U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

Towards non-inductive operation in NSTX-U

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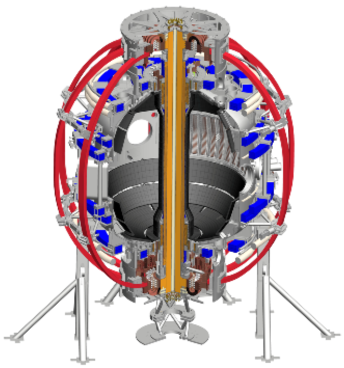
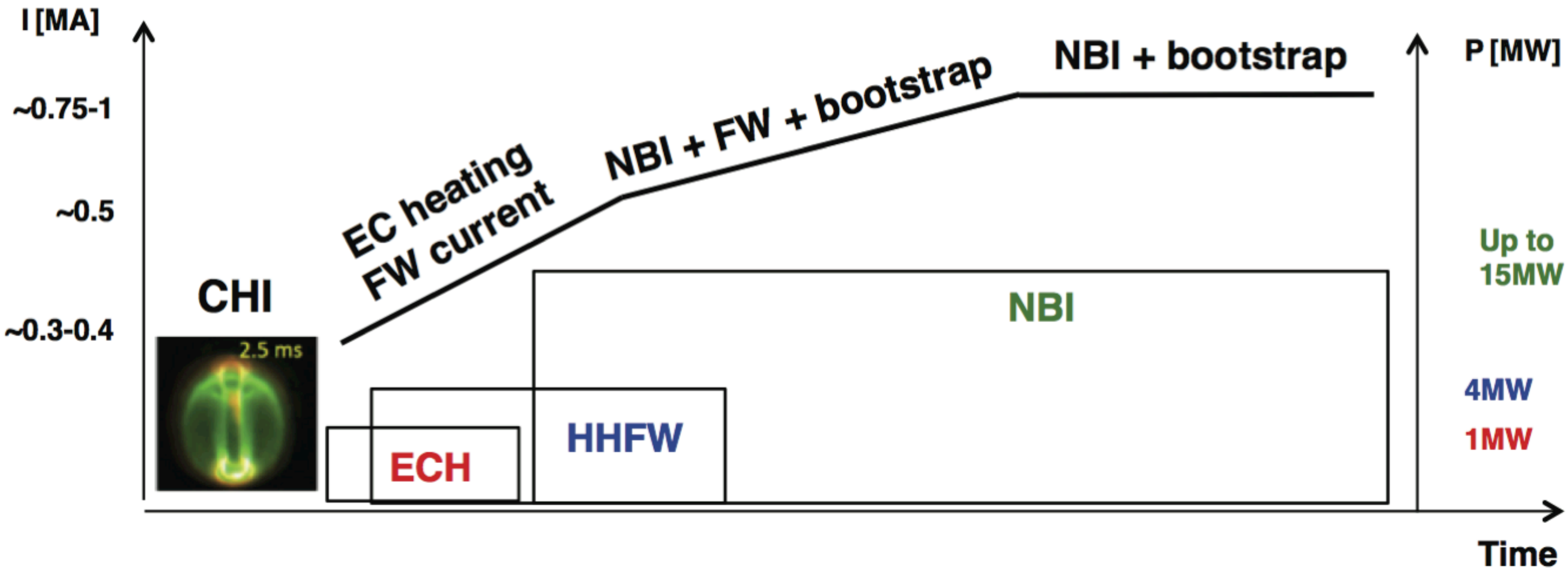
PPPL



Our strategy: combine integrated modeling and experiments to address issues



- Heat CHI plasma to maximize efficiency of H/CD sources
- Minimize beam losses at low current
- Combine RF and NBI for profile control
- Optimize NBI source combination for CD.
- Maintain control over position, current profile, MHD stability.

Identify challenges and needs towards non-inductive operation

- Optimizing non-inductive current at startup with NBI.
- Optimizing non-inductive current at startup with HHFW.
- Prepare a target plasma with Electron Cyclotron Heating.
- Why is ECH a game changer for the startup?
- Experiments and modeling towards non-inductive operation.

