VALEN Analysis of RWM Active Feedback in NSTX

study is part of group design effort:
NSTX Global Mode Stabilization

NSTX Results & Theory Review
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PPPL

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OUTLINE

- Motivation
- **VALEN** computer code, quick review & necessary background
- calculation of passive growth rates for n=1 NSTX instabilities (always > 0)
- RWM Active Feedback in NSTX using mode control (goal: n=1 growth rate with feedback < zero)
- Proposed configurations and predicted performance
- Conclusions and near term plans

Motivation

- Stabilization of kink/ballooning modes is essential for high (β_n) performance.

- A Resistive Wall Mode (RWM) is a Kink Mode that would be stabilized if the nearby wall surrounding the plasma were a perfect conductor.

- RWM stability depends on choice of plasma parameters, passive stabilization, and active stabilization (control coils are energized when a RWM is detected)

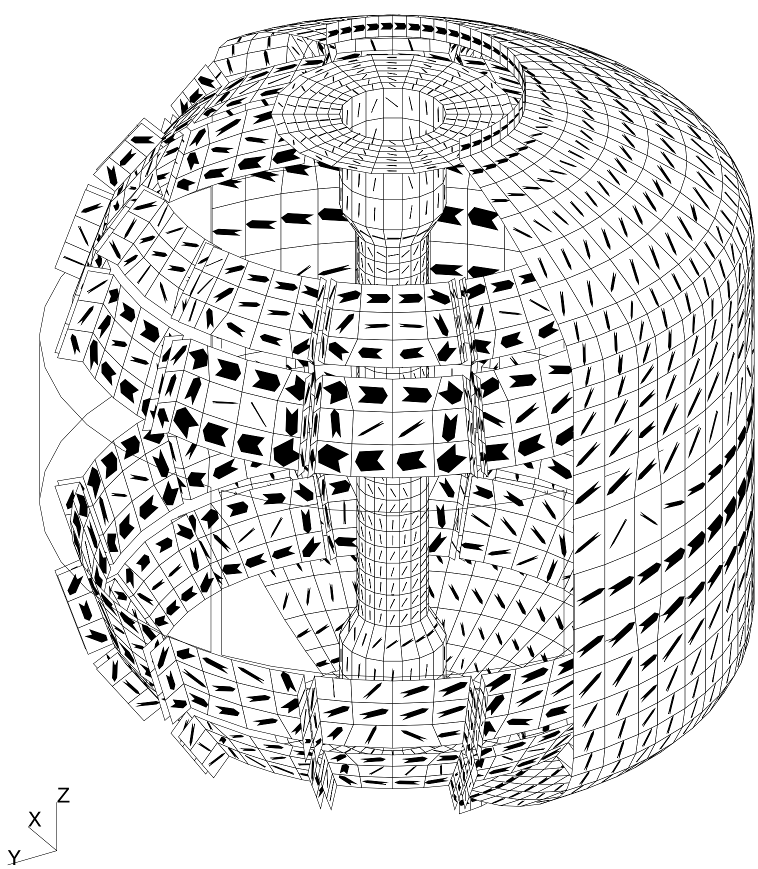
- Realistic modeling of NSTX geometry includes conducting structure, magnetic sensors, and control coils.

- **VALEN** was created to study stabilization of RWM via passive and active techniques

VALEN combines 3 capabilities

see PoP **8 (5)**, 2170 (2001) – Bialek J., et al.

- Unstable Plasma Model (PoP Boozer 98)
- General 3D finite element electromagnetic code
- Arbitrary sensors, arbitrary control coils, and most common feedback logic (smart shell and mode control)



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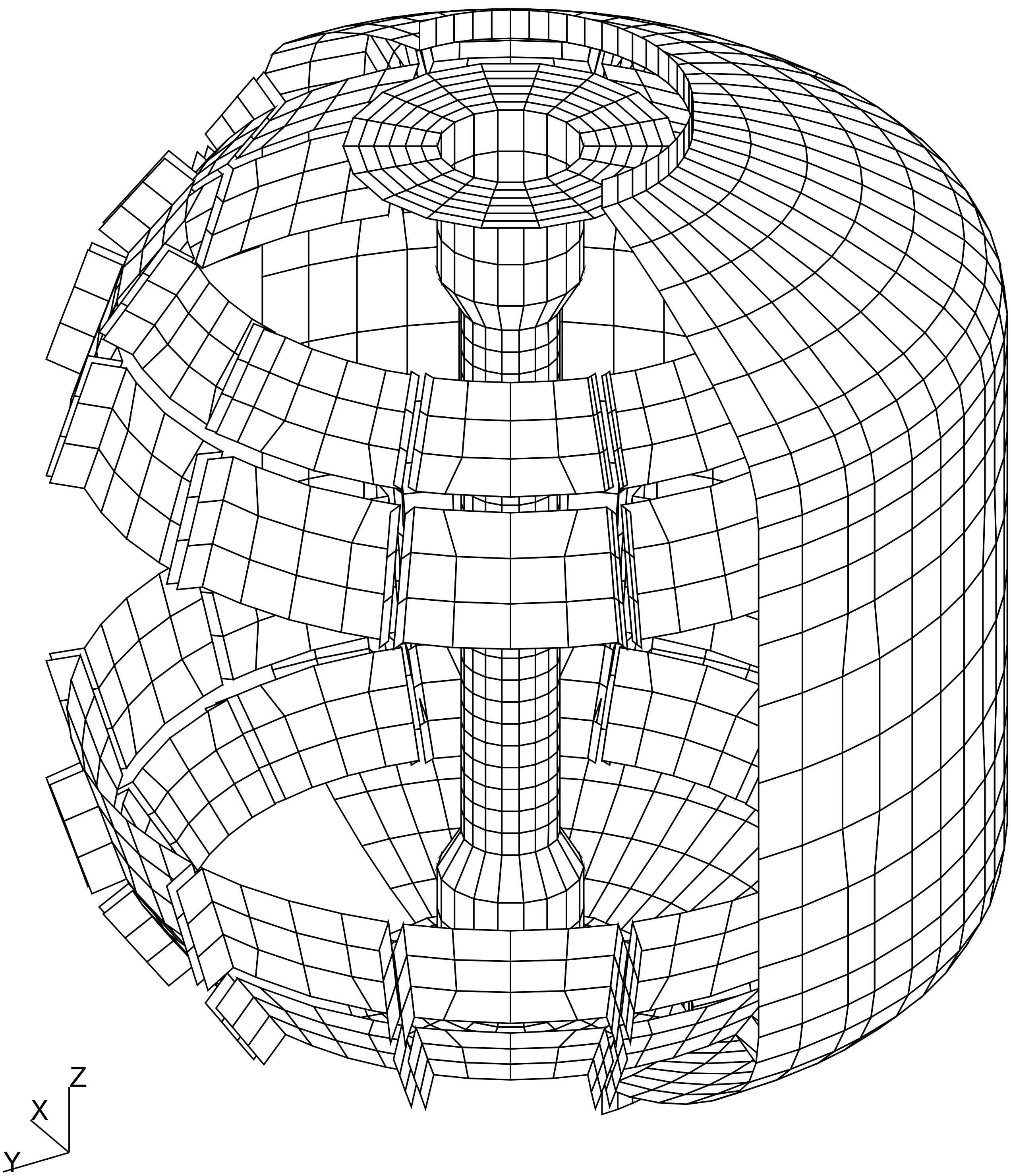
NSTX model

NSTX geometry modeled in VALEN



Computation of passive growth rates for unstable plasmas

- unstable mode taken from EFIT reconstruction of actual NSTX experimental data, used in DCON stability calculation, then analyzed with VALEN

