Unity Beta Equilibrium and Stability : A new challenge for DIII-D

DIII-D AT Workshop Feb 27-28 2007

Pierre-Alexandre Gourdain

UCLA

Physics and Astronomy Department

Introduction

Recent research demonstrated that unity beta plasmas are stable to the major ideal MHD criteria. Furthermore a path exists from low to high beta plasma for high aspect ratio machines. A preliminary study shows that unity beta plasmas requires (at least):

1- control of free boundary modes

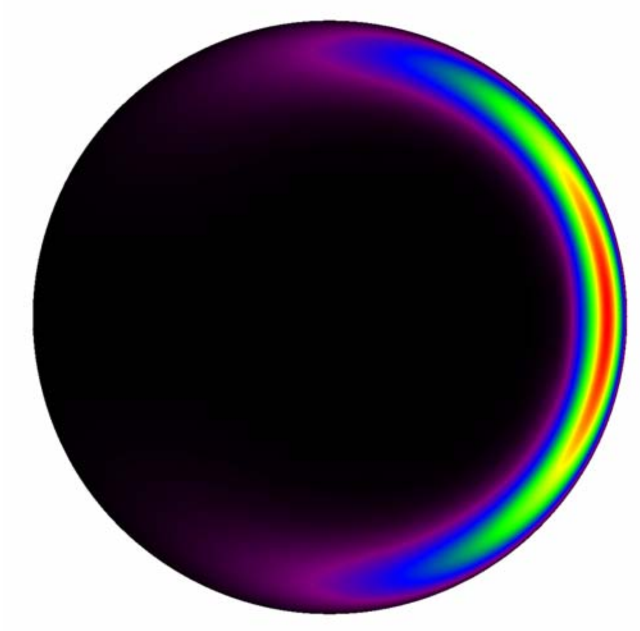
2- control of the current profile

3- control of pressure

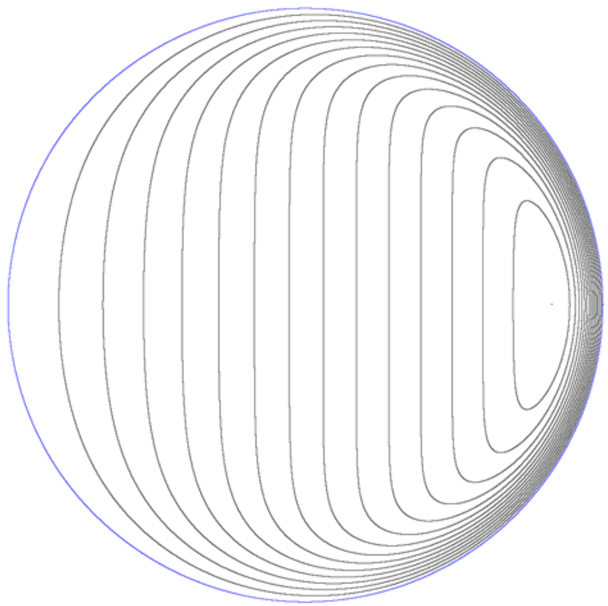
The major benefits to unity beta are:
1-the factor of 10 in confined pressure compared to low beta, for the same magnetic field;
2-fully bootstrap driven.

Since these targets are also necessary to the AT program, it seems appropriate to start a unity beta program for DIII-D in parallel to the AT program. Both programs will benefit from one another.

