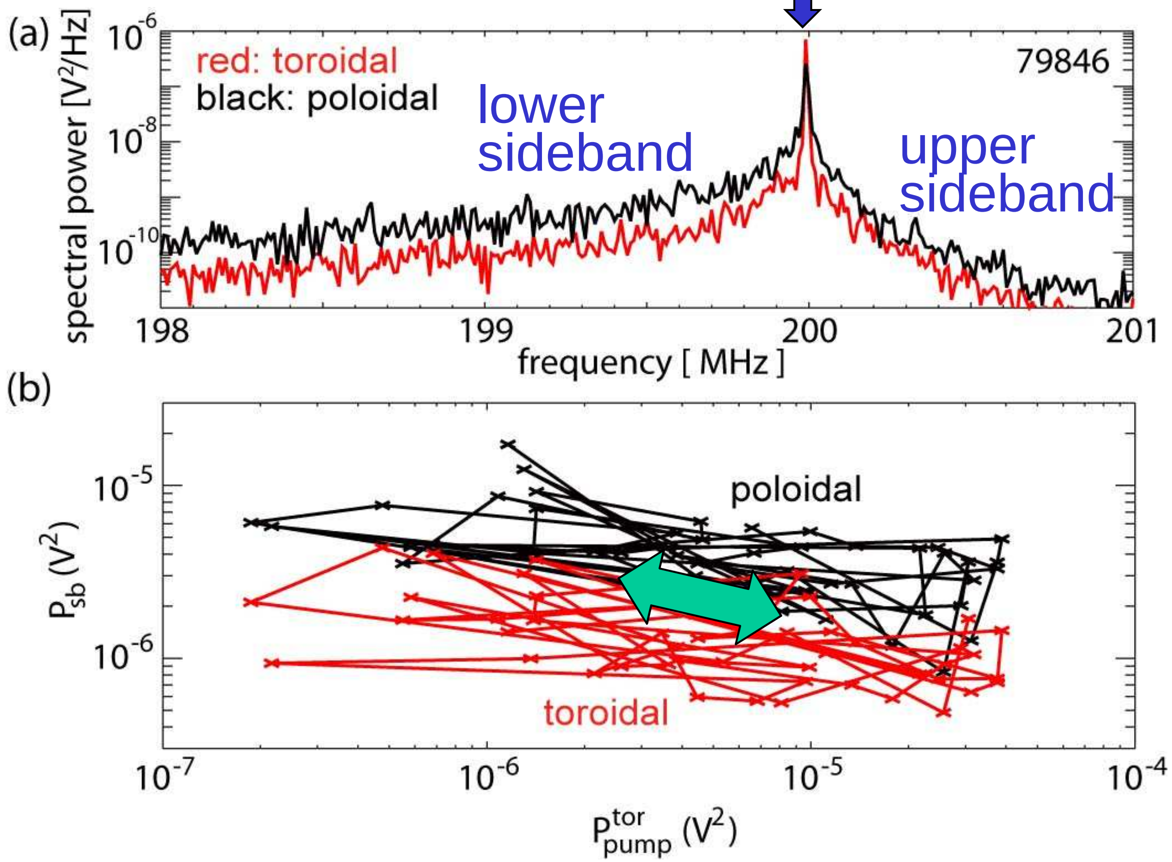




- Photon flux is an order of magnitude higher in the co direction.
- Photon temperature is higher in the co direction (60 keV vs. 40 keV).
- Consistent with acceleration of electrons by a uni-directional RF wave.

