Solenoidless Start-up Scenarios for NSTX

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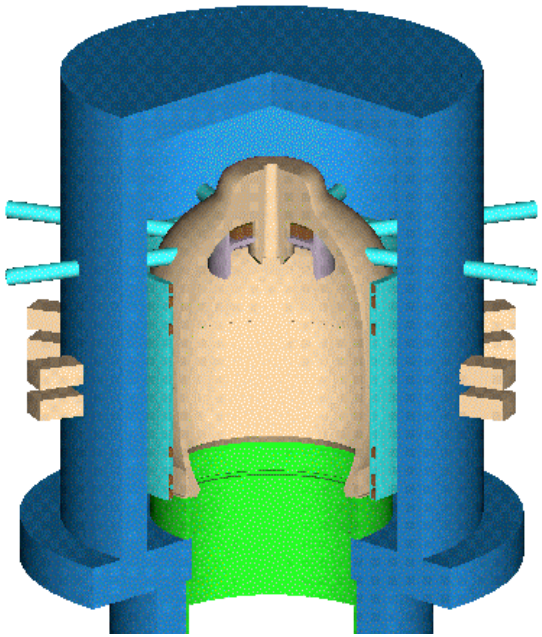
ST reactors require CS-less operation

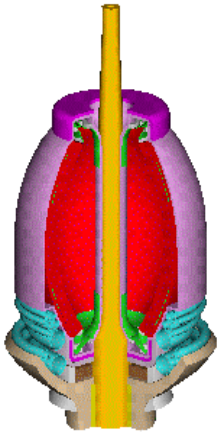
- CS-less operation is a requirement for ST reactors

ARIES-ST
(1 GWe)

R = 3.2 m
R/a = 1.6
I_p = 31 MA
B_T = 2.1 T
β_T = 54%
f_{BS} = 99%
P_{fusion} = 2.9 GW
Neutron wall load
= 4.1 MW/m^2
Recirculating power
fraction = 0.32



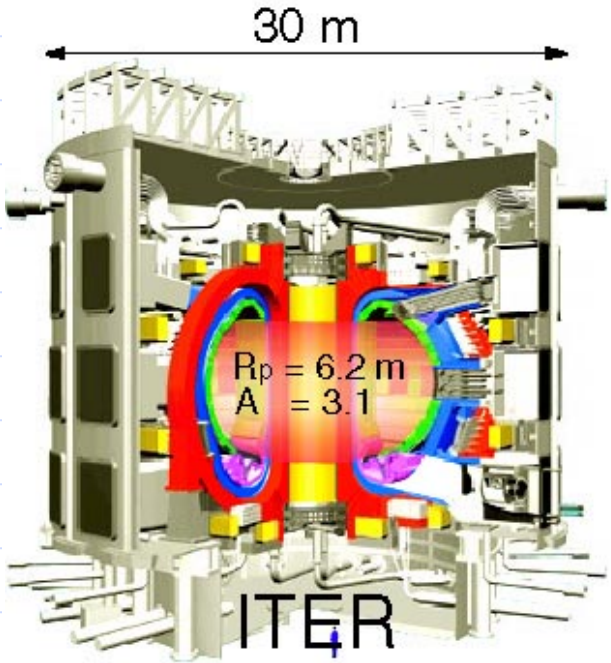
Fixed
Components



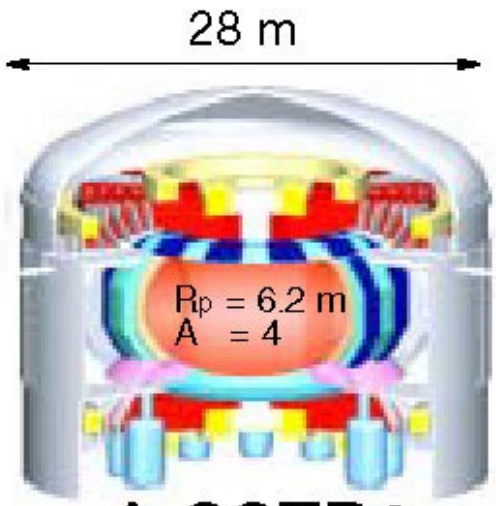
Replaceable
Components

Examples of CS-less tokamak reactors

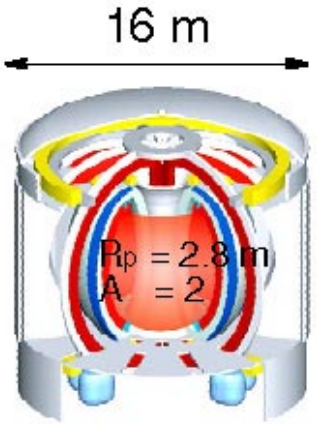
- Improved economic competitiveness may be realized by a CS-less design.



ITER
(18000 ton)
P_F=0.5 GW



A-SSTR2
(28000 ton)
P_F=4 GW



VECTOR
(~9000 ton)
P_F = 3.7 GW

S. Nishio, et al., paper FT/P1-21, 19th Fusion Energy Conference, Lyon 2002.

CS-less I_p ramp-up scenarios investigated

- ECH pressure driven currents (Forest scenario)
  - Only low current, low density plasmas produced so far
    - CDX-U, DIII-D, TST-2
  - Challenge to combine with other CS-less scenarios
    - EBW, HHFW, bootstrap-overdrive

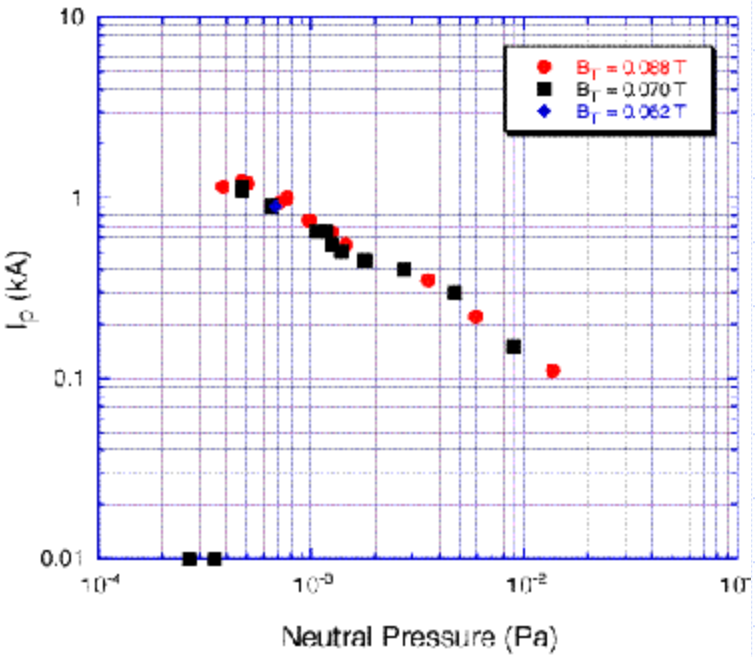
- PF induction + RF (EC/HHFW)
  - B_v swing from + to – (JT-60 scenario)
    - Is field null required? → scenarios with/without field null
    - Initially no force balance
    - Requires strong plasma source

