MHD Stability of Negative Triangularity Tokamaks

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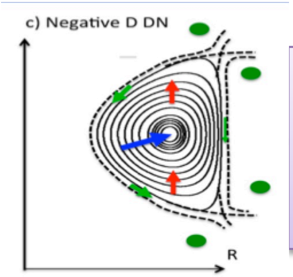
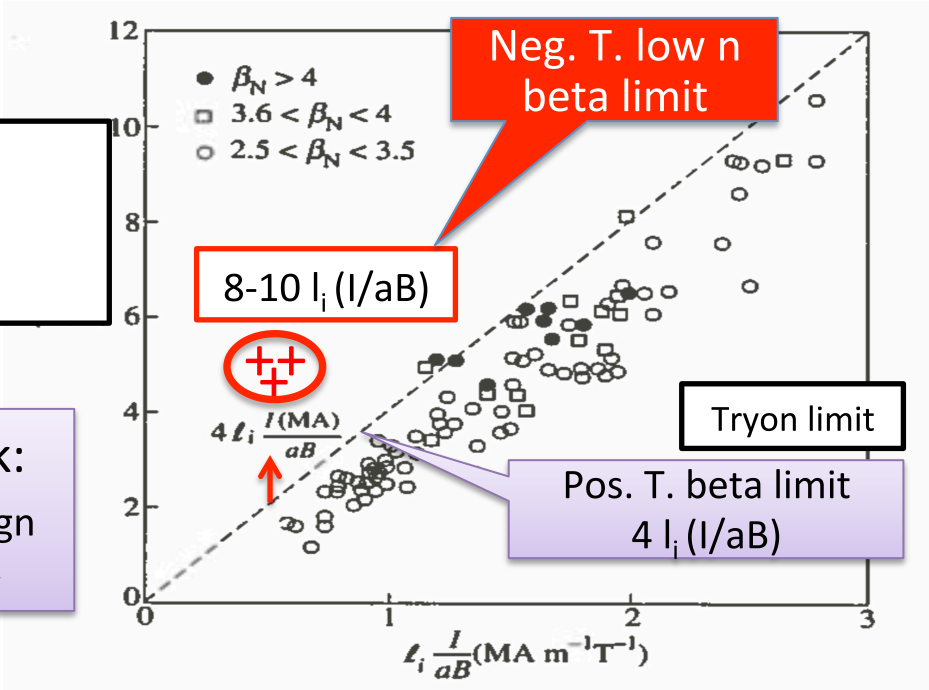


Negative triangularity tokamak:

- Not only good for divertor design
- But also good for MHD stability



Outline

1. Motivations: why negative triangularity
   - Design philosophy prioritizes solution of divertor heat load issue
2. Concern about the MHD Stability of negative triangularity tokamaks
   - H mode confinement is poor
   - L mode gets the H mode level confinement, beta limit is lower, but acceptable
3. Our NEW results: L mode with high bootstrap current fraction can achieve even higher beta than H mode in the positive triangularity case
   - High beta confinement: 8-10 Li (I/aB), beta limit doubled for low n modes!
   - ELM free, no major concern about RWMs, kink disruption, etc.
   - Steady state confinement, “soft” beta limit (high n ballooning)
   - Experiments show low turbulence level
4. Conclusions and discussion

