SOLENOID-FREE STARTUP EXPERIMENTS IN DIII-D

by

Jim Leuer

for

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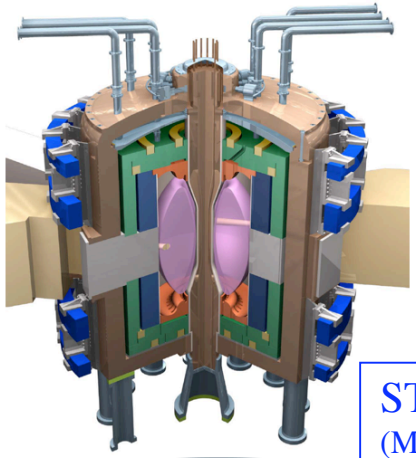
MOTIVATION: Solenoidless Startup Leads to Compact Design

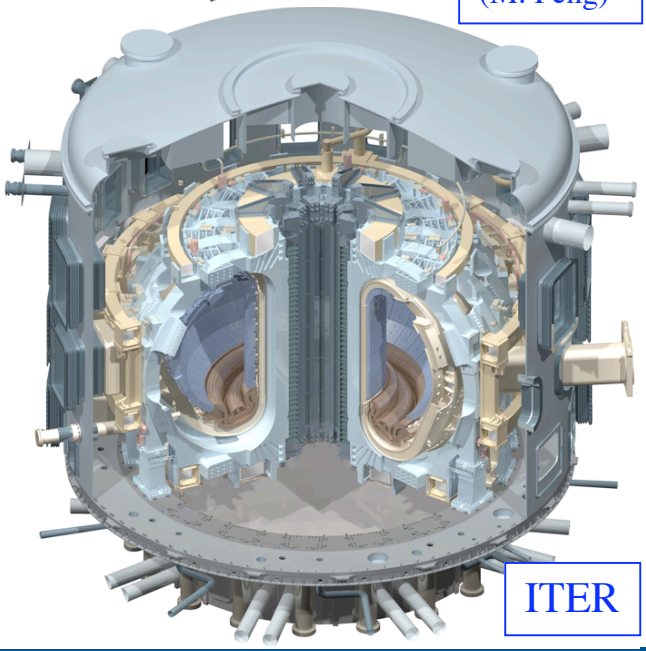
- **Motivation:**
  - Elimination of Inner PF coils leads to compact design - Requirement for fusion ST path

- **Outline:**
  - Quick Results / Initial Proposal
  - Scenario Development: Null/Flux/Stability
  - Experimental Results
  - Summary/Future

- **Scenario Overview**
  - Startup using non-solenoid coils (F5-9)
  - 2.3 MW ECH for breakdown & heating
  - Maximize Ip for hand-off to NBCD
  - Two 1/2 day experiments



ST-CTF
(M. Peng)



ITER

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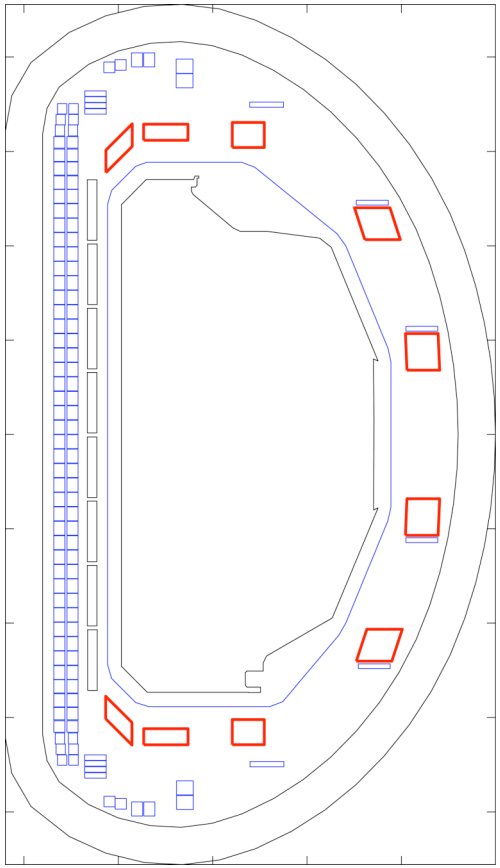

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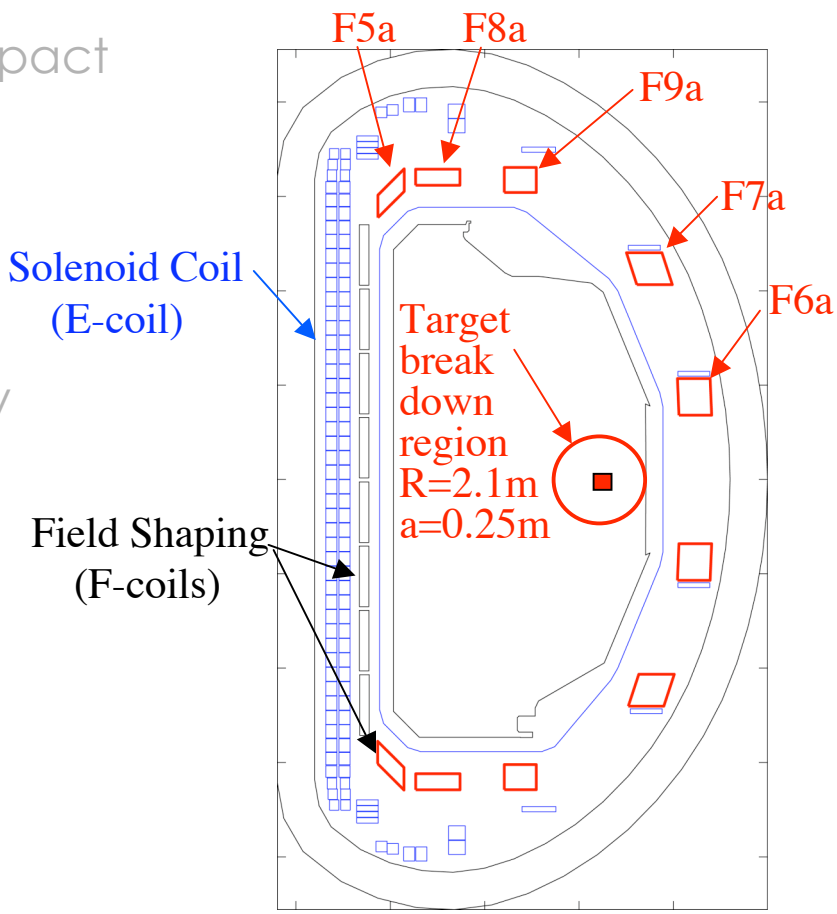
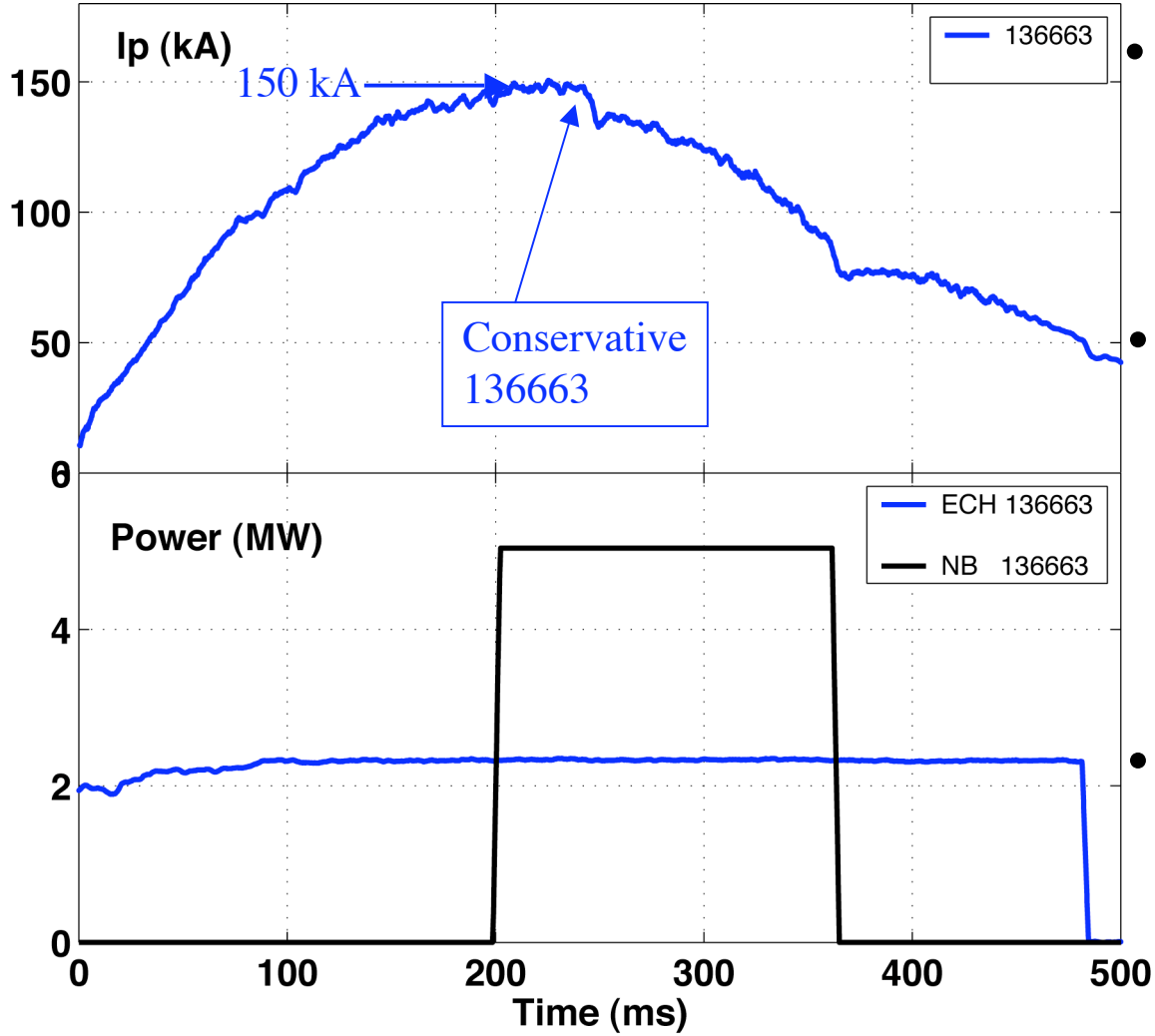
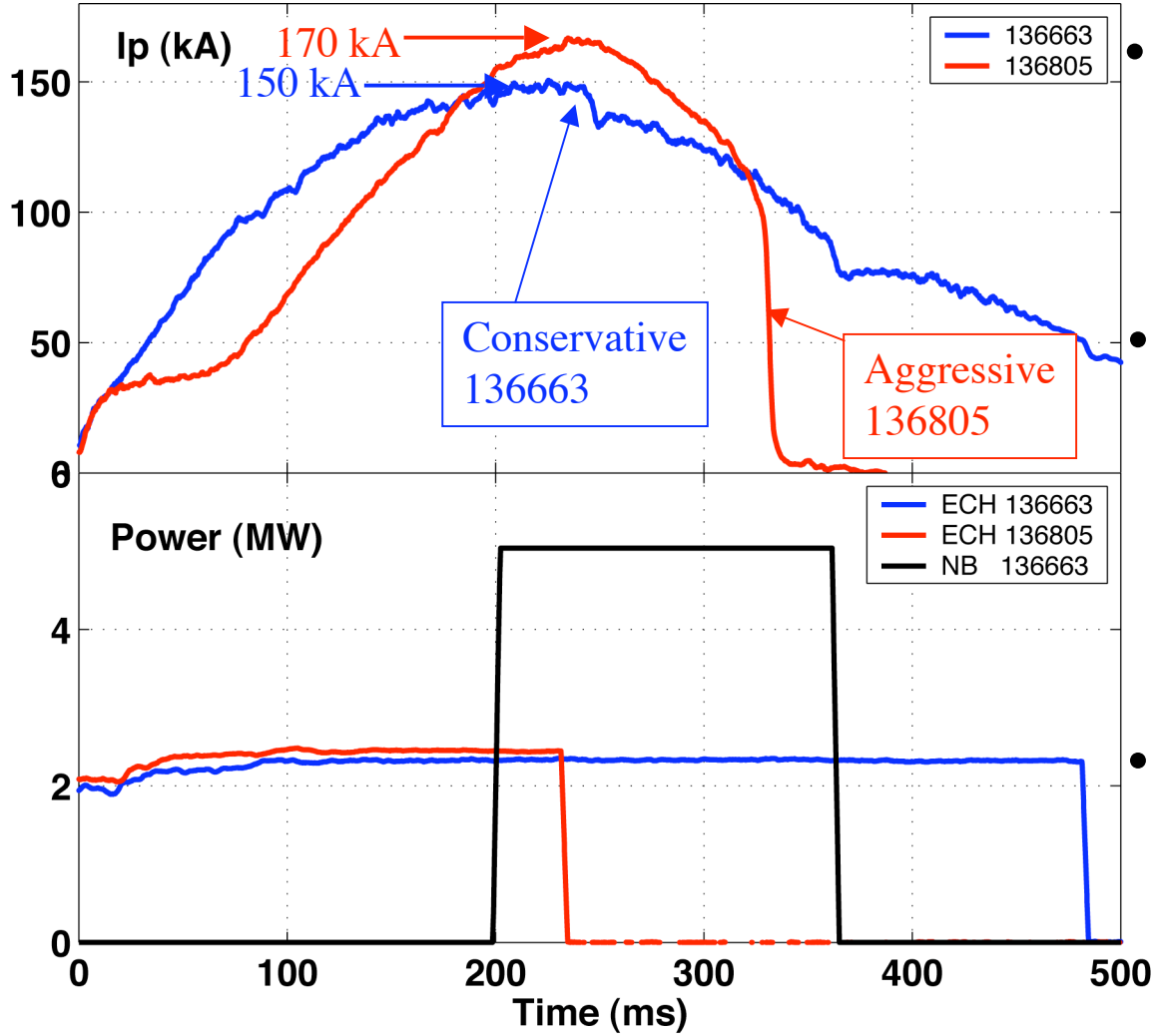