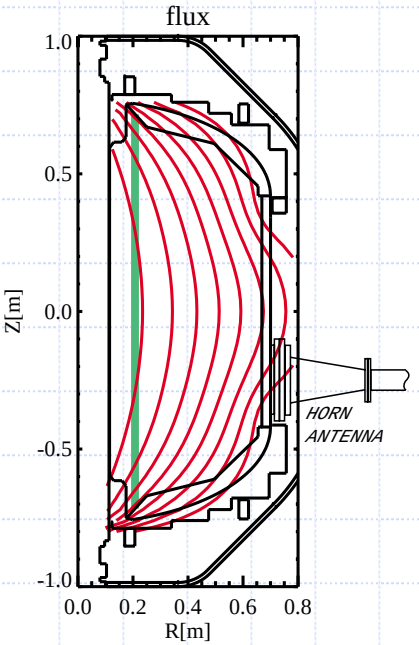
- Merging/compression (MAST/TS-3 scenario)
  - Demonstration of merging/compression start-up by external coils

Plasma current generation by ECH in TST-2

Believed to be pressure driven currents
(Forest scenario)

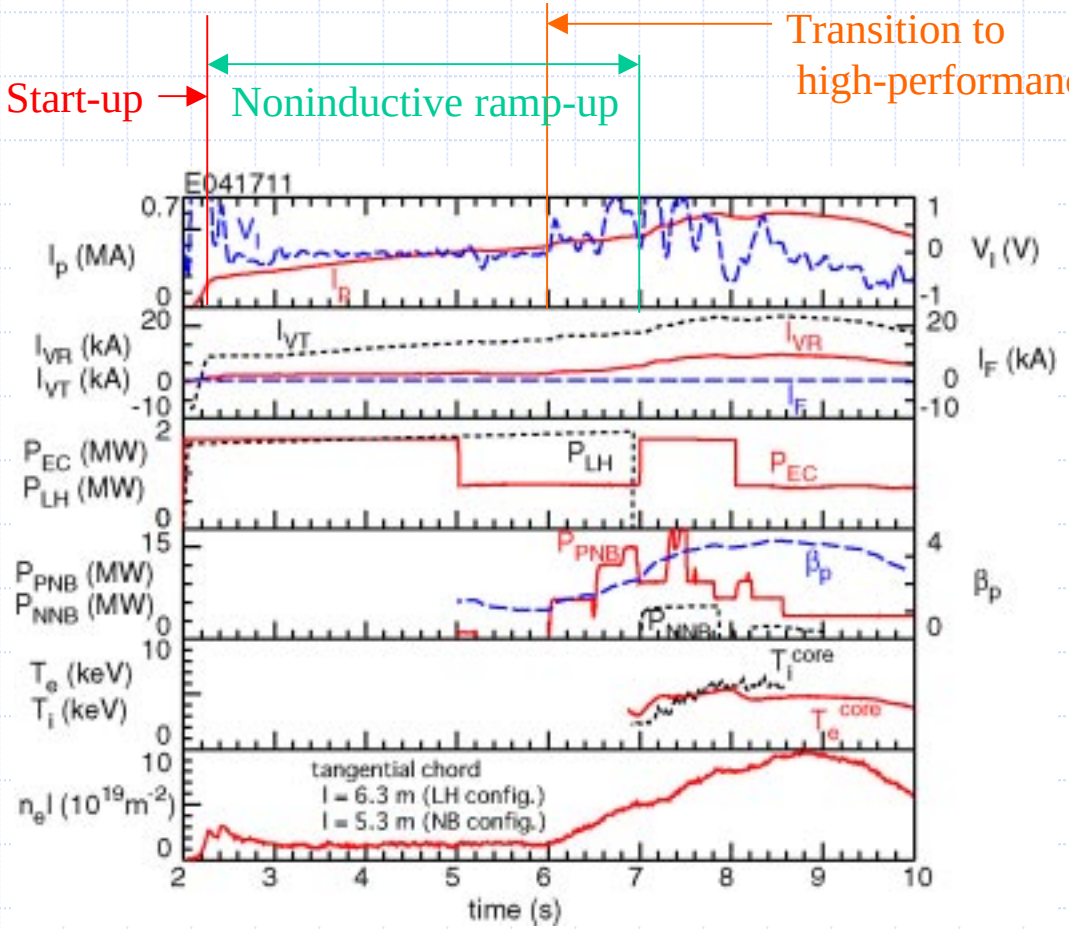
- ECH (2.45 GHz)Å
  → 1 kA / 1 kW
- Low gas pressures
  → low collisionality
- Vertical field with
  positive curvature
  → trapped electrons

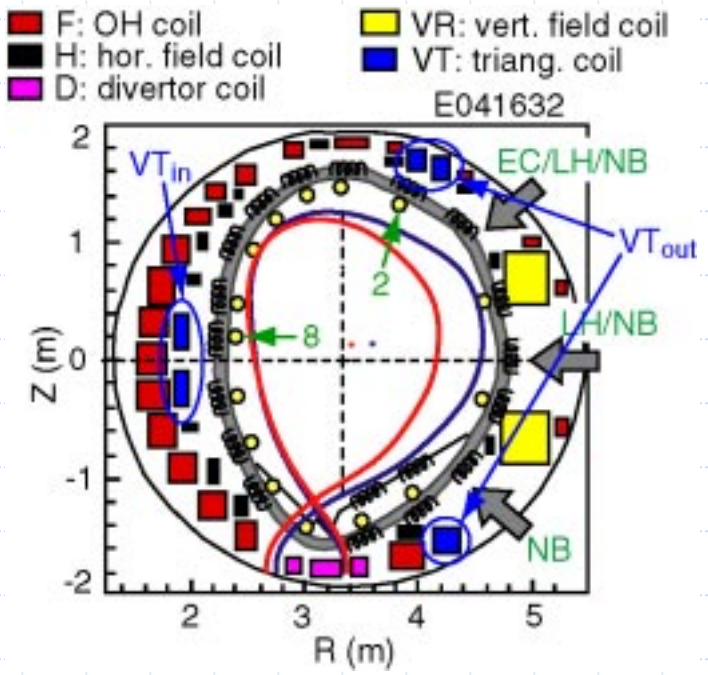




CS-less formation of high-performance plasma demonstrated in JT-60U

$\beta_p = 3.6$
$\beta_N = 1.6$
$H_H = 1.6$
$f_{BS} > 90\%$





Vacuum Field Evolution

41497: no I_p start-up (no gas)

