Operational requirements for high-β, high bootstrap fraction discharges in NSTX

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TG3: Macroscopic Stability
Parallel Session III
2002-2005 Research Proposals and Discussion

NSTX Research Forum 2001
Wednesday, January 17th, 2001
LSB Auditorium, PPPL

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Example: Optimized NSTX Target Developed 1996-1998

Profile, BS, and stability optimization done at PPPL for fixed boundary, followed by free boundary EFIT reproductions using actual NSTX coils (+new PF5), Columbia U.

$A = 1.28$

$k = 2.0$

$\delta = 0.45$

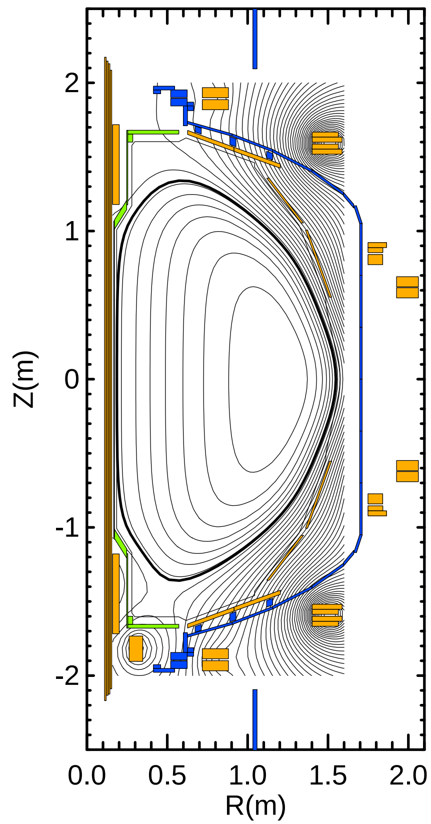
$I_P = 1$ MA

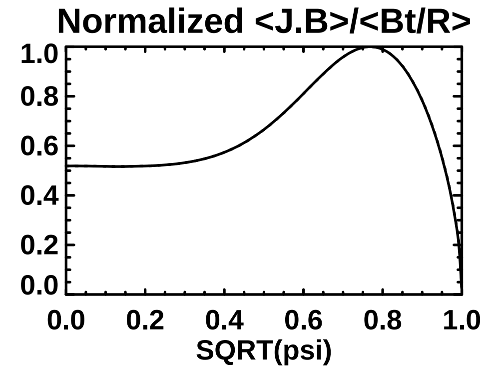
$B_T = 0.3$ T

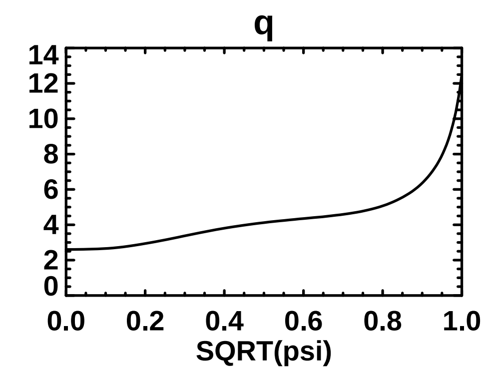
$\beta_N = 8.1$

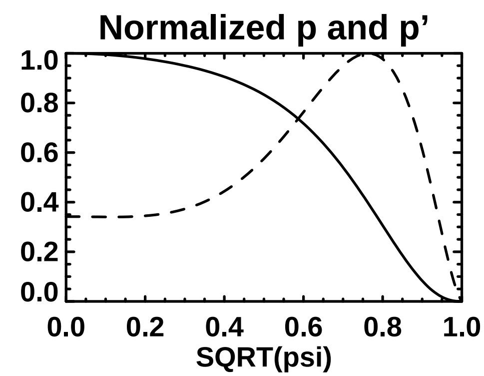
$\beta = 40.4\%$

$f_{BS} = 70\%$









Ideally stable to ballooning & n=1-6 kinks with idealized NSTX passive plate structure