Good Overall Success on First Half Day of Testing



- Two 1/2 day Experiments
  - Conservative 150kA
- ECH essential for breakdown and heating
  - 4 Gyrotrons utilized
  - t_{on} = -15ms pre-ionization
- 2-Co Beams into 136663
  - Lack of Rp control
    => Limited NBCD

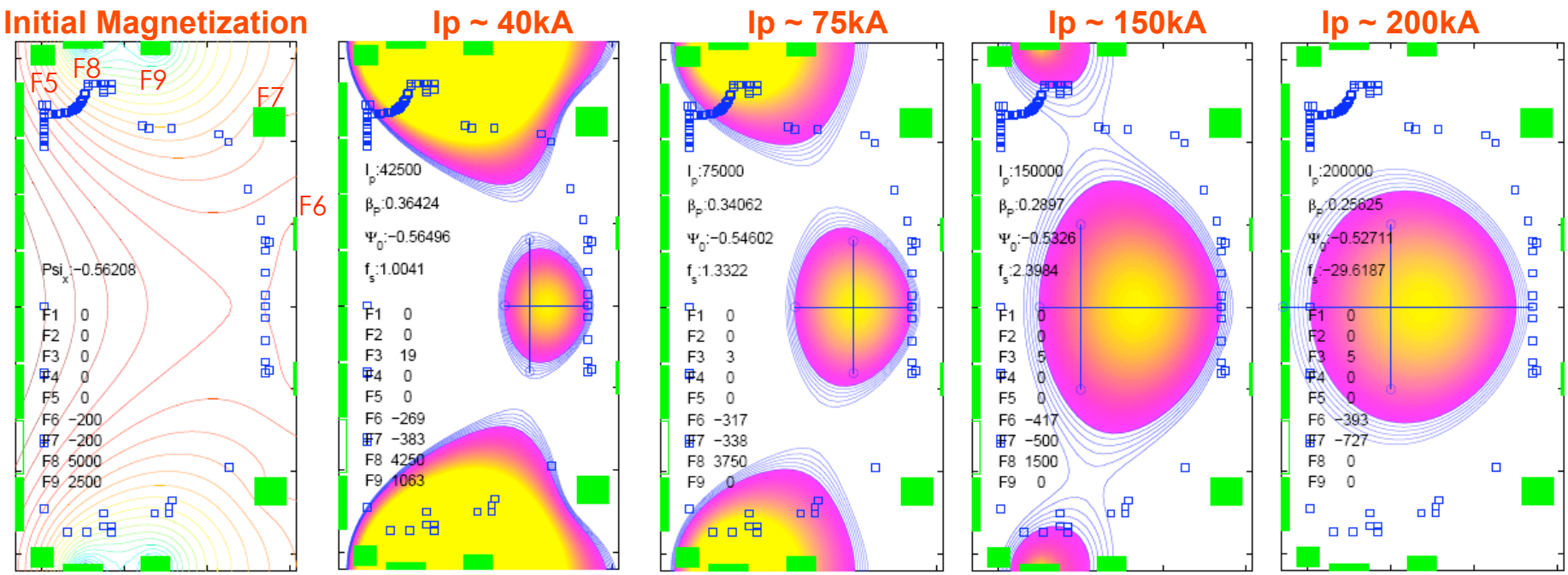
Good Success on 2nd Half Day => 170 kA



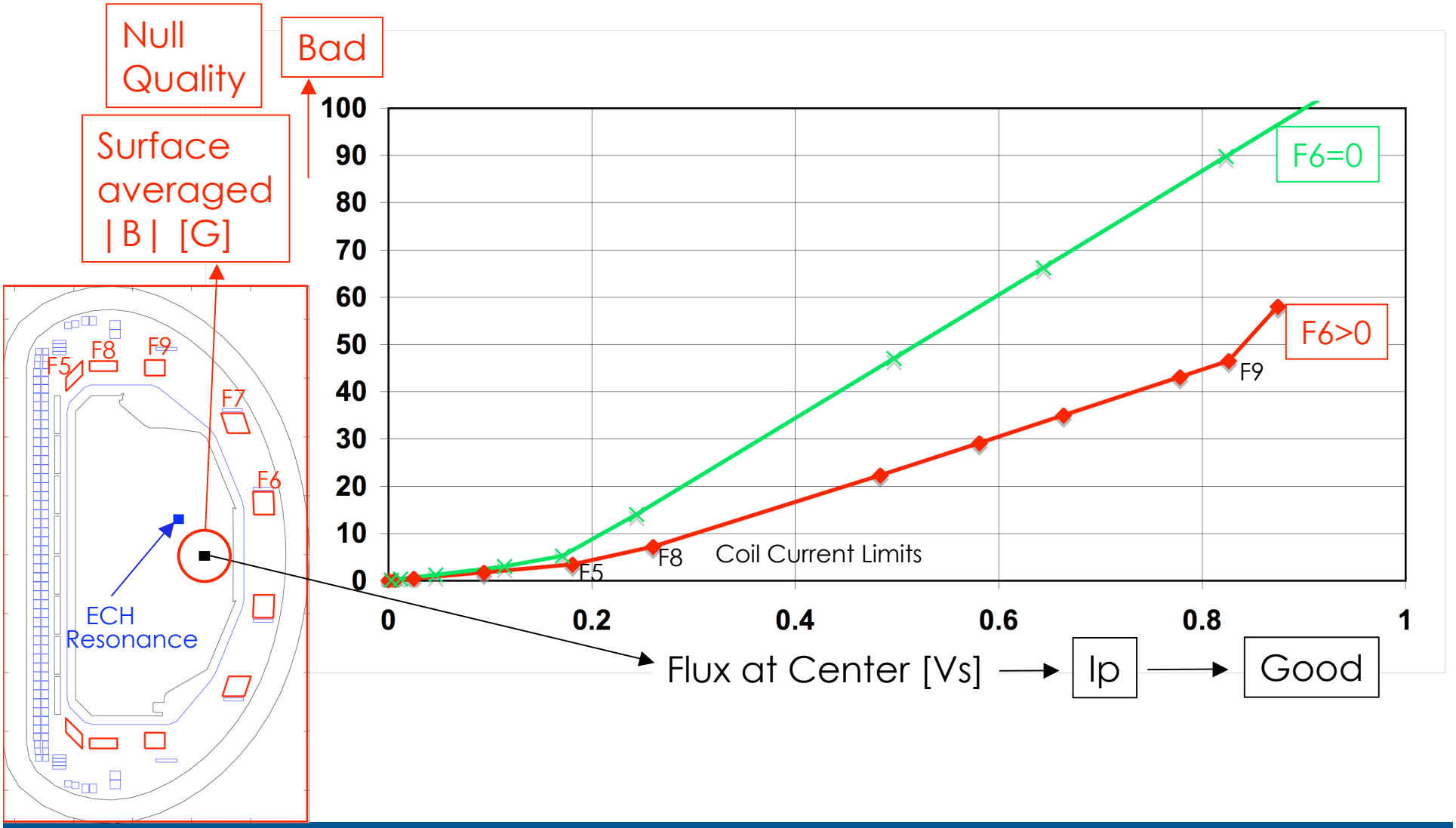
- Two 1/2 day Experiments
  - Conservative 150kA
  - Aggressive 170kA
- ECH essential for breakdown and heating
  - 4 Gyrotrons utilized
  - t_{on} = -15ms pre-ionization
  - 136805 250ms pulse limit
- 2-Co Beams into 136663
  - Lack of Rp control => Limited NBCD

Perspective: Where We Were in December '08 Research Opportunities Forum

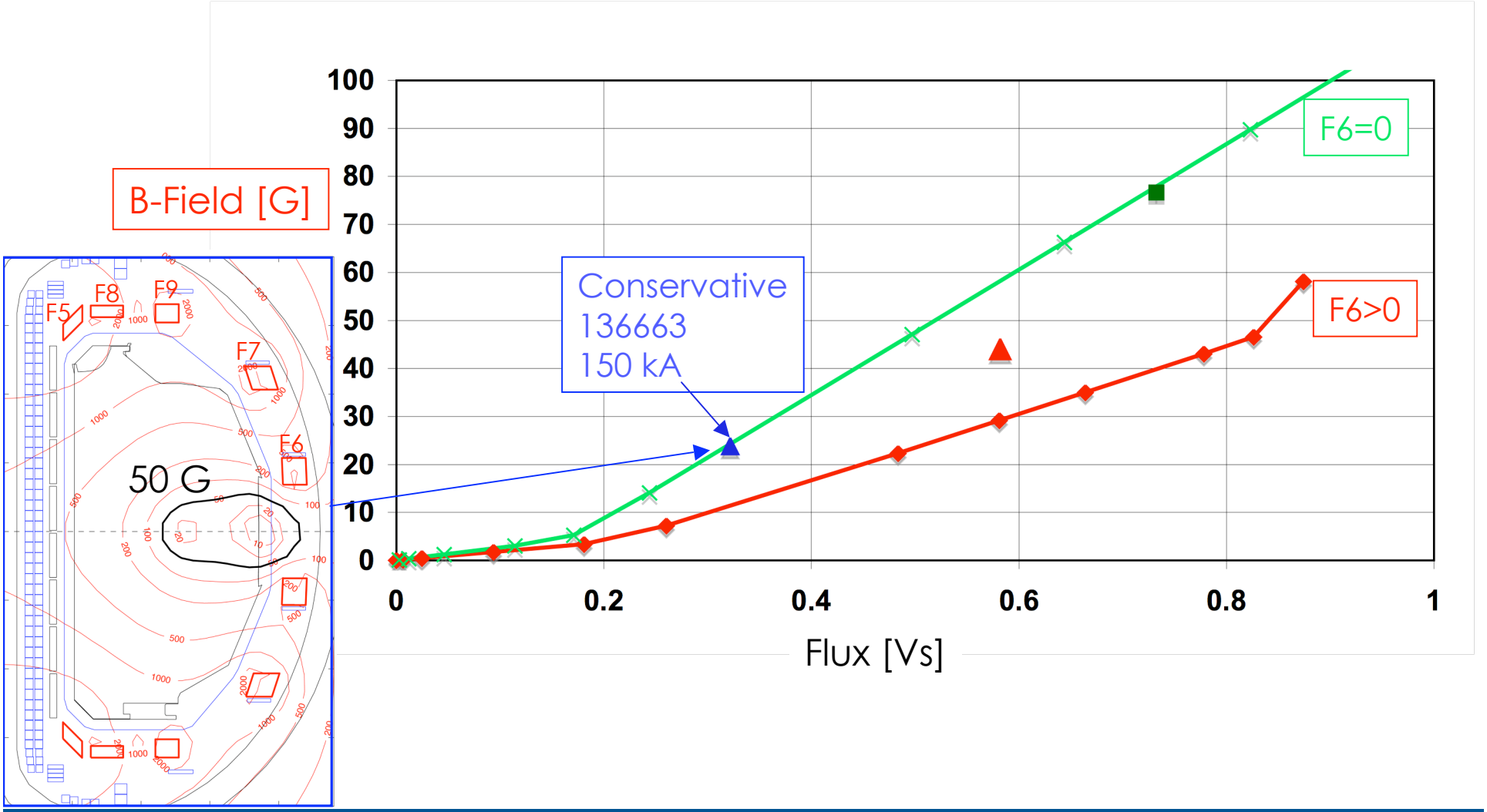
- Cunningham original scenario simulation
  - F5 not used
  - F6 negative
  - Small 1st order null - Unstable plasma during formation