Unity Beta profiles



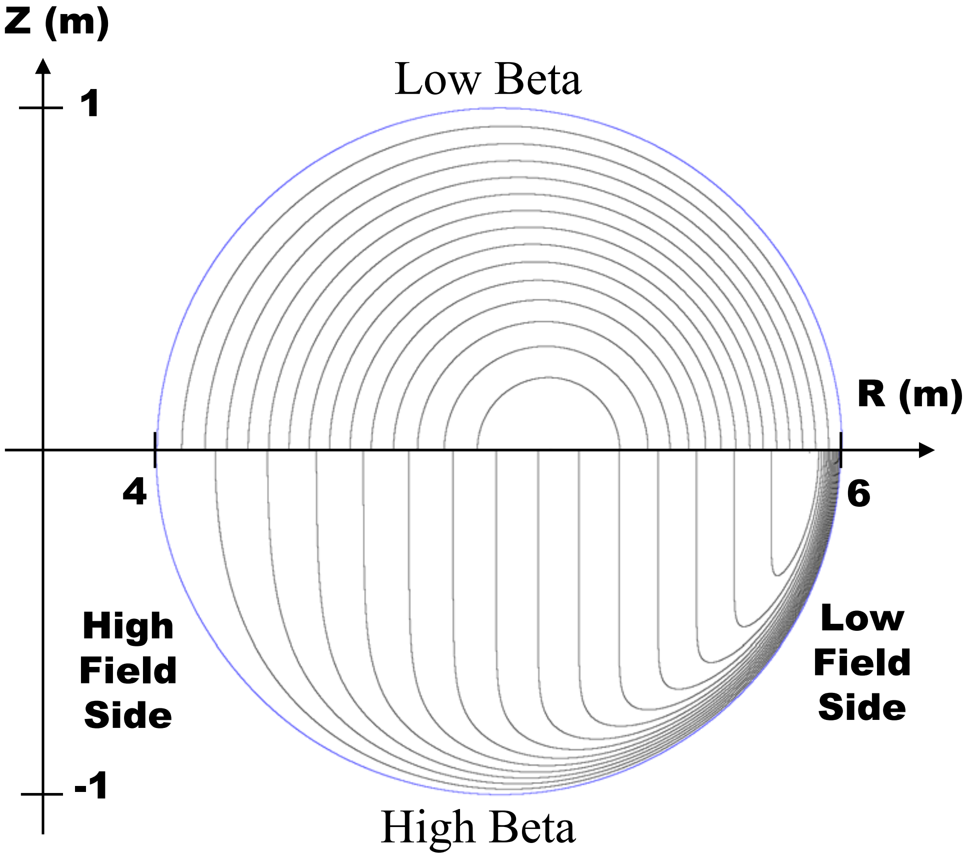
Toroidal Current

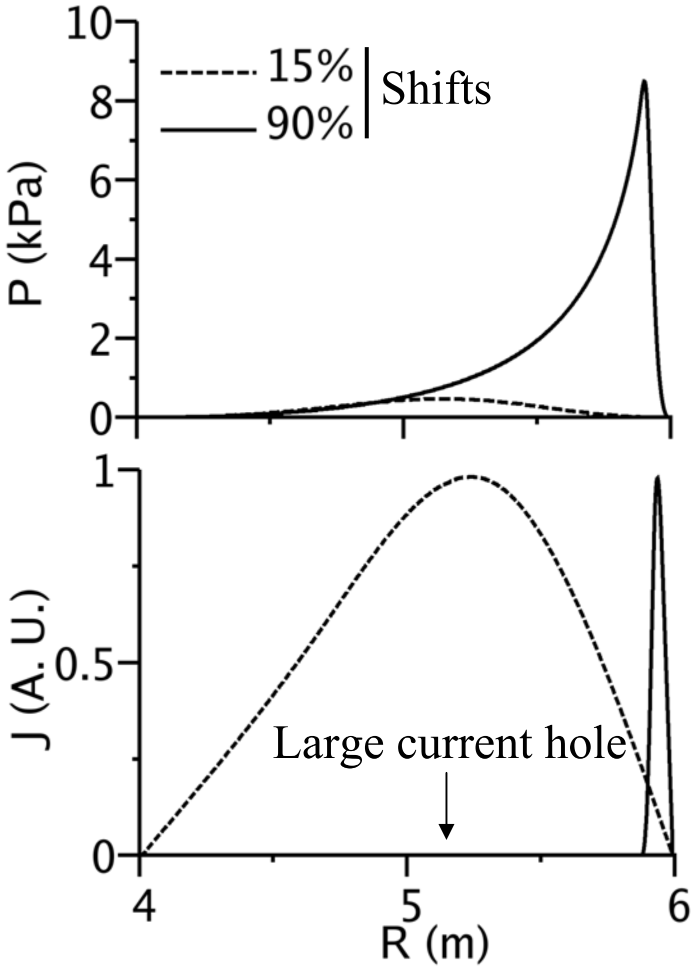


Flux surfaces

The shift in plasma pushes the toroidal current density on the LFS and reinforces the poloidal