NSTX-U

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Progress and Plans for Non-inductive Ramp-up/Sustainment Modeling

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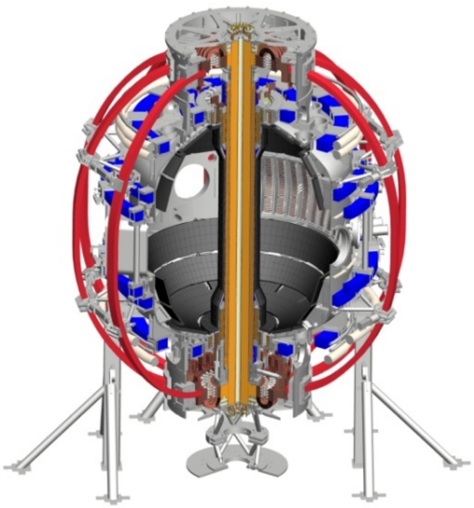

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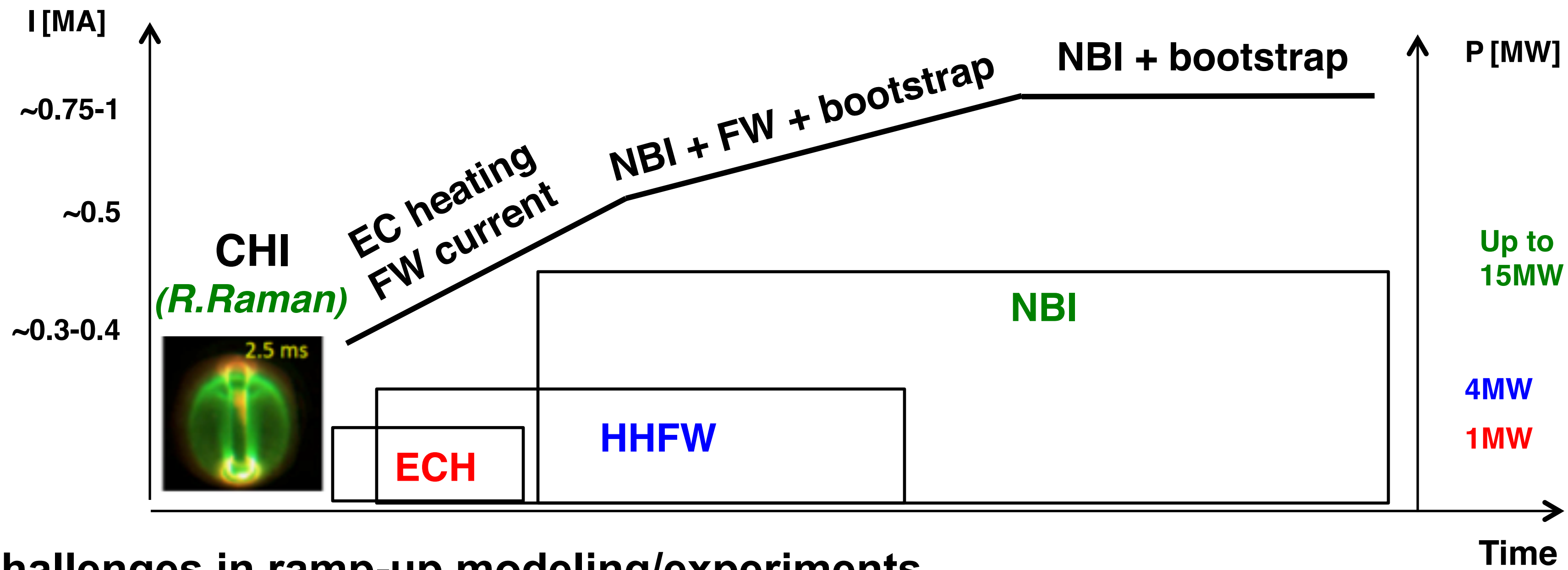
NSTX-U experiments will guide development of ST-FNSF strategies for non-inductive ramp-up and sustainment

1. Develop and understand non-inductive start-up and ramp-up (overdrive) to project to ST-FNSF with small/no solenoid
   – Contributes to the finalization of the EC system design
   – Contributes to optimized use and synergy of RF and NBI in ramp-up
2. Demonstrate 100% non-inductive sustainment at performance that extrapolates to ≥ 1MW/m^2 neutron wall loading in FNSF
   – Contributes to the optimization of profile evolution and control in the ramp-up to access advanced operation

"the gap in demonstrating non-inductive startup and ramp-up is larger than the gap in demonstrating 100% non-inductive sustainment in the ST" [PAC33]

Also emphasized in FESAC TAP 2008, RENEW 2009

Detailed modeling of ramp-up phases informs plans for dedicated experiments in FY15-16



Challenges in ramp-up modeling/experiments

1. Heat CHI target plasma to maximize efficiency of external H/CD sources
2. Combine RF and NBI, aim at best synergy of sources
3. Minimize beam losses at low current => density control, heat start-up plasma
4. Optimize NBI source combination for profile control

