ST Potential

S. M. Kaye
PPPL
Princeton University
Princeton, N.J. 08543

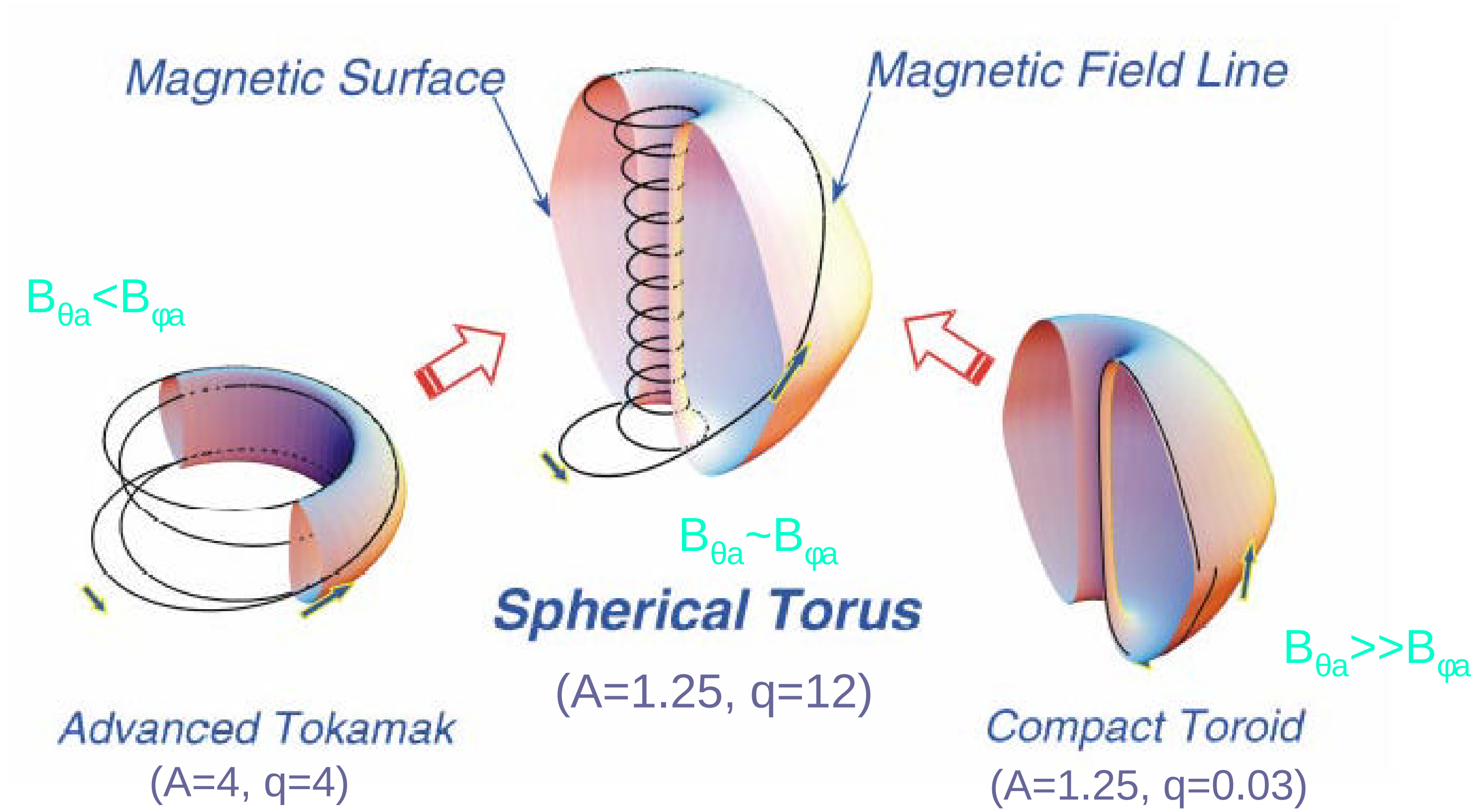
SNOMASS Meeting
July 13, 1999

Spherical Torus Path

- Low aspect ratio configuration (R/a~1.1-1.6)
- Different plasma regimes/operational approaches to those of conventional R/a
  - High-β_t, β_n with absolute magnetic well and high bootstrap fraction
  - Reduced disruptivity (high-q_ψ operation)
  - Potential enhancements in confinement, MHD stability, heat dispersal
- Small STs have already shown some success of concept
  - START: β_t=40% (P_{NBI}~P_{oh}), =24% (P_{oh}); H-mode access
  - CDX-U: e^- heating with High Harmonic Fast Waves
- ST research is beginning: many outstanding issues of optimizing ST configuration and identifying reactor potential
  - Physics (confinement and transport, MHD, steady-state ops, boundary)
  - Design (optimum aspect ratio, single-turn center stack with little or no shielding)