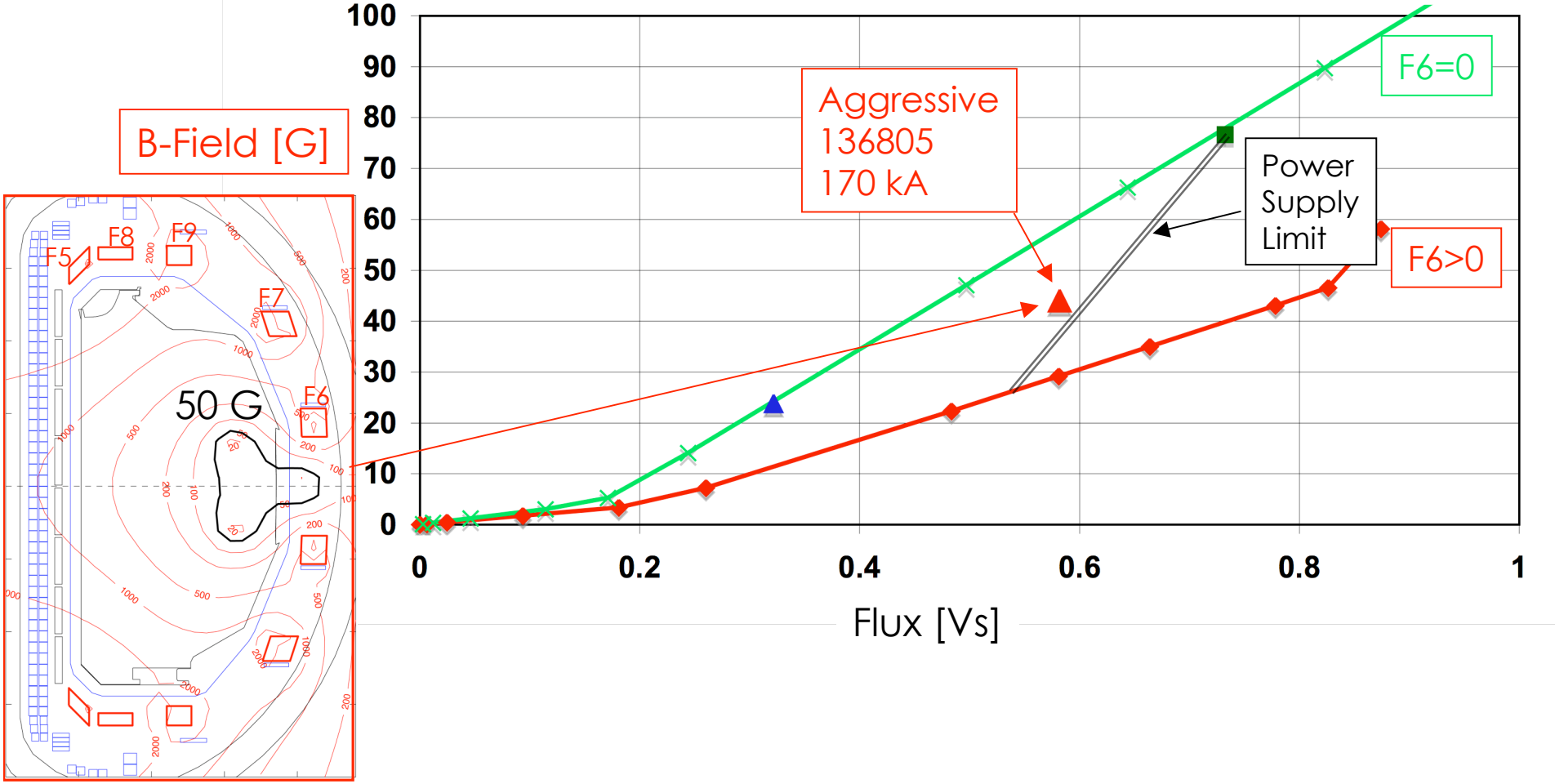
Startup Properties Best Quantified in Null Quality / Flux Space at Initial Magnetization (IM) State



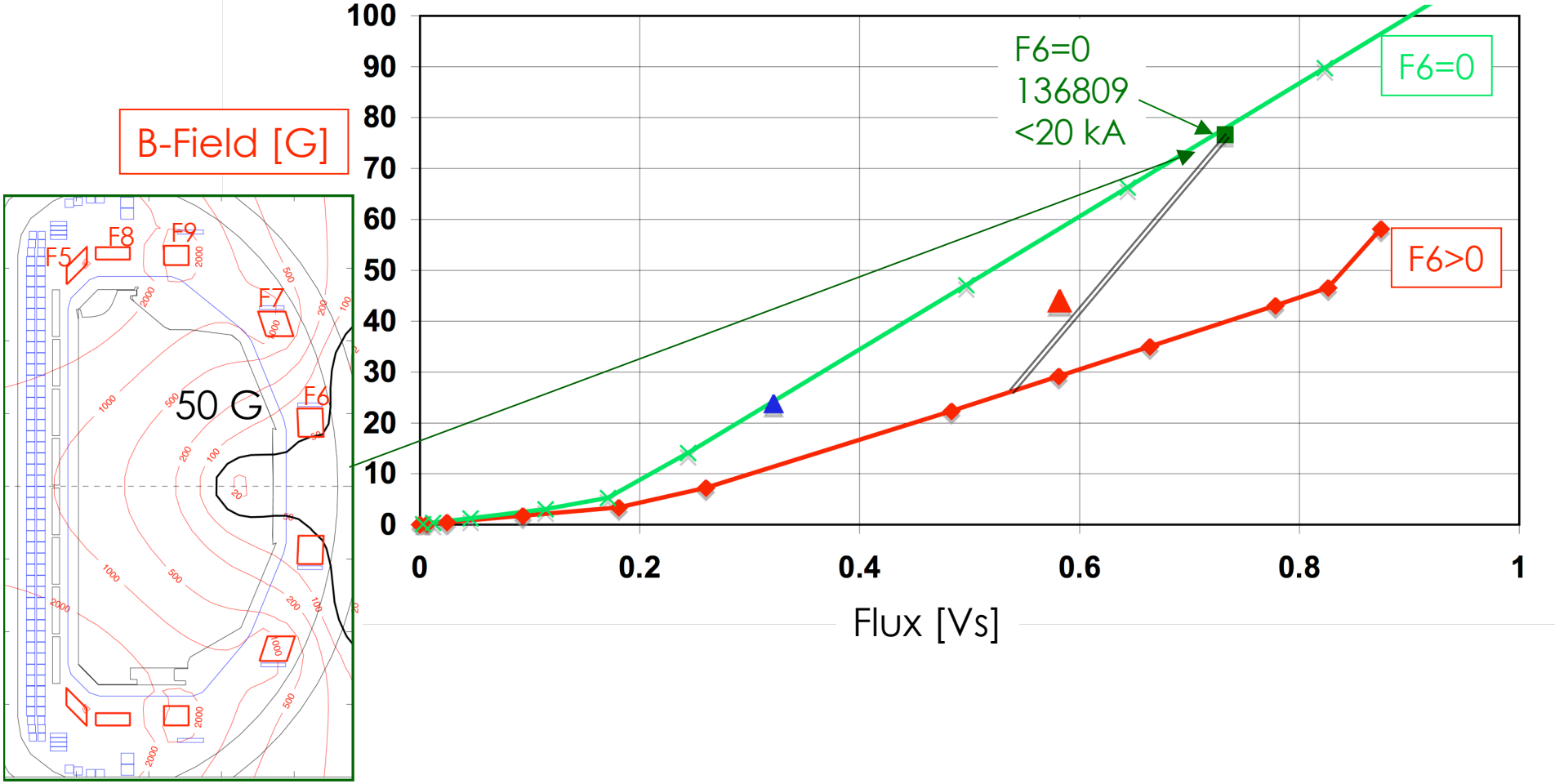
Conservative Scenario had Moderate Null and Moderate Flux



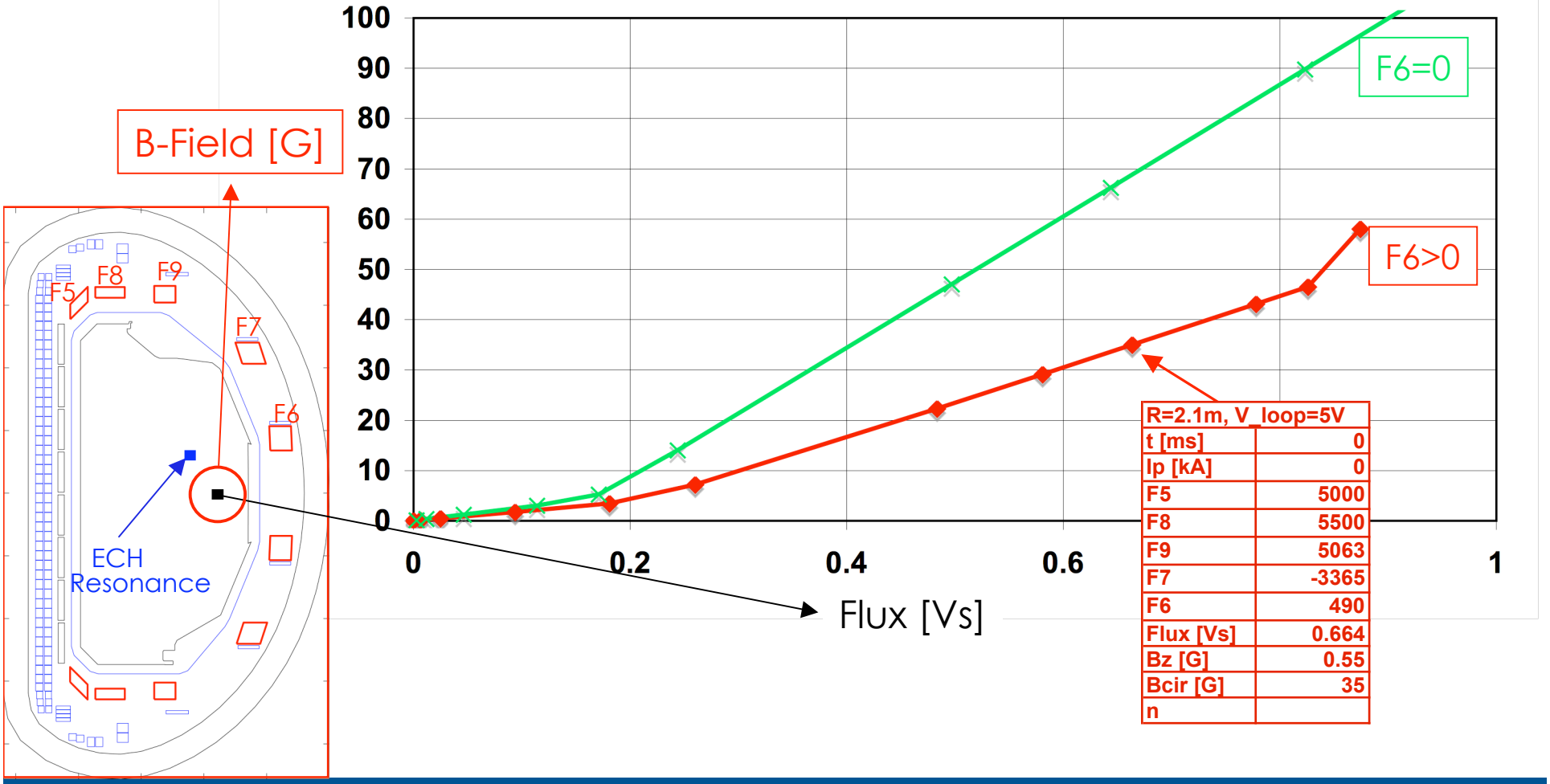
Aggressive Scenario Increased Flux with Lower Quality Null



