XP 448 - A solenoid-free current-start-up scenario utilizing outer poloidal field coils including PF 4 - Establish breakdown condition

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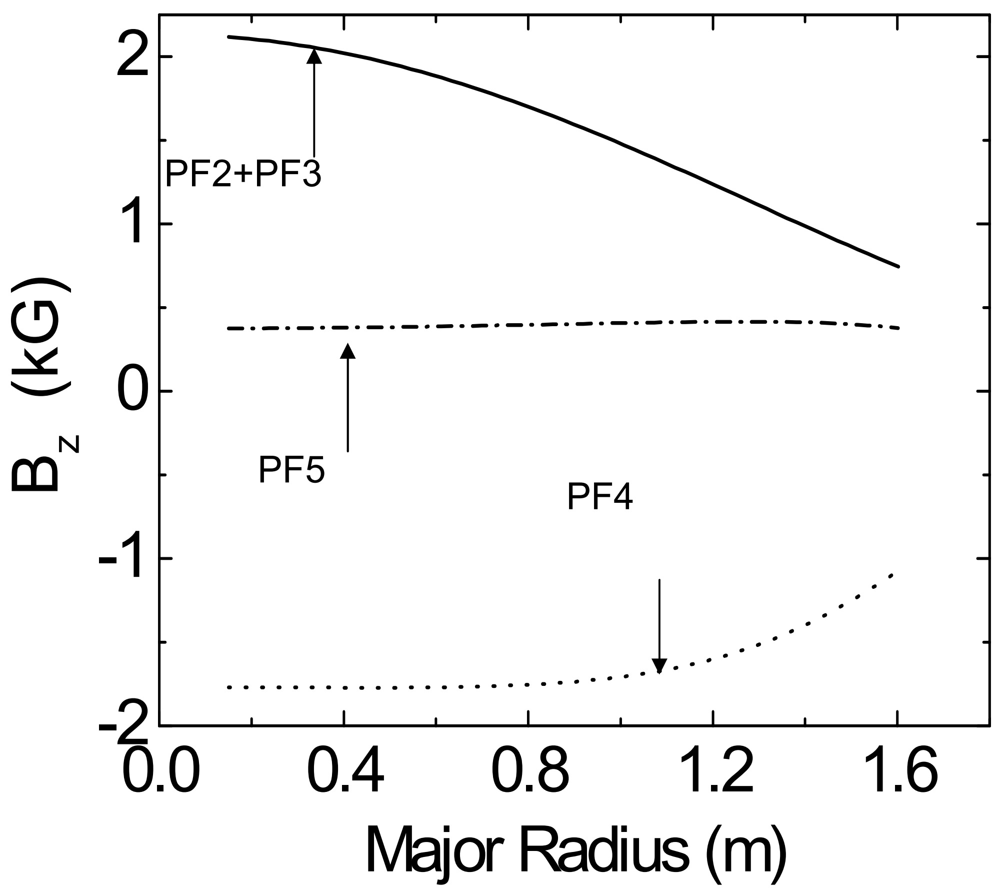
Motivation: To demonstrate a solenoid-free start-up concept using outer PF coils on NSTX by optimizing high loop-voltage, field null quality and available poloidal flux. If successful in achieving ~ 100 kA, this induction-based concept will contribute to the NSTX five year plan and it should scale well to future devices such as NSST.

XP 448 Key Objectives:

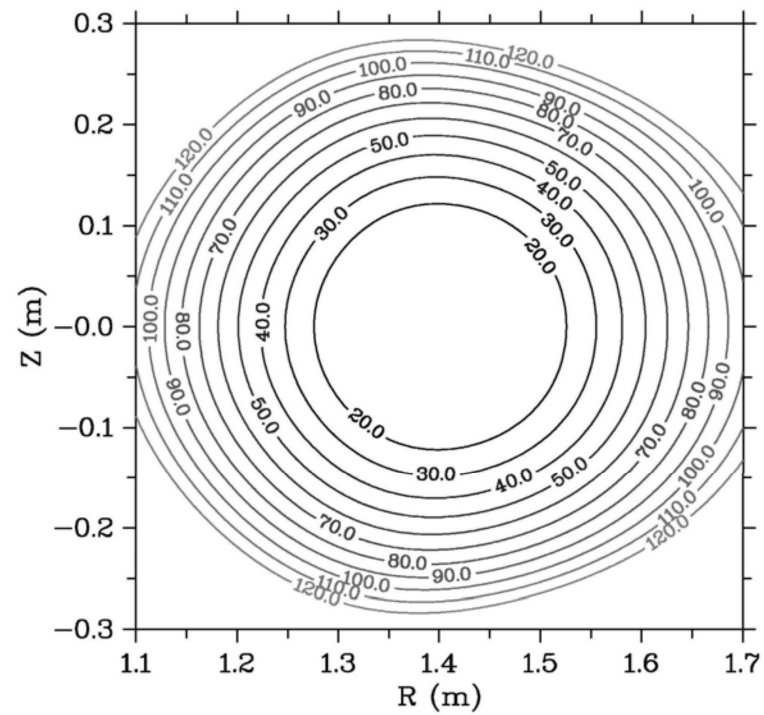
#1. Achieve and establish successful breakdown conditions.

#2. Optimize wave forms to achieve significant plasma current of ~ 100 kA.

