Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Rotation and Aspect Ratio Effects near the high β_p Equilibrium Limit

OP-XP-528	**Revision: 1.0**	Effective Date: 5/24/05 *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Author: S.A. Sabbagh	Date: 5/24/05
ATI – ET Group Leader: D.A. Gates	Date: 5/24/05
RLM - Run Coordinator: J.E. Menard	Date
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Rotation and aspect ratio effects near the high β_p equilibrium limit OP-XP-528

1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

The overall goal of the experiment is to examine toroidal rotation and aspect ratio effects on important plasma equilibrium variables and to compare experimental results to theory. Modifications of the equilibria due to rotation and aspect ratio increase with poloidal beta, so the experiment will utilize high poloidal beta plasmas. Another goal of the experiment is to generate equilibria that have only yet been theoretically envisioned. These equilibria will provide a full test of NSTX equilibrium reconstruction techniques with toroidal rotation included. Present MSE measurement capability will allow internal magnetic pitch angle constraint for superior equilibrium reconstruction. There is potential for accessing very high normalized beta, $\beta_N > 8$, reaching the NSTX conceptual design target for this parameter. Data will be taken over a high range of β_p, approaching the equilibrium limit, $\varepsilon\beta_p \sim 1.8$ at the highest values. This experiment aims to produce NSTX plasmas in a new region of operational stability space – one that theoretically has been expected to have improved confinement due to increased omnigeniety and drift reversal. Theoretical scalings of the bootstrap current can also be investigated in this ultra-high β_p regime.

2. Theoretical/ empirical justification

Brief justification of activity including supporting calculations as appropriate

Theoretical studies have shown that tokamak equilibria depend on aspect ratio, toroidal rotation velocity, and beta. For example, in the limit of high aspect ratio (small ε), the Shafranov shift is expected to scale with these parameters for a circular plasma as

$$\Delta_{\mathrm{Shafranov}}/a = 1/(2A)*(\beta_p\ (1 + 5/6\ M^2) + 1/4)$$

where is the toroidal Mach number. In standard and advanced tokamak operating regimes, dependencies on these key parameters have been addressed. However, the scalings on these parameters have never been addressed experimentally at extreme values. NSTX allows us to investigate the dependence of the equilibrium at very low aspect ratio, high Mach number, and β_p approaching the equilibrium limit. Although the attainable variation of aspect ratio in NSTX is not large (1.27 - 2+), the A^{-1} dependence of parameters such as shown in Equation 1 will allow the variation to be observed. The relative shift between magnetic axis and peak pressure at finite toroidal rotation also exhibits an A^{-1} dependence, as shown in Fig. 1 for D-shaped theoretical equilibria. As indicated in Equation 1, the variation as a function of A is amplified at high β_p and Mach. This is one motivation for operating this experiment at the highest values possible.

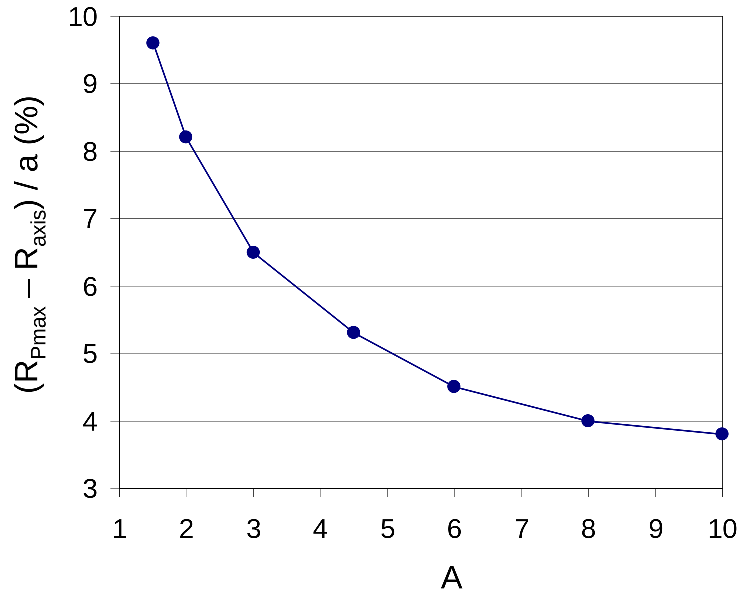


Fig. 1: Dependence of difference between magnetic axis and peak pressure position as a function of aspect ratio for theoretical D-shaped equilibria.