Tailor kinetic and current profiles to access target flattop plasmas (see Gerhardt)

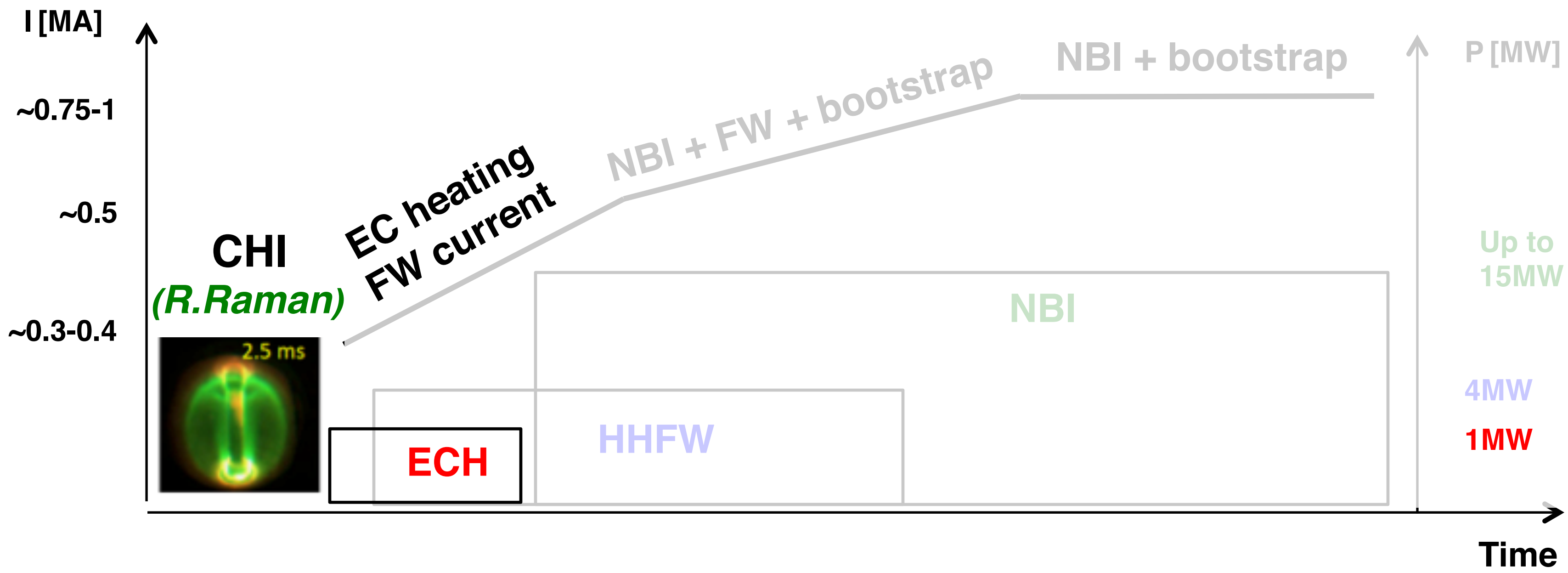
(and do this while maintaining the discharge in the MHD stable operational space)

H/CD sources are evolved self-consistently in TRANSP with free-boundary equilibrium solver (Isolver)

- Use NSTX discharges to build-up discharge in NSTX-U geometry
- Addressing challenges along the way:
  - Self-consistent evolution of equilibrium and pressure evolution during startup with external H/CD
  - Confinement level typically $H_{98,y2}$~1.0-1.2
  - Thermal transport => either predictive or scale analytic temperature profiles (use MMM95 in RF phase, analytic T_e and χ_i=χ_e in NBI phase)
  - Particle transport => density profiles are prescribed (0.5-1.0 n_{Gw})

- ECRH: ray tracing codes (TORAY-GA)
- HHFW: full wave code TORIC with Fokker-Planck treatment for resonant species
- NBI: Monte-Carlo orbit NUBEAM

Time-dependent simulations of EC heating in startup plasma support FY15 facility milestone for ECH system design