41495: I_p start-up at 0.105 s

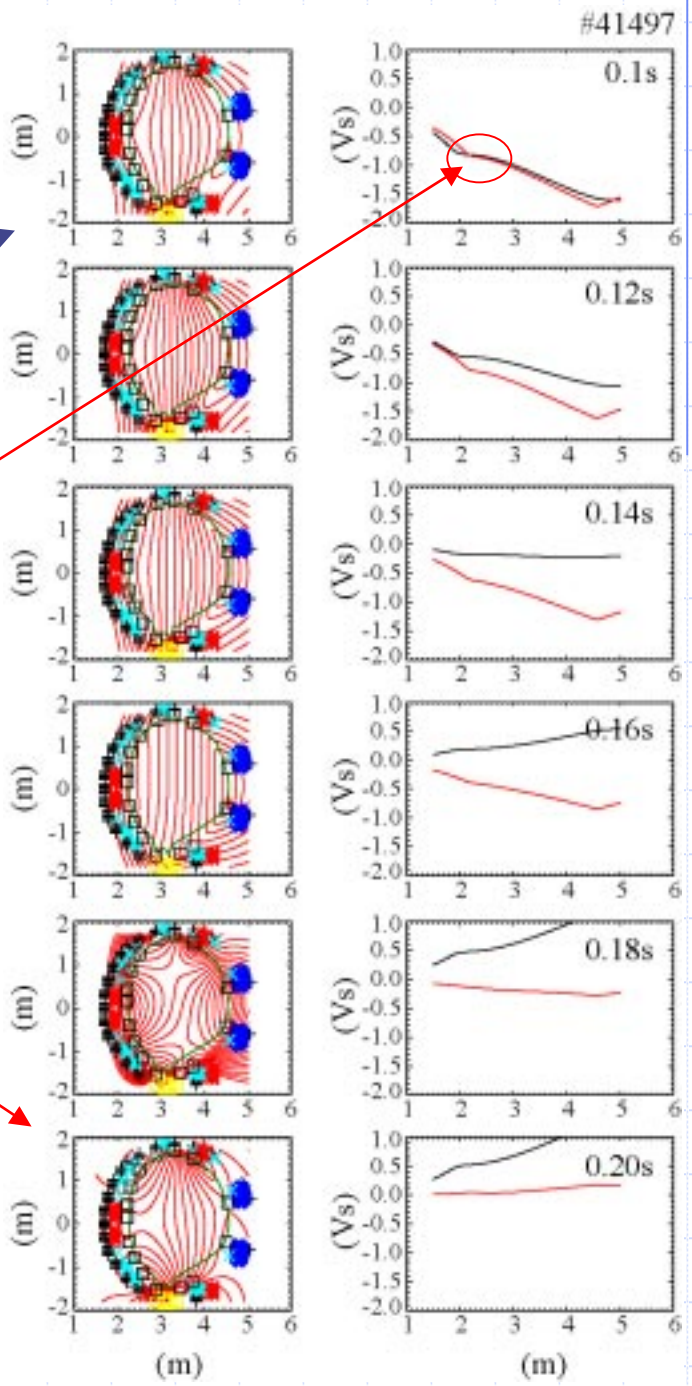
- A small "field null" exists on the inboard midplane before VT and VR coil ramp
- Initially B_v is in the wrong direction
- B_v does not reverse sign until 0.19 s (0.09s after start of VT and VR ramp)
- Poloidal equilibrium, but no toroidal equilibrium?

