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Plans for Integrated Scenario Development Research in 2007-2009

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Presented by
R. Maingi, ORNL

Acknowledgement to:
D. Gates, C. Kessel, J. Menard, NSTX Team

NSTX PAC-21 meeting

Princeton, NJ
January 17-19, 2007

Culham Sci Ctr
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ISD Research Goal

- **High β, high f_{NI}, long-pulse optimization**
- **Integration with optimal boundary plasma**

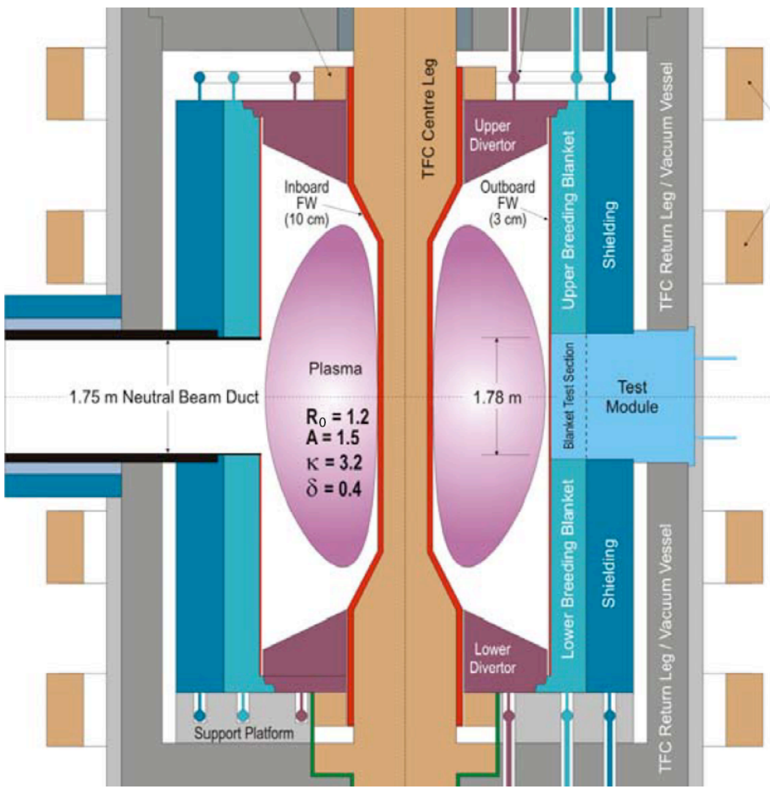
❖ Integrated modeling provides important guidance in ISD experimental planning

✓ **Action Item from PAC-19 - integrated modeling**

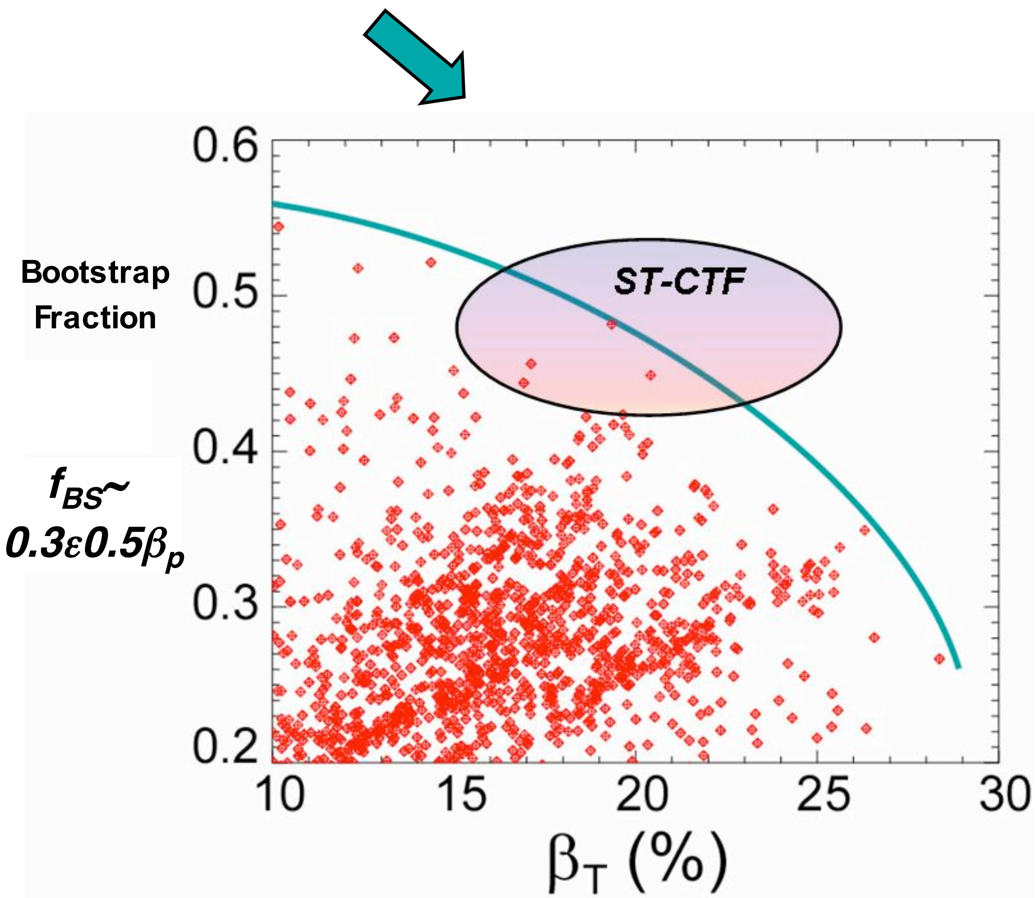
  – *The PAC encourages activities in integrated modeling and long-pulse operation… The PAC requests that, at its Jan. 2007 meeting, the NSTX would provide an update about the work on start-up/long-pulse integrated modeling and how it relates to future plans.*

