Stability considerations for optimizing ST geometry

J.E. Menard, PPPL

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P_{fusion} scalings for fixed R_0

- Combining Troyon and BS scalings $\Rightarrow$

  $$\beta_t(\%) = \varepsilon^{1/2} C_{BS} (1+\kappa^2) (\beta_N)^2 / 8 f_{BS}$$

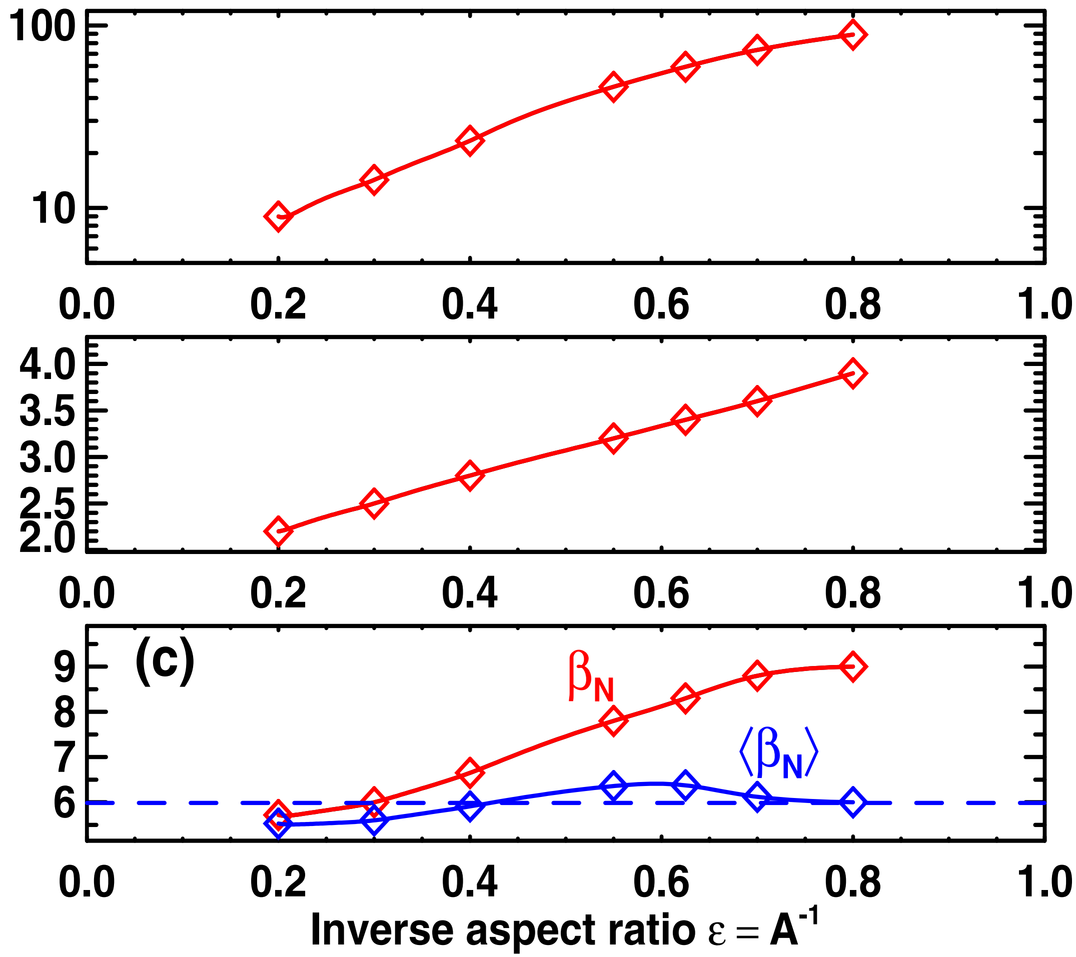
- $B_{t0} = B_{MAX}(1 - \varepsilon - \Delta_{SHIELD}/R_0)$