Right: Flux profile on the midplane

Black: coil currents only

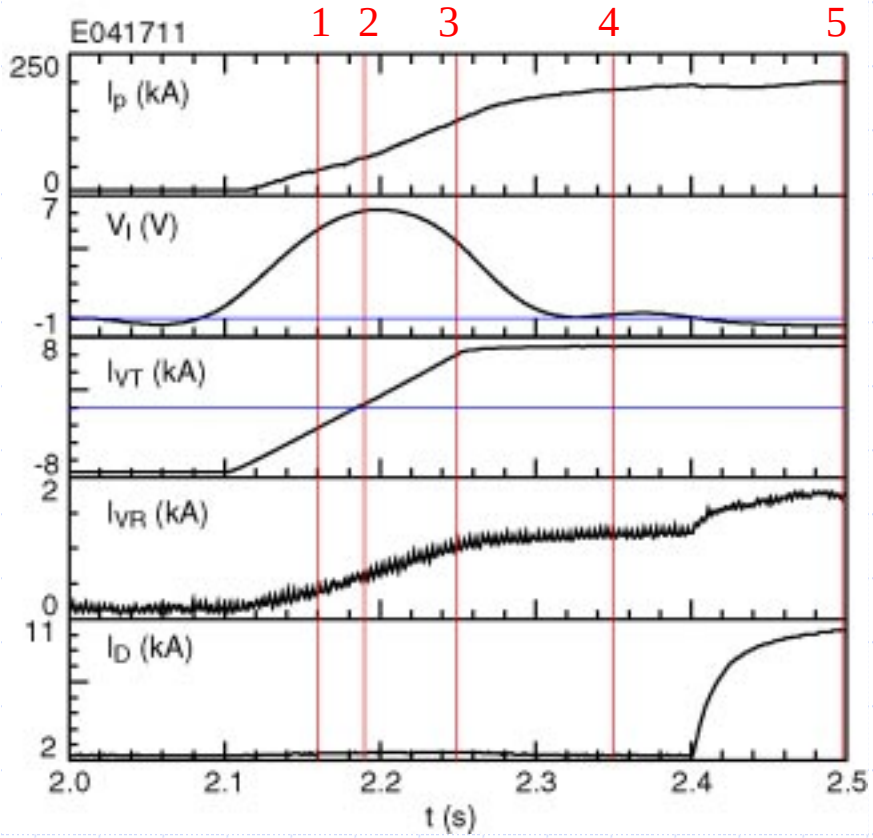
Red: coil currents and eddy currents

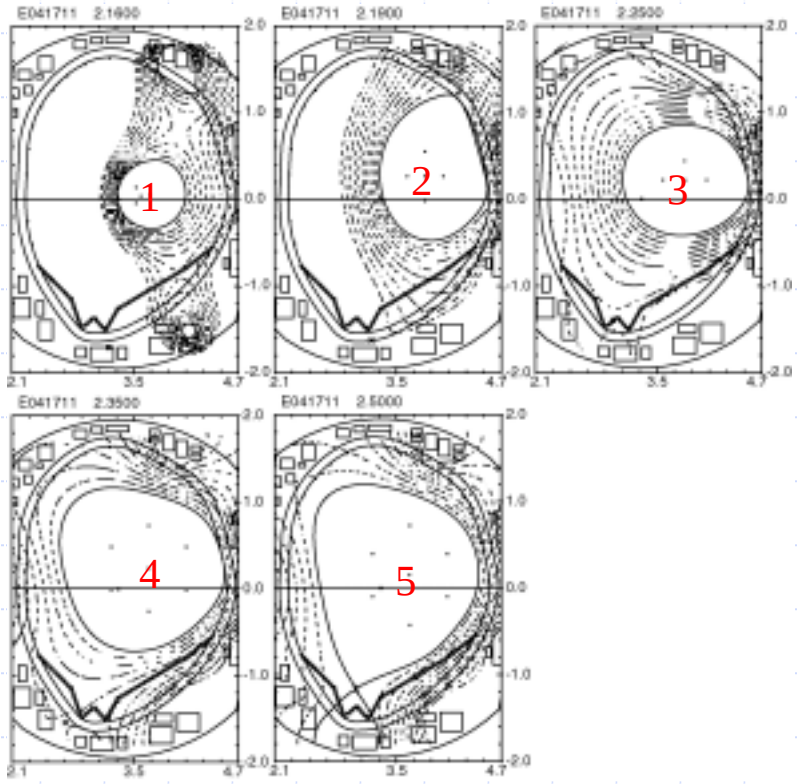
Left: flux contours (with eddy currents)



Configuration Evolution During CS-less I_p Start-up

- I_p ramp-up accomplished by EC/LH preionization and VT/VR coil ramps
- Transition to divertor configuration (5) and further I_p ramp-up by LHCD





Scenario development for NSTX

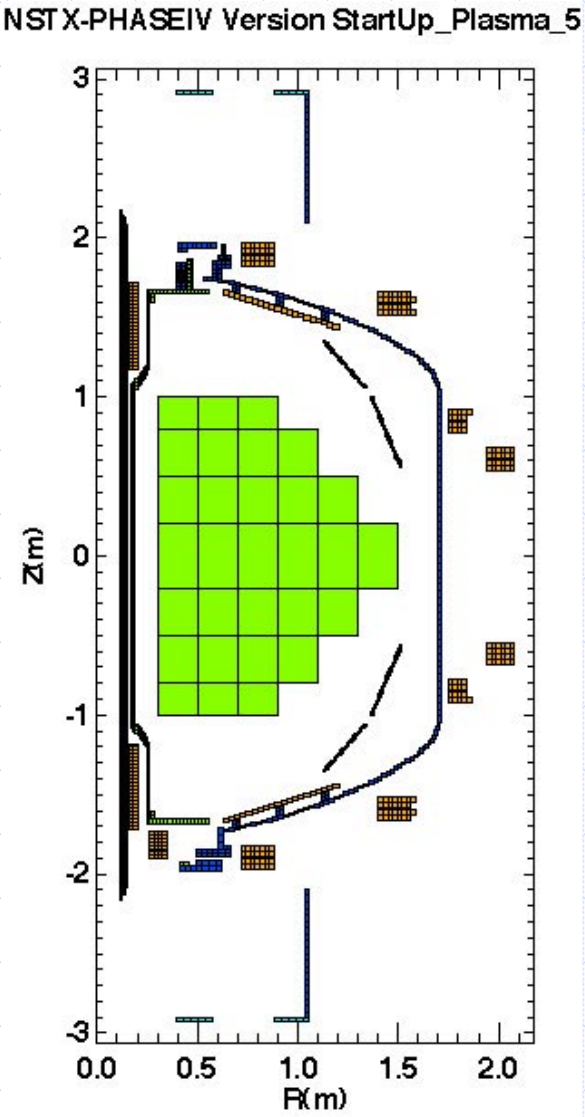
Analysis by Menard's LRDIAG

- Circuit equation solver
  - NSTX coils and conducting structures
  - Eddy currents taken into account
  - Very well benchmarked