Basic Idea: NSTX Outer Poloidal Field Coils have different B_v profiles at mid-plane: By combining those fields, one can generate a good quality field null around R =1.3-1.4m



Mod-B contours in G



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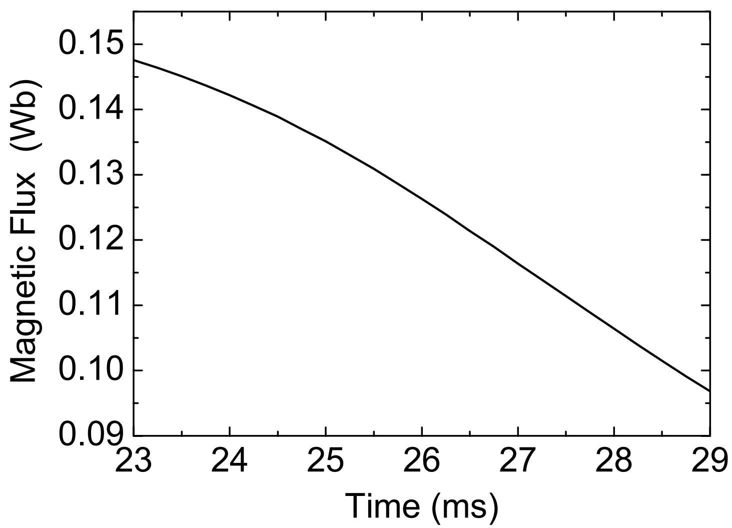
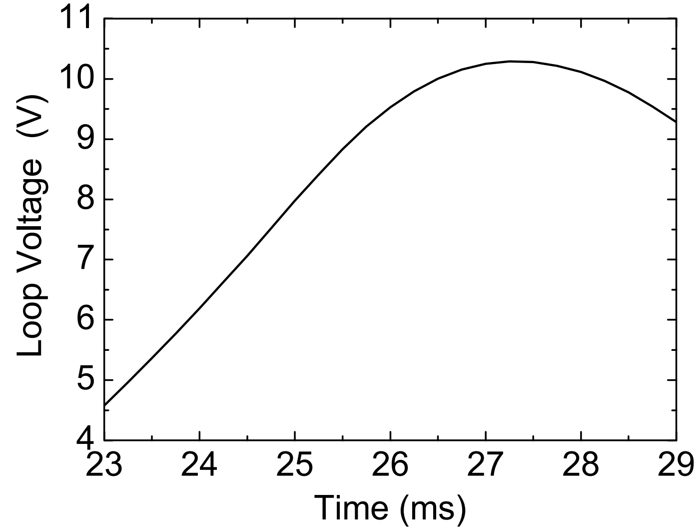
Wall-eddy currents plays an important role:

• Wall-eddy currents cause the time delay and changes in the magnetic field profiles.

• Wall-eddy currents reduce the peak loop-voltage value.





J. Kim, et al., APS03

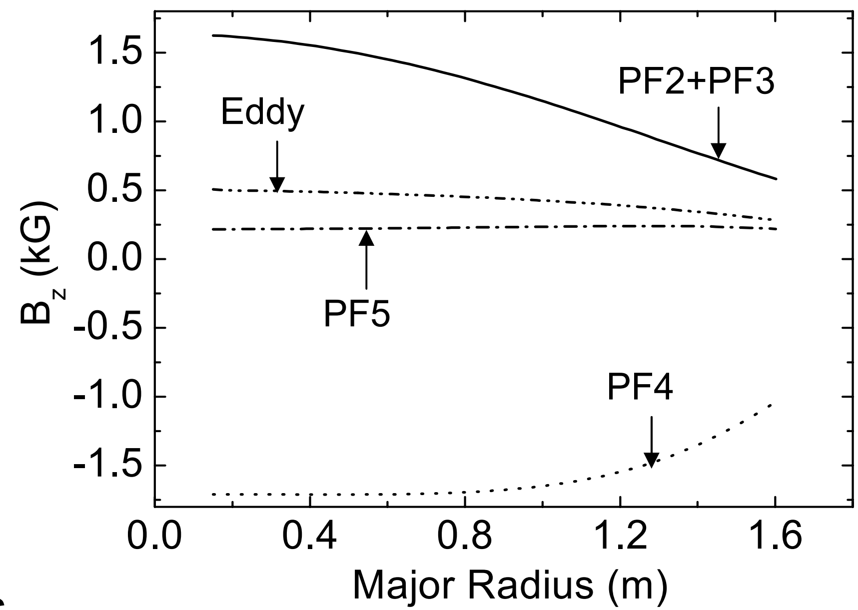
Issues for PF 4 and PF 5:

• Due to the present mechanical support structure limitation (which can be remedied in the future but not for this run), the combined current values for PF 4 and PF 5 are rather limiting. (C. Neumeyer)

Approach for XP 448:

• PF 5 will be only energized at low current ≤ 1.5 kA. This level of current is well within the current limit set forth by engineering.

• Since this would be the first time to energize PF 4, lower PF 4 current scenarios A, B, and C, in addition to the base case was developed



Plasma initiation: a crucial issue

-XMP030 (Menard) demonstrated pre-ionization by HHFW operating in phase at the low pressure of 10^{-5} torr comparable to the OH start-up pressure.

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-HHFW pre-ionization was used successfully for XP 443 (Menard) but was not low enough for Takase's XP 415 which called for low 10^{-6} torr.