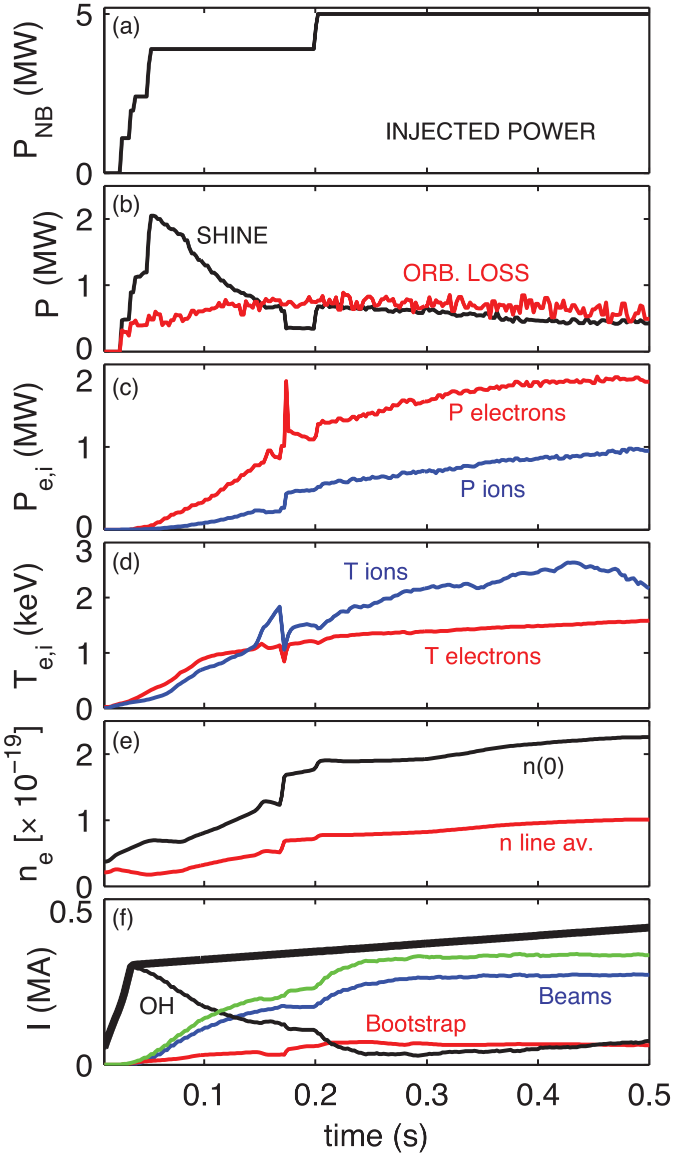
NOTE: focus here on startup and ramp-up, not sustainment.

*[F. Poli et al, Nucl. Fusion **55** (2015) 123011]*

Assumptions in the simulations

- Select NSTX discharges, compare transport models on:
  - RF and NB at low, constant current
  - NB in the ramp-up and at high current flattop
- CAVEAT: Startup/rampup not the same as relaxed, flattop plasma.
- Transport will be addressed during the next campaign
  - pedestal structure, confinement, rotation, turbulence ...
- All simulations run with free-boundary TRANSP
  - Isolver for equilibrium evolution and coil currents
  - TORIC for HHFW, NUBEAM for NBI, GENRAY for ECH
  - MMM for thermal transport
  - Prescribe I_P waveform and maximize non-inductive current drive

NBI alone likely unable to provide needed current on low temperature CHI target



- Optimize beam configuration to:
  - minimize shine-thru and losses
  - maximize non-inductive current

Why?