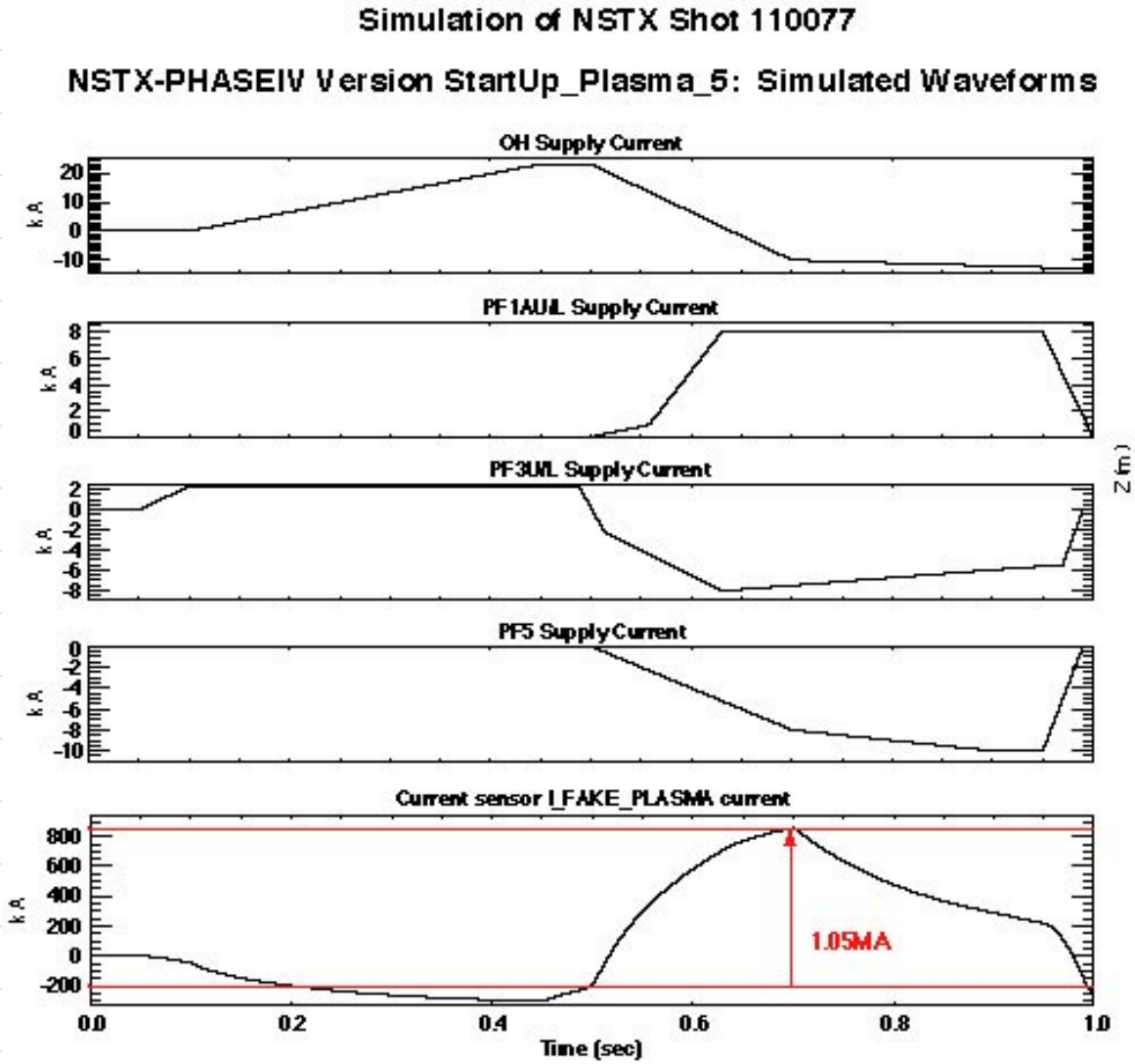
  but does not calculate plasma equilibrium

- Plasma modelled by passive coils
  - Various distribution of "plasma" coils
  - Each coil can have different resistivity