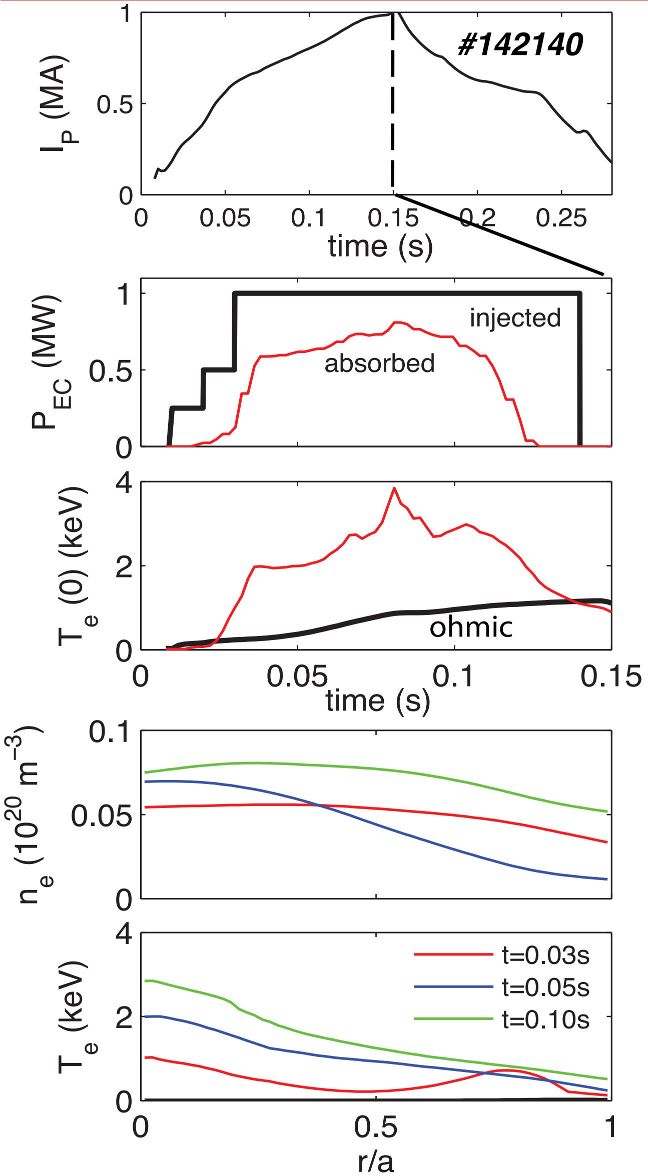


- Without electron heating, CHI current would decay within 5-10ms
- expect it to be difficult to couple FW directly to CHI-only target

➢ **Planned EC-EBW system: 1MW power @28GHz, O-mode heating (*see Perkins*)**

➢ **The role of EC is to heat CHI plasma to a level where FW and/or NBI can be efficiently absorbed**

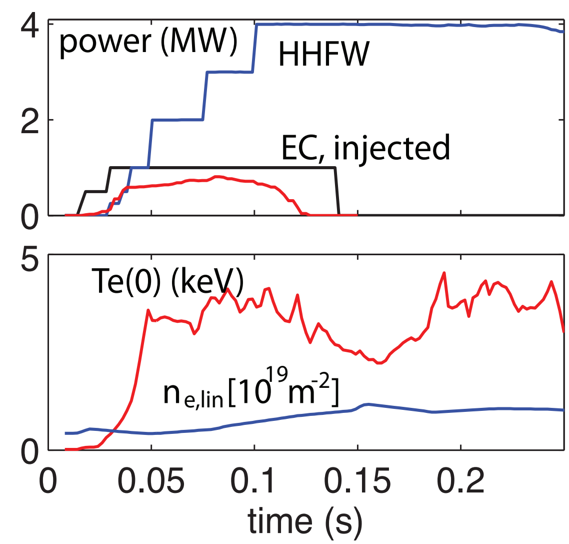
Planned ECH system needed to heat CHI targets from 10eV to above 500eV in 30ms



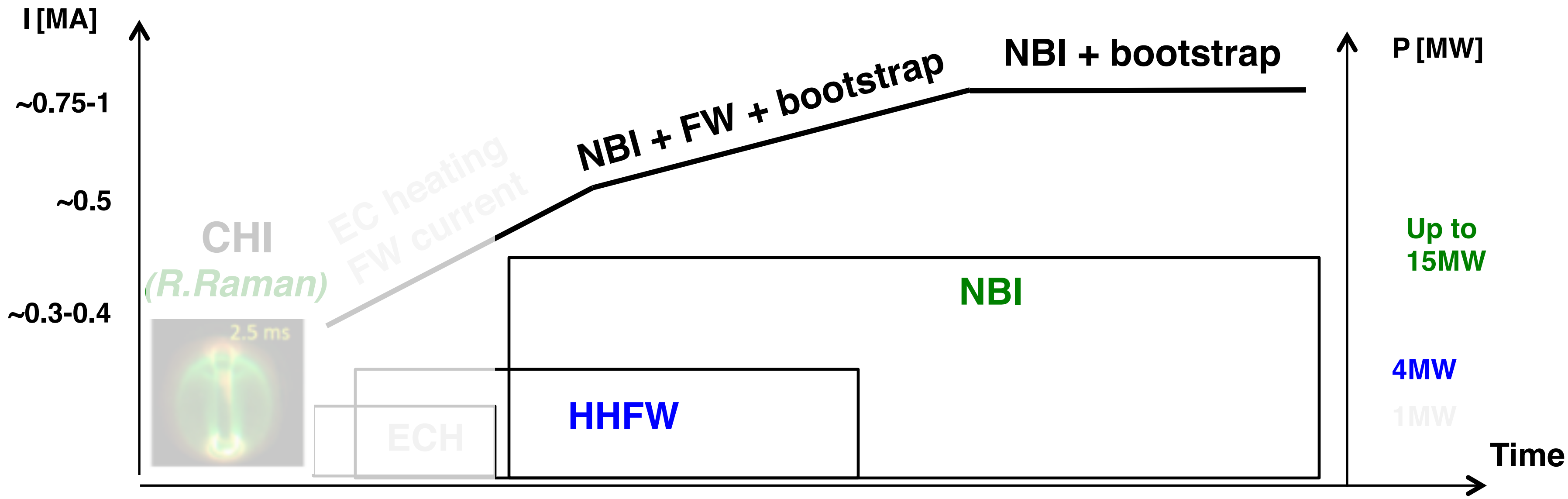
Ref: NSTX CHI→OH+NBI H-mode discharge #142140 (*Raman, NF2013*)

