Towards Assessing the ST: the NSTX Research Program for FY ‘04 - ‘08

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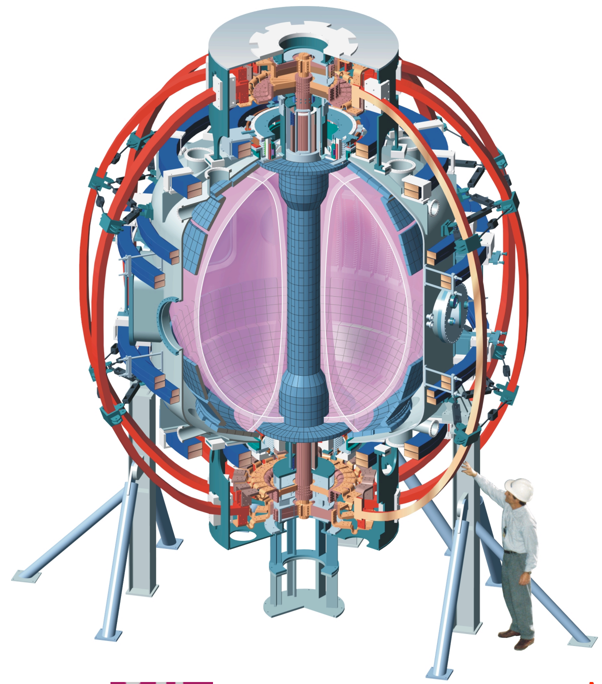
for the NSTX Research Team



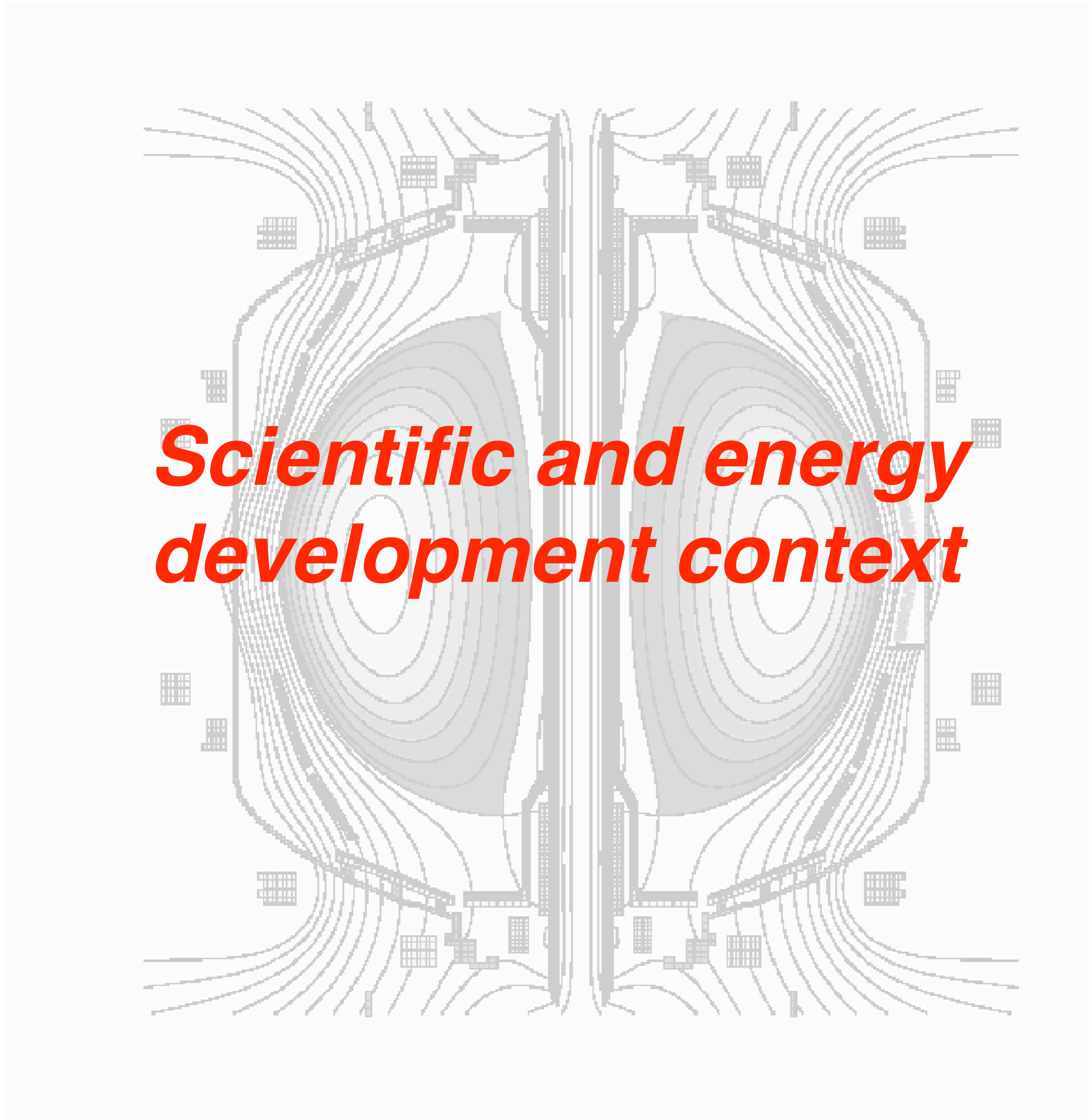
Presentation for the 14th NSTX Program Advisory Committee Meeting

January 21, 2003

NSTX research is both a U.S. and international enterprise

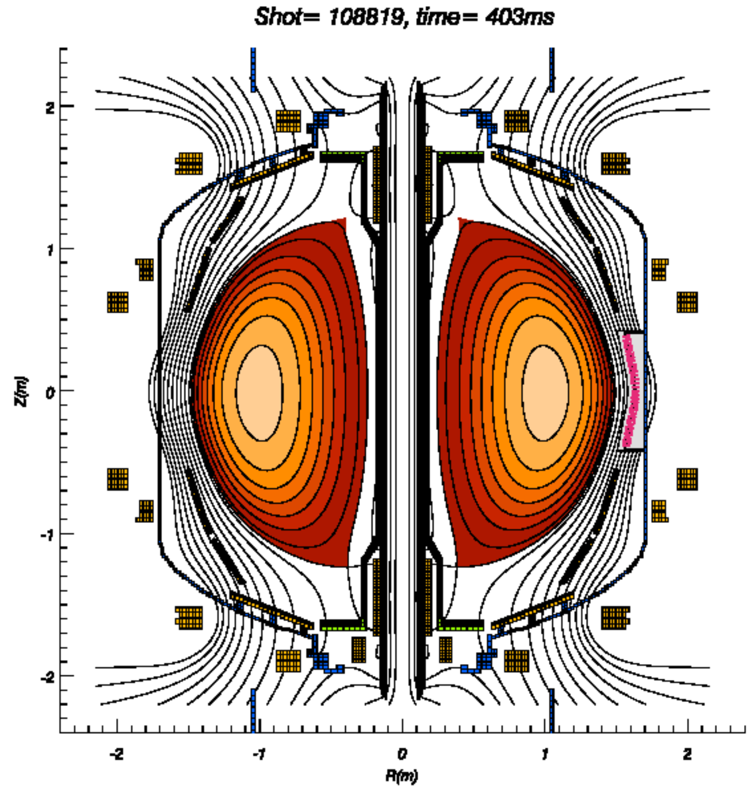
- CEA Cadarache, France
- Columbia University, New York, N.Y., U.S.A.
- CompX, Del Mar, California, U.S.A.
- ENEA, Frascati, Italy
- Euratom-UKAEA Fusion Association, Abingdon, Oxfordshire, UK
- General Atomics, San Diego, California, U.S.A.
- Kyushu Tokai University, Kumamoto, Japan
- Himeji Institute of Technology, Okayama, Japan
- Hiroshima University, Hiroshima, Japan
- Johns Hopkins University, Baltimore, Maryland, U.S.A.
- Korea Basic Science Institute, Taejon, Republic of Korea
- Lawrence Livermore National Laboratory, Livermore, California, U.S.A.
- Los Alamos National Laboratory, Los Alamos, New Mexico, U.S.A.
- Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A.
- Nova Photonics, Princeton, New Jersey, U.S.A
- Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.
- Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ
- Princeton Scientific Instruments, Princeton, New Jersey, U.S.A.
- Sandia National Laboratories, Albuquerque, New Mexico, U.S.A.
- Tokyo University, Tokyo, Japan
- University of California, Davis, California, U.S.A.
- University of California, Irvine, California, U.S.A.
- University of California, Los Angeles, California, U.S.A.
- University of California, San Diego, California, U.S.A.
- University of Washington, Seattle, Washington, U.S.A.
- University of Wisconsin, Madison, Wisconsin, U.S.A.

Scientific and energy development context



The NSTX Team is developing a research plan aimed at meeting two broad goals

- *Assessing the attractiveness of the ST as a fusion energy concept*
  - *CTF and DEMO*
  - Grounded in integration of topical science
- Using ST plasma characteristics to *further a deeper understanding of critical toroidal physics issues*
- Both pursuits are guided by the IPPA implementation approach



Challenges: Understand the new physics of high beta and low aspect ratio, and integrate it to expand the limits of the ST operating space.

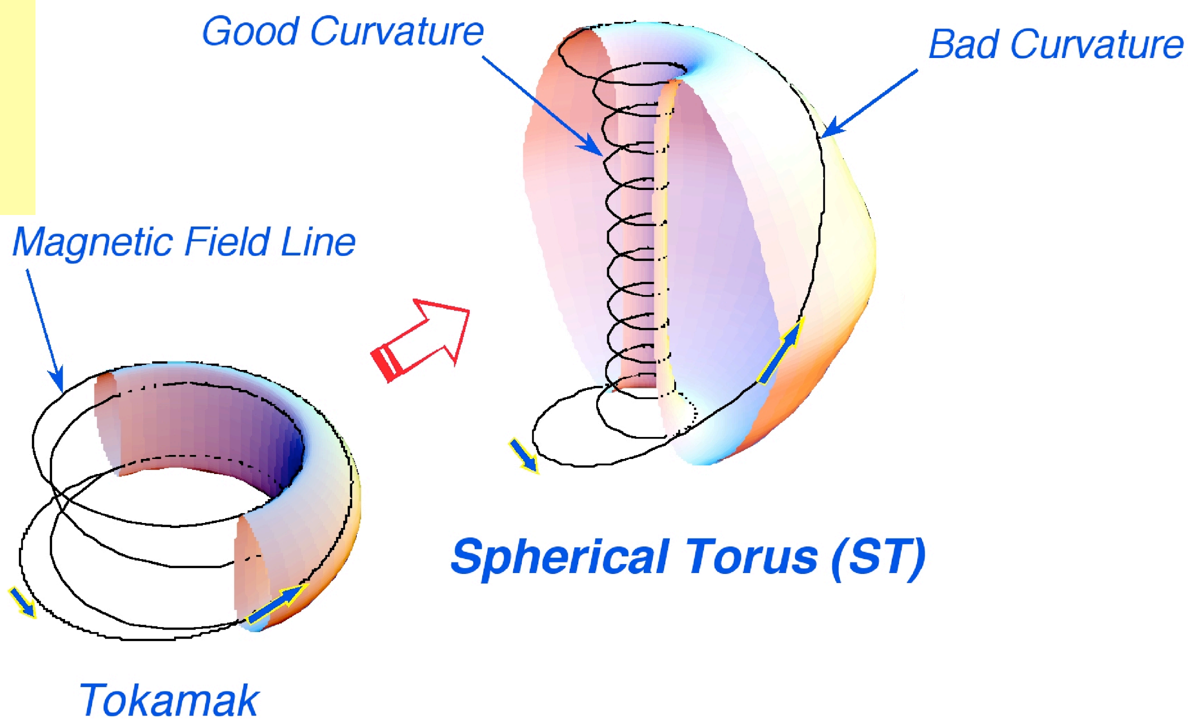
NSTX science is emerging at a time of rapid change in our field

"From my own reviews of recent research on magnetically confined plasmas, I believe this field has benefited, as many other fields have, from the revolutionary improvements in *computing power* and *instrumentation*. The ability to predict plasma parameters in realistic simulations and then test them in detail in actual devices *has changed the character of the entire field* substantially...." (italics added)

Jack Marburger
Director
Office of Science and Technology Policy
Testimony for the NRC panel

The differences in field line geometry between devices can be viewed as the basis of a scientific experiment

Change the aspect ratio, increase beta: what physics changes?



A strong NSTX science program enables physics tests in areas of high concern to any next-step device

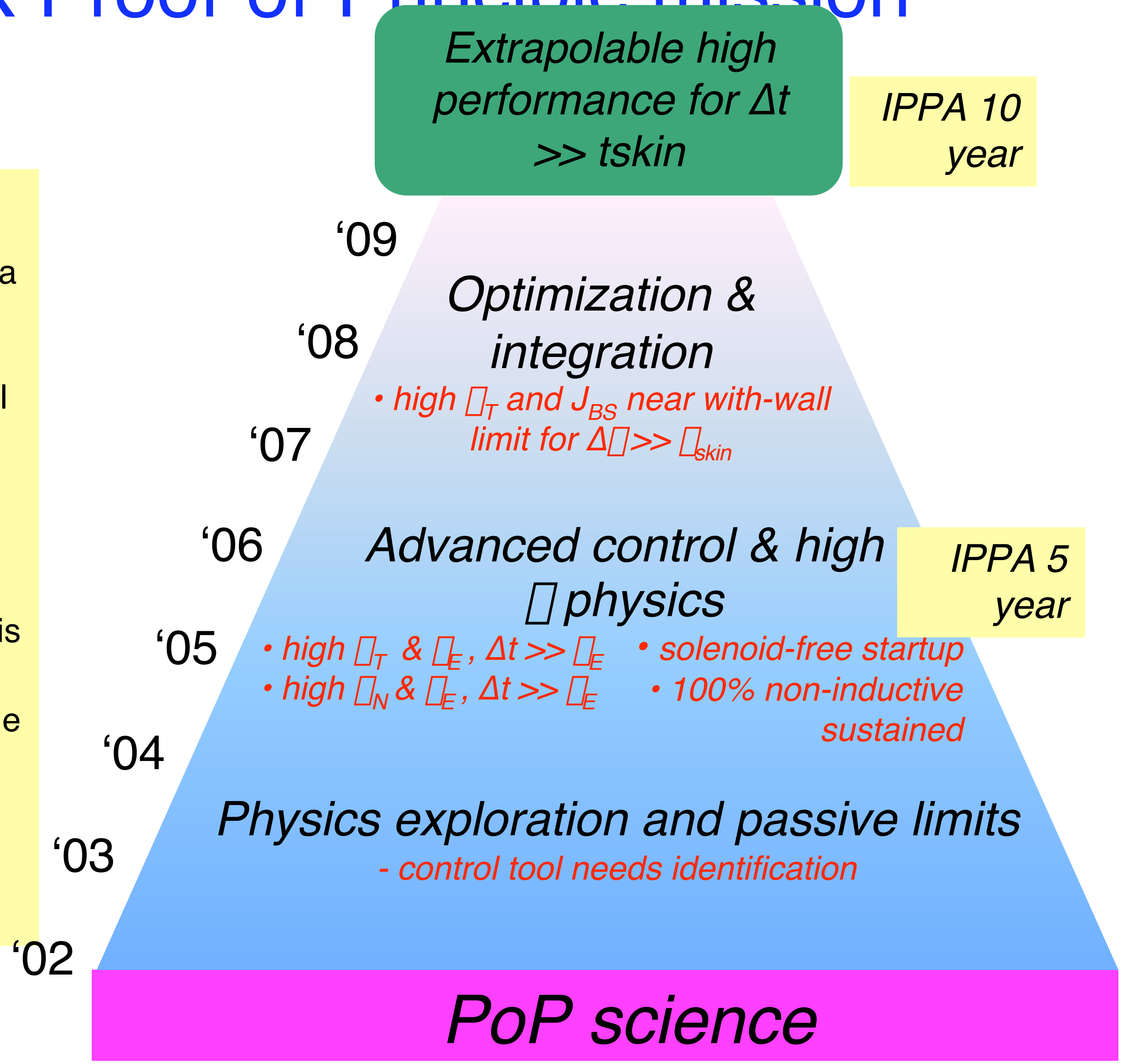
Moderate A, lower □	Lower A □(0) □ 1		Testable toroidal physics
Strong flow shear: possible Electrostatic turbulence	Strong flow shear: typical? Strong electromagnetic turbulence?	□	Global scalings Barrier dynamics Electron thermal transport
$V_{Alfven} > V_{beam} > V_{th}$	$V_{beam} > V_{Alfven} \sim V_{th}$	□	Equilibrium theory Rotational shear effects on MHD MHD wall coupling theories Fast ion & wave coupling
Smaller Larmor radius More modest average curvature Less poloidal damping	Larger Larmor radius Higher average curvature Stronger poloidal damping	□	Pedestal models H mode theories
Lower flux expansion in divertor	Higher flux expansion in divertor	□	SOL transport and divertor physics