Frequency Spectra Measured by RF Magnetic Probes (Combline Antenna)



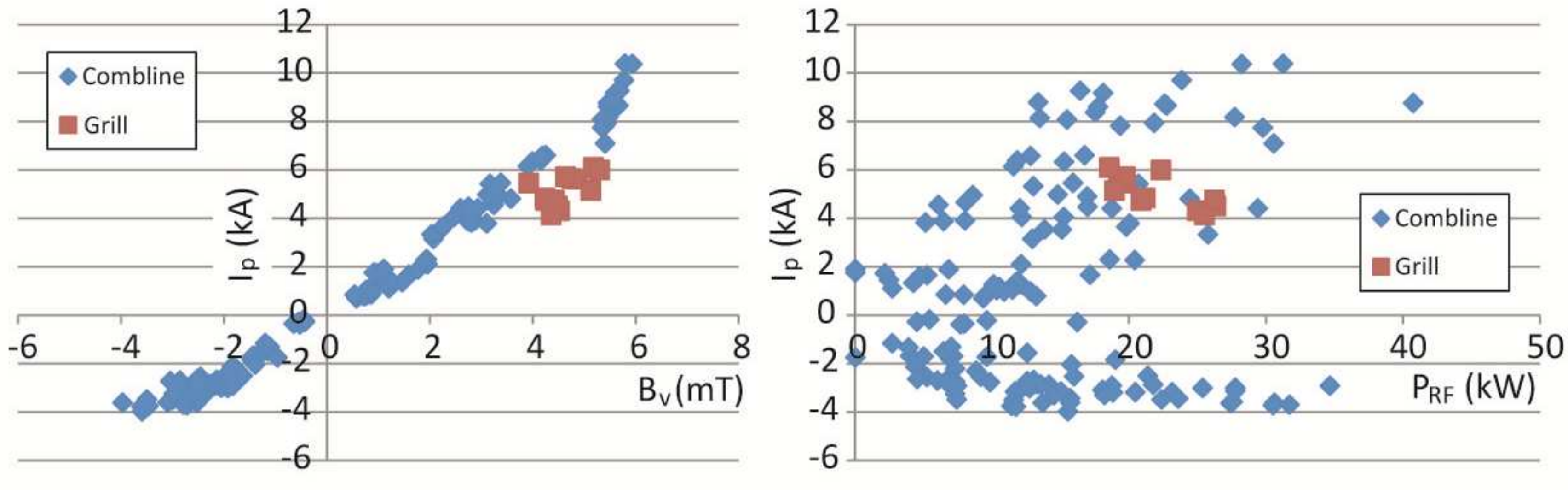


- LHW excited by PDI?
  - Pump wave (f = 200 MHz ± 1 kHz) has FW polarization ($|B_t| > |B_p|$).
  - PDI sidebands have SW (LHW) polarization ($|B_t| < |B_p|$).
- Pump wave weakens when sidebands intensify.

Dielectric-Loaded Waveguide Array Antenna (Grill Antenna)

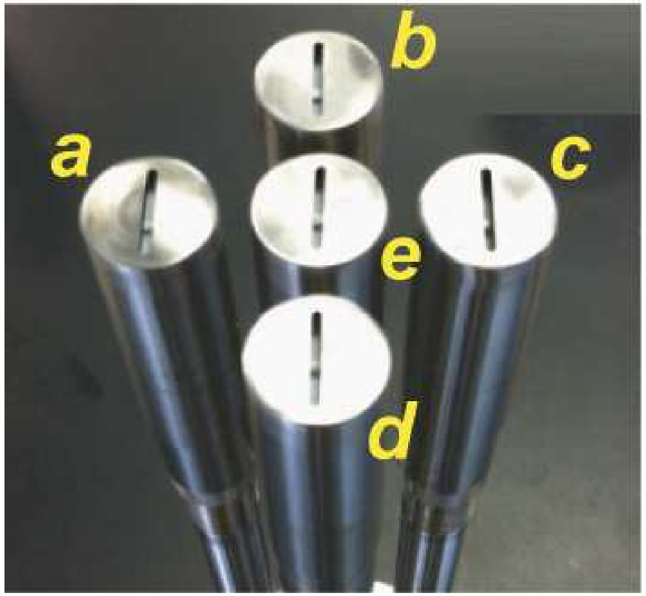
- excites traveling SW (LHW)