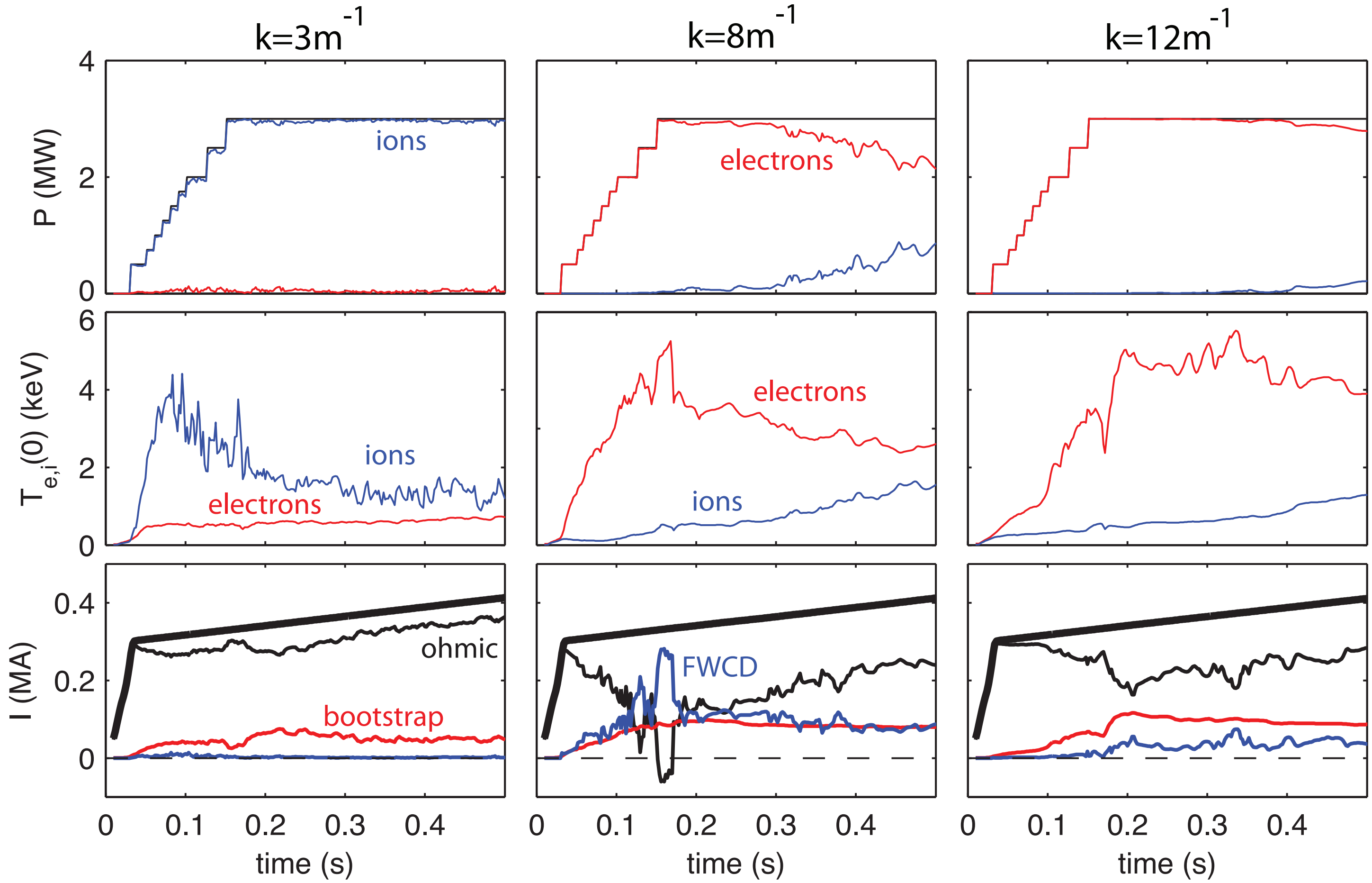
- NBI provides flexibility for current profile control

In progress: current and q profile control

[startup/rampup: W. Wehner, Lehigh university]

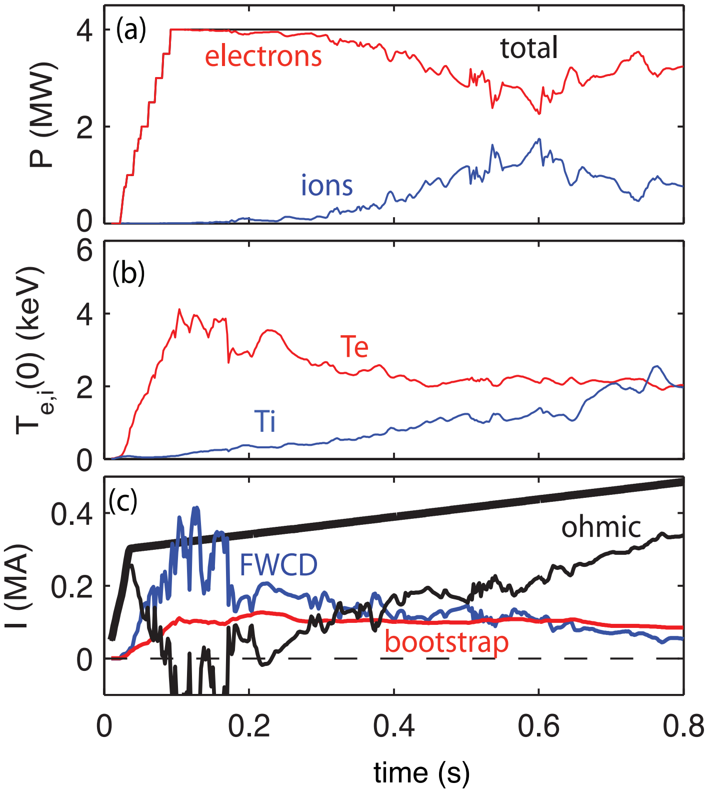
[flattop: D. Boyer, PPPL]