NSTX plasmas approach the normalized performance levels needed for a Spherical Torus - Component Test Facility (ST-CTF)

β_T = 15-25%, f_{BS}=45-55%



Peng et al, PPCF **47**, B263 (2005)



Menard, IAEA 2006

Integrated Scenario Development Topics and Outline

NSTX

Discharge tailoring for high β, high f_{NI}, long pulse operation

- optimization of the discharge shape, plasma profiles and fueling
  - I_p ~ 1 MA DN plasmas
  - I_p ~ 0.7 MA LSN plasmas
- optimization of plasma ramp-up evolution

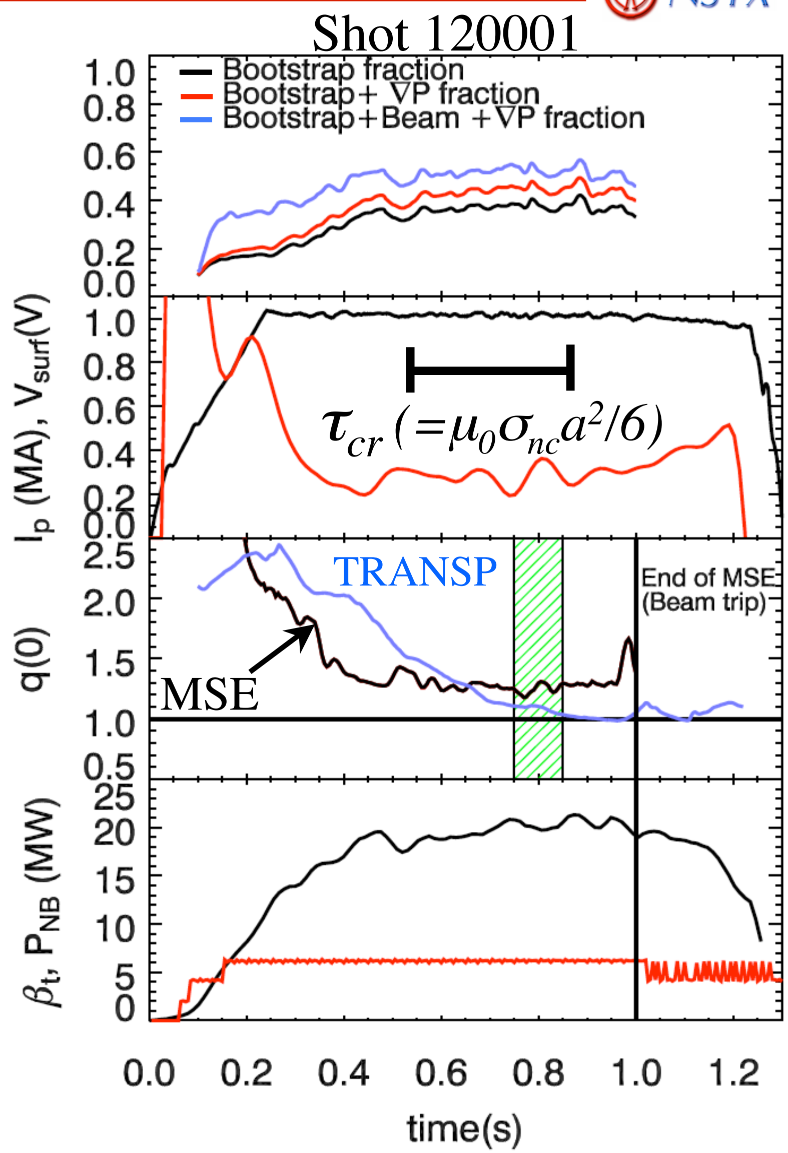
Integration with optimal boundary plasma

- Small or no ELM scenarios
- High temperature pedestal scenarios
- Low heat flux solutions

Milestone R08-4 : Perform high-kappa wall stabilized plasma operation. *(9/09 baseline, 9/08 incremental)*

Highlights of progress in Double-null discharges - 2006

- Pulse length in I_p~1 MA high-δ DN plasmas increased
  - 20% β_t sustained for ~ τ_{cr}
  - 50% non-inductive current fraction, 40% pressure driven
  - Improved reproducibility with rtEFIT
  - q(0) elevated longer than predicted by TRANSP magnetic diffusion calculation with neoclassical resistivity
- Also achieved κ=3 transiently, but with lower β_N