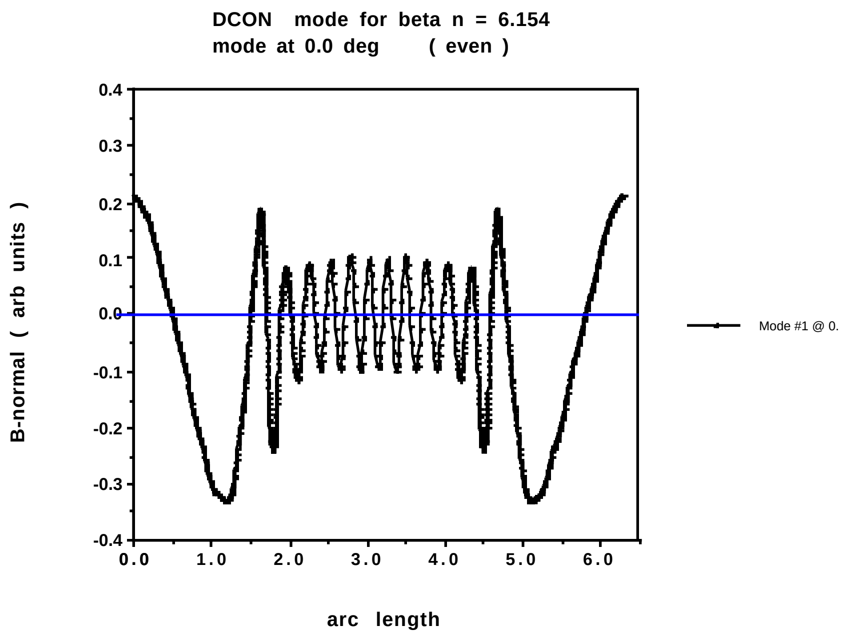
- NSTX, in shot #106165 RWM was observed with a growth time of 5 ms, VALEN estimate was 4.6 ms !
(Sabbagh APS invited talk, 2001)

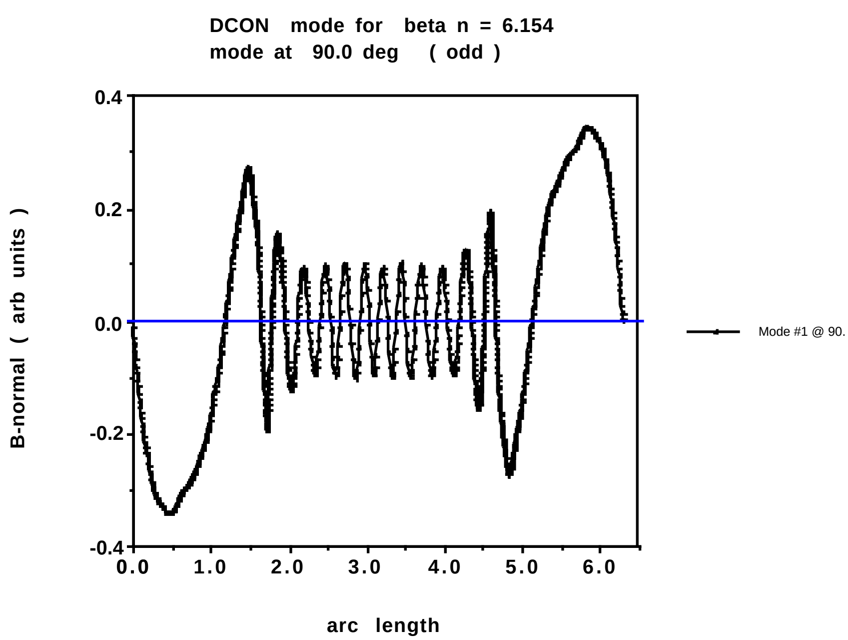
- Sabbagh talk on recent NSTX experimental results (previous talk)

- We have used VALEN to predict passive performance for proposed equilibria (vary β_n)

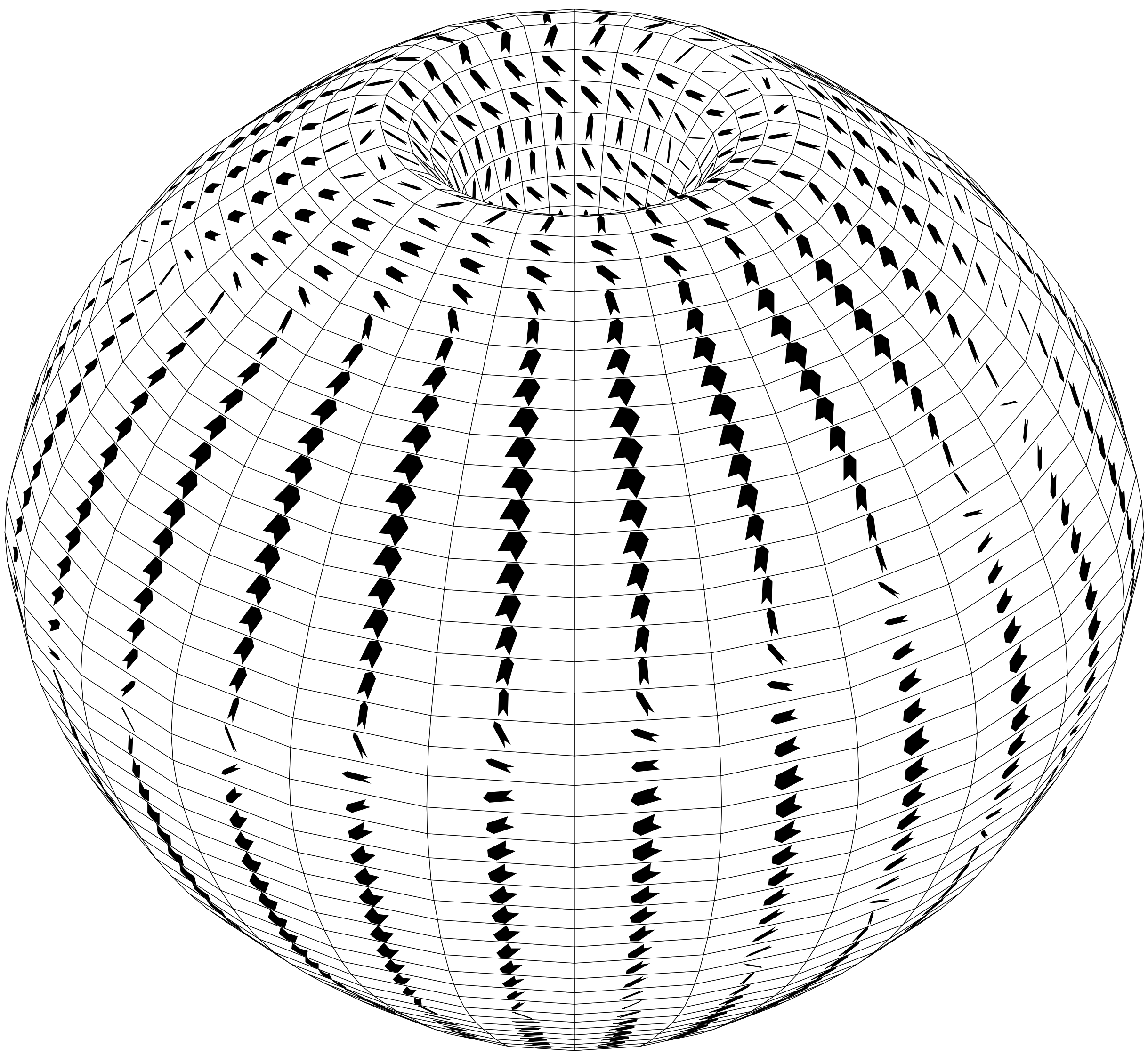
DCON computation of mode structure NSTX - derived from EFIT reconstruction of #106165

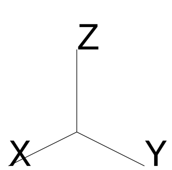
β_n = 6.154, Fp = 2.2, n = 1





Equivalent Surface Current which produces mode field
from dcon_surf_Fp2.2_bn6.154 24 by 72
Input to VALEN for NSTX 's'= 2.0590e-1