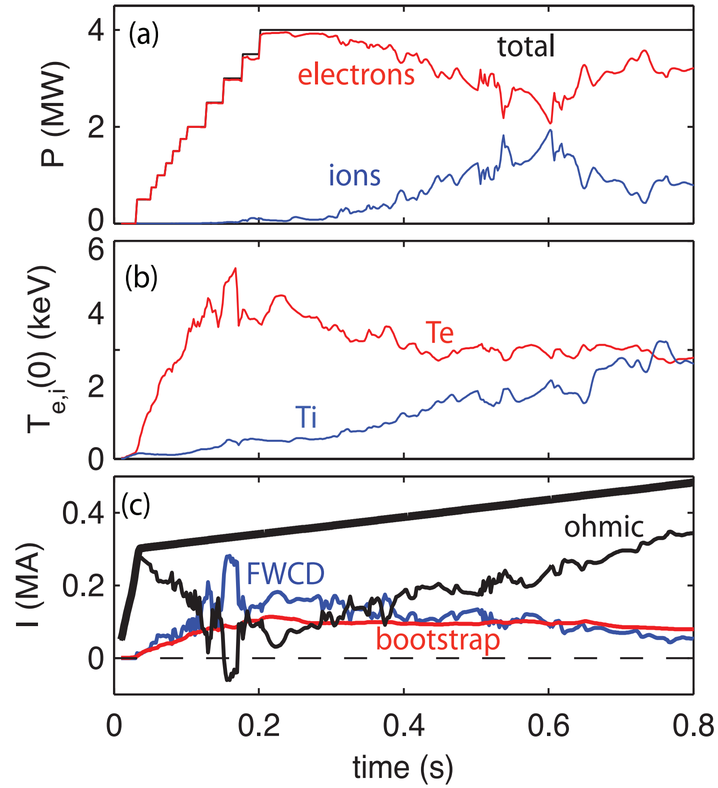
HHFW can provide needed current at startup



- Intermediate launched k most favorable for FWCD
- However, not large enough current drive