Past experimental plasma operation shows good potential for reaching the target conditions of this experiment. The present experiment is a continuation of XP414. That experiment could not be completed in 2004 due to the restriction of toroidal field to 0.3T during the last several weeks of the run. The initial experiments in 2004 yielded high β_N nearly reaching 7, with β_p up to 2 (FIG. 2).

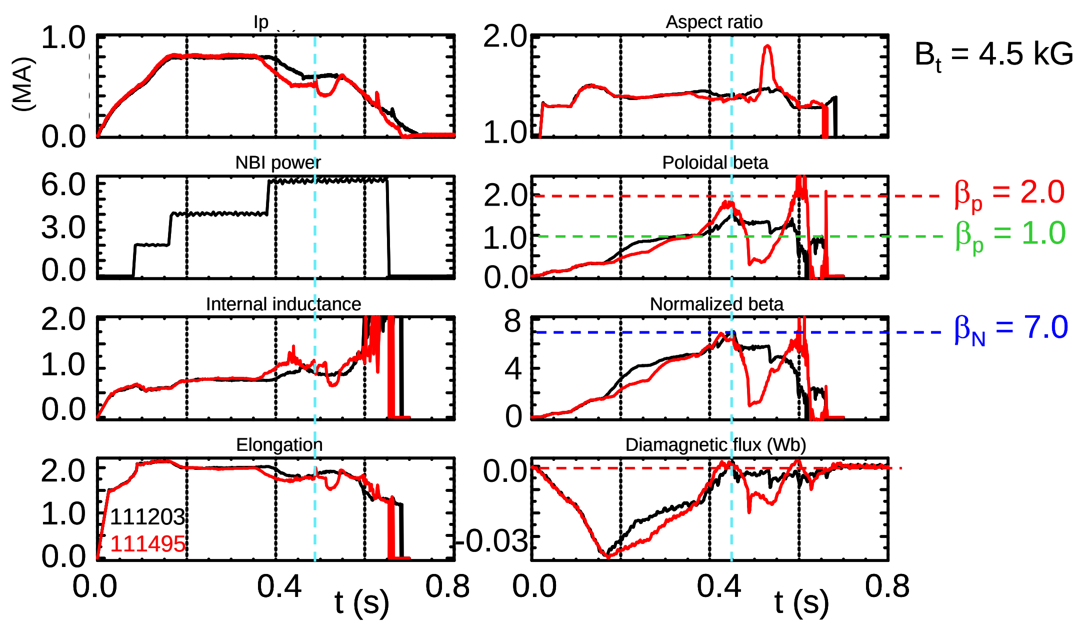


Fig. 2: Time evolution of several plasma parameters in an existing NSTX plasma that reached $\beta_p \sim 2$ and $\beta_N \sim 7$.

The plasma current ramp-down technique was successful in producing increased l_i, β_p, β_N, and produced a clear swing in the diamagnetic flux toward diamagnetism. Mild diamagnetism ~ 2 mWb was produced. These plasmas were performance-limited by toroidal mode number n = 1 activity that resulted in the termination of the high β_p phase before the equilibrium limit was reached. Poloidal flux plots of the equilibria during the initial high β_p phase and at maximum β_p are shown in FIG. 3. In the latter phase, the vertical field at the inboard midplane is reduced by more than a factor of four, and is close to the equilibrium limit – the point at which the poloidal field at the inboard plasma midplane becomes zero.

