Thrust 16:
Demonstrate and understand sustained high beta confinement at reduced aspect ratio

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Research thrust is designed to achieve the ST goal in the ITER era

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GOAL: *Establish the ST knowledge base to be ready to construct a low aspect ratio fusion component testing facility that provides high heat flux, neutron flux, and duty factor needed to inform the design of a demonstration fusion power plant*

⇒Aggressively pursue improvements to advance a low-A device for energy production

Elements of thrust aim to:

- Leverage extensive knowledge-base of higher-A tokamak
- Extend understanding to unique high-β + low ν regime
- Advance ST as reduced size and cost configuration for fusion

Elements of the reduced aspect ratio thrust

16.1 - Develop plasma startup, rampup with low or no transformer flux

16.2 - Develop a plasma-material interface at high heat flux, high temperature , and low density in the ST

16.3 - Deploy liquid metals, especially lithium, as PFCs in the ST

16.4 - Understand electron, fast/thermal ion confinement in high β, low ν ST plasmas

16.5 - Understand stability, develop steady-state control of high β ST plasmas

16.6 - Develop normally-conducting radiation-tolerant magnets

16.7 - Demonstrate integrated, continuous high β, broad current profile ST plasmas

16.8 - Explore linkages with compact tori

16.9 - Evaluate the RFP at low aspect ratio, with maximized bootstrap current

16.1 Develop plasma startup and ramp-up with no or very low transformer flux

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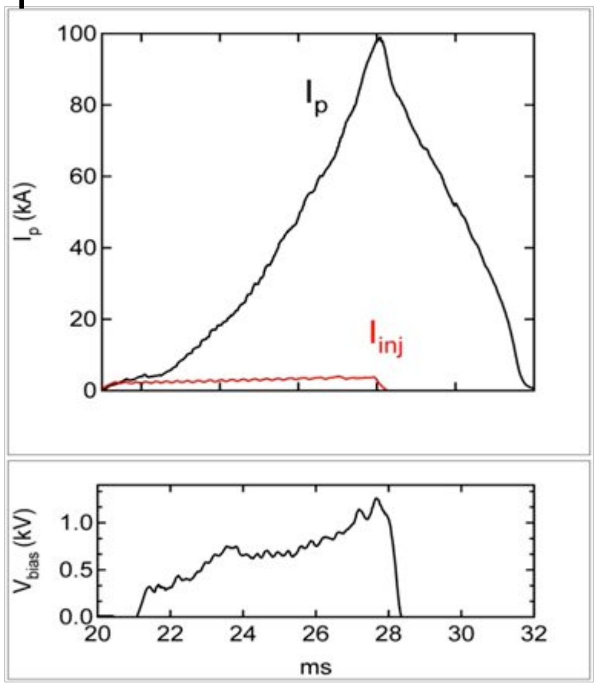
- Develop reliable plasma initiation and growth schemes
  - Establish science basis for helicity injection
    - » Current limiting mechanisms, resulting plasma characteristics
  - Implement EBW/ECH/ECCD coupling to startup plasma
- Demonstrate ramp-up to full current
  - Effective coupling to RF/NBI
- Develop predictive modeling capability
  - Validate transport-based CD modeling against ST database
    - » Effects of fast-particle transport on NBCD
- Assess feasibility of central induction
  - MIC & retractable solenoid technology
  - Modeling & engineering assessment of iron-core



Non-solenoidal startup with HI and PF induction

- **Demonstrate integrated test at ST-CTF relevant level of performance**
  - Similar transport regime, magnetic field, I_p, etc.

16.2 Demonstrate and understand a viable plasma-material interface at high heat flux and low density

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Compact geometry drives need for high power handling PFCs

- Develop divertor and wall power reduction and handling solutions
  - Innovative divertors, flux expansion, stochastic edge
  - Divertor targets: liquid metals, moving “pebbles” as PFCs
  - Develop edge transport and turbulence models for predictive capability
- Reduce divertor heat flux from 20-60 MW/m^2 to <10 MW/m^2
  - Transient loads to <0.5 MJ/m^2
  - Nuclear environment, long pulse
- Develop particle control for continuous, low density H-mode operation
  - Cryo-pumping and/or liquid metals for impurity, helium, density control
  - Achieve steady-state $n_e/n_G \sim 0.2$-0.3
- Demonstrate integration with high-performance pedestal and core high-β plasma in upgraded and scaled ST configurations