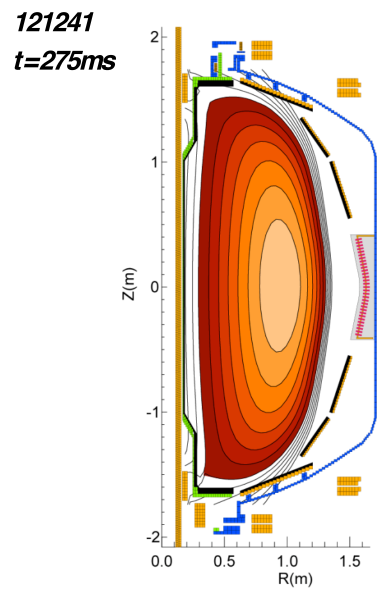


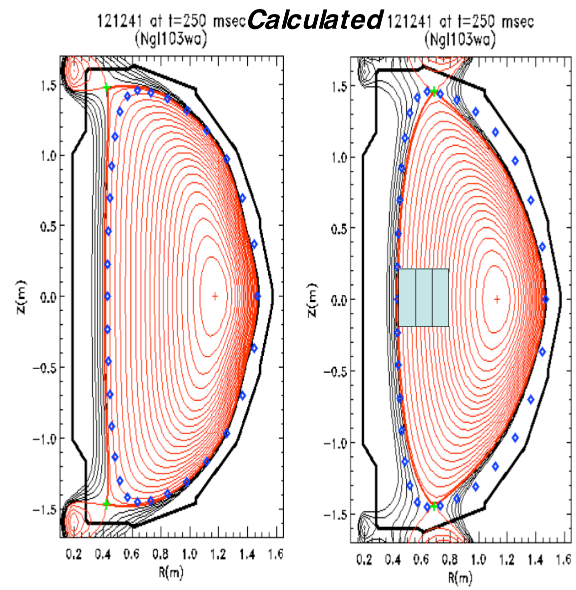
Gates, APS 2006

Double-null Discharge Optimization - 2007 plan

- High NI fraction plasmas at high κ
  - Sustained operation at κ = 2.8 with goal of higher β_N and f_{BS}