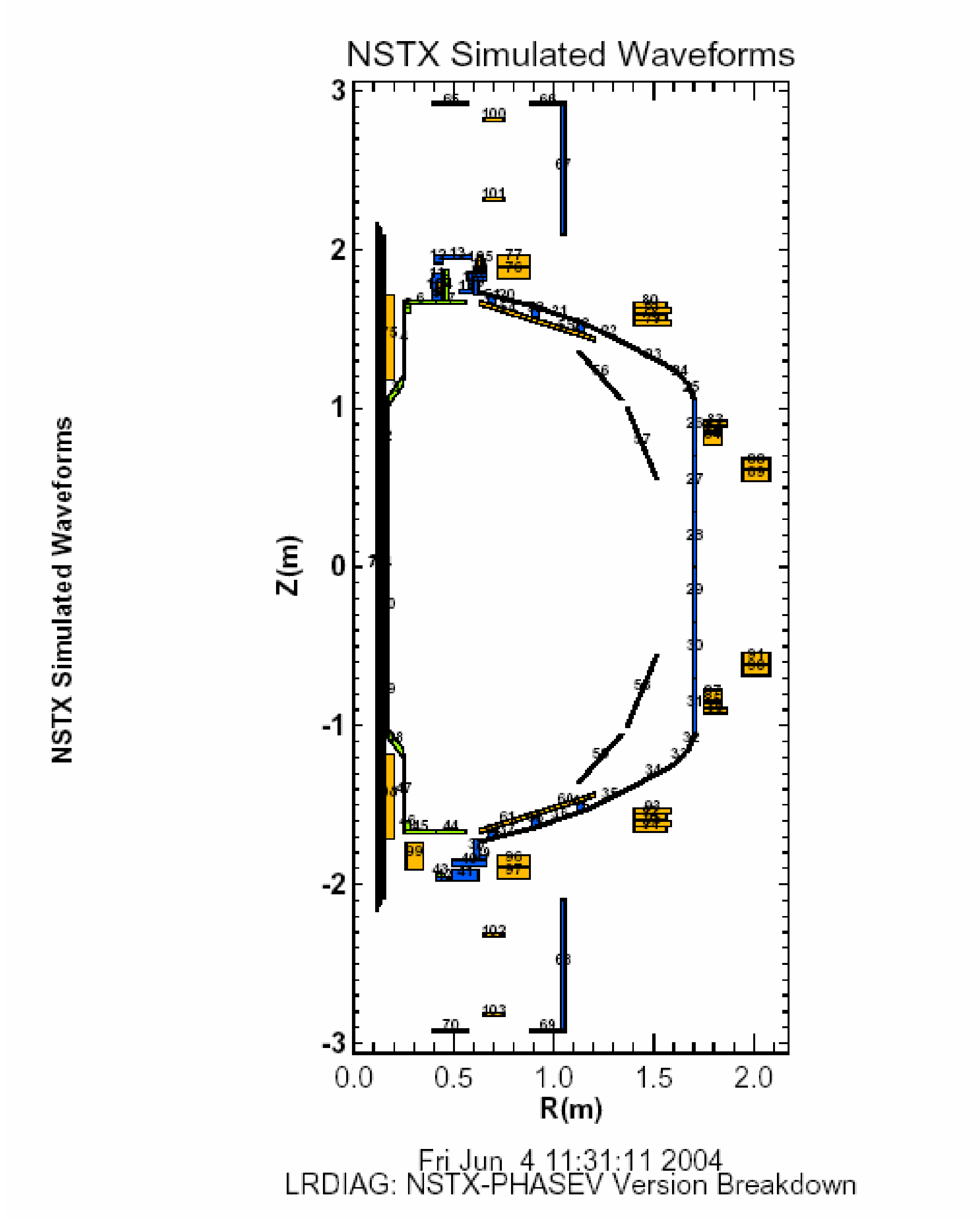
XP443 had $E_T B_T / B_p \sim 0.3$ at t=0, produced ~ 10 kA. NBI was observed to heat electrons

XP415 had $E_T B_T / B_p < 0.1$, produced ~ 5 kA?

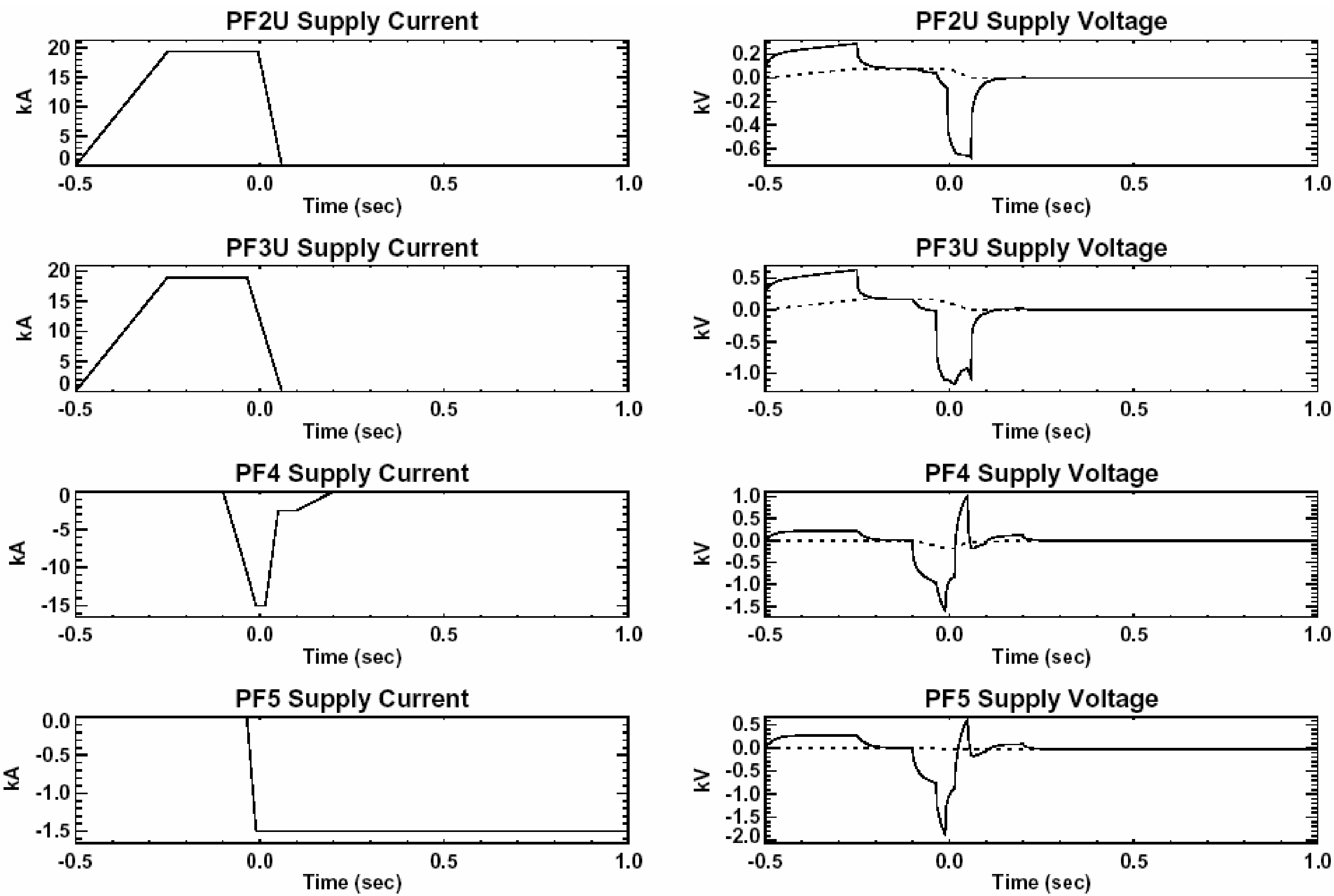
- For XP448, wave forms were chosen to maximize the chance of success for plasma initiation:
  - –Apply as high loop voltage as feasible at the time of initiation
  - –Create as large volume region $E_T B_T / B_p > 0.1$ kV/m as feasible
  - –Utilize proven HHFW pre-ionization at 1-2 x 10^{-5} Torr