field there. The current gradient takes care of the pressure gradient on the LFS. Diamagnetic currents take care of HFS pressure gradient.

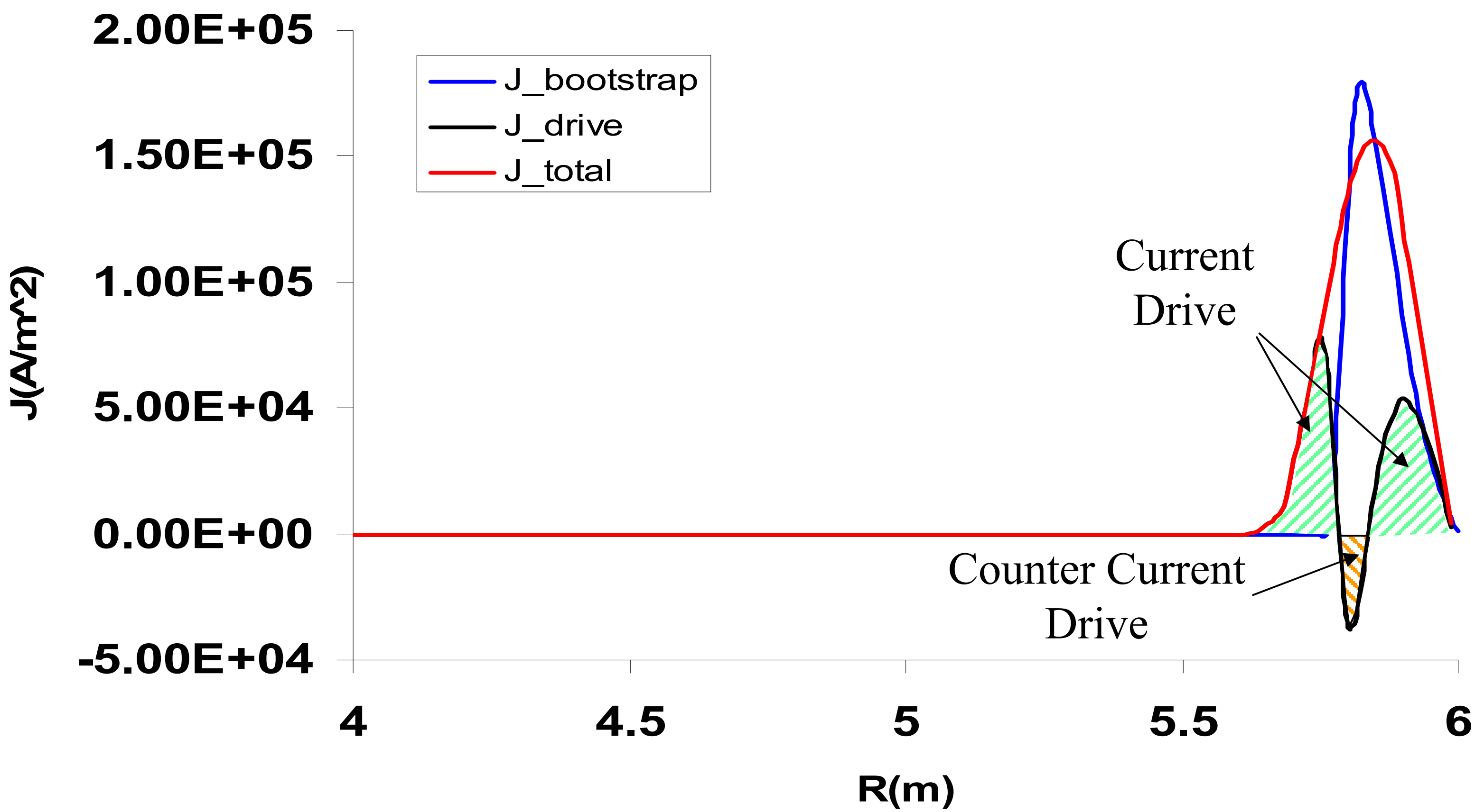
Comparison between low and high beta equilibria