Plan overview

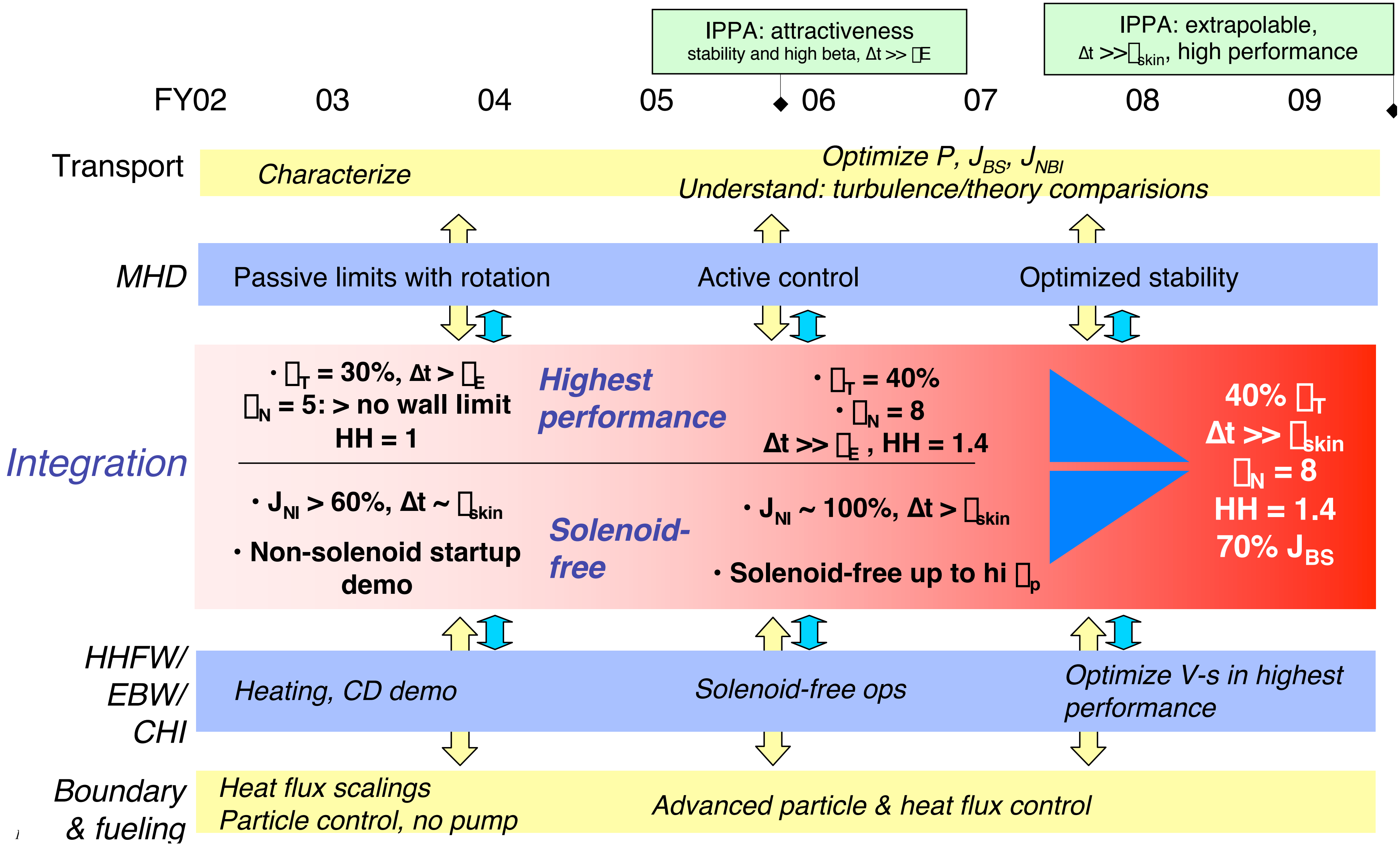
- High-level goals
- Facility
- MHD
- Transport & turbulence
- HHFW, EBW, & Solenoid-free startup
- Boundary physics

Integration of topical science is at the foundation of the NSTX Proof-of-Principle mission

- PoP □ establishing an *extrapolable basis* for advancing the ST that is grounded in plasma science
- Integration with advanced control tools and diagnostics central to the performance and scientific missions
- Strong coupling with theory is at the heart of establishing this basis
- High beta, low aspect ratio enable stringent tests of toroidal plasma physics



Integrating topical science & control tools is central to advancing the NSTX mission



The NSTX Program can meet the FESAC objectives in a timely manner

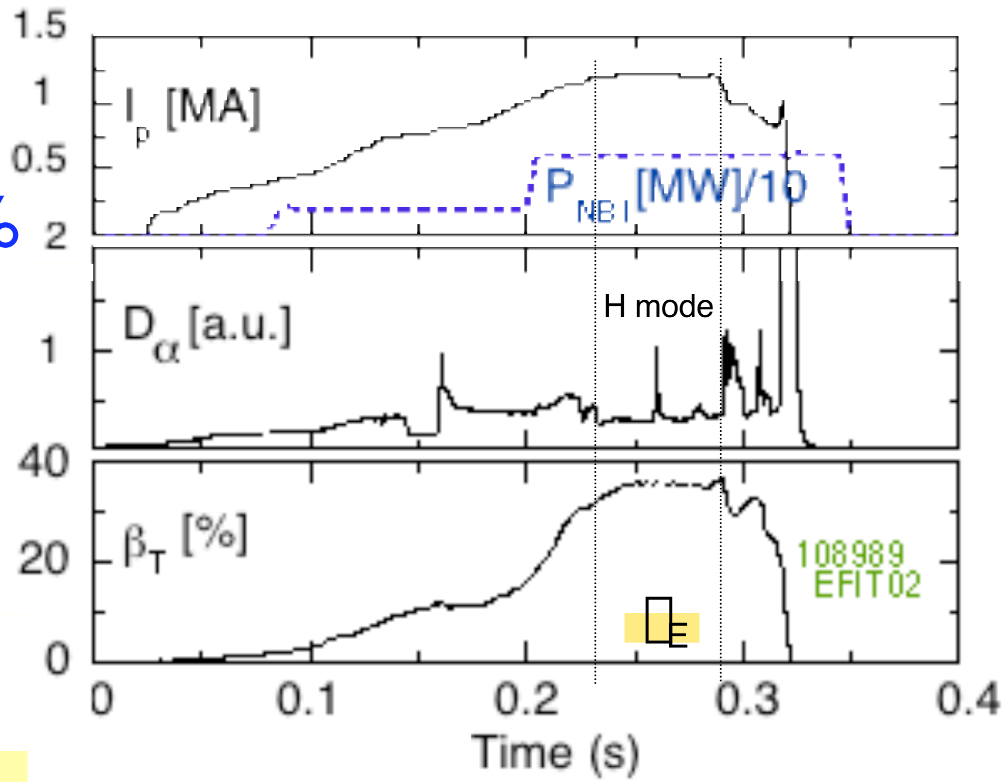
- Assessing the ST as an attractive fusion concept
  - End of 2005: 5 year IPPA Goal 2.1
    - *Make a preliminary assessment of the attractiveness of the ST by assessing high β stability, confinement, self-consistent high-bootstrap operation, and acceptable heat fluxes, for τ_{pulse} >> τ_E*
      - Non-inductive startup & sustainment should show progress
  - 2009+: 10 year IPPA goals
    - *Goal 2: Assess the attractiveness of extrapolable, long-pulse operation of the ST for τ_{pulse} >> τ_{skin}*
    - *Goal 3: Assess the potential of the ST as a basis for burning plasma studies and/or fusion-nuclear component testing*

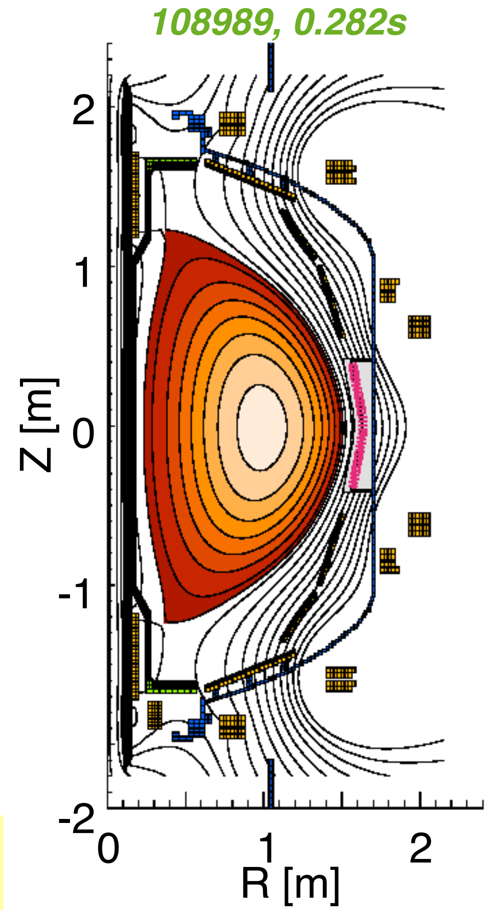
- Developing ST contributions to toroidal physics
  - Toward the 10-year IPPA science goal
    - *Develop fully integrated capabilityfor predicting the performance of externally-controlled systems including turbulent transport, macroscopic stability, wave-particle physics, and multi-phase interfaces*

  - The research plan is guided by individual IPPA topical science goals

Recent results are encouraging for high beta

$\beta_T = 35\%$





$$\beta_T \equiv \frac{<p>}{B_{T0}^{\;2}/2\mu_0}$$

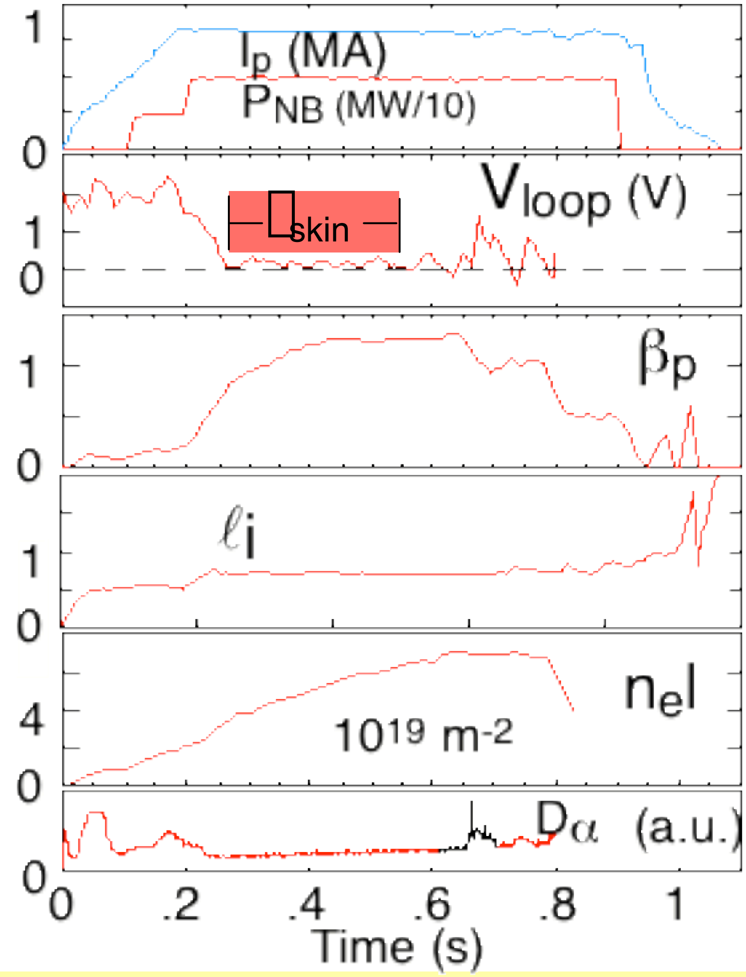
- H-mode: routine access
  - broadens pressure profile
- Enabled by maturing shape & position control system
- $\beta_N = 5.5$, $l_i = 0.6$

$B_T = 0.3T$, $A = 1.4$
$\kappa = 2.0$, $\delta = 0.8$
q(0) = 1.4 (EFIT)

