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NSTX Program Update:
NSTX upgrade discussion
5 year plan schedule

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INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
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PSI
Princeton U
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Think Tank, Inc.
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UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

J. Menard, M. Ono

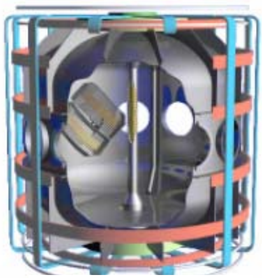
May 28, 2008
NSTX Team Meeting
Princeton Plasma Physics Laboratory

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAERI
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

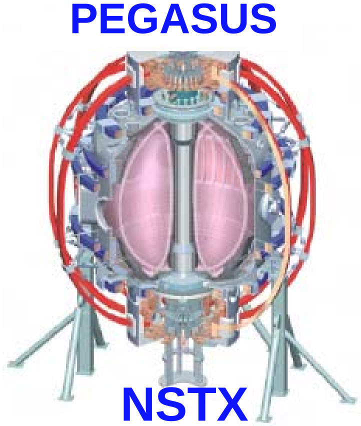
NSTX Research Program Contributes Strongly to US and World Fusion Development

ST offers compact geometry + high β for attractive fusion applications

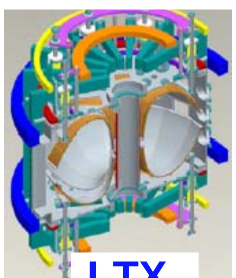
STs



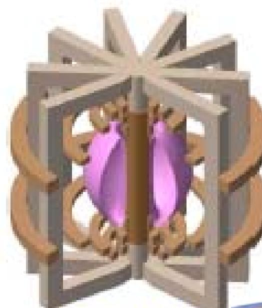
PEGASUS



NSTX



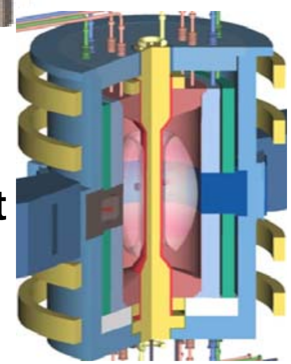
LTX