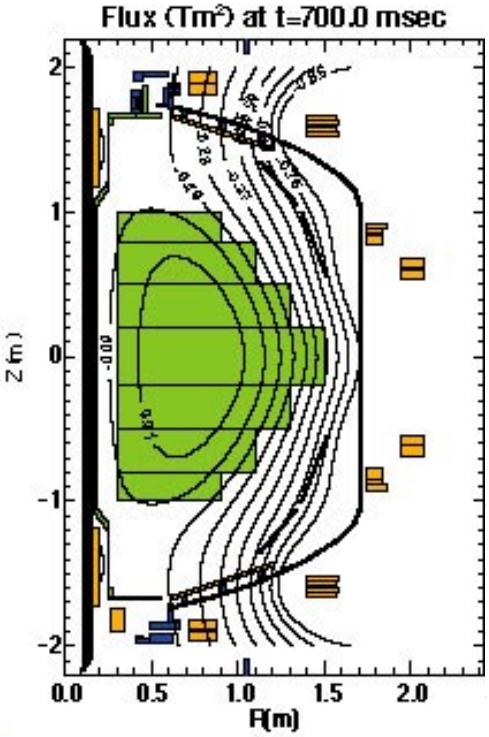
  but constant in time



Plasma model selected to reproduce I_p ramp-up of a 1MA NSTX plasma

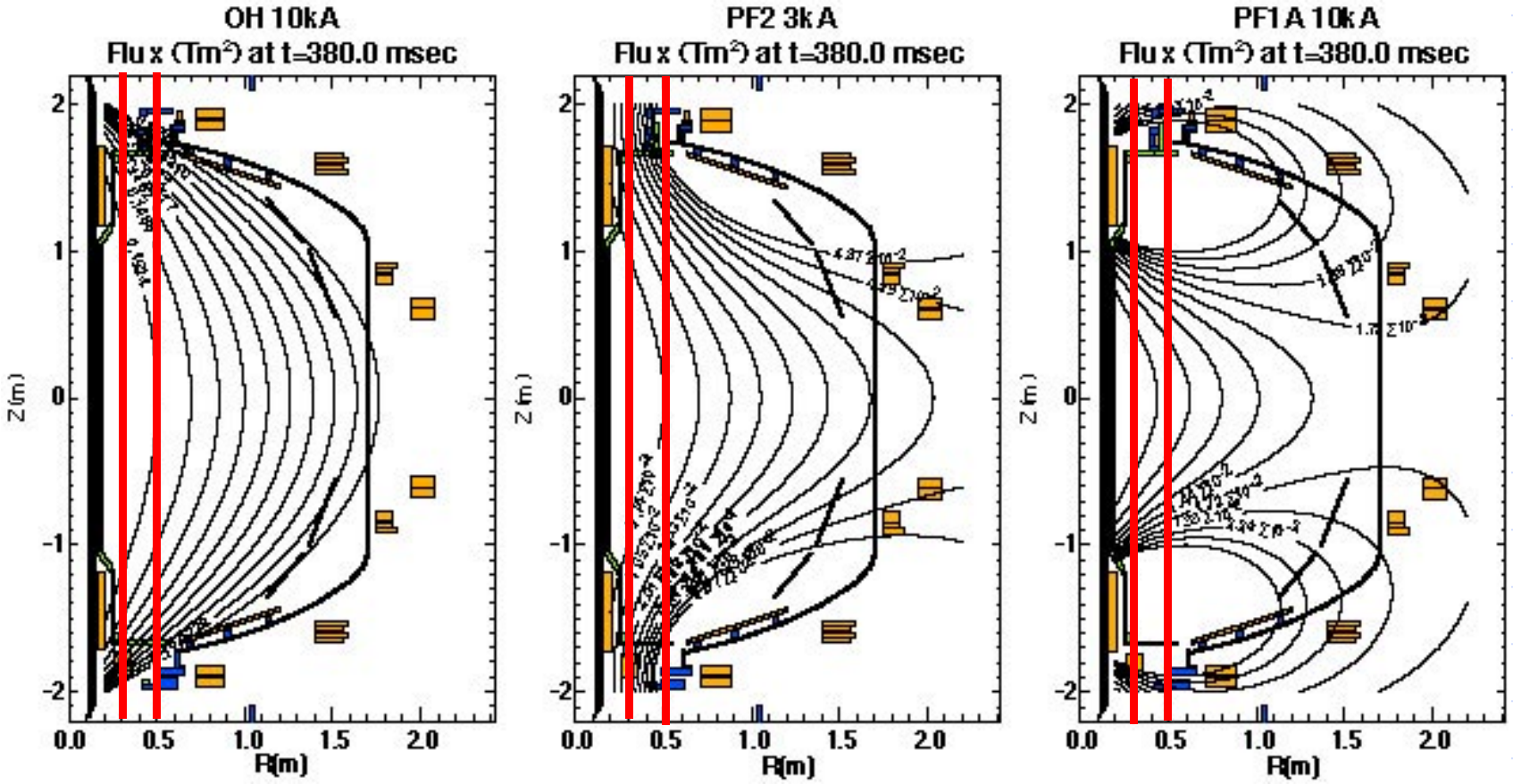


Resistivity of Inconel 625
(equiv. to 70 eV plasma)



This model reproduces
inductively driven (OH start-up)
1MA NSTX discharge

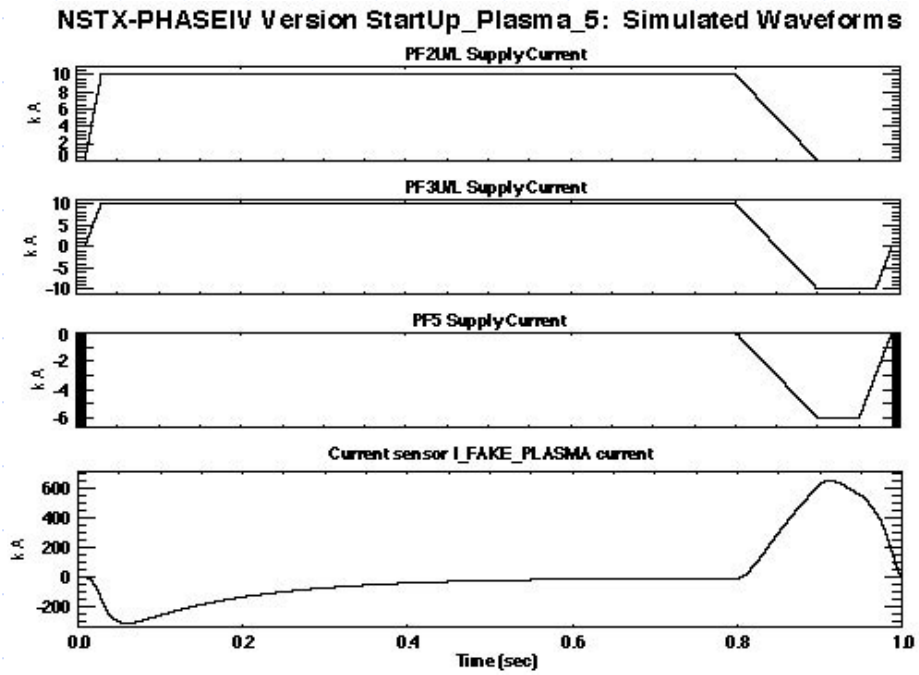
Pressure-driven I_p start-up (Forest scenario) with various field curvatures

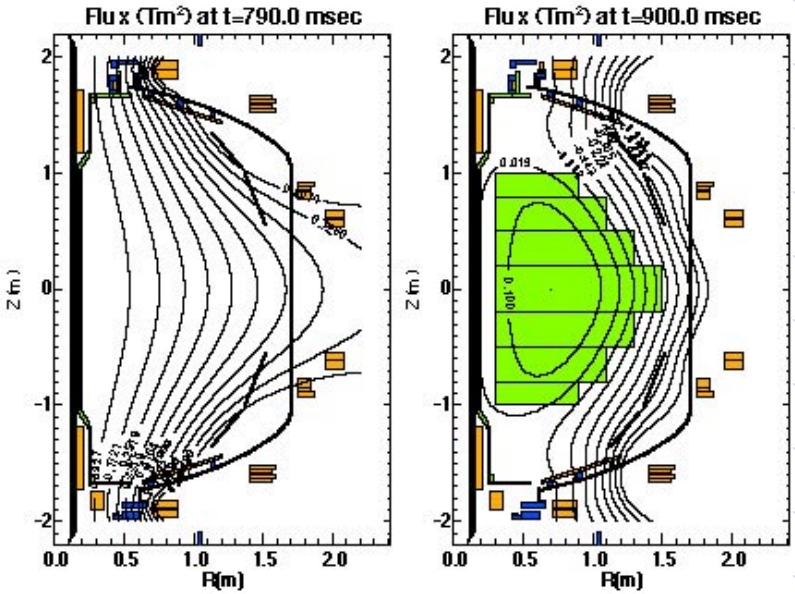


EC resonance at R = 0.3 – 0.5 m corresponds to B_T = 0.19 – 0.32 T at R = 0.85 m

JT-60U scenario
B_v ramp from + to – (no field null)