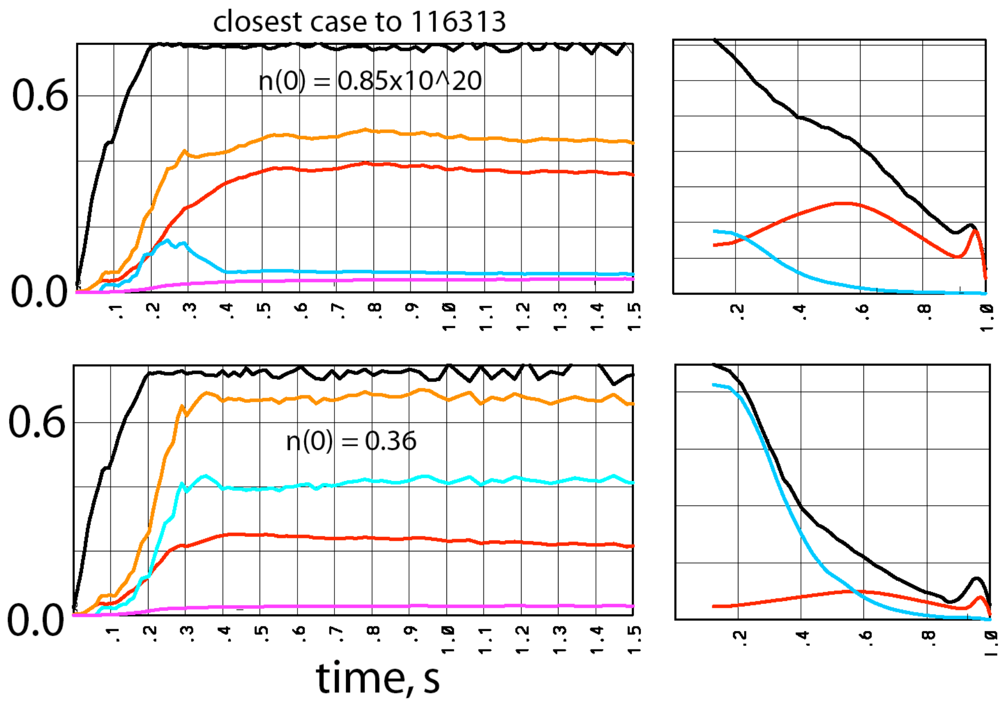
✓*Higher inner target bake-out temp.*



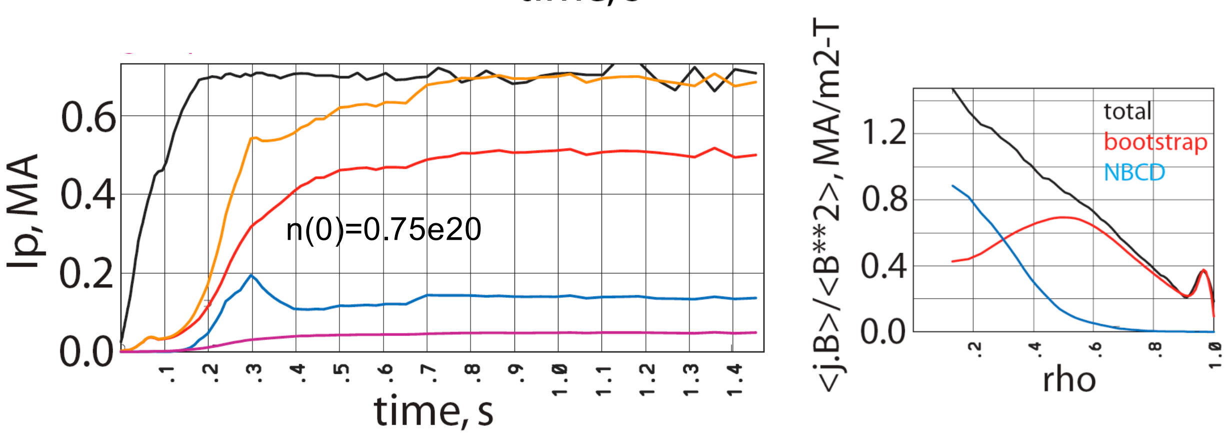


Integrated modeling points to importance of shaping, reduced n_e, and increased T_e/τ_E for higher f_{NI} and high β_N

total
total NI
bootstrap
NBCD
grad p



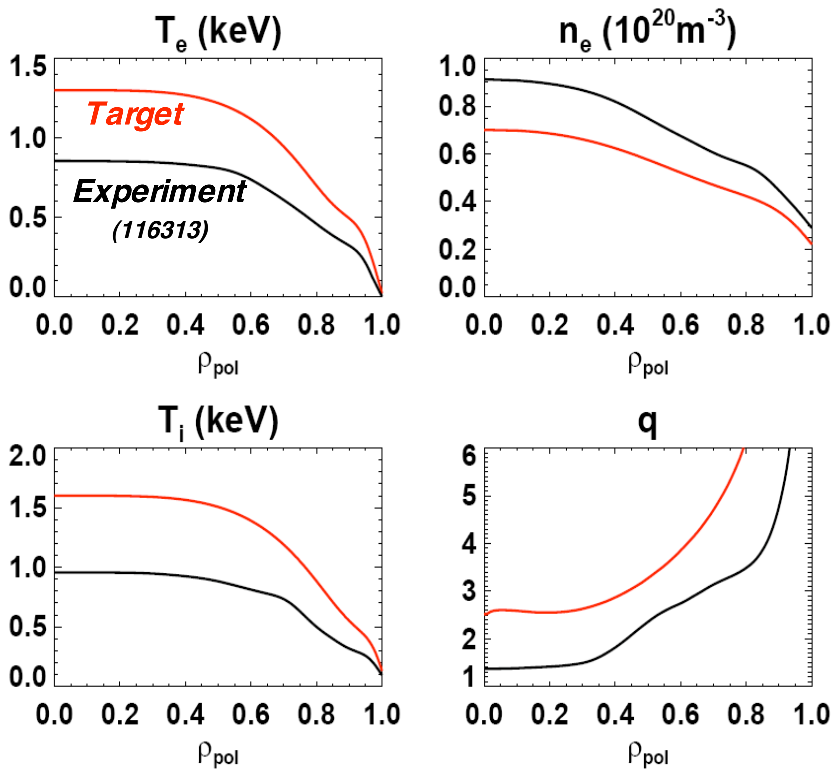
- $n_{20}(0)$=0.85,
  κ=2.2
  H_{98}=1.1
  β_N = 5.6
  q(0) ≥ 1.15
- $n_{20}(0)$=0.36,
  κ=2.2
  H_{98}=1.1
  β_N = 5.6
  q(0) = 1 @ 0.8 s



- $n_{20}(0)$=0.75,
  κ=2.55
  H_{98}=1.35
  β_N = 6.6
  q(0) ≥ 1.4

Kessel

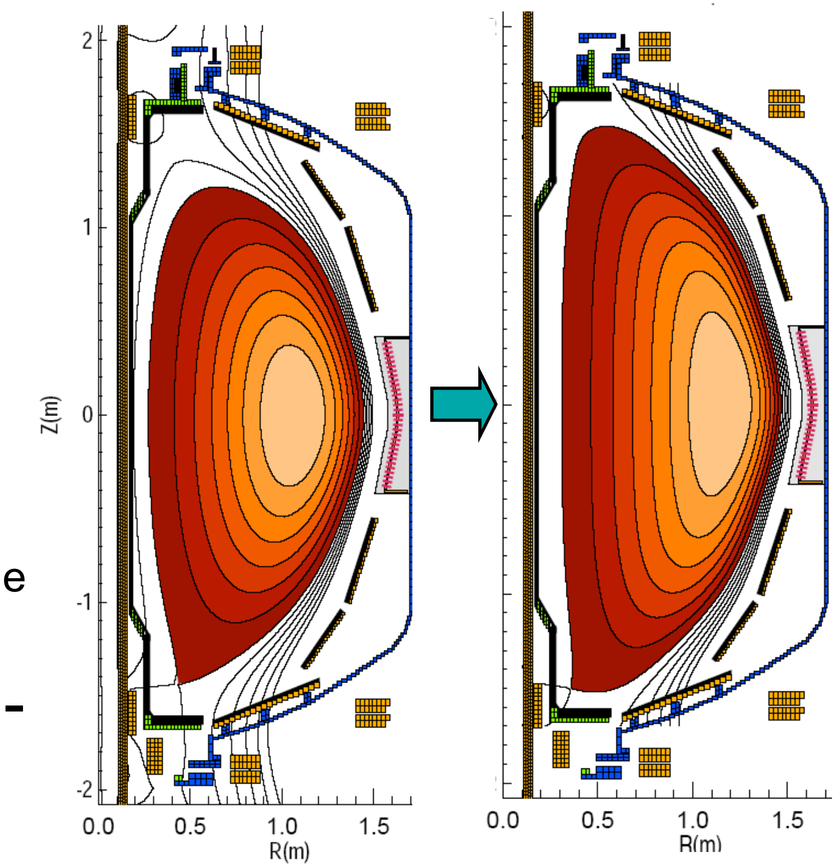
Fully non-inductive scenario at high β_N requires higher confinement, higher *q*, strong plasma shaping