Main experimental aim: To establish plasma initiation conditions in terms of $E_T B_T / B_p$, V-loop, and volume for > 0.1 kV/m

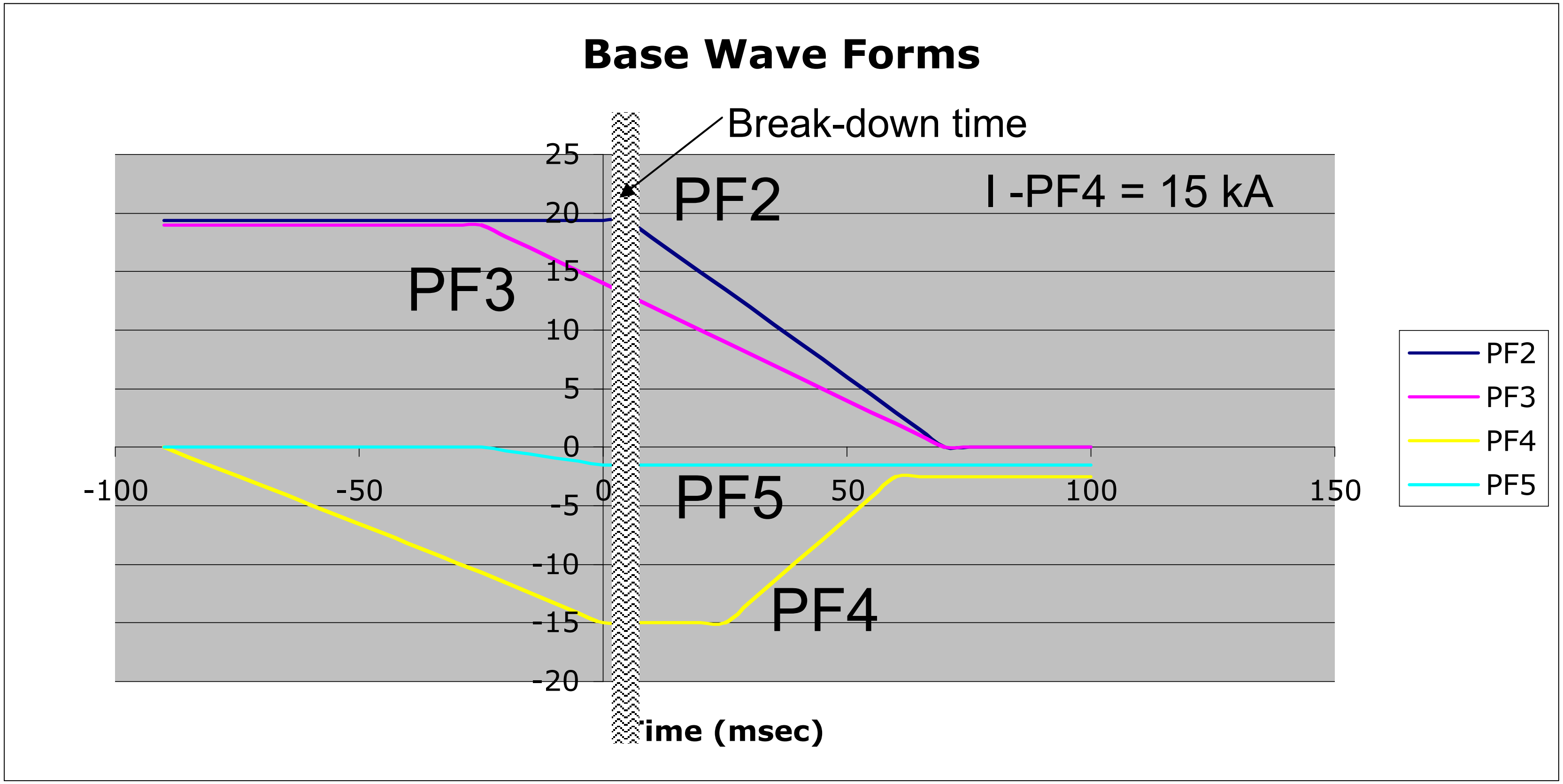
LRDIAG code (J. Menard) was used to optimize the wave forms:



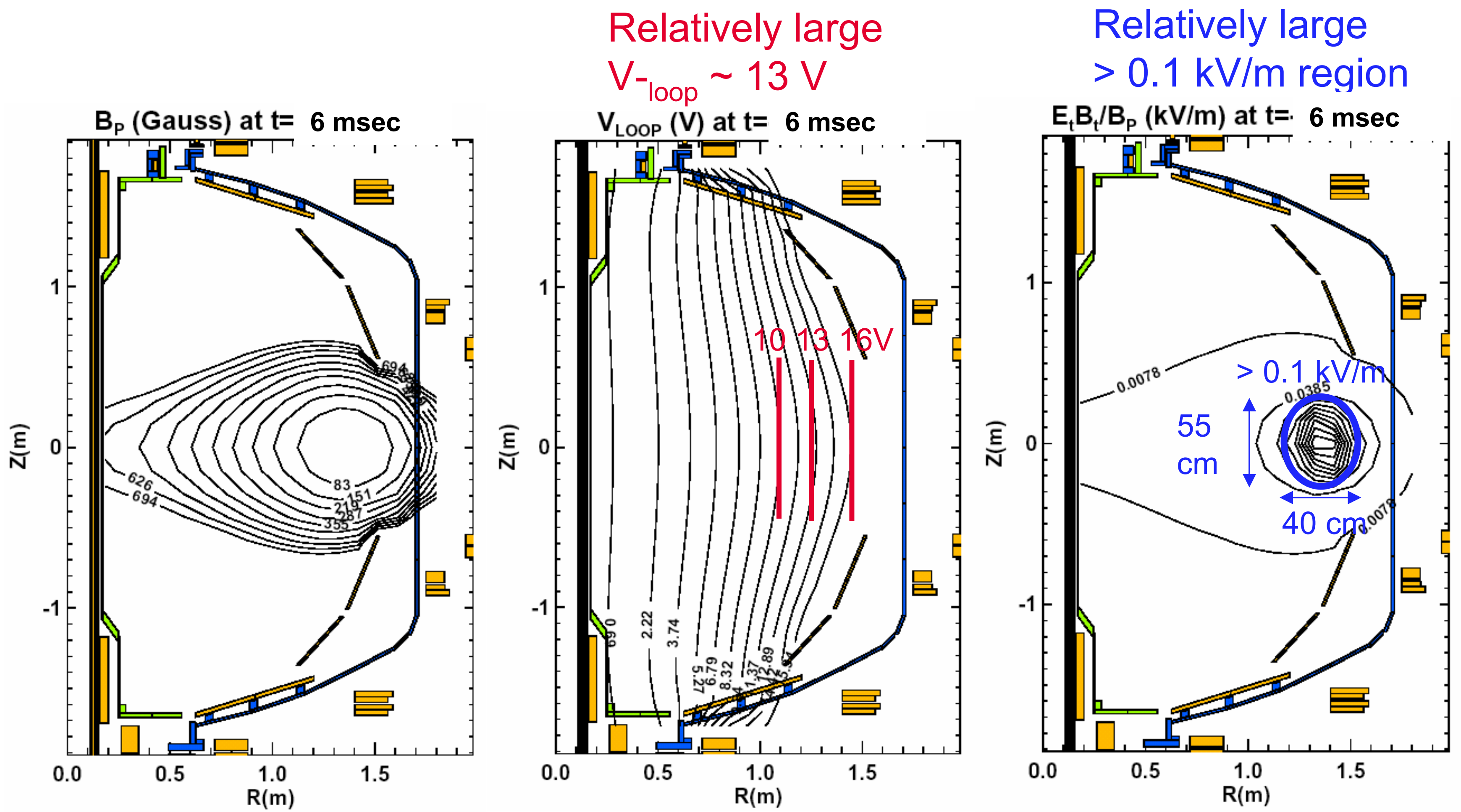
Poloidal field coil waves forms were chosen to be within the engineering specification.



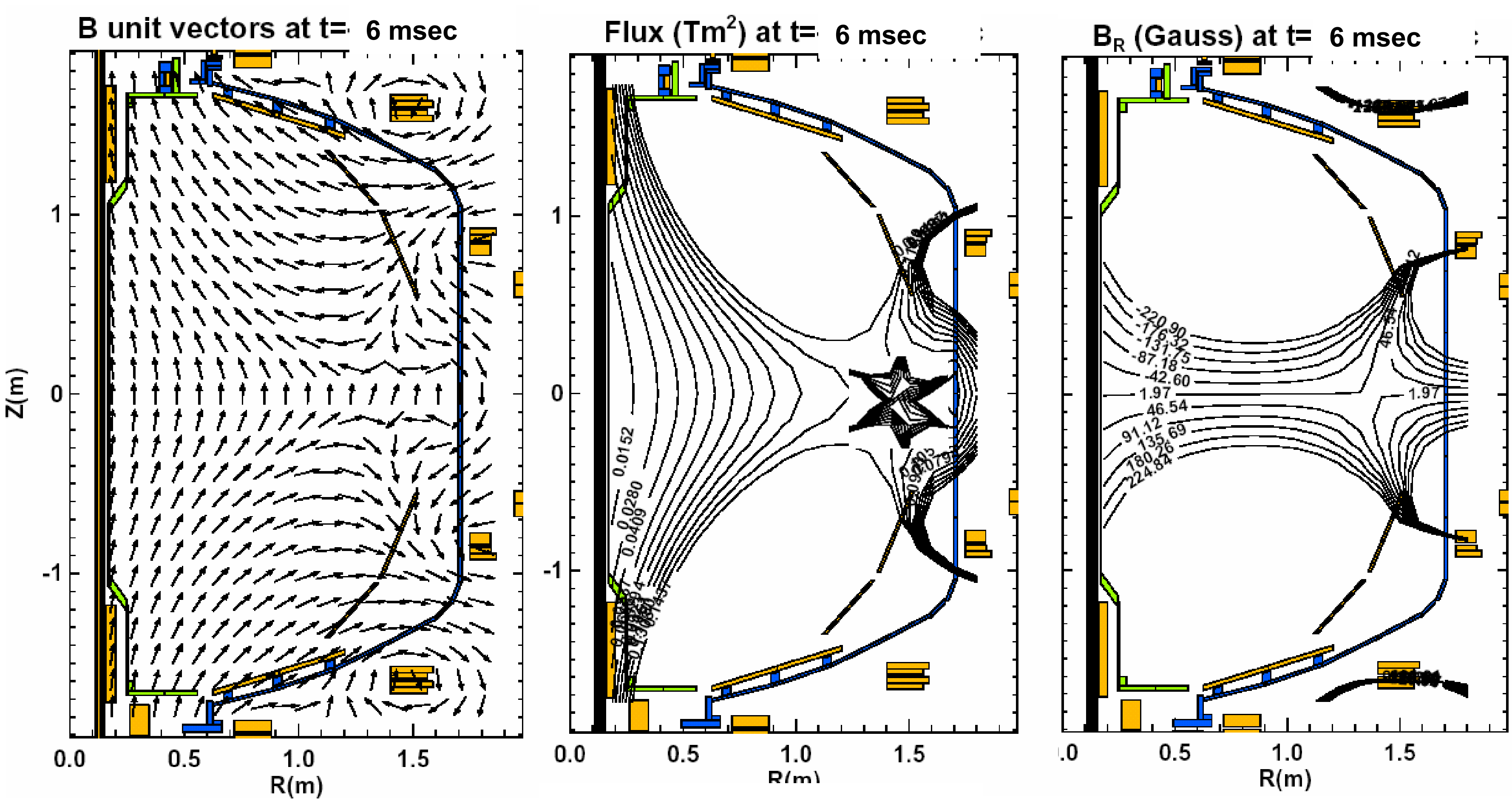
PF coil current waveform to maximize loop voltage