- First-pass absorption in low density startup plasma
- Simulations confirm that HHFW cannot efficiently heat CHI-only target, but HHFW can heat ECH-heated CHI target (see lower right)
- EC accessibility @ t<100-150ms depending on density

NOTE: preliminary results



Detailed modeling of ramp-up phases highlights requirements for dedicated experiments in FY15-16

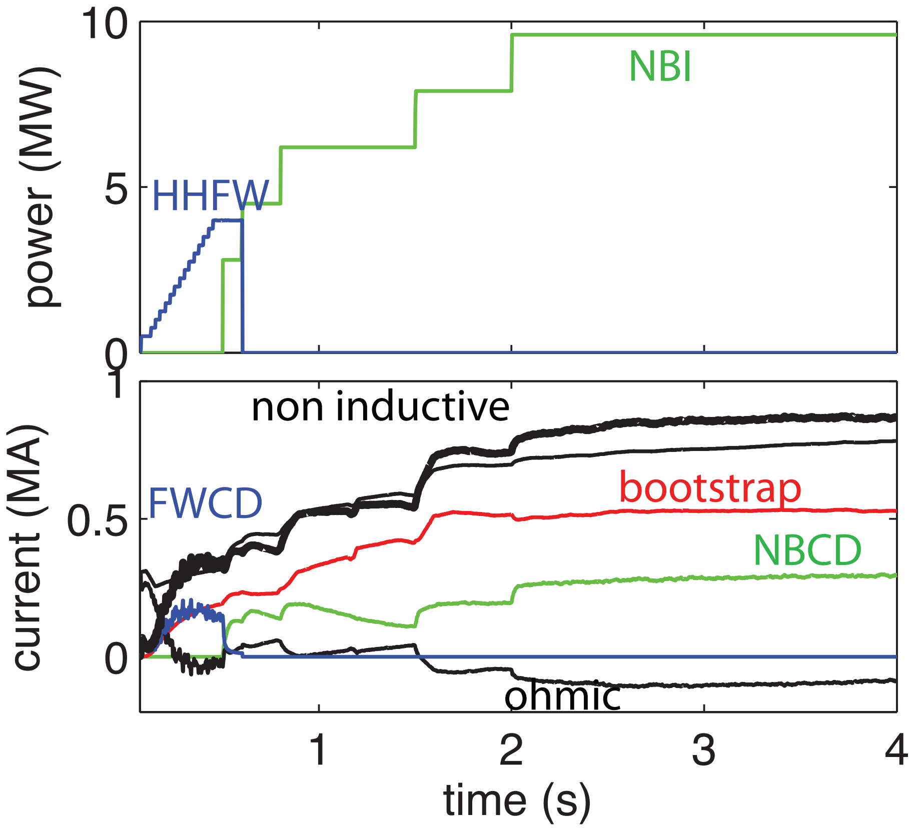


Select target scenario (*Menard et al, NF 2012, Table I, Gerhardt NF 2012*)