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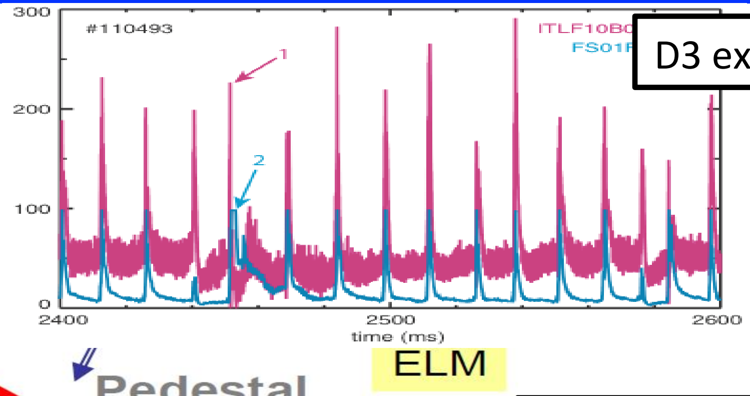
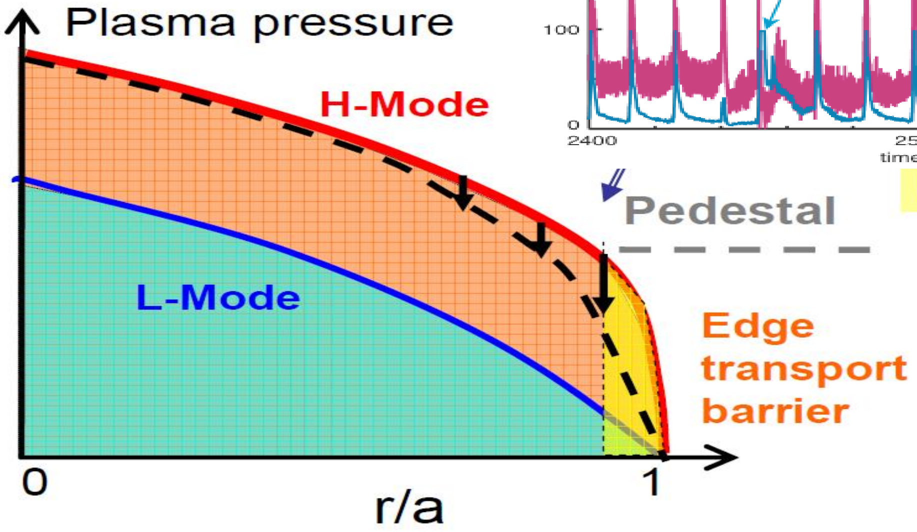
H-modes are good, but ELMs are unacceptable



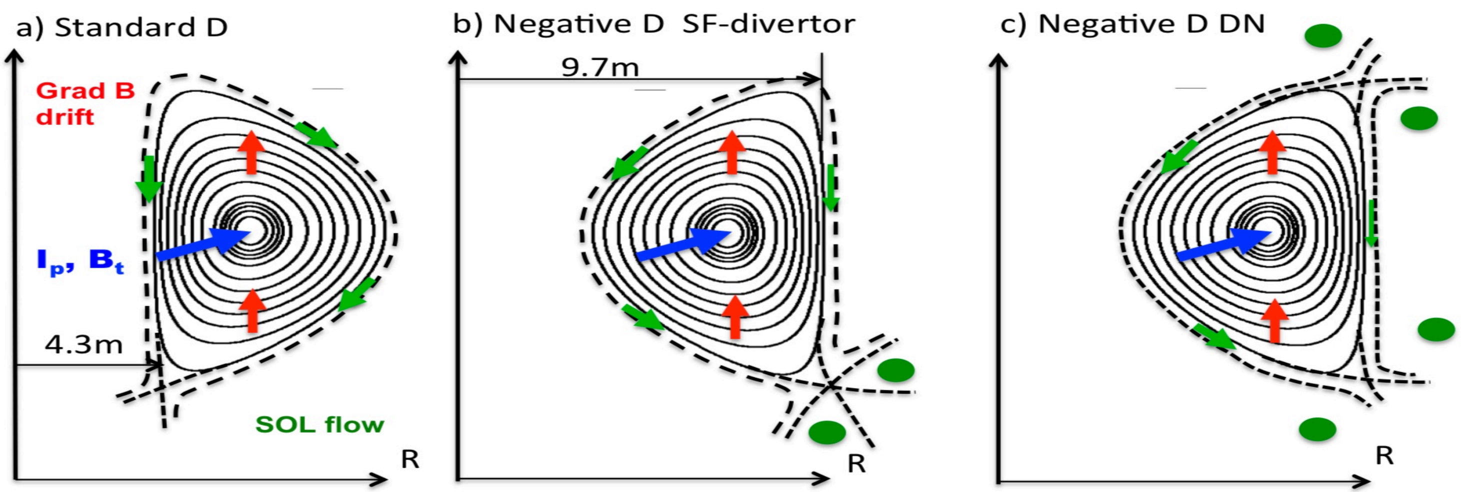
D3 experiment results



Kichuchi, et al, EPS 2014

For foreseeable material limit, divertor heat load is a challenging problem for positive triangularity tokamaks, especially for fusion reactors

Non core-the-first design philosophy: Negative triangularity tokamaks (Kikuchi,et al.)



Original thoughts: Negative triangularity can gain for divertor design, but may give up in the beta limit

- a larger separatrix wetted area,
- wider trapped particle-free scrape-off layer,
- larger pumping conductance from the divertor room.