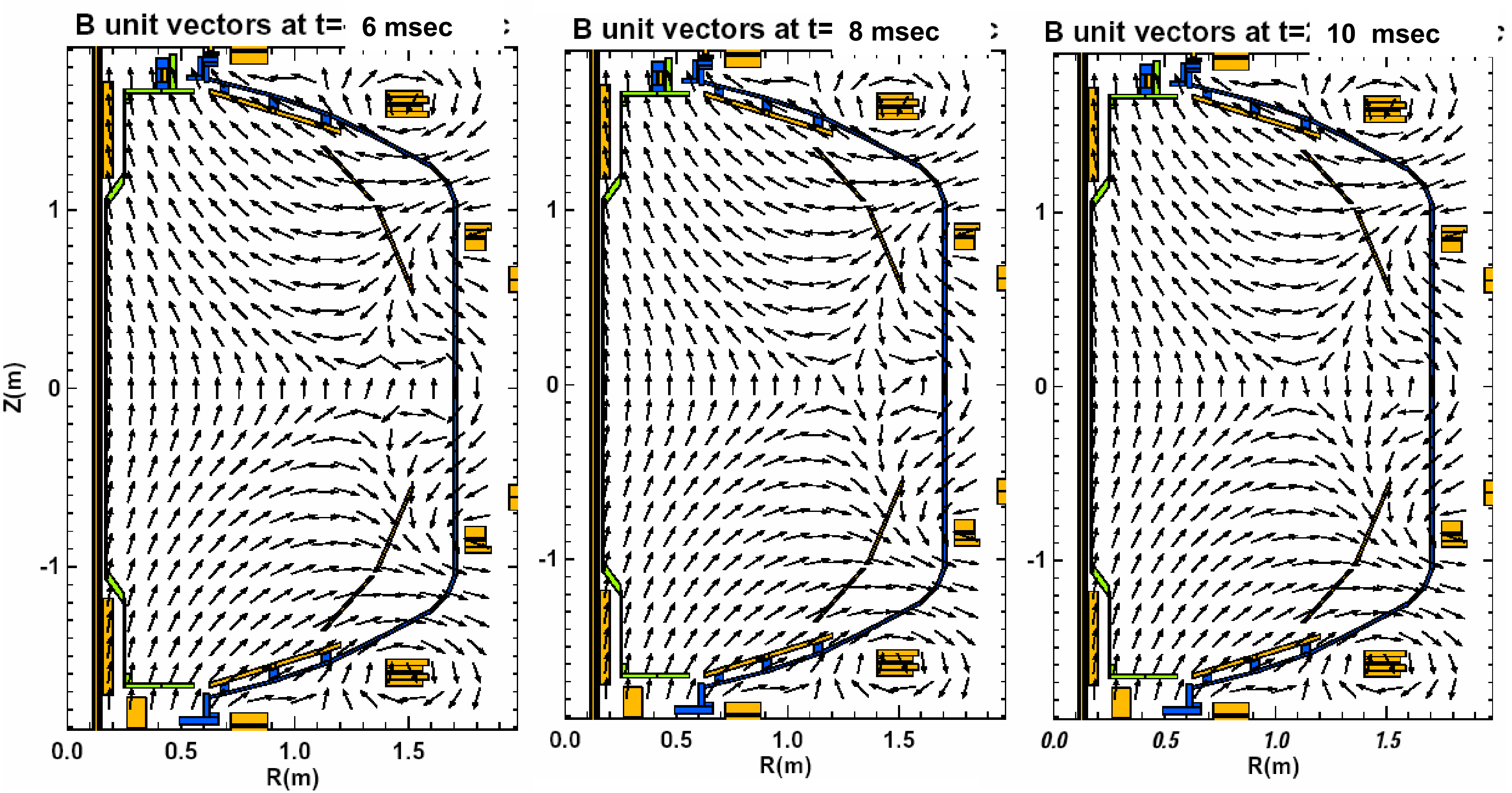
Relatively high loop-voltage ~ 13V, large >0.1 kV/m region created for a few msec with available poloidal flux ~ 0.1 V-S.