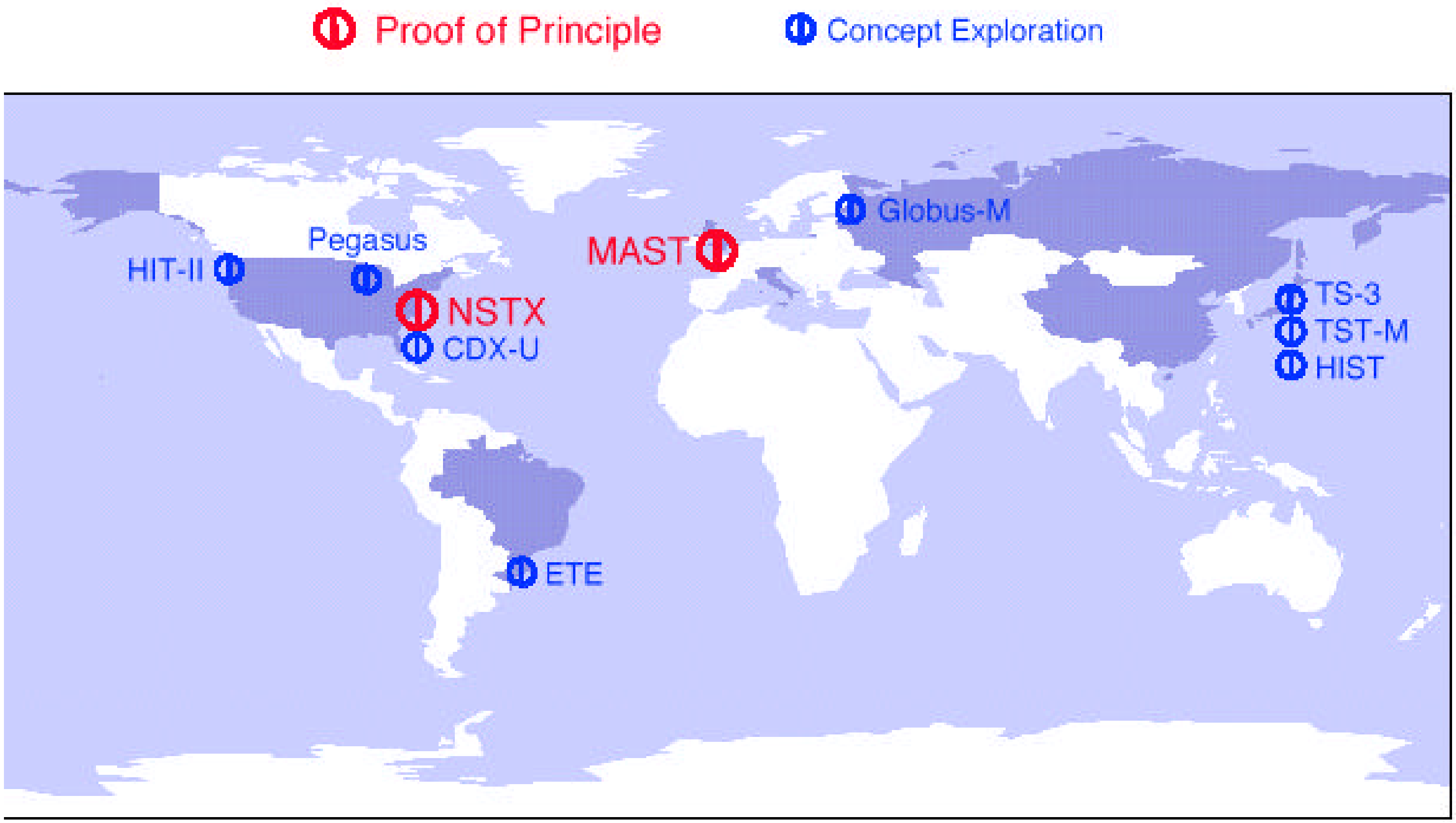
A unique ST features is the large field pitch on the outboard (bad curvature) side, which maximizes the good curvature field length

- Captures elements of Compact Tori



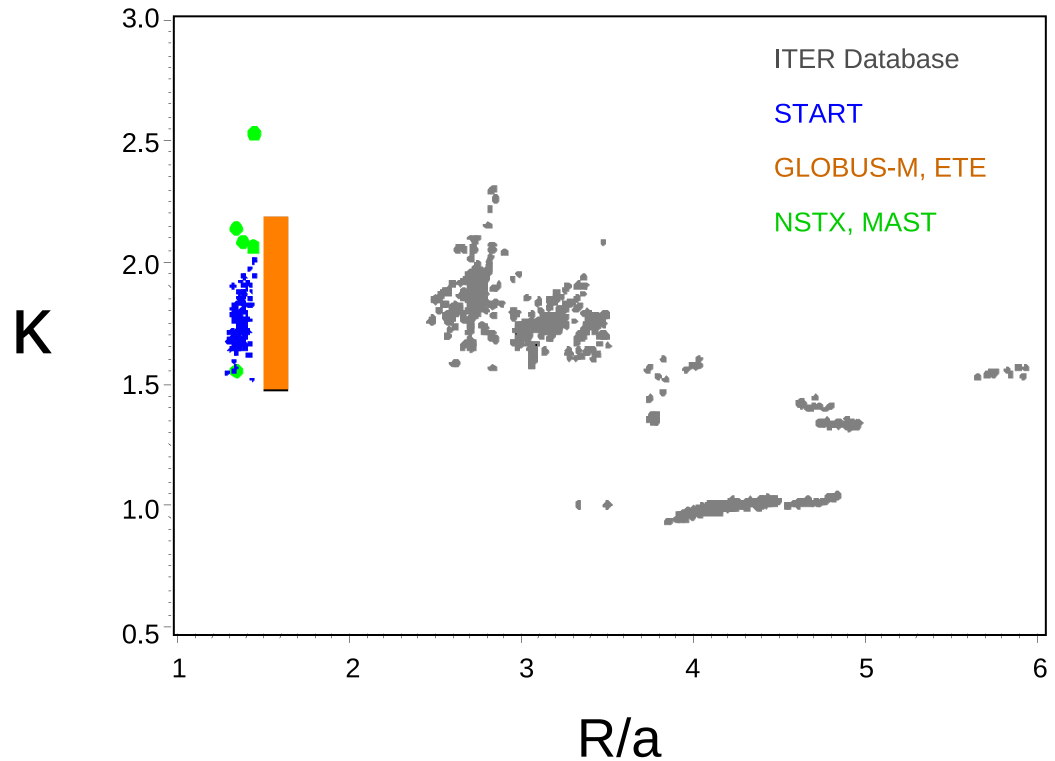
The large outboard field pitch yields potential benefits for both confinement and stability, and it has implications for boundary physics ($L_{||}$)

ST research is worldwide



Global confinement:

- H-mode access in START, but with $P_{th} >> P_{th,scal}$
- Parametric dependence of global confinement uncertain (START)