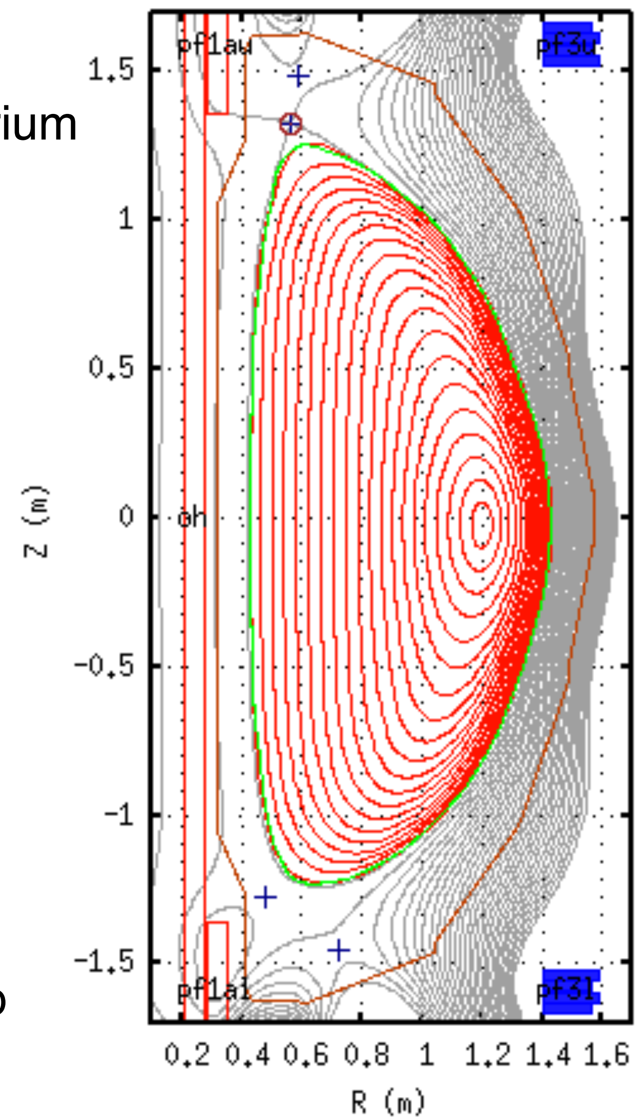
100% NICD (1T/1MA) with 10MW of NBI @0.5-1.0n_G, bootstrap fraction 0.61-0.85

- Use reference discharge #142305, κ~2.55, li(1)~0.5, A~1.55 (*Gerhardt, NF 2011*)
- Assume initial target of 300kA and plasma heated at ~400eV (needed for HHFW)
- Use 4MW of HHFW and 10MW of NBI at 80keV
- HHFW drives L-H transition and current at low density where NBI shine-thru large
- NBI second beam-line ramps current to the target plasma

2nd NB line can ramp-up current from HHFW-heated plasma and sustain stationary 900kA



Isolver equilbrium
t = 3.5s
κ~2.50
δ~0.75

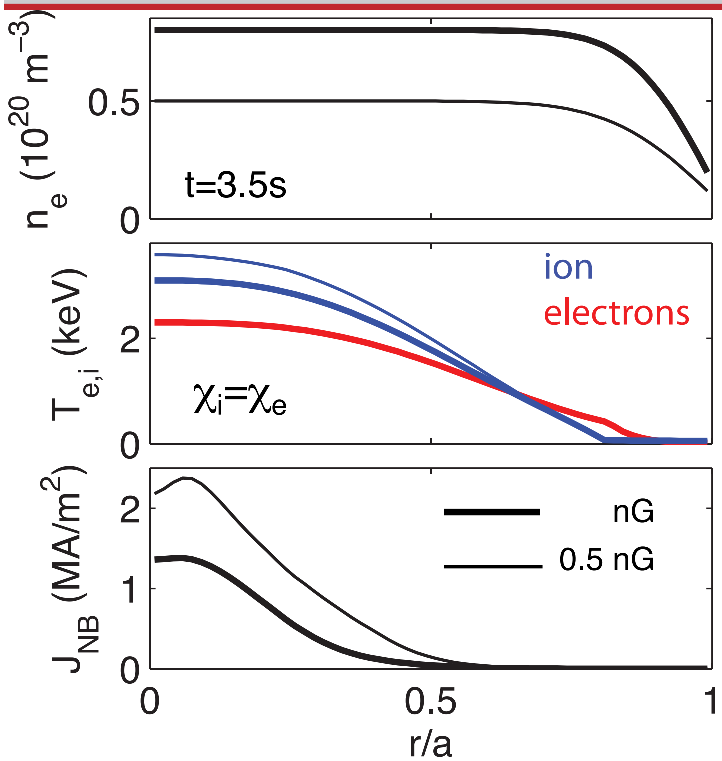


HHFW used @ t<0.5 to ramp to ~400kA

$n_{e,lin}$ = 8x10^{19} m^{-2} -> ~900kA non-inductive, ~60% bootstrap

β_T~7%, β_P~6%, β_{FAST}/β_{TOT}~0.25-0.35, H_{98}~1.2 (τ_{98}~70ms)

Results sensitive to Greenwald fraction, which affects the beam pressure and shape control