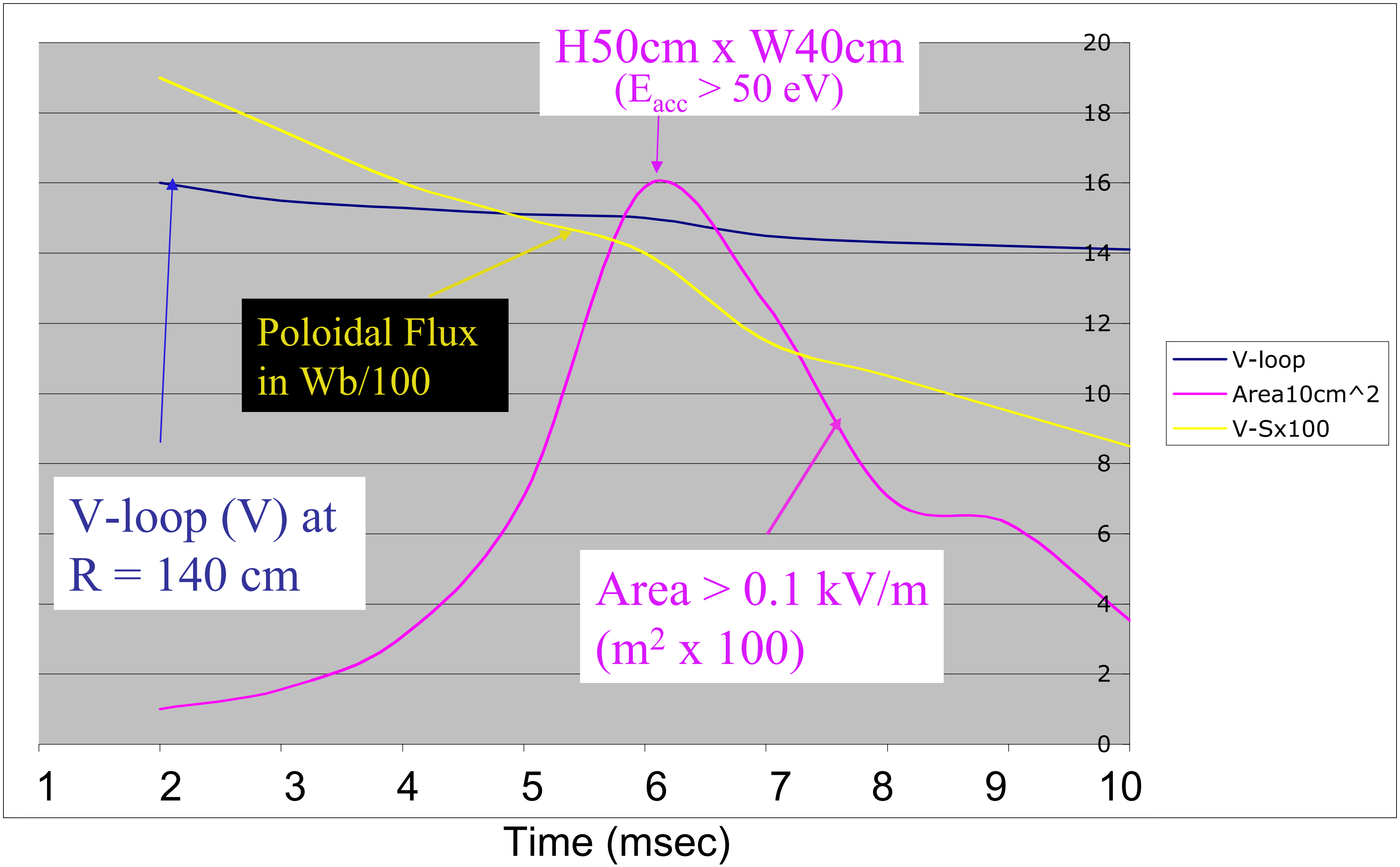
Initially, the plasma is expected to drift outward but vertically relatively stable.



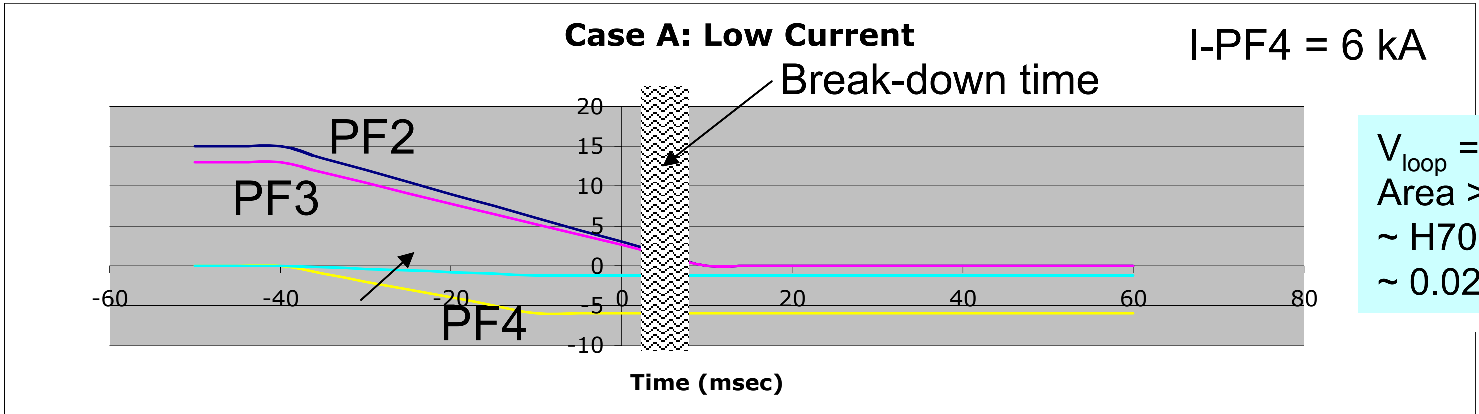
The plasma is expected to become radially stable after a few msec.



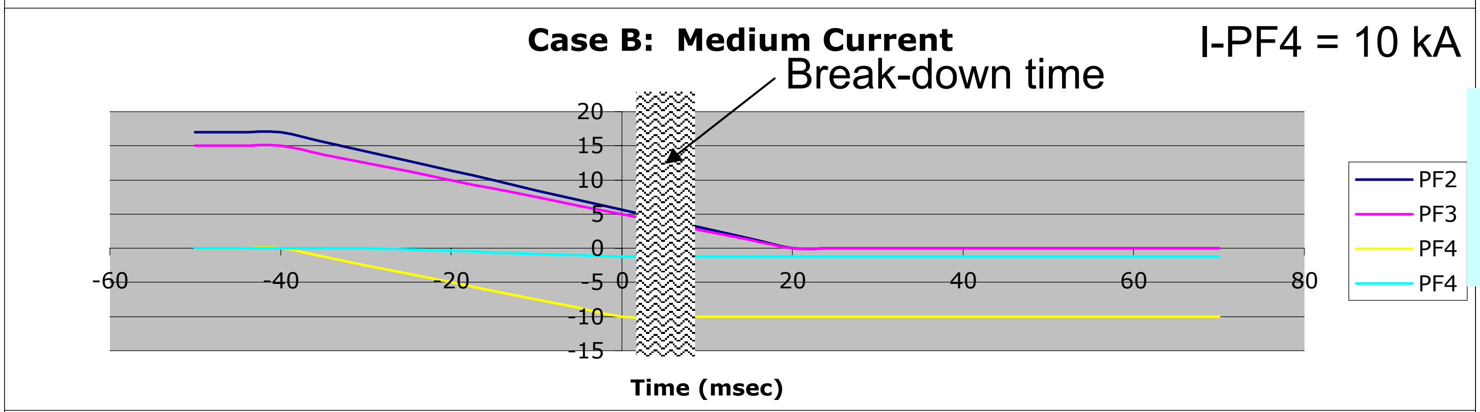
Available flux increases if breakdown can take place earlier