- Higher κ for higher q, β_P, f_{BS}
- High δ for improved kink stability

κ= 2.3, $\delta_{X\text{-}L}$ = 0.75 **δR_{SEP} = -1cm**

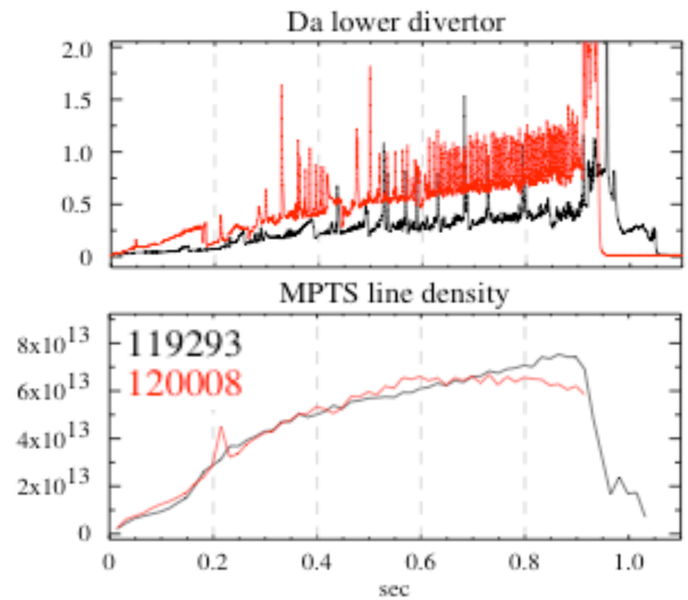
κ= 2.6, $\delta_{X\text{-}L}$ = 0.85 **δR_{SEP} = -2mm**



- Need 60% higher T, 25% lower n_e
- higher $q_0 \approx q_{min} \approx 2.4$ (higher with-wall limit $\beta_N \leq 7.2$)

Lower-single-null Discharge Optimization - 2007 plan

- Improved density control
  - Fueling optimization using supersonic gas injector (SGI); transition from Type I to Type III ELMs
  - Use of Improved Lithium evaporator



2007 plan

- reduced density (lithium/less fueling)

✓ *Improved SGI pulse control*

✓ *Higher inner target bake-out temp.*

✓ *Lithium evaporator aiming improved*

Optimization of the discharge shape, profiles and fueling 2008-9

- Possible directions
  - Continue high κ, high q_{min}, and SGI fueling optimization
  - Improved density control from proposed liquid lithium (2009)
  - Improved τ_E: Variation of H-mode transition timing
  - Improved τ_E: Ohmic H-mode as a target plasma
  - Development of DN early H-mode scenarios
  - Optimize rtEFIT control for single-null discharges
  - Testing of X-point limiter concept

- *Facility Upgrades*
  - *Control system latency to be reduced from 1 ms to 0.5 ms (end 2007)*
  - *NBI feedback on β (2008)*
  - *Proposed liquid lithium tray for density control (2009)*

Optimization of plasma ramp-up evolution
2007 plan

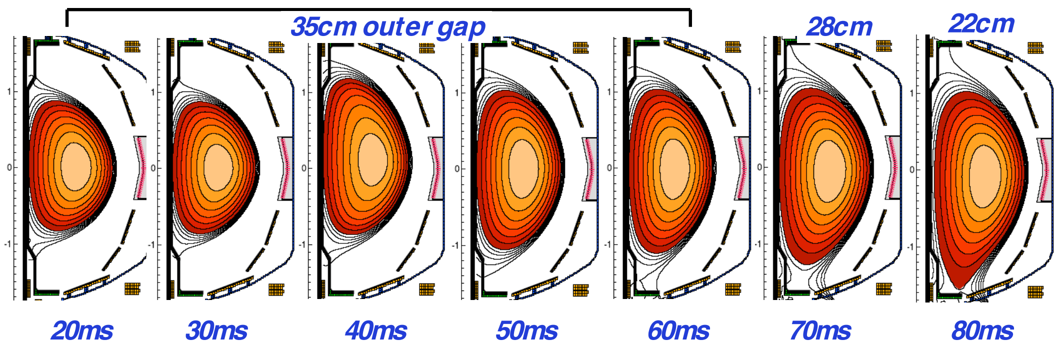
- Improved break-down scenario for higher q during I_p ramp
  - Plasma CS limited for first 80ms until I_P=500kA, small-bore cross-section for first 50-60ms