Parameters of the study
B_t = 0.25 T R =5 m a = 1 m I_p = 50 kA
Circular plasma

Bootstrap

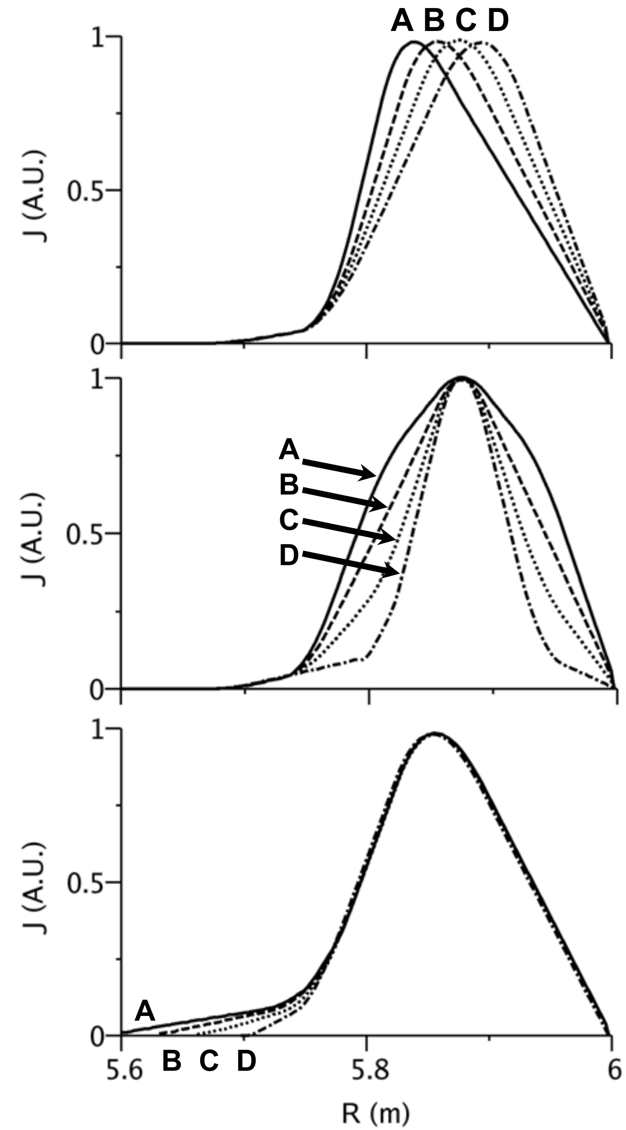


Bootstrap currents in high beta tokamaks largely drive the current necessary to the equilibrium. Additional current drive is needed to supply current where bootstrap is weak (edge and axis)=> current profile corrections only.