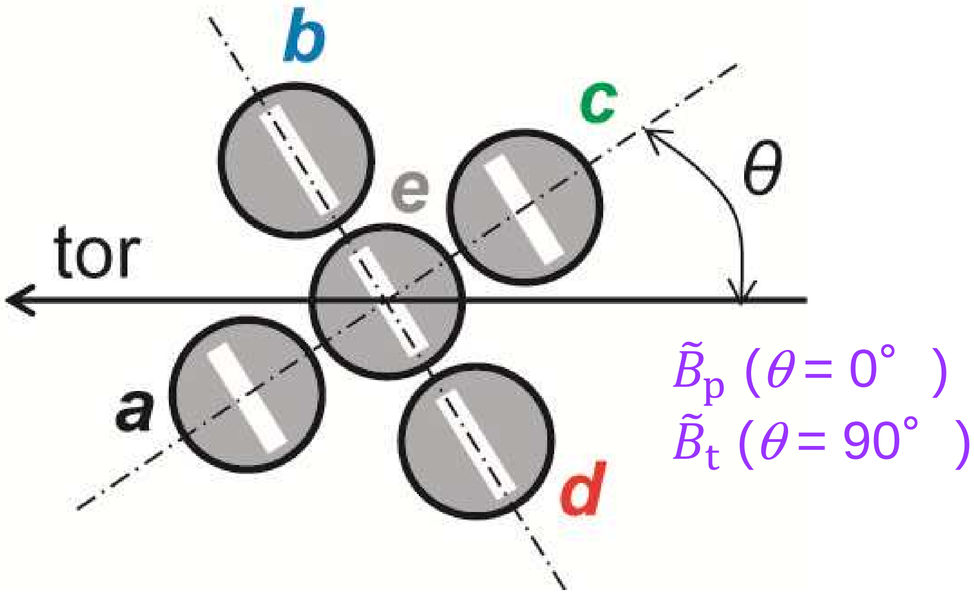
Comparison of Driven I_p
(Combline Antenna vs. Grill Antenna)



- For similar B_v and P_{RF}, driven I_p is slightly lower for grill antenna.
  - Due to lower directivity of the waves excited by the grill antenna?