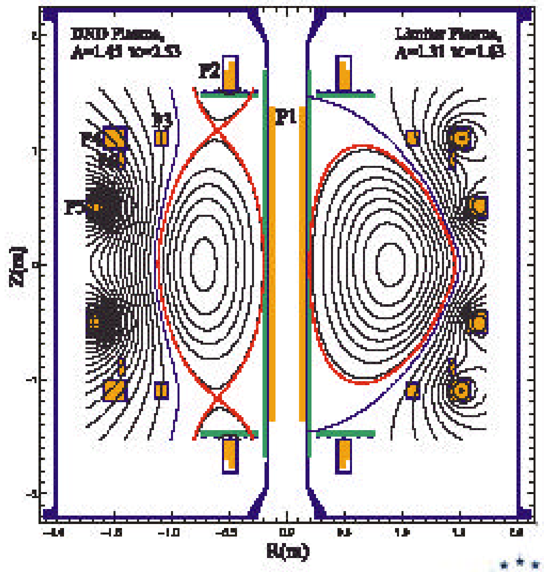


M. Valovic

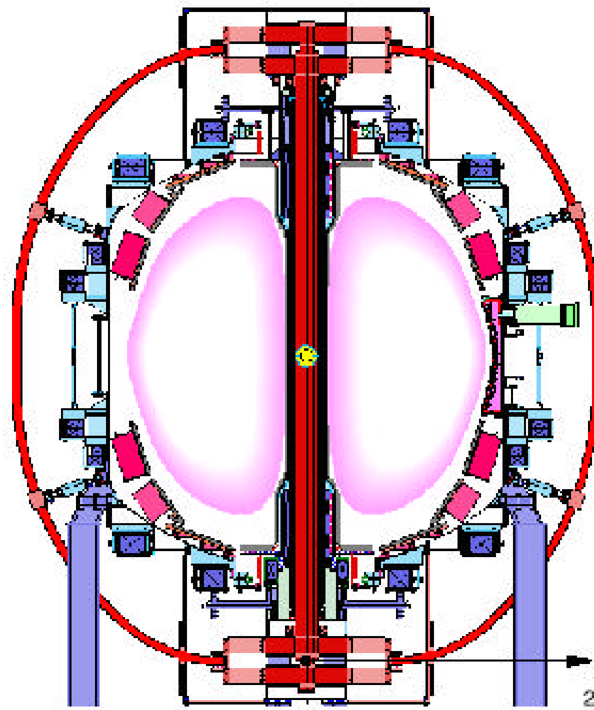
- NSTX/MAST will be good testbeds of threshold, confinement scalings
  - Allow scalings to be developed over a wider range
  - Give more credence to 0-D performance extrapolations
  - Complementarily will allow assessment of role of neutral density

Complementary capabilities of MAST and NSTX

MAST (U.K.)



UKAEA Fusion



• Nearby Stabilizing Shell	No	Yes	(beta limits)
• Poloidal Field Coils	In-vessel	Ex-vessel	(plasma shaping flexibility)
• RF Heating&Current Drive	ECH	HHFW	(efficient sustainment)
• Plasma Current Startup	Compression	CHI	(eliminate solenoid)

⇒ **Development of comprehensive database for Performance Extension step**

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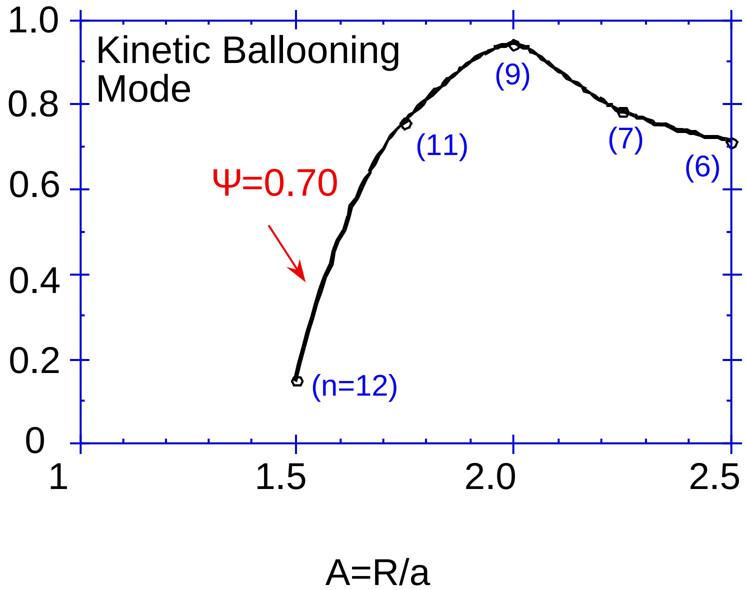
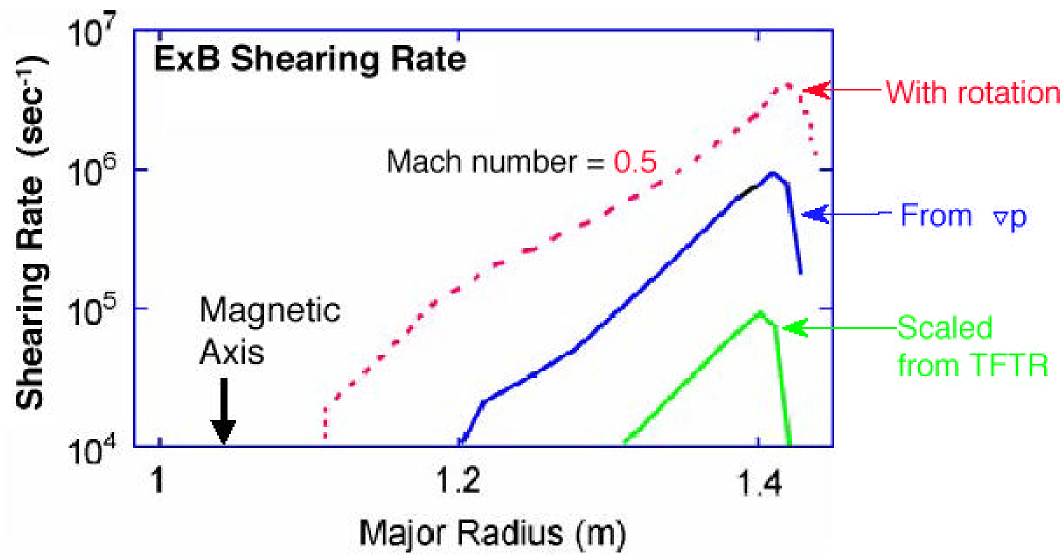
Transport: STs provide potential benefit in suppression of μinstabilities through both geometric and flow shear properties

Suppression of μinstabilities due to decrease in orbit-averaged bad curvature (Rewoldt, 1996)