F6=0 Scenario Was Tried with Ip < 20kA



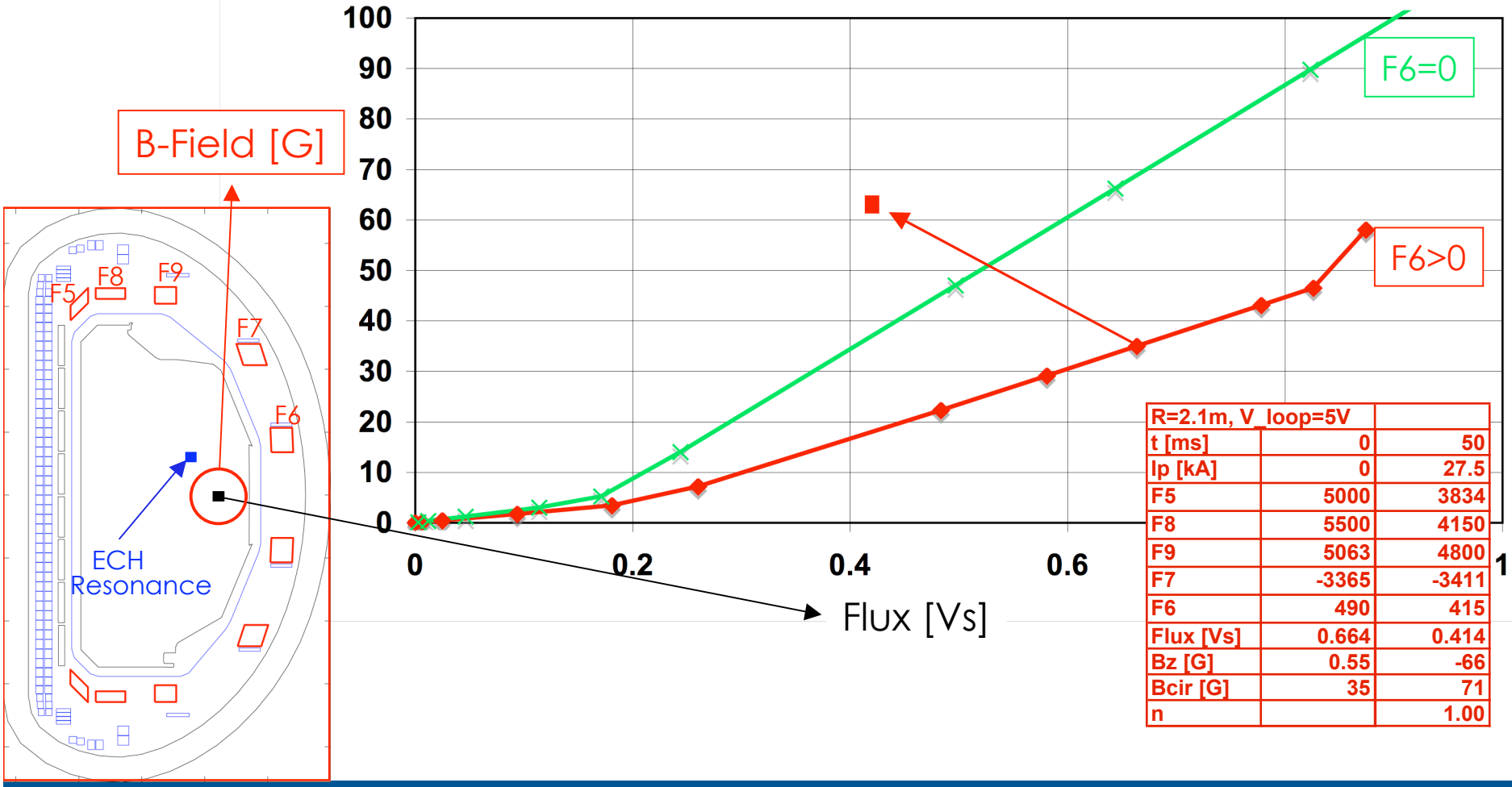
Vacuum Field Trajectory After Breakdown Equally Important in Scenario Development



R=2.1m, V_loop=5V	
t [ms]	0
Ip [kA]	0
F5	5000
F8	5500
F9	5063
F7	-3365
F6	490
Flux [Vs]	0.664
Bz [G]	0.55
Bcir [G]	35
n	

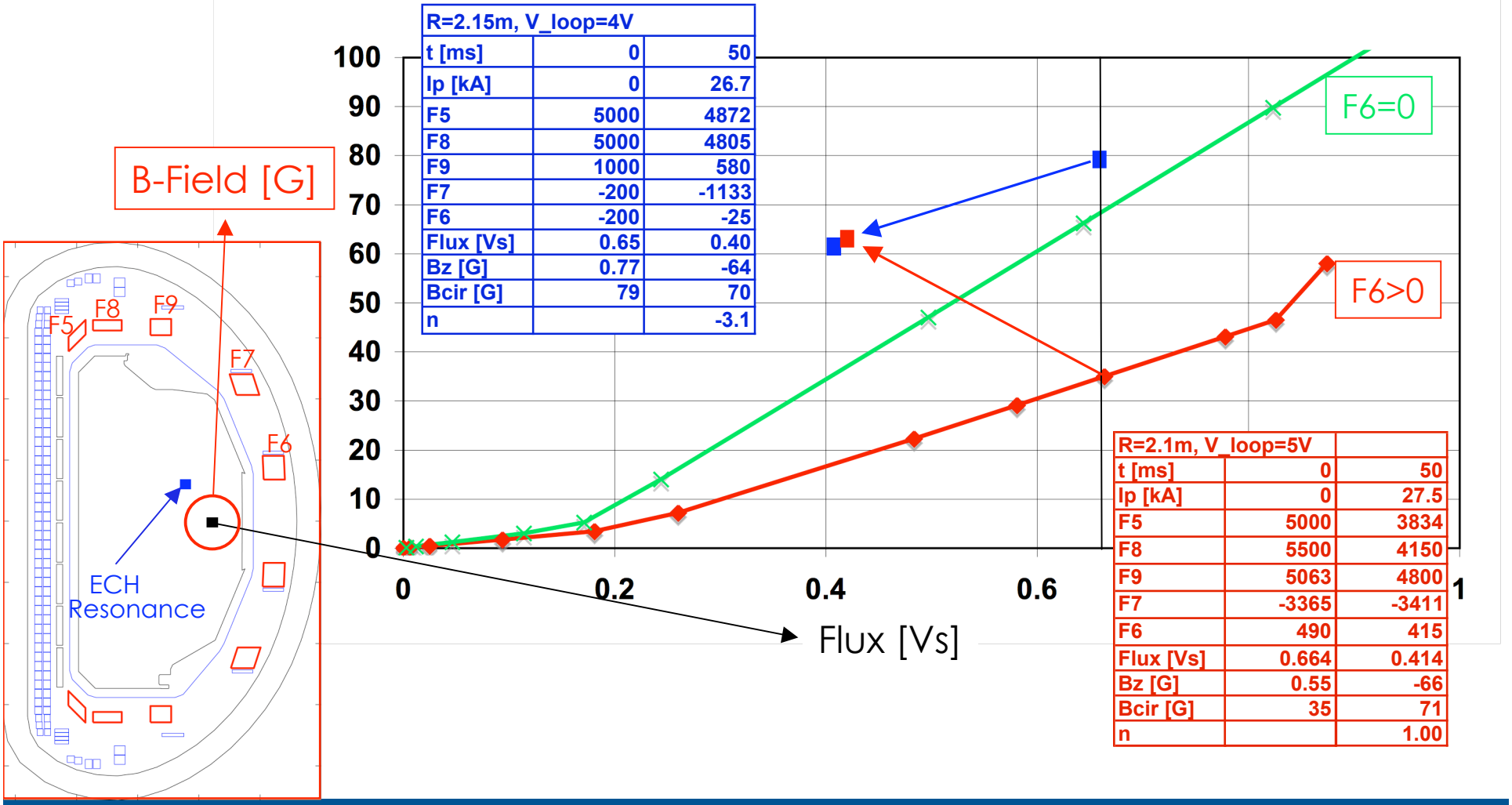
Field Trajectories after Breakdown must match plasma requirements: $\Delta\Phi$, ΔI_p, B_z, decay index (n)

Trajectory Defined by Machine Constraints & Circular Plasma Formula



R=2.1m, V_loop=5V		
t [ms]	0	50
Ip [kA]	0	27.5
F5	5000	3834
F8	5500	4150
F9	5063	4800
F7	-3365	-3411
F6	490	415
Flux [Vs]	0.664	0.414
Bz [G]	0.55	-66
Bcir [G]	35	71
n		1.00

Similar Analysis Can Be Done on F6>0 Case



R=2.15m, V_loop=4V		
t [ms]	0	50
Ip [kA]	0	26.7
F5	5000	4872
F8	5000	4805
F9	1000	580
F7	-200	-1133
F6	-200	-25
Flux [Vs]	0.65	0.40
Bz [G]	0.77	-64
Bcir [G]	79	70
n		-3.1

R=2.1m, V_loop=5V		
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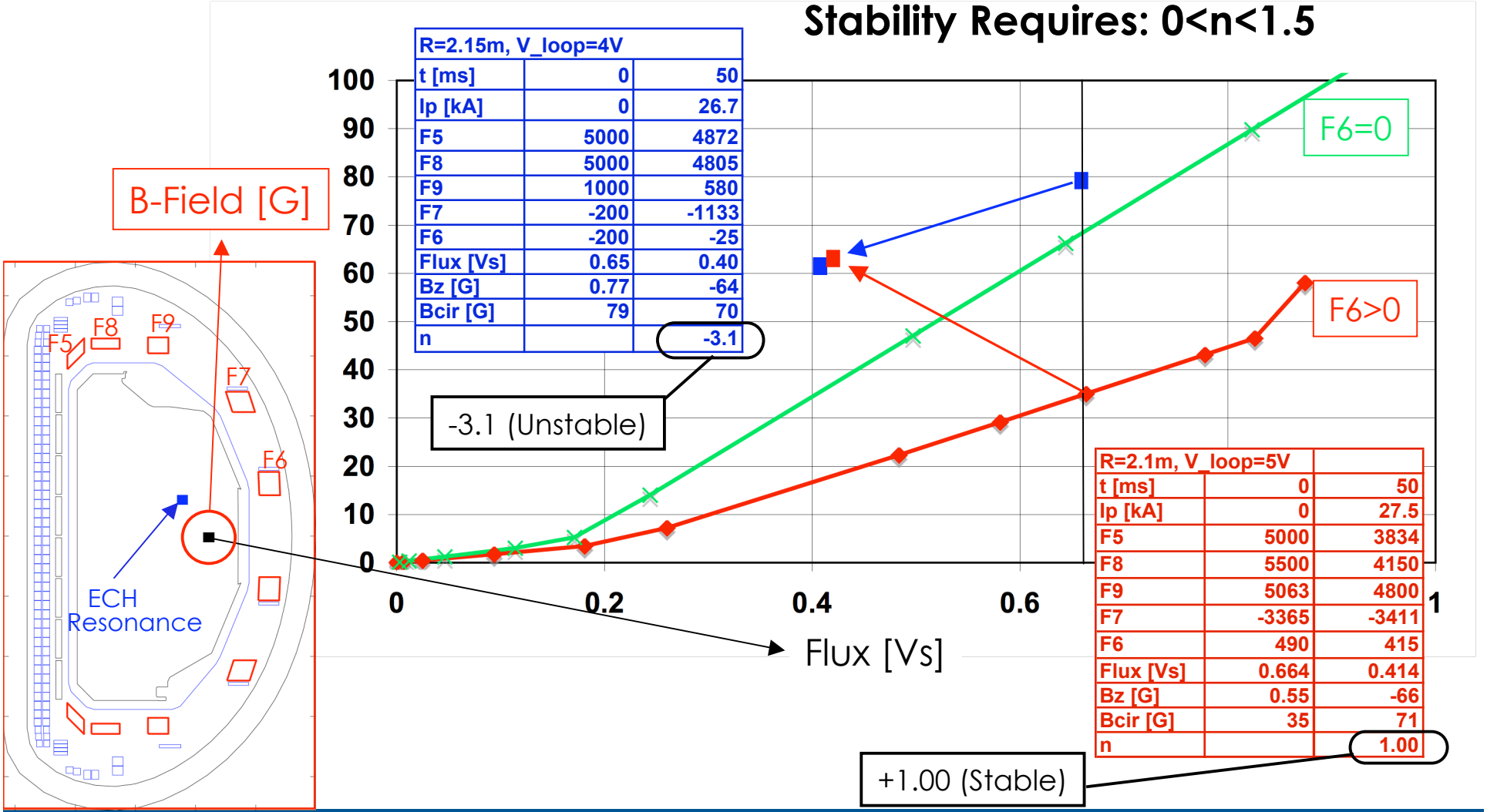
Negative F6 Leads to Unstable Plasma