Recent results are encouraging for long pulse

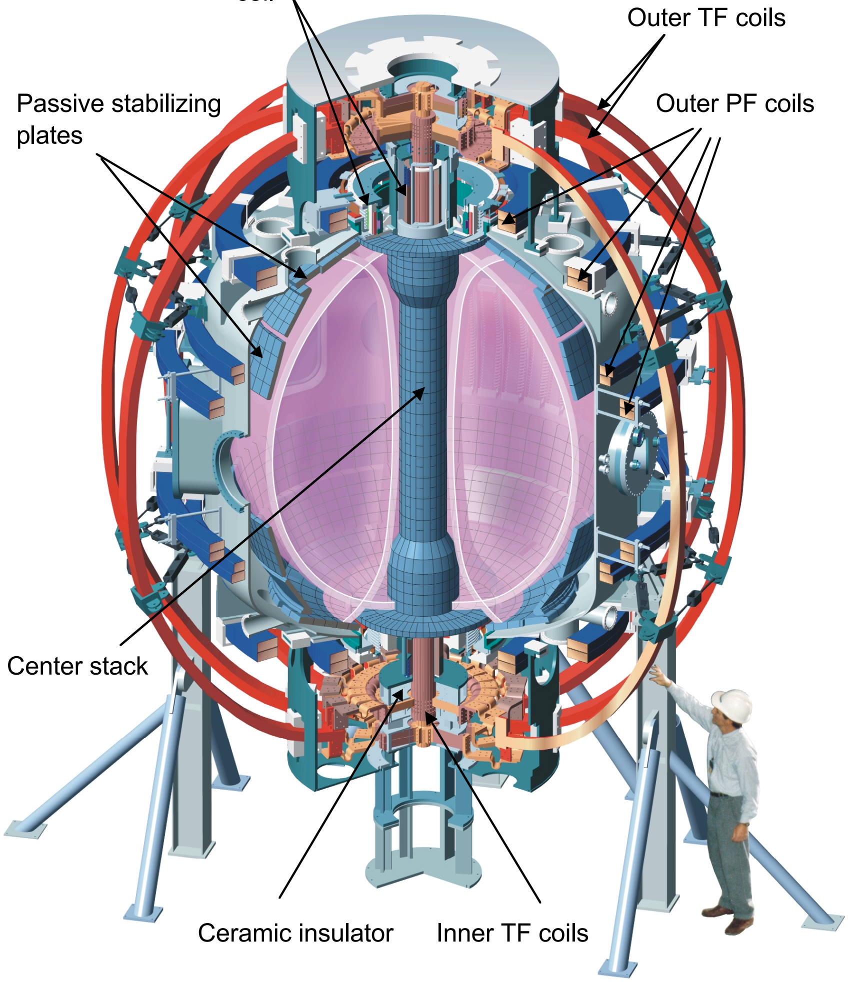
- J_{NI} = 60%
- β_N = 5.8 > no-wall stability limit
- Many parameters that are relevant to a CTF

	NSTX Long pulse	CTF base case	ARIES-ST
β_T	15%	20%	50%+
β_N	5	5	8
β_p	1.2	1	1.4
q_{cyl}	3.2	3	3



Operational challenge: *<u>Integrating</u> highest performance and long pulse*
Science challenge: *<u>Physics understanding</u> of operating limits & their scalings*

Facility capabilities have enabled the research program to advance in the last two years



Bakeout	350°C
Gas fueling	LFS + HFS
Aspect ratio	1.27
Elongation	2.2
Triangularity	0.8
Plasma Current	1.5 MA
Toroidal Field	0.6T
Heating and Current Drive	
Induction	0.7Vs
NBI	7MW
HHFW (30MHz)	6MW
CHI	0.4MA
Pulse Length	1s achieved, 5 s with 3 kG possible

NSTX

Integrating MHD science with control strategies is key to establishing physics basis

IPPA: attractiveness
stability and high beta, $\Delta t \gg \tau_E$

IPPA: extrapolable,
$\Delta t \gg \tau_{skin}$, high performance

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MHD

- β limiting modes vs. shape, li, P
- RWM, V_ϕ, & wall → RWM mode suppression → *Optimize stability in long-pulse high beta regimes*
- β limits & V_ϕ shear
- Fast ion modes
- Internal mode characterize → NTM suppression → *Optimize stability in long-pulse high beta regimes*

Integration

Highest performance

- β_T = 30%, $\Delta t > \tau_E$
  β_N = 5: > no wall limit
  HH = 1
- β_T = 40%,
- β_N = 8
  $\Delta t \gg \tau_E$, HH = 1.4

Solenoid-free

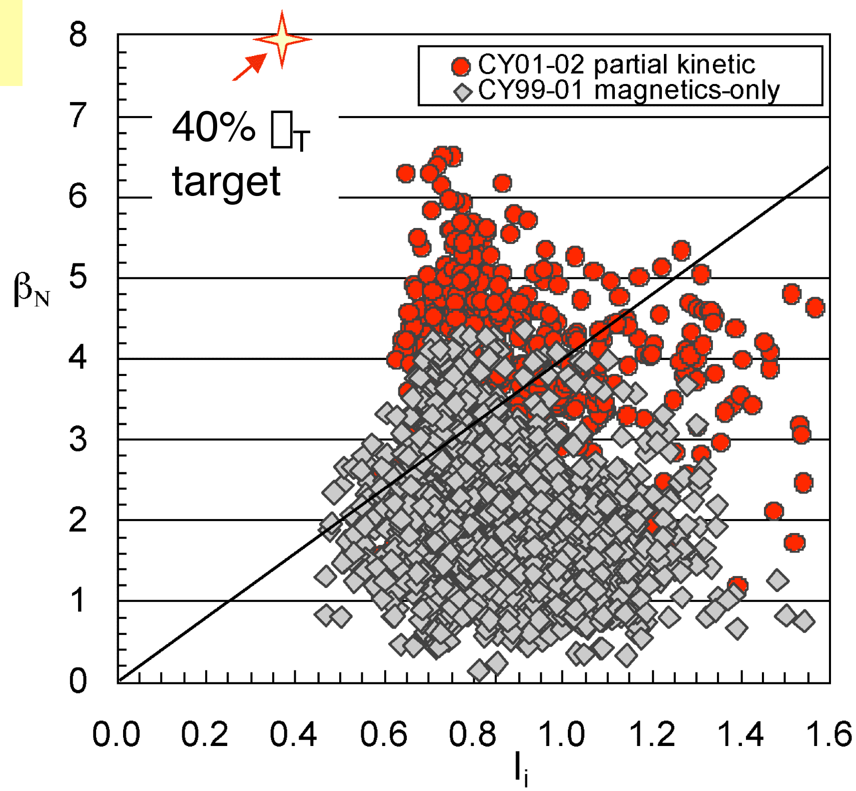
- J_{NI} > 60%, $\Delta t \sim \tau_{skin}$
- Non-solenoid startup demo
- J_{NI} ~ 100%, $\Delta t > \tau_{skin}$
- Solenoid-free up to hi β_p

40% β_T
$\Delta t \gg \tau_{skin}$
β_N = 8
HH = 1.4
70% J_{BS}

Developing the science of controlling the plasma MHD near the with-wall beta limit is a key element of the 5 year plan

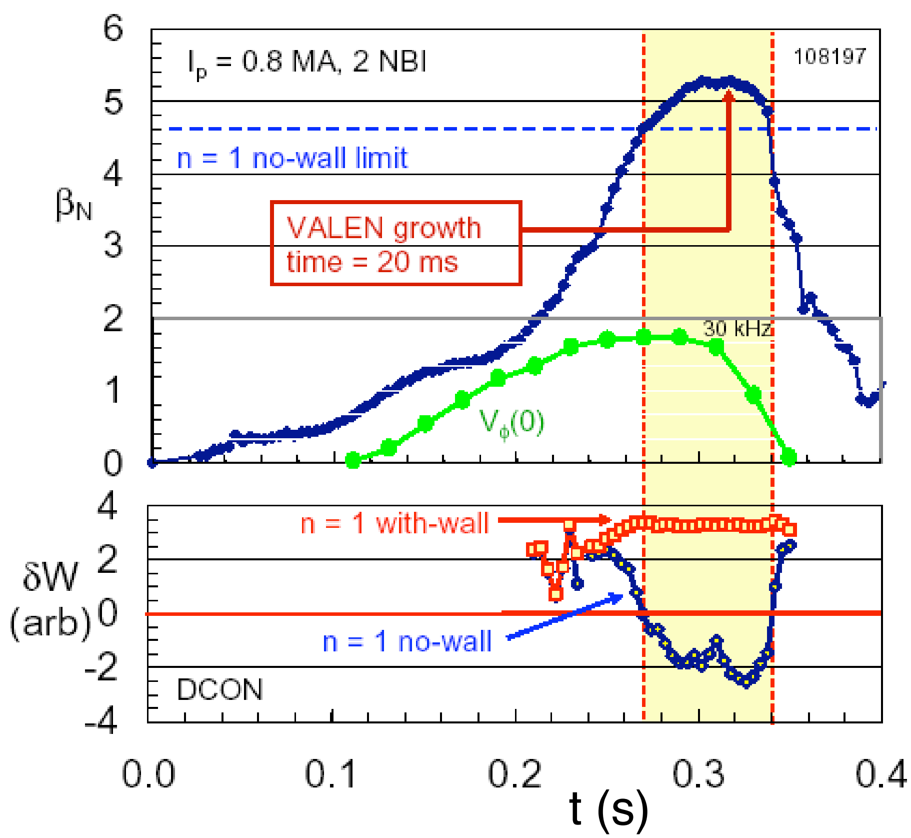
IPPA Goal 3.1.2: Develop detailed predictive capability for macroscopic stability, including resistive and kinetic effects

- High β_N needed for high J_{BS} & effective coupling to wall or stabilizing coils
- Routine operation above the no-wall limit
  - Broad H mode, rotation & passive stabilization are key elements
  - Exceeded goals for passive stability of 25% β_T. Good progress towards 40%



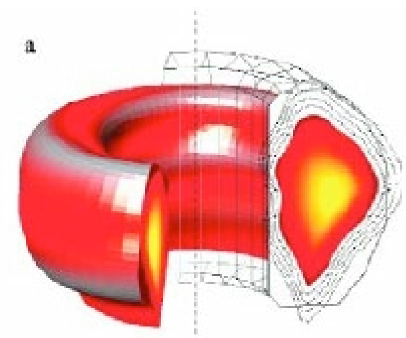
MHD control tools are central elements to developing robust path to high performance, long pulse targets

Interplay between stability, wall, error fields, and rotation is a key element of the program



Real-time mode identification & feedback control are required

- β initially above no-wall limit, but collapses after V_ϕ falls below critical value
  - Timescale ~ τ_{wall}
  - Exceeded no-wall limit for up to ~20 τ_{wall} in best case
- Modeling shows effective coupling of mode to wall

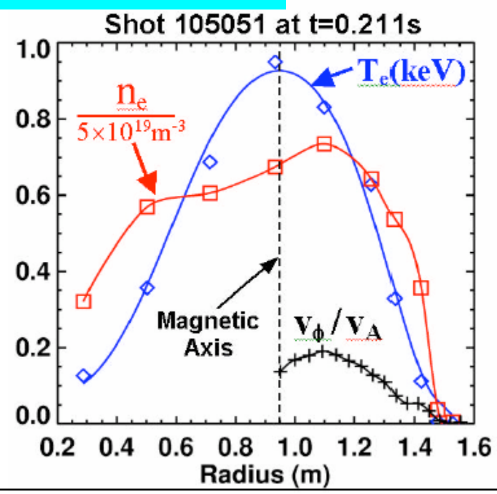


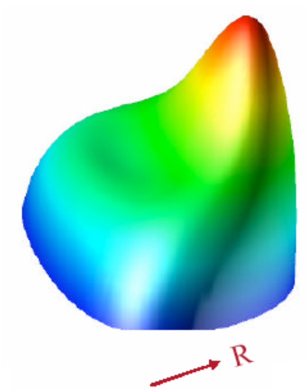
With DIII-D: reveal nature of scaling of critical rotation

Sabbagh will discuss MHD plan, issues, and options

Influence of high V_{ϕ}/V_A already seen in equilibria: relevant to stabilization?

R. Bell, LeBlanc, Menard

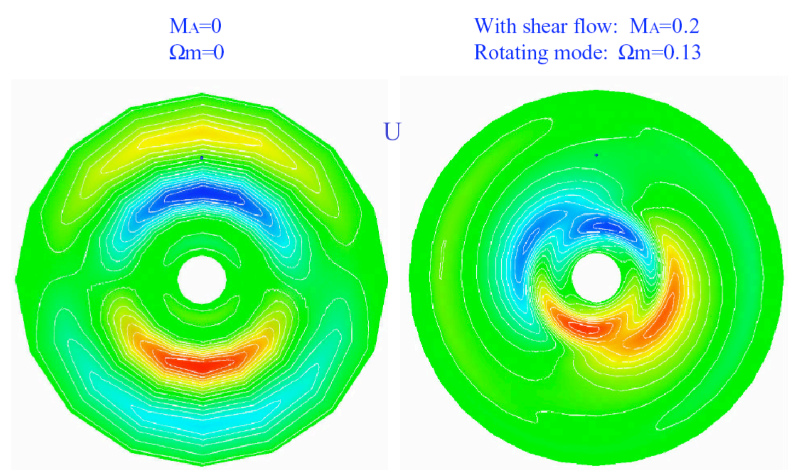




- Experiment: Density shows in-out asymmetry
- Effect of high Mach number of driven flow

M3D: Park

- Experiment: kinks saturate (Stutman, JHU)
- Theory: reduction of linear growth rates. Saturation due to rotational shear can occur



For physics basis: *Need to understand how rotational effects scale to other devices*

Transport studies will emphasize P(r) optimization and transport & turbulence understanding

IPPA: attractiveness
stability and high beta, Δt >> □E

IPPA: extrapolable,
Δt >>$□_{skin}$, high performance

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Transport

Global scalings and local □ → □ & high electron & ion heating, $V_{□}$ → □ and maximizing P, J_{BS}, J_{NBI} → *Optimize P, J_{BS}, J_{NBI}*

Edge turbulence

□ and wall fueling →

Electron, ion transport & core & edge turbulence vs. □, E_r → *Understanding: turbulence/theory compare*

Integration

- $□_T$ = 30%, Δt > $□_E$
  $□_N$ = 5: > no wall limit
  HH = 1

Highest performance

- $□_T$ = 40%,
- $□_N$ = 8
  Δt >> $□_E$, HH = 1.4

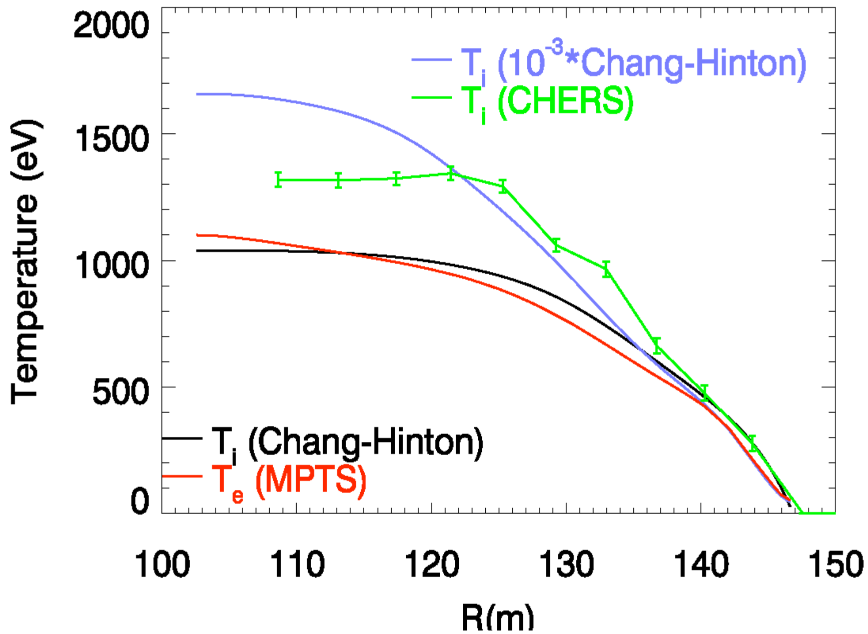
- J_{NI} > 60%, Δt ~ $□_{skin}$
- Non-solenoid startup demo