⇒ST presents the opportunity to push to higher neutron wall loading

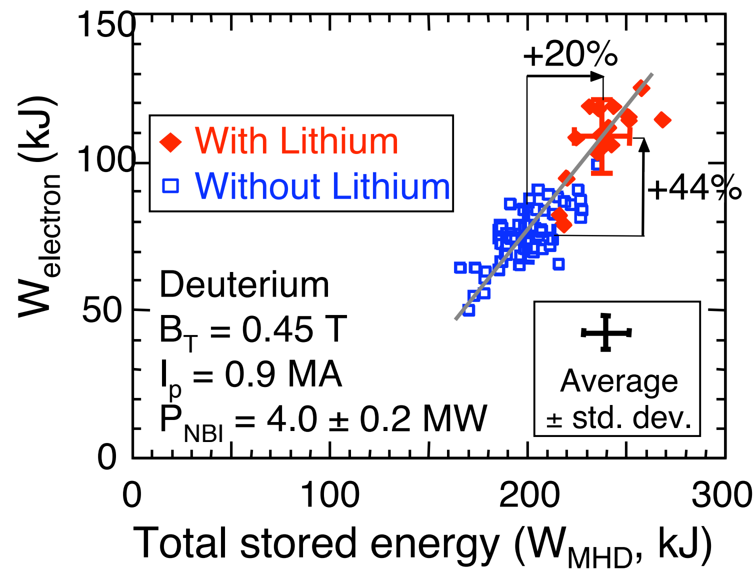
⇒ Common to other compact alternates (spheromak, FRC, RFP)

Deploy liquid metal, especially lithium, PFCs in the ST

Integration of PMI, confinement in the ST

- Implement full liquid lithium wall in an ST, with NB core fueling
  - Does performance continuously improve in the ST as recycling is reduced?
- Implement a full liquid lithium divertor in an ST, with core fueling
  - Is a low recycling *divertor* sufficient?
  - Characterize PMI, transport in a low recycling ST

Electron confinement improves with reduced recycling - NSTX



- Validate models for the core, edge, and PMI, for arbitrary global recycling
  - Determine optimum global recycling coefficient for the ST
- Construct an “optimized”, reduced recycling liquid metal-walled DD ST

⇒ST provides rapid, cost-effective test of flowing liquid metal PFCs discussed in Thrust 11

16.4 Understand electron and fast/thermal ion confinement in high β, low ν ST plasmas

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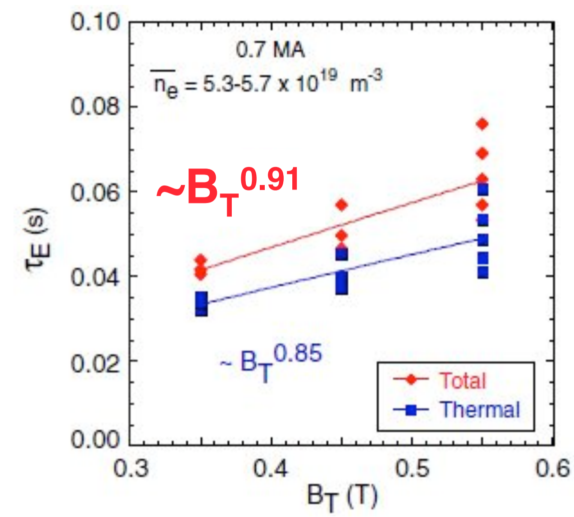
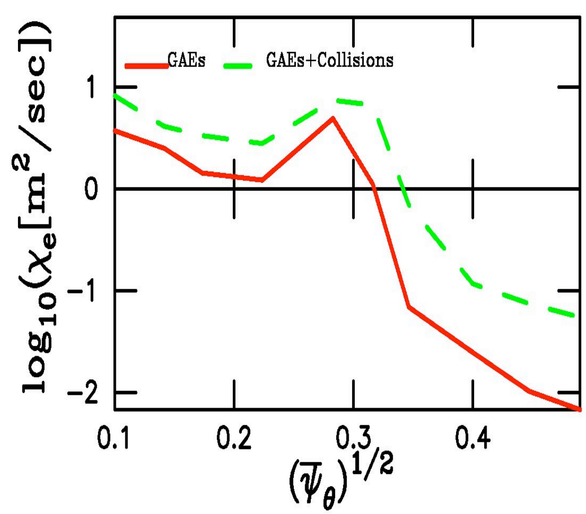
- Does stronger B_T , ν scaling of τ_E in present STs lead to improved fusion performance at low-A?
- Study transport in upgraded (x2) and new (x4) STs (near term focus: electrons)
- Measure high and low-k EM turbulence (n.t. focus: ETG 'streamers'+ μ-tearing islands)
- Develop predictive understanding (models+control)