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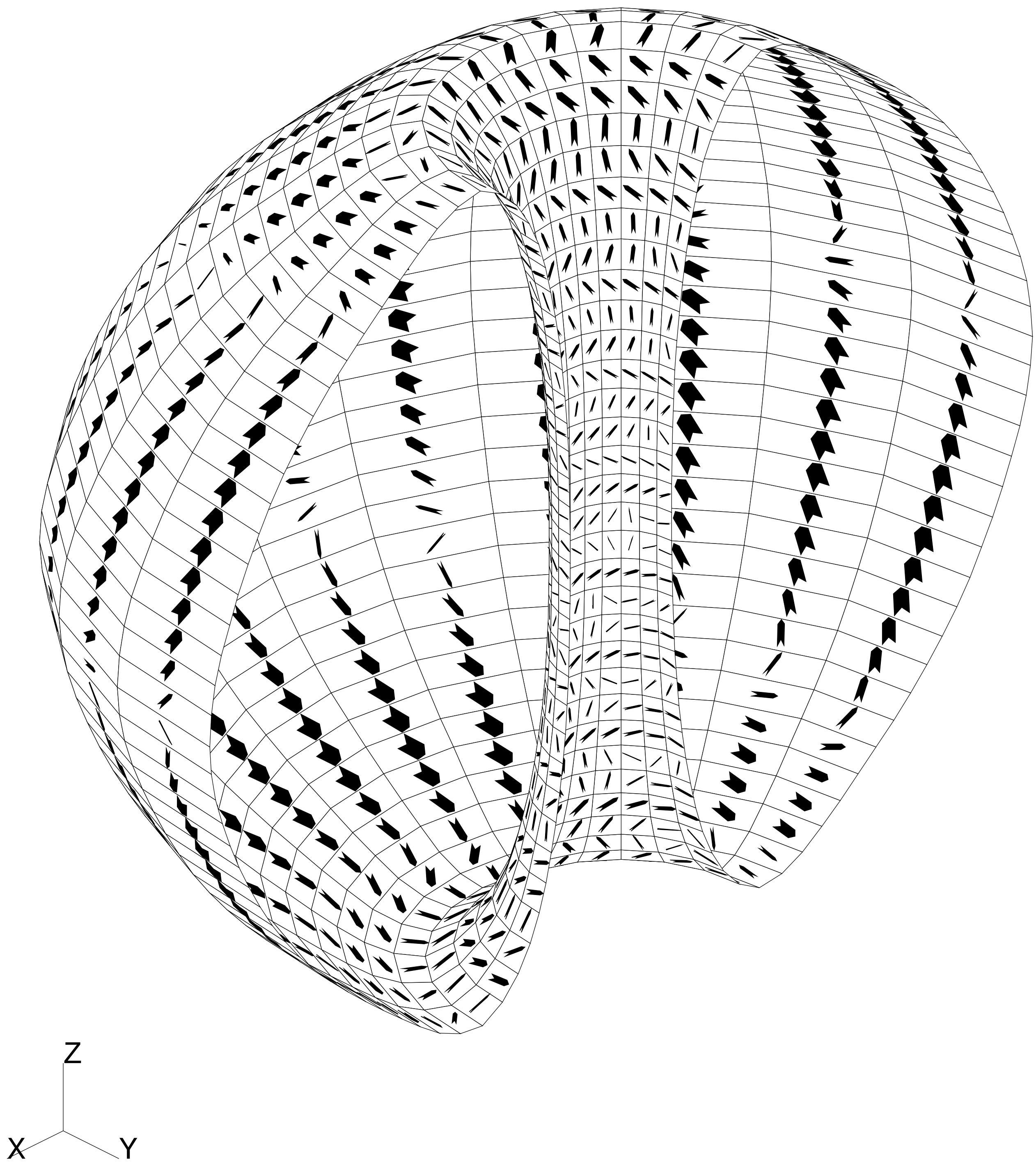
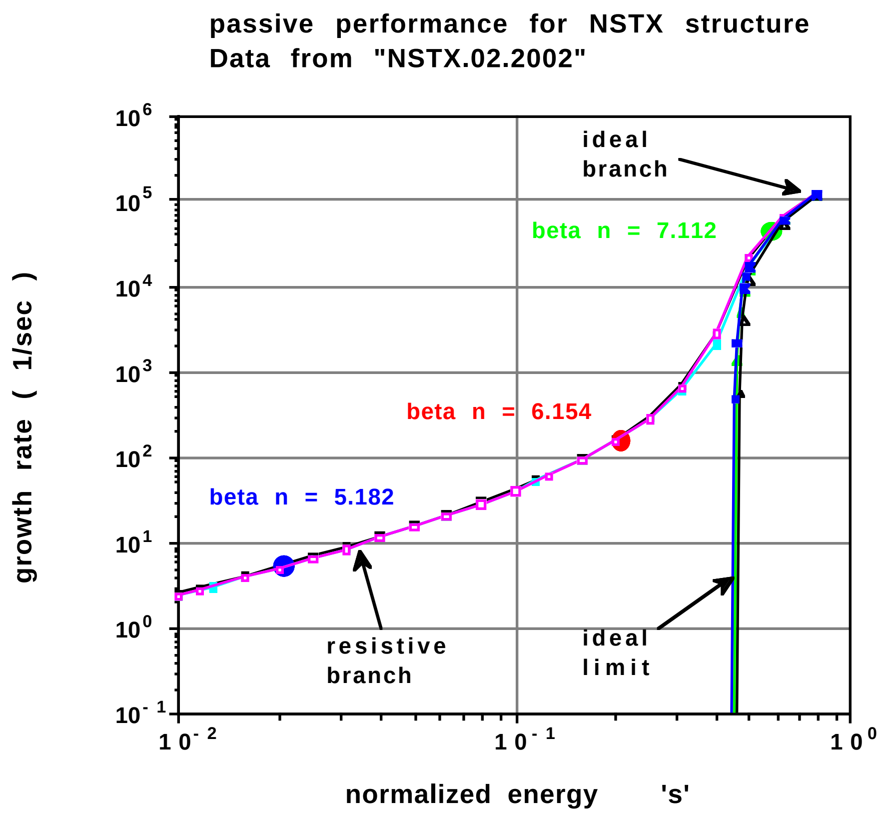


VALEN predicts growth rate for plasma instability as function of 's'

- examine limit of perfect conductors
- connect s to β_n



now add mode control feedback

RWM Active Feedback - mode control

- Other experiments (HBT, DIII-D) have tried both 'smart shell' and 'mode control' configurations for active feedback on RWM, mode control performs best.

- Mode control uses magnetic sensors to globally identify a RWM and then activates all control coils.

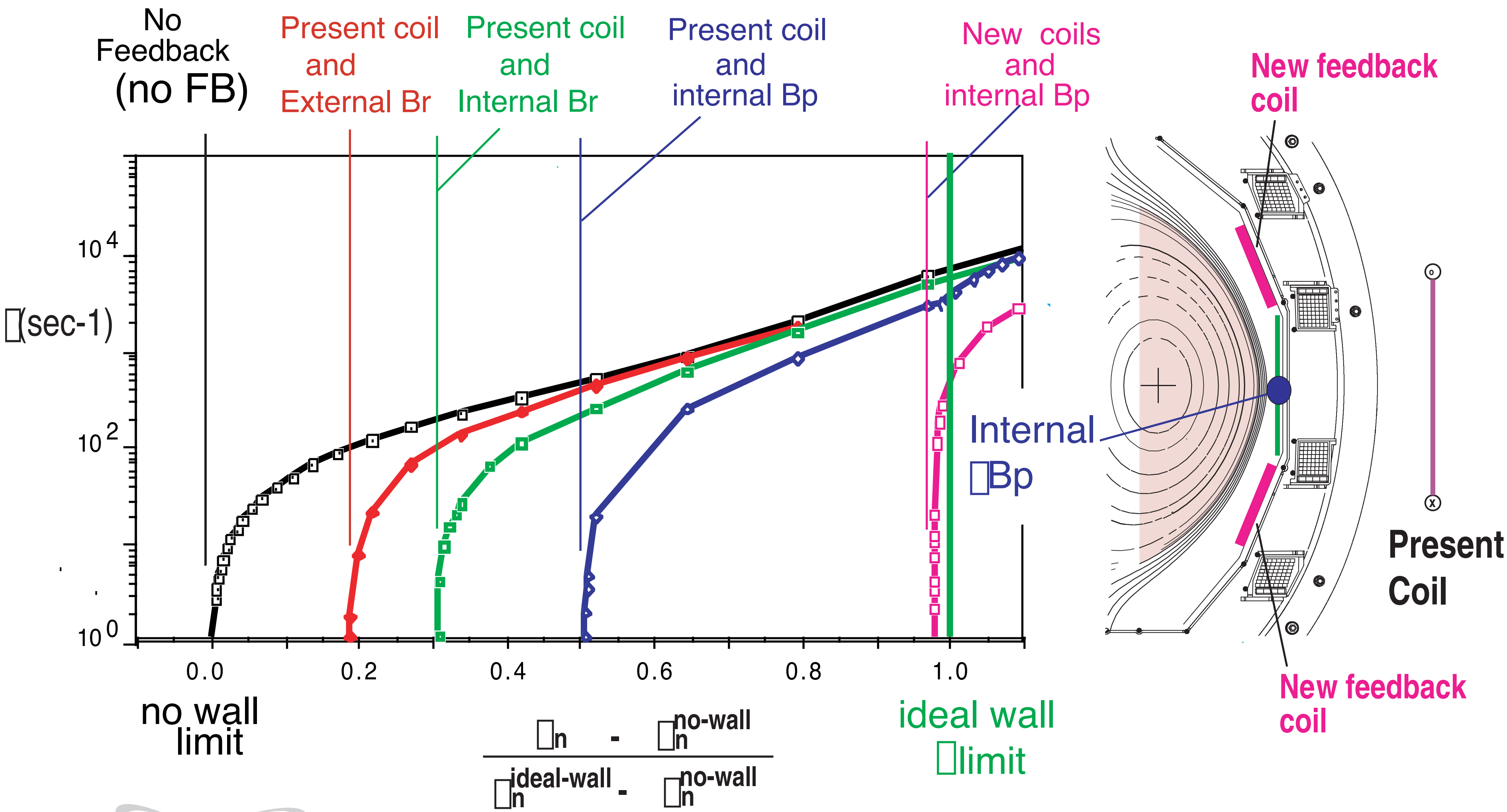
- Experiment and VALEN computations agree, best performance when:

1) magnetic sensors are located inside the vacuum vessel and perpendicular to field from control coils

2) control coils as close as possible to the plasma, and have minimum coupling to conducting structure.

PROPOSED IMPROVEMENT OF RWM FEEDBACK ON DIII-D

Additional six upper- and six lower- coils and internal Bp sensors increase achievable β very close to ideal-wall β limit (VALEN CODE / no rotation)



DIII-D NATIONAL FUSION FACILITY SAN DIEGO

PPPL PRINCETON PLASMA PHYSICS LABORATORY

294-01/jy

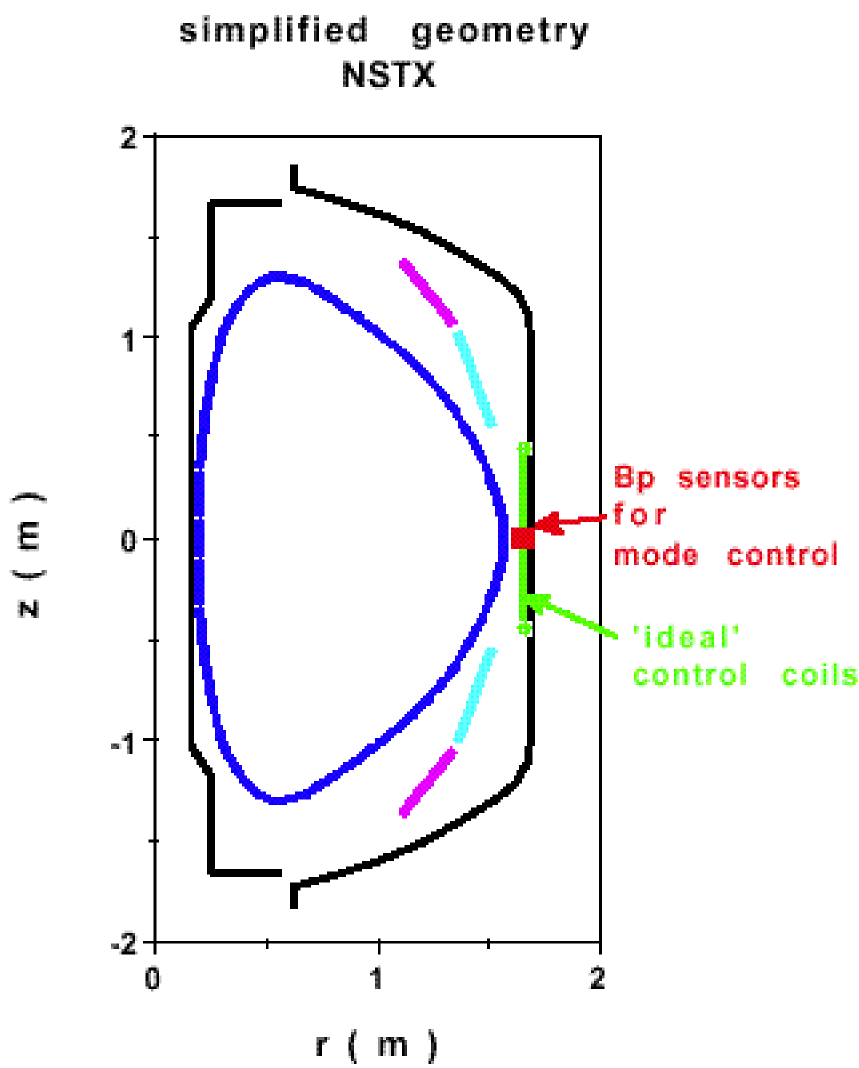
PROPOSED CONFIGURATIONS & PREDICTED PERFORMANCE

- 'best option' Control Coils inside vacuum vessel, 6 'picture frame' coils on machine mid plane connected pairwise (3 circuits), B_p magnetic sensors at center of control coils, mode control.

- 'exterior option' Control Coils outside vacuum vessel, 6 'picture frame' coils on machine mid plane connected pairwise (3 circuits), Bp magnetic sensors still inside the vacuum vessel (same as 'best option'), mode control

- 'primary plate option' Control Coils inside vacuum vessel, each coil surrounds 2 adjacent primary passive plates, 12 coils total (6 up & 6 down), connected pairwise (6 circuits), same sensors as 'best option', mode control.

- we want the control coils to be directly coupled to the plasma with minimum coupling to the copper passive plates