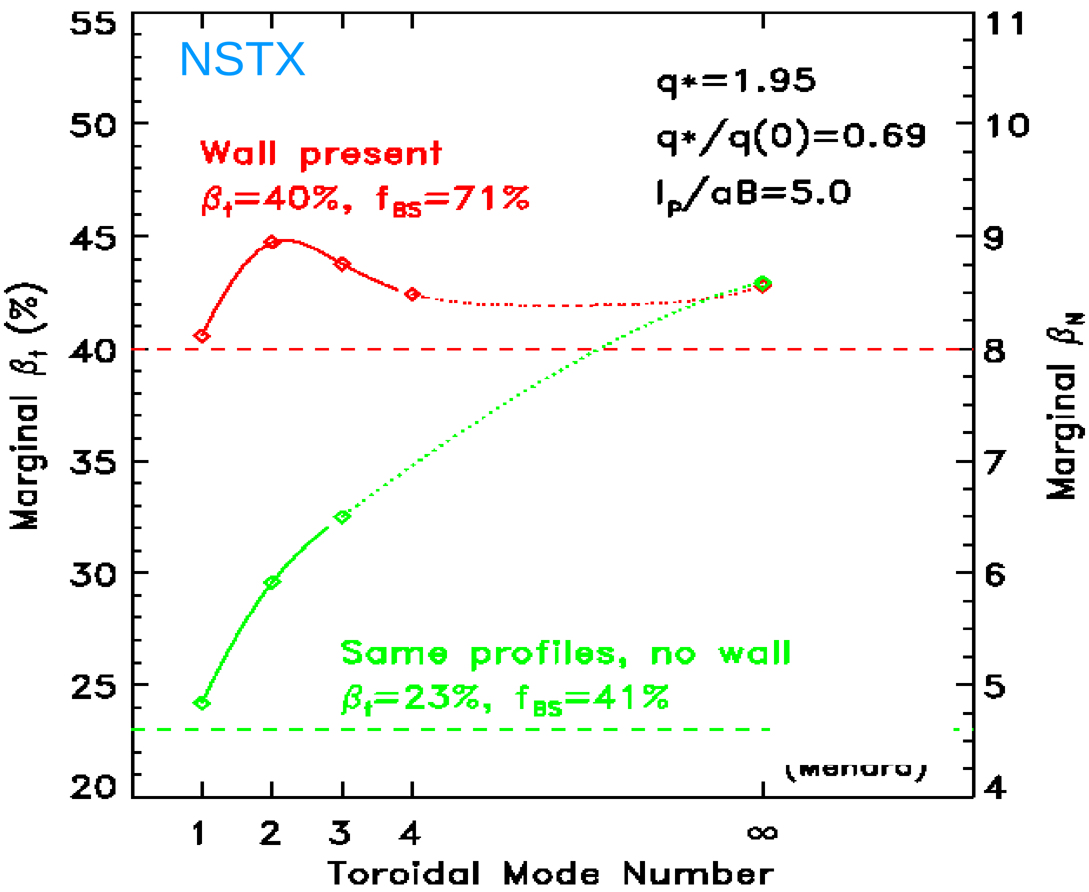
Strong diamagnetic flow shear suppression of residual instabilities



ITG growth rates for low and high-R/a comparable near ballooning β-limit
- flow shear suppression dominates for low R/a (Kotschenreuther et al., 1999)

MHD: A conducting wall is important for stabilizing low-n modes to optimize β and boostrap current (q_ψ~10)

- Optimized wall case requires 30% edge current drive for full non-inductive sustainment
- Need to develop a self-consistent operational scenario for achieving target

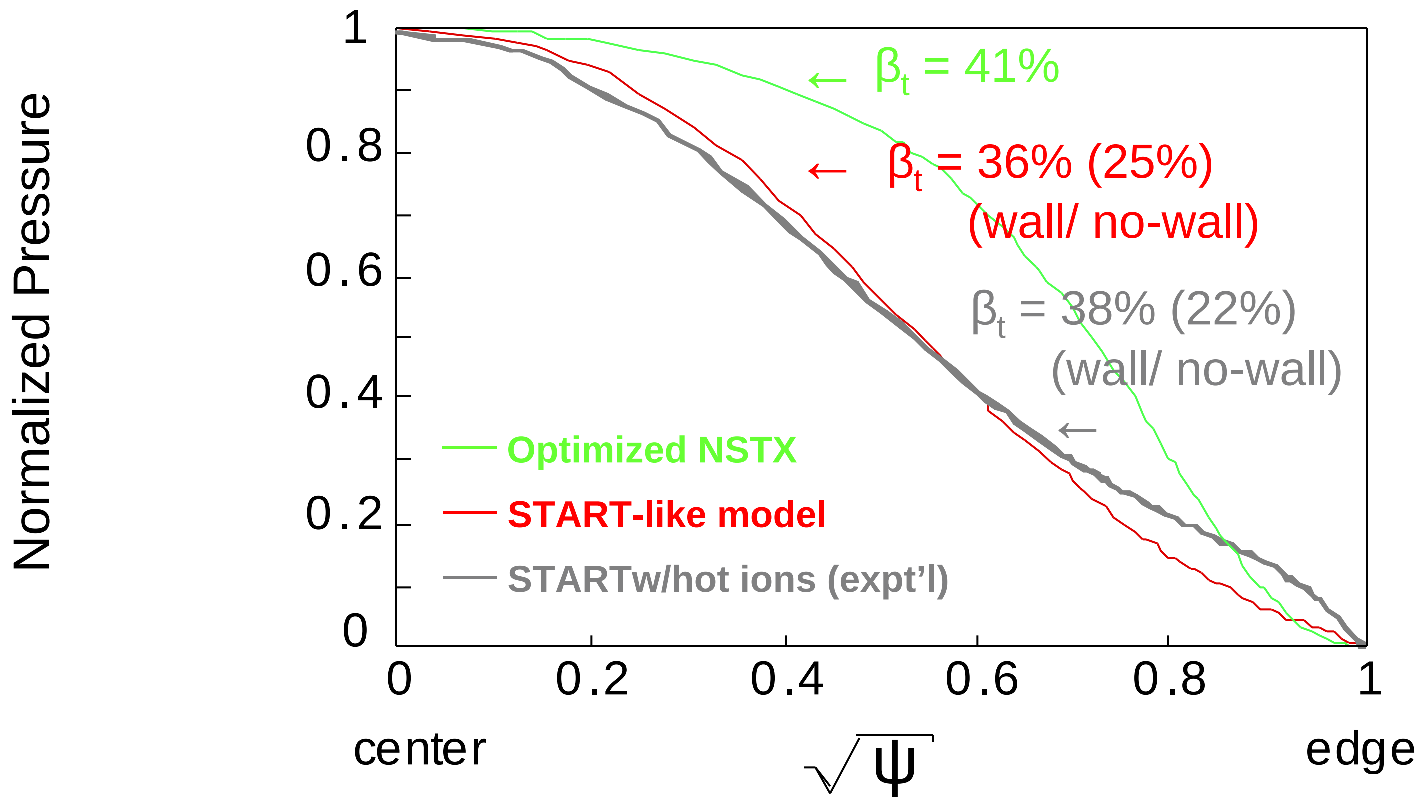


(J. Menard)