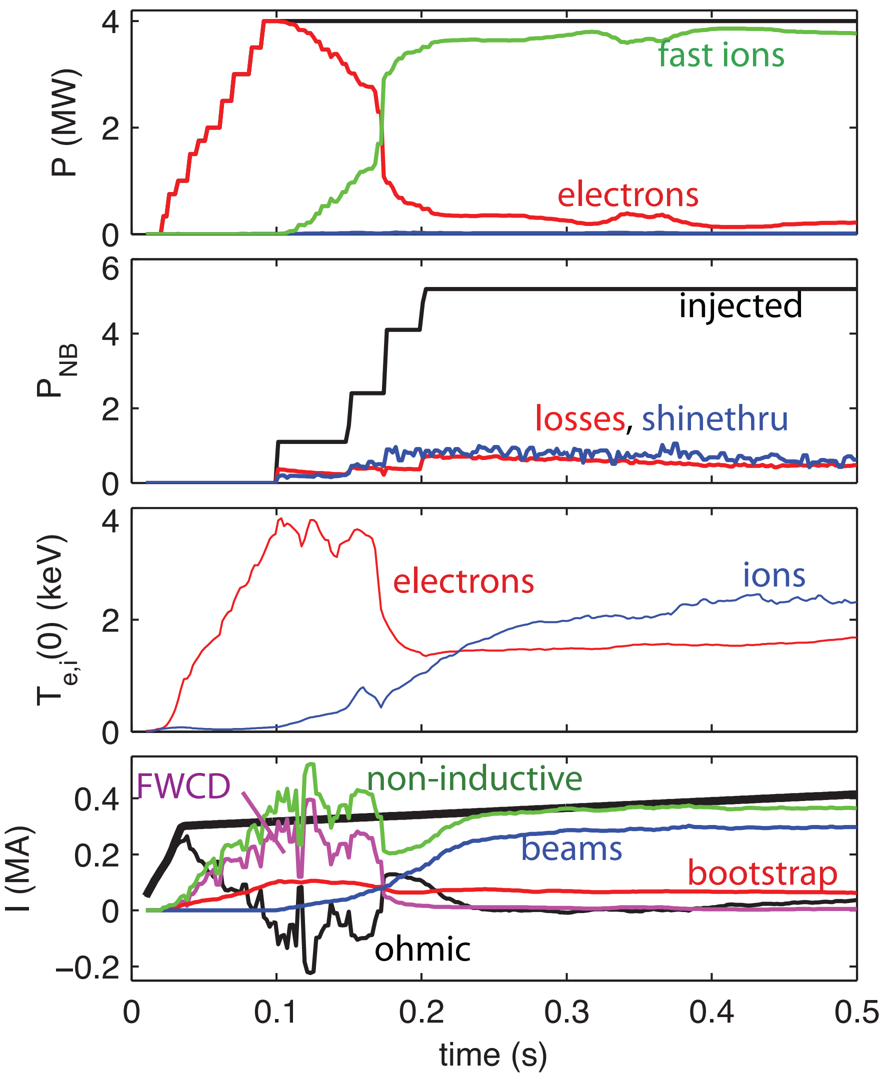
Good wave absorption is critical





- Need 4 MW for ~350kA current (to be verified in exp.)
- FWCD drops after L-H: higher n_e, lower electron absorption.
- Current profiles peaked => challenge for control and MHD.