B_T scaling of τ_E in NSTX



- Will large population of super-Alfvenic energetic particles affect heating/current drive in a ST reactor?
- Study EP transport over extended range of ρ^* (n.t. focus: intermediate ρ^*)
- Study EP interaction with background plasma via AEs (n.t. focus: ion heating/alpha channeling, electron transport)

Modeling of Alfven eigenmode - induced electron transport



16.5 Understand stability and develop control of low l_i, high β ST plasmas

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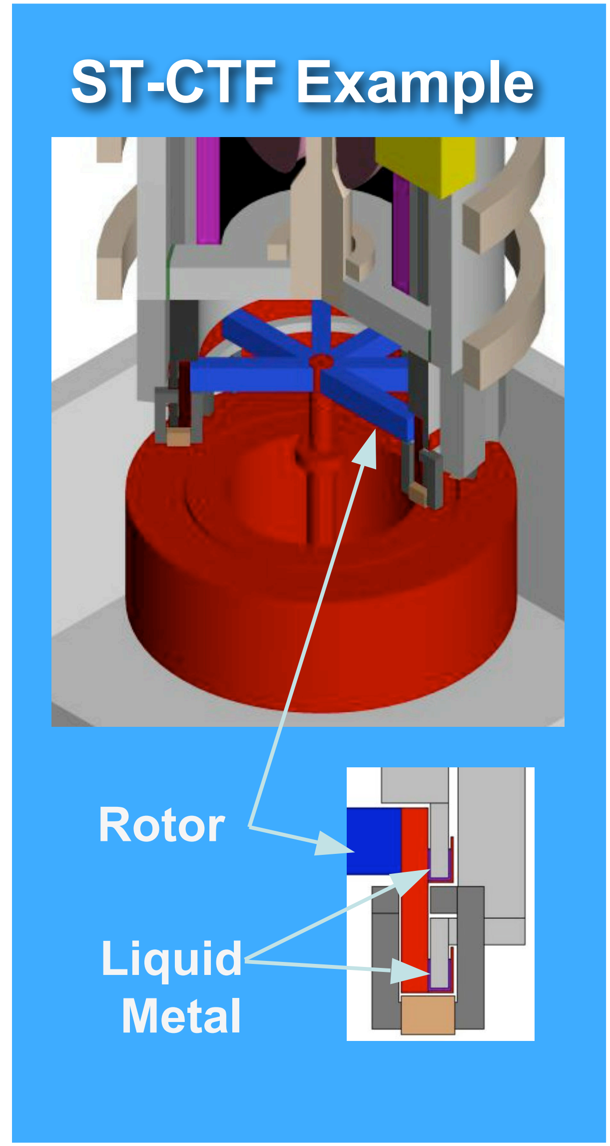
- Achieve, understand global mode stability near low l_i current-driven kink limit, over full range of β_N, with controlled broad pressure, V_ϕ profiles
  - Steady-state current profiles; near-burning plasma conditions
- Explore/validate key stability science for low A at reduced collisionality (~order of magnitude; near burning plasma levels), at increased field
  - Extend capability to alter V_ϕ and shear (e.g. expanded NBI, 3-D fields)
  - Understand stability at intermediate V_ϕ; effects of V_ϕ shear on NTMs
  - Characterize disruptions at low A and l_i
- Demonstrate/study high β_N with minimal disruptivity, transients using multiple controls - compatible with a high neutron fluence environment
  - RWM and ELM control, $q_0 > 2$ for NTM control

⇒Operate continuous high β_N beyond CTF ($\beta_N > 5.8$), approaching ST-DEMO levels ($\beta_N > 7$), with flexible controls

Develop normally-conducting radiation-tolerant magnets

- Design, evaluate single-turn centerpost magnet
  - Evaluate candidate multiturn designs
  - Develop matching low impedance power supplies
- Construct, test candidate TF magnet + PS
  - High field (2-3T); ~10 sec. pulse
- Design, test radiation-tolerant OH solenoids
  - **Backup** for noninductive approach
- Implement a testing program for radiation tolerance
  - DPA limits, tritium migration, joints, electrical, mechanical degradation