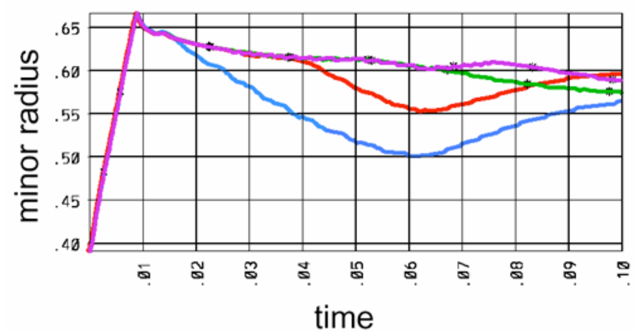
2007-8 plan

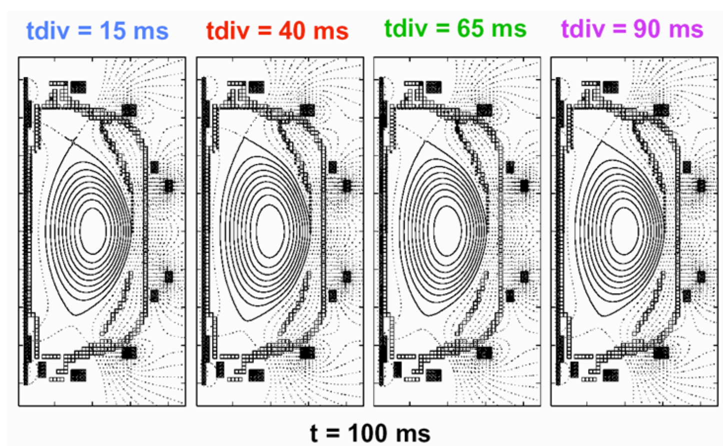
- increase bore, κ

→ higher q early H-mode

- Add early RF heating if gap acceptable (TSC shows gap control possible)