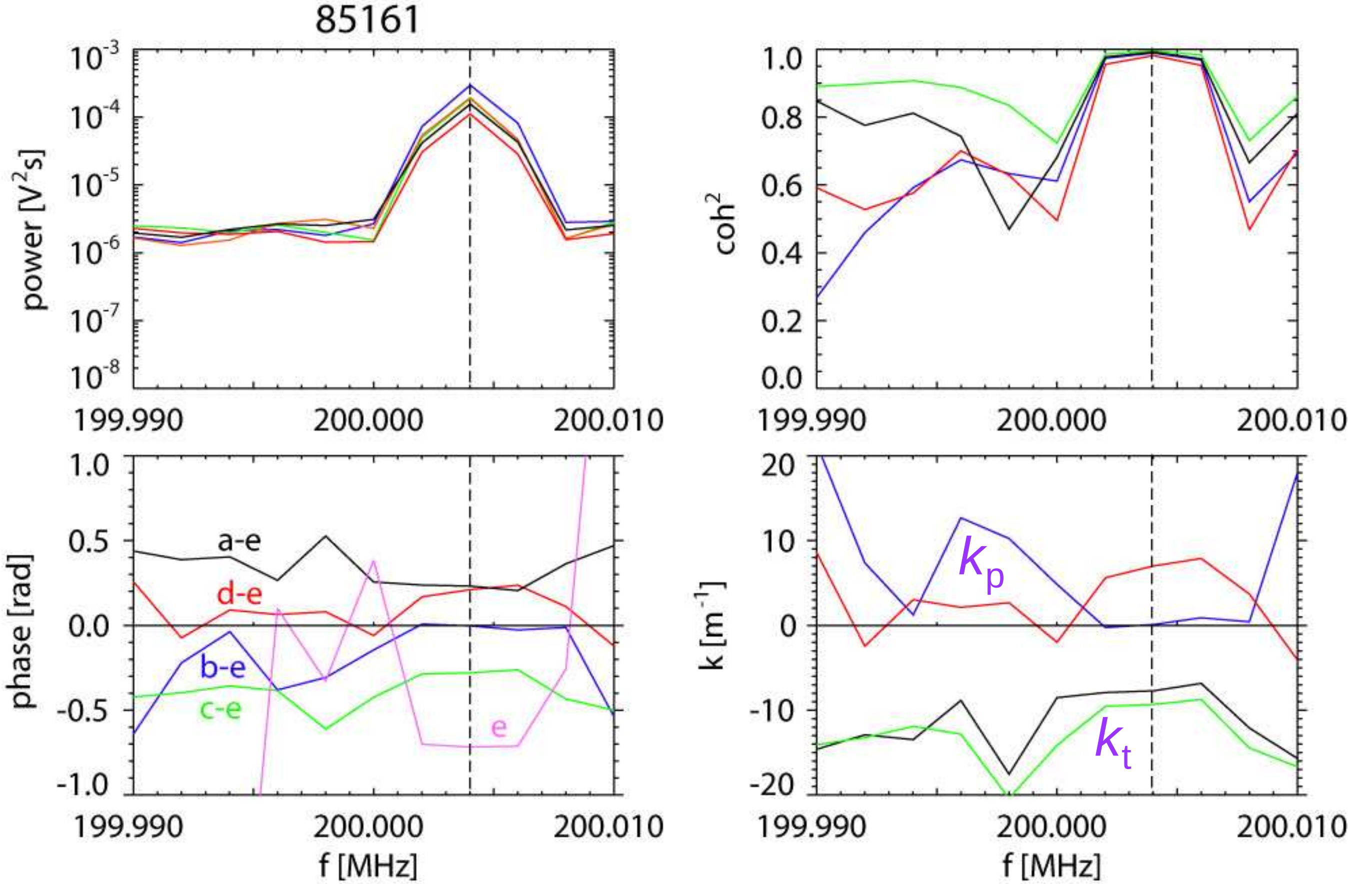
RF Magnetic Probe Array for *k* Measurement (Grill Antenna)





- Array can be rotated about its axis
  - to distinguish RF magnetic field polarization
    - $\tilde{B}_t$ (toroidal) and $\tilde{B}_p$ (poloidal)
  - to measure wavevector components
    - k_t (toroidal) and k_p (poloidal)