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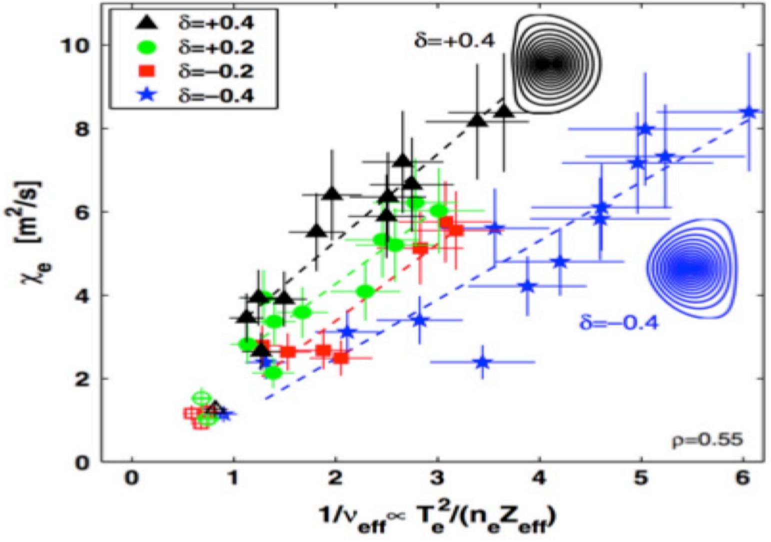
Earlier TCV negative triangularity experiments

DIII-D Experiment Was Motivated by Results From TCV

- TCV saw x2 confinement improvement in negative (-δ) over positive (+δ) triangularity discharges
- Achieved H-mode confinement in L-mode discharge
- Saw reduced turbulence levels in neg. compared to pos.



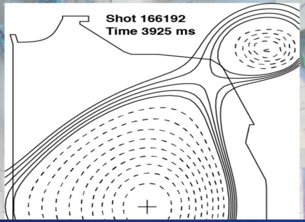
Y. Camenen, Nucl. Fus. 2007

Recent DIII-D experiments

Initial Results from MP 2017-11-02: Transport Variation with Positive and Negative Triangularity

Presented by
Max Austin

with
A. Marinoni, J.A. Boedo, M.W. Brookman, A.W. Hyatt, G.R. McKee, A.E. Neuman, C.C. Petty, T.L. Rhodes, K.E. Thome, M.L. Walker and the DIII-D Team

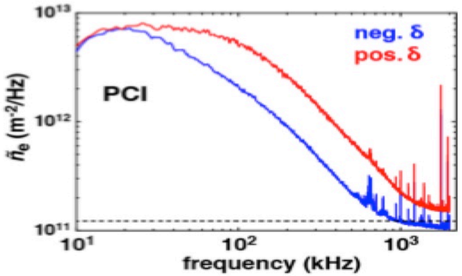


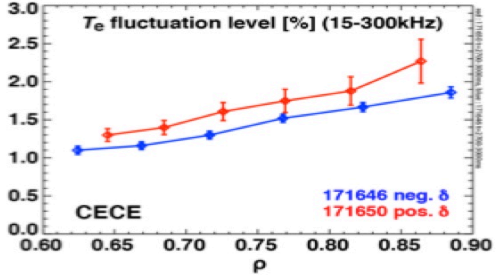
Present
DIII-D I

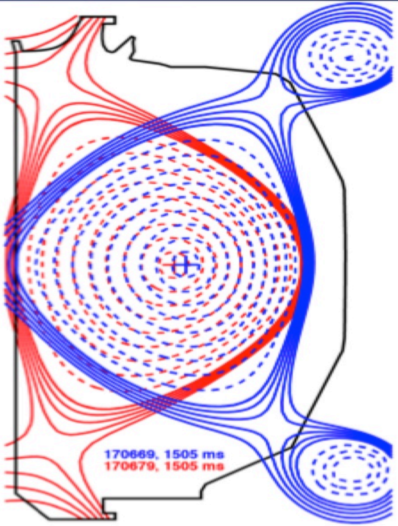
May 1

Summary: Negative Triangularity Discharges Created in DIII-D

- Unconventional negative triangularity ($-\delta$) discharges have been created in DIII-D
- Compared to matching positive δ, they have reduced turbulence and transport