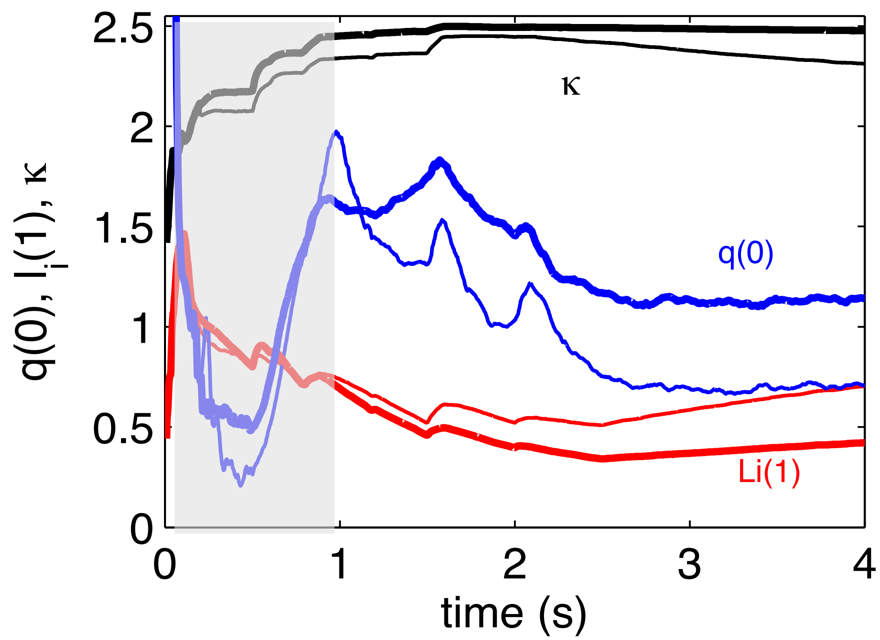


- Second beam line has high efficiency
- Peaked deposition profiles at low density (~50%n_G)

=> elongation decreases, l_i increases

=> q(0) drops below 1 in the flattop

=> q(0) drops below 1 during the HHFW phase



NBI phase needs optimization: broad deposition

⇒ Optimize outer gap

⇒ Beam modulation

Early phase needs optimization: elevate q(0)

⇒ Use beams early in the discharge (with RF)

Goals FY15: validate simulations for non-inductive startup and ramp-up

Modeling:

- ECRH: TSC CHI startup simulations as initial conditions to improve time-dependent predictions using ECRH (*with SFSU-TSG*)
- Simulate EC+NBI and EC+FW combinations for CHI target
- HHFW: Explore effect of FW phasing on scenarios (*with WEP-TSG*)
- NBI: scan density and temperature and source energy to optimize deposition

Experiments:

- NBI: assess NBI injection and CD profiles in targets with 0.5-1.0MA, 0.75T with density of 0.5-1.0 Greenwald (R15-2)
- Use results from R15-1 (H-mode characteristic, pedestal, see *Diallo*) to improve predictions of H-mode ramp-up plasmas with NBI.

=> experiments, including National Campaign on DIII-D to constrain simulations of NSTX-U overdrive ramp-up discharges at 1T with inductive seeding to guide experiments in FY16.

Goals FY16: guide ramp-up experiments with inductive seeding

R16-3: Assess FW coupling to NBI and modeling (*with WEP and ASC TSGs*)

- Optimize FW phasing to maximize electron heating (at 300-500kA)
- use FY15 simulations to guide experiments and results for model validation.

R16-4: Develop high-non-inductive fraction NBI H-modes for ramp-up and sustainment.

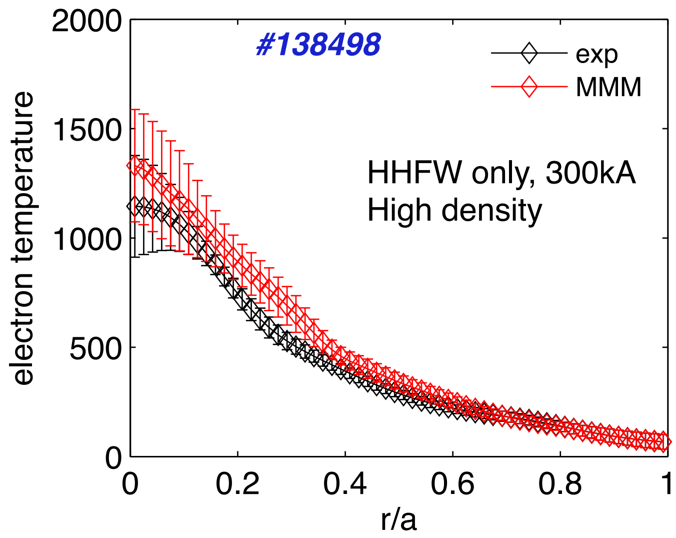
- Obtain full non-inductive target in flattop phase with ohmic seeding, then
- Clamp OH coil current to constant value progressively earlier in time

Attempt use of FW (phasing for electron heating) and NBI at low current on CHI target with inductive seeding (*support for SFSU-TSG*)