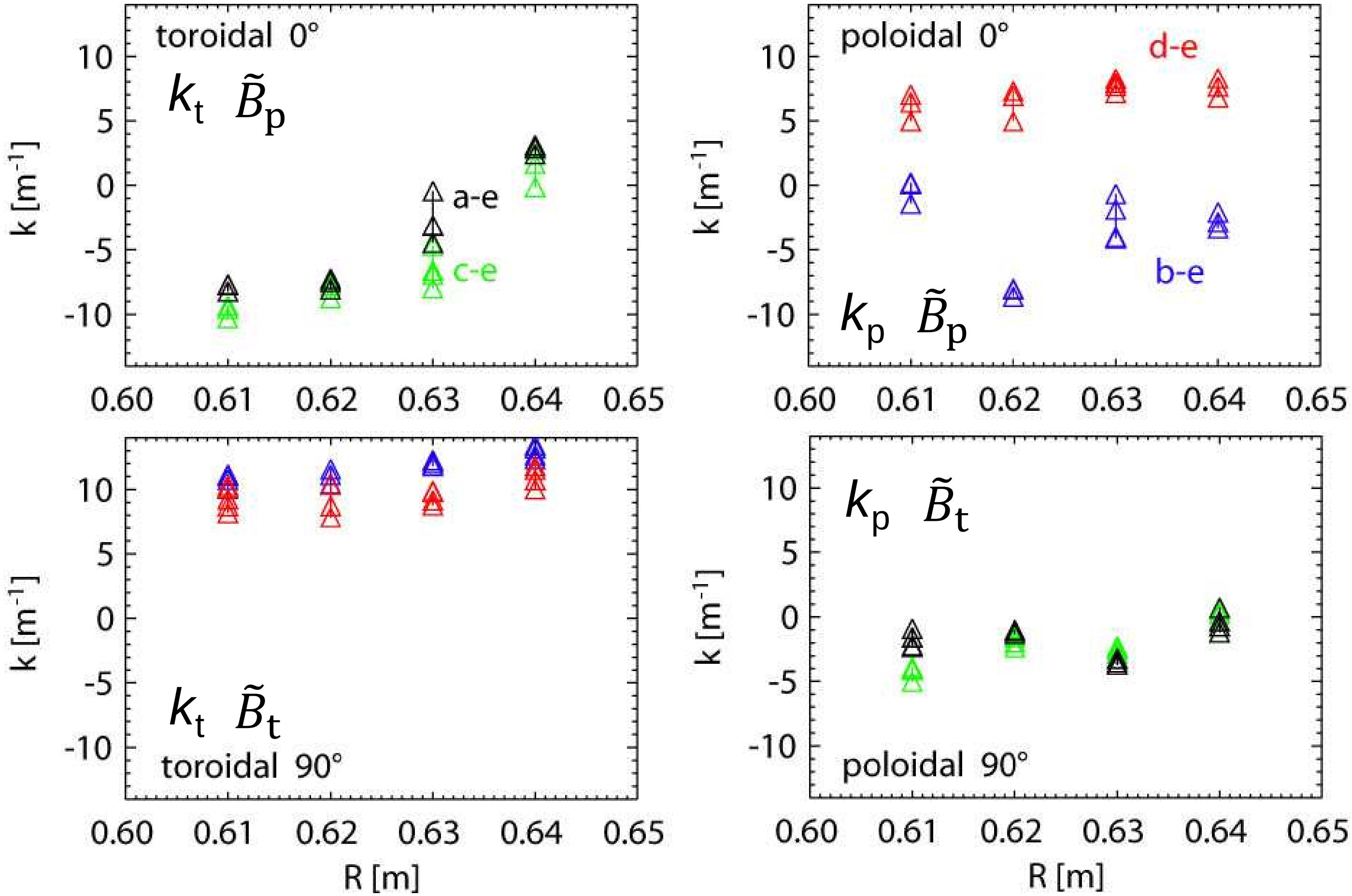
Measurement of k_t and k_p (Grill Antenna)



SW (LHW) polarization $\tilde{B}_p$ ($\theta = 0°$)

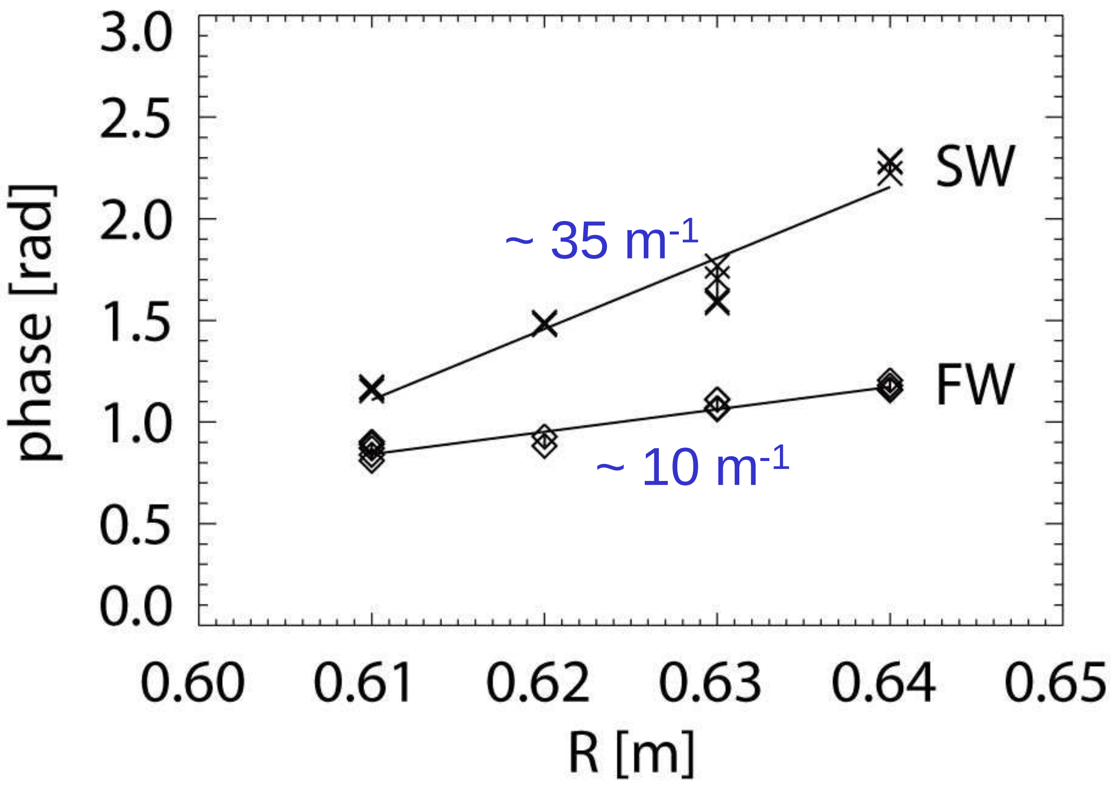
- Wavevector components are derived from phase differences of probes a, b, c, d relative to probe e.