Combine HHFW and NBI to drive current when HHFW becomes less efficient



Large absorption to fast ions => reduces efficiency

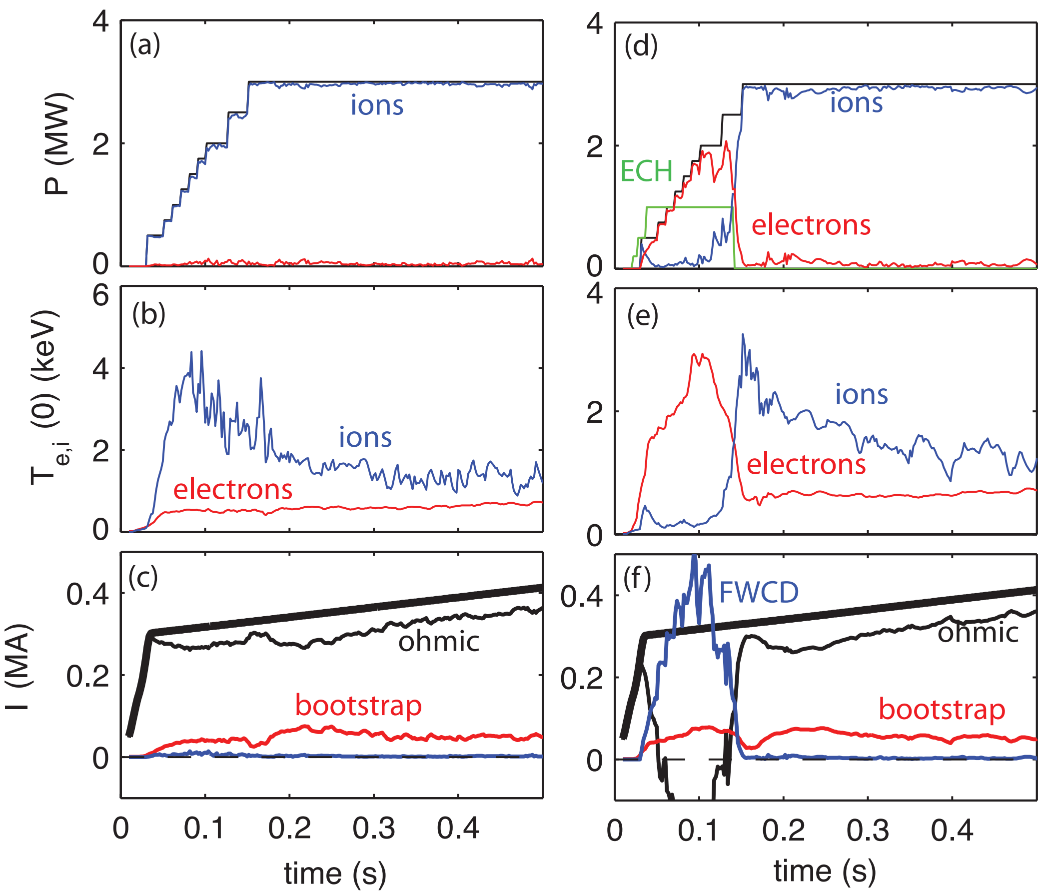
Delay NBI to minimize losses

Lower electron absorption decreases T_e

Switch from HHFW to NBI after ~150 ms and ramp-up to full current

What about the startup phase ?

Use ECH to improve HHFW efficiency

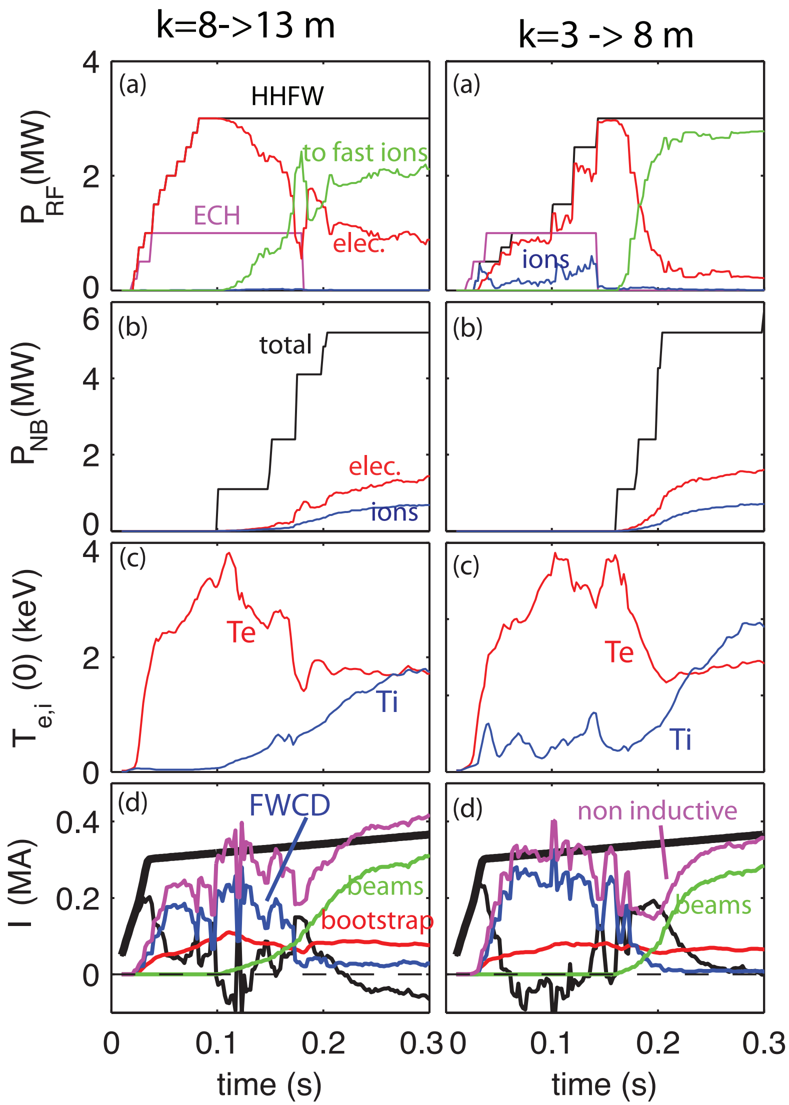


- HHFW with lowest $k=3\ m^{-1}$
- ECH heats to 1-2 keV
- Up to 2 MW of (absorbed) HHFW to drive 400 kA
- 4 MW needed w/o ECH

=> Less HHFW power needs to be absorbed in the plasma to reach the same conditions.