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Flux [Vs]	0.664	0.414
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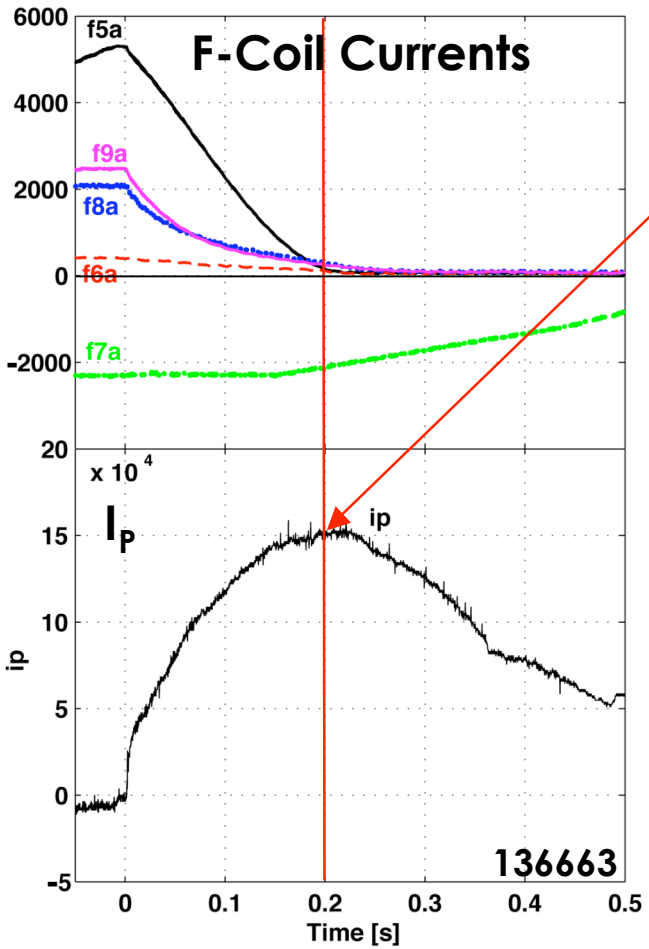
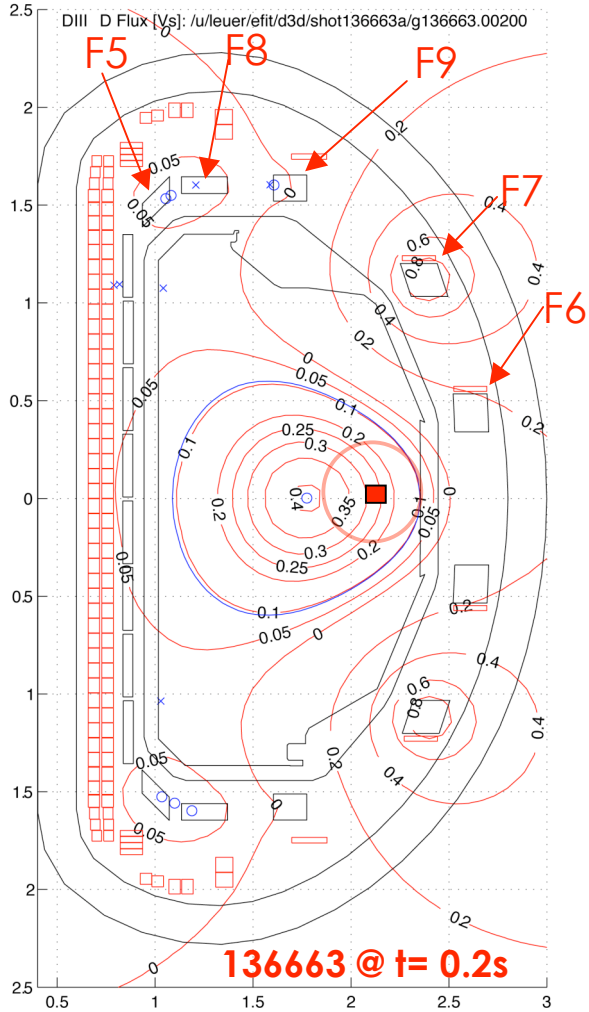
Bcir [G]	35	71
n		1.00

F-Coil Current Swing Is Fully Utilized at Peak Plasma Current

- Conservative Scenario

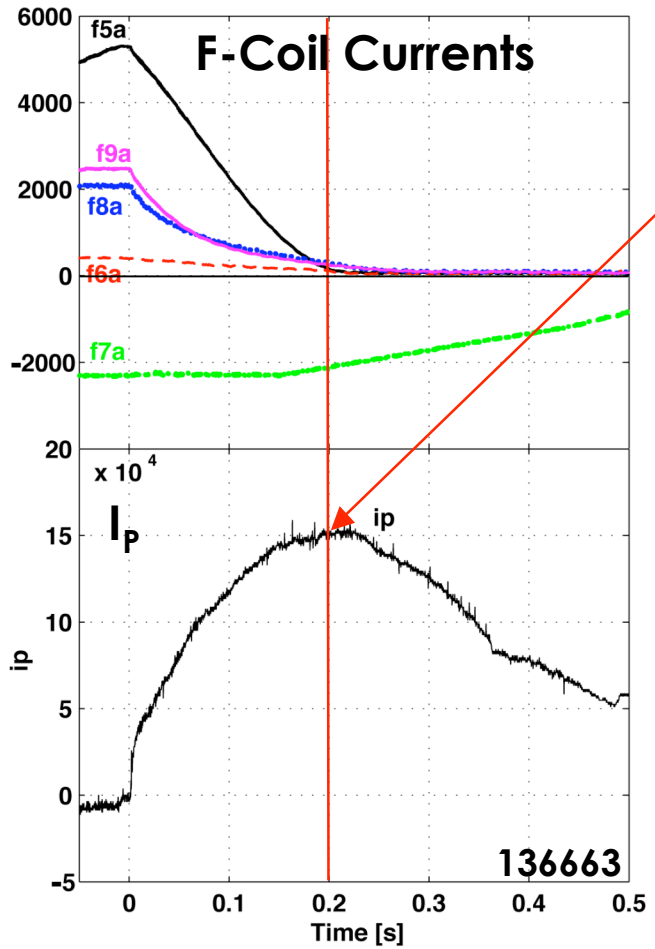


I_p = 150kA



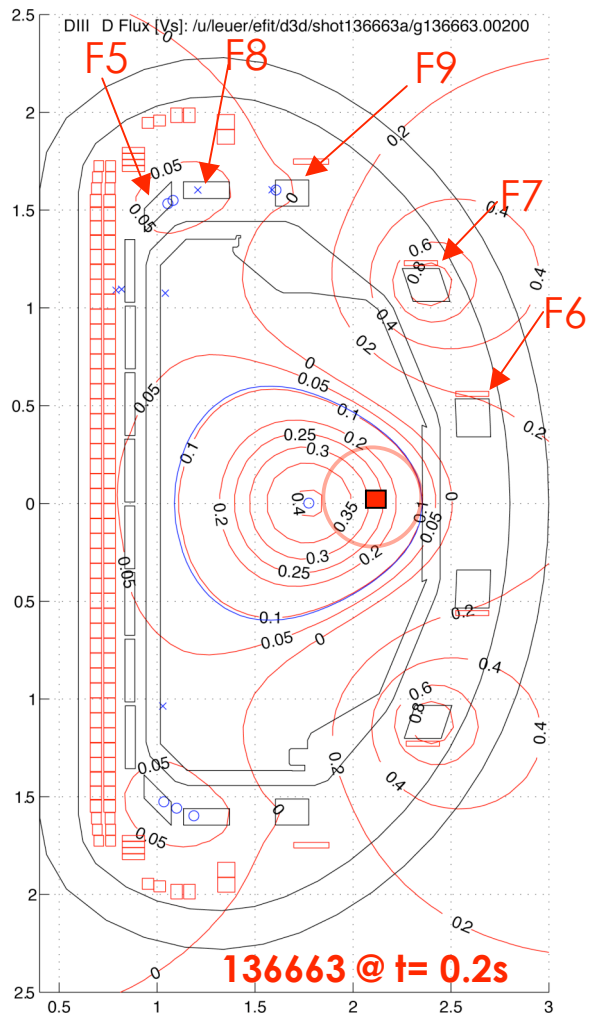
Flux Utilization Quantified by Resistive Flux Consumption (C_{Ejima})