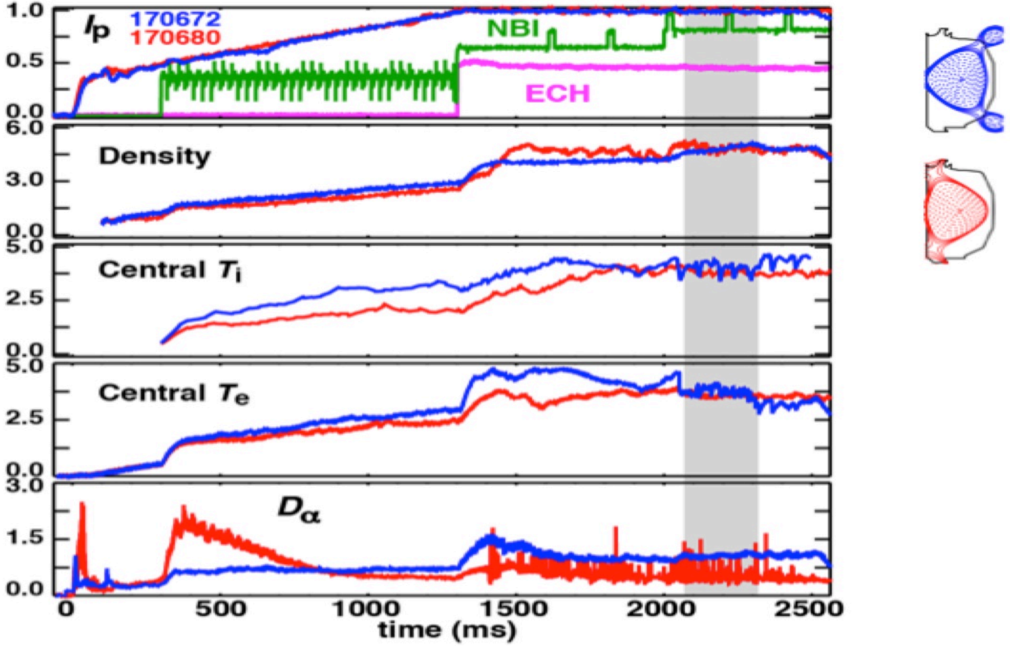




Important development of DIII-D experiment

$T_e = T_i$ case At High Beam Power, Compared Neg. δ L-mode and Pos. δ H-mode

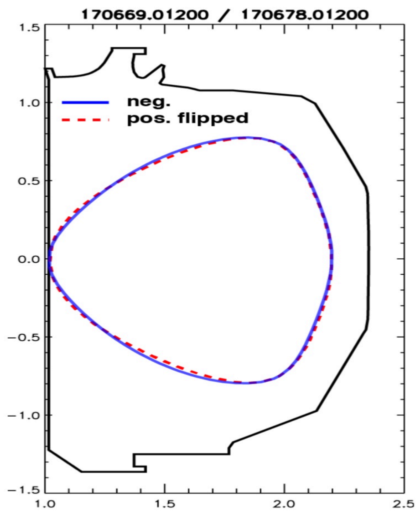
- **Same heating trajectory both shapes**
  - 7 MW NBI
  - 3 MW ECH
- **Pos. δ goes into ELMing H-mode at 1400 ms**

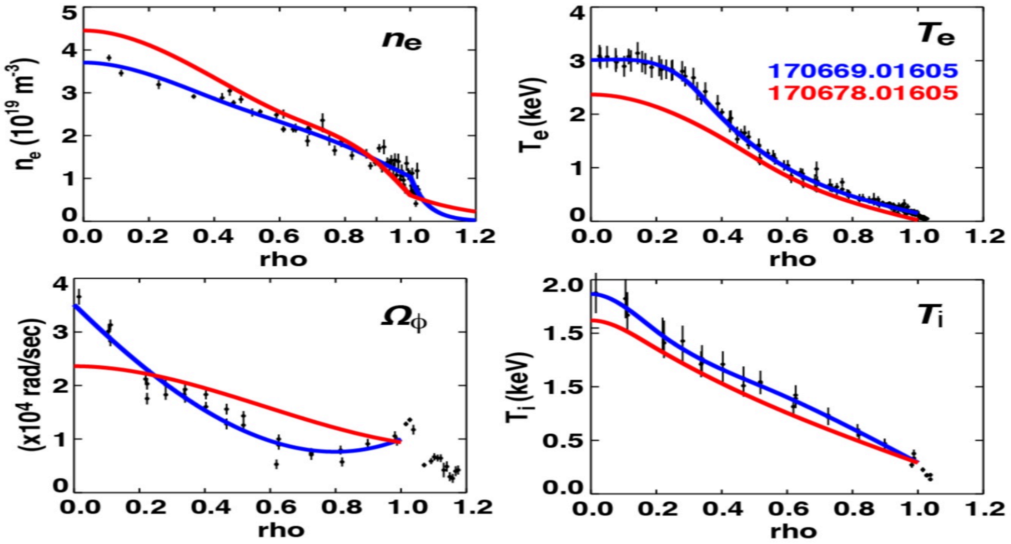


M.E. Austin/APS-DPP/2017-10-23

> ➢ the H-mode-level confinement (H98yp=1.2) with L-mode-like edge behavior without ELMs