Work in progress: optimize the use of EC at startup,
modeling of EC/EBW at startup [N. Lopez, Princeton University]

The best conditions obtained with dynamical change of HHFW antenna phasing



- Minimize HHFW power needs with lowest k=3 m^{-1}
- Minimize absorption to fast ion with largest k=13 m^{-1}
- Maximize non-inductive current

Everything works on paper …

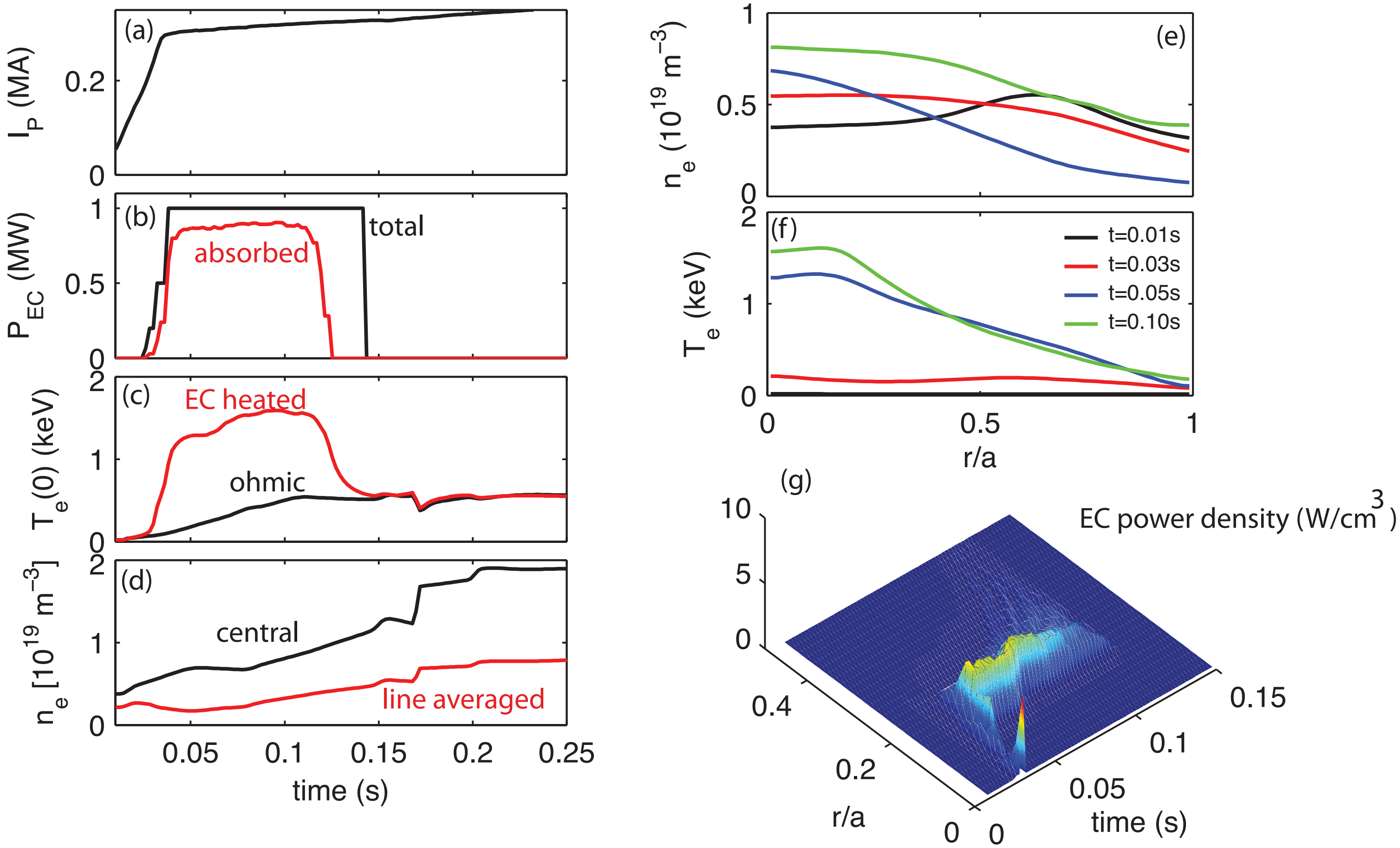
The challenge now is to demonstrate in experiments

Summary: all sources needed for non-inductive ramp-up

- EC: to reduce HHFW power requirements
- HHFW: to drive current where NBI has high losses
- NBI: to ramp-up to full current
- Current and pressure profile control is critical
- ‘creative’ HHFW phasing can help to optimize scenario