⇒Thrust element can provide the core of a high field, moderate pulse-length ST



16.7 Achieve and understand integrated, continuous high beta, low collisionality, broad current profile ST plasmas

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- Reduce collisionality 1 - 2 orders of magnitude at high beta
  - Toroidal field, current, heating power increase by ~ 2 - 4×
  - Pumping to reduce recycling, density, collisionality
  - ⇒ **Assess impact on ST transport and stability**
- 100% sustained non-inductive current-drive, at ≥ 50% bootstrap
  - Non-inductive ramp-up to MA, or multi-MA, level in the ST
  - ⇒ **Control of core safety factor profile; optimize stability, confinement**
- Mitigate steady-state, high heat and particle exhaust in the ST
- Increase plasma pulse length by 1 - 3 orders of magnitude
  - Control fully-non-inductive ST for many current relaxation times
  - Develop disruption avoidance, mitigation for integrated ST conditions

⇒ Sustained high performance with equilibrated first-wall conditions

16.8 Extend low aspect-ratio science and technology – Compact Tori

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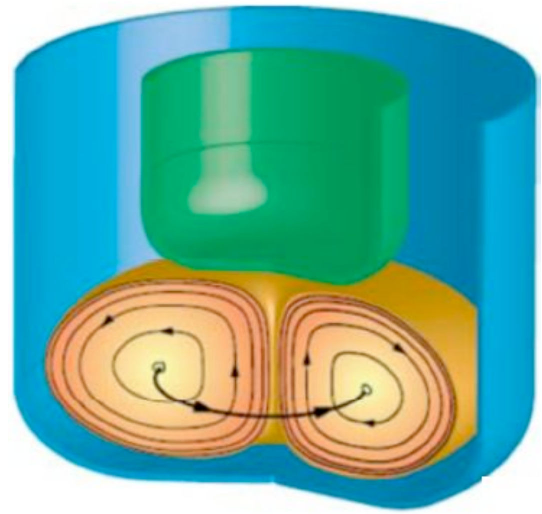
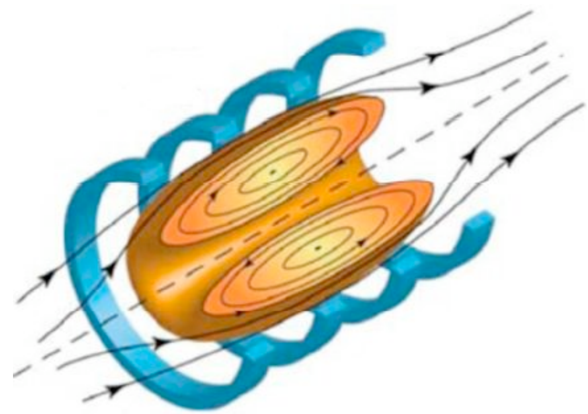
- CTs have near unity aspect ratio
  - Vanishingly small linked poloidal flux outside the last-closed flux surface
  - Removal of center column leads to a cylindrical vacuum chamber
- Actions that overlap with STs include:
  - Expand further the application of Helicity Injection from spheromak to ST (Element 16.1)
  - Understand divertor configurations at ultra-low aspect ratio. (Element 16.2)
  - Compare the effects of plasma facing liquid metals in the 3 configurations. (Element 16.3)
  - Understand electron energy transport in a spheromak ($q < 1$) and compare with ST ($q > 1$) (Element 16.4)

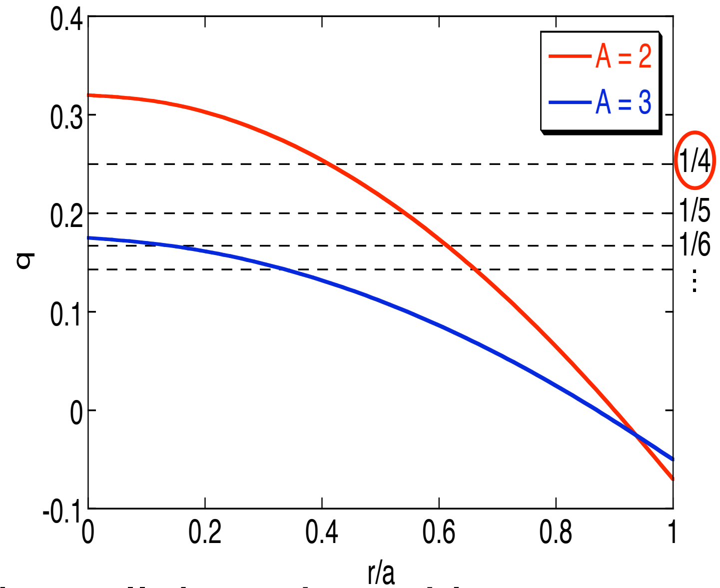




Evaluate RFP stability and confinement at low-A

- Motivation: potential benefits at low-A
  - bootstrap current increase at high beta,
  - Less stochasticity due to laminar relaxation
  - ease in generating single-helicity states.
- Actions:
  - theoretically assess RFP equilibrium, stability, and transport at low aspect ratio
  - experimentally explore low-A RFP physics by collaborating with a Japanese device and by extending small STs to RFP regimes

  inform the optimum choice of aspect ratio (geometry) of the next-step advanced-PoP RFP device