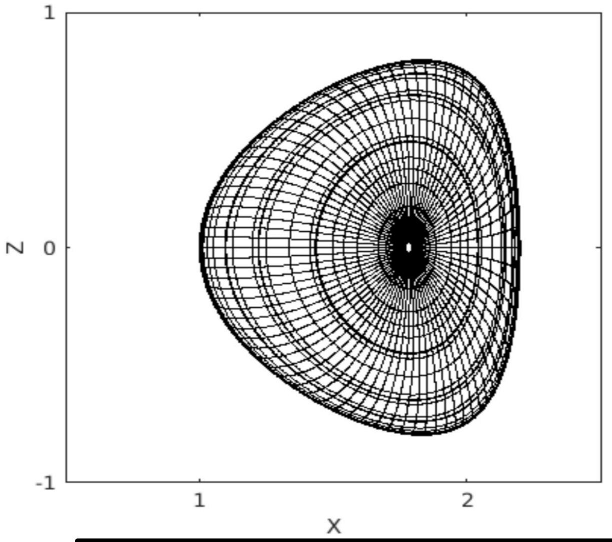
Stability: DIII-D experiment interpretation

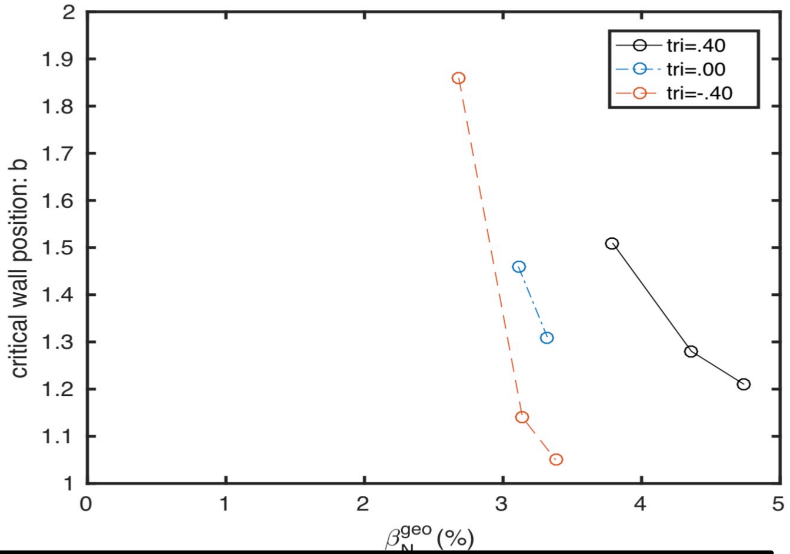




- ➢ Equilibrium: use the g file from experimental data reconstruction
- ➢ Ideal MHD Stability is confirmed with critical wall position 1.11, consistent with the D3D limiter experiments

Numerical exploration of D3D type of L-mode equilibria





- Three types of triangularity cases: δ = 0.4, 0, and - 0.4 are investigated
- L mode profile is assumed (close to DIIID experiments)
- Results: Positive triangularity: best
  Zero triangularity: stay at middle
  Negative triangularity: worst, but acceptable
- Negative triangularity is bad for H mode