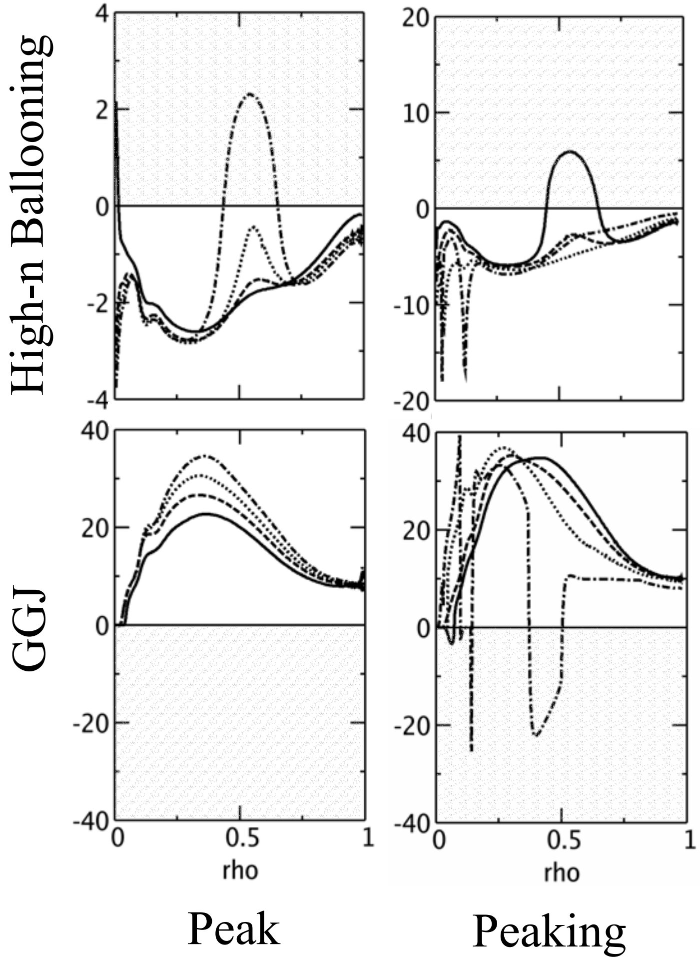
Stability for different current shapes

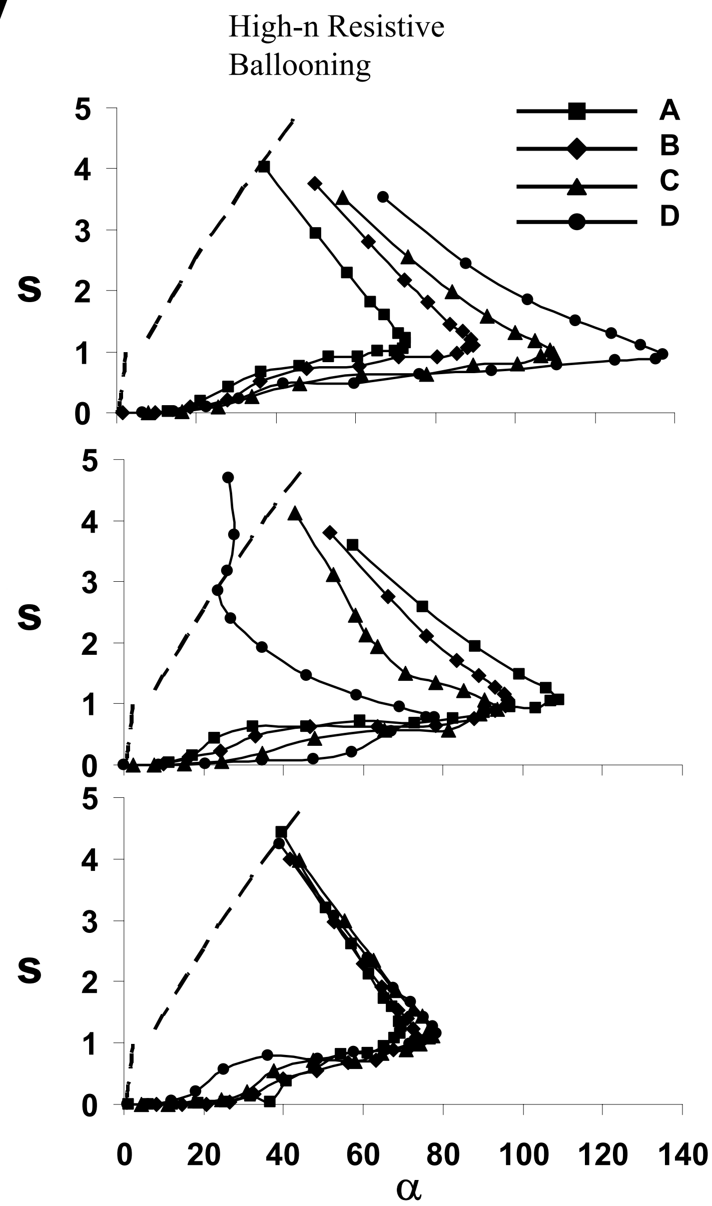
- Current Density Peak
- Current Density Peaking
- Current Density Transition