Summary

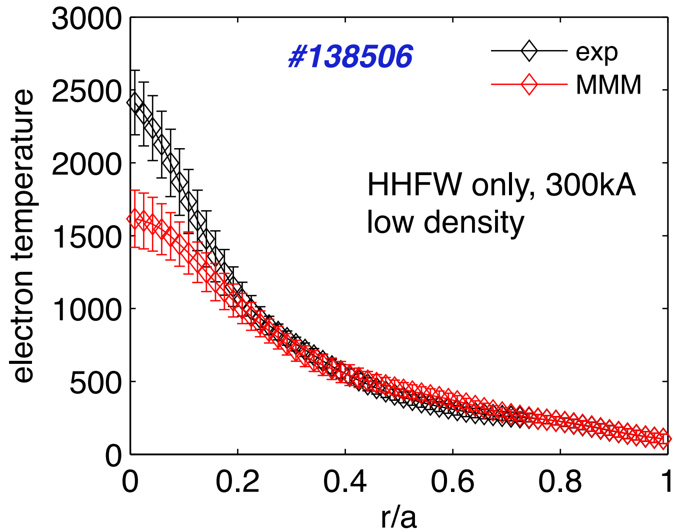
- Substantial progress in ramp-up modeling using TRANSP
  - Compute RF NBI absorption and CD self-consistently for the first time
  - Use experimental discharges from NSTX for projection
  - Simulations of the startup phase present computational challenges
  - Density control is crucial to the scenario solution and to the evolution in the ramp-up and flattop sustainment.
- Future work:
  - more physical constraint on surface voltage, use coil currents to drive the simulation and control the discharge (shape, gaps, aspect ratio)
  - Specification of Greenwald fraction vs time in TRANSP simulations
  - Sensitivity studies on choice of thermal transport models

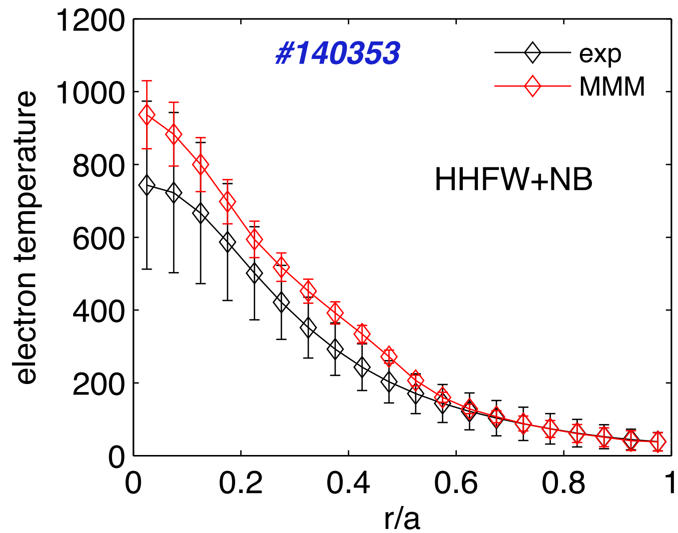
MMM95 reproduces average amplitude and peaking of electron temperature profile during the HHFW phase



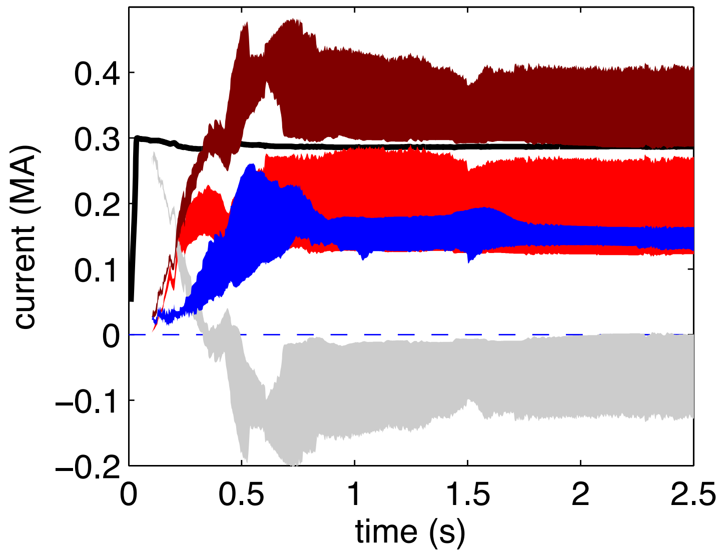
Profiles averaged over the heating phase

- MMM95 reproduces the average amplitude and peaking in HHFW discharges and in discharges with HHFW+NBI.
- Ion temperature overestimated in NBI discharges
- Electron temperature too peaked in NBI discharges

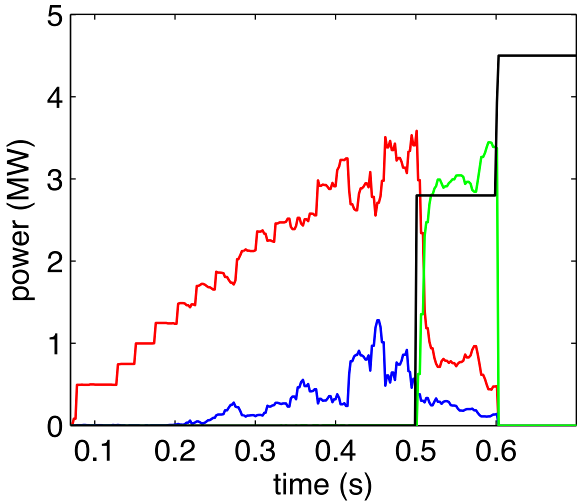




Optimal range of 350-400kA for non-inductive current from HHFW in startup plasma conditions