Initial B_v is opposite to that required for radial force balance

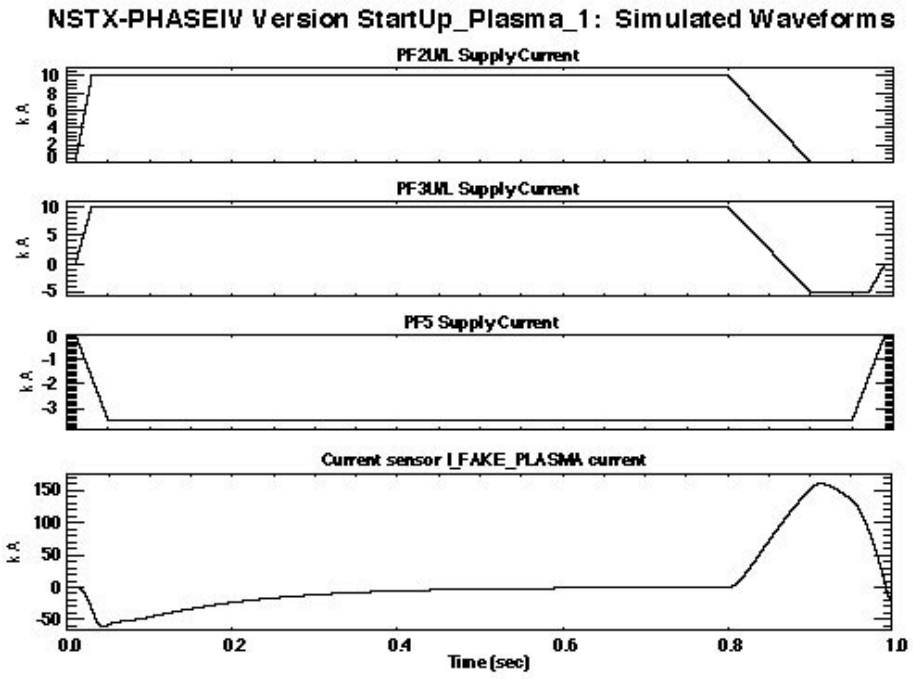


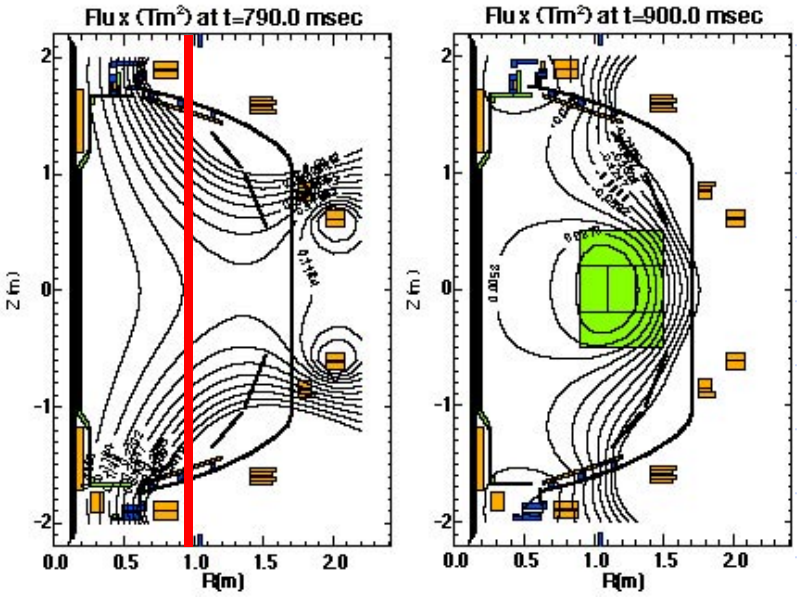


- Requires a strong plasma source (HHFW/ECH)
- Ramp up to I_p = 650 kA may be possible

Start-up scenario with outboard X-point

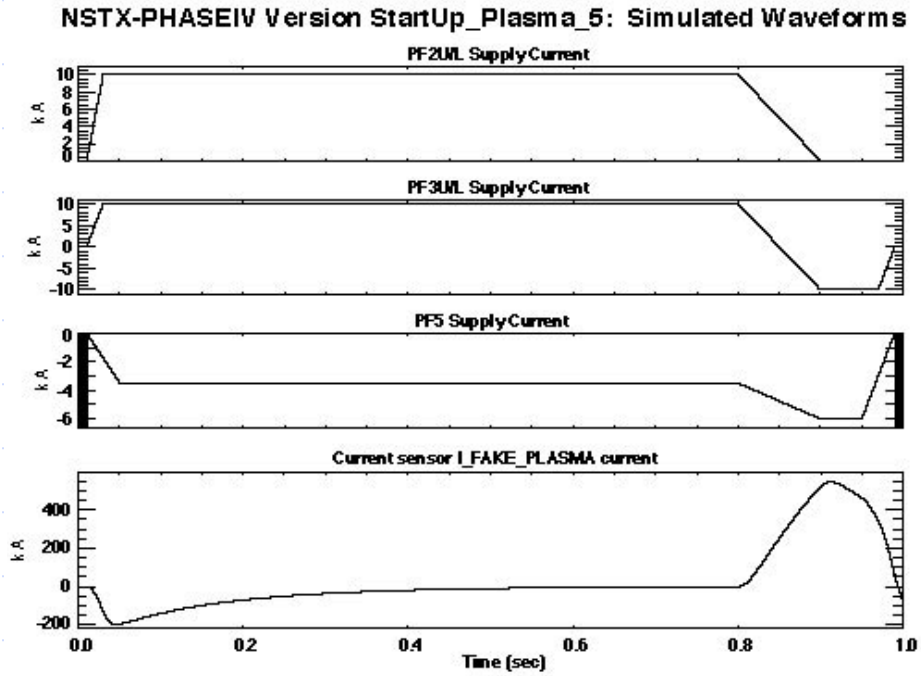
For B_T = 0.6 T (at R = 0.85 m)
EC resonance is at R = 0.95 m

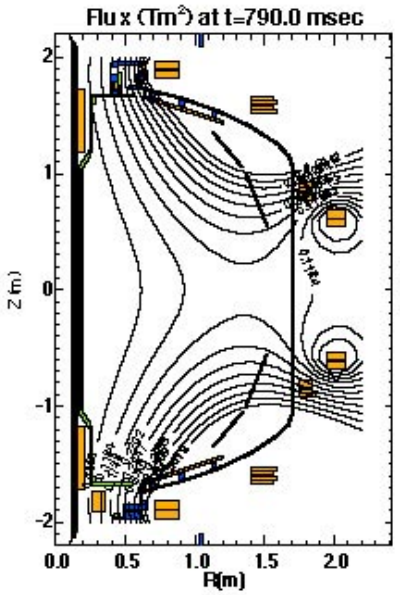


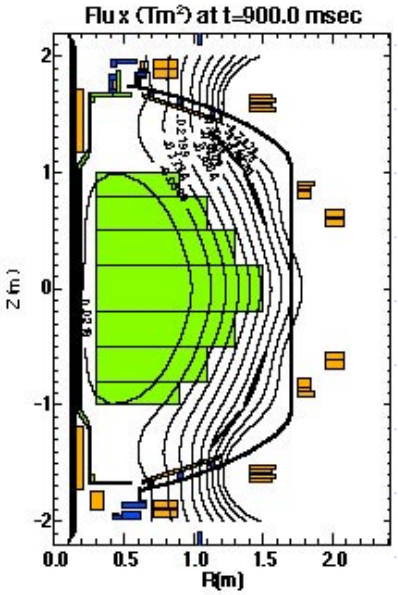


Ramp-up at large R → limited to I_p = 160 kA
(but could be amplified by compression)