  Δ_{SHIELD} = inboard shield thickness

- $V_{plasma} \propto R^3{}_0 \, \varepsilon^2 \, \kappa$
- $P_{fusion} \propto \beta_t{}^2 B_{t0}{}^4 V_{plasma}$

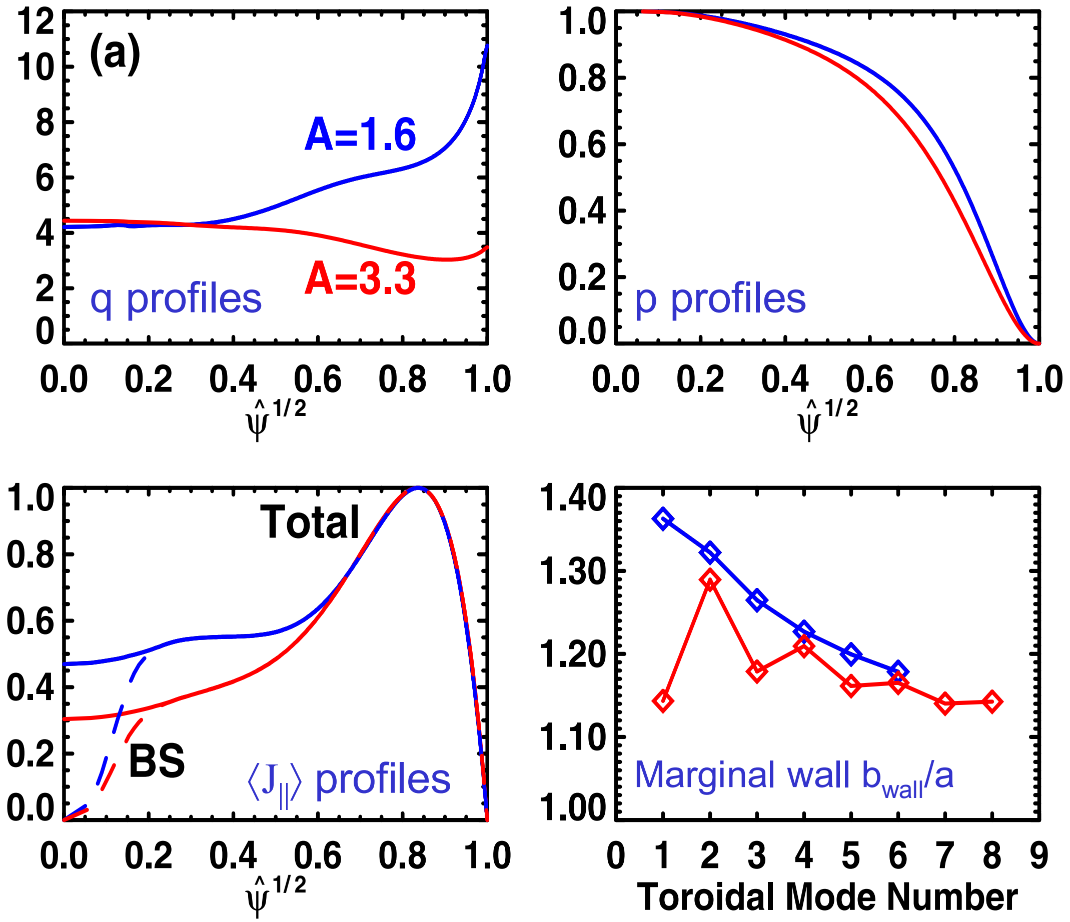
How do κ and β_N limits vary with aspect ratio?