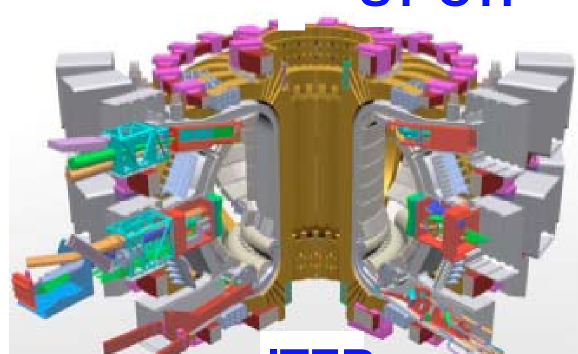
NHTX

Plasma-Materials Interactions, Advanced Physics,

Nuclear Component Testing



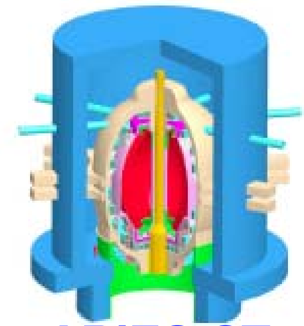
ST-CTF



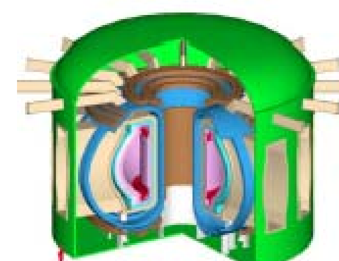
ITER

Burning Plasma Physics

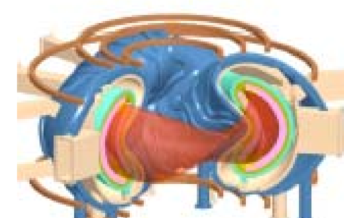
Demo



ARIES-ST

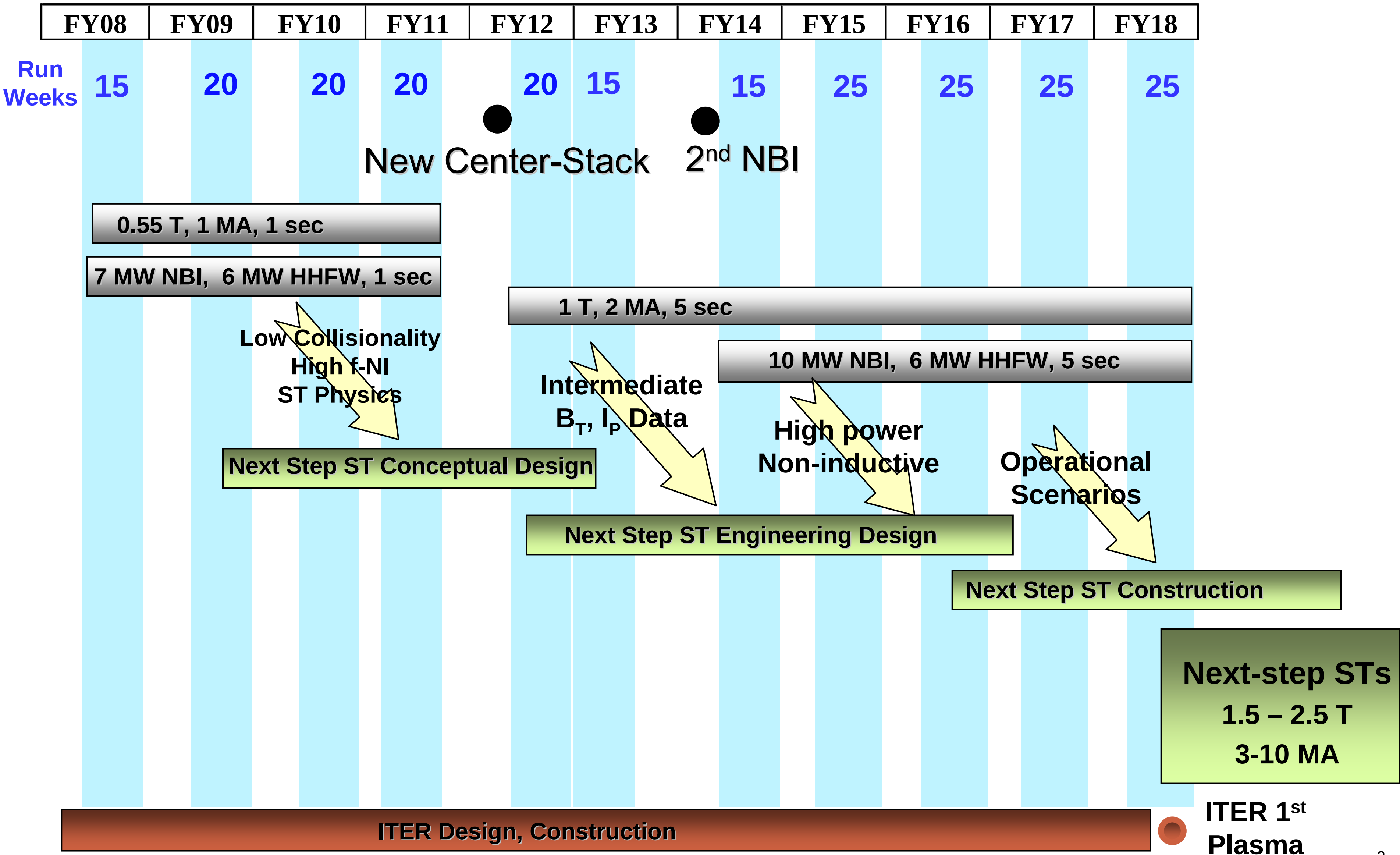


ARIES-AT

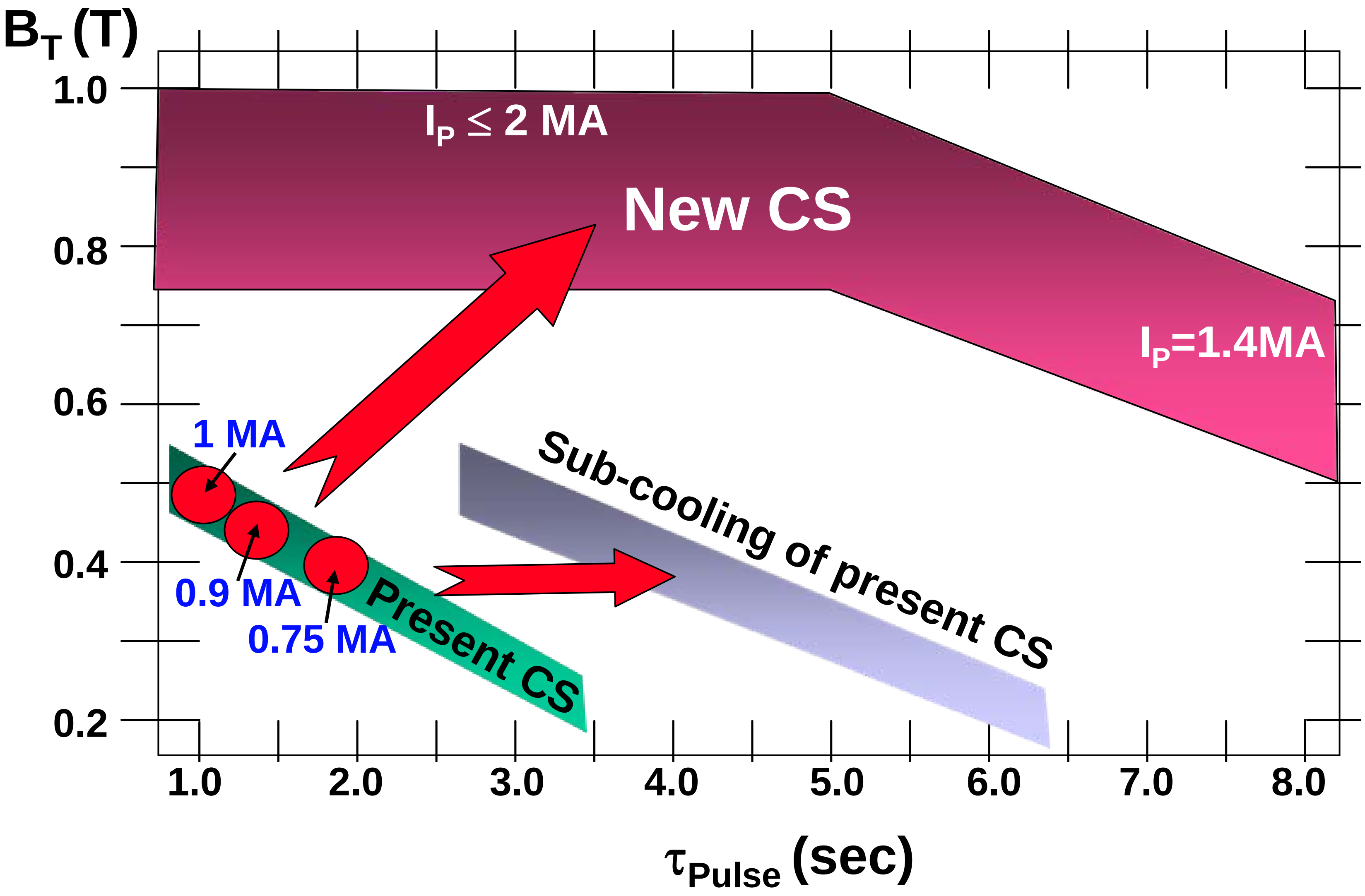


ARIES-CS

Proposed NSTX 10 year plan supports ST community goal of constructing and operating a next-step ST during the ITER era