• NSTX/ MAST complementarily allows wall/no-wall comparison

MHD: Stability is relatively robust to variations in pressure and current profiles - still retain relatively high-β_t with conducting walls

Experimental p(r) more peaked than the optimized ones



F. Paoletti,
S. Sabbagh

Stability also relatively robust to 30% changes in q-profile ($\beta_t \rightarrow 32\%$)

Opportunity for wide range of operating space at high-β_t, high bootstrap
- Profile control less restrictive ?

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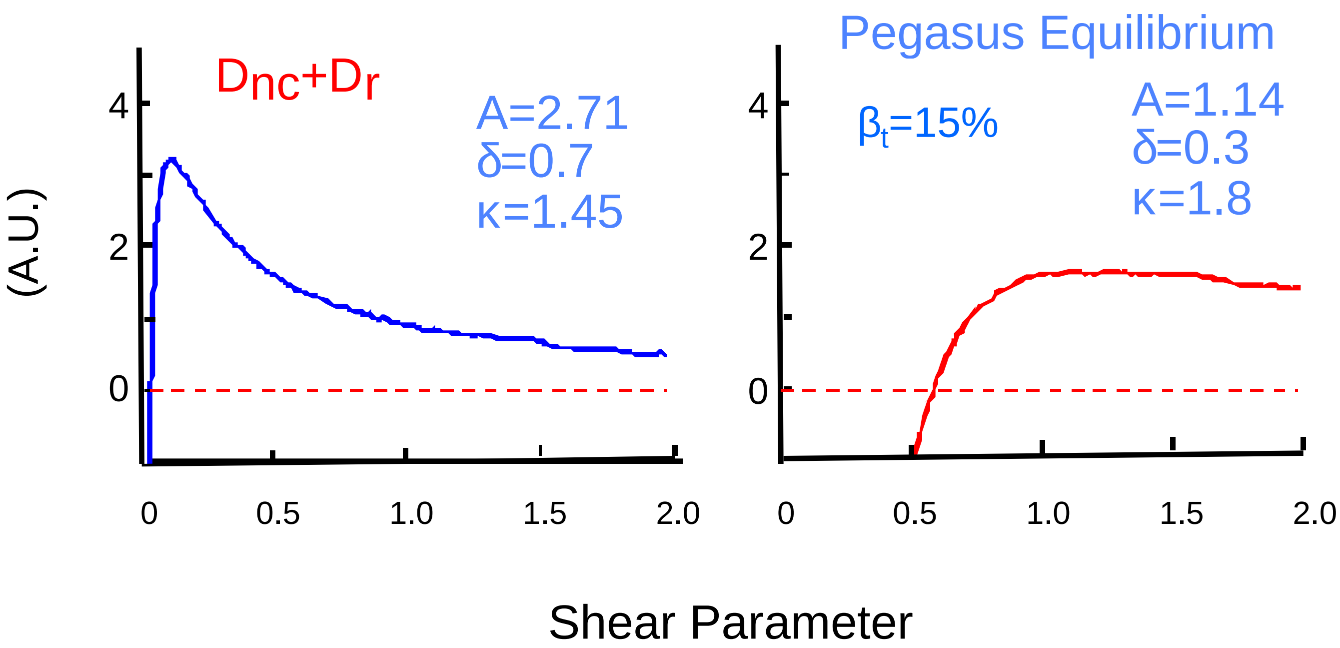
MHD: Neoclassical Tearing Modes are expected to be less virulent in STs than at conventional aspect ratio

$D_{nc} \sim \varepsilon^{1/2}\beta_\theta/s$ (destabilizing)

$D_r \sim \beta_t/s^2$ (stabilizing)
(large Pfirsch-Schluter current in ST)

β_t large, s low at low aspect ratio



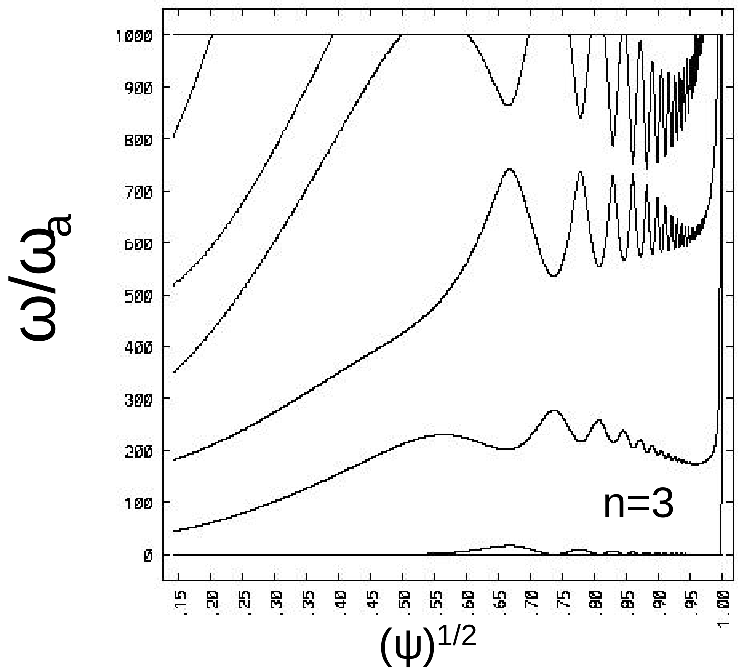
(Kruger et al.)