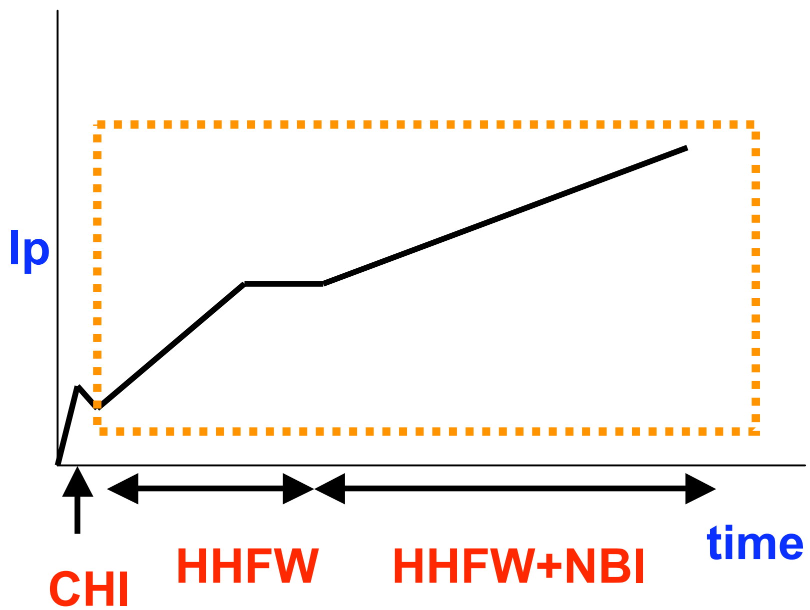


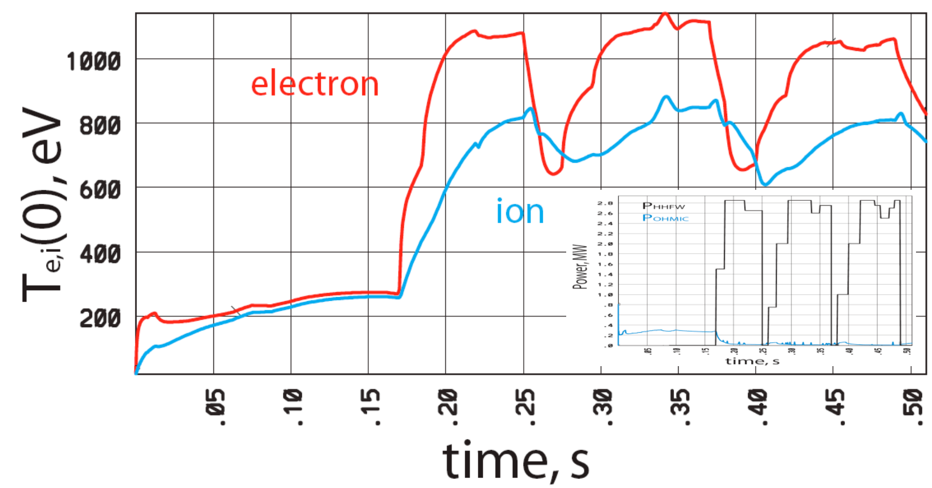


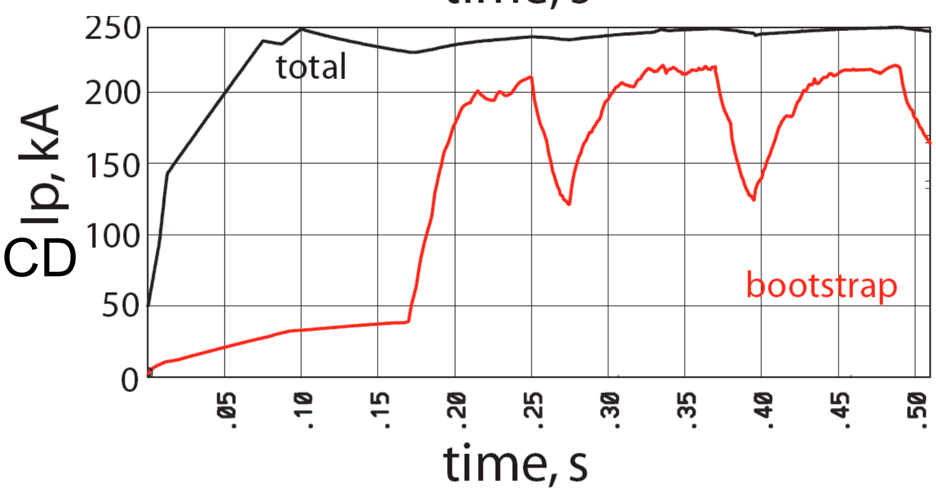


Optimization of plasma ramp-up evolution 2007 plan

- Non-solenoidal ramp-up using HHFW (simulated with integrated modeling)







- Good heating observed in 2006 with CD phasing at B_T = 5.5kG

2007 plan

- Attempt HHFW CD overdrive to ramp up I_p
- Add NBI to higher I_P target plasma

Optimization of plasma ramp-up evolution 2008-9

- Continue ramp-up optimization, and extend to other discharge scenarios
- Optimize gap for early HHFW heating

Outline

Discharge tailoring for high β, high f_{NI}, long pulse operation

- optimization of the discharge shape, plasma profiles and fueling
- optimization of plasma ramp-up evolution for reduced volt-second consumption

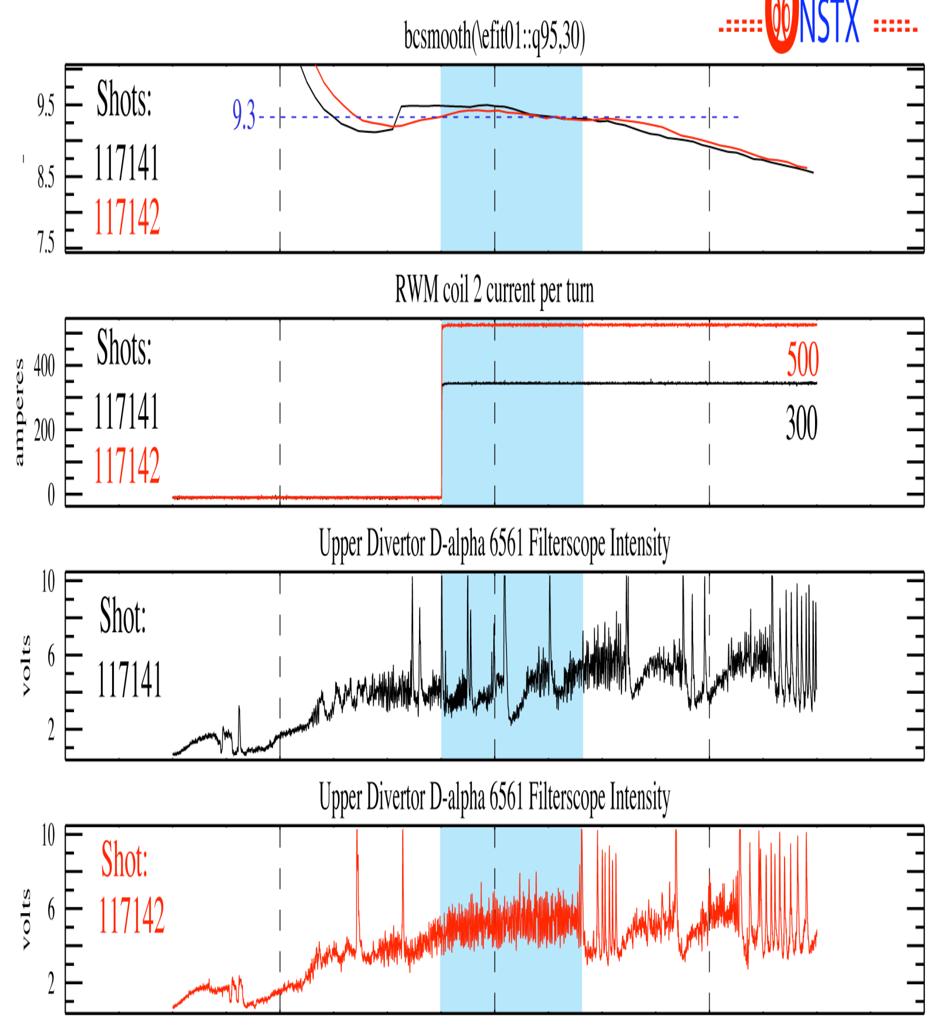
Integration with optimal boundary plasma

- Small or no ELM scenarios
- Low heat flux solutions
- High temperature pedestal scenarios

Milestone R08-4 : Perform high-kappa wall stabilized plasma operation. *(9/09 baseline, 9/08 incremental)*