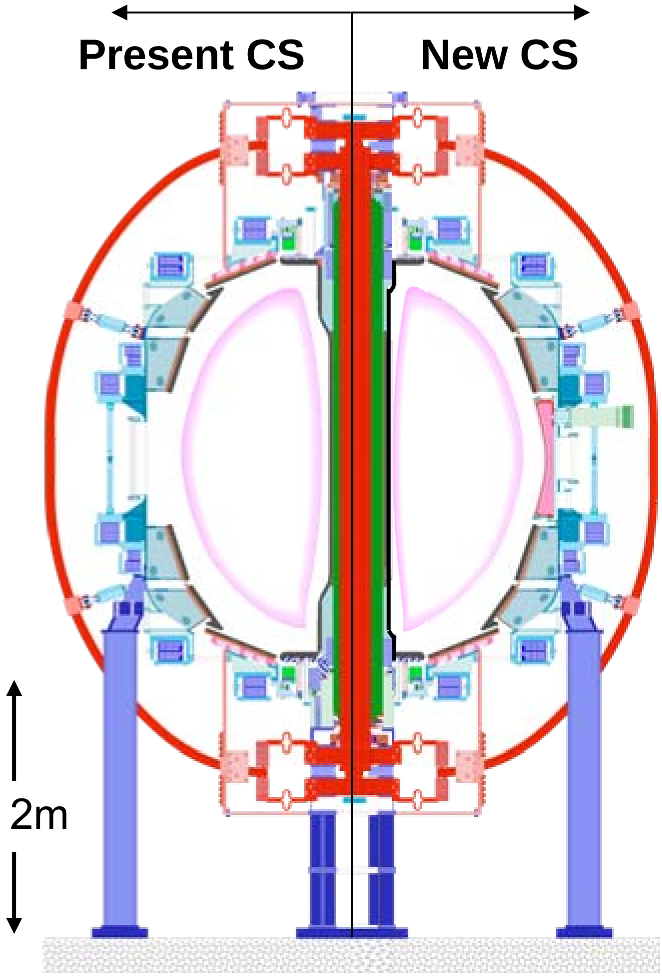


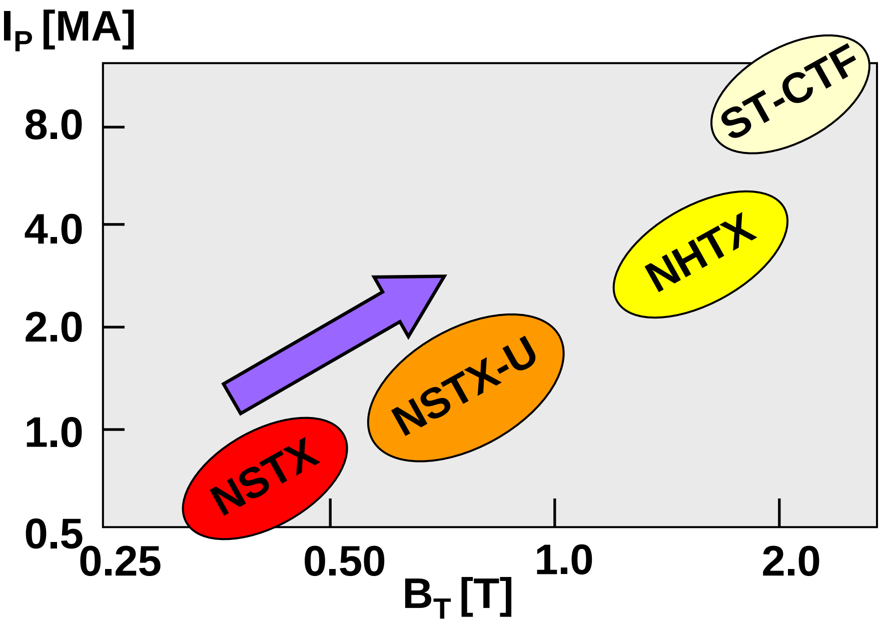
New CS would greatly expand performance range of NSTX