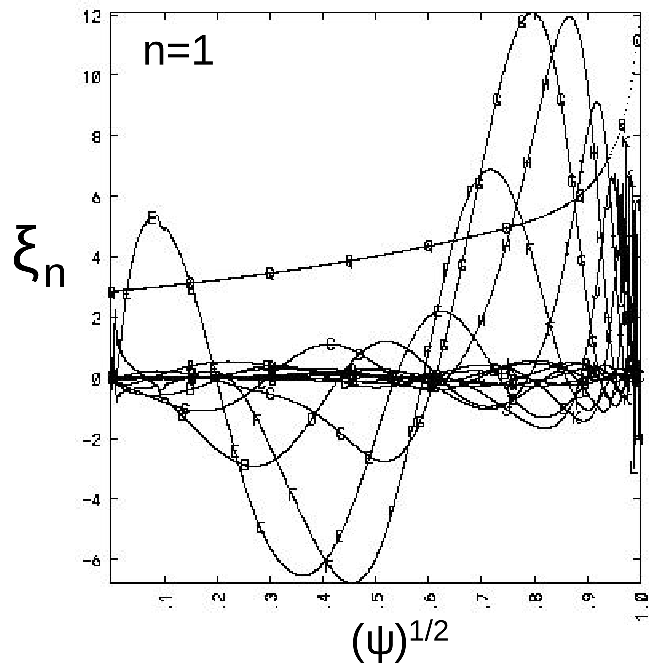
- Stability improved, island size reduced at low R/a
- Plasma shape important through shear (require low shear)
- Effect of fast particles, kinetic effects on NTMs?

MHD: Super-Alfvenic fast ion population produced by high-energy NBI - 80 keV D^0 in NSTX

- $v_b > v_A$
- ρ_{Lb}/a ~ 1/5-1/3
- Δ_b/a ~ 1/3-1/2

- Large spectrum of modes for each n
- Modes exist for many n
- Broad, global structure
- TAEs exist in high-β plasmas





(N. Gorelenkov)

Modeling indicates little fast ion loss due to TAEs
- Magnetic well and large $B_{\theta a}$ help particle confinement
- TAEs on START appear to be "benign" (McClements)

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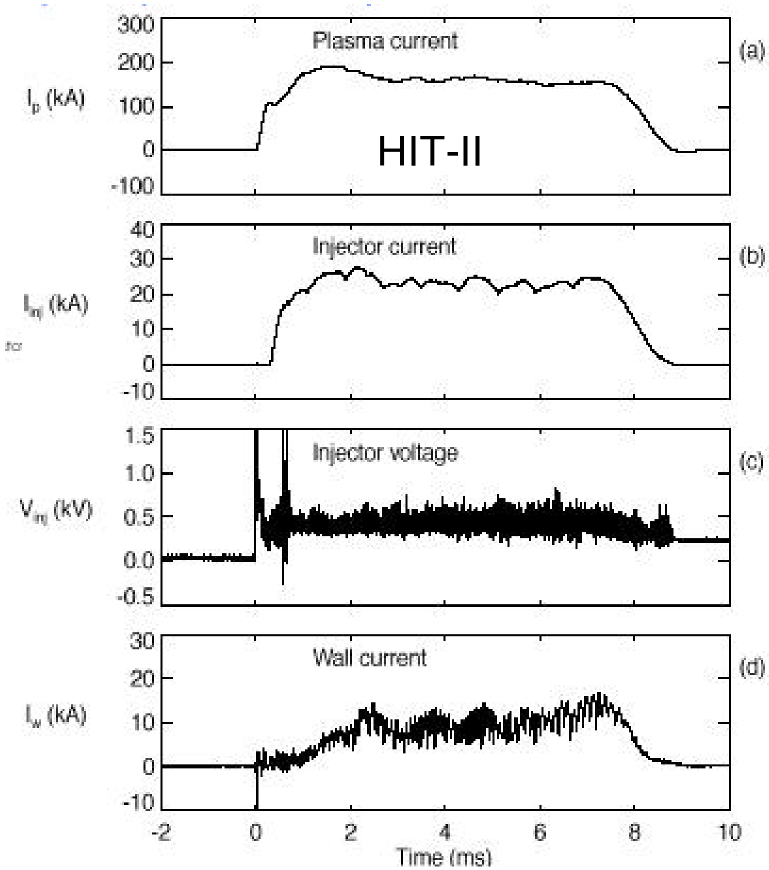
Steady-State Ops: Non-inductive startup is an essential element to develop for STs

STs inherently
- V-sec limited due to skinny center post

Non-inductive assist important for present day devices (NSTX/ MAST)

Fully non-inductive startup - CHI to be attempted on NSTX



Other non-inductive techniques include
- ECH, HHFW on NSTX
- Compression on MAST

Steady-State Ops: Heating and current drive

- STs have high plasma dielectric constant ($\varepsilon = \omega_{pe}^2/\omega_{ce}^2 \sim 50\text{-}100$)
  - Conventional R/a have $\varepsilon \sim 1$

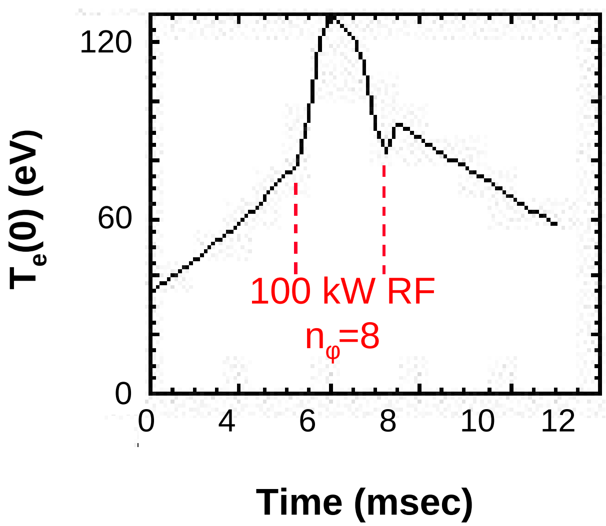
- Poor accessibility for Lower Hybrid Waves
- Virtually no access for Electron Cyclotron Waves