- Conservative Scenario



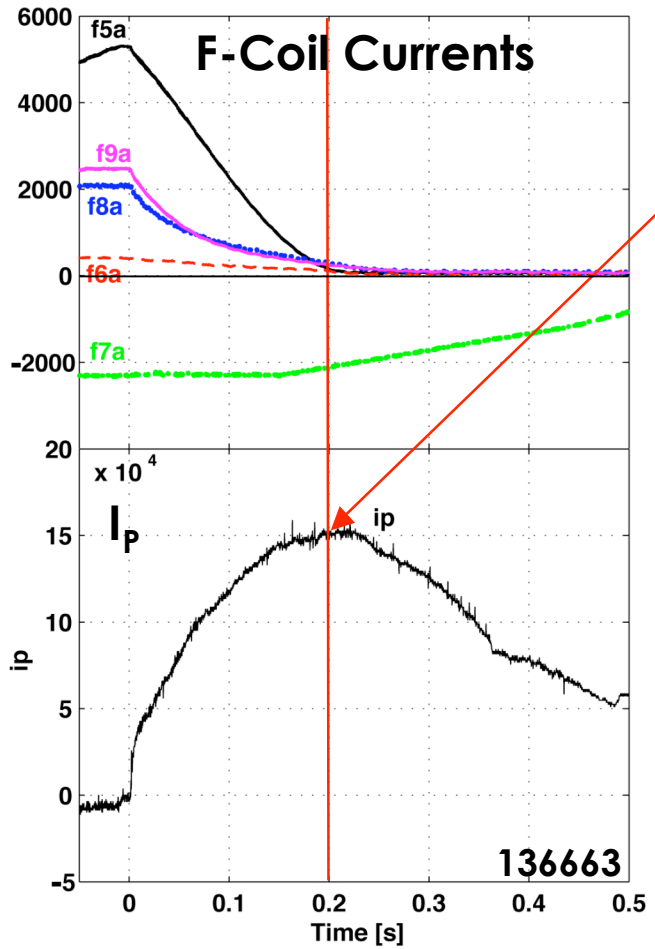
I_p = 150kA

Flux Consumption
C_{ejima}
$\Delta\Phi_{res}/(\mu_o R_p I_p)$
= 0.33



Flux Utilization (C_{Ejima}) Similar to Normal DIII-D ECH

- Conservative Scenario



I_p = 150kA

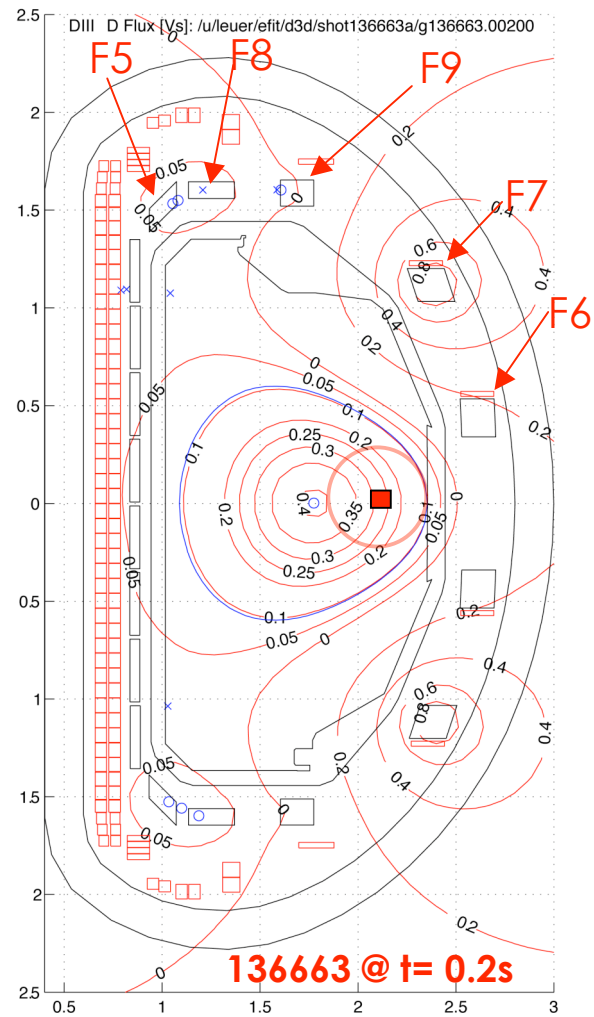
Flux Consumption

C_{ejima}

$\Delta\Phi_{res}/(\mu_o R_p I_p)$

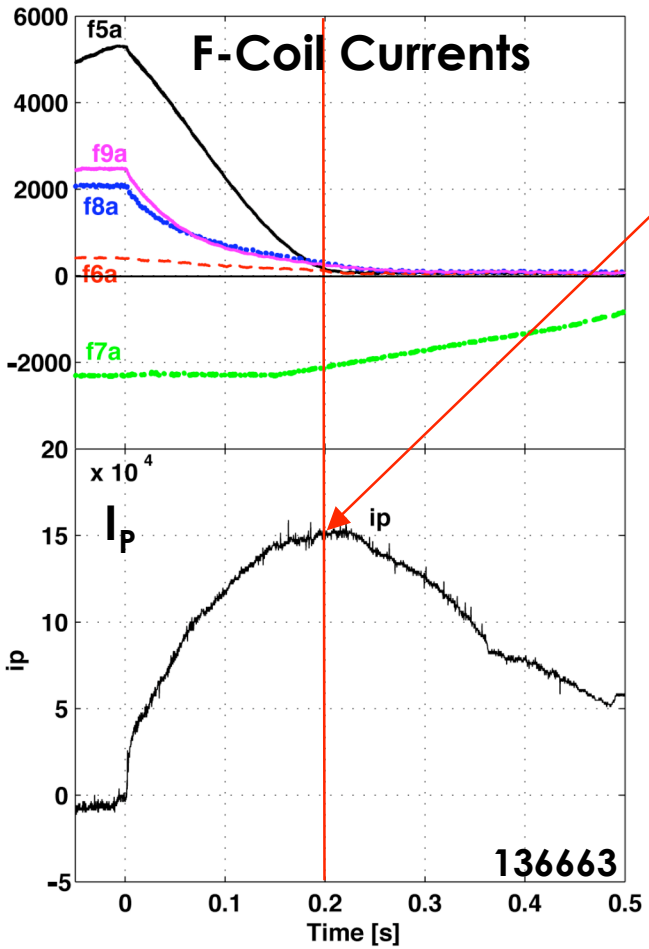
= 0.33

Normal ~ 0.3



Outboard Limited Plasma Maintained During Most of Discharge

- Conservative Scenario



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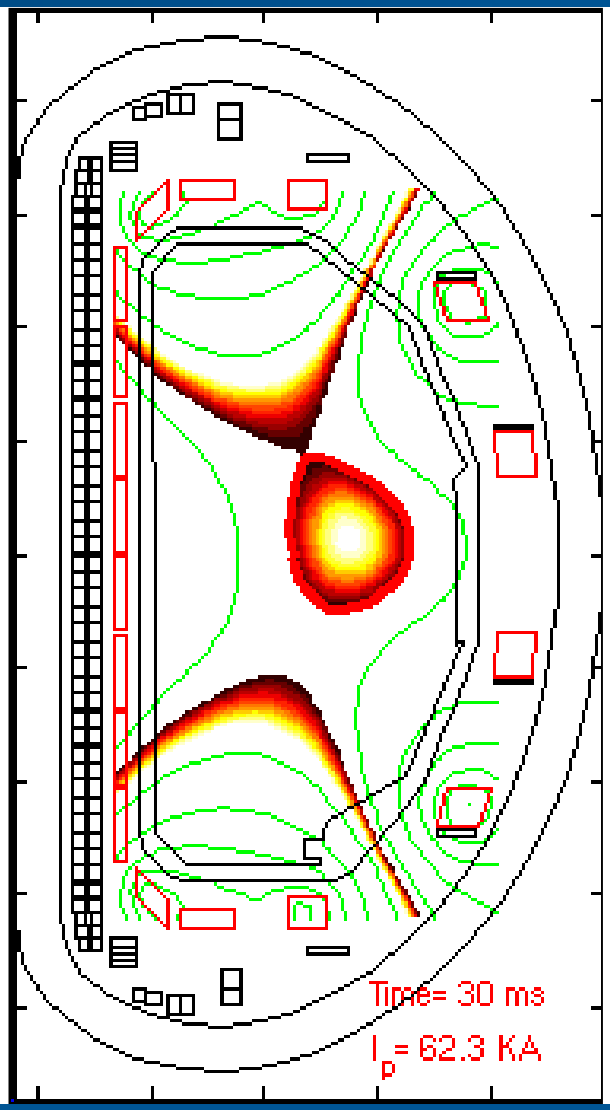
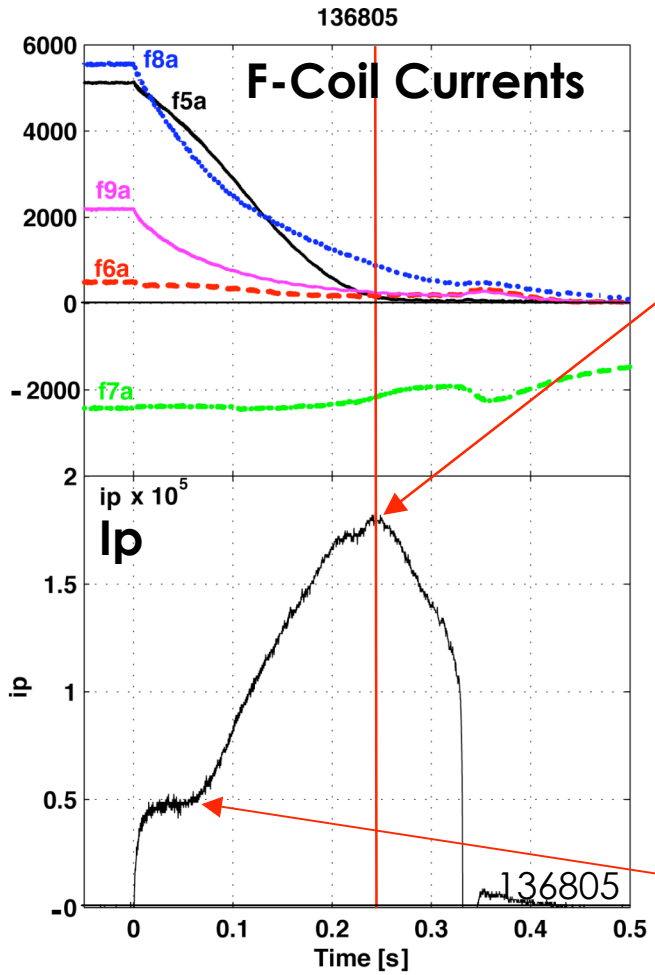


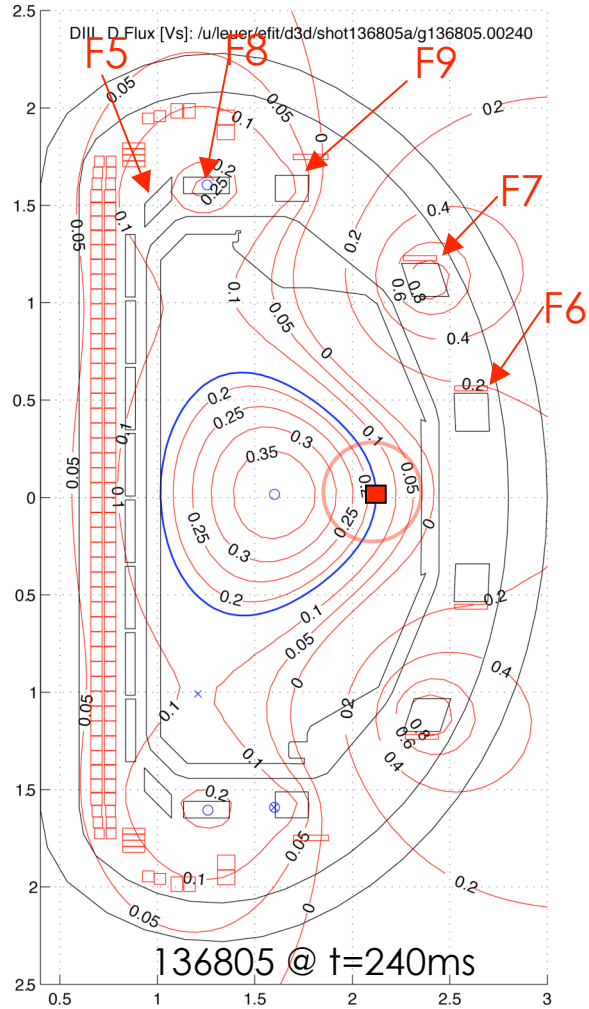
More Aggressive Scenario Under-Utilizes Flux at Start