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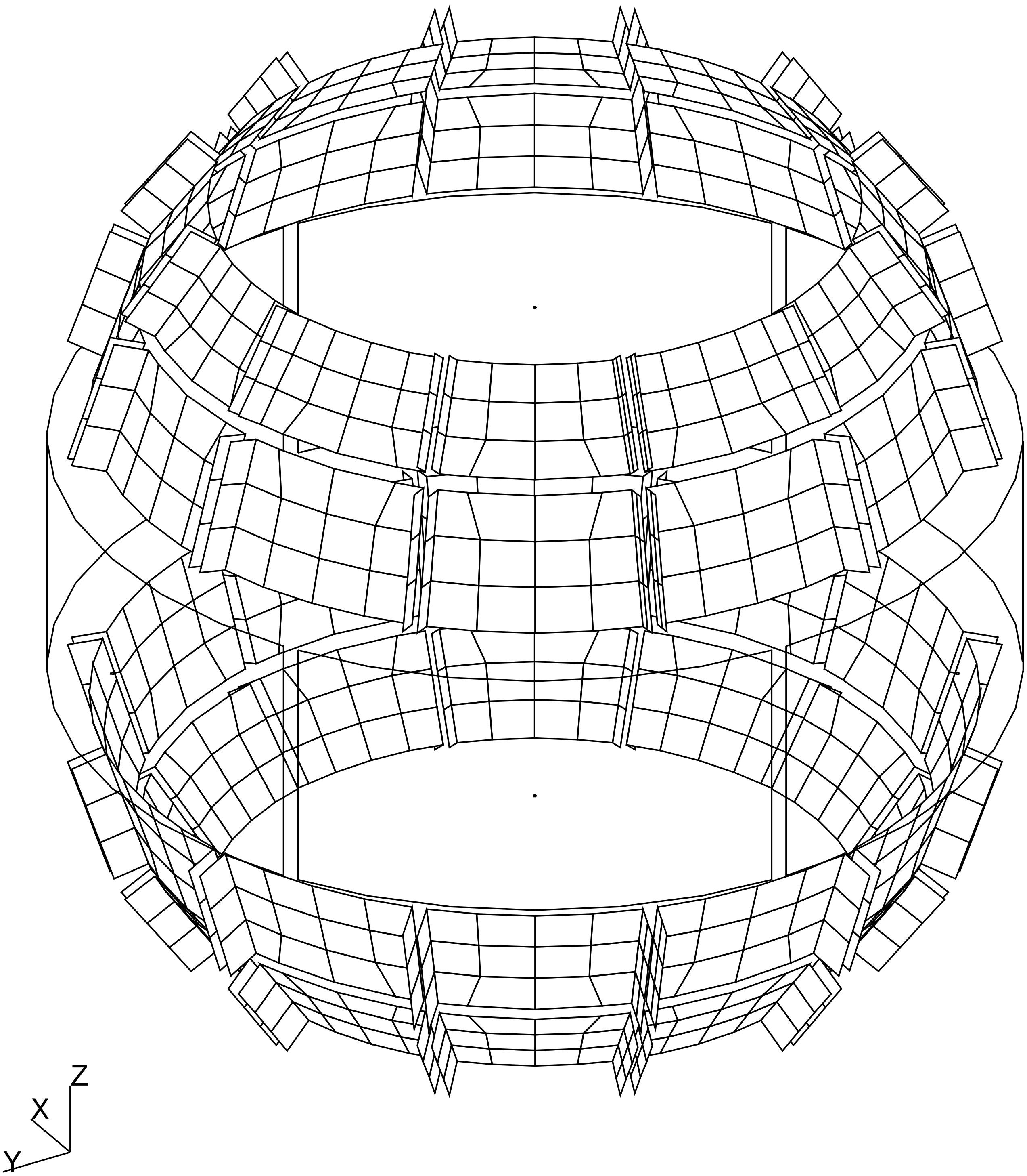
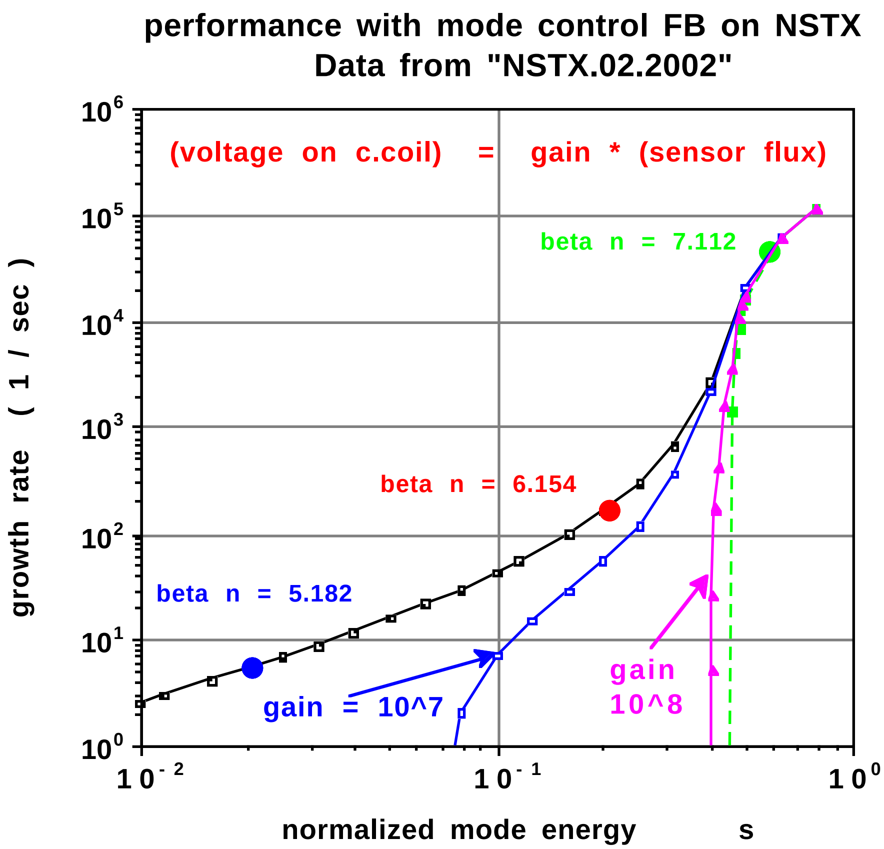
NSTX FB model#1

Geometry for model #1 (internal c.coils with Bp sensors)



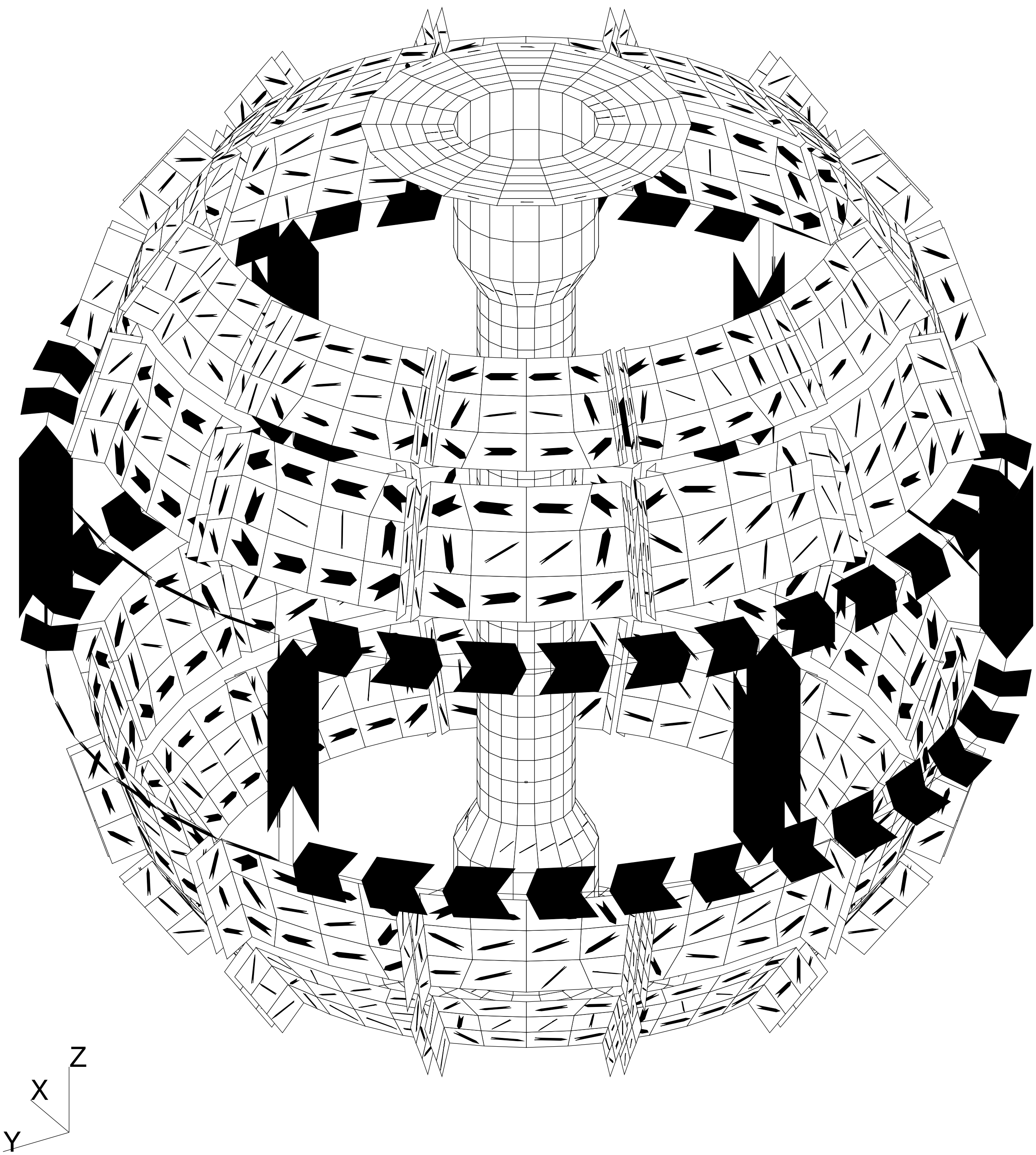
NSTX can reach 94% of the ideal wall limit using mode control active feedback in 'optimal system'