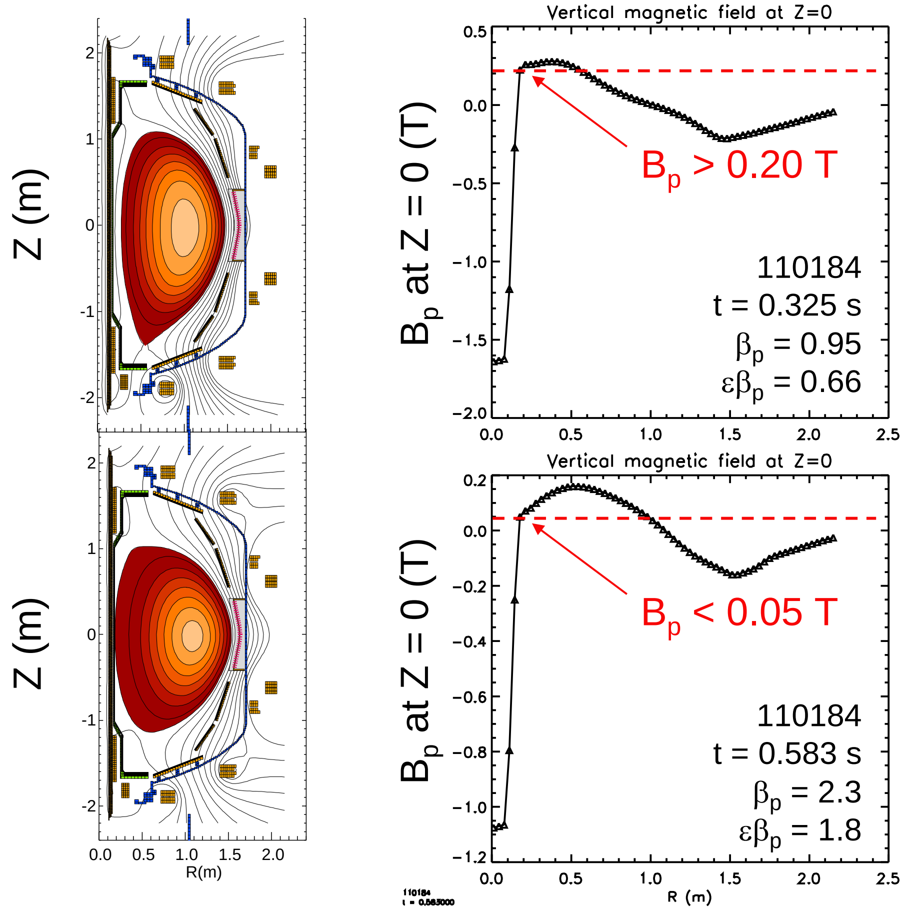


Fig. 3: Poloidal flux plots for high β_p = 0.95 plasma before decrease in I_p in discharge 110184 and subsequent maximum β_p = 2.3 – near the equilibrium limit.

Xp414 was run for an afternoon at the end of 2004 when the machine was constrained to operation at B_t = 0.3T. While the performance targets could not be reached with this constraint, a potential answer to the limiting n = 1 instability may have been found. Notice in FIG. 2 that the plasma elongation was basically left uncontrolled during the reduction in I_p leading to high l_i. In the last run of Xp414, elongation was maintained to be greater than 2 during the high l_i phase, and this eliminated the strong n=1 activity, allowing β_N to further increase ($\Delta\beta_N$ = 1).

3. Experimental run plan

The plan is to complete the original Xp414 run plan using our present superior target plasmas at B_t = 0.45T and to develop a discharge evolution that maintains plasma elongation above 2, with the goal of minimizing or eliminating n=1 MHD activity. Three independent variables in the present study are β_p, aspect ratio, and toroidal flow velocity. Since the most interesting and unique results are had at the highest possible rotation speed, attention would be placed on varying the former variables. Two or three values of aspect ratio are desired and β_p will naturally be scanned during plasma heating and I_p reduction.

A recent high β_p, high β_N plasma with I_p = 0.9 – 1.0 MA, B_t = 0.45T would be used as a template from which to develop. Targets with small or no n=1 MHD activity during the period of I_p reduction, such as 115763 would be used. This plasma reached β_N = 5.7 without current profile modification, and so has good potential for reaching new highs in β_N and β_p. Shot 115856 is another good template plasma, since it has I_p = 1.0 MA and reached a recent high for plasma stored energy of 0.3 kJ. This shot does show a longer period of n = 1 activity, but a window of time without this activity occurs after t = 0.47s (reduce I_p between t = 0.5 – 0.6s). This shot also has higher elongation exceeding 2.4. The present experimental run would utilize plasmas in the approximate range 0.5 < I_p (MA) < 1.2. Gas puffing will be used during the I_p ramp-down if reconnection events lead to reduction in beta.

A major efficiency in data collection in this experiment is that equilibrium data can be taken throughout a discharge. Shot 115763 showed a slow evolution of aspect ratio. As β_p saturates before the decrease in I_p, a small variation in aspect ratio can be had. However, it will most likely be necessary to vary aspect ratio over several shots (for development), with β_p primarily chosen just before, and just after the decrease in I_p. NBI power would be set to maximum for most discharges. The β_p will then be varied by changing plasma current.