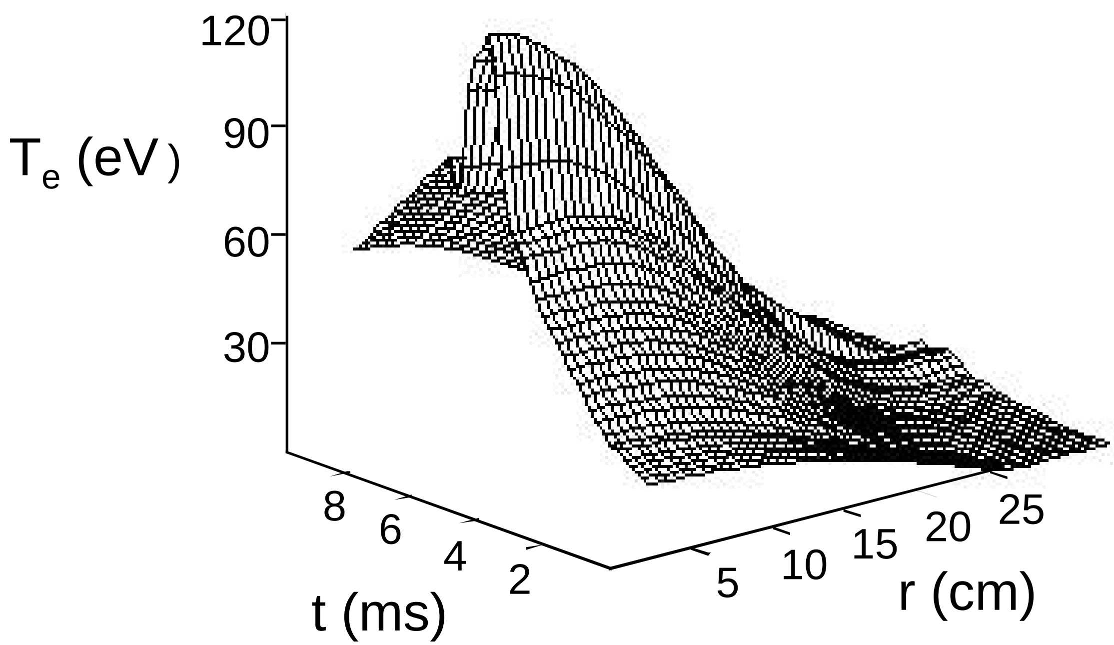
- High Harmonic Fast Waves offer good potential for electron heating in NSTX
  - Good wave accessibility, single pass absorption
  - Initial central e- heating (@100's eV) to enhance bootstrap current
  - Ability to control current profile → current drive in outer region during developed phase of discharge

- Critical issue is potential for significant ion absorption when $T_i/T_e \geq 2$, and by fast ions from NBI

Steady-State Ops: Heating and current drive

13th harmonic HHFW heating on CDX-U exhibits electron heating





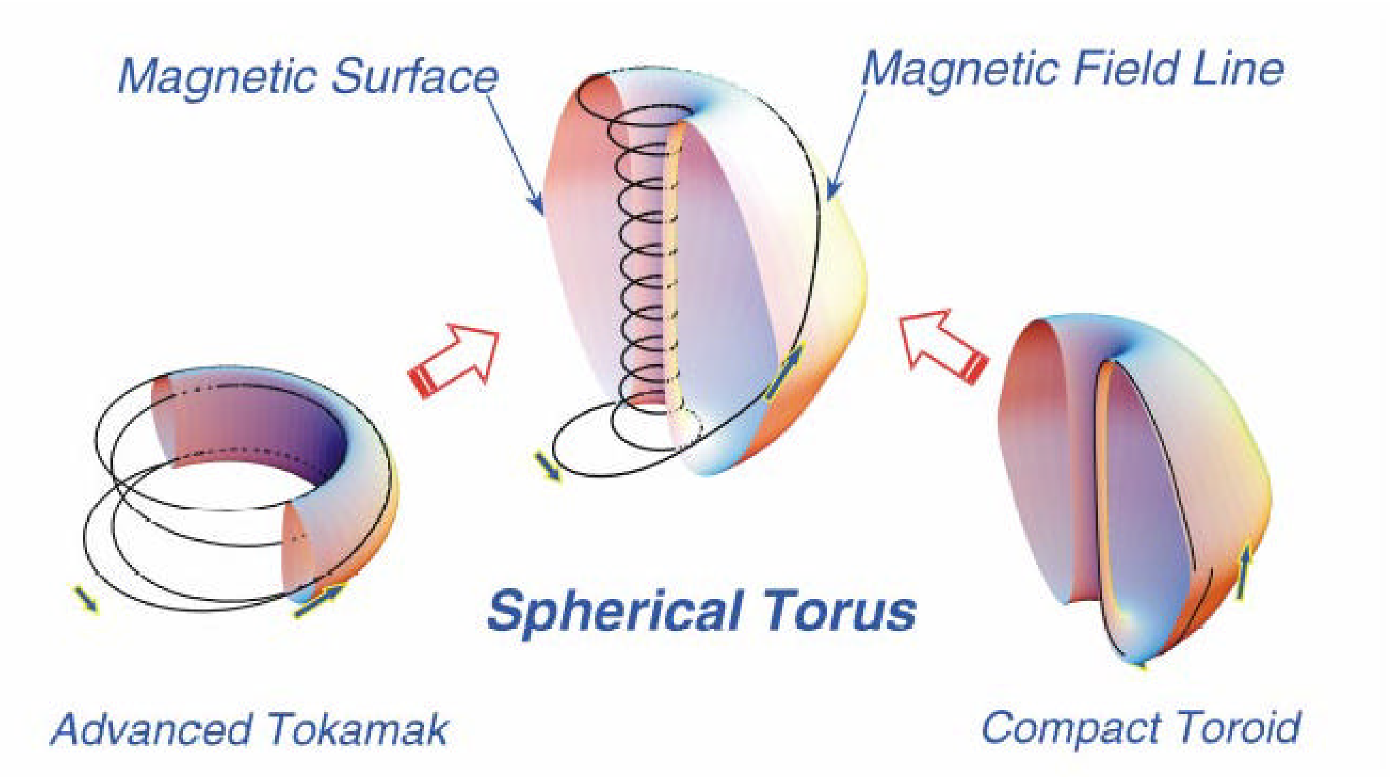
Boundary and Divertor Physics: STs exhibit distinct differences from conventional aspect ratio

- High heat fluxes due to compact configuration (large P/R)
- Large mirror ratio ($R_m = B_{T,max}/B_{T,mp} \sim 4$ as compared to ~2 at R/a~3)
  - Modified velocity space distribution (smaller loss cone, beam-like features at midplane)
- Δ_p comparable to thermal ion Larmor radius
- High local β_t (electromagnetic effects important?)