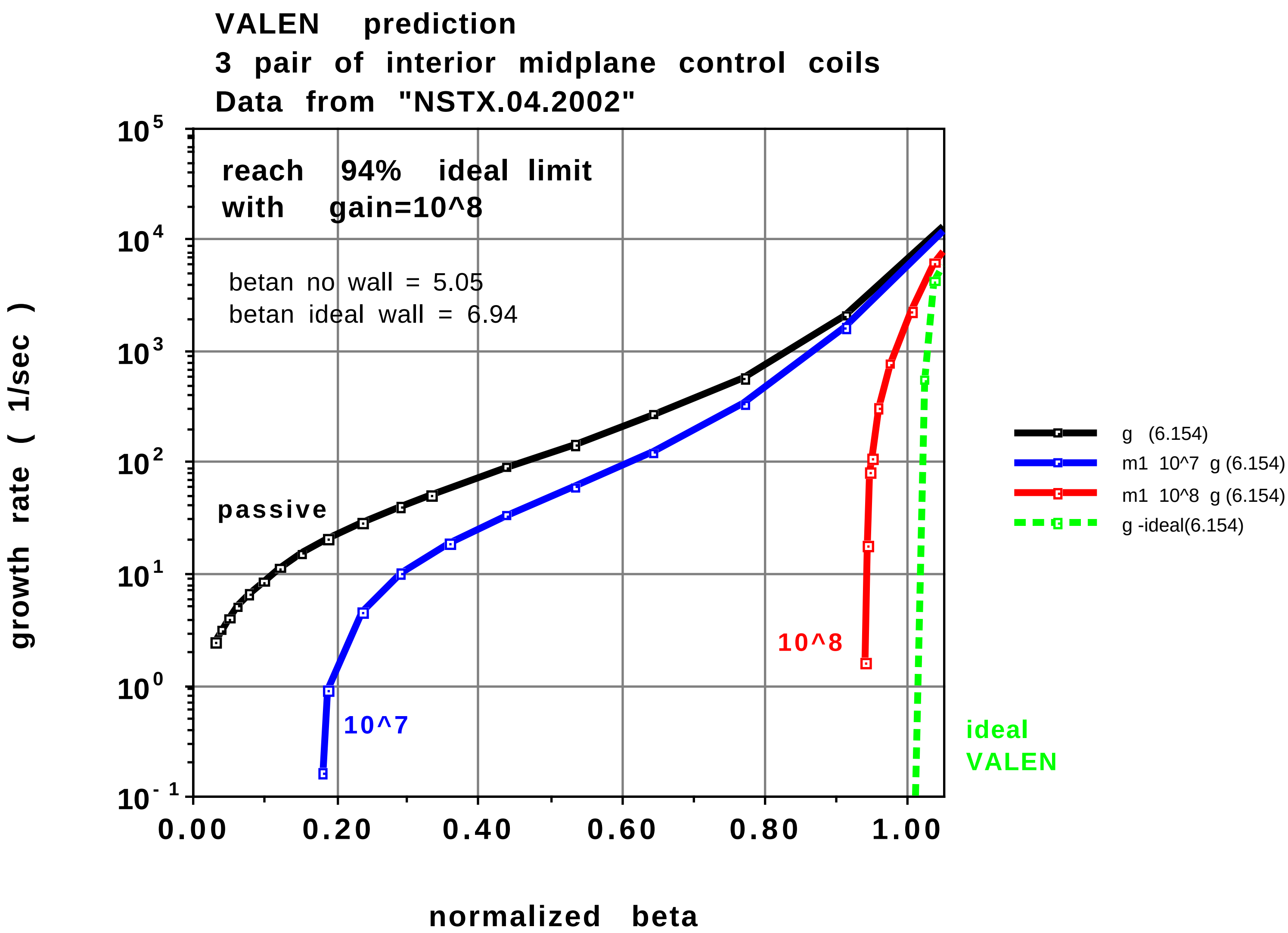


- max B_p sensor flux * gain = max voltage on control coil, for 1 gauss at sensor and 10^8 gain, we would apply 1.0 volt to control coil, units for gain are [volt / weber]
- β_n = 5.182 stable at a gain of 10^7

  β_n = 6.154 stable at a gain of 10^8

03/15/02 current in coil 3* mesh current in p. pp
VALEN s = 0.205900 gamma = 0.653959E+02
gain = 10^7 and betan = 6.154 (mode not stabilized)





VALEN prediction
3 pair of interior midplane control coils
Data from "NSTX.04.2002"
reach 94% ideal limit
with gain=10^8
betan no wall = 5.05
betan ideal wall = 6.94
passive
10^7
10^8
ideal
VALEN
growth rate (1/sec)
normalized beta
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0.00
0.20
0.40
0.60
0.80
1.00
g (6.154)
m1 10^7 g (6.154)
m1 10^8 g (6.154)
g -ideal(6.154)

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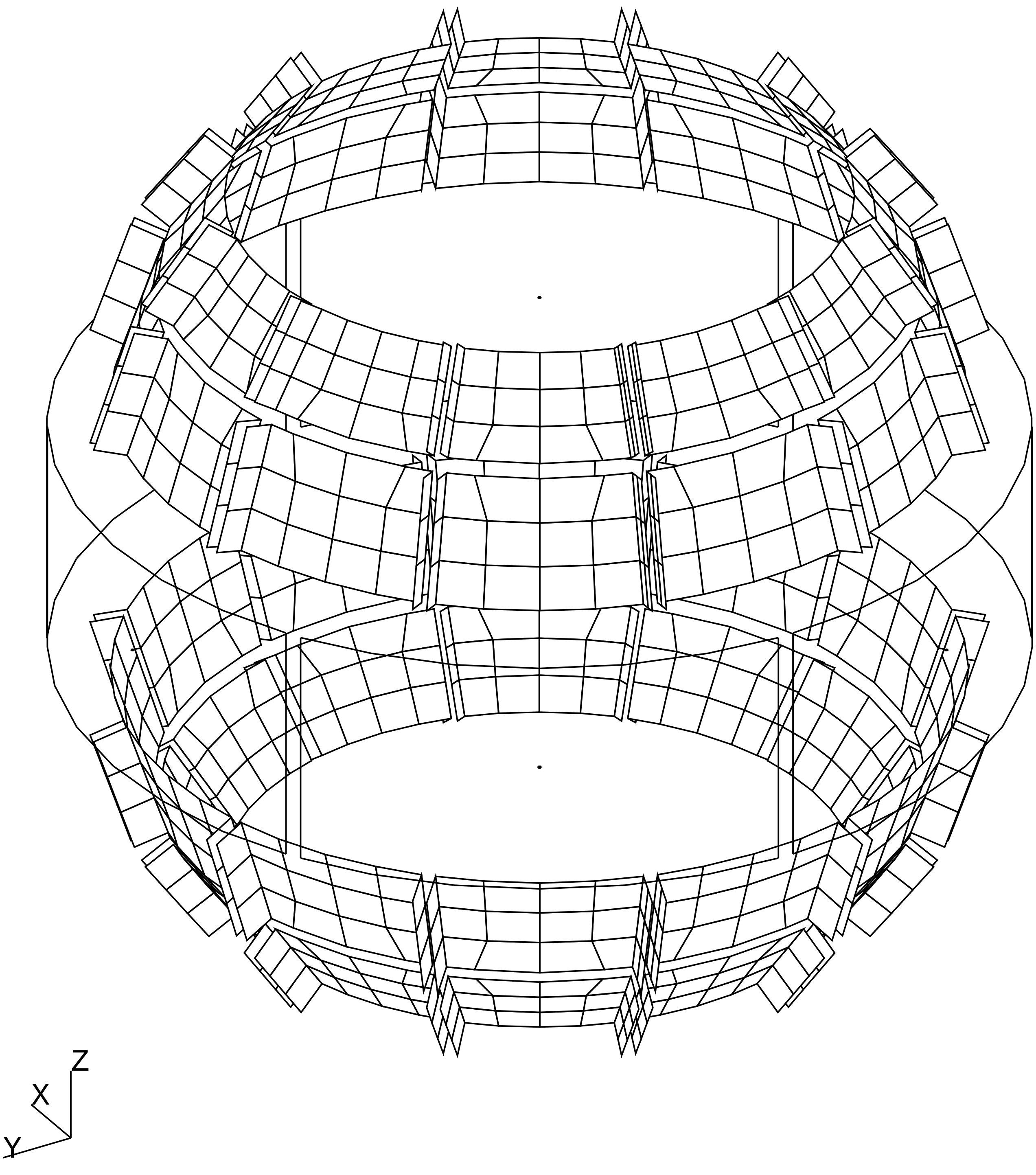
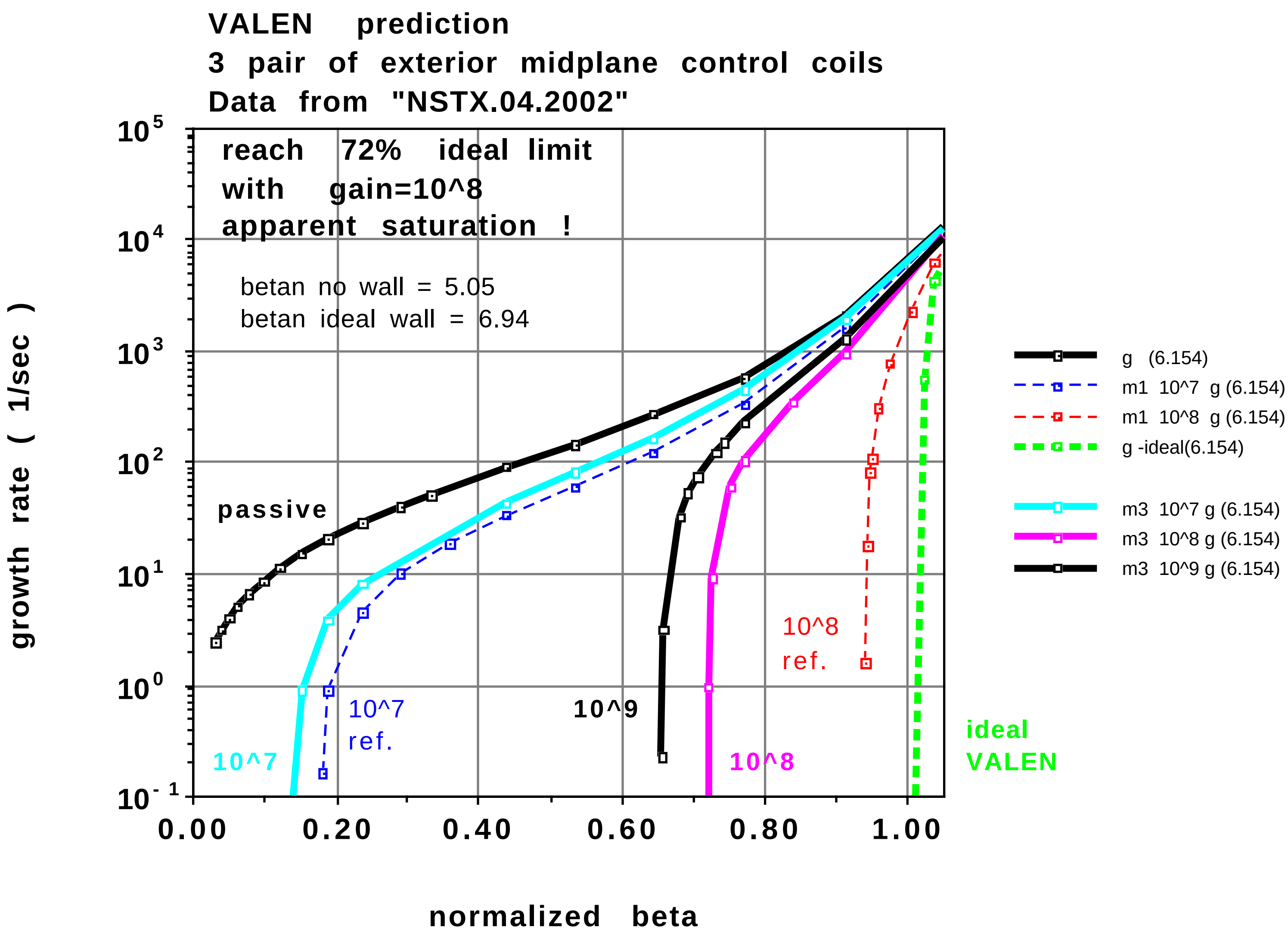
NSTX FB model#3