New NSTX center stack would enable significant step toward parameter regime of next-step STs

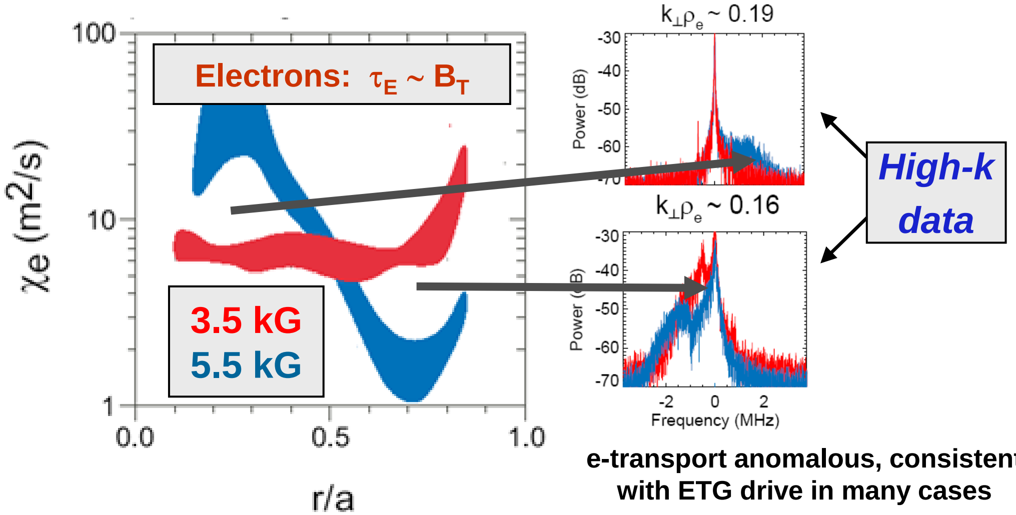
- NSTX-U would operate within a factor of 2 in B_T and 2-4 in I_P of next-step STs
- NSTX-U would have higher aspect ratio = 1.5-1.6 similar to next-step STs

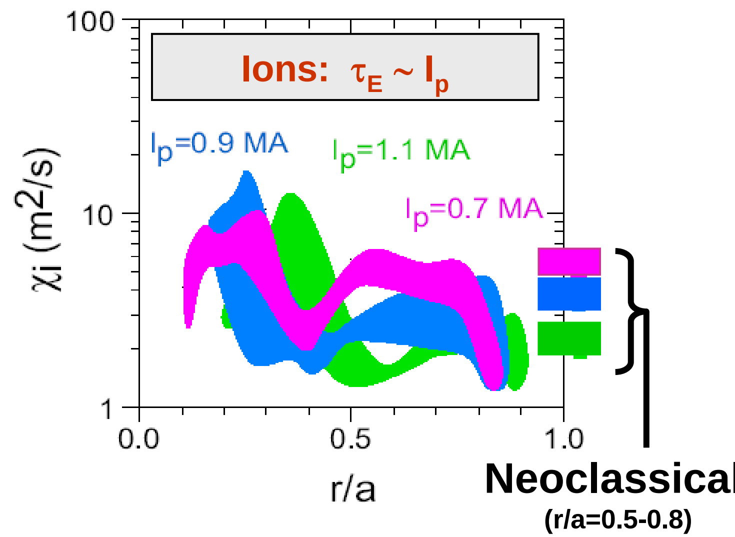




Parameters	Units	Present CS	2nd CS
A		1.28	1.5
Ro	cm	85	91
a	cm	67	61
R0-a	cm	18.5	30.5
I-TF	kA	71	119
BT0	T	0.55	1
τ-TF-flat top	sec	0.8	5.6
OH-flux	VS	0.75	2.59
Ip	MA	1 MA	2MA
OH-flux-ramp	VS	0.46	1