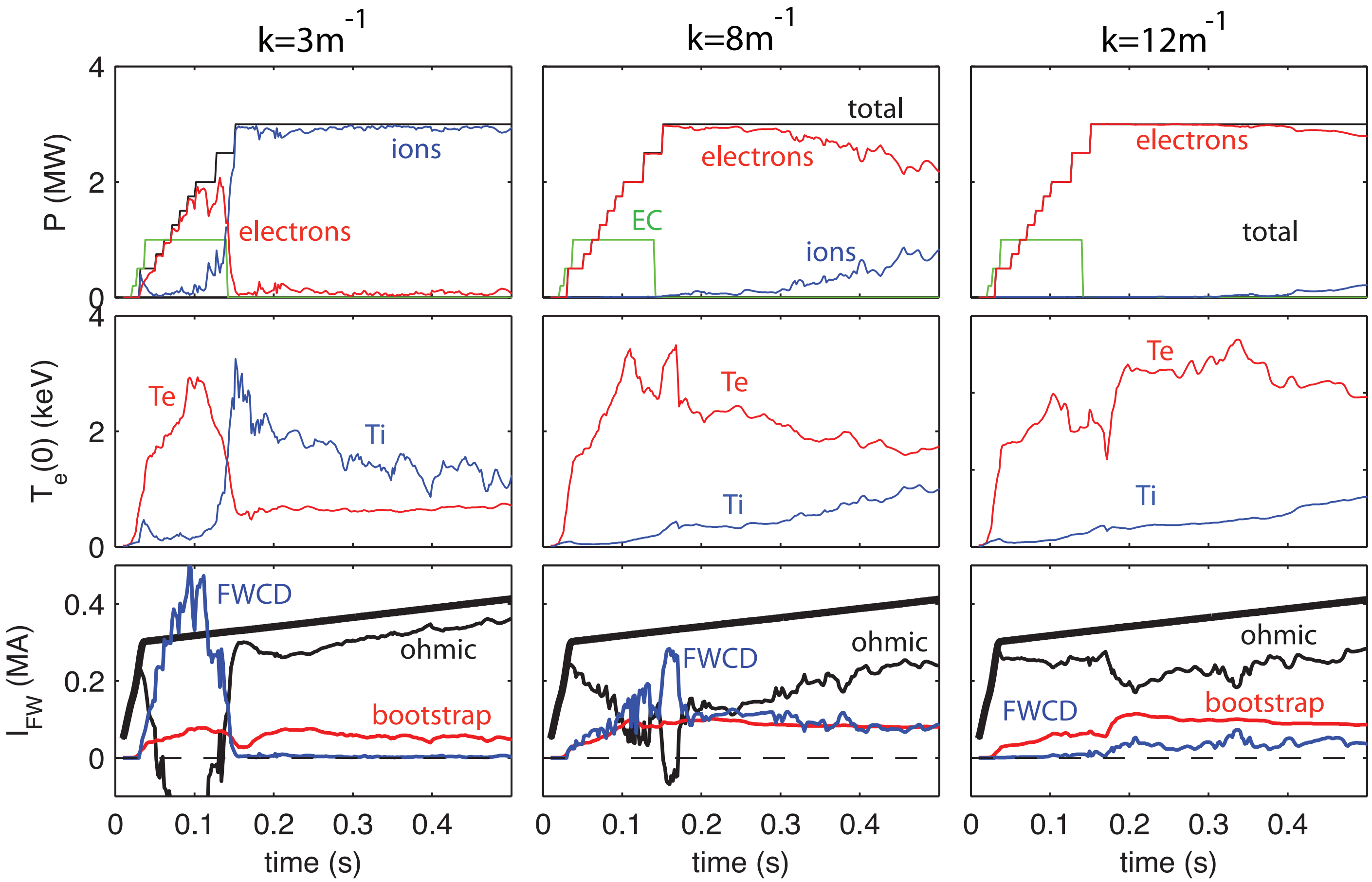
Backup slides

ECH is a game changer for non-inductive rampup



- it heats low temperature plasma to 1keV in 30ms
- However, accessibility limited to low density.

ECH creates flattop temperature conditions



- when combined with EC, lowest phasing most favorable
- half power needed to drive 400kA compared to w/o EC