Geometry model#3 (exterior c.coils, internal Bp sensors)





VALEN prediction
3 pair of exterior midplane control coils
Data from "NSTX.04.2002"
reach 72% ideal limit
with gain=10^8
apparent saturation !
betan no wall = 5.05
betan ideal wall = 6.94
passive
10^7
10^7 ref.
10^9
10^8
10^8 ref.
ideal VALEN
g (6.154)
m1 10^7 g (6.154)
m1 10^8 g (6.154)
g -ideal(6.154)
m3 10^7 g (6.154)
m3 10^8 g (6.154)
m3 10^9 g (6.154)
growth rate (1/sec)
normalized beta

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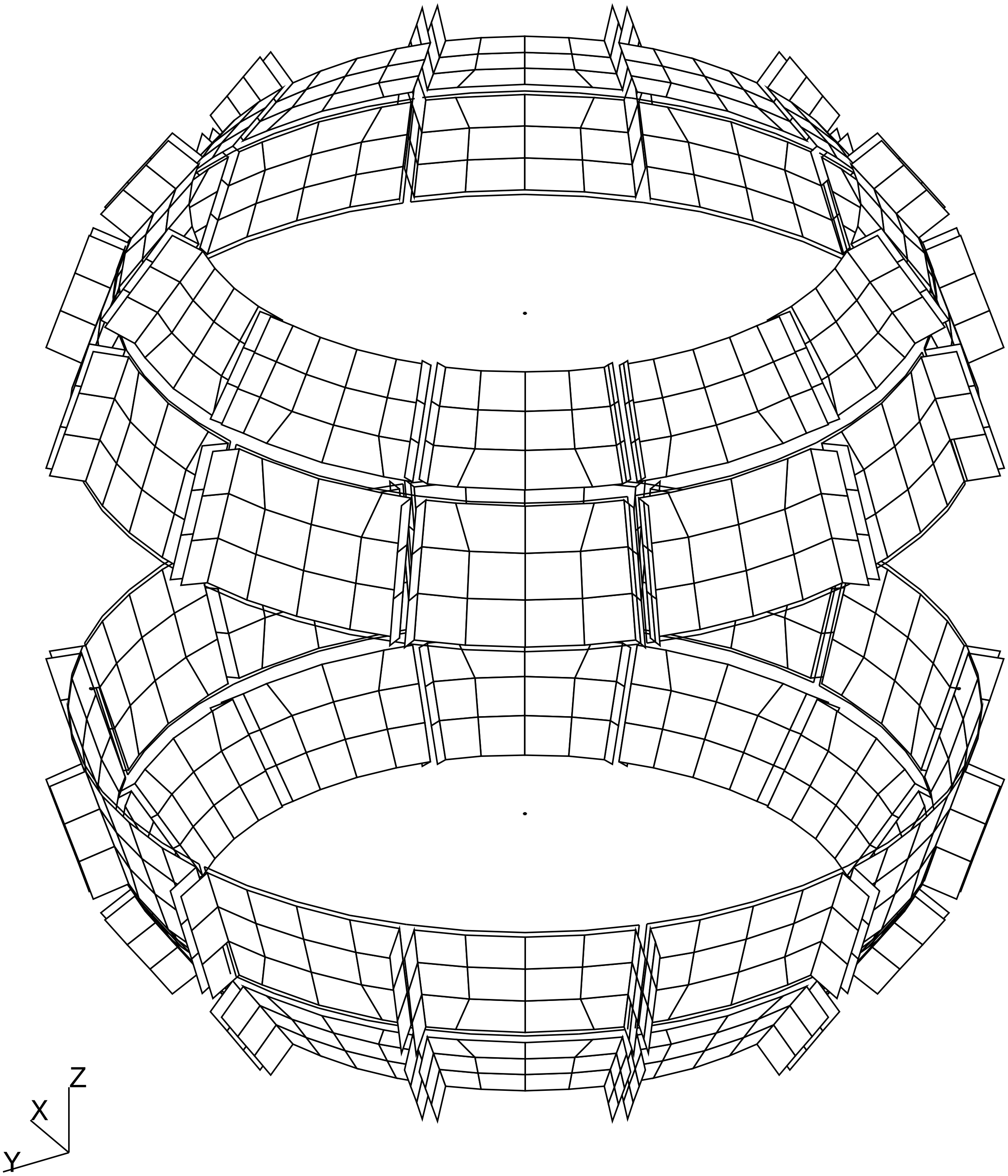
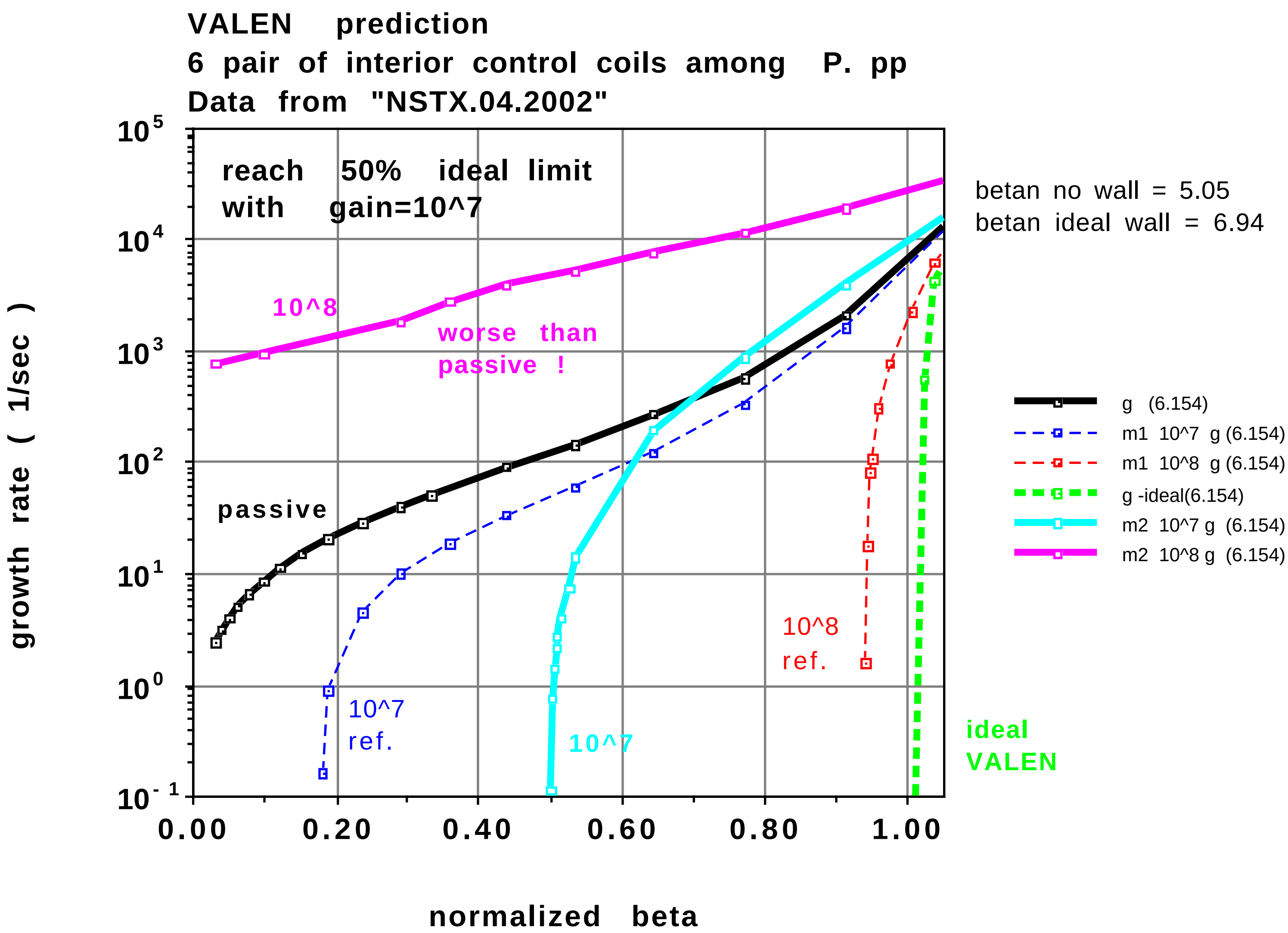
NSTX FB model#2