Start-up scenario with outboard X-point (full cross section plasma)

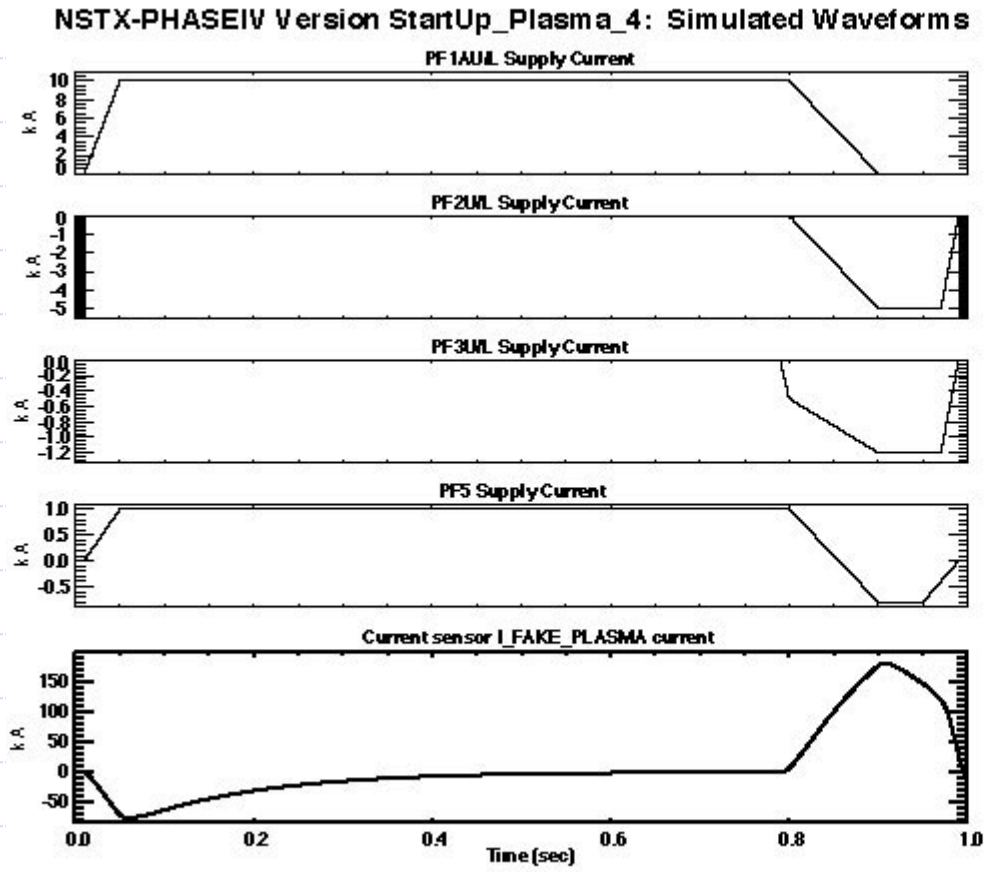


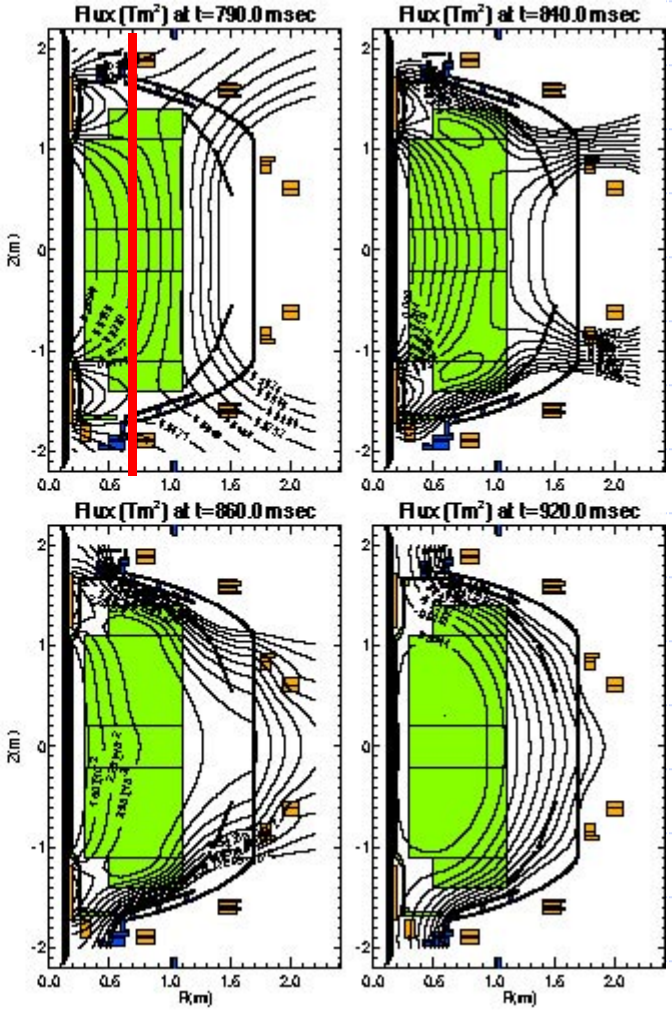




Ramp up to I_p = 550 kA may be possible

Merging/compression (MAST scenario)
Start-up from PF1A-PF5 nulls





Ramp up to I_p = 180 kA predicted

B_T = 0.44 T (at R = 0.85 m) locates EC resonance at R = 0.7 m

Conclusions

- ECH pressure driven current start-up is straightforward
  - Configurations with different field curvatures can be tested on NSTX
  - Several kA of plasma current expected with 20 kW ECH
- Several promising PF induction scenarios identified
  - Optimistic (but reasonable) scenarios predict over 500 kA of plasma current
  - Even pessimistic scenarios predict at least 100 kA
  - Can be further ramped up by NB/RF heating and/or CD
- Merging/compression scenario identified
  - Dynamic evolution of plasma current more difficult to model
  - Field null by PF1A + PF5, plus induction by PF2 + PF3 + PF5
  - Expect over 100 kA