Solenoid-free

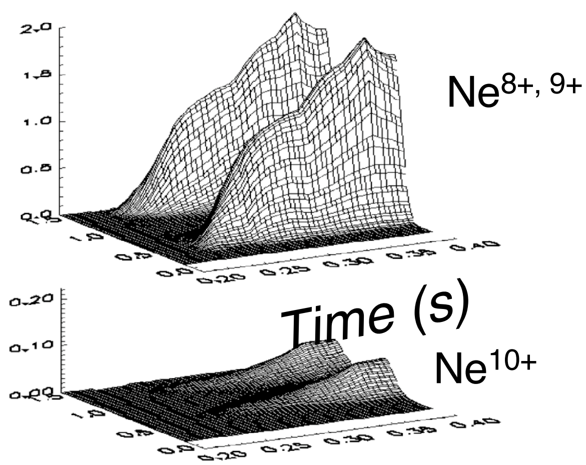
- J_{NI} ~ 100%, Δt > $□_{skin}$
- Solenoid-free up to hi $□_p$

40% $□_T$
Δt >> $□_{skin}$
$□_N$ = 8
HH = 1.4
70% J_{BS}

NSTX transport studies already reveal important surprises



Ne puff



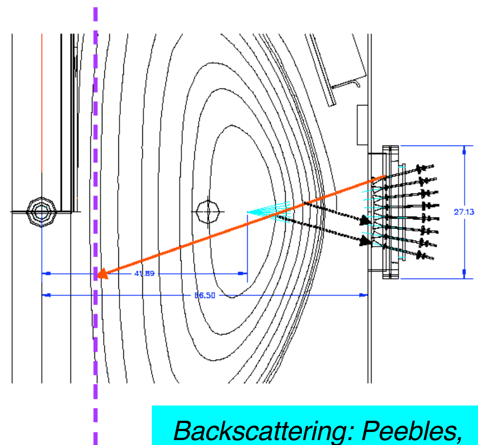
- T_i can exeed prediction of classical NBI heating & neoclassical ion transport
- Impurity puffing reveals naturally occuring core barrier in plasmas with L mode edge
- High scientific and practical value: with a change of aspect ratio and beta, we've created a system we cannot yet explain
- Understanding physics of confinement trends needed for accurately predicting properties of ST CTF or DEMO

Turbulence diagnostics can enable unique NSTX contributions to universally important transport issues

IPPA Goal 3.1.1: Advance transport physics based on understanding of turbulence & turbulence dynamics

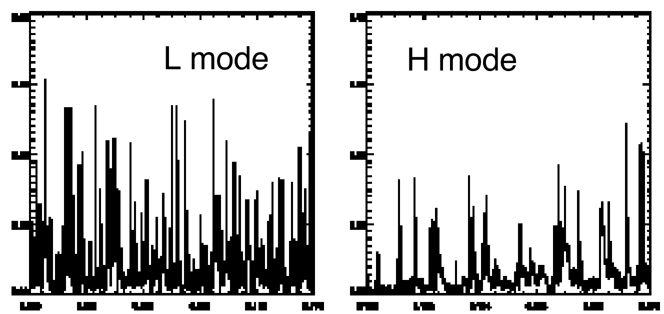
- Long wavelengths: naturally suppressed?
  - Reflectometry imaging being developed on TEXTOR.
- Short wavelengths: key to ubiquitous electron transport problem?
  - Large [illegible]$_e$ [illegible] big modes, ideal scattering geometry on NSTX
- SOL: high intermittency seen in imaging (LANL), probes (UCSD). Determinant in heat fluxes?

High k: scattering



ST advantage: large changes in direction of B in scattering with FIR yields high localization (Mazzucato)

Backscattering: Peebles, Kubota (UCLA)



Boedo (UCSD)

Maingi will discuss transport and boundary physics research plan

HHFW, EBW, and CHI science all part of solenoid-free startup strategy

IPPA: attractiveness
stability and high beta, Δt >> τ_E

IPPA: extrapolable,
Δt >> τ_{skin}, high performance

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HHFW/ EBW/ CHI

- HHFW heating & phasing → CD → CD - local J, ΔJ
- Real-time HHFW heating & phasing →
- EBW emissions
- EBW CD 1 MW → 3 MW
- CHI → Couple to ohmic → CHI + Non-inductive rampup
- *Optimize non-solenoid ops*

Integration

Highest performance

- β_T = 30%, Δt > τ_E
  β_N = 5: > no wall limit
  HH = 1
- β_T = 40%,
- β_N = 8
  Δt >> τ_E , HH = 1.4

Solenoid-free

- J_{NI} > 60%, Δt ~ τ_{skin}
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40% β_T
Δt >> τ_{skin}
β_N = 8
HH = 1.4
70% J_{BS}

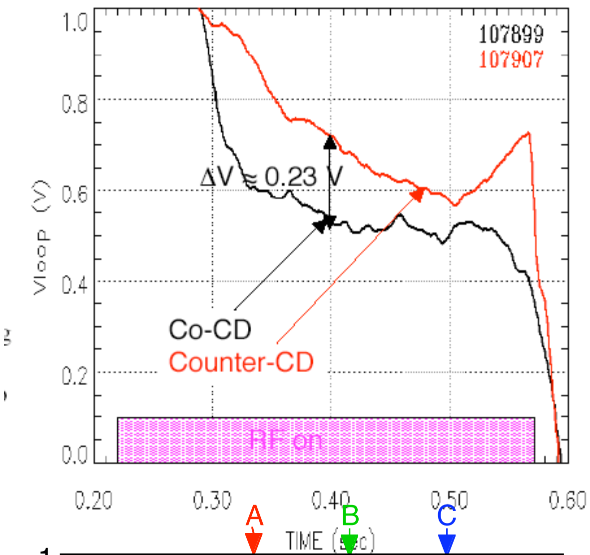
Several current drive tools are being pursued to provide needed flexibility in FY '04 - '08

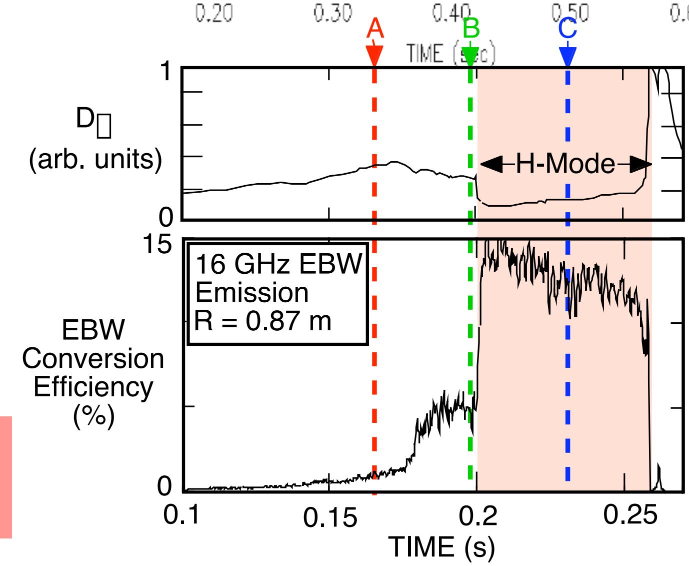
IPPA Goal 3.1.3: Develop predictive capability for plasma heating, flow, and current drive, as well as energetic particle driven instabilities…

- HHFW heats effectively. CD indicated by surface voltage
- HHFW interactions with fast ions found (Rosenberg (Ph.D. Thesis), Medley)
  - Important for assessing CD efficiency
- EBW emissions being studied to identify requirements for possible new system.
  - Development path for EBW as a NTM and CD tool outlined

Taylor will discuss HHFW & EBW , and CHI plans

Ryan, Swain (ORNL); Hosea, Wilson





Plan approaches solenoid-free startup research with different tasks

- Startup: 0 - 150 kA
  - CHI the primary tool at present
  - EBW may contribute as well

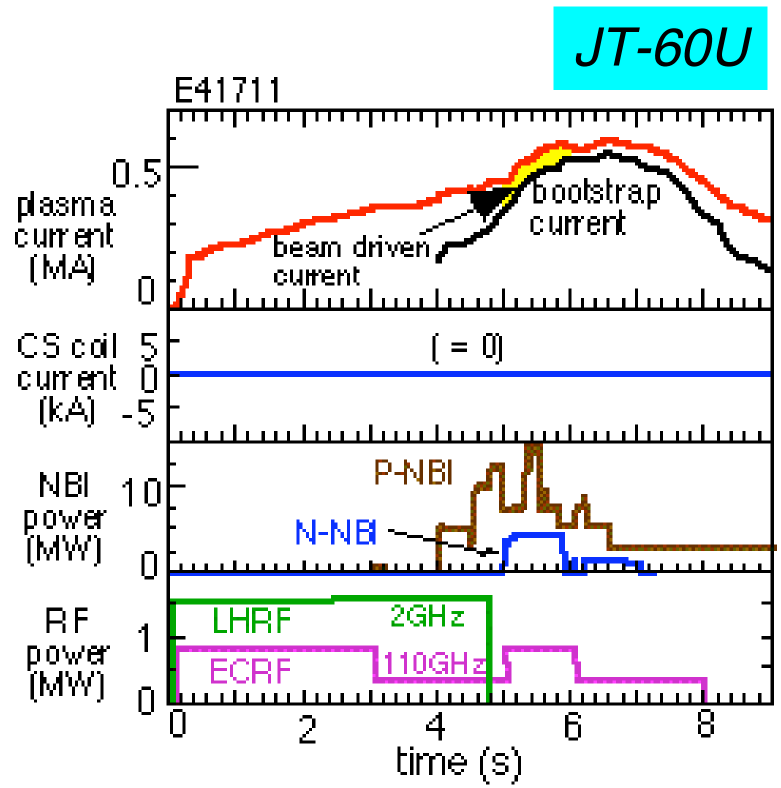
- Initial rampup: 150 - 500 kA
  - HHFW, EBW, bootstrap
  - Research can be performed with an ohmic start
  - PF induction - scenarios being assessed

- Final ramp to flattop
  - 500 - 800+ kA: NBI CD, bootstrap current overdrive are candidates

Each step is separable. Combining all three is a control challenge

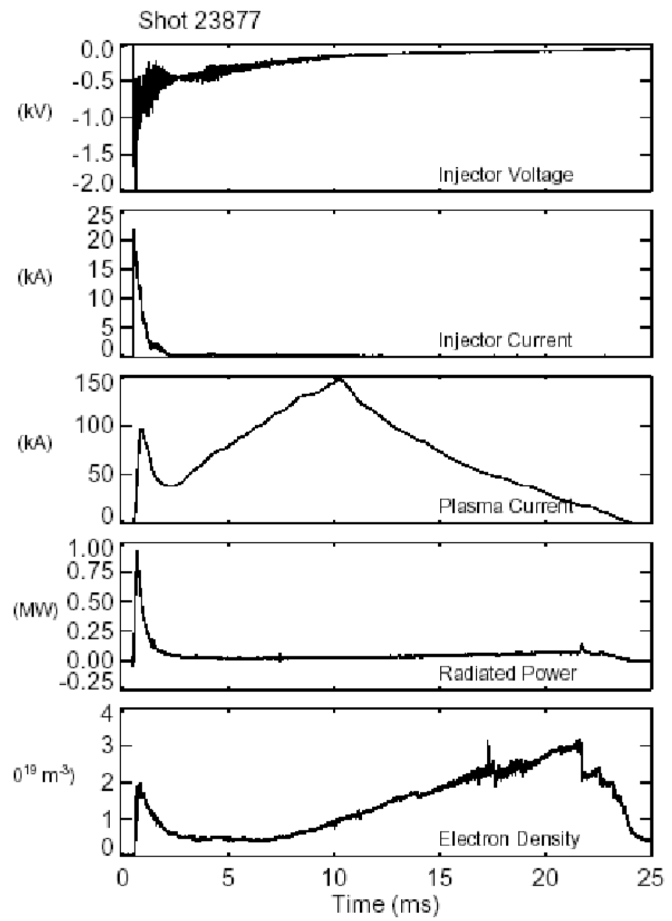
Two recent results have (re)shaped our thinking about solenoid-free rampup: I. Recent JT-60U results

- Significant bootstrap fraction
- Resultant plasma was high performance (HH = 1.6)
- Small inboard triangularity coil contributed flux in initial period



II. Recent work on HIT-II demonstrates that short-pulse CHI and induction can be coupled

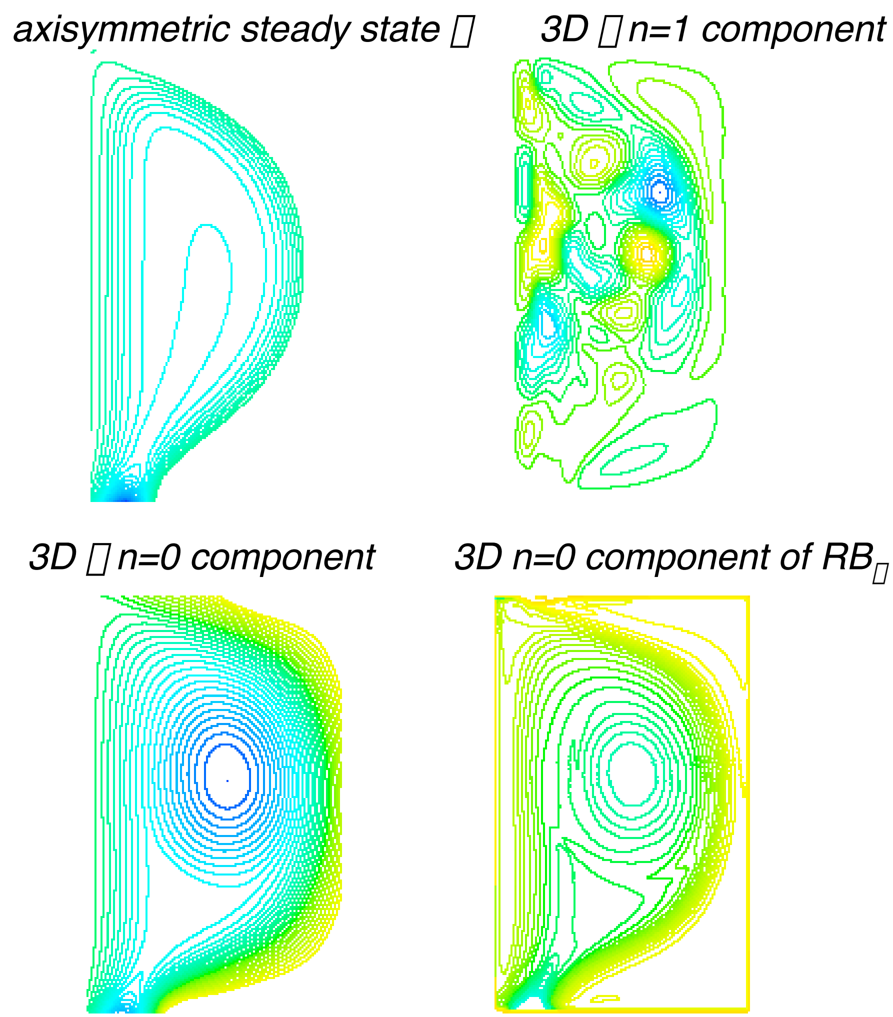
- HIT-II record currents now with CHI + induction
- Knowledge that a CHI solution exists emboldens our program
  - Aim for CHI+ohmic in FY '03, initial work with CHI + HHFW
- Change in CHI strategy
  - *Transient* CHI startup + hand-off: a new element
- High current CHI-to-handoff will also be developed