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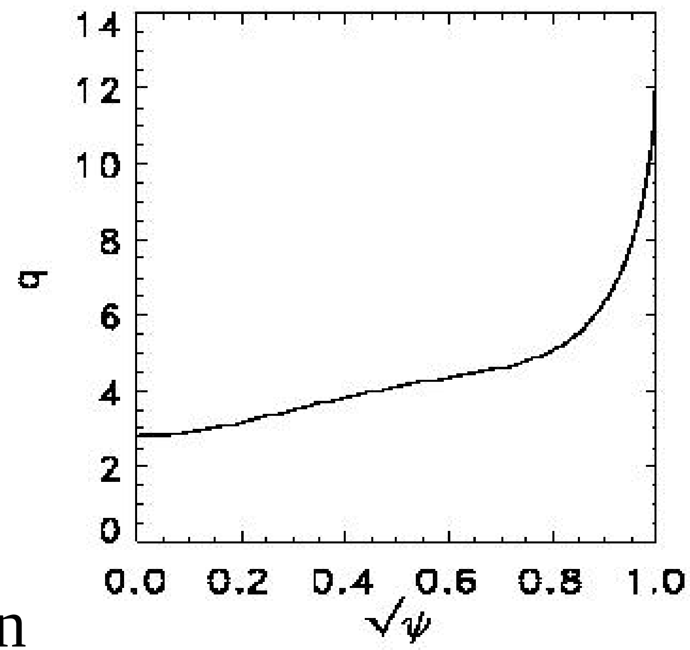
Optimized target is very aggressive - challenges nearly all operational limits simultaneously

- Required q-profile is highly "non-ohmic"
  - Elevated q(0) = 2-2.8
    - Stabilizes ballooning modes
    - Increases BS fraction
  - Strong edge shear
    - Allows large p' near edge while remaining stable to kink modes (with wall)



- Achieving this profile requires innovation
  - Group is challenged to figure out ways of pinning q(0) > 2 early
  - HHFW has shown some success, but may not be enough
    - Are beams really incapable of doing this?
    - What about EBW heating and/or CD?
- Standard MSE + edge MSE essential for measuring these details

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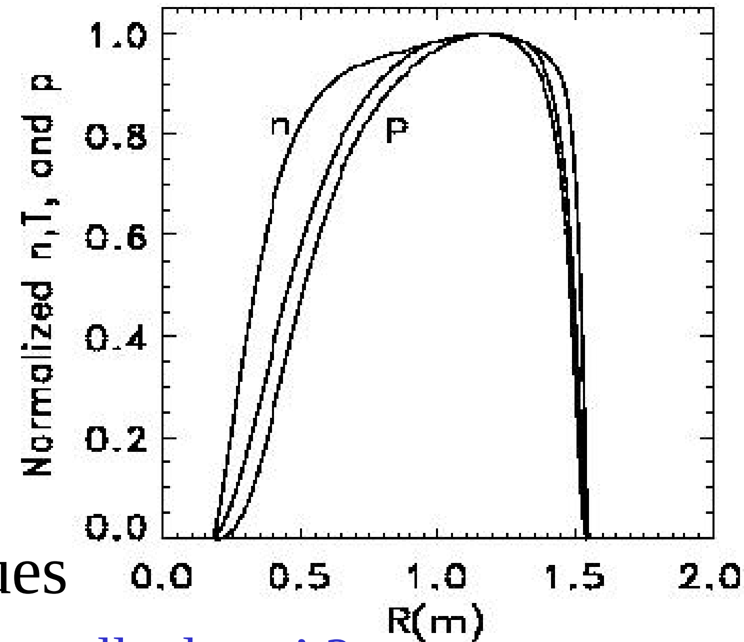
Optimized target requires development of profile control knobs compatible with machine capabilities

- Required pressure profile is quite broad
  - p(0)/<p> = 1.6-1.8   (NBI is typically 2-3)
    - places p’ in region of high shear and near wall
    - Provides good BS current alignment
  - But, equilibrium has p’(edge) = 0
    - Non-zero p’ drives J(edge), degrades stability