New center stack would greatly expand understanding and performance of ST plasmas

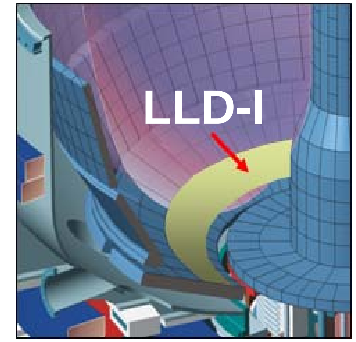




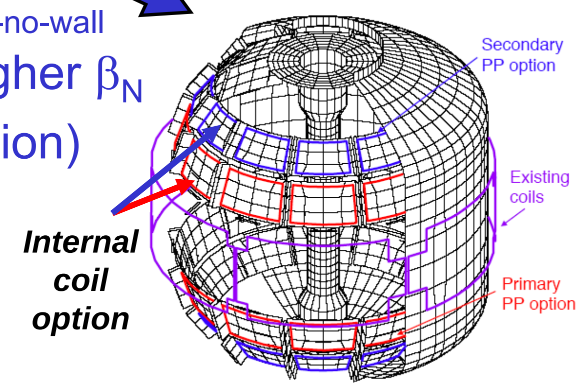
- Access higher temperature, lower collisionality plasma
  - Reduced ν^* impacts transport, MHD, boundary physics, fast-ion-driven instabilities
- Improve understanding of transport and turbulence:
  - Assess if electron $\tau_E \sim B_T$ is result of low B_T, high β, suppressed ion transport, other
  - Assess if near-neoclassical ion transport is maintained at lower $\nu*$, higher B
- Assess heating, CD, start-up, ramp-up closer to parameters of next-step STs:
  - Higher field, current → improved fast-ion confinement, higher T_e → higher NBICD
  - NBI v_{fast} / $v_{Alfvén}$ lower → fast-ion instabilities reduced and variable over wider range
  - HHFW surface waves reduced → improved power coupling
  - Higher B_T, T_e aids plasma start-up (CHI, guns, PF)

FY2009-13 plan upgrades (beyond new center stack) would significantly enhance NSTX research capabilities

- Long-pulse divertor development for next-steps
  - If LLD-I & II achieve particle control, test long-pulse LLD for sustained pumping and high heat flux
  - Study long-pulse ELM stabilization and τ_E improvement
  - If LLD unsuccessful, implement cryo-pumps



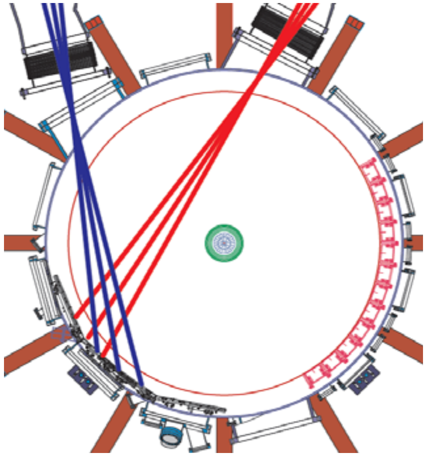
- Improved MHD mode control with off-midplane coils
  - **NSTX is only ST** that can study ELM control at $\beta_N > \beta_{N\text{-no-wall}}$
  - ELM mitigation w/ n up to 6, RWM control w/ $n > 1$ & higher β_N
  - EF correction w/ $n \leq 6$, Ω_ϕ control ($n \leq 6$; $n > 1$ propagation)



- Core fueling development
  - Needed for fueling strongly-pumped LLD plasmas
  - D-ice pellets, CT Injection
  - CT injection also useful for momentum input/control

- 350kW ECH pre-ionization for improved CHI, plasma gun, and PF start-up
  - Collaborate with MAST for EBW start-up and current drive?