Raman, Jarboe, Nelson

Growing the theoretical understanding of CHI will take advantage of resistive MHD codes and simulation of magnetics measurements

- Fundamentally a nonlinear, resistive MHD problem
- Advanced computation key to forming physics basis
- Time-dependence of diagnostics can be used to decipher MHD dynamics



X. Tang, LANL

Many boundary tools are available or planned to help enable NSTX's integration goals

IPPA: attractiveness
stability and high beta, $\Delta t >> \tau_E$

IPPA: extrapolable,
$\Delta t >> \tau_{skin}$, high performance

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Boundary & fueling

- Heat flux scaling → Heat & DND, sweeping → Pellets
- Divertor power balance
- Particle influx, wall prep
- Li studies → Liquid Li?
- Cryopump? → *Optimize fueling for long pulse, high J_{BS}, high J_{NBI}*

Integration

Highest performance

- β_T = 30%, $\Delta t > \tau_E$
  β_N = 5: > no wall limit
  HH = 1
- β_T = 40%,
- β_N = 8
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40% β_T
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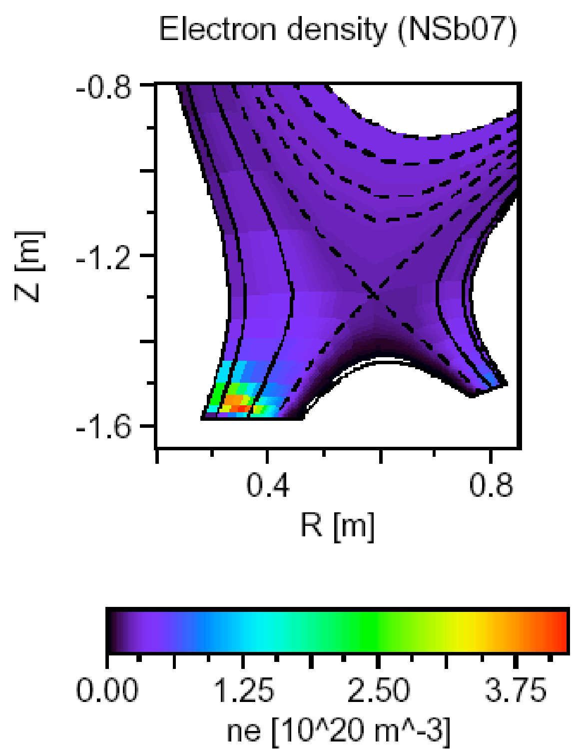
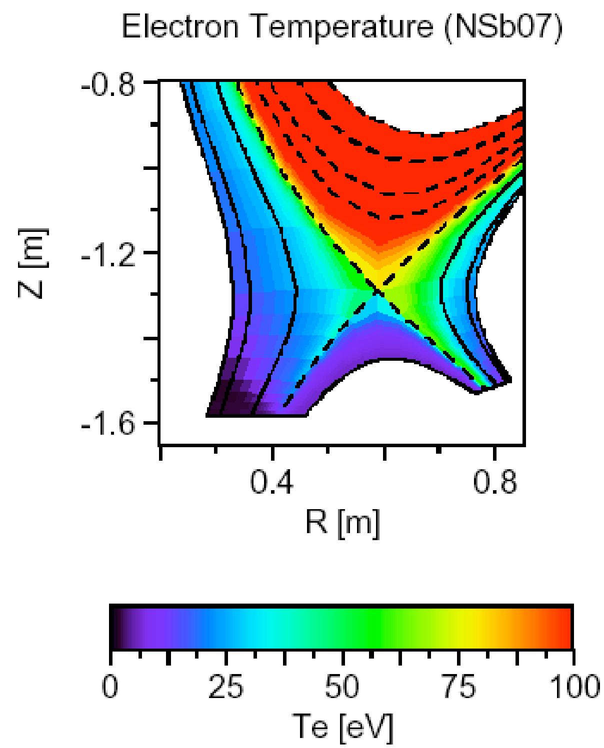
70% J_{BS}

Coupling of edge measurements and modeling are central for establishing ST boundary science

- Required to integrate atomic and plasma physics in complex, 3D problem
- Collaboration with VLT may indicate a path for Li module
- Further involvement with MAST will be important



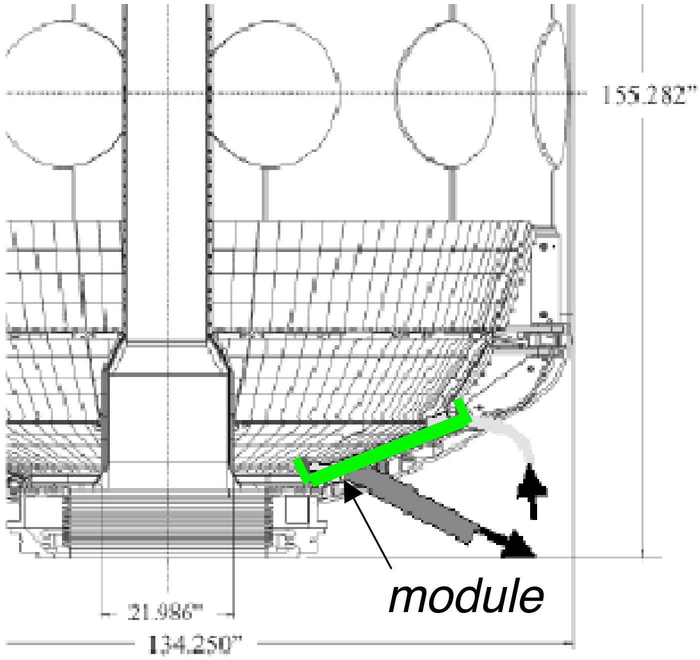


Rensink, Porter, Wolf (LLNL); Stotler

IPPA 3.1.4: Advance the capability to predict detailed multi-phase plasma-wall interfaces at very high power and particle fluxes

Advanced particle and heat flux control techniques are being considered

- Liquid lithium model a possibility in the second half of the plan
- Li pellet injection on NSTX contributes to assessment of applicability
- Assessment in conjunction with APEX, CDX-U research
- Success might have broad implications for fusion



ALIST liquid surface module concept

Integrating the physics: towards high performance, long pulse targets

- Scenario development strategy and tools

-Issues identified

Detailed scenario assessments: quantify & clarify performance and sustainment goals and requirements

- Assessments involve integration of plasma models to simulate the self-consistent plasma behavior in a full discharge, in a reasonable computational time
- Primary tools: TSC (free-boundary) and TRANSP (fixed boundary)
- Supporting modeling results from SCIDAC and NTCC

Simulations are underway to explore the requirements for integration and solenoid-free operations

- Non-inductively sustained, $\tau_{pulse} >> \tau_{skin}$,
  - HHFW + NBI: varied density and β — *Discussed first*
  - HHFW only
- Solenoid-free ramp-up to high β_p
  - CHI, HHFW, NBI — *Discussed next*
- High performance, $\tau_{pulse} >> \tau_{skin}$ — *Simulation plan outlined*
  - 40% β_T; probable active MHD feedback
  - Identify current drive requirements and stability in light of recently obtained profiles

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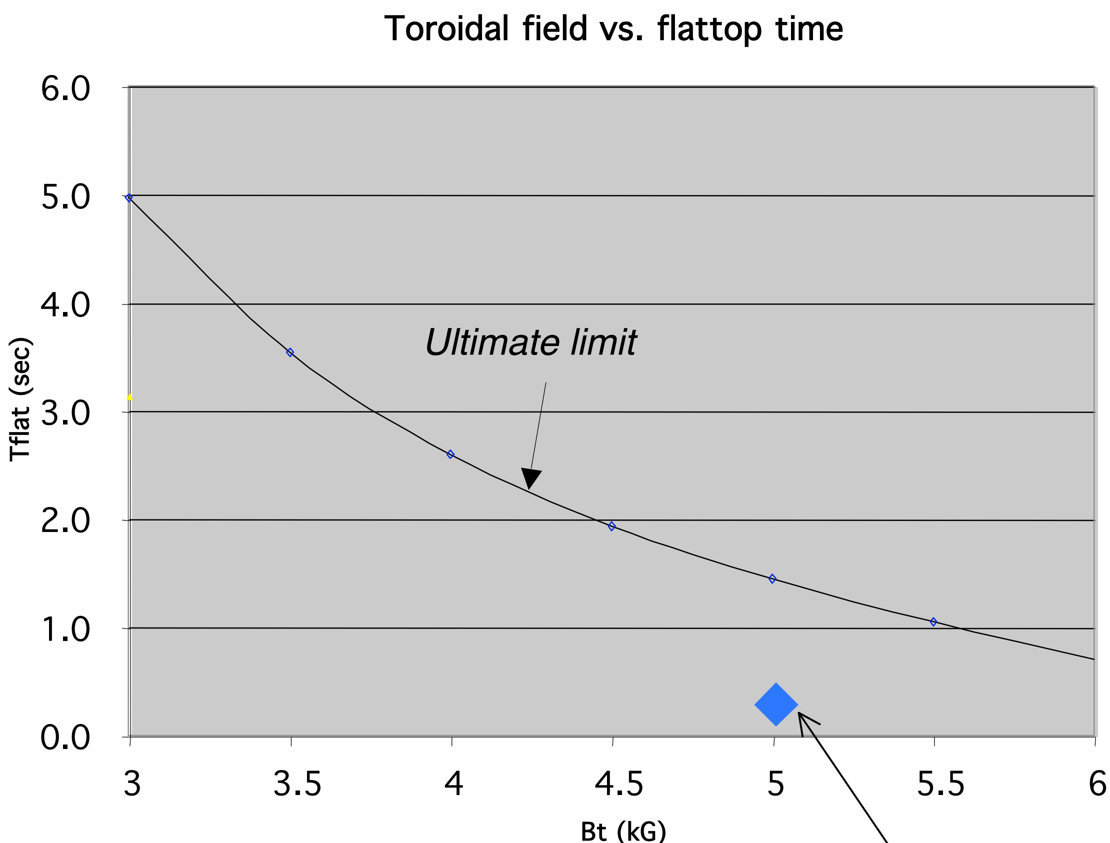
HH = 1.4
70% J_{BS}

NSTX can operate for several current relaxation times at TFs of interest



τ_{skin} = 230 ms (109070)

Developing fully non-inductive sustained scenarios begins with high β_p long-pulse plasmas

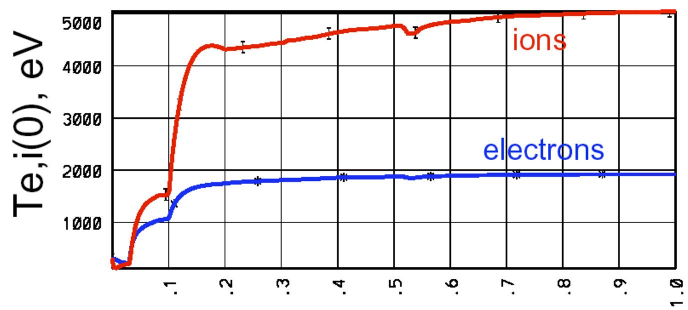
- Shot 109070 is a good prototype for longer pulse since $\Delta t > \tau_{skin}$ and $I_{NI} > 50\%$
  - I_p = 800 kA: I_{BS} = 240 kA, I_{NBI} = 160 kA, $I_{\nabla p}$ = 50 kA
  - High confinement HH > 1.0, and $\beta_N \approx 5.9$

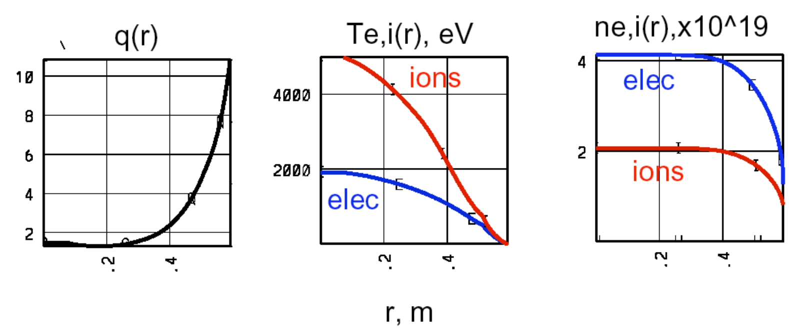
In simulations

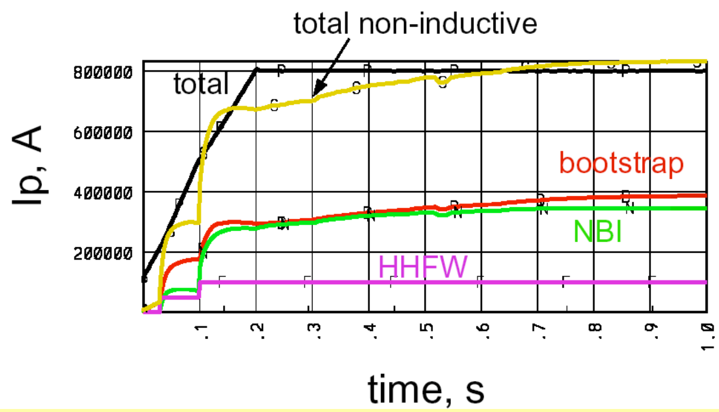
- First add 6 MW of HHFW power to 6 MW of NBI. Assume 50/50 electron/ion heating split with HHFW
  - Raises temperature, increases I_{BS} and decreases collisionality

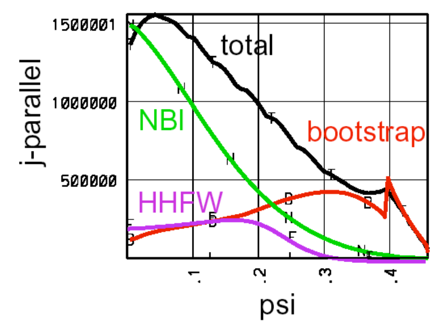
- Then, in this exercise
  - A. Lower the density
    - Improve CD efficiency of NBI and HHFW external sources
  - B. Raise the elongation
    - Increases q_{cyl} as $(1+\kappa^2)$, increasing I_{BS}