Geometry model #2 (c.coils among P pp, internal Bp sensors)




VALEN prediction
6 pair of interior control coils among P. pp
Data from "NSTX.04.2002"
reach 50% ideal limit
with gain=10^7
betan no wall = 5.05
betan ideal wall = 6.94
10^8
worse than
passive !
passive
10^7
ref.
10^7
10^8
ref.
ideal
VALEN
g (6.154)
m1 10^7 g (6.154)
m1 10^8 g (6.154)
g -ideal(6.154)
m2 10^7 g (6.154)
m2 10^8 g (6.154)
growth rate (1/sec)
normalized beta
0.00
0.20
0.40
0.60
0.80
1.00

Conclusions & plans

- 'best option' reaches 94 % of ideal limit, hardest to install

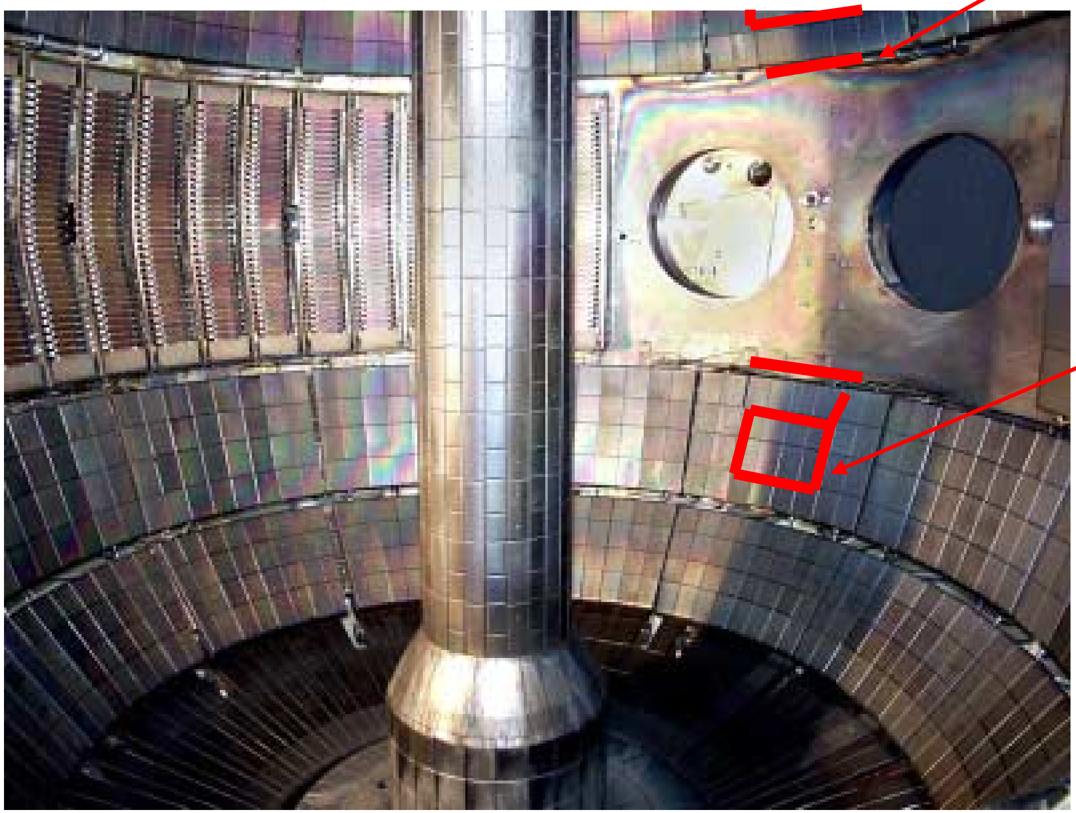
- 'exterior option' reaches 72% of ideal limit, easier to install

- 'primary plate option' reaches 50% of ideal limit. Increasing gain too far can make performance worse than passive alone. Takes twice as many coils and power supplies.

- ongoing work, using most recent experimental high β_n plasmas examine effectiveness of passive plates

- NSTX now installing magnetic sensors inside the vacuum vessel that are equivalent to sensors used in simulation (pairs of B_p sensors above & below mid plane)

RWM+EF sensor conceptual design



- 2 B_P sensors per bay
  - Use average for feedback
  - Use individual for up/down asymmetric mode structure
  - Use individual for EF measurements
- 2 B_R sensors per bay
  - 1 sensor per PPP
  - Optimal place for static EF measurement
    - closer to PF3, PF2, plates
  - Best way to measure slowly growing modes slowed by or locked to passive plates
  - Control applications?