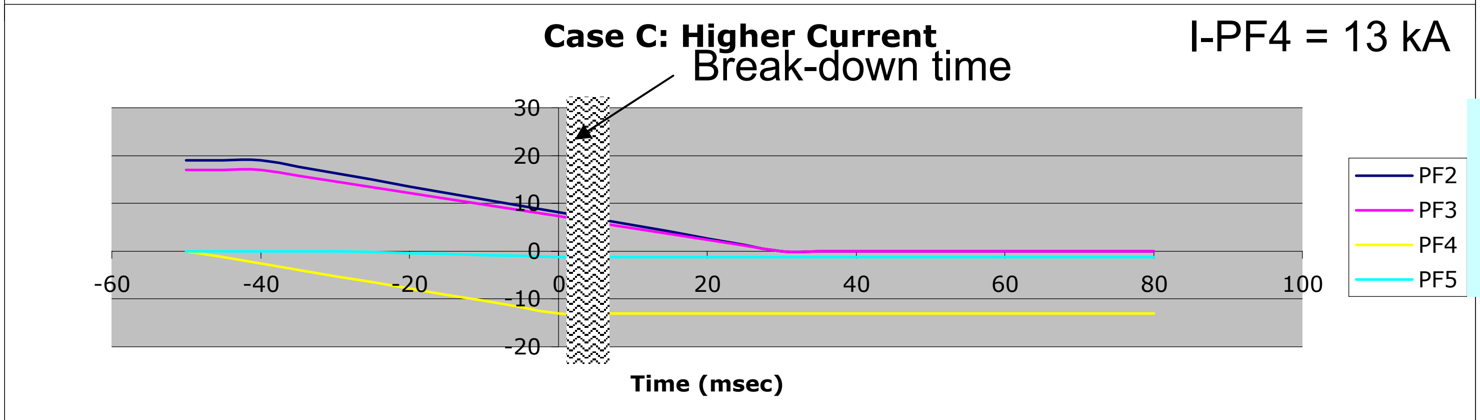
Lower PF4 Coil Current Cases Developed To allow incremental (safer) experimentation



V_{loop} = 13V
Area > 0.1 kV/m
~ H70cm x W50cm
~ 0.02 Wb



V_{loop} = 17V
Area > 0.1 kV/m
~ 70cm x 45cm
~ 0.04 Wb



V_{loop} = 18V
Area > 0.1 kV/m
~65 cm x 45cm
~ 0.06 Wb

Summary of Scenarios A, B, C and Base

	Case A	Case B	Case C	Base
Breakdown time (msec)	0 -10	0 -10	0 -10	0 -10
PF 4 Current (kA)	6	10	13	15
PF 5 Current (kA)	1.2	1.2	1.2	1.5
Available loop voltage	13	17	18	15
Available flux (Wb)	0.02	0.04	0.06	0.1
Size of < 0.1 kV/m region	70 x 50 cm^2	70 x 45 cm^2	65 x 45 cm^2	50 x 40 cm^2

Experimental Conditions

- Plasama initiantion is expected to be at t = 0 - 10 msec.
- TF at 4.5 kG flat top from -100 msec to + 200 msec
- Energize PF 2, 3, 4, 5 (see the PF wave forms).
- OH, PF#1a and #1b disconnected
- Gas: Deuterium - outboard injector: gas puss to start at t = - 20 msec?
- Preionization:

  - ECH from -10 msec to +10 msec.

  - HHFW in phase at 1-2 x 10^{-5} Torr turn on at t = -5 msec. If possible, energize all available antennas for maximum power and combination of in-phase and out-of-phase. ~ 1 MW
- NBI: Turn on from t = 0 to 50 msec at 60 kV.
- Plasma control: preprogrammed.
- 10 minute cycle - 5 x 7 hours = 35 shots

XP 448 Shot List

1. Low Current Case A:

   Determine an optimum condition for break-down: **(10 shots)**

   i. Start with nominal pre-fill pressure of 1.5×10^{-5} Torr. (2 shots)

   ii. Adjust the gas injection timing and HHFW timing to optimize the break down (4 shots)

   iii. Try 1.75×10^{-5} Torr and 1.25×10^{-5} Torr. (4 shots)

   ii. If no observable problem with operation, proceed to Case B.

2. Medium Current Case B: **(5 shots)**

   i. Start with the optimum setting from Case A

   ii. Adjust the gas injection timing and HHFW timing by noting the difference in the breakdown timing. If needed adjust the gas pressure.

   ii. If no observable problem with operation, proceed to Case C.

XP 448 Shot List

3. Higher Current Case C: **(5 shots)**

   i. Start with the optimum setting from Case B

   ii. Adjust the gas injection timing and HHFW timing by noting the difference in the breakdown timing. If needed adjust the gas pressure.

   ii. If no observable problem with operation, proceed to Base case.

4. Base case: **(5 shots)**

   i. Start with the optimum setting from Case C

   ii. Adjust the gas injection timing and HHFW timing by noting the difference in the breakdown timing. If needed adjust the gas pressure.

5. Pulse optimization: Choose the most promising case from A, B, C, and Base cases **(10 shots)**

   i. Adjust the PF 4 ramp down rate to optimize the current ramp up. If the plasma is shifting inward, increase the PF 4 ramp down rate. If plasma is shifting outward, reduce the PF 4 ramp down rate.

Required Diagnostics

Diagnostic	Need	Desire	Instructions
CHERS		X	
Edge rotation spectroscopy		X	
Filterscopes	X		
FIReTIP	X		
Magnetics - Flux loops	X		
Magnetics - Locked modes	X		
Magnetics - Pickup coils	X		
Magnetics - Rogowski coils	X		
Magnetics - RWM sensors	X		
Mirnov coils – toroidal array	X		
Plasma TV	X		
Reflectometer – core		X	
Reflectometer - SOL		X	
RF antenna camera	X		
RF antenna probe		X	
SPRED	X		
Thomson scattering	X		
Ultrasoft X-ray arrays	X		