RUN PLAN: Scan aspect ratio and poloidal beta

Task		Number of Shots
A) **<u>Use shot 115763 or 115856 as setup, B_t = 4.5 kG</u>**, maintain fixed, low aspect ratio < 1.35; I_p ramp-down to 0.5 MA, full NBI power standard control system (*** don't use rtEFIT for this XP ***)		
(i) Rerun template shot (β_N = 5.7 pre-I_p ramp target); early H-mode)		1
(ii) Initial Ip = 1.0 MA		4
(iii) Initial Ip = 0.5 MA (2 NBI sources first, 3 if required to raise b)		2
(iv) Attempt initial Ip = 1.2 MA		4
(v) (optional) Bt = 4.5kG ramp-down to 3.0kG at time of I_p ramp	(2)	
B) Repeat with A increasing to 1.6 by increasing inner gap		6
C) Repeat with A increasing to maximum by increasing inner gap		6
Total shots:	(25)	23

It is expected that 1.0 - 1.5 run days will be required to complete the planned shot list.

I_p will be decreased to a plateau value and held constant for at least 2 energy confinement times (~ 100 ms). Aspect ratio may decrease (until the equilibrium limit is reached) during this time and will be difficult to control. Variation on aspect ratio near the equilibrium limit will be attempted, but it is not expected that a straightforward, independent scan of aspect ratio and β_p will possible for all values of these parameters. Although the template shot is a double null configuration for most of the shot, we need not maintain this configuration for the present experiment. It is desired to use the same configuration throughout the XP.

4. Required machine, NBI, RF, CHI and diagnostic capabilities

Describe any prerequisite conditions, development, XPs or XMPs needed.
Attach completed Physics Operations Request and Diagnostic Checklist

As usual, standard magnetic diagnostics are essential. Diamagnetic loop and Thomson scattering are required since partial kinetic EFIT reconstructions will be essential for this experiment. The MSE diagnostic is also required for superior q profile reconstruction. Since the experiment also needs to have rotation profile data for equilibrium reconstruction, the CHERS diagnostic is required. If CHERS data is made available between-shots, the full equilibrium analysis of the experiment can also be produced between-shots, and will provide the most efficient execution of the experiment. However, it is not required to have calibrated CHERS available between-shots to run the experiment.

5. Planned analysis

What analysis of the data will be required: EFIT, TRANSP, etc.

Normal magnetics-only and partial-kinetic EFIT will guide the experimental run. EFIT with toroidal rotation will provide the primary analysis for the experimental results. TRANSP runs will be requested to investigate bootstrap current fraction and profile as a function of β_p and aspect ratio. DCON analysis will be used to verify that very high β_N plasmas are indeed stable, verifying that a favorable scaling of β_N with internal inductance applies to the operational regime near the equilibrium limit.

6. Planned publication of results

What will be the final disposition of the results; where will results be published and when?

The EFIT reconstruction technique including plasma rotation has never been published in a refereed journal. It would be appropriate to publish this general technique as part of the present experiment. Lang Lao, the author of EFIT, has endorsed this publication approach. The scaling studies made in this experiment would also published, along with an illustration of the low aspect ratio, high β_N , high β_p equilibria generated, and the associated high β_p physics examined including magnetic field alteration, stability physics, and detail of the bootstrap current.

PHYSICS OPERATIONS REQUEST

Rotation and aspect ratio effects near the high β_p equilibrium limit **OP-XP-528**

Machine conditions (specify ranges as appropriate)