β limits with wall stabilization, f_{BS}=99%



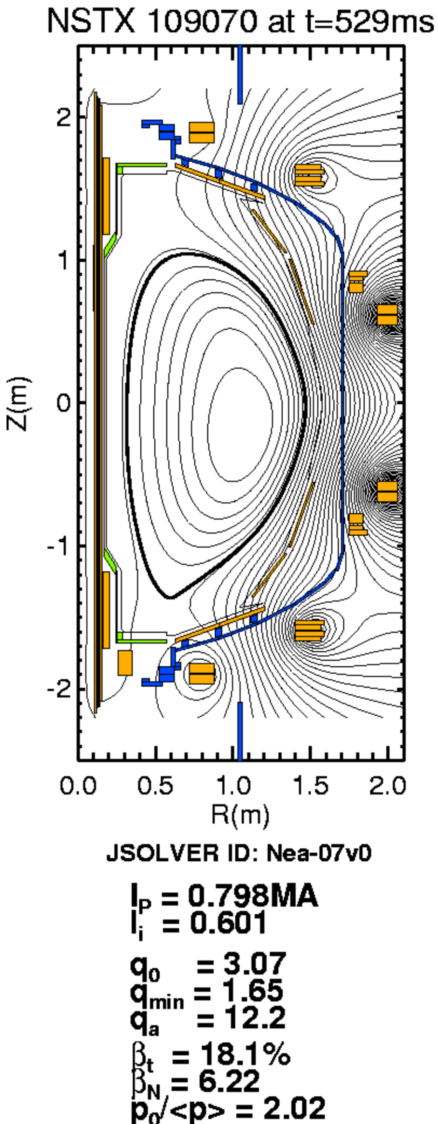
- Factor of 10 increase in β_t from A=5 to A=1.25
  - Result of increased κ, β_N, ε
- κ increases from 2 to 4 over same range of aspect ratio
  - With-wall n=1 stability limits maximum elongation, assuming n=0 is stabilized
  - $\kappa \rightarrow 4 \Rightarrow$ very low li = 0.1-0.2
- β_N approaching 9 possible near A=1.3-1.5
- **Higher β_N and κ at low A combine to yield highest P_f at fixed R_0 for A=1.6**

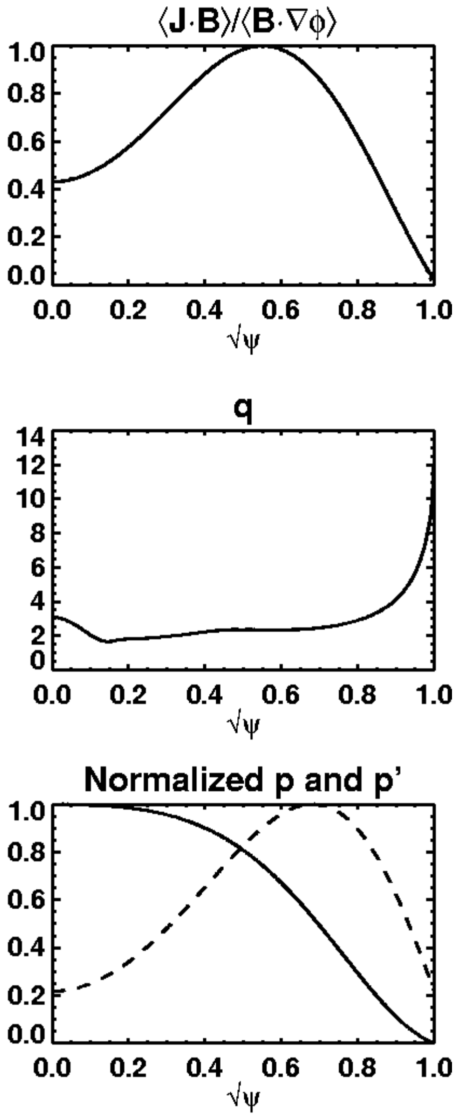
Profile details for wall-stabilized optimized cases



- Safety factor
  - Flat but monotonic q profile for A < 2
  - Reversed shear for A > 2
- Pressure profiles
  - Very broad, p(0)/⟨p⟩ = 1.4-1.6
- J profile
  - Hollow with large off-axis J_{BS}
  - Zero at edge to avoid peeling
- Wall position
  - Stable to n=1-8 w/ wall at 1.1
  - Intermediate-n most unstable