Are differences significant in terms of driving or modifying X-SOL transport processes?

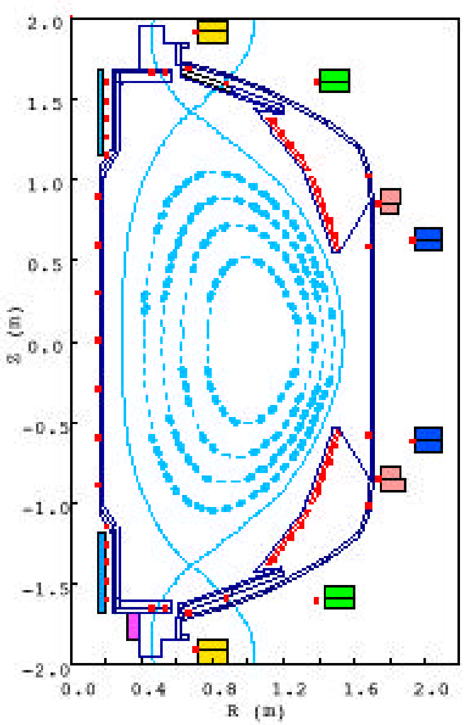
- Long connection lengths and large flux expansions in certain configurations due to field line pitch

STs have large field line pitch on outside



Boundary Issues: Inner Wall Limited configuration effective in dispersing heat flux due to large flux expansion, long connection length

Double Null Divertor

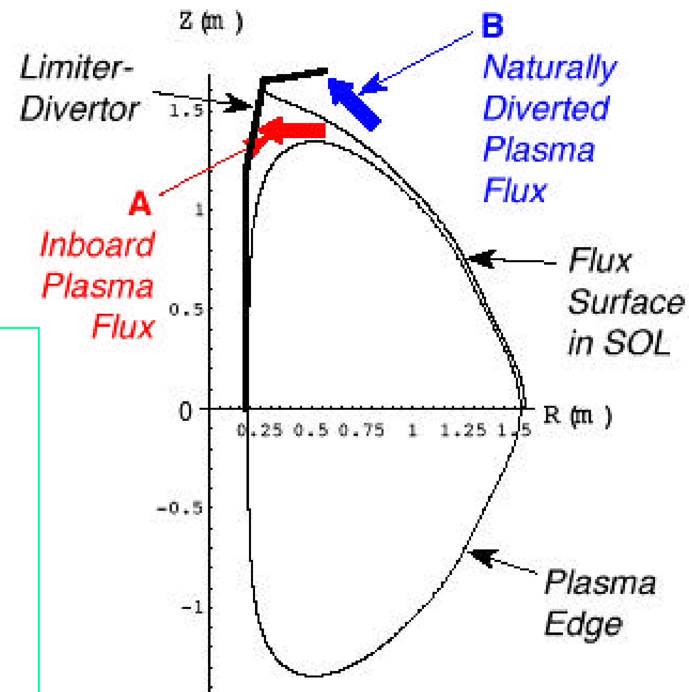


$L_{||}$~ 4 m
f_{exp}~1.5

Short $L_{||}$ for DND

- May impact impurity transport to core
- Limits SOL footprint at divertor plate
- Ability to maintain large $T_{||}$ (high (T_e(a) for H-mode, low T_e at plate)?

Inner Wall Limited



$L_{||}$~ 8-10 m
f_{exp}>10-15

SMK-Snomass-13Jul99

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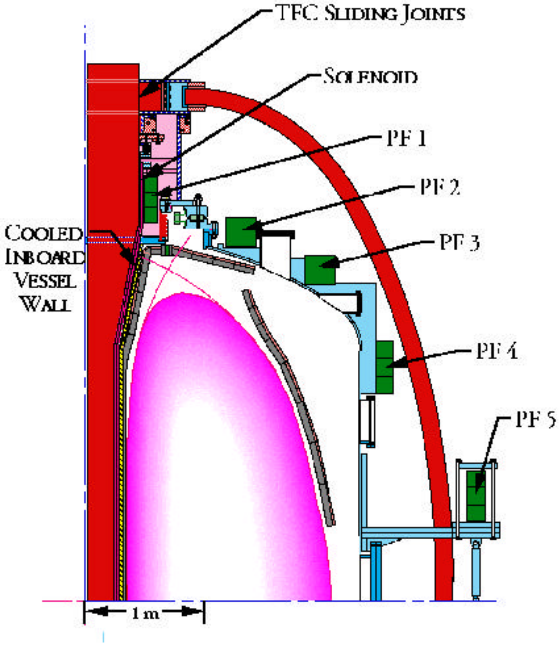
Present ST research provides a link between basic scientific advances and practical fusion energy

Science	→	*Energy*
Order Unity Stable Beta-Toroidal	→	Low Device Cost
Non-Inductive Startup, Self-Sustaining Current	→	Simplified Magnets
Turbulent Transport Suppression	→	Small Unit Size
Plasma Exhaust Dispersion	→	Reduced Wall Heat Flux
		Lower Development Costs

10 MA ST Performance Extension Test



10 MA Options

Low-Q	High-Q
B_{T0}=1.67 T	1.67 T
R_0=1.2 m	1.2 m
a=0.86 m	0.86 m
κ=3	3
q_{95}=10	10
$\langle n_e \rangle = 1\times10^{20}\ m^{-3}$	$0.76\times10^{20}\ m^{-3}$
P_{aux}=35 MW	4 MW
β_t=23%	34%
β_n=3.5	5.0
Q=1	10

May need τ_E at ion neoclassical level

ARIES-ST

$A = 1.6,\ \beta_n = 8.2,\ \beta_t = 56\%,\ \langle\beta\rangle = 42\%,\ f_{bootstrap} = 99\%$