Added HHFW power at lower density can help obtain $f_{NI} \approx 1$







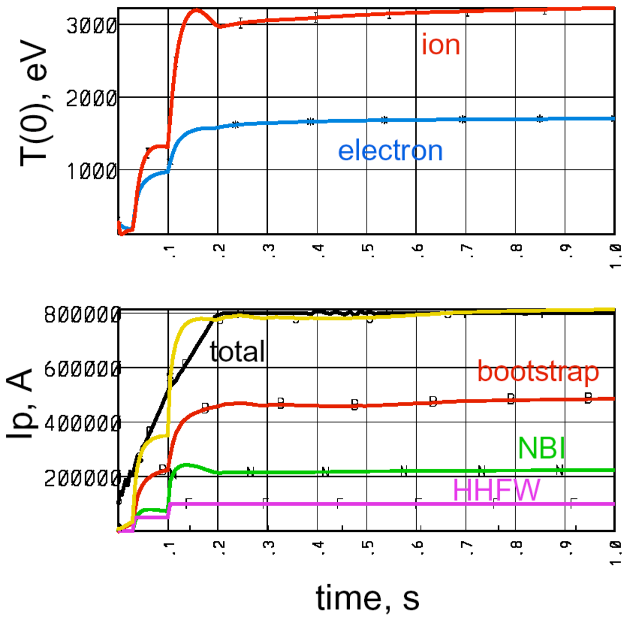


$n(0) = 0.4 \times 10^{20}\ /m^3$
$Z_{eff} = 3.5$

□= 2.1, $□_N^{thermal} = 5.8$
$□_N^{total} = 8.2$
HH = 1.2
100 kA HHFW power *prescribed*

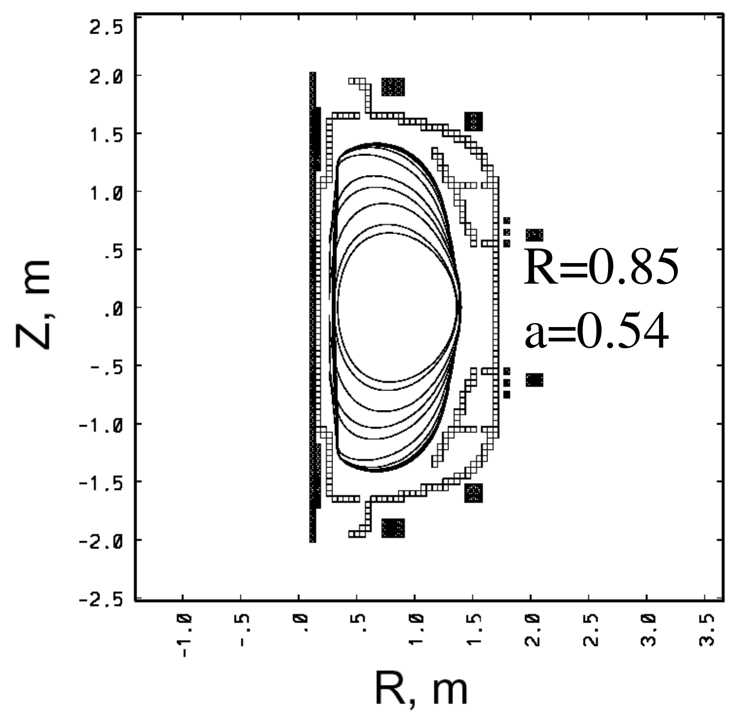
- Lower n_e, higher power, higher T_e yield lower $□_□$, higher J_{NI}
  - I_{BS} (model/exp't) = 380 kA/240 kA
  - I_{NB} (model/exp't) = 345 kA/160 kA
- Underscores need to seriously consider active particle control
- High total $□_N$: demand for active MHD control likely

Higher elongation, addition of HHFW can help obtain $f_{NI} \approx 1$



$n(0) = 0.5 \times 10^{20}/m^3$, $Z_{eff} = 3.5$.
100 kA I_{HHFW}, 50/50 heating split assumed

Plasma Boundaries During
High κ Simulation

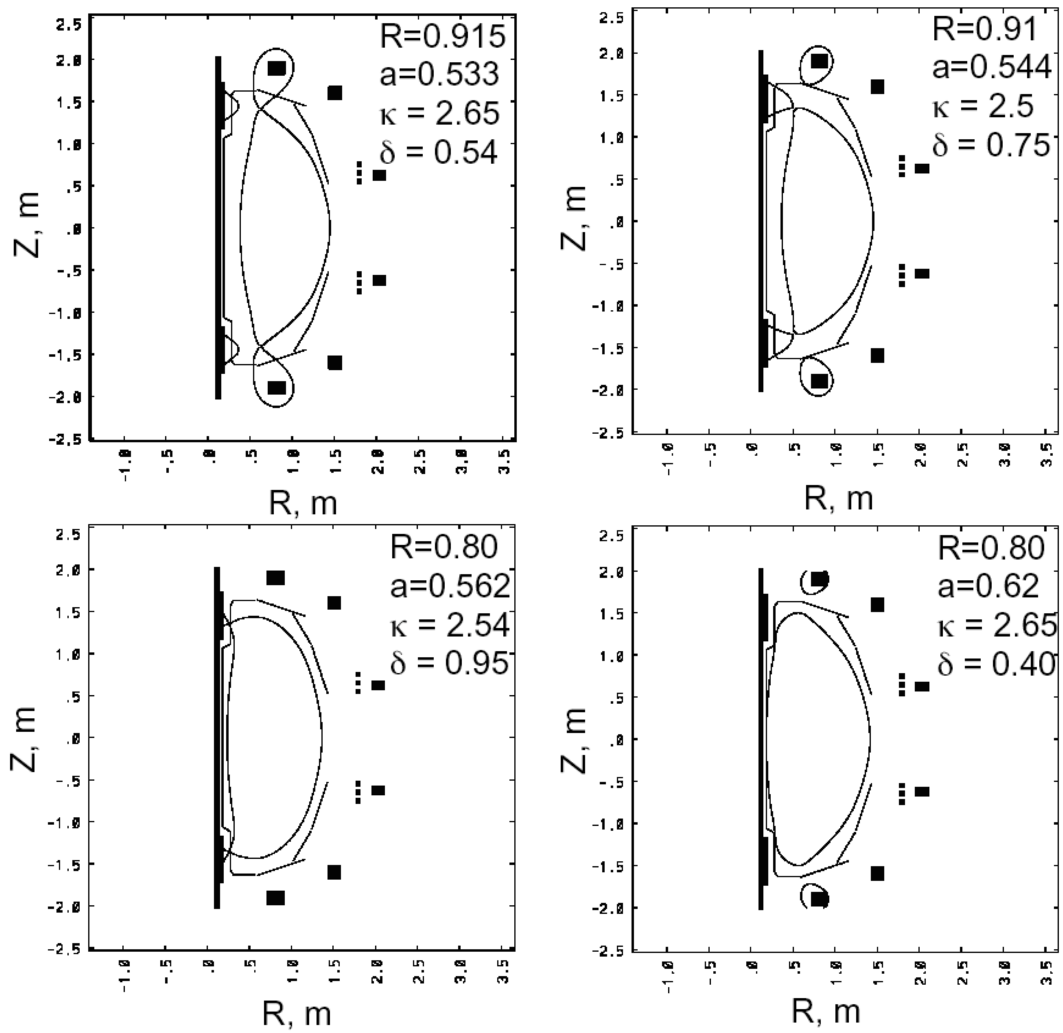


- I_{BS} (model/exp't) = 490 kA/230 kA
- I_{NB} (model/exp't) = 220 kA/155 kA
- β_N = 7.1 (5.2 thermal), HH - 1.2
- High elongation a key element of ARIES reactor visions

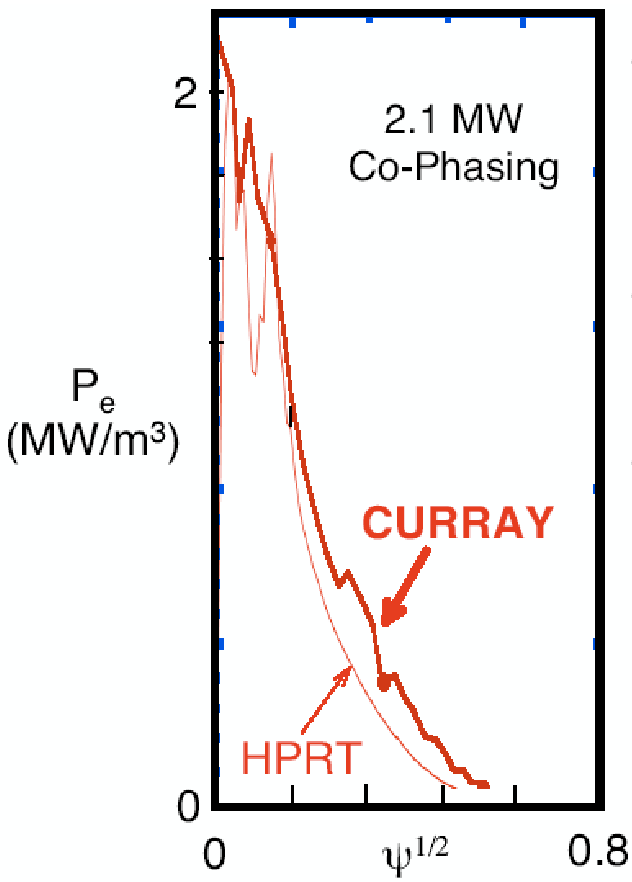
Several high elongation configurations will require further development of advanced control

- Questions pertain to
  - robustness of vertical stability
  - H mode access
  - heat flux management

- To be investigated in the plan's research period: upgraded vertical control
  - Passive plate optimization for vertical stability
  - Power supply upgrades
  - Internal control coils



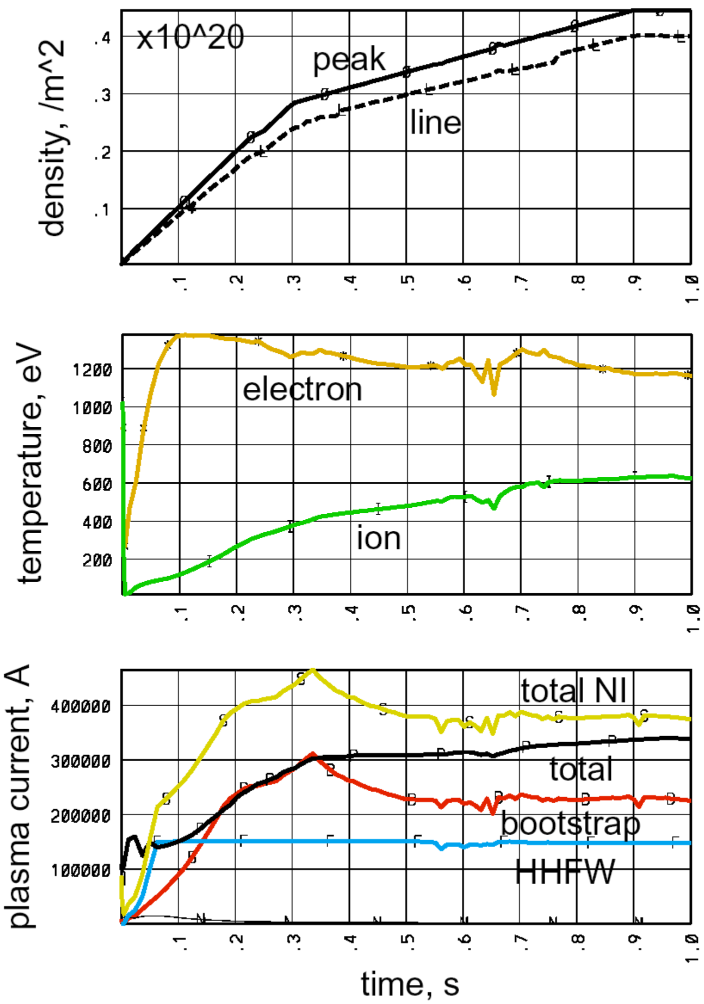
CD codes being benchmarked, parametric scans being performed

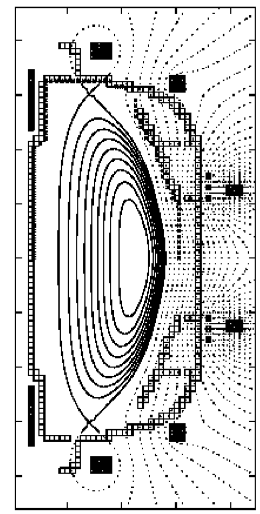


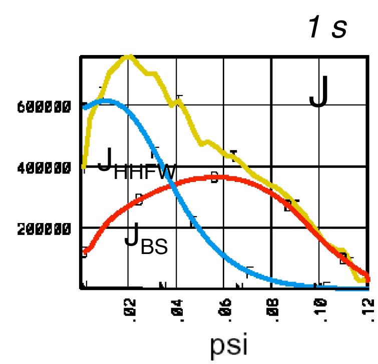
- Reasonable agreement between ray tracing codes for HHFW CD experiments
- Full wave codes predict similar deposition to ray tracing codes
- In progress: comparison of HHFW fast ion absorption to measurements of high energy fast ion tail populations

HHFW can be used following CHI to raise the current to several hundred kA

- A significant control challenge
- Assume a 100 kA plasma for coupling to 6 MW HHFW
- HHFW CD assumed scaled from CURRAY calculations for similar n_e and T_e.
- J_{BS} a major player in the total current.
- Hardware requirements
  - Control with open field lines needs to be developed
  - Assess diagnostic input needs for handoff between CD techniques



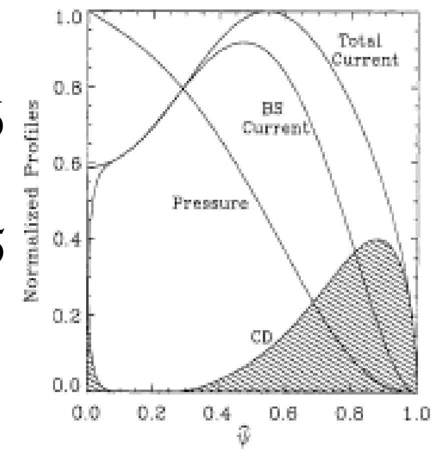




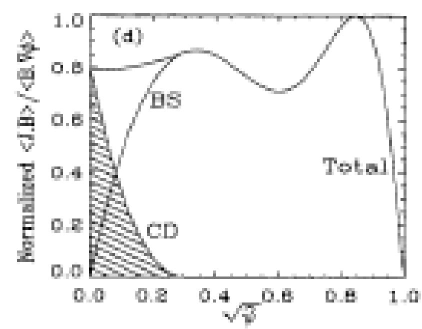
Requirements to meet 40% β_T target to be examined in light of NSTX data

- To do for the plan: model based on 30 - 35% β_T plasmas
  - What $J_{BS}(r)$ and $J_{NB}(r)$ does predictive modeling suggest based on measured profiles?
    - Different splitting of n_e, T_e, T_i implies different J_{BS}
    - Improved bootstrap models (Sauter, NCLASS,…)
  - Evaluate HHFW CD, EBW CD efficiency and location for range of predicted scenarios
  - Reevaluate stability with suite of ideal stability codes