- **Aggressive Scenario**



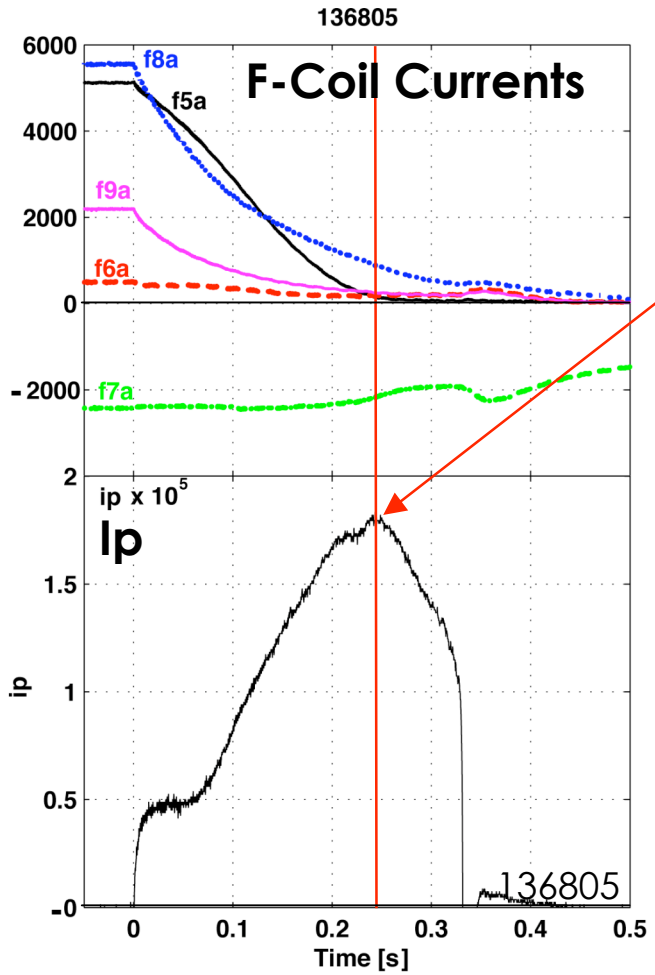
I_p = 170kA

Initial I_p dip loses 25-30 kA



Plasma Compresses on Centerpost During Rampdown

- **Aggressive Scenario**



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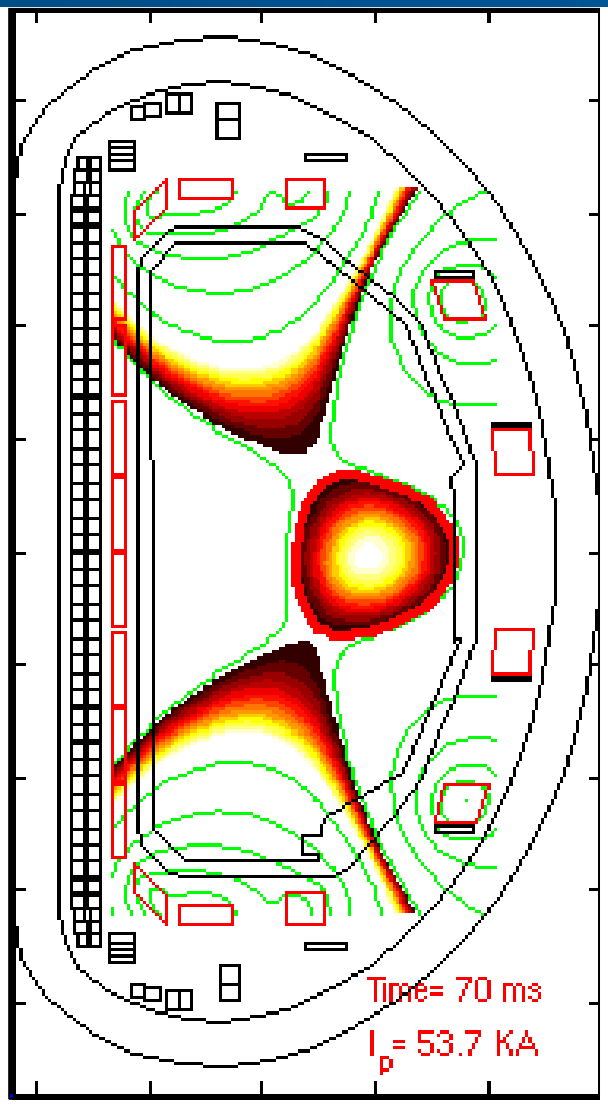
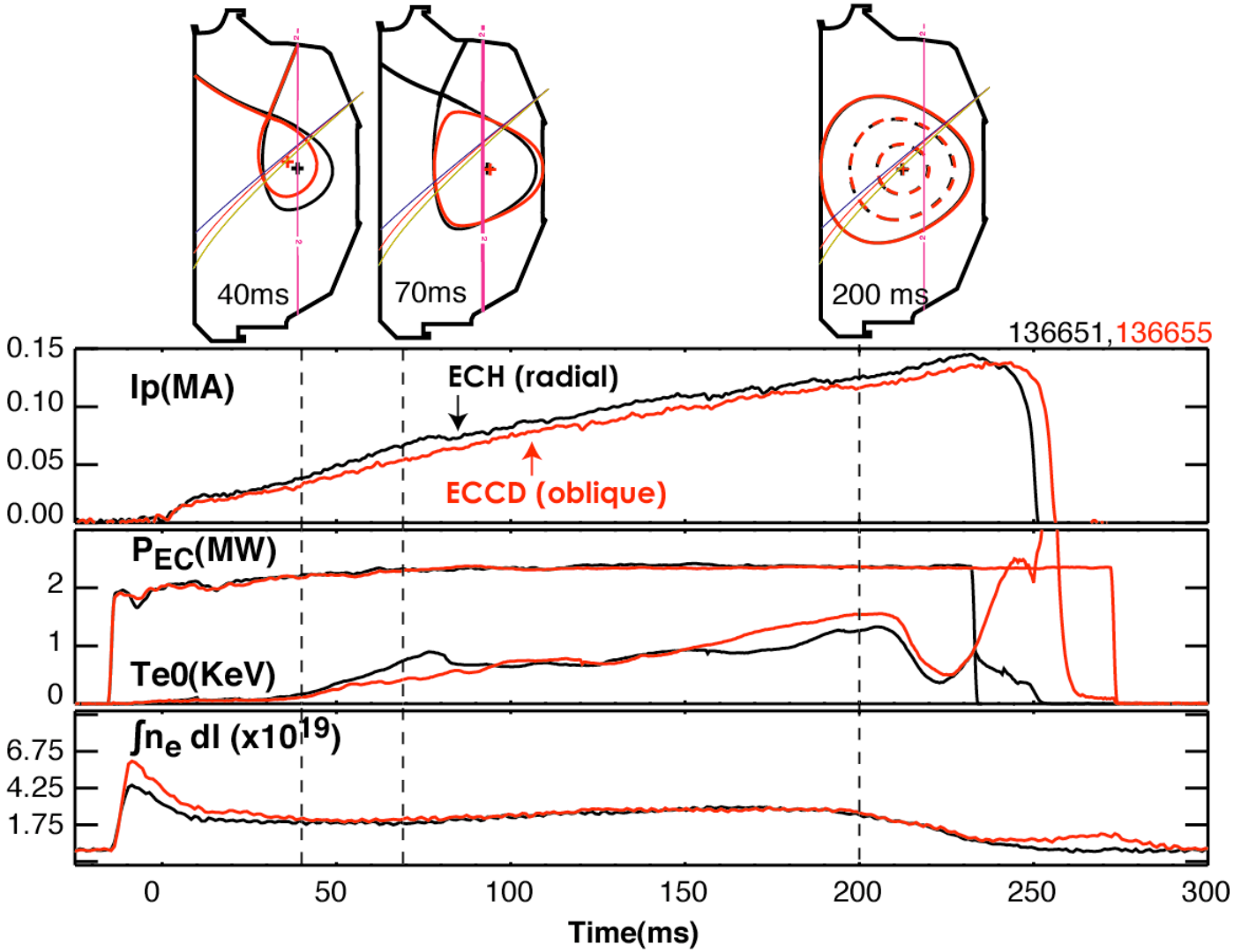


No evidence of ECCD in preliminary experiment (heating effectiveness may dominate dIp/dt, not ECCD)



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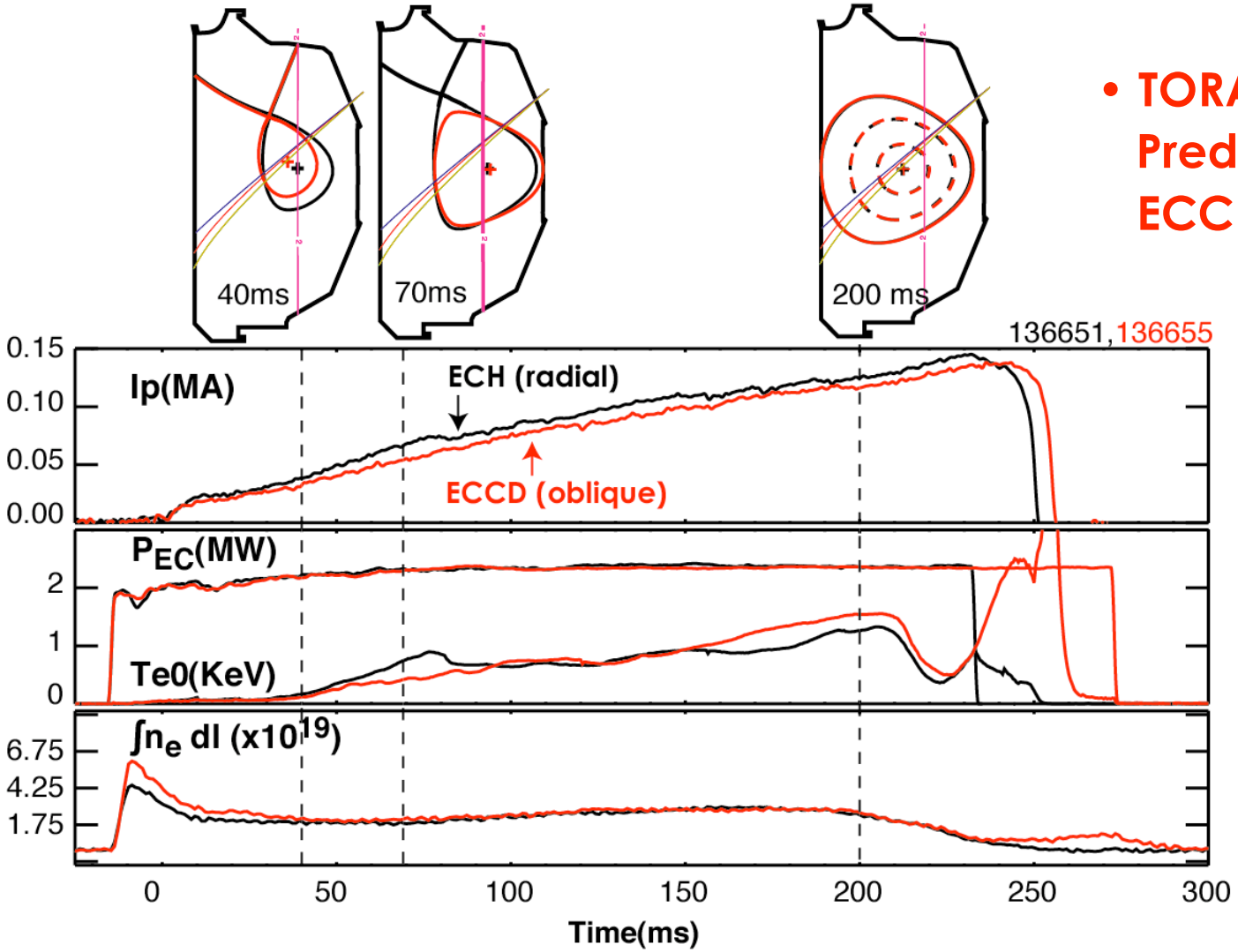
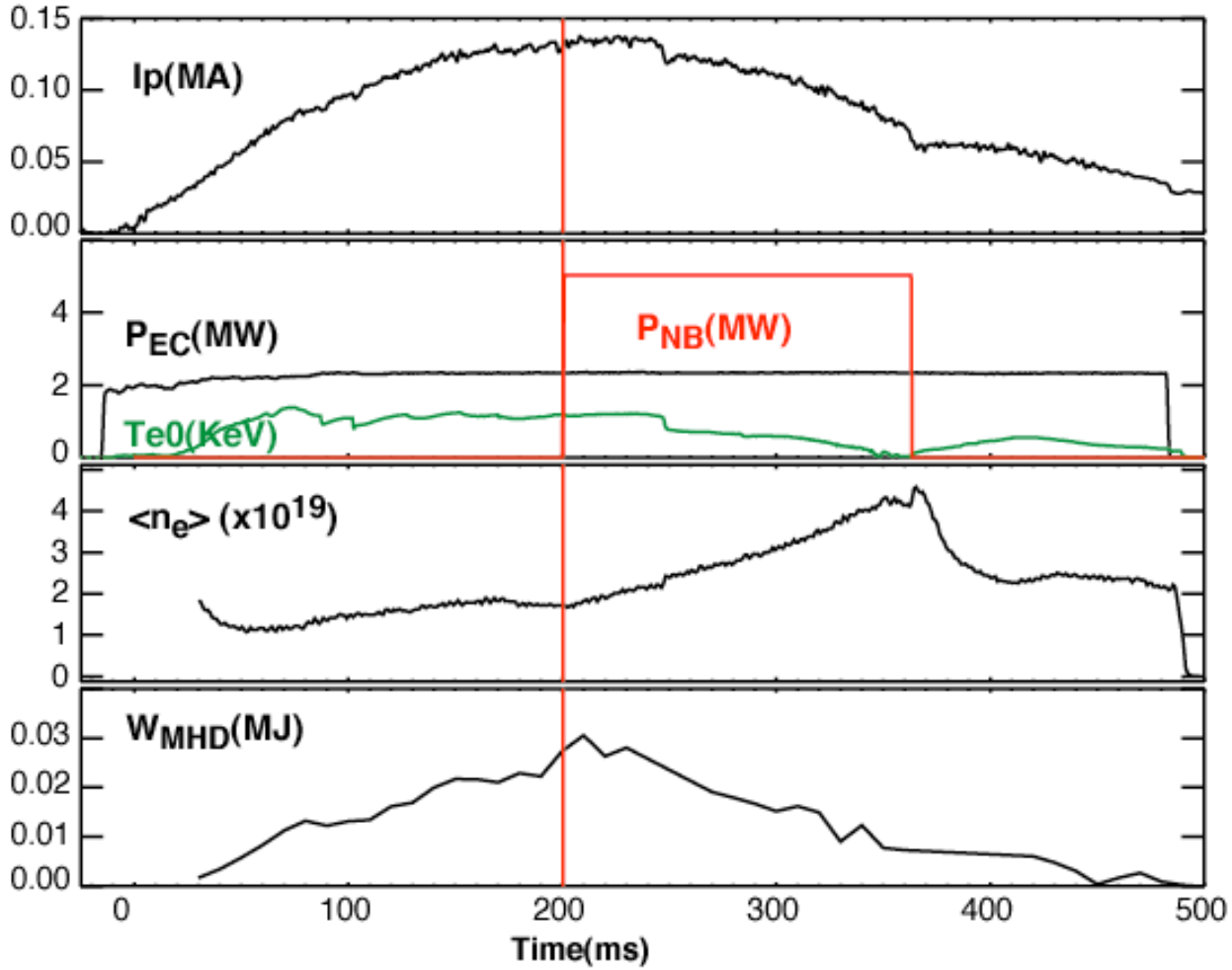
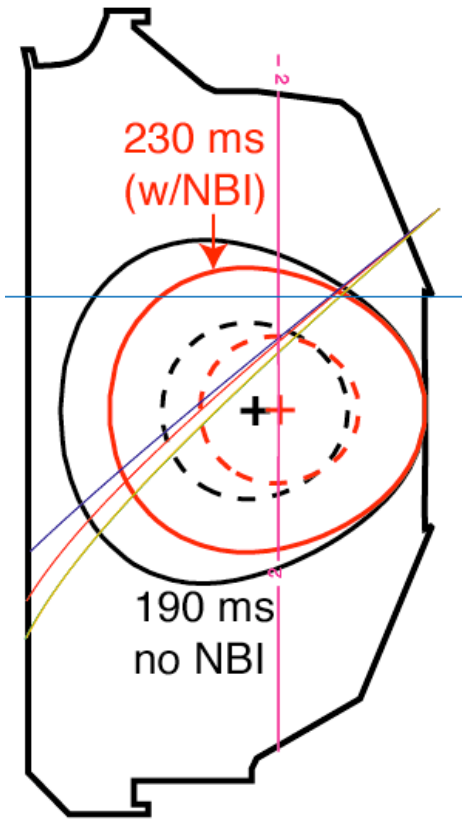