For more details -> PRL 97, 055003 (2006)



Stability





Mercier stable and all fixed boundary modes for toroidal mode numbers n = 1, 2, 3 are stable.

High beta path

It is possible to transition smoothly from low to high beta in a stable manner. This requires :

- Avoiding fixed boundary modes
- Correcting for free boundary modes (especially n =1 Troyon limit)
- Precise current profile control

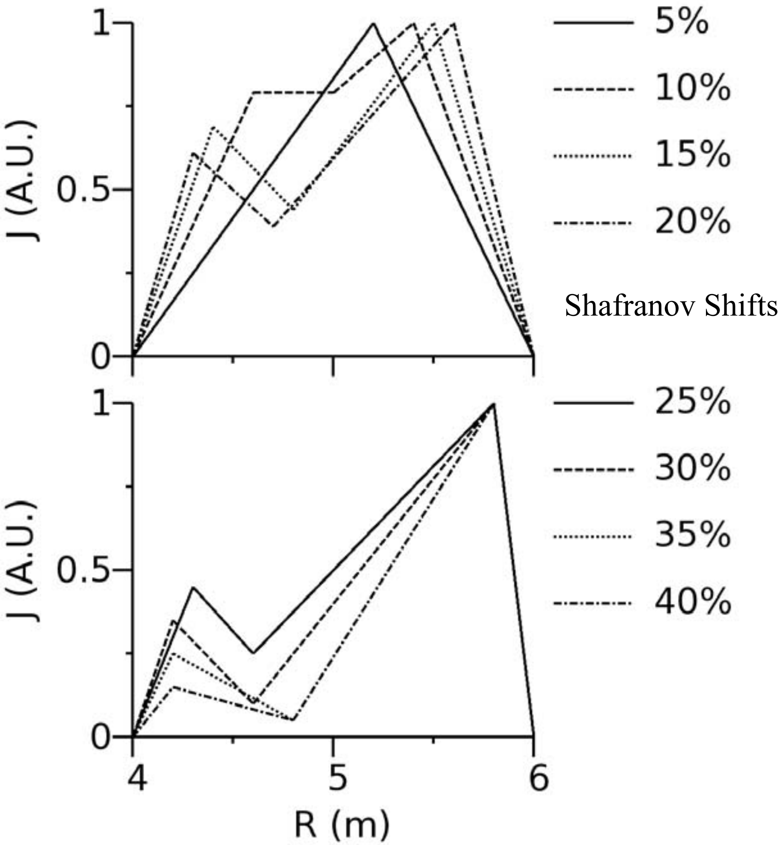
Free-boundary modes suppression by using a perfectly conducting wall or a set of coils that reproduce the effect of a perfectly conducting wall. DIII-D demonstrated the viability of such a scheme. Fixed boundary mode have to be avoided since they cannot be controlled by external means and their presence would make the whole operation impossible.