NSTX beginning to access "advanced" profiles





- EFIT02 without MSE, kinetic p, etc., but these shots appear to have:
- $\beta_N = 6.2$, l_i=0.6, $q \geq 2$
  - β_N / li > 10
  - ≥ ½ way between theoretical no-wall and with-wall limit?
- Hollow J profile
  - Flat q profile?
  - or reversed shear?
- Broad pressure profiles
  - $p_e(0)/\langle p_e \rangle = 1.8$ (H-mode)

ST reactor relies on wall stabilization and extreme κ

$A = 1.6$

$\kappa = 3.4$

$\delta = 0.64$

$\beta_t = 56\%$

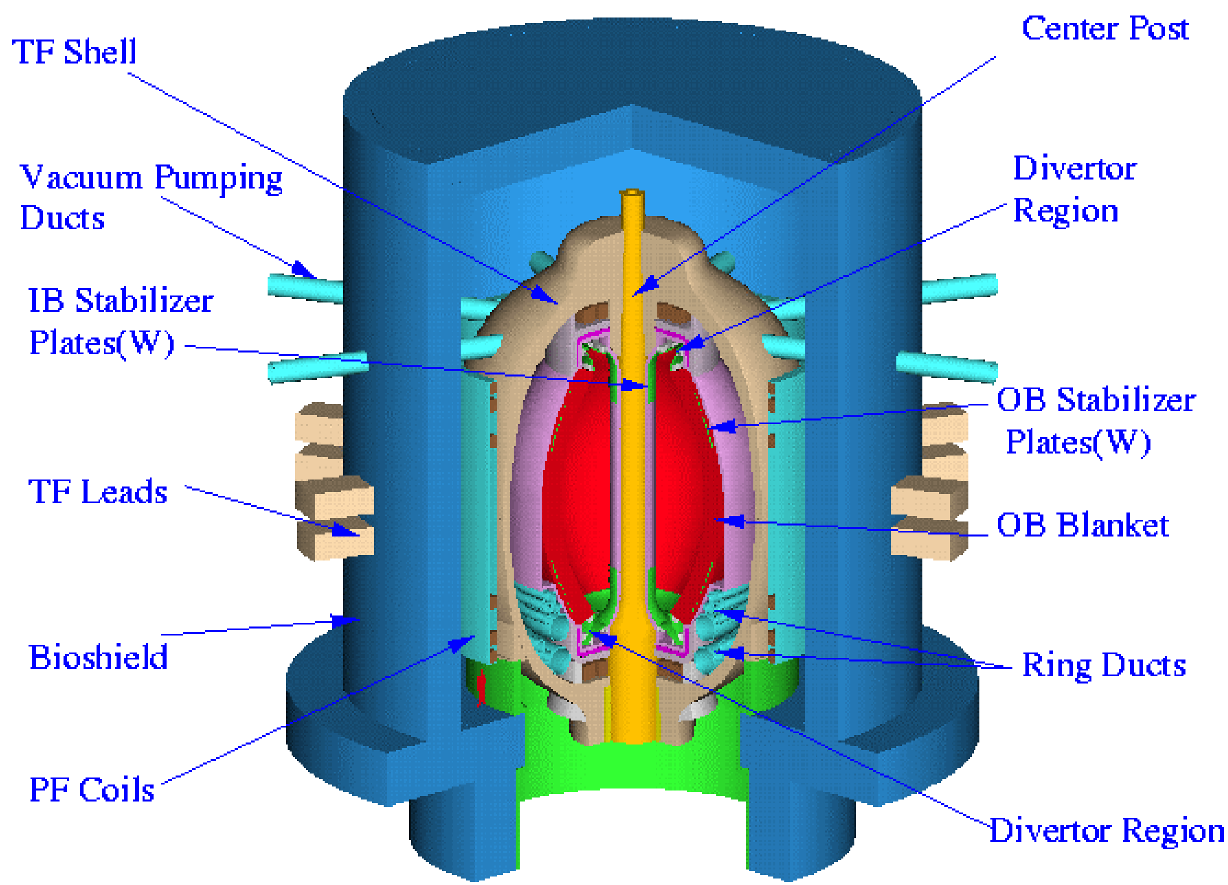
$\beta_N = 8.2$

$f_{BS} = 99\%$

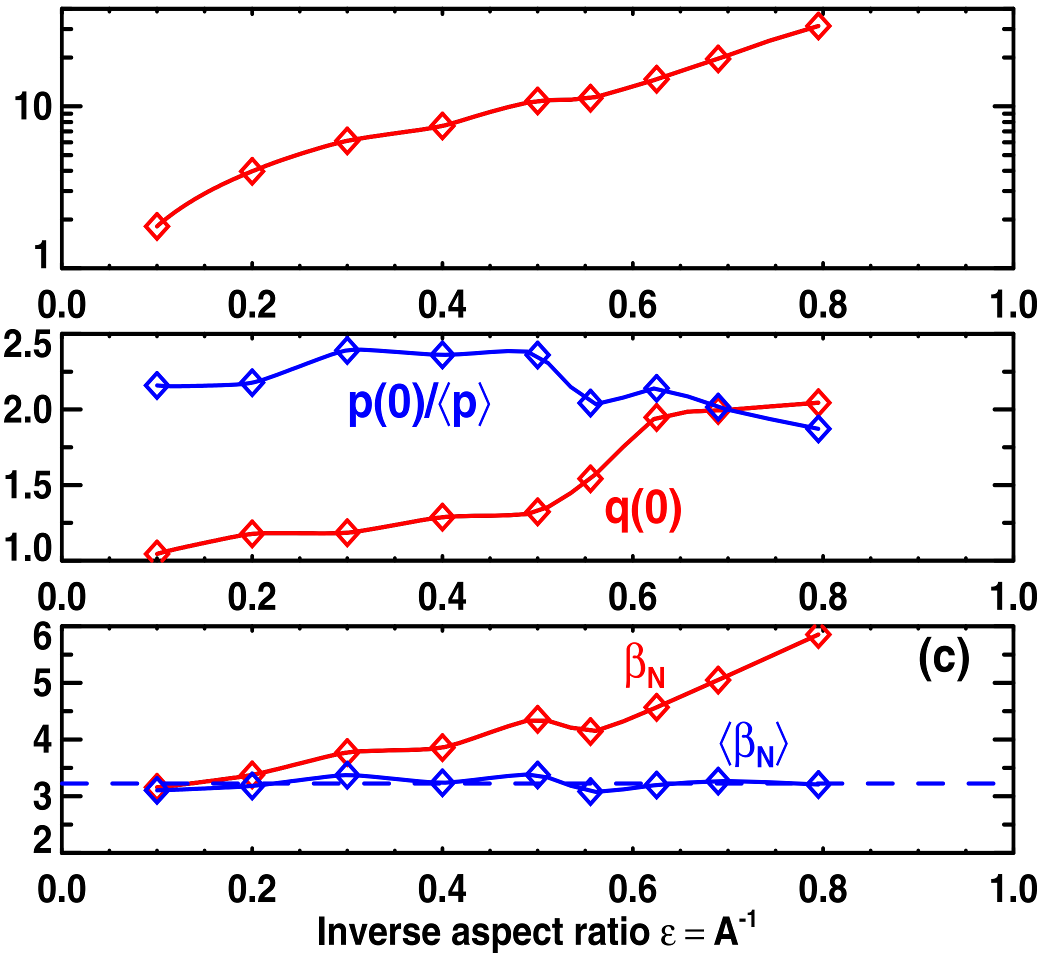
$I_P = 35\text{MA}$

$p(0)/\langle p \rangle = 1.4$

Cutaway of the ARIES-ST Power Core

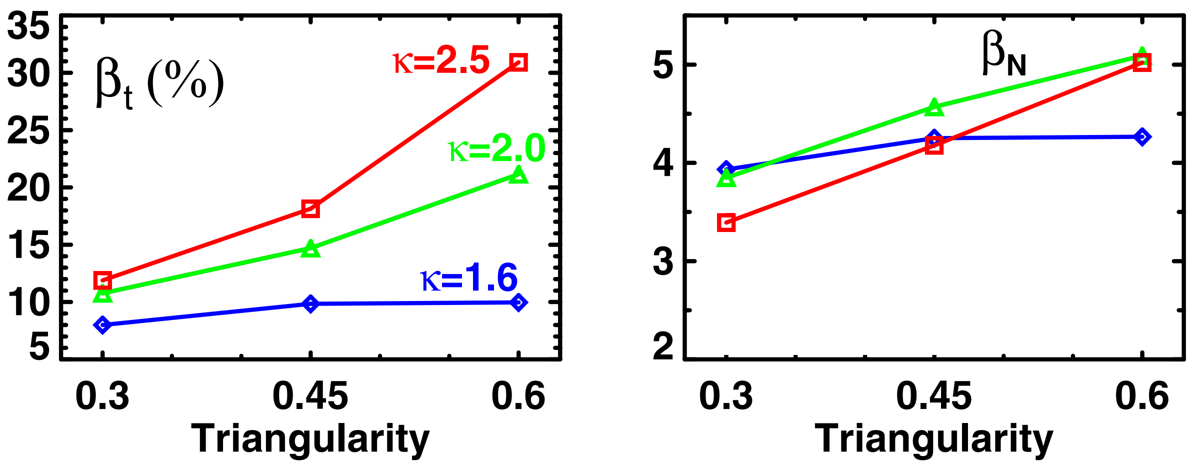


β limits *without* wall stabilization, f_{BS}=50%