FY14-18: 2nd NBI in combination with new CS would greatly expand understanding and performance of ST plasmas



- Assess full non-inductive regimes of next-step STs
  - Test prediction of higher CD efficiency from larger R_{TAN}
  - Test off-axis NBI-CD for maintaining $q_{min} > 1$
  - Test ability to avoid NTMs with $q_{MIN} > 2$ operation
    - Higher field increases q at fixed I_P
  - Optimize mix of BS and NBI-CD for full-NI operation
    - Higher B_T lowers β_N at fixed I_P and f_{BS} → expanded operating range
    - Compare full-NI operation near no-wall and ideal-wall β_N limits
  - 5s TF → can sustain full non-inductive operation for $\tau_{flat} >> \tau_{CR}$

- Test NBI current ramp-up at higher B_T, I_P, and P_{NBI}
- Assess high-power scaling of confinement at high B_T, I_P
- Develop long-pulse divertor at high heat flux up to 20MW/m^2

- Greatly expand research flexibility by varying:
  - *q*-shear for transport, MHD, fast-ion physics
  - Heating, torque, and rotation profiles
  - β, including higher β at higher I_P and B_T
  - Fast-ion $f(v_{||},v_{\perp})$ and *AE instabilities
    - 2nd NBI more tangential – like next-step STs

Prioritization of understanding and performance gaps will not change in near-term (i.e. for FY08-10)

1. Increase and understand beam-driven current at lower n_e, ν^*

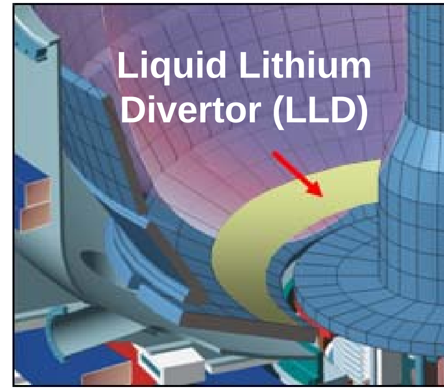
2. Increase and understand H-mode confinement at low ν^*

3. Demonstrate & understand non-inductive start-up & ramp-up

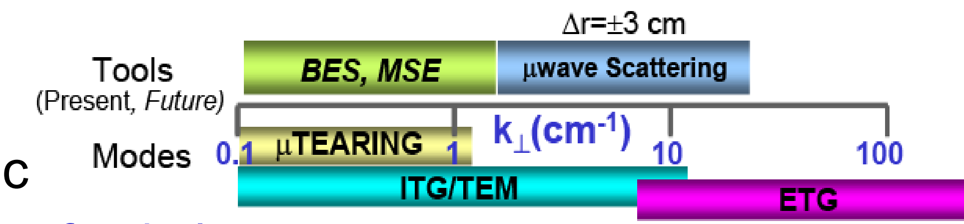
4. Sustain β_N and understand MHD near and above no-wall limit

Near-term upgrades will continue to support highest research priorities identified previously for FY08-10

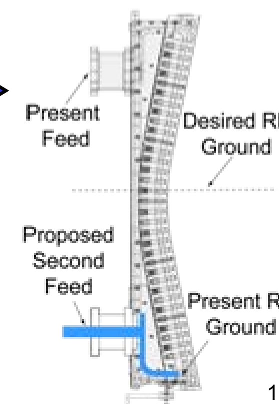
1. Implement liquid lithium divertor for pumping, and investigate other potential benefits:
   - Improved confinement
   - Reduction/elimination of ELMs
   - Compatibility of LLD with high flux expansion
   - Longer-term: steady-state high-heat-flux handling



2. Implement BES to complement existing high-k scattering diagnostic
   - Measure full wavenumber spectrum of turbulence
   - Determine modes responsible for anomalous transport of energy & momentum



3. Upgrade HHFW system for higher P_{RF} + ELM resilience
   - Determine if HHFW can ramp-up I_P in H-mode (BS+RF overdrive)
   - Determine if HHFW can heat high-β_N advanced H-mode scenarios
   - HHFW/ICRF also important for NHTX/CTF/ITER