- Getting this profile requires new techniques
  - How can we form equilibria with broad p but small edge p’ ?
  - Possibilities:
    - Off-axis power deposition from HHFW + L-mode edge
    - Heat with NBI or HHFW into well-behaved ELMY H-mode
    - Form ITB with NBI, then grow outward in minor radius? ST-QDB mode?
- Standard kinetic profiles + hi-res edge MPTS and CHERs needed

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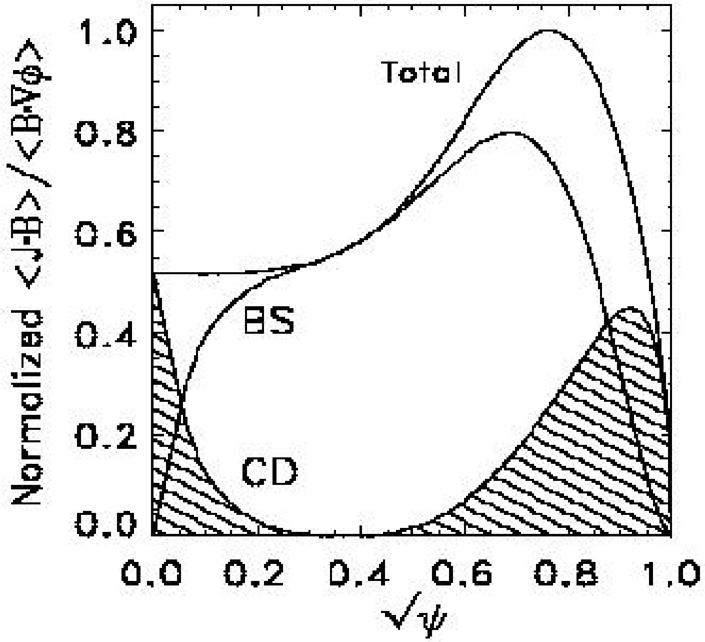
Is near-edge current really needed or beneficial?



- Current profile is very hollow
  - Aligned with BS current profile shape
  - 20-30% external J required near edge
    - Designed to suppress near-edge ballooning
  - CHI originally planned to provide this CD
- Is so much J near edge really needed?
  - Is ballooning really an issue in this region?
  - Do resistive or kinetic effects completely dominate? Can we measure this?
- In general, do we want this much current density here?
  - J(edge) is assumed to be 0 at boundary to improve stability
  - Assuming we can make a hollow current profile, can we control J(edge)?
- Operational techniques will need to be developed for fine-scale current profile control at the edge.

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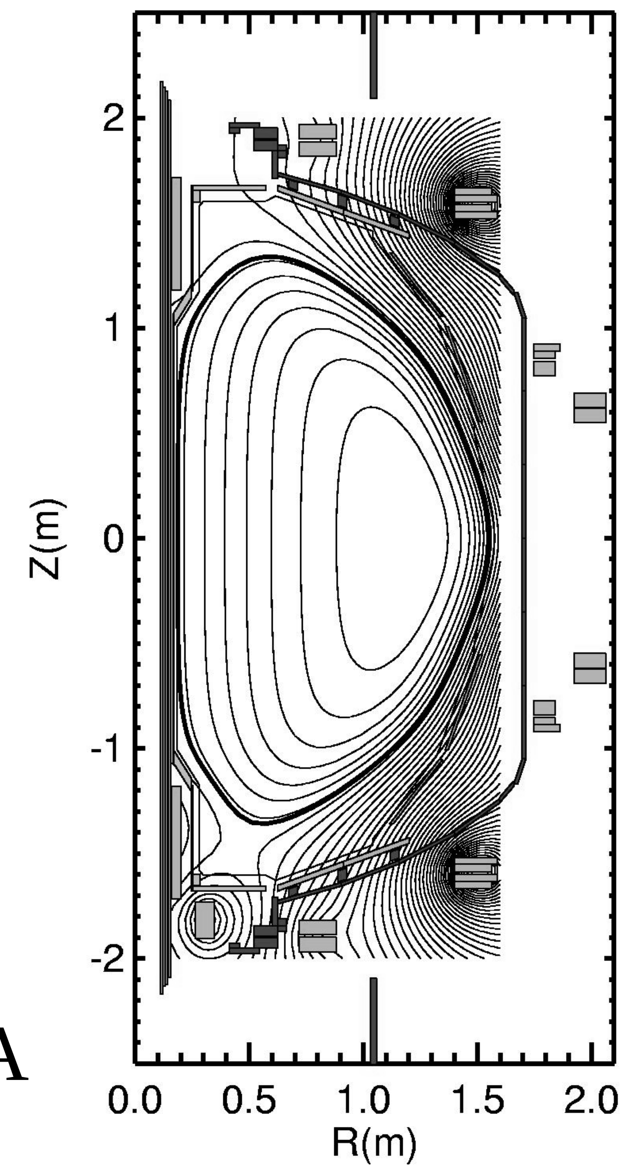
These equilibria exist, but can we control them?