- **Fixed κ=2.0, δ=0.45**
- Factor of 8 increase in β_t from A=5 to A=1.25
  - Result of increased β_N and ε
- q(0) for optimal ideal stability at or above 2 for A < 1.8
  - Improved NTM stability
- β_N approaching 6 possible at lowest A treated (A=1.25)
- **Higher β_N at low A with fixed κ yields highest P_f at fixed R_0 when A=1.8**
  - **Including ε dependence of κ would lower optimal A**

β limits without wall, A=1.6, f_{BS}=50%



- High δ crucial to no-wall stability of high κ and f_{BS} regime
  - 30% increase in β_t as δ=0.3 $\rightarrow$ 0.6 for κ = 1.6
  - **Factor of 2 increase for κ=2, $\times$2.5 for κ=2.5**

- With κ=2.5 and δ=0.6, can theoretically achieve NSTX-like β_t~30% at higher A=1.6 w/o wall and with higher f_{BS}
  - Utilizing wall stabilization, κ=2.5, and δ=0.6, β_t~40% and f_{BS} = 70% are theoretically achievable – similar to lower A=1.25 target

Summary

- Stability $\Rightarrow$ optimal A for max. P_{fusion} is A=1.6-1.8
  - Requires minimal inboard shielding, "free" non-inductive CD
  - Similar scaling results with and without wall stabilization
    - **β_N limit increases naturally with increasing ε**
    - n=0,1 elongation limits also increase at lower A
  - Optimal $q(0) \geq 2$ for $A \leq 1.8 \Rightarrow$ improved NTM stability
- Large increase in β_t with increased κ
  - Above κ=2, increased δ required for highest κ
  - Very broad p profiles in optimized regimes
- Optimized A=1.6 targets:
  - A=1.6, κ=2.5, δ=0.6, β_t=30%, f_{BS}=50%
  - β_t=40%, f_{BS}=70% possible with wall, like present target
- Can NSTX study higher A, κ, δ in next 5 years?