⇒Common physics with ST and spheromak

- Helical deformation connects with the stellarator

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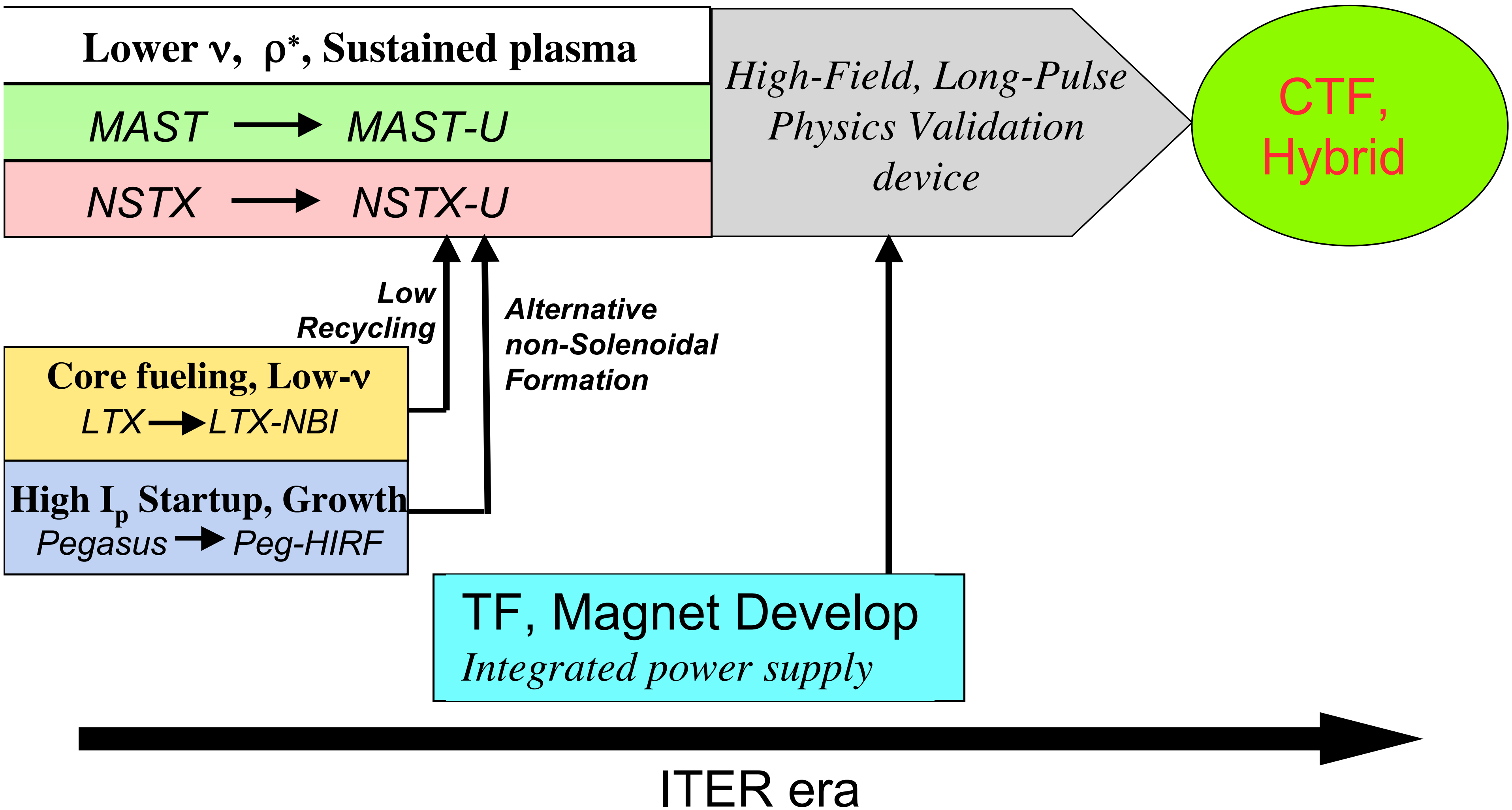
ST thrust goal: nuclear testing, applications



- Exploit synergies with the AT, stellarator, RFP, CT…