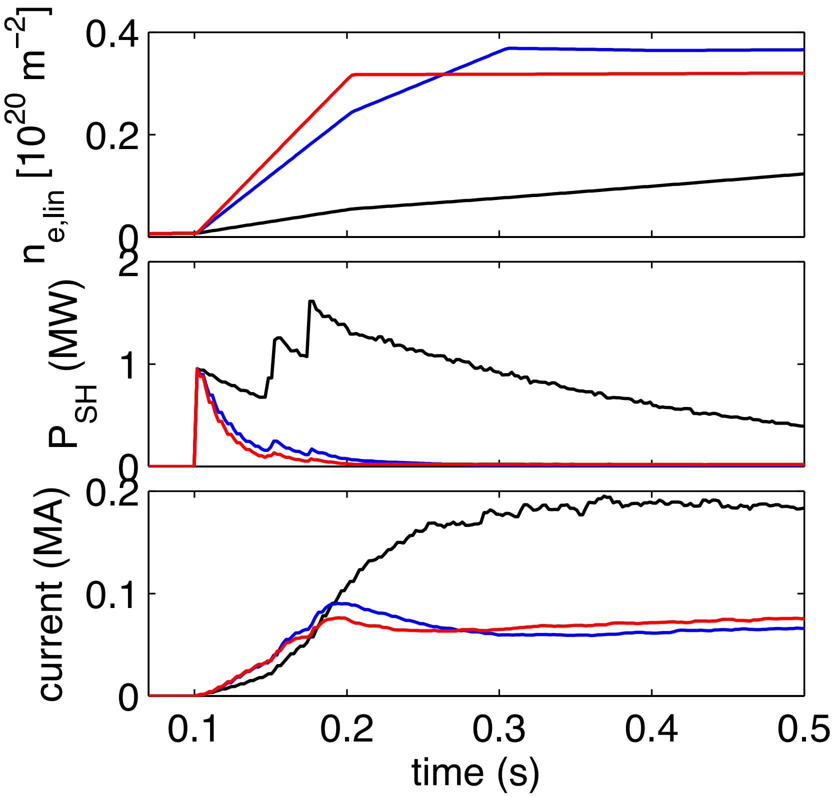


- NSTX experiments demonstrated sustainment of 300kA with 1.5MW of HHFW, with 80% bootstrap current
- However, we aim at using HHFW at startup
  - Density is low
  - Coupling might be an issue



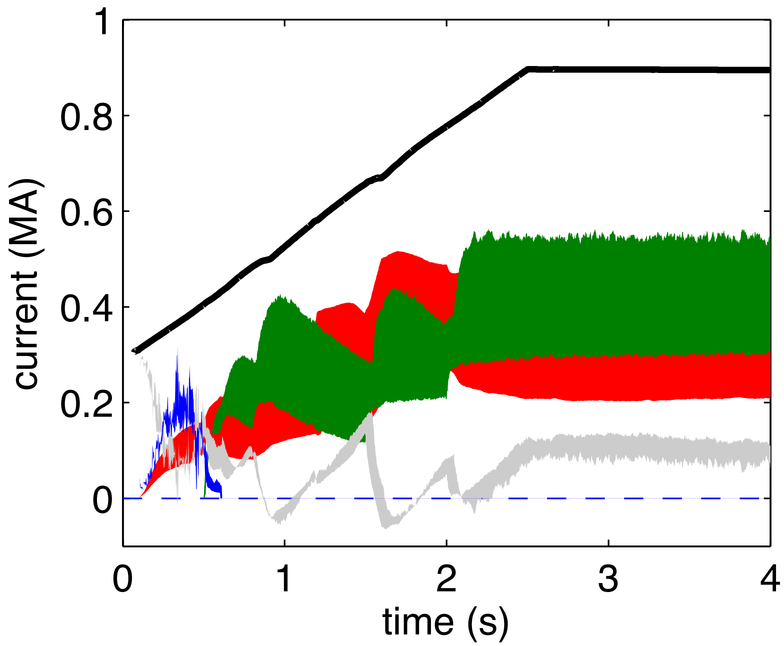
- Absorption of FW to fast ions is an issue
- => avoid to superpose FW and NBI in simulations

Large beam shine-thru at low density prevents use of beam on CHI-only target



- Shine-thru can be reduced by controlling density at low current
- Might be an issue for EC accessibility
- Low driven current => need to optimize window before 0.3s for external current drive

Procedure for non-inductive ramp-up experiments



- Start with a fully inductive discharge
- Optimize non-inductive fraction (density is critical)
- Clamp ohmic at progressively earlier times

Clamp ohmic at progressively earlier times