□ = 2
□ = 1.26
□ = .45
$□_□$ = 8.5



□ = 3
□ = 1.4
□ = .45
$□_□$ = 7.7



Both with conducting wall

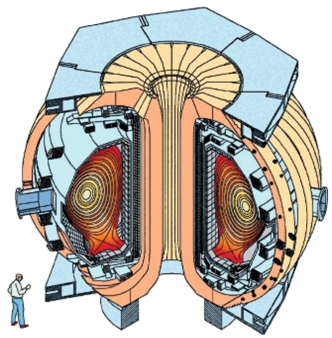
From Menard *et al.*, NF 37 (595) 1997

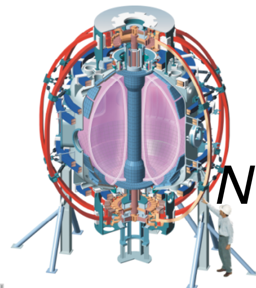
Towards a stronger scientific foundation: connections with other laboratories and disciplines

-Examples of opportunities

NSTX can contribute to a community-wide advance on transport & turbulence science

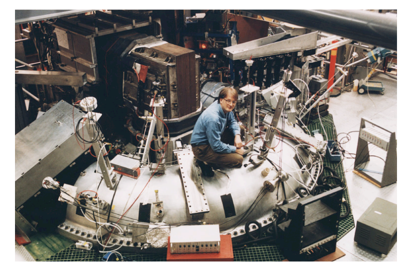
DIII-D



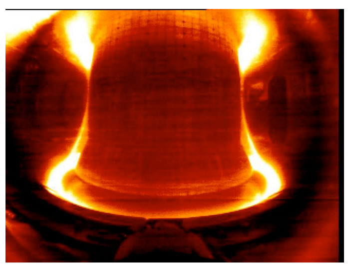


NSTX

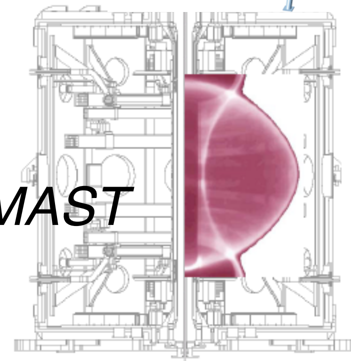
MST



C-Mod



MAST



Pegasus

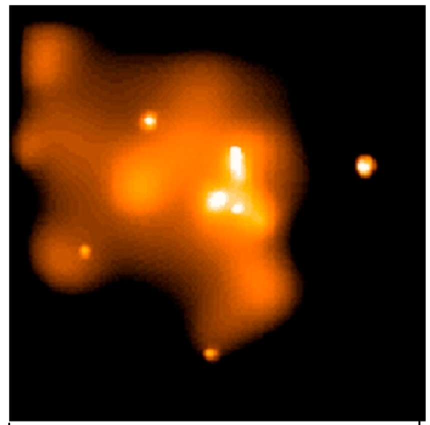
Electrostatic — *E-M effects emerge* — *Electromagnetic*

- χ_e: a deep transport mystery. Understanding is a need for burning plasmas
- TTF is developing a proposal for a renewed transport initiative.
- Suite of machine types can develop a powerful scientific story

Detailed diagnosis and gyrokinetic comparisons of β ~ unity turbulence is of broad scientific importance

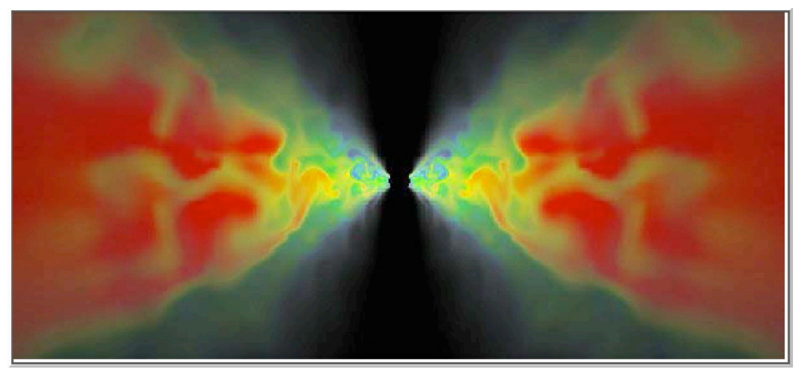
- Astrophysics and turbulence dynamics: cascading of MHD turbulence to ion scales is of fundamental importance in beta ~ unity systems
- Fusion's gyrokinetic formalism applicable to high beta astrophysical turbulence problems
- Astrophysicists have keen interest in benchmarked codes

Subluminous black hole accretion disks



10 light years

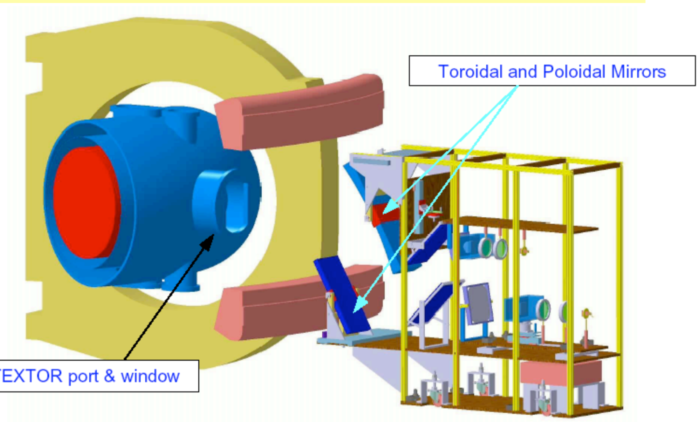
Chandra X-ray Observatory
Galactic center
10^5 times "too dim"



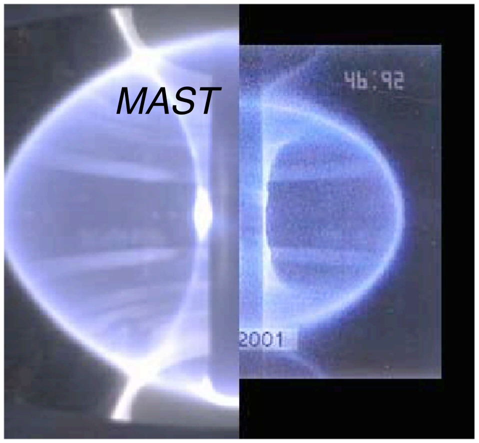
Quataert (Berkeley), Dorland (MD)

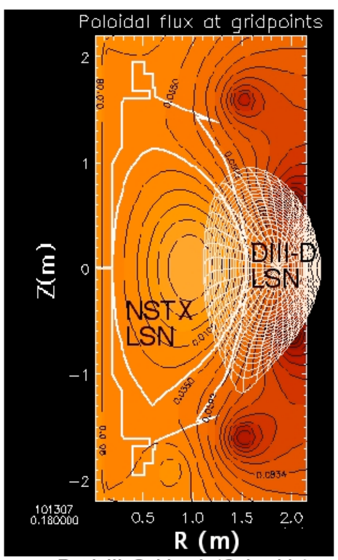
Armitage (U. Colorado)

Possible approach for low k: imaging



The NSTX program looks to help make maximal scientific advantage of intermachine comparisons

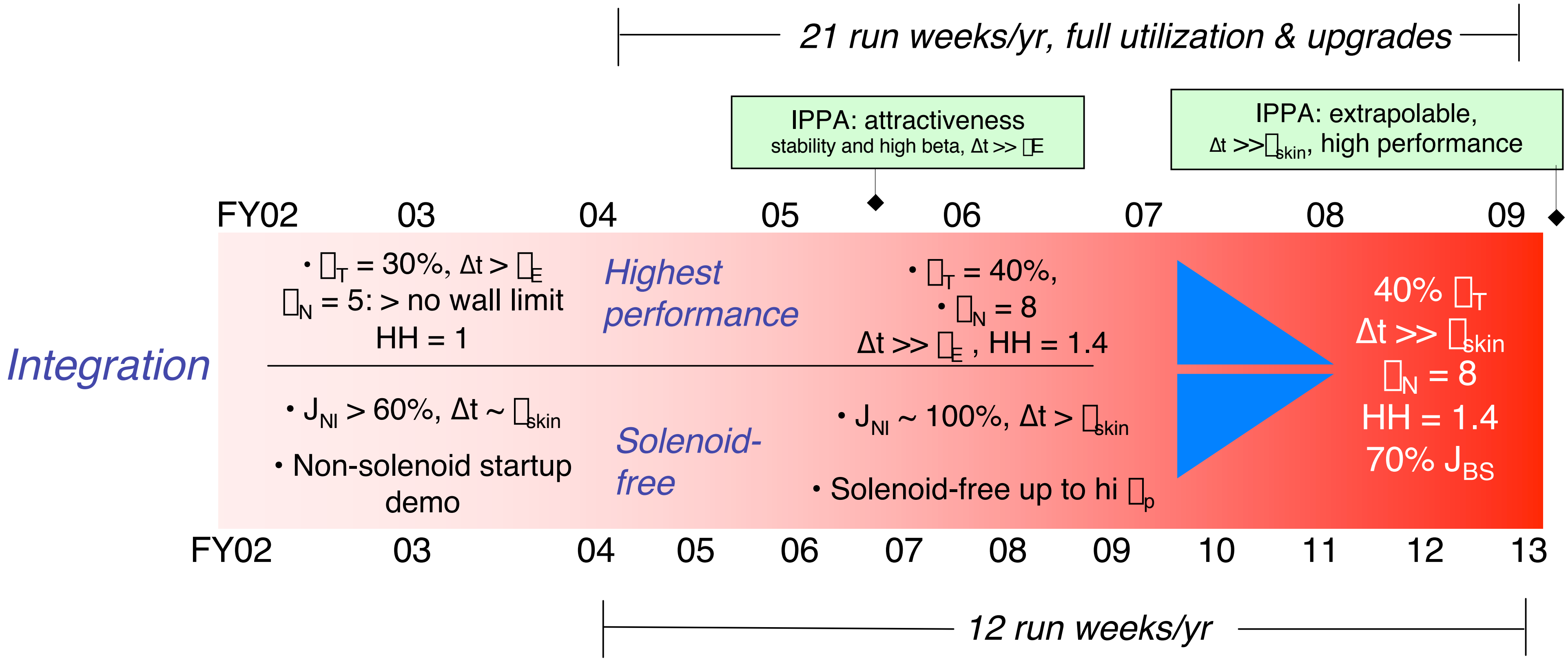




Paoletti, Sabbagh (Columbia)

- Well-aligned with ITPA process
- One opportunity: beta dependence of τ_E
  - A concern for burning plasmas
  - NSTX is an ideal place to explore this
- MAST: plans for constructing identical configurations, merging of databases
- With DIII-D: Joint experiments being proposed and implemented
  - RWM
  - Fast ion MHD: CAE, TAE
  - Pedestal similarity
  - Core confinement

Full facility utilization & upgrades permits timely realization of goals



- Constant budget scenario will lead to significant delays in reaching primary goals
- Integration emphasis demands a balanced program even in limited budgets

The NSTX program is headed to meet IPPA goals as defined by the community

- The plan is constructed to meet the 5 year ST assessment by the end of '05, and major progress for the 10 year goals by the end of ‘08
  - Plan makes optimal use of facility and upgrades
  - Less funding significantly slows progress
- Emphases: leading contributions to ST assessments for energy development, cross-cutting toroidal physics, and high beta plasma science
  - expand the operating space of high beta ST plasmas. Demonstrate and develop the basis for solenoid-free operations
- NSTX research aims to couple strongly to advanced computation and other experiments, through the ITPA, to form an extrapolable ST physics basis
- Assessments on attractiveness (5 and 10 year) will be based on successful integration of many topical science areas

Supporting slides

IPPA: attractiveness
stability and high beta, $\Delta t >> \tau_E$

IPPA: extrapolable,
$\Delta t >> \tau_{skin}$, high performance

FY02 | 03 | 04 | 05 | 06 | 07 | 08 | 09

Transport
- Global scalings and local χ → χ & high electron & ion heating, V_ϕ → χ and maximizing P, J_{BS}, J_{NBI} → *Optimize P, J_{BS}, J_{NBI}*
- χ and wall fueling
- Edge turbulence → Electron, ion transport & core & edge turbulence vs. χ, E_r → *Understanding: turbulence/theory compare*

MHD
- β limiting modes vs. shape, li, P
- RWM, V_ϕ, & wall → RWM mode suppression → *Optimize stability in long-pulse high beta regimes*
- *Error field & V_ϕ*
- β limits & V_ϕ shear
- Fast ion modes
- Internal mode characterize → NTM suppression →

Integration
- β_T - 25%, $\Delta t > \tau_E$, β_N = 5, HH = 1
- J_{NI} > 60%, $\Delta t \sim \tau_{skin}$
- Non-solenoid startup demo
- β_T = 40%, $\Delta t >> \tau_E$, HH = 1.4
- β_N = , $\Delta t >> \tau_E$, HH = 1.4
- J_{NI} ~ 100%, $\Delta t > \tau_{skin}$
- Non-solenoid start & ramp to hi I_p
- 40% β_T, $\Delta t >> \tau_{skin}$, β_N = 8, HH = 1.5, 70% J_{BS}

HHFW/ EBW/ CHI
- HHFW heating & phasing
- CD
- CD - local J, ΔJ
- Real-time HHFW heating & phasing →
- EBW emissions →
- EBW CD 1 MW → EBW CD 3 MW
- *Optimize non-solenoid ops*
- CHI → Couple to ohmic → CHI + Non-inductive rampup →

Boundary & fueling
- Heat flux scaling → Heat & DND, sweeping
- Divertor power balance →
- Particle influx, wall prep
- Li studies →
- Pellets
- Cryopump?
- Advanced Liquid Li? →
- *Optimize fueling for long pulse, high J_{BS}, high J_{NBI}*