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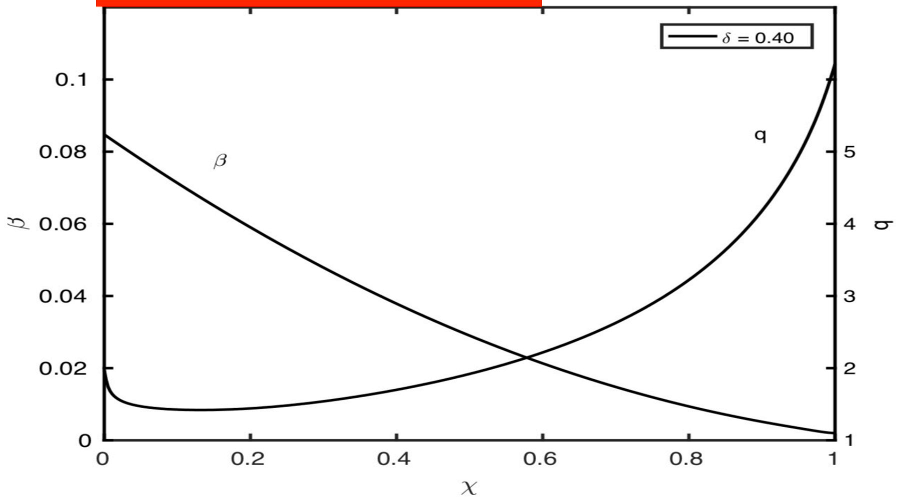
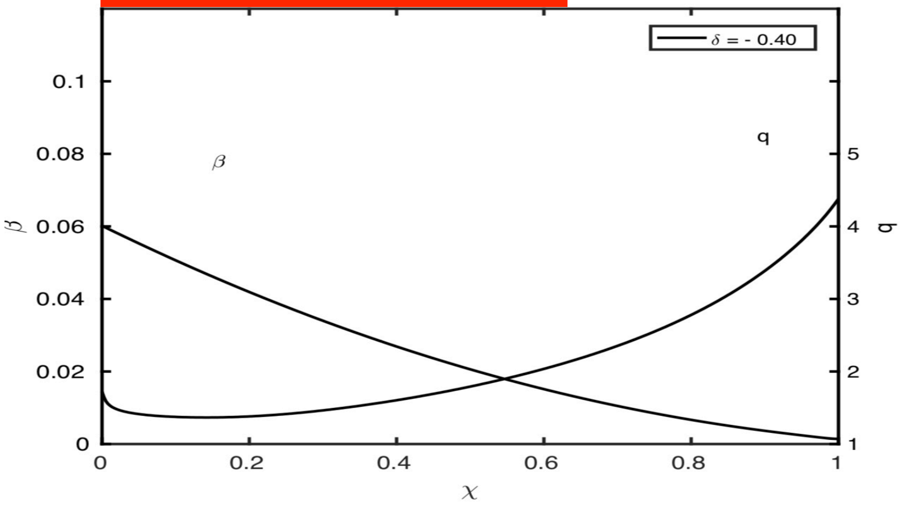
Profile comparison between positive and negative triangularity cases

Positive triangularity

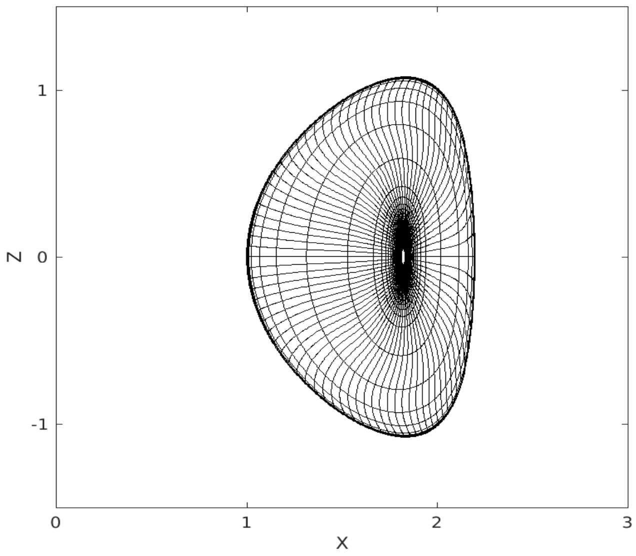


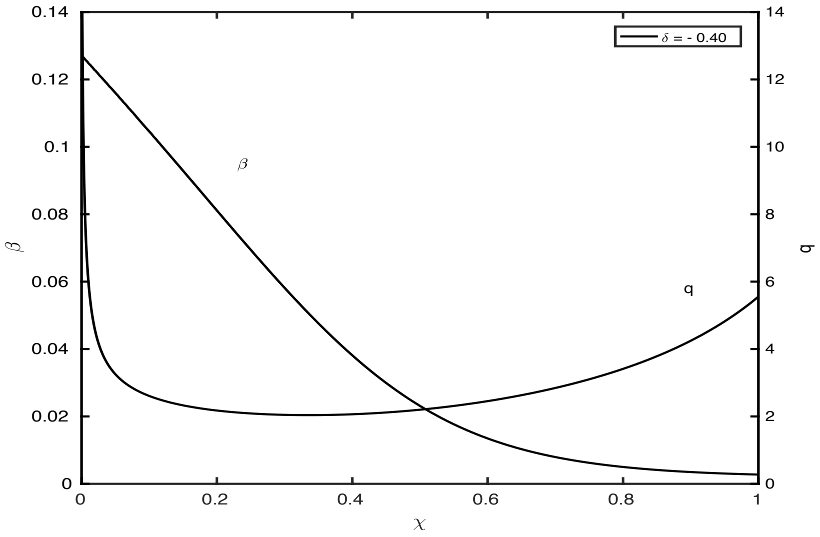
Negative triangularity



- Observation: the safety factor q at edge is smaller for negative triangularity case
- Motivate us to reduce the Ohmic current to consider the advanced tokamak scenario with high bootstrap current fraction