- **TORAY & ONETWO Predict very low ECCD <2%**

No evidence of NBI CD in preliminary experiment (but outward shift in plasma makes evaluation difficult)





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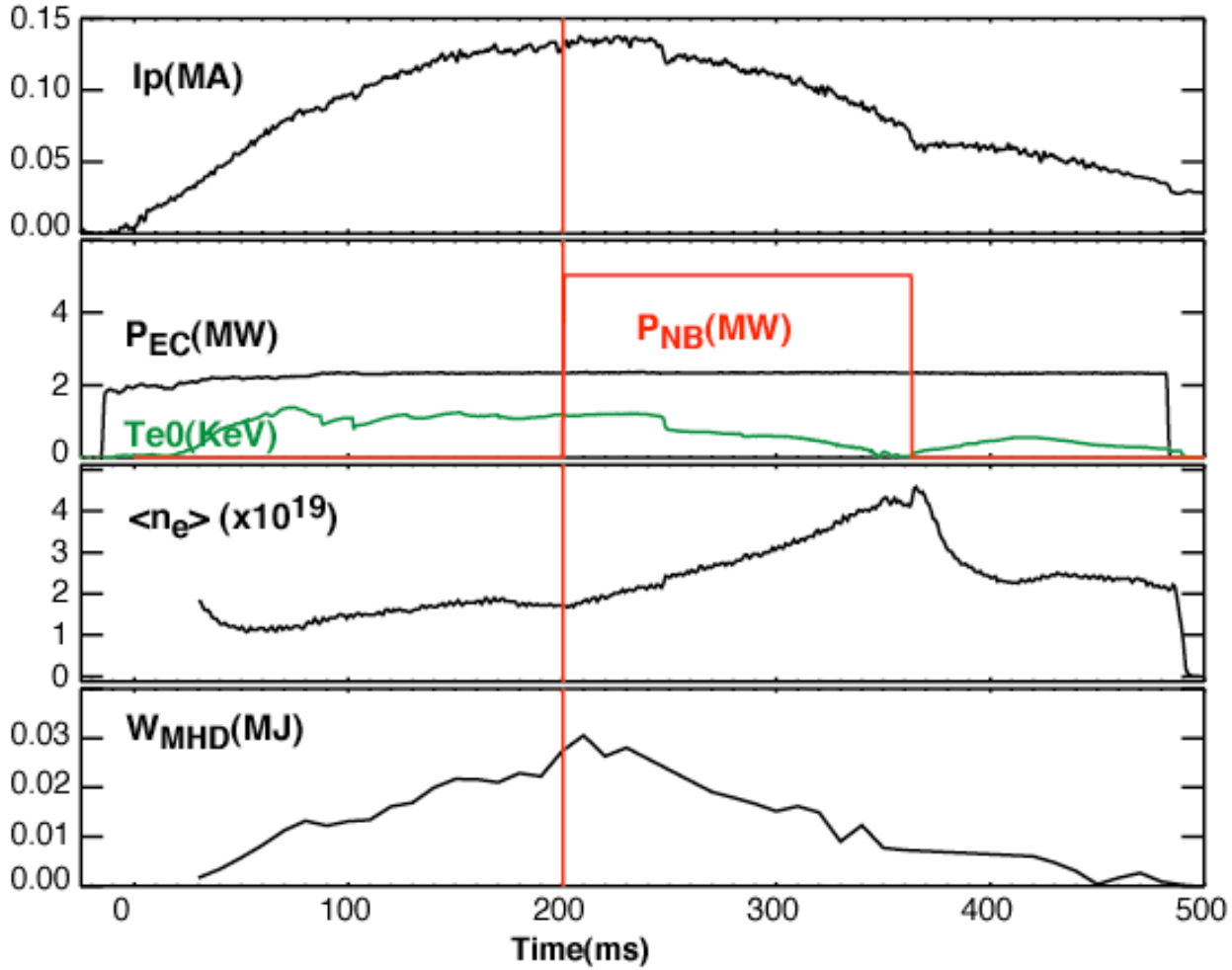
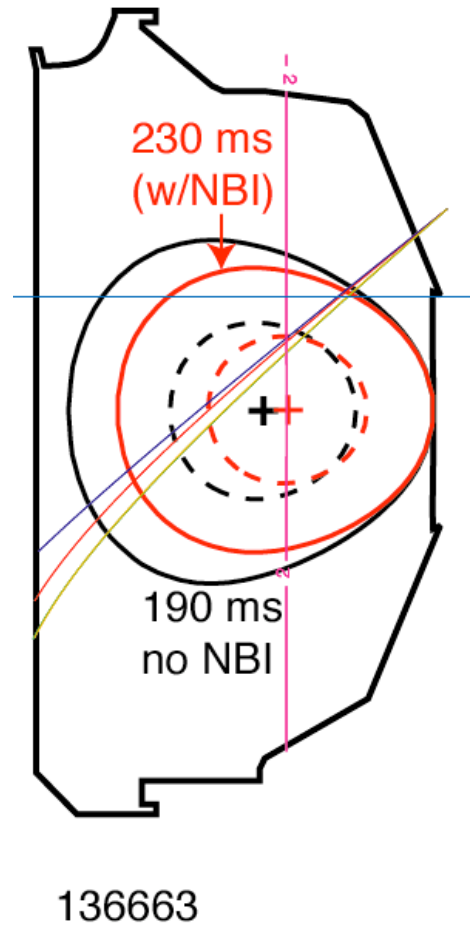
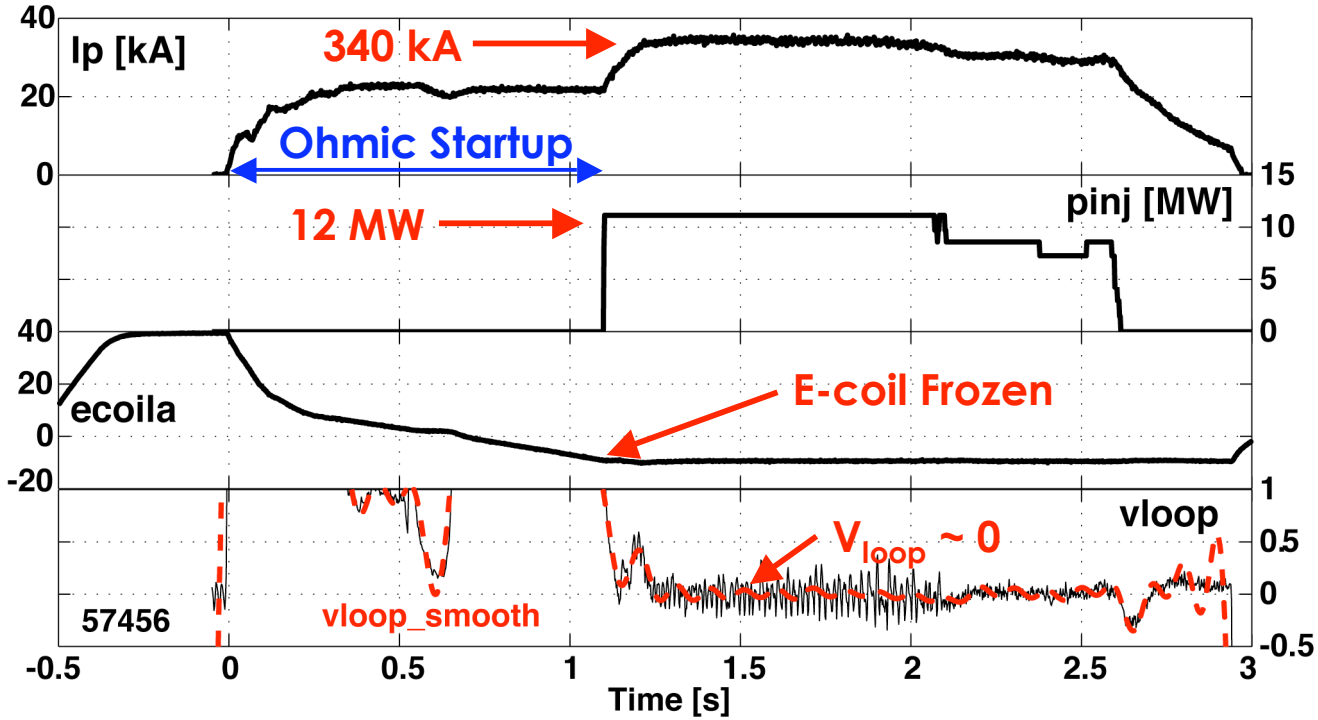
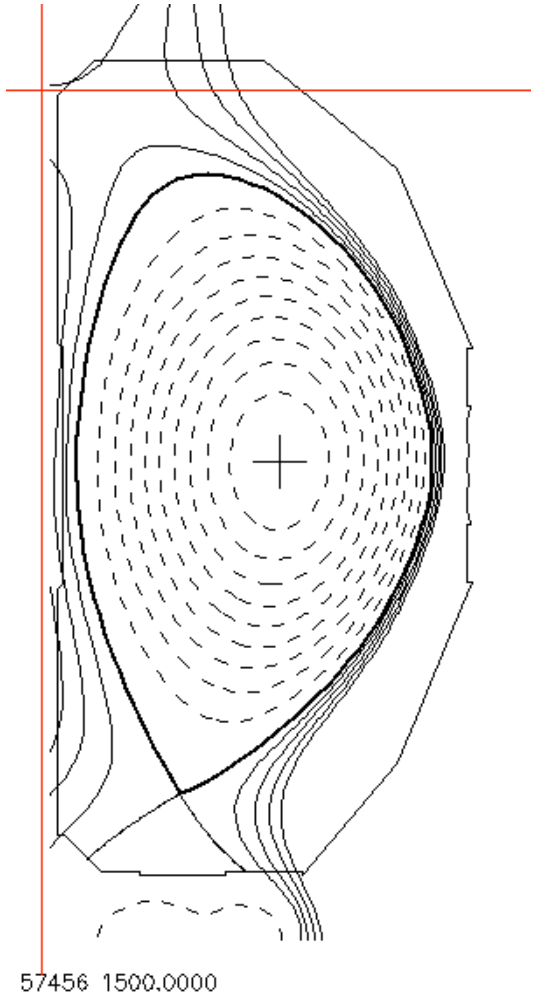
- **ONETWO Predicts: 45% NB current, 14% BS current**





Our Target in Present 2010 Campaign is Handoff to Non-Inductive CD (Simonen NBCD Experiment (1987)



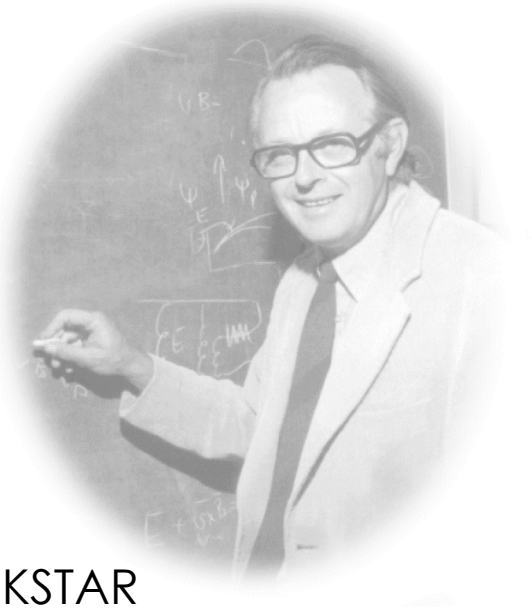


- Some Peculiarities of Experiment
  - Hydrogen beams into helium plasma
  - 8 Co-injected beams at 12MW injected
  - Shape well controlled

Summary

- **1st Soleniodless operation in DIII-D very successful**
  - Non-solenoid scenario operated well
  - 2.3 MW ECH used for breakdown & heating
  - Achieved 170 kA plasma current
  - Preliminary testing of ECCD and NBCD

- **Challenges ahead**
  - Achieve Rp control using F7
  - Power supply modification to use ±F6 current
  - NB handoff

- **This was a very successful use of the new DIII-D Torkil Jensen Award Category**
  - Excellent collaboration between DIII-D, MAST, NSTX, KSTAR

In Memory of Torkil Jensen: A Brilliantly Innovative Researcher 1930-2004