Firm run-time guidance is not yet available, but we expect increased run-time and additional (incremental) milestones

	FY2008	FY2009	FY2010
Expt. Run Weeks:	15	20 (?)	20 (?)
1) **Transport & Turbulence**	Measure poloidal rotation at low A and compare w/ theory		Study turbulence regimes responsible for ion and electron energy transport
2) **Macroscopic Stability**		Understand physics of RWM stabilization & control as a function of rotation	Assess sustained operation above the no-wall limit at reduced collisionality
3) **Boundary Physics**	Study variation and control of heat flux in SOL		Assess H-mode characteristics as a function of collisionality and lithium conditioning
4) **Wave-Particle Interaction**		Study how j(r) is modified by super-Alfvénic ion-driven modes Accelerate high-power HHFW 1yr Integrate MHD mode modification of j(r) into optimized operation	Characterize HHFW heating, CD, and ramp-up in deuterium H-mode Test predictive capability of mode-induced fast-ion redistribution/loss
5) **Start-up, Ramp-up, Sustainment**	Couple inductive ramp-up to CHI plasma	Investigate methods for solenoid-free current initiation using induction from the outer poloidal field coils	Test non-inductive current generation using plasma guns
6) **Scenario Integration & Control**		Perform high-elongation wall-stabilized operation at lower n_e	
"JOULE" Milestones:	Rotation and momentum transport & stability physics	Particle control and hydrogenic fuel retention	TBD

5 year plan document completion schedule

- NSTX 5 year plan **review** will be week of **July 28, 2008**
  - 2 major themes: (1) physics from new CS, (2) impact of reduced ν^*
    - Up to 10× lower ν^*, similar ρ^*_{th}, smaller ρ^*_{fast}, lower $v_{fast}/v_{Alfvén}$, 5s pulses, etc…
    - You should also consider diagnostic impact
      - For example, need to move MPTS sightline & dump, and measure up to $T_e(0)$ = 10keV
  - Keep discussion of merits of 2nd NBI, but be clear this is at end of 5yr plan
  - Provide strong *scientific* justification for all major upgrades

We are here →

Start NOW!	**Incorporate new CS, low ν^* into chapters**
June 9-13	**EPS**
June 16, 2008	**Complete draft plan edits complete**
June 23, 2008	**5 year plan text complete**
Week of July 7	**Dry runs of presentations**
Week of July 14	**Final presentation material ready**
Week of July 28	**2009-13 Five year plan review**

Reduced ν^* and normalized n_e represent the largest gap between present and next-step ST operating scenarios

Next-step ST's: ν^* will be 10-100× lower, n_e/n_{GW} 2-4× lower

Reduced density and collisionality impact all topical science areas:

- Transport & Turbulence
  - Underlying instabilities (micro-tearing, TEM, and ETG) scale differently versus ν^*
  - If $T_e(r)$ is determined by critical ∇T_e, H-mode confinement may be reduced at reduced n_e
- Macroscopic Stability
  - RWM critical rotation and viscous torques may increase at lower ν_i
- Boundary Physics
  - ELM ΔW increases with reduced ν^*_e - could impact confinement, plasma purity, divertor
  - Detachment schemes for heat flux reduction more challenging with reduced SOL ν
- Wave-Particle Interaction
  - AE avalanches more easily triggered at reduced n_e – possible fast-ion redistribution/loss
- Start-up, Ramp-up, Sustainment
  - NBI-CD and RF-CD efficiency for ramp-up are increased at reduced n_e, increased T_e
- Scenario Integration and Control
  - Steady-state scenarios rely on reduced n_e/n_{GW} to increase NBI-CD to achieve 100% NI-CD

- Expect higher B_T and I_P will increase T_e and T_i
- Expect LITER + LLD and/or cryos will pump D to control and reduce density
  - Need to understand LLD operation, Li transport in SOL and to core, etc.
  - Separate dependence on collisionality vs. Lithium