Negative triangularity tokamak in advanced scenario with high bootstrap current fraction



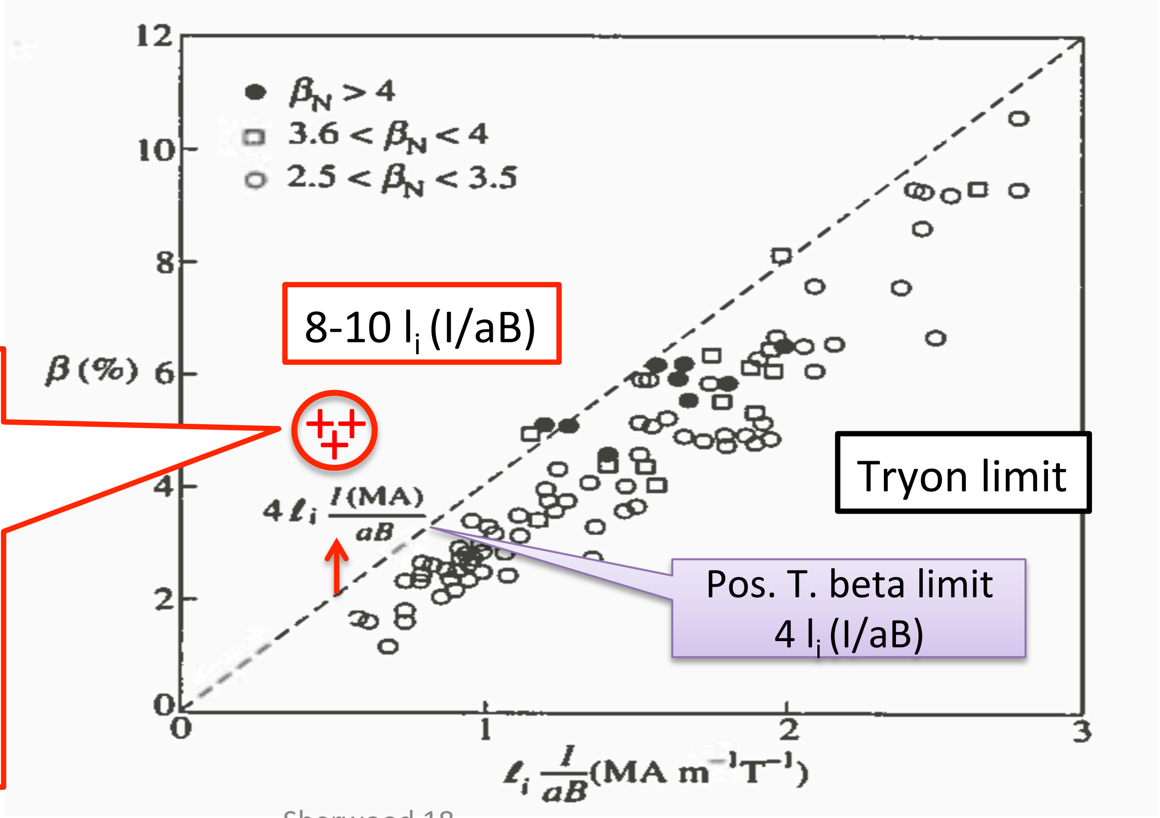


Given density and temperature profiles, the current is computed self consistently

Low n (1-5) kink mode stability for negative triangularity tokamak in advanced scenario