- Current profile is essentially a skin current
  - Current centroid is close to plasma boundary
  - Enormous outboard flux compression
  - Inner gap essentially uncontrollable
  - Do we have enough coils even for the outboard?
  - Rigid plasma response models will likely fail
- It will be a large development effort just to implement the present control system plan:
  - Plan = rtEFIT + isoflux control algorithm
    - How precise will our boundary control be?
    - Can we maintain the outer gap to mm precision?
  - At this level of precision, do 3D effects matter?
    - Plate circulating current may be needed in rtEFIT?
- We welcome any and all help from GA

Optimized case



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What about control of basic β knobs?

- We need density feedback - the most basic β control
  - *I won't dwell on this…*
- Beam modulation is planned
  - Will greatly aid fine control of β as limits are approached
  - Can we eventually go beyond this and control the injection voltage?
    - Modify bulk rotation rate and rotation shear
    - Useful for MHD and transport studies
    - Possibly modify transport as a means of p profile control?
- HHFW would also benefit from control
  - Real-time power control planned
  - Real-time phasing control for deposition profile control desired
  - Real-time ray-tracing for predictive deposition?
- Anything else?

Steady-state wall stabilization of optimized NSTX plasmas is a big assumption

- DIII-D RWM feedback results are encouraging, but
  - Have not yet provided 30-50% β improvement which NSTX wants
  - Upgrades to DIII-D saddle coil coverage, etc., will be telling for NSTX
- NSTX no-wall cases exist with β=31%, f_{BS}=40%, similar profiles
  - These are interesting and impressive in themselves
  - They are certainly easier to achieve operationally
- For ST reactor, RWM stabilization $\Rightarrow$ factor of 2 increase in β
  - Economical power only achieved if kinks can be stabilized
  - Feedback stabilization is a promising means of achieving this
  - There are few alternative methods
- NSTX ET1 already has plans in place to investigate high-β physics and eventually resistive wall mode physics.
  - Team effort will be vital to success

MHD TG should aid in planning of upgrades

- New center-stack (for example)
  - CS will require all new magnetic sensors - **WHAT DO WE WANT?**
  - Should we design the CS around a no-wall optimized case?
    - **A=1.6, κ=3, δ=0.7, β=30% cases exist with f_{BS}=99% and no wall**
  - What shapes can we get? Where do we put the divertor coils? ….
  - Can we control κ=3?
- Suppose RWM feedback is a flop 3 years from now, what are our contingency plans?
  - Are there novel forms of inner wall stabilization?
  - What can we contribute to liquid metal flow stabilization ideas?
- What magnetic diagnostics are we missing overall? Do we want another toroidal array, B_{RADIAL} Mirnovs, more SXR, other?
  - Now is the time to ask, because these things take time and $$

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Summary

- Fusion physics is fun

- Economical fusion is difficult

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