Local current profile control	have to be demonstrated experimentally …
Local pressure profile control	at high beta

Stable high beta path

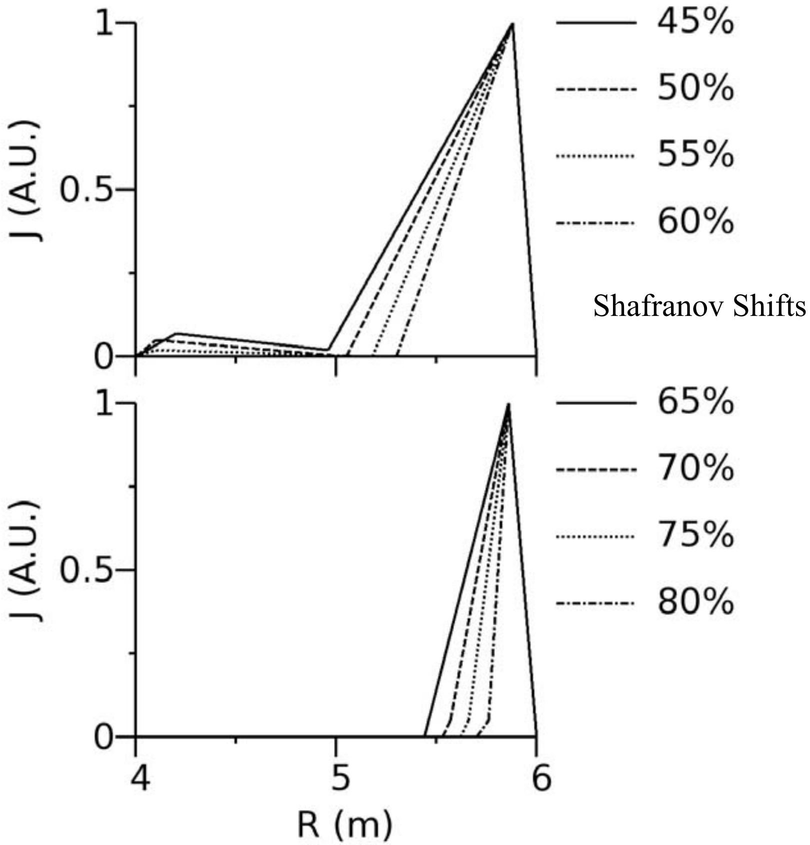
To obtain a stable path to high beta it is necessary to control locally the current profile.
Reverse shear generally triggers high-n ballooning modes and should be avoided.

Step 1



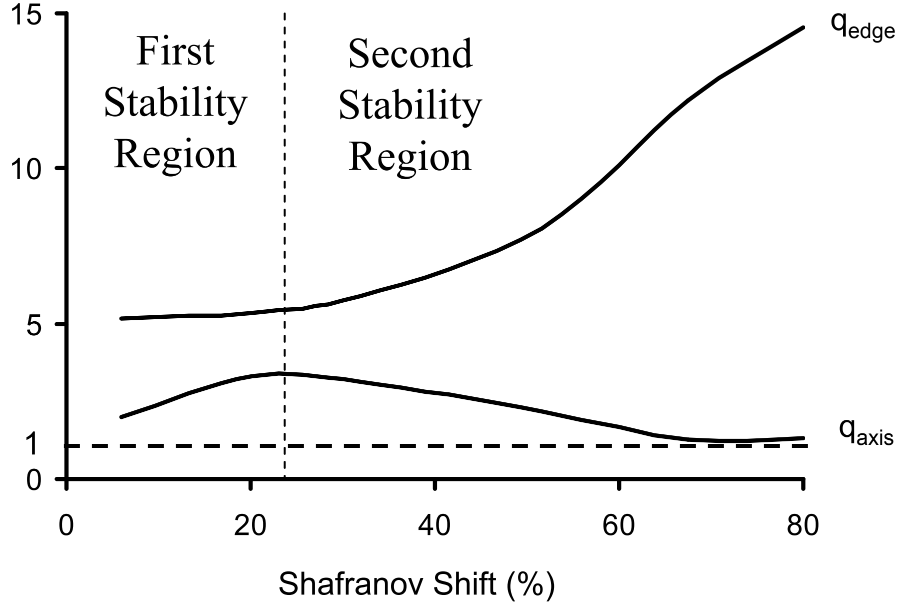
Counter current drive necessary

Step 2



Local heating for current diffusion to the LFS
Pressure profile control for bootstrap