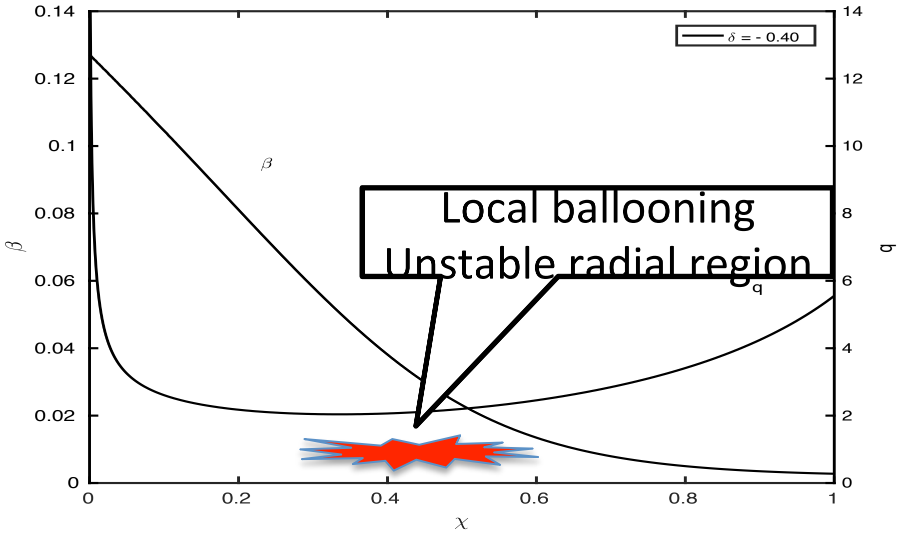
Low n kink modes stable cases:

- n=1-5 stable
- No-wall limit
- Stability confirmed both by AEGIS and DCON



High n ballooning mode stability for negative triangularity tokamak in advanced scenario

- Because of peaked pressure profile, high n ballooning modes tend to give lower $beta_N$ limit: 4 li (I/aB)
- Further profile optimization is still in process

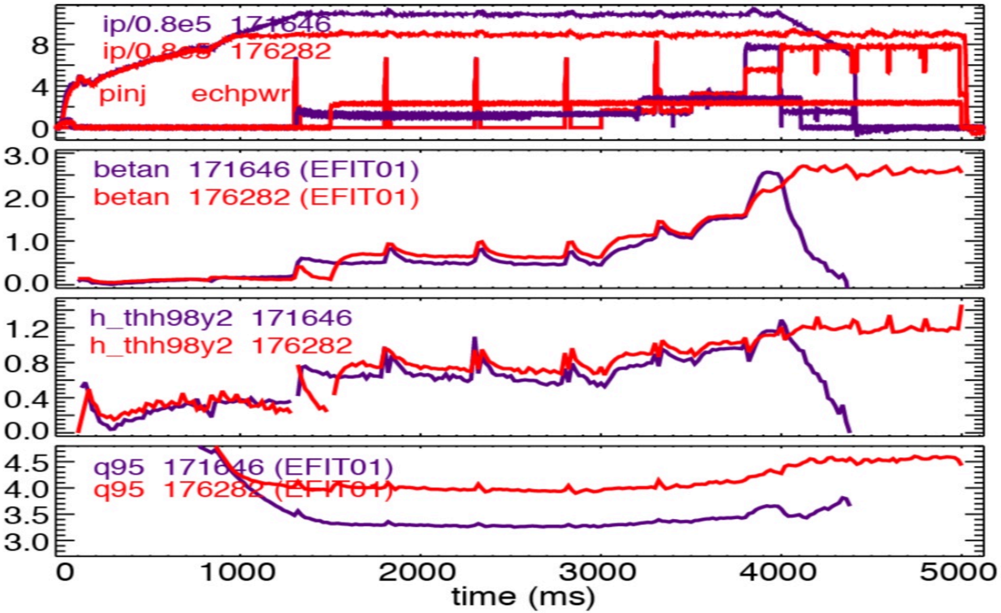


- High n ballooning mode theory keeps only lowest order, global calculation shows that the n=5-10 stability can be achieved.
- Possible FLR stabilization for high n modes
- “Soft” beta limit

Further D3D experiments, guided by our calculations, yield interesting results based on the preliminary analyses

Shots with lower Ip did not exhibit reduced confinement

- Comparison of neg. triang., last year 0.9 MA, this year 0.75 MA
- H-factor higher for lower Ip
- Tau_e about the same



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Note that: the confinement time usually goes with the current in the positive triangularity case

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Conclusions: Negative triangularity & L - mode & low I_p and high bootstrap current

- The benefits of negative triangularity are not limited to divertor
  - NEW: negative triangularity also improves MHD stability
    - ✓ Steady state confinement with high bootstrap current fraction
    - ✓ ELM free
    - ✓ high resistive wall mode beta limit
    - ✓ Low n stability, reduce the kink type disruption possibility
    - ✓ soft instabilities (high n ballooning modes) to avoid high inevitable beta state, that eventually causing disruption, FLR stabilization? Global effects
    - ✓ Experiments already show a reduced anomalous transport