Integration with optimal boundary plasma

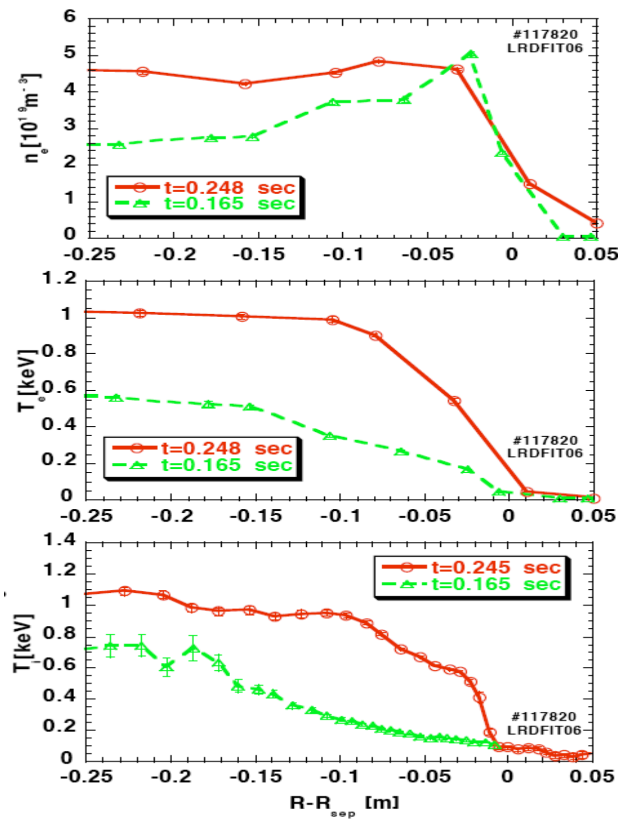
- Suppression of ELMs with Resonant Magnetic Perturbations
  - ITER Decision needed soon on internal versus external coils
    - Data is desired from the NSTX EF/RWM coil to assess external coils
  - Experiment in 2005 showed possible periods of ELM suppression
  - Improved NSTX modeling since 2005, success on JET w/ n=1



- Integration of radiative & dissipative divertors
  - Outer divertor heat flux reduction with divertor D_2 , CD_4 or N_2 puffing

Integration with optimal boundary plasma 2007 plan

- Develop the enhanced pedestal H-mode
  - Much higher pedestal temperature and lower collisionality than normal H-mode
  - Termination due to ideal MHD instability from extreme central reversed shear



- 2007 plan
  - ELM suppression: reproduce earlier results and monitor upper divertor recycling
  - EPH mode: reproduce and document with P-CHERs; trigger with magnetic braking
  - Radiative divertor: test for compatibility with highly shaped plasmas (piggyback)

Integration with optimal boundary plasma 2008-9

NSTX

- Continue ELM suppression studies, with more focus on underlying physics
- Develop ELM control through shape modifications, e.g. smooth USN/DN/LSN variations, and/or higher order shape variations, such as squareness
- Continue development of Enhanced Pedestal H-mode long-pulse scenarios, including use of magnetic braking for triggering
- Dedicated heat flux reduction scenario development in long pulse discharges
- Development of USN or reversed B_t H-mode discharge scenarios

Integrated Scenario Development Run Plan in 2007

XP Title (Abbreviated)	Run Days Requested (original)	Priority 1 Days	Priority 2 Days	Priority 3 Days	ST Develop	Toroidal Physics	ITER/ ITPA
High NI fraction at high kappa (DN) ***FY09 Milestone***	2.0	1.0		1.0	x	x	
Improved break-down for higher q (LSN)	1.5	1.0		0.5	x		
Long-pulse with reduced fueling, higher qmin	2.0	0.5	1.0	0.5	x	x	
Density and Type I ELM control w/ SGI	0.5	***Combine with above***			x		
Non-solenoidal Ip rampup	1.5	1.5			x	x	
Suppression of ELMs with RMPs	1.5	1.0	0.5		x	x	x
Development of the EP H-mode	1.5	1.0		0.5	x	x	
High perf. w/ radiative & dissipative divertors	0.5		0.5		x	x	
NSTX MIMO Control Collaboration	0.5		0.5		x		
X-point limiter plasmas	1.0		0.5	0.5	x	x	
ITB from NBI into Ohmic H-mode	1.0		0.5	0.5	x		
Early HHFW heating	1.5		0.5	0.0	x		
Variation of Long-Pulse Front-End	1.5		1.0	0.5	x	x	
Hybrid Plasma Development on NSTX	1.5			1.5	x		x
Totals	16.5	6.0	5.0	5.5			

Backup

Stable & fully non-inductive target scenario utilizing only NBI and BS current drive has been identified

NSTX

Present high-f_{NI} long-pulse H-modes:

I_P = 750kA

β_N < 5.6, β_P < 1.5, β_T < 17%

l_i = 0.6, q_{min}=1.3, B_T=4.5kG

κ = 2.3, δ_{X-L} = 0.75, q*=3.9

Target scenario:

I_P = 700kA

β_N = 6.7, β_P = 2.7, β_T =15%

l_i = 0.5, q_{min} = 2.4, B_T=5.2kG

κ = 2.6, δ_{X-L} = 0.85, q*=5.6

Inductive current drive is replaced by:

Higher J_{NBI} from higher T_e

Higher J_{BS} from higher $\beta_{P\text{-}thermal}$