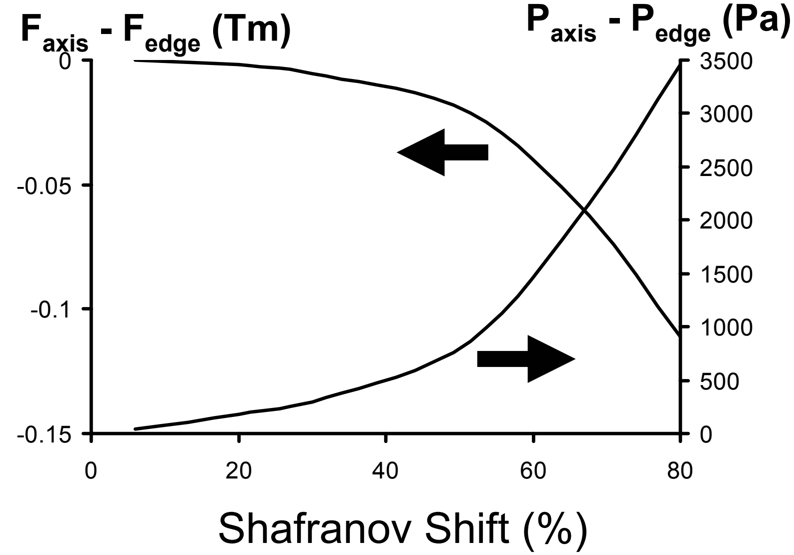
Profiles evolution without reverse shear



The evolution of the profiles show two phases.

1- Shear reduction at low pressure.

2- Once a low shear is obtained, the pressure can be increased until the profiles are in the second stability region.



The effects of the well are noticeable only when a shift of 50 % as been reached.

The ratio of pressures at low and high betas is roughly 10.

Unity beta scenario

The study presented above was for a low field high aspect ratio tokamak. But the path previously described can be adapted to DIII-D. Once a path has been identified, we propose a four-step experimental plan. The first steps will merge with the AT program target, the other steps will bring the machine beyond the AT performances.

Unity Beta

AT

Free boundary modes control

+

Step 1: Obtain a double winged current profile with a weak shear q-profile;

Step 2: Reduce then suppress the high field side current wing (entering the second stability regime);

Step 3: Use targeted ECH to let the current diffuse to the low field side;

Step 4: Increase the plasma pressure->bootstrap; correct current profile from bootstrap using localized current drive (magnetic axis and plasma edge)

Necessities for unity beta

To obtain a successful unity beta plasma on DIII-D many requirements are necessary

1- Control of free boundary modes using feedback coils (*extremely* important)
    on-going experiments with good success for $\beta_N \sim 4$
2- Current profile control using current drive and current diffusion
    ECCD hardware is present and will be upgraded
3- Long pulse necessary so current diffusion can take place (~ 100 s)
    is this planned on DIII-D ?
4- Pressure profile control
    density profile control (pellet, beam) -> already there
    temperature profile control (beams, ECCD) -> this is being improved

These requirements are also necessary upgrades to the AT program and the tokamak program in general. Diagnostics are necessary since feedback is key to stability: all necessary diagnostics are present on DIII-D but more precision is needed.

Also, computations have to be performed to tailor a high beta path for DIII-D => UCLA proposal jointly with GA (Alan Turnbull) to look at stability, modes and flows.