B_{TF} (T): **0.45** Flattop start/stop (s): _____/_____

I_P (MA): **1.2 MA** Flattop start/stop (s): _____/_____

Configuration: **Inner Wall / Lower Single or Double Null**

Outer gap (m): **0.04,** Inner gap (m): **0.0 – 0.025**

Elongation κ: **2.0 – 2.6**, Triangularity δ: **0.4 – 0.6**

Z position (m): **0.00**

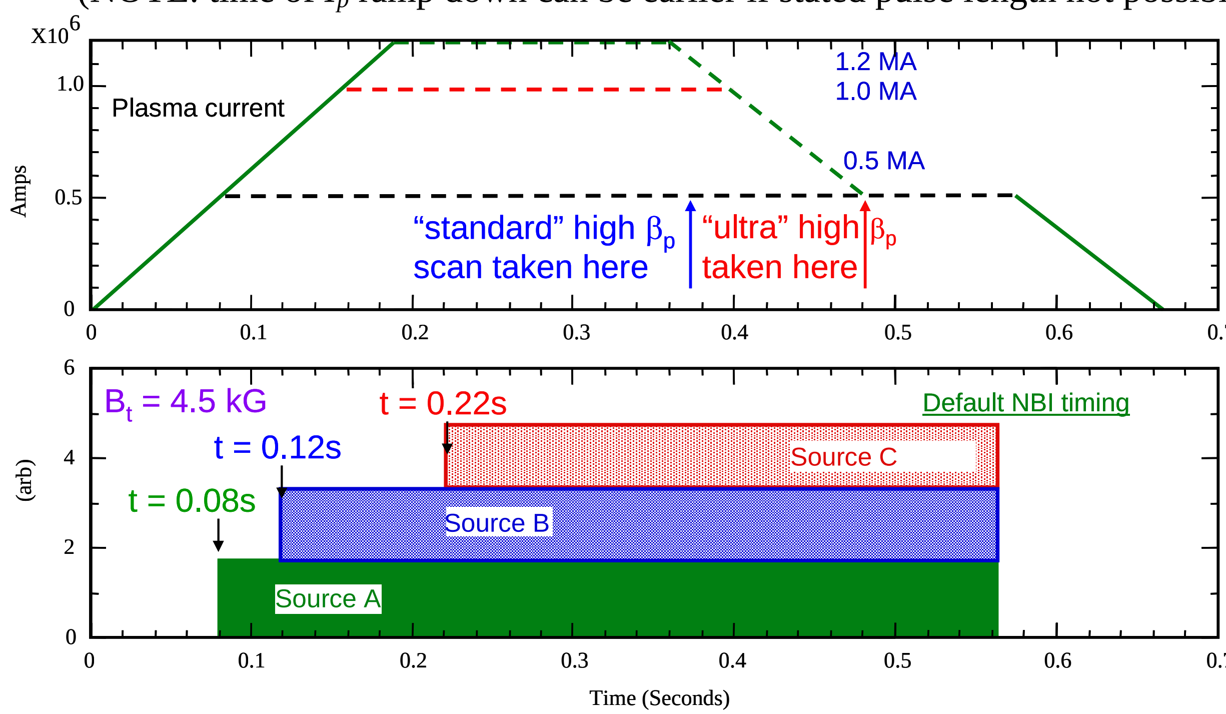
Gas Species: **D: During I_P ramp if required** Injector: **Midplane / Inner Wall**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **90,100,100 kV** Duration (s): **0.6 s**

ICRF – Power (MW): ____, Phasing: Heating / CD, Duration (s): _____CHI: Off

Either: List previous shot numbers for setup: **115763, 115856, +attached waveforms**

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating. (NOTE: time of I_p ramp down can be earlier if stated pulse length not possible.



DIAGNOSTIC CHECKLIST

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Diagnostic	Need	Desire	Instructions
Bolometer – tangential array			
Bolometer array - divertor			
CHERS	X		
Divertor fast camera		X	
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy		X	
Fast lost ion probes - IFLIP			
Fast lost ion probes - SFLIP			
Filtered 1D cameras			
Filterscopes			
FIReTIP			
Gas puff imaging			
Infrared cameras			
Interferometer - 1 mm			
Langmuir probe array			
Magnetics - Diamagnetism	X		
Magnetics - Flux loops	X		
Magnetics - Locked modes	X		
Magnetics - Pickup coils	X		
Magnetics - Rogowski coils	X		
Magnetics - RWM sensors	X		
Mirnov coils – high frequency		X	
Mirnov coils – poloidal array		X	
Mirnov coils – toroidal array	X		
MSE	X		
Neutral particle analyzer			
Neutron measurements			
Plasma TV	X		
Reciprocating probe			
Reflectometer – core			
Reflectometer - SOL			
RF antenna camera			
RF antenna probe			
SPRED			
Thomson scattering	X		
Ultrasoft X-ray arrays		X	
Visible bremsstrahlung det.			
Visible spectrometers (VIPS)			
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray pinhole camera			