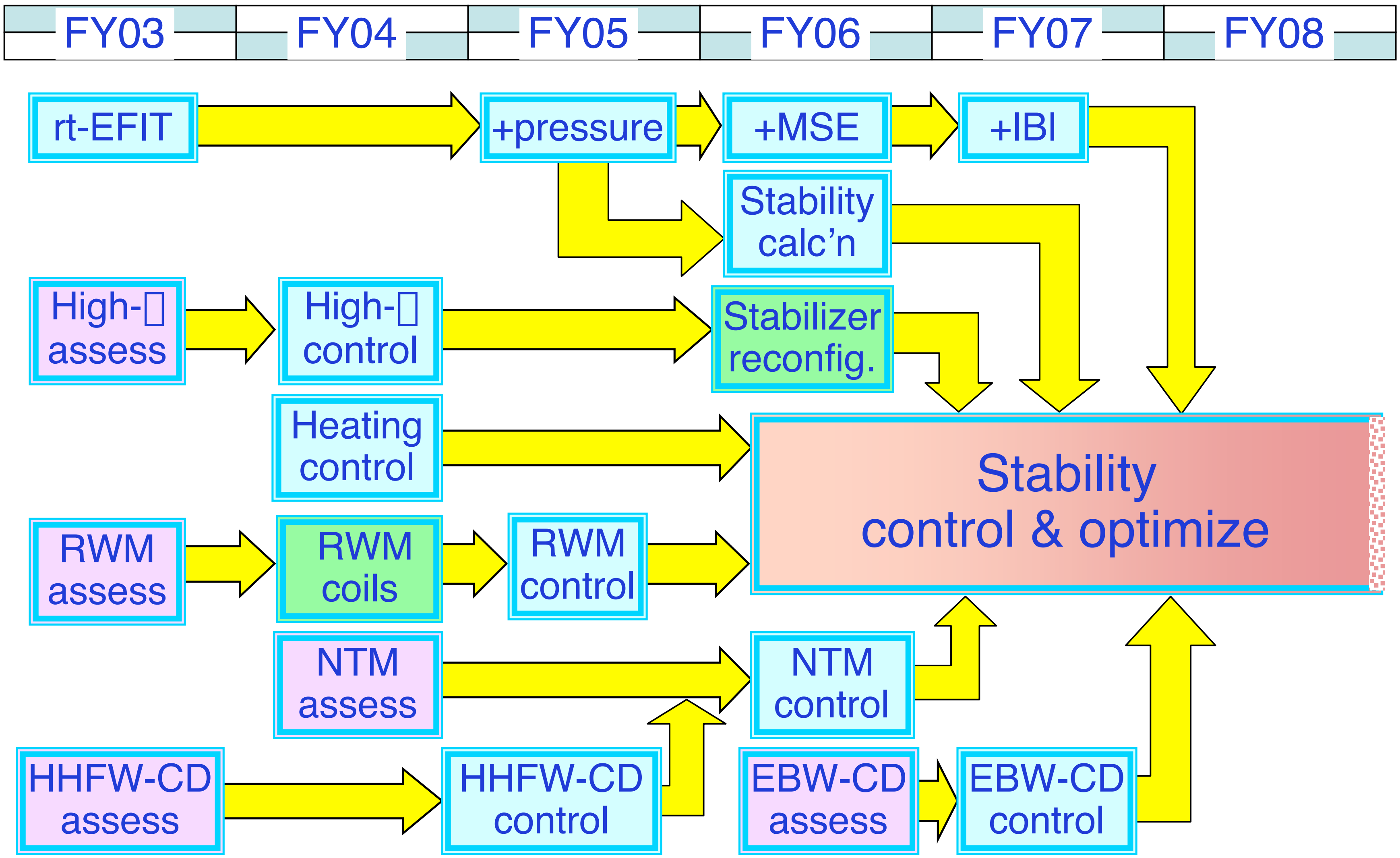
1/20/03 5:58 PM

IPPA goals and objectives

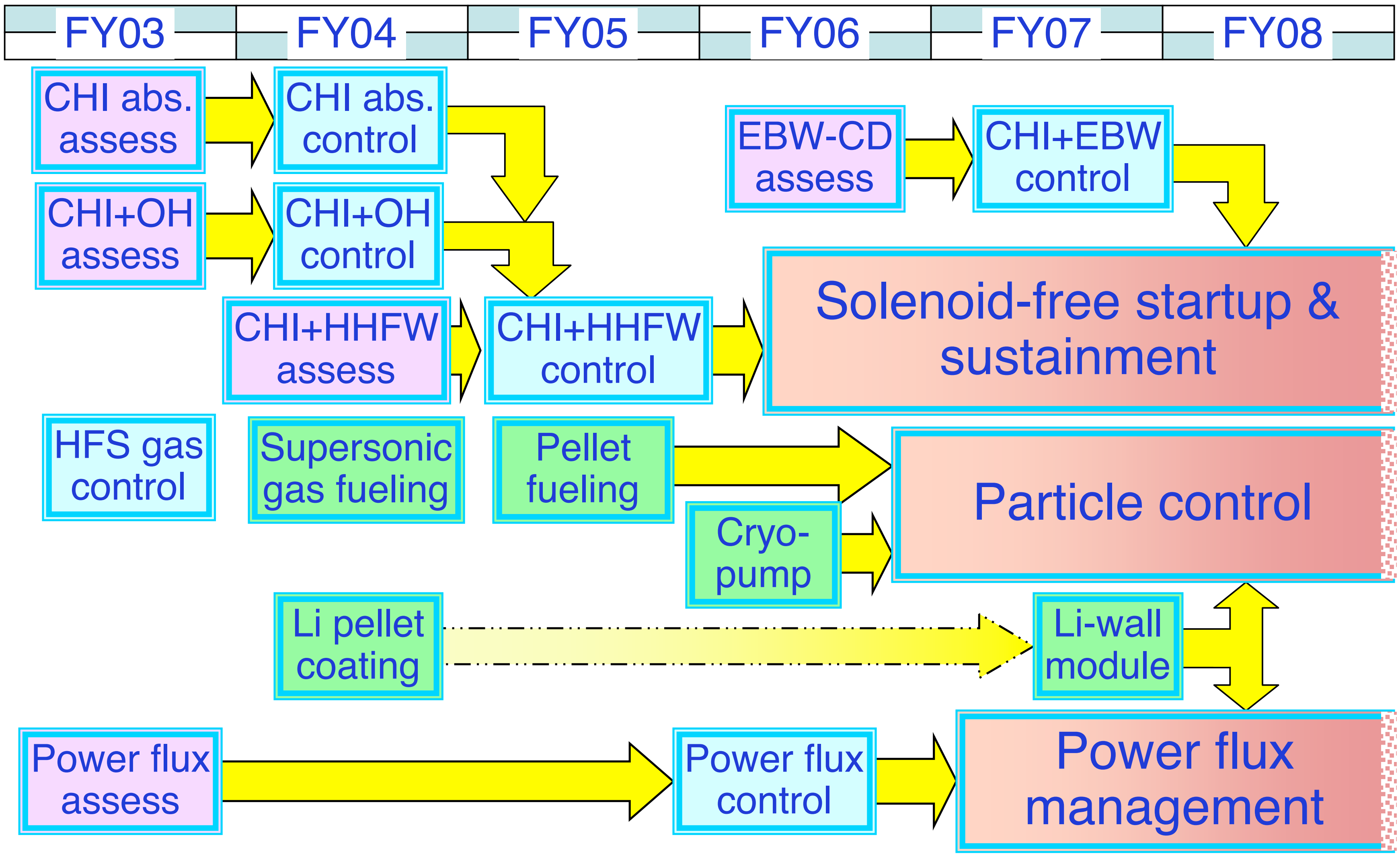
Goals	5-Year Objectives	10-Year Objectives
Goal 1: Advance understanding of plasma, the fourth state of matter, and enhance predictive capabilities, through comparison of well-diagnosed experiments, theory and simulation.	**1.1 Turbulence and Transport** Advance scientific understanding of turbulent transport forming the basis for a reliable predictive capability in externally controlled systems. **1.2 Macroscopic Stability** Develop detailed predictive capability for macroscopic stability, including resistive and kinetic effects. **1.3 Wave Particle Interactions** Develop predictive capability for plasma heating, flow, and current drive, as well as energetic particle driven instabilities, in a variety of magnetic confinement configurations and especially for reactor-relevant regimes. **1.4 Multiphase Interfaces** Advance the capability to predict detailed multi-phase plasma-wall interfaces at very high power- and particle-fluxes. **1.5 General Science** Advance the forefront of non-fusion plasma science and plasma technology across a broad frontier, synergistically with the development of fusion science in both MFE and IFE.	**Develop fully integrated capability** for predicting the performance of externally-controlled systems including turbulent transport, macroscopic stability, wave particle physics and multi-phase interfaces. **Develop qualitative predictive capability** for transport and stability in self-organized systems. **Advance the forefront of non-fusion plasma science and technology** across a broad frontier, synergistically with the development of fusion science.

	5-year Objectives	10-year Objectives
Goal 2: Resolve outstanding scientific issues and establish reduced-cost paths to more attractive fusion energy systems by investigating a broad range of innovative magnetic confinement configurations.	**2.1 Spherical Torus** Make preliminary determination of the attractiveness of the Spherical Torus (ST), by assessing high-beta stability, confinement, self-consistent high-bootstrap operation, and acceptable divertor heat flux, for pulse lengths much greater than energy confinement times.	**Assess the attractiveness of extrapolable, long-pulse operation of the Spherical Torus** for pulse lengths much greater than current penetration time scales.

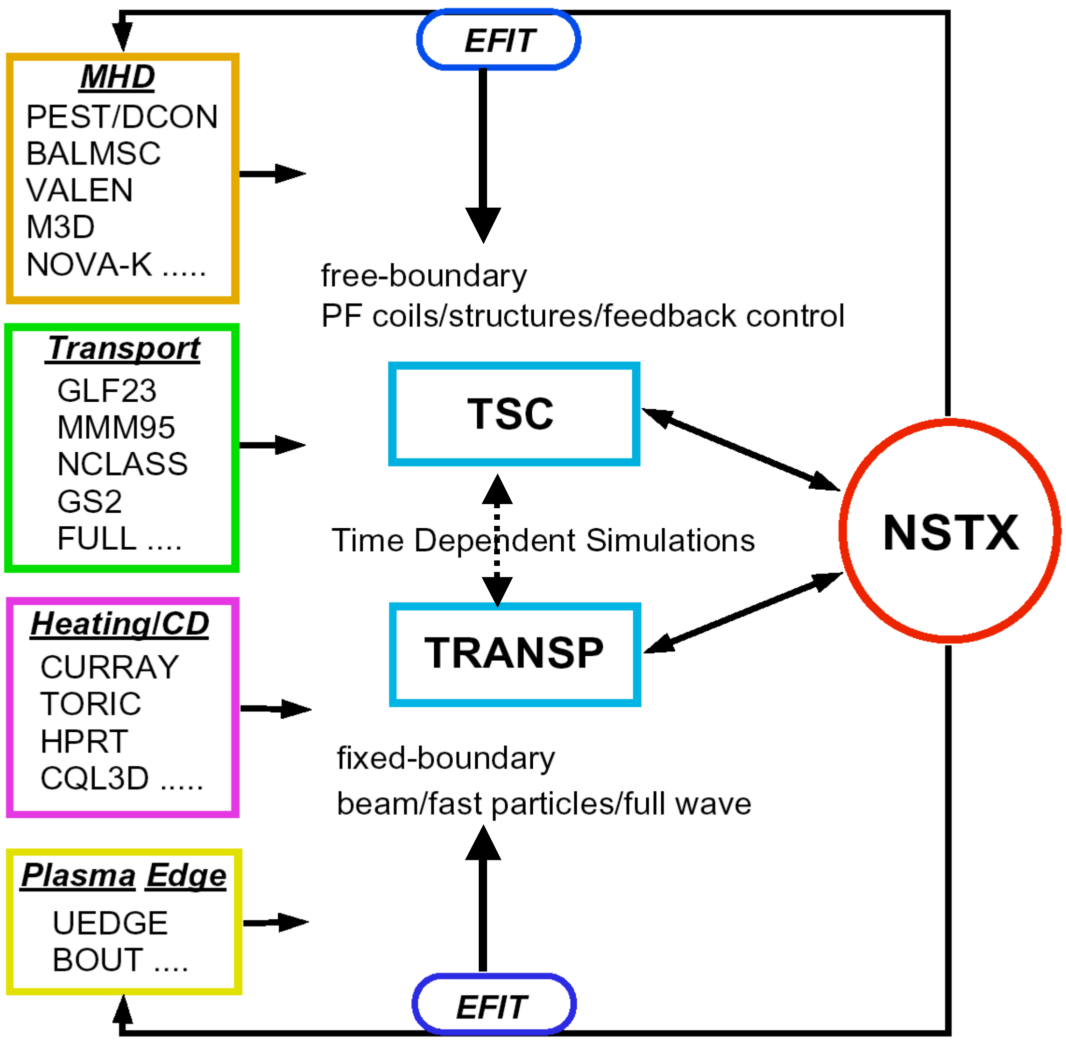
Integration & Control Builds on Progress in Facility, Diagnostics & Topical Research



Integration & Control Timeline (2)

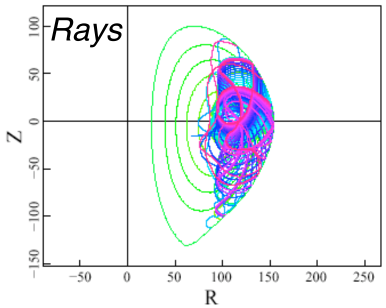


TSC (free boundary), predictive TRANSP (fixed boundary), and models are the primary integration tools

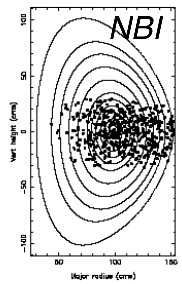


- Effort draws upon several resources for code development
  - SciDac modeling
  - NTCC physics module library
  - New Advanced Computing Integrated Simulation Initiative

Forming scientific basis requires benchmarking between most comprehensive codes (SCIDAC), faster models, and data



GENRAY



CQL3D

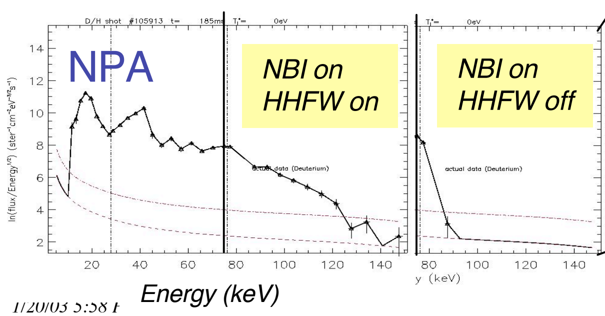
Benchmark with complete wave theory
AORSA-2D
(SciDAC)

Faster model: Ray tracing
GENRAY
CURRAY
HPRT

Analysis of transport, current drive
TRANSP

Faster model: Full wave
TORIC
METS (SciDAC)

Benchmarking with NSTX Data
Wave-particle interactions
Source measurements



Scenario modeling takes advantage of existing data & clarifies research needs

Examples of issues and plans: Long-pulse, non-inductively sustained plasmas

Topic	Issue	Approach for this spring's plan	Needed research beyond this spring
Transport	$□_i$ and $□_e$ with HHFW and NBI	Power balance results, scaled with power degradation. Parametric dependence of □'s inferred this run.	'03 - '04: assess □ parametric behavior
HHFW and EBW	• Where is J_{CD} needed? • Efficiency, location of HHFW & EBW-driven J(r).	• Evaluate theoretically RF deposition profiles based on long pulse & high beta scenarios • Compare to V_{loop} changes	• SciDAC modeling. • Measure J(r) and changes as HHFW and EBW are applied.
MHD	Stabilization requirements for projected scenarios	• Evaluate stability with extrapolated P and J profiles • Use modeled fast ion pressure	• Clarify role of rotation on stability • Measure fast ion P
Boundary physics	• Pumping needs. • Heat flux management needs	• Identify desired range of n_e to maximize I_{NI} with modeling. • Perform heat flux scaling exp'ts & assess particle inventory	• Lithium studies • Heat flux scaling experiments & modeling
CHI	Ability of CHI to supply edge current	• Identify possible edge J(r) needs with modeling. • Perform edge biasing studies.	• Experimental studies in '03 - '05 • ΔJ with MSE
Control	Accessiblity and control of high □	• Perform experimental shaping studies & assess limitations	• Control system optimization • Hmode access @ high □