Radial Profiles of Pump Wave k_t and k_p (Grill Antenna)



- Dominant wavevector components excited by the grill antenna (for 90° phasing) are $k_t \cong 50$ m^{-1} and $k_p \cong 10$ m^{-1}.
  - Measured $k_t \lesssim 10$ m^{-1} is much smaller (higher k_t absorbed?)

Measurement of k_R (Grill Antenna)



- Radial component of wavevector can be derived from radial profile of phase measured by probes relative to the injected wave.

Typical Values of Wavevector Components (Grill Antenna)

	$\tilde{B}_p$ (SW component)	$\tilde{B}_t$ (FW component)
$\lvert k_t \rvert \cong \lvert k_{\parallel} \rvert$	$< 10\ m^{-1}$	$\sim 10\ m^{-1}$
$\lvert k_p \rvert$	$< 10\ m^{-1}$	$< 5\ m^{-1}$
$\lvert k_R \rvert$	$\sim 35\ m^{-1}$	$\sim 10\ m^{-1}$
$\lvert k_{\perp} \rvert$	$\sim 35\ m^{-1}$	$\sim 10\ m^{-1}$

$k_{\parallel} = 10\ m^{-1}$ corresponds to $n_{\parallel} = 2.4$

New Traveling Wave LHW Antenna

- Consists of 13 mutually coupled vertical bars arrayed in the toroidal direction.
- Electric field polarized in the toroidal direction (SW polarization).
- Power is fed to the outermost element. Successive elements are excited through mutual capacitance.
- Antenna is undergoing low-power testing.

6-element array for
low-power testing

Conclusions (1)

- ST plasma initiation and I_p ramp-up by waves in the LH frequency range were demonstrated on TST-2.
  - Combline antenna (FW launch) and dielectric-loaded waveguide array ("grill") antenna (SW launch) drive similar I_p.
  - Slightly lower I_p for the grill antenna may be a result of lower directivity of the excited wave.
- Combline antenna results:
  - X-ray measurements indicate acceleration of electrons by a uni-directional wave.
  - Combline antenna excites the FW, but SW is excited by parametric decay.

Conclusions (2)

- Grill antenna results:
  - Wavevector components for FW and SW were measured by an array of RF magnetic probes.
  - Results are consistent with expectations based on dispersion relations for FW and SW.
  - Lower observed k_t ($\cong k_{||}$) compared to k_t excited by the antenna may indicate absorption of higher $k_{||}$ components.

- A new type of traveling SW antenna (capacitively coupled array) is being tested at low power.
  - Scheduled to be tested on TST-2 